

**Final Technical Report  
Grant DE-SC0014525**

**Fourteenth Exotic Beam Summer School EBSS 2015  
Florida State University  
Tallahassee, Florida  
August 2<sup>nd</sup> to August 7<sup>th</sup>, 2015**

Final Report, 7-11-2016

The Fourteenth Annual Exotic Beam Summer School EBSS 2015 was held August 2<sup>nd</sup> - August 7<sup>th</sup>, 2015 and belongs to the series of summer programs aimed at educating future workforce in nuclear physics related areas, mostly about the challenges of radioactive ion beam physics. Through these schools the research community will be able to exploit fully the opportunities created by the exotic beam facilities. These facilities in the US include CARIBU at ANL, the NSCL and the future FRIB laboratory as well as smaller scale university laboratories. The schools are jointly organized by the ANL (M. Carpenter), LBNL (R. Clark), ORNL (K. Rykaczewski), MSU/NSCL (H. Iwasaki), LLNL (M. Stoyer) and the ARUNA association (I. Wiedenhoever). Since it is an annual event, the organization is rotating among these laboratories. The EBSS 2015 school was held for the first time by one of the ARUNA laboratories hosted at the John D. Fox Accelerator Laboratory at Florida State University. The local organizing committee were I. Wiedenhoever, Paul D. Cottle and Jonathan Yeargan.

The skill sets needed by the future workforce is very diverse and a fundamental understanding of theoretical, technical, computational and applied fields are all important. Therefore, the Exotic Beam Summer Schools follow a unique approach, in which the students not only receive lectures but also participate in hands-on activities. By applying what they hear in the lectures immediately in the activities, the impact of what they learn is optimized. Moreover, they return to their home institutions with an excellent overview of the various aspects associated with preparing, performing and analyzing experiments with rare isotope beams and be able to put that into practice immediately for their own thesis projects. The impact of the school is therefore immediate, as well as long-term. Presentation of the research opportunities offered by national laboratories helps to recruit later the best candidates for the graduate and post-doctoral assignments.

The development of techniques for studying exotic nuclei has opened a wide range of new research possibilities and given researchers insight in what can be achieved by studying isotopes that are far from the valley of stability. The excitement over the opportunities has led to the creation of a new National User Facility for Rare Isotope Beams (FRIB). FRIB will provide beams of rare isotopes with unprecedented intensities and will allow scientists to map the nuclear landscape, to understand the forces that bind nucleons into nuclei, to answer questions about the astrophysical origin of nuclear matter and to address societal needs related to material science, medical diagnostics and national security in which nuclear physics plays a key role.

The opportunities presented by FRIB come with challenges that can only be met by adequately preparing the next generations of researchers that will use FRIB and other (existing) rare-isotope beam facilities. The Exotic Beam Summer School (EBSS) series help to provide young scientists with the necessary background to meet these challenges and to plant the seeds for future discoveries and technical innovations. Since the participating students also have diverse backgrounds, the school is aimed at helping students see the connections between the various topics and to stimulate contacts between students, and students and lecturers, from the various subfields.

## 1. Participation

- 38 graduate and two undergraduate students. 35 students were affiliated with the US universities and laboratories, and five from Japan, Great Britain and Germany. In addition, a talk on “Radiological safety” was presented by P. Buress (FSU) and all hands-on instructors presented the activities pointing to the potential hazards and safety precautions.
- There were thirteen lecturers from US institutions, See the program at [http://aruna.physics.fsu.edu/ebss\\_lectures/EBSS2015\\_Schedule.html](http://aruna.physics.fsu.edu/ebss_lectures/EBSS2015_Schedule.html)
- 4 School Directors (Iwasaki, Carpenter, Stoyer, Wiedenhoever)
- 11 instructors (two faculty, two staff and six graduate students from FSU with 1 faculty from Umass Lowell), offered hands-on activities.

Those interested in participating in the summer school were applying electronically by sending the following information: Name, Year of study, Institution, Research interests, Contact information (postal address, e-mail address, phone number, fax number), and Supervisor (Professor): name and contact information. The applications were followed by a recommendation letter from a supervisor. The School received 66 applications. The participants were selected by the School Directors. Priority was given to students affiliated with the U.S. institutions (35 out of 40 participants).

## 2. Sponsors

- Laboratories (ANL – Physics Division, LBNL – Nuclear Science Division, MSU - NSCL, MSU-FRIB, ORNL – Physics Division, LLNL – N Division, FSU)
- Agencies (DOE, NSF)

### 3. Program

The program with the hands-on activities is available at [http://aruna.physics.fsu.edu/ebss\\_lectures/EBSS2015\\_Schedule.html](http://aruna.physics.fsu.edu/ebss_lectures/EBSS2015_Schedule.html)

The mornings were devoted to lectures on the science which can be addressed by exotic beam facilities. The lectures covered broad topics in both the experimental and theoretical physics of nuclei far from stability as well as radioactive ions production and applications. The lecture notes have been posted on the program web page (click on lecture title to see and download the respective file).

- An introduction to a broad field of nuclear physics and future opportunities was given by B. Sherrill (NSCL/MSU). The program included lectures on the following topics:
- Nuclear Theory – Alexander Volya (FSU), 2 lectures
- Neutron Stars – J. Piekarewicz (FSU), 1 lecture
- Exotic Nuclei – M. Thoenessen (NSCL, MSU), 2 lectures
- Nuclear Reactions – S. Yennello (Texas A&M), 2 lectures
- Gamma-spectroscopy – M. Allmond (ORNL), 1 lecture
- Transfer Reactions – B. Kay (ANL), 2 lectures
- Nuclear Astrophysics – J. Blackmon (LSU), 3 lectures
- Fundamental Symmetries – P. Mueller (ANL), 1 lecture
- Precision Nuclear Mass Measurements – M. Redshaw (CMU), 1 lecture
- Super-heavy Elements Research – M. Stoyer (LLNL)
- Beam Optics and Spectrometers – M. Couder (UND)
- Nuclear Data – E. Mc Cutchan (BNL)

The afternoons provided opportunities for "hands-on" projects with experimental equipment and techniques useful in FRIB research. Five activities were performed in groups of eight students, rotating through the activities over the five afternoons of the school. The center of the activities was an experiment at the FSU tandem accelerator, measuring the angular distribution and cross section of the  $^{12}\text{C}(d,p)^{13}\text{C}$  transfer reaction, measured with a Silicon telescope in a scattering chamber. The experiment was performed every afternoon of the week in about three hours of beam time. The same group analysed the experimental data on the following afternoon. They performed a DWBA calculation with the program DWUCK and the resulting spectroscopic factors were compared to a and a shell model calculation. The other activities included target preparation, digital Gamma-spectroscopy and modern Neutron – detection methods.

- Target preparation and characterization, Powell Barber, Sergio Almaraz-Calderon
- Measurement of the  $^{12}\text{C}(d,p)^{13}\text{C}$  reaction at the FSU accelerator, Kirby Kemper and Lagy T. Baby
- Analysis of transfer reactions, DWBA and shell-model calculations, Jessica Baker and Sean Kuvin

- Analysis of high-resolution Gamma-spectra from Beta-decay, Vandana Tripathi, S.L. Tabor, Rutger Dungan, and John Parker
- Methods of neutron detection, C.J. “Kim” Lister (University of Massachusetts Lowell) and Nabin Rijal

#### 4. **Support**

Thanks to the multi-sponsorship of EBSS 2015, the students received necessary support. The EBSS funds fully covered their lodging, meals, coffee breaks, social events (welcome reception and school dinner) . The expenses of several lecturers