FY 2016 Budget Request to Congress for DOE's Office of Science

February 2015

Dr. Patricia M. Dehmer
Acting Director, Office of Science
science.energy.gov

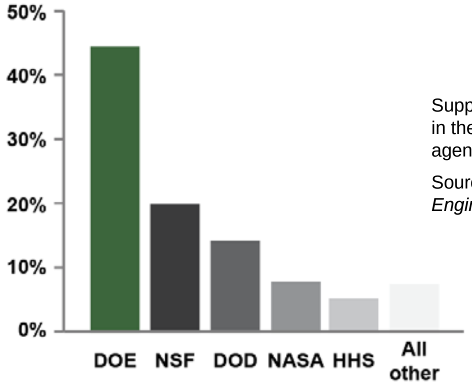
Office of Science
By the numbers

Shown is a portion of SLAC's two-mile-long linear accelerator (or linac), which provides the electron beam for the new Linac Coherent Light Source (LCLS) – the world's first hard x-ray, free-electron laser. For nearly 50 years, SLAC's linac had produced high-energy electrons for physics experiments. Now researchers use the very intense X-ray pulses (more than a billion times brighter than the most powerful existing sources) much like a high-speed camera to take stop-motion pictures of atoms and molecules in motion, examining fundamental processes on femtosecond timescales.

SC delivers scientific discoveries and tools to transform our understanding of nature and advance the energy, economic, and national security of the U.S.

Research

- Support for 47% of the U.S. Federal support of basic research in the physical sciences;
- ~22,000 Ph.D. scientists, grad students, engineers, and support staff at >300 institutions, including all 17 DOE labs;
- U.S. and world leadership in high-performance computing and computational sciences;
- Major U.S. supporter of physics, chemistry, materials sciences, and biology for discovery and for energy sciences.



Support for basic research in the physical sciences by agency.

Source: *NSF Science and Engineering Indicators 2012*

Scientific User Facilities

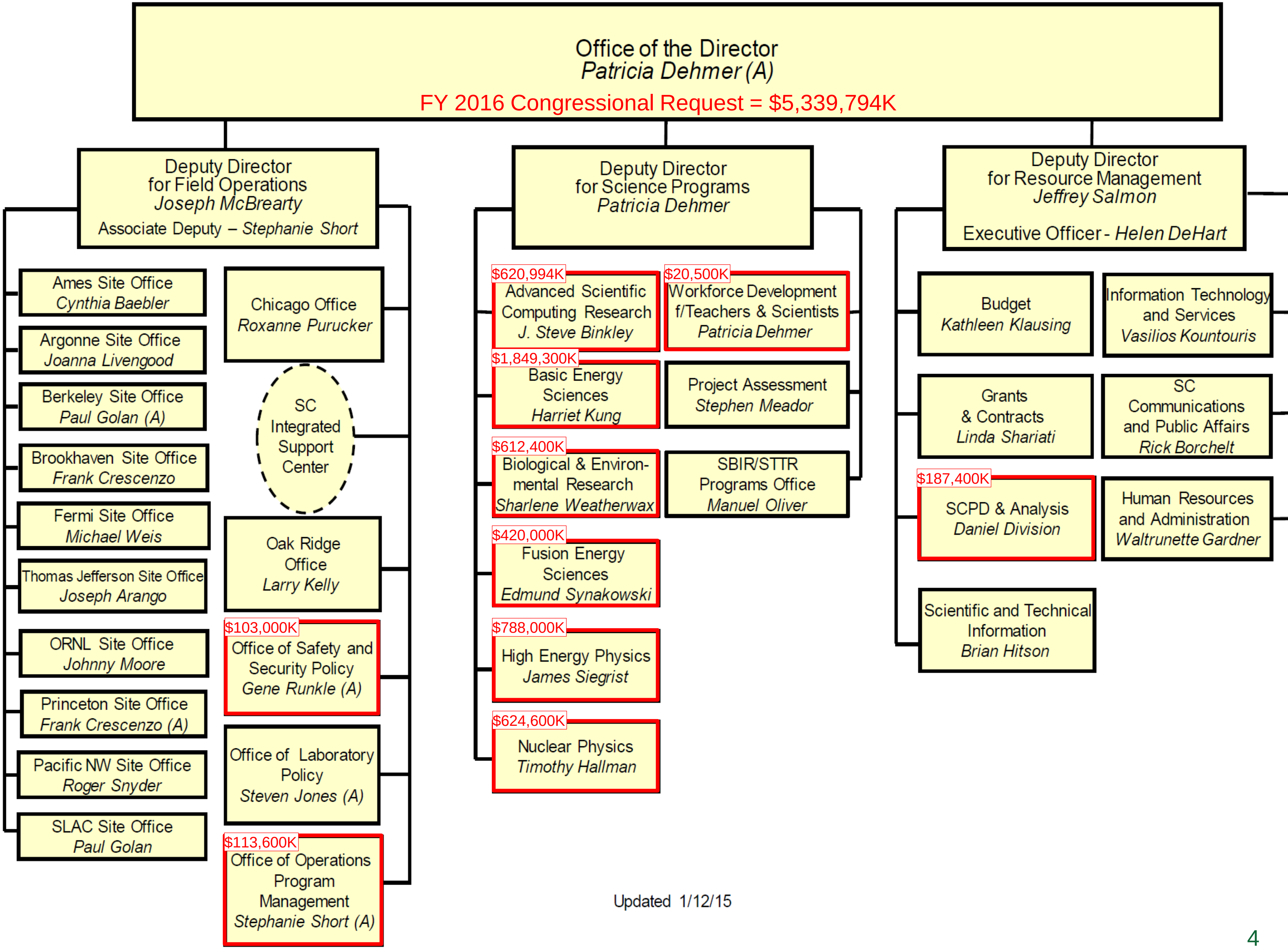
- The world's largest collection of scientific user facilities (aka research infrastructure) operated by a single organization in the world, used by 31,000 researchers each year.

Office of the Under Secretary for Science & Energy

Lynn Orr
Under Secretary for Science and Energy

Director/Ass't Sec'y FY 2016 Cong. Req.	Office	13 of the 17 DOE Labs are managed by the US for S&E
Pat Dehmer (A) $5,339,794K	**Office of Science**	AMES, ANL, BNL, FNAL, LBNL, ORNL, PNNL, PPPL, SLAC, TJNAF
Chris Smith $842,100K	**Assistant Secretary for Fossil Energy**	NETL
Dave Danielson $2,722,987K	**Assistant Secretary For Energy Efficiency And Renewable Energy**	NREL
Pete Lyons $907,574K	**Assistant Secretary for Nuclear Energy**	INL
Pat Hoffman $270,100K	**Assistant Secretary for Electricity Delivery and Energy Reliability**	
David Conrad (A) $20,000K	**Indian Energy Policy and Programs**	

The remaining 4 DOE labs are:
NNSA—LANL, LLNL, SNL
EM—SRNL



Updated 1/12/15

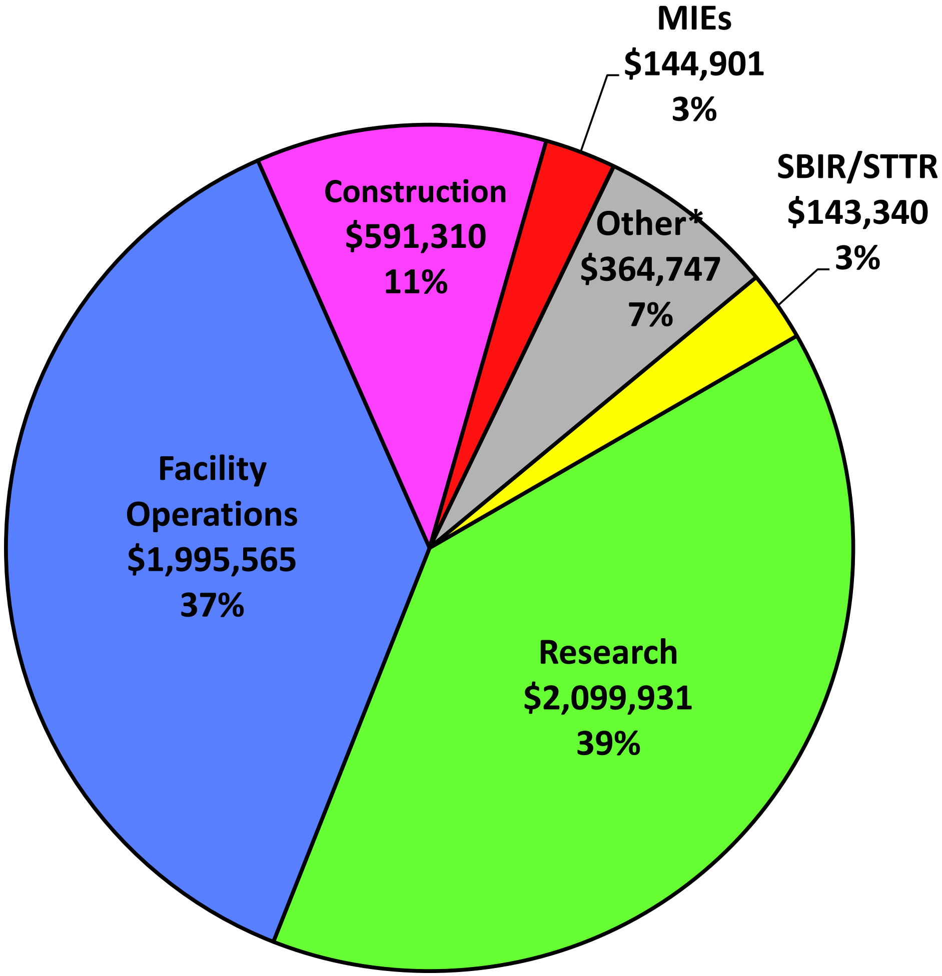
Office of Science FY 2016 Budget Request to Congress

(Dollars in thousands)

	FY 2014 Enacted Approp. (prior to SBIR/STTR)	FY 2014 Current Approp.	FY 2015 Enacted Approp.	FY 2016 President's Request	FY 2016 President's Request vs. FY 2015 Enacted Appropriation	
Advanced Scientific Computing Research	478,093	463,472	541,000	620,994	+79,994	+14.8%
Basic Energy Sciences	1,711,929	1,662,702	1,733,200	1,849,300	+116,100	+6.7%
Biological and Environmental Research	609,696	593,610	592,000	612,400	+20,400	+3.4%
Fusion Energy Sciences	504,677	495,855	467,500	420,000	-47,500	-10.2%
High Energy Physics	796,521	774,920	766,000	788,000	+22,000	+2.9%
Nuclear Physics	569,138	554,802	595,500	624,600	+29,100	+4.9%
Workforce Development for Teachers and Scientists	26,500	26,500	19,500	20,500	+1,000	+5.1%
Science Laboratories Infrastructure	97,818	97,818	79,600	113,600	+34,000	+42.7%
Safeguards and Security	87,000	87,000	93,000	103,000	+10,000	+10.8%
Program Direction	185,000	185,000	183,700	187,400	+3,700	+2.0%
SBIR/STTR (SC)	......	128,539	......	......	......	......
Subtotal, Office of Science	**5,066,372**	**5,070,218**	**5,071,000**	**5,339,794**	**+268,794**	**+5.3%**
SBIR/STTR (DOE)	......	64,666	......	......	......	......
Subtotal, Office of Science	**5,066,372**	**5,134,884**	**5,071,000**	**5,339,794**	**+268,794**	**+5.3%**
Use of Prior Year Balances (SBIR)	......	-3,846	......	......	......	......
Rescission of Prior Year Balances	......	......	-3,262	......	+3,262	-100.0%
Total, Office of Science	**5,066,372**	**5,131,038**	**5,067,738**	**5,339,794**	**+272,056**	**+5.4%**

FY 2016 SC Budget Request by Category

Dollars in Thousands



*Other includes GPP/GPE amounts for BES, GPP for FES, Other (DOE/SC/Fermi/Lawrence) for NP, WDTS, SLI non-construction funding, S&S, and Program Direction.

Highlights of the FY 2016 Budget Request

- Exascale computing is a top priority within DOE and across SC
  (SC Exascale Crosscut: FY 2015 = $99,000K; FY 2016 = $208,624K)
  (DOE Exascale Crosscut: FY 2015 = $149,000K; FY 2016 = $272,624K
  - ASCR: Support for HPC vendors to design and develop exascale node technologies and systems.
  - BES, BER: Support for disciplinary computing in materials sciences and climate sciences, both incorporating data and results from research programs and facilities.
- Research activities see both general and targeted increases, for example
  - BES: Increases for EFRCs, Computational Materials Sciences, and mid-scale instrumentation.
  - NP: Research increases by more than 8% to support high-priority work.
- Workforce Development
  - ASCR: The Computational Science Graduate Fellowship is restored at $10,000K to fully fund a new cohort.
- Facility operations are >98% of optimal for most facilities
  - ASCR, BER, BES, HEP: Facilities operate at or near to optimal, >98%.
  - FES: NSTX operates for 14 weeks; DIII-D for 12 weeks until installation of upgrades; Alcator C-Mod operates for 5 weeks prior to final shutdown at the end of FY 2016.
  - NP: RHIC operates 22 weeks, same as in FY 2015, and has funding for capital equipment and spares; ATLAS operates 37 weeks; CEBAF is supported for continued machine development and commissioning of beam to Halls B and C.

Highlights of the FY 2016 Budget Request

- Construction –
  - FY 2016
    - BES: Linac Coherent Light Source-II is in its peak funding year ($200,300K).
    - FES: ITER continues ($150,000K).
    - HEP: Long Baseline Neutrino Facility ($20,000K for PED); Muon to Electron Conversion ($40,100K).
    - NP: Facility for Rare Isotope Beams is at the peak of its funding profile ($100,000K); CEBAF12 GeV upgrade continues experimental hall commissioning ($12,000K).
    - SLI: Materials Design Lab at ANL ($23,910K); Photon Science Lab Building at SLAC ($25,000K); Integrative Genomics Building at LBNL ($20,000K).

  - FY 2014 and FY 2015 saw final funding/successful completion of many projects including several large ones:
    - BES: National Synchrotron Light Source – II ($912,000K) met all CD-4 milestones
    - BES: SNS Instruments - Next Generation II ($60,000K)
    - HEP: NUMI Off-axis Neutrino Appearance ($274,260K)
    - SLI: Energy Sciences Building ($95,956K)

- Major Items of Equipment –
  - BES: Advanced Photon Source Upgrade ($20,000K) and NSLS-II Experimental Tools (NEXT) (15,500K).
  - HEP: LHC Detector Upgrades (ATLAS and CMS) ($9,500K each); Large Synoptic Survey Telescope camera (LSSTcam) ($40,800K); Muon g-2 ($10,200K); LUX-ZEPLIN ($9,000K); SuperCDMS-SNOLab ($2,000K); Dark Energy Spectroscopic Instrument (DESI) ($5,300K).

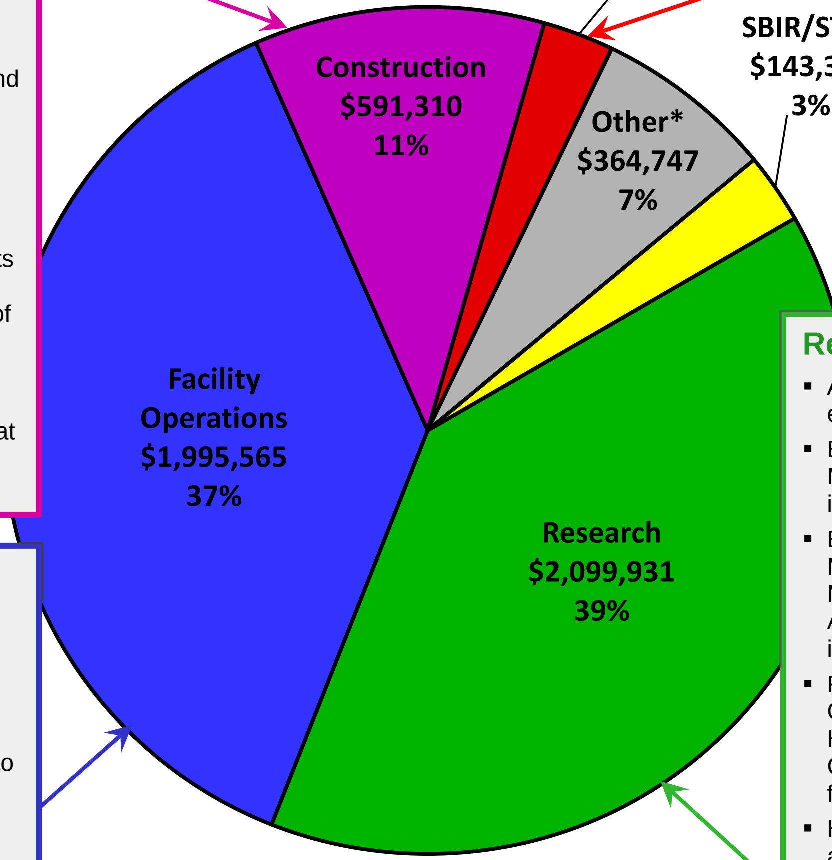
SC is Contributing to Four DOE Crosscuts

	Exascale Computing	Subsurface Engineering	Energy-Water Nexus	Cyber Security	Total
Advanced Scientific Computing Research	177,894	0	0	0	177,894
Basic Energy Sciences	12,000	5,000	0	0	17,000
Biological and Environmental Research	18,730	0	11,800	0	30,530
Safeguards and Security	0	0	0	33,156	33,156
Total, Crosscuts	208,624	5,000	11,800	33,156	258,580

- **Exascale:** The advanced computing crosscut addresses the needs of SC, NNSA, and the energy technology offices in the development of advanced computing technologies to provide better understanding complex physical systems. BES funding for exascale is the FY 2016 request for Computational Materials Sciences; BER funding is for Climate Model Development and Validation.
- **Subsurface Engineering:** The subsurface crosscut addresses: intelligent wellbores using advanced sensors and adaptive materials; subsurface stress and induced seismicity to reduce risks associated with subsurface injection; permeability manipulation to control fluid flow; and new subsurface signals to enhance our ability to characterize subsurface systems.
- **Energy-Water Nexus:** The water-energy crosscut addresses RD&D; robust datasets; and integrated models to inform decision-making, aligning with SC’s leadership in high-performance computing and in modeling and simulation.
- **Cyber Security:** The SC Request supports proper protection of the SC laboratories’ computer resources and sensitive data. A review of the SC Cyber Security program recommended increased funding to protect the SC laboratories from cyber threats.

FY 2016 SC Budget Request by Category

Dollars in Thousands



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- NP: FRIB continues and is at the peak of its funding profile ($100,000K); accelerator commissioning and detector construction of the CEBAF12 GeV upgrade continue ($12,000K).
- SLI: Materials Design Lab at ANL ($23,910K); Photon Science Lab Building at SLAC ($25,000K); Integrative Genomics Building at LBNL ($20,000K).

Facility Operations

- ASCR, BER, BES, HEP: Facilities operate at or near to optimal, >98%.
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Major Items of Equipment

- BES: Advanced Photon Source Upgrade (APS-U) ($20,000K) and NSLS-II Experimental Tools (NEXT) (15,500K).
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Research

- ASCR: There is a significant increase for the exascale initiative (Δ = +$86,895K).
- BES: Increases for EFRCs, Computational Materials Sciences, and mid-scale instrumentation.
- BER: Increases for Climate and Earth System Modeling with largest percent increases for Climate Model Development & Validation and Integrated Assessment. Some decreases offset the increases.
- FES: Research continues in all areas. Increase for GPP for PPPL in support of NSTX-U operations. HEDLP is reduced, but the Matter in Extreme Conditions end station at LCLS remains fully funded.
- HEP: Research funding is nearly flat with FY 2015 and supports scientific results from operating experiments and R&D for future projects.
- NP: Research increases by more than 8% to support high-priority work.

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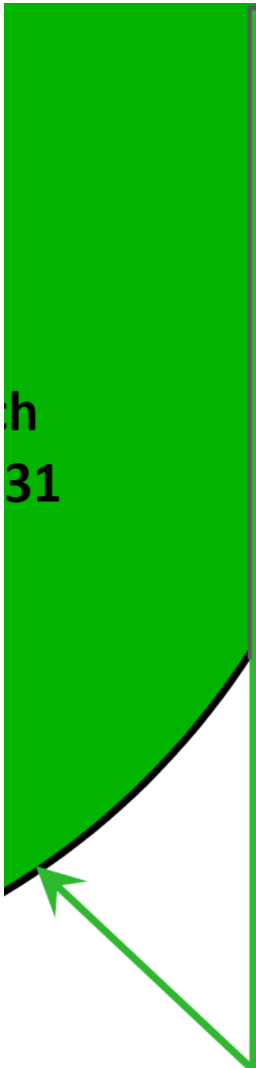

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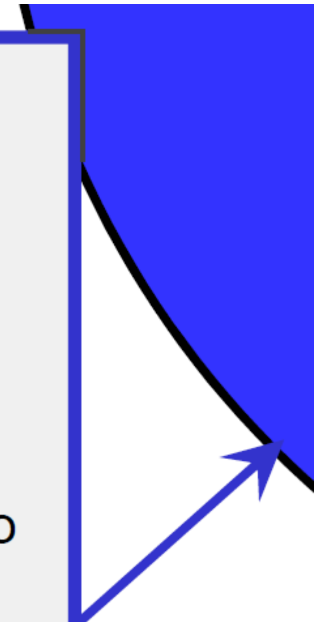

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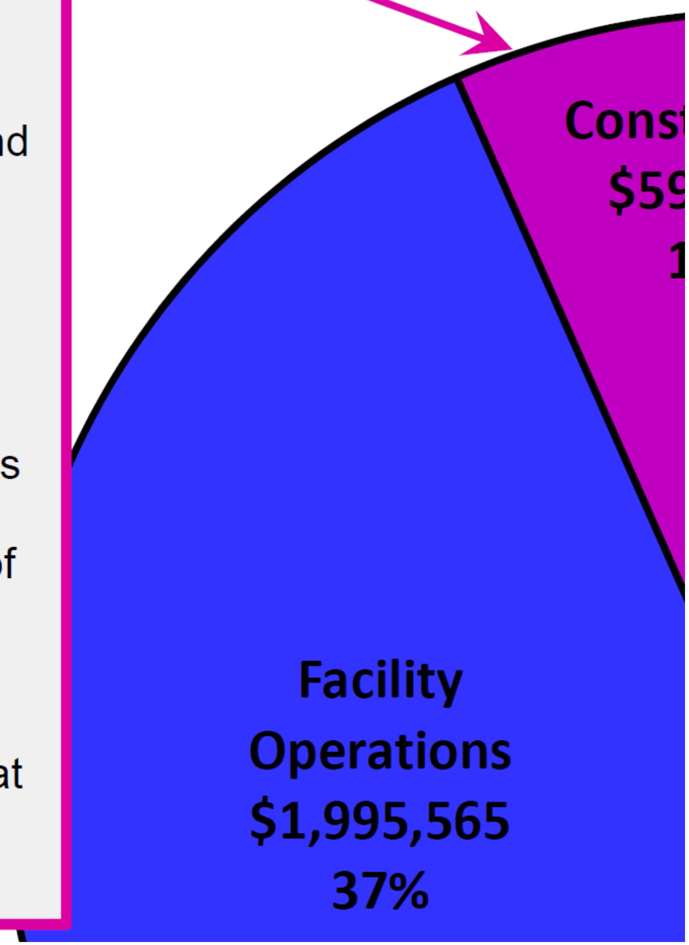

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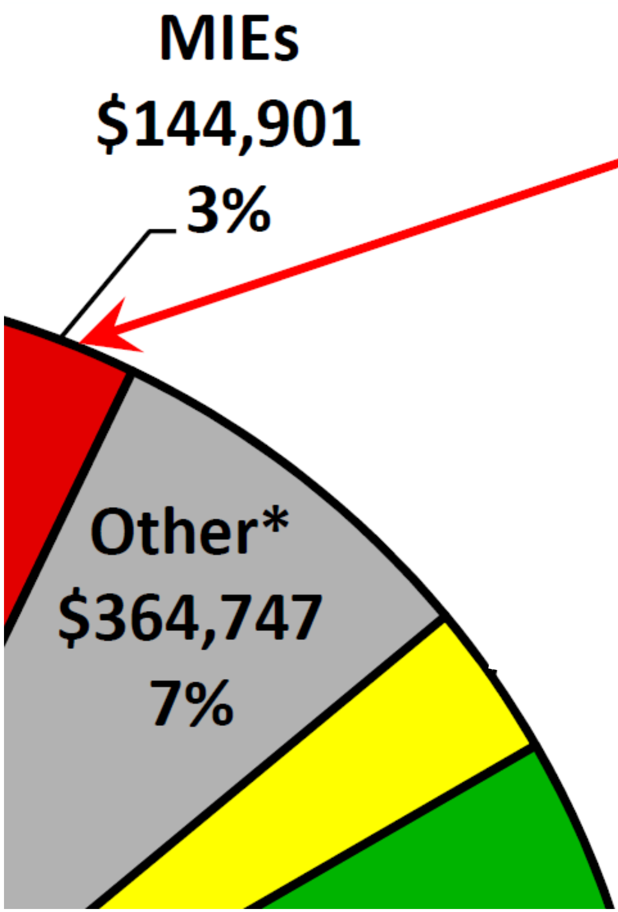

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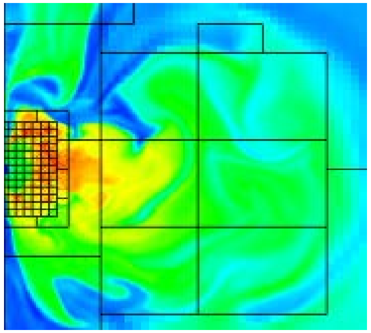
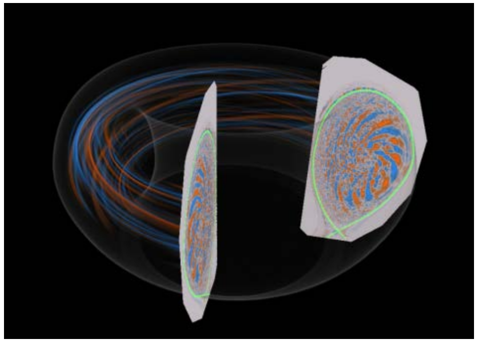
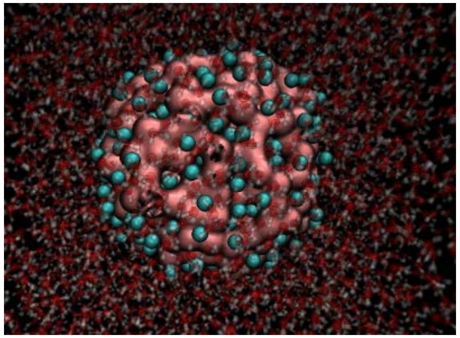
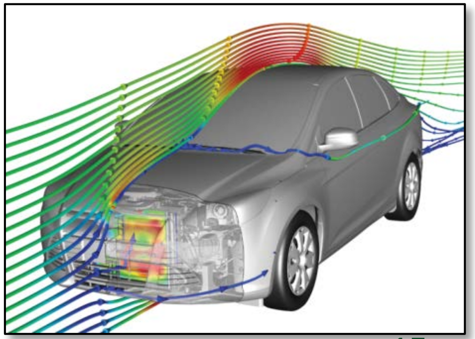
Advanced Scientific Computing Research

Computational and networking capabilities to extend the frontiers of science and technology

- **Exascale computing** – (Exascale Crosscut: FY 2015 = \$91,000K; FY 2016 = \$177,894K; Δ = +\$86,894K) Exascale crosscut includes engagement with HPC vendors to design and develop exascale node technologies and exascale hardware and software computer designs at the system level (Δ = +\$69,000K); hardware architectures and system software; programming for energy-efficient, data-intensive applications.
- **Facilities** operate optimally and with >90% availability; deployment of 10-40 petaflop upgrade at NERSC and continued preparations for 75-200 petaflop upgrades at the Leadership Computing Facilities.
- **SciDAC partnerships** continue to accelerate progress in scientific computing.
- The **Computational Science Graduate Fellowship** is restored at \$10,000K to fully fund a new cohort.
- **Mathematics research** addresses challenges of increasing complexity and **Computer science research** addresses productivity and integrity of HPC systems and simulations, and supports data management, analysis, and visualization techniques.

Path Toward Exascale in FY 2016

High Performance Computing and Network Facilities

- **Next Generation Computing Platforms:** Initiate integrated design efforts for computing environments, ranging from application workflow to hardware architecture and system software; establish partnerships with high-performance computer vendors, to design and develop exascale node and system architectures that will achieve the exascale computing initiative goals.

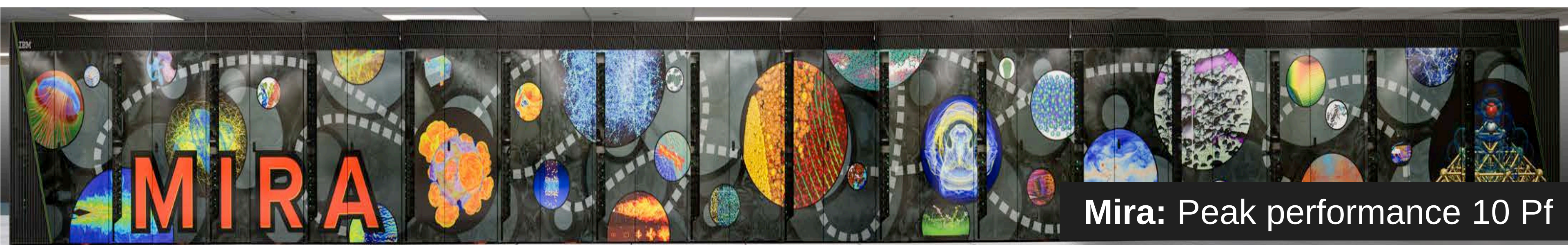
Mathematical, Computational, and Computer Sciences Research

- **Applied Mathematics:** Initiate research addressing predictive simulation for DOE mission applications, in exascale computing environments. This research aims to produce scalable, resilient models, algorithms and numerical libraries for analysis and uncertainty quantification.
- **Exascale Software Environment:** Initiate research addressing programming environments that encompass languages, compilers, runtime systems, and libraries, and serve as a bridge from high-level algorithms to lower-level hardware and operating-system platforms.
- **Co-Design:** Continue Co-design efforts, which provide the over-arching framework used to evaluate exascale options. Co-design efforts investigate a diverse set of technical areas, including architecture aware algorithms, programming models, system software, hardware architectures, resiliency, and power management.

ASCR Production and Leadership Computing Facilities

Edison XC30: Peak performance 2.4 Pf

Titan: Peak performance 27.1 Pf



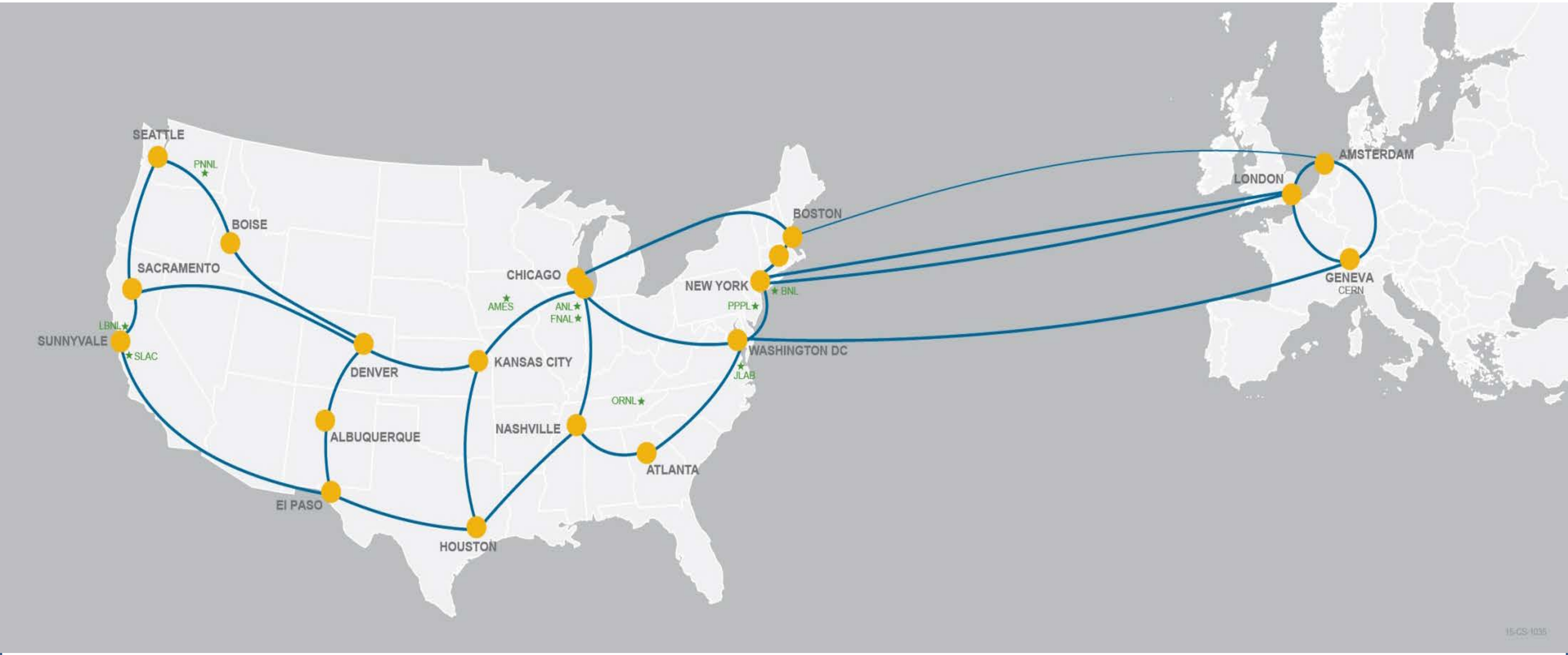
Mira: Peak performance 10 Pf

ASCR Computing Upgrades at a Glance

System attributes	NERSC Now	OLCF Now	ALCF Now	NERSC Upgrade	OLCF Upgrade	ALCF Upgrade
Name/Planned Installation	**Edison**	**TITAN**	**MIRA**	**Cori 2016**	**Summit 2017-2018**	**Aurora 2018-2019**
System peak (PF)	2.4	27	10	>30	150	>150
Peak Power (MW)	3	8.2	4.8	<3.7	10	~13
System memory per node	64 GB	38 GB	16 GB	64-128 GB DDR4 16 GB High Bandwidth	> 512 GB (High Bandwidth memory and DDR4)	TBA
Node performance (TF)	0.460	1.452	0.204	>3	>40	>15 times Mira
Node processors	Intel Ivy Bridge	AMD Opteron Nvidia Kepler	64-bit PowerPC A2	Intel Knights Landing many core CPUs Intel Haswell CPU in data partition	Multiple IBM Power9 CPUs & mulitple Nvidia Voltas GPUS	TBA
System size (nodes)	5,200 nodes	18,688 nodes	49,152	9,300 nodes 1,900 nodes in data partition	~3,500 nodes	~50,000 nodes
System Interconnect	Aries	Gemini	5D Torus	Aries	Dual Rail EDR-IB	TBA
File System	17.6 PB, 168 GBs, Lustre®	32 PB, 1 TB/s, Lustre®	GPFS™	28 PB, 744 GB/sec , Lustre®	120 PB, 1 TB/s, GPFS™	TBA

U.S. DEPARTMENT OF ENERGY | Office of Science

ESnet Goes Global: Extension to Europe

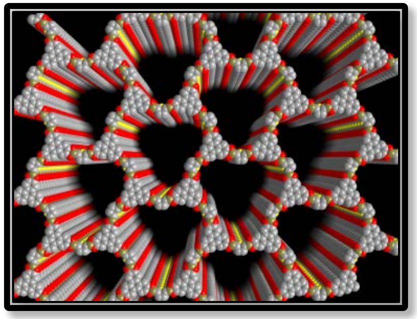


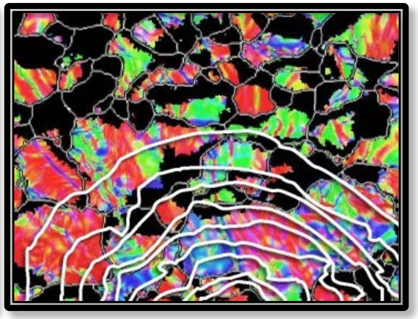
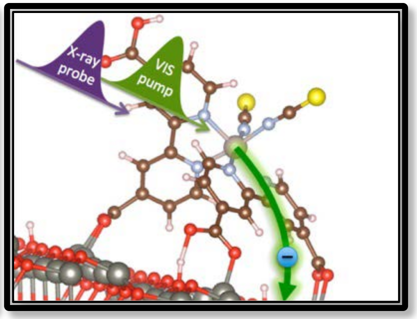
- ESnet funding increases (+$3M) to support the upgrade of the ESnet 100 Gbps testbed to 400 Gbps.
- 25% of all DOE traffic goes to/from Europe
- 3x100+ Gbps across the Atlantic with redundant paths to serve all DOE missions
- 10x increase over current transatlantic network to support the forthcoming Large Hadron Collider Run 2

Basic Energy Sciences

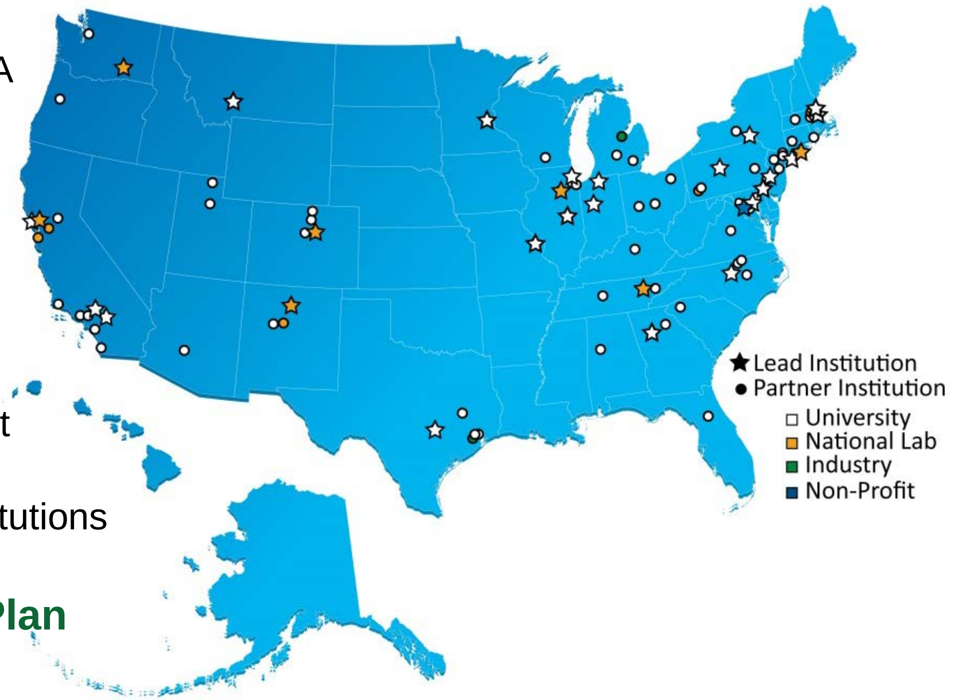
Understanding, predicting, and controlling matter and energy at the electronic, atomic, and molecular levels

- Increased funding for additional **Energy Frontier Research Centers** (EFRCs) (Δ = +$10,000K)
- Increased funding for **computational materials sciences** research to expand technical breadth of code development for design of functional materials (Δ = +$4,000K)
- New funding for **mid-scale instrumentation** for ultrafast electron scattering (Δ = +$5,000K)
- **Energy Innovation Hubs**:
    - Joint Center for Energy Storage Research (JCESR) will be in its 4th year.
(FY 15 = $24,175K; FY 2016 = $24,137K)
    - Joint Center for Artificial Photosynthesis (JCAP) is under review for renewal starting in September 2015. (FY 2015 = $15,000K; FY 2016 = $15,000K)
- **National Synchrotron Light Source-II** (NSLS-II) begins its 1st full year of operations.
- **Linac Coherent Light Source-II (LCLS-II)** construction continues.
- BES **user facilities** operate at near optimum levels (~99% of optimal).
- Two **major items of equipment**: NSLS-II Experimental Tools (NEXT) and Advanced Photon Source Upgrade (APS-U) are underway.



Energy Frontier Research Centers, 2009 - present



FY 2009 46 EFRCs were launched

- $777M for 5 years, $100M/year base + $277M ARRA

FY 2014 Recompetition Results

- $100M/year base
- 32 EFRCs in 32 States + Washington D.C.
  (22 renewals+ 10 new)
- Each $2-4M/yr for up to 4 years
- Led by 23 Universities, 8 DOE Labs, and 1 non-profit
- ~525 senior investigators and ~900 students, postdoctoral fellows, and technical staff at ~100 institutions

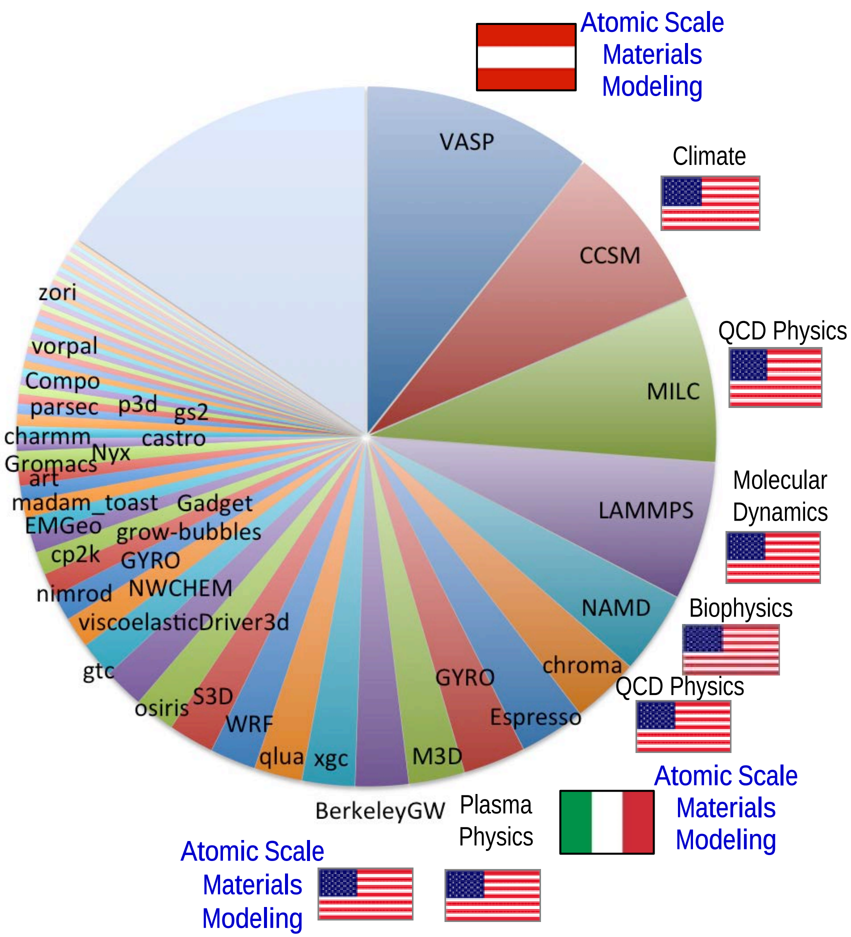
FY 2015 – FY 2016 Review and Management Plan

- Management review of new centers in FY 2015.
- Full mid-term progress review for all centers in FY 2016, with funding for final two years contingent upon review outcome.

FY 2016 Funding and New Solicitation

- Funding for EFRCs increases $10,000K (FY 2015 = $100,000K; FY 2016 = $110,000K).
- Call for new EFRC proposals with topical areas that complement current portfolio and that are informed by new community workshops.
- The EFRC program will transition to a biennial solicitation cycle starting in FY 2016.

Increase for Computational Materials Sciences



2013 Top Application Codes at NERSC

Funding

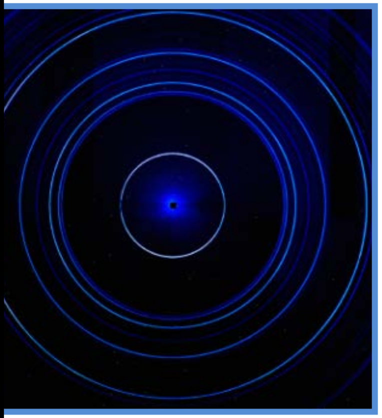
- FY 2015 included $8,000K for new awards. FOA announced January 26, 2015, for proposals to study functional materials; 4-year awards to be funded at $2,000-4,000K per year.
- FY 2016 Request of $12,000K will continue support for the FY 2015 awards and will fund additional awards to broaden the technical scope of the research.

Why computational materials sciences? The U.S. trails competitors in computational codes for materials discovery and engineering

- At NERSC, the most used code is VASP, a commercial Austrian atomic scale materials modeling code requiring purchase of license.
- (Quantum) Espresso, a popular materials modeling code, was developed by Italy.
- Top codes for other fields used at NERSC were developed in the U.S. and are all free, community codes.

National Synchrotron Light Source II

Successfully completed on time and within budget



First Diffraction Data

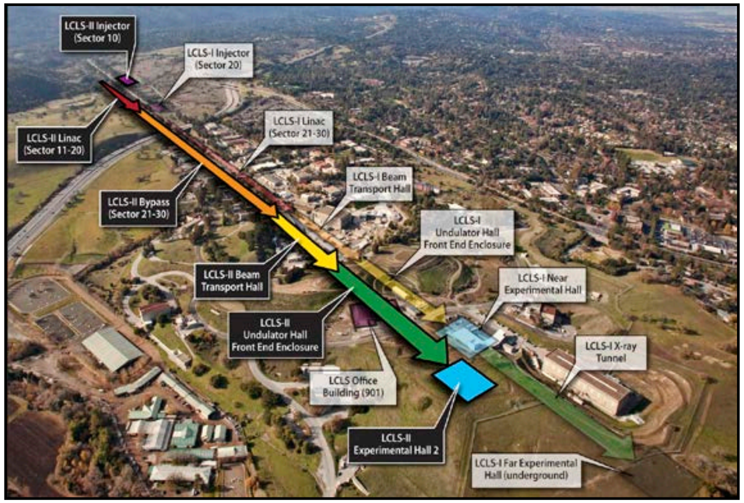
National Synchrotron Light Source-II (NSLS-II)

- First light was achieved on Oct 23, 2014. Six project beamlines were approved for commissioning by Oct 31, 2014. All key performance parameters and project scope were delivered by December 2014.
- NSLS-II provides over 600k square feet of space to house the 3 GeV storage ring and 5 lab and office buildings. The ring will be capable of 500 mA operation.
- NSLS operations ceased September 30, 2014, and it will transition to safe storage in FY 2015. NSLS-II FY 2015 operations is $90.4M. FY 2016 request includes operations funding of $110,000K.

LCLS-II and APS-U Underway

Linac Coherent Light Source-II (LCLS-II)

- FY 2015 = $148,000K; FY 2016 = $200,300K for R&D, design, prototyping, long lead procurement, and construction of technical systems.
- LCLS-II will provide high-repetition-rate, ultra-bright, transform-limited, femtosecond x-ray pulses with polarization control and pulse length control to ~1 femtosecond. The hard x-ray range will be expanded to 25 keV.
- Added are a 4 GeV superconducting linac; an electron injector; and two undulators to provide x-rays in the 0.2–5 keV energy range.



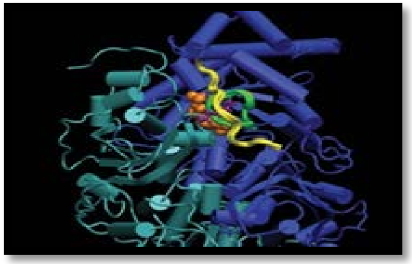
Advanced Photon Source Upgrade (APS-U)

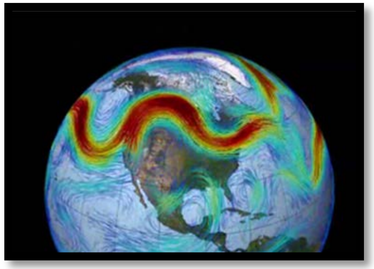
- FY 2015 = $20,000K; FY 2016 = $20,000K for R&D, design, and limited prototyping.
- APS-U will provide a multi-bend achromat lattice to provide extreme transverse coherence and extreme brightness.
- Initial conceptual design for the new lattice completed; conducting R&D and key component prototyping in support of the new design. Key performance parameters are being defined for the project and the new storage ring.

Biological and Environmental Research

Understanding complex biological, climatic, and environmental systems

- **Genomic sciences** supports the Bioenergy Research Centers and increases efforts in biosystems design for bioenergy and renewable bioproducts (Δ = +$2,145K).
- **Mesoscale-to-molecules** research supports the development of enabling technology to visualize key metabolic processes in plant and microbial cells at the subcellular and mesoscale.
- **Climate and Earth System Modeling** develops physical, chemical, and biological model components to simulate climate variability and change at regional and global scales. (Δ = +$11,763K).
- A new activity in **Climate Model Development and Validation** combines code development and numerical methods with ARM data to design an Earth system model with sub-10 km resolution for use on next generation and exascale computers. (Δ = +$18,730K).
- **Atmospheric System Research (ASR)** addresses major uncertainties in climate change models: the role of clouds and the effects of aerosols on precipitation, and the atmospheric radiation balance.
- **Environmental System Science** supports research to provide a robust, predictive understanding of terrestrial surface and subsurface ecosystems. Includes Next Generation Ecosystem Experiments targeting climatically sensitive terrestrial ecosystems not well represented in models.
- **Climate and Environmental Data Analysis and Visualization** employs server side analysis to simplify analysis of large scale observations with model-generated data. (Δ = +$2,066K).
- **User facilities operate at optimal levels: ARM** continues measurements at fixed sites, and mobile facilities deploy to the Arctic, Antarctic, and the Pacific Ocean. **JGI** provides genome sequence data, synthesis, and analysis. **EMSL** initiates work using the High Resolution and Mass Accuracy Capability.

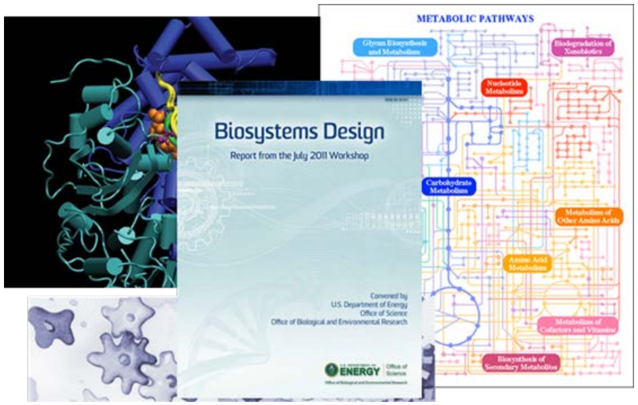


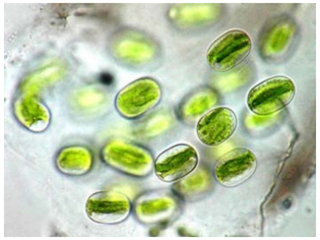
Biological Systems Science

Biological Systems Science supports basic research and technology development to achieve a predictive, systems-level understanding of complex biological systems.

Foundational knowledge in genome science with advanced computational and experimental approaches serves as the basis for the confident redesign of microbes and plants for sustainable biofuel production, improved carbon storage and contaminant remediation



- Genomic Science research continues work in sustainability for bioenergy and microbial community impacts on carbon and nutrient cycling.
- Increase in biosystems design for bioenergy and renewable bioproducts
- Mesoscale to Molecules supports integrative bioimaging technology to visualize metabolic processes in plant and microbial cells at the subcellular and mesoscale scales.



jbei Joint BioEnergy Institute
BESC BioEnergy Science Center
GREAT LAKES BIOENERGY RESEARCH CENTER

KBase PREDICTIVE BIOLOGY
DOE Systems Biology Knowledgebase

JGI JOINT GENOME INSTITUTE DEPARTMENT OF ENERGY

The Bioenergy Research Centers

- **Established in 2007; in the 7 years of operations:**
  - 602 invention disclosures and/or patent applications
  - 19 patents awarded
  - 108 licensing agreements
  - 1661 peer-reviewed publications

- **Renewed for 5 years following merit review in September 2012**

  BioEnergy Science Center (Oak Ridge National Lab)
  - Strategic focus on overcoming biomass "recalcitrance"
  - Goal of "Consolidated Bioprocessing" – one-microbe or microbial community approach going from plants to fuel

  Great Lakes Bioenergy Research Center (U. of Wisconsin, Michigan State U.)
  - Goal of re-engineering plants to produce more starches and oils
  - Using high throughput technologies to optimize chem/bio process for biomass deconstruction
  - Major research thrust on sustainability of biofuels

  Joint BioEnergy Institute (Lawrence Berkeley National Lab)
  - Experimenting with new pretreatment process using room temperature ionic liquids
  - Engineering *E.coli* and yeast to produce hydrocarbons, "green" gasoline, diesel, jet fuel

Systems Biology Knowledgebase (KBase)

A Community Resource for Predictive Biology

- Kbase is an open-source, open-architecture environment for integrating large, diverse datasets (generated by the Genomic Sciences program and other sources) and for using this information for predictive understanding, manipulation, and design of biological systems.

- Kbase:
  - encourages best science practices: access to data, sharing, publishing, reproducibility of analyses
  - provides access to the best tools for the analysis of large, complex data sets
  - provides metrics for success and utility of data, tools etc.
  - lowers the bar for the analysis of complex data sets and modeling with high performance computers
  - synthesizes biological data from the community to answer questions beyond the ability of the single investigator or small teams of researchers
  - Currently includes
    - 22,253 microbial genomes
    - 96 eukaryotic genomes (56 plants)
    - 15,462 metagenomic datasets
    - 13,111 public reference models
    - 28 analysis services
    - 60+ point-and-click analysis functions

KBase PREDICTIVE BIOLOGY

DOE Systems Biology Knowledgebase

http://www.kbase.us

- *"Takes the known biology away from the analysis (i.e.: known biochemistry) so the scientist can focus on new biology"*
- *"Prior to using KBase, extensive effort was expended in manual analysis (1 year of effort). The KBase workflow and analysis described here was done in 2 weeks."*
- *"Accelerated my metagenomics research and provided a clear set of flexible tools that I can use in conjunction with my collaborators."*

DOE's Role in Climate Science Research

- SC relies on unique facilities and long term observing capabilities, most hosted or managed by DOE national laboratories, to collect and analyze data to understand climate processes. These facilities are:
  - The Atmospheric Radiation Measurement (ARM) Climate Research Facility, to understand cloud-aerosol-precipitation interactions with the earth's radiant energy balance
  - Next Generation Ecosystem Experiments (NGEE), to explore ecological, biogeochemical, and soil process interactions
  - Ameriflux, to measure ecosystem carbon, water, and energy fluxes to support environmental research
  - Data from ARM, NGEE, and Ameriflux are coordinated under a DOE data informatics capability, enabling efficient use and integration by the scientific community
  - The petascale Leadership Computing Facilities at ORNL and ANL, to understand earth and environmental system process interactions based on synthesis of complex data sets

- SC grand science challenges that frame priorities include:
  - Atmospheric and terrestrial process level interactions, in particular cloud, aerosol, ecological, hydrological, and biological processes that affect the earth's energy balance at various scales
  - Understanding processes that control internal climate variability and extremes
  - Understanding uncertainty of the climate system

- DOE is a leader in climate science and has been since the 1950s, when the AEC was charged with understanding atmospheric transport for national security and, later, the impacts of CO_2. Today, DOE coordinates with other agencies through collaborative partnerships and through the U.S. Global Change Research Program.

Climate Model Development and Validation

Model capabilities today

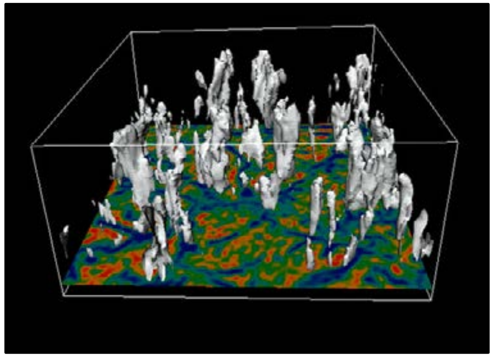
- Global and regional simulations to 50 km resolution in full integration mode; to 25 km with limited integration. *Unable to adequately represent extreme events, important to DOE and energy infrastructure*.
- No standard uncertainty quantification methodology applied to climate predictions. *Improved confidence in predictions is needed by scientists and stakeholders*.
- No common software infrastructure strategy in climate modeling community. *Current climate models will be unable to exploit DOE's next generation exascale computer architectures.*

FY 2016 Research Efforts

- Combine major upgrades in advanced software code development, downscaling methodologies, and validation against testbeds for sites in U.S. (Oklahoma, Alaska) using the Atmospheric Radiation Measurement Climate User Facility (ARM)
- Develop scale-aware physics appropriate for very high resolution phenomena extending 10 km to below 1 km.
- Integrate scale-aware physics into improved climate modeling codes for use on next generation and exascale computers.


ARM Oklahoma

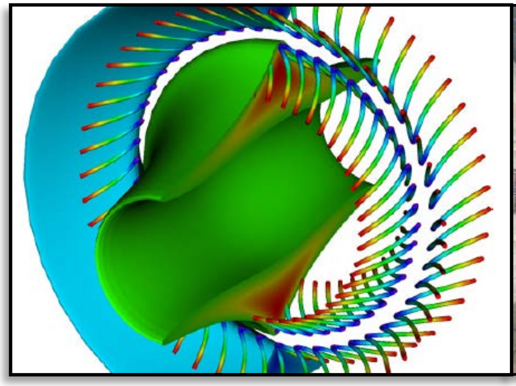
Best-in-class software and hardware


First modeling of high-res extreme phenomena with Uncertainty Quantification methodologies

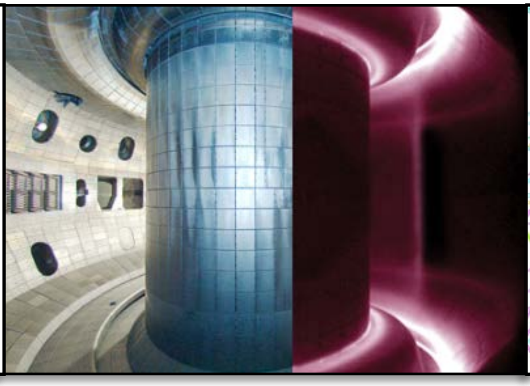
Fusion Energy Sciences

Matter at very high temperatures and densities and the scientific foundations for fusion

- Research is supported for the DIII-D and NSTX-U national programs.
- NSTX-U operates for 14 weeks; DIII-D operates for 12 weeks; and Alcator C-Mod operates for 5 weeks prior to facility close-out at the end of FY 2016.
- Support continues for U.S. research involvement on international machines EAST (China), KSTAR (Korea), and W7-X (Germany).
- HEDLP research is focused on the MEC instrument at LCLS.
- General plasma science activities continue, including the partnership with NSF.
- U.S. contributions to ITER support U.S. ITER Project Office; the US direct contribution; and progress on hardware contributions, including fabrication of the central solenoid magnet modules and structures and the toroidal field magnet conductor.

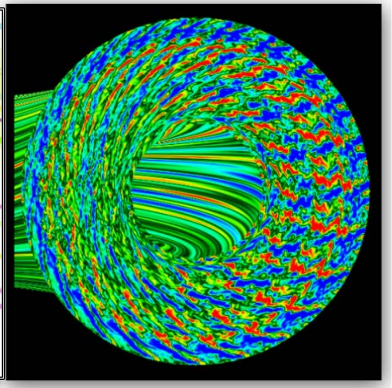


Magnetic reconnection on Swarthmore spheromak



Interior of DIII-D tokamak

Dislocation loops forming and moving inside fusion materials

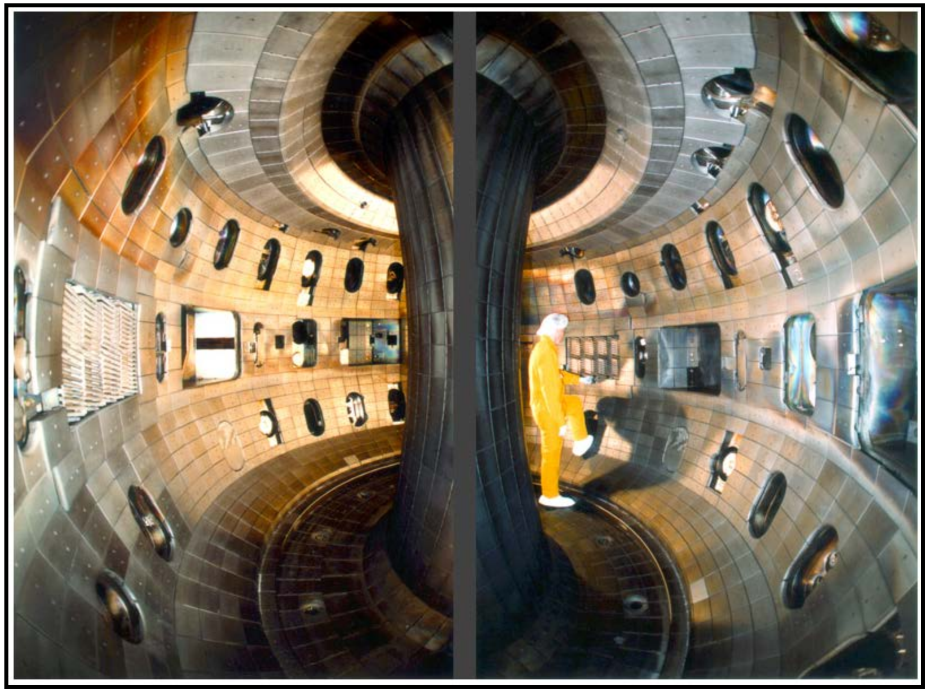


Gyrokinetic simulation of turbulent transport in tokamak plasma

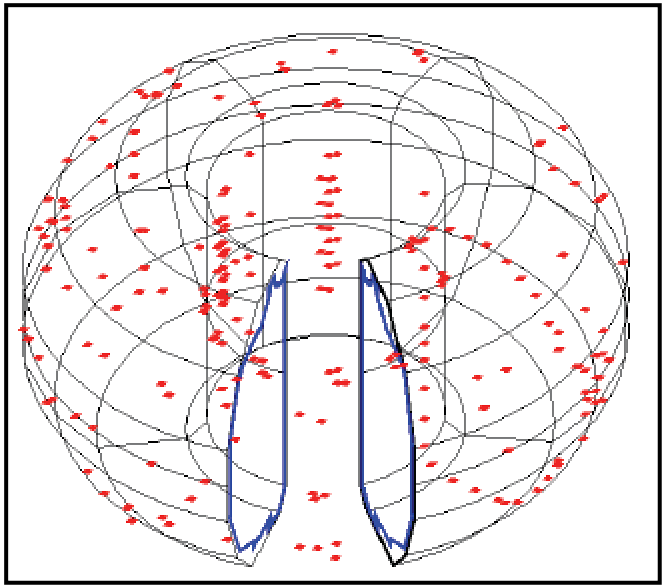
NSTX Upgrade at PPPL

- FY 2016 is the first full year of operation of NSTX-U after completion of the multi-year upgrade construction project in mid-FY 2015.
- Funding will allow 14 weeks of run time (up 4 weeks from the FY 2015 Enacted level).
- NSTX-U will extend its performance to the new full field and current values (both double what had been achieved prior to the upgrade) and address divertor heat flux mitigation, enhanced plasma confinement, and non-inductive discharge sustainment.
- In mid-FY 2016, a shutdown is planned for installation of a cryopump in the lower divertor and a row of tungsten tiles on the cryo-baffle.

DIII-D and its Upgrades at General Atomics



Interior of DIII-D vacuum vessel

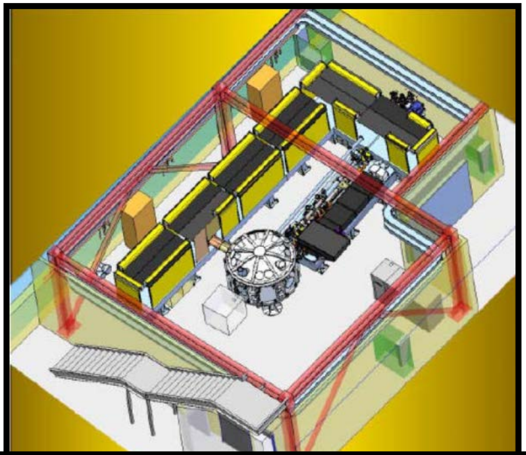


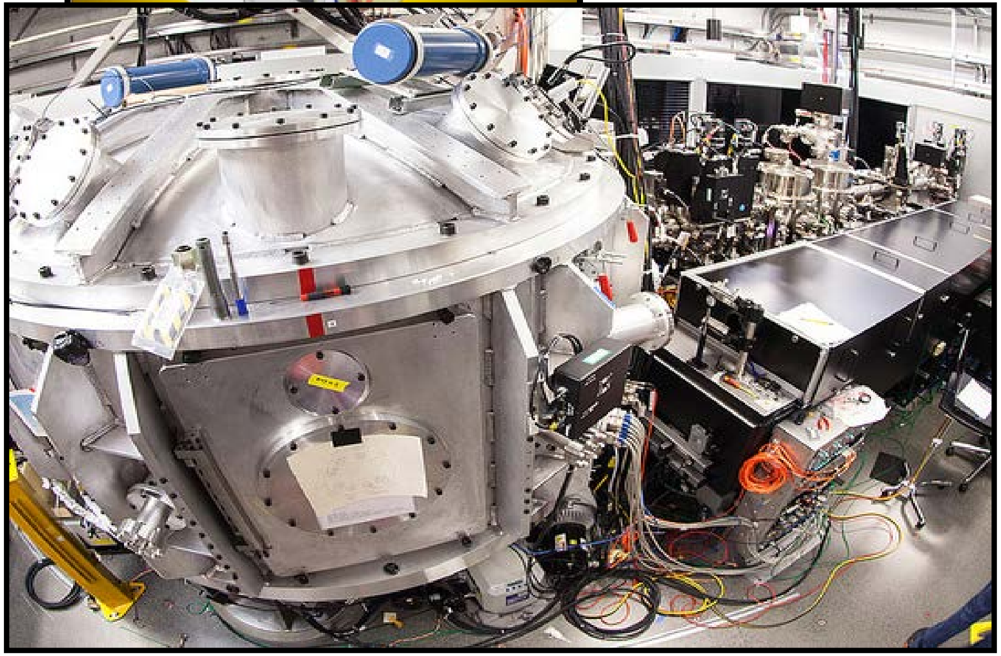
Red dots are sensors on DIII-D tokamak for three-dimensional magnetic field structure measurements

- DIII-D will continue high-priority studies of transport, disruption physics and mitigation systems, methods to exploit three-dimensional magnetic field control for improved performance, and high plasma pressure operation.
- After 12 run weeks, DIII-D will have a planned outage for installation of upgrades, including an additional high-power microwave heating system, new magnet power supplies for the 3D coils and shaping coils, and improvements to the neutral beam heating control system. Also, design modifications necessary for a second off-axis neutral beam will begin.

Matter at Extreme Conditions (MEC) End Station at LCLS

- MEC provides access to high-energy-density regimes, uniquely coupled with the LCLS high-brightness x-ray source.
- This enables experiments at the frontier of high energy density physics, laboratory astrophysics, laser-particle acceleration, and nonlinear optical science.
- The MEC instrument combines the LCLS beam with high power optical laser beams and a suite of dedicated diagnostics (including an X-ray Thomson scattering spectrometer, an XUV spectrometer, a Fourier domain interferometer, and a VISAR system).
- The large vacuum target chamber provides a versatile environment for key scientific areas including Warm Dense Matter physics, high pressure studies, shock physics, and high energy density physics.





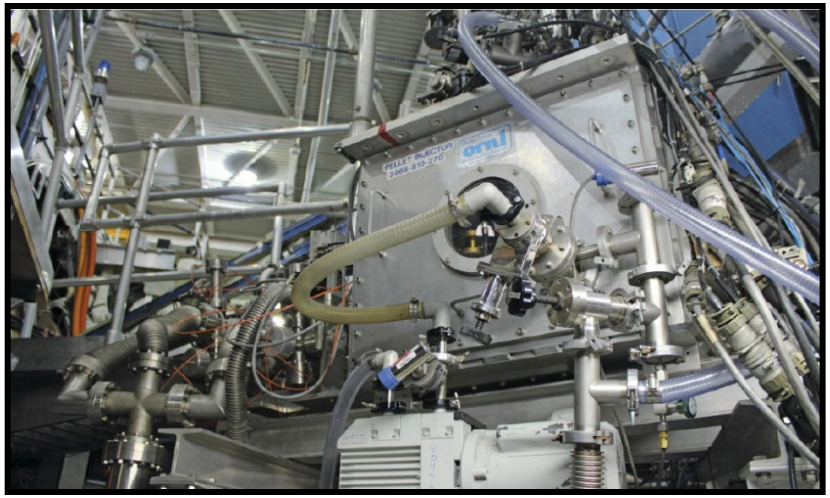
Community Engagement Workshops

- Following the Fusion Energy Sciences Advisory Committee (FESAC) *Strategic Planning and Priorities Report* (2014), FES will undertake a series of four technical workshops in May-June 2015. Workshop topics address the main recommendations of the FESAC report.
  - Workshop on Integrated Simulations for Magnetic Fusion Energy Sciences
  - Workshop on Transients
  - Workshop on Plasma Science Frontiers
  - Workshop on Plasma-Materials Interaction

- Each workshop will deliver a written report prepared by its steering committee (a group of community scientists selected for topical expertise who will lead/participate in the workshop). The reports will address scientific challenges and potential implementation options.

U.S. Fabrication of ITER Hardware Progressing

Toroidal field conductor jacketing at High Performance Magnetics (Tallahassee, FL)



Pellet injector to feed ITER with frozen fuel pellets, developed by ORNL (Oak Ridge, TN)

Toroidal field cable produced at New England Wire Technologies (Lisbon, NH)

Installation of the first winding station for the central solenoid at General Atomics (San Diego, CA)

High Energy Physics

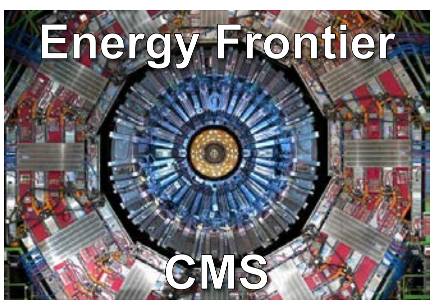
Understanding how the universe works at its most fundamental level

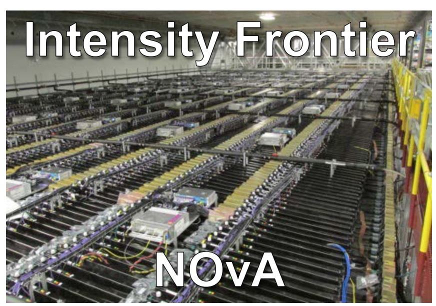
- HEP is implementing the strategy detailed in the May 2014 report of the Particle Physics Project Prioritization Panel (P5), formulated in the context of a global vision for the field
  - HEP Addresses the five compelling science drivers with research in three frontiers and related efforts in theory, computing and advanced technology R&D
  - Increasing emphasis on international partnerships (such as LHC) to achieve critical physics goals

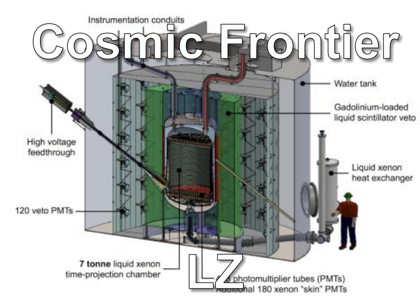
- Energy Frontier: Continue LHC program with higher collision energy (13+ TeV)
  - The U.S. will continue to play a leadership role in LHC discoveries by remaining actively engaged in LHC data analysis and the initial upgrades to the ATLAS and CMS detectors

- Intensity Frontier: Develop a world-class U.S.-hosted Long Baseline Neutrino Facility
  - Continue the design process for an internationalized LBNF and development of a short baseline neutrino program that will support the science and R&D required to ensure LBNF success
  - Fermilab will continue to send world's highest intensity neutrino beam to NOvA, 500 miles away

- Cosmic Frontier: Advance our understanding of dark matter and dark energy
  - Immediate development of new capabilities continue in dark matter detection with baselining of 2nd-generation experiments; and in dark energy exploration with baselining of DESI and fabrication of LSST camera.







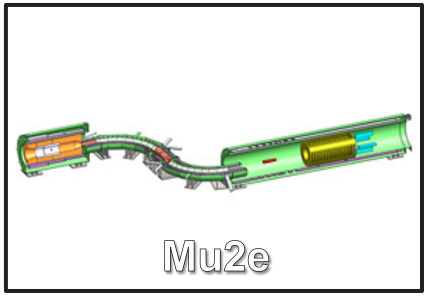
	Energy Frontier	Intensity Frontier	Cosmic Frontier
Higgs Boson	●		
Neutrino Mass		●	●
Dark Matter	●	●	●
Cosmic Acceleration			●
Explore the Unknown	●	●	●

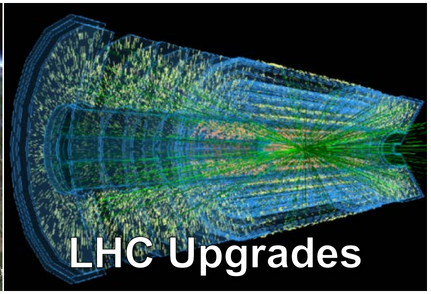
High Energy Physics

Understanding how the universe works at its most fundamental level

- Accelerator Stewardship
  - This subprogram focuses on the broader applications of accelerator technologies, including major thrusts in technology to enable ion-beam cancer therapy and R&D for high-power ultrafast lasers
  - The FY 2016 Budget Request provides support for a new research thrust in energy and environmental applications of accelerators and expands the open test facilities effort
  - The main facility supporting this subprogram, the Brookhaven Accelerator Test Facility (ATF), will undergo relocation at BNL and expansion in FY 2016 to accommodate more users

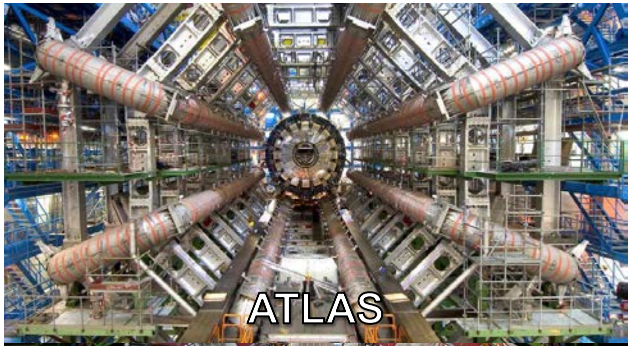
- Construction/Major Items of Equipment (MIEs) reflect P5 priorities:
  - The Long Baseline Neutrino Facility (LBNF) continues its design phase as the project baseline cost and technical scope are revised while incorporating international in-kind contributions
  - The LHC ATLAS and CMS Detector Upgrade projects continue fabrication
  - Muon g-2 continues accelerator modifications and fabrication of the beamline and detectors
  - LSSTcam fabrication support increases according to planned profile
  - Dark Energy Spectroscopic Instrument (DESI) will be baselined in 2016
  - Fabrication proceeds on the dark matter experiment MIEs: SuperCDMS-SNOLab and LZ
  - Construction continues for the Muon to Electron Conversion Experiment (Mu2e)

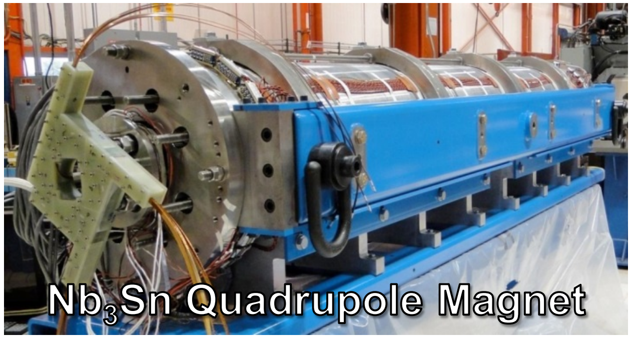




LHC – a Central Component of the Energy Frontier Program

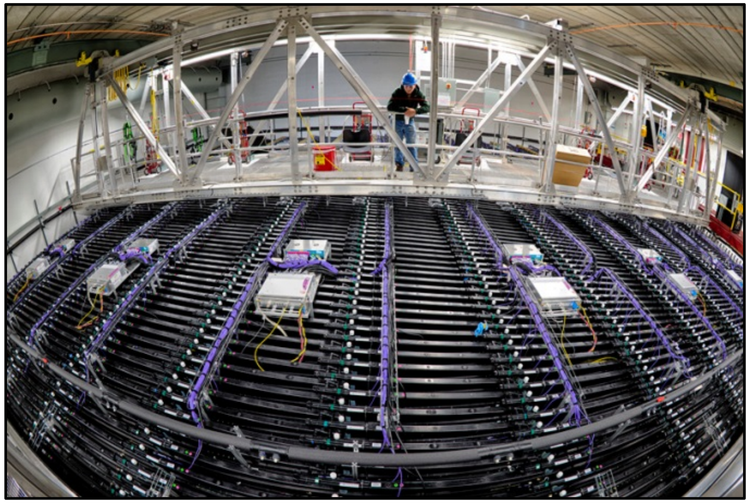
- U.S. investments enable leading roles in the global LHC physics collaborations
- P5 report identified LHC upgrades as the highest priority near-term large project and specifically recommends:
    - Complete in 2018 modest upgrades of ATLAS and CMS experiments to maintain performance.
    - Continue collaborations with the High-Luminosity LHC (HL-LHC) upgrades of the accelerator and the ATLAS and CMS experiments (2023-25)
        - HL-LHC upgrades will increase LHC luminosity by a factor of 10 beyond its design value and significantly extend discovery potential
- U.S. leadership in superconducting magnet technology in general, and with Nb_3Sn in particular, is widely recognized and acknowledged
    - U.S. LHC Accelerator Research Program (LARP) aims to leverage this expertise to serve needs of HEP community





Short- and Long-baseline Neutrino Experiments at Fermilab

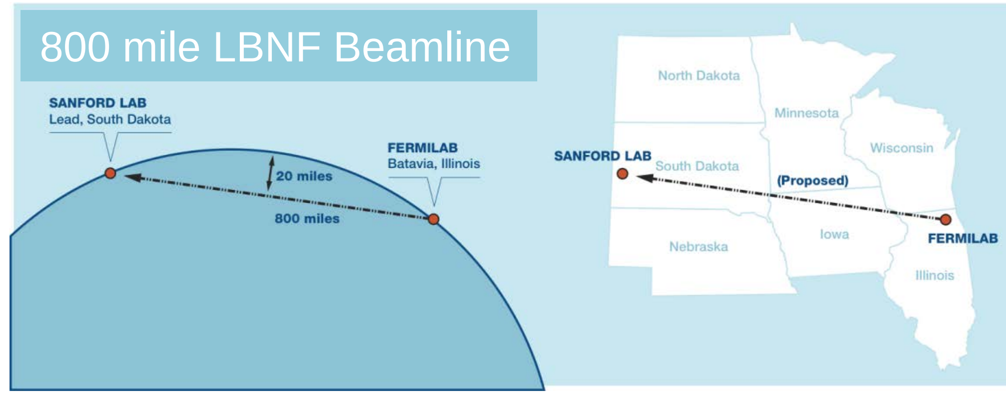
- NOvA taking data using the world's most powerful neutrino beam and the world's longest baseline
  - World's highest intensity neutrino beam sent 500 miles from Fermilab to Ash River, MN
  - Project completed on time and under budget in September 2014
  - Currently operating as part of the planned six-year run

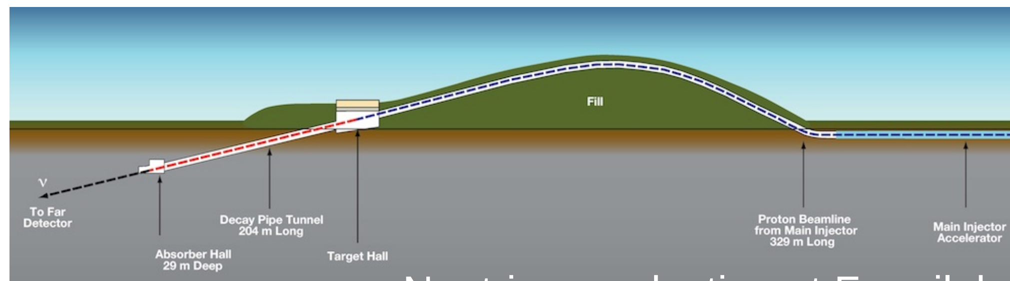


- MicroBooNE, a key first step in the Fermilab short baseline neutrino program, begins three year run in 2015
  - Largest liquid argon based neutrino detector built in the U.S., at 170 tons of total liquid argon mass
  - Important step in development of large-scale liquid argon technology for future Long Baseline Neutrino Facility detector

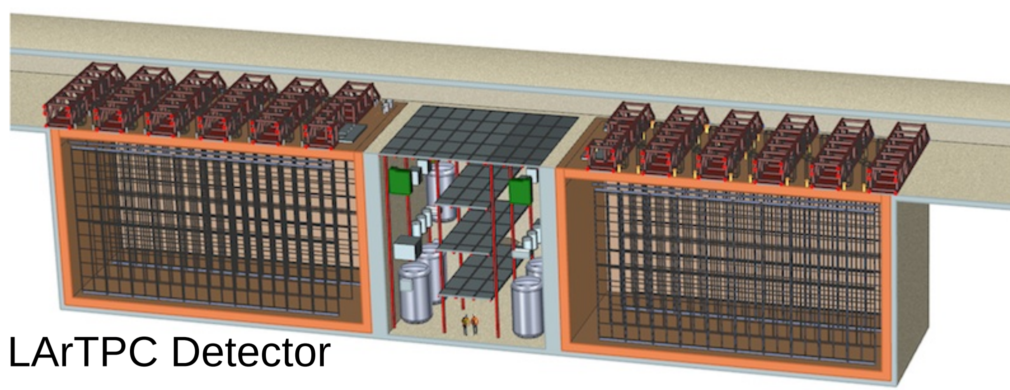
Long Baseline Neutrino Facility

- U.S.-hosted, world-class Long Baseline Neutrino Facility identified by P5 as “the highest-priority large project in its timeframe.”
- Community, led by Fermilab, is continuing the design process for an internationalized LBNF, with current design featuring:
  - New neutrino beam at Fermilab with over 1 megawatt of initial beam power
  - 800 mile distant large Liquid Argon Time Projection Chamber (LArTPC) detector deep underground at Homestake mine in Lead, SD





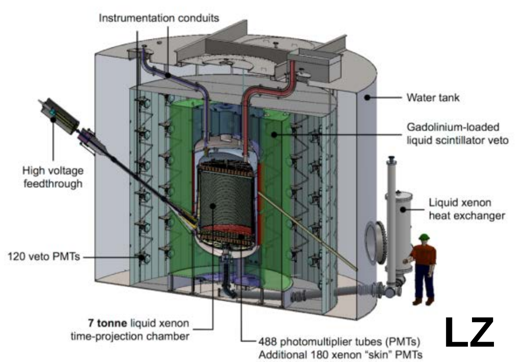
Neutrino production at Fermilab



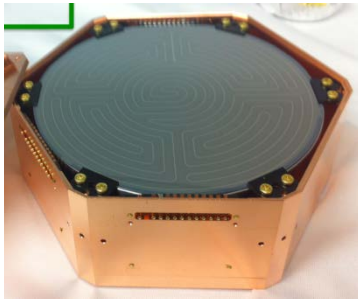
LArTPC Detector

Investments in Dark Matter and Dark Energy

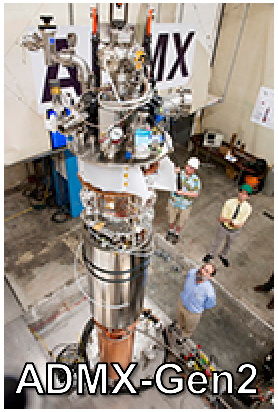
- P5 recommended strong immediate investments into the second generation dark matter direct detection program
  - FY 2015 MIEs, FY 2016 baselining for LUX-Zeplin (LZ) and SuperCDMS–SNOLab to collectively provide sensitivity to both low- and high-mass WIMPs
  - Small-scale ADMX-Gen2 supported to perform complementary search for axions
  - Program includes broad, coordinated R&D for future experiments



LZ



SuperCDMS-SNOLab

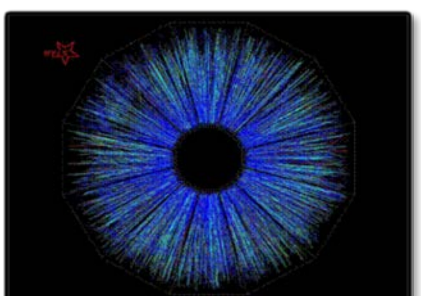
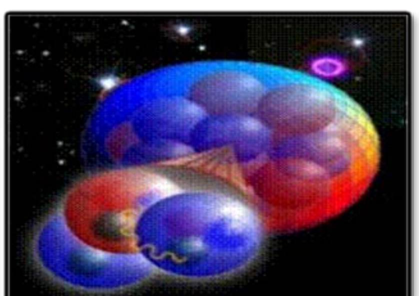
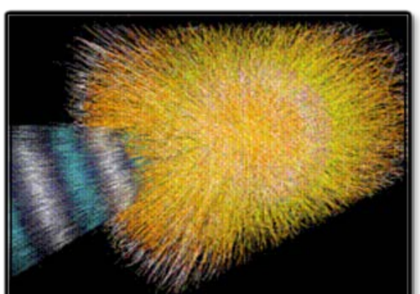
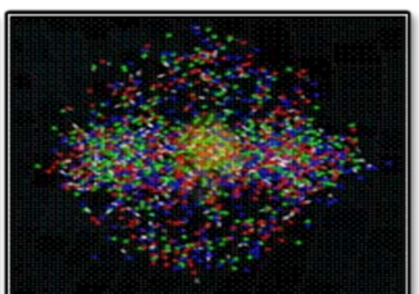


- P5 encouraged support for the Dark Energy Spectroscopic Instrument (DESI) as part of the dark energy program
  - DESI has MIE start in 2015 and will be baselined in 2016
  - Will provide spectroscopic complement to imaging-based LSST

Nuclear Physics

Discovering, exploring, and understanding all forms of nuclear matter

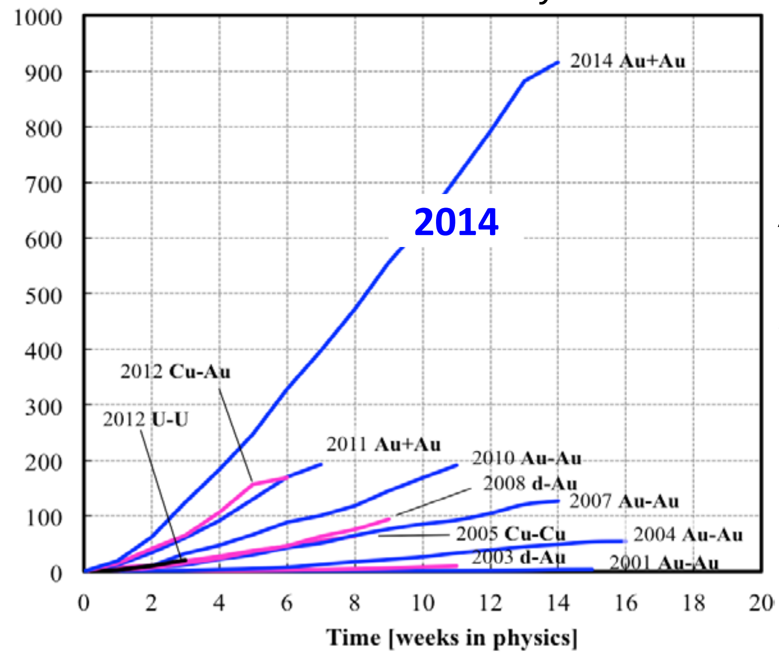
- Funding for **research** increases in every NP subprogram to support high priority research areas, e.g., in nuclear structure, nuclear astrophysics, the study of matter at extreme conditions, hadronic physics, fundamental properties of the neutron, and neutrinoless double beta decay. (Increase = +$13,483K or 8.1%)
- Research at **RHIC** capitalizes on record luminosity and new capabilities to probe the perfect Quark-Gluon liquid. The FY 2014 run commissioned the Heavy Flavor Tracker, (new microvertex detector); the FY 2015 run will generate baseline data from proton+proton and proton+Au collisions; the FY 2016 run will generate the definitive Au+Au data to inform our understanding of the perfect liquid, discovered at RHIC in 2005.
- The **12 GeV CEBAF Upgrade** continues beam development and commissioning activities in preparation for project completion and the full start of the 12 GeV physics program in 2017.
- Construction continues on the **Facility for Rare Isotope Beams** to provide unparalleled opportunity for research on nuclear structure and nuclear astrophysics.
- Upgrades of the **ATLAS** ion source and Booster Cryomodule provide new scientific capability for understanding nuclear structure and the origin of the elements in the cosmos.
- Research, development, and production of **stable and radioactive isotopes** is provided for science, medicine, industry, and national security.

Relativistic Heavy Ion Collider

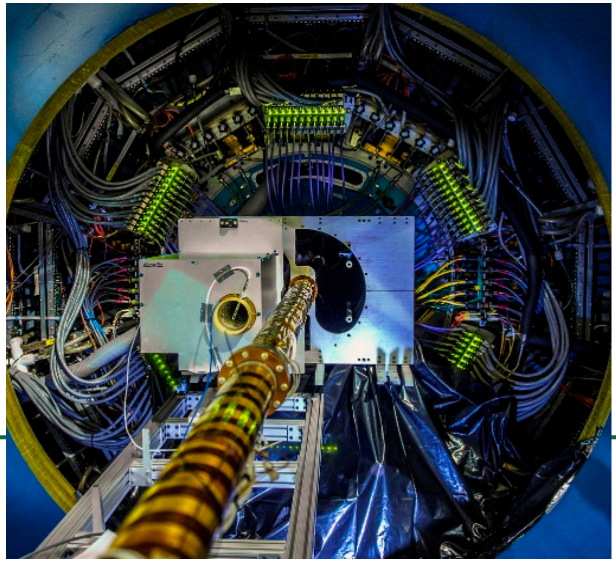
- RHIC operates for 22 weeks, the same as FY 2015.
- The FY 2016 run (Run-16) is essential to understand results on heavy quark propagation in the quark-gluon plasma discovered at RHIC.
- The high statistics data planned for Run-16 will address these phenomena and are required for researchers to interpret the data acquired from the last two years.
- Funds for experimental equipment, accelerator R&D, and materials and supplies are provided to optimize operations, maintenance, and support critical staff.

Record RHIC Luminosity Achieved

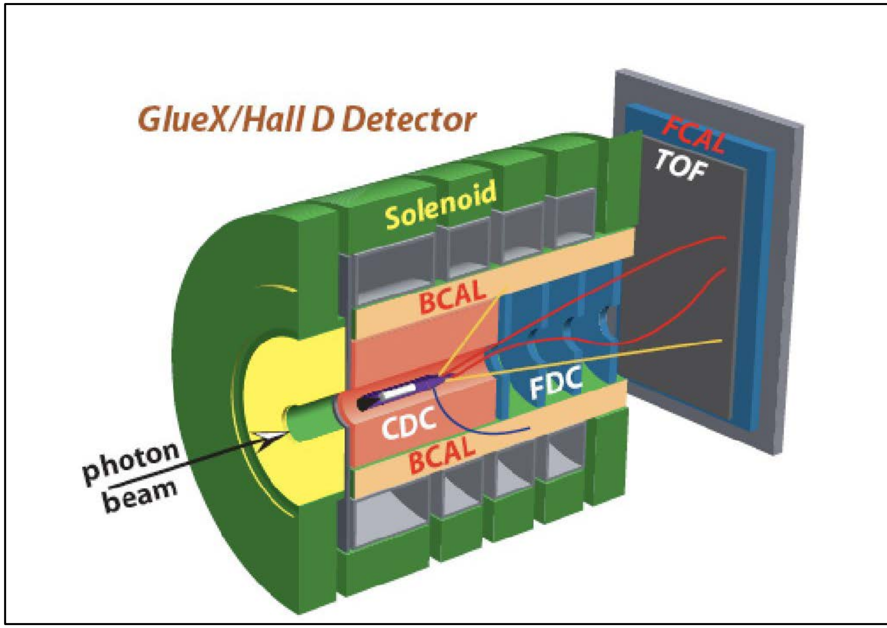


Au + Au integrated luminosity from Run 14 exceeded all previous Au+ Au runs combined

New micro-vertex detector (Heavy Flavor Tracker) will detect particles containing charm and bottom quarks to characterize the quark-gluon plasma



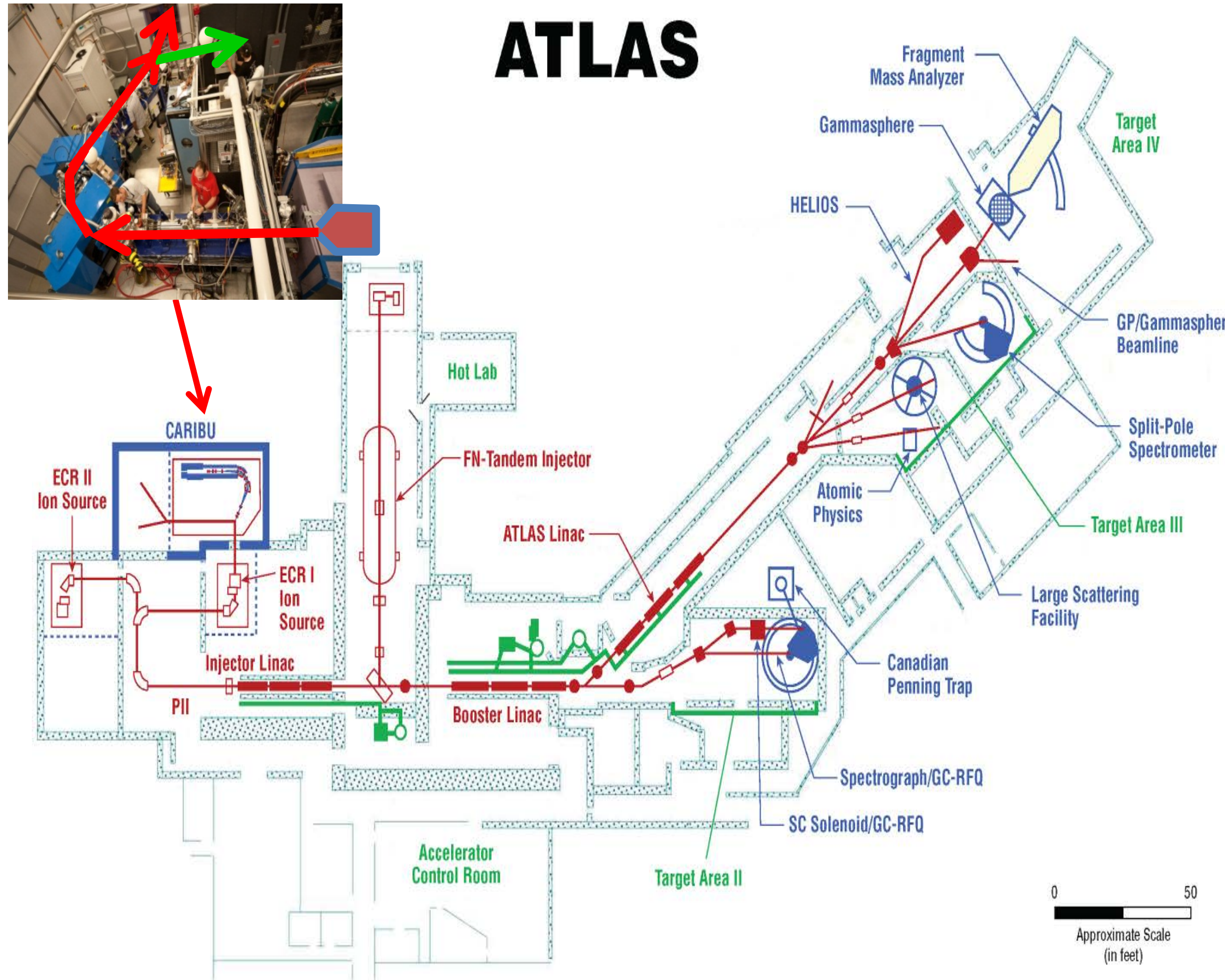
The 12 GeV Upgrade at CEBAF



- FY 2016 funding supports continued machine development and associated incremental power costs to support the 12 GeV research program, including engineering operations to Hall D and commissioning of newly installed hall equipment for physics running starting in FY 2017.
- Major activities in FY 2016 will be developing beams for Halls B and C for commissioning activities.
- Increased funding for commissioning the upgraded CEBAF facility is provided for operations and experimental support for staff, incremental power costs, and experimental equipment for Halls B, C, and D as the 12 GeV CEBAF experimental program is initiated.

Argonne Tandem Linac Accelerator System

- FY 2016 funding supports 37 weeks of beam time and a program of upgrades for work in nuclear structure and astrophysics.
- Continued operation of ATLAS in a 7 day per week mode is a high priority as demand for ATLAS beam time continues to far exceed availability.
- Funding increases support of key personnel required to provide robust operations, implement new capabilities of the accelerator and support the increasing demand from the user community for a wider variety of beams.



Facility for Rare Isotope Beams

FRIB will increase the number of isotopes with known properties from ~2,000 observed over the last century to ~5,000 and will provide world-leading capabilities for research on:

Nuclear Structure

- The limits of existence for nuclei
- Nuclei that have neutron skins
- Synthesis of super heavy elements

Nuclear Astrophysics

- The origin of the heavy elements and explosive nucleo-synthesis
- Composition of neutron star crusts

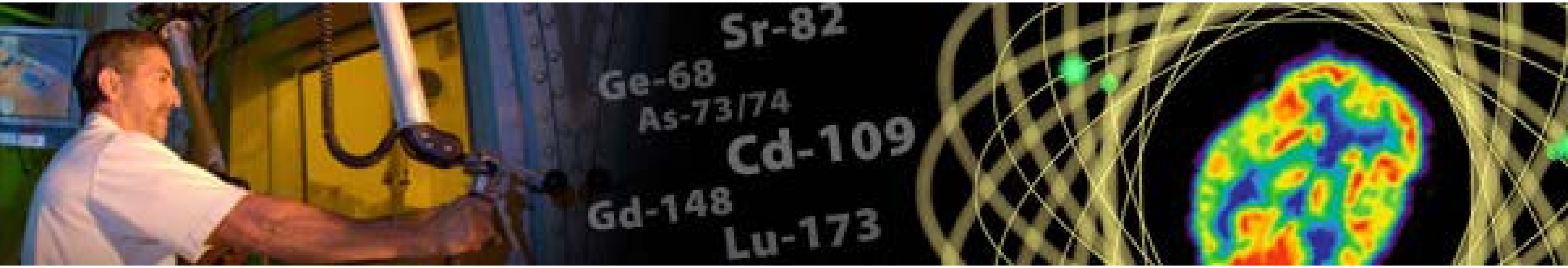
Fundamental Symmetries

- Tests of fundamental symmetries, Atomic EDMs, Weak Charge

This research will provide the basis for a model of nuclei and how they interact.

Concrete for the floor of the target area was placed December 1-2. It took around 30 hours and 300 concrete trucks to place the 2,700 cubic yards of concrete. FRIB received Critical Decision 3B, Approval to Start Technical Construction, on August 26, 2014.

The DOE Isotope Program Managed by NP



- Support continues for R&D competitive awards to universities and laboratories, as well as support to laboratory research groups at LANL, BNL, and ORNL.
- Development of production techniques for alpha-emitting radionuclides for medical therapy continues to be a priority, implemented through collaborative R&D at the national laboratories, particularly at BNL, LANL, and ORNL.
- Research at universities and national laboratories is supported for new isotope production technologies. Funding increases to enhance core research capabilities at the national laboratories and universities, and the program of competitive R&D, in order to address the high priorities especially with regard to the research to produce Ac-225, an isotope that shows great promise in the treatment of diffuse cancers and infections.
- Maintains the infrastructure required to produce and supply isotope products and related services.
- More than 225 customer orders and 470 shipments in FY 2013.

Increased Availability of Isotopes

Bk-249	Produced 22 mg target that led to the discovery of element 117; produced 26 mg for further super-heavy element research
Cf-249	Provided for actinide borate research
Cf-252	Re-established production in FY 2009, new six-year contract for FY 2013-2018; industrial applications
Cu-67	Production campaigns available starting Feb 13; cancer therapy
Li-6	Production of metal form for neutron detector isotope sales
Np-237	Established inventory for dispensing bulk quantities and capability to fabricate reactor dosimeters
Se-72/As-72	Developed production capability for Se-72 for use in a generator to provide the positron emitter As-72; medical diagnostic
Si-32	Produced in the 1990s for oceanographic and climate modeling research, inventory depleted, new production campaign has made the isotope available again
Th-227/Ra-223	Established Ac-227 cows for the provision of Th-227 and Ra-223 (alpha emitters for medical applications)
Y-86	Established production capability of the positron emitter Y-86; medical diagnostic
Cm-243	Acquired curium with a high Cm-243 content for research applications

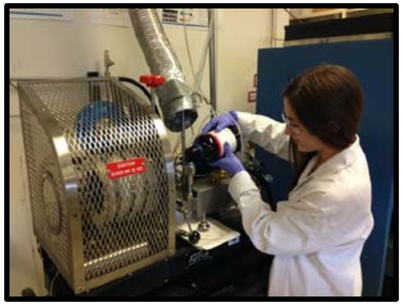
Isotopes under Development

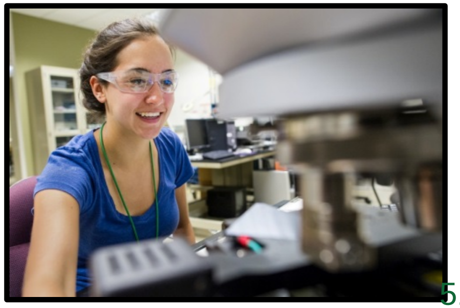
Ac-225:	Developing accelerator production capability
At-211:	Funding production development at four institutions to establish nationwide availability
Am-241:	Initiated project to produce Am-241 in association with an industrial consortium
C-14:	Investigating economic feasibility of reactor production
Cd-109:	Working with industry to assess product specific activity
Co-57:	Evaluating production of Co-57 for commercial source fabricators
Cs-137 HSA:	Pursuing reactor production feasibility for research applications
Cu-64:	Funding production development at multiple institutions
Gd-153:	Pursuing feasibility of reactor production
Ho-166:	Establishing reactor production capability
I-124:	Funding production development at one institution
K-40:	Evaluating possibility of reactor production by irradiating K rather than electromagnetically enriching K-40
Li-7:	Working to establish reserve for nuclear power industry to mitigate potential shortage
Np-236:	Pursuing feasibility of accelerator-based production for security reference materials
Pa-231:	Purifying 100 mg for applications such as fuel cycle research
Sr-89:	Investigating economic feasibility of reactor production
U-233:	Acquisition of mass separated U-233 for research applications
U-234:	Investigating alternatives for provision of U-234 for neutron flux monitors
Zn-62/Cu-62:	Funding production development for Zn-62 for use in a generator to provide the positron emitter Cu-62
Zr-89:	Funding production development at multiple institutions

Workforce Development for Teachers and Scientists

Ensuring a pipeline of STEM workers to support the DOE mission

- At DOE labs and facilities, WDTS will support ~1,000 students and faculty
  - 750 Science Undergraduate Laboratory Interns (SULI) placed at one of 17 DOE labs or facilities
  - 70 Community College Interns (CCI)
  - ~100 graduate students engaged in Ph.D. thesis research for 3-12 months at a DOE laboratory
  - 60 faculty and 25 students in the Visiting Faculty Program (VFP)
- Support for the National Science Bowl
  - More than 20,000 students, coaches, and volunteers participate in the regional and final competitions.
  - In FY 2015, there are 118 regional events, involving 14,000 students from all fifty states, the District of Columbia, Puerto Rico, and the U.S. Virgin Islands. WDTS brings the regional winners, the top 4% of the teams, to Washington, D.C. for the final competitions.
- Support for 6 Albert Einstein Distinguished Educator Fellows
- Support for on-line business systems modernization
  - This activity modernizes on-line systems that are used to manage applications and their review, data collection, and evaluation for all WDTS programs.
- Support for program evaluation and assessment
  - This activity will assess whether programs meet established goals using collection and analysis of data and other materials, such as pre- and post-participation questionnaires, participant deliverables, notable outcomes, and longitudinal participant tracking.





Visiting Faculty Participant (VFP) helps enable new STEM programs at Alabama A&M University

Professor Stephen Egarievwe, Alabama A&M University, at BNL with his VFP student, Ariel Dowdy

- Professor Egarievwe is a 3-time VFP participant at BNL, where he explored room temperature semiconductor nuclear detectors.
- Based on this experience, he established the Nuclear Engineering and Radiological Science Center at Alabama A&M; graduate students have since completed M.S. and Ph.D. research projects.
- He also developed research proposals, including a 5-year, $2 million grant from the Applied Research Initiative Program at the DHS's Domestic Nuclear Detection Office.
- In addition, the VFP program and collaboration with BNL helped the Electrical Engineering Technology and Mechanical Engineering Technology programs at Alabama A&M achieve full ABET accreditation. These efforts also led to the development and establishment of "Nuclear Systems" as a new concentration in Electrical Engineering and Mechanical Engineering programs at Alabama A&M.

Science Laboratories Infrastructure (SLI)

More than $600 million of line item investments on time, within budget since 2006

FY 2016 provides continued funding for:

- **Materials Design Laboratory (ANL)** to house research in materials science and related disciplines.
- **Photon Science Laboratory Building (SLAC)** to provide modern lab and office space for the expansion of SLAC's photon science programs, using SSRL and LCLS-II.
- **Integrative Genomics Building (LBNL)** to begin the consolidation of a significant fraction of the biosciences research currently now located in widely distributed commercially leased space.

Funding is also provided for:

- General purpose infrastructure: electrical upgrades at SLAC and ANL and facility improvements at FNAL.
- Continued funding of the New Brunswick Laboratory for infrastructure support and for transfer and shipment of material.
- Nuclear operations support at ORNL.

Safeguards and Security

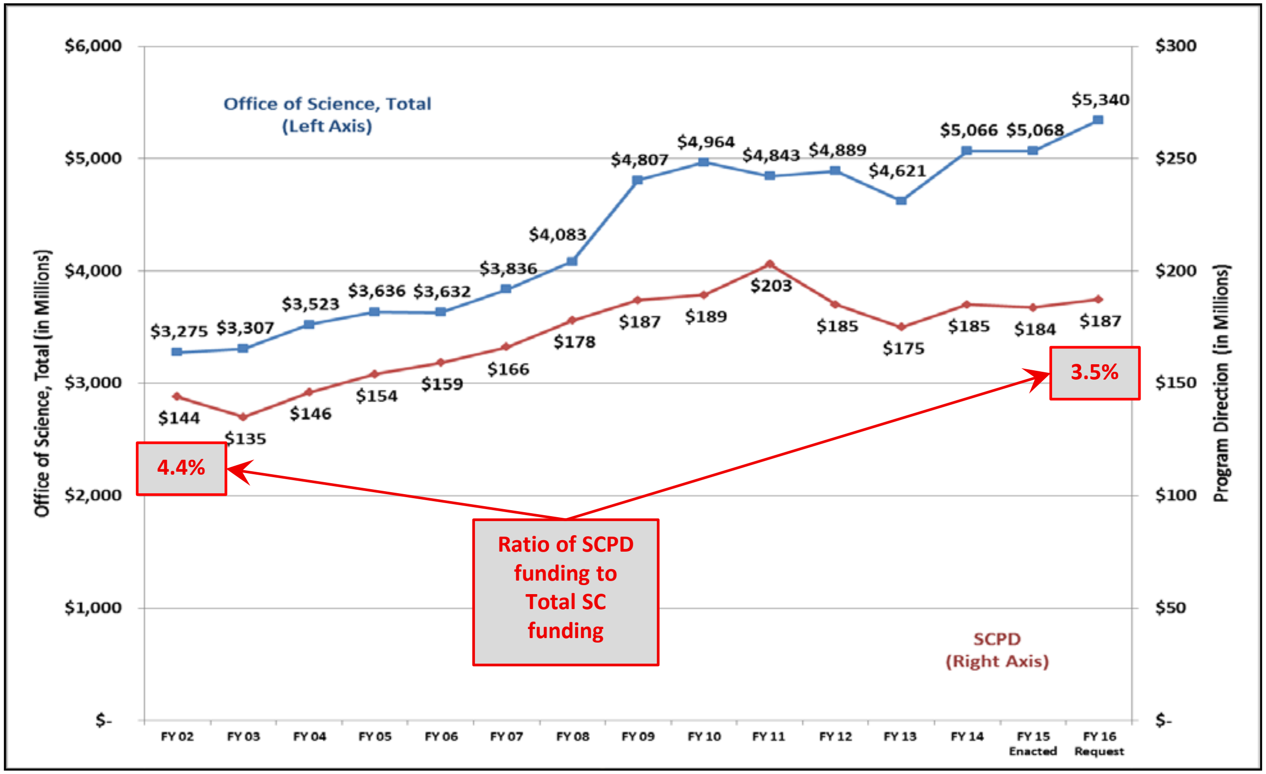
Supporting protection against unauthorized access, theft, or destruction of assets

The FY 2016 Request includes support for:

- Maintaining adequate security for the special nuclear material housed in Building 3019 at the Oak Ridge National Laboratory.
- Increasing cyber security investments to ensure the Cyber Security Program has the funds needed to defend against cyber security compromises, minimize future losses of protected information, and detect repeated attempts to access information technology assets critical to support the SC mission.
- The CyberOne strategy—DOE’s solution for managing enterprise-wide cyber-security for incident response and identity management to mitigate the risk of intrusion.

Program Direction

The FY 2016 PD budget supports 945 FTEs



During the past 15 years, the ratio of the Program Direction budget to the SC appropriation has decreased from 4.4% to about 3.5% -- now the lowest ratio in DOE. This decrease has been accomplished through detailed analyses and execution of optimum staffing levels in both the SC Site Offices and the SC Headquarters program offices.

Support for:

- Management of the Office of Science programs, facilities, and projects;
- Business operations associated with portfolio management;
- Office of Science Information Technology Modernization Plan (ITMP) – the consolidation of data centers, IT support service contracts, and more efficient technologies;
- Federal travel for scientific program and laboratory operations oversight; and
- President's Council of Advisors on Science and Technology (PCAST).