Frontiers, Challenges, and Opportunities for U.S. Nuclear Science

FESAC Meeting
March 13, 2015

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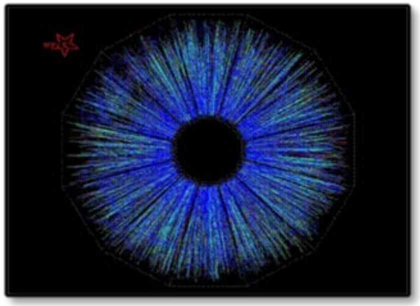
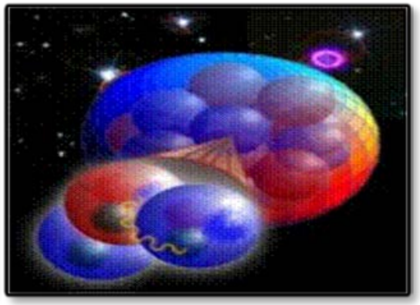
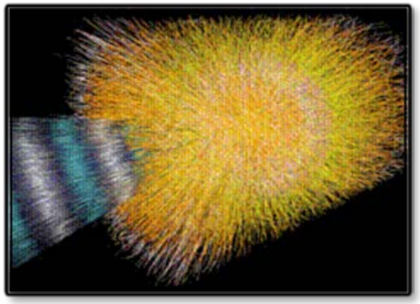
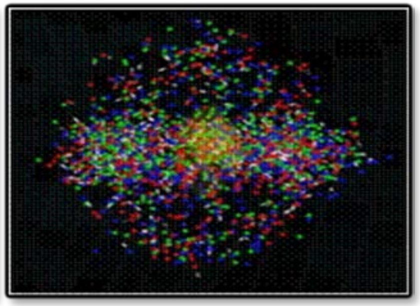
Associate Director for Nuclear Physics
DOE Office of Science

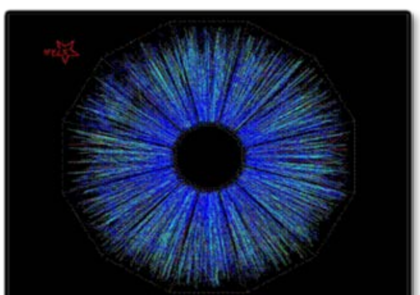





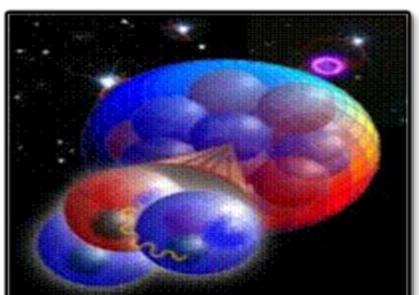
Nuclear Physics' Mission

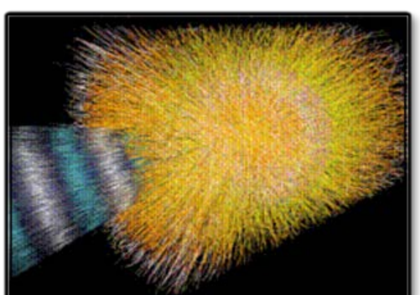
Discovering, exploring, and understanding all forms of nuclear matter

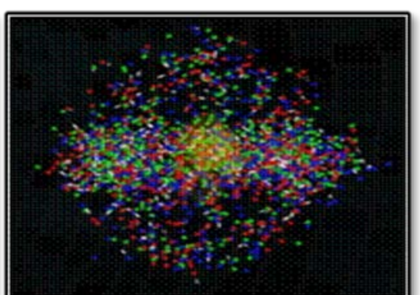
The Scientific Challenges

- 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 neutrons and the neutrino and their role in the evolution of the early universe







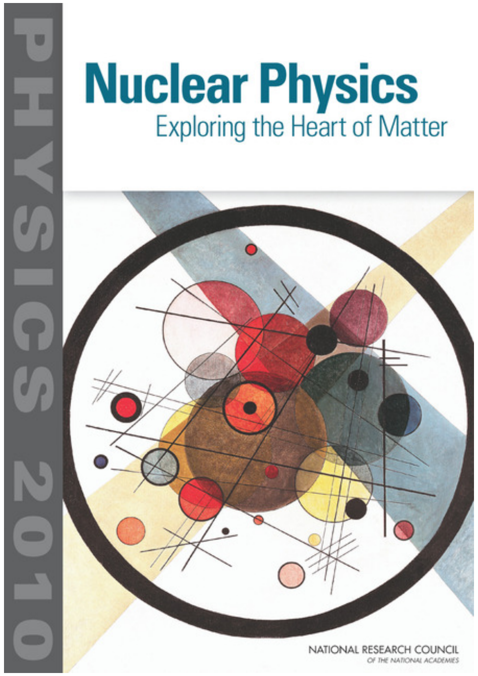


SC NP is the Primary Federal Steward of U.S. Nuclear Science

DOE/NP is the largest supporter of nuclear physics in the U.S. and operates large Scientific User Facilities

Responsible for Strategic Planning and Funding

- Identify the scientific opportunities for discoveries and advancements
- Build and operate forefront facilities to address these opportunities
- Develop and support a research community that delivers significant outcomes
- Work with other agencies/countries to optimize use of U.S. resources



Goals

- **World-class facility research capabilities**
  - to make significant discoveries/advancements
- **A strong, sustainable research community**
  - to deliver significant outcomes
- **Forefront advanced technologies, capabilities**
  - for next-generation capabilities
- **A well-managed and staffed, strategic sustainable program**
  - that ensures leadership/optimizes resources

Deliverables

- New insights and advancements in the fundamental nature of matter and energy
- New and accumulated knowledge, developed and cutting-edge technologies, and a highly-trained next-generation workforce that will underpin the Department's missions and the Nation's nuclear-related endeavors
- Isotopes for basic and applied sciences

Nuclear Physics Program in the U.S.

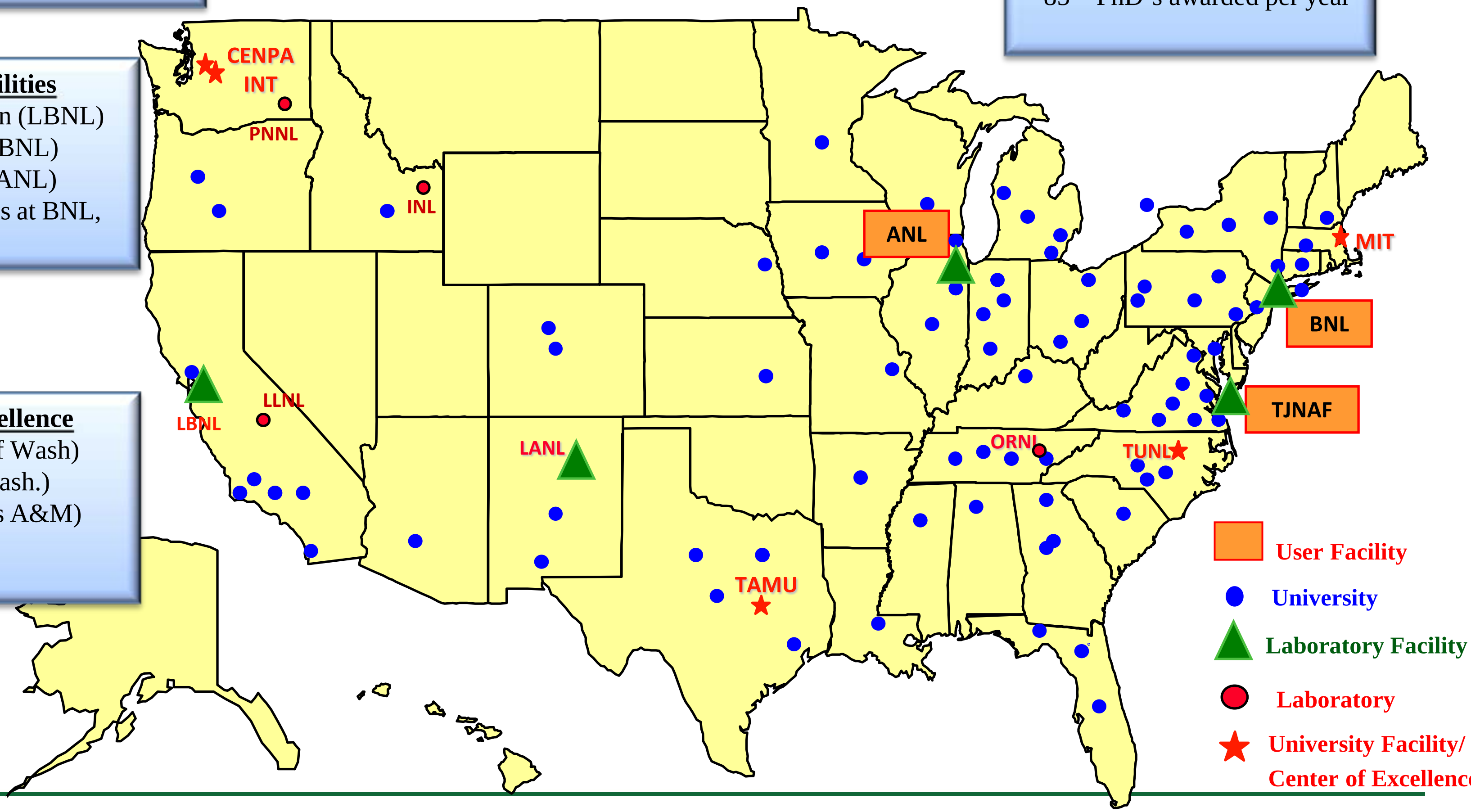
National User Facilities
- RHIC (BNL)
- CEBAF (TJNAF)
- ATLAS (ANL)
- ~2,900 users

Research Groups
- 9 National Laboratories
- 85 Universities

NP Workforce
~700 Faculty & Lab Res Staff
~345 Post-docs
~515 Graduate Students
~1000 Technical/admin
~100 Undergraduate Students
~ 85 PhD's awarded per year

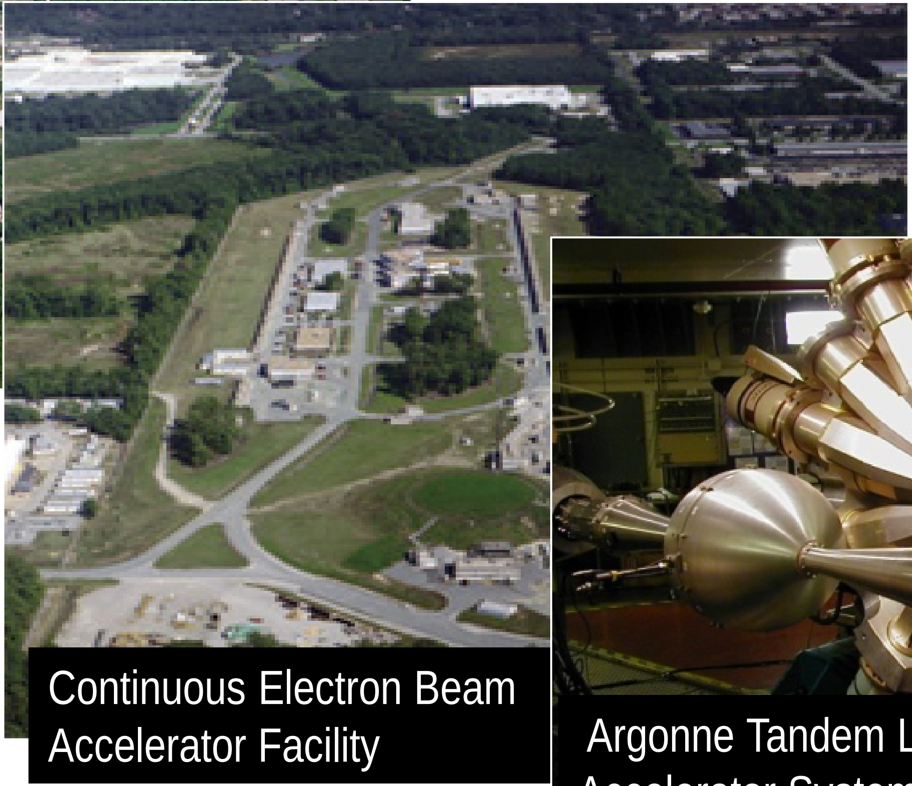
Other Lab. Facilities
- 88-Inch Cyclotron (LBNL)
- 200 MeV BLIP (BNL)
- 100 MeV IPF (LANL)
- Hot Cell Facilities at BNL, LANL, ORNL

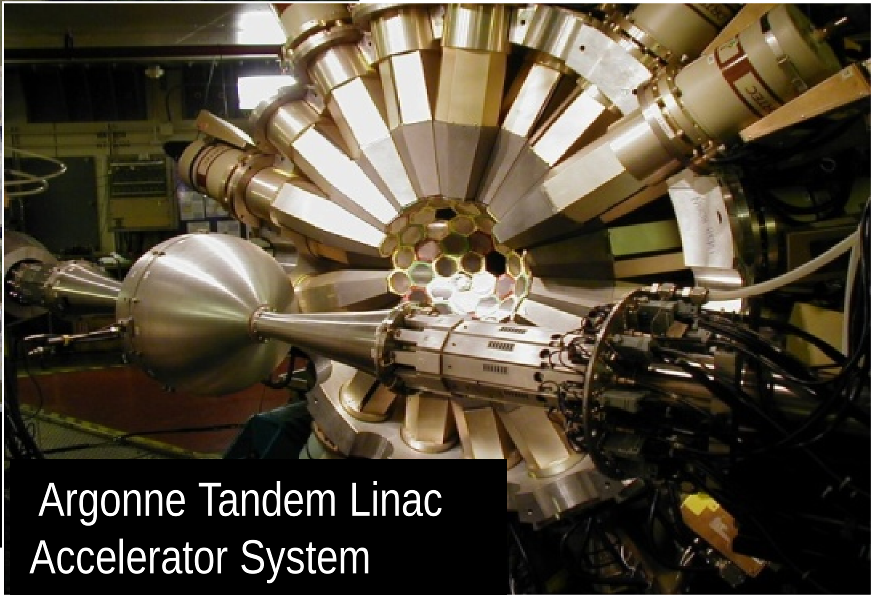
Centers of Excellence
- CENPA (U. of Wash)
- INT (U. of Wash.)
- TAMU (Texas A&M)
- TUNL (Duke)
- REC (MIT)



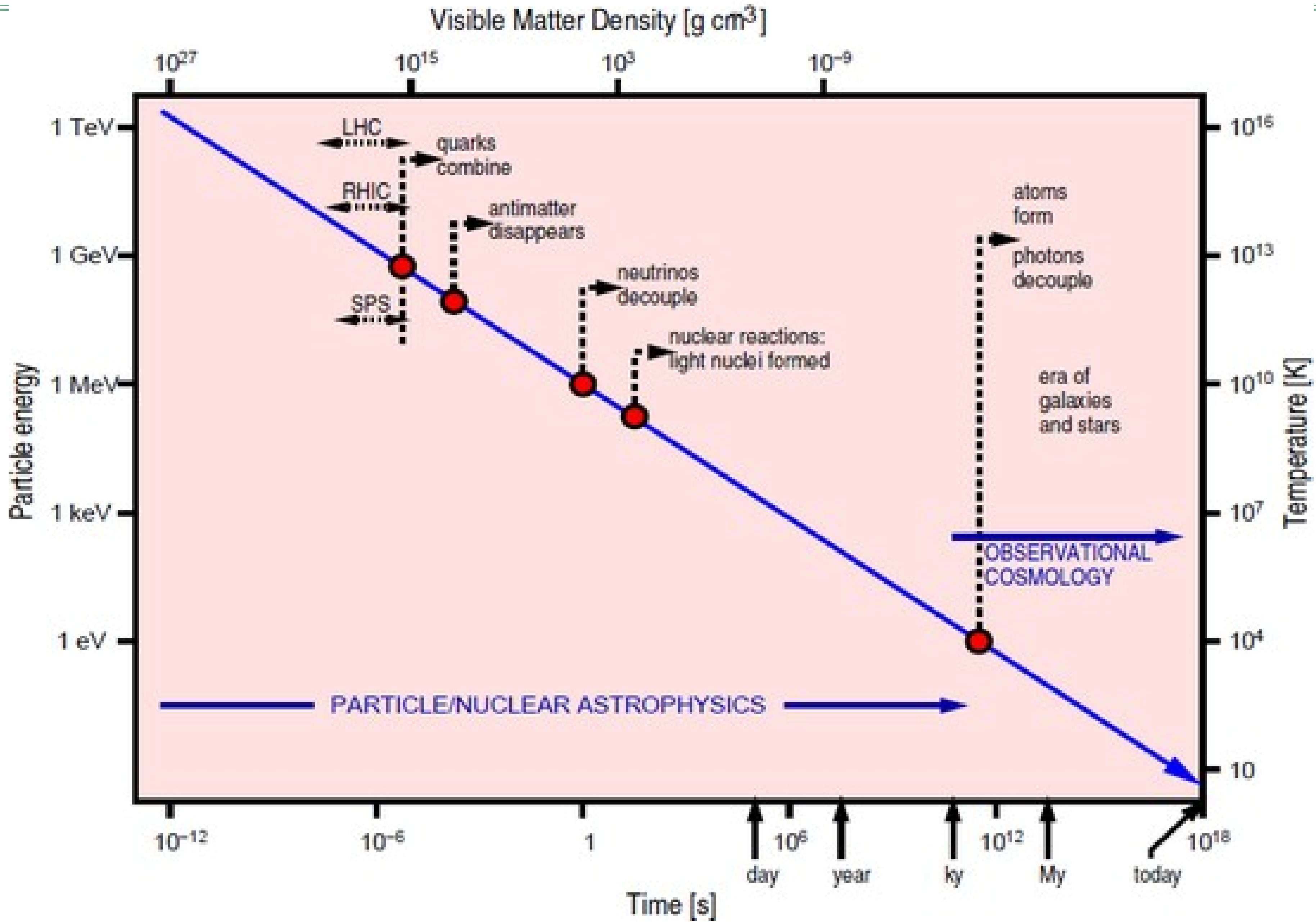
NP National User Facilities

“Microscopes” pursuing groundbreaking research

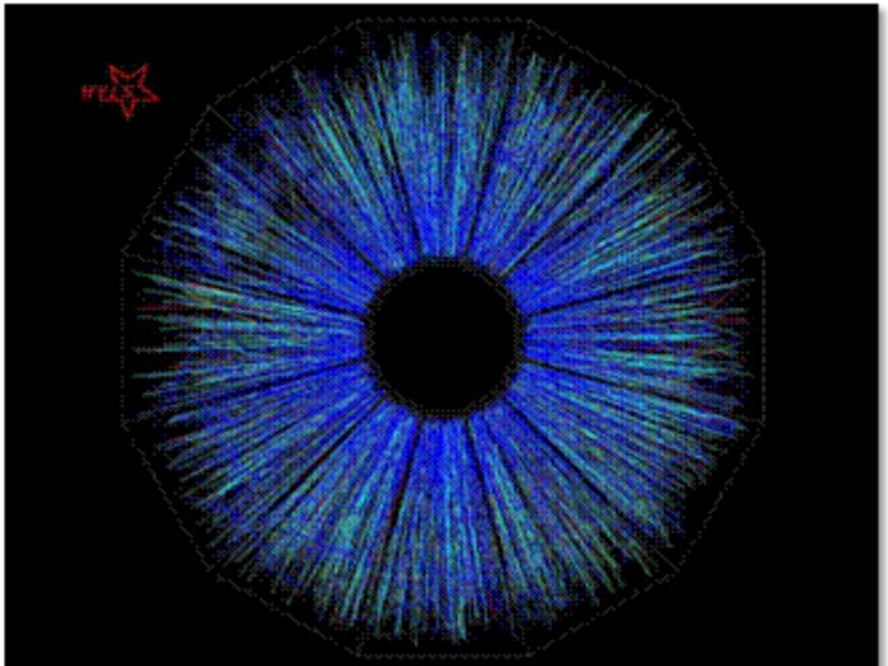


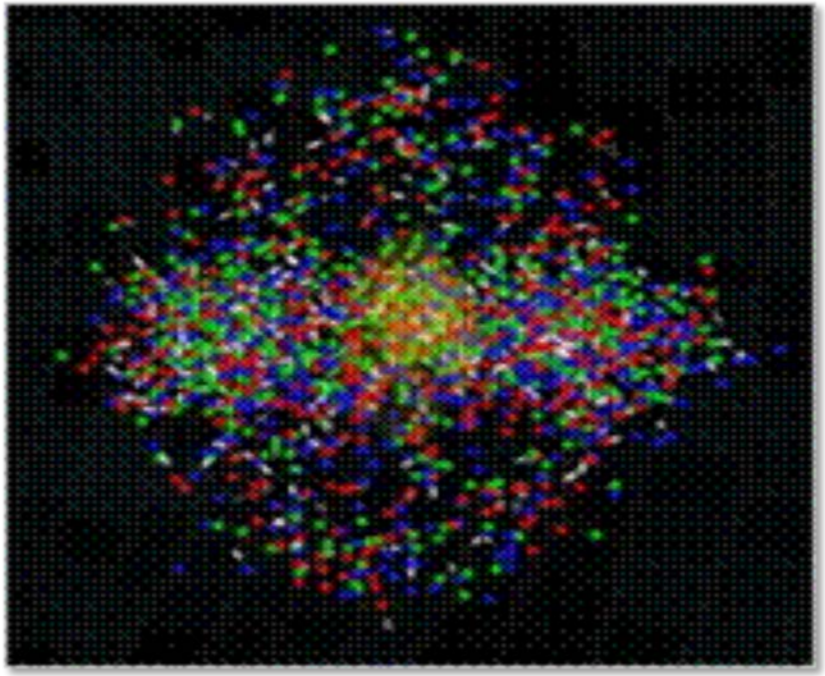


Stages in the evolution of the Universe



In the Debris of Collisions of Relativistic Au Ions, a Remarkable Discovery

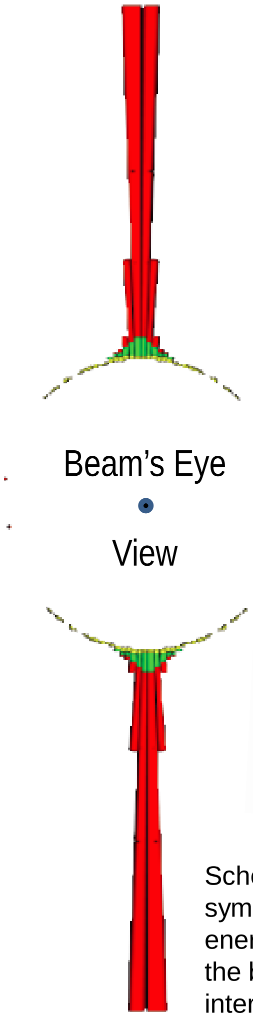


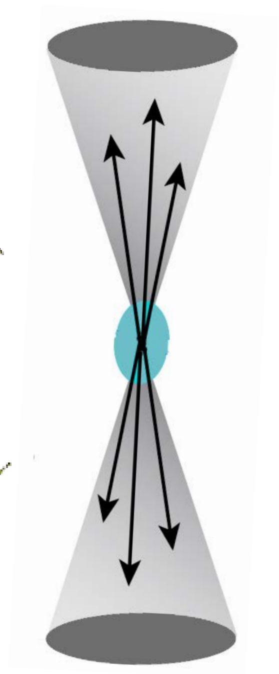


Left: Head on view of measured pattern of sub-atomic particles emitted in RHIC collisions

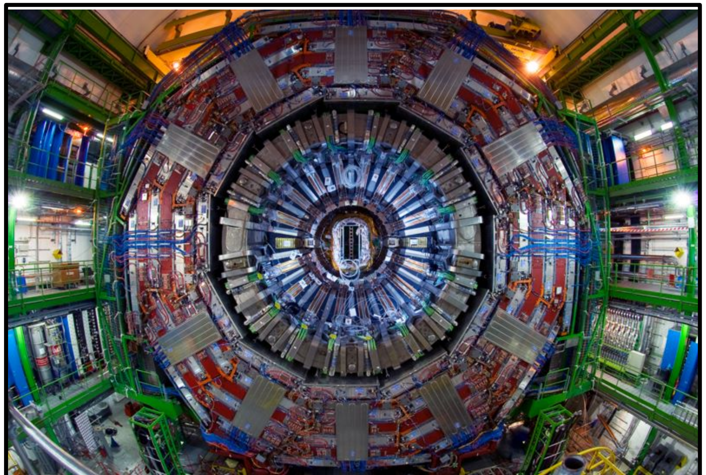
Right: Side view of Monte Carlo Simulation of Perfect Liquid produced in head-on collisions of gold nuclei at RHIC

A New State of Matter is Produced in Relativistic Nucleus-Nucleus Collisions





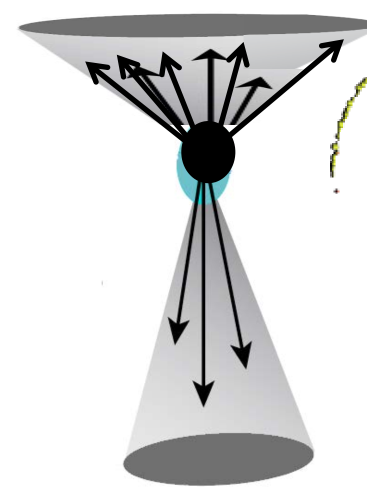
Schematic of expected symmetric back-to-back energy flow ("jets") around the beam direction from the interaction of two energetic partons (quarks, gluons) in proton – proton collisions



Heavy ion data at the LHC indicate a new state of opaque, strongly interacting matter similar to that first discovered at RHIC is produced in heavy ion collisions. "Jets" of energetic particles that traverse the new form of matter are disrupted (right) unlike in proton-proton collisions (left).

The results show that this new form of matter, believed to have influenced the evolution of the early universe, has unique properties and interacts more strongly than any matter previously produced in the laboratory.

Energy deposition in the CMS detector at the Large Hadron Collider (LHC) as a function of angle around the beam direction



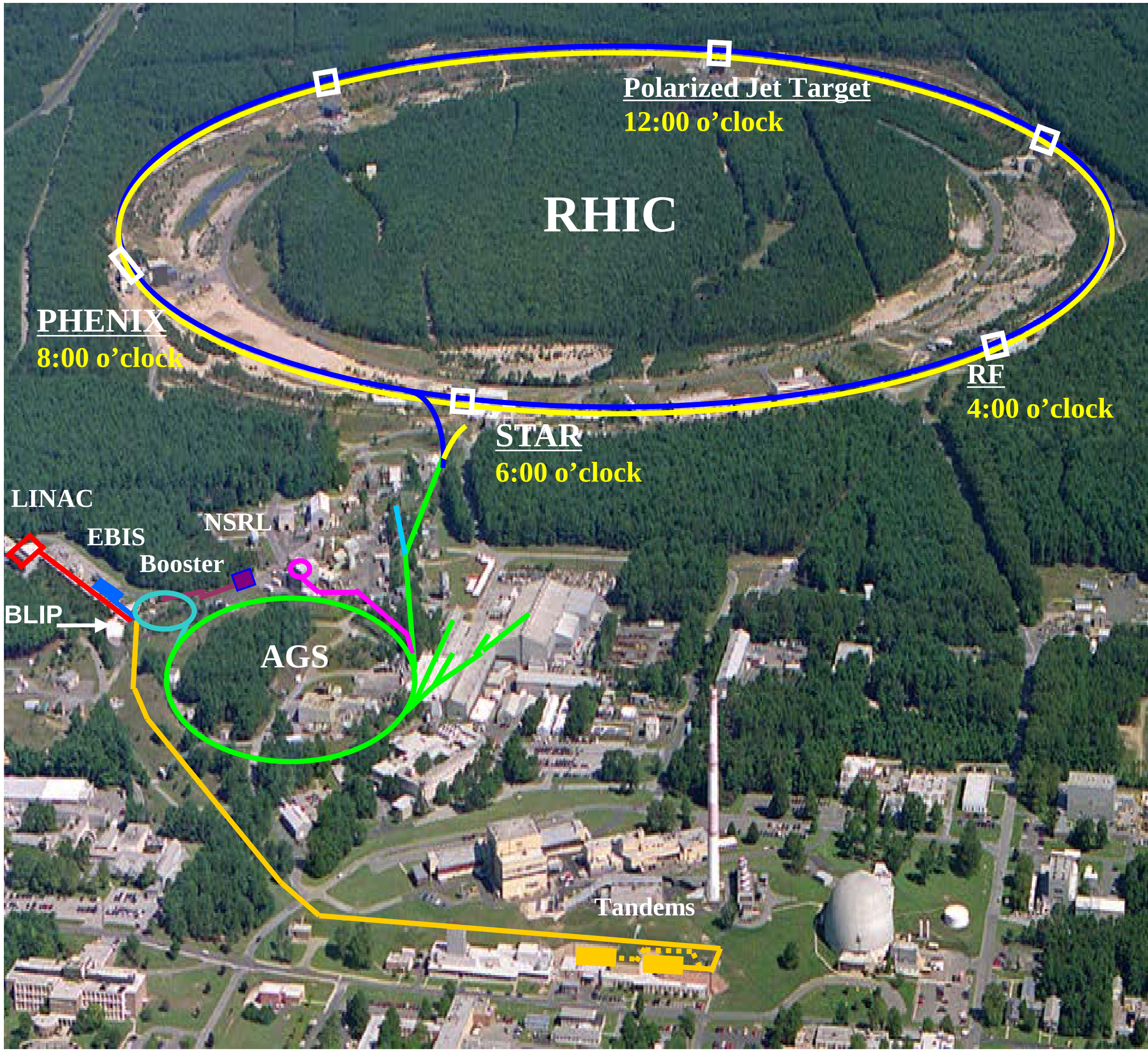
Observation in CMS of large asymmetric non back-to-back (jet) energy flow around the beam direction from the interaction of two energetic partons (quarks, gluons) in relativistic nucleus-nucleus collisions

Scientific Discovery Continues at the Relativistic Heavy Ion Collider

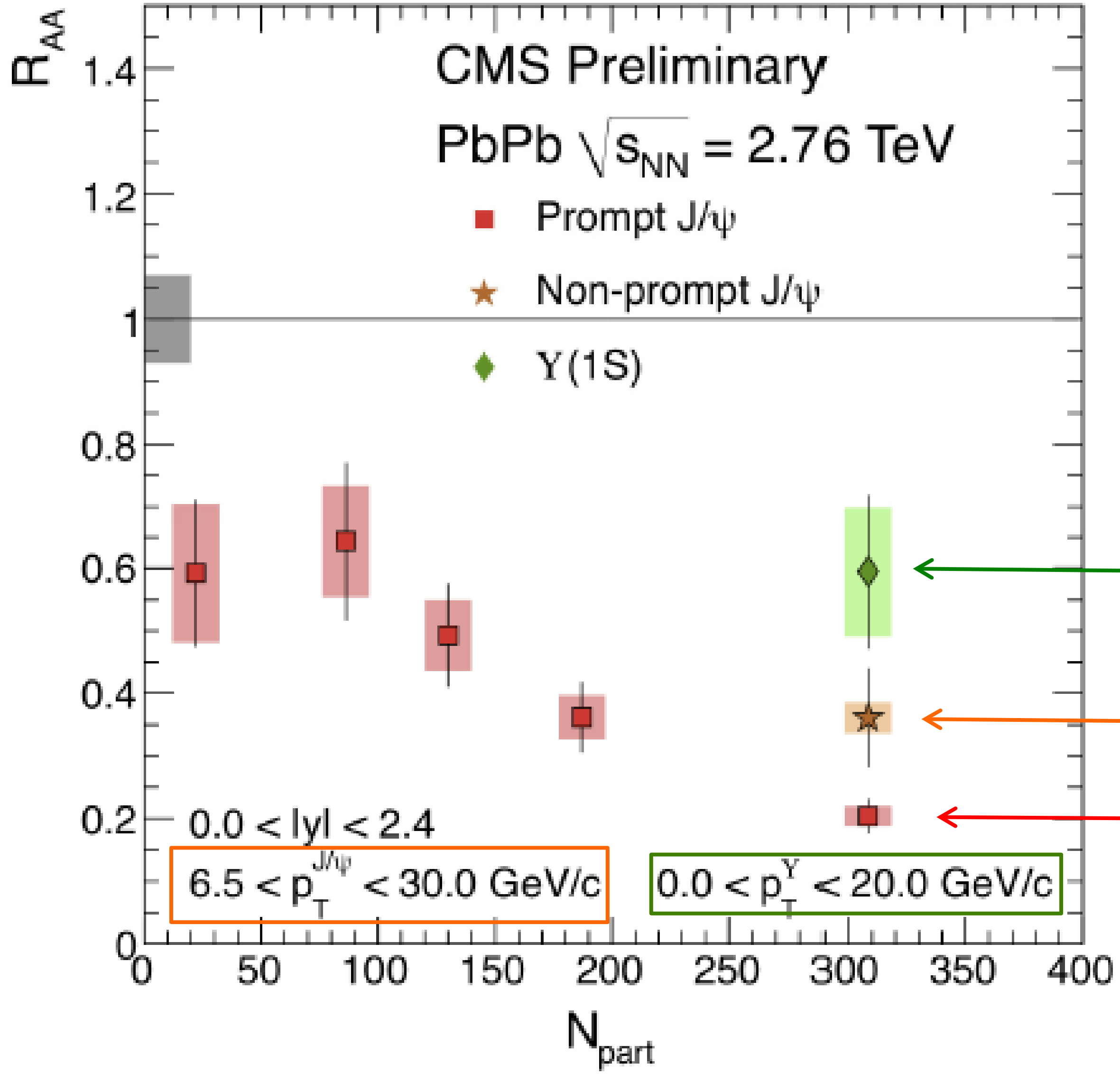
RHIC discovered a completely new state of matter—a perfect quark-gluon liquid. The RHIC science campaigns planned in the next 3-5 years will:

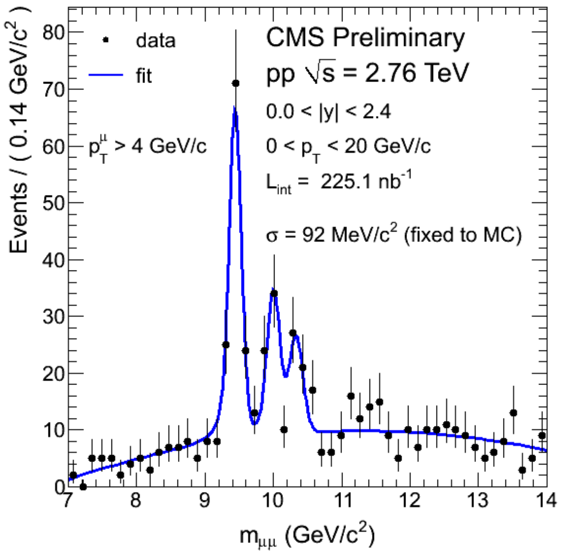
- determine, with precision, the properties of this perfect liquid
- search for new discoveries such as the postulated Critical Point in the phase diagram of QCD
- explore the gluon and sea quark contributions to the spin of the proton using RHIC, the only collider with polarized beams
- explore and develop intellectual connections and broader impacts to other subfields

No other facility worldwide, existing or planned, can rival RHIC in range and versatility.



A Mystery: Propagation of Heavy Quarks





Inclusive Υ (1s) suppressed

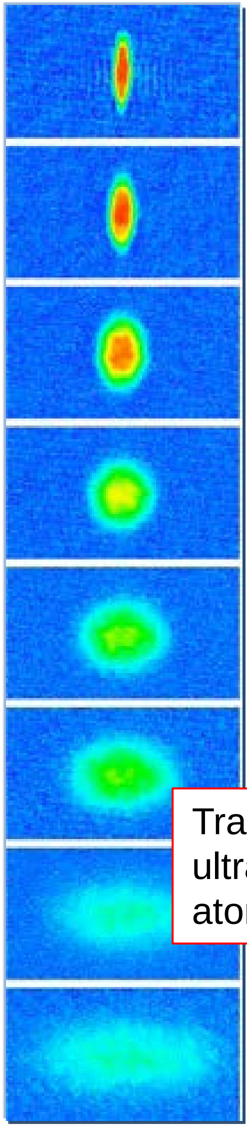
Non-Prompt J/ψ from B-decays

Prompt J/ψ suppressed

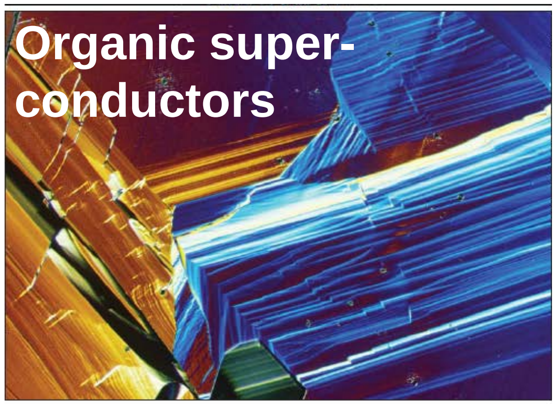
Unanticipated Intellectual Connections to Hot QCD Research at RHIC

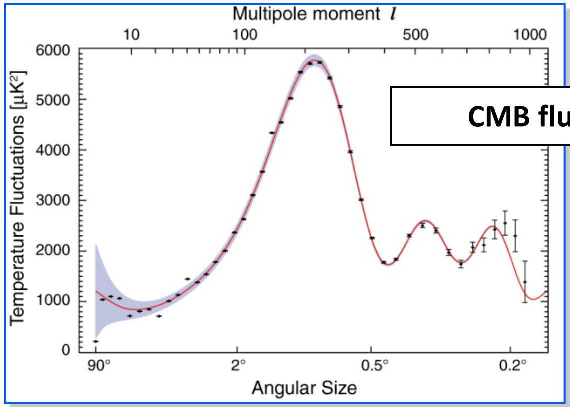
RHIC results have established ties to other forefront science:

- String Theory studies of black hole behavior led to prediction of a conjectured quantum lower bound on η/s — a "perfect fluid"
- Ultra-cold atomic gases, at temperatures 19 orders of magnitude below QGP, can also be "nearly perfect liquids"
- Similar liquid behavior seen and studied in a number of strongly correlated condensed matter systems
- Symmetry-violating bubbles in QGP analogous to speculated cosmological origin of baryon-antibaryon imbalance in universe
- Power spectrum of flow analogous to power spectrum of cosmic microwave background, used to constrain baryon acoustic oscillations & dark energy



Trapped ultra-cold atom clouds





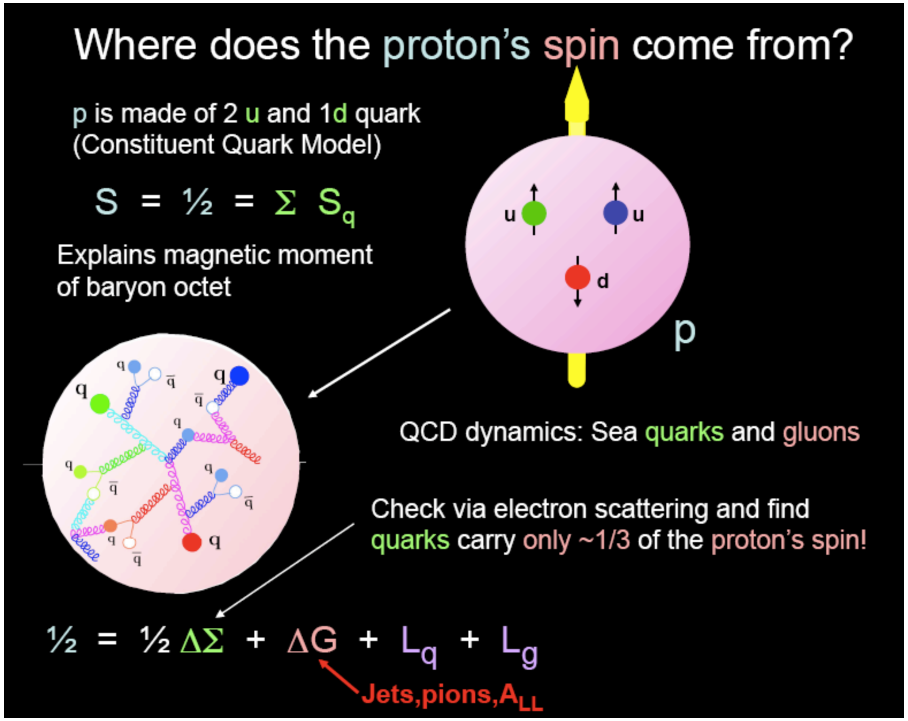
CMB fluctuations

Main Remaining RHIC Questions

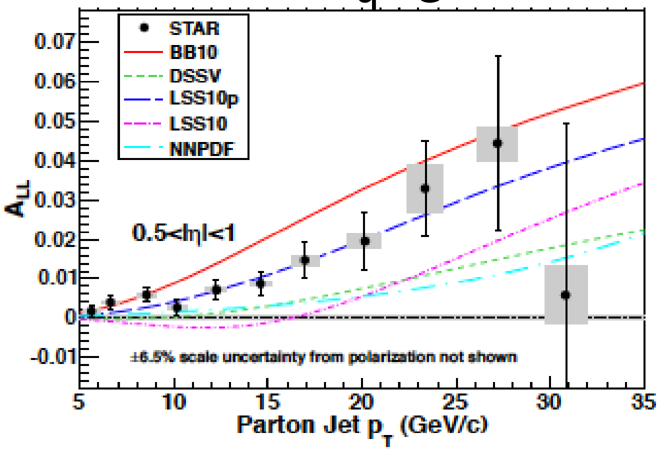
- What do we need to know about the initial state? Is it a weakly coupled color glass condensate? How does it thermalize?
- What do the data tell us about the initial conditions for the hydro-dynamic expansion? Can we determine it unambiguously?
- What is the smallest collision system that behaves collectively?
- What does the QCD phase diagram look like? Does it contain a critical point in the HG-QGP transition region? Does the HG-QGP transition become a first-order phase transition for large μ_B?
- What can jets and heavy flavors tell us about the structure of the strongly coupled QGP?
- What do the quarkonium (and other) data tell us about quark deconfinement and hadronization?
- Can we find unambiguous proof for chiral symmetry restoration?

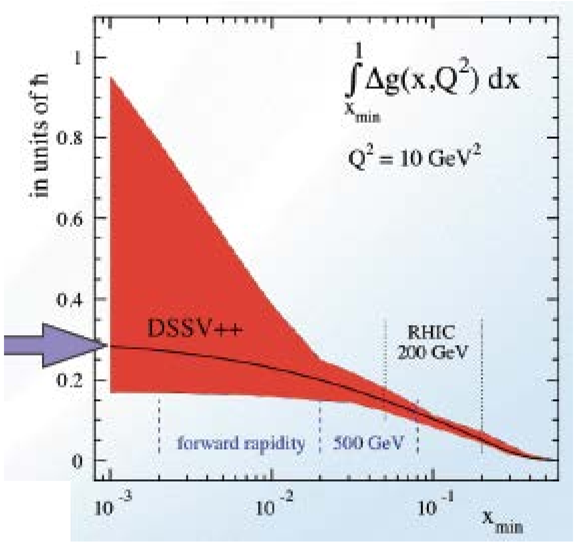
The Other Scientific Frontier at RHIC

A worldwide scientific quest:



$A_{LL} \sim \frac{\Delta q}{q} \frac{\Delta G}{G}$

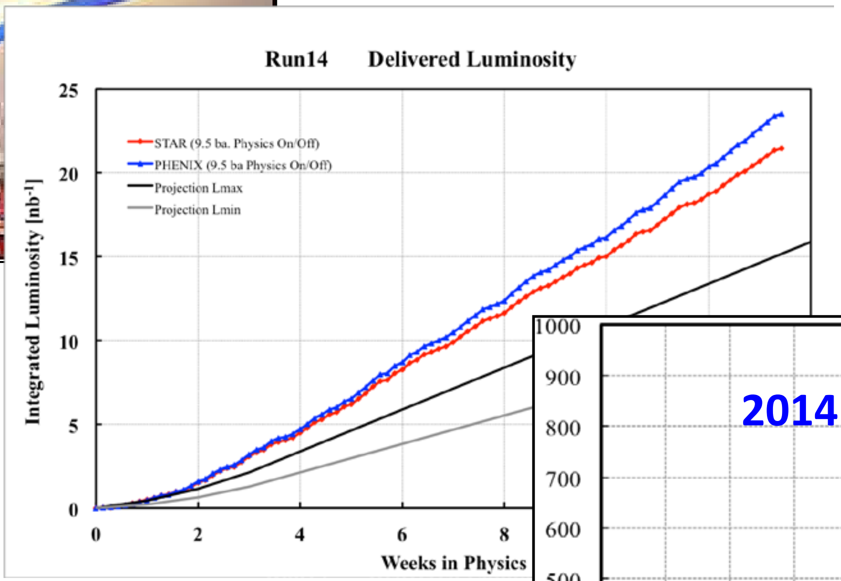


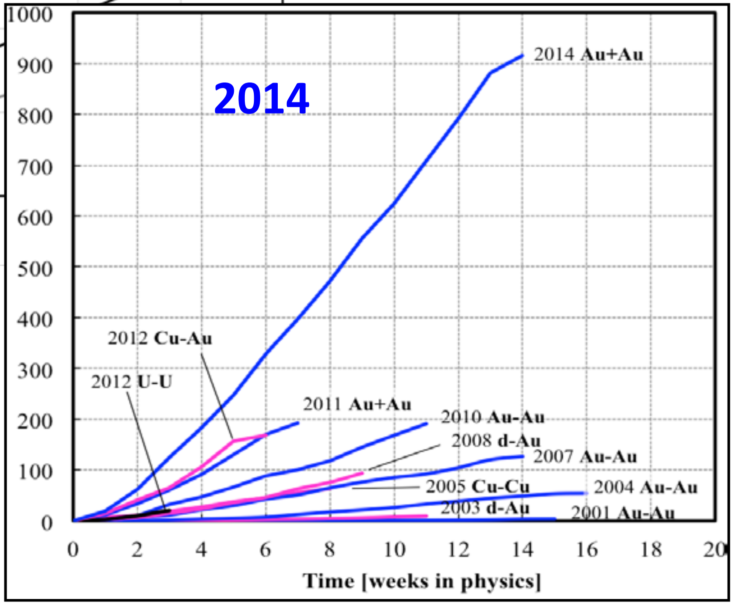


After almost two decades of focused study, RHIC results indicate the contribution to the proton spin is significant and within uncertainties, accounts for ~ 60% of the proton spin.

RHIC Machine Performance Sets New Records in FY 2014

Heavy ion runs



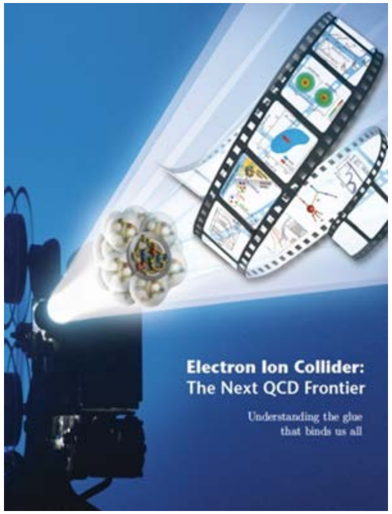


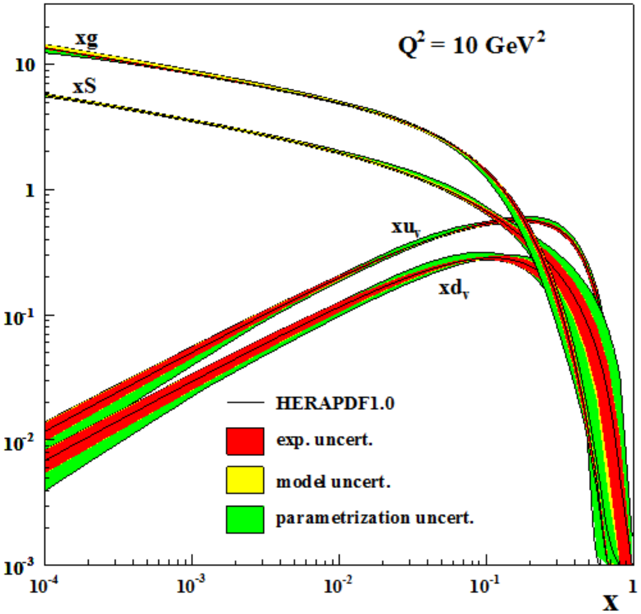
Au + Au integrated luminosity from Run 14 exceeded all previous Au+ Au runs combined

No other facility worldwide, existing or planned, can rival RHIC in range and versatility as a heavy ion collider. It is the only polarized proton collider in the world.

Understanding the glue that binds us all

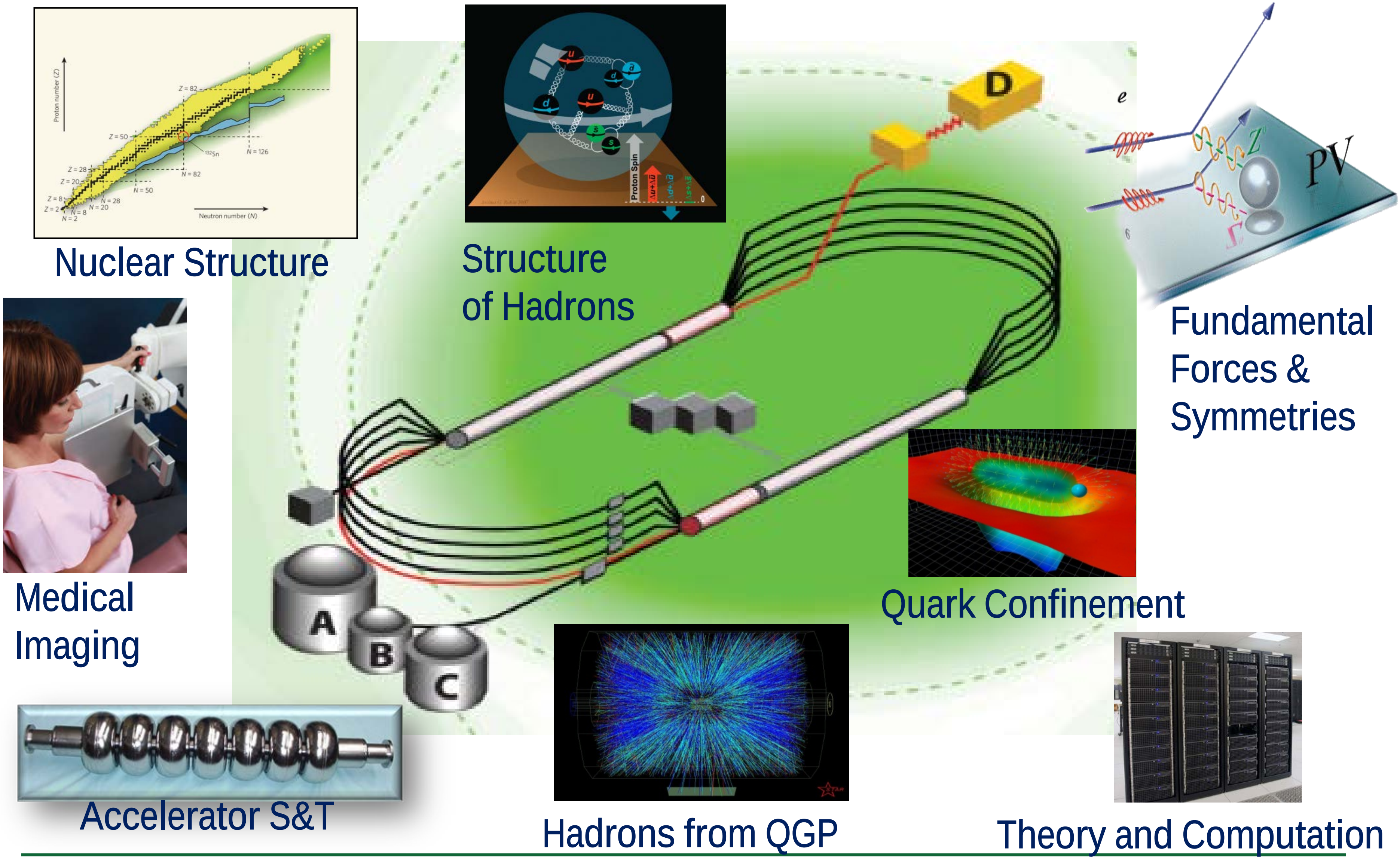
- Proton (and nuclei) and black holes are the only fully relativistic (high enough energy density to excite the vacuum) stable bound systems in the universe. Protons can be studied in the laboratory.
- Protons are fundamental to the visible universe (including us) and their properties are dominated by emergent phenomena of the self-coupling strong force that generates high density gluon fields:
    - The mass of the proton (and the visible universe)
    - The spin of the proton
    - The dynamics of quarks and gluons in nucleons and nuclei
    - The formation of hadrons from quarks and gluons
- The study of the high density gluon field that is at the center of it all requires a high energy, high luminosity, polarized Electron Ion Collider





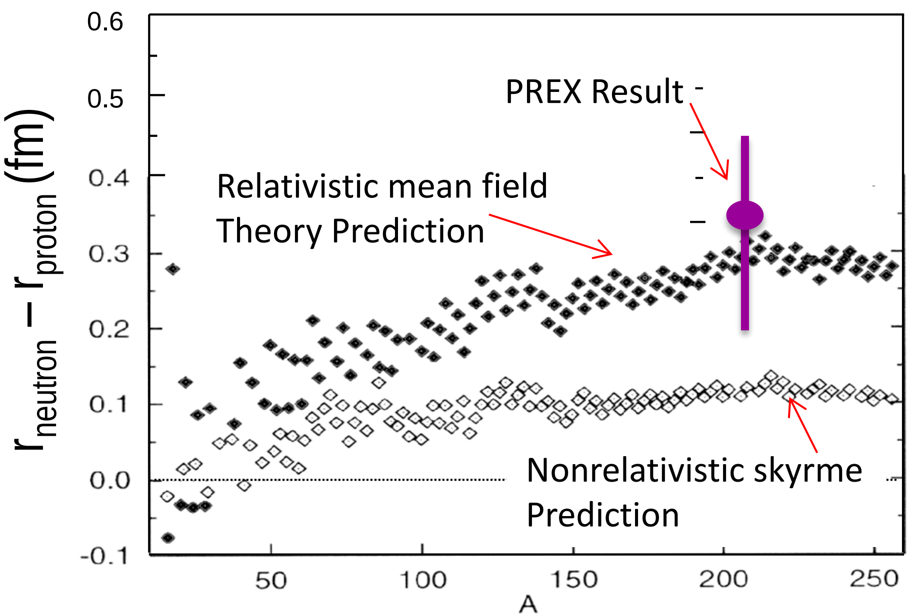
The 2013 NSAC *Subcommittee on Future Facilities* identified the physics program for an Electron-Ion Collider as ***absolutely central*** to the nuclear science program of the next decade.

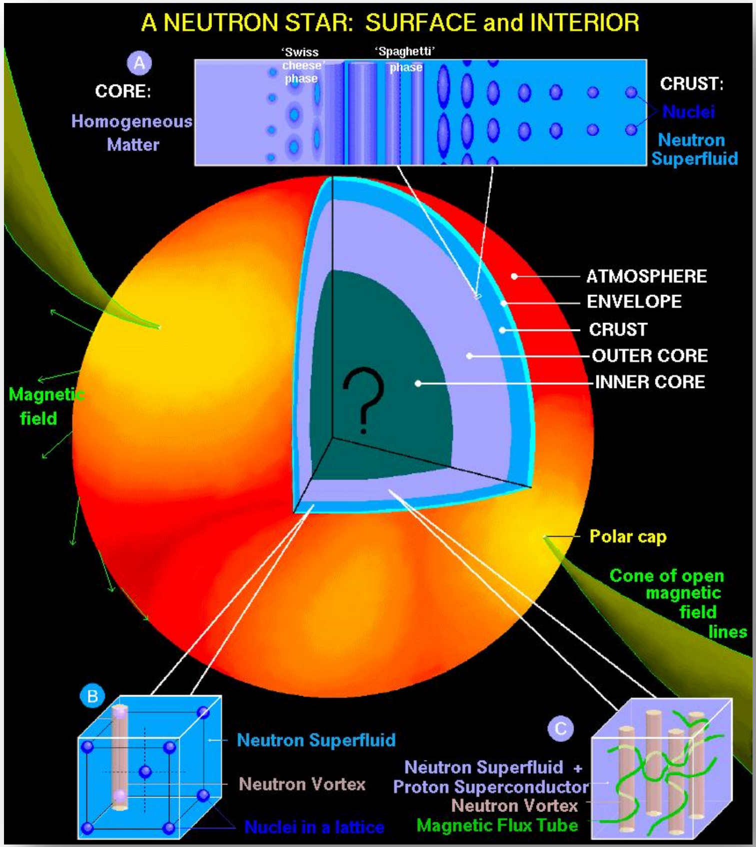
JLab: Medium Energy Nuclear Science and Its Broader Impacts



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

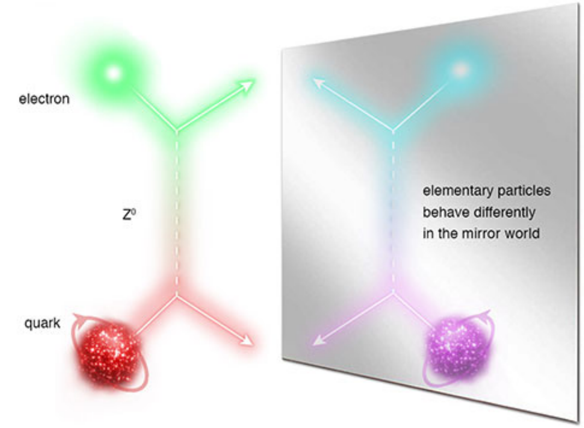
A neutron skin of 0.2 fm or more has implications for our understanding of neutron stars and their ultimate fate

Measurement of the Parity-Violating Asymmetry in eD Deep Inelastic Scattering

Nature 506, 67–70 (06 February 2014)

The Jefferson Lab PVDIS Collaboration

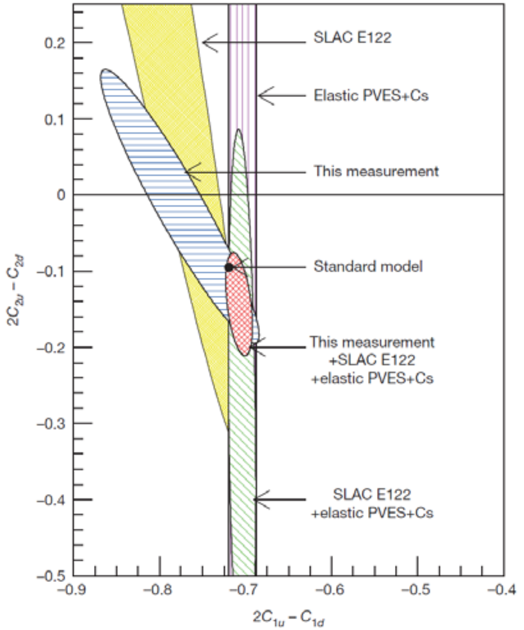
See also News & Views, *Nature* 506, 43–44 (06 February 2014)



Longitudinally Polarized Electron Scattering from Unpolarized Deuterium

$$A_{LR} = A_{PV} = \frac{\sigma_{\uparrow} - \sigma_{\downarrow}}{\sigma_{\uparrow} + \sigma_{\downarrow}} \sim \frac{A_{weak}}{A_{\gamma}} \sim \frac{G_F Q^2}{4\pi\alpha} (\alpha\, [2C_{1u} - C_{1d}] + \beta\, [2C_{2u} - C_{2d}])$$

- The present result leads to a determination of the effective electron-quark weak coupling combination $2C_{2u} - C_{2d}$ that is five times more precise than previously determined.
- It is the first experiment to isolate, when combined with previous experiments like Qweak, a non-zero C_{2q} (at 95% confidence level).
- This coupling describes how much of the mirror-symmetry breaking in the electron-quark interaction originates from the quarks' spin preference in the weak interaction. The result provides a mass exclusion limit on the electron and quark compositeness and contact interactions of ~5 TeV.



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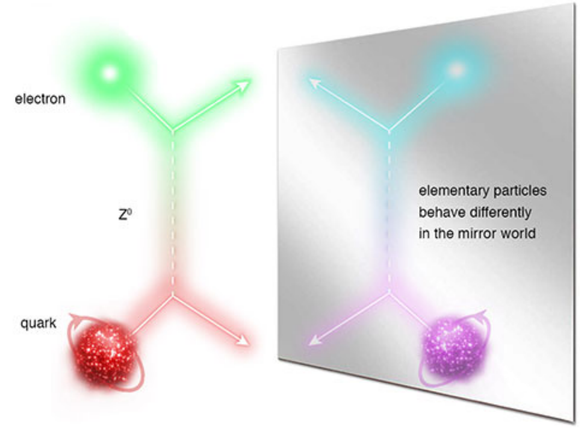

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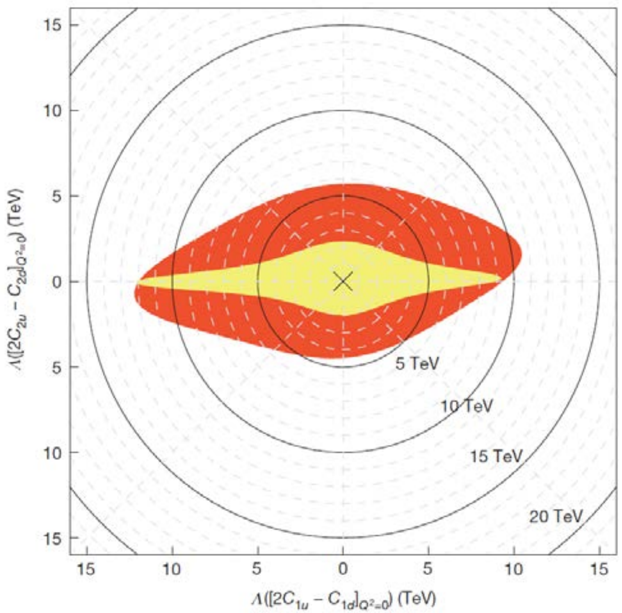
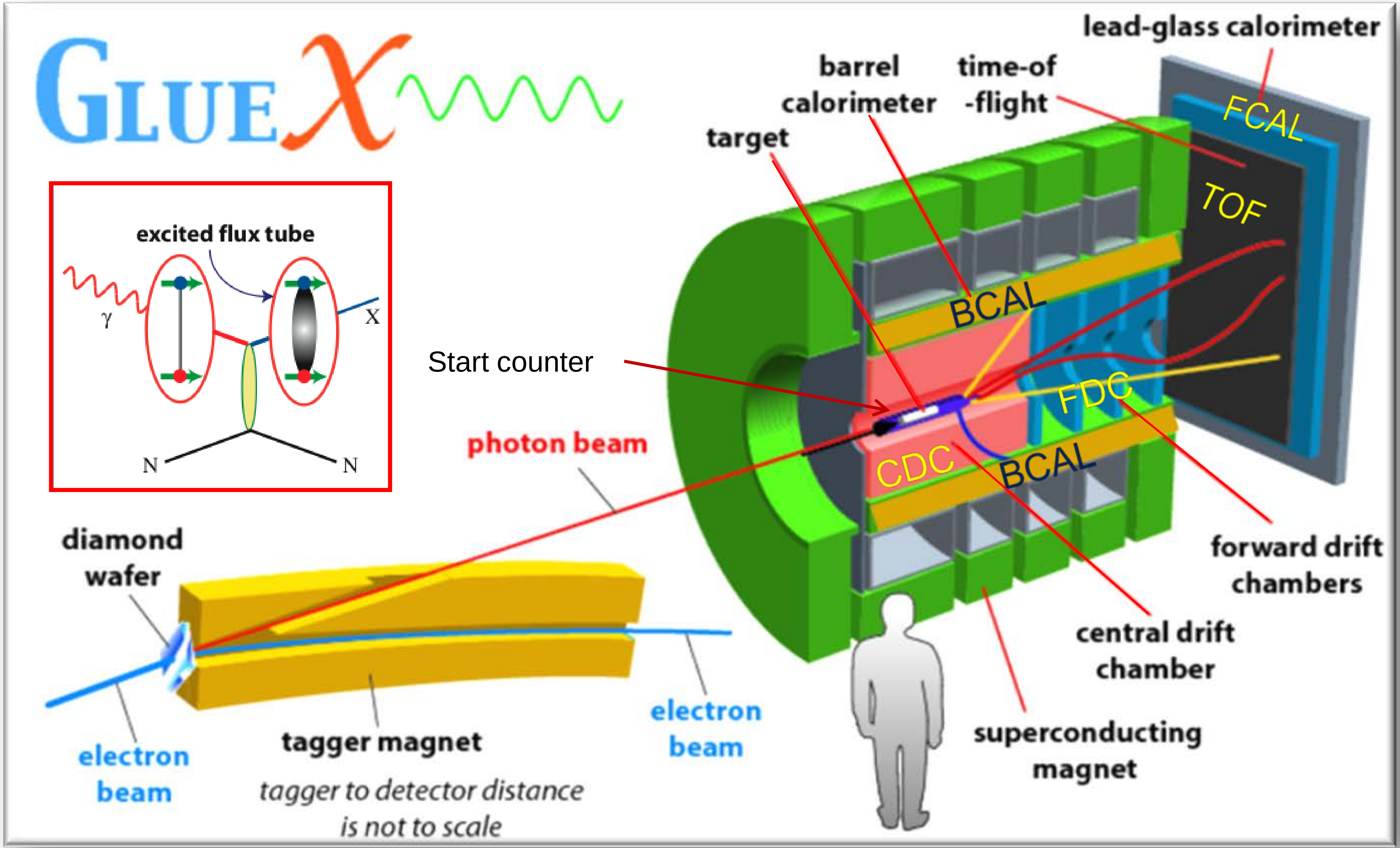


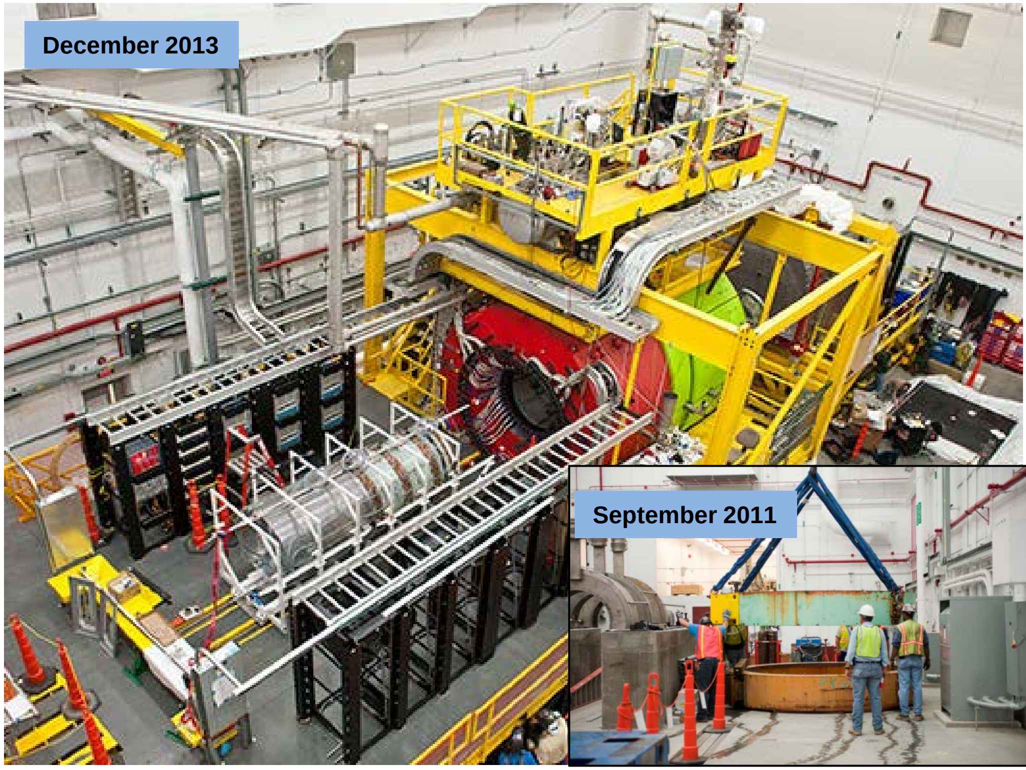
The Newly Constructed Hall D Promises a New NP Science Watershed

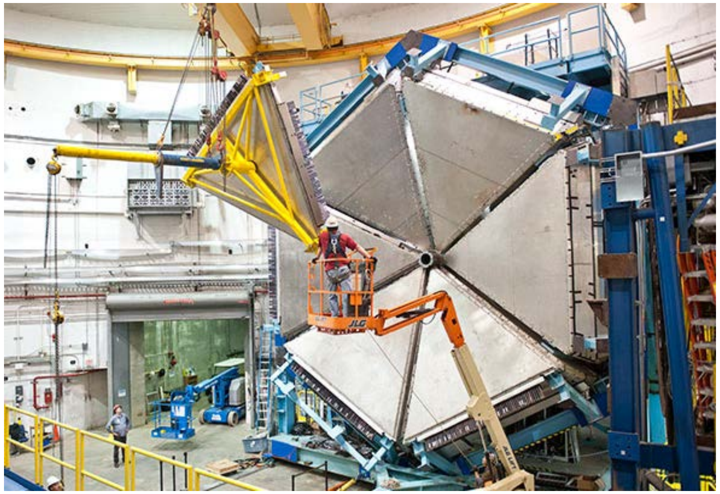


The 12 GeV CEBAF Upgrade is More Than 90% Complete

With the completion of the 12 GeV CEBAF Upgrade, researchers will address:

- The search for exotic new quark anti-quark particles to advance our understanding of the strong force
- Evidence of new physics from sensitive searches for violations of nature's fundamental symmetries
- A detailed microscopic understanding of the internal structure of the proton, including the origin of its spin, and how this structure is modified when the proton is inside a nucleus





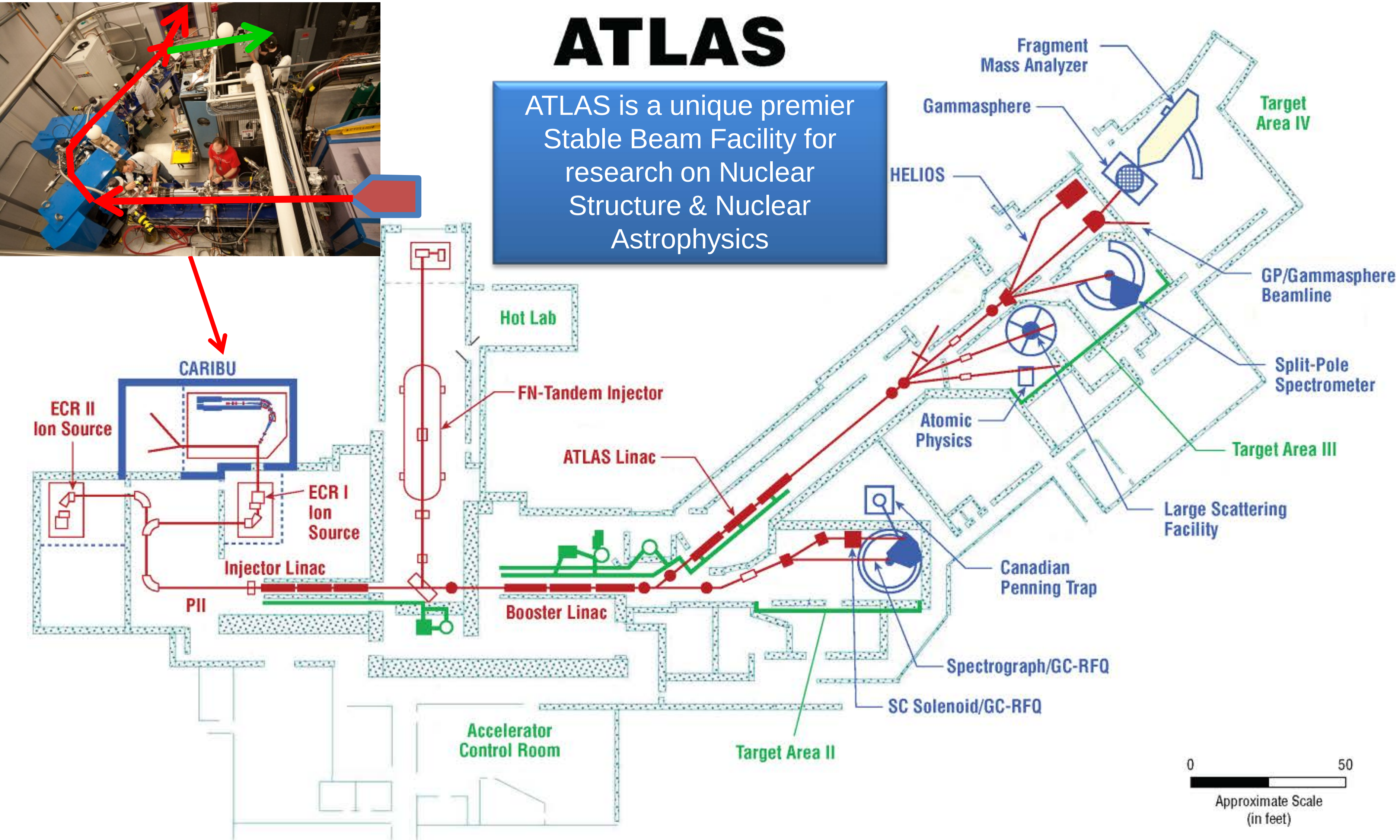
Mounting of the Forward Time-of-Flight detector arrays onto the forward carriage in Hall B

Project was re-baselined in September 2013 with a Total Project Cost of $338M and completion in September 2017

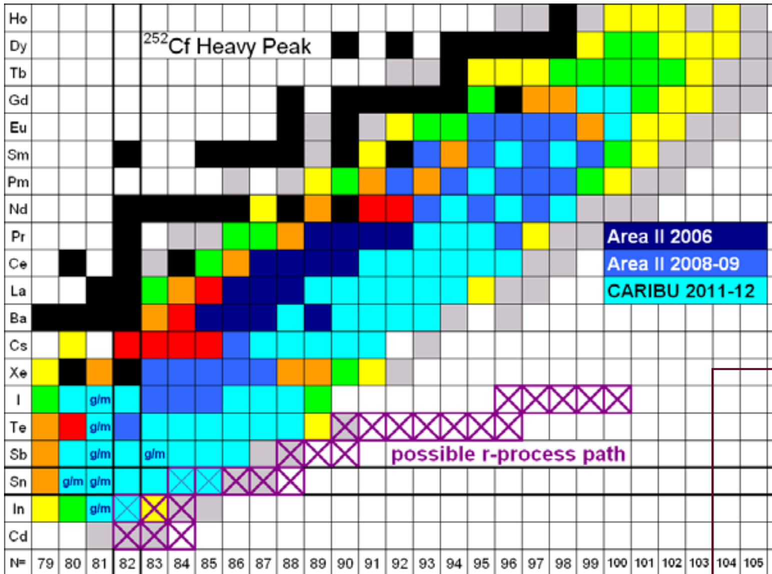
JLab: 21st Century Science Questions

- 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?

ATLAS at ANL Uniquely Provides Low Energy SC Research Opportunities

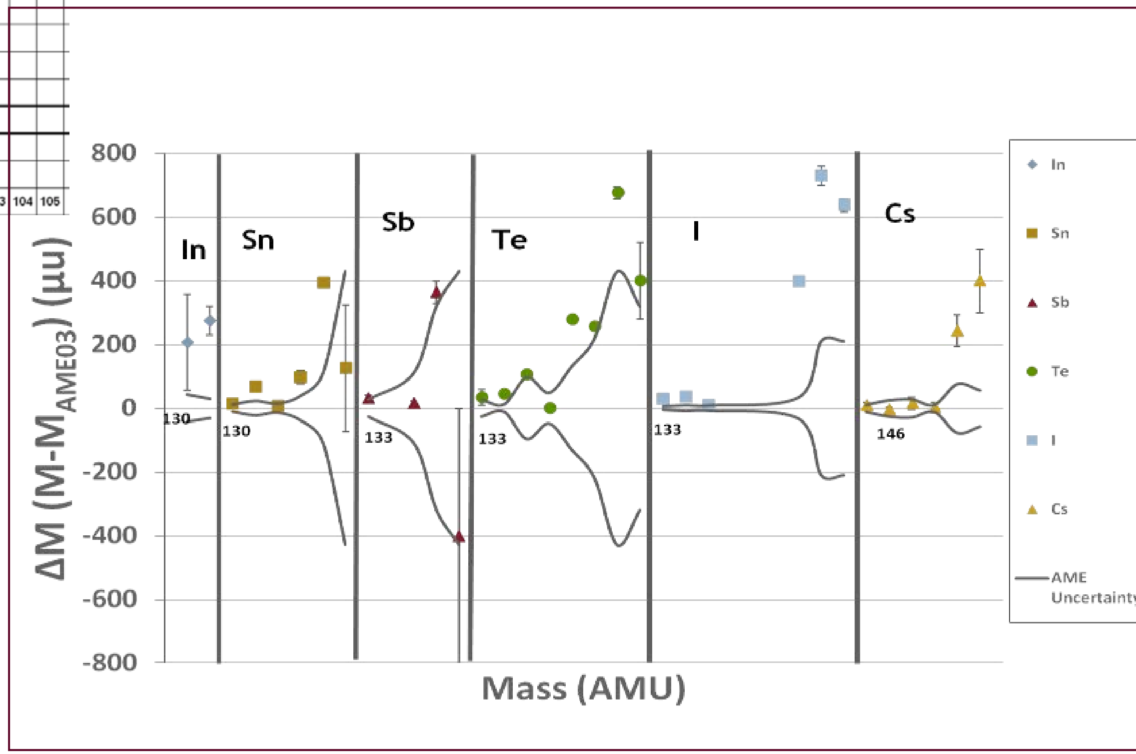


First Physics With CARIBU



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

Mass measurements with the CPT at CARIBU



Facility for Rare Isotope Beams

Ground breaking ceremony with participation by DOE officials and Senate and House representatives was held on March 17, 2014.

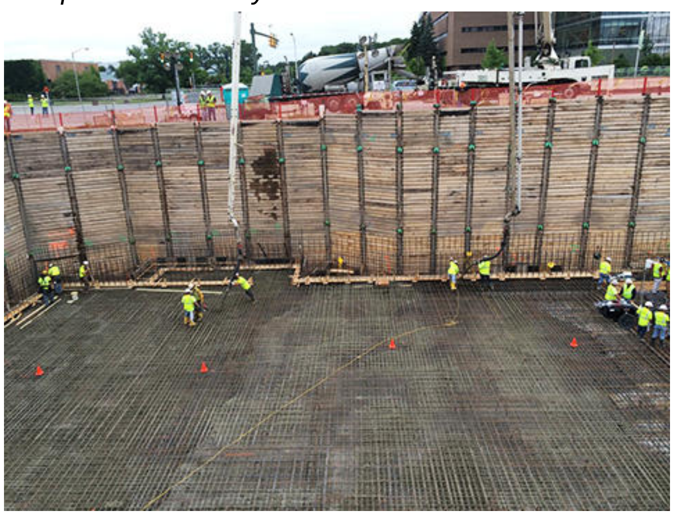
TPC $000s	PYs	FY13	FY14	FY15	FY16	FY17	FY18	FY19	FY20	FY21	TOTAL
FRIB	51,000	22,000	55,000	90,000	100,000	100,000	97,200	75,000	40,000	5,300	635,500

Progress of the Facility for Rare Isotope Beams at MSU

Ground breaking ceremony on March 17, 2014.

In July 2014, 140 truckloads of concrete arrived at MSU.

Workers placing 1,400 cubic yards of concrete in the first structural concrete placement in July for the linear accelerator tunnel.



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 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

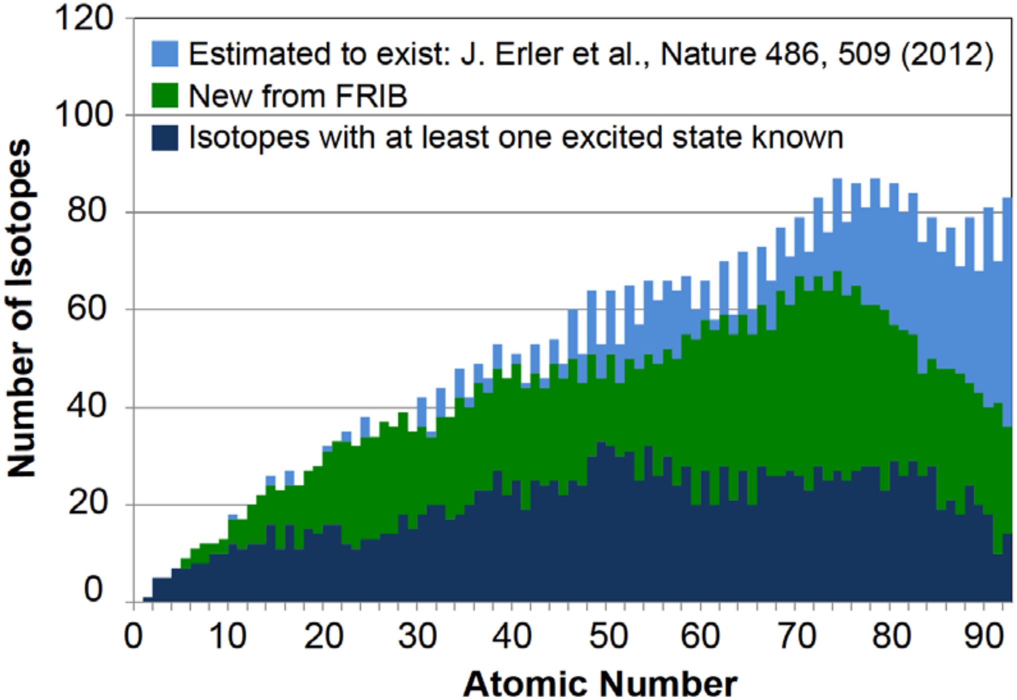
This research will provide the basis for a model of nuclei and how they interact.

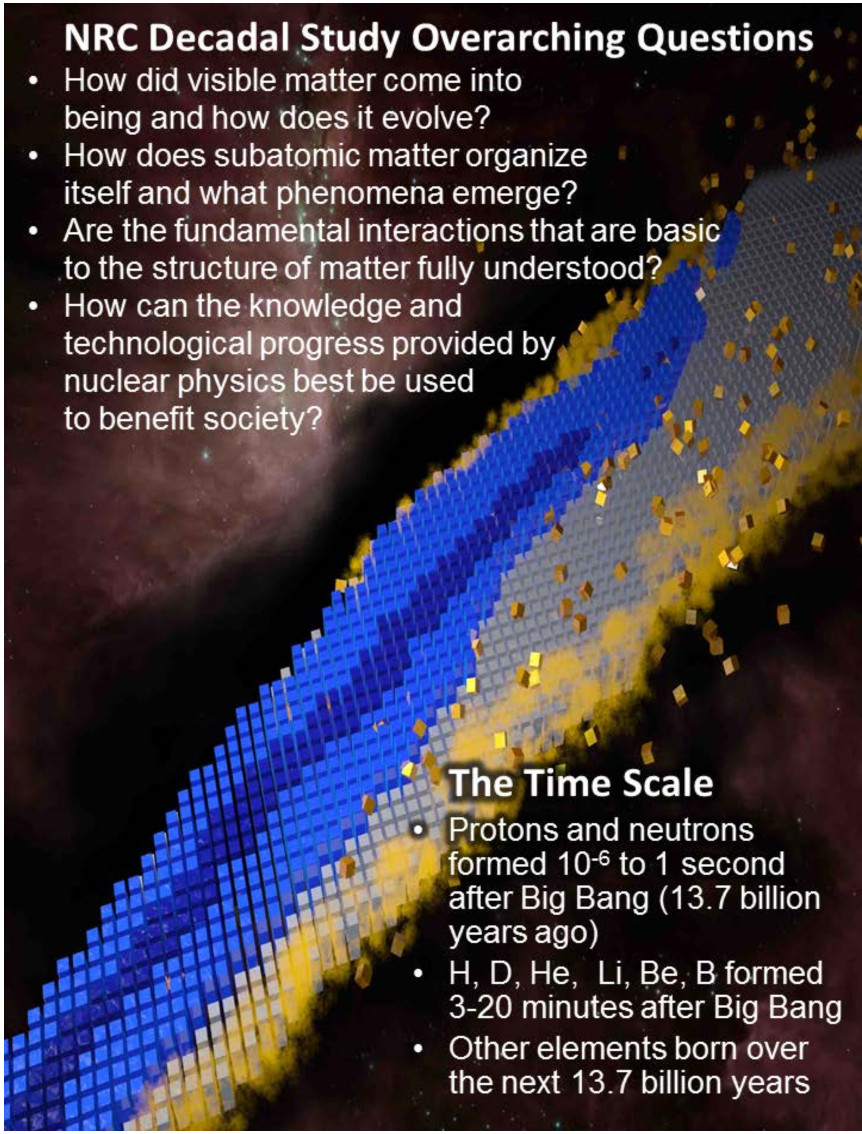
Project received CD-3B, *Approval to Start Technical Construction*, on August 26, 2014.

Five of fifteen nonconventional utility process tanks to be installed during conventional construction.

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





Preparations for NP Stewarded Neutrino-less Double Beta Decay Experiments

R&D on one of several approaches by U.S. scientists is ongoing at Lead, South Dakota

Recent progress on the Majorana Demonstrator 4800 feet below ground at the Sanford Underground Research Facility (SURF)

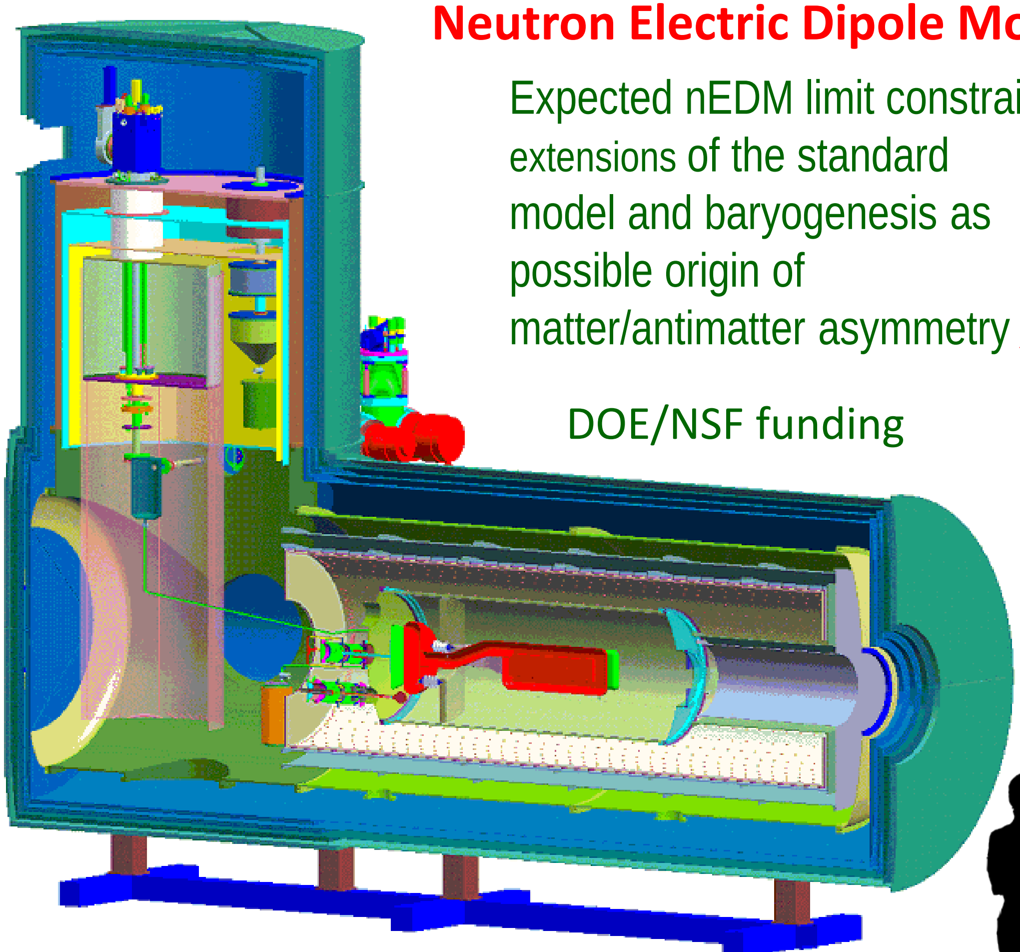
With techniques that use nuclear isotopes inside cryostats, often made of ultra-clean materials, scientists are “tooling up” to study whether neutrinos are their own anti-particle.

NSAC has been charged to identify the criteria for a next generation double beta decay experiment.

Inspection of copper being electroformed at the Temporary Clean Room in SURF

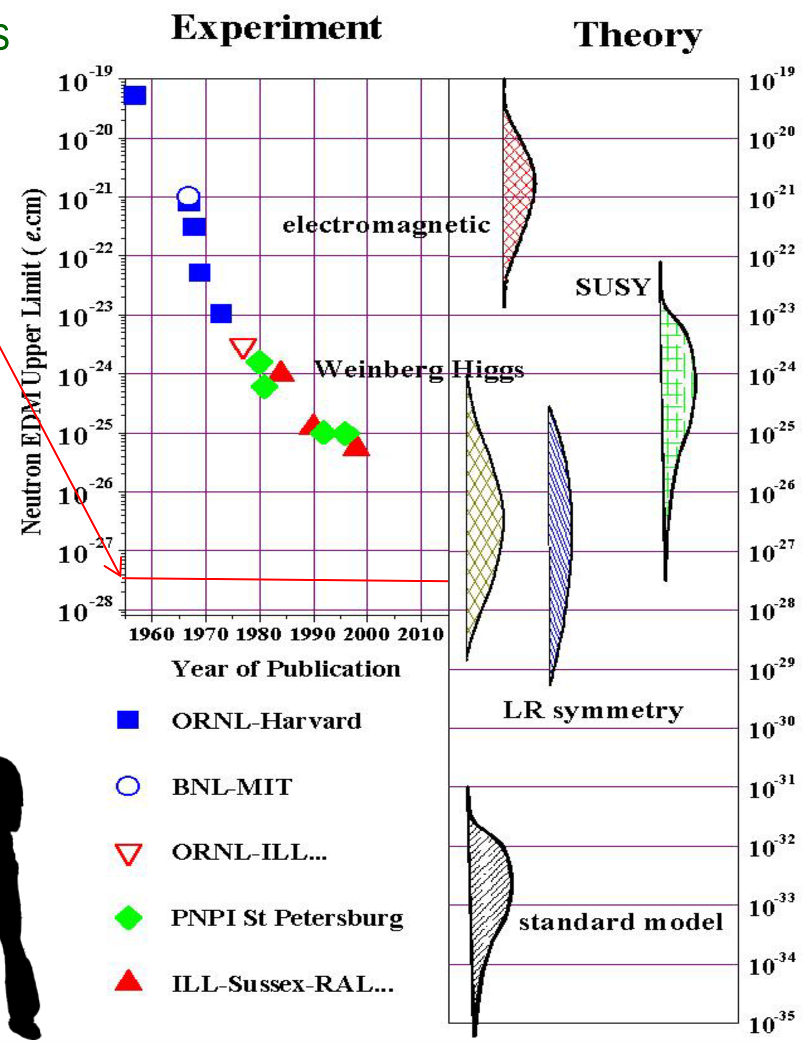
Fundamental Symmetries Using Neutrons

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

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

Developed ATTA-3 instrument with greatly improved sensitivity and selectivity

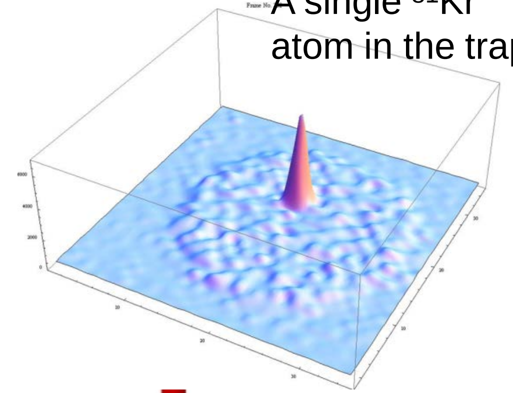
- Sensitivity: Capable of ^{81}Kr-dating with a sample of 10 micro-liter (STP) of krypton gas;
- Selectivity: Analyzed ^{39}Ar in environmental samples at the isotopic abundance level of 8×10^{-16}.

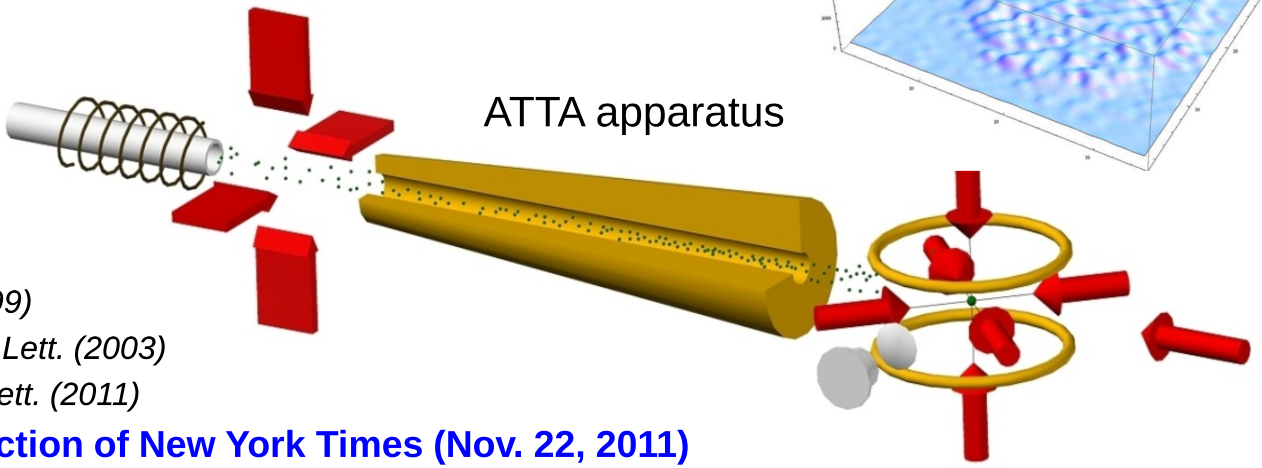
^{81}Kr-dating realized with a range of applications in earth & environmental sciences

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).

A single ^{81}Kr atom in the trap





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)**

NP Science "In The News"

The New York Times

A Rare Isotope Helps Track an Ancient Water Source

By FELICITY BARRINGER

DEA/C. SAPPA/De Agostini/Getty Images

The Dakhla Oasis in western Egypt is fed by the Nubian Aquifer.

Knowing how long water has been underground helps researchers understand how fast aquifers are recharged by surface water and how fast they move, leading to more accurate geological models. Groundwater is becoming an increasingly crucial component of the world's available fresh water, and the findings could significantly increase understanding of how it behaves. …

The Nubian Aquifer, the font of fabled oases in Egypt and Libya, stretches languidly across 770,000 square miles of northern Africa, a pointillist collection of underground pools of water migrating, ever so slowly, through rock and sand toward the Mediterranean Sea.

The aquifer is one of the world's oldest. But its workings — how it flows and how quickly surface water replenishes it — have been hard to understand, in part because the tools available to study it have provided, at best, a blurry image.

Now, to solve some of the puzzles, physicists at the Department of Energy's Argonne National Laboratory in Illinois have turned to one of the rarest particles on earth: an elusive radioactive isotope usually ricocheting around in the atmosphere at hundreds of miles an hour.

Their first success was in distilling these elusive isotopes, krypton 81, from the water in the huge Nubian Aquifer, part of which lies two miles below the oases of western Egypt where temples honor Alexander the Great. Their second was in holding these isotopes still and measuring how much they had decayed since they last saw sunlight.

…..

Nuclear Theory

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

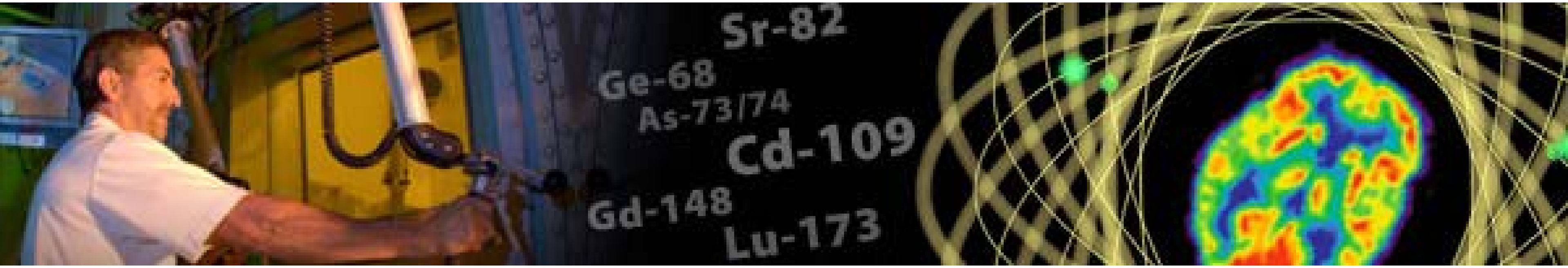
A strong Nuclear Theory effort:

- Poses scientific questions and presents new ideas that potentially lead to discoveries and 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 and interprets the results

A successful new approach for NP—Theory Topical Collaborations are fixed-term, multi-institution collaborations established to investigate a specific topic

- “A new direction to enhance the research effort by bundling scientific strength and expertise located at different institutions to reach a broader scientific goal for the benefit of the entire nuclear science community… an extremely promising approach for funding programmatic and specific science goal oriented research efforts.”

Isotope Program Mission



The mission of the DOE Isotope Program is threefold

- Produce and/or distribute radioactive and stable isotopes that are in short supply, associated byproducts, surplus materials and related isotope services.
- Maintain the infrastructure required to produce and supply isotope products and related services.
- Conduct R&D on new and improved isotope production and processing techniques which can make available new isotopes for research and applications.

Produce isotopes that are in short supply only –
the Isotope Program does not compete with industry

The NP Isotope Program Continues 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
Spectrum Techniques
Pain Therapeutics, Inc.
BOSTON MEDICAL CENTER
Linde
Alpha V
ThermoFisher SCIENTIFIC
EXCELITAS TECHNOLOGIES
CIL
SANDERS MEDICAL
Medical Isotopes, Inc.
ALDRICH Chemistry

It Also Serves a Very Important Role in Coordination and Communication: The 2nd Workshop on Isotope Federal Supply and Demand (Sept 19-20, 2013)

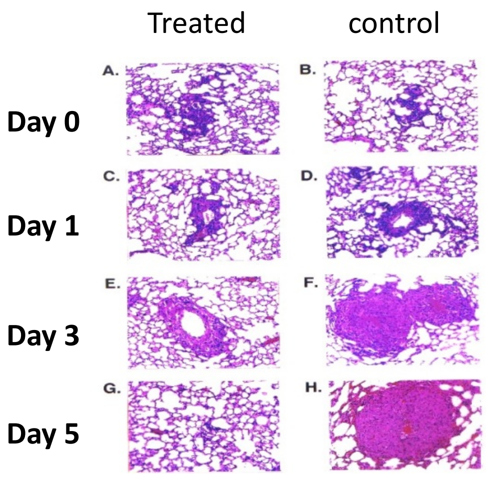
70 attendees
23 different federal institutions
Over 200 isotopes identified

- Armed Research Institute
- Defense Logistics Agency
- Defense Threat Reduction Agency
- Department of Agriculture
- DOE/National Isotope Development Center
- DOE/National Nuclear Security Administration
- DOE/New Brunswick Laboratory
- DOE/Office of Fossil Energy-Oil and Natural Gas
- DOE/Office of Intelligence
- DOE/Office of Nuclear Energy
- DOE/Office of Science
- Department of Homeland Security
- Department of State
- Department of Transportation
- Federal Bureau of Investigation
- Food and Drug Administration
- National Aeronautics and Space Administration
- National Institutes of Health
- National Institute of Standards and Technology
- National Science Foundation
- National Security Staff
- Office of Science & Technology Policy
- Office of the Director of National Intelligence

R&D Creates New Production Method for Actinium-225

- Using proton beams, LANL and BNL could match current annual worldwide production of the actinium-22 in just a few days.
- Ac-225 emits alpha radiation. Alpha particles are energetic enough to destroy cancer cells but are unlikely to move beyond a tightly controlled target region and destroy healthy cells. Alpha particles are stopped in their tracks by a layer of skin—or even an inch or two of air.

Cancer-cell culture experiment: Tumor cells treated with Ac-225 radiopharmaceutical were “cured” while untreated control cells proliferated



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

The Breadth of the Horizon for Discovery in Nuclear Science

Neutron-rich Nuclei;
Structure Of Nuclei;

Reactions in Core
Collapse Super Novae;

Super Heavy Element 117
Heavy Nuclei Formation;
Density Effects in
Nuclei;
Neutron Skins;

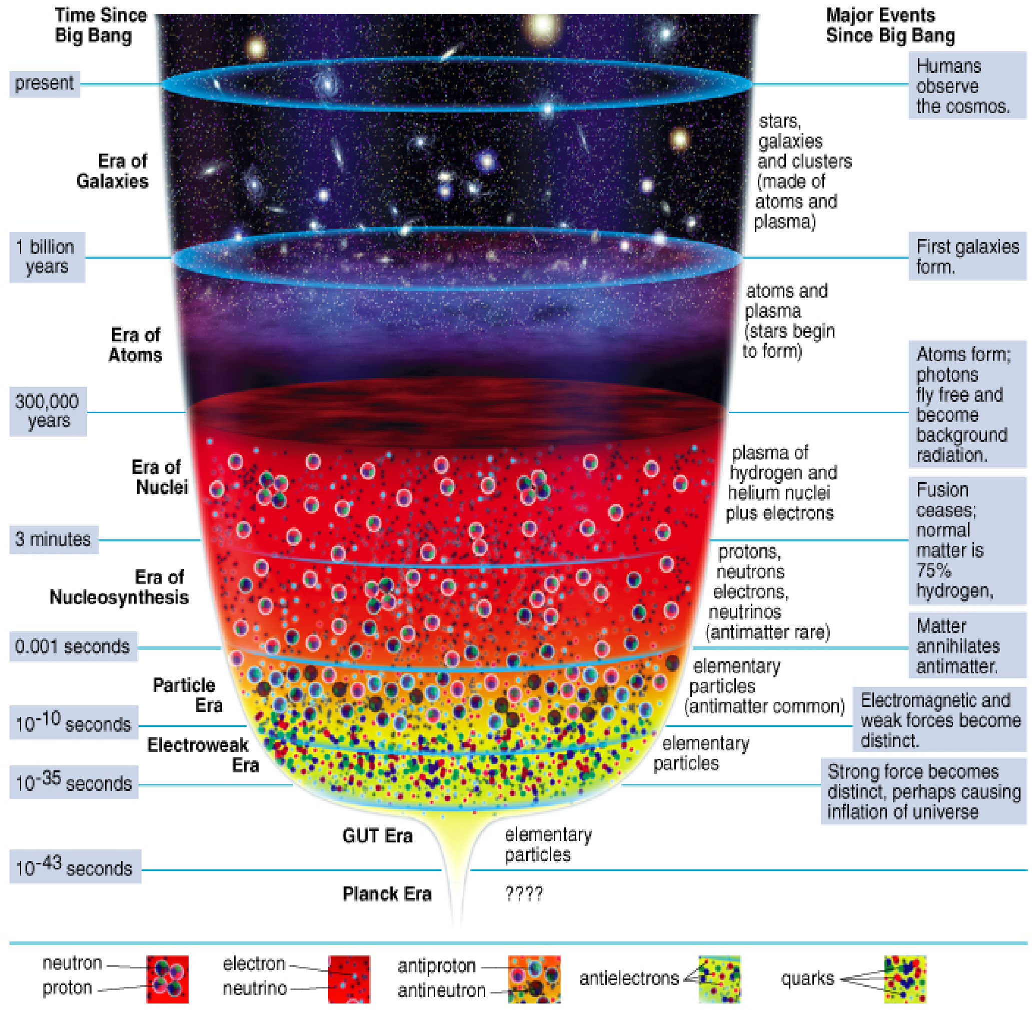
Nuclear-Reactions;

NP
Discovery
Horizon

Anti-Helium 4;
Proton Spin
Majorana/DIRAC Neutrino;
Perfect QGP Liquid

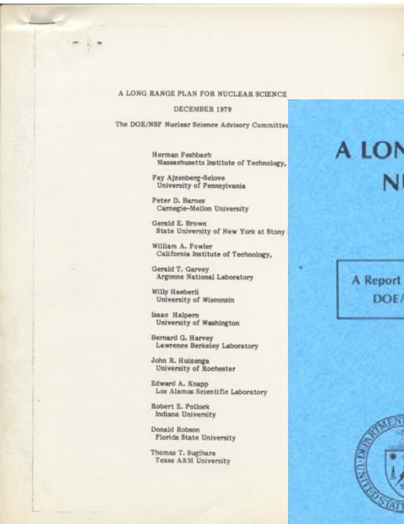
Neutron Beta Decay;
Neutron EDM;
Parity Violation
Searches;

Evolution of the Universe

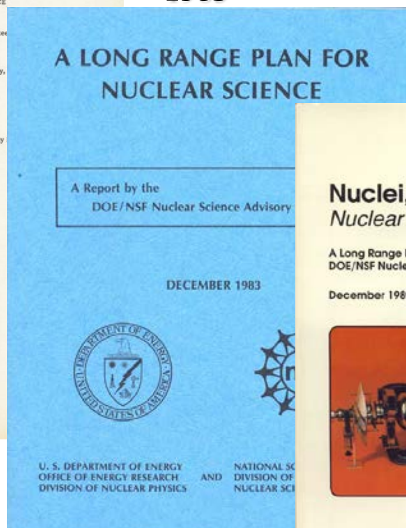


Defining the Science – Long Range Plans

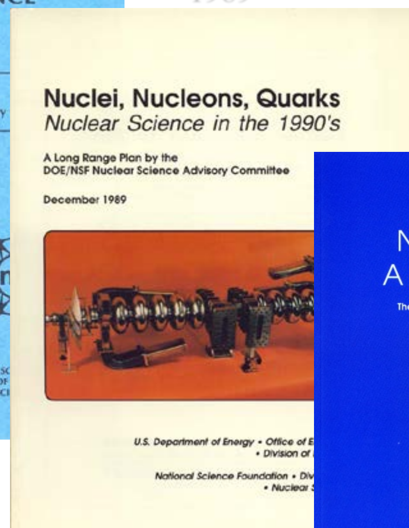
1979



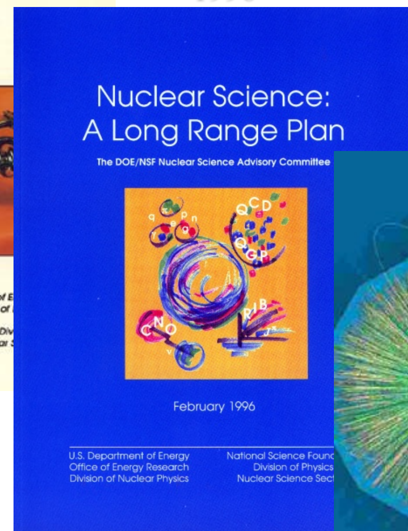
1983



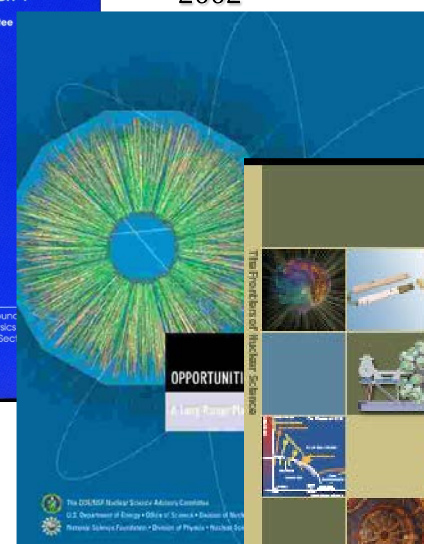
1989



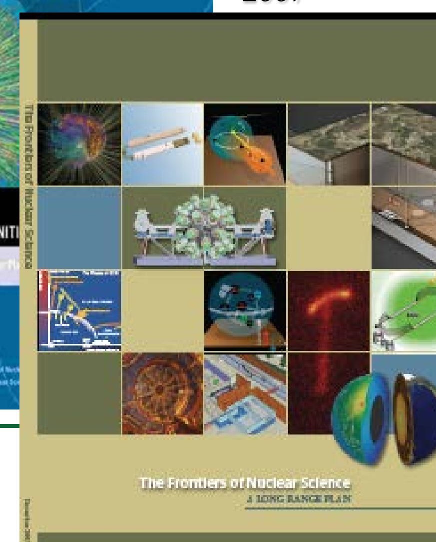
1996



2002



2007



The Long Range Plans have:

- Identified the scientific opportunities
- Recommended scientific priorities

Effectively defining the field of Nuclear Physics for the Nation

Last LRP in 2007

Nation's leadership role today is largely a result of:

- The responsible/visionary **strategic planning** embodied in the NSAC Long Range Plans
- Federal government's decision to utilize the guidance and provide the needed resources

The 2016 Long Range Plan: A Tool for Evidence-Based Planning

NSAC partnership with the Division of Nuclear Physics of the APS to tap the full intellectual capital of the US nuclear science community in identifying exciting, compelling science opportunities and a strategic plan for the next 5-10 years:

Nuclear Structure & Nuclear Astrophysics meeting *Nuclear Structure Conveners:* Mark Riley (Florida State University) and Charlotte Elster (Ohio University); *Nuclear Astrophysics Conveners:* Hendrik Schatz (Michigan State University) and Michael Wiescher (University of Notre Dame), *Venue:* Mitchell Institute, Texas A&M University, Aug. 21-23, 2014
Meeting website: http://www.lecmeeting.org/

Hadron and Heavy Ion QCD meeting, *QCD Heavy Ion Conveners:* Paul Sorensen (Brookhaven National Laboratory) and Ulrich Heinz (Ohio State University), *QCD Hadron Conveners:* Haiyan Gao (Duke University) and Craig Roberts (Argonne National Laboratory), *Venue:* Temple University, Howard Gittis Student Center, 1743 N 13th St., Philadelphia, PA 19122, Sept. 13-15, 2014
Website: https://phys.cst.temple.edu/qcd

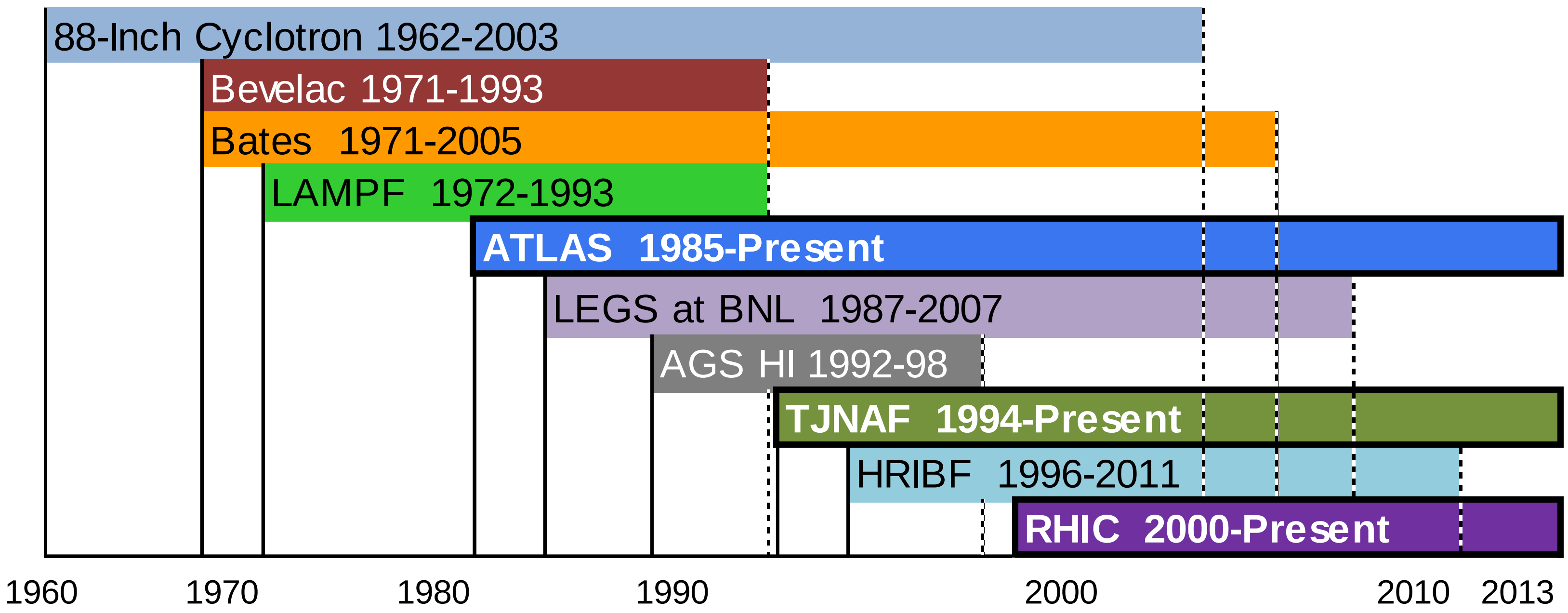
Fundamental symmetries, Neutrinos, Neutrons, and the relevant Nuclear Astrophysics, *Conveners:* Hamish Robertson (University of Washington), Michael Ramsey-Musolf (University of Massachusetts), *Dates:* Sept. 28-29, 2014
Venue: Crowne Plaza hotel near Chicago's O'Hare airport on 5440 North River Road, Rosemont, IL 60018
Website: http://fsnutown.phy.ornl.gov/fsnuweb/index.html

Nuclear Theory Computing:
High performance computing (Computation in nuclear physics), Washington DC, July 14-15, 2014

Education [NSF scope - Workforce Training in DOE] **and Innovation... across all areas of nuclear physics** *Conveners:* Michael Thoennessen (Michigan State University), Graham Peaslee (Hope College) *Venue:* NSCL, Michigan State University, Aug. 6-8, 2014; *Website:* http://meetings.nscl.msu.edu/Education-Innovation-2014

Resolution Meeting: spring of 2015 **Long Range Plan: October 2015**

Timeline of DOE Nuclear Physics Facilities



Additional Comments:

Indiana University Cyclotron Facility (begun 1978, closed 2001)

Opportunities passed over due to prioritization in the field are not shown: e.g., KAON, LISS, ORLAND

Outlook

- **The future of nuclear science in the United States continues to be rich with science opportunities.**
- **Long term, an electron-ion collider may be the optimum path towards new opportunities in QCD research.**
- **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

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?