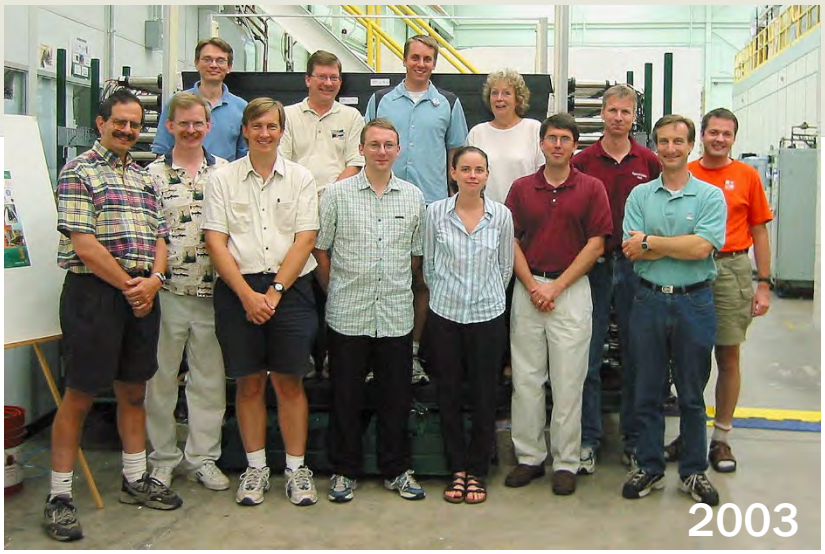
# Latest news from the MoNA Collaboration at NSCL

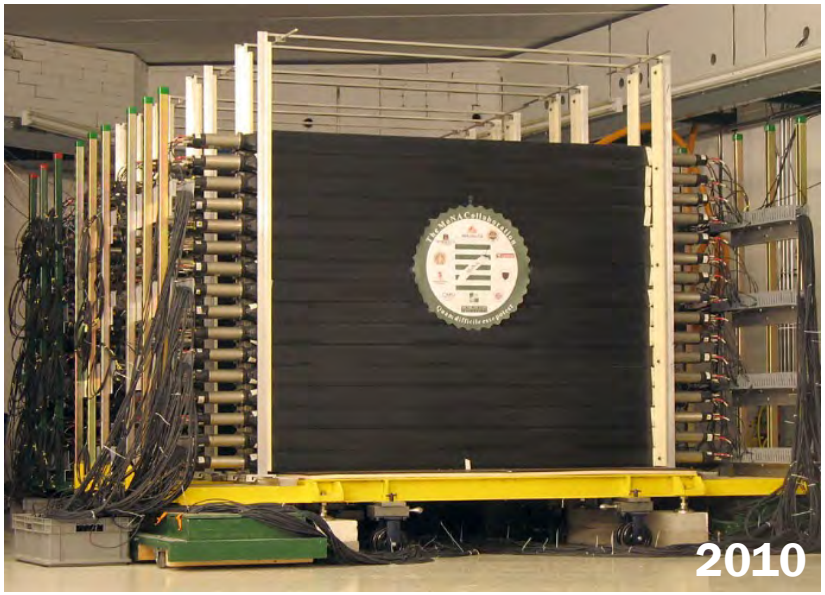
*Thomas Baumann, NSCL*

**Outline:**

- The Collaboration
- Physics Method
- Current Research
  - *recent experiments*
  - *new results*
- Future Plans
  - *Sweeper-less experiments*
  - *MoNA-LISA at FRIB & HRS*

# The MoNA Collaboration



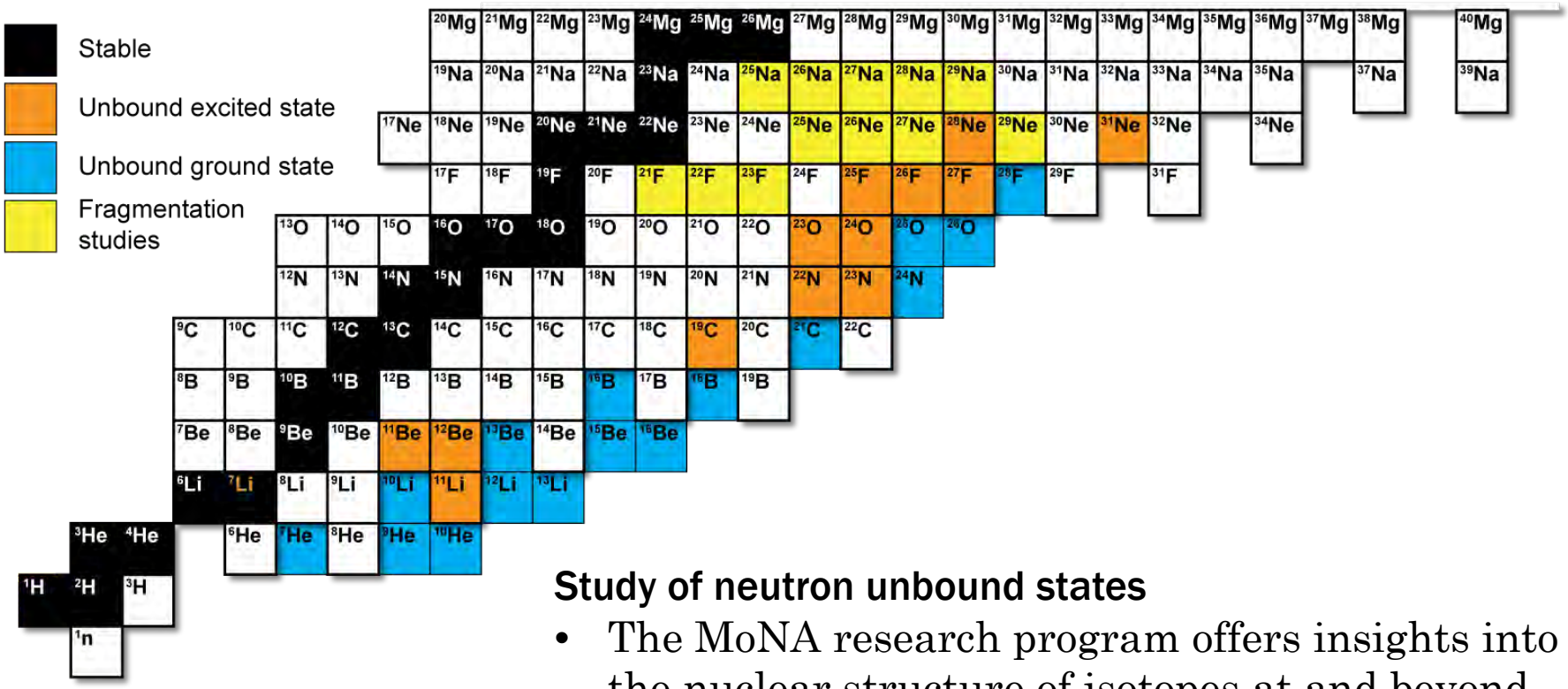

**The collaboration:**

- The MoNA collaboration was formed in 2001 when a joint MRI proposal was submitted to fund the Modular Neutron Array.
- The collaboration assembled and tested the detector modules, and continues to this day with a cutting-edge research program.

**The detector:**

- MoNA-LISA is a large, highly efficient neutron time-of-flight detector array.
- It consists of 288 plastic scintillator detector modules.
- It is used to detect fast neutrons stemming from breakup reactions of neutron-unbound states.
- It measures flight time and position.

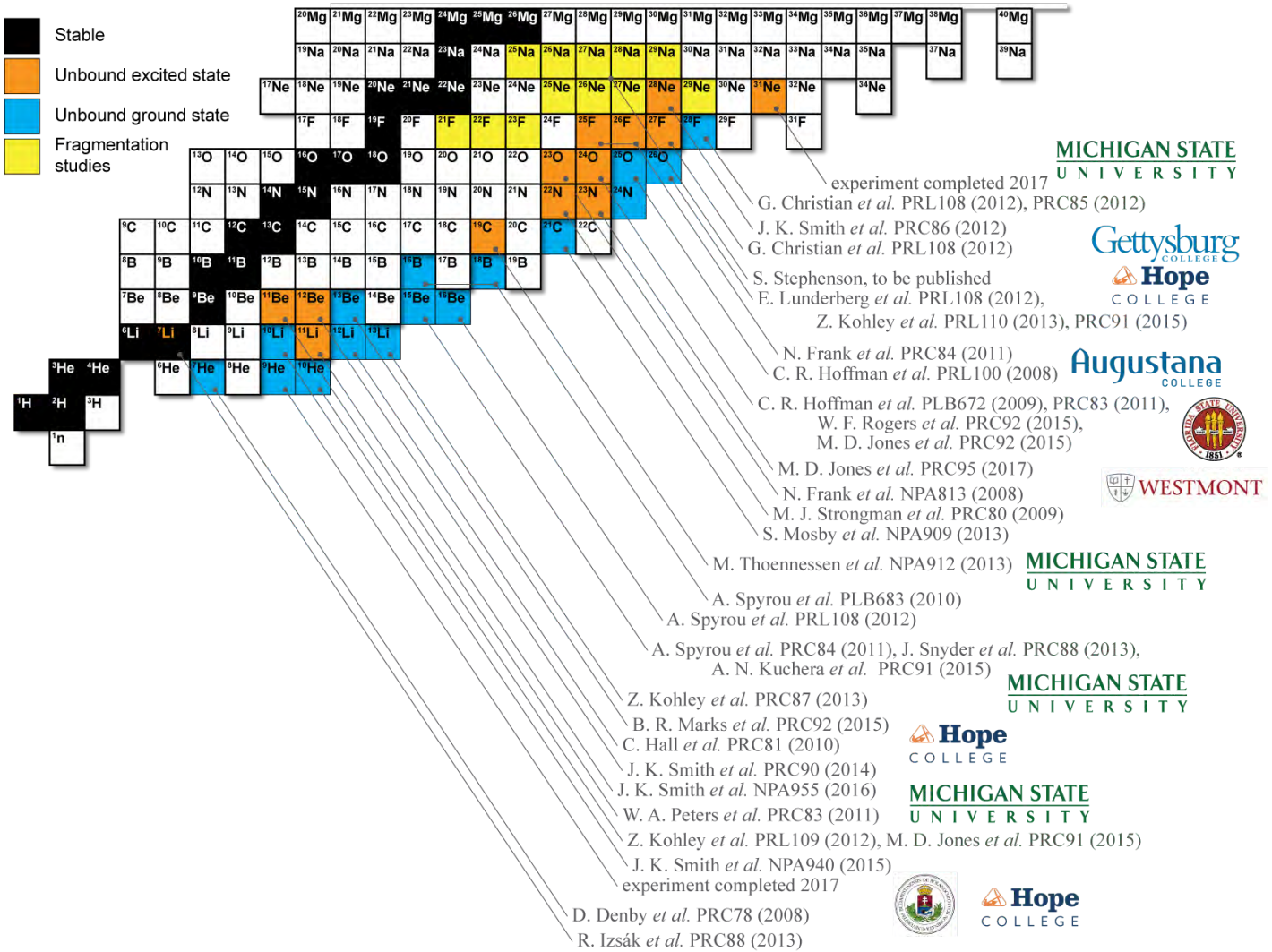
# MoNA Physics




**Study of neutron unbound states**

- The MoNA research program offers insights into the nuclear structure of isotopes at and beyond the neutron drip line.
- Nuclei that have been investigated by the MoNA Collaboration run along the neutron drip line from He to Ne.

# MoNA Physics

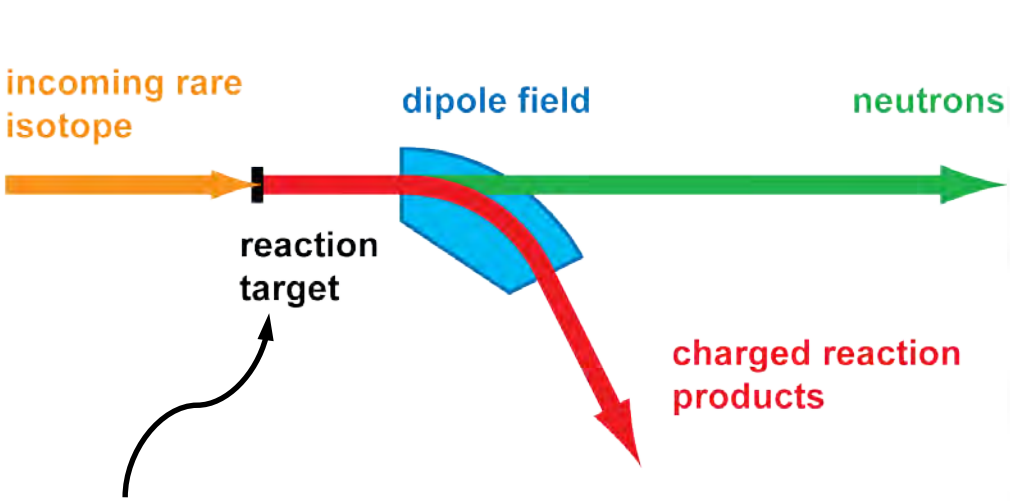


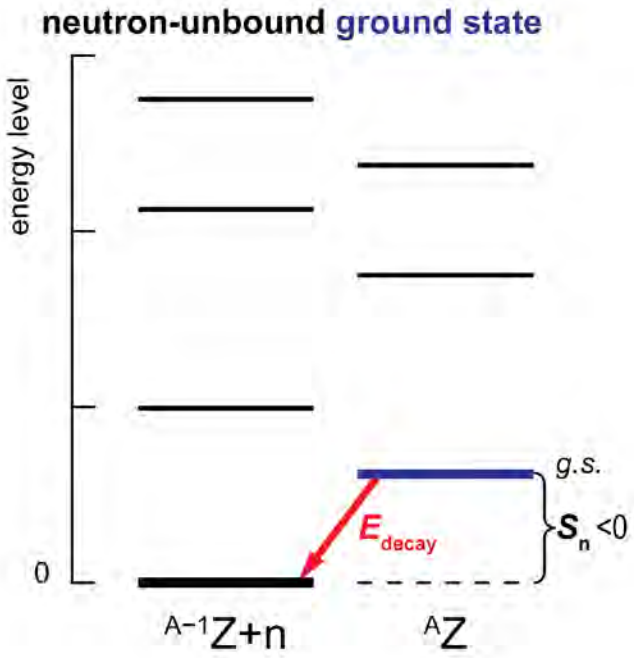
# MoNA Physics

## *Study of Neutron-Unbound States*

### Method: Invariant Mass Spectroscopy

- Reconstruction of unbound state by determining momentum vectors of constituents.




***Populate unbound state***

- proton knockout
- (d,p) reaction
- Coulomb excitation

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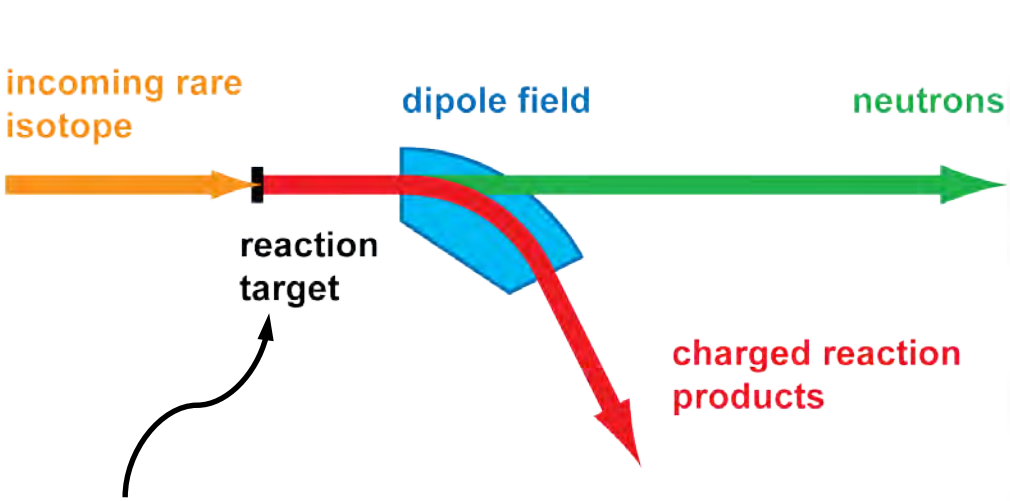


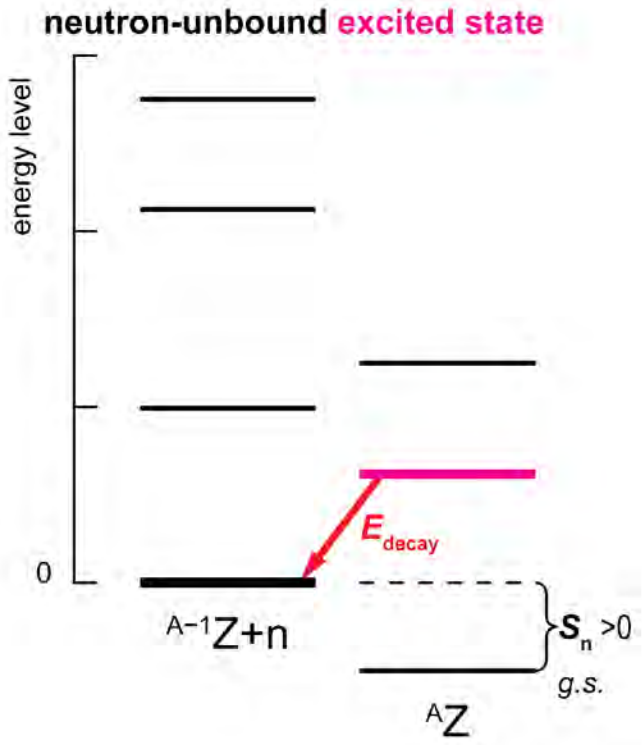


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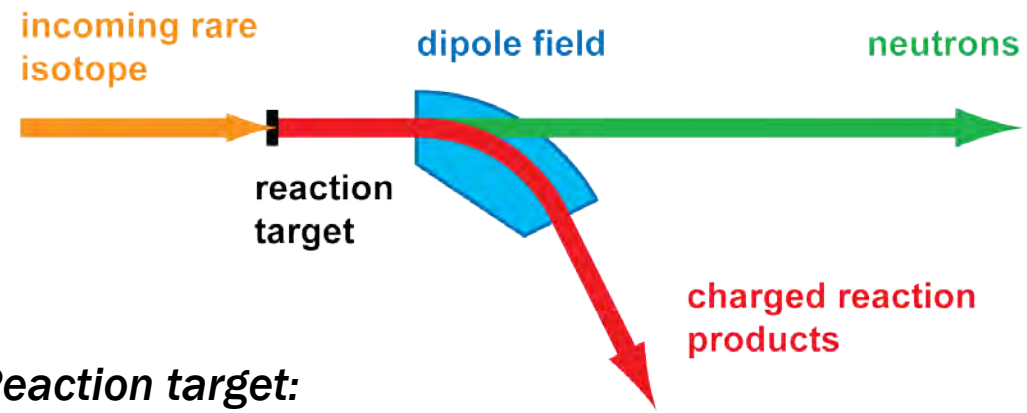



***Reaction target:***

- populate unbound state
- optimize reaction yield vs. resolution

***Neutron detector:***

- neutron energy
- neutron position
- neutron multiplicity

***Charged particle detectors:***

- particle identification
- particle tracking

***Auxiliary detectors:***

- γ-ray detection

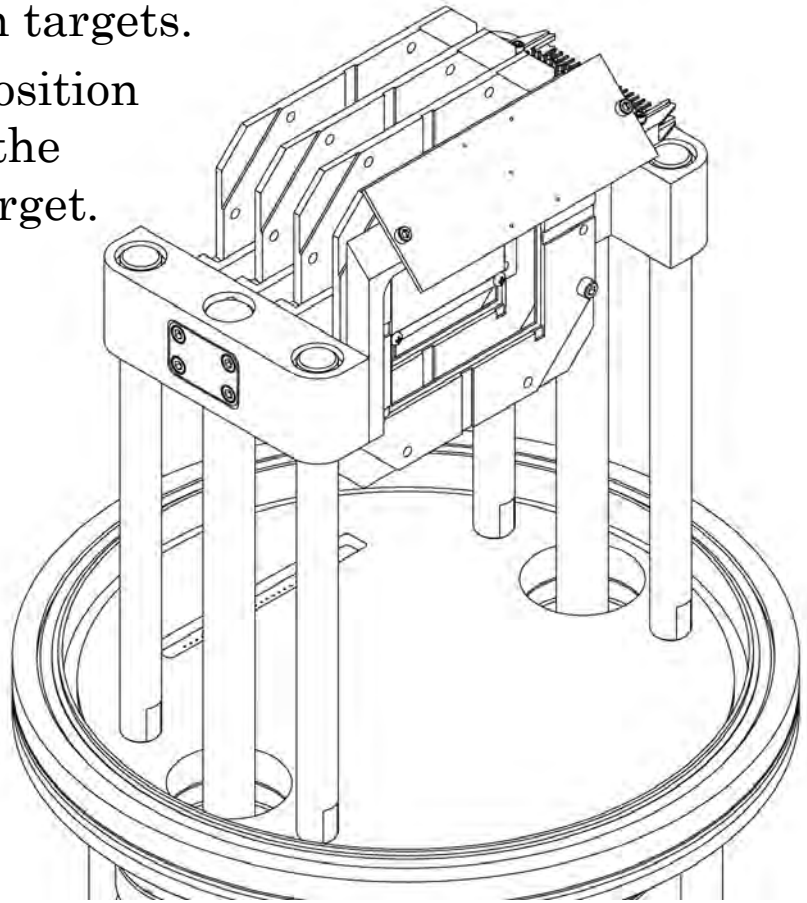
# MoNA Collaboration Current Research

## *Segmented Target*

Nathan Frank, *Augustana College*

**How can we optimize reaction yield *and* resolution?**

- Sandwich four 140 μm Si detectors and three Be reaction targets.
- Measure position and dE at the reaction target.



Augustana COLLEGE

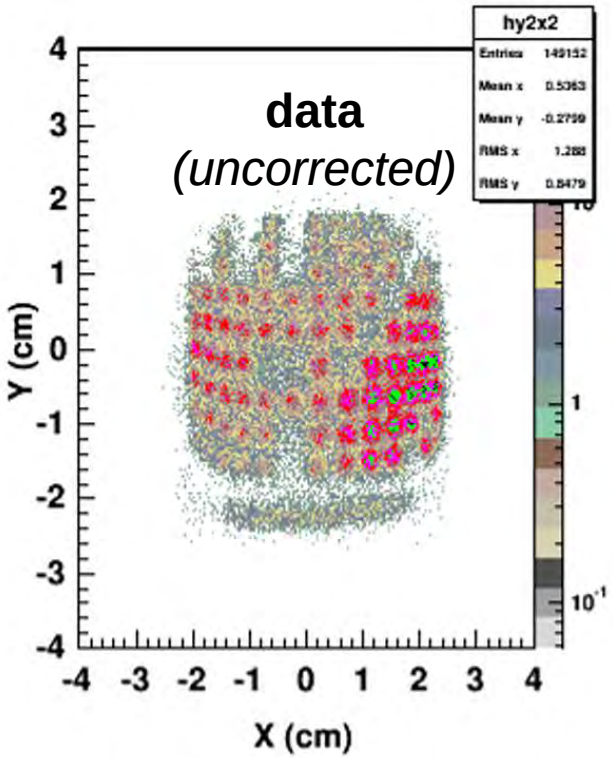
# MoNA Collaboration Current Research

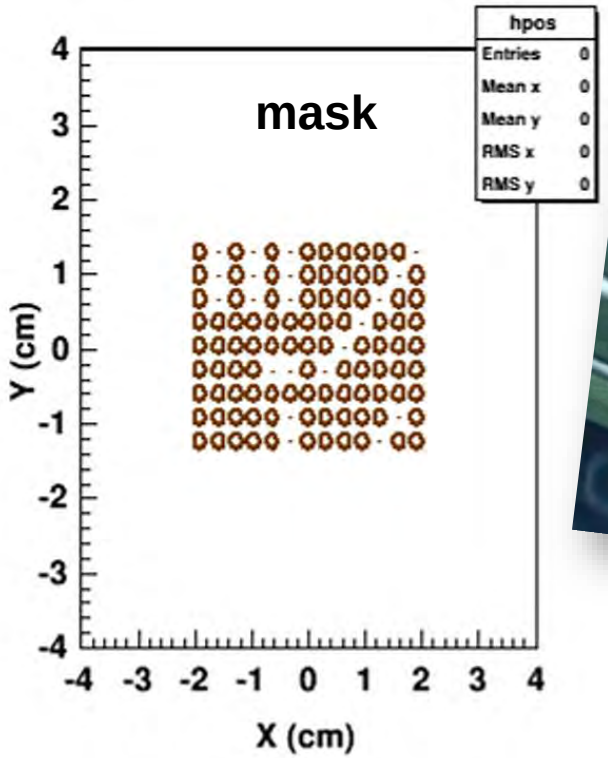
## *Segmented Target*

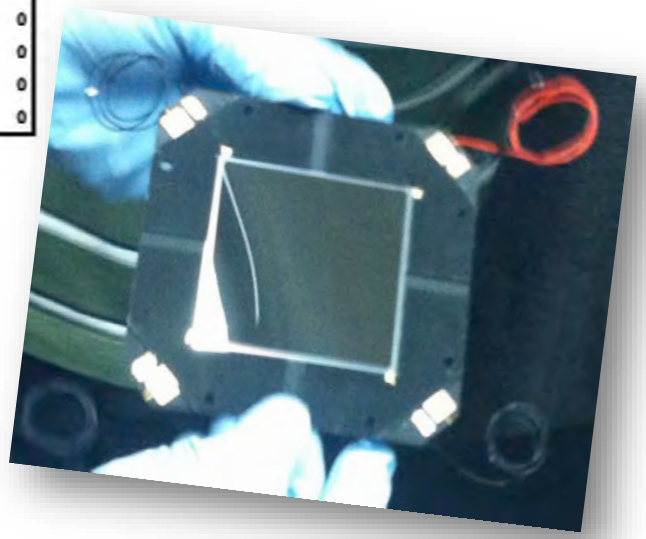
Paul Gueye, *MSU*

**Position sensitive Si detectors with corner readout:**

- 62 mm by 62 mm
- front: 4 corner signals for position
- back: anode signal for energy loss



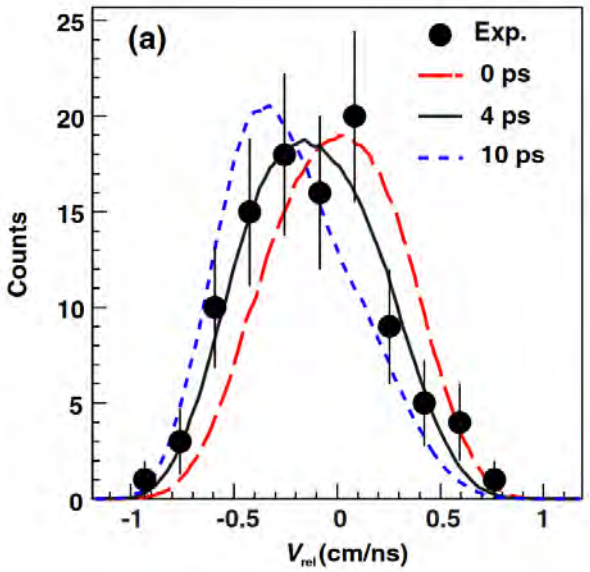



# MoNA Collaboration Current Research

## *Segmented Target*

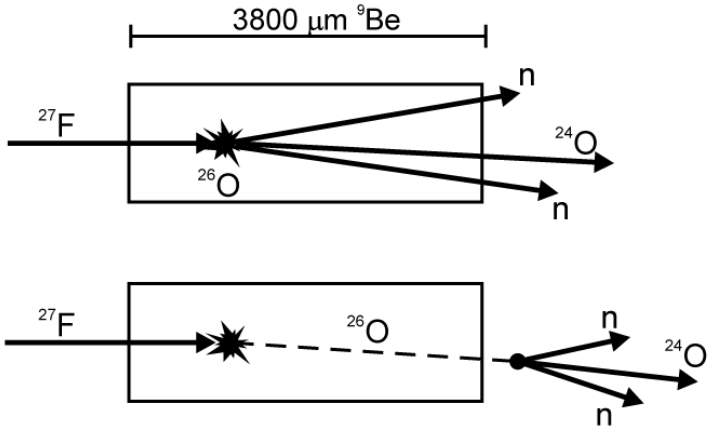
Thomas Redpath, *MSU grad student*




### Decay-in-target method

Thoennessen *et al.* Nucl. Inst. Meth. A 729, 207 (2013)
Kohley *et al.* Phys. Rev. Lett. 110, 152501 (2013)

- Measure life time of $^{26}$O by neutron velocity shift caused by a delayed decay.
- Relative velocity between charged fragment and neutron is calibrated to peak at zero for instant decay.



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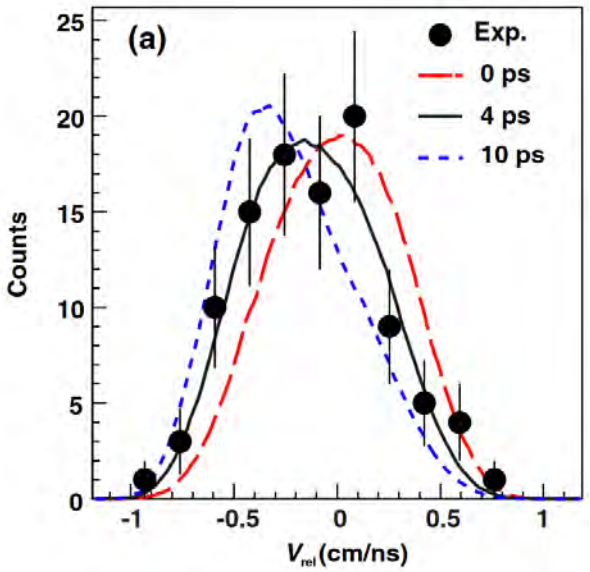


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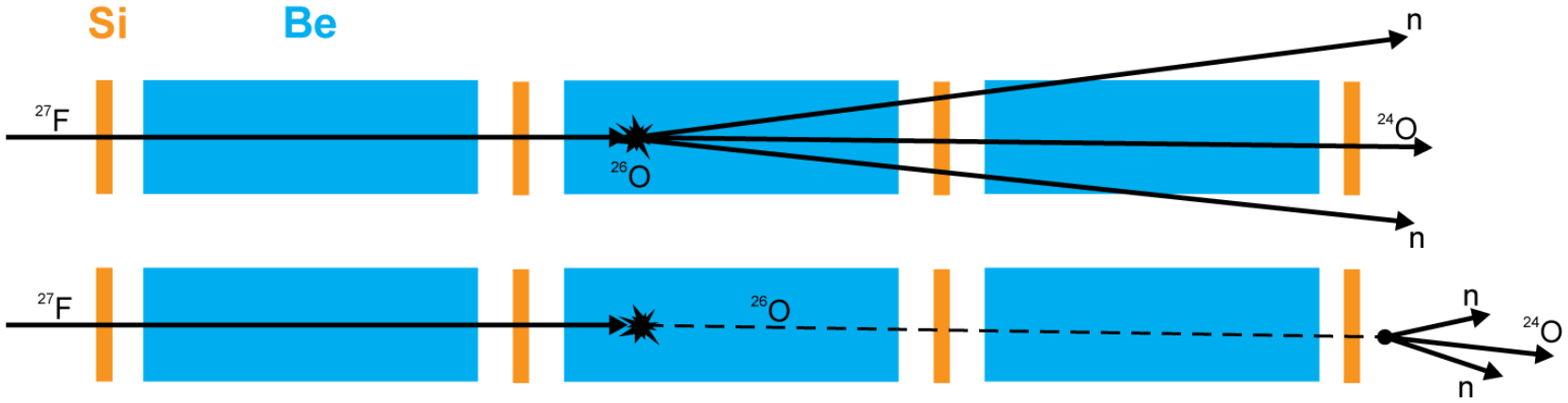

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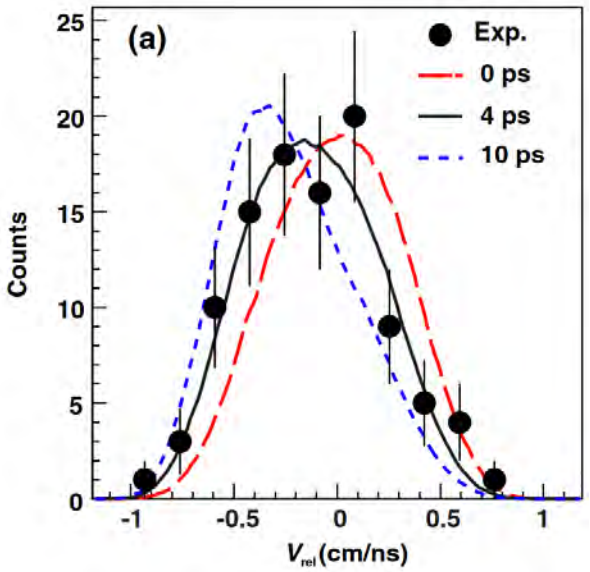


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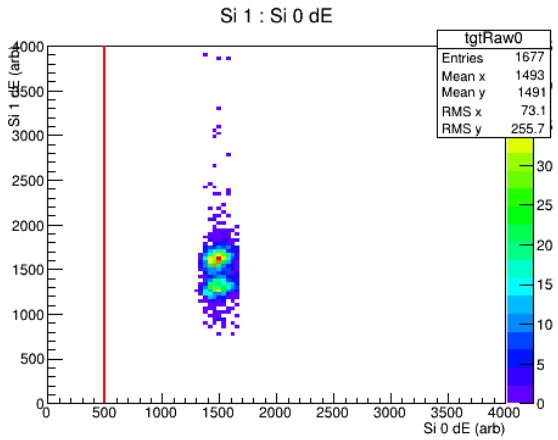
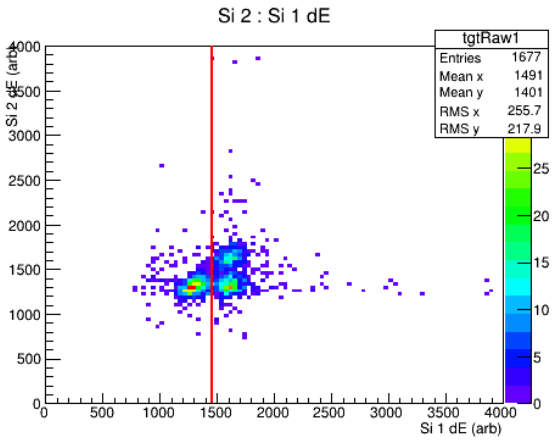
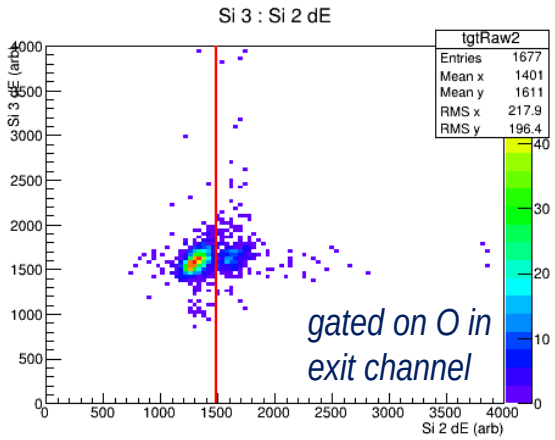


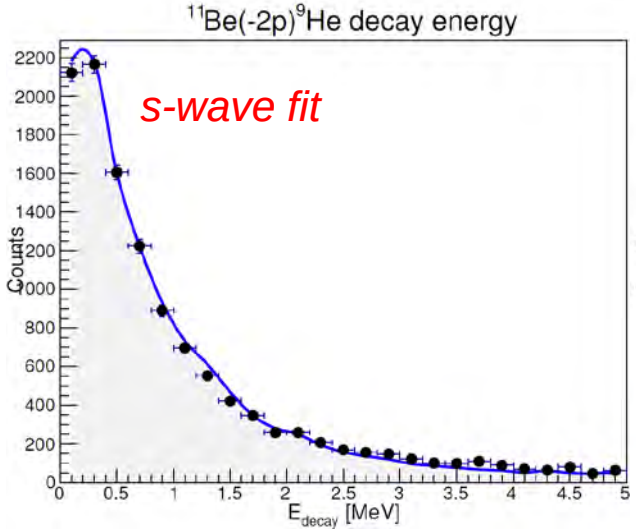
# MoNA Collaboration Current Research

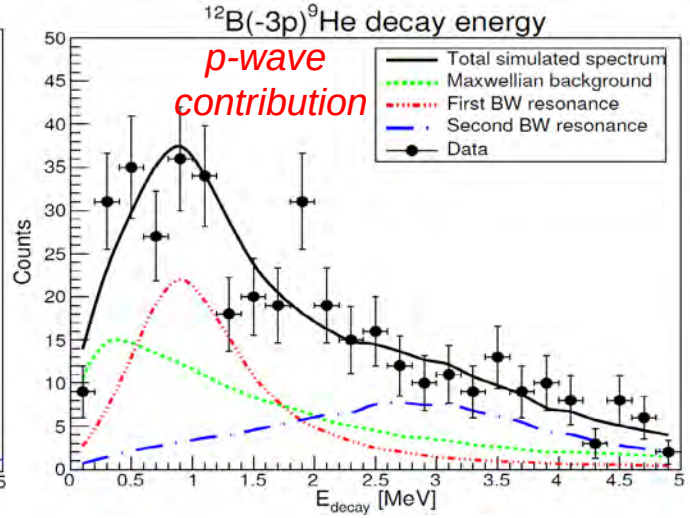
## *$^{9}$He and the light island of inversion*

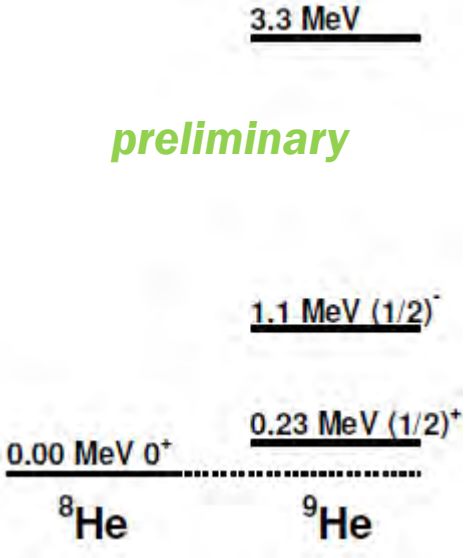
Daniel Votaw, *MSU grad student*

**The unbound $^{9}$He has been studied extensively, but:**

- Is there a shell inversion in the lightest N = 7 nucleus?
- We populated $^{9}$He by
  - 2 p removal from $^{11}$Be – dominant configuration is $\mathbf{v(1s_{1/2})}$, and
  - 3 p removal from $^{12}$B – dominant configuration is $\mathbf{v(0p_{1/2})}$



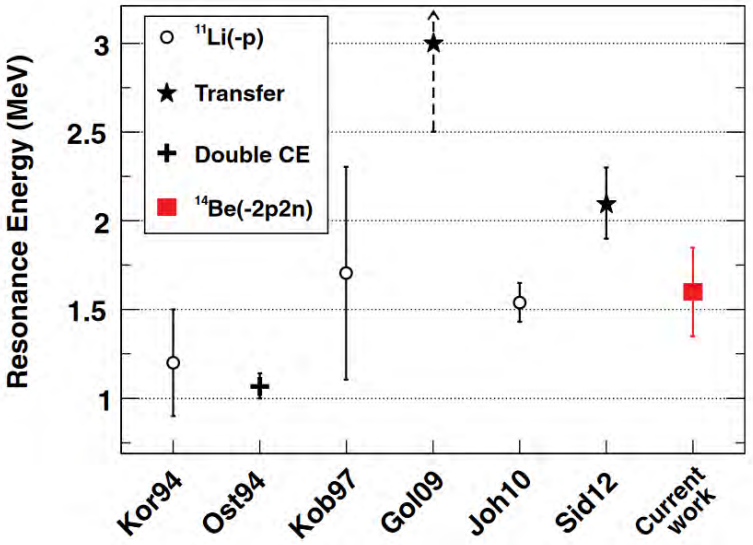



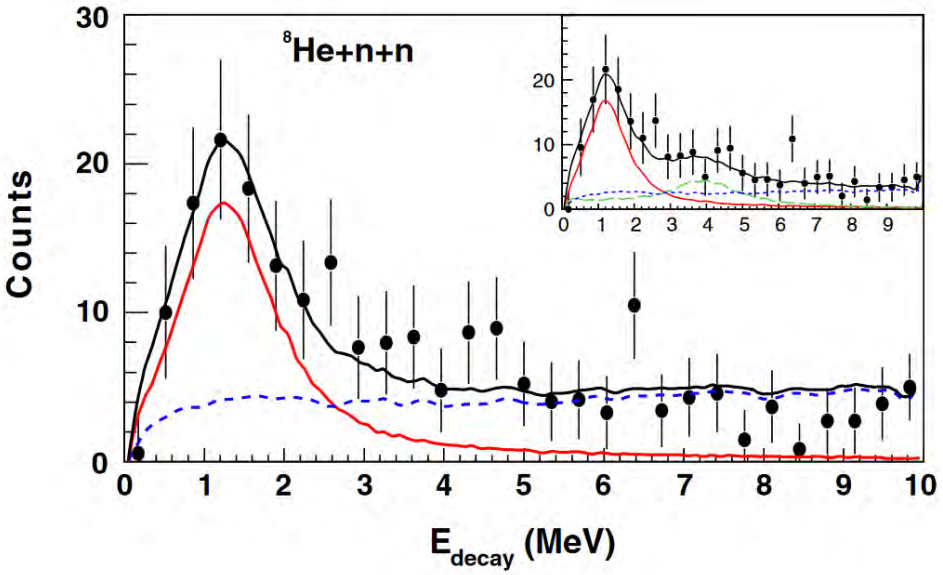
# MoNA Collaboration Current Research

## *$^{10}$He and the effect of halo structures*

### Question about the $^{10}$He ground state

$^{10}$He populated by 2p2n knockout from $^{14}$Be:




Kohley, *et al.* Phys. Rev. Lett. 109, 232501 (2012)

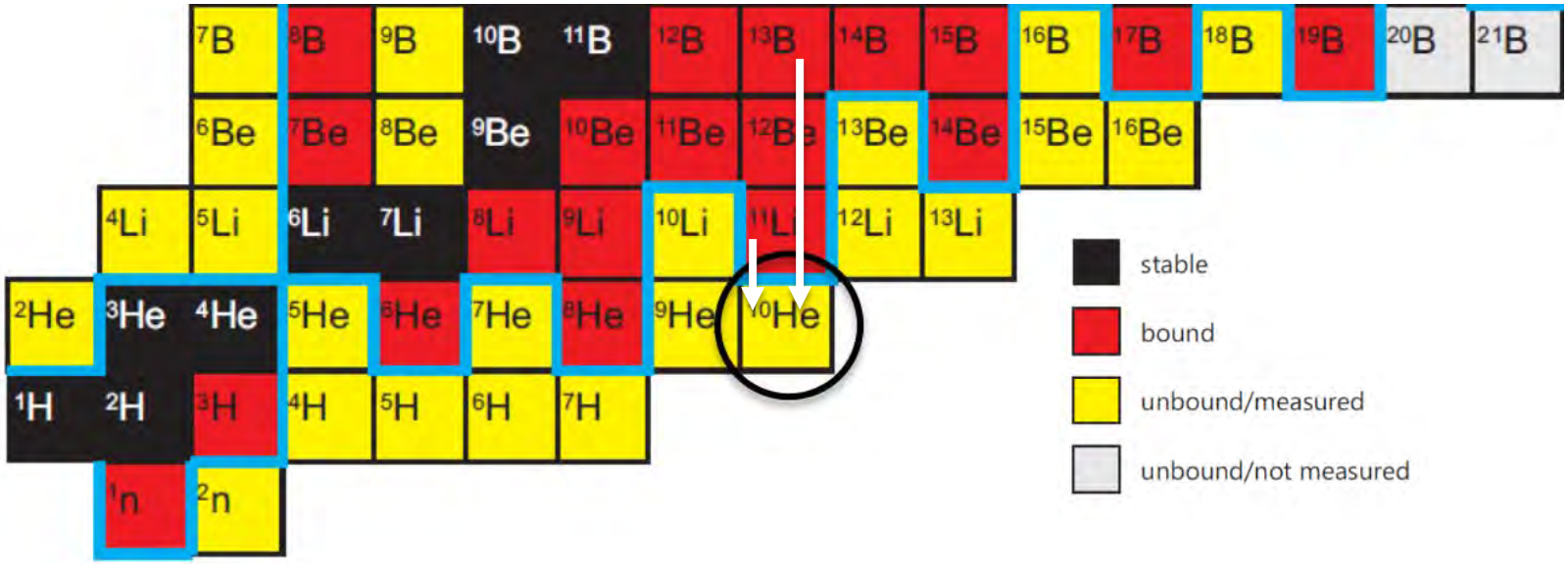
# MoNA Collaboration Current Research

## *$^{10}$He and the effect of halo structures*

Han Liu, *MSU grad student*

**Use two different beams to populate $^{10}$He: $^{13}$B and $^{11}$Li.**

- Differences were observed.
- Due to the stronger population of non-resonant contributions in 3p1n removal from $^{13}$Be, the low energy $^{10}$He resonances cannot be resolved.
- The $^{11}$Li data are dominated by the remnant of the initial halo structure rather than a resonance.



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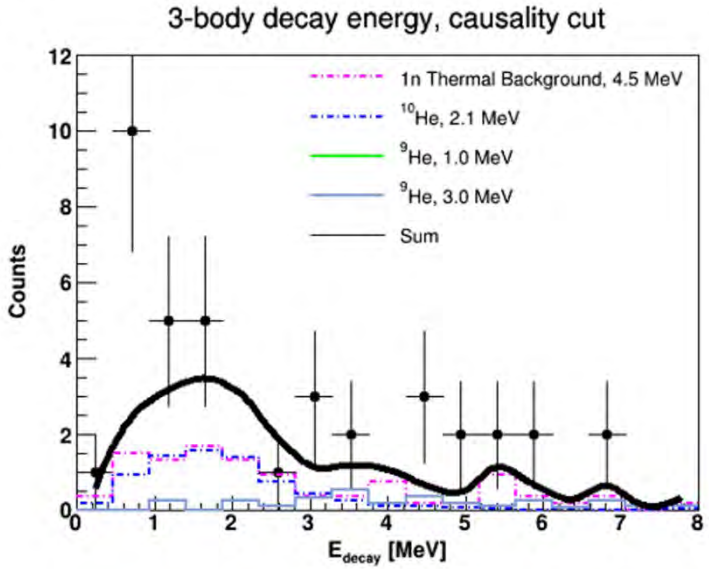
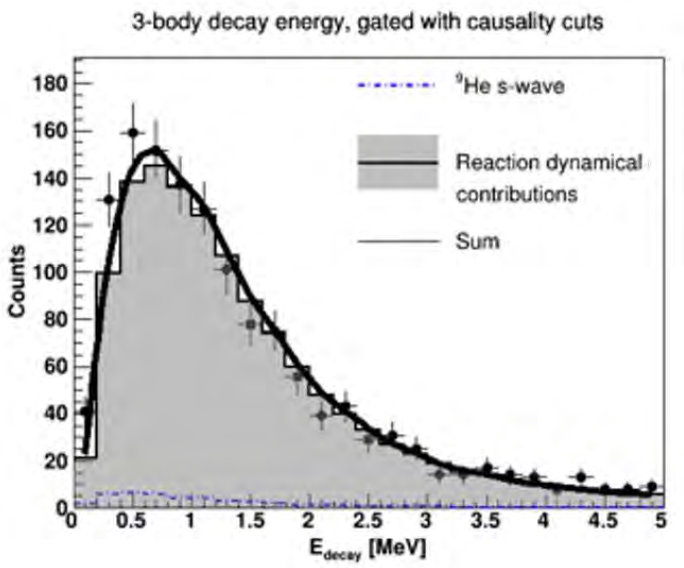
*preliminary*



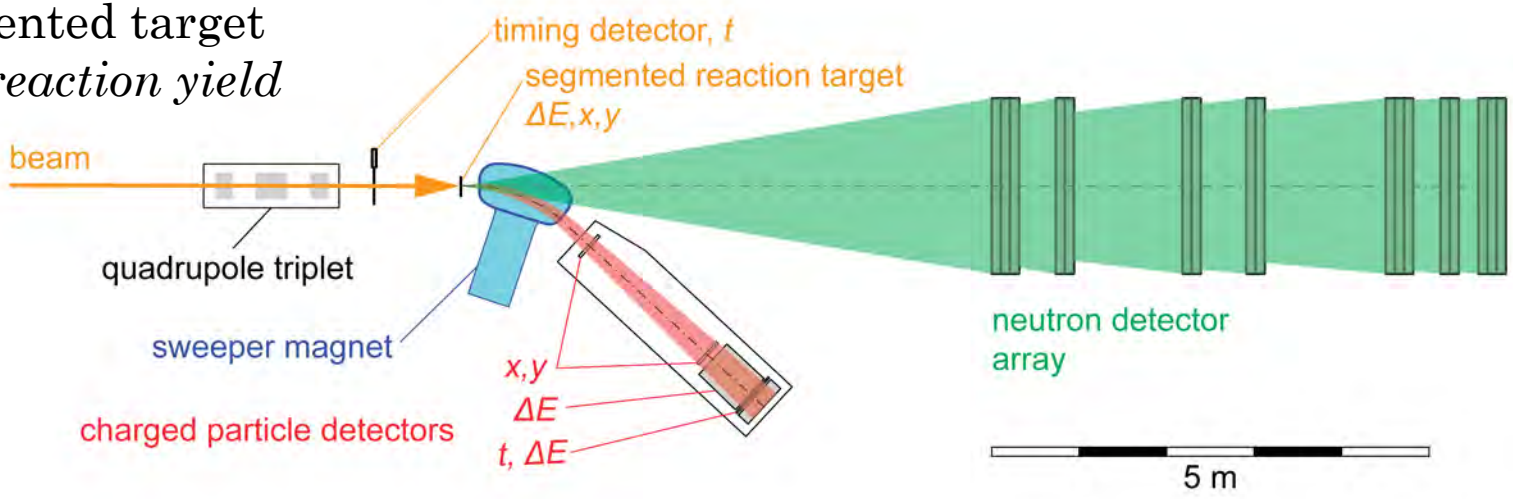
# MoNA Collaboration Current Research

## *N=20 island of inversion*

Dayah Chrisman, *MSU grad student*

**In the most recent experiment, we moved up in mass to investigate the N=20 island of inversion:**

- MoNA-LISA in stacked configuration
  *optimize detection efficiency and multi-neutron discrimination*
- Segmented target
  *high reaction yield*



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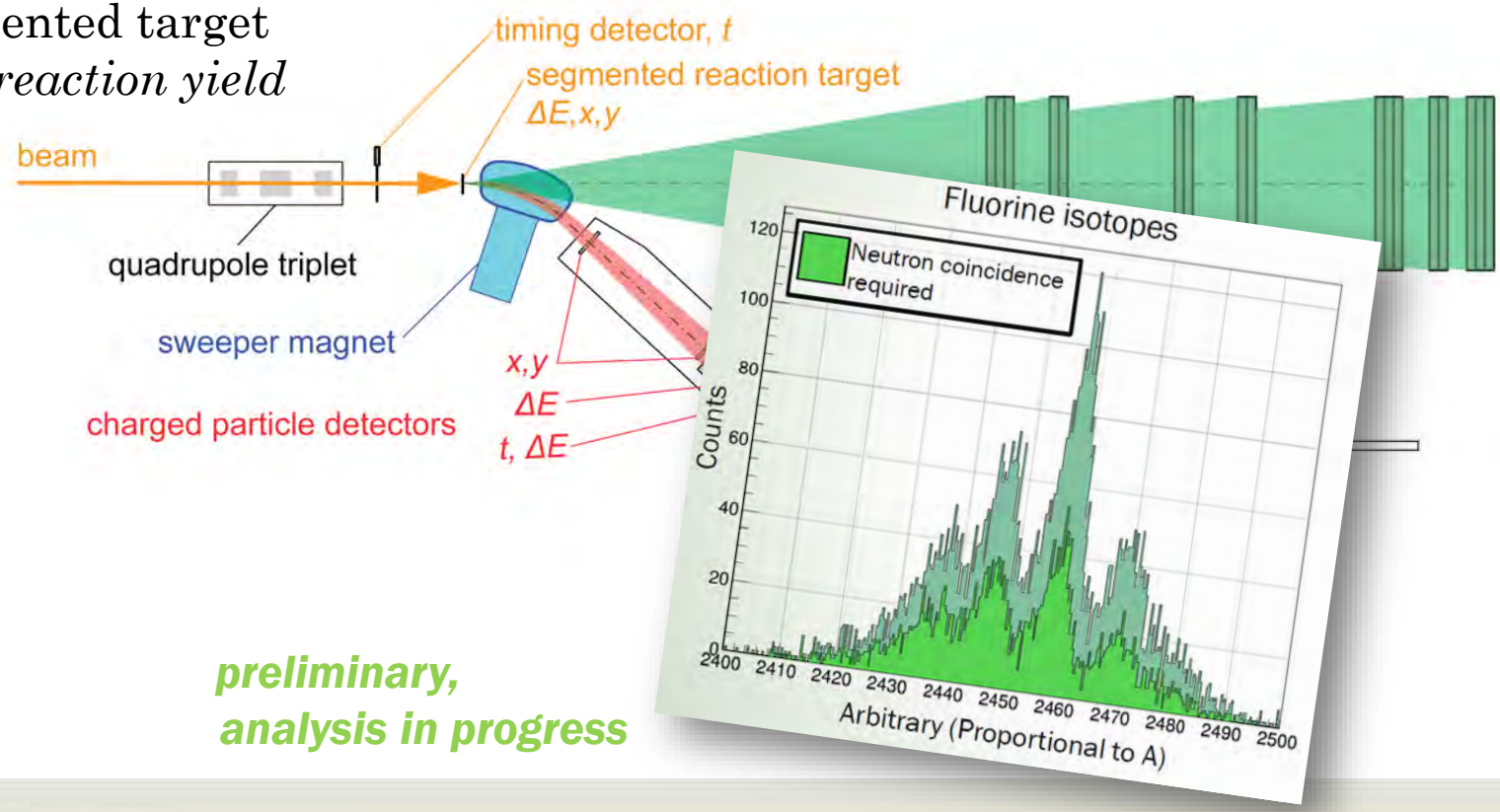



***preliminary, analysis in progress***

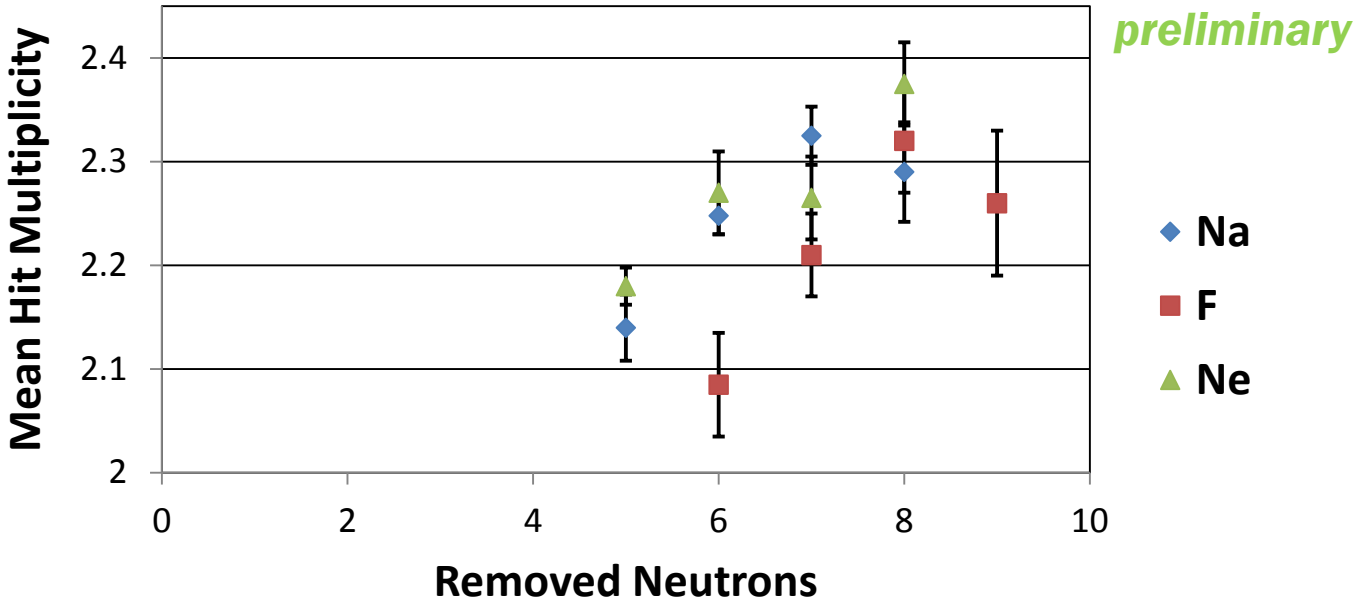
# MoNA Collaboration Current Research

## *Projectile-like fragment production studies*

Sharon Stephenson, *Gettysburg College*

**Deduce information of projectile like fragment formation by looking at neutron multiplicities.**

- Select fragmentation products from $^{32}$Mg secondary beam.
- Compare observables to CoMD, INCL++, and ISApace.
- Simulations of hit multiplicity overestimate data.



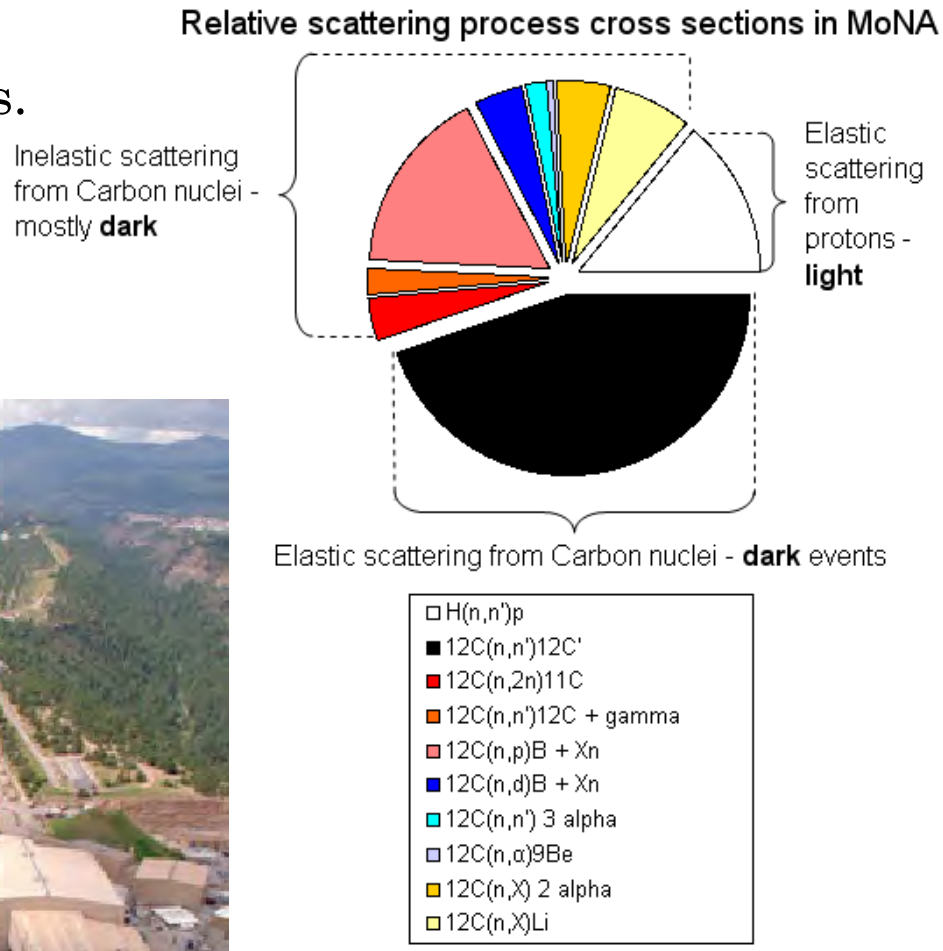
# MoNA Collaboration Current Research

## *Improve Neutron Simulations*

Warren Rogers, *Indiana Wesleyan*

### Collect data to refine simulations

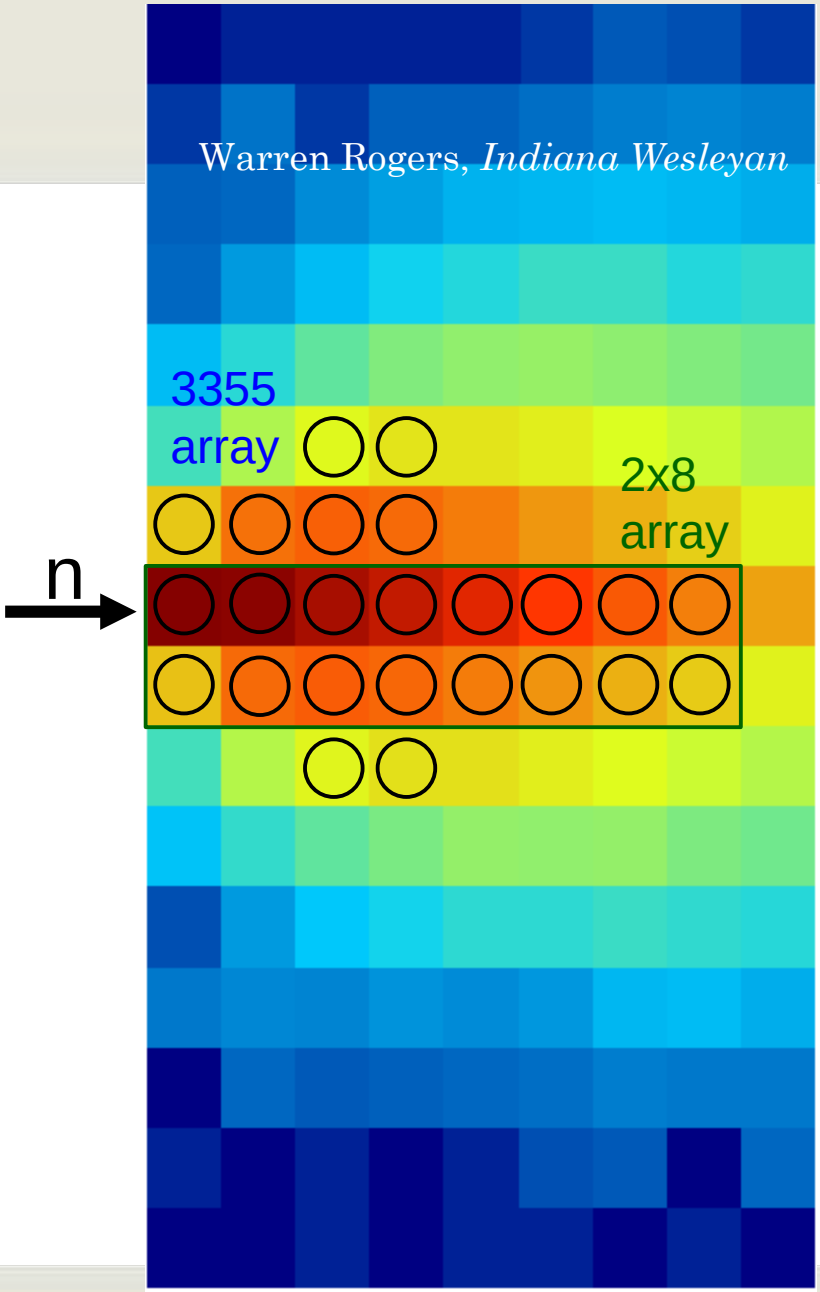
- Using LANSCE neutron beams.



# MoNA Current Research

## *Improve Neutron Simulations*

- 90 m from spallation target, 3 mm collimator!
- 20 MeV to 200 MeV neutrons.



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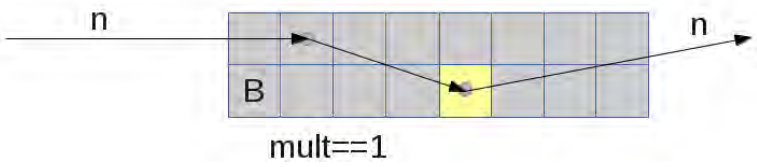
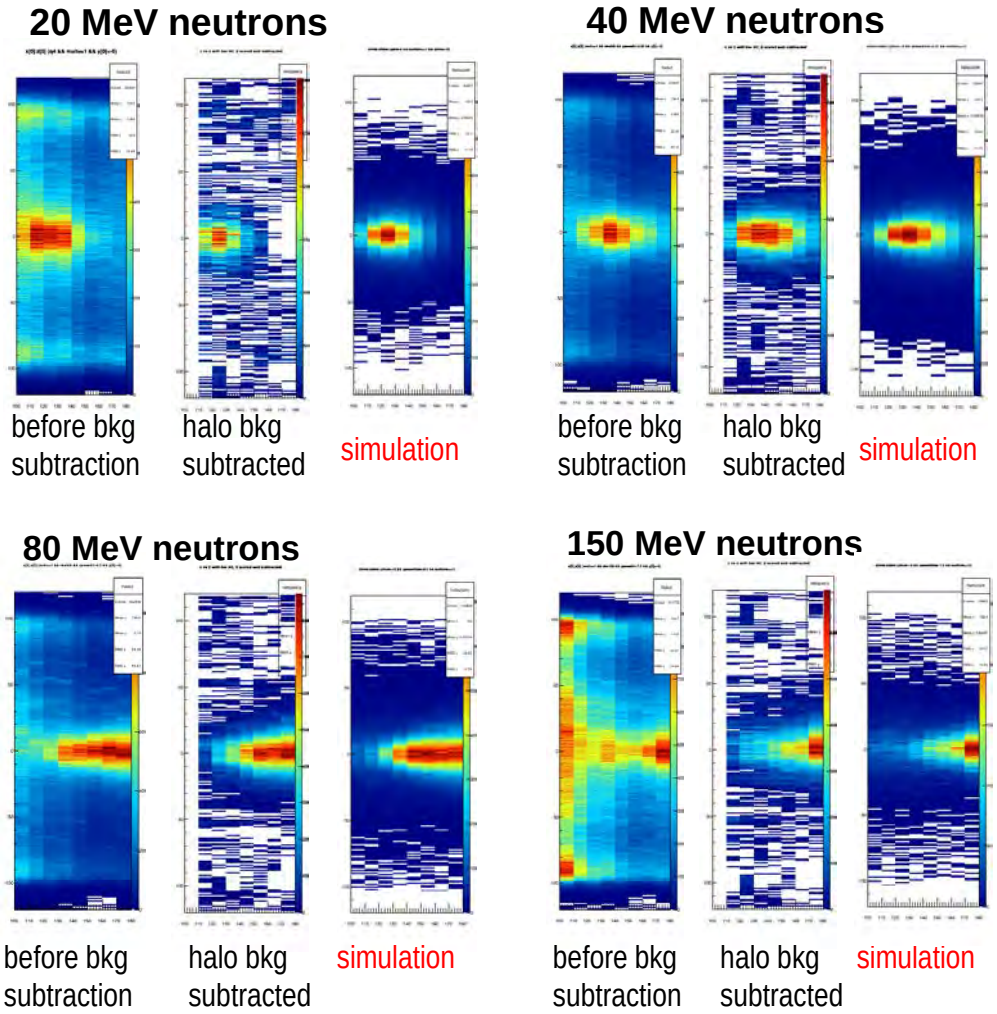



**Elastic scattering from C**
("dark" scattering)

- Beam enters upper layer, dark scatters, and produces first light in lower layer.
- Compare to GEANT4 / MENATE_R simulations.




INDIANA WESLEYAN UNIVERSITY

# MoNA Collaboration Current Research

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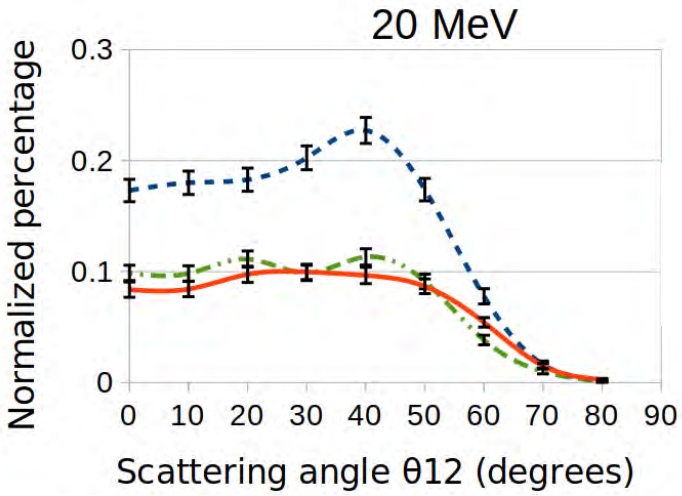
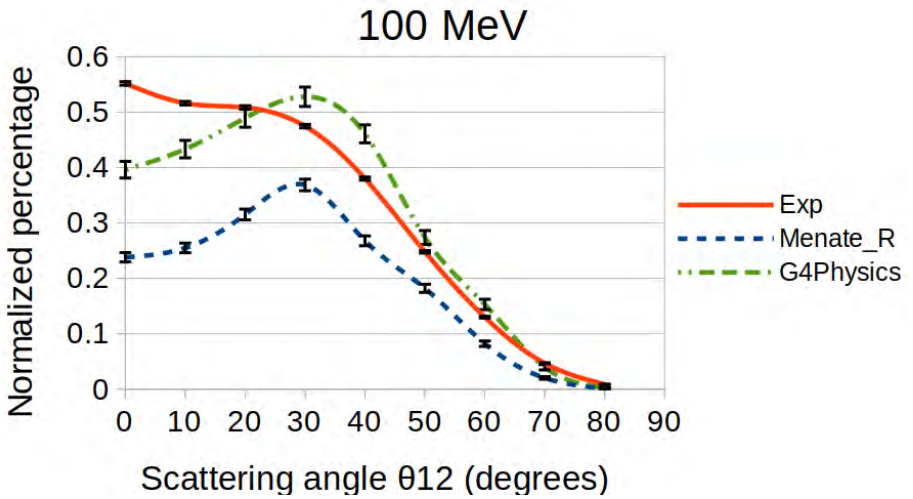
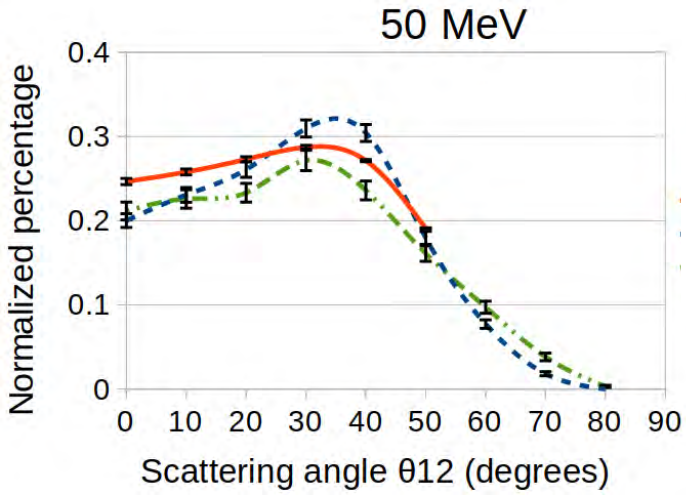
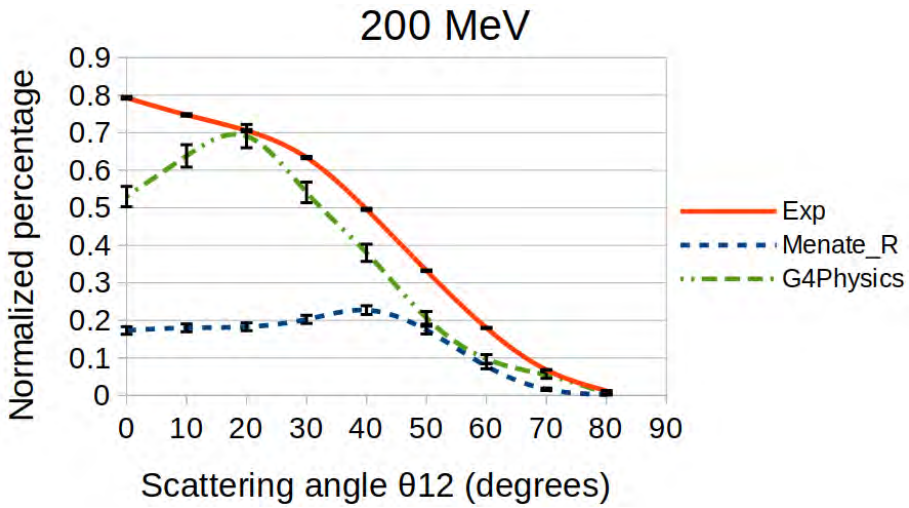


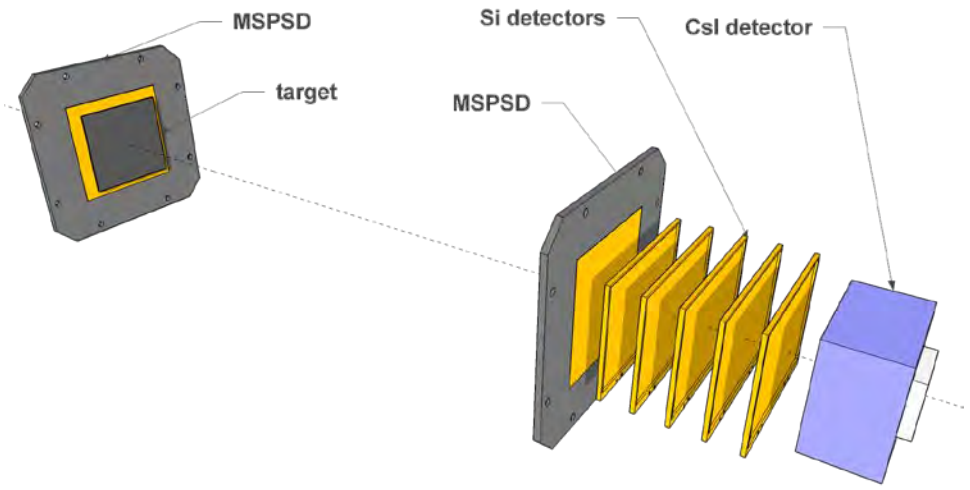



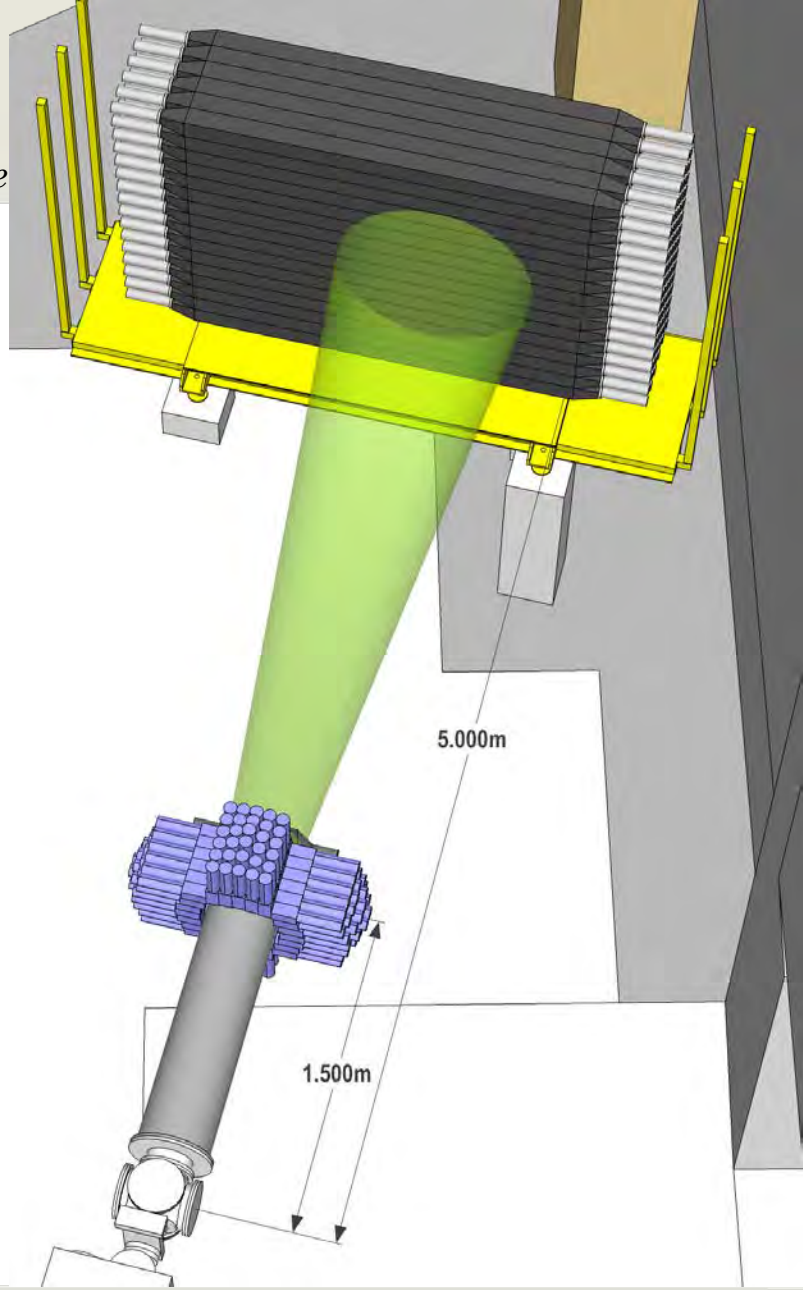



# Future Plans
## *NSCL*

Nathan Frank, *Augustana*
Paul DeYoung, *Hope College*

- The Sweeper dipole magnet and MoNA-LISA were located in the N2 vault for past 10 years.
- The N2 vault is being reconfigured for the cyclotron beam stopper.
- Proposed sweeper-less experiments in the S2 vault are under review.
- The MoNA Collaboration is in the process of developing a detector telescope consisting of Si (dE) and CsI (TKE) detectors.

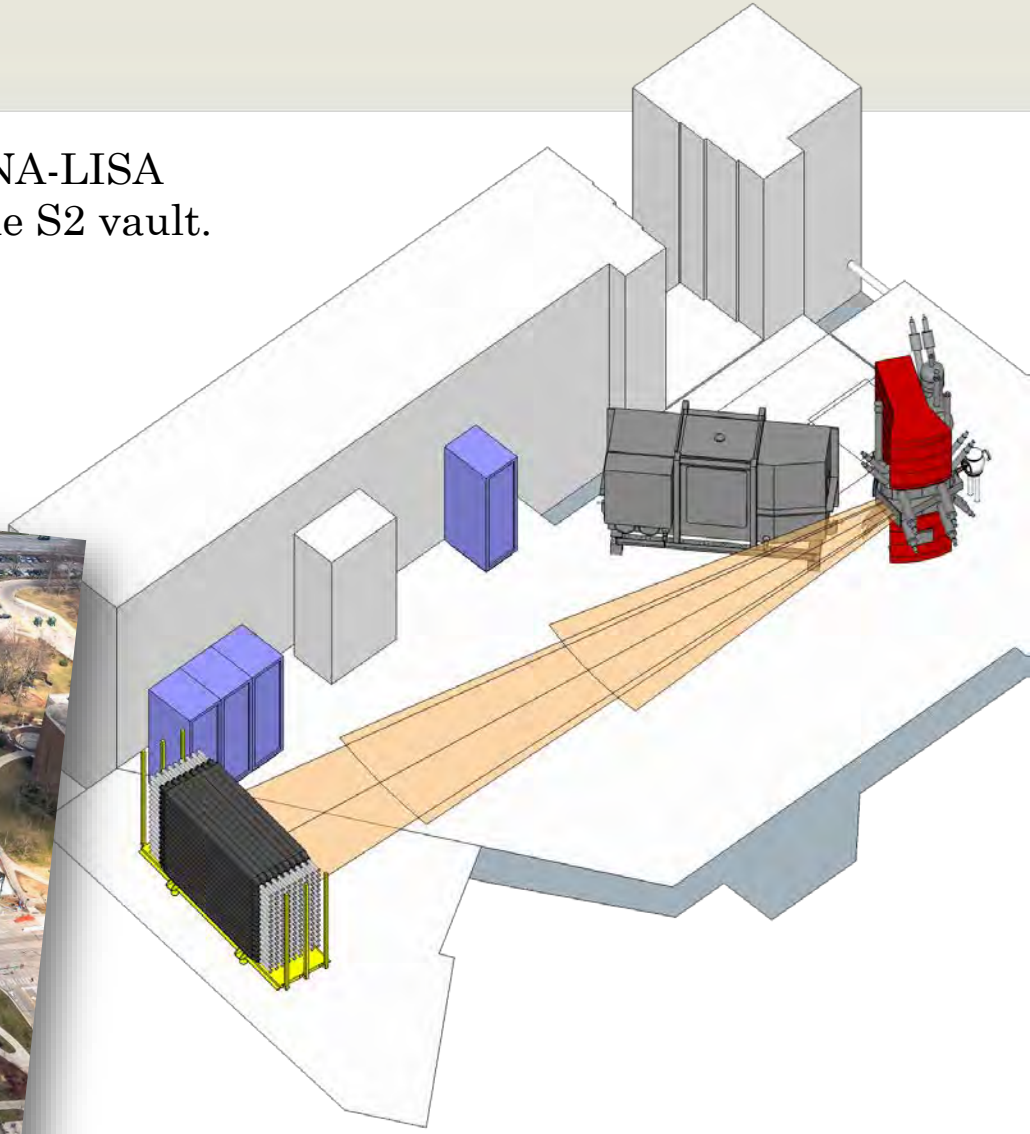


# Future Plans

## *FRIB & HRS*

- The Sweeper dipole magnet and MoNA-LISA neutron detectors will be set up in the S2 vault.
- Available when FRIB comes on-line.
- We are prototyping a next-generation neutron detector.



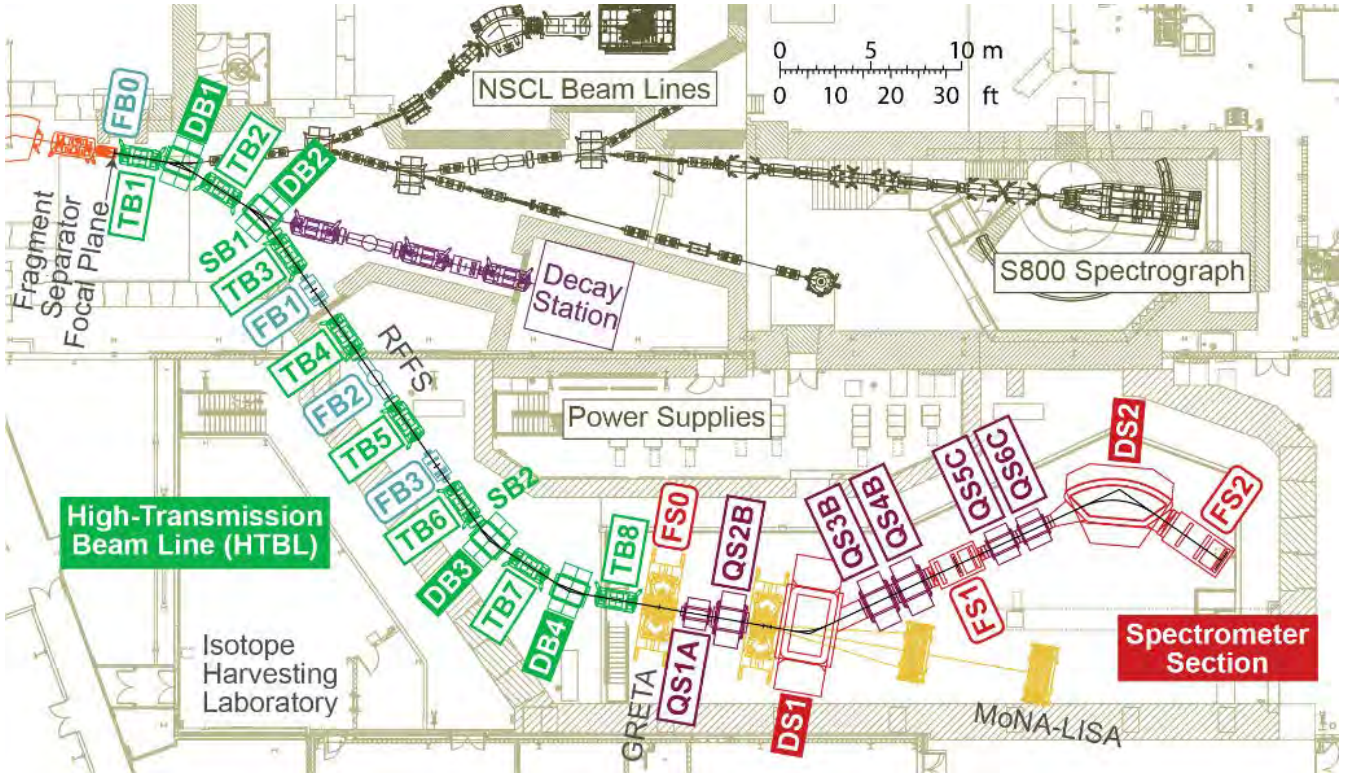
# Future Plans

## *FRIB & HRS*

Remco Zegers, Shumpei Noji, MSU

**The High Rigidity Spectrometer (HRS) is proposed as the first major addition to FRIB. It allows studies with rare isotope beams up to 8 Tm in magnetic rigidity.**

- High-acceptance analysis line and spectrograph matched to FRIB beam (8 Tm).
- Momentum resolving power of 1300, solid angle of 15 msr (full HRS).



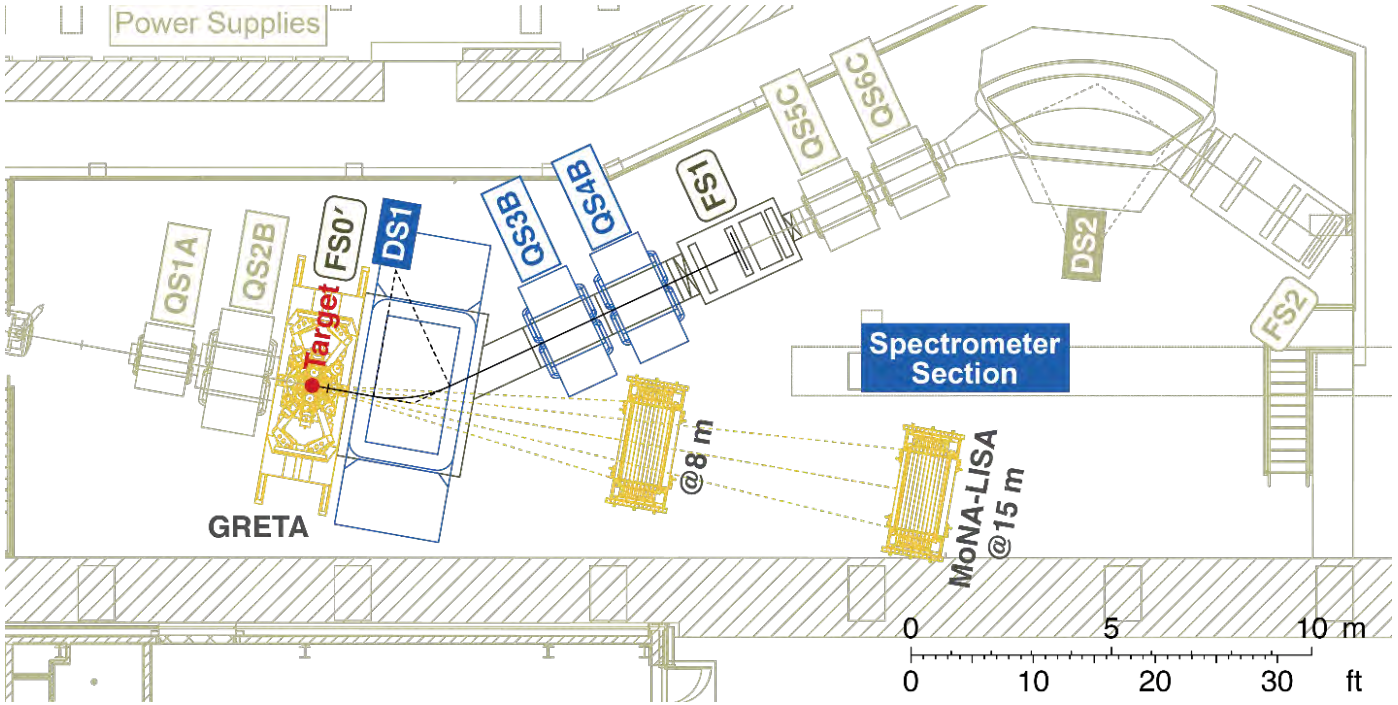
# Future Plans

## *FRIB & HRS*

Remco Zegers, Shumpei Noji, MSU

**The HRS consists of:**

- 35° sweeper dipole magnet section to deflect charged particles from 0° neutron path. *This section is used for invariant mass measurements.*



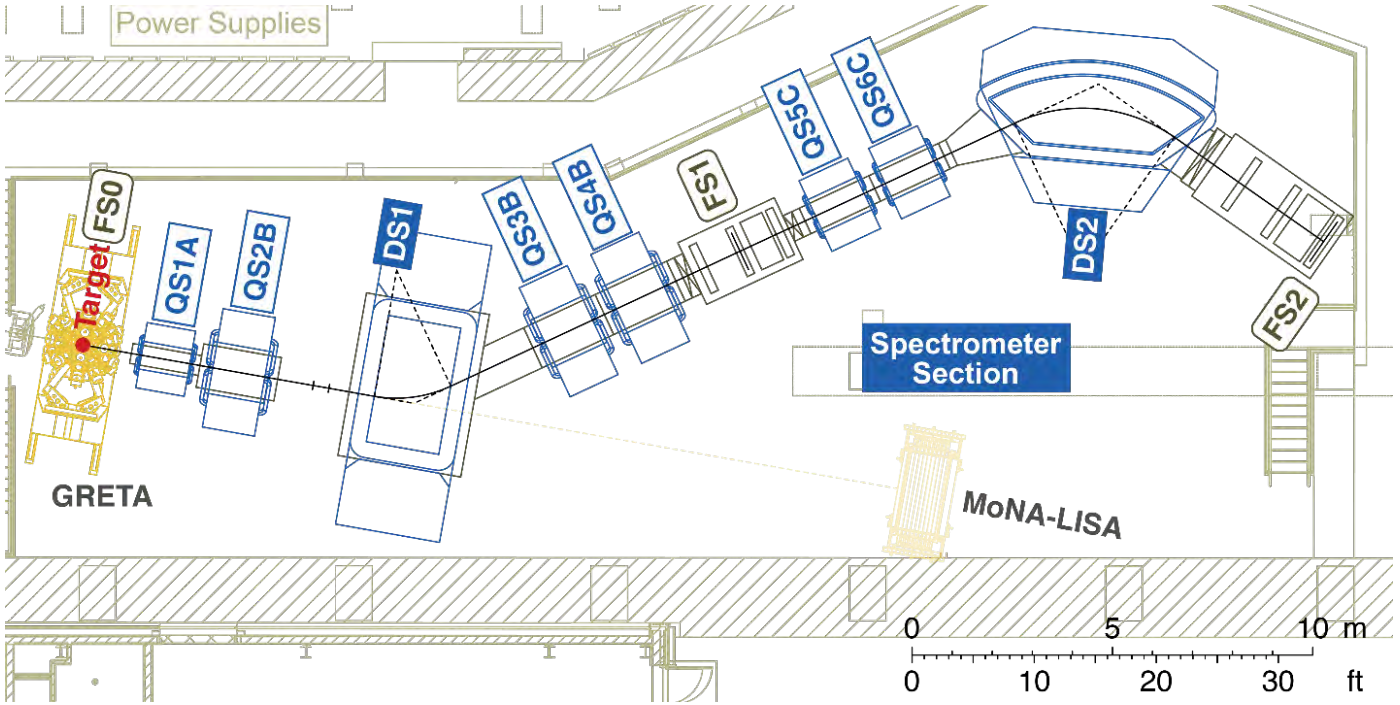
# Future Plans

## *FRIB & HRS*

Remco Zegers, Shumpei Noji, MSU

**The HRS consists of:**

- 35° sweeper dipole magnet section to deflect charged particles from 0° neutron path.
  *This section is used for invariant mass measurements.*
- Spectrometer section with a 60° dipole magnet
  *This section is needed for high resolution experiments.*



# Future Plans

## *FRIB & HRS*

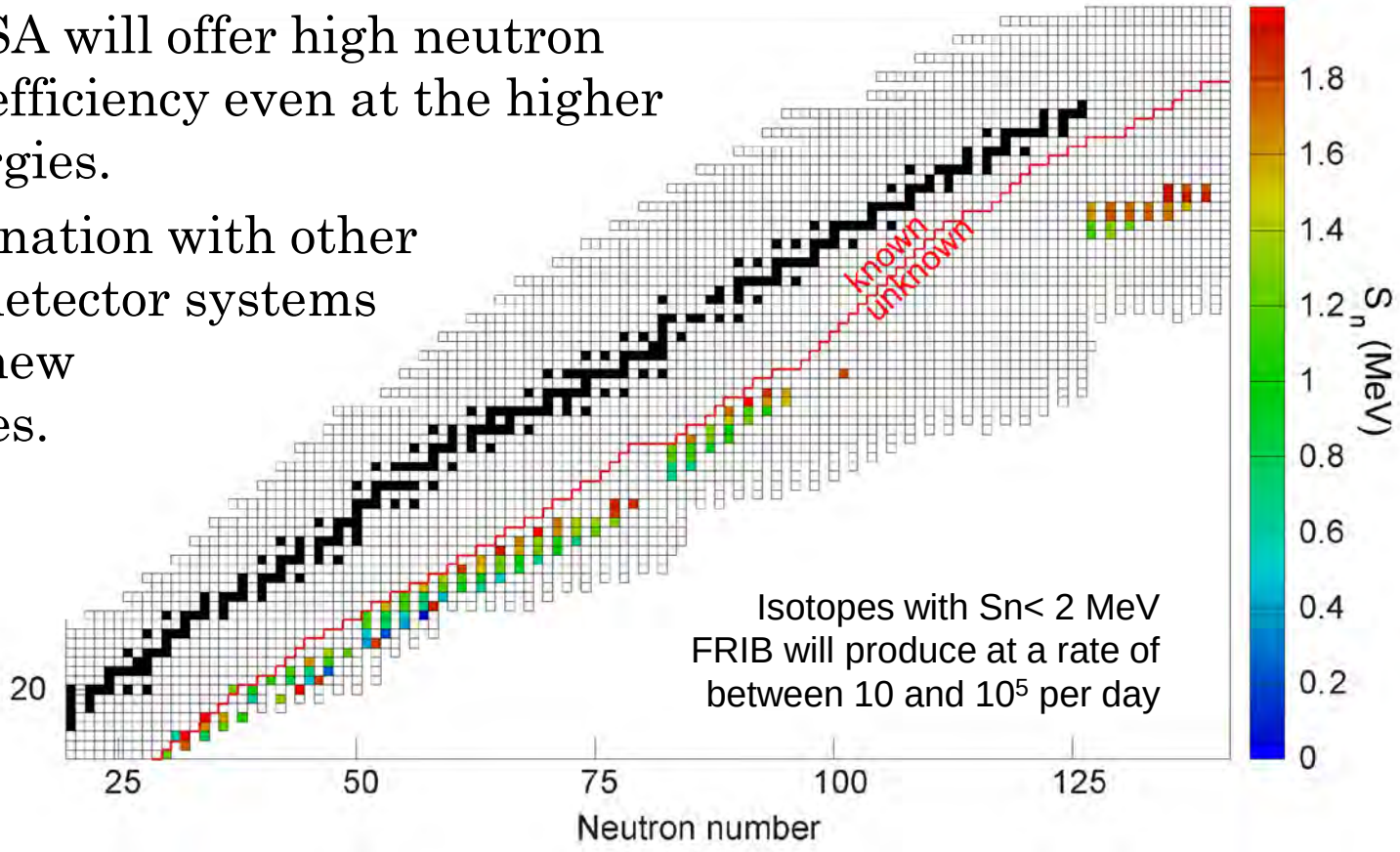
Shumpei Noji, MSU

The High Rigidity Spectrometer (HRS) high bay is under construction.

# Future Plans

## *FRIB & HRS*

- Higher FRIB intensities and rigidities will make more neutron-rich isotopes accessible.
- MoNA-LISA will offer high neutron detection efficiency even at the higher FRIB energies.
- The combination with other powerful detector systems will offer new possibilities.



# Acknowledgement

*The MoNA project thrives because of the dedication and support of its collaboration members and outstanding students.*

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