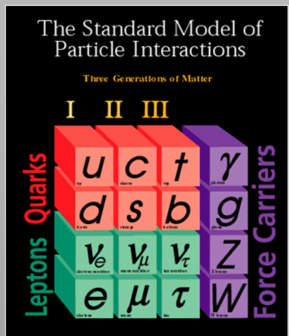
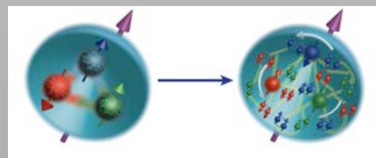
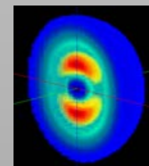

HEPAP
10 December 2015

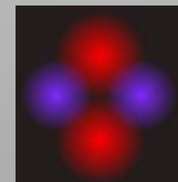
# The 2015 LONG RANGE PLAN for NUCLEAR SCIENCE

# 21st Century Nuclear Science { Probing nuclear matter in all Its forms & exploring their potential for applications

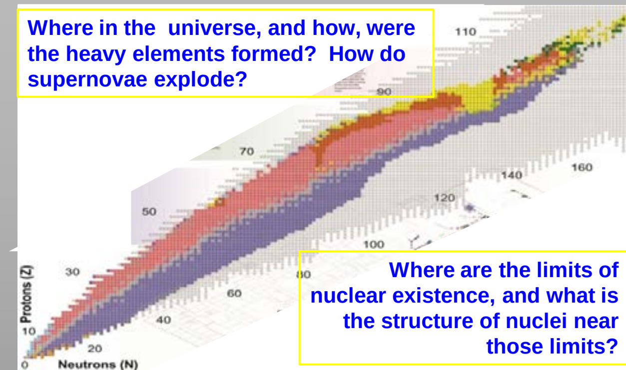




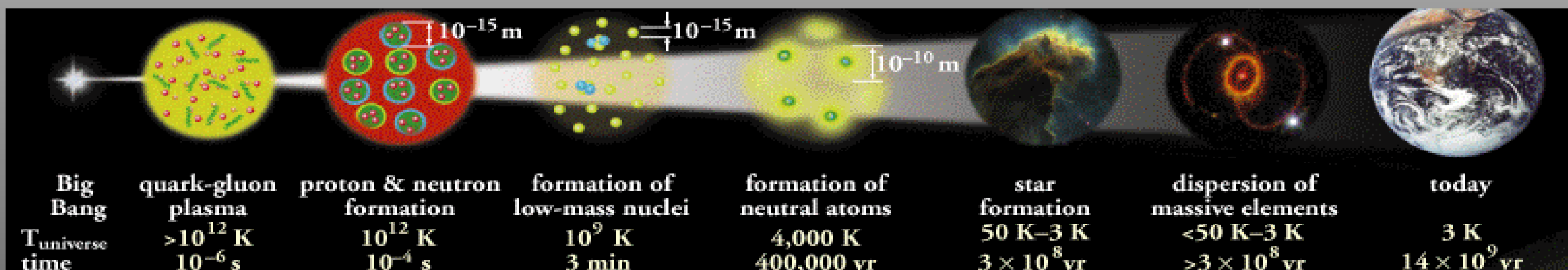


How are the properties of protons and neutrons, and the force between them, built up from quarks, antiquarks and gluons? What is the mechanism by which these fundamental particles materialize as hadrons?

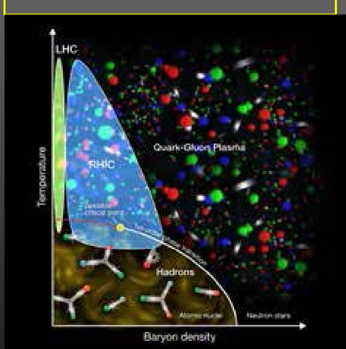



Where in the universe, and how, were the heavy elements formed? How do supernovae explode?

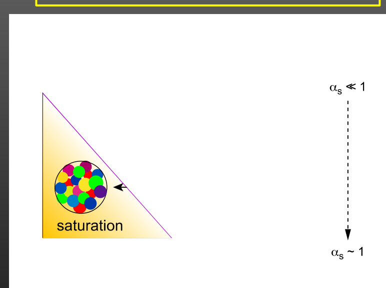
Where are the limits of nuclear existence, and what is the structure of nuclei near those limits?



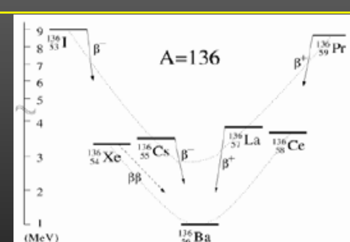

What is the nature of the different phases of nuclear matter through which the universe has evolved?



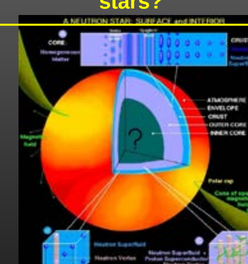

Do nucleons and all nuclei, viewed at near light speed, appear as walls of gluons with universal properties?



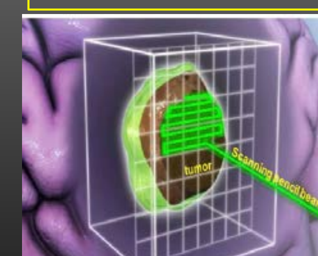

How can the properties of nuclei be used to reveal the fundamental processes that produced an imbalance between matter and antimatter in our universe?



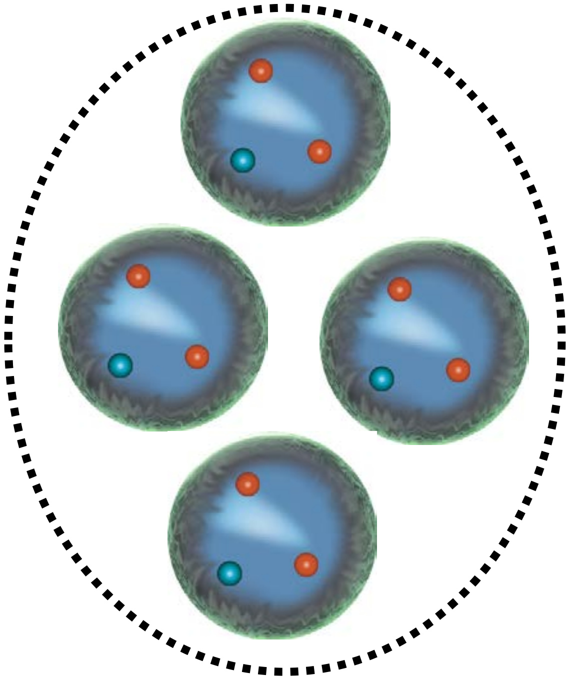

How are the nuclear building blocks manifested in the internal structure of compact stellar objects, like neutron stars?




How can technologies developed for basic nuclear physics research be adapted to address society's needs?



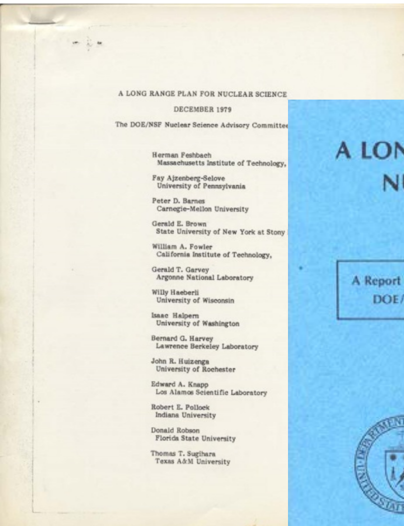
# Nuclear Science is at a Launching Point in Reaching for the Horizon



| | |
|---|---|
| Valence quarks and gluons | **JLAB 12 GeV Upgrade** – Valence 3D Imaging and Valence Glue |
| Quark Gluon Plasma<br>The most perfect liquid | **RHIC** – Low Energy Search for critical point<br>Exploit jets and high mass probes |
| The Structure and Limits of Nuclei<br>The Origin of Nuclei | **FRIB** – Twice the number of nuclei available<br>**NSCL, ATLAS** and<br>**University Facilities** |
| Unique Nuclear Probes of Physic beyond the Standard Model | **Neutrinoless Double Beta Decay, Electric Dipole Moments** and other nuclear tests of the Standard Model |
| Understanding the Glue that binds us all | A future **Electron Ion Collider** |

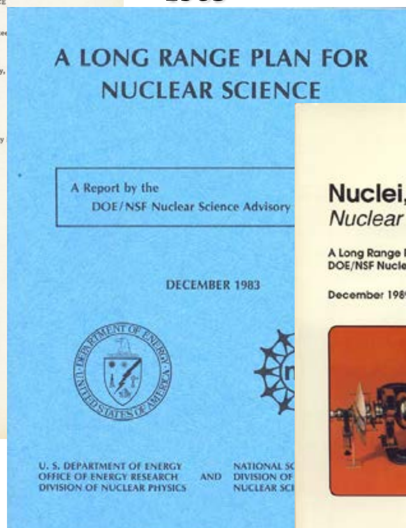
# Nuclear Science in the U.S. has been guided by the NSAC Long Range Plans

1979



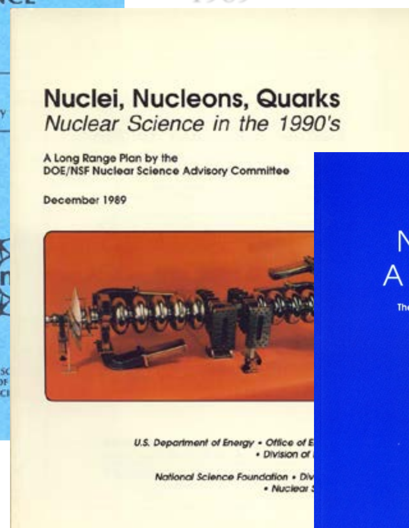

CW Electron Accelerator

1983

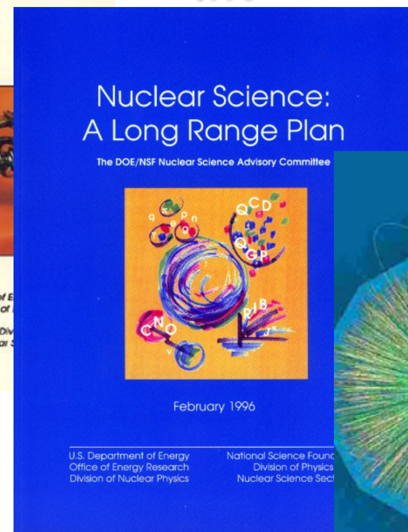



RHIC

1989



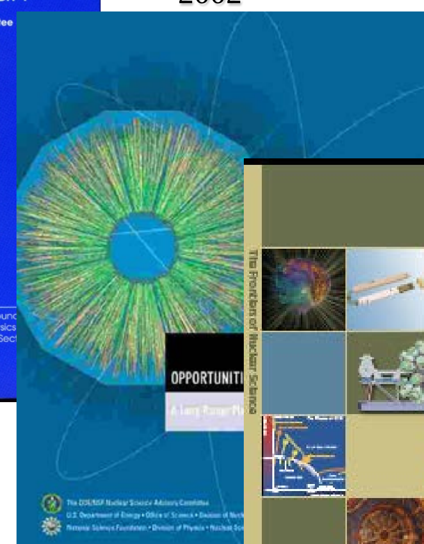

1996




Two Rare Isotopes Facilities –in-flight, ISOL

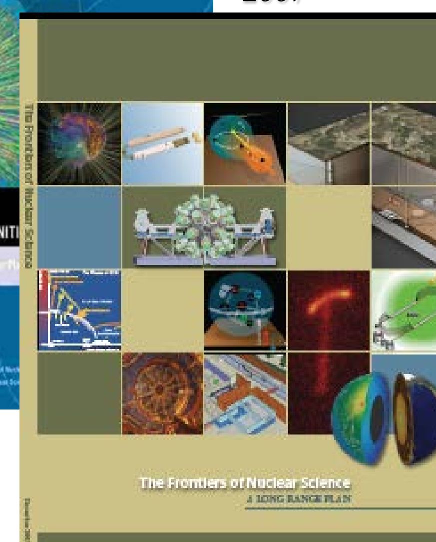
RIA
JLAB 12 GeV

2002




FRIB
RHIC Upgrade

2007



# Charge to NSAC to Develop a New Long Range Plan

**“a framework of coordinated advancement of the Nation’s nuclear science research programs over the next decade”**

**“articulate the scope and scientific challenges”**

**“what progress has been made and the impact of these accomplishments both within and outside the field”**

**“identify and prioritize the most compelling scientific opportunities”**

**“coordinated strategy for the use of existing and planned capabilities, both domestic and foreign”**

**“what resources and funding levels would be required … to maintain a world-leadership position in nuclear physics research”**

**“what the impacts are and priorities should be if funding provides for constant level of effort.”**

**“key element should be the Program’s sustainability under the budget scenarios considered”**

# LRP Schedule

- ✓ Charge delivered at 24 April 2014 NSAC Meeting
- ✓ LRP Working Group formed in early June ~ 60 members
  - Observers from nuclear physics associations in Europe and Asia
- ✓ Community organization summer 2014
- ✓ DNP town meetings in the July/September 2014
- ✓ Joint APS-DNP-JPS Meeting Oct 7-11, 2014
- ✓ Working Group organizational meeting Nov 16, 2014
- ✓ White papers submitted by end of January
- ✓ Cost review of EIC – Report at April 3 NSAC meeting
- ✓ Most of text of report assembled by April 10
- ✓ Resolution meeting of Long Range Plan working group April 16-20, 2015 in Kitty Hawk, NC
- ✓ Second draft of full report by May 18
- ✓ Draft report reviewed by external wise women and men
- ✓ LRP final report October 2015 – NSAC Meeting and Public Presentation

# FY07 LRP Recommendations are being implemented!

These were made after a period, 2001-2006, of little major construction.

- Complete JLAB 12 GeV - almost complete
- Build FRIB - now well underway
- Targeted program in fundamental symmetries - underway
- Upgrade RHIC - completed at 1/7 the anticipated cost

- Resources for R&D for EIC – steps forward

- Initiatives in theory, gamma-ray tracking and Accelerator R&D - major progress, theory topical collaborations, GRETINA

# Recommendations from the Town Meetings

# These flow into LRP recommendations

Not Priority Ordered Here!

- Run JLAB12
- Run RHIC RHI
- Run RHIC Spin
  and other existing facilities
- Run ATLAS and NSCL
- Participation in LHC

Finish and run FRIB — Recommendation of both low energy and astrophysics meetings

Lead NLDBD → $250M

Build EIC — Recommendation of both hadron and hot qcd meetings → <$1500M

Increase Instrumentation and MIE →

| Requests | |
|---|---|
| JLAB | $75M |
| LE | $116M |
| RHI | $31M |
| ASTRO | $25M |
| OTHER FS&N | $116M |
| TOTAL | $363M |

Increase theory and theory computing

Increase experimental research in Astro, FS&N

# How were recommendations and priorities set?

The recommendations were developed by consensus in the context of illustrative budget scenarios. Having sample budgets to work through was very important. It was understood that hard choices had to be made or the budgets would be completely unrealistic. The only votes were on details of word choice.

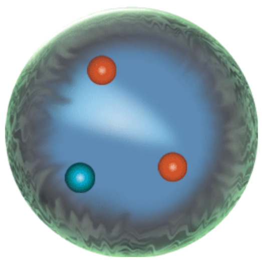
**RECOMMENDATION I**
**The progress achieved under the guidance of the 2007 Long Range Plan has reinforced U.S. world leadership in nuclear science. The highest priority in this 2015 Plan is to capitalize on the investments made.**

- *With the imminent completion of the CEBAF 12-GeV Upgrade, its forefront program of using electrons to unfold the quark and gluon structure of hadrons and nuclei and to probe the Standard Model must be realized.*
- *Expeditiously completing the Facility for Rare Isotope Beams (FRIB) construction is essential. Initiating its scientific program will revolutionize our understanding of nuclei and their role in the cosmos.*
- *The targeted program of fundamental symmetries and neutrino research that opens new doors to physics beyond the Standard Model must be sustained.*
- *The upgraded RHIC facility provides unique capabilities that must be utilized to explore the properties and phases of quark and gluon matter in the high temperatures of the early universe and to explore the spin structure of the proton.*

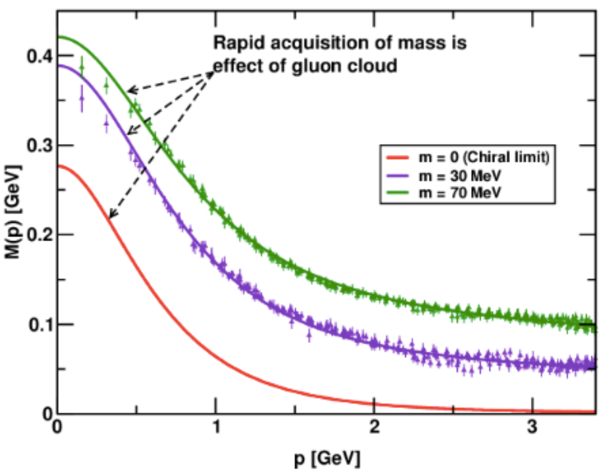
*Realizing world-leading nuclear science also requires robust support of experimental and theoretical research at universities and national laboratories and operating our two low-energy national user facilities —ATLAS and NSCL— each with their unique capabilities and scientific instrumentation.*

The ordering of these four bullets follows the priority ordering of the 2007 plan.

# The CEBAF 12 GeV Era

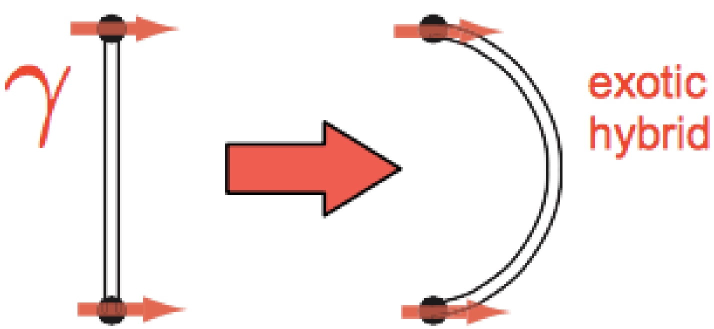


The upgraded CEBAF has the ideal beam properties to learn about the dynamics of the valence quarks that determine the quantum numbers of strongly interacting particles.




We have learned this dynamics is strongly influenced by the mechanism that develops mass in QCD, dynamical chiral symmetry breaking.

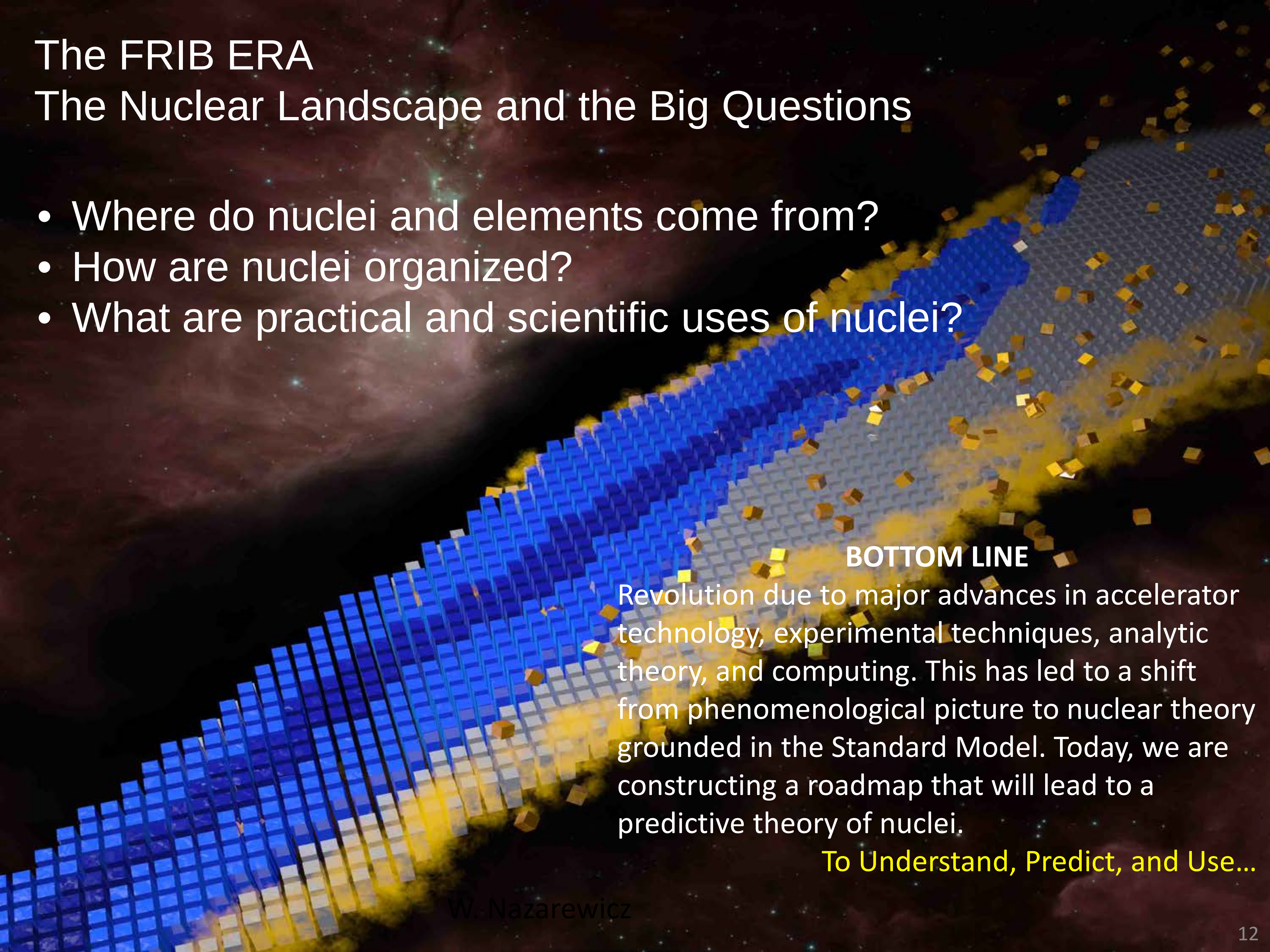
We have a firm theoretical framework to measure the correlations between quark momentum and transverse position, 3D imaging.




We will search for particles where the glue determine the quantum numbers.

# The FRIB ERA
# The Nuclear Landscape and the Big Questions

- Where do nuclei and elements come from?
- How are nuclei organized?
- What are practical and scientific uses of nuclei?



**BOTTOM LINE**

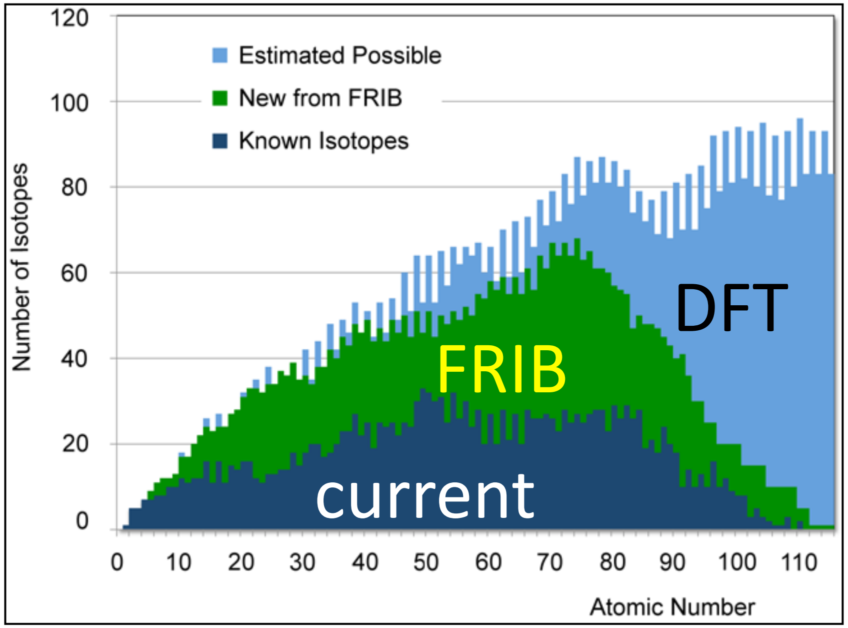
Revolution due to major advances in accelerator technology, experimental techniques, analytic theory, and computing. This has led to a shift from phenomenological picture to nuclear theory grounded in the Standard Model. Today, we are constructing a roadmap that will lead to a predictive theory of nuclei.

To Understand, Predict, and Use…

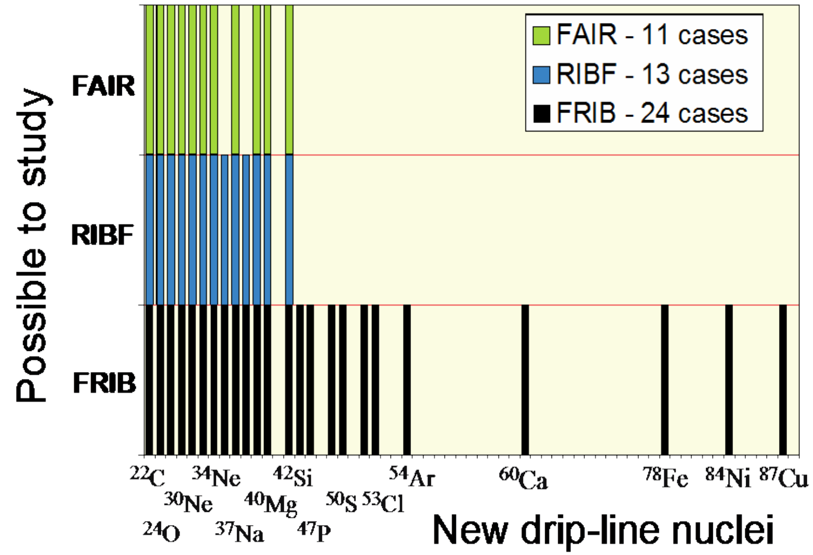
W. Nazarewicz

# What FRIB's power buys you (examples)

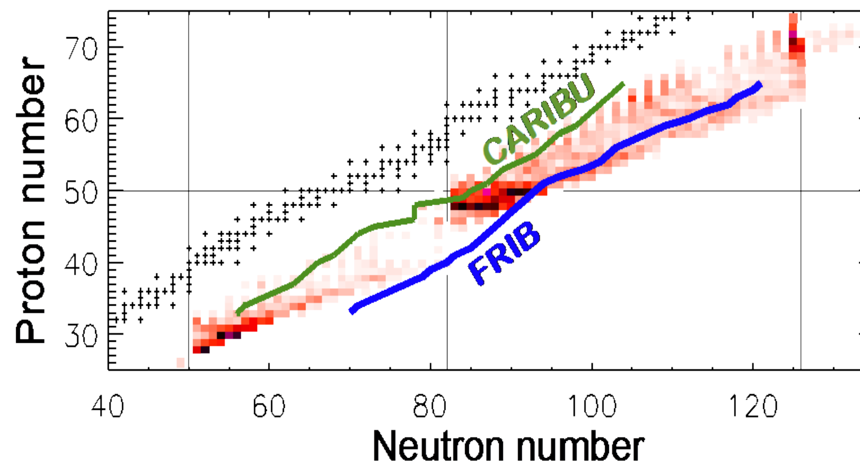
More discovery potential




Access to nuclei with large neutron skins




Reach into the r-process nuclei: masses and detailed spectroscopy of the r-process path nuclei




Access to the *N/Z* dependence and continuum effects broadly. This will allow us to explore new paradigms of nuclear structure in the domain where *many-body correlations*, rather than the *nuclear mean-field*, dominate.

# NSCL / FRIB Laboratory

1400 Users, 418 Staff, 42 Faculty, 82 Graduate and 112 Undergraduate students

as of April 7, 2015

- NSCL is funded by the U.S. National Science Foundation to operate a national user facility for rare isotope research and education. Unique reaccelerated beams, ReA3.
- NSCL will transition to FRIB 2020/2021
- Science of NSCL: Study of atomic nuclei, nuclear astrophysics, fundamental symmetries, accelerator physics, and societal applications of nuclei


National Science Foundation
Michigan State University

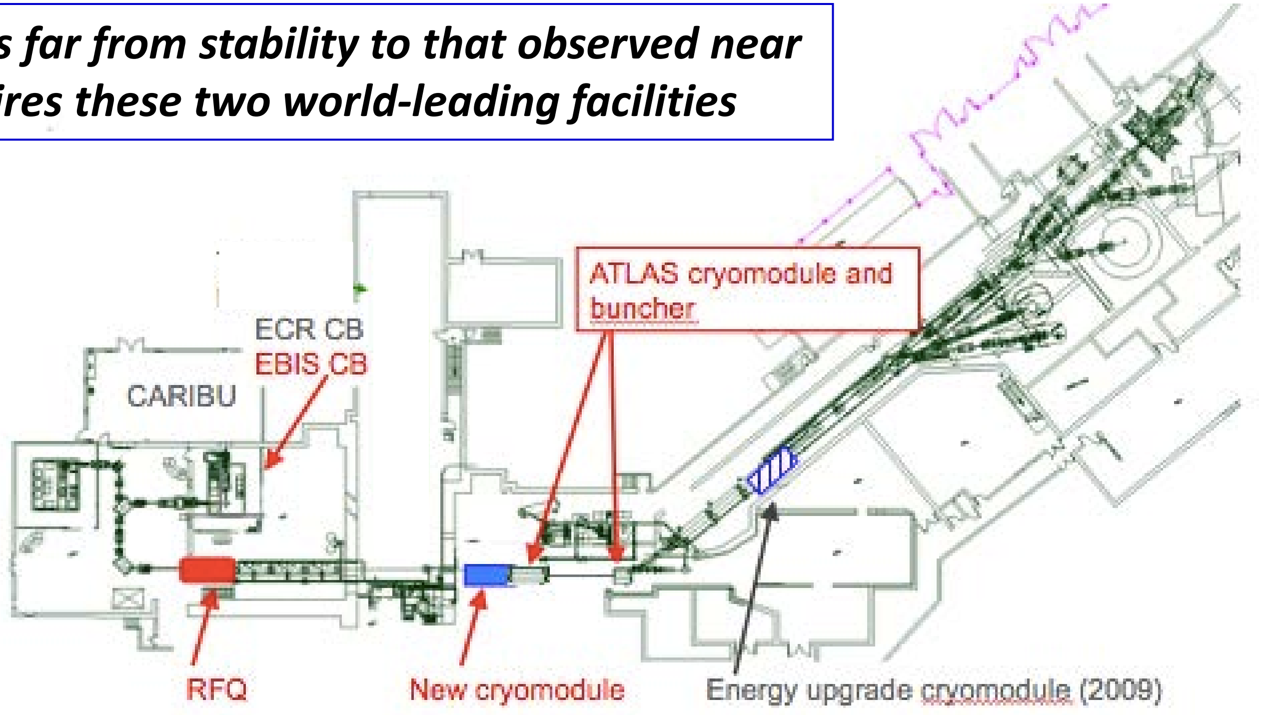
DOE/NSF coordination with FRIB via FRIB Joint Oversight Group

# Roles in 2024

- Two DOE user facilities needed to accommodate the physics goals of the low-energy nuclear physics community in the US, down from four low-energy user facilities in 2001.
  - FRIB: the radioactive beam facility with the furthest reach from stability
  - ATLAS: unique high-intensity stable beam facility for low cross section and high precision experiments closer to stability

***Connecting the physics far from stability to that observed near or at stability requires these two world-leading facilities***

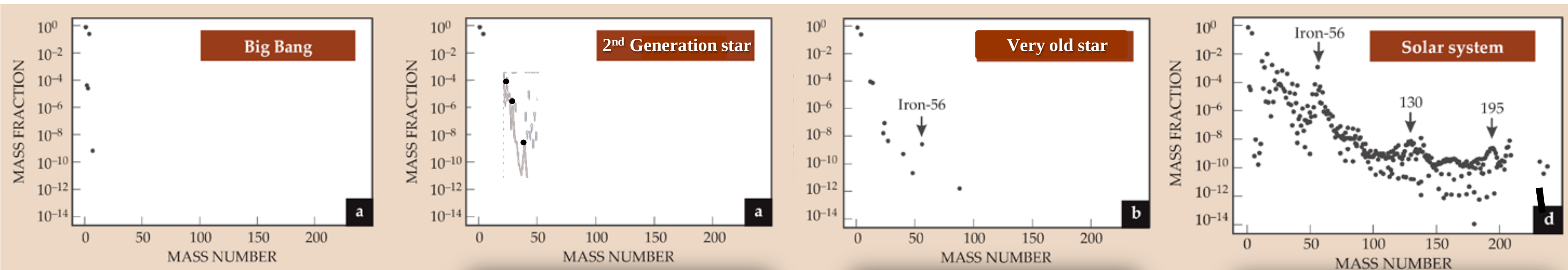
ATLAS

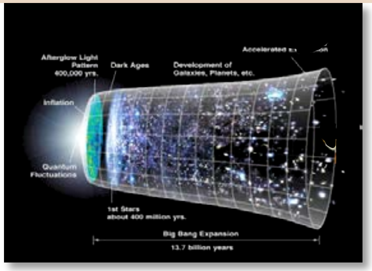


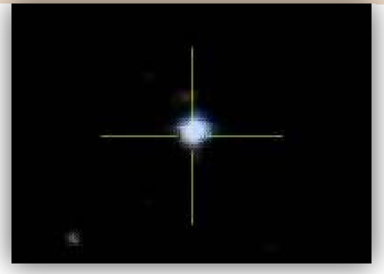
# Nuclear Astrophysics
# Compelling Open Questions

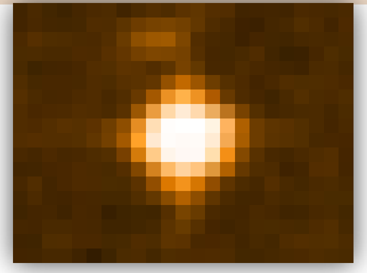
## ➢ What is the origin of the elements?

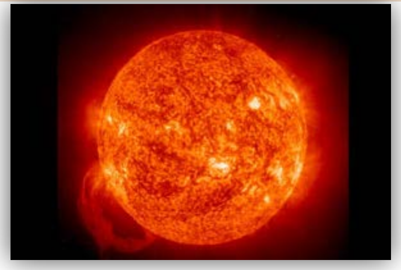
- What nuclear processes contribute to the origin of elements
- How did the chemical composition of the universe evolve?



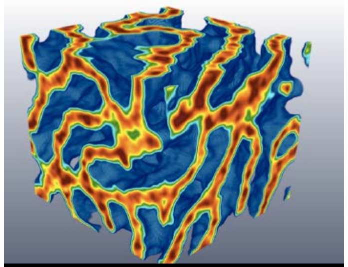
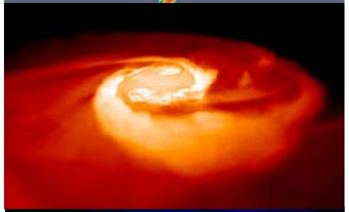







Big Bang – Li Problem – what is primordial abundance?
Early Stars – dynamic nucleosynthesis – how are C and O formed?
Quiescent burning and seed material – what are burning and ignition conditions
r-process, s-process, p-process, i-process and the origin of the heavy materials
Weak interaction and neutrino physics in Big Bang, core collapse, and dense objects

# Compelling Open Questions

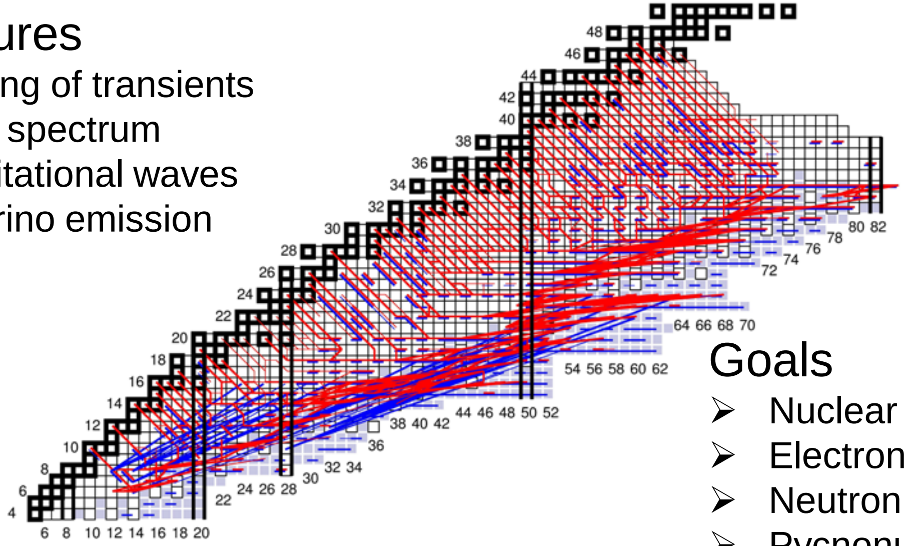





## ➢ What is the nature of dense matter?

- What is the equation of state for neutron star matter
- Transition from nuclei to nuclear pasta
- What is its effect on isolated neutron stars, thermonuclear bursts, superbursts, neutron star mergers, and supernova observables?
- How can we address the question using accreting neutron star observations, Advanced LIGO results and FRIB experiments?

### Signatures

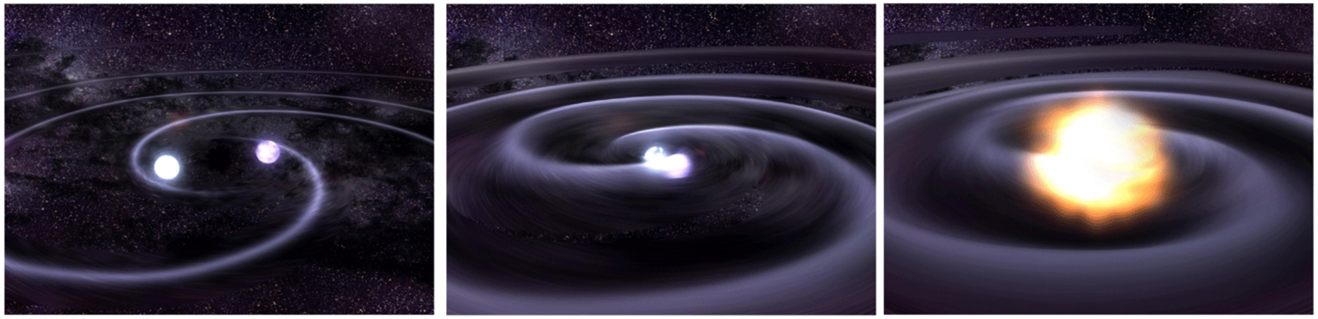
- ➢ Cooling of transients
- ➢ x-ray spectrum
- ➢ Gravitational waves
- ➢ Neutrino emission



### Goals

- ➢ Nuclear reactions far of stability
- ➢ Electron capture and decay processes
- ➢ Neutron capture and photodisintegration
- ➢ Pycnonuclear fusion

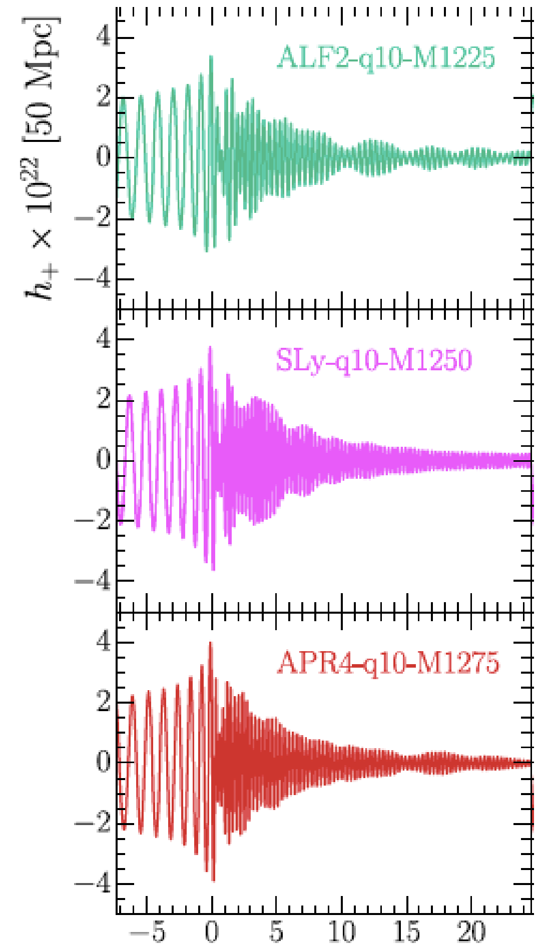
# Nuclear Physics in Gravitational Waves



One of the best signals for the NSF's Advanced LIGO is the merger of two neutron stars

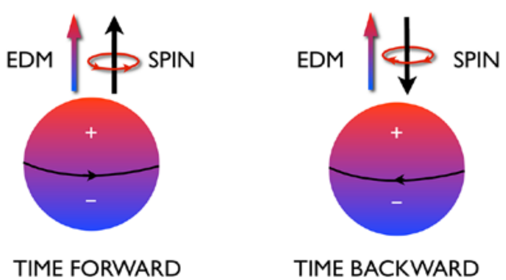
- This will immediately tell us the rate of neutron star mergers. Are there enough to create the heavy elements through the r-process?

- The waveform is sensitive to the nuclear equation of state for neutron stars

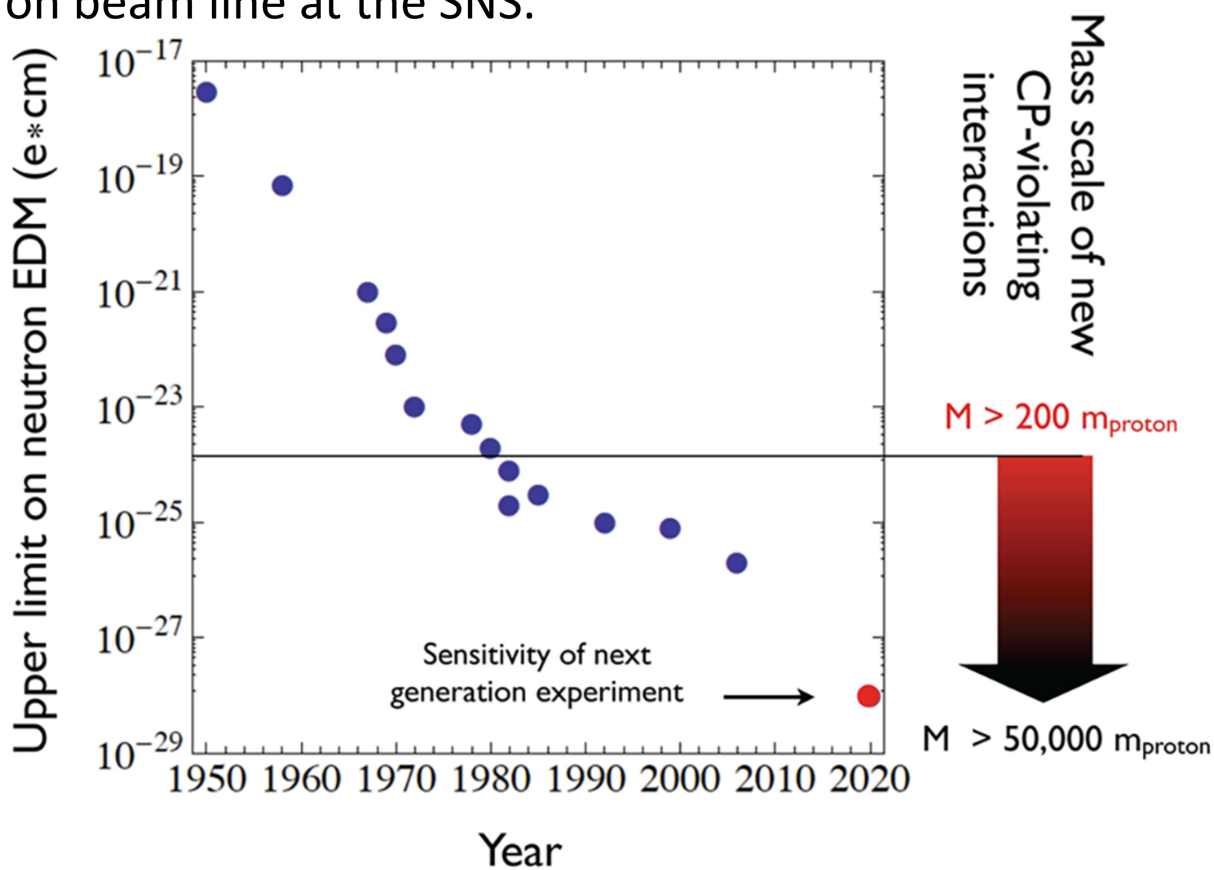


# Fundamental Symmetries - Example
# Search for CP Violation in Electric Dipole Moments

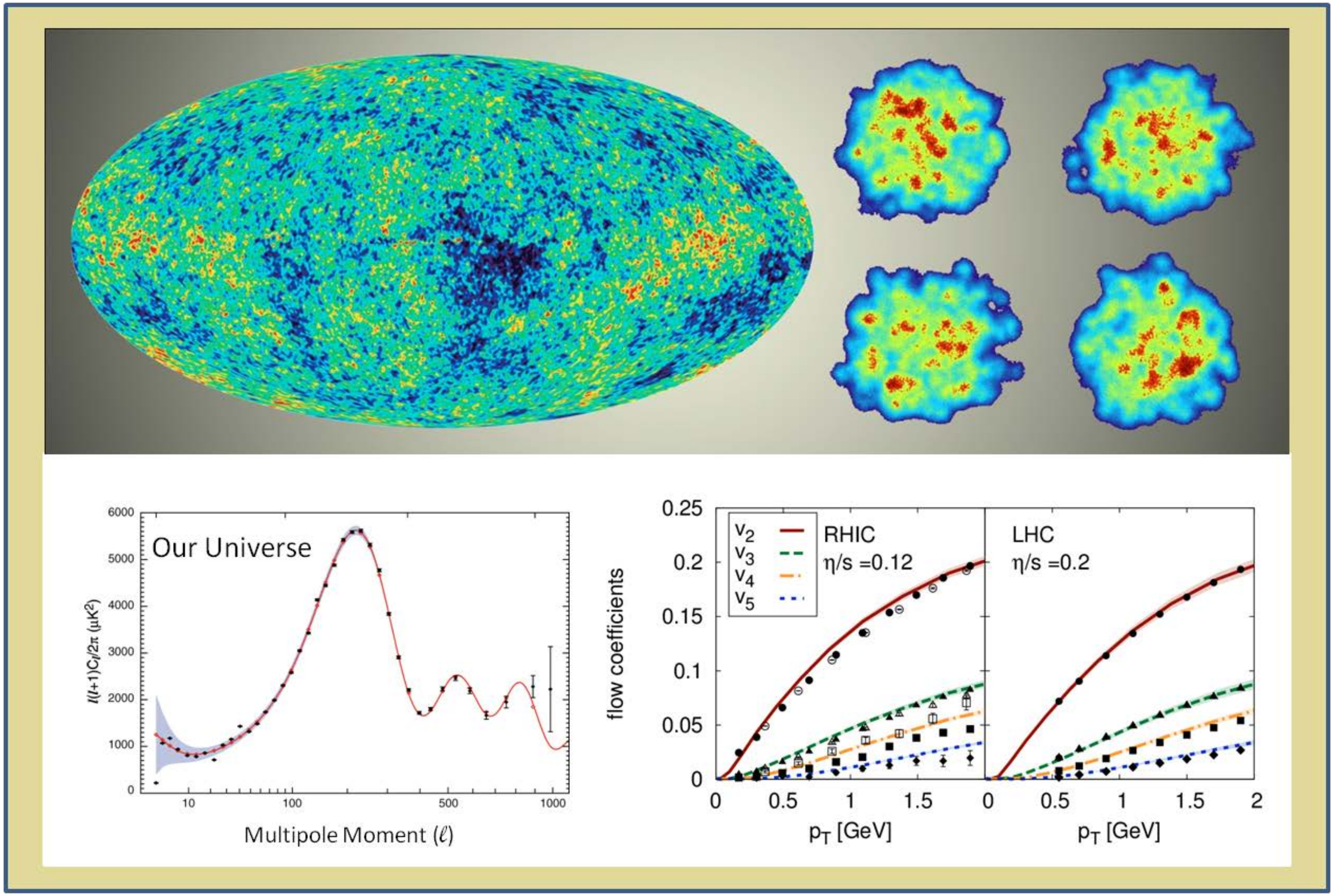
There is a full court press searching for new mechanisms for CP violation to explain the matter/antimatter asymmetry of the universe. A measurement of an electric dipole moment of the neutron is one of the most sensitive of these searches. The U.S. effort is jointly funded by NSF and DOE and will use the fundamental physics neutron beam line at the SNS.




Reversing time reverses the relative direction of the spin and EDM. By the CPT theorem, this is CP violating

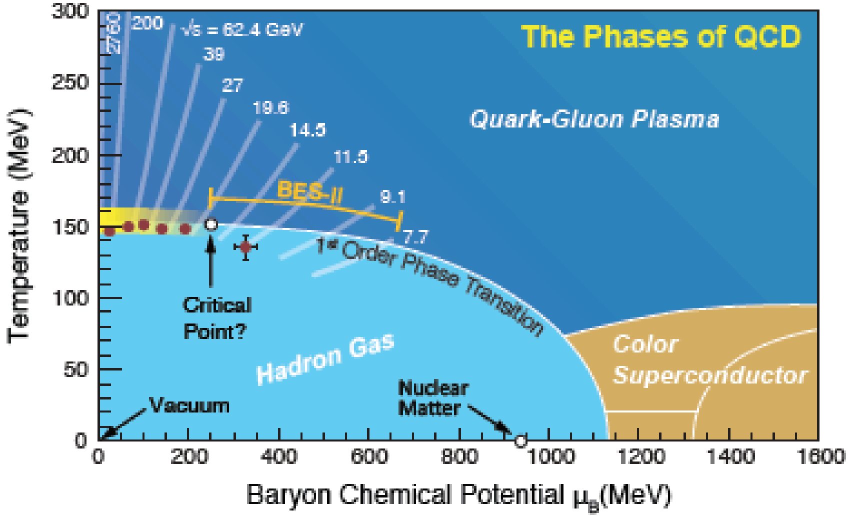


# RHIC and the LHC
# The Big Bang vs Lots of Little Bangs

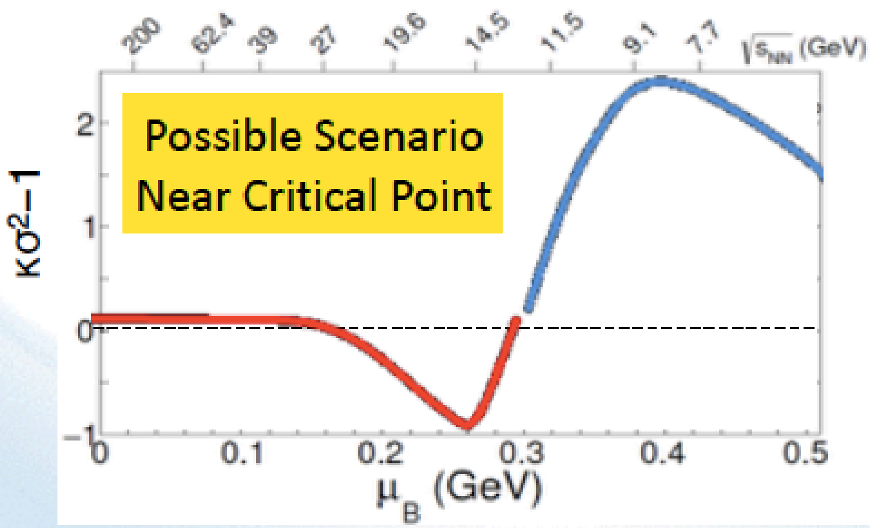


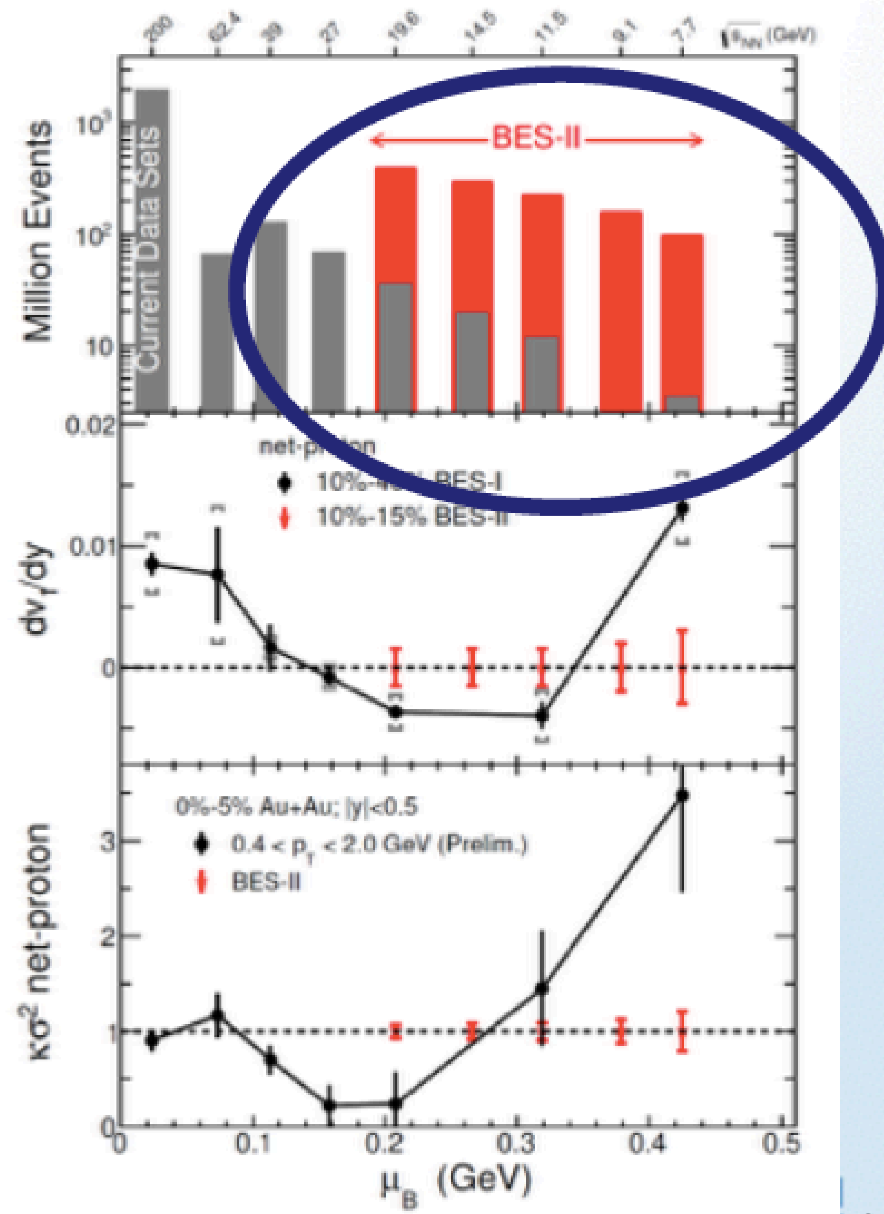

In both cases the measurements at later time reveal the fluctuations in the initial conditions which are remarkably preserved during the expansion.

# Toward critical fluctuations




**Model independent structure of net baryon number kurtosis**



**RECOMMENDATION II**

*The excess of matter over antimatter in the universe is one of the most compelling mysteries in all of science. The observation of neutrinoless double beta decay in nuclei would immediately demonstrate that neutrinos are their own antiparticles and would have profound implications for our understanding of the matter-antimatter mystery.*

**We recommend the timely development and deployment of a U.S.-led ton-scale neutrinoless double beta decay experiment.**

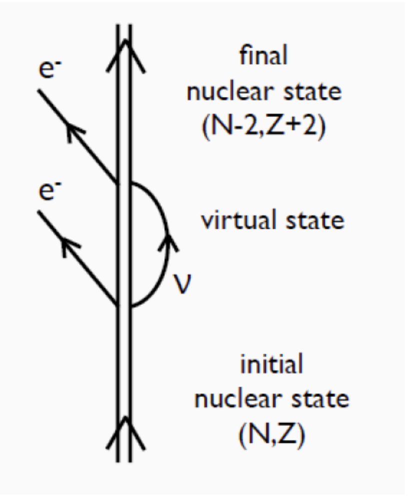
*A ton-scale instrument designed to search for this as-yet unseen nuclear decay will provide the most powerful test of the particle-antiparticle nature of neutrinos ever performed. With recent experimental breakthroughs pioneered by U.S. physicists and the availability of deep underground laboratories, we are poised to make a major discovery.*

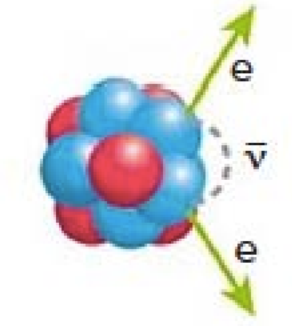
This recommendation flows out of the targeted investments of the third bullet in Recommendation I. It must be part of a broader program that includes U.S. participation in complementary experimental efforts leveraging international investments together with enhanced theoretical efforts to enable full realization of this opportunity.

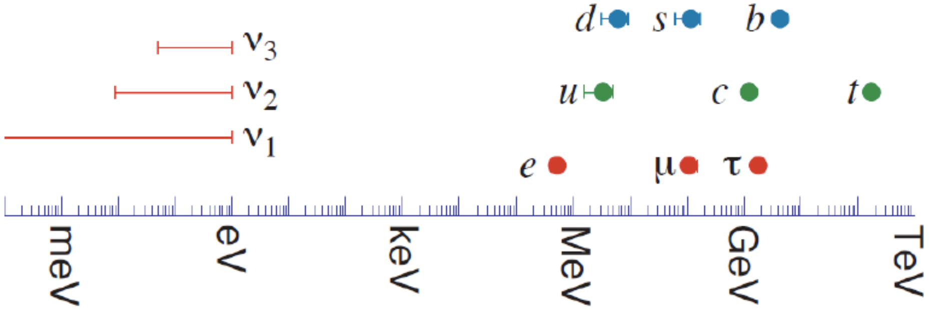
# Neutrinoless Double Beta Decay

Observation of Neutrinoless Double Beta Decay would

- Demonstrate the **lepton number is not conserved**
- Prove that a neutrino is an elementary Majorana particle, that is, **its own antiparticle**.
- Suggest that a **new mechanism for mass generation**, not the Higgs mechanism, is at work.
- Provide evidence for one of the key ingredients that could explain the preponderance of matter over antimatter in the universe, leptogenesis.



# The Nobel Prize in Physics 2015

Photo © Takaaki Kajita

**Takaaki Kajita**

**Prize share:** 1/2

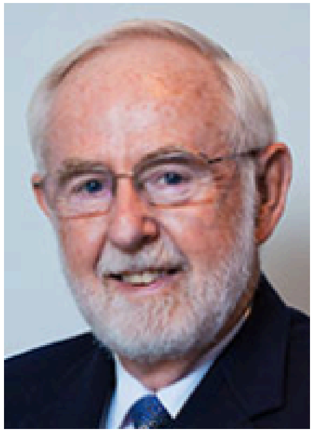


Photo: K. MacFarlane. Queen's University /SNOLAB

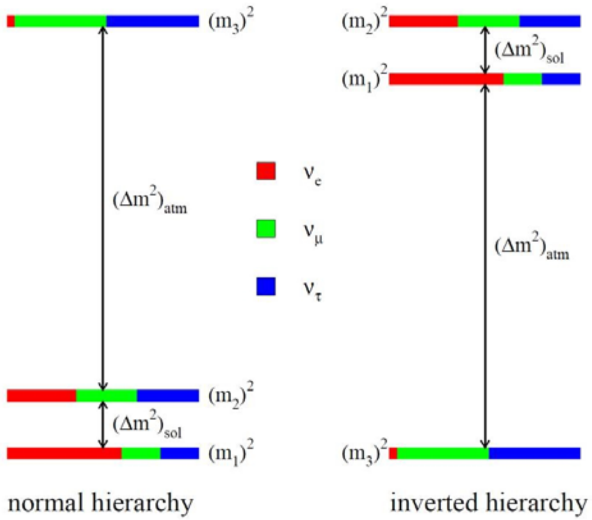
**Arthur B. McDonald**

**Prize share:** 1/2

This work sets a minimum mass for the heaviest of the three neutrinos of 58 meV.

The Nobel Prize in Physics 2015 was awarded jointly to Takaaki Kajita and Arthur B. McDonald *"for the discovery of neutrino oscillations, which shows that neutrinos have mass"*

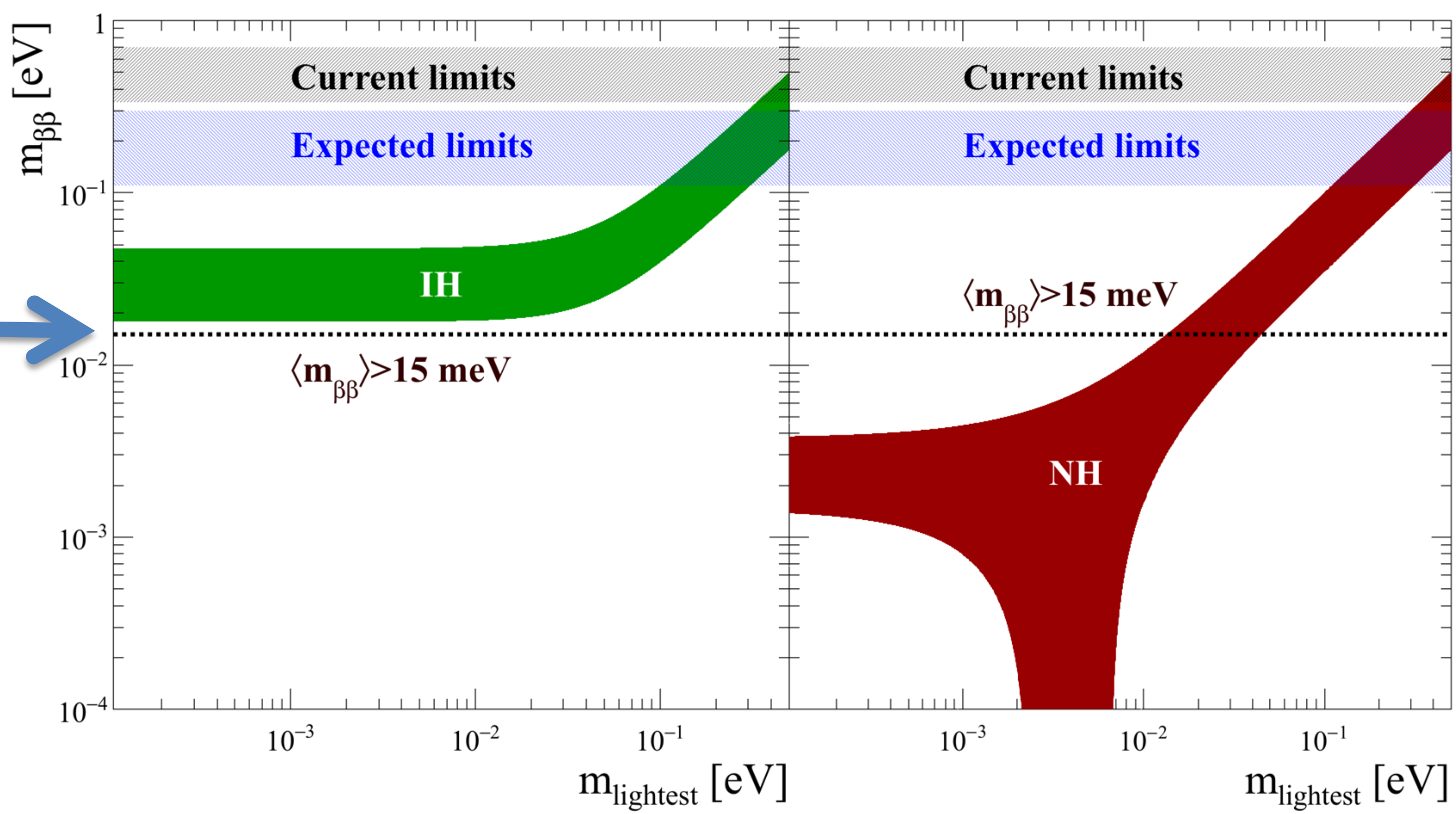
This prize follows the 2002 Nobel prize winning work of Davis and Koshiba for detecting cosmic neutrinos.




In the light neutrino exchange mechanism the decay rate depends directly on a weighted sum of the masses of light neutrinos. With data from neutrino oscillations which only measure mass differences, we know the expected weighted sum, subject to knowing the mass of the lightest neutrino and which hierarchy is realized in nature.

$$|m_{\beta\beta}| = \left| |U_{e1}|^2 m_1 + |U_{e2}|^2 e^{i\alpha_2} m_2 + |U_{e3}|^2 e^{i\alpha_3} m_3 \right.$$

Goal of ton-scale experiments



# Other Information on Neutrino Masses

- Direct measurement in nuclear beta decay: KATRIN aiming for 200 meV
- Long-Baseline Neutrino Oscillations (HEP): NOVA expects 3 sigma determination of hierarchy in three years
  - First data release of T2K and Nova provide 1-2 sigma hints of normal hierarchy
  - In both cases only a few events and requires excellent control of backgrounds
- Cosmology:
  - Current limit: Planck + BAO: < 230 meV implies $m_{\beta\beta}$ < 90 meV
  - CMB-S4 + DESI project < 15 meV (early 2020's)

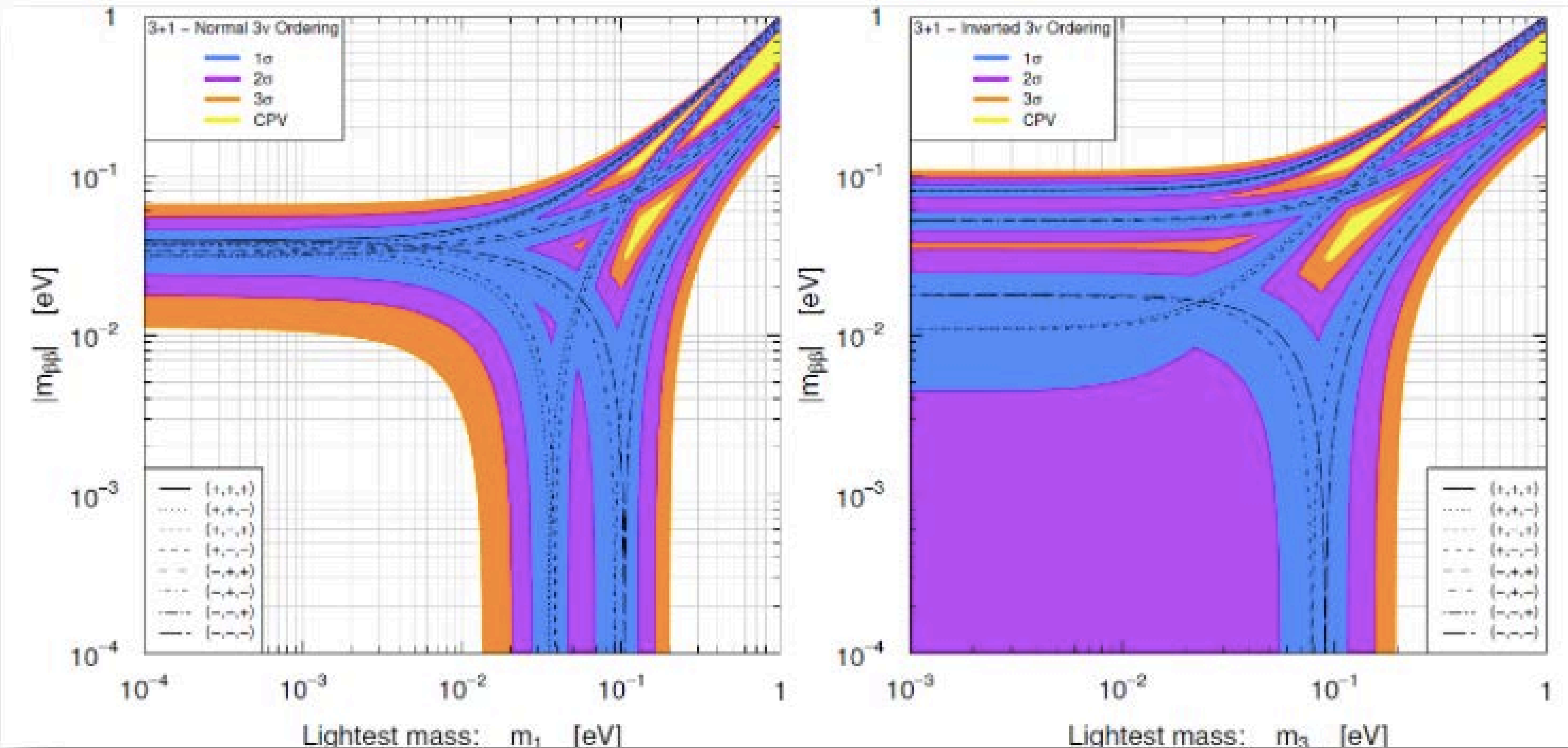
These constraints rely on an underlying set of simplifying model assumptions [scale invariance, flatness, w = -1, etc.]. This introduces a level of theoretical model (systematic) uncertainty. Laboratory complementarity is essential.

- eV sterile neutrinos also can increase the weighted mass sum

We need to have double beta decay results on the same time scale as these complementary results. Tension between them can point to other well motivated neutrinoless double beta decay mechanisms or issues in cosmology.

# Sterile Neutrinos and NLDBD

$$|m_{\beta\beta}| = \left| |U_{e1}|^2 \, m_1 + |U_{e2}|^2 \, e^{i\alpha_2} \, m_2 + |U_{e3}|^2 \, e^{i\alpha_3} \, m_3 + |U_{e4}|^2 \, e^{i\alpha_4} \, m_4 \right|$$




arXiv:1507.08204

# Neutrinoless Double Beta Decay Context

- We are aiming for U.S. leadership of the most promising ton-scale experiment, and expecting significant international and interagency collaboration. For the highest cost options, we only projected about 60% funding from U.S.
- If a positive result is seen, it needs to be confirmed on another isotope and with another technique. We expect secondary U.S. involvement in at least one other international effort would go ahead with a similar time scale.
- Total integrated U.S. budgets for two projects ~ $250M in $FY15
- Ongoing NSAC Subcommittee activities. McKeown talk next.

**RECOMMENDATION III**

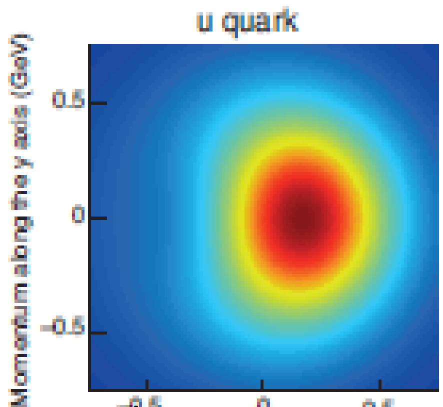
*Gluons, the carriers of the strong force, bind the quarks together inside nucleons and nuclei and generate nearly all of the visible mass in the universe. Despite their importance, fundamental questions remain about the role of gluons in nucleons and nuclei. These questions can only be answered with a powerful new Electron Ion Collider (EIC), providing unprecedented precision and versatility. The realization of this instrument is enabled by recent advances in accelerator technology.*

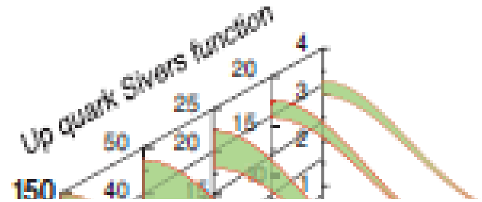
**We recommend a high-energy high-luminosity polarized Electron Ion Collider as the highest priority for new facility construction following the completion of FRIB.**

*The EIC will, for the first time, precisely image gluons in nucleons and nuclei. It will definitively reveal the origin of the nucleon spin and will explore a new Quantum Chromodynamics (QCD) frontier of ultra-dense gluon fields, with the potential to discover a new form of gluon matter predicted to be common to all nuclei. This science will be made possible by the EIC's unique capabilities for collisions of polarized electrons with polarized protons, polarized light ions, and heavy nuclei at high luminosity.*

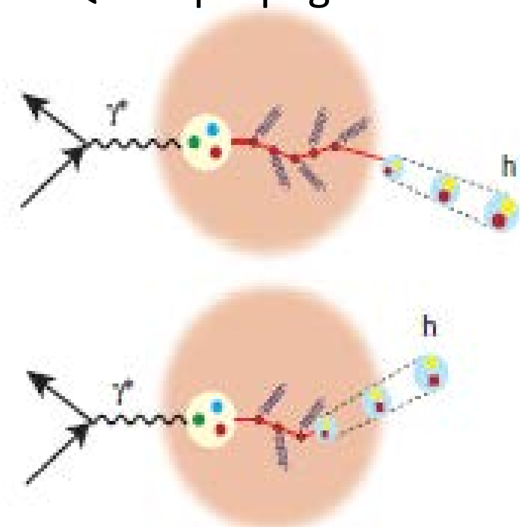
# The Science Questions for the EIC as laid out by the community

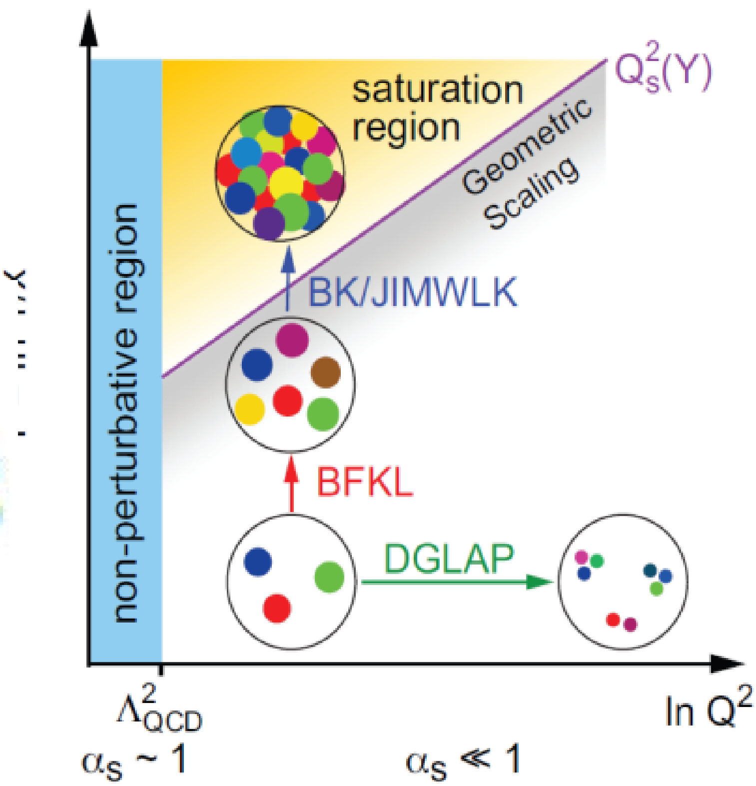
- **How are the sea and momentum** distributions cor direction? **What in building the n**
- **Where does the** boundary that se matter? If so, ho crosses the bour properties in the light?
- **How does the n gluons and their** distribution of gl matter respond response differe




Quark propagation



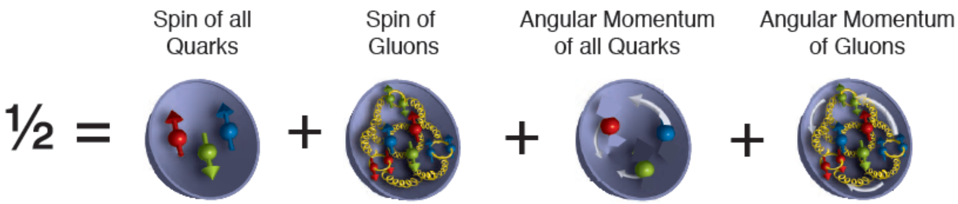
# Wasn't this already done at HERA?

- ✓ EIC would have 1000 times higher luminosity
  - Critical for 3D tomography of gluons and sea quarks
- ✓ EIC would have polarized proton and light nuclei beams
  - Critical to understand gluon contribution to spin of the proton
- ✓ EIC would have heavy nuclear beams.
  - Large boost in gluon density to see saturation and coherent effects like the colored glass condensate.

- HERA did have 2.5 times the energy

$$x_{ep}(Q_s^2) = \frac{x_{eA}(Q_s^2)}{(\frac{4}{3}A^{1/3})^{1/\delta}}$$

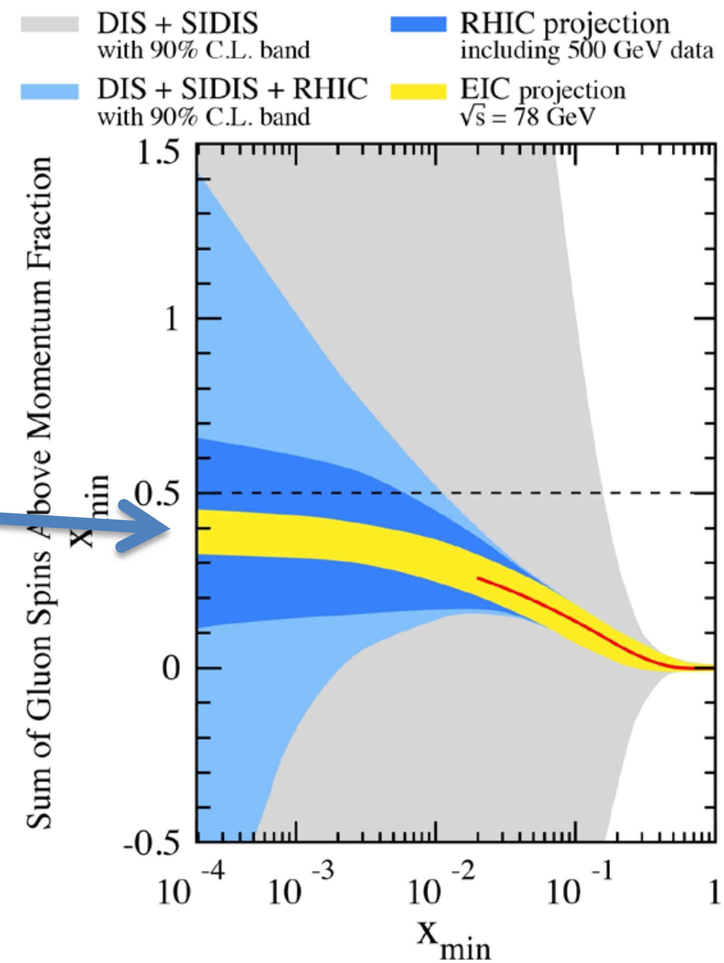
# Why isn’t the Spin Settled by JLAB and RHIC?




Done CEBAF EIC

Valuable Information from RHIC

Requires EIC to fully answer



**RECOMMENDATION IV**
**We recommend increasing investment in small-scale and mid-scale projects and initiatives that enable forefront research at universities and laboratories.**

*Innovative research and initiatives in instrumentation, computation, and theory play a major role in U.S. leadership in nuclear science and are crucial to capitalize on recent investments. The NSF competitive instrumentation funding mechanisms, such as the Major Research Instrumentation (MRI) program and the Mathematical & Physical Sciences mid-scale research initiative, are essential to enable university researchers to respond nimbly to opportunities for scientific discovery. Similarly, DOE-supported research and development (R&D) and Major Items of Equipment (MIE) at universities and national laboratories are vital to maximize the potential for discovery as opportunities emerge.*

Similar to the P5 recommendation

# The Role of the NSAC Long Range Plan in Projects

NSAC is asked to identify scientific opportunities and a level of resources necessary to achieve these. The recommendations express priorities. But, except for the largest-scale facilities, projects named in this report are given as examples to carry out the science. The funding agencies have well-established procedures to evaluate the scientific value and the cost and technical effectiveness of individual projects. There is a long-standing basis of trust that if NSAC identifies the opportunities, the agencies will do their best to address these, even under the constraints of budget challenges.

In this way our charge is different than that of the HEP Particle Physics Prioritization Panel which considers individual projects.

**A: Theory Initiative**

Advances in theory underpin the goal that we truly understand how nuclei and strongly interacting matter in all its forms behave and can predict their behavior in new settings.

*To meet the challenges and realize the full scientific potential of current and future experiments, we require new investments in theoretical and computational nuclear physics.*

- *We recommend new investments in computational nuclear theory that exploit the U.S. leadership in high-performance computing. These investments include a timely enhancement of the nuclear physics contribution to the Scientific Discovery through Advanced Computing program and complementary efforts as well as the deployment of the necessary capacity computing.*
- *We recommend the establishment of a national FRIB theory alliance. This alliance will enhance the field through the national FRIB theory fellow program and tenure-track bridge positions at universities and national laboratories across the U.S.*
- *We recommend the expansion of the successful Topical Collaborations initiative to a steady-state level of five Topical Collaborations, each selected by a competitive peer-review process.*

**B: Initiative for Detector and Accelerator Research and Development**

*U.S. leadership in nuclear physics requires tools and techniques that are state-of-the-art or beyond. Targeted detector and accelerator R&D for the search for neutrinoless double beta decay and for the Electron Ion Collider is critical to ensure that these exciting scientific opportunities can be fully realized.*

- *We recommend vigorous detector and accelerator R&D in support of the neutrinoless double beta decay program and the Electron Ion Collider.*

**Workforce, Education, and Outreach**

A workforce trained in cutting-edge nuclear science is a vital resource for the Nation.

*Our Nation needs a highly trained workforce in nuclear science to pursue research, develop technology, and ensure national security. Meeting this need relies critically on recruiting and educating early career scientists.*

*We recommend that the NSF and DOE take the following steps.*

- *Enhance programs, such as the NSF-supported Research Experience for Undergraduates (REU) program, the DOE-supported Science Undergraduate Laboratory Internships (SULI), and the DOE-supported Summer School in Nuclear and Radiochemistry, that introduce undergraduate students to career opportunities in nuclear science.*
- *Support educational initiatives and advanced summer schools, such as the National Nuclear Physics Summer School, designed to enhance graduate student and postdoctoral instruction.*
- *Support the creation of a prestigious fellowship program designed to enhance the visibility of outstanding postdoctoral researchers across the field of nuclear science.*

# We rely on off-shore facilities

- Higher energy relativistic heavy ions – LHC
- Multi-GeV energy hadron beams – J-PARC, FAIR, CERN
- Higher energy radioactive beams – RIBF, GSI, FAIR
- ISOL radioactive beams – TRIUMF, ISOLDE
- To a large part, neutrons and neutrinos from reactors
- Lower energy electron beams – Mainz
- High resolution transfer reactions with stable beams - RCNP

In some cases, U.S. scientists are users of these facilities. In others, we count on experiments at these facilities to provide complementary information.

# Budgets

It is well recognized that resources are always limited, and hard choices have been made concerning parts of the program that could not go forward in a realistic budget scenario. For example, the 2013 NSAC report *Implementing the 2007 Long Range Plan* responded to a more constrained budget picture than was originally expected. The resulting focused plan has been widely supported by the community, the Administration and the Congress. This 2015 Long Range Plan also involves hard choices to go forward with constrained budget scenarios.

# Project Sequencing

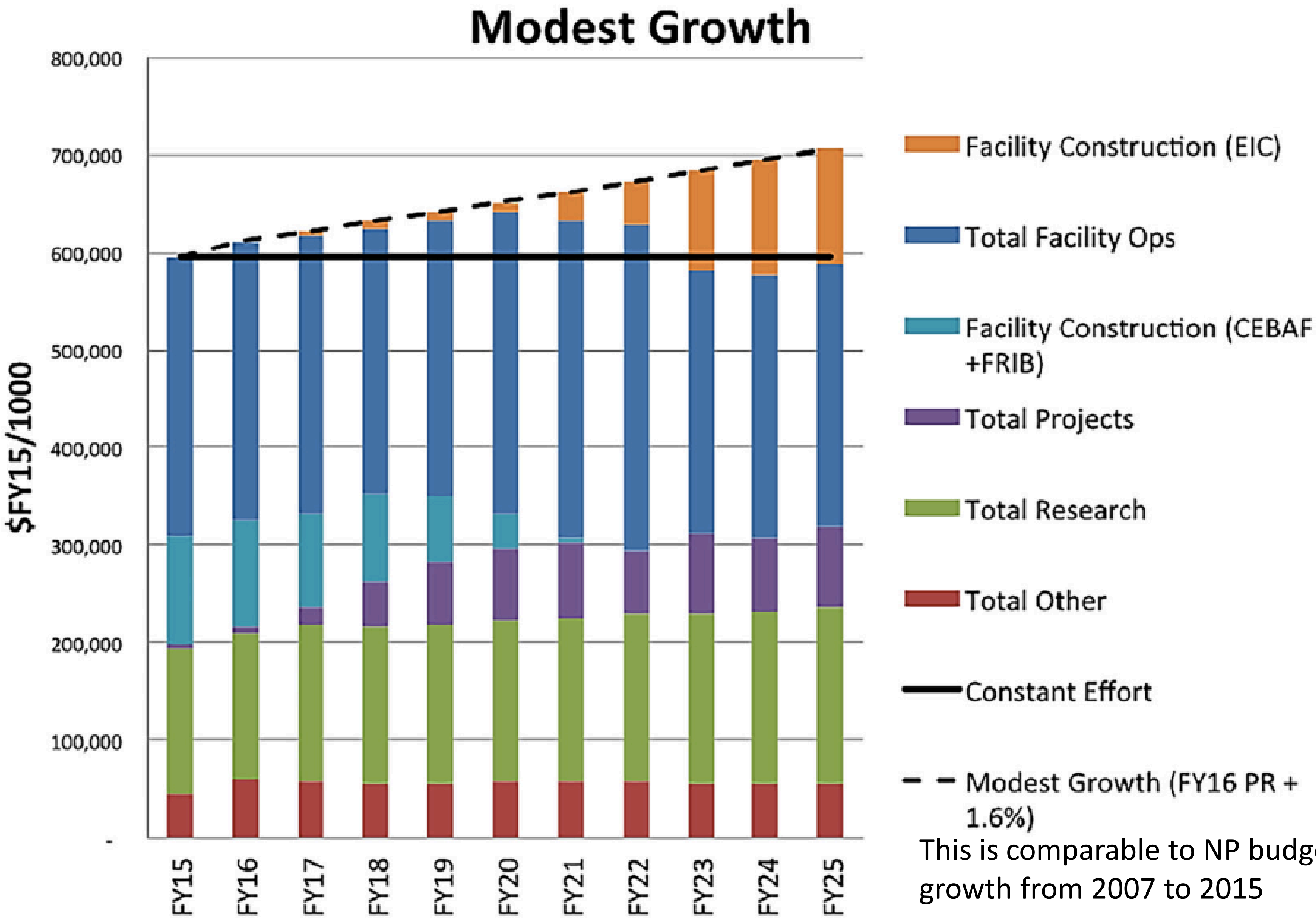
- FY15-18 as in 2013 Implementation Plan and consistent with the FY16 President's budget request
- Ton-scale neutrinoless double beta decay starts near end of the decade after FRIB peak.
  - Need for demonstration projects to show what they can do and need for more R&D
  - A standing NSAC subcommittee is providing advice.
- EIC construction after completion of FRIB construction.
  - Time scale set, in part, by exciting physics at current facilities, by R&D required, and, in part, to avoid the need for large sudden budget increase.
  - Significant redirection from existing facilities when construction begins

# Other Budget Priorities

- Increased small-scale and mid-scale projects including theory computing. This was temporarily sacrificed in 2013 implementation plan to start construction program.

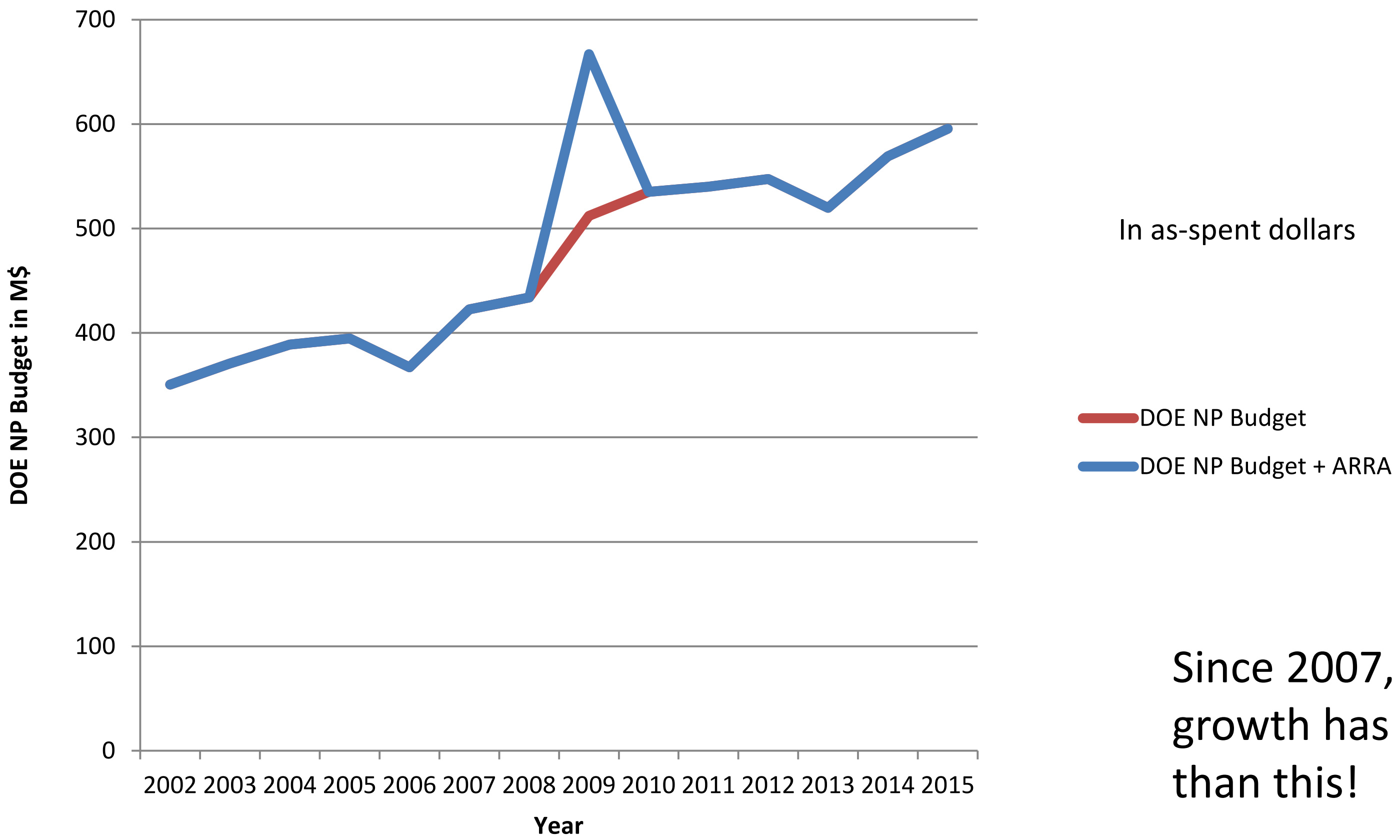
- Increased research funding. It has fallen over the past few years to less than 30% of total in 2015 in DOE-NP.

# DOE Budget Projections




This is comparable to NP budget growth from 2007 to 2015

# Is This Realistic?
# DOE NP Budget history Since the 2007 LRP




Since 2007, the real growth has been larger than this!

# NSF Nuclear Physics Budget

- FRIB begins operation at the mid-point of this LRP and NSCL transitions from NSF stewardship. Before the transition , NSCL will remain the premier national user facility for rare isotope research in the U.S., with unique rare isotope reacceleration capabilities following fast beam fragmentation.

- We project increasing mid-scale funding at NSF and believe NP can compete well across the Physics Division for new initiatives. This is essential to ensure NSF-supported scientists have the resources to lead significant initiatives. We did not specifically associate any one initiative with NSF except as significant partners/leaders in neutrinoless double beta decay and neutron EDM where they already play important roles.

- We project a total NSF nuclear physics funding increasing slightly each year in line with the modest growth scenario.

# Impacts of Constant Effort Budget

Under a budget that represents constant effort at the level of the appropriated FY 2015 budget, the decisions become more difficult. Promising opportunities will be lost. The technology choices for some of the major projects may become driven more by cost rather than by optimizing the science reach. This could affect the international competitiveness of the ton-scale neutrinoless double beta decay experiment. While the FRIB facility operations can be maintained, completion of experimental equipment needed to fully utilize FRIB beams would be stretched out in time. There would be less scope to follow up new discoveries at FRIB, CEBAF, and RHIC. The EIC must begin more slowly. U.S. leadership would be maintained in some areas but would be given up in others.

The most difficult choices would occur at or beyond the mid-point of time window of this LRP.

Nonetheless, a constant effort budget can fund a sustainable program for nuclear science, one of the elements of the charge.

# Summary

- We have an exciting science program
- There are broader impacts to technology and medicine as well as other sciences such as astrophysics, HEP, material science and chemistry.
- New powerful world leading tools are coming on-line and being constructed
- We see two important major initiatives for the future.
- The recommendations were developed by consensus. There was unanimous agreement among the working group for the recommendations and the report. The community will unite to support this vision of the future.
- This is a sustainable world-leading nuclear science program.
- We recognize that physics goals are not diagonalized with agency funding categories. We expect HEP scientists to have an important interest and role in topics like NLDBD, RHI and EIC physics.