NSAC Subcommittee Interim Report

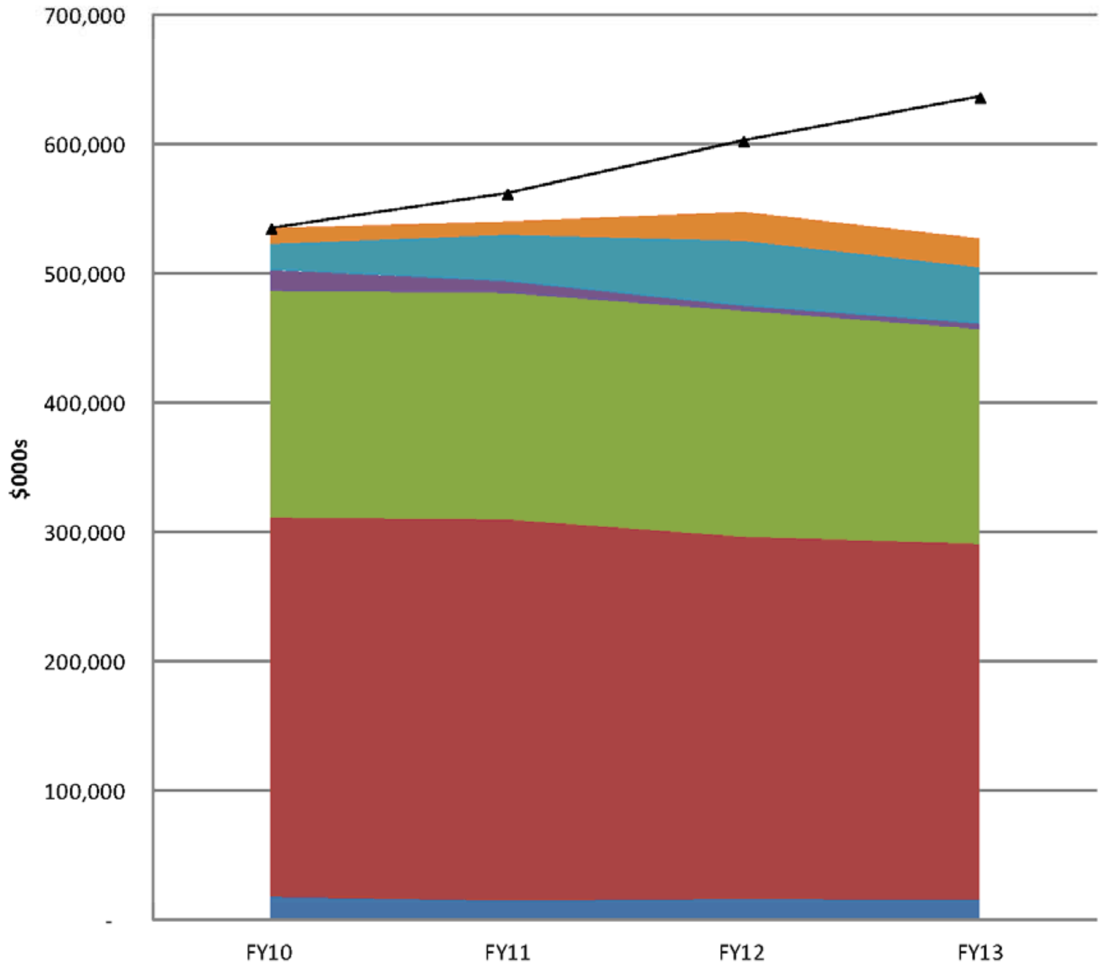
Robert E. Tribble

Texas A&M University

September 21, 2012

The Budget Problem

Office of Nuclear Physics FY 2013 Congressional Request



This chart reflects the enacted FY 2010-FY 2012 appropriations and the FY 2013 Congressional Request for the Nuclear Physics program.

The black line represents estimated funding needed to implement the majority of elements of the NSAC 2007 Long Range Plan (LRP).

Charge to NSAC from DOE and NSF

U.S. Department of Energy
and the
National Science Foundation

April 5, 2012

Dr. Donald Geesaman
Chair
DOE/NSF Nuclear Science Advisory Committee
Argonne National Laboratory
9800 South Cass Avenue,
Argonne, Illinois 60439

Dear Dr. Geesaman:

In 2007 the Department of Energy (DOE)/National Science Foundation (NSF) Nuclear Science Advisory Committee (NSAC) completed work on a Long Range Plan for nuclear science for the decade. This plan provided a roadmap for the development of new and existing facilities to maintain U.S. leadership in nuclear science, including completion of the 12 GeV CEBAF Upgrade at Jefferson Lab, and construction of the Facility for Rare Isotope Beams (FRIB). The plan also recommended a targeted program of experiments on fundamental symmetries and a luminosity upgrade to determine the properties of a new state of matter discovered at the Relativistic Heavy Ion Collider. The NSAC identified the need to maintain funding above the FY 2007 constant-effort level to effectively utilize the nuclear science program's facilities, mount strong university and theory programs, and develop new research capabilities.

DOE and NSF are making significant progress toward achieving the vision of the 2007 Long Range Plan for Nuclear Science. However, DOE and NSF now seek your advice to continue the vision in the Plan so that the recommendations can move forward in light of projected constrained budgets.

We seek advice from NSAC on implementing the priorities and recommendations of the 2007 Long Range Plan in light of projected budgetary constraints and for guidance on developing a plan to implement the highest priority science in the context of likely available funding and world-wide capabilities. We request that NSAC examine the existing research capabilities and scientific efforts, assess their role and potential for scientific advancements, and advise the two agencies regarding the time and resources needed to achieve the planned programs. Your report should describe how to optimize the overall nuclear science program over the next five years (FY 2014-2018), under at least the following funding scenarios for the nuclear science budgets at the two agencies: (1) flat funding at the FY 2013 request level, and (2) modest increases over the next five years.

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Charge to NSAC from DOE and NSF

Based on the priorities and opportunities identified and recommended in the 2007 Long Range Plan, the report should discuss what scientific opportunities will be addressed, and what existing and future facilities and instrumentation capabilities would be needed by the Federal nuclear science program to mount a productive, forefront program for each of the funding scenarios.

NSAC should submit the report by January 2013. We are aware that this is a difficult task. However, the involvement and input of the research community is essential to inform the Department's decisions regarding the strategy for implementing a world-leading U.S. Nuclear Physics program in times of fiscal constraint.

Sincerely,

W. F. Brinkman
Director
Office of Science

Edward Seidel
Assistant Director
Directorate for Mathematical
and Physical Sciences

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Charge from NSAC to the subcommittee

Donald F. Geesaman
Distinguished Argonne Fellow
1-630-252-4059 phone
1-630-252-3903 fax
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Argonne National Laboratory
9700 South Cass Avenue, Bldg. 203
Argonne, IL 60439-4845

Argonne NATIONAL LABORATORY

May 1, 2012

Prof. Robert Tribble
Cyclotron Institute
Department of Physics and Astronomy
4242 Texas A & M University
College Station, TX 77843-4242

Dear Bob,

As you know William Brinkman, Director of the Office of Science at DOE, and Edward Seidel, Associate Director for the Directorate of Mathematical and Physical Sciences at the NSF, have charged NSAC to provide advice on implementing the priorities and recommendations of the 2007 NSAC Long Range Plan in light of projected budgetary constraints and for guidance on developing a plan to implement the highest priority science in the context of likely available funding and world-wide capabilities.

The charge, of which you have a copy, asks that the report should describe how to optimize the overall nuclear science program over the next five years (FY2014-2018) under at least two budget scenarios: (1) flat funding at the FY2013 request level and (2) modest increases over the next five years.

I am writing to formally ask you to serve as the Chair of an NSAC subcommittee to consider this charge and report back to NSAC. The work of this subcommittee is of utmost importance for the future of nuclear science, both for the U.S. and the international science community. Based on the priorities and opportunities identified and recommended in the 2007 Long Range Plan, the report should discuss what scientific opportunities will be addressed and what existing and future facilities and instrumentation capabilities would be needed to mount a productive forefront program for each of the funding scenarios. It should also present what opportunities would be lost in each scenario. These opportunities should include the impact on education and training of the workforce in nuclear science.

The time scale of the charge requires NSAC to submit its report by January 2013. Therefore I must ask your subcommittee to submit its report to NSAC by 7 January 2013. I realize this is a heavy responsibility. I and our whole community will, once more, owe you an enormous debt of gratitude.

Sincerely yours,

Donald F. Geesaman

Subcommittee Membership

Joseph Carlson – LANL
Brad Filippone – Caltech
Stuart Freedman – UCB & LBL
Haiyan Gao – Duke
Donald Geesaman – ANL (ex officio)
Barbara Jacek - SUNYSB
Peter Jacobs - LBL
David Kaplan – UW and INT
Kirby Kemper – FSU
Krishna Kumar – U Mass
Naomi Makins – UI

Curtis Meyer - CMU
James Nagle - CU
Witold Nazarewicz – UT & ORNL
Krishna Rajagopol – MIT
Michael Ramsey-Musolf – U Wisc
Lee Sobotka – Wash U
Robert Tribble (chair) – TAMU
Michael Wiescher – ND
John Wilkerson – UNC
Adam Burrows – Princeton
George Crabtree – ANL

[Posted on subcommittee website: http://cyclotron.tamu.edu/nsac-subcommittee-2012/]

TEXAS A&M UNIVERSITY

Subcommittee May Meeting

May 15, 2012

Meeting schedule:

08:00 – 0:830 – Welcome and introductions – Don G., Robert T. and subcommittee members

08:30 – 0:915 – Mission, Vision, and Research – T. Hallman

09:15 – 10:05 – Facilities and Initiative – J. Gillo

10:05 am – 10:30 – Break

10:30 am – 11:15 – NSF Program and Budget – B. Keister

11:15 – 15:00 – Subcommittee Discussion

Outcomes: (1) outlined program for second meeting
(2) created questions to guide presentations
(3) discussed report structure
(4) after discussion, added way to post comments on website (http://cyclotron.tamu.edu/nsac-subcommittee-2012/)

TEXAS A&M UNIVERSITY

Subcommittee September Meeting

- Meeting agenda was set to minimize conflicts of presenters with other obligations and to provide some coherence to presentations
- Treated as ‘fact finding’ meeting for subcommittee
- A lot of excellent questions asked – created problems for the schedule and led to adjustments
- Saw ***many*** excellent examples of science accomplishments since 2007 LRP, which I will skip
- Will focus on a forward look and big issues today

Subcommittee September Meeting

Friday, September 7

<u>RHI</u>

08:00 – 08:45 – W. Zajc, RHI Overview

08:45 – 09:00 – S. Aronson, BNL Strategy

09:00 – 09:45 – S. Vigdor, RHIC Plans

09:45 – 10:15 – U. Wiedemann, Theoretical Issues and LHC Perspective

10:15 – 10:30 – Cof[illegible]reak

10:30 – 11:00 – P. Sorenson, Soft Probes

11:00 – 11:30 – Y. Akib[illegible]ard Probes

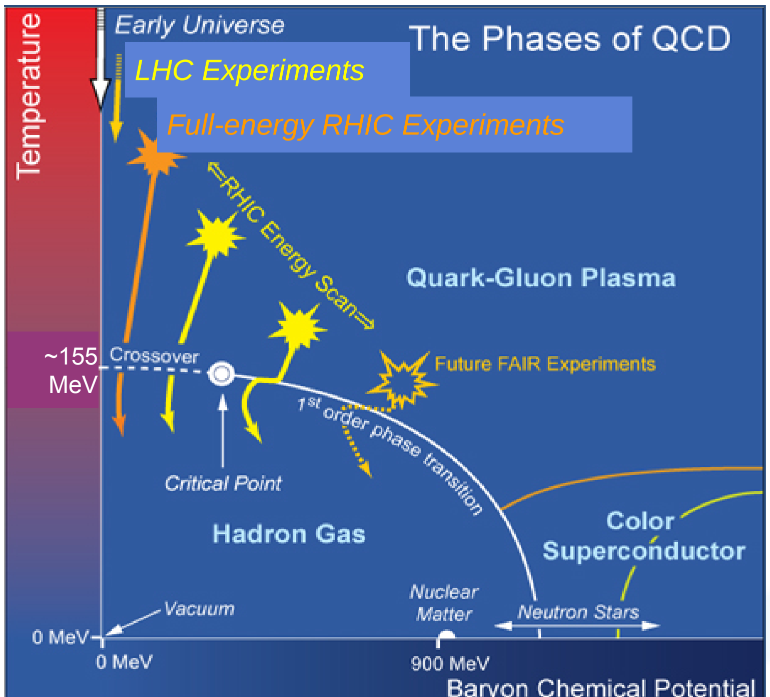
11:30 – 11:45 – S. Vigdor, Wrap Up

11:45 – 12:30 – Executive Session with RHIC management

Broad Science Goals for the Next Decade

Quantify properties of the QGP and features of the QCD phase diagram, as functions of temperature and net quark density from the onset of deconfinement toward even earlier universe conditions.

Exploit new discovery potential in searches for a QCD critical point and for the nature and influence of quantum fluctuations in initial densities and the excited QCD vacuum (sphalerons).



Search for a QCD Critical endpoint via low-energy scan in RHIC-II era

Continue explorations of the role of soft gluons in cold nuclear matter (gluon saturation, contributions to proton spin).

RHIC and LHC are complementary. Both are needed to explore the temperature-dependence of QGP properties (span factor ~1000 in √s). RHIC has unique reach to search for the QGP onset, unique ion species versatility and unique polarized proton capability, until EIC is realized. And QCD matter is RHIC's primary focus.

Questions For the Next Decade

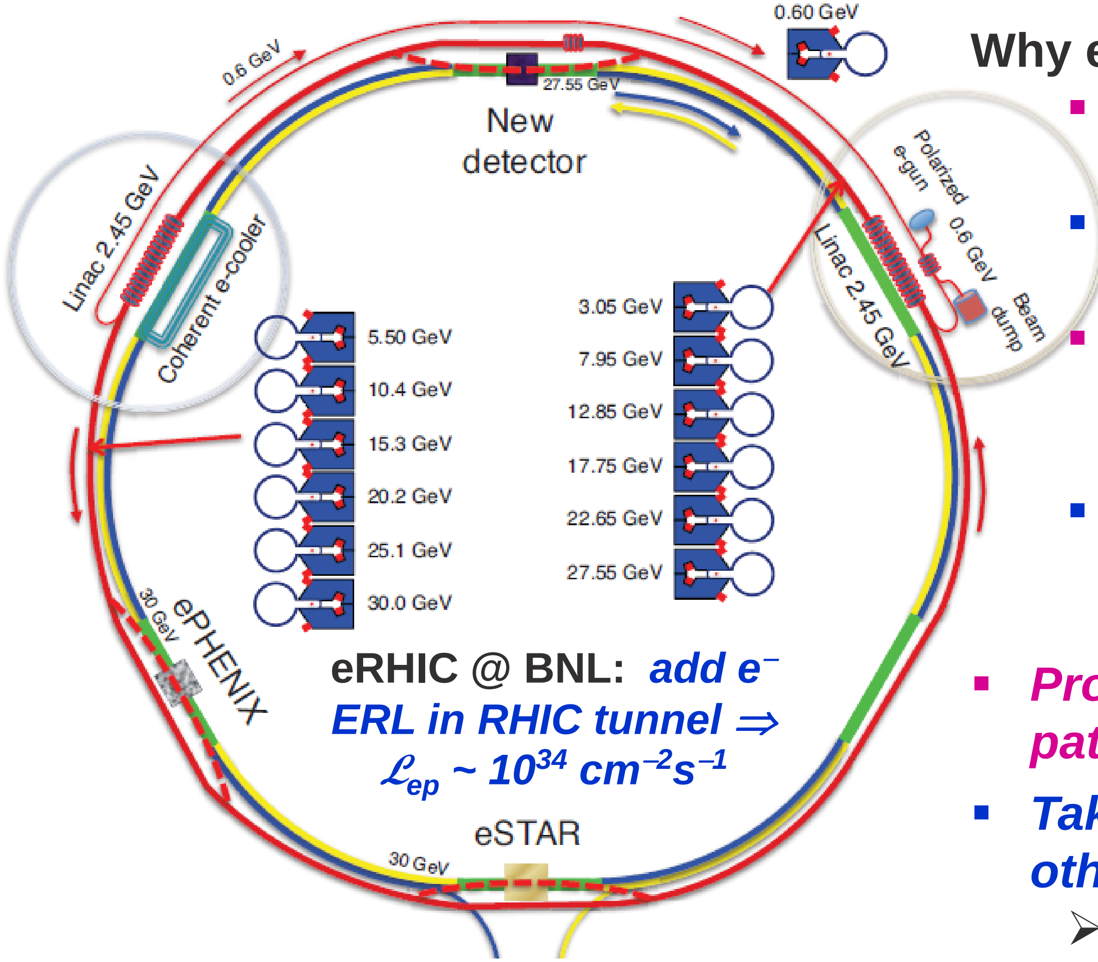
Question	Facilities Needed to Answer	Comments	Related Table 1 Question #'s
1) How perfect is "near-perfect" liquid?	RHIC & LHC (& ⇒ BOTH REQ'D)	Flow power spectra, next 5 years	1 + 2
2) Nature of initial density fluctuations?	RHIC, LHC & EIC	Benefits from asymmetric ion collisions at RHIC	2 + 8
3) How does strong coupling emerge from asymptotic freedom?	RHIC & LHC	Following 5 years @ RHIC; jets need sPHENIX upgrade	2 + 4
4) Evidence for onset of deconfinement and/or critical point?	RHIC; follow-up @ FAIR, NICA	Phase 2 E scan in following 5 years, needs low-E electron cooling	3 + 7
5) Sequential melting of quarkonia?	RHIC & LHC	LHC mass resolution a plus; RHIC det. upgrades help; $\sqrt{s}$-dependence important	5
6) Are sphaleron hints in RHIC data real?	Mostly RHIC	Exploits U+U and $\mu_B \neq 0$ reach at RHIC	6
7) Saturated gluon densities?	RHIC, LHC & EIC	Want to see onset at RHIC; need EIC to quantify	8
8) Where is missing proton spin?	RHIC & EIC	EIC will have dramatic impact	9 + 10

Addressing these questions requires an ~10-year program of A+A (various ion species), p+p and p/d + A runs at various RHIC energies.

Timeline for RHIC's Next Decade

Years	Beam Species and Energies	Science Goals	New Systems Commissioned
2013	• 500 GeV $\vec{p}+\vec{p}$ • 15 GeV Au+Au	• Sea antiquark and gluon polarization • QCD critical point search	• Electron lenses • upgraded pol'd source • STAR HFT
2014	• 200 GeV Au+Au and baseline data via 200 GeV p+p (needed for new det. subsystems)	• Heavy flavor flow, energy loss, thermalization, etc. • quarkonium studies	• 56 MHz SRF • full HFT • STAR Muon Telescope Detector • PHENIX Muon Piston Calorimeter Extension (MPC-EX)
2015-2017	• High stat. Au+Au at 200 and ~40 GeV • U+U/Cu+Au at 1-2 energies • 200 GeV p+A • 500 GeV $\vec{p}+\vec{p}$	• Extract $\eta/s(T_{min})$ + constrain initial quantum fluctuations • further heavy flavor studies • sphaleron tests @ $\mu_B \neq 0$ • gluon densities & saturation • finish p+p W prod'n	• Coherent Electron Cooling (CeC) test • Low-energy electron cooling • STAR inner TPC pad row upgrade
2018-2021	• 5-20 GeV Au+Au (E scan phase 2) • long 200 GeV + 1-2 lower $\sqrt{s}$ Au+Au w/ upgraded dets. • baseline data @ 200 GeV and lower $\sqrt{s}$ • 500 GeV $\vec{p}+\vec{p}$ • 200 GeV $\vec{p}+A$	• x10 sens. increase to QCD critical point and deconfinement onset • jet, di-jet, γ-jet quenching probes of E-loss mechanism • color screening for different $q\bar{q}$ states • transverse spin asyms. Drell-Yan & gluon saturation	• sPHENIX • forward physics upgrades

RHIC's 3rd Decade: Reinvention as eRHIC ⇒ Path Forward for Cold QCD Matter



Design allows easy staging (start w/ 5-10 GeV, upgrade to ~20 GeV e^-). Underwent successful technical design review in 2011. Bottom-up cost eval. + value engineering in progress.

Why eRHIC is a cost-effective approach:

- ***Reuses RHIC tunnel & detector halls ⇒ minimal civil construct'n***
- ***Reuses significant fractions of STAR & PHENIX detectors***
- ***Exploits existing HI beams for precocious access to very high gluon density regime***
- ***Polarized p beam and HI beam capabilities already exist – saves ~$2B RHIC replacement cost***
- ***Provides straightforward upgrade path by adding SRF linac cavities***
- ***Takes advantage of RHIC needs and other accelerator R&D @ BNL:***
  - ***E.g., coherent electron cooling can also enhance RHIC pp lumi.***
  - ***E.g., FFAG developments for muon collider considered for significant cost reductions***

Subcommittee September Meeting

Friday, September 7

<u>Fundamental Symmetries and Neutrinos</u>

13:30 – 14:15 – Fundamental Symmetries overview – M. Ramsey-Musolf

14:15 – 15:00 – Neutrinos overview – H. Robertson

15:00 – 15:20 – JLab Parity experiments – K. Paschke

15:20 – 15:40 – EDM overview – B. Filippone

15:40 – 16:10 – Other FS experiments – D. Hertzog

16:10 – 16:40 – ββ-decay overview – S. Freedman

1 – 17:15 – Neutrino experiments – K. Heeger

17:15 – 18:00 – Executive S ion with questions to focus on FS&N

Four Components

EDM searches: *BSM CPV, Origin of Matter*	**$0\nu\beta\beta$ decay searches:** *Nature of neutrino, Lepton number violation, Origin of Matter*
Lepton accelerators: *SM Precision Tests, BSM "diagnostic" probes*	**Smaller scale:** *Weak decays, m_ν, "dark photons", non-Newtonian gravity, theory…*

Major objectives in Neutrino Physics

Known Unknowns

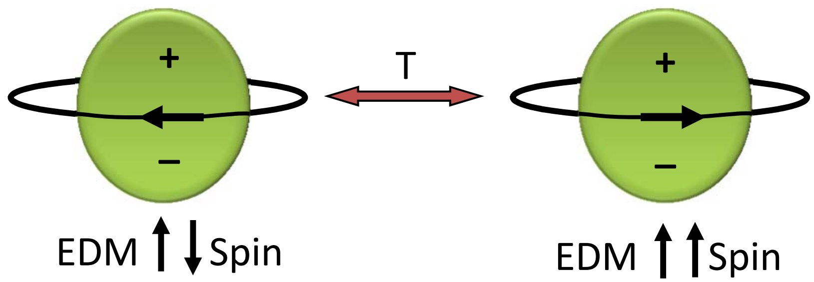
- ~~θ_{13}~~
- Hierarchy
- Mass
- CP violation
- Majorana or Dirac

Unknown Unknowns

- ~~OPERA~~
- $N_\nu \sim 4$ from cosmology
- LSND, MiniBooNE
- Reactor anomaly
- Ga source anomaly

(DOE Nuclear Physics plays a strong role)

EDM Overview



- Motivation for EDM searches
  – Physics reach has been discussed
  – Why so many systems to study?
- EDMs and Nuclear Physics
  – Radioactive atom EDMs
  – Proton EDM in storage ring
  – Neutron EDM in worldwide context

(Potentially biggest budget impact over next 5 years)

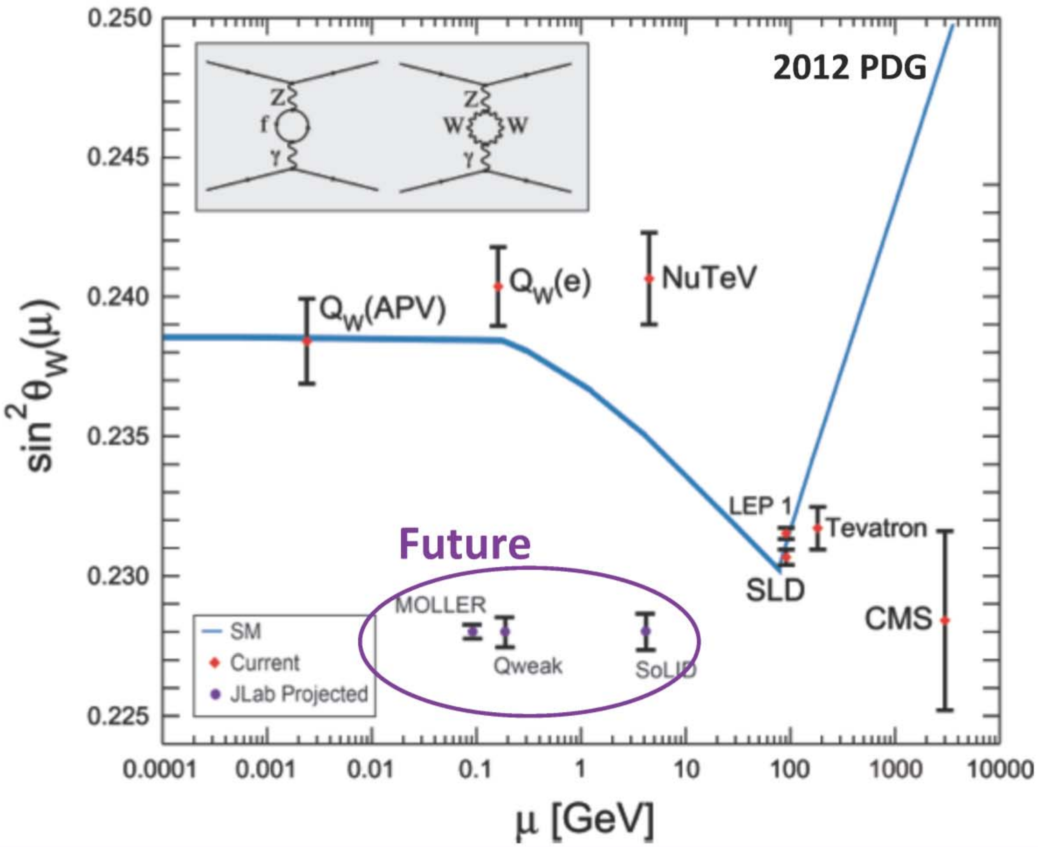
B. Filippone
NSAC Subcommittee
9/7/12

Running Weak Charge

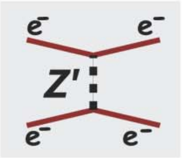
Improvement in SM prediction

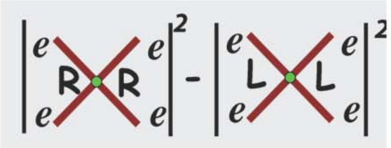
- *Czarnecki and Marciano (1995, 2000)*
- *Petriello (2002)*
- *Erler and Ramsey-Musolf (2004)*
- *Sirlin et. al. (2004)*
- *Zykonov (2004)*

Deviation from this SM curve would indicate observation of a new interaction, beyond the SM Z^0



E158: First confirmation of SM running
Constraints on new physics into
15 TeV (lepton compositeness)
0.5-2 TeV (Z', extra dimensions)





Future Program of Precision Weak Charge Measurements

- **Elastic Electron-Proton Scattering**
- **Moller Scattering**
- **Deep Inelastic Scattering off Deuterium**

Each tests different couplings and plays a role in constraining/detailing possible BSM physics

Running Weak Charge

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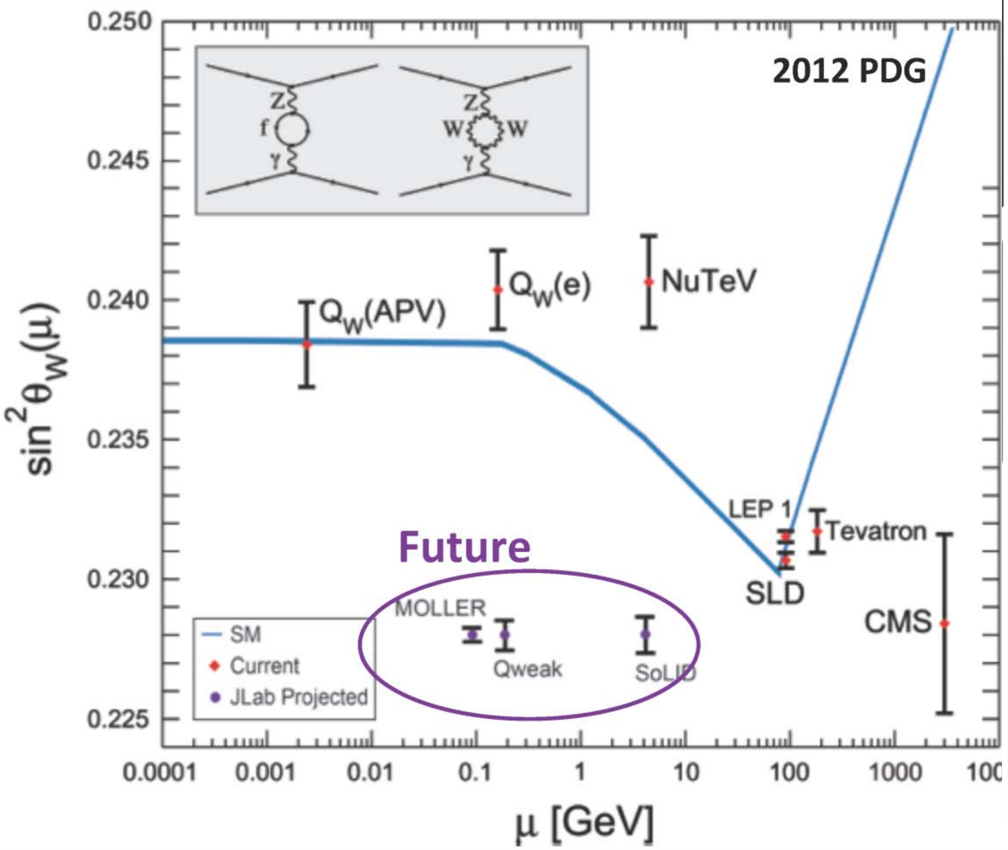
Deviati... observatio...

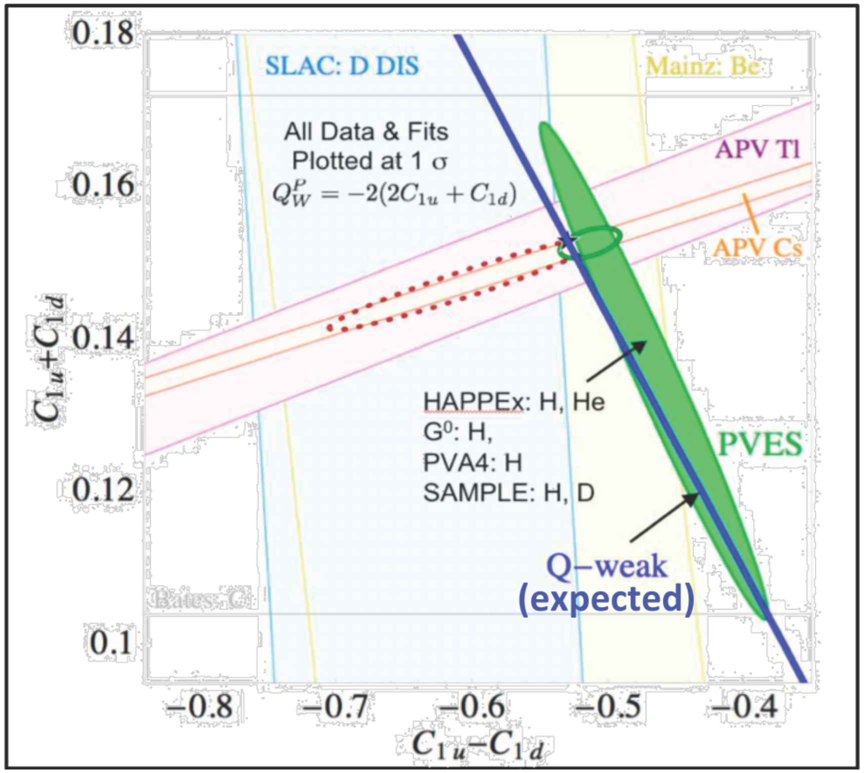


Program to study strange quark contribution to the nucleon form-factors

Strange Quark FF: shape of curve

Proton weak vector charge: projection to $Q^2 = 0$

The strange quark program has led to significant improvement measurement of quark weak vector couplings



Subcommittee September Meeting

Saturday, September 8

Medium Energy Physics

08:00 – 08:45 – R. Holt, MEP overview

08:45 – 09:05 – R. Ent, JLab Recent Accomplishments

09:05 – 09:35 – R. McKeown, JLab Future Science Program

09:35 – 09:55 – J. Dudek, Meson Spectroscopy and GlueX

09:55 – 10:15 – M. Guidal, Nucleon Imaging

10:15 – 10:30 – Coffee Break

10:30 – 10:50 – C. Rode, 12 GeV Project Status

10:50 – 11:10 – A. Hutton, Accelerator Science

11:10 – 11:30 – A. Lung, Budget Impacts

11:30 – 11:45 – H. Montgomery, Summary and Outlook

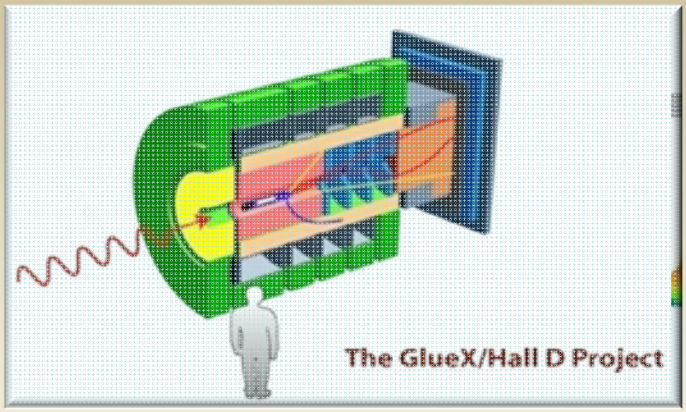
11:45 – 12:30 – Executive Session with JLab management

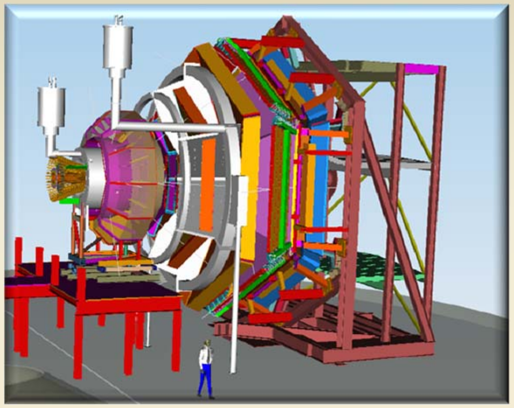
JLab: 21st Century Science Questions

- What is the role of gluonic excitations in the spectroscopy of light mesons? Can these excitations elucidate the origin of quark confinement?
- Where is the missing spin in the nucleon? Is there a significant contribution from valence quark orbital angular momentum?
- Can we reveal a novel landscape of nucleon substructure through measurements of new multidimensional distribution functions?
- What is the relation between short-range N-N correlations and the partonic structure of nuclei?
- Can we discover evidence for physics beyond the standard model of particle physics?

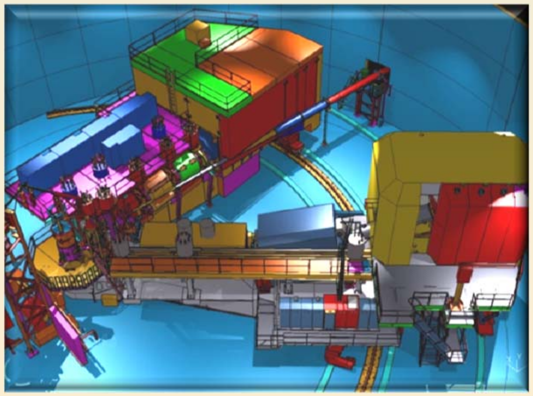
12 GeV Scientific Capabilities

Hall D – exploring origin of confinement by studying exotic mesons

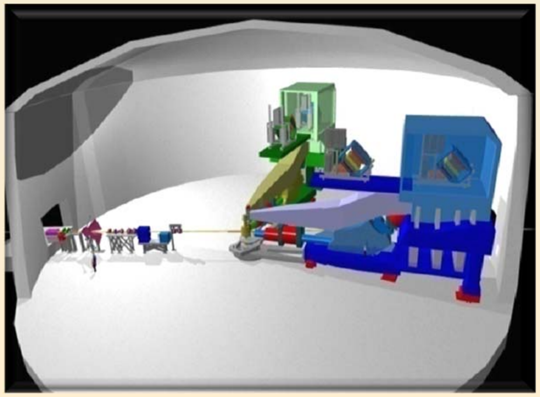




Hall B – understanding nucleon structure via generalized parton distributions



Hall C – precision determination of valence quark properties in nucleons and nuclei

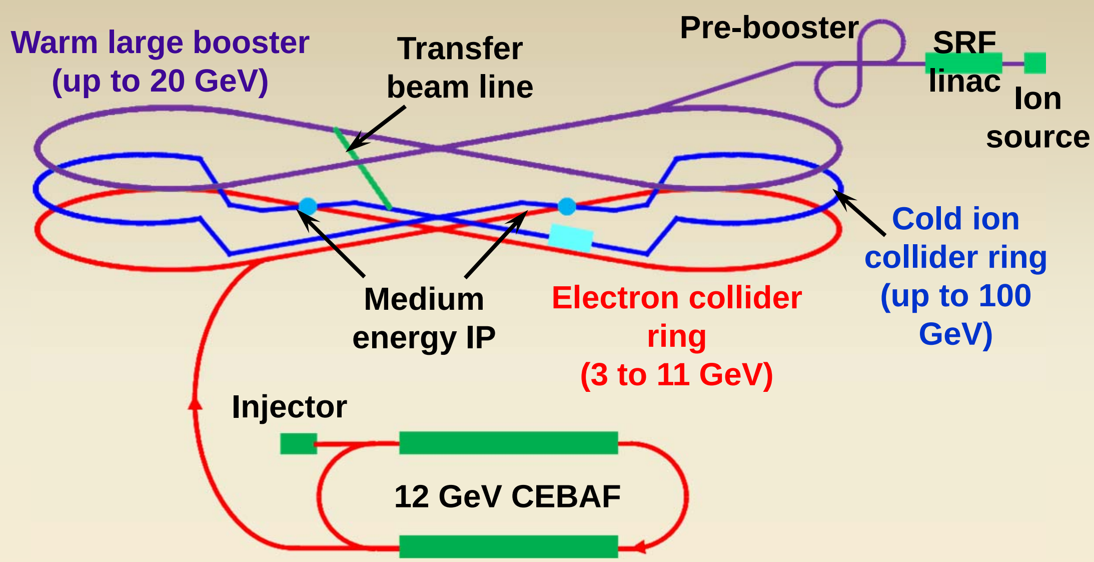


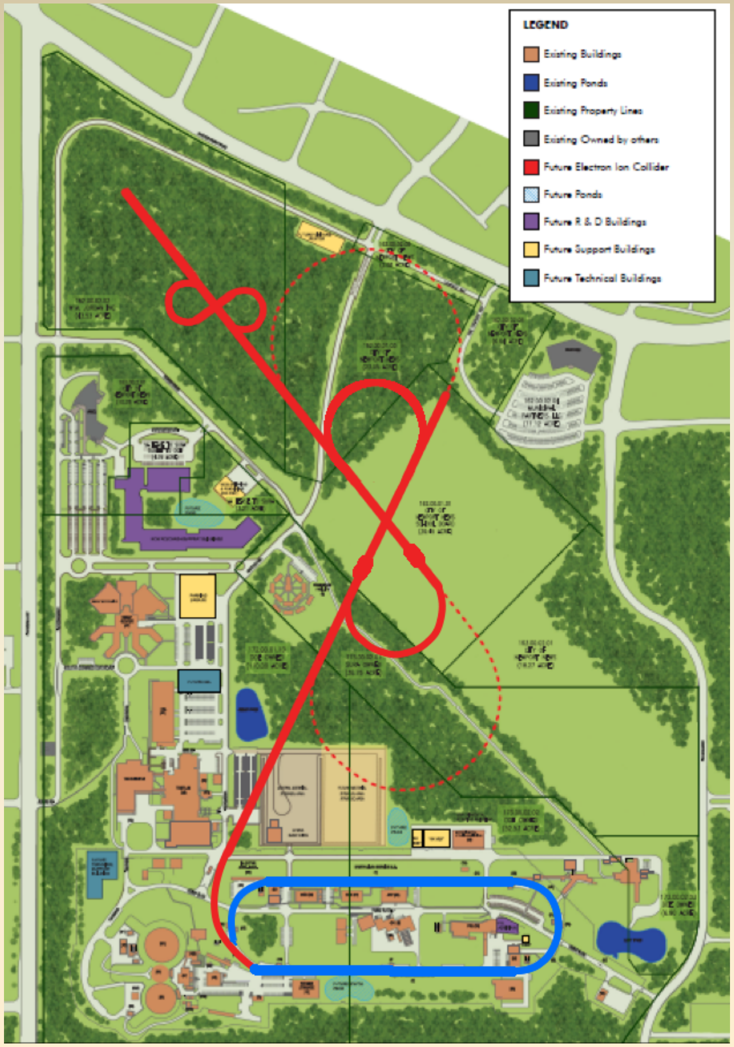
Hall A –form factors, future new experiments (e.g., SoLID and MOLLER)

12 GeV JLab – The Potential

- Opportunity to discover and study new exotic mesons to elucidate the mechanism of confinement.
- Open a new landscape of nucleon tomography, with potential to identify the missing angular momentum.
- Establish the quantitative foundation for the short-distance behavior in nuclei, underpinning the development of precision nuclear structure studies.
- Provide stringent new tests of the standard model and extensions, complementing the information obtained at LHC.
- Establish a firm basis for higher energy studies with a future **Electron Ion Collider**

Medium Energy EIC@JLab





JLab Concept

- Initial configuration (MEIC):
  - 3-11 GeV on 20-100 GeV ep/eA collider
  - fully-polarized, longitudinal and transverse
  - luminosity: up to few x 10^{34} e-nucleons cm^{-2} s^{-1}
- Upgradable to higher energies (250 GeV protons)

Subcommittee September Meeting

Saturday, September 8

<u>Low Energy – FRIB/NSCL</u>

13:30 – 14:15 – David Dean, LE (NS&NA) overview

14:15 – 14:35 – K. Gelbke, FRIB Laboratory Overview

14:35 – 15:00 – T. Glasmacher, FRIB Project

15:00 – 15:15 – A. Gade, FRIB Science – Nuclear Structure and Reactions

15:15 – 15:30 – H. Schatz, FRIB Science – Nuclear Astrophysics

15:30 – 15:40 – Z. Lu, FRIB Science – Fundamental Symmetries

15:40 – 15:50 – G. Bollen, FRIB Science – Applications of Isotopes

15:50 – 16:05 – Discussion of FRIB Science

16:05 – 16:20 – Break

16:20 – 16:35 – B. Sherrill, Uniqueness of FRIB

16:35 – 16:50 – D. Leitner, NSCL Capabilities and Operations

16:50 – 17:15 – P. Mantica, NSCL Science Program and Results

17:15 – 18:00 – Executive Session with FRIB management

FRIB Laboratory Building Plan

FRIB will take full advantage of evolving NSCL infrastructure and benefit from NSF-funded CCF/ReA operations for users

FRIB is Needed to Understand Atomic Nuclei

F (2)
G (5)

- A reliable model of atomic nuclei with predictive power does not yet exist
- In recent years, enormous progress has been made with measurements of properties of rare isotopes and developments in nuclear theory and computation
- Access to key regions of the nuclear chart constrains poorly known model parameters and identifies missing physics
- Theory identifies key nuclei and properties to be studied

Dean

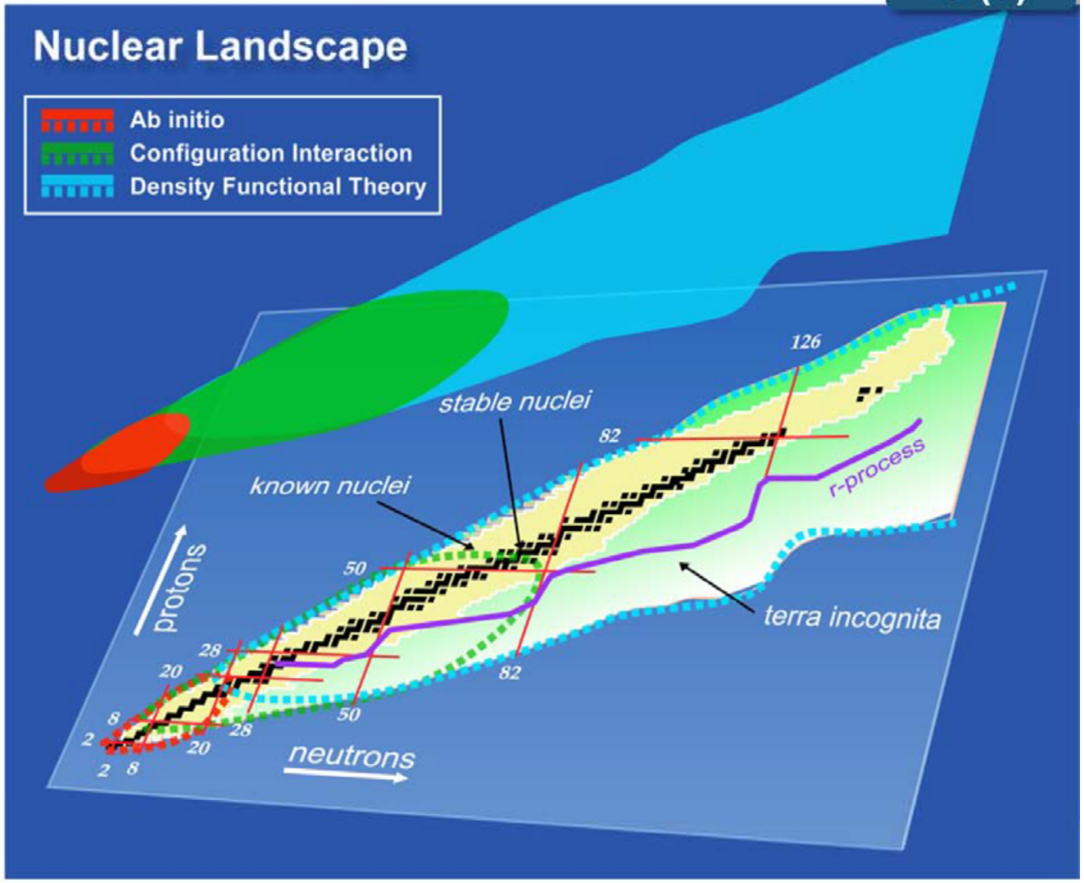


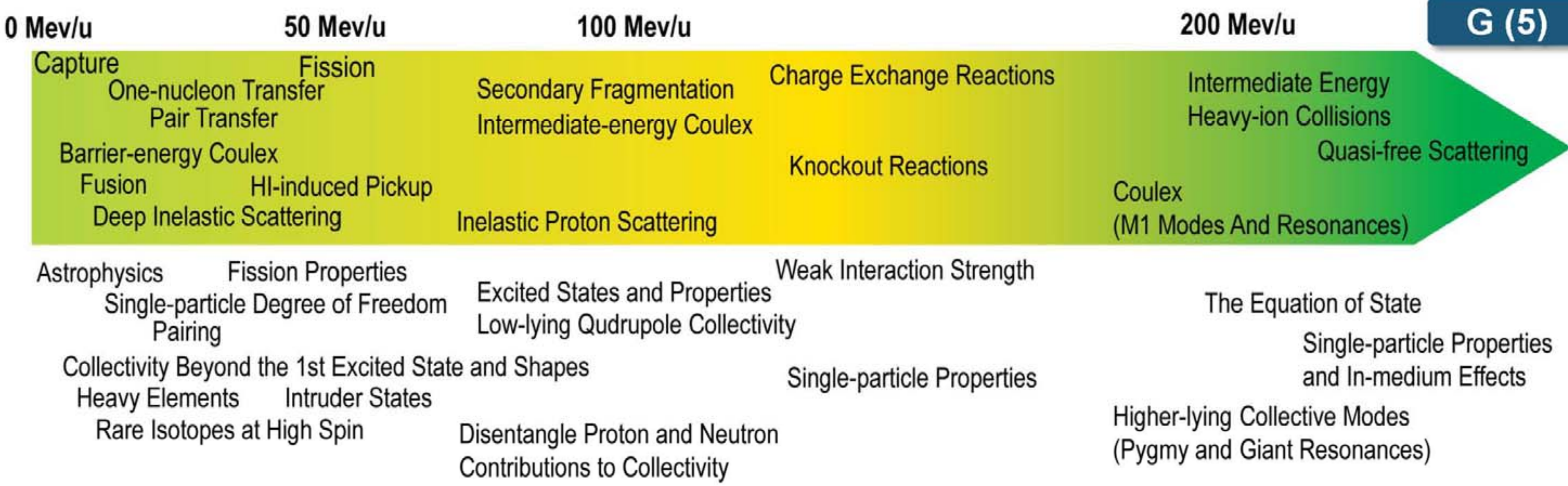
Figure adapted from www.scidacreview.org/0704/html/unedf.html

Rare isotopes produced at FRIB will guide nuclear models towards a comprehensive picture of nuclei

FRIB's Beam Energy Range Will Be a Game-changer for Nuclear Reactions

F (2)

G (5)



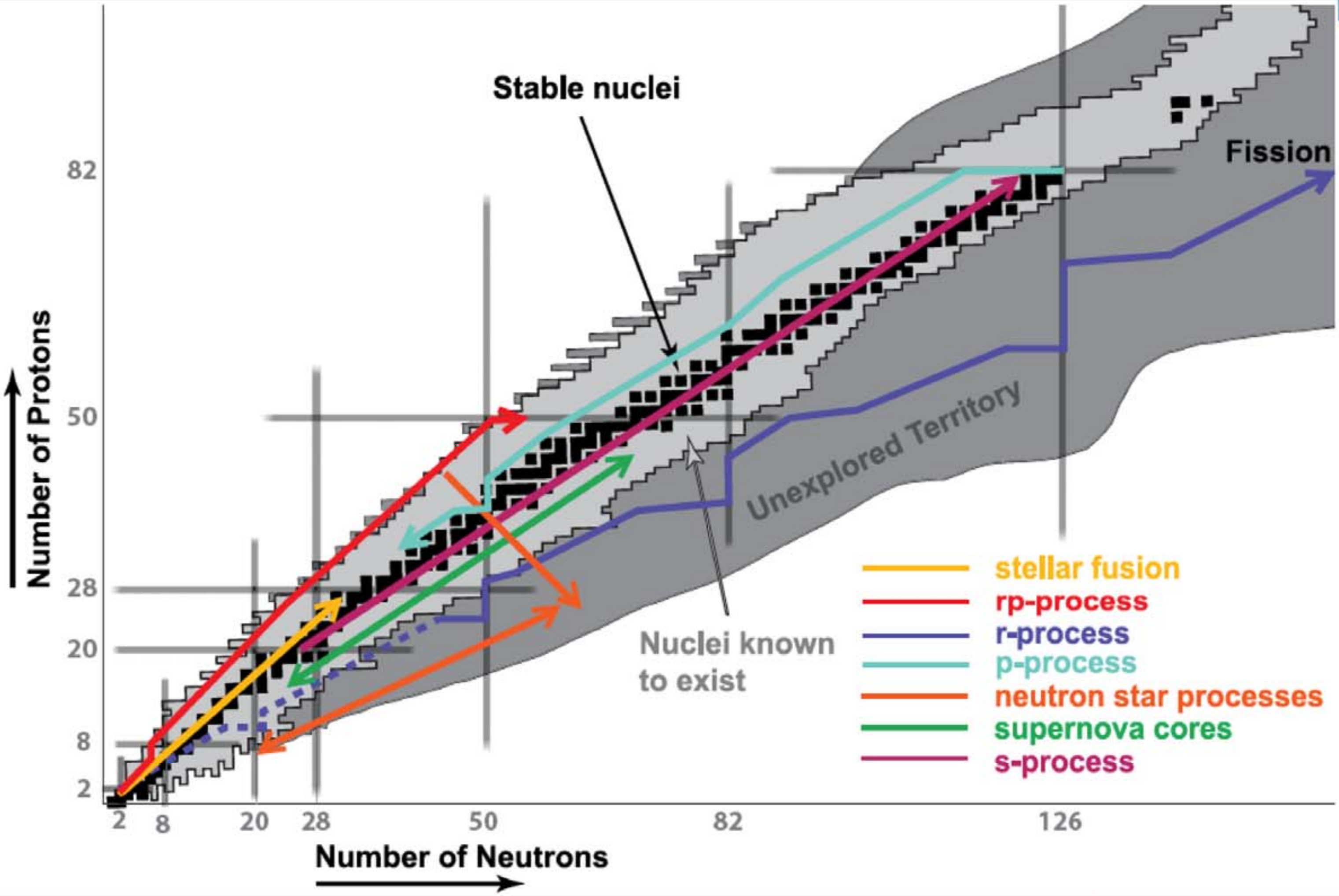
- Nuclear reactions are an essential tool for the extraction of crucial information for nuclear structure physics and nuclear astrophysics
- The required beam energy range spans from keV/u (astrophysics) to above 200 MeV/u for heavy-ion reactions that will constrain the nuclear EOS

FRIB provides the full range of beam energies required to exploit nuclear reactions for nuclear structure and astrophysics

FRIB Will Be a Game-changer for Nuclear Astrophysics [1]

F (2)

G (5)



Data on rare isotopes and their reactions are required to elucidate many astrophysical scenarios

FRIB Will Be a Game-changer for Nuclear Astrophysics [2]

F (2)
G (5)

rp-process in X-ray bursts/Novae/Supernovae
- Direct reaction rates (SECAR)
- Indirect reaction rate studies
- Masses and p-drip line

s-process in AGB stars
- Harvesting of targets for n-capture on branchpoints

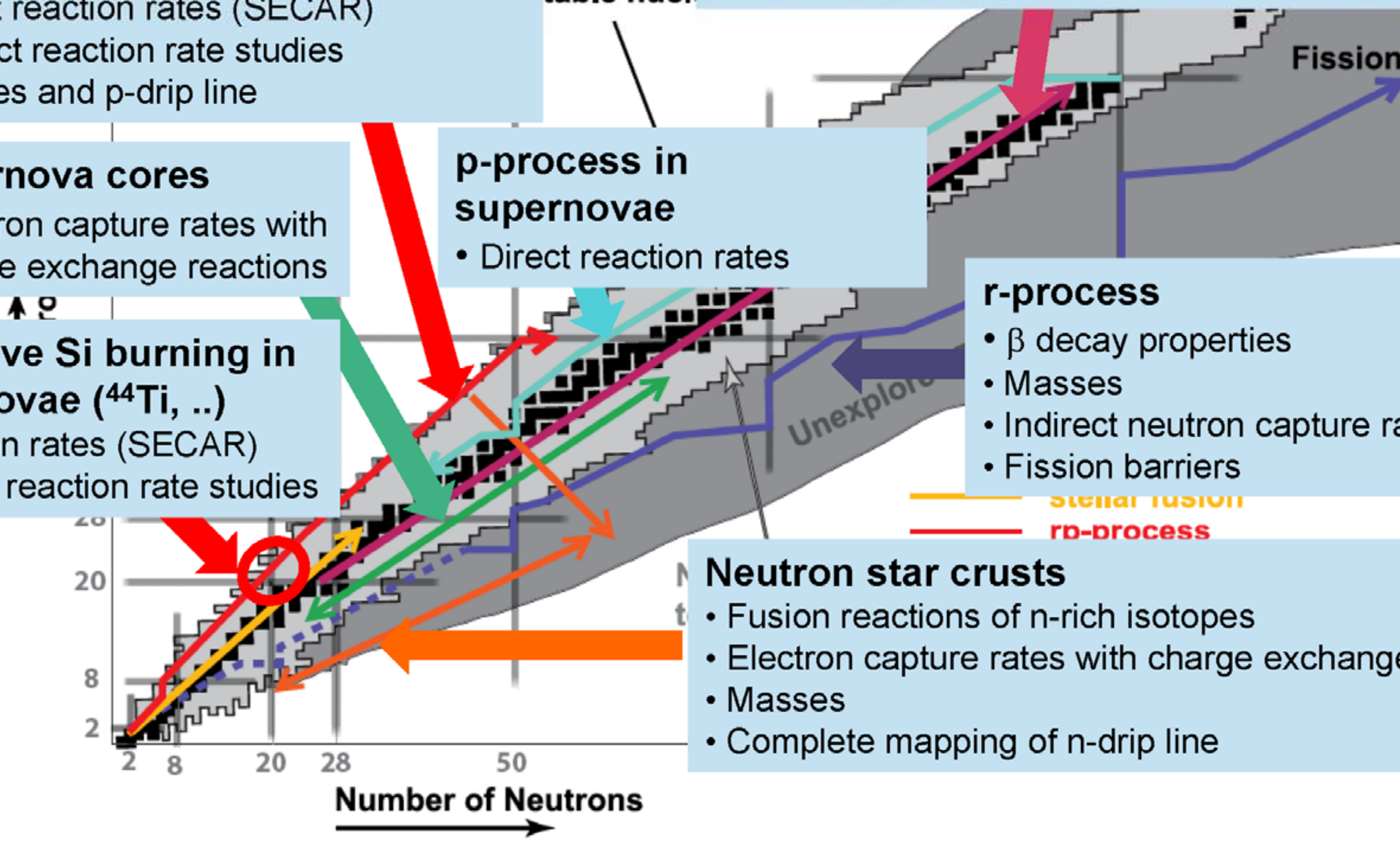
Supernova cores
- Electron capture rates with charge exchange reactions

p-process in supernovae
- Direct reaction rates

Explosive Si burning in supernovae (^{44}Ti, ..)
- Reaction rates (SECAR)
- Indirect reaction rate studies

r-process
- β decay properties
- Masses
- Indirect neutron capture rate studies
- Fission barriers

Neutron star crusts
- Fusion reactions of n-rich isotopes
- Electron capture rates with charge exchange
- Masses
- Complete mapping of n-drip line



Data on rare isotopes and their reactions are required to elucidate many astrophysical scenarios

Subcommittee September Meeting

Sunday, September 9

<u>Low Energy, Nuclear Astrophysics, Theory, and Computation</u>

08:00 – 08:30 – ATLAS – G. Savard

08:30 – 09:15 – ARUNA – I. Wiedenhoever

09:15 – 10:00 – Nuclear Astrophysics (interface to NP) – A. Burrows, M. Wiescher

10:00 – 10:45 – Nuclear Theory – D. Kaplan

10:45 – 11:15 – Computational Physics – M. Savage

11:15 – 16:00 – Closed Executive Session and lunch

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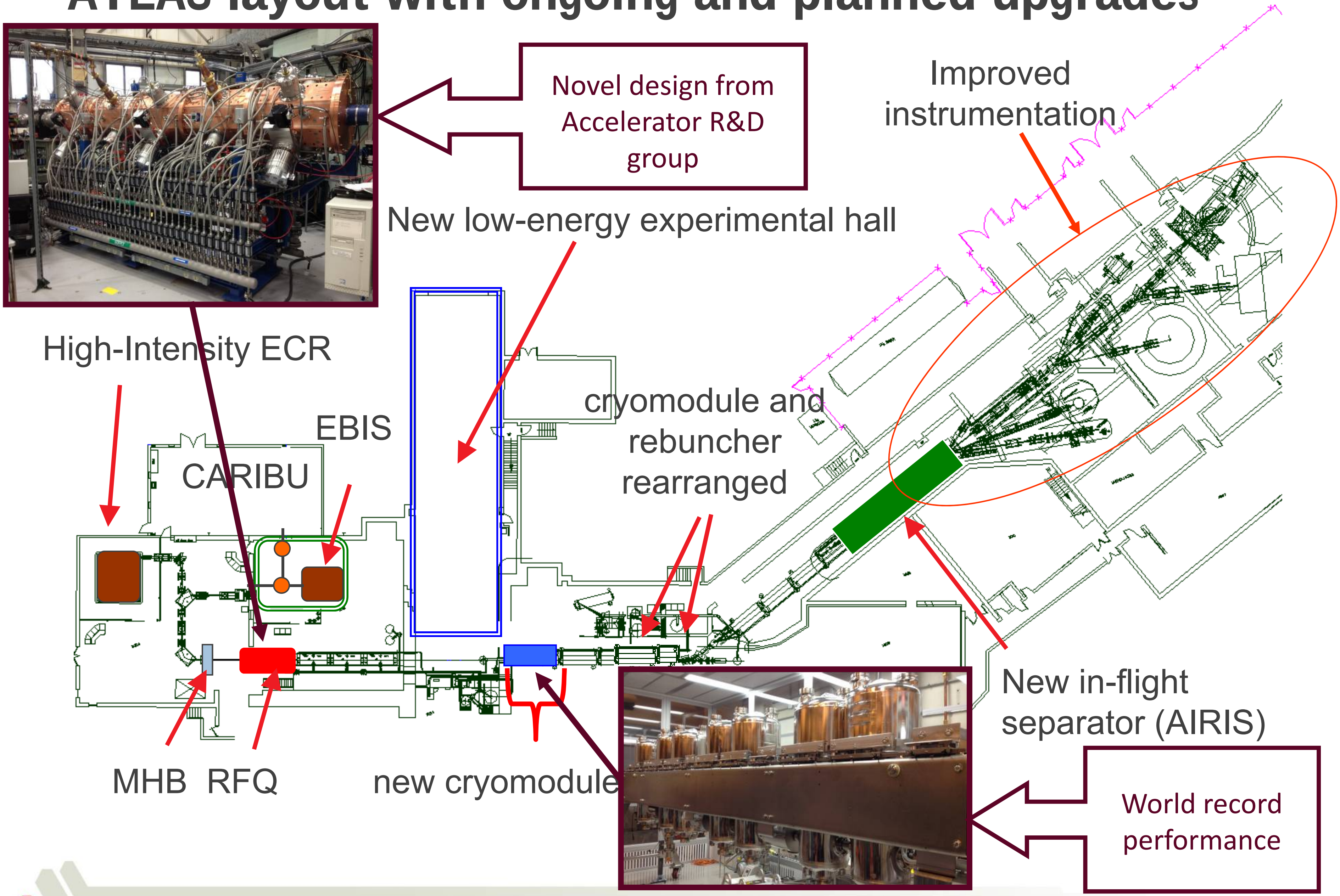
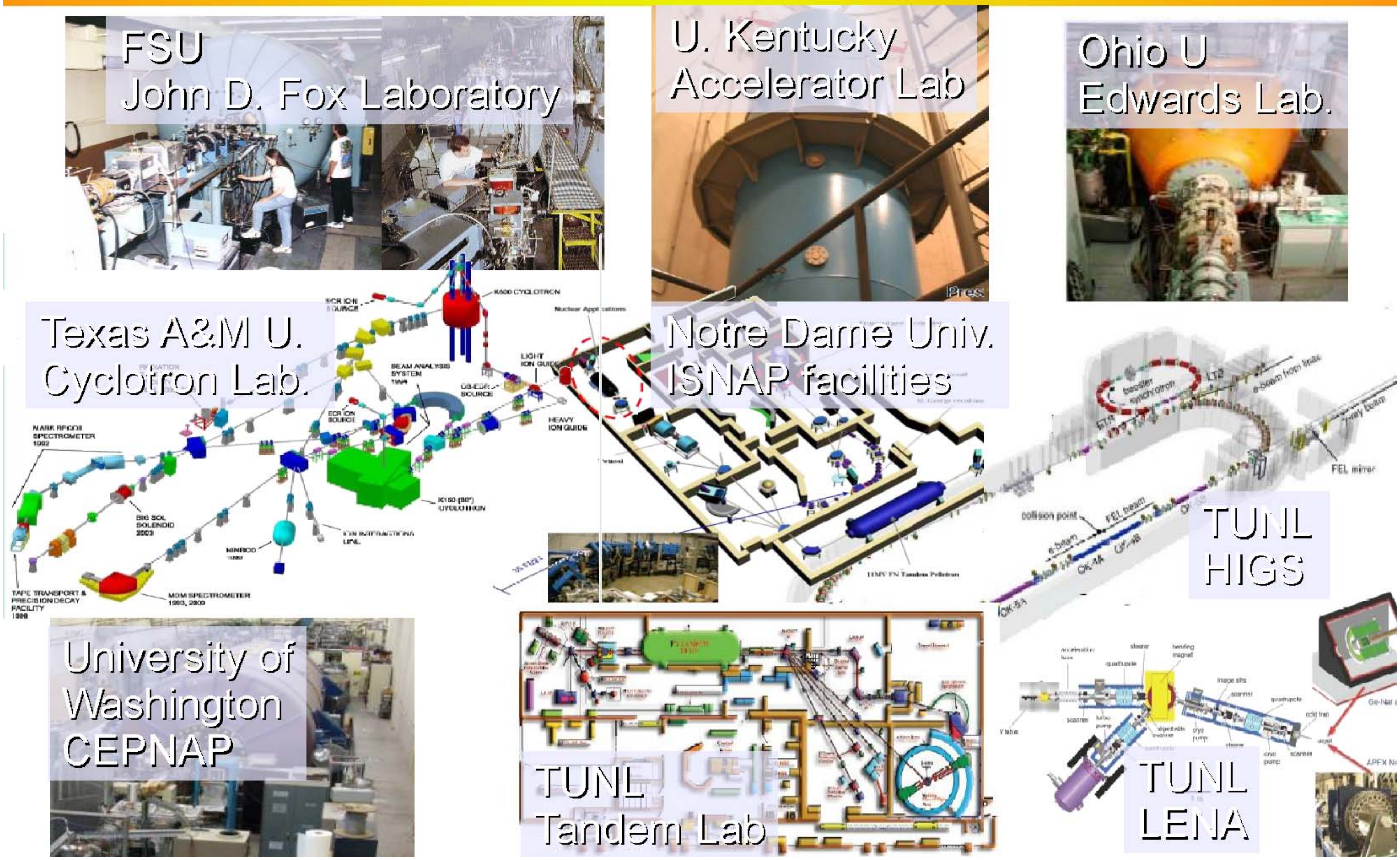
ATLAS layout with ongoing and planned upgrades



ARUNA-
Association for Research at University Nuclear Accelerators

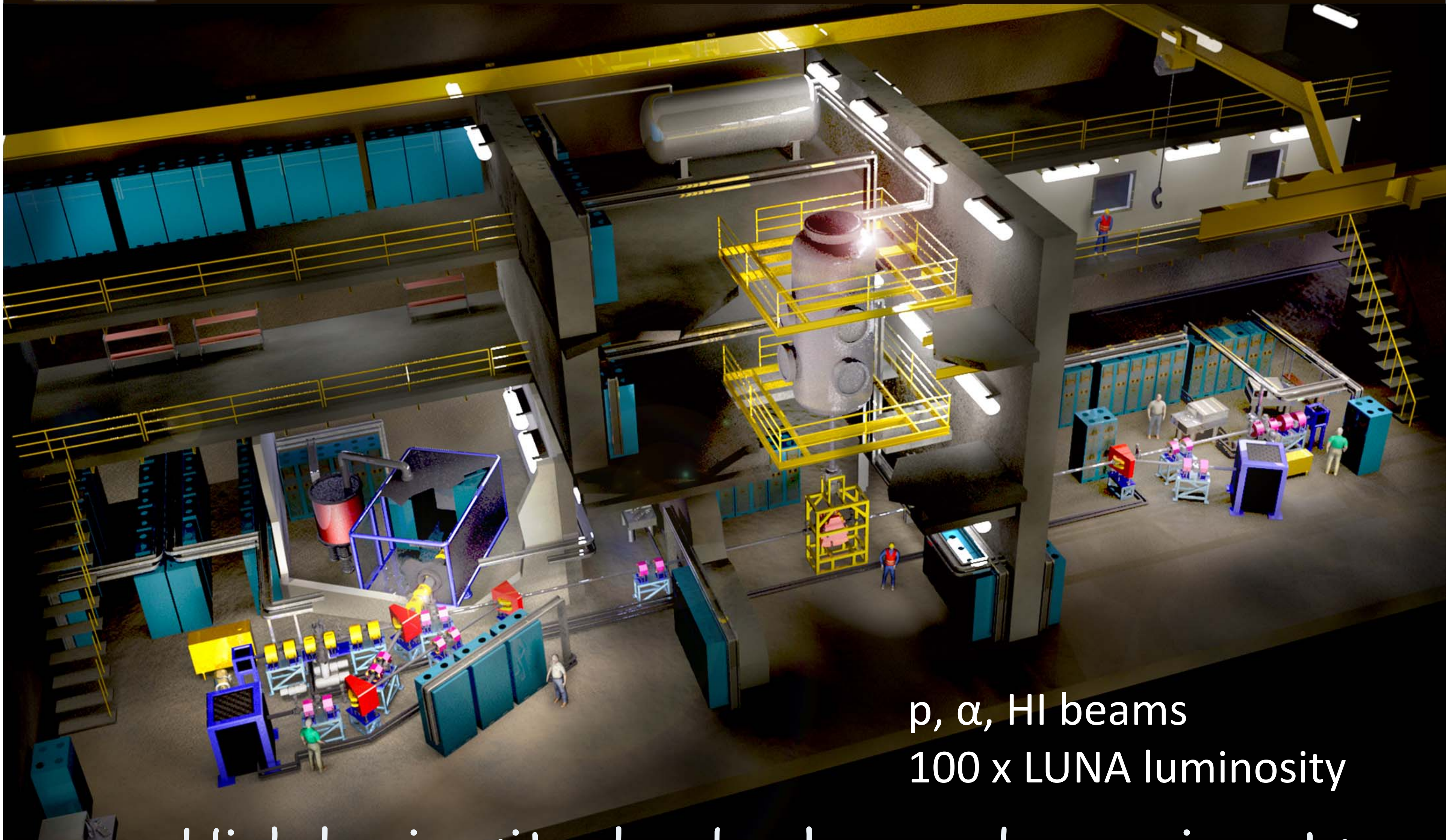


Key Science Drivers of Computational Nuclear Astrophysics

- Primary Goal: Explanation of the Origin of the Elements and Isotopes
- Overwhelmingly, Elements are produced in Stars - quiescently or explosively
- Core-Collapse Supernovae (CCSN) - the Deaths of Massive Stars and Birth of Neutron Stars
- Thermonuclear Supernovae - the Source of much of the Iron Peak
- Novae - source of some light elements
- X-ray bursts - the rp-Process Nuclei
- Merging Neutron stars - with CCSN, the likely source of the r-process Nuclei
- Stellar Evolution involves nuclear reaction rates generated theoretically or experimentally - convective processes and magnetic couplings - multi-dimensional
- Stellar Explosions are always Multi-dimensional, requiring state-of-the-art radiation/hydrodynamic simulations with significant Nuclear Physics input.

- Nuclear astrophysics entails sophisticated multi-dimensional numerical simulations employing the latest computational tools and the most powerful supercomputers of the DOE complex to address key goals of the Office of Nuclear Physics.

Underground accelerator project DIANA for low energy studies



p, α, HI beams
100 x LUNA luminosity

High luminosity, low background experiments

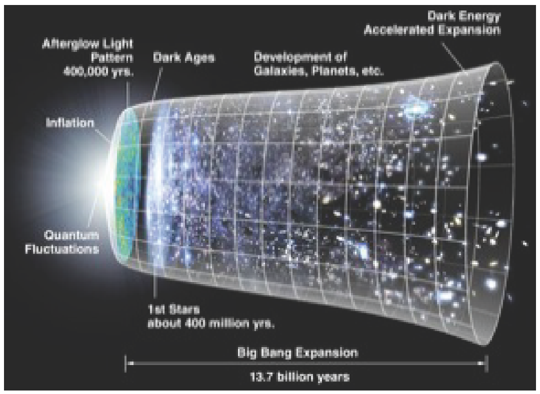
Some highlights:

- Relativistic heavy ion physics
- Nuclear astrophysics
- Lattice QCD
- Nuclear structure and many-body physics
- Fundamental symmetries
- Teaching and mentoring

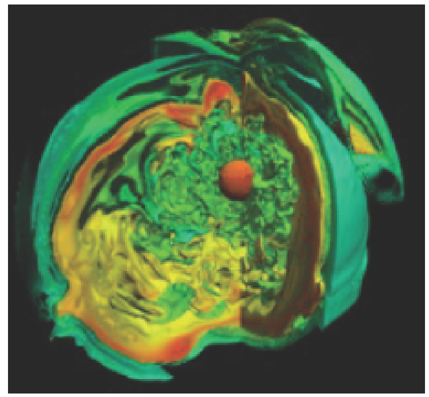
Computational Nuclear Physics

Computation is Crucial to a Broad and Balanced Nuclear Physics Program

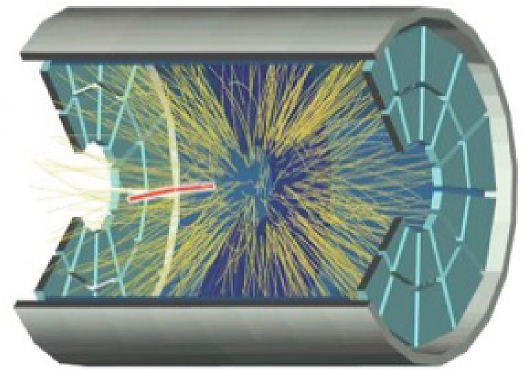
Phase transition(s) at early times, light sources at later times



Production of most elements in the cosmos

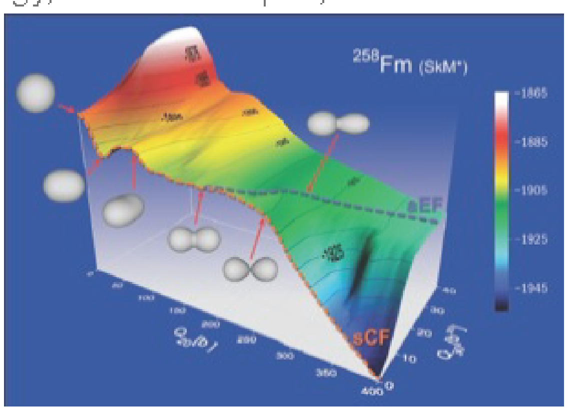


Matter under extreme conditions

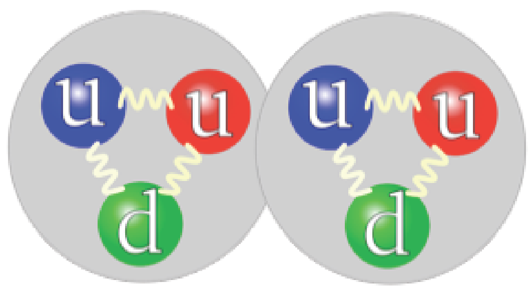


Nuclei and their reactions:

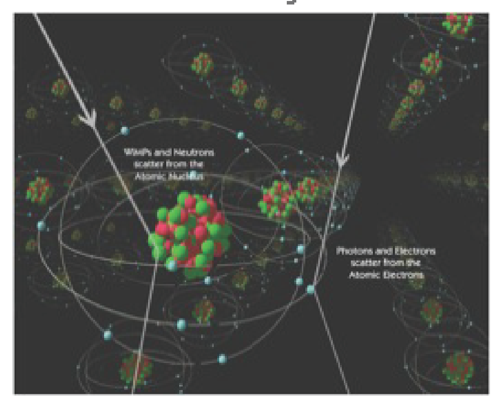
Energy, Medical Isotopes, National Security,...



The structure of, and forces between, nucleons



Search for New Physics



Enormous range of length scales involved

Present and Future Activities

- Assignments for report drafts made and writing now underway
- DNP fall meeting plans – community input
  - Mini Town Meetings – Thursday 10/26
  - Joint Town Meeting – Friday 10/27
- Resolution Meeting – 11/30-12/2
- Report goals are:
  - science sections and intro done before 11/30
  - conclusions and recommendations draft by 12/14 with comments by 12/23
  - Full report for review by 12/31
- Report to NSAC by **1/7/2013**

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