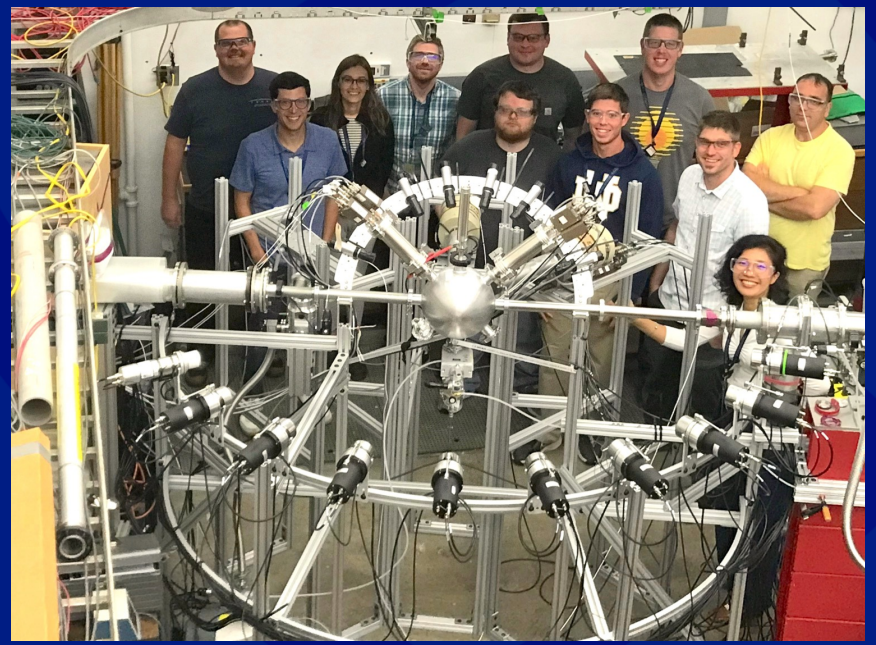
Reaction Cross Sections, Secondary Gamma-Ray Yields, and Measured Neutron Spectra for Alpha-Induced Reactions on Light Nuclei

Hye Young Lee
(Los Alamos National Lab)



Workshop for Applied Nuclear Data Activities (WANDA) 2025
Feb 10 – Feb 13, 2025
Arlington, VA

LA-UR-25-21109

Project objectives:

”A Comprehensive Self-Consistent Campaign to Determine Reaction Cross Sections, Secondary Gamma-Ray Yields, and Measured Neutron Spectra for Alpha-Induced Reactions on Light Nuclei”

1. Experimentally determine alpha-induced cross sections, secondary gamma-ray yields, and neutron spectra using the same setup for all reactions

^{7}Li(α,n), ^{10}B(α,n), ^{11}B(α,n), ^{13}C(α,n), ^{19}F(α,n)

2. Perform an R-matrix assessment and dissemination of results as self-consistent, high-fidelity analysis

3. Perform calculations to evaluate the impact of these new data sets compared using codes such as SOURCES4C, Geant4, and/or MCNP.

Project Team:

Dr. Seth McConchie (PI)

Dr. James DeBoer (Co-PI)
Dr. Ed Stech
Dr. Dan Robertson
Dr. Wanpeng Tan
Dr. Khachatur Manukyan
Dr. Maxwell Sorenson (postdoc)

Dr. Hye Young Lee (Co-PI)
Dr. Sean Kuvin
Dr. Chris Prokop
Dr. Som Paneru (postdoc)
Dr. Ken Hanselman (postdoc)

Dr. Michael Febbraro (Co-PI)
Dr. Juan Manfredi
Dr. Zach Meisel
Mr. Tyler Smith
(TBD Military Student)

Workforce Development

University of Colorado Denver
Prof. Amy Roberts
Prof. Anthony Villano
students

Jackson State University
Prof. Felicite Noubissi
students

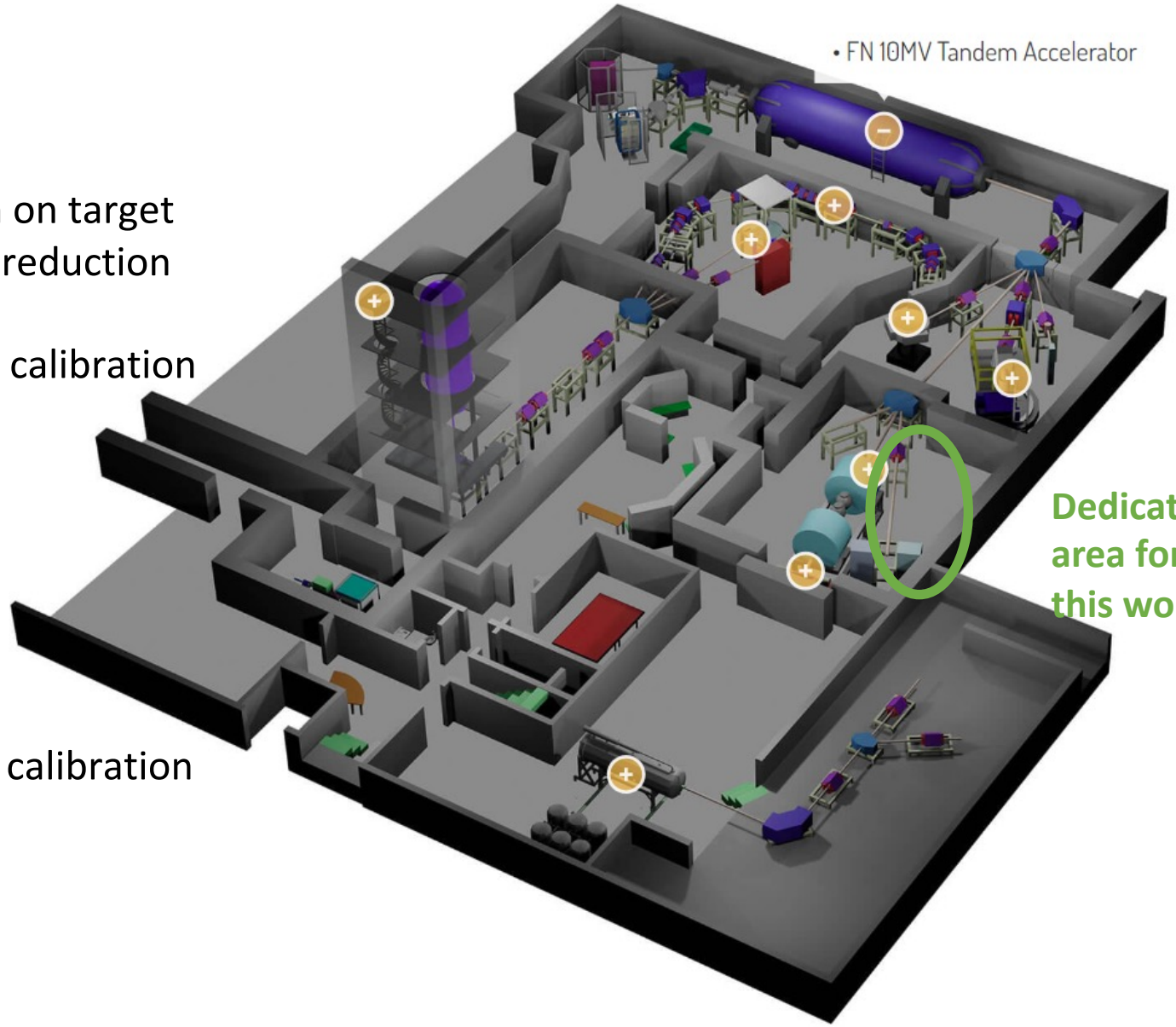
Team is building a dedicated beam line for this campaign at Institute for Structure and Nuclear Astrophysics at U. of Notre Dame

FN

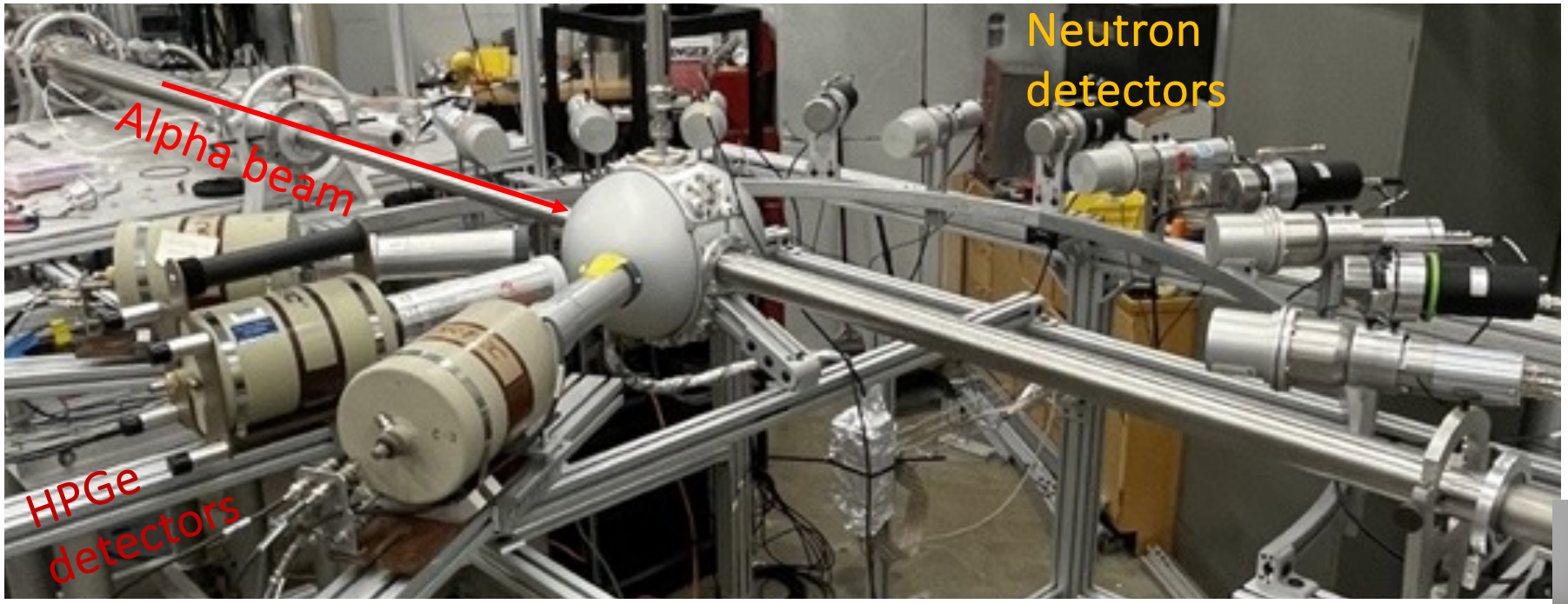
-Tandem type
-1 to 10 MV
-Around 200 nA of proton or alpha particle beam on target
-Bunching available, but comes with factor of 10 reduction in beam intensity
-0.05% energy resolution and about 0.1% energy calibration

5U

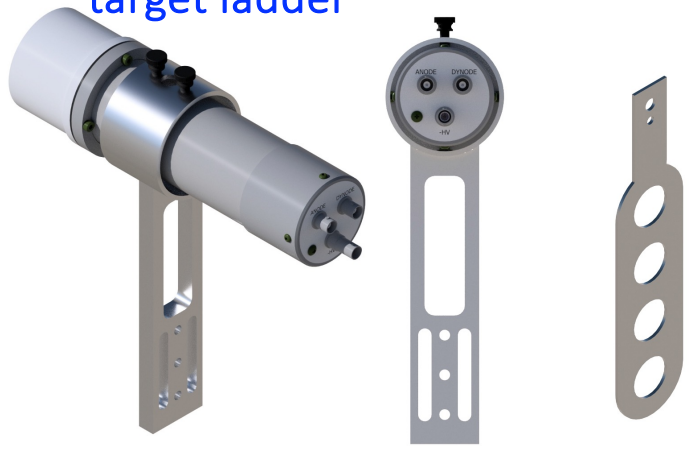
-High current, single ended
-0.3 to 4 MV range
-Around 50 uA of proton or alpha particle beam
-No bunching capability, so no time-of-flight
-0.05% energy resolution and about 0.1% energy calibration



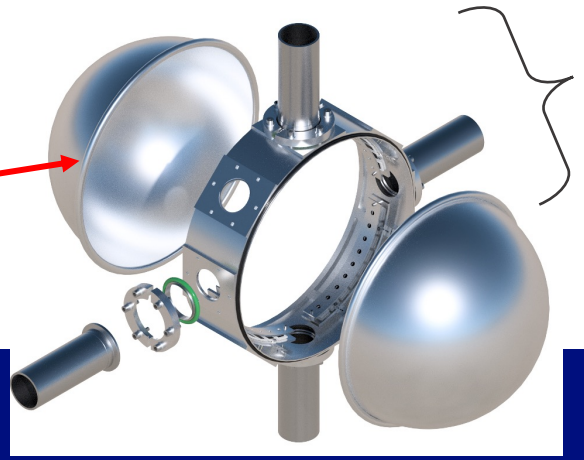
Dedicated beamline for (α,n) project campaign at U of Notre Dame



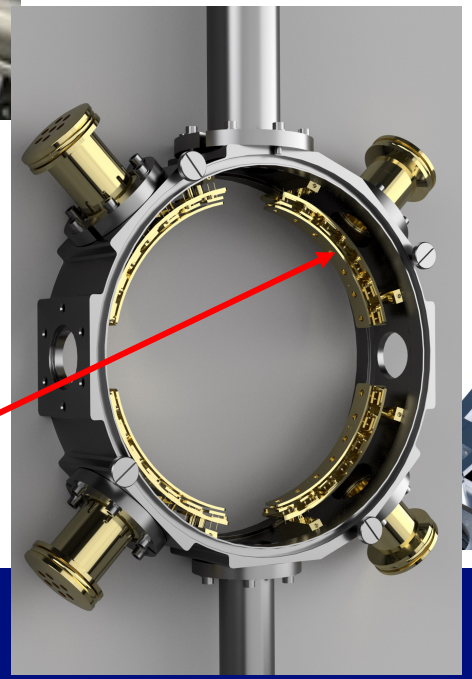
Light mass structure designs for detector holders and the target ladder



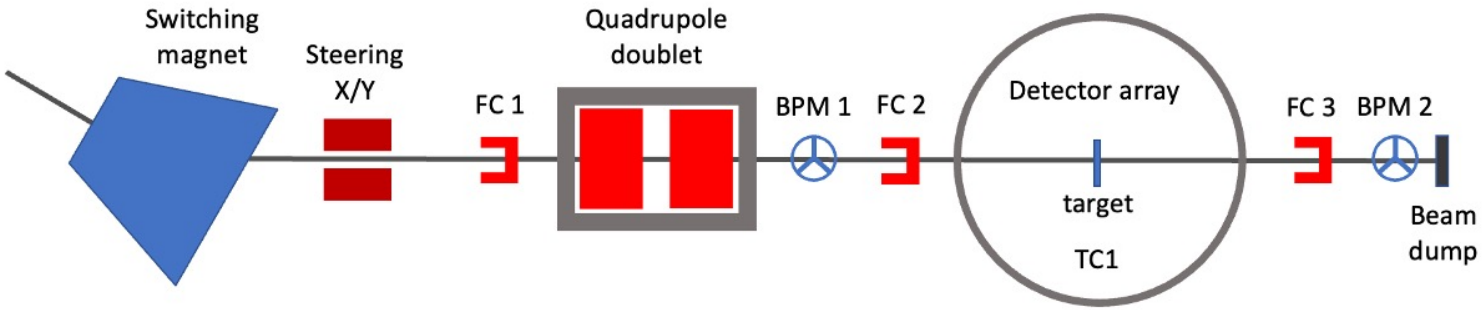
Half-ball Cake pan, aluminum



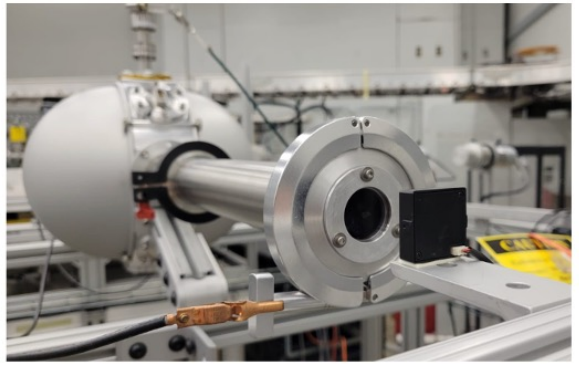
photodiodes to cover 28 angles for detecting charged particles



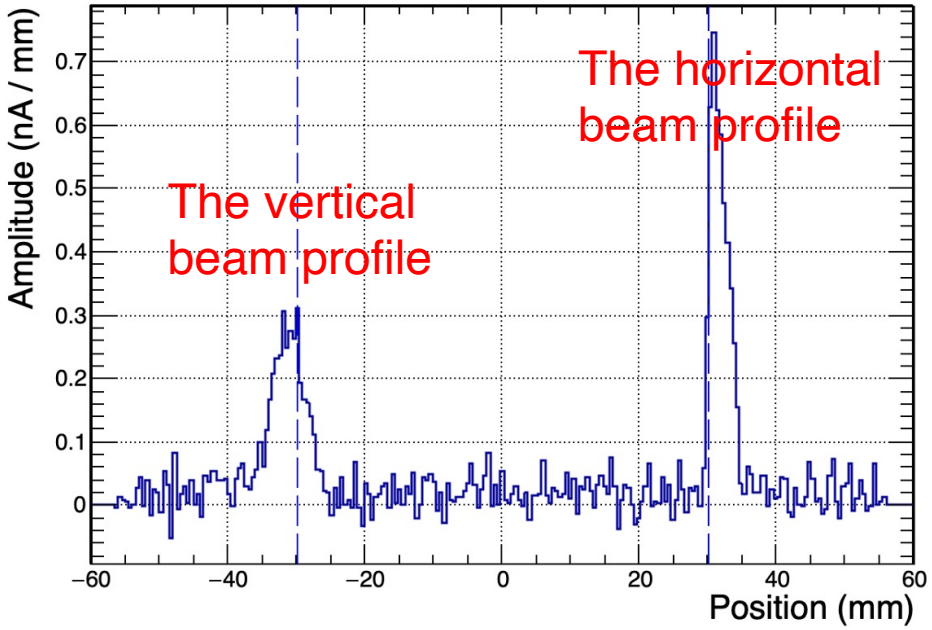
Beam characterization at the newly built beamline:

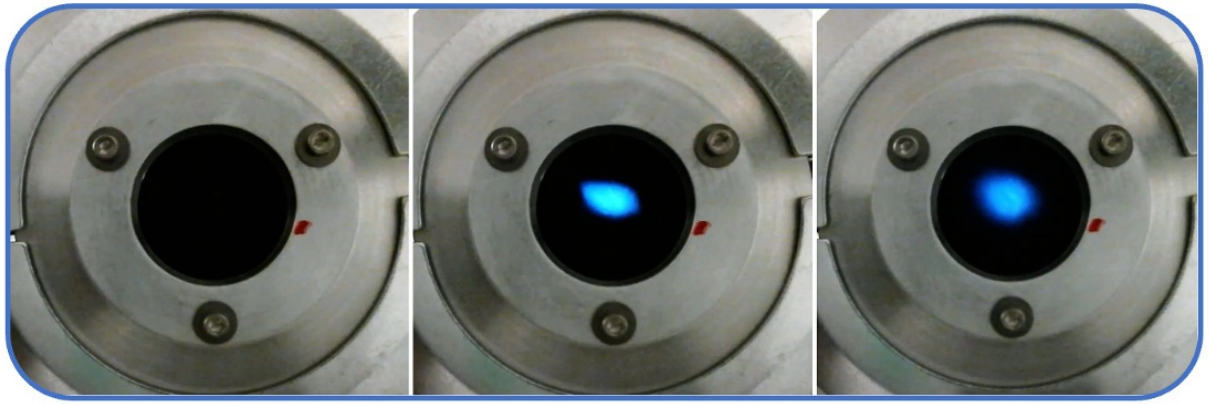


Images of ^{4}He beam on an iridium-coated quartz viewer showing the effect of increased beam emittance from the 107 μg/cm^2 ^{13}C target.



Digitized beam profile measured by BPM

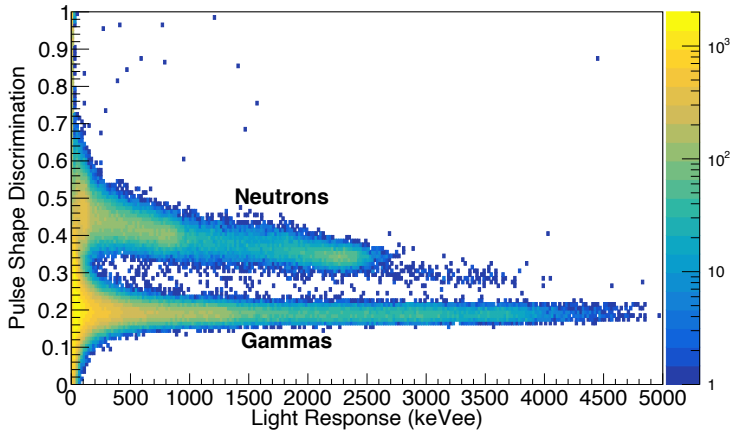




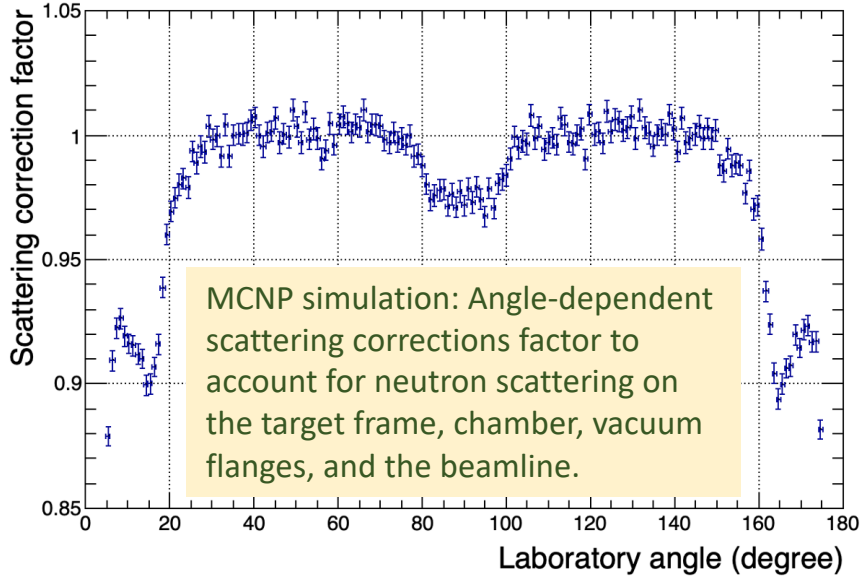
No beam | Beam w/o target | Beam w/ 107 μg/cm^2 ^{13}C target

Detector Characterization

Neutron detector (ODeSA): Pulse Shape Discrimination between neutrons and gammas

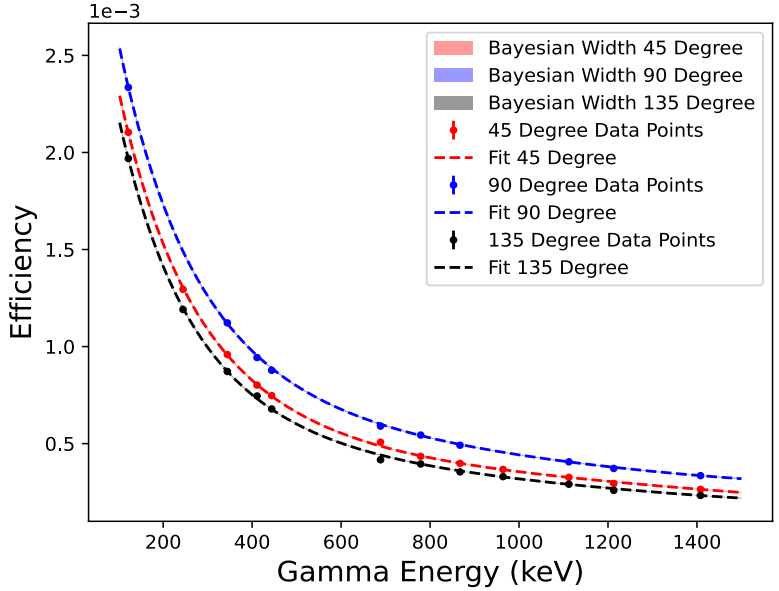


Neutron detector: MCNP simulation

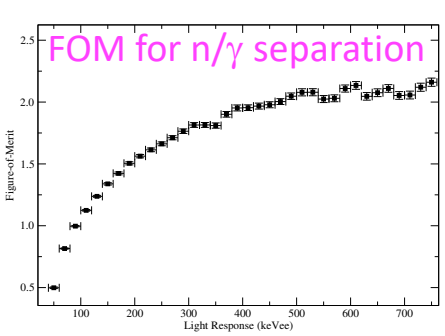


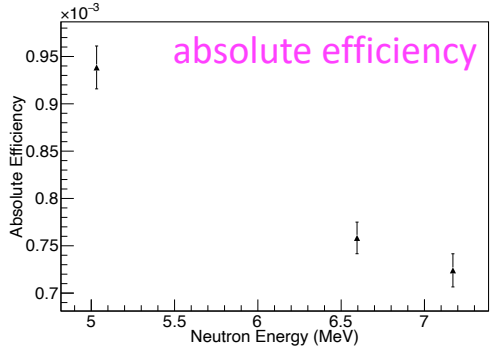
MCNP simulation: Angle-dependent scattering corrections factor to account for neutron scattering on the target frame, chamber, vacuum flanges, and the beamline.

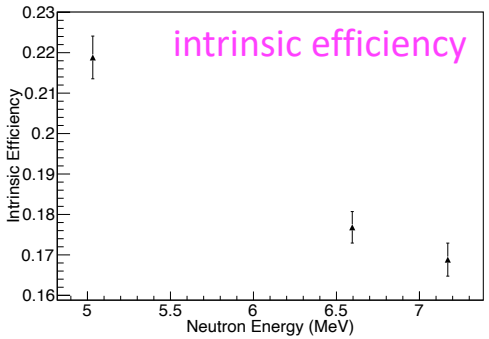
Three HPGe detectors efficiency curves using calibration sources



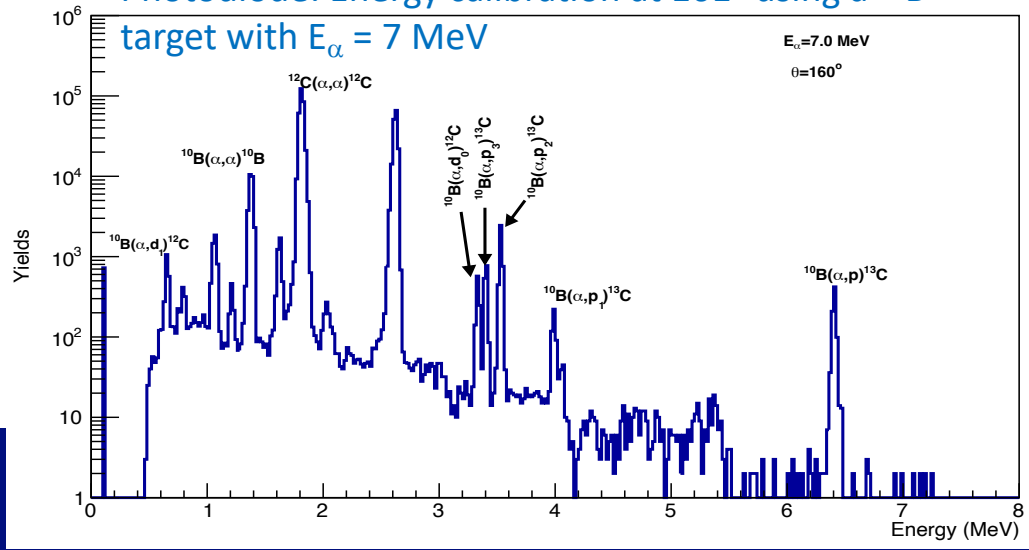
Neutron detector: Figure of Merit to show the neutron/gamma separation, absolute efficiency, and intrinsic efficiency form alpha-beam measurements





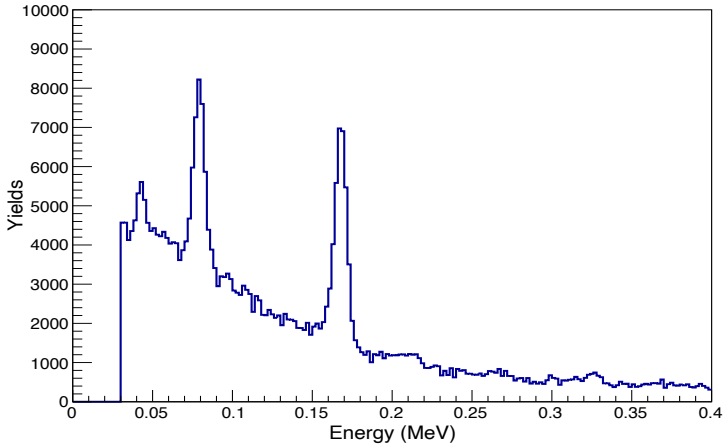


Photodiode: Energy calibration at 161° using a ^{10}B target with E_α = 7 MeV

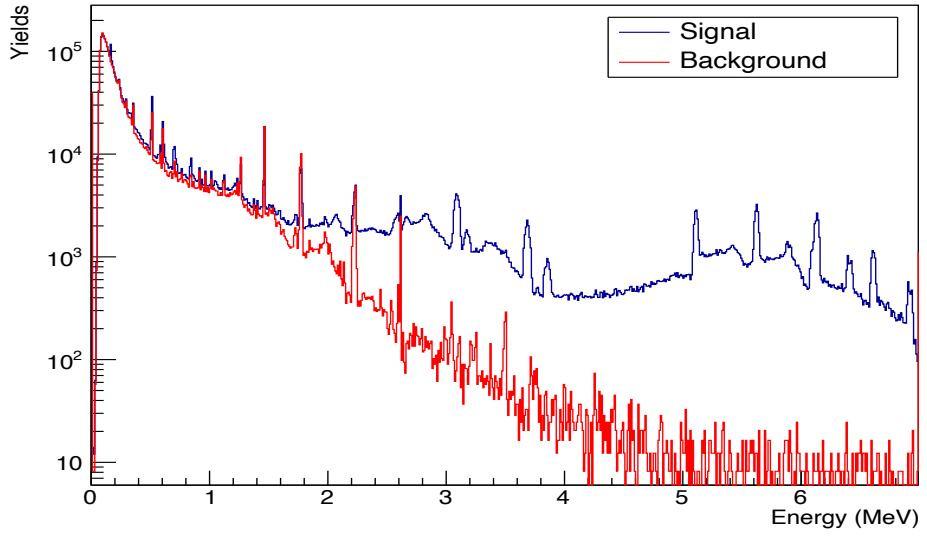


Reaction Studies during campaign readiness experiments

Background subtracted HPGe spectra observed for the $^{19}F(\alpha,n)^{22}Na$ reaction, measured at E_α = 5.5 MeV with a LaF_2 target on a gold backing

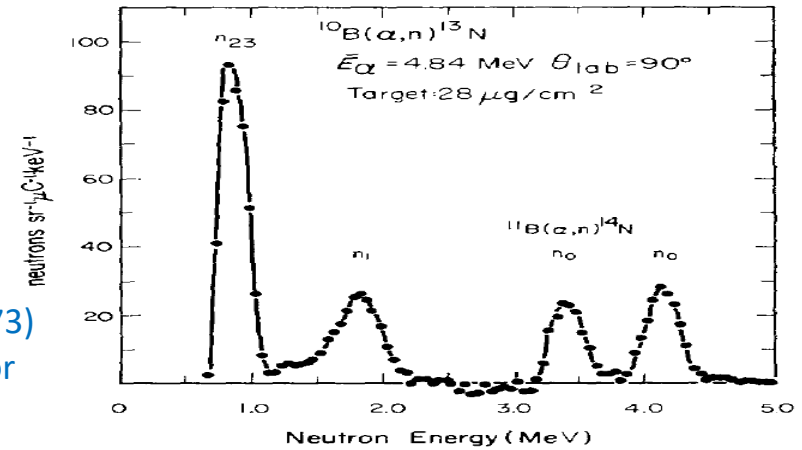


The measured γ-ray spectra from the background and the $^{13}C(\alpha, n)^{16}O$ reaction are shown in the red and blue histograms, respectively. The γ-rays above 5 MeV are produced by the $^{13}C(\alpha, n)^{16}O$ and $^{13}C(\alpha, \alpha'\gamma)^{13}C$.

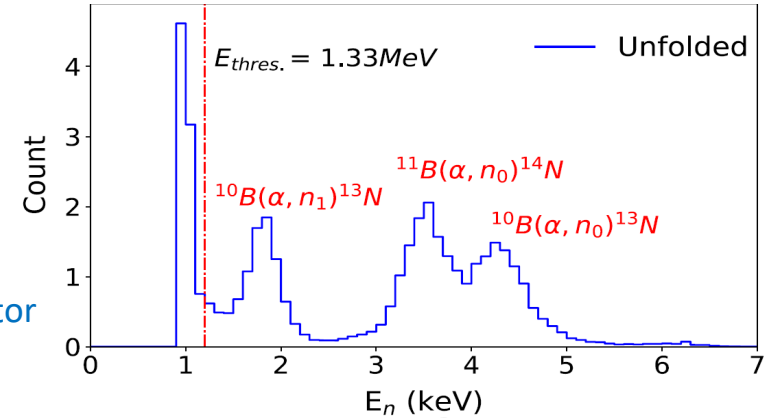


$^{10}B(\alpha, n)^{13}N$ reaction measurements

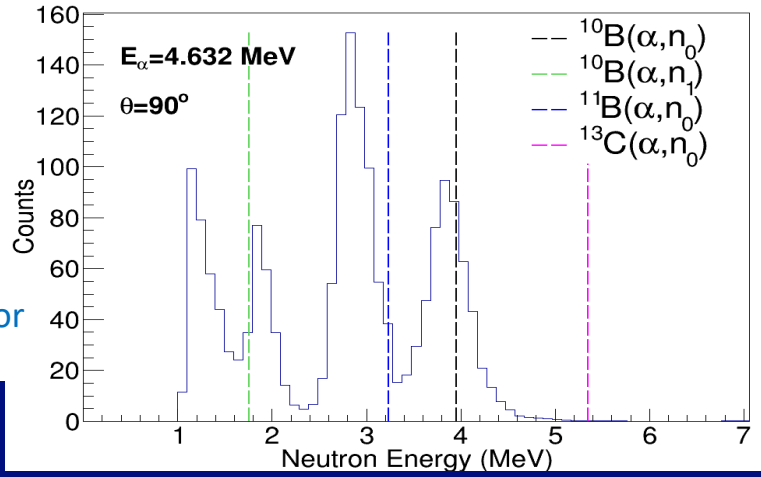
Van Der Zwan et al. (1973) using Stilbene scintillator



Liu et al. (2019) using deuterated liquid scintillator



Our commissioning experiment using deuterated liquid scintillator



Summary of campaign readiness measurements

Targets:

[1] Develop fabrication methods for thin ^{13}C targets and isotopically enriched ^{13}C backing foils

[2] Optimize the best reaction ^{19}F target – explored CaF_2(20μg/cm^2), LaF_3(30 μg/cm^2), and UF_4 (250μg/cm^2)targets with 2 MeV and 5.5 MeV alpha beams. Demonstrated the UF_4 target shows the least background in gamma-ray spectra.

[3] Made a thin ^{10}B target, which was used in the commissioning run

In-beam Reactions:

[1] d(d,n)^{3}He & ^{12}C(d,n)^{13}C for neutron detector efficiency

[2] $^{27}Al(p,\gamma)$ for measuring gamma efficiency up to 10 MeV

[3] $^{10}B(\alpha,n)$ at E_α = 3 – 8 MeV for testing all the detector arrays to prepare for the production run

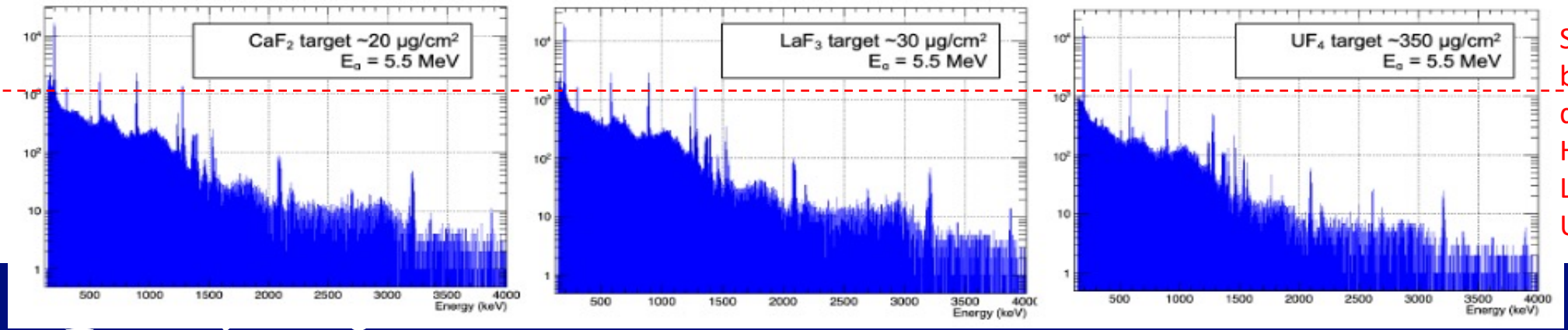
Upcoming Runs in FY25:

[1] Fully characterize detector response functions on ODeSA and Stilbene by utilizing white neutron source at LANSCE in June and mono energetic neutrons at Ohio University in February

[2] Production runs of $^{10}B(\alpha,n)$ and $^{13}C(\alpha,n)$ are schedule in March-April

[3] For absolute cross section data, activation measurements will be performed at U. of Notre Dame in summer 2025

Gamma-ray spectra from $^{19}F(\alpha,\alpha')^{19}F$ and $^{19}F(\alpha,p\gamma)^{22}Ne$ reactions for 5.5 MeV alpha beam on F targets



Same scale of gamma backgrounds considering different amount of F content. However, Likely we will use LaF_3 target due to difficulty of UF_4 availability

Planned experiments on (α,n) reactions at E_α = 2 – 9 MeV using FN and 5U accelerators at U. of Notre Dame

1. Year 1 (FY24): Campaign Readiness measurements ✓
2. Year 2 (FY25): $^{10}B(\alpha,n)^{13}N$ & $^{13}C(\alpha,n)^{16}O$ measurements
3. Year 3 (FY26): $^{11}B(\alpha,n)^{14}N$ measurement
4. Year 4 (FY27): $^{19}F(\alpha,n)^{22}Na$ measurement
5. Year 5 (FY28): $^{7}LI(\alpha,n)^{10}B$ measurement

Correlated data analysis paper

PHYSICAL REVIEW C **110**, 044603 (2024)

Comprehensive study of $d + {}^6Li$ via observing simultaneous outgoing neutrons, γ rays, and charged particles

S. N. Paneru,* H. Y. Lee,† C. Prokop, S. A. Kuvin, C. Fichtl, P. Gastis, G. M. Hale, E. Leal-Cidoncha, M. Mosby, and M. Paris
Los Alamos National Laboratory, Los Alamos, New Mexico 87545, USA

M. Febbraro
Air Force Institute of Technology, Wright-Patterson AFB, Ohio 45433, USA and Oak Ridge National Laboratory, Oak Ridge, Tennessee 37830, USA

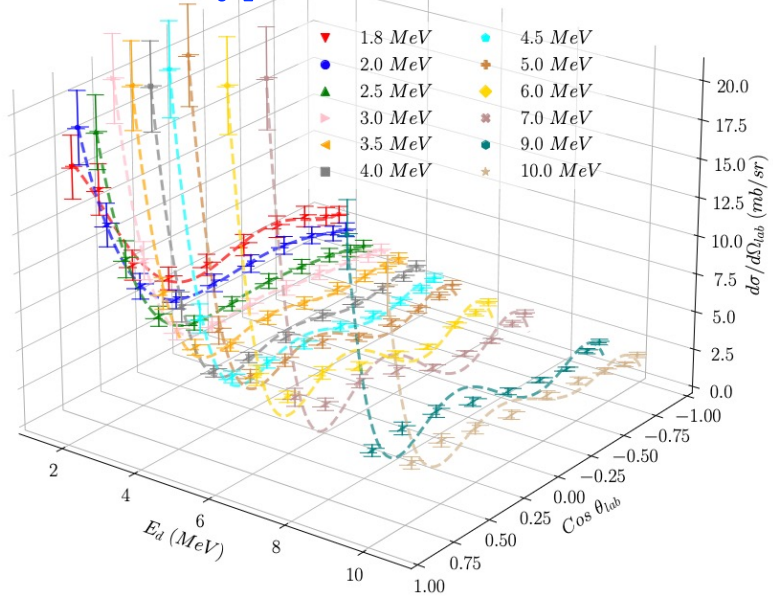
T. T. King, J. Nattress, and T. J. Ruland
Oak Ridge National Laboratory, Oak Ridge, Tennessee 37830, USA

R. J. deBoer, E. Stech, T. Bailey, C. Boomershine, S. Carmichael, A. Clark, R. Fang, J. Görres, R. Kelmar, K. Lee, K. Manukyan, M. Matney, J. McDonaugh, A. Miller, A. Nelson, P. O'Malley, D. Robertson, Shahina, W. Tan, W. W. von Seeger, and M. Wiescher
University of Notre Dame, Notre Dame, Indiana 46556, USA

Expected comprehensive self-consistent data

1. Cross sections of total, partial channels ✓
2. Angular distributions on neutrons, gammas, and charged particles ✓
3. Secondary gamma-ray yields, neutron spectra ✓
4. Multi-channel R-matrix analyses with all measured channels for ENDF evaluators ✓
5. Impact assessment using Source4C, MCNP, and Geant4

Measured neutron angular distributions for $^6Li(d,n_{0+1})^7Be$



R-matrix analysis paper is under review in PRC

***R*-matrix analysis of ^{8}Be system**

S. N. Paneru,[1,*] H. Y. Lee,[1,†] R. J. deBoer,[2] M. W. Paris,[1] G. M. Hale,[1] M. Febbraro,[3] E. A. Bennett,[1] C. Fichtl,[1] N. A. Gibson,[1] J. Görres,[2] C. Hamilton,[1] S. A. Kuvin,[1] K. Manukyan,[2] M. Mosby,[1] C. Prokop,[1] D. Robertson,[2] H. Sasaki,[1] E. Stech,[2] W. P. Tan,[2] and M. Wiescher[2]
[1]*Los Alamos National Laboratory, Los Alamos, NM 87545, USA*
[2]*University of Notre Dame, Notre Dame, IN 46556, USA*
[3]*Air Force Institute of Technology, Wright-Patterson AFB, OH 45433, USA*

Impact calculations to evaluate our new data and ideas beyond the current scope

• We will evaluate potential new data sets in the Defense Nuclear Nonproliferation mission space

SOURCES 4C: A Code for Calculating (α,n), Spontaneous Fission, and Delayed Neutron Sources and Spectra

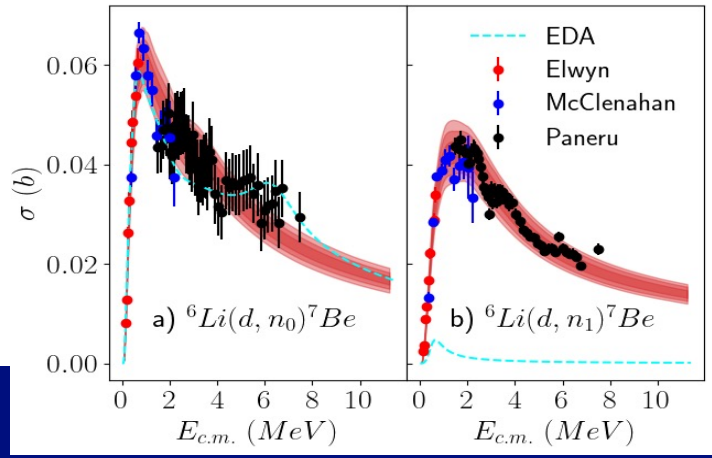
• Gamma-ray anisotropy data will be tested to improve the evaluation

MCNP MONTE CARLO N-PARTICLE

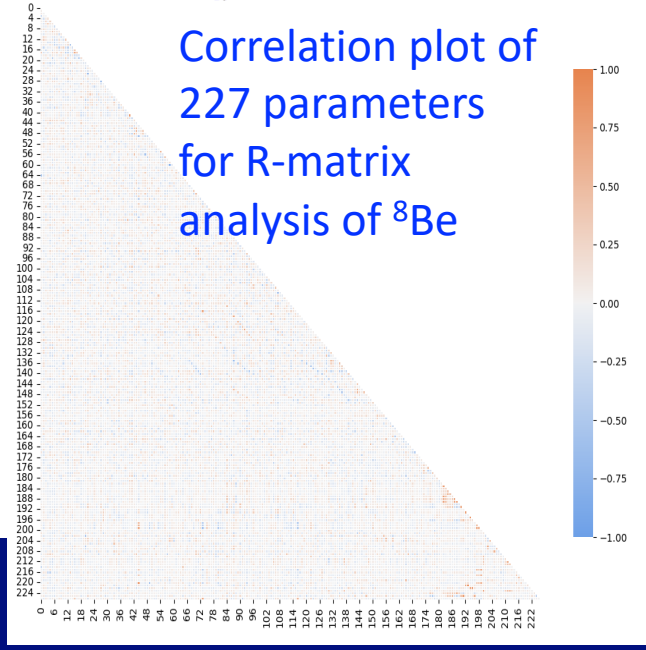
• Analysis tools that developed in this project can provide advanced uncertainty quantifications (refer to "R-matrix analysis of ^{8}Be system" under review in Phys. Rev. C)

GEANT4 A SIMULATION TOOLKIT

• Our first data files based on our measurements (neutron yields and γ yields) will be used for immediate testing of any available benchmarks



used Bayesian analysis (BRICK code) to quantify the uncertainties in the *R*-matrix parameters and the calculated cross sections



Correlation plot of 227 parameters for R-matrix analysis of ^{8}Be