Two Neutron Correlations in Photofission

a possible IAC experiment

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Who cares?

NNSA Funding Opportunity Announcement

(Proliferation Detection Research, Issue date 09/30/10, page 6):

"Applications are sought in addressing gaps in our current understanding of ionizing radiation and neutron emission. In general, gamma-ray and neutron emissions from special nuclear materials have been well characterized across various parameters including magnitude, energy, and time. *Gaps persist in the understanding of joint probability distributions, for example when considering correlated neutron emissions across energy and angle* or correlations between prompt gamma-ray and neutron emissions. Other gaps in nuclear data are needed to fully exploit photo fission and nuclear resonance fluorescence signatures. Applications are sought that address these data gaps and clearly articulate their relevance to developing systems or methods for nonproliferation missions."

How nuclei decay – lots of photons

- Single particle states – shell model
- Nuclear rotations – semi-rigid rotor
- Nuclear vibrations – 1,2,3 phonons
- …

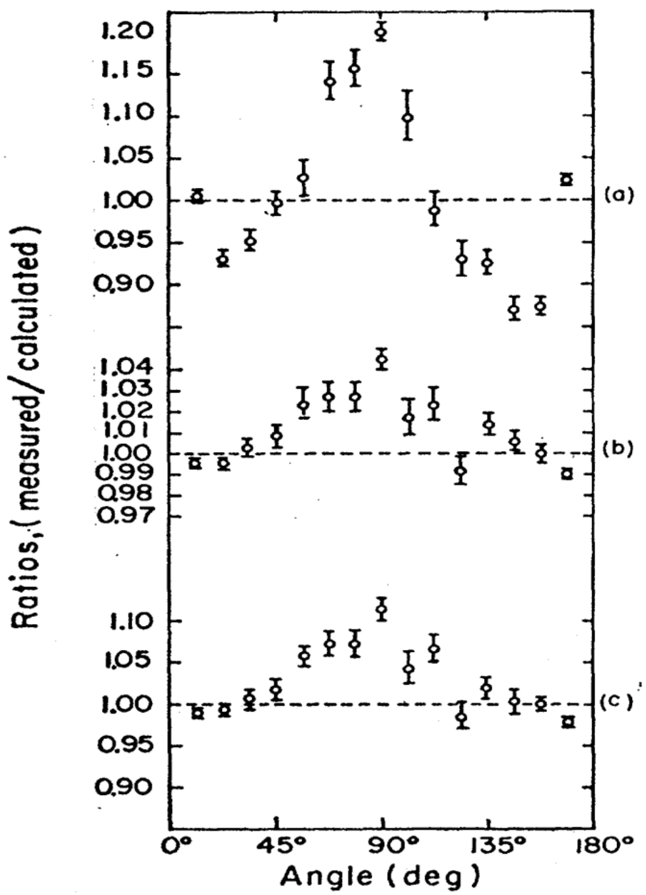
Possible sources of prompt fission neutrons

- Scission neutrons.
- Emitted from fully accelerated fission fragments.
- Something in between.

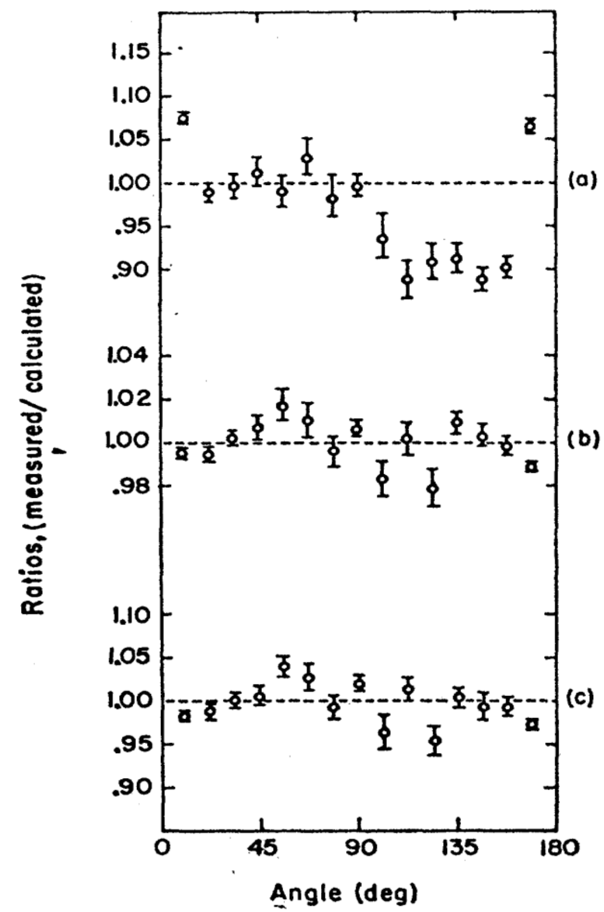
Velocity and Angular Distributions of Prompt Neutrons from Spontaneous Fission of Cf^{252}.

(Bowman, et al., Phys. Rev. 126, Number 6, 2120, 1962.)

No scission neutrons



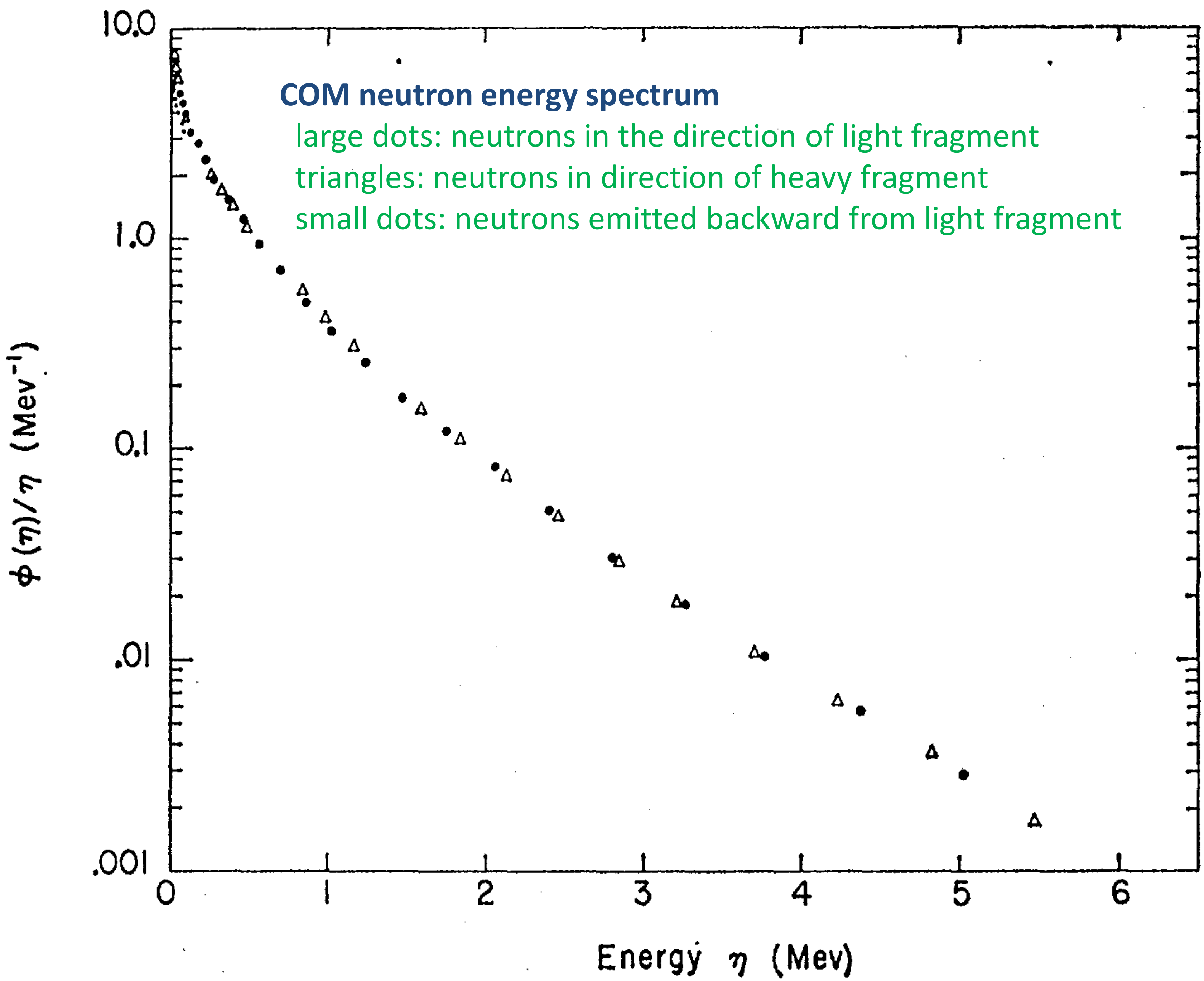
10% scission neutrons



Neutron number

Average speed

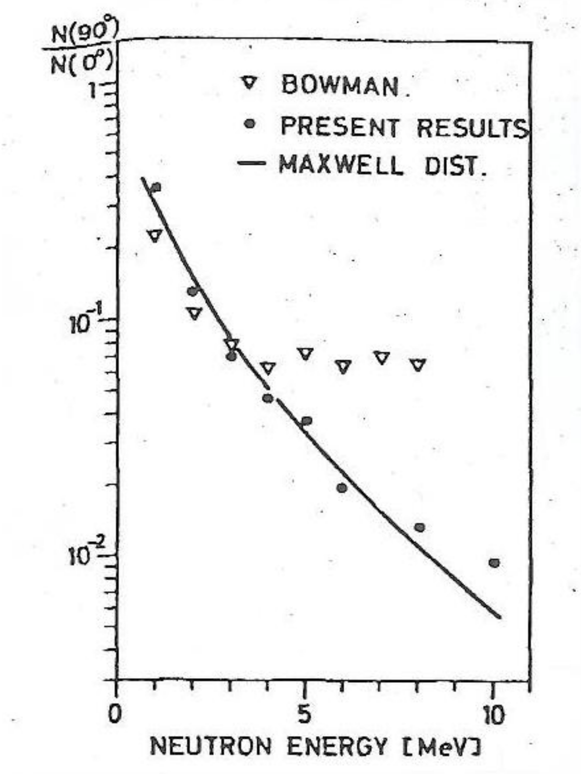
Average energy

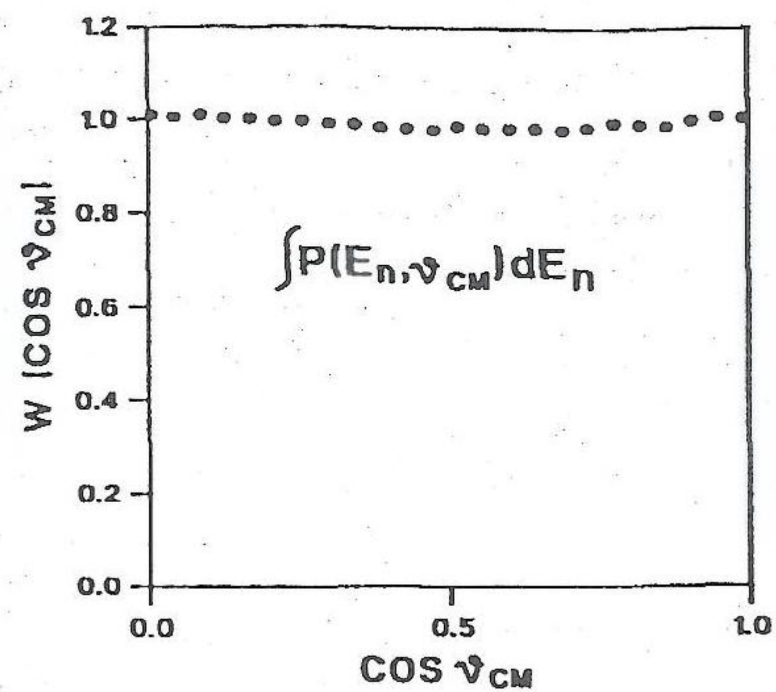


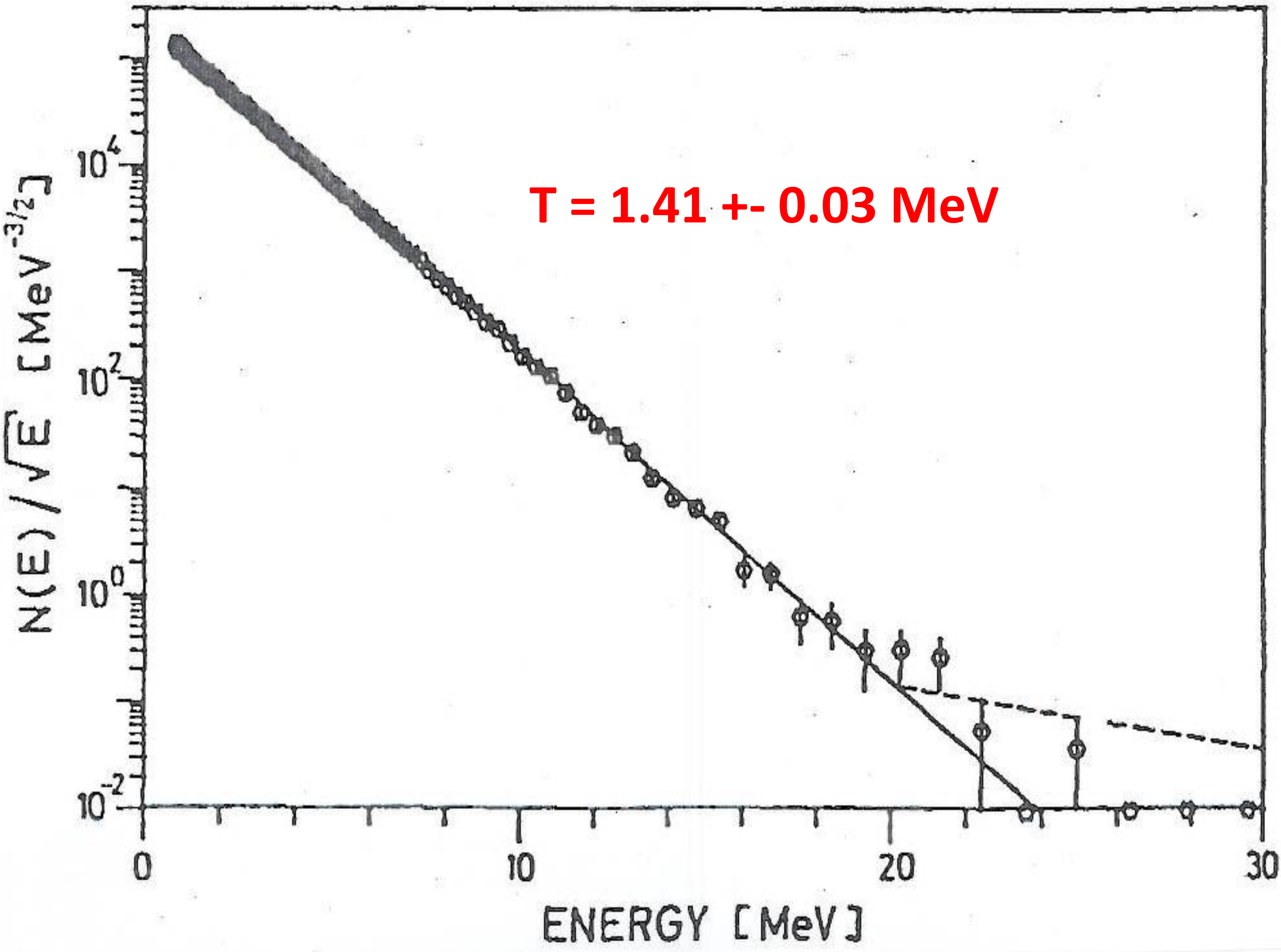
COM neutron energy spectrum
large dots: neutrons in the direction of light fragment
triangles: neutrons in direction of heavy fragment
small dots: neutrons emitted backward from light fragment
10.0
1.0
0.1
.01
.001
0
1
2
3
4
5
6
φ (η)/η (Mev⁻¹)
Energy η (Mev)

Simultaneous Investigation of Fission Fragments and Neutrons in ^{252}Cf (SF).

(C. Budtz-Jorgensen and H.-H. Knitter, Nuc. Phys A490, p. 307, 1988.)



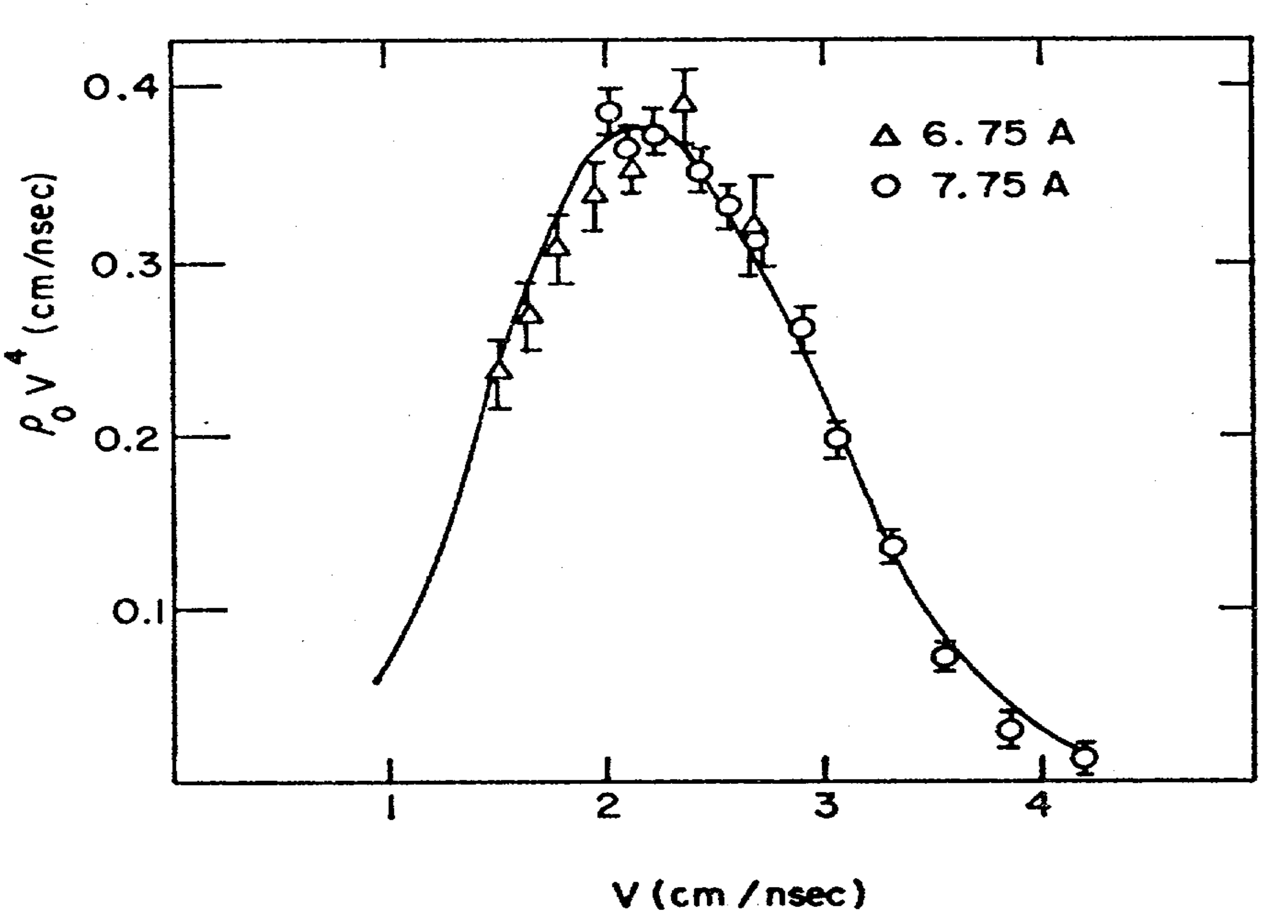




T = 1.41 +- 0.03 MeV
N(E) / √E [MeV^-3/2]
10^4
10^2
10^0
10^-2
0
10
20
30
ENERGY [MeV]

Prompt Neutrons from Thorium Photofission

(C.P. Sargent, et al., Phys. Rev. vol. 137, no. 1B, 89, (1965)



Scission neutron fraction: 0.07+-0.09

Basic idea

- **Fission fragments are essentially back to back.**
- **Rather than look at FF-neutron correlations, look at neutron-neutron correlations.**
- **Neutrons "boil off" of fission fragments isotropically in their c.o.m. frame. $\beta_n \sim 0.04c$.**
- **Fission fragments have $\beta_{FF} \sim 0.05c$, boosting neutrons along direction of motion.**

→ Will this be seen in correlations between two neutrons?

Monte Carlo simulation assumptions:

- The fission fragment mass distribution was sampled uniformly between $85<A<105$ and $130<A<150$.

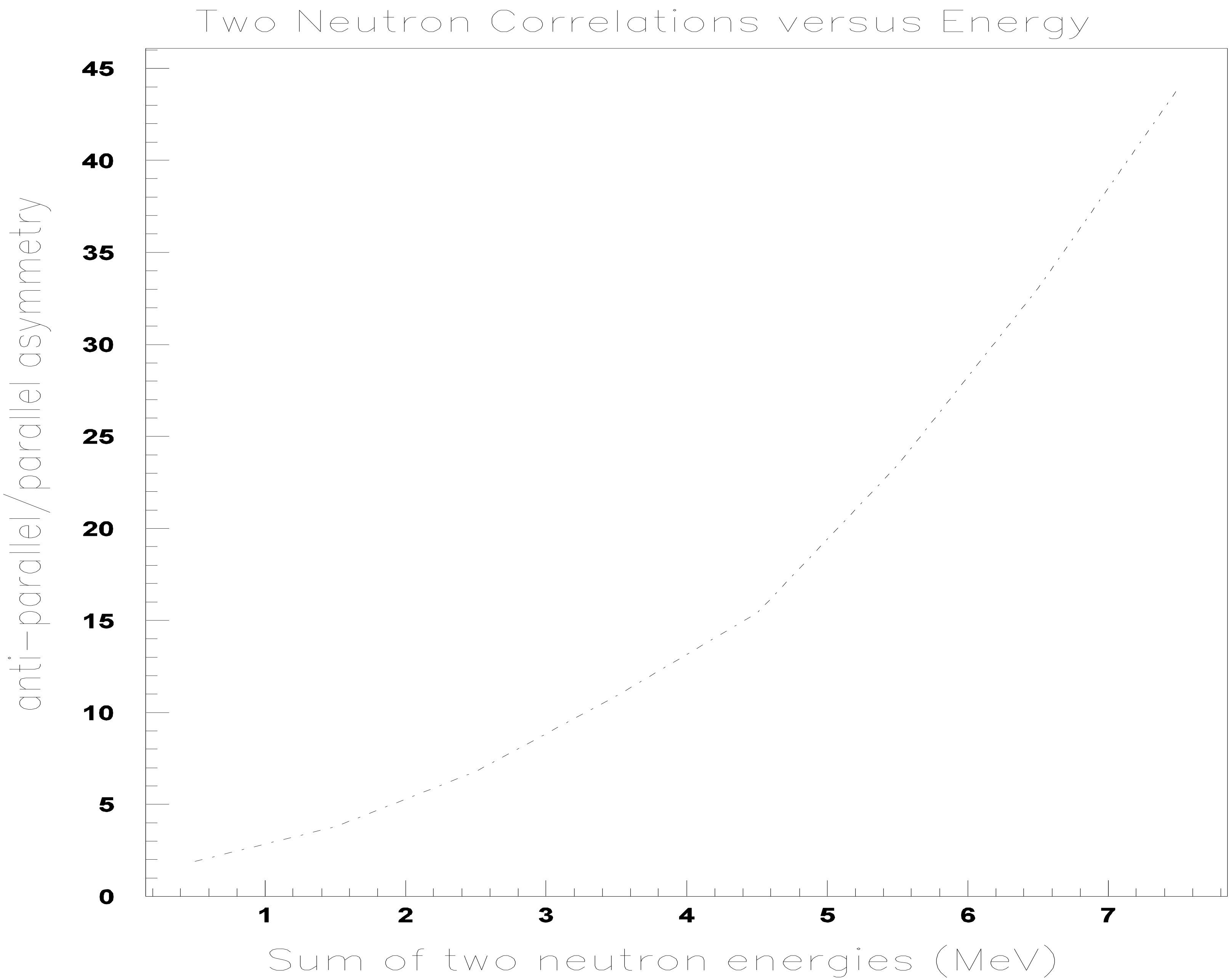
- A fixed amount of total kinetic energy, 175 MeV, is given to the two fission fragments.

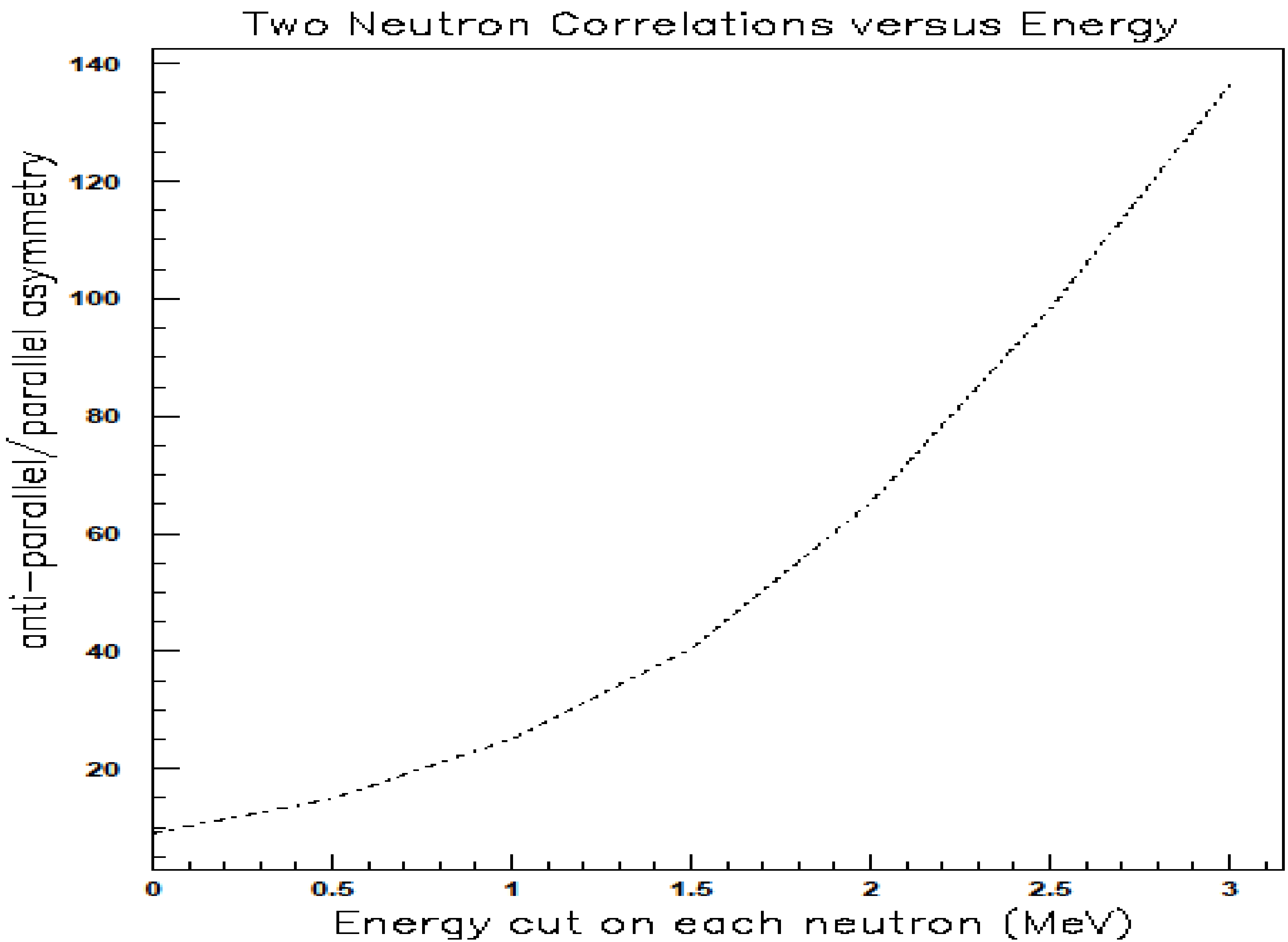
- Each fission fragment emits one neutron.

- Neutrons are emitted isotropically in the center of mass of the fully accelerated fission fragments with an energy distribution given by:

$$N(E) = E^{1/2} \exp(-E/0.75)$$

- The fission fragment angular distribution is sampled in both θ and ϕ for either $K = 0$ or $K = 1$, and the neutrons were given the appropriate kinematic boost.


Two Neutron Correlations versus Energy
anti-parallel/parallel asymmetry
Sum of two neutron energies (MeV)
0
5
10
15
20
25
30
35
40
45
1
2
3
4
5
6
7



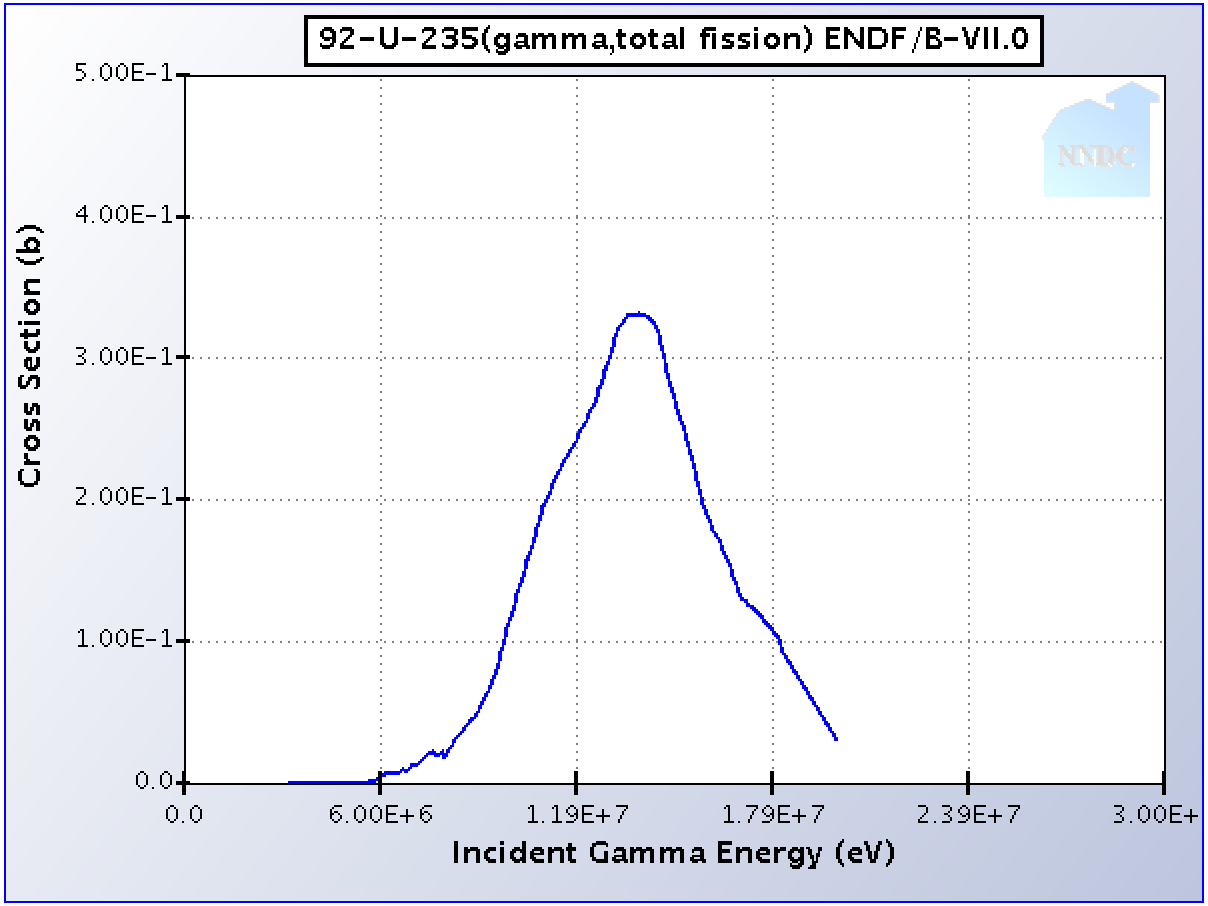
Two Neutron Correlations versus Energy
anti-parallel/parallel asymmetry
140
120
100
80
60
40
20
0
0.5
1
1.5
2
2.5
3
Energy cut on each neutron (MeV)

Example:

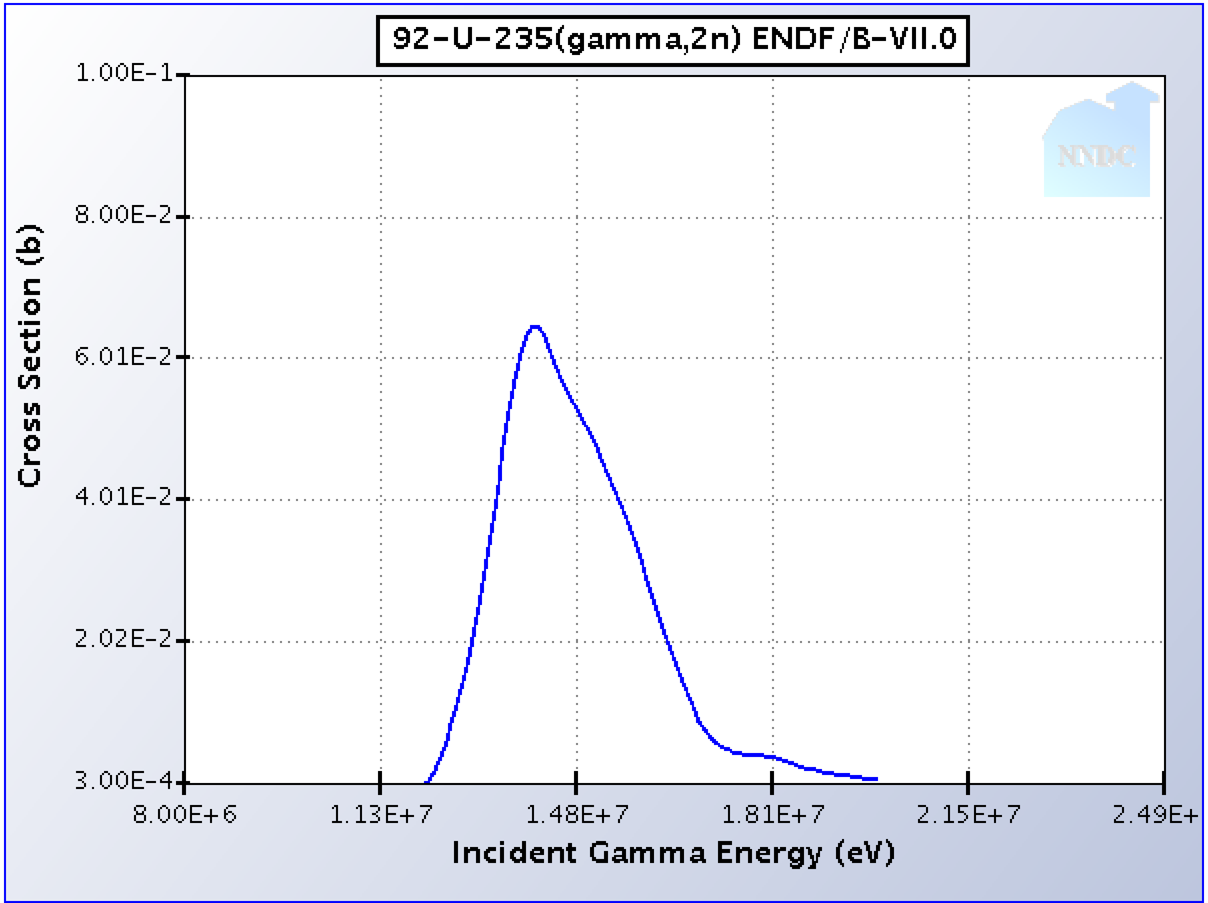
- Take HRRL, ^{235}U target.
- trues/(accidental+trues) α $1/N_f$.
- Need 1 fission/pulse.
- Take 20mAmps peak, 20 nsec pulse.

$\Rightarrow$ 1.25×10^9 electrons/pulse

Optimal beam energy is above 6 MeV



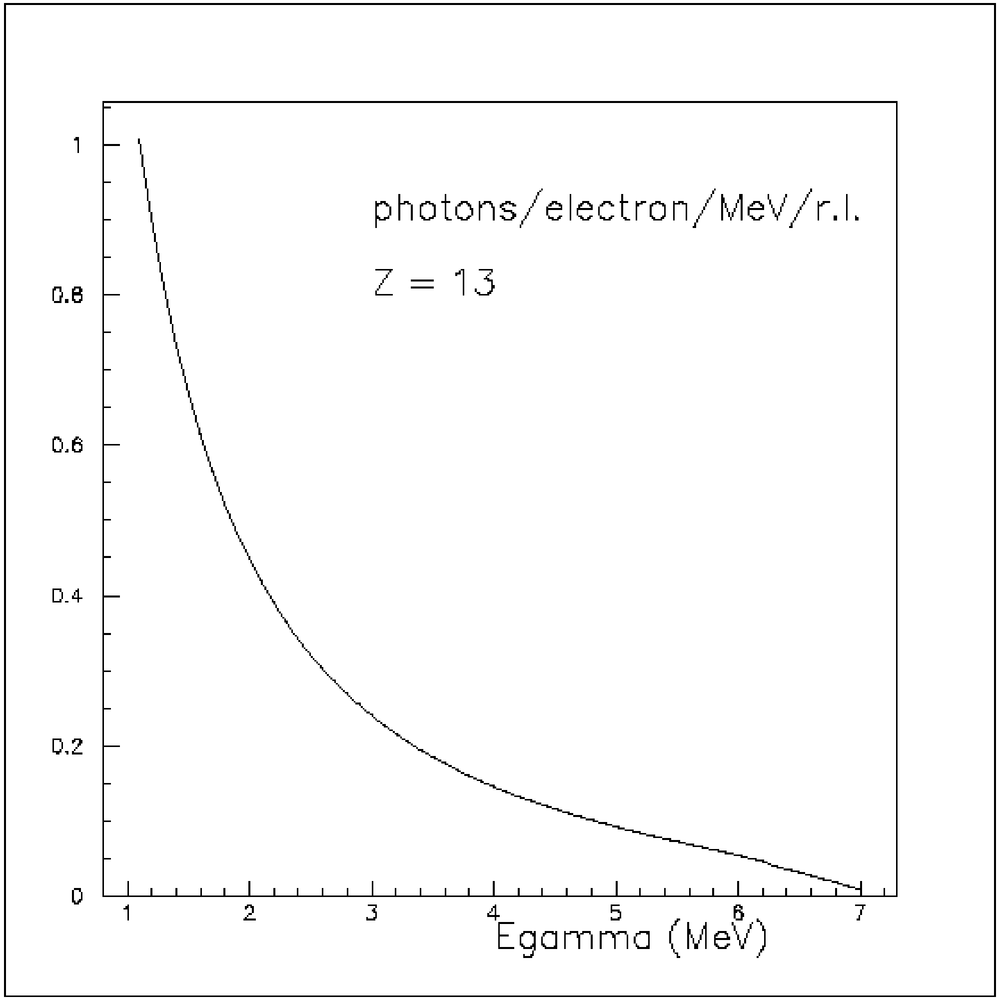
Optimal beam energy is below 12 MeV



Run at 7 MeV endpoint

- No two neutron knockout.
- Few neutrons from beamline elements, particularly higher energy ones.
- Low fission cross section – few fissions per pulse.

Brems lineshape (Owens and Matthews)



0.05 photons/e^-/MeV/radiation length in 6-7 MeV range.

Radiator and target

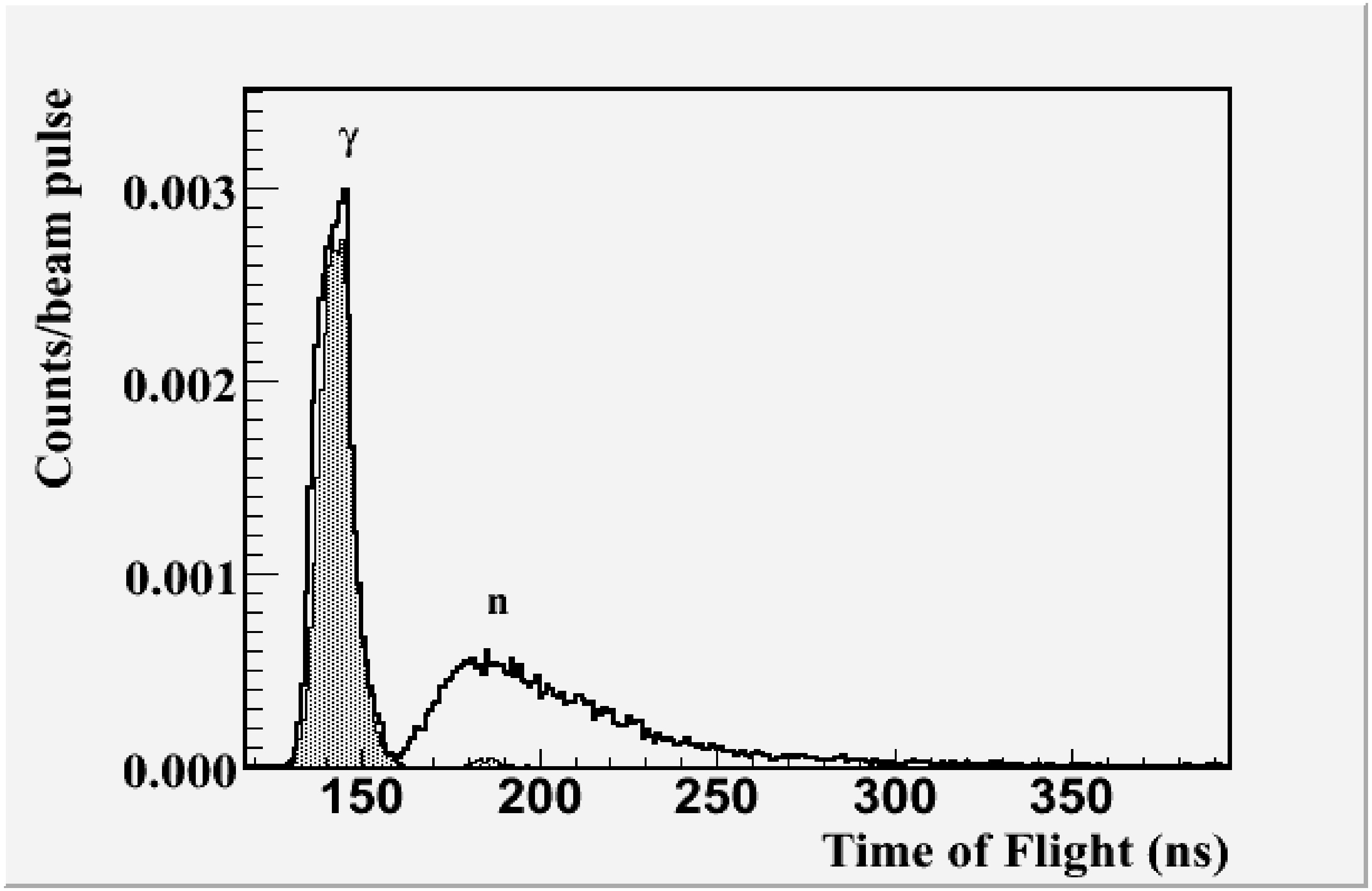
- 10^{-3} r.l. Al radiator (90 microns) gives:

6.3 x 10^4 photons/pulse in the 6-7 MeV range.

- 1 fission/pulse = #atoms/cm^2 x 7x10^{-27} cm^2/atom x 6.3x10^4 photons/pulse

2.3 x 10^{21} atoms/cm^2 or 470 micron thick target

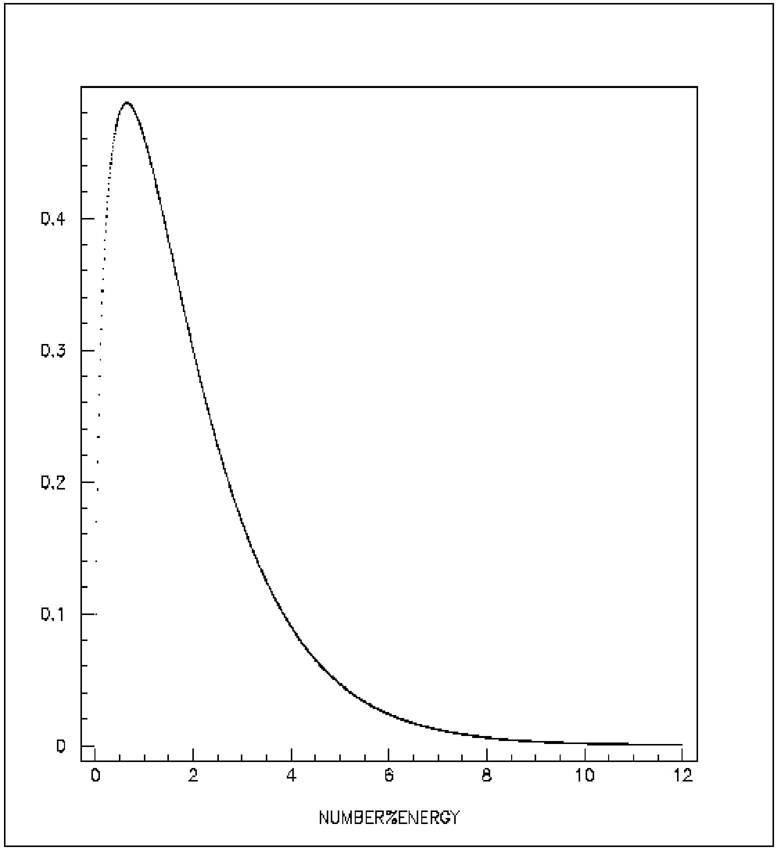
From a previous HRRL run



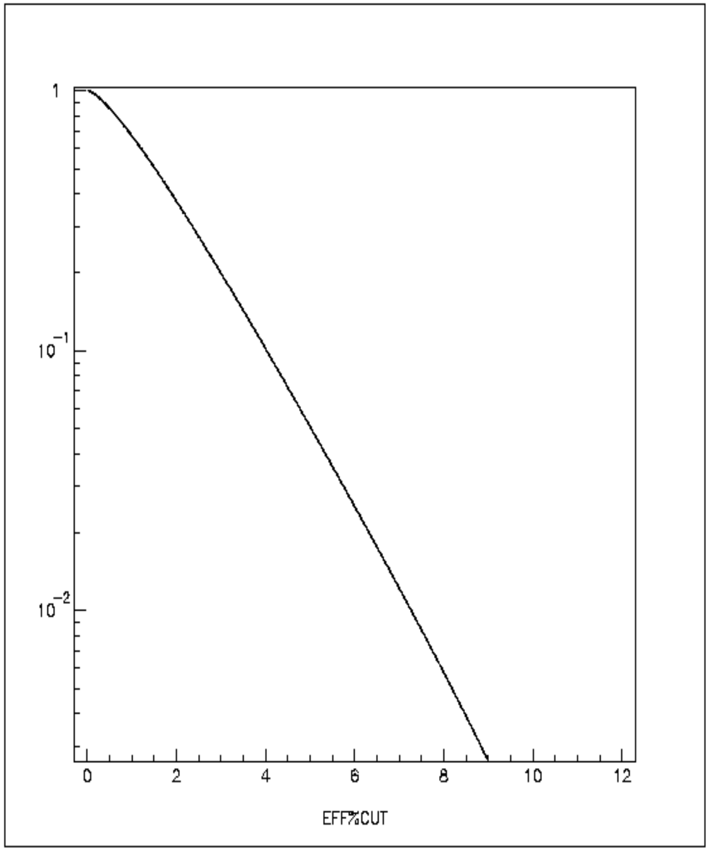
Take about 2 m flight path.

Neutron detectors

- 15 cm x 88 cm x 1.5 inch thick.
- Currently one PMT at one end.
- We have 16 of these.



Fission neutron spectrum



Efficiency of energy cut

- Intrinsic neutron detection efficiency 25%.
- Detector 2 m from the target.
- 1000 Hz repetition rate.
- 2.2 neutrons/fission.
- 1 MeV neutron energy cut efficiency = 0.65.

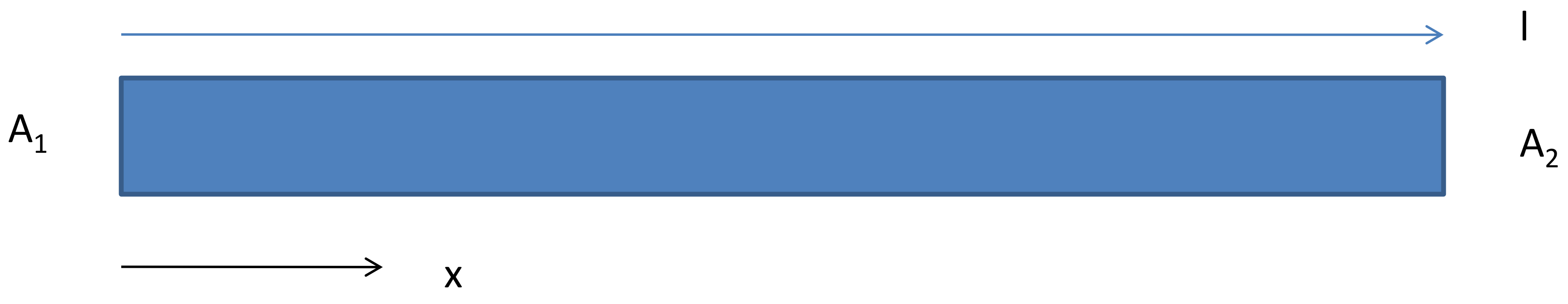
4.0×10^{-4} two neutron coincidences/second for two detectors

2.6×10^{-2} two neutron coincidences/second for 16 detectors

750 counts/day


KIMTECH
Kimwipes
USA DOT 7A

Amplitude technique for y coordinate



- $A_1 \sim e^{-\alpha x}$
- $A_2 \sim e^{-\alpha(l-x)}$

- $x = l/2 - 1/(2\alpha) \ln(A_1/A_2)$

Timing technique for y coordinate

- $T_1 \sim xn/(c)$
- $T_2 \sim (l\text{-}x)n/c$

- $x = l/2 - c/(2n)\,(T_1\text{-}T_2)$

What if we had a CW beam with a tagger?

Improvement with a CW beam

- Take 60 tagging counters, each at 1 MHz – similar photon flux.
- Now, 1 fission/microsecond rather than 1 fission/millisecond.
- Thicker targets are possible (centimeters).

Measurement times can be 50 X shorter.

Conclusions

- Model is crude, but large effects from two neutron correlations in fission may be present.

- Measurement times on the order of days with current facilities.

- Huge advantages if we get CW beam and a tagger.