Correlations in Prompt Neutrons and Gamma Rays from Fission

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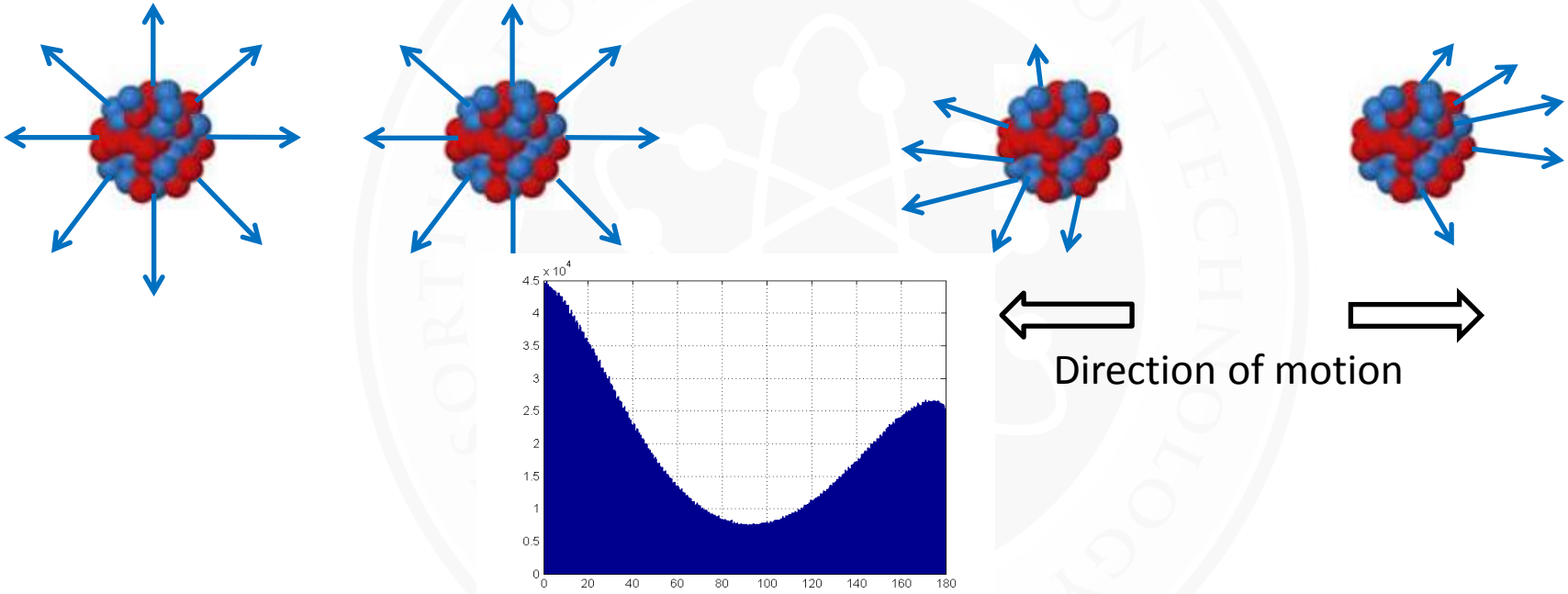
Motivation

- Nuclear nonproliferation and safeguards applications require improved models for physics of nuclear fission and detector response.
- Specifically, the correlated neutron and gamma ray emission properties of important nuclear isotopes such as ^{235}U and ^{239}Pu are not well known. These data are important in nuclear safeguards and nonproliferation.
- A past DOE – NEUP project has led to a successful measurement campaigns at LANSCE for the measurement of the ^{235}U fission neutron spectrum (without information on angular distribution or multiplicity).
- The present work builds on that experience and includes *correlated* information.

Nuclear Fission

Center of Mass Frame

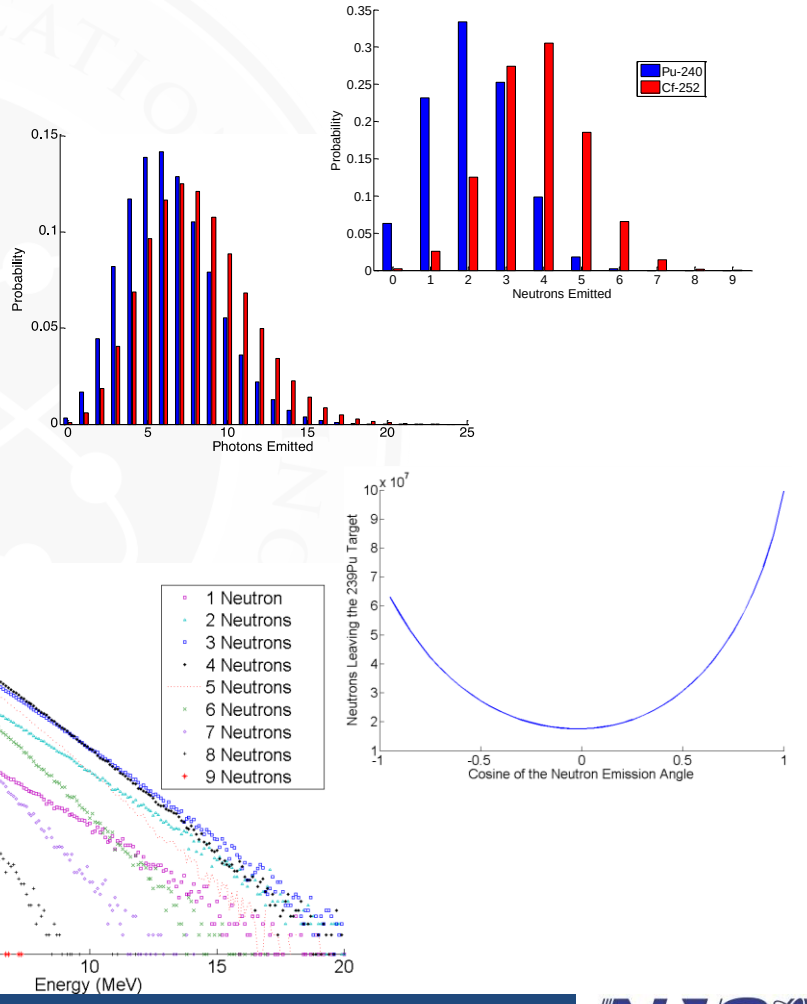
Lab Frame



- Neutrons emitted in the direction of motion of the fission fragment (FF) have the FF momentum added to their energy

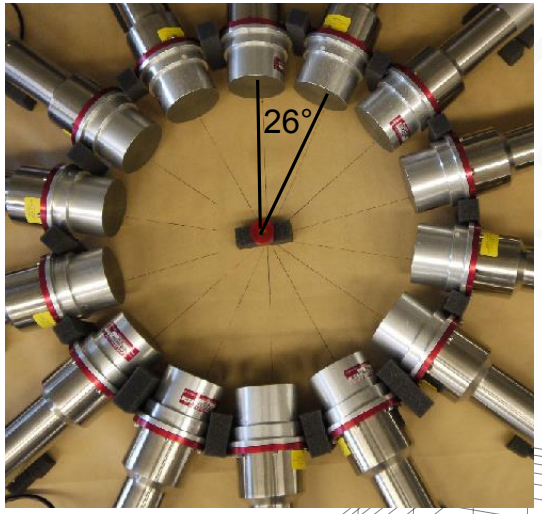
Nuclear Fission Modeling

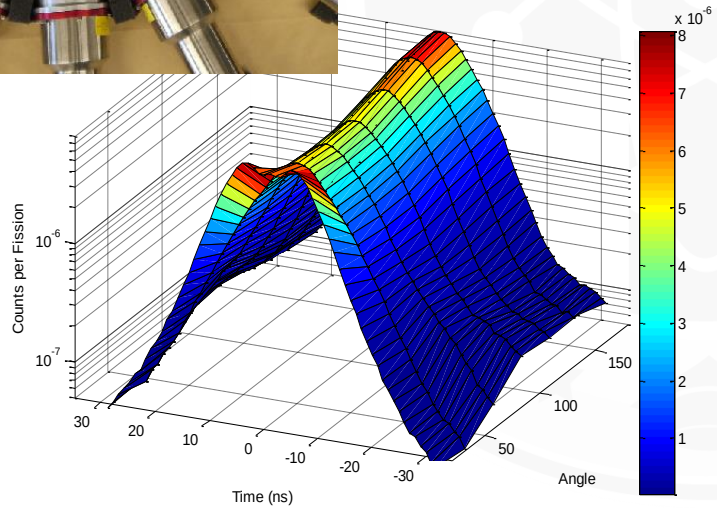
- The multiple variables associated with nuclear fission are sampled independently by most Monte Carlo codes
- Theoretical research is underway at LANL and LLNL to develop models between fission-particle correlations
- Active collaboration is underway to verify these models with our own code MCNPX-PoliMi



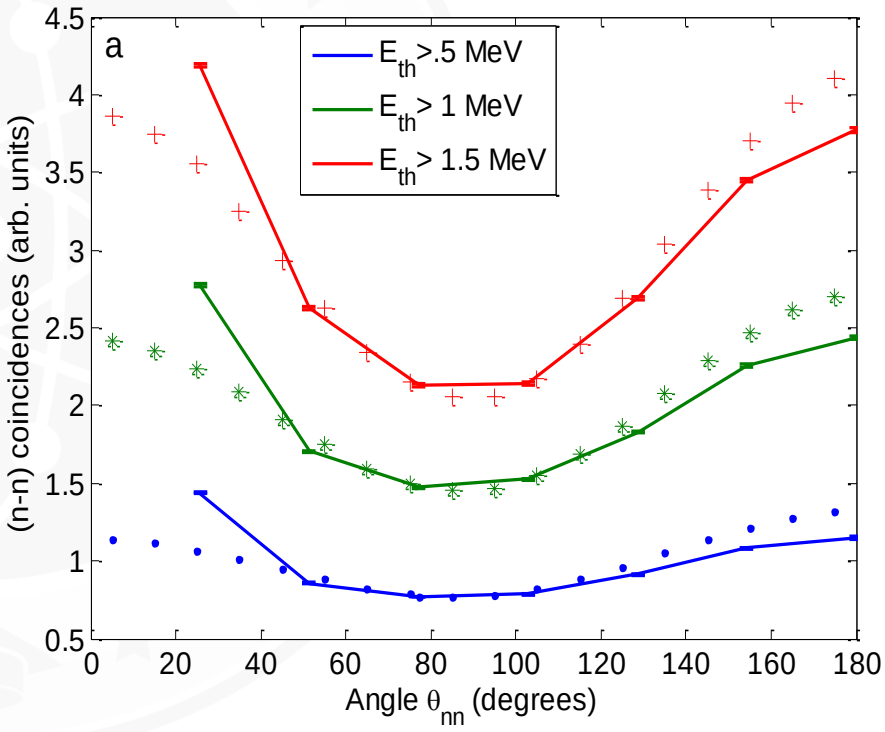
Spontaneous Fission Measurements

^{252}Cf Measurements at UM





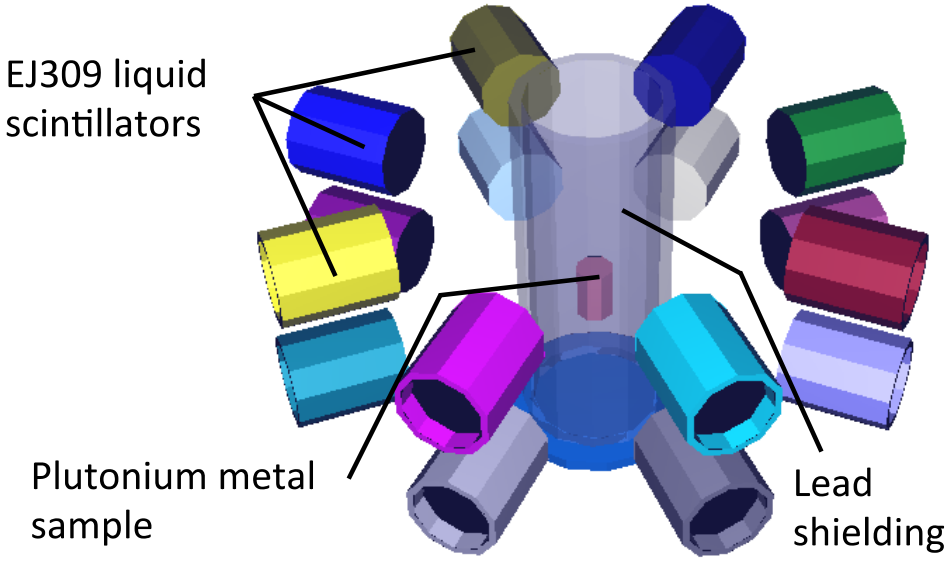
Compared to theory results from LLNL/LBNL using FREYA (symbols) (Vogt and Randrup)

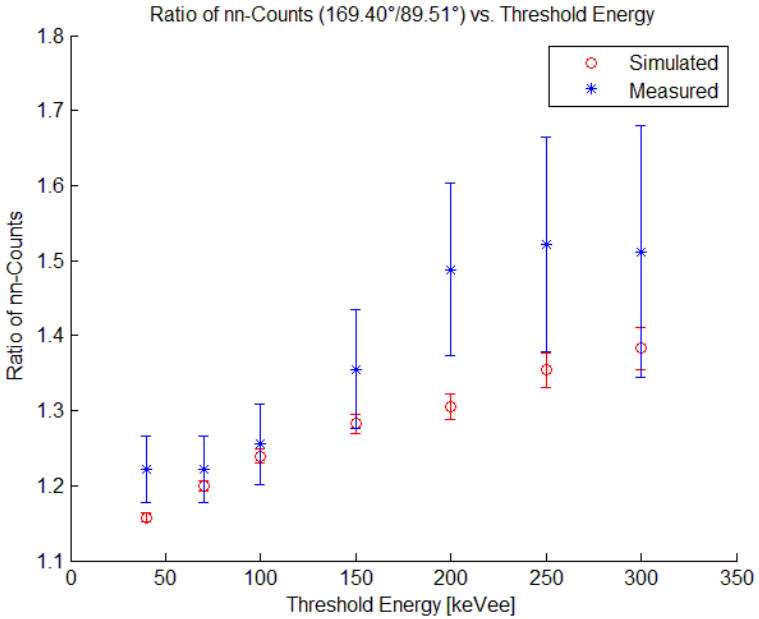


Spontaneous Fission Measurements

Pu Metal Samples at JRC, Ispra Italy

- A prototype fast-neutron multiplicity counter was tested at JRC, Ispra in 2013
- 1.63 g of $^{240}Pu_{eff}$ was measured with 1-cm of lead shielding and a 70 keVee threshold

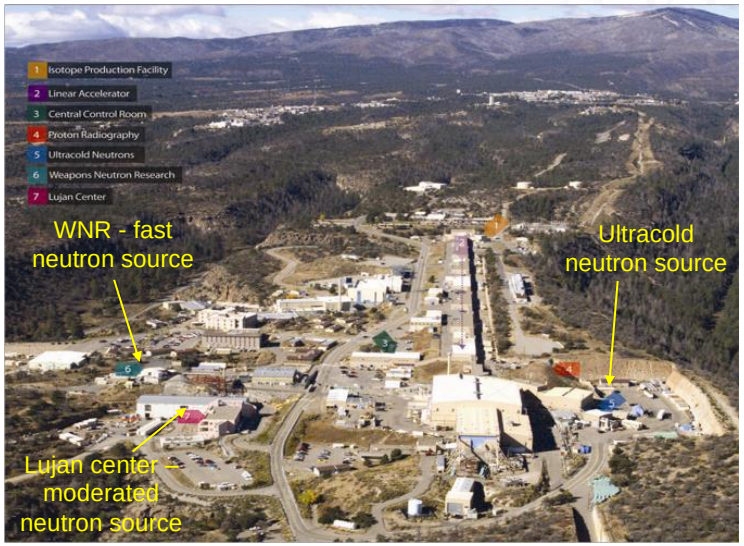


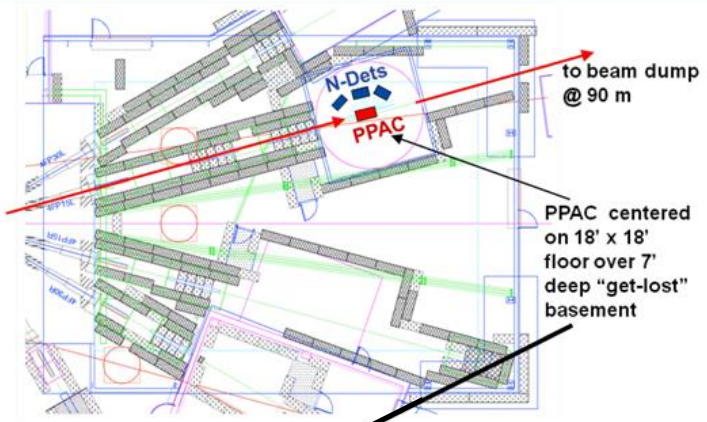


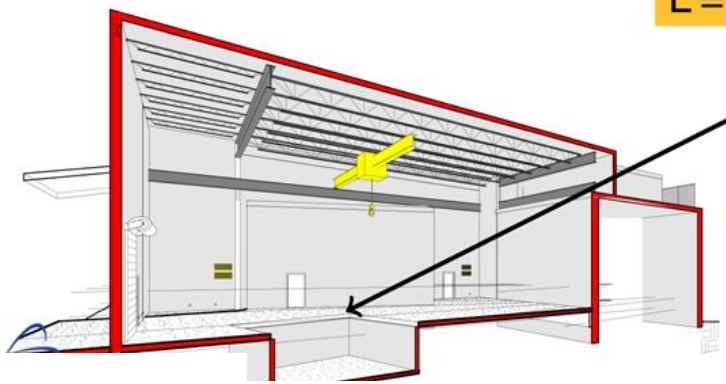
Increasing the detection threshold increases the observed anisotropy

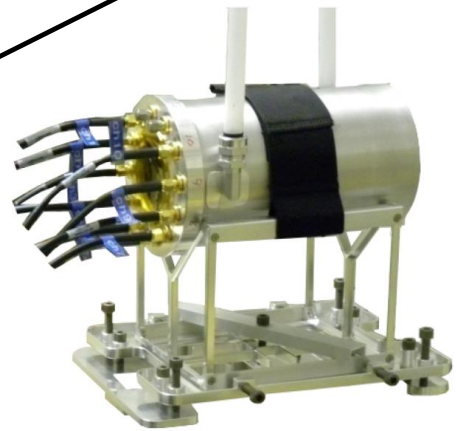
Induced-Fission Measurements

LANSCE Facility at LANL





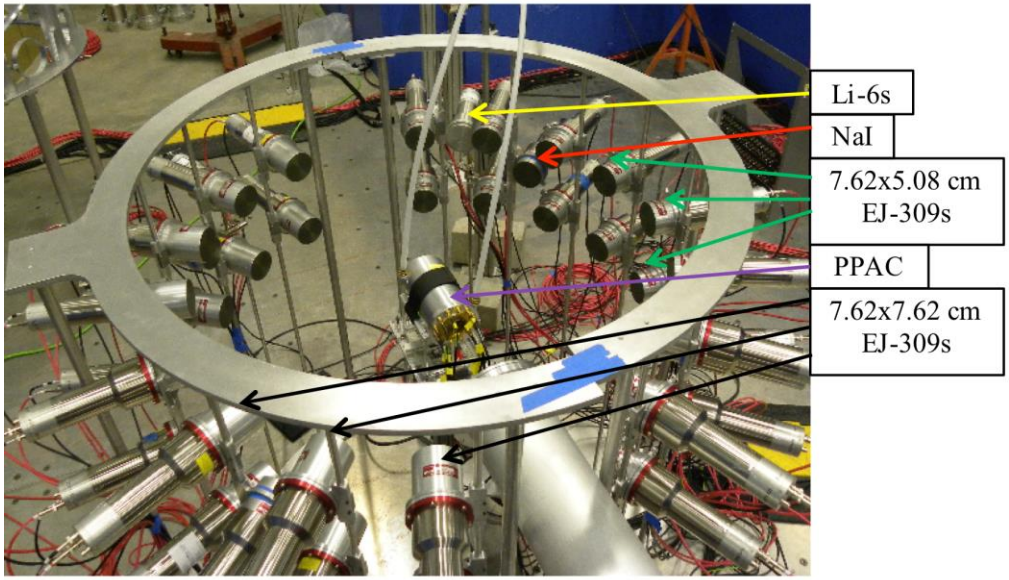


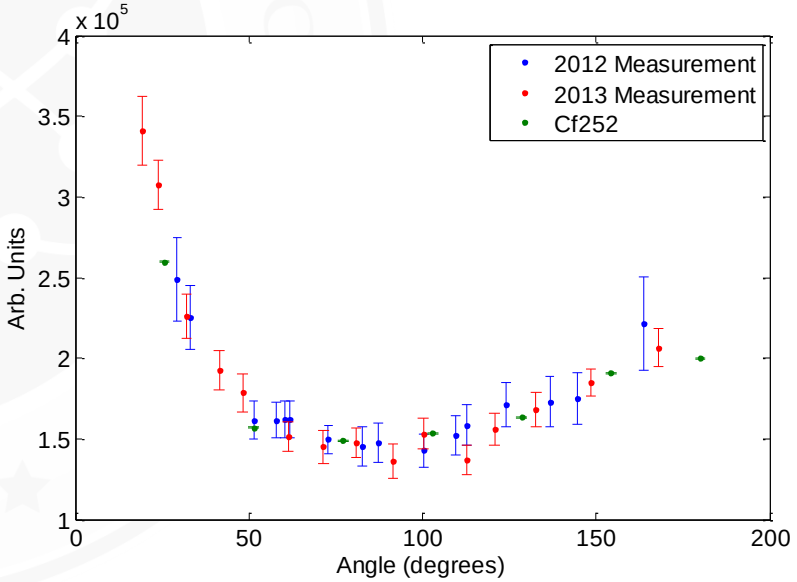


Induced Fission Experiments

^{235}U Fission Chamber

- A double-TOF experiment was performed using a LLNL-designed ^{235}U fission chamber
- The total measurement was 1.5 weeks of on the WNR-15L beamline
- A total of 2.6×10^7 fissions were observed

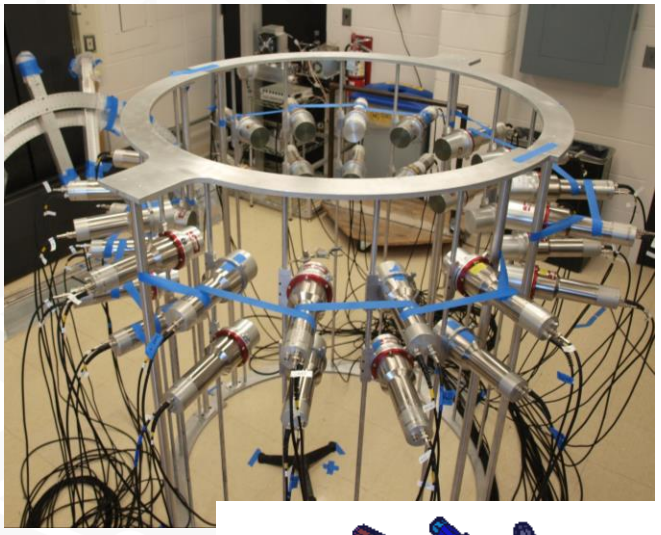




Neutron-Gamma-ray Correlations

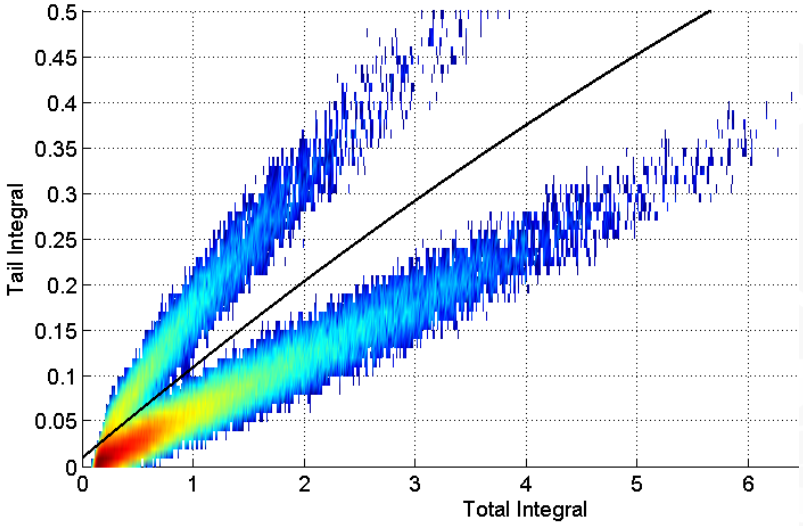
Scintillator Array at UM

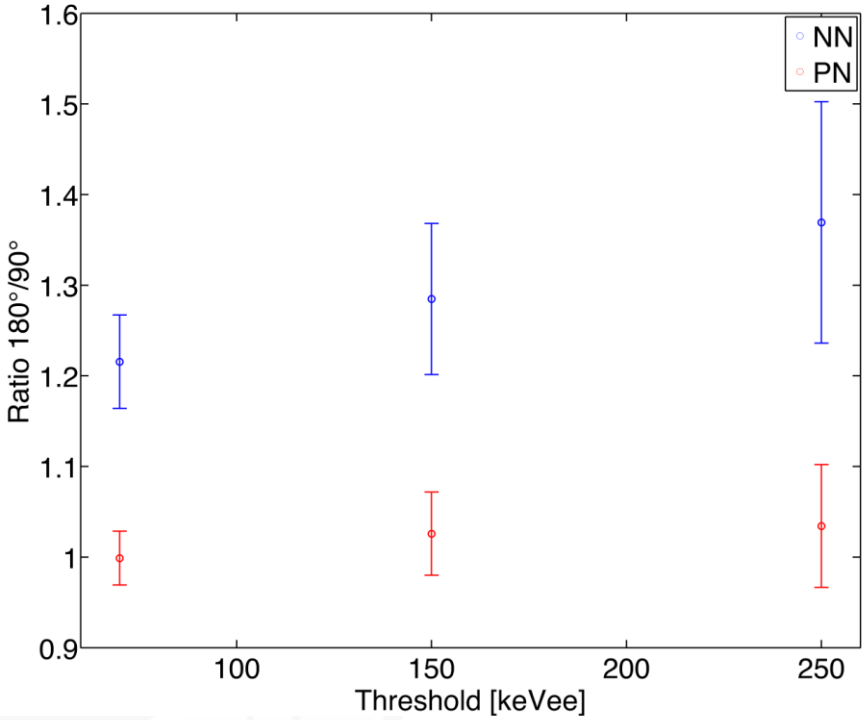
- Inorganic scintillators have been incorporated to improve gamma-ray efficiency and spectroscopy
- This improved array provides a range of correlated measurables
  - Number of detected neutrons and number detected photons
  - Photon PHD as a function of the number of detected neutrons
  - Neutron PHD as a function of the number of detected photons
  - Neutron spectrum from TOF as a function of the number of detected photons



Neutron-Gamma-ray Correlations

- Approximately 15 TB have been acquired to date
- Analysis of these data is underway to extract the relevant correlations





Summary and Conclusions

- Advanced verification system could rely on detailed correlated emissions from fission
- Accurate models are necessary to In order to effectively design such systems
- Measurements of correlated, prompt emissions from ^{252}Cf, ^{240}Pu, and ^{235}U have been performed
  - Neutron-neutron, neutron-gamma-ray correlations
  - Experimental results used to validate codes: MCNPX-PoliMi treatments are more physical than the standard MCNPX treatment
- New fission models have been implements in MCNPX-PoliMi
  - Anisotropic neutron emission from fission
  - Multiplicity-dependent neutron energy spectra

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