U.S. DEPARTMENT OF ENERGY | Office of Science

Perspectives from the DOE Office of Nuclear Physics

Nuclear Science Advisory Committee Meeting
September 21, 2012

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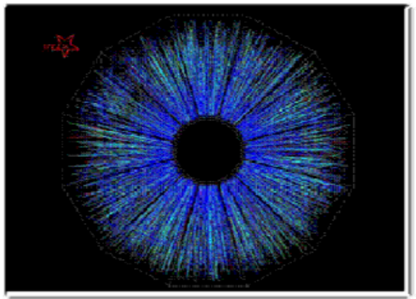
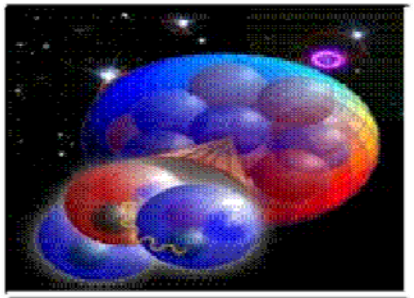
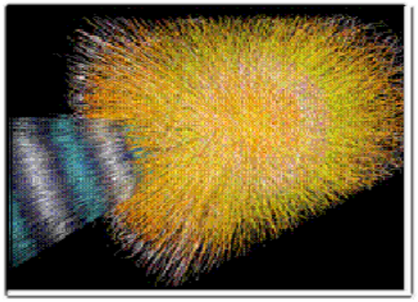
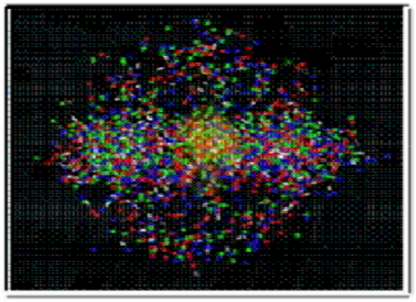





Nuclear Physics

Discovering, exploring, and understanding all forms of nuclear matter

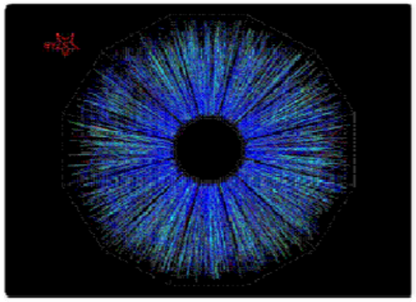
The Scientific Challenges:

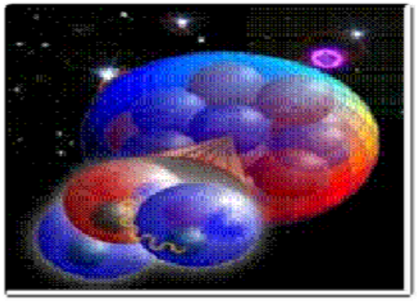
Understand:

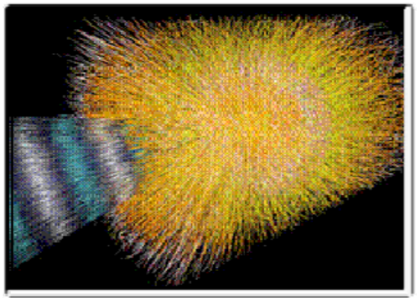
- The existence and properties of nuclear matter under extreme conditions, including that which existed at the beginning of the universe
- The exotic and excited bound states of quarks and gluons, including new tests of the Standard Model
- The ultimate limits of existence of bound systems of protons and neutrons
- Nuclear processes that power stars and supernovae, and synthesize the elements
- The nature and fundamental properties of neutrinos and neutrons and their role in the matter-antimatter asymmetry of the universe

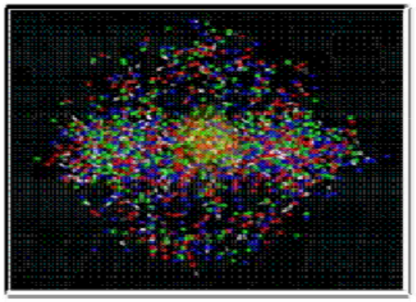
FY 2013 Highlights:

- Operations and research at three national nuclear science user facilities (RHIC, CEBAF, ATLAS).
- 12 GeV CEBAF Upgrade to study systems of quarks and gluons and the force that creates protons and neutrons.
- Continued preparation for construction of the Facility for Rare Isotope Beams to study the limits of nuclear existence.
- Research, development, and production of stable and radioactive isotopes for science, medicine, industry, and national security.
- New strategic planning activity begins in FY 2012.









Nuclear Physics – FY 2013 Congressional Request

Budget Structure/Subprogram	FY 2011 Approp	FY 2012 Approp	FY 2013 Request	FY 2013 to FY2012 Change $k	%
Medium Energy Nuclear Physics	134,563	132,577	135,260	+2,683	+2.0%
Heavy Ion Nuclear Physics	201,594	200,594	197,201	-3,393	-1.7%
Low Energy Nuclear Physics	105,424	105,727	98,018	-7,709	-7.3%
Nuclear Theory	42,935	39,407	37,179	-2,228	-5.7%
Isotope Program	19,670	19,082	18,708	-374	-2.0%
Construction	35,928	50,000	40,572	-9,428	-18.9%
Total *	**540,114**	**547,387**	**526,938**	**-20,449**	**-3.7%**

- FY 2011 includes SBIR/STTR for comparability

DOE—NSF Charge to NSAC

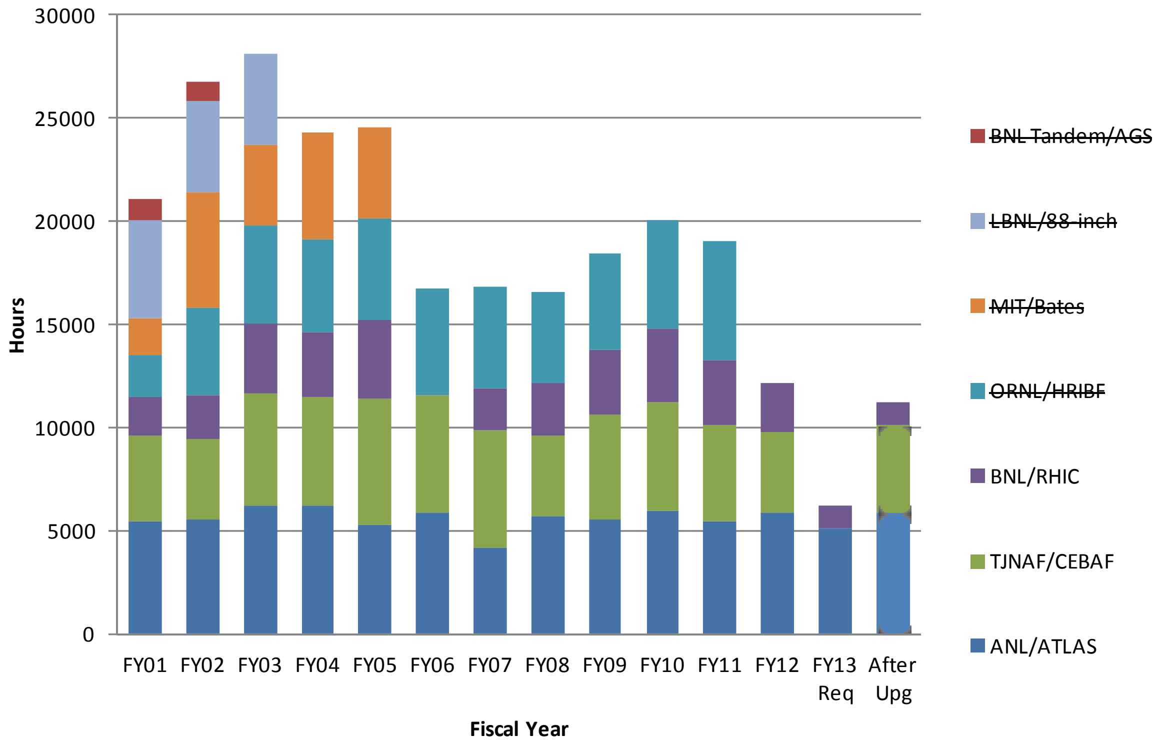
Seeking guidance in light of constrained funding

DOE and NSF are making significant progress toward achieving the vision of the 2007 Long Range Plan for Nuclear Science. However, DOE and NSF now seek your advice to continue the vision in the Plan so that the recommendations can move forward in light of projected constrained budgets.

We seek advice from NSAC on implementing the priorities and recommendations of the 2007 Long Range Plan in light of projected budgetary constraints and for guidance on developing a plan to implement the highest priority science in the context of likely available funding and world-wide capabilities. We request that NSAC examine the existing research capabilities and scientific efforts, assess their role and potential for scientific advancements, and advise the two agencies regarding the time and resources needed to achieve the planned programs. Your report should describe how to optimize …

Based on the priorities and opportunities identified and recommended in the 2007 Long Range Plan, the report should discuss what scientific opportunities will be addressed, and what existing and future facilities and instrumentation capabilities would be needed by the Federal nuclear science program to mount a productive, forefront program for each of the funding scenarios.

Status of Running Hours at NP User Facilities



	FY2012	FY 2013 PB	Optimum	FY13 %
RHIC	2,390	1,360	4,100	33%
CEBAF	3,940	0	0	0%
ATLAS	5,900	4,000	5,000	80%
Total	12,230	5,360	9,100	38%

NP Facilities operate at well below optimum utilization in FY2013

- RHIC Operations – In FY2013 request RHIC is supported for 1,360 hours (9-11 weeks) which will likely be combined with FY 2014 running
- CEBAF Operations – Planned shutdown during FY 2013 for installation of 12 GeV Upgrade (lengthened)
- ATLAS Operations – Maximum number of hours ATLAS can operate in FY 2013 is 5,000 due to intensity upgrade
- HRIBF Operations – Operations as a national user facility ceased April 15, 2012

Review of NP Facilities in the FY 2013 House and Senate Marks

	FY 2012 Approp	FY 2013 Request	FY 2013 House Mark	+/- Request	FY 2013 Senate Mark	+/- Request
12 GeV CEBAF Upgrade (TEC)	50,000	40,572	40,572		40,572	
Facility for Rare Isotope Beams	22,000	22,000	40,000	+18,000	30,000	+8,000
Heavy Ion Operations						
RHIC Operations	157,617	156,571	159,571	+3,000	161,600	+5,029
Other Operations (BNL GPE)	3,000	2,000	2,000		2,000	
Total Heavy Ion Operations	160,617	158,571	161,571	+3,000	163,600	+5,029
All Other NP	314,770	305,795	305,795		305,766	-29
TOTAL NP *	**547,387**	**526,938**	**547,938**	**+21,000**	**539,938**	**+13,000**

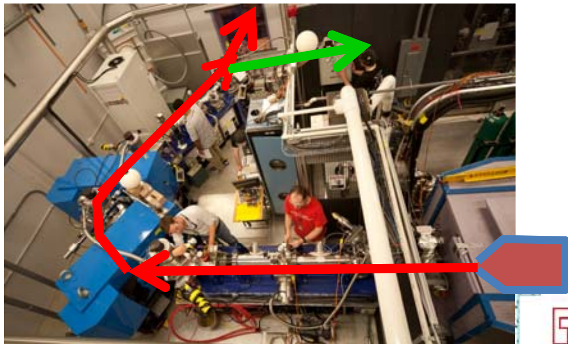
* Includes SBIR/STTR in all years for comparability

- The **House Mark** provides an increase of **$21M above the FY 2013 Request** : $18M for FRIB to "continue activities leading towards the approval of construction;" and, $3M for RHIC to "support a standalone run of approximately 15 weeks in FY 2013."
- The **Senate Mark** provides an increase of **$13M above the FY 2013 Request** : $8M for FRIB to "complete design and engineering work and, if the Office of Science approves a performance baseline, site preparation activities;" and, an increase of $5M for RHIC to "maintain 20 weeks of operations."
- Both reports included language supporting NSAC's charge to review the scientific priorities of the Nuclear Physics program within constrained budgets.

Management Priorities Going Forward

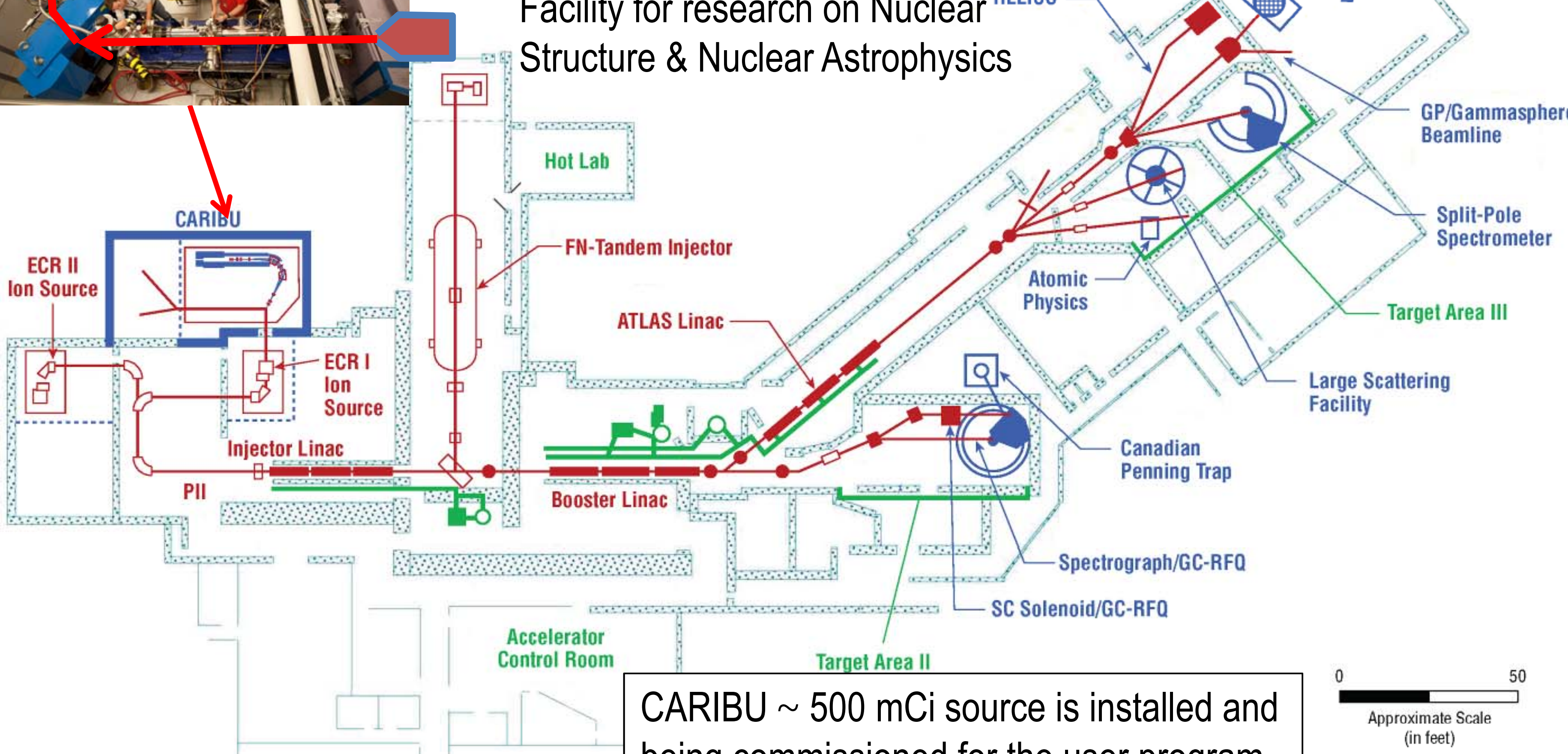
- Establishing short-term and long-term programmatic priorities in the face of significant fiscal uncertainty
- Maintaining scientific productivity with reduced facility operations
- Managing construction funding profiles and adressing the impacts of the directed change in the 12 GeV CEBAF funding profile in FY2012
- Optimizing core national laboratory and university research within constrained budgets
- D&D of HRIBF and transition of essential staff
- Nurturing the nuclear structure and astrophysics community prior to FRIB
- Meeting the stable and radioisotope needs of the Nation, and mitigating impacts, to the extent possible, of possible reduced production capability

ATLAS Uniquely Provides Low Energy Research Opportunities Within SC Until FRIB



ATLAS

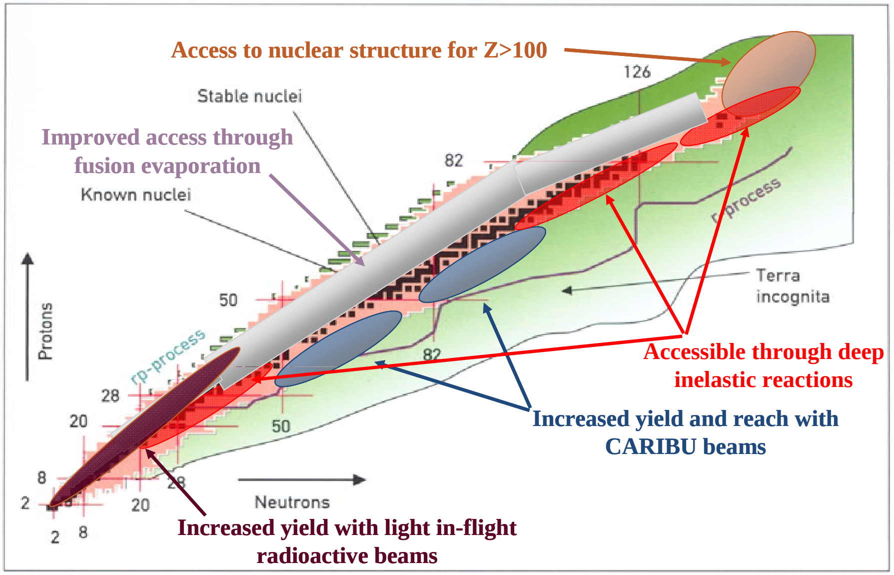
In the out years, ATLAS continues as a unique premier Stable Beam Facility for research on Nuclear Structure & Nuclear Astrophysics



CARIBU ~ 500 mCi source is installed and being commissioned for the user program

ATLAS Role and Goals

- It provide beams and facilities enabling world leading research at around Coulomb barrier energy, answering key questions in the fields of:
  - nuclear structure
  - low-energy tests of the Standard Model
  - nuclear astrophysics
  - applications of low-energy nuclear phy
- This is done through:
  - providing beamtime for research programs
    - Any stable beam from proton to uranium
    - some in-flight radioactive beams
    - Low-energy and reaccelerated CARIBU beams
  - developing new capabilities to address evolving needs of the field
    - new experimental equipment
    - new accelerator capabilities (accelerator R&D group)



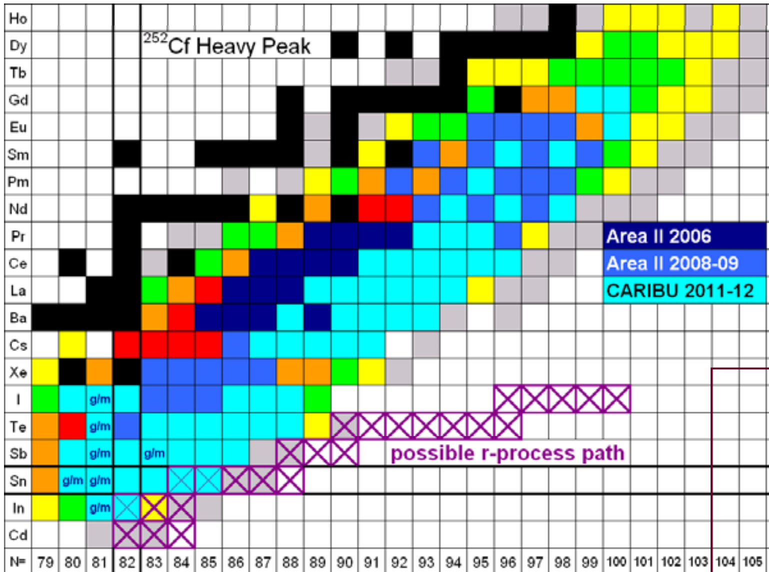
- ATLAS is developing capabilities and expertise that will be important for the physics program (focused mainly on reaccelerated beams) at FRIB and positioning ATLAS for its expected role as the high-intensity stable beam facility in the FRIB era.

Main ATLAS Research Thrusts

Nuclear astrophysics

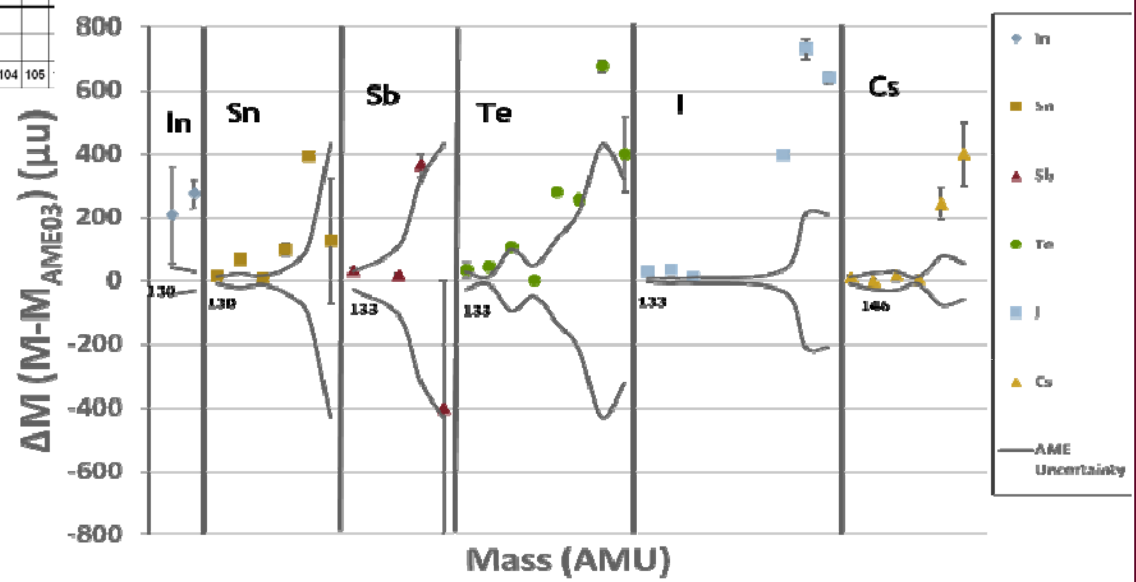
- High level goal is the understanding of the production of the elements in the cosmos through studies of the nuclear physics input to
  - rp-, αp- and np- process nucleosynthesis (reaction rates, masses, important spectroscopic information)
  - r-process path (masses, lifetimes, beta-delayed neutrons, surrogate reactions)
  - sub-barrier fusion hindrance
  - Break out from CNO cycle
  - Important quiescent reactions
- Main tools used
  - in-flight radioactive ion beam (RIB) separator, Enge, HELIOS, CPT Penning trap mass spectrometer
- Program pushes forward in new regions and with new capabilities offered by
  - New beams: CARIBU, deep-inelastic reactions, new in-flight RIB separator (AIRIS)
  - Higher efficiency: HELIOS with full detector array and gas target, bubble chamber detector

First Physics With CARIBU

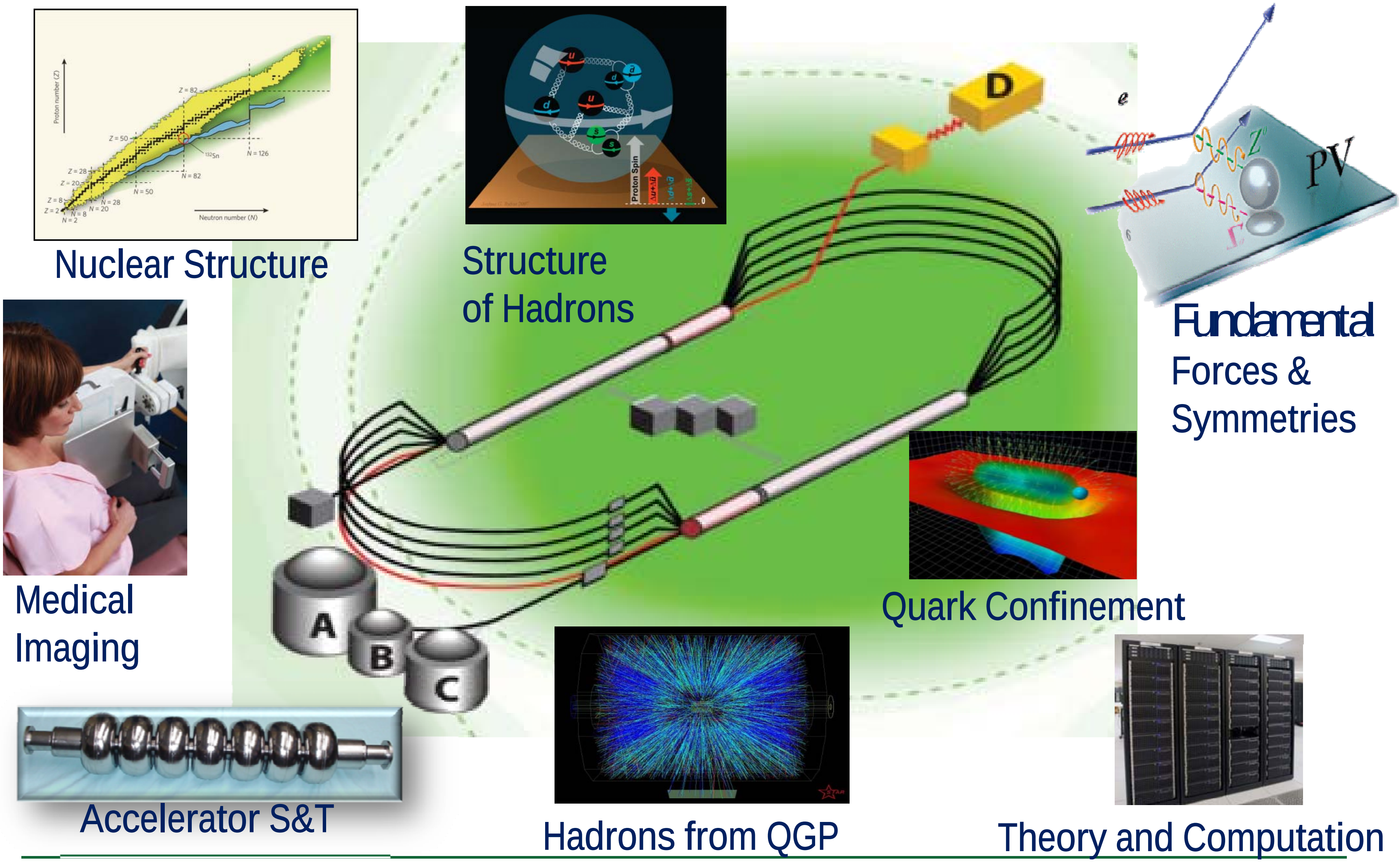


Neutron-rich isotopes are found to be systematically less bound than predicted

Mass measurements with the CPT at CARIBU

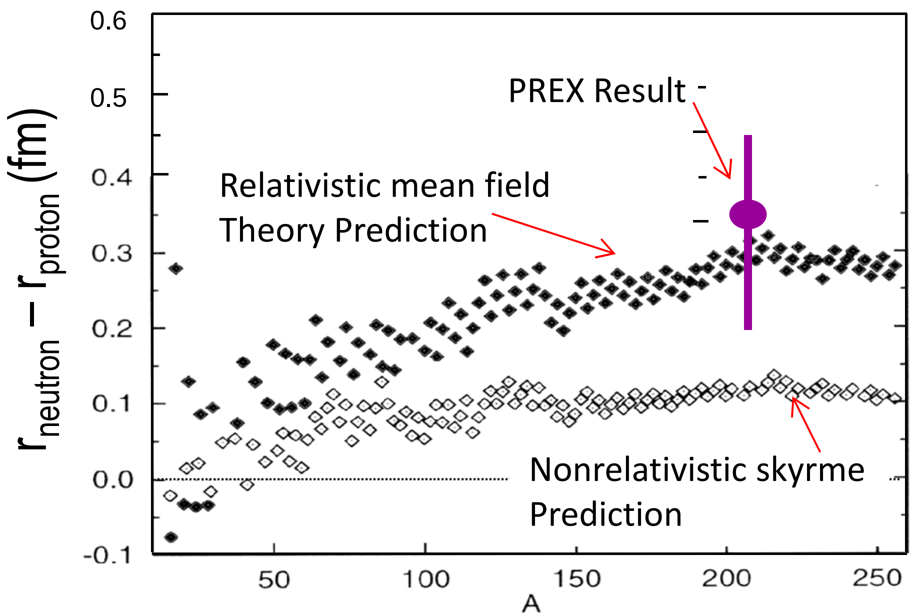


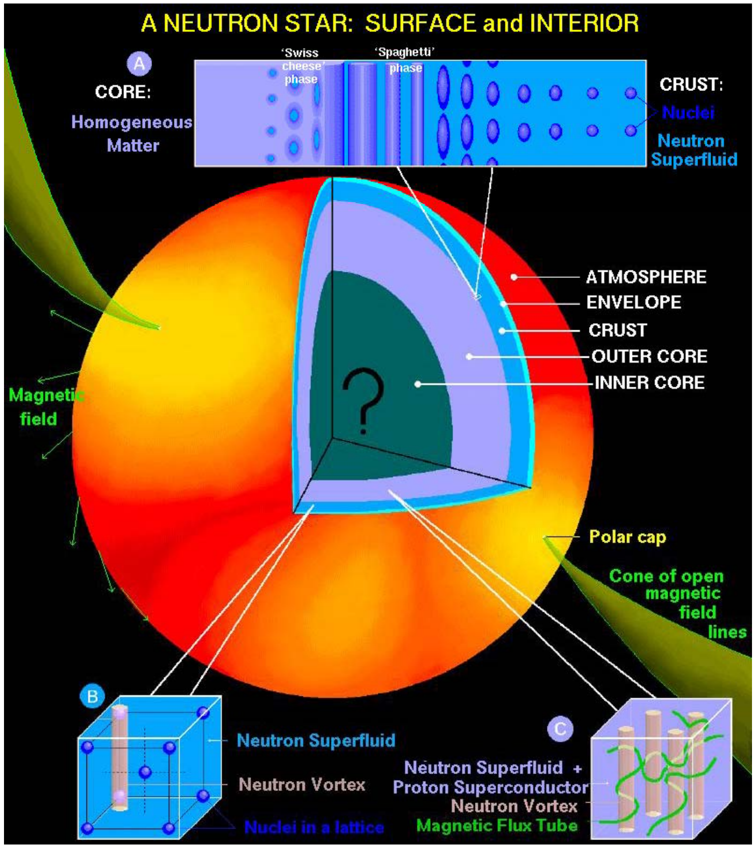
JLAB: A Multi-Thrust Laboratory for Nuclear Science



The PREX Experiment at TJNAF: “Skin-Deep Matters”

By studying a parity-violating asymmetry in elastic scattering of electrons off Lead (^{208}Pb) nuclei, the PREX experiment found that the neutron radius of the nucleus is larger than proton radius by +0.35 fm (+0.15, -0.17).

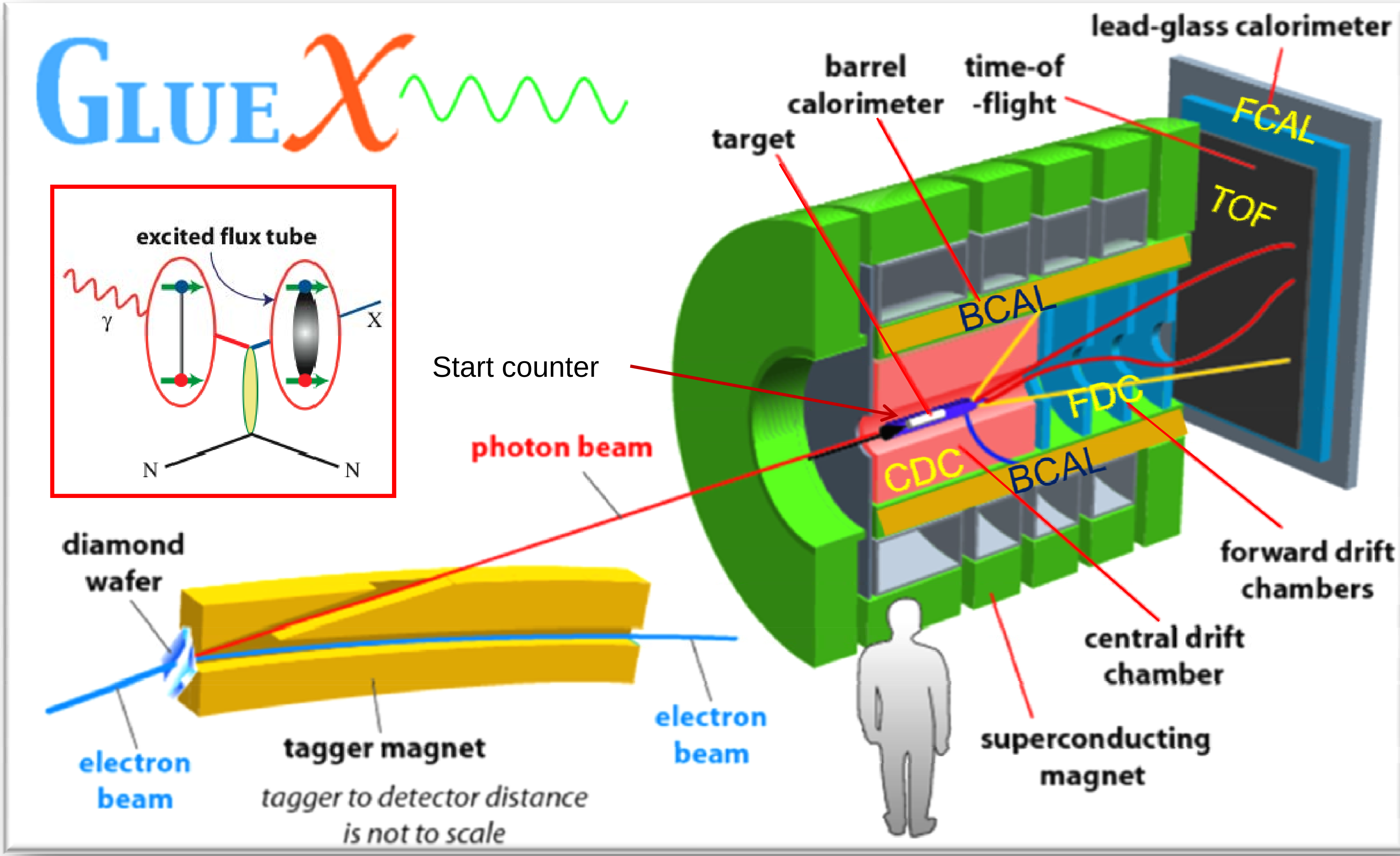




This result provides model-independent confirmation of the **existence of a neutron skin** relevant for neutron star calculations. Follow-up planned to reduce uncertainty by factor of 3 and pin down symmetry energy in EOS

A neutron skin of 0.2 fm or more has implications for our understanding of neutron stars and their ultimate fate

The Newly Constructed Hall D Promises a New NP Science Watershed



JLab: 21st Century Science Questions

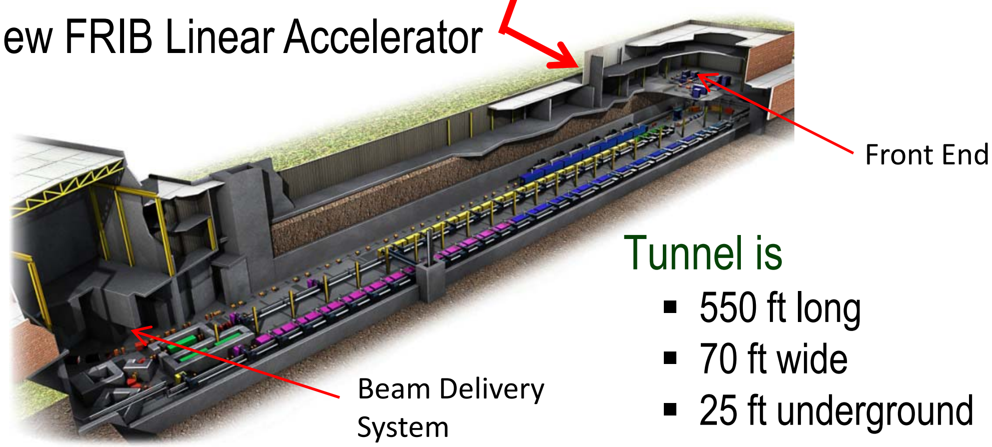
- What is the role of gluonic excitations in the spectroscopy of light mesons? Can these excitations elucidate the origin of quark confinement?
- Where is the missing spin in the nucleon? Is there a significant contribution from valence quark orbital angular momentum?
- Can we reveal a novel landscape of nucleon substructure through measurements of new multidimensional distribution functions?
- What is the relation between short-range N-N correlations and the partonic structure of nuclei?
- Can we discover evidence for physics beyond the standard model of particle physics?

The Office of Science is in the final phase of a major upgrade of the CEBAF Accelerator at TJNAF to provide forefront capability to address this science.

The Future of the Low Energy Subfield in the U.S. Depends on Construction of the Facility for Rare Isotope Beams

Existing National Superconducting Cyclotron Laboratory

New FRIB Linear Accelerator



Tunnel is

- 550 ft long
- 70 ft wide
- 25 ft underground

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 ultimate limits of existence for nuclei
- Nuclei which have neutron skins
- The synthesis of super heavy elements

Nuclear Astrophysics

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

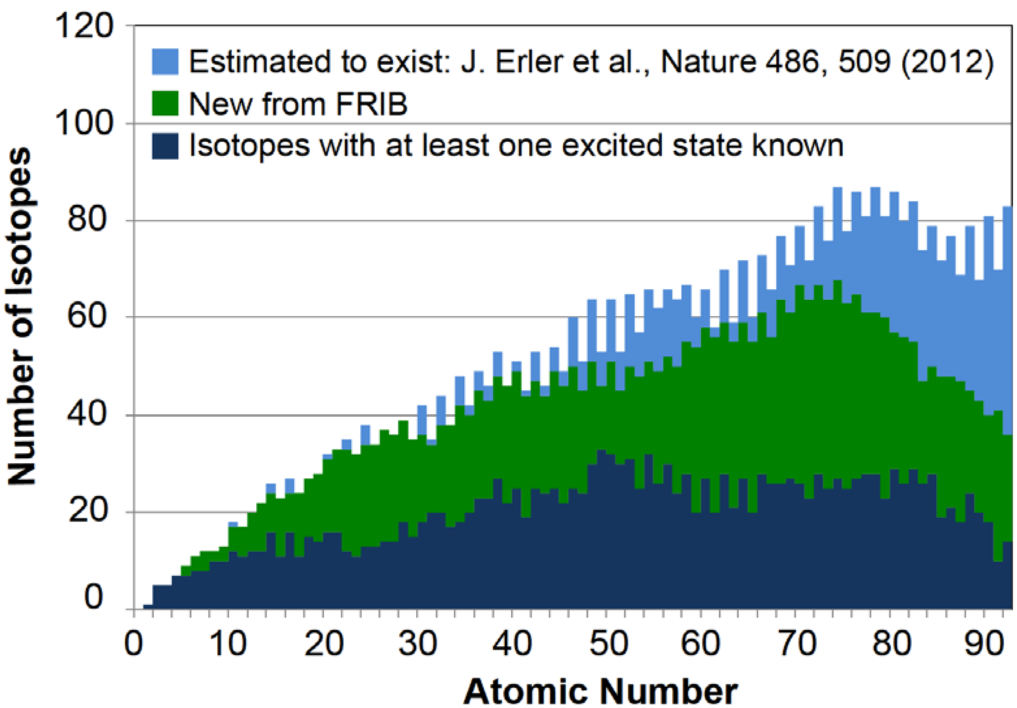
Fundamental Symmetries

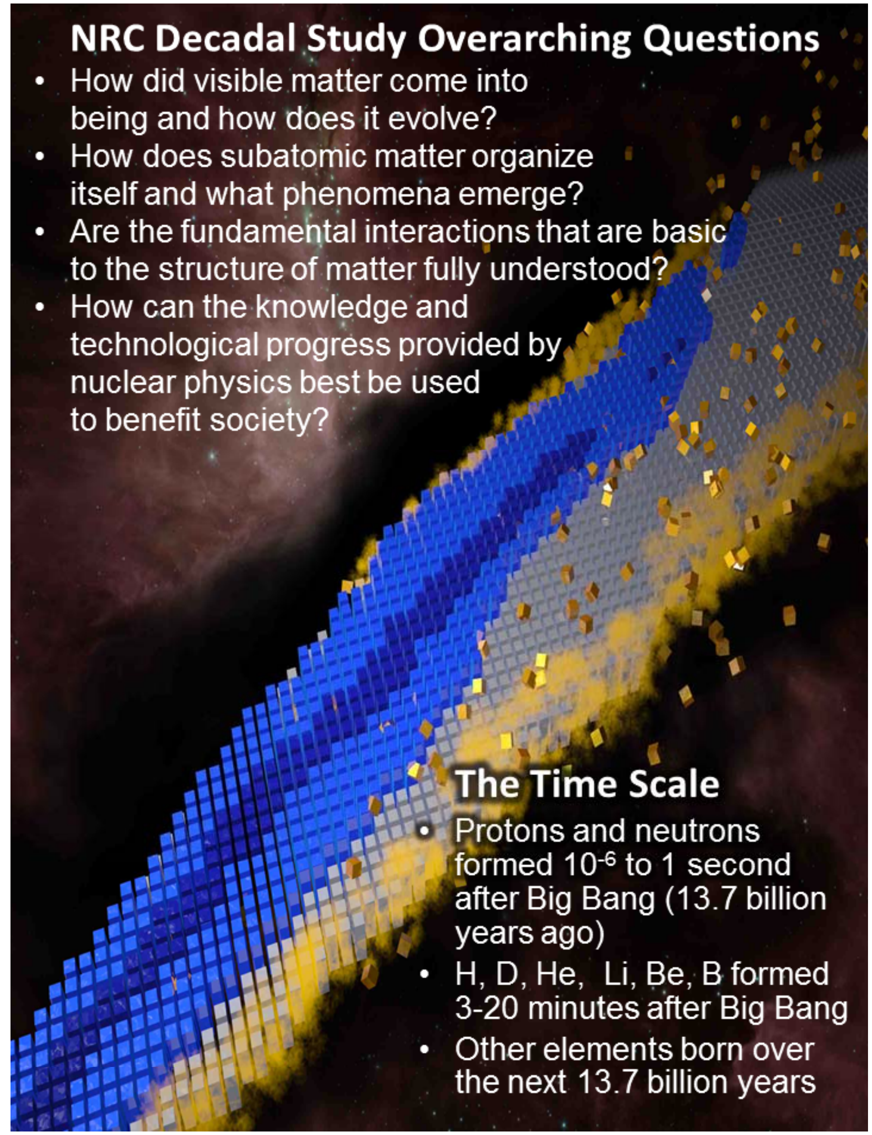
- Tests of fundamental symmetries, Atomic EDMs, Weak Charge

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

FRIB: 21st Century Science Questions

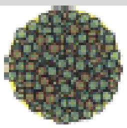
- FRIB physics is at the core of nuclear science: "To understand, predict, and use"
- FRIB provides access to a vast unexplored terrain in the chart of nuclides





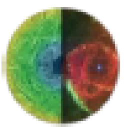
FRIB Science Is Important for the Nation

Articulated by National Research Council RISAC Report (2006), NSAC LRP (2007), NRC Decadal Survey of Nuclear Physics (2012)



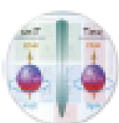
Properties of nuclei

- Develop a predictive model of nuclei and their interactions
- Many-body quantum problem: intellectual overlap to mesoscopic science, quantum dots, atomic clusters, etc.



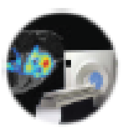
Astrophysical processes

- Origin of the elements in the cosmos
- Explosive environments: novae, supernovae, X-ray bursts …
- Properties of neutron stars



Tests of fundamental symmetries

- Effects of symmetry violations are amplified in certain nuclei



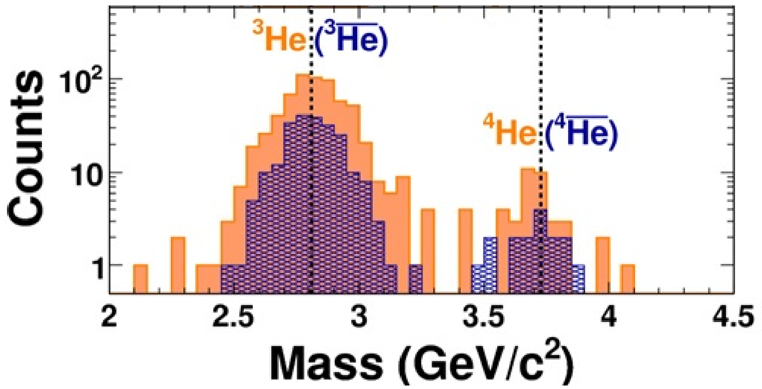
Societal applications and benefits

- Bio-medicine, energy, material sciences
- National security

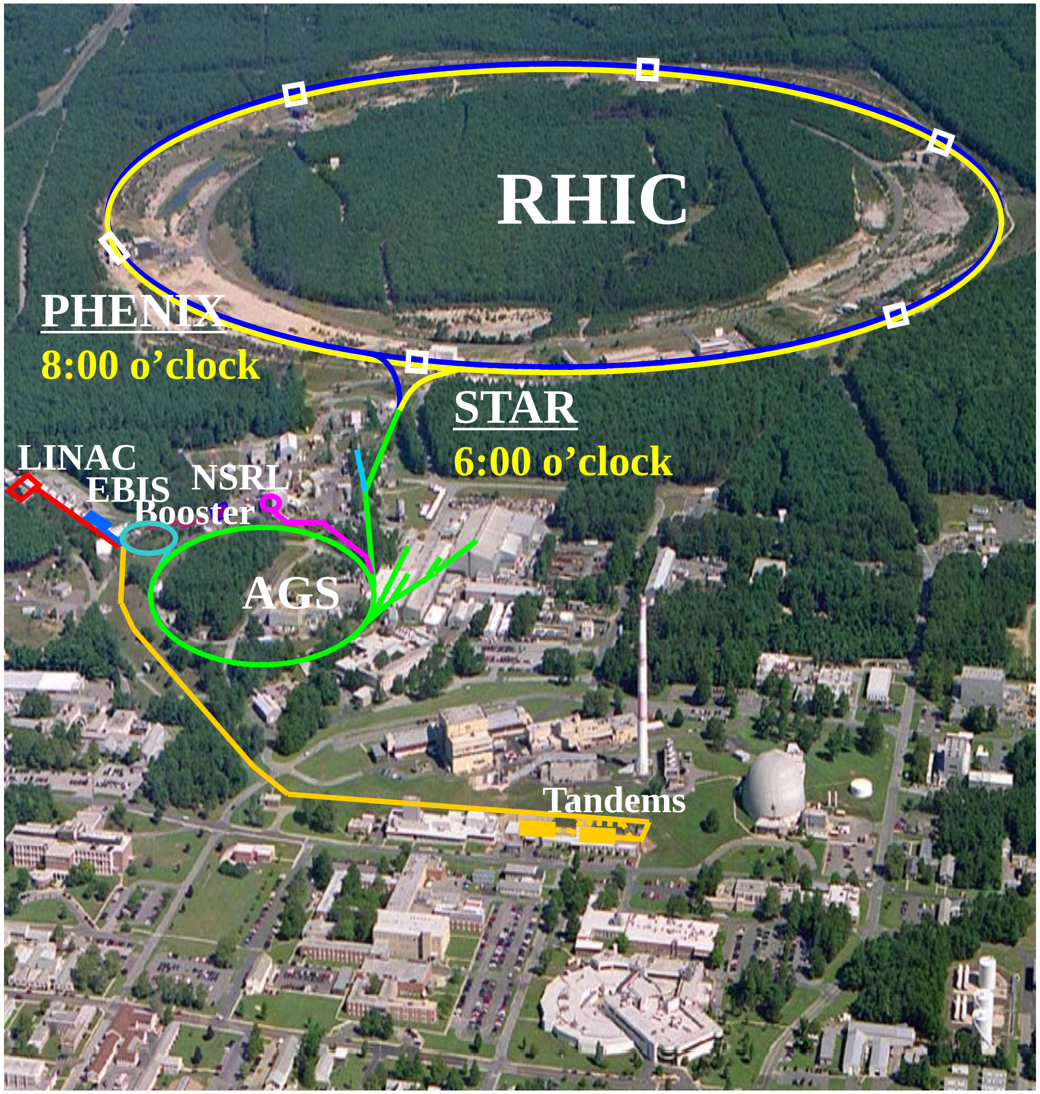
> *"Data to date on exotic nuclei are already beginning to revolutionize our understanding of the structure of atomic nuclei. FRIB will enable experiments in uncharted territory at the limits of nuclear stability. FRIB will provide new isotopes for research related to societal applications, address long-standing questions about the astrophysical origin of the elements and the fundamental symmetries of nature."*
>
> 2012 NRC Decadal Study

Research Focus of the Relativistic Heavy Ion Collider

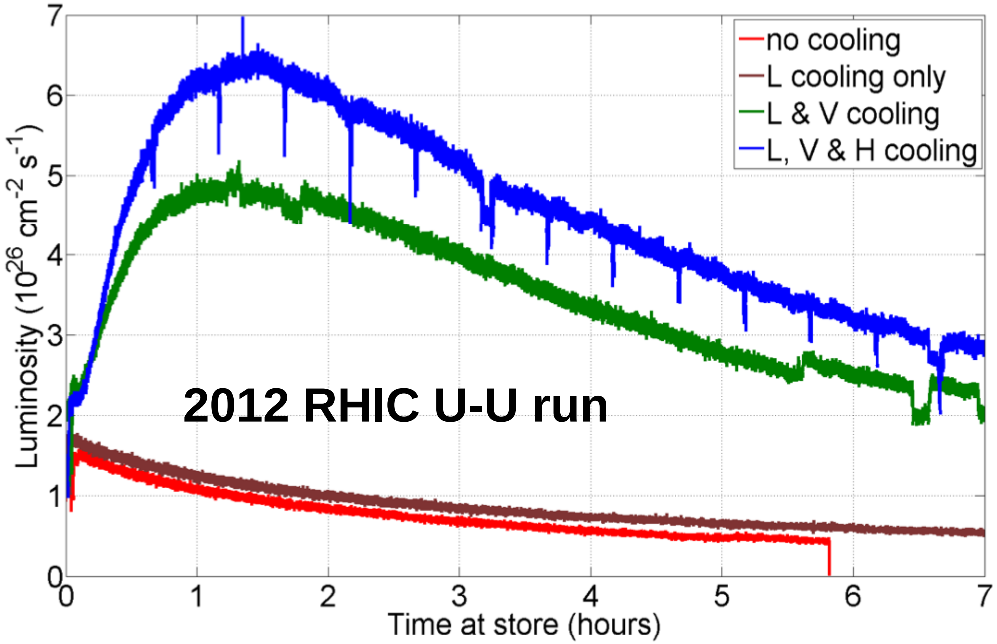
- To elucidate the fundamenal properties of the Perfect Liquid discovered in Au+Au collisions
- To determine the contribution to the proton spin from gluons, sea quarks/anti-quarks; to study transversity and advance understanding of contributions from orbital motion within the proton
- To address other scientific “targets of discovery opportunity” afforded by RHIC’s capabilities



RHIC also stewards strong core competencies in accelerator physics



The Advantage of Keeping Cool



- A technical tour de force for the 2012 RHIC run saw completion of a stochastic cooling upgrade and 1st use of an electron beam ion source (EBIS)
- EBIS provided new capability for U+U collisions, while stochastic cooling resulted in the dramatic luminosity increase shown above from no cooling (red curve) to longitudinal, horizontal, and vertical cooling

New insight from this new capability:

Ultra-central U+U collisions made possible by this advance suggest there is little flow-related background to the chiral magnetic event EDM (charge separation) signal observed in high energy Au+Au collisions.

This lends further support for an interpretation of the event EDM effect in terms of hot matter manifestations of excited QCD vacuum fluctuations ("sphalerons"), analogous to electroweak sphalerons speculated as the site of baryon asymmetry in the infant universe.

Summary Outlook Going Forward:

RHIC has discovered a completely new state of matter (a perfect quark-gluon liquid) which is just as momentous and exciting as the discovery of high temperature superconductivity in condensed matter physics.

There is a rich program of science ongoing and goingn forward to:

- determine, with precision, the detailed properties of this new matter
- further explore and develop intellectual connections and broader impacts in other subfields of new insights &knowledge gained
- search for new discoveries such as the postulated Critical Point in the phase diagram of QCD
- further unfold the spin structure of the nucleon

RHIC: 21st Century Science Questions Yet to be Answered

Are there new states of matter at extremely high temperature and density?

Can the phase structure of a fundamental gauge theory be explored via nuclear collisions?

Can the study of strongly-coupled QCD matter inform the understanding of other gauge theories (including gravity)?

Is there a critical point in the QCD phase diagram?

Are exotic (locally CP-violating) states of matter formed in nuclear collisions?

At what (energy, mass, length) scale does the perfect liquid become resolvable into the underlying quarks and gluons?

What is the value of η/s and does it respect the conjectured quantum bound?

What is the numerical value (and energy dependence) of the coupling constant in the quark-gluon plasma at RHIC and LHC energies?

What is the value of the jet energy loss parameter, and is it consistent with purely perturbative calculations?

What are the magnitudes of cold nuclear matter (CNM) effects as a function of probe, root-s, and momentum, and how do these impact precision measurements in hot nuclear matter?

Vision for Fundamental Symmetries, Neutrons, and Neutrinos

Based on Science:

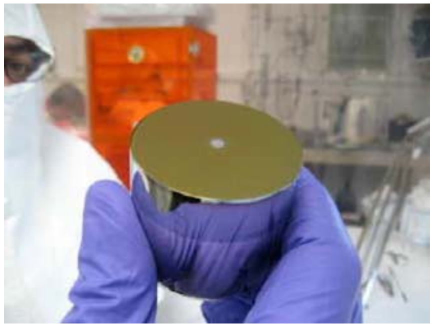
- There are selected NP science targets of opportunity with the potential for high-impact in fundamental symmetries, neutrons, and neutrinos.
- These experiments may take on even greater significance depending on the results of accelerator research in the next few years
- To the extent there are resources to pursue them and they are complementary to HEP research, such opportunities may be pursued.
- For nEDM the science goal continues to be stronly motivated and R&D continues; a decision point is expected within ~ 2 years whether to proceed with the full experiment
- $0\nu\beta\beta$ experiments are sufficiently costly, a down-select to the best technology across HEP and NP makes sense and is planned.

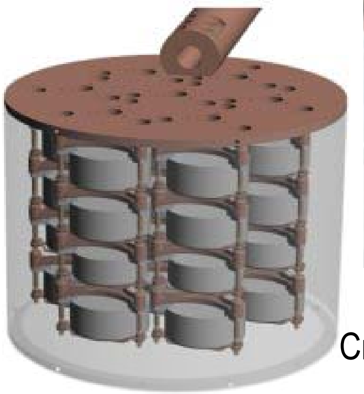
Neutrino-less Double Beta Decay

Grand challenge question: Is the neutrino its own anti-particle?

- An R&D effort on the Majorana Demonstrator (MJD) will help establish the feasibility of a tonne-scale ^{76}Ge neutrino-less double beta-decay experiment.
- The MJD technology demonstration is planned prior to a down-select between competing technologies
- MJD is on track with electroforming and with procurement and processing of enriched Ge.
- MJD went underground at the Sanford Laboratory (South Dakota) in summer 2012.
- The technology and the location of a future, international tonne-scale experiment is TBD based on the best value and the best science capability.

Germanium detector and the cryostat for the Majorana Demonstrator (MJD 40-kg ultra-clean Ge detector).

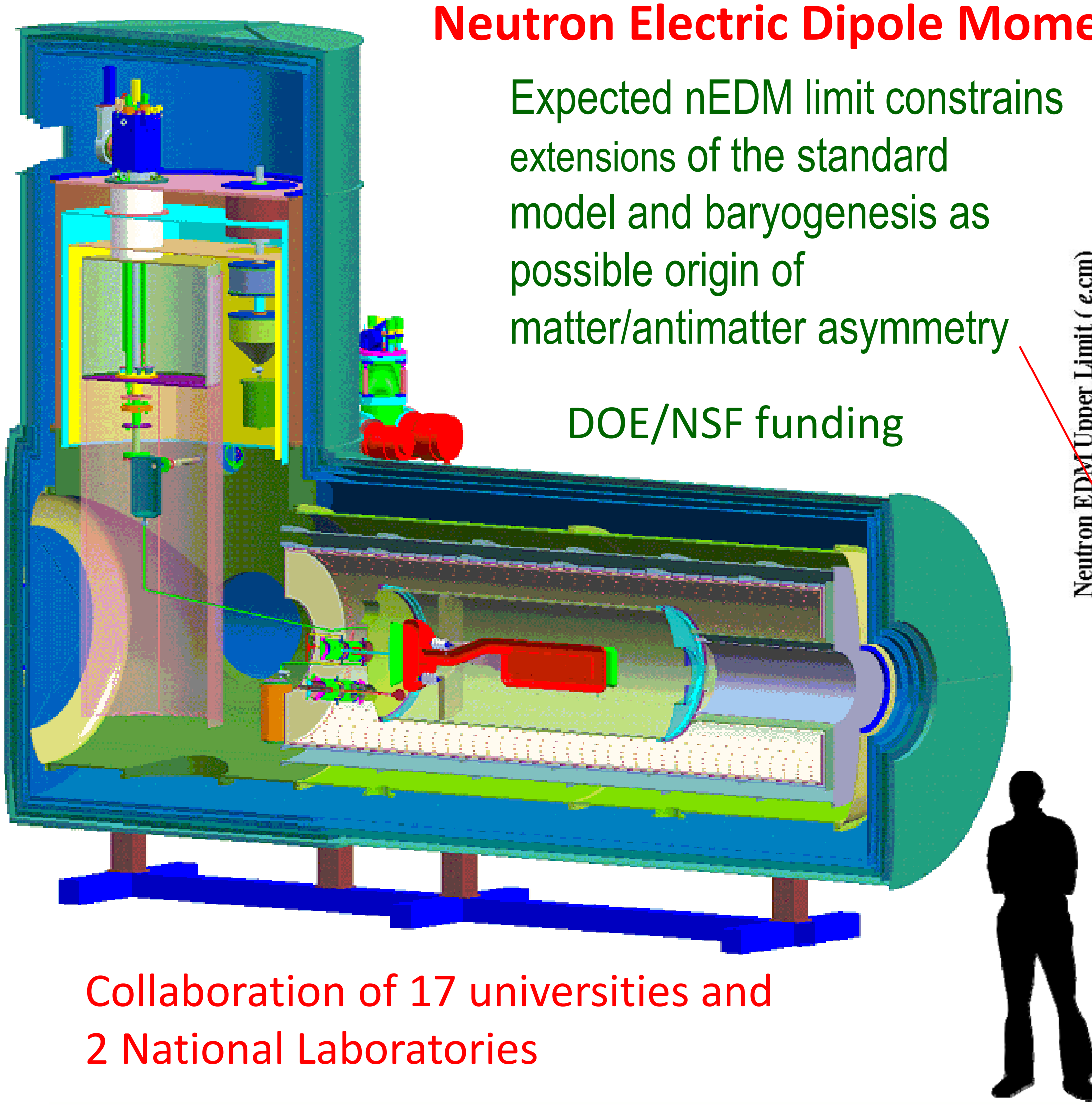




Cryostat for MJD

MJD Underground Electroforming lab at Sanford

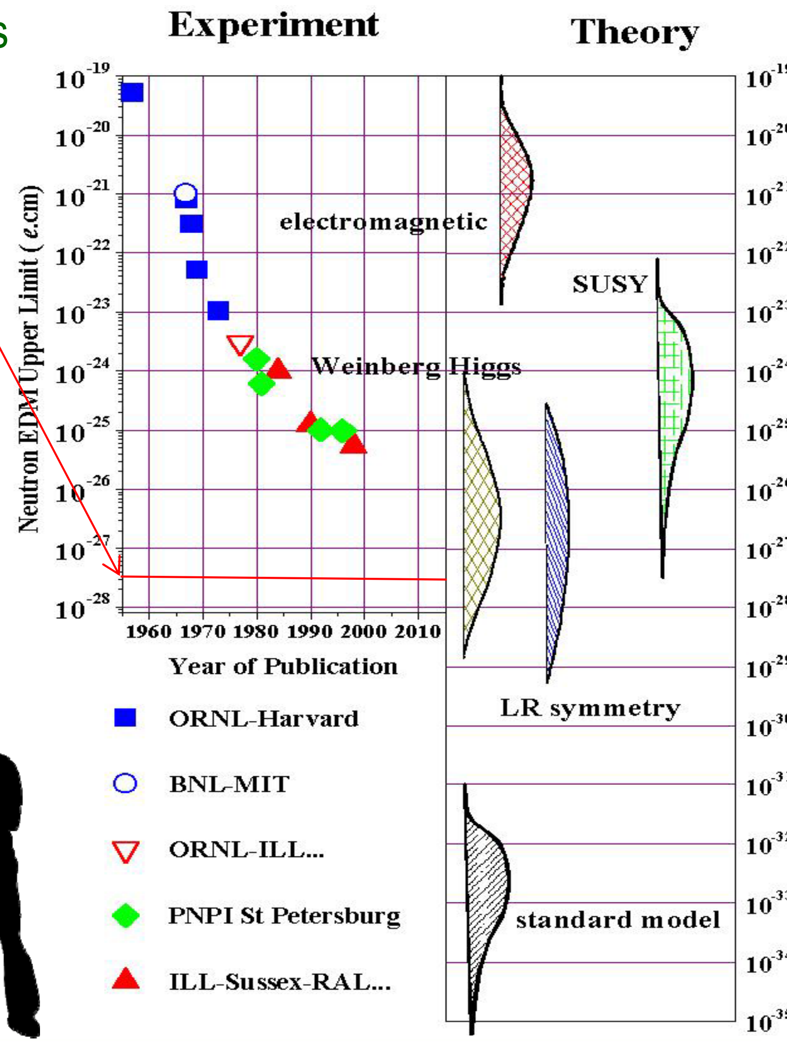
Fundamental Symmetries Using Neutrons



Neutron Electric Dipole Moment (nEDM)

Expected nEDM limit constrains extensions of the standard model and baryogenesis as possible origin of matter/antimatter asymmetry

DOE/NSF funding



Collaboration of 17 universities and 2 National Laboratories

Nuclear Theory

Research in nuclear theory spans the entire NP program

The essential role of a strong nulcear theory effort goes without saying:

- Poses scientific questions that lead to the construction of facilities
- Helps make the case for, and guide the design of new facilities, their research programs and their strategic operations plan
- Provides a framework for understanding measurements made at facilities
- Topical Collaborations (fixed-term, multi-institution collaborations established to investigate a specific topic) appear to have been very successful and, resources permitting, the model will likely be continued

Maintaining adequate support for a robust nuclear theory effort is essential to the productivity and vitality of nuclear science

NP will continue to provide Isotopes and Radioisotopes in Short Supply

Some key isotopes and radioisotopes and the companies that use them

Strontium-82, Rubidium-82	Imaging / Diagnostic cardiology
Germanium-68, Gallium-68	Calibration / PET scan imaging
Californium-252	Oil and gas exploration and manufacturingcontrols
Selenium-75	Radiography / Quality control
Actinium-225, Yttrium-90, Rhenium 188	Cancer / Infectious disease treatment
Nickel-63	Explosives detection at airports
Gadolinium-160, Neodymium-160	Tracers and contrast agents for biological agents
Iron-57, Barium-135	Standard sources for mass spectroscopy
Sulfur-34	Environmental monitoring
Rubidium-87	Atomic frequency / GPS applications
Lithium-6, Helium-3	Detection of Special Nuclear Materials
Samarium-154	Solar energy /transportation applications

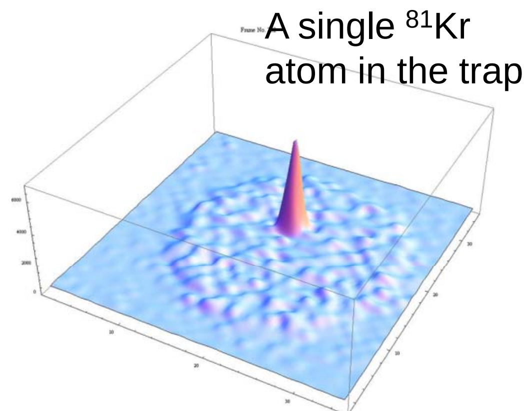
NRD
ISOFLEX
GE Healthcare
Bracco Diagnostics Inc.
QSA GLOBAL
GE Energy
Schlumberger
Westinghouse
Inorganic Ventures
Isotope Products Laboratories
General Atomics and Affiliated Companies
Frontier Technology Corporation
Memorial Sloan-Kettering Cancer Center
Actinium Pharmaceuticals
PerkinElmer
NEC Corporation of America
Pain Therapeutics, Inc.
Spectrum Technique
Boston Medical Center
The Linde Group
Alpha V
ICON
Excelitas Technologies
Thermo Fisher Scientific
CIL
Sanders Medical
Medical Isotopes, Inc.
Aldrich Chemistry

ATTA-3 at ANL to be Used to Map Major Aquifers around the World

Developed ATTA-3 instrument with greatly improved sensitivity and selectivity

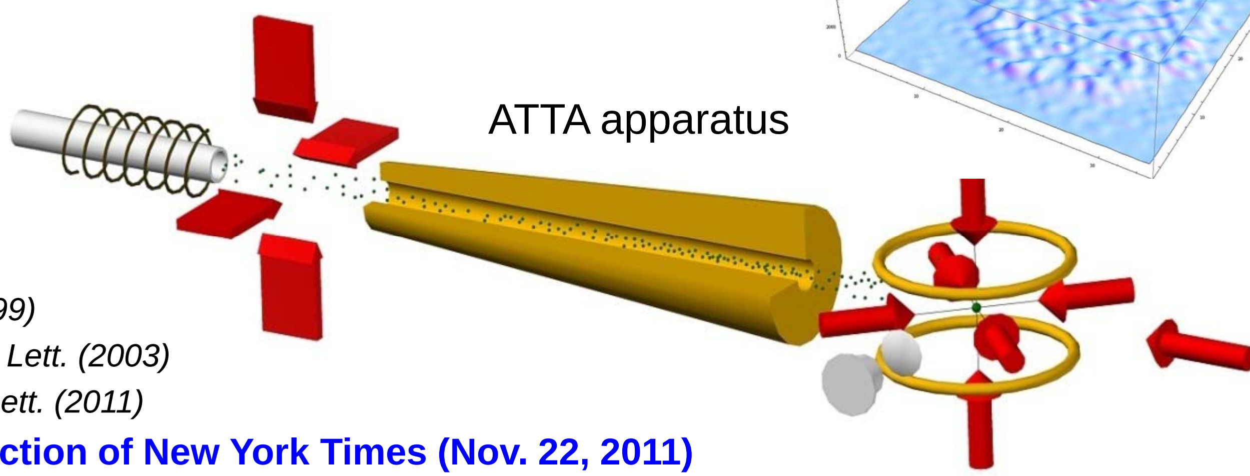
- Sensitivity: Capable of ^{81}Kr-dating with a sample of 10 micro-liter (STP) of krypton gas;
- Selectivity: Analyzed ^{39}Ar in environmental samples at the isotopic abundance level of 8×10^{-16}.

^{81}Kr-dating realized with a range of applications in earth & environmental sciences



Samples to be analyzed in 2011-2012

- Done: Yellowstone National Park, WIPP sites (with Sandia);
- In progress: Great Artesian Basin, Australia;
- In plan: Participate in a comprehensive study of world-wide aquifers (with IAEA).



References

- ATTA-1: *Chen et al., Science (1999)*
- ATTA-2: *Du et al., Geophys. Res. Lett. (2003)*
- ATTA-3: *Jiang et al., Phys. Rev. Lett. (2011)*
- **Featured in the Science Section of New York Times (Nov. 22, 2011)**

Conclusion

The future of nuclear science in the United States may not be exactly as envisioned in the 2007 Long Range Plan, but it remains rich with science opportunities.

The United States continues to provide resources for and to expect:

- U.S. world leadership in discovery science illuminating the properties of nuclear matter in all of its manifestations.
- Tools necessary for scientific and technical advances which will lead to new knowledge, new competencies, and groundbreaking innovation and applications.
- Strategic investments in tools and research to provide the U.S. with premier research capabilities in the world.

Nuclear Science will continue to be an important part of the U.S. science investment strategy to create new knowledge and technology innovation supporting U.S. security and competitiveness