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Progress with the STEFF Fission-Fragment Spectrometer

LANL FIESTA Fission School & Workshop, Sep. 8-12, 2014

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

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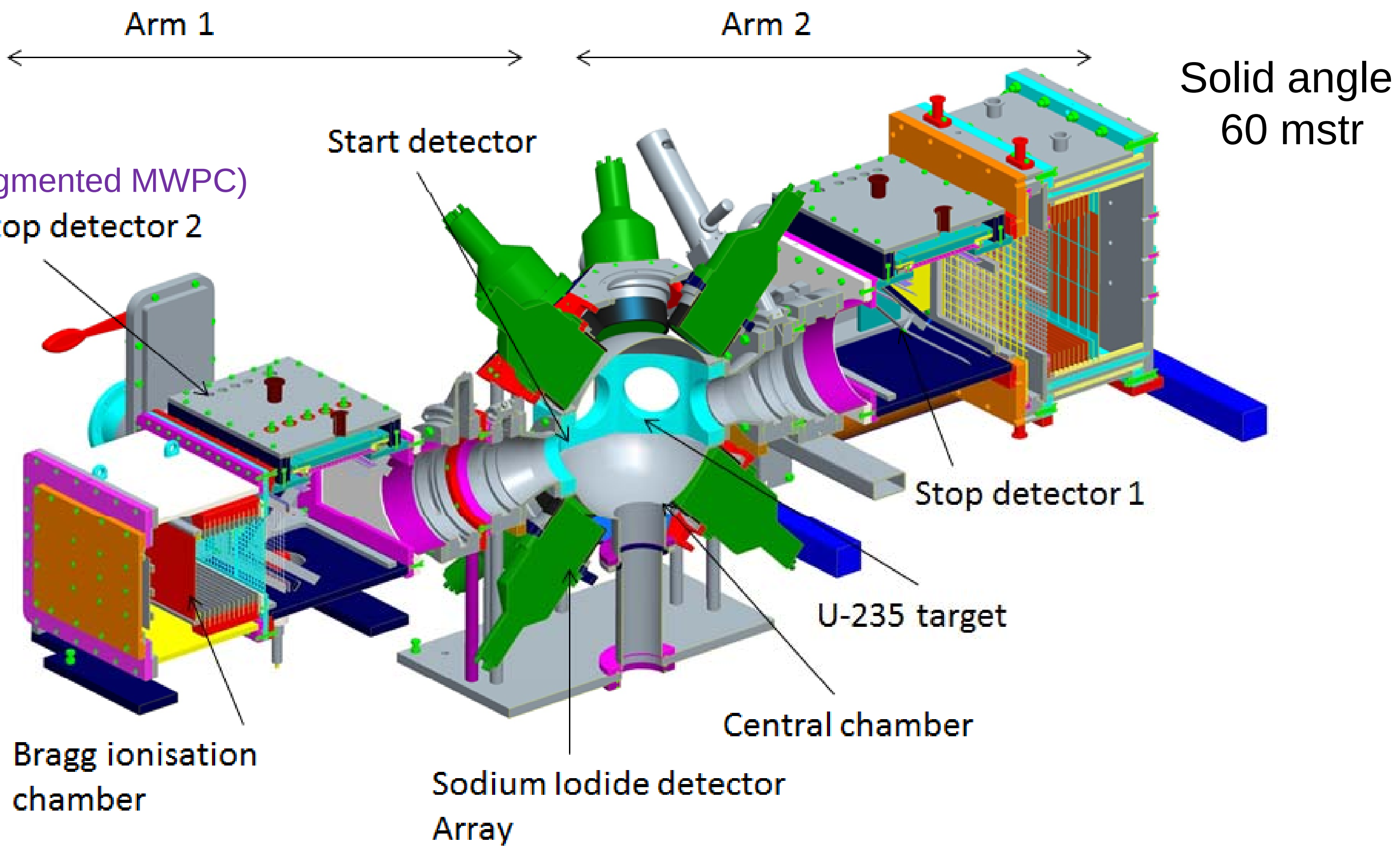
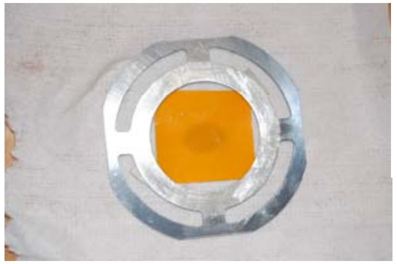
Design

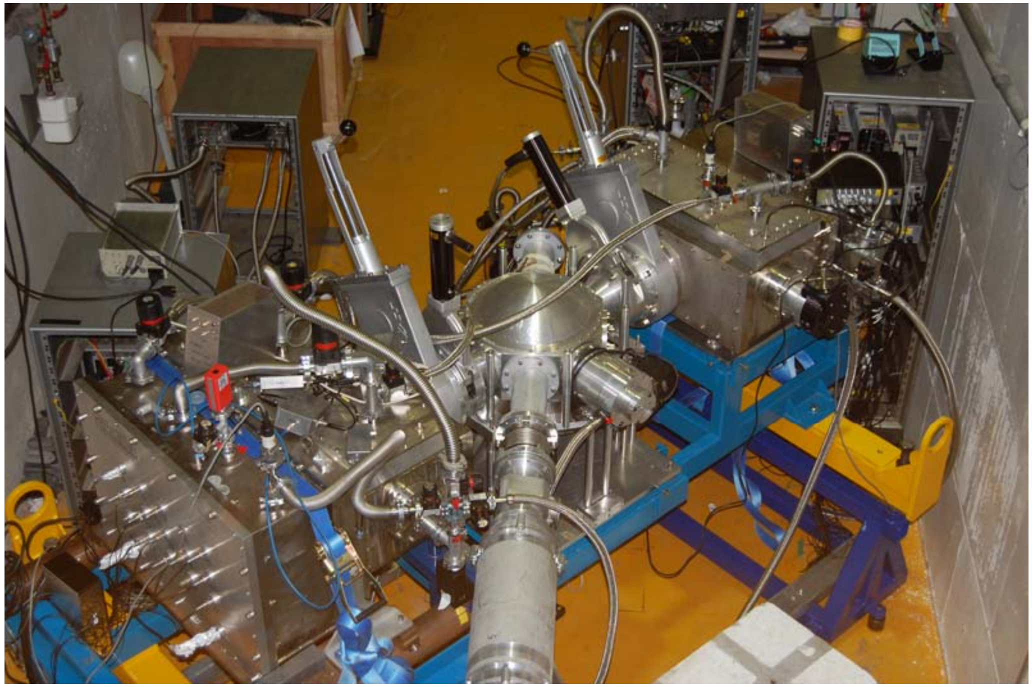
2-Energy, 2-velocity Spectrometer – Manchester & ILL Grenoble

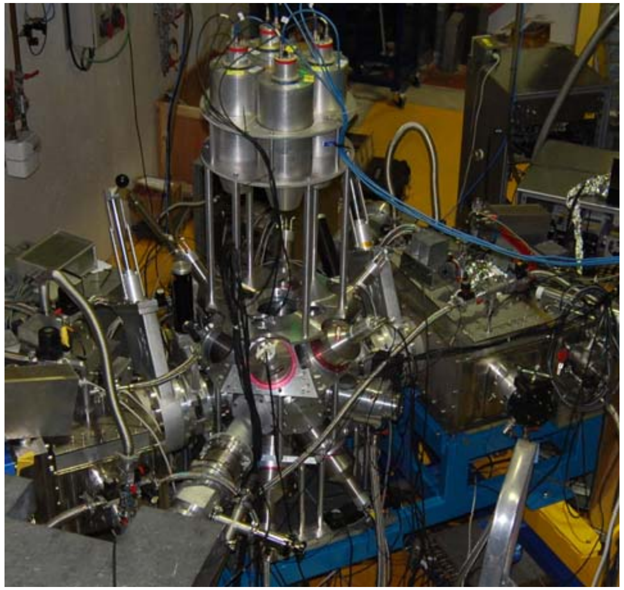


STEFF @ ILL

- Installed in PF1b Institut Laue-Langevin, Grenoble for 2x 25 days
- ^{235}U target 100µgcm^{-2} on a Nickel backing
- Thermal neutron flux 1.8x10^{10} neutrons cm^{-2}s^{-1}







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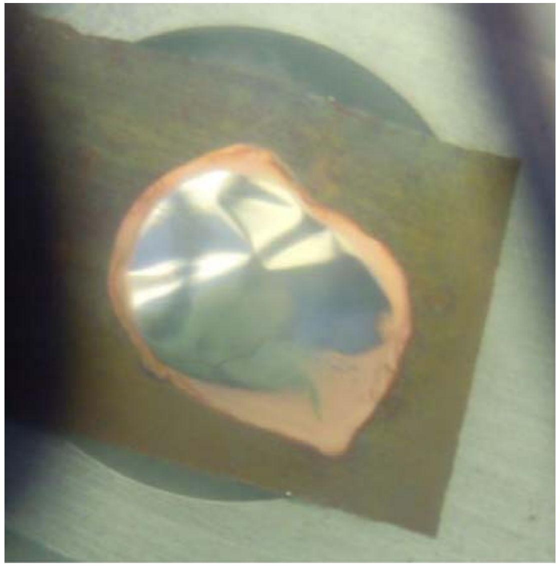
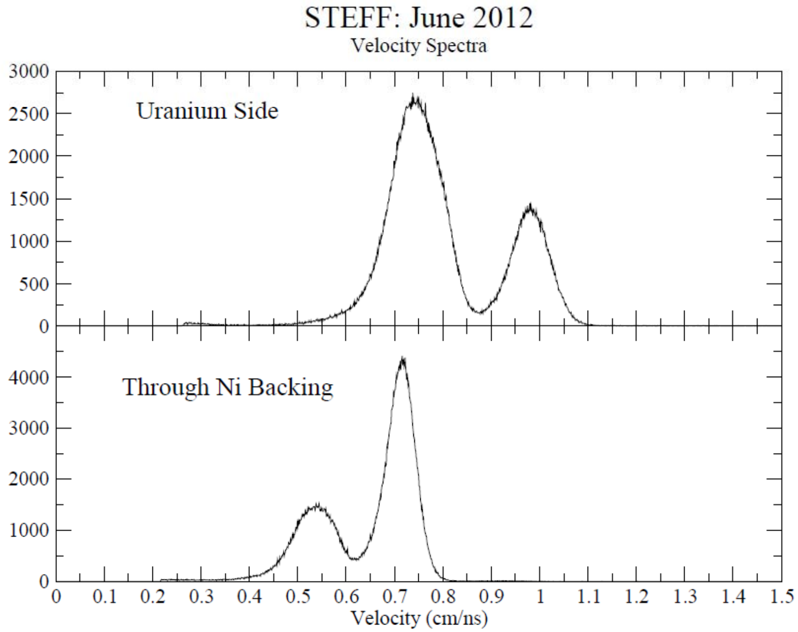
$100\,\mu g\,cm^{-2}$ ^{235}U on a $50\,\mu g\,cm^{-2}$ Ni foil





Target problems.
235U target on Ni backing
Cu support chemically etched away.
50% energy loss on Ni side.

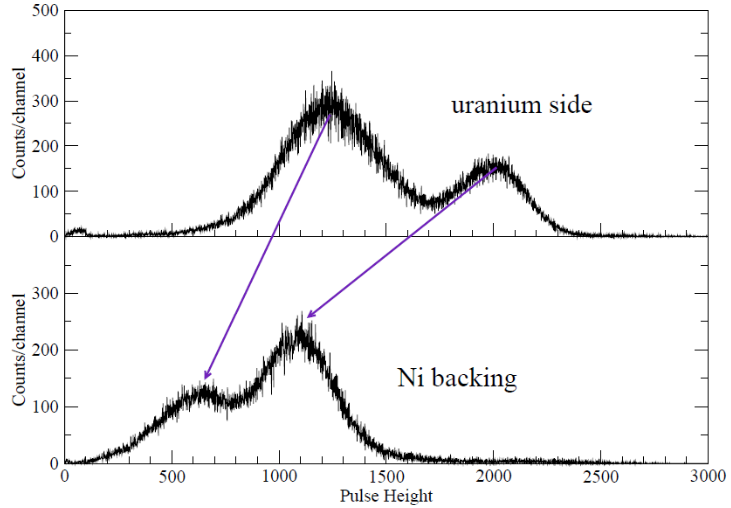
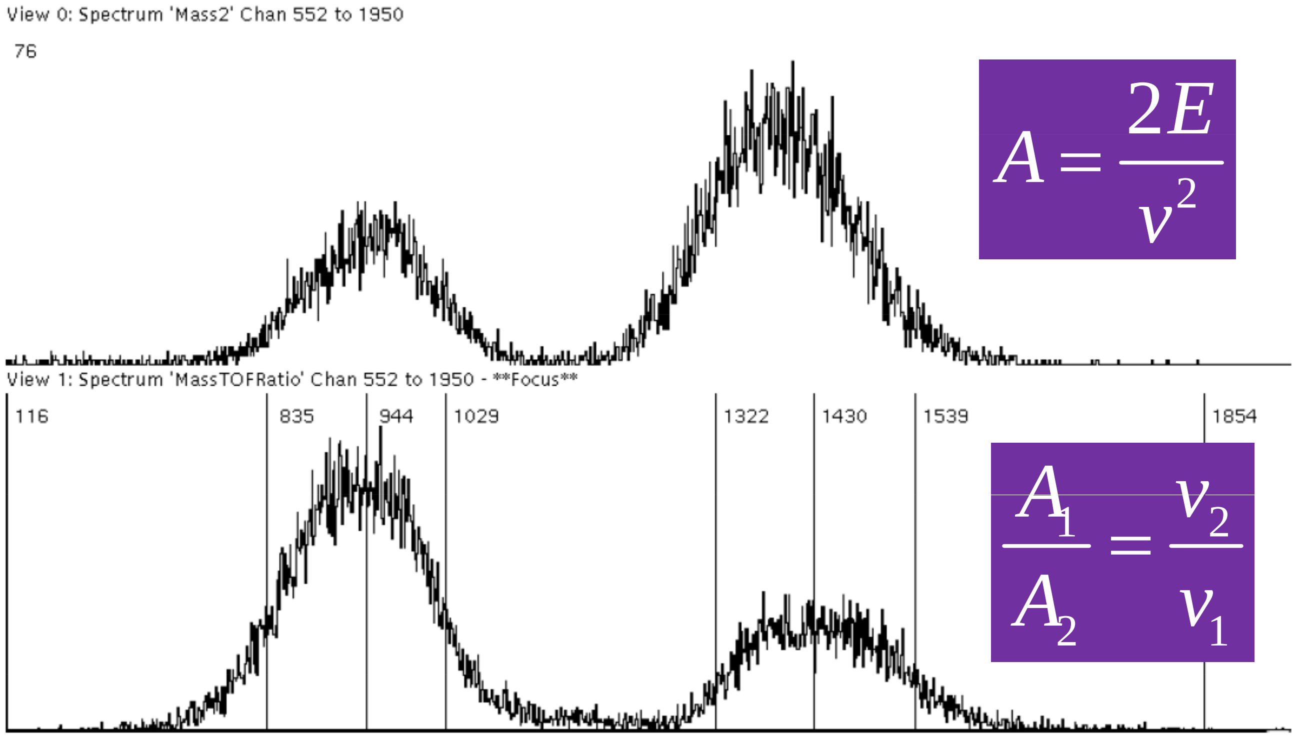


Figure 7: Energy spectra from Bragg1 and Bragg2

Fragment mass measurement

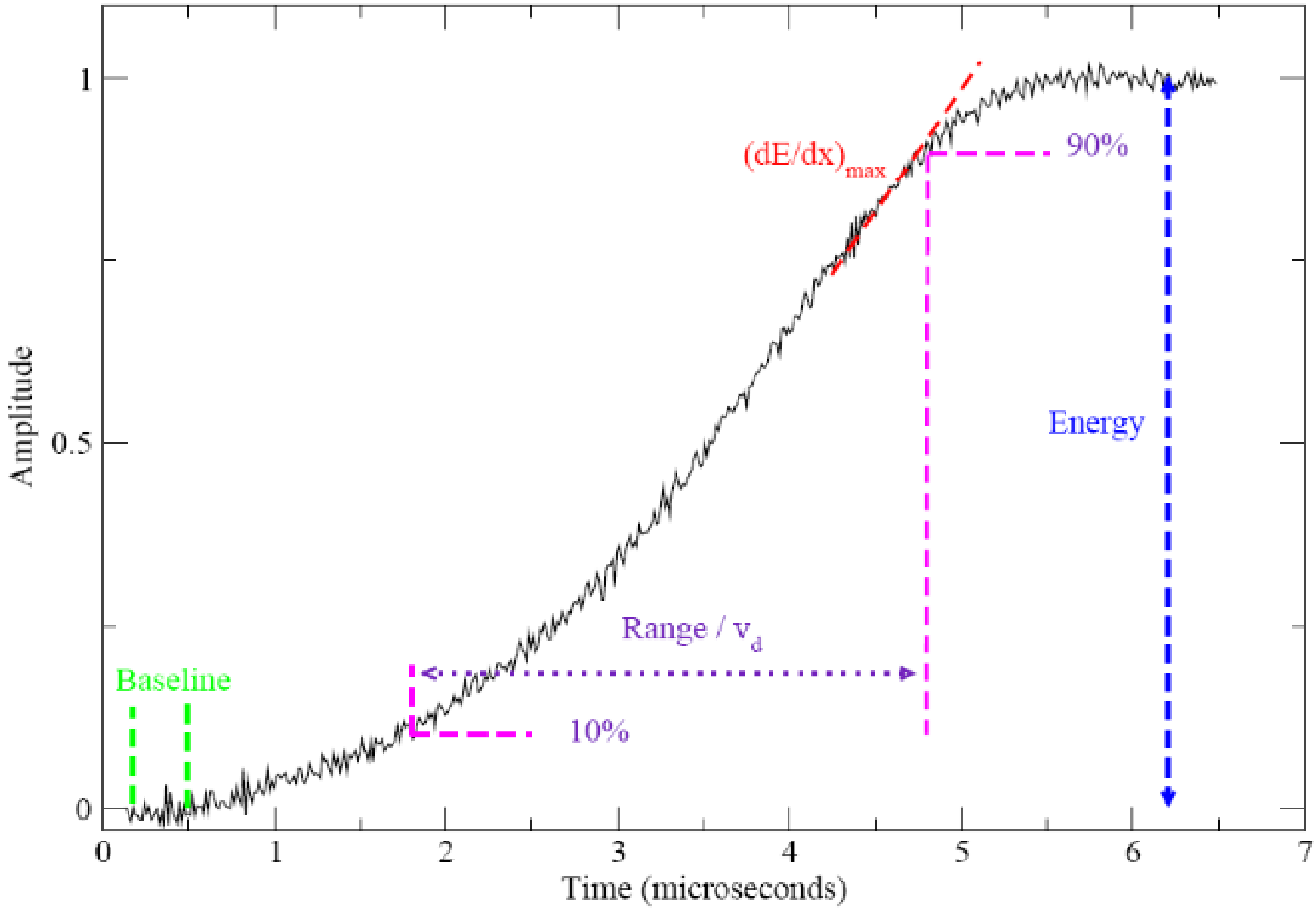
- Time-of-flight -> velocity
- Bragg Ionisation chamber->energy
- Mass resolution 4 amu – Limited by TOF resolution (STOP) (~ 1ns)



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

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

Characteristics of bragg pulse



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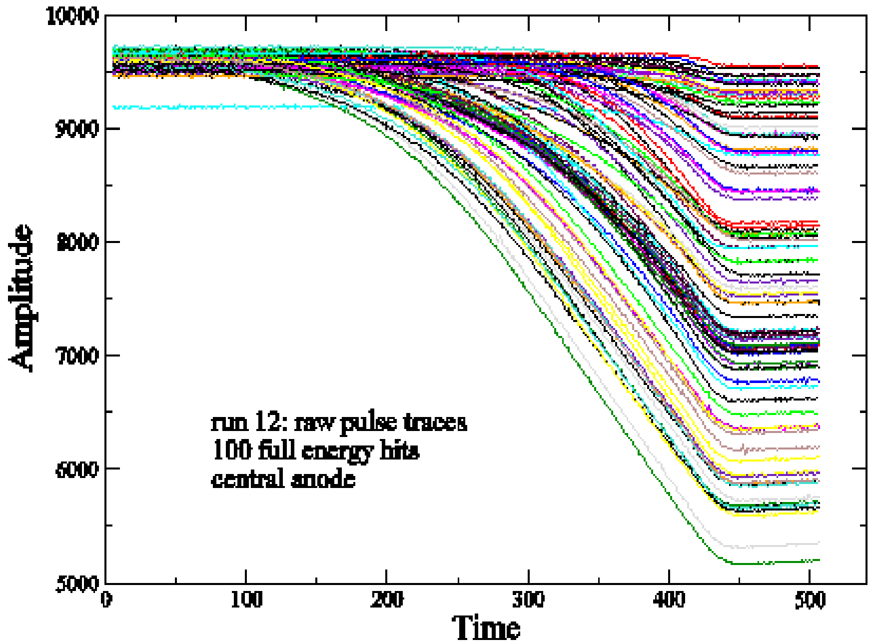
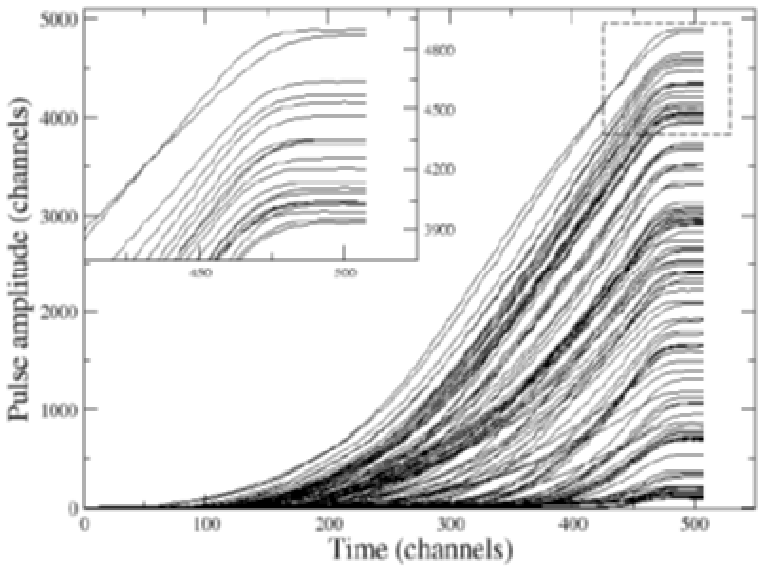
Digital Bragg Pulse Processing



- 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

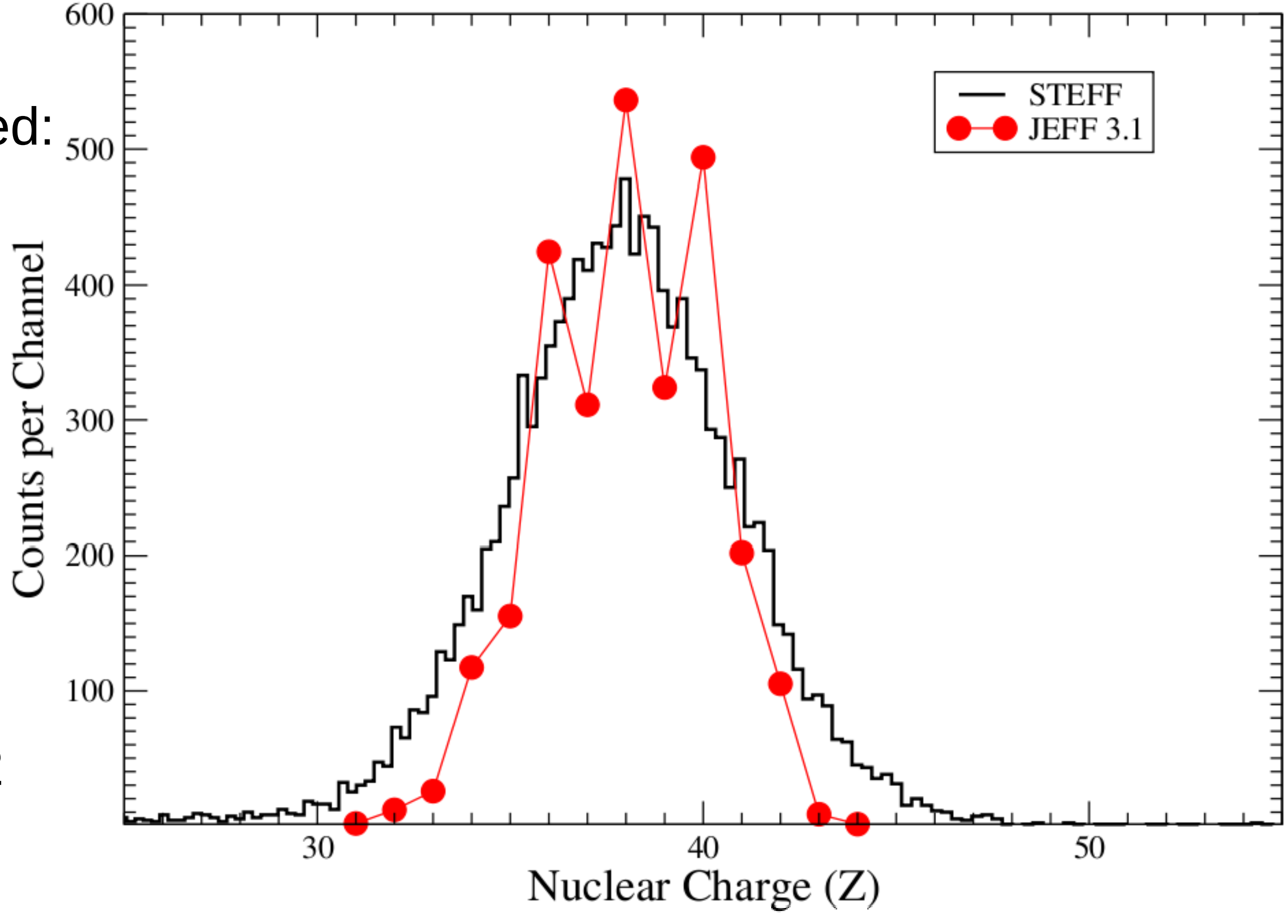
IC measurements, when velocity if fixed:

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

Where

$$b = 2/3$$

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



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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 NaI detectors around the uranium target provide a 6.8% photo peak detection efficiency
- Measure gamma-ray energy and multiplicity distributions

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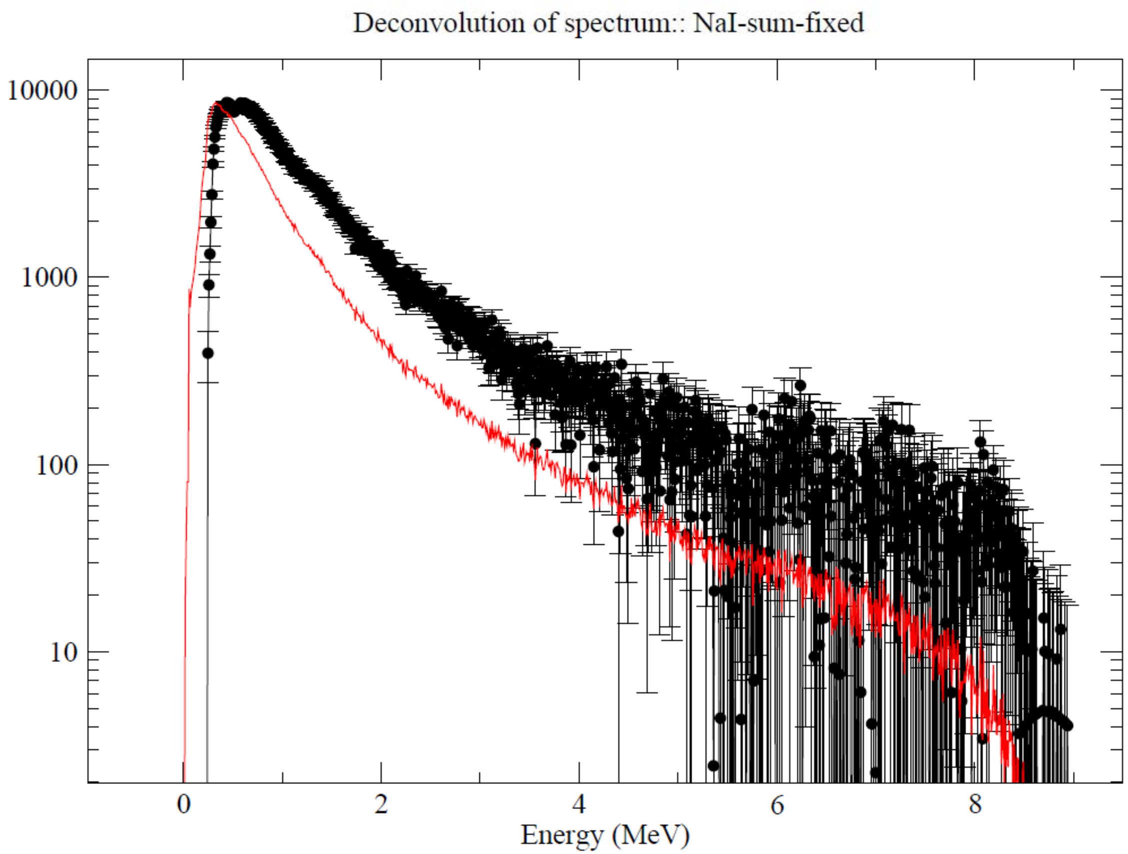
^{235}U Single γ Energy distribution (ILL)



•Time random coincidences removed (gating E/TAC)

•Multiple-hit effects removed (GEANT4)

• Deconvolution (Compton/Backscatter, etc. removal) using GEANT4 response functions.

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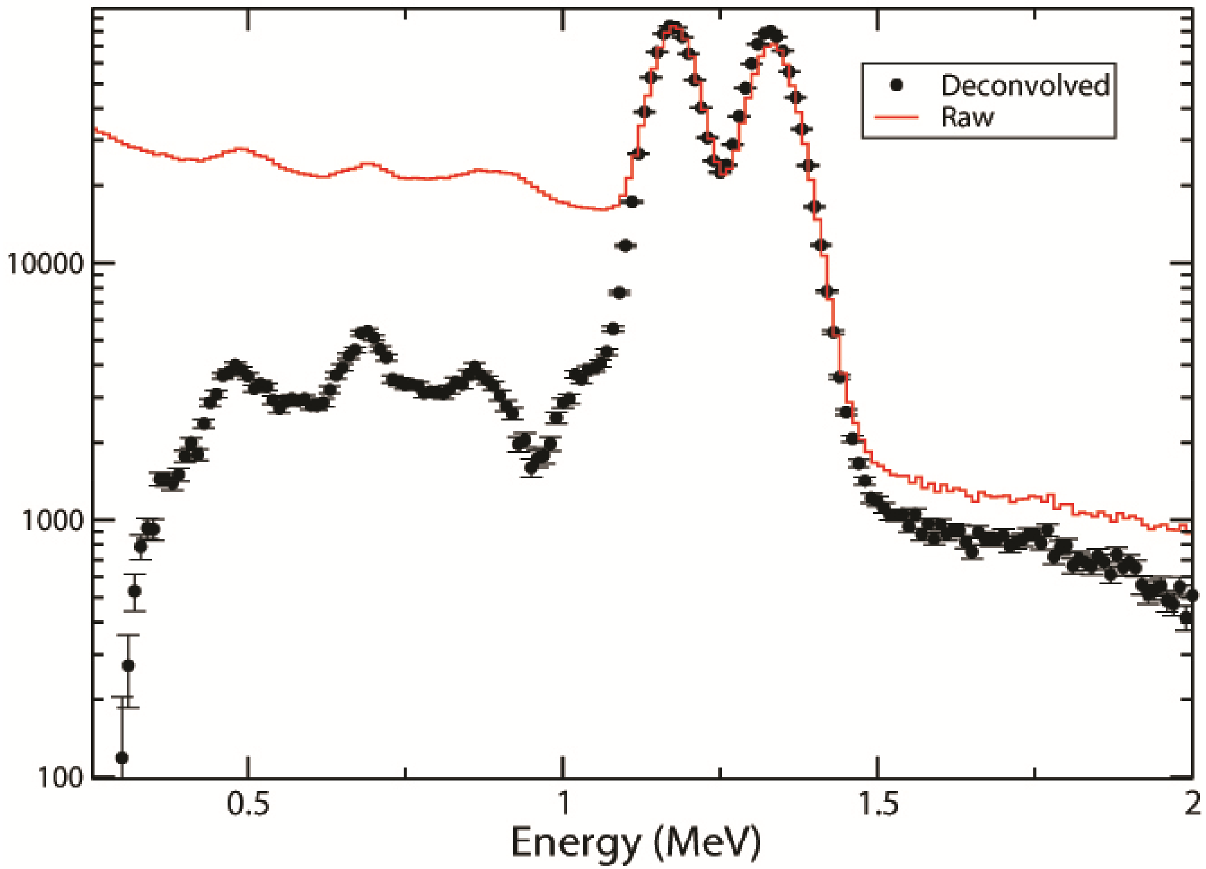
L. Murray PhD Project

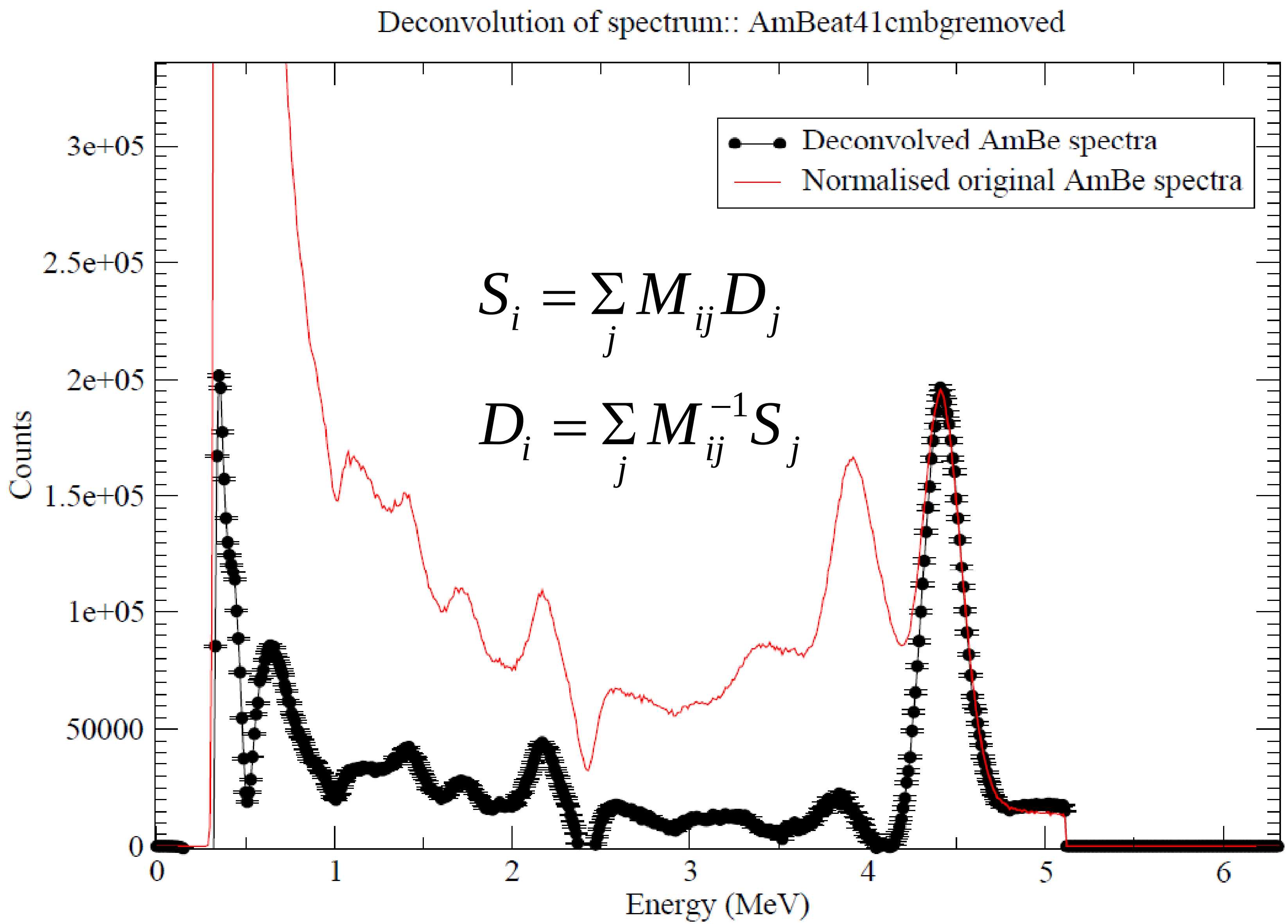
Deconvolution by Inversion of a Response Matrix (^{60}Co Spectrum) (non-iterative technique)



Matrix M from GEANT4

$$S_i = \sum_j M_{ij} D_j$$

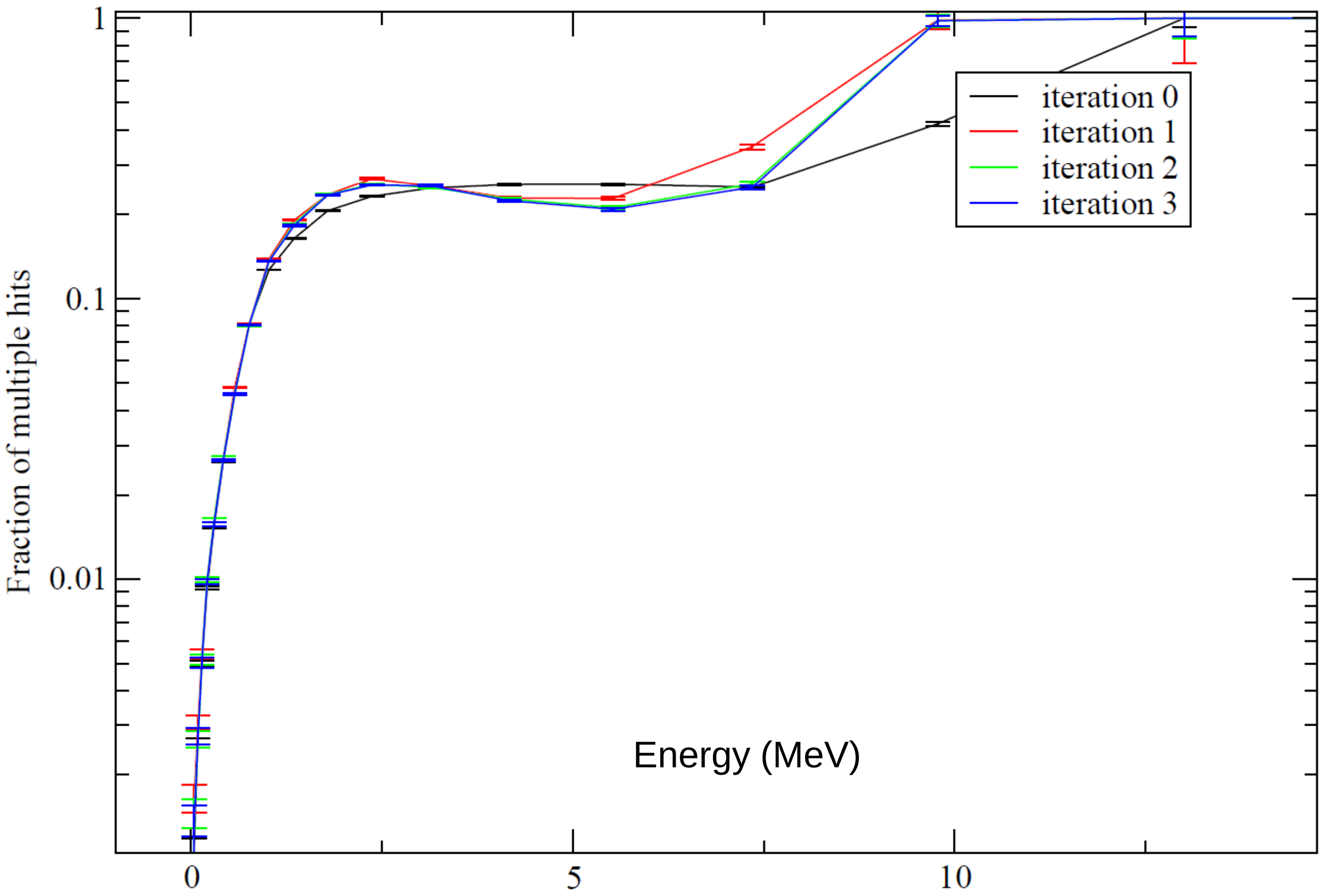
$$D_i = \sum_j M_{ij}^{-1} S_j$$

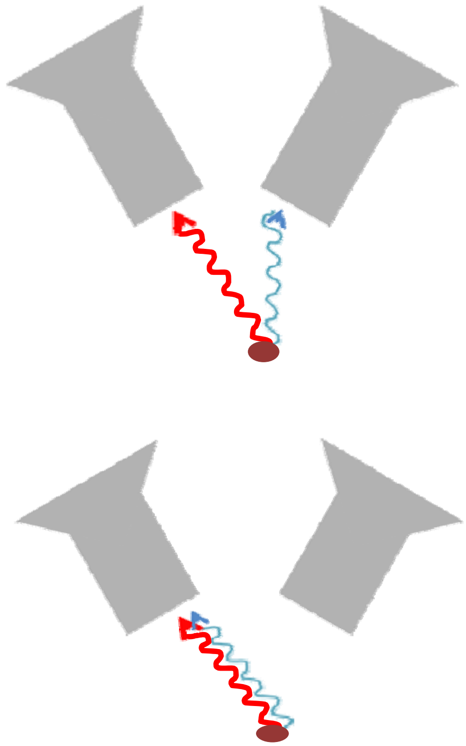


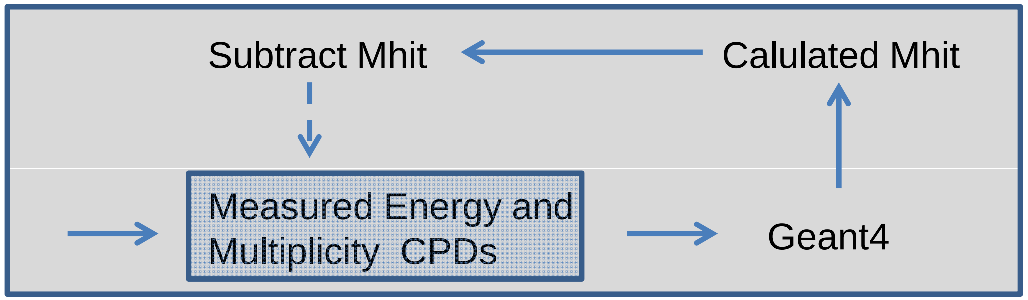
$$S_i = \sum_j M_{ij} D_j$$

$$D_i = \sum_j M_{ij}^{-1} S_j$$

Multiple Hit Subtraction.:GEANT4







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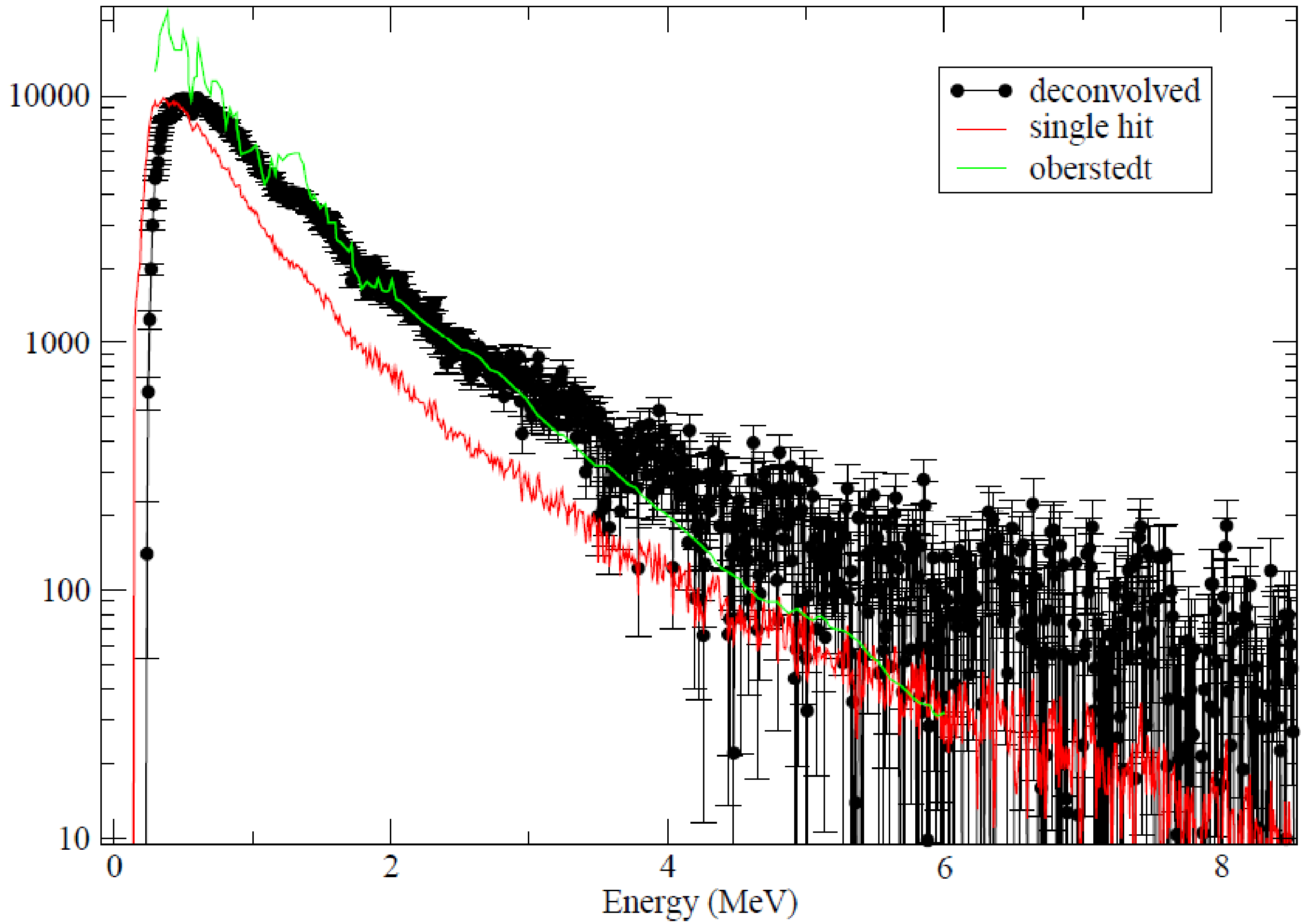


Spectrum flatter than recent measurements (e.g by Oberstedt et al.)

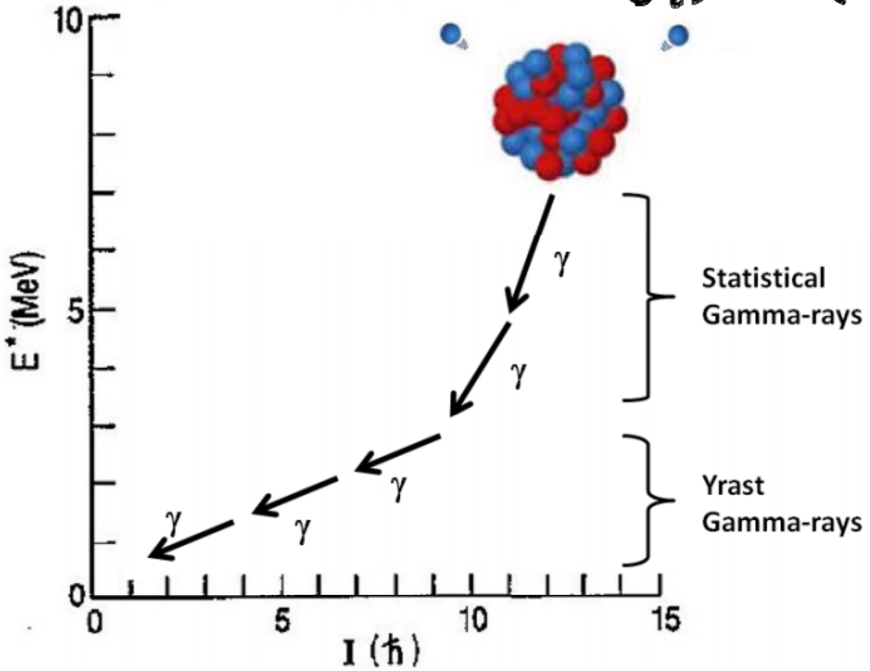
Larger detectors? Deconvolution? Multiple hits?

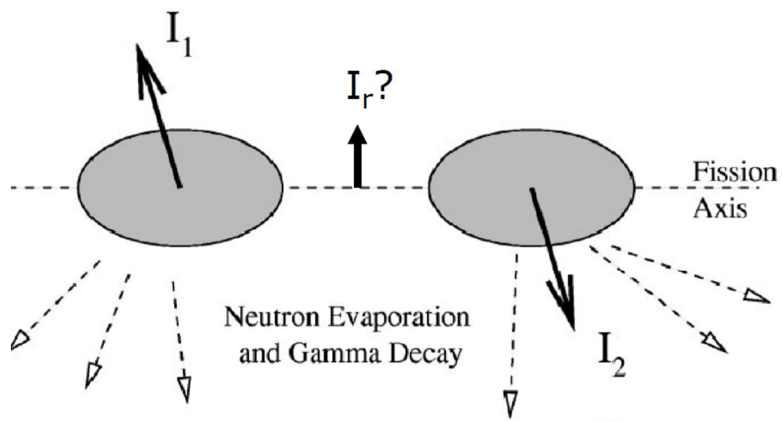
Gamma decay of fission fragment

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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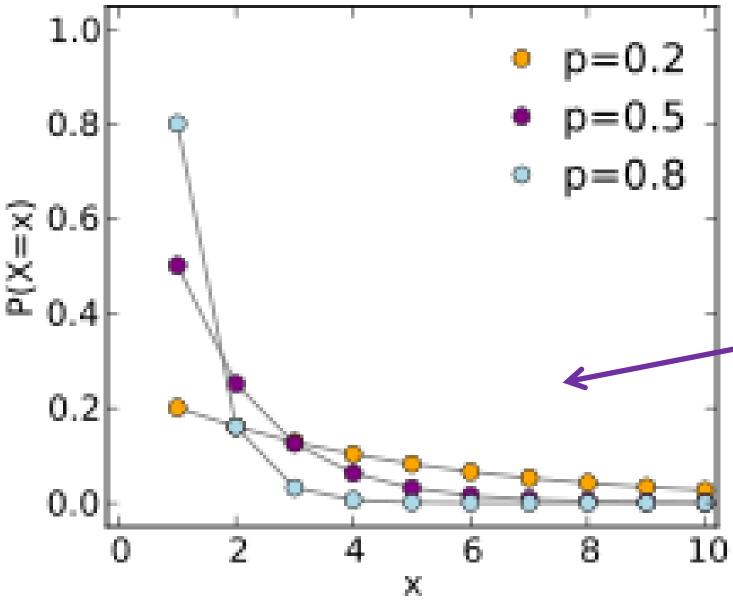
Monte Carlo simulation (decay)

Probability of spin state is generated based statistical model:

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



- Number of yrast gamma rays linked to mean spin ~ B.
- Geometric distributions give statistical gamma rays for each fragment.
- Interaction with array: ε, scattering

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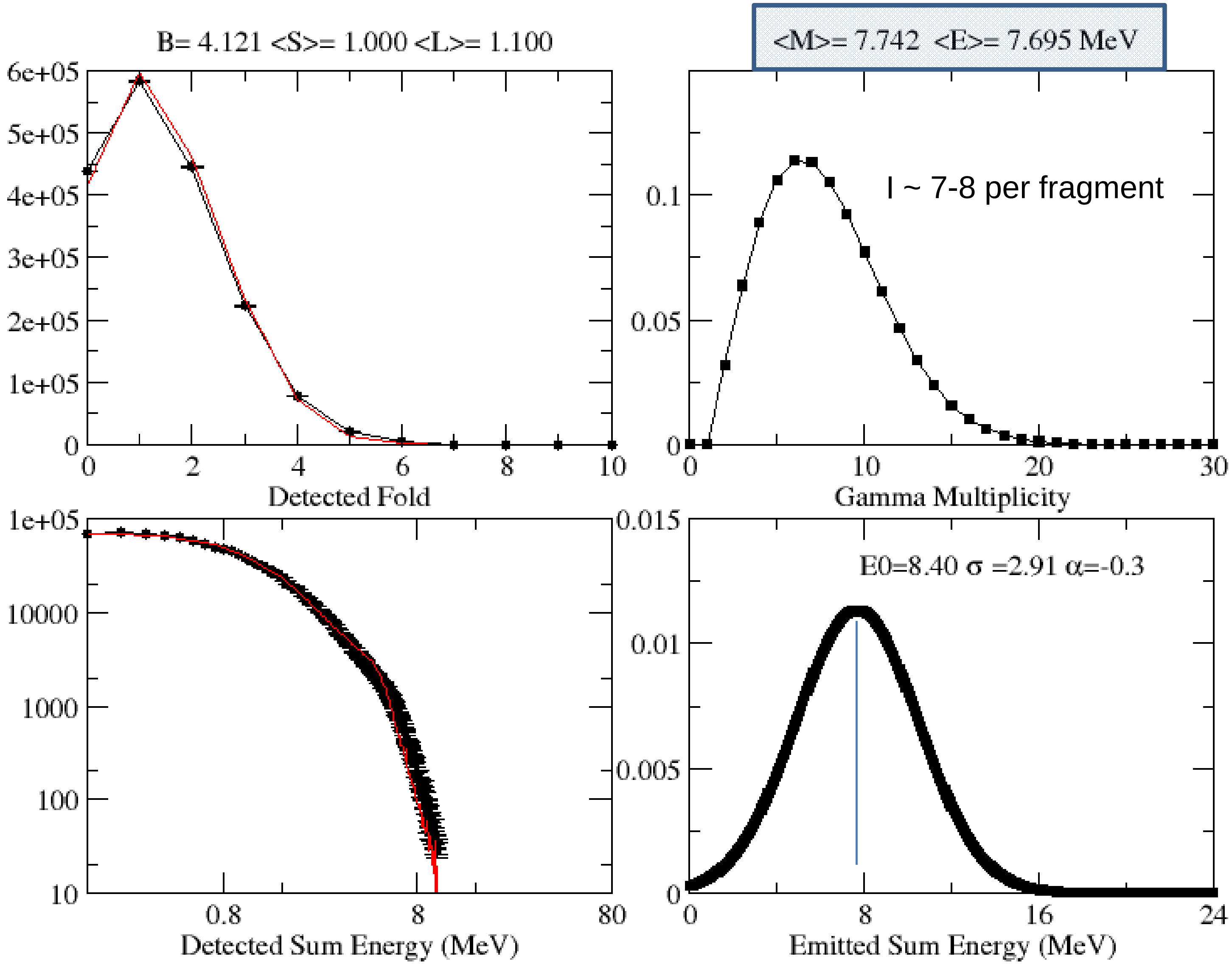
Using GEANT4 simulations of response functions of NaI detectors - ^{235}U (ILL)



^{252}Cf SF Angular Correlation Data (Gammasphere Ge Array)

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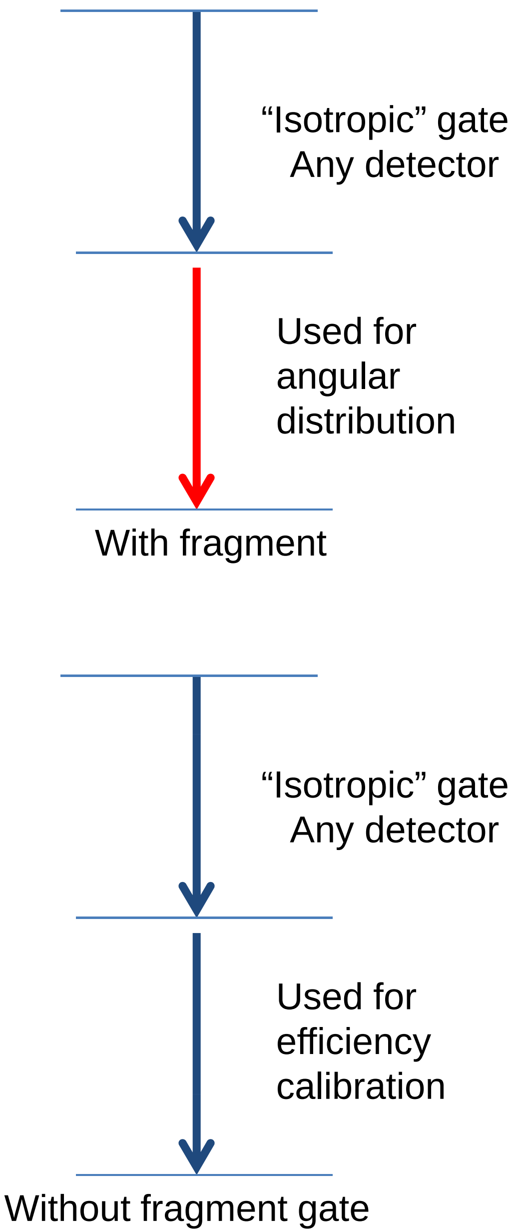
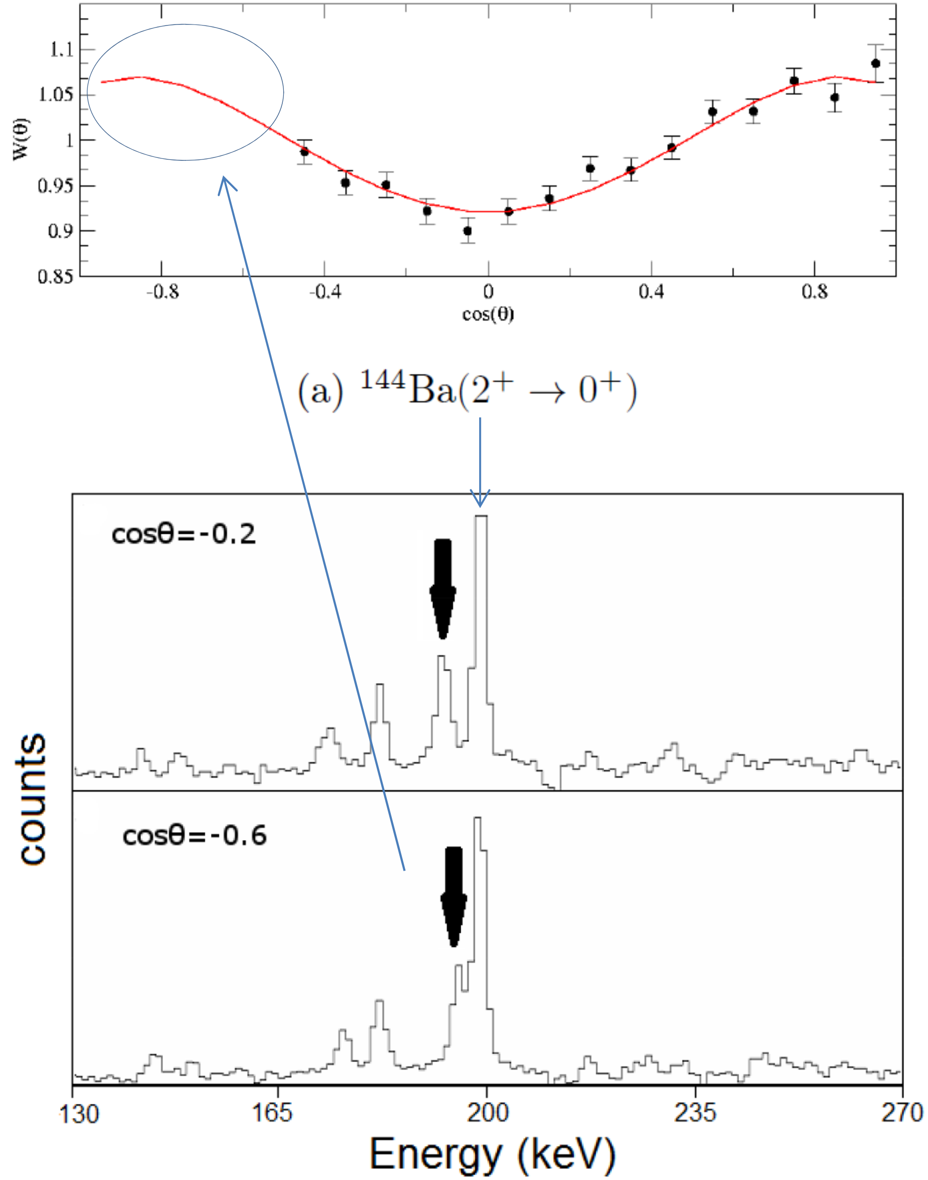




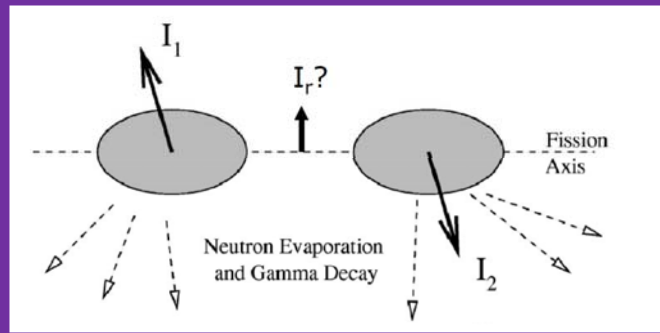
Statistical Model Code. Initial Spin Distribution.

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

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

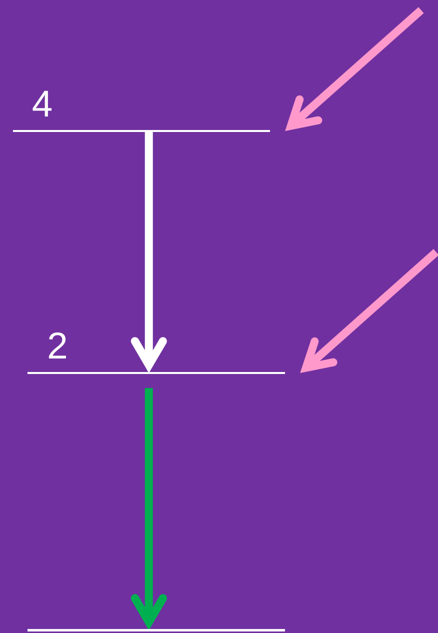
$B \sim J_{rms}$+1/2

Spread in M sub-states



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

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

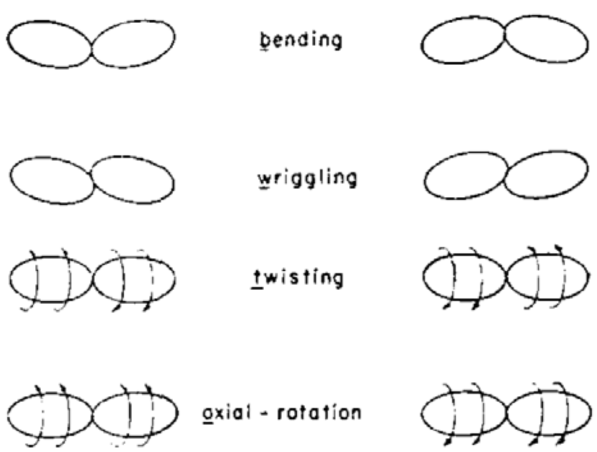


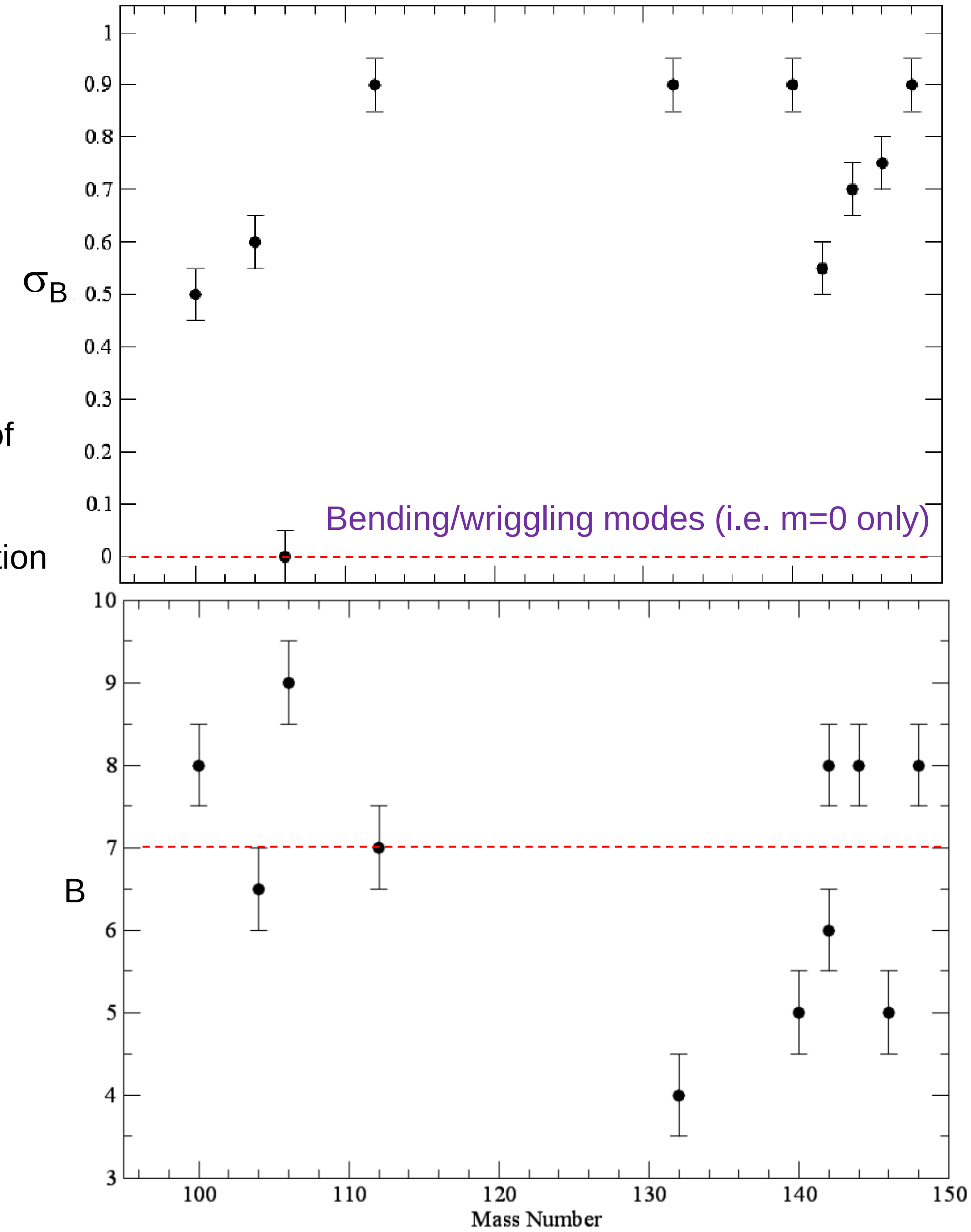
Calculates: Feeding intensities of Yrast states and a_2 , a_4

Data largely inconsistent with m=0 only

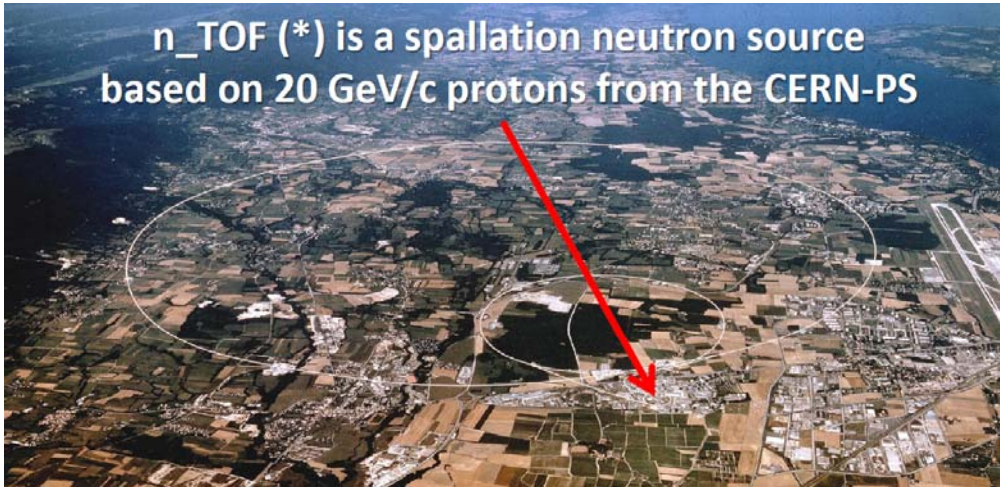
Conclusion not very sensitive to number of Neutrons and statistical gamma rays

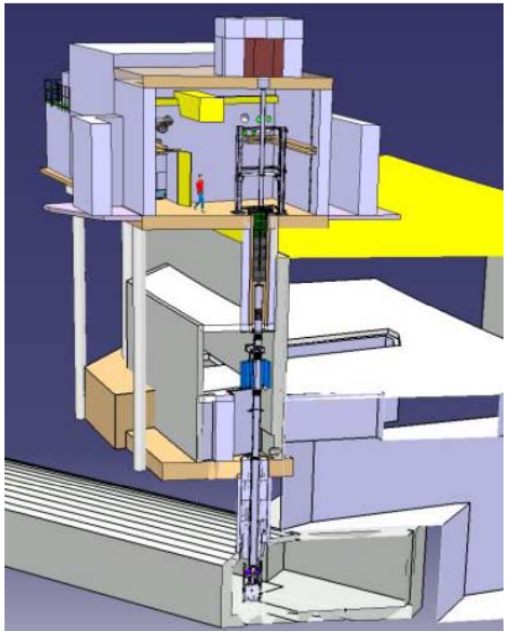
Some data may suffer unseen contamination

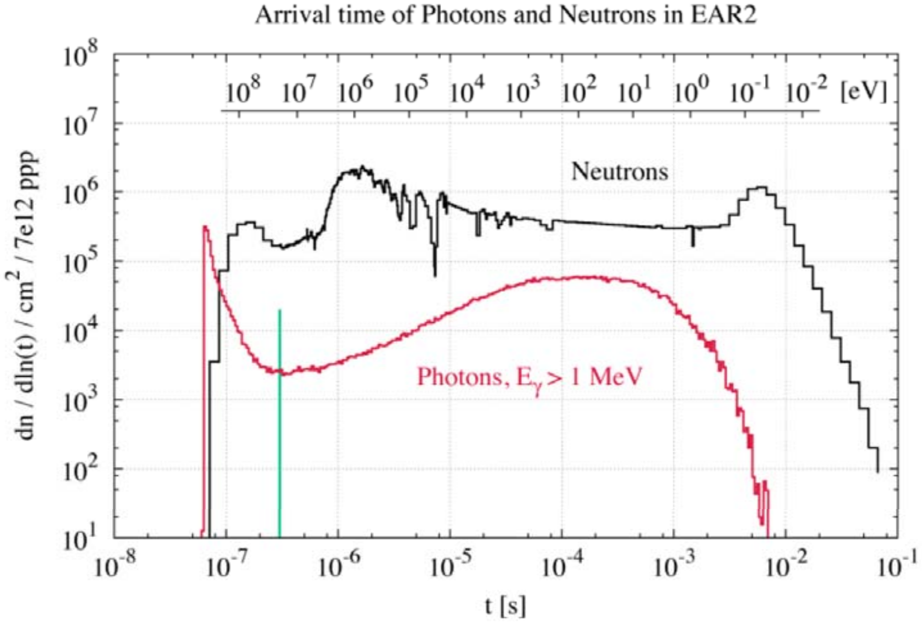


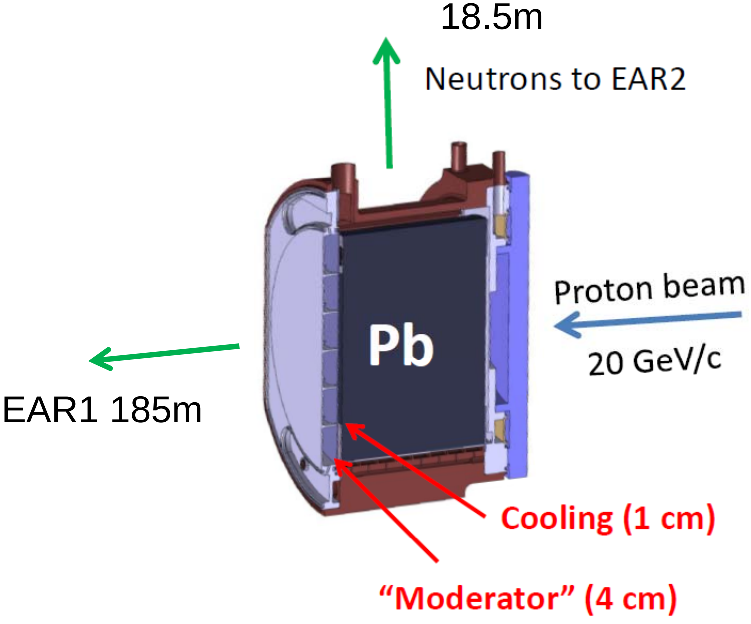


EAR2 n_TOF

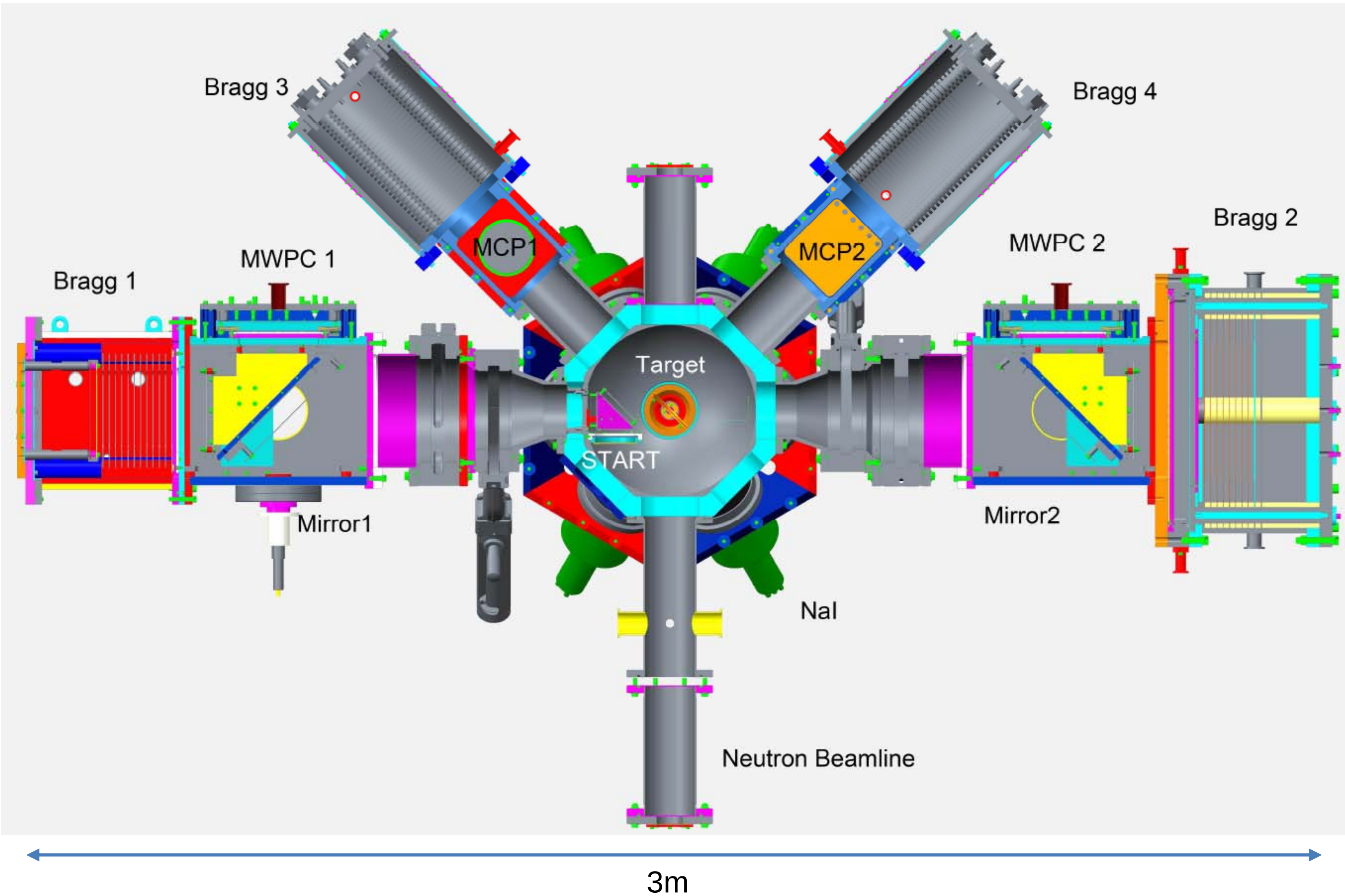

n_TOF (*) is a spallation neutron source
based on 20 GeV/c protons from the CERN-PS




Arrival time of Photons and Neutrons in EAR2
dn / dln(t) / cm^2 / 7e12 ppp
t [s]
[eV]
Neutrons
Photons, E_γ > 1 MeV


18.5m
Neutrons to EAR2
Proton beam
20 GeV/c
EAR1 185m
Pb
Cooling (1 cm)
"Moderator" (4 cm)

STEFF (with upgrade for EAR2)



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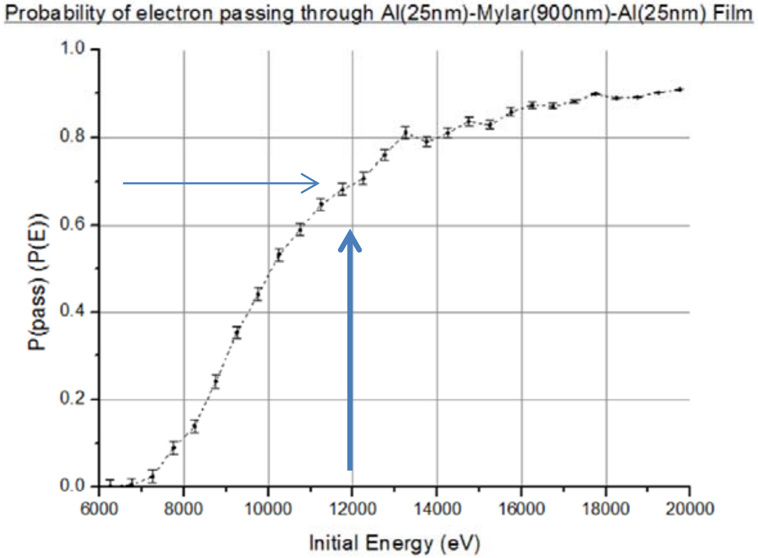
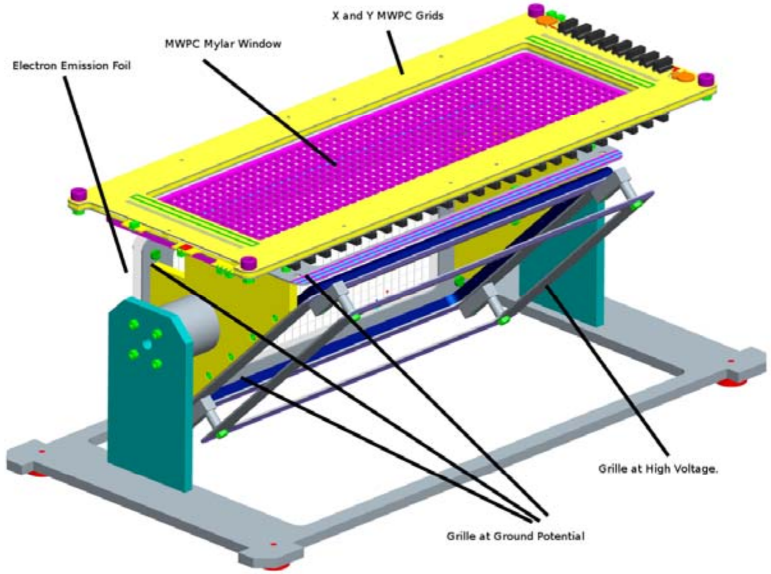
Improvements to STEFF Stop Detectors

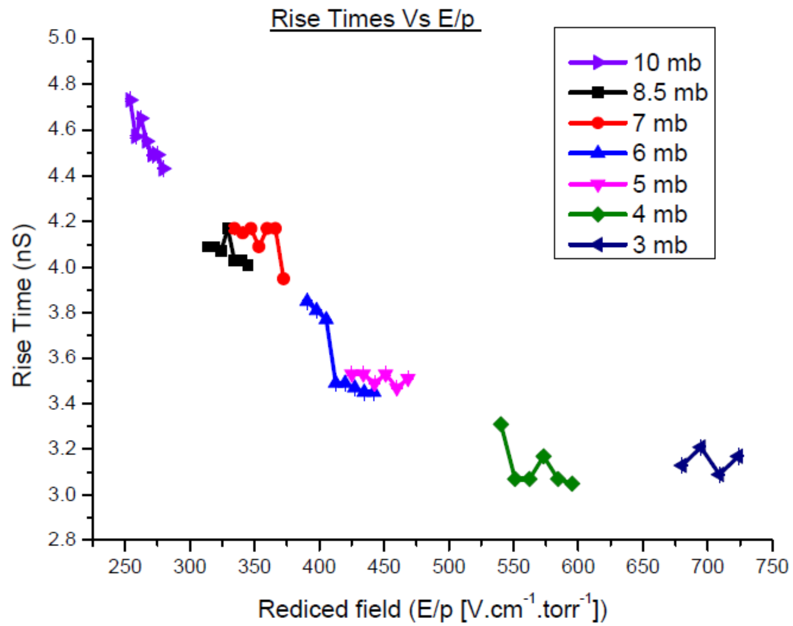


Secondary electrons get through mylar (70% prob)
Low interaction probability in thin gas volume
Previously used higher pressure ~ 10mb isobutane

Improved detector depth – multilayer (for efficiency)
Operate at 5mb isobutane
Better fast amplifiers.

Lab tests indicate timing resolution ~ 0.5 ns





STEFF nTOF Objectives

- To move STEFF to a EAR2 to study neutron-induced fission.
- Measurement of E,A,Z and directions of fragments.
- 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).

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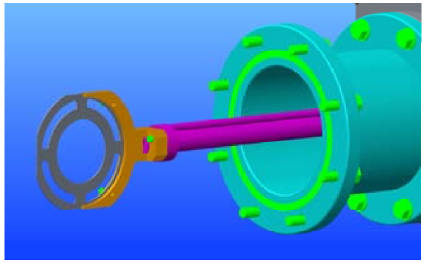
Parameters for STEFF@EAR2



- 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.

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STEFF @ EAR2

- Gamma Flash – Simulations and Test with NaI (T. Wright, J.Ryan)
- Target manufacture: currently 0.2um Al self-supporting backing (Manchester). Electrodeposition at IPN Orsay
- Improvements to STOP detectors; Efficiency and timing (S. Warren)