Neutron-induced cross sections of actinides via de surrogate reaction method

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Neutron-induced cross sections of short-lived nuclei in reactor physics

- Incineration of minor actinides
  - Fission and capture cross of e.g. 241,243Am,243Cm(29.1y), 244Cm(18.1y),245Cm (8500y)
- 232Th/233U cycle
  - Fission and capture cross sections of e.g. 232U(69y), 231Th (26h), 233Th(22m)

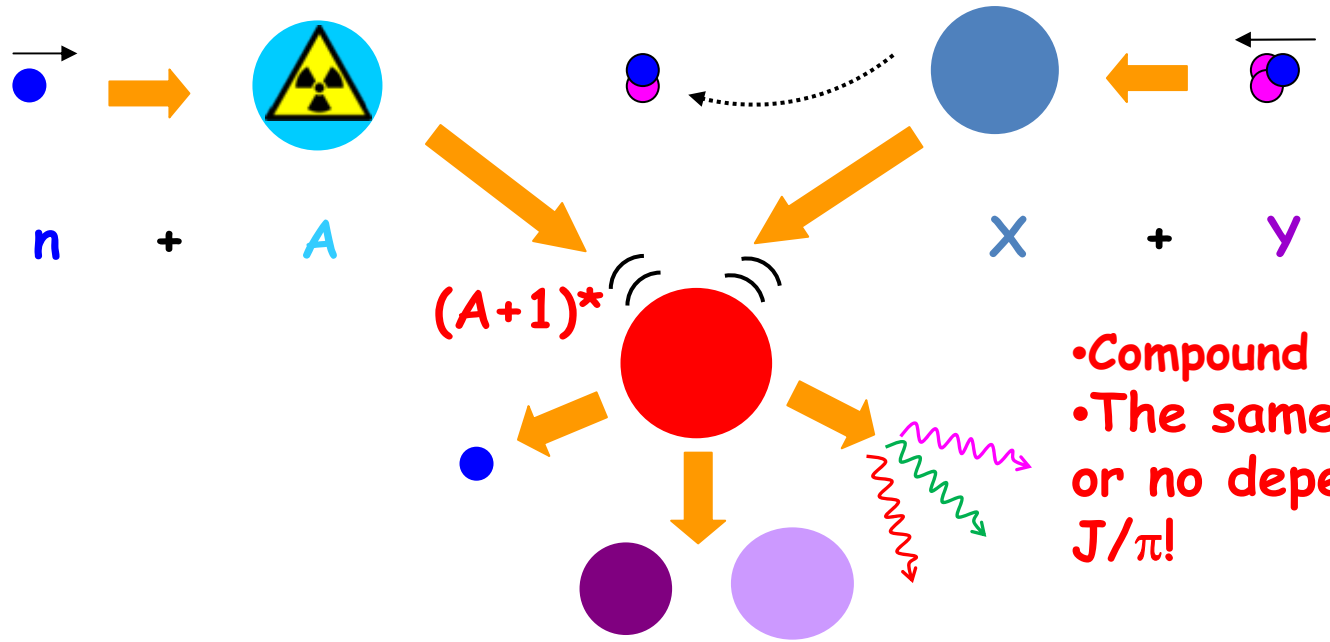
The data are missing (in particular for capture) due to the high radio-toxicity of the targets involved!

Indirect (n,f) and (n,γ) measurements: the surrogate method

Neutron-induced reaction

Surrogate reaction

Cramer and Britt (Los Alamos 1970…!!)



- Compound nucleus!
- The same spin/parity or no dependence on J/π!

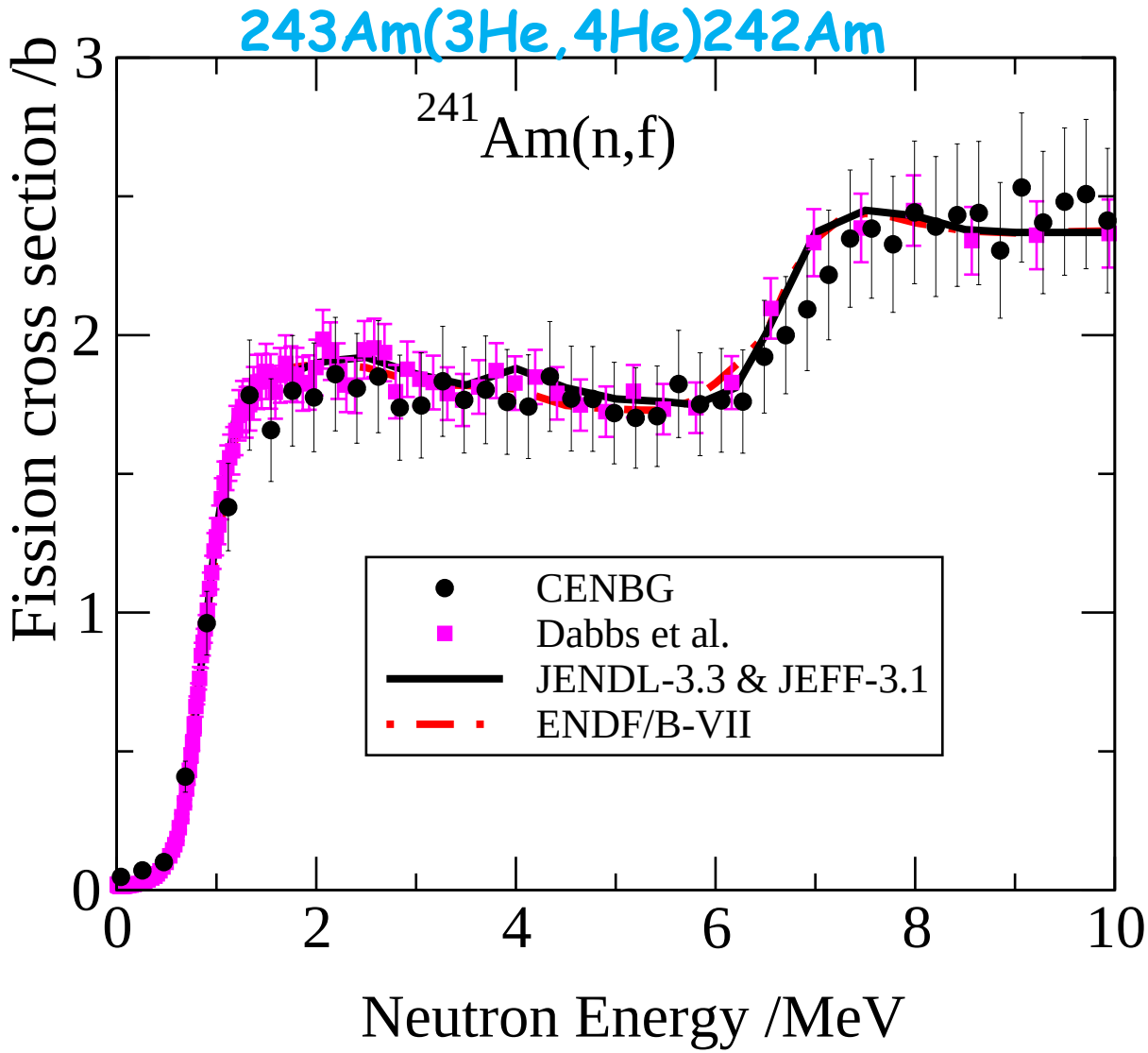
$$\sigma^{A}_{(n,\chi)}(E^*) = \underbrace{\sigma^{A+1}(E^*)}_{\text{Calculated}} . \underbrace{P^{A+1}_{\chi}(E^*)}_{\text{Measured}}$$

Calculated

(Optical model calculations CEA/Bruyeres le Chatel)

Measured

Surrogate method and fission cross sections

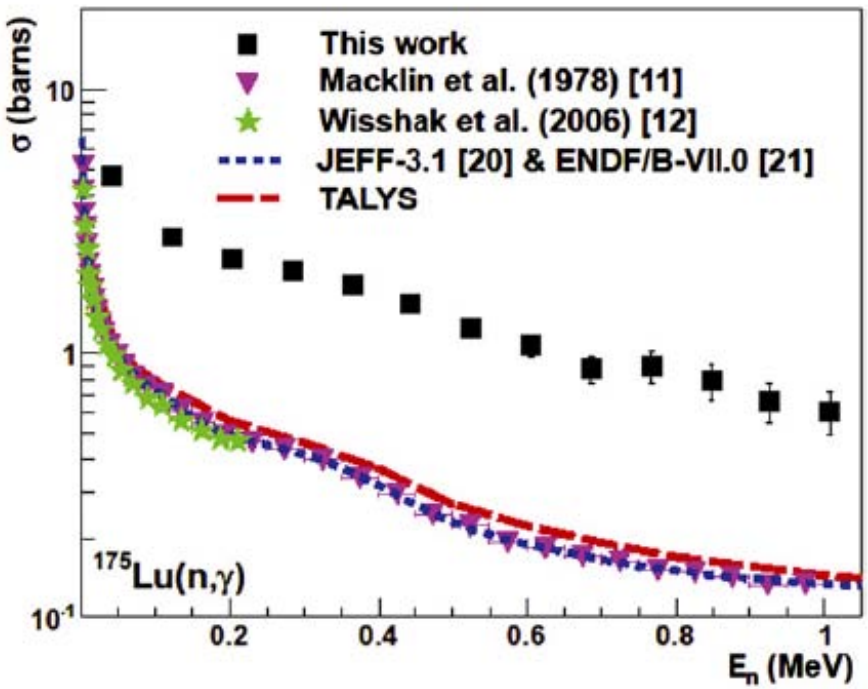


G. Kessedjian, et al., Phys. Lett B 692 (2010) 297

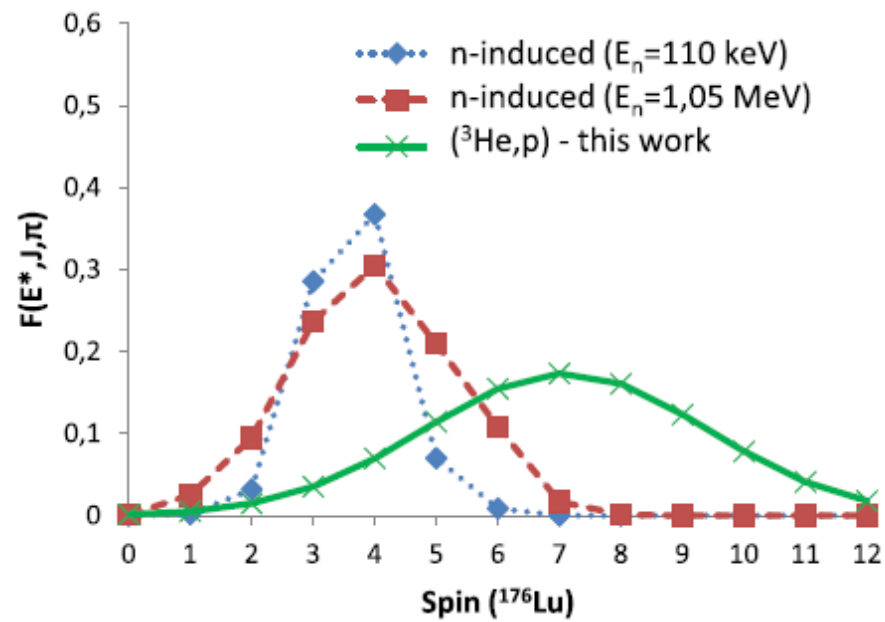
How about radiative capture??

Surrogate method applied to capture in rare-earth region
Results for 174Yb(3He,p)176Lu

175Lu(n,γ)



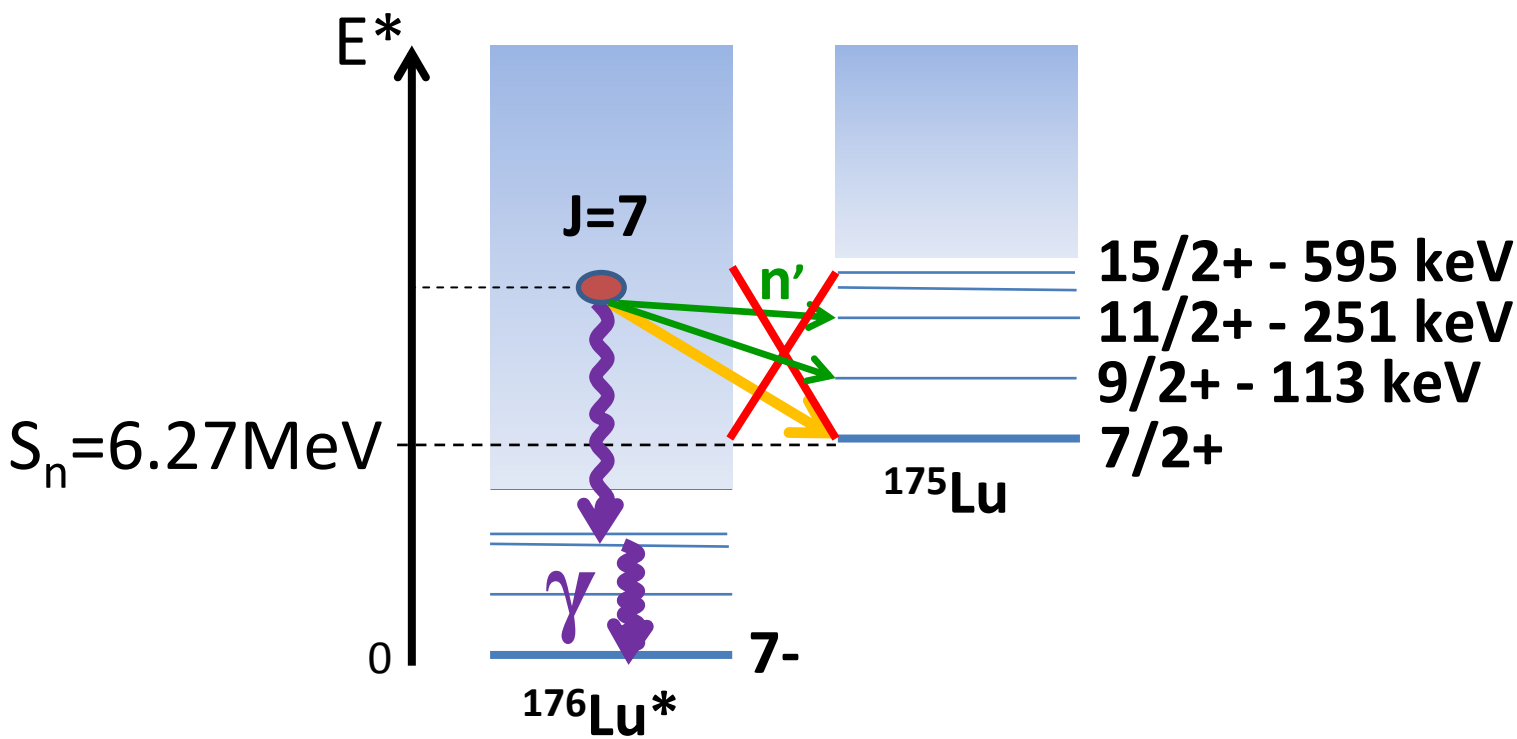
Spin distributions



G. Boutoux, et al., Phys. Lett B 712 (2012) 319

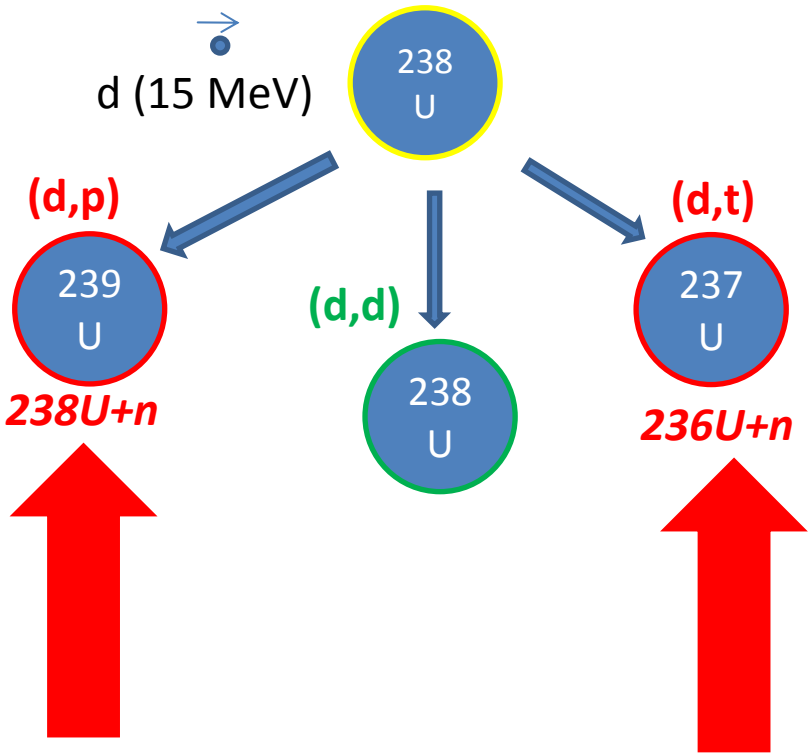
Very important discrepancies!

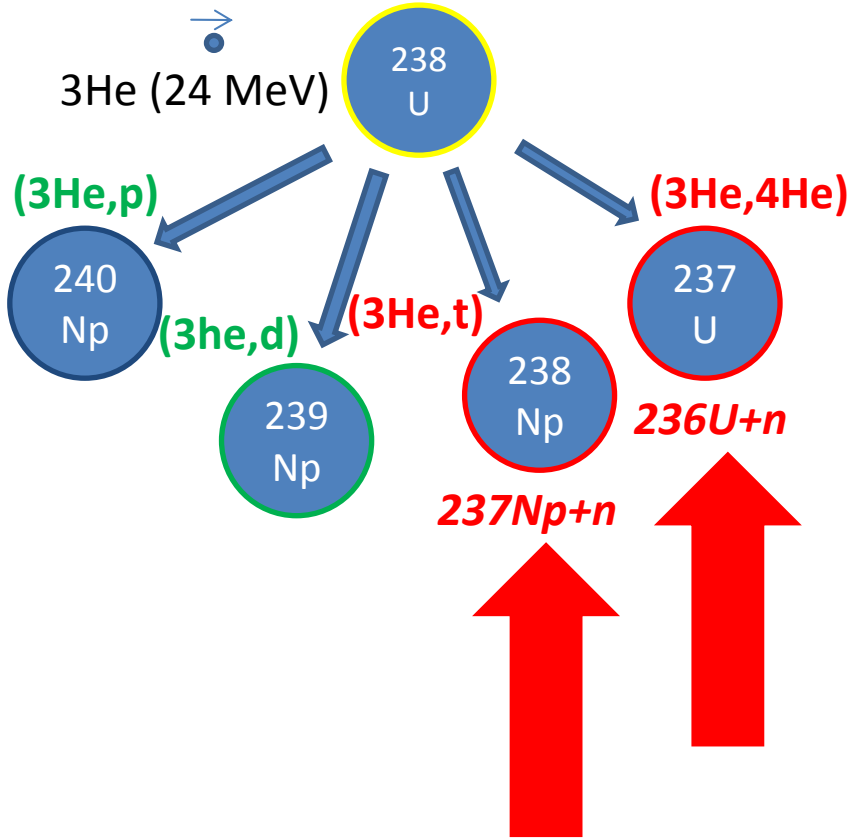
Why do we obtain such big differences?



Due to the high spin of the decaying nucleus, neutron emission to the ground- and first excited states is highly improbable and gamma emission is highly enhanced!
Things should get better when the level density of the nucleus after neutron emission increases --> better for actinides

Surrogate method applied to capture in actinide region
Experiment at the Oslo cyclotron:
Reactions studied

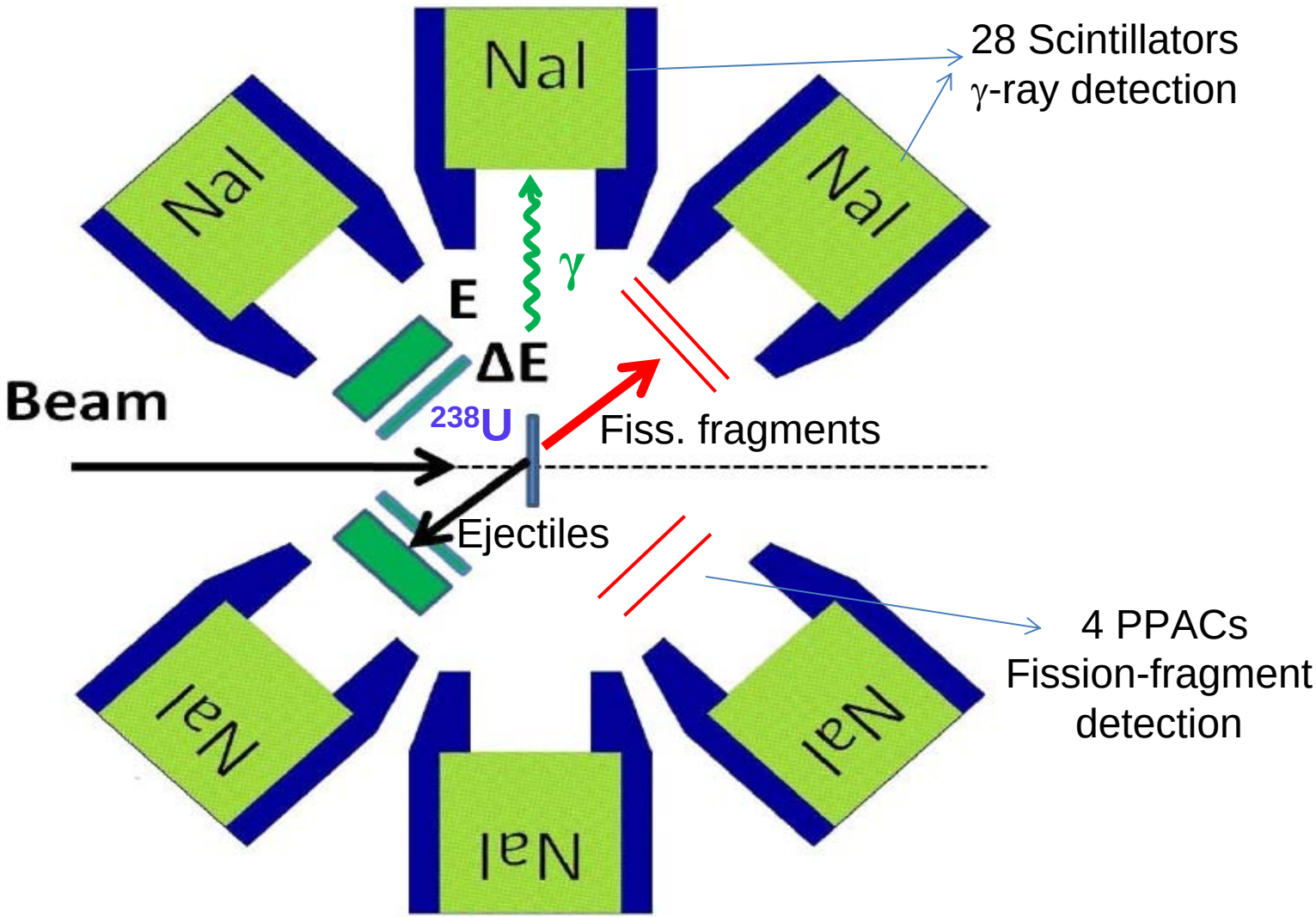




Good quality neutron-induced data exist!
(d,p) interesting for inverse kinematics

Good quality neutron-induced data exist

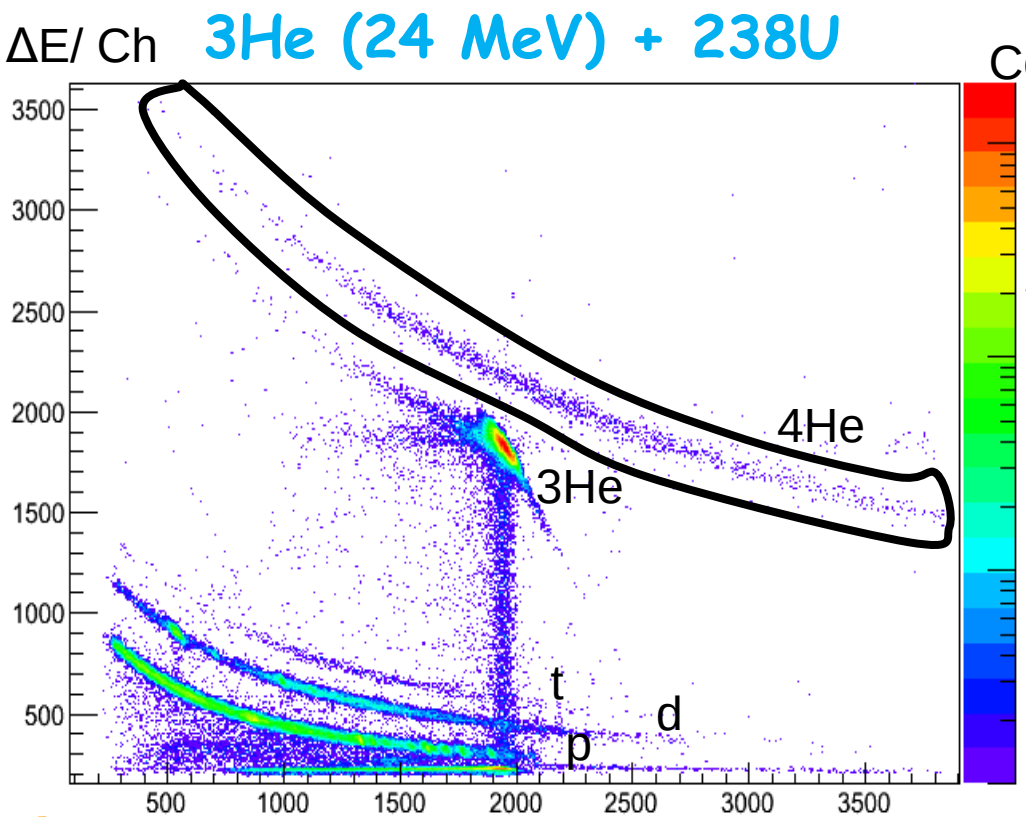
Experimental set-up at the Oslo cyclotron

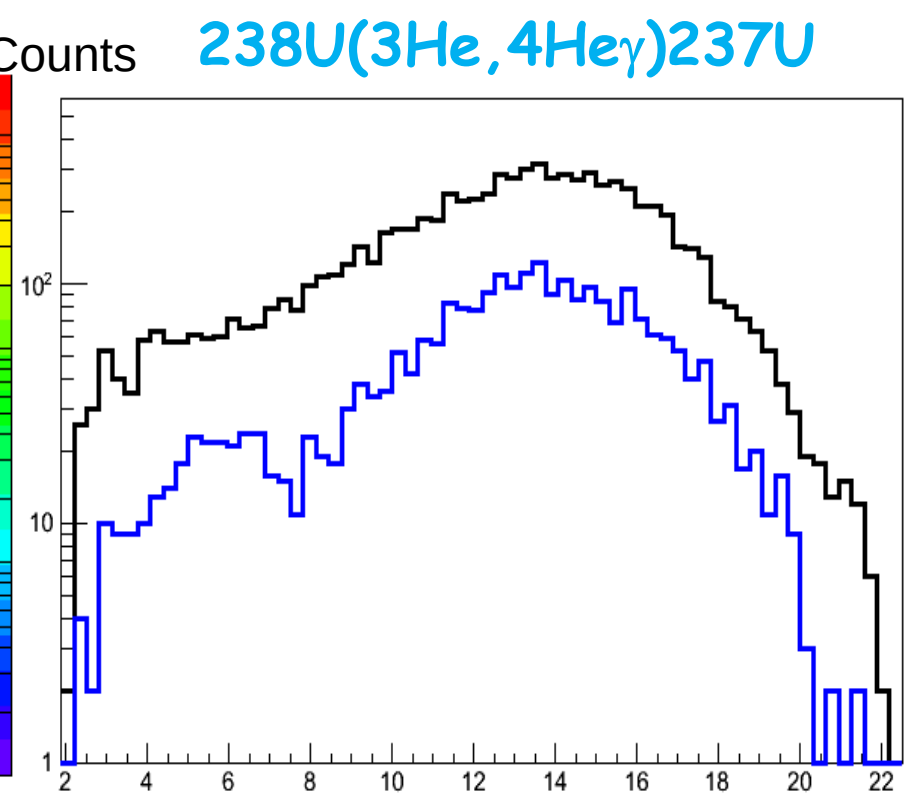


High efficiency

Simultaneous measurement of gamma and fission decay

Determination of decay probability



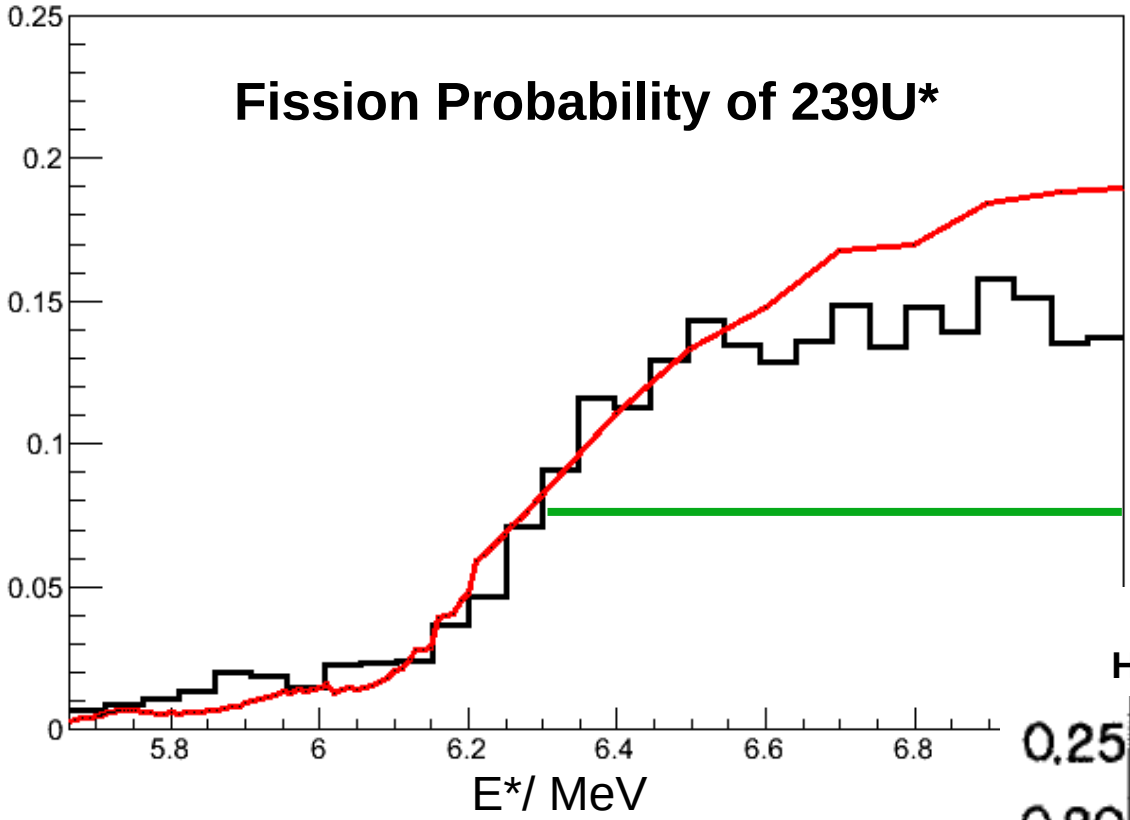


Light-particle kinematics + Q-values
E* of the CN

$$P\left(E^*\right) = \frac{N_{coin}\left(E^*\right)}{N_{CN}\left(E^*\right)\cdot Eff\left(E^*\right)}$$

$$E^* = \frac{A}{A+1}E_n + B_n$$

First preliminary results: Fission

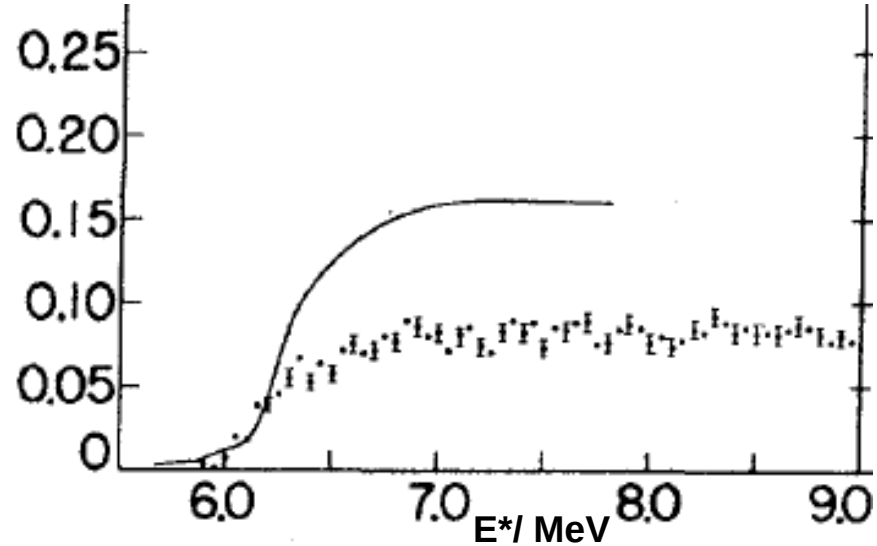


ENDF-VII.1
238U(n,f)

CENBG
238U(d,p) at 15 MeV

Britt, Cramer
238U(d,p) at 18 MeV

238U(d,p) at 18 MeV
H. C. Britt , J. D. Cramer, PRC 2 (1970) 1758

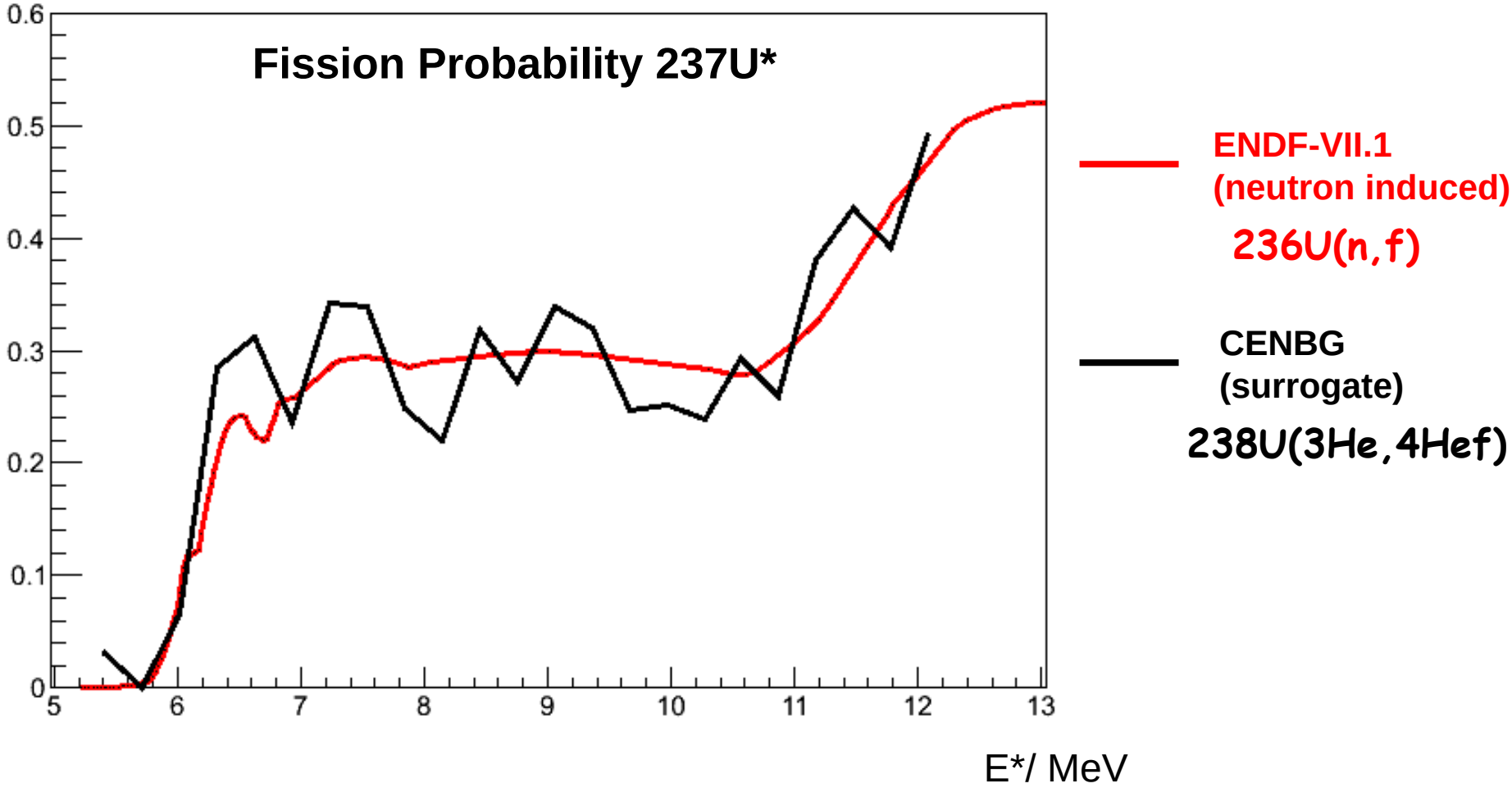


Deuteron breakup!

The neutron is emitted before CN formation

(I. Thompson, 2012)

First very preliminary results: Fission
(Analysis with very low statistics, only 1 telescope strip!)



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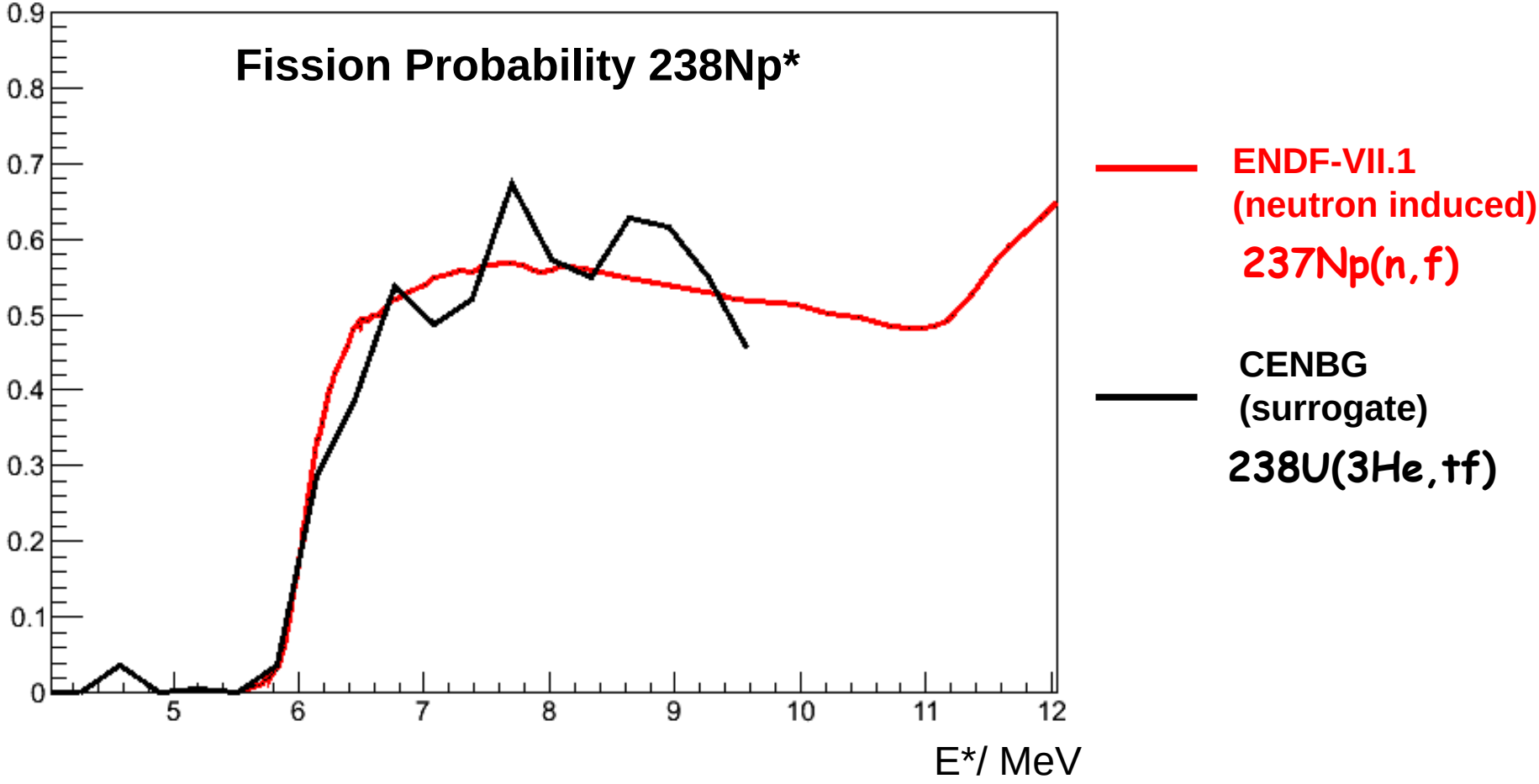
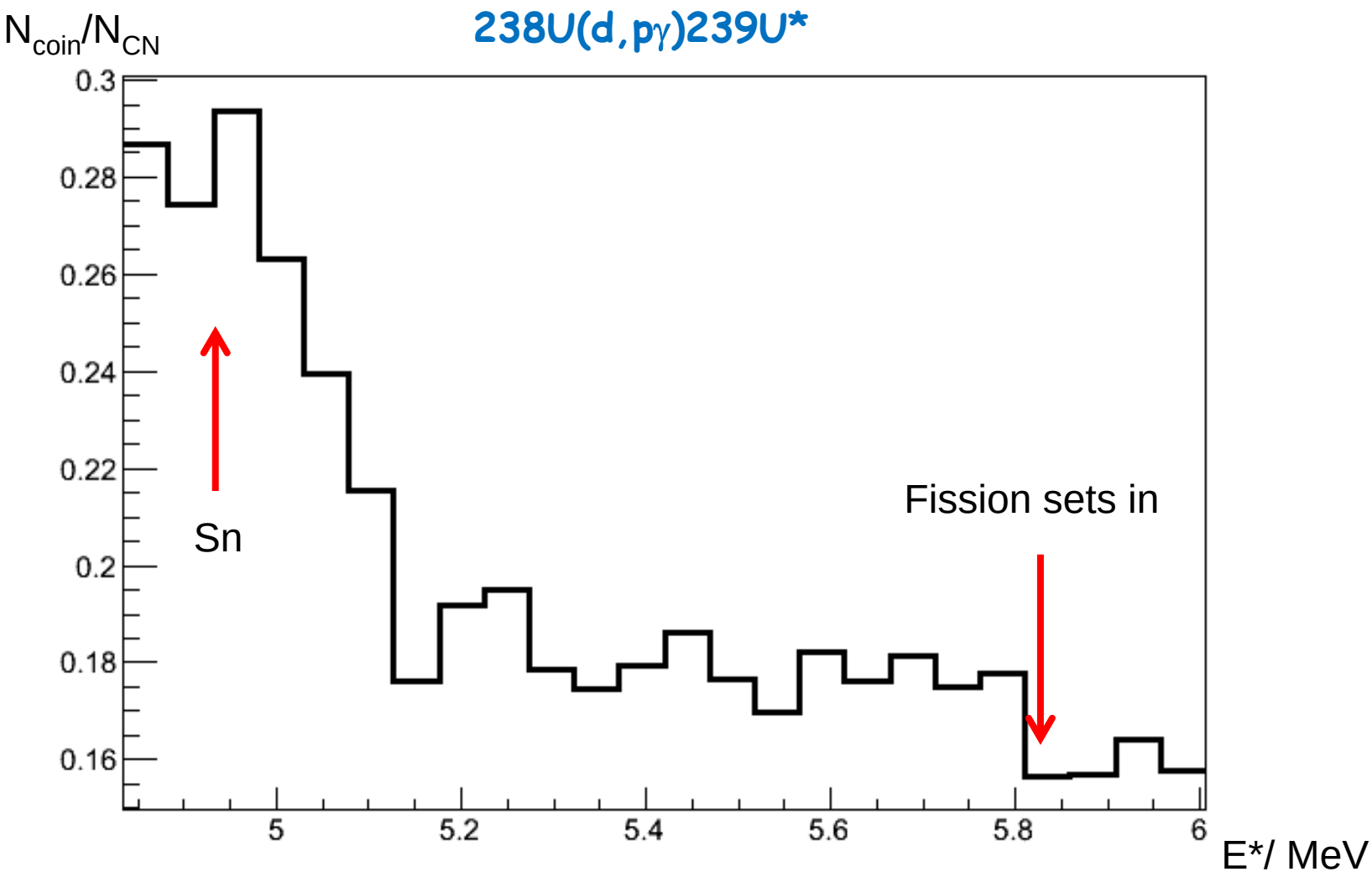


First very preliminary results: gamma decay



This ratio needs to be corrected
for the gamma-cascade detection efficiency to get Pgamma!

Conclusions…

•Surrogate-reaction method :
-->works well for fission
-->important discrepancies for capture in rare-earth region due to spin selectivity of neutron emission

•New experiment to study capture in actinide region at the Oslo cyclotron
→ d+238U & 3He+238U
→238U(d,p): fission cross section 25% lower than 238U(n,f), d breakup!
→Preliminary fission probabilities from 238U(3He,4He) & 238U(3He,t) agree well with n-induced data
→Analysis on the way to extract gamma-decay probabilities

…Perspectives

•Further study of d-breakup involving theoreticians

•Gamma-decay probabilities to be extracted for:
238U(d,p)239U <-> 238U(n,γ)
238U(d,t)237U <-> 236U(n, γ)
238U(3He, 4He) 237U <-> 236U(n, γ)
238U(3He, t) 238Np <-> 237Np(n, γ)

•Evaluate to which extent the surrogate method can be used to extract unknown capture cross sections of short-lived actinides