Geant4 Simulation of A Multi-layered Target for the Study of Neutron-Unbound Nuclei

$$^{26}F + ^{9}Be \rightarrow ^{25}O \rightarrow ^{24}O + n \quad or \quad ^{27}F + ^{9}Be \rightarrow ^{26}O \rightarrow ^{24}O + 2n$$

Paul Guèye Jessica Freeman* Hampton University	Nathan Frank Abdul Merhi* Augustana College	Michael Thoennessen Michigan State University National Superconducting Cyclotron Laboratory

A. Merhi Segmented Target Design (***EA.00074***)
N. Frank Simulation of a novel active target for neutron-unbound state measurements (***DJ. 00009***)

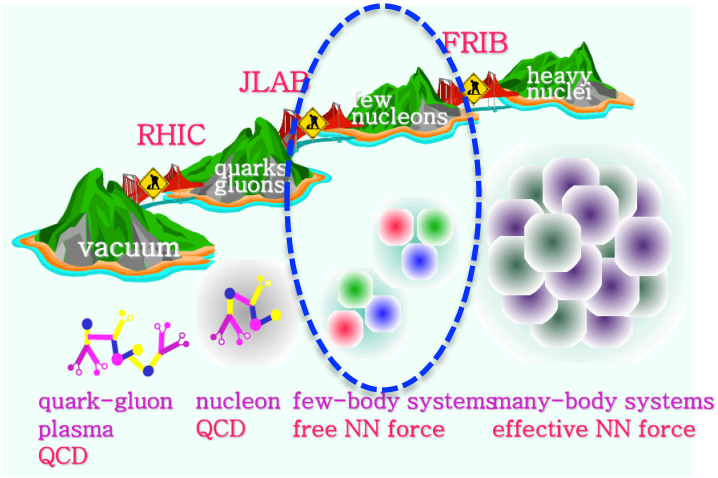
This work is supported by the Department of Energy National Nuclear Security Administration under Award Number DE-NA0000979

Outline

- **Project Goals**
- **Physics with neutron-rich nuclei**
- **Neutron unbound identification**
- **Geant4 simulation: unbounds in a multi-layered target**
- **Conclusion**

Project Goals

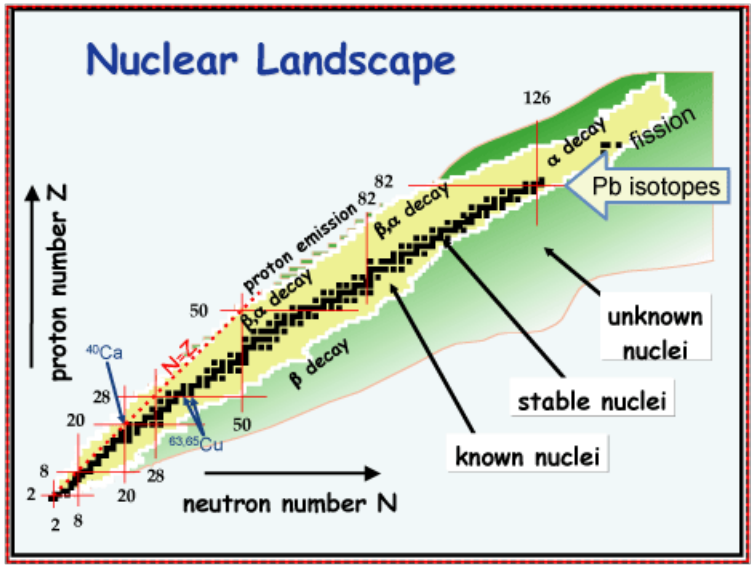
- **Physics**
  - Improve our understanding of the nuclear matter
    - Nucleon-nucleon forces
    - Unbound states/nuclei at and beyond the neutron drip line
  - Tools
    - National Superconducting Cyclotron Laboratory
    - Two dedicated forward neutron detectors
      MONA: **M**odular **N**eutron **A**rray
      LISA: **L**arge multi-**I**nstitutional **S**cintillator **A**rray
    - One charge (fragments) detector
    - Dedicated Be/Si segmented target

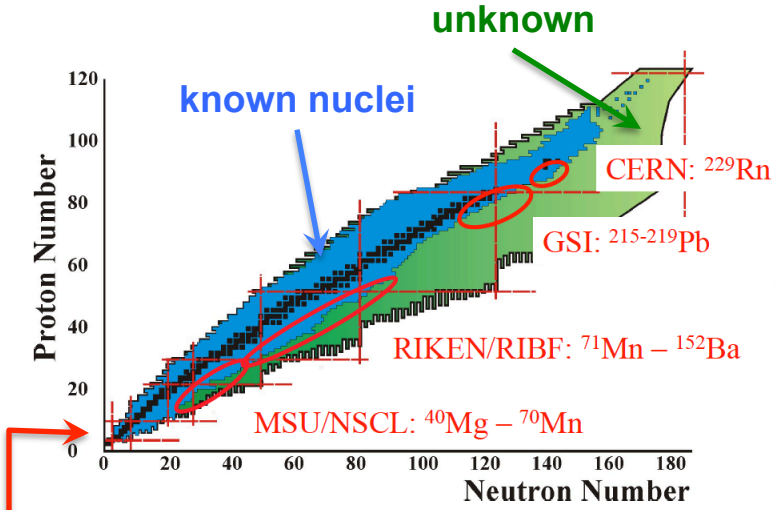


- **Education**
  - Increase participation of African-Americans
    - MSU/NSCL research
    - Establish possible new “nuclear physics” track (current: intermediate and high-energy physics)
  - Collaboration with a minority institution
    - Possibility to reach out to nearby Historically Black Colleges and Universities in the future (within 1 hr)
      VA: Norfolk State University, Virginia State University and Virginia Union University
      NC: Elizabeth City State University

Probing the Nuclear Structure - 1

- **Hadronic beams**
  - Nuclear interactions (fragmentation)
  - Allow to study n-rich (rare) isotopes
  - Need 3-body forces (**later**)





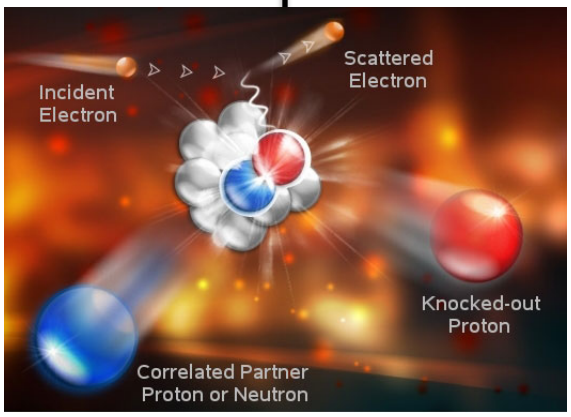
neutron-rich limit is only known up to oxygen

$$A \rightarrow B + n$$

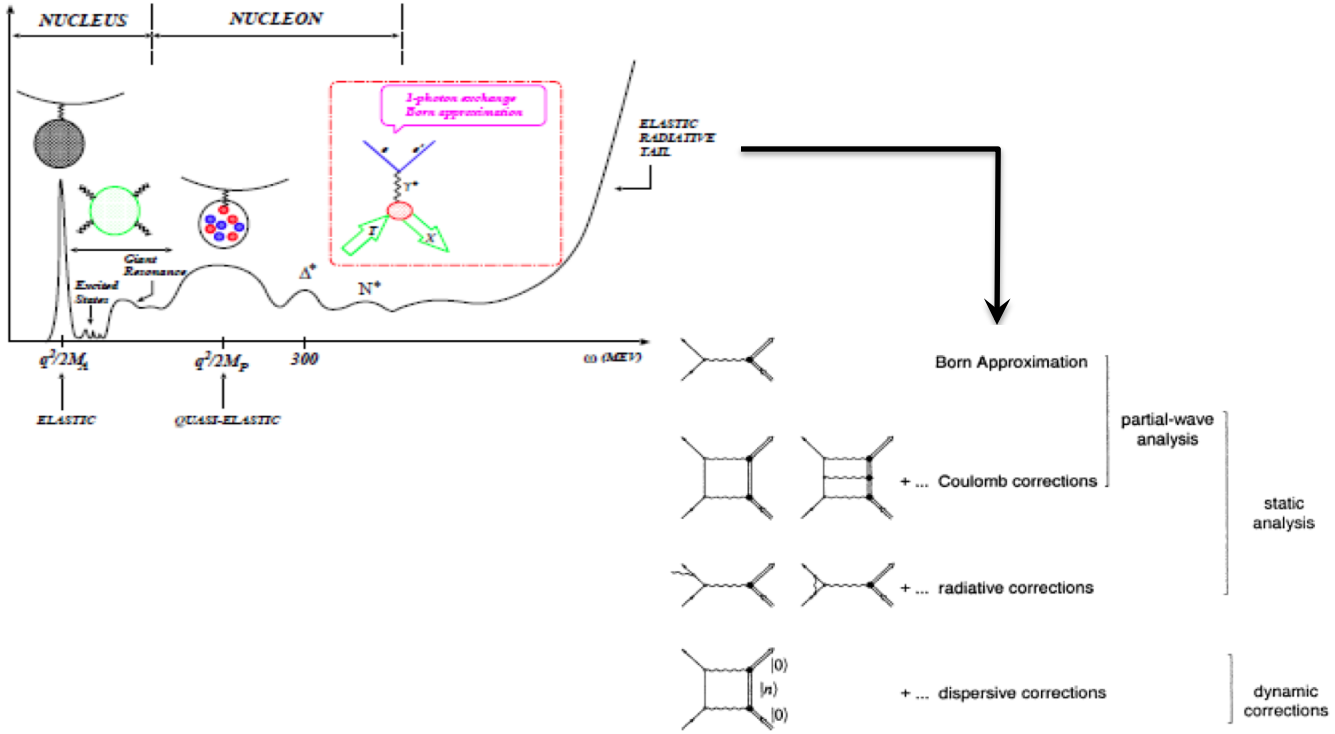
MONA/LISA n-detector at MSU/NSLC

Probing the Nuclear Structure - 2

- **Electromagnetic beams (JLab)**
  - Cleanest tool
  - Processes: elastic and inelastic
  - Physics: nuclei form factors, N-N correlations, polarized/unpolarized observables



courtesy of JLab, www.jlab.org



Probing the Nuclear Structure - 3

2N and 3N correlations in nuclear matter [JLab data]

K. S. Egiyan *et al.*, Phys. Rev. **C68** (2003) 014312 and Phys. Rev. Lett. **96** (2006) 082501

R. Subedi *et al.*, Science **320** (2008) 1476

R. Shneor *et al.*, Phys. Rev. Lett. **99** (2007) 072501

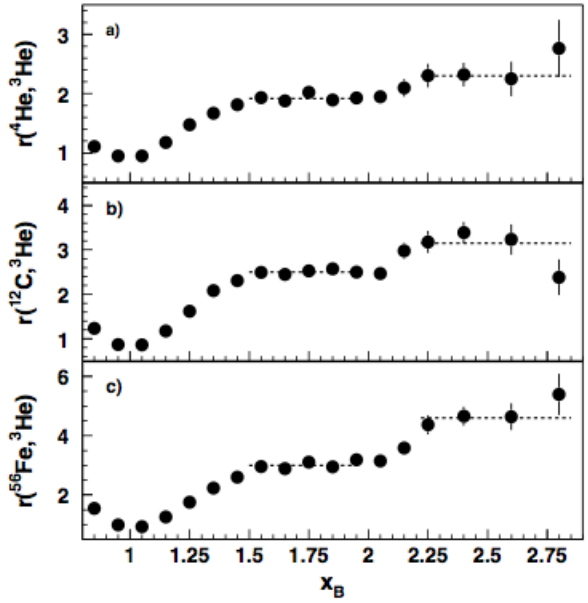
M. M. Sargsian *et al.*, Phys. Rev. **C71** (2005) 044615

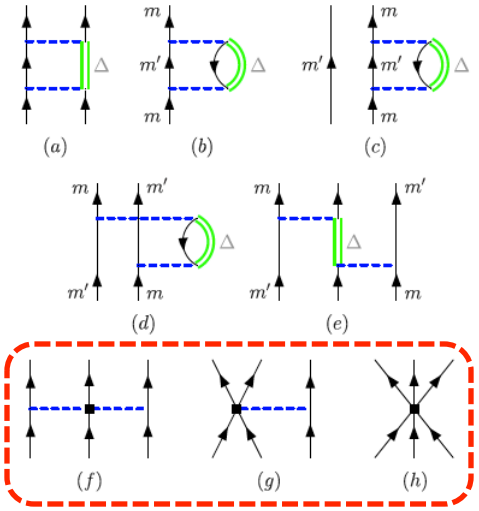
R. Schiavilla *et al.*, Phys. Rev. Lett. **98** (2007) 132501

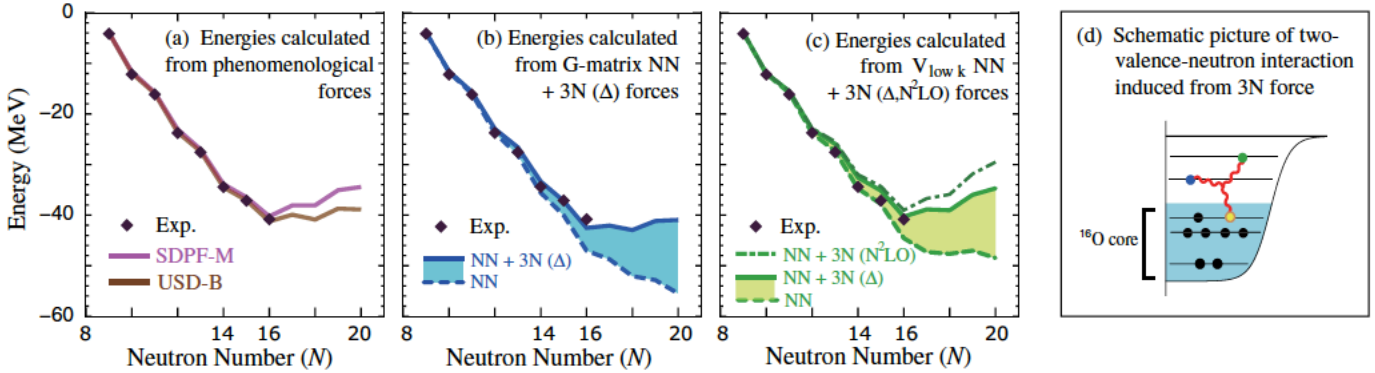
SRC from ^{12}C ratio: **2N** is 20±5% and **3N** is ~1%

JLab Physics

NSCL Physics

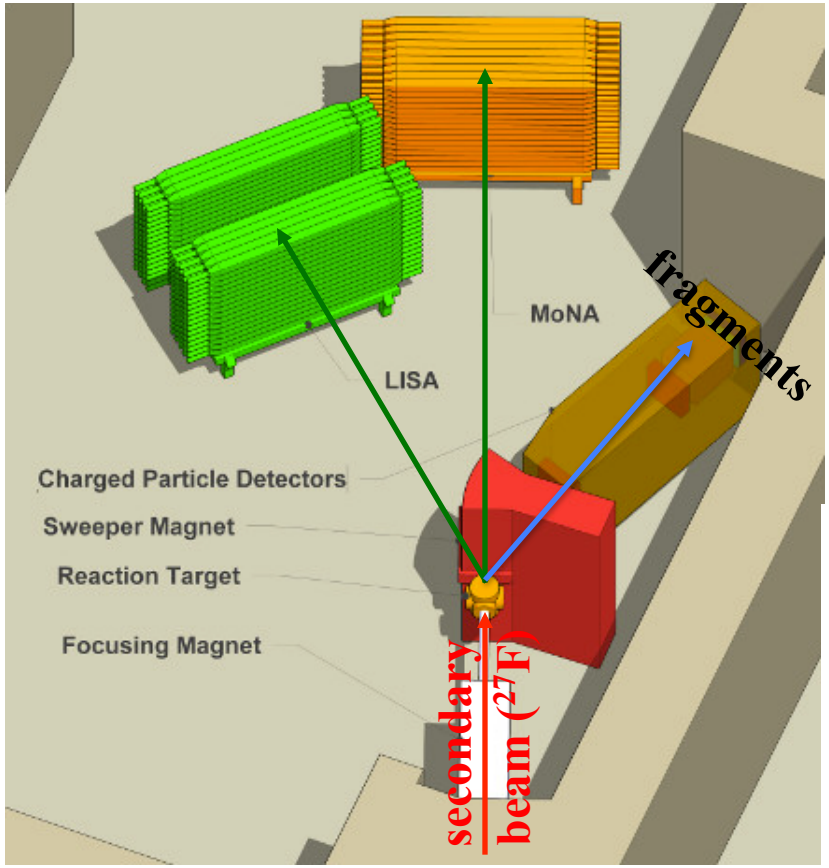




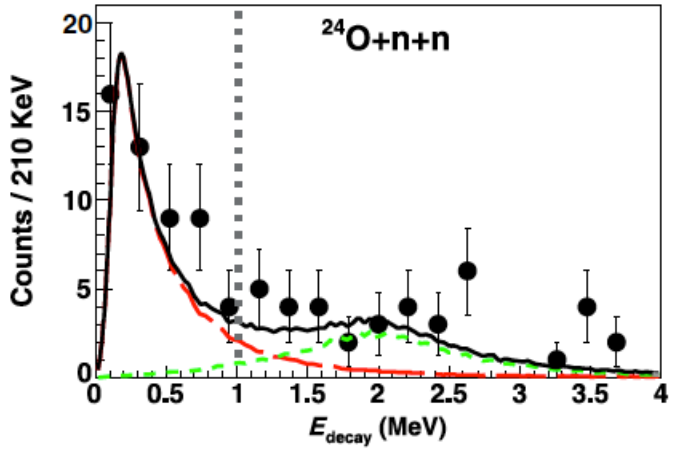


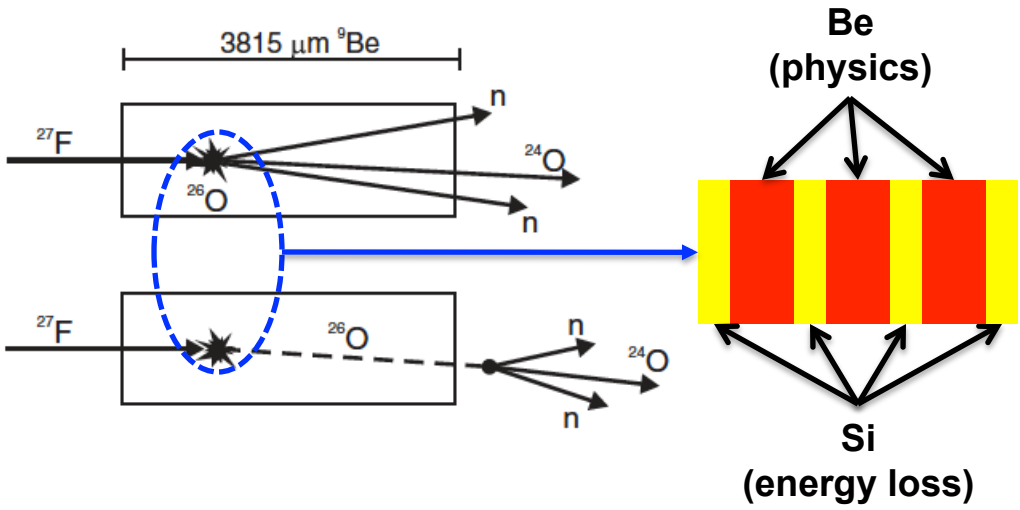
T. Otsuka, PRL, **105**, 032501 (2010)

Neutron Unbound Identification



Kohley et al., PRL, **110**, 152501 (2013)





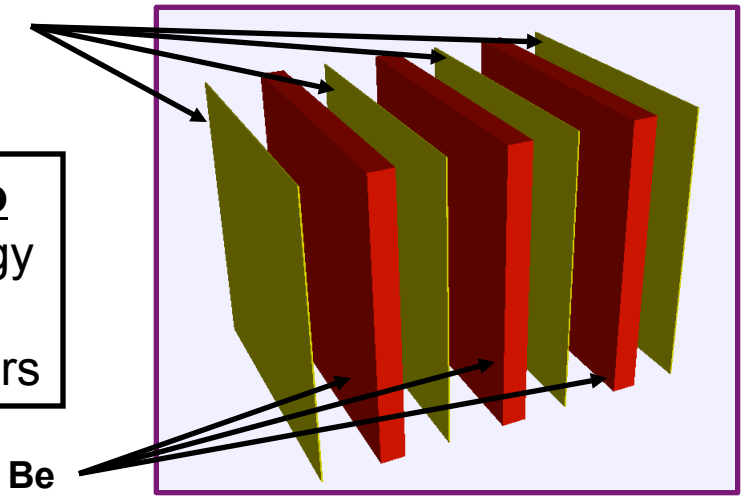
"New" segmented target
- Improve vertex reconstruction
- Better handle on ΔE

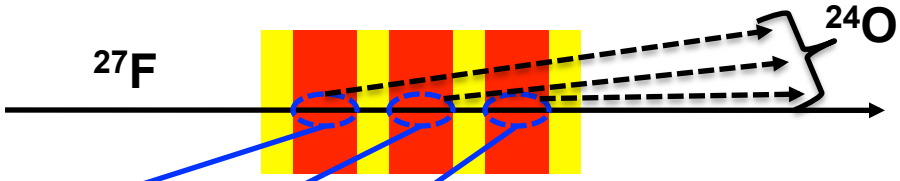
Geant4 Simulation - 1

Single Slab (Beth-Bloch) - Expected				
Ion	Thickness (mm)	Target	E_{inc} (GeV)	ΔE (MeV)
^{27}F	0.14	Si	2.214	18
	2.165	Be	2.214	232
^{24}O	0.14	Si	1.968	14
	2.165	Be	1.968	182

~30% ratio
Within energy resolution of Si detectors

Geant4 model





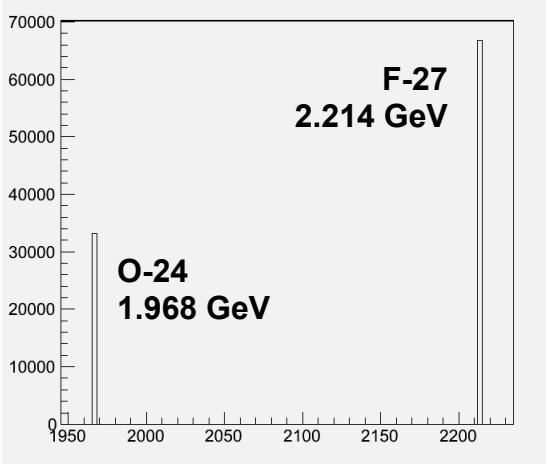
$$^{27}F + ^{9}Be \rightarrow ^{26}\cancel{O} \rightarrow ^{24}O + \cancel{n}$$

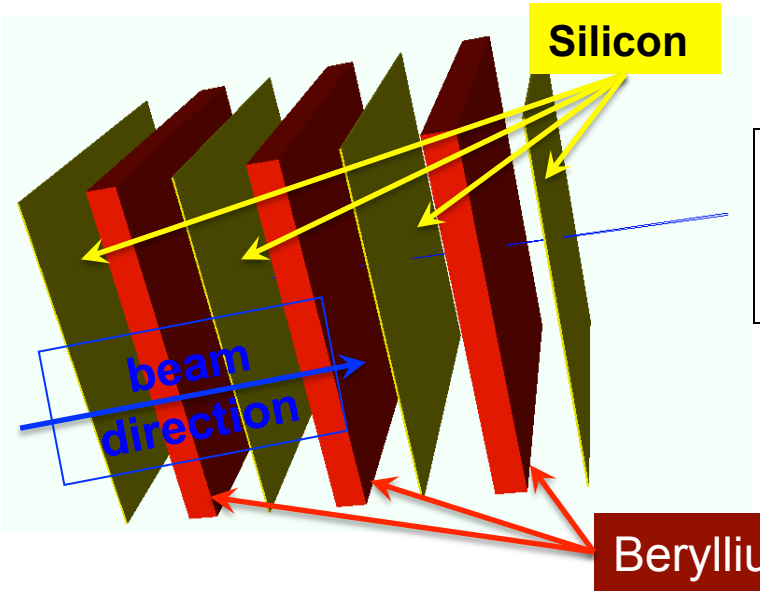
New Unbound Class in Geant4
- Decay of intermediate states
- No tracking of n (current)
- Production of ^{24}O only in Be targets

Current implementation: ^{27}F decay 100% into ^{24}O

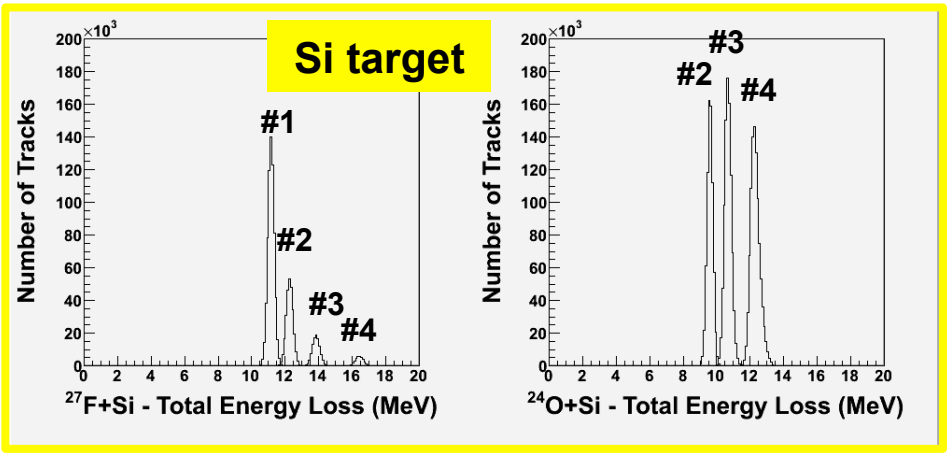
Geant4 Simulation - 2

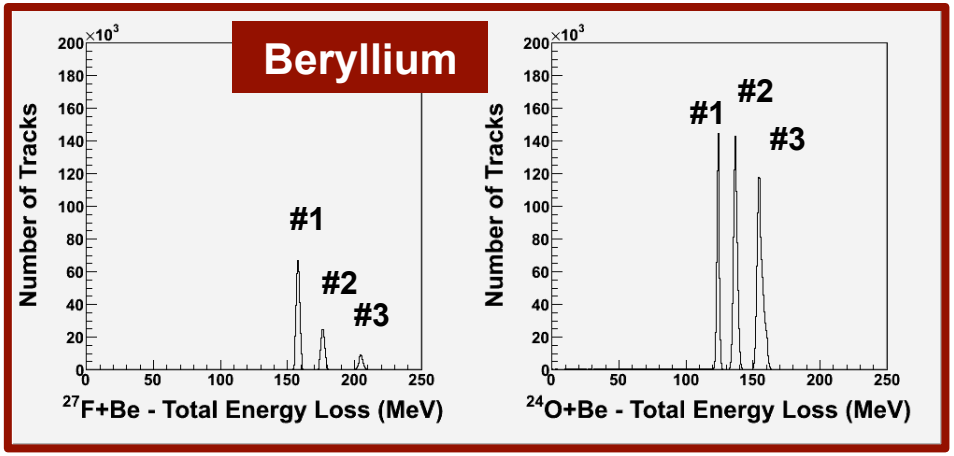
Incident Beam
2.214 GeV F-27





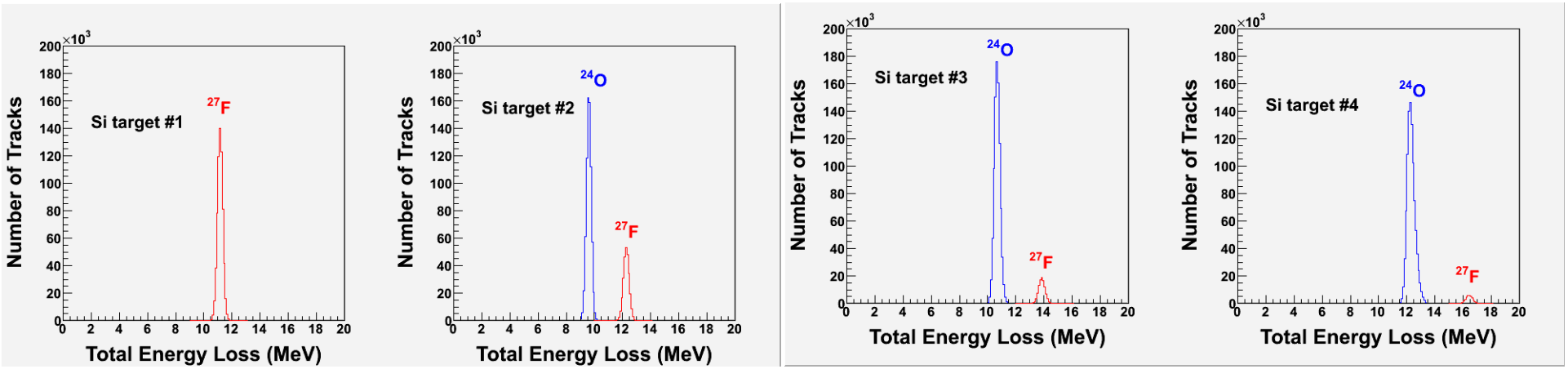
Particle Switch
^{27}F to ^{24}O
along target lengths





Geant4 Simulation - 3

Mean Energy Loss (MeV)				
Ion	**Si #1**	**S1 #2**	**S1 #3**	**Si #4**
^{27}F	11.155 ± 0.001	12.260 ± 0.001	13.842 ± 0.002	16.432 ± 0.004
^{24}O	-	9.596 ± 0.001	10.678 ± 0.001	12.295 ± 0.001
Ratio	-	**1.278**	**1.296**	**1.336**



Si detectors can easily discriminate between ^{27}F & ^{24}O

Collaborators

Augustana College	**: Nathan Frank, Abdul Merhi**
Hampton University	**: Jessica Freeman (PhD student)**
Michigan State University & NSCL	**: Michael Thoennessen**
MONA Collaboration