Cf-252 spontaneous fission prompt neutron and photon correlations

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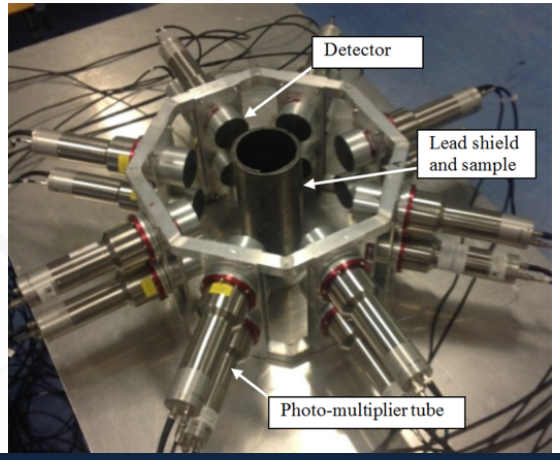
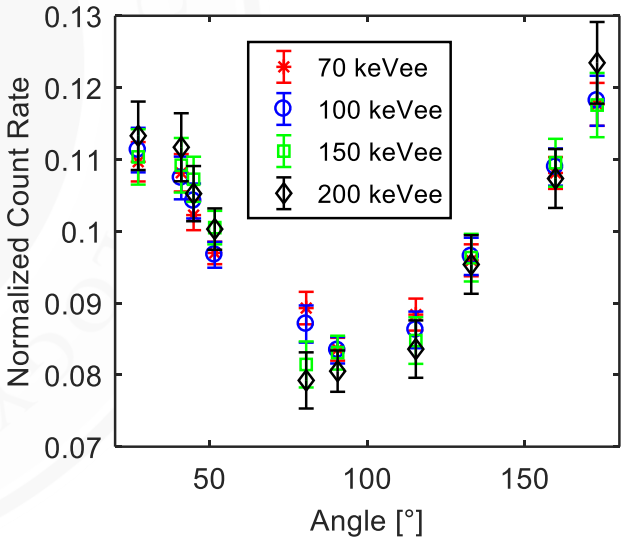
Motivation

Improved fission models enables novel system design

- Key neutron and photon correlations to measure:
  - Multiplicity
  - Energy spectra
  - Relative angle of emission
- Improved models of nuclear fission would benefit nuclear nonproliferation and safeguards applications.
- Specifically, the correlated neutron and gamma ray emission data for important isotopes such as U-235 and Pu-239 are not well known.
- There is a need for experimental data to compare to fission models under development.



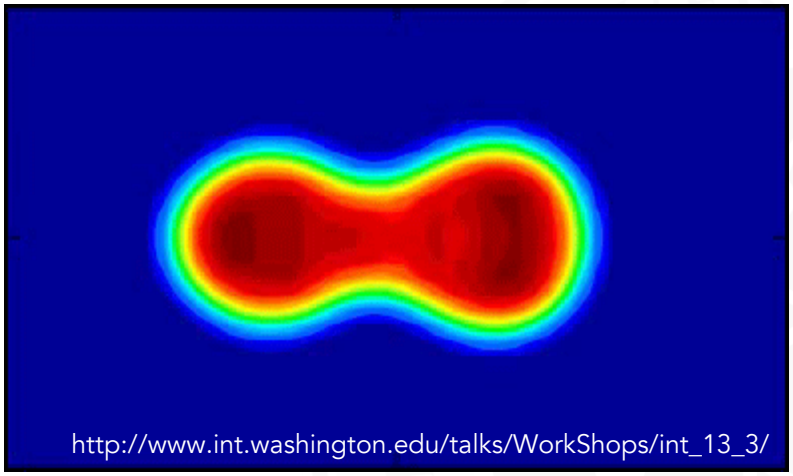
Experiment to measure Pu-240 SF neutron correlations with an organic scintillator array.

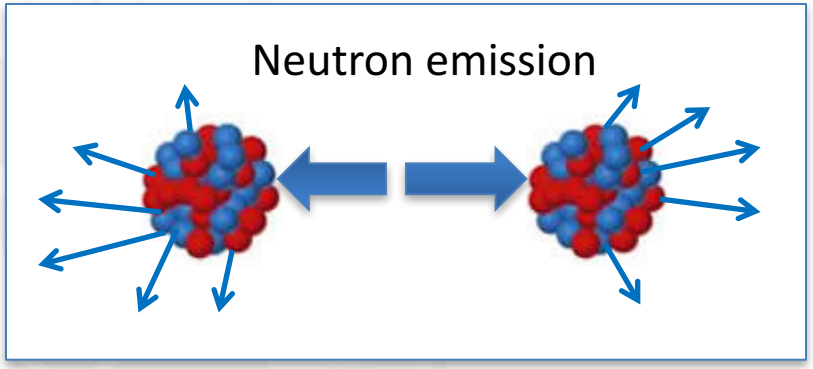


Measured Pu-240 SF neutron doubles versus detector angle.

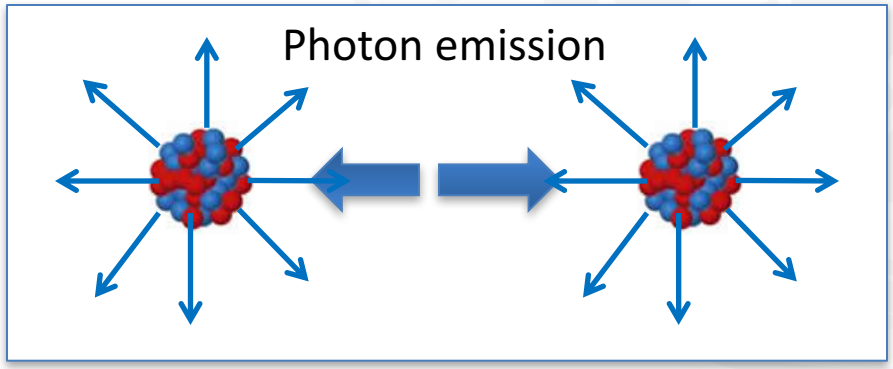
Nuclear fission

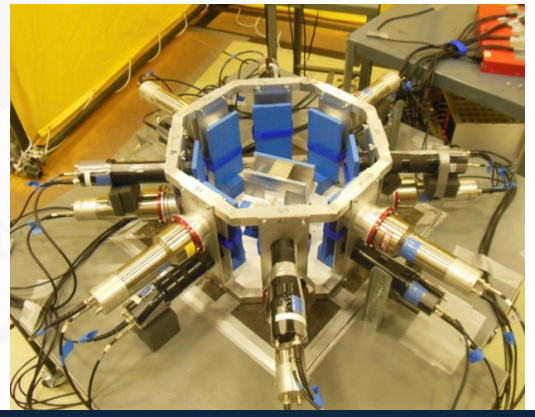
Nuclear fission produces correlated neutrons and photons





Neutron and photon correlations arise from the transition from neutron to photon emission.





Fast-neutron multiplicity counter

Experiment and methods

Measure and simulate correlated neutrons and photons from Cf-252

- Measure Cf-252 spontaneous fission neutron and photon correlations relevant to nonproliferation and safeguards for the first time.
- Evaluate new fission models using experimentally measured correlations.
  - MCNPX-PoliMi
  - CGMF (LANL) [1]
  - FREYA (LLNL & LBNL) [2]

} New, physics based fission models with correlations.

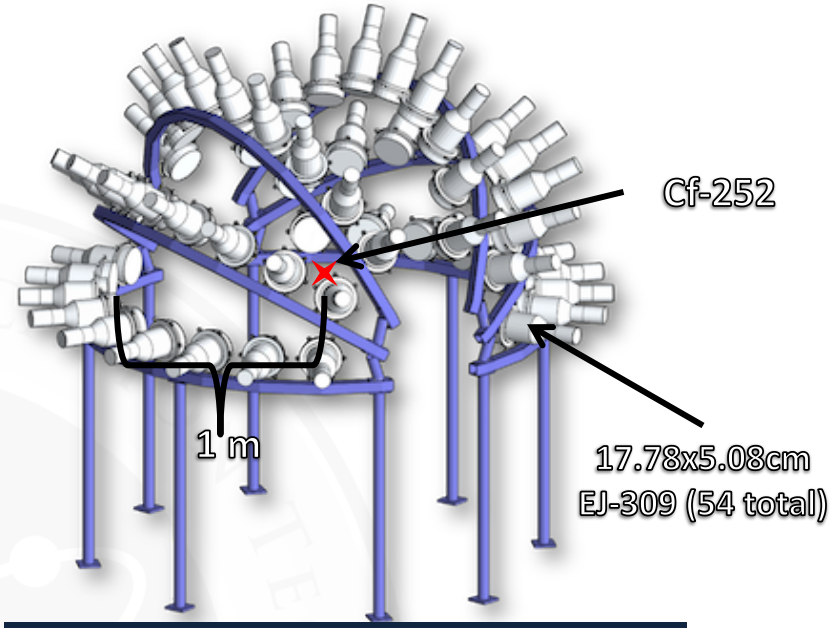
Chi-Nu array with liquid organic scintillators and a Cf-252 ionization chamber.

[1] P. Talou, et. al, LA-UR-12-25059, Los Alamos, NM (United States), 2012.
[2] J. Randrup and R. Vogt, *Phys. Rev. C*, vol. 80, no. 2, p. 024601, 2009.

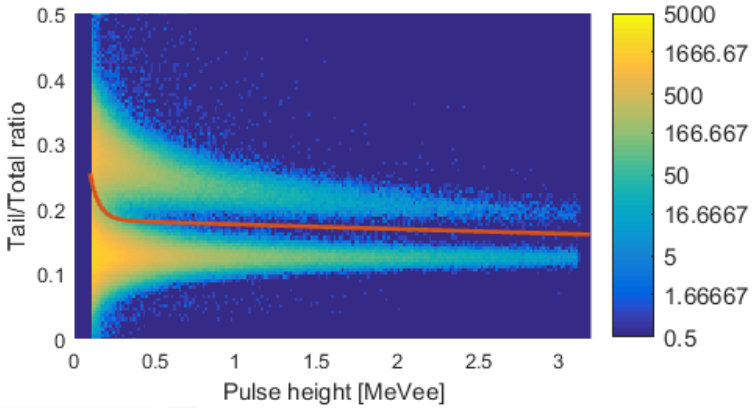
Experiment details

LANL Chi-Nu array with Cf-252

- 54- 17.78Øx5.04 EJ-309 organic liquid scintillators in the array, 45 are used.
- Cf-252 fission chamber signal split to each digitizer board for coincidence triggering.
- 1 m flight path.
- 3- CAEN V1730's were used for digital waveform acquisition.
- 33 TB of waveform data acquired.



Chi-Nu organic liquid scintillator array of 54-17.78Øx5.04 EJ-309s.

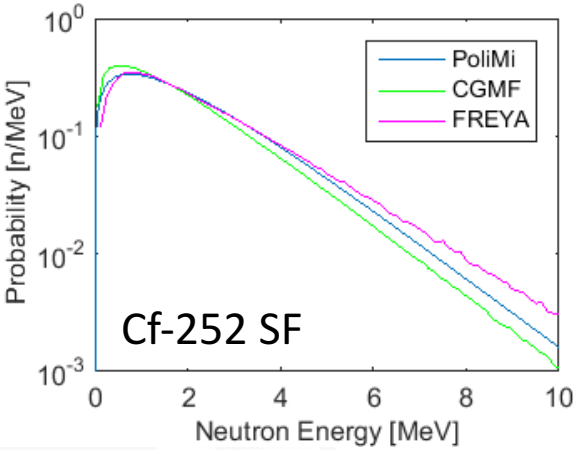


Tail-to-total ratio against pulse height where the upper band includes primarily neutron detections and the bottom gamma-ray detections separated by the discrimination line in red.

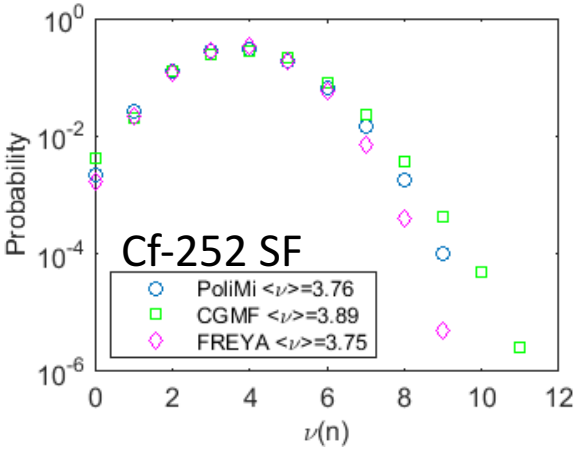
Nuclear fission models

Physics-based event-by-event fission model development is ongoing

- Research is underway to develop models that exhibit fission-particle correlations.
- CGMF (LANL) and FREYA (LLNL & LBNL) are event-by-event Monte Carlo codes.
- Model output was integrated with MCNPX-PoliMi to enable comparison with measured data.



Fission model neutron spectra for Cf-252.



Fission model neutron multiplicity distributions for Cf-252.

Nuclear fission models

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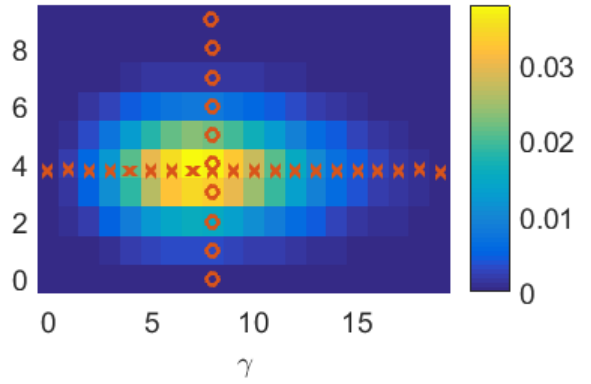
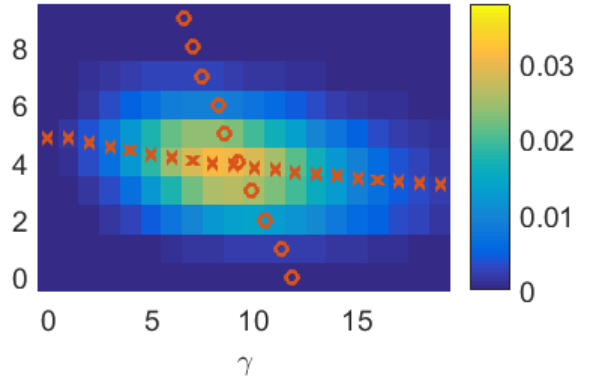
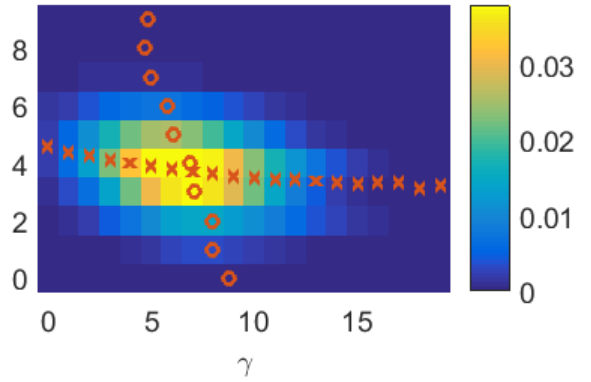
PoliMi



CGMF



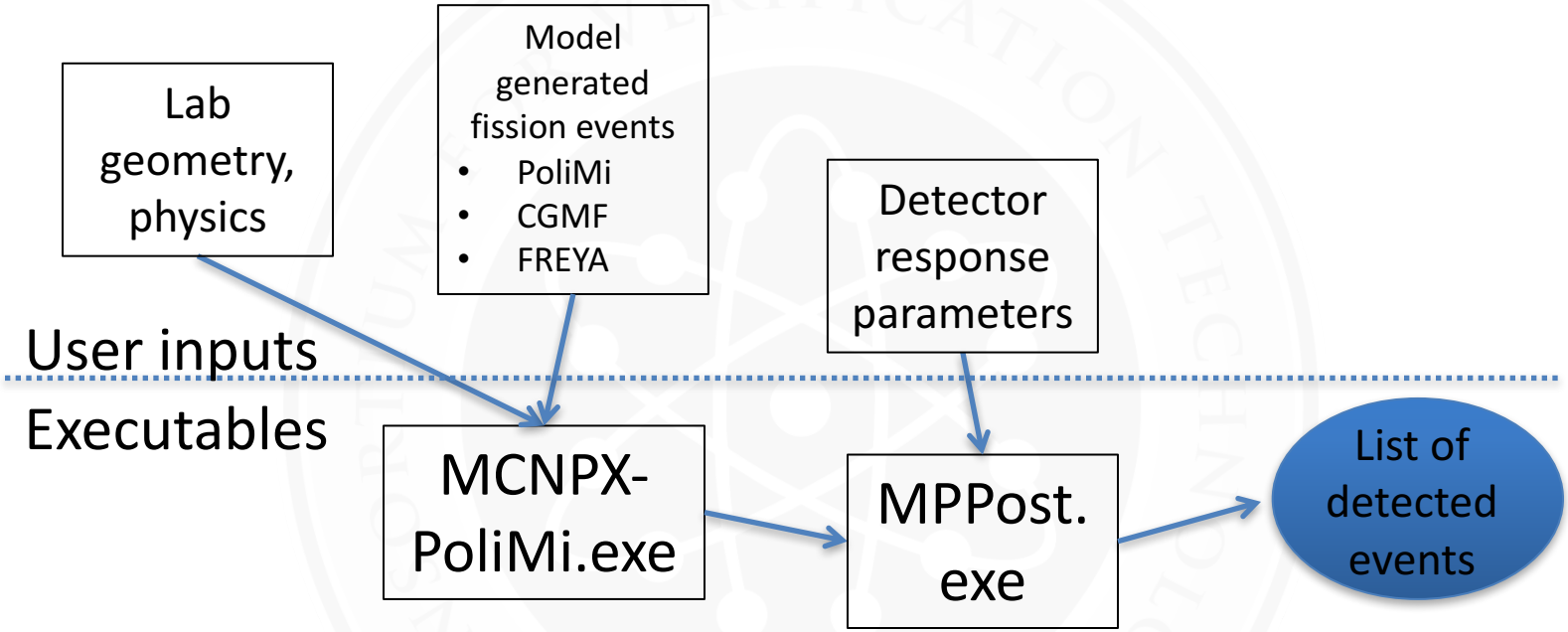
FREYA



Emitted Cf-252 SF prompt neutron (y-axis) and photon (x-axis) multiplicity from the fission models with overlaid E[ν|γ] (x) and E[γ|ν] (o).

Fission model evaluation

Physics-based fission event generators are coupled to MCNPX-PoliMi

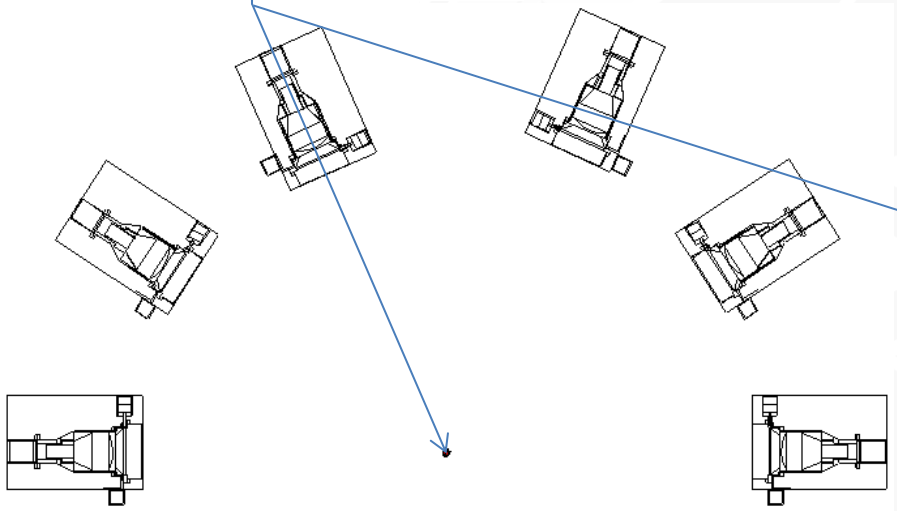


This approach facilitates direct comparison of simulation and measurement results.

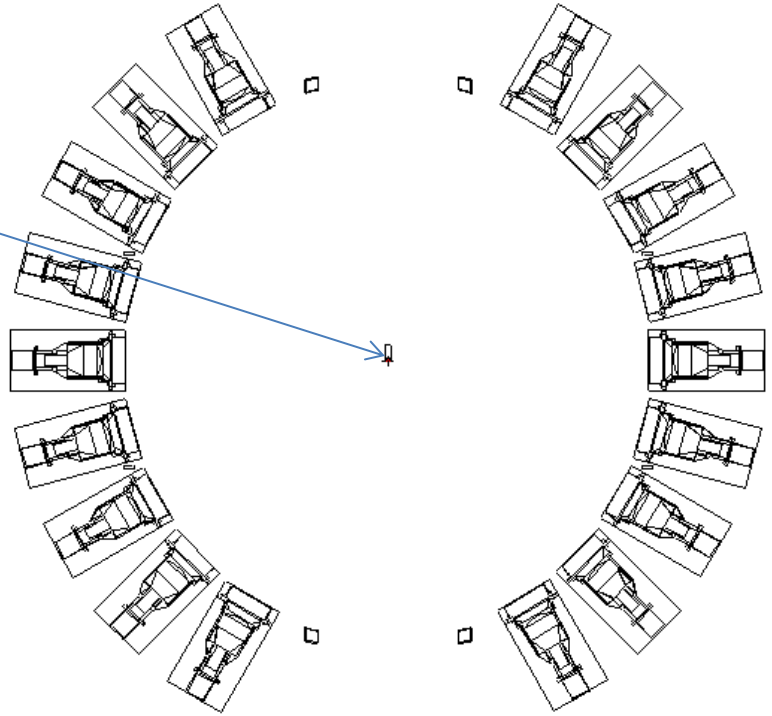
Modeling and simulation details

Laboratory geometry

Ionization
chamber detail



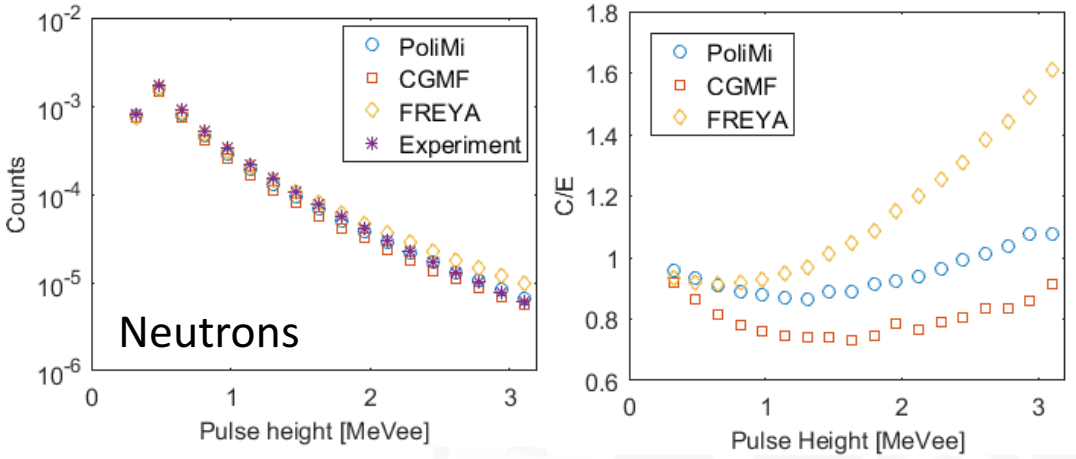
Side



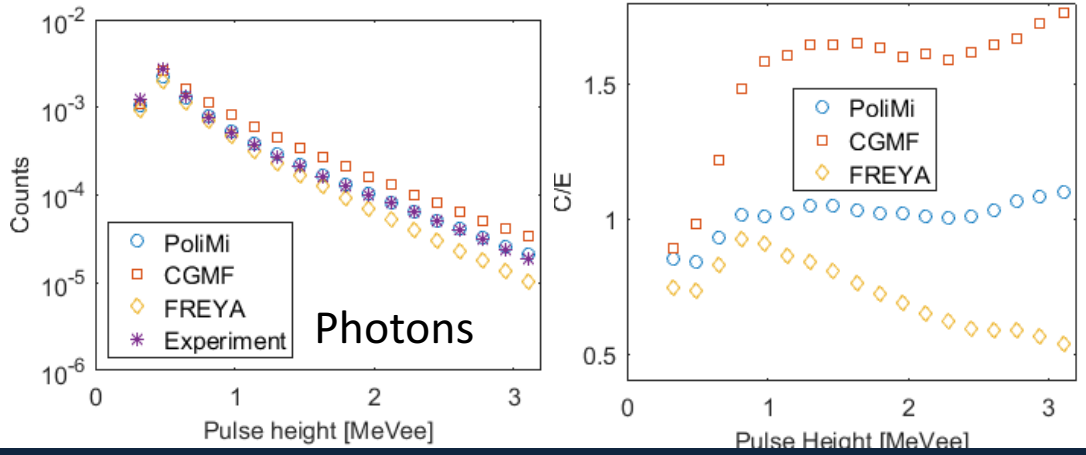
Top

Results

Pulse height distributions from experiment and simulations



Neutron pulse height distributions of simulated and experimental results (left) and simulated over experiment (right). The uncertainties are smaller than the points.

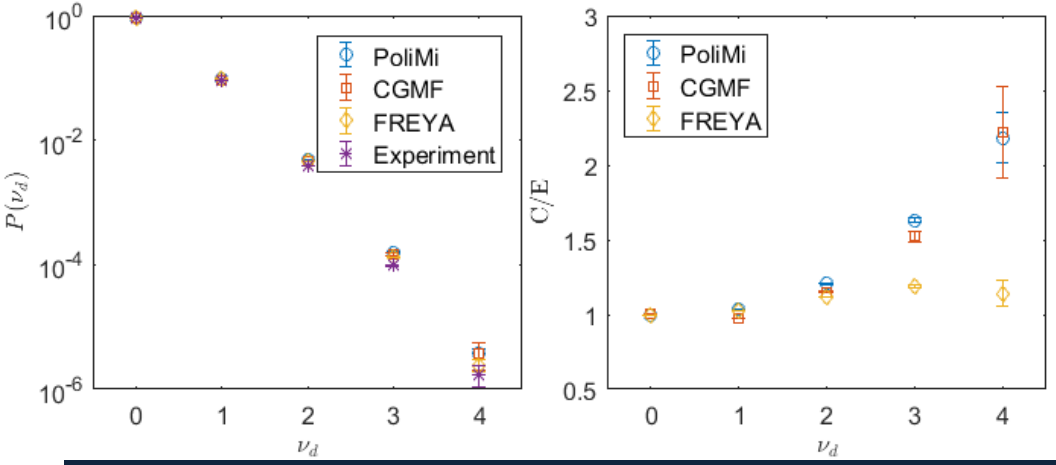


Photon pulse height distributions of simulated and experimental results (left) and simulated over experiment (right). The uncertainties are smaller than the points.

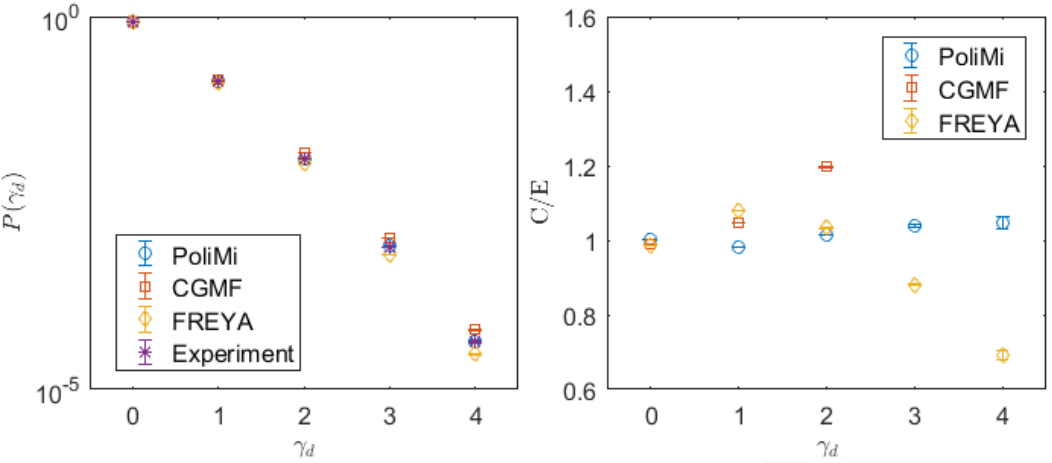
- Experiment and simulation pulse height distributions show general agreement.
- MCNPX-PoliMi agrees best for both neutron and photon distributions.

Results

High-order coincidence distributions from experiment and simulations



Detected number of neutrons, P(ν), for simulation and experiment results (left). The simulated result divided by experiment is also shown (right).

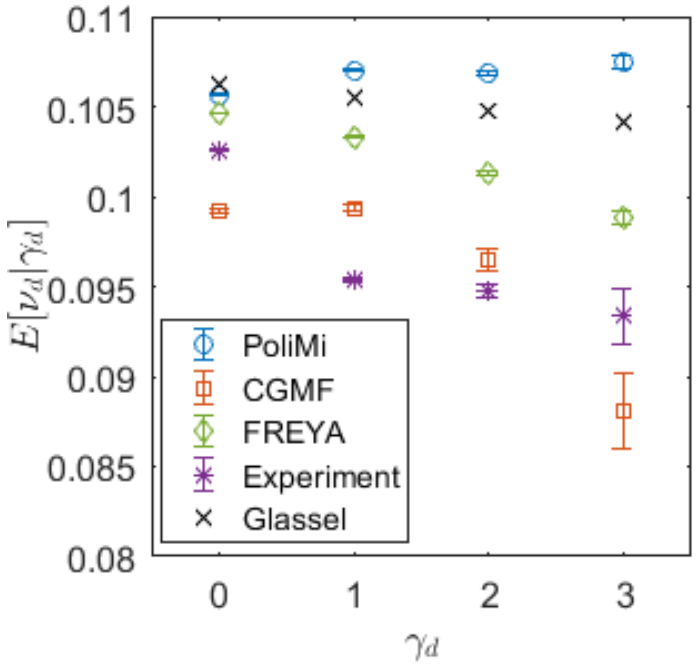


Detected number of photons, P(γ), for simulation and experiment results (left). The simulated result divided by experiment is also shown (right).

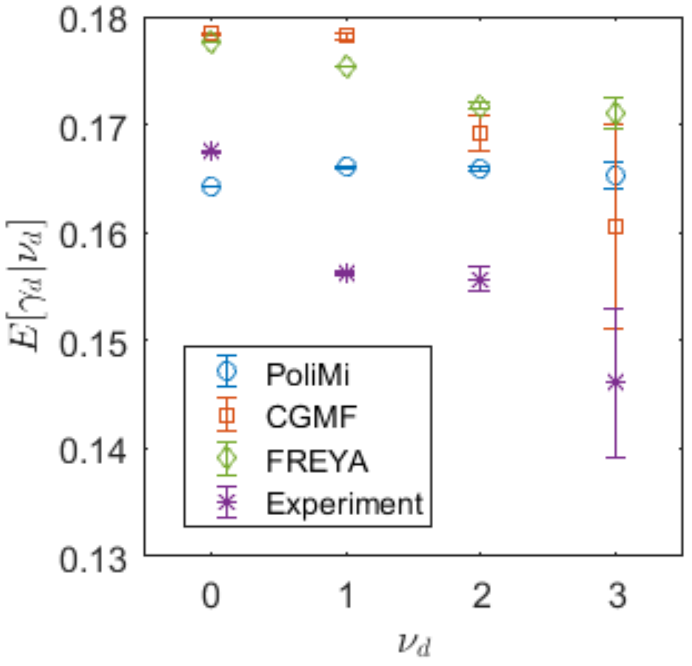
- High-order coincidences from experiment show mixed agreement to simulations.
- FREYA best captures neutron coincidences.
- PoliMi best captures photon coincidences.

Results

Neutron-photon multiplicity correlations from experiment and simulations



Average number of detected neutrons given γ photons detected in coincidence, E[ν|γ].



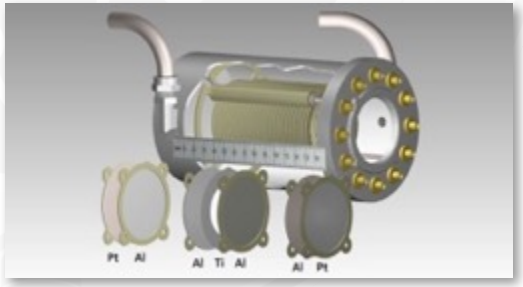
Average number of detected photons given ν neutrons detected in coincidence, E[γ|ν].

- Experiment $E[\nu_d|\gamma_d]$ and $E[\gamma_d|\nu_d]$ indicates negative neutron-photon correlation.
- No simulation result agrees well with the experiment.

Conclusions

- A dedicated experiment to observe neutron-photon multiplicity correlations was performed and results from simulations using correlated emission fission models were also shown.
- The experiment showed small negative neutron-photon multiplicity correlation on an event-by-event basis, suggesting neutron and photon competition for emission.
- Future work with Pu-240 and U-235 measurements using organic scintillator arrays could further improve model comparisons, particularly in neutron energy measurements.

Chi-Nu array with liquid organic scintillators and a Cf-252 ionization chamber.



U-235 parallel plate avalanche chamber.

Chi-Nu array with liquid organic scintillators.

Acknowledgements

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