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Gamma-ray Production Cross Sections for Active Neutron Interrogation with GENESIS

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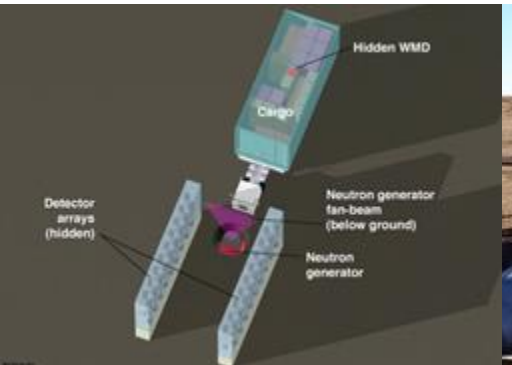
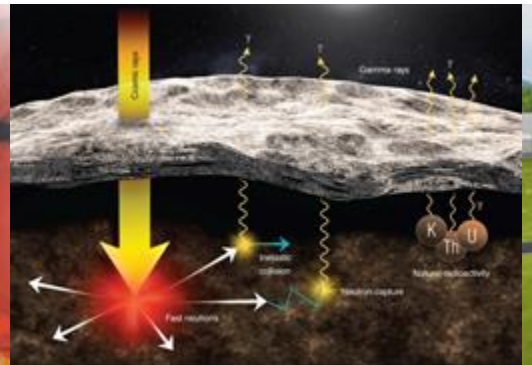
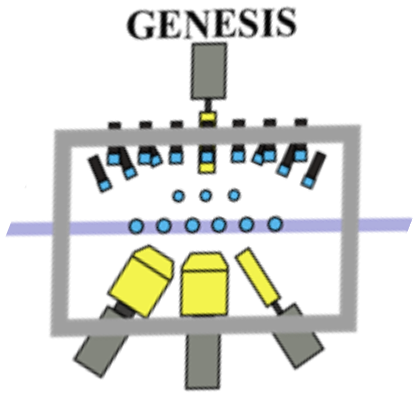






Nuclear Data Needs for Active Neutron Interrogation



Goal: Provide partial γ-ray cross sections for high priority nuclides for neutron active interrogation applications

Priority	Elements
First	C, N, O, Na, Al, Si, Fe, Cu Pb, W, U, Pu
Follow-up	He, Li, Be, B, Cl, Cr, Mn, Ni, Ge, Br, Cd, I, Cs, La
Remaining	F, Mg, P, S, Ar, K, Ca, Ti, As, Kr, Mo, Sn, Sb, Xe, Gd, Bi, Np, Am, Tm

S. McConchie, et al., Technical Report No. ORNL/TM-2021/1900, 2021.

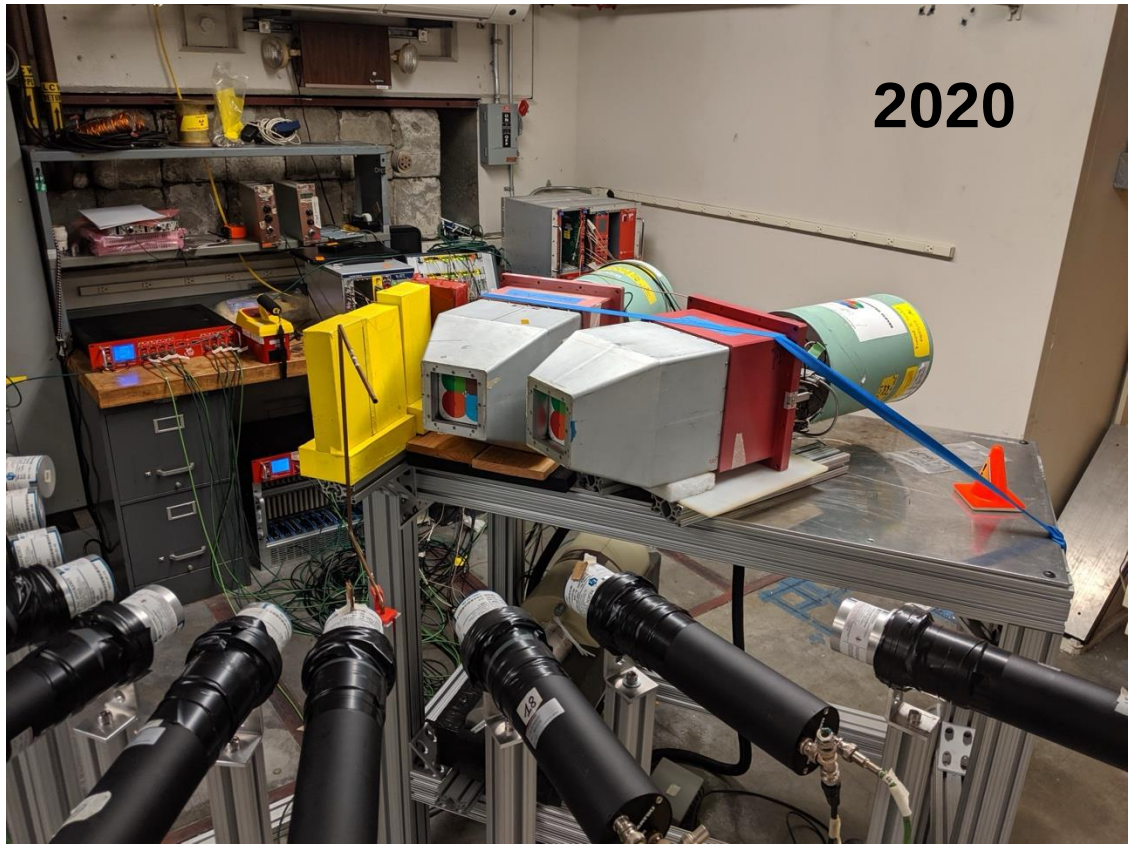
GENESIS Activities

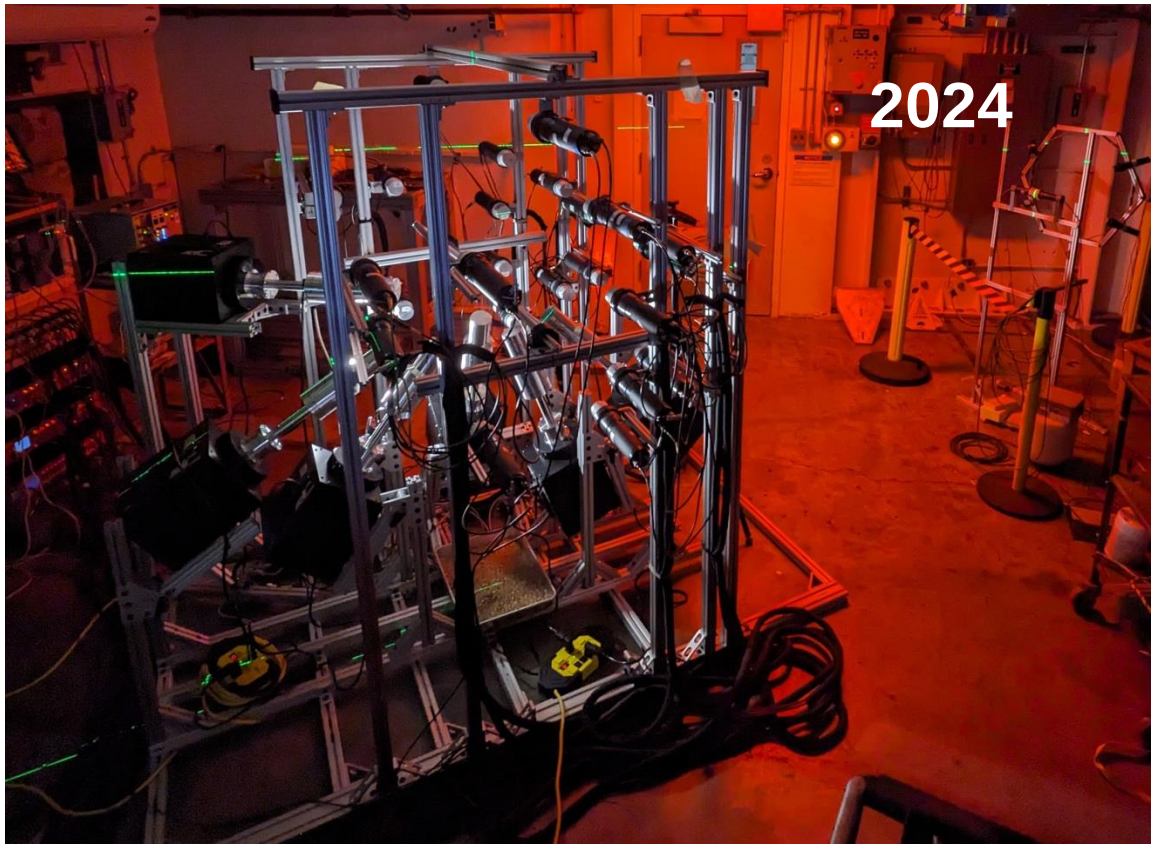
- Published/Submitted for publication
- Datasets that have been produced and are under investigation
- Focus of this project
- Future work

Collaboration/Strategic Partnerships

- Stockpile Stewardship Academic Alliance (Bernstein)
- DT-API measurement program w/ NASA/JHUAPL Goddard team (Peplowski, Ayllon)
- NA-113 at LLNL (Bleuel, Vogt)
- NA-113 at LANL (Kelly, Kawano)
- DOE-SC/NP at BNL (Brown)

The GENESIS Array



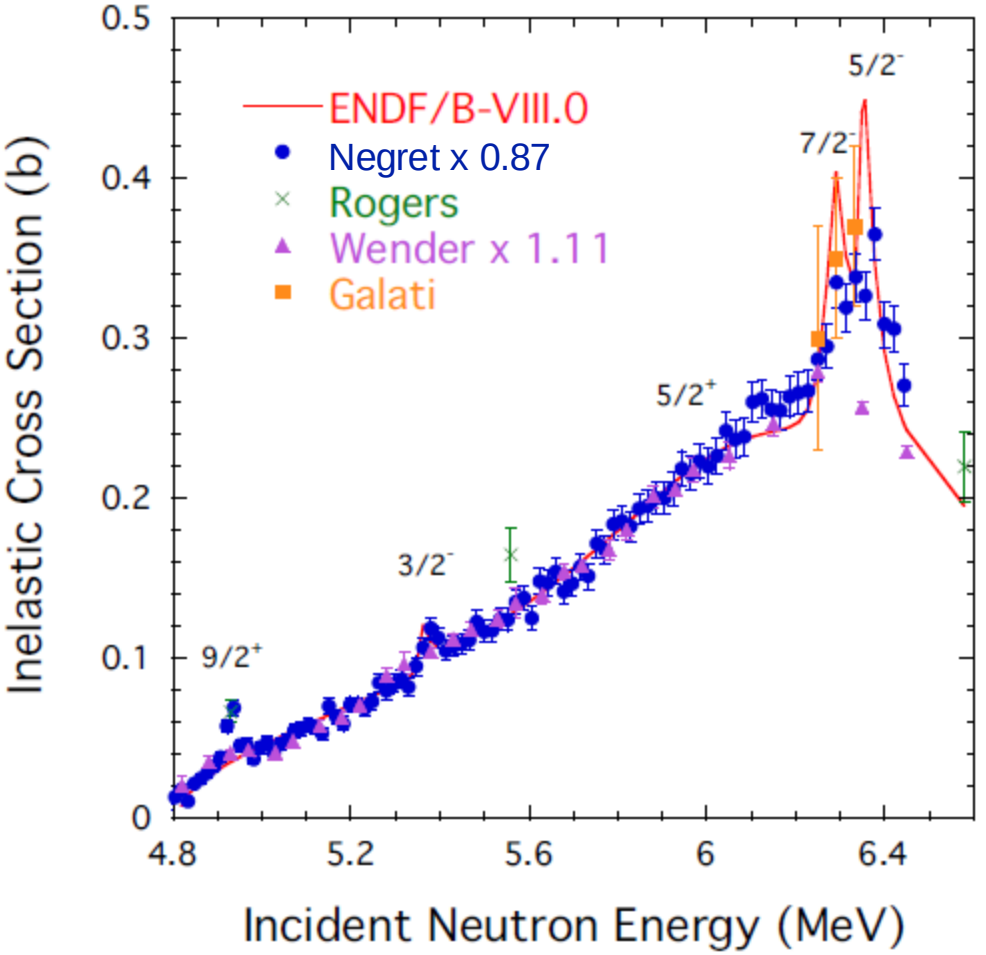


Array commissioned under prior DOE-NE project (PI: Bernstein)

Expanded to include 7 dedicated mechanically-cooled HPGe detectors

$^{12}C(n,n'\gamma)$ has been extensively measured but uncertainties persist

- ENDF/B-VIII.0 evaluation relied on two data sets
  - Wender et al.[1] – re-scaled
  - Negret et al.[2] – re-scaled and shifted in energy
- More recent measurements shed further light:
  - Ramirez et al.[3] – normalized to other cross sections
  - Kelly et al.[4] – scaled cross section shape to ENDF/B-VIII.0[5]

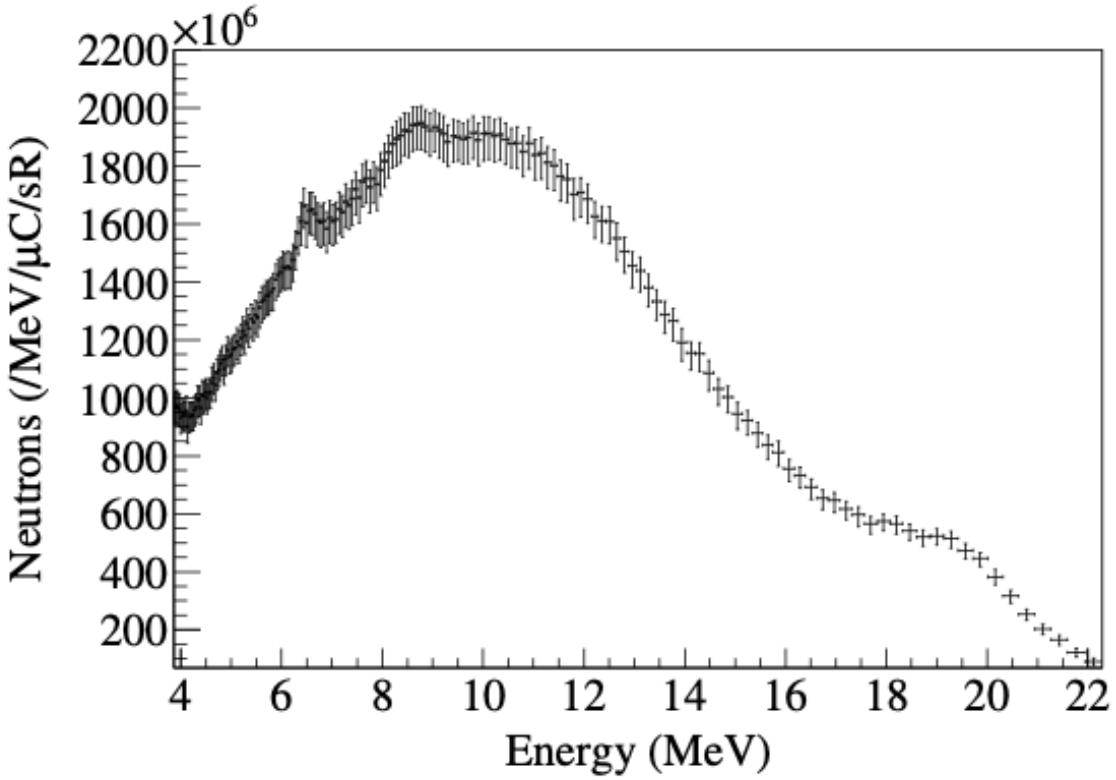


D.A. Brown et al. NDS **148** (2018).

[1]S.A. Wender *et al.* J. Phys. G. **14** (1988); [2]A. Negret *et al.*, NDS **199** (2014); [3] A.P.D. Ramirez *et al.,* Nucl. Phys. A **1023** (2022); [4]K. Kelly *et al.* PRC **108** (2023); [5]D.A. Brown *et al.,* NDS **148** (2018).

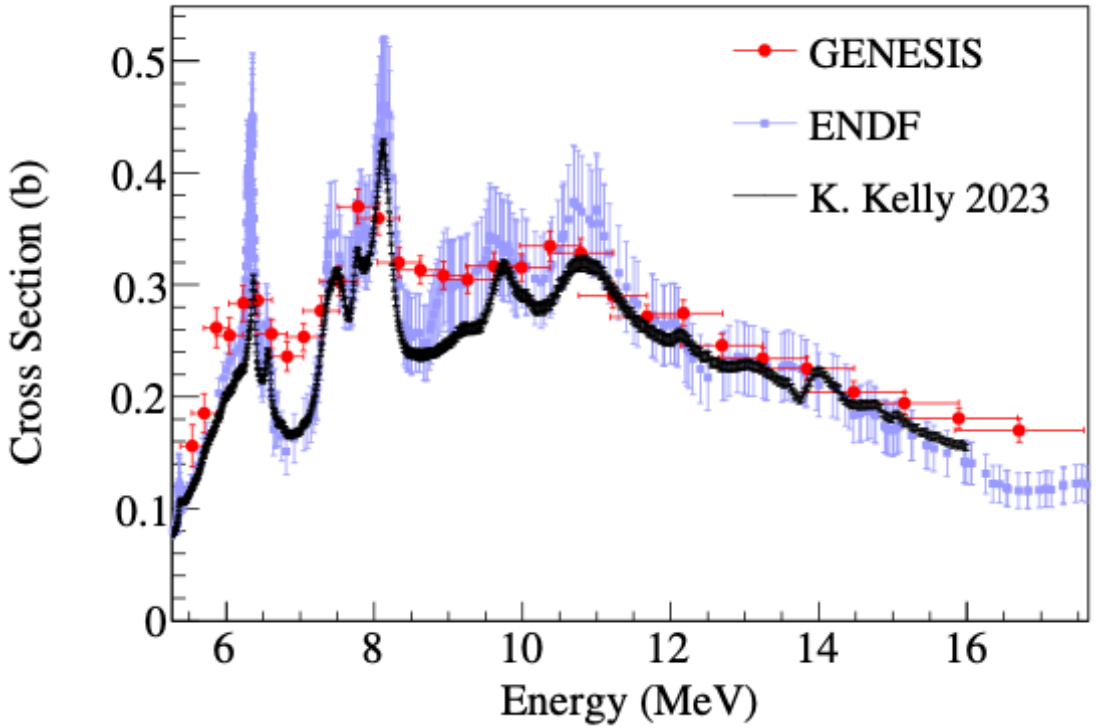
$^{12}C(n,n_1'\gamma)$ Experimental Details

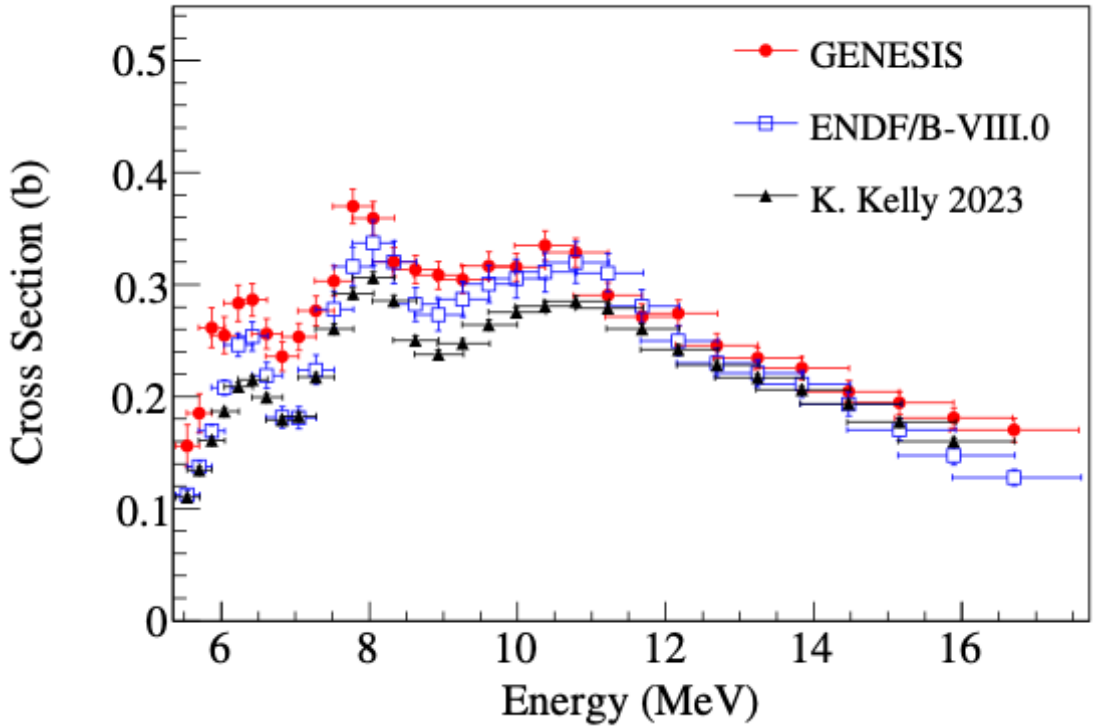
- 25 MeV $^{2}H^{+}$ beam – RF Period = 127.236 ns
- 99.98% pure, 1-mm-thick graphite target, 6.564 g
- 10 Day experiment – 100 hours on target, 10 hours of “blank”
- Neutron flux measured using sTOF spectrometer
- Two activation foil packs fielded at array center and sTOF location
  - Au, Al, Ni, Zr, In



Neutron flux on the ^{12}C target at the center of the GENESIS array

Measured $^{12}C(n,n_1'\gamma)$ Cross Section



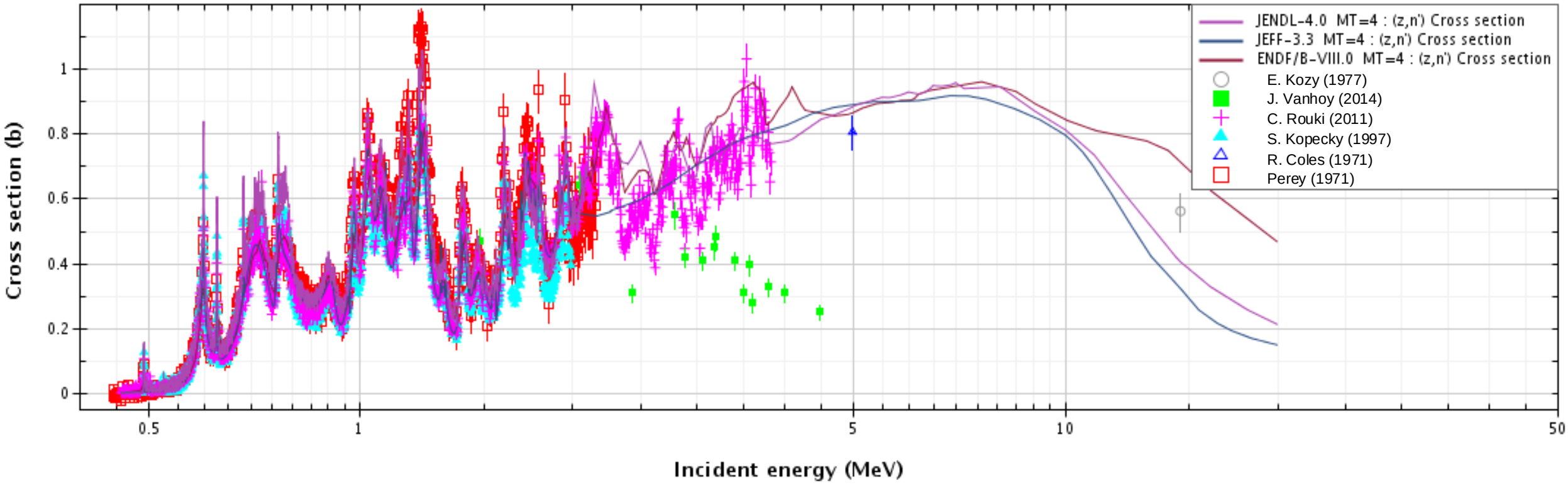


Agreement with ENDF/B-VIII.0 from 8.5-16 MeV but diverges at lower energies demonstrating a cross section more consistent with Negret et al. 2014

J. Gordon, et al., "$^{12}C(n,n_1'\gamma)$ partial γ-ray cross section measured using the GENESIS array," Phys. Rev. C (submitted for publication).

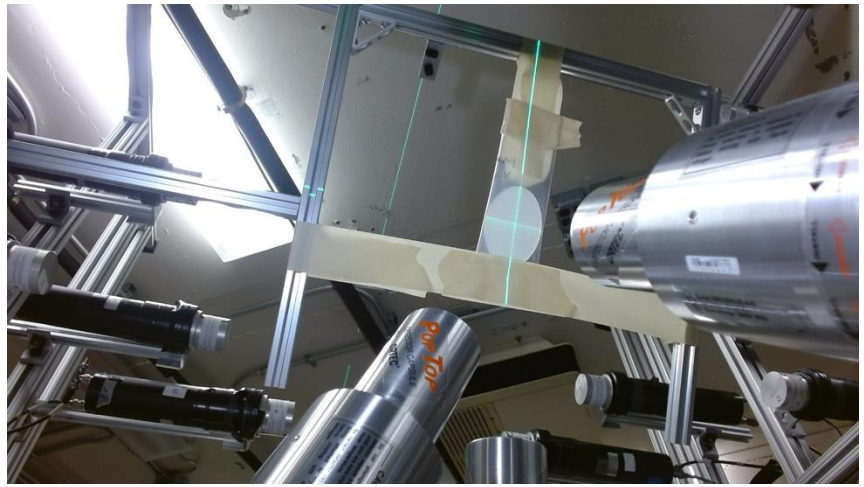
^{23}Na(n,n'): Latest Evaluation and EXFOR data

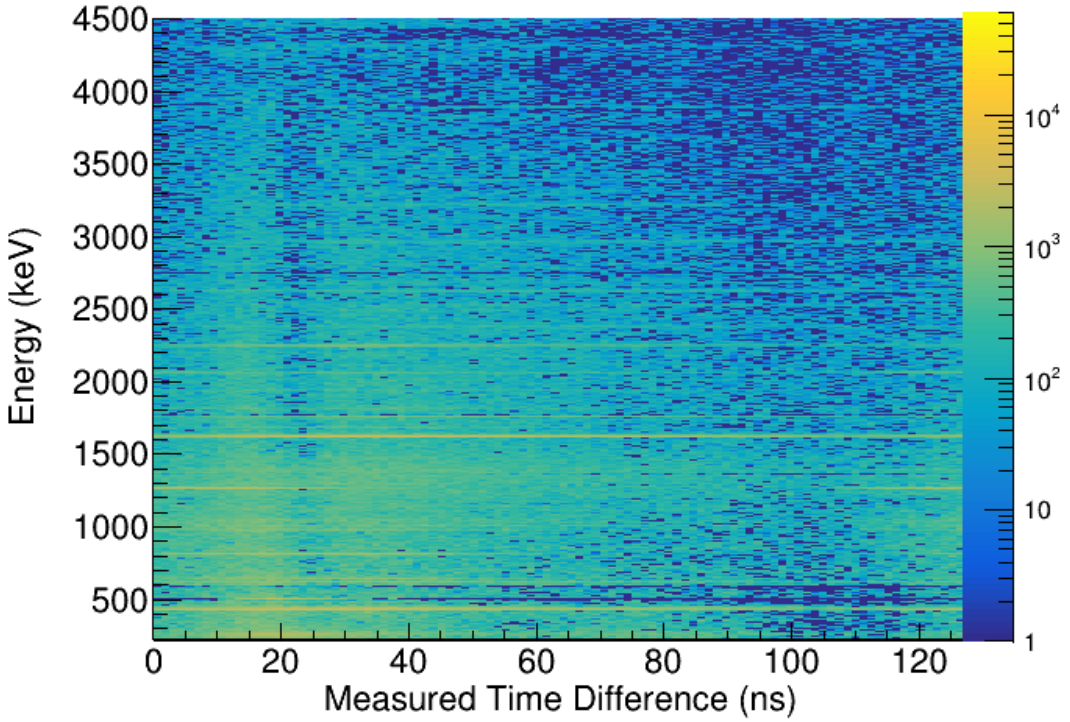
- Lack of data above 4 MeV
- Large discrepancies (>x2) between ENDF/B-VIII.0 and other libraries at 14.1 MeV
- No ENDF update since at least 2001



GENESIS Experiment on ^{23}Na metallic target

- 25 MeV $^{2}H^{+}$, ~8 uA
- Integration of 6 new HPGes (45-160°)
- 26 organic liquid scintillators in groups of 4 (20°, 40°, 66°, 90°, 110°, and 145°)
- 115 h on ^{23}Na, 75 h on epoxy blank





Prominent 440 keV and 1636 transitions with many γ-rays showing significant Doppler broadening

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Lee Bernstein
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Tech Lead, UC Berkeley

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Res. Engr, UC Berkeley

Joseph Gordon
Postdoc, UC Berkeley

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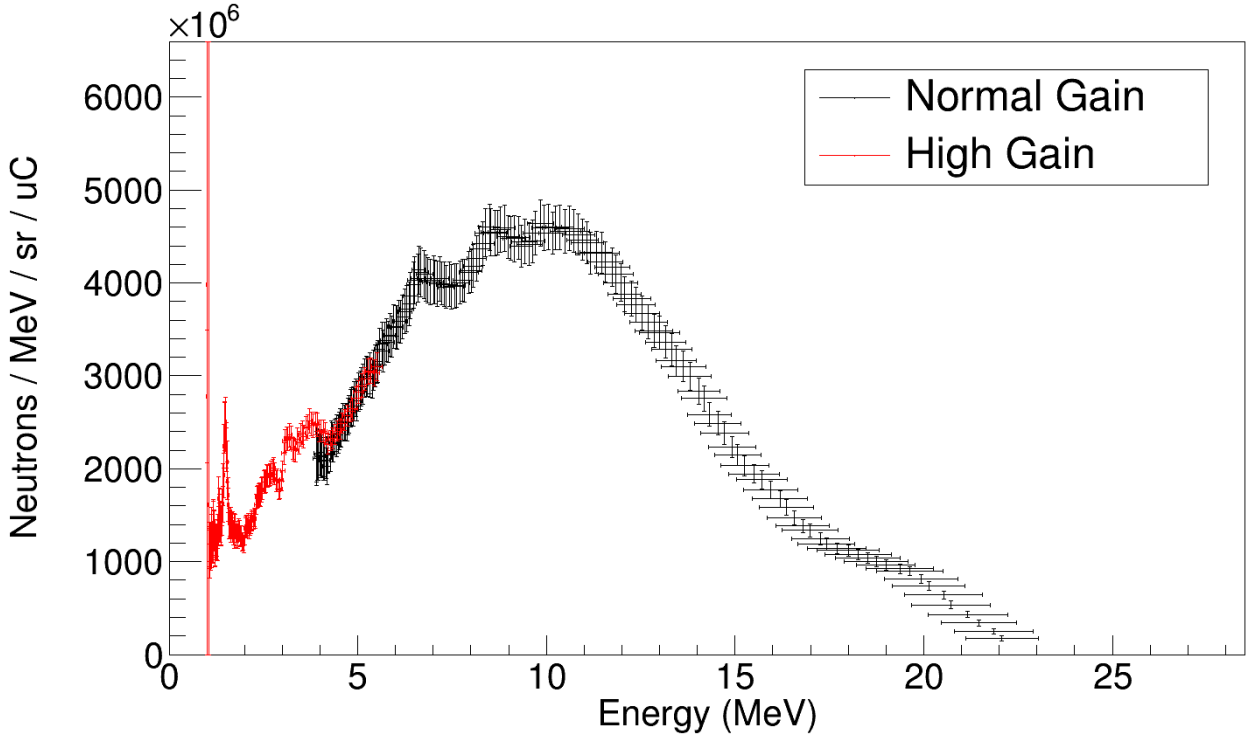
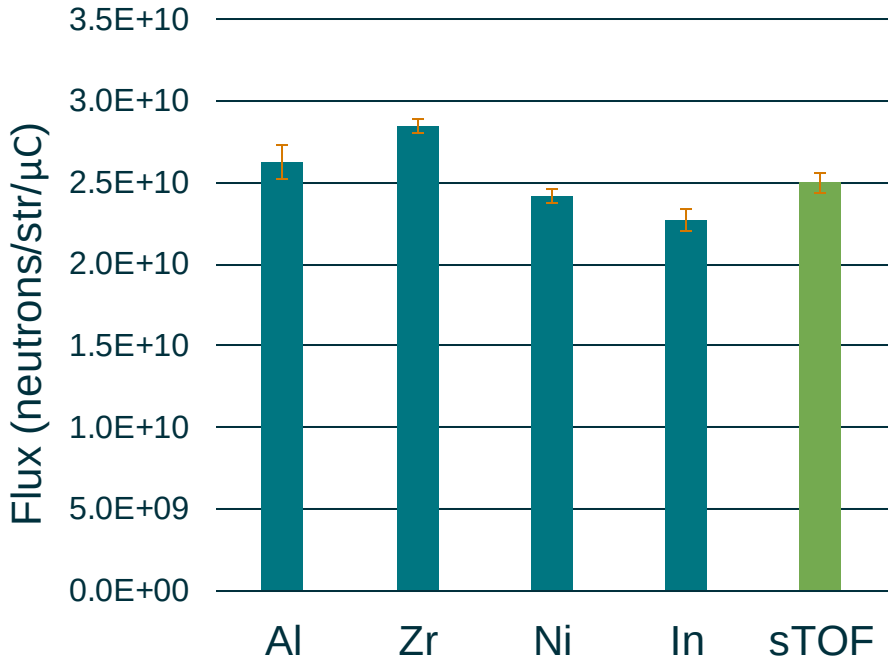
Backup Slides

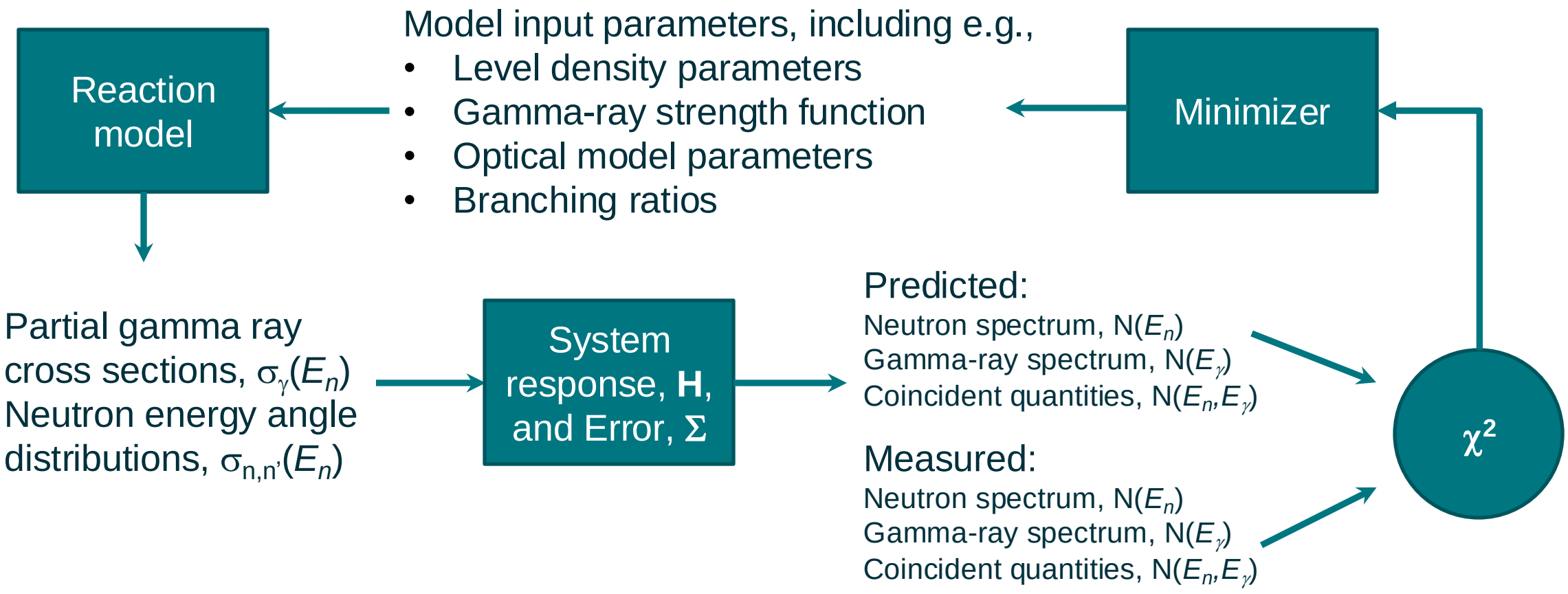
Neutron flux for 25 MeV deuterons incident on a carbon breakup target as measured in Na experiment





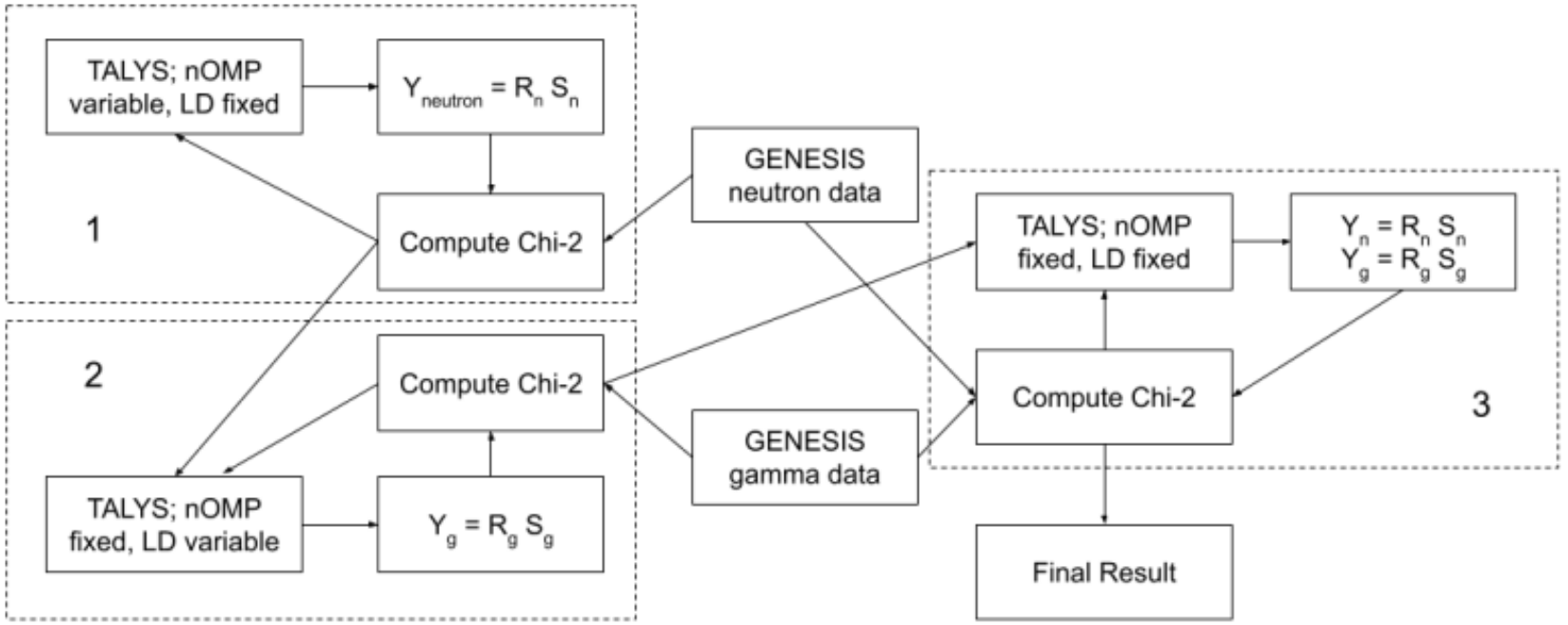
Good agreement between integrated neutron flux obtained from sTOF spectrometer and activation foil analysis

Working with GENESIS Observables



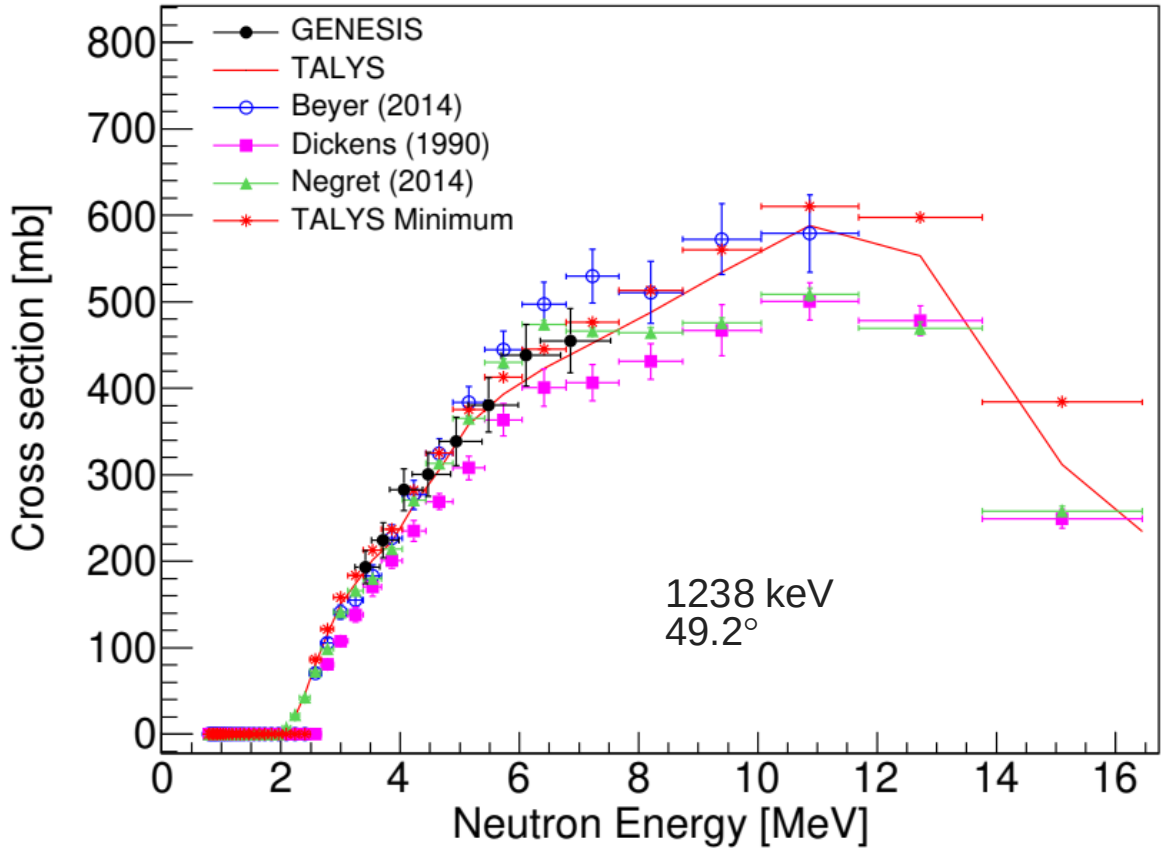
Forward modeling approach

Successfully implemented on ^{56}Fe but requires generalization of codebase



J.M. Gordon, Ph.D. thesis

Forward modeling approach – successful implementation on ^{56}Fe for γ-ray yield



J.M. Gordon, Ph.D. thesis