Calculation of Antineutrino Fluxes Using ENDF/B-VII.1

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BROOKHAVEN NATIONAL LABORATORY

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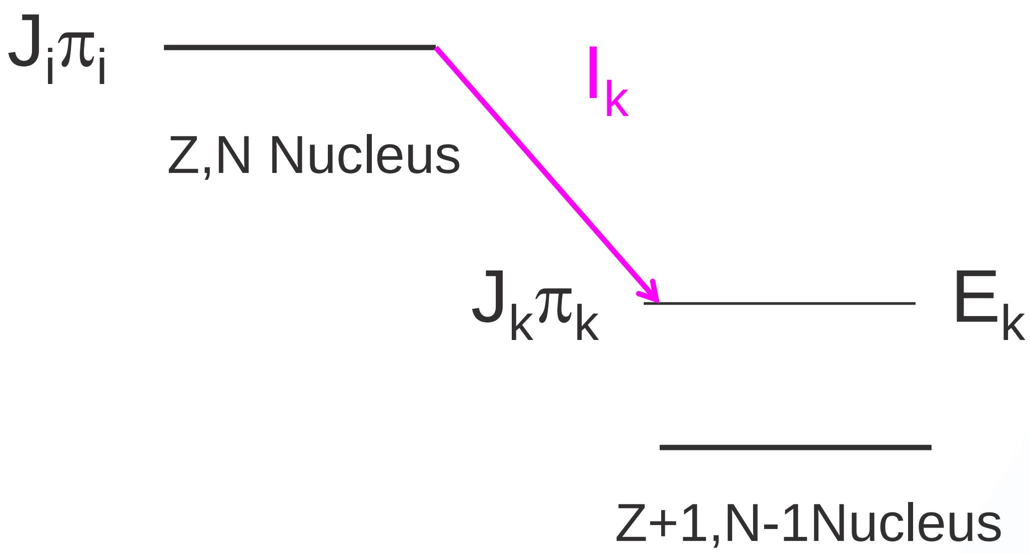
β- decay from Level *i* to level *k*

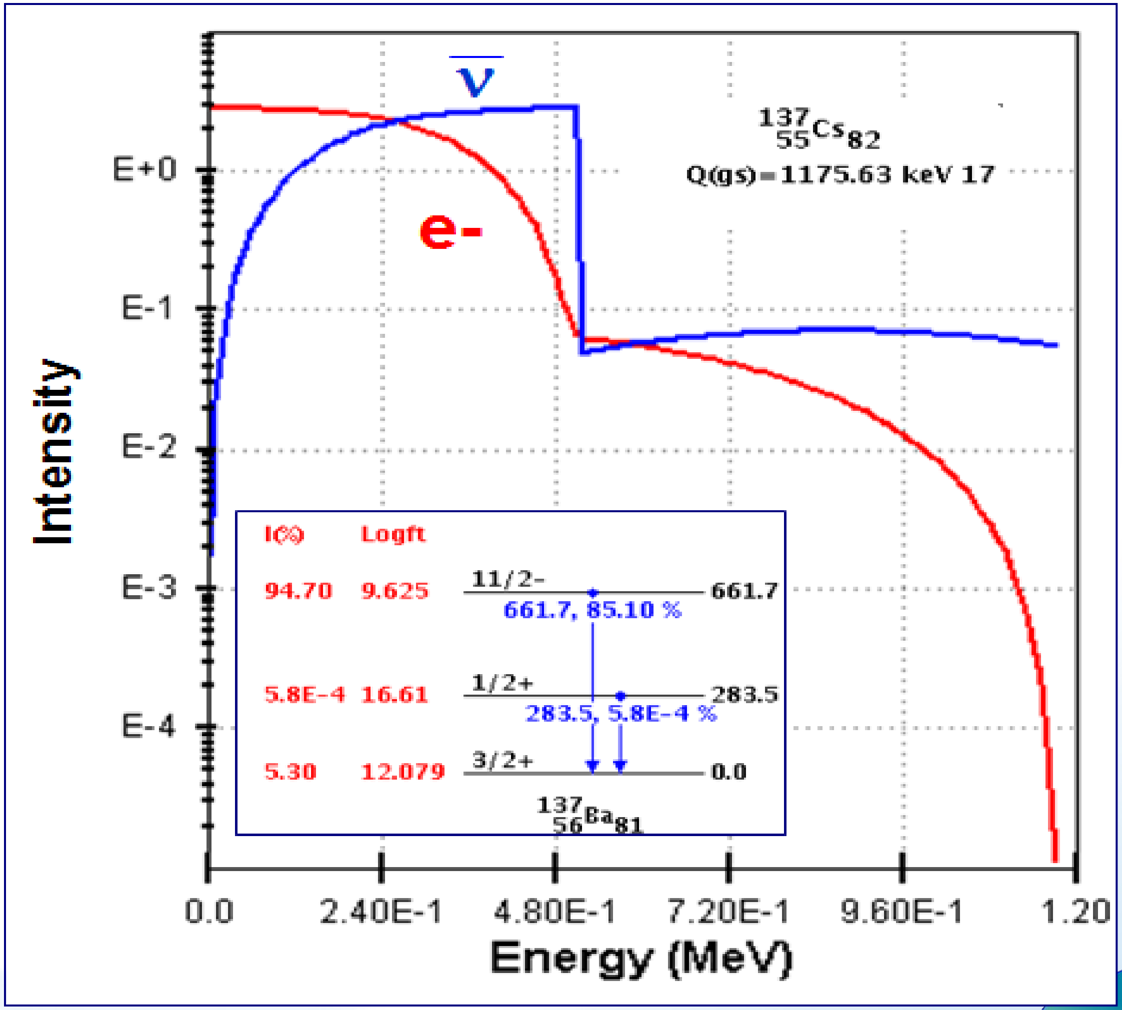


Spectrum for each transition: $S(Q\text{-}Ek, J_i\pi_i, J_k\pi_k)$

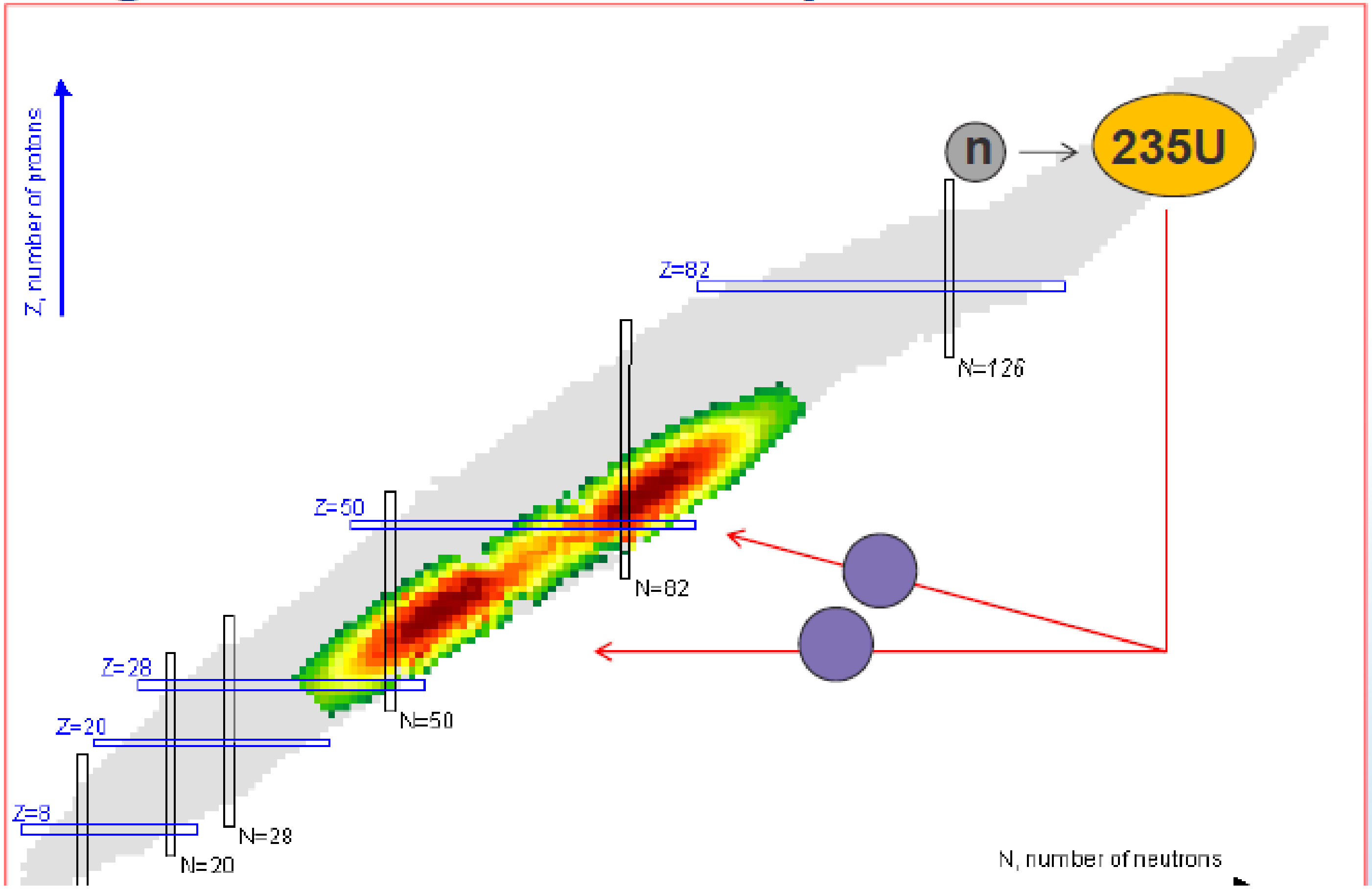
Spectrum for decay $\sum I_k \, S(Q\text{-}Ek, J_i\pi_i, J_k\pi_k)$

All nuclear decay data from **ENDF/B-VII.1** (December 2011)

Example, 137Cs



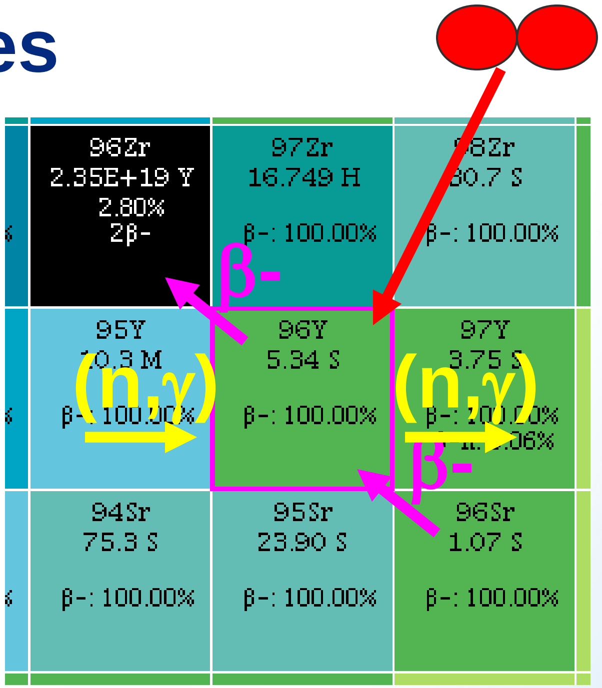
Fission of an actinide nuclide can produce a large number of fission products



236U has Z/N=92/144=0.64, around Z=50, the valley of stability has Z/N=50/70=0.71 as a result, most fission products are neutron rich and undergo beta-minus decay

How to calculate anti-neutrino rates

The nuclei in the core form a decay/processing network:



$$\frac{dN_i}{dt} = r(t)FY_i - \lambda_i N_i + \sum \lambda_{ik} N_k - \Phi_n(t)\sigma_i N_i + \Phi_n(t)\sum \sigma_{ik} N_k$$

Neglect processing as $\Phi_n\sigma << \lambda$ and consider an equilibrium situation:

$$\frac{dN_i}{dt} = 0 = rFY_i - \lambda_i N_i + \sum \lambda_{ik} N_k \longrightarrow N_i = rCFY_i / \lambda_i$$

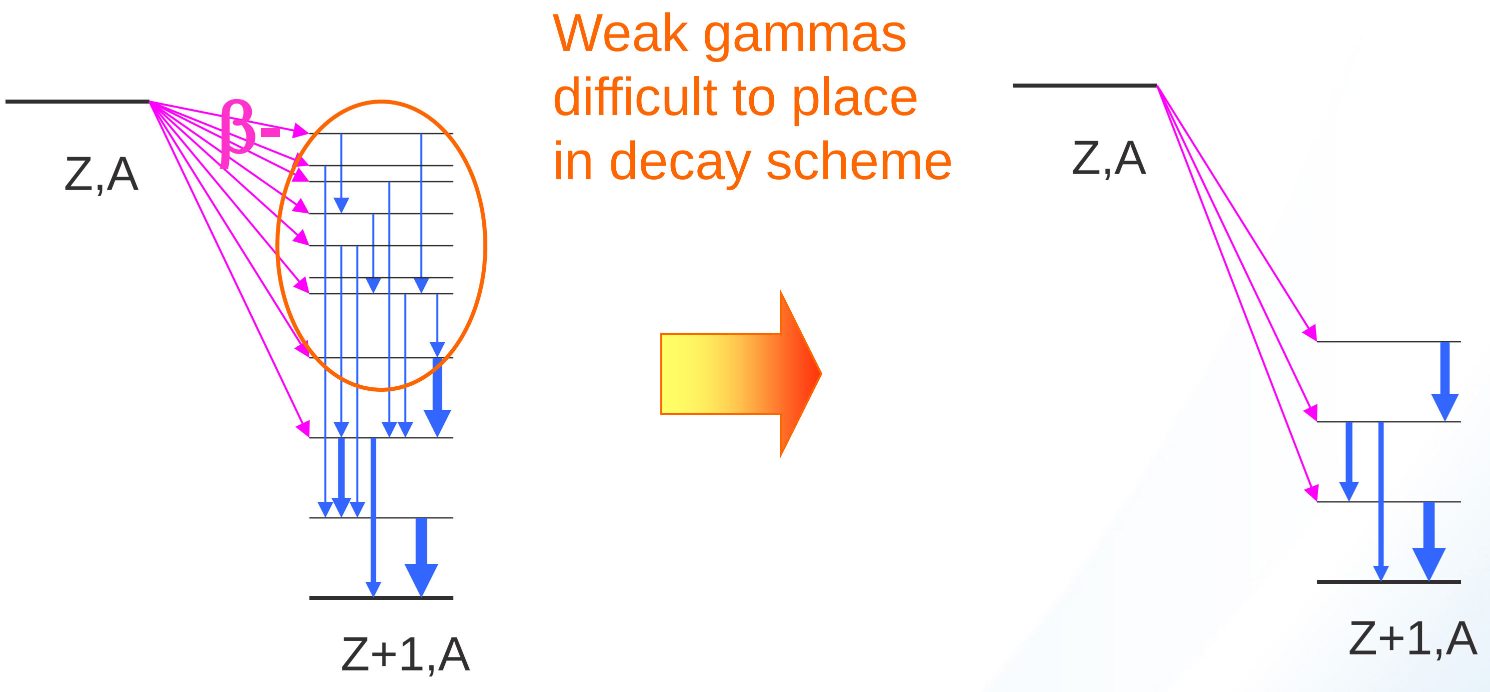
Then the anti-neutrino rate per fission is:

$$S(E) = \sum \lambda_i N_i S_i(E) / r = \sum CFY_i S_i(E)$$

Used by Vogel *et al*, 1981, ENDF/B-V

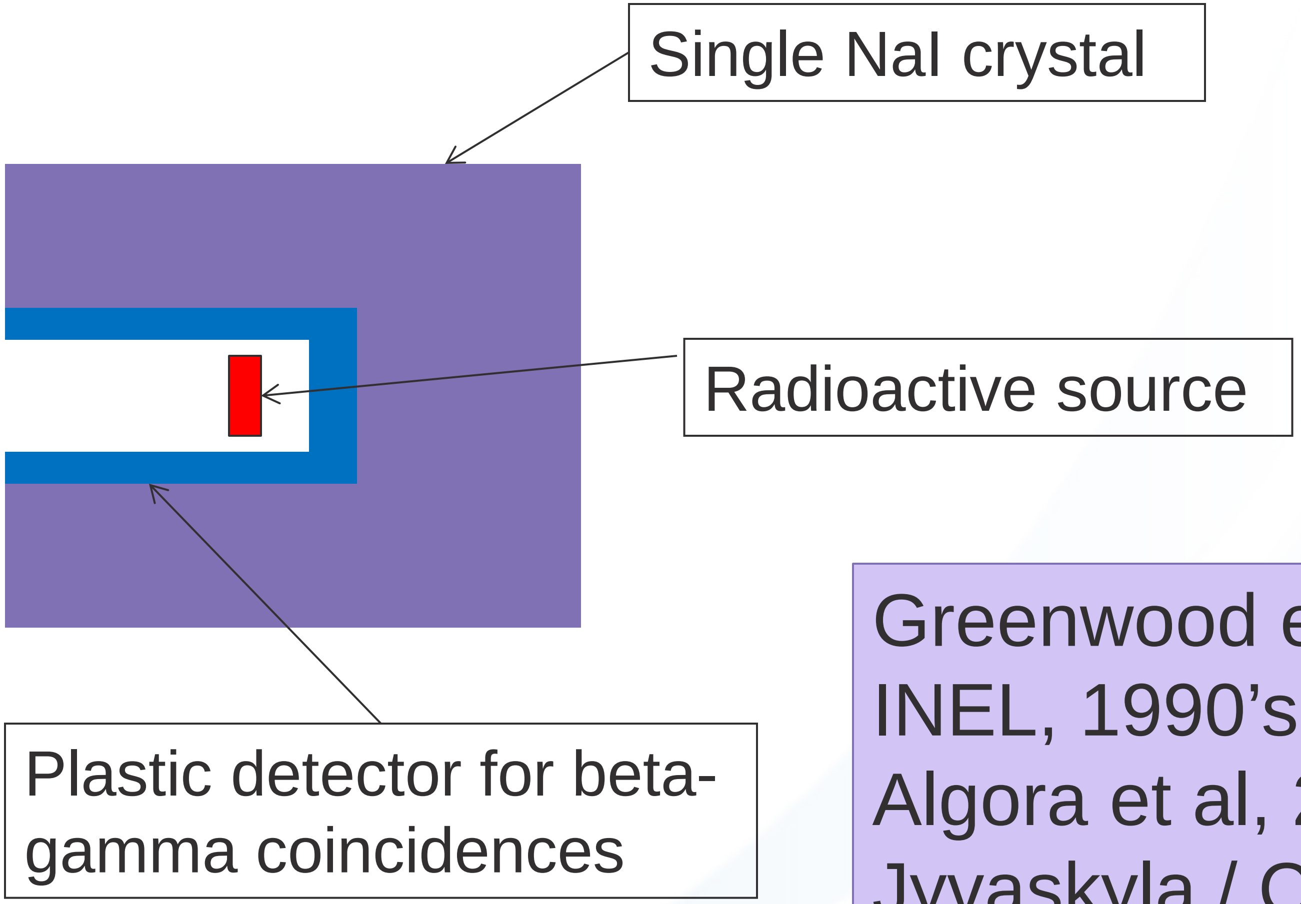
We'll repeat the calculations using the fission yields from the JEFF library

Pandemonium effect in β- decay



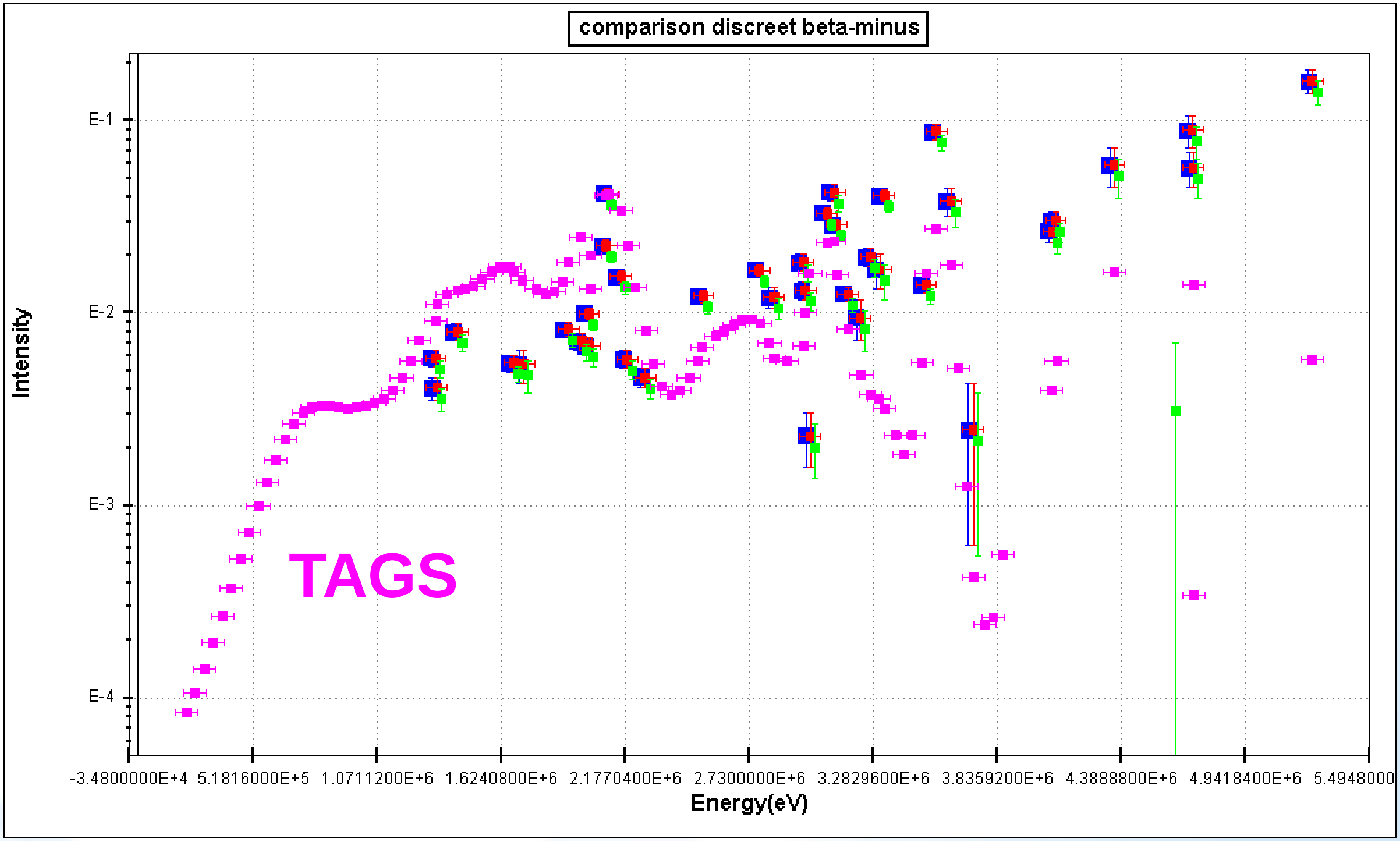
Incomplete decay schemes lead to more energetic β- and anti-neutrino spectra

TAGS (Total Absorption Gamma Spectrometers) experiments, large efficiency, poor energy resolution.



Greenwood et al, INEL, 1990's
Algora et al, 2010, Jyvaskyla / CERN

104Tc Beta feeding TAGS vs Ge high resolution data



Tengblad's data

Rudstam *et al.*, At.Data Nucl.Data Tables 45, 239 (1990)

Measured beta and gamma single spectra for the decay of 80+ fission products

Gammas measured in a NaI(Tl) crystal.

Electrons measured in a Plastic (ΔE) plus HPGe(E) and Si(Li) with Plastic (veto) telescopes

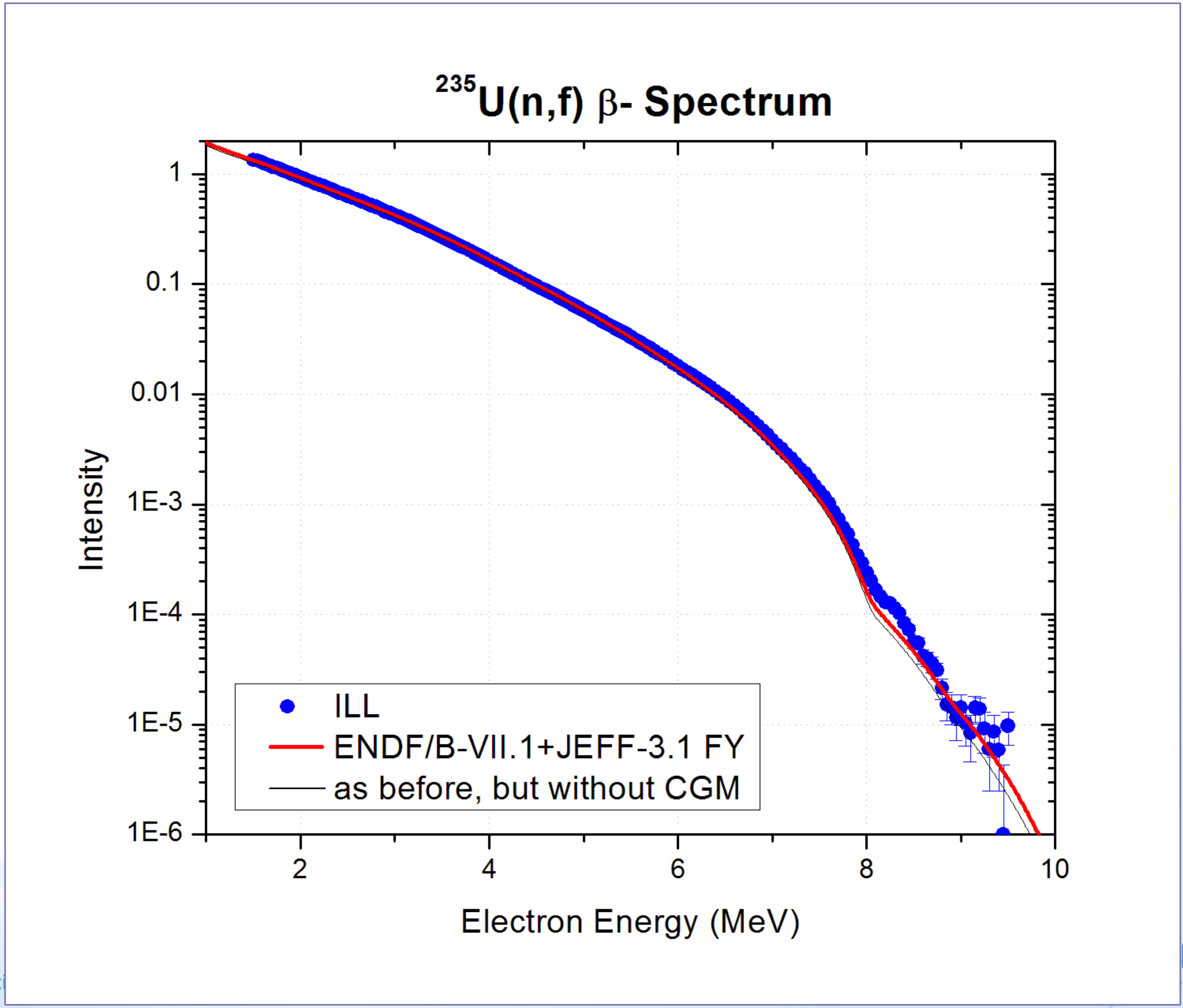
The obtained mean energies are very useful for decay heat calculations

Use of theory for incomplete decay data

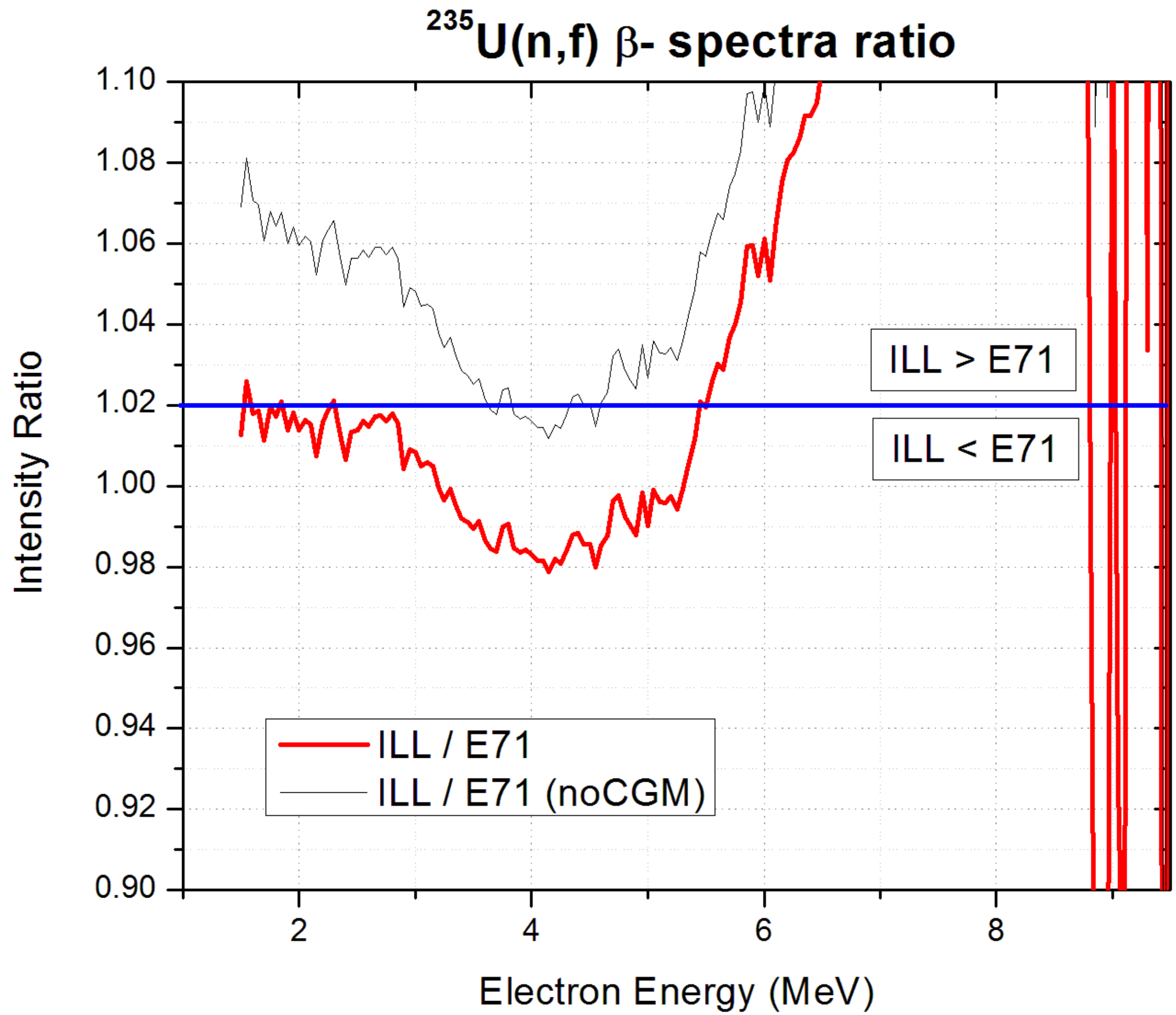
We have used results from the CGM code, T. Kawano, LANL

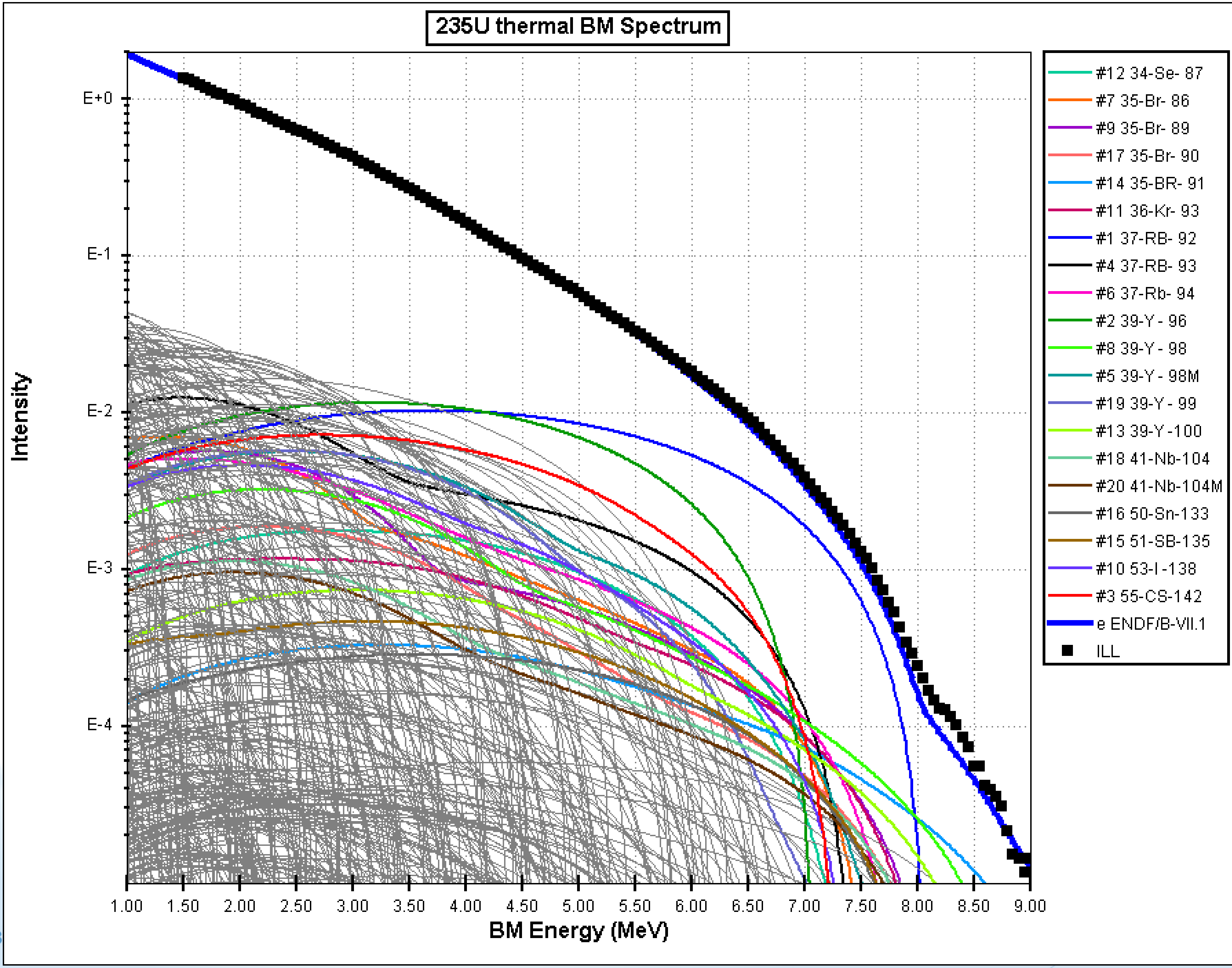
- Beta strength functions from QRPA calculations by P. Moller (allowed transitions only)
- Hauser-Fesbach calculations to model gamma vs neutron competition
- Q-values from the 2012 Atomic Mass Evaluation

Results for 235-U at thermal energies



Results for 235-U at thermal energies





235U thermal BM Spectrum
Intensity
E+0
E-1
E-2
E-3
E-4
1.00
1.50
2.00
2.50
3.00
3.50
4.00
4.50
5.00
5.50
6.00
6.50
7.00
7.50
8.00
8.50
9.00
BM Energy (MeV)
#12 34-Se- 87
#7 35-Br- 86
#9 35-Br- 89
#17 35-Br- 90
#14 35-BR- 91
#11 36-Kr- 93
#1 37-RB- 92
#4 37-RB- 93
#6 37-Rb- 94
#2 39-Y - 96
#8 39-Y - 98
#5 39-Y - 98M
#19 39-Y - 99
#13 39-Y -100
#18 41-Nb-104
#20 41-Nb-104M
#16 50-Sn-133
#15 51-SB-135
#10 53-I -138
#3 55-CS-142
e ENDF/B-VII.1
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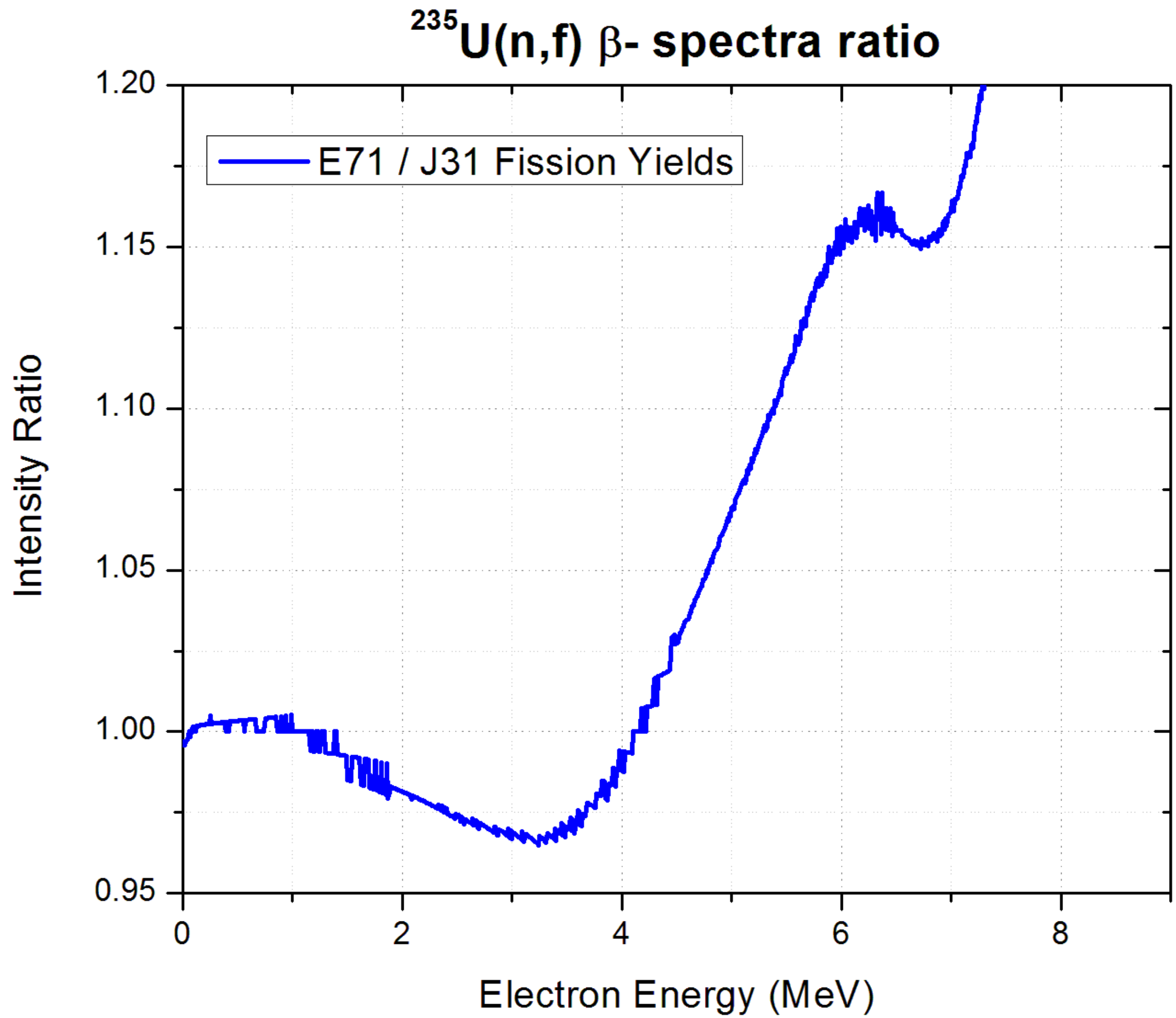
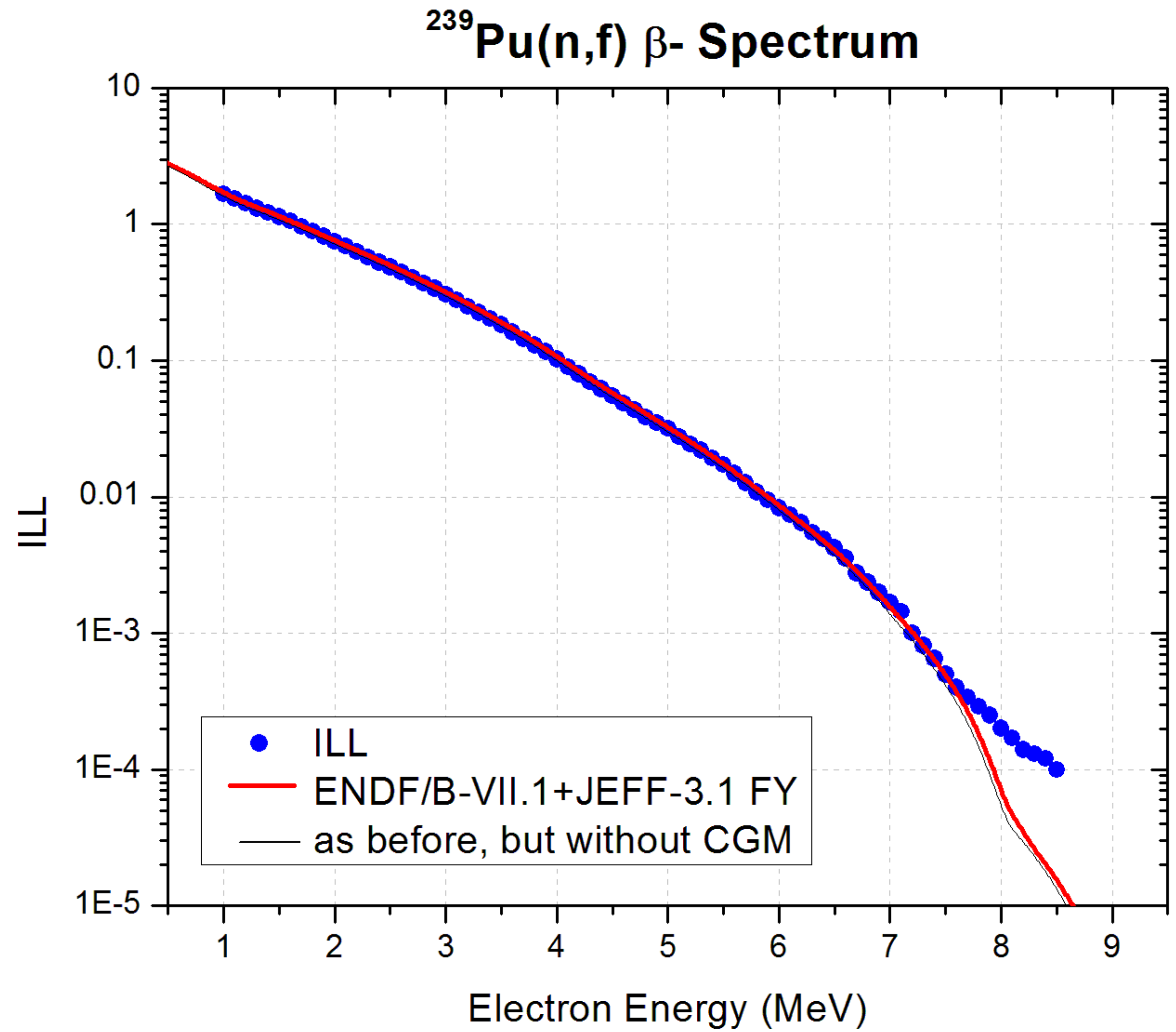
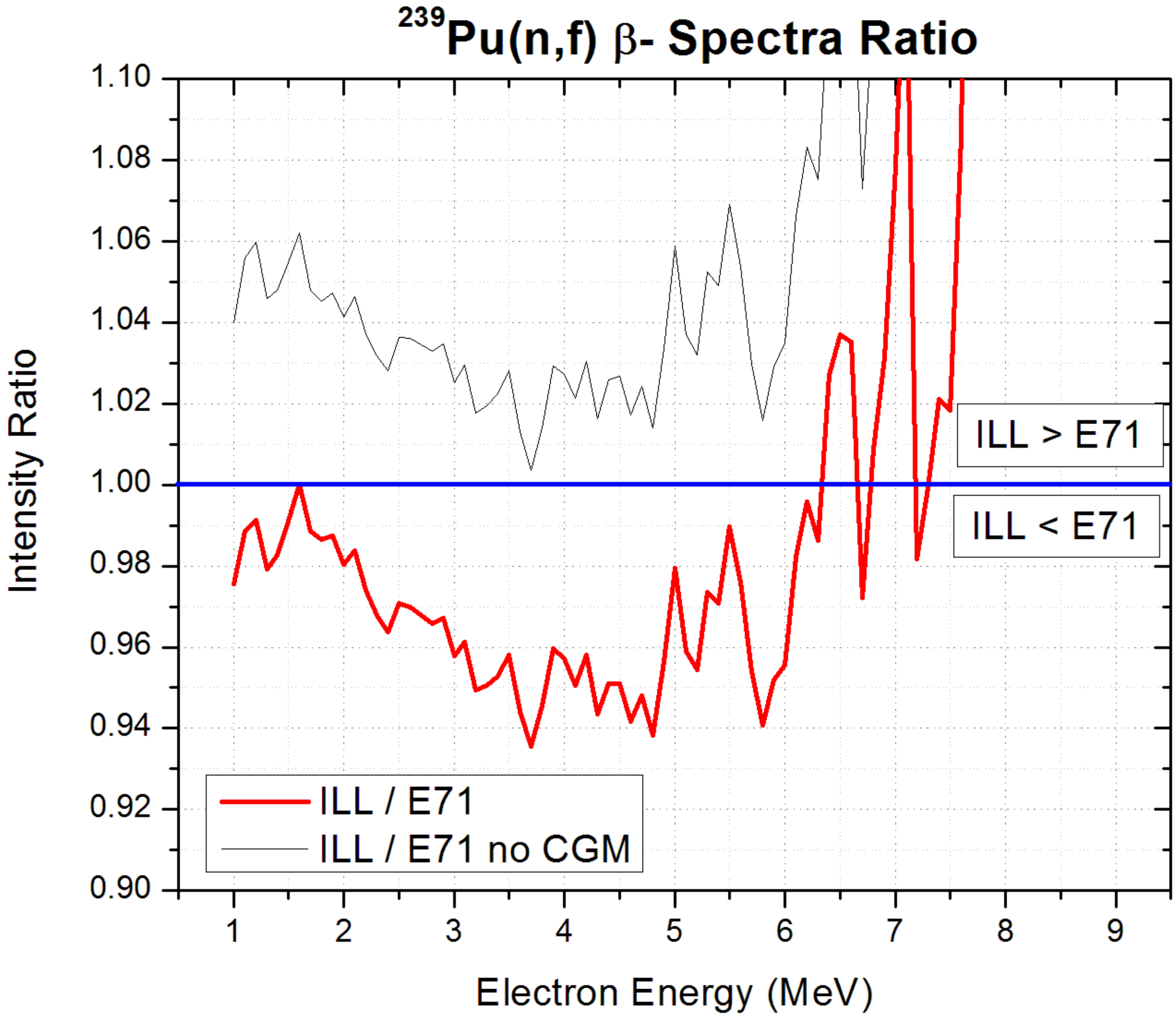
ENDF/B-VII.1 vs JEFF-3.1 Fission Yields effect



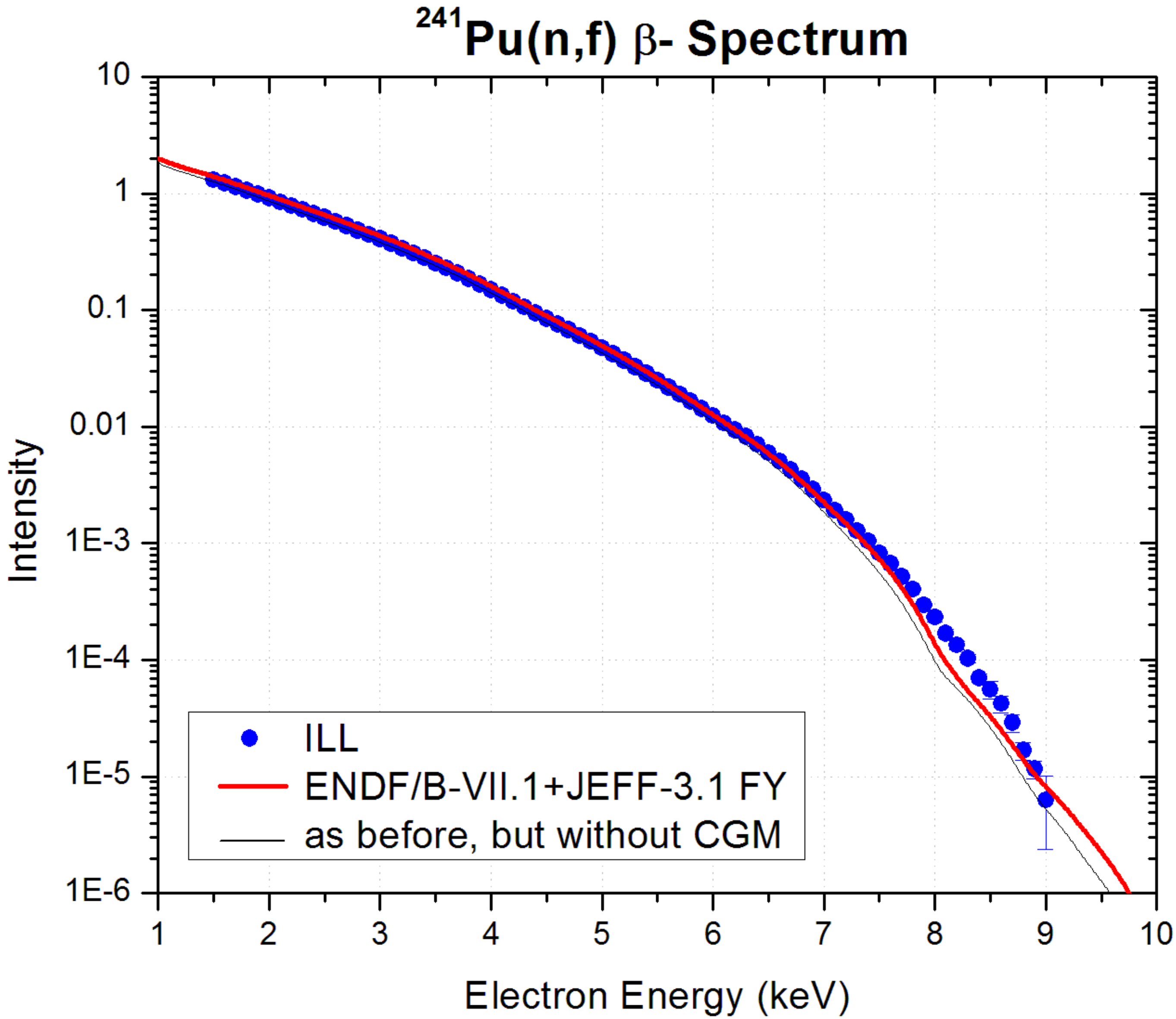
Results for 239-Pu at thermal energies



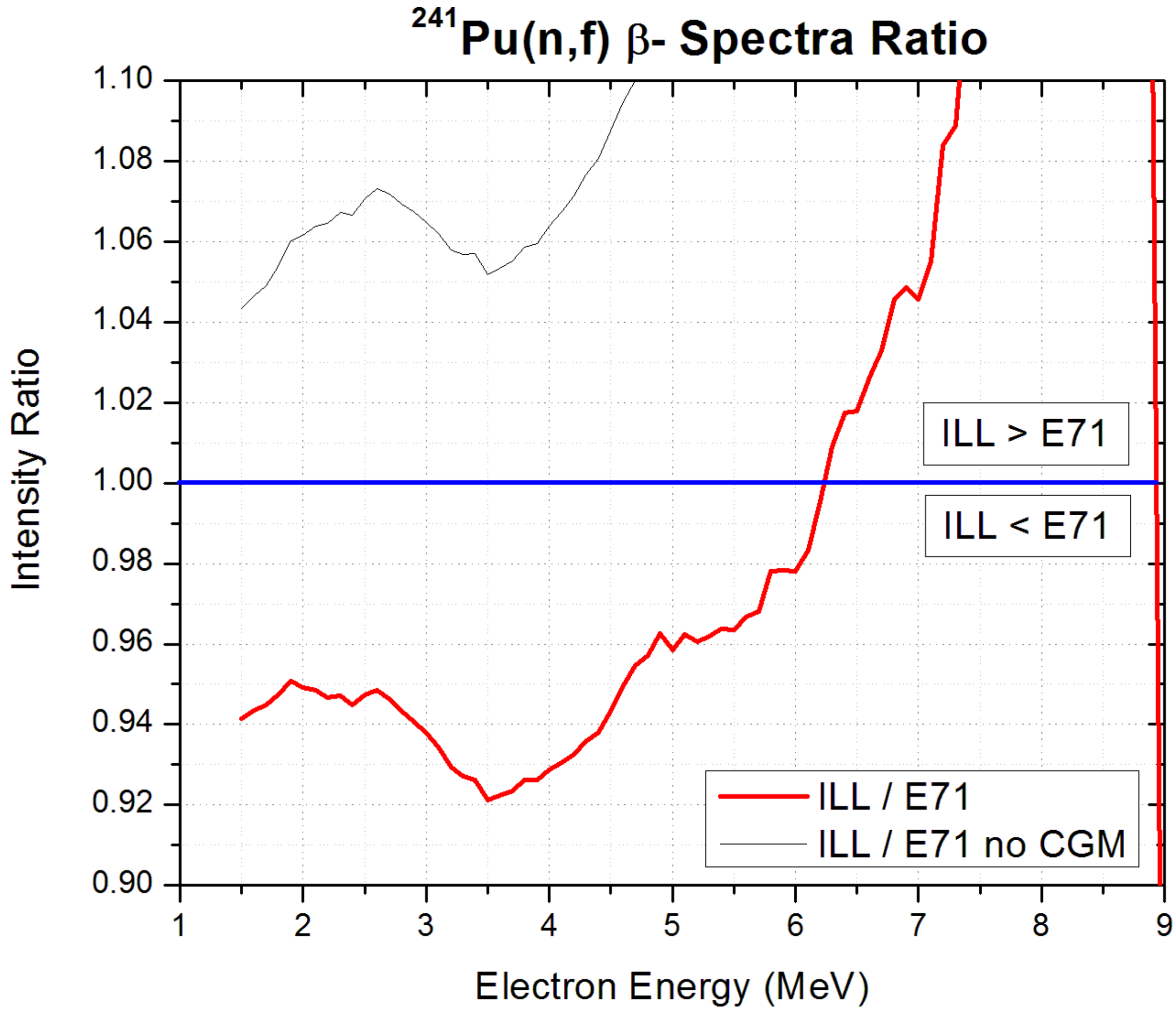
Results for 239-Pu at thermal energies



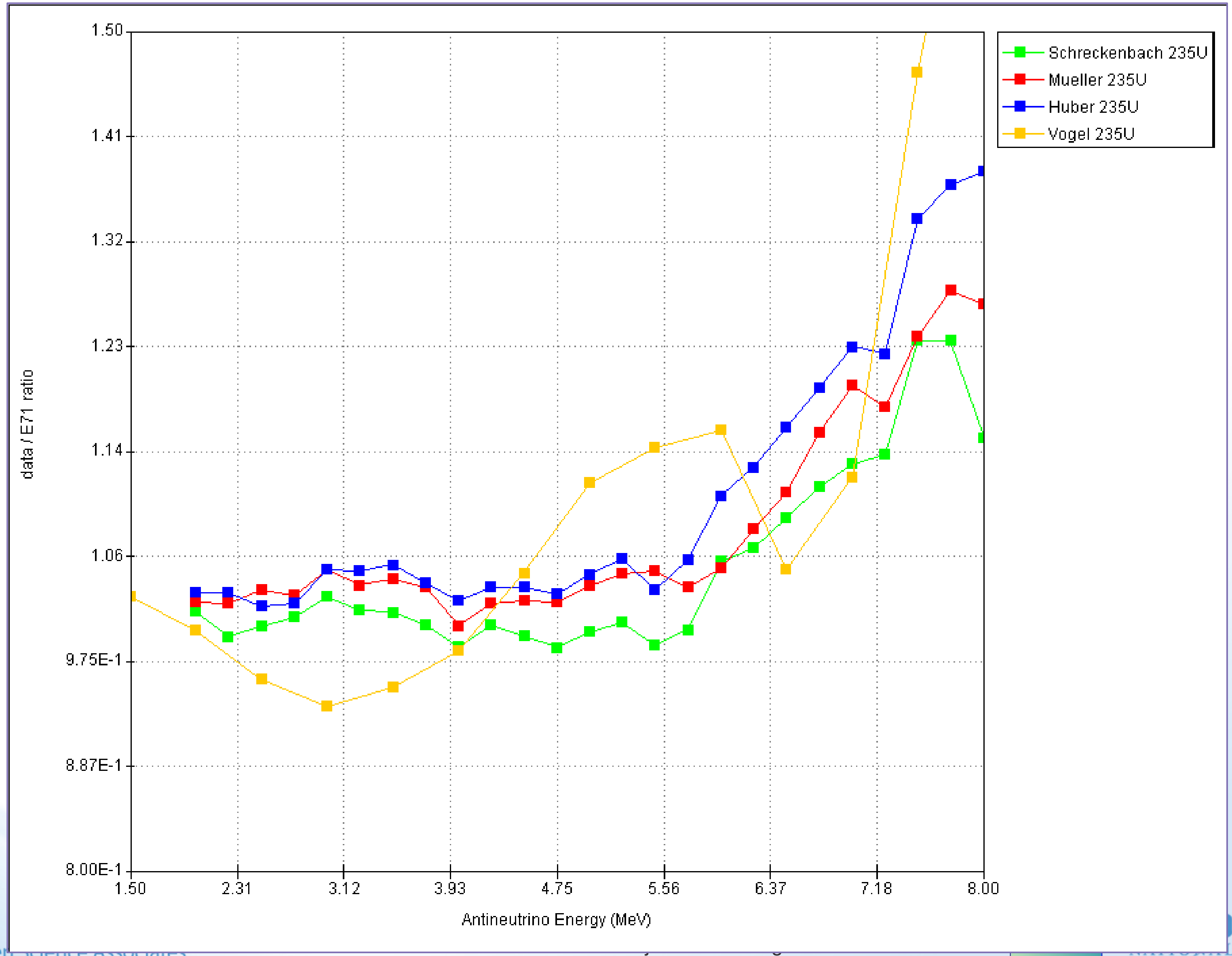
Results for 241-Pu at thermal energies



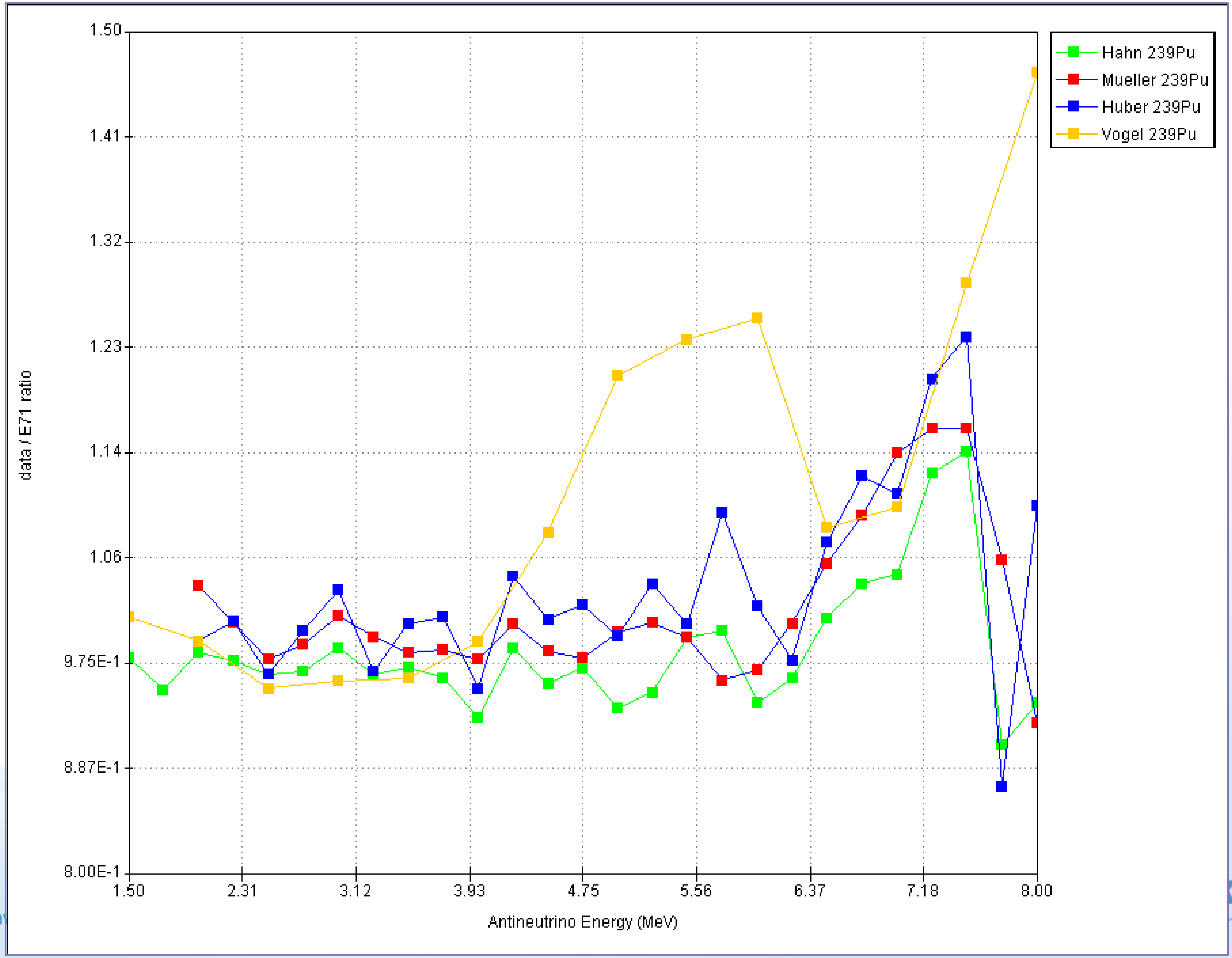
Results for 241-Pu at thermal energies



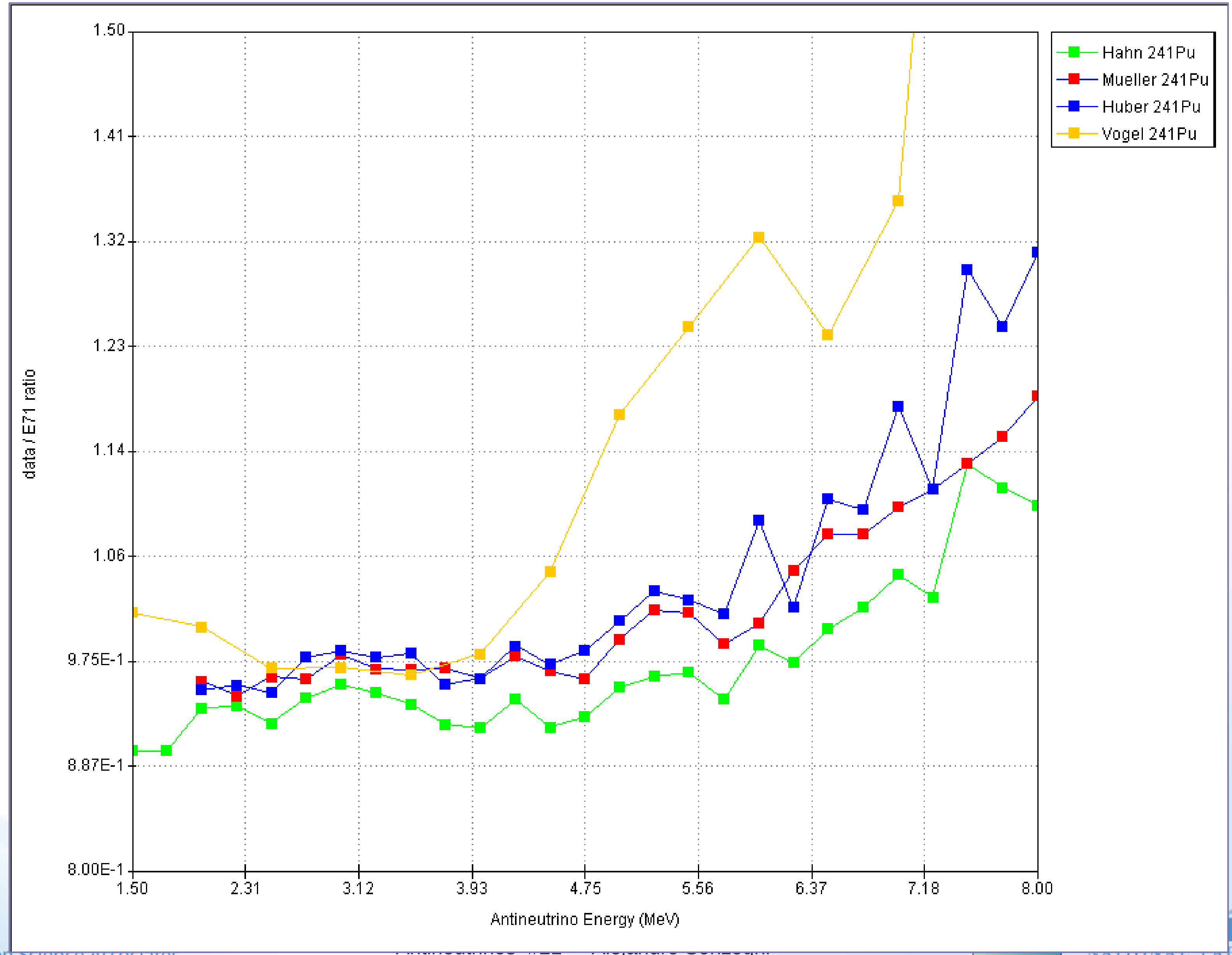
Antineutrino flux ratios for 235-U at thermal energies



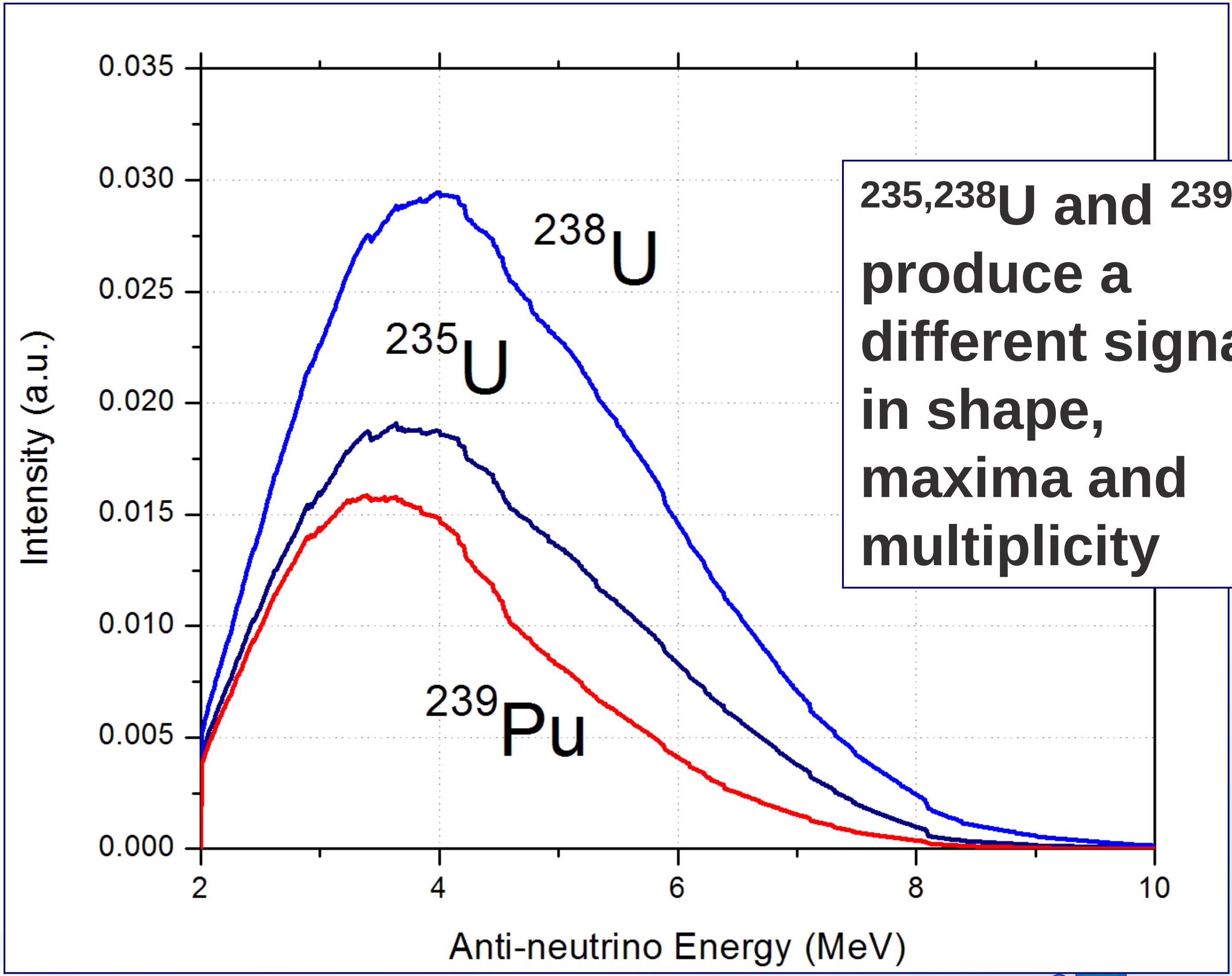
Antineutrino flux ratios for 239-Pu at thermal energies



Antineutrino flux ratios for 241-Pu at thermal energies

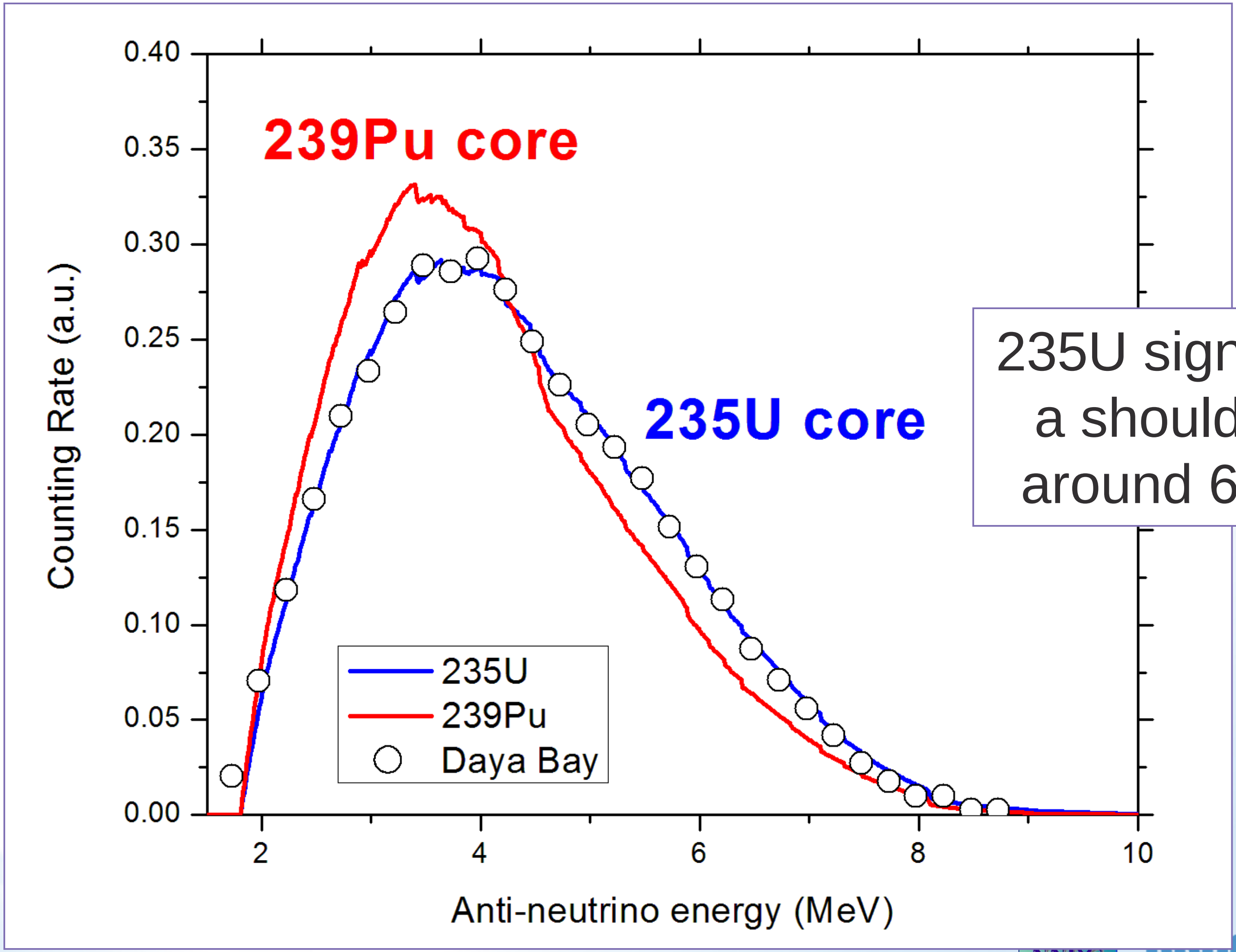


Anti-neutrino Signal, neutrino spectrum x cross section



^{235,238}U and ^{239}Pu produce a different signal, in shape, maxima and multiplicity

NNDC calculations on the Daya-Bay signal shape = spectrum x cross section



235U signal has a shoulder at around 6 MeV

Summary

There is a close link between basic nuclear structure research and the calculation of anti-neutrino spectra.

We think there is a strong need of higher-quality decay data from neutron-rich nuclides to fully understand the anti-neutrino spectra from nuclear reactors.

238U(n,f) beta spectrum is the missing piece to understand the anomaly issue.