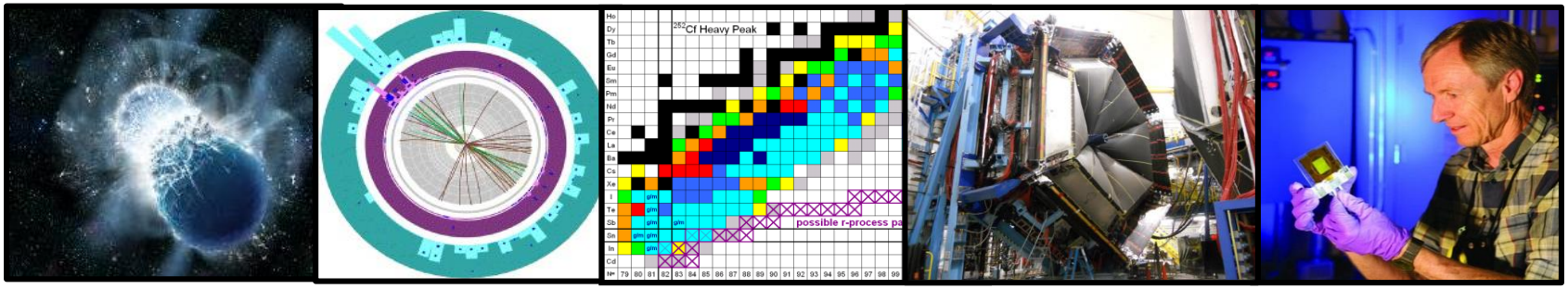
U.S. DEPARTMENT OF ENERGY | Office of Science

Perspectives From the DOE Nuclear Physics (NP) Program

U.S. LHC Users Meeting

October 17, 2019

Dr. Timothy J. Hallman
Associate Director of the Office of Science
for Nuclear Physics



Nuclear Physics FY2019 Budget Status

Nuclear Physics	FY 2018 Enacted	FY 2019 Enacted	FY 2019 Enacted vs FY 2018 Enacted
Operations and maintenance			
Medium Energy	174,953	184,190	+9,237
TJNAF Ops	*112,000*	*117,440*	*+5,440*
Heavy Ions	226,612	230,479	+3,867
RHIC Ops	*187,284*	*193,125*	*+5,841*
Low Energy	96,683	100,745	+4,062
ATLAS Ops	*21,000*	*21,630*	*+630*
FRIB Ops	*3,750*	*3,950*	
Nuclear Theory	47,852	55,327	+7,475
Isotope Program	40,700	44,259	+3,559
Undistributed	—	—	—
Total, Operations and maintenance	**586,800**	**615,000**	**+28,200**
Construction			
14-SC-50 Facility for Rare Isotope Beams	97,200	75,000	-22,200
Total, Construction	**97,200**	**75,000**	**-22,200**
Total, Nuclear Physics	**684,000**	**690,000**	**+6,000**

FY2020 PR for DOE NP $624, 854M

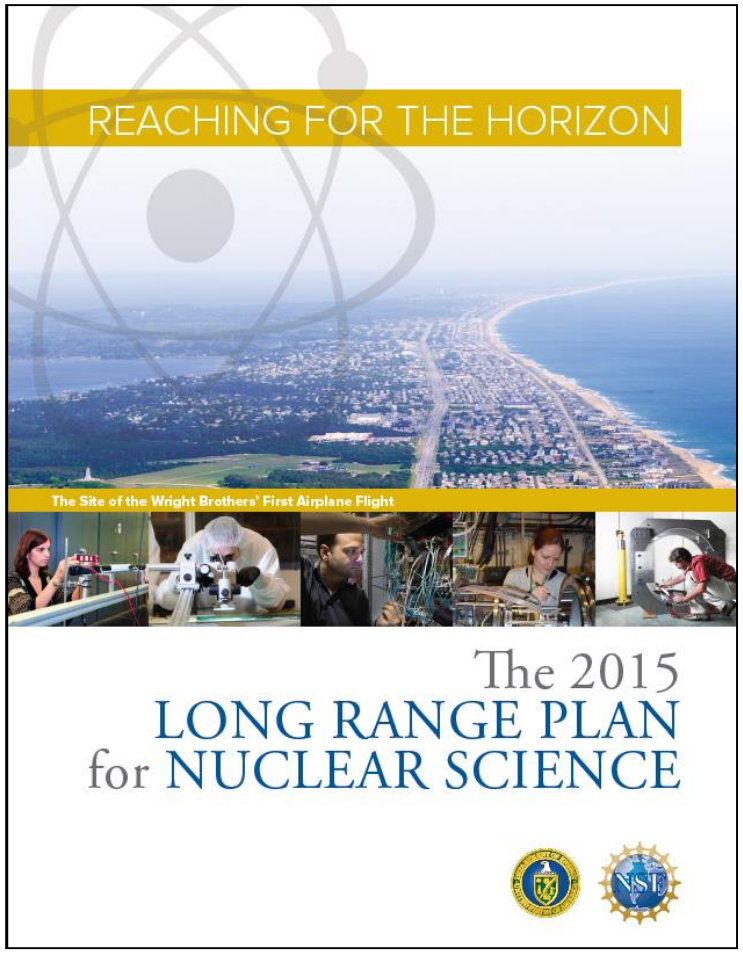
For FY2020, the House recommends $735,000,000 for NP: *Operations and Maintenance.*—Within available funds, the recommendation provides $10,000,000 for Electron Ion Collider R&D. The Department is directed to give priority to optimizing operations within Medium Energy Nuclear Physics and at the Facility for Rare Isotope Beams. Within available funds, the recommendation provides $10,200,000 for the Gamma-Ray Energy Tracking Array, $9,520,000 for the Super Pioneering High Energy Nuclear Interaction Experiment, and not less than $2,500,000 for MOLLER. Also, in accompanying table $1M in TEC funding for the EIC.

For FY2020, the Senate recommends $736,000,000 for NP: *Operations and Maintenance.*—Within available funds, the Committee recommends $45,300,000 for construction of the Facility for Rare Isotope Beams [FRIB], $1,000,000 for the Electron Ion Collider, and $30,000,000 for the U.S. Stable Isotope Production and Research Center. The Committee also recommends $28,500,000 for early operations at FRIB. […] Within major items of equipment and other project costs, the Committee recommends $1,500,000 for the Stable Isotope Production Facility; $10,200,000 for the Gamma-Ray Energy Tracking Array; $9,520,000 for sPHENIX; $5,330,000 for MOLLER; $5,000,000 for Ton-Scale Neutrino-less Double Beta Decay; $10,000,000 for the Electron Ion Collider; and $1,000,000 for the High Rigidity Spectrometer.

The 2015 Long Range Plan for Nuclear Science

Recommendations:

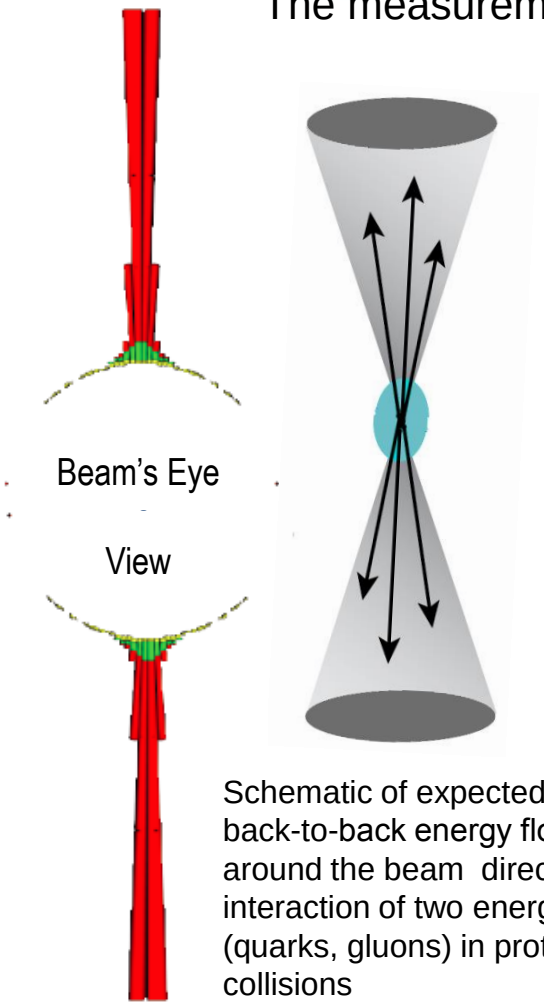
1. Capitalize on investments made to maintain U.S. leadership in nuclear science.
2. Develop and deploy a U.S.-led ton-scale neutrino-less double beta decay experiment.
3. Construct a high-energy high-luminosity polarized electron-ion collider (EIC) as the highest priority for new construction following the completion of FRIB.
4. Increase investment in small-scale and mid-scale projects and initiatives that enable forefront research at universities and laboratories.



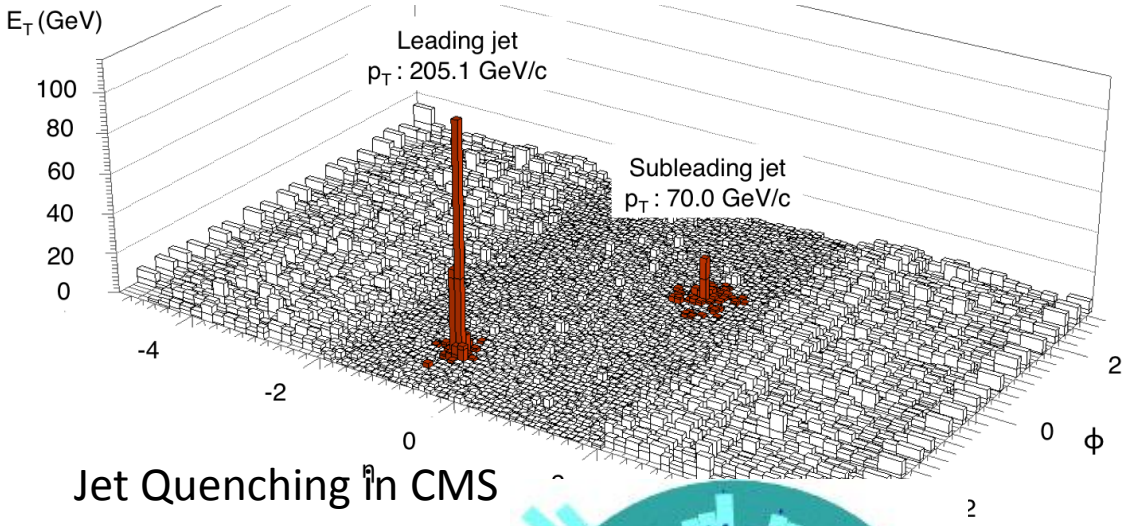
The FY 2019 appropriation continues to support progress toward the 2015 LRP Vision.

Current RHIC Focus: Understanding Phenomena Discovered at RHIC and Confirmed at the LHC

The measurement of jets yielded a signature discovery: "Jet Quenching"

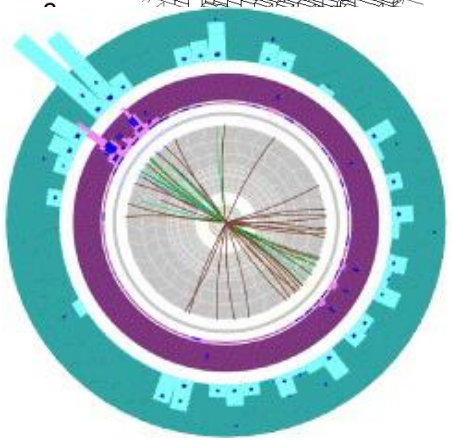


Schematic of expected symmetric back-to-back energy flow ("jets") around the beam direction from the interaction of two energetic partons (quarks, gluons) in proton – proton collisions



Jet Quenching in CMS

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



Research continues to discover the science underlying phenomena exhibited by this unique form of QGP matter

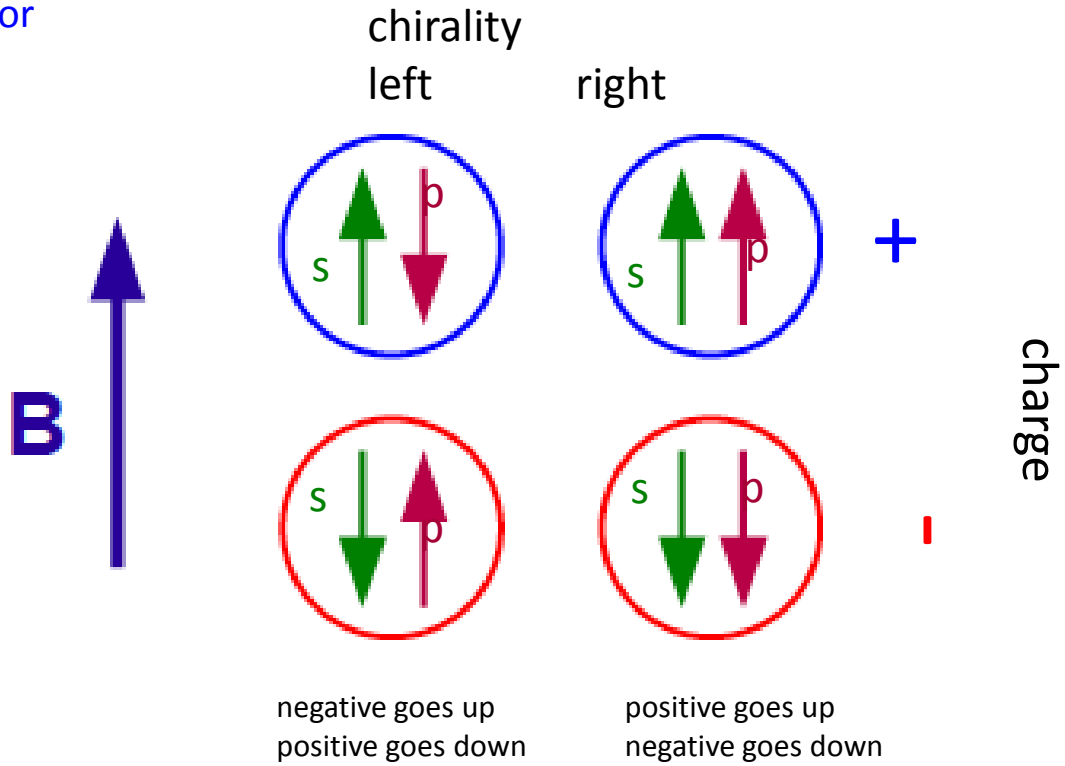
The Chiral Magnetic Effect

The chiral anomaly of QCD creates differences in the number of left and right handed quarks.

a similar mechanism in electroweak theory is likely responsible for the matter/antimatter asymmetry of our universe

spin alignment in B-field: opposite direction for opposite charges

handedness: momentum and spin, aligned or anti-aligned

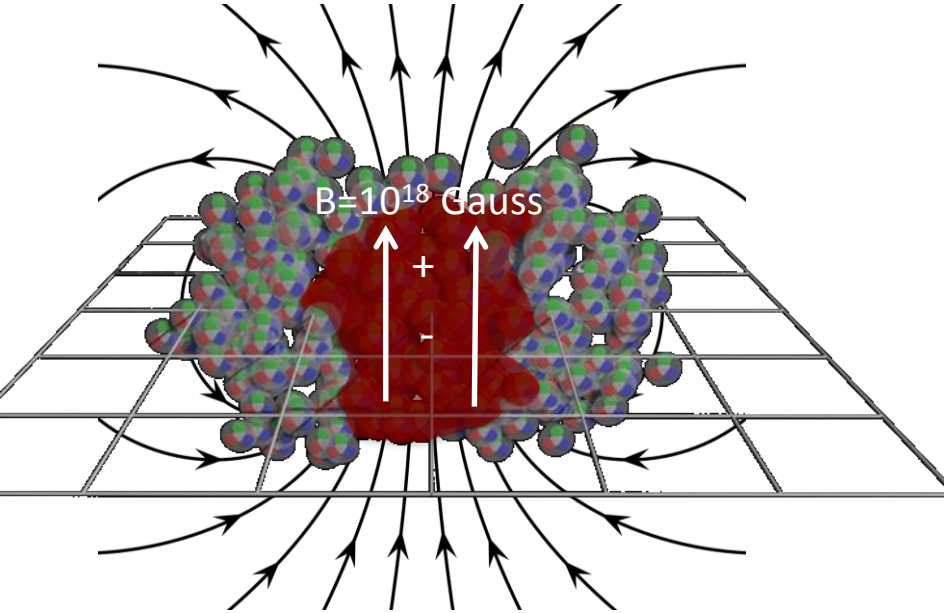


An excess of right or left handed quarks should lead to a current flow along the magnetic field

Measuring Topological Charge Transitions

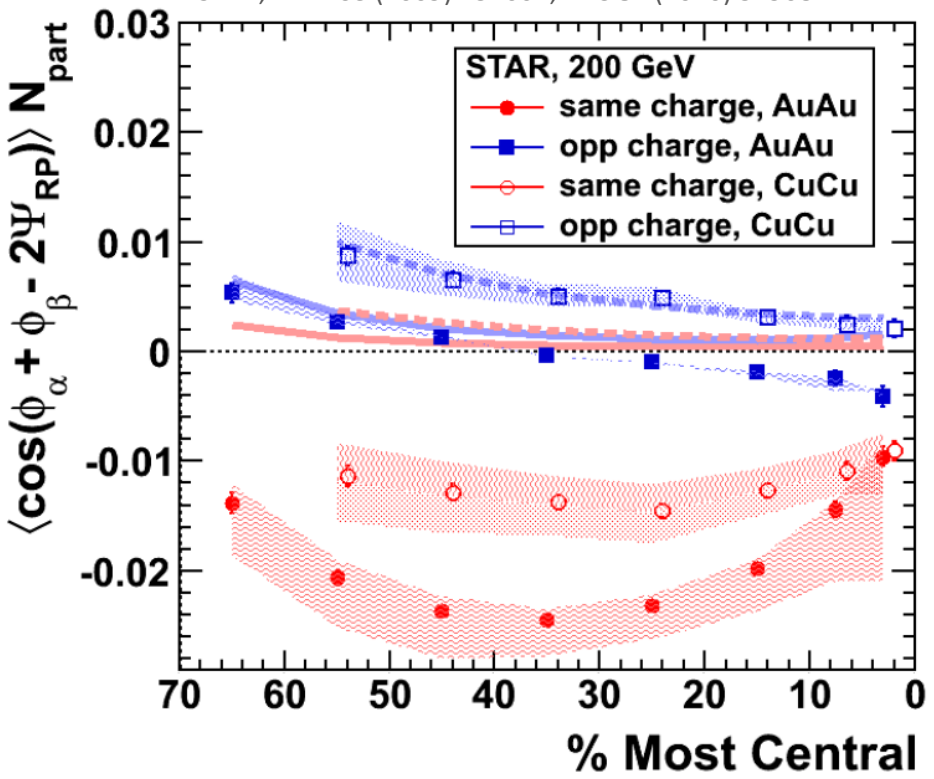
Charge separation observed. But behavior is more complicated than initial cartoon

charge separation



Signal is 10^{24}×larger than upper limit on neutron electric dipole moment

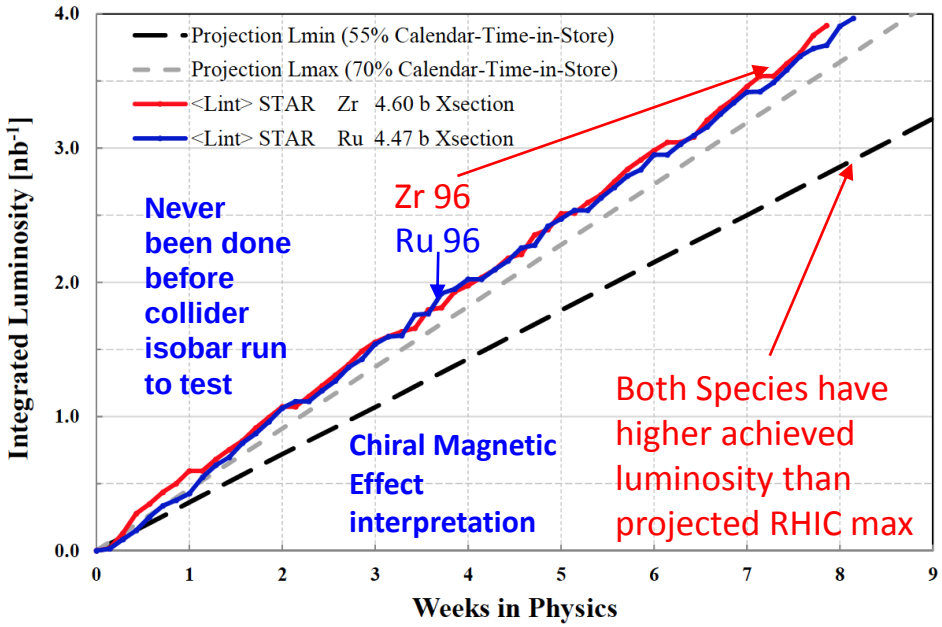
STAR; PRL **103** (2009) 251601; PRC **81** (2010) 54908



Implementing New Capability for New Discoveries Continues

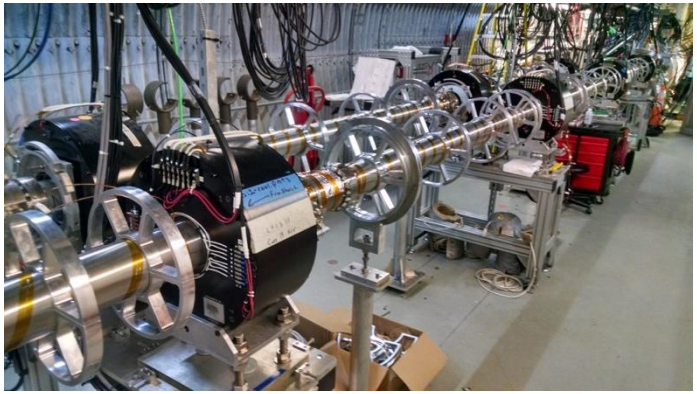
2018 Run

Understanding the origin of charge separation wrt the reaction plane



2019 Run

- The next focus at RHIC: a search for a critical point between the phases of nuclear matter begins in FY2019. A critical factor is electron cooling:



Cooling of low energy, bunched heavy ion beams (3.85–5.75 GeV/n) to increase luminosity

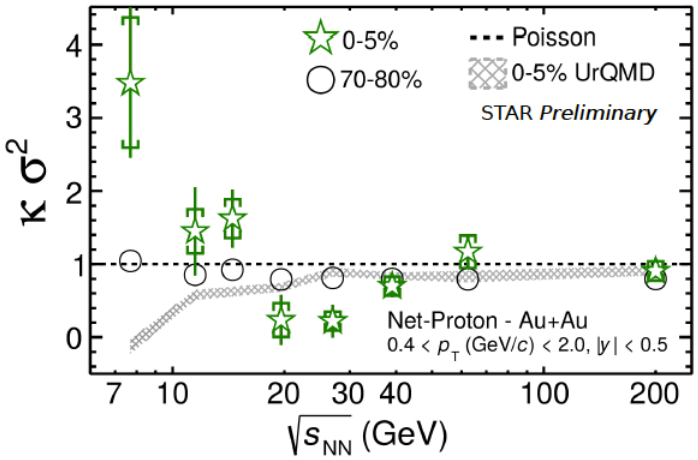
Project on track for completion in 2018 and use in low-energy RHIC runs

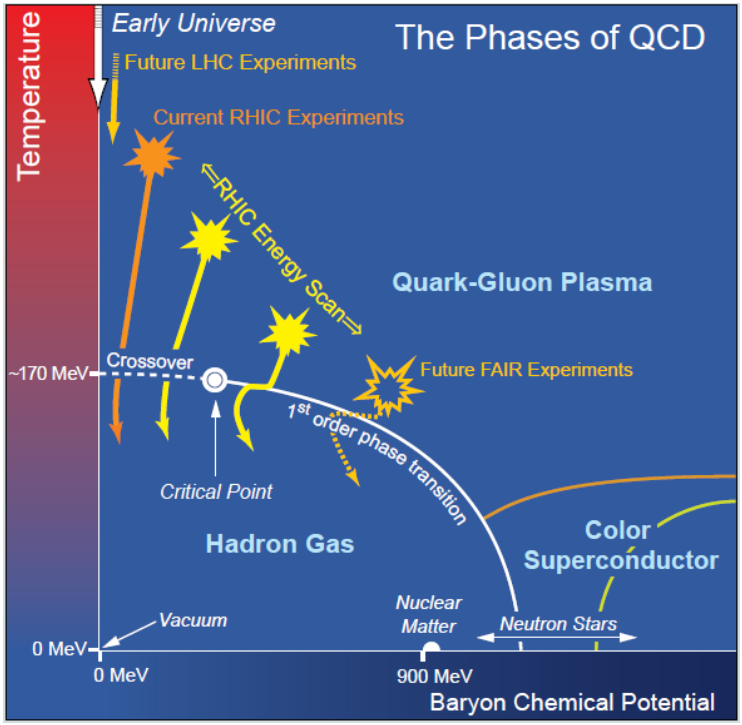
- Consistently high facility availability (~85%)
- No other facility worldwide, existing or planned, rivals RHIC in science reach and versatility as a heavy ion collider. It is the only polarized proton collider in the world.

The Current Focus Beam Energy Scan II (BESII), A Statistics Challenge

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.



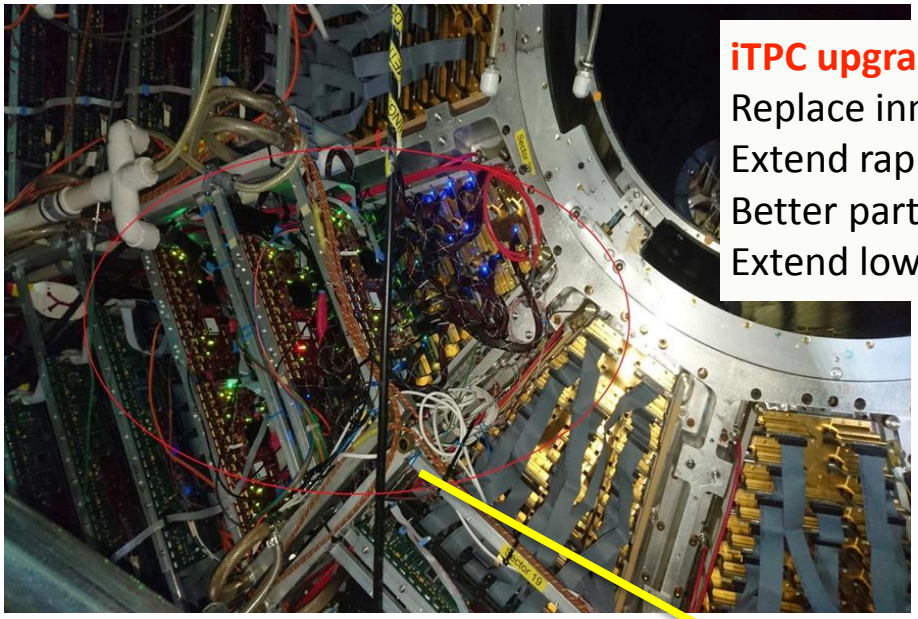


A primary signature of the Critical Point will be non-Poissonian scaled kurtosis (net baryon number fluctuations)

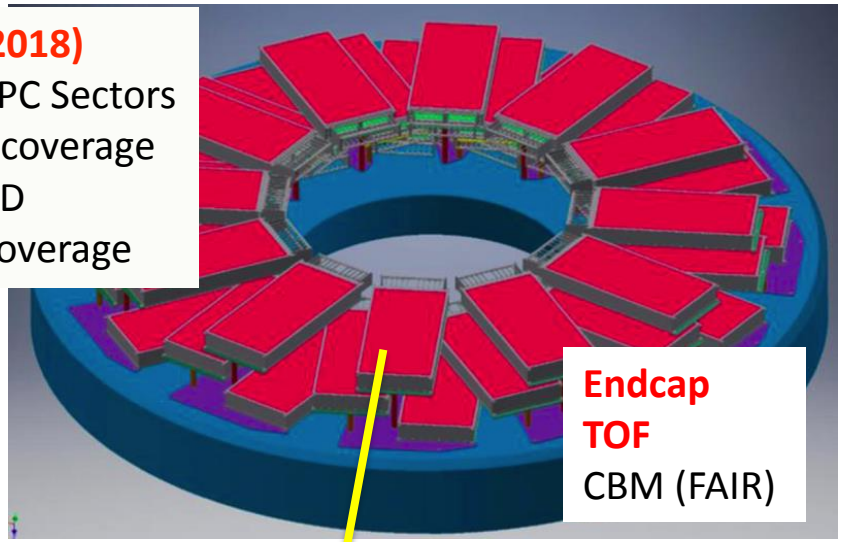
Results from the first survey run appear tantalizing, but the statistics do not allow a conclusion. Fluctuations consistent with Poissonian behavior fall along the line at unity

For BES II, a 2 year campaign (~ 48 weeks) is planned

Important STAR Upgrades Implemented for Beam Energy Scan II (BES-II)

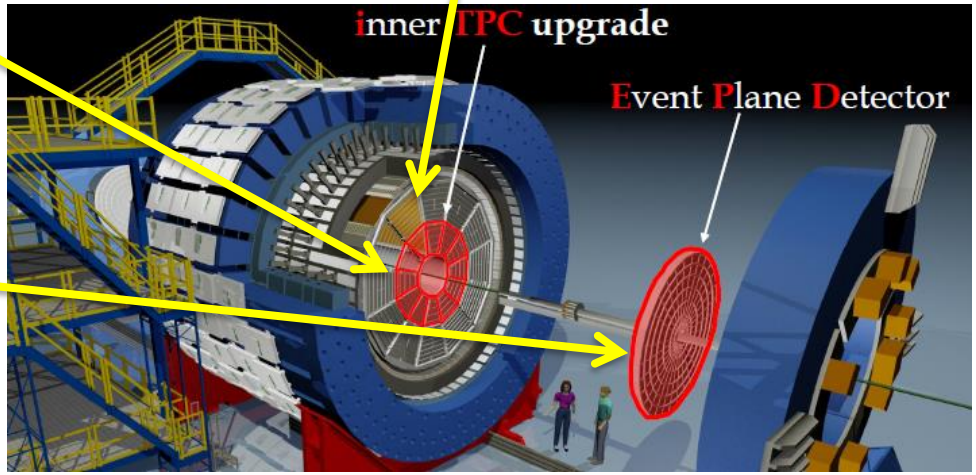


iTPC upgrade (2018)
Replace inner TPC Sectors
Extend rapidity coverage
Better particle ID
Extend low p_T coverage

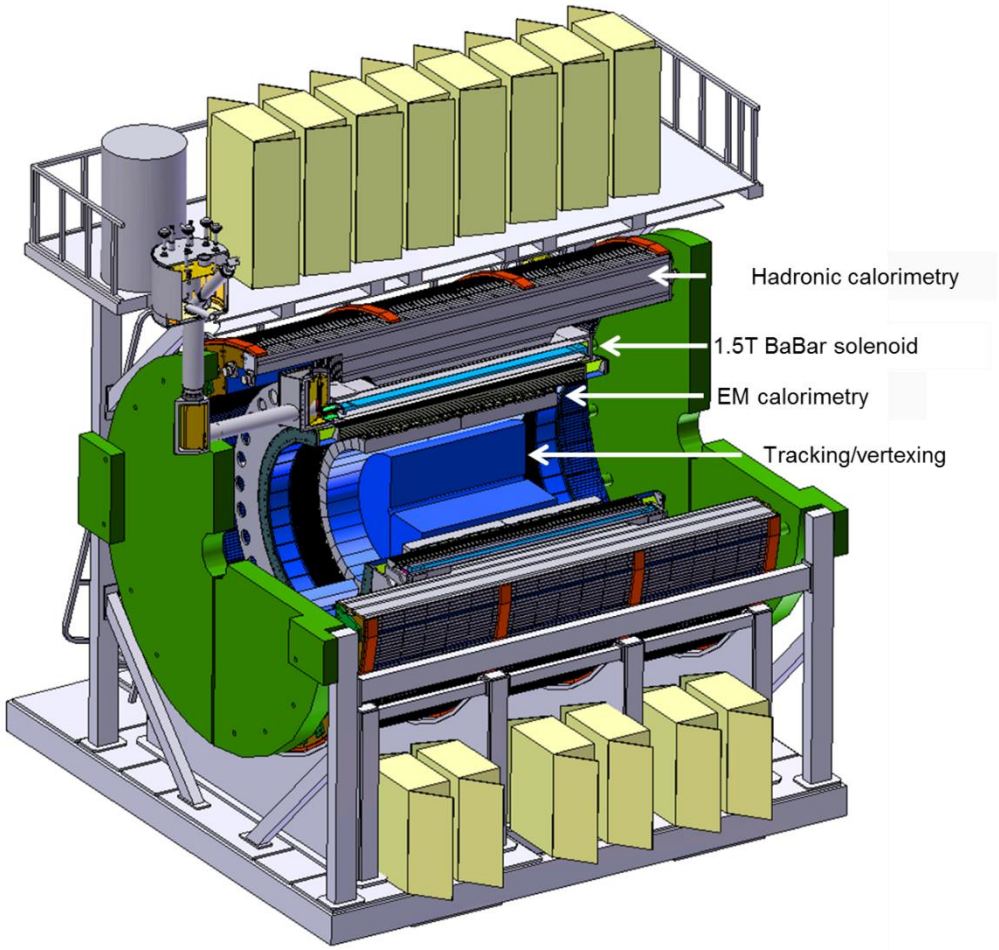


Endcap TOF
CBM (FAIR)

Event Plane Detector
Improved Event Plane Resolution
Centrality definition
Improved trigger



Within Available Funds in FY2020 OMB Request, the sPHENIX Upgrade is Continued



August 16, 2018: CD-1 and CD-3a for long lead procurements

$6M Proposed for FY2020 Request, approaching plans

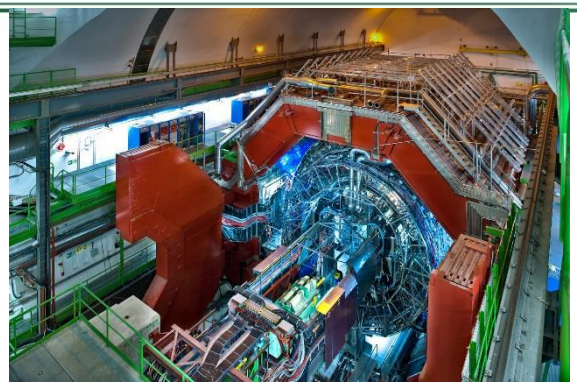
- mapping the character of the hadronic matter under extreme conditions by varying the temperature of the medium, the virtuality of the probe, and the length scale within the medium.
- understanding the parton–medium interactions by studying heavy-flavor jets.
- probing the effect of the quark–gluon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

implemented from within RHIC base by limiting operations to one detector and periodically not operating facility.

At the LHC…

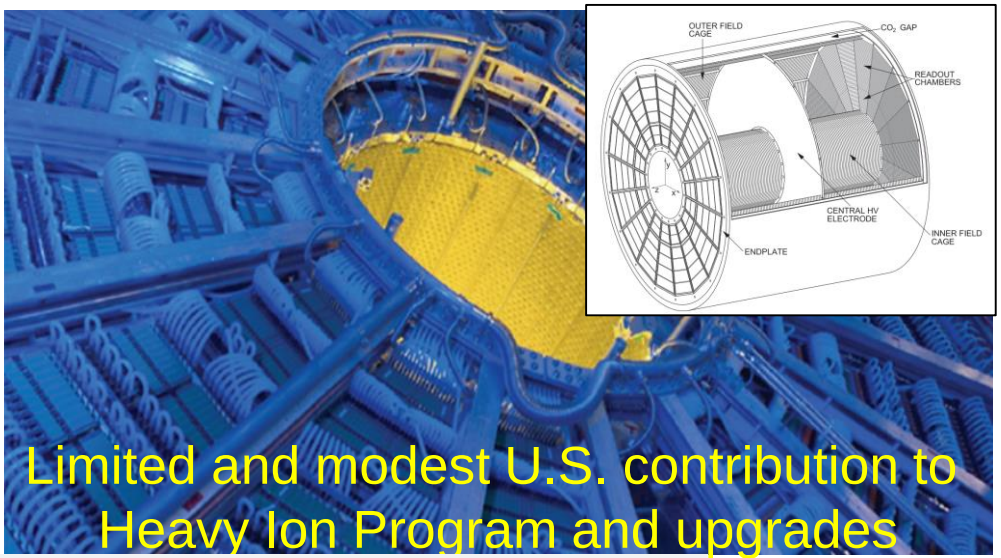
DOE NP Has Maintained Modest But Significant Participation in the LHC Heavy Ion Program

- NP DOE supports U.S. groups in ALICE, ATLAS, and CMS collaborations
  - ALICE – 41 PhDs
    - Leading role in ECal and Dcal
    - Currently contributing to Inner Tracking System and Time Projection Chamber upgrades
    - Tier 2 computing sites at ORNL and LBNL
  - CMS – 27 PhDs
    - Zero Degree calorimeter
    - Trigger
    - Tier 2 computing sites at Vanderbilt and MIT
  - ATLAS – 11 PhDs
    - Recently added U. of Colorado, Livermore Nat. Lab and Iowa State U.

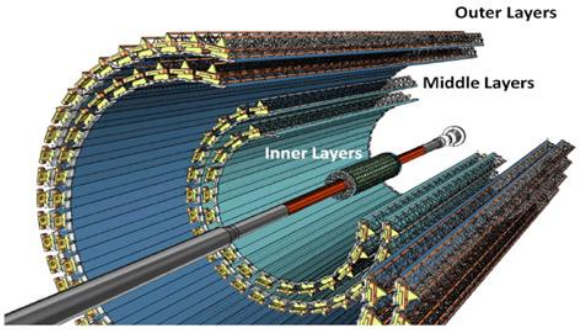


FY 2020 Request Continues Participation in ALICE/LHC Upgrades

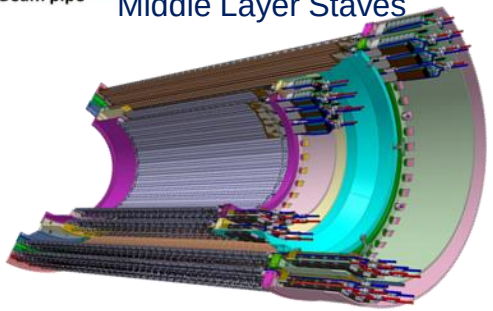
Continue participation in heavy ion program at the LHC – complimentary to RHIC program; provide scientific leadership and modest equipment contributions (university led) to ALICE, CMS, and ATLAS



Limited and modest U.S. contribution to Heavy Ion Program and upgrades



Middle Layer Staves

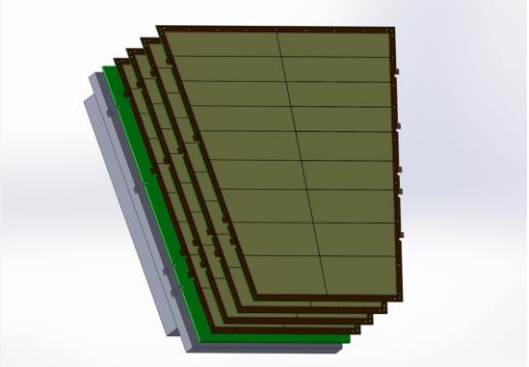


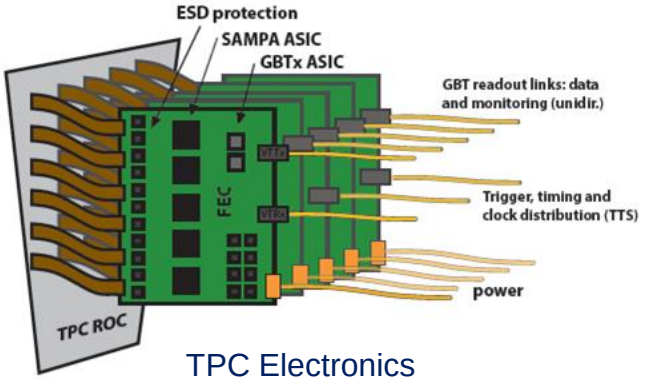
Composite Material Support Structure

U.S. contribution to ALICE:

Time Projection Chamber (TPC):
- Inner Readout Chambers
- Readout Electronics

Silicon Inner Tracker System (ITS)
- Middle layer detector staves
- Electronics readout system
- Carbon Fiber support structure





TPC Electronics

Going Forward

Budget permitting, NP intends to continue participation in the LHC HI program at a level comparable to that it has maintained to this point.

DOE NP is open to hearing new ideas about what future participation might "look like".

With the understanding that there will be no immediate commitments, proponents of possible new instrumentation upgrades for

CMS: second endcap timing layer of the MTD W/supports and electronics
ALICE: a forward calorimeter system
ATLAS: ATLAS/CMS combined ZDC development for high lumi LHC running

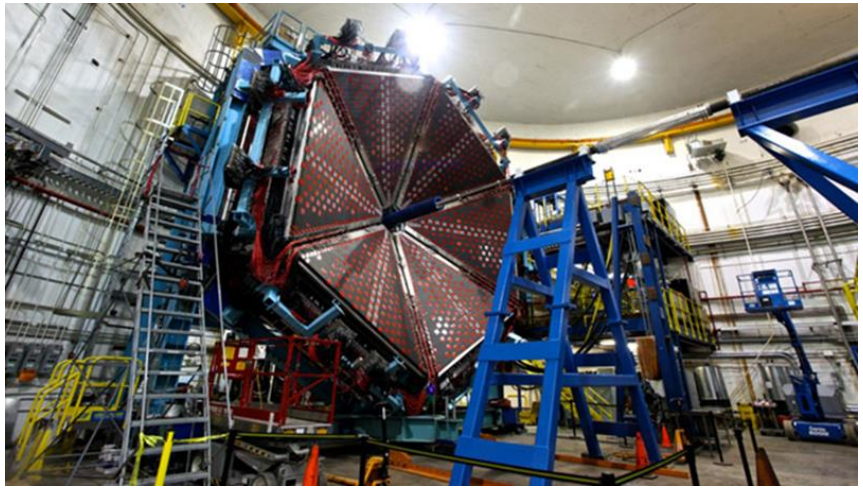
are discussing visits to DOE NP to articulate their ideas.

Elsewhere in DOE NP: 12 GeV CEBAF Science Program is in Full Swing

CEBAF operates for 32 weeks in FY19

- Recent technical challenges in 17/18 have limited reliability and machine availability. CEBAF ops capped at ~ 26 weeks in FY18.
- Larger investments in maintenance and investments to improve reliability. A larger portion of operations towards cryomodule refurbishment to maintain energy of beam.
- Simultaneous 4-Hall operations.

Hall D Solenoidal Spectrometer



Hall B Time of Flight Detector

Researchers conduct experiments with the 12 GeV CEBAF Upgrade, to:

- Search for exotic new quark-anti-quark particles to advance our understanding of the strong force.
- Find evidence of new physics from sensitive searches for violations of nature's fundamental symmetries.
- Gain a 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.

Facility for Rare Isotope Beams is > 91% Complete and Being Commissioned

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

Nuclear Structure

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

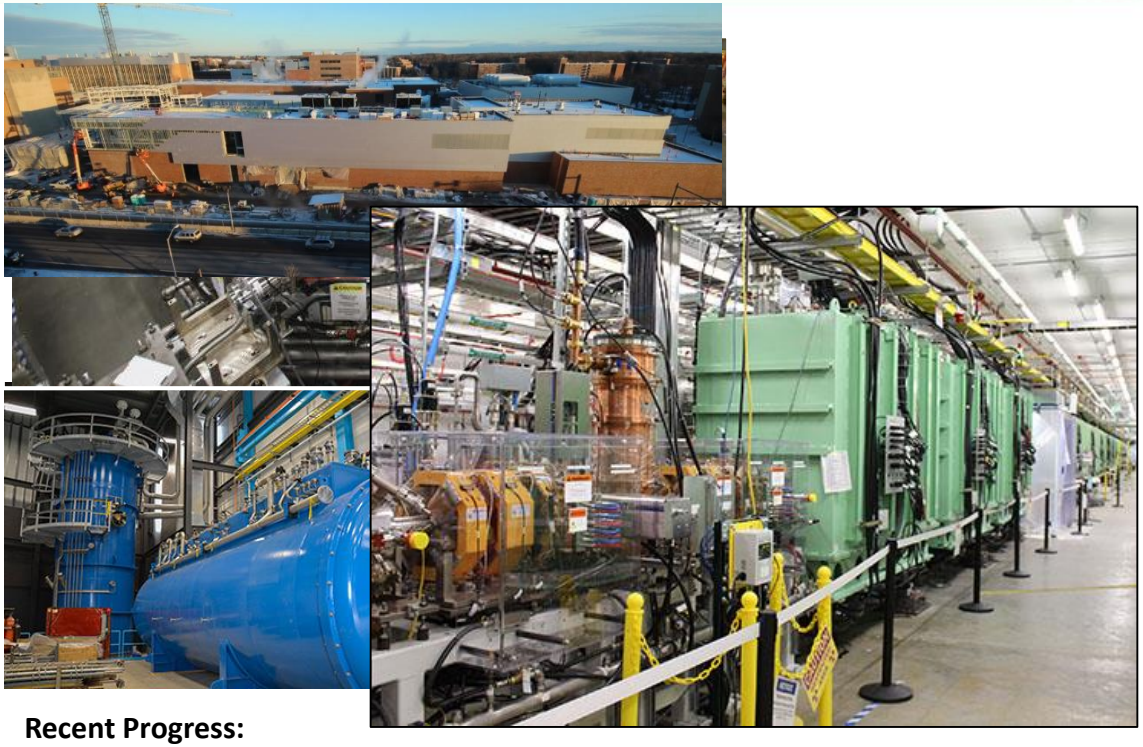
Nuclear Astrophysics

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

Fundamental Symmetries

- Tests of fundamental symmetries, Atomic EDMs, Weak Charge

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



Recent Progress:

- Accelerated argon and krypton beam in first three cryomodules demonstrating that cryoplant, RF, cryomodules and controls work together
- Have installed all 14 accelerating quarter-wave cryomodules in tunnel and are preparing to accelerate beam in them early next year
- Constructing and testing remaining half-wave cryomodules at a rate of 1.5/month (18/yr), will be done with cryomodule construction in 2019.

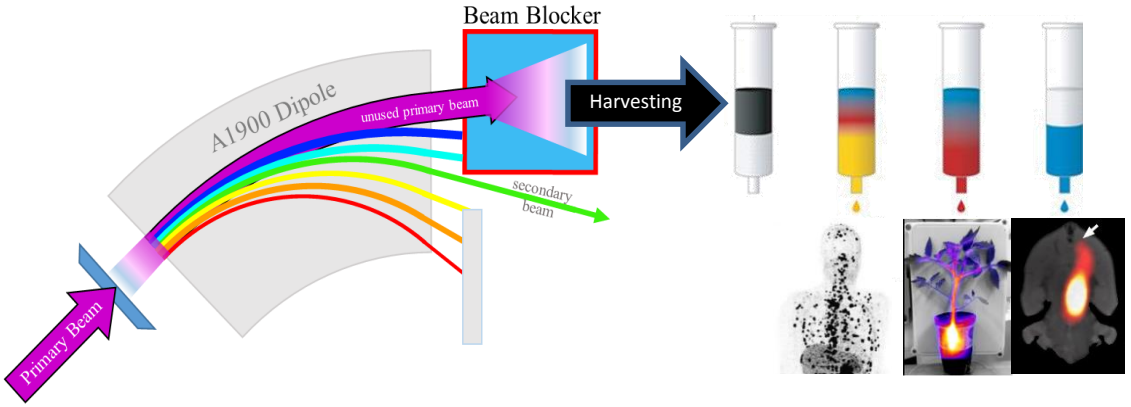
	PYs	FY 2017	FY 2018	FY 2019	FY 2020	FY 2021	DOE Total	MSU	TOTAL
FUNDING PROFILE	318,000	100,000	97,200	75,000	40,000	5,300	635,500	94,500	730,000

FRIB Isotope Harvesting

- NSCL-scale beam dump for R&D efforts:
  - Beam dump water purification system is tested and ready for routine use.
  - R&D irradiations and processing have successfully extracted ^{47}Ca and ^{76}Kr, parent radionuclides for nuclear medicine generators.
- FRIB beam dump design supports harvesting of isotopes
- Conceptual design complete:
  - Beam dump water and gas processing system
  - Radiochemistry processing hot-cells and infrastructure
- Proposal submitted to DOE-NP
- Isotope program:
  - 3-year design, construction, commissioning period

Towards realization of the 2015 NSAC recommendation:

> ***Infrastructure for isotope harvesting at FRIB*** – During routine operation for its nuclear physics mission, FRIB will produce a broad variety of isotopes that could be harvested synergistically without interference to the primary user.

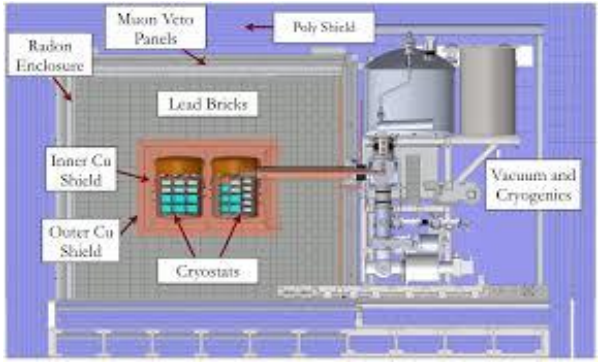


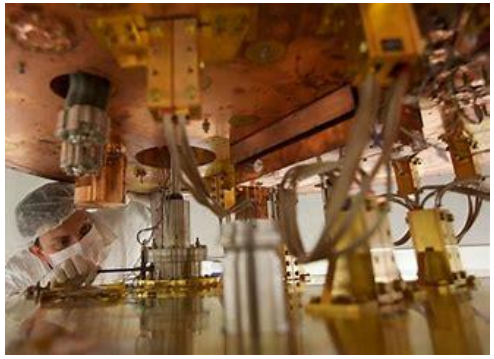
Purifying radionuclides using chemistry instead of magnets

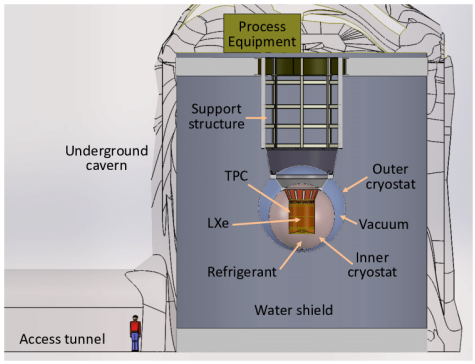
TEC Funding of $2M requested in FY2020
Project at CD0
Project Completion Goal: Q4FY22

Current Status of Ton-Scale 0νββ

- Within DOE, Office of Science, NP is the steward of the ton-scale experiment
- Critical Decision – 0, Mission Need, approved in November 2018
- TEC construction start for a ton-scale 0νββ experiment requested in the FY2020 President's Budget Request. TEC Funding of $1.44M Requested. R&D funding is continuing
- Meeting on the margins of IUPAP WG9 Meeting in London (8/2019) to discuss possible international collaboration
- Processes for technology down-select and site selection for a 1 ton experiment are under discussion:
  - Three front runner candidate experiments, LEGEND-1000 (Ge-76), CUPID (Mo-100), nEXO (Xe-136).
  - Three current candidate site locations: Gran Sasso (Italy), SNOLAB (Canada) and SURF (U.S)







Funding not included for ton-scale 0νββ in the House Mark
$5.0M included for ton-scale 0νββ in the Senate Mark Language

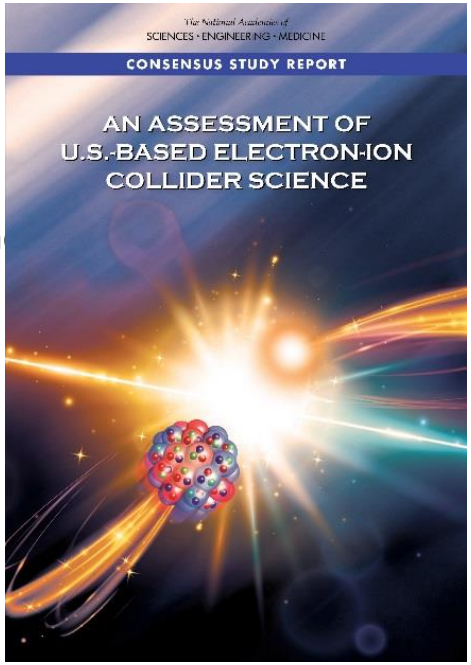
NAS Assessment of a U.S. Based Electron-Ion Collider

Finding 1: An EIC can uniquely address three profound questions about nucleons—neutrons and protons—and how they are assembled to form the nuclei of atoms:

How does the mass of the nucleon arise?

How does the spin of the nucleon arise?

What are the emergent properties of dense systems of gluons?



Finding 2: These three high-priority science questions can be answered by an EIC with highly
polarized beams of electrons and ions, with sufficiently high luminosity and sufficient, an variable, center-of-mass energy.

As a result of the comprehensive survey the committee made of existing and planned accelerator facilities in both nuclear and particle physics around the world, it finds that

Finding 3: An EIC would be a unique facility in the world and would maintain U.S. leadership in nuclear physics.

An EIC would be the only high-energy collider planned for construction in the United States. Its high design luminosity and highly polarized beams would push the frontiers of accelerator science and technology. For these reasons, the committee finds that

Finding 4: An EIC would maintain U.S. leadership in the accelerator science and technology of colliders and help to maintain scientific leadership more broadly.

Current Status and Path forward for the EIC

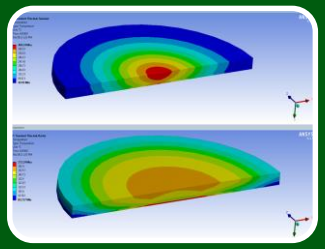
The “wickets” are substantially aligned for a major step forward on the EIC

- A Mission Need Statement for an EIC has been approved by DOE
- An Independent Cost Review (ICR) Exercise mandated by DOE rules for projects of the projected scope of the EIC has been completed
- DOE is moving forward towards a request for CD-0 (approve “Mission Need”)
- DOE convened a panel to assess options for siting between two proposed concepts.
- The Deputy Secretary is the Acquisition Executive at CD0 for this level of DOE Investment
- The FY 2020 President’s Request includes $ 1.5 million OPC. The FY 2020 House Mark includes $ 10 million OPC and $ 1 million TEC.
  Senate Mark includes $ 10 million OPC and $ 1 million TEC.

DOE Isotope Program Mission

Produce and/or distribute radioactive and stable isotopes that are in short supply; includes by-products, surplus materials and related isotope services

Maintain the infrastructure required to produce and supply priority isotope products and related service



Conduct R&D on new and improved isotope production and processing techniques which can make available priority isotopes for research and application. Develop workforce.

Senate Mark includes $30,000,000 for the U.S. Stable Isotope Production and Research Center (SIPRC), and $1,500,000 for the Stable Isotope Production Facility (SIPF)

Early NP QIS/QC Awards

Lead Insititution	PI	Title	Description
University of Washington	Martin Savage	Nuclear Physics Pre-Pilot Program in Quantum Computing	to support pre-pilot research activities that will begin to bring Quantum Computing (QC) and Quantum Information Science (QIS) expertise into the nuclear theory community, including starting to address scientific applications of importance for nuclear physics research. This pre-pilot proposal will organize the nuclear theory community at the national level in order to address Grand Challenge problems in nuclear physics through the use of QC and QIS.
MIT	Joseph Formaggio	Investigating Natural Radioactivity in Superconducting Qubits	to measure the impact of background radioactivity on qubit coherence times. MIT will be responsible for simulation of radiation transport models and development of calibration sources to be deployed in various qubit measurements. MIT will also coordinate this effort with Prof. William Oliver (MIT and Lincoln Labs). PNNL will be responsible for radioassay of materials using their calibrated measurement stations.
ANL	Ian Cloet	Quantum Simulators for Nuclear Physics: Theory	to support a postdoctoral fellow to work on the proposal for Quantum Simulations for Nuclear Physics. This pilot effort will begin to develop the expertise and knowledge that builds toward a QCD simulations on Quantum Computers and Analog Quantum Simulators.
ANL	Valentine Novosad	Superconducting Quantum Detectors for Nuclear Physics and QIS	to work on the proposal for Superconducting Quantum Detectors for Nuclear Physics and QIS.
LLNL	Stephan Frederich	Thorium 229mTh	to study of the feasibility of suppressing the internal conversion transition of 229mTh by implanting it in high band gap materials such as MgF2

FY 2018 Awards Made Through Annual Solicitation

Quantum Information Science

- EOP and Legislative Priority
  - National Quantum Initiative Act Public Law 115-368
- Cuts across all SC research programs, including DOE Isotope Program
- Cuts across several other DOE programs
  - OE and NNSA
- QIS funded in FY 2018 ($62M) and FY 2019 ($123M)
- FY 2020 proposal would focus on establishment of at least one DOE quantum center, budget request - $168.5M

DOE NP FY 2019 Funding for QIS: $6.8M Peer Review in Progress for Proposals in Response to FY 2019 FOA

Comments and Items of Interest

- Peer review for FY2019 QIS FOA underway. FY 2020 FOA is planned. The NSAC subpanel report on QIS will be presented at the NSAC meeting October 18, 2019. There have been some notional discussions of a Town-Meeting to get the NP community organized to respond to potential opportunities.

- Peer review for FY2019 Inter-Agency Nuclear Data FOA underway' FY2020 FOA is possible

- SC is coordinating with its communities to "organize interest" in the Fed related to making Machine Learning and Artificial Intelligence a priority initiative. On a related note, JLAB will be organizing a community wide workshop on this topic.

- Four new program managers have joined NP: Paul Sorensen for Fundamental Symmetries; Sharon Stephenson for Nuclear Structure and Nuclear Astrophysics' Arne Freyberger for Isotope Accelerator Facilities; Jon Neuhoff for Isotope Reactor Facilities
- The Office of Science continues to intensify focus and emphasis on D&I

- The first ever "Distinguished Scientist" awards, a new recognition by SC, have been publicly announced. In the first-ever cohort, Barbara Jacak is an award recipient from the nuclear science community.

The SC Microsite on Diversity, Equity & Inclusion now posted on the SC website.

The direct link is:

https://science.energy.gov/sc-2/research-and-conduct-policies/diversity-equity-and-inclusion/

"The DOE Office of Science (SC) is fully committed to fostering safe, diverse, equitable, and inclusive work, research, and funding environments that value mutual respect and personal integrity. Effective stewardship and promotion of diverse and inclusive workplaces that value and celebrate a diversity of people, ideas, cultures, and educational backgrounds is foundational to delivering on the SC mission. The scientific community engaged in SC-sponsored activities is expected to be respectful, ethical, and professional.

The DOE SC does not tolerate discrimination or harassment of any kind, including sexual or non-sexual harassment, bullying, intimidation, violence, threats of violence, retaliation, or other disruptive behavior in the federal workplace, including DOE field site offices, or at national laboratories, scientific user facilities, academic institutions, other institutions that we fund, or other locations where activities that we support are carried out…"

Harassment

Harassment of any kind, including sexual and non-sexual harassment, bullying, intimidation, violence, threats of violence, retaliation, or other disruptive behavior is not tolerated in the federal workplace, including Department of Energy (DOE) site offices, or at DOE national laboratories, scientific user facilities, academic institutions, other institutions receiving Office of Science funding, or at locations where activities are funded by the DOE Office of Science.

Harassment includes any unwelcome conduct or reprisal (verbal, written, or physical) that is based on an individual's race, color, sex (including pregnancy, gender identity, and sexual orientation), religion, national origin, age, disability (physical or mental), genetic information, or participation in protected equal employment opportunity (EEO) activities including reporting allegations of harassment or providing information related to harassment allegations.

Harassing behaviors include any unwelcome conduct that: (1) has the purpose or effect of unreasonably interfering with an employee's work performance; (2) creates an intimidating, hostile, or offensive work environment; or (3) affects an employee's employment opportunities or compensation.

Sexual harassment is any unwelcome behavior of a sexual nature including, but not limited to, unwelcome sexual advances, requests for sexual favors (i.e., sexual coercion, including quid pro quo), physical conduct of a sexual nature, or other similar behavior. Sexual harassment also includes verbal and nonverbal behaviors that convey hostility, objectification, exclusion, or second-class status about members of a particular gender (e.g., gender harassment) (NAS 2018). Sexual harassment, like non-sexual harassment, is not always obvious and often subtle.

General Outlook

- The experience with FY18 and FY19 budgets has required readiness for big swings in the budget. FY2020 may be similar.
- We need to stay focused and continue to deliver important outcomes for the nation.
- Delivering exciting discoveries, important scientific knowledge, technological advances, and workforce training is what we do.
- We need to keep up the good work!