Investigating the surrogate-reaction via the simultaneous measurement of gamma-emission and fission probabilities

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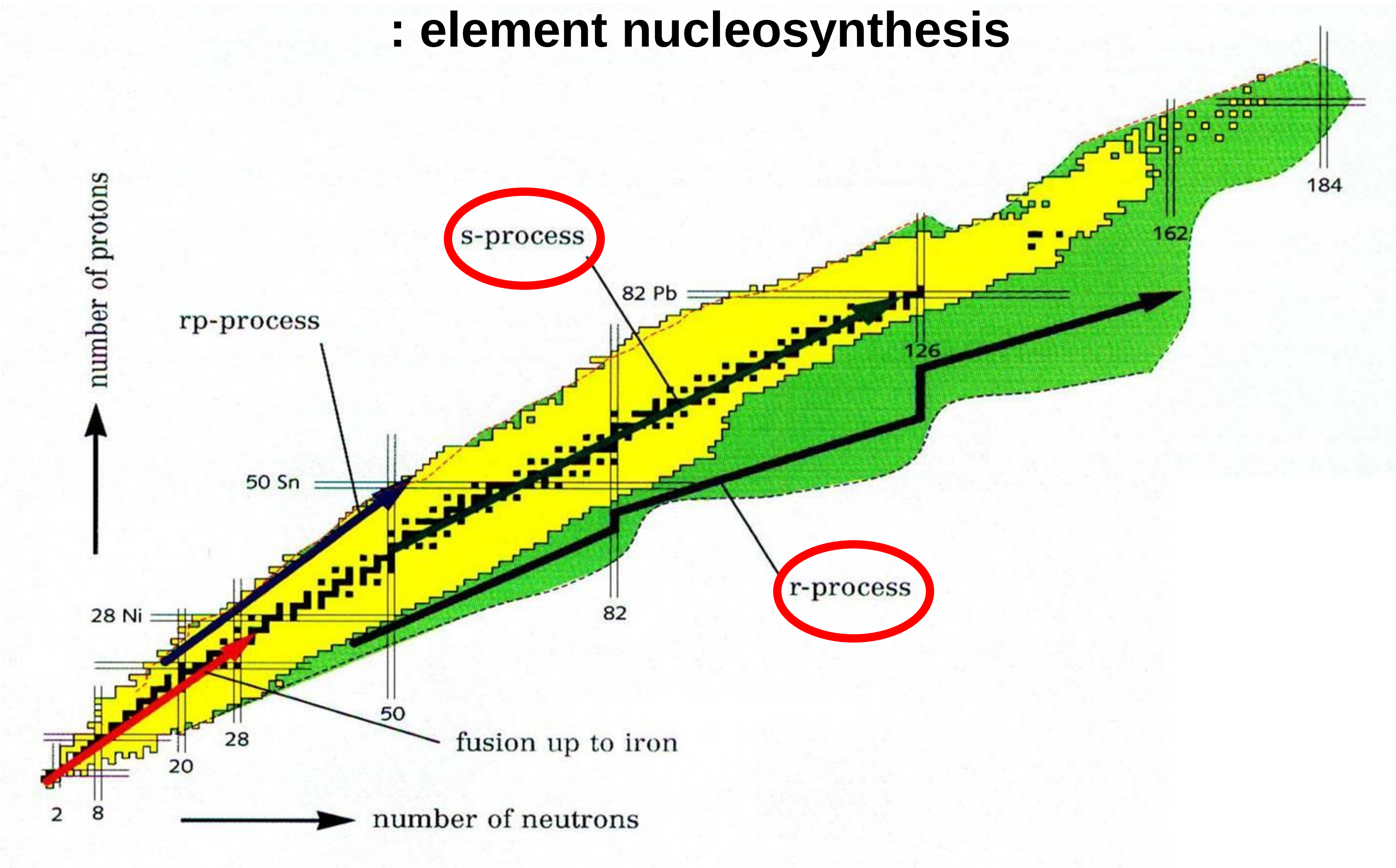
Need for neutron-induced cross sections of short-lived nuclei : element nucleosynthesis



Need for neutron-induced cross sections on short-lived nuclei : transmutation of nuclear waste

Minor actinides

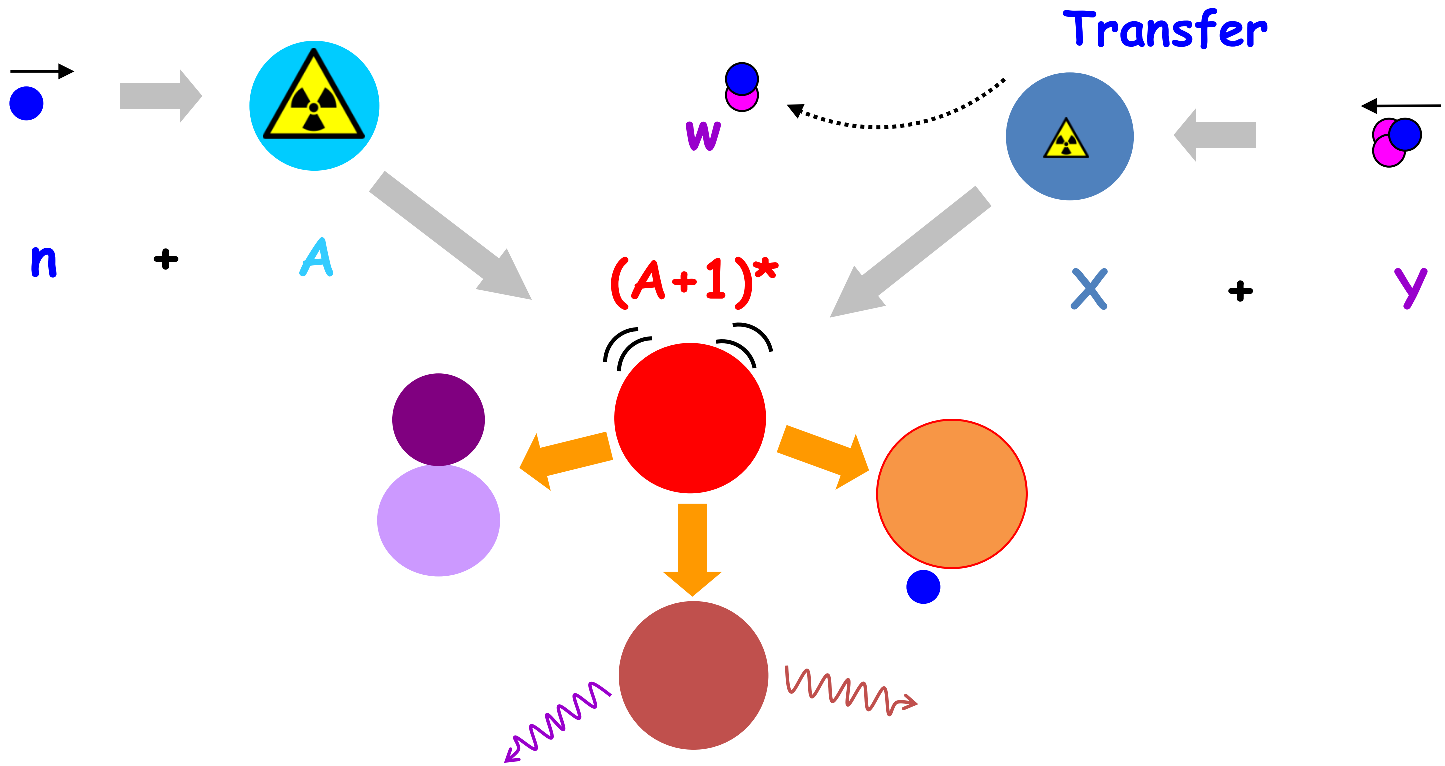
Neutron-induced fission and capture cross sections of short-lived nuclei needed. Very difficult or even impossible to measure!

Surrogate-reaction method

Cramer and Britt (Los Alamos 1970…!!)

Neutron-induced reaction

Surrogate reaction



$$\sigma_{n,decay}^{A}(E^*) = \sigma_{CN}^{A+1}(E^*) \cdot P_{decay}^{surro}(E^*)$$

Theory
Optical model

Experiment

Validity of the surrogate method

$$\sigma^{A}_{n,decay}(E^*) = \sigma^{A+1}_{CN}(E^*) \cdot P^{surro}_{decay}(E^*)$$

Neutron-induced and surrogate reaction must lead to the formation of a compound nucleus :
Decay only depends on *E, *J* and π !!**

$$P^{surro}_{decay}(E^*) = P^{n}_{decay}(E^*)$$

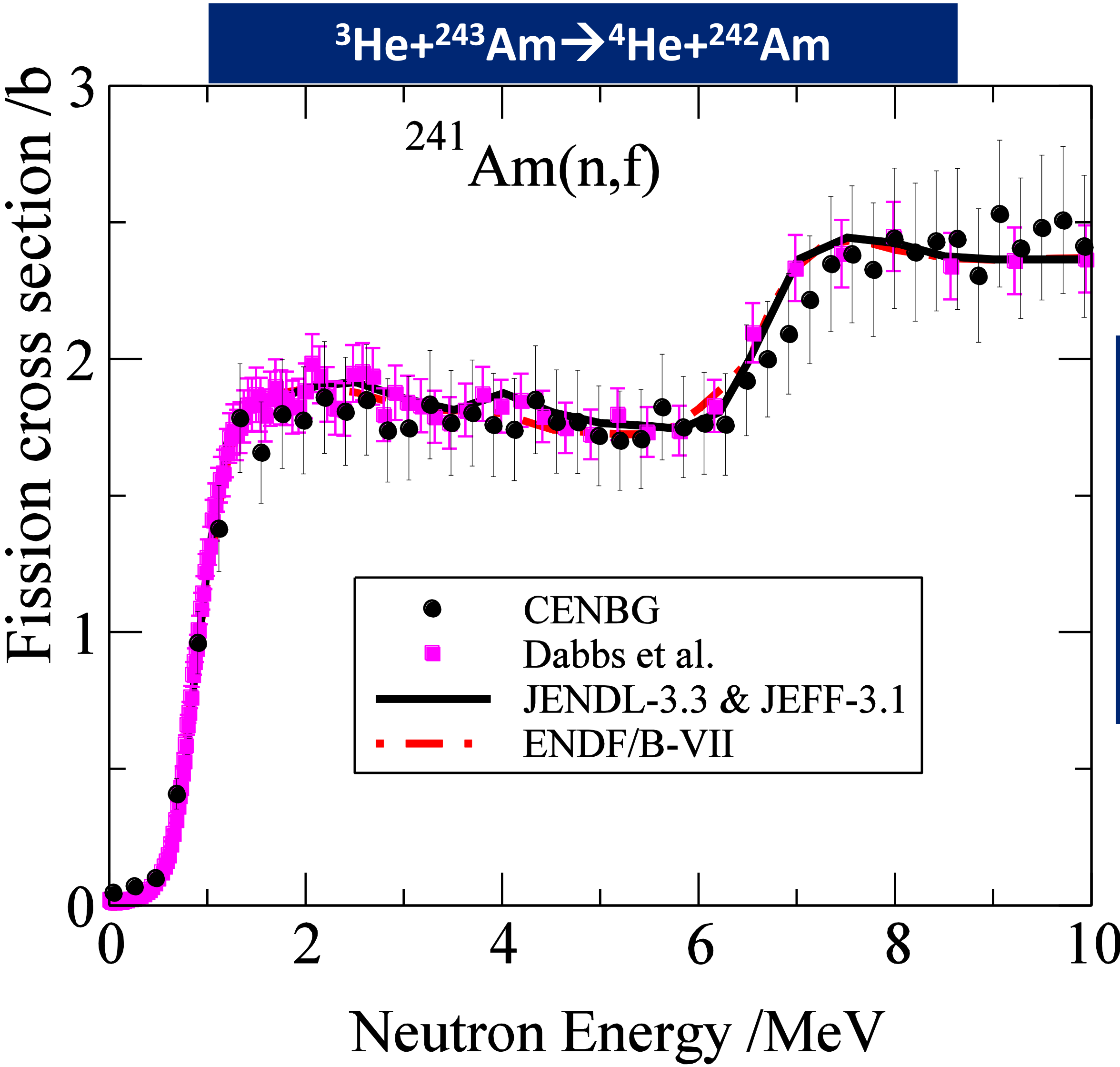
Populated *J* and π distributions are equal

OR

Decay independent of *J* and π
(Only valid at high E* in the Weisskopf-Ewing limit)

Not possible to say a priori if a reaction meets these conditions.
Data obtained with the surrogate method need to be compared to neutron-induced data!

Results for fission



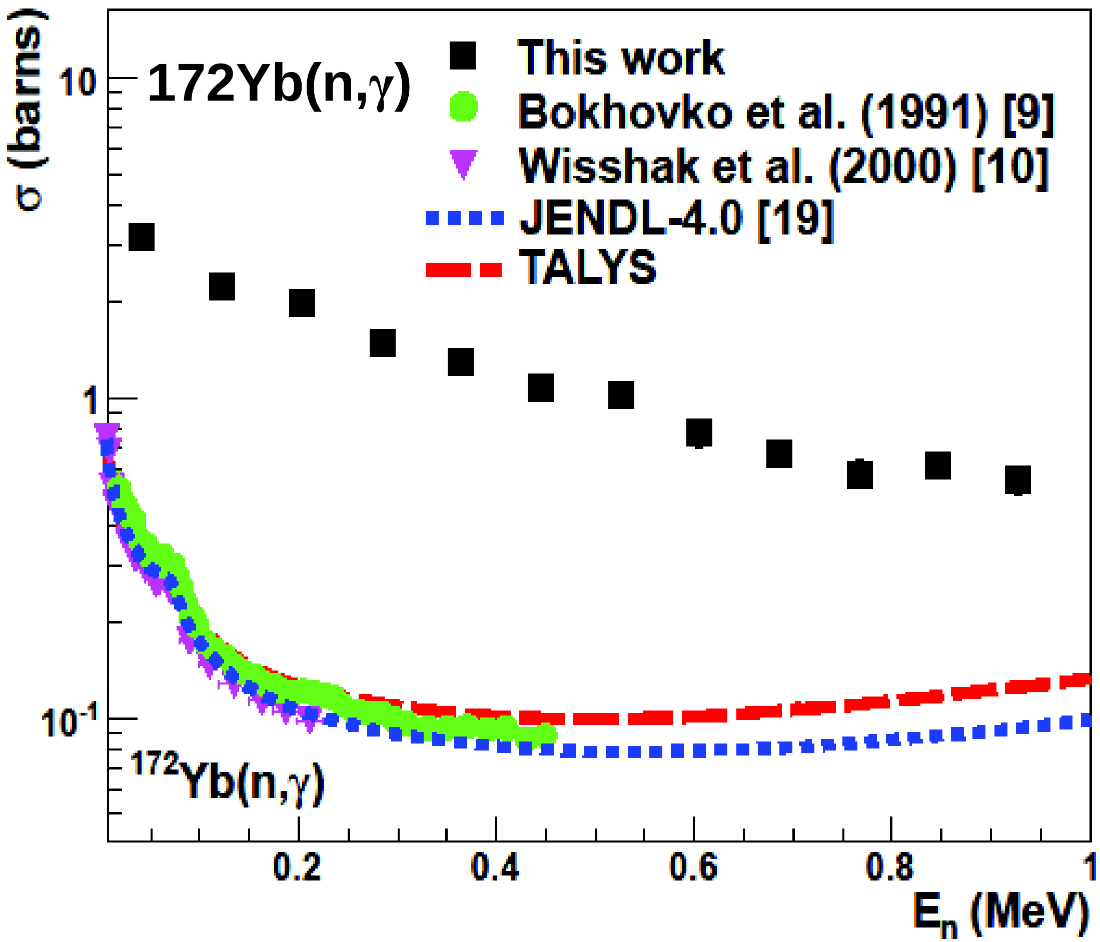
General finding: the cross sections obtained with surrogate method are in good agreement with n-induced data for fission!

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

G. Kessedjian et al., Phys. Rev. C 91 (2015) 044607

Results for radiative capture

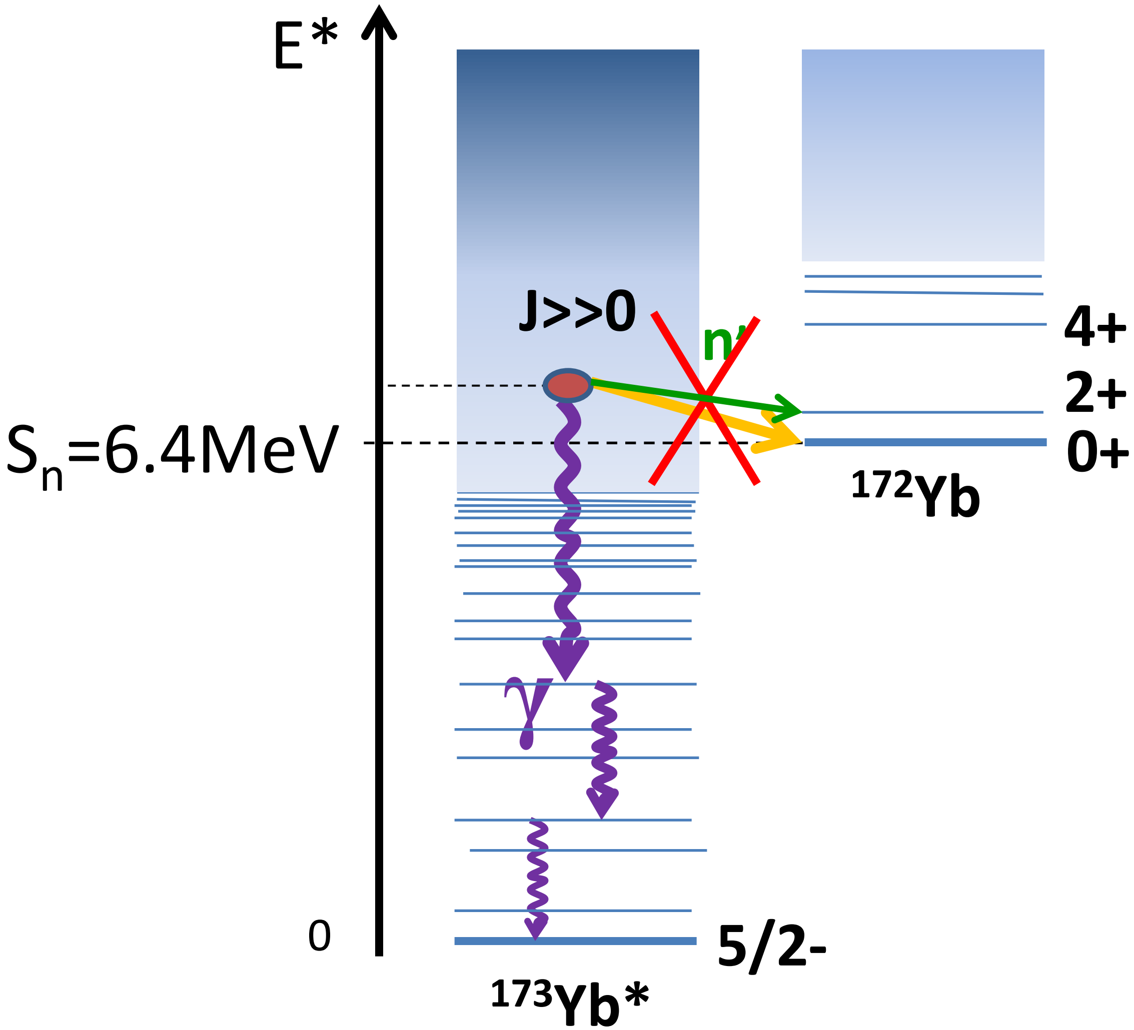
3He + 174Yb -> 4He + 173Yb



The cross sections obtained with surrogate method are in clear disagreement with n-induced data for capture!

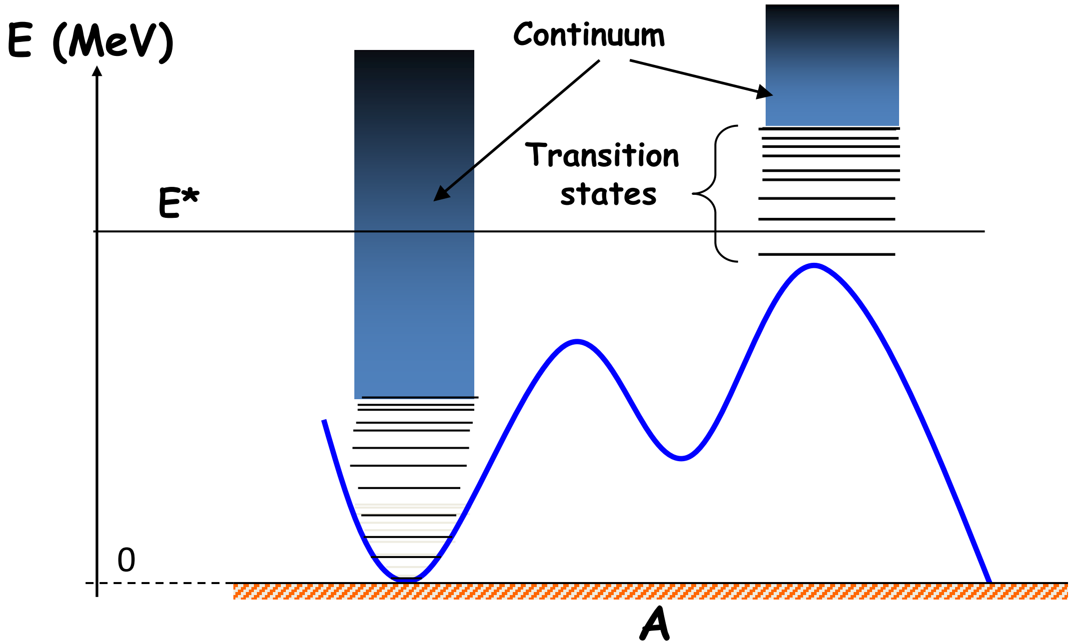
G. Boutoux et al., Phys. Lett. B 712 (2012) 319

Why do we obtain such discrepancies?



Strong sensitivity of neutron emission to Jπ

Fission seems to be much less sensitive to spin/parity differences, why?



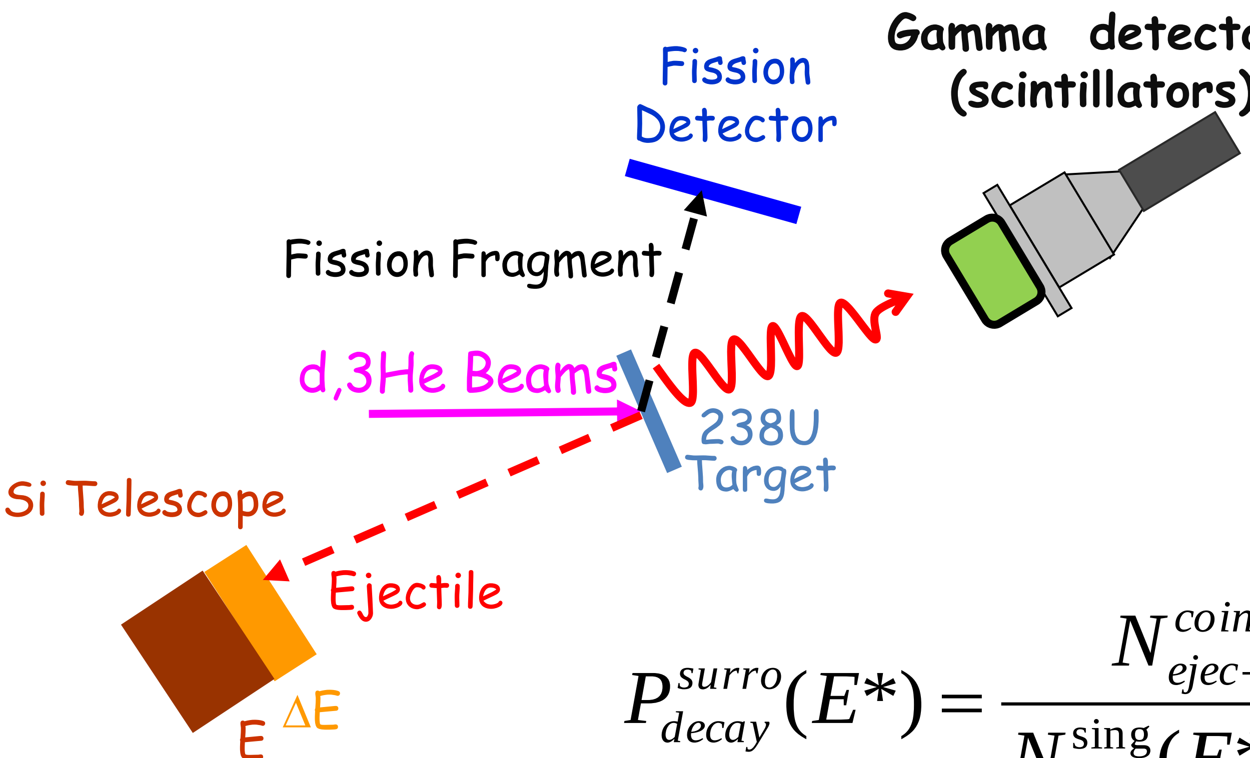
The top of the fission Barrier is also a region of low density of states!

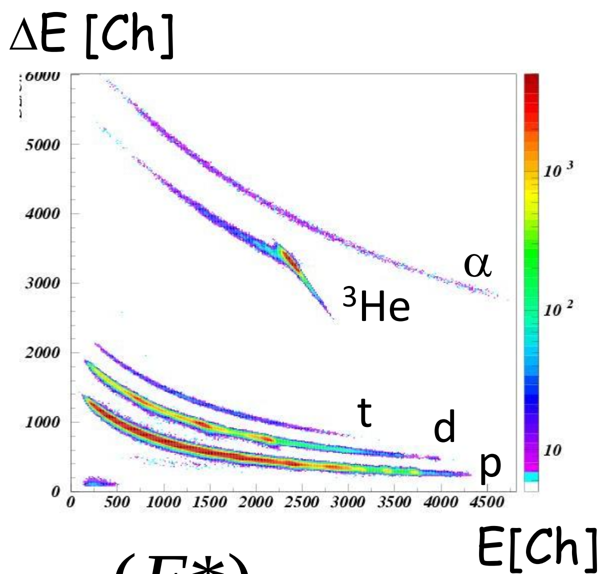
First step to understand:

Simultaneous measurement of fission and gamma-decay probabilities!

Never done before!

Setup for simultaneous measurement of fission and gamma-decay probabilities



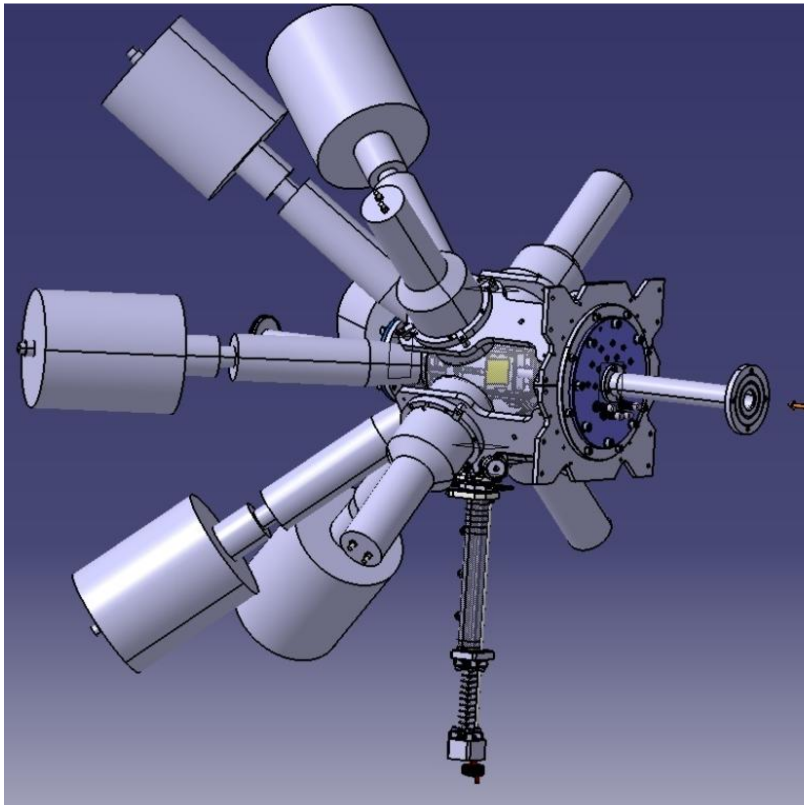


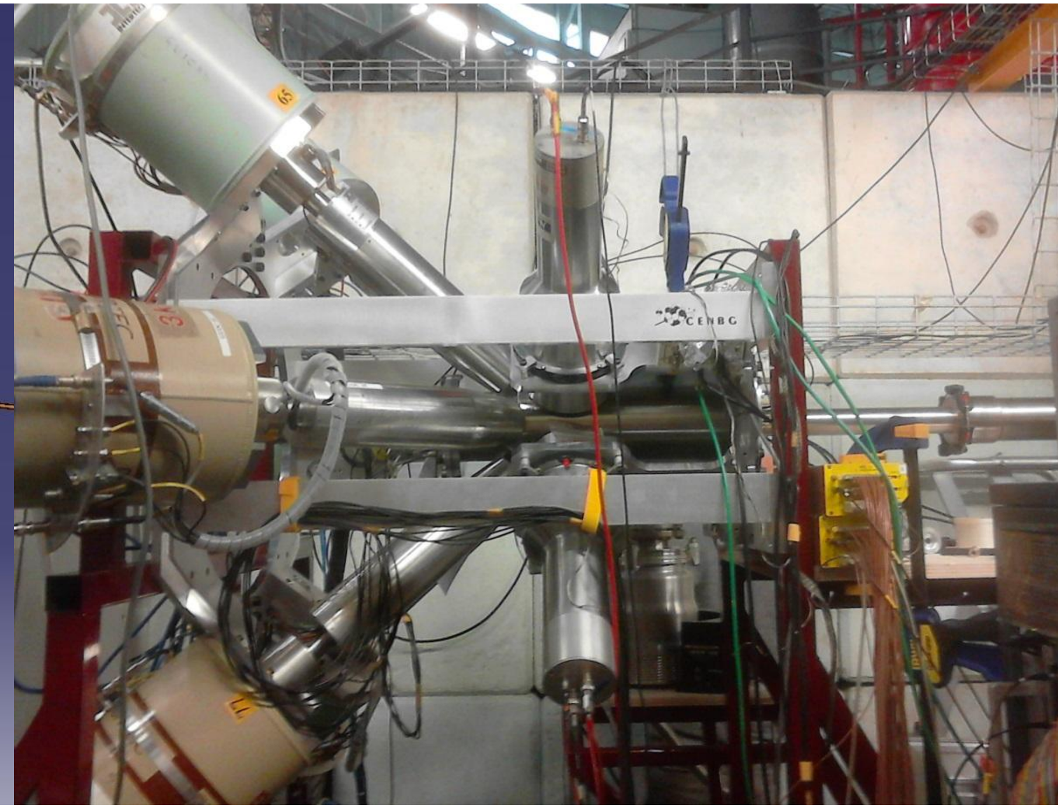
$$P_{decay}^{surro}(E^*) = \frac{N_{ejec-decay}^{coin}(E^*)}{N_{ejec}^{sing}(E^*) \cdot \varepsilon_{decay}(E^*)}$$

Challenge: removal of gamma rays emitted by the fission fragments !

$$N_{ejec-\gamma}^{coin}(E^*) = N_{ejec-\gamma}^{coin,tot}(E^*) - \frac{N_{ejec-f-\gamma}^{coin}(E^*)}{\varepsilon_f(E^*)}$$

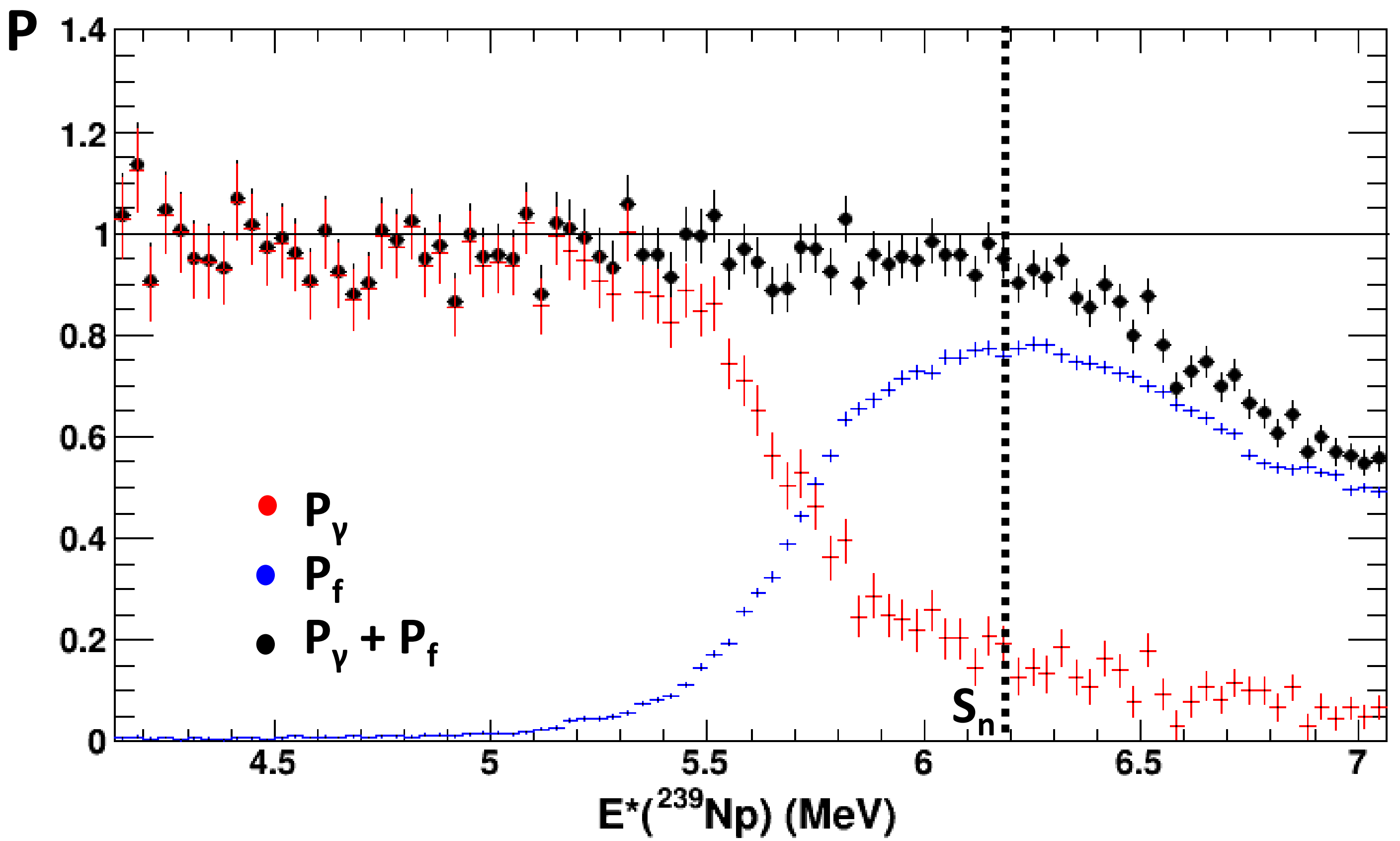
Setup used for experiment at the Orsay tandem





Preliminary results!

3He + 238U-> d + 239Np ↔ n + 238Np (2,1d)

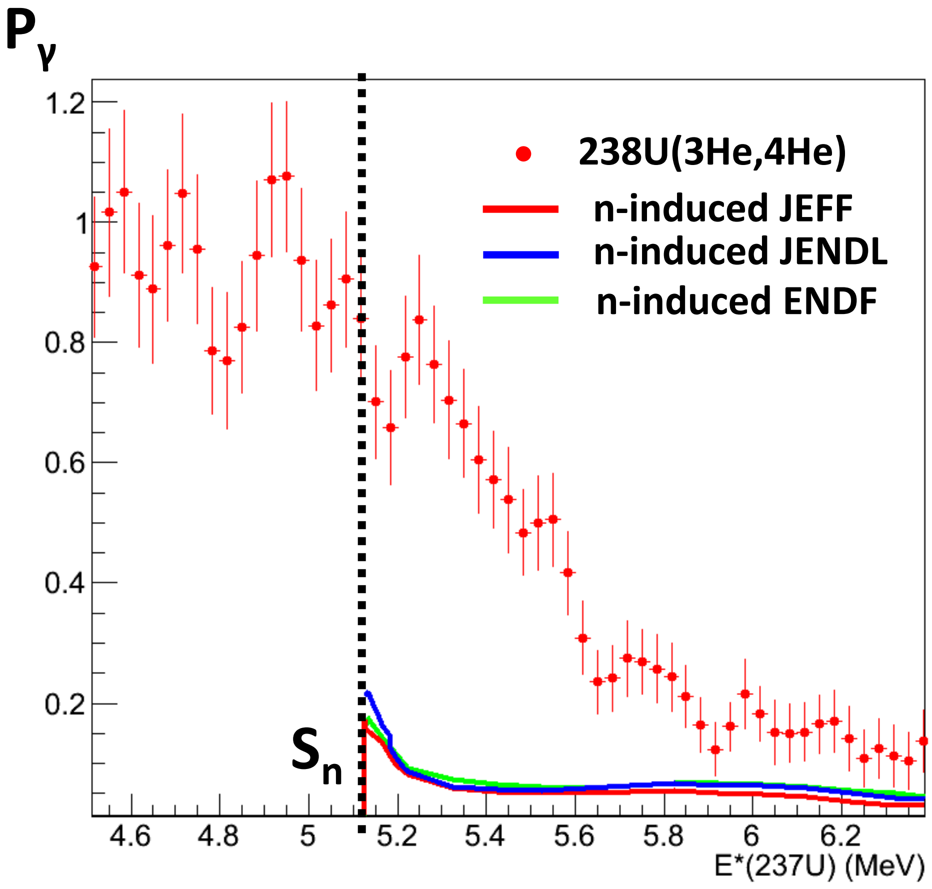


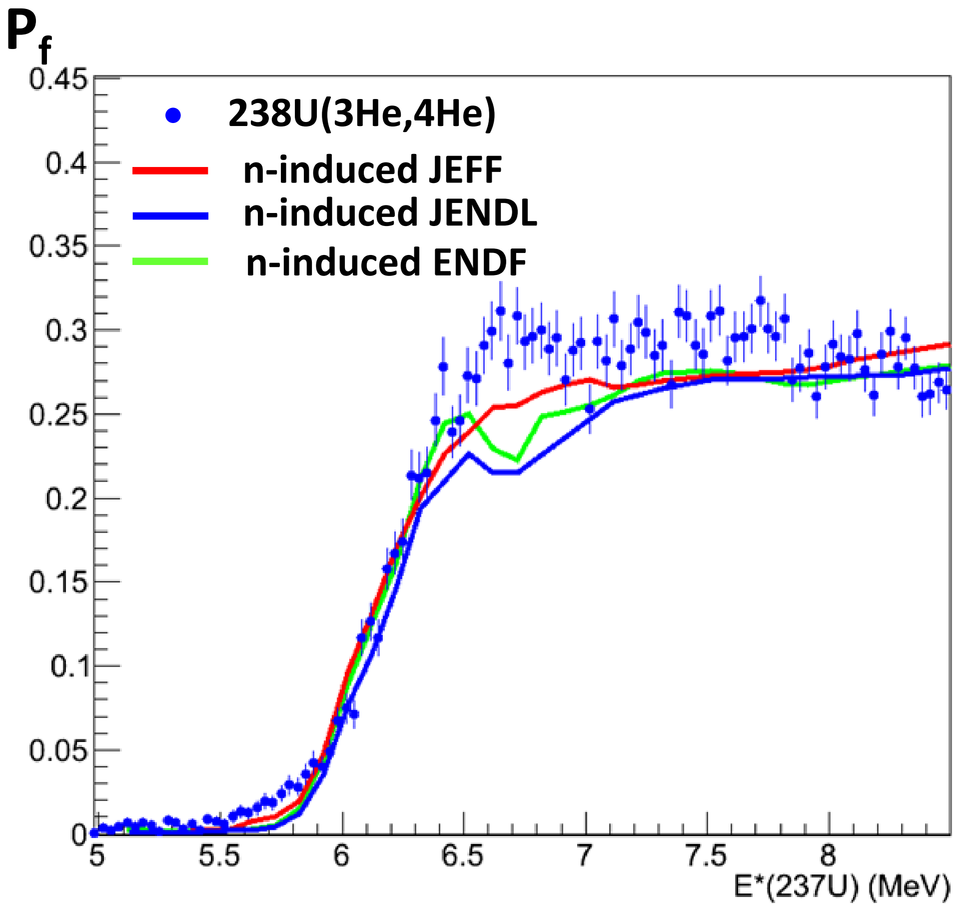
$P_f + P_\gamma = 1$ at $E^* < S_n$:
Validation of analysis procedure!

P. Marini et al., to be published

Preliminary results!

3He + 238U-> 4He + 237U ↔ n + 236U



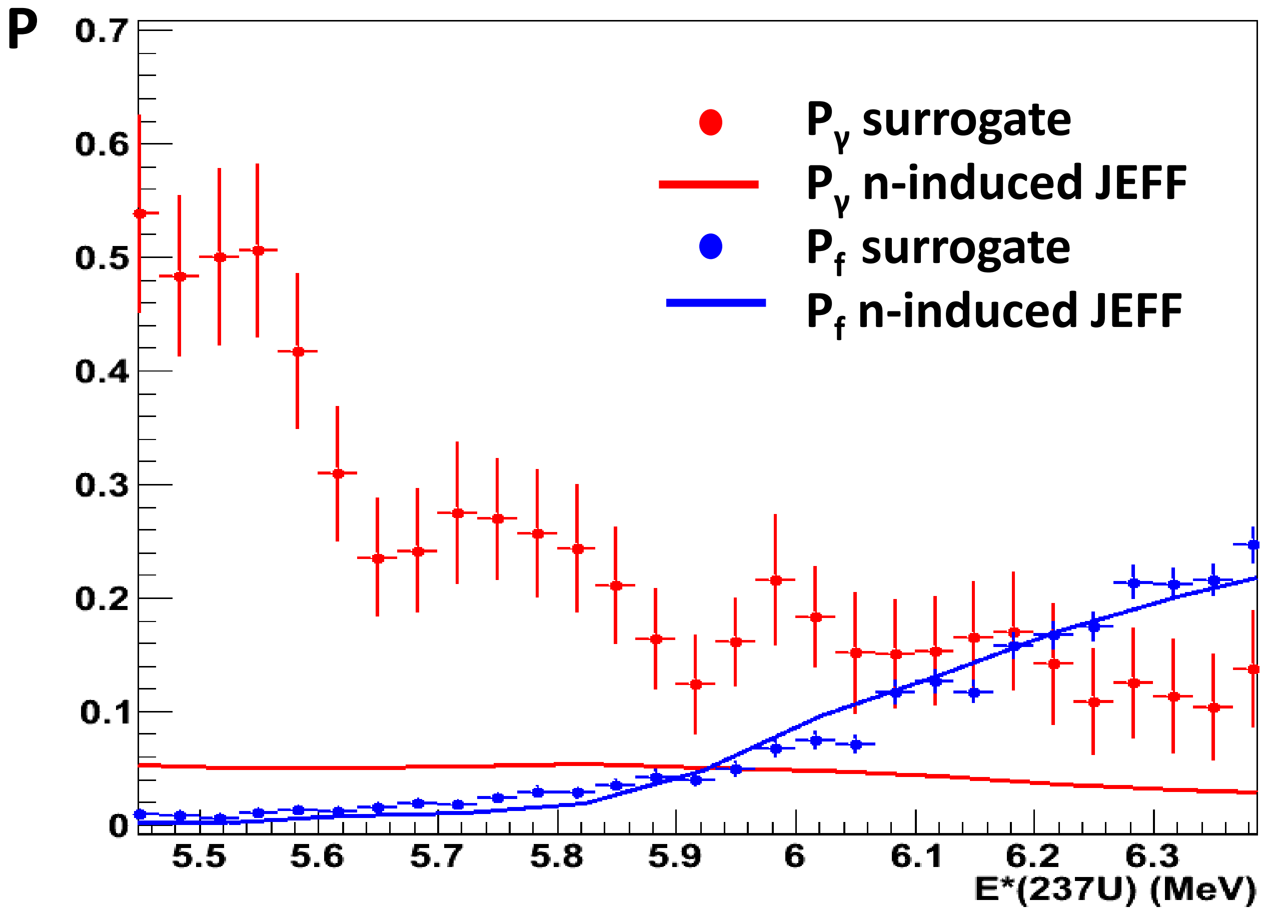


P. Marini et al., to be published

Focus on the overlap region

Preliminary results!

3He + 238U-> 4He + 237U ↔ n + 236U

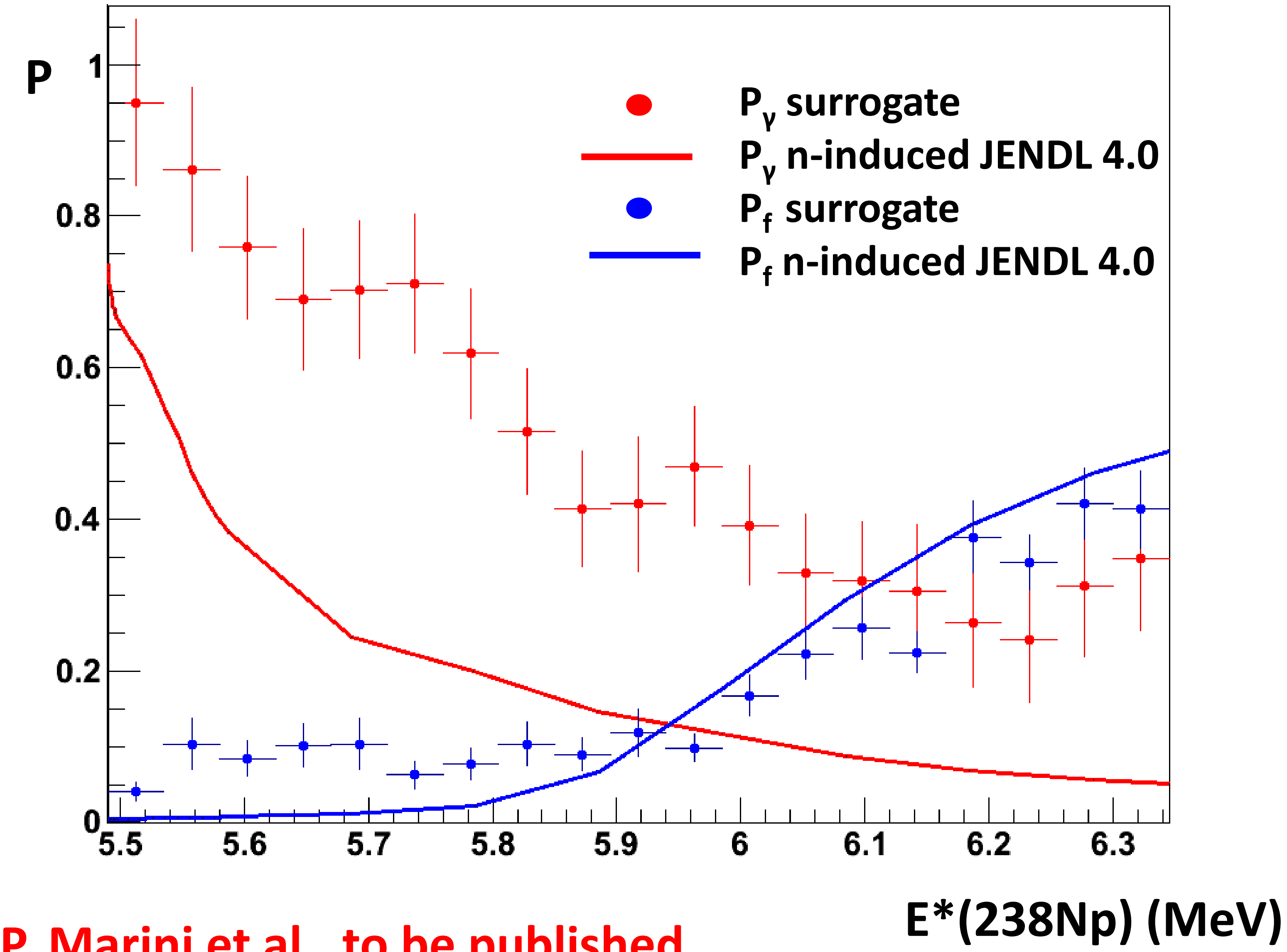


The fission probability is much less sensitive to the entrance channel than the gamma-decay probability!

P. Marini et al., to be published

Preliminary results!

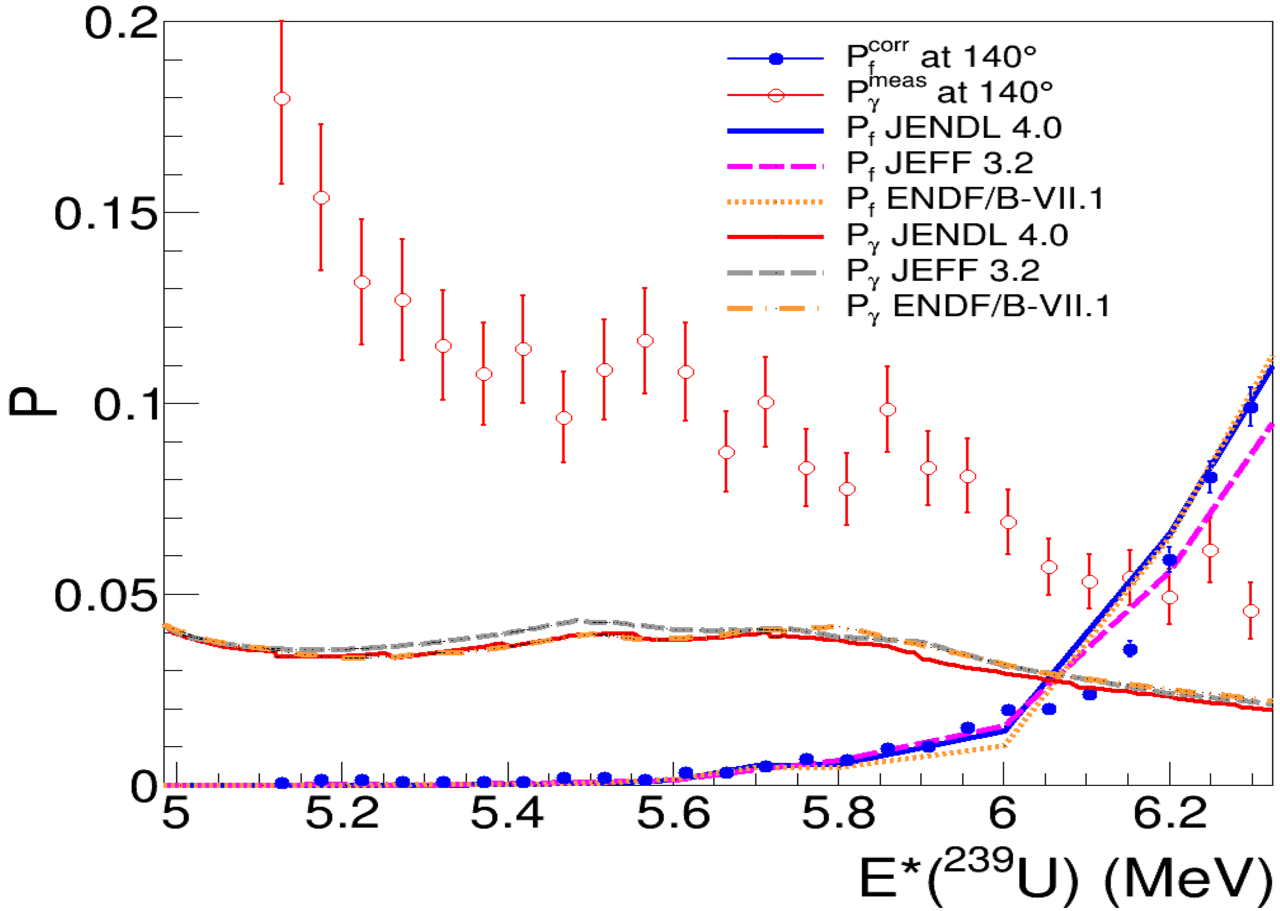
3He + 238U-> t + 238Np ↔ n + 237Np



P. Marini et al., to be published

d + 238U-> p + 239U ↔ n + 238U

→Closest reaction to a neutron-induced reaction in inverse kinematics
→Problem: deuteron breakup, corrected with method based on DWBA by J. Lei and A. Moro Phys. Rev. C 92(2015) 044616
(Other approaches to breakup in talks by B. Carlson, M. Avrigeanu)

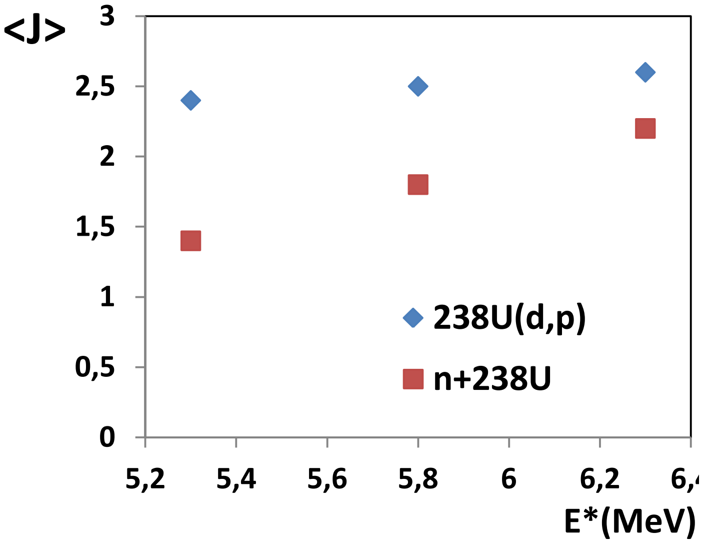


Q. Ducasse et al., Phys. Rev. C 94 (2016) 024614

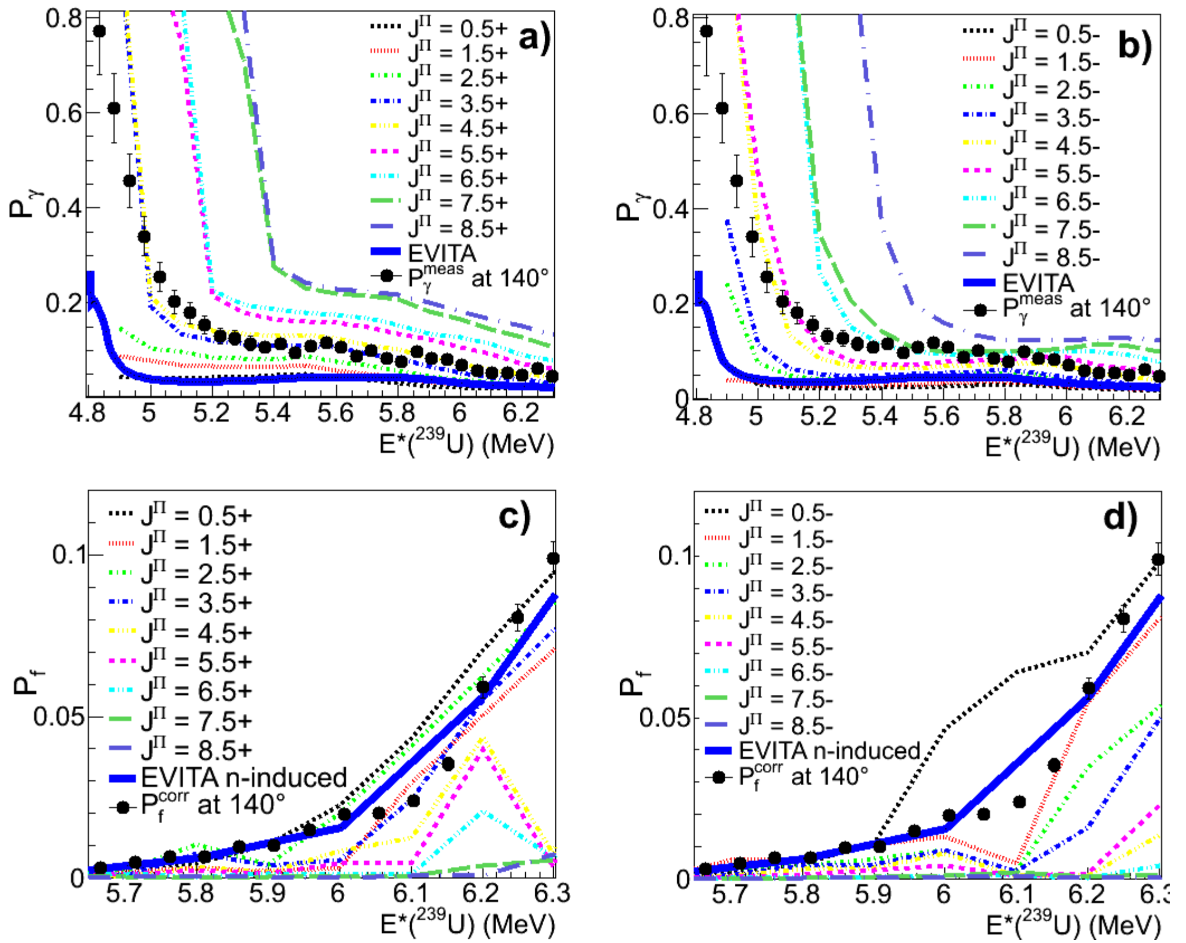
Can we explain these results within the framework of the statistical model?

238U(d,p)

Calculated average spin of 239U



Monte-carlo Hauser Feshbach code EVITA
(Based on TALYS and run by CEA evaluator B. Morillon)

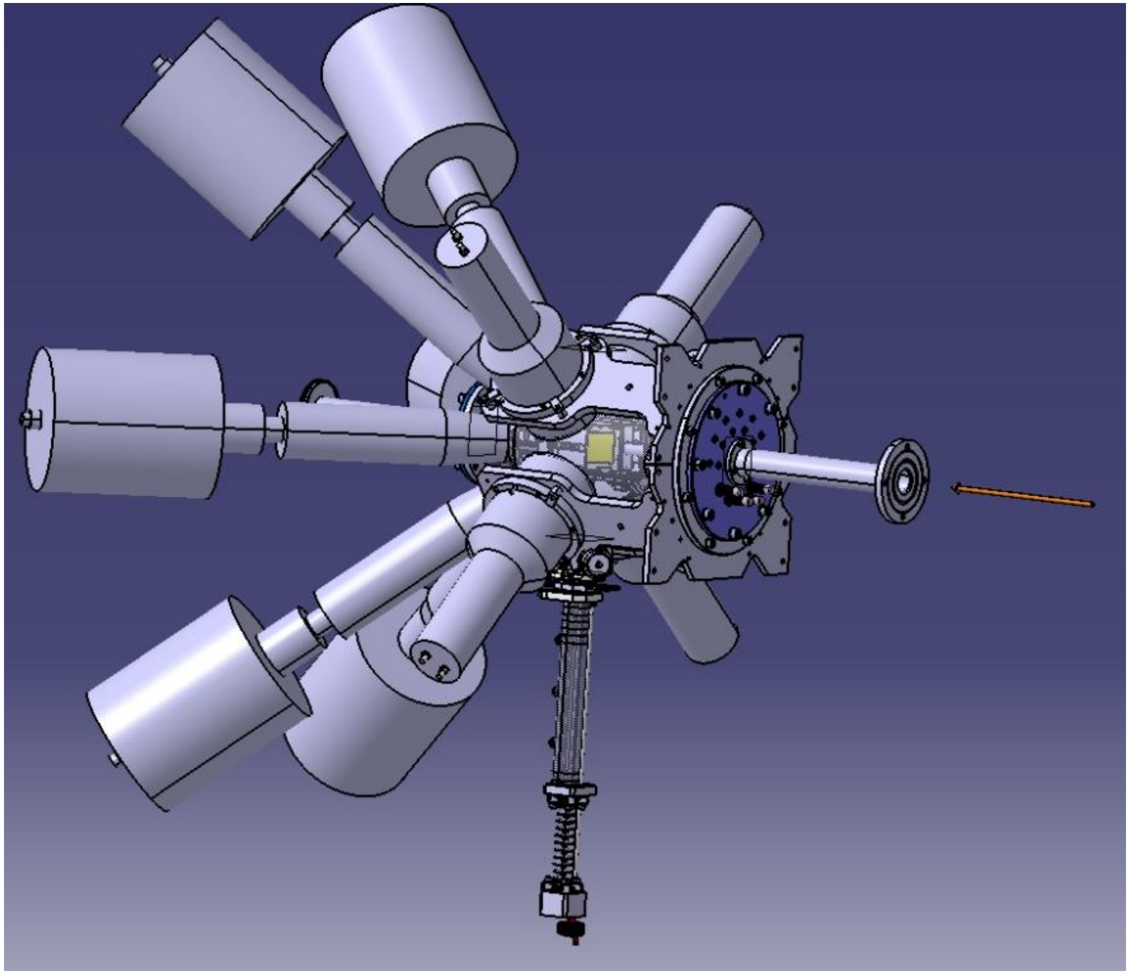


Perspectives: Determine full spin &parity distribution and couple it to the HF results to see if we can reproduce our data

Q. Ducasse et al., Phys. Rev. C 94 (2016) 024614

Perspectives

3He + 240Pu-> 3He’ + 240Pu ⟷ n + 239Pu



240Pu: Even-even fissioning nucleus expected to be more sensitive to spin/parity differences!

Good-quality n-induced data available!

Perspectives

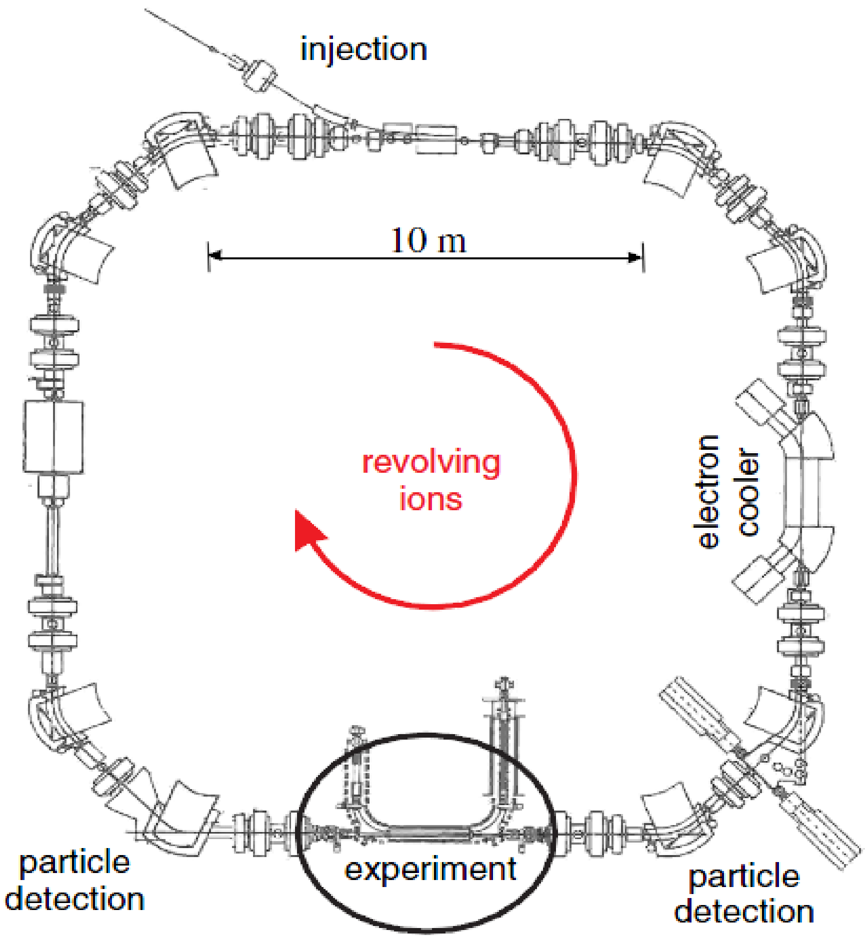
Measurements in direct kinematics are limited by the availability and the quality of the targets!

↓

Experiments in inverse kinematics with RIBs!

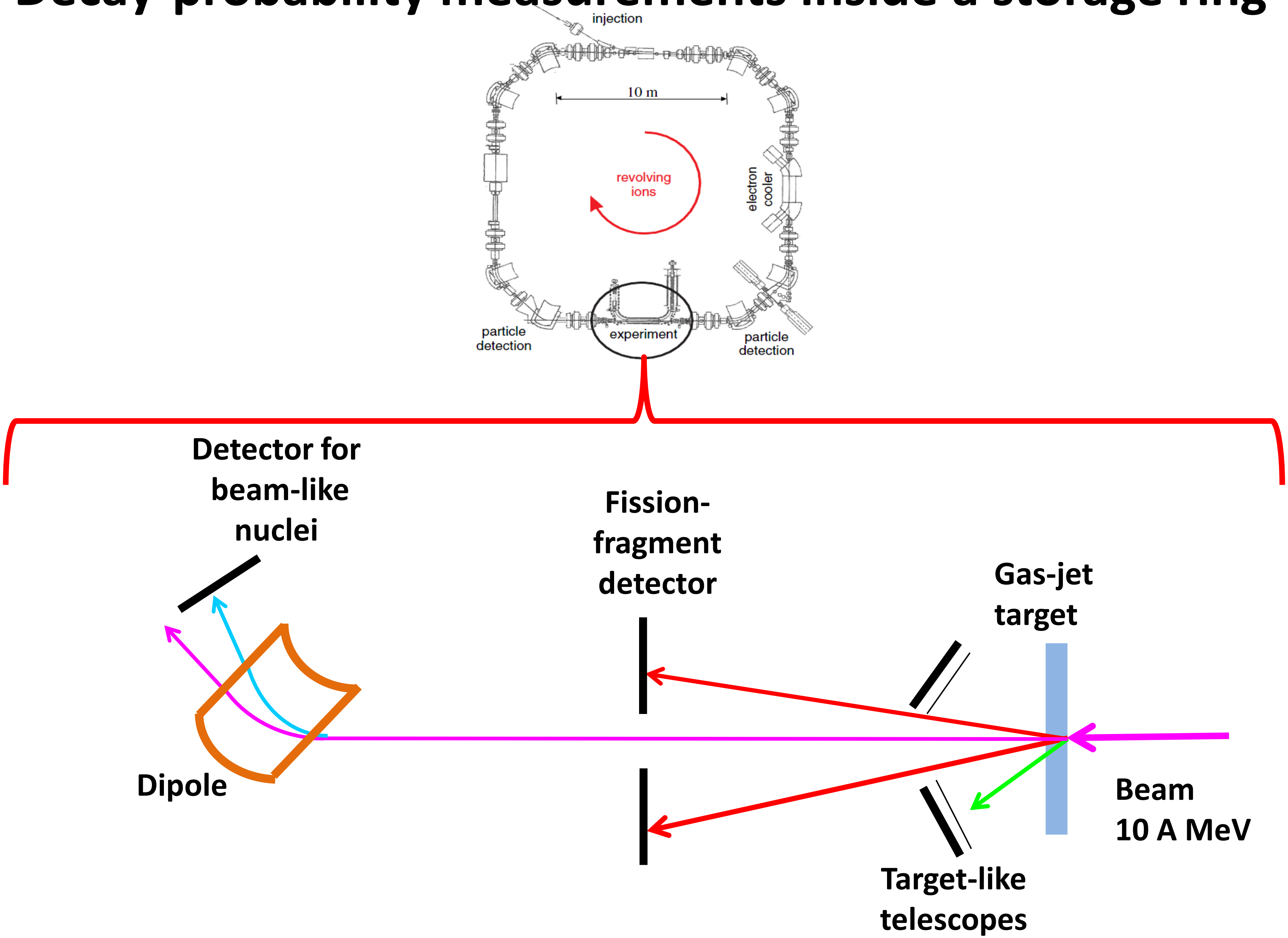
But, RIBs have low quality: large dispersion in energy (few MeV) and size (few mm)

Decay-probability measurements inside a storage ring



•Excellent beam –energy definition, beam-energy resolution of few hundreds keV at 10 A MeV, beam size 1 mm!!
•In-ring measurements with gas-jet targets (H2, D2, 3He, 4He). Effective target thickness increased by ~10^6 due to revolution frequency
•Pure beams, pure targets (no contaminants, no backing)!
•Pure isomeric beams!
•Measurements possible at the ESR at GSI in the near future

Decay-probability measurements inside a storage ring



Conclusions…

- **First simultaneous measurement of gamma-decay and fission probabilities for surrogate reactions**

- **The fission probability is much less sensitive to the populated angular momentum than the gamma-decay probability**

- **No obvious explanation yet, our data are useful to establish to which extent the surrogate method can be used to infer fission cross sections in regions where no data are available.**

- **Very promising perspectives open up for decay probability measurements in inverse kinematics with RIBs at storage rings**

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