NP Low Energy Facilities and the SBIR/STTR Program

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DOE NP SBIR/STTR Exchange Meeting
November 6-7, 2013
Community (User) Meeting (Aug. 23-24)

A great place to start to get
– facility descriptions and status
– instrumentation initiatives and projects
– who to contact

http://meetings.nscl.msu.edu/CommunityMeeting2013/program.htm

• **FRIB/NSCL** Status and Overview – Georg Bollen/Daniela Leitner
• **ATLAS** Status and Overview – Guy Savard
• Agency Comments
  Brad Keister - NSF
  Tim Hallman – **DOE**

14 Working Groups

*Super-heavy Elements, Theory, Precision Measurements, High Rigidity Spectrograph, Astrophysics and Astrophysics Equipment, In-Flight Gamma-ray Detection, Neutron Detectors, HELIOS, Recoil Separator, Decay Spectroscopy, EOS, Data Acquisition, Applications*
Acknowledgments

Brazen “use” of material, input, and the effort of others

slides from
Birger Back, Guy Savard (ANL)
Georg Bollen, Thomas Glasmacher, Brad Sherrill (MSU)
Augusto Macchiavelli (LBNL)

DOE NP office

Thank you
Outline

• Context

• Science

• Major Facilities

• Advanced Instruments
• Refers to the energy scale of the science - of order few MeV (*nuclear binding scale*)

• Encompasses the physics governing nuclear decays and how they combine to create elements.

• It is where our field most directly impacts and touches our lives (energy, medicine, security)

• Provides a unique way to study fundamental properties of our universe (e.g. neutrinos)
Context

*much activity, exciting time...*

- New facilities to create and accelerate beams of exotic, radioactive ions are under construction in the US (FRIB at Michigan State University) and word-wide.

- New innovative instruments are being developed (e.g. gamma-ray tracking arrays).

- A new generation of measurements in heavy element science is underway.

- Pursuing ultra-sensitive measurements for neutrino science.
Facility for Rare Isotope Beams

FRIB Site February 2013

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 ultimate limits of existence for nuclei
- Nuclei which have neutron skins
- The 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 model of nuclei and how they interact.

Left: Titanium-shell beam dump prototype in final preparation for testing under rotation, a capability essential to handle very high power FRIB beams.
The “FRIB Era”

Major new facility for low energy nuclear science in the US. August 2013, CD-2/CD-3a approval

Sets the context:

- Science (weakly-bound exotic nuclei, nuclear astrophysics)
- Priorities for our field (current number 1 for new construction)
- Timeframe(s)

<table>
<thead>
<tr>
<th>Year</th>
<th>Event</th>
</tr>
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<tbody>
<tr>
<td>2014</td>
<td>Start construction</td>
</tr>
<tr>
<td>2022</td>
<td>FRIB CD4 (early date 2020)</td>
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<tr>
<td>2022+</td>
<td>Science (upgrades)</td>
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Rare Isotope Beams are part of a major world-wide effort: RIKEN(RIBF), TRIUMF(ISAC), GANIL(SPIRAL), GSI(FAIR), CERN(ISOLDE) ... others planned.
Rare Isotope Facilities – World View

Brad Sherrill
circa 2010
Chart of Nuclei

Number of protons

Available today

Domain of Rare Isotope Beams

Number of neutrons

Domain of Stable Beams

88-Inch Cyclotron
FRIB will increase the number of isotopes with known properties from ~2,000 observed over the last century to ~5,000.

Rates are available at http://groups.nscl.msu.edu/frib/rates/
Advanced Instruments Optimize Science Reach

New detectors are being discussed to optimally exploit FRIB

GRETINA (used at NSCL/ANL)

GRETA 4π array for FRIB

Other Instruments
The Facilities in more detail
Low Energy Nuclear Physics Facilities

DOE National User Facilities

  - High intensity stable beams
  - Limited radioactive beam program with stopped, re-accelerated and in-flight beams

- Facility for Radioactive Ion Beams (FRIB)
  - being constructed at MSU
  - Fast radioactive beams produced by fragmentation and in-flight fission
  - Stopped beams
  - Re-accelerated beams at near Coulomb barrier energies

NSF User Facility

- National Superconducting Cyclotron at MSU (http://nscl.msu.edu)
  - Fast radioactive beams produced by fragmentation (re-accelerated beams coming online)
Other DOE facilities (local use)

- LBNL 88-Inch Cyclotron (http://cyclotron.lbl.gov)
  - Basic and applied research w. stable beams

- Texas A&M Cyclotron Institute (http://cyclotron.tamu.edu)
  - Nuclear physics research with stable and radioactive re-accelerated beams

- Triangle-Universities Nuclear Laboratory (TUNL) (http://www.tunl.duke.edu)
  - High Intensity Gamma Source (HIGS)
  - Laboratory for Experimental Nuclear Astrophysics
  - Tandem Van de Graaff accelerator - neutrons
The ATLAS Facility

- Stable beams at high intensity and energy up to 10-20 MeV/u
- Light in-flight radioactive beams
  - light beams, no chemical limitations, close to stability, acceptable beam properties
- CARIBU beams
  - heavy n-rich from Cf fission, no chemical limitations, low intensity, ATLAS beam quality, energies up to 15 MeV/u
- State-of-the-art instrumentation for Coulomb barrier and low-energy experiments
- Operating over 5000 hrs/yr at about 95% efficiency
  - Users performing experiments at ATLAS:
    - FY10: 390  FY11: 326  FY12: 394
  - About 10 Ph.D. theses per year (16 in FY12)
40 Different Isotopes (a record)
*14.4% of beam time for Radioactive Beams
†2.3% of beam time for accelerated CARIBU runs (not incl. Develop.)
ATLAS layout with ongoing and planned upgrades

- Improved instrumentation
- New low-energy experimental hall
- Cryomodule and rebuncher rearranged
- New in-flight separator (AIRIS)
Main components of CARIBU

- **PRODUCTION:** “ion source” is $^{252}\text{Cf}$ source inside gas catcher
  - Thermalizes fission fragments
  - Extracts all species quickly
  - Forms low emittance beam

- **SELECTION:** Isobar separator
  - Purifies beam

- **DELIVERY:** beamlines and preparation
  - Switchyard
  - Low-energy buncher and beamlines
  - Charge breeder to increase charge state for post-acceleration
  - Post-accelerator ATLAS and weak-beam diagnostics
ATLAS In-flight radioactive beam production (AIRIS)

Few nucleon transfer reactions
Inverse kinematics

- **Stable**
- **Red** Reachable via \((p,n),(d,n),(d,^3\text{He}),(d,p)\)
- **Green** Reachable via \((^3\text{He},n)\)
- **Blue** Two-accelerator method
- **X** Used in experiments
Radioactive beams from CARIBU and AIRIS
■ Rare isotope production via in-flight technique with primary beams up to 400 kW, 200 MeV/u uranium

■ Fast, stopped and reaccelerated beam capability

■ Upgrade options
  ■ Energy 400 MeV/u for uranium
  ■ ISOL production – Multi-user capability

World-leading next-generation rare isotope beam facility
FRIB Science


Properties of nuclei
- Develop a predictive model of nuclei and their interactions
- Many-body quantum problem: intellectual overlap to mesoscopic science, quantum dots, atomic clusters, etc.

Astrophysical processes
- Origin of the elements in the cosmos
- Explosive environments: novae, supernovae, X-ray bursts ...
- Properties of neutron stars

Tests of fundamental symmetries
- Effects of symmetry violations are amplified in certain nuclei

Societal applications and benefits
- Bio-medicine, energy, material sciences
- National security

“Data to date on exotic nuclei are already beginning to revolutionize our understanding of the structure of atomic nuclei. FRIB will enable experiments in uncharted territory at the limits of nuclear stability. FRIB will provide new isotopes for research related to societal applications, address long-standing questions about the astrophysical origin of the elements and the fundamental symmetries of nature.”

2012 NRC Decadal Study
FRIB Major Systems

Experimental Systems

Accelerator Systems
FRIB Accelerator Systems: SRF Driver Linac

- Accelerate ion species up to $^{238}$U with energies of no less than 200 MeV/u
- Provide beam power up to 400kW
  - Highest power heavy ion accelerator in the world
FRIB Experimental Systems: FRIB Rare Isotope Production

- Production of rare isotope beams with 400 kW beam power using light to heavy ions up to $^{238}$U with energy $\geq 200$ MeV/u
- Three separation stages for high beam purity
- Provisions for isotope-harvesting
- 400 kW heavy-ion beams pose challenges
  - High-power density
  - Radiation damage
FRIB Timeline

- 8 June 2009 – DOE-SC and MSU sign Cooperative Agreement
- Sept 2010 – Critical Decision 1 (CD-1) approved
- April 2012 – Lehman review, baseline and start of civil construction
  - Project is ready “to establish the performance baseline when funding profile guidance from DOE is provided”
- Start of detailed design
- June 2013 – Successful Lehman Review
- **August 1, 2013 DOE Office of Science Approves CD-2 and CD-3a**
  - Baseline for FRIB established
  - Civil construction expected to start by April 2014
- Summer 2014 – CD-3b (technical construction)
- June 2022 - CD-4 (project complete)
  - Project managed for early completion in Dec 2020
The Instruments
Main tools enabling the physics: ATLAS suite of experimental equipment

- CPT mass spectrometer
- X-array
- HELIOS spectrometer
- Digital Gammasphere
- GRETINA
- FMA
- AGFA
- Si-array (Ludwig) and Enge spectrometer
- In-flight RIBs production
- Laser Lab
- Beta decay Paul trap

+ outside instruments: CHICO-II, HERCULES, ORRUBA, APOLO...
Gamma-ray Spectroscopy has played a major role in our current understanding of the structure of atomic nuclei. It will continue to be a unique tool in the experimental studies of the nuclear structure as we push the limits of $A$ (size), $(N-Z)$ (Isospin), $I$ (rotational frequency), and $E^*$ (Temperature).

Ingredients:

“Effective” Energy resolution ($\delta E$), Efficiency ($\varepsilon$), Peak-to-Total (P/T) plus auxiliary devices

The calculated resolving power is a measure of the ability to observe faint emissions from rare and exotic nuclear states.
Towards the “Ultimate” Ge Array

Gamma-ray tracking detectors
I.Y. Lee
Lawrence Berkeley National Laboratory, Berkeley, CA 94720, USA

Pulse shape analysis in segments
⇒ 3D position of interaction points

Tracking of photon interaction points
⇒ energy and position of γ-ray

GRETA: utilizing new concepts in γ-ray detection
Nuclear Science Division, Lawrence Berkeley National Laboratory, Berkeley, CA 94720, USA
The Gamma-ray Tracking Array GRETINA

One of the most advanced gamma-ray detector array for nuclear science – uses highly segmented detectors to track and reconstruct gamma-rays.

First campaign successfully completed at Michigan State University

Over 3000 hrs of beam-time and 200 users in the first year

Broad experimental program in nuclear structure and nuclear astrophysics

GRETA, the full $4\pi$ array, will be a major instrument at the Facility for Rare Isotope Beams (FRIB) under construction at MSU
Majorana - search for $^{76}\text{Ge} \ 0\nu 2\beta$ decay

$n \Rightarrow p + e^- + \bar{\nu}_e \quad \nu_e + n \Rightarrow p + e^-$

Fig. from arXiv:0708.1033
The Majorana Demonstrator

Funded by DOE Office of Nuclear Physics and NSF Particle Astrophysics, with additional contributions from international collaborators.

Goals:  
- Demonstrate backgrounds low enough to justify building a tonne scale experiment.  
- Establish feasibility to construct & field modular arrays of Ge detectors.  
- Test Klapdor-Kleingrothaus claim.  
- Searches for additional physics beyond the standard model.

• Located underground at 4850’ Sanford Underground Research Facility  
• Background Goal in the 0vββ peak region of interest (4 keV at 2039 keV)  
  3 counts/ROI/t/y (after analysis cuts)  
  scales to 1 count/ROI/t/y for a tonne experiment

• 40-kg of Ge detectors  
  – 30 kg of 86% enriched $^{76}$Ge crystals  
  – 10 kg of $^{nat}$Ge  
  – Detector Technology: P-type, point-contact.

• 2 independent cryostats  
  – ultra-clean, electroformed Cu  
  – 20 kg of detectors per cryostat  
  – naturally scalable

• Compact Shield  
  – low-background passive Cu and Pb shield with active muon veto
Within NP, and in preliminary discussion with HEP, there has begun to be some rumination about how to carry out a possible down-select process **if the science “demands” that a ton-scale 0νββ experiment be carried out**, and resources are available.

Discussion with HEP suggests that one approach could be an NSAC subpanel with members from NP and HEP to consider DBD R&D and downselect criteria. The subpanel could consider U.S. (pre-conceptual) R&D proposals for next generation experiments, in the context of related international planning efforts and report on:

- Merit of U.S. pursuing a next generation double beta decay experiment in current international landscape
- Identify potential candidates of next generation experiments – description, Status of R&D, remaining risks, priorities for future R&D
- Down select criteria for an internationally competitive experiment, including a sensitivity goal

Charge related to 0νββ and Mo⁹⁹ direction from Congress planned to be given to NSAC
Many examples of SBIR projects that have direct relevance to the LE program
- Several discussed here
- From personal interest: gamma-ray tracking (GRETINA), Majorana.
- FRIB related developments

Research community welcomes collaboration

Continued opportunities and needs

One thought
high rate and data throughput capabilities: from intense beams AND the desire/need to collect “full” data information (digital data streaming mode – “rate independent”)
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