FIDGET: A Widget for Simulating Fission Neutron Spectra and Fission Fragment Distributions

Ramona Vogt (LLNL and UC Davis)

Jørgen Randrup (LBNL)

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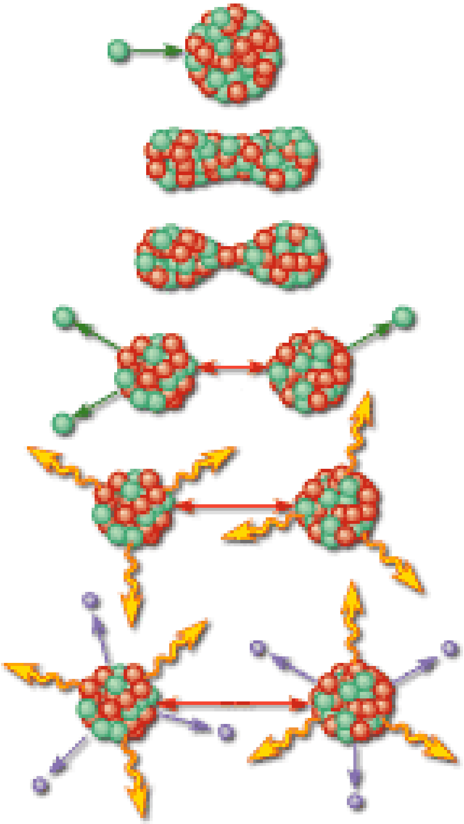
Schematic Fission Process:
Compound Nucleus to Fission Products



The neutron strikes the nucleus and is absorbed.

The absorbed neutron causes the nucleus to undergo deformation.

In about 10^{-14} second, one of the deformations is so drastic that the nucleus cannot recover.

The nucleus fissions, releasing two or more neutrons.

In about 10^{-12} second, the fission fragments lose their kinetic energy and come to rest, emitting a number of gamma rays. Now the fragments are called fission products.

The fission products lose their excess energy by radioactive decay, emitting beta particles and gamma rays over a lengthy time period (seconds to years).

🟢 neutrons	🔴 protons	● beta particles	⚡ gamma rays

We Are Developing a Detailed Event-by-Event Model of Fission Correlations:

- Binary fission
- Excited, moving fragments
- Prompt neutron emission simulated by neutron evaporation
- Gamma and charged particle emission to be added later

Our Monte Carlo Method Allows Rich Account of Fission in Codes:

- Accounts for microphysics leading to neutron production

- Event-by-event nature of calculation means that any correlation observable, such as energy, neutron multiplicity and angular correlations, are accessible

- Follows neutrons from individual fragments

Why Event-by-Event Monte Carlo?

Monte Carlo event-by-event simulations provide full information and can thus give access to any correlation observable of interest:

- The treatment is based on available data supplemented by models.

- The code can make predictions of new observables and can help identify future measurements of particular importance.

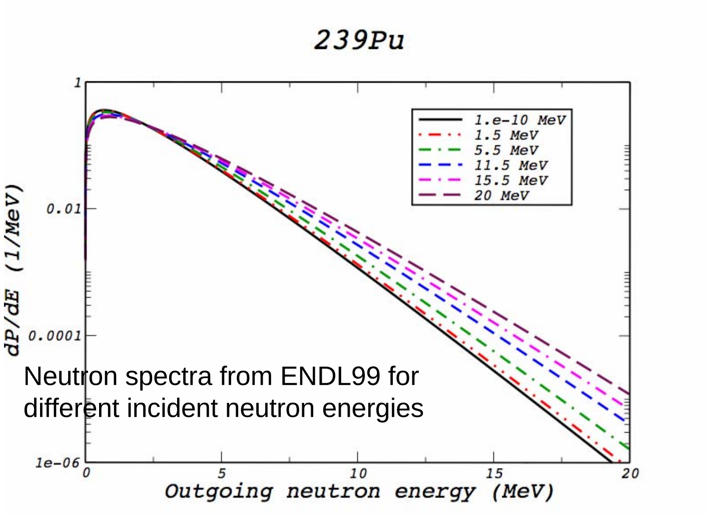
- Monte Carlo can provide energy and momentum of all emitted particles in an event: fission products, neutrons, gammas and charged particles (p, d, t, ^{3}He, ^{4}He).

- Since all particles are followed, all correlations are retained so that any correlation observable can be readily extracted from an event sample.

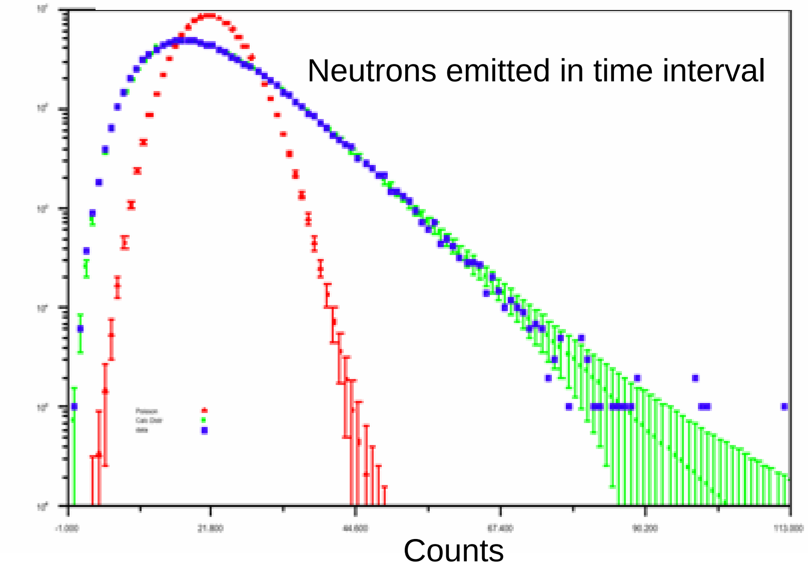
- Fast: FIDGET generates 1,000,000 events in 12 s on a MacBook.

Applications: Why we need to go beyond averages in fission modeling

- Current databases can provide neutron spectra for average but don’t know about the neutron number
- Models can calculate number of neutrons but have no information about energy dependence [Random source is Poisson (red) while neutrons from fission chains (green, Snyderman and Prasad) agree with data (blue)]
- Correlations between neutron number and energy are missing
- Event-by-event Monte Carlo can follow fission chains and automatically provide correlations



Neutron spectra from ENDL99 for different incident neutron energies



Neutrons emitted in time interval

Basic Method:

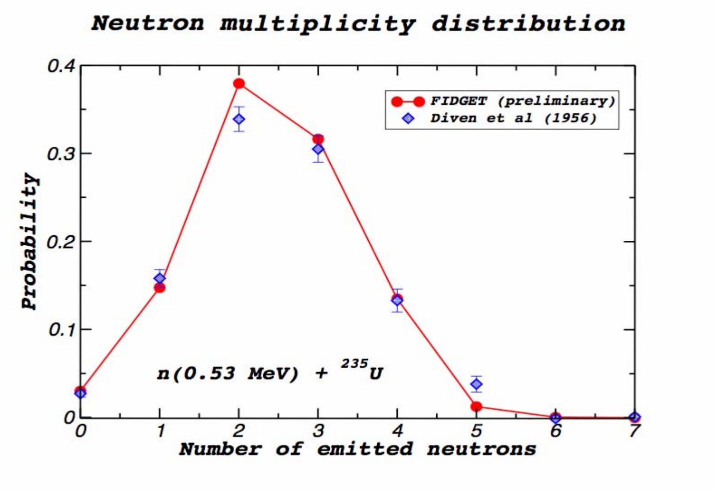
For a given incident neutron energy, E_n, and target nucleus, *A,* with charge *Z*:

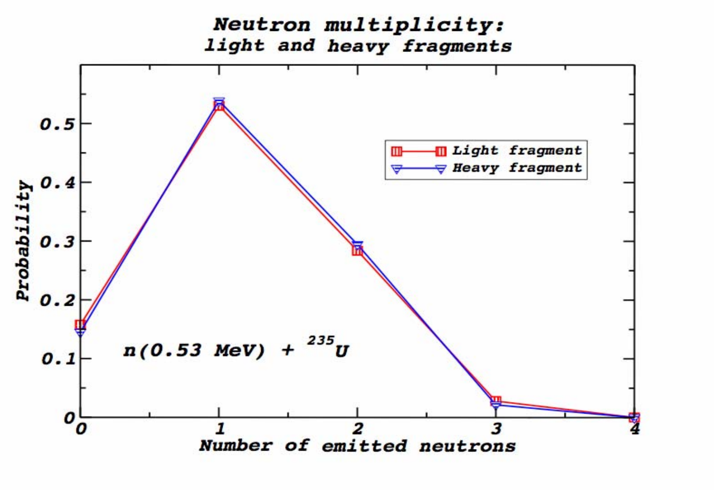
- Select mass and charge of light, *L*, and heavy, *H*, fragments from fission fragment distributions;
- Pick velocities and excitation energies of the fission fragments;
- Evaporate neutrons from the moving & excited fragments until their excitation energy is too low for further neutron emission;
- Preliminary results shown here for 0.53 MeV neutrons on ^{235}U.

Neutron multiplicities

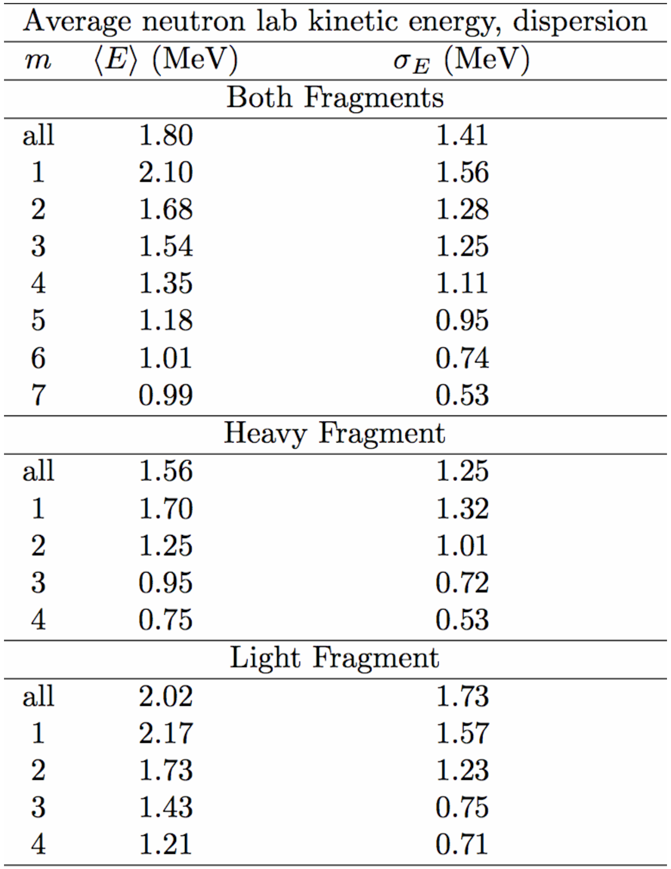
Average number of emitted neutrons

Fragment	$\langle m \rangle$	σ_m
Both	2.37	0.75
Light	1.18	0.67
Heavy	1.19	0.42

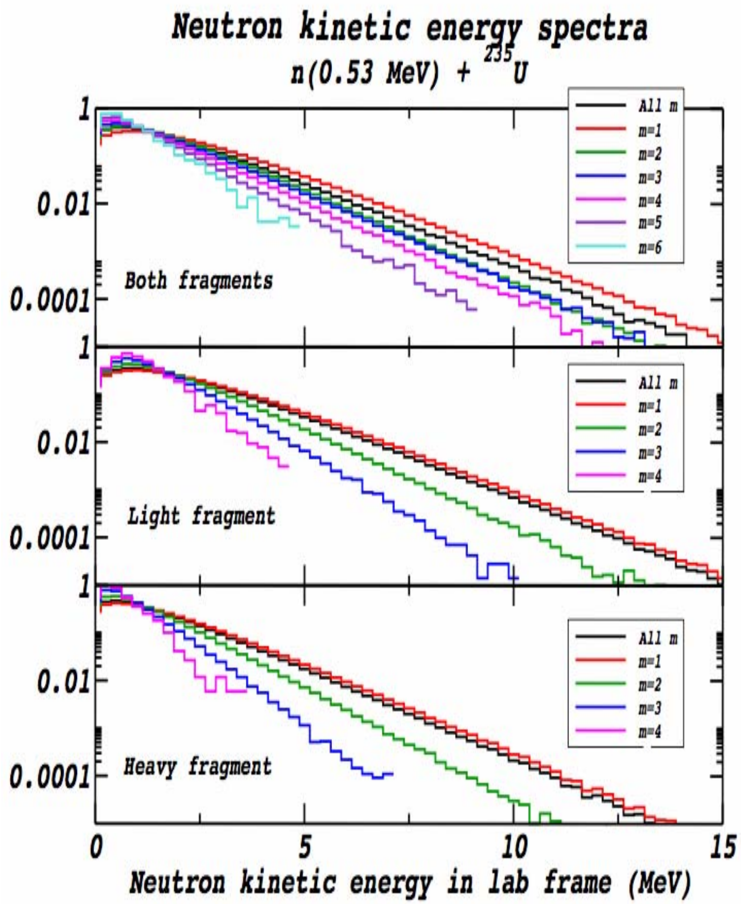




Neutron kinetic energy spectra in lab frame

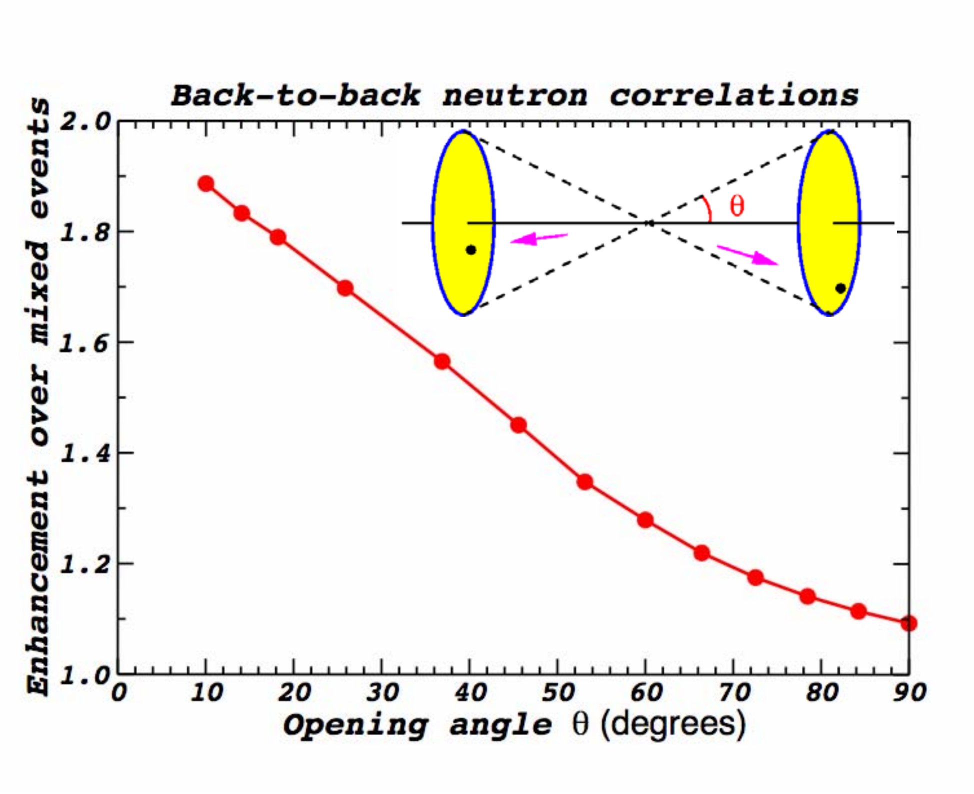


Average neutron lab kinetic energy, dispersion		
m	$\langle E \rangle$ (MeV)	σ_E (MeV)
	Both Fragments	
all	1.80	1.41
1	2.10	1.56
2	1.68	1.28
3	1.54	1.25
4	1.35	1.11
5	1.18	0.95
6	1.01	0.74
7	0.99	0.53
	Heavy Fragment	
all	1.56	1.25
1	1.70	1.32
2	1.25	1.01
3	0.95	0.72
4	0.75	0.53
	Light Fragment	
all	2.02	1.73
1	2.17	1.57
2	1.73	1.23
3	1.43	0.75
4	1.21	0.71



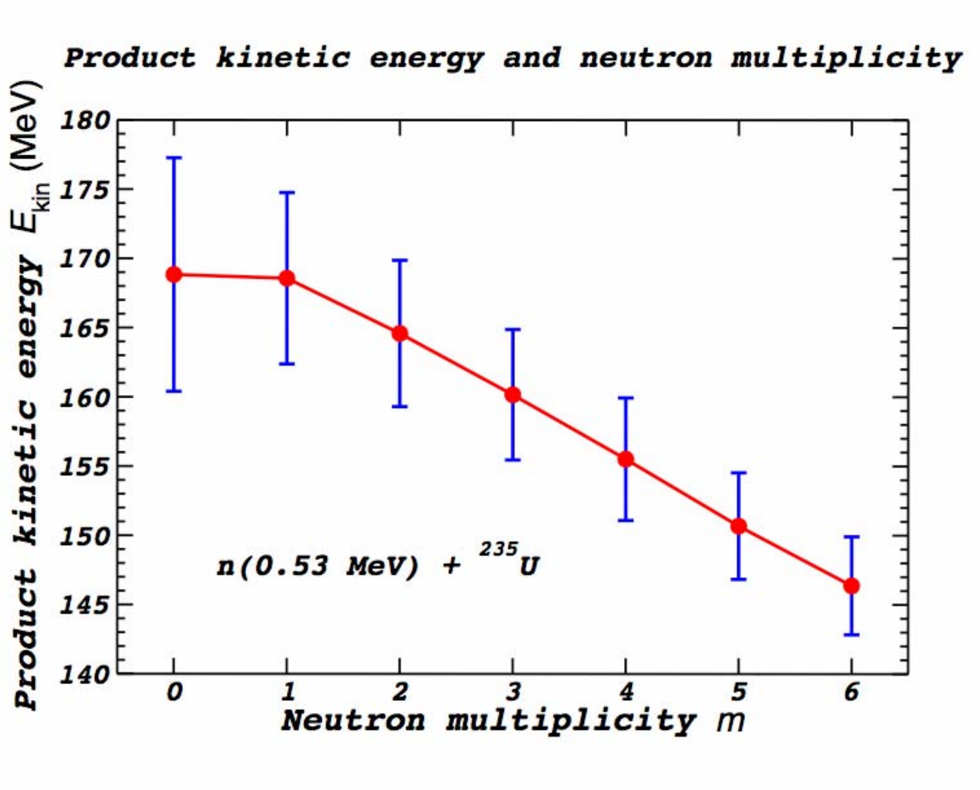
Neutron angular correlations

- Emitted neutrons should exhibit enhanced angular anti-correlation since they come from two oppositely-moving, excited fragments.
- Coincident emission into two opposite angular cones is enhanced for smaller opening angle θ.
- Mixed-event background takes the two neutrons from separate events -- enhanced emission occurs for neutrons from the same event.



Correlation of neutron multiplicity with fission product kinetic energy

- Product kinetic energy decreases with increasing neutron multiplicity
- Lower kinetic energy correlated with greater fragment excitation energy
- ‘Error bars’ indicate kinetic energy dispersion -- narrower dispersion for large multiplicity



Summary

- Monte Carlo goes beyond average quantities
- Powerful new method for studying correlations event-by-event
- Includes available data and employs extrapolation of data with plausible models to make predictions
- Modular code to facilitate inclusion of new data
- Fast for incorporation into transport studies