DOE Perspectives on Frontiers, Challenges, and Opportunities for U.S. Nuclear Science

NSAC Meeting

July 16, 2015

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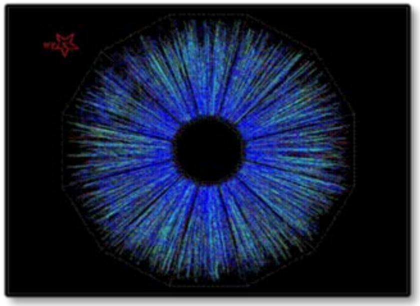
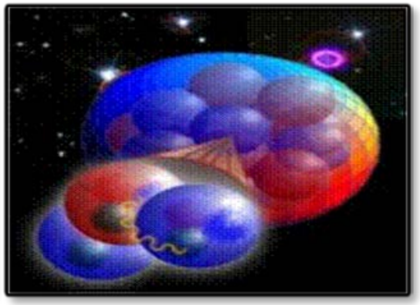
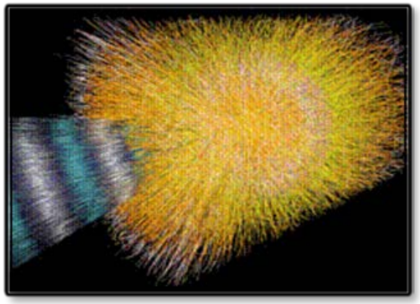
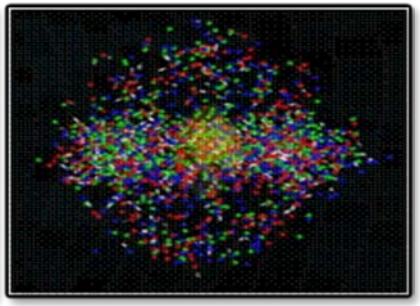
DOE Office of Science

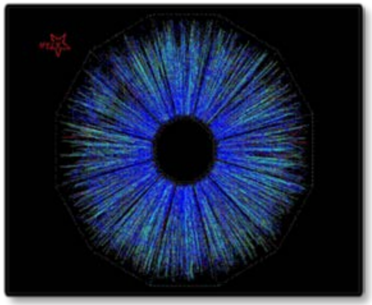





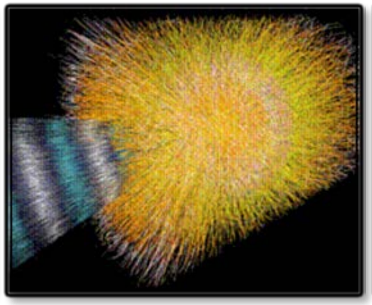
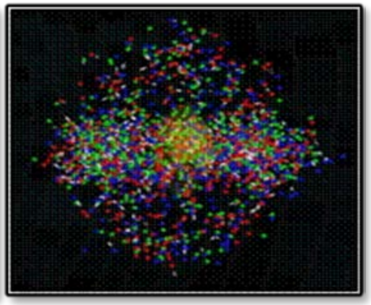
Three Broad Scientific Thrusts of Nuclear Science

Quantum Chromodynamics (QCD) seeks to develop a complete understanding of how quarks and gluons assemble themselves into protons and neutrons, how nuclear forces arise, and what forms of bulk strongly interacting matter can exist in nature, such as the quark-gluon plasma.

Nuclei and Nuclear Astrophysics seeks to understand how protons and neutrons combine to form atomic nuclei, including some now being observed for the first time, and how these nuclei have arisen during the 13.8 billion years since the birth of the cosmos.

Fundamental Symmetries of neutrons and nuclei seeks to develop a better understanding of fundamental interactions by studying the properties of neutrons and targeted, single focus experiments using nuclei to study whether the neutrino is its own anti-particle.



DOE NP Supported Research and Operations in the U.S. Nuclear Physics Program

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

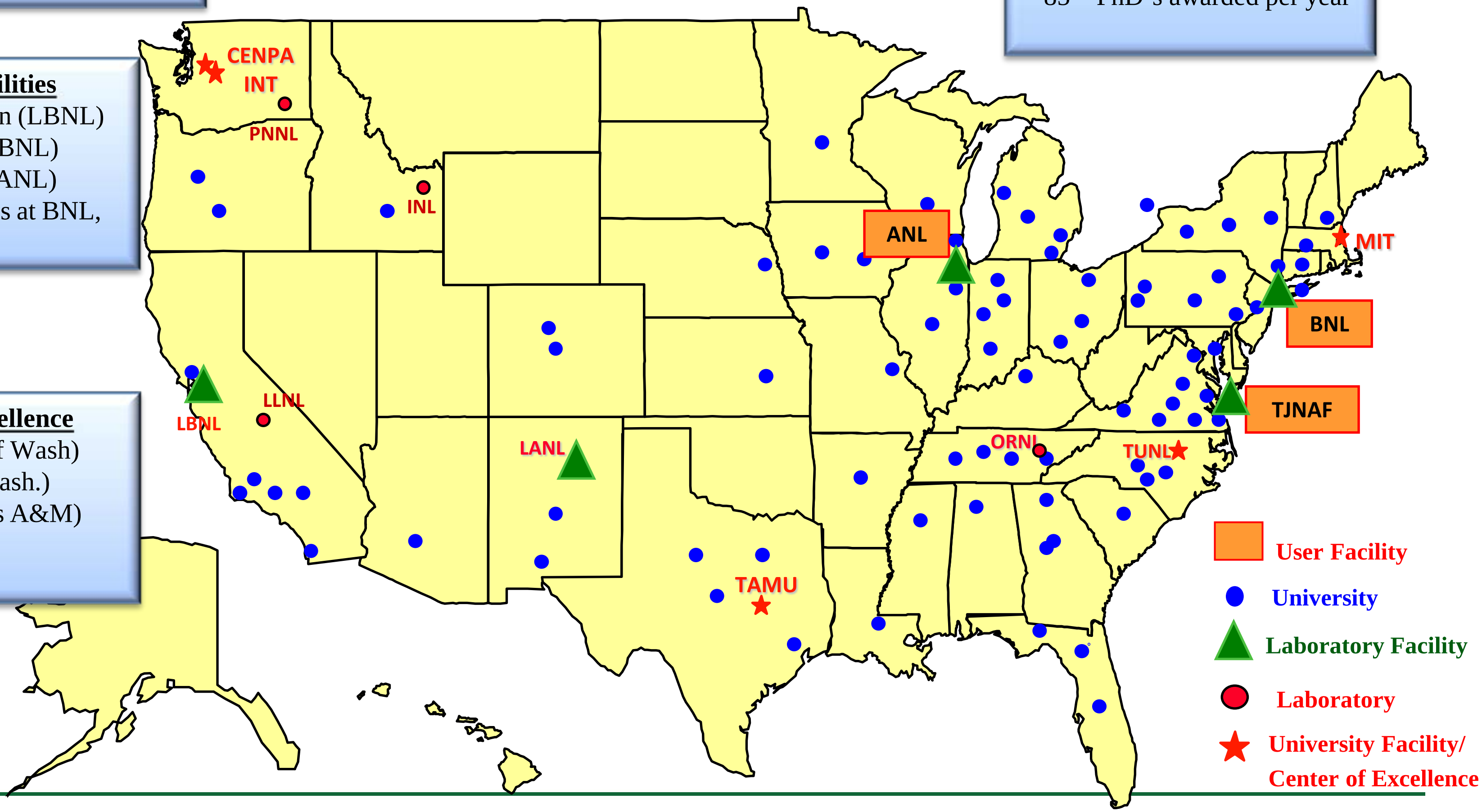
Research Groups
- 9 National Laboratories
- 85 Universities

NP Research Workforce

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

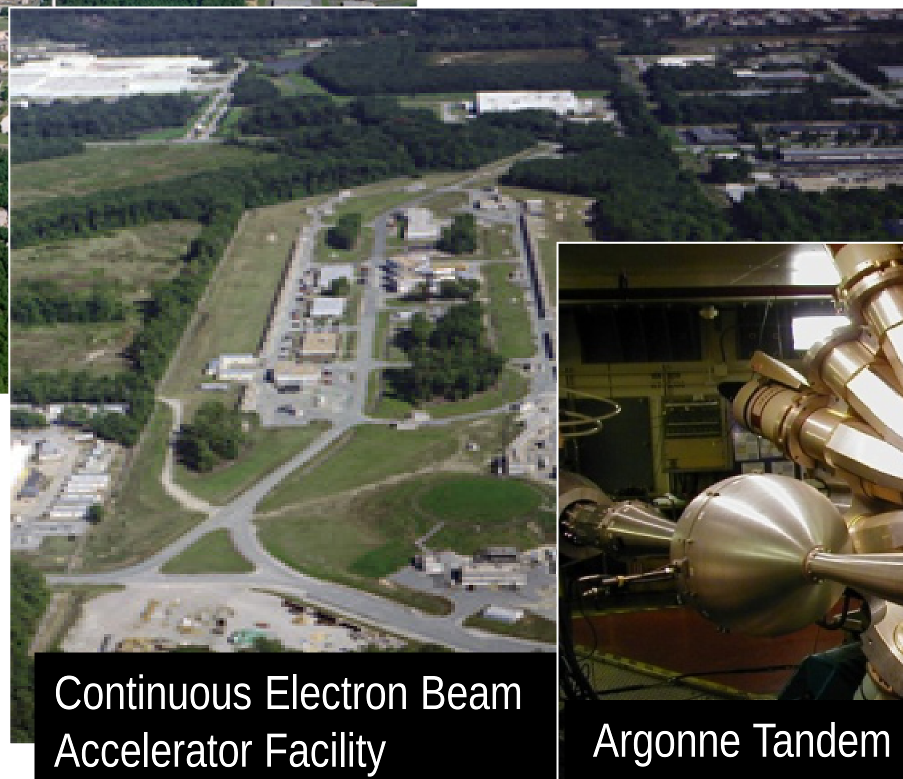
Other Lab. Facilities
- 88-Inch Cyclotron (LBNL)
- 200 MeV BLIP (BNL)
- 100 MeV IPF (LANL)
- Hot Cell Facilities at BNL, LANL, ORNL

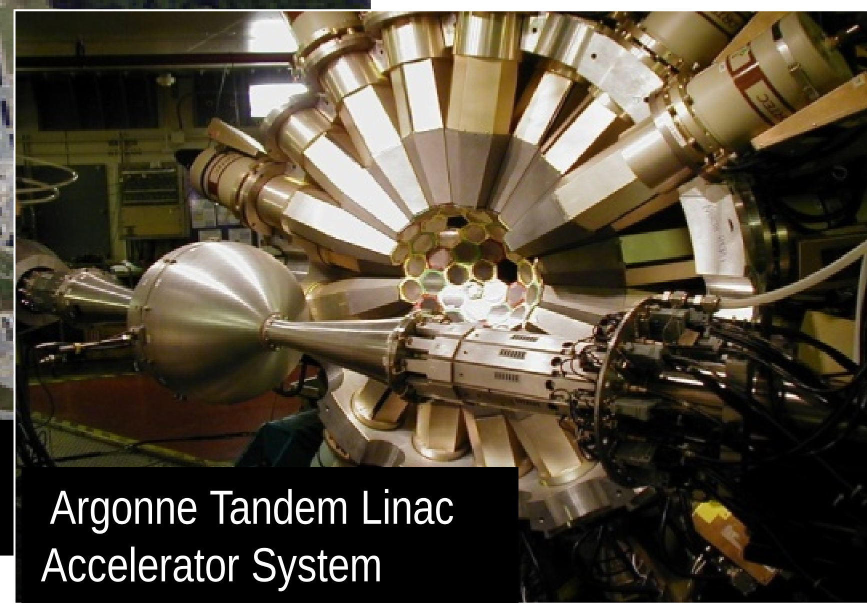
Centers of Excellence
- CENPA (U. of Wash)
- INT (U. of Wash.)
- TAMU (Texas A&M)
- TUNL (Duke)
- REC (MIT)



NP National User Facilities

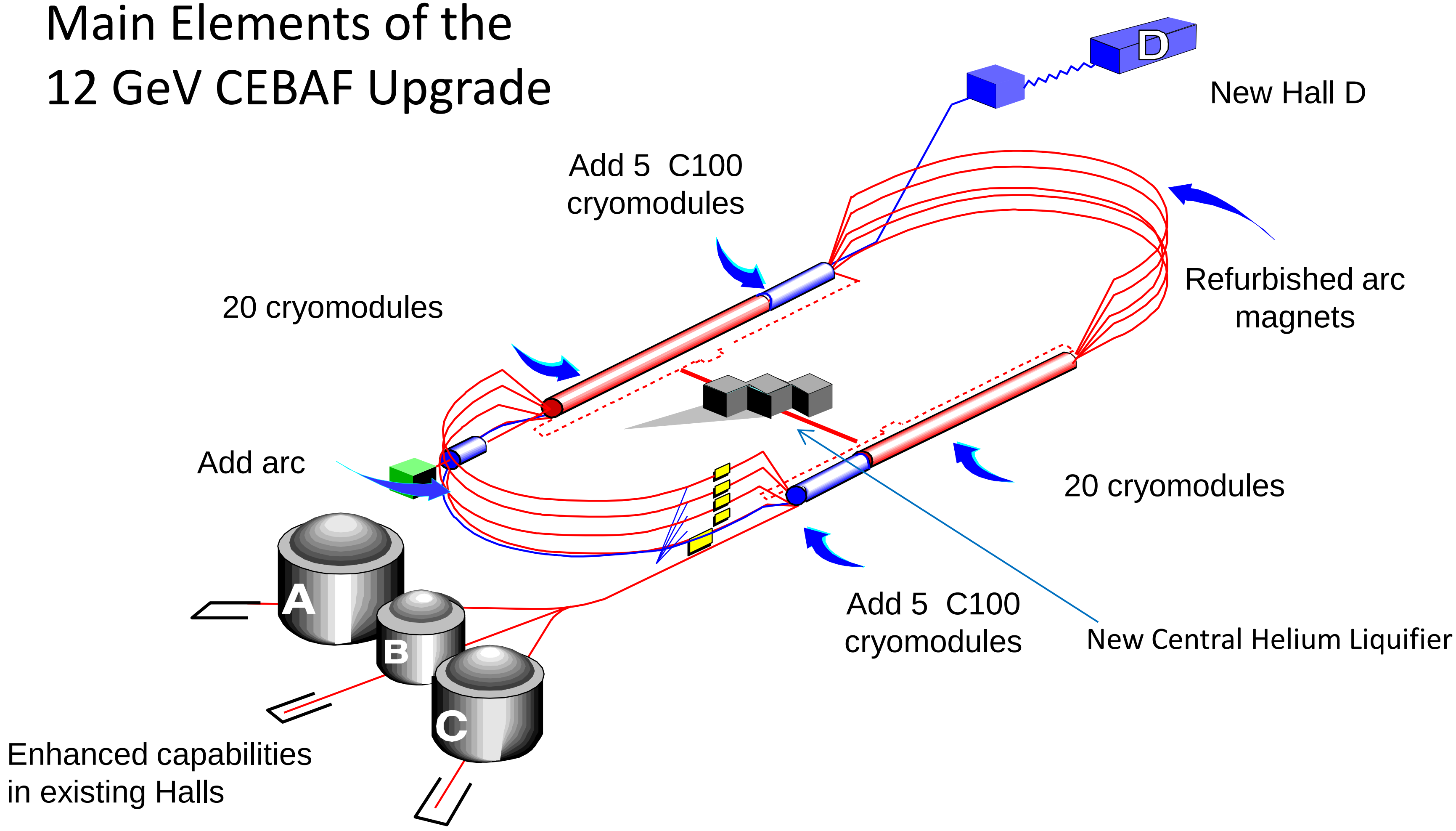
"Microscopes" pursuing groundbreaking research





CEBAF is in the Final Phases of a Major Upgrade in Energy to 12 GeV From 6 GeV

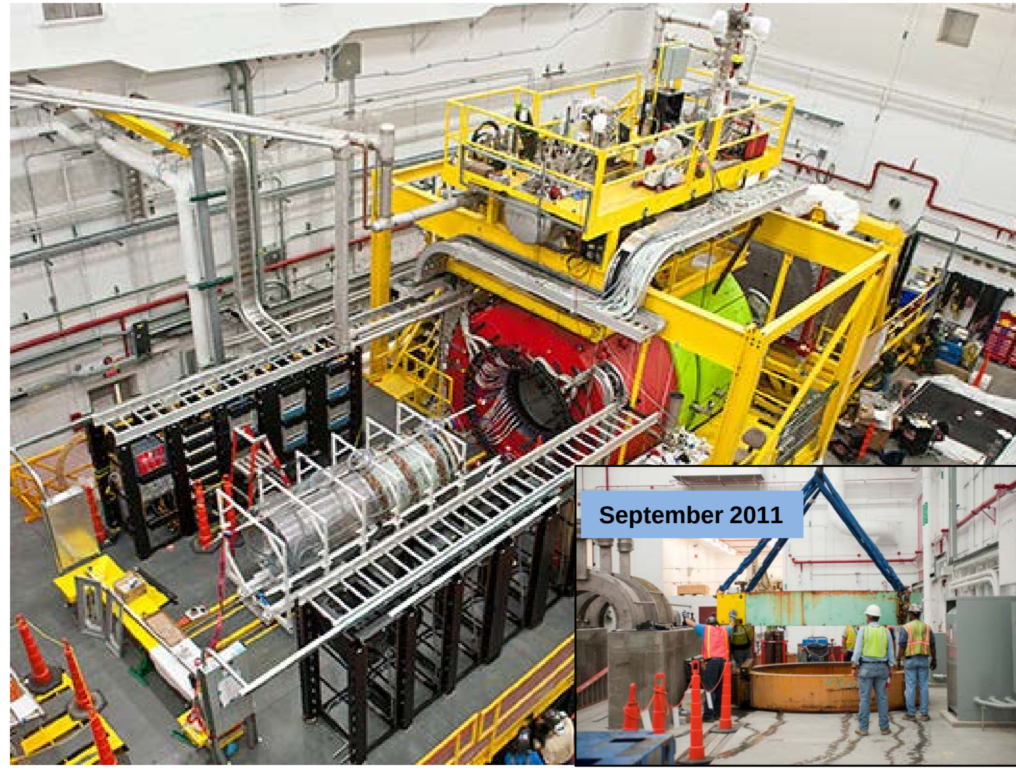
Main Elements of the 12 GeV CEBAF Upgrade

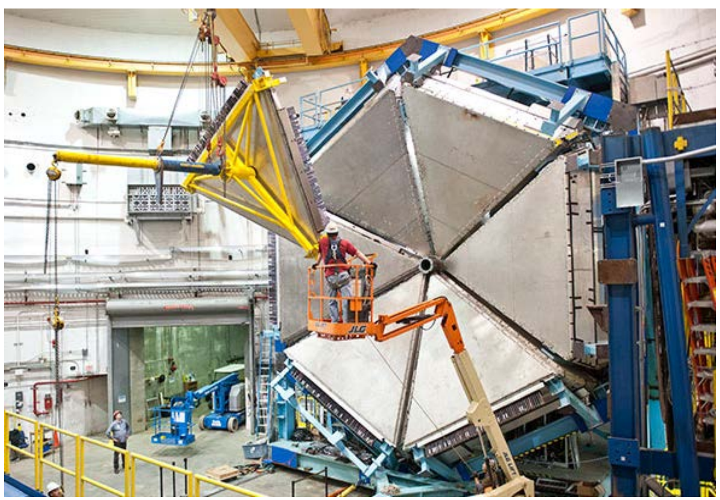


The 12 GeV CEBAF Upgrade is More Than 94% Complete

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

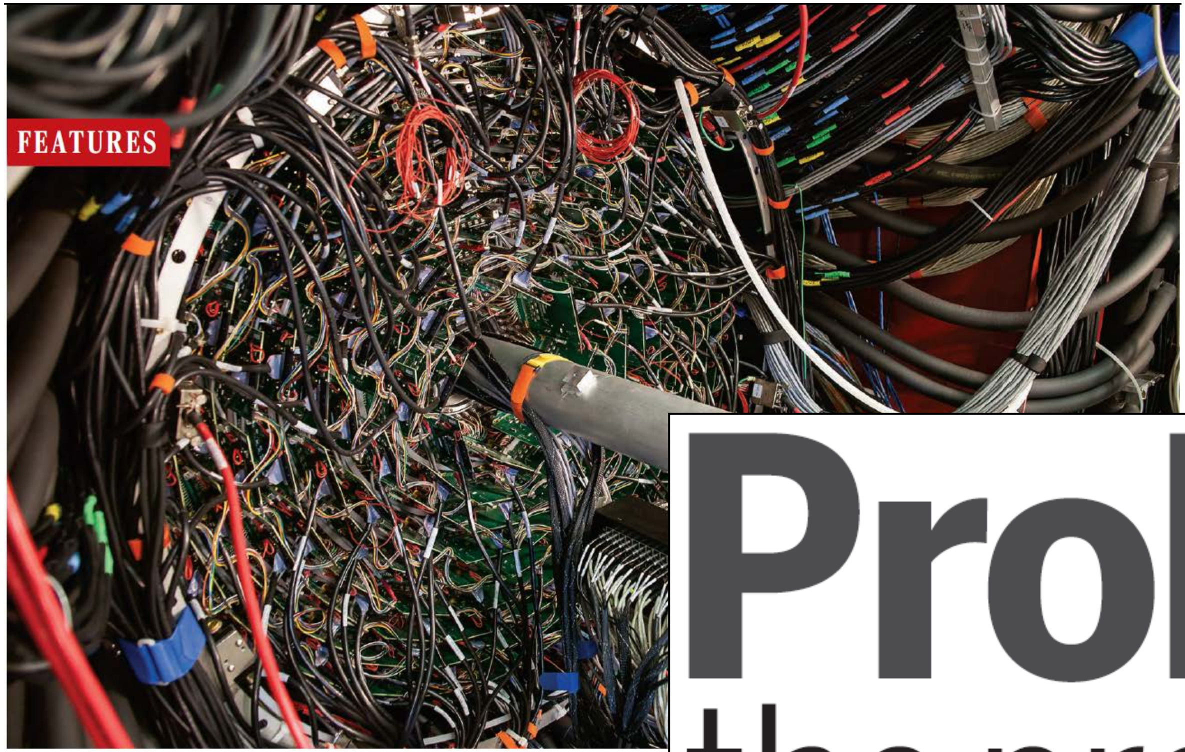




Mounting of the Forward Time-of-Flight detector arrays onto the forward carriage in Hall B

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

Great Expectations

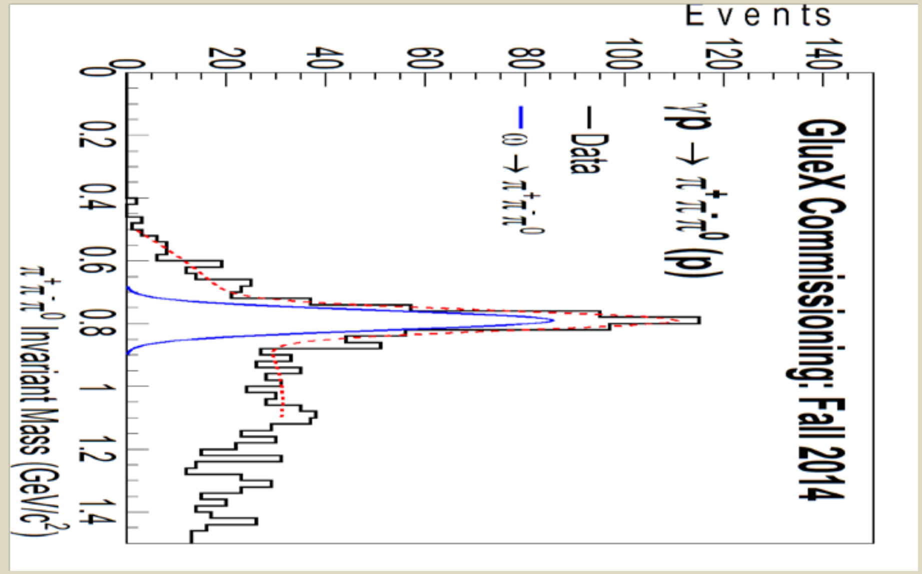


Probing the proton

A newly upgraded accelerator explores the seething maelstrom at the heart of matter

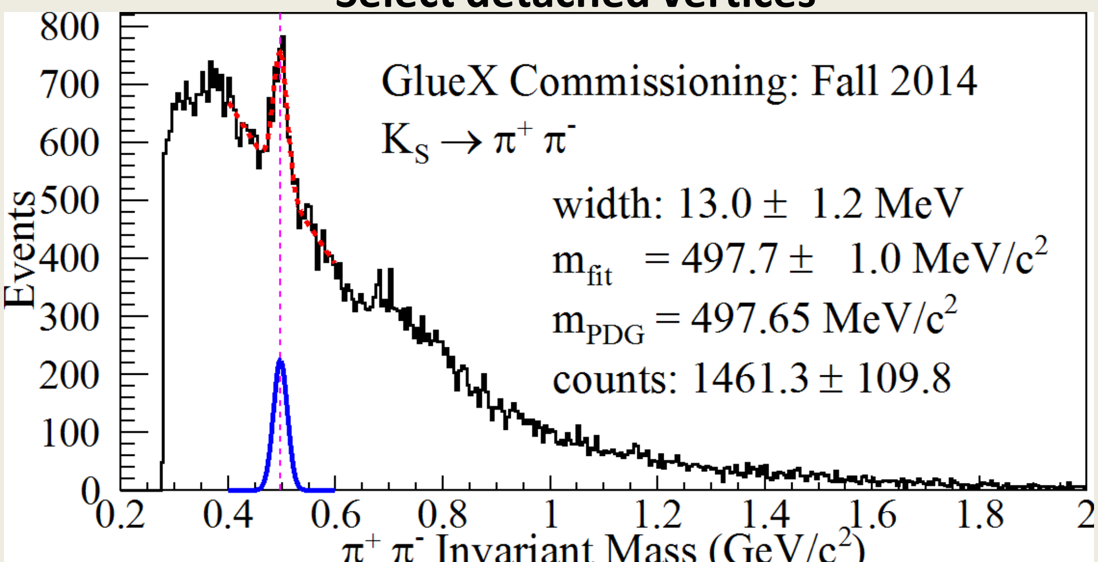
By **Adrian Cho**, *in Newport News, Virginia*

GlueX February 2015

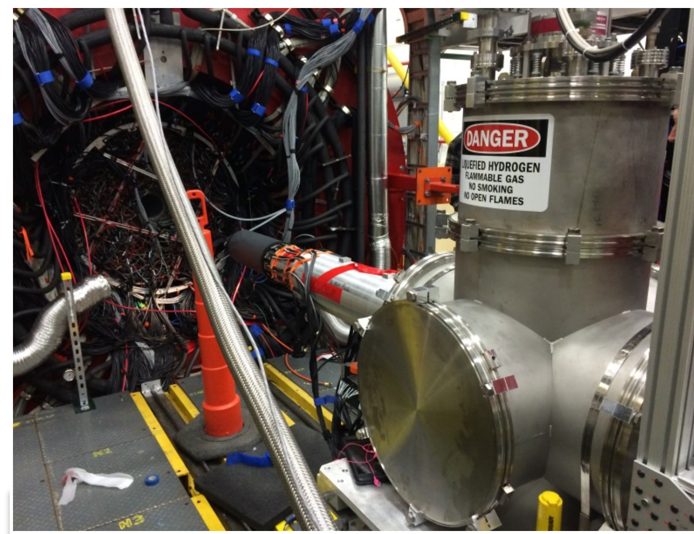


$\omega \to \pi^+\pi^-\pi^0$

Select detached vertices



$K_S \to \pi^+\pi^-$

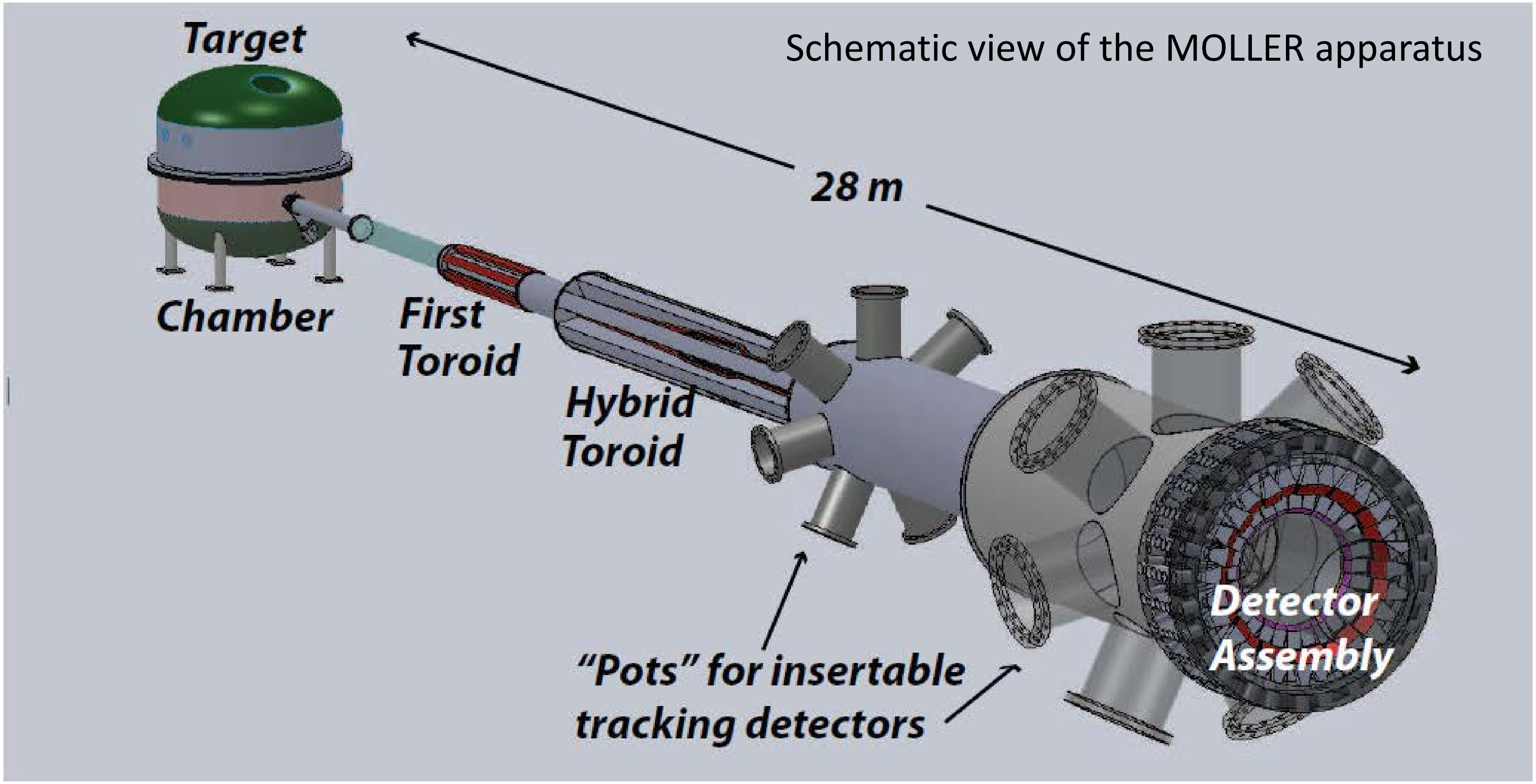


Start Counter mounted to LH2 target prior to installation in GlueX, February 2015

JLab: 21st Century Science Questions

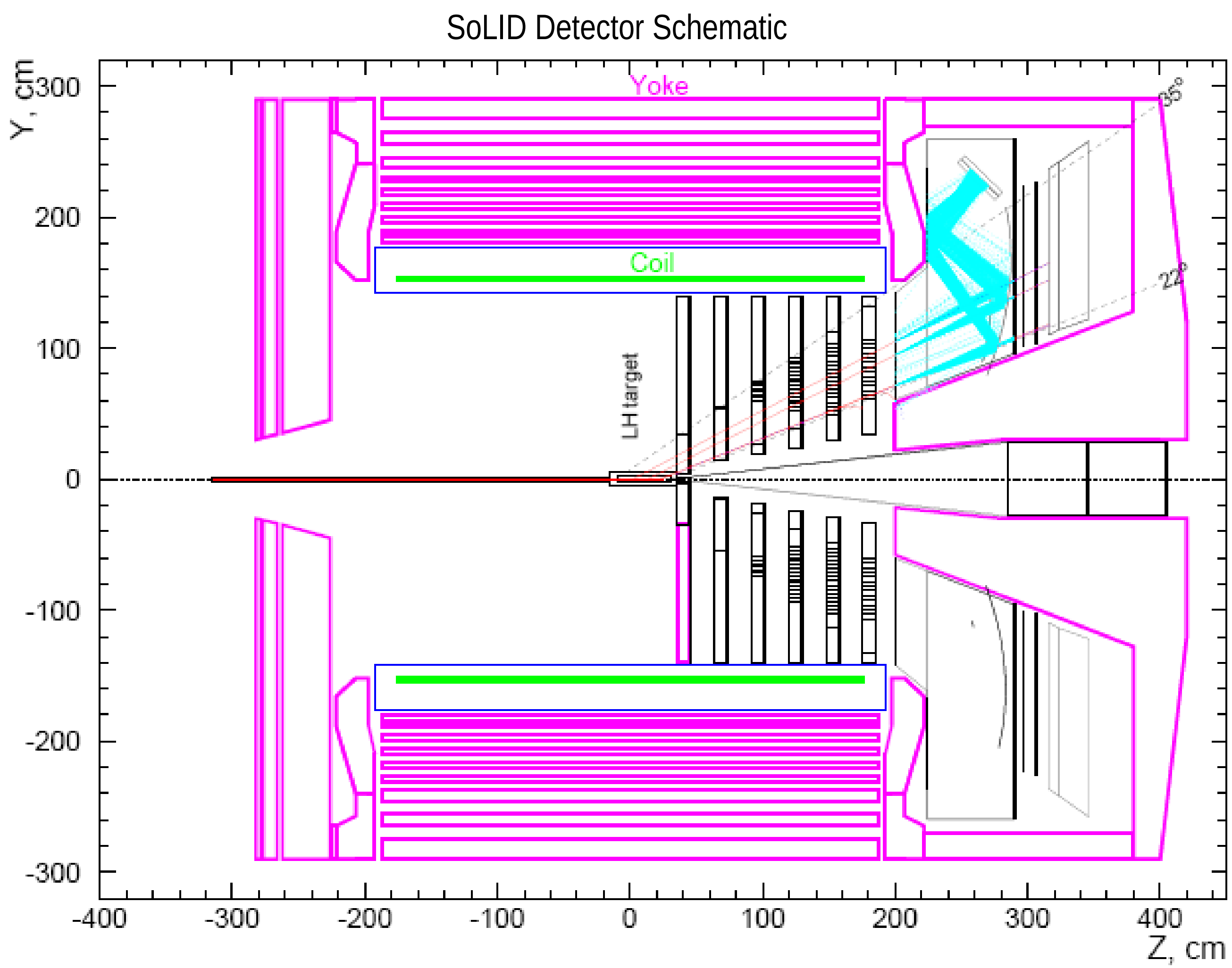
- What is the role of gluonic excitations in the spectroscopy of light mesons? Can these excitations elucidate the origin of quark confinement?
- Where is the missing spin in the nucleon? Is there a significant contribution from valence quark orbital angular momentum?
- Can we reveal a novel landscape 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?

Looking to the future



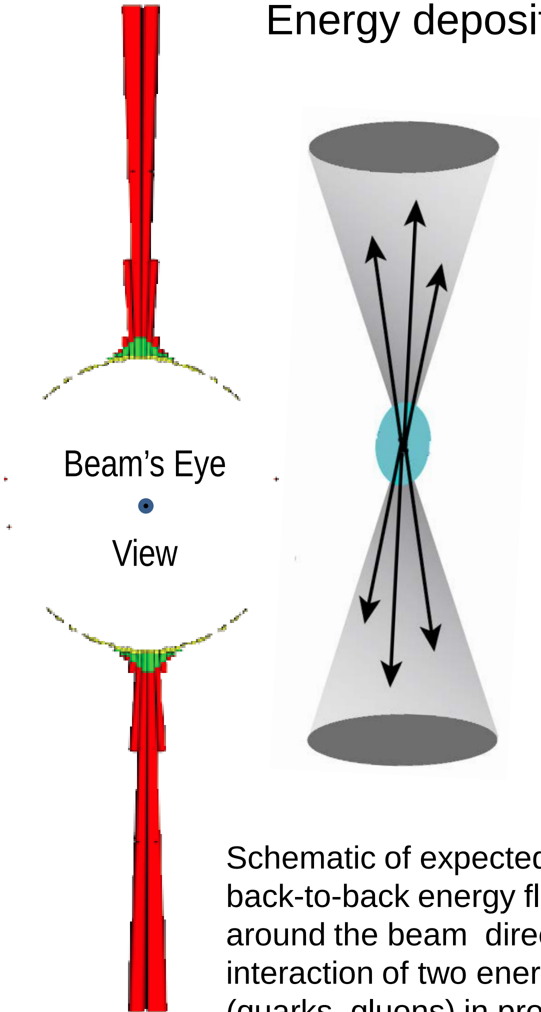
MOLLER had a successful science review. NP working to define the next steps to continue progress

Another Major New Detector Being Envisioned for JLAB 12 GeV



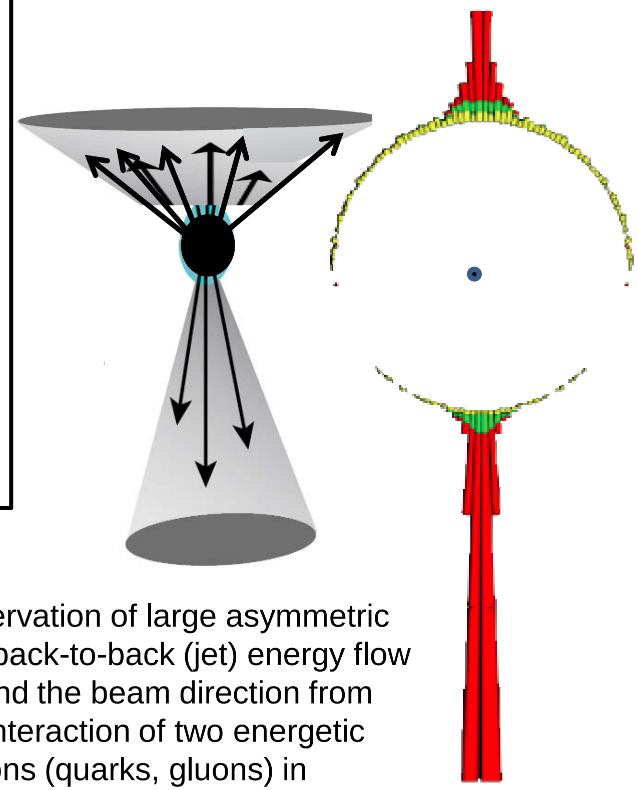
Continued research on the RHIC Discovery: The Densest, Most Strongly Interacting, Perfect Quark-Gluon Liquid Matter-- Ever

Energy deposition as a function of angle around the beam direction reveals a signature discovery: “Jet Quenching”



The 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.

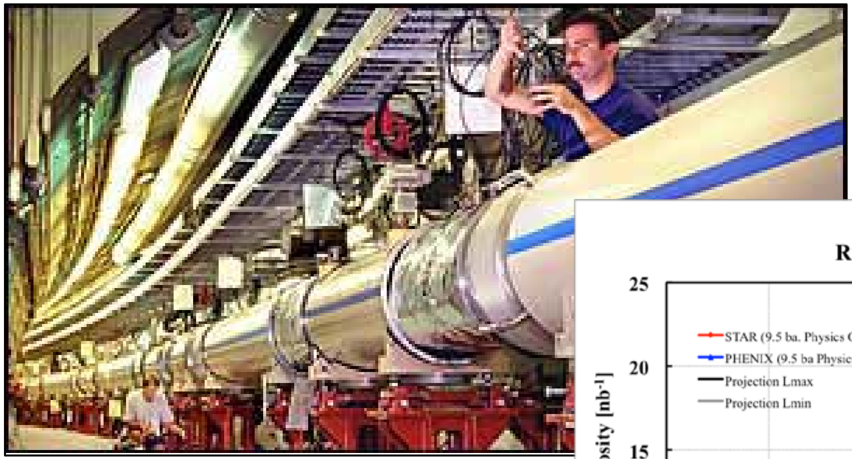
“Jets” of energetic particles that traverse the new form of matter in relativistic heavy ion collisions are completely disrupted (right) unlike in proton-proton collisions (left).



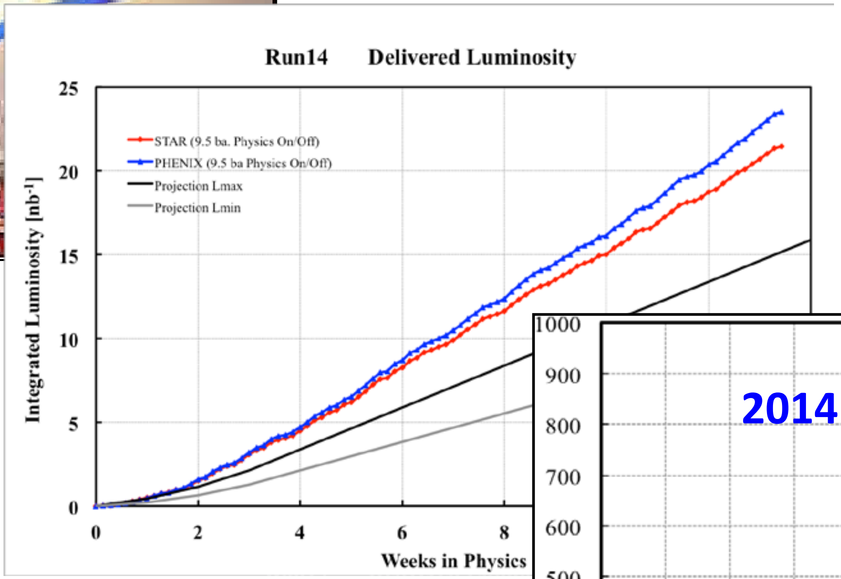
Schematic of expected symmetric back-to-back energy flow (“jets”) around the beam direction from the interaction of two energetic partons (quarks, gluons) in proton – proton collisions

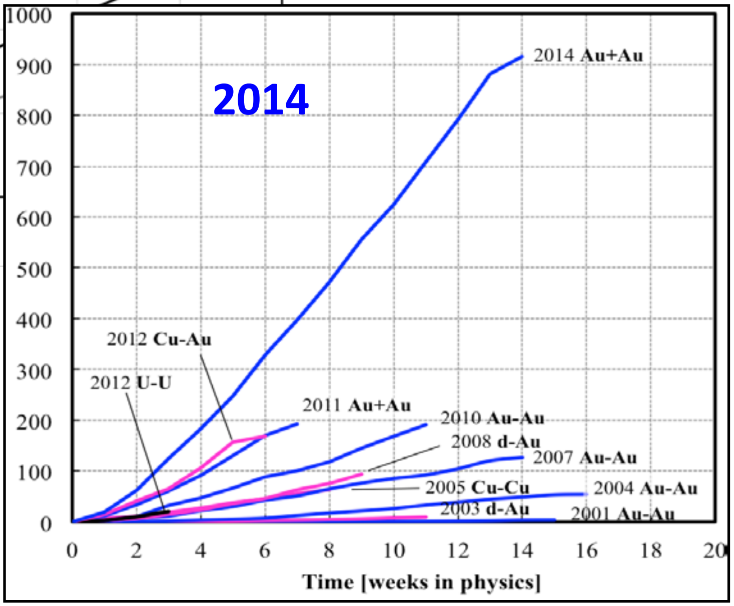
Observation of large asymmetric non back-to-back (jet) energy flow around the beam direction from the interaction of two energetic partons (quarks, gluons) in relativistic nucleus-nucleus collisions

RHIC Machine Performance Continues to Set New Records



Heavy ion runs





Au + Au integrated luminosity from Run 14 exceeded all previous Au+ Au runs combined. Run 15 was similarly successful.

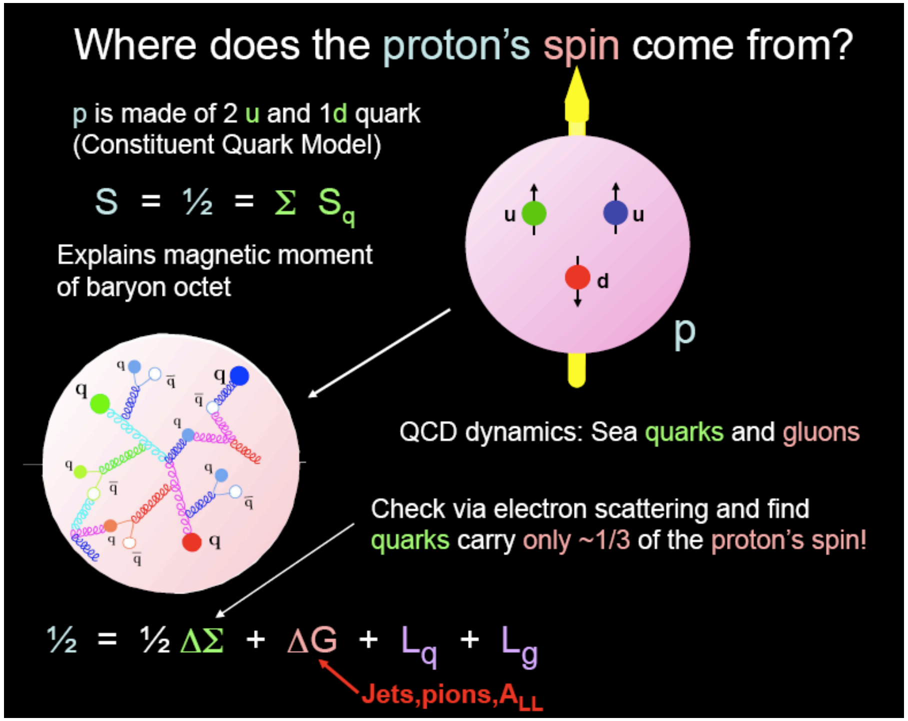
No other facility worldwide, existing or planned, can rival RHIC in range and versatility as a heavy ion collider. It is the only polarized proton collider in the world.

Main Remaining RHIC Questions

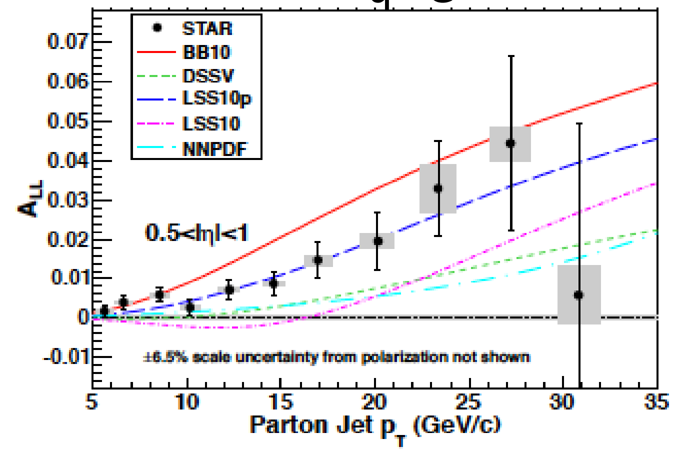
- What do we need to know about the **initial state**? Is it a weakly coupled color glass condensate? How does it thermalize?
- What do the data tell us about the **initial conditions** for the hydro-dynamic expansion? Can we determine it unambiguously?
- What is the smallest collision system that behaves **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**?

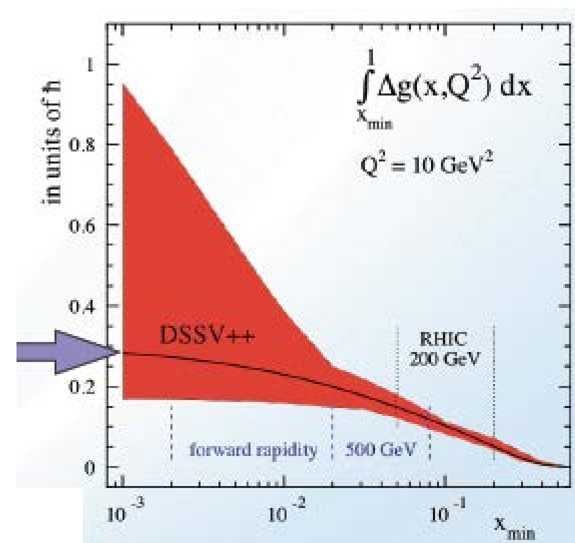
The Other Scientific Frontier at RHIC

A worldwide scientific quest:



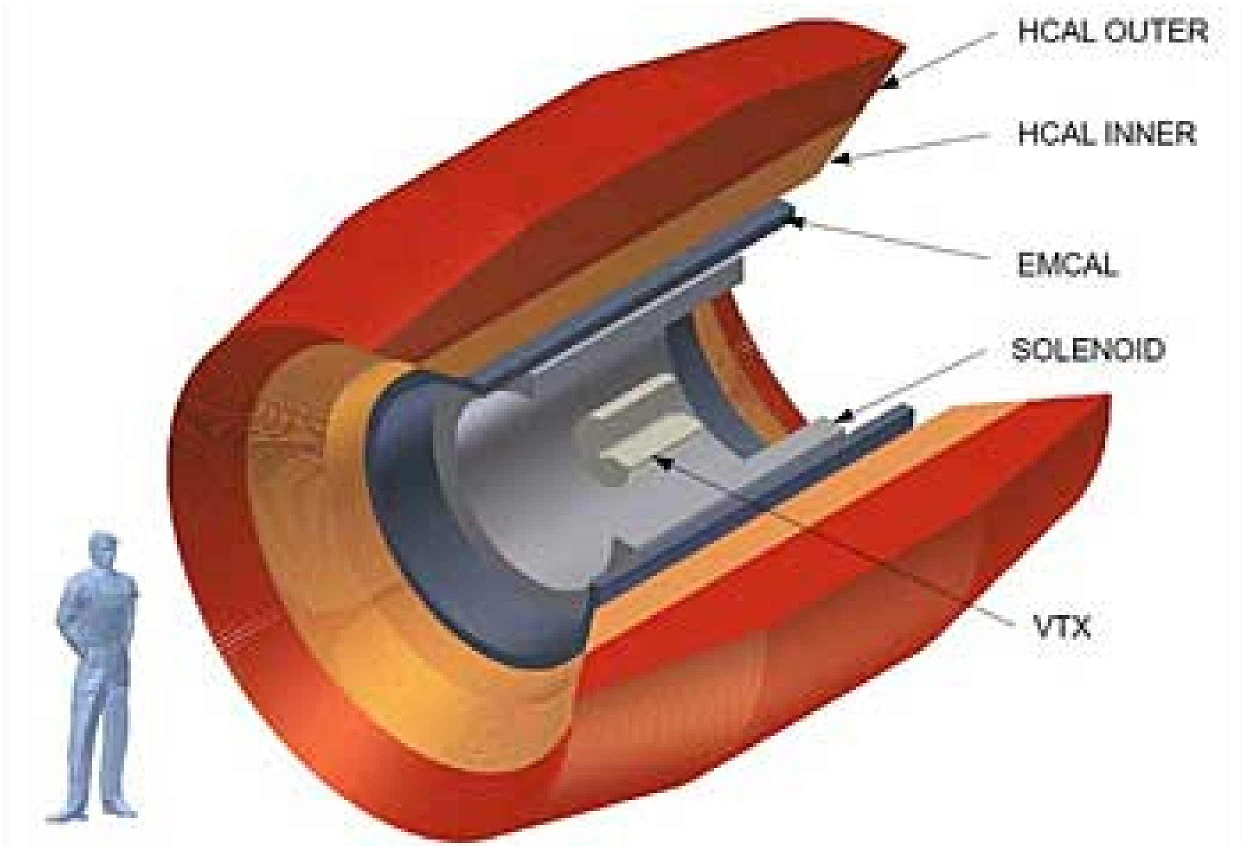
$$A_{LL} \sim \frac{\Delta q}{q}\,\frac{\Delta G}{G}$$





After almost two decades of focused study, RHIC results indicate the contribution to the proton spin is significant.

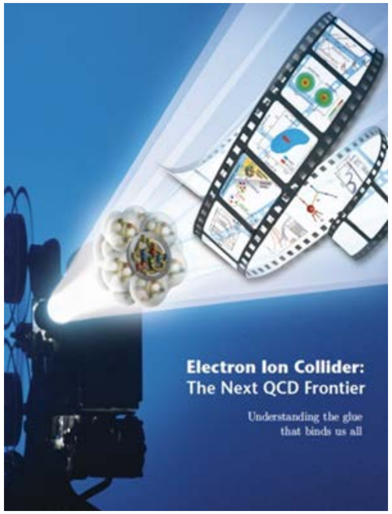
Looking Forward: Advanced Instrumentation to Help Complete the Mission

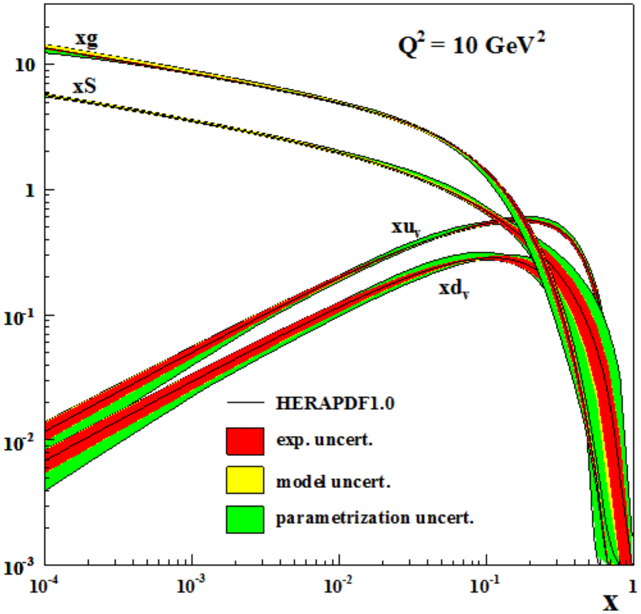


A rendering of the proposed upgrade showing the inner silicon tracker (VTX), the solenoid, and the calorimeters. The solenoid has a diameter of 1.4 m. This upgrade completed a successful science review in the spring of 2015.

The Future of QCD: Understanding the Glue That Binds Us All

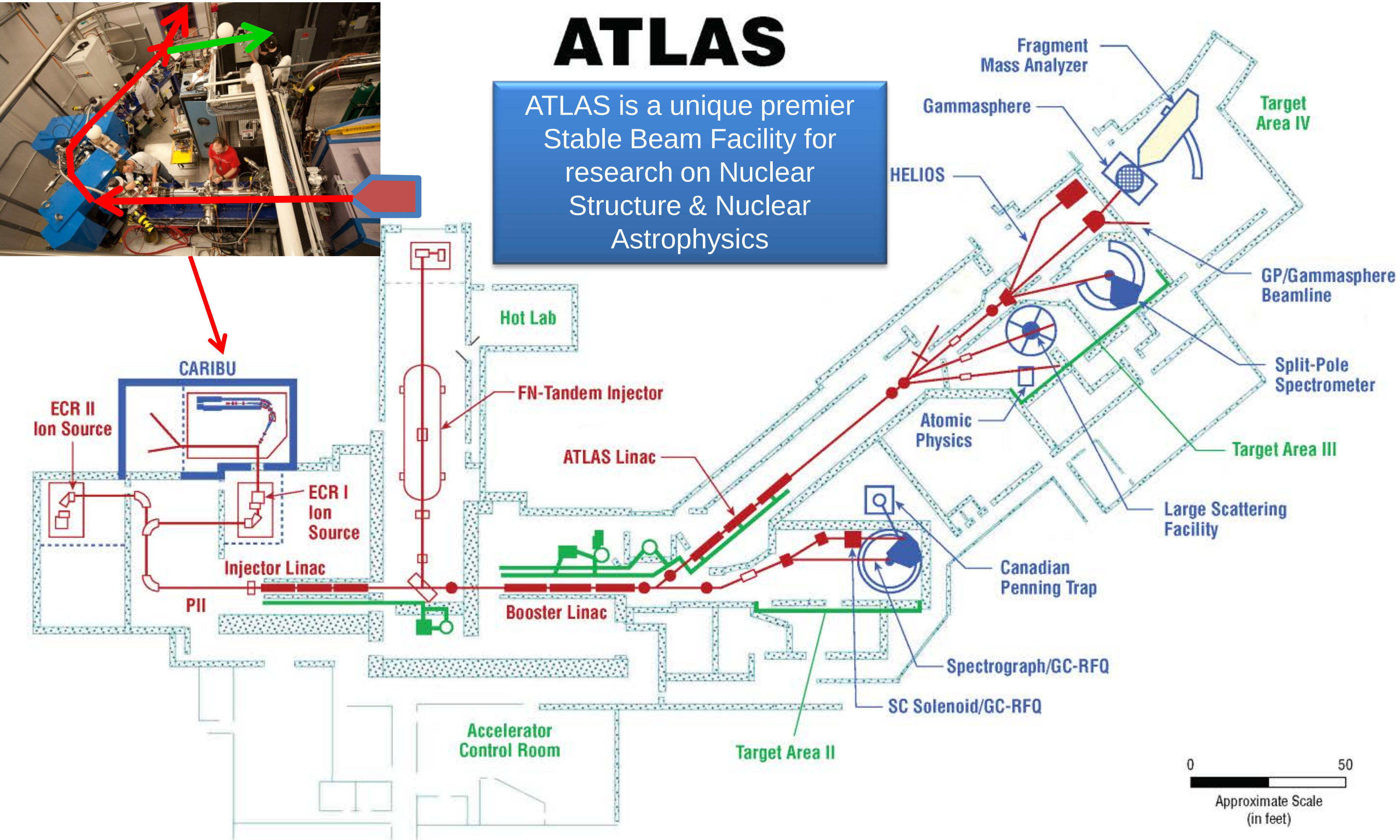
- Proton (and nuclei) and black holes are the only fully relativistic (high enough energy density to excite the vacuum) stable bound systems in the universe. Protons can be studied in the laboratory.
- Protons are fundamental to the visible universe (including us) and their properties are dominated by emergent phenomena of the self-coupling strong force that generates high density gluon fields:
  - o The mass of the proton (and the visible universe)
  - o The spin of the proton
  - o The dynamics of quarks and gluons in nucleons and nuclei
  - o 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.

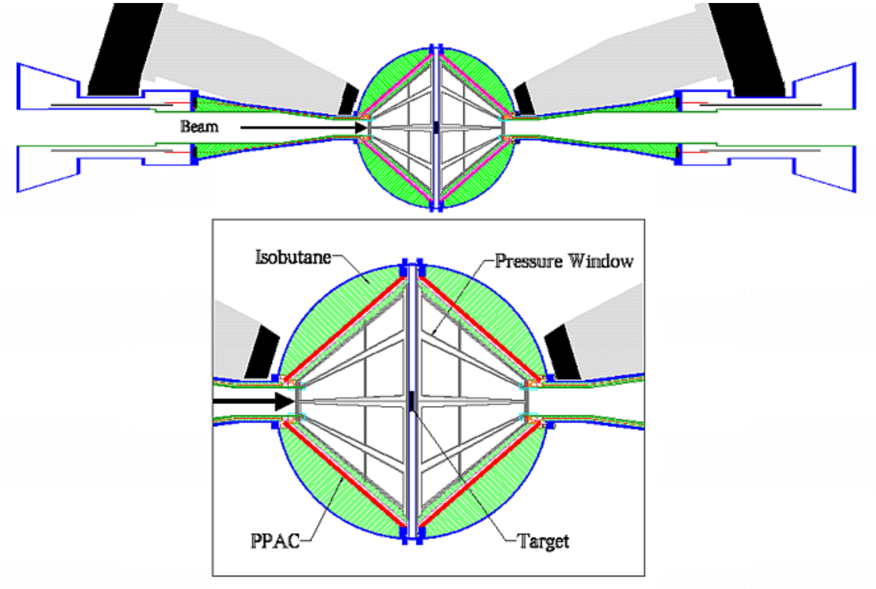
ATLAS at ANL Uniquely Provides Low Energy SC Research Opportunities



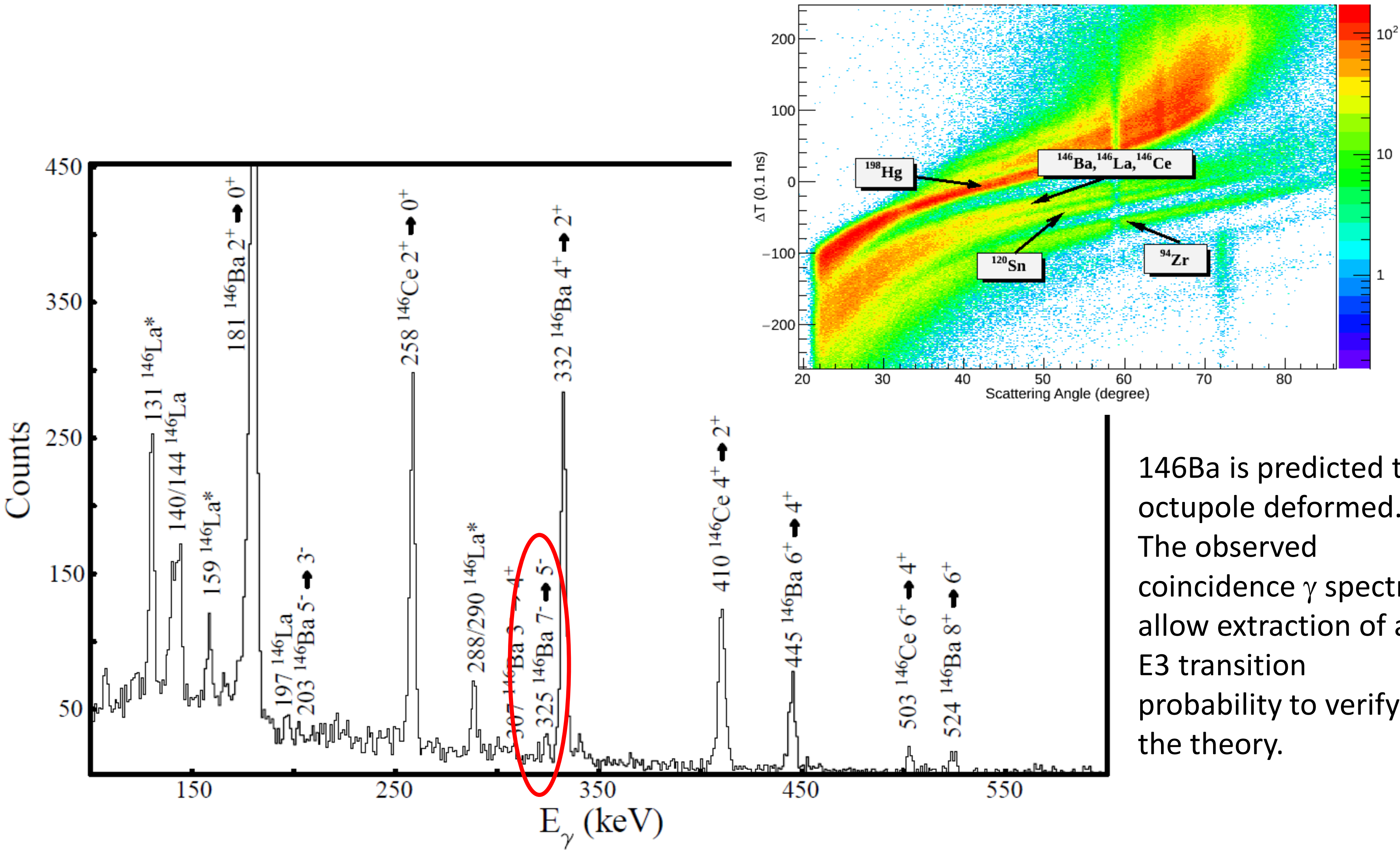
CHICO-II and GRETINA at ATLAS

Programs:

- Coulomb Excitation of stable and CARIBU beams;
- Structure studies of neutron-rich nuclei using deep-inelastic reactions;
- CHICO-II: high segmentation for both θ (1°) and φ (1.4°)
- GRETINA: about 3.50(2)% absolute efficiency at 1332.5 keV



^{146}Ba Coulomb Excitation

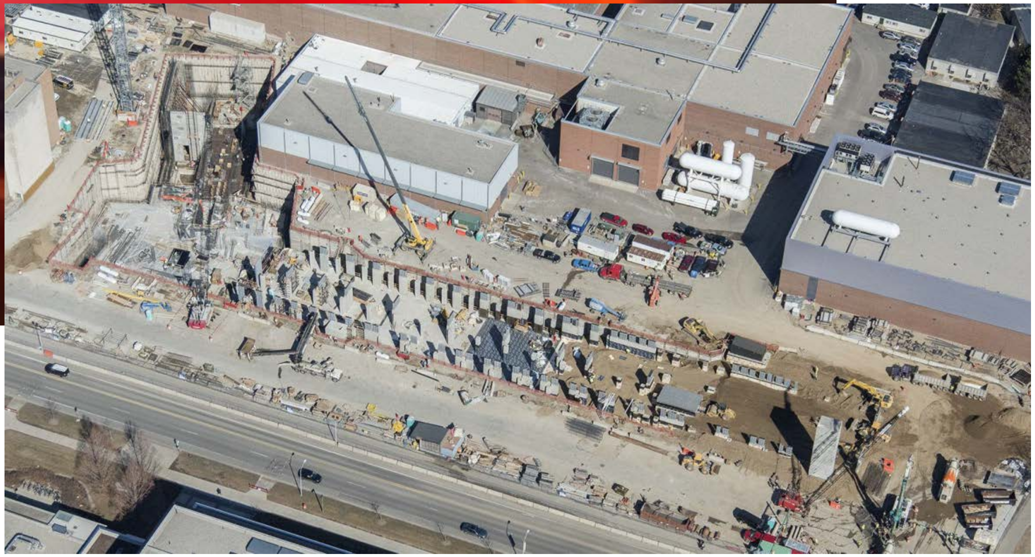


146Ba is predicted to octupole deformed. The observed coincidence γ spectra allow extraction of an E3 transition probability to verify the theory.

Facility for Rare Isotope Beams

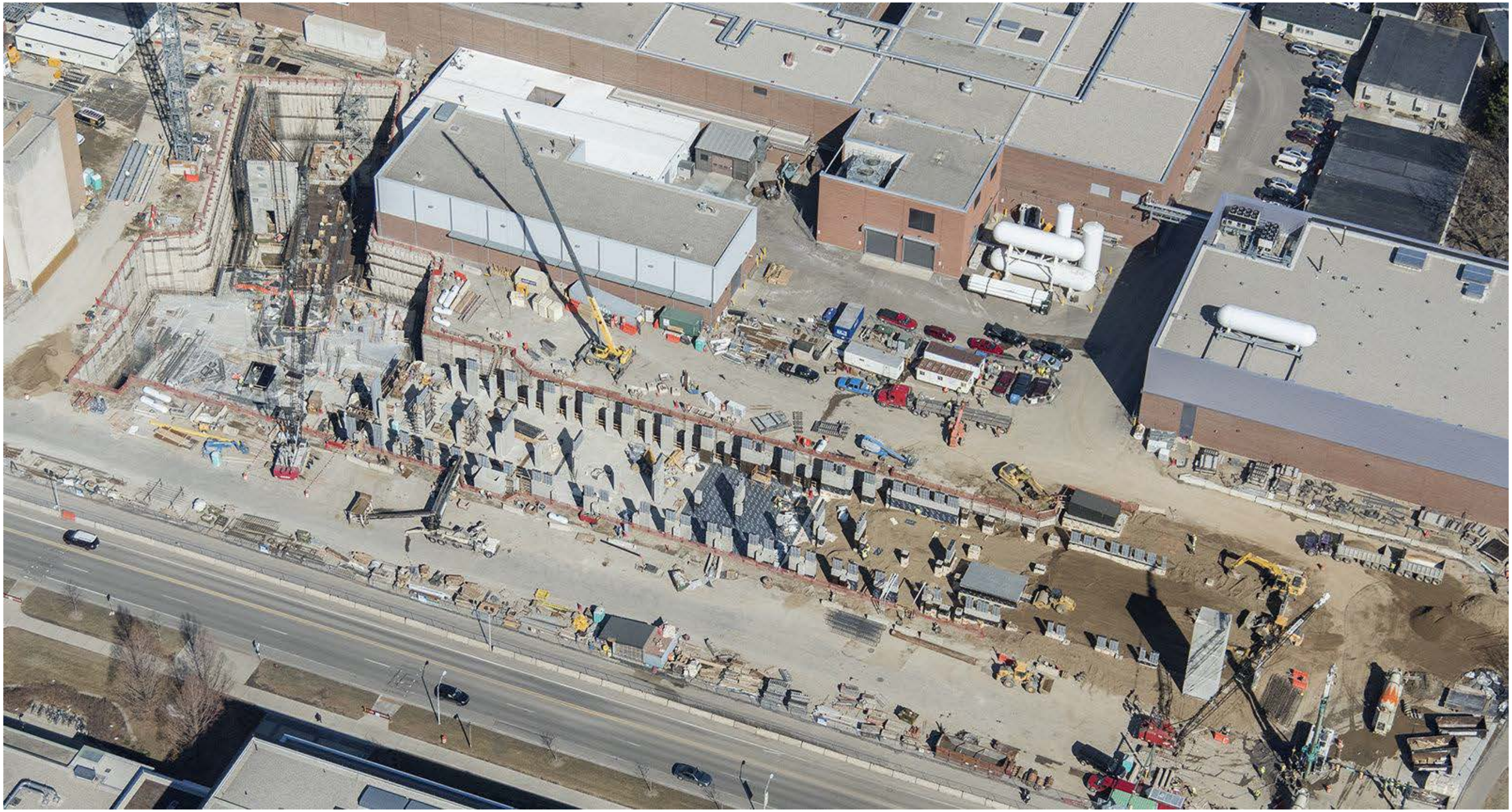
Ground breaking ceremony with participation by DOE officials and Senate and House representatives was held on March 17, 2014.

FRIB Construction is Now Like a Speeding Train



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 on the Facility for Rare Isotope Beams



A lot can happen in a year

Progress on the Facility for Rare Isotope Beams

Tunnel warm and painted

View of target area from the north

Pour for the tunnel foundation slab

First technical installation: NCU Low-level liquid waste tanks in target area

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

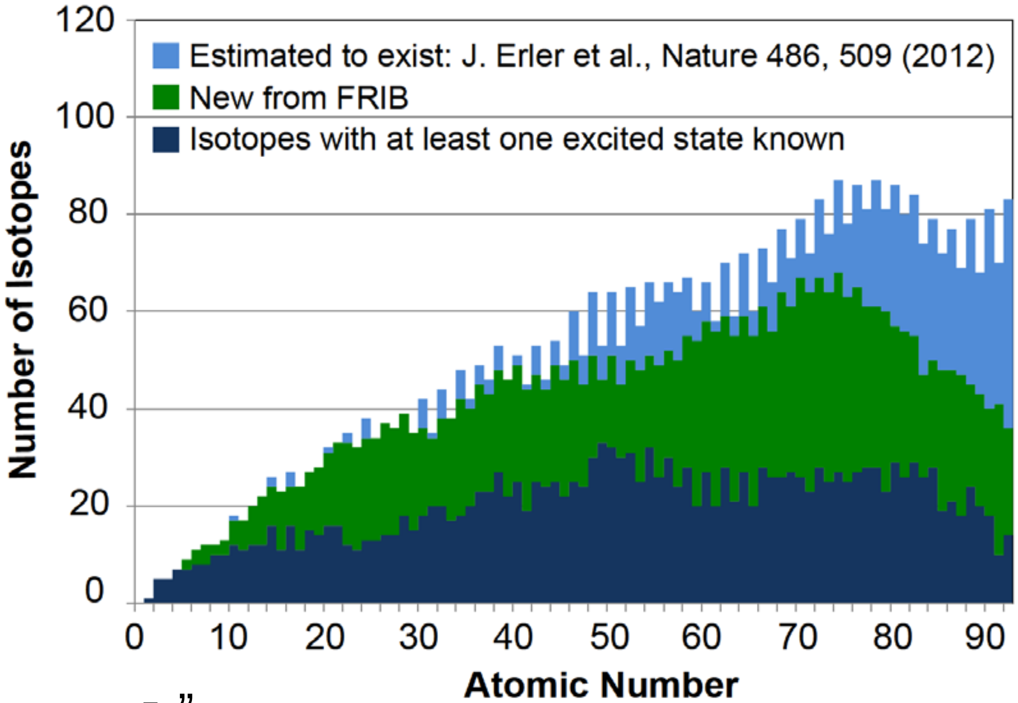
Nuclear Astrophysics

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

Fundamental Symmetries

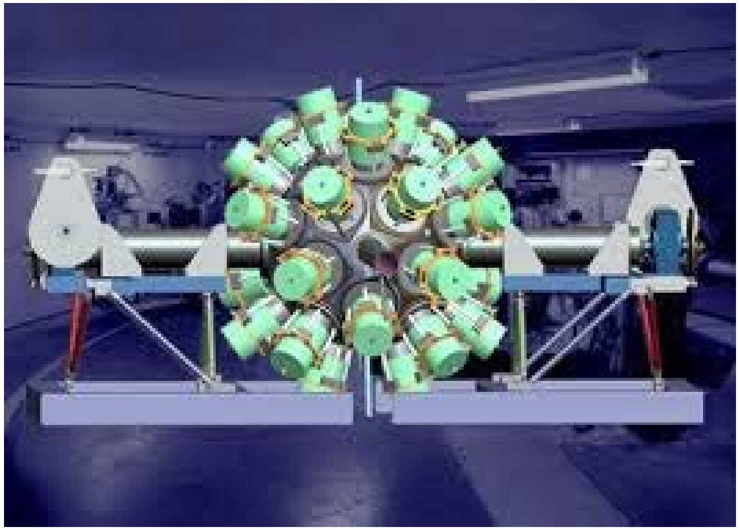
- Tests of fundamental symmetries, Atomic EDMs, Weak Charge

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

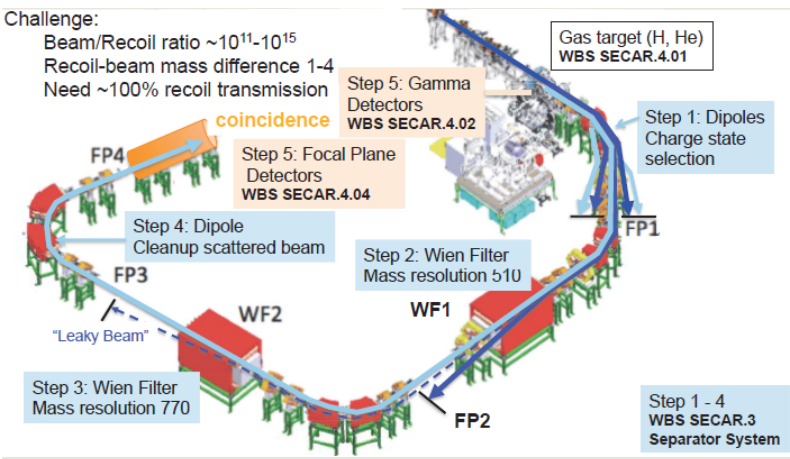


- ”
- FRIB provides access to a vast unexplored terrain in the chart of nuclides

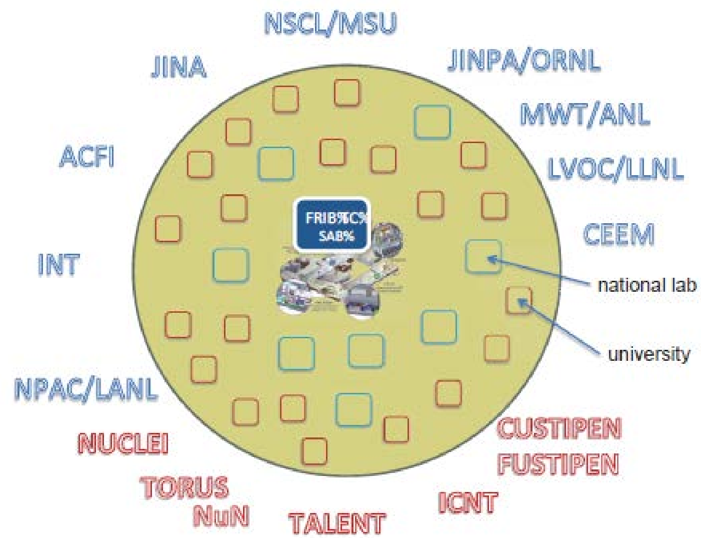
FRIB Instrumentation/Theory Effort is Just Getting Underway



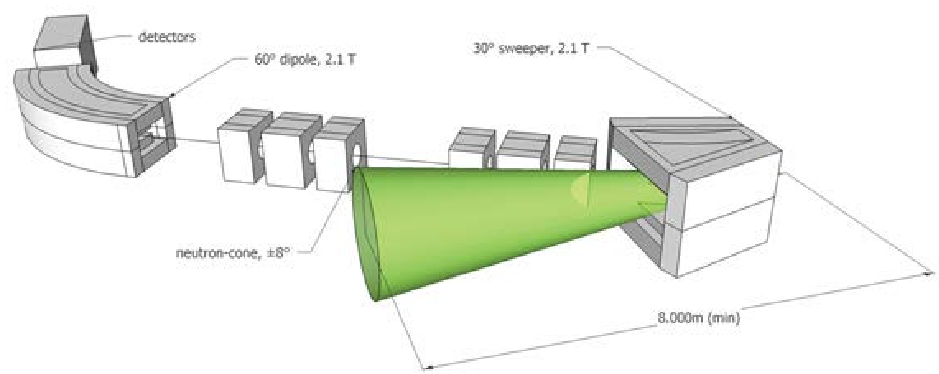
GRETA



SECAR



FRIB Theory Alliance



High Rigidity Spectrometer (HRS)

Breakthrough Gamma Ray Detection Technology Enables Key Astrophysical Observation

X-ray bursts are among the most energetic explosions in the Universe. They are triggered by a thermonuclear runaway on the surface of a neutron star. Detailed understanding of the specific nuclear reactions responsible for such bursts is still largely hampered by the lack of experimental data

A reaction rate key to the underlying physics of x-ray bursts –capture of a proton by a short-lived isotope of copper (^{57}Cu), leading to an isotope of zinc (^{58}Zn)– has now been precisely determined using the GRETINA segmented germanium gamma ray tracking array (above).

GRETINA enables a new window on the synthesis of elements in powerful stellar reactions.

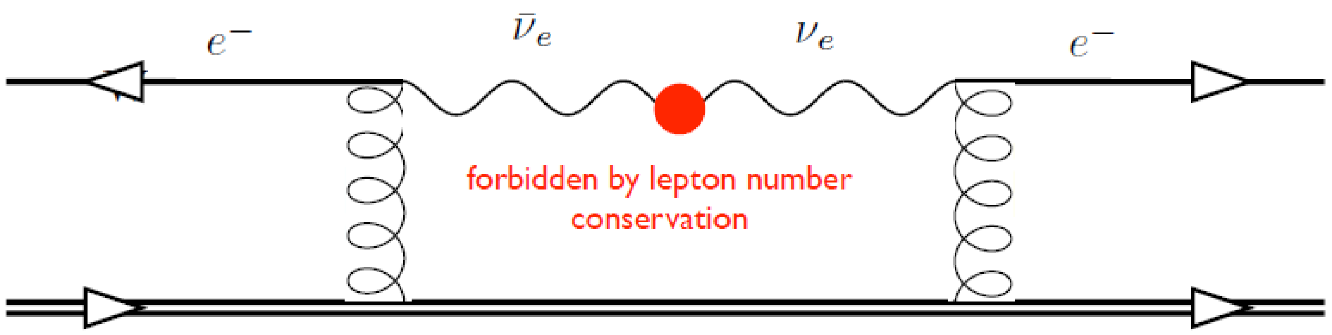
A High Priority NP Frontier: Neutrino-less Double Beta Decay

Three Light Neutrinos: What Do We Know ?

2ν DBD: $A(Z,N) \rightarrow A(Z+2, N-2) + e^- e^- \; \nu \, \nu$

If own antiparticle, can be emitted then absorbed during decay

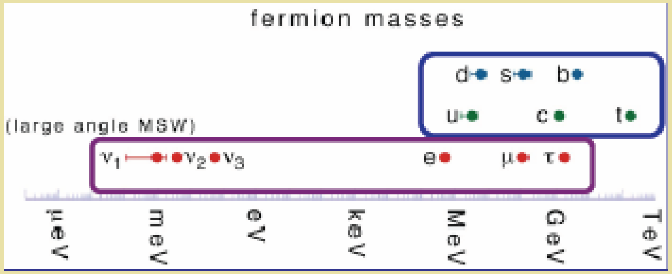
0ν DBD: $A(Z,N) \rightarrow A(Z+2, N-2) + e^- e^-$



Why Is $0\nu\beta\beta$ a Science "Must Do" Experiment

What Questions Does It Address ?

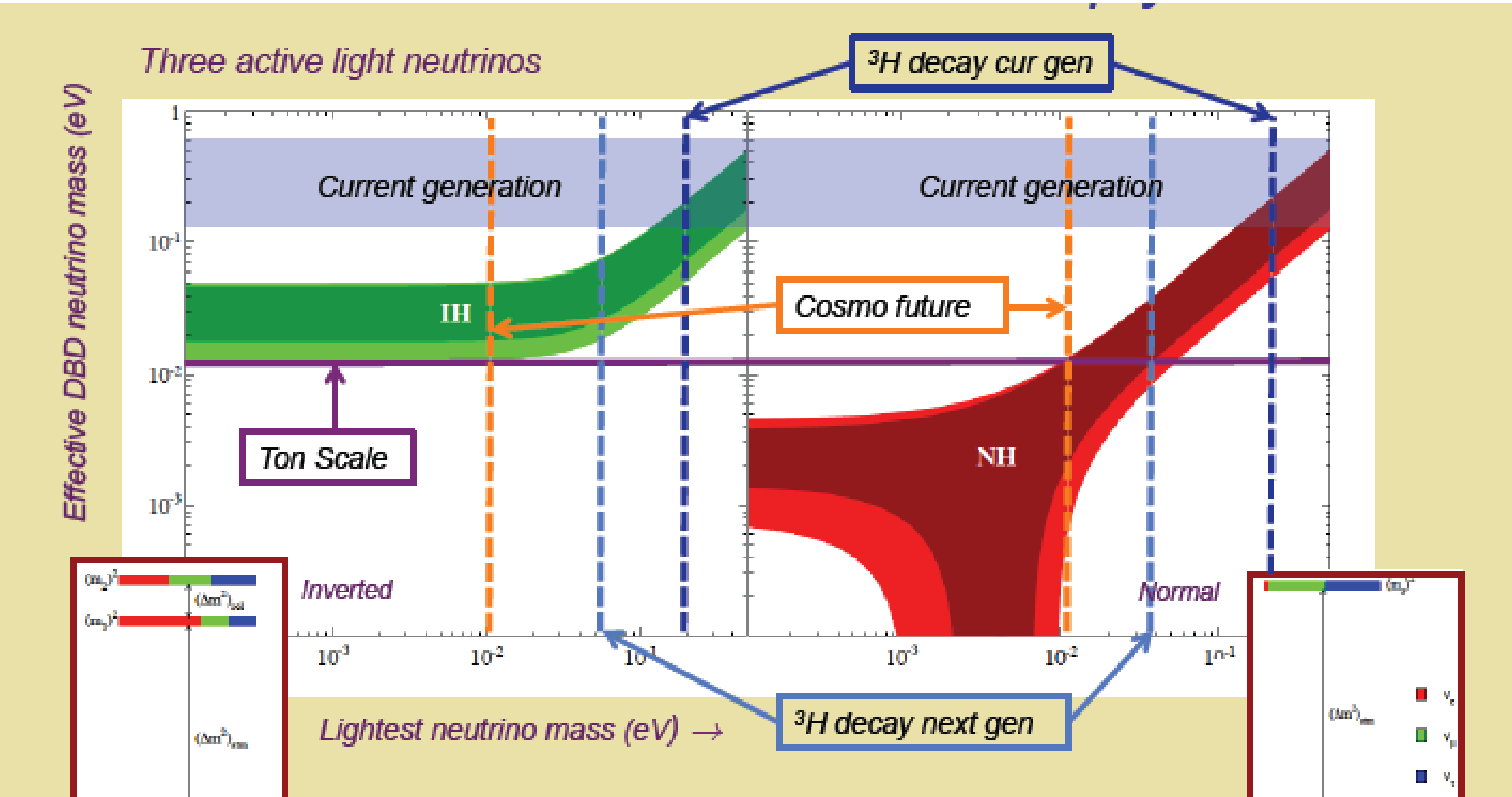
- *Is the neutrino its own antiparticle ?*
- *Why is there more matter than antimatter in the present universe?*
- *Why are neutrino masses so much smaller than those of other elementary fermions ?*



Partners

Partners

Current Outlook on the Challenge



Null result in NLDBD & non-zero m_ν from cosmology → Conclusion depends on $m_{lightest}$ & hierarchy

The Experimental Challenge

Experimental searches for 0νββ-decay

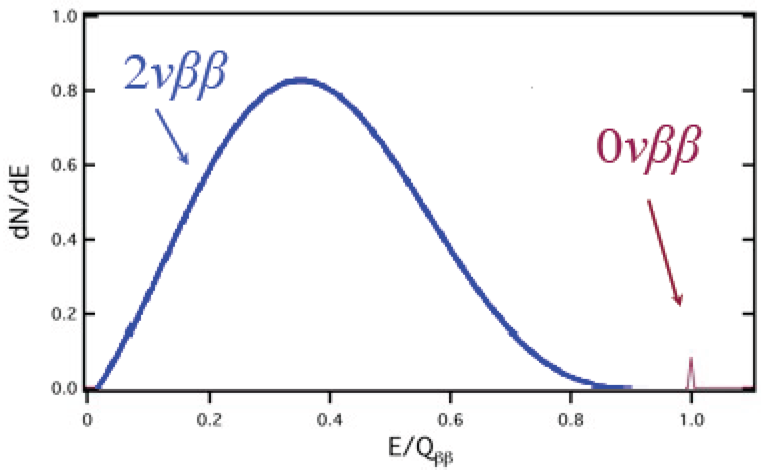
Most sensitive experiments to date using ^{76}Ge, ^{130}Te, and ^{136}Xe have attained results for $T_{1/2} > 10^{25}$ years

(source mass) × (exposure times) of 30 - 100 kg-years

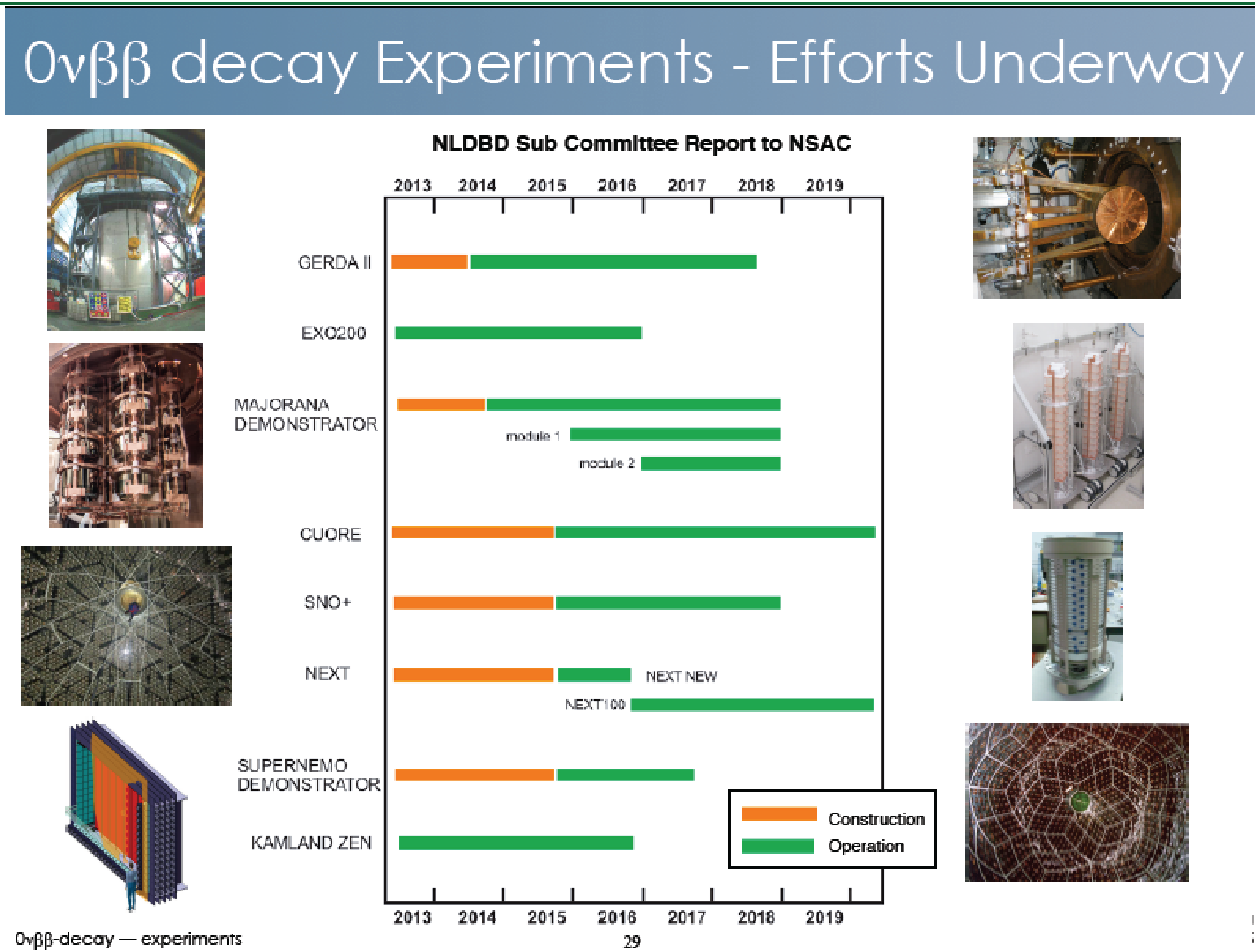
To reach IH region requires sensitivities of

0νββ $T_{1/2} \sim 10^{27}$ - 10^{28} years

(2νββ $T_{1/2} \sim 10^{19}$ - 10^{21} years)



International Efforts Underway



Current Status of Demonstration Efforts

Backgrounds in experiments

Experiment		Mass [kg] (total/FV*)	Bkg (cnts/ROI† -t-y)	Width (FWHM)	
CUORE0	^{130}Te	32/11	300	5.1 keV ROI	Measured
EXO-200	^{136}Xe	170/76	130	88 keV ROI	Measured
GERDA I	^{76}Ge	16/13	40	4 keV ROI	Measured
KamLAND-Zen (Phase 2)	^{136}Xe	383/88	210 per t(Xe)	400 keV ROI	Measured
CUORE	^{130}Te	600/206	50	5 keV ROI	Projected
GERDA II	^{76}Ge	35/27	4	4 keV ROI	Projected
MAJORANA DEMONSTRATOR	^{76}Ge	30/24	4	4 keV ROI	Projected
NEXT 100	^{136}Xe	100/80	9	17 keV ROI	Projected
SNO+	^{130}Te	2340/160	45 per t(Te)	240 keV ROI	Projected

* FV = $0\nu\beta\beta$ isotope mass in fiducial volume (includes enrichment factor)
† Region of Interest (ROI) can be single or multidimensional (E, spatial, ...)

Next Steps

An NSAC Subpanel to determine essential R&D to demonstrate down-select criteria for a ton-scale experiment is underway

Following that exercise a joint NSF-DOE peer review will be convened by NSF to provide guidance on prioritizing R&D needs

Nuclear Theory

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

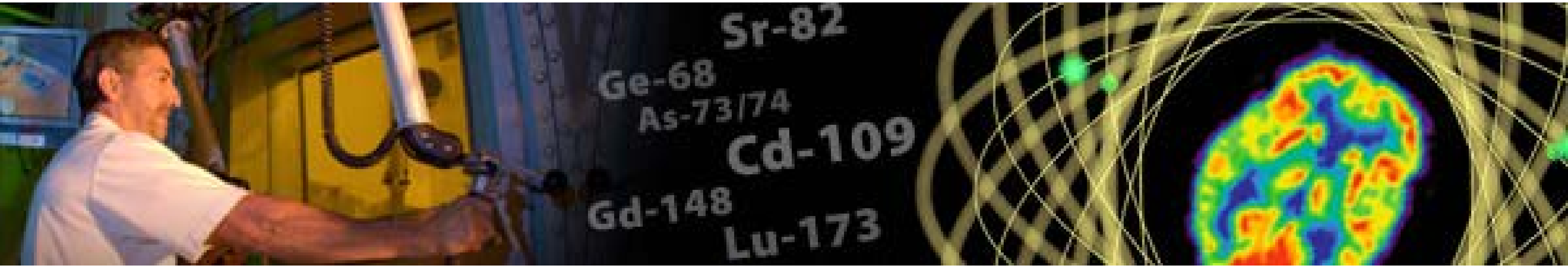
A strong Nuclear Theory effort:

- 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." Processing of the proposals received in response to the new FOA is under way.

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.
BRACCO LIFE FROM INSIDE
QSA GLOBAL
GE Energy
Schlumberger
Westinghouse
INORGANIC VENTURES
Isotope Products Laboratories
GENERAL ATOMICS AND AFFILIATED COMPANIES
FRONTIER TECHNOLOGY CORPORATION WORLD'S EXPERT IN NEUTRON SOURCES
Memorial Sloan-Kettering Cancer Center
ACTINIUM PHARMACEUTICALS
PerkinElmer For the Better
Pain Therapeutics, Inc.
NEC Corporation of America
Spectrum Technique
BOSTON MEDICAL CENTER EXCEPTIONAL CARE. WITHOUT EXCEPTION.
THE LINDE GROUP Linde
Alpha V
ICON
CIL
EXCELITAS TECHNOLOGIES
ThermoFisher SCIENTIFIC
SANDERS MEDICAL
Medical Isotopes, Inc.
ALDRICH Chemistry

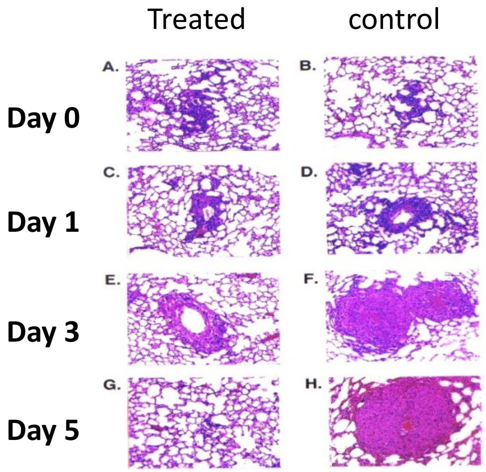
It Also Serves a Very Important Role in Coordination and Communication, Sponsoring an Annual Meeting on Isotope Federal Supply and Demand

- 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 exposed to Ac-225 radiopharmaceutical were radically reduced while untreated control cells proliferated

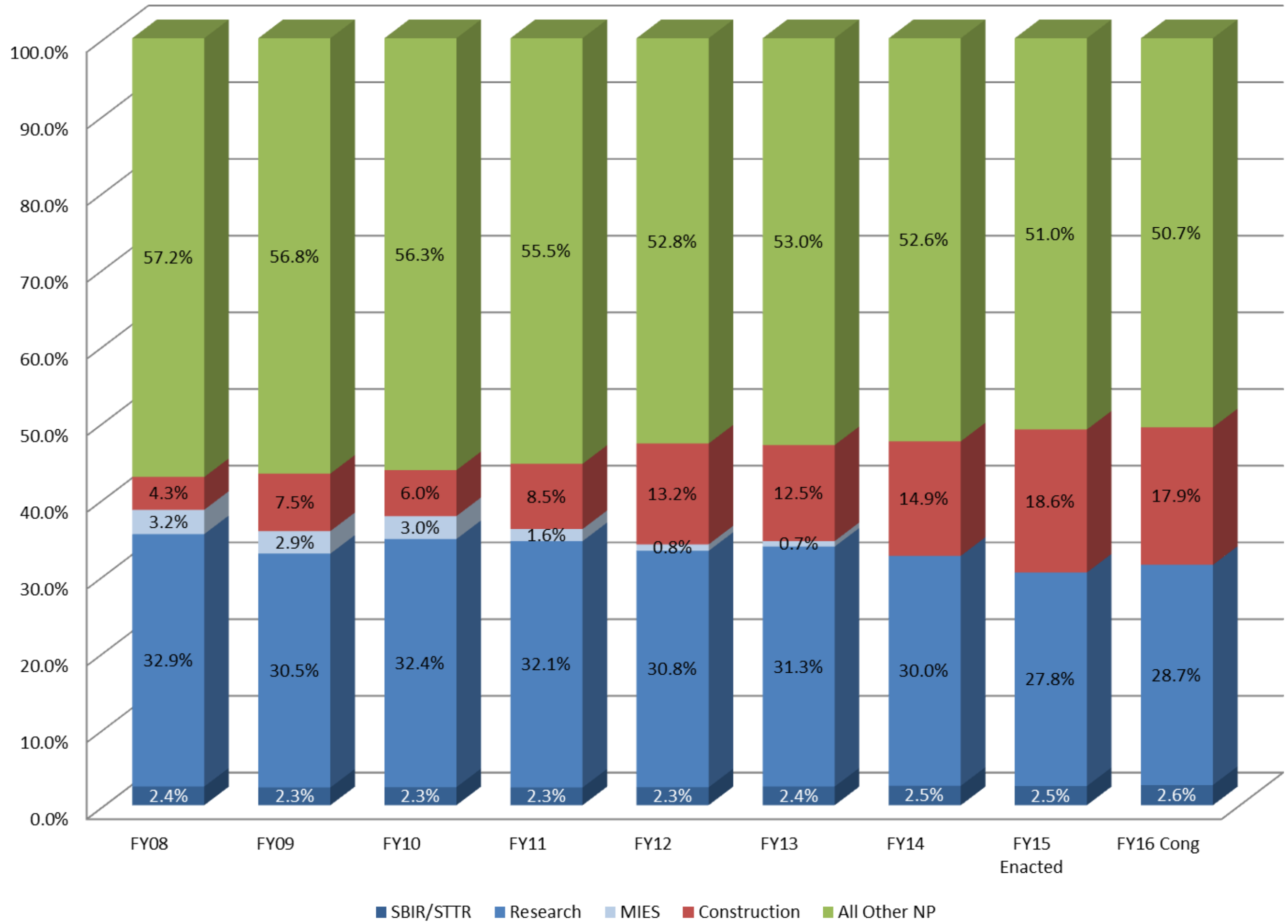


Isotopes under Development

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

Research as a Percentage of the NP Budget
FY 2008-FY2015

Construction has stressed all aspects of the NP program – not just Research



Nuclear Physics – Research

	FY 2015 Enacted	FY 2016 Request	FY16 vs. FY15
Medium Energy	35,646	38,402	+2,756
Heavy Ions	33,894	36,431	+2,537
Low Energy	48,377	52,125	+3,748
Theory	43,096	46,220	+3,124
Isotope Program	4,815	6,133	+1,318
Total	**165,828**	**179,311**	**+13,483**

- **Funding for Research has been constrained as NP has pursued construction of two major facilities.**
- **The FY 2016 Request reflects a strong commitment to Research within the overall NP budget.**

Research is increased for high priority research in all five NP subprograms

- **Medium Energy**: research focuses on the 12 GeV era scientific program and analysis of RHIC polarized proton beam data.
- **Heavy Ions**: research at RHIC focuses on heavy quark propagation in the quark-gluon plasma discovered at RHIC; commitments in LHC computing; and research activities on current and future experimental capabilities of the heavy ion LHC ALICE detector.
- **Low Energy**: research to develop and implement instrumentation in nuclear structure and astrophysics at ATLAS and FRIB, and research in fundamental symmetries in neutrinos and neutrons.
- **Theory**: a second round of targeted theory topical collaborations following competitive peer review; the final year of SciDAC-3 awards; and support for the U.S. Nuclear Data Program to enable provision of the highest quality nuclear data for basic science and users' needs.
- **Isotope Program**: enhanced research capabilities at national laboratories and universities to address high priorities identified by NSAC, particularly with regard to the research effort to produce alpha-emitters for cancer treatment, such as Ac-225.

Nuclear Physics – Facility Operations

	FY 2015 Enacted	FY 2016 Request	FY16 vs. FY15
Medium Energy: TJNAF Operations	97,050	100,170	+3,120
Heavy Ions: RHIC Operations	166,072	174,935	+8,863
Low Energy Operations	26,819	27,663	+844
Isotope Program	15,035	15,531	+496
Total	**304,976**	**318,299**	**+13,323**

- **Increased funding in FY 2016 supports NP's national scientific user facilities (CEBAF, RHIC, ATLAS), the isotope production facilities, and other NP facility commitments.**

- **Medium Energy**: Increased funding for commissioning the upgraded CEBAF accelerator is provided for operations and experimental support staff, incremental power costs, and experimental equipment for Halls B, C, and D in support of initiating the 12 GeV CEBAF experimental program in FY 2017.
- **Heavy Ions**: RHIC operates for 22 weeks, the same as FY 2015. Increased funding is needed for experimental equipment, accelerator R&D, and materials and supplies to reduce risk and provide reliable operations (all were reduced in the FY 2015 Request to optimize data taking within available resources). The FY 2016 run is essential to interpret the data acquired from the last two years and understand results on heavy quark propagation in the quark-gluon plasma.
- **Low Energy**: Funding increases primarily to optimize new capabilities of the ATLAS scientific user facility and support the increasing demand for beam time. 5,900 hours of research beam time (95% of optimal operations) is supported. Funding also supports continued equipment disposition at HRIBF and operations of the 88-Inch Cyclotron at LBNL jointly with the NRO.
- **Isotope Program**: Funding maintains mission readiness at constant effort for safe and reliable operations of IPF, BLIP and Hot Cell facilities at LANL,ORNL and BNL.

Nuclear Physics
FY 2016 President's Request – Summary

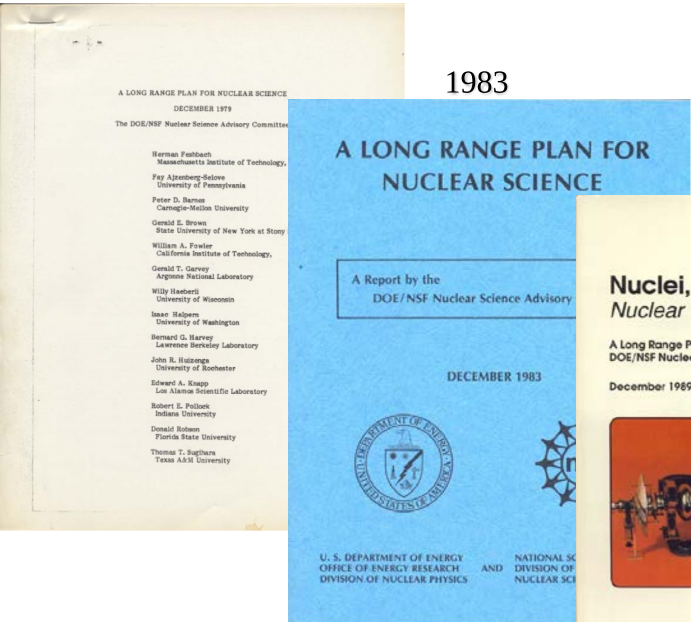
($ in 000s)	FY 2014 Enacted	FY 2015 Enacted	FY 2016 Request	FY 2016 vs. FY 2015
Research	170,668	165,828	179,311	+13,483
User Facility Operations	276,887	280,663	293,304	+12,641
Other Operations	24,120	24,313	24,995	+682
Projects	80,500	106,500	107,500	+1,000
Other	16,963	18,196	19,490	+1,294
TOTAL NP	**569,138**	**595,500**	**624,600**	**+29,100**

Explanation of Requested Increases

- **Research** – Support for university and lab research increases across the program to address important opportunities identified by the research community, and to enhance high priority research that will foster significant advances in nuclear structure, nuclear astrophysics, the study of matter at extreme conditions, hadronic physics, fundamental properties of the neutron, and neutrinoless double beta decay.
- **User Facility Operations** – Operations of RHIC are maintained at the FY 2015 level with increases provided for critical staff, equipment, and materials required for reliable operations and support research focused on characterizing the perfect quark-gluon liquid discovered in collisions of relativistic heavy nuclei. Beam development and commissioning activities continue at CEBAF as the 12 GeV CEBAF Upgrade project approaches completion, and scientific instrumentation is implemented in the experimental halls in preparation for the full start of the physics program in FY 2017. Operations of ATLAS are optimized, exploiting the new capabilities of CARIBU and completing the campaign with the GRETINA gamma ray spectrometer.
- **Other Operations** – Requested funding for the Isotope Program maintains mission readiness for the production of radioisotopes.
- **Projects** –12 GeV CEBAF Upgrade and FRIB construction are supported according to baselined profiles.
- **Other** – Increased funding is provided for the SBIR/STTR programs consistent with the legislative mandate.

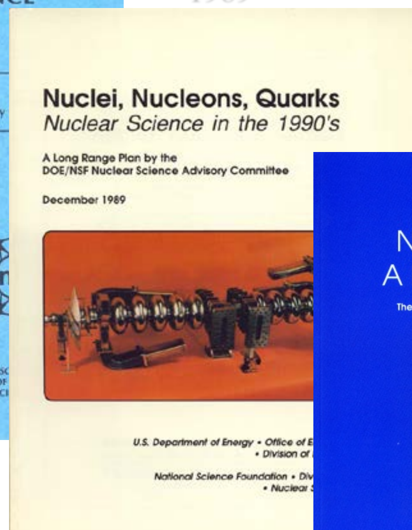
Defining the Science – Long Range Plans

1979



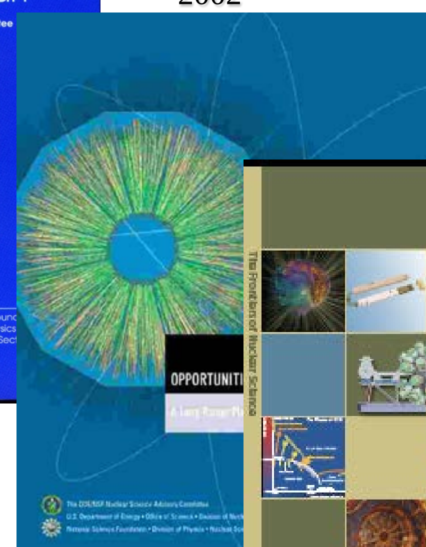
1983

1989

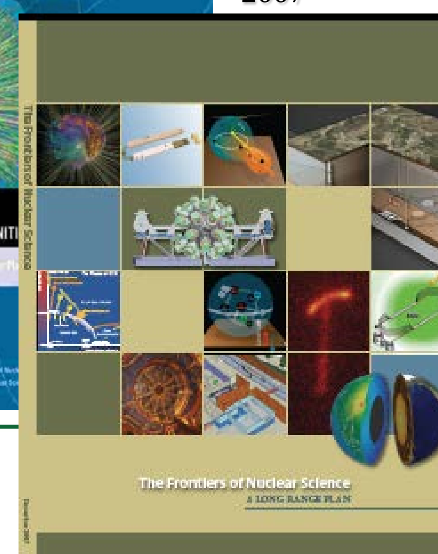


1996

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 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;

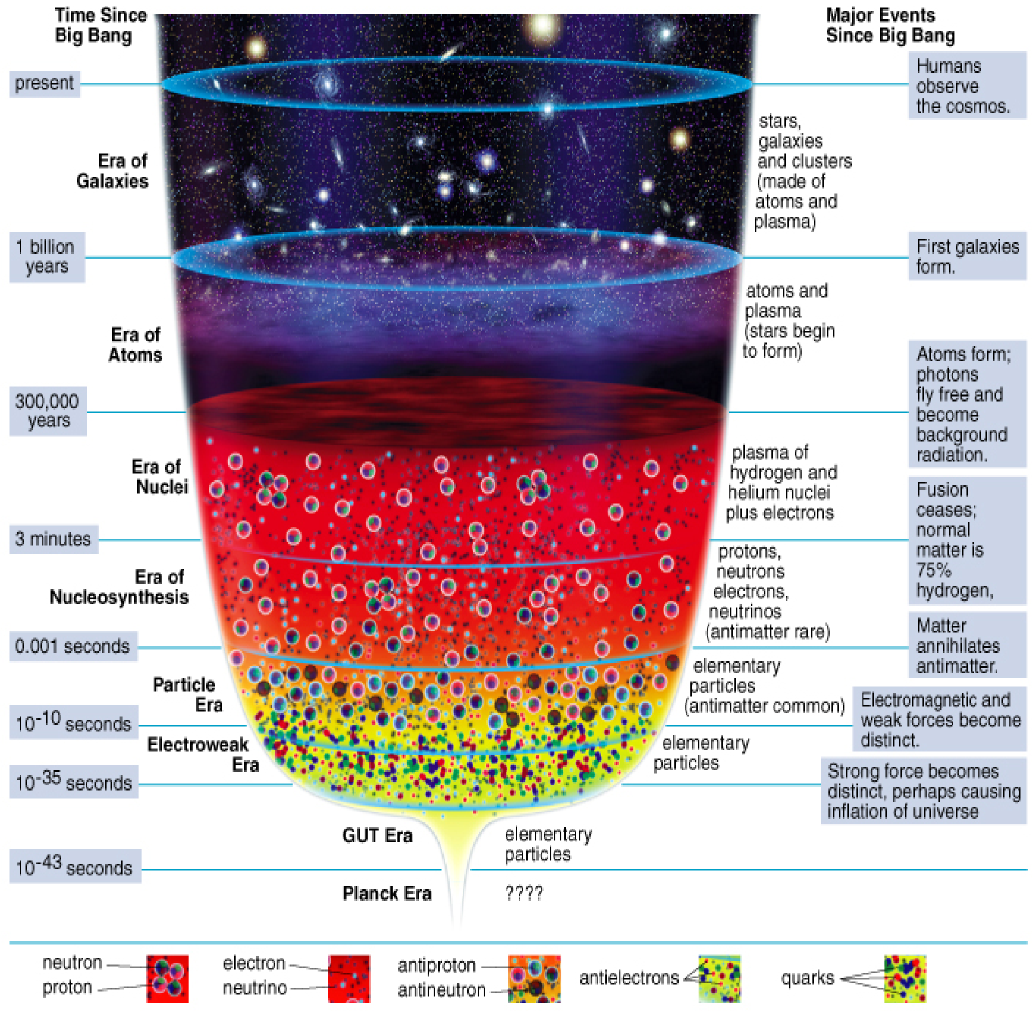
Nuclear-Reactions;

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



Status and Outlook

- The CEBAF and RHIC programs are both unique and at the “top of their game” with compelling “must-do” science in progress or about to start.
- Long term, an electron-ion collider is envisioned to be the facility which provides exciting opportunities fort the entire experimental QCD research community. An important challenge is charting and being able to follow a course to this future which realizes expected scientific return on existing investment and does not leave important science discoveries “on the table” –forever, perhaps.
- A very high priority for the NP community is not losing U.S. leadership in the science of neutrino-less double beta decay.
  - A specific challenge will be ensuring essential R&D for candidate technologies is completed in the next 2-3 years prior to a down-select for a ton-scale experiment
  - A concomitant challenge will be ensuring inclusiveness and fairness for all demonstration efforts in progress and completing the down-select in a timely way so as not to endanger US leadership in this science.
- An equally high priority for the NP community is increasing investment in research and projects as a percentage of the total NP budget. This will have to be accomplished while still respecting the unitarily limit.

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

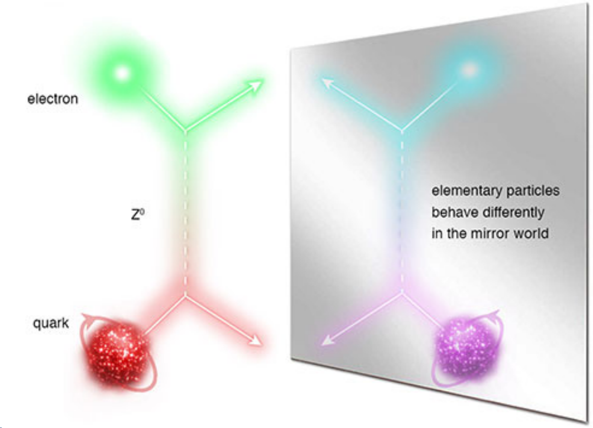
Resolution Meeting: spring of 2015 **Long Range Plan: October 2015**

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

Nature 506, 67–70 (06 February 2014)

The Jefferson Lab PVDIS Collaboration

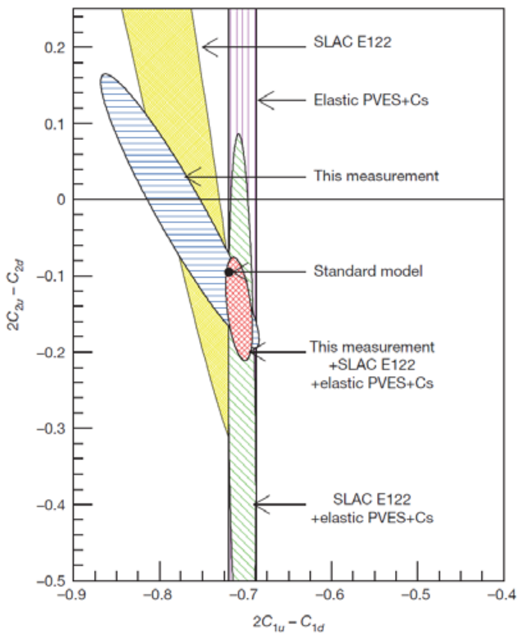
See also News & Views, *Nature* 506, 43–44 (06 February 2014)



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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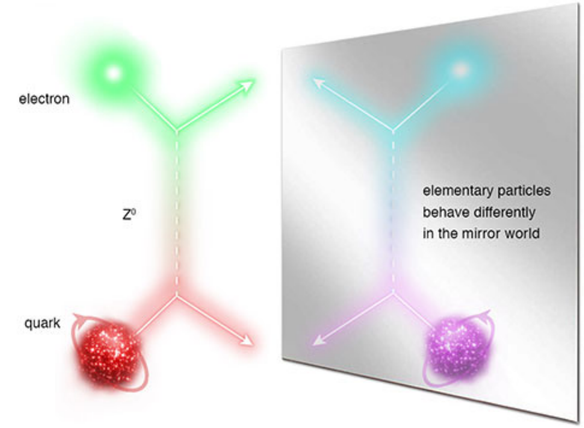

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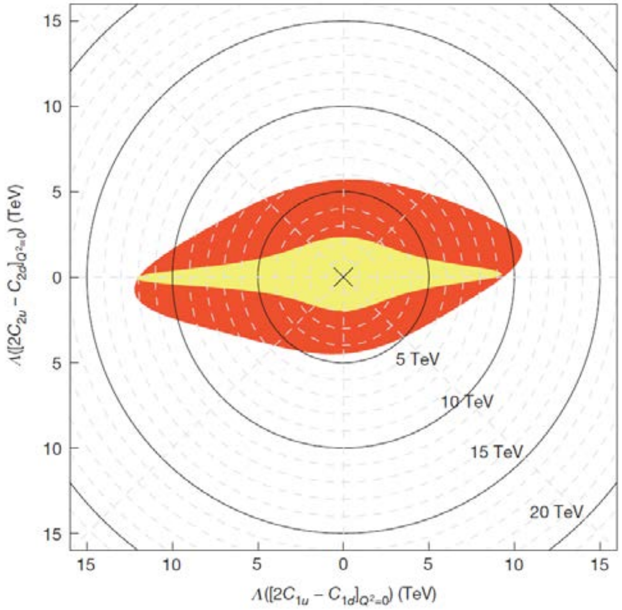
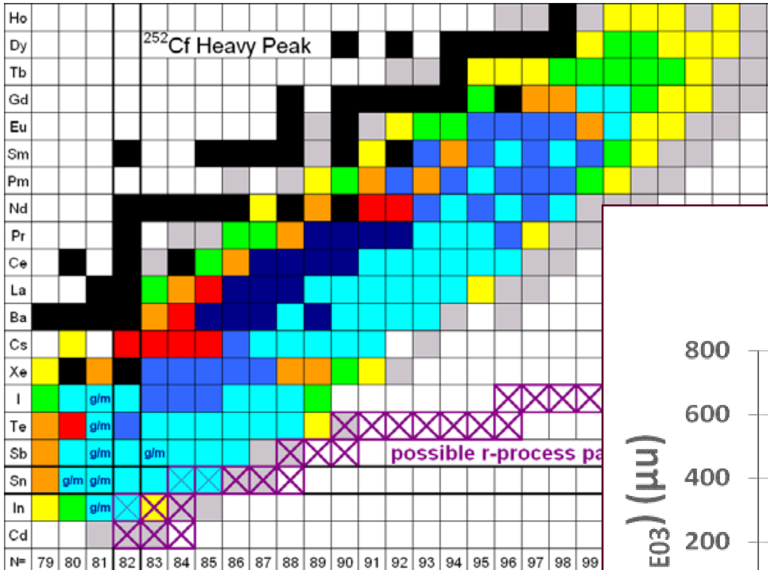
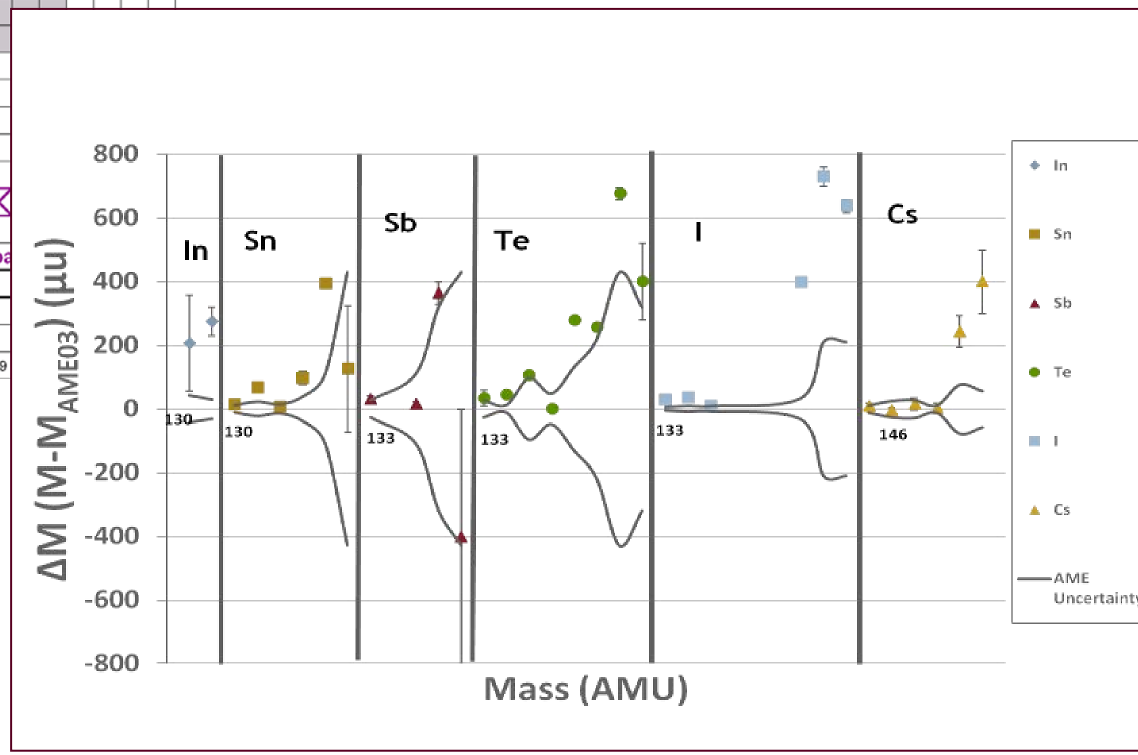


First Physics With CARIBU



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



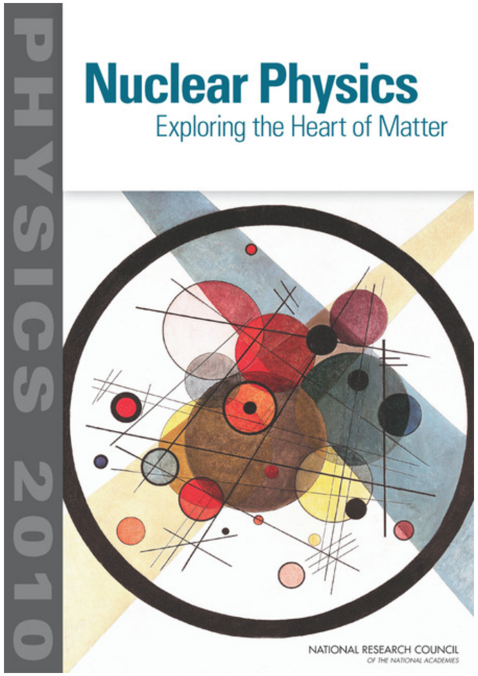
Mass measurements at CARIBU

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



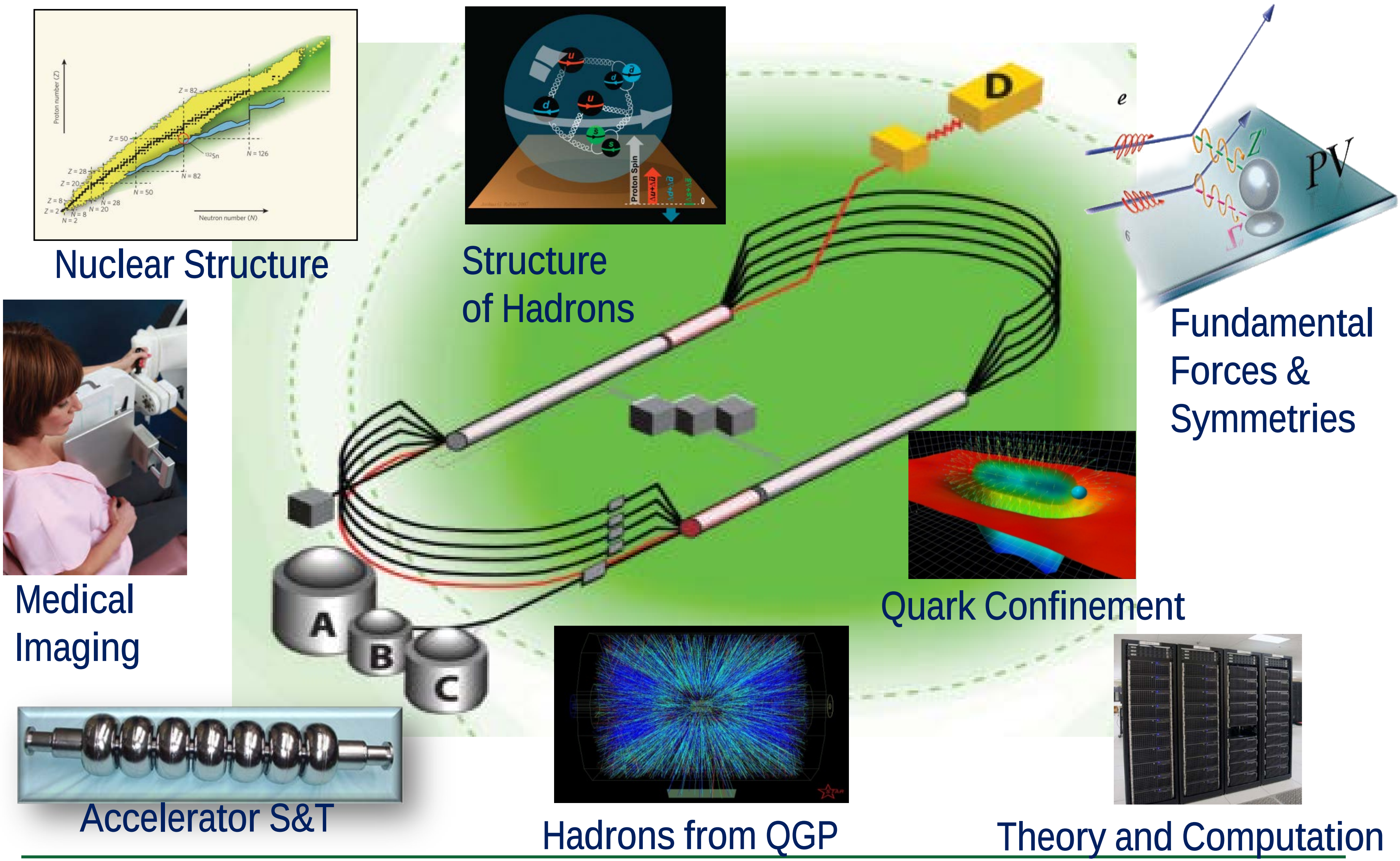
Goals

- **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

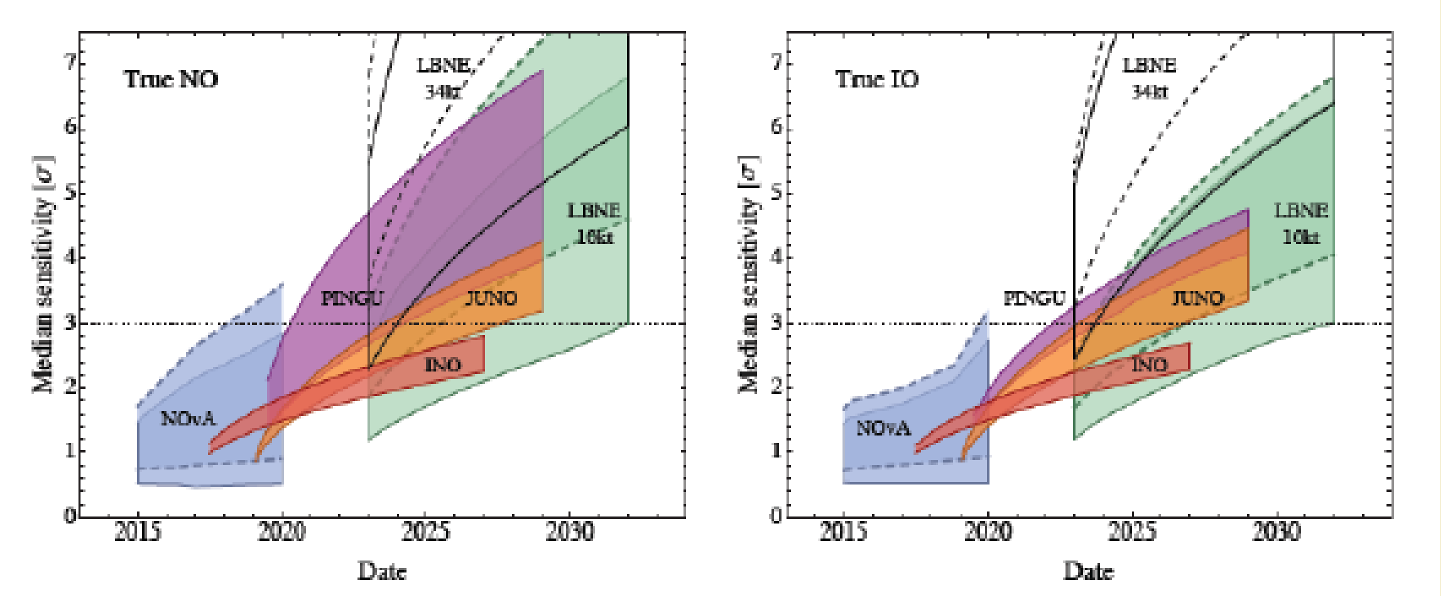
- New insights and advancements in the fundamental nature of matter and energy
- New and accumulated knowledge, developed and cutting-edge technologies, and a highly-trained next-generation workforce that will underpin the Department's missions and the Nation's nuclear-related endeavors
- Isotopes for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

JLab: Medium Energy Nuclear Science and Its Broader Impacts



Additional Experimental Information Expected to Emerge

Neutrino Mass Hierarchy



Expected significance for rejecting wrong hierarchy hypothesis

Blennow et al. 1311.1822