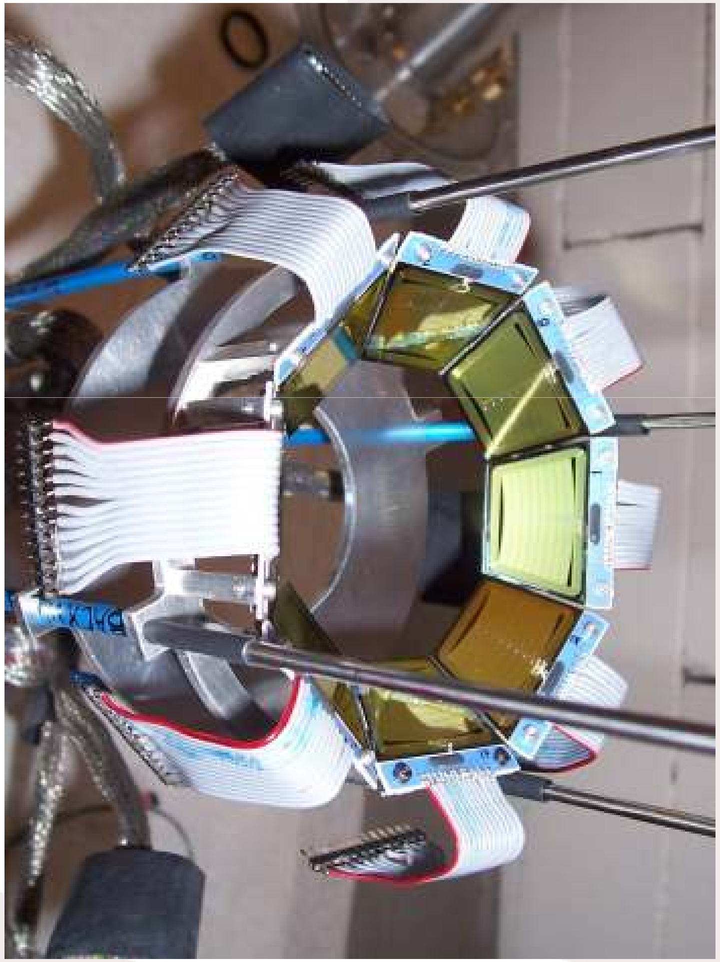
LEVEL DENSITIES IN THE ACTINIDE REGION AND INDIRECT CROSS SECTION MEASUREMENTS USING THE SURROGATE METHOD

J.N. Wilson, IPN Orsay

Unité mixte de recherche
CNRS-IN2P3
Université Paris-Sud 11

91406 Orsay cedex
Tél. : +33 1 69 15 73 40
Fax : +33 1 69 15 64 70
http://ipnweb.in2p3.fr

OSLO CYCLOTRON LAB EXPERIMENTS



THE SURROGATE METHOD

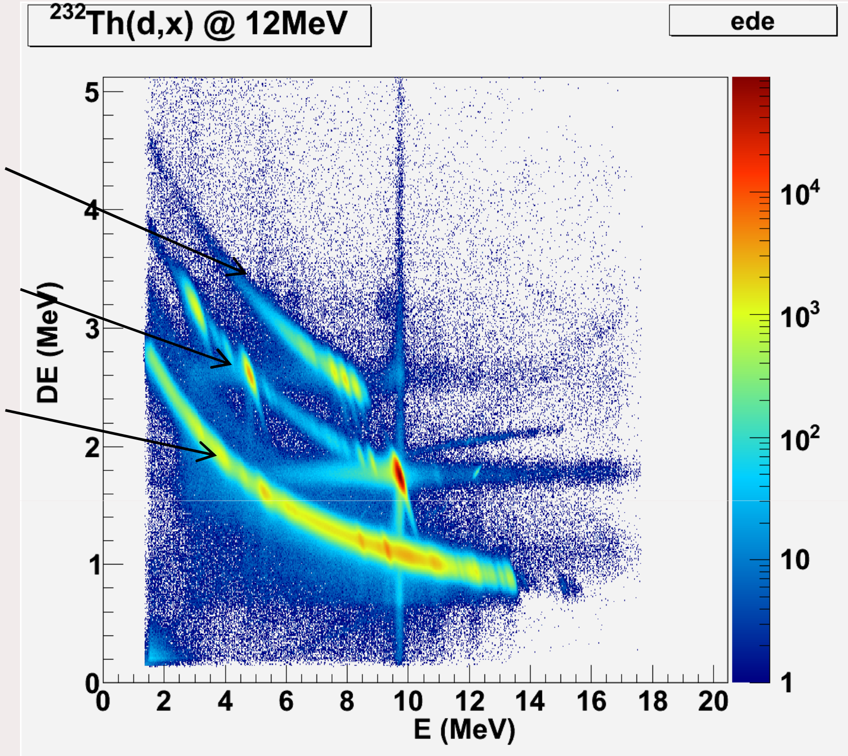
d + ^{232}Th @ 12 MeV

^{3}He + ^{232}Th @ 24 MeV

t (^{231}Th*)

d (^{232}Th*)

p (^{233}Th*)



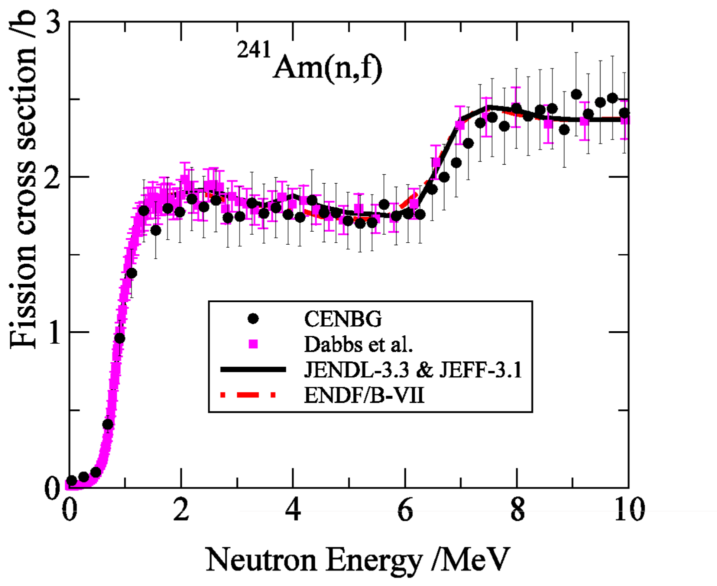
$$E_p \rightarrow E_x \rightarrow \quad E_n = \frac{A}{A+1}(E_x - S_n)$$

$$\sigma_{n,\gamma}(E_n) = \sigma_{CN}(E_n) \times P_{n,\gamma}(E_n)$$

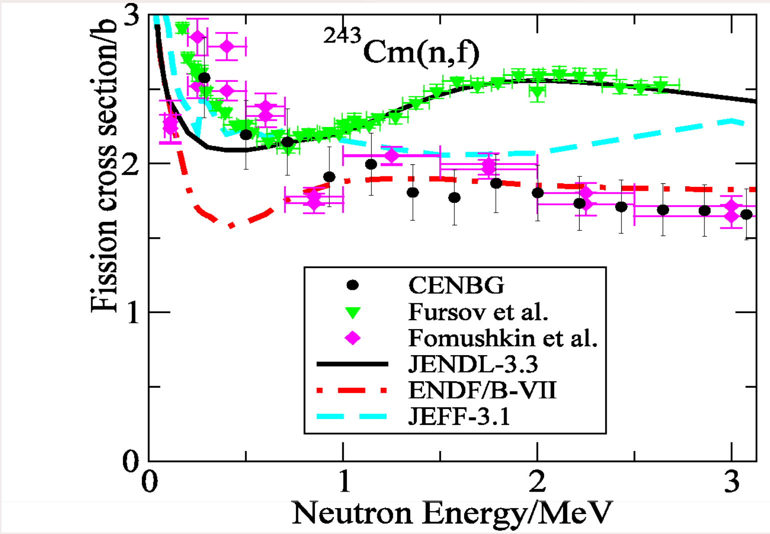
OMP calculation ↑ (for $\sigma_{CN}(E_n)$)

Measurement ↑ (for $P_{n,\gamma}(E_n)$)

SURROGATE METHOD FOR (N,FISSION) X-SECTIONS

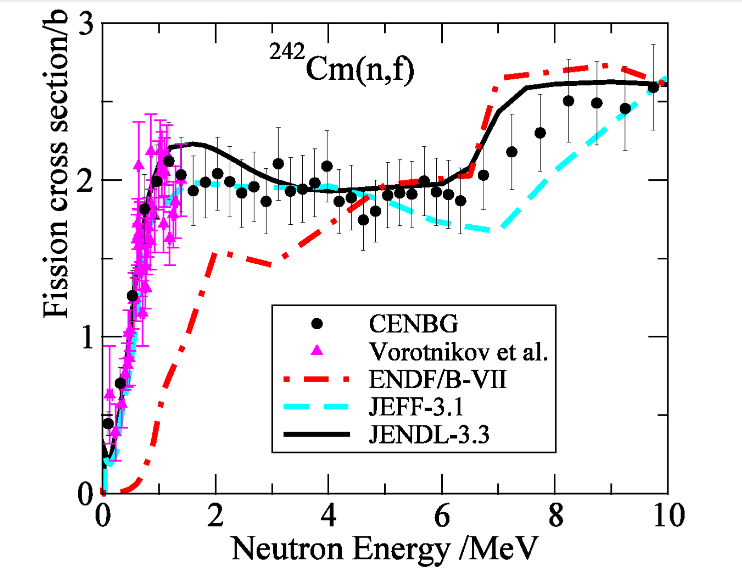


^{243}**Am(^{3}He,^{4}He)** ($t_{1/2}$ = 432 d)



^{243}**Am(^{3}He,d)** ($t_{1/2}$=163 d)

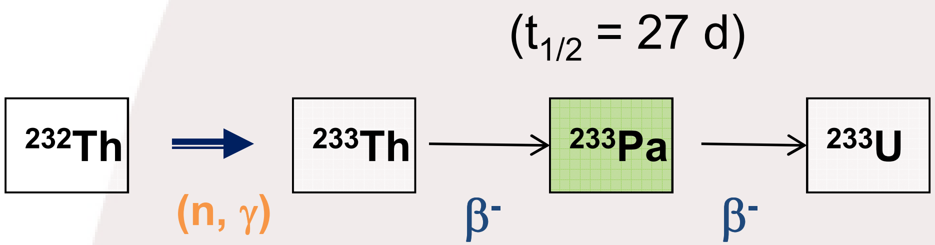
G. Kessedjian, B. Jurado et *al.*
Phy. Lett. B. 692 297 (2010)

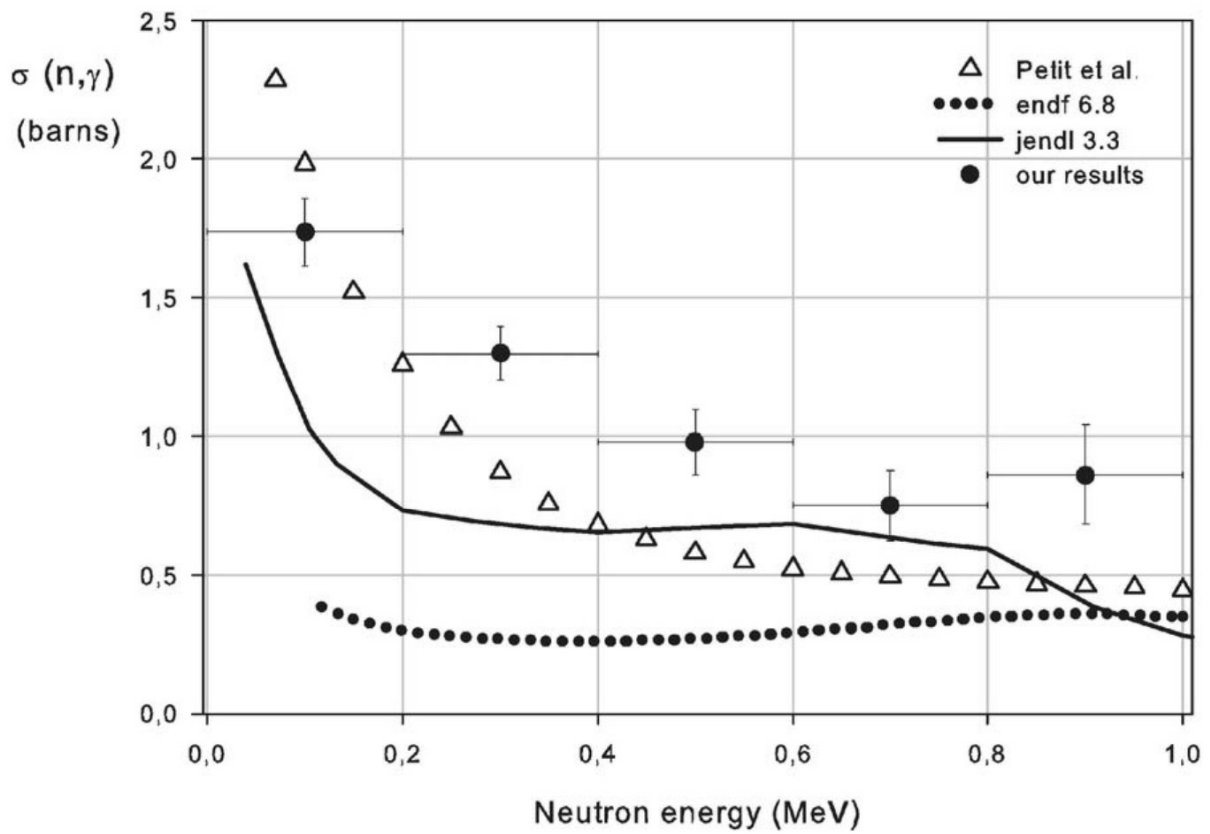


^{243}**Am(^{3}He,t)**

($t_{1/2}$=29 d)

SURROGATE (N,GAMMA) X-SECTION IN 233PA



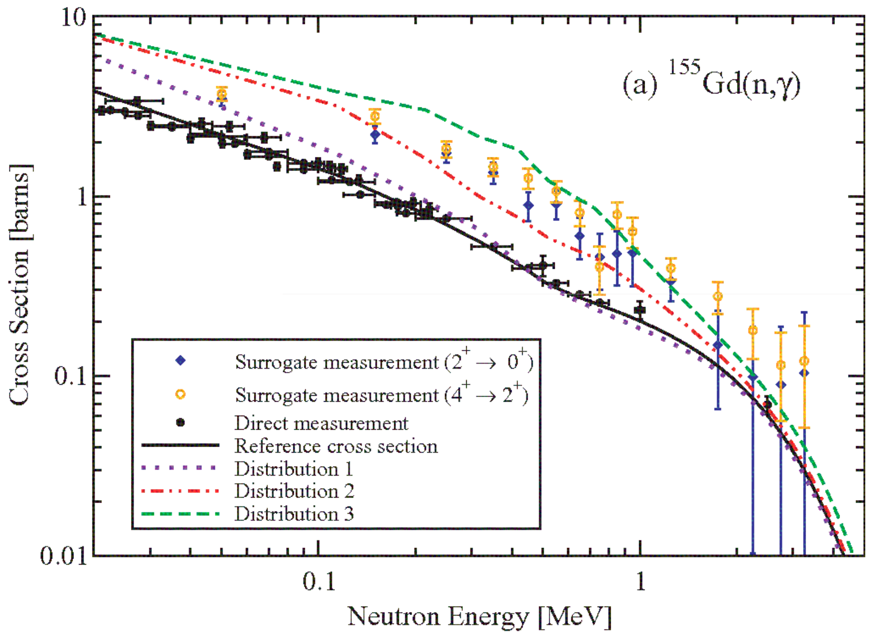


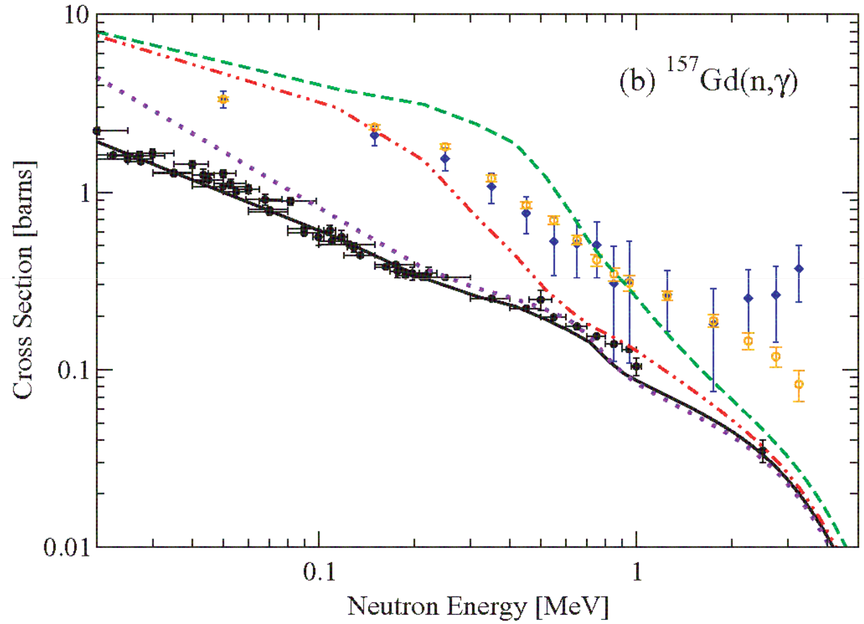
S. Boyer et al. Nucl. Phys. A775, 175 (2006)

SURROGATE (N,GAMMA) IN GADOLINIUM NUCLEI

N.D. Scielzo *et al*.

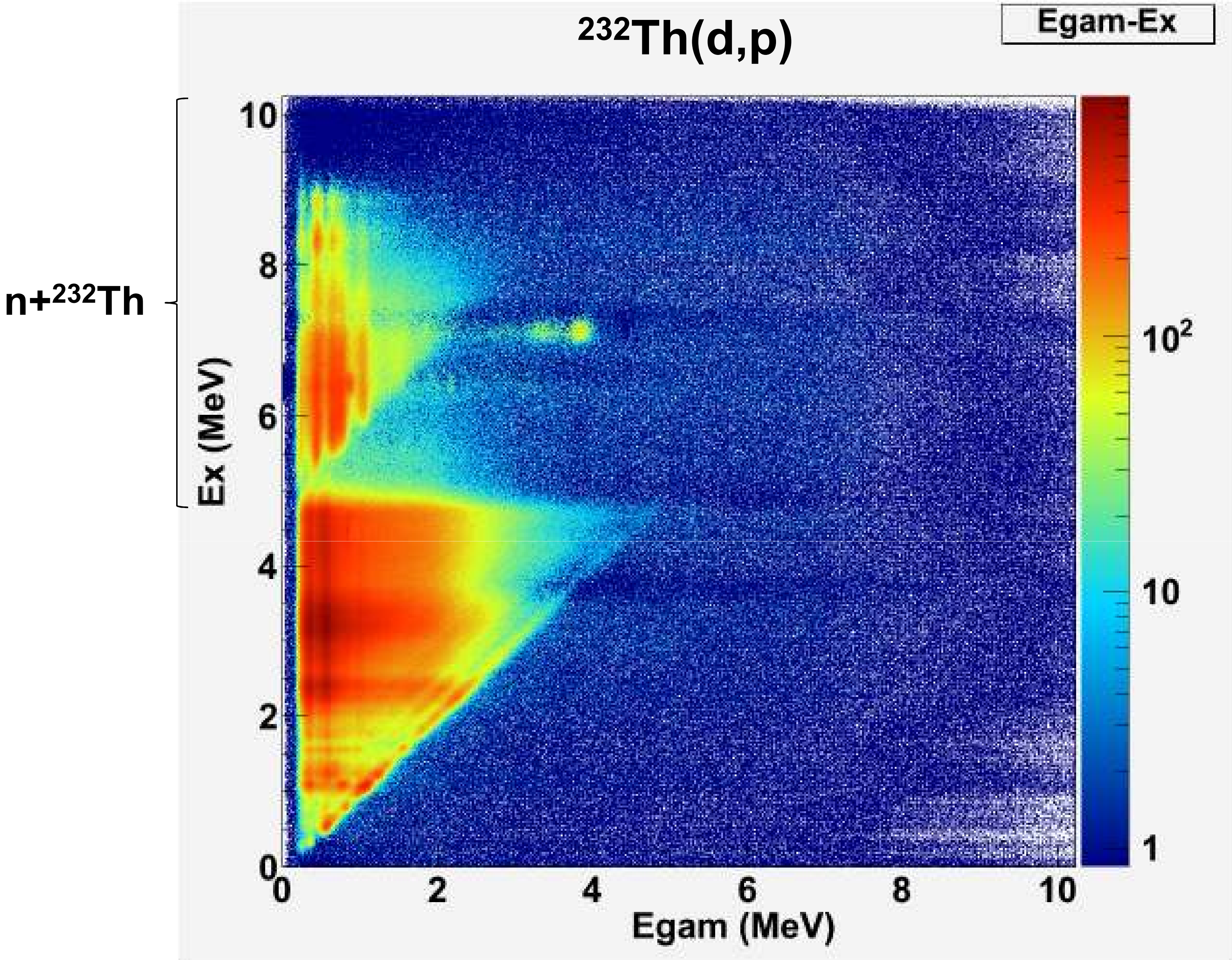
PHYSICAL REVIEW C **81**, 034608 (2010)



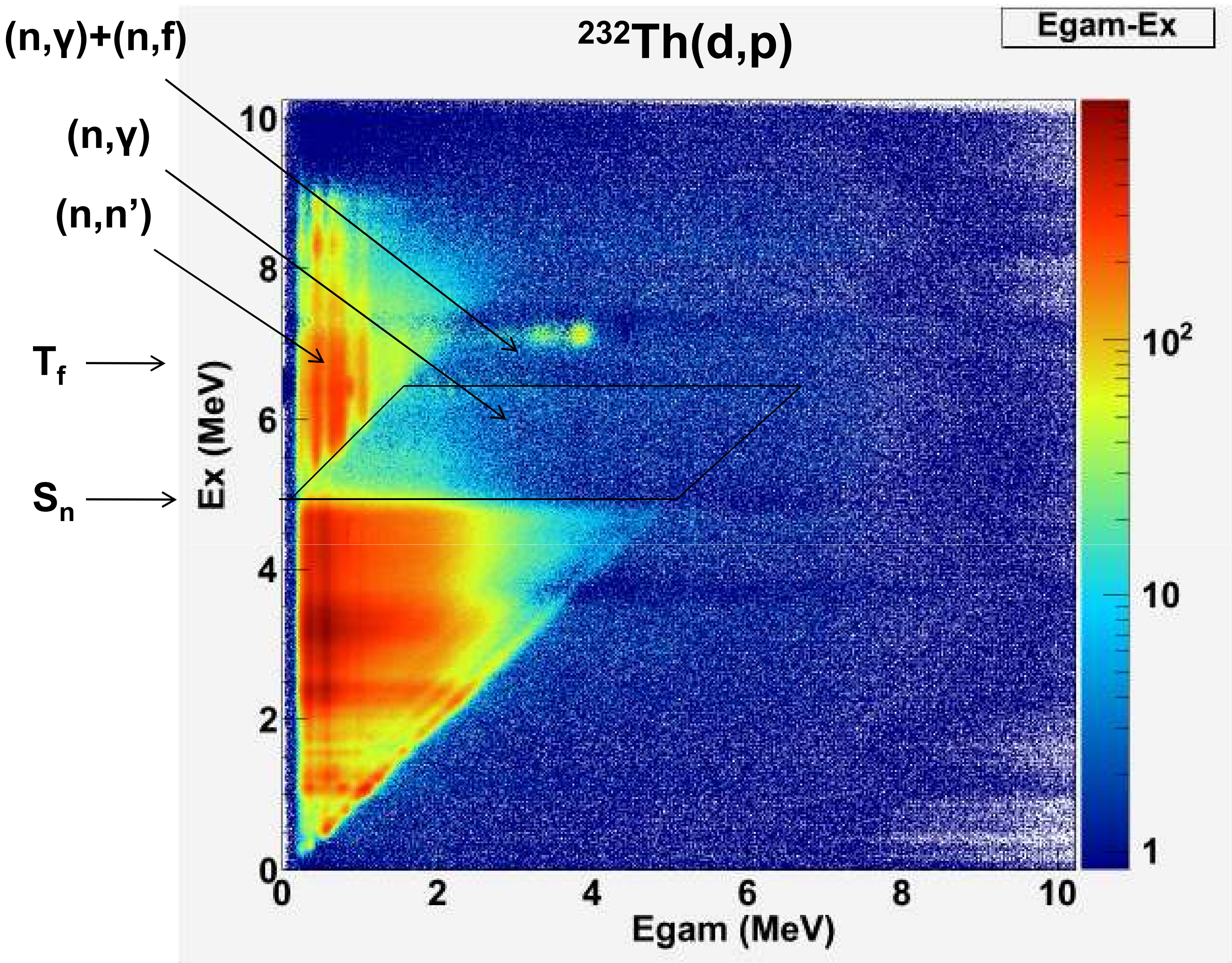


Large discrepencies between direct and surrogate methods at low energy

« To extract reliable x-sections, a more sophisticated analysis should be developed that takes into account angular momentum differences between the neutron induced and surrogate reactions. »



n+^{232}Th
^{232}Th(d,p)
Egam-Ex
Ex (MeV)
Egam (MeV)
0
2
4
6
8
10
1
10
10^2



(n,γ)+(n,f)
(n,γ)
(n,n')
T_f
S_n
232Th(d,p)
Egam-Ex
Ex (MeV)
Egam (MeV)
0
2
4
6
8
10
1
10
10^2

THE WEIGHTING FUNCTION TECHNIQUE

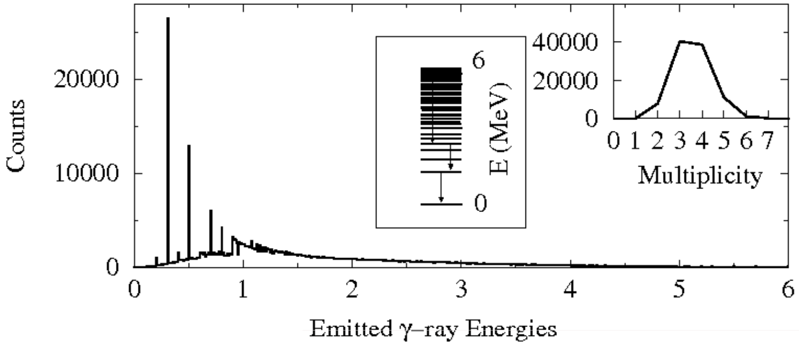
Efficiency of detecting a cascade, *Ec* of *m* gammas is:

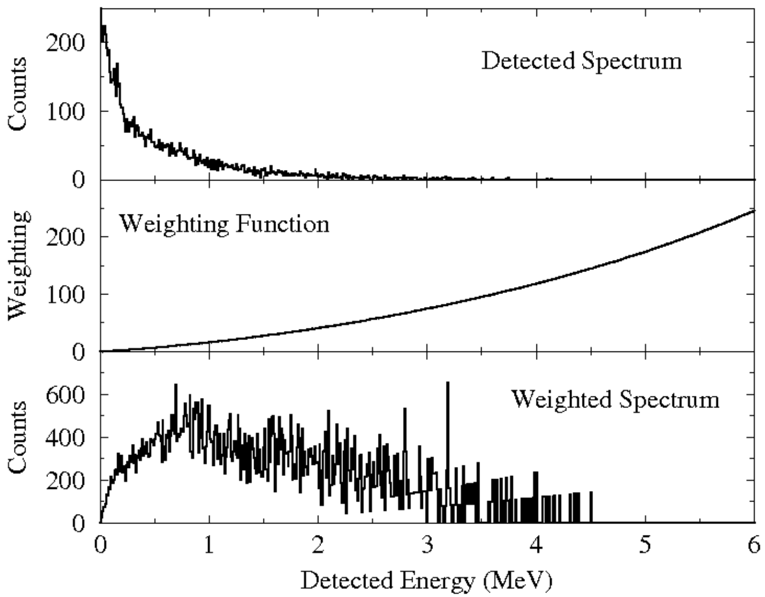
$$\varepsilon_c = 1 - \prod_{j=1..m} (1 - \varepsilon_j)$$

If ε is small then: $\varepsilon_c \approx \sum_{j=1..m} \varepsilon_j$

Suppose detector has this property: $\varepsilon = k\,E_\gamma$

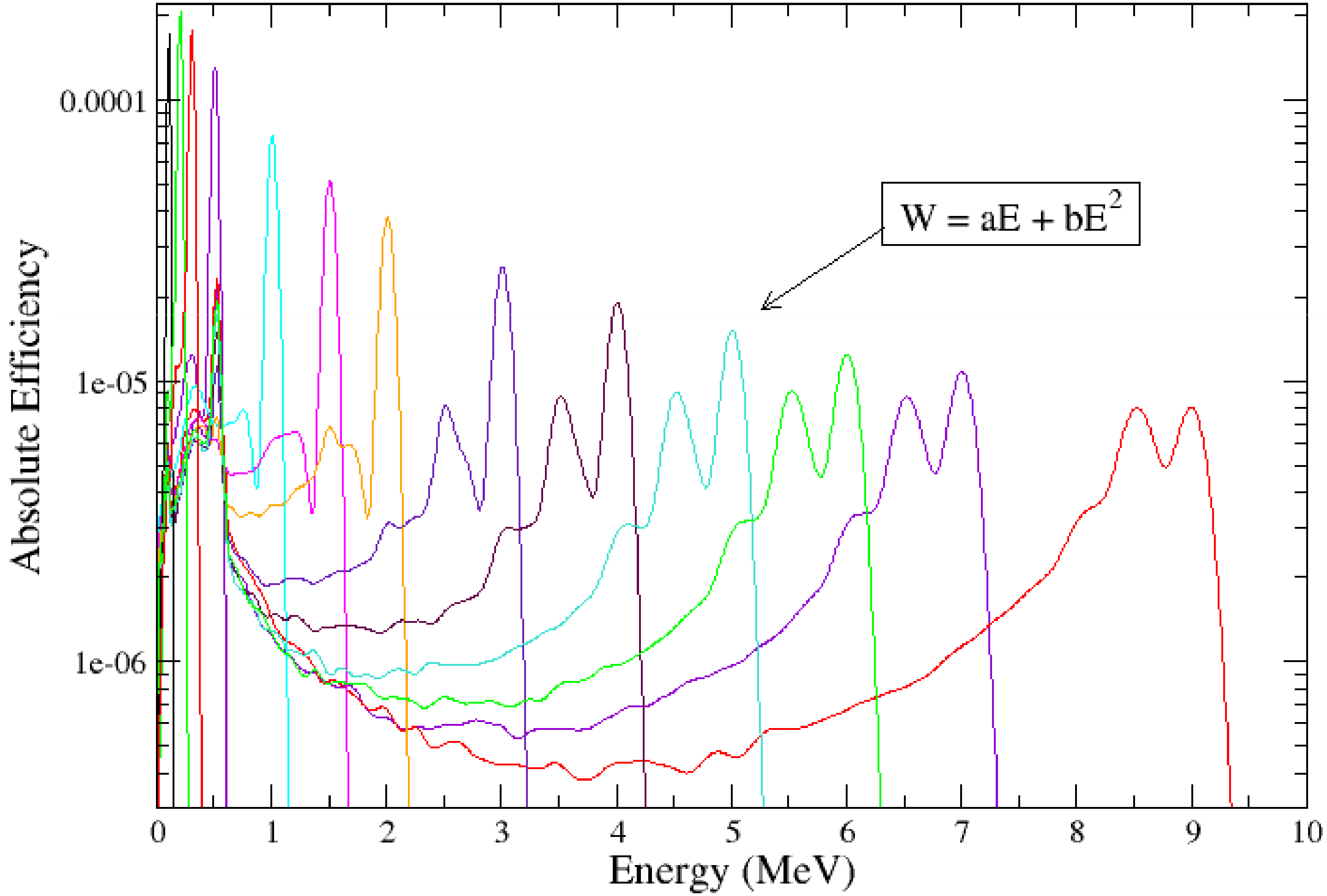
<u>Then effeciency of detecting a cascade becomes proportional to cascade energy and independent of cascade path!!</u>



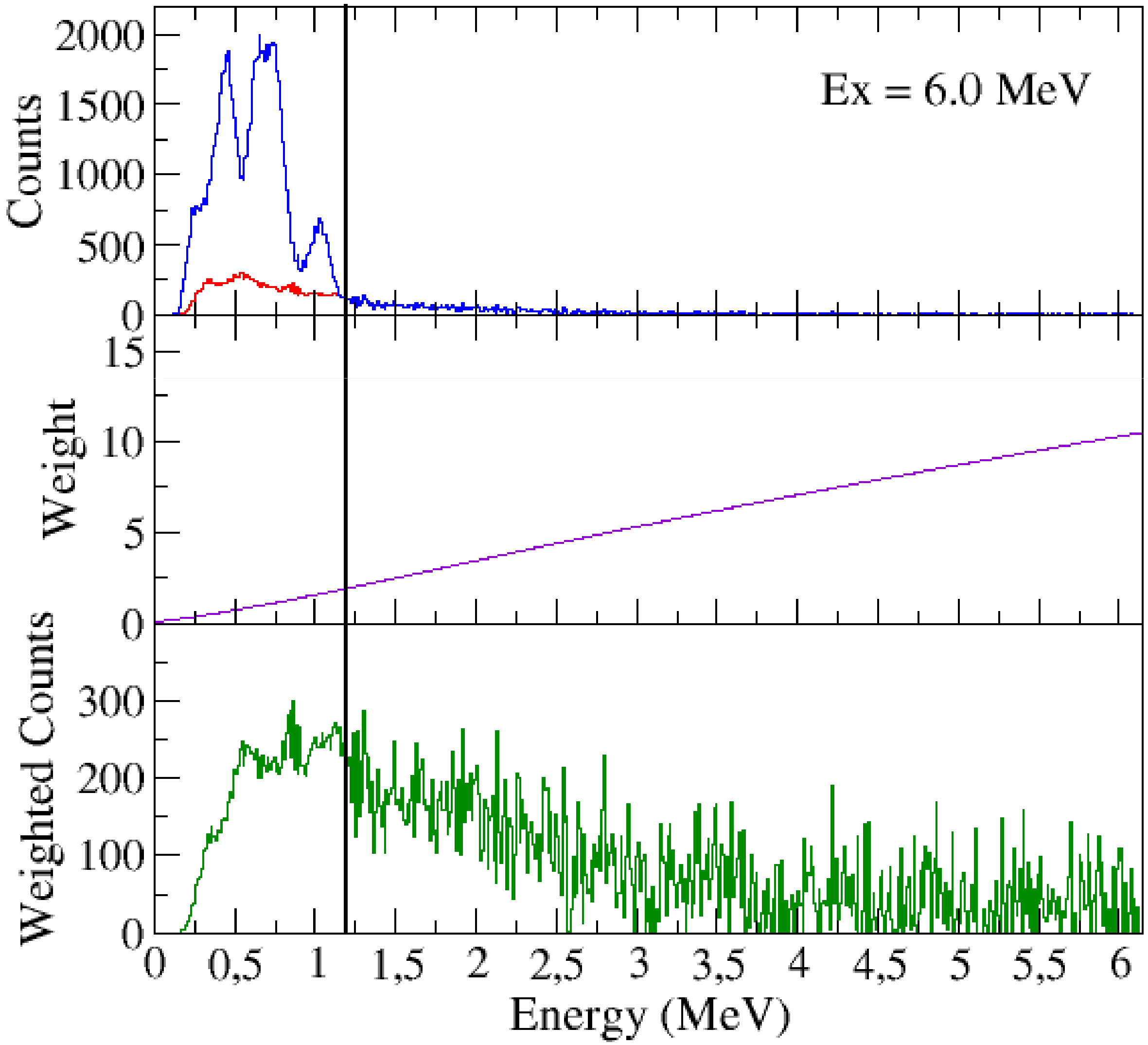


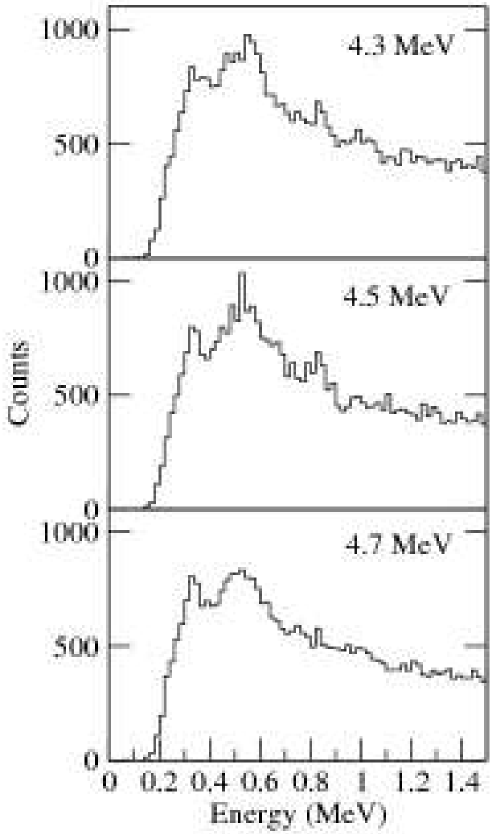
$$\sum_d W(E_d) R(E_d, E_\gamma) = k E_\gamma$$

SIMULATED CACTUS RESPONSE WITH MCNP5

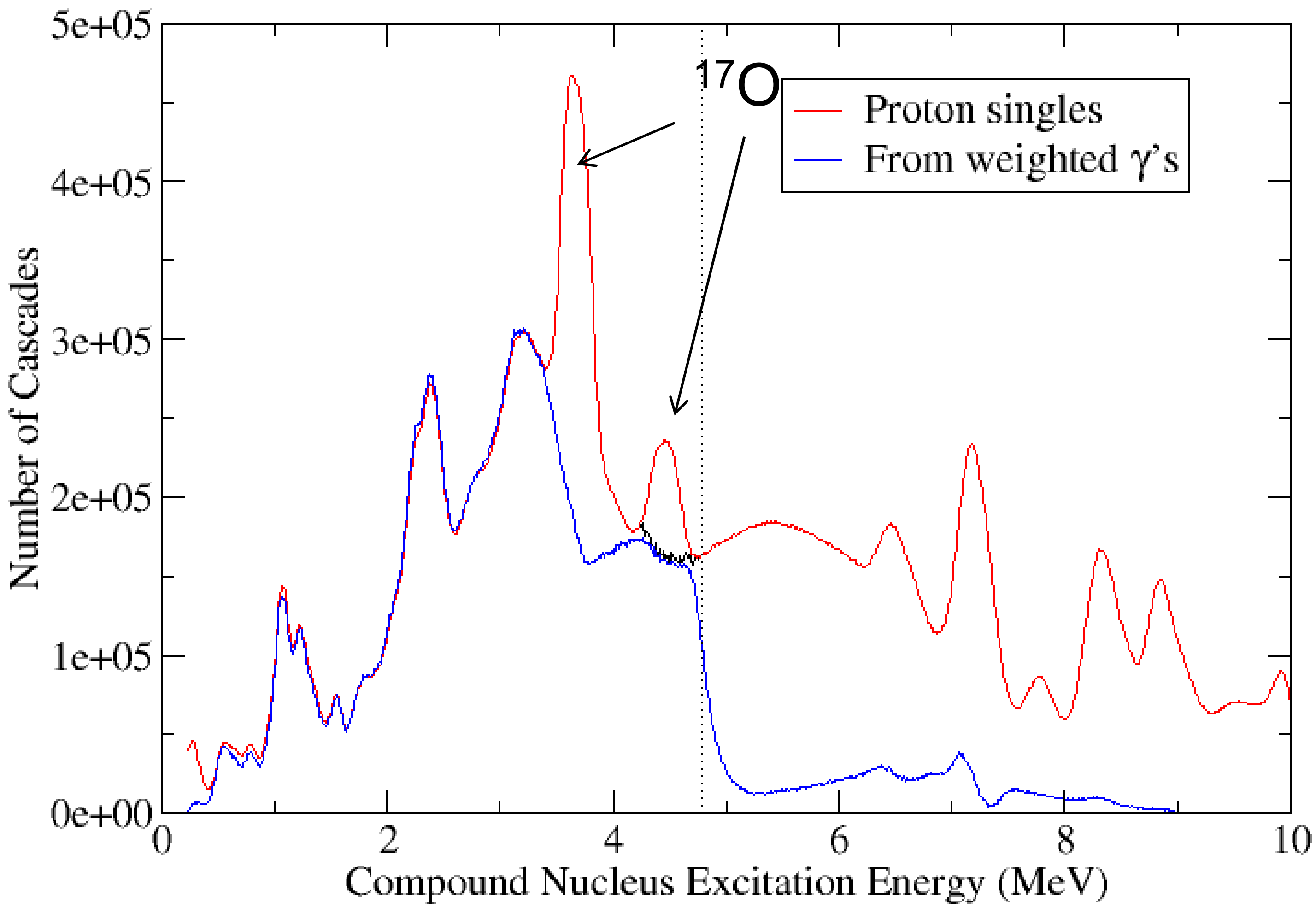


EXTRAPOLATION BELOW THRESHOLD

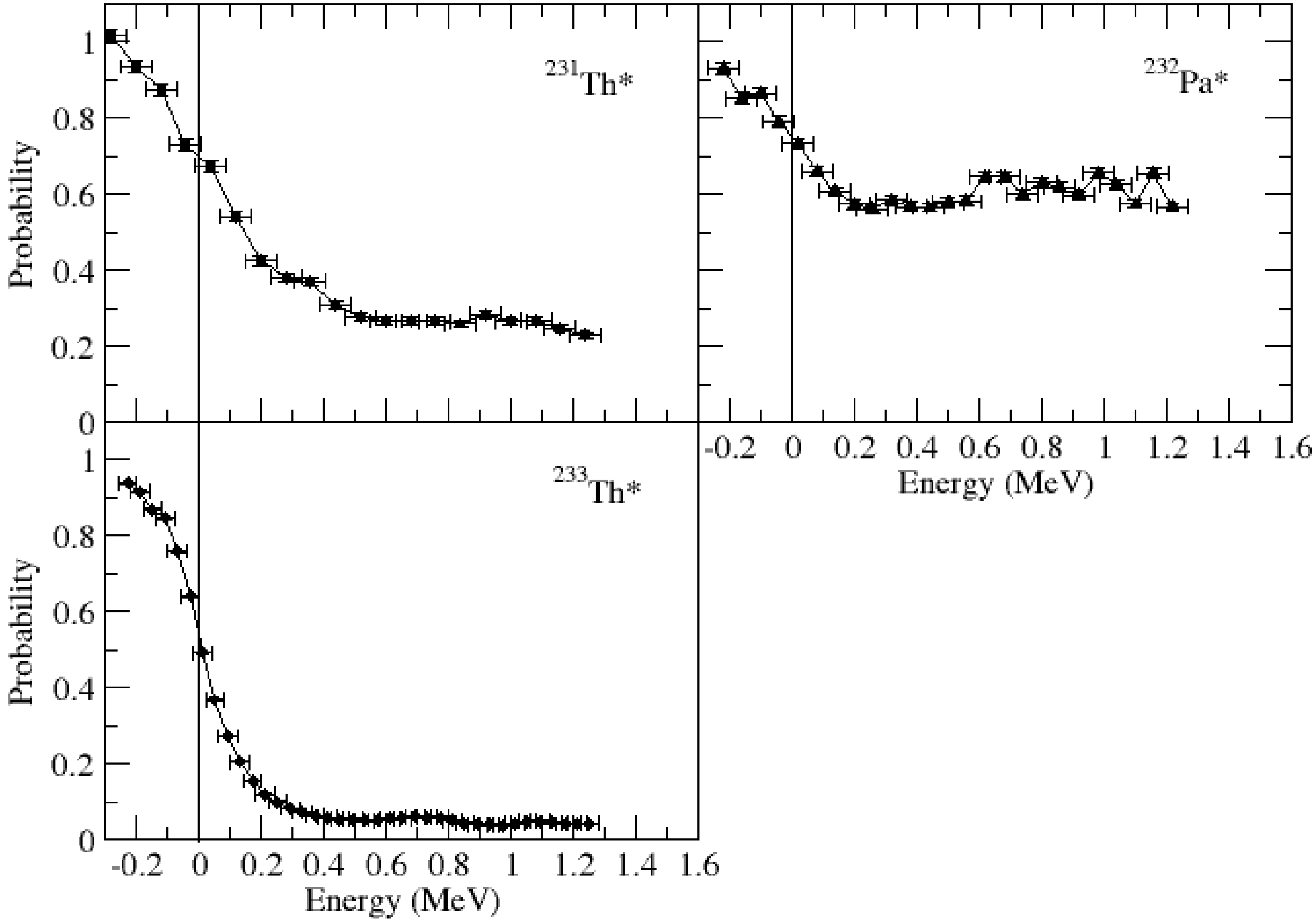




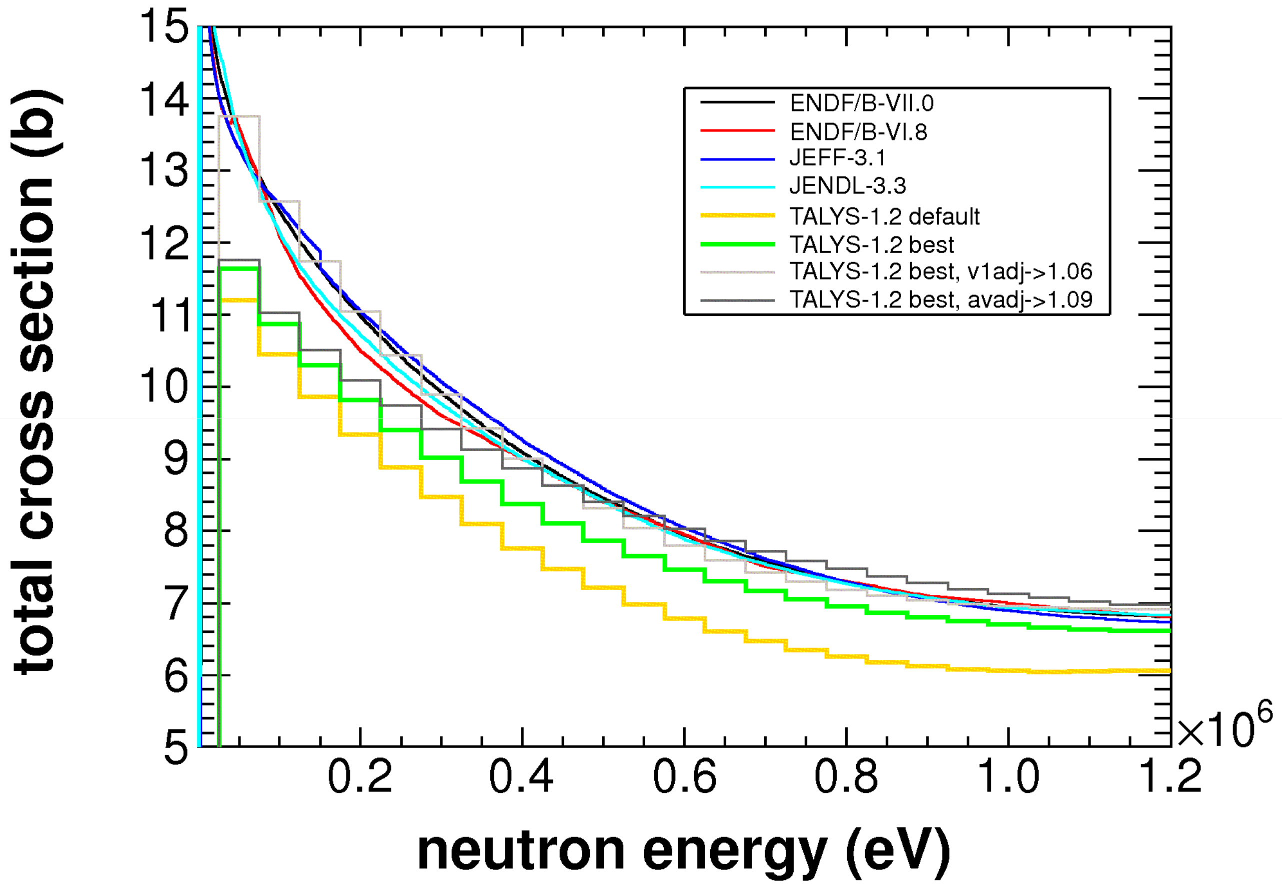
CASCADE COUNTING IN 233TH*



RESULTS(1) : MEASURED DECAY PROBABILITIES

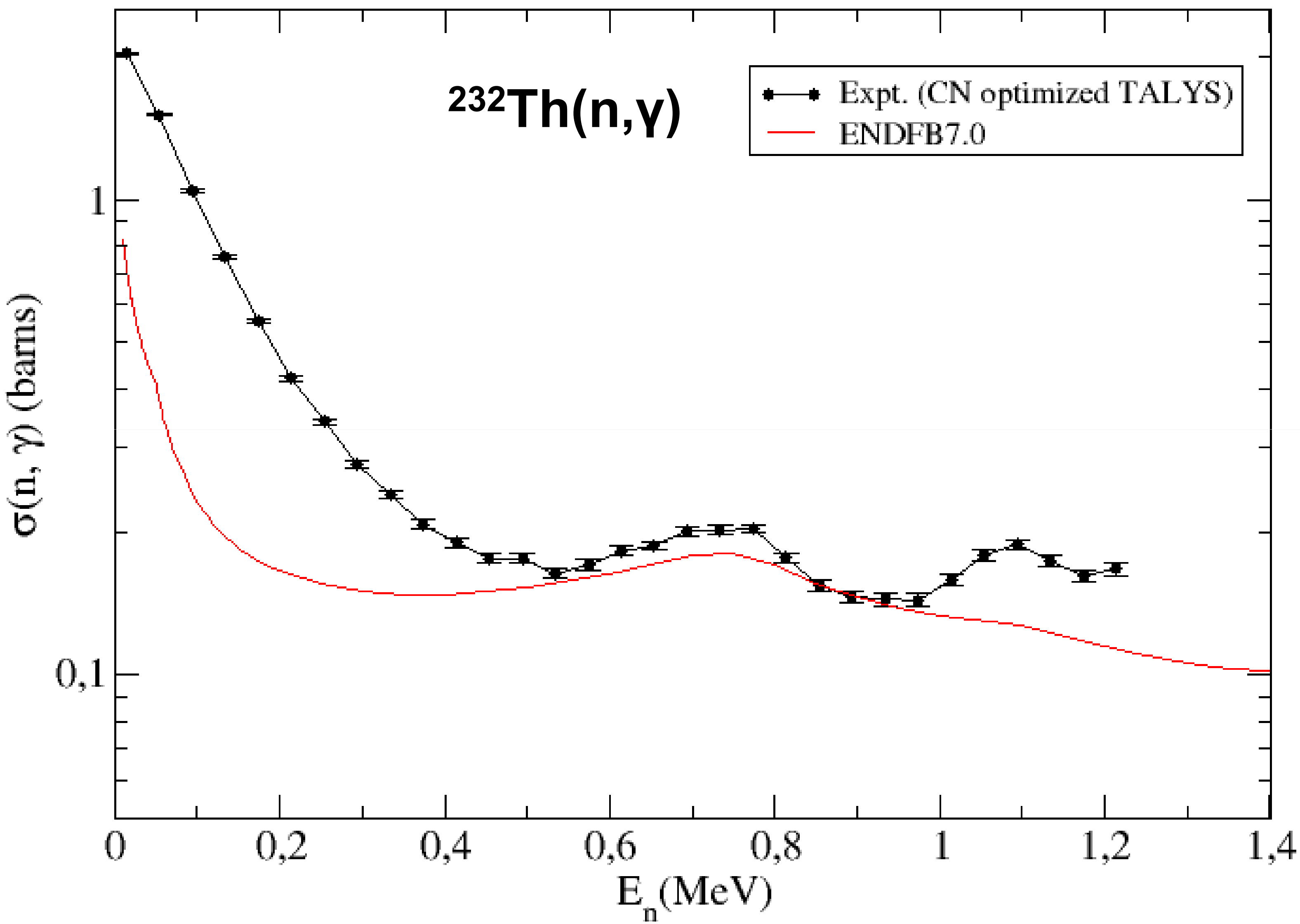


TALYS OMP CALCULATIONS

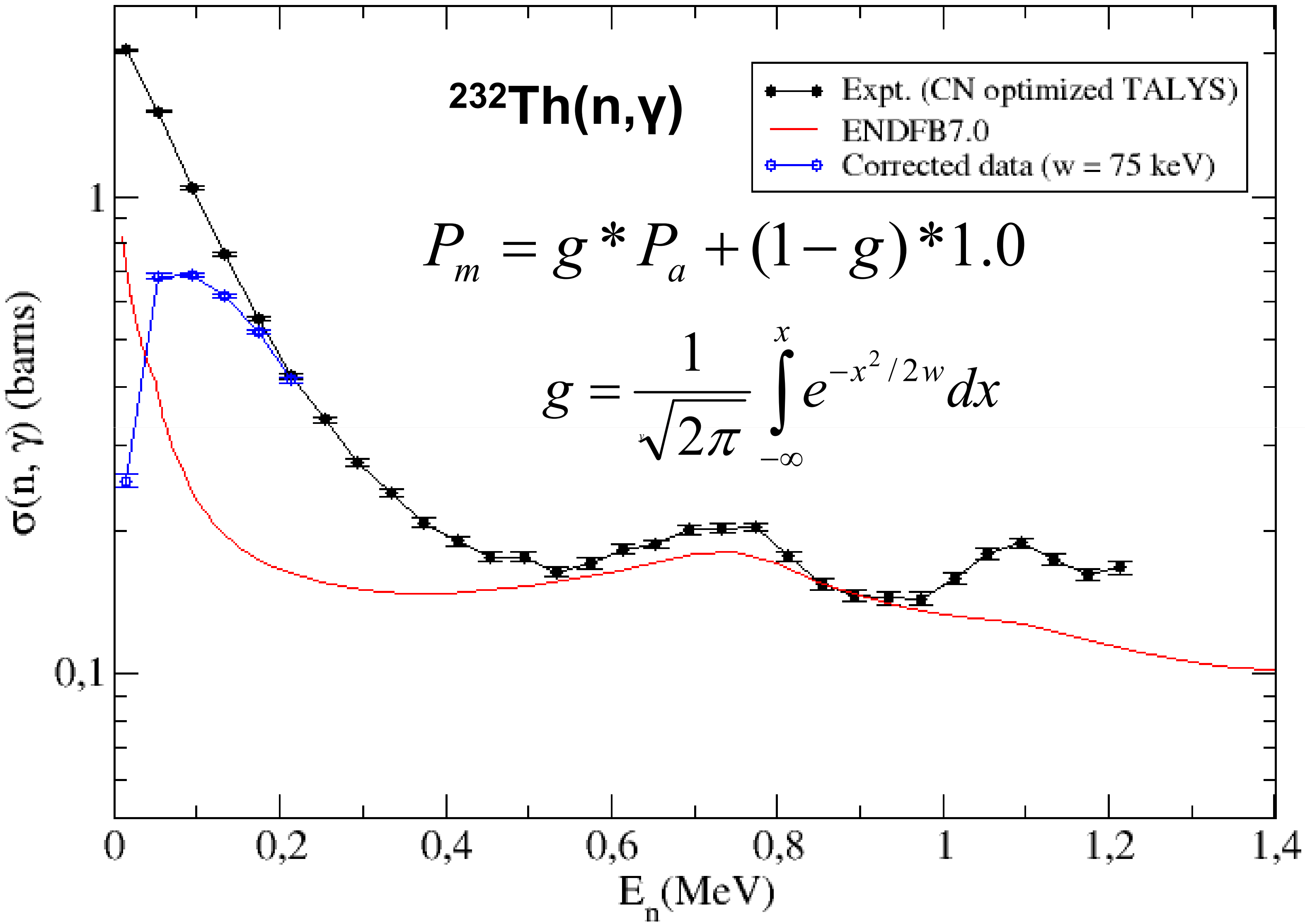


σ_{CN} is calculated from TALYS OMP, where input parameters are chosen to minimize the difference between measured and calculated total x-sections

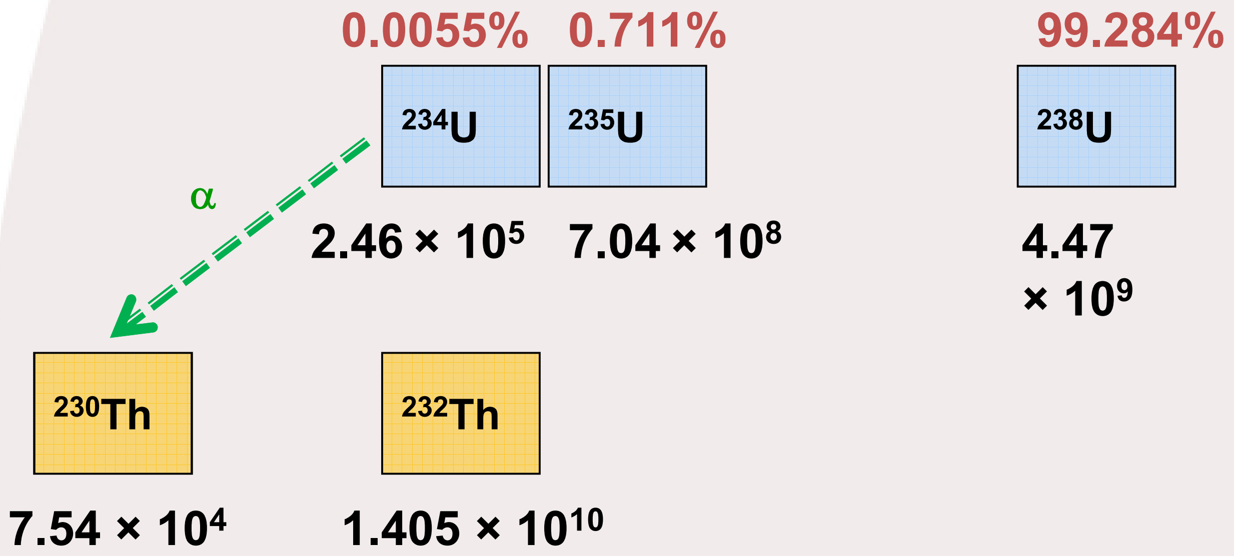
SURROGATE 232TH(N,GAMMA) X-SECTION



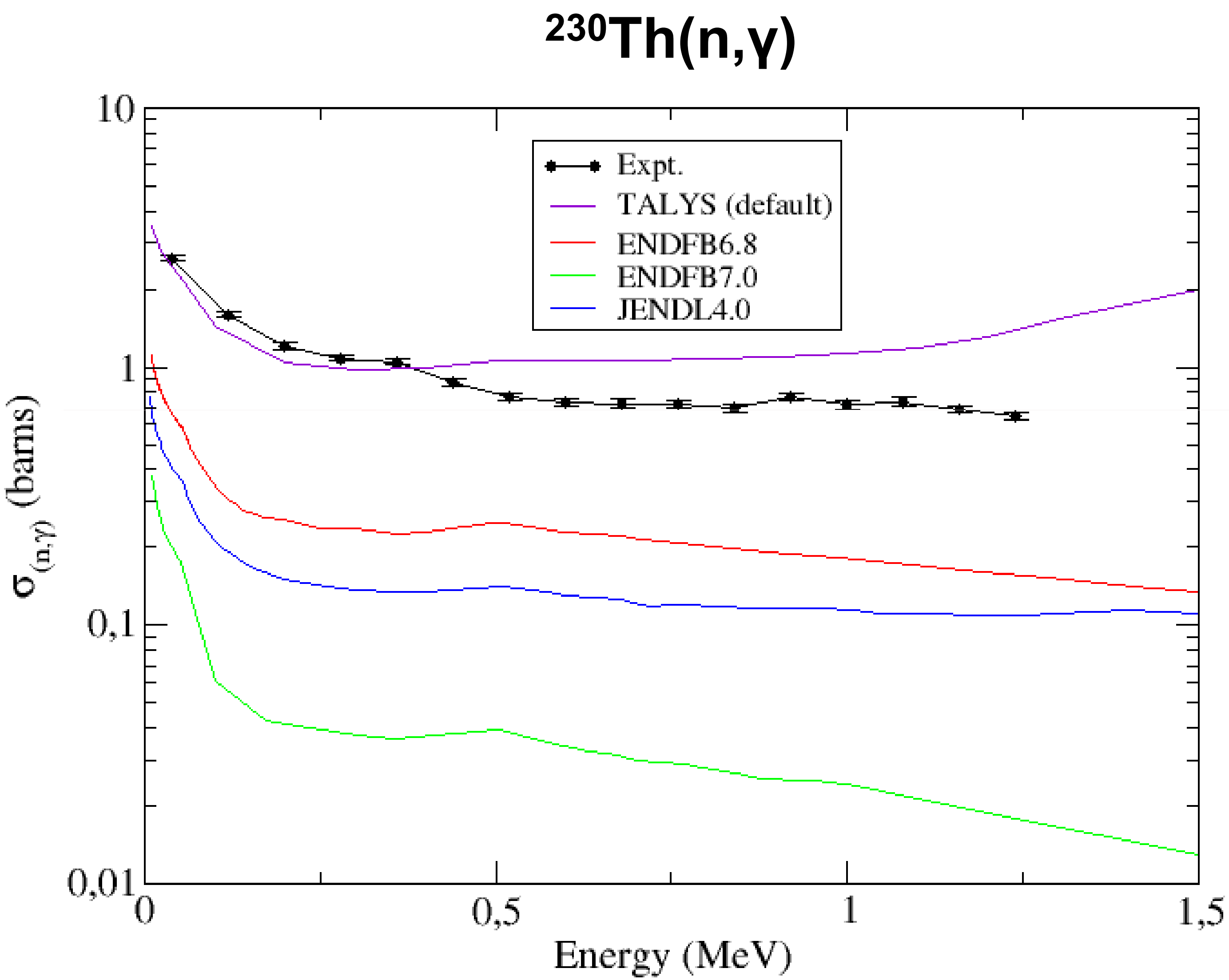
SURROGATE 232TH(N,GAMMA) X-SECTION



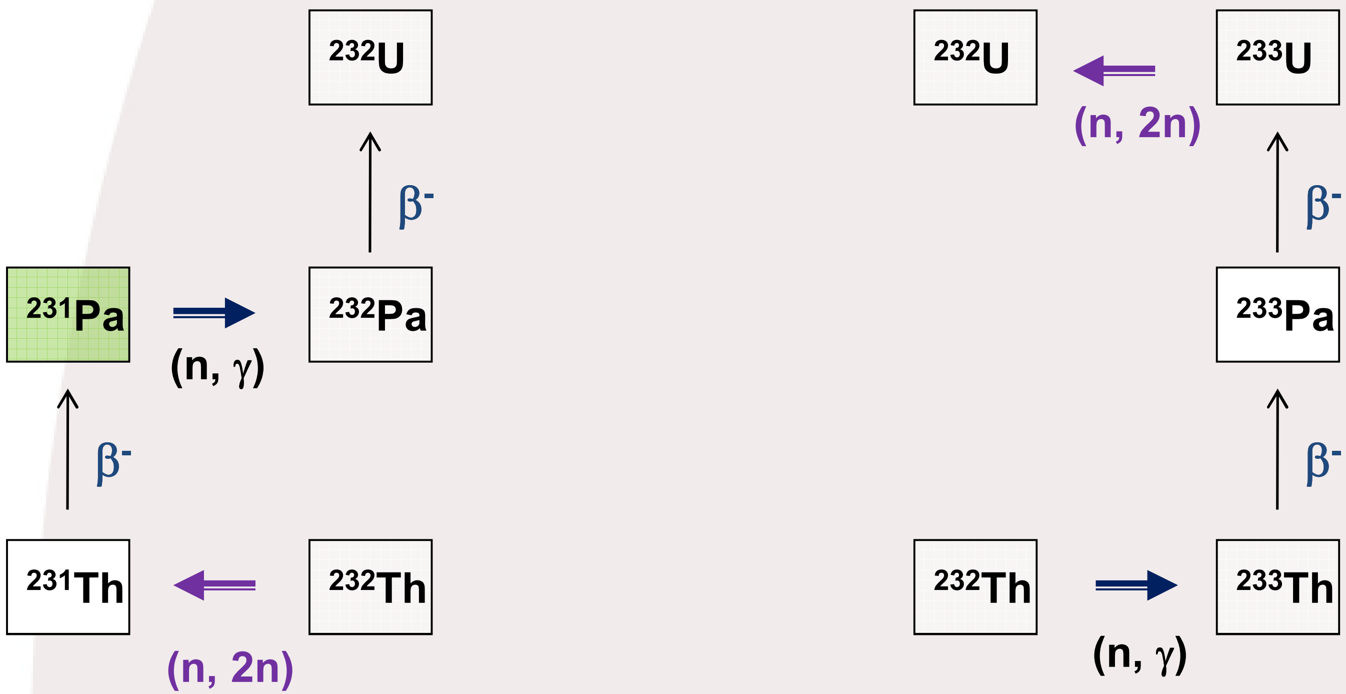
230TH(N,GAMMA) X-SECTION



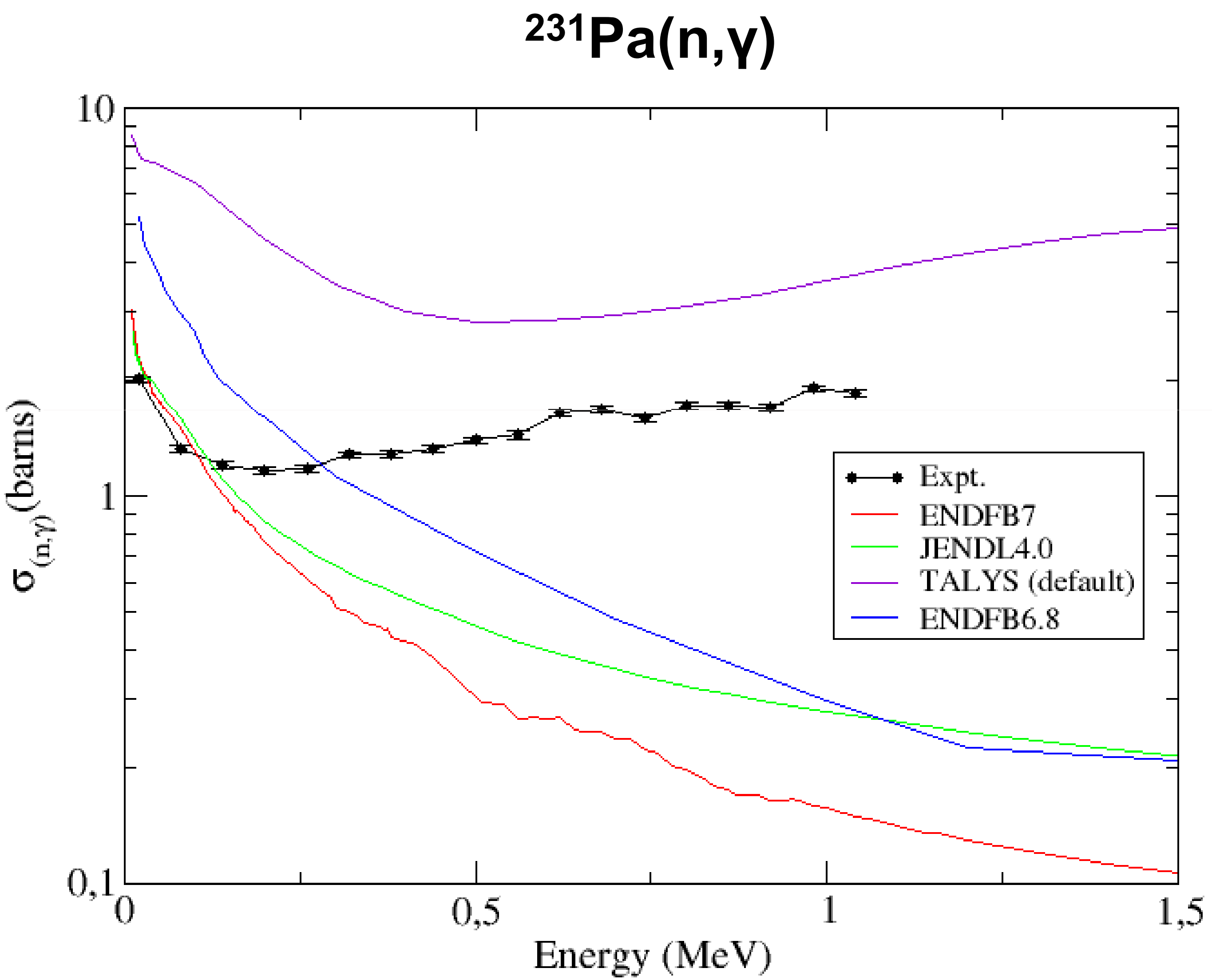
SURROGATE 230TH(N,GAMMA) X-SECTION

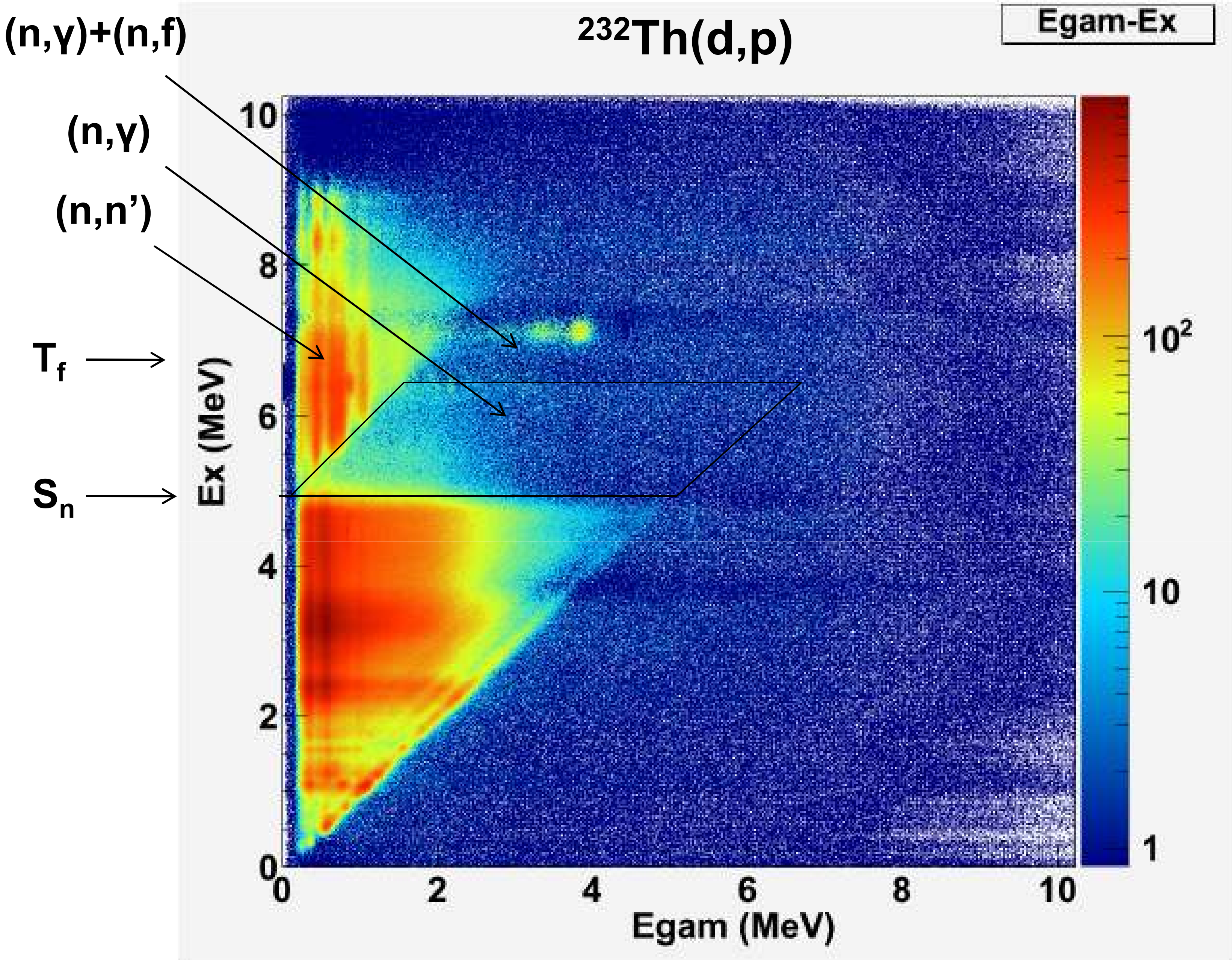


231PA(N,GAMMA) X-SECTION

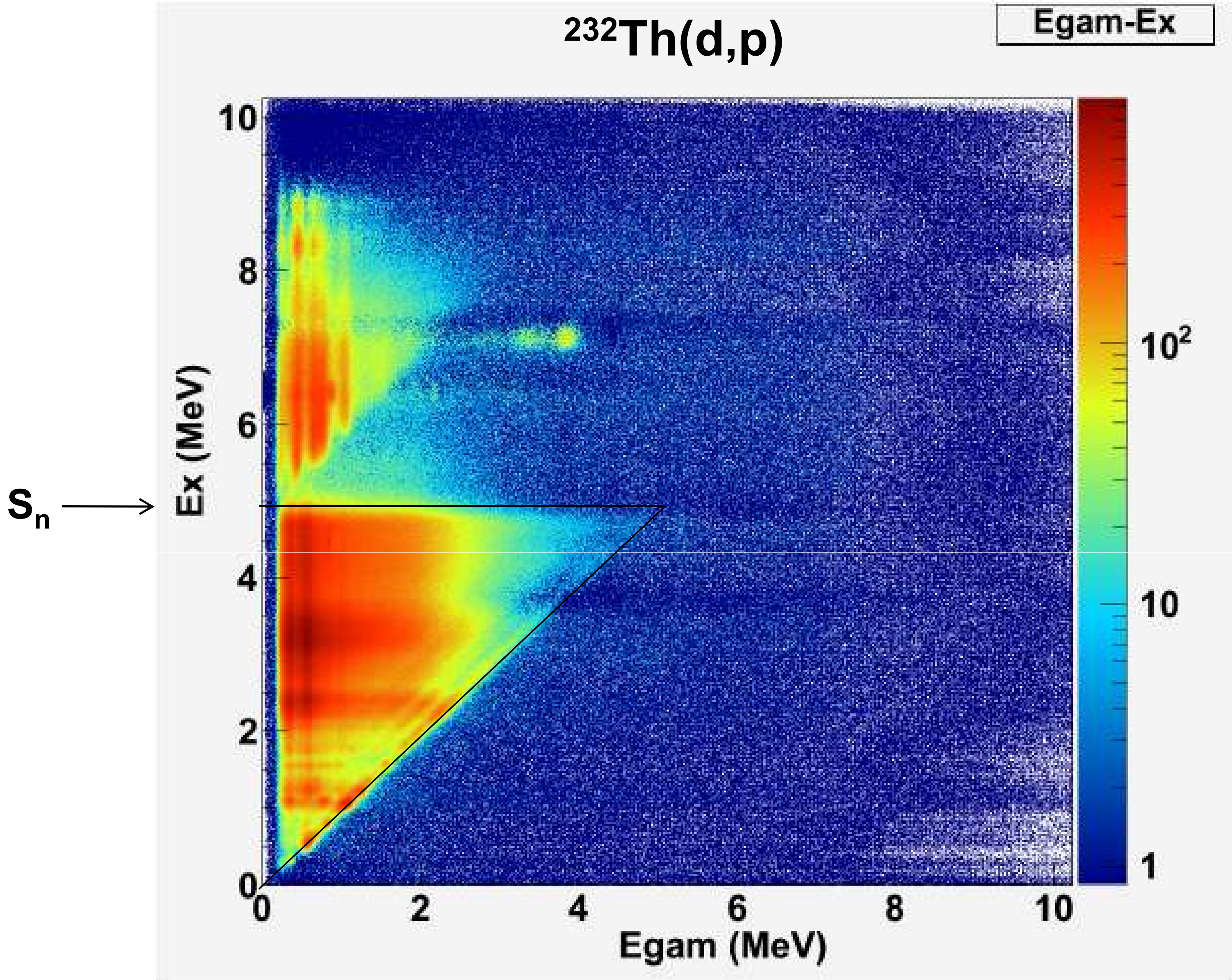


SURROGATE 231PA(N,GAMMA) X-SECTION



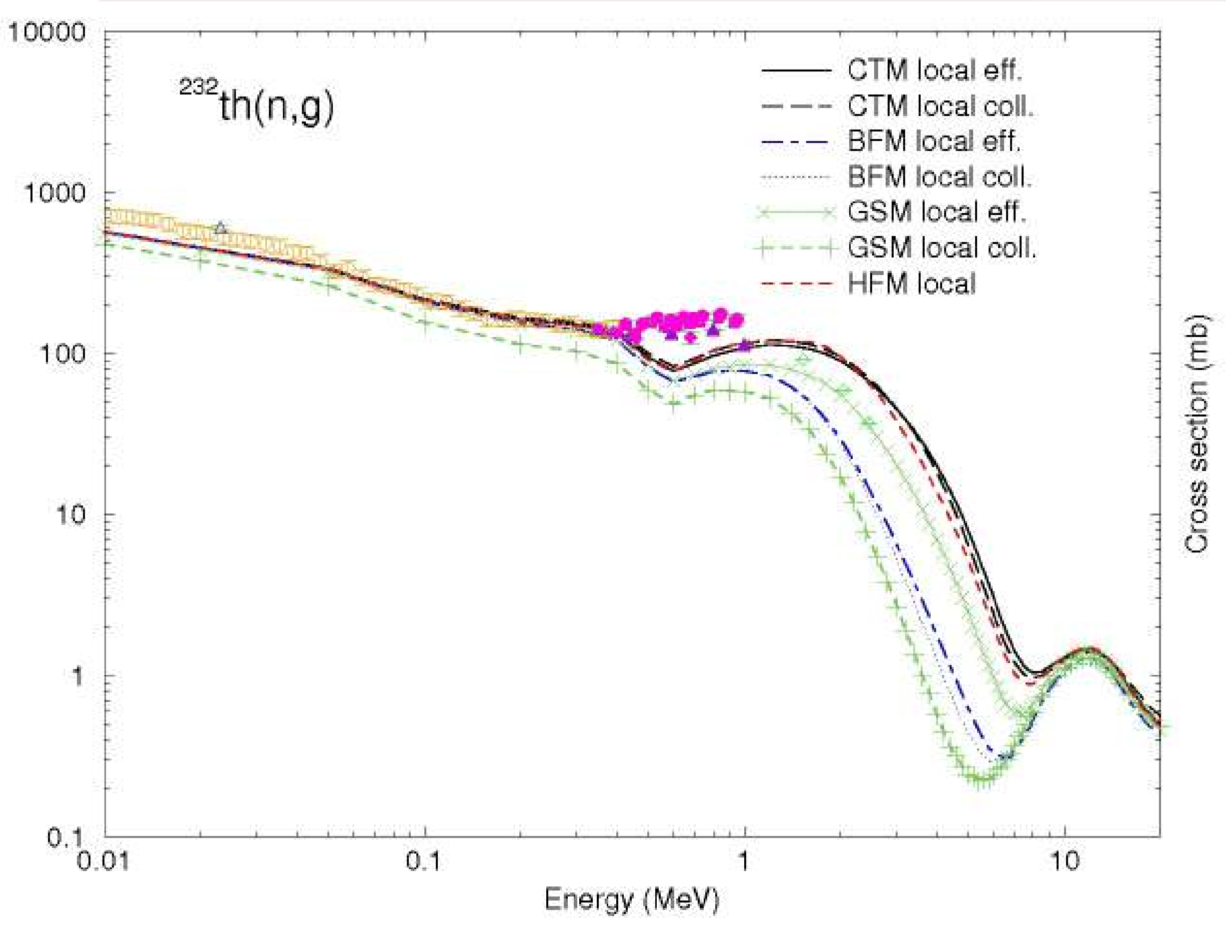


(n,γ)+(n,f)
(n,γ)
(n,n')
T_f
S_n
232Th(d,p)
Egam-Ex
Ex (MeV)
Egam (MeV)
0
2
4
6
8
10
1
10
10^2

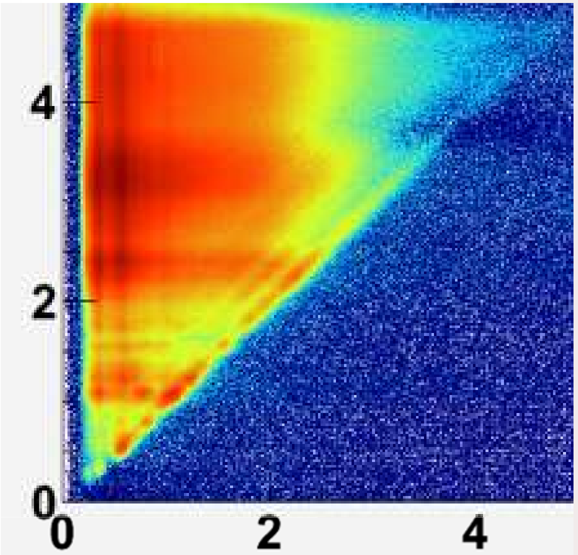


232Th(d,p)
Egam-Ex
Ex (MeV)
Egam (MeV)
Sn
0
2
4
6
8
10
1
10
10^2

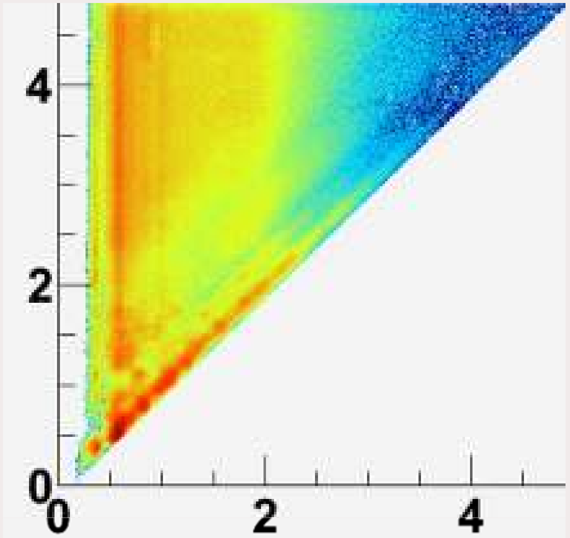
LEVEL DENSITY MODEL IMPORTANT FOR X-SECTIONS



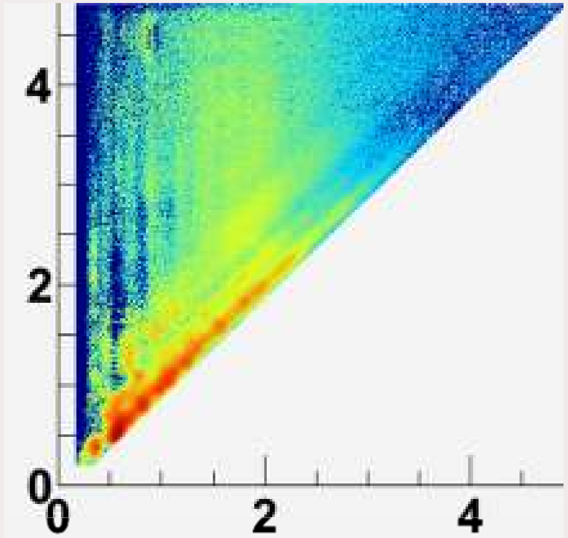
OSLO METHOD



1) Sort the raw data to obtain the set of gamma spectra *F(E$_i$)*



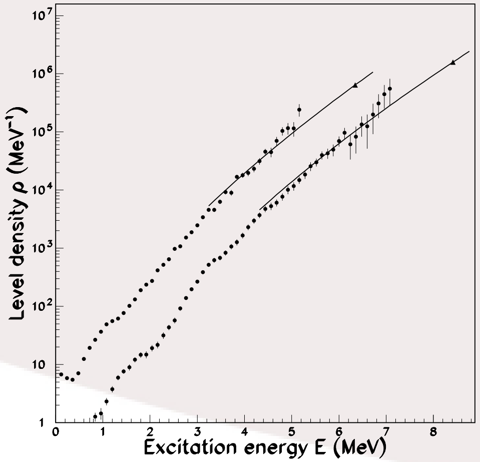
2) Unfold the response of the gamma detector to obtain the spectra *U(Ei)*



3) Obtain the set of primary gamma spectra *P(E$_i$,E$_\gamma$)* iteratively by subtracting contributions from higher generations

4) $P(E_i, E_\gamma) \propto \rho(E_f) \cdot T(E_\gamma)$

Find *ρ(E$_f$)* and *T(E$_\gamma$)* iteratively



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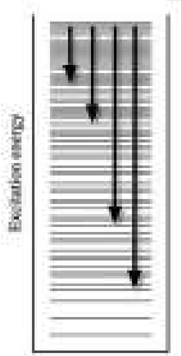
NEW METHOD FOR EXTRACTING NLD AND GSF

1) Trial NLD + GSF Functions



2) Monte-Carlo Cascade Generator

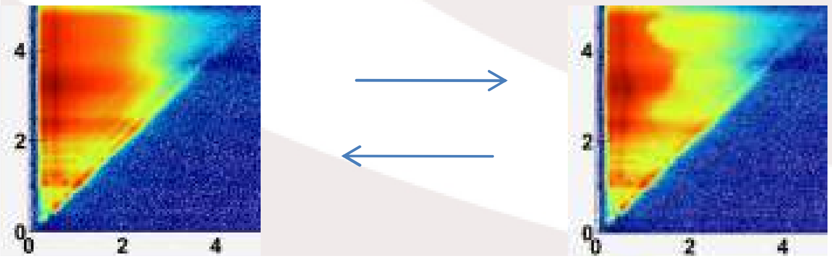
(Known states below 1 MeV +
D_0 value at S_n)

3) Fold with the Detector Response

4) Simulated set of $F(E_i)$ spectra

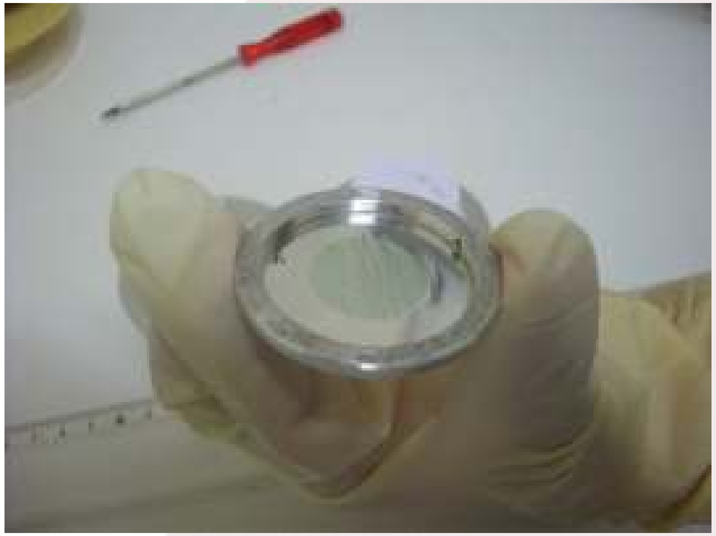
X^2 minimization
(40-80 free parameters)

5) Compare Expt. Data and
Simulated Data. Compute X^2

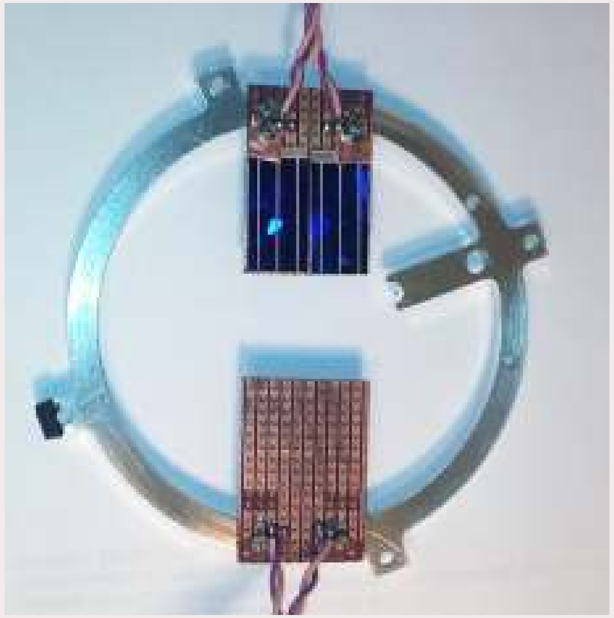


One X^2 evaluation 10^7 cascades
takes ~ 1 min. = one week of computer
time to perform 10000 X^2 evaluations

Experiments 2011-2012: $^{233}U(d,p)$, $^{235}U(p,d)$ and ^{238}U

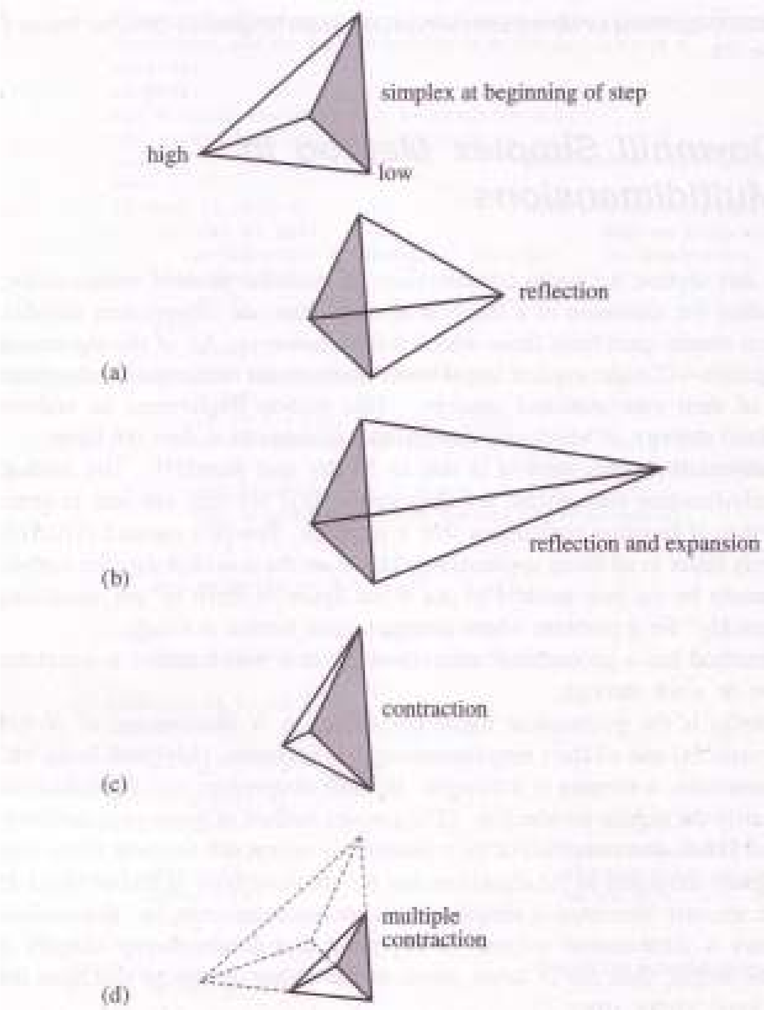


Fission detectors



Inverse Kinematics

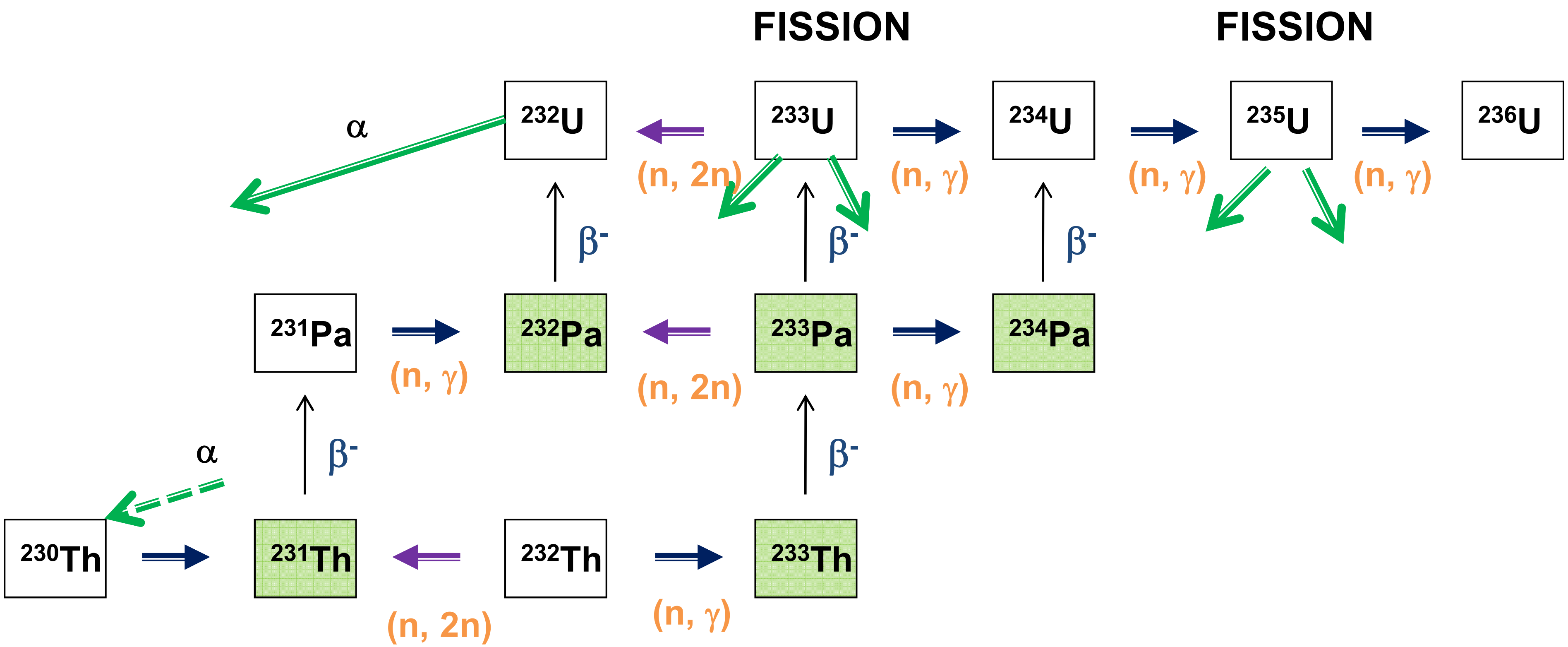
Minimisation with the Downhill simplex method



$$\sum_{d} W(E_\gamma) R(E_d, E_\gamma) - kE_\gamma = 0$$

« With four parameters, I could fit an elephant, with five I could make him wiggle his trunk »

$$W(E) = a + bE + cE^2 + d\,E^3 + eE^4 + f\,E^5$$



FISSION
FISSION
232U
233U
234U
235U
236U
α
(n, 2n)
(n, γ)
(n, γ)
(n, γ)
β-
β-
β-
231Pa
232Pa
233Pa
234Pa
(n, γ)
(n, 2n)
(n, γ)
α
β-
β-
230Th
231Th
232Th
233Th
(n, 2n)
(n, γ)