Perspectives from DOE Nuclear Physics

NSAC Meeting
October 15, 2015

Dr. Timothy J. Hallman
Associate Director for Nuclear Physics
DOE Office of Science
Discovering, exploring, and understanding all forms of nuclear matter

The Scientific Challenges

- The existence and properties of nuclear matter under extreme conditions, including that which existed at the beginning of the universe
- The exotic and excited bound states of quarks and gluons, including new tests of the Standard Model
- The ultimate limits of existence of bound systems of protons and neutrons
- Nuclear processes that power stars and supernovae, and synthesize the elements
- The nature and fundamental properties of neutrons and the neutrino and their role in the evolution of the early universe
The Nuclear Science Community Stewarded by DOE NP

**National User Facilities**
- RHIC (BNL)
- CEBAF (TJNAF)
- ATLAS (ANL)
- ~3,000 users

**Research Groups**
- 9 National Laboratories
- 90 Universities

**NP Workforce**
- ~700 Faculty & Lab Res Staff
- ~320 Post-docs
- ~520 Graduate Students
- ~1000 Technical/admin
- ~100 Undergraduate Students
- ~85 PhD’s awarded per year

**Other Lab. Facilities**
- 88-Inch Cyclotron (LBNL)
- 200 MeV BLIP (BNL)
- 100 MeV IPF (LANL)
- Hot Cell Facilities at BNL, LANL, ORNL

**Centers of Excellence**
- CENPA (U. of Wash)
- INT (U. of Wash.)
- TAMU (Texas A&M)
- TUNL (Duke)
- REC (MIT)

**Location Map**
- User Facility
- University
- Laboratory Facility
- Laboratory
- University Facility/Center of Excellence
NSAC partnership with the Division of Nuclear Physics of the APS to tap the full intellectual capital of the U.S. nuclear science community in identifying exciting, compelling science opportunities and a strategic plan for the next 5-10 years:


**Nuclear Theory Computing**: *High performance computing* (Computation in nuclear physics), Washington DC, July 14-15, 2014

**Education** [NSF scope - Workforce Training in DOE] and **Innovation... across all areas of nuclear physics** *Conveners*: Michael Thoennessen, Graham Peaslee *Venue*: NSCL, Michigan State University, Aug. 6-8, 2014; *Website*: [http://meetings.nscl.msu.edu/Education-Innovation-2014](http://meetings.nscl.msu.edu/Education-Innovation-2014)

**Resolution Meeting**: Spring of 2015

**Long Range Plan**: October 15, 2015
NSACI Strategic Planning Exercise Completed

New Report released July 20, 2015:
- All prior recommendations addressed

New recommendations:
- Significant increase in R&D funding
  - Continue R&D on alpha-emitters (Ac-225, At-211)
  - High specific activity theranostic isotopes
  - Electron accelerators for isotope production
  - Irradiation materials for targets
- Complete creation of stable isotope capability
- Increase in infrastructure investments and operating base
  - Isotope harvesting at FRIB
  - Separator for radioactive isotopes
  - BLIP intensity upgrade and second target station
  - IPF intensity, stability and energy upgrades
- Continue integration of university facilities

New 2015 LRP for the DOE-NP Isotope Program
With the completion of the 12 GeV CEBAF Upgrade, researchers will address:

- The search for exotic new quark–anti-quark particles to advance our understanding of the strong force.
- Evidence of new physics from sensitive searches for violations of nature’s fundamental symmetries.
- A detailed microscopic understanding of the internal structure of the proton, including the origin of its spin, and how this structure is modified when the proton is inside a nucleus.
Déjà vu all over again
Run-15 integrated luminosity at $\sqrt{s} = 200$ GeV exceeds sum of all previous runs

No other facility worldwide, existing or planned, can rival RHIC in range and versatility as a heavy ion collider. It is the only polarized proton collider in the world.
The Facility for Rare Isotope Beams is ~ 50% Complete

FRIB – September 16, 2015
(TPC: $635.5M DOE + $94.5M MSU)
Project Completion: 3Q FY 2022

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Progress on the Facility for Rare Isotope Beams

- View of linac tunnel from the west
- Surface building structural steel from the west end
- View of target area
- Eastern view showing exterior brick work
FRIB Instrumentation/Theory Effort is Just Getting Underway

GRETA

SECAR

Pre-Conceptual High Rigidity Spectrometer (HRS)

FRIB Theory Alliance

NSCL/MSU
JINPA/ORNL
MWT/ANL
LVOC/LLNL
CEEM
ACFI
INT
NPAC/LANL
NUCLEI
TORUS/TalN
TALENT
ICNT
CUSTIPEP
FUSTIPEP

national lab
university

Challenge:
Beam/Recoil ratio $\sim 10^{11} - 10^{13}$
Recoil-beam mass difference 1-4
Need $\sim 100\%$ recoil transmission
Coincidence

Step 1: Dipole
Charge state selection
Step 2: Wien Filter
Mass resolution $\gtrsim 10$
Step 3: Wien Filter
Mass resolution 770
Step 4: Dipole
Cleanup scattered beam
"Leaky Beam"
Step 5: Focal Plane
Detectors
WBS SECAR.4.02
Step 5: Gamma
Detectors
WBS SECAR.4.04

Gas target (H, He)
WBS SECAR.4.01
ATLAS is a unique premier Stable Beam Facility for research on Nuclear Structure & Nuclear Astrophysics.

New low-energy experimental hall

Improved instrumentation

Future in-flight separator (AIRIS)

cryomodule and rebuncher rearranged

ATLAS layout after recent upgrades

EBIS

CARIBU

MHB RFQ

new cryomodule
CHICO-II and GRETINA at ATLAS

Programs:

- Coulomb Excitation of stable and CARIBU beams;
- Structure studies of neutron-rich nuclei using deep-inelastic reactions;
- CHICO-II: high segmentation for both $\theta$ ($1^\circ$) and $\phi$ ($1.4^\circ$)
- GRETINA: about 3.50(2)% absolute efficiency at 1332.5 keV
\(^{146}\text{Ba} \) Coulomb Excitation

Statistics ~ 100 times higher than previously obtained
- higher yield
- more stable operation
- more efficient post-acceleration
- better diagnostics

\(^{146}\text{Ba} \) is predicted to be octupole deformed. The observed coincidence \(\gamma\) spectra allow extraction of an E3 transition probability to verify the theory.
Preparations for an NP Stewarded Neutrino-less Double Beta Decay Experiment

With techniques that use nuclear isotopes inside cryostats, often made of ultra-clean materials, scientists are “tooling up” to study whether neutrinos are their own anti-particle. NSAC charged to provide additional guidance on effective strategy for implementing a possible 2nd generation U.S. experiment.

“Grand Challenge” science questions that will be addressed:

- Is the neutrino its own anti-particle?
- Why is there more matter than anti-matter in the present universe?
- Why are neutrino masses so much smaller than other elementary fermions?

Mandrel insertion in MJD electroforming lab
Proton (and nuclei) and black holes are the only fully relativistic (high enough energy density to excite the vacuum) stable bound systems in the universe. Protons can be studied in the laboratory.

Protons are fundamental to the visible universe (including us) and their properties are dominated by emergent phenomena of the self-coupling strong force that generates high density gluon fields:
- The mass of the proton (and the visible universe)
- The spin of the proton
- The dynamics of quarks and gluons in nucleons and nuclei
- The formation of hadrons from quarks and gluons

The study of the high density gluon field that is at the center of it all requires a high energy, high luminosity, polarized Electron Ion Collider.

The 2013 NSAC Subcommittee on Future Facilities identified the physics program for an Electron-Ion Collider as absolutely central to the nuclear science program of the next decade.
Trends in Research and MIEs as a Percentage of the NP Budget FY 2008-FY2016

Constructing major new research tools has constrained other aspects of the NP program
Mid-Scale instrumentation plays an essential role in realizing the full science return on investment at National User Facilities. A few examples of ideas from the community are shown.
The Office of Nuclear Physics (NP), on the basis of a peer review, has selected the following Topical Collaborations (to start in FY 2016) for funding recommendation:

Coordinated Theoretical Approach to Transverse Momentum Dependent Hadron Structure in QCD (TMD Collaboration)
Principal Investigator/Project Director: Jianwei Qiu; Lead Institution: Brookhaven National Laboratory
Participating Institutions: Duke University, Jefferson Laboratory, Lawrence Berkeley National Laboratory, Lawrence Livermore National Laboratory, Los Alamos National Laboratory, MIT, New Mexico State University, Penn State University at Berks, Old Dominion University, Temple University, University of Arizona, University of Kentucky, University of Maryland, University of Virginia

Nuclear Theory for Double-Beta Decay and Fundamental Symmetries (DBD Collaboration)
Principal Investigator/Project Director: Jonathan Engel; Lead Institution: University of NC at Chapel Hill
Participating Institutions: Central Michigan University, College of William and Mary, Iowa State University, Michigan State University, Los Alamos National Laboratory, Lawrence Livermore National Laboratory, San Diego State University, University of California Berkeley, University of Massachusetts, University of Tennessee

Beam Energy Scan Theory Collaboration (BEST Collaboration)
Principal Investigator/Project Director: Swagato Mukherjee; Lead Institution: Brookhaven National Laboratory
Participating Institutions: Indiana University, Lawrence Berkeley National Laboratory, McGill University, Michigan State University, MIT, North Carolina State University, Ohio State University, Stony Brook University, University of Chicago, University of Connecticut, University of Houston, University of Illinois at Chicago

Topical Collaborations are fixed-term, multi-institution collaborations established to investigate a specific topic in nuclear physics of special interest to the community, which is well aligned with programmatic NP goals.
The mission of the DOE Isotope Program is threefold

- Produce and/or distribute radioactive and stable isotopes that are in short supply, associated byproducts, surplus materials and related isotope services.
- Maintain the infrastructure required to produce and supply isotope products and related services.
- Conduct R&D on new and improved isotope production and processing techniques which can make available new isotopes for research and applications.

Produce isotopes that are in short supply only – the Isotope Program does not compete with industry

More than 225 customers in FY 2015
More than 400 shipments in FY 2015
DOE Isotope Program Production Sites

PNNL
Sr-90  Y-90 generator for cancer therapy
Ra-223 Cancer therapy
Np-237 Research

INL (ATR)
Co-60  Gamma knife, sterilization of medical equipment

Univ. of Washington
Pending supplier of research isotopes (e.g., At-211)

BNL (BLIP)
Ge-68  Ga-68 generator for tumor imaging
Sr-82  Rb-82 generator for cardiac imaging
Cu-67  Antibody labeling for targeted cancer therapy

UC Davis
Pending supplier of research isotopes (e.g., At-211, Zr-89, Y-86, Pb-203)

INL (ATR)
Co-60  Gamma knife, sterilization of medical equipment

Univ. of Missouri (MURR)
Pending supplier of research isotopes (e.g., Ho-166, Lu-177, Sm-153)

Y-12 (NNSA Facility)
Li-6  Neutron detection
Li-7  Radiation dosimeters

LANL (IPF)
Ge-68  Ga-68 generator for tumor imaging
Sr-82  Rb-82 generator for cardiac imaging
As-73  Environmental tracer
Si-32  Oceanographic research

Washington Univ.
Pending supplier of research isotopes (e.g., Cu-64)

ORNL
HFIR:
Se-75  Industrial NDA
Cf-252  Industrial sources
W-188  Cancer therapy
Ra-223 Cancer therapy
Np-237 Neutron flux monitors
Stable Isotopes Inventory:
E.g., Ca-48, Ga-69, Rb-87, Cl-37, Pt-195, Nd-146, Sm-149, Ru-99, Zr-96
Radioisotopes Inventory:
Ac-225 Cancer therapy

Duke University
Pending supplier of research isotopes (e.g., At-211)

SRNL (NNSA Tritium Facility)
He-3  Neutron detection
Fuel source for fusion reactors
Lung testing
Next Workshop on Isotope Federal Supply and Demand, November 9, 2015

Valuable for isotope demand forecasting

- Armed Research Institute
- Defense Logistics Agency
- Defense Threat Reduction Agency
- Department of Agriculture
- DOE/National Isotope Development Center
- DOE/National Nuclear Security Administration
- DOE/New Brunswick Laboratory
- DOE/Office of Fossil Energy-Oil and Natural Gas
- DOE/Office of Intelligence
- DOE/Office of Nuclear Energy
- DOE/Office of Science
- Department of Homeland Security
- Department of State
- Department of Transportation
- Federal Bureau of Investigation
- Food and Drug Administration
- National Aeronautics and Space Administration
- National Institutes of Health
- National Institute of Standards and Technology
- National Science Foundation
- National Security Staff
- Office of Science & Technology Policy
- Office of the Director of National Intelligence
A Serious Challenge: Domestic Stable Isotopes Inventory

- Currently there is no existing domestic broad-scope U.S. enrichment capability.
- Existing Inventory is from Y12 Calutron enrichment from 1945 – 1998.
- The inventory of 11 stable isotopes has been exhausted.
- These are unique materials with few other suppliers; demand is high (500 POs in FY14).
- U.S. is dependent upon Russia for new production of stable enriched isotopes.
The SIPF directly supports the DOE Isotope Program mission, restoring domestic capability that has been lacking since 1998. Renewed enrichment capability will benefit nuclear and physical sciences, industrial manufacturing, homeland security, and medicine.

- 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.”

- SIPF would mitigate U.S. foreign dependence of stable isotope enrichment

Notional Cost Range: $9.5M-$10.5M
Notional time frame for completion: FY 2020
SIPF Received Mission Need CD0 9/4/2015
### The FY16 Request for Nuclear Physics

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<th>($ in 000s)</th>
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- **Research** – Support for university and lab research increases across the program to address important opportunities identified by the research community, and to enhance high priority research that will foster significant advances in nuclear structure, nuclear astrophysics, the study of matter at extreme conditions, hadronic physics, fundamental properties of the neutron, and neutrinoless double beta decay.

- **User Facility Operations** – Operations of RHIC are maintained at the FY 2015 level with increases provided for critical staff, equipment, and materials required for reliable operations and support of research focused on characterizing the perfect quark-gluon liquid discovered in collisions of relativistic heavy nuclei. Beam development and commissioning activities continue at CEBAF as the 12 GeV CEBAF Upgrade project approaches completion, and scientific instrumentation is implemented in the experimental halls in preparation for the full start of the physics program in FY 2017. Operations of ATLAS are optimized, exploiting the new capabilities of CARIBU and completing the campaign with the GRETINA gamma ray spectrometer.

- **Other Operations** – Requested funding for the Isotope Program maintains mission readiness for the production of radioisotopes.

- **Projects** – 12 GeV CEBAF Upgrade and FRIB construction are supported according to baselined profiles.

- **Other** – Increased funding is provided for the SBIR/STTR programs consistent with the legislative mandate.
## Nuclear Physics
### FY 2016 Budget Status

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### Construction

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<td><strong>591,500</strong></td>
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Other DOE/NP News

• Adena Walker has joined NP as Program Assistant
• Brian Knesel has joined NP as Financial Management Specialist
• NP has additional active considerations ongoing in the Isotope and SBIR programs
• NP has a continuing need for program managers in Nuclear Structure/Fundamental Symmetries; HI; PRD Division Director
• GRETA has received CD0
• SIPF has received CD0
• First meeting of the Nuclear Data Advisory Committee is upcoming
• Workshop Report, “Nuclear Data Needs and Capabilities for Applications” in final preparation
• NP leading a discussion focused on establishing a pan-Federal communication/coordination forum on Nuclear Data
• ASCR-NP Computing Needs Workshop in discussion for June 2016
• PRD Deadline for proposals seeking FY16 funding is December 31, 2015.
Outlook

- There is a wealth of science opportunity near term at ATLAS, and longer term at FRIB which will be world leading. It is not too soon to begin to position the low energy community to take full advantage of FRIB as soon as it becomes operational.

- The CEBAF and RHIC programs are both unique and at the “top of their game” with compelling “must-do” science in progress or about to start. Long term, the future of QCD science is pointing to the need for an electron-ion collider.

- A very high priority for the NP community is U.S. leadership in the science of neutrino-less double beta decay.
  - A specific challenge will be ensuring essential R&D for candidate technologies is completed in the next 2-3 years prior to a down-select for a ton-scale experiment.

- An equally high priority for the NP community is increasing investment in research and projects as a percentage of the total NP budget. This will have to be accomplished while still respecting the unitarily limit.

- Research and production efforts to meet the Nation’s need for isotopes in short supply are being strengthened; re-establishing U.S. capability for stable isotopes will be a major advance and will help address community concerns in this area documented in the 2009 and 2015 NSACI Strategic Plans.