Neutron-Gamma Angular Correlations in Fission

MTV Workshop, 2022

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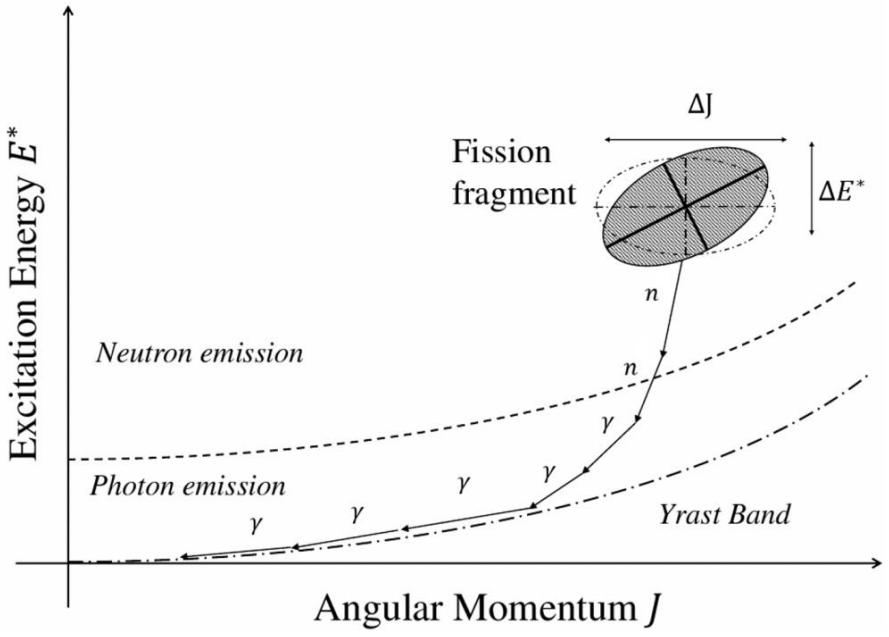
Introduction and Motivation

Accurate simulation codes of nuclear fission are foundational in nonproliferation applications

- Importance of correlations in coincidence counting
- Highly asymmetric and inefficient detection systems

Some aspects of nuclear fission are not known

- Gamma-ray emission and angular distributions are regulated by the fragments *angular momentum*
- The angular momentum is the least understood of all aspects of fission



The excitation and de-excitation of fission fragments.

S. Marin *et al.*, "Structure in the event-by-event energy-dependent n-γ multiplicity correlations in fission", PRC **104**, 024602, (2021)

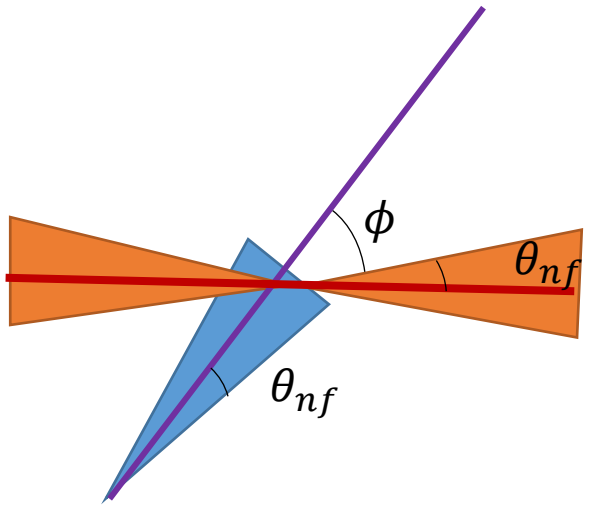
Mission Relevance

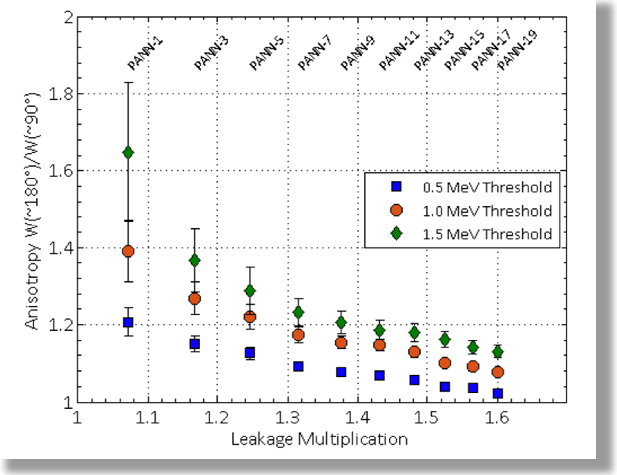
We work closely with the developers of fission codes used routinely in nuclear nonproliferation applications:

- CGMF (LANL)
- FREYA (LLNL,LBNL)

Code improvements have two effects:

- Reduce errors in known nonproliferation techniques
- Reveal new signatures of fission for improved characterization





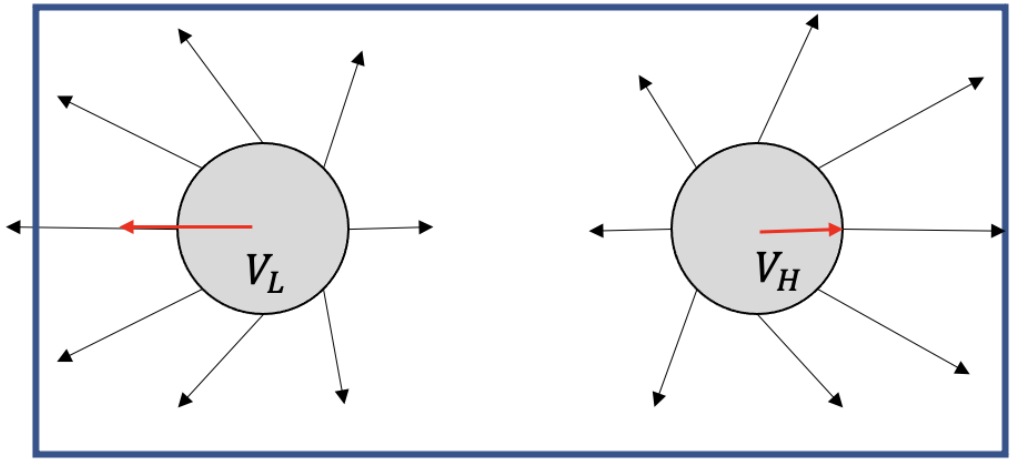
Anisotropy of neutrons can be used to assess the multiplication of a sample

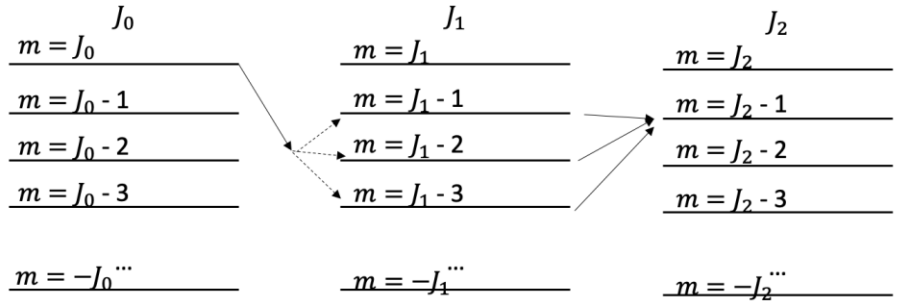
T. H. Shin *et al.* *"Prompt fission neutron anisotropy in low-multiplying subcritical plutonium metal assemblies"* Nuclear Instruments and Methods A **915** (2019)

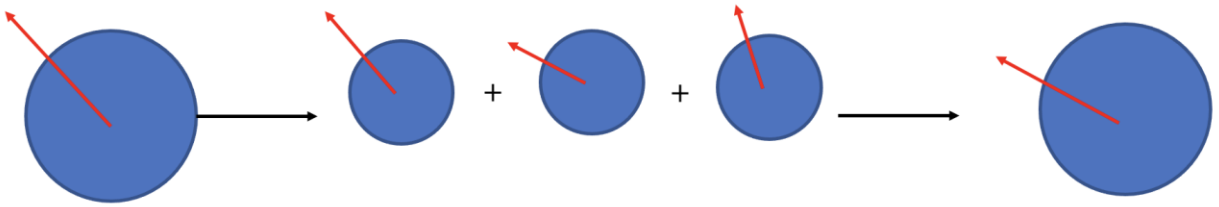
Sources of Angular Correlations

Several sources of n-γ angular correlations:

- **Angular momentum alignment with fission axis**
- Doppler effect and γ aberration
- Quantum-mechanical entanglement







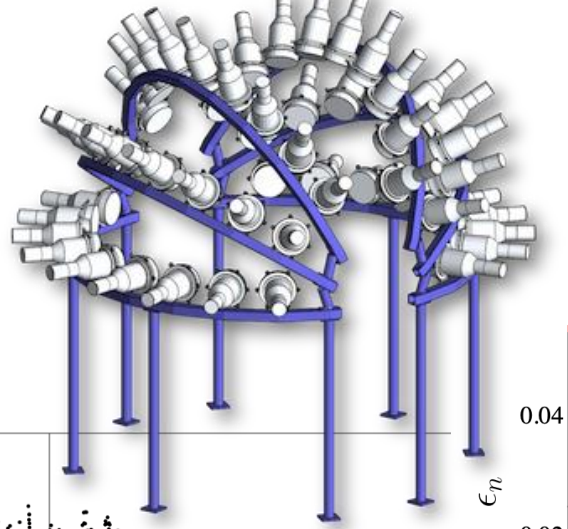
Technical Approach

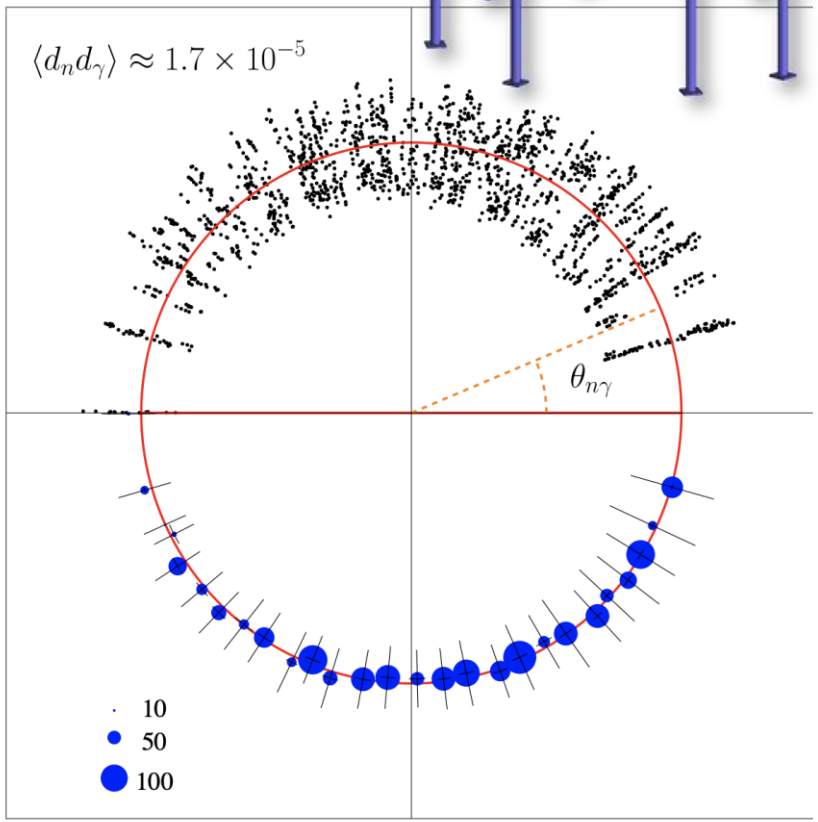
We analyze experimental data to draw conclusions on the microscopic description of the fragment angular momenta

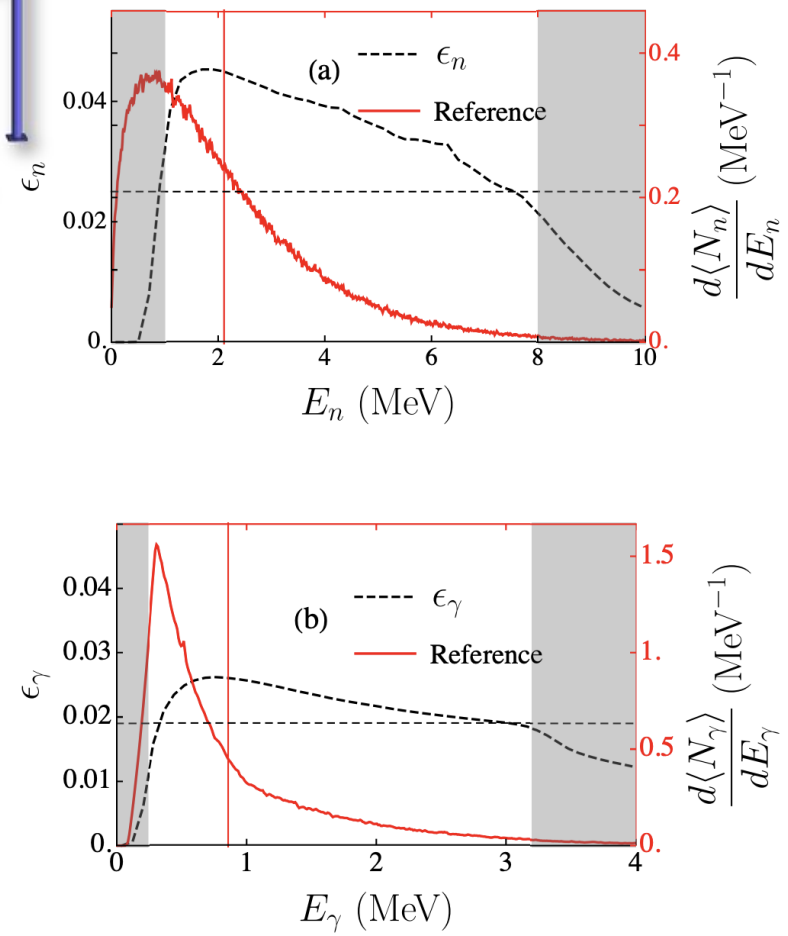
The data were collected using Chi-Nu, an array of organic scintillators sensitive to neutrons and gamma rays

The response of the system was simulated in MCNPX-PoliMi and analyzed for systematic biases

We analyze the $n-\gamma$ emission correlations and their relative angles of emission







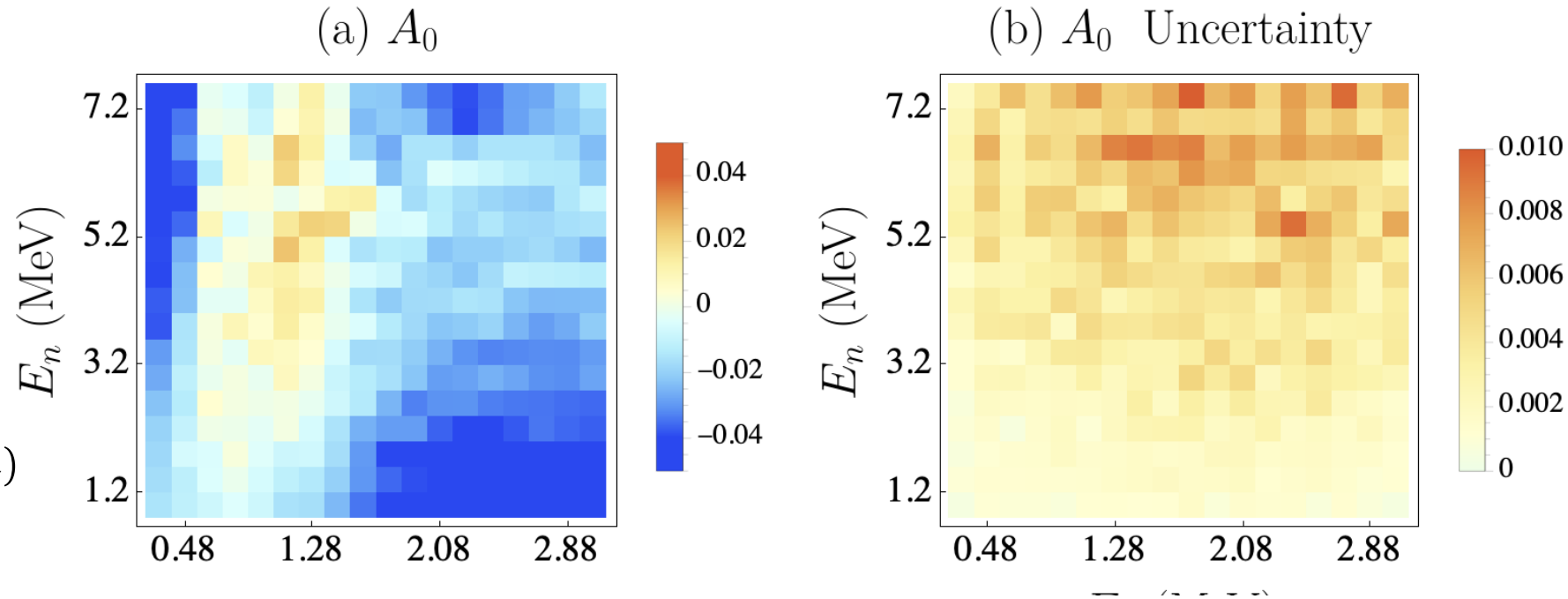
Schuster et al. , Phys. Rev. C **100**, 014605
Marin et al. 2021, Phys. Rev. C **104**, 024602
Mari et al. 2022, Submitted to Phys Rev C.

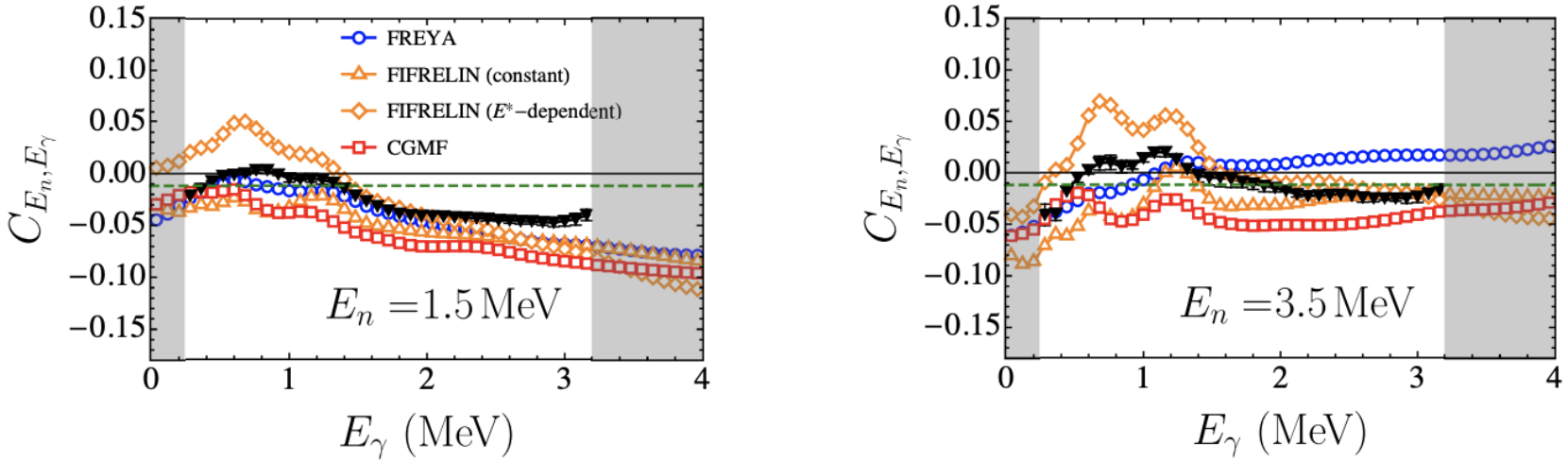
Emission

The angular dependence of the event-by-event $n-\gamma$ emission correlations can be separated

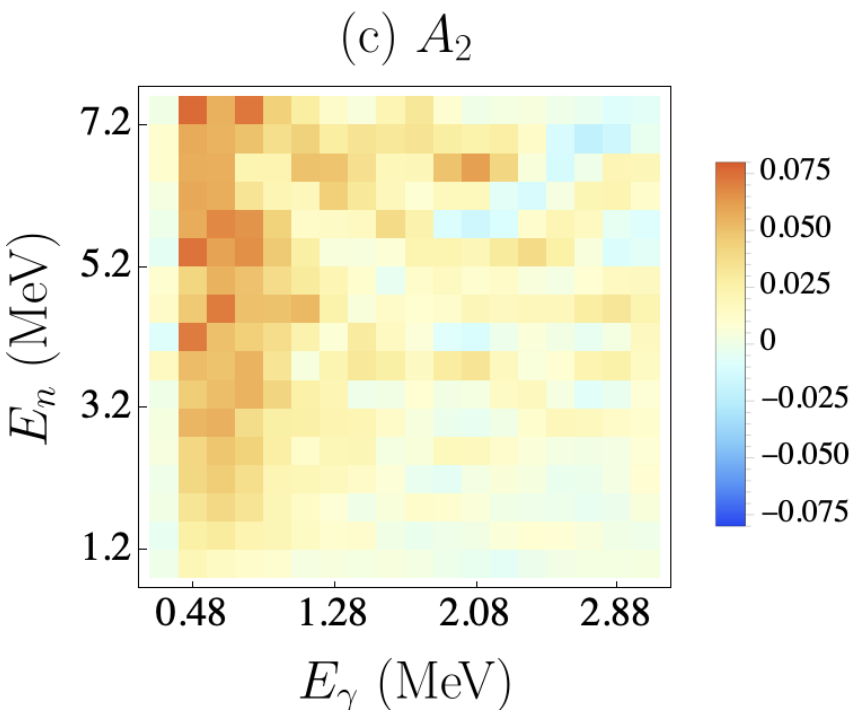
$$C_{E_n,E_\gamma,\theta_{n\gamma}} = A_0(E_n,E_\gamma) + A_2(\mathrm{E_n},\mathrm{E}_\gamma)P_2(\theta_{n\gamma})$$

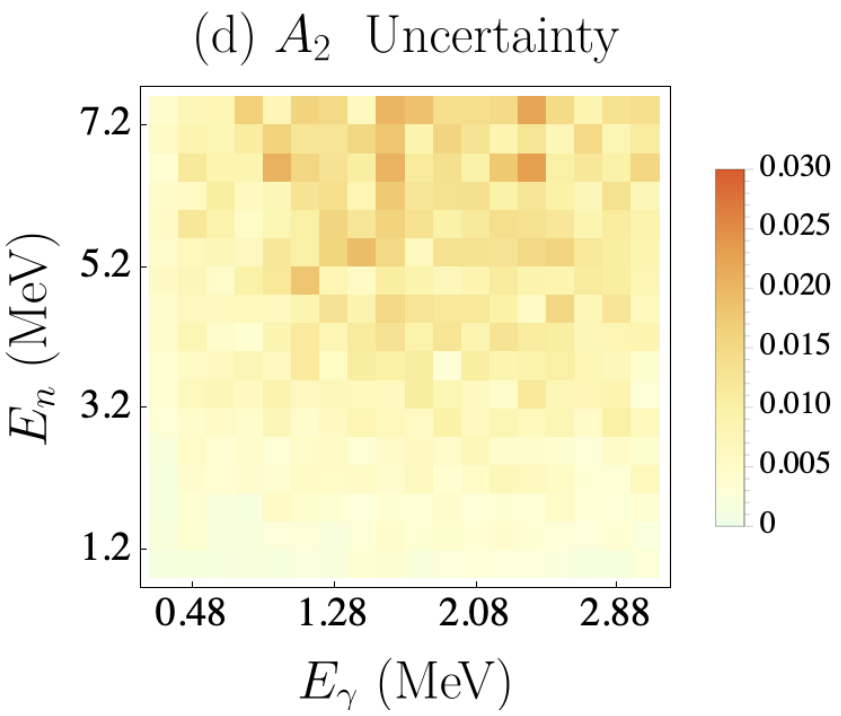
The tendency of neutrons and gammas to align parallel or perpendicular to one another is described by A_2

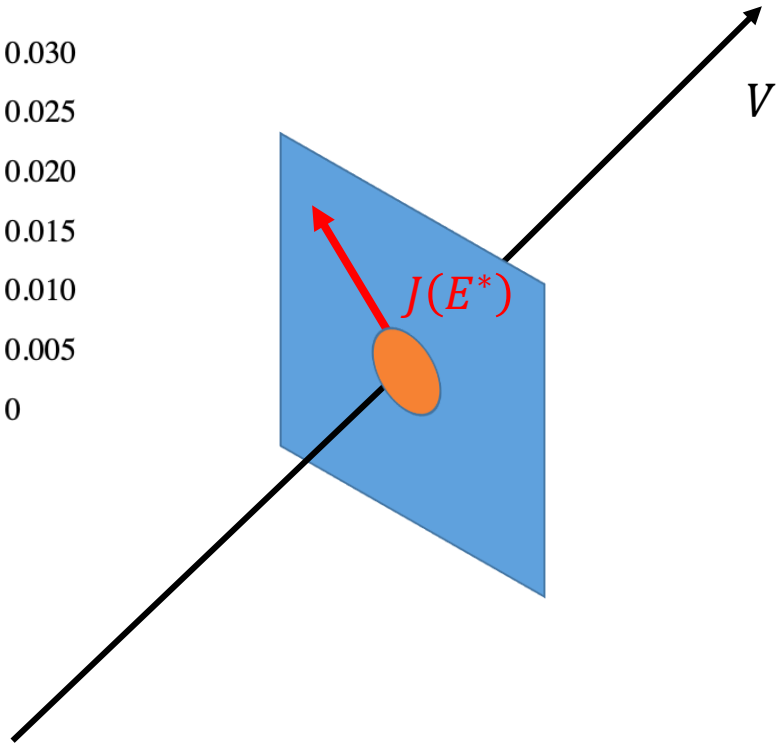




Angular Correlation







Expected Impact

Our research group is currently focused on the generation of fragment angular momentum and its effects on n-γ emission correlations

We are taking several approaches to solving this problem:

- Event-by-event n-γ correlations to understand how internal variations in energy correlate to angular momentum
- Neutron induced fission, to understand how external sources of energy correlate to angular momentum
- Fragment-based investigation, to understand the linearity of angular moementum

If successful, we expect the results of our investigation to improve current theoretical models of nuclear fission

Fission Team Members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Lab Collaborations

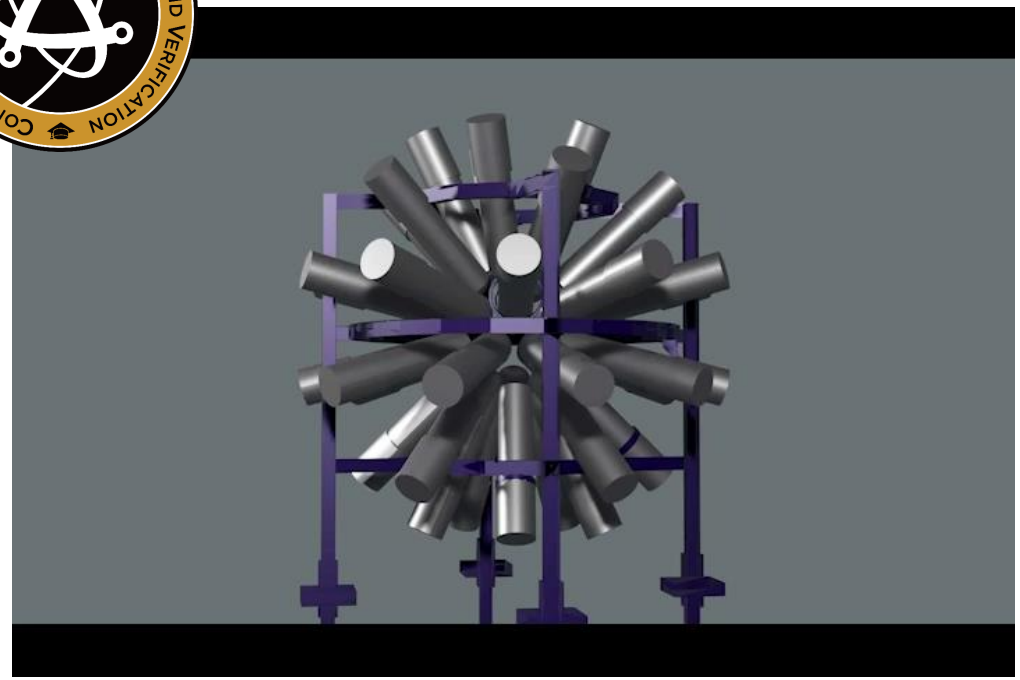
MTV Impact

The support of MTV has made this research possible:

- Research funding and instrumentation
- Motivated students to work on projects
- **Many** national lab collaborations

Thanks to MTV, we have been able to realize the entire experimental cycle:

- Studying the theory
- Designing the experiment
- Analyzing the data
- Drawing physical conclusions



Conclusion

Our investigation of fission has shown for the first time that there is a dependence of angular momentum on excitation energy on an event-by-event basis.

The results we have developed so far are not yet precise enough to be considered data; however, they indicate that further refined experimental investigation is needed.

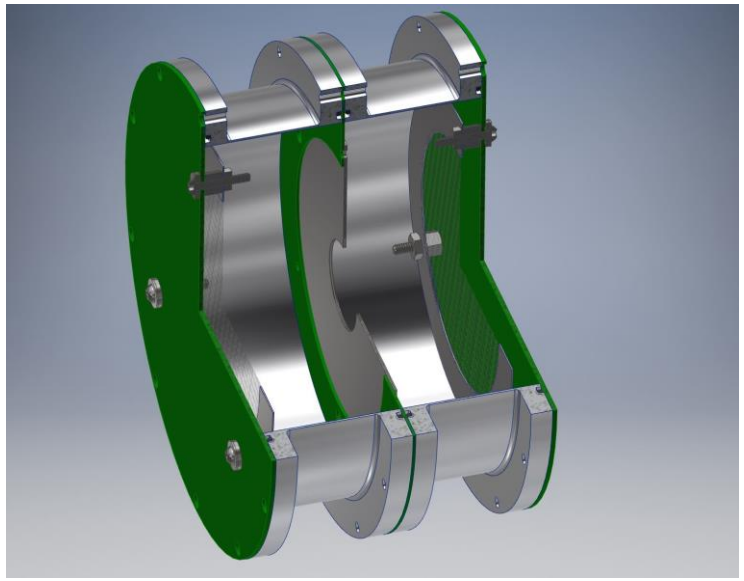
The topic of fission fragment angular momentum has received incredible interest in the past two years, the outcome of current research will shape how we understand fission in the future.

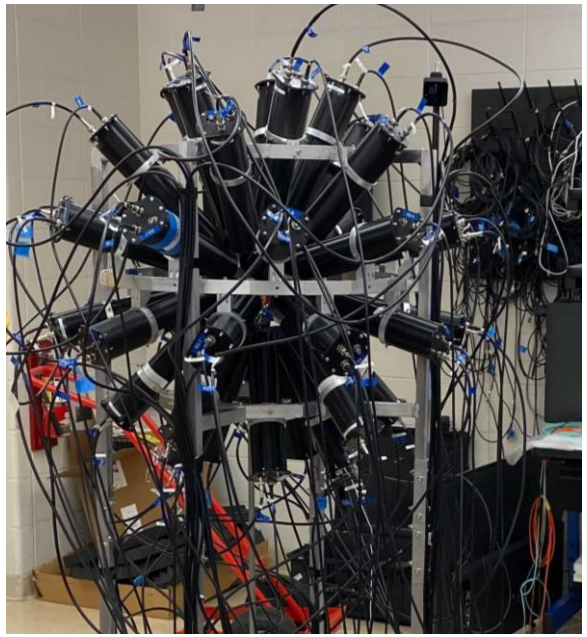
Next Steps

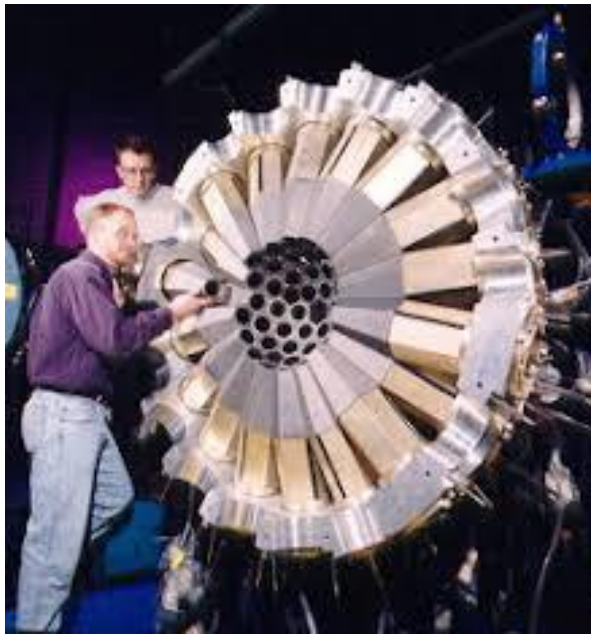
I am currently at Argonne National Laboratory to work on the next phase of the project

Fragment-based investigation of $n - \gamma$ emission correlations

Experiment will be performed in April, and results will be presented by the Fall 2022







Acknowledgements

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