The 2021 MoNA Report

The MoNA Collaboration

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Preface

During this interim period between the NSCL shutdown and the start of full FRIB operations, and while the country and the world continue to struggle with the COVID-19 virus, the MoNA Collaboration has remained remarkably busy and productive. The collaboration conducted its final NSCL-based experiment in September 2020, and submitted three experiment proposals for the first round of experiments at FRIB. It has also been busy in active and polarized target design and construction, charged fragment telescope development and implementation for use in experiments without the Sweeper Magnet, DDAS development and implementation, Monte-Carlo simulation development, analysis of data from previous experiments for physics involving other isotope-neutron correlations, analysis of neutron scattering data from experiments at LANL, development of multi-neutron sorting algorithms and machine learning for datasets involving multi-neutron decays, and development of next generation neutron detectors and array designs for use at FRIB. Student and post-doctoral participation in MoNA remains strong, evidenced in part by the number of 2021 MoNA Collaboration meeting presentations given by 6 high school, 11 undergraduate, and 7 graduate students, as well as by 3 post-doctoral associates. The future of the MoNA Collaboration remains bright, ensured in large part by the significant quality and talent of our younger PIs, who as a group will help carry MoNA into the future. And as I pass executive leadership for this coming year to Nathan Frank, I am pleased to announce the addition of our newest PIs, Thomas Redpath and Calem Hoffmann. Despite the challenges of these past two years, the MoNA Collaboration remains strong.

Warren Rogers, Indiana Wesleyan University

Warren Rogers
Executive Director, the MoNA Collaboration
Indiana Wesleyan University by ZOOM, August 2, 2021
1 Introduction

The exploration of the limits of stability and the observation of new phenomena in nuclei far from stability has been identified as one of the key science drivers for a next generation U.S. facility for rare-isotopes \[1\]. The first step following the discovery of new isotopes is the study of fundamental properties, for example, masses, binding energies, and lifetimes.

At the very extreme of neutron-rich nuclei, the nuclei beyond the dripline are very short lived and can only be studied by reconstruction based on information gathered from their decay products. Also, nuclei close to the neutron dripline have no or only a few bound excited states, so that traditional $\gamma$-ray spectroscopy cannot be applied. However, these states can be explored by neutron–fragment coincidence measurements. Reactions on such exotic nuclei reveal dynamical nuclear properties such as new preferred modes of excitations. When such reactions involve neutrons they are often of interest for explosive astrophysical scenarios. The most efficient and economical way to produce and perform experiments on these nuclei is with rare isotopes produced by high-energy projectile fragmentation. In order to reconstruct the decay energy spectrum, a magnet to deflect the charged fragments and a highly efficient position sensitive neutron detector are necessary.

The Modular Neutron Array (MoNA) was constructed and is operated by a unique collaboration of primarily undergraduate physics departments in partnership with Michigan State University. It has already involved more than 100 undergraduates from over 25 colleges and universities in nuclear physics experiments. The MoNA collaboration is poised to play an important role in educating the next generation of nuclear physicists. This paper outlines the importance of the physics which MoNA can do at a fast fragmentation facility and the potential role of the collaboration in educating future nuclear physicists.

The publications and presentations that detail the results obtained by the collaboration can be found in Section \[6\]. Also cataloged are the students that have benefitted from work with the device in Section \[7\]. A summary of the systems studied is shown in Figure \[1\].

2 Physics With MoNA

2.1 Results and Perspectives

Nuclear structure and reactions at and beyond the dripline

Along the neutron dripline where the neutron binding energy becomes zero, the relatively small enhancement of the total binding energy for paired neutrons has an important effect. The stability of nuclei with even numbers of neutrons $N$ compared to their neighbors with odd numbers creates a saw-tooth pattern in which the heaviest odd-$N$ isotopes of a given element are neutron-unbound, while heavier isotopes with an even number of neutrons can be bound. Well-known examples are $^{10}$Li (bound) and $^{11}$Li (bound), or $^{21}$C (unbound) and $^{22}$C (bound). The properties of the alternating neutron-unbound nuclei provide important insights into the neutron–nucleus interaction far from stability, the coupling to the continuum in neutron-rich systems, and the delicate structure of multi-neutron halos or skins. In addition, the wave functions of the even-$N$ nuclei at the dripline are not well known, and studies of the adjacent neutron-unbound (odd-$N$) nuclei can yield single-particle information crucial for the characterization of the heavier bound nuclei.

Properties of neutron-unbound nuclei

Intense fragment beams of the most exotic bound nuclei have been used at the National Superconducting Cyclotron Laboratory (NSCL) and elsewhere to extend mass determinations from reaction $Q$-value measurements to neutron-rich nuclei beyond the dripline, where the ground state is an unbound resonance. In a typical experiment, the energies and angles of the neutron and the fragment from the decay of the unbound parent nucleus must be detected with sufficient precision to allow reconstruction of the energies of the resonant states. The observed decay energy determines the mass while the width of the resonance is related to the angular momentum of the state. Just as for traditional transfer reactions, different reaction channels provide complementary information, and both proton and neutron removal reactions are important and necessary to populate the neutron-unbound states. Nuclear masses and angular momenta of ground-state wave functions of unbound nuclei provide information on the shell structure at the neutron dripline that cannot be obtained by other means.

Neutron-unbound excited states

Neutron-unbound excited states of bound nuclei can be populated either in nuclear breakup reactions via excitations from the ground state or via particle removal reactions from neighboring nuclei.

Breakup reactions where the nucleus is excited via the nuclear or Coulomb interaction are versatile tools to study continuum properties. For example, Coulomb-breakup of halo nuclei is mostly sensitive to the $s$-wave component of the ground-state wave function and hence will be able to provide a spectroscopic factor for a core $\otimes s_{1/2}$ configuration in the ground state of the nucleus of interest \[2\]. Such measurements could be precision tests of results from the more common knockout or transfer reactions, since the reaction mechanism of Coulomb breakup is better understood theoretically.

Several interesting quantities are accessible by particle removal reactions. For one, the energy and decay path of resonances are of interest for nuclear structure. Also, high-lying first excited states are indicative of gaps in the single-particle level scheme and suggest new magic numbers. The energy of resonances can shed light on the
role of the continuum in nuclear structure at the dripline. Moreover, particle-removal cross sections to resonances yield spectroscopic factors, which can again be compared with theory.

**Neutron Halos**

Weakly bound few-body systems have been found to exhibit properties such as halo structures, which are very different from those of well-bound systems. The study of these neutron halos is important for a better understanding of nuclear structure close to the dripline and also helps to understand the universal features of weakly bound few-body systems in general. For example, halo structures are also found in atomic and molecular systems [3, 4]. Close to the neutron dripline, a number of nuclei have been found to exhibit neutron halos [5], and many more are predicted to exist [4].

When the last neutrons in a nucleus are weakly bound and have predominant s-wave character, the absence of a confining Coulomb and angular-momentum barrier allows the extension of the neutron wave function far beyond the nuclear core via quantum-mechanical tunneling. The attraction of the nuclear potential is weak in this extended region and, as a result, the nucleus develops a diffuse halo with one or a few neutrons distributed over a large volume. The radial wave function of such a halo depends critically on the neutron separation energy. Thus, precise measurements of nuclear masses and separation energies of these exotic systems provide important information for theoretical descriptions as well as for the identification of new halo candidates.

### 2.2 Invariant Mass Measurements

The study of neutron-unbound systems using the Sweeper and MoNA-LISA devices are based on the well-established technique of invariant mass measurements. Determining the population of unbound states in nuclear reactions through knock-out, breakup, or transfer reactions, followed by detection of all of the decay products in coincidence, i.e., the neutron (or neutrons, indexed \( n \)) and the charged fragment (indexed \( f \)), is necessary. Measurement of the energies \( E_n \) and \( E_f \) and momentum vectors \( \vec{p}_n \) and \( \vec{p}_f \) of the involved particles enables the reconstruction of the invariant mass or the decay energy (see Figure 2). The decay energy \( E_d \) is the invariant mass of the unbound system minus the sum of the separate particles’ masses and for one-neutron decay is given by:

\[
E_d = \sqrt{m_f^2 + m_n^2 + 2(E_f E_n - \vec{p}_f \cdot \vec{p}_n) - (m_f + m_n)}
\]

These invariant mass measurements are performed with a large-gap dipole magnet or “Sweeper” that separates the unreacted beam, charged reaction products, and neutrons in such a way that the forward-going undeflected neutrons are cleanly detected in a high-efficiency neutron detector such as MoNA-LISA (see Figure 2).

### 2.3 Recent Studies

The MoNA collaboration has performed an experiment (e16027) to look at neutron unbound excited states in the
The MoNA Collaboration

February 24, 2022

Figure 2: The reconstructed decay-energy spectrum for the neutron-unbound ground state in $^7$He, which is unbound by 450 keV and which has a width of 160 keV. The data were taken during the commissioning of the Sweeper Magnet and the MoNA neutron detector at NSCL.

$N=20$ island of inversion. The experiment used a $^{33}$Mg beam and focused it onto the segmented target in attempt to reconstruct the decay energies. The analysis has been performed with members from Davidson College, Hope College, Augustana College, and Michigan State University. Currently decay energies are being finalized and simulations are beginning. Figure 3 is a picture of a Davidson College student, Robbie Seaton-Todd, who participated in the experiment at NSCL and has worked on the analysis both summer 2018 and 2019.

The MoNA Collaboration is in the process of analyzing data from experiments e14091 (thesis experiment of H. Liu) and e15091 (thesis experiment of D. Votaw) in order to investigate shell evolution in the $N=7.8$ region. These experiments aim to selectively populate states in $^9$He, $^{10}$He, and $^{10}$Li. All three of these unbound systems are interesting test beds for the evolution of nuclear structure far from stability, and can shed some light on the formation of exotic structures, like the 1- and 2-neutron halos of $^{11}$Be and $^{11}$Li respectively. It has even been suggested (by K. Fossez, et al. [6]) that the 2n-unbound $^{10}$He may have a “double halo” structure, where the 2n-halo nucleus $^8$He has an additional 2n halo. e15091 is a search for the controversial s-wave ground state resonance of $^{10}$Li and $^9$He, in order to confirm or refute parity inversion in the neutron-unbound N=7 isotones. e14014 is an investigation of the reaction mechanism dependence of the observed $^{10}$He resonance. Both experiments were successfully run at the NSCL, and the data analyses are nearing the end. Manuscripts describing the results are currently in preparation.

The MoNA Collaboration conducted an invariant mass measurement of neutron-unbound $^{13}$Be in the S2 vault. This was the Collaboration’s final experiment with the Coupled Cyclotron Facility. It was a “Sweeper-less” experiment, meaning that the Sweeper magnet that is usually used for invariant mass measurements was not used. Not only did this experiment (e19013, Paul DeYoung, Hope College) look for neutron unbound states in $^{13}$Be, it will also shed light on isomeric states in the daughter nucleus, $^{12}$Be, which complicates the invariant mass measurement of $^{13}$Be if not detected. This measurement made use of the Modular Neutron Array (96 of the possible 288 bars), employed the gamma-ray detector CAESAR, and featured the newly developed charged particle telescope. The new charged particle telescope was developed by Prof. Nathan Frank of Augustana College in Rock Island, IL was used for particle ID. This new telescope will have the enhanced resolution needed to push the invariant mass measurements to heavier neutron-unbound systems that will become accessible with future FRIB beams. In addition to new detectors, the signals were recorded with new acquisition. A Digital Data Acquisition System (DDAS) was used for recording traces from CAESAR and the charged particle detector telescope. Trace fitting is superior to the parameters resulting from DDAS’s internal algorithms for determining the energy deposited by charged particles. Fig. 4 shows a sample trace for one of the SiPIN detectors, which shows a typical trace. The trace fitting algorithm developed within the collaboration includes various corrections and identification of double pulses due to two secondary beam particles entering the detector within a 10-microsecond range of the trace.

2.4 Additional Analysis of Past Data Sets

The MoNA experiment e09067 was performed to make the first observation of the unbound nuclide $^{15}$Be. This
was done using a neutron pickup reaction with a $^{14}$Be beam and search for decays by $^{14}$Be+n. The observed state could not be confirmed as the ground state because of an alternate decay path through the first excited (unbound) state in $^{14}$Be which would decay by another two neutrons to $^{12}$Be. To search for the predicted state lower than what was observed requires reconstructing $^{12}$Be+3n. A re-analysis of e09067 has produced the 2-, 3-, and 4-body decay energy plots. The group at Davidson College in partnership with Augustana College is finalizing simulations and fitting those simulations to the data to search for the predicted ground state of $^{15}$Be.

An analysis of two-proton removal from $^{27}$Ne (e12001) resulting in $^{25}$O has been completed and a paper is currently under review by Physical Review C. The analysis identified unbound states in $^{25}$O at an excitation energy of $\approx 9$ MeV that decay sequentially by the emission of three neutrons. The unbound states were not resolved but the four-body decay energy spectrum showing the strength was successfully reconstructed. These states are predicted by OXBASH.

### 2.5 Projectile-Like Fragment Studies

The MoNA Collaboration’s research program has grown to include relatively novel studies of projectile fragmentation reactions. Two separate experiments, (e09096 and e12011) made exclusive measurements of neutrons in coincidence with isotopically identified products. Neutron signatures are then compared to models that simulate collisions and reactions on nuclei. The results have sparked discussion about neutron signatures and how they can inform relative populations and excitation energies of projectile-like fragments in beam-target interactions, participated in a larger discussion regarding how we interpret ‘neutron hit multiplicity,’ and how to design future experiments to further inform this work.
momentum for the invariant mass calculation. Initial testing of detectors has started at Augustana College. Characterization of detectors includes verifying manufacturer specifications and determining any position sensitive effects on electronic signals. This testing utilizes a compact VME setup and a homemade raster scanner.

2.7 Development of New Neutron Detectors With GEMS

As MoNA has passed the age of 15 years it is timely to look at new developments in detector technology and at the same time take a detailed look at the requirements for future experiments, in order to answer the question what a next generation detector could look like. While MoNA (and LISA) were mainly optimized for high neutron detection efficiency, this is not all that is needed. Resolution, discrimination capability, reliability, etc. are other factors to consider. Clearly, to achieve the best physics data, a balance between these design criteria has to be identified. New techniques in photon detection are available, and advanced electronics are already realized in other neutron detector arrays (NeuLAND and NEBULA). To answer the question where can the MoNA collaboration make an impact, detector simulations are undertaken and prototypes are being constructed.

Technological advances of gas detector technologies, especially in the areas of micromegas and gas electron multipliers (GEMs), have now enabled sub-mm position accuracy and pico-seconds timing resolution that have impacted greatly the fields of low and high energy nuclear physics research [7]. Coupled with their relatively low material budget, these devices are increasingly becoming the standard for tracking of energetic particles (charged and neutral). GEM detectors are becoming the standard for new detector tracking systems and active targets at the NSCL/FRIB using readout scheme based on a position-sensitive micromegas element combined to thick GEMs (THGEMs, developed by the Detector group at NSCL) as pre-amplification stages. The MoNA Collaboration is investigating the development of a low cost Gas Photo-Multiplier (GPM) that will be coupled to plastic scintillator detectors with the capability to allow for visible light detection, sub-mm position reconstruction of the emitted light and picosecond timing resolution along with new pulsed shaped scintillators. Since 2018, the Collaboration initiated some R&D that includes coupling with GEM detectors or SiPM as depicted in Fig. 6. Such device will also enable to build detectors with any shape and size since GPMs are not subject to particular geometrical restrictions (PMTs are either circular or rectangular and with finite small sizes).

2.8 Development of New GEM Based Segmented Target

In 2013, a segmented (active) target was proposed to increase the decay energy resolution and that consisted of alternating layers of $\sim 140 \mu m$ Si detectors and $\sim 3 \text{ mm}$...
The MoNA Collaboration
February 24, 2022

Figure 7: Left Panel: Schematic of the MAME target. Middle Panel: ANSYS design of the GEM E-field. Right Panel: Cosmic tests of a GEM from the SRS DAQ at NSCL.

Be targets [8]. This design has three main limiting factors: (i) Sub-MeV resolution is required in the reconstructed decay energy spectrum for some experiments being considered at NSCL, such as $^{26}$F(-2p) to measure the decay energy of $^{24}$N to probe the tensor-force part of the nucleon–nucleon interaction [9]; (ii) The possibility to detect/tag very low energy fragments/recoils to improve our understanding of neutron rich nuclei through missing mass reconstruction capabilities; and (iii) develop a (segmented) target capable of handling FRIB high rates while maintaining a high resolution in the reconstructed invariant mass spectrum. A Multilayered Active target for MoNA Experiments (MAME) is under development to address the aforementioned. It uses a series of thin (0.5 mm) Be foils immersed in a gas-filled GEM box with a $10 \times 10 \text{ cm}^2$ transverse size (Fig. 7) and the Scalable Readout System (SRS) data acquisition framework (to handle the large number of readout channels).

2.9 Detector Characterization at LANSCE

Simulation of neutron scattering in MoNA-LISA provides a critical tool for the analysis of experimental data. In 2012 the collaboration published tests for two simulation GEANT4-based packages (G4-Physics, based on the JENDL library, and MENATE_R, based on n-H and n-C cross sections) for neutrons with energy 55 MeV/u [10]. In order to expand this study to much higher neutron energies, the collaboration transported 16 MoNA bars to the LANSCE facility at Los Alamos National Laboratory in order to place them in the path of a 10-800 MeV neutron beam. Observations of specific scattering observables could then be compared with simulation as a measure of its effectiveness over a broad range of energy.

Two experiments were performed, each in the 90-m station at the LANSCE WNR facility on the 4FP15L flight path. The goal for both was to compare several neutron scattering observables with the same two Geant4-based simulation packages used in the previous study [10]. For the first experiment (January 2017) 16 MoNA bars were arranged in two horizontal layers of 8 bars each (see Fig. 8). The beam impinged on the center of the first upper layer bar and neutron scattering throughout the array was recorded, analyzed, and compared with each of the two simulation predictions [11]. The second experiment (November 2019) was focused on better understanding neutron dark scattering. The MoNA bars were reconfigured to include one bar located near the collimator at the entrance of the 90-m station, and the other 15 detectors arranged in a staircase configuration 1–2 meters away (see Fig. 9). This new configuration was designed to better pin down the location of the initial dark-scatter site (confined to the center of the target bar), since dark-scatter neutrons leave no detectable signal. Analysis of results are currently led by the groups at Davidson College and Indiana Wesleyan University.
2.10 MoNA/LISA-Sweeper Relocation

The complete experimental setup of MoNA-LISA and the Sweeper Magnet used to be located in a dedicated vault (N2). The N2 vault is now being re-purposed for a different setup, and all MoNA-LISA equipment, including the Sweeper magnet, has been moved into storage. Late in 2017 the discussion about the future location of the Sweeper started and included the options of moving to the S3 vault to have a combined Sweeper-S800 setup, or to create a setup in the S2 vault. There was no strong response with experiment proposals that would have relied on a Sweeper-S800 setup, at the same time this setup appeared to be technically challenging to realize. Thus the discussion settled on a new setup in the S2 vault. In order to create an optimized setup in S2, current planning realigns the beam line and has MoNA-LISA placed on a platform above the S3 vault. This maximizes the neutron flight path. A longer charged particle flight path is also possible in the proposed configuration to achieve improved particle time of flight separation, and the Sweeper bending angle could be reduced from 43 degree to 30 degree, thus raising the beam rigidity limit. These major reconfigurations of the existing S2 vault will happen after the CCF ceases operation and will be available with FRIB beams. Details of this configuration are being worked out at the time of the writing of this report.

2.11 Technical Overview

**Modular Neutron Array**

The Modular Neutron Array (MoNA) is a large-area, high efficiency neutron detector designed for neutrons resulting from breakup reactions of fast fragmentation beams.

In its standard configuration, MoNA has an active area of 2.0 m wide by 1.6 m tall (see Figure 10). It measures both the position and time of neutron events with multiple-hit capability. The energy of a neutron is based on a time-of-flight measurement. This information together with the detected position of the neutron is used to construct the momentum vector of the neutrons [12][13]. The detection efficiency of MoNA is maximized for the high-beam velocities that are available at the NSCL Coupled Cyclotron Facility (CCF). For neutrons ranging from 50 to 250 MeV in energy, it is designed to have an efficiency of up to 70% and expands the possible coincidence experiments with neutrons to measurements which were previously not feasible. The detector is used in combination with the Sweeper magnet [14][18] and its focal plane detectors for charged particles [19]. In addition, the modular nature of MoNA allows it to be transported between experimental vaults and thus to be used in combination with the Sweeper magnet installed at the S800 magnet spectrograph [20]. Due to its high-energy detection efficiency, this detector in conjunction with LISA (see next section) will be well suited for experiments with fast fragmentation beams at FRIB.

**Large-area multi-Institution Scintillator Array (LISA)**

A collaborative MRI proposal was submitted by nine PUI institutions in the collaboration (CMU, Concordia, Gettysburg, Hope, IUSB, OWU, Rhodes, Wabash, and Westmont) to enhance the neutron detection capabilities. LISA is a second large array (144 modules, see Figure 11) which can be configured for additional angle coverage or for additional efficiency. The increased neutron detection efficiency possible with the combined MoNA-LISA array means it will be an effective day-one FRIB detector system.

LISA was constructed by undergraduate students at the nine institutions (Figure 11). Construction was essentially completed during the summer of 2010. Each institution carried out testing and used their subset of detector modules for student education. The projects being undertaken by students at each institution range from muon-lifetime measurements, to cosmic-ray shower size measurements, to \(\gamma\)-\(\gamma\) correlation measurements using the full position reconstruction. The modules were moved to
NSCL in January of 2011. After mechanical installation was completed, LISA was integrated with MoNA and the Sweeper and the commissioning experiment (neutron unbound states in $^{24}$O) took place in June of 2011.

**Sweeper Magnet**

The Sweeper magnet is a large-gap dipole magnet that was developed and built at the National High Magnetic Field Laboratory at Florida State University [14–18]. It was funded by the NSF with a Major Research Instrumentation (MRI) grant to a MSU/FSU consortium. The superconducting magnet is able to deflect charged particles up to a rigidity of 4 Tm in order to separate neutrons, charged reaction products, and the non-reacting beam particles. The vertical gap between the pole tips measures 14 cm and a large neutron window enables the neutrons coming from the reaction target placed in front of the Sweeper to reach MoNA and LISA, typically placed at 0° with respect to the incoming beam direction.

**Segmented Active Target**

A segmented target is now available for experiments at NSCL after successful construction and installation at the NSCL in the Spring 2016 (Figs. 13 and 14). The target consists of alternating layers of Silicon detectors (62 mm x 62 mm x 140 μm) and passive Beryllium targets around 600 mg/cm² targets. The energy loss of secondary beam and charged reaction product nuclei are measured in each detector to determine event-by-event in which beryllium target the nuclear reaction occurred. This determination will provide a means to keep the resolution in decay energy measurements constant while using thicker target to increase statistics. In addition, the readout from each corner of the detector provides a position measurement at the target position.

This system was successfully used in an experiment to more precisely measure the lifetime of $^{26}$O with respect to 2n-emission. Figures 15) and 16 show the position resolution of the system and the capability to separate the reaction products resulting from the incoming beam impinging on each Be-target. The segmented target system is expected to be used in future experiments.

**CsI Hodoscope repair**

Even while new approaches to measurements of the fragment energy are being developed, an effort to affect a repair of the existing flawed CsI hodoscope has begun. The excellent machine shop facilities at Hope College will be used to lap the existing CsI modules. The hope is that the issue with the detectors is damage to the front few millimeters from residual moisture left at the time of manufacture. CsI is relatively easy to lap and polish [21, 22] but the process will have to be done to the 15 inch long assemblies rather than individual crystals. The assemblies were glued into monolithic blocks gentle at-
temps to disassemble were unsuccessful. More radical attempts to break the crystals from their light guides and support structure could cause them to fracture. After lapping a few millimeters from the front, they will be tested with oxygen beams for uniformity with the Hope tandem accelerator. If the repair is successful, the repaired hodoscope could be used while the improved version is implemented. Potentially, the repaired hodoscope could be used with the Sweeper in the S2 location even after the HRS and new hodoscope are in place.

Liquid Hydrogen Target

The Liquid Hydrogen Target at the NSCL offers a high-density, low-background proton or deuteron target for elastic scattering, nucleon transfer reactions, secondary fragmentation, and charge exchange experiments. The target (see [17]) works by pumping deuterium gas into a cylindrical chamber sealed with $\sim 100 \mu m$ thick kapton foils on either side. The target chamber has a diameter of 5 cm and can provide several target thicknesses depending on the depth of the chamber and density of the gas. Thicknesses of 200 or 400 mg/cm$^2$ are currently available for deuterium. Liquid helium is then used to cryogenically cool the gas close to the triple point, and a heating block warms the deuterium to approximately 1.5K below the boiling point to keep it in a liquid state. The system can hold 160 L of deuterium at 1 atm. It was used at NSCL for the $^{24}$O(d,p) experiment (e12004) whose goal was to measured negative parity states in neutron-unbound $^{25}$O.

Experimental layouts

The complete experimental setup of MoNA-LISA and the Sweeper Magnet used to be located in a dedicated vault (N2 vault, see Fig. [18]). The N2 vault has now been repurposed for a different setup, and all MoNA-LISA equipment, including the Sweeper magnet, has been moved into storage.

Late in 2017 the discussion about the future location of the Sweeper started and included the options of moving to the S3 vault to have a combined Sweeper-S800 setup, or to create a setup in the S2 vault. There was no strong response with experiment proposals that would have relied on a Sweeper-S800 setup, or to create a setup in the S2 vault. There was no strong response with experiment proposals that would have relied on a Sweeper-S800 setup, at the same time this setup appeared to be technically challenging to realize. Thus the discussion settled on a new setup in the S2 vault (see Fig. [19]). In order to create an optimized setup in S2, current planning realigns the beam line and has MoNA-LISA placed on a platform above the S3 vault. This maximizes the neutron flight path. A longer charged particle flight path is also possible in the proposed configuration to achieve improved particle time of flight separation, and the Sweeper bending angle could be reduced from 43 degree to 30 degree, thus raising the beam rigidity limit. These major reconfigurations of the existing S2 vault will happen after the CCF ceases operation and will be available with FRIB beams.
**Figure 17:** A diagram of the Liquid Deuterium Target illustrating how it will sit in the beam-pipe.

**Figure 18:** Recent layout of MoNA-LISA in the N2 vault.
Details of this configuration are being worked out at the time of the writing of this report.

**Event-tagged readout**

For MoNA-LISA-Sweeper experiments the data from the various detector subsystems are read out in an event-tagged scheme. Each detector subsystem runs its own readout and records its data separately. By using separate data acquisition computers, the system becomes easily expandable, e.g. if an additional detector subsystem like a γ-ray detector needs to be added, while the overall readout time is reduced compared to a system with a large number of VME bins. A common system-wide trigger is generated by the trigger logic. A clock signal is fed into scalers that create an event tag for each time the subsystems are read out. This event tag is used off line to match and re-assemble event data from the subsystems.

### 2.12 G4MoNA

A Geant4 

Monte Carlo simulation for the MoNA Collaboration (G4MoNA) is in its last stage of benchmarking using the setup from experiment e15118 (PI-N. Frank, ²⁶O lifetime) in the N2 vault that includes CAD drawings of all beamline and detector elements. A dedicated unbound class was developed to construct the short-lived isotopes and their subsequent decay processes as shown on Fig. 19.

**Figure 19:** Left Panel: Geant4 simulation for the $^{27}$F $\rightarrow$ $^{26}$O $\rightarrow$ $^{24}$O + 2n reaction. Tracks shows correspond to $^{27}$F (green), $^{24}$O (gray), gammas (yellow), neutrons (blue) and photons (brown). Right Panel: G4MoNA geometries developed for ongoing R&D work of the MoNA Collaboration.

The experimentally reconstructed 3-body decay energy is compared to the in-house single track ST-MoNA (solid blue) and G4MoNA (light blue) simulations for each of the three beryllium targets housed within the segmented target in Fig. 20.

G4MoNA is being developed to handle various R&D projects and experimental setup configurations for the MoNA Collaboration as depicted in Fig. 19.

**2.13 Machine Learning Applied to Multi-neutron Events**

Correlations between particles give rise to a range of interesting phenomena. In the case of atomic nuclei, one example involves the spatial localization of two nucleons near the surface of a nucleus resulting from the attractive nuclear force [24, 25], sometimes referred to as dineutron and diproton correlations. In general, nucleon correlations, including the dineutron effect [26–29], are expected to be more easily probed through the study of two-neutron decays due to the absence of the Coulomb interaction present in the case of two-proton decays [30]. One method for probing neutron correlations is to study the two-neutron decays of exotic neutron-unbound systems. In these cases, the goal is to observe three body decays (fragment plus two neutrons) of systems that simultaneously emit two neutrons as opposed to a sequential decay through an intermediate state (see Figure 21). Two-neutron emission has been observed from $^{5}$H, $^{10}$He (see Chapter 2 of Ref. [35] for a summary of the $^{10}$He measurements), $^{13}$Li [36, 37], $^{16}$Be [38], and $^{26}$O [39,41] [8], and studies of neutron correlations have been made for several systems $^{3}$H [34], $^{14}$C [42], $^{15}$O [43, 48], $^{16}$O [44, 46]. The specific case of the $^{26}$O ground state has been the subject of theoretical [46, 30, 47, 48], and experimental studies, however, an experimental determination of the nature of the neutron correlations for this case remains ambiguous due to the near-threshold ground state resonance and to statistical limitations [49]. This indicates a need for innovative experimental techniques to study certain systems.

Accumulating sufficient statistics will always be a challenge for experiments that study nuclei along the neutron dripline. The intensities of the rare isotope beams used to populate the neutron unbound systems can range from $\sim$10 to $\sim$1000 particles per second [50, 51]. The new beam production capabilities of FRIB will enable heavier exotic nuclei to be studied, and these restrictions will apply to eventual studies of neutron-unbound systems. Furthermore, the cross-sections for the types of reactions used to produce the unbound systems are small, $\sim$1 to $\sim$0.1 mb [52]. Apart from increasing the reaction yield, improvements to the event selection procedures for analyzing two-neutron decay data can reduce the number of
Figure 20: The 3-body decay energy of $^{26}$O comparing experimental data (red crosses), the in-house ST-MoNA simulation (dark blue) and G4MoNA (light blue) without (top row) and with (bottom row) contribution from excited states. The three figures in each row corresponds to the individual three beryllium targets composing the Si-Be segmented target.

Figure 21: Contrasting energy conditions characteristic of sequential (top panel) and simultaneous (bottom panel) three body decays.

good events that are rejected in the course of the analysis. This avenue is also being investigated by the MoNA Collaboration and a new analysis procedure for identifying two-neutron events is showing promising results. It should be noted that these analysis techniques can be useful for studies of sequential two-neutron decays as well as three- and four-neutron decays (e.g. [53, 54]), not just the simultaneous two-neutron emission mentioned above.

As an extension to this technique, we plan to investigate the possible uses for machine learning techniques in determining neutron trajectories from measurements made by large scintillator arrays in order to improve the identification of events in which two neutrons resulting from the decay of a neutron-unbound system are detected. This project will expand the research activities of the nascent nuclear science research group at Virginia State University (VSU) while offering engaging research opportunities for VSU undergraduate students.

2.14 Auxiliary Uses of MoNA-LISA

In addition to the primary fragmentation physics, there are some off-line uses for MoNA. These include measurements of the temporal and spatial dependence of the cosmic-ray flux. These efforts provide additional student training with acquisition, detectors, and analysis.

3 The MoNA Collaboration

3.1 History

When the NSCL upgraded their capabilities to the Coupled Cyclotron Facility, an FSU/MSU consortium built the Sweeper magnet to be used with two existing neutron walls to perform neutron–fragment coincidence experiments. The neutron walls were originally built for lower beam energies and had only a neutron detection efficiency of about 12% for the energies expected from the CCF. During the 2000 NSCL users meeting a working group realized the opportunity to significantly enhance the efficiency with an array of more layers using plastic scintillator detectors.

Several NSCL users from undergraduate schools were present at the working group meeting and they suggested that the modular nature and simple construction would offer great opportunities to involve undergraduate students.

In the spring of 2001 the idea evolved into several MRI proposals submitted by 10 different institutions, most of them undergraduate schools. The proposals were funded by the NSF in the summer of 2001. Following the detailed design, the first modules of the detector array were delivered in the summer of 2002. During the following year all modules were assembled and tested by undergraduate students at their schools [56], and finally added to form the complete array at the NSCL (Figure 22).

17
The MoNA collaboration continued after the initial phase of construction and commissioning was concluded, and is now using the detector array for experiments, giving a large number of undergraduate students from all collaborating schools the opportunity to take part in cutting-edge nuclear physics experiments at one of the world’s leading rare-isotope facilities. The research at the undergraduate institutions is funded by the NSF through several RUI grants (Research at Undergraduate Institutions). Since the completion of the original set of MoNA detectors, there have been several changes to the membership of the Collaboration. Most recently, the Collaboration welcomed Anthony Kuchera (Davidson College) and said goodbye to Joe Finck (retiring from CMU).

3.2 The Role of Undergraduate Students

The physical characteristics and performance of MoNA were not the only things carefully considered by the collaboration. From the outset, several goals for the education of undergraduate students were identified: How can these students be continually and effectively involved in forefront research? What are the benefits to the students from this participation? What are the benefits to institutions and faculty members? When students participate in the experiments and when they work with the data sets, how can they evolve from passive watchers to active doers with the responsibility to get answers?

The collaboration has addressed this challenge by creating intensive summer sessions designed for undergraduates, encouraging students to participate in all phases of experiments, holding several meetings a year that include undergraduate participants, and employing information technology to bring the distant undergraduate students together (Figure 23).

Many voices have recognized the need for a strong basic science program in the United States. Most recently the National Academy of Sciences published the “Rising Above the Gathering Storm” study that outlines consequences and needed actions. The coming decade will need a steady stream of people (new physicists) as well as strong financial support. As in the past many of these people will come from undergraduate institutions and the most prepared will be those involved in meaningful undergraduate research as done by the MoNA collaboration at the NSCL involving fragmentation. While planning future installations for nuclear physics, the value of this educational approach and training must be recognized. Undergraduates must be involved in an affirming environment where they are engaged at a high intellectual level and truly challenged so they are ready for the work yet to be done. The MoNA Collaboration has now established itself as a powerful collaboration with a strong track record in training undergraduate students to do research and produce peer reviewed articles in nuclear physics.
Outcomes

Since the start of this collaboration, more than 100 undergraduate students from over 25 different colleges and universities as well as a few high school students have been actively involved in building, testing, and operating the MoNA and LISA detectors (see Section 7).

These diverse undergraduate students have worked with one another in assembling and testing MoNA and LISA and in operating it during experiments. They have pulled shifts and put in the long hours that are characteristic of work in experimental nuclear physics. The graduate students and post docs at the NSCL provide approachable role models for them, and they feel free to ask questions of any of the faculty members in the group. For students from small undergraduate physics departments, participation in the MoNA collaboration provides a chance to experience the way physics is done in a large graduate physics department and at a world-class nuclear physics laboratory. The experience is particularly important for students who do not go on to graduate school in physics because they gain an understanding of how hard experimental scientists work to uncover the data points that underpin the theories written up in science texts and news magazines. The support of physics students who do not work as nuclear physicists but have careers in industry, K-12 education, or even the arts is important in reaching the non-scientists who control the funding for nuclear physics.

Distributed analysis

A feature of the MoNA collaboration that is an outgrowth of our collective work with undergraduate researchers is the emphasis on doing more than detector assembly or running shifts. In particular, the collaboration has a mechanism in place that allows the undergraduates to carry out the actual data analysis of the experiments.

One mode is that a student, with guidance from their mentor and the collaboration, has the primary responsibility for the analysis much like a traditional graduate student; other students may be involved but that student does much of the work and oversees and integrates the work of others. Students can work with more senior researchers where they provide hours on task and have a good overview of the experiment but do not have the ultimate responsibility for the results. Undergraduate students with limited time for work can still participate by working on very focused aspects such as the calibration of a single detector subsystem, code checking, or validation of the work of others (Figure 24).

Lastly, some collaboration members have undertaken the difficult task of improving the analysis algorithms and extending the detailed understanding of operations. MoNA undergraduate students at Westmont College have developed an algorithm to distinguish neutron multiplicity based on the kinematic propagation properties of neutrons though MoNA. Initial analysis of several one- and two-neutron experiments show promise. Scatter plots of neutron velocity and energy deposition versus scattering angle reveal a locus of points in which single-neutron events lie. Multiple-neutron events show as relatively uniform scatter throughout the plots, as there is no correlation between each individual neutron interaction in those instances besides the kinematics of the breakup which produced them.

Every student who wanted to work on analysis has been able to do so. Undergraduate work has contributed to a number of publications and presentations (see Section 6).

We are able to involve undergraduate students in this way because we have the tradition of expecting such work from our students but also because of the close working relationship between the members of the collaboration. Frankly, it would be difficult for single researchers from a primarily undergraduate institution to work successfully with their students on the analysis of such measurements in isolation. The fact that both students and faculty involved in the research participate in regular video-conferences where recent results and problems can be discussed with others also working on the same experiment or related analyses is crucial. This shared expertise strengthens the group effort and provides undergraduates and their faculty mentors with needed support in the analysis of the data.
Giving the students responsibility for the analysis in these ways additionally results in increased effectiveness during the actual experiments. They are much more involved and make significant contributions by doing preliminary analysis as the data is being recorded.

But the largest benefit to this type of undergraduate involvement is that they are enthused to continue on to graduate study and they are extremely well prepared to continue in research. They have mastered many fundamental research skills and understand the problem solving process that is essential to carry research through to a conclusion. In fact, the MoNA collaboration has dramatically impacted the interest of undergraduate students in pursuing physics graduate school with an emphasis in nuclear physics (Figures 26 and 27).

The MoNA collaboration has had a significant impact regarding the increase of the STEM workforce. The current job distribution of students is shown in Fig. 28 about 75% of the students go into graduate school or are pursuing a STEM career.

**Summer research**

Summer is still the best time for undergraduates to get involved in major research projects. In addition to the undergraduate students from the collaborating institutions, many REU students joined the research efforts during the summers. The collaboration used this opportunity for workshops to teach the students about all aspects of MoNA. These workshops include formal presentations.
The MoNA Collaboration

February 24, 2022

and mini-lectures on the experimental details and pertinent background material such as radioactive beam production, laboratory safety, and experimental electronics. These duties are shared amongst the collaboration’s undergraduate professors and NSCL staff. The talks last an hour and a half each morning and then the students are put to work—finishing preparations, calibrating, and testing components—throughout the afternoon and into the evening. This intense and rigorous training period typically lasts for two weeks and culminates with an experiment that employs a lot of what the students just learned. At the end of the three week session, the students return to their summer obligations or begin analyzing the data from the experiment. Several of these students, well prepared by the MoNA Summer Session, return during the school year to help with other experiments.

Collaboration retreat

Near the end of each summer the MoNA Collaboration has historically held a retreat at the Central Michigan Biological Station on Beaver Island, located in the northern tip of Lake Michigan (from 2004 to 2013). In 2014, the retreat was held at Michigan State University, in 2015 the retreat was held at Westmont College in Santa Barbara, CA, and in 2016 the meeting was hosted at Wabash College, IN, and the 2017 meeting was held at the MSU Kellogg Biological Station in Hickory Corners, MI. The 2018 and 2019 meetings were held at the NSCL. Faculty and students participate in this annual gathering to write papers, discuss analysis, develop proposals for experiments and external support, and plan for the year ahead (Figure 30).

At the 2005 Beaver Island retreat a proposal was developed and subsequently received funding of $50,000 from the Research Excellence Fund of Michigan to purchase digital video-conferencing equipment. In addition to the specific needs of the MoNA collaboration that this hardware is intended to address, the video-conferencing infrastructure has offered substantial benefits to individual student and faculty participants at the member undergraduate institutions, to these institutions themselves, to the collaboration, and to the broader profession.
The equipment has allowed undergraduate students to participate in the real-time acquisition and off-line analysis of data. This novel remote approach to doing physics will give students the opportunity to participate in MoNA experiments together with other collaborators from multiple off-site locations and from the NSCL. Students are no longer prevented from participating in an experiment due to academic-year course commitments or travel constraints. The digital video conferencing system also allows faculty and students to have regular group, subgroup and point-to-point meetings where pre-experiment planning is being discussed and post-experimental data analysis is coordinated. The system is further being used for training, educating and motivating students who are new to the project. The system compliments the other forms of communication used by the collaboration, such as databases, websites, phones, and e-mail.

Data analysis and real-time experimental participation, facilitated by the conferencing system, will help students to foster stronger and more confident ties to the MoNA collaboration. This aspect of regular collaborative face-to-face interaction with members of the MoNA collaboration will continue to allow students to be genuine members of the group and contribute to the physics results produced by the collaboration.

Why undergraduate participation works so well with MoNA at NSCL

The MoNA collaboration has found it very easy to involve students in the fragmentation studies at NSCL. The students can readily grasp the basic goals of the measurements. As stated above, the academic atmosphere works well for the faculty and the undergraduate students fit in well (they especially relate to the graduate students), but additionally, the physics is easy for the students to understand. The reconstruction of the original nuclear mass is based on relativistic four-vectors. The nuclear shell model and single particle states, while complex in detail, can easily be related to atomic shells. The students are able to see the big picture while being involved in the experimental detail. Students see moderately complex detector systems but which are actually easily understood. (The concept of determining neutron energy from time-of-flight can be understood by first-year students.) The physics based on fragmentation provides tremendous opportunities for the undergraduate researcher (and their mentors).

In no small measure, the MoNA collaboration has been able to successfully and meaningfully involve undergraduates because the NSCL is an academic setting. The significant interaction of the undergraduate students with the graduate students and senior researchers, that are also instructors, has been very beneficial. The undergraduates are always greatly affirmed and encouraged. The mentors of these students also appreciate the support received from fellow academics.

MoNA Collaboration statement on membership

The MoNA Collaboration is committed to performing research at the forefront of nuclear science with significant involvement of undergraduate students. It was founded by multiple PIs who were awarded NSF grants to construct the original 144 MoNA bars. A second round of proposals was awarded to another group of PIs to build the next 144 bars, known as LISA. Other members have become PIs by a significant contribution in the form of equipment development or expertise in an area of value to the collaboration. Examples include a CsI hodoscope, Si-Be segmented target, simulation development, and digital data acquisition testing. We aim to be an inclusive collaboration and welcome new members with the understanding that new members will work with the existing members to determine how they too can best bring new value to the collaboration.

3.3 Physicists Inspiring the Next Generation

Physicists Inspiring the Next Generation (PING) is a program for pre-college students and undergraduate students. The program was started by Paul Guèye in 2014 as a collaboration between the National Society of Black Physicists (NSBP) and the National Radio Astronomy Observatory (NRAO) in partnership with Associated Universities, Inc. Since then it developed into a two-week summer research “Exploring the Nuclear Matter at the Facility for Rare Isotope Beams” which was piloted in 2019. This program is now fully funded by the NSF (NSF award PHY-2012040 since fall 2020), but was held on-line in 2020 and 2021 due to COVID (see Fig. 31).

The purpose of the program is to inspire high school students to work in research fields, nuclear physics in particular, and at the same time to offer undergraduates an opportunity in mentoring. Each undergraduate student is paired with a high school student, and they work on a specific simple research project that can show some results within the two weeks of the summer research (see e.g. Fig. 32). The students are also offered to continue this research throughout the fall semester if they are interested (and many are). Participants present their work annually at the National Society of Black Physicists (NSBP) meeting and the American Physical Society Division of Nuclear Physics (DNP) fall meeting.

While the program is not limited to MoNA physics, many projects are associated with MoNA research topics.

4 Conclusion

A great deal of cutting edge physics remains to be done utilizing fast fragmentation beams. The evolution of shell closures (magic numbers) as the stabilizing influence of protons in the same orbitals is lost for the most neutron-rich nuclei, which continues to be of particular interest. An additional focus is the study of neutron pairing correlations, which can be studied using neutron-rich nu-
clei in which sequential two-neutron decay is energetically forbidden, and only direct two-neutron decay can occur. Moreover, reaction studies and cross-section measurements can reveal, e.g., neutron and radiative strength functions. Reactions on exotic nuclei involving neutrons are also often of importance for explosive scenarios in astrophysics.

Many of these neutron-rich nuclei will be accessible at sufficient intensities and at nearly optimal beam velocities as fragmentation beams at a facility like FRIB.

The MoNA collaboration has been able to take advantage of the varying areas of expertise of its members to create a collaboration which has effectively involved undergraduate students from its beginning and continues to do so to this day. Students readily understand the nature of these experiments, and can participate in meaningful ways. The impact on these students of exposure to the international-level research currently conducted at NSCL is significant, and helps to train the next generation of physicists. A future isotope research facility that could continue this excellent support of undergraduate research would be welcomed by the MoNA collaboration, and would be an asset for our field of research.

5 Previous Director’s Statements

The MoNA Collaboration consists of a group of researchers, most from primarily undergraduate institutions, who are pursuing studies of nuclei close to and beyond the neutron dripline using the Modular Neutron Array (MoNA). These experiments can only be done with neutron-rich nuclei produced via projectile fragmentation, as carried out, for example, at the National Superconducting Cyclotron Laboratory (NSCL) at Michigan State University, where MoNA is currently located.

Since the first detectors of MoNA arrived for assembly in 2002, 64 undergraduate and high school students (as of Spring 2007) have participated in cutting-edge research in nuclear physics as part of the MoNA Collaboration. These students have assembled and tested the components of MoNA, participated in MoNA experiments and workshops at the NSCL and in the annual collaboration retreat, and played a central role in data analysis.

The MoNA collaboration has been a model for involvement of undergraduates in forefront research. The collaboration is committed to continuing its role in the study of nuclei at the limits of stability and in the training of the next generation of nuclear scientists. Our experience over the last six years leads us to the following observations:

• Studies of nuclei at the neutron dripline utilizing beams produced by fast fragmentation produce cutting-edge science. These experiments are well suited to meaningful participation by undergraduate students in a multi-institution collaboration.

• The collaboration has thrived in a university setting, where undergraduate education is at the core of the institutional mission.

We look forward to a next generation facility for rare-isotope beams which would ensure the continuation of this successful scientific and educational collaboration for years to come.

Jerry Hinnefeld
Executive Director, the MoNA collaboration
South Bend, January 17, 2007

Since the last version of this document the MoNA Collaboration has continued to thrive and grow. More than 100 undergraduate students have now been part of the collaboration’s scientific endeavors playing vital roles in the study of the nuclei at the limits of stability. Our collaboration has grown in other ways as well. New institutions and investigators have joined the collaboration. Sharon L. Stephenson (Gettysburg College), Nathan Frank (Augustana College in Rock Island, IL), Artemis Spyrou (Michigan State University), Robert A. Kaye (Ohio Wesleyan University) and Deseree Meyer Brittingham (Rhodes College) are bringing new skills and
insights to the collaboration’s work. In addition a new detector system is under construction by undergraduates at the collaboration schools. LISA, the Large multi-Institution Scintillator Array, will work in conjunction with MoNA to increase our ability to measure angular distributions of reaction neutrons as well as improve the resolution and efficiency of detection in our experiments.

The MoNA Collaboration has always been forward-looking whether in the preparation of the next generation of physicists or in the construction of detectors that are ready for use in the next generation of rare isotope beam facilities (FRIB). Today, we see a bright future for the collaboration, the NSCL, and rare-isotope physics.

Bryan A. Luther
Executive Director of the MoNA Collaboration
Moorhead, MN, Sept. 9, 2010

In the last two years, the MoNA Collaboration has completed LISA, the Large multi-Institutional Scintillator Array. Twenty-three undergraduates worked on construction, testing, and installation of LISA, with additional students playing key roles in data analysis. A successful commissioning experiment in June 2011 continues our scientific program of probing nuclei at the limits of stability. The higher efficiency and better resolution of MoNA LISA combined will allow the collaboration to study a wide array of isotopes that will be available when the Facility for Rare Ion Beams (FRIB) comes online. Extensive, meaningful undergraduate involvement in the cutting-edge science provides pivotal research experiences for students and contributes to training the next generation of nuclear scientists. The collaboration continues to exemplify a successful partnership between primarily undergraduate institutions and a large research university. We are excited about future research and educational opportunities that will be possible with FRIB and as our collaboration continues to grow.

Deseree Meyer Brittingham
Executive Director, the MoNA Collaboration
Beaver Island, MI, August 20, 2011

The MoNA (Modular Neutron Array) Collaboration continued to find success over the past year. To date, we have 37 peer reviewed papers with over half of those having undergraduate students as co-authors. In 2014 three graduate students completed their PhDs and another has data in hand to study the energy gap between the sd–pf neutron shells in $^{25}$O. This year the total number of MoNA Collaboration undergraduate students has surpassed our lucky number of 144 – the number of neutron detectors in MoNA or LISA. Our 147 undergraduate students have presented over fifty times at national physics conferences. The infrastructure of the MoNA Collaboration and the tradition of expecting quality work from our students at all levels of their academic careers has led to our improving research opportunities and preparing the next generation of physicists.

Sharon Stephenson
Executive Director, the MoNA Collaboration
East Lansing, MI July 20, 2014

At the time of this 2016 MoNA (Modular Neutron Array) Report, our collaboration remains as strong as ever. Since we first began 13 years ago using MoNA for nuclear physics experiments, we have published 40 peer reviewed articles, primarily in Physical Review Letters, Physical Review C, Physics Letters B, Nuclear Physics A, and Nuclear Instruments
and Methods A, with over half of them including undergraduate co-authors. Recent scientific highlights of our group’s work include a study of neutron correlations in the decay of excited $^{11}$Li, selective population of unbound states in $^{10}$Li, population of $^{13}$Be using charge-exchange reactions, characterization of low-lying states in $^{12}$Be, a search for unbound $^{13}$Be states using the $^{12}$Be + 3n channel, three-body correlations in the decay of the $^{26}$O ground state, analysis of $^{10}$He production mechanism using a $^{14}$Be secondary beam and a deuterated target, and a measurement of the low-lying excited states of $^{24}$O (which served as the LISA commissioning run). Recently completed experiments under analysis include a study of the of the equation of state using rare isotope beams, knockout reactions on p-shell nuclei, and in summer 2015 an experiment to measure the ground state energy of $^{10}$He using two separate production mechanisms was completed. Approved experiments for the near future include a measurement of the $^9$He ground state, and lifetime measurements with a decay-in-target method. To date 8 graduate students have completed their PhD degrees in MoNA research, 2 will be completing them soon, and 3 are relatively new to the group. By now 159 undergraduate students have participated in MoNA research, and have presented their research 56 times at national physics conferences. And for the first time our summer working retreat workshop was held outside of the state of Michigan, in sunny Santa Barbara, CA.

The main goal of our collaborative effort is the execution of high quality research in nuclear science, with undergraduate participation at the heart of our efforts. This vision will continue to drive our efforts in future years with a shared goal of helping inspire and prepare the next generation of physicists.

Warren Rogers

Executive Director, the MoNA Collaboration
Santa Barbara, CA, July 31, 2015

The MoNA collaboration had another successful year and has been busily preparing for the completion of FRIB and the eventual construction of the High Rigidity Spectrograph. The addition of our active target system allows for experiments with even more exotic nuclei, and the system saw its first use in an experiment to measure the groundstate lifetime of $^{26}$O. The collaboration continues to do cutting edge science in the structure and reactions of the most neutron-rich nuclei accessible. Beyond the scientific and technical the project continues to shape the careers of students, post-doctoral researchers, and faculty alike. The collaboration has touched the lives and careers of 171 undergraduates, who have participated in the running and analysis of our experiments or the construction of the detectors. This work has resulted in 44 peer-reviewed publications and many conference presentations, proceedings, and CEU posters. The collaboration remains vibrant and effective.

James Brown

Executive Director, the MoNA Collaboration
Crawfordsville, IN, August 13, 2016

The MoNA collaboration had another successful year of science and education, and we have also been presented with future challenging technical and personnel changes. In July the entire Collaboration, including 12 undergraduates, conducted an experiment to measure the $^9$He ground and excited states. We are now busy preparing in late November to look for neutron unbound states in the island of inversion. This will possibly be our last experiment in the N2 vault. To permit the testing of a CycStopper, we were asked to move the MoNA LISA detectors and Sweeper. In order to continue our scientific program we developed a plan to place our devices in front of the S800. We submitted a Letter of Intent to PAC 41 and they recognized and agreed with our proposal that this “would enable interesting studies on the nuclear structure and reactions involving the population of neutron-unbound excited states in medium mass neutron-rich nuclei, by giving improved PID resolution necessary to identify higher mass fragments.” To stimulate interest in an experimental MoNA LISA/Sweeper/S800 campaign, the Collaboration led a Working Group at the 2017 Low Energy Community Meeting where six potential experiments were presented and discussed. We will be busy leading up to PAC 42 in March of 2018 writing proposals and addressing the technical issues for this experimental campaign.

Sadly, in mid-June Michael Thoennessen informed us that the APS Board of Directors approved his appointment as the new APS Editor in Chief. This is a great honor and opportunity for Michael. We are proud of him. But we are very sad to see him go. Without Michael there would be no MoNA collaboration and nearly 200 undergraduate students would have missed an unparalleled scientific opportunity. While we are indebted to him for his scientific leadership, we will mostly miss him as a
friend.
Joe Finck
Executive Director, the MoNA Collaboration
Gull Lake, Michigan, August 12, 2017

The National Superconducting Cyclotron Laboratory is in its last years of operation and the construction of its upgrade, the Facility for Rare Isotope Beams, is near completion with an expected start date around 2021/2022. The MoNA collaboration has established itself as one of the most successful collaborations with unprecedented impact in undergraduate physics training (more than 200) through its decade of existence. Over the past year, the Collaboration achieved several milestones toward its transition from NSCL to FRIB science. One experiment to study neutron unbound states in the island of inversion was completed in the Fall 2017 and another experiment was approved by the PAC42 centered on the MoNA/LISA neutron detector arrays. A NSF/MRI to build a Si/CsI based telescope was awarded (N. Frank, PI) to improve the identification of heavy fragments. The expertise of the MoNA Collaboration also started expanding its impact on non-MoNA science at NSCL by participating in the SUN experiment over the Summer 2018 (P. DeYoung). The MoNA/LISA campaign in the N2 vault has ended after 14 years of operation. The entire experimental setup is being moved to the S2 vault for a future exciting and productive research program. The Collaboration contributed to the 2018 Nuclear Structure and Low Energy Community Conferences over the Summer with posters and oral presentations highlighting its research and impact in the field of fast neutrons science, and several students and faculty will be attending and presenting at the 2018 DNP meeting in the Fall. FRIB has initiated the investigation of an upgrade from 200 MeV/u to 400 MeV/u and the Collaboration is making plans for new detectors. P. Gueye has accepted a new position with FRIB/MSU. Through this new appointment, the MoNA Collaboration is reorganizing itself to grow its science for a bright future.
Paul Gueye
Executive Director, the MoNA Collaboration
NSCL/FRIB, East Lansing, August 12, 2018

Summer of 2019 finds the MoNA Collaboration looking back at a successful year and looking forward to a variety of challenges and opportunities. A number of our Ph.D. students are completing their degrees and starting the next chapter in their careers. Our undergraduate students are making meaningful contributions to our publications and well-positioned for graduate programs and STEM fields. Faculty have reached milestones, changed home institutions, and been awarded federal funding for our work. Over the past year we have dealt with physical changes – a large-scale move from one experimental area to another, detector development and data acquisition upgrades, as well as planning for new experiments – two at the NSCL/Frib and one at Los Alamos National Laboratory. Our productivity is tied to our group’s commitment to educating the next generation of scientists while pursuing new and exciting physics. We anticipate an exciting year ahead!
Sharon Stephenson
Executive Director, the MoNA Collaboration
National Superconducting Cyclotron Laboratory, July 19, 2019

The year 2020 will be remembered historically as the year of COVID-19. The low energy nuclear physics community will also remember it as the end of the NSCL era. The final two MoNA experiments at the NSCL were scheduled for summer 2020 but due to the pandemic were delayed. The Collaboration anticipates running at least one of the two approved experiments before the NSCL shuts down in an unfortunately shortened run schedule. As one era ends another begins. The MoNA Collaboration continues to plan and develop looking ahead to the FRIB era. This has been done through the development of next generation detectors, simulations, analysis techniques, and a deeper understanding of the MoNA bars. The Collaboration successfully ran a second experiment at LANSCE Fall 2019 and a test run at NSCL in Winter 2020 to commission the newly developed charged particle telescope. Three MoNA graduate students have defended their dissertations and have begun new jobs. Several undergraduate students have been involved and made an impact with many participating in the 2019 CEU program at the fall DNP meeting. There is a lot of uncertainty in the world right now, but the MoNA Collaboration has always found a way to rise to the occasion. This next year will be no exception.
Anthony Kuchera
Executive Director, the MoNA Collaboration
Davidson College by ZOOM, July 30, 2020
6 Presentations, Publications, Experiments, Grants

6.1 Invited Talks

1. The Modular Neutron Array at the NSCL
   T. Baumann for the MoNA Collaboration
   CAARI 2002: 17th International Conference on the Application of Accelerators in Research and Industry, CAARI, Denton TX, November 12–16, 2002

2. The MoNA project: doing big science projects with small-college undergraduates
   B. Luther

3. Explorations of the driplines and first results from MoNA
   M. Thoennessen
   International Conference on Frontiers In Nuclear Structure, Astrophysics, and Reactions (FINUSTAR), Kos, Greece, September 12–17, 2005

4. Studies of neutron-rich nuclei with the MoNA/Sweeper system at the NSCL
   P. A. DeYoung

5. First excited state of doubly-magic $^{24}$O
   A. Schiller, N. Frank, T. Baumann, J. Brown, P. DeYoung, J. Hinnefeld, R. Howes, J.-L. Lecouey, B. Luther, W. A. Peters, and M. Thoennessen

6. Unbound states of neutron-rich oxygen isotopes

7. Unbound states of neutron-rich oxygen isotopes: Investigation into the N = 16 shell gap

8. Unbound states of neutron-rich oxygen isotopes

9. Unbound states of neutron-rich oxygen isotopes
   C. Hoffman
   JUSTIPEN-EFES workshop on shell structure of exotic nuclei 4th workshop by the DOE project JUSTIPEN and the JSPS core-to-core project EFES, RIKEN, Tokyo, Japan, June 23, 2007

10. Unbound states of neutron-rich oxygen isotopes: Investigation into the N = 16 shell gap

11. Unbound states of neutron-rich oxygen isotopes: Investigation into the N = 16 shell gap
    C. Hoffman
    Direct Reactions with Exotic Beams, RIKEN, Tokyo, Japan, May 30–June 2, 2007
12. Proton knock-out reactions to neutron unbound states
   M. Thoennessen

13. Investigating the N = 16 shell closure at the oxygen dripline
   C. Hoffman

14. Neutron-decay spectroscopy of neutron-rich oxygen isotopes
   5th International Conference ENAM08 on Exotic Nuclei and Atomic Masses, Ryn, Poland September 7–13, 2008; Abstracts, p. 30 (2008)

15. Spectroscopy of unbound states at the oxygen drip line
   C. Hoffman
   Unbound Nuclei Workshop, INFN, Pisa, Italy, November 3–5, 2008

16. Big physics and small colleges: The mongol horde model of undergraduate research
   B. Luther

17. Exploration of the neutron dripline at the NSCL
   M. Thoennessen
   Annual NuSTAR Meeting, March 23–27, 2009, GSI, Darmstadt, Germany

18. Explorations of the driplines
   M. Thoennessen
   Step Forward to FRIB, RIA/FRIB Workshop, May 30–31, 2009, Argonne, IL

19. Shell evolution at the oxygen drip line
   C. Hoffman
   VIII Latin American Symposium on Nuclear Physics and Applications, Universidad de Chile, Santiago, Chile, December 15–19, 2009

20. Unbound systems along the neutron drip line
   A. Spyrou
   Workshop on Perspectives on the modern shell model and related experimental topics, Michigan State University, East Lansing, MI, February 4–6, 2010

21. Dissertation award in nuclear physics
   C. Hoffman
   American Physical Society April Meeting, Washington, D. C., February 13–16, 2010

22. Exploration of the neutron dripline and discovery of new isotopes
   M. Thoennessen
   Carpathian Summer School of Physics 2010, June 20–July 3, 2010, Sinaia, Romania

23. Beyond the driplines with nuclear reactions
   M. Thoennessen
   24th International Nuclear Physics Conference, July 4–9, 2010, Vancouver, Canada

24. Undergraduate research with the MoNA Collaboration at the National Superconducting Cyclotron Laboratory
   B. Luther
   21st International Conference on the Application of Accelerators in Research and Industry, CAARI, Fort Worth, TX, Aug. 8–13, 2010

25. Neutron decay spectroscopy at and beyond the limit of stability
   A. Spyrou
   The Limits of Existence of Light Nuclei, ECT* Workshop, October 25–30, 2010, Trento, Italy
26. Nuclear structure physics with MoNA-LISA  

27. New experimental work on structure beyond the neutron drip-line  
A. Spyrou  

28. Going beyond the dripline with MoNA-LISA  
M. Thoennessen  
1st Topical Workshop on Modern Aspects in Nuclear Structure Advances in Nuclear Structure with arrays including new scintillator detectors, February 22–25, 2012, Bormio, Italy

29. Exploration of light unbound nuclei  
M. Thoennessen  
Zakopane Conference on Nuclear Physics, August 27–September 2, 2012, Zakopane, Poland

30. Correlated two-neutron emission of nuclei beyond the neutron dripline  
M. Thoennessen  
4th International Conference on Collective Motion in Nuclei under Extreme Conditions COMEX 4, October 22–26, 2012, Shonan Village Center, Kanagawa, Japan

31. Recent results from MoNA-LISA  
Artemisia Spyrou  

32. Nuclear structure physics beyond the neutron drip line  
Artemisia Spyrou  
1WA.00001, Division of Nuclear Physics Fall Meeting, Newport Beach, CA, Bull. Am. Phys. Soc. 57 (2012)

33. Evidence for the ground-state resonance of $^{26}$O.  
Zachary Kohley  
Direct Reactions with Exotic Beams (DREB) Workshop, Pisa, Italy, March 2012

34. Nuclear structure along the neutron drip line  
A. Spyrou  
8th Balkan School on Nuclear Physics, Bulgaria, July 3-12, 2012

35. Nuclear structure experiments beyond the neutron drip line  
Michael Thoennessen  
International Nuclear Physics Conference (INPC2013), Florence Italy, 2 - 7 June 2013

36. Measuring oxygen isotopes beyond the neutron dripline: Two-neutron emission and radioactivity  
Zachary Kohley  
APS Division of Nuclear Physics Fall Meeting, Newport News, VA, October, 2013

37. Simulation of a novel active target for neutron-unbound state measurements  
Nathan Frank Abstract DJ.00009, APS Division of Nuclear Physics Fall Meeting, Newport News, VA, October, 2013

38. Structure and decay correlations of two-neutron unbound systems beyond the dripline  
Zachary Kohley  
State of the Art in Nuclear Cluster Physics Workshop (SOTANCP3), Yokohama, Japan, May 2014

39. Three-body forces in two neutron decay experiments  
A. Spyrou  

40. Study of neutron-unbound states with MoNA-LISA  
M. Thoennessen  
8th International Workshop on Direct Reactions with Exotic Beams, June 30 - July 4, 2014, Darmstadt, Germany
41. Recent results from MoNA-LISA
   M. Thoennessen
   VII International Symposium on Exotic Nuclei, September 7-12, 2014, Kaliningrad, Russia

42. Neutron-unbound nuclei
   M. Thoennessen
   4th Joint Meeting of the APS Division of Nuclear Physics and the Physical Society of Japan, Oct. 7-11, 2014, Waikoloa, HI

43. Direct Reactions with MoNA-LISA.
   A. Kuchera,
   Abstract B3.00002, APS April Meeting 2016, April 16-19, 2016, Salt Lake City, UT.

44. Identification of multiple neutrons with MoNA.
   A. Kuchera,

45. Reaction Mechanism Dependence of the Population and Decay of $^{10}\text{He}$.
   M. Thoennessen

46. Identification of multiple neutrons with MoNA.
   A. Kuchera

47. Direct Reactions with MoNA-LISA
   A. Kuchera
   APS April Meeting 2016, Salt Lake City, UT, April 16-19, 2016.

48. The Value of Undergraduate Research Participation in Physics, and in National DNP Meetings via the Conference Experience for Undergraduates. (APS Prize to a faculty member for research in an undergraduate institution)
   Warren Rogers

49. Two Decadal Survey of Unbound Nuclei with the Mona-lisa Detector: Past, Present and Future Outlook.
   P. Guèye
   1WKA.00003, 5th Joint Meeting of the APS Division of Nuclear Physics and the Physical Society of Japan. Waikoloa, HI October 23-27, 2018.

50. Latest news from the MoNA Collaboration at NSCL
   T. Baumann
   NUSTAR Annual Meeting, Darmstadt, Germany, February 25–March 1, 2019

51. Another FRIB Impact: Is Tomography of Heavy Ions Experimentally Possible?
   Paul Guèye
   NSCL Nuclear Science Seminar, March 18, 2019

52. MoNA and Dripline Search
   Paul Guèye
   NSCL/NSF Site Review, August 2019

53. Welcoming remarks (co-organizer)
   Paul Guèye
   Geant4 Collaboration Meeting, September 26–28, 2019

54. Welcoming/Goals (co-organizer)
   Paul Guèye
   JINA-CEE Minority Serving Institutions Workshop, December 14, 2019

55. MoNA-LISA: drip-oil painting with Leonardo da Vinci to drip-line with FRIB
   Paul Guèye, MSU
   FRIB Staff Talk, January 8, 2020
56. Un Voyage Dans la Vie des Nucléons  
Paul Guèye  
Université Cheikh Anta Diop, Sénégal, Africa, February 26, 2020

57. The (Hidden) Shades of Physics - Perspectives of being a Black Physicist  
Paul Guèye, MSU  
Women and Minorities in Science Lecture Series, Michigan State University, August 5, 2020

58. MoNA in HRS  
Paul Guèye, MSU  
Low Energy Community Meeting, August 10–12, 2020

59. Probing the neutron dripline: challenges and prospects  
Belen Monteagudo Godoy, MSU  

60. Partnerships with Minority Serving Colleges and Universities  
Paul Guèye, MSU  

61. MoNA-LISA  
Thomas Baumann  

### 6.2 Abstracts of Talks and Posters at Conferences

1. MONA: The Modular Neutron Detector  

2. Improving neutron detection efficiency by using passive converters  

3. MONA: The Modular Neutron Detector  

4. Construction of a Modular Neutron Array (MoNA)—A multi-college collaboration  

5. The status of the MoNA project  
T. Baumann, MoNA Collaboration  

6. MoNA: Detector development as undergraduate research  
Ruth Howes  
Workshop on Detector Development, Bloomington, IN, May 30, 2003

7. FPGA-based trigger logic for the Modular Neutron Array (MoNA)  
T. Baumann, P. A. DeYoung, MoNA Collaboration  

8. Commissioning of the MSU/FSU sweeper magnet  
9. Characteristics and preliminary results from MoNA at MSU/NSCL
   W. A. Peters, N. Frank, M. Thoennessen, T. Baumann, J. Brown, D. Hecksel, P. DeYoung, T. Pike, J. Finck, P. Voss, B. Luther, M. Kleber,
   J. Miller, R. Pipen, W. Rogers, L. Elliott, M. Strongman, K. Watters, MoNA Collaboration

10. How undergraduates from four-year departments can do “big” physics
    R. Howes for the MoNA Collaboration
    The Announcer 34, No. 4, 93 (2004)

11. Excitation and decay of neutron-rich Be isotopes
    W. Peters, MoNA Collaboration

12. Ground state wave function of $^{12}\text{Be}$
    W. A. Peters, T. Baumann, N. Frank, J.-L. Lecouey, A. Schiller, M. Thoennessen, K. Yoneda, P. DeYoung, G. Peaslee, J. Brown, K. Jones,
    B. Luther, and W. Rogers

13. Search for the first excited state of $^{24}\text{O}$
    J. Hinnefeld, R. Howes, R. A. Kryger, B. Luther

14. First excited state of doubly-magic $^{24}\text{O}$
    N. Frank, A. Schiller, T. Baumann, J. Brown, P. DeYoung, J. Hinnefeld, R. Howes, J.-L. Lecouey, B. Luther, W. A. Peters, M. Thoennessen

15. Population of neutron-unbound states from direct fragmentation
    G. Christian, D. Bazin, N. Frank, A. Gade, B. Golding, W. Peters, A. Ratkiewicz, A. Stump, A. Stolz, M. Thoennessen, M. Kleber, J. Miller,
    J. Brown, T. Williams, J. Finck, P. DeYoung, J. Hinnefeld, MoNA Collaboration

16. Detection efficiency of the Modular Neutron Array
    T. Baumann, W. A. Peters, MoNA Collaboration

17. Cosmic muon detection using the NSCL Modular Neutron Array
    W. F. Rogers, S. Mosby, S. Mosby, J. Gillette, M. Reese, MoNA Collaboration

18. Study of Coulomb and nuclear dissociation for astrophysical neutron capture cross sections
    A. Horvath, K. Ieki, A. Kiss, A. Galonsky, M. Thoennessen, T. Baumann, D. Bazin, C. A. Bertulani, C. Bordeanu, N. Carlin, M. Csanad,
    F. Deak, P. DeYoung, N. Frank, T. Fukuchi, Zs. Fulop, A. Gade, D. R. Galaviz, C. Hoffman, R. Izsak, W. A. Peters, H. Schelin, A. Schiller,
    R. Sugi, Z. Seres, and G. I. Veres

19. Ground state of $^{25}\text{O}$ and the first excited state of $^{24}\text{O}$
    J. E. Finck, J. Hinnefeld, R. Howes, N. Frank, B. Luther, MoNA Collaboration

20. Unbound states of neutron-rich oxygen isotope
    C. R. Hoffman, S. L. Tabor, M. Thoennessen, T. Baumann, D. Bazin, A. Gade, W. A. Peters, A. Schiller, J. Brown, P. A. DeYoung, R. Howes,
    N. Frank, B. Luther, H. Scheit, J. Hinnefeld, MoNA Collaboration

21. Measurement of the ground state of $^{15}\text{Be}$
    A. Russell, N. Frank, E. Breitbach, R. Howes, W. A. Peters, A. Schiller
<table>
<thead>
<tr>
<th>Title</th>
<th>Authors</th>
<th>Conference/Event</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nuclear structure studies along the neutron drip line: The case of $^{22}$N</td>
<td>A. Spyrou and the MoNA Collaboration</td>
<td>8th International Conference on Radioactive Nuclear Beams (RNB8), Grand Rapids, MI, USA, 26–30 May 2009</td>
</tr>
<tr>
<td>Creating a collaboration to perform big science at small schools</td>
<td>Joseph E. Finck, Bryan Luther, and Graham Peaslee</td>
<td>CUR 13th Nation Conference, Undergraduate Research as Transformative Practice, June 19–22, 2010, Weber State University, Ogden UT</td>
</tr>
<tr>
<td>Nuclear structure along the neutron dripline</td>
<td>A. Spyrou, MoNA Collaboration</td>
<td>Nuclear Structure 2010, Clark-Kerr Campus U. C. Berkeley, CA, 8–13 August 2010</td>
</tr>
</tbody>
</table>
35. Measurement of excitation energy of neon prefragments  
M. Mosby, D. J. Morrissey, M. Thoennessen  

36. Spectroscopy of neutron unbound carbon isotopes  
S. Mosby, M. Thoennessen, P. DeYoung  

37. Spectroscopy of neutron-unbound $^{15}$Be  
Jesse Snyder, Michael Thoennessen, Thomas Baumann, Artemis Spyrou, Michael Strongman, Greg Christian, Shea Mosby, Michelle Mosby, Jenna Smith, Anna Simon, Bryan Luther, Sharon Stephenson, Alex Peters, Paul DeYoung, Eric Lunderberg, Joseph Finck  

38. Fast fragmentation studies with the MoNA and LISA neutron detectors  
Joseph E. Finck and the MoNA Collaboration  
XII International Symposium on Nuclei in the Cosmos, Cairns, Australia (August 5–10, 2012)

39. Unbound excited states in $^{28}$Ne and $^{25}$F  
Jenna Smith, B. Alex Brown, Greg Christian, Shea Mosby, John F. Novak, Steven J. Quinn, Jesse Snyder, Artemis Spyrou, Michael J. Strongman, Michael Thoennessen, Thomas Baumann, Zachary Kohley, Joseph E. Finck, and Calem R. Hoffman  
DD.00003, Division of Nuclear Physics Fall Meeting, Newport Beach, CA (2012)

40. Spectroscopy of neutron-unbound $^{15}$Be  
Jesse Snyder, Michael Thoennessen, Thomas Baumann, Artemis Spyrou, Michael Strongman, Greg Christian, Shea Mosby, Michelle Mosby, Jenna Smith, Anna Simon, Bryan Luther, Sharon Stephenson, Alex Peters, Paul DeYoung, Eric Lunderberg and Joseph Finck  
CD.00009, Division of Nuclear Physics Fall Meeting, Newport Beach, CA (2012)

41. The controversial $^{10}$He ground state resonance: A new observation using a 2p2n-removal from $^{14}$Be  
Z. Kohley, J. Snyder and M. Thoennessen  
CD.00005, Division of Nuclear Physics Fall Meeting, Newport Beach, CA (2012)

42. Simulation of a novel active target for neutron-unbound state measurements  
Nathan Frank  
Abstract DJ.00009, APS Division of Nuclear Physics Fall Meeting, Newport News, VA, October, 2013

43. Measuring the partial width of the $^{56}$Ni proton-capture resonance through (d,n) with VANDLE and MoNA-LISA  
Abstract CF.00001, APS Division of Nuclear Physics Fall Meeting, Newport News, VA, October, 2013

44. 4n contributions in populating unbound $^{10}$He from $^{14}$Be  
Michael Jones, Zach Kohley, Jesse Snyder, Thomas Baumann, Jenna Smith, Artemis Spyrou, Michael Thoennessen  
Abstract PD.00004, APS Division of Nuclear Physics Fall Meeting, Newport News, VA, October, 2013

45. Two-neutron decay of excited states of $^{11}$Li  
J. Smith, MoNA Collaboration  

46. Measurement of neutron knockout cross-section of $^{24}$O to the ground-state of $^{23}$O  

47. Two-neutron decay from the ground state of $^{26}$O  
H. Attanayake, P. King, C. Brune, D. Diaratne, MoNA Collaboration  

48. A Multi-layered target for the study of neutron-unbound nuclei  
Paul Gueye, Nathan Frank and Michael Thoennessen  
49. Measurement of neutron knockout cross section of $^{24}$O to the ground-state of $^{23}$O  
D. Divaratne, C. Brune, P. King, H. Attanayake, S. Grimes, and M. Thoennessen  

50. VANDLE-izing north america; first results from the versatile array of neutron detectors at low energy  
INPC2013 Book of Abstracts, NF070 (2013)

51. Experimental check of Coulomb dissociation method for neutron capture measurements  

52. Determining the resonance strength of the $^{56}$Ni rp-process waiting point through (d,n) with VANDLE and MoNA-LISA  
Abstract K6.00008, American Physical Society, Savannah, Georgia, April 2014

53. Search for $^{15}$Be in the 3n+$^{12}$Be channel.  

54. Search for 4n contributions in the reaction $^{14}$Be(CH$_2$X)$_{10}$He.  

55. Knockout reactions on p-shell nuclei for tests of structure and reaction models.  

56. Direct Observation of Neutron Scattering in Plastic Scintillators.  
A.N. Kuchera  

57. Neutron multiplicity distributions for neutron-rich projectile fragments at the NSCL.  
Maria Mazza, Peter Christ, and Sharon Stephenson  

Krystin Stiefel, Zachary Kohley, Dave Morrisey, and Michael Thoennessen  

59. Reaction Mechanism Dependence Of The Population And Decay Of $^{10}$He.  
Han Liu, Thomas Redpath, Michael Thoennessen, and the MoNA Collaboration  

60. Lifetime Measurement of $^{26}$O.  
Thomas Redpath  
61. Direct Observation of Neutron Scattering in MoNA Scintillator Detectors.
   Rogers, W. F.; Mosby, S.; Frank, N.; Kuchera, A. N.; Thoennessen, M.; and the MoNA Collaboration

62. A multi-layered active target for the study of neutron-unbound nuclides at NSCL.
   Jessica Freeman, Paul Gueye, and Thomas Redpath

63. The new Digital Data Acquisition System for MoNA-LISA.
   Dayah Chrisman and Paul DeYoung

64. G4MoNA - A Geant4 Simulation for unbound nuclides detected with MoNA/LISA.
   Paul Gueye, Jessica Freeman, and Nathan Frank

65. Determining fragmentation dynamics through a study of neutron multiplicity at the NSCL.
   Sharon Stephenson, Peter Christ, and Maria Mazza

66. Development of a forward-angle gamma-ray detector array for MoNA-LISA.
   Daniel Votaw

67. Selective Population of Unbound Positive Parity States in $^{25}$F and $^{26}$F.
   Nathan Frank, Jacob Herman*, Ali Rabeh*, and Matthew Tuttle-Timm*

68. Direct Observation of Neutron Scattering in BC408 Scintillator for Comparison with Simulation.
   W. F. Rogers, J. E. Boone, A. Wantz, N. Frank, A. N. Kuchera, S. Mosby, and M. Thoennessen

69. Search for unbound nuclides and beam/fragment optics with the MoNA/LISA segmented target at NSCL.
   Paul Gueye, Nathan Frank, Michael Thoennessen, Thomas Redpath

70. Development of a forward-angle gamma array for MoNA-LISA.
   D. Votaw
   Poster presented at NNSA UPR, Walnut Creek, CA, June 2017.

71. Measurement of $^{9}$He ground and excited states.
   D. Votaw
   Poster presented at NSSC workshop, LBNL, September 2017.

72. Direct Neutron Scattering Observations in BC408 Scintillator, and Comparison to Simulation.
   W.F. Rogers, J.E. Boone, A. Wantz*, N. Frank, A.N. Kuchera, S. Mosby, and M. Thoennessen

73. A Dual Phase TPC/Thick-gem Based Target to Study Unbound Nuclei.
   Angel C. Christopher, Paul L Gueye, Thomas Baumann, Marco Cortesi, Malinga Rathnayake

74. Projectile-like fragment production studies using coincident neutrons.
   Sharon Stephenson, the MoNA Collaboration

75. Measurement of $^{9}$He ground and excited states.
76. Neutron Unbound States in the Island of Inversion.
   Dayah Chrisman, Thomas Baumann, Paul A Deyoung, Nathan Frank, Anthony N Kuchera, John McDonough, Robbie Seaton-Todd*, William
   vonSeeger*, the MoNA Collaboration,

77. The MoNA-LISA research program at NSCL and FRIB.
   Thomas Baumann, James Aaron Brown, Paul A DeYoung, Joseph Finck, Nathan Frank, Paul L Gueye, Jerry D Hinnefeld, Robert A Haring-
   Kaye, Anthony N Kuchera, Bryan A Luther, Warren F Rogers, Artemis Spyrou, Sharon L Stephenson, Michael R Thoennessen,

   Paul L Gueye, Thomas Baumann, Dayah Chrisman, Paul A DeYoung, Nathan Frank, Anthony N Kuchera, Thomas H Redpath, Michael R
   Thoennessen, William von Seeger*,

79. Geant4 study of the electric field effect on the signals from GEM detectors
   Malinga Rathnayake
   2018 National Society of Black Physicists annual meeting, Columbus, OH, November 4-7 (2018)

80. Measurement of $^9$He ground and excited states.
   D. Votaw
   Poster presented at NNSA UPR, Ann Arbor, MI, June 2018.

   Nathan Frank, Georgia Votta, Thomas Baumann, James Brown, Paul DeYoung, and the MoNA Collaboration

82. Search for the $^{15}$Be ground state.
   Anthony Kuchera, Rida Shahid, Nathan Frank, Hayden Karrick*,

83. Parity inversion in the unbound N = 7 isotones.
   D. Votaw
   NNSA UPR, Raleigh, NC, 2019.

84. Investigation of a Gas Phot-multiplier as a next generation neutron detector.
   Maya Watts, Thomas Baumann, Marco Cortesi, Alder Fulton, Paul Gueye, Phuonghan Pham, and Thomas Redpath
   18-21, (2020).

85. Mirror nucleon removal reactions in p-shell nuclei
   Anthony Kuchera, Tan Phan, Daniel Bazin, and the MoNA Collaboration

86. Neutron-Unbound States in the N=20 Island of Inversion
   Dayah Chrisman, Thomas Baumann, Paul Gueye, Anthony Kuchera, Robbie Seaton-Todd, Nathan Frank, John McDonough, and the MoNA
   Collaboration

87. Physicists Inspiring the Next Generation: Exploring the Nuclear Matter
   Yannick Gueye

88. Trace Fitting of a Charged Particle Telescope to use with MoNA
   Georgia Votta, Nathan Frank, Thomas Baumann, Paul Gueye, Thomas Redpath, Belen Monteagudo Godoy, Anthony Kuchera, and the MoNA
   Collaboration
89. A Search for the $^{12}$Be Isomeric State.

XINYI WANG and the MoNA Collaboration


90. Nuclear Science Research and the Undergraduate Experience.

Warren Rogers


Thomas Redpath, Megan Brayton, Darrius Sykes, and the MoNA Collaboration


From Engineering to Physics and Back: A Mixture of Two Worlds.

Grace M Townley, Paul L Gueye, Thomas Baumann, Yannick Gueye, Casey Hulbert, and the MoNA Collaboration


Preliminary investigations of a polarized target for the study of neutron unbound systems.

Georgia Votta, Paul L Gueye, and the MoNA Collaboration


92. Preliminary Simulations of the Multi-layer Active target for MoNA Experiments (MAME).

Nicholas Mendez, Thomas Redpath, Phuonganh Pham, Paul L Gueye, and the MoNA Collaboration


93. Search for $^{15}$Be+3n.

Anthony N. Kuchera, Rida Shahid, Aidan J. Edmondson, Jinpai Zhao, Nathan H. Frank, and Oscar Peterson-Veatch


94. Designing a neutron detector with improved position resolution for the MoNA Collaboration.

Thomas Baumann


95. Performance of a charged particle detector system to study unbound systems at FRIB.

Nathan H. Frank, Thomas Baumann, Paul A. DeYoung, Paul L. Gueye, Anthony N. Kuchera, Belen Monteagudo, Geogia Votta, Henry Webb, and Xinyi Wang


96. Fast neutron scattering and multiple-neutron detection in MoNA.

W.F. Rogers, A. Munroe, J. Hallett, and the MoNA Collaboration


97. A search for the $^{12}$Be Isomeric State.

Xinyi Wang, Paul L. Gueye, Thomas Baumann, Paul A. DeYoung, Nathan H. Frank, and Anthony N. Kuchera


98. Neutron-unbound excited states in $^{31}$Ne.

Dayah N Chrisman, Anthony N Kuchera, Thomas Baumann, B A Brown, Nathan H Frank, Paul L Gueye, Belen Monteagudo, and Jeffrey A Tostevin

99. Investigation of the reaction mechanism in the neutron emission from unbound excited states in 27F by the MoNA Collaboration.
Paul L Gueye, Thomas Redpath, Thomas Baumann, Alaura Cunningham, Belen Monteagudo, and Jared Bloch

100. Shell spectroscopy sensitivity via the ground state population of 26O from halo nuclei in proton removal reactions.
Paul L Gueye, Thomas Baumann, Thomas Redpath, Belen Monteagudo, Alaura Cunningham, Kevin Fossez, Nathan H Frank, Jimmy Rotureau, and Anthony N Kuchera

101. 2021 Physicists Inspiring the Next Generation: Exploring the Nuclear Matter – Pre-College Students Perspectives.
Paul L Gueye, Paul L Gueye, Thomas Baumann, and Casey Hulbert

102. Preliminary Simulations of the Multi-layer Active target for MoNA Experiments (MAME).
Nicholas Mendez, Thomas Redpath, Phuonganh Pham, and Paul L Gueye

103. Preliminary Performance Studies of the MoNA-Sweeper setup in S2 at FRIB.
Andrew Wantz, Paul L Gueye, Thomas Baumann, and Belen Monteagudo

104. From Engineering to Physics and Back: A Mixture of Two Worlds.
Grace M Townley, Paul L Gueye, Thomas Baumann, Yannick Gueye, and Casey Hulbert

6.3 Abstracts of Standard Talks and Posters at Conferences by Undergraduates

1. Accurate energy calibrations from cosmic ray measurements
A. DeLine, J. Finck, A. Spyrou, M. Thoennessen, and P. DeYoung

2. Nuclear astrophysics outreach program now employs researcher’s equipment for enhancement
Amy DeLine, Zach Constan, and Joseph Finck
Winter Meeting of the AAPT, Chicago, IL (2009)

3. Undergraduate experiences in cutting-edge research experiments
A. Haagsma, K. Rethman, MoNA Collaboration

4. Spectroscopy of 13Li

5. Dual Phase TPC/TH-GEM based target to study unbound nuclei
Angel Christopher
2018 National Society of Black Physicists annual meeting, Columbus, OH, November 4-7 (2018)

6.4 Seminars and Colloquia

1. MoNA: the Modular Neutron Array
Joseph E. Finck
Physics Department Seminar, Central Michigan University, Mount Pleasant, MI, October 25, 2001

2. Physics at the neutron dripline: The MoNA Project and the NSCL
Bryan Luther
Department of Physics Seminar, North Dakota State University, Fargo, ND, October 16, 2002
3. Giving students a taste of research
   Bryan Luther
   Department of Physics Seminar, North Dakota State University, Fargo, ND, October 16, 2002

4. The Coupled Cyclotron Facility and MoNA at the NSCL
   Thomas Baumann
   Triangle Universities Nuclear Laboratory Seminar, Durham, NC, November 21, 2002

5. MoNA: The Modular Neutron Array
   Bryan Luther
   Centennial Scholars Program, Moorhead, MN, February 11, 2003

6. Development of neutron detectors
   Ruth Howes
   Seminar at Mt. San Antonio College, Walnut, CA, March 28, 2003

7. MoNA: detector development as undergraduate research
   Ruth Howes
   Workshop on Detector Development, Bloomington, IN, May 30, 2003

8. MoNA and physics at the nuclear dripline
   Ruth Howes
   Colloquium at Marquette University, Milwaukee, WI, January 29, 2004

9. Status of the Modular Neutron Array, new opportunities near the neutron dripline
   James A. Brown
   Ball State University, Muncie, IN, November 11, 2004

10. Where the sidewalk ends: MoNA and the neutron dripline
    Bryan Luther
    Physics Department Colloquium, Carleton College, Northfield, MN, March 10, 2005

11. Exploring the neutron dripline with MoNA
    Michael Thoennessen
    Physics Department Colloquium, Argonne National Laboratory, Argonne, IL, February 3, 2006

12. Nuclear structure studies with the Modular Neutron Array
    James A. Brown
    Duke University, Triangle Universities Nuclear Structure Laboratory, Durham, NC, March 2, 2006

13. The Modular Neutron Array & the MoNA collaboration
    Thomas Baumann
    Physics Department Seminar, Central Michigan University, Mount Pleasant, MI, March 30, 2006

14. Selective population and neutron decay of the first excited state of semi-magic $^{23}$O
    A. Schiller
    Nuclear Physics Seminar, Argonne National Laboratory, Argonne, IL, December 18, 2006

15. Physics with the Modular Neutron Array
    Joseph E. Finck
    Physics Department Seminar, Central Michigan University, Mount Pleasant, MI, January 11, 2007

16. Exploring the edge of the nuclear universe
    Michael Thoennessen
    Physics Department Colloquium, Smith College, Northampton, MA, February 17, 2007

17. Nuclear physics near the dripline: Present and future of MoNA
    Nathan Frank
    Physics Department Seminar, Central Michigan University, Mount Pleasant, MI, March 23, 2007

18. Exploring the edge of the nuclear universe
    Michael Thoennessen
    Seminar, Department of Biological & Physical Sciences, South Carolina State University, Orangeburg, SC, February 26, 2008
19. Studying exotic nuclei with the Modular Neutron Array (MoNA)
   Artemis Spyrou
   Seminar, Physics Department, Indiana University South Bend, November 13, 2008

20. Explorations of the driplines at the NSCL
   Michael Thoennessen
   College 3 Seminar, Institute Laue Langevin, Grenoble, France, November 21, 2008

21. Studying exotic nuclei with the Modular Neutron Array (MoNA)
   Artemis Spyrou
   Seminar, Department of Physics, Grand Valley State University, November 2, 2009

22. Discovery of new isotopes at and beyond the neutron dripline
   Michael Thoennessen
   Kernphysikalisches Kolloquium, Institut für Kernphysik, Universität zu Köln, Germany, February 3, 2010

23. Traveling beyond the neutron dripline with MoNA
   A. Spyrou
   Seminar given at Oakridge National Lab, June 2010

24. Physics at the neutron dripline
   Sharon Stephenson
   Physics Department Colloquium, Franklin and Marshall College, Lancaster, PA, October 13, 2011

25. Construction, testing, and installation of the Large Multi-Institutional Scintillator Array (LISA)
   D. A. Meyer
   University of Kentucky, Lexington, KY, 21 April 2011

26. Exploring the edge of the nuclear universe
   Michael Thoennessen
   Seminar, Dept. of Physics and Astronomy, Indiana University South Bend, South Bend, IN, February 10, 2011

27. Exploring the edge of the nuclear universe
   Michael Thoennessen
   Muller Prize Lecture, Ohio Wesleyan University, Delaware, OH, Feb. 22, 2011

28. Expanding the nuclear horizon
   Michael Thoennessen
   Department of Physics & Astronomy Colloquium, Stony Brook University, Stony Brook, NY, March 1, 2011

29. Expanding the nuclear horizon
   Michael Thoennessen
   iThemba Laboratory Colloquium, Stellenbosch, South Africa, March 8, 2011

30. Physics at the neutron dripline
    Sharon Stephenson
    Franklin and Marshall College, October 13, 2011

31. Undergraduate research in nuclear physics
    Nathan Frank
    Indiana University South Bend, South Bend, IN, March 8, 2012

32. MoNA-LISA and the rare, shortlived world of exotic nuclei
    Sharon Stephenson
    SUNY-Geneseo, April 12, 2012

33. Going beyond the neutron dripline: Recent measurements of two-neutron unbound nuclei
    Zachary Kohley
    Webinar for the Nuclear Science and Security Consortium, October 2012

34. First observation of ground state di-neutron decay: $^{16}$Be
    A. Spyrou
    Seminar given at NSCL, February 2012
35. Nuclear structure along the neutron drip line: recent results of MoNA
   A. Spyrou
   Seminar at Argonne National Lab, April 2012

36. Nuclear structure along the neutron dripline
   A. Spyrou
   Colloquium at Fermi Lab, September 2012

37. Research on unstable atomic nuclei with undergraduates
   Nathan Frank
   Celebration of Scholarship at Augustana College, February 18, 2013

38. Neutron-rich nuclear physics at Michigan State University
   Jenna Smith
   Seminar, Indiana University - South Bend, March 28, 2013

39. Measuring oxygen isotopes beyond the neutron dripline: Two-neutron emission and radioactivity
   Zachary Kohley
   Australian National University, Canberra, Australia, November 2013

40. Measuring oxygen isotopes beyond the neutron dripline: Two-neutron emission and radioactivity
   Zachary Kohley
   Central Michigan University, Mount Pleasant, MI, September 2013

41. Studying Atomic Nuclei with Undergraduates
   Nathan Frank
   Colloquium, Department of Physics, Hampton University, Hampton, VA, April 3, 2014

42. The MoNA collaboration and undergraduate education.
   Paul A. DeYoung

43. Making Beautiful Physics with the Help of MoNA-LISA
   Sharon Stephenson
   Ithaca College April 28, 2015.

44. The unbound nuclei and the dineutron.
   Bryan A. Luther
   Concordia College, April 10, 2015.

45. Investigations near the neutron dripline.
   James Brown
   Ball State University, November 2015.

46. Sweeper/MoNA-LISA setup to the S800.
   N. Frank.
   Low Energy Community Meeting, University of Notre Dame, South Bend, IN, Aug. 10-13, 2016.

47. Neutron detection with MoNA for nuclear structure and reaction studies.
   A. Kuchera
   Argonne National Laboratory, Physics Division Seminar, May 22, 2017.

48. Nuclear Physics Fun at the Edge, Department of Physics.
   Nathan Frank
   Marquette University, Milwaukee, WI, November 9, 2017.

49. Sweeper/MoNA-LISA setup to the S800: Study of $^{37}$Mg.
   Nathan Frank
   Low Energy Community Meeting, Argonne National Laboratory, Aug. 3-4, 2017.

50. Fast-neutron spectroscopy at FRIB: how well does simulation predict neutron scattering in plastic scintillator at
    FRIB energies? A critical test using direct single-neutron scattering observations.
    W. Rogers
    University of Notre Dame, Physics Department, October 1, 2018.
51. Study of Neutron-Decay of Exotic Nuclei using the MoNA-LISA Detector Arrays and Monte Carlo Simulation.  
W. Rogers  
Indiana University Purdue University Indianapolis (IUPUI), Physics, March 29, 2018.

52. Neutron Drip Line Studies with MoNA-LISA.  
S. Stephenson  
Rutgers University, May 6, 2019

53. Next Generation Neutron Detector  
Thomas Baumann  
NSCL Research Discussion, April 9, 2020

6.5 Undergraduate Presentations: CEU Posters

**CEU, 2002 DNP Fall Meeting, East Lansing, MI**

1. Veto detectors for the micro-modular neutron array  
Y. Lu, T. Baumann, M. Thoennessen, E. Tryggestad, M. Evanger, B. Luther, M. Rajabali, R. Turner  

2. First radioactive beam experiment with the Modular Neutron Array MoNA  
M. Rajabali, M. Evanger, R. Turner, B. Luther, T. Baumann, Y. Lu, M. Thoennessen, E. Tryggestad  

3. Neutron testing of the micro-Modular Neutron Array  
M. Evanger, M. Rajabali, R. Turner, B. Luther, T. Baumann, Y. Lu, M. Thoennessen, E. Tryggestad  

4. Cosmic ray testing of the micro-Modular Neutron Array  
R. Turner, M. Evanger, M. Rajabali, B. Luther, T. Baumann, Y. Lu, M. Thoennessen, E. Tryggestad  

5. The MoNA project  

**CEU, 2003 DNP Fall Meeting, Tucson, AZ**

1. Calibration of the Modular Neutron Array (MoNA)  
S. Clark, N. Walker, W. Rogers, T. Baumann, M. Thoennessen, A. Stolz, W. Peters  

2. High voltage control of the Modular Neutron Array  
S. Marley, T. Baumann, N. Frank, E. Johnson, W. Peters, M. Thoennessen, B. Luther  

3. Cosmic rays in MoNA  
E. Johnson, M. Thoennessen, T. Baumann, W. Peters, S. Marley, B. Luther  

**CEU, 2004 DNP Fall Meeting, Chicago, IL**

1. Determination of position resolution for the Modular Neutron Array using cosmic rays  
J. Miller, M. Kleber, B. Luther, MoNA Collaboration  

2. MoNA and initial measurements with $^7$He resonance  
T. Pike, R. Pepin, MoNA Collaboration  

3. Cosmic muon tracking with MoNA  
K. Watters, L. Elliott, M. Strongman, W. Rogers  

4. Calibration of the Modular Neutron Array  
R. Pepin, T. Pike, MoNA Collaboration  
CEU, 2005 DNP Fall Meeting, Maui, HI

1. Tracking single and multiple events in MoNA
   A. Stump, A. Ratkiewicz, MoNA Collaboration

2. MoNA calibration and neutron tracking
   S. Mosby, E. Mosby, W. F. Rogers, MoNA Collaboration

CEU, 2006 DNP Fall Meeting, Nashville, TN

1. An automated relative time calibration for MoNA
   D. Albertson, MoNA Collaboration

2. Analysis of kinematics and decay energy in the breakup of $^7$He
   D. Denby, P. DeYoung, G. Peaslee, MoNA Collaboration

3. Calibration of the thick and thin scintillators for the NSCL/FSU Sweeper magnet system
   A. Hayes, MoNA Collaboration

4. Cosmic muon flux variations using the Modular Neutron Array
   E. Mosby, S. Mosby, J. Gillette, M. Reese, W. F. Rogers, MoNA Collaboration

5. Neutron multiplicity discrimination in MoNA
   S. Mosby, E. Mosby, W. F. Rogers, MoNA Collaboration

CEU, 2007 DNP Fall Meeting, Newport News, VA

1. Search for upward cosmic rays
   E. White, A. Spyrou, M. Thoennessen, T. Yoast-Hull, MoNA Collaboration

2. Efficiency and multi-hit capability improvements of MoNA
   T. Yoast-Hull, A. Spyrou, M. Thoennessen, E. White, MoNA Collaboration

CEU, 2008 DNP Fall Meeting, Oakland, CA

1. Geant4 simulation of MoNA
   A. Fritsch, M. Heim, T. Baumann, S. Mosby, A. Spyrou

2. Investigation of neutron scattering in the Modular Neutron Array (MoNA)
   M. Gardener, W. F. Rogers

3. Experimental observation of decay energy of $^{12,13}$Li
   C. Hall, P.A. DeYoung, S. Mosby, A. Spyrou, M. Thoennessen

CEU, 2009 DNP Fall Meeting, Waikoloa, HI

1. Spectroscopy of $^{12}$Li
   E. Lunderberg, C. Hall, P. DeYoung, A. Spyrou, M. Thoennessen, MoNA Collaboration
2. Observation of neutron-unbound resonant stated in $^{23}$O and $^{28}$Ne

3. Non-resonant neutron emission of excited neutron-rich nuclei

4. Accurate position calibration for charged fragments

CEU, 2010 DNP Fall Meeting, Santa Fe, NM

1. Testing the Large-area multi-Institutional Scintillator Array (LISA) neutron detector
   L. Elliott, and P. Kasavan
   CEU Poster EA.00078, Division of Nuclear Physics Fall Meeting, Santa Fe, NM (2010)

2. Performance comparison of MoNA and LISA neutron detectors
   Kimberly Purtell, Kaitlyne Rethman, Autumn Haagsma, Joseph Finck, Jenna Smith, Jesse Snyder
   CEU Poster EA.00090, Division of Nuclear Physics Fall Meeting, Santa Fe, NM (2010)

3. Construction of the Large-area multi-Institutional Scintillator Array (LISA) neutron detector
   Kaitlyne Rethman, Kimberly Purtell, Autumn Haagsma, Casey DeRoo, Megan Jacobson, Steve Kuhn, Alexander Peters, Tim Nagi, Sam
   Stewart, Zack Torstrick, Mathieu Ndong, Rob Anthony, Hengzhi Chen, Alex Howe, Nicholas Badger, Matthew Miller, Brad Vest, Ben Foster,
   Logan Rice, Alegra Aulie, Amanda Grovom, Philip Kasavan, Lewis Elliott
   CEU Poster EA.00093, Division of Nuclear Physics Fall Meeting, Santa Fe, NM (2010)

4. Search for angular anisotropies in neutron emissions of fragmentation reactions with secondary beams
   Sam Novario, Greg Christian, Jenna Smith, Michael Thoennessen
   CEU Poster EA.00081, Division of Nuclear Physics Fall Meeting, Santa Fe, NM (2010)

5. Tagging the decay of neutron unbound states near the dripline
   Alissa Wersal, Greg Christian, Michael Thoennessen, Artemis Spyrou
   CEU Poster EA.00126, Division of Nuclear Physics Fall Meeting, Santa Fe, NM (2010)

6. Analysis of an experiment on neutron-rich isotopes
   CEU Poster EA.00005, Division of Nuclear Physics Fall Meeting, Santa Fe, NM (2010)

7. MoNA and two-neutron decay analysis
   Amanda Grovom, Alegra Aulie, Warren F. Rogers
   CEU Poster EA.00007, Division of Nuclear Physics Fall Meeting, Santa Fe, NM (2010)

CEU, 2011 DNP Fall Meeting, East Lansing, MI

1. Modeling neutron events in MoNA-LISA using MCNPX
   Margaret Kendra Elliston, Alexander Peters, Kristen Stryker, Sharon Stephenson, MoNA Collaboration
   CEU Poster EA.00039, Division of Nuclear Physics Fall Meeting, East Lansing, MI (2011)

2. Calibration of the MoNA and LISA arrays for the LISA commissioning experiment
   A. Grovom, J. Kwiatkowski, W. F. Rogers, MoNA Collaboration
   CEU Poster EA.00058, Division of Nuclear Physics Fall Meeting, East Lansing, MI (2011)

3. Calibration of the sweeper chamber charged-particle detectors for the LISA commissioning experiment
   J. Kwiatkowski, A. Grovom, W. Rogers, Westmont College, MoNA Collaboration
   CEU Poster EA.00073, Division of Nuclear Physics Fall Meeting, East Lansing, MI (2011)

4. Optical attenuation in MoNA and LISA detector elements
   Logan Rice, Jonathan Wong, MoNA Collaboration
   CEU Poster EA.00112, Division of Nuclear Physics Fall Meeting, East Lansing, MI (2011)
5. Testing and installation of a high efficiency CsI scintillator array
   Natalie Viscariello, Stuart Casarotto, Nathan Frank, Jenna Smith, Michael Thoennessen
   CEU Poster EA.00135, Division of Nuclear Physics Fall Meeting, East Lansing, MI (2011)

**CEU, 2012 DNP Fall Meeting, Newport Beach, CA**

1. Simulating neutron interactions in the MoNA-LISA/Sweeper setup with Geant4
   Magdalene MacArthur
   CEU Poster EA.00054, Division of Nuclear Physics Fall Meeting, Newport Beach, CA (2012)

2. Analysis of LISA commissioning run data for study of $^{24}O$ excited state decay energies
   N. Taylor, S. Garrett, A. Barker and W. F. Rogers
   CEU Poster EA.00060, Division of Nuclear Physics Fall Meeting, Newport Beach, CA (2012)

3. Calibration of charged-particle detectors for the LISA commissioning experiment
   S. Garrett, N. Taylor, A. Barker and W. Rogers
   CEU Poster EA.00059, Division of Nuclear Physics Fall Meeting, Newport Beach, CA (2012)

4. Active target simulation
   Nathan Smith, Peter Draznik and Nathan Frank
   CEU Poster EA.00003, Division of Nuclear Physics Fall Meeting, Newport Beach, CA (2012)

5. Exploration of three-body decay using jacobian coordinates
   Mark Hoffmann, Kyle Williams and Nathan Frank
   CEU Poster EA.00002, Division of Nuclear Physics Fall Meeting, Newport Beach, CA (2012)

6. Composition of the $^{24}O$ ground state wave function
   CEU Poster EA.00066, Division of Nuclear Physics Fall Meeting, Newport Beach, CA (2012)

7. Preparation for MoNA/LISA VANDLE $^{56}Ni(d,n)$ experiment at the NSCL
   CEU Poster EA.00071, Division of Nuclear Physics Fall Meeting, Newport Beach, CA (2012)

**CEU, 2013 DNP Fall Meeting, Newport News, VA**

1. Precise timing calibration for MoNA and LISA detectors
   Sierra Garrett, Alyson Barker, Nathaniel Taylor, Warren F. Rogers
   CEU Poster EA.00062, Division of Nuclear Physics Fall Meeting, Newport News, VA (2013)

2. Isotope separation and decay energy calculation for LISA commissioning experiment
   Nathaniel Taylor, Alyson Barker, Sierra Garrett, Warren F. Rogers
   CEU Poster EA.00063, Division of Nuclear Physics Fall Meeting, Newport Beach, CA (2013)

3. Commissioning a hodoscope detector
   Andrew Lulis, Abdul Merhi, Nathan Frank, Daniel Bazin, Jenna Smith, Michael Thoennessen
   CEU Poster EA.00072, Division of Nuclear Physics Fall Meeting, Newport News, VA, October, 2013

4. Segmented target design
   Abdul Rahman Merhi, Nathan Frank, Paul Gueye, Michael Thoennessen
   CEU Poster EA.00074, Division of Nuclear Physics Fall Meeting, Newport News, VA, October, 2013

5. Converting VANDLE data into ROOT for merging with other systems
   CEU Poster EA.00080, Division of Nuclear Physics Fall Meeting, Newport News, VA, October, 2013
CEU, 2014 DNP Fall Meeting, Waikoloa, HI

1. Detector calibrations for fragmentations reactions with relativistic heavy ions at the NSCL
Heather Garland, Sharon Stephenson, Michelle Mosby
CEU Poster GB.00042, Division of Nuclear Physics Fall Meeting, Waikoloa, HI October, 2014

2. Unbound Resonances in Light Nuclei
Elizabeth Havens, Joseph Finck, Paul Gueye, Michael Thoennessen
CEU Poster GB.00041, Division of Nuclear Physics Fall Meeting, Waikoloa, HI October, 2014

3. Decay energies for $^{24}\text{O} \rightarrow ^{23}\text{O} + n$ using MoNA-LISA-Sweeper detector systems and Monte Carlo simulations
Sierra Garrett, Alyson Barker, Rachel Parkhurst, Warren Rogers, Anthony Kuchera
CEU Poster GB.00043, Division of Nuclear Physics Fall Meeting, Waikoloa, HI October, 2014

CEU, 2015 DNP Fall Meeting, Sante Fe, NM

1. Production of Unbound Resonance in $^{23}\text{O}$.
CEU poster EA.00098, 2015 Fall Meeting of the APS Division of Nuclear Physics, Santa Fe, NM (2015).

2. Population of $^{13}\text{Be}$ with a Nucleon-Exchange Reaction.
CEU poster EA.00104, 2015 Fall Meeting of the APS Division of Nuclear Physics, Santa Fe, NM (2015).

3. Unbound Resonance of $^{26}\text{F}$.
CEU poster EA.00108, 2015 Fall Meeting of the APS Division of Nuclear Physics, Santa Fe, NM (2015).

CEU poster EA.00102, 2015 Fall Meeting of the APS Division of Nuclear Physics, Santa Fe, NM (2015).

5. Calibrations for studies of neutron-rich precursor fragments.
Maria Mazza, Rachel Parkhurst, Samuel Wilensky, Michelle Mosby, Sharon Stephenson, Warren Rogers.
CEU poster EA.00105, 2015 Fall Meeting of the APS Division of Nuclear Physics, Santa Fe, NM (2015).

CEU 2016 DNP Fall meeting, Vancouver BC, Canada

1. Neutron multiplicity distributions for neutron-rich projectile fragments at the NSCL
Maria Mazza, Peter Christ, and Sharon Stephenson.
CEU poster EA.00115, 2016 Fall Meeting of the APS Division of Nuclear Physics, Vancouver BC, Canada (2016).

CEU 2017 DNP Fall meeting, Pittsburg, PA

1. Neutron Radioactivity in $^{26}\text{O}$ and Lifetime Analysis of Neutron-Rich Isotopes.
C. Persch*, P. A. DeYoung, N. Frank, P. Gueye, A. Kuchera, T. Redpath, and the MoNA Collaboration,
CEU Poster EA.00169 Fall Meeting of the APS Division of Nuclear Physics, Pittsburgh, PA (2017).

2. First Observation of Three-Neutron Sequential Emission from $^{25}\text{O}$.
C. Sword*, J. Brett*, P. A. DeYoung, N. Frank, H. Karrick*, A. N. Kuchers*, and the MoNA Collaboration,
CEU Poster EA.00170 Fall Meeting of the APS Division of Nuclear Physics, Pittsburgh, PA (2017).

3. Sequential Decay of $^{26}\text{F}$.
CEU Poster EA.00167 Fall Meeting of the APS Division of Nuclear Physics, Pittsburgh, PA (2017).

4. Test of Monte Carlo Simulation for MoNA neutron detectors.
CEU Poster EA.00165 Fall Meeting of the APS Division of Nuclear Physics, Pittsburgh, PA (2017).
5. Determination of Partial Cross Sections in Single Nucleon Knockout Reactions
   Tan Phan*, Anthony Kuchera, Daniel Bazin
   CEU Poster EA.00155 Fall Meeting of the APS Division of Nuclear Physics, Pittsburgh, PA (2017).

   A. Wantz*, J.E. Boone*, W.F. Rogers, N. Frank, A.N. Kuchera, S. Mosby, M. Thoennessen,
   CEU Poster EA.00171 Fall Meeting of the APS Division of Nuclear Physics, Pittsburgh, PA (2017).

CEU 2018, 5th Joint Meeting of the APS Division of Nuclear Physics and the Physical Society of Japan, Waikoloa, HI

1. Projectile-like fragment production studies: the role of magnetic rigidity.
   Jonathan Hu, the MoNA Collaboration
   CEU Poster HA.00081 5th Joint Meeting of the APS Division of Nuclear Physics and the Physical Society of Japan, Waikoloa, HI (2018).

2. Projectile-like Fragment production studies using coincident neutrons.
   Edith Tea, the MoNA Collaboration
   CEU Poster HA.00082 5th Joint Meeting of the APS Division of Nuclear Physics and the Physical Society of Japan, Waikoloa, HI (2018).

CEU 2019 Meeting of the APS Division of Nuclear Physics, Crystal City Virginia, Oct. 13–17.

1. Neutron Unbound States in the N=20 Island of Inversion.
   Robbie Seaton-Todd, Anthony Kuchera, Nathan Frank, John Mcdonough, Paul DeYoung, William Von Seeger, Thomas Baumann, Dayah Chrisman, Paul Gueye, and the MoNA Collaboration
   CEU Poster HA.00019 Fall Meeting of the APS Division of Nuclear Physics, Crystal City, VA (2019).

2. Study of Neutron-rich Nuclides of Z = 13, 12.
   John Mcdonough, Nathan Frank, Robbie Seaton-Todd, Anthony Kuchera, Paul Gueye, Paul DeYoung, Hope College, and the MoNA Collaboration
   CEU Poster HA.00058 Fall Meeting of the APS Division of Nuclear Physics, Crystal City, VA (2019).

3. Characterizing a Charged Particle Detector Telescope
   Georgia Votta, Nathan Frank, Thomas Baumann, James Brown, Paul DeYoung, and the MoNA Collaboration
   CEU Poster HA.00059 Fall Meeting of the APS Division of Nuclear Physics, Crystal City, VA (2019).

CEU 2020 DNP Fall meeting, virtual

1. Angular distributions of dark scattered neutrons in plastic scintillators
   Andrea Robinson, Caroline Capuano, Anthony Kuchera, Paul Gueye, and the MoNA Collaboration
   CEU Poster HA.00006 Fall Meeting of the APS Division of Nuclear Physics, virtual (2020).

2. Behavior of Neutrons in Plastic Scintillators
   Caroline Capuano, Andrea Robinson, Anthony Kuchera, Paul Gueye, and the MoNA Collaboration
   CEU Poster JA.00006 Fall Meeting of the APS Division of Nuclear Physics, virtual (2020).

3. Development of a multi-neutron filter for use in the study of dripline nuclei
   Jeremy Hallett, Andrea Munroe, Warren Rogers, and the MoNA Collaboration
   CEU Poster PA.00011 Fall Meeting of the APS Division of Nuclear Physics, virtual (2020).

4. Exploring the Physics of Neutron-Unbound Nuclei Produced from Ne-28 and Ne-29 Fragment Beams
   Alaura Cunningham and the MoNA Collaboration
   CEU Poster QA.00002 Fall Meeting of the APS Division of Nuclear Physics, virtual (2020).

5. G4Beamline simulation for the study of Be isomers
   Yannick Gueye, Paul Gueye, Thomas Baumann, and the MoNA Collaboration
   CEU Poster NA.00003 Fall Meeting of the APS Division of Nuclear Physics, virtual (2020).

6. Investigation of a GEM based neutron detector for the MoNA Collaboration
   Maya Watts, Alder Fulton, Thomas Baumann, Thomas Redpath, (Michigan State University, National Superconducting Cyclotron Laboratory, Facility for Rare Isotope Beams) and the MoNA Collaboration
   CEU Poster HA.00003 Fall Meeting of the APS Division of Nuclear Physics, virtual (2020).
7. Measurement of Nuclear Isomer Gamma Emissions in Geant4
   Lauren Fisher, Andrea Bracamonte, Adam Fritsch, and Jim Brown
   CEU Poster JA.00013 Fall Meeting of the APS Division of Nuclear Physics, virtual (2020).

8. Non-Linear Behavior in Plastic Scintillator Neutron Detectors
   Andrea Munroe, Jeremy Hallett, Warren Rogers, and the MoNA Collaboration
   CEU Poster QA.00009 Fall Meeting of the APS Division of Nuclear Physics, virtual (2020).

9. Simulations of various GEM foil hole geometries using Garfield
   Pham Phuonganh and the MoNA Collaboration
   CEU Poster JA.00004 Fall Meeting of the APS Division of Nuclear Physics, virtual (2020).

10. Studying neutron-unbound states produced from a Na-30 beam
    Grant Bock and the MoNA Collaboration
    CEU Poster NA.00004 Fall Meeting of the APS Division of Nuclear Physics, virtual (2020).

11. Visualization and Interpolation of Field Mapping Data
    Anita Agasaveeran, Thomas Baumann, Paul Gueye, and the MoNA Collaboration
    CEU Poster JA.00003 Fall Meeting of the APS Division of Nuclear Physics, virtual (2020).

**CEU 2021 DNP Fall meeting, virtual**

1. Behavior of light and dark scattered neutrons in MoNA bars in comparison and simulation.
   Olivia Guarinello
   CEU Poster GA.00049 Fall Meeting of the APS Division of Nuclear Physics, Boston, MA (2021).

2. Behavior of dark scattered neutrons in plastic scintillators.
   Ari Maki
   CEU Poster HA.00049 Fall Meeting of the APS Division of Nuclear Physics, Boston, MA (2021).

   Hannah Erington, Thomas Baumann, and Paul Gueye
   CEU Poster HA.00046 Fall Meeting of the APS Division of Nuclear Physics, Boston, MA (2021).

4. Utilizing a Novel Neutron Filtering Technique to Analyze Multi-Neutron Datasets.
   Oscar Peterson-Veatch
   CEU Poster HA.00044 Fall Meeting of the APS Division of Nuclear Physics, Boston, MA (2021).

5. Analysis and simulation of $^{36}$Si and $^{36}$Al Reaction Products.
   Furman Doty
   CEU Poster HA.00047 Fall Meeting of the APS Division of Nuclear Physics, Boston, MA (2021).

   Andrea Munroe, Jeremy Hallett, Warren Rogers, and the MoNA Collaboration
   CEU Poster HA.00050 Fall Meeting of the APS Division of Nuclear Physics, Boston, MA (2021).

7. Cluster production in MoNA through charge exchange.
   Jeremy Hallett, Andrea Munroe, Warren Rogers, and the MoNA Collaboration
   CEU Poster HA.00048 Fall Meeting of the APS Division of Nuclear Physics, Boston, MA (2021).

8. Behavior of light and dark scattered neutrons in MoNA bars in comparison with simulation.
   Olivia Guarinello, Ari Maki, Anthony N Kuchera, and the MoNA Collaboration
   CEU Poster GA.00016 Fall Meeting of the APS Division of Nuclear Physics, Boston, MA (2021).

**6.6 Regional Undergraduate Presentations: Talks and Other Posters**

1. The MoNA project
   U. Onwuemene and T. Grant
   Illinois Section of the AAPT Fall Meeting, Decatur, IL, October 18–19, 2002

2. The MoNA project
   M. R. Evanger and R. E. Turner
   Minnesota Area Association of Physics Teachers Fall Meeting, Morris, MN, October 25–26, 2002
3. Calibration of organic scintillator bars for the Modular Neutron Detector Array
   J. W. Longacre
   Indiana Section of the AAPT Spring Meeting, Bloomington, IN, April 25–26, 2003

4. Neutron detection by the Modular Neutron Array (MoNA)
   D. McCollum
   Indiana Section of the AAPT Spring Meeting, Bloomington, IN, April 25–26, 2003

5. Experimental developments along the neutron dripline
   J. Robertson
   Indiana Section of the AAPT Spring Meeting, Bloomington, IN, April 25–26, 2003

6. Tracking single and multiple neutron events in the Modular Neutron Array
   A. Ratkiewicz
   Society of Physics Students, Zone 9 Fall 2005 Meeting, Marquette University, Milwaukee WI, October 13–14, 2005

7. Tracking single and multiple neutron events in the Modular Neutron Array
   A. Ratkiewicz
   Joint Meeting of the 16th Annual Argonne Symposium for Undergraduates in Science, Engineering and Mathematics & the Central States Universities, incorporated (CSUI), November 4–5, 2005

8. Tracking single and multiple neutron events in the Modular Neutron Array
   A. Ratkiewicz
   20th National Conference on Undergraduate Research, Asheville, NC, April 5–8, 2006

9. Accurate energy calibrations from cosmic ray measurements
   A. DeLine
   Posters at the Capitol, Capitol Rotunda, Lansing, Michigan, April 16, 2008

10. Observation of a resonance state in $^{25}$F
    Alison R. Smith, Mark S. Kasperczyk, Nathan H. Frank

11. Observation of a resonance state in $^{25}$F
    Alison R. Smith, Mark S. Kasperczyk, Nathan H. Frank
    Spring Meeting of the Illinois Section of the AAPT, Illinois Wesleyan University, Bloomington, Illinois, April 3–4, 2009

12. Observation of a resonance state in $^{26}$F
    Mark S. Kasperczyk, Alison R. Smith, Nathan H. Frank
    Spring Meeting of the Illinois Section of the AAPT, Illinois Wesleyan University, Bloomington, Illinois, April 3–4, 2009

13. Assembly and testing of the Large Area Multi-Institutional Array: LISA
    Mathieu Ndong, Samuel Stewart, and Zachary Torstrick
    Notre Dame Science and Engineering Summer Research Symposium, August 6, 2010

14. Assembly and testing of scintillation neutron detectors for LISA
    Alex R. Howe
    Ohio Five Summer Science Research Symposium, Ohio Wesleyan University, Delaware, OH, July 23, 2010

15. Assembly and testing of LISA neutron detectors
    Robert E. Anthony
    Ohio Five Summer Science Research Symposium, Ohio Wesleyan University, Delaware, OH, July 23, 2010

16. Assembly and testing of the Large Area multi-Institutional Scintillator Array (LISA)
    Zachary Torstrick, Samuel Stewart, Mathieu Ndong
17. Analysis of neutron-rich isotopes
   Natalie Viscariello
   Celebration of Learning, Augustana College, Rock Island, IL, May 5, 2012

18. Testing and installation of a high-efficiency CsI scintillator array
   Stuart Casarotto
   Celebration of Learning, Augustana College, Rock Island, IL, May 5, 2012

19. Active target simulation
   Nathan Smith
   2012 Quadrennial Physics Congress, Orlando, FL, Nov. 8-10, 2012

20. Testing and installation of a high-efficiency CsI scintillator array
   Natalie Viscariello
   2012 Quadrennial Physics Congress, Orlando, FL, Nov. 8-10, 2012

21. Active target simulation
   Nathan Smith
   Celebration of Learning, Augustana College, Rock Island, IL, Jan. 29, 2013

22. Testing and efficiency of a high-efficiency CsI scintillator array
   Natalie Viscariello
   Sigma Xi Research Presentations, Augustana College, Rock Island, IL, Jan. 29, 2013

23. Exploration of three-body decay using Jacobian coordinates
   Mark Hoffmann
   Sigma Xi Research Presentations, Augustana College, Rock Island, IL, Jan. 29, 2013

24. Exploration of three-body decay using Jacobian coordinates
   Mark Hoffmann and Kyle Williams
   Sigma Xi Research Presentations, Augustana College, Rock Island, IL, May 4, 2013

25. Atomic Nuclei on the Edge: The Story of $^{25}$O
   Joseph Bullaro
   Celebration of Learning, Augustana College, Rock Island, IL, May 6, 2015

   Joseph Bullaro
   Celebration of Learning, Augustana College, Rock Island, IL, May 6, 2015.

27. Unbound Resonances of $^{26,25}$F.
   Jacob Herman, Ali Rabeh, Matthew Tuttle-Timm
   Spring 2016 Meeting of the Illinois Section of the AAPT, University of Illinois, Urbana, IL, April 22-23, 2016.

   Matthew Tuttle-Timm

29. Light Output for Unbound Neutron Emission and Simulation Comparison.
   Jacob Herman

   Charlie Baird
   Indiana University South Bend Undergraduate Research Conference, South Bend, IN, March 31, 2017.

31. Sequential Decay of $^{26}$F.
   Hayden Karrick, Nathan Frank, Anthony Kuchera, Caleb Sword, Jaclyn Brett, Paul DeYoung, Michael Thoennessen, MoNA Collaboration,
   Celebration of Learning, Augustana College, Rock Island, IL, May 1, 2019.

   John McDonough, Nathan Frank, Dayah Chrisman, MoNA Collaboration,
   Sigma Xi Research Presentations, St. Ambrose University, March 5, 2019.
33. Sequential Decay of $^{26}$F.
   Hayden Karrick*, Nathan Frank, Anthony Kuchera, Caleb Sword, Jaclyn Brett, Paul DeYoung, Michael Thoennessen, MoNA Collaboration, Sigma Xi Research Presentations, St. Ambrose University, March 5, 2019.

34. Investigation of a Gas Photo-Multiplier (GPM) Based MoNA-LISA Detector
   Malinga Rathnayake, Angel Christopher, and Paul Gueye
   2019 Mid-Michigan Symposium for Undergraduate Research Experiences

6.7 MoNA in the Media

1. MoNA: The Modular Neutron Array Video
   Bryan Luther
   Centennial Scholars Program, Moorhead, MN, February 11, 2003

2. Undergraduates assemble neutron detector
   T. Feder
   Physics Today, p. 25, March 2005

3. Undergraduates as researchers
   MoNA Collaboration
   http://chronicle.com/subscribe/login?url=/weekly/v53/i33/33b02102.htm

4. Raising MoNA
   A. Jia
   Symmetry Vol. 4 p. 6 Aug. 2007
   http://www.symmetrymagazine.org/cms/?pid=1000511

5. Giving students a taste of research
   M. Thoennessen
   Physics World, p. 16, Feb. 2008

6. Going beyond the neutron drip-line with MoNA
   J. A. Brown for the MoNA Collaboration
   Nuclear Physics News 20, p. 23, 2010

7. Focus: Nuclei emit paired-up neutrons
   Michael Schirber
   Physics 5, 30 (2012)

8. MoNA makes first confirmed sighting of dineutron decay
   CERN COURIER, April 27 (2012)
   cerncourier.com/cws/article/cern/49341

9. Michigan’s MoNA LISA
   http://nscl.msu.edu/general-public/news/2012/michigan039s-mona-lisa

10. MoNA makes first confirmed sighting of dineutron decay. CERN COURIER, April 27, 2012
    http://cerncourier.com/cws/article/cern/49341

11. R&D News April 16, 2012
    http://goo.gl/EWIxd1

12. Dineutron emission seen for the first time

13. Unknown form of nuclear decay
    Popular Science, Science and Technology Portal. May 9, 2012 http://popular-science.net/tag/dineutron

14. LIFELONG EXPOSURE TO SCIENCE LEADS TO CAREER IN PHYSICS

6.8 MoNA on the Web

1. The MoNA homepage
   http://mona.wabash.edu/

2. MoNA Wikipedia article
   http://en.wikipedia.org/wiki/Modular_Neutron_Array

3. MoNA YouTube video
   http://www.youtube.com/watch?v=qPlsFu5m41s

4. MoNA on Facebook
   http://www.facebook.com/pages/Modular-Neutron-Array/143503835659905

5. Research.gov insights into nuclear decay
   http://goo.gl/hQw3O8

6. 60 seconds with Maria Massa ‘18
   https://www.youtube.com/watch?v=SLW_Fce2HLA

6.9 Publications in Refereed Journals

1. Using passive converters to enhance detection efficiency of 100-MeV neutrons

2. MONA—The Modular Neutron Array

3. Fabrication of a modular neutron array: A collaborative approach to undergraduate research
   American Journal of Physics 73, 122 (2005)

4. Construction of a Modular Large-Area Neutron Detector for the NSCL

5. Selective population and neutron decay of an excited state of $^{23}$O

6. Production of nuclei in neutron unbound states via primary fragmentation of $^{48}$Ca

*undergraduate student
7. Big physics at small places: The Mongol horde model of undergraduate research

8. Determination of the N = 16 shell closure at the oxygen drip line

9. Ground state energy and width of $^{7}$He from $^{8}$Li proton knockout

10. Neutron decay spectroscopy of neutron-rich oxygen isotopes

11. Evidence for a doubly magic $^{24}$O

12. Disappearance of the N = 14 shell

13. First evidence for a virtual $^{18}$B ground state

14. First observation of excited states in $^{12}$Li

15. Observation of a two-neutron cascade from a resonance in $^{24}$O

16. Neutron knockout of $^{12}$Be populating neutron-unbound states in $^{11}$Be

17. Neutron unbound states in $^{25,26}$F

18. Search for the $^{15}$Be ground state

19. Nuclear structure at and beyond the neutron drip line
T. Baumann, A. Spyrou, and M. Thoennessen
20. First observation of ground state dineutron decay: $^{16}$Be

21. Evidence for the ground-state resonance of $^{26}$O

22. Exploring the low-$Z$ shore of the island of inversion at $N = 19$

23. Modeling interactions of intermediate-energy neutrons in a plastic scintillator array with GEANT4

24. Spectroscopy of neutron-unbound $^{27,28}$F

25. Reply to “Comment on: ‘Neutron knockout of $^{12}$Be populating neutron-unbound states in $^{11}$Be’”

26. Reply to “Comment on: ‘First observation of ground state dineutron decay: $^{16}$Be’”

27. Unresolved question of the $^{10}$He ground state resonance

28. Neutron unbound states in $^{28}$Ne and $^{25}$F

29. First observation of $^{13}$Li ground state

30. Study of two-neutron radioactivity in the decay of $^{26}$O

31. Observation of a low-lying neutron-unbound state in $^{19}$C

32. Novel techniques to search for one- and two-neutron radioactivity
M. Thoennessen, G. Christian, Z. Kohley, T. Baumann, M. Jones, J. K. Smith, J. Snyder, A. Spyrou,
33. First observation of $^{15}$Be  

34. Exploiting neutron-rich radioactive ion beams to constrain the symmetry energy  

35. Search for $^{21}$C and constraints on $^{22}$C  

36. Determining the $^7$Li(n,$\gamma$) cross section via Coulomb dissociation of $^8$Li  

37. Low-lying neutron unbound states in $^{12}$Be  

38. Selective population of unbound states in $^{10}$Li  

39. Search for unbound $^{15}$Be states in the $3^n+^{12}$Be channel  

40. Three-body correlations in the ground-state decay of $^{26}$O  

41. Further insights into the reaction $^{14}$Be(CH$_2$X)$_{10}$He  

42. Two-Neutron Sequential Decay of $^{24}$O.  

43. Population of $^{13}$Be in nucleon exchange reactions  

44. Unbound excited states of the $N = 16$ closed-shell nucleus $^{24}$O.  
45. Neutron correlations in the decay of excited $^{11}$Li.
   J.K. Smith, T. Baumann, D. Bazin, J. Brown, P. A. DeYoung, M. D. Jones, Z. Kohley, B. Luther, B. Marks*, A. Spyrou, S. L. Stephenson, M. Thoennessen, and A. Volya,

46. Neutron Unbound Excited States of $^{23}$N.

47. Erratum: Neutron-unbound excited states of $^{23}$N.

48. Search for excited states in $^{25}$O.

49. Observation of Fast Neutron Scattering in Plastic Scintillator as a Test for Simulation
   W. F. Rogers, A. N. Kuchera, J. Boone*, N. Frank, M. Thoennessen, and A. Wantz*

50. Observation of Three-Neutron Sequential Emission from $^{25}$O.

51. Thermal Characterization of Ti2LiYCl6:Ce (TLYC).
   M. M. Watts, K. E. Mesick, K. D. Bartlett, and D. D. S. Coupland

52. New Segmented Target for Studies of Neutron Unbound Systems.

53. Shell inversion in the unbound N=7 isotones.

54. Neutron-unbound states in $^{31}$Ne.

55. Mirror nucleon removal reactions in p-shell nuclei.

56. Reaction mechanism dependence of the population and decay of $^{10}$He.
57. Evidence for $^{15}\text{Be}$ from $^{12}\text{Be}+3\text{n}$ events.
   A. N. Kuchers, et. al.

6.10 Conference Proceedings

1. MONA: The Modular Neutron Array at the NSCL
   T. Baumann, J. A. Brown, P. DeYoung, J. E. Finck, J. D. Hinnefeld, R. Howes, K. W. Kemper, B. A. Luther, P. V. Pancellia, G. F. Peaslee, W. F. Rogers, S. L. Tabor, and M. Thoennessen

2. First results from MoNA

3. Can the neutron capture cross sections be measured with Coulomb dissociation?

4. Observation of the first excited state in $^{23}\text{O}$

5. Exploring neutron-rich oxygen isotopes with MoNA

6. Population of neutron unbound states via two-proton knockout reactions

7. Efficiency of the Modular Neutron Array (MoNA)

8. Nuclear structure physics with MoNA-LISA

9. Exploring the neutron dripline two neutrons at a time: The first observations of the $^{26}\text{O}$ and $^{16}\text{Be}$ ground state resonances
10. New measurements of the properties of neutron-rich projectile fragments

11. Observation of ground-state two-neutron decay

12. Structure and decay correlations of two-neutron systems beyond the dripline

13. Study of Neutron-Unbound States with MoNA

14. Search for 4n contributions in the reaction $^{14}$Be(CH$_2$X)$^{10}$He.

### 6.11 MoNA Experiments at the NSCL

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<td>micro MoNA</td>
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<td>03502</td>
<td>2003</td>
<td>W. A. Peters</td>
<td>MoNA test run</td>
<td>[13]</td>
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<td>04503</td>
<td>2004</td>
<td>N. Frank</td>
<td>Sweeper magnet test</td>
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<td>03048</td>
<td>2004</td>
<td>J. Finck</td>
<td>Ground state wave function of $^{13}$Be</td>
<td>[60-63]</td>
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<td>03033</td>
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<td>J.-L. Lecouye</td>
<td>Is $^{24}$O a doubly magic nucleus?</td>
<td>[19, 64-70]</td>
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<td>05502</td>
<td>2005</td>
<td>P. DeYoung</td>
<td>$^7$He breakup</td>
<td>[71]</td>
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<td>2005</td>
<td>P. DeYoung</td>
<td>Going beyond the $N = 16$ shell in oxygen</td>
<td>[72-77]</td>
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<td>Population of neutron-unbound states from direct fragmentation, test</td>
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<td>05034</td>
<td>2006</td>
<td>A. Schiller</td>
<td>Two-neutron decay of $^{13}$Li</td>
<td>[78, 36, 79]</td>
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<td>05124</td>
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<td>Neutron-dripline studies with direct fragmentation</td>
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<td>07503</td>
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<td>W. A. Peters</td>
<td>Measurement of MoNA’s Efficiency</td>
<td>[80, 51]</td>
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<td>0625</td>
<td>2008</td>
<td>T. Baumann</td>
<td>Di-neutron decay of $^{16}$Be</td>
<td>[82, 83, 38, 84]</td>
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<td>08016</td>
<td>2008</td>
<td>A. Spyrou</td>
<td>Ground State of Neutron-Unbound $^{24}$N</td>
<td>insufficient statistics, [89]</td>
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<td>A. Schiller</td>
<td>Two-Neutron Decay from the ground state of $^{26}$O</td>
<td>[39, 90, 91, 86, 85, 79, 45]</td>
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<td>07039</td>
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<td>P. DeYoung</td>
<td>Ground-State Neutron Decay of $^{21}$C</td>
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### MoNA Experiments at LANSCE

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## 7 People

### 7.1 MoNA Undergraduate Students

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<th>Year</th>
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<th>Employment</th>
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<td>Melanie Evanger</td>
<td>Concordia</td>
<td>2001–2002</td>
<td>MS</td>
<td>Sr Principal Engineer</td>
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<tr>
<td>Maria-Teresa Herd</td>
<td>Bryn Mawr</td>
<td>2001–2002</td>
<td>PhD</td>
<td>Assistant Professor</td>
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<td>Mustafa Rajabali</td>
<td>Concordia</td>
<td>2001–2002</td>
<td>PhD</td>
<td>Associate Professor</td>
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<td>Ramsey Turner</td>
<td>Concordia</td>
<td>2001–2002</td>
<td>BS</td>
<td>Solutions Architect</td>
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<td>Anna Volftsun</td>
<td>Bergen Ct. HS</td>
<td>2001–2002</td>
<td>MA</td>
<td>General Counsel</td>
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<td>Paul Yeager</td>
<td>Michigan State</td>
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<td>Joseph Bychowski</td>
<td>Hope</td>
<td>2002–2003</td>
<td>MS</td>
<td>Sales Engineer</td>
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<td>Jim Evans</td>
<td>IUSB</td>
<td>2002–2003</td>
<td>MS</td>
<td>Advisory Board Member</td>
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<td>Tony Grant</td>
<td>Millikin</td>
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<td>Instructor</td>
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<td>Brett Isselhardt</td>
<td>Westmont</td>
<td>2002–2003</td>
<td>PhD</td>
<td>Staff Scientist</td>
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<td>Walter Kiefer</td>
<td>Western Michigan</td>
<td>2002–2003</td>
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<td>Adam Lincoln</td>
<td>Western Michigan</td>
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<td>Data Scientist</td>
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<td>James Longacre</td>
<td>Ball State</td>
<td>2002–2003</td>
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<td>Rad. Safety Officer</td>
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<td>Yao Lu</td>
<td>Okemos HS</td>
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<td>Scott Marley</td>
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<td>David McCollum</td>
<td>Ball State</td>
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<td>Eric McDonald</td>
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<td>Jennifer Robertson</td>
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<td>Medical Physicist</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Ralph Peterson-Veatch</td>
<td>Augustaana</td>
<td>2020–</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Andrew Rippy</td>
<td>Wabash</td>
<td>2020–</td>
<td></td>
<td>Student</td>
</tr>
<tr>
<td>Andrea Munroe</td>
<td>Indiana Wesleyan</td>
<td>2020–2021</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Jason Reinoehl</td>
<td>IUSB</td>
<td>2020–</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hannah Erington</td>
<td>Univ. of Texas/MSU REU</td>
<td>2021</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Forest Rulison</td>
<td>Hope</td>
<td>2021</td>
<td>BS</td>
<td>Grad Student</td>
</tr>
<tr>
<td>Olivia Guarinello</td>
<td>Davidson College</td>
<td>2021</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ari Maki</td>
<td>Davidson College</td>
<td>2021</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Anas Akkar</td>
<td>Augustana</td>
<td>2021</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Furman Doty II</td>
<td>Augustana</td>
<td>2021</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Henry Webb</td>
<td>Augustana</td>
<td>2021</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
### 7.2 MoNA Graduate Students

<table>
<thead>
<tr>
<th>Name</th>
<th>Affiliation</th>
<th>Graduated</th>
<th>Experiment</th>
<th>Project/Title of Thesis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nathan Frank</td>
<td>MSU</td>
<td>2006</td>
<td>03033</td>
<td>Spectroscopy of neutron unbound states in neutron rich oxygen isotopes</td>
</tr>
<tr>
<td>William Peters</td>
<td>MSU</td>
<td>2007</td>
<td>03048</td>
<td>Commissioning and first results from MoNA</td>
</tr>
<tr>
<td>Calem Hoffman</td>
<td>FSU</td>
<td>2009</td>
<td>05039</td>
<td>Investigation of the neutron-rich oxygen isotopes at the dripline</td>
</tr>
<tr>
<td>Greg Christian</td>
<td>MSU</td>
<td>2008</td>
<td>05124</td>
<td>Production of unbound nuclei via fragmentation; <em>MS thesis</em></td>
</tr>
<tr>
<td>Assistant Professor, Saint Mary’s University, Nova Scotia Canada</td>
<td>2011</td>
<td>09040</td>
<td>Spectroscopy of neutron unbound fluorine</td>
<td></td>
</tr>
<tr>
<td>Michael Strongman</td>
<td>MSU</td>
<td>2011</td>
<td>08016</td>
<td>Neutron spectroscopy of $^{22}$N and the disappearance of the N = 14 shell; <em>MS thesis</em></td>
</tr>
<tr>
<td>Shea Mosby</td>
<td>MSU</td>
<td>2011</td>
<td>07039</td>
<td>Spectroscopy of neutron unbound states in neutron rich carbon</td>
</tr>
<tr>
<td>Jesse Snyder</td>
<td>MSU</td>
<td>2013</td>
<td>09067</td>
<td>$^{15}$Be via (d,p)</td>
</tr>
<tr>
<td>Jenna Smith</td>
<td>MSU</td>
<td>2014</td>
<td>10007</td>
<td>Two-neutron decay of $^{11}$Li</td>
</tr>
<tr>
<td>Michael Jones</td>
<td>MSU</td>
<td>2016</td>
<td>12004</td>
<td>$^{24}$O (d,p)</td>
</tr>
<tr>
<td>Jessica Freeman</td>
<td>Hampton</td>
<td></td>
<td>15118</td>
<td>Calibration of the Si-Be segmented target for $^{26}$O life-time experiment; <em>left 2016</em></td>
</tr>
<tr>
<td>Krystin Stiefel</td>
<td>MSU</td>
<td>2018</td>
<td>12011</td>
<td>Measurement and Modeling of Fragments and Neutrons Produced from Projectile Fragmentation Reactions</td>
</tr>
<tr>
<td>Thomas Redpath</td>
<td>MSU*</td>
<td>2019</td>
<td>15118</td>
<td>Lifetime measurements with decay-in-target method</td>
</tr>
<tr>
<td>Han Liu</td>
<td>MSU</td>
<td>2019</td>
<td>14014</td>
<td>Understanding two-neutron unbound systems</td>
</tr>
<tr>
<td>Daniel Votaw</td>
<td>MSU*</td>
<td>2019</td>
<td>15091</td>
<td>Measurement of $^{9}$He ground and excited state</td>
</tr>
<tr>
<td>Dayah Chrisman</td>
<td>MSU*</td>
<td></td>
<td>16027</td>
<td>Neutron unbound states in the island of inversion</td>
</tr>
<tr>
<td>Ameer Blake</td>
<td>Hampton</td>
<td>2020</td>
<td></td>
<td>Development of a GEM based segmented target for the study of unbound nuclei; <em>MS thesis</em></td>
</tr>
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</table>

*continued on next page*
<table>
<thead>
<tr>
<th>Name</th>
<th>Affiliation</th>
<th>Graduated</th>
<th>Experiment</th>
<th>Project/Title of Thesis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Malinga Nathrayake</td>
<td>Hampton</td>
<td>2019</td>
<td></td>
<td>CAD drawing using OnShape and GEANT4 simulation for GEM based neutron detector; <em>MS thesis</em></td>
</tr>
<tr>
<td>Xinyi Wang</td>
<td>MSU</td>
<td>19013</td>
<td></td>
<td>Are there unexpected structural changes in $^{13}$Be?</td>
</tr>
<tr>
<td>Henry Thurston</td>
<td>MSU</td>
<td></td>
<td></td>
<td><em>left 2020</em></td>
</tr>
<tr>
<td>Andrew Wantz</td>
<td>MSU</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nicholas Mendez</td>
<td>MSU</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### 7.3 Other Graduate Students

These students were mentored by researchers outside the MoNA Collaboration.

<table>
<thead>
<tr>
<th>Name</th>
<th>Affiliation</th>
<th>Start</th>
<th>Graduated</th>
<th>Experiment</th>
<th>Project/Title of Thesis</th>
<th>Current Position</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rudolf Izsak</td>
<td>Budapest</td>
<td>2005</td>
<td>2013</td>
<td>03038</td>
<td>Coulomb-breakup of neutron-rich nuclei</td>
<td>Electronic and Computer Engineering, Brunel University, London</td>
</tr>
<tr>
<td>Michelle Mosby</td>
<td>MSU</td>
<td>2007</td>
<td>2014</td>
<td>09069</td>
<td>Excitation energy of neon prefragments</td>
<td>Postdoc, LANL, NM</td>
</tr>
<tr>
<td>Dilupama Divaratne</td>
<td>OU</td>
<td>2008</td>
<td>2013</td>
<td>09028</td>
<td>$^{24}$O neutron knockout to $^{23}$O excited states</td>
<td>Visiting Assistant Professor, Miami University, OH</td>
</tr>
</tbody>
</table>

*Other graduate students that worked on MoNA projects*

<table>
<thead>
<tr>
<th>Name</th>
<th>Affiliation</th>
<th>Year</th>
<th>Current Position</th>
</tr>
</thead>
<tbody>
<tr>
<td>Harsha Attanayake</td>
<td>OU</td>
<td>2008</td>
<td>Engineering company in Columbus, OH</td>
</tr>
<tr>
<td>Adeleke Adeyemi</td>
<td>Hampton</td>
<td>2014</td>
<td>International Monetary Fund</td>
</tr>
<tr>
<td>Nathaniel Lashley</td>
<td>Hampton</td>
<td>2016</td>
<td>graduate student</td>
</tr>
<tr>
<td>Felix Ndayisabye</td>
<td>MSU</td>
<td>2017</td>
<td>graduate student</td>
</tr>
</tbody>
</table>

### 7.4 MoNA Post-Doctoral Researchers

<table>
<thead>
<tr>
<th>Name</th>
<th>Dates</th>
<th>Current Position</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jean-Luc Lecouye</td>
<td>2003–05</td>
<td>Staff Physicist, LPC Caen, France</td>
</tr>
<tr>
<td>Ken Yoneda</td>
<td>2003–05</td>
<td>Laboratory Head, RIKEN, Japan</td>
</tr>
<tr>
<td>Andreas Schiller</td>
<td>2003–07</td>
<td>Research Scientist, Norwegian Defence Research Establishment, Oslo, Norway</td>
</tr>
<tr>
<td>Heiko Scheit</td>
<td>2006</td>
<td>Research Scientist, GSI, Germany</td>
</tr>
<tr>
<td>Artemis Spyrou</td>
<td>2007–09</td>
<td>Associate Professor, Michigan State University, East Lansing, MI</td>
</tr>
<tr>
<td>Zachary Kohley</td>
<td>2011–12²</td>
<td>Kohley’s Superior Water &amp; Propane, Muskegon, MI</td>
</tr>
<tr>
<td>Anthony Kuchera</td>
<td>2014–17³</td>
<td>Assistant Professor, Davidson College, Davidson, NC</td>
</tr>
<tr>
<td>Belén Monteagudo Godoy</td>
<td>2020–21²</td>
<td>Hope Faculty Fellow, Hope College, Holland, MI</td>
</tr>
</tbody>
</table>

### 7.5 MoNA Institutions Through the Years

Argonne National Laboratory  
Augustana College  
Ball State University  
Central Michigan University  
Concordia University  

*supported by NNSC  
²supported by NNSC  
³supported by NNSC
Davidson College  
Florida State University  
Augustana College  
Ball State University  
Central Michigan University  
Concordia University  
Davidson College  
Florida State University  
Gettysburg College  
Hampton University  
Hope College  
Indiana University South Bend  
Indiana Wesleyan University  
Michigan State University  
Milikin University  
Ohio Wesleyan University  
Rhodes College  
St. Johns College  
Wabash College  
Western Michigan University  
Westmont College  
Virginia State University

### 7.6 MoNA Collaboration Directors

<table>
<thead>
<tr>
<th>Year</th>
<th>Name</th>
<th>Institution</th>
</tr>
</thead>
<tbody>
<tr>
<td>2001–2002</td>
<td>Bryan A. Luther</td>
<td>Concordia College</td>
</tr>
<tr>
<td>2002–2003</td>
<td>Thomas Baumann</td>
<td>Michigan State University</td>
</tr>
<tr>
<td>2003–2004</td>
<td>Joseph E. Finck</td>
<td>Central Michigan University</td>
</tr>
<tr>
<td>2004–2005</td>
<td>Paul A. DeYoung</td>
<td>Hope College</td>
</tr>
<tr>
<td>2005–2006</td>
<td>James A. Brown</td>
<td>Wabash College</td>
</tr>
<tr>
<td>2006–2007</td>
<td>Jerry D. Hinnefeld</td>
<td>Indiana University at South Bend</td>
</tr>
<tr>
<td>2007–2008</td>
<td>Warren F. Rogers</td>
<td>Westmont College</td>
</tr>
<tr>
<td>2008–2009</td>
<td>Paul A. DeYoung</td>
<td>Hope College</td>
</tr>
<tr>
<td>2009–2010</td>
<td>Bryan A. Luther</td>
<td>Concordia College</td>
</tr>
<tr>
<td>2010–2011</td>
<td>Deseree Meyer</td>
<td>Rhodes College</td>
</tr>
<tr>
<td>2011–2012</td>
<td>Nathan Frank</td>
<td>Augustana College</td>
</tr>
<tr>
<td>2012–2013</td>
<td>Robert Haring-Kaye</td>
<td>Ohio Wesleyan University</td>
</tr>
<tr>
<td>2013–2014</td>
<td>Sharon Stephenson</td>
<td>Gettysburg College</td>
</tr>
<tr>
<td>2014–2015</td>
<td>Warren Rogers</td>
<td>Westmont College</td>
</tr>
<tr>
<td>2015–2016</td>
<td>James A. Brown</td>
<td>Wabash College</td>
</tr>
<tr>
<td>2016–2017</td>
<td>Joe Finck</td>
<td>Central Michigan University</td>
</tr>
<tr>
<td>2017–2018</td>
<td>Paul Gueye</td>
<td>Hampton University</td>
</tr>
<tr>
<td>2018–2019</td>
<td>Sharon Stephenson</td>
<td>Gettysburg College</td>
</tr>
<tr>
<td>2019–2020</td>
<td>Anthony Kuchera</td>
<td>Davidson College</td>
</tr>
<tr>
<td>2020–2021</td>
<td>Warren Rogers</td>
<td>Indiana Wesleyan University</td>
</tr>
<tr>
<td>2021–</td>
<td>Nathan Frank</td>
<td>Augustana College</td>
</tr>
</tbody>
</table>

### 7.7 Awards

1. Paul DeYoung: 2001 Prize for a Faculty Member for Research in an Undergraduate Institution.


7. Sharon Stephenson: Johnson Center for Creative Teaching and Learning Excellence In Teaching Award, 2015.

8. Warren Rogers: 2018 Prize for a Faculty Member for Research in an Undergraduate Institution.

9. Nathan Frank: 2019 Quad Cities Engineering and Science Council (QCESC) Senior Scientist of the Year.


### 7.8 Undergraduate Faculty Grants

1. **RUI: Radioactive nuclear beam physics with undergraduates at Hope College**  
   Paul A. DeYoung and Graham F. Peaslee  
   NSF 0098061, 06/01/2001–05/31/2005

2. **MRI: Construction of one layer of a highly efficient neutron detector to study neutron-rich rare isotopes at the NSCL (Hope College)**  
   Paul A. DeYoung and Graham F. Peaslee  
   NSF 0132405, 09/01/2001–12/31/2004

3. **MRI: Construction of one layer of a highly efficient neutron detector to study neutron-rich rare isotopes at the NSCL**  
   Joseph Finck  
   NSF 0132532, 09/01/2001–08/31/2004

4. **MRI: High efficiency neutron detector layer**  
   James Brown  
   NSF 0132507, 0432042, 09/01/2001–08/31/2004

   Jerry Hinnefeld  
   NSF 0132567, 09/01/2001–08/31/2004

6. **MRI: Fabrication of One Layer of a High-Efficiency Neutron Detector**  
   Ruth Howes  
   NSF 0132367, 09/01/2001–08/31/2004

7. **MRI: Constructing a Layer for the Large Neutron Detector at NSCL**  
   Paul Pancella  
   NSF 0132438, 09/01/2001–08/31/2004

8. **MRI: A Highly Efficient Neutron Detector Array to Study Neutron-Rich Rare Isotopes at the NSCL**  
   Bryan Luther  
   NSF 0132725, 09/01/2001–08/31/2004

9. **MRI: Large high-efficiency neutron array detector at MSU**  
   Warren Rogers  
   NSF 0132641, 09/01/2001–08/31/2003

10. **RUI: Multifaceted opportunities in nuclear physics for undergraduates at Hope College**  
    Paul A. DeYoung and Graham F. Peaslee  
    NSF 0354920, 05/15/2004–04/30/2008

11. **Nuclear physics research at Westmont College**  
    Warren Rogers  
    NSF 0502010, 06/01/2005–05/31/2010

12. **An RUI proposal to investigate the neutron drip line using the Modular Neutron Array**  
    Joseph Finck  
    NSF 0555439, 07/15/2006–06/30/2009

13. **RUI: Using MoNA, exploring neutron unbound states in nuclei near and beyond the neutron dripline**  
    James Brown  
    NSF 0555488, 07/01/2006–06/30/2010
14. RUI: Fundamental and applied nuclear physics with undergraduates
   Paul A. DeYoung and Graham F. Peaslee
   NSF 0651627, 05/15/2007–04/30/2011

15. RUI: Studying exotic nuclei with the Modular Neutron Array (MoNA)
   Joseph Finck
   NSF 0855456, 9/01/2009–08/31/2012

16. MRI-Consortium: Development of a neutron detector array by undergraduate research students for studies of exotic nuclei
   Bryan Luther NSF 0922559, 10/01/2009–09/30/2012

17. MRI-Consortium: Development of a neutron detector array by undergraduate research students for studies of exotic nuclei
   Robert Kaye
   NSF 0922409, 10/01/2009–09/30/2012

18. MRI-Consortium: Development of a neutron detector array by undergraduate research students for studies of exotic nuclei
   Deseree Meyer
   NSF 0922473, 10/01/2009–09/30/2012

19. MRI-Consortium: Development of a neutron detector array by undergraduate research students for studies of exotic nuclei
   Sharon Stephenson
   NSF 0922335, 10/01/2009–09/30/2012

20. MRI-Consortium: Development of a neutron detector array by undergraduate research students for studies of exotic nuclei
    James Brown
    NSF 0922446, 10/01/2009–09/30/2012

21. MRI-Consortium: Development of a neutron detector array by undergraduate research students for studies of exotic nuclei
    Jerry Hinnefeld
    NSF 0922537, 10/01/2009–09/30/2012

22. MRI-Consortium: Development of a neutron detector array by undergraduate research students for studies of exotic nuclei
    Joseph Finck
    NSF 0922462, 10/01/2009–09/30/2012

23. MRI-Consortium: Development of a neutron detector array by undergraduate research students for studies of exotic nuclei
    Warren Rogers
    NSF 0922622, 10/01/2009–09/30/2012

24. MRI-Consortium: Development of a neutron detector array by undergraduate research students for studies of exotic nuclei
    Paul A. DeYoung and Graham F. Peaslee
    NSF 0922794, 10/01/2009–09/30/2012

25. RUI: Studies of unstable neutron-rich nuclei and interdisciplinary applications of nuclear physics with undergraduates
    Paul A. DeYoung
    NSF 0969058, 05/15/2010–04/30/2013

26. RUI: Establishing an Undergraduate Research Group in Nuclear Physics
    Nathan Frank
    NSF 0969173, 09/15/2010–08/31/2014
27. RUI: Study of light exotic nuclei near the neutron dripline
   Warren Rogers
   NSF 1101745, 05/15/2011–05/14/2014

28. RUI: Studies of exotic nuclei with the MoNA LISA neutron detectors
   Joseph Finck
   NSF 1205357, 06/01/2012–05/31/2016

29. RUI: Neutron physics from $^4$He to the edge of the dripline
   Sharon Stephenson
   NSF 1205537, 10/1/2012–09/30/2015

30. RUI: Cutting-Edge Nuclear Physics Research (Collaborative and Interdisciplinary) at Hope College
    Paul A. DeYoung
    NSF 1306074, 06/15/2013–05/31/2016

31. Active target development for the study of neutron-unbound nuclei
    P. Gueye, M. Thoennessen, and N. Frank
    NSSC-MSI Research Grant Award, NNSA, 1/1/2013- 12/31/2015

32. RUI: Undergraduate Research on Neutron-Rich Nuclei
    Nathan Frank
    NSF 1404236, 08/1/2014–07/31/2017

33. RUI: Study of Exotic Neutron-Rich Nuclei at Westmont College and NSCL,MSU
    Warren Rogers
    NSF 1506402, 07/15/2015–07/14/2018

34. RUI: High Impact Nuclear Physics Research with Undergraduates
    Paul DeYoung and Graham Peaslee
    NSF 1613188, 06/1/2016–05/31/2019

35. RUI: Exploring Nuclear Structure through Collaborative Research
    Sharon Stephenson
    NSF 1613429, 8/1/2016–7/31/2018

36. RUI: Collaboration to Enhance Participation of Minority and Undergraduate Students in Nuclear Science
    Paul Gueye, Sharon Stephenson, Jim Brown, Nathan Frank
    NSF 1713589, 1713956, 1713245, 1713522 08/15/2017–08/15/2020

    Nathan Frank

38. RUI: Nuclear Physics at Hope College With Undergraduates: New Science Enhancing the STEM Workforce.
    Paul DeYoung
    NSF 1911418, 2019–2022.

    Jerry Hinnefeld
    NSF 1913553, 2019–2022

40. RUI: Collaboration to Enhance Participation of Minority and Undergraduate Students in Nuclear Science
    Paul Gueye
    NSF 19364040, 2019–2020

41. Collaborative Research: RUI: Study of Exotic Nuclei and Neutron Detector Response
    Anthony Kuchera
    NSF 2011398, 2020–2023
42. Catalyst Award: Nuclear Science at Virginia State University, Building Connections to FRIB Science
   Thomas Redpath
   NSF 2100969, 2021–2023

43. Machine learning methods for analyzing multi-neutron decay measurements
   Thomas Redpath
   DoE DE-SC0022037

7.9 NSCL/FRIB Faculty Grants

1. MSU/FSU Consortium Development of a Compact Sweeper Magnet for Neutron Coincidence Experiments at the NSCL
   Michael Thoennessen (Principal Investigator); Kirby Kemper, Steven Van Sciver, Gregers Hansen, Bradley Sherrill (Co-Principal Investigators)

2. MRI: MSU/FSU Consortium to Develop a Highly Efficient Neutron Detector Array to Study Neutron-Rich Rare Isotopes at the NSCL
   Michael Thoennessen (Principal Investigator); Kirby Kemper, Samuel Tabor, Gregers Hansen, Thomas Baumann (Co-Principal Investigators)
   NSF 0132434, 2001–2004

   Paul Gueye (Principal Investigator), Bradley Sherrill (Co-Principal Investigator), Thomas Baumann (Co-Principal Investigator), Wolfgang Mittig (Co-Principal Investigator), Oleg Tarasov (Co-Principal Investigator)
   NSF 2012040, 2020–2023
References


