Indirect measurements of neutron-induced reaction cross-sections at storage rings

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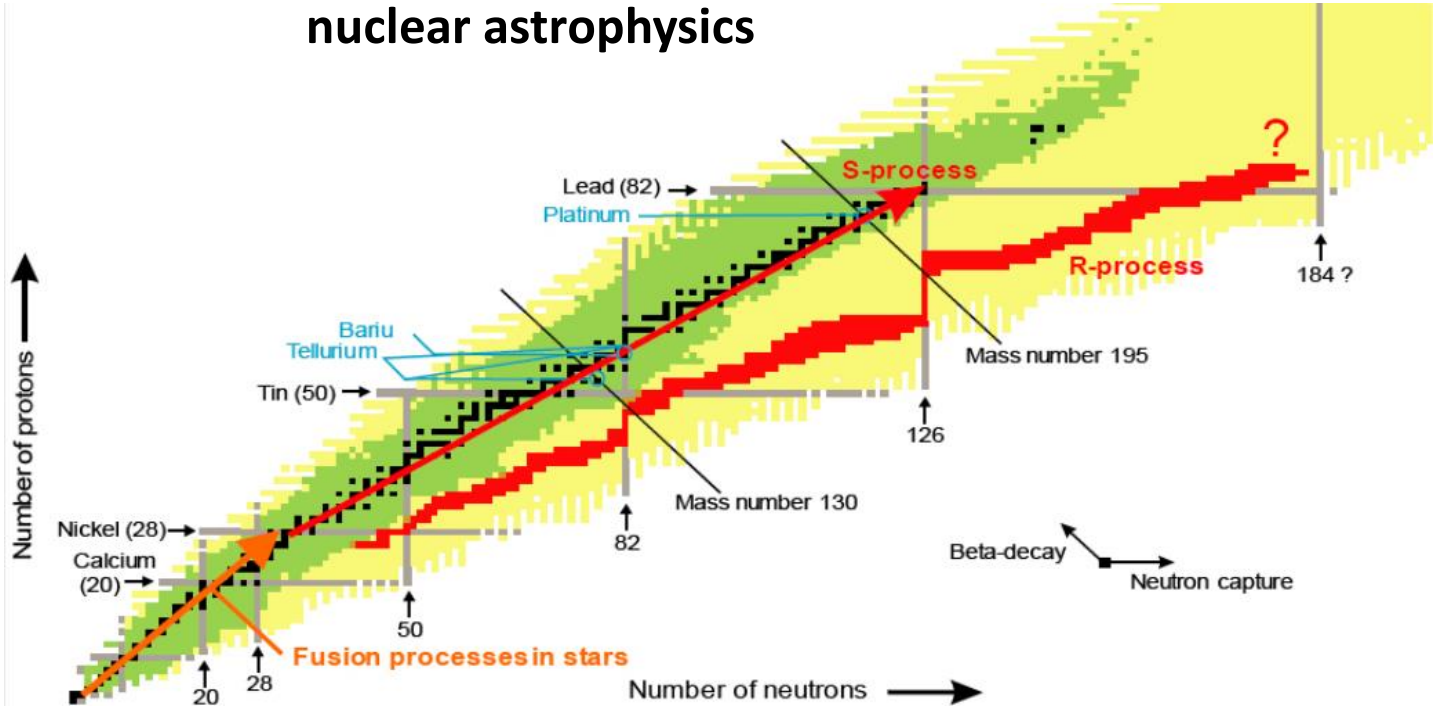
Need for neutron-induced reaction cross sections of short-lived nuclei

Understanding the origin of heavy elements in nuclear astrophysics



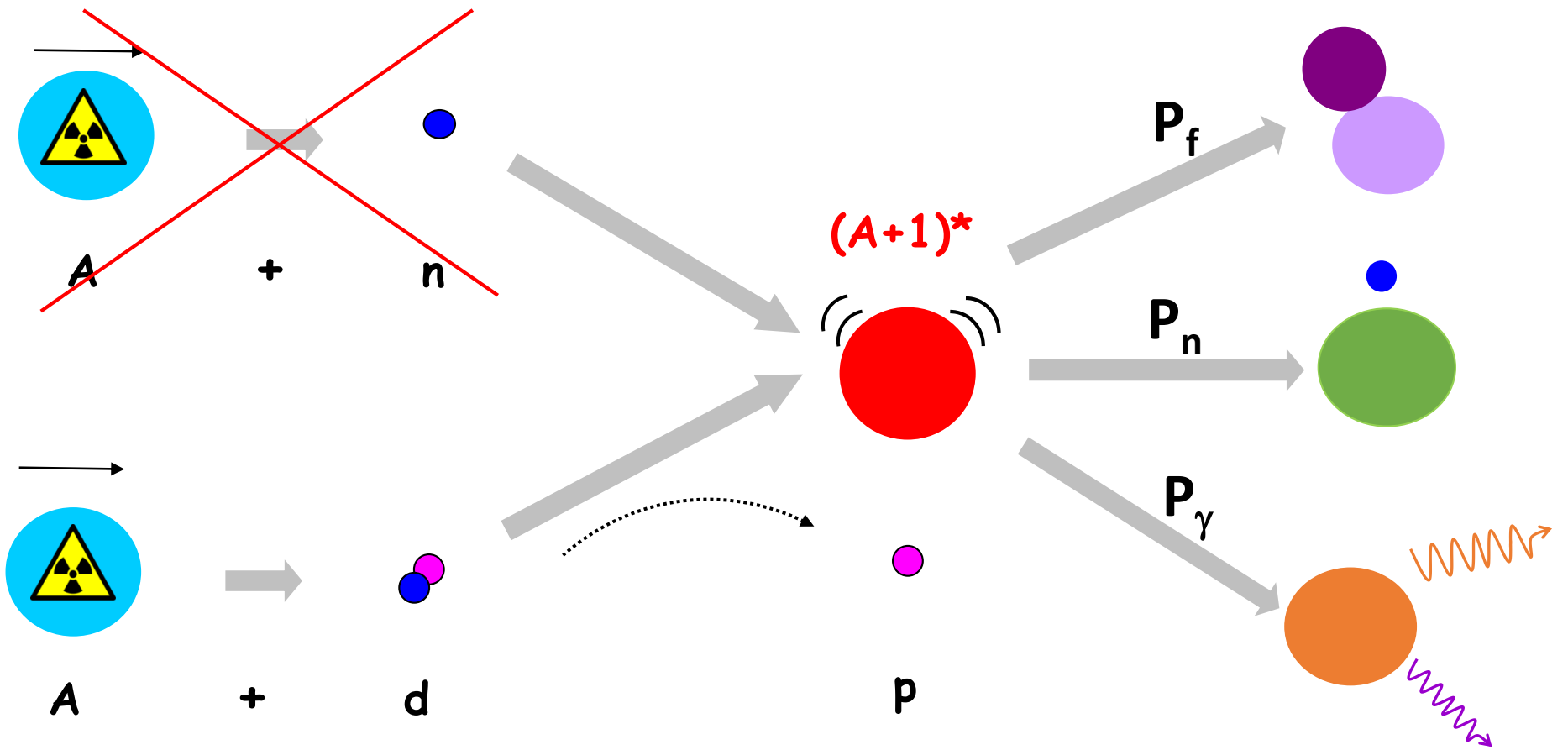
Also important for applications:

Production of energy and radio isotopes for medecine

→Very difficult or even impossible to measure with standard techniques because of the radioactivity of the targets.

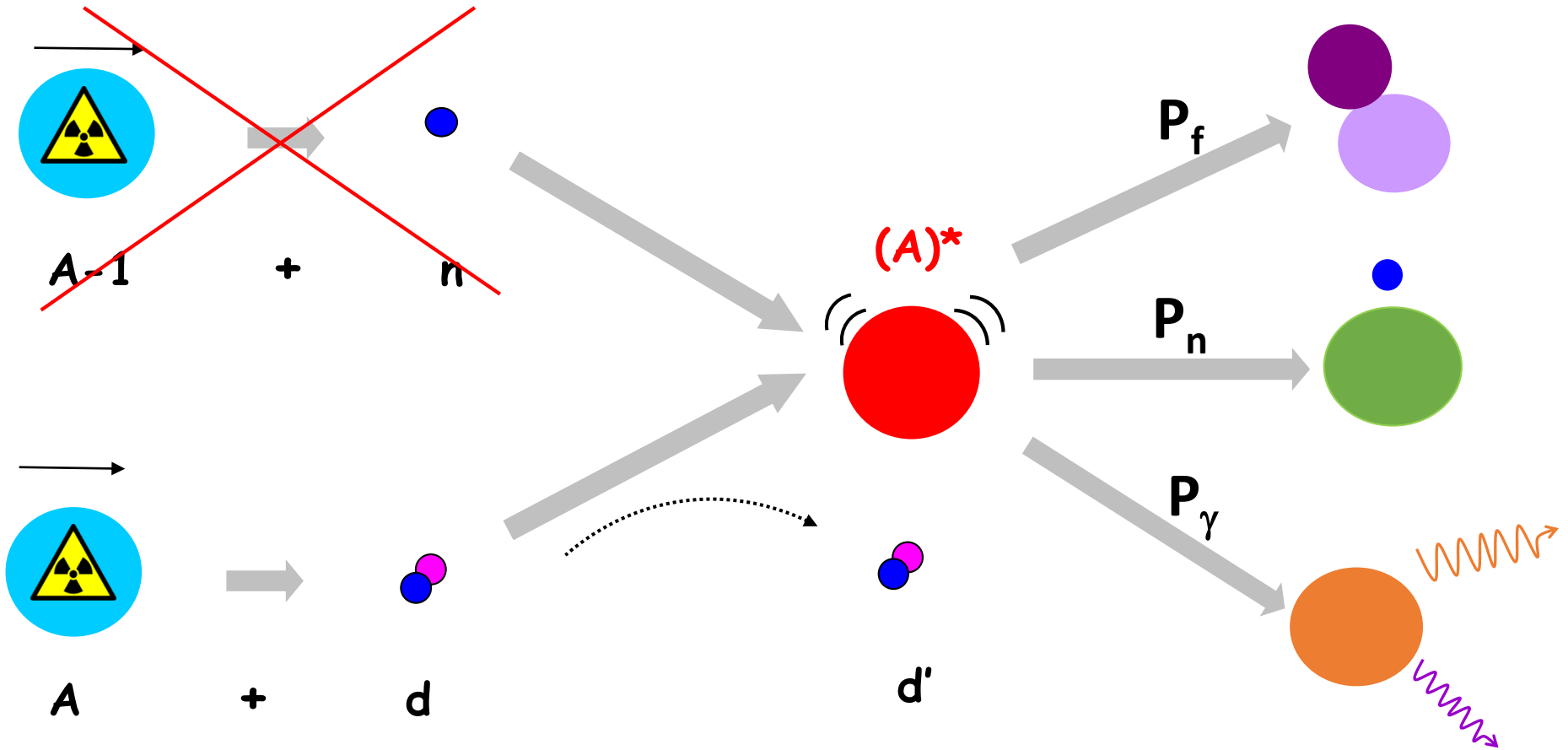
→Complicated to calculate due to the difficulty to describe the de-excitation process. Calculations can be wrong by several orders of magnitude!

Surrogate-reaction method in inverse kinematics



Decay probabilities as a function of excitation energy are precious observables to constrain models and provide much more accurate predictions for neutron-induced cross-sections of nuclei far from stability.

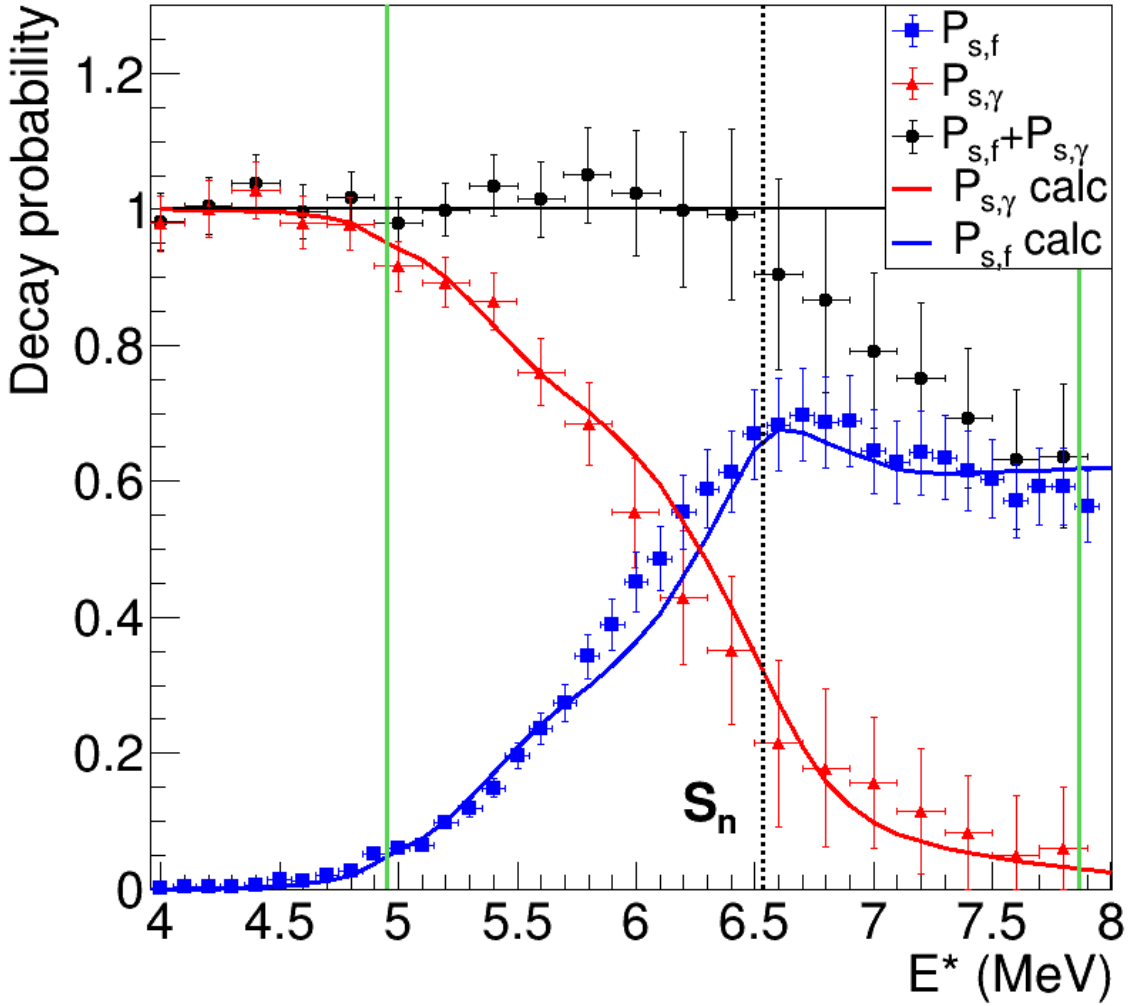
Inelastic scattering as surrogate reaction



and also (p,p') or (4He,4He')…

Benchmark:

4He+240Pu→4He'+240Pu*⇔n+239Pu→240Pu*



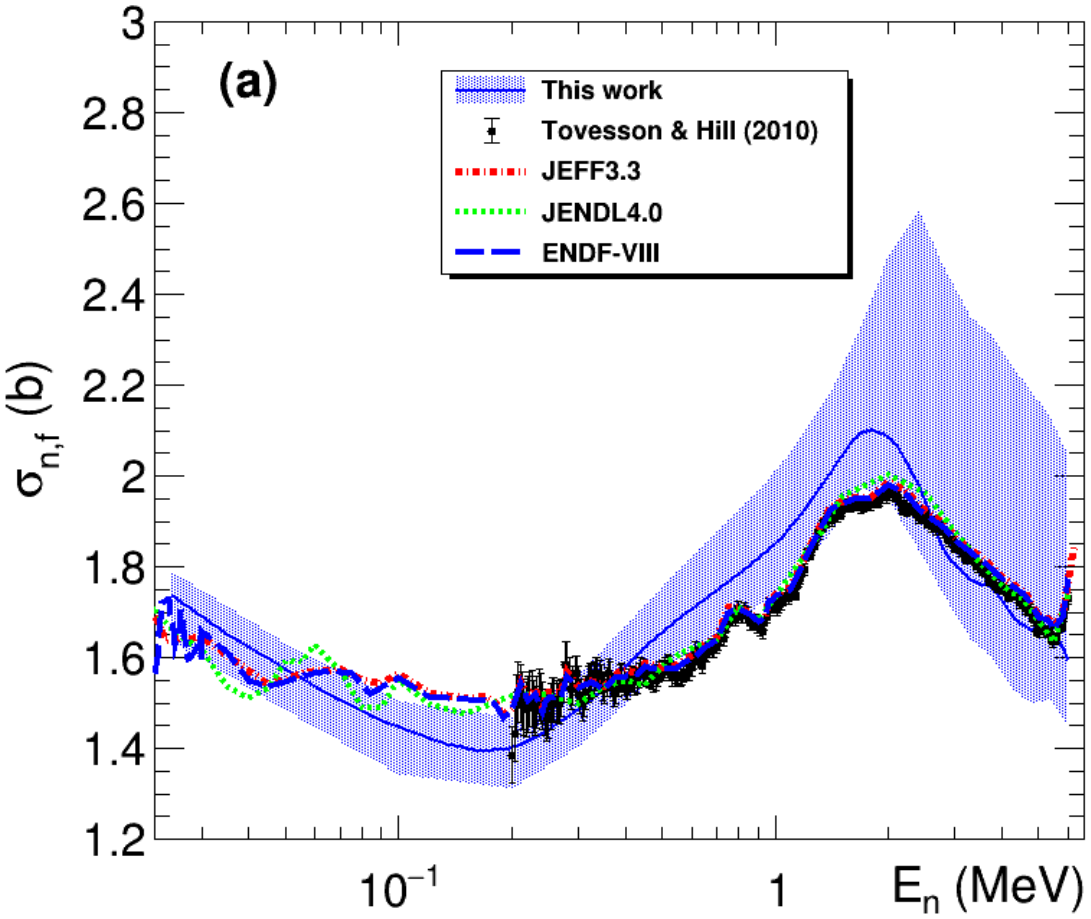
First simultaneous measurement of P_f and P_γ!

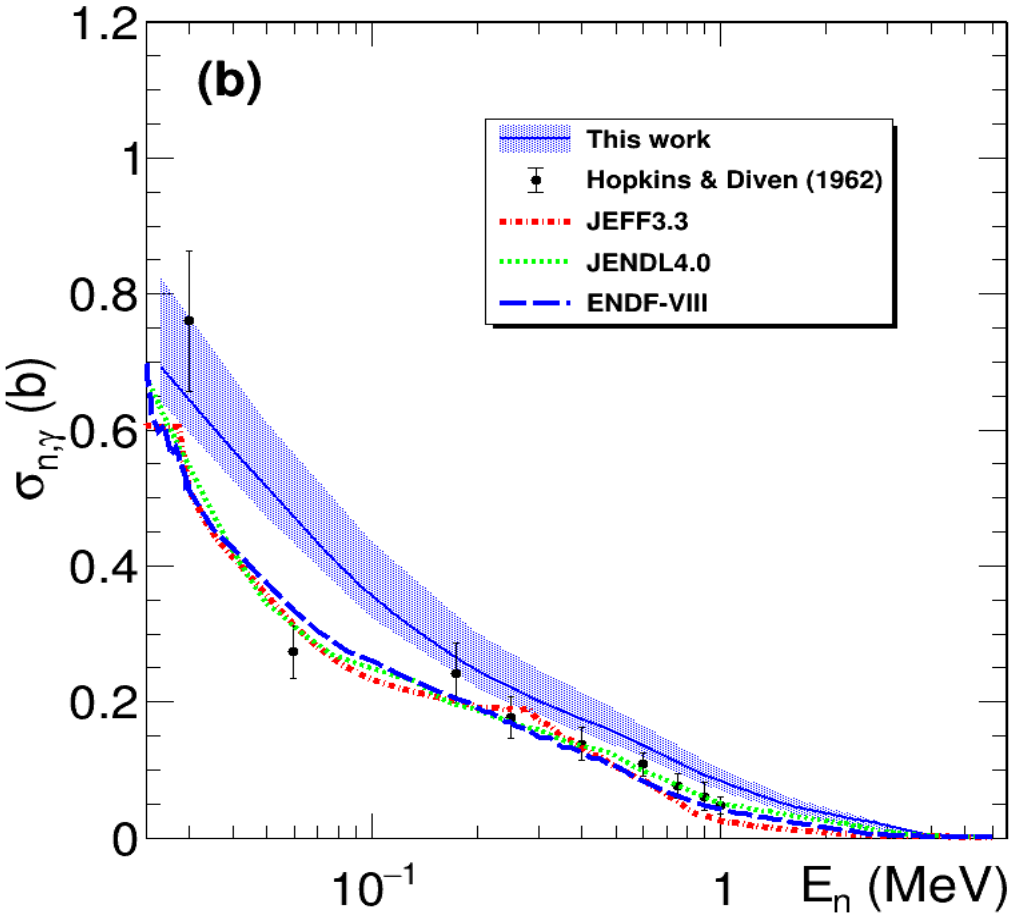
Stringent test of experimental method!

Accurate determination of model parameters!

R. Perez Sanchez, BJ et al., Phys. Rev .Lett. 125 (2020) *122502*

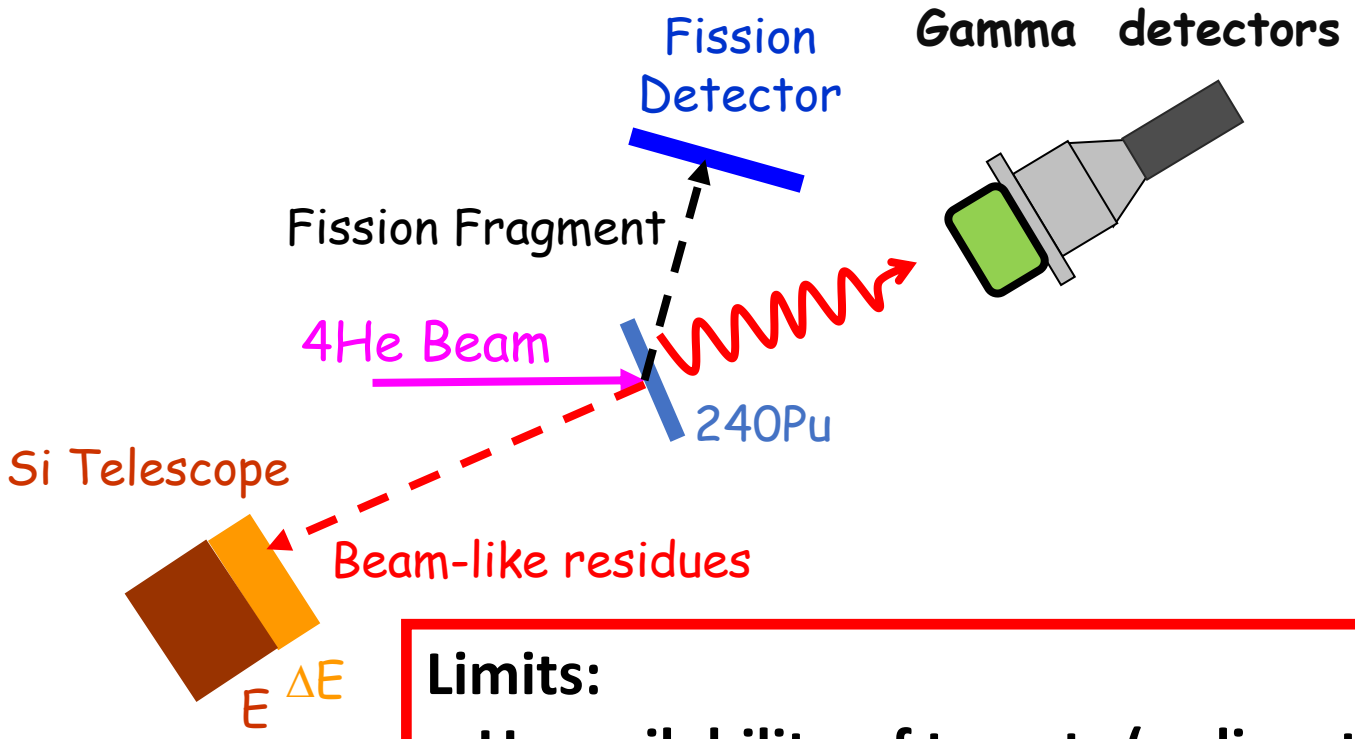
First simultaneous determination of neutron-induced fission and capture cross sections n+239Pu→240Pu*





R. Perez Sanchez, BJ et al., Phys. Rev .Lett. 125 (2020) 122502

Setup for the measurement of fission and gamma-emission probabilities in direct kinematics



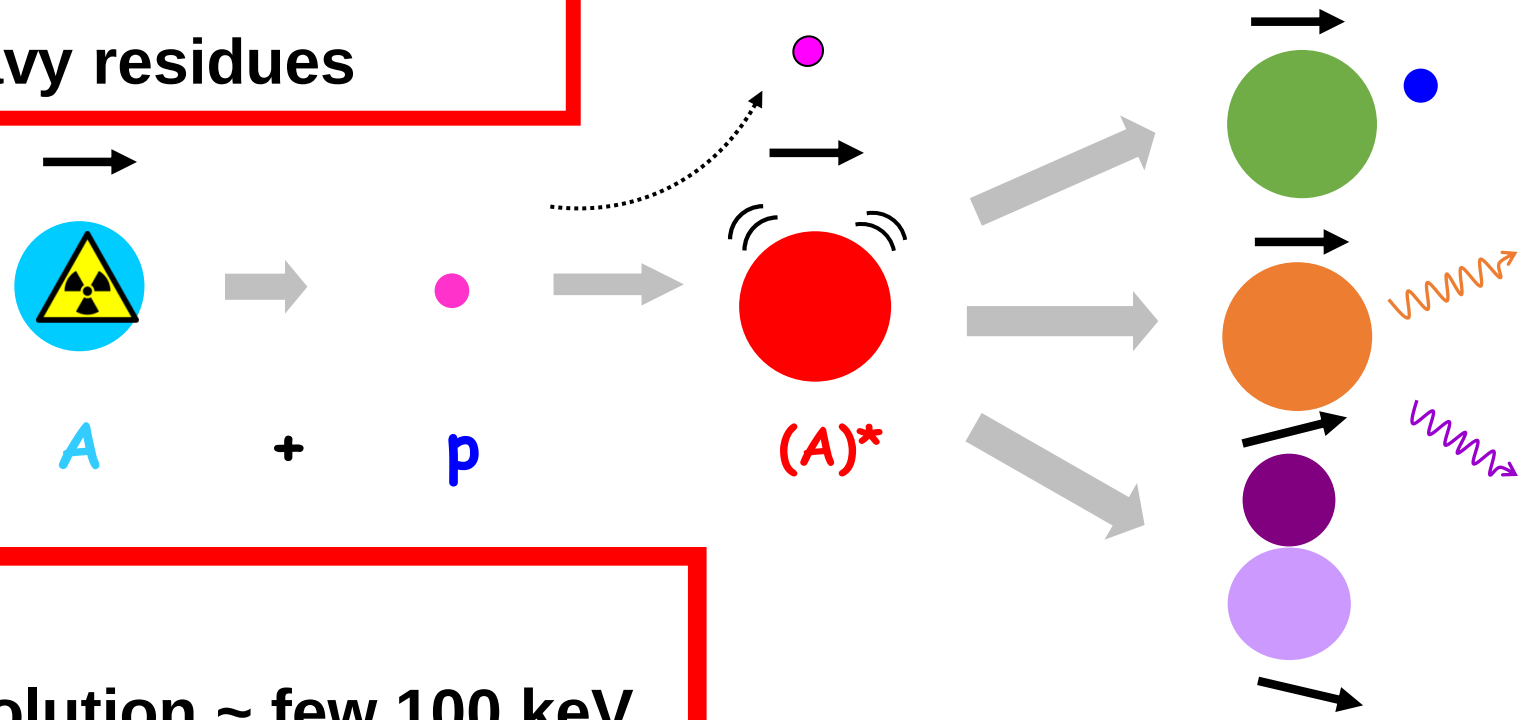
Limits:

- **Unavailability of targets (radioactive samples)**
- **Target contaminants and target support**
- **P_γ : discrimination of γ's from fission fragments, very low detection efficiency**
- **P_n: measurement of low-energy neutrons and neutron efficiency**

Advantages of Inverse kinematics:

-Access to very short-lived nuclei

-Detection of heavy residues



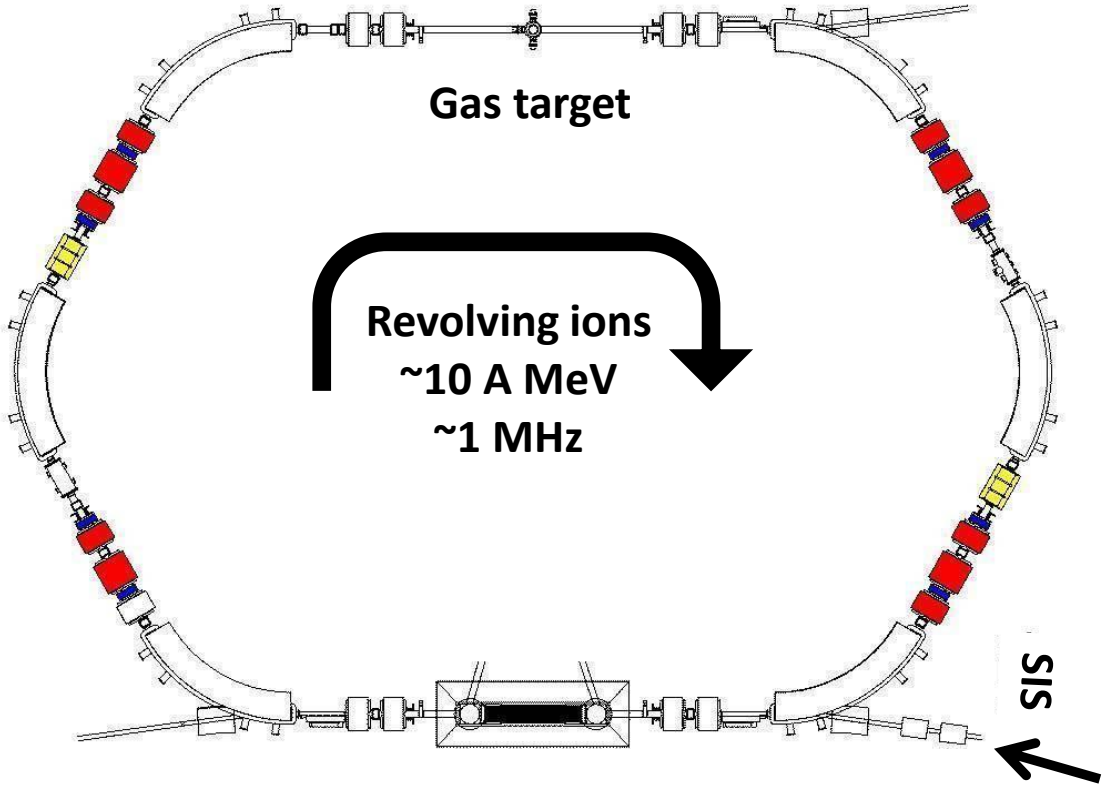
BUT!

- **Required E* resolution ~ few 100 keV, $E^* = f(E_{beam}, E_{target\_like}, \theta)$**
- **Target contaminants and target windows have to be avoided**

STORAGE RINGS!

Advantages of heavy-ion storage rings

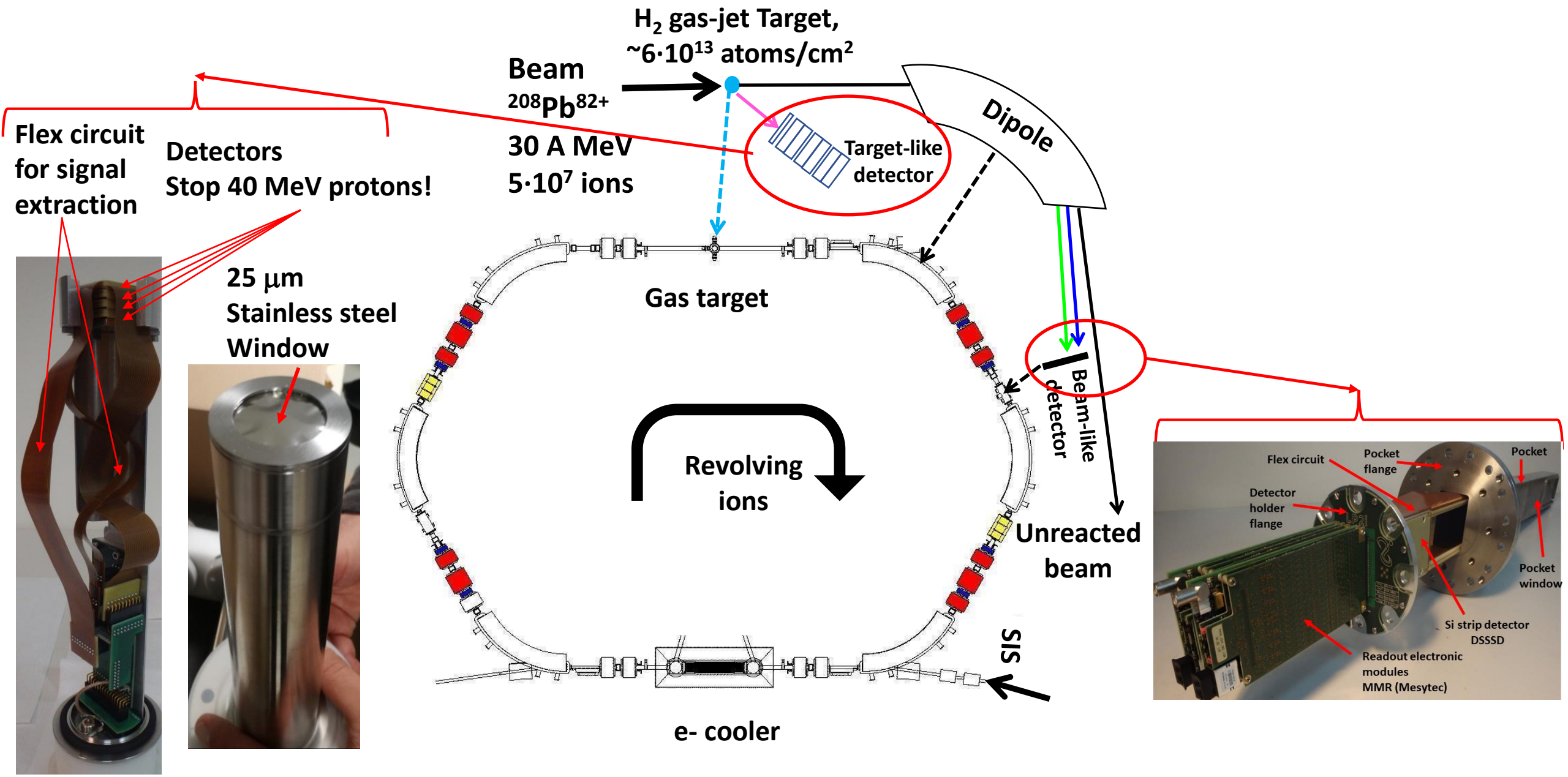
The ESR at GSI/FAIR



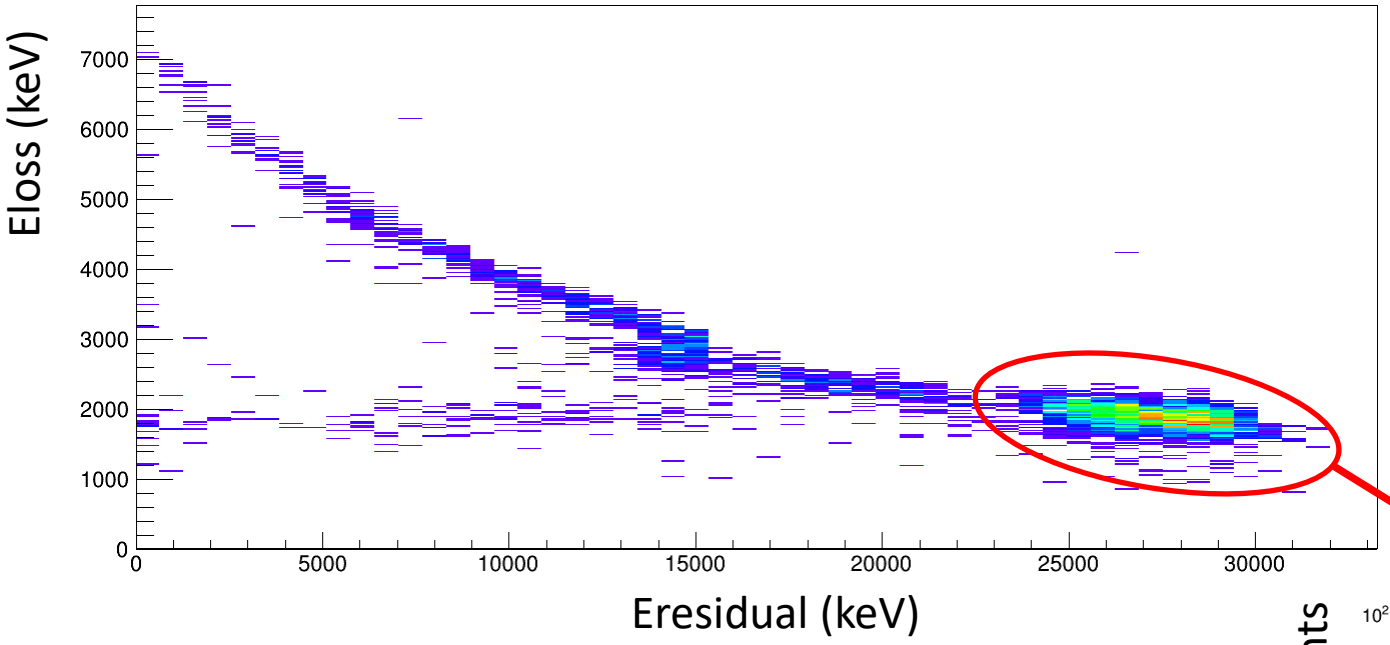
- **Beam cooling → Excellent energy and position resolution of the beam, maintained after each passage through the target, negligible, E-loss & straggling effects**
- **Use of ultra-thin in-ring gas-jet targets ~10^{13}/cm^2. Effective target thickness increased by ~10^6 due to revolution frequency (at 10 A MeV)**
- **High-quality, pure, fully-stripped beams and pure, ultra-thin, windowless targets→ unique!**

Challenge: Detectors in Ultra-High Vacuum (10^{-11}-10^{-12} mbar)!

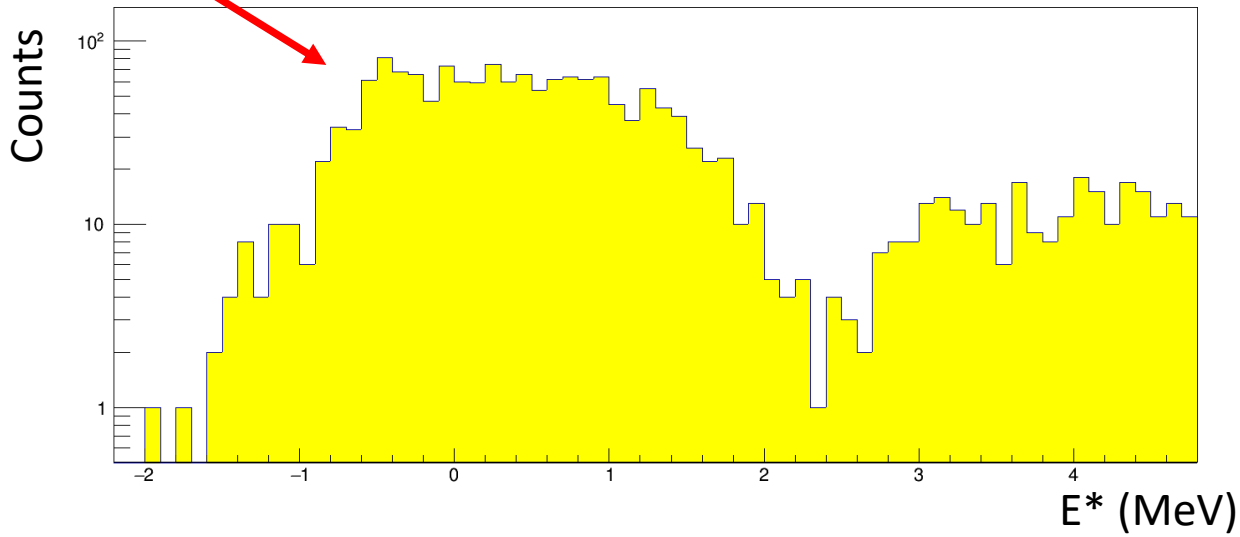
Proof-of-principle experiment at the ESR, 20-27 June 2022



First, preliminary results, detection of protons



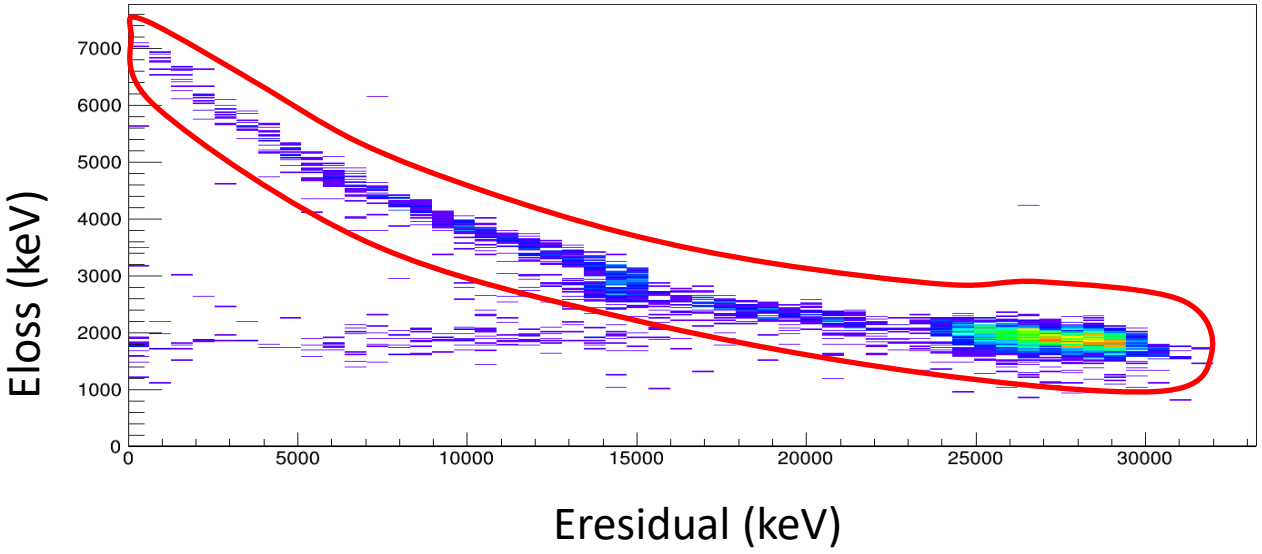
Ground state of 208Pb



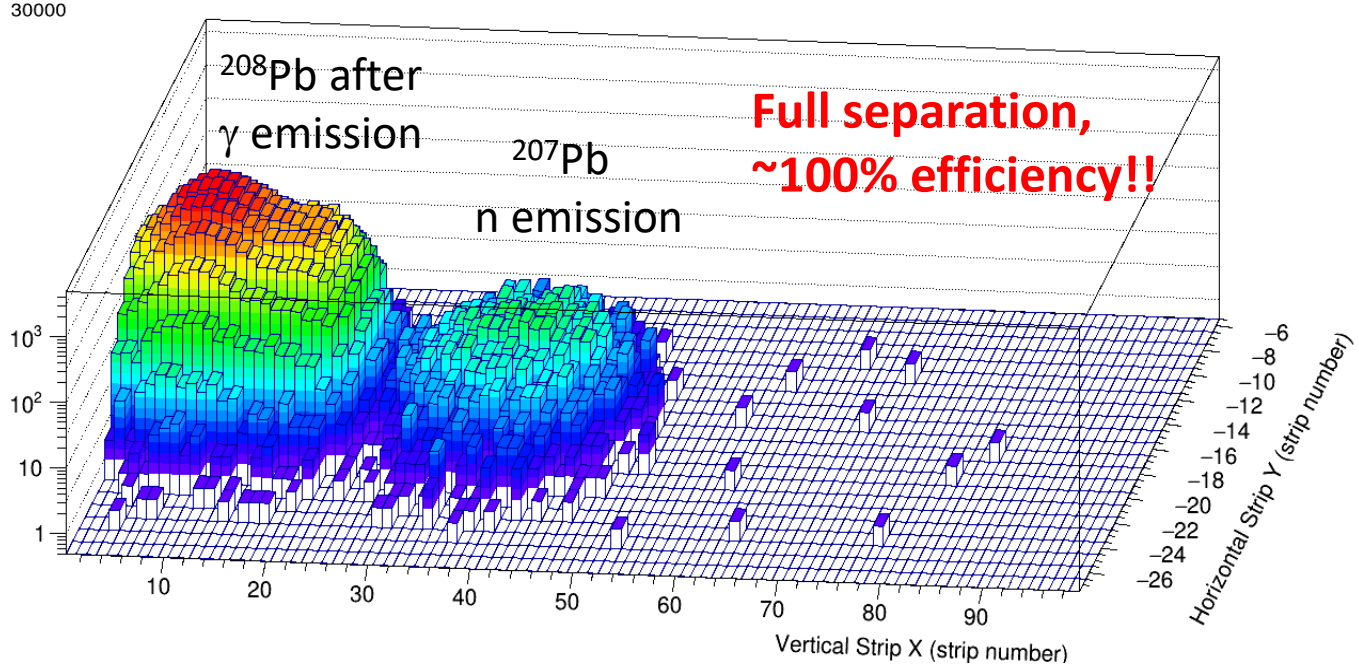
ΔE*=770 keV, dominated by the angular uncertaintiy due to target radius of 2.5 mm

First results, detection of beam residues

Detected protons



Position of detected beam residues in coincidence with protons



Conclusions…

-Surrogate reactions in inverse kinematics, powerful tool to infer neutron-induced cross sections of short-lived nuclei
-Storage rings offer the ideal conditions to investigate surrogate reactions
-First proof of principle experiment succesfully conducted at the ESR storage ring of GSI/FAIR in June 2022
→Validation of detection set-up
→E* resolution in accordance with expectations, full separation and 100% detection efficiency for beam residues
→Validation of new methodology for simultaneous measurement of P_γ and P_n probabilities

…Perspectives

-Analysis of data to infer for the first time simultaneously neutron and gamma emission probabilities
-Infer neutron-induced cross sections of 207Pb
-Add a fission detection system to our set-up, to measure simultaneously Pg, Pn and Pf . Target radius 0.5 mm. (~2024)
-Perform measurements with radioactive beams

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NECTAR: Nuclear rEaCTions At storage Rings

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