Topics in US Nuclear Physics

Some issues in budget planning

Work Force Development

Facility for Rare Isotope Production-Current Status

Kirby Kemper, Florida State University

Map of Florida

Westcott Building, Florida State University, Tallahassee.

Physics Letters B 321 (1994) 183–188
North-Holland

PHYSICS LETTERS B

J Dependence in $^{12}C(^{6}\vec{Li},^{3}He)$

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Editor: R.H. Siemssen

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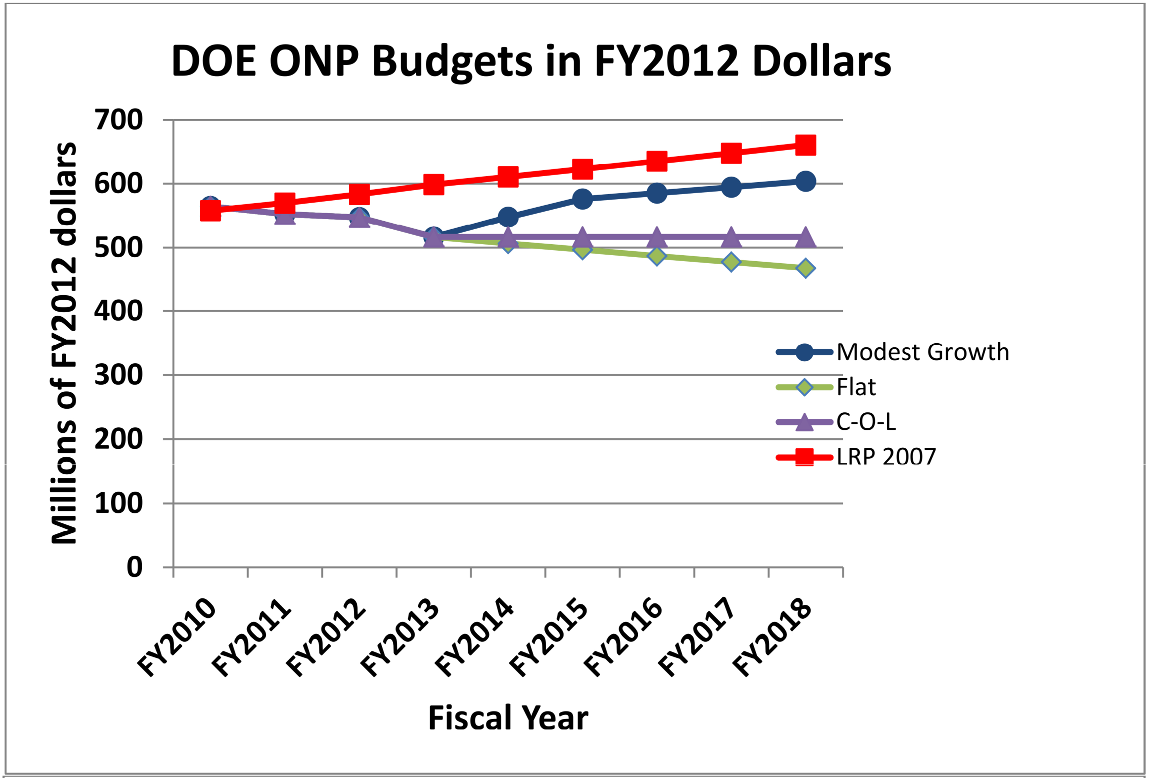
In 2012 a panel of 18 Nuclear Physicists including two outside nuclear physics was convened by the Department of Energy to address the following question: If budgets for Nuclear Physics are flat for the next 5 years how do we implement the 2007 Long Range Plan: which facility should be closed- FRIB, JLAB or RHIC

The physics areas were broken up into Nuclear Structure/ Nuclear Astrophysics, Relativistic Heavy-Ion Physics, Hadronic Physics and Fundamental Symmetries/Neutrino Physics

Each Area Had to Convince the other areas that their the facility for their area should get a higher priority then one of the other areas

Most difficult panel I have ever served on- five panel meetings plus three area meetings to develop arguments for why our area of nuclear physics is more important than another area


DOE ONP Budgets in FY2012 Dollars
Millions of FY2012 dollars
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FY2010
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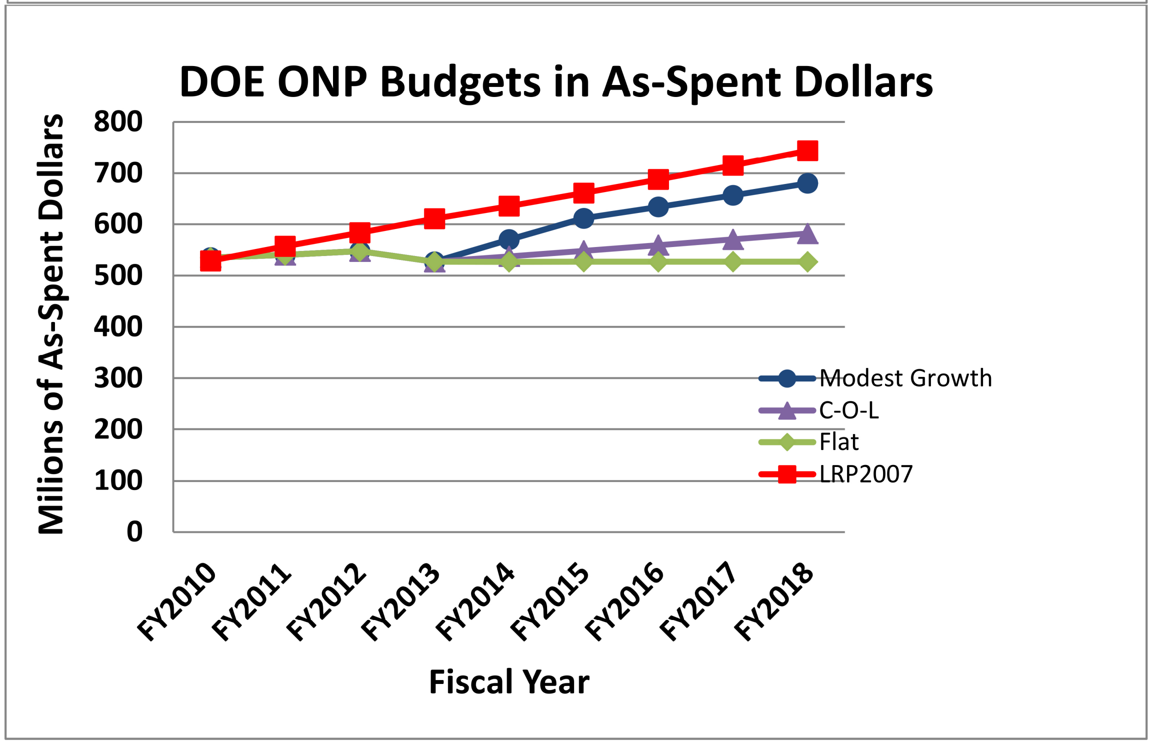
FY2018
Fiscal Year
Modest Growth
Flat
C-O-L
LRP 2007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Fiscal Year
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C-O-L
Flat
LRP2007

A major charge to our nuclear physics community in the US is called workforce development-By this is meant making sure that enough students are produced to satisfy the personnel needs of the National Labs, University Faculty and Industries.

So as part of the review to decide which major facility to shut down in the case of financial flat lines, the question was asked "Which field provides the most work force personnel and which universities are the major producers?"

Naturally each nuclear physics area claimed a huge number of graduates with lots of double and triple counting. It was decided that for the first time we would get the name of each graduate, their year of graduation, the title of their dissertation and the university from which they graduated- This was a huge task-

Various groups claimed names left off the list-The response was "Give us their names and other required information " In the end the following data were agreed to be accurate.

	Last Name	First Name	Year	PhD Institution	Employer	Country	Title
59	Plaster	Bradley Robert	2004	Massachusetts Institute of Technology	University of Kentucky	USA	Associate Professor
60	Poplawski	Nikodem J	2004	Indiana University	Indiana University	USA	Visiting Research Associate
61	Prok	Yelena Alexandrovna	2004	University of Virginia	Old Dominion University	USA	Visiting Assistant Professor
62	Purwar	Anuj Kumar	2004	Stony Brook University	Varian Medical Systems	USA	Senior Physicist
63	Rutel	Bonnie Gwen	2004	Florida State University			
64	Sacco	Gian Franco	2004	University of Connecticut	NASA Jet Propulsion Laboratory	USA	Key Scientist
65	Santoro	Joseph P.	2004	Virginia Polytechnic Institute and State University	Beth Israel Medical Center	USA	Medical Physicist
66	Schoen	Keary	2004	University of Missouri - Columbia	Prince George's County Public Schools	USA	Mathematics Instructional Lead Teacher
67	Slifer	Karl J.	2004	Temple University	University of New Hampshire	USA	Assistant Professor
68	Stapels	Christopher John	2004	Oregon State University	Radiation Monitoring Devices	USA	Research Scientist
69	Stech	Edward J.	2004	University of Notre Dame	University of Notre Dame	USA	Associate Professional Specialist
70	Tiburzi	Brian Charles	2004	University of Washington	City University of New York	USA	Assistant Professor
71	Torrieri	Giorgio	2004	University of Arizona	Goethe Universitaet Frankfurt	Germany	FIAS fellow
72	Tumey	Scott Joseph	2004	University of Maryland	Lawrence Livermore National Laboratory	USA	
73	Ungaro	Maurizio	2004	Rensselaer Polytechnic Institute	Jefferson Lab	USA	
74	Vale	Carla Manuel	2004	Massachusetts Institute of Technology	Carnegie Mellon University	USA	MBA Candidate
75	Vaman	Constantin	2004	Stony Brook University	Virginia Commonwealth University	USA	Postdoctoral Researcher
76	Wang	Huangsheng	2004	City University of New York			
77	Wang	Yiqun	2004	University of Texas			
78	Whitaker	Thomas Jenkins	2004	Indiana University	WellStar Health Systems	USA	Physicist
79	Wilde	Justin Lynn	2004	University of Utah	ITT Industries	USA	Engineer
80	Young	Alaine	2004	Arizona State University			
81	Zetocha	Valeriu Ioan	2004	Stony Brook University	Banco Santander	Spain	Vice President
82	Zhang	Haibin	2004	Yale University	PIMCO	USA	VP Asset Analyst
83	Zhou	Leming	2004	The George Washington University	University of Pittsburgh	USA	Assistant Professor
84	Zhu	Lingyan	2004	Massachusetts Institute of Technology	Hampton University	USA	Adjunct and Research Support Faculty
85	Zhu	Shaofei	2004	University of Notre Dame	Argonne National Laboratory	USA	Assistant Physicist
86	Abdel-Aziz	Mohamed Hassan	2005	Wayne State University			
87	Bell	Elizabeth	2005	Texas A&M University	Blinn College	USA	Faculty
88	Bhagwat	Mandar S	2005	Kent State University			

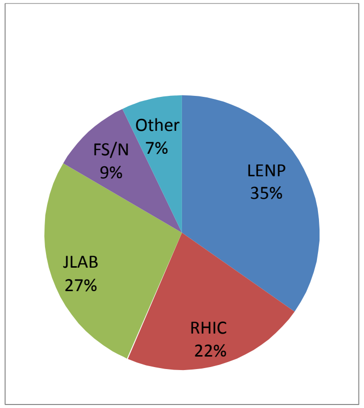
	Last Name	First Name	Year	PhD Institution	Employer	Country	Title
630	Walker	Matthew	2011	Massachusetts Institute of Technology			
631	Wang	Lai	2011	The George Washington University			
632	Zickefoose	James	2011	University of Connecticut	University of Connecticut	USA	Adjunct Faculty
633	Becerril Reyes	Ana Delia	2012	Michigan State University	CSIC Consejo Superior de Investigaciones Cientificas	Spain	Postdoctoral Researcher
634	Capuano	Carissa Lee	2012	College of William and Mary			
635	Cendejas	Ramon	2012	University of California, Los Angeles	Pennsylvania State University	USA	Postdoctoral Researcher
636	Hanks	J. A. (Ali)	2012	Columbia University	Stony Brook University	USA	Postdoctoral Researcher
637	Harsono	Tutun	2012	The George Washington University		USA	High School Teacher
638	Jawalker	Sucheta Shrikant	2012	College of William and Mary	Duke University	USA	Postdoctoral Researcher
639	Kirscher	Johannes	2012	The George Washington University		Germany	
640	Lai	Yue Shi	2012	Columbia University	MIT	USA	Postdoctoral Researcher
641	Lau	Kit Yu	2012	Michigan State University		Hong Kong	Higher Education Professional
642	Myers	Katherine E.	2012	The George Washington University	Rutgers University	USA	Postdoctoral Researcher
643	Voss	Philip Jonathan	2012	Michigan State University	Simon Fraser University	Canada	Postdoctoral Researcher
644	Wang	Hui	2012	Michigan State University	Brookhaven National Laboratory	USA	Postdoctoral Researcher
645	Yao	Huan	2012	Temple University	College of William and Mary	USA	Postdoctoral Researcher

Between 2004 and May 2012, 645 Ph.D.s were awarded at U.S. Institutions in Nuclear Physics (based on ProQuest queries: http://www.proquest.com/en-US/). Of these theses, 224 were awarded in Low- energy Nuclear Physics (LENP), 174 in JLAB related physics, 140 in RHIC related physics, and 61 in Fundamental Interactions/Neutrinos (FS/N).

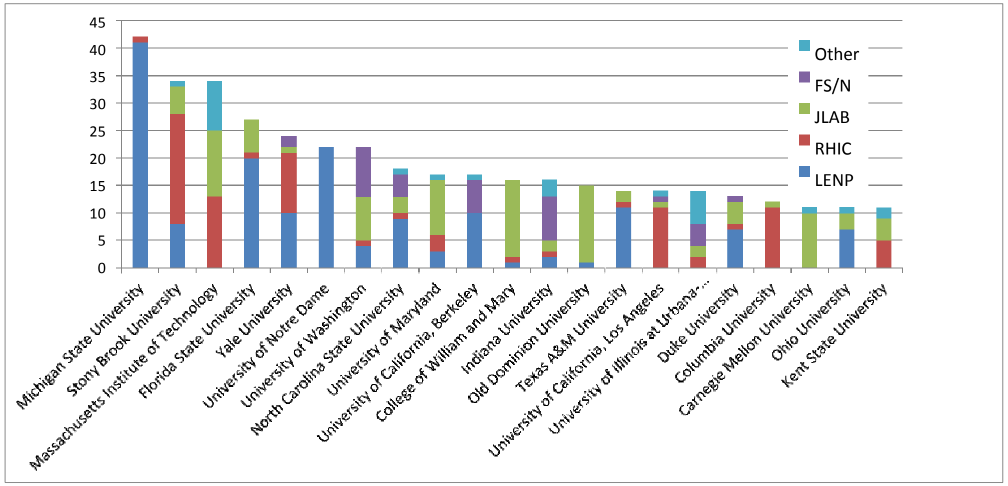
Employment Analysis of U.S. PhD Recipients in Nuclear Physics (2004 – May 2012)

Between 2004 and May 2012, 645 Ph.D.s were awarded at U.S. Institutions in Nuclear Physics (based on ProQuest queries: http://www.proquest.com/en-US/). Of these theses, 224 were awarded in Low-energy Nuclear Physics (LENP), 174 in JLAB related physics, 140 in RHIC related physics, and 61 in Fundamental Interactions/Neutrinos (FS/N). The relative percentages are shown below.

Nuclear Science Graduates from U.S. Institutions (2004 - May 2012)



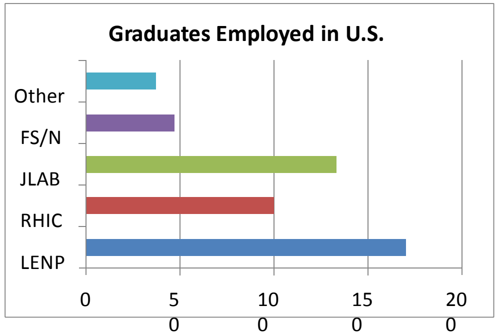
The leading institutions granting more than 10 Ph.D.s are displayed in the following graph with the color coding corresponding to the three areas.

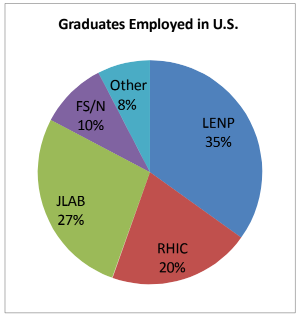


A comprehensive internet search was performed to find the current or most recent known employers of these graduates. The employment of 581 graduates (>90%) was determined almost equally distributed over the four areas (LENP 202, 90.2%, JLAB 157, 90.2%, RHIC 127, 90.7%, and FS/N 53, 86.9%).

The next question our committee was asked to determine is the employment of our graduates

The majority of the students remained employed in the U.S. as shown in the graphs below:

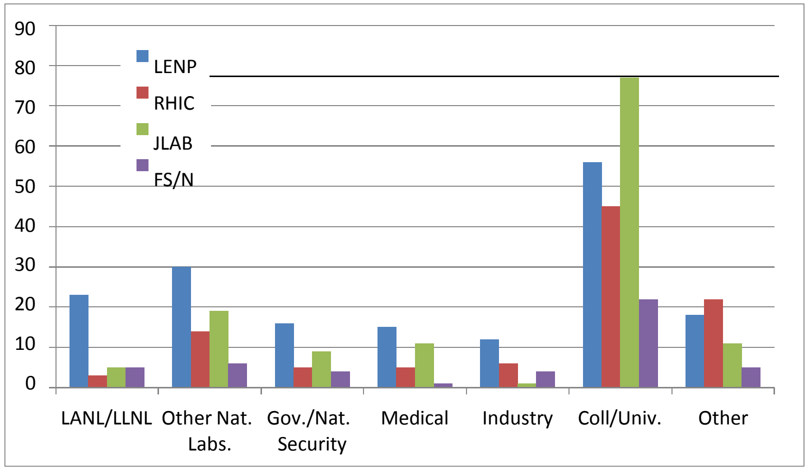




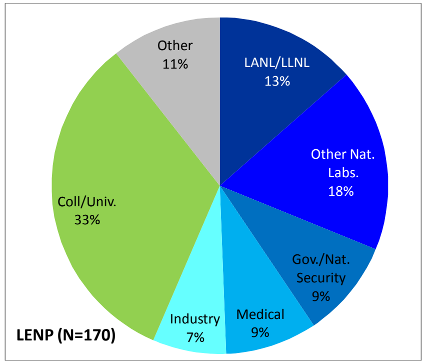
The employers were sorted into the following categories:

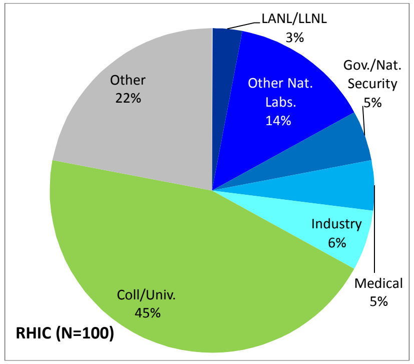
LLNL/LANL:	The NNSA laboratories: Lawrence Livermore National Laboratory and Los Alamos National Laboratory
Gov./Nat. Security:	Government or Agencies or Institutions directly working on National Security Related Issues.
Industry:	Industrial companies
Medical:	Medical companies or medical schools
Coll/Univ.:	Colleges or Universities (including temporary, postdocs, and staff positions)
Other Nat. Labs:	Nuclear Physics National Laboratories (ANL, BNL, LBL, ORNL)
Other:	Employment in finance, computing, consulting, etc., as well as unemployed.

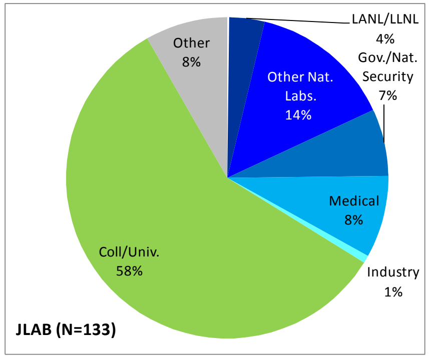
The distribution between these categories for the four areas is shown below:

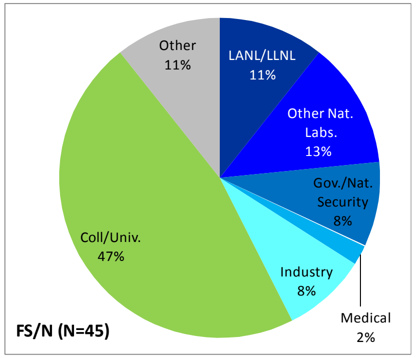


The relative distributions for the LENP, JLAB, RHIC, and FS/N are shown below:

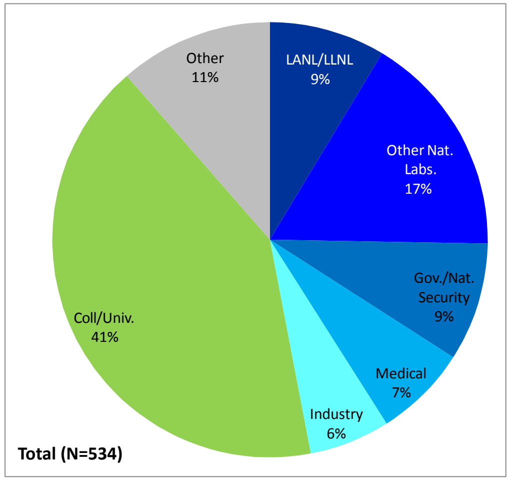








Overall the employment of the 534 graduates working in the U.S. is distributed as shown below:



What jobs do the nuclear physics PhDs take in the US?

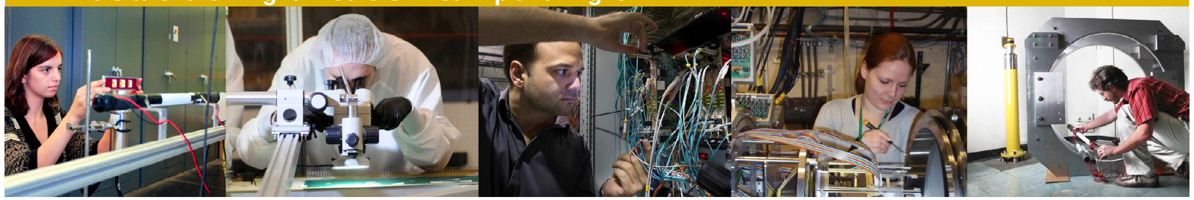
- 40% at colleges or universities
- 10% by government or national security organizations
- 10% in the nuclear weapons complex (LANL/LLNL)
- 17% at other national laboratories
- 6% in industry
- 7% in medical applications
- 10% in other areas

In the US we have the Nuclear Science Advisory Committee (NSAC) to provide the advice to the Department of Energy and National Science Foundation on future activities and nuclear Science. This is a formally constituted committee allowed to give advice to federal agencies.

Other committees are often formed to produce reports such as those for the production of isotopes but these are merely advisory, whereas NSAC reports must be followed if possible by the funding agencies.

Our 2012 advisory report was adopted by NSAC and so would be followed by the funding agencies if we have budget shortfalls.

The Site of the Wright Brothers' First Airplane Flight



THe 2015 LONG RANGE PLAN for NUCLEAR SCIENCE

The process by which the LRP is developed involves the Division of Nuclear Physics of the APS, the DOE and NSF staff members

The first step is to appoint groups to write "white papers". This is accomplished by groups holding "Town Hall" meetings. Every town hall meeting has designated "conveners" who make sure a final report is produced. Any group can self-assemble and develop a white paper. For example, in 2000 a group called for the establishment of an underground laboratory in the US. The different white papers always end with resolutions the wording of which is argued about for many hours. There is always a call for more funding for the area of nuclear physics covered in the white paper.

Next the conveners meet to produce documents to present to the Long Range Planning Committee which is typically 40 or so people who are appointed by the funding agencies and the Division of Nuclear Physics. This group then has a three or so day meeting to produce the recommendations that will appear in the report. The fight for the order of the recommendations and the sub bullets under each one is intense and very difficult. Once the recommendations are agreed upon then a writing group is appointed to prepare the section of the LRP that backup the recommendation.

The last step is for NSAC to approve the report and present it to the funding agencies

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.

RECOMMENDATION II

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.

RECOMMENDATION III

We recommend a high-energy high-luminosity polarized EIC 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 vision of an EIC was already a powerful one in the 2007 Long Range Plan. The case is made even more compelling by recent discoveries. This facility can lead to the convergence of the present world-leading QCD programs at CEBAF and RHIC in a single facility. This vision for the future was expressed in the 2013 NSAC report on the implementation of the 2007 Long Range Plan with the field growing towards two major facilities, one to study the quarks and gluons in strongly interacting matter and a second, FRIB, primarily to study nuclei in their many forms. Realizing the EIC will keep the U.S. on the cutting edge of nuclear and accelerator science.

INITIATIVES

A number of specific initiatives are presented in the body of this report. Two initiatives that support the recommendations made above and that will have significant impact on the field of nuclear science are highlighted here.

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 EIC 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 EIC.

WORKFORCE, EDUCATION, AND OUTREACH

A workforce trained in cutting-edge nuclear science is a vital resource for the Nation. *We recommend that the NSF and DOE take the following steps.*

Enhance programs, such as the NSF-supported Research Experiences 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.

Research in theory, experiment, and computation as well as instrumentation initiatives from university groups and laboratories provide a unique education and training environment that must be nurtured.

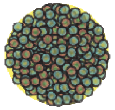
Facility for Rare Isotope Beams

- FRIB will be a $730 million national user facility funded by the Department of Energy Office of Science (DOE-SC), Michigan State University, and the State of Michigan
- FRIB Project completion date is June 2022, managing to an early completion in fiscal year 2021
- FRIB will serve as a DOE-SC national user facility for world-class rare isotope research supporting the mission of the Office of Nuclear Physics in DOE-SC

FRIB will enable scientists to make discoveries about the properties of these rare isotopes in order to better understand the physics of nuclei, nuclear astrophysics, fundamental interactions, and applications for society

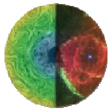
FRIB Science Is Aligned with National Priorities

Articulated by NSAC LRP (2015), NRC Decadal Survey of Nuclear Physics (2012), National Research Council RISAC Report (2006)



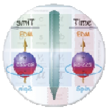
Properties of nuclei

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



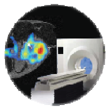
Astrophysical processes

- Explore origin of the elements in the cosmos
- Model explosive environments: novae, supernovae, X-ray bursts …
- Determine properties of neutron stars



Tests of fundamental symmetries

- Complementary tests for physics beyond the Standard Model

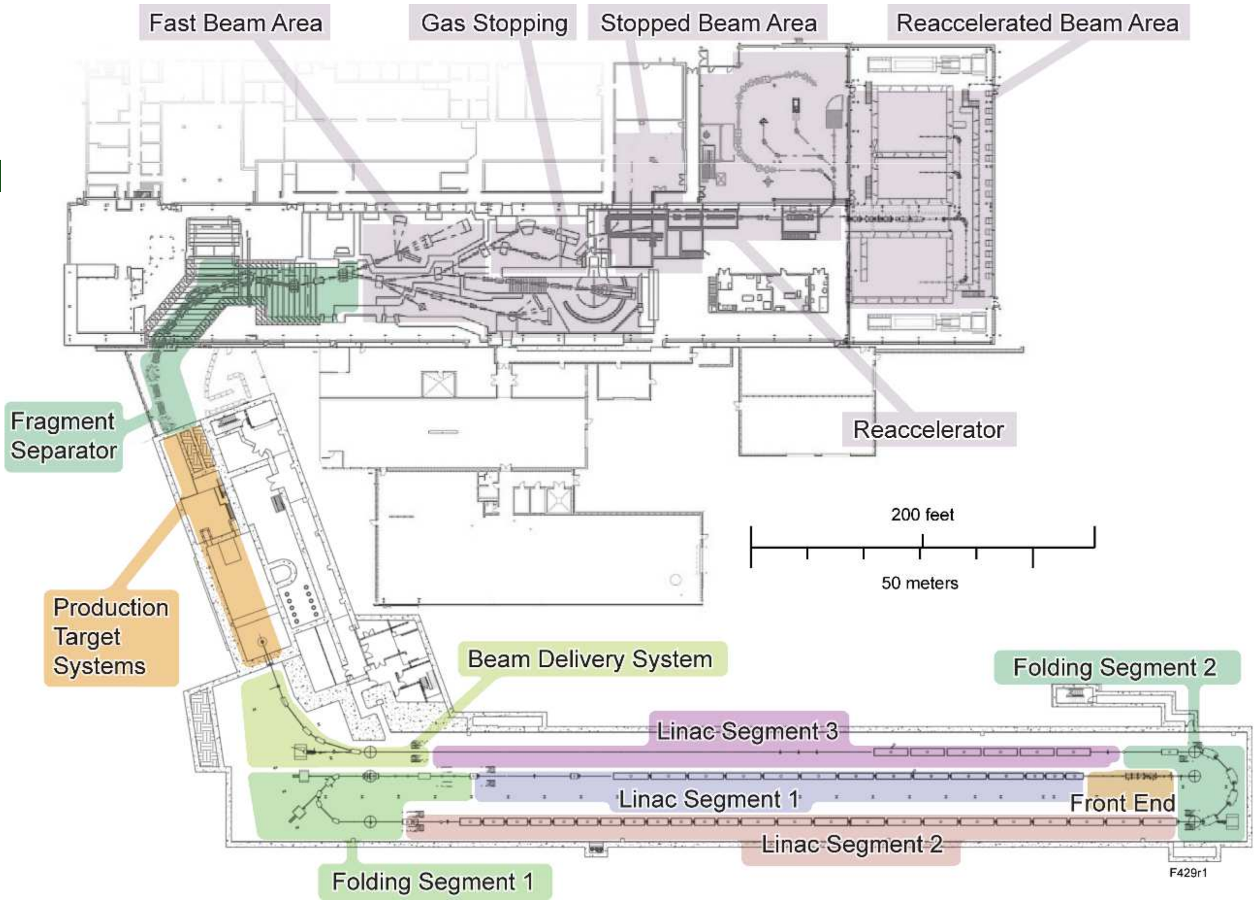


Societal applications and benefits

- New tools for bio-medicine, energy, material sciences
- National security

FRIB Scientific Capabilities

- Key capabilities: fast, stopped, reaccelerated beams



FRIB Project Update, February 2017

FRIB is a heavy-ion superconducting linac driver with beam power of up to 400kW. It will deliver beams from protons with energy up to 500 MeV and uranium with energy up to 200MeV/nucleon. Fast beams through fragmentation or stopped and reaccelerated beams will be available for experiments.

Its expected completion is 2021 with full operation in 2022

At present its cost is $730M and its operating cost in present dollars is set at $120M

Space has been left to install more cryomodules that would increase the driver energy to 400 MeV/nucleon which would increase secondary beam intensities by a factor of 10.

Civil Construction is 90% complete and is 3 months a head of schedule

Civil Construction Tracking to Beneficial Occupancy in March 2017

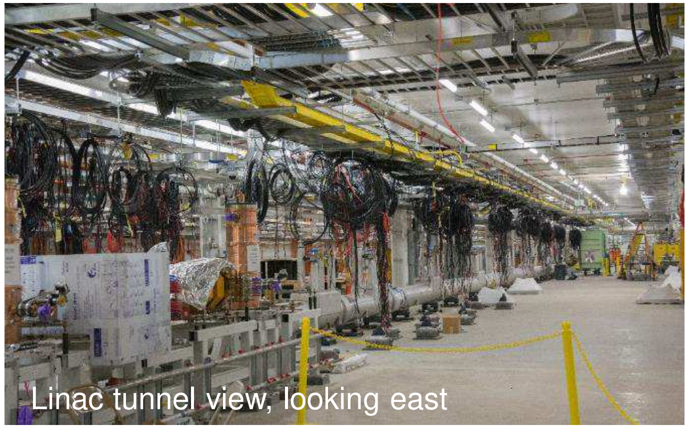
- Front-end building turned over with conventional utilities operational in December 2016
- Civil construction to be substantially complete in March 2017
- FRIB construction site on February 13, 2017. Web cameras at www.frib.msu.edu

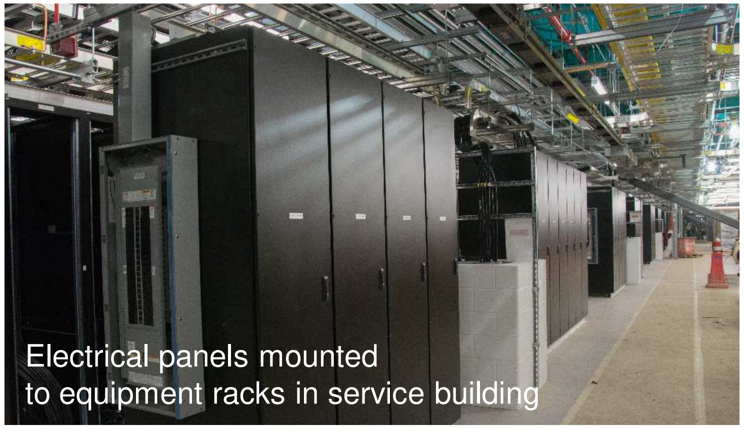
On 29 September, the FRIB Project installed the first of 48 cryomodules into its linear accelerator tunnel.

This installation involved the β=0.085 cryomodule, which is FRIB's first completed and tested cryomodule. It is approximately 20 feet long and weighs approximately 26,000 pounds.

The β=0.085 cryomodule contains eight superconducting radiofrequency (SRF) β=0.085 quarter-wave resonators, three superconducting focusing solenoids and three beam-position monitors.

Technical Construction Progress [2]

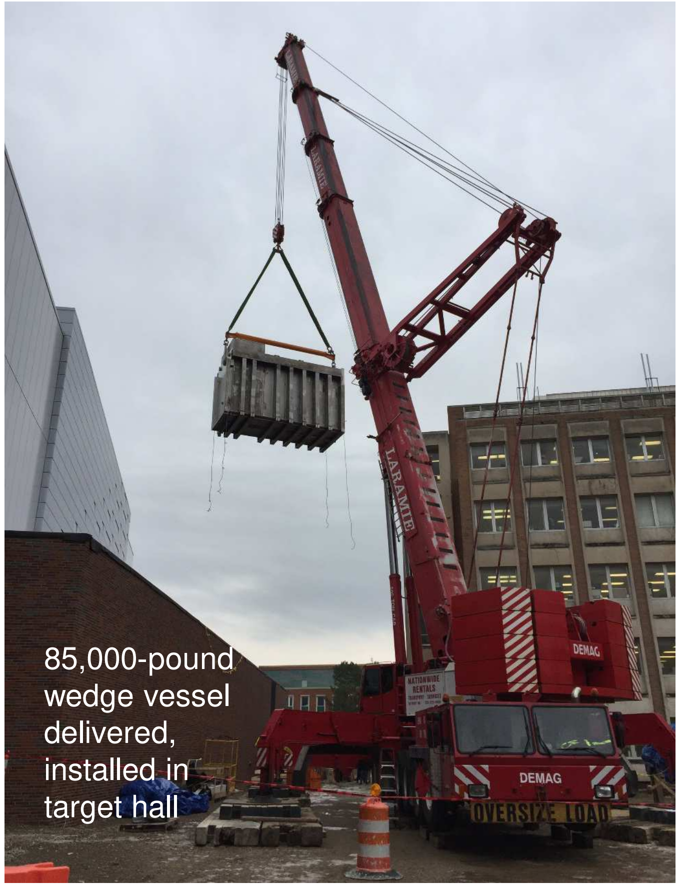




Technical Construction Progress

First of 48 cryomodules installed in linac tunnel

First beam from ARTEMIS ion source

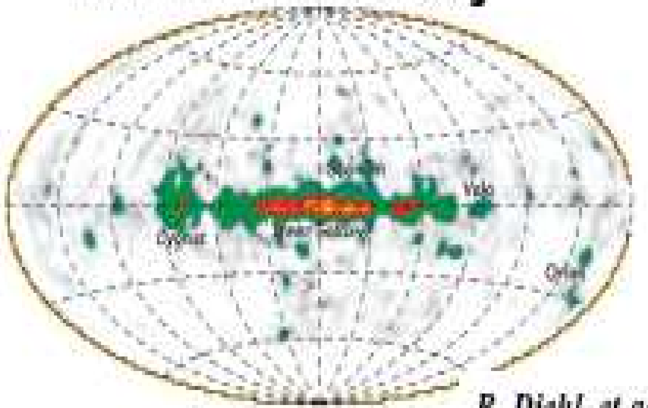


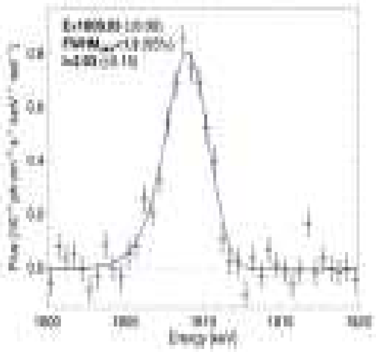
85,000-pound wedge vessel delivered, installed in target hall

A major research program at FRIB will be in Coulomb excitation where the reaccelerated beam will allow experiments at the neutron dripline up to Ca and maybe Ni.

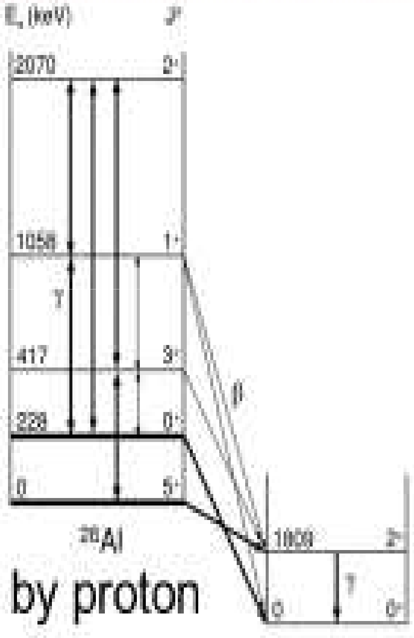
Nuclear reactions with isomeric beams (Sergio Almaraz-Calderon, Florida State University)

^{26}Al in the Galaxy





R. Diehl, et al. A&A 522, A51 (2010)



Destruction of ^{26}Al in AGB, CN, CCSN, is dominated by proton captures on both, $^{26}Al^{g}$ and $^{26}Al^{m}$

Uncertainties in the $^{26}Al^{m}(p,\gamma)$ reaction rate are important to understand production of ^{26}Al in massive stars and isotopic abundances of ^{26}Mg in nova. No experimental $^{26}Al^{m}(p,\gamma)$ reaction rate!

$^{26}Al^{m}(d,p)^{27}Al \rightarrow {}^{26}Al^{m}(p,\gamma)^{27}Si$
using (^{27}Al, ^{27}Si) mirror symmetry

Previous Studies

Deibel et al., PRC 80, 035806 (2009)

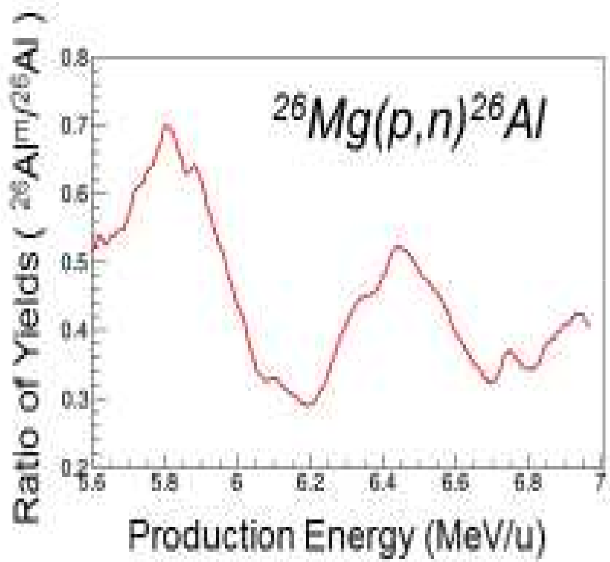
Lotay et al., PRL 102, 162502 (2009), PRC C 80, 055802 (2009)

Measurement of the $^{26}Al^{m}$(d,p) reaction

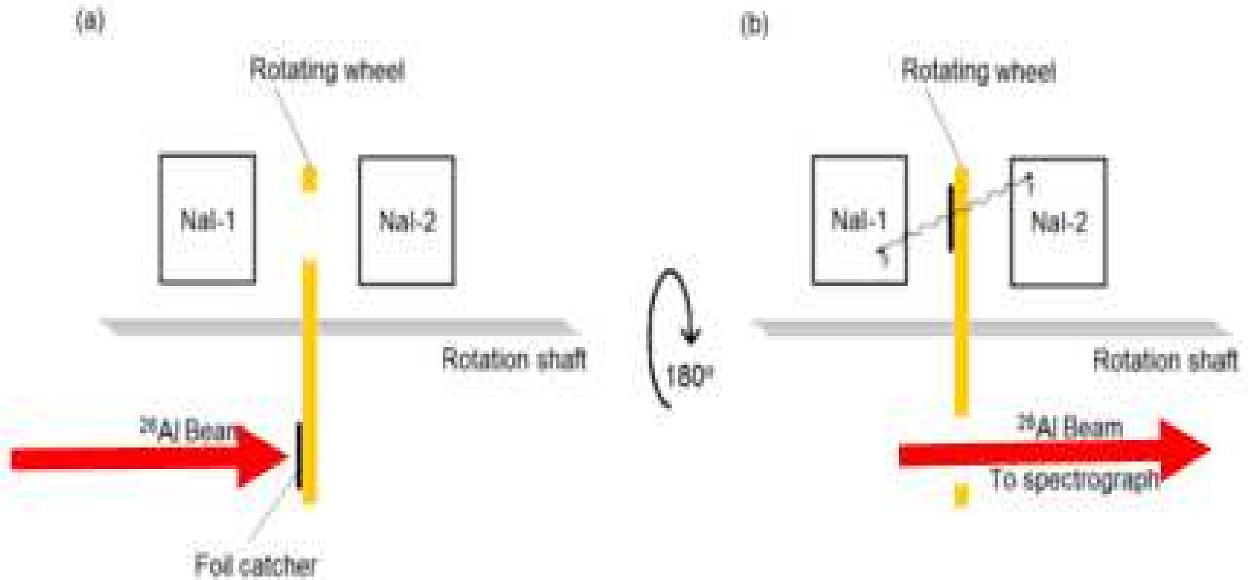
Step 1. Making of an isomeric beam

In-flight via the ^{26}Mg(p,n) reaction
→ we can choose the production energy!

Argonne NATIONAL LABORATORY



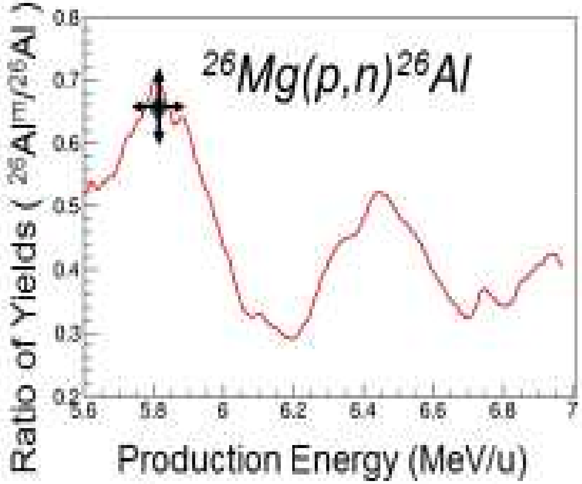
Characterization of the beam using a Rotating wheel setup

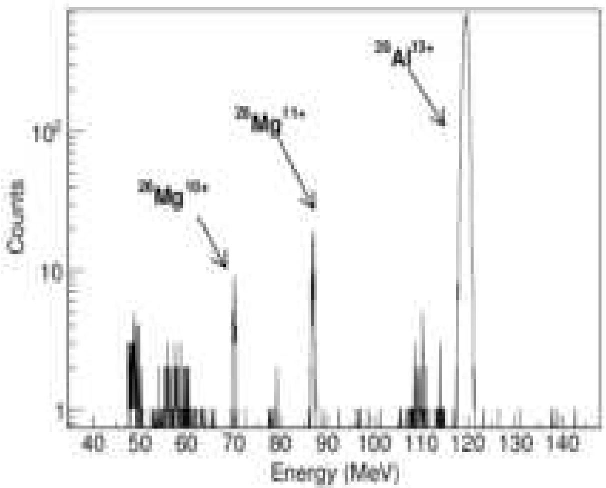


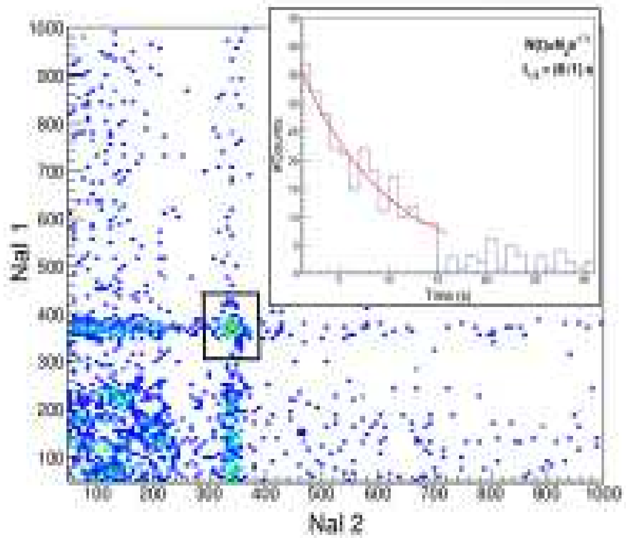
Measurement of the $^{26}Al^{m}(d,p)$ reaction

Step 1. Making of an isomeric beam

First time that a $^{26}Al^{m}$ beam with:
High purity → 98% purity,
Good energy resolution → FWHM~1%
High intensity I~$2x10^{5}$ pps,
Isomer content → 70% Isomer, 30% g.s.



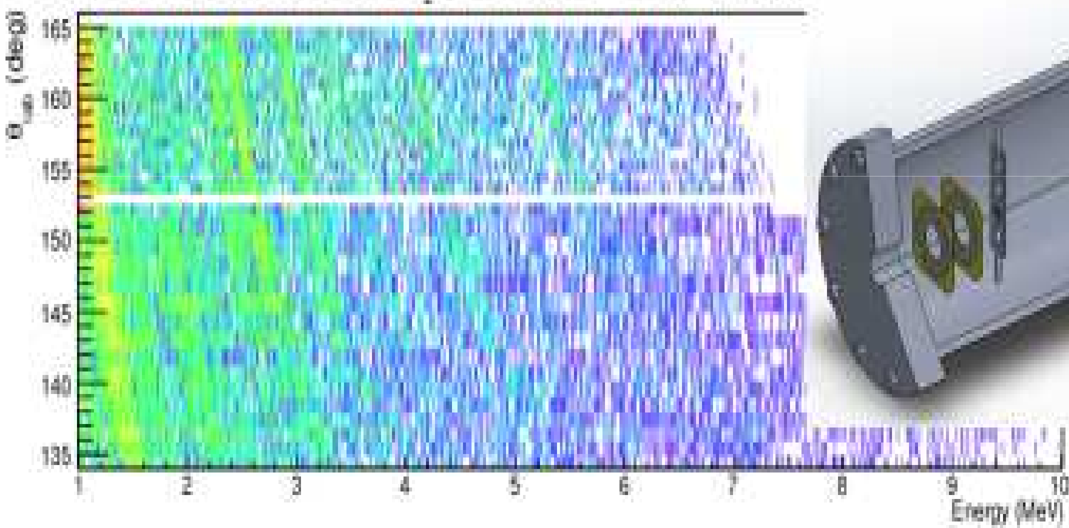


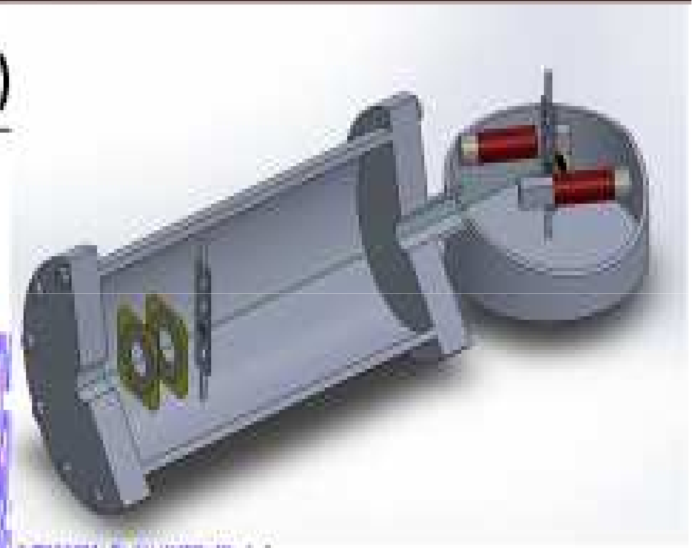


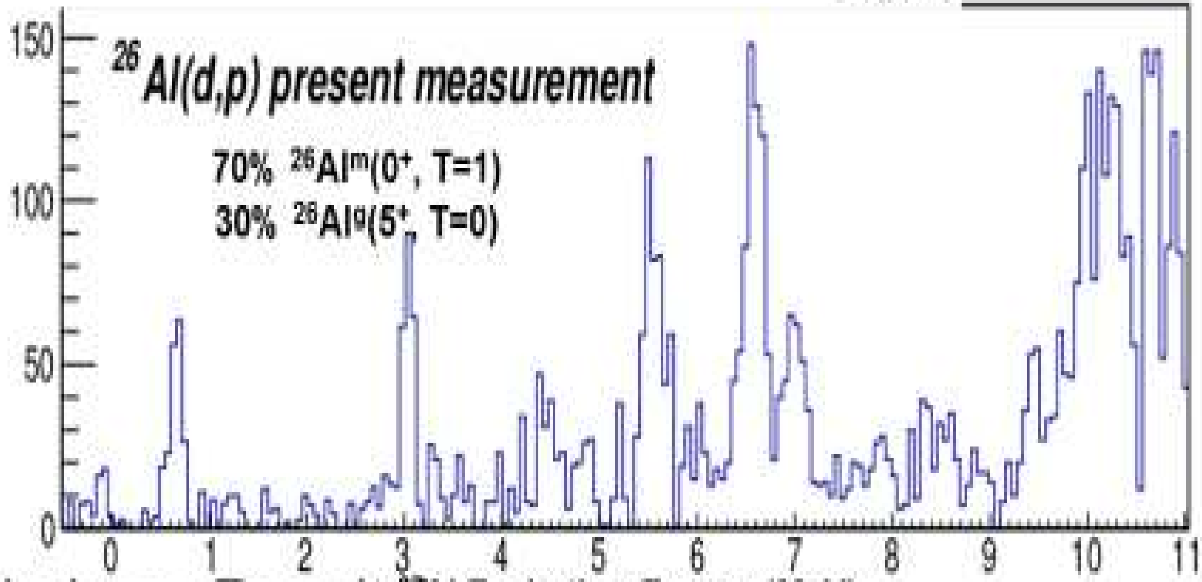
Preliminary Results!

Measurement of the $^{26}Al^{m}(d,p)$ reaction

Step 2. Measurement of the $^{26}Al^{m}(d,p)$



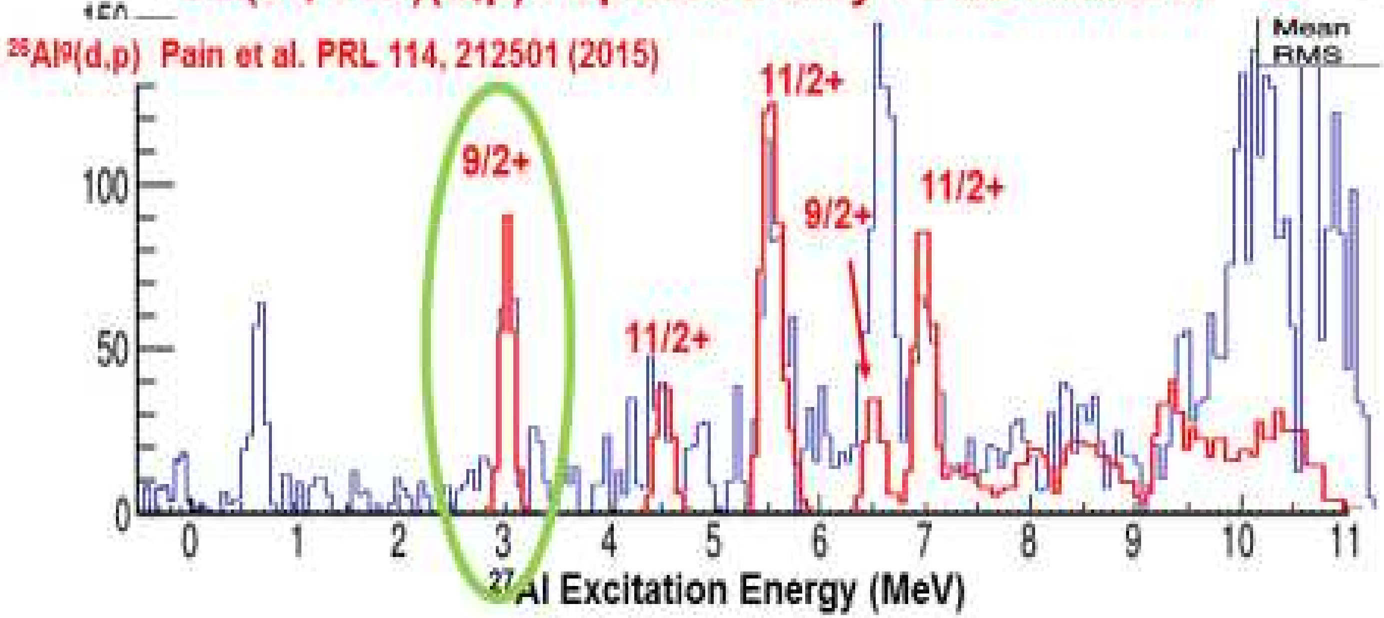




Preliminary Results!

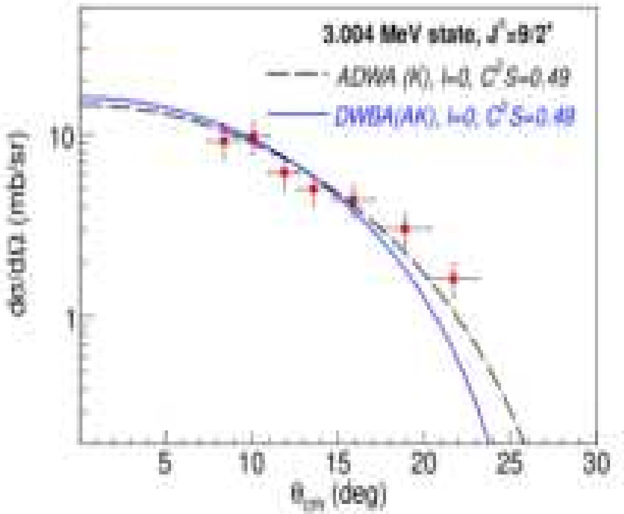
Measurement of the $^{26}Al^{m}$(d,p) reaction

$^{26}Al^{g}(5^{+}, T=0)$(d,p) Populates only T=1/2 states in ^{27}Al



Normalizing to the 9/2+ state at 3.004 MeV to get absolute cross sections

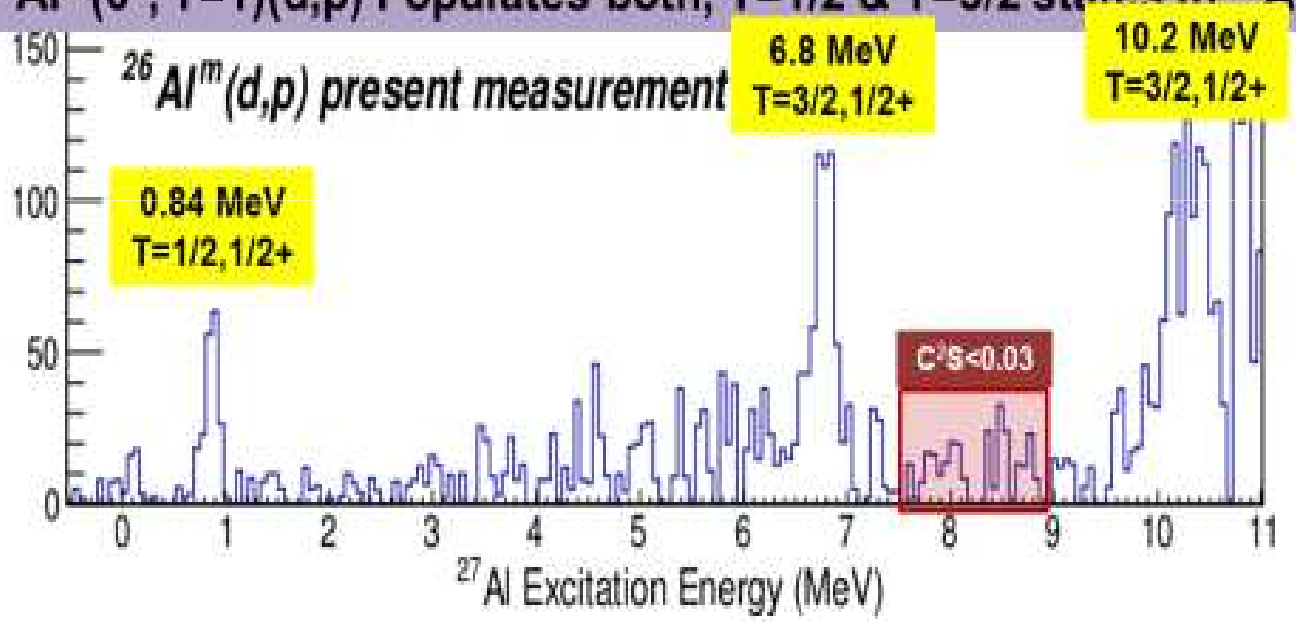
Margerin et al. PRL **115**, 062701 (2015)

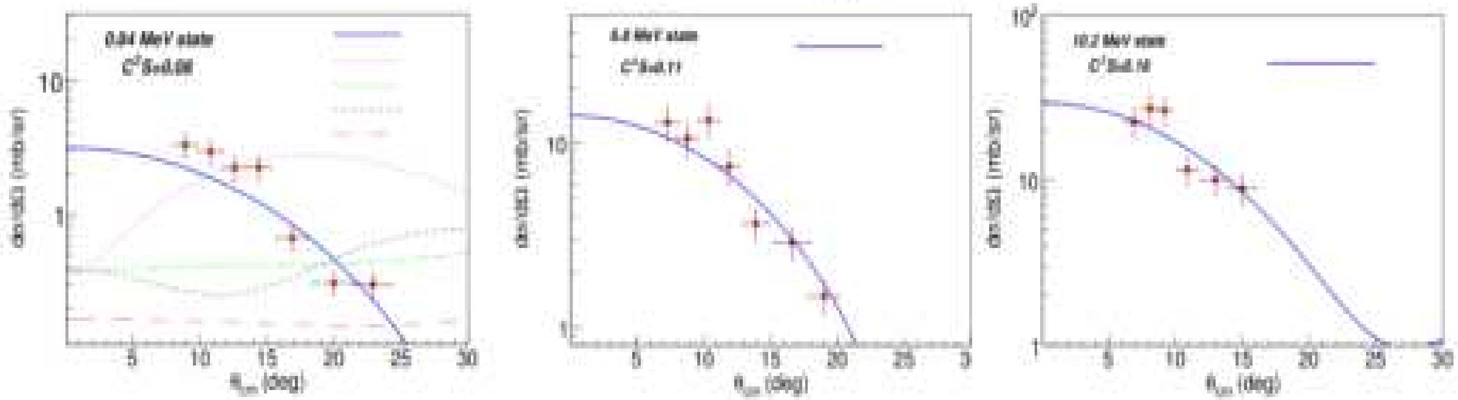


Preliminary Results!

Measurement of the $^{26}Al^{m}$(d,p) reaction

$^{26}Al^{m}(0^{+}, T=1)$(d,p) Populates both, T=1/2 & T=3/2 states in ^{27}Al





Preliminary Results!

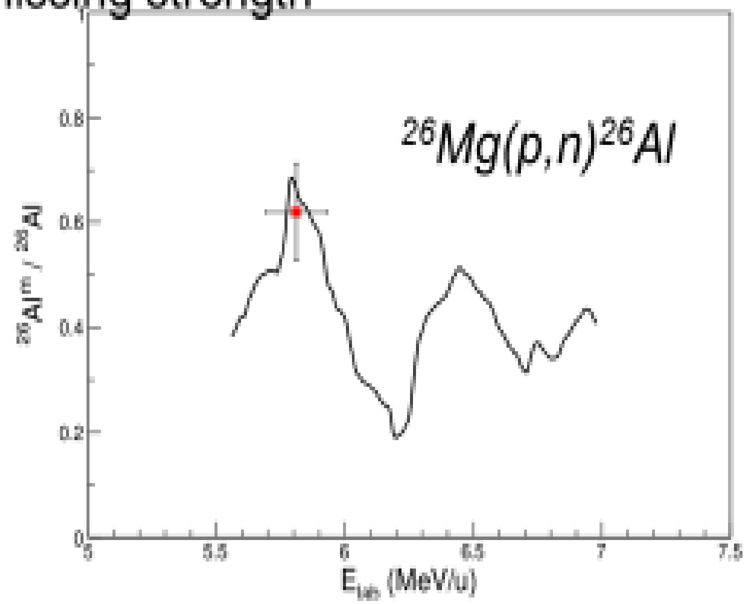
Summary

- Developed and characterized a high-quality ^{26}Al isomeric beam
- Performed a measurement of the $^{26}Al^{m}(d,p)^{27}Al$ reaction
- Highly selective reaction to study T=3/2, 1/2^{+} states in ^{27}Al
- Extracted an upper limit for the $^{26}Al^{m}(p,\gamma)^{27}Si$ reaction rate

Preliminary Results!

Future measurements:

- Higher beam energy → Change the isomer-to-ground state ratio
  → Look for missing strength
- Other reactions (^{3}He,d), (d,n)



I want to thank members of the nuclear physics group here in Warsaw for the opportunity to visit and collaborate for almost 25 years now. The beautiful new physics building and the change in the science complex here on Pasteura has been amazing to behold. The future here is so bright that one needs to wear sunglasses in walking around.