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Progress with STEFF and Prospects for Experiments at n_TOF

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Collaborating Institutions:
Manchester(U.K.), Bordeaux (Fr), ANL (USA), IPN(Fr), ILL (Fr), CERN,

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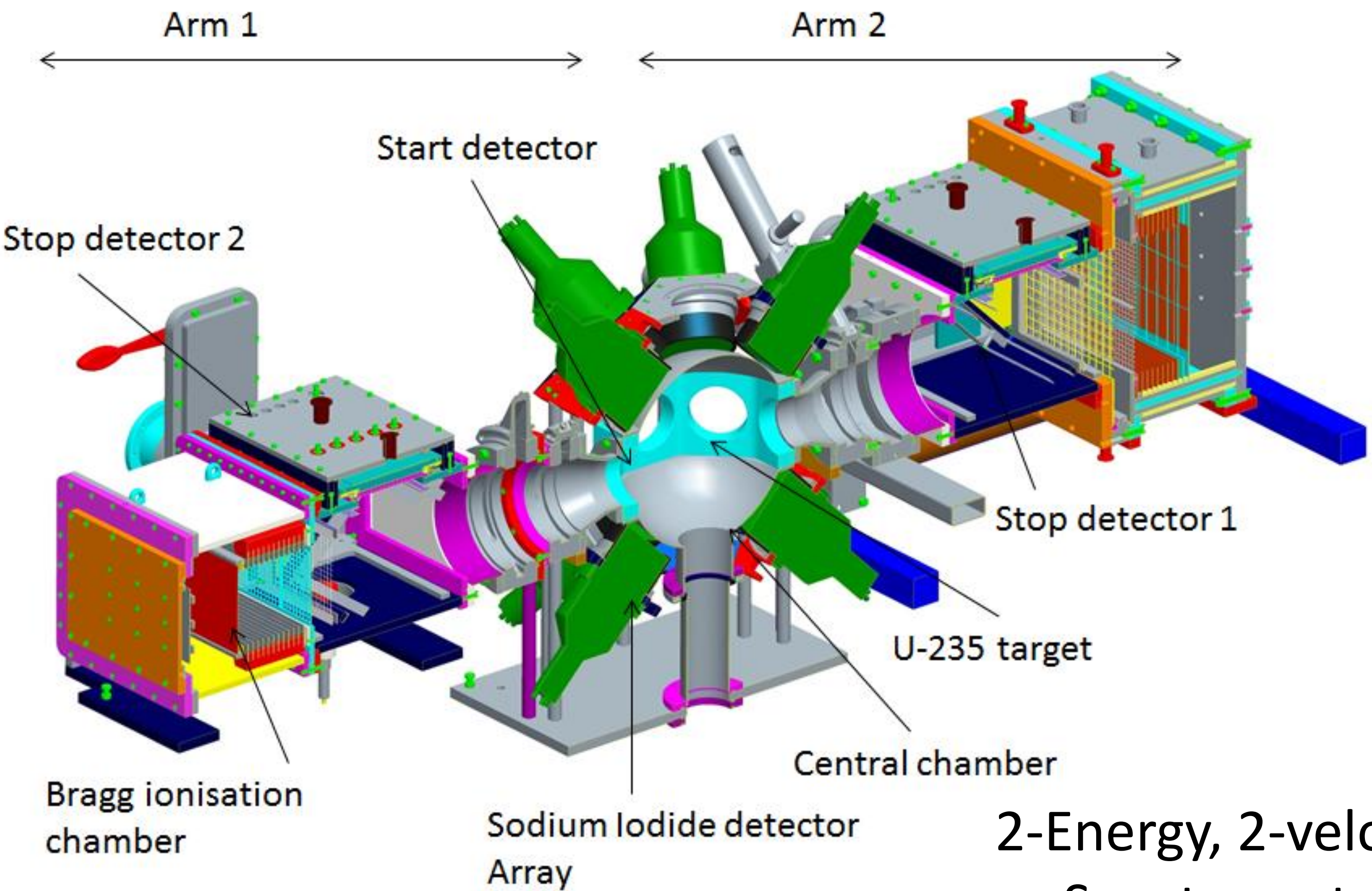
Design

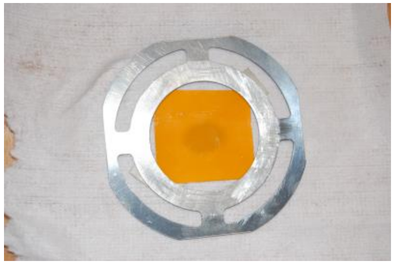
Solid angle 60 mstr

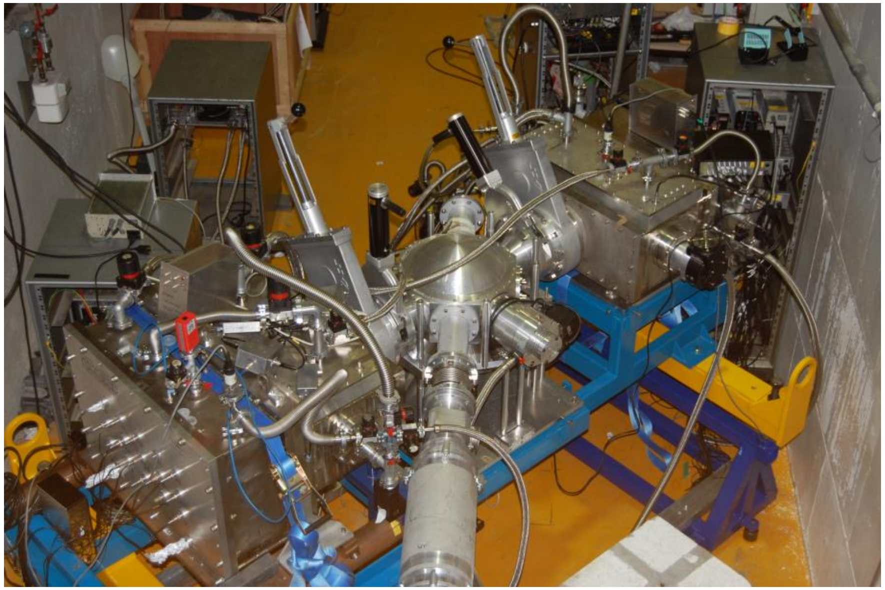


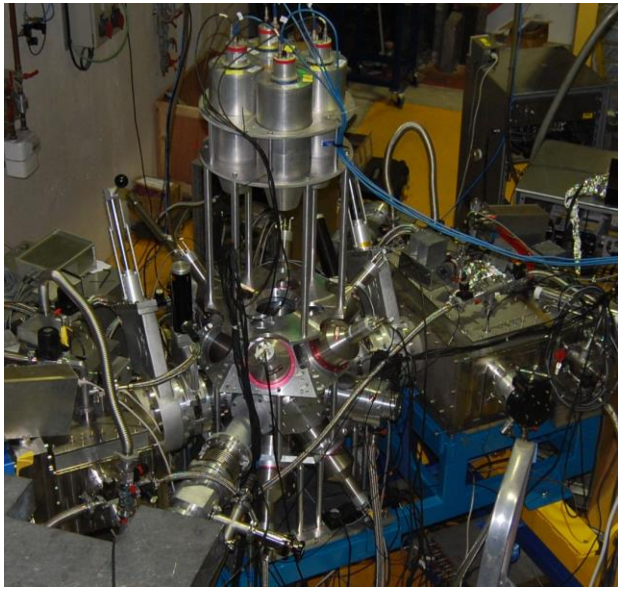
2-Energy, 2-velocity Spectrometer.

STEFF@ ILL

- Installed in PF1B Institut Laue-Langevin, Grenoble
- ^{235}U target 100μgcm^{-2} on a Nickel backing
- Thermal neutron flux 1.8x10^{10} neutrons cm^{-2}s^{-1}

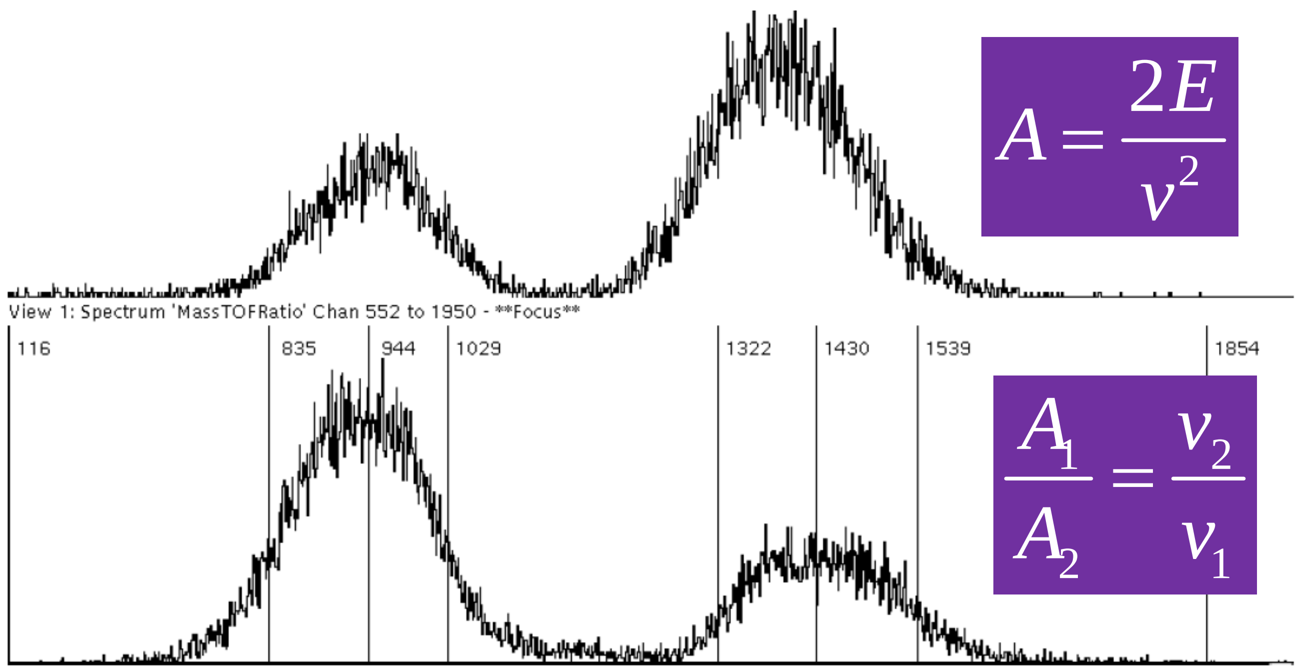






Fragment Mass Distributions

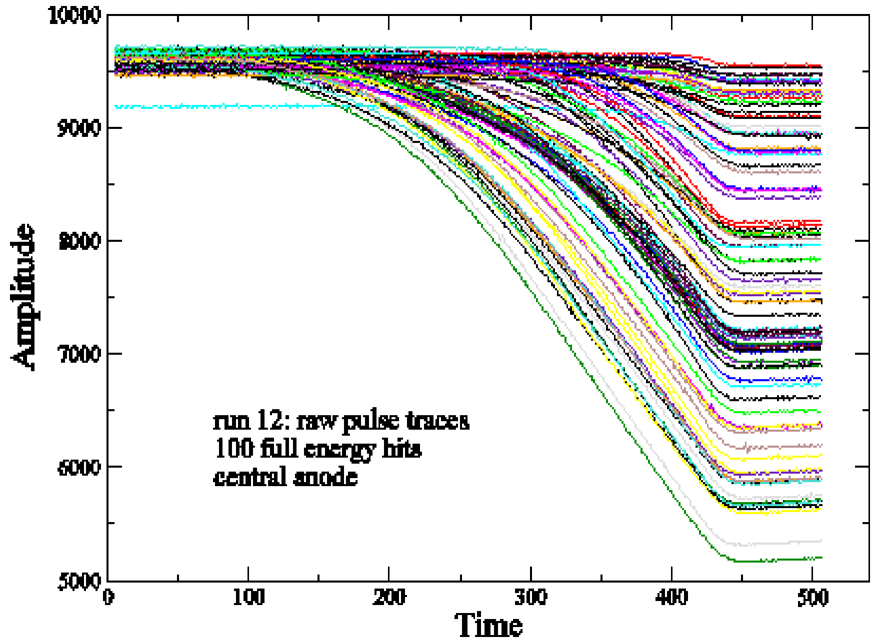
- Time-of-flight -> velocity
- Bragg Ionisation chamber->energy
- Uneven triggering H/L : Increase depth of SED STOP Detectors
- Mass resolution 4 amu



$$A = \frac{2E}{v^2}$$

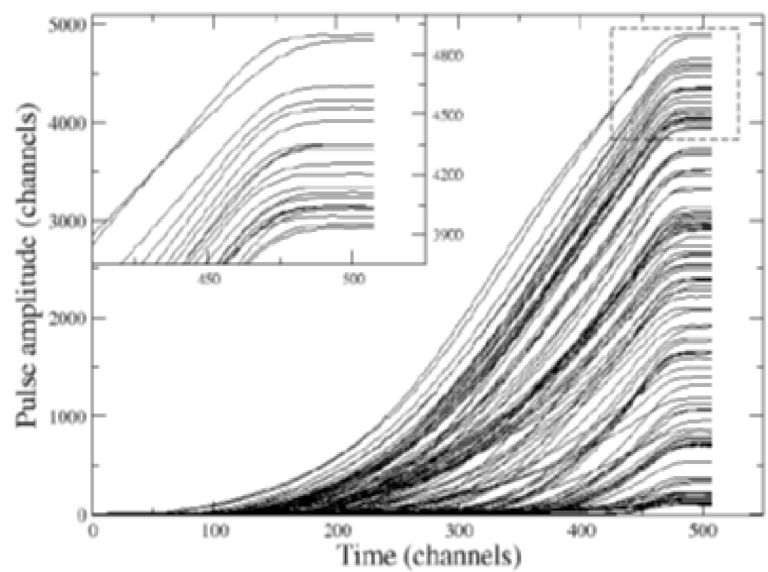
$$\frac{A_1}{A_2} = \frac{v_2}{v_1}$$

Digital Bragg Pulse Processing



- Digital Pulse Processing:
- High-pass filter
- Ballistic Def. Correction

- Integration
- Low-pass filter: noise reduction
- Currently Noise ~0.2 percent



Nuclear charge distribution for light mass group

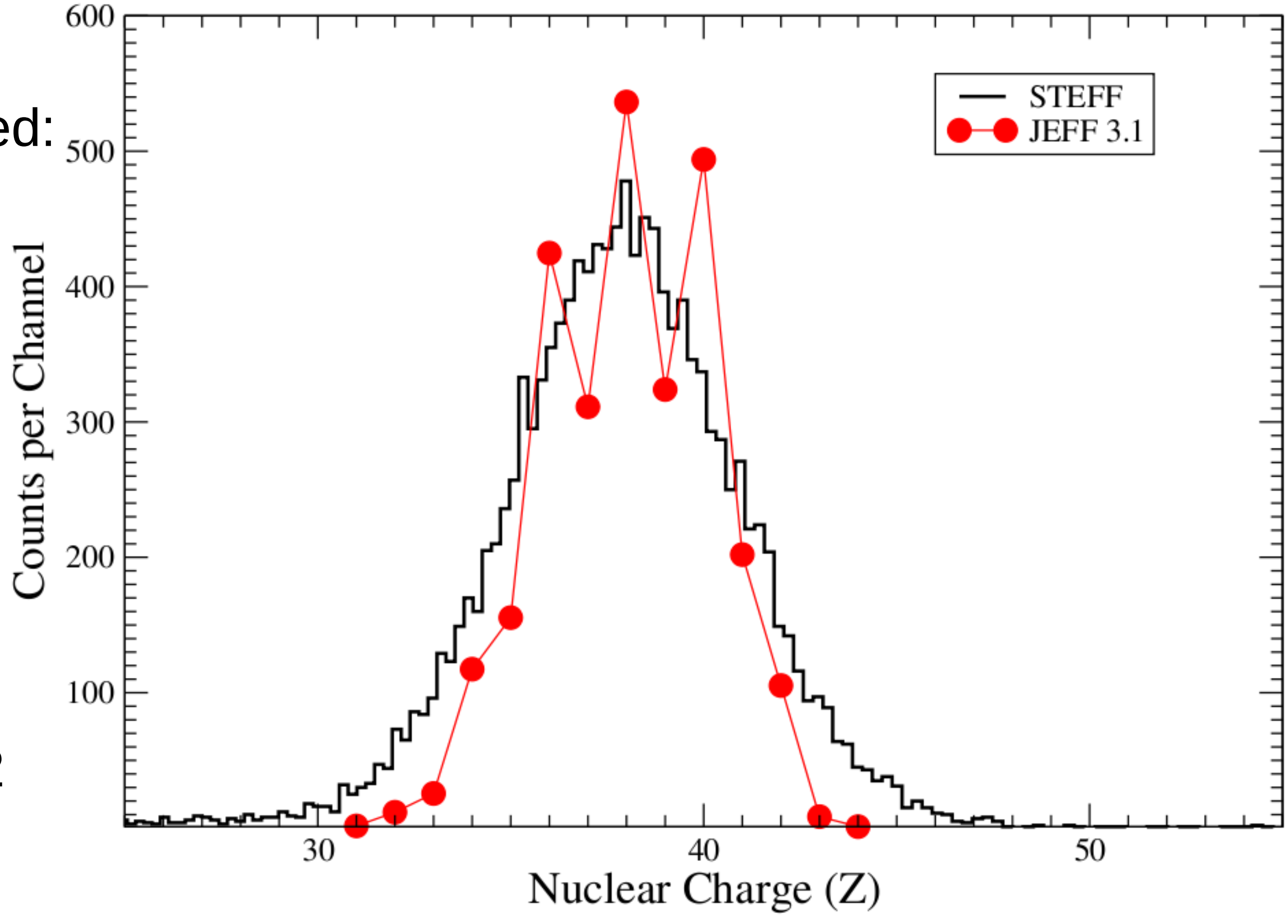
IC measurements, when velocity if fixed:

$$\frac{dE}{dx} \propto Z^b$$

Where

$$b = 2/3$$

before any corrections: Sensitivity to Z (FWHM) of about 2 units.



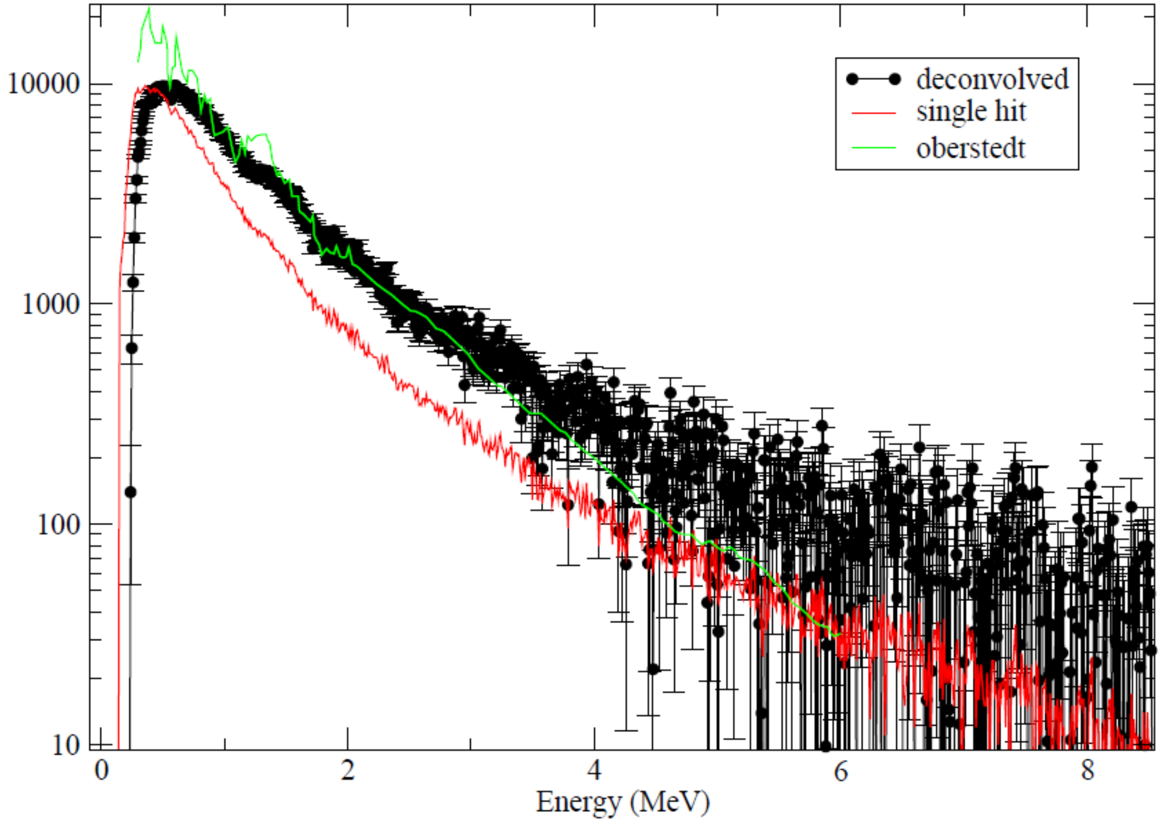
Gamma-ray Energy and Multiplicity

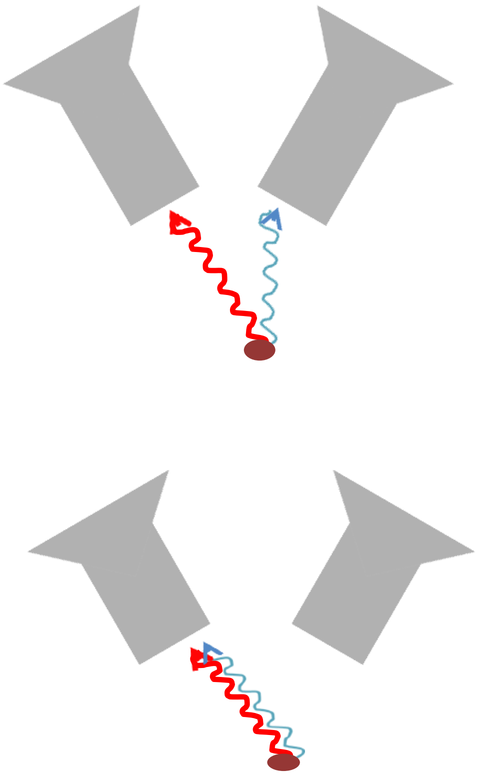
- Response to NEA High Priority Request of more accurate knowledge of heating caused by gamma emission in the next generation of nuclear reactors

- Coincidence with emission of prompt gamma rays as a function of the fragment mass and energy

- 12 5"x4" NaI detectors around the uranium target provide a 6.8% photo peak detection efficiency

^{235}U Single γ Energy distribution (ILL)





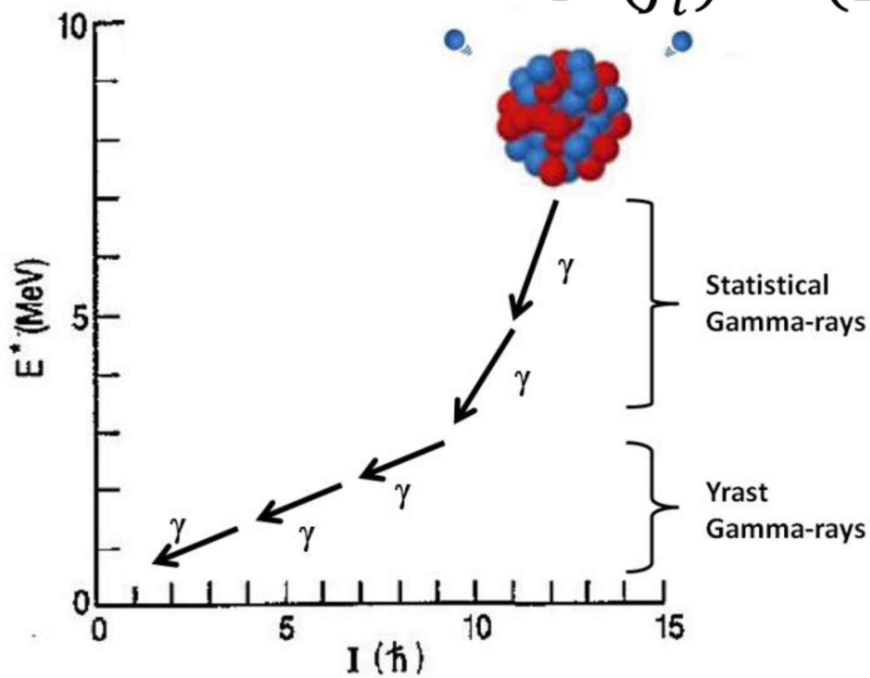
- Time random coincidences removed
- Multiple-hit effects removed (GEANT4)
- Deconvolution (Compton/Backscatter, etc. removal) using GEANT4 response functions.

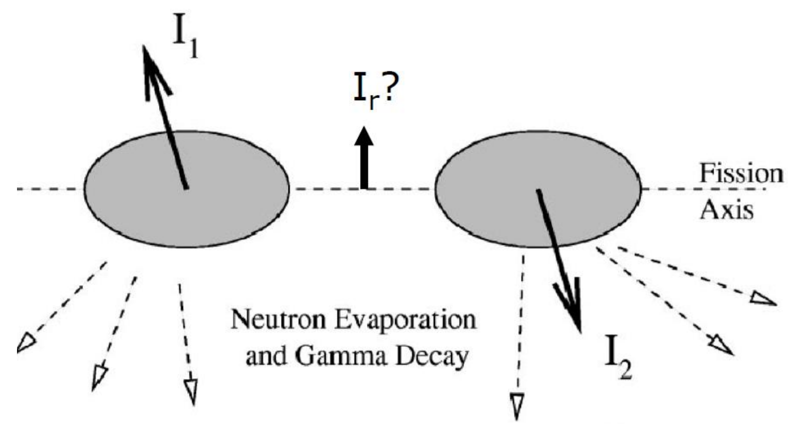
Gamma decay of fission fragment

Spin linked to γ **multiplicity** and **feeding** by statistical models.

Spin alignment to γ-ray **angular correlations**

$$P\,(J_i) \propto (2J+1)exp\left\{\frac{(J_i+\frac{1}{2})^2)}{B^2}\right\}$$





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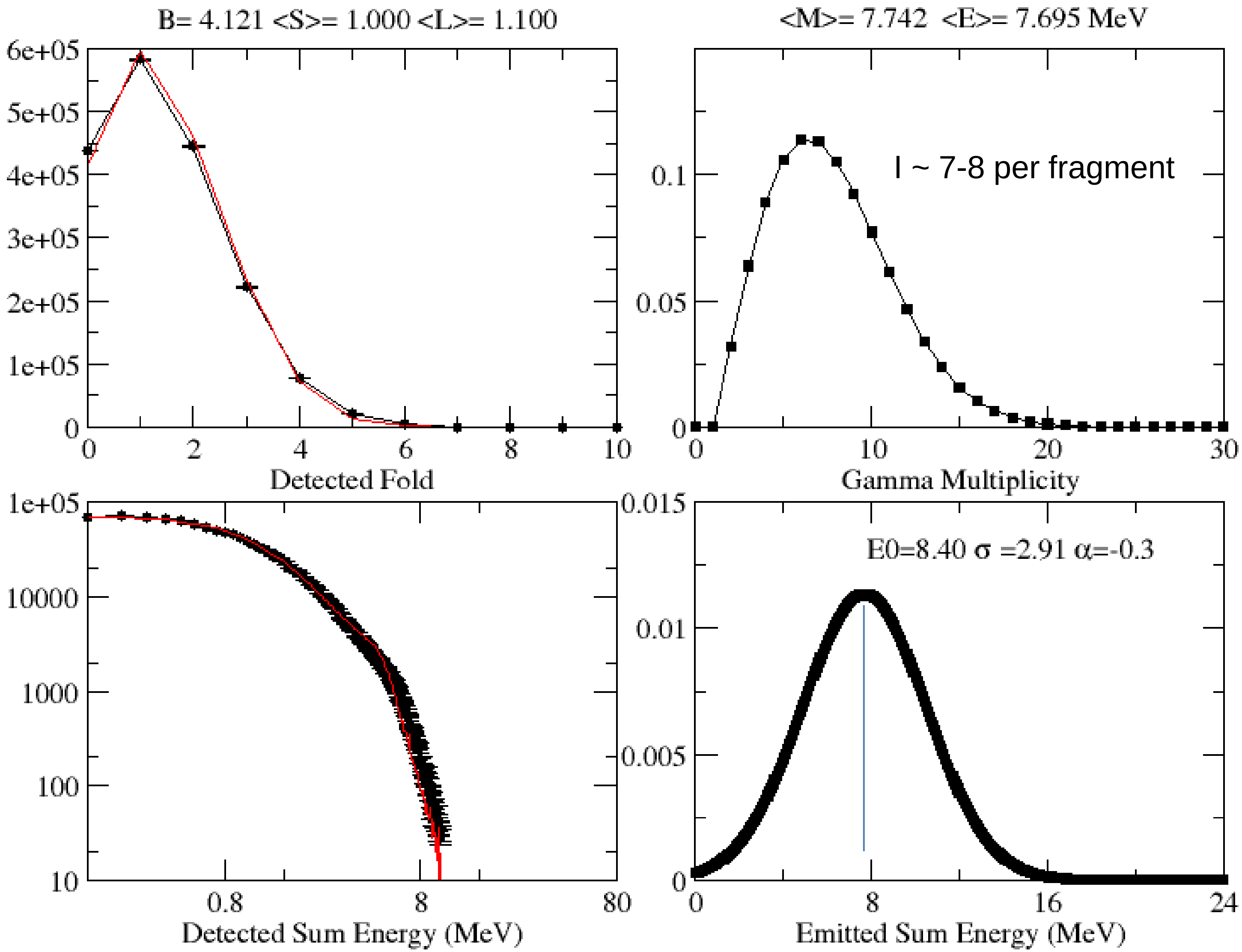
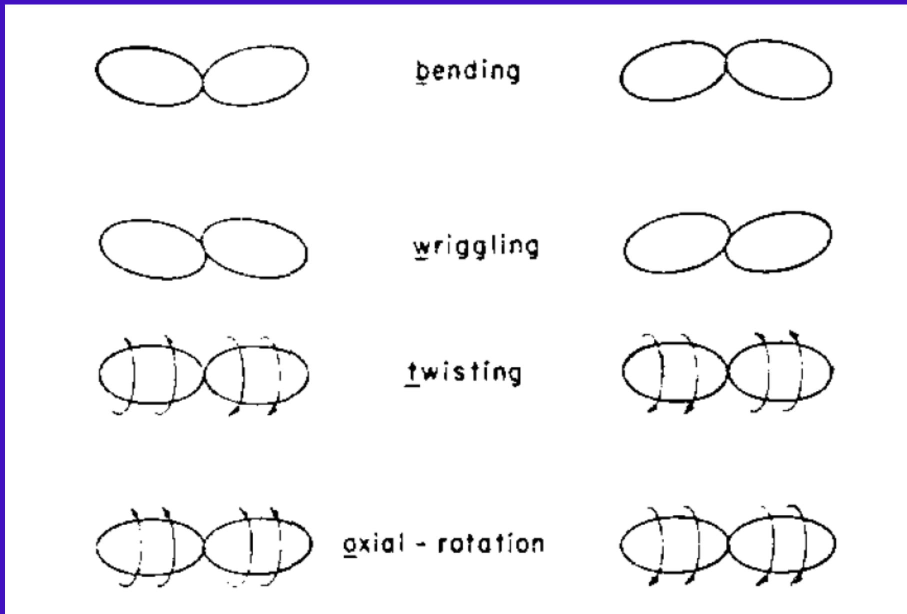
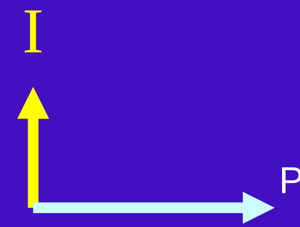
Using GEANT4 simulations of response functions of NaI detectors - ^{235}U (ILL)

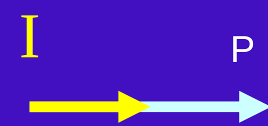


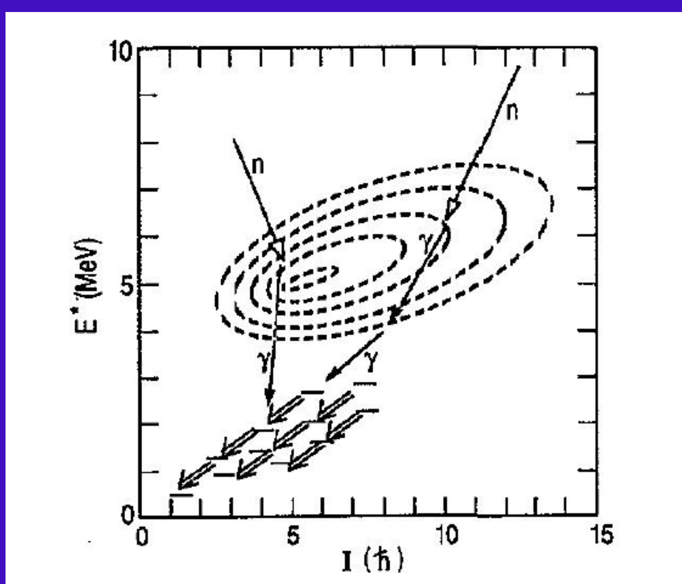
How is the fragment angular momentum generated? Macroscopic modes of motion?





Or something else?
Particles in a tube (QM uncertainty)

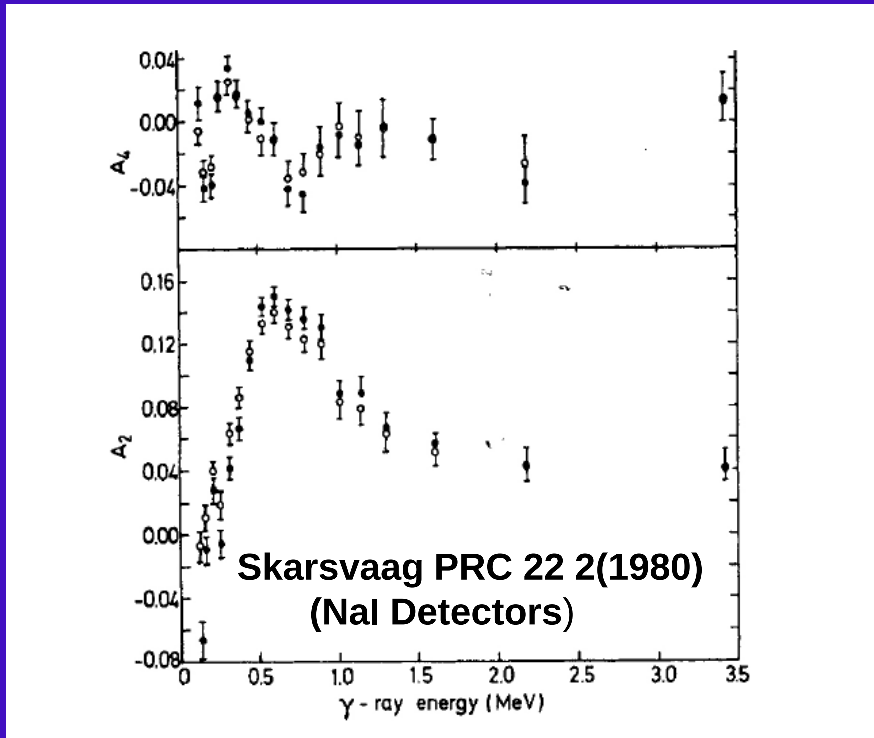


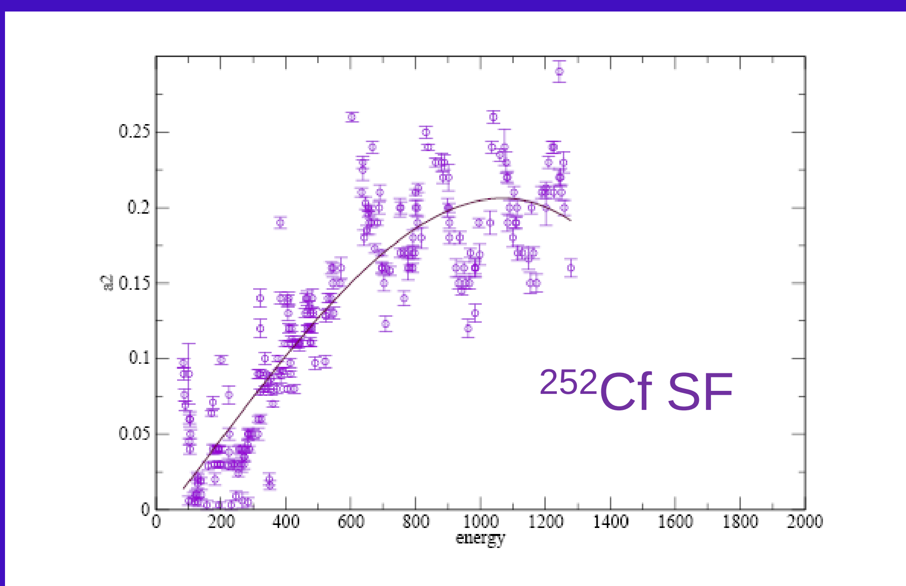


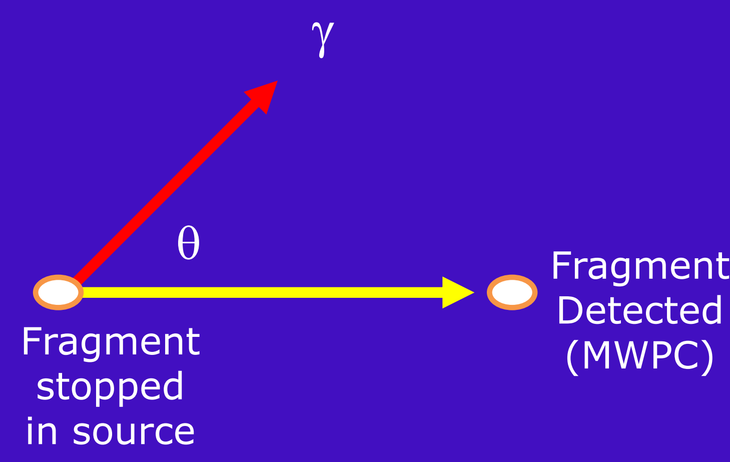
Statistical Decay.

Populates yrast states of known spin.

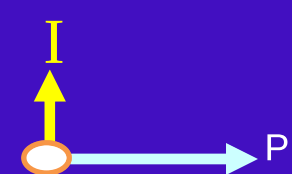
Measure gamma-ray Angular
Distributions relative to fission (z)
axis







I ~ perpendicular to fission axis



With much higher resolution
(HPGe , Gammasphere)
we observe strong fluctuations

Correlations depend on spins of
particular excited states.

^{252}Cf SF

"Isotropic" gate
Any detector

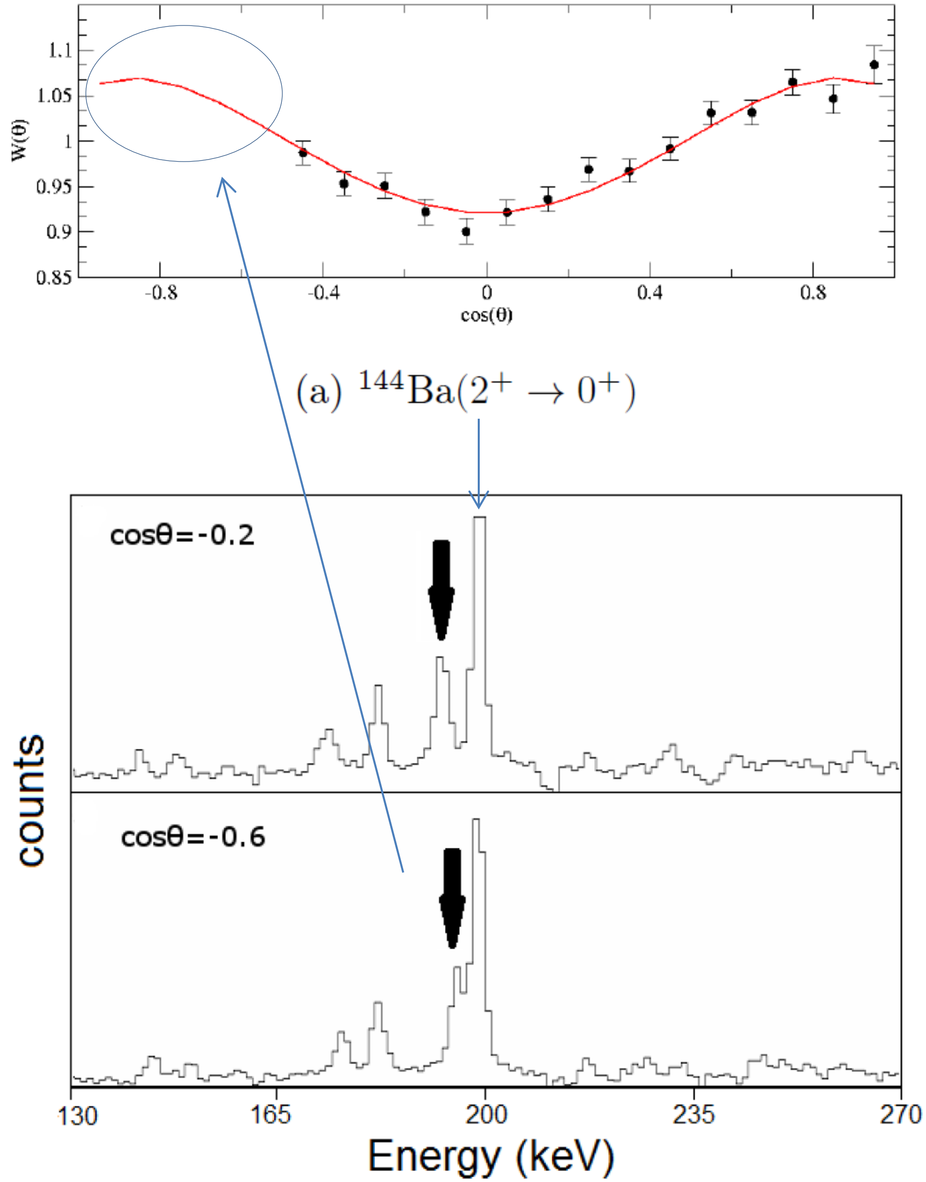
Used for angular distribution

With fragment

"Isotropic" gate
Any detector

Used for efficiency calibration

Without fragment gate



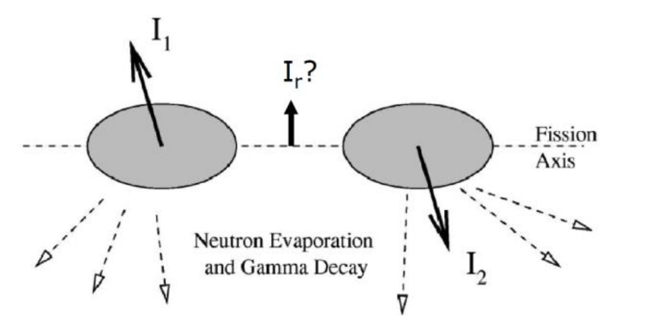
Statistical Model Code. Initial Spin Distribution.

$$P(J,M) = (2J+1)exp\left(-\frac{J(J+1)}{B^2}\right) exp\left(-\frac{(|M|-J+2)^2}{J^2\sigma_B^2}\right)$$

Model follows Wilhelmy et al.
Phys. Rev. C5, (1972) 2041
With added m-substate distn.

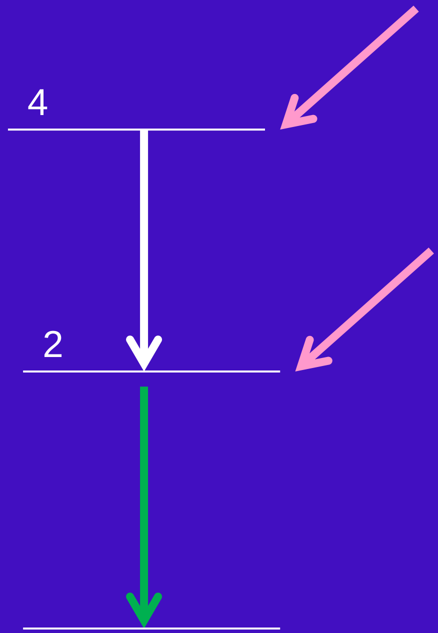
B ~ J_{rms}+1/2

Spread in M sub-states



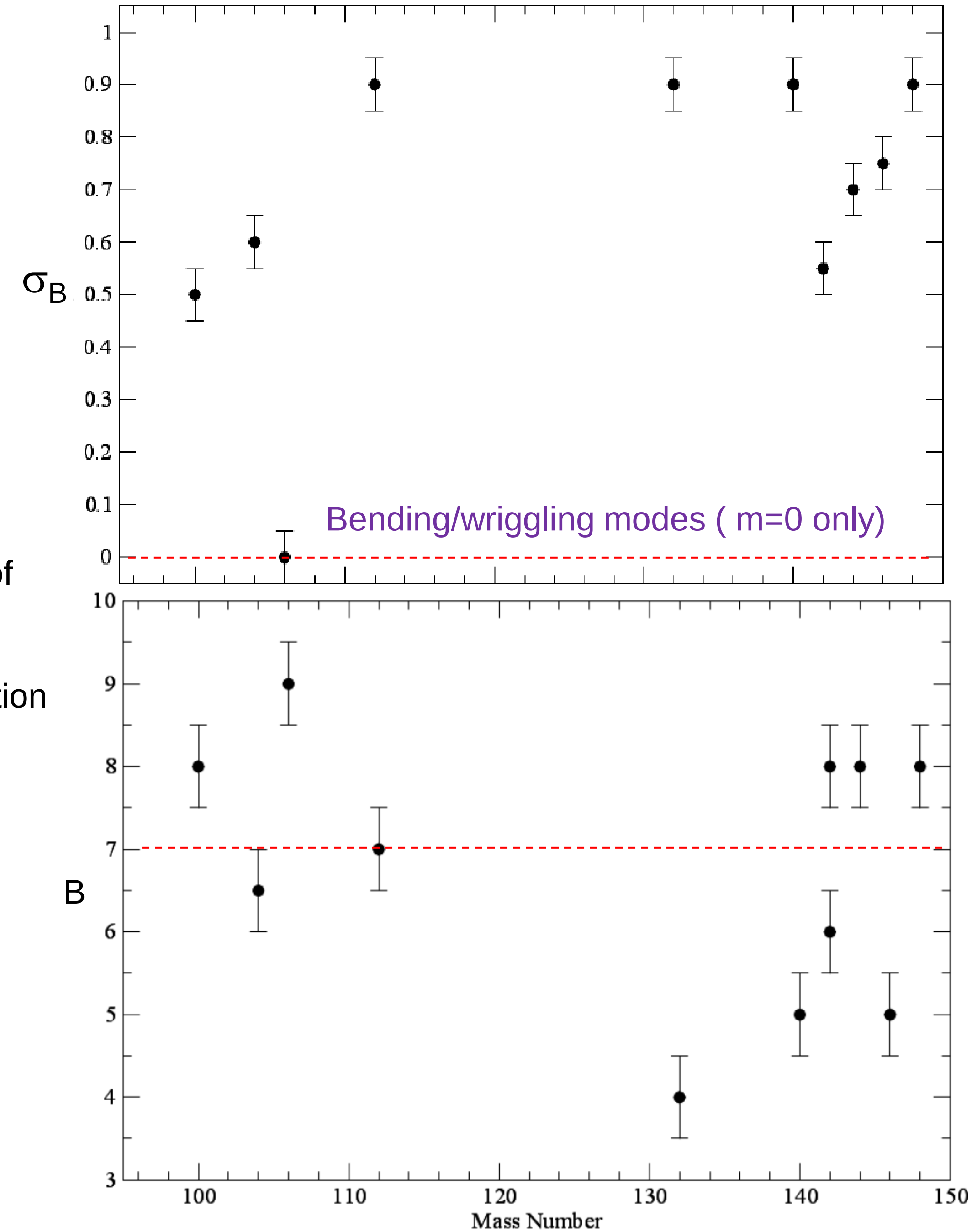
Decay: Neutron transmission factors, C.G coupling, number of neutrons and E1 γ rays.

$$P(J',M') = \sum_{J_I=J_{min}}^{J_{max}} \sum_{M_I=-J_I}^{J_I} P(J_I,M_I) \sum_{L=0}^{L_{max}} T(L) \sum_{M_I=-L}^{L} \langle J_I, M_I, L, M_L | J', M_I+M_L\rangle^2 \times \frac{exp\left[\frac{-(J'+\frac{1}{2})^2}{2\sigma^2}\right]}{\sum_{J''=|J_I-L|}^{J_I+L} exp\left[\frac{-(J''+\frac{1}{2})^2}{2\sigma^2}\right]}.$$



Calculates: Feeding intensities of Yrast states and a_2 , a_4

^{252}Cf SF



Data largely inconsistent with m=0 only

Conclusion not very sensitive to number of Neutrons and statistical gamma rays

Some data may suffer unseen contamination

Fragment Angular Distributions

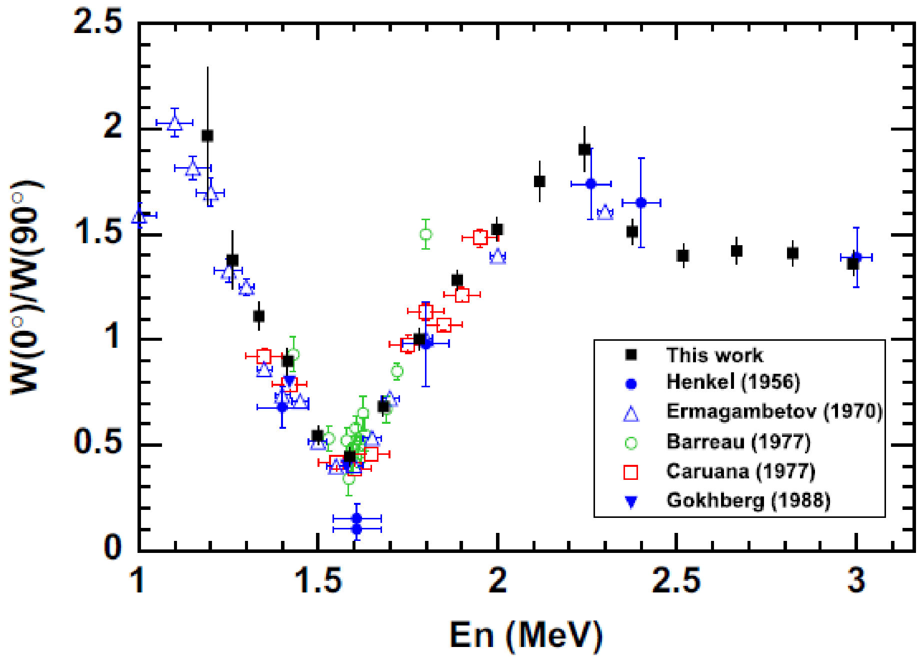


Fig. 10. Dependence of the anisotropy parameter on the neutron energy in the ^{232}Th(n,f) reaction. Present data are indicated by the black squares for comparison with previous results [15,19–22].

D. Tarrío et al. / Nuclear Instruments and Methods in Physics Research A 743 (2014) 79–85

Constrains calculations of fission barrier.   STEFF: Anisotropy with A,Z,E* ?

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γ-ray Energy Spectra and Multiplicities from the Neutron-induced Fission of ^{235}U using STEFF.

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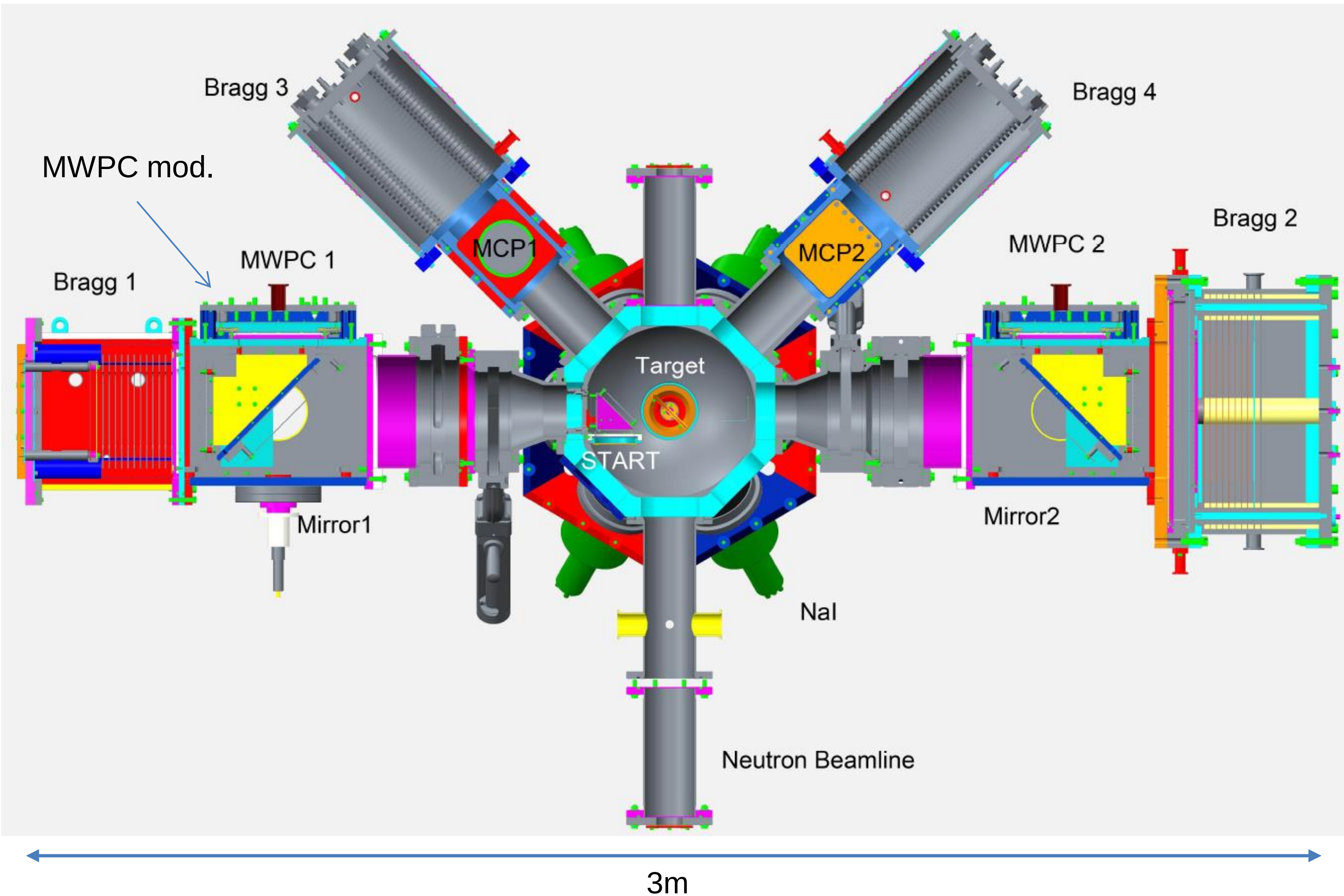
Proposal now accepted by the INTC for n_TOF: to be run 2015

STEFF (with upgrade for EAR2)



Rate Calculation for STEFF@EAR2

- Target 25cm^2 ^{235}U at $100\,\mu g\ \mathrm{cm}^{-2}$
- Beam flux $7.54\times10^{6}\,\mathrm{n\,cm}^{-2}\times0.4\,\mathrm{s}^{-1}$
- Neutron energy range 1eV - 10 MeV
- 3×10^{18} protons (~30 days running time)
- Intrinsic Fragment detection efficiency 0.5*
- 5×10^{5} Fragment-gamma events with A,Z,E
- 5.6 fissions per pulse in 3ms†; Δt_γ~15ns

*For both fragments. Limited by efficiency of STOP : to be improved. S.Warren PhD project.
† charge collection in anodes in ~3us.

STEFF@ EAR2 Objectives (2015)

- To move STEFF to a EAR2 n_TOF to study neutron-induced fission at a range of neutron energies.
- Measurement of E,A,Z and directions of fragments in coincidence with gamma rays.
- Use gamma multiplicities and angular distributions to look at spin effects.
- Meet NEA high-priority request for gamma-ray data.
- Study fragment angular distributions vs. A,Z and E (E_x).