Perspectives from DOE Nuclear Physics (NP)

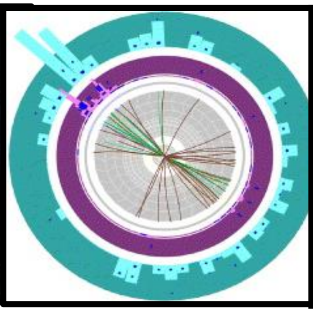
NSAC Meeting

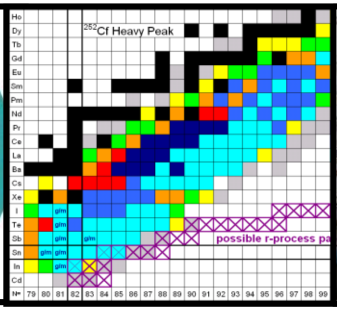
April 8, 2019

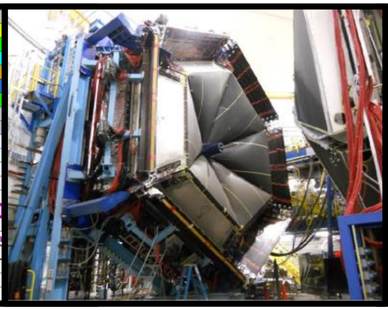
Dr. T. J. Hallman

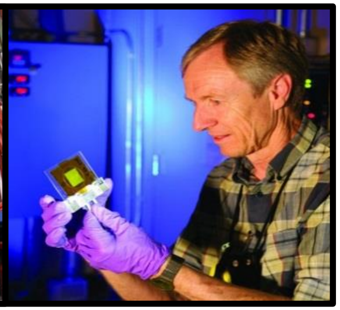
Associate Director of the Office of Science

for Nuclear Physics









FY 2020 SC President's Budget Request

(Dollars in Thousands)

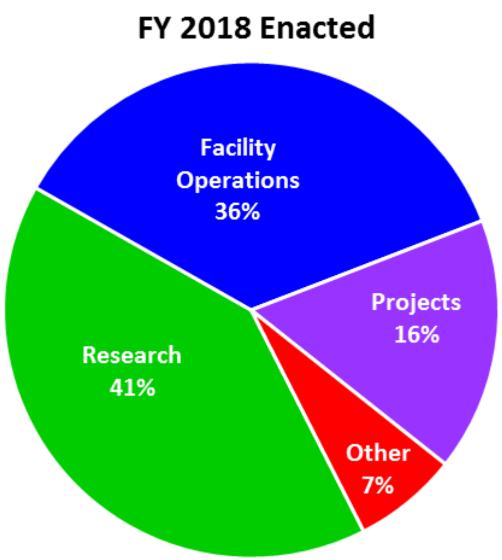
	FY 2018		FY 2019	FY 2020 Request		
	Enacted Approp.	Current Approp.	Enacted Approp.	President's Request	Request vs. FY 2019 Enacted	
Advanced Scientific Computing Research	810,000	788,224	935,500	920,888	-14,612	-1.6%
Basic Energy Sciences	2,090,000	2,028,719	2,166,000	1,858,285	-307,715	-14.2%
Biological and Environmental Research	673,000	648,600	705,000	494,434	-210,566	-29.9%
Fusion Energy Sciences	532,111	518,824	564,000	402,750	-161,250	-28.6%
High Energy Physics	908,000	883,573	980,000	768,038	-211,962	-21.6%
Nuclear Physics	684,000	664,694	690,000	624,854	-65,146	-9.4%
Workforce Development for Teachers and Scientists	19,500	19,500	22,500	19,500	-3,000	-13.3%
Science Laboratories Infrastructure	257,292	257,292	232,890	163,600	-69,290	-29.8%
Safeguards and Security	103,000	103,000	106,110	110,623	+4,513	+4.3%
Program Direction	183,000	183,000	183,000	183,000	...	...
SBIR/STTR (SC)	...	164,477	...	...	...	...
Subtotal, Office of Science	**6,259,903**	**6,259,903**	**6,585,000**	**5,545,972**	**-1,039,028**	**-15.8%**
SBIR/STTR (DOE)	...	116,972	...	...	...	...
Total, Office of Science	**6,259,903**	**6,376,875**	**6,585,000**	**5,545,972**	**-1,039,028**	**-15.8%**

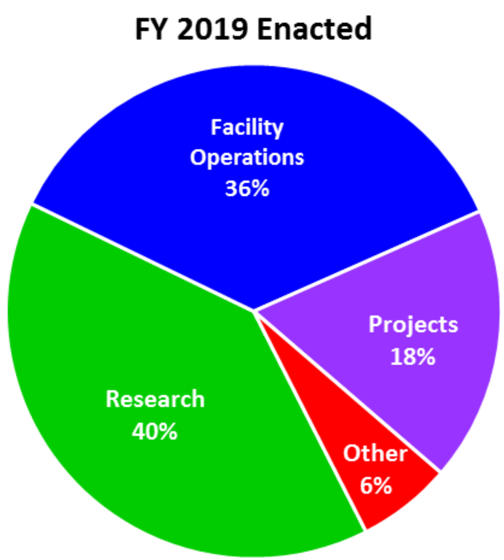
FY 2020 President's Request by Budget Element

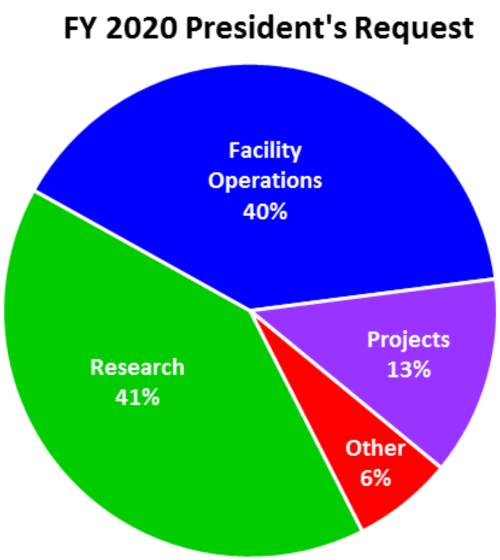
(Dollars in Thousands)

	FY 2018		FY 2019		FY 2020 Request					
	Enacted	% of Total	Enacted	% of Total	President's Request	% of Total	vs. FY 18 Enacted		vs. 19 Enacted	
							$ Change	% Change	$ Change	% Change
Research	2,547,870	40.7%	2,613,322	39.7%	2,250,665	40.6%	-297,205	-11.7%	-362,657	-13.9%
Facility Operations	2,249,689	35.9%	2,381,966	36.2%	2,210,865	39.9%	-38,824	-1.7%	-171,101	-7.2%
Projects	1,034,250	16.5%	1,183,556	18.0%	721,452	13.0%	-312,798	-30.2%	-462,104	-39.0%
Other	428,094	6.8%	406,156	6.2%	362,990	6.5%	-65,104	-15.2%	-43,166	-10.6%
Total	**6,259,903**	**100.0%**	**6,585,000**	**100.0%**	**5,545,972**	**100.0%**	**-713,931**	**-11.4%**	**-1,039,028**	**-15.8%**

*Other includes GPP/GPE, WDTS, S&S, and PD.







Nuclear Physics

Discovering, exploring, and understanding all forms of nuclear matter

- Funding for research at national labs and universities is focused on the highest priority research in relativistic nuclear collisions, hadron physics, nuclear structure and nuclear astrophysics, and fundamental symmetries. NP continues its participation in planned coordinated SC **Quantum Information Science (QIS)** research and facility activities.

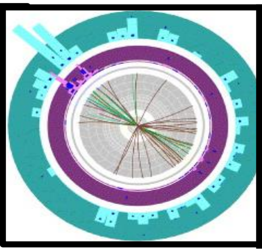
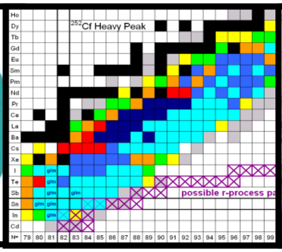
- **RHIC** operates at ~41% optimal to explore the properties of the quark gluon plasma first discovered there. The recently upgraded **12 GeV CEBAF** operates at ~24% optimal, promising new discoveries and an improved understanding of quark confinement. Operations at **ATLAS** are supported at ~31% optimal, providing high-quality beams of all the stable elements up to uranium, as well as selected beams of short-lived nuclei for nuclear structure and astrophysics experiments. **FRIB operations** begins to ramp up.

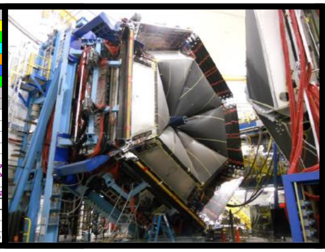
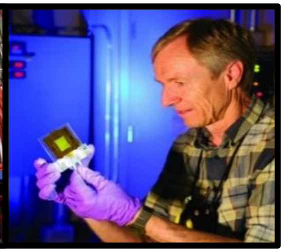
- Construction continues on the **Facility for Rare Isotope Beams. The Gamma-Ray Energy Tracking Array (GRETA)** MIE is continued to extend FRIB's reach in studying the nuclear landscape**.** The **sPHENIX MIE** continues within current RHIC funding levels for precision, high rate particle jet studies. The last year of funding is provided to the **Stable Isotope Production Facility (SIPF)** MIE to produce kilogram quantities of enriched stable isotopes.

- The **Moller MIE** is initiated for ultra-precise measurements with the upgraded CEBAF machine. The **Ton-Scale Neutrinoless Double Beta Decay MIE** is initiated to determine whether the neutrino is its own antiparticle. **The High Rigidity Spectrometer (HRS)** scientific equipment is supported to study beams of rare isotopes at maximum production rates for fragmentation.

- Conceptual design efforts and R&D (OPC) are supported for the planned **Electron Ion Collider (EIC)** whose critical importance to world-leadership in nuclear physics and accelerator science was recently affirmed by the National Academy of Sciences.

- Increased funding for the DOE Isotope Program supports robust mission readiness of facilities for isotope production and processing, university network operations, development of production capabilities of isotopes for QIS, and critical capital investments to increase availability of isotopes, including FRIB isotope harvesting. The **U.S. Stable Isotope Production and Research Center (SIPRC)** construction project is initiated to significantly increase production capabilities for stable isotopes and eliminate sole dependence on foreign supply.

NP FY 2020 President's Request

(Dollars in thousands)

	FY 2018		FY 2019	FY 2020 Request		
	Enacted Approp.	Current Approp.	Enacted Approp.	President's Request	Request vs. FY 2019 Enacted	
Medium Energy Nuclear Physics						
Research	40,050	40,585	43,286	35,500	-7,786	-18.0%
Operations	112,000	112,000	117,390	114,500	-2,890	-2.5%
SBIR/STTR	19,248	...	19,862	18,633	-1,229	-6.2%
Other Research	4,152	3,062	3,652	2,667	-985	-27.0%
Total, Medium Energy Nuclear Physics	**175,450**	**155,647**	**184,190**	**171,300**	**-12,890**	**-7.0%**
Heavy Ion Nuclear Physics						
Research	40,050	39,328	37,354	30,000	-7,354	-19.7%
Operations	187,500	187,284	193,125	186,000	-7,125	-3.7%
Total, Heavy Ion Nuclear Physics	**227,550**	**226,612**	**230,479**	**216,000**	**-14,479**	**-6.3%**
Low Energy Nuclear Physics						
Research	66,500	67,433	70,530	58,450	-12,080	-17.1%
Operations	29,250	29,250	30,215	36,838	+6,623	+21.9%
Total, Low Energy Nuclear Physics	**95,750**	**96,683**	**100,745**	**95,288**	**-5,457**	**-5.4%**
Nuclear Theory						
Theory Research	38,750	38,750	46,469	37,040	-9,429	-20.3%
Nuclear Data Activities	8,600	9,102	8,858	7,726	-1,132	-12.8%
Other Project Costs (OPCs)	...	...	...	1,500	+1,500	...
Total, Nuclear Theory	**47,350**	**47,852**	**55,327**	**46,266**	**-9,061**	**-16.4%**
Isotope Development and Production for Research and Applications						
Research	11,000	9,900	9,808	12,000	+2,192	+22.3%
Operations	29,700	30,800	34,451	39,000	+4,549	+13.2%
Total, Isotope Production and Applications	**40,700**	**40,700**	**44,259**	**51,000**	**+6,741**	**+15.2%**
Subtotal, Nuclear Physics	**586,800**	**567,494**	**615,000**	**579,854**	**-35,146**	**-5.7%**
Construction						
14-SC-50, Facility for Rare Isotope Beams (FRIB), MSU	97,200	97,200	75,000	40,000	-35,000	-46.7%
20-SC-51, U.S. Stable Isotope Production and Research Center, ORNL	...	...	...	5,000	+5,000	...
Total, Nuclear Physics	**684,000**	**664,694**	**690,000**	**624,854**	**-65,146**	**-9.4%**

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**

Senate recommends $710,000,000 for NP. Recommends $75,000,000 for FRIB and encourages early FRIB operations. Recommends $11,500,000 for SIPF MIE and $6,600,000 for GRETA MIE. Recommends optimal operations for RHIC, CEBAF, ATLAS and BLIP.

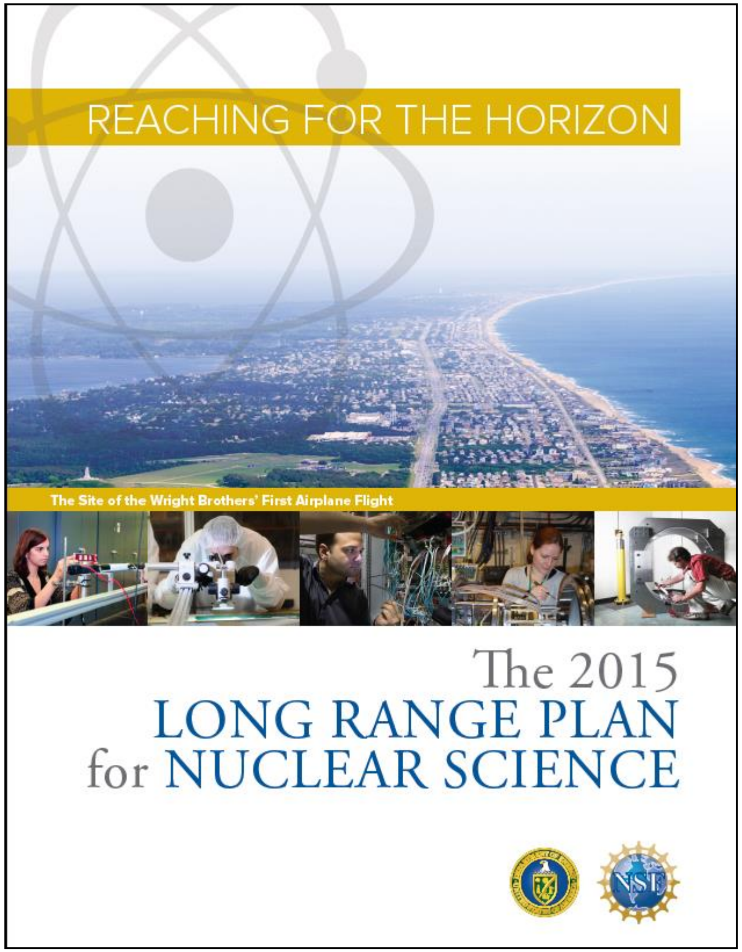
House recommends $690,000,000 for NP. Recommends $10,000,000 for SIPF MIE, $6,600,000 for GRETA MIE, and $5,660,000 for sPHENIX MIE. Encourages optimal operations of RHIC, CEBAF, ATLAS and BLIP.

Enacted Appropriation: $690,000,000 for NP. Recommends $75,000,000 for FRIB and encourages early FRIB operations. Recommends $11,500,000 for SIPF MIE, $6,600,000 for GRETA MIE, and $5,660,000 for sPHENIX MIE (within the RHIC base). Recommends optimal operations for RHIC, CEBAF, ATLAS and BLIP.

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 FY2020 Request allows NP to continue to pursue aspects of the 2015 LRP Vision

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!

Facility for Rare Isotope Beams is > 89% 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 limits of existence for nuclei
- Nuclei that have neutron skins
- Synthesis of super heavy elements

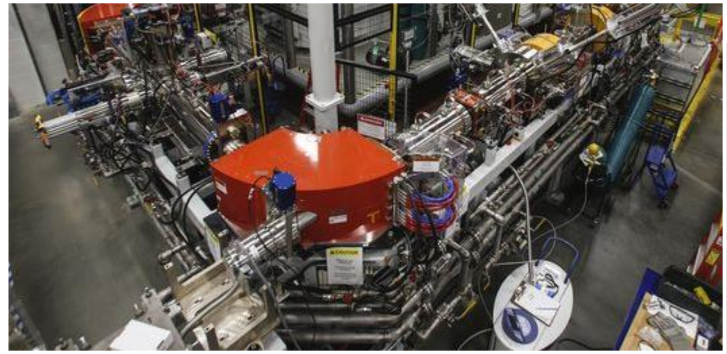
Nuclear Astrophysics

- 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.



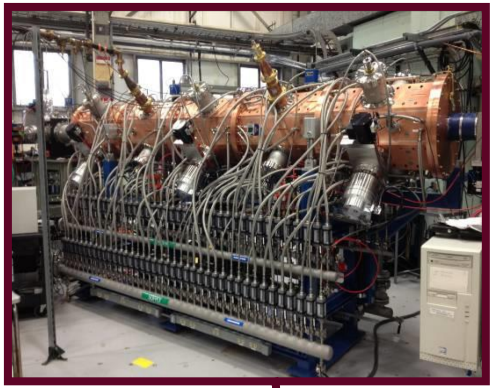
Recent Progress:

- 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.

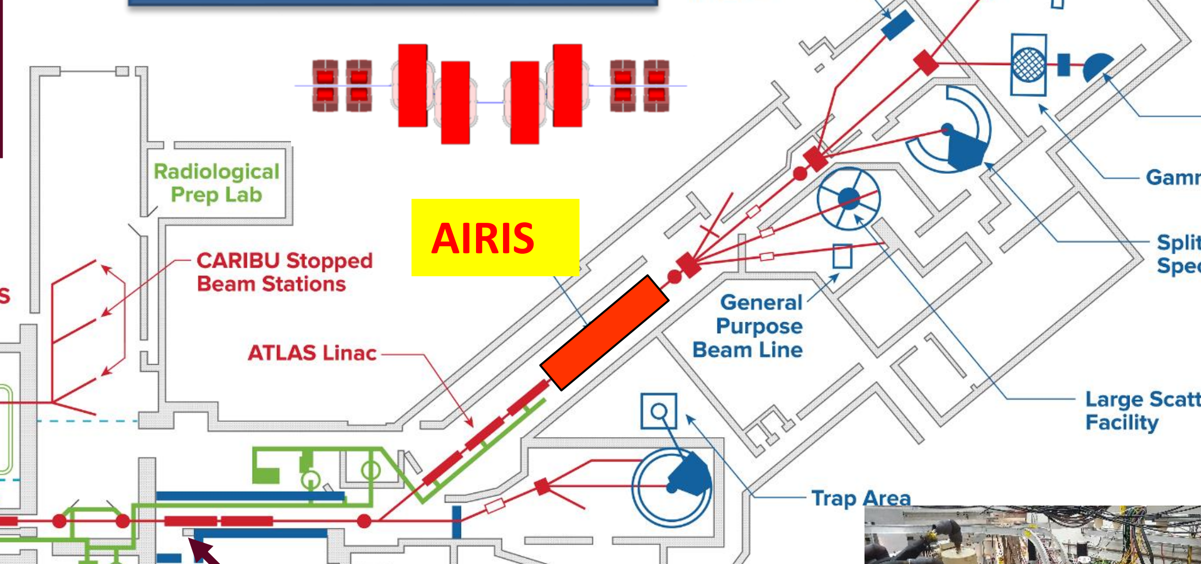
	PYs	FY 2017	FY 2018	FY 2019	FY 2020	FY 2021	DOE Total	MSU	TOTAL
FUNDING PROFILE	**318,000**	**100,000**	**97,200**	**75,000**	**40,000**	**5,300**	**635,500**	**94,500**	**730,000**

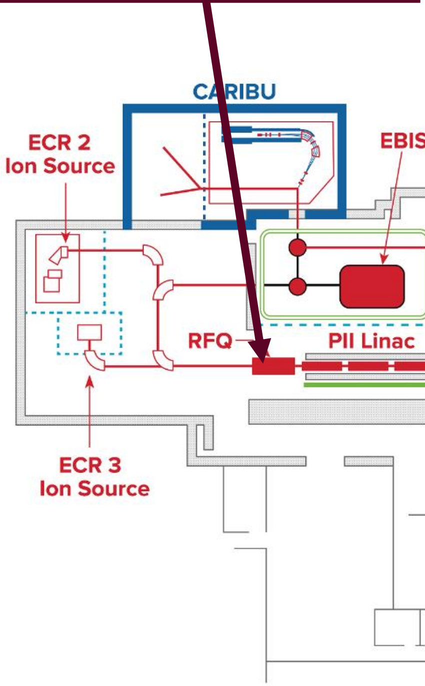
ATLAS Continues as a Premier Stable Beam Facility

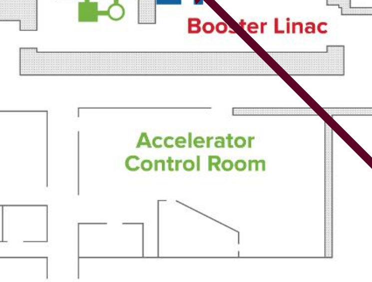
ATLAS is a unique premier Stable Beam Facility for research on Nuclear Structure & Nuclear Astrophysics

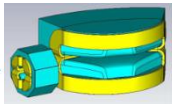


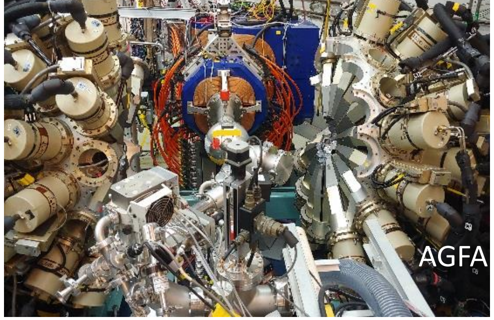
Multi-User Upgrade AIP Planned







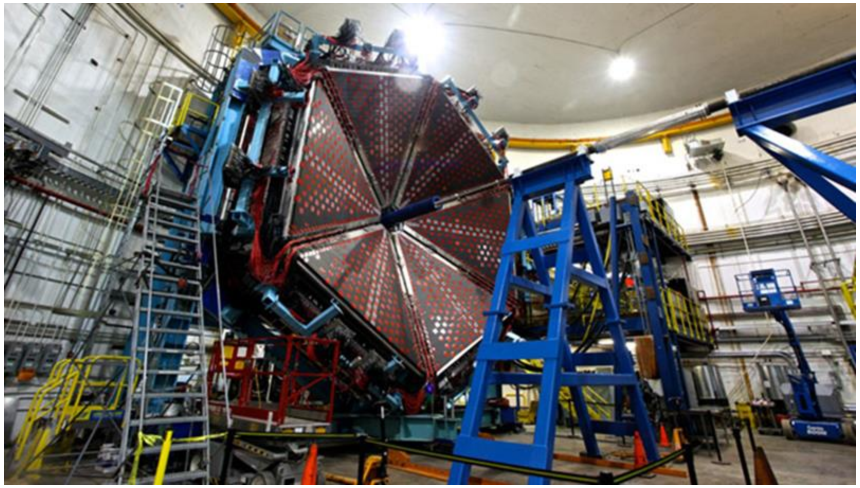




12 GeV CEBAF Science Program is Underway

CEBAF operates for 32 weeks inFY19

- 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 B Time of Flight Detector

Hall D Solenoidal Spectrometer

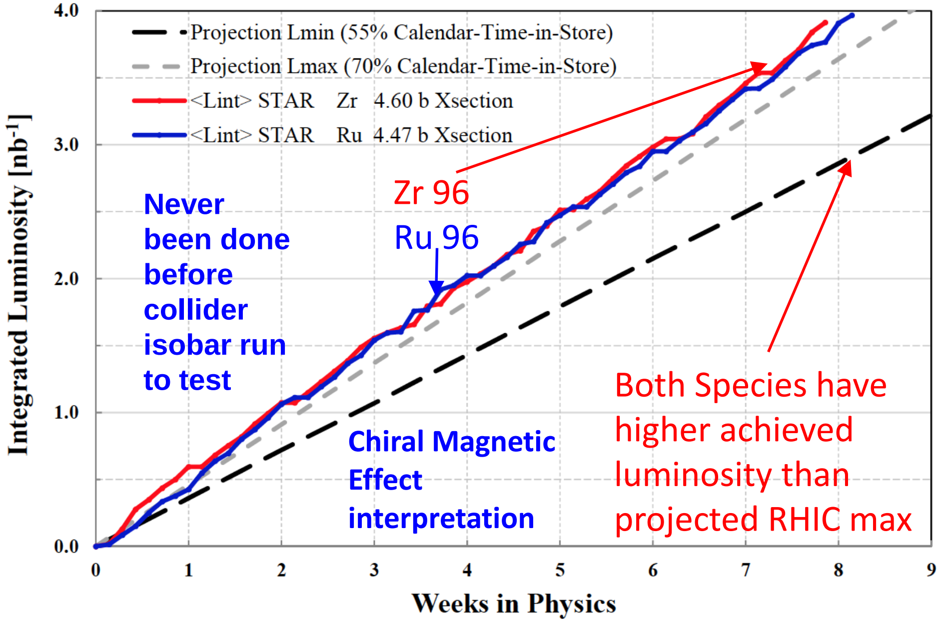
Researchers conduct experiments with the 12 GeV CEBAF Upgrade, to:

- 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.

At RHIC, Implementing New Capability for New Discoveries Continues

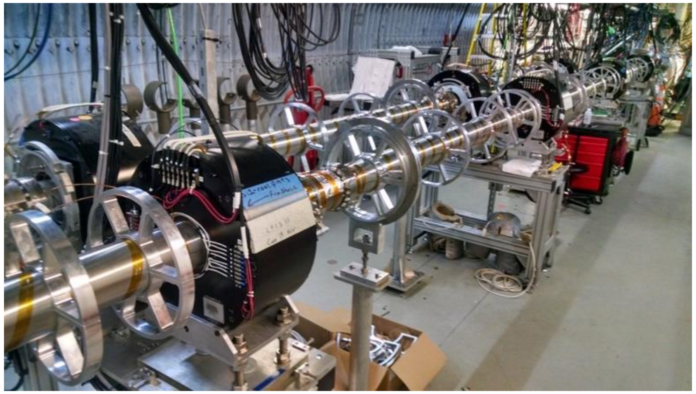
2018 Run

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

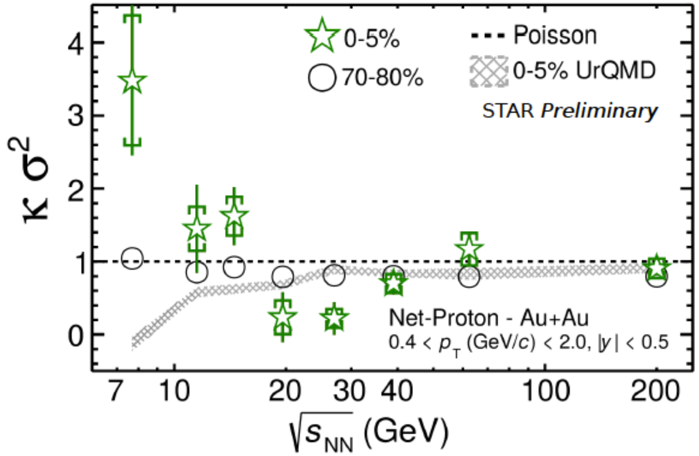
Project on track for use in low-energy RHIC runs

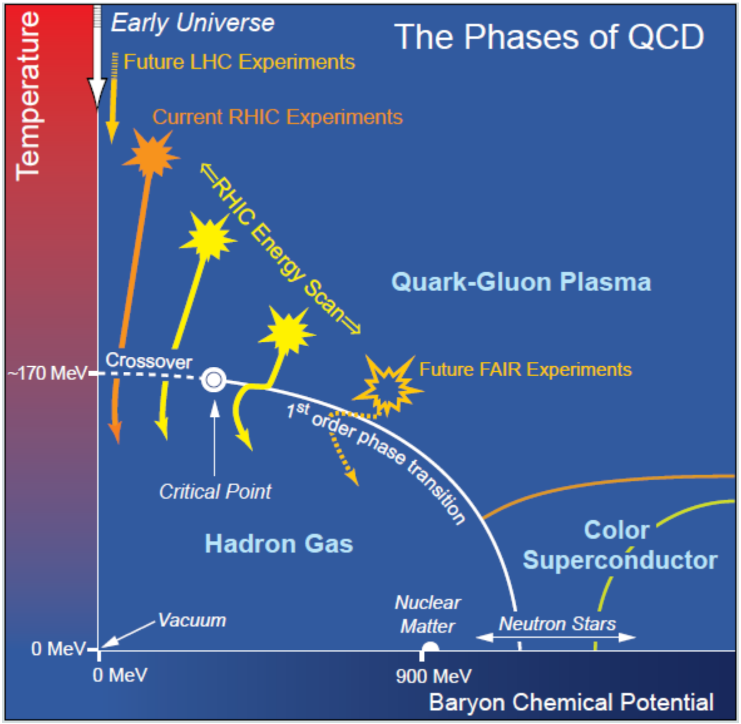
- Consistently high facility availability (~85%)
- No other facility worldwide, existing or planned, rivals RHIC in science reach and versatility as a heavy ion collider. It is the only polarized proton collider in the world.

For Beam Energy Scan II (BESII) Statistics One of the Challenges

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)

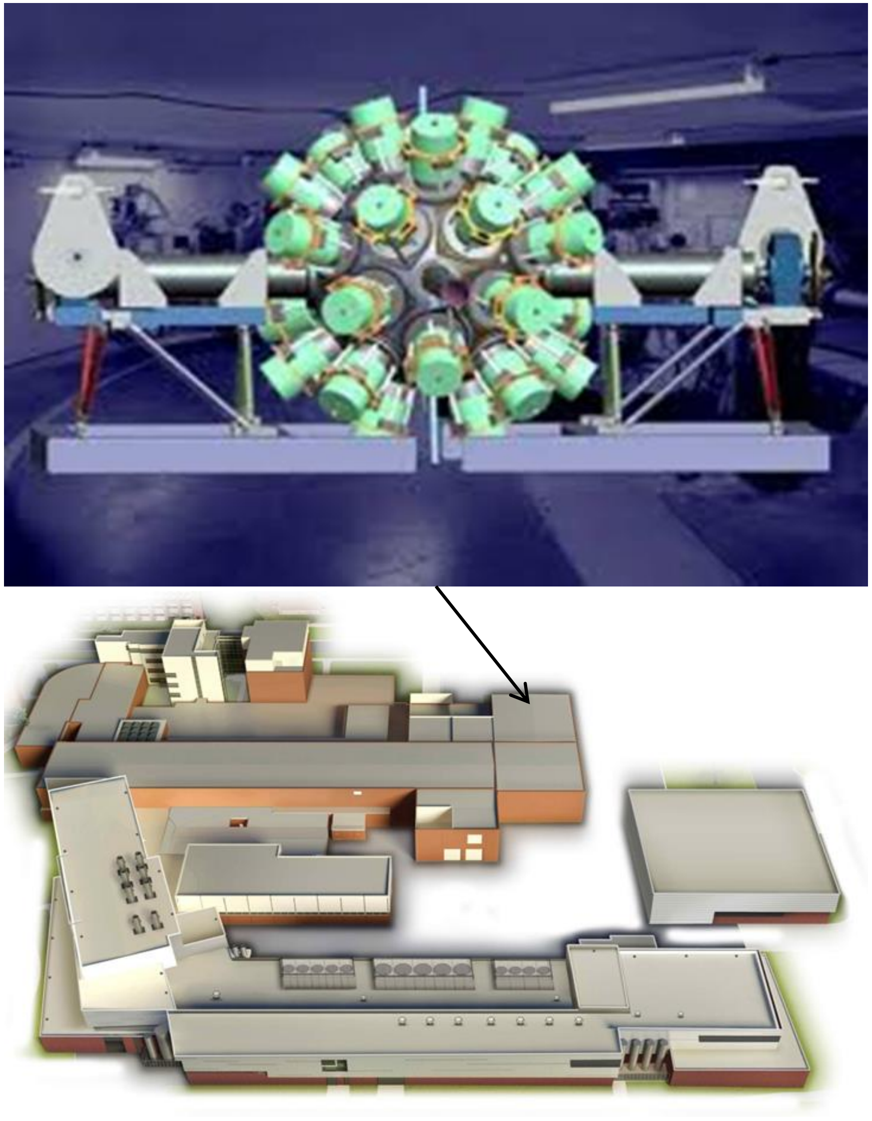
For BES II, a 2 year campaign (~ 48 weeks) is planned

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

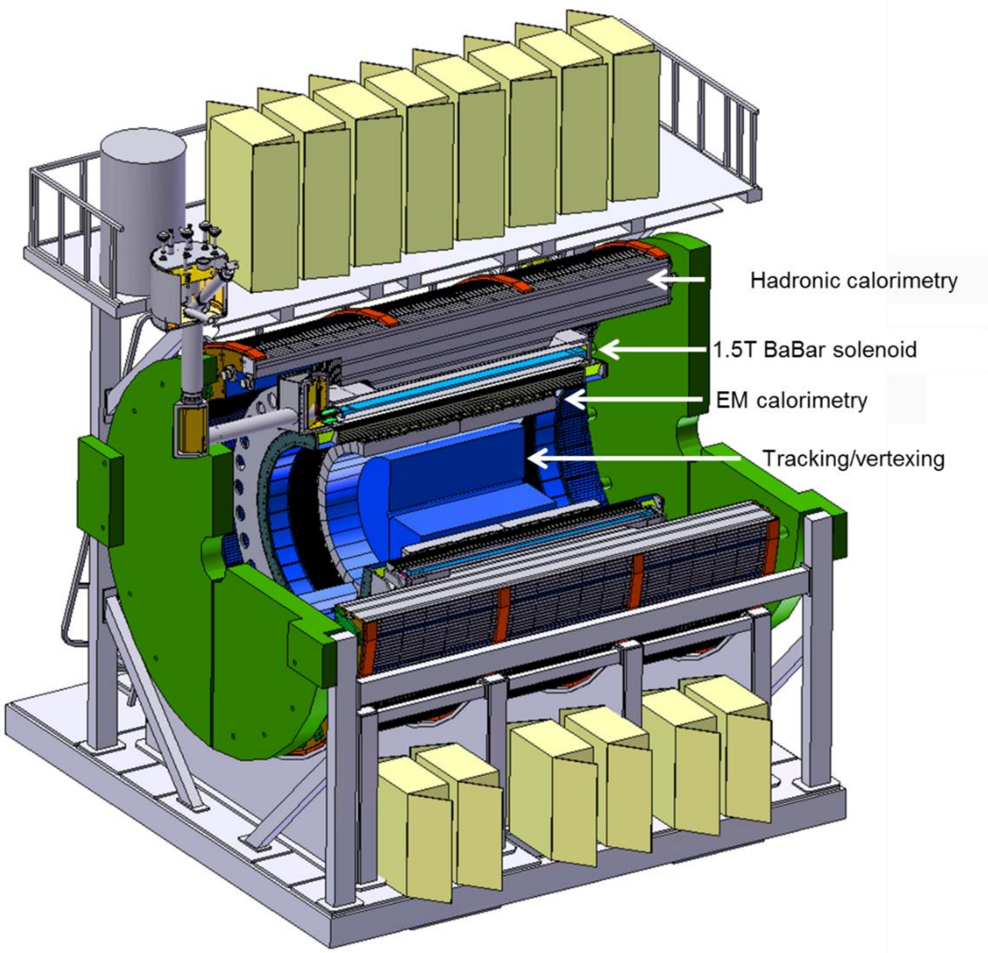
Ongoing MIEs that continue in the FY2020 Request

Fabrication of the Gamma-Ray Energy Tracking Array (GRETA) for FRIB Continues

- The Gamma Ray Energy Tracking Array (GRETA) is a Major Item of Equipment (MIE) initiated in FY 2017: a premiere gamma-ray tracking device that will exploit the new capabilities of FRIB.
- GRETA was identified by NSAC as an instrument that will “revolutionize gamma-ray spectroscopy and provide sensitivity improvements of several orders of magnitude.”
- GRETA will advance the rare-isotope science at FRIB and investigate reactions of importance for nuclear structure and nuclear astrophysics.
- GRETA Progress continues
- Est. Total Project Cost: $52M-$65M
- $2.5M included in the FY2020 Request



Within Available Funds, the sPHENIX Upgrade is Continued



- 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.

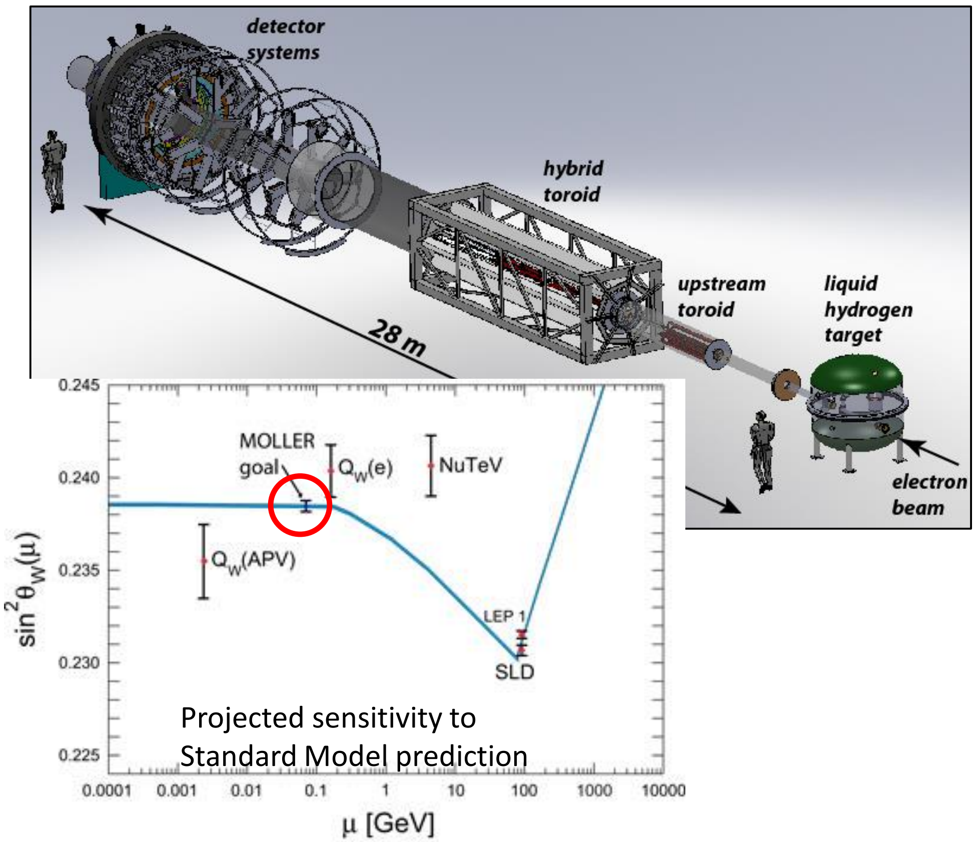
August 16, 2018: CD-1 and CD-3a for long lead procurements

$3M included in the FY2020 Request

New Starts Included in the FY2020 Request

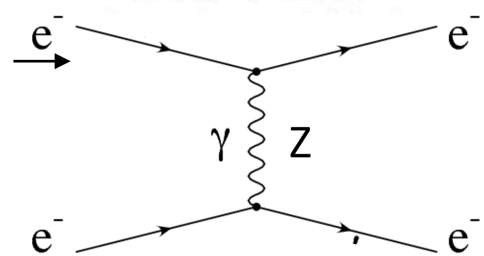
MOLLER: a "Must Do" Experiment To Point the Way to New Science

The scientific world rather desperately needs additional markers due to the consistency thus far of LHC data with Standard Model Predictions. Due to the technical challenge of constructing a next generation accelerator with very high accelerating gradients, those markers will have to come from "indirect" discovery experiments like MOLLER.



parity-violating Moller scattering

$\vec{e} + e \rightarrow e + e$



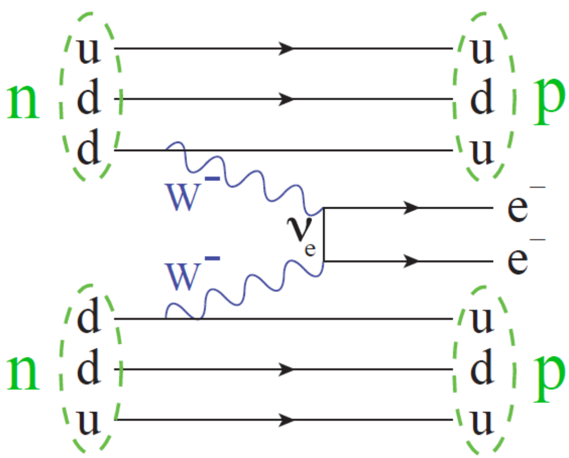
In MOLLER, polarized electrons are scattered of unpolarized electrons. The amount of parity violation due to interference of the two possible exchange mechanisms (γ or Z) is precisely predictable in QED. (No messy quarks or color charge, or QCD to worry about, only quantum electrodynamics). The theory is so "clean" that like the g-2 approach, If the level of parity violation is greater than expected, a new particle must be the source of the discrepancy.

Has CD0, TEC funding of $300k Included in the FY2020 Request

The Campaign to Finally Determine the Fundamental Nature of the Neutrino

How can it be determined whether the neutrino is a Majorana Particle?

Search for Neutrino-less Double Beta Decay ($0\nu\beta\beta$): in a selected nucleus, two neutrons decay into two protons and two electrons, with no neutrinos being emitted.



It can only happen if the two neutrinos from the two W^- particles annihilate internally because the neutrino is its own anti-particle

Scientists have been eagerly working to demonstrate the necessary sensitivity

TeO_2 from CUORE and CUOREcino
1.5×10^{25} years, 90% CL

Ge^{76} from Majorana Demonstrator
1.9×10^{25} years, 90% CL

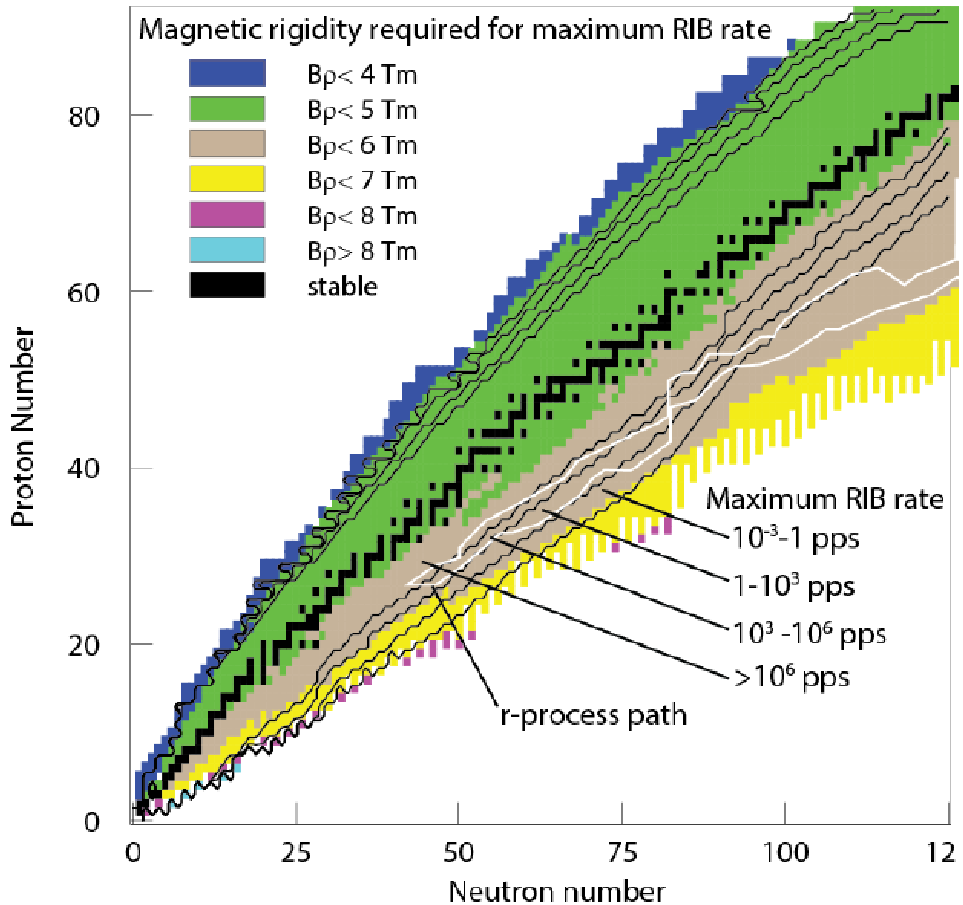
Ge^{76} from GERDA
8.0×10^{25} years, 90% CL

Xe^{136} from EXO-200
1.8×10^{25} years, 90% CL

Xe^{136} from Kamland-Zen
1.1×10^{26} years, 90% CL

Has CD0, TEC Funding of $1.44M Requested in FY2020

The Need For a High Rigidity Spectrometer (HRS) at FRIB



By design, the day-1 physics program will make use of existing NSCL infrastructure. The S800 and Sweeper Spectrometers currently available at NSCL have magnetic rigidity (bending power) limits of 4 Tesla-Meters

The magnetic rigidity for achieving the maximum rare isotope beam intensity is greater than 4 Tesla-meters for almost all species produced at FRIB and ranges up to 8 Tesla-meters for the most neutron rich rare isotopes

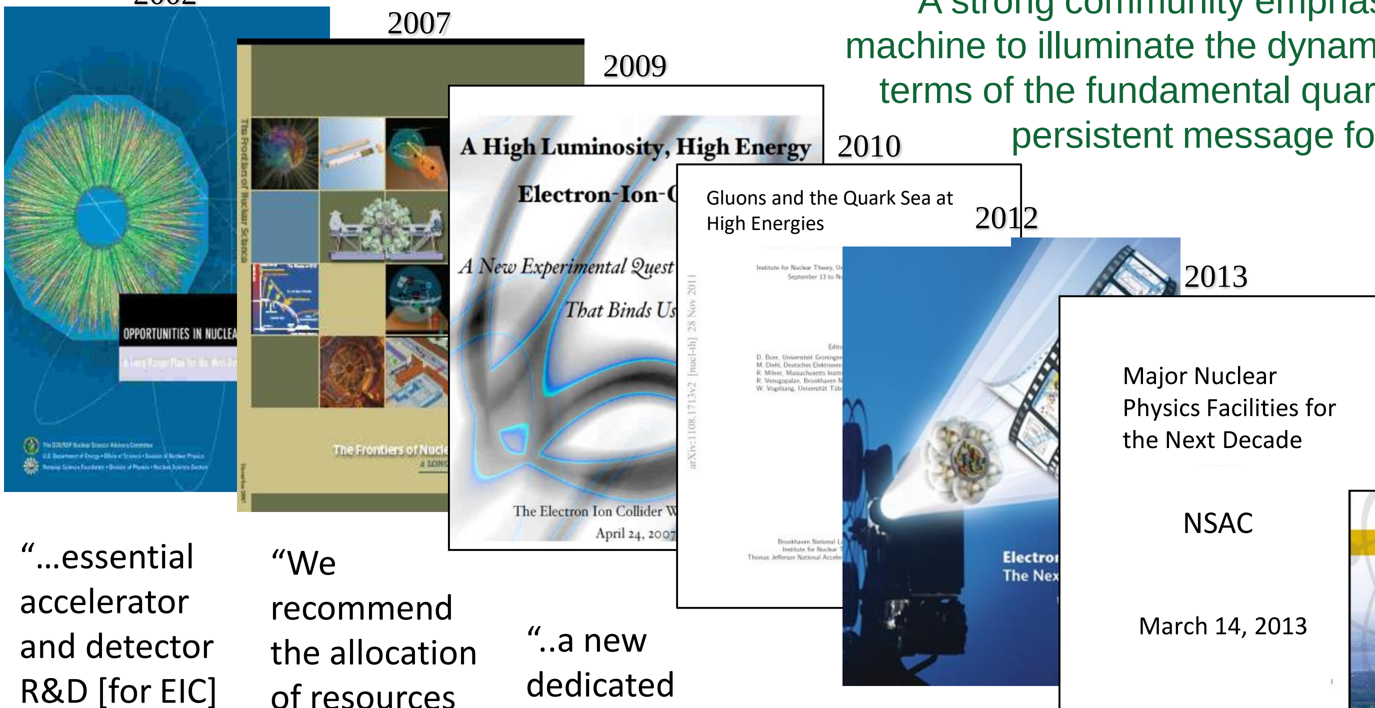
The regions most interesting for research on heavy element production in the cosmos (the nuclei with maximum neutrons) needs almost 8 T-m. Current NSCL instrumentation limit is 4 T-m so, upgraded capability is required

Has CD0, TEC Funding of $1.0M Requested in FY2020

The Science Case for An Electron-Ion Collider

A strong community emphasis on the urgent need for a machine to illuminate the dynamical basis of hadron structure in terms of the fundamental quark and gluon fields has been a persistent message for almost two decades

2002 2007 2009 2010 2012 2013



"a high-energy high-luminosity polarized EIC [is] the highest priority for new facility construction following the completion of FRIB."

2015 2018

"…essential accelerator and detector R&D [for EIC] should be given very high priority in the short term."

"We recommend the allocation of resources …to lay the foundation for a polarized Electron-Ion Collider…"

"..a new dedicated facility will be essential for answering some of the most central questions."

"The quantitative study of matter in this new regime [where abundant gluons dominate] requires a new experimental facility: an Electron Ion Collider.."

Electron-Ion Collider..*absolutely central* to the nuclear science program of the next decade.

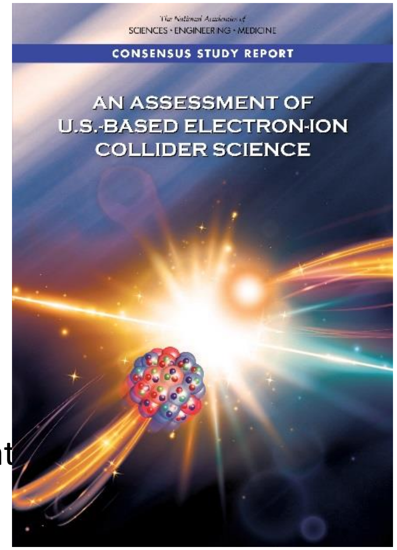
NAS Assessment of a U.S. Based Electron-Ion Collider

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, and variable, center-of-mass energy.

As a result of the comprehensive survey the committee made of existing and planned accelerat 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.

Working towards CD0, OPC Funding of $1.5M Requested in FY2020

FY 2020 Priority #1 Research Initiatives

- Machine Learning/Artificial Intelligence
- Bio (security, materials, manufacturing)
- Quantum Information Science - includes quantum sensing, computing, networking, and isotope production
- Exascale Computing
- Microelectronics Innovation
- National Isotopes Strategy
- U.S. Fusion Program Acceleration

FY 2020 Priority #1 Research Initiatives

Dollars in Thousands

Research Initiative	ASCR	BES	BER	FES	HEP	NP	Total
Machine Learning / Artificial Intelligence	36,000	10,000	3,000	7,000	15,000		**71,000**
Biosecurity			20,000				**20,000**
Quantum Information Science	51,161	52,503	12,000	7,520	38,308	7,000	**168,492**
Exascale Computing	463,735	26,000	10,000				**499,735**
Microelectronics		25,000					**25,000**
Isotope Development and Production for Research and Applications						47,500	**47,500**
U.S. Fusion Program Acceleration				4,000			**4,000**
Total	**550,896**	**113,503**	**45,000**	**18,520**	**53,308**	**54,500**	**835,727**

Early FY 2018 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 MgF_2

FY 2018 Awards Made Through Annual Solicitation

NSAC Assessment of the Role of Nuclear Science is Ongoing

In some ways QIS/QC is not new to Nuclear Physics…

That said, the dramatic strengthening of this emphasis by the nation motivates a fresh look at the unique roles nuclear physics can and should play.

Decades of accumulated intellectual capital, extensive experience in interdisciplinary research, considerable technical infrastructure at labs and universities, and a long history of international leadership in collaborative research have positioned the DOE Office of Nuclear Physics and the NSF nuclear physics research programs to engage in QIS relevant research. However, QIS is newly emergent as a priority area for Research & Development (R&D) investment in nuclear science. Furthermore, private sector R&D investment in QIS, as well as investment by other Federal agencies, has been ongoing for some time. NSAC is therefore requested, in the context of Federal and private sector research efforts already underway, to articulate the unique role nuclear science research, aligned with the DOE and NSF nuclear physics programs, can and should play in Quantum Information Science. While unique, this role should nevertheless align broadly with the goals outlined in the national strategy for QIS[1].

[1] https://www.whitehouse.gov/wp-content/uploads/2018/09/National-Strategic-Overview-for-Quantum-Information-Science.pdf

An FY2019 FOA is Coming Soon

U. S. Department of Energy Office of Science Nuclear Physics (NP)

Quantum Horizons: QIS Research and Innovation for Nuclear Science

A new initiative to identify, prioritize, and coordinate emerging opportunities in both fundamental research and applied challenges at the interface of Nuclear Physics and QIST. NP's Quantum Horizon's program emphasizes the science first approach and is guided by NP community research workshops: "Opportunities for Nuclear Physics & Quantum Information Science" and "Quantum Computing for Theoretical Nuclear Physics" and the "National Strategic Overview for Quantum Information Science", the Interagency Working Group on Quantum Information Science and the Exploration of the Quantum Landscape meetings of the Nuclear Science Advisory Committee

In the long-term have a transformative impact on NP mission area and/or advance QIS development enabled by NP-supported science, technologies, and laboratory infrastructure….

Plan is to Conduct Peer Review and Award $6.8M in FY2019

Machine Learning / Artificial Intelligence

- Executive Office of the President (EOP) Priority
  - Major U.S. Government initiative is in planning stage
- Cuts across SC programs
  - ASCR, BES, BER, FES, and HEP
- Cuts across many DOE programs
  - OE, EE, FE, NE, NNSA
- Cuts across multiple U.S. Government Agencies, including NIH and DoD
- FY 2020 SC request - $71M
  - patterned after the Exascale Computing Project

This thrust in NP may also require input from NSAC

Inter-Agency FOA on Nuclear Data to Come Out Shortly

DEPARTMENT OF ENERGY
OFFICE OF SCIENCE, NUCLEAR PHYSICS
OFFICE OF SCIENCE, NUCLEAR PHYSICS, ISOTOPES PROGRAM
OFFICE OF NUCLEAR ENERGY
NATIONAL NUCLEAR SECURITY ADMINISTRATION, OFFICE OF DEFENSE NUCLEAR NONPROLIFERATION R&D

….Accordingly, the purpose of the research program associated with this FOA is to support new activities (*e.g.* experiments, infrastructure, models, and so forth) that will provide new nuclear data or related predictions where needed in areas in which the existing data is inadequate or does not exist, and insure that the new data is transferred to the appropriate nuclear databases in a timely manner.

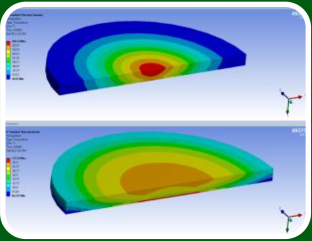
Technical/Scientific Program Contacts:

DOE NP: **Timothy Hallman**
DOE NE: **Dave Henderson**
DOE IP: Ethan Balkin
DOE NNSA DNN: Donald Hormback

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

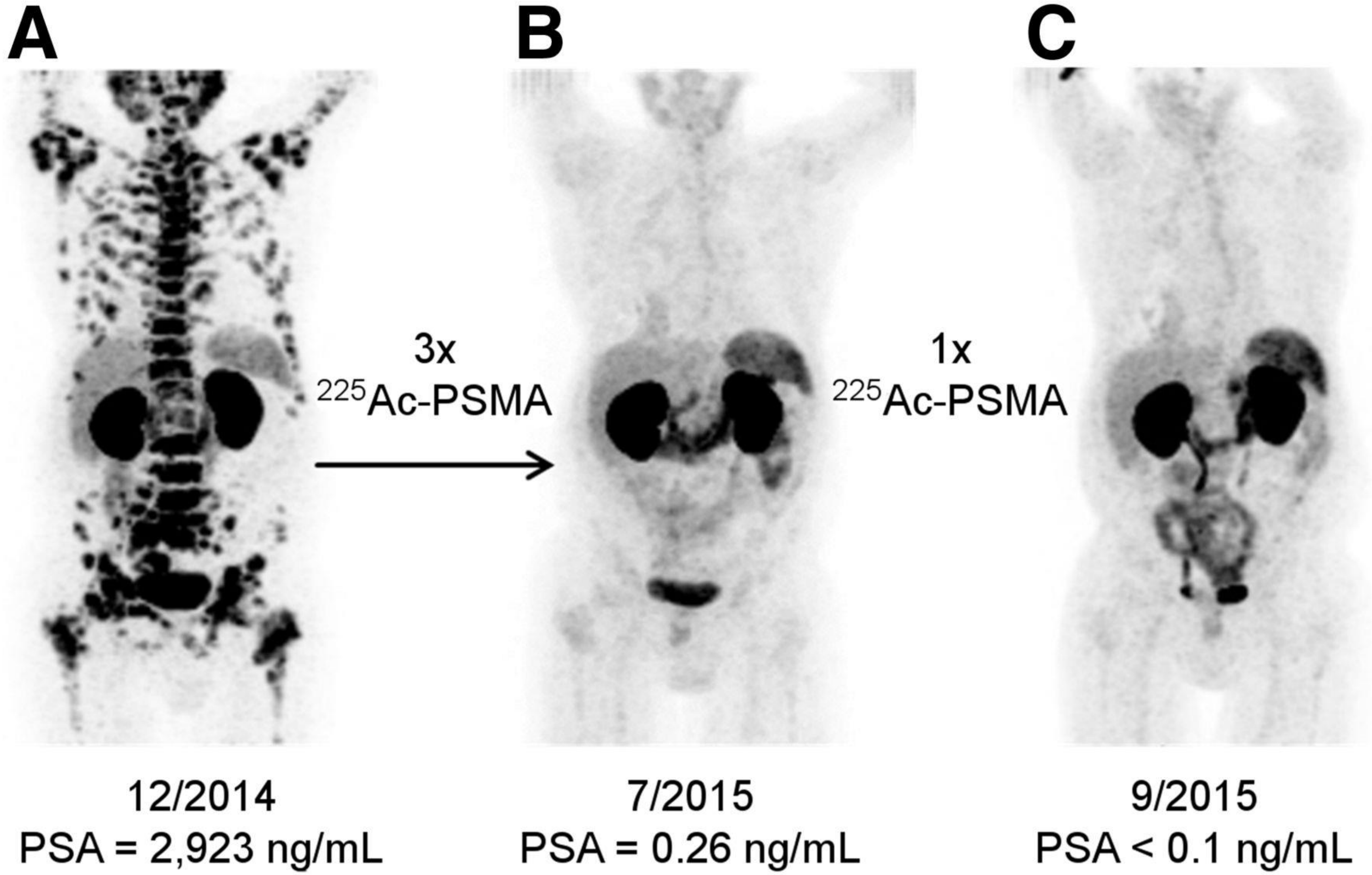
Maintain the infrastructure required to produce and supply priority isotope products and related service



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

OMB moved Isotope Program from Office of Nuclear Energy to NP in FY 2009 Passback

Support for Isotope Research/Mission Readiness is Enabling the Saving of Lives



Ga-68 PET/CT scans of a different patient with metastatic prostate cancer. Image **A** shows pre-therapeutic tumor spread. Image **B** was taken 2 months after the third cycle of treatment with the α-emitting isotope Ac-225 attached to a tumor seeking drug. Image **C** was taken 2 months after one additional treatment dose. Clemens Kratochwil et al. J Nucl Med 2016;57:1941-1944

Stable Isotope Production Facility (SIPF) and SIPRC

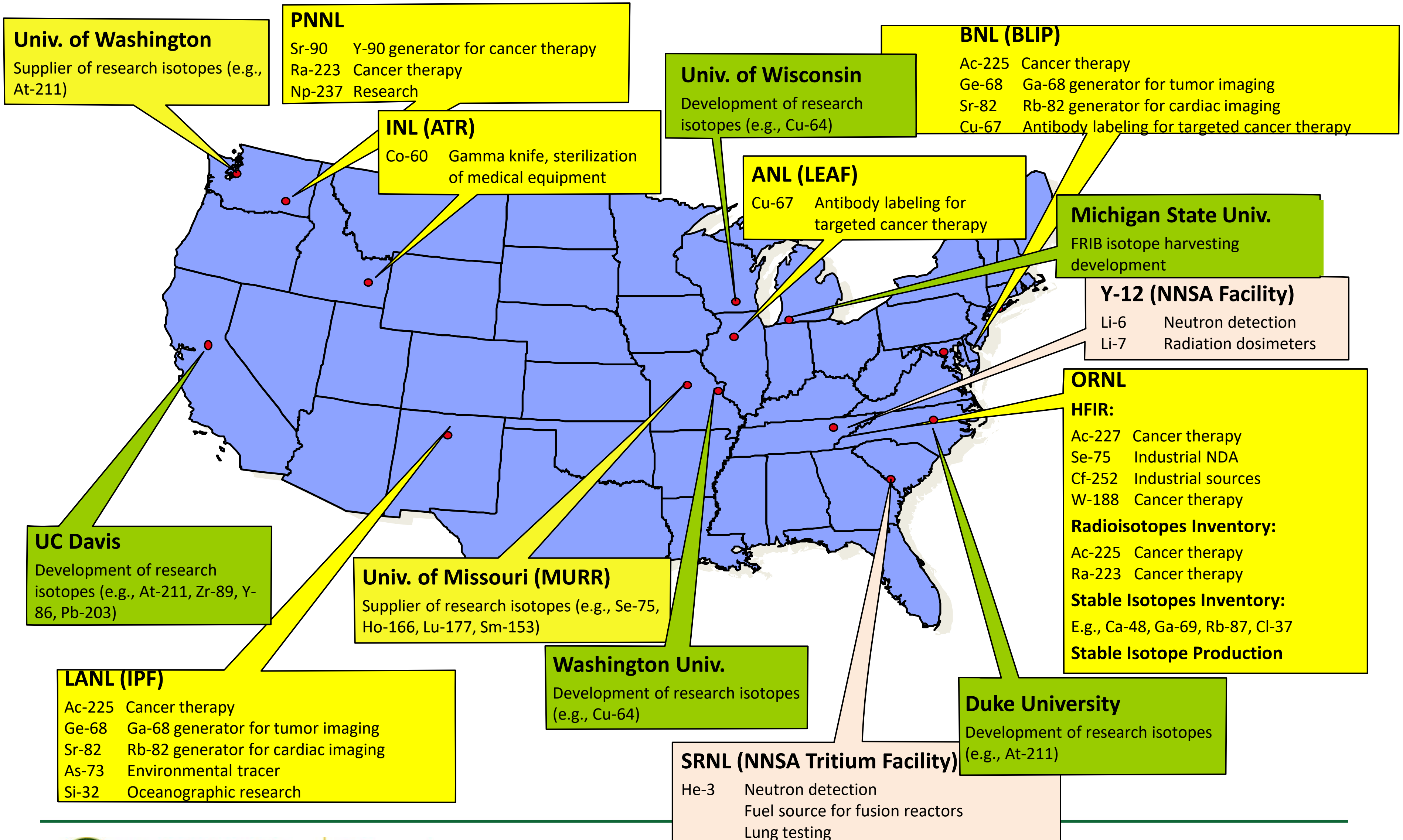
- The upcoming FY 2020 Request will be the last year of support ($1.5M) for the SIPF MIE, which directly supports the DOE Isotope Program mission, upgrading domestic capability that has been lacking since 1998.
  - Renewed enrichment capability will benefit nuclear and physical sciences, industrial manufacturing, homeland security, and medicine.
  - Nurtures U.S. expertise in centrifuge technology and isotope enrichment that could be useful for a variety of peaceful-use activities.
  - Addresses U.S. demands for high priority isotopes needed for suite of activities: neutrinoless double beta decay, dark matter experiments, target material for Mo-99 production.
  - Help mitigate U.S. foreign dependence on stable isotope enrichment.

The next major step towards reliable U.S. supplies at scale is SIPRC at ORNL. TEC funding of $5M is requested in FY2020 as part of the National Isotope Strategy

SIPF responds to Nuclear Science Advisory Committee – Isotopes (NSACI):

- 2009 Recommendation: "Construct and operate an electromagnetic isotope separator facility for stable and long-lived radioactive isotopes."
- 2015 Long Range Plan: "We recommend completion and the establishment of effective, full intensity operations of the stable isotope separation capability at ORNL."

DOE Isotope Program Production and/or Development Sites -2018



FRIB Isotope Harvesting

FRIB will create Ci-quantities of useful radioisotopes as byproducts of normal operations.

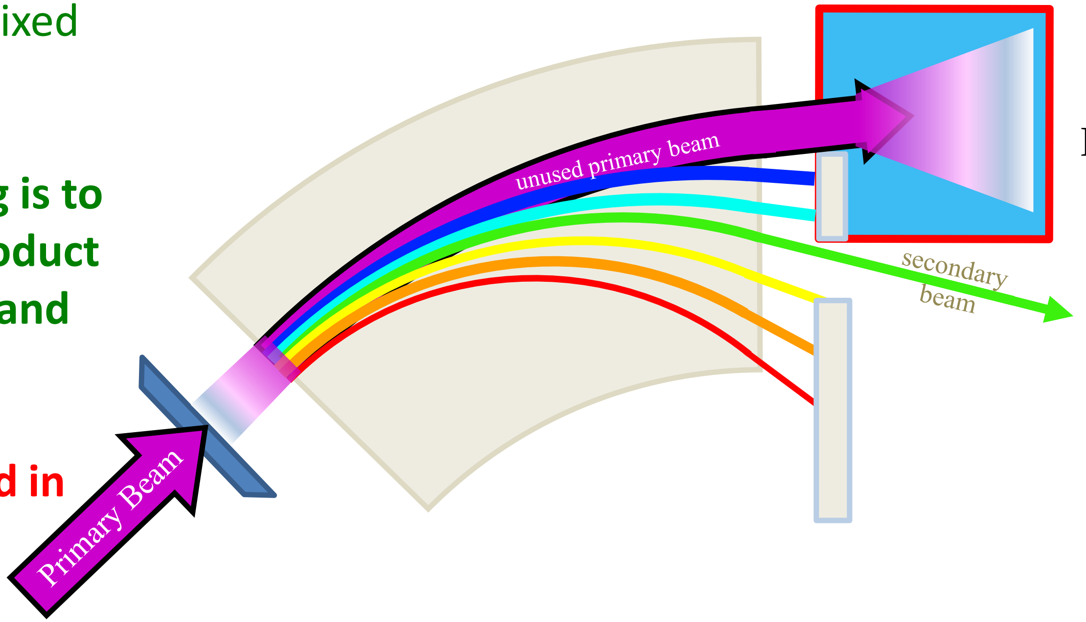
They will mostly be present as ions, or as dissolved gases in beam-dump cooling water.

The radionuclides will be all mixed together.

The goal of isotope harvesting is to collect and purify FRIB's byproduct radionuclides for use in basic and applied research.

TEC Funding of $2M requested in FY2020

- FRIB linac provides a "primary beam"
  - e.g. $^{48}Ca^{20+}$ 240 MeV/u ~33 pμA (2 x10^{14} particles per second)
- Primary beam hits a thin target (e.g. Be) and fragments
  - Reaction produces almost any nucleus with mass <50 and Z<Ti
    - » Probabilities for conversion are ~10^{-3} for masses near A = A_0, ~10^{-6} for other masses
    - » 90% of the primary beam does not react!
- Fragments are still moving, and a "secondary beam" is purified based on charge-to-mass
    - » Unreacted primary beam is directed to a "beam blocker" where many more nuclear reactions occur.



Latest SCGSR NP Award Recipient

Stacyann Stephanie Nelson Received the latest SCGSR Award

Final Research Area	Current Graduate Institution	Additional Graduate Education	Primary Graduate Thesis Advisor	Graduate Thesis Title	Host DOE Laboratory	Collaborating DOE Laboratory Scientist	Research Proposal Title
NP - Heavy Ion Nuclear Physics	Florida Agricultural and Mechanical University / Physics / Experimental Particle physics	The University of the West Indies / Physics / Physics (M.Phil. 5/2014)	Carol Scarlett / Florida Agricultural and Mechanical University / Physics / Associate professor Tallahassee, FL	J/Psi Photoproduction in Ultra-peripheral Au+Au collisions at PHENIX and 20 Picosecond TOF Detector R&D for sPHENIX	Brookhaven National Laboratory (BNL)	Mickey Chiu / Department of Physics / Physicist and Operation Manager NY	J/Psi Photoproduction in Ultra-peripheral Au + Au collisions at PHENIX and 20 Picosecond TOF Detector R&D for sPHENIX

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…”

General Outlook

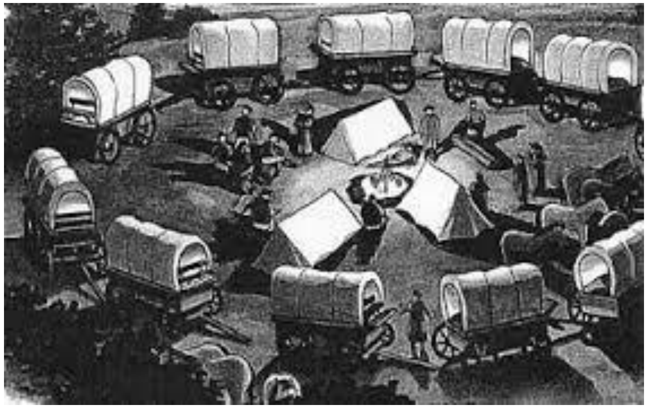
- The experience with FY18 and FY19 budgets maybe similar in the next budget cycle.
- We need to stay focused and continue to deliver important outcomes for the nation.
- Delivering exciting discoveries, important scientific knowledge, technological advances, and workforce training is what we do.
- We need to keep up the good work!

A Long Tradition of Partnership and Stewardship

There has been a long tradition in Nuclear Science of effective partnership between the community and the agencies in charting compelling scientific visions for the future of nuclear science.

Key factors:

1) Informed scientific knowledge as the basis for recommendations and next steps
2) Mutual respect among scientific sub-disciplines
3) Commitment to the greater good of nuclear science as a discipline
4) Meticulously level playing field leading to respect for process and outcomes
5) Deep appreciation for the wisdom of Ben Franklin



Additional Information

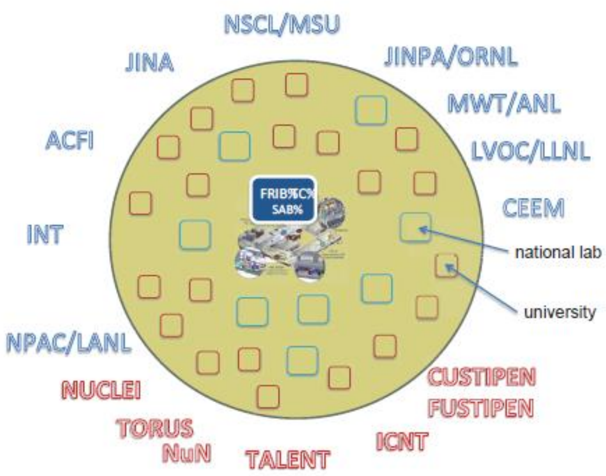
Nuclear Theory

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.

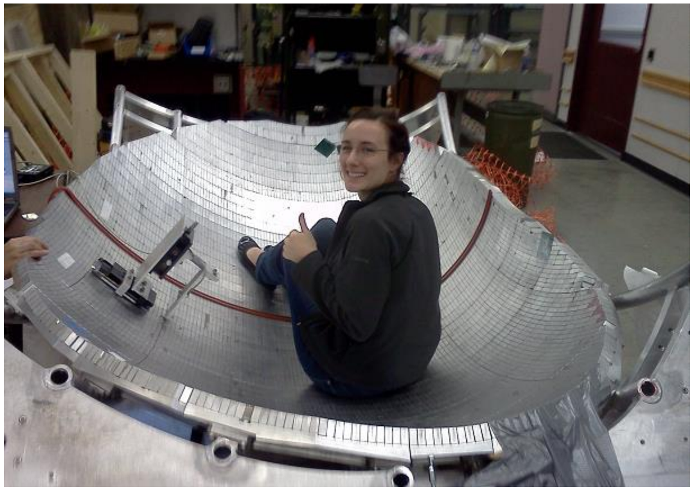
- In FY20, 4 fixed-term, multi-institution Theory Topical Collaborations are continued to investigate specific topics
- The FRIB Theory Alliance is continued
- LQCD computing is restored
- Funding maintains support for SciDAC-4 projects that received 5-year awards starting in FY17



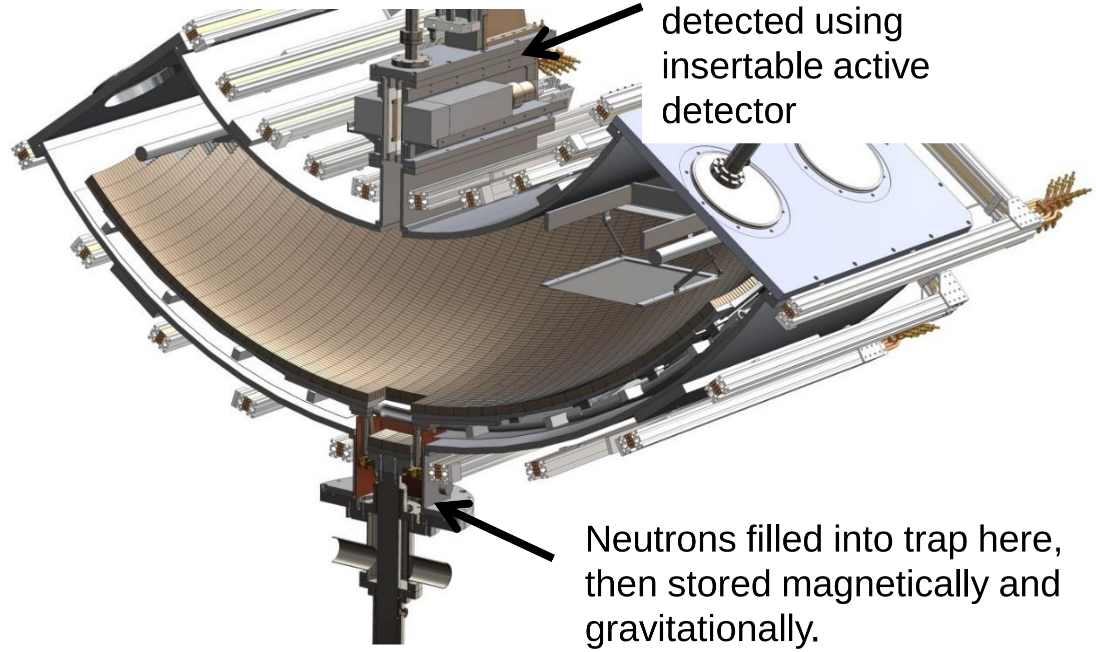
FRIB Theory Alliance

An Important “Other Low Energy” Advance from UCNtau

The UCNτ 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.



Surviving neutrons detected using insertable active detector

Neutrons filled into trap here, then stored magnetically and gravitationally.

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

A Breakthrough Neutron Lifetime Experiment

Measurement of the neutron lifetime using a magneto-gravitational trap and in situ detection

R. W. Pattie Jr.[1], et al.

Science 11 May 2018:
Vol. 360, Issue 6389, pp. 627-632

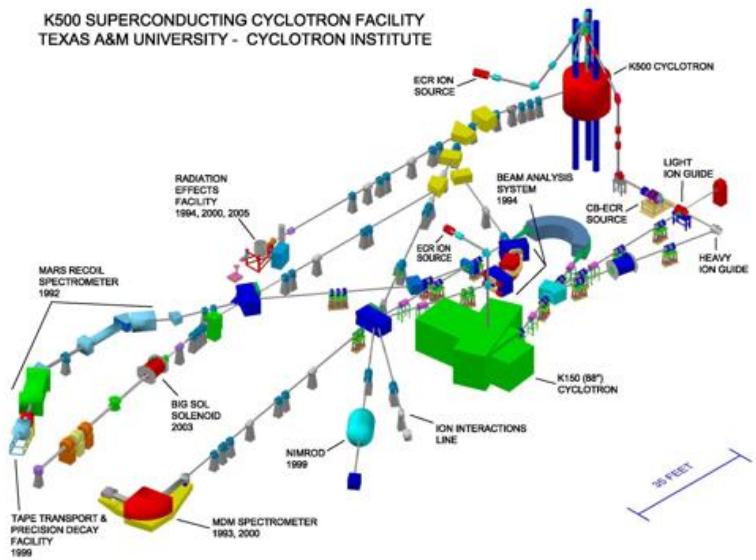
Abstract

The precise value of the mean neutron lifetime, τ_n, plays an important role in nuclear and particle physics and cosmology. It is used to predict the ratio of protons to helium atoms in the primordial universe and to search for physics beyond the Standard Model of particle physics. We eliminated loss mechanisms present in previous trap experiments by levitating polarized ultracold neutrons above the surface of an asymmetric storage trap using a repulsive magnetic field gradient so that the stored neutrons do not interact with material trap walls. As a result of this approach and the use of an in situ neutron detector, the lifetime reported here [877.7 ± 0.7 (stat) +0.4/–0.2 (sys) seconds] does not require corrections larger than the quoted uncertainties.

Two NP Centers of Excellence at TUNL and Texas A&M

1967 - 2017 50 YEARS OF BEAM exploring the nuclear frontier

CYCLOTRON INSTITUTE
TEXAS A&M UNIVERSITY

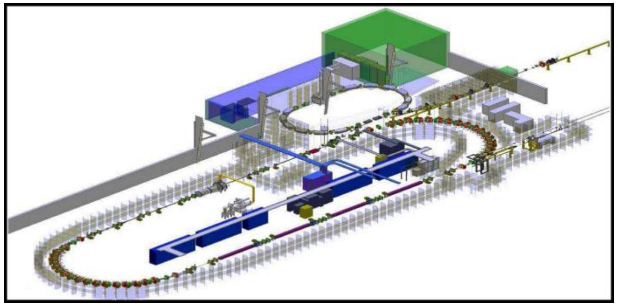


The Texas A&M University Cyclotron Institute jointly supported by DOE and the State of Texas focuses on conducting basic research, educating students in accelerator-based science and technology, and providing technical capabilities for a wide variety of applications in space science, materials science, analytical procedures and nuclear medicine.

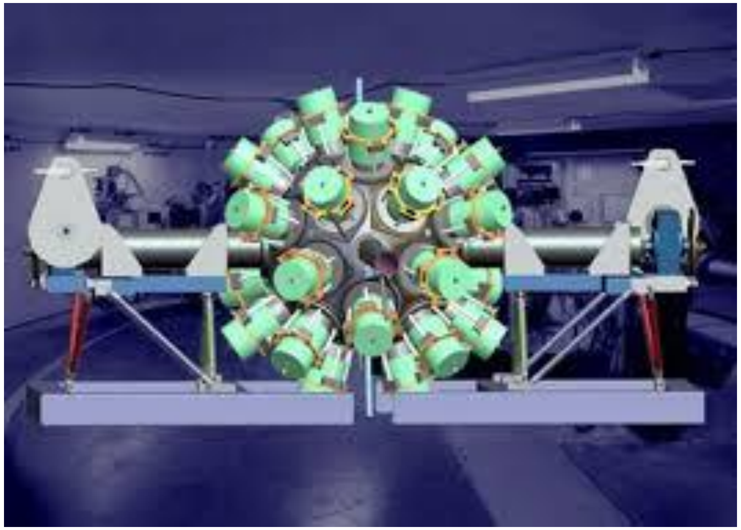
The 88 inch cyclotron also plays a crucial role in space radiation effects chip testing for the Air Force

TUNL TRIANGLE UNIVERSITIES NUCLEAR LABORATORY
Durham, North Carolina
A US Department of Energy Center of Excellence in Nuclear Physics

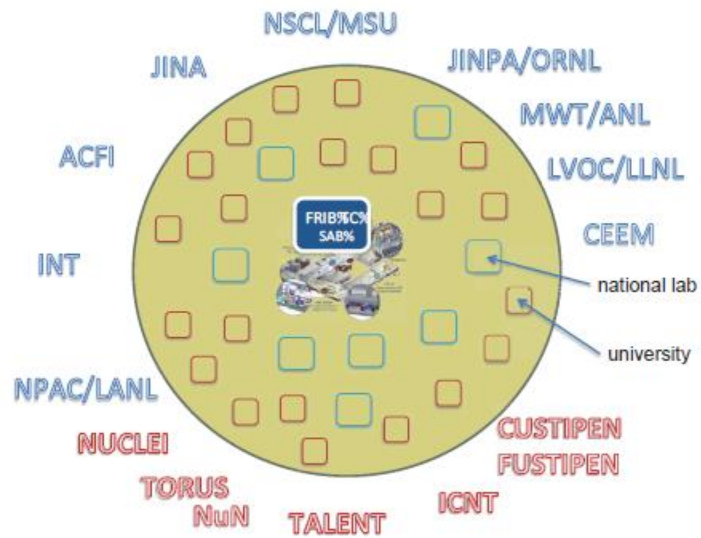
The Triangle Universities Nuclear Laboratory (TUNL) is Center of Excellence that focuses on low-energy nuclear physics research. TUNL is a consortium Duke University, North Carolina State University, and the University of North Carolina at Chapel Hill comprising about 30 faculty members, 20 postdocs and research scientists, and 50 graduate students.



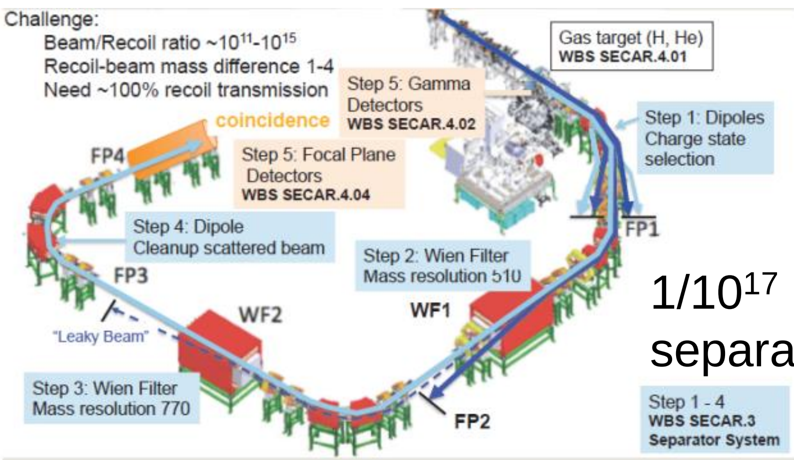
FRIB Instrumentation/Theory Effort Are Underway



GRETA CD3a 8/2018

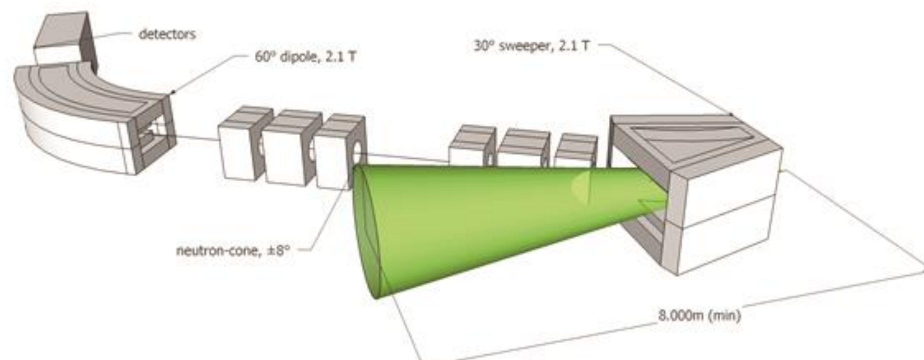


FRIB Theory Alliance



$1/10^{17}$ separation

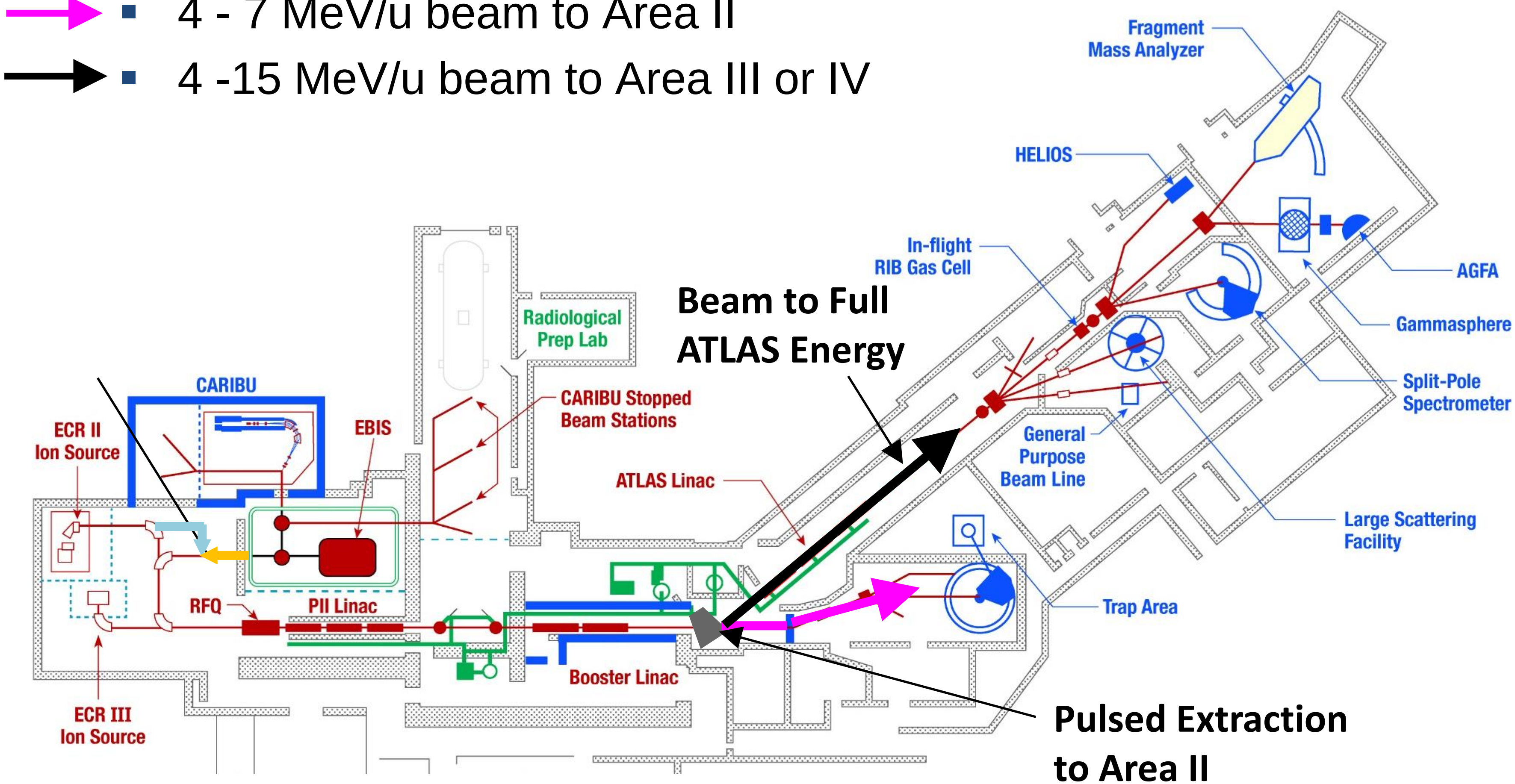
SECAR Complete FY20/21



Pre-Conceptual High Rigidity Spectrometer (HRS)

Scope of the Proposed Multi-User Upgrade AIP

- Injection from ECR
- Injection from CARIBU-EBIS
- 4 - 7 MeV/u beam to Area II
- 4 -15 MeV/u beam to Area III or IV

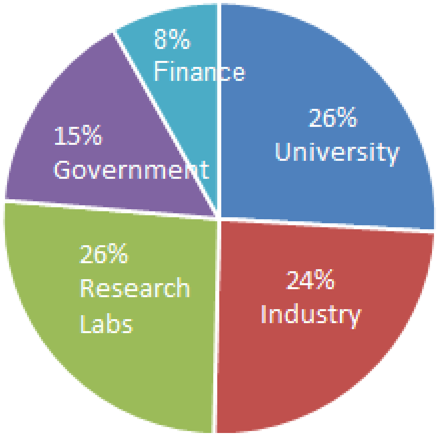


How An NP Trained Workforce Benefits the Nation

Where Do the Entrants into Industry Go?

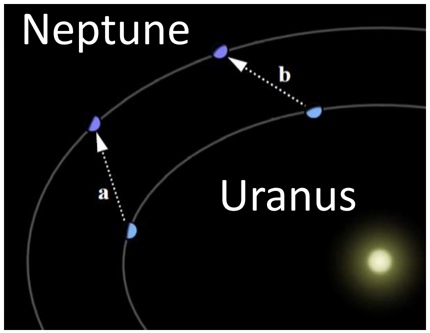
Data scientist at a company that develops software for predictive maintenance of machines
Chemist at a European large home fragrance company
Research Scientist at a mining technology company
Sr. technical staff at an international internet-of-things company
Sr. Chemist at a mining company
Sr. Research Scientist at a Fotune-100 conglomerate
Founder of a cloud company and Founder/General Partner of a venture capital firm
Sr. Scientist at an international optics company
Head of bioinformatics at a molecular therapy company
Director of Radiological Product Development of a global healthcare technology company
Scientist at a global image sensor company
Vice President of Engineering of a software application development company
Chief Researcher at an international industrial research lab
Director of Innovation at a popular data science platform company
Scientific Translator and Editor
Senior Manager at a EU-listed company that provides microstructuring equipment for the semiconductor industry.
Software engineer at an international computer game company, specializing in physics simulations for games.
Technical Lead of a NYSE-listed company that provides high-speed data movement interconnects
Accelerator and materials technical lead at the radiation effects laboratory of a major Fortune-50 aerospace company.
Owner of a private technology/consulting company

Case Study of an
NP supported Experiment



The Experimental Discovery Strategy Behind MOLLER

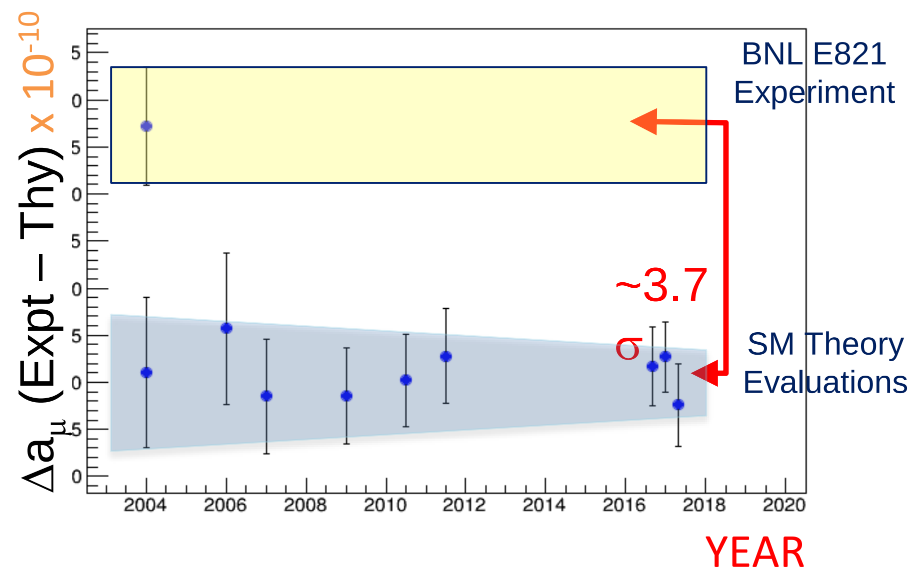
An “old-school” analogy to the experimental approach in MOLLER: --indirect observation and discovery of Neptune.



Neptune could not be seen because of its distance, but its gravitational effects on Uranus could be, and because the theory of Newtonian gravity was precise, it was inescapable that another planet must exist at a location that was predictable.

In the search for new physics, the same approach can be used. In this case the theory is quantum electro-dynamics (QED) (not gravity), but if a deviation from theory is observed, there must be another “hidden” particle interacting with the known ones. A key to the success of this technique is that QED is the only theory that applies, and after years of refinement, it is one of the most precise theories in science

The strongest current experimental scientific “marker” that implies new science beyond our present understanding is the g-2 result measured at BNL. It is currently being repeated at FNAL. It relies on the fact that the rotation of a charged particle with spin in a magnetic field should be exactly predictable via QED unless other particles--thus far invisible--are interacting with the known rotating particle.



Summary of 2020 Changes Relative to FY 2019

FY 2019 Enacted	FY 2020 PR - relative to FY19 Enacted
Lab and University research is increased 3% from FY18 Enacted.	Lab and university research is reduced 16% from the FY19 Enacted level (~$34M). RIFs of roughly 50 FTEs are expected.
RHIC operates 28 weeks.	RHIC operates for 12 weeks (40.5% of optimal).
TJNAF operates 32 weeks and work continues on several aspects of the CEBAF reliability plan.	TJNAF operates for 8 weeks (23.6% of optimal). The reliability plan continues to be pursued. The End Station Refrigerator GPP project is initiated.
ATLAS operates for 43 weeks.	ATLAS operates for 14 weeks (30.7% of optimal).
TJNAF, RHIC, and ATLAS Facilities receive CE and AIP funding; TJNAF also receives GPP funding.	AIP and CE levels at TJNAF, RHIC, and ATLAS are reduced to FY18 Enacted levels. GPP at TJNAF is directed entirely to the End Station Refrigerator project.
88-inch Cyclotron support is maintained.	88-inch Cyclotron support is reduced ~7% from the FY19 Enacted level.
FRIB Operations is supported at $3.95M, with the support in FY18 and 19 matching the $7.7M as agreed to in the operations cooperative agreement.	FRIB Operations ramps up but is below tentative profile ($13.5M in PR compared to $28.5M in the CoAg). 52 FTEs are unable to transition from construction project to operations.
Medium Energy subprogram research is increased.	Medium Energy subprogram is reduced by 13% from the FY19 Enacted level.
Heavy Ion subprogram research is increased.	Heavy Ion subprogram is reduced by 13% from the FY19 Enacted level. Commitments to LHC program are deferred.
Fundamental Symmetries subprogram research is increased and continues investments in NLDBD and nEDM.	Fundamental Symmetries subprogram is reduced by 13% from the FY19 Enacted level.
Nuclear Structure and Nuclear Astrophysics subprogram research is increased.	Nuclear Structure and Nuclear Astrophysics subprogram is reduced by 13% from the FY19 Enacted level. There is no specific support for NSF scientists transitioning to FRIB research.
Theory subprogram is increased.	Theory subprogram is reduced by 13% from the FY19 Enacted level.

Summary of 2020 Changes Relative to FY 2019

FY 2019 Enacted	**FY 2020 PR**
Investment in LQCD computing continues.	Investment in LQCD computing continues.
The NP QIS program begins with $6.8M in FY19 funds. In the Isotope Program, $1.5M is provided for production of QIS-relevant isotopes.	NP QIS investment drops to $3.5M. Isotope Program QIS funding increases to $3.5M.
Accelerator R&D efforts are increased to support EIC-related R&D efforts.	Accelerator R&D efforts continued at a significantly lower level, impacting the ability to conduct EIC research and address high risks in EIC.
SciDAC effort is increased.	SciDAC effort continues at the FY19 level.
National Nuclear Data Center subprogram is increased, with continued support of nuclear data experimental efforts.	National Nuclear Data Center subprogram is reduced 13% from the FY19 Enacted level, with limited funds for new ND experimental efforts.
Isotope R&D bases increased and NSAC-recommended plus-up in R&D partially addressed (focus on Ac-225).	Isotope R&D bases increased in alignment with the NSAC-recommended plus-up.
University network for unique medical isotopes continues.	University network for unique medical isotopes is increased.
Mission readiness of Isotope Production facilities mostly supported through appropriated funds.	Funding to support mission readiness of Isotope Production facilities is increased.
Ac-225 production/extraction increased and facilities upgraded to full-scale production capabilities.	Ac-225 production/extraction are again increased and facilities are upgraded to full scale production capability.
ESIPF mission readiness is increased.	ESIPF mission readiness is increased.
The FRIB Isotope Harvesting AIP is not pursued.	$2M is provided for the FRIB Isotope Harvesting AIP.
Targeted Isotope Program capital investments are pursued.	Funding is provided for investments capital equipment, including improved processing infrastructure, a new He-3 initiative, and a new EMIS for heavier isotopes.

Summary of 2020 Changes Relative to FY 2019

FY 2019 Enacted	FY 2020 PR
FRIB construction is supported at baselined level.	FRIB construction is supported at baselined level.
SIPF MIE support is increased for addition of scope ($11.5M in FY19).	SIPF MIE receives its final year of funding ($1.5M)
No funding is provided for the Ton Scale Neutrinoless Double Beta Decay MIE.	The Ton Scale Neutrinoless Double Beta Decay MIE receives its first year of TEC funding ($1.44M).
No funding is provided for the High Rigidity Spectrometer.	The High Rigidity Spectrometer is supported for its first year of funding ($1M).
MOLLER MIE not started.	The MOLLER MIE is initiated with $300k of TEC funds.
GRETA supported at $6.6M in FY19, per the planned profile.	GRETA MIE supported at $2.5M in FY20, $7.7M below the planned profile.
The first year of sPHENIX TEC funds are provided ($5.66M).	Funding for sPHENIX is $6.5M below the planned level ($3M as opposed to the planned $9.5M). Support for this MIE comes from redirected RHIC operations funding.
EIC funds are not provided.	$1.5M of EIC OPC funds are provided.
No funding is provided for the U.S. Stable Isotope Research and Production Center.	$5M in TEC funds are provided for the U.S. SIPRC construction effort.