Correlated Neutron and Gamma-Ray Emissions from Nuclear Fission

Sara A. Pozzi[1], Shaun D. Clarke[1], Stefano Marin[1], Matthew J. Marcath[2], Michael T. Febbraro[3], Ramona Vogt[4,5], Jørgen Randrup[6], Patrick Talou[2], Michael E. Rising[2]

1. *University of Michigan, Ann Arbor, MI*
2. *Los Alamos National Laboratory, Los Alamos, NM*
3. *Oak Ridge National Laboratory, Oak Ridge, TN*
4. *Lawrence Livermore National Laboratory, Livermore, CA*
5. *University of California, Davis, CA*
6. *Lawrence Berkeley National Laboratory, Berkeley, CA*

MTV Kickoff Meeting

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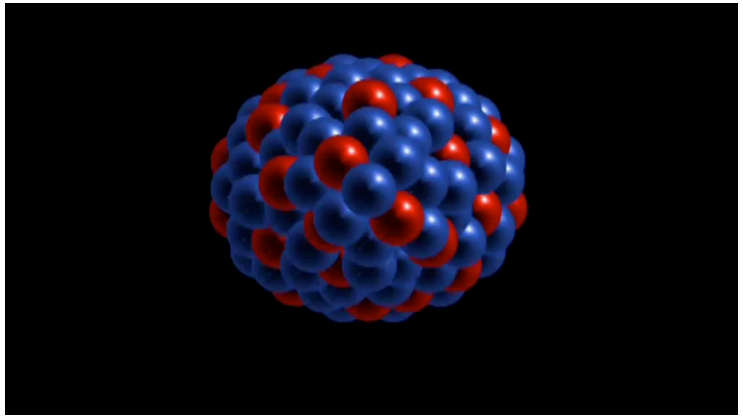
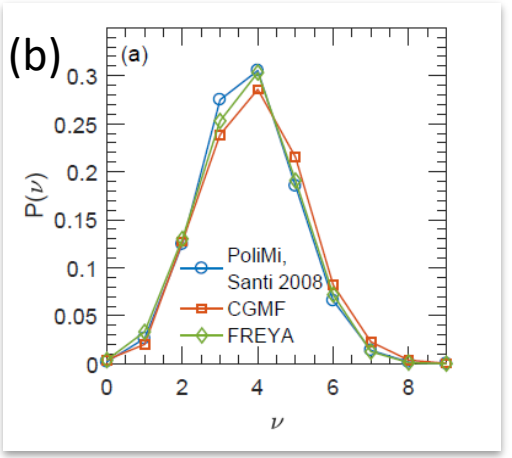
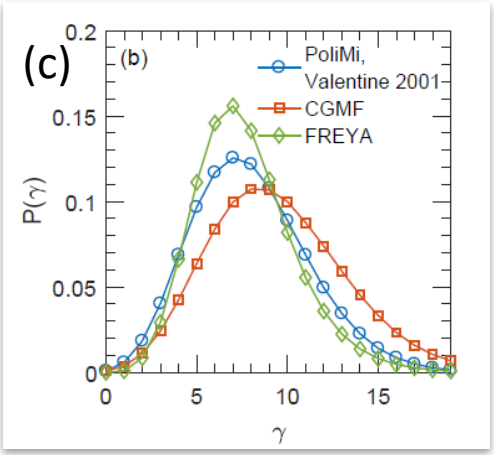
Introduction and Motivation

- Isotopes classified as *special nuclear material* (SNM) are characterized by their propensity to fission:
  - Spontaneous fission
  - Neutron-induced fission
  - Photon-induced fission
- Gamma-rays and neutrons are emitted in fission, and represent one of the most prominent fission signatures in nonproliferation
- Theory predicts correlations in the emission of neutrons and photons from fission, but we lack experimental data to validate the theory

(a)







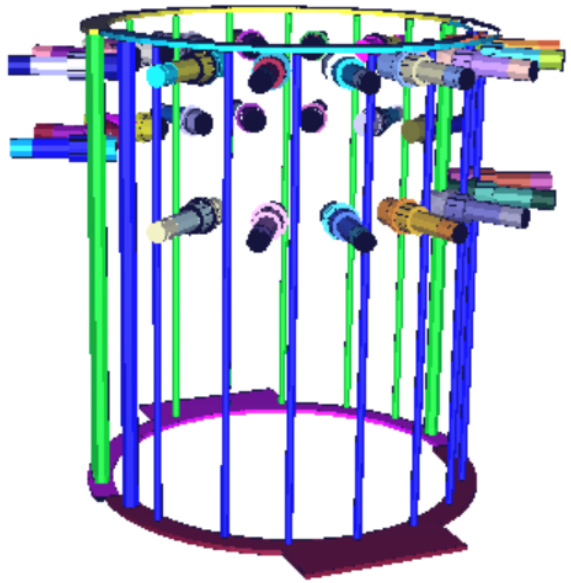
(a) Animation of the nuclear fission process and subsequent neutron photon emission [CVT-2016]
(b-c) neutron and photon multiplicity distributions in spontaneous fission of ^{252}Cf [Marcath *et al.* PRC **97**, 044622 (2018)].

M. J. Marcath, R. C. Haight, R. Vogt, M. Devlin, P. Talou, I. Stetcu, J. Randrup, P. F. Schuster, S. D. Clarke, and S. A. Pozzi *"Measured and simulated 252Cf(sf) prompt neutron-photon competition"* Physical Review C **97**, 044622 (2018)

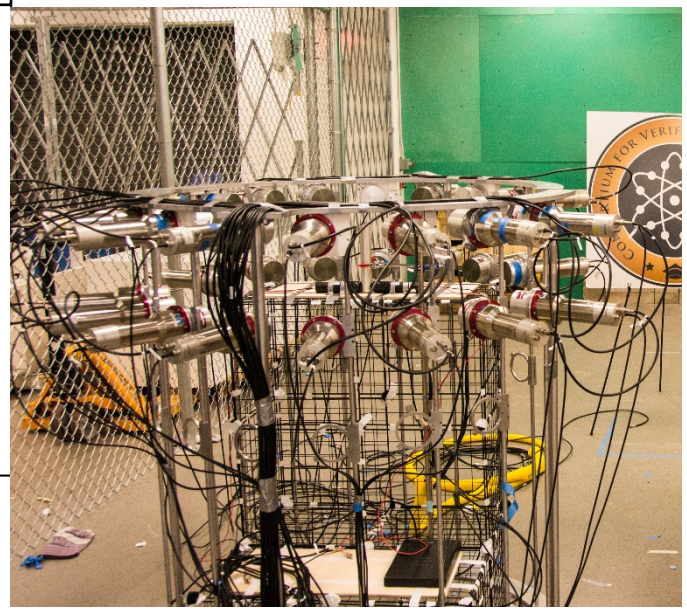
Mission Relevance

- Nuclear nonproliferation seeks to prevent the further spread of nuclear weapons around the world. SNM is a key component of nuclear weapons
  - We need robust, reliable, and fast assay techniques to identify and characterize SNM
  - The characterization of fission signatures help us develop techniques that distinguish SNM from non-SNM sources
- The development and experimental investigation of fission signatures will prompt the development of new detection technologies and techniques

MCNP model for the current multiplicity analysis experimental setup at the University of Michigan. We will use this experiment to investigate event-by-event multiplicity correlations

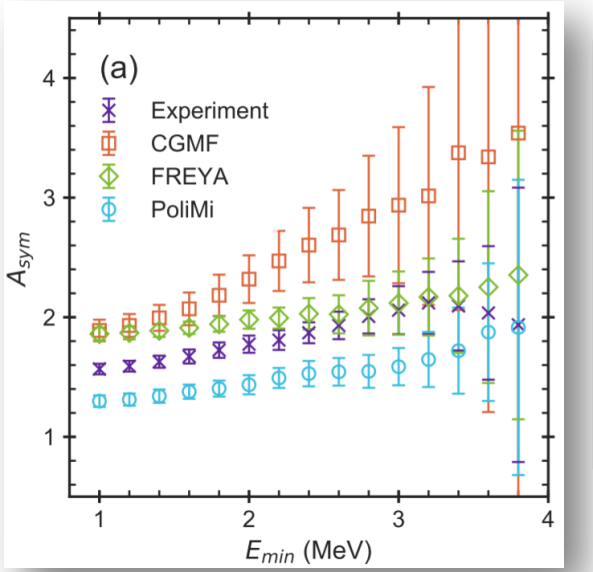


Detection array of 30 scintillators (EJ-309) surrounding a fission source. Fissions are tagged by coincident detection of two photons.

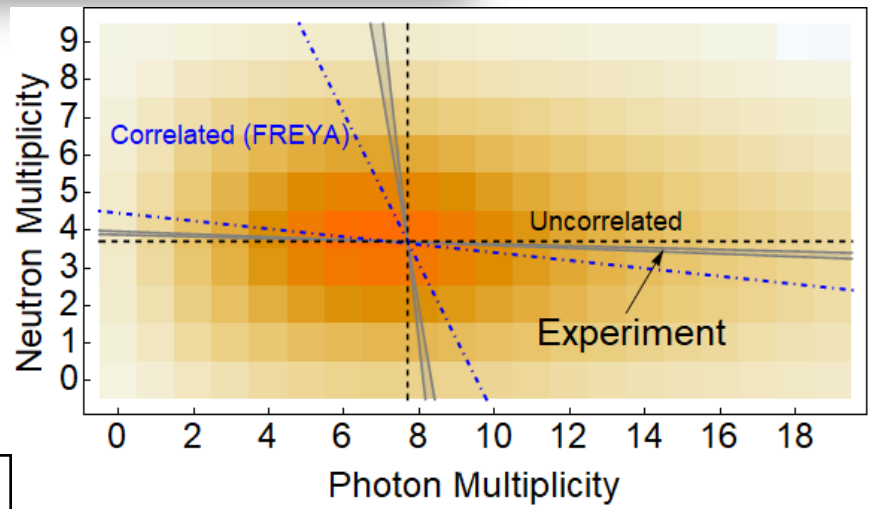


Prior work

- We experimentally investigated the energy-angular correlations of fission neutrons.
  - Characterized the anisotropic angular emission of neutrons as a function of energy
  - Found a correlation in the energies of neutrons: negative for neutrons from the same fragment, positive from the same fragment
- We experimentally investigated the multiplicity correlation of fission neutrons.
  - Neutron and photon multiplicities are functions of the same variables, a correlation is predicted
  - Unfolded the experimentally determined from the system response
  - Compared our result with theoretical and experimental results. We found a small competition in neutron and photon multiplicities



The relationship between directional asymmetry and energy. This correlated signature can be used to assess the multiplication of an unknown sample.



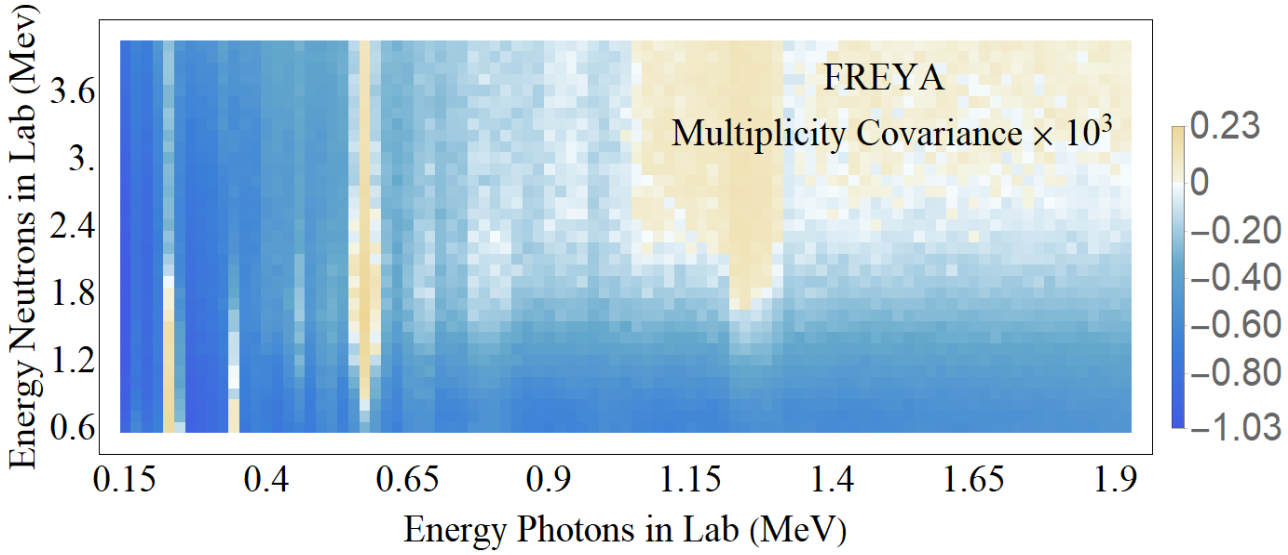
A multiplicity competition was observed in the emission of neutrons and photons from Cf252

P. F. Schuster, M. J. Marcath, S. Marin, S. D. Clarke, M. Devlin, R. C. Haight, R. Vogt, P. Talou, I. Stetcu, T. Kawano, J. Randrup, S. A. Pozzi *"High resolution measurement of tagged two-neutron energy and angle correlations in Cf-252(sf)".* Submitted to Physical Review C (2019)

Technical Work Plan: Multiplicity-momentum

We will simultaneously measure the event-by-event spectra and multiplicities of neutrons and photons from ^{252}Cf(sf):

- Experiment: simultaneously unfold multiplicity and energy
- Simulation: new emission models and system response generated with MCNPX-PoliMi
- Theory: FREYA CGMF; Preliminary results show energy-dependent competition in particle emission

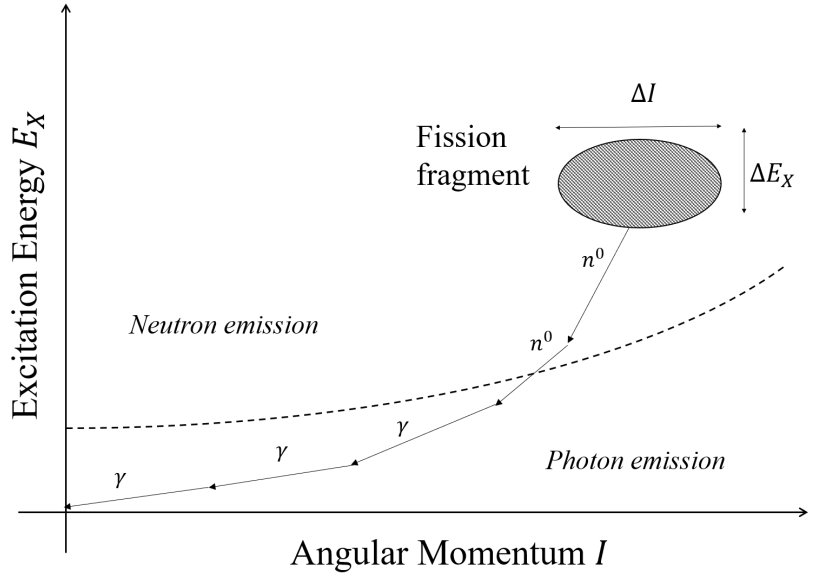


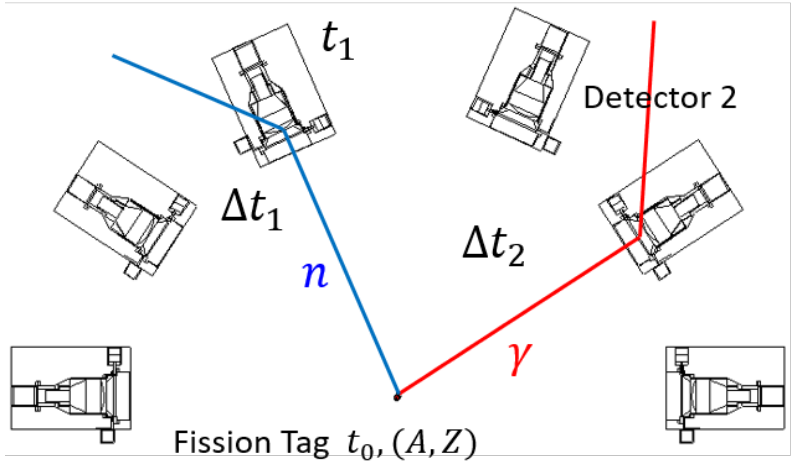
Theory: a preliminary investigation of the multiplicity-energy correlation in ^{252}Cf shows a previously unknown structure.

Technical Work Plan: Fragments

We use fragment-sensitive fission tagging in experiment (e.g. at ORNL and LANL) and perform neutron-photon analysis on ^{252}Cf(sf) for selected fragments:

- Experiment: we collect neutron-photon multiplicities in coincidence with fragment identity
- Simulation: Compare event-by-event correlations from individual fragments with prediction by fission event generators (CGMF/FREYA)
- Theory: Known values of fragment properties can be used to reconstruct nuclear de-excitation path



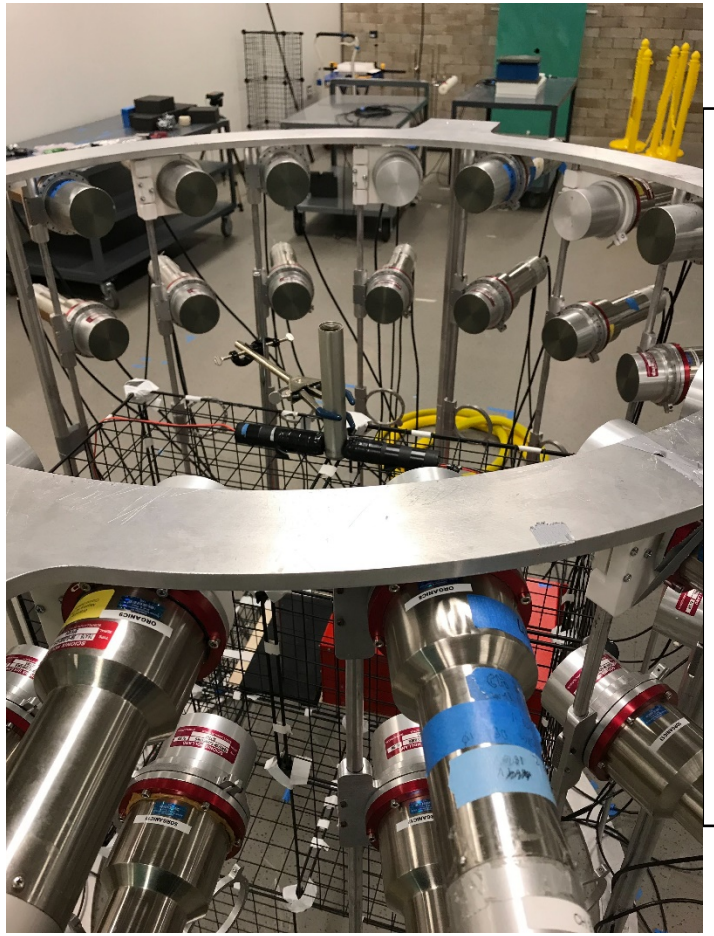


We can measure the neutrons and photons emitted by specific fragments during de-excitation. We can compare the measurements directly with the predictions based on physics models.

Technical Work Plan: SNM

We apply the unfolding techniques developed for ^{252}Cf(sf) to isotopes of interest in nonproliferation:

- ^{240}Pu spontaneous fission:
  - Compare de-excitation emission with ^{252}Cf
  - Background contamination from (α, n) on oxides
- ^{235}U induced fission:
  - Find correlations in emitted neutrons and photons as functions of inducing particle energy
  - Predictions of correlations in fission chains and subcritical SNM

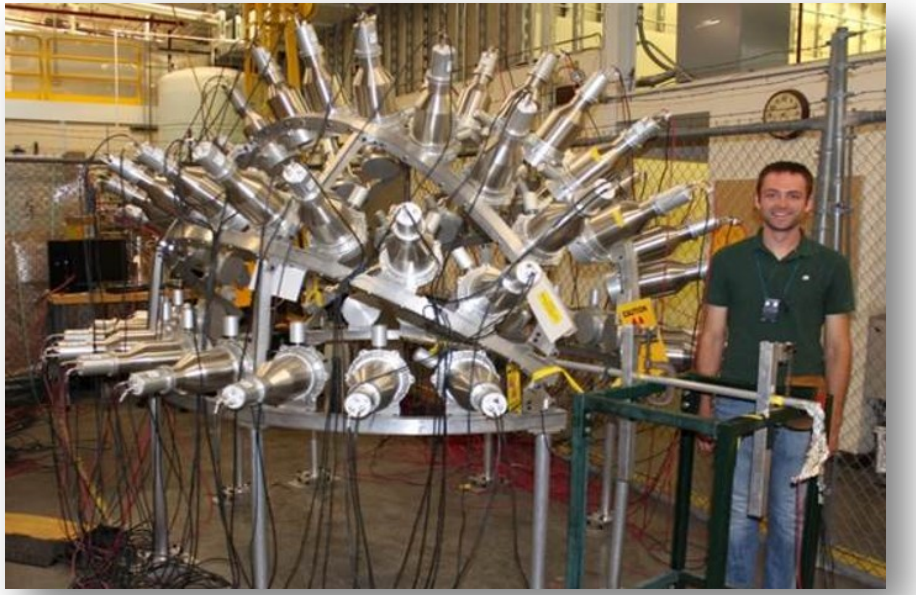


Experimental data for all the proposed measurements are collected in a similar way:

- Large number organic scintillators (30+ stilbenes/EJ309) to detect neutrons and photons.
- Fission tagging system to provide time of flight (and fragment ID)

MTV Impact

- Thanks to the connections provided by the MTV consortium, we will collaborate with national labs to investigate neutron-photon emission from fission fragments.
- Facilities at national labs will provide us access to fragment detection technologies:
  - TRIFECTA detection system at **ORNL** (collaborators: M. Febbraro, M. Smith, W. Peters)
  - SPIDER detection system at **LANL**-LANSCE (collaborators: P. Talou, M. Rising)
- Validation of fission physics models:
  - CGMF code, **LANL** (collaborators: P. Talou, M. Rising)
  - FREYA code, **LLNL/LBNL** (collaborators: R. Vogt, J. Randrup)
- We will improve the precision of our scintillation detection system for neutron-photon measurements:
  - Increasing number of detectors
  - Refining system response models



We collaborated with LANL to investigate neutron-photon multiplicity correlations. Pictured: Matthew Marcath (now at LANL) in front of the Chi-Nu array at LANSCE.

Expected Impact

- New experimental data will be used to validate and improve theoretical physics-based fission event generators CGMF and FREYA
  - Publish results in peer-reviewed publications and include in ENDF libraries
- We will explore the relationship between fragment identity and event-by-event neutron and photon correlations for the first time
  - Inform a complete description of the fission process and the correlated emission from SNM
- We will identify and characterize new correlated signatures
  - The results of our experimental investigation will be published in peer-reviewed publications and included in ENDF and MCNP libraries

Conclusion

- Thanks to improvements in measurement technologies and techniques, previously inaccessible fission signatures can be directly observed
- We will validate and improve physics-based and data-based fission event generators, for use in nonproliferation applications
- The relationship between fragment identity and event-by-event correlations will be explored for the first time, to inform a complete description of the fission process

Acknowledgements

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