



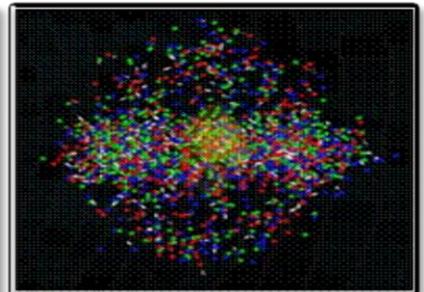
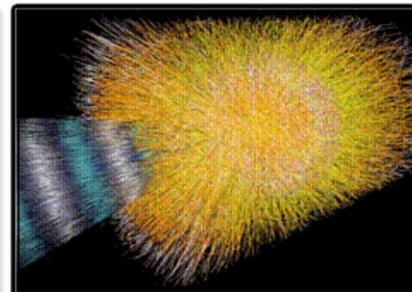
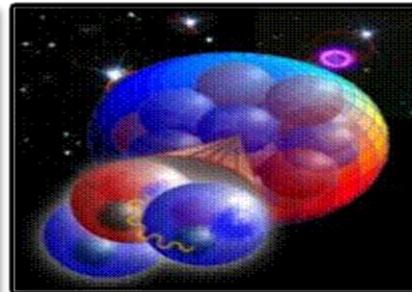
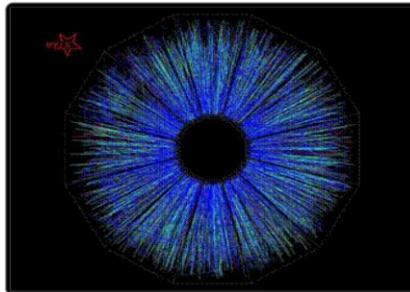
U.S. DEPARTMENT OF  
**ENERGY**

Office of  
Science

# Frontiers, Challenges, and Opportunities for DOE/NP Stewardship of U.S. Nuclear Science

RHIC User Meeting  
June 9, 2016

Dr. Timothy J. Hallman  
Associate Director for Nuclear Physics  
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.



# 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

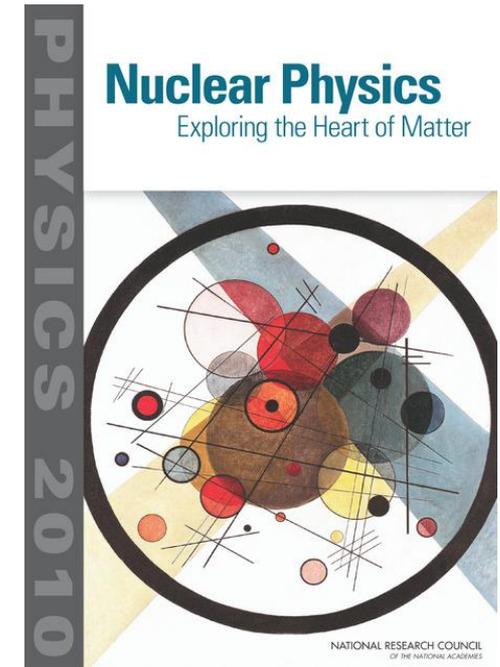
- Identify the scientific opportunities for discoveries and advancements
- Build and operate forefront facilities to address these opportunities
- Develop and support a research community that delivers significant outcomes
- Work with other agencies/countries to optimize use of U.S. resources

## 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

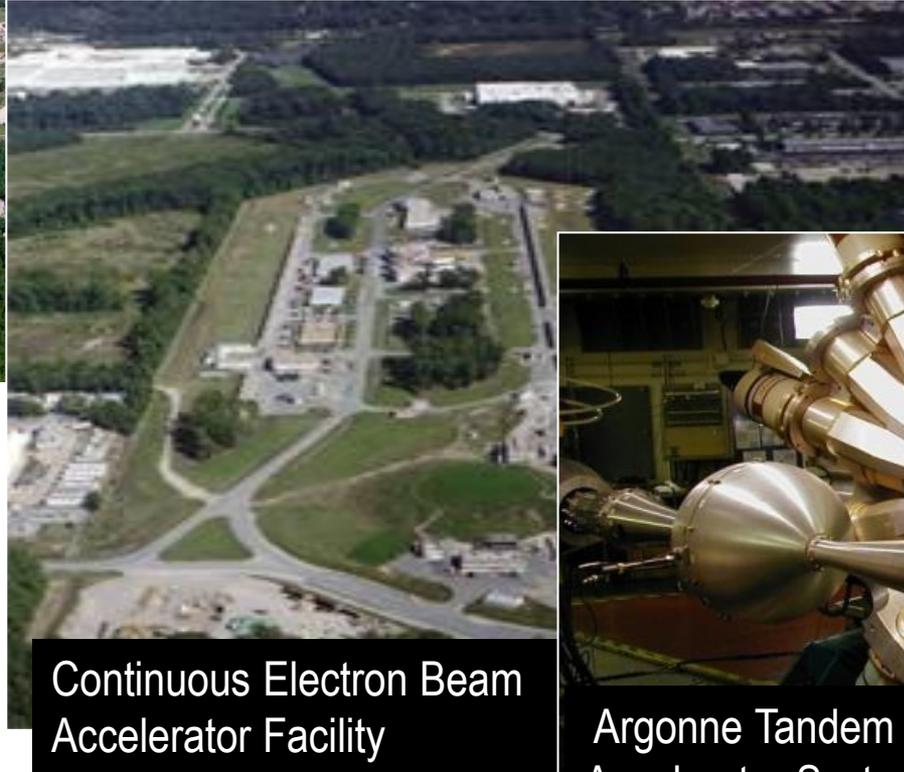
## Deliverables

- 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



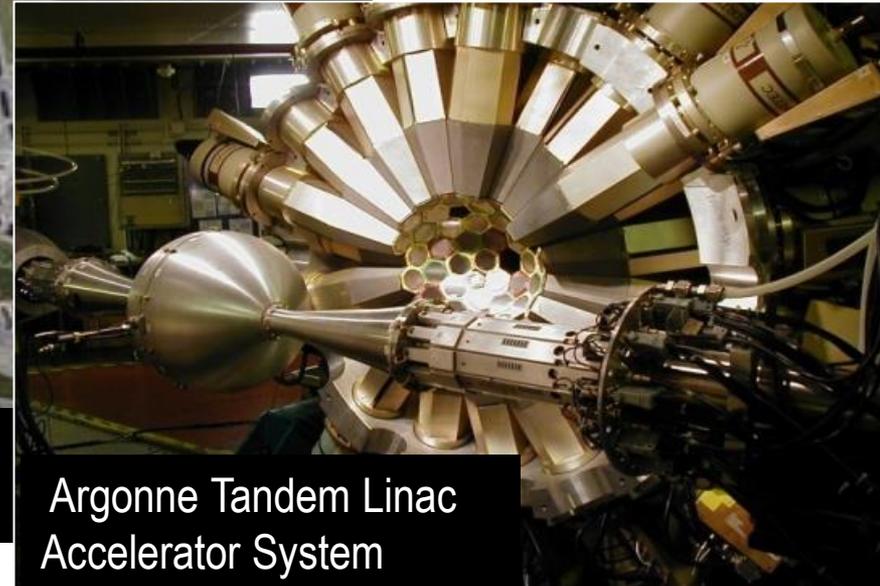


Relativistic Heavy Ion Collider



Continuous Electron Beam Accelerator Facility

“Microscopes” pursuing groundbreaking research



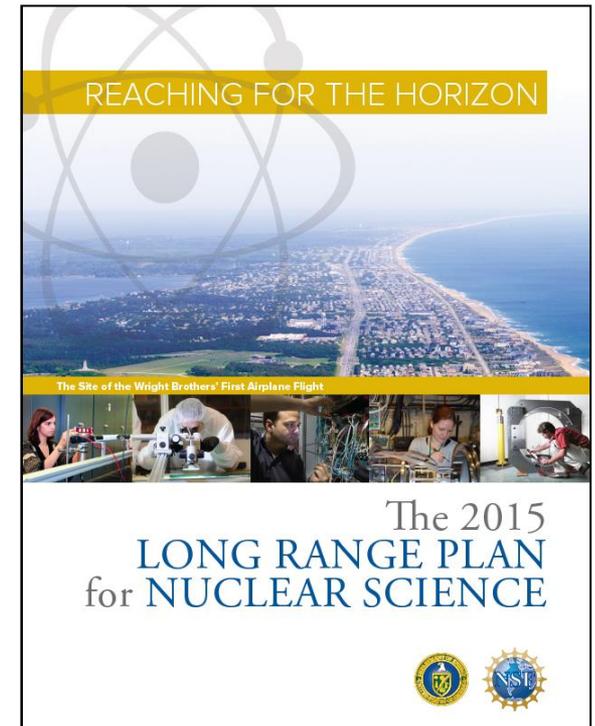
Argonne Tandem Linac Accelerator System

# The 2015 Long Range Plan for Nuclear Science

NSAC and APS DNP partnered to tap the full intellectual capital of the U.S. nuclear science community in identifying exciting, compelling, science opportunities

## Recommendations:

- The progress achieved under the guidance of the 2007 Long Range Plan has reinforced U.S. world leadership in nuclear science. ***The highest priority in this 2015 Plan is to capitalize on the investments made.***
- The observation of neutrinoless double beta decay in nuclei would...have profound implications.. ***We recommend the timely development and deployment of a U.S.-led ton-scale neutrinoless double beta decay experiment.***
- Gluons...generate nearly all of the visible mass in the universe. Despite their importance, fundamental questions remain.... These can only be answered with a powerful new electron ion collider (EIC). ***We recommend a high-energy high-luminosity polarized EIC as the highest priority for new facility construction following the completion of FRIB.***
- ***We recommend increasing investment in small-scale and mid-scale projects and initiatives that enable forefront research at universities and laboratories.***



NP is implementing these recommendations which are supported in the President's FY 2017 request

# Next Formal Step on the EIC

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## **THE NATIONAL ACADEMIES OF SCIENCES, ENGINEERING, AND MEDICINE**

Division on Engineering and Physical Science

Board on Physics and Astronomy

### **U.S.-Based Electron Ion Collider Science Assessment**

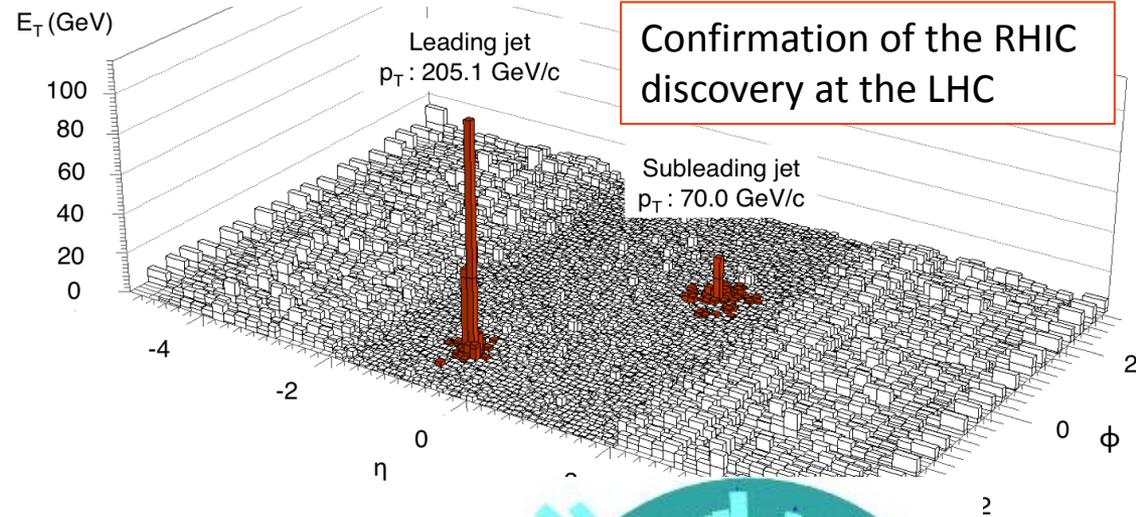
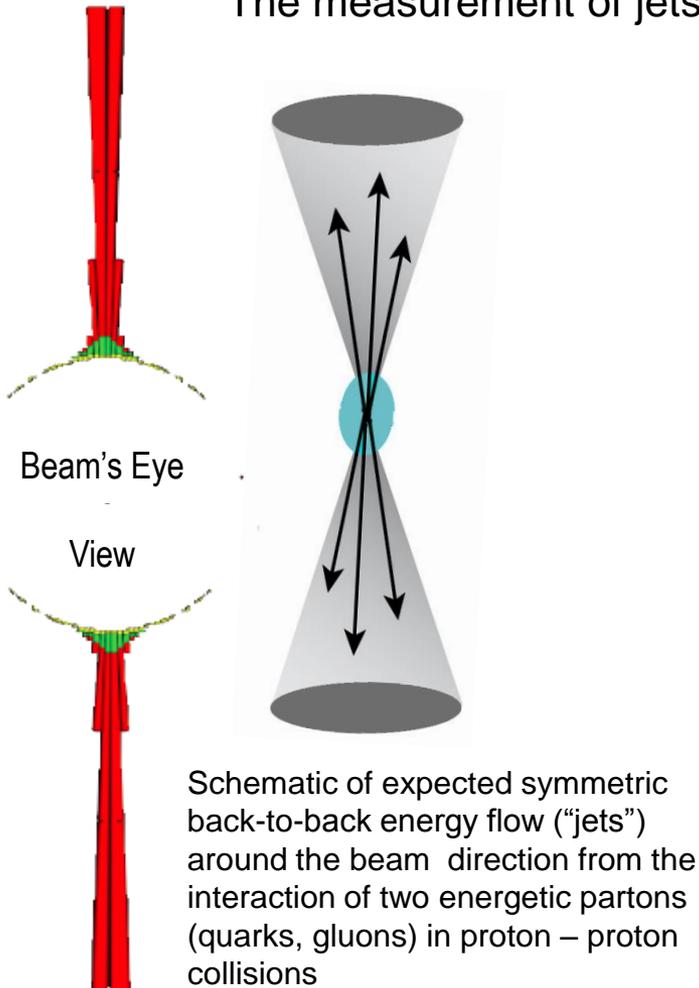
#### ***Summary***

The National Academies of Sciences, Engineering, and Medicine (“National Academies”) will form a committee to carry out a thorough, independent assessment of the scientific justification for a U.S. domestic electron ion collider facility. In preparing its report, the committee will address the role that such a facility would play in the future of nuclear science, considering the field broadly, but placing emphasis on its potential scientific impact on quantum chromodynamics. The need for such an accelerator will be addressed in the context of international efforts in this area. Support for the 18-month project in the was requested from the Department of Energy.

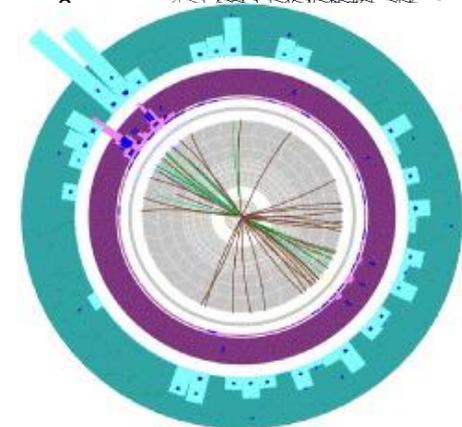
#### NAS Study Underway

# A Brief Reprise of The RHIC Discovery: A Strongly Interacting, Perfect Liquid of Quark and Gluons

The measurement of jets yields a signature discovery: “Jet Quenching”



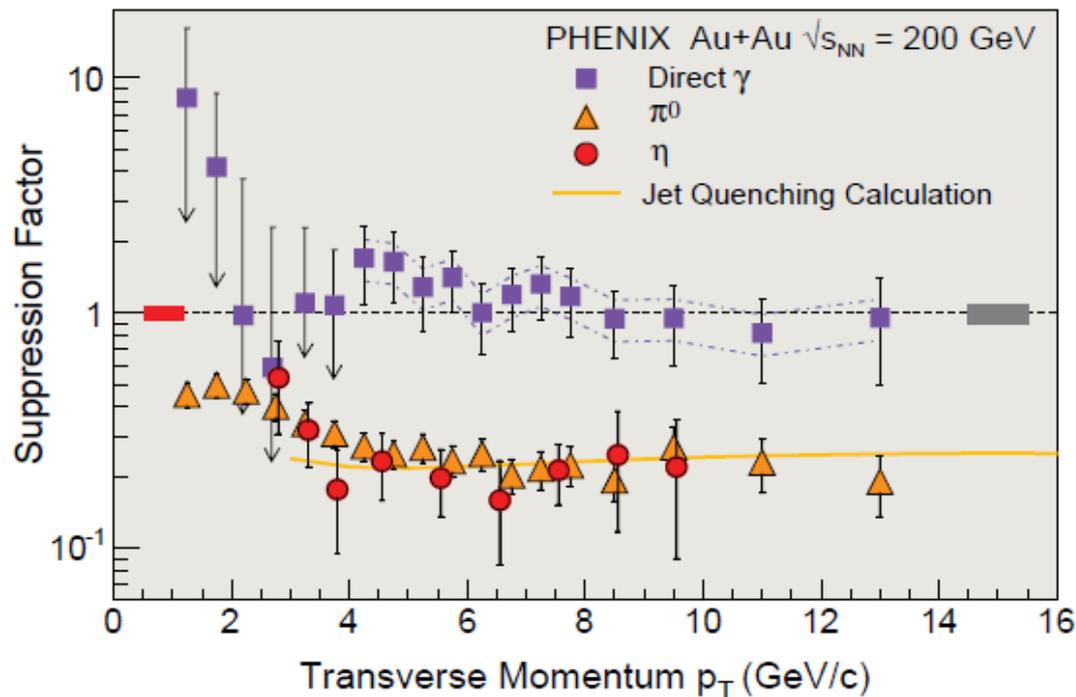
Asymmetric non back-to-back (jet) energy flow around the beam direction from the interaction of two energetic partons (quarks, gluons) in relativistic nucleus-nucleus collisions



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.

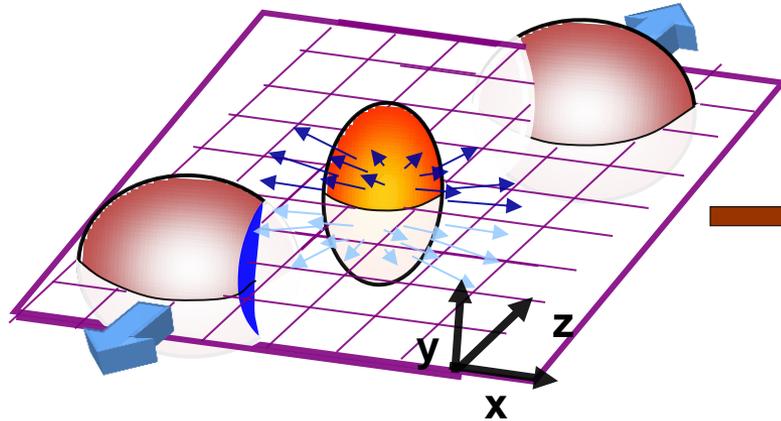


# Also, Stuff That Shouldn't Be suppressed, Isn't



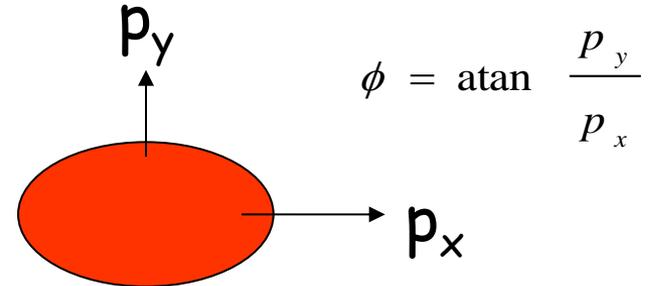
**Figure 2.9:** Suppression factor  $R_{AA}$  of the production rates of high transverse-momentum ( $p_T$ ) photons ( $\gamma$ ) and  $\pi^0$  and  $\eta$  mesons measured in central Au + Au and p + p collisions, scaled to be unity if nuclear collisions are a simple superposition of p + p collisions. Mesons are suppressed in Au + Au collisions ( $R_{AA} < 1$ ), while direct photons are not ( $R_{AA} \approx 1$ ). This distinction is indicative of jet quenching. The solid line shows  $R_{AA}$  values for a model calculation that incorporates jet quenching.

# The Other Signature RHIC Discovery: Collective Motion & “Elliptic Flow”



$$\varepsilon = \frac{\langle y^2 \rangle - \langle x^2 \rangle}{\langle y^2 \rangle + \langle x^2 \rangle}$$

Initial coordinate-space anisotropy



$$v_2 = \left\langle \frac{p_x^2 - p_y^2}{p_x^2 + p_y^2} \right\rangle$$

Final momentum-space anisotropy

Elliptic flow establishes there is strongly interacting matter at  $t \sim 0$

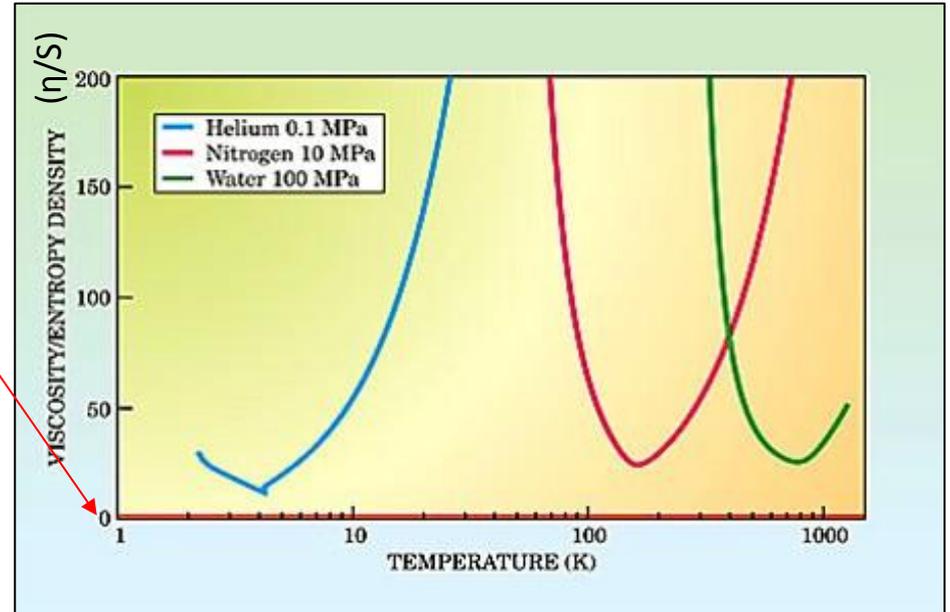
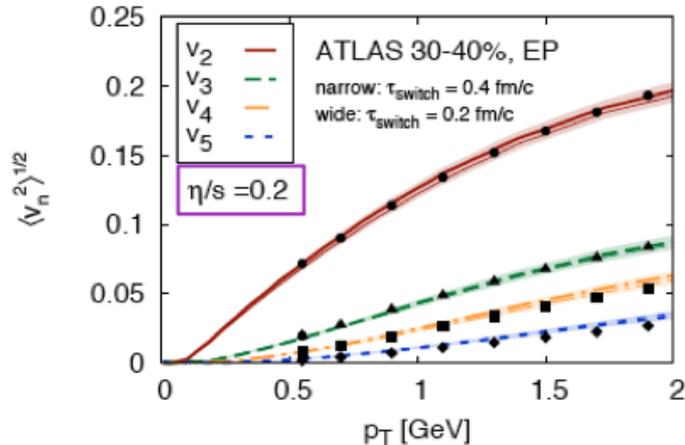
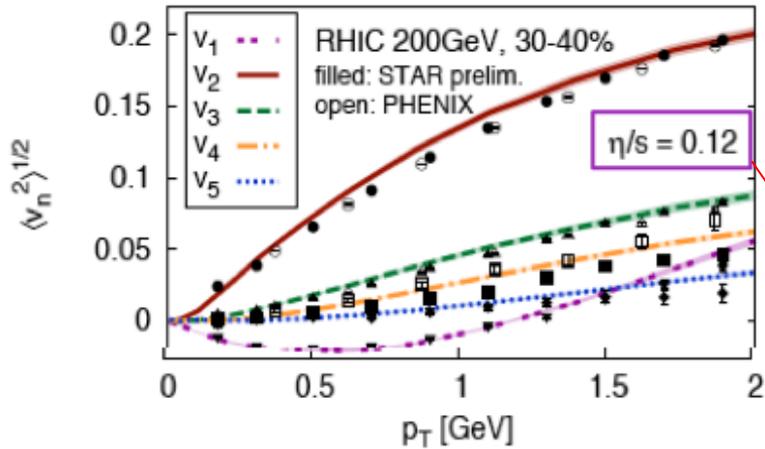
$$\frac{dN}{d\phi} \propto 1 + 2v_2 \cos[2(\phi - \Psi_R)] + 2v_4 \cos[4(\phi - \Psi_R)] + \dots$$

↑  
Elliptic term

Anisotropy self-quenches, so  $v_2$  is sensitive to early times

# RHIC Discovered a Form of Matter with Remarkable Properties

## Shear Viscosity per Unit Entropy ( $\eta/s$ ) Near the Quantum Limit



The Perfect Liquid has a shear viscosity per unit entropy ( $\eta/s$ ) lower than any matter ever observed, near a quantum limit

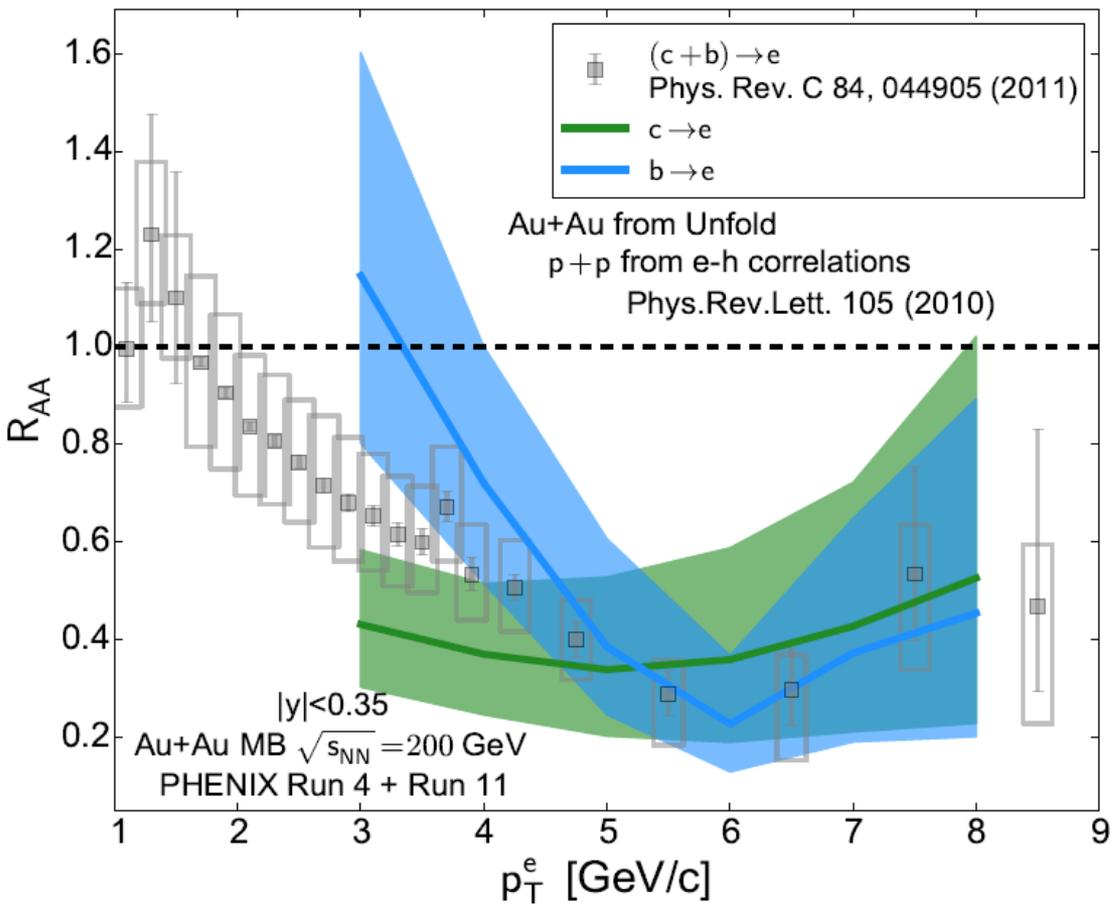
$$\frac{\eta}{s} \geq \frac{1}{4\pi} \quad \begin{array}{l} \eta = \text{shear viscosity} \\ s = \text{entropy density} \\ (\hbar = k_B = 1) \end{array}$$

The lower value of  $\eta/s$  at RHIC compared to the LHC means RHIC is the laboratory to study this strongly interacting matter



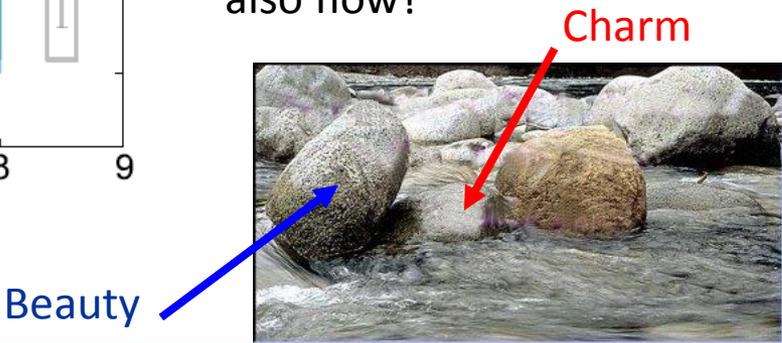
# Much to the (Shock &) Amazement of the Theory and Experimental Communities

Charm and Beauty were also suppressed !

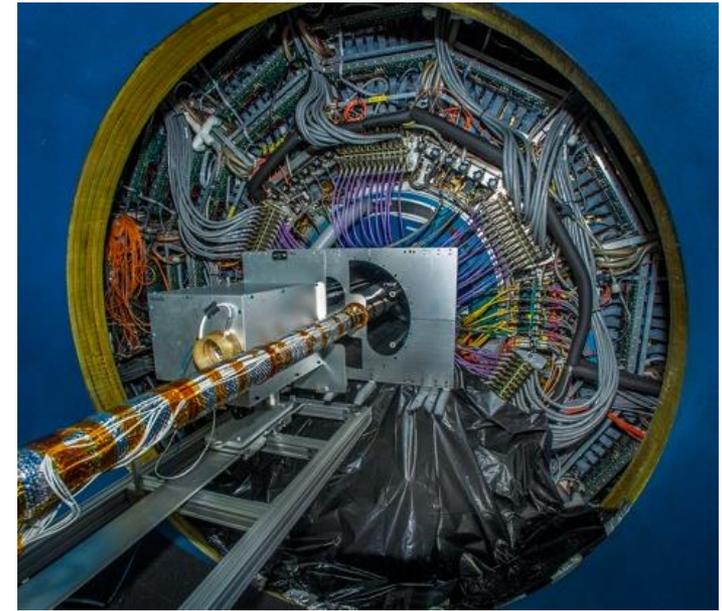


Particles containing charm and beauty quarks are apparently just as suppressed as up, down, and strange quarks

Another key question: do charm and beauty quarks also flow?



# These Compelling Questions Have Motivated the Recent RHIC Heavy Ion Runs



Recently completed new, innovative micro-vertex capability installed in both large detectors (STAR, and PHENIX) including the STAR Heavy Flavor Tracker (above left) enable the measurement of heavy quarks

Innovative, forefront machine accelerator R&D which increased the RHIC luminosity by more than an order of magnitude and novel microvertex detector upgrades (now being copied at the LHC) place RHIC in the perfect position to definitively answer compelling scientific questions about the nature and properties of the new state of matter it discovered.

The data from these runs is being analyzed now

# Why “Done!” $\neq$ “Finished!”

(W.A. Zajc, LRP QCD Town Meeting)

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- **To date:**

Data from RHIC and LHC

together with

Mature and sophisticated theoretical modeling...

***Tell us what the QGP does.***

- **Yet we have only very limited insight into**  
***How the QGP does it.***

- Creates near-perfect fluidity
- Approaches first order phase transition
- Modifies jet fragmentation
- Many other observed signals...

# Key Science Drivers For The Next Decade

(W.A. Zajc, LRP QCD Town Meeting)

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- How does the perfect liquid behavior emerge from the short-distance degrees of freedom?
- What conditions produce the most nearly perfect liquid behavior?
- Is there a critical end point and change to a 1<sup>st</sup> order phase transition in the QCD phase diagram?
- Which mechanisms or conditions drive early thermalization in nuclear collisions?
- Can the effects of quantum anomalies be detected in the final state?

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# An Intriguing New Focus: Verification of the Chiral Magnetic Effect



## Comparison of magnetic fields



The Earth's magnetic field 0.6 Gauss

A common, hand-held magnet 100 Gauss



The strongest steady magnetic fields achieved so far in the laboratory  $4.5 \times 10^5$  Gauss

The strongest man-made fields ever achieved, if only briefly  $10^7$  Gauss



Typical surface, polar magnetic fields of radio pulsars  $10^{13}$  Gauss

Surface field of Magnetars  $10^{15}$  Gauss

<http://solomon.as.utexas.edu/~duncan/magnetar.html>

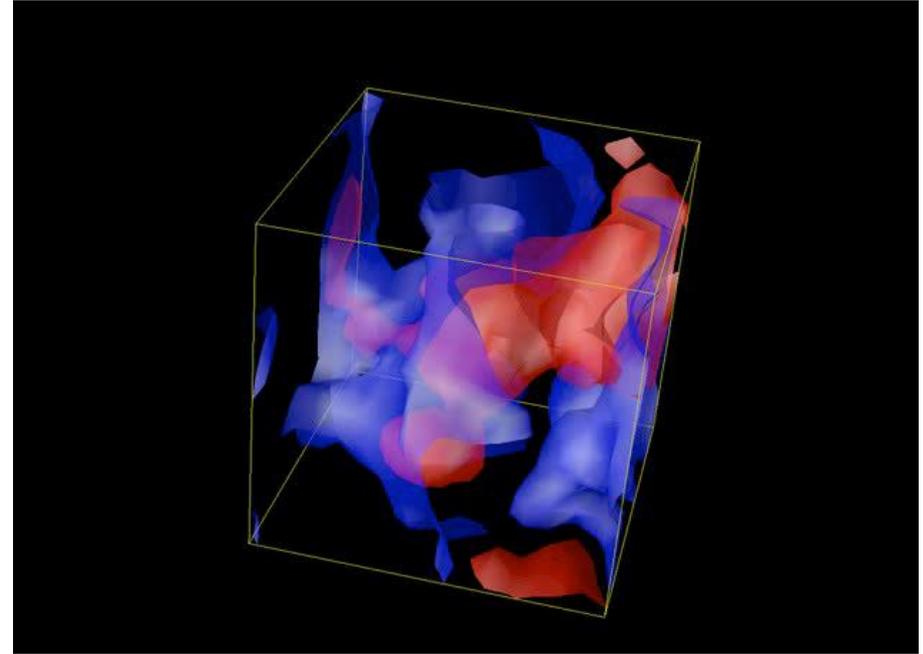
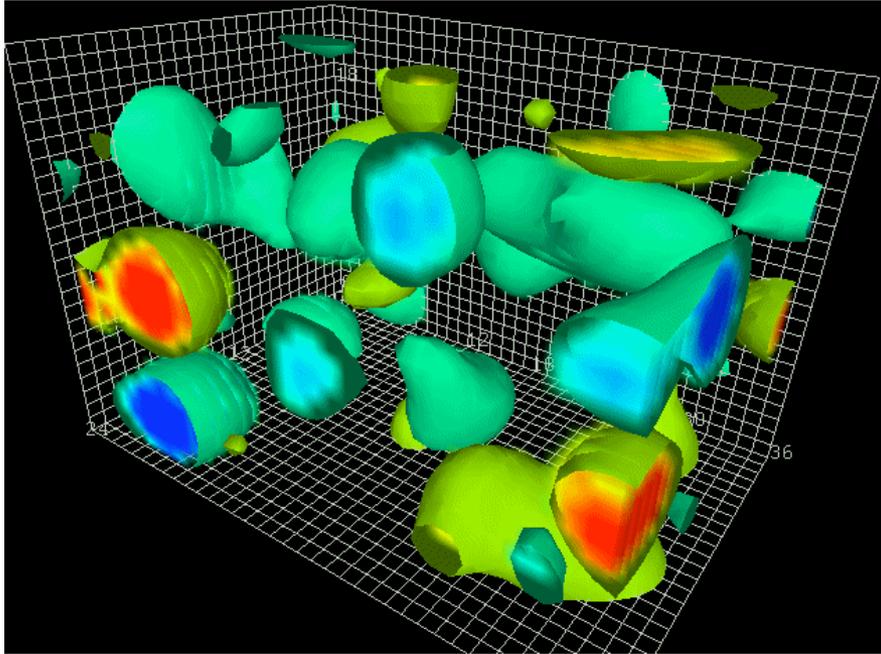


**Heavy ion collisions: the strongest magnetic field ever achieved in the laboratory**

Off central Gold-Gold Collisions at 100 GeV per nucleon  
 $e B(\tau=0.2 \text{ fm}) = 10^3 \sim 10^4 \text{ MeV}^2 \sim 10^{17} \text{ Gauss}$

# The Next Ingredient

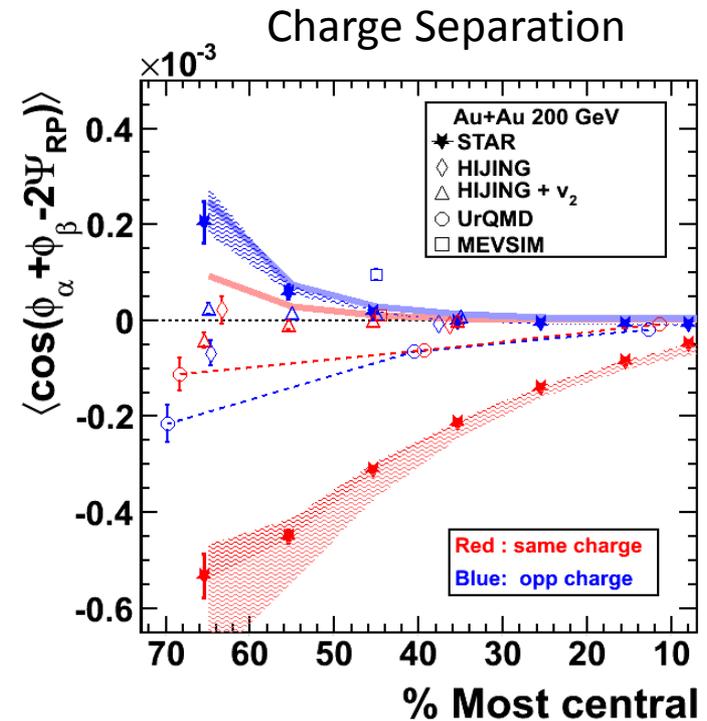
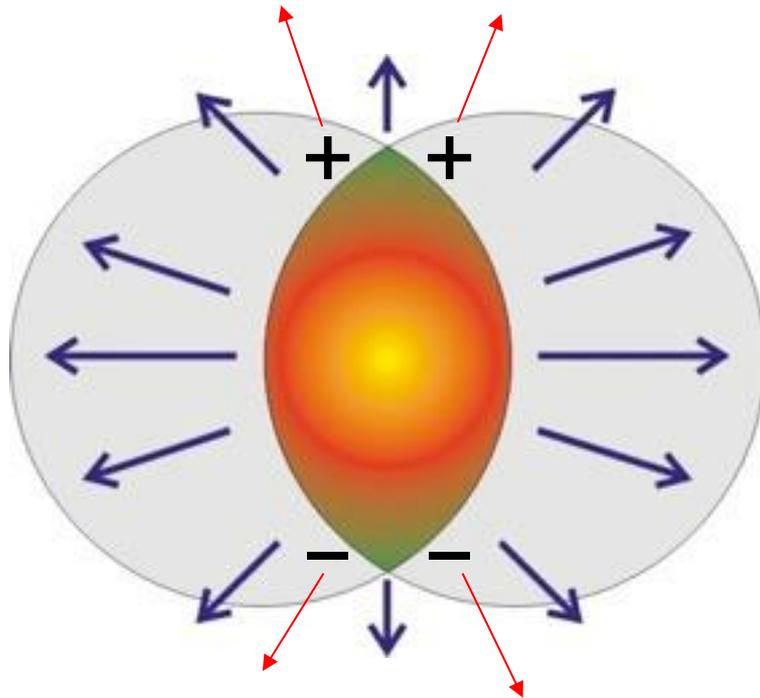
Topological Number Fluctuations Which Occur in the QCD Vacuum Continuously



- Topological gluonic configurations produce asymmetry in right- vs left-handed quarks



# The Response of a Chirally Imbalanced System to an External Magnetic Field?



Other experimental observables studied,

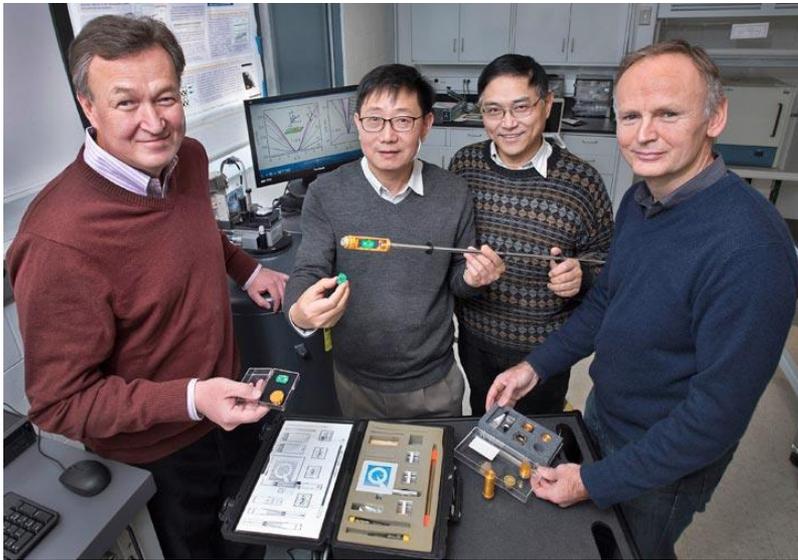
- in-plane (left/right) vs. out-of-plane (up/down) charge correlations
- Beam energy dependence
- System size dependence

All observables studied to date are consistent with the CME Interpretation

Final test: vary the magnetic field using isobars  $^{96}\text{Ru}$  and  $^{96}\text{Zr}$

A 20% effect expected if the Chiral Magnetic Effect Interpretation is confirmed

# Direct Contact with Topologically Non-trivial Phases in Condensed Matter Physics



Nuclear theorist Dmitri Kharzeev of Stony Brook University and Brookhaven Lab with Brookhaven Lab materials scientists Qiang Li, Genda Gu, and Tonica Valla in a lab where the team measured the unusual high conductivity of zirconium pentatelluride.

UPTON, NY—Scientists at the U.S Department of Energy's (DOE) Brookhaven National Laboratory and Stony Brook University have discovered a new way to generate very low-resistance electric current in a new class of materials. The discovery, which relies on the separation of right- and left-"handed" particles, points to a range of potential applications in energy, quantum computing, and medical imaging, and possibly even a new mechanism for inducing superconductivity—the ability of some materials to carry current with *no* energy loss. The material the scientists worked with, zirconium pentatelluride, has a surprising trait: When placed in parallel electric and magnetic fields, it responds with an imbalance in the number of right- and left-handed particles—a chiral imbalance. That imbalance pushes oppositely *charged* particles in opposite directions to create a powerful electric current.

This "chiral magnetic effect" had long been predicted theoretically, but never observed definitively in a materials science laboratory at the time this work was done.

"The resistance of this material drops as the magnetic field strength increases, which could open up a completely different route toward achieving something like superconductivity."

Dmitri Kharzeev

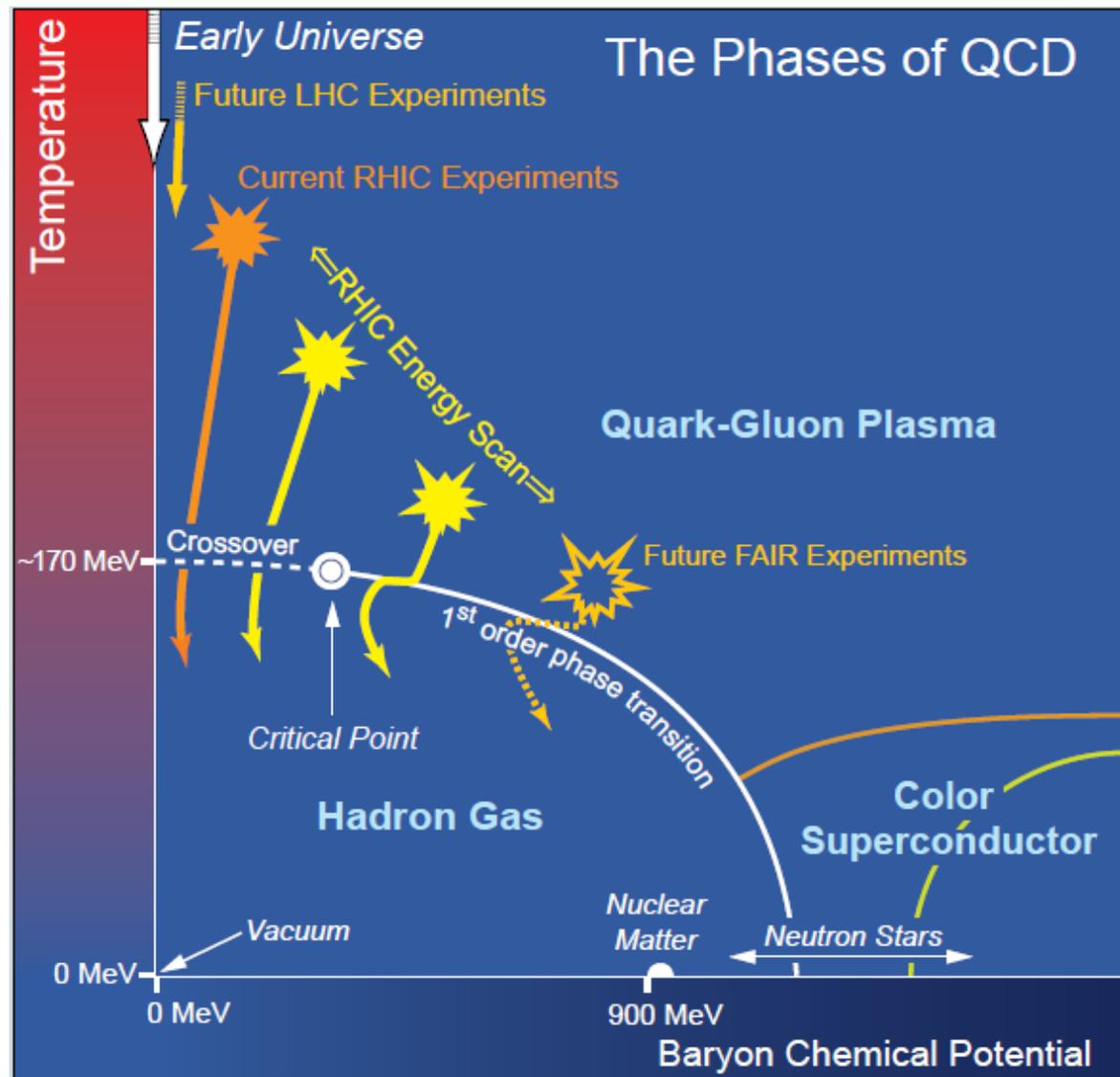
# The QCD Critical Point Search: A Main Focus of RHIC Running in FY19-20

One striking fact is that the liquid-vapor curve can end. Beyond this “Critical Point” the sharp distinction between liquid and vapor is lost. The location of the Critical Point and of the phase boundaries represent two of the most fundamental characteristics for any substance.

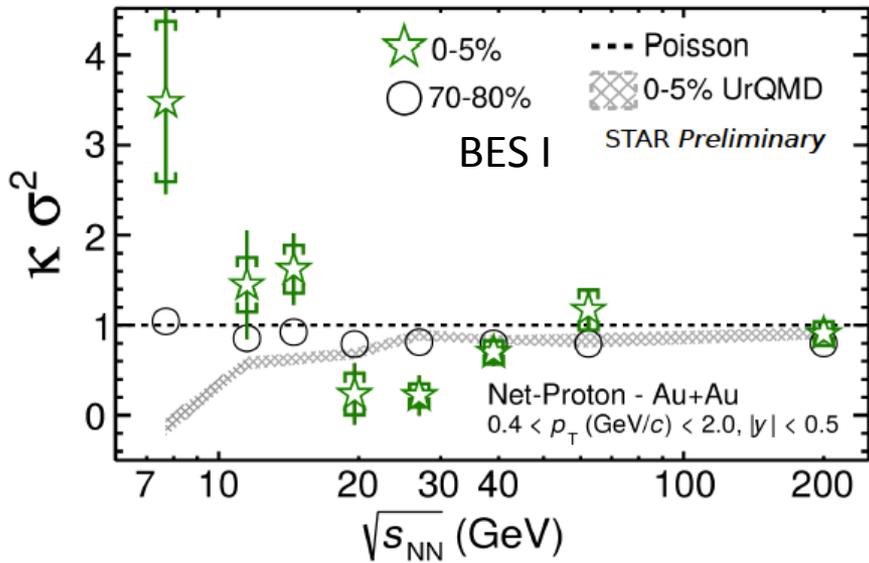
Experimentally verifying the location of fundamental QCD “landmarks” is central to a quantitative understanding of the nuclear matter phase diagram. Lattice QCD indicates that the Critical Point is in the range of temperatures and chemical potentials accessible with RHIC. The approach to the Critical Point will be signaled by large-scale fluctuations in key observables.

Status:

- BES I data are very intriguing
- Further high statistics data require e-cooling (LEReC) implemented in FY18
- BES II planned for FY19-20



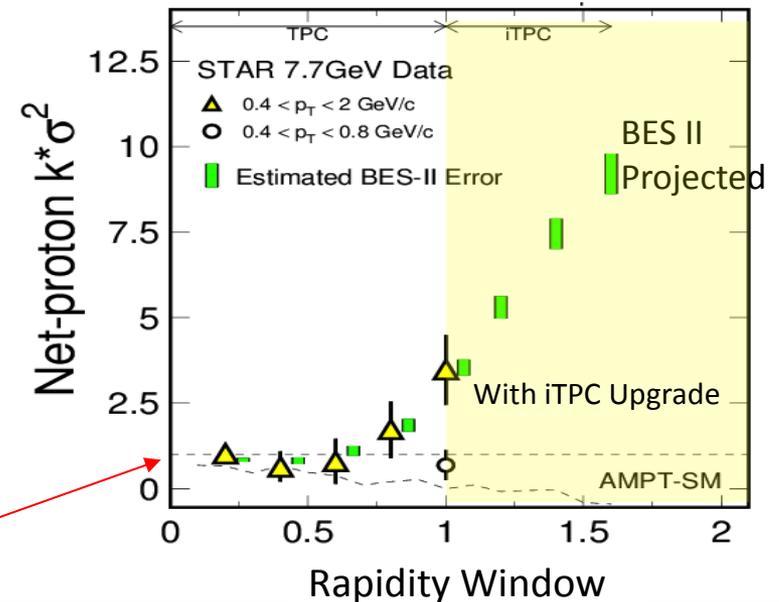
# Upgrading the STAR Inner TPC Sectors is Critical for This Discovery



A primary signature of the Critical Point will be non-Poissonian scaled kurtosis (baryon fluctuations)

Results from the first survey run appear tantalizing, but the statistics do not allow a conclusion. Fluctuations consistent with Poissonian behavior fall along the line at unity

The conjectured sensitivity to this observable improves dramatically at forward pseudo-rapidity (yellow shaded region at right) for which the inner TPC Upgrade is essential

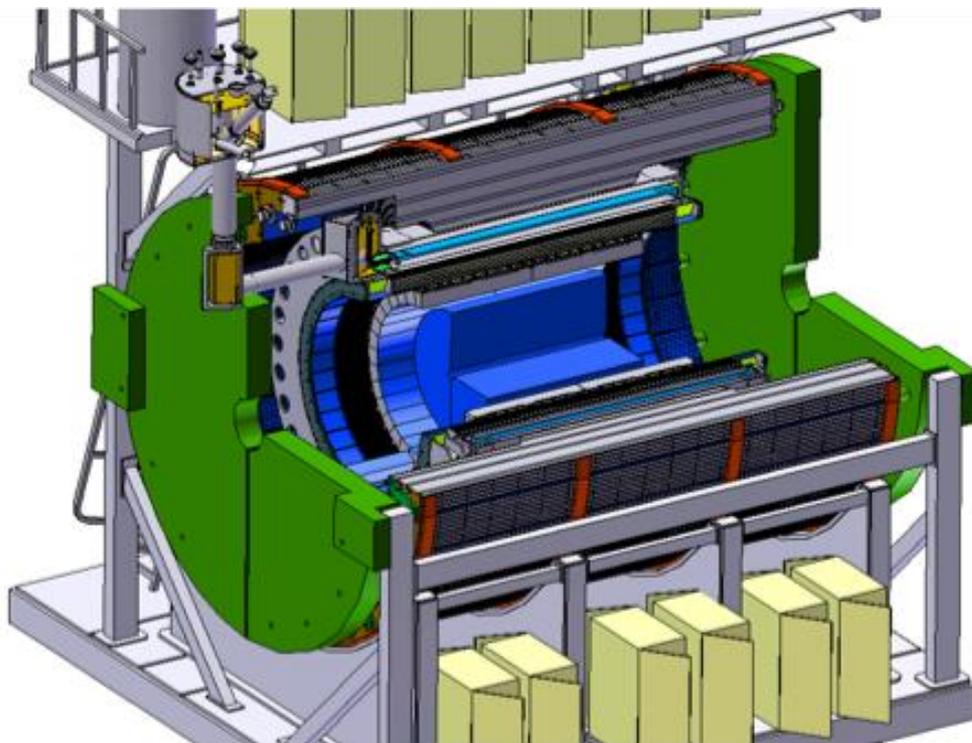


Poissonian Reference

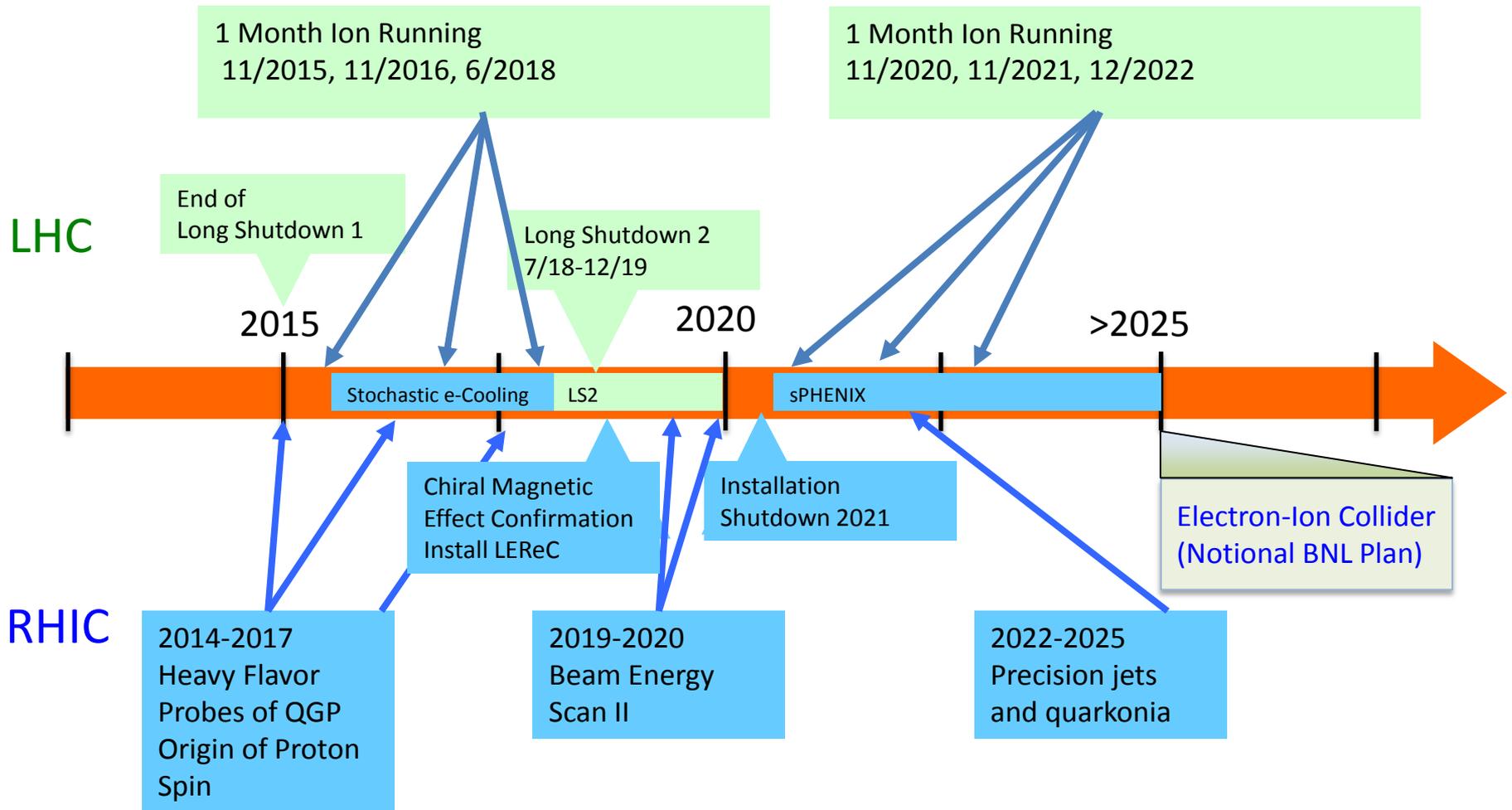
# The Physics Thrusts of sPHENIX

The main scientific thrusts are

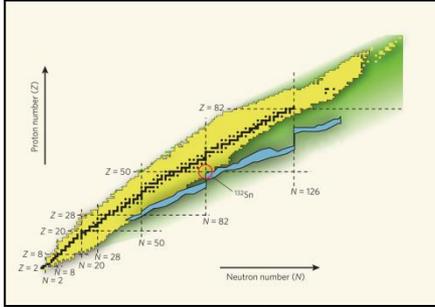
- mapping the character of the hadronic matter under conditions of extreme temperature or net baryon density by varying the temperature of the medium, the virtuality of the probe, and the length scale within the medium
- understanding the parton-medium interactions by studying heavy-flavor jets
- probing the effect of the quark-gluon plasma on the Upsilon states by comparing the p-p (proton-proton), p-A (proton-nucleus), and A-A (nucleus-nucleus) collisions.



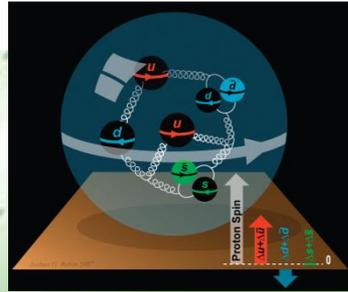
# RHIC / LHC Timeline



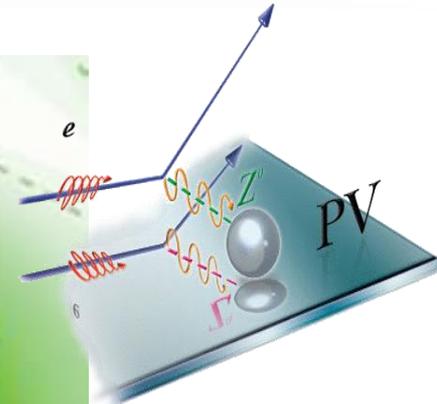
# JLab: Medium Energy Nuclear Science and Its Broader Impacts



**Nuclear Structure**



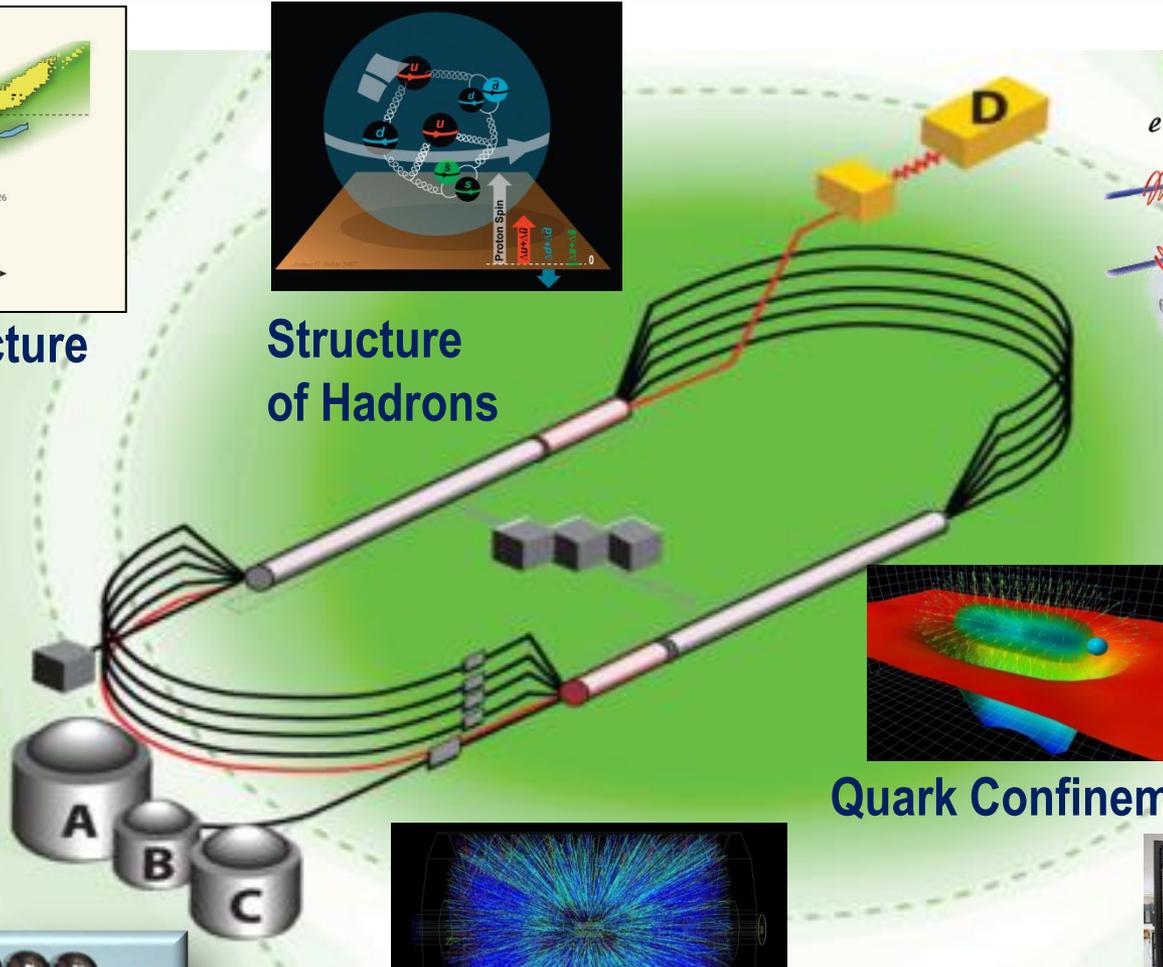
**Structure of Hadrons**



**Fundamental Forces & Symmetries**



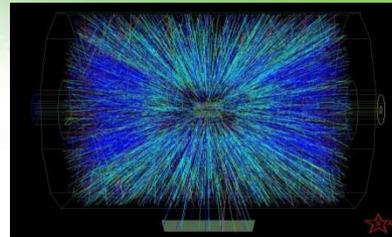
**Medical Imaging**



**Quark Confinement**



**Accelerator S&T**



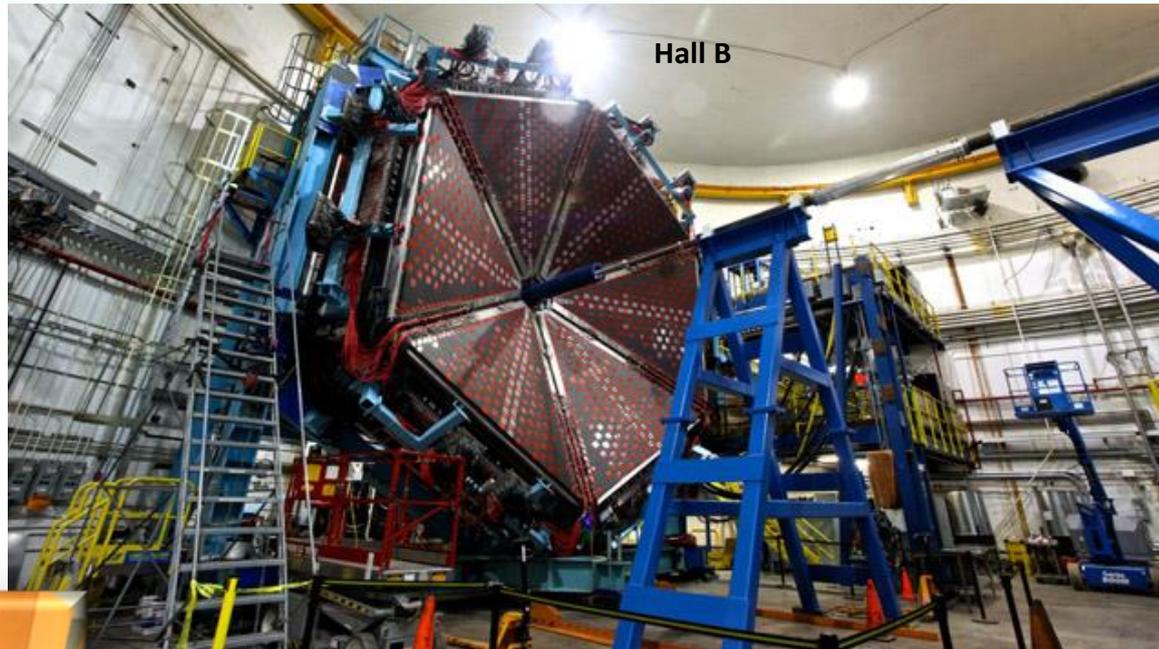
**Hadrons from QGP**



**Theory and Computation**

# The 12 GeV CEBAF Upgrade at TJNAF is > 97% Complete

Project completion (CD-4B) is planned by the end of FY 2017

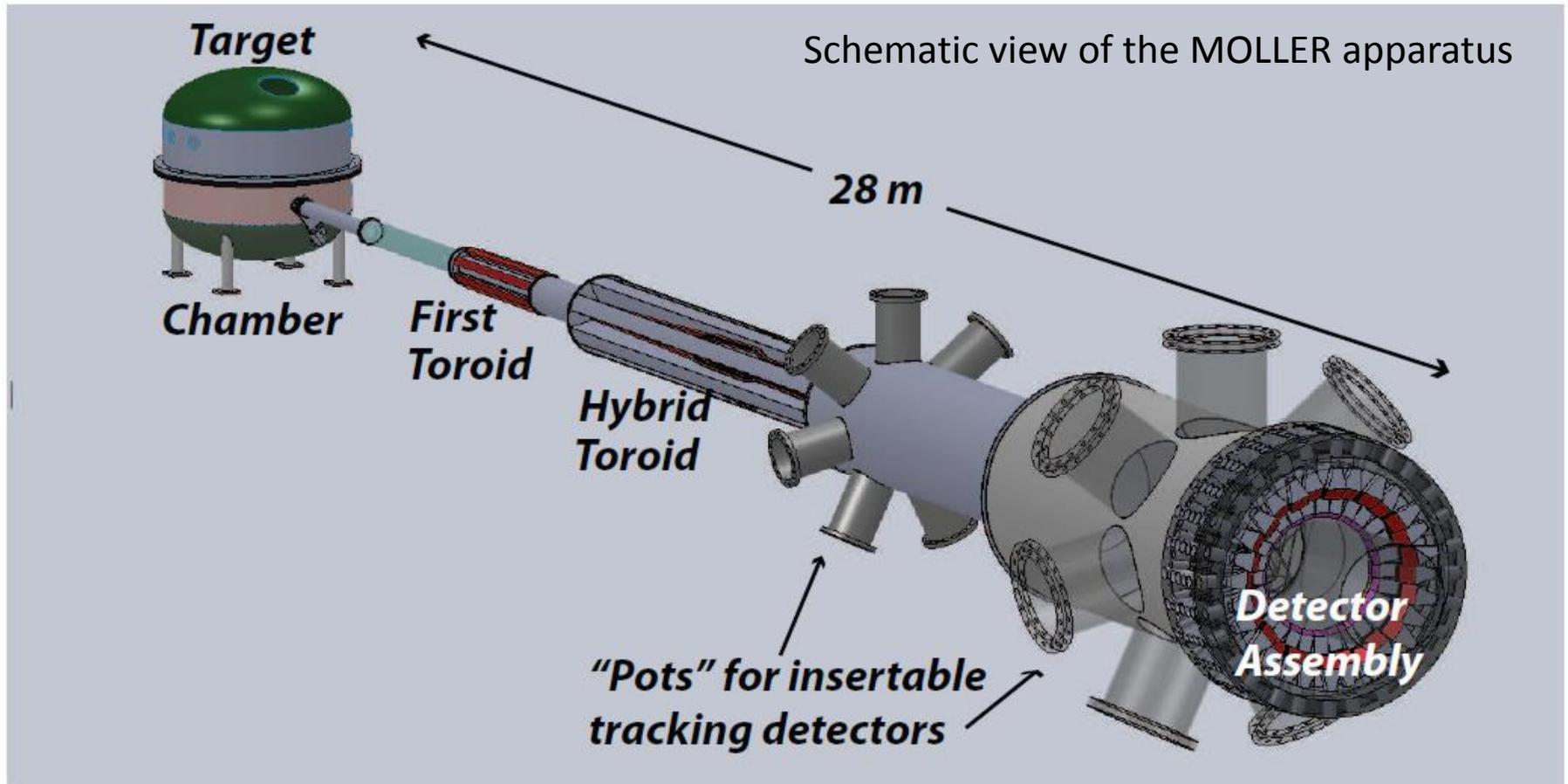


**With the completion of the 12 GeV CEBAF Upgrade, researchers will address:**

- 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.



# Looking to the future: MOLLER at JLAB



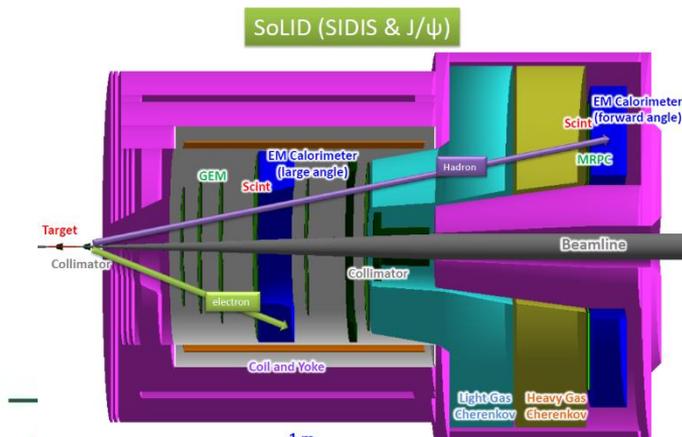
MOLLER had a successful science review. NP working to define the next steps to continue progress



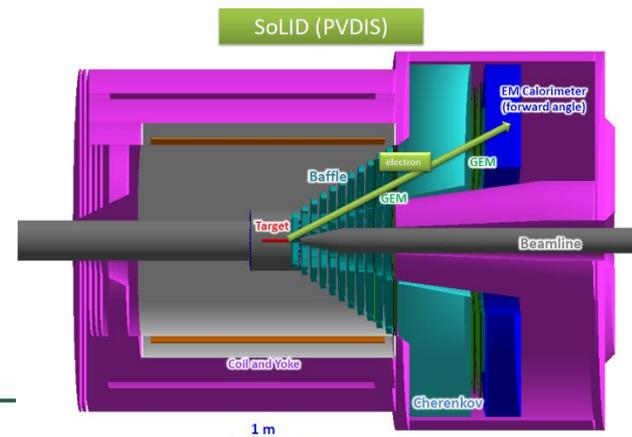
# Overview of SoLID

## The Solenoidal Large Intensity Device

- SoLID will full exploit the JLab 12 GeV Upgrade
- SoLID has a **Large Acceptance Detector** and Can Handle **High Luminosity** ( $10^{37}$ - $10^{39}$ )
- It takes advantage of the latest developments in detectors and data acquisition to:
  - Reach ultimate precision for SIDIS (TMDs), providing three-dimensional imaging of nucleon in momentum space
  - Study PVDIS in high- $x$  region providing sensitivity to new physics at 10-20 TeV, and QCD
  - Measure threshold  $J/\psi$ , probing strong color field in the nucleon, trace anomaly
- 5 highly rated experiments have been approved
  - Three SIDIS experiments, one PVDIS, one  $J/\psi$  production
  - Run group experiments: di-hadron, Inclusive-SSA, and much more ...
- A strong collaboration exists (250+ collaborators from 70+ institutes, 13 countries)
  - Significant international (Chinese) contributions and strong theoretical support

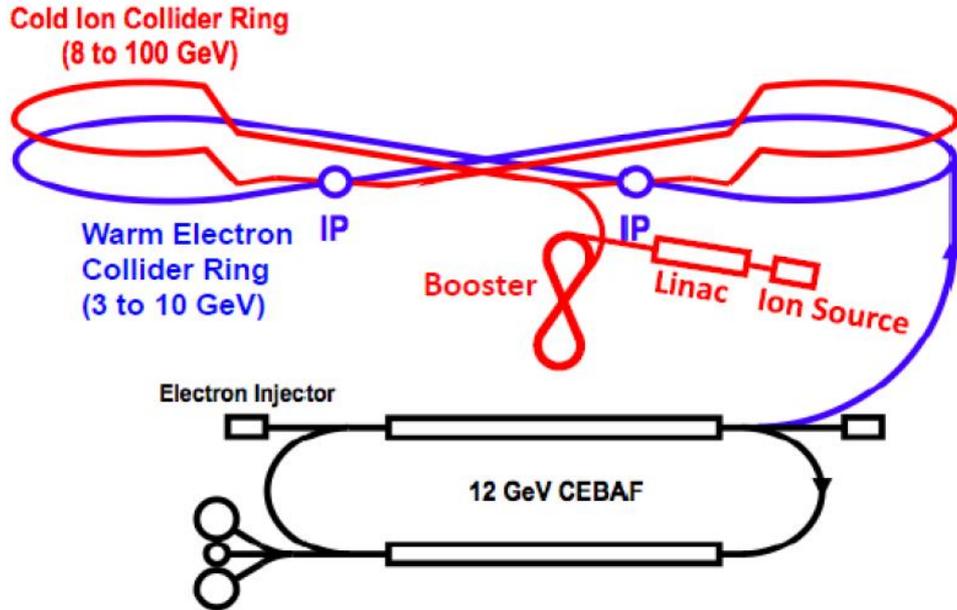


RHIC User Meeting

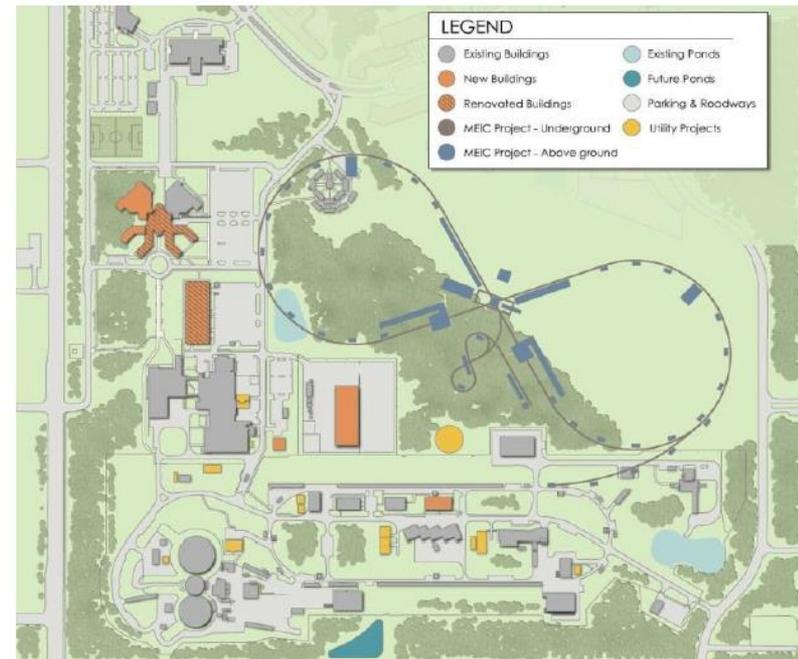


June 9, 2016

# A Possible Future MEIC at JLAB



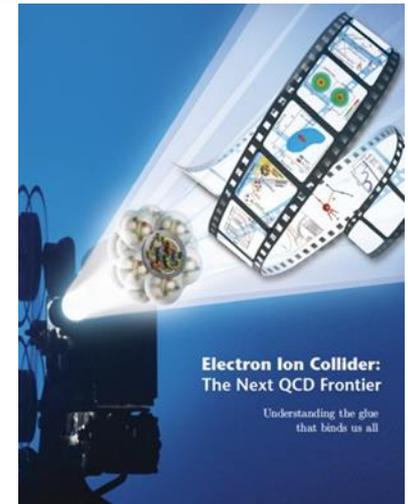
MEIC on the Jefferson Lab Site Map



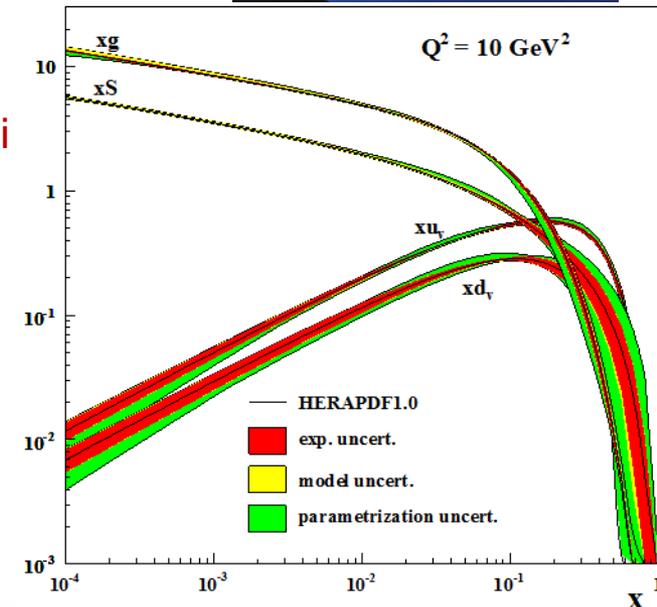
A schematic layout of MEIC. The ion collider ring is stacked vertically above the electron collider ring and take a vertical excursion to the plane of the electron ring for a horizontal crossing

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

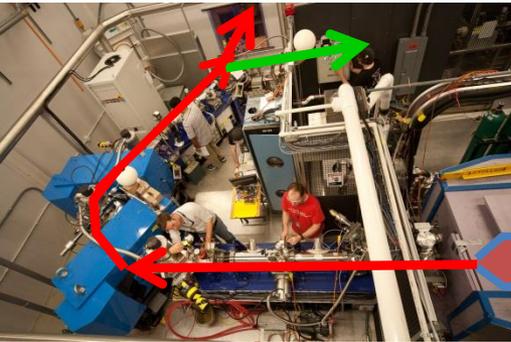
- Proton (and nuclei) and black holes are the only fully relativistic (high enough energy density to excite the vacuum) stable bound systems in the universe. Protons can be studied in the laboratory.
- Protons are fundamental to the visible universe (including us) and their properties are dominated by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

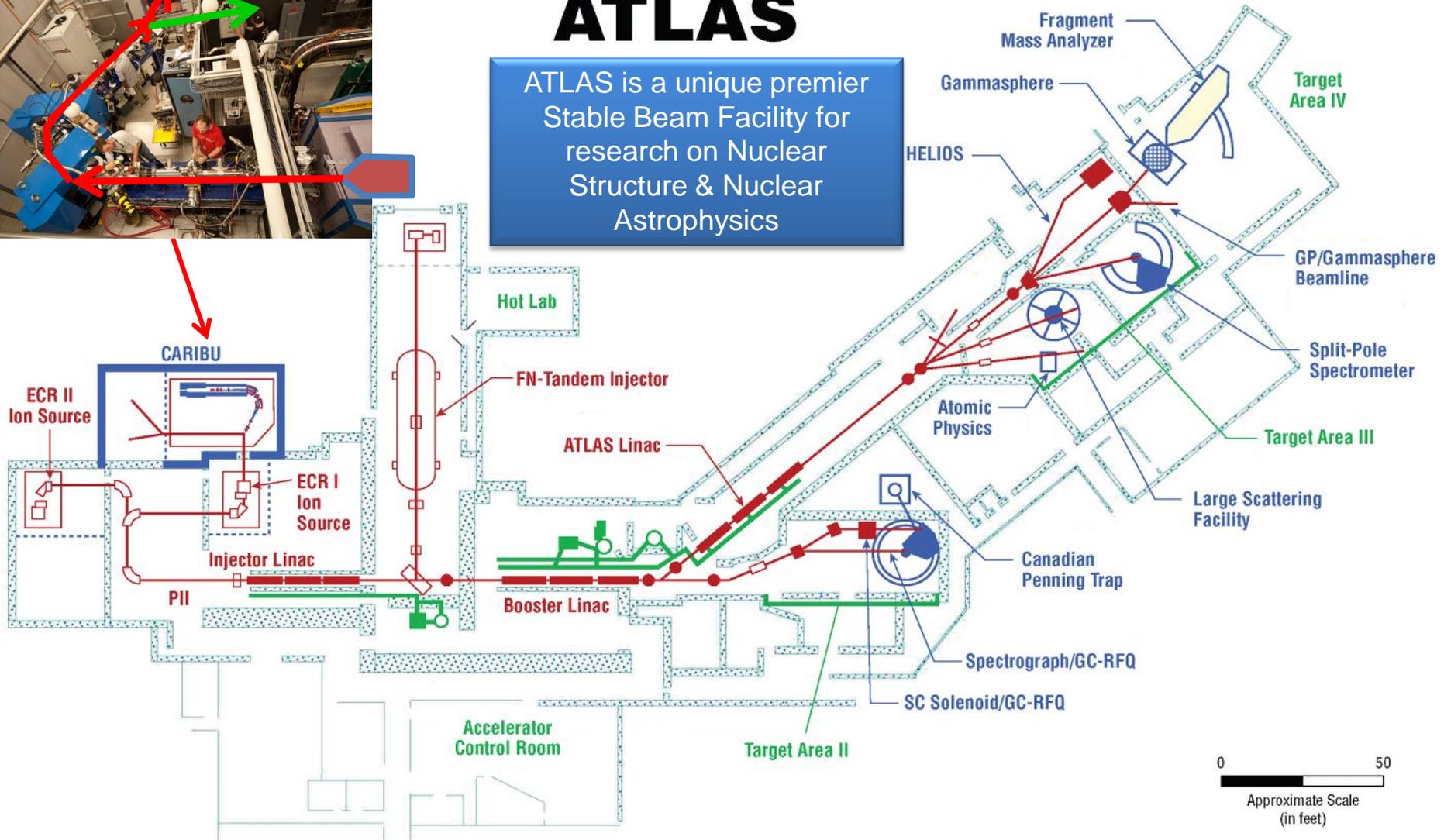


# ATLAS at ANL Uniquely Provides Low Energy SC Research Opportunities



## ATLAS

ATLAS is a unique premier Stable Beam Facility for research on Nuclear Structure & Nuclear Astrophysics



# Facility for Rare Isotope Beams is > 60% Complete

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

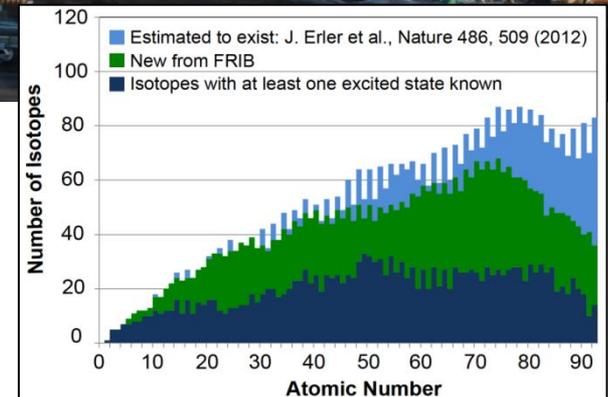
## Nuclear Astrophysics

- The origin of the heavy elements and explosive nucleosynthesis
- 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.**



	PYs	FY 2017	FY 2018	FY 2019	FY 2020	FY 2021	DOE Total	MSU	TOTAL
FUNDING PROFILE	318,000	100,000	97,200	75,000	40,000	5,300	635,500	94,500	730,000

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## Fundamental Symmetries in DOE NP:

Topics where nuclear science contributes uniquely to knowledge, experimental techniques or both

Topics that are non-overlapping with DOE HEP

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

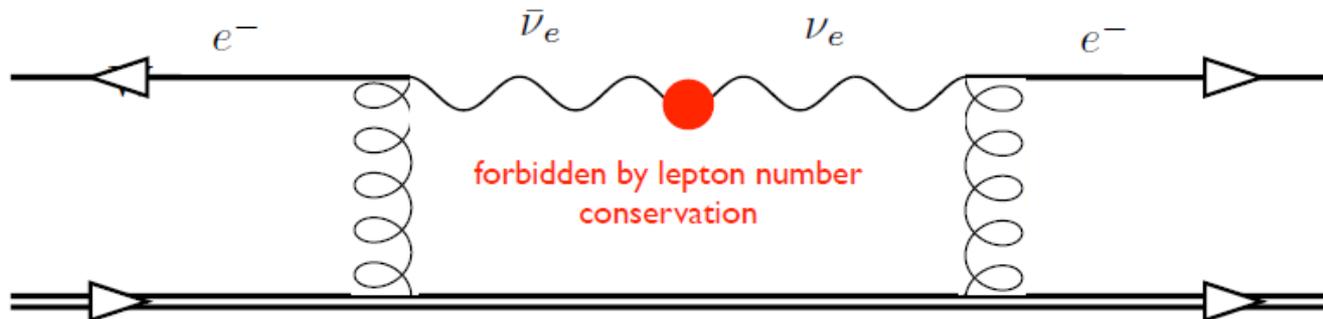
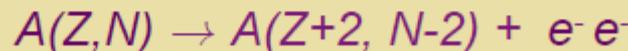
## Three Light Neutrinos: What Do We Know ?

$2\nu$  DBD:



If own antiparticle, can be emitted then absorbed during decay

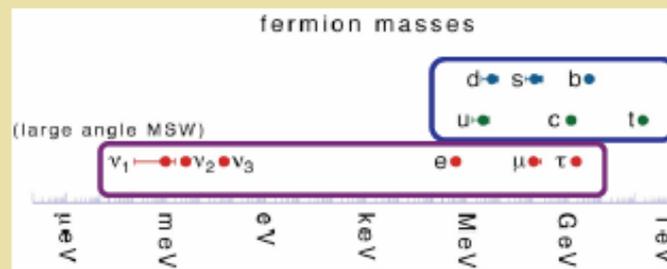
$0\nu$  DBD:



# 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

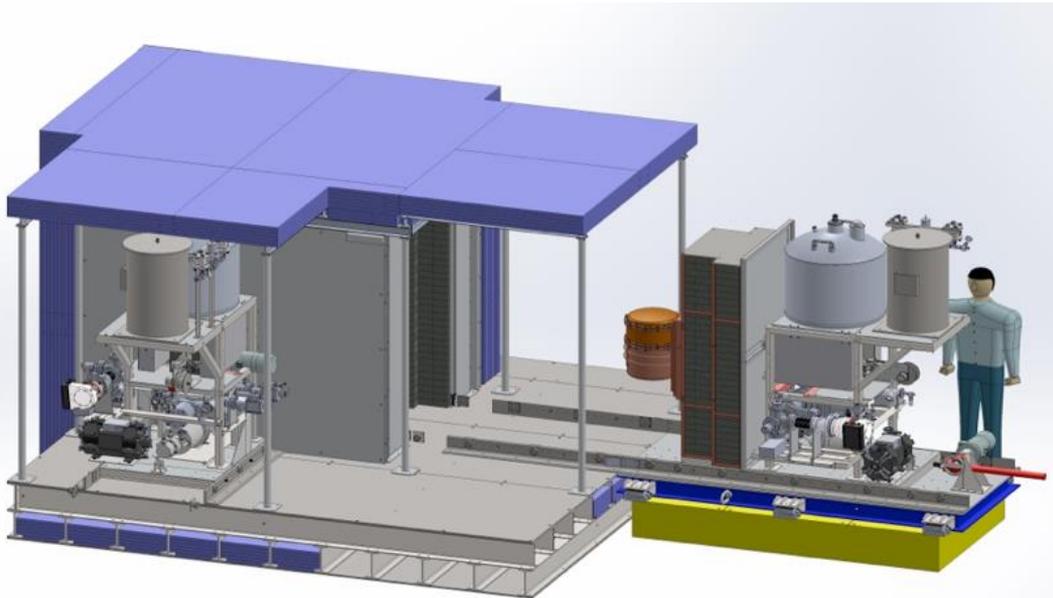
Partners



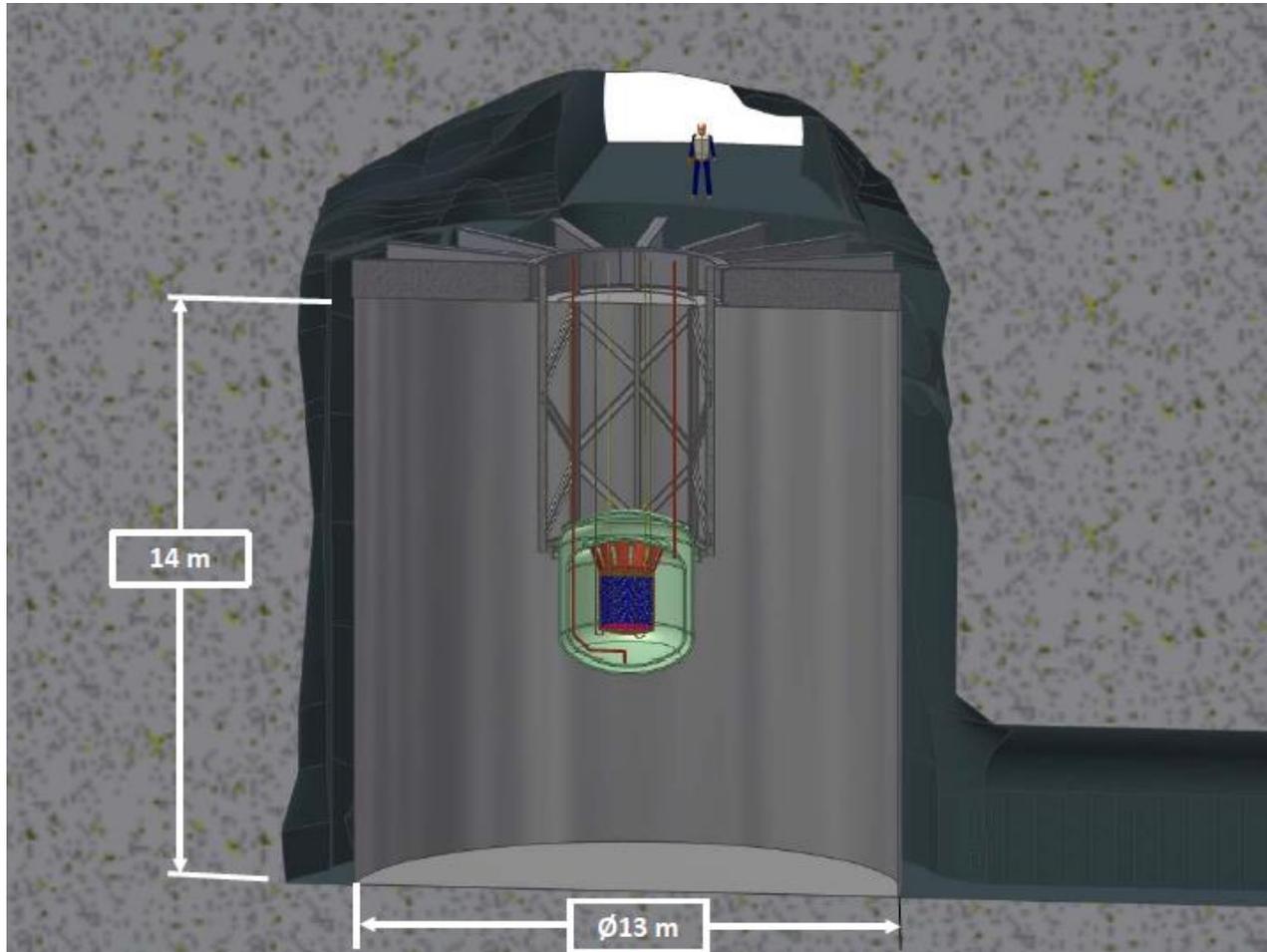
# MAJORANA DEMONSTRATOR Progress



- Goal:** Demonstrate backgrounds needed for a tonne scale  $0\nu\beta\beta$  experiment.
- Configuration:** 44-kg of Ge detectors, in two independent cryostats  
29 kg of 87% enriched  $^{76}\text{Ge}$  crystals; 15 kg of  $^{\text{nat}}\text{Ge}$ , P-type point-contact detectors
- Module One:** Installed in-shield and taking low background data since January 2016.  
End-to-end analysis underway from July - Oct. 2015 dataset to shake down data cleaning and analysis tools (relatively insensitive because of partial shielding).  
Expect to have first background information from 2016 run in the spring.
- Module Two:** construction and assembly proceeding on schedule, in-shield commissioning beginning ~ May 2016



# nEXO Stewardship Transferred to NP in FY2017

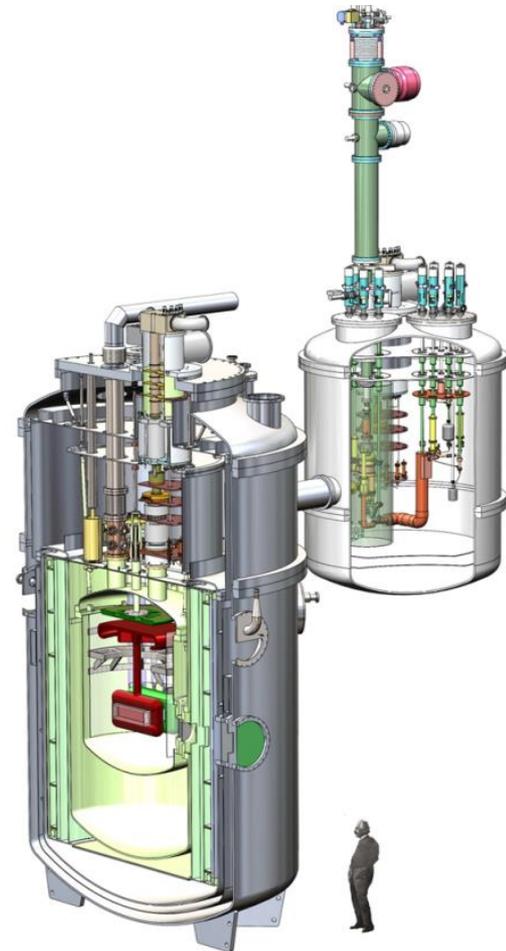


Artist's concept of the nEXO detector in SNOLab's. In this model the TPC is housed in a large graphite composite cryostat which in turn is submerged in a water shield equipped with photomultiplier tubes to double as a cosmic ray veto detector.



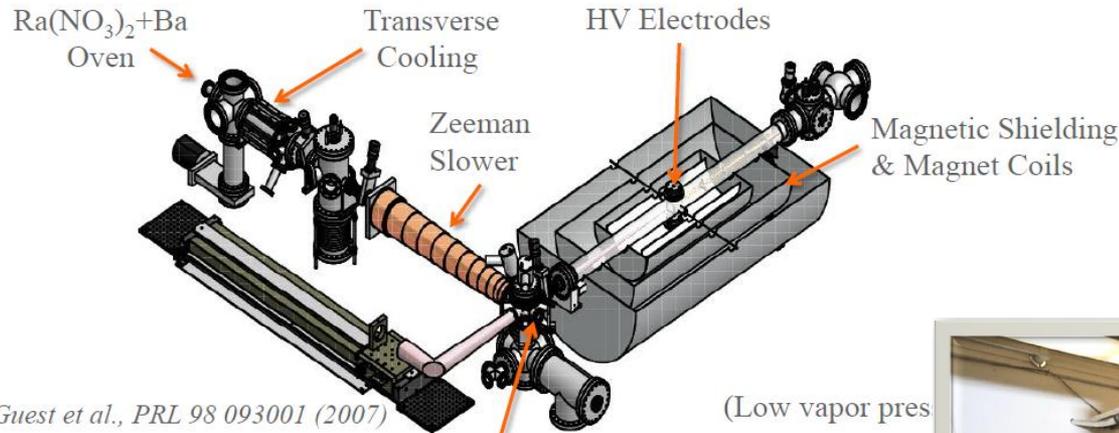
# Progress on nEDM at the Spallation Neutron Source

- Completed half of 4-year Critical Component Demonstration (CCD) program
  - Goal: reduce technical risk by demonstrating full-scale modules at operating conditions
    - High-power non-magnetic dilution refrigerator
    - Polarized Helium-3 (co-magnetometer) injection/transport
    - Magnet coil package
    - High-voltage
    - Ultracold neutron storage
    - Light collection system
- To be followed by Large Subsystem Integration (LSI) (assembling the modules into a complete experiment) and Conventional Component Procurements (CC)



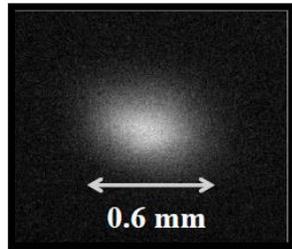
# $^{225}\text{Ra}$ EDM Experiment: New Results

## Collect Atoms in MOT



*J. R. Guest et al., PRL 98 093001 (2007)*

(Low vapor pres



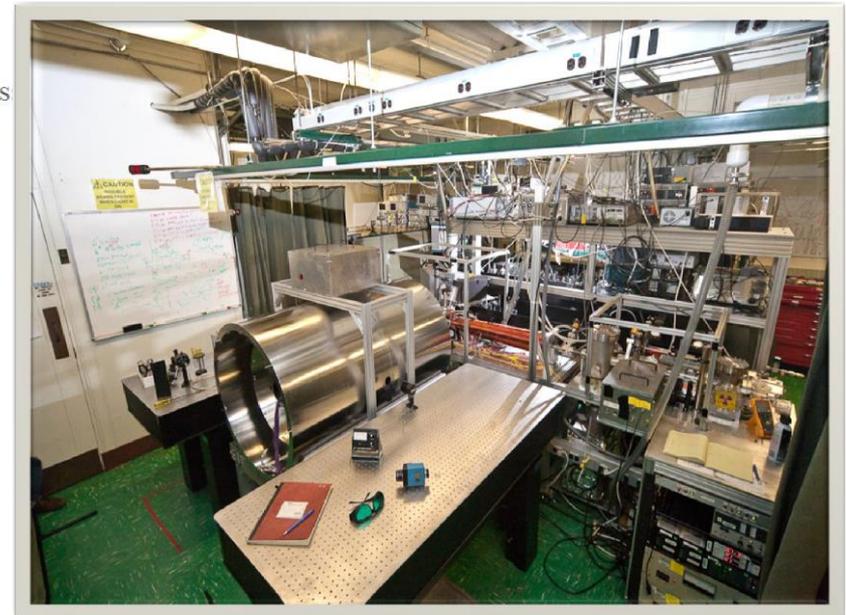
$^{226}\text{Ra}$  MOT  
20,000 atoms

For EDM:  
Ra-225  
 $I = 1/2, J = 0$   
 $t_{1/2} = 15$  days

ANL, MSU, USTC and Kentucky

2014: First  $^{225}\text{Ra}$  measurement M. Dietrich *et al.*, PRL 114, 233002 (2015)

2015: Updated measurement:  
factor of 35 improvement  
 **$|d| < 1.4 \times 10^{-24} \text{ e cm}$**   
M. Bishof *et al.*, in preparation



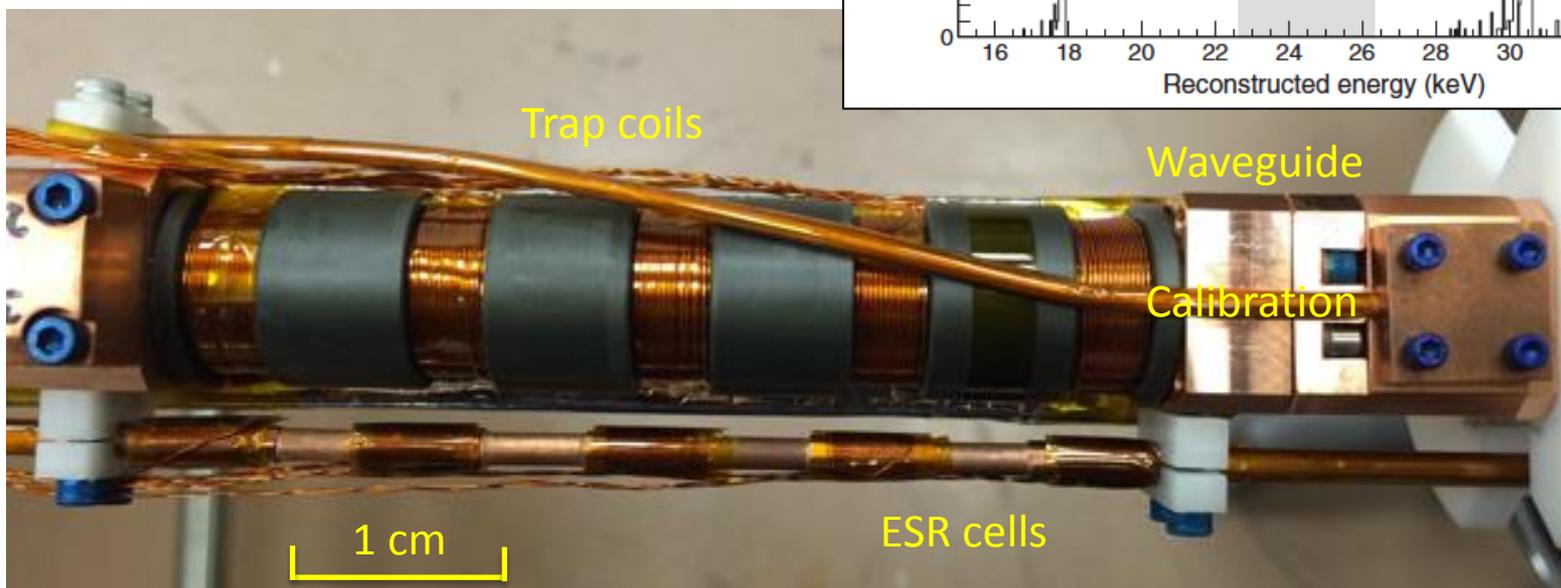
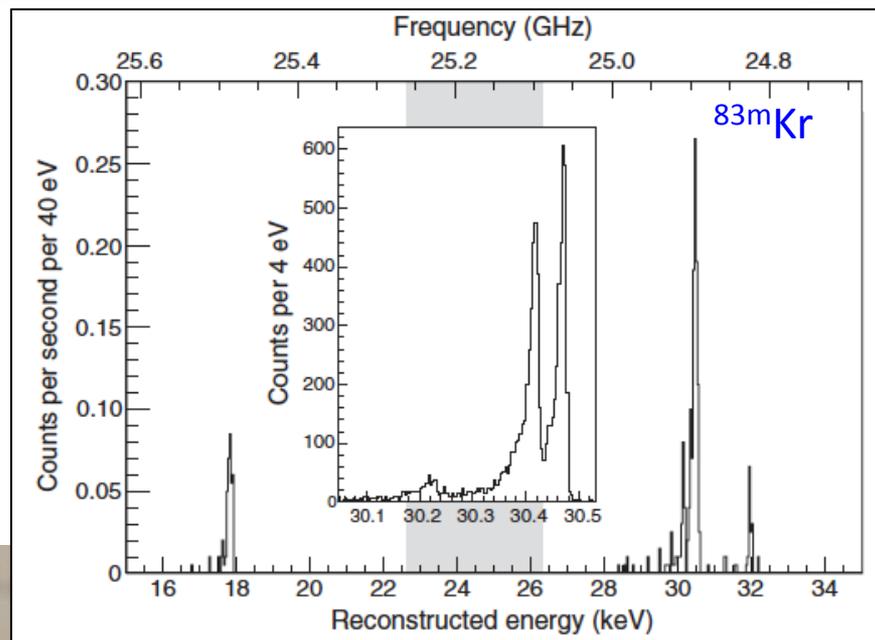
# PROJECT 8

## A Potential Major Advance On Measuring $m_\nu$

A new concept for direct measurement of **neutrino mass** by observation of cyclotron radiation in tritium beta decay.

Successful proof of concept with  $^{83m}\text{Kr}$ : [PRL 114, 162501 \(2014\)](#).

26-GHz tritium cell ready for first data – larger systems to follow.



# Feasibility Study for a Neutron Lifetime Experiment

The UCN $\tau$  experiment testbed is operational and acquiring data to study systematic effects.

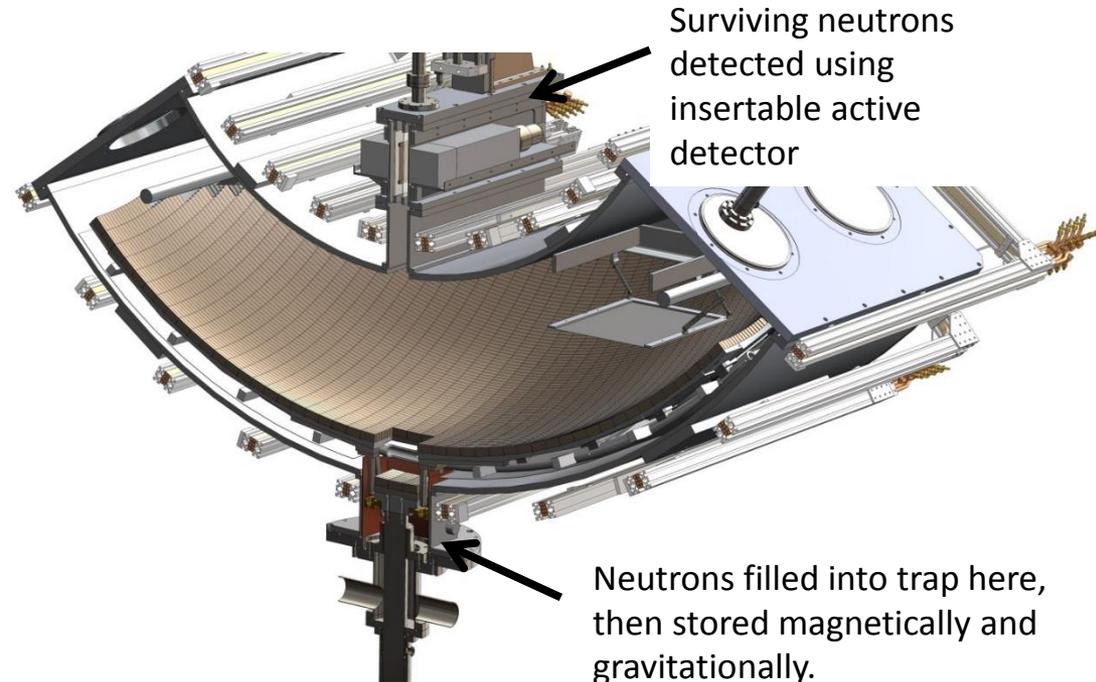


Cubic meter trap stores tens of thousands of neutrons per fill, allowing rapid study of small effects.

Key features of experiment:

- 1) Magnetic bottle has storage time much greater than free neutron lifetime, rapid phase space mixing
- 2) Rapid internal neutron detection scheme counts surviving neutrons with constant efficiency
- 3) No absolute counting efficiencies needed: only relative neutron counting

Progress in 2015-2016 LANSCE run cycle: commissioned an active in situ detector; performed intensive studies of neutron phase space evolution, superbarrier UCN removal (“cleaning”), normalization, and detector efficiency effects.



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Although significant, the NP investment in Fundamental Symmetries is modest to date, and to an extent the planned new structure for managing this scope is reorganization at HQ rather than revolution in the balance among NP investments

# Nuclear Theory

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

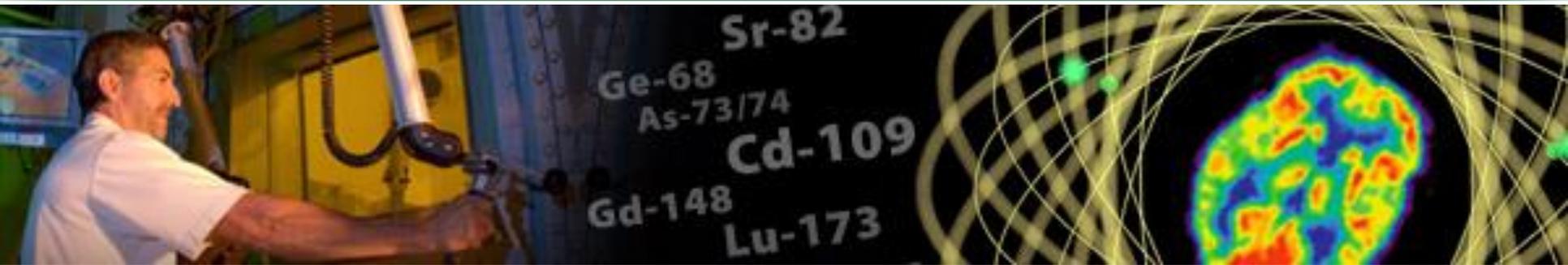
A strong Nuclear Theory effort:

- 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**



# Nuclear Physics

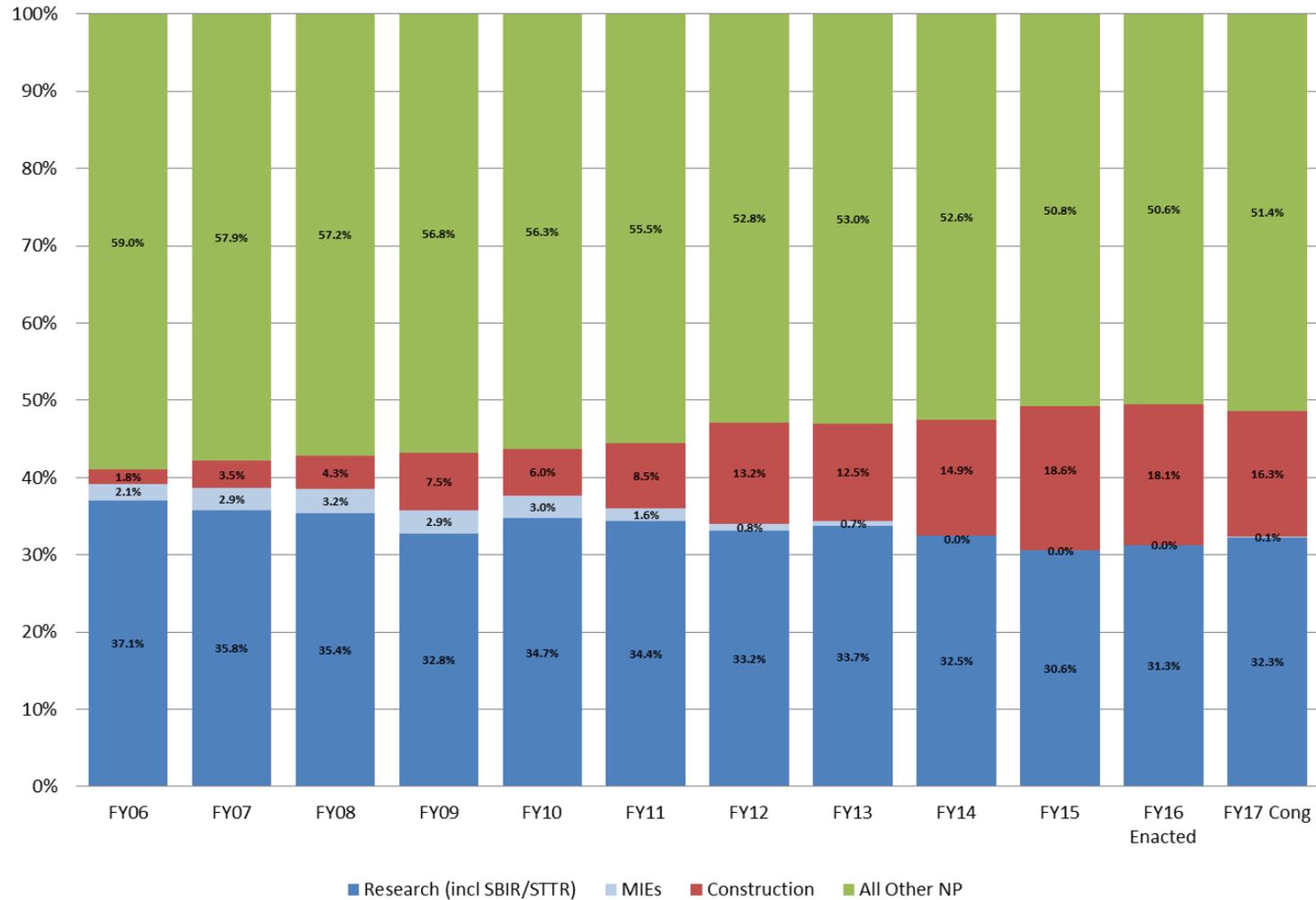
## FY 2017 President's Request – Summary

(\$ in 000s)	FY 2015 Actual	FY 2016 Enacted	FY 2017 Request	FY 2017 vs. FY 2016
Research	167,195	176,815	187,151	+10,366
User Facility Operations	280,873	288,957	303,038	+14,081
Other Operations	24,313	24,507	22,826	-1,681
Projects	106,500	107,500	103,000	-4,500
Other	16,619	19,321	19,643	+322
<b>TOTAL NP</b>	<b>595,500</b>	<b>617,100</b>	<b>635,658</b>	<b>+18,558</b>

- **Research** – Support university and laboratory research 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, neutrinoless double beta decay, and isotope production and processing techniques.
- **User Facility Operations** – Operate the three Nuclear Physics user facilities by supporting staff, equipment, and materials required for reliable operations for research focused on: advancing the understanding of strongly interacting matter and its description in QCD, and to search for evidence of new physics beyond the Standard Model at CEBAF; characterizing the perfect quark-gluon liquid discovered in collisions of relativistic heavy nuclei at RHIC; and advancing the areas of nuclear structure and reactions, low-energy tests of the standard model, and nuclear astrophysics at ATLAS.
- **Other Operations** – Maintain mission readiness of the Isotope Program facilities for the production of radioisotopes; continue operations of the 88-Inch Cyclotron at LBNL, and complete disposition activities for HRIBF at ORNL.
- **Projects** – Continue FRIB construction according to its baselined profile, and initiate two MIEs – GRETA and SIPP.
- **Other** – Provide required funding for the SBIR/STTR programs consistent with the legislative mandate (offset partially by transfer of WCF to SCPD).

# Funding Trends Within the NP Portfolio

Constructing 2 major facilities has stressed the NP program –  
 Research trend is beginning to reverse starting in FY 2016 and continuing in FY 2017



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## Big Picture Challenges:

Balance Between Research and Operations

Effective Utilization of Facilities

Ability to take advantage of cross-cutting opportunities



# Status and Outlook

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- The RHIC and CEBAF 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 for 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 maintaining 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.
- A second 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.