U.S. Department of Energy

Small Business Innovation Research (SBIR) and Small Business Technology Transfer (STTR) Program

Topics

FY 2024

Phase I

Release 1

July 10, 2023

- Office of Advanced Scientific Computing Research
- Office of Basic Energy Sciences
- Office of Biological and Environmental Research
- Office of Fusion Energy Sciences
- Office of High Energy Physics
- Office of Nuclear Physics

Schedule

Event	Dates
Topics Released:	Monday, July 10, 2023
Funding Opportunity Announcement Issued:	Monday, August 7, 2023
Letter of Intent Due Date:	Monday, August 28, 2023 5pm ET
Application Due Date:	Tuesday, October 10, 2023 11:59pm ET
Award Notification Date:	Tuesday, January 2, 2024*
Start of Grant Budget Period:	Monday, February 12, 2024*

*** Date Subject to Change**

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INTRODUCTION TO DOE SBIR/STTR TOPICS

This SBIR/STTR topics document is issued in advance of the FY 2024 DOE SBIR/STTR Phase I Release 1 Funding Opportunity Announcement scheduled to be issued on August 7, 2023. The purpose of the early release of the topics is to allow applicants an opportunity to identify technology areas of interest and to begin formulating innovative responses and partnerships. Applicants new to the DOE SBIR/STTR programs are encouraged to attend upcoming topic and Funding Opportunity Announcement webinars. Dates for these webinars are listed on our website: https://science.osti.gov/sbir/Funding-Opportunities.

Topics may be modified in the future. Applicants are encouraged to check for future updates to this document, particularly when the Funding Opportunity Announcement is issued. Any changes to topics will be listed at the beginning of this document.

General introductory information about the DOE SBIR/STTR programs can be found online here: https://science.osti.gov/SBIRLearning. Please check out the tutorials--a series of short videos designed to get you up to speed quickly.

COMMERCIALIZATION

Federal statutes governing the SBIR/STTR programs require federal agencies to evaluate the commercial potential of innovations proposed by small business applicants. To address this requirement, the DOE SBIR/STTR programs require applicants to submit commercialization plans as part of their Phase I and II applications. DOE understands that commercialization plans will evolve, sometimes significantly, during the course of the research and development, but investing time in commercialization planning demonstrates a commitment to meeting objectives of the SBIR/STTR programs. During Phase I and II awards, DOE provides small businesses with technical and business assistance (TABA) either through a DOE-funded and selected contractor or through an awardee-funded and selected vendor(s).

The responsibility for commercialization lies with the small business. DOE's SBIR/STTR topics are drafted by DOE program managers seeking to advance the DOE mission. Therefore, while topics may define important scientific and technical challenges, we look to our small business applicants to define how they will bring commercially viable products or services to market. In cases where applicants are able identify a viable technical solution, but unable to identify a successful commercialization strategy, we recommend that they do not submit an SBIR/STTR application.

TECHNOLOGY TRANSFER OPPORTUNITIES

Selected topic and subtopics contained in this document are designated as **Technology Transfer Opportunities (TTOs)**. The questions and answers below will assist you in understanding how TTO topics and subtopics differ from our regular topics.

What is a TTO?
A TTO is an opportunity to leverage technology that has been developed at a university or DOE National Laboratory. Each TTO will be described in a particular subtopic and additional information may be obtained by using the link in the subtopic to the university or National Laboratory Contractor that has

developed the technology. Typically, the technology was developed with DOE funding of either basic or applied research and is available for transfer to the private sector. The level of technology maturity will vary, and applicants are strongly encouraged to contact the appropriate university or Laboratory Contractor prior to submitting an application.

How would I draft an appropriate project description for a TTO?

For Phase I, you would write a project plan that describes the research or development that you would perform to establish the feasibility of the TTO for a commercial application. The major difference from a regular subtopic is that you will be able to leverage the prior R&D carried out by the university or National Laboratory Contractor and your project plan should reflect this.

How do I draft a subaward?

The technology transfer office of the collaborating university or DOE Laboratory will typically be able to assist with a suitable template.

Am I required to show I have a subaward with the university or National Laboratory Contractor that developed the TTO in my grant application?

No. Your project plan should reflect the most fruitful path forward for developing the technology. In some cases, leveraging expertise or facilities of a university or National Laboratory Contractor via a subaward may help to accelerate the research or development effort. In those cases, the small business may wish to negotiate a subaward with the university or National Laboratory.

Is the university or National Laboratory Contractor required to become a subawardee if requested by the applicant?

No. Collaborations with universities or National Laboratory Contractors must be negotiated between the applicant small business and the research organization. The ability of a university or National Laboratory Contractor to act as a subcontractor may be affected by existing or anticipated commitments of the research staff and its facilities.

Are there patents associated with the TTO?

The TTO will be associated with one or in some cases multiple patent applications or issued patents.

Will the rights to the TTO be exclusive or non-exclusive?

Each TTO will describe whether an exclusive or non-exclusive license to the technology is available for negotiation. Licenses are typically limited to a specific field of use.

If selected for award, what rights will I receive to the technology?

Those selected for award under a TTO subtopic will be granted rights to perform research and development of the technology during their Phase I or Phase II grants. Please note that these are NOT commercial rights which allow you to license, manufacture, or sell, but only rights to perform research and development. In addition, an awardee is required to obtain a no-cost, six-month option to license the technology at the start of the Phase I award. It will be the responsibility of the small business to demonstrate adequate progress towards commercialization and negotiate an extension to the option or convert the option to a license. A copy of an option agreement template will be available at the university or National Laboratory Contractor which owns the TTO.

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How many awards will be made to a TTO subtopic?

We anticipate making a maximum of one award per TTO subtopic, but multiple awards may be made if the license is non-exclusive.

How will applying for an SBIR or STTR grant associated with a TTO benefit me?

By leveraging prior research and patents from a university or National Laboratory Contractor you will have a significant “head start” on bringing a new technology to market. To make greatest use of this advantage it will help for you to have prior knowledge of the application or market for the TTO.

Is the review and selection process for TTO topics different from other topics?

No. Your application will undergo the same review and selection process as other applications.

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PROGRAM AREA OVERVIEW: OFFICE OF ADVANCED SCIENTIFIC COMPUTING RESEARCH

The primary mission of the Advanced Scientific Computing Research (ASCR) program is to discover, develop, and deploy computational and networking capabilities to analyze, model, simulate, and control complex phenomena important to the Department of Energy. A particular goal of this program is fulfilling the scientific potential of computing systems, tools, and techniques that require significant modifications to deliver on the promise of exascale science. ASCR funds research at public and private institutions and at DOE laboratories with the purpose of fostering and supporting fundamental progress in applied mathematics, computer science, and high-performance networks. In addition, ASCR supports multidisciplinary science activities under the Computational Partnerships program within the Office of Science and throughout the Department of Energy.

ASCR also operates high-performance computing (HPC) centers and maintains a high-speed network infrastructure (ESnet) at Lawrence Berkeley National Laboratory (LBNL) to support computational science research activities. The HPC facilities include the Oak Ridge Leadership Computing Facility (OLCF) [1] at Oak Ridge National Laboratory (ORNL), the Argonne Leadership Computing Facility (ALCF) [2] at Argonne National Laboratory (ANL), and the National Energy Research Scientific Computing Center (NERSC) [3] at Lawrence Berkeley National Laboratory (LBNL).

Examples of areas supported by ASCR:

a) Applied and computational mathematics to develop the algorithms, tools, and libraries needed to model complex physical and biological systems;
b) HPC science to develop scalable software and programming models that facilitate the effective utilization of exascale computers for the DOE mission;
c) Distributed network environments to develop software tools and network services to enable large-scale scientific collaboration and that make effective use of distributed computing and science facilities in support of the DOE science mission;
d) Applied computational partnership to achieve scientific breakthroughs via computer simulation technologies that are impossible without interdisciplinary efforts.

For additional information regarding ASCR priorities, click here.

Please note that all DOE SBIR/STTR grant projects requiring high performance computing support are eligible to apply to use DOE National Energy Research Scientific Computing Center (NERSC) resources [3]. See more info and how to apply: https://science.osti.gov/sbir/Applicant-Resources/National-Labs-Profiles-and-Contacts/National-Energy-Research-Scientific-Computing-Center.

In addition, applicants desiring access to any of DOE's Open Science Computing facilities (OLCF [1], ALCF [2], and NERSC [3]) may submit an application to the facility's Director's Discretionary allocation program. Applicants who already have used the DOE facilities, may consider applying for the ASCR Leadership Computing Challenge (ALCC) program [4]. ALCF has a website that includes the information an applicant may need to know to apply for allocation and get training: http://www.alcf.anl.gov/user-guides/how-get-allocation. Questions concerning allocations on the ALCF can be sent to David Martin, dem@alcf.anl.gov. Descriptions of the allocation programs available at the OLCF are available at http://www.olcf.ornl.gov/support/getting-started/. Questions concerning allocations on the OLCF can be sent to Bronson Messer, bronson@ornl.gov.

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Proprietary research may be done at the ALCF and OLCF facilities using a cost-recovery model.

References:

1. Oak Ridge Leadership Computing Facility, U.S Department of Energy, 2021, OLCF Director's Discretion Project Application, *Oak Ridge National Laboratory Leadership Computing Facility,* https://www.olcf.ornl.gov/for-users/documents-forms/olcf-directors-discretion-project-application/, (June 23,2021) Contact: Bronson Messer, bronson@ornl.gov
2. Argonne Leadership Computing Facility, U.S Department of Energy, 2021, Director's Discretionary Allocation Program, *Argonne Leadership Computing Facility,* https://www.alcf.anl.gov/science/directors-discretionary-allocation-program, (June 23, 2021) Contact: Katherine Riley, riley@alcf.anl.gov
3. NERSC, U.S. Department of Energy, Lawrence Berkeley National Laboratory, 2021, Apply For Your First NERSC Allocation, NERSC, https://www.nersc.gov/users/accounts/allocations/first-allocation/ , (June 23, 2021) Contact: Richard Gerber, ragerber@lbl.gov
4. DOE ALCC Program, U.S Department of Energy, 2021, ASCR Leadership Computing Challenge (ALCC), U.S. Department of Energy Office of Science, https://science.osti.gov/ascr/Facilities/Accessing-ASCR-Facilities/ALCC, (June 23, 2021)

C57-01 ACCELERATING THE DEPLOYMENT OF ADVANCED SOFTWARE TECHNOLOGIES

Maximum Phase I Award Amount: $200,000	Maximum Phase II Award Amount: $1,100,000
Accepting SBIR Applications: YES	Accepting STTR Applications: YES

The Office of Science (SC) Office of Advanced Scientific Computing Research (ASCR) has spent decades on, and invested millions of dollars in, the development of HPC software that operates efficiently on large, heterogeneous supercomputers. Today, this hardware (e.g., CPUs, GPUs, TPUs, ASICs) has permeated society at large, finding its way into everything from smart phones to cloud computers. However, many of the software packages and libraries that can take advantage of this heterogeneity have remained solely within the HPC ecosystem.

Work proposed under this topic must critically depend on one or more ASCR-funded software packages. Applications should include a reference (webpage or other citation) to show that the relevant software has been supported by ASCR. Relevant ASCR-funded software packages include, but are not limited to:

- **Mathematical Libraries:** SuperLU (https://portal.nersc.gov/project/sparse/superlu/), STRUMPACK (https://portal.nersc.gov/project/sparse/strumpack/), HYPRE (https://www.llnl.gov/casc/hypre/), Trilinos (https://trilinos.github.io/), PETSc (https://www.mcs.anl.gov/petsc/), SUNDIALS (https://computing.llnl.gov/projects/sundials), MFEM (https://mfem.org/).
- **Programming Models:** Kokkos (https://github.com/kokkos/kokkos), RAJA (https://github.com/LLNL/RAJA), Umpire (https://github.com/LLNL/umpire), Legion (https://legion.stanford.edu/)
- **I/O:** ADIOS2 (https://github.com/ornladios/ADIOS2), Parallel NetCDF (https://parallel-netcdf.github.io/), HDF5 (https://www.hdfgroup.org/)
- **Compilers and Runtimes:** LLVM (https://llvm.org/), Argobots (https://www.argobots.org/)
- **MPI:** OpenMPI (https://www.open-mpi.org/), MPICH (https://www.mpich.org/)
- **Package Management:** Spack (https://spack.io/)

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- **Software Stacks and SDKs:** E4S (https://e4s-project.github.io/), xSDK (https://xsdk.info/).
    - Please note that E4S and xSDK include many ASCR-funded software packages that are not separately listed in this document.

Note that software packages that have received ASCR funding as part of SciDAC and other computational partnerships are eligible. Please see the references for an additional, partial listing of available software packages and examples of their uses. Applications without a critical dependence on one or more ASCR-funded software packages are out of scope.

ASCR understands that a diverse community of stakeholders contributing to the maintenance and evolution of a software package lowers the long-term risks associated with commercialization of that software. Risks that are lowered by contributions from a diverse community of stakeholders include, but are not limited to, risks associated with a lack of timely correction of software defects. Accordingly, ASCR encourages contributing fixes for defects in the ASCR-funded software, changes needed to make the ASCR-funded software function on generally available platforms, and other *non-proprietary* enhancements of general utility to the ASCR-funded software back to the project in a manner consistent with any applicable licensing requirements and other project policies. While not required, applicants are encouraged to provide letters of support from at least one developer of each ASCR-funded software package that plays a significant role in the proposed work. This letter should outline the mutually understood procedure via which any relevant contributions will be reviewed for acceptance into the project and *briefly outline* any anticipated prerequisites to initiating that procedure (e.g., the future execution of a Contributor License Agreement).

ASCR will consider collaborative applications from teams of small businesses under this topic, with up to three small businesses forming a team. Each institution in such a team must be a small business. Each institution may include one or more academic or lab partners as subcontractors. Each institution must submit an application that contains an identical narrative section and a common statement describing how any intellectual property issues will be addressed by the collaboration. Each application must have an institution-specific budget and budget-justification forms, biographical data for the PI and senior personnel involved in the project, and a commercialization plan. The budget proposed for each participating business must separately comply with the ceiling, floor, and other requirements in the Funding Opportunity Announcement. The cover sheet for each submission must clearly show all institutions involved in the collaboration.

a. Deployment of ASCR-Funded Software

Accelerating the deployment and use of advanced, ASCR-funded software technologies, packages, and libraries can significantly improve the performance, reliability, and stability of commercial applications while lowering the cost of developing new capabilities. While many ASCR-supported software packages are open source, they are often complicated to use, distributed primarily in source-code form targeting common HPC systems, and potential adopters lack options for purchasing commercial support, training, and custom-development services. The expertise required to install and use these software packages poses a significant barrier to many organizations due to the levels of complexity built into them to facilitate scientific discovery and research. Moreover, without a commercial interest in broadly marketing the capabilities of the software, possibly including in markets beyond HPC, adoption is limited by a lack of exposure within the wider technology ecosystem. Providing simpler interfaces targeted for specific markets or offering a spectrum of commercial services around the underlying open-source software, would make these software packages more usable for commercial, industrial, and non-scientific applications.

Grant applications are sought to take one or more ASCR-funded software packages and make them easier to use by a wide variety of industries or in commercial venues by developing commercial offerings based on those ASCR-funded software packages. This may include design, implementation, and usability testing of graphical user interfaces, web interfaces, or interfaces for alternative programming languages (e.g., Python, R, or Julia); porting to other platforms (e.g., cloud, mobile); simplification of user input; decreasing complexity of the code by stripping out components that are not required; hardening the code to make it more robust; adding new capabilities; adding user-support tools or services; or other ways that make the code more widely useable to industrial applications.

Questions – Contact: Hal Finkel, Hal.Finkel@science.doe.gov and/or William Spotz, William.Spotz@science.doe.gov

b. Integration of ASCR-Funded Libraries

Adopting and integrating advanced ASCR-funded libraries into commercial products can lower the cost of developing new capabilities while simultaneously providing improved performance, reliability, and stability. The advanced mathematical and computational algorithms, and support for state-of-the-art hardware, can be leveraged by commercial software internally, thereby providing important capabilities without users interacting directly with the capabilities provided by the underlying ASCR-funded libraries. These commercial applications need not be targeted at HPC systems, but rather, may integrate and adapt the relevant ASCR-funded libraries for use in cloud, mobile, or other computing environments.

Grant applications are sought to take one or more ASCR-funded libraries and integrate them into new or existing, commercially supported software products to provide unique, transformative capabilities. Applicants may choose to strip out code components, harden them, or perform any other tasks necessary to meet deployment requirements in the context of the envisioned commercial product.

Questions – Contact: Hal Finkel, Hal.Finkel@science.doe.gov and/or William Spotz, William.Spotz@science.doe.gov

c. Other

In addition to the specific subtopic listed above, the Department invites grant applications in other areas that fall within the scope of the topic description above.

Questions – Contact: Hal Finkel, Hal.Finkel@science.doe.gov and/or William Spotz, William.Spotz@science.doe.gov

References:

1. U.S. Department of Energy, 2022, Software, Scientific Discovery through Advanced Computing (SciDAC), U.S. Department of Energy, https://www.scidac.gov/software-list.html (June 23, 2022)
2. U.S. Department of Energy, 2022, SciDAC Feature, Scientific Discovery through Advanced Computing (SciDAC), U.S. Department of Energy, http://www.scidac.gov (June 23, 2022)
3. Heroux, M. A., Carter, J., Thakur, R., Vetter, J. S., McInnes, L. C., Ahrens, J., Munson, T., and Neely, J. R., 2020, ECP Software Technology Capability Assessment Report-Public, ECP-RPT-ST-0002-2020-Public,

ECP, https://www.exascaleproject.org/wp-content/uploads/2020/02/ECP-ST-CAR-V20-1.pdf (February 1, 2020)
4. U.S. Department of Energy, 2022, Exascale Computing Project, https://www.exascaleproject.org/ (June 23, 2022)
5. U.S. Department of Energy, 2022, DOE CODE, U.S. Department of Energy, Office of Scientific and Technical Information, https://www.osti.gov/doecode/ (June 23, 2022)
6. Market Research Study: Applications of ASCR HPC Software, 2022, https://science.osti.gov/ascr/Community-Resources/Program-Documents (June 27, 2022)

C57-02 HPC CYBERSECURITY

Maximum Phase I Award Amount: $200,000	Maximum Phase II Award Amount: $1,100,000
Accepting SBIR Applications: YES	Accepting STTR Applications: YES

The Office of Science (SC) provides world-class research infrastructure to accelerate scientific discovery within the DOE mission space. DOE SC ASCR user facilities include a high-performance network (HPN) and three HPC systems dedicated to open science research.

Each user facility is uniquely designed for the science it serves. For instance, HPC systems offer a massively parallel computing environment with numerous distributed nodes—login, compute, and data transfer nodes; high-speed interconnects; thousands of heterogeneous advanced processers such as CPUs and GPUs; and sophisticated schedulers, highly distributed file systems, and data storage systems. Scientific research infrastructure requires tailored cybersecurity approaches that accommodate specialized computational platforms and networks and respect an open science paradigm.

HPC platforms are different from enterprise systems in ways that require tailored cybersecurity solutions. Operating system level tools traditionally used for enterprise systems may be inapplicable to distributed operating systems. The balance between performance and cybersecurity, as well as cybersecurity benchmarking, may be more challenging on HPC systems that are designed to deliver unprecedented performance. In addition, HPC software infrastructures evolve more rapidly than commercial counterparts while at the same time some HPC practitioners are actively investigating deployment of approaches more common in conventional server environments, such as, but not limited to, container software architectures.

This topic area seeks applications that are tailored specifically to the unique needs of HPC systems. The narrative must convey a clear understanding of how HPC system architectures differ from enterprise platforms and consequently require tailored cybersecurity solutions, and how the applicant's proposed solution meets these unique needs. For instance, but not limited to, the narrative must describe the applicant's plan to ensure that the proposed HPC cybersecurity tool or technology does not impede HPC performance.

In order to be considered in scope, grant applications for this topic area must clearly propose a cybersecurity solution that specifically reduces the cyberattack surface of HPC systems or component technology unique to HPC platforms. Component technologies unique to HPC platforms are not used in enterprise platforms.

The narrative must clearly articulate how the proposed cybersecurity solution will not impede HPC performance.

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Subtopics:

a. Strengthening Isolation between HPC Users

This topic's goal is to strengthen the isolation between HPC users, specifically in the context of either the HPC scheduler or the HPC filesystem. Developing a tool or technology that, for instance but not limited to, ensures an HPC node allocated to an authenticated user can only mount parts of the HPC file system to which the authenticated user has authorized access and ensures compute node sanitation following completion of one project and prior to the start of the next.

Questions – Contact: Carol Hawk, carol.hawk@science.doe.gov

b. Other

In addition to the specific subtopic listed above, the Department invites grant applications in other areas that fall within the scope of the topic description above.

Questions – Contact: Carol Hawk, carol.hawk@science.doe.gov

References:

1. NIST Special Publication NIST SP 800 223, 2023, "High Performance Computing (HPC) Security: Architectures, Threat Analysis and Security Posture", *NIST*, https://doi.org/10.6028/NIST.SP.800-223.ipd (February, 2023)
2. Peisert, S., 2015, DOE Workshop Report, ASCR Cybersecurity for Scientific Computing Integrity - Research Pathways and Ideas Workshop, DOE Workshop Report, Lawrence Berkeley National Laboratory, https://escholarship.org/uc/item/89s6w301 (September 18, 2015)
3. U.S. Department of Energy, Office of Science, 2015, ASCR Cybersecurity for Scientific Computing Integrity, DOE Workshop Report, (*DOE*) https://science.osti.gov/-/media/ascr/pdf/programdocuments/docs/ASCR_Cybersecurity_For_Scientific_Computing_Integrity_Report_2015.pdf (January 9, 2015)

C57-03 DIGITAL-TWIN CAPABILITIES FOR SCIENCE NETWORK INFRASTRUCTURES

Maximum Phase I Award Amount: $200,000	Maximum Phase II Award Amount: $1,100,000
Accepting SBIR Applications: YES	Accepting STTR Applications: YES

Digital twins are an emerging area of modern science where a physical object (i.e., device, process, or infrastructure) is paired with a digital (virtual) version of that same object. Operations of the physical object can generate data to validate the virtual objects behavior while the virtual object allows rapid exploration of input parameters that might damage the physical object. It is this close interaction between the physical and virtual object that makes this digital-twin environment so productive.

DOE has a long history of building and operating high performance physical network infrastructures. The Energy Science Network (ESnet) supports the Office of Science lab complex and it also peers with other research and education networks (RENs) both domestically and internationally. ESnet also operates an internal 100G SDN network testbed and the NSF funded FABRIC external network testbed. Specifically:

a) The ESnet 100G Software-Defined Networking (SDN) testbed's objective is to provide network researchers with a realistic environment for testing. The current testbed enables 100G application / middleware experiments in addition to Science DMZ and SDN control/data plane experiments.

b) FABRIC: The National Science Foundation (NSF) collaboration is building a national research infrastructure that will enable the computer science and networking community to develop and test novel architectures that could yield a faster, more secure Internet.

What is missing is a virtual companion, a digital twin, to these testbeds.

This topic solicits applications that would create the network simulation capabilities that would accurately and reliably duplicate the operational and performance capabilities of these testbeds creating their digital twin.

a. Network Simulation Tools

Over the past few decades, the network research community has developed multiple network simulators (i.e., NS-3, OMNeT++, OPnet, ROSS) and emulators (i.e., Mininet) tools. While these tools have demonstrated value, there are limitations on the speed and capability that must be addressed for them to become an effective digital twin of one of these testbeds. In addition, there are new functionalities and devices (i.e., P4 switches, Optical Add/Drop Muxes, security) that are integral components of these testbeds that need to be incorporated.

To be an effective digital twin, the simulator/emulator must be as fast as, or faster than, the physical network. They should also be capable of evaluating new network link technologies or speeds (up to 1 Tbps links) that are expected in the next few years. Both of these testbeds span national (U.S.) and international (E.U.) boundaries. This means round-trip times range from a few msec to over 100 msec. It also means that the event rate can vary from 8.3M pkts/sec (1500 Byte Ethernet frames) to 1.9B pkts/sec (64 Byte Ethernet frames). These event rates will place a heavy burden on simple discrete event simulators (DESs). Work on Parallel DES's, artificial-intelligence / machine-learning (AI/ML) based surrogate models, and/or hybrid tools that automatically combine both methods are the focus of this subtopic.

Specifications:
The simulation/emulation tool(s) must meet the following criteria:

1) link Speed that is equal to or 10x faster than the physical testbed;
2) topology that exactly matches the physical testbed;
3) node support that exactly matches the operational capabilities of the installed routers, switches, and hosts;
4) protocol support for the physical (optical), network (IPv4 and IPv6), transport (all current variants), and commonly used science applications;
5) event rate of a minimum of 2 billion events/sec (discrete or surrogate model)

Applications are solicited to enhance or extend one or more existing simulation/emulation tools to create a digital twin of either the ESnet 100 G SDN testbed or the FABRIC testbed.

Out of scope:

- creation of new simulation/emulation tools from scratch,
- creation of a digital twin of other testbeds or infrastructures,
- enhancements or extensions that only meet a subset of the specifications.

Questions – Contact: Kalyan Perumalla, kalyan.perumalla@science.doe.gov

b. Other

In addition to the specific subtopic listed above, the Department invites grant applications in other areas that fall within the scope of the topic description above.

Questions – Contact: Kalyan Perumalla, kalyan.perumalla@science.doe.gov

Reference:

1. ESnet Energy Science Network, 2022, 100G SDN Testbed, ESnet Energy Sciences Network, https://www.es.net/network-r-and-d/experimental-network-testbeds/100g-sdn-testbed/ (June 24, 2022)
2. Esnet Energy Sciences Network, 2022, Fabric, Esnet Energy Sciences Network, https://www.es.net/network-r-and-d/fabric/ (June 24, 2022)
3. FABRIC Knowledge Base, 2023, FABRIC Knowledge Base, https://learn.fabric-testbed.net/ (May 28, 2023)
4. Wikipedia, 2022, Digital Twin, Wikipedia, https://en.wikipedia.org/wiki/Digital_twin (June 24, 2022)
5. Wikipedia, 2023, DMZ (Computing), Wikipedia, https://en.wikipedia.org/wiki/DMZ_(computing) (January 27, 2023)

References: Subtopic a:

1. NSnam, 2022, NS-3 Network Simulator, *NS-3*, https://www.nsnam.org/ (2022)
2. OMNeTpp, 2022, OMNeT++ Discrete Event Simulator, https://omnetpp.org/ (2022)
3. Mininet, Mininet An Instant Virtual Network On Your Laptop (or other PC), http://mininet.org/ (No Date)
4. OPnet, 2022, OPnet Network Simulator, https://opnetprojects.com/opnet-network-simulator/ (June 24, 2022)
5. ROSS, 2022, ROSS, https://ross-org.github.io/about.html (June 24, 2022)
6. Carothers, C.D., Bauer, D., and Pearce, S., 2002, ROSS: A high-performance, low-memory, modular Time Warp system, Journal of Parallel and Distributed Computing, (Volume 62, Issue 11, 1648–1669), *ScienceDirect,* https://www.sciencedirect.com/science/article/abs/pii/S0743731502000047 (November, 2002)
7. Wikipedia, 2022, Surrogate models, *Wikipedia,* https://en.wikipedia.org/wiki/Surrogate_model (June 18, 2023)
8. Wolfe, N., Misbah M., Carothers, C.D., Ross, R.B., and Carns, P.H., 2018, Modeling Large-Scale Slim Fly Networks Using Parallel Discrete-Event Simulation, ACM Transactions on Modeling and Computer Simulation (TOMACS), (28, no. 4 (2018): 1-25), *ResearchGate,* https://www.researchgate.net/publication/327430844_Modeling_Large-Scale_Slim_Fly_Networks_Using_Parallel_Discrete-Event_Simulation (August, 2018)

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C57-04 TECHNOLOGY TO FACILITATE THE USE OF NEAR-TERM QUANTUM COMPUTING HARDWARE

Maximum Phase I Award Amount: $200,000	Maximum Phase II Award Amount: $1,100,000
Accepting SBIR Applications: YES	Accepting STTR Applications: YES

This topic is focused on specific technologies that are required to advance the state of quantum computing and networking. One focus is to facilitate effective implementation of gate-based quantum computing methods on quantum processors available or expected to be available within the next five years.

Grant applications are sought in the following subtopics:

a. Software for Calibration, Characterization, and Control of Quantum Processors

Effective use of near-term quantum processors requires device-specific optimization of individual operations ranging from state preparation and measurement through gate implementation and compilation. Specialized techniques and tailored pulse sequences can suppress noise, mitigate crosstalk and control errors, and maintain optimally high-fidelity operations in the absence of formal error correction. In many cases, regular calibration and device characterization are necessary to ensure optimal performance. As algorithmic complexity and the size of qubit arrays grow, control software also increases in complexity. It is increasingly important to develop control software that combines knowledge of specific characteristics of a device, quantum algorithms, and high-efficiency optimization techniques. Grant applications are sought to develop and validate software tools for automated processor tune-up, characterization, calibration, and optimization of quantum processors; implementation of techniques for suppressing decoherence and mitigating errors; and automation of benchmarking and compiling protocols. Open-source software solutions are strongly encouraged, as is testing the software solutions on fully transparent quantum computing platforms available in research laboratories.

Grant applications focused on quantum annealing, analog simulation, or other non-gate-based approaches to quantum computing will be considered out of scope.

Questions – Contact: Claire Cramer, Claire.Cramer@science.doe.gov

References:

1. U.S. Department of Energy, 2017, ASCR Report on a Quantum Computing Testbed for Science, Office of Advanced Scientific Computing Research, (p. 46), *DOE*, https://science.osti.gov/~/media/ascr/pdf/programdocuments/docs/2017/QTSWReport.pdf (June 24, 2022)

C57-05 ARTIFICIAL INTELLIGENCE TOOLS FOR CATALYZING INTERDISCIPLINARY SCIENCE

Maximum Phase I Award Amount: $200,000	Maximum Phase II Award Amount: $1,100,000
Accepting SBIR Applications: YES	Accepting STTR Applications: YES

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This topic is focused on new artificial intelligence (AI) tools that enhance the productivity of scientists and engineers when making use of scholarly publications and engaging in interdisciplinary interactions in the areas of science and engineering supported by SC. While scientists are deeply knowledgeable in their areas of expertise, they are often not as highly informed in other important disciplines. For example, experts in several subareas of high-performance computing are not as deeply knowledgeable about the terminology, concepts, and state of the art in other areas such as biological sciences or high energy physics. The advent of new service-oriented access to technology that is based on large language models (LLM), which may include multi-modal data, has now opened the possibility of utilizing LLM-based commercial services to enable new interdisciplinary synergy. These services can now be envisioned to be used to digest large amounts of scientific publications and documentation across disciplines and enable interdisciplinary interactions that were not conceivable before.

Against this backdrop, grant applications are sought on the topic of "AI Tools for Catalyzing Interdisciplinary Science." This topic will be focused on increasing the synergy among disciplines supported by the Office of Science. For example, this would include AI-based tools that can catalyze the interactions among scientists in nuclear physics and material sciences. Innovative methods are needed to assimilate the scientific publication corpus of two or more disciplines and enable scientists in any of those disciplines to collate scientific ideas, concepts, questions, and solutions from the other disciplines.

Included in scope is the integration with commercial AI services (Google, Microsoft, OpenAI, etc.) and open/commercial sources of publications and other data. Proposed approaches must display a short-term path to success and commercial viability. The proposed work should include a plan to perform demonstration activities with scientists and demonstrate verification and validation of results, including data validation.

Grant applications focused on the following will be considered out of scope:

- Tools that address less than two scientific disciplines in Office of Science research areas.
- Tools that build LLM-based services from scratch.
- Security and hardening of LLM.

a. Interdisciplinary Training and Interfaces

Applications responsive to this subtopic will address the challenge of ingesting a multi-modal corpus of scientific publications of two or more scientific disciplines in Office of Science research areas into a knowledgebase to be built using LLM-based services.

Additionally, applications may address the creation of modern interfaces with natural language-based prompt-and-response support necessary for scientists to interact with the LLM back-ends of interdisciplinary knowledgebases.

Questions -- Contact: Kalyan Perumalla, Kalyan.Perumalla@science.doe.gov, Margaret Lentz, Margaret.Lentz@science.doe.gov, Hal Finkel, Hal.Finkel@science.doe.gov

References:

1. "Artificial Intelligence for Science, Energy, and Security," http://www.anl.gov/ai-for-science-report

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C57-06 MIXED INTEGER SOLVER TECHNOLOGY FOR ACCELERATED COMPUTING SYSTEMS

Maximum Phase I Award Amount: $200,000	Maximum Phase II Award Amount: $1,100,000
Accepting SBIR Applications: YES	Accepting STTR Applications: YES

This topic is focused on specific technologies that are required to advance the state of accelerated computing applied to mixed integer programming (MIP) problems arising in scientific applications. The primary focus of this topic is on the computer science needed to address the challenges in manifestation of scalable, distributed (multi-node) algorithmic techniques and not on combinatorial theory development.

MIP problems underlie many important application areas of interest to DOE, including biological systems, transportation networks, electric grids, and user facility infrastructures. While significant advances have been made in the theory and implementation of MIP solver methods on conventional central processing unit (CPU)-based hardware, new advances are necessary to fully utilize the DOE investments in accelerated computing platforms such as graphical processing unit (GPU)-based computers and high-performance computing systems. Preference may be given to applications that leverage existing ASCR software investments.

Grant applications focused on the following will be considered out of scope:

- Cut generation, cut storage, cut manipulation methods,
- Column generation methods,
- Theory,
- Fragments of technology that are isolated and cannot be demonstrated as part of a working MIP solver on standard problems such as found in the MIPLIB series, and
- Solutions that cannot be demonstrated to run on GPU-based accelerators used in current or planned supercomputing systems of DOE leadership computing facilities.

Grant applications are sought in the following subtopics:

a. Efficient Distributed Tree Management

This topic is focused on tree management that arises in branch-and-bound or branch-and-cut (B&C) methods to MIP solution methods. Research must focus on efficient representation and encoding of the B&C tree on accelerated memory hierarchies and address the challenges of efficient tree node movement, including exploitation of direct memory access (DMA) of accelerated memory across high-speed networks. Methods must solve the problem of
scalable and efficient manipulation of B&C tree nodes. This includes the ability to query the quality of linear program relaxation, node ancestor identification, node deletion, and updates to the node data.

Questions – Contact: Kalyan Perumalla, Kalyan.Perumalla@science.doe.gov

b. Efficient Linear Program Relaxation Solution

Implementations of interior or exterior point methods must be developed specifically optimized for accelerated hardware using single-instruction-multiple-thread (SIMT) control flows or reconfigurable field programmable gate arrays (FPGAs). Methods must build on existing or new sparse and dense solvers and capable of static or dynamic (on-the-fly) choice of sparse versus dense solver based on the density of matrices encountered in the input scenarios. Applicants may propose solving the linear program relaxations of MIP problem matrices that either fit entirely within a single node's memory or large problem sizes where matrices do not fit within a single node's memory but span multiple node memories.

Milestones must aim to solve the relaxations of root nodes in increasing fractions (10%, 50%, 75%, 90%) of the problems in the MIPLIB 2017 problem set (with priming or probing methods not necessarily applied to the root problems).

Questions – Contact: Kalyan Perumalla, Kalyan.Perumalla@science.doe.gov

c. Other

In addition to the specific subtopic listed above, the Department invites grant applications in other areas that fall within the scope of the topic description above.

Questions – Contact: Kalyan Perumalla, Kalyan.Perumalla@science.doe.gov

References:

1. Gleixner, A., et al, 2021 "MIPLIB 2017: data-driven compilation of the 6th mixed-integer programming library," Mathematical Programming Computation volume 13, pages 443–490, Springer Link, https://link.springer.com/article/10.1007/s12532-020-00194-3 (January 7, 2021)
2. Wolsey, L., et al, 1999 "Integer and Combinatorial Optimization," Wiley-Interscience, ISBN 978-0471359432 Wiley, https://www.wiley.com/en-us/Integer+and+Combinatorial+Optimization-p-9780471359432 (July, 1999)

PROGRAM AREA OVERVIEW: OFFICE OF BASIC ENERGY SCIENCES

The Office of Basic Energy Sciences (BES) supports fundamental research to understand, predict, and ultimately control matter and energy at the electronic, atomic, and molecular levels in order to provide the foundations for new energy technologies and to support Department of Energy (DOE) missions in energy, environment, and national security. The results of BES-supported research are routinely published in the open scientific literature.

A key function of the program is to plan, construct, and operate premier scientific user facilities that enable the development and characterization of novel chemical and materials systems across scales. This is accomplished through support for facilities providing diverse X-ray and neutron scattering capabilities, as well as unique instrumentation for nanoscience at five Nanoscale Science Research Centers. These national resources are available free of charge to all researchers based on the quality and importance of proposed nonproprietary experiments, and at cost recovery for meritorious proprietary work. For additional information on BES user facilities, click here. The link to each facility webpage leads to detailed descriptions of the experimental instruments and facilities and the listing of available experimental techniques.

A major objective of the BES program is to promote the transfer of the results of its basic research and advance the use of its world-leading tools to enable the development and demonstration of technologies important to DOE missions in areas of energy efficiency, renewable energy resources, emission reduction from the use of fossil fuels, mitigation of the adverse impacts of energy production and use, and future nuclear energy sources. To that end, the DOE's Office of Technology Transitions provides the Laboratory Partnering Service to help researchers discover and partner with DOE's national laboratories. The DOE SBIR/STTR site under applicant resources also contains a resource to explore collaboration with the national laboratories.

The SBIR/STTR program represents one important mechanism by which the BES program augments its system of university and laboratory research programs and integrates basic science, applied research, and development activities within the DOE. The BES program is currently interested in receiving applications on the following set of technical topics. For additional information regarding the Office of Basic Energy Sciences programs, click here.

C57-07 COST-EFFECTIVE CRYOGENIC COOLING SYSTEMS FOR HIGH POWER X-RAY OPTICS

Maximum Phase I Award Amount: $200,000	Maximum Phase II Award Amount: $1,100,000
Accepting SBIR Applications: YES	Accepting STTR Applications: YES

In support of DOE's high-brightness X-ray light sources, grant applications are being solicited for the development of technologies that support cost-effective cryogenic cooling of high-power X-ray optics. X-ray mirrors and crystals in the most demanding beamline applications must maintain their ideal shapes to nanometer tolerances under high-power-density illumination. Mitigating thermal distortion is therefore a significant challenge for X-ray instrumentation. Silicon mirror substrates and monochromator crystals are widely used in X-ray beamlines due to their relatively high thermal conductivity and ability to achieve polished, sub-nm surface roughness values. Yet it is their temperature-dependent coefficient of thermal expansion that is most compelling for their application in high power X-ray optics. Near 125 K, the coefficient of thermal expansion crosses zero, meaning that cryogenically cooled silicon optics can operate with significant heat loads but without problematic levels of thermal distortion.

Grant applications are sought in the following subtopics:

a. Development of Cost-Effective, Compact, Closed-Loop, Cryogenic Systems for Cooling of High-Power X-Ray Optics

This subtopic seeks the development of innovative cryogenic cooling systems for silicon mirrors and crystals that can reach and maintain temperatures close to 125 K. Such systems can improve the quality, stability, resolution, and focusing performance of cutting-edge X-ray beamlines and optical systems. The systems should be compatible with a variety of optic-cooling geometries. Additionally, the systems should be compatible with and easily integrable into new and existing X-ray beamline infrastructure at synchrotron and other X-ray facilities and require minimal maintenance and upkeep. The cost, size, and operational stability are primary concerns driving the need for new and innovative designs and concepts. Important cost and performance requirements include:

i. The cost of the system once commercialized should be < $50,000.
ii. The preferred size of the system should be < 1 m^3.
iii. The system must be capable of delivering > 250 W cooling power at 125 K.
iv. For vibration considerations of the beamline optics implementation, the coolant transfer lines should be flexible with a minimum bend radius of < 20 cm.

Questions – Contact: Eliane Lessner, Eliane.Lessner@science.doe.gov

b. Other

In addition to the specific subtopic listed above, the Department invites grant applications in other areas that fall within the scope of the topic description above.

Questions – Contact: Eliane Lessner, Eliane.Lessner@science.doe.gov

References:

1. V. Rehn, 1986, “Optics for Insertion-Device Beam Lines,” *Proc. SPIE* 582, 238. https://doi.org/10.1117/12.950935 (May 5, 1986)
2. D. Bilderback, 1986, "The potential of cryogenic silicon and germanium X-ray monochromators for use with large synchrotron heat loads." *Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment* 246, 434. *ScienceDirect*, https://doi.org/10.1016/0168-9002(86)90126-9 (May 15, 1986)
3. G. Cutler, et al., 2020, “An update on development of a cryogenically cooled-silicon mirror for the Advanced Light Source Upgrade project,” *Proc. SPIE* 11491, 114910F. https://doi.org/10.1117/12.2568101 (August 21, 2020)
4. G. Cutler, *et al.*, 2020, “A cantilevered liquid-nitrogen-cooled silicon mirror for the Advanced Light Source Upgrade,” *J. Synchrotron Rad.* 27, 1131. https://doi.org/10.1107/S1600577520008930 (2020)
5. L. Zhang, *et al*., 2013, "Thermal deformation of cryogenically cooled silicon crystals under intense X-ray beams: measurement and finite-element predictions of the surface shape." *J. Synchrotron Rad.* 20, 567. https://doi.org/10.1107/S0909049513009436 (2013)

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6. M. Rowen, M., J. Peck, and T. Rabedeau., 2001,"Liquid nitrogen cooled X-ray monochromator for high total power loads." *Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment* 467, 400. *ScienceDirect*, https://doi.org/10.1016/S0168-9002(01)00336-9 (July 21, 2001)

C57-08 THERMAL AND COLD NEUTRON BEAM TRANSPORT TECHNOLOGY FOR SCATTERING INSTRUMENTATION AT PULSED AND CONTINUOUS NEUTRON SOURCES

Maximum Phase I Award Amount: $200,000	Maximum Phase II Award Amount: $1,100,000
Accepting SBIR Applications: YES	Accepting STTR Applications: YES

Thermal and cold neutron scattering is a technique that provides unique information about materials due to the uncharged nature of the neutron, while still maintaining sensitivity to magnetic structures and different isotopes of the same chemical element. This topic seeks the development or improvement of equipment that would ultimately enhance neutron instrumentation capabilities towards meeting those goals at existing neutron sources. Additional information about neutron sources can be found here. Developments should improve performance by improving measured signal-to-noise, on-sample beam flux, or measurement resolution, or provide a novel capability that will enable new techniques at those neutron sources.

Grant applications are sought in the following subtopics:

a. Large-Scale Fabrication of Super-Mirror Reflection Surfaces for Neutron Guides, Mirrors, Polarizers and Filters

A domestic manufacturer is sought to develop the capability to fabricate and deliver neutron super-mirror guides and associated neutron optics systems, including traditional, polarizing, and non-depolarizing varieties. Thin-film Nickel/Titanium or Iron/Silicon nano-composite coatings on glass, silicon and metallic substrates are used to construct enclosed guide systems, singular and compound mirrors, as well as energy and polarization reflectors and filters. High-quality components of this kind are essential to prepare incident neutron beams for new and upgraded instruments at user-focused scattering facilities anticipated in the next five to ten years. Key requirements are:

i. Coated surfaces should be able to reflect neutron wavelengths of 2.0 Å up to 0.8º grazing incident angle (m=4) with reflectivity greater than 80%.
ii. Polarizing surfaces should provide polarization efficiency of 90% or better.
iii. Typical guide cross-section dimensions range from 4 cm to 15 cm, with complete segmented systems as long as 100 m.
iv. Guide systems can be split into multiple channels for optical or compact design purposes.
v. Enclosed guide volumes should maintain vacuum < 1 mbar or be purged with Helium. Non-enclosed optics must be able to reside in an evacuated or purged enclosure.

Questions – Contact: Mikhail Zhernenkov, Mikhail.Zhernenkov@science.doe.gov

b. Other

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In addition to the specific subtopic listed above, the Department invites grant applications in other areas that fall within the scope of the topic description above.

Questions – Contact: Mikhail Zhernenkov, Mikhail.Zhernenkov@science.doe.gov

References:

1. Saxena, AM T., and B. P. Schoenborn, 1977, "Multilayer neutron monochromators", *Acta Cryst.* A33, 805. *Foundations of Advances,* https://doi.org/10.1107/S056773947700196X (1977)
2. Elsenhans, O., *et al*., 1994, "Development of Ni/Ti multilayer supermirrors for neutron optics", *Thin Solid Films* 246, 110. *ScienceDirect,* https://doi.org/10.1016/0040-6090(94)90739-0 (June 15, 1994)
3. Hayter, J.B. and H. A. Mook, 1989. "Discrete thin-film multilayer design for X-ray and neutron supermirrors", *J. Appl. Cryst.* 22, 35., *Journal of Applied Crystallography*, https://doi.org/10.1107/S0021889888010003 (1989)

C57-09 SOFTWARE TOOLS AND DATA MOVEMENT SYSTEMS SOLUTIONS FOR HIGH BRIGHTNESS X-RAY SOURCES

Maximum Phase I Award Amount: $200,000	Maximum Phase II Award Amount: $1,100,000
Accepting SBIR Applications: YES	Accepting STTR Applications: YES

The complexity and production of experiment data is rapidly increasing at DOE's modern X-ray facilities, presenting enormous challenges in data acquisition, processing, analysis, storage, and management. These challenges, if left unresolved, will ultimately impact scientific productivity.

Grant applications are sought in the following subtopics:

a. Machine-Guided Visualization Tool to Explore and Coalesce Multi-Channel and Multi-Modal Nanoscale Imaging Data

Reconstruction software of nanoscale imaging data produces volumetric representations which are often multi-channel and multi-modal. However, visualizing such datasets is extremely difficult, often requiring substantial human effort to select suitable display parameters that can highlight the complex interactions among channels and modalities in a volumetric display. Current visualization tools do not scale well to multi-channel and multi-modal data, and they also do not offer machine-guidance to enable more rapid exploration, analysis, and validation. Given the multivariate complexity of the data such guidance would significantly accelerate the scientific discovery process.

Applications are being sought to develop a set of coordinated software tools that can simultaneously visualize multi-channel and multi-modal 2D and 3D microscopy/imaging datasets. These tools should use advanced methods to automatically select visualization parameters (such as color maps, brightness, contrast, thresholds, etc.) tuned to the scientific problem space and the underlying data, but at the same time allow the user to effectively participate in the analysis and discovery process. The system should become more intelligent with use and as such accelerate future analyses and discoveries.

Key performance requirements for the new tool are as follows:

- The new system should visualize all channels simultaneously. This would address a main shortcoming of the current state of the art implementation, allowing scientists to better and more expeditiously observe the spatial composition variation and chemical heterogeneity in the data.
- The new system should automatically generate a meaningful first impression about the data, and then provide effective selection and filtering tools by which users can control display complexity while exploring desired aspects of the data autonomously.
- The system should gain intelligence with use and learn associations among structures within the multi-channel and multimodal imagery from the user interactions within the visual interface.
- Additionally, the system should run on major operating systems and should be platform independent.

Questions – Contact: Eliane Lessner, Eliane.Lessner@science.doe.gov

b. Efficient High-Performance Data Transfer Over ESnet for Massive-Scale Data Analytics

Large ultra-high-rate detectors at modern X-ray light sources produce so much data that even modern storage systems struggle to keep up. To reduce the problem, it is common to include a data reduction pipeline to reduce the data volume by an order of magnitude or more. Nevertheless, even after data reduction, the data rate is still at multiple terabits per second, corresponding to multiple petabytes per day. Streaming data at such speeds over the Department's Energy Sciences Network (ESnet) from the X-ray light sources to a DOE supercomputing center, and, in the future, to the DOE's High-Performance Data Facility (HPDF), will be critical for real-time processing.

To tackle such high data rates, a proven way is to use a cluster of data transfer nodes (DTNs). Such setups are complex and costly, take up a lot of rack space, and consume significant energy to operate. Therefore, it's highly desirable that such DTN clusters be simplified with as few nodes as possible while keeping the energy efficiency high. A smaller cluster is inexpensive to acquire, set up, run, and it is also more manageable.

In principle, with the advance in hardware for both edge-to-core/cloud paradigms and for composable infrastructure (also known as disaggregated infrastructure), the traditional large footprint of a DTN cluster can be reduced. Many of the aforementioned modern hardware components, like Infrastructure Processing Units (IPU) and Data Processing Units (DPU), are more energy efficient by construction (e.g., by using low-power processors). Furthermore, after its introduction in 2002, the Linux kernel has replaced the epoll scalable IO interface. This makes it possible to design a far more efficient threading model for data movers, and with efficient software, it's possible to use fewer pieces of hardware. The result is an overall reduction of footprint and energy consumption, and a more manageable system.

Applications are encouraged to explore modern hardware components as used in composable infrastructure, in combination with original data mover software, that meet the four goals of simplifying, boosting efficiency, miniaturizing, and reducing the energy consumption of data transport systems at X-ray light sources. Applications must integrate novel software and hardware solutions.

Specifically, the new data mover system will:

i. Provide a small chassis/enclosure (2-4 rack units) that can replace the functionality of an entire DTN cluster.
ii. Host multiple DPUs in the enclosure, with each DPU able to utilize > 99% of its 400 Gb/s network interface over a wide area network.

iii. Access all the most common high-performance distributed file systems, including Lustre, WekaIO, GPFS, and S3-based object stores like CEPH and MinIO.
iv. Operate it like an appliance, if desired. Users who are not interested in the internals of the system will be able to operate it like a black box if they so desire.
v. Operate it in sync-up mode, if required. the user will be able to point the system to one or more folders in the distributed file system and the appliance will automatically copy all the files/objects that follow predefined patterns from the local to the remote site.
vi. Operate it in streaming mode, if required. In this mode, the appliance will start streaming the data as soon as it becomes available, not wait for the file to be closed.
vii. Provide both a graphical user interface and a command line interface for the user to control and monitor the appliance.
viii. Include 800 Gb/s capable DPUs if the relative technology becomes widely available within the lifetime of the project.

Questions – Contact: Eliane Lessner, Eliane.Lessner@science.doe.gov

c. Other

In addition to the specific subtopic listed above, the Department invites grant applications in other areas that fall within the scope of the topic description above.

Questions – Contact: Eliane Lessner, Eliane.Lessner@science.doe.gov

References: Subtopic a:

1. U.S. Department of Energy, 2019, Basic Energy Sciences, "Roundtable on Producing and Managing Large Scientific Data with Artificial Intelligence and Machine Learning", *OSTI,* https://www.osti.gov/biblio/1616153 (October 1, 2019)
2. U.S. Department of Energy, 2023, "Visualization for Scientific Discovery, Decision-Making, and Communication," *OSTI*, https://www.osti.gov/biblio/1845708/ (March 23, 2023)
3. U.S. Department of Energy, 2022, "Position Papers for the ASCR Workshop on Visualization for Scientific Discovery, Decision-Making, and Communication," *OSTI,* https://www.osti.gov/biblio/1843572/ (January 1, 2022)
4. U.S. Department of Energy, 2021, "Data Reduction for Science: Brochure from the Advanced Scientific Computing Research Workshop", *OSTI*, https://www.osti.gov/biblio/1770192 (April 15, 2021)

References: Subtopic b:

1. U.S. Department of Energy, 2019, Basic Energy Sciences, "Roundtable on Producing and Managing Large Scientific Data with Artificial Intelligence and Machine Learning", *OSTI,* https://www.osti.gov/biblio/1616153 (October 1, 2019)
2. U.S. Department of Energy, 2021, "Data Reduction for Science: Brochure from the Advanced Scientific Computing Research Workshop", *OSTI*, https://www.osti.gov/biblio/1770192 (April 15, 2021)
3. U.S. Department of Energy, 2022, "Energy Sciences Network, Science DMZ: Data Transfer Nodes", *Energy Science Network,* https://fasterdata.es.net/DTN/ (2022)
4. U.S. Department of Energy, 2022, "Energy Sciences Network, DTN tuning", *Energy Science Network*,
5. https://fasterdata.es.net/DTN/tuning/ (2022)

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6. Intel Corporation, 2022, "Intel® Infrastructure Processing Unit (Intel® IPU) and SmartNICs". *Intel*, https://www.intel.com/content/www/us/en/products/network-io/smartnic.html (2022)
7. NVIDIA Corporation, 2022, "NVIDIA BlueField Data Processing Units". *NVIDIA*, https://www.nvidia.com/en-us/networking/products/data-processing-unit/ (2022)
8. Linus Torvalds, 2022, "Development kernel 2.5.44 released", *LWN*, https://lwn.net/Articles/13197/ (October 18, 2022)

C57-10 SPIN-POLARIZED AND TIME-RESOLVED ELECTRON BEAM SOURCE FOR ELECTRON MICROSCOPY

Maximum Phase I Award Amount: $200,000	Maximum Phase II Award Amount: $1,100,000
Accepting SBIR Applications: YES	Accepting STTR Applications: YES

The development of a commercially viable electron source capable of providing an ultrafast pulsed and spin-polarized electron beam to be integrated with low-energy electron microscopes, particularly a spin-polarized low-energy electron microscope (SPLEEM) or a low-energy Scanning Electron Microscope (SEM), provides researchers with the ability to probe and manipulate the quantum degeneracy associated with electron spins. For example, a time-resolved, spin-polarized beam will enable real-space investigation of the dynamics of magnetic textures and magnetic domains, which is critical for the development of novel magnetic data storage, sensors, and spintronic devices. A spin-polarized, sub-picosecond, nm-scale source could differentiate between the effects of Coulomb pressure and the polarization-dependent degeneracy pressure in free electron antibunching, leading to a better understanding and harnessing of quantum degeneracy in magnetic materials. Probing the interplay between spins with low energy electron microscopy will pave the way for understanding and controlling phenomena depending on the spin texture of the surface, such as surface phase transitions, photo-chemical reactions, melting-crystallization processes, self-assembly, charge harvesting in solar cells, and switching in phase change memory. With the ability to operate on a femtosecond timescale and achieve nanometer-level resolution, the sought electron sources open avenues for exploring the intricate dynamics of magnetic materials and structures in unprecedented detail. This capability is highly desirable to further develop our understanding of nanoscale magnetic properties and processes, which dominate the performance of quantum spintronic devices. In combination with ultrafast spin-polarized low-energy electron diffraction (LEED) and imaging, such novel sources will enable us to understand the correlation between structure and magnetism in ultrafast processes on surfaces at the nanoscale.

Grant applications are sought in the following subtopics:

a. Development of a Commercially Viable Spin-Polarized and Time-Resolved Electron Gun from a GaAs Emitter

In this subtopic, we seek applications for the development of a pulsed, spin-polarized electron beam gun with a pulse width of the order of 100 fs at around 80 MHz [1], an emission current in the nA range [1], spin polarization near 20% [2], and a narrow beam energy distribution of the order of 200 meV [3,4]. The electron emission is stimulated by a circularly polarized pulsed fs-laser. Currently, ultrafast spin-polarized sources are not commercially available, yet they hold immense value for experiments on quantum degeneracy and pulse-probe measurements in spin-polarized low-energy electron microscopy (SPLEEM). The technique we seek to further develop in this topic builds upon established principles of continuous wave laser-excited, spin-polarized electron GaAs sources [5,6]. Initial demonstrations of pulsed laser-excited, spin-polarized electron pulses have yielded promising results using GaAs nanotip emitters and planar GaAs photocathodes where cesium and oxygen are deposited to lower the work function [3-6]. Phase I deliverables will consist of design studies of the pulsed emitter and initial test measurements aimed at addressing the technical specifications reported above, which will be extensively addressed in Phase II. The outcome of Phase II will be a prototype spin-polarized, pulsed electron gun that can be integrated into a commercial low-energy SEM or SPLEEM. An example of such a design is described in Ref. [7]. The final technical report should include a design of the sample holder, electron and laser guiding and focusing optics, and the surface preparation chamber where Cs is deposited on the cathode to lower the work function.

The choice between GaAs nanotip emitters and planar GaAs photocathodes should be carefully considered based on the specific application. Nanotips offer potentially higher coherence and brightness but are more challenging to fabricate and align with the excitation laser. Moreover, it remains unclear whether a reliable coating to lower the work function can be effectively applied to the nanotip apex. On the other hand, planar photocathodes are easier to handle and are extensively studied with respect to cesium and oxygen deposition for achieving a low work function, as well as the implementation of strain layers to increase spin polarization. But their emission area depends on the laser focus on the sample and is comparably larger. The suitability of electron excitation directly from pristine GaAs through multiphoton absorption or via a single photon absorption process in connection with work function lowering coatings also depends on the characteristics of the excitation laser, such as its wavelength and intensity.

Questions - Contact: Claudia Cantoni, claudia.cantoni@science.doe.gov

b. Other

In addition to the specific subtopic listed above, the Department invites grant applications in other areas that fall within the scope of the topic description above.

Questions - Contact: Claudia Cantoni, claudia.cantoni@science.doe.gov

References:

1. Brunkow, E., et al., 2019, *Femtosecond-laser-induced spin-polarized electron emission from a GaAs tip*, Appl. Phys. Lett. 114, 073502, AIP, Publishing, https://pubs.aip.org/aip/apl/article/114/7/073502/37090/Femtosecond-laser-induced-spin-polarized-electron (February 20, 2019)
2. Klaer, P., et al., 2013, *Spin-polarized photoelectrons resonantly excited by circularly polarized light from a fractional Ag film on GaAs(100)*, Phys. Rev. B 88, 214425, APS, https://journals.aps.org/prb/abstract/10.1103/PhysRevB.88.214425 (December 26, 2013)
3. Sanford and MacDonald, 1989, *Laser pulsed GaAs cathodes for electron microscopy,* J. Vac. Sci. & Techn. B 7, AIP Publishing, https://pubs.aip.org/avs/jvb/article/7/6/1903/1046516/Laser-pulsed-GaAs-cathodes-for-electron (November 1, 1989)
4. Kuwahara, M., et al., 2012, *30-kV spin-polarized transmission electron microscope with GaAs–GaAsP strained super lattice photo cathode*, Appl.Phys. Lett101,033102, AIP, https://pubs.aip.org/aip/apl/article/101/3/033102/24922/30-kV-spin-polarized-transmission-electron (July 16, 2012)

5. Clayburn, N., et al., 2013, *Search for spin-polarized photoemission from GaAs using light with orbital angular momentum,* Phys. Rev. B 87, 035204, APS, https://journals.aps.org/prb/abstract/10.1103/PhysRevB.87.035204 (January 22, 2013)
6. Pierce and Meier, 1976, *Photoemission of spin-polarized electrons from GaAs,* Phys. Rev. B 13, 5484, APS, https://journals.aps.org/prb/abstract/10.1103/PhysRevB.87.035204 (January 26, 2013)
7. Wan, W., et al., 2017, *Design and commissioning of an aberration-corrected ultrafast spin-polarized low energy electron microscope with multiple electron sources*, Ultramicroscopy 174, 89, ScienceDirect, https://www.sciencedirect.com/science/article/abs/pii/S0304399116304053 (March, 2017)

Additional information:
The five Nanoscale Science Research Centers (NSRCs) are DOE's premier user centers for interdisciplinary research at the nanoscale, serving as the basis for a national program that encompasses new science, new tools, and new computing capabilities. Each center has particular expertise and capabilities in selected theme areas, such as synthesis and characterization of nanomaterials; catalysis; theory, modeling and simulation; electronic materials; nanoscale photonics; soft and biological materials; imaging and spectroscopy; and nanoscale integration. These laboratories contain clean rooms, nanofabrication resources, one-of-a-kind signature instruments, and other instruments not generally available except at major user facilities. NSRC resources and capabilities are available to the international academic, industry and government research community for successfully peer-reviewed research projects at no cost for published research and at cost recovery for proprietary research.
For more information see:
https://science.osti.gov/bes/suf/User-Facilities/Nanoscale-Science-Research-Centers
NSRC Portal: https://nsrcportal.sandia.gov/

C57-11 ARTIFICIAL INTELLIGENCE/MACHINE LEARNING APPROACHES TO REVEAL STRUCTURE AND DYNAMICS OF FRACTURE SYSTEMS AND INDUCED SEISMICITY IN THE EARTH'S CRUST

Maximum Phase I Award Amount: $200,000	Maximum Phase II Award Amount: $1,100,000
Accepting SBIR Applications: YES	Accepting STTR Applications: YES

Although it has long been believed that earthquake foreshock sequences cannot be used to predict major earthquakes, recent breakthroughs in data science indicate that failure events in fractured rock may be preceded by signals continuously emitted from active fault systems that were previously believed to be noise (Bergen et al., 2019; Johnson et al. 2021).

Grant applications are sought in the following subtopics:

a. Development of AI/ML Data-Driven Algorithms for Assessing the Potential of Induced Seismicity
Applications are sought aimed at developing AI/ML data-driven algorithms (and, possibly, data collection/monitoring/characterization protocols) that can be used on geophysical signals to assess the potential for induced seismicity in geologic reservoirs used for energy extraction, storage, and storage of energy wastes. To be considered for funding, applications must demonstrate access to appropriate datasets

and demonstrate how the developed open-source algorithms and data collection protocols would advance the state-of-the-art.

Questions – Contact: Raul Miranda, Raul.Miranda@science.doe.gov

b. Other

In addition to the specific subtopic listed above, the Department invites grant applications in other areas that fall within the scope of the topic description above.

Questions – Contact: Raul Miranda, Raul.Miranda@science.doe.gov

References:

1. Bergen, K., et al., (2019) Machine learning for data-driven discovery in solid Earth geoscience, Science, Mar 22; 363(6433):eaau0323. doi: 10.1126/science.aau0323, *OSTI*, https://www.osti.gov/pages/biblio/1547596 (March 21, 2019)
2. Johnson, et al., (2021) Laboratory earthquake forecasting: A machine learning competition. Proceedings of the National Academy of Sciences 118 (5) e2011362118 doi:10.1073/pnas.2011362118, OSTI, https://www.osti.gov/pages/biblio/1762534 (January 1, 2021)

C57-12 RARE EARTH AND CRITICAL ELEMENTS RECOVERY VIA SELECTIVE MEMBRANES: AI/ML-GUIDED MEMBRANE DEVELOPMENT

Maximum Phase I Award Amount: $200,000	Maximum Phase II Award Amount: $1,100,000
Accepting SBIR Applications: YES	Accepting STTR Applications: YES

The separation of rare-earth elements (RE) and critical elements (CE) by organic or organometallic polymeric membranes usually occurs through three mechanisms: (1) complexation of RE or CE ions with extractants embedded in the membrane matrix, (2) adsorption of RE or CE ions on the surface-active sites on the membrane and (3) the rejection of RE or CE ions or complexes with organic functionalities present in the membrane. This topic seeks to optimize selectivity and rate of extraction or rejection using AI/ML methodology for the membrane synthesis design, the experimental design and the data analysis. The basic research and development must lead to hybrid models (physical/AI models) that incorporate the mentioned fundamental mechanisms and must lead to feasible material structures that would be readily synthesizable for large scale processes and complex systems, such as mine tail extractions, CE recovery from reprocessed materials, or separation of CE from sea water. Recent reports (references 1 and 2) pinpoint opportunities to increase the impact of fundamental research on applied technologies for RE and CE separations from complex solutions. Grant applications are sought in the following subtopics:

a. AI/ML Framework for Hybrid Data/Physics Modelling and Design of RE/CE Separation Membranes

The general goal is to produce physical models or hybrid data/physical models and design protocols that predict organic/organometallic membrane structure and performance for RE/CE separations from solution, with appropriate experimental validation from a subset of predicted structures. The platform materials and structures should be synthesizable organic or organometallic polymers functionalized appropriately to achieve separation selectivity, rate, and stability. An AI/ML supervisor algorithm should down-select the predicted structural variations on the basis of synthesizability and chemical stability in solution, based on empirical information obtained from well-known structural families, such as MOFs and COFs. The model and design protocol should be extensible to closely related families, that is, it should identify parameters and features that distinguish among the various structural families. While this topic calls for computational models and design protocols as products of the Phase I or II research, the SBIR or STTR company may partner with or subcontract other companies or institutions that synthesize membranes in order to produce the validation data.

Questions – Contact: Raul Miranda, Raul.Miranda@science.doe.gov

b. Other

In addition to the specific subtopic listed above, the Department invites grant applications in other areas that fall within the scope of the topic description above.

Questions – Contact: Raul Miranda, Raul.Miranda@science.doe.gov

References:

1. Bashiri, A., et al., 2022, Rare Earth Elements Recovery Using Selective Membranes via Extraction and Rejection, Membranes, 12(1), 80; https://doi.org/10.3390/membranes12010080 (January 11, 2022)
2. National Academies of Sciences, Engineering, and Medicine, 2019. *A Research Agenda for Transforming Separation Science*. Washington, DC: The National Academies Press. https://doi.org/10.17226/25421 (2019)

C57-13 HIGH PERFORMANCE MATERIALS FOR NUCLEAR APPLICATION

Maximum Phase I Award Amount: $250,000	Maximum Phase II Award Amount: $1,600,000
Accepting SBIR Applications: YES	Accepting STTR Applications: YES

To achieve energy security and clean energy objectives, the United States must develop and deploy clean, affordable, domestic energy sources as quickly as possible. Nuclear power will continue to be a key component of a portfolio of technologies that meets our energy goals. Nuclear Energy R&D activities are organized along four main R&D objectives that address challenges to expanding the use of nuclear power: (1) develop technologies and other solutions that can improve the reliability, sustain the safety, and extend the life of current reactors; (2) enable the deployment of advanced reactors to help meet the Administration's energy security and clean energy goals; (3) develop sustainable nuclear fuel cycles; and (4) maintain US leadership in nuclear energy technology.

To support these objectives, the Department of Energy is seeking to advance engineering materials for service in nuclear reactors.

Grant applications are sought in the following subtopics:

a. Powder Metallurgy-Hot Isostatic Pressing of High Temperature Metallic Alloys

Advanced manufacturing (AM) technologies can play an important role in reducing the fabrication costs of fission reactor components. Powder Metallurgy-Hot Isostatic Pressing (PM-HIP) shares many of the cost-saving attributes of the other AM methods such as powder bed fusion and directed energy deposition. Also, PM-HIP is a competitive and proven AM technology that is used in many non-nuclear industries to fabricate structural components. It can be readily deployed for advanced reactor applications. However, recent tests conducted on PM-HIP structural materials showed that while the mechanical properties are comparable to or better than wrought product at low temperatures, the high-temperature cyclic performance is less favorable. This is a challenge for advanced reactor applications, as creep-fatigue damage due to thermal transients from reactor operations is the most severe structural failure mode. The cause of the degradation in cyclic properties is currently not known, but it could be due to powder compositions, oxygen content, processing conditions, and/or other factors.

Applications are sought to develop an improved PM-HIP process for high-temperature alloys, including, but not limited to, powder chemistry specification, powder manufacturing, container manufacturing, container filling and outgassing, hipping parameters, container removal, so that the high-temperature fatigue, creep, and creep-fatigue properties of the fabricated components are the same as or exceed those of wrought product for very long design lifetimes.

Questions – Contact: Dirk Cairns-Gallimore, dirk.cairns-gallimore@nuclear.energy.gov

b. Salt Vapor Trap + Reversible Chlorine Gas Absorber Technology for Recovery and Recycle of Chlorine
Several molten chloride pyrochemical processes for recycling solid and molten chloride reactor fuels involve the generation of chlorine gas, such as electrolytic separations processes and conversion of fission product metal chlorides to metal phosphates. When the evolved chlorine gas has been enriched in ^{37}Cl or contains ^{36}Cl (formed from ^{35}Cl) it is essential to recover and recycle the chlorine to the molten chloride process salt or to new molten chloride reactor fuel. Therefore, there is a need for a remotely handled turnkey chlorine gas absorber system that can remove chlorine gas from an Ar/Cl_2 gas mixture. The Ar/Cl_2 gas mixture will also likely contain metal chloride vapors such as LiCl, KCl, or NaCl. For gas streams that contain chloride salt vapor, a reversible two-stage cartridge system that reversibly traps salt vapor in one stage and absorbs chlorine gas in the other stage would be one option. In order to minimize waste generation, both the salt vapor trap as well as the Cl_2 absorber must be reversible, clean, and regeneratable, i.e. capable of returning both the trapped chloride salt and absorbed Cl_2 gas to the system without additional impurities, thereby regenerating the trap and absorber materials for reuse. This project includes both the design of the cartridge-based system as well as development of the reversible salt vapor trap and Cl_2 absorber materials.

Questions – Contact: James Willit, James.Willit@nuclear.energy.gov

c. Other
In addition to the specific subtopics listed above, the Department invites grant applications in other areas that fall within the scope of the topic description above.

Questions – Contact: Dirk Cairns-Gallimore, dirk.cairns-gallimore@nuclear.energy.gov

Additional information:
Following an award, all DOE SBIR/STTR grant projects requiring high performance computing support are eligible to apply to use the DOE National Energy Research Scientific Computing Center (NERSC) resources. NERSC is the primary scientific computing facility for the DOE. If you think you will need to use the computing

capabilities of NERSC during your Phase I or Phase II project, you may be eligible for this free resource. Learn more about NERSC and how to apply for NERSC resources following the award of a Phase I or Phase II project at http://www.nersc.gov/users/accounts/allocations/request-form/.

References:

1. U.S. Department of Energy, 2021, Office of Nuclear Energy: Strategic Vision, *DOE,* https://www.energy.gov/ne/downloads/office-nuclear-energy-strategic-vision (July 9, 2021)
2. U.S. Department of Energy, 2021, Fuel Cycle Technologies, Office of Nuclear Energy, Science and Technology, *DOE*, http://www.energy.gov/ne/nuclear-reactor-technologies/fuel-cycle-technologies, (July 9, 2021)
3. U.S. Department of Energy, 2021, Nuclear Reactor Technologies, Office of Nuclear Energy, Science and Technology. *DOE*, http://www.energy.gov/ne/nuclear-reactor-technologies, (July 9, 2021)
4. Greene, S.R., Gehin, J. C., Holcomb, D. E., Carbajo, J. J., et al., 2010, Pre-Conceptual Design of a Fluoride-Salt-Cooled Small Modular Advanced High Temperature Reactor (SmAHTR), Oak Ridge National Laboratory, Oak Ridge, TN., (ORNL/TM-2010/199, p. 125), *Energy.gov*, http://info.ornl.gov/sites/publications/files/Pub26178.pdf, (December, 2010)
5. U.S. Department of Energy, 2017, Technology and Applied R&D Needs of Molten Salt Chemistry, *DOE*, https://www.ornl.gov/sites/default/files/Molten%20Salt%20Workshop_Final_092917.pdf, (2017)
6. Agca, C., Johnson, K., McMurray, J., Yingling, N., Bessman, T., 2021, FY21 status report on the Molten Salt Thermal Properties Database (MSTDB) development, ORNL/SPR-2021/2102, *OSTI*, https://www.osti.gov/biblio/1814280 (August 31, 2021)
7. Payam, A.F., Trewby, W., and Voitchovsky, K., 2017, Simultaneous viscosity and density measurement of small volumes of liquid using a vibrating microcantilever, Analyst, (142, 1492), *Journaling*, https://pubs.rsc.org/en/content/articlelanding/2017/an/c6an02674e (March 20, 2017)
8. Gavoille, T., Pannacci, N., Bergeot, G., Marliere, C., and Marre, S., 2019, Microfluidic approaches for accessing thermophysical properties of fluid systems, React. Chem. Eng., (4, 1721), *Publishing*, https://pubs.rsc.org/en/content/articlelanding/2019/re/c9re00130a (June 19, 2019)

C57-14 ADVANCED SUBSURFACE ENERGY TECHNOLOGIES

Maximum Phase I Award Amount: $200,000	Maximum Phase II Award Amount: $1,100,000
Accepting SBIR Applications: YES	Accepting STTR Applications: YES

Next-generation advances in subsurface technologies will enable access to more than 100 gigawatt-electric (GWe) of clean, renewable geothermal energy, as well as safer development of domestic oil and gas supplies. The subsurface can also serve as a reservoir for energy storage for power produced from intermittent generation sources, such as wind and solar. As such, understanding and effectively harnessing subsurface resources while mitigating impacts of their development and use are critical pieces of the Nation's forward energy strategy.

In order to advance the state of the art for such potential geothermal systems, the Department of Energy's Office of Basic Energy Science and Geothermal Technologies Office (GTO) have teamed together to support R&D in the subtopic below. The goal of this subtopic is to improve the accuracy of flow data measurements from individual production wells to enable improved management of geothermal reservoirs and power plants.

Grant applications are sought in the following subtopic:

a. Geothermal

This subtopic focuses on accurate measurement of flow data from production wells. Applications of interest under this subtopic should focus on the challenges related to improving technologies related to geothermal energy development in conditions with elevated temperatures (> 390°F or approximately 200°C) for purposes of energy production.

In general, measurement of geothermal reservoir production rates for purposes of power plant optimization is completed on a bulk level, i.e., reservoir/power plant efficiency is determined using the combined flow data from several production wells that have varying flow rates, temperatures, and liquid/vapor fractions. Utilizing the bulk production flow data for purposes of reservoir management is certainly a useful metric, but understanding of the production flow data based on individual wells would provide much greater insight on the evolution of geothermal reservoirs over time.

GTO is seeking projects that will provide innovative technologies and methods for accurate, continuous, real-time data of production flow rates, temperatures, liquid/vapor fractions, chemical composition, etc. from individual production wells. Proposed technologies may be based in the subsurface and/or on the surface. Of particular interest is the determination of liquid and vapor composition of liquid/steam produced by each production well before the brine is combined and sent to the power plant. The technical goal is to fully characterize multiphase flow systems from a thermodynamic standpoint in a way that allows operators to understand changes in individual production wells and/or zones of geothermal reservoirs.

A Phase I application should focus on proof of concept via engineering design, materials development, modeling, and/or laboratory scale testing (as applicable). Phase I efforts should be scalable to subsequent Phase II development including model validation, prototype development, and/or pilot or field-scale testing (as applicable).

Proposed projects with modeling or analysis components could propose analysis of new data sets, existing data sets within the Geothermal Data Repository (GDR) at https://gdr.openei.org/, or other existing data sets. DOE is seeking as much emphasis on open-source data and/or methods as possible.

Applications must be responsive to the subtopic of improving the accuracy of flow data measurements from individual production wells for purposes of creating electricity from geothermal energy. Applications focusing on measurement of flow data via traditional technologies, ground source heat pumps, direct use applications, or gathering of data that is not of interest under this subtopic via surface/downhole sensors will be deemed non-responsive.

Questions – Contact: William Vandermeer, william.vandermeer@ee.doe.gov

References:

1. Geothermal Technologies Office, U.S. Department of Energy, https://energy.gov/eere/geothermal
2. Department of Energy, *GeoVision: Harnessing the Heat Beneath our Feet,* Geothermal Technologies Office, U.S. Department of Energy, Sub-Action 1.3.5: Improve Well Life Cycles, https://www.energy.gov/eere/geothermal/geovision

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3. Department of Energy, Subsurface Science, Technology, Engineering, and R&D Crosscut (SubTER), U.S. Department of Energy, https://www.energy.gov/subsurface-science-technology-engineering-and-rd-crosscut-subter

C57-15 TECHNOLOGY TRANSFER OPPORTUNITIES: BASIC ENERGY SCIENCES

Maximum Phase I Award Amount: $250,000	Maximum Phase II Award Amount: $1,600,000
Accepting SBIR Applications: YES	Accepting STTR Applications: YES

Grant applications are sought in the following subtopics:

a. TTO: Advanced X-Ray Emission Spectrometer

To fully utilize the high flux and small beam size of DOE's X-ray synchrotron radiation sources, there is an urgent need for a giant leap forward in the manufacturing capabilities of advanced X-ray emission spectrometers that are required for simultaneous multi-element X-ray Emission Spectroscopy (XES) measurements. To meet these goals, Argonne National Laboratory researchers have developed a customizable strategy to manufacture and deploy advanced X-ray emission spectrometers at synchrotron beamlines (US Patent Pending #17/692,004). The high efficiency X-ray emission spectrometer is capable of simultaneous measurements of multiple emission lines for various X-ray emission techniques such as resonant XES, High Energy Resolution Fluorescence Detection X-ray Absorption Spectroscopy (HERFD-XAS), and microprobe measurements. The central purpose of the spectrometer is the simultaneous acquisition of spectra from multiple X-ray emission lines that can interrogate various mixed element species to extract electronic information such as spin dynamics/spin state, oxidation state and orbital interactions within the materials. The high efficiency, flexibility, and the ability to simultaneously measure a variety of emission lines that contain electronic and molecular information, as well as the relative ease of setup for the spectrometer module, will interest any synchrotron radiation facility with XES capabilities, as well as a variety of commercial laboratory X-ray sources. The current X-ray Emission Spectrometer (XES) includes up to 7 Kβ emission lines consisting of a variety of transition metal elements including Zn, Cu, Ni, Co, Fe, Mn, and Cr.

Partnership is sought with industry to rapidly commercialize this technique for wide applications at various synchrotron facilities and other X-ray delivery systems. The joint advanced R&D project will focus on the following aspects:

i. Improve XES hosting box and fly-path with metal enclosures for better sealing and X-ray shielding to minimize the scattering.
ii. Design and expand the current 7 element XES spectrometer to various sizes of pixel array area detectors.
iii. Scale-up the procedure for high-throughput crystal holder fabrication and crystal installation, aiming at experiment specific crystal sets for different X-ray emission spectrometers such as a set of crystals of Ni Kβ, Co Kβ, and Mn Kβ for Li-ion battery research.
iv. Investigate and expand the current 7 element XES spectrometer capability (Z from 24 to 30) to include an additional 18 elements (Z from 31 to 48).
v. Design a commercialization-ready assembly scheme for a revolving crystal holder that allows fast change of crystals and flexible operation to meet various experimental requirements at synchrotron beamlines such as X-ray emission mapping or/and time-resoled X-ray emission measurements. Crystal changes should be on the order of a few minutes.

vi. Design and integrate the advanced X-ray emission spectrometer with commercially available lab X-ray sources.
vii. Integrate the X-ray emission spectrometer with the Argonne X-ray Emission Analysis Package (AXEAP-1) for imaging data processing, and AXEAP-2 for analysis of X-ray emission spectra with a friendly user interface.

Licensing Information:
Argonne National Laboratory
Contact: Elina Kasman, ekasman@anl.gov, (630) 252-9395
ANL Technology ID: IN-21-050; IN-21-165, SF-21-050
Patent Status: US Patent pending #17/692,004

Questions – Contact: Dava Keavney, Dava.Keavney@science.doe.gov

b. TTO: Force-Neutral Adjustable Phase Undulator
Undulators are devices made of a linear array of periodic dipole magnets to produce high-brightness radiation, from infrared to hard X-rays, at synchrotron radiation and Free-Electron Laser facilities worldwide. Over the past few decades, these undulator sources have enabled revolutionary discoveries in various scientific, biomedical, and engineering disciplines. However, conventional undulators, which can be up to several meters long and more than two meters tall, are bulky, require a complex motion system, and are affected by inherent magnetic forces impacting the undulator's periodic magnetic structure. This makes their tunability to generate specific radiation wavelengths cumbersome, limited, and slow.

To overcome this limitation, Argonne National Laboratory (ANL) developed a next generation undulator that uses a force-neutral adjustable phase undulator (FNAPU) technology, making high-precision, long undulators more compact, cost effective to fabricate and assemble, and straightforward to operate. An FNAPU consists of adding to the primary adjustable phase undulator (APU) a magnet structure to neutralize the magnetic forces of the APU. Since the APU is a fixed gap undulator, using two additional rows of weaker magnets at a smaller gap will fully neutralize the magnetic forces when both structures have the same period length and are arranged to have the offset by a half period. The lower rows of the force compensation magnet structure and the undulator magnetic structure are fixed to the supporting frames. The upper magnet rows of both structures are mechanically coupled. To produce X-rays with variable polarization, two FNAPUs can be arranged in a crossed configuration to form an X-undulator.

The undulator tuning technology developed at ANL includes trajectory tuning using magnetic shims and correcting phase errors by reshaping the gap profile with mechanical shimming. These technologies can be applied for planar and X-undulators that produce X-rays with variable polarization. Moreover, multiple FNAPUs and X-undulators can be packed together to form a matrix undulator array, covering a more extensive X-ray energy range and broader applications.

Partnership is sought with industrial companies with proven records of building and delivering permanent magnet undulators to customers. Exact undulator specifications will depend on the application and the required radiation properties. It is expected that industrially produced FNAPUs will find their way to numerous synchrotron and Free-Electron Laser facilities around the world and will significantly advance the performance of light sources.

Licensing Information:
Argonne National Laboratory
Contact: Elina Kasman, ekasman@anl.gov, (630) 252-9395
ANL Technology ID: ID: DOE-S-164,091; ANL-IN-19-104; ANL-IN-21-171; ANL-IN-23-018
Patent Status: US Patent 11,222,741; US Provisional Patent 17/891,769 (field August 19, 2022)

Questions – Contact: Eliane Lessner, Eliane.Lessner@science.doe.gov

References: Subtopic a:

1. Solovyev, M., et al., 2021, *Rev. Sci. Instrum*. 92, 073105. *Review of Scientific Instruments,* https://doi.org/10.1063/5.0048726 (July 20, 2021)
2. Z Hwang, I.-H., Solovyev, M. A., Han, S.-W., Chan, M. K. Y., Hammonds, J. P., Heald, S. M., Kelly, S. D., Schwarz, N., Zhang, X. & Sun, C.-J., 2022, "AXEAP: A software package of X-ray emission data analysis using unsupervised machine learning", *J. Synchrotron Rad*. 29, 1309., *Journal of Synchrotron Radiation*, https://doi.org/10.1107/s1600577522006786 (2022)

References: Subtopic b:

1. Carr, R., 1991, "Adjustable phase insertion devices as X-ray sources," *Nucl. Instrum. Methods Phys. Res., Sect. A* 306, 391., *ScienceDirect*, https://doi.org/10.1016/0168-9002(91)90346-R (August 15, 1991)
2. Temnykh, Dale, Fontes, Lyndaker, Li, Ruff, Revesz, and Woll, 2016, "Chess upgrade with compact undulator magnets: operating experience and first results", 1741, 020003. *AIP Publishing,* https://doi.org/10.1063/1.4952782 (July 27, 2016)
3. Diviacco, Bracco, and Millo, 2019, "Fixed-gap Undulators for Elettra and FERMI", *Proc. IPAC'19*, Melbourne, Australia, p.1760. *JAWoW*, https://doi.org/10.18429/JACoW-IPAC2019-TUPRB033 (May 24, 2019)
4. Qian, Dejus, Piao, Vasserman, and Xu, 2021, "A New Method of Undulator Phase Tuning with Mechanical Shimming", *Proc. IPAC'21*, p.2912, *JAWoW*, https://jacow.org/ipac2021/papers/wepab129.pdf (2021)

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PROGRAM AREA OVERVIEW: OFFICE OF BIOLOGICAL AND ENVIRONMENTAL RESEARCH

The mission of the Biological and Environmental Research (BER) program is to support transformative science and scientific user facilities to achieve a predictive understanding of complex biological, earth, and environmental systems for energy and infrastructure security and resilience. The program seeks to understand the biological, biogeochemical, and physical principles needed to fundamentally understand and be able to predict processes occurring at the molecular and genomics-controlled smallest scales to environmental and ecological processes at the scale of planet Earth. Starting with the genetic information encoded in organisms' genomes, BER research seeks to discover the principles that guide the translation of the genetic code into the functional proteins and metabolic and regulatory networks underlying the systems biology of plants and microbes as they respond to and modify their environments. Gaining a predictive understanding of biological processes will enable design and reengineering of microbes and plants for improved energy resilience and sustainability, including improved biofuels and bioproducts, improved carbon storage capabilities, and controlled biological transformation of materials such as nutrients and contaminants in the environment. BER research also advances the fundamental understanding of dynamic, physical, and biogeochemical processes required to systematically develop process and Earth system models that integrate across the atmosphere, land surfaces, oceans, sea ice, coasts, terrestrial ecosystems, watersheds and subsurface required for predictive tools and approaches responsive to future energy and resource needs.

BER has interests in the following areas:

(1) Biological Systems Science subprogram carries out basic research to underpin development of sustainable bioenergy production and to gain a predictive understanding of carbon, nutrient, and metal transformation in the environment in support of DOE's energy and environmental missions. Genomic Science research is multifaceted in scope and includes a complementary set of activities in basic biological research focused on DOE's efforts in bioenergy development. The portfolio includes the DOE Bioenergy Research Centers (BRCs), team-oriented research within the DOE National Laboratories and focused efforts in plant feedstocks genomics, biosystems design, sustainability research, environmental microbiology, computational bioscience, and microbiome research. These activities are supported by a bioimaging technology development program and user facilities and capabilities such as the Joint Genome Institute (JGI), a primary source for genome sequencing and interpretation, the DOE Systems Biology Knowledgebase (KBase) for advanced computational analyses of "omic" data and, instrumentation at the DOE synchrotron light and neutron sources for structural biology. The research is geared towards providing a scientific basis for producing cost effective advanced biofuels and chemicals from sustainable biomass resources.

(2) Earth and Environmental Systems Sciences Division (EESSD) activities include fundamental science and research capabilities that enable major scientific developments in Earth system-relevant atmospheric and ecosystem process and modeling research in support of DOE's mission goals for transformative science for energy and national security. This includes research on components such as clouds, aerosols, terrestrial ecology, watersheds, terrestrial-aquatic interfaces, as well as modeling of component interdependencies under a variety of forcing conditions, interdependence of climate and ecosystem variabilities, vulnerability, and resilience of the full suite of energy and related infrastructures to extreme events, and uncertainty quantification. It also supports terrestrial ecosystem and subsurface biogeochemical research that advances fundamental understanding of coupled physical, chemical, and biological processes controlling energy byproducts in the environment. The subprogram supports three primary research activities, two national scientific user facilities, and a data activity. The two national scientific user facilities are the Atmospheric

Radiation Measurement Research Facility (ARM) and the Environmental Molecular Sciences Laboratory (EMSL). ARM provides unique, multi-instrumented capabilities for continuous, long-term observations and model-simulated high-resolution information that researchers need to develop and test understanding of the central role of clouds and aerosols on a variety of spatial scales, extending from local to global. EMSL provides a wide range of premier experimental and computational resources for studying the physical, biogeochemical, chemical, and biological processes that underlie DOE's energy and environmental mission. The data activity encompasses observations collected by dedicated field experiments, routine and long term observations accumulated by user facilities, and model generated information derived from Earth models of variable complexity and sophistication.

For additional information regarding the Office of Biological and Environmental Research priorities, visit https://science.osti.gov/ber/Research.

C57-16 URBAN MEASUREMENT TECHNOLOGY

Maximum Phase I Award Amount: $250,000	Maximum Phase II Award Amount: $1,600,000
Accepting SBIR Applications: YES	Accepting STTR Applications: YES

The Earth and Environmental Systems Sciences Division (EESSD) within the Biological and Environmental Research (BER) program has recently initiated a new focus on urban regions through development of an Urban Integrated Field Laboratories research effort (References 1-3). EESSD's objective for its urban research initiative is to advance the science underpinning understanding of the predictability of urban systems and their two-way interactions with the climate system and to provide the knowledge and information necessary to inform equitable climate and energy solutions that can strengthen community scale resilience across urban landscapes. As part of this focus on urban research, BER has identified the need for improved measurement technologies for urban regions.

This topic is focused on addressing measurement and data challenges to improve the spatial characterization of key atmospheric and environmental variables across urban regions. Urban regions are densely populated areas and are highly heterogeneous, i.e., having uneven distribution of physical landforms and vegetation, environmental processes, the built environment and infrastructure, population density, and socioeconomic clustering in the urban landscape. These complex, heterogeneous environments make representative measurements of urban regions and systems challenging. New sensors and/or tools to merge and visualize data from multiple sensors are required to address these challenges.

Some of the challenges of urban observations include: measurements conducted at a single location may not be representative of other areas in the urban region; properties and characteristics are likely to change rapidly over short distances and times and may be influenced by anthropogenic flows and sources of emissions, heat, and water; measurement techniques may not be designed for the variable surfaces and complex atmospheric flows experienced in urban areas; sensors need to be robust, self-cleaning, low powered, resistant to tampering; and data from disparate sources may need to be integrated to get a full view of the urban system (References 4-6).

Particular emphasis is placed on new measurement technologies that can provide information on spatial variabilities across urban regions and how these variabilities affect urban communities or that can provide observations for understanding biogeochemical cycling and atmospheric composition in urban systems. Of particular interest are individual or networked systems suitable for unattended and/or remote operation that have independent/low power requirements and on-board or centralized/remote data storage and download capability for extended unattended operation and data collection.

Applications to this topic could include new measurement sensors or instrument systems; low-cost or adaptable sensors that could be deployed in distributed networks or mounted on surface vehicles; or new tools for analysis or visualization of data merged from multiple sensors.

Applications to this topic that propose development or improvement of hardware should (1) demonstrate performance characteristics of the proposed technology, and (2) show a capability for deployment in urban environments. Phase I projects must perform feasibility and/or field tests of proposed technologies to assure the ability to survive the complex physical and human conditions common to an urban environment. Applications must provide convincing documentation (experimental data, calculations, and/or simulations as appropriate) to show that the proposed method is appropriate to make the desired measurements and can feasibly be deployed in urban environments without violating rules, regulations, and laws, including privacy concerns.

Applications proposing development of data visualization and analysis tools that merge data from multiple sensors must clearly explain the availability of the data to be used. Applications proposing collection of data from non-traditional sources (e.g., crowd-sourced, mobile phone, vehicle, or community-based observing data) must clearly explain the feasibility of collecting the proposed data, and how collection of such data will be done without violating rules, regulations, and laws, including privacy concerns.

Applicants are encouraged to consider novel and innovative approaches. Applications must clearly indicate how the proposed technology is a significant advance over existing commercially available technologies for the measurement variables of interest. Applications that propose only incremental improvements to existing sensors may be declined. Applications should clearly describe planned calibration, verification, and/or quality control procedures for any proposed instrument, sensor, or data product.

EXCLUSIONS/RESTRICTIONS:
Applications that include development of uncrewed aerial system (UAS) platforms, autonomous ground vehicles, autonomous aquatic vehicles, or development of sensors or control systems for such autonomous vehicles are not responsive and will not be accepted. However, use of data from existing UAS or other autonomous platforms in Subtopic b, “Urban Visualization and Data Analysis Tools”, is not excluded.

Applications for instrument development that propose only theoretical research and development and do not include development or modification of physical hardware in the Phase I application are not responsive and will not be accepted.

a. Urban Atmospheric Characterization

This subtopic solicits applications for novel and innovative measurement technologies for improved characterization of the spatial distribution of atmospheric properties in the urban boundary layer with a particular focus on boundary layer height, atmospheric turbulence, vertical wind profiles, aerosol composition, aerosol absorption, and aerosol size distribution, including coarse aerosols, pollen, and pollen fragments.

High spatial and temporal-resolution measurements of the boundary layer height, atmospheric turbulence, and vertical profiles of atmospheric wind speed and direction within and around urban regions are important for understanding transport and dispersion of atmospheric pollutants, the maintenance of the urban heat island, and large-scale flow within and around cities (References 7-8). Additionally, such profiles are needed for initializing and validating high-resolution urban models (Reference 9). The heterogeneity of the urban environment makes it challenging to characterize atmospheric flow features such as dead zones, eddies, and flow through street canyons and around built and natural structures in urban areas (Reference 9).

Existing measurement techniques such as radar wind profilers, Doppler lidars, scintillometry, and eddy covariance are increasingly being deployed in urban environments, but improvements in capabilities, size, power, cost, autonomous operation, reduced ground clutter, and portability are needed to make them more suitable for deployment as part of urban sensor networks (References 10-13). Additionally, improved methods for quality control, calibration, and interpretation of measured data over complex urban surfaces are needed (Reference 11).

In addition to measurements of quantities relevant to physical meteorology, measurements of aerosol properties are sought as well. Aerosol properties can vary significantly over short time and space scales in urban environments due to the variability of emission sources, transport and dispersion, and chemical transformations. Therefore, low-cost sensors capable of being deployed as sensor networks are needed to better characterize aerosol properties (coarse and fine) in urban environments (References 14-15). The impacts of atmospheric dust have recently been identified as masking some recent climate change, while other adverse effects are also well known (References 16-17). Similarly, pollen and pollen fragments may serve as ice nuclei and act synergistically with air pollutants to create other adverse effects (References 18-19).

While many low-cost sensors for measurement of aerosol particulate mass currently exist, measurements of aerosol size distributions, absorption, ice nucleating ability, surface properties, and composition are typically performed by more complex instruments. Applications are sought for development of low-cost, low-power sensors for aerosol particle size distribution, aerosol absorption, and/or aerosol composition and aerosol surface properties that are suitable for unattended and remote operation in urban environments.

Applications to this subtopic must clearly indicate how proposed sensors are an advance over existing commercially available technologies or existing sensors (e.g., increased capabilities; significantly lower size, power or cost) and why the proposed sensors are more suitable than existing commercial technologies for measurements in urban environments.

Questions – Contact: Jeff Stehr, Jeff.Stehr@science.doe.gov or Sally McFarlane, Sally.McFarlane@science.doe.gov

b. Urban Visualization and Data Analysis Tools
This subtopic solicits applications for novel and innovative visualization and data analysis tools for urban climate and environmental data to inform urban research, stakeholders and decision makers. Existing urban measurements are collected by a variety of agencies, organizations, and institutions and cover a wide range of data types, resolutions, and formats. Tools are needed to integrate, quality control, and visualize urban data sets from existing in situ networks, ground-based remote sensing data, aircraft or unmanned aerial vehicles,

satellite data, models, and other non-traditional data sources (such as edge devices) to make them easier to access by research and user communities.

Applications to this subtopic must propose data analysis or visualization tools that:

- Merge multiple different data types (i.e., in situ, remote sensing, or model data)
- Be applicable to multiple urban areas, measurements, and applications
- Consider measurement uncertainties
- Make use of machine learning, artificial intelligence, instrument simulators, or advanced statistical techniques for merging, intelligent mapping, gap filling, downscaling, interpolation, or derivation of additional environmental parameters
- Include a graphical user interface (GUI) or other easily used/configurable interface (i.e., one suitable for use by a wide variety of stakeholders)

Applications to this subtopic are strongly encouraged to:

- Couple urban climate/environmental data with building, energy, socioeconomic, demographic, modeling, and/or health impacts data to inform equitable climate and energy solutions
- Develop tools for neighborhood-scale visualization and analysis

Applications must clearly indicate what datasets will be integrated, the types of algorithms/approaches to be used, and how the proposed tools are an advance over commercial off the shelf software.

Questions – Contact: Justin Hnilo, justin.hnilo@science.doe.gov

c. Other

In addition to the specific subtopics listed above, the Department invites grant applications in other areas that fall within the scope of the topic description above.

Questions – Contact: Jeff Stehr, Jeff.Stehr@science.doe.gov, Sally McFarlane, Sally.McFarlane@science.doe.gov, or Justin Hnilo, Justin.Hnilo@science.doe.gov

References:

1. Department of Energy, Office of Science, 2023, Urban Integrated Field Laboratories (IFL) website https://ess.science.energy.gov/urban-ifls/ (June 26, 2023)
2. Ehleringer, J., Grimm, N., Hutyra, L., Janetos, A., and Leung, R., 2015, BERAC Workshop on Input for Development of an Integrated Field Laboratory With a Focus Incorporating Urban Systems as Part of Human – Earth System Interactions, Draft of BERAC IFL Initial Workshop Report, https://science.osti.gov/-/media/ber/berac/pdf/20150226/Draft_BERAC_Feb_IFL_workshop_report.pdf?la=en&hash=7908AF4FFA9B2B26B69AB4E6A0DBD7259A238E72 (June 21, 2023)
3. BERAC, 2017, Grand Challenges for Biological and Environmental Research: Progress and Future Vision; A Report from the Biological and Environmental Research Advisory Committee, DOE/SC–0190, BERAC Subcommittee on Grand Research Challenges for Biological and Environmental Research, https://science.osti.gov/-/media/ber/berac/pdf/Reports/BERAC-2017-Grand-Challenges-Report.pdf (June 21, 2023)

4. Muller, C.L., Chapman, L., Grimmond, C. S. B., Young, D. T., and Cai, X., 2013, Sensors and the City: a review of urban meteorological networks, International Journal of Climatology, (v. 33, p. 1585-1600), https://rmets.onlinelibrary.wiley.com/doi/abs/10.1002/joc.3678 (June 21, 2023)
5. Qian, Y., Chakraborty, T. C., Li, J., Li, D., He, C., et al., 2022, Urbanization Impact on Regional Climate and Extreme Weather: Current Understanding, Uncertainties, and Future Research Directions, Advances in Atmospheric Sciences, (p. 1-42), Springer Link, https://link.springer.com/article/10.1007/s00376-021-1371-9 (June 21, 2023)
6. Marquès, E., Masson, V., Naveau, P., et al., 2022, Urban Heat Island Estimation from Crowdsensing Thermometers Embedded in Personal Cars, Bulletin of the American Meteorological Society (103.4, E1098-E1113), https://journals.ametsoc.org/view/journals/bams/103/6/bams.103.issue-6.xml (June 21, 2023)
7. National Academies of Sciences, Engineering, and Medicine, 2012, Urban Meteorology: Forecasting, Monitoring, and Meeting Users' Needs, Washington, DC: The National Academies Press, https://doi.org/10.17226/13328 (June 21, 2023)
8. Menzer, O., Meiring, W., Kyriakidis, P. C., and McFadden, J. P., 2015, Annual sums of carbon dioxide exchange over a heterogeneous urban landscape through machine learning based gap-filling, Atmospheric Environment, (v. 101, p. 312–327), https://www.sciencedirect.com/science/article/abs/pii/S1352231014008644 (June 22, 2023)
9. Filioglou, M., Preissler, J., Troiville, A., Thobois, L., Vakkari, V., Auvinen, M., Fortelius, C., Gregow, E., Hämäläinen, K., Hellsten, A., Järvi, L., O'Connor, E., Schönach, D., & Hirsikko, A., 2022, Evaluating modelled winds over an urban area using ground-based Doppler lidar observations. Meteorological Applications, 29 (2), e2052, https://rmets.onlinelibrary.wiley.com/doi/full/10.1002/met.2052 (June 22, 2023)
10. Ward, H.C., 2017, Scintillometry in urban and complex environments: a review, *Meas. Sci. Technol*, (28 064005), https://iopscience.iop.org/article/10.1088/1361-6501/aa5e85 (June 22, 2023)
11. Biraud, S., Chen, J., Christen, A., Davis, K., Lin, J., McFadden, J., C. Miller, E. Nemitz, G. Schade, S. Stagakis, J. Turnbull, and R. Vogt. 2021. Eddy Covariance Measurements in Urban Environments, *AmeriFlux Urban Fluxes ad hoc committee;* https://ameriflux.lbl.gov/wp-content/uploads/2021/09/EC-in-Urban-Environment-2021-07-31-Final.pdf (May 29, 2023)
12. Cimini, D., Rizi, V., Di Girolamo, P., Marzano, F. S., Macke, A., Pappalardo, G., and Richter, A., 2014, Overview: Tropospheric profiling: state of the art and future challenges – introduction to the AMT special issue, *Atmos. Meas. Tech*., (7, 2981–2986), https://amt.copernicus.org/articles/7/2981/2014/ (June 22, 2023)
13. Liu, Z., Barlow J.F., Chan P.W., et al., 2019, A review of progress and applications of pulsed doppler wind LiDARs, Remote Sens. (11: 2522), *MDPI*, https://www.mdpi.com/2072-4292/11/21/2522 (June 22, 2023)
14. Munir, S., Mayfield, M., Coca, D. et al., 2019, Analysing the performance of low-cost air quality sensors, their drivers, relative benefits and calibration in cities—a case study in Sheffield, Environ. Monit. Assess. (191, 94), https://doi.org/10.1007/s10661-019-7231-8, (June 22, 2023)
15. Kimbrough, S., Clements, A., McArthur T., Cansler, J., and Deshmukh, P., 2020, Phoenix as a Test bed for Air Quality Sensors (P-TAQS) Sensor Pod Design, Operation, and Maintenance, *U.S. Environmental Protection Agency, Washington, DC,* (EPA/X-20/099), https://cfpub.epa.gov/si/si_public_record_Report.cfm?dirEntryId=349226&Lab=CEMM (June 22, 2023)
16. Kok, J.F., Storelvmo, T., Karydis, V.A. *et al.* Mineral dust aerosol impacts on global climate and climate change. *Nature Reviews Earth & Environment* 4, 71–86 (2023). https://doi.org/10.1038/s43017-022-00379-5 (June 22, 2023)

17. Liu C., Cai J., Chen R., Sera F., Guo Y., Tong S., Li S., Lavigne E., Correa P.M., Ortega N.V., Orru H., Maasikmets M., Jaakkola J.J.K., Ryti N., Breitner S., Schneider A., Katsouyanni K., Samoli E., Hashizume M., Honda Y., Ng C.F.S., Diaz M.H., la Cruz Valencia C., Rao S., Palomares A.D., Pereira da Silva S., Madureira J., Holobâc I.H., Fratianni S., Scovronick N., Garland R.M., Tobias A., Íñiguez C., Forsberg B, Åström C., Vicedo-Cabrera A.M., Ragettli M.S., Guo Y.L., Pan S.C., Milojevic A., Bell M.L., Zanobetti A., Schwartz J., Gasparrini A., Kan H. Coarse Particulate Air Pollution and Daily Mortality: A Global Study in 205 Cities. *American Journal of Respiratory and Critical Care Medicine*. 2022 Oct 15;206(8):999-1007. https://www.atsjournals.org/doi/10.1164/rccm.202111-2657OC (June 22, 2023)
18. Hader, J. D., Wright, T. P., and Petters, M. D.: Contribution of pollen to atmospheric ice nuclei concentrations, *Atmospheric Chemistry and Physics*., 14, 5433–5449, https://doi.org/10.5194/acp-14-5433-2014, 2014. (June 22, 2023)
19. Anenberg, S.C., Haines, S., Wang, E. et al. Synergistic health effects of air pollution, temperature, and pollen exposure: a systematic review of epidemiological evidence. *Environmental Health* 19, 130 (2020). https://ehjournal.biomedcentral.com/articles/10.1186/s12940-020-00681-z (June 22, 2023)

C57-17 COMPLEX DATA: ADVANCED DATA ANALYTIC TECHNOLOGIES FOR SYSTEMS BIOLOGY AND BIOENERGY

Maximum Phase I Award Amount: $250,000	Maximum Phase II Award Amount: $1,600,000
Accepting SBIR Applications: YES	Accepting STTR Applications: YES

The Biological and Environmental Research (BER) program supports transformative science to achieve a predictive understanding of complex biological, earth and environmental systems. BER's Biological Systems Science Division (BSSD) programs integrate multidisciplinary scientific discovery driven science with technology development to understand plant and microbial systems relevant to national priorities in sustainable energy and innovation in life sciences. BSSD program spans Bioenergy research focused on plant genomics, microbial conversion, sustainable energy, Biosystems Design (including secure biosystems design), and Environmental Microbiome Research. BSSD's Computational Biology, Biomolecular Characterization and Bioimaging (including Quantum enabled Bioimaging) programs combined with DOE User Facilities (such as the Joint Genome Institute https://gbc-word-edit.officeapps.live.com/we/jgi.doe.gov and the Environmental Molecular Sciences Laboratory https://www.emsl.pnnl.gov/science) serve as key enabling capabilities.

a. Complex Data: Advanced Data Analytic Technologies for Systems Biology and Bioenergy

BSSD science programs generate very large, complex, and multimodal data sets that have all the characteristics of Big Data – these data sets and associated analytics are critical to BSSD scientific discovery and bio-design applications. Technology improvements in biological instruments from sequencers to advanced imaging devices are continuing to advance at exponential rates, with data volumes in petabytes today and expected to grow to exabytes in the future. These data are highly complex ranging from high throughput "omics" data, protein structures, experimental and contextual environmental data across multiple scales of observations spanning molecular to cellular to multicellular scale (plants and microbial communities); multiscale 3D and 4D images for conceptualizing and visualizing spatiotemporal expression and function of biomolecules, intracellular structures, and the flux of materials across cellular compartments.

Currently, the ability to generate complex multi- "omic" environmental data and associated meta-datasets greatly exceeds the ability to interpret these data. The current need is for general solutions for managing and interpreting complex data and extracting knowledge and information from data sets rather than generating primary data. The objective of analytical and algorithmic approaches could include taxonomy but should also enable integration and functional connection of experimental components. The objective of generalized approaches to data integration should be generation of testable hypotheses and models that propose functional or causal connections among system components.

Innovative solutions and frameworks for management and analysis of large-scale, multimodal, and multiscale data leveraging artificial intelligence and machine learning methods, that enhance effectiveness and efficiency of data processing for investigations across spatial scales and scientific disciplines and computational approaches correlating protein structural data with genome sequencing and functional information are needed. These include interoperable computational platforms and data resources to facilitate specialized data workflows starting from data collection, processing, access, sharing, integration, and analysis for large-scale, integrated omics, instrumental, and imaging datasets. Novel approaches, software tools and modelling frameworks for managing, integrating, and analyzing 'big data' will be considered.

Questions – Contact: Ramana Madupu, Ramana.Madupu@science.doe.gov, or Resham Kulkarni Resham.Kulkarni@science.doe.gov

b. Other

In addition to the specific subtopics listed above, the Department invites grant applications in other areas that fall within the scope of the topic description above.

Questions – Contact: Ramana Madupu, Ramana.Madupu@science.doe.gov, or Resham Kulkarni Resham.Kulkarni@science.doe.gov

References:

1. U.S. Department of Energy, ASCR BER Exascale Requirements Review (GSP-Related Report) https://genomicscience.energy.gov/ascr-ber-exascale-requirements-review-gsp-related-report/ (June 22, 2023)
2. Stacey, G., Hungate, B.A., 2018, Scientific User Research Facilities and Biological and Environmental Research: Review and Recommendations https://science.osti.gov/-/media/ber/pdf/community-resources/2018/BERAC_UserFacilities_Report.pdf (June 22, 2023)
3. U.S. Department of Energy, 2021, DOE BER Biological Systems Science Division Strategic Plan, https://science.osti.gov/-/media/ber/pdf/bssd/BSSD_Strategic_Plan_2021_HR.pdf (June 22, 2023)
4. U.S. Department of Energy, 2022, Genomes to Structure and Function Workshop Report 2022 https://science.osti.gov/-/media/ber/pdf/workshop-reports/2023/Genomes-to-Structure-and-Function-Workshop-Report.pdf (June 22, 2023)
5. U.S. Department of Energy, 2023, Artificial Intelligence and Machine Learning for Bioenergy Research: Opportunities and Challenges, DOE/SC-0211. U.S. Department of Energy Office of Science and Office of Energy Efficiency and Renewable Energy. https://doi.org/10.2172/1968870 (June 22, 2023)

C57-18 ENABLING TOOLS FOR MOLECULAR STRUCTURE OR MORPHOLOGICAL CHARACTERIZATION OF BIOLOGICAL AND BIOGEOCHEMICAL INTERACTIONS WITHIN OR AMONG MICROBES, PLANTS, MINERALS, SOILS

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Maximum Phase I Award Amount: $250,000	Maximum Phase II Award Amount: $1,600,000
Accepting SBIR Applications: YES	Accepting STTR Applications: YES

BER supports research across scales to support missions in scientific discovery and innovation, energy security, and environmental responsibility. BER's Biological Systems Science Division (BSSD) seeks to understand the fundamental genome-encoded properties of plants and microbes that can be harnessed or redesigned for optimizing the production of biofuel and bioproducts. Functional interpretation of genomic information often requires additional molecular level characterization of individual proteins, protein assemblies and their interactions. Structural characterization of the macromolecules responsible for plant and microbial interactions, and rhizosphere processes, can provide insights into metabolism, molecular interactions, and function that aren't evident from genomic information. Structural and morphological characterization of organelles, cells and tissues provide insights into strategic spatio-temporal organization and process hierarchy. The knowledge described above is necessary for planning and designing optimized biological systems to meet BER mission needs.

BER's Environmental Systems Science program area examines complex ecological and hydro-biogeochemical processes within terrestrial and coastal systems to understand inherent and emergent properties of changes to Earth and environmental systems. Biogeochemical processes underlie the transport and transformation of nutrients; carbon sequestration and storage; and other molecular processes that impact the environment. Because oxidation-reduction reactions govern these critical processes, characterizing the chemistry and speciation of the molecular components gives insights into their participation in important environmental functions.

BER supports and provides access to powerful experimental approaches for structural and morphological characterization at scales from angstrom to millimeters, and temporal information in a range of femtoseconds to hours. The techniques available, which use electrons, photons, or neutrons as the interrogating probe, can be accessed for free at DOE Office of Science user facilities where BER supports access, training, and user support for a variety of experimental capabilities. These BER-supported capabilities are freely available to all researchers through peer-reviewed facility application processes. They are described at http://www.BERStructuralBioPortal.org.

This SBIR-STTR topic encourages the development of tools necessary for taking measurements on BER mission experiments using the experimental capabilities described at http://www.BERStructuralBioPortal.org.

a. Tools or Instruments for Structural or Morphological Characterization of Biological Systems Ranging from Atomic to Multi-cellular Scales

This subtopic solicits the development of robust tools that are needed to improve facility-based structural biology and imaging capabilities for researchers studying microbial, plant, rhizosphere or environmental systems, or their components, relevant to BER mission interests. Applications must include an explicit intention and explanation for utility of the tools in characterizing a biological or biogeochemical system clearly relevant to BER mission space (see https://genomicscience.energy.gov/ and https://ess.science.energy.gov/). An explanation of how the proposed technical development can be coupled to biological or biogeochemical objectives must be included. Plans for technical validation in biological or biogeochemical space of the proposed technology should be clearly described.

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For this solicitation, tools, devices, or automation can be proposed for characterizing targets at or within the atomic to multi-cellular scale. Technology areas include facility-based x-ray, neutron or infrared beamline-based techniques and cryo-electron microscopy or tomography, or micro-electron diffraction, for determining the 3D structures of macromolecules, macromolecular complexes, cells, cellular components or tissues, or soils and soil components. Examples of concepts responsive to this announcement include but are not restricted to tools or instruments for sample preparation, handling, positioning or detection; robotics or other automation approaches; beam focus or alignment with specific value to BER targets of interest; and tools that aid correlative approaches.

The purpose is to encourage development and commercialization of tools that ease use, improve results, or overcome obstacles associated with existing technologies.
Algorithm development, software or informatics solutions are not included under this subtopic, but could be submitted under the SBIR/STTR Topic C57-17, "COMPLEX DATA: ADVANCED DATA ANALYTIC TECHNOLOGIES FOR SYSTEMS BIOLOGY AND BIOENERGY".

Questions – Contact: Amy Swain, Amy.Swain@science.doe.gov

b. Other

In addition to the specific subtopics listed above, the Department invites grant applications in other areas that fall within the scope of the topic description above.

Questions – Contact: Amy Swain, Amy.Swain@science.doe.gov

References:

1. U.S. Department of Energy, 2021, BER BSSD Strategic Plan https://genomicscience.energy.gov/doe-ber-biological-systems-science-division-strategic-plan/ (June 22, 2023)
2. U.S. Department of Energy, 2023, BER Environmental Systems Science program https://ess.science.energy.gov/ (June 22, 2023)
3. U.S. Department of Energy, 2023, BER BSSD Genomic Science Program https://genomicscience.energy.gov/ (June 22, 2023)
4. U.S. Department of Energy, 2023, BER Environmental System Science program https://ess.science.energy.gov/?s=biogeochemical (June 22, 2023)
5. U.S. Department of Energy, 2023, BER Structural Biology and Imaging Resources http://www.BERStructuralbioportal.org (June 22, 2023)
6. U.S Department of Energy, Office of Biological and Environmental Research, 2017, Technologies for Characterizing Molecular and Cellular Systems Relevant to Bioenergy and Environment Workshop, September 21-23, 2016, DOE/SC-0189. https://www.osti.gov/biblio/1471216 (June 22, 2023)
7. U.S. Department of Energy, Office of Biological and Environmental Research, 2021, *Biological Systems Science Division, Strategic Plan* https://genomicscience.energy.gov/wp-content/uploads/2021/09/BSSD_Strategic_Plan_2021_HR.pdf (June 22, 2023)

C57-19 BIOIMAGING TECHNOLOGIES FOR BIOLOGICAL SYSTEMS

Maximum Phase I Award Amount: $250,000	Maximum Phase II Award Amount: $1,600,000
Accepting SBIR Applications: YES	Accepting STTR Applications: YES

The Bioimaging Science Technology development effort in BER is targeted at creating multifunctional technologies to image, measure, and model organisms, tissues, and key metabolic processes within biological systems of microbial cells and multicellular plant tissues. BER's current focus on developing a scientific basis for plant biomass-based biofuel production requires detailed understanding of the interaction among plant tissues and microbes. In complex communities the identity of cellular and tissue components under different environmental and physical conditions is a necessary first step to prioritize advantageous and deleterious organismal interactions. Further, the ability to track materials and chemical exchanges within and among cells and their environment is crucial to understanding the activity of microbial communities in environmental settings. Grant applications are sought in the following subtopics:

a. Automated Bioimaging Devices for Structural and Functional Characterization of Plant and Microbial Communities

Applications are invited that develop automated stand-alone imaging and measurement microscopes, instrumentation, or analysis software that can identify microbial species, tissue characteristics and chemical exchanges under different environmental and physical conditions. The output should be derived from imaging systems and should generate and manage large complex data sets. Automation must include aspects of instrumentation control, image acquisition, and data storage, and might also include automated data analysis. Automated systems that characterize multiple metabolic or phenotypic transformations and should measure more than one parameter and enable characterization of the relationship among parameters. The system should provide the integrative systems-level data needed to gain a more predictive understanding of complex biological processes relevant to BER. Systems should have a detailed intention for utility in solving a well described biological problem within the scope of the mission of BER. Initial technical development should be coupled to intended biological objectives and plans for technical and biological validation should be clearly described.

The instrumentation and devices to be developed for imaging biological systems will have high likelihood to enable an understanding of the elements of complex biological systems or ecological niches related to bioenergy or a bioeconomy. The instrumentation would be capable of identifying individual species, tissues, organelles, or biological and structural components in an image and discover the physical conditions, spatial/temporal relationships, physical connections, and chemical exchanges that facilitate the flow of information and materials among organisms or biological components. The primary interest for this solicitation is for innovative bioimaging devices with small footprints, which are fully capable of operation independently of heavy equipment and large instruments (e.g., neutron and light sources, cry electron microscopes, high resolution mass spectrometers), and can be easily deployed in public and private sector to make them accessible to the larger scientific community. Instrumentation could use culture chambers in a laboratory setting with defined biological constructs or could be deployed for field-based evaluation of plants and microbes. The instrumentation should be able to characterize biological systems in controlled physical chemical and environmental conditions for validation and investigate biological systems under experimental conditions that support basic research to understand and optimize biomass-based biofuel production and a bioeconomy.

Instrumentation originally developed for biomedical research could be adapted to investigate biological research supported by BER. However, real, or perceived device developments for medical imaging and/or applications including disease diagnostics or therapies in biological, animal and/or human systems are excluded.

Algorithm development and software that supports instrumentation for the generation of biological images, data and knowledge would be included in this topic. However, general informatics solutions are not included under this subtopic. However, applications for the management and analysis of large-scale, multimodal, and multiscale data leveraging artificial intelligence and machine learning methods could be submitted under the SBIR/STTR Topic C57-17 “COMPLEX DATA: ADVANCED DATA ANALYTIC TECHNOLOGIES FOR SYSTEMS BIOLOGY AND BIOENERGY”.

Tools that support facility-based x-ray, neutron or infrared beamline-based techniques and cryo-EM/ET or micro-ED for determining the 3D structures of macromolecules, macromolecular complexes, cells, cellular components, or tissues are not included under this subtopic. However, tools that ease use, improve results, or overcome obstacles associated with existing technologies could be supported under the SBIR/STTR Topic C57-18, “ENABLING TOOLS FOR MOLECULAR STRUCTURE OR MORPHOLOGICAL CHARACTERIZATION OF BIOLOGICAL AND BIOGEOCHEMICAL INTERACTIONS WITHIN OR AMONG MICROBES, PLANTS, MINERALS, SOILS”

Questions – Contact: Paul Sammak, Paul.Sammak@science.doe.gov

b. Quantum Enabled Bioimaging and Sensing Approaches for Bioenergy

Applications are invited that employ innovative, use-inspired technologies that exploit quantum phenomena to surpass limitations of classical optics including resolution and detection limits, signal-to-noise ratio, limitations on temporal dynamics, long term signal stability, sample photodamage and limited penetration, or selective biomolecule sensing. Quantum approaches should propose a comparative advantage over competing classical optical methods. Processes of interest to BER include measuring the chemical and physical environment within individual cells or organelles, enzyme function within cells, tracking metabolic pathways in vivo, monitoring the transport of materials into and out of cells or across cellular membranes and, measuring signaling processes between cells and within plant-microbe and microbe-microbe interactions. Measuring extracellular environmental characteristics including physical and chemical parameters in plants, soil-based rhizosphere communities, or synthetic model systems of microbe communities would also be of interest. Imaging in 2 or 3 dimensions is emphasized while time varying measurements are desirable but not necessary in early-stage development. Networks of quantum-enabled sensors that provide discontinuous but expansive environmental maps of measurements might also be considered if spatial or temporal resolution are appropriate to the biological or environmental problem to be addressed.

Current technical limitations and challenges associated with optical imaging and microscopy include: 1) depth imaging - light scattering and diffraction in biological tissue, a major barrier to imaging biological processes deep within tissue (plants or rhizosphere) - restricts optical microscopy to superficial layers, leaving many important biological questions unanswered; 2) photo-damage - classical high flux multiphoton optical imaging causes photo-damage to cellular viability and perturbation to molecular biology for in situ imaging of biological processes in living systems, rendering the sample useless for repeat imaging and measurement of dynamic processes to be performed within the same biological system over different time intervals; and 3) suboptimal stability, brightness and photo-bleaching of the fluorophore when used in combination with an optical imaging approach.

Under this subtopic, applications are sought to explore new quantum science-enabled light sources, imaging detectors or biosensors envisioned to overcome the current challenges of in-depth imaging including associated scattering and diffraction problems, and suboptimal stability and photo-bleaching issues to enable prolonged imaging studies. Quantum entanglement imaging could also be combined with quantum science-based probes for sensing and measurement. These probes can be tailor-made to have high multiphoton cross-sections, multiple chemical functionalities for protein binding and molecular tracking properties, spectrally tunable emission, and quantized absorption/emission states to enable high absorption of multiple entangled photons. Quantum-based biosensors might also detect other physical or chemical cues from the local biological environment and report conditions with photon emissions. Such systems may offer substantial improvement in signal detection and spatial and spectral selectivity by utilizing non-classical properties of light under low excitation power without causing significant photo-damage to cell composition or perturbing the natural biological processes within the cell. Quantum sensor signal readout could be optical or other non-optical methods including electromagnetic or particle detection.

This subtopic for applications seeks fundamental research towards development of new quantum science-enabled probes and sensors applicable for imaging of plant and microbial systems relevant to bioenergy and environmental research conducted within BER programs. These quantum approaches and imaging systems would need to visualize cellular structures and processes in a nondestructive manner, and at sufficient resolution to enable the validation of hypotheses of cellular function occurring in depth. Systems capable of cellular dynamics in vivo would be encouraged but not required. Some research areas of major emphasis within BER include understanding plant metabolism impacting cell wall composition/decomposition, deconstruction of plant polymers (lignin, cellulose, hemicellulose) to monomers, engineered microbial pathways for conversion of plant biomass-derived substrates to fuels and chemicals, and signaling and interactions within environmental microbiomes. Investigations at a larger scale including rhizosphere or whole plant responses to changing environments.

This subtopic for Applications encourages the development of new quantum-based imaging approaches and demonstration of their utility for imaging biological systems of relevance to bioenergy and environmental research. Potential applications should address one or more of the topics according to examples outlined below, for prototype development:

- New quantum entanglement-based approaches for probes and sensors, to allow the observation and characterization of multiple complex biological processes occurring in depth within plant and microbial systems nondestructively or in living matter in real-time.
- New quantum entanglement enabled imaging devices with desirable photon intensities and wavelengths to overcome the problems of diffraction and scattering to allow the detection of image signals occurring in depth in a 3D volumetric composition within living plant and microbial systems.
- Quantum-enabled sensors of selective biomolecules, metabolites, or physical and chemical environments either within or outside of cells and microbes.

EXCLUSIONS/RESTRICTIONS:

- Real or perceived developments for medical imaging and/or applications including disease diagnostics or therapies in biological, animal and/or human systems are excluded.
- Standalone development of quantum dots for routine or innovative biological imaging experiments is excluded.

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- The use of commercially available quantum dots (QDs), probes, or sensors as standards for data calibration and to study instrument performance for optical imaging experiments as a part of research application, are excluded from consideration.

Questions – Contact: Paul Sammak, Paul.Sammak@science.doe.gov

c. Other

In addition to the specific subtopics listed above, the Department invites grant applications in other areas that fall within the scope of the topic description above.

Questions – Contact: Paul Sammak, Paul.Sammak@science.doe.gov

References: Subtopic a:

1. U. S. Department of Energy, 2022, Bioimaging Science Program, Principal Investigator Meeting Proceedings, *Office of Science*, https://genomicscience.energy.gov/wp-content/uploads/2022/06/Bioimaging_Science_Program_PI_Meeting_Proceedings_2022_No_Bib.pdf (June 22, 2023)
2. Jabusch, L.K., et al, 2021, Microfabrication of a Chamber for High-Resolution, In Situ Imaging of the Whole Root for Plant–Microbe Interactions, National Library of Medicine, 2021, https://www.ncbi.nlm.nih.gov/pmc/articles/PMC8348081/. (June 22, 2023)
3. Miller, L. et al., 2019, Fluidic Chamber for root-fungi culture: Increasing access to microfluidics for studying fungi and other branched biological structures, *Fungal Biology and Biotechnology*, https://fungalbiolbiotech.biomedcentral.com/articles/10.1186/s40694-019-0071-z. (June 22, 2023)
4. Hansen, R, et al., 2022, Microwell arrays for bacterial community culture, Stochastic Assembly of Bacteria in Microwell Arrays Reveals the Importance of Confinement in Community Development. *PLOS ONE (2016).* https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0155080 (June 23, 2023)

References: Subtopic b:

1. U.S. Department of Energy, 2022, DOE BER Market Research Study: Transitioning Quantum Imaging and Sensing Technologies to Bioimaging Markets, https://science.osti.gov/-/media/sbir/pdf/Market-Research/DOE_QuantumSenorTechToMarket-071422.pdf (June 23, 2023)
2. U. S. Department of Energy, 2021, Quantum-Enabled Bioimaging and Sensing Approaches for Bioenergy, *Office of Science, Biological and Environmental Research*, https://science.osti.gov/grants/FOAs/FOAs/2022/DE-FOA-0002603 (June 23, 2023)
3. Subcommittee On Quantum Information Science Committee On Science Of The National Science & Technology Council, 2022, Bringing Quantum Sensors to Fruition, https://www.quantum.gov/wp-content/uploads/2022/03/BringingQuantumSensorstoFruition.pdf (June 23, 2023)

C57-20 DELIVERY TECHNOLOGIES FOR GENETIC ENGINEERING BIOENERGY CROPS

Maximum Phase I Award Amount: $250,000	Maximum Phase II Award Amount: $1,600,000
Accepting SBIR Applications: YES	Accepting STTR Applications: YES

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Genetic engineering is essential to accelerate breeding efforts and to improve traits in ways unachievable by classical breeding. In bioenergy and biomass crops, traits of interest could include end-use applications for biofuels and bioproducts to offset reliance on fossil resources, or plant tolerance to abiotic and biotic stress (1-3). This topic seeks to support new methods to engineer plant genomes for a clean energy future. A key challenge for the implementation of genetic engineering is transformation, the process of introducing DNA or protein into plant cells and regenerating engineered plants (4-6). Current methods to transform bioenergy crops are often time-consuming, technically challenging, and germplasm dependent, hindering the pace of development of bioenergy crops with improved traits (1; 7-10). Strategies to simplify and shorten the transformation process, develop cultivar independent protocols, and perform genetic modification without DNA integration are all needed (4-6; 11). One opportunity to address these limitations is to improve the delivery of nucleic acids and/or proteins into plant cells.

a. Improved Delivery Technologies

The objective of this subtopic is to support the development and commercialization of new technologies that deliver nucleic acids and/or protein into cells to facilitate the development of engineered bioenergy crop plants. Applications should clearly state how the technology will ease use and/or overcome obstacles associated with current delivery technologies. Qualifying technologies include but are not limited to tools that simplify protocols, reduce, or eliminate time in tissue culture, or facilitate gene editing without incorporation of foreign DNA. Phase I applications should focus on design, development, and optimization at the lab scale. It is highly recommended that applicants discuss their technology with the program contact to ensure fit prior to applying.

Questions – Contact: Kari Perez, Kari.Perez@science.doe.gov

b. Other

In addition to the subtopic listed above, the Department invites grant applications in other areas that fall within the scope of the topic description above. It is highly recommended that applicants discuss their technology with the program contact to ensure fit prior to applying.

Questions – Contact: Kari Perez, Kari.Perez@science.doe.gov

References:

1. Nelson, R.S., et al., 2017, Development and use of a switchgrass (Panicum virgatum L.) transformation pipeline by the BioEnergy Science Center to evaluate plants for reduced cell wall recalcitrance Biotechnol Biofuels, *Biotechnology for Biofuels and Bioproducts*, 10:309. https://doi.org/10.1186/s13068-017-0991-x (June 23, 2023)
2. Hamdan, M.F., et al.,2022, Genome Editing for Sustainable Crop Improvement and Mitigation of Biotic and Abiotic Stresses, *Plants*, 11:2625. https://doi.org/10.3390/plants11192625 (June 23, 2023)
3. Muguerza, M.B., et al,2022, Tissue Culture and Somatic Embryogenesis in Warm-Season Grasses—Current Status and Its Applications: A Review, *Plants*, 11:1263. https://doi.org/10.3390/plants11091263 (June 23, 2023)
4. Altpeter et al., 2016, Advancing Crop Transformation in the Era of Genome Editing, *The Plant Cell*, 28:1510. https://doi.org/10.1105/tpc.16.00196 (June 23, 2023)

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5. Anjanappa, R.A. and Gruissem, W, 2021, Current progress and challenges in crop genetic transformation, *Journal of Plant Physiology*, 261: 153411, https://doi.org/10.1016/j.jplph.2021.153411 (June 23, 2023)
6. Hopp, H.E. et al.,2022, Editorial: Plant Transformation, *Frontiers in Plant Science*, 13: 18. https://doi.org/10.3389/fpls.2022.876671 (June 23, 2023)
7. Xi, Y., et al., 2009, Agrobacterium-Mediated Transformation of Switchgrass and Inheritance of the Transgenes, *Bioenergy Research*, 2:275–283. https://doi.org/10.1007/s12155-009-9049-7 (June 23, 2023)
8. Lin, C-Y. et al., 2017, Evaluation of parameters affecting switchgrass tissue culture: toward a consolidated procedure for Agrobacterium-mediated transformation of switchgrass (Panicum virgatum),*Plant Methods*, 13:113. https://doi.org/10.1186/s13007-017-0263-6 (June 23, 2023)
9. Silva, T.N., et al., 2022, Progress and challenges in sorghum biotechnology, a multipurpose feedstock for the bioeconomy, *Journal of Experimental Botany*, 73:646. https://doi.org/10.1093/jxb/erab450 (June 23, 2023)
10. Trieu, A. et al., 2022, Transformation and gene editing in the bioenergy grass Miscanthus, *Biotechnology for Biofuels and Bioproducts*, 15:148 https://doi.org/10.1186/s13068-022-02241-8 (June 23, 2023)
11. Son, S. and Park, S.R., 2022, Challenges Facing CRISPR/Cas9-Based Genome Editing in Plants, *Front. Plant Sci*., 13:902413. https://doi.org/10.3389/fpls.2022.902413 (June 23, 2023)

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PROGRAM AREA OVERVIEW: OFFICE OF FUSION ENERGY SCIENCES

FES's mission is to expand the fundamental understanding of matter at very high temperatures and densities and to build the scientific foundation needed to develop a fusion energy source. This is accomplished through the study of plasma, the fourth state of matter, and how it interacts with its surroundings.

Once developed, fusion will provide a clean energy source well-suited for on-demand, dispatchable electricity production, supplementing intermittent renewables and fission. Energy from fusion will be carbon-free, inherently safe, with a virtually limitless fuel supply, and without the production of long-lived radioactive waste. Among the priorities of the program is to address the science and technology needs for the design basis of a Fusion Pilot Plant (FPP). To accelerate this move to a fusion based clean energy source, the administration "is developing a bold decadal vision to accelerate fusion – a clean energy technology that uses the same reaction that powers the Sun and stars".

To achieve its mission, FES invests in flexible U.S. experimental facilities of various scales, international partnerships leveraging U.S. expertise, large-scale numerical simulations based on experimentally validated theoretical models, development of advanced fusion-relevant materials, future blanket concepts and tritium fuel cycle, and invention of new measurement techniques.

In addition to its fusion energy mission, FES also supports discovery plasma science, which is focused on research at the frontiers of basic and low temperature plasma science (with applications to microelectronics) and high-energy-density laboratory plasmas.

Finally, FES invests in transformational technologies such as artificial intelligence and machine learning (AI/ML), fundamental science to transform advanced manufacturing, and quantum information science (QIS), that have the potential to accelerate progress in several mission areas.

The following topics are restricted to advanced technologies and materials for fusion energy systems, fusion science, technology relevant to magnetically confined plasma, high energy density laboratory plasmas and low temperature plasmas.

For additional information regarding the Office of Fusion Energy Sciences priorities, click here.

C57-21 FUSION MATERIALS

Maximum Phase I Award Amount: $200,000	Maximum Phase II Award Amount: $1,100,000
Accepting SBIR Applications: YES	Accepting STTR Applications: YES

Fusion materials and structures must function for extended lifetimes in a uniquely hostile environment that includes a combination of high temperatures, high stresses, reactive chemicals, and intensely damaging radiation. The goal of this program is to establish the feasibility of designing, constructing and operating a fusion power plant with materials and components that meet demanding objectives for safety, performance, economics, and environmental impact.

Grant applications are sought in the following areas:

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a. Advanced and Additive Manufacturing Technologies

Advanced and additive manufacturing will enable the realization of resilient components that are essential to survive the harsh fusion environment and to optimize system performance. The novel features enabled by advanced manufacturing and additive manufacturing includes complex geometries and transitional structures; the potential for local control of material microstructure; rapid design-build-test iteration cycles; and exploration of fundamentally new types of materials and structures. Applications are sought to develop these emerging technologies, with a focus on enabling resilient materials and components for future fusion energy systems.

Questions – Contact: Guinevere Shaw, guinevere.shaw@science.doe.gov

b. Neutron Source Enabling Technologies and Components

The scientific and engineering demonstration of fusion energy will require mastering materials science and performance issues, particularly those associated with materials degradation due to bombardment by the energetic (14.1 MeV) deuterium-tritium (D-T) fusion neutrons. This performance degradation provides the basis for and is one of the single largest inherent limiting factors for the economic, safety, and environmental attractiveness of fusion energy. As such, the FES program places a high priority on gaining an improved understanding of the science of materials degradation due to fusion neutron bombardment, particularly as it pertains to enabling the development of next-generation, high-performance materials for future fusion devices. Applications are sought to pursue technologies required to enable this capability, consistent with community requirements identified in recent workshops.

Questions – Contact: Guinevere Shaw, guinevere.shaw@science.doe.gov

c. Other

In addition to the specific subtopics listed above, the Department invites grant applications in other areas that fall within the scope of the topic description above.

Questions – Contact: Guinevere Shaw, guinevere.shaw@science.doe.gov

References:

1. Wiffen, F., 2019, FPNS Workshop Report, https://science.osti.gov/-/media/fes/pdf/2022/2018-FPNSSummaryReport.pdf (January 10, 2019)
2. EPRI, 2022, FPNS Workshop Report, EPRI https://www.epri.com/research/products/000000003002023917 (November 30, 2022)
3. DOE, 2023, FPNS Request for Information Document, National Archives, https://www.federalregister.gov/documents/2023/03/27/2023-06176/fusion-prototypic-neutron-source-fpns (March 27, 2023)
4. Regulation.gov, 2023, FPNS Request for Information Comments, https://www.regulations.gov/document/DOE-HQ-2023-0038-0001/comment (No Specific Date)

C57-22 SUPERCONDUCTING MAGNETS

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Maximum Phase I Award Amount: $200,000	Maximum Phase II Award Amount: $1,100,000
Accepting SBIR Applications: YES	Accepting STTR Applications: YES

Magnets are the primary machine core cost driver for magnetic fusion devices. Fusion pilot plant (FPP) concepts and supporting magnet technologies must be developed in parallel to meet aggressive U.S. fusion power program schedules and beyond to a first of a kind plant. Alongside the public program, the SBIR/STTR program can help support the technology development required to meet this schedule. Below are topics of interest to the FES:

a. QA/QC Tools

Developing cost-effective QA/QC tools is needed to provide fusion device manufacturers with an accurate portrayal of conductor and cable performance for fusion prototypic environments (14T-20T; 4.2 K to 40 K). In addition, these tools should provide necessary performance spaces that increase utilization of LTS/HTS conductors through effective manufacturing & minimizing impacts of drop-outs and non-uniformity on device stability, especially as field increases.

Questions – Contact: Guinevere Shaw, guinevere.shaw@science.doe.gov

b. Innovative Structural and Stabilization Approaches

Innovative structural and stabilization approaches can be integrated into relevant cable and magnet geometries that increase strength under steady-state and cyclic mechanical loading. Improvements in tolerances to compact bend radii would enable stellarators and other non-tokamak magnet geometries.

Questions – Contact: Guinevere Shaw, guinevere.shaw@science.doe.gov

c. Radiation-Resistant Electrical Insulators

Radiation-resistant electrical insulators that exhibit low gas generation and retention of mechanical strength under radiation, less expensive resins and insulation systems with high bond and higher strength and flexibility in shear environments.

Questions – Contact: Guinevere Shaw, guinevere.shaw@science.doe.gov

d. Diagnostics

Diagnostics are needed to serve a multifunctional role in fusion magnet geometries. Cost-effective approaches should add value to the ability to protect superconducting magnets and also provide the opportunity to monitor steady-state performance for radiation-induced degradation that could predict changes in performance margin and device lifetime.

Questions – Contact: Guinevere Shaw, guinevere.shaw@science.doe.gov

e. Other

In addition to the specific subtopics listed above, the Department invites grant applications in other areas that fall within the scope of the topic description above.

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Questions – Contact: Guinevere Shaw, guinevere.shaw@science.doe.gov

C57-23 LOW TEMPERATURE PLASMAS AND MICROELECTRONICS

Maximum Phase I Award Amount: $200,000	Maximum Phase II Award Amount: $1,100,000
Accepting SBIR Applications: YES	Accepting STTR Applications: YES

Low-temperature plasmas (LTPs) have continued to play a major role in breathtaking technological advances, ranging from the development of cost-effective lighting to advanced microelectronics, that have improved the quality of our lives in many ways. LTPs are continuing to enable technological advances in new fields, such as deactivation of antibiotic resistant bacteria, disinfection of viruses, and cancer therapy in plasma medicine. All of these advances are enabled by the unique properties of low-temperature, non-equilibrium plasma and the chemistry they drive. Building upon fundamental plasma science, further developments are sought in plasma sources, plasma-surface interactions, and plasma control science that can enable new plasma technologies, marketable product, or impact in other areas or disciplines leading to even greater societal benefit. The focus of this topic is utilizing fundamental plasma science knowledge and turning it into new applications.

LTP science and engineering addresses research and development in partially ionized gases with electron temperatures typically below 10 eV. This is a field that accounts for an enormous range of practical applications, from light sources and lasers to surgery and making computer chips, among many others. The commercial and technical value of LTP is well established where much of this benefit has resulted from empirical development. As the technology becomes more complex and addresses new fields, such as advanced microelectronics and biotechnology, empiricism rapidly becomes inadequate to advance the state of the art. Predictive capability and improved understanding of the plasma state becomes crucial to address many of the intellectually exciting scientific challenges of this field.

All low-temperature plasma applications must have a strong commercialization potential. Grant applications are sought in the specific areas listed under the following subtopics:

a. LTP Science and Engineering for Microelectronics and Nanotechnology

This subtopic is focused on improving our current understanding and scientific knowledge in the area of plasma-surface interactions and plasma assisted material synthesis related to advanced microelectronics and nanotechnology. Current challenges include: controlling the interaction of LTP with a single layer of atoms (through atomic layer etching or deposition) to manufacture integrated circuits, continued miniaturization of integrated circuits, LTP processing of material surfaces and thin films to enable industrial scale fabrication of advanced microelectronics, synthesis of new materials, nanomaterials, nanotubes, and complex materials, etc.

Note: The two subtopics: (i) LTP Science and Engineering for Microelectronics and Nanotechnology including topics in renewable energy applications and (ii) LTP Science and Technology for Biomedical Applications including topics in plasma-based water treatment, sterilization, food sanitation, and agriculture (fertilizer or nitrogen fixation) are planned to be rotated biennially.

Questions – Contact: Nirmol Podder, Nirmol.Podder@science.doe.gov

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b. Other

In addition to the specific subtopic listed above, the Department invites grant applications that can enhance the understanding of other emerging areas of plasma applications, including efficient production of hydrogen, CO2 engineering related to economically and permanently removing CO2 from the environment, plasma assisted breakdown of CO2, carbon capture and storage.

Questions – Contact: Nirmol Podder, Nirmol.Podder@science.doe.gov

References:

1. U.S. Department of Energy Office of Science, Basic Research Needs Workshop for Microelectronics, October 23-24, 2018, *DOE,* https://science.osti.gov/-/media/bes/pdf/reports/2018/Microelectronics_Brochure.pdf?la=en&hash=5FEFD0131FA3DA1CC8C3196452D1AFB5558DE720 (October 26, 2022)
2. U.S. Department of Energy Office of Fusion Energy Science, 2016, Plasma: At The Frontier of Scientific Discovery, Report of the Panel on Frontiers of Plasma Science, chapter 5, pp. 85-96, *DOE*, https://science.osti.gov/-/media/fes/pdf/program-news/Frontiers_of_Plasma_Science_Final_Report.pdf?la=en&hash=85B22EBF1CF773FFC969622524D603D755881999 (October 26, 2022)
3. National Academies of Sciences, Engineering, and Medicine, 2020, Plasma Science: Enabling Technology, Sustainability, Security, and Exploration, *Washington, DC: The National Academies Press*, *National Academics,* https://doi.org/10.17226/25802 (October 26, 2022)
4. Powering the Future Fusion & Plasmas, *A Report of the Fusion Energy Sciences Advisory Committee*, *DOE*, https://science.osti.gov/-/media/fes/fesac/pdf/2020/202012/FESAC_Report_2020_Powering_the_Future.pdf (October 26, 2022)

C57-24 INERTIAL FUSION ENERGY (IFE)

Maximum Phase I Award Amount: $200,000	Maximum Phase II Award Amount: $1,100,000
Accepting SBIR Applications: YES	Accepting STTR Applications: YES

The manufacturing readiness level for mass production of IFE targets is extremely low. For IFE to be an attractive and a credible energy source, mass production of robust and cost-effective targets is required. However, it is important to consider trade-offs between the driver and the target specifications for self-consistent solutions. Therefore, applicants are strongly encouraged to engage or partner with the IFE private sector and/or institutions pursuing IFE.

a. Targets for Laser Inertial Fusion Energy

We encourage applications that aim to address the following Priority Research Opportunity (PRO) from the IFE Basic Research Workshop Report: “Demonstrate high-volume techniques for spherical capsule or wetted foam capsule fabrication” (PRO 5-1).

Questions – Contact: Kramer Akli, Kramer.akli@science.doe.gov

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b. Other
In addition to the specific subtopics listed above, we invite applications that address the PRO 5-2 from the IFE Basic Research Workshop Report, in the context of laser fusion.

Questions – Contact: Kramer Akli, Kramer.akli@science.doe.gov

References:

1. National Research Council, et al, 2013, An Assessment of the Prospects for Inertial Fusion Energy, *National Academics,* https://nap.nationalacademies.org/catalog/18289/an-assessment-of-the-prospects-for-inertial-fusion-energy (2013)
2. DOE, Report of the 2022 Fusion Energy Sciences Basic Research Needs Workshop, Chapter-5, DOE, https://www.dropbox.com/s/go3doegms6pjgc8/IFE%20BRN_full%20report_v20230111.pdf?dl=0 2022

C57-25 PLASMA ACTUATORS FOR FUSION POWER PLANTS

Maximum Phase I Award Amount: $200,000	Maximum Phase II Award Amount: $1,100,000
Accepting SBIR Applications: YES	Accepting STTR Applications: YES

Advancing our understanding of how plasmas perform and extending that performance to fusion power plants, requires the development of new heating, current drive and plasma momentum control technologies. These technologies include actuators for plasma profile and stability control.

a. Heating and Current Drive
Magnetic confinement devices require plasma heating and current drive actuators to generate and sustain desirable plasma profiles. This topic aims to develop commercial technologies capable of generating and transmitting the necessary power efficiently. The topics includes but is not limited to the development of gyrotrons, klystrons, transmission systems, compact antennas, radio frequency current drive methods, neutral beam injectors, and other candidate technologies that can support steady-state, or long-pulse operation of fusion device concepts. Proposed systems must satisfy the following requirements: 1) localized heating and/or current drive; 2) high efficiency (>65%); 3) capable of functioning across a range of magnetic fields (e.g., multi-frequency gyrotrons); 4) >1MW/unit; and 5) compatible with long pulse operation. A high priority is to establish U.S. vendors of these essential technologies.

Questions – Contact: Matthew Lanctot, matthew.lanctot@science.doe.gov

b. Plasma Momentum Injection
Plasma flows play a key role in the performance of tokamaks. This topic aims to encourage the submission of applications to develop actuators capable of controlling the plasma flow through controlled momentum injection. Uses include the stabilization of the tokamak tearing modes through the control of flow profile near rational surfaces, the control of the plasma flow in the edge regions and other possible uses of improving the tokamak performance that would be made available through the development of actuators capable of controlling the plasma flow.

Questions – Contact: Matthew Lanctot, matthew.lanctot@science.doe.gov

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c. Other

In addition to the specific subtopics listed above, the Department invites grant applications in other areas that fall within the scope of the topic description above.

Questions – Contact: Matthew Lanctot, matthew.lanctot@science.doe.gov

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PROGRAM AREA OVERVIEW: OFFICE OF HIGH ENERGY PHYSICS

The goal of the Department of Energy's (DOE or the Department) Office of High Energy Physics (HEP) is to provide mankind with new insights into the fundamental nature of energy and matter and the forces that control them. This program is a major component of the Department's basic research mission. Such foundational research enables the nation to advance its scientific knowledge and technological capabilities, to advance its industrial competitiveness, and to discover new and innovative approaches to its energy future.

The DOE HEP program supports research in three discovery frontiers, namely, the energy frontier, the intensity frontier, and the cosmic frontier. Experimental research in HEP is largely performed by university and national laboratory scientists, using particle accelerators as well as telescopes and underground detectors located at major facilities in the U.S. and abroad. Under the HEP program, the Department operates the Fermi National Accelerator Laboratory (Fermilab) near Chicago, IL. The Department also has a significant role in the Large Hadron Collider (LHC) at the CERN laboratory in Switzerland. The Fermilab complex includes the Main Injector (which formerly fed the now dormant Tevatron ring), which is used to create high-energy particle beams for physics experiments, including the world's most intense neutrino beam. The Main Injector is undergoing upgrades to support the operation of Fermilab's present and planned suite of neutrino and muon experiments at the intensity frontier. Another Fermilab upgrade project called PIP-II (Proton Improvement Plan II) will greatly increase the intensity of proton beams sent to the Main Injector. The SLAC National Accelerator Laboratory and the Lawrence Berkeley National Laboratory are involved in the design of state-of-the-art accelerators and related facilities for use in high-energy physics, condensed matter research, and related fields. SLAC facilities include the two-kilometer-long Stanford Linear Accelerator capable of generating high energy, high intensity electron beams. The first kilometer of the linear accelerator is used for the Facility for Advanced Accelerator Experimental Tests (FACET-II). At Argonne National Laboratory resides the Argonne Wakefield Accelerator (AWA) facility, which houses two test electron accelerators, one for 15 MeV electrons, and the other for 70 MeV electrons. Experiments focus on two-beam and collinear wakefield acceleration as well as tests of novel accelerator structures and beam-line components. Brookhaven National Laboratory operates the Accelerator Test Facility, which supports accelerator science and technology demonstrations with electron and laser beams. While much progress has been made during the past five decades in our understanding of particle physics, future progress depends on the availability of new state-of-the-art technology for accelerators and detectors.

As stewards of accelerator technology for the nation, HEP also supports development of new concepts and capabilities that further scientific and commercial needs beyond the discovery science mission. Artificial Intelligence/Machine Learning science and technology is another rapidly-developing area that both benefits from expertise in the HEP community and offers novel approaches for extending HEP science. The DOE SBIR program provides a focused opportunity and mechanism for small businesses to contribute new ideas and new technologies to the pool of knowledge and technical capabilities required for continued progress in HEP research, and to turn these novel ideas and technologies into new business ventures.

Grant applications must be informed by the state of the art in High Energy Physics applications, commercially available products, and emerging technologies. An application based on merely incremental improvements or little innovation will be considered non-responsive unless context is supplied that convincingly shows its potential for significant impact or value to the DOE High Energy Physics program. DOE also expects all applicants to address commercialization opportunities for their product or service in adjacent markets such as medicine, homeland security, the environment and industry.

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For additional information regarding the Office of High Energy Physics priorities, click here.

C57-26 ADVANCED CONCEPTS AND TECHNOLOGY FOR PARTICLE ACCELERATORS

Maximum Phase I Award Amount: $200,000	Maximum Phase II Award Amount: $1,100,000
Accepting SBIR Applications: YES	Accepting STTR Applications: YES

The DOE HEP program supports a broad research and development (R&D) effort in the science, engineering, and technology of charged particle accelerators, storage rings, and associated apparatus. The strategic plan for HEP includes initiatives in the energy and intensity frontiers that rely on accelerators capable of delivering beams with the required energy and intensity. As high energy physics facilities get bigger and more costly, the DOE HEP program seeks to develop advanced technologies that can be used to reduce the overall machine size and cost, and also to develop new concepts and capabilities that further scientific and commercial needs beyond HEP's discovery science mission.

In many cases the technology sought is closely tied to a specific machine concept which sets the specifications (and tolerances) for the technology. Applicants are strongly encouraged to review the references provided. Applications to subtopics specifically associated with a machine concept that do not closely adhere to the specifications of the machine will be considered non- responsive. For subtopics that are not machine-specific, applicants are strongly advised to understand the state-of- the-art and to clearly describe in the application what quantitative advances in the technology will result.

Grant applications are sought only in the following subtopics:

a. Graphical User-Interfaces for Accelerator Modeling

The HEP program supports theoretical and experimental research in elementary particle physics and fundamental accelerator science and technology [1]. Particle accelerator and beamline modeling for both conventional and advanced accelerator concepts has undergone major advances with the advent of the world's first Exascale supercomputer in the US DOE (Frontier at OLCF), GPU-accelerated computing and novel algorithms [2]. Yet, advanced modeling tools could have a significantly wider impact in research and industry if they were accessible via modern, intuitive design-centric interfaces and were able to be coupled easily to control systems in experiments. Addressing these points, applications are sought after that can develop extensible, graphical user interfaces, which can leverage community standards in modeling for simulation control and data [1-3] and control asynchronous particle accelerator modeling workflows on remote computing hardware (edge computing close to experiments, on clusters, cloud, and/or HPC).

Questions – Contact: Derun Li, Derun.Li@science.doe.gov

b. Digital Twin for HEP Accelerator Beam Test Facilities

Applications are sought for the creation of a digital twin of one or more DOE HEP accelerator beam test facilities, as outlined in the 2022 ABP Roadmap [1]. The digital twin should serve several key purposes. Primarily, it should provide an accessible platform for both existing and potential users of the facility to intuitively explore ideas and design experiments. Secondly, this initiative presents an opportunity to

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experiment with advanced control system algorithms for both specific subsystems and the facility. Special focus should be given to automated tuning, particularly in situations where the machine exhibits drift. Lastly, it is anticipated that the digital twin will incorporate multiple community modeling codes for various subsystems. While a variety of approaches can be considered, there should be a particular emphasis on AI/ML representations such as surrogate models and model-free representations.

Questions – Contact: Derun Li, Derun.Li@science.doe.gov

c. Non-Destructive Electron Beam Position Monitors

Advancements in RF-driven and plasma-driven accelerators have resulted in the production of femtosecond-duration electron beams in an environment potentially subject to strong background EMP radiation. To integrate active stabilization, machine learning and artificial intelligence, as well as shot-tagged correlation studies, it is desirable to develop shot-correlated non-perturbative diagnostics for the electron beam position and pointing angle. Challenges related to the shortness of the electron beam and EMP-noise chamber environment have frustrated conventional BPMs (beam position monitors). Applications are sought for either improvements to BPMs (cavity BPMs), or for novel technologies such as fiber-integrated electro-optic sampling components and/or near-field imaging of aperture-based coherent diffraction radiation. These diagnostics should provide a path for robust, reliable, and operation-friendly passive centroid and pointing monitors for high-current ultra-short electron beams in noisy environments.

Questions – Contact: Derun Li, Derun.Li@science.doe.gov

d. Other

In addition to the specific subtopics listed above, the Department invites grant applications in other areas that fall within the scope of the topic description above.

Questions – Contact: Derun Li, Derun.Li@science.doe.gov

References: Subtopic a:

1. US DOE HEP General Accelerator R&D (GARD) Program, 2023, Accelerator and Beam Physics Roadmap, https://science.osti.gov/hep/-/media/hep/pdf/2022/ABP_Roadmap_2023_final.pdf (June 29, 2023)
2. Elvira, V.D., et al., 2022, The Future of High Energy Physics Software and Computing, Report of the 2021 US Community Study on the Future of Particle Physics, https://arxiv.org/abs/2210.05822 (June 26, 2023)
3. The Beam and Accelerator Modeling Interest Group (BAMIG), 2022, Snowmass21 Accelerator Modeling Community White Paper, Cornell University, https://arxiv.org/abs/2203.08335 (June 26, 2023)

References: Subtopic b:

1. 2022 ABP Roadmap Available at: https://science.osti.gov/hep//media/hep/pdf/2022/ABP_Roadmap_2023_final.pdf

C57-27 RADIO FREQUENCY ACCELERATOR TECHNOLOGY

Maximum Phase I Award Amount: $200,000	Maximum Phase II Award Amount: $1,100,000

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Accepting SBIR Applications: YES	Accepting STTR Applications: YES

Radio frequency (RF) technology is a key technology common to all high energy accelerators. RF sources with improved efficiency and accelerating structures with increased accelerating gradient are important for keeping the cost down for future machines. DOE-HEP seeks advances directly relevant to HEP applications and new concepts and capabilities that further scientific and commercial needs beyond HEP's discovery science mission.

In many cases the technology sought is closely tied to a specific machine concept which sets the specifications (and tolerances) for the technology. Applicants are strongly encouraged to review the references provided. Applications to subtopics specifically associated with a machine concept that do not closely adhere to the specifications of the machine will be considered non- responsive.

For subtopics that are not machine-specific, applicants are strongly advised to understand the state-of- the-art and to clearly describe in the application what quantitative advances in the technology will result.

a. Low-Cost Radio Frequency Power Sources for Accelerator Application

Low cost, highly efficient RF power sources are needed to power accelerators. Achieving power efficiencies of 50-70% or better (depending on the application) and decreasing capital costs below $2/Watt of average power output is essential. For accelerator applications, RF sources must phase lock stably (<1 degree RMS phase noise) to an external reference and have excellent output power stability (<1% RMS output power variation) and device lifetime must exceed 10,000 operating hours.

Applications for either vacuum electronics devices or solid-state power amplifiers are sought. Please note that the R&D priority varies by type of tube. Priority will be given to applications that develop RF power sources operating at frequencies that are in widespread use at the large Office of Science accelerators.

Five major types of RF power sources are sought. For each RF source type, the principal R&D challenges have been *marked* and meeting the relevant specifications should be the focus of proposed work.

1) Short-pulse (microsecond) L-band or S-band, low duty factor (0.1%), very high efficiency (>70%), *low cost (<$2 per average Watt)* RF sources, with beam operating voltages below 100 kV preferred, and peak output power of 10 MW (L-band) to 50 MW (S-band);
2) Short-pulse (microsecond) C-band or X-band, low duty factor (>0.1%), *high efficiency (>50%)* RF sources, with peak output power of >50 MW, moderate bandwidth (-3dB BW >0.5%) and capable of *high repetition rate (>>1 kHz) operation*;
3) Long-pulse (millisecond) UHF or L-band, high duty factor (>5%), *very high efficiency (>70%)*, *low cost (<$2 per average watt)* RF sources, with beam operating voltages below 100 kV preferred (if a vacuum electronic device), and peak output power of >100 kW;
4) CW UHF or L-band, very high duty factor (100%), *very high efficiency (>70%)*, *low cost (<$2 per average watt)* RF sources, with beam operating voltages (if a vacuum electronic device) below 100 kV preferred, and peak power output of >50 kW;
5) Short-pulse (microsecond) C-band or X-band, low duty factor (0.1%), *high efficiency (>50%)* solid-state power amplifiers, with peak output power of >5 kW, with an early production cost of <$10/(peak Watt) and a *volume production cost of <2$(peak Watt)*.

Background Information about each RF Source Type follows:

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1) This type of RF source is typical of warm linear accelerators. [1,2,3]

2) This type of RF source is typical of high energy physics accelerators [1] next-generation compact x-ray free electron laser (XFEL) facilities [4] and relativistic, ultra-fast electron diffraction facilities (MeV-UED) [5], [6]. Current sources, such as those used at SACLA (Japan), SwissFEL and CERF-NM [7] preclude the use of C-Band technology to its fullest capability.

   X-band accelerating structures have been demonstrated to work above 300 MV/m [11] using ultra-short RF pulses, a gradient that can substantially reduce the size of high energy accelerators. This demonstration was done in a two-beam accelerator scheme using a Power Extraction and Transfer Structure (PETS, a beam driven source) [12]. With available klystrons, RF pulses are typically > 100 ns and gradients are ~100 MV/m [13].

   In order to fully realize the potential for these high frequency, high gradient accelerating structures, an ultra-high-power source with ultra-short pulses is required. A possible source could be based on a high-bandwidth klystron (the subject of this topic) [14] and an active, high-bandwidth, RF pulse compressor (the subject of a future SBIR topic) [15].

   The very high gradient accelerators made possible could be used for High Energy Physics, Basic Energy Sciences, and other basic research in material science. C-Band MeV-UED facilities would allow for the study of non-equilibrium dynamic processes in materials at sub- angstrom scales and femtosecond time resolution. Potential users of such a capability are interested in “burst mode” operation, for instance repetition rates on the order of 1 MHz while still maintaining an overall duty factor of ~0.01%. Compact C-Band XFELs that can provide multiple pulses (10s – 100s) of high photon energy (~42 keV) x-ray pulses with variable separation from 100 picoseconds to 100 microseconds would enable dynamic imaging of dense, high Z materials. However, such a system would require a new power source that could meet the desired pulse structure.

3) This type of RF source is typical of superconducting linear accelerators. [1,2,3]

4) This type of RF source is typical of storage ring accelerators, CW linear accelerators, and industrial accelerators. [1,2,3]

5) This type of RF source is typically used as a TWT replacement for driving short-pulse klystrons but also finds uses driving beam diagnostics and beam manipulation in compact linacs. For example, [8] describes the use of an X-band cavity to deflect a high energy electron beam (14 GeV) to measure its longitudinal profile. Solid state RF sources are sought for beam diagnostics and manipulation (as TWT replacements) at much lower electron beam energies (~MeV) in compact accelerators based on C- and X-band. Peak or continuous wave (CW) power is needed at > 5 kW for adequate deflection of these beams, higher power than what is currently available from solid state amplifiers.

   A solid-state narrowband amplifier is required (< 100 MHz) at high power (> 5 kW peak power or CW) in the C and X bands. Cost should target $10/W with a path forward for volume production costs of around $2/W.

Compact Linacs are used in industry and medicine [9]. RF power sources are additionally used in radar and space telecommunications [10].

Applications must clearly articulate how the proposed technology will meet all metrics listed in this section.

Questions – Contact: Eric Colby, Eric.Colby@science.doe.gov

b. New Superconducting RF Cavity Design

Grant applications are sought to develop:

- New SRF cavity designs with reduced RF frequency sensitivity to Lorentz-force detuning (<0.5 $Hz/(MV/m)^2$ for elliptical cavities and (<0.5 $Hz/(MV/m)^2$ for QWR, HWR and SSR) and helium bath pressure fluctuations (<10 Hz/mbar) for use in future accelerators requiring narrow-bandwidth systems, e.g., upgrade of PIP-II linac at FNAL or energy recovery linacs.
- New tunable SRF cavity designs for operation with high current beams (up to 1 A) The tuning range is to be up to 10^{-2}. The cavity should provide efficient high-order mode extraction while not sacrificing good SRF performance.
- New fabrication and processing techniques for niobium cavities to reduce the cost and improve quality factor and accelerating gradient (e.g., improved welding technique, hydroforming, doping, Nb_3Sn coating, etc.) along with new materials for SRF cavity manufacturing.
- Improved SRF low-beta cavity designs with mitigated multipacting compared to existing QWR, HWR, and SSR cavities, reduced field emission, and reduced losses.
- Development of the universal data interface for data exchange between the different commercial codes used for SRF cavity design. For example, the data interface between EM codes – CST, HFSS, COMSOL, and mechanical – ANSYS. For example, an interface between EM codes – CST and beam dynamics code MICHELLE.

Questions – Contact: Ken Marken, ken.marken@science.doe.gov

c. Auxiliary Components and Instrumentation for SRF Cavities

Grant applications are sought to develop:

1) New cost-efficient and improved reliability designs of high-power and low-power components - input couplers, circulators, windows, tuners, etc., in the frequency range of 325 MHz to 1.3 GHz.
2) New and improved methods for cavity diagnostics in a cryomodule that would aid in preserving the high performance achieved by SRF cavities during vertical tests throughout the SRF cryomodule assembly, commissioning and operation, including in situ quality factor measurements, inexpensive sensors for residual magnetic field measurements at cryogenic temperatures, novel sensors for helium pressure, flow, and level based on fiber optics or other technologies, vibration sensors operating in a cryogenic environment, distributed radiation and dark current/field emission sensors using fiber optics at cryogenic temperatures.
3) New cavity tuner concepts for Lorentz force detuning and microphonics mitigation (for example, ferroelectric, electromagnetic, etc.).
4) Algorithms and electronics for resonance control of the narrow-band SRF cavities to counteract Lorentz-force detuning and microphonic noise in pulsed and CW operation regimes.

Questions – Contact: Ken Marken, ken.marken@science.doe.gov

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d. Other

In addition to the specific subtopics listed above, the Department invites grant applications in other areas that fall within the scope of the topic description above.

Questions – Contact: Ken Marken, ken.marken@science.doe.gov

References: Subtopic a:

1. Hartill, D. 2015, Accelerating Discovery: A Strategic Plan for Accelerator R&D in the U.S., *U.S. Department of Energy Office of Science*, https://science.osti.gov/-/media/hep/hepap/pdf/Reports/Accelerator_RD_Subpanel_Report.pdf (see especially section 7). (June 27, 2023)
2. Blazey, G., 2017, Radiofrequency Accelerator R&D Strategy Report, *DOE HEP General Accelerator R&D RF Research Roadmap Workshop*, https://science.osti.gov/-/media/hep/pdf/Reports/DOE_HEP_GARD_RF_Research_Roadmap_Report.pdf (see especially section 5). (June 27, 2023)
3. Henderson, S., Waite, T., 2015, Workshop on Energy and Environmental Applications of Accelerators*.,* *U.S. Department of Energy Office of Science* (see especially section 2.11) http://science.osti.gov/~/media/hep/pdf/accelerator-rd-stewardship/Energy_Environment_Report_Final.pdf (June 27, 2023)
4. Inagaki, T., et. al., 2014, High-gradient C-band linac for Compact X-Ray Free-Electron Laser Facility, *Physical Review Special Topics – Accelerators and Beams*, 17, 080802 https://doi.org/10.1103/PhysRevSTAB.17.080702 (June 27, 2023)
5. Lingyu, M., et. al., 2020, Ultrafast x-ray and electron scattering of free molecules: A comparative evaluation, *Structural Dynamics* 7, 034102, https://doi.org/10.1063/4.0000010 (June 27, 2023)
6. Junior, J.B.S., et. al., 2021, Pair Distribution Function Obtained from Electron Diffraction: An Advanced Real-Space Structural Characterization Tool, *Matter* 4, 441-460, http://dx.doi.org/10.1016/j.matt.2020.10.025 (June 28, 2023)
7. E.I. Simakov et al., 2022, Update on the Status of C-Band Research and Facilities at LANL, 5th North American Particle Accel. Conf., pp. 855-858. https://epaper.kek.jp/napac2022/papers/thyd3.pdf (June 28, 2023)
8. Dolgashev, V.A., et al., 2012, RF design of X-band RF deflector for femtosecond diagnostics of LCLS electron beam, *AIP Conference Proceedings* 1507, 682–6, https://doi.org/10.1063/1.4773780 (June 28, 2023)
9. M. El-Ashmawy et al., 2003, Overall Quality Comparison of C-Band and X-Band Medical Linacs, *The 14th Symposium on Accelerator Science and Technology*, Tsukuba, Japan, http://conference.kek.jp/sast03it/WebPDF/2P055.pdf (June 28, 2023)
10. Blanchard, P., 2013, RF & Microwave Capability & Roadmap, *Microsemi Corporation*, https://ww1.microchip.com/downloads/aemDocuments/documents/RFDS/ProductDocuments/SupportingCollateral/rf_and_microwave_capability_and_roadmap_gaas_gan_mmics_p_blanchard.pdf (June 28, 2023)
11. Shao, J., et al., 2022, Demonstration of Gradient Above 300 MV/m in Short Pulse Regime Using an X-Band Single-Cell Structure, *13th Int. Particle Acc. Conference*, https://jacow.org/ipac2022/papers/froxsp2.pdf (June 28, 2023)

12. Picard, J., et al., 2022, Generation of 565 MW of X-band power using a metamaterial power extractor for structure-based wakefield acceleration, *Phys. Rev. Accel. Beams* 25, 051301, https://journals.aps.org/prab/abstract/10.1103/PhysRevAccelBeams.25.051301 (June 28, 2023)
13. Dolgashev, V.A., et al., 2021, High-gradient rf tests of welded X-band accelerating cavities, *Phys. Rev. Accel. Beams* 24, 081002, https://journals.aps.org/prab/pdf/10.1103/PhysRevAccelBeams.24.081002 (June 28, 2023)
14. Lin, X., et al., 2022, X-band two-stage rf pulse compression system with correction cavity chain, *Phys. Rev. Accel. Beams* 25, 120401, https://journals.aps.org/prab/abstract/10.1103/PhysRevAccelBeams.25.120401 (June 28, 2023)
15. Ivanov, O.A., et al., 2013, Active Microwave Pulse Compressor Using an Electron-Beam Triggered Switch, *Phys. Rev. Lett*. 110, 115002, https://doi.org/10.1103/PhysRevLett.110.115002 (June 28, 2023)

C57-28 LASER TECHNOLOGY R&D FOR ACCELERATORS

Maximum Phase I Award Amount: $200,000	Maximum Phase II Award Amount: $1,100,000
Accepting SBIR Applications: YES	Accepting STTR Applications: YES

Lasers are used or proposed for use in many areas of accelerator applications: as drivers for novel accelerator concepts for future colliders; in the generation, manipulation, and x-ray seeding of electron beams; in the generation of electromagnetic radiation ranging from THz to gamma rays; and in the generation of neutron, proton, and light ion beams. In many cases ultrafast lasers with pulse lengths well below a picosecond are required, with excellent stability, reliability, and beam quality. With applications demanding ever higher fluxes of particles and radiation, the driving laser technology must also increase in repetition rate—and hence average power—to meet the demand. Please note that applications submitted in this topic should clearly articulate the relevance of the proposed R&D to HEP's mission.

This topic area is aimed at developing technologies for (1) ultrafast lasers capable of high average power (kilowatt-class) operating at the high electrical-to-optical efficiency (>20%) needed for advanced accelerator applications, and (2) high average power custom-pulse-structure lasers for proton and ion beam manipulation and diagnosis.

In category (1), accelerator applications of ultrafast lasers call for one of the following four basic specifications:

	Type I	**Type II**	**Type III**	**Type IV**
Wavelength (micron)	1.5-2.0	0.8-2.0	2.0-5.0	2.0-10.0
Pulse Energy	3 microJ	3 J	0.03–1 J	300 J
Pulse Length	300 fs	30–100 fs	50 fs	100–500 fs
Repetition Rate	1–1300 MHz	1 kHz	1 MHz	100 Hz
Average Power	Up to 3 kW	3 kW	3 kW and up	30 kW
Energy Stability	<1 %	<0.1%	<1%	<1%
Beam Quality	M^2<1.1	Strehl>0.95	M^2<1.1	M^2<1.1
Wall-plug Efficiency	>30%	>20%	>20%	>20%
Pre-Pulse Contrast	N/A	>10^{-9}	N/A	>10^{-9}
CEP-capable	Required	N/A	Required	N/A

Optical Phase Noise	<5º	N/A	<5º	N/A
Wavelength Tunability Range	0.1%	0.1%	10%	0.1%

In category (2), longer-pulse lasers are finding increasing application in the control and diagnosis of proton and H-minus beams. Near IR lasers are used in a variety of applications ranging from partial neutralization of H-minus beams (0.75 eV binding energy) for diagnostics to total neutralization (for notching and phase space sculpting). UV lasers are used for stripping neutral hydrogen beams (13.6 eV binding energy) by resonantly exciting the atom, then Lorentz stripping the more loosely bound electron in a strong magnetic field. As proton machines move steadily into the megawatt beam power range, the need for non-intercepting techniques to control and diagnose such beams will motivate increased use of lasers, and the increased duty factor of such machines will motivate increases in the average power of lasers used for this purpose.

Grant applications are sought to develop lasers and laser technologies for accelerator applications only in the following specific areas:

a. High Energy and Broadband Components for Fiber Lasers and Arrays

Due to their high average power capability and high wall-plug efficiency, ultrafast fiber lasers are promising for driving high rep-rate laser-plasma accelerators, generating radiation from THz to gamma rays, and as important tools for material processing. Realizing this requires pulse energies and durations not now achievable from fiber lasers. Coherent combination of ultrafast fiber lasers, in spatial and temporal domains, potentially provides a path to pulse energies up to Joules, with high average powers and efficiencies well beyond the current generation of lasers. Pulse duration limitation of fiber lasers can be overcome using spectral combining of multi-band fiber lasers, which has the potential to achieve tens of femtosecond durations.

The practicality of aggregating a large number of fiber amplifiers requires that each is implemented as a compact and robust module. However, current state-of-the-art specialty fibers with 50–100 micron core diameters, which produce the highest pulse energies in diffraction-limited beams, lack fiber-optic components which can be fusion-spliced into monolithically-integrated subsystems.

Spectral combining of ultrafast fiber lasers (Yb-doped) will need fiber components optimized at different bands within the Yb gain spectrum. However, most fiber components in the current market are optimized with a central wavelength only in the range of 1040-1065 nm, and a bandwidth up to ~30 nm.

Grant applications are sought to demonstrate and develop fiber laser components for module integration (monolithic pump combiners, mode adapters, optical interconnects, residual-pump-power strippers, etc.), as well as complete integrated amplifier subsystems using 50–100 micron core specialty fibers with diffraction-limited output. These components and subsystems should sustain multi-mJ pulse energies and average powers in the 100 W – 1 kW range, when operating within the ~1 micron gain spectrum of Yb-doped fibers. In addition, applications are sought to develop and demonstrate fiber components for spectral combination (WDMs, isolators, etc.), both single-mode and large-mode-area, with spectral boundaries extended to <1010 nm OR >1090 nm and covering a broad band (>30-40 nm bandwidth). Cost-effective solutions are particularly encouraged.

Questions – Contact: Eric Colby, eric.colby@science.doe.gov

b. High Damage Threshold Large Area Spatial Light Modulators

The size and damage tolerance of active laser optics are a key limit in the compactness, performance, and durability of lasers. Realizing compact, high efficiency lasers combining high peak and average powers strongly motivates improved damage threshold for active optics.

Active shaping of the laser mode is key to many applications, and active elements such as spatial light modulators currently suffer from low intensity and fluence tolerance which limits their application.

Applications are sought to develop larger area SLMs (30mm width up to 100mm) to allow for (chirped) Joule-class lasers to be spatially manipulated. Increasing the active aperture, power density tolerance, and damage fluence by applying high reflectance dielectric coatings, active cooling, and stabilization mechanisms is needed. SLMs may be optimized for 0.8- or 1-micron lasers and must be designed with minimal GVD to support ultrafast pulses (>10% bandwidth). A finished large-area SLM that can tolerate incident average power densities of >300 W/cm^2 and incident fluences of >0.25 J/cm^2 per pulse in 30 fsec (stretched) pulses is the goal.

Questions – Contact: Eric Colby, eric.colby@science.doe.gov

c. Other

In addition to the specific subtopics listed above, the Department invites grant applications in other areas that fall within the scope of the topic description above.

Questions – Contact: Eric Colby, eric.colby@science.doe.gov

References:

1. U.S Department of Energy Office of Science, 2013, Workshop on Laser Technology for Accelerators: Summary Report, *U.S. Department of Energy*, p. 47, https://science.osti.gov/-/media/hep/pdf/accelerator-rd-stewardship/Lasers_for_Accelerators_Report_Final.pdf (June 28, 2023)
2. Hogan, M.J., 2016, Advanced Accelerator Concepts 2014: 16th Advanced Accelerator Concepts Workshop, *AIP Conference Proceedings*, Vol. 1777, 010001, ISBN: 978-0-7354-1439-6, https://aip.scitation.org/toc/apc/1777/1?expanded=1777 (June 28, 2023)
3. Simakov, E., et al., 2018, 18th Advanced Accelerator Concepts Workshop (AAC 2018), *Advanced Accelerator Concepts Workshop (AAC),* https://ieeexplore.ieee.org/xpl/conhome/8607198/proceeding (June 28, 2023)
4. Fazio, M., et al., 2019, Basic Research Needs Workshop on Compact Accelerators for Security and Medicine, *U.S. Department of Energy & Office of Scientific and Technical Information*, https://www.osti.gov/servlets/purl/1631121 (June 28, 2023)

C57-29 HIGH FIELD SUPERCONDUCTING MAGNET TECHNOLOGY

Maximum Phase I Award Amount: $200,000	Maximum Phase II Award Amount: $1,100,000
Accepting SBIR Applications: YES	Accepting STTR Applications: YES

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Superconducting magnets are widely used in particle accelerators for beam steering and focusing. Advanced R&D is needed in support of this research in high-field superconductor and superconducting magnet technologies. This topic addresses only those superconducting magnet development technologies that support accelerators, storage rings, and charged particle beam transport systems and only those superconducting wire technologies that support long strand lengths suitable for winding magnets without splices. For referral to lab and university scientists in your area of interest contact: Ken Marken, ken.marken@science.doe.gov.

Grant applications are sought only in the following subtopics:

a. High-Field HTS Wire and Cable Technologies for Magnets

Grant applications are sought to develop improved High Temperature Superconducting (HTS) wire for magnets that operate above 18 Tesla (T). Applications should address demonstration scale (>1 km lengths) and/or production scale (> 3 km continuous lengths) wire technologies. Current densities should be at least 400 amperes per square millimeter of strand cross-section (often called the engineering current density) at 20 T and 4.2 K temperature. Tooling and handling requirements restrict wire cross-sectional area to the range 0.4 to 2.0 square millimeters, with transverse dimension not less than 0.25 mm. Of specific interest are the HTS materials Bi2Sr2CaCu2O8 (Bi-2212) and (RE) Ba2Cu3O7 (ReBCO) that are engineered for high field magnet applications. All grant applications must result in wire technology that will be acceptable for accelerator magnets, including not only the operating conditions mentioned above, but also production of a sufficient amount of material (1 km minimum continuous length) for winding and testing cables and subscale coils.

New or improved wire or cable technologies must demonstrate at least one of the following criteria in comparison to present art:

- property improvement, such as higher current density at fields above 18 T;
- improved tolerance to property degradation as a function of applied strain;
- reduced transverse dimensions of the superconducting filaments (sometimes called the effective filament diameter), in particular to less than 30 micrometers at 1 mm wire diameter, with minimal concurrent reduction of the thermal conductivity of the stabilizer or strand critical current density;
- HTS cables supporting 10 to 30 kA currents with engineering current density above 600 A/mm^2, lower losses under changing transverse magnetic fields, and/or improved tolerance to transverse stress;
- significant cost reduction for equal performance in all regards, especially current density and length.

Questions – Contact: Ken Marken, ken.marken@science.doe.gov

b. Superconducting Magnet Technology

Grant applications are sought to develop:

- very high field (greater than 16 T) HTS/LTS hybrid dipole magnets;
- designs and prototypes for HTS/LTS hybrid solenoid systems capable of achieving 30 to 40T axial fields and warm bores with a diameter ≥2 cm;
- liquid-helium-operating electronics for superconducting magnets to enable higher speed and lower noise diagnostic data transfer.

Questions – Contact: Ken Marken, ken.marken@science.doe.gov

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c. Cryogenic Power Electronics for Distributed Powering and Quench Protection of HTS and Hybrid Magnets

Powering and protection of high-field superconducting magnets are traditionally accomplished with current control and energy extraction systems operating at ambient temperature. These systems are costly, have low energy efficiency and put significant limitations on the powering and depowering profiles that can be executed. Recent advances in power electronics have enabled a new class of MOSFET devices that exhibit extremely low resistance in the "closed" state and allow for cryogenic operation. Implementation of these devices with superconducting magnets would significantly reduce cost and complexity of magnet powering infrastructure and enable novel capabilities such as independent current control for hybrid HTS/LTS magnet coils from a single power supply and generation of special AC current waveforms for clearing remnant magnetization or boosting protection through ac loss mechanisms.

Applications for practical implementation of a viable cryogenic power control system for superconducting magnets are sought.

Questions – Contact: Ken Marken, ken.marken@science.doe.gov

d. Other

In addition to the specific subtopics listed above, the Department invites grant applications in other areas that fall within the scope of the topic description above.

Questions – Contact: Ken Marken, ken.marken@science.doe.gov

References:

1. Larbalestier, D., Jiang, J., Trociewitz, U.P., et al., 2014, Isotropic Round-Wire Multifilament Cuprate Superconductor for Generation of Magnetic Fields Above 30 T, *Nature Materials,* vol.13, p. 375, https://www.nature.com/articles/nmat3887 (June 28, 2023)
2. Maeda, H., Yanagisawa, Y., 2014, Recent Developments in High-Temperature Superconducting Magnet Technology (Review), *IEEE Transactions on Applied Superconductivity*, vol. 24, no. 3, 4602412, https://ieeexplore.ieee.org/document/6649987 (June 28, 2023)
3. Todesco, E., Bottura, L., Rijk, G., et al., 2014, Dipoles for High-Energy LHC*, IEEE Transactions on Applied Superconductivity*, vol. 24, no. 3, 4004306, https://ieeexplore.ieee.org/document/6656892 (June 28, 2023)
4. IOP Science, 2021, Advances in Cryogenic Engineering – Materials: Proceedings of the International Cryogenic Materials Conference (ICMC) 2021, *2021 IOP Conference Series: Materials Science and Engineering*, https://iopscience.iop.org/issue/1757-899X/1241/1 (June 29, 2023)
5. IOP Science, 2021, Advances in Cryogenic Engineering: Proceedings of the Cryogenic Engineering Conference (CEC) 2021*, IOP Conference Series: Materials Science and Engineering*, https://iopscience.iop.org/issue/1757-899X/1240/1 (June 29, 2023)
6. Scanlan, R., Malozemoff, A.P., Larbalestier, D.C., 2004, Superconducting Materials for Large Scale Applications, *Proceedings of the IEEE,* vol. 92, issue 10, pp. 1639-1654, https://www.researchgate.net/publication/2986363_Superconducting_materials_for_large_scale_applications (June 29, 2023)
7. Proceedings of the 2020 Applied Superconductivity Conference, IEEE Transactions on Applied Superconductivity, *A Publication of the IEEE Council on Superconductivity*, vol. 31 no. 5, 2021,

https://ieeexplore-ieee-org.proxy.scejournals.org/xpl/tocresult.jsp?isnumber=9351575&punumber=77 (June 29, 2023)

8. The 26th International Conference on Magnet Technology, *IEEE Transactions on Applied Superconductivity*, vol. 30 no. 4, 2020, https://ieeexplore-ieee-org.proxy.scejournals.org/xpl/tocresult.jsp?isnumber=8952829 (June 29, 2023)

C57-30 HIGH ENERGY PHYSICS ELECTRONICS

Maximum Phase I Award Amount: $200,000	Maximum Phase II Award Amount: $1,100,000
Accepting SBIR Applications: YES	Accepting STTR Applications: YES

High Energy Physics experiments require advanced electronics and systems for the acquisition and processing of experimental data. As an example, high-priority future experiments in the DOE Office of High Energy Physics (HEP) portfolio need advances that can benefit from small business contributions. These experiments include potential upgrades to the High Luminosity Large Hadron Collider (HL-LHC) detectors currently under construction (see https://home.cern/science/accelerators/large-hadron-collider) or other potential future High Energy Colliders, neutrino experiments including those sited deep underground (e.g., https://www.dunescience.org), next-generation direct searches for dark matter, and astrophysical surveys to understand dark energy, including cosmic microwave background experiments.

We seek small business industrial partners to advance the state of the art and/or increase cost effectiveness of electronics needed for the above experiments and for the wider HEP community. Specific technical areas are given in the subtopics below. These are areas where experimental needs have been defined and shortcomings of existing technology identified. R&D seeking new technology will typically be in progress at DOE national laboratories and/or DOE-funded universities. While the subtopics offer initial guidance about specific technology areas, the scientists involved are the best source of detailed information about requirements and relevance to the experimental programs listed above. Applicants are therefore urged to make early contact with lab and university scientists to develop germane applications. Clear and specific relevance to HEP programmatic needs is required and supporting letters from lab and university scientists are an excellent way to show such relevance. Direct collaboration between small businesses and national labs and universities is strongly encouraged. For referral to lab and university scientists in your area of interest contact:
Helmut Marsiske, helmut.marsiske@science.doe.gov.

Grant applications are sought in the following subtopics:

a. Radiation-Hard Sensors and Engineered Substrates for Detectors at High Energy Colliders

Silicon detectors for high energy particle physics are currently based on hybrid technology, with separately fabricated diode strip or pixel sensors and bump-bonded Complementary Metal Oxide Semiconductor (CMOS) readout chips. As larger area detectors are required for tracking, and for new applications such as high-granularity calorimetry, new sensor concepts and lower manufacturing cost are needed. Sensors must withstand both ionizing and displacement damage radiation, and they must have fast signal collection and fast readout. Requirements for radiation tolerance depend on the distance from the interaction point, ranging from 0.1 to 3 Gigarad and 1E15 to 1E18 neutron-equivalent fluence depending on application.

Of interest are applications in the following focus areas:

- We seek monolithic CMOS-based sensors with moderate depth (5–20 micron) high resistivity substrates that can be fully depleted and can achieve charge collection times of 20 ns or less. Technologies of interest include deep n- and p-wells to avoid parasitic charge collection in CMOS circuitry and geometries with low-capacitance charge collection nodes. We aim for stitched, large-area arrays of sensors with sensor thickness less than 50 microns and pixel pitch of less than 25 microns.
- We also seek low to moderate gain (×10–50) reach-through silicon avalanche diodes (LGADs) as a proposed sensor type to achieve ~10 ps time resolution for collider experiments. The current generation of reach-through diodes suffers from large fractional dead area at the edges of the pixel and only moderate radiation hardness. A moderately doped thin buried (~5 micron) layer replacing a reach-through implant can address some of these problems. We seek substrate fabrication technologies to improve the radiation hardness and stability of these devices by using graded epitaxy or wafer bonding to produce a buried and moderately doped (1E16) thin buried gain layer on a high resistivity substrate. We also seek techniques to arrange internal doping of detectors by multiple thick epitaxial layers or other methods to allow engineering of the internal fields and resulting pulse shape.
- Development of sensors fabricated in materials other than silicon and with enhanced performance was identified as a priority research direction in [1]. A promising direction is ultrafast sensors using Silicon Carbide (SiC), a large bandgap material for which industry is currently focused mainly on power electronics applications. For wide bandgap materials, we seek sources for thick (50–75 microns) epitaxially grown n-type layers with low doping concentration in the range 1E13 to 1E14, to serve as substrate materials for the development of ultrafast, radiation-hard sensors that can operate at room temperature or above (i.e., without cooling).

Questions – Contact: Helmut Marsiske, helmut.marsiske@science.doe.gov

b. High-Density Interconnects and Integration

With the large channel counts and fine granularity of HEP detectors, there is an ever-increasing need for higher-density interconnects and integration. Applications are sought for the development of new technologies for reducing cost while increasing the density of interconnections or integration of pixelated sensors to readout electronics by enhancing or replacing solder bump-based technologies.

Of interest are cost-effective technologies to connect arrays of thinned integrated circuits (<50 microns with areas of ~2×2 cm^2) to silicon sensors with interconnect pitch of 25 microns or less. Technologies are sought that can minimize dead regions at device edges and/or enable wafer-to-wafer interconnection, by utilizing 3D integration with through-Si vias or other methods. Present commercial chip packaging and mounting technologies can, at cryogenic temperatures, put mechanical stress on the silicon die which distorts the operation of the circuit. Low-cost, robust packaging and/or interconnect solutions that do not introduce such stresses would be of advantage, especially in the case of large-area circuit boards (>0.5 m on each edge).

Also of interest is the development of readout electronics matched to new sensor characteristics, including new packaging such as 3D integration. We seek developments that demonstrate vertical integration of sensors, front-end electronics, and data-processing elements utilizing novel interconnect techniques to enable low-mass tracking devices with excellent resolution in timing (~10 ps) and position (<= 5 microns). We also seek heterogenous integration with non-silicon materials, such as diamond, large-bandgap materials, thin films, and other new emerging materials.

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Questions – Contact: Helmut Marsiske, helmut.marsiske@science.doe.gov

c. Electronics and Sensors for Ultra-Low-Temperature Experiments (4 K and Below)

Many HEP experiments are operated in the deep cryogenic regime (10–100 mK) with large numbers of readout channels required. Data acquisition and control signals from the mK stage out to room temperature require advanced sensors, high-fidelity RF signals, extremely low noise, and low thermal load on the cryogenic systems. Applications range from future CMB experiments that will have large focal plane arrays with ~500,000 superconducting detector elements, to axion dark matter searches with large channel counts to reach to high axion masses, to large-scale phonon-based particle-like dark matter searches.

Specific areas of interest include: low-noise cryogenic amplifiers (HEMT, SQUID, parametric, etc.); high-density interconnects for mK to LHe to room temperature stages; low-power (<100 mW per channel), high-resolution (14 bits or more), high-sampling rate (200 kHz or more) ADCs operating at 4 K or below; scalable high-density superconducting interconnects for microfabricated devices; high-frequency superconducting flex circuits; specialized electronics for processing large numbers of frequency-domain multiplexed RF signals; electronic frequency tuning mechanisms for microwave resonators; fabrication of miniature, ultra-low loss, superconducting resonator arrays; wafer processing combining niobium metal and MEMS; superconducting sensor (e.g., TES, MKID, qubit) microfabrication techniques, including micromachining, MEMS, and novel thin films; and sensors based on quantum evaporation (e.g., to detect ^{3}He atoms), including low-vibration cryogenics technology, and advanced controls for LHe layers on absorbers and electrons on LHe surfaces.

Questions – Contact: Helmut Marsiske, helmut.marsiske@science.doe.gov

d. Other

In addition to the specific subtopics listed above, the Department invites grant applications in other areas that fall within the scope of the topic description above.

Questions – Contact: Helmut Marsiske, helmut.marsiske@science.doe.gov

References:

1. DOE Basic Research Needs Study on High Energy Physics Detector Research and Development, 2020, *BRN Report*, https://science.osti.gov/hep/Community-Resources/Reports (June 29, 2023)
2. Stony Brook University, 2022, CPAD Workshop 2022, *Indico, Stony Brook University*, https://indico.bnl.gov/event/17072/ (June 29, 2023)
3. Kluge, A., et al., 2022, TWEPP 2022 Topical Workshop on Electronics for Particle Physics, *Indico, CERN*, Bergen, Norway, https://indico.cern.ch/event/1127562/ (June 29, 2023)
4. vCHEP, 2021, 25th International Conference on Computing in High Energy and Nuclear Physics (vCHEP), *Indico, CERN*, https://indico.cern.ch/event/948465/ (June 29, 2023)
5. Forti, F., et al., 2021, PM2021 – 15th Pisa Meeting on Advanced Detectors, *Indico*, https://agenda.infn.it/event/22092/ (June 29, 2023)
6. Retiere, F., et al., 2021, International Conference on Technology and Instrumentation in Particle Physics (TIPP2021), *Indico, CERN*, https://indico.cern.ch/event/981823/ (June 29, 2023)
7. 23rd IEEE Real-Time Conference, *Indico, CERN*, Online, Aug 1–5, 2022, https://indico.cern.ch/event/1109460/ (June 29, 2023)

8. Vienna University of Technology, 2022, VCI2022 – The 16th Vienna Conference on Instrumentation, *Indico, CERN*, Online, Feb 21–25, 2022, https://indico.cern.ch/event/1044975/ (June 29, 2023)
9. Braga, D., Li, S., and Fahim, F., 2021, Cryogenic Electronics Development for High-Energy Physics: An Overview of Design Considerations, Benefits, and Unique Challenges, *IEEE Solid-State Circuits Magazine* 13 (2021) 36–45, https://doi.org/10.1109/mssc.2021.3072804 (June 29, 2023)

C57-31 HIGH ENERGY PHYSICS DETECTORS AND INSTRUMENTATION

Maximum Phase I Award Amount: $200,000	Maximum Phase II Award Amount: $1,100,000
Accepting SBIR Applications: YES	Accepting STTR Applications: YES

High Energy Physics experiments require specialized detectors for particle and radiation detection. As an example, high-priority future experiments in the DOE Office of High Energy Physics (HEP) portfolio need advances that can benefit from small business contributions. These experiments include potential upgrades to the High Luminosity Large Hadron Collider (HL-LHC) detectors currently under construction (see https://home.cern/science/accelerators/large-hadron-collider) or other potential future High Energy Colliders, neutrino experiments including those sited deep underground (e.g., https://www.dunescience.org), next-generation direct searches for dark matter, and astrophysical surveys to understand dark energy, including cosmic microwave background experiments.

We seek small businesses to advance the state of the art and/or increase cost effectiveness of detectors needed for the above experiments and for the wider HEP community. Specific technical areas are given in the subtopics below. These are areas where experimental needs have been defined and shortcomings of existing technology identified. Improvements in sensitivity, robustness, and cost effectiveness are sought. R&D towards these ends will typically be in progress at DOE national laboratories and/or DOE-funded universities. While the subtopics offer initial guidance about specific detector areas, the scientists involved are the best source of detailed information about requirements and relevance to the experimental programs listed above. Applicants are therefore urged to make early contact with lab and university scientists to develop germane applications. Clear and specific relevance to HEP programmatic needs is required and supporting letters from lab and university scientists are an excellent way to show such relevance. Direct collaboration between small businesses and national labs and universities is strongly encouraged. For referral to lab and university scientists in your area of interest contact: Helmut Marsiske, helmut.marsiske@science.doe.gov.

Grant applications are sought in the following subtopics:

a. Low-Cost, High-Performance (V)UV/Visible/Near-IR Photon Detection

Particle physics detectors need to cover large areas with high-sensitivity photodetectors. Requirements include combinations of the following: 1) Wavelength sensitivity in the range 100–1500 nm over large photosensitive areas; 2) Fast response, radiation hardness, magnetic field compatibility, and high quantum efficiency for collider and intensity frontier experiments; 3) Compatibility with cryogenic operation and built with low-radioactivity materials for neutrino and dark matter experiments; and 4) Low cost and high reliability. Technologies using modern manufacturing processes and low-cost materials are of interest. These include use of semiconductor-based Geiger mode SPAD arrays, SiPM arrays, large-area microchannel plate-based systems (highly pixilated, fast readback with position resolution of less than ~0.3 mm and time resolution of ~10 ps), new alkali and non-alkali photocathode materials, and high-volume manufacturing of large-area, ultra-clean, sealed vacuum assemblies.

For collider and intensity frontier experiments, grant applications are sought to develop and advance wide-bandgap solid-state photodetector technology with internal gain that has low dark current, good radiation hardness, and reduced gain sensitivity to temperature.

Questions – Contact: Helmut Marsiske, helmut.marsiske@science.doe.gov

b. Scintillating Detector Materials and Wavelength Shifters

HEP utilizes scintillating materials for large calorimeters in colliding beam and intensity frontier experiments as well as for the active medium in some neutrino and dark matter detectors. Development of radiation-hard (tens of Megarad), fast (tens of ns) scintillators and wavelength shifting materials is of particular interest for colliding beam experiments. Development of fast (tens of ns), wavelength-matched shifting materials is of interest for liquid-argon and liquid-xenon detectors for neutrinos and dark matter. Large (>100 cm^3), bright (>10,000 ph/MeV), fast (tens of ns), radiation-hard (tens to hundreds of Megarad) ceramics or glasses with high density (>6 g/cm^3) are of interest for intensity frontier experiments as well as colliding beam experiments if high-volume (multi-m^3), cost-effective (few $\$/cm^3$) production methods can be developed. Scintillating crystals are not within the scope of this subtopic.

Questions – Contact: Helmut Marsiske, helmut.marsiske@science.doe.gov

c. Low Radioactivity Integration Solutions for Cryogenic Detectors

Cryogenic detectors used to search for rare dark matter and neutrino interactions, as well as some quantum devices, are sensitive to radioactive backgrounds (see, e.g., [16–19]). As future experiments aim to achieve unprecedented sensitivities, material radiopurity requirements are becoming ever more stringent. The most concerning contaminants are the primordial radionuclides ^{40}K, ^{232}Th, ^{238}U, and their decay progeny. Radioactive impurities in materials located close to active detector components have a disproportionately large impact, resulting in the need for new integration solutions for the packaging and wiring of cryogenic detectors.

Applications are sought in the following areas:

- A common element in superconducting device packaging (e.g., qubits, advanced sensors) for operation at mK temperatures is an interconnect board: a printed circuit board laminate to which active elements are wire bonded and to which RF coax connectors are attached. The laminate must have low dielectric loss to avoid negatively impacting device performance and often has a thermal expansion coefficient close to that of copper to avoid delamination of traces. Commonly used materials (e.g., alumina, Rogers TMM and RO4000 laminates) typically include ceramics, which are often high in natural radioactivity that can negatively impact device performance or sensitivity. We seek identification of a new material or process improvement to reduce the laminate radioactivity to less than ~100 mBq/kg, while maintaining the desired electrical and physical properties.
- Radiopure superconducting cables are needed for next-generation dark matter detectors and possibly quantum sensors. The cables must achieve ppt levels of U and Th and a ppb level of K. Non-superconducting radiopure flexible cables have been developed [21], but additional R&D is required for superconducting materials. Cables must satisfy thermal and electrical requirements for HEP instrumentation; general considerations include operation at mK temperatures, traces with an

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appropriate superconducting transition temperature (T_c > 2 K with > 4 K preferred), low thermal conductivity (example heat loads are available in the literature; see, e.g., [22] and Table 2 in [23]), low parasitic resistance (~mOhm/trace), and possibly low inductance (~100 nH/trace).

Questions – Contact: Helmut Marsiske, helmut.marsiske@science.doe.gov

d. Other

In addition to the specific subtopics listed above, the Department invites grant applications in other areas that fall within the scope of the topic description above.

Questions – Contact: Helmut Marsiske, helmut.marsiske@science.doe.gov

References:

1. U.S. Department of Energy, 2020DOE Basic Research Needs Study on High Energy Physics Detector Research and Development, *BRN Report*, https://science.osti.gov/hep/Community-Resources/Reports (June 29, 2023)
2. Workshop 2022, *Indico, Stony Brook University*, Nov 29 to Dec 2, 2022, https://indico.bnl.gov/event/17072/ (June 29, 2023)
3. Barbeau, P., Merkel, P., Zhang, J., et al., 2022, Report of the Instrumentation Frontier Working Group for Snowmass 2021, *arXiv:2209.14111*, https://arxiv.org/abs/2209.14111 (June 29, 2023)
4. Demarteau, M., and Shipsey, I., 2019, New Technologies for Discovery, *A report of the 2018 DPF Coordinating Panel for Advanced Detectors (CPAD) Community Workshop*, https://cds.cern.ch/record/2688980/?ln=en (June 29, 2023)
5. Proceedings of Science, 2016, International Conference on New Photo-Detectors, *PhotoDet 2015*, Moscow, Troitsk, Russia, Jul 6–9, 2015, https://pos.sissa.it/252/ (June 29, 2023)
6. iNSPIRE HEP, 2017, 8th International Conference on New Developments in Photodetection (NDIP17), Tours, France, Jul 3–7, 2017, *Conference Proceedings*, https://inspirehep.net/conferences/1633680 (June 29, 2023)
7. Parzefall, U., et al., 2022, 17th Trento Workshop on Advanced Silicon Radiation Detectors, *TREDI 2022*, Online, Mar 2–4, 2022, https://indico.cern.ch/event/1096847/ (June 29, 2023)
8. Casse, G., Moll, M., et al., 2021, Radiation Hard Semiconductor Devices for Very High Luminosity Colliders, *RD50 Status Report at 147th LHCC Meeting,* Sep 1–2, 2021, https://indico.cern.ch/event/1062348/ (June 29, 2023)
9. Brau, J.E., Jaros, J.A., and Ma, H., 2010, Advances in Calorimetry, *Annual Review of Nuclear and Particle Science*, Vol. 60 (2010) p. 615–644, http://www.annualreviews.org/doi/abs/10.1146/annurev.nucl.012809.104449 (June 29, 2023)
10. Snowmass, 2022, Report of the Topical Group on Calorimetry, *arXiv:2208.12861*, https://arxiv.org/abs/2208.12861 (June 29, 2023)
11. NIST, 2021, The 19th International Workshop on Low Temperature Detectors (LTD19), *NIST*, Online, Jul 19–29, 2021, https://www.nist.gov/news-events/events/2021/07/19th-international-workshop-low-temperature-detectors-ltd19 (June 29, 2023)
12. PM2021 – 15th Pisa Meeting on Advanced Detectors, *Indico*, La Biodola, Isola d'Elba, Italy, May 22–28, 2022, https://agenda.infn.it/event/22092/ (June 29, 2023)
13. International Conference on Technology and Instrumentation in Particle Physics (TIPP2021), *Indico, CERN*, Online, May 24–28, 2021, https://indico.cern.ch/event/981823/ (June 29, 2023)

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14. 2021 IEEE Symposium on Radiation Measurements and Applications, *IEEE SORMA West*, Online, May 19–28, 2021, http://sormawest.org/ (June 29, 2023)
15. Vienna University of Technology, 2022, VCI2022 – The 16th Vienna Conference on Instrumentation, *Indico, CERN*, Online, Feb 21–25, 2022, https://indico.cern.ch/event/1044975/ (June 29, 2023)
16. Akerib, D.S., et al., 2020, The LUX-ZEPELIN (LZ) radioactivity and cleanliness control programs, *Eur. Phys. J. C* 80 (2020) 1044, https://doi.org/10.1140/epjc/s10052-020-8420-x (June 29, 2023)
17. Agnese, R., et al., 2017, Projected sensitivity of the SuperCDMS SNOLAB experiment, *Phys. Rev. D* 95 (2017) 082002, https://doi.org/10.1103/PhysRevD.95.082002 (June 29, 2023)
18. Vepsäläinen, A.P., et al., 2020, Impact of ionizing radiation on superconducting qubit coherence. *Nature* 584 (2020) 551–556, https://doi.org/10.1038/s41586-020-2619-8 (June 29, 2023)
19. McEwen, M., et al., 2020, Resolving catastrophic error bursts from cosmic rays in large arrays of superconducting qubits, *Nature Phys.* 18 (2022) 107–111, https://doi.org/10.1038/s41567-021-01432-8 (June 29, 2023)
20. Aguilar-Arevalo, A., et al., 2022, The Oscura Experiment, 2022 *Preprint*, https://doi.org/10.48550/arXiv.2202.10518 (June 29, 2023)
21. Arnquist, I.J., et al., 2020, Ultralow radioactivity Kapton and copper-Kapton laminates, *NIMA* 959 (2020) 163573, https://doi.org/10.1016/j.nima.2020.163573 (June 29, 2023)
22. Krinner, S., et al., 2019, Engineering cryogenic setups for 100-qubit scale superconducting circuit systems, *EPJ Quantum Technol.* 6 (2019) 2, https://doi.org/10.1140/epjqt/s40507-019-0072-0 (June 29, 2023)
23. Hollister, M.I., et al., 2017, The cryogenics design of the SuperCDMS SNOLAB experiment, *IOP Conf. Ser. Mater. Sci. Eng.* 278 (2017) 012118, https://doi.org/10.1088/1757-899X/278/1/012118 (June 29, 2023)

C57-32 ARTIFICIAL INTELLIGENCE/MACHINE LEARNING FOR HIGH ENERGY PHYSICS

Maximum Phase I Award Amount: $200,000	Maximum Phase II Award Amount: $1,100,000
Accepting SBIR Applications: YES	Accepting STTR Applications: YES

Motivation:
HEP simulation, reconstruction, controls, and analyses have in recent years seen a transformation from Artificial Intelligence and Machine Learning (AI/ML) methods that allow to, respectively, (i) cut-short full, computationally-demanding simulations while remaining faithful to the correct physics, (ii) provide sophisticated detector objects derived from processing the particle energy-depositions in detectors, (iii) monitor beam-lines and instrumentation to provide feedback control, as well as trigger detectors, and finally, (iv) give intelligent inference of the physics under study in the event sample or images.

HEP has unique concerns and demands of the field of AI/ML: work with extremely large data sets streaming from multi-modal detectors and observatories is common to most experiments, as is the need for online monitoring and control of the facilities producing the data that are sensitive to environmental conditions and are constantly evolving through upgrades. AI/ML across generations of facility upgrades either to process and gain information from the data, or to provide real-time monitoring requires ever-larger sophistication and compute power.

Large data sets and continuous learning may be required to detect, monitor, and control HEP detection facilities. However, typically datasets over which training occurs, that might naturally be on the scale of petabytes, are frequently reduced to terabytes or gigabytes for convenience. In so doing, information may be lost or not properly captured as a function of time. Similarly, continuous learning can be employed to avoid model sensitivity to changing data input. Continuous learning avoids the need to train multiple models for each generation in a facility's evolution and for all possible conditions that may affect elements of the facility's performance.

Further to HEP needs, visualization of all aspects of the AI/ML process are desired. The HEP paradigm is to compare simulated data predictions with experimental data observations and visualization tools aid the process of drawing scientific conclusions. Tools that allow comparison between multiple datasets that may have data values spanning multiple orders of magnitude and represent physical systems are essential. Integrating HEP visualization with AI/ML software allows HEP scientists to gain insight into the ML network under study for a better physical interpretation of not just the extracted physics, but of the network and its performance. Further, the visualization of uncertainties in data sets is essential in drawing scientifically valid conclusions.

HEP seeks applications under this SBIR FOA that build software tools that are aligned with the above purposes. Applications are sought that conform to the following two descriptions. Letters of Intent should demonstrate the proposed tools will be relevant to specific AI/ML applications in more than one HEP sub-program, and the software developed will be usable in standard HEP AI/ML workflows to be considered responsive.

a. HEP AI/ML Training Tools

Software tools to facilitate training on PB scale datasets either through distributed, real-time, or asynchronous training; or algorithms for life-long learning of continuously evolving systems. Large scale data set training tools can be optimized for either homogeneous or heterogenous computing systems and may include training in multiple stages or with hyperparameter optimization. Continuous learning can be applied to algorithms that either adapt for data source evolution or a changing facility as a whole. These tools should be applicable for time-varying systems with an ability to adapt and utilize feedback, physics constraints, and active learning techniques.

Questions – Contact: Eric Church, Eric.Church@science.doe.gov

b. HEP AI/ML Visualization Tools – Description

Software tools to improve visualization of scientific information natively integrated with both AI/ML and HEP software libraries. Applications submitted to this topic should focus on the ability to generate scientific publication quality plots of widely varying types of data and their associated uncertainties using a straightforward user interface; or develop visualization techniques to identify and display anomalous outcomes when comparing to reference data.

Questions – Contact: Eric Church, Eric.Church@science.doe.gov

c. Other

In addition to the specific subtopics listed above, the Department invites grant applications in other areas that fall within the scope of the topic description above.

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Questions – Contact: Eric Church, Eric.Church@science.doe.gov

References:

1. U.S. Department of Energy, 2019, Basic Research Needs Workshop on Compact Accelerators for Security and Medicine, Tools for the 21st Century, May 6-8, 2019, https://science.osti.gov/-/media/hep/pdf/Reports/2020/CASM_WorkshopReport.pdf?la=en&hash=AEB0B318ED0436B1C5FF4EE0FDD6DEB84C2F15B2 (See sections 2.2 and 5.2.1-5.2.3) (June 29, 2023)
2. Litos, M., Adli, E., An, W., Clarke, C., Clayton, C., Corde, S., Delahaye, J., England, R., Fisher, A., Frederico, J., et al., 2014, High-efficiency acceleration of an electron beam in a plasma wakefield accelerator, *Nature 515*, 92, 2014, https://www.nature.com/articles/nature13882 (June 29, 2023)
3. Corde, S., Adli, E., Allen, J., An, W., Clarke, C., Clayton, C., Delahaye, J., Frederico, J., Gessner, S., Green, S., et al., 2015, Multi-gigaelectronvolt acceleration of positrons in a self-loaded plasma wakefield, *Nature 524*, 442 (2015), https://www.nature.com/articles/nature14890 (June 29, 2023)
4. Adli, E., Ahuja, A., Apsimon, O., Apsimon, R., Bachmann, A. M., Barrientos, D., Batsch, F., Bauche, J., Olsen, V.B., Bernardini, M., et al., 2018, Acceleration of electrons in the plasma wakefield of a proton bunch, *Nature 561*, 363–367, 2018, https://www.nature.com/articles/s41586-018-0485-4 (June 29, 2023)
5. Joshi, C., Adli, E., An, W., Clayton, C.E., Corde, S., Gessner, S., Hogan, M.J., Litos, M., Lu, W., Marsh, K.A., et al., 2018, Plasma wakefield acceleration experiments at FACET II, *Plasma Physics and Controlled Fusion 60*, 034001, 2018, https://iopscience.iop.org/article/10.1088/1361-6587/aaa2e3/meta (June 29, 2023)
6. Scheinker, A., and Gessner, S., 2015, Adaptive method for electron bunch profile prediction, *Physical Review Special*, Topics-Accelerators and Beams 18, 102801, 2015, https://doi.org/10.1103/PhysRevSTAB.18.102801 (June 29, 2023)
7. Scheinker, A., Edelen, A., Bohler, D., Emma, C., and Lutman, A., 2018, Demonstration of model-independent control of the longitudinal phase space of electron beams in the linac-coherent light source with femtosecond resolution, *Physical review letters 121*, 044801, 2018, https://doi.org/10.1103/PhysRevLett.121.044801 (June 29, 2023)

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PROGRAM AREA OVERVIEW: OFFICE OF NUCLEAR PHYSICS

Nuclear physics research seeks to understand the structure and interactions of atomic nuclei and the fundamental forces and particles of nature as manifested in nuclear matter. Nuclear processes are responsible for the nature and abundance of all matter, which in turn determines the essential physical characteristics of the universe. The primary mission of the Office of Nuclear Physics (NP) is to develop and support the scientists, techniques, and facilities that are needed for basic nuclear physics research. Attendant upon this core mission are responsibilities to enlarge and diversify the Nation's pool of technically trained talent and to facilitate transfer of technology and knowledge to support the Nation's economic base.

Nuclear physics research is carried out at national laboratories, international accelerator facilities, and universities. In the US, the Continuous Electron Beam Accelerator Facility (CEBAF) at the Thomas Jefferson National Accelerator Facility (TJNAF) allows detailed studies of how quarks and gluons bind together to make protons and neutrons. The Relativistic Heavy Ion Collider (RHIC) at Brookhaven National Laboratory (BNL) is forming new states of matter which have not existed since the first moments after the birth of the Universe. The Argonne Tandem Linac Accelerator System (ATLAS) at Argonne National Laboratory (ANL) provides stable and radioactive beams directed toward understanding the properties of nuclei at their limits of stability. The Facility for Rare Isotope Beams (FRIB) at Michigan State University (MSU) produces and studies highly unstable nuclei that are now formed only in supernovae and neutron star mergers in sufficient numbers, enabling scientists to better understand stellar evolution and the origin of the elements. NP is also constructing the Electron-Ion Collider (EIC) at BNL to unravel the origin of both mass and spin of nucleons through the interactions of quarks and gluons.

NP supports an in-house program of basic research focused on heavy elements at the 88-Inch Cyclotron of the Lawrence Berkeley National Laboratory (LBNL); the operations of accelerators for in-house research programs at two universities (Texas A&M University and the Triangle Universities Nuclear Laboratory (TUNL) at Duke University), which provide unique instrumentation with a special emphasis on the training of students; and non-accelerator experiments, such as large stand-alone detectors and observatories for rare events. Of particular interest is R&D related to future experiments in fundamental symmetries such as neutrinoless double-beta decay experiments and measurement of the electric dipole moment of the neutron, where extremely low background and low count rate particle detections are essential.

Our ability to continue making a scientific impact on the general community relies heavily on the availability of cutting-edge technology and advances in detector instrumentation, electronics, software, and accelerators. The technical topics that follow describe research and development opportunities in the equipment, techniques, and facilities needed to conduct and advance nuclear physics research at existing and future facilities.

For additional information regarding Office of Nuclear Physics priorities, click here.

C57-33 NUCLEAR PHYSICS SOFTWARE AND DATA MANAGEMENT

Maximum Phase I Award Amount: $200,000	Maximum Phase II Award Amount: $1,100,000
Accepting SBIR Applications: YES	Accepting STTR Applications: YES

Large scale data storage and processing systems are needed to record, store, distribute, and process data from nuclear physics experiments conducted at large facilities in the US, such as Brookhaven National Laboratory's (BNL) Relativistic Heavy Ion Collider (RHIC), the Thomas Jefferson National Accelerator Facility (TJNAF) Continuous Electron Beam Accelerator (CEBAF), and for the Facility for Rare Isotope Beams (FRIB) at MSU. The Electron-Ion Collider (EIC), being constructed at BNL is anticipated to produce data at rates that will also challenge current computing and storage resources. Experiments at such facilities are extremely complex, involving thousands of detector elements that produce raw experimental data at rates in excess of several tens of GB/sec, resulting in an anticipated annual production of raw data sets of size 50 to 100 Petabytes (PB) at RHIC now, and the EIC in the future. A single experiment can produce reduced data sets of many 100s of Terabytes (TB) to a petabyte (PB) which are then distributed to institutions worldwide for analysis, and with the increasing data generation rates at these facilities, multi-PB reduced datasets will soon be common. Increased adoption and implementation of streaming readout protocols will only accelerate the data acquisition rates and the resulting volume of raw data. Similarly, high-performance computing (HPC) simulations are essential to develop the theory needed to guide and interpret nuclear physics experiments. These "theoretical experiments" can also generate hundreds of TB of raw data, which needs to be analyzed by means of custom software pipelines and archived for future analysis. These simulations include models of nuclear collisions and the astrophysical events that are responsible for the creation of atomic nuclei, as well as calculations of structure of atomic nuclei and nucleons. Specific use examples are in Ref 1.
Research on the management and storage of such large data sets will be required to support these large scale nuclear physics activities.

Note that software applications for control or diagnosis of accelerator hardware or data should apply to SBIR/STTR Topic C57-35, "NUCLEAR PHYSICS ACCELERATOR TECHNOLOGY"

All applications must explicitly show relevance to the DOE Nuclear Physics (NP) program and must be informed by the state of the art in nuclear physics software and data management applications, commercially available products, and emerging technologies. An application based on merely incremental improvements or little innovation will be considered non-responsive unless context is supplied that convincingly shows its potential for significant impact or value to the DOE nuclear physics program.

Applications which are largely duplicative of previously funded research by the Office of Nuclear Physics and/or the Office of Advanced Scientific Computing Research will be considered nonresponsive to this topic. Applicants are strongly encouraged to review recent SBIR/STTR awards from the Office of Nuclear Physics. Those awards can be found at https://science.osti.gov/sbir/Awards (Release 1, DOE Funding Program: Nuclear Physics or Advanced Scientific Computing Research).

The subtopics below refer to innovations that will advance our nation's capability to perform nuclear physics research, and more specifically to improve DOE NP Facilities and the wider NP community's programs. Although applicants may wish to gather information from and collaborate with experts at DOE National Laboratories to establish feasibility for their innovations, DOE expects all applicants to address commercialization opportunities for their product or service in adjacent markets such as medicine, homeland security, the environment and industry. Applications using the resources of a third party (such as a DOE laboratory) must include in the application a letter of certification from an authorized official of that organization.

Please note: Following award, all DOE SBIR/STTR grant projects requiring high performance computing support are eligible to apply to use the DOE National Energy Research Scientific Computing Center (NERSC) resources. NERSC is the primary scientific computing facility for the DOE. If you think you will need to use the computing capabilities of NERSC during your Phase I or Phase II project, you may be eligible for this free resource. Learn more about NERSC and how to apply for NERSC resources following the award of a Phase I or Phase II project at http://www.nersc.gov/users/accounts/allocations/request-form/.

Applications are sought only in the following subtopics:

a. Tools for Large Scale, Widely Distributed Nuclear Physics Data Processing

A trend in nuclear physics is to maximize the use of distributed storage and computing resources by constructing end-to-end data handling and distribution systems, with the aim of achieving fast data processing and/or increased data accessibility across many disparate computing facilities. Such facilities include local computing resources, university-based clusters, major DOE funded computing resources, and commercial cloud offerings.

Applications are sought for:

1) Software techniques to improve the effectiveness of storing, retrieving, and moving such large volumes of data (> 1 PB/day), possibly including but not limited to automated data replication, data transfers from multiple sources, or network bandwidth scheduling to achieve the lowest wait-time or fastest data processing;
2) Effective new approaches to data mining or data analysis through data discovery or restructuring. Such tools should be aligned with FAIR principles (findability, accessibility, interoperability, and reusability). Examples of such approaches might include fast information retrieval through advanced metadata searches or in-situ data reduction and repacking for remote analysis and data access;

Open-source software solutions are strongly encouraged. Applications must clearly indicate how Phase I research and development will result in a working prototype or method that will be completed by the end of Phase II. The prototype or method must be suitable for testing in an application of use to a nuclear physics subprogram, e.g. Medium Energy, Heavy Ions, etc. and/or at a nuclear physics facility. All applications must identify a current or future NP experiment or a data management facility interested in the deployment of the proposed tools. Applications not meeting this requirement will be considered nonresponsive and declined without review.

Questions – Contact: Michelle Shinn, Michelle.Shinn@science.doe.gov or the NP SBIR/STTR Topic Associate for Software and Data Management: Gulshan Rai, Gulshan.Rai@science.doe.gov

b. Application of Emerging Data Science Techniques to Nuclear Physics

As discussed above, analysis of experimental, theoretical, and simulation data is a central task in the NP community. In the case of medium scale experiments, data sets will be collected with each event having a large number of independent parameters or attributes. The manipulation of these complex datasets into summaries suitable for the extraction of physics parameters and model comparison is a difficult and time-consuming task. Currently, both the national laboratory and university-based groups carrying out experimental and simulation analyses maintain local computing clusters running domain specific software, often written by nuclear physicists. Likewise, theoretical groups, after generating data on a multitude of HPC platforms, perform analysis on the HPC resources and analysis machines at a leadership computing facility (LCF) and on local clusters. Concurrently, the nuclear physics, particle physics, and data science communities have developed tools and techniques to apply machine learning (ML) and artificial intelligence (AI) for pattern finding and classification in large datasets, promising new avenues for analyses of this kind. These tools are generally open-source and can be effectively deployed on platforms ranging from distributed computing resources provided by commercial cloud services to leadership computing facilities. Application of these new ML and AI technologies to the analysis of nuclear physics data or to accelerate simulations requires the development of domain specific tools. Such tools include the application of specific AI algorithms and techniques for the preparation and staging of large training sets. Sources of such data are described in SBIR/STTR Topic C57-36, "NUCLEAR PHYSICS INSTRUMENTATION, DETECTION SYSTEMS AND TECHNIQUES".

Applications are sought to develop:

1) ML and AI technologies to address a specific application domain in experimental, simulation, and/or theoretical nuclear physics data analysis. Applications should address performance and plan to demonstrate feasibility to non-experts in computer systems with working prototypes and comprehensive tutorials and/or documentation.
2) ML and AI technologies implemented within high-performance computing simulations to encapsulate essential physics to increase the fidelity of simulations and/or reduce the time to solution.
3) ML and AI technologies that integrate methods in nuclear theory, simulations and data analysis to improve real-time decision making for nuclear physics experiments.

Applicants are strongly encouraged to consult the references and open literature to best understand the tools already in use by the community. Open-source software solutions are strongly encouraged. Applications must clearly indicate how Phase I research and development will result in a working prototype or method that will be completed by the end of Phase II. The prototype or method must be suitable for testing in an application of use to a nuclear physics subprogram, e.g. Medium Energy, Heavy Ions, etc. and/or at a nuclear physics facility. All applications must identify a current or future NP experiment or theory collaboration interested in the proposed ML and AI technologies. Applications not meeting this requirement will be considered nonresponsive and declined without review.

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c. Heterogeneous Concurrent Computing

Computationally demanding theory calculations as well as detector simulations and data analysis tasks are significantly accelerated through the use of general-purpose Graphics Processing Units (GPUs). The use of Field Programmable Gate Arrays (FPGAs) based computing is also being explored by the community.
Utilizing DOE's High Performance Computing (HPC) and Leadership Computing Facilities (LCFs) is of growing relevance and importance to experimental NP as well. Most HPC and LCF facilities are evolving toward hybrid CPU and GPU architectures oriented towards machine learning. Existing analysis codes do not sufficiently reveal the concurrency necessary to exploit the high performance of the architectures in these systems. NP analysis problems do have the potential data concurrency needed to perform well on multi- and many-core architectures, but currently struggle to achieve high efficiency in both thread-scaling and in vector utilization. NP experimental groups are increasingly invited and encouraged to use such facilities, and DOE is assessing the

needs of computationally demanding experimental activities such as data analysis, detector simulation, and error estimation in projecting their future computing requirements.

Applications are sought to develop:

1) Tools and technologies that can facilitate efficient use of large-scale CPU-GPU hybrid systems for the data-intensive workflows characteristic of experimental NP. Such tools can provide capability to utilize the heterogeneous LCF architectures and/or they can mask the embarrassingly parallel nature of the analysis needs and support the simultaneously scheduling of GPU-intense and CPU-only workflows on the same nodes with sophisticated workflow management tools. Ideally, tools should be designed, and interfaces constructed, in such a way to abstract low-level computational performance details away from users who are not computer scientists, while providing users who wish to perform optimizations effective and expressive application programming interfaces to accomplish this.

Open-source software solutions are strongly encouraged. Applications must clearly indicate how Phase I research and development will result in a working prototype or method that will be completed by the end of Phase II. The prototype or method must be suitable for testing in a nuclear physics application of use to a nuclear physics subprogram, e.g. Medium Energy, Heavy Ions, etc. and/or at a nuclear physics facility. All applications must identify a current or future NP experiment or theory collaboration interested in the Heterogeneous Concurrent Computing technologies. Applications not meeting this requirement will be considered nonresponsive and declined without review.

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d. Other

In addition to the specific subtopics listed above, the Department invites applications in other areas that fall within the scope of the general description at the beginning of this topic.

Questions – Contact: Michelle Shinn, Michelle.Shinn@science.doe.gov or the NP SBIR/STTR Topic Associate for Software and Data Management Gulshan Rai, Gulshan.Rai@science.doe.gov

References:

1. Armstrong, W., 2019, Nuclear Physics Network Requirements Review Report. *Energy Sciences Network,* https://science.osti.gov/-/media/np/pdf/Reports/2020/NP_Network_Requirements_Review_Report.pdf (May 9, 2019)
2. Khalek, R., et al, 2022, The EIC Science Requirements and Detector Concepts for the Electron-Ion Collider: EIC Yellow Report, *Cornell University*, https://arxiv.org/abs/2103.05419 (March 8, 2021)
3. USQCD: US Lattice Quantum Chromodynamics, National Computational Infrastructure for Lattice Quantum Chromodynamics. www.usqcd.org/
4. Joo, B., et al, 2019, USQCD: Status and Future Perspectives for Lattice Gauge Theory Calculations to the Exascale and Beyond, Eur.Phys.J.A. 55 *USQCD,* https://link.springer.com/article/10.1140/epja/i2019-12919-7 (November 14, 2009)
5. Fowler, R., 2012, U.S. Department of EnergySciDAC Scientific Discovery Through Advanced Computing SciDAC, The Secret Life of Quarks, *UNC*, https://www.osti.gov/servlets/purl/1062585 (October 12, 2012)

6. Livney, M., 2007, HTCondor: High Throughput Computing, University of Wisconsin. www.cs.wisc.edu/condor/, (2007)
7. Keahey, K., 2009, Cloud Computing and Virtual Workspaces, Nimbus, *University of Chicago*. https://workspace.glrobus.org/ (June 2009)
8. CERN VM Software Appliance. http://cernvm.cern.ch/portal/
9. The Open Science Grid consortium https://osg-htc.org/
10. CERN, Welcome to the Worldwide LHC Computing Grid, Worldwide Large Hadron Collider (LHC), Computing Grid (WLCG). http://wlcg.web.cern.ch/
11. European Grid Infrastructure (EGI). http://www.egi.eu/
12. Baru, C., 2015, SDSC's Storage Resource Broker Links, NPACI Data-Intensive Infrastructure, San Diego Supercomputer Center (SDSC). https://www.sdsc.edu/pub/envision/v14.1/srb.html (2015)
13. Event-Driven Architectures (EDA), Wikipedia. http://en.wikipedia.org/wiki/Event_driven_architecture
14. IEEE 1588TM Standard for A Precision Clock Synchronization Protocol for Networked Measurement and Control Systems, National Institute of Standards and Technology. https://www.nist.gov/el/intelligent-systems-division-73500/ieee-1588
15. Welcome to the XRootD Webpage, XRootD. http://xrootd.slac.stanford.edu/
16. Rademakers, F., 2002, CERN, PROOF (Parallel ROOT Facilities), ROOT Data Analysis Framework. http://root.cern.ch/drupal/content/proof (September 2002)
17. The White Rabbit Project Webpage, Open Hardware Repository. https://www.ohwr.org/projects/white-rabbit
18. Martoiu, S., Muller, H., Tarazona, A., and Toledo, J., 2012, Development of the Scalable Readout System (SRS) for Micro-pattern Gas Detectors and Other Applications, Journal of Instrumentation, Vol. 8, p. 12. https://iopscience.iop.org/article/10.1088/1748-0221/8/03/C03015/pdf (September 2012)
19. Muller, H., 2017, Scalable Readout System: from APV to VMM frontends, p. 37. https://indico.cern.ch/event/676702/contributions/2818988/attachments/1575628/2488041/From_APV_to_VMM_frontends.pdf (November 9, 2017)
20. Hasell, D. and Bernauer, J., 2017, Summary of the Streaming Readout Workshop, p. 4. https://eic.jlab.org/wiki/images/c/c4/SR_Summary.pdf (2017)
21. Cuevas, C., (2022) Workshop on Streaming Readout, *Jefferson Lab,* https://www.jlab.org/streaming-readout-x (May 19, 2022)
22. Di Bello, F., et al., 2020 Towards a Computer Vision Particle Flow, *Cornell University,* https://arxiv.org/abs/2003.08863 (March 19, 2020)
23. Cisbani, E., et al., (2019) AI-optimized detector design for the future Electron-Ion Collider: the dual-radiator RICH case, *Cornell University*, https://arxiv.org/abs/1911.05797 (June 6, 2020)
24. Strong, G., (2020), On the impact of selected modern deep-learning techniques to the performance and celerity of classification models in an experimental high-energy physics use case, *Cornell University*, https://arxiv.org/abs/2002.01427, (May 8, 2020)
25. Albertsson, K., et al., (2018) Machine Learning in High Energy Physics Community White Paper, Cornell University, https://arxiv.org/abs/1807.02876 (May 16, 2019)
26. Bedaque, P., et al., 2020, Report from the A.I. For Nuclear Physics Workshop, *Cornell University*, https://arxiv.org/abs/2006.05422 (July 13, 2020)
27. Boehnlein, A., et al., 2022, Machine Learning in Nuclear Physics, *Cornell University*, https://arxiv.org/abs/2112.02309 (May 2, 2022)
28. DOE, 2023, Machine Learning Takes Hold in Nuclear Physics, DOE, https://www.energy.gov/science/np/articles/machine-learning-takes-hold-nuclear-physics (February 21, 2023)

C57-34 NUCLEAR PHYSICS ELECTRONICS DESIGN AND FABRICATION

Maximum Phase I Award Amount: $200,000	Maximum Phase II Award Amount: $1,100,000
Accepting SBIR Applications: YES	Accepting STTR Applications: YES

The DOE Office of Nuclear Physics (NP) seeks new developments in detector electronics with significantly improved energy, position, and timing resolution, sensitivity, rate capability, stability, dynamic range, and signal to noise ratio. Of particular interest are innovative readout electronics for use with the nuclear physics detectors described in SBIR/STTR Topic C57-36, "NUCLEAR PHYSICS INSTRUMENTATION, DETECTION SYSTEMS AND TECHNIQUES". An important criterion is the cost per channel of electronic devices and modules.

Nuclear physics detectors range in complexity, from those that fill a modest-sized laboratory to those that fill a multistory building. While most detectors may operate at or near room temperature, those used in rare decay experiments like neutrinoless double beta decay operate at cryogenic temperatures, below 20 mK for some experiments. This underscores that, in general, nuclear physics electronics may operate in extreme environments, whether at extreme cryogenic temperatures or where radiation levels are high.

All applications must explicitly show relevance to the NP program. Applications must be informed by the state of the art in nuclear physics applications, commercially available products and emerging technologies. An application based on incremental improvements or little innovation will be considered non-responsive unless context is supplied that convincingly shows its potential for significant impact or value to the DOE nuclear physics program.

Applications which are largely duplicative of previously funded research by the NP will be considered nonresponsive to this topic. Applicants are strongly encouraged to review recent SBIR/STTR awards from the NP to avoid duplication. Those awards can be found at https://science.osti.gov/sbir/awards/ (Release 1, DOE Funding Program: Nuclear Physics).

The subtopics below refer to innovations that will advance our nation's capability to perform nuclear physics research, and more specifically to improve scientific productivity at NP facilities and the wider NP community's programs. Applicants may wish to gather information from and collaborate with experts at DOE National Laboratories to establish feasibility for their innovations. DOE expects all applicants to address commercialization opportunities for their product or service in adjacent markets such as medicine, homeland security, the environment and industry. Applications that propose using the resources of a third party (such as a DOE laboratory) must include in the application, a letter of certification from an authorized official of that organization.

Applications are sought only in the following subtopics:

a. Advances in Digital Processing Electronics

Digital signal processing electronics are needed, following low noise amplification and anti-aliasing filtering, in nuclear physics applications. Applications are sought to:

1) develop high speed digital processing electronics that, relative to current state of the art, improve the effective number of bits to 16 at sampling rates of > 4GHz and a bandwidth > 2 GHz, with minimal

integral non-linearity, and minimal, or at least repeatable differential non-linearity. Such devices should have at a minimum 64 channels with fast timing (< 10 ps). If deployed where radiation levels are high, then they must be rad-hard (tolerate 10 Mrad with 10^{15} n/cm^2).

Emphasis should be on low power dissipation and low cost per channel.

Applications must clearly indicate how Phase I research and development will result in a working prototype or method that will be completed by the end of Phase II. The prototype or method must be suitable for testing in a nuclear physics application and/or at a nuclear physics accelerator facility. Applications not meeting this requirement will be considered nonresponsive and will not undergo merit review.

Questions – Contact: Michelle Shinn, Michelle.Shinn@science.doe.gov or the NP SBIR/STTR Topic Associate(s) for Electronics and Circuits: Manouchehr Farkhondeh, Manouchehr.Farkhondeh@science.doe.gov

b. Front-End Application-Specific Integrated Circuits

Applications are sought to develop front-end application-specific integrated circuits (ASICs) for amplifying and processing data from highly segmented solid-state and gas detectors in pixels, strips or drift configurations, including silicon photomultipliers (SiPM), multi-channel plate photomultipliers (MCP-PMTs), large area picosecond photodetectors (LAPPD) and germanium detectors. Specifications are provided below.

Microelectronics of specific interest include:

1) Very low power (< 10 mW/channel), and/or very low noise charge amplifiers (<100 electrons into 30pF at detector input) and filters, very high rate photon-counting circuits (> 10 MHz), high-precision charge and timing measurement circuits, low-power and small-area ADCs and TDCs, efficient sparsifying and multiplexing circuits. Native control and readout using fiber w/DWDM so multiple ASICs can be serviced by one fiber is desired. The proposed hardware must clearly advance in the state-of-the-art for the rare isotope beam facilities or the high intensity (e.g., CEBAF or EIC) communities;
2) Two-dimensional high-channel-count circuits for small pixels combined with high-density, high-yield, and low-capacitance (< 1pF) interconnection techniques. Layering these 2D ASICS via interconnects to increase functionality is also of interest;
3) Microelectronics for extreme environments such as high-radiation (both neutron and ionizing), vacuum, magnetic fields, and low temperature, depending on the application. Specifications for the former are: high channel count ($\geq$ 64 channels) ASIC with fast timing (< 5 ps), high radiation hardness (10 Mrad with 10^{15} n/cm^2), fast waveform sampling (> 8GHz) and bandwidth (≥ 3GHz); and
4) Very-large-scale systems-on-chip, multicore and multiprocessors systems-on-chip, experiments-on-chip characterized by high functionality, high programmability, DSP capabilities, high data rate interface.

Relative to the state of the art these circuits should be low-cost, user friendly, and capable of communicating with commercial auxiliary electronics.

Applications must clearly indicate how Phase I research and development will result in a working prototype or method that will be completed by the end of Phase II. The prototype or method must be suitable for testing in a nuclear physics application and/or at a nuclear physics accelerator facility. Applications not meeting this requirement will be considered nonresponsive and will not undergo merit review.

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c. Next Generation Pixel Sensors

The Electron-Ion Collider (EIC) is designed to operate at luminosities in the range 10^{33}–10^{34} cm^{-2} s^{-1} and will require radiation hard tracking devices placed at radii less than 10 cm (current design is 5 mm) from the interaction region where radiation is the highest. Upgrades to detectors at other NP facilities would benefit as well. Therefore, alternatives to the present generation high density Active Pixel Sensors will be required.

Applications are also sought for:

1) The next generation of monolithic active pixel sensors. Options may include integrated CMOS detectors which combine initial signal processing and data sparsification on a high-resistivity silicon, superconducting large area pixel detectors, and novel 2.5D- and 3D-pixel materials and geometric structures. Reducing the frame accumulation time below the current state of the art of > 5 µs is highly desirable.

Applications must clearly indicate how Phase I research and development will result in a working prototype or method that will be completed by the end of Phase II. The prototype or method must be suitable for testing in a nuclear physics application and/or at a nuclear physics accelerator facility. Applications not meeting this requirement will be considered nonresponsive and will not undergo merit review.

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d. Other

In addition to the specific subtopics listed above, the Department invites applications in other areas that fall within the scope of the topic description above.

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References:

1. sPHENIX, 2014, An Upgrade Proposal from the PHENIX Collaboration, p.243.
2. http://www.phenix.bnl.gov/phenix/WWW/publish/documents/sPHENIX_proposal_19112014.pdf (November 19, 2014)
3. Khalek, A., et al., 2021, Science Requirements and Detector Concepts for the Electron-Ion Collider: EIC Yellow Report, *Inspire*, https://inspirehep.net/literature/1851258 (March 8, 2021)
4. Pastika J., Rominsky M., Rubinov P., et al, "Preliminary Specifications for a 1-Picosecond Resolution ASIC for the FTBF TOF System", http://lappddocs.uchicago.edu/documents/364/sendit
5. Abelev, B., Adam, J., Adamova, D., Aggarwal, M.M., et. al., 2021, The ALICE Collaboration, 2014, Technical Design Report for the Upgrade of the ALICE Inner Tracking System, Journal of Physics G: Nuclear and Particle Physics, Vol. 41, Issue 8, p. 181. http://iopscience.iop.org/article/10.1088/0954-3899/41/8/087002/meta (December 3, 2021)
6. The SoLID Collaboration, 2014, SoLID (Solenoidal Large Intensity Device) Preliminary Conceptual Design Report, p. 225. http://hallaweb.jlab.org/12GeV/SoLID/files/solid_precdr.pdf (July 8, 2014)

7. Generic Detector R&D for an Electron Ion Collider, Wikipedia. https://wiki.bnl.gov/conferences/index.php/EIC_R%25D and https://www.jlab.org/research/eic_rd_prgm
8. EIC Project Detector R&D (2022) https://wiki.bnl.gov/conferences/index.php/General_Info (October 21, 2022)
9. Aune, S., Delagnes, E., Garcon, M., Mandjavidze, I., et. al., 2012, Design and Assembly of Fast and Lightweight Barrel and Forward Tracking Prototype Systems for an EIC, p. 11. MIT/Temple University, https://wiki.bnl.gov/conferences/images/6/6f/RD_2011-2_F.Sabatie.pdf (2012)
10. Adrian, P.H., Field, C., Graf, N., Graham, M., et. al., 2012, Status of the Heavy Photon Search, Experiment at Jefferson Laboratory, p. 89., *Jefferson Laboratory*, https://www.jlab.org/exp_prog/proposals/12/C12-11-006.pdf (May 7, 2012)
11. Niinikoski, T.O., Abreu, M., Anbinderis, P., Anbinderis, T., et al., 2004, Low-temperature Tracking Detectors, Nuclear Instruments and Methods in Physics Research, Section A--Accelerators, Spectrometers, Detectors and Associated Equipment, Vol. 520, Issues 1-3, p. 87-92. *ScienceDirect,* https://www.sciencedirect.com/science/article/pii/S0168900203031310 (March 11, 2004)
12. Paschalis, S., Lee, I.Y., Machiavelli, A.O., Campbell, C.M., et al., 2013, The Performance of the Gamma-Ray Energy Tracking In-beam Nuclear Array GRETINA, Nuclear Instruments and Methods Physics Research A, Vol. 709, p. 44-55. *Harvard University*, http://adsabs.harvard.edu/abs/2013NIMPA.709...44P (May, 2013)
13. Ionascut-Nedelcescu, A., Carlone, C., Houdayer, A., Raymond, S., et al., 2002, Radiation Hardness of Gallium Nitride, IEEE Transactions on Nuclear Science, Vol. 49, Issue 6, Part 1, p. 2733-2738, ISSN: 0018-9499. IEEE http://ieeexplore.ieee.org/abstract/document/1134213/ (December, 2002)
14. Schwank, J.R., Dodd, P.E., Shaneyfelt, M.R., Vizkelethy, G., et al., 2002, Charge Collection in SOI (Silicon-on-Insulator) Capacitors and Circuits and Its Effect on SEU (Single-Event Upset) Hardness, IEEE Transactions on Nuclear Science, Vol. 49, Issue 6, Part 1, p. 2937-2947, ISSN: 0018-9499. IEEE, http://ieeexplore.ieee.org/xpl/abstractKeywords.jsp?arnumber=1134244 (2002)
15. IEEE, 2014, Complete Technical Program, IEEE Nuclear Science Symposium and Medical Imaging Conference, Seattle, WA, IEEE, https://ieeexplore.ieee.org/xpl/mostRecentIssue.jsp?punumber=7422433 (November 15, 2014)
16. Polushkin. V., 2004, Nuclear Electronics: Superconducting Detectors and Processing Techniques, J. Wiley, p. 402, ISBN: 0-470-857595. *Wiley*, https://www.wiley.com/en-us/Nuclear+Electronics%3A+Superconducting+Detectors+and+Processing+Techniques-p-9780470857687 (November, 2004)
17. Argonne National Laboratory, 2014, Front End Electronics (FE 2014), 9th International Meeting on Front-End Electronics. . http://indico.cern.ch/event/276611/ (May 19, 2014)
18. De Geronimo, G., D'Andragora, A., Li, S., Nambiar, N., et al., 2011, Front-end ASIC for a Liquid Argon TPC, IEEE Transactions on Nuclear Science, Vol. 58, Issue 3, p. 1376-1385., IEEE, https://ieeexplore.ieee.org/document/5752881 (April 21, 2011)
19. Physics with Integrated CMOS Sensors and Electron Machines (PICSEL), Institut Pluridisciplinaire Hubert Curien (IPHC). http://www.iphc.cnrs.fr/-PICSEL-.html
20. Omega Micro, Polytechnique. http://omega.in2p3.fr/
21. Large-Area Picosecond Photo-Detectors Project, PSEC. https://psec.uchicago.edu/
22. DRS Chip Home Page, Paul Scherrer Institute (PSI). https://www.psi.ch/en/drs
23. Ritt, S., 2014, A New Timing Calibration Method for Switched Capacitor Array Chips to Achieve Sub-picosecond Timing Resolutions, Workshop on Picosecond Photon Sensors, Scherrer Institute, p.26. http://psec.uchicago.edu/library/chipdesign/ritt_timing_calibration_method.pdf (March 13, 2014)

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24. RD51 Collaboration, 2010, Development of Micro-Pattern Gas Detectors Technologies, CERN. http://rd51-public.web.cern.ch/RD51-Public/ (2010)
25. Bedaque, P., 2020, Report from the A.I. For Nuclear Physics Workshop *Cornell University,* https://arxiv.org/abs/2006.05422 (June 9, 2020)
26. Cuevas, C., 2022, Workshop on Streaming Readout X, *Jefferson Lab*, https://www.jlab.org/streaming-readout-x (May 19, 2022)
27. Y. Lee, A.O. Macchiavelli, 2021" Effects of magnetic fields on HPGe tracking detectors", Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment, Vol 992, 2021, *ScienceDirect*, https://doi.org/10.1016/j.nima.2021.165017 (March11, 2021)
28. S. Capra, D. Mengoni, J.A. Dueñas, P.R. John, A. Gadea, R.J. Aliaga, J.J. Dormard, M. Assie, A. Pullia, 2021, "Performance of the new integrated front-end electronics of the TRACE array commissioned with an early silicon detector prototype", Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment, Vol 935 2019, Pages 178-184, *ScienceDirect* https://doi.org/10.1016/j.nima.2019.05.039 (August 11, 2019)
29. Varner, G., , et al, , (Undated) "Large Analog Bandwidth Recorder and Digitizer with Ordered Readout (LABRADOR) ASIC, *University of Hawaii,* https://www.phys.hawaii.edu/~idlab/publications/LABRADOR.pdf (Undated)

C57-35 NUCLEAR PHYSICS ACCELERATOR TECHNOLOGY

Maximum Phase I Award Amount: $200,000	Maximum Phase II Award Amount: $1,100,000
Accepting SBIR Applications: YES	Accepting STTR Applications: YES

The Nuclear Physics (NP) Program supports a broad range of activities aimed at research and development related to the science, engineering, and technology of heavy ion, electron, and proton accelerators and their associated systems. Research and development (R&D) is desired that will advance fundamental accelerator technology and its applications to nuclear physics scientific research. Areas of interest include the enabling technologies of the Brookhaven National Laboratory's (BNL) Relativistic Heavy Ion Collider (RHIC), the Continuous Electron Beam Accelerator Facility (CEBAF) at Thomas Jefferson National Accelerator Facility (TJNAF), the Argonne Tandem Linac Accelerator System (ATLAS) at Argonne National Laboratory, and the Facility for Rare Isotope Beams (FRIB) at Michigan State University. Also of interest are technologies relevant to the Electron-Ion Collider (EIC) being constructed at BNL. All of the above facilities make use of superconducting technologies, including superconducting radio frequency (SRF) accelerator components, superconducting magnets, and supporting infrastructure and technologies. Relevance to nuclear physics must be explicitly described, as discussed in more detail below.

All applications must explicitly show relevance to the DOE NP Program. Applications must be informed by the state of the art in nuclear physics accelerator applications, commercially available products, and emerging technologies. An application based on merely incremental improvements or little innovation will be considered non-responsive unless context is supplied that convincingly shows its potential for significant impact or value to the DOE NP Program.

Applications largely duplicative of previously funded research by NP, the Office of Basic Energy Sciences, and the Office of High Energy Physics will be considered nonresponsive to this topic. Applicants are strongly encouraged to review recent SBIR/STTR awards from NP to avoid duplication. Those awards can be found at https://science.osti.gov/sbir/awards/ (Release 1, DOE Funding Program: Nuclear Physics).

The subtopics below refer to innovations that will advance our nation's capability to perform nuclear physics research, and more specifically to improve existing or planned DOE NP Scientific User Facilities and the wider NP community's experimental programs. Although applicants may wish to gather information from and collaborate with experts at DOE National Laboratories, for example, to establish feasibility of their innovations, or desirability of the capabilities to be developed, DOE expects all applicants to address commercialization opportunities for their product or service in adjacent markets such as medicine, homeland security, the environment and industry. Applications using the resources of a third party (such as a DOE laboratory) must include in the application a letter of certification from an authorized official of that organization.

Please note: following award, all DOE SBIR/STTR grant projects requiring high performance computing (HPC) support are eligible to apply to use the DOE National Energy Research Scientific Computing Center (NERSC) resources. NERSC is the primary scientific computing facility for the DOE. If you think you will need to use the HPC capabilities of NERSC during your Phase I or Phase II project, you may be eligible for this free resource. Learn more about NERSC and how to apply for NERSC resources following the award of a Phase I or Phase II project at http://www.nersc.gov/users/accounts/allocations/request-form/.

Applications are sought only in the following subtopics:

a. Materials and Components for Radio Frequency Devices

Applications are sought to improve or advance superconducting and normal-conducting materials or components for RF devices used in particle accelerators. Areas of interest include;

- techniques for removal of 1 μm and larger in diameter particulates from the inner surfaces of superconducting cavities to replace or complement high-pressure water rinsing e.g., methods for cleaning whole cryomodules, alternative techniques to dry ice and high-pressure water cleaning

Applications must clearly indicate how Phase I research and development will result in a working prototype or method that will be completed by the end of Phase II. The prototype or method must be suitable for testing in a nuclear physics application and/or at a nuclear physics accelerator facility. Applications not meeting this requirement will be considered nonresponsive and will not undergo merit review.

Questions – Contact: Michelle Shinn, Michelle.Shinn@science.doe.gov

b. Design and Operation of Radio Frequency Beam Acceleration Systems

Applications are sought for the design, fabrication, and operation of radio frequency accelerating structures and systems for electrons, protons, as well as light- and heavy-ion particle accelerators as enumerated.

- An RF control system for relative field control and synchronization of multiple SRF crab cavities (0.01° of phase and 0.01% amplitude RMS jitter) in the presence of 10-100 Hz microphonics-induced variations of the structures' resonant frequencies (0.1-1.5 GHz), with high gain (for example, with quality factor at a few hundred) & low delay (a few hundred nano-seconds)

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Applications must clearly indicate how Phase I research and development will result in a working prototype or method that will be completed by the end of Phase II. The prototype or method must be suitable for testing in a nuclear physics application and/or at a nuclear physics accelerator facility. Applications not meeting this requirement will be considered nonresponsive and will not undergo merit review.

Questions – Contact: Michelle Shinn, Michelle.Shinn@science.doe.gov

c. Particle Beam Sources and Techniques

Applications are sought to develop:

- novel technologies for ion sources capable of generating high-intensity, high-brightness, high charge state heavy ion beams, for example: ~12 pμA of uranium beam at charge states between q=32 and 46 with rms emittance of 0.1π mm-mrad. If an oven is used to provide uranium beams with these properties, the high temperature oven must reliably reach 2300 °C within the high field of the electron-cyclotron resonance (ECR) ion source injection region;
- novel quench protection systems for Nb3Sn and high-temperature superconducting (HTS) 4th and 5th Generation ECR ion source combined function magnets (sextupole and solenoids) and;
- efficient continuous wave (cw) positron beam sources (polarized and unpolarized) motivated by the nuclear physics community, aimed at improving aspects of pair-production targets, operating at low energy (10-200 MeV), high power (50-100 kW), and at several 100 MHz

Applications must clearly indicate how Phase I research and development will result in a working prototype or method that will be completed by the end of Phase II. The prototype or method must be suitable for testing in a nuclear physics application and/or at a nuclear physics accelerator facility. Applications not meeting this requirement will be considered nonresponsive and will not undergo merit review.

Questions – Contact: Michelle Shinn, Michelle.Shinn@science.doe.gov

d. Polarized Beam Sources and Polarimeters

With respect to polarized sources, applications are sought to develop:

- Associated components for significantly improving performance of high current CW polarized electron sources for delivering beams of ~1-10 mA, with longitudinal polarization greater than 90%; and a photocathode quantum efficiency > 5% at ~780 nm.
- absolute polarimeters for spin polarized 3He beams with energies up to 160 GeV/nucleon;
- polarimeters for bunch by bunch hadron polarimetry with a bunch spacing as short as 2 ns;
- advanced electron or positron beam polarimeters such as those that operate in the energy range of 1-100 MeV, with average currents exceeding 100 uA, with accuracies that are <1%
- steering and/or lens magnets for helicity correlated beam corrections, providing rectangular waveforms with rise time <10 microseconds; and,
- low energy <10 MeV electron spin rotators providing < +/- 5 deg precession, with minimum disturbance to beam properties

For applications involving software, open-source solutions are strongly encouraged. Applications must clearly indicate how Phase I research and development will result in a working prototype or method that will be completed by the end of Phase II. The prototype or method must be suitable for testing in a nuclear physics application and/or at a nuclear physics accelerator facility. Applications not meeting this requirement will be considered nonresponsive and will not undergo merit review.

Questions – Contact: Michelle Shinn, Michelle.Shinn@science.doe.gov

e. Rare Isotope Beam Production Technology

Applications are sought to develop:

- Radiation resistant stepper motor with radiation tolerance to 10^4 Gy (10^6 rad);
- Development of radiation hard tracking detector system for phase space diagnostics of ions. If possible, it should avoid the need for gases. Ideal conditions as follows: particle rates up to ~10^6 Hz, 30 cm by 20 cm detection region; ~1mm position resolution for ions with Z>10 [21];
- Development of time-of-flight detector system for momentum measurement for the same beams as described above. Ideally, a detector incorporating both functions is highly desired;
- Development of additive manufacturing technologies (3D printing) for construction of superconducting coils for Walstrom type [24] large aperture multipoles for fast rare isotope beam spectrometers

Applications must clearly indicate how Phase I research and development will result in a working prototype or method that will be completed by the end of Phase II. The prototype or method must be suitable for testing in a nuclear physics application and/or at a nuclear physics accelerator facility. Applications not meeting this requirement will be considered nonresponsive and will not undergo merit review.

Questions – Contact: Michelle Shinn, Michelle.Shinn@science.doe.gov

f. Accelerator Control and Diagnostics

As accelerator facilities advance in their capabilities, it is important that diagnostics and controls keep pace. Applications are sought to develop advanced beam diagnostics for concepts and devices that provide high speed measurements, real-time monitoring, and readout of particle beam intensity, position, emittance, polarization, luminosity, transverse profile, longitudinal phase space, time of arrival, and energy. More specifically:

For facilities that produce high average power beams, applications are sought for

- Measurement devices/systems for cw beam currents in the range 0.01 to 100 µA, with very high precision ($<10^{-4}$) and short integration times;
- Non-intercepting beam diagnostics for stored proton/ion beams, and/or for ampere class electron beams; and
- devices/systems that measure the emittance of intense (>100 kW) CW ion beams

For heavy ion linear accelerator beam facilities, applications are sought for

- Diagnostics for ion beams with intensities less than 10^7 nuclei/second over a broad energy range up to 400 MeV/u (an especially challenging region is for intensities of 10^2 to 10^5 with beam energy from 25 keV to 1 MeV/nucleon);
- Diagnostics for time-dependent, multicomponent, interleaved heavy ion beams. The diagnostic system must separate time-dependent constituents (total period for switching between beams >10 ms), where one species is weaker than the other, and is ~5% of a 30 - 100 ms cycle. The more

intense beam would account for the remainder. Proposed solutions which work over a subset of the total energy range are acceptable for consideration;

- On-line, minimally interceptive systems for measurement of beam contaminant species or components. (Energy range of primary ion species should be 500 keV/nucleon to 2 MeV/nucleon.);
- Development of a non-destructive diagnostics system to measure intensities of fast (~100-200 MeV/u) rare isotope beams in the range from 10^4 to 10^{11} ions/sec;
- Advanced diagnostic methods and devices for fast detection (e.g. < 10 us) of stray beam loss for low energy heavy ion beams (e.g. ions heavier than argon at energies above 1 MeV/nucleon and below 100 MeV/nucleon) to facilitate accelerator machine protection.
- High-sensitivity non-intercepting BPMs for heavy ion Re-Accelerators for ion beamlines that transport pulse-averaged currents >1 epA up to 100 enA. Systems should demonstrate spatial resolution <1 mm in both horizontal and vertical planes over apertures >50 mm diameter, and provide phase measurement for highly bunched beams in the 20-100 MHz range with resolution <1-degree

Applications to this subtopic should indicate familiarity with complex accelerator systems and the interfaces between the beamline diagnostics and the control systems in use at large accelerator installations. That could also include smaller accelerators like those at Texas A&M's Cyclotron Institute, TUNL at Duke University, and tandem accelerator facilities supported by the National Science Foundation at universities like Notre Dame and Ohio University.

For applications involving software, open-source solutions are strongly encouraged. Applications must clearly indicate how Phase I research and development will result in a working prototype or method that will be completed by the end of Phase II. The prototype or method must be suitable for testing in a nuclear physics application and/or at a nuclear physics accelerator facility. Applications not meeting this requirement will be considered nonresponsive and will not undergo merit review.

Questions – Contact: Michelle Shinn, Michelle.Shinn@science.doe.gov

g. Other

In addition to the specific subtopics listed above, NP invites applications in other areas that fall within the scope of the topic description above.

Questions – Contact: Michelle Shinn, Michelle.Shinn@science.doe.gov

References:

1. U.S. Department of Energy, 2015, The 2015 Long Range Plan for Nuclear Science, Reaching for the Horizon, Office of Science, p. 160., *DOE*, http://science.osti.gov/~/media/np/nsac/pdf/2015LRP/2015_LRPNS_091815.pdf (2015)
2. Argonne Tandem Linac Accelerator System (ATLAS), U. S. Department of Energy. https://science.osti.gov/np/facilities/user-facilities/atlas/
3. Labs at-a-Glance: Thomas Jefferson National Accelerator Facility, Future Science at Thomas Jefferson National Accelerator Laboratory, U.S. Department of Energy. http://science.osti.gov/laboratories/thomas-jefferson-national-accelerator-facility/

4. Relativistic Heavy Ion Collider (RHIC), U.S. Department of Energy. https://science.osti.gov/np/facilities/user-facilities/rhic/
5. Facility for Rare Isotope Beams, Michigan State University. http://frib.msu.edu/
6. Leitner, D., Abbot, S.R., Abell, D., Aberle, O., et al., 2003, Proceedings of 2003 Particle Accelerator Conference, PAC 2003 Particle Accelerator Conference, Portland, OR, p. 3377. http://accelconf.web.cern.ch/accelconf/p03/INDEX.HTM (May 16, 2003)
7. Angoletta, M.E., 2006, Digital Low Level RF, Proceedings of the European Particle Accelerator Conference, AB/RF, EPAC'06, Edinburgh, WEXPA03, p. 19., *CERN*, https://accelconf.web.cern.ch/accelconf/e06/TALKS/WEXPA03_TALK.PDF (June 28, 2006)
8. 7th SRF Materials Workshop, Thomas Jefferson National Accelerator Laboratory. https://www.jlab.org/indico/conferenceDisplay.py?confId=20 (July 17, 2012)
9. Freeman, H., 2000, Heavy Ion Sources: The Star, or the Cinderella, of the Ion-Implantation Firmament?, Review of Scientific Instruments, Vol. 71, Issue 2, p. 603-611, ISSN: 0034-6748. *Harvard University*, http://adsabs.harvard.edu/abs/2000RScI...71..603F (February, 2000)
10. Trbojevic, D., Berg, J.S., Brooks, S., Hao, Y., et al., 2015, ERL with Non-scaling Fixed Field Alternating Gradient Lattice for eRHIC, Proceedings of the International Particle Accelerator Conference (IPAC'15), *Brookhaven National Laboratory*, Richmond, VA, p. 6. https://www.bnl.gov/isd/documents/88876.pdf (May 8, 2015)
11. Tesla, 2014, TESLA Technology Collaboration Meeting, KEK,. *Tesla*, https://indico.desy.de/indico/event/10663/ (December 5, 2014)
12. Schwarz, S., Bollen, G., Kester, O., Kittimanapun, K., et al., 2010, EBIS/T Charge Breeding for Intense Rare Isotope Beams at MSU, Journal of Instrumentation, Vol. 5, Issue 10, C10002, p. 10. *Journal of Instrumentation*, https://iopscience.iop.org/article/10.1088/1748-0221/5/10/C10002/pdf (October, 2010)
13. 17th International Conference on RF Superconductivity, SRF2015 Whistler. http://srf2015.triumf.ca (September 18, 2015)
14. Perry, A., Mustapha, B., and Ostroumov, P.N., 2013, Proposal for Simultaneous Acceleration of Stable and Unstable Ions in ATLAS, Proceedings of PAC2013, p. 306-308., *PAC2013*, http://accelconf.web.cern.ch/accelconf/pac2013/papers/mopma06.pdf (2013)
15. Afanasev, A., et al., 2019, Physics with Positron Beams at Jefferson Lab 12 GeV, *Cornell University*, https://arxiv.org/abs/1906.09419 (June 22, 2019)
16. Solopova, A.D., Carpenter, A., Powers, T., Roblin, Y., et al., 2019, SRF Cavity Fault Classification Using Machine Learning at CEBAF, Proc. IPAC'19, Melbourne, Australia, p. 17. *Cornell University*, http://accelconf.web.cern.ch/AccelConf/ipac2019/talks/tuxxplm2_talk.pdf (May, 2019)
17. Edelen, A.L., Biedron, S.G., Chase, B.E., Milton, S.V., et al., 2016, Neural Networks for Modeling and Control of Particle Accelerators, IEEE Transactions on Nuclear Science, Vol. 63, Issue 2, p. 878-897, *IEEE*, https://fast.fnal.gov/papers/07454846.pdf (April, 2016)
18. Bedaque, P., et al, 2020, Report from the A.I. For Nuclear Physics Workshop, *Cornell University,* https://arxiv.org/abs/2006.05422 (June 9, 2020)
19. U.S. Department of Energy, 2017, Report of the Community Review of Electron Ion Collider (EIC) Accelerator R&D for the Office of Nuclear Physics, Office of Nuclear Physics, p. 62., DOE, https://science.osti.gov/~/media/np/pdf/Reports/Report_of_the_Community_Review_of_EIC_Accelerator_RD_for_the_Office_of_Nuclear_Physics_20170214.pdf (February 13, 2017)
20. Willeke, F., 2019, An Electron-Ion Collider Study, Brookhaven National Library, https://wiki.bnl.gov/eic/upload/EIC.Design.Study.pdf (August, 2019)

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21. H. Kumagai, et al., (2013) Development of Parallel Plate Avalanche Counter (PPAC) for BigRIPS fragment separator, Nucl. Instrum. Meth. B p.717., *ScienceDirect*, https://www.sciencedirect.com/science/article/pii/S0168583X13009932?via%3Dihub (December 15, 2013)
22. J. Hwang, et al., 2019, Angle-tunable wedge degrader for an energy-degrading RI beamline, Volume 2019, Issue 4, *PTEP*, https://doi.org/10.1093/ptep/ptz028 (April 26, 2019)
23. Folger, H., et al., 1991, Targets and degraders for relativistic heavy ions at GSI, NIM-A, Volume 303, Issue 1, 1991, *ScienceDirect*, https://doi.org/10.1016/0168-9002(91)90759-J (May 15, 1991)
24. Walstrom, P., 2004, Soft-edged magnet models for higher-order beam-optics map codes NIM A 519 pp. 216–221, *ScienceDirect*, https://www.sciencedirect.com/science/article/pii/S0168900203030237?via%3Dihub (February 21, 2004)

C57-36 NUCLEAR PHYSICS INSTRUMENTATION, DETECTION SYSTEMS AND TECHNIQUES

Maximum Phase I Award Amount: $200,000	Maximum Phase II Award Amount: $1,100,000
Accepting SBIR Applications: YES	Accepting STTR Applications: YES

The Office of Nuclear Physics (NP) supports grants that will lead to advances in detection systems, instrumentation, and techniques for nuclear physics experiments. Opportunities exist for developing equipment beyond the present state-of-the-art needed at universities, national scientific user facilities, and facilities worldwide. Next-generation detectors, and upgrades to existing detectors, are needed for the Continuous Electron Beam Accelerator Facility (CEBAF) at the Thomas Jefferson National Accelerator Facility (TJNAF), the Facility for Rare Isotope Beams (FRIB) at Michigan State University, the Relativistic Heavy Ion Collider (RHIC) at Brookhaven National Lab (BNL), the Argonne Tandem Linac Accelerator System (ATLAS) at Argonne National Laboratory, and the Electron-Ion Collider (EIC) being constructed at BNL. Also of interest is technology related to future experiments in fundamental symmetries, such as neutrinoless double-beta decay (NLDBD). In the case of NLDBD experiments, extremely low background and low count rate in particle detection are essential.

All applications must explicitly show relevance to the DOE NP Program. Applications must be informed by the state of the art in nuclear physics applications, commercially available products and emerging technologies. An application based on merely incremental improvements or little innovation will be considered non-responsive unless context is supplied that convincingly shows its potential for significant impact or value to the DOE NP Program.

Applications which are largely duplicative of previously funded research by NP will be considered nonresponsive to this topic. Applicants are strongly encouraged to review recent SBIR/STTR awards from NP to avoid duplication. Those awards can be found at https://science.osti.gov/sbir/Awards (Release 1, DOE Funding Program: Nuclear Physics).

The subtopics below refer to innovations that will advance our nation's capability to perform nuclear physics research, and more specifically to improve scientific productivity at DOE NP facilities and the wider nuclear physics community's programs. Applicants may wish to gather information from and collaborate with experts at DOE National Laboratories to establish feasibility for their innovations. DOE expects all applicants to address commercialization opportunities for their product or service in adjacent markets such as medicine, homeland security, the environment and industry. Applications that propose using the resources of a third party (such as a DOE laboratory) must include in the application, a letter of certification from an authorized official of that organization.

Please note: following award, all DOE SBIR/STTR grant projects requiring high performance computing (HPC) support are eligible to apply to use the DOE National Energy Research Scientific Computing Center (NERSC) resources. NERSC is the primary scientific computing facility for the DOE. If you think you will need to use the HPC capabilities of NERSC during your Phase I or Phase II project, you may be eligible for this free resource. Learn more about NERSC and how to apply for NERSC resources following the award of a Phase I or Phase II project at http://www.nersc.gov/users/accounts/allocations/request-form/.

Grant applications are sought in the following subtopics:

a. Advances in Detector and Spectrometer Technology

Nuclear physics research has a need for devices to detect, analyze, and track photons, charged particles, and neutral particles such as neutrons, neutrinos, and single atoms. Applications are sought to develop and advance the following types of detectors:

Particle identification and counting detectors such as:

- Large area Multigap Resistive Plate Chamber (MRPC) detectors with very high rate capability (≥200 kHz/cm^2) radiation hardness (10 Mrad with 10^{15} n/cm^2), magnetic field tolerance (2-3 T), and high timing resolution≤ 10 ps for time-of-flight detectors. Applications should specify the accompanying readout system to describe how the proposed system ensure operation without data loss under the same environmental conditions (i.e., radiation flux, magnetic field, heat dissipation etc.) as the detector itself, including any effects that the cabling for data flow and/or power distribution to the readout system will impose upon the detector that may limit its efficiency.; and
- Cherenkov detectors (Threshold, Ring-Imaging (RICH), Detection of Internally Reflected Cherenkov Light (DIRC)) with broad particle identification capabilities over a large momentum range and/or large area that can operate at a high rate in noisy (very high rate, low-energy particle background) environments at an affordable cost that are also non uniform (in strength and direction) magnetic field tolerant for uniform response across the detector;

Applications must clearly indicate how Phase I research and development will result in a working prototype or method that will be completed by the end of Phase II. The prototype or method must be suitable for testing in a nuclear physics application and/or at a nuclear physics facility. Applications not meeting this requirement will be considered nonresponsive and will not undergo merit review.

Questions – Contact: Michelle Shinn, Michelle.Shinn@science.doe.gov or the NP SBIR/STTR Topic Associate for Instrumentation, Detection Systems and Technique: Elizabeth Bartosz, Elizabeth.Bartosz@science.doe.gov

b. Development of Novel Gas and Solid-State Detectors

Nuclear physics research has the need for devices to track charged and neutral particles such as neutrons and photons. Items of interests are detectors with very good energy resolution for low- and medium-energy applications, high precision tracking of different types of particles, with fast triggering capabilities, as well as detectors that provide high energy and position resolution at high count rates (e.g. > 1 Mcps).

Grant applications are sought to develop detector systems with focus on:

- Next generation, heavy ion focal plane detectors or integrated detector systems for magnetic spectrometers and recoil separators with high time resolution (< 150ps FWHM), high energy loss resolution (<1%), and high total energy resolution (<1%), and high position resolution (<0.4 mm FWHM);
- Improved position resolution for Micropattern Gas Detectors (GEMs, Micromegas, MicroRWELLs, etc) and Parallel Plate Avalanche Chambers. Improvements include submillimeter position resolution (less than a few hundred micrometers) possibly by using novel readout plane geometries to lower channel counts, high counting rate capability (> 1 MHz and/or (>200 kHz/cm^2), uniform energy-losses independent of the position, high dynamic range and low thickness (< a few mg/cm^2); and
- Cost effective readout for the above with high-speed data buffering compatible with trigger decisions up to 3 μsec later and fast data ports to allow second level triggers. Applications for readout electronics shall specify how the readout electronics will maintain deadtime-less operation at event rates > 1MHz, the specifics of how the analog signals from the detector are converted to digital data including physical connectivity and shall specify the range of magnetic field and radioactive flux under which the proposed design will operate while meeting all specifications.

Applications must clearly indicate how Phase I research and development will result in a working prototype or method that will be completed by the end of Phase II. The prototype or method must be suitable for testing in a nuclear physics application and/or at a nuclear physics facility. Applications not meeting this requirement will be considered nonresponsive and will not undergo merit review.

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c. Technology for Rare Decay and Rare Particle Detection

Applications are sought for detectors and techniques to measure very weak or rare event signals. Such detector technologies and analysis techniques are required in searches for rare events such as NLDBD or for new isotopes produced far from stability at rare isotope beam and high intensity stable beam facilities. Rare decay and rare event detectors require large quantities of ultra-clean materials for shielding and targets. Future detectors require unprecedented sensitivity and accuracy and could benefit from the use of quantum information sensors and adjacent supporting technologies. The adoption of these sensors in NP applications depends on the development of fabrication techniques at scale to increase availability at lower cost.

Applications are sought to develop:

1) Detectors based on uniquely quantum properties such as superposition, entanglement, and squeezing;
2) Detectors with very high resolution (tenths of micrometers spatial resolution and tenths of eV energy resolution). Bolometers, including the required thermistors, based on cryogenic semiconductor materials, transition edge sensors, Superconducting Tunnel Junction (STJ) radiation detectors, or other new materials are eligible;

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3) Novel methods capable of discriminating between interactions of gammas, charged particles, and neutrons in rare event experiments; and
4) Methods by which the background interactions in rare event searches, such as those induced by gamma rays or neutrons, can be tagged, reduced, or removed entirely.

Applications must clearly indicate how Phase I research and development will result in a working prototype or method that will be completed by the end of Phase II. The prototype or method must be suitable for testing in a nuclear physics application and/or at a nuclear physics facility. Applications not meeting this requirement will be considered nonresponsive and will not undergo merit review.

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d. Other

In addition to the specific subtopics listed above, the Department invites grant applications in other areas that fall within the scope of the topic description above.

Questions – Contact: Michelle Shinn, Michelle.Shinn@science.doe.gov or the NP SBIR/STTR Topic Associate for Instrumentation, Detection Systems and Technique: Elizabeth Bartosz, Elizabeth.Bartosz@science.doe.gov

References:

1. Khalek, A., et al., 2021, Science Requirements and Detector Concepts for the Electron-Ion Collider: EIC Yellow Report, *InspireHEP,* https://inspirehep.net/literature/1851258 (March 8, 2021)
2. Generic Detector R&D for an Electron Ion Collider, Wikipedia. https://wiki.bnl.gov/conferences/index.php/EIC_R%25D and https://www.jlab.org/research/eic_rd_prgm
3. EIC Project Detector R&D https://wiki.bnl.gov/conferences/index.php/General_Info
4. SNOWMASS 2021 Instrumentation report https://www.slac.stanford.edu/econf/C210711/Instrumentation.html
5. Facility for Rare Isotope Beams (FRIB), Michigan State University. http://frib.msu.edu/
6. Wei, J., Ao, H., Beher, S., Bultman, N., et al., 2019, Advances of the FRIB Project, International Journal of Modern Physics E, Vol. 28, Issue 3, 1930003. *ResearchGate*. https://www.researchgate.net/publication/331838290_Advances_of_the_FRIB_project (March, 2019)
7. Ahmed, M., et al, 2019 "A new cryogenic apparatus to search for the neutron electric dipole moment", JINST 14 P11017, *IOPScience,* https://doi.org/10.1088/1748-0221/14/11/P11017 (November, 2019)
8. Adare, A., Daugherity, M.S., Gainey, K., Isenhower, D., et.al., 2012, sPHENIX: An Upgrade Proposal from the PHENIX Collaboration, p. 200. *Phenix Collaboration*, http://www.phenix.bnl.gov/phenix/WWW/publish/dave/PHENIX/sPHENIX_MIE_09272013.pdf (October 1, 2013)
9. Andersen, T. C., Blevis, I., Boger, J., Bonvin, E., et al., 2003, Measurement of Radium Concentration in Water with Mn-coated Beads at the Sudbury Neutrino Observatory, Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment, Vol. 501, Issues 2-3, p. 399-417., *ScienceDirect*, https://www.sciencedirect.com/science/article/pii/S0168900203006168 (April 1, 2003)

10. Alduino, C., Alfonso, K., Artusa, D.R., Avignone, F.T., et al., 2016, (CUORE Collaboration). CUORE-0 Detector: Design, Construction and Operation, Journal of Instrumentation, Vol. 11, P07009. *IOPScience*, https://iopscience.iop.org/article/10.1088/1748-0221/11/07/P07009 (July, 2016)
11. Andersen, T. C., Black, R.A., Blevis, I., Boger, J.N., et al., 2003, A Radium Assay Technique Using Hydrous Titanium Oxide Absorbant for the Sudbury Neutrino Observatory, Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment, Vol. 501, Issues 2-3, p. 386-398., *ResearchGate*, https://www.researchgate.net/publication/222666014_A_radium_assay_technique_using_hydrous_titanium_oxide_adsorbent_for_the_Sudbury_Neutrino_Observatory (April, 2003)
12. Rau., and Heusser, G., 2000, "^{222}Rn emanation measurements at extremely low activities", Applied Radiation and Isotopes 53 (2000) 371-375 *ScienceDirect*, https://www.sciencedirect.com/science/article/abs/pii/S096980430000155X (July, 2000)
13. Heusser, G., 1995, "Low-Radioactivity Background Techniques", Annu. Rev. Nucl. Part. Sci. 1995.45:543-590 Public database of material radio-purity measurements, https://www.radiopurity.org
14. sPHENIX, 2014, An Upgrade Proposal from the PHENIX Collaboration, p.243., *PhenixCollaboration*, http://www.phenix.bnl.gov/phenix/WWW/publish/documents/sPHENIX_proposal_19112014.pdf (November 19, 2014)
15. Abelev, B., Adam, J., Adamova, D., Aggarwal, M.M., et. al., 2014, The ALICE Collaboration, Technical Design Report for the Upgrade of the ALICE Inner Tracking System, Journal of Physics G: Nuclear and Particle Physics, Vol. 41, Issue 8, p. 181., *IOPScience*, http://iopscience.iop.org/article/10.1088/0954-3899/41/8/087002/meta (July 2, 2014)
16. The SoLID Collaboration, 2014, SoLID (Solenoidal Large Intensity Device) Preliminary Conceptual Design Report, p. 225, *SoLID Collaboration*, http://hallaweb.jlab.org/12GeV/SoLID/files/solid_precdr.pdf (July 8, 2014)
17. Aune, S., Delagnes, E., Garcon, M., Mandjavidze, I., et. al., 2012, Design and Assembly of Fast and Lightweight Barrel and Forward Tracking Prototype Systems for an EIC, p. 11. https://wiki.bnl.gov/conferences/images/6/6f/RD_2011-2_F.Sabatie.pdf (2012)
18. Adrian, P.H., Field, C., Graf, N., Graham, M., et. al., 2012, Status of the Heavy Photon Search Experiment at Jefferson Laboratory, p. 89., *Jefferson Lab*, https://www.jlab.org/exp_prog/proposals/12/C12-11-006.pdf (May 7, 2012)
19. Niinikoski, T., Abreu, M., Anbinderis, P., Anbinderis, T., et al., 2004, Low-temperature Tracking Detectors, Nuclear Instruments and Methods in Physics Research, Section A--Accelerators, Spectrometers, Detectors and Associated Equipment, Vol. 520, Issues 1-3, p. 87-92., *ScienceDirect*, https://www.sciencedirect.com/science/article/pii/S0168900203031310 (March 11, 2004)
20. Scintillator Properties Database, Lawrence Berkeley National Laboratory, http://scintillator.lbl.gov/
21. Nakamura, T. and Heilbronn, L., 2005, Handbook of Secondary Particle Production and Transport by High-Energy Heavy Ions, World Scientific Publishing Co. Pte. Ltd., Singapore, p. 236, ISBN: 978-981-256-558-7. https://www.amazon.com/Handbook-Secondary-Production-Transport-High-energy/dp/9812565582
22. Sato, T., Niita, K., Matsuda, N., Hashimoto, S., et al., 2013, Particle and Heavy Ion Transport code System (PHITS), Journal of Nuclear Science and Technology, Vol. 50, Issue 9, p. 913-923. http://www.tandfonline.com/doi/full/10.1080/00223131.2013.814553
23. X Theoretical Design (XTD) Division, Los Alamos National Laboratory, MCNPX. https://www.lanl.gov/org/ddste/aldsc/theoretical/
24. CERN, INFN, 2010, FLUKA, Fluktuierende Kaskade. http://www.fluka.org/fluka.php

25. Cooper, R., Amman, M., and Vetter, K., 2018, High Resolution Gamma-ray Spectroscopy at High Count Rates with a Prototype High Purity Germanium Detector, Nuclear Instruments and Methods in Physics A, Vol. 886, p. 1-6., *ScienceDirect*, https://www.sciencedirect.com/science/article/pii/S0168900217314596 (April 1, 2018)
26. Cooper, R., Amman, M., Luke, P.N., and Vetter, K., 2015, A Prototype High Purity Germanium Detector for High Resolution Gamma-ray Spectroscopy at High Count Rates, Nuclear Instruments and Methods in Physics A, Vol. 795, p. 167-173. *ScienceDirect*, https://www.sciencedirect.com/science/article/pii/S0168900215007123 (September 21, 2015)
27. U.S. Department of Energy, 2019, QUANTUM HORIZONS: QIS RESEARCH AND INNOVATION FOR NUCLEAR SCIENCE, Office of Science, Nuclear Physics, p. 5-10., DOE, https://science.osti.gov/-/media/grants/pdf/foas/2019/SC_FOA_0002210.pdf (May 31, 2019)
28. U.S. Department of Energy, 2018, Opportunities for Nuclear Physics & Quantum Information Science, Office of Science, p. 22., DOE, https://science.osti.gov/~/media/np/pdf/Reports/npqi_whitepaper_20Feb2019.pdf (February 20, 2018)
29. Di Bello, F., et al., 2020, Towards a Computer Vision Particle Flow, *Cornell University*, https://arxiv.org/abs/2003.08863 (March 19, 2020)
30. E. Cisbani, et al., (2019) AI-optimized detector design for the future Electron-Ion Collider: the dual-radiator RICH case, *Cornell University*, https://arxiv.org/abs/1911.05797 (November 13, 2019)
31. Giles Chatham Strong (2020), On the impact of selected modern deep-learning techniques to the performance and celerity of classification models in an experimental high-energy physics use case, *Cornell University*, https://arxiv.org/abs/2002.01427 (February 3, 2020)
32. Albertsson, A., et al., (2018) Machine Learning in High Energy Physics Community White Paper, *Cornell University*, https://arxiv.org/abs/1807.02876 (July 8, 2018)
33. Nirbhay, A., et al, 2020, Report from the A.I. For Nuclear Physics Workshop, *Cornell University*, https://arxiv.org/abs/2006.0542 (May 31, 2020)