Surrogate-reaction studies by the CENBG collaboration: status and perspectives

Beatriz Jurado, Centre d'Etudes Nucleaires de Bordeaux-Gradignan (CENBG), France

The CENBG collaboration

M.Aiche, G. Barreau, S.Czajkowski, Q. Ducasse, B. Jurado, P. Marini, L. Mathieu, I. Tsekhanovich

Centre d'Etudes Nucléaires de Bordeaux-Gradignan, France

F. Gunsing, V. Méot, O. Roig, O. Sérot

CEA, France

L. Audouin, L. Tassan-Got, J. Wilson

Institut de Physique Nucléaire d'Orsay, France

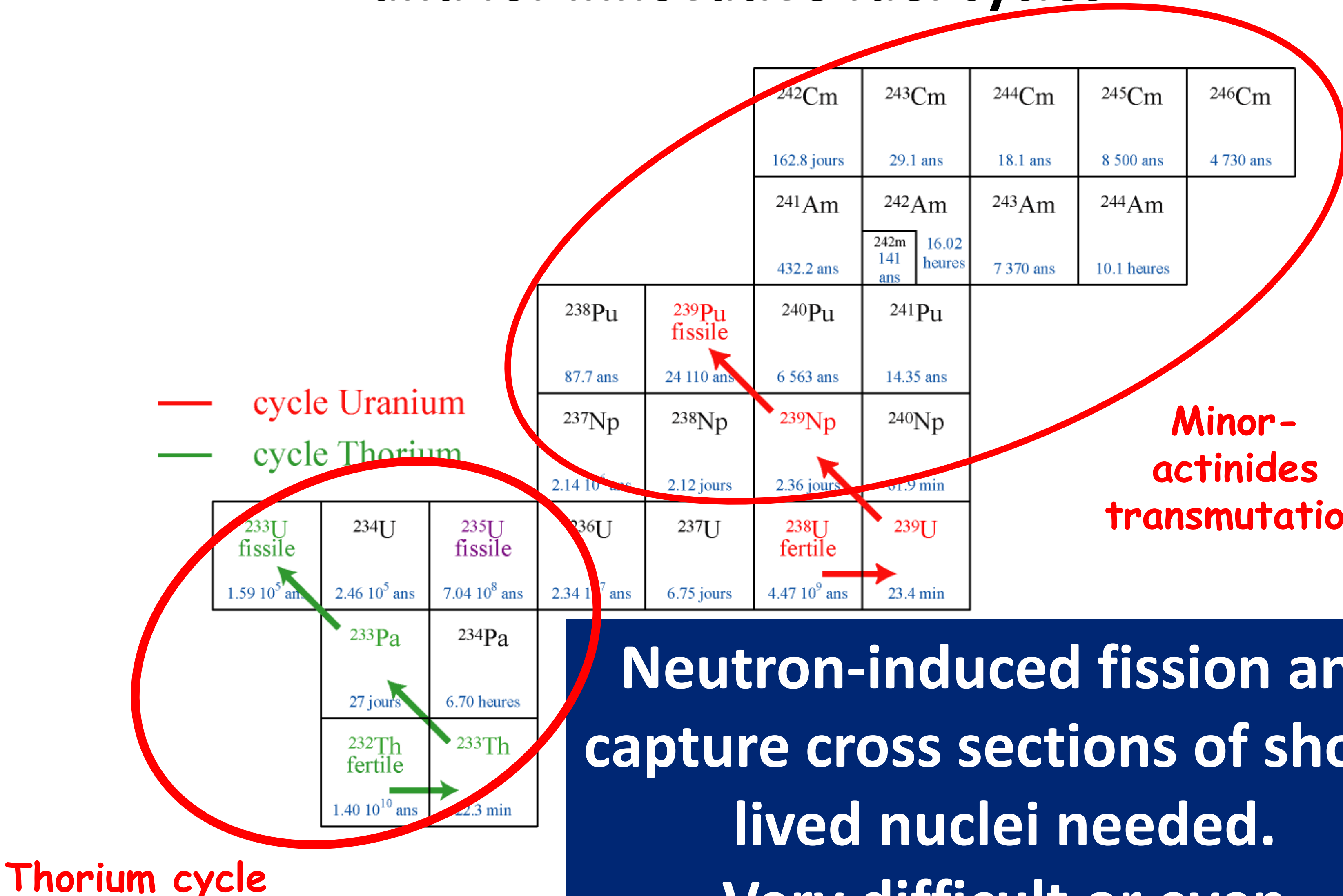
J. Burke, J. Escher

Lawrence Livermore National Laboratory, USA

A. Goergen, M. Guttormsen, A.-C. Larsen, S. Siem

University of Oslo, Norway

Nuclear data for the transmutation of nuclear-waste and for innovative fuel cycles

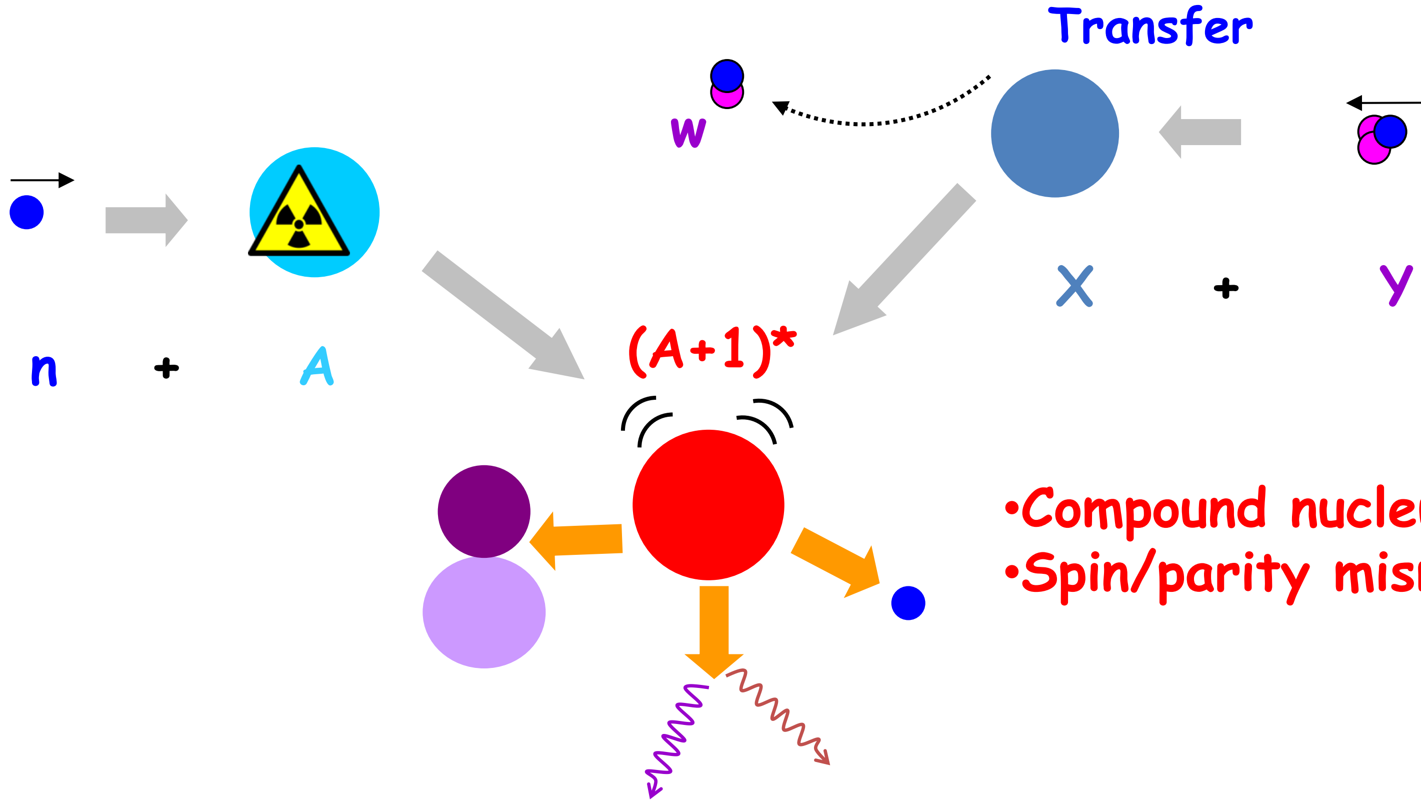


Neutron-induced fission and capture cross sections of short-lived nuclei needed. Very difficult or even impossible to measure!

Surrogate-reaction method

Cramer and Britt (Los Alamos 1970…!!)

Neutron-induced reaction | **Surrogate reaction**



- Compound nucleus
- Spin/parity mismatch

$$\sigma^{A}_{n,decay}(E^*) \cong \underbrace{\sigma^{A+1}_{CN}(E^*)}_{\text{Calculated, optical model}} . \underbrace{P^{\text{surro}}_{decay}(E^*)}_{\text{Measured}}$$

Investigated surrogate reactions

PhD Thesis of M. Petit (2002) and S. Boyer (2004)

3He+232Th ($T_{1/2}=1.4 \cdot 10^{10}$ y)
- → p+234Pa ↔ n+233Pa ($T_{1/2}=27$ d), fission
- → d+233Pa ↔ n+232Pa ($T_{1/2}=1.32$ d), fission
- → t+232Pa ↔ n+231Pa ($T_{1/2}=3.3 \cdot 10^{4}$ y), fission
- → 4He+231Th ↔ n+230Th($T_{1/2}=7.5 \cdot 10^{4}$ y), fission

PhD Thesis of G. Kessedjian (2008)

3He+243Am ($T_{1/2}=7370$ y)
- → d+244Cm ↔ n+243Cm ($T_{1/2}=29.1$ y), fission
- → t+243Cm ↔ n+242Cm ($T_{1/2}=163$ d), fission
- → 4He+242Am ↔ n+241Am($T_{1/2}=432.2$ y), fission

PhD Thesis of G. Boutoux (2011)

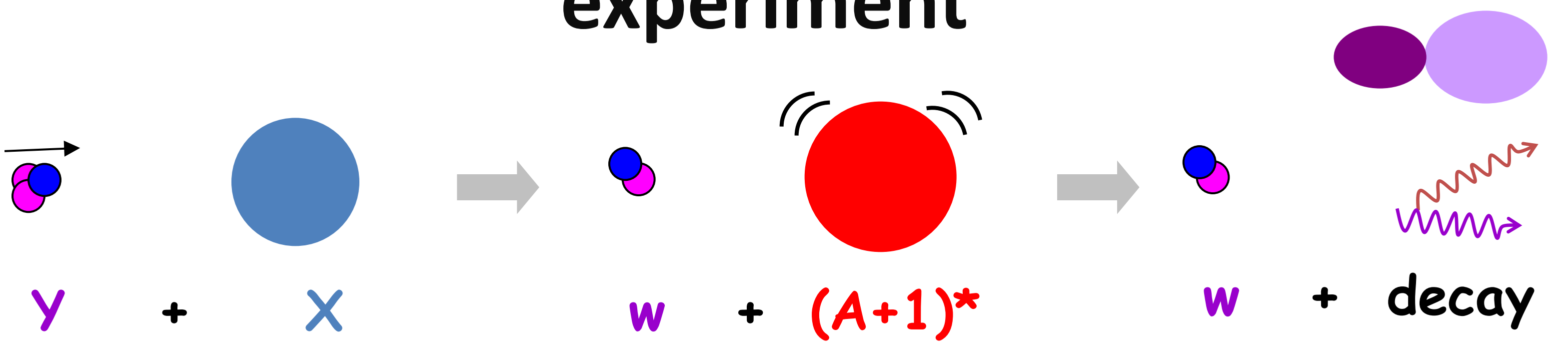
3He+174Yb (Stable)
- → p+176Lu ↔ n+175Lu (Stable), gamma decay
- → 4He+173Yb ↔ n+172Yb(Stable), gamma decay

PhD Thesis of Q. Ducasse (2012)

d+238U ($T_{1/2}=4.47 \cdot 10^{9}$ y) → p+239U ↔ n+238U, fission and gamma decay

3He+238U ($T_{1/2}=4.47 \cdot 10^{9}$ y)
- → d+239Np ↔ n+238Np ($T_{1/2}=2.1$ d), fission
- → t+238Np ↔ n+237Np ($T_{1/2}=2.14 \cdot 10^{6}$ y), fission
- → 4He+237U ↔ n+236U($T_{1/2}=2.34 \cdot 10^{7}$ y), fission

How to measure the decay probability in a surrogate experiment



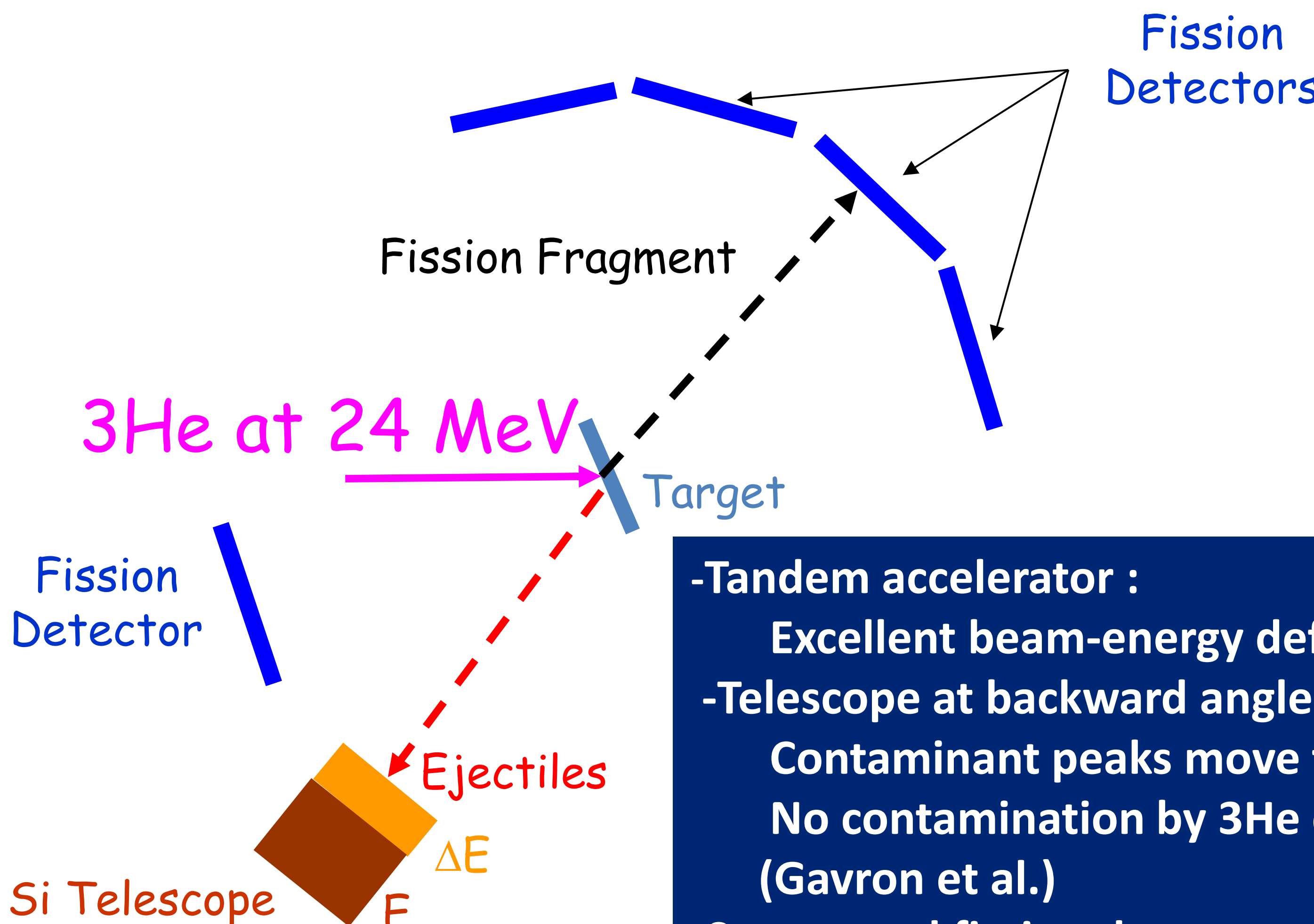
$$P_{surro,decay}(E^*) = \frac{N^{coin}_{ejec-decay}(E^*)}{N^{\mathrm{singles}}_{ejec}(E^*)\mathrm{Eff}_{decay}(E^*)}$$

Main issues:

- E* :
  - Good beam-energy definition
  - Calibration of ejectile detectors for very high kinetic energies
- $N^{singles}$, N^{coinc}:
  - High chemical purity of targets required (e.g. no oxygen!)
  - No projectile or ejectile breakup
  - Be sure that you detect the gammas from CN

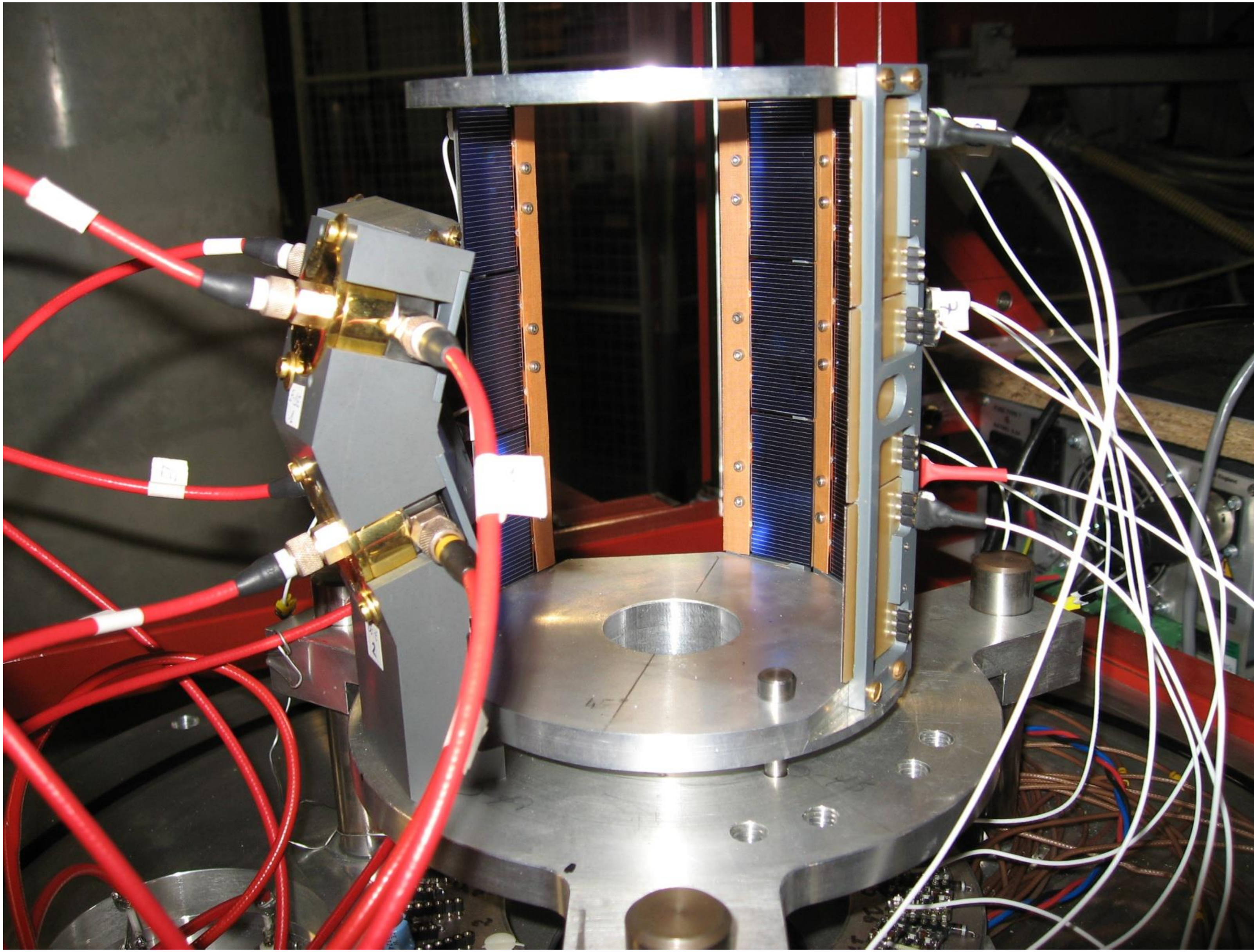
Experimental set-ups used

Set-up for fission probability measurements at the Tandem of the IPN Orsay, France

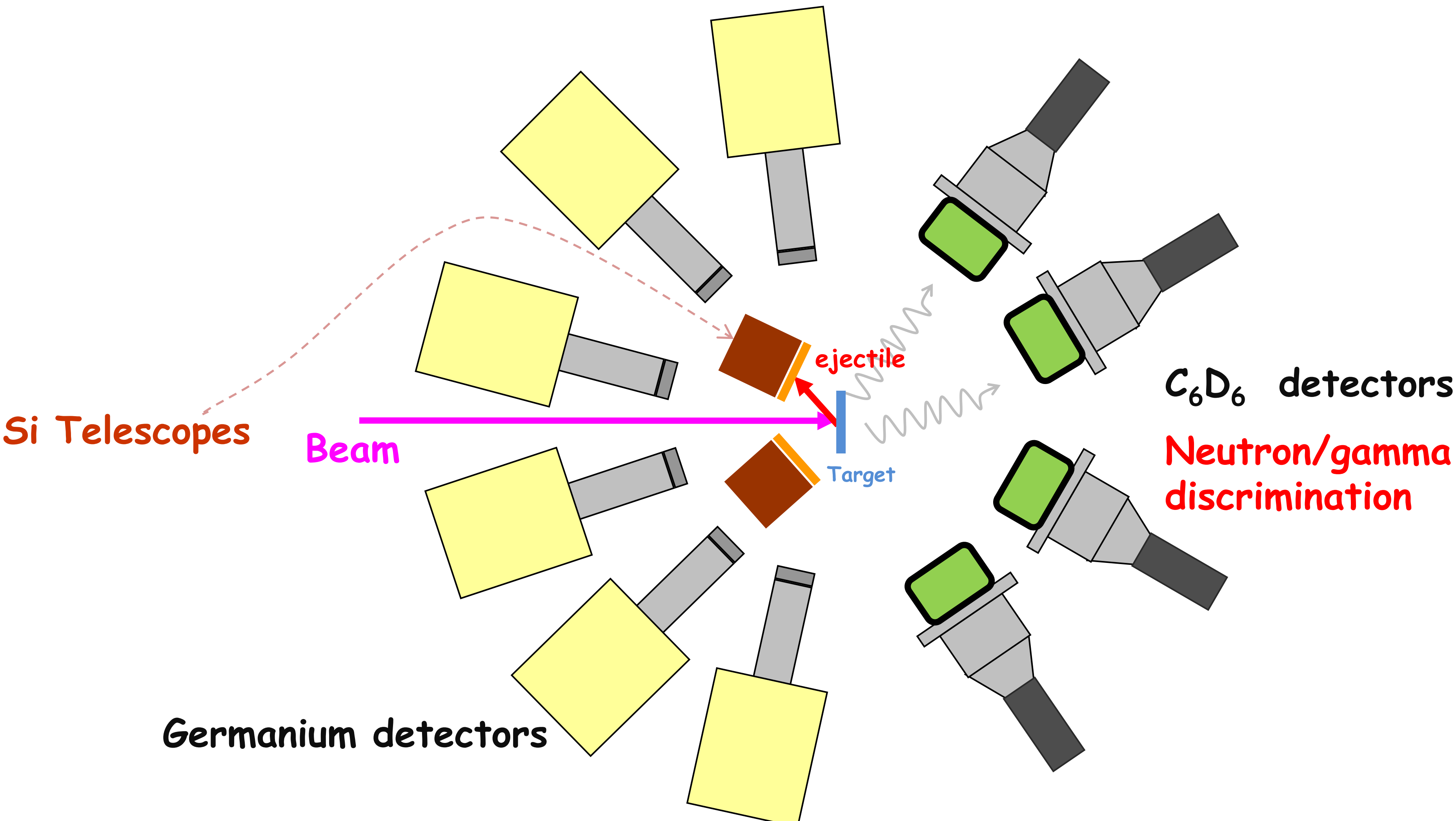


- -Tandem accelerator :
  - Excellent beam-energy definition
- -Telescope at backward angles:
  - Contaminant peaks move to high E*
  - No contamination by 3He or t breakup (Gavron et al.)
- -Segmented fission detector:
  - Impact of fiss. Fragment angular distribution on fission efficiency

Experimental set-up for fission

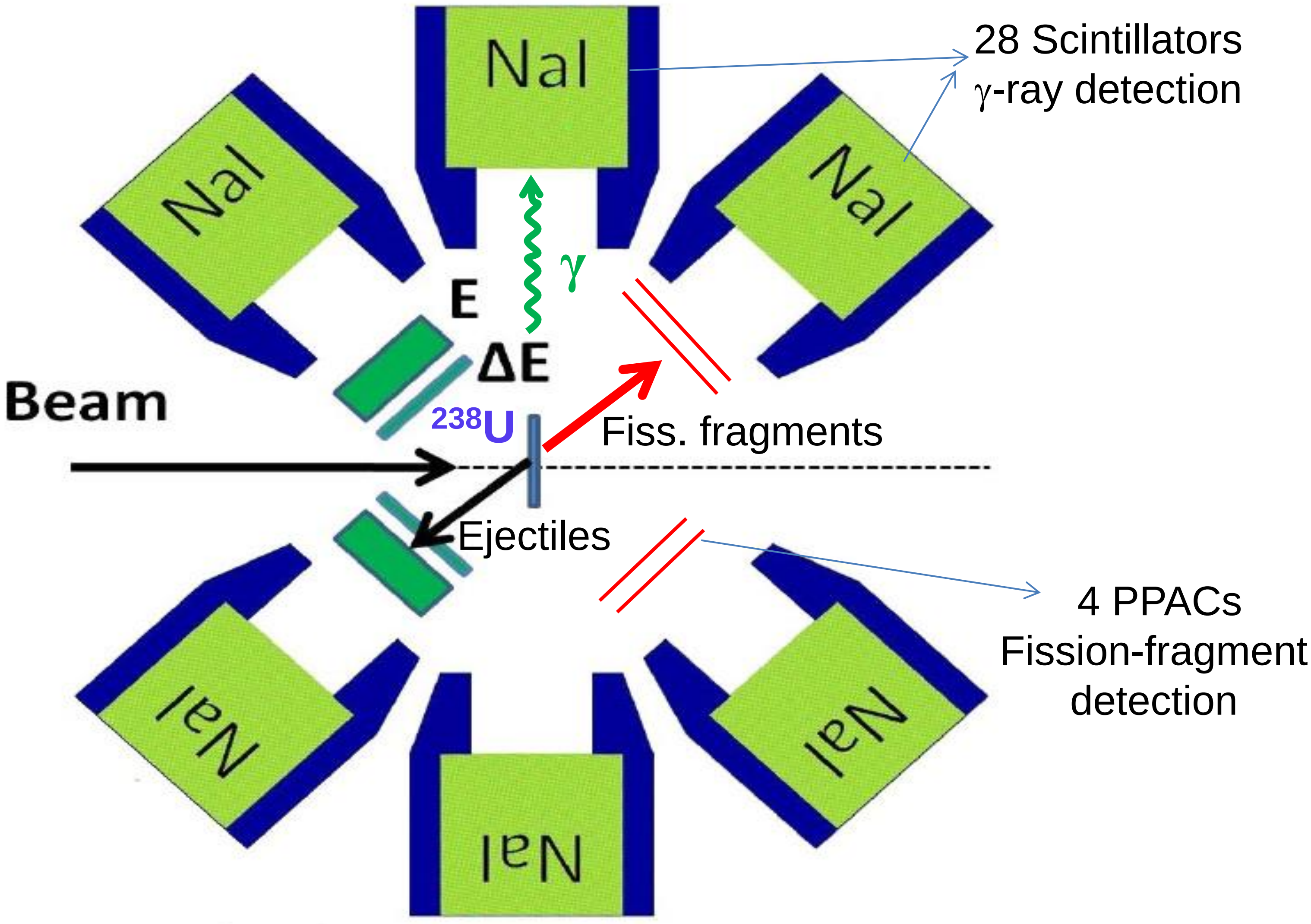


Experimental set-up for gamma-decay probability measurements at IPN Orsay



Ge --> verify the gamma-decay probabilities measured with the scintillators!
No gamma-ejectile coincidences coming from contaminants, from nucleus A-1!

Experimental set-up at the Oslo cyclotron

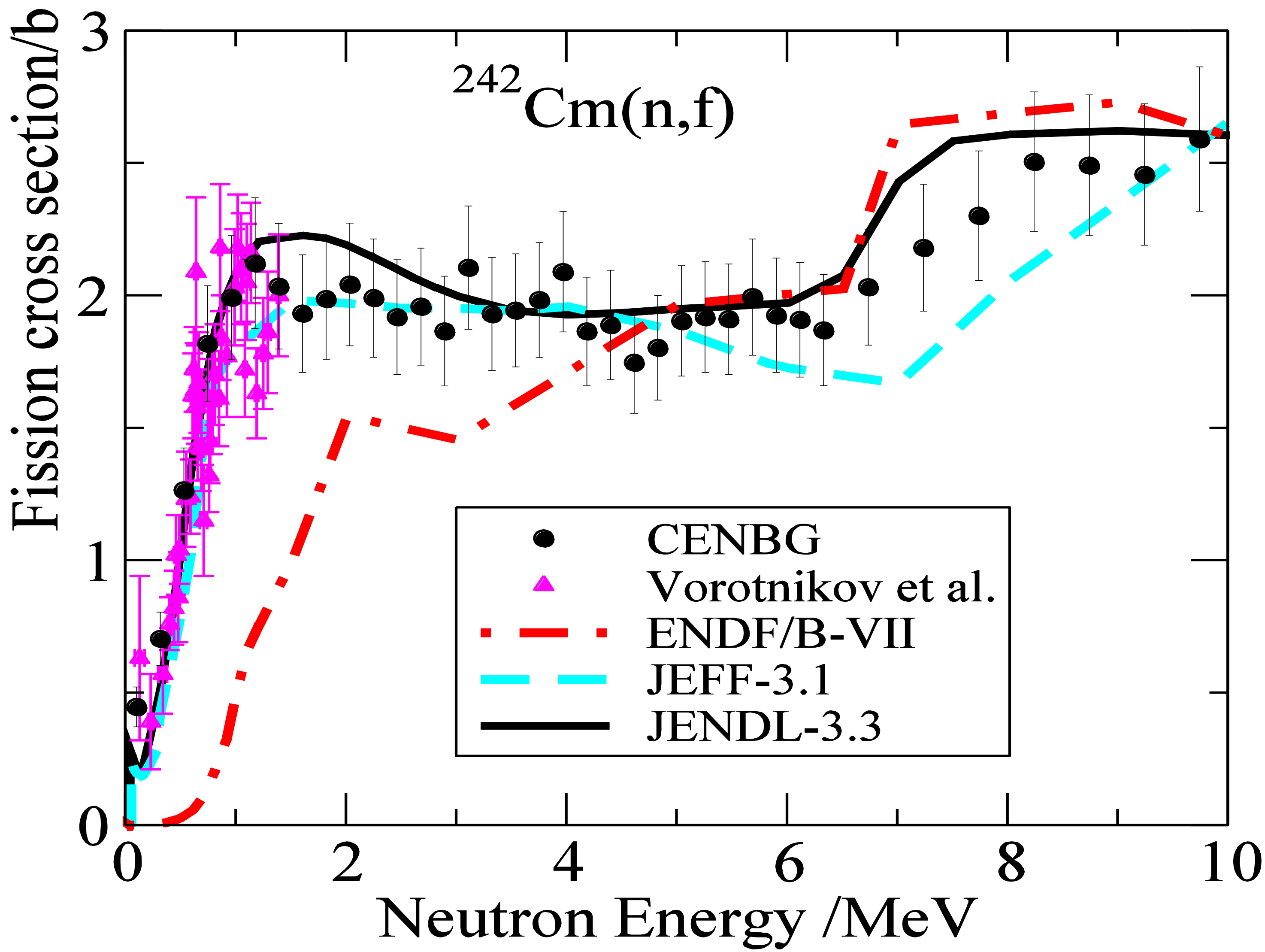


High gamma-detection efficiency

Measurement of gamma- and fission-decay probabilities

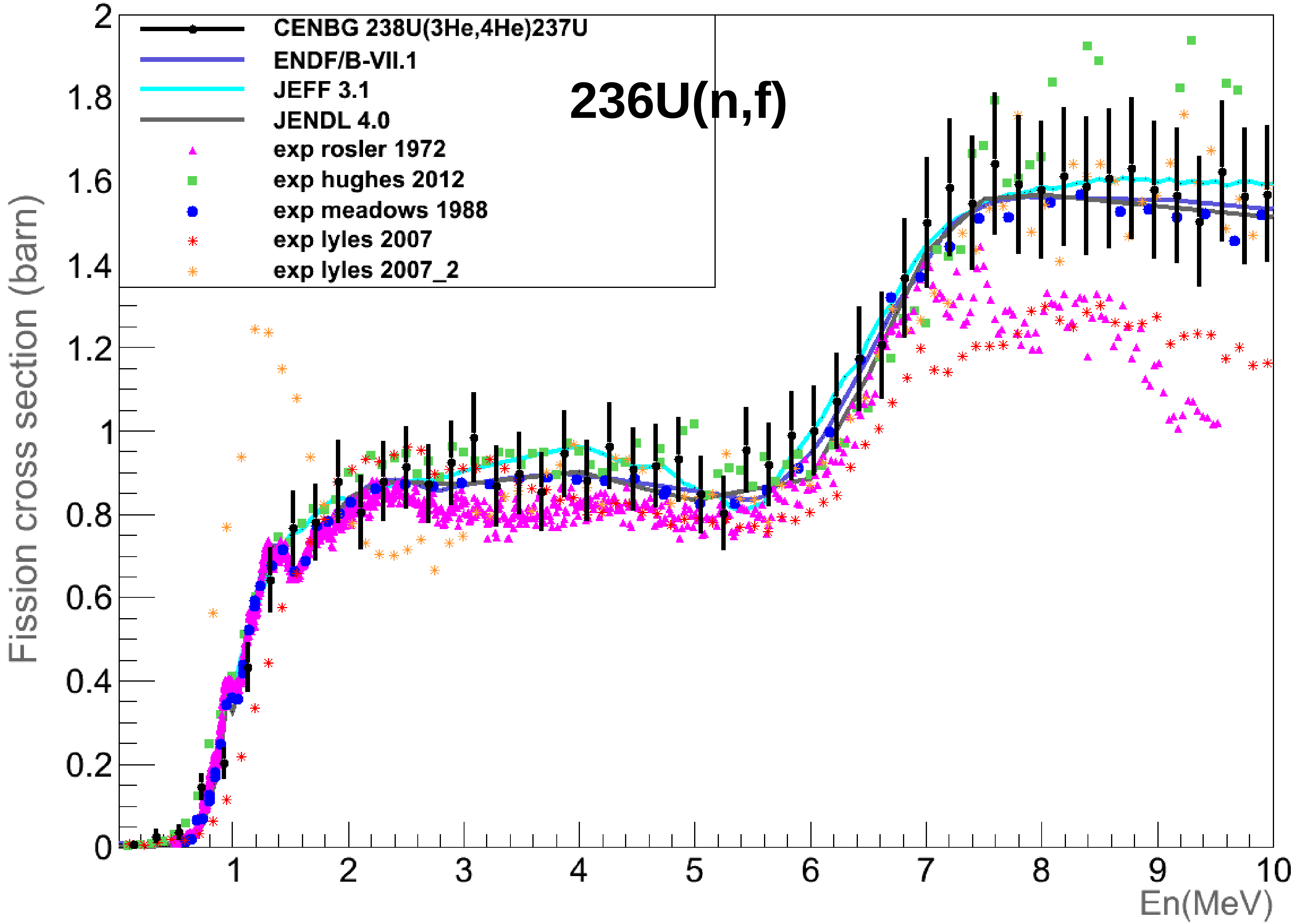
Selected results for fission

3He + 243Am -> t + 243Cm



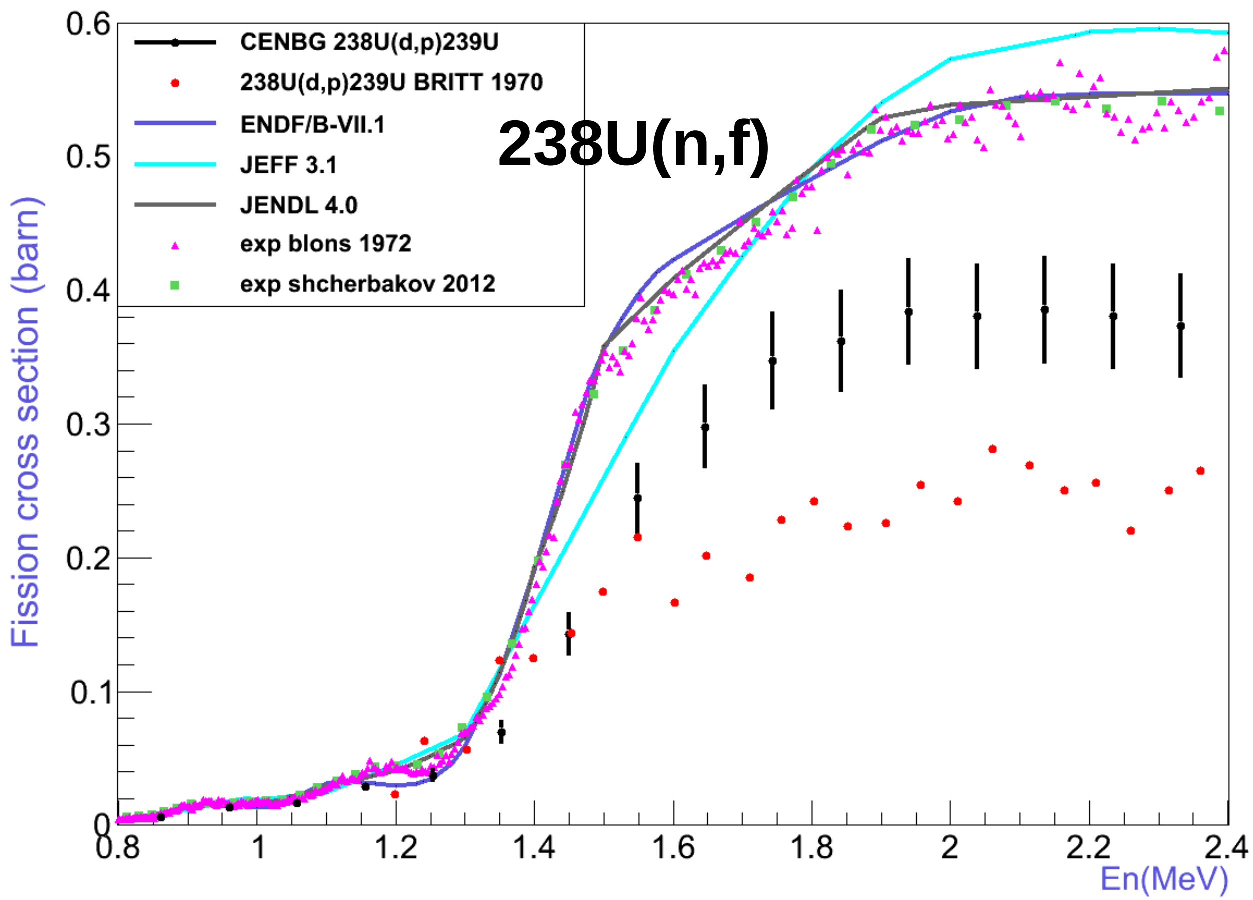
G. Kessedjian, et al., Phys. Lett. B 692 (2010) 297

3He + 238U -> 4He + 237U, preliminary results



Q. Ducasse, PhD. Thesis, Univ. Bordeaux, started in 2012

d + 238U -> p + 239U, preliminary results!



Deuteron breakup?

Neutron emission before compound nucleus formation? I. Thompson (2012)

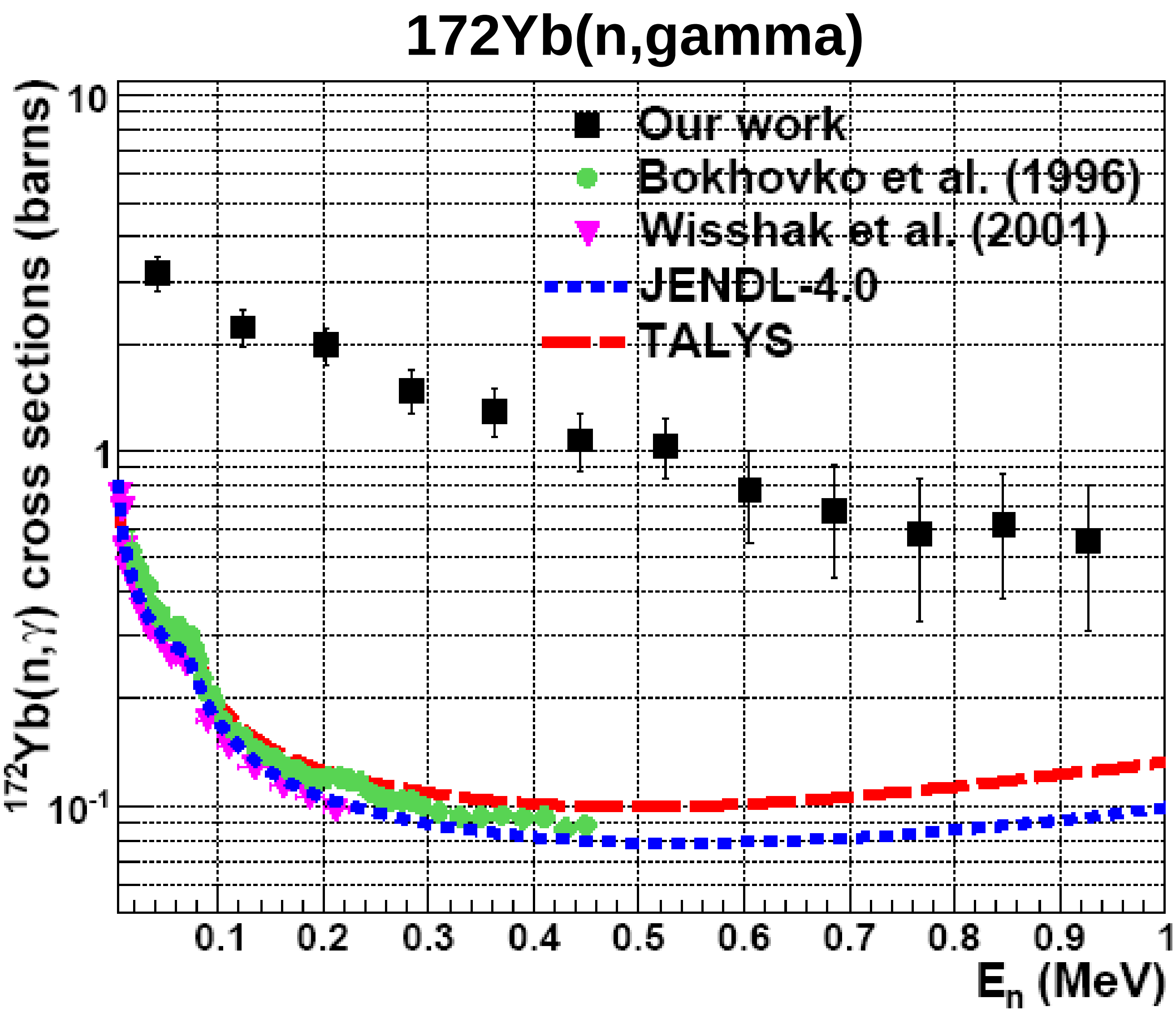
(Should also be seen in e.g. (12C,11C) or (18O, 17O)!)

Fusion d+16O and p evaporation? (PACE4 calculations)

Q. Ducasse, PhD. Thesis, Univ. Bordeaux, started in 2012

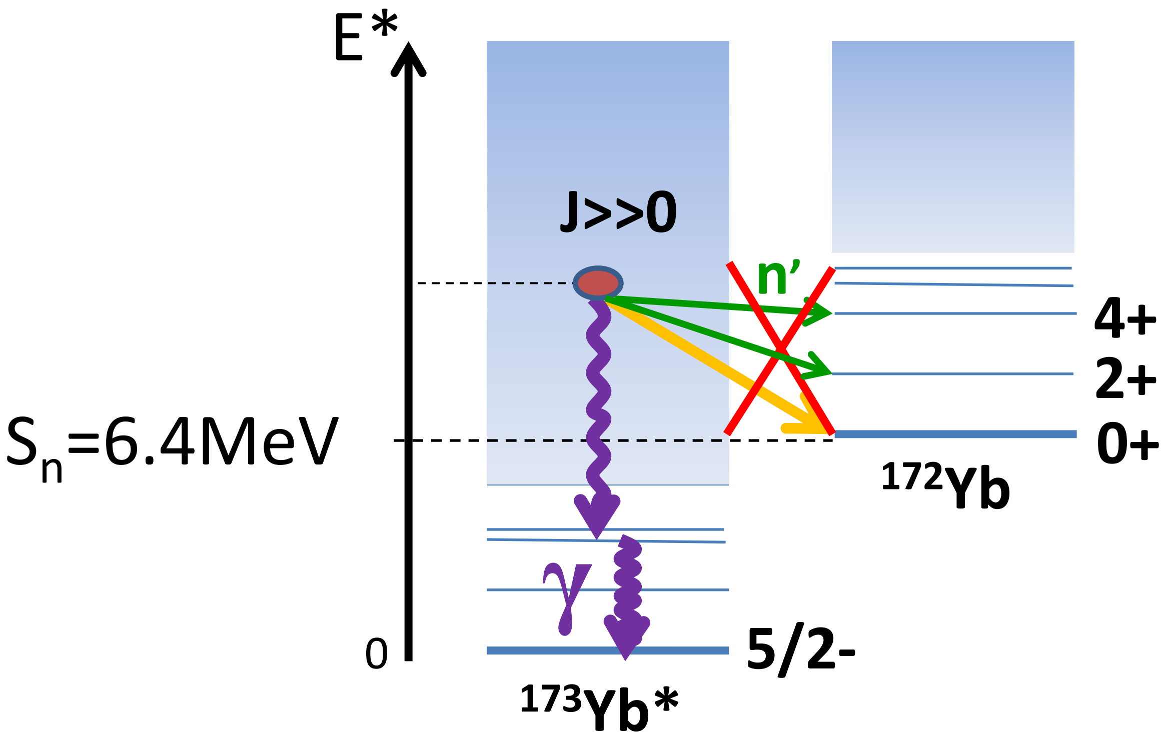
Selected results for capture

3He + 174Yb -> 4He + 173Yb



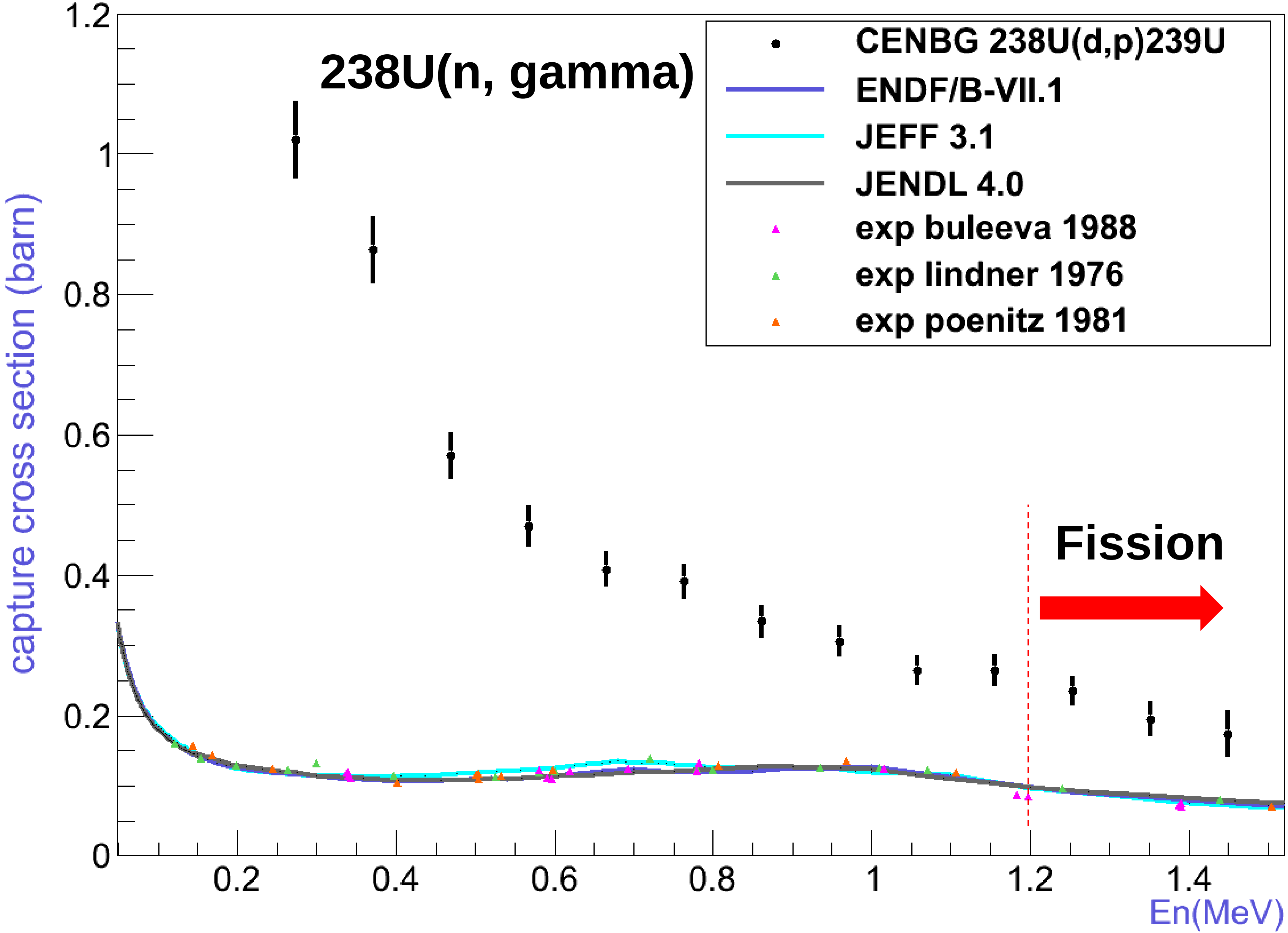
G. Boutoux et al., Phys. Lett. B 712 (2012) 319

Why do we obtain such big differences?



Things should get better when the level density of the nucleus after neutron emission increases --> better for actinides!

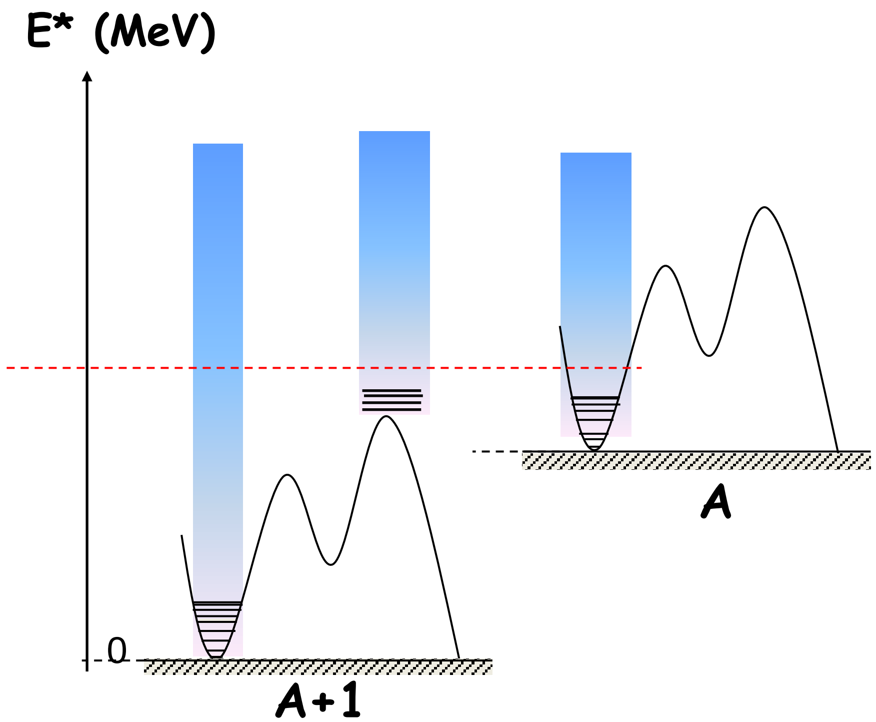
d + 238U -> p + 239U, preliminary results



Q. Ducasse, PhD. Thesis, Univ. Bordeaux, started in 2012

Why does the surrogate method work for fission?

Simplest hypothesis:



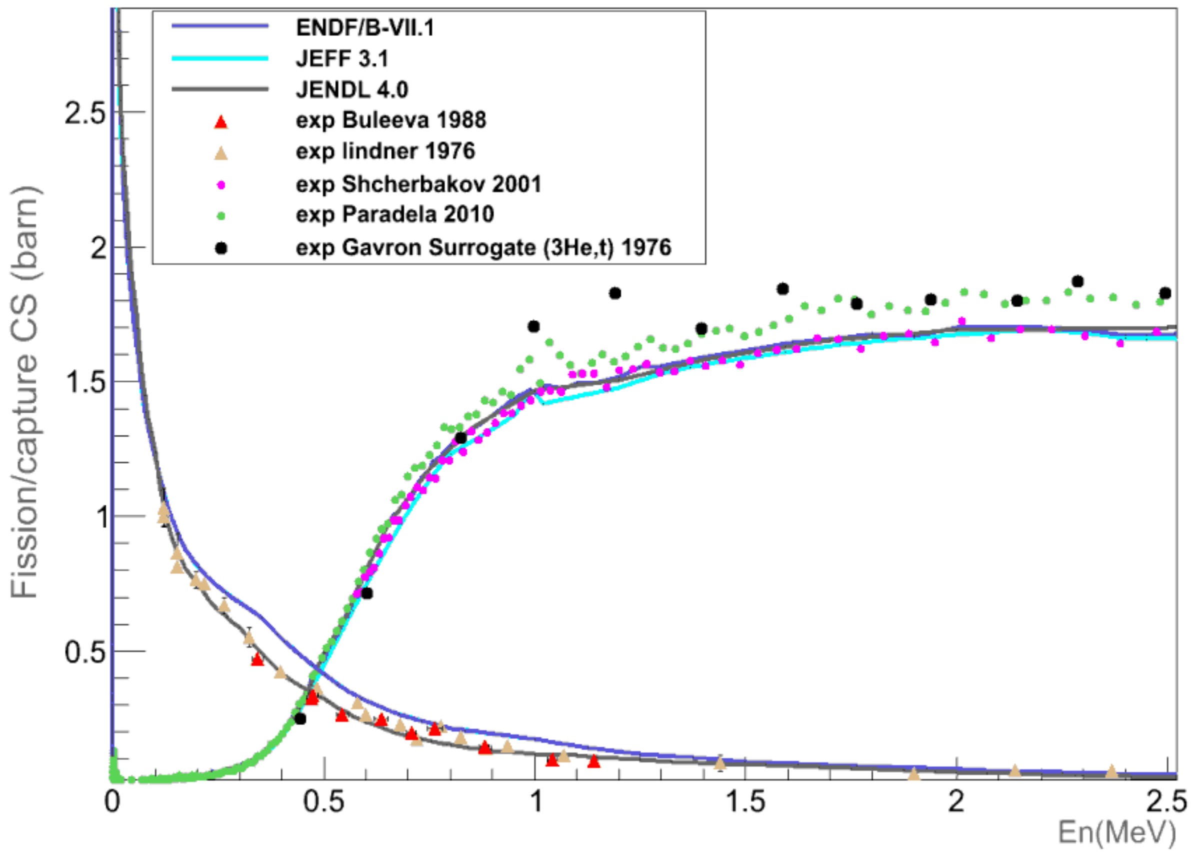
For the cases studied the level densities of nucleus A and above the barrier are high enough to make fission and neutron emission insensitive to J!

But then..., capture should work where fission works!

Perspectives: Simultaneous measurement of fission and gamma-decay probabilities

Challenge: subtraction of gammas emitted by fission fragments is required!

237Np(n,γ);(n,f) <-> 238U(3He,tf)



Conclusions

•Our results for (n,f) using (3He,4He), (3He,t) and (3He,d) surrogate reactions are in agreement with n-induced data above E_n>0.5

•238U(d,p) gives a (n,f) cross section that is systematically lower than the neutron-induced data. Theoretical calculations and further measurements are required to understand the results.

•(n,gamma) cross sections we obtained with the surrogate-reaction method are several times higher than the neutron-induced data.

•However, we can reasonably expect that the surrogate method gives goods results for capture in the region where it gives goods results for fission.

•Simultaneous measurement of fission and gamma-decay will give the answer!