Measurement of Correlated Data from Nuclear Fission

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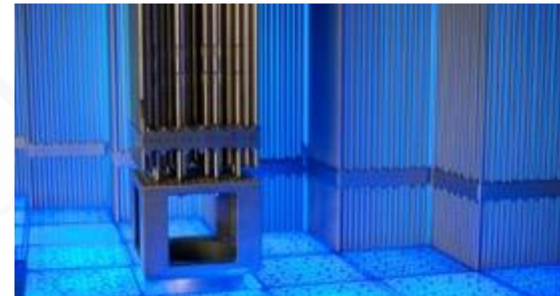
Motivation

Nuclear Nonproliferation and Safeguards

- 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.
- Key neutron and gamma ray quantities to measure:
  - Detected multiplicity
  - Energy spectra
  - Relative angle of emission

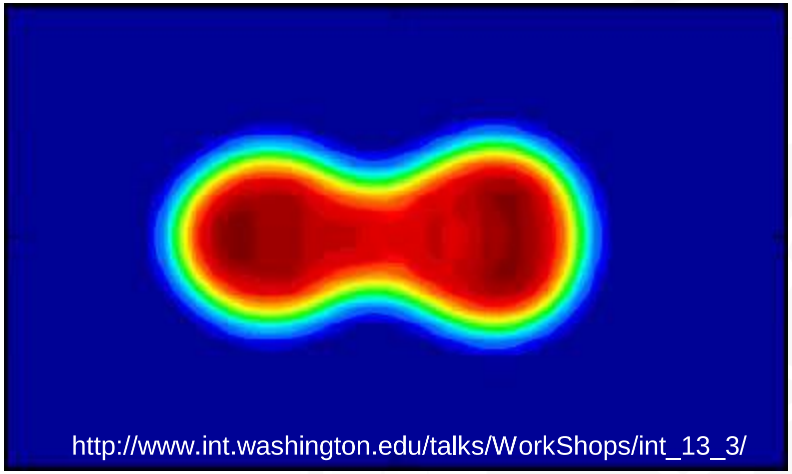


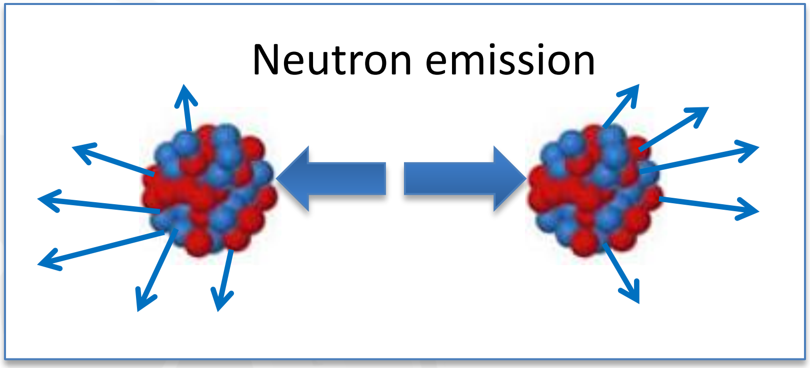
Nuclear reactor fuel bundles

Uranium hexafluoride containers

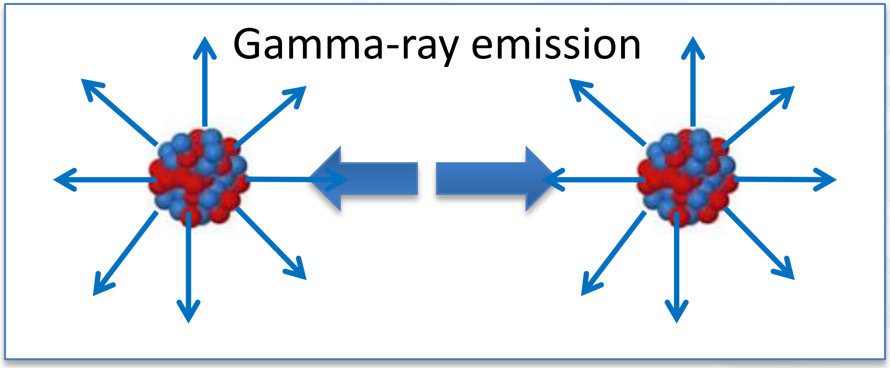
Canberra AWNCC

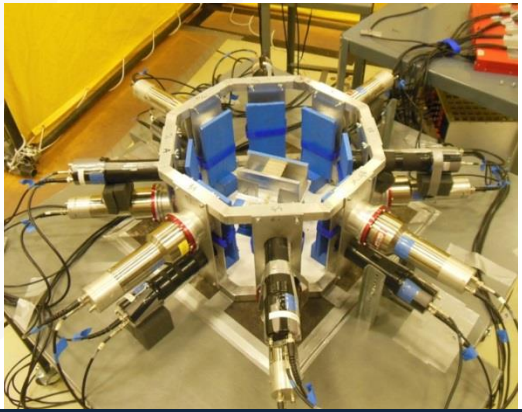
Nuclear Fission





Neutron and gamma-ray correlations arise from the transition from neutron to gamma-ray emission.

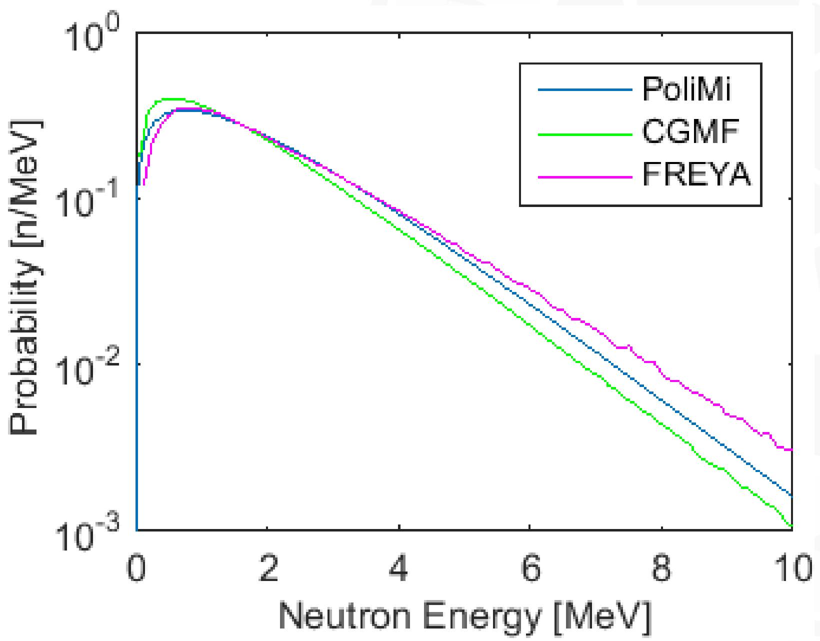




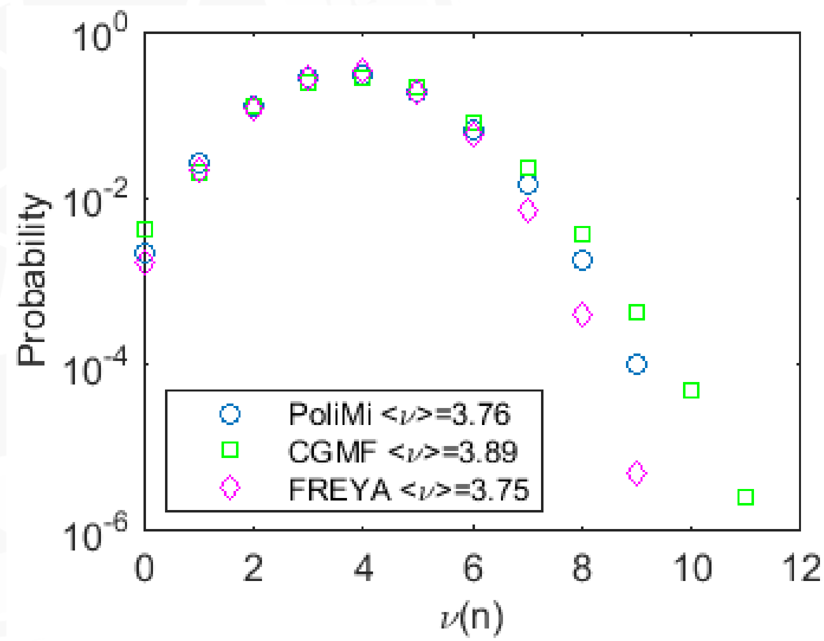
Fast-neutron multiplicity counter

Ongoing nuclear fission modeling

- 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.

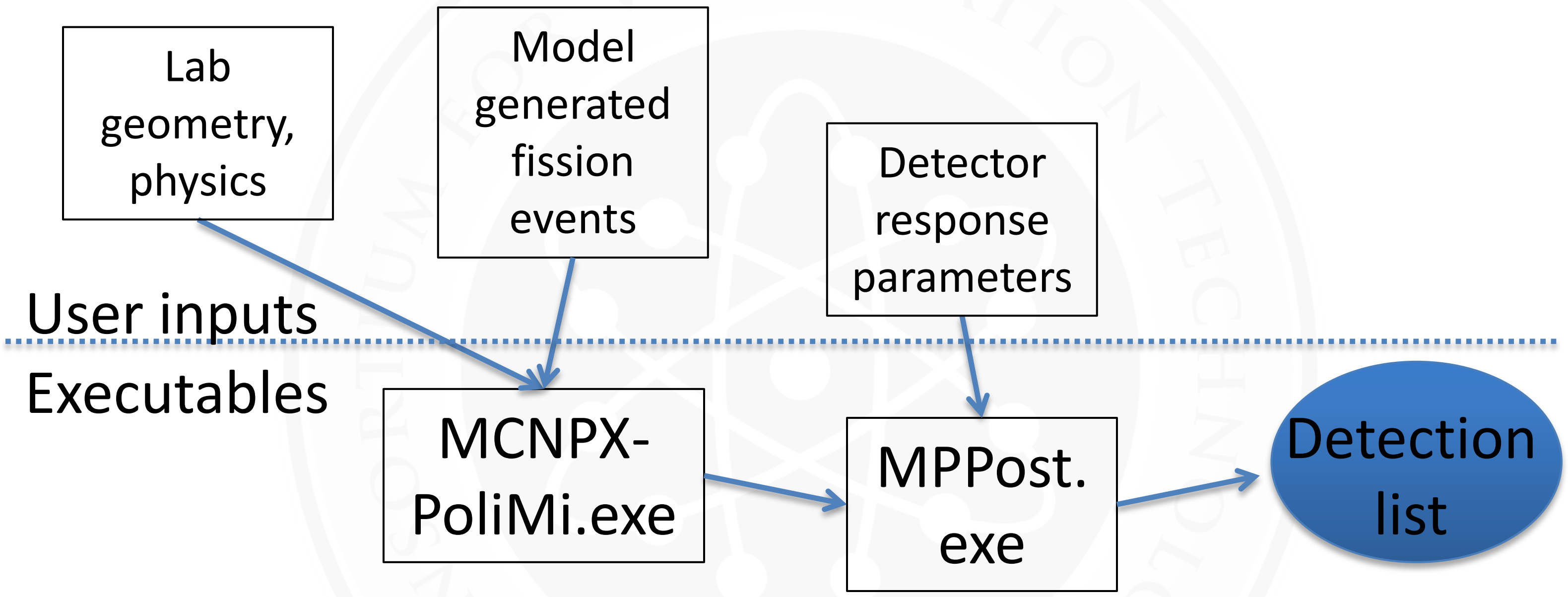


Fission model neutron spectra for Cf-252.



Fission model neutron multiplicity distributions for Cf-252.

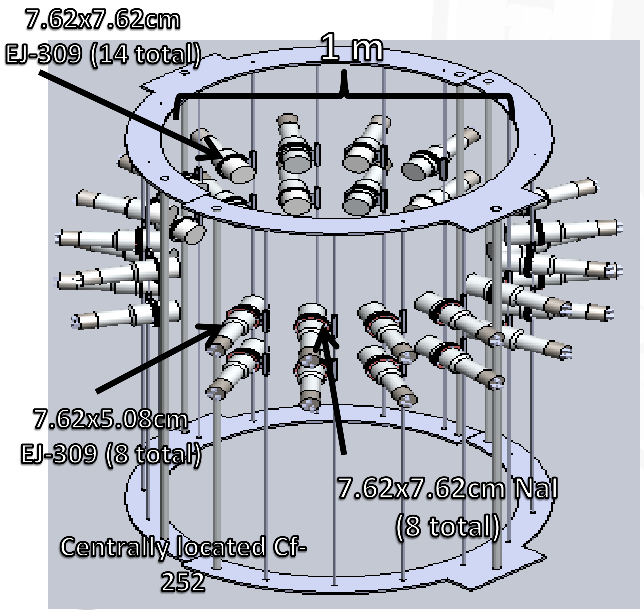
Fission model evaluation approach

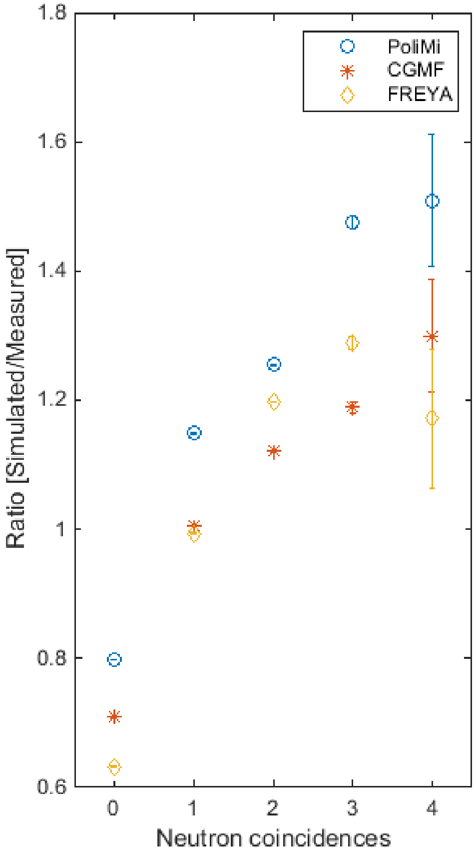


This approach facilitates direct comparison of simulation and measurement results.

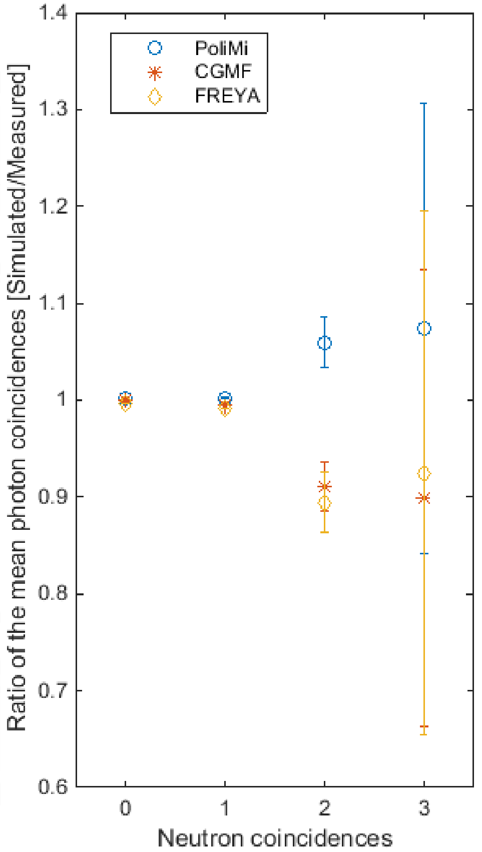
Neutron coincidences

- Simulated results over-estimate the number of measured neutron coincidences, except at zero.
- Both CGMF and FREYA have negative correlation in energy and multiplicity.





Ratio of neutron coincidence histogram of simulations fission models to the measured.

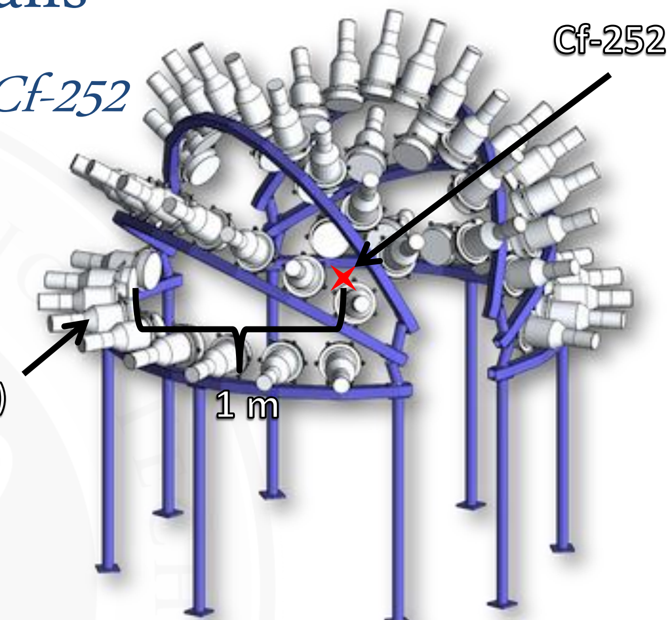


Ratio of mean photon coincidences as a function of neutron coincidences from simulations to measurement.

Measurement details

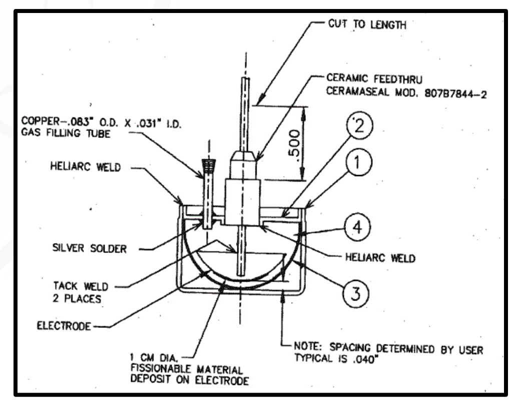
LANL Chi-Nu array with Cf-252

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



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

- The collaboration with LANL enabled improved detection limits and efficiency over U-M measurements.
  - Larger source-detector distance
  - Larger solid angle coverage
  - Better fission timing resolution and trigger



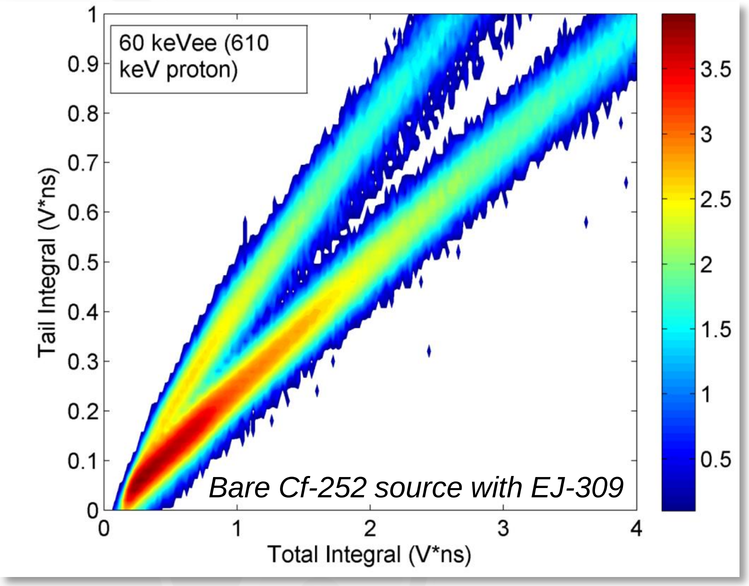
ORNL designed Cf-252 ionization chamber.

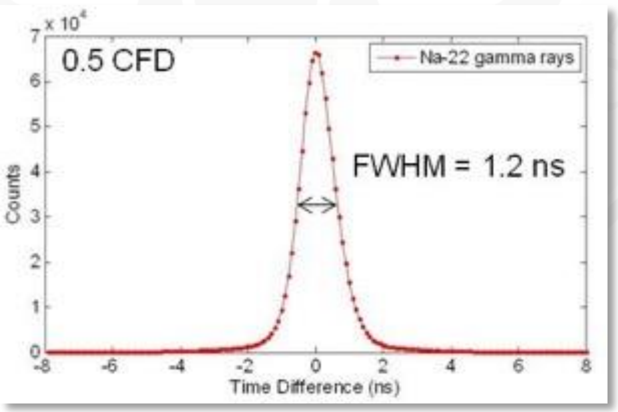
Measurement details

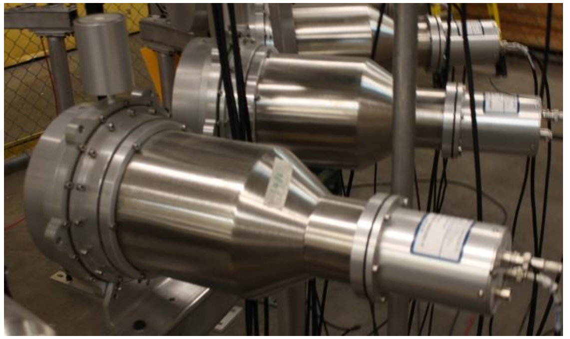
Organic-Liquid Scintillator Characteristics

Organic scintillators have several advantages for detecting SNM signatures

- Nanosecond-scale response times
- Response is proportional to the energy deposited
- Good intrinsic efficiency
- Pulse shape discrimination
- Good scalability and low cost

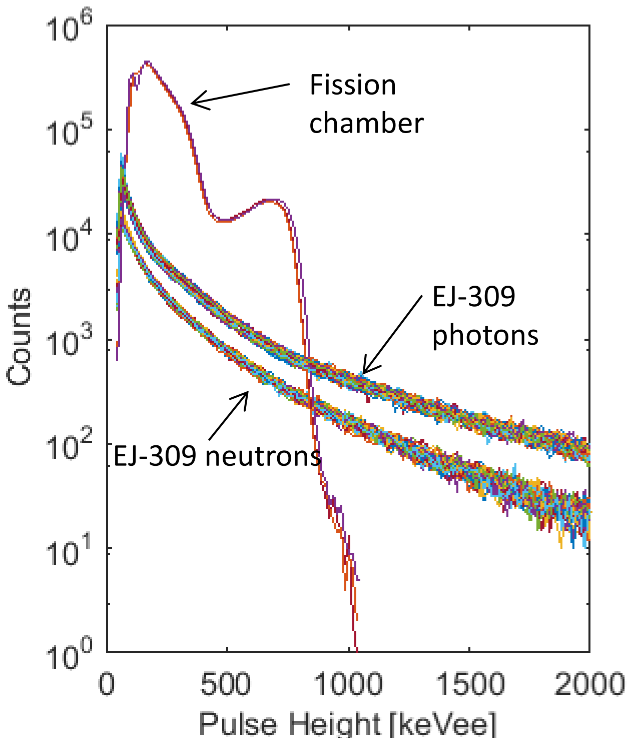




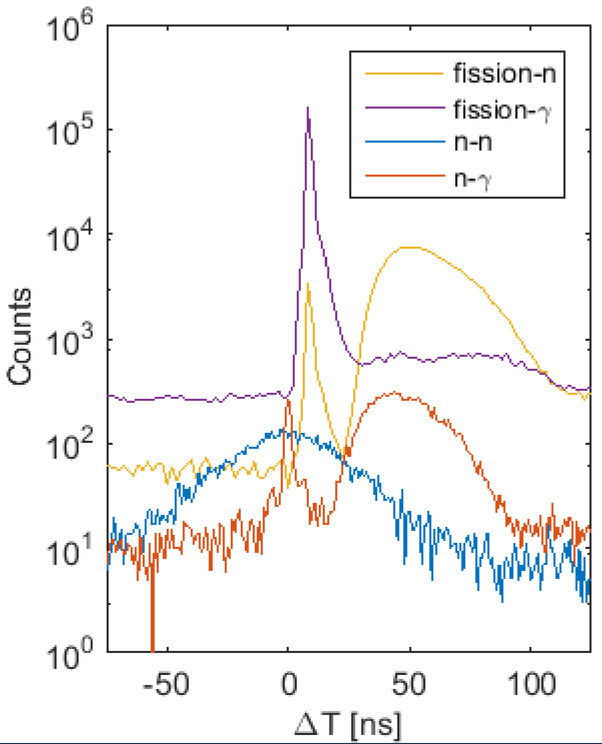


Measured quantities

LANL Chi-Nu array with Cf-252



Ionization chamber and detector pulse height histograms.



Detector-detector and detector-ionization chamber detection time difference histograms.

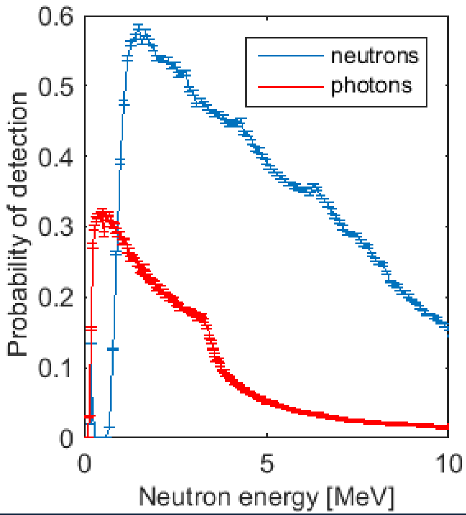
Measured quantities:

- Pulse heights - energy deposited
- Time of detection
- Neutron energy from time-of-flight
- Relative angle of emission

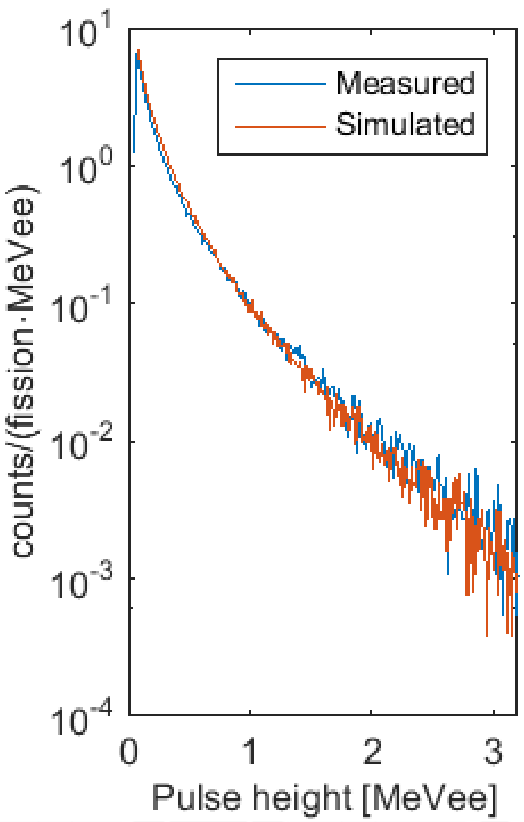
Detector characterization

LANL Chi-Nu array with Cf-252

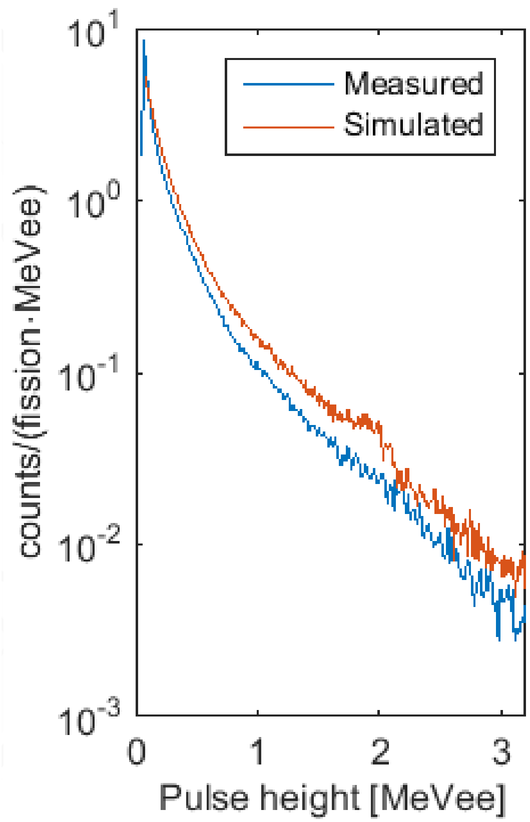
- Measurement-simulation results rely on the ability to emulate detector response.
- It is critical to understand the detector response.



Simulated efficiency of a 17.78Ø×5.08 cm EJ-309 with a 70 keVee threshold =~0.5 MeV deposition.



Neutron pulse height histogram of a 17.78Ø×5.08 cm EJ-309 with a 70 keVee threshold (~0.6 MeV deposition).

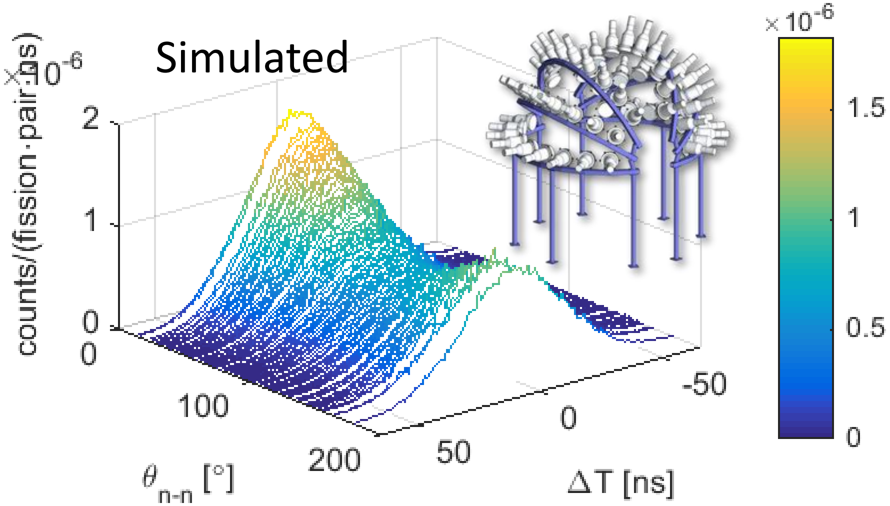


Photon pulse height histogram of a 17.78Ø×5.08 cm EJ-309 with a 70 keVee threshold (~0.6 MeV deposition).

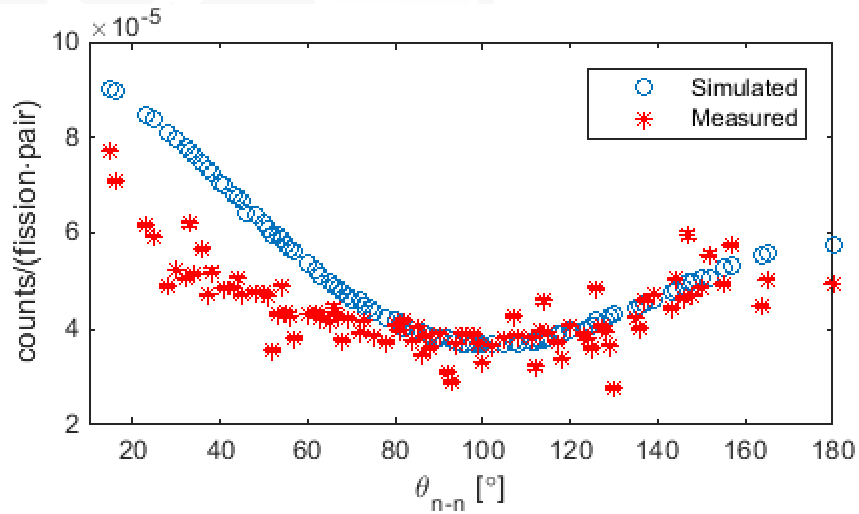
Correlated results

LANL Chi-Nu array with Cf-252

- Neutron-neutron coincidence are being analyzed for correlations.
- CGMF and FREYA comparisons are ongoing.



Simulated neutron-neutron detection time difference histogram for each detector-to-detector angle.



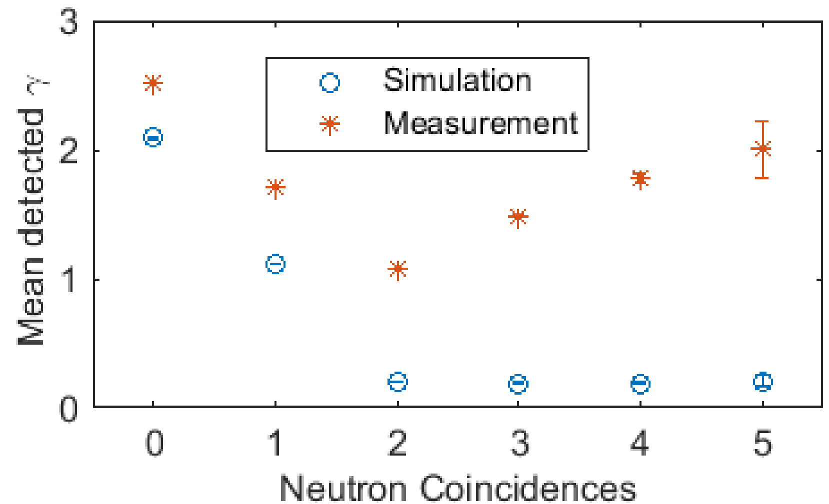
Neutron-neutron coincidences histogrammed by detect-to-detector angle.

Ongoing work

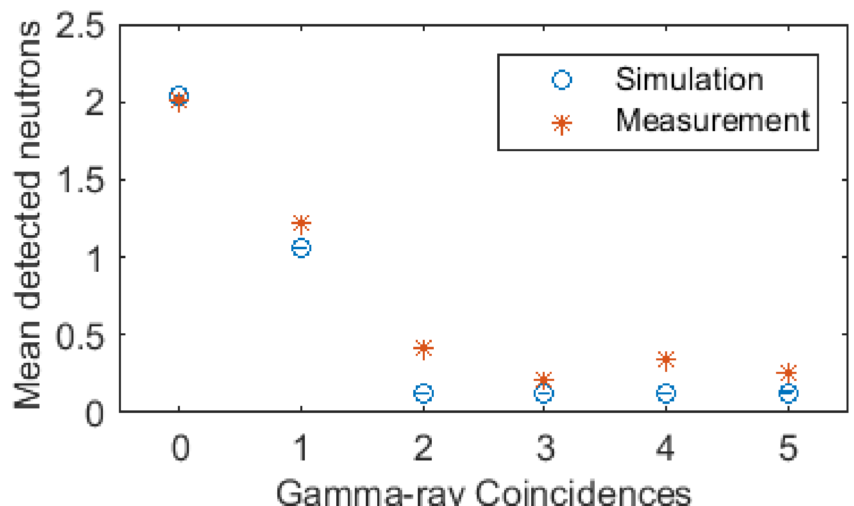
LANL Chi-Nu array with Cf-252

- Coincident neutron and photon detections are sensitive to neutron-photon correlations.

- Future work includes comparison to CGMF and FREYA simulation results.



Mean detected gamma-rays as a function of coincident neutrons.

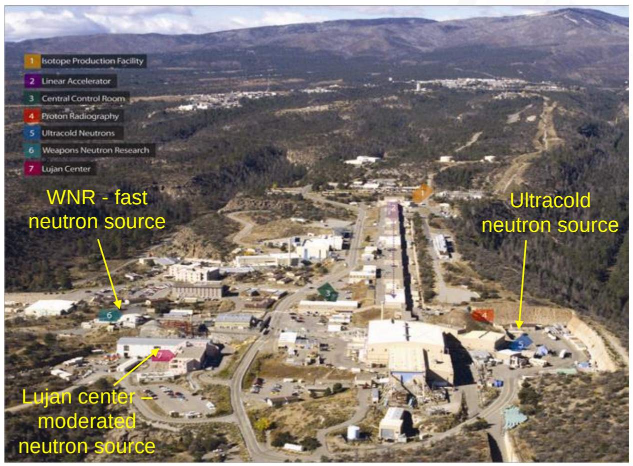


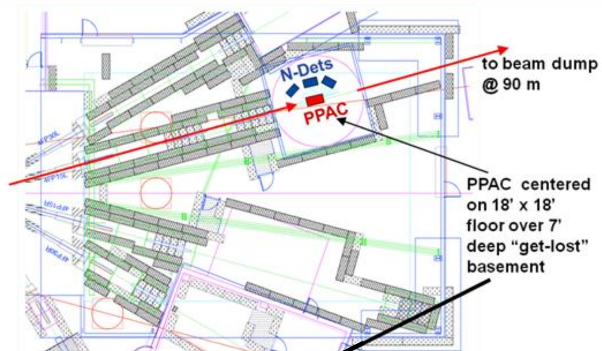
Mean detected neutrons as a function of coincident photons.

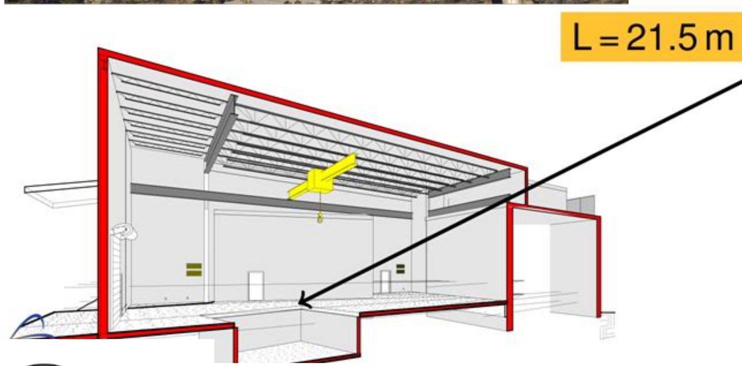
Ongoing work

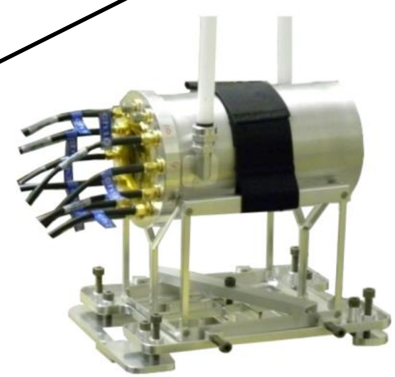
Induced-fission measurements at WNR facility at LANSCE

- In February 2016 at the WNR facility, U-235 induced fission neutrons and photons from a parallel plate avalanche chamber were measured with the Chi-Nu array.
- 700 keV through 800 MeV inducing neutron energies.





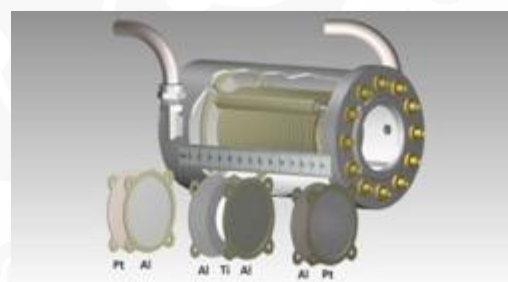




Conclusions

- Measurements of correlated, prompt emissions from Cf-252 have been performed and analyzed.
- Comparisons have been made of fission models from MCNPX-PoliMi, CGMF, and FREYA to experimentally measured correlations.
- Ongoing work with Cf-252 and U-235 measurements using the LANL Chi-Nu liquid organic array could 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.

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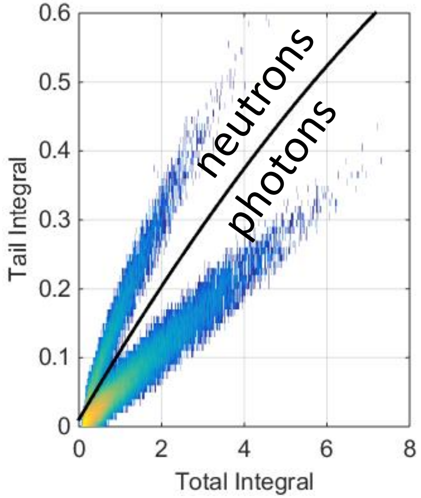
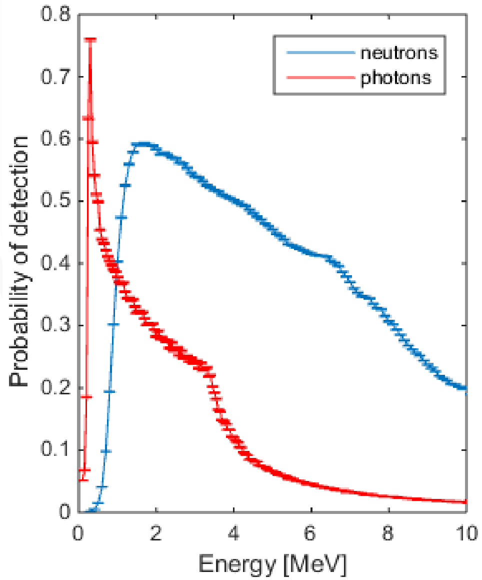
Detection tools

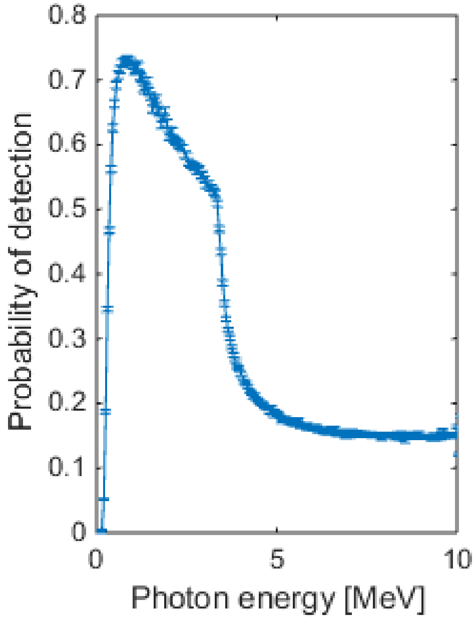
- EJ-309
  - Primary mechanisms of detection
    - Neutron elastic scattering on hydrogen
    - Photon Compton scattering
  - Time resolution 1 ns FWHM
- NaI(Tl)
  - Photoelectric absorption and Compton scattering
  - Good photon efficiency
  - Time resolution 3.5 ns at FWHM



Measured tail to total plot for pulse shape discrimination



Simulated EJ-309 neutron and photon efficiency



Simulated NaI(Tl) photon efficiency

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