PISTA, a new detection system for transfer-induced fission in inverse kinematics at VAMOS

EUNPC 2025

GANIL

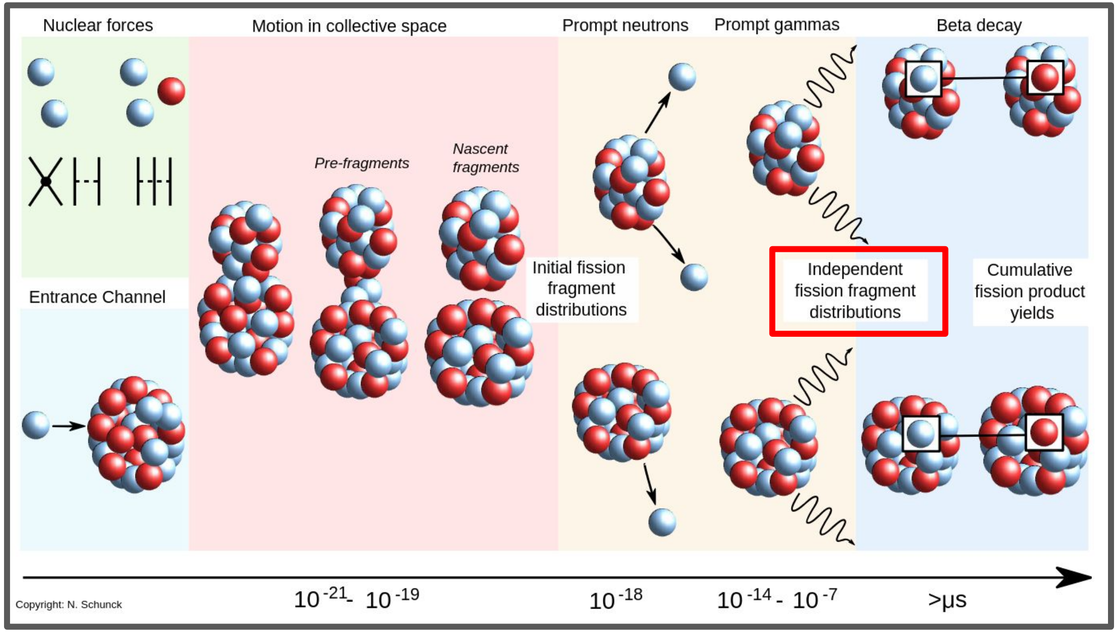
cea

UNIVERSITÉ
CAEN
NORMANDIE

Lucas Bégué–Guillou on behalf of the E850 collaboration

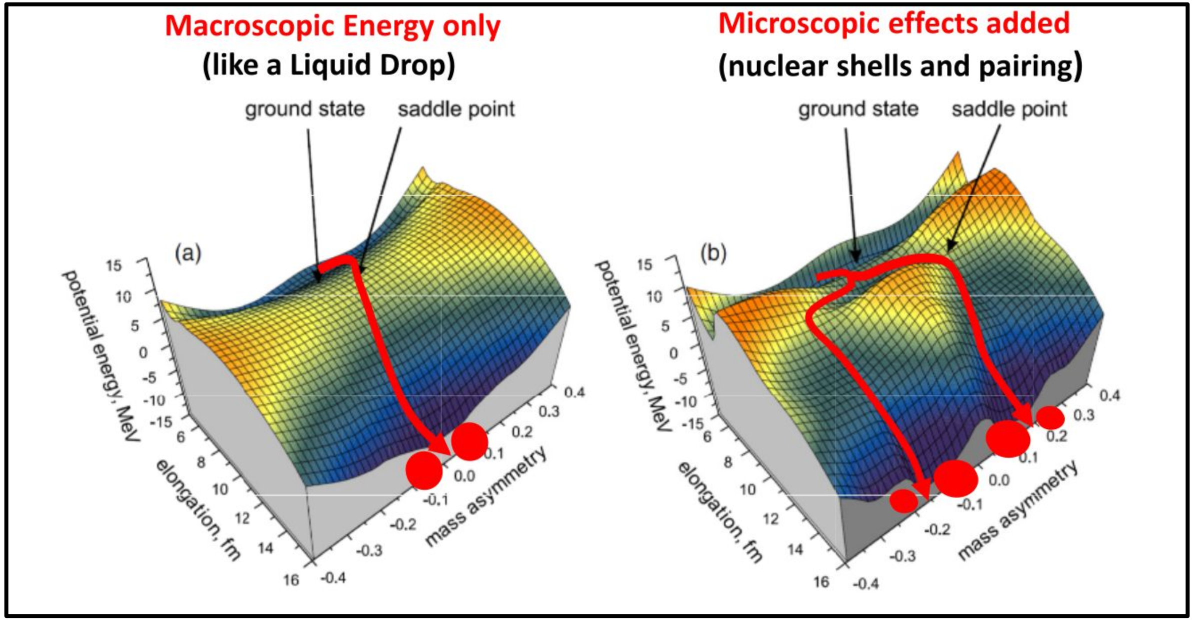
The Fission process

During Fission, nuclear matter goes under **extreme level of deformation** and eventually the nucleus splits into two fragments. Results shows that this many-body dynamic problem involve both **microscopic** and **macroscopic** aspects of nuclear matter. Still a complete description of the fission process remains a challenge.

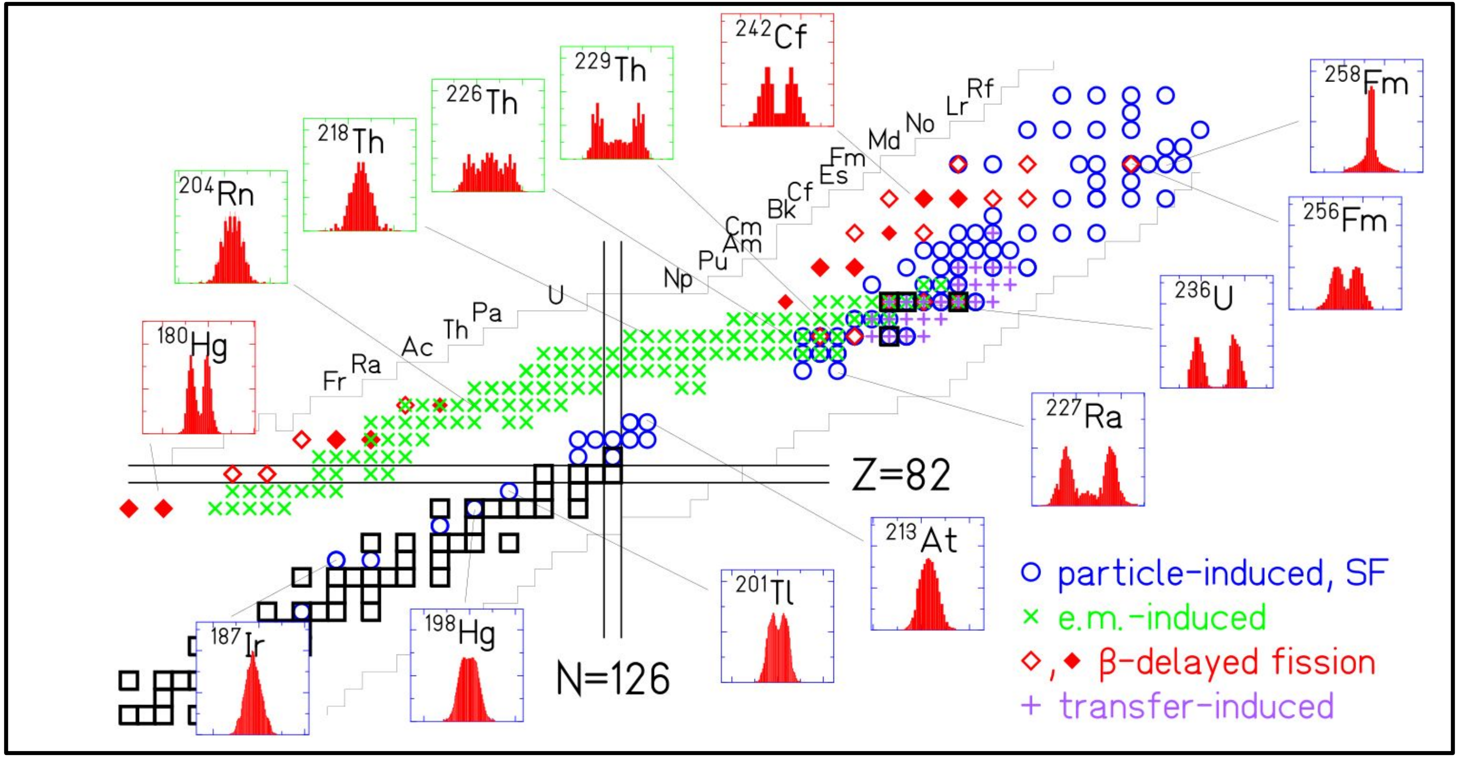


The Fission process

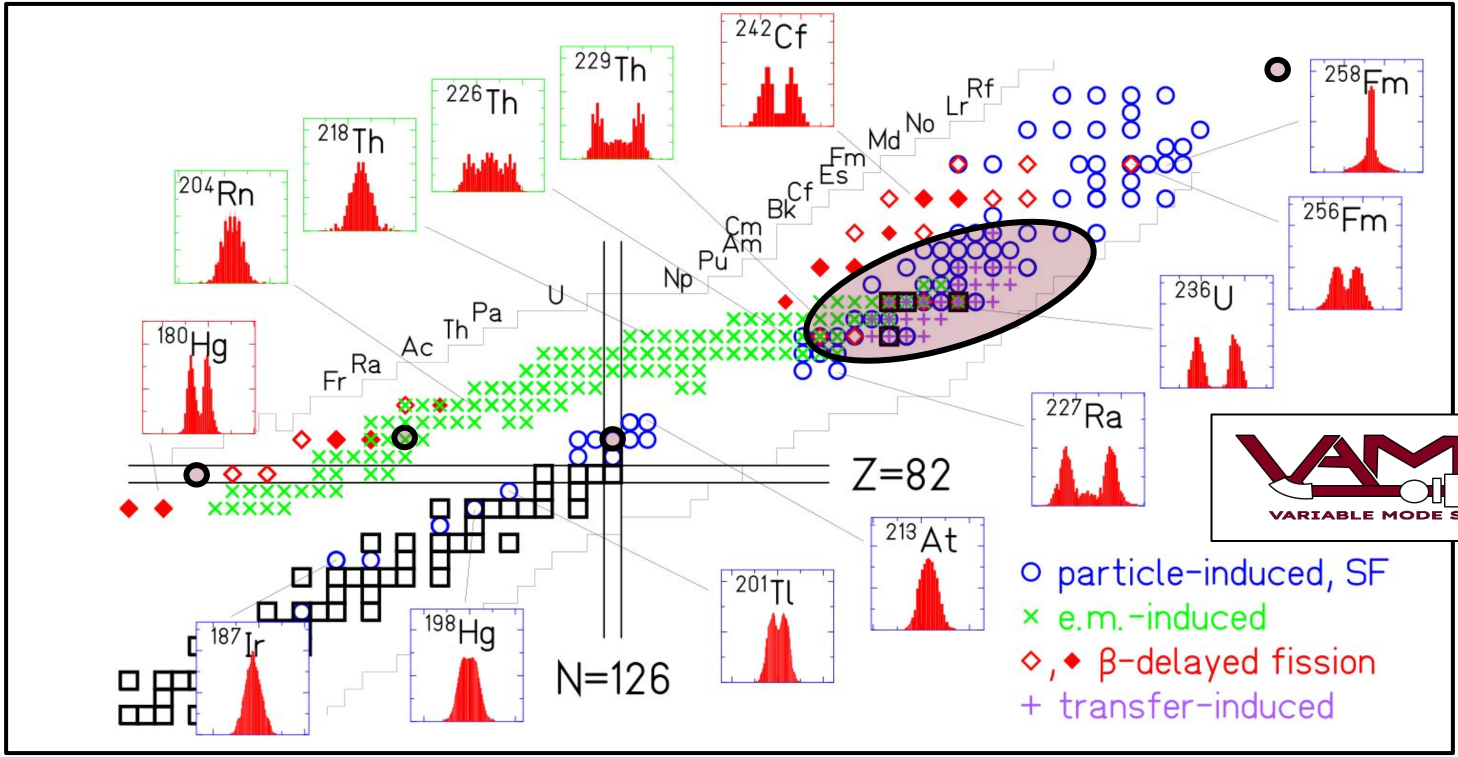
During Fission, nuclear matter goes under **extreme level of deformation** and eventually the nucleus splits into two fragments. Results shows that this many-body dynamic problem involve both **microscopic** and **macroscopic** aspects of nuclear matter. Still a complete description of the fission process remains a challenge.



The Fission process

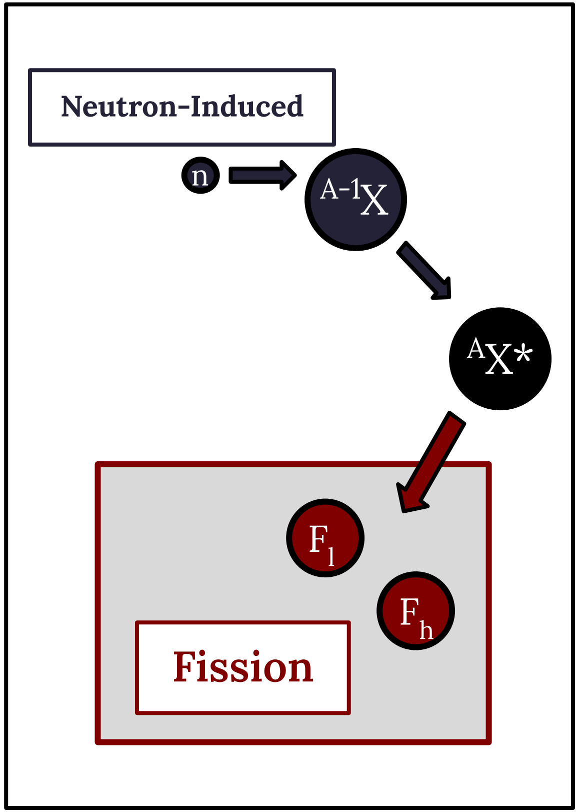


The Fission process



VARIABLE MODE SPECTROMETER

Direct Measurements



Neutron-Induced Reaction
Direct Measurement of observables for nuclear-energy application, nuclear astrophysics, national security ...

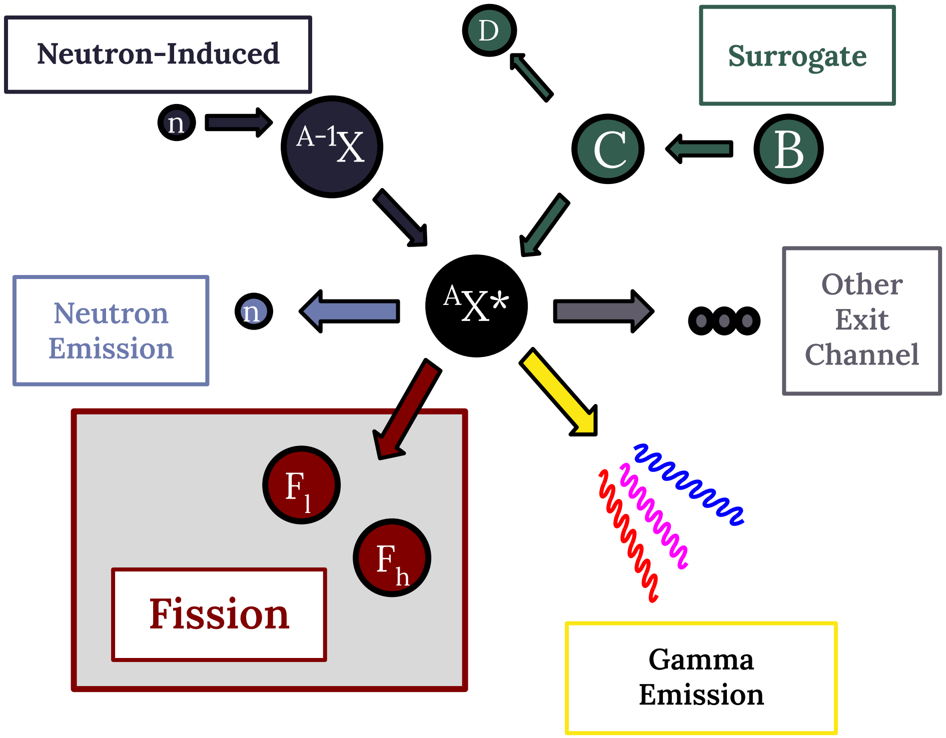
Production of $^{A}X^{*}$ and measurements of products properties may encounter many difficulties by direct reaction

- **Limited number of fissionning system**
- **Fragments are slow (~1 cm.ns^{-1})**

⇒ Challenging identification in A and Z

- **E* > S_n only , often above B_f .....**

Surrogate Reaction Strategy



Neutron-Induced Reaction
Direct Measurement of observables for nuclear-energy application, nuclear astrophysics, national security …

Production of $^{A}X^*$ and measurements of products properties may encounter many difficulties by direct reaction

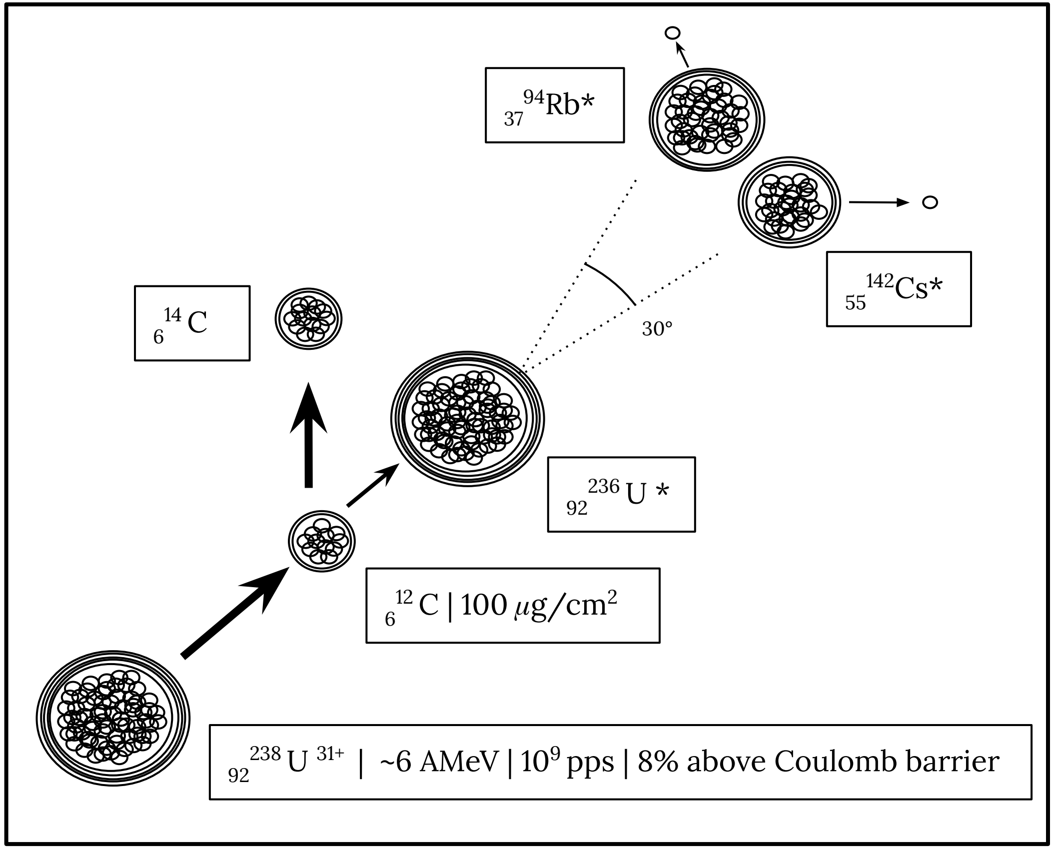
- Important reactions involve unstable nuclei, i.e. difficult to produce targets

SURROGATE REACTIONS METHOD

transfer reactions (t, pf), (d,p) (^{3}He,df)…
Scattering reactions (^{4}He,^{4}He'), (p,p') …
Coulomb-Induced Fission on ^{208}Pb thick target

To what extent do we populate the same system ?
How can we account for the differences ?

The Inverse Kinematic technique, A Surrogate Method



Neutron-Induced

- Limited number of fissionning system

- Fragments are slow
  ⇒ Challenging identification in A and Z

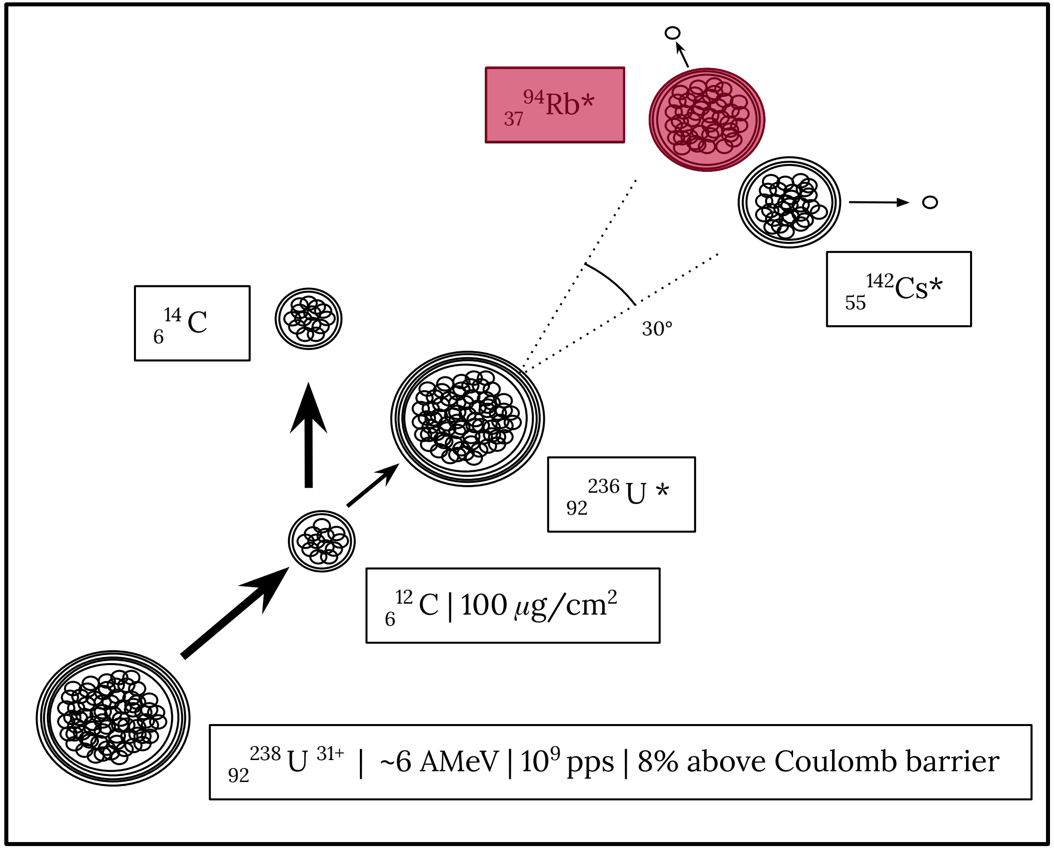
Inverse Kinematic

- Various number of fissionning system

-Fragments are faster (~3 cm.ns^{-1})
⇒ Identification in A and Z, $\Delta Z/Z$ = 1/66 and $\Delta M/M$ = 1/220

Challenge = Identification of the fissioning system

The Inverse Kinematic technique, A Surrogate Method



Neutron-Induced

- Limited number of fissionning system

- Fragments are slow
  ⇒ Challenging identification in A and Z

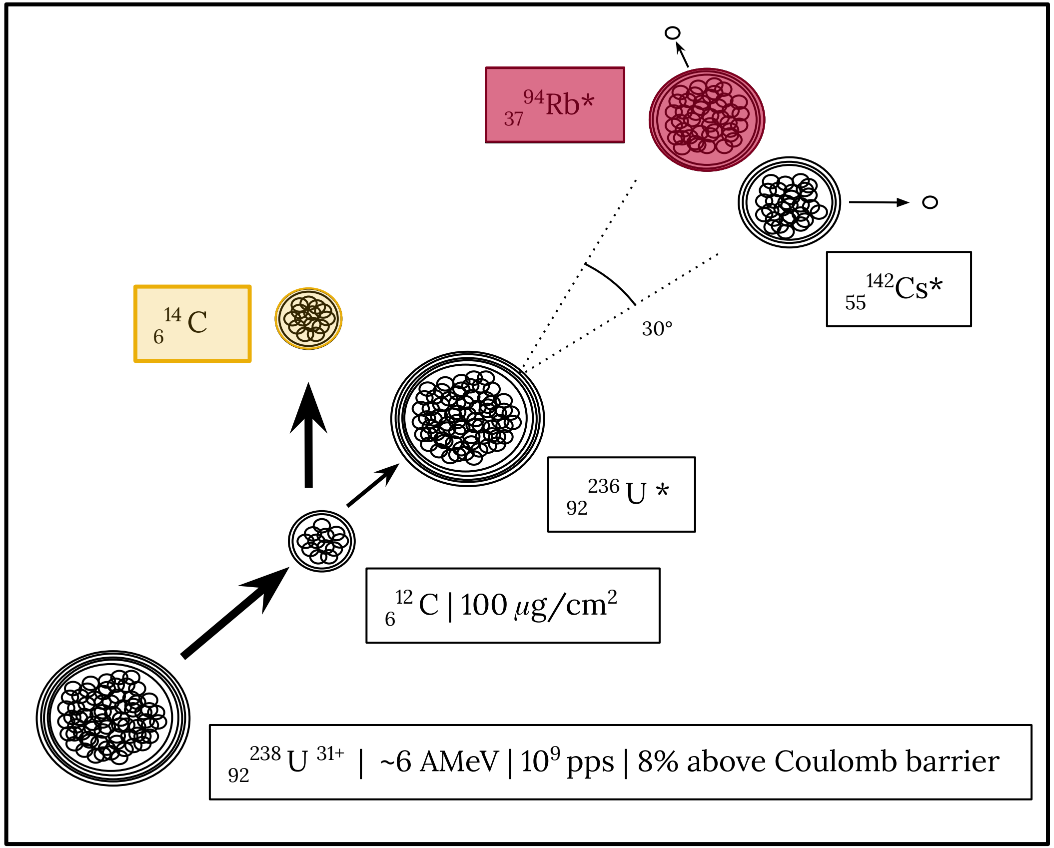
Inverse Kinematic

- Various number of fissionning system

-Fragments are faster (~3 $cm.ns^{-1}$)
⇒ Identification in A and Z, $\Delta Z/Z$ = 1/66 and $\Delta M/M$ = 1/220 ⟹ **VAMOS**

Challenge = Identification of the fissioning system

The Inverse Kinematic technique, A Surrogate Method



Neutron-Induced

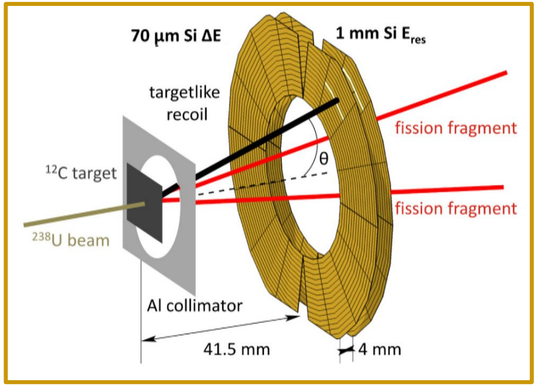
- Limited number of fissionning system
- Fragments are slow
  ⇒ Challenging identification in A and Z

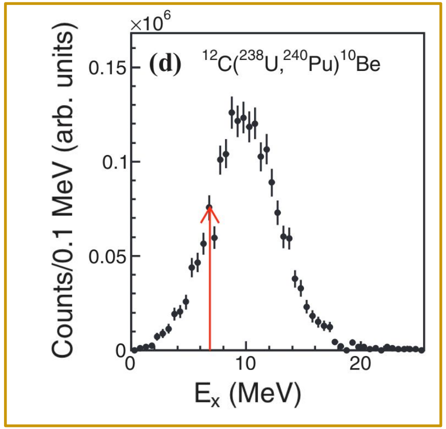
Inverse Kinematic

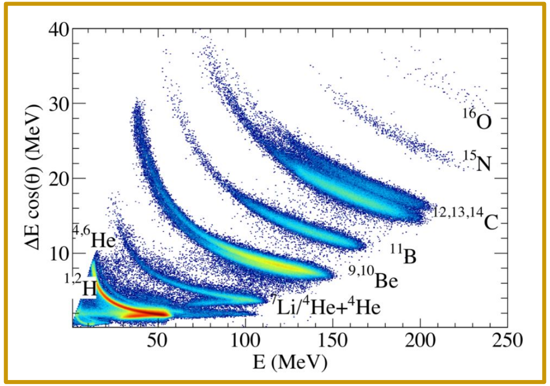
- Various number of fissionning system
- Fragments are faster (~3 $cm.ns^{-1}$)
  ⇒ Identification in A and Z, $\Delta Z/Z = 1/66$ and $\Delta M/M = 1/220$ ⟹ **VAMOS**

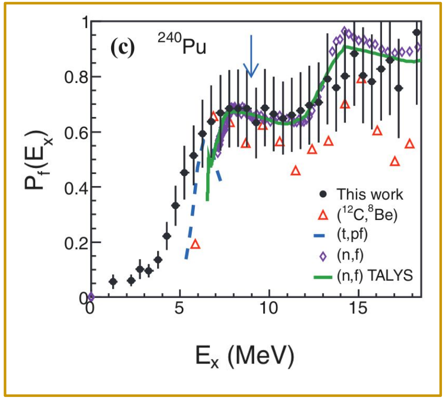
Challenge = Identification of the fissioning system ⟹ **PISTA**

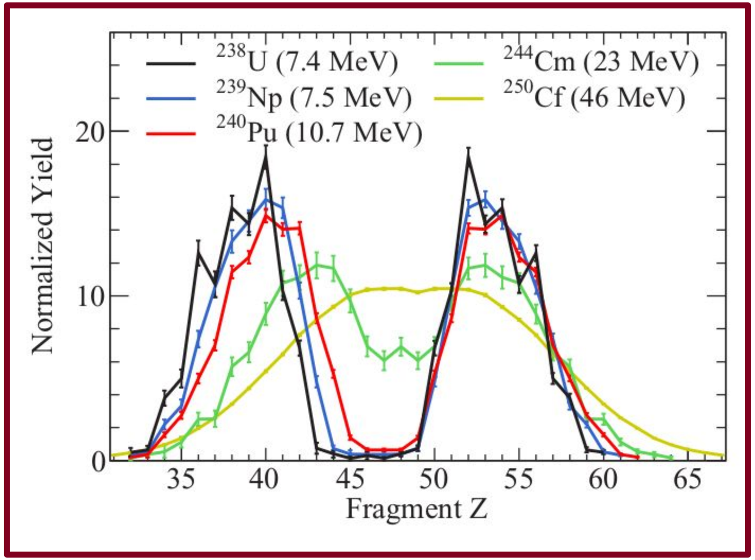
Results of SPIDER@VAMOS











PISTA@VAMOS Setup, E850 Campaign

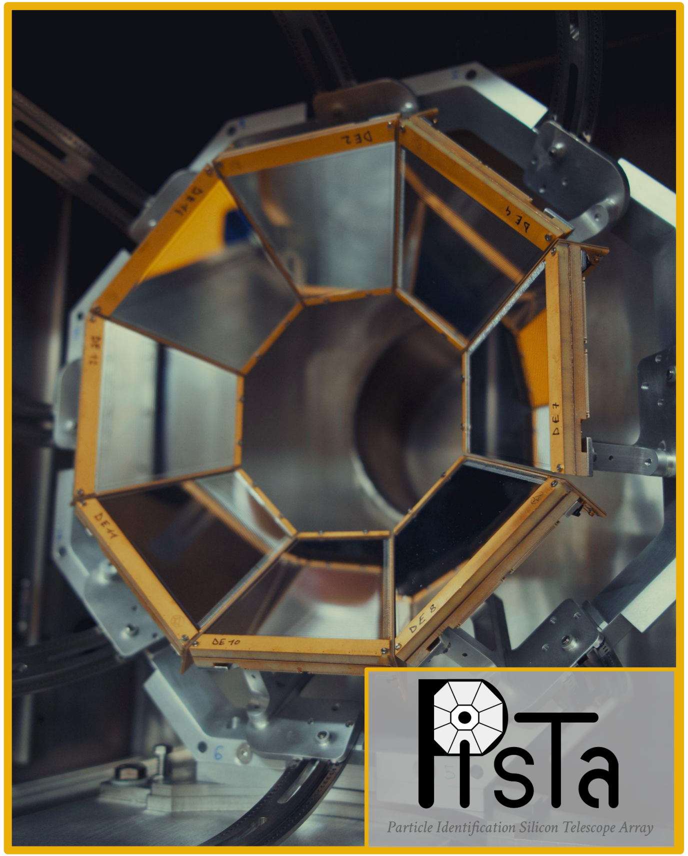
This Experiment used a **^{238}U beam at 6 A MeV** impinging on a **100 µg.cm-2 thick ^{12}C target** and used PISTA detector for the **first time** It has been held in two part, a first in June 2023 and a second april 2024.

WHAT WE AIM FOR IS

The production of **Isotopic fission yields** with high statistics per bin of about **1 MeV** in excitation energy from 6 up to 20 MeV

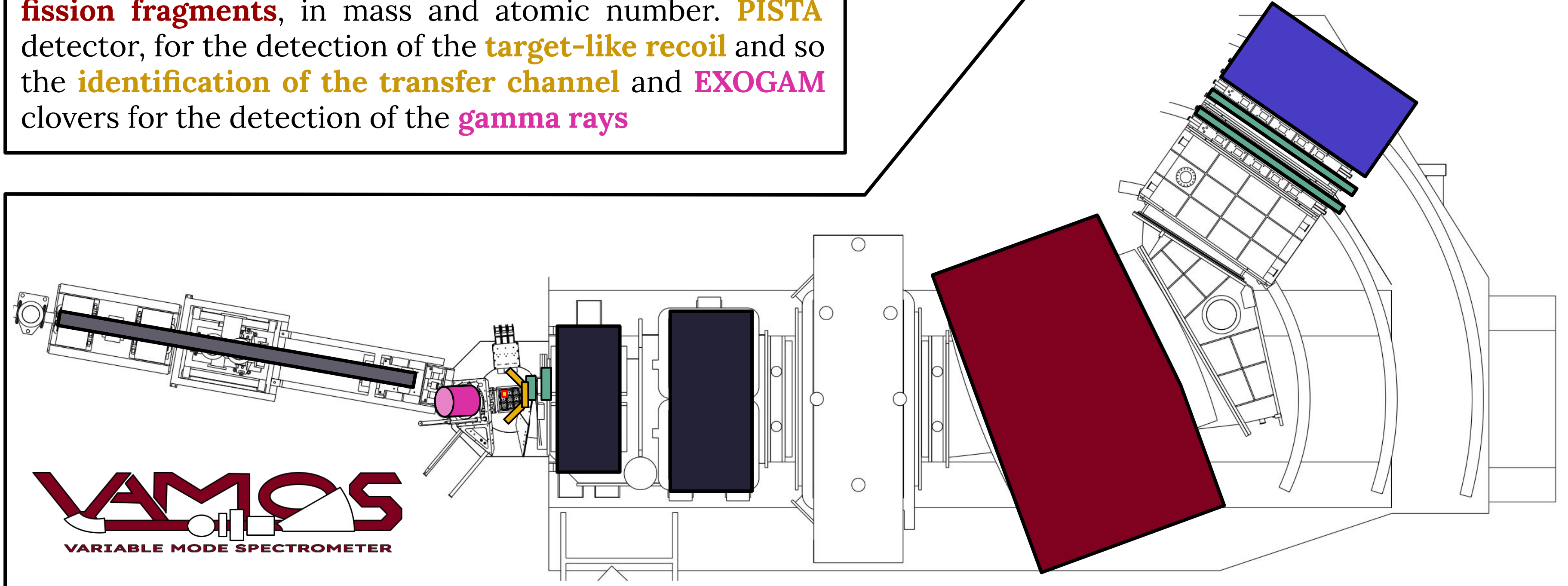
for the two key fissioning systems of interest which are **^{236}U** and **^{240}Pu**

This should bring new insights on the **disappearance** of shell effects with the excitation energy

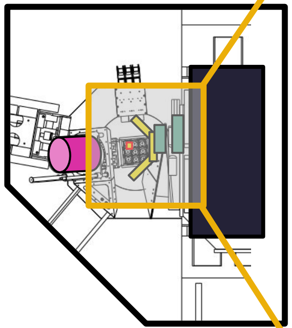


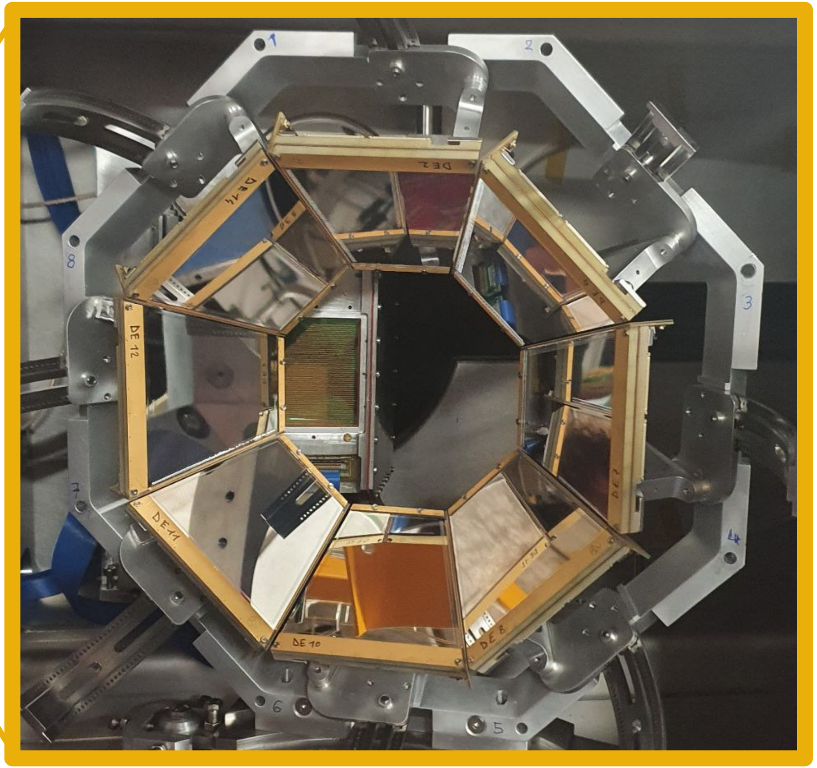
PISTA@VAMOS Setup

When a fission event occurs, it is detected by a set of different detectors. **VAMOS** for the identification of the **fission fragments**, in mass and atomic number. **PISTA** detector, for the detection of the **target-like recoil** and so the **identification of the transfer channel** and **EXOGAM** clovers for the detection of the **gamma rays**



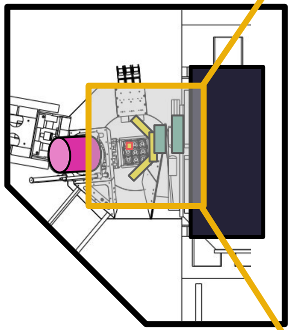
PISTA, General Description

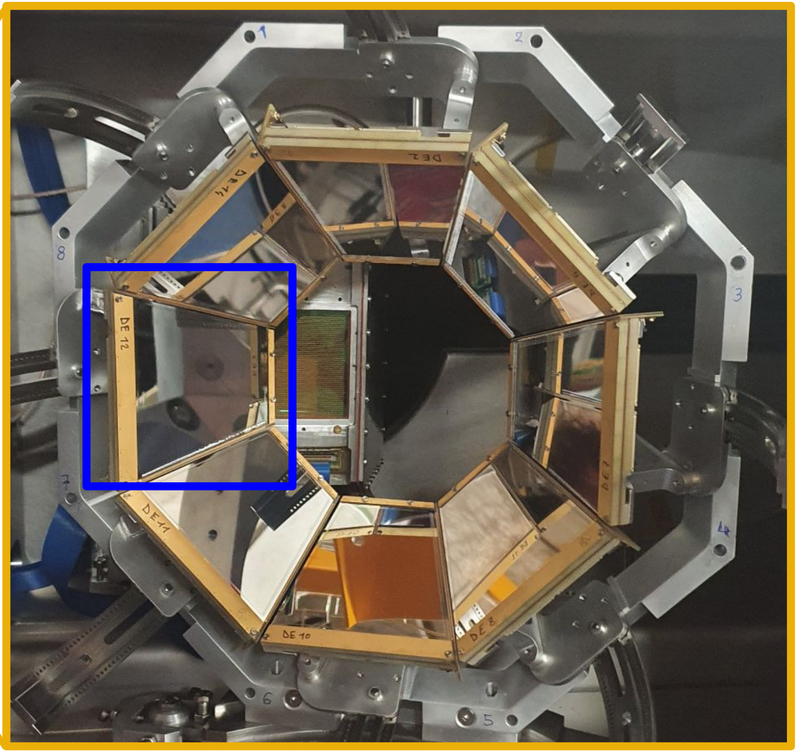




PISTA is an array of **8 trapezoidal silicon telescopes** arranged in corolla configuration

PISTA, General Description

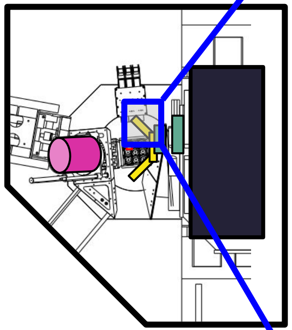


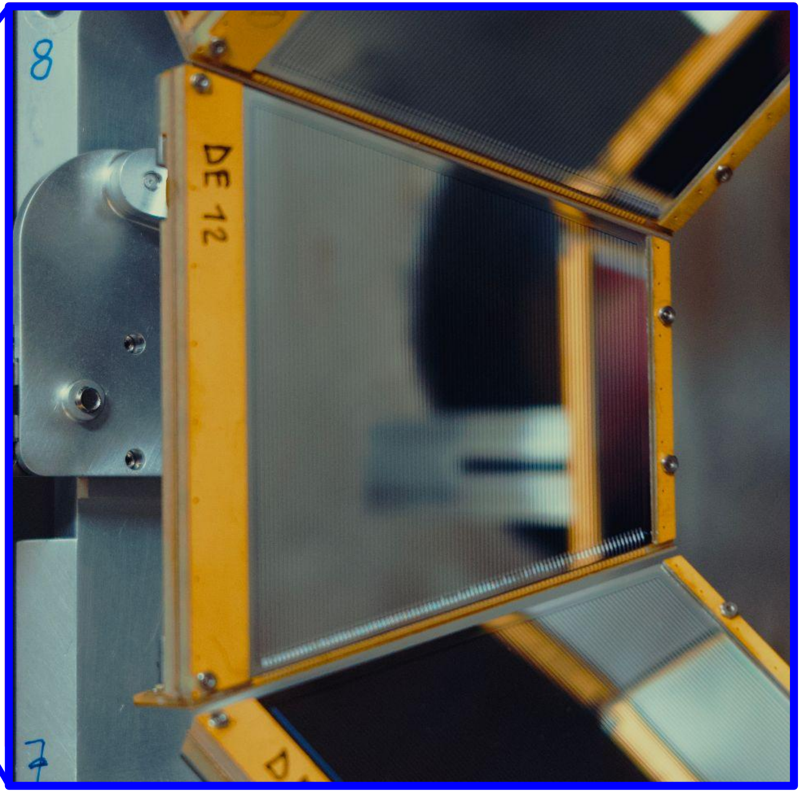


PISTA is an array of **8 trapezoidal silicon telescopes** arranged in corolla configuration

Each telescope consists of **two *"single-sided stripped"* silicon detectors**, with thicknesses of **100 µm** and **1000 µm**, positioned **100 mm from the target.**

PISTA, General Description

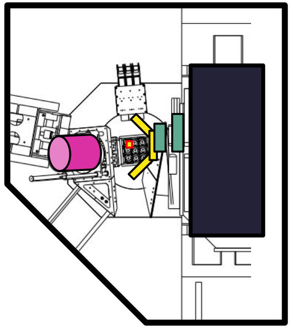


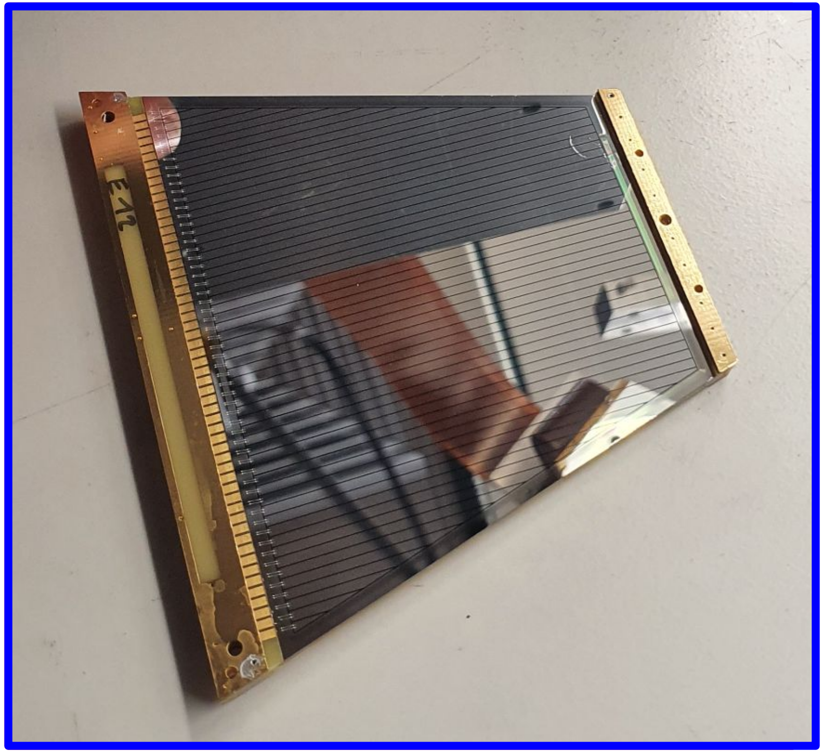


PISTA is an array of **8 trapezoidal silicon telescopes** arranged in corolla configuration

Each telescope consists of **two "*single-sided stripped*" silicon detectors**, with thicknesses of **100 μm** and **1000 μm**, positioned **100 mm from the target.**

PISTA, General Description



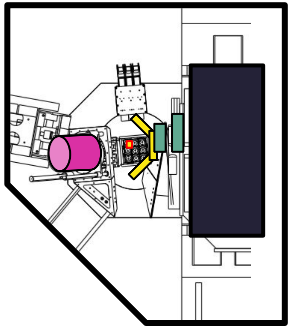


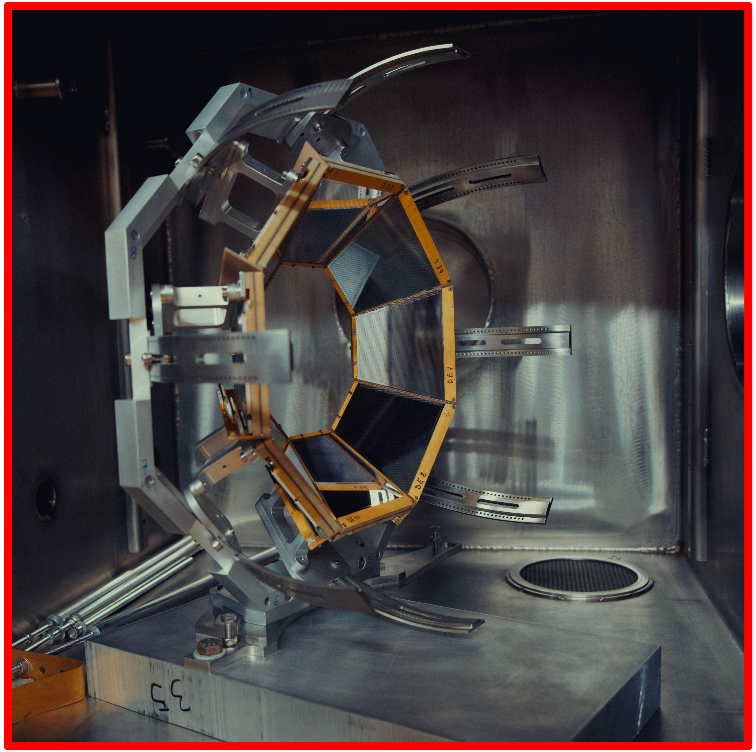
PISTA is an array of **8 trapezoidal silicon telescopes** arranged in corolla configuration

Each telescope consists of **two *"single-sided stripped"* silicon detectors**, with thicknesses of **100 µm** and **1000 µm**, positioned **105 mm from the target.**

σ(Θ) ~ 0.14 °
σ(φ) ~ 0.4 °

PISTA, General Description





PISTA is an array of **8 trapezoidal silicon telescopes** arranged in corolla configuration

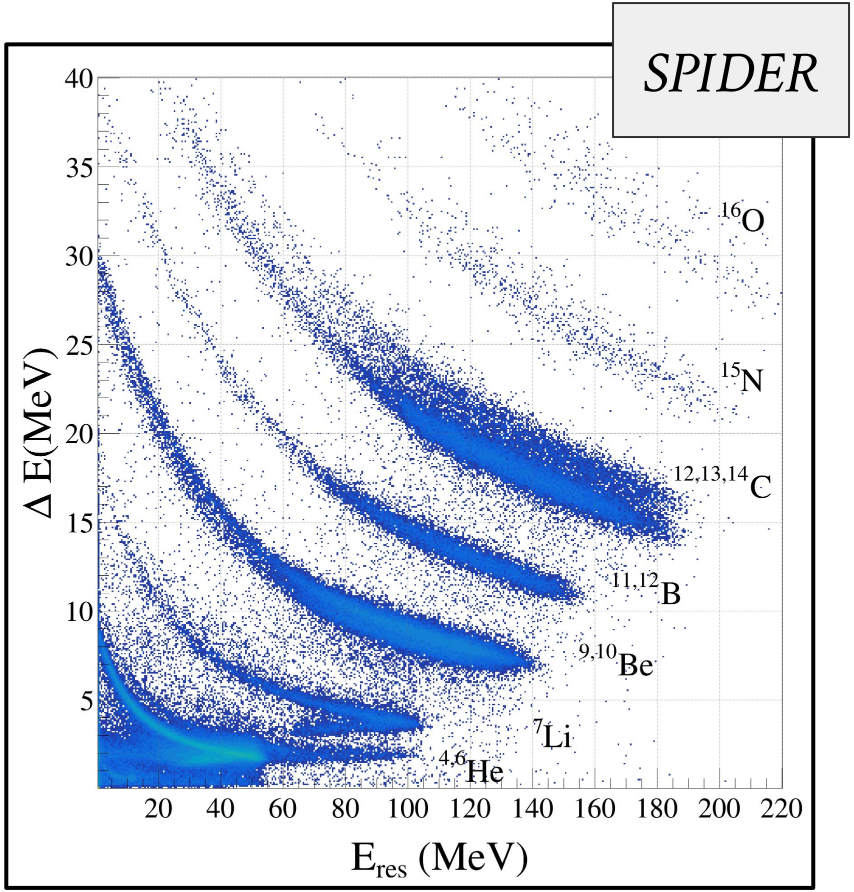
Each telescope consists of **two *"single-sided stripped"* silicon detectors**, with thicknesses of **100 µm** and **1000 µm**, positioned **100 mm from the target.**

Identification of "target-like" ions (**T~200 MeV**) with (ΔE, E) technique **up to Oxygen**

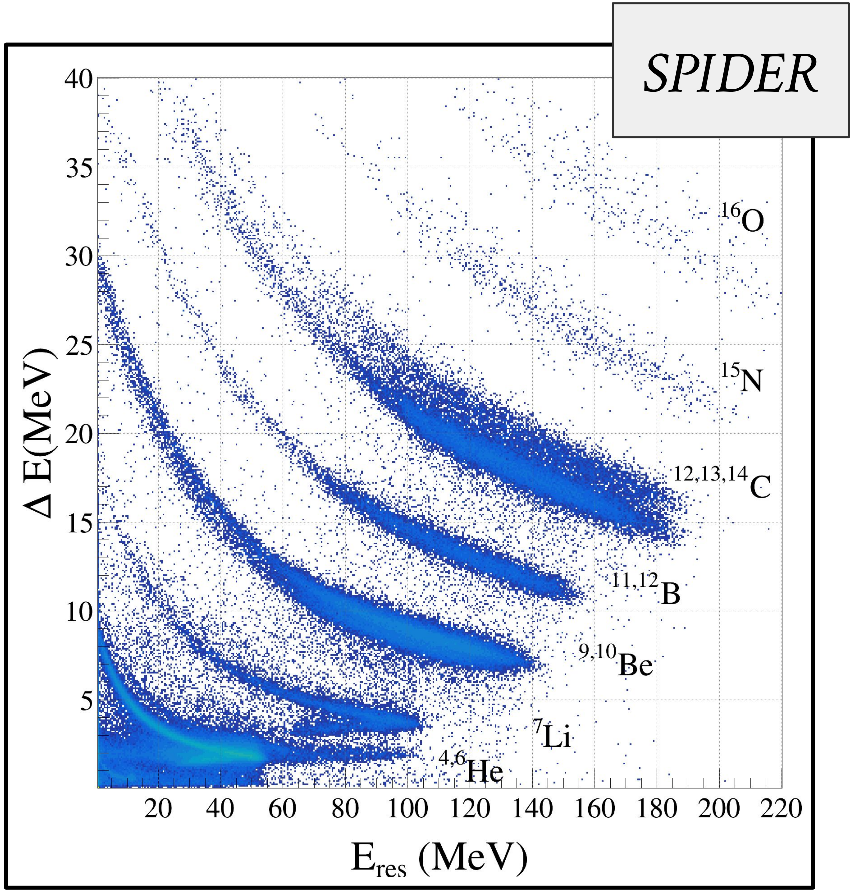
σ(E) ~ 3 ‰

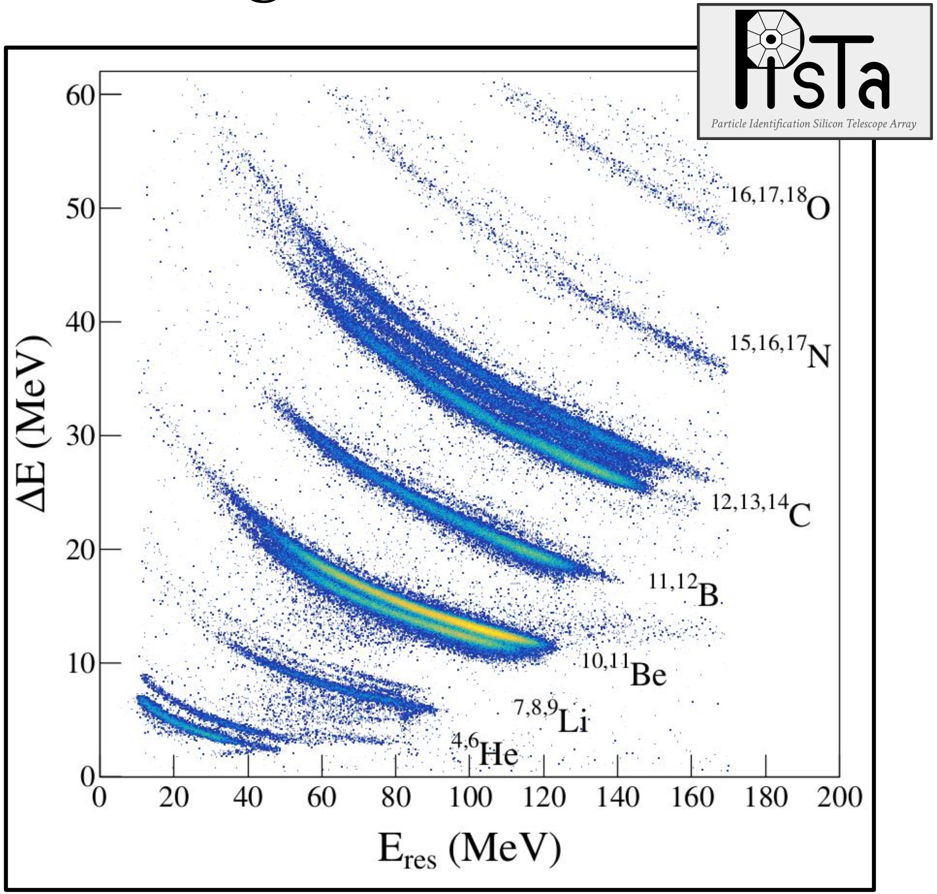
E* Reconstruction using **$(\Theta,T)_{type-cible}$**

PISTA, the Identification of the Target-like Recoil

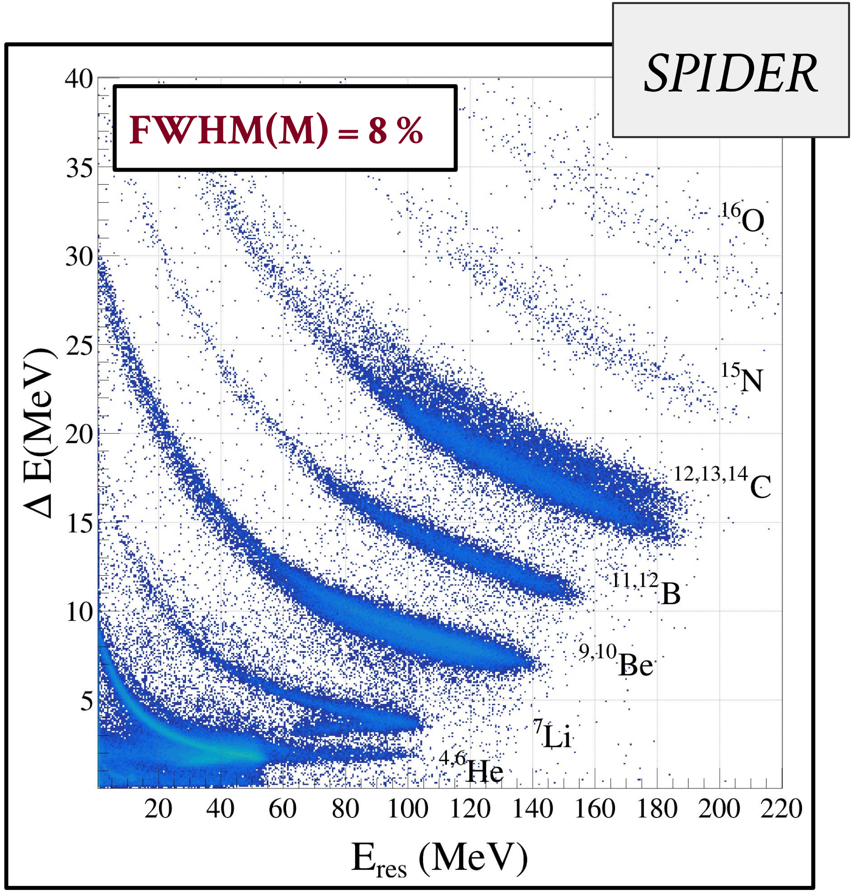


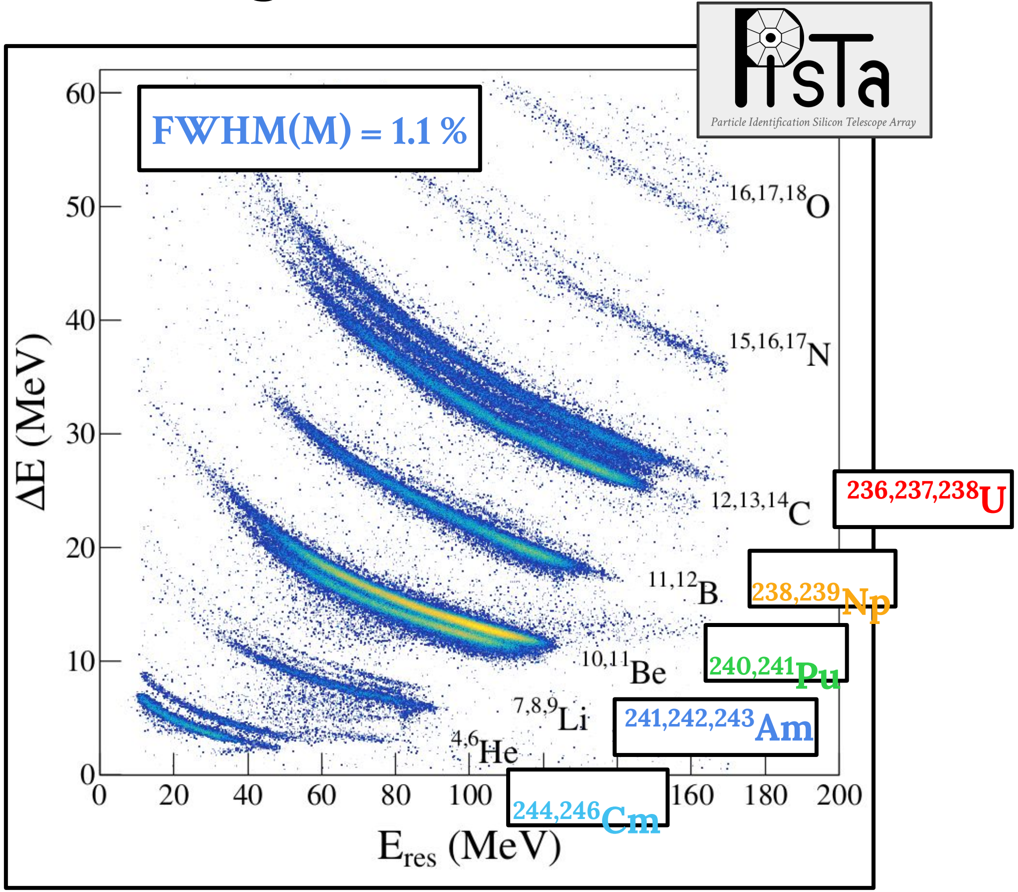
PISTA, the Identification of the Target-like Recoil



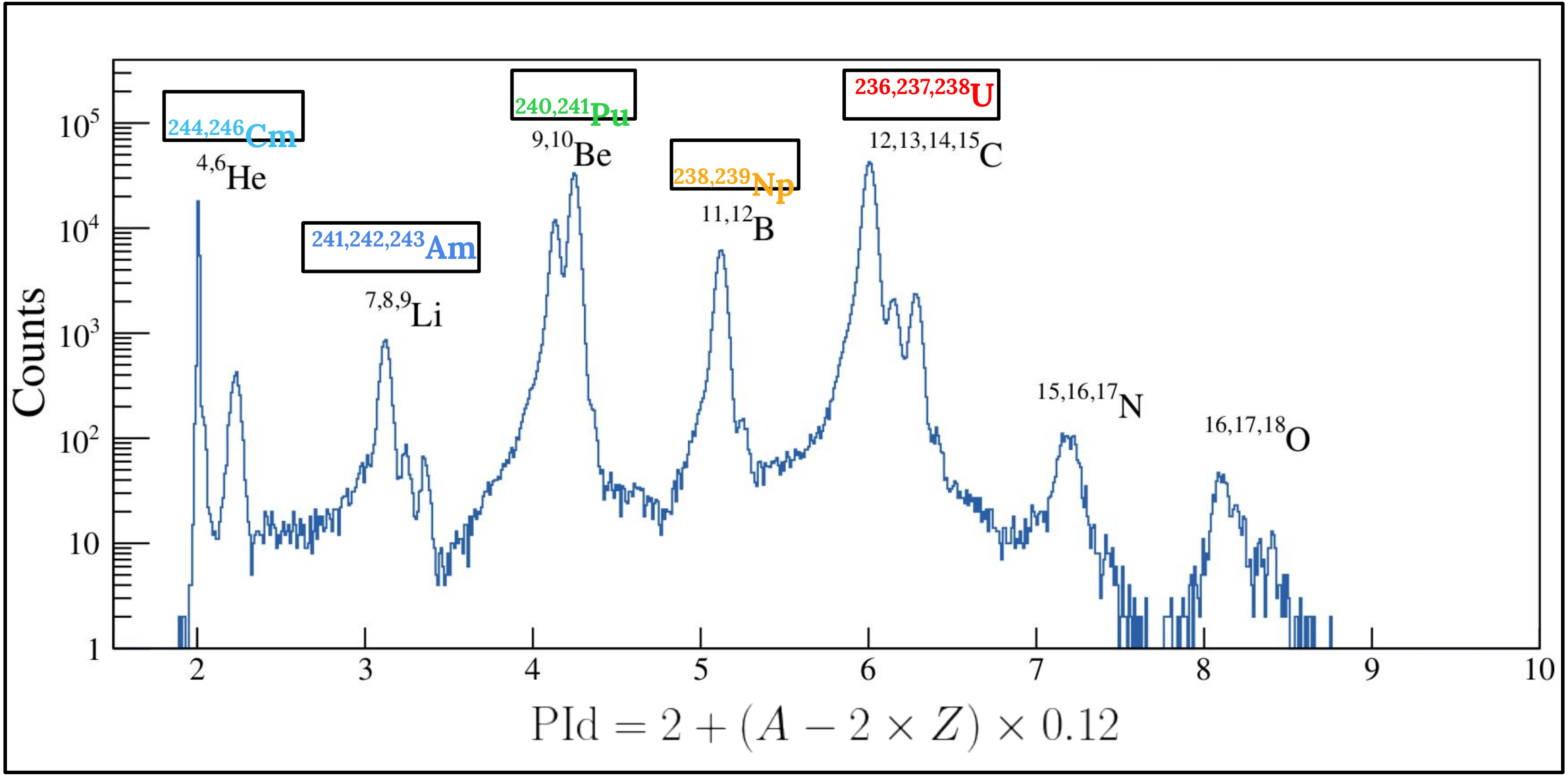


PISTA, the Identification of the Target-like Recoil



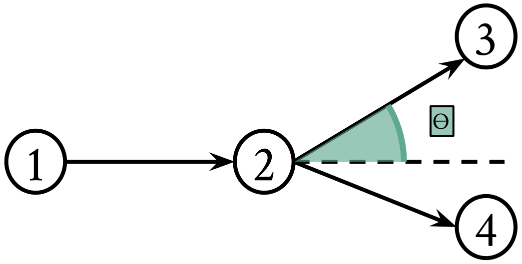


PISTA, the Identification of the Target-like Recoil



Reconstruction of the total E* Energy

Assuming that **energy** and **linear momentum** are **conserved** during this two body interaction and that the target-like nucleus **is not excited** after the interaction we have :



$$\vec{p}_1 + \cancel{\vec{p}_2} = \vec{p}_3 + \vec{p}_4$$

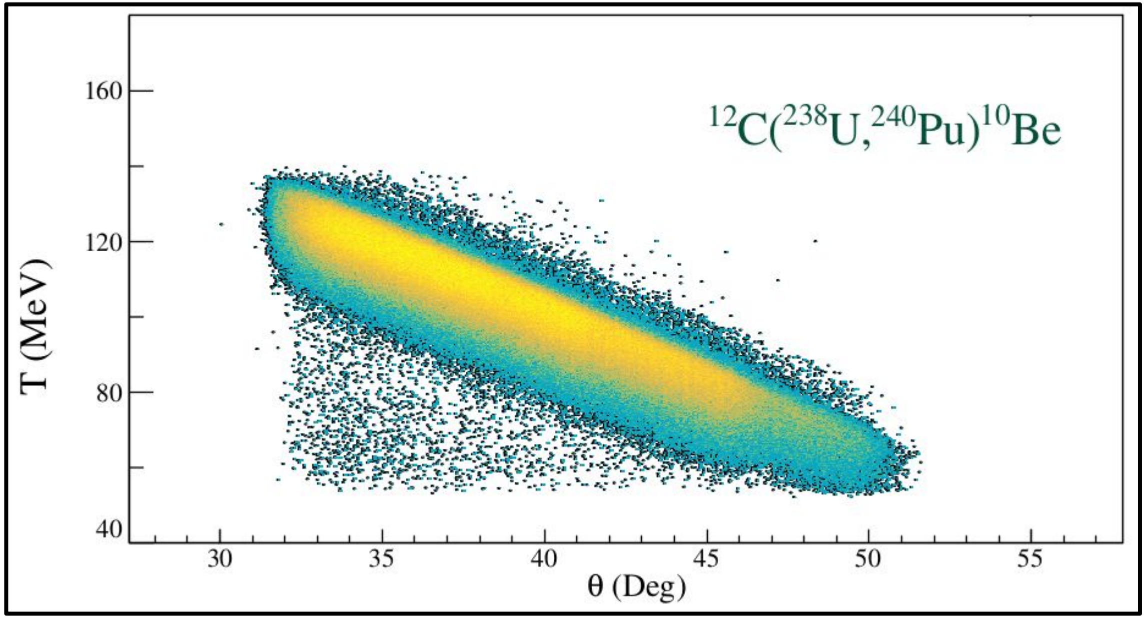
$$\vec{p}_4 = \sqrt{p_1^2 + p_3^2 - 2 * p_1 * p_3 * cos(\theta)}$$

$$E_1 + E_2 = E_3 + E_4$$

$$E_4 = T_1 + m_1 + \cancel{T_2} + m_2 - (T_3 + m_3)$$

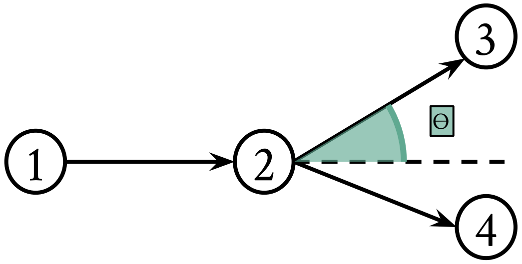
$$m_4^* = \sqrt{E_4^2 - p_4^2} \qquad E_4^* = m_4^* - m_4$$

$$Since\ T_1\ and\ the\ masses\ are\ fixed, \quad E_4^* = f(\theta, T_3)$$



Reconstruction of the total E* Energy

Assuming that **energy** and **linear momentum** are **conserved** during this two body interaction and that the target-like nucleus **is not excited** after the interaction we have :



$$\vec{p}_1 + \cancel{\vec{p}_2} = \vec{p}_3 + \vec{p}_4$$

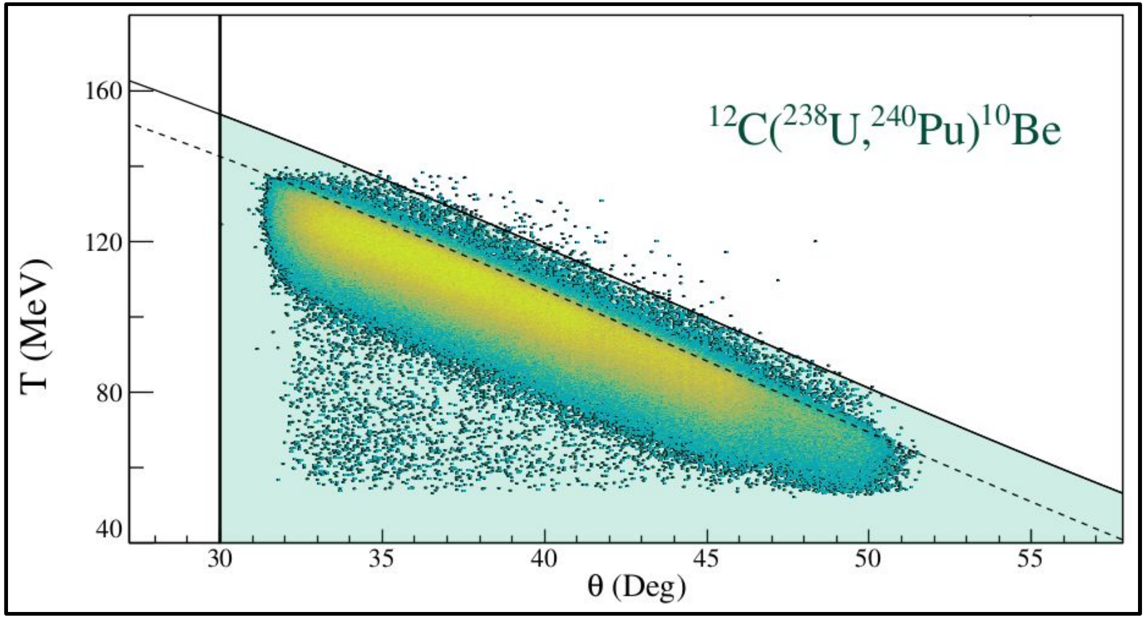
$$\vec{p}_4 = \sqrt{p_1^2 + p_3^2 - 2 * p_1 * p_3 * cos(\theta)}$$

$$E_1 + E_2 = E_3 + E_4$$

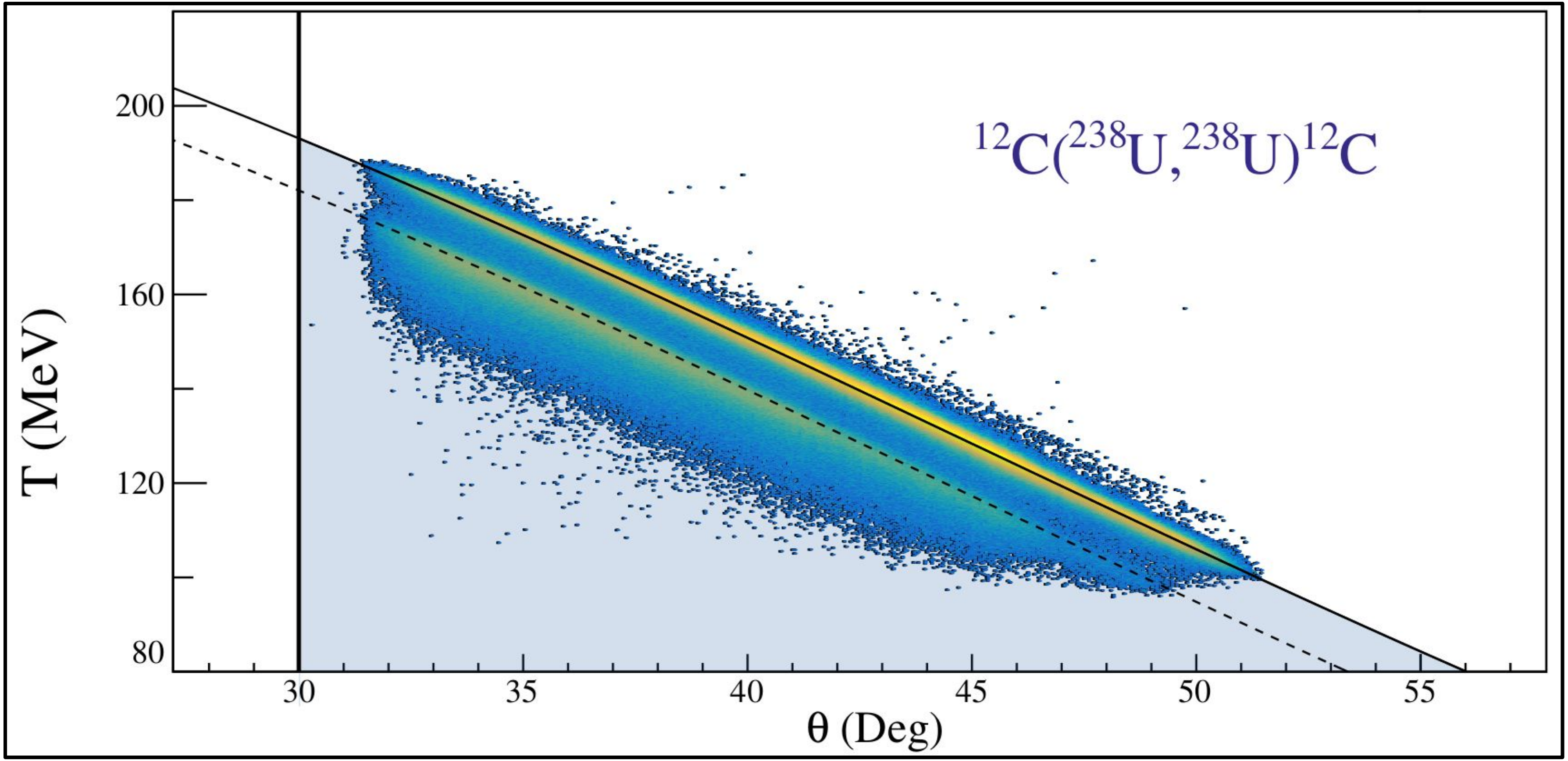
$$E_4 = T_1 + m_1 + \cancel{T_2} + m_2 - (T_3 + m_3)$$

$$m_4^* = \sqrt{E_4^2 - p_4^2} \qquad E_4^* = m_4^* - m_4$$

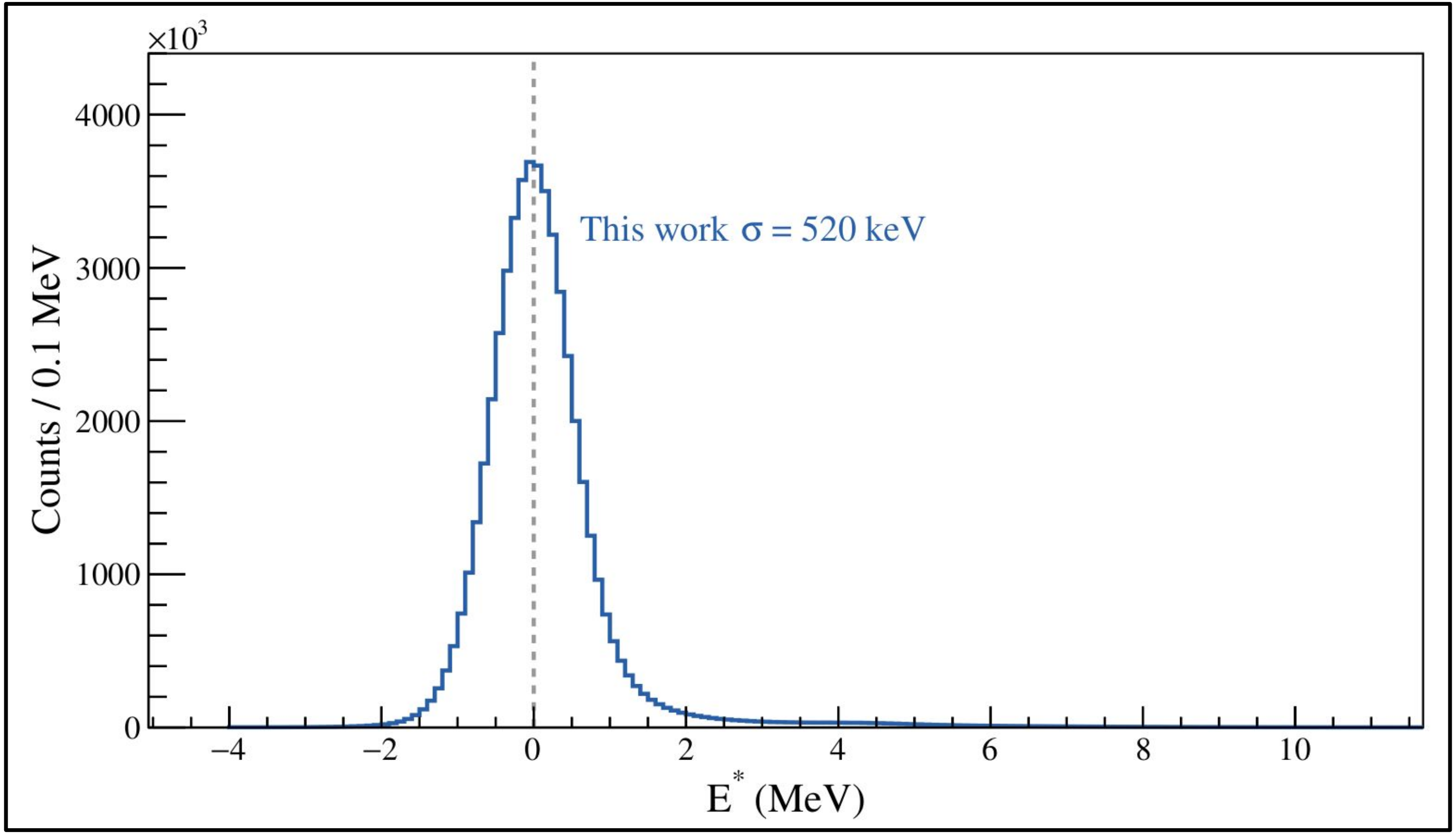
$$Since\ T_1\ and\ the\ masses\ are\ fixed, \quad E_4^* = f(\theta, T_3)$$



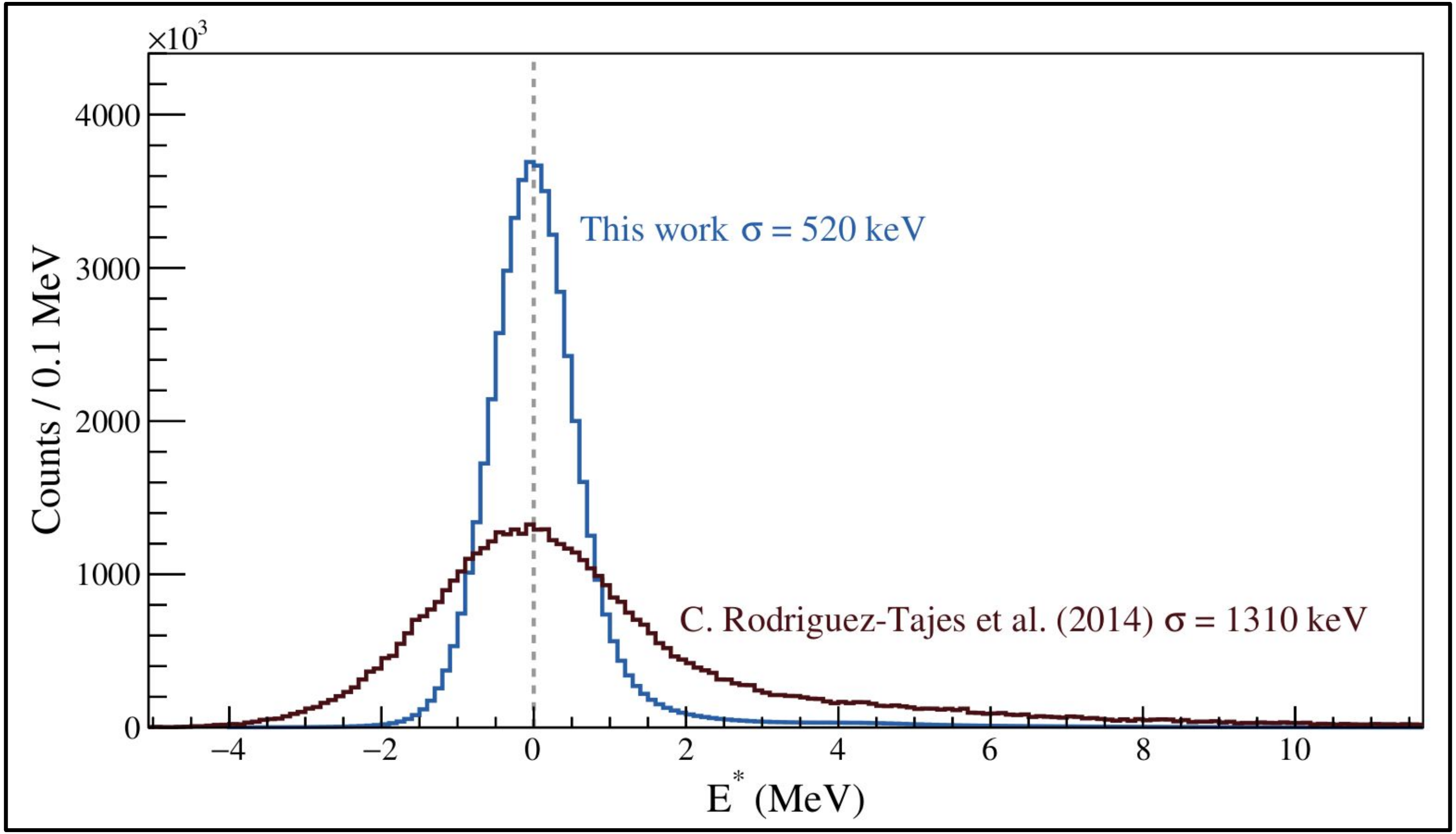
Excitation energy Resolution



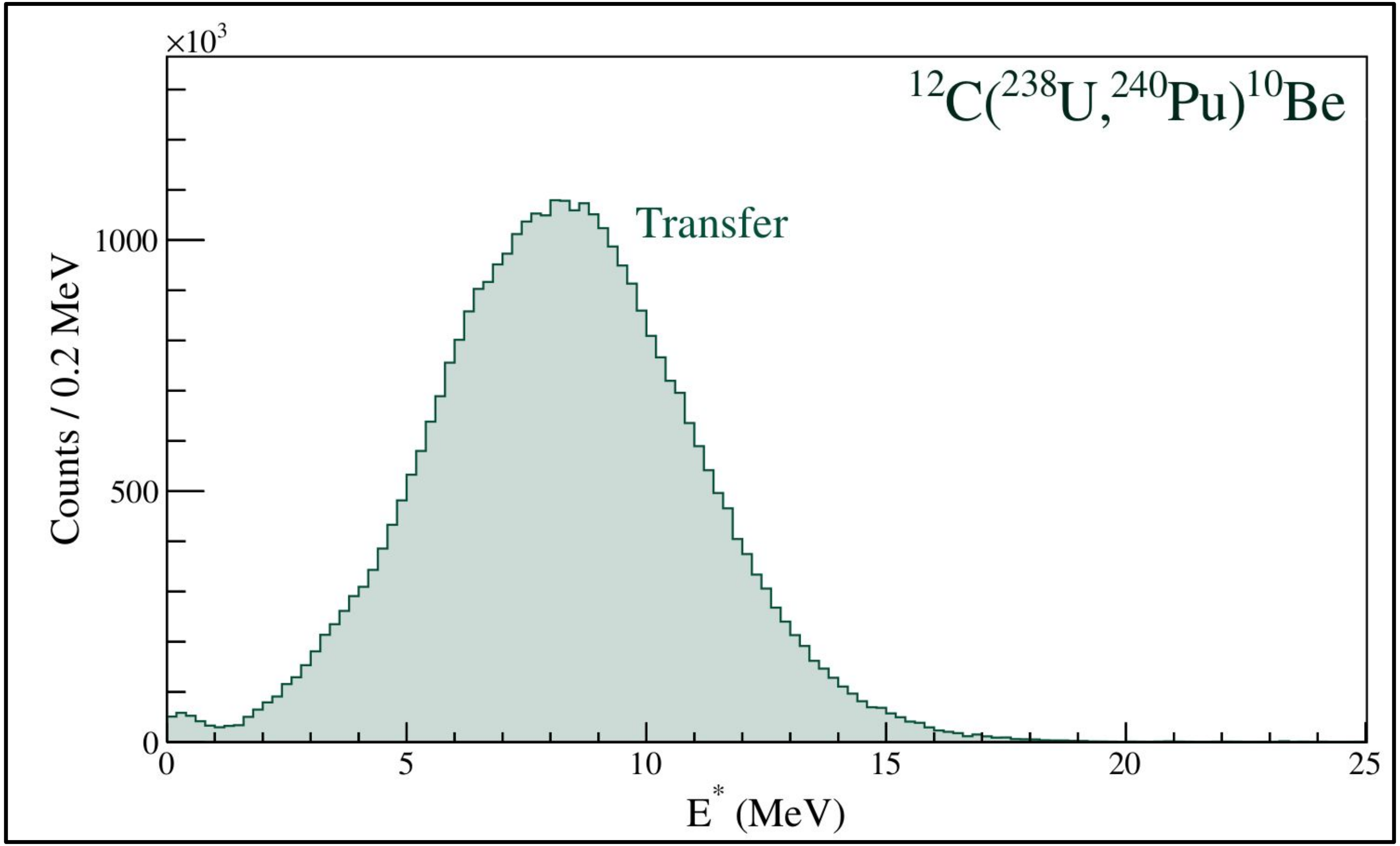
Excitation energy Resolution



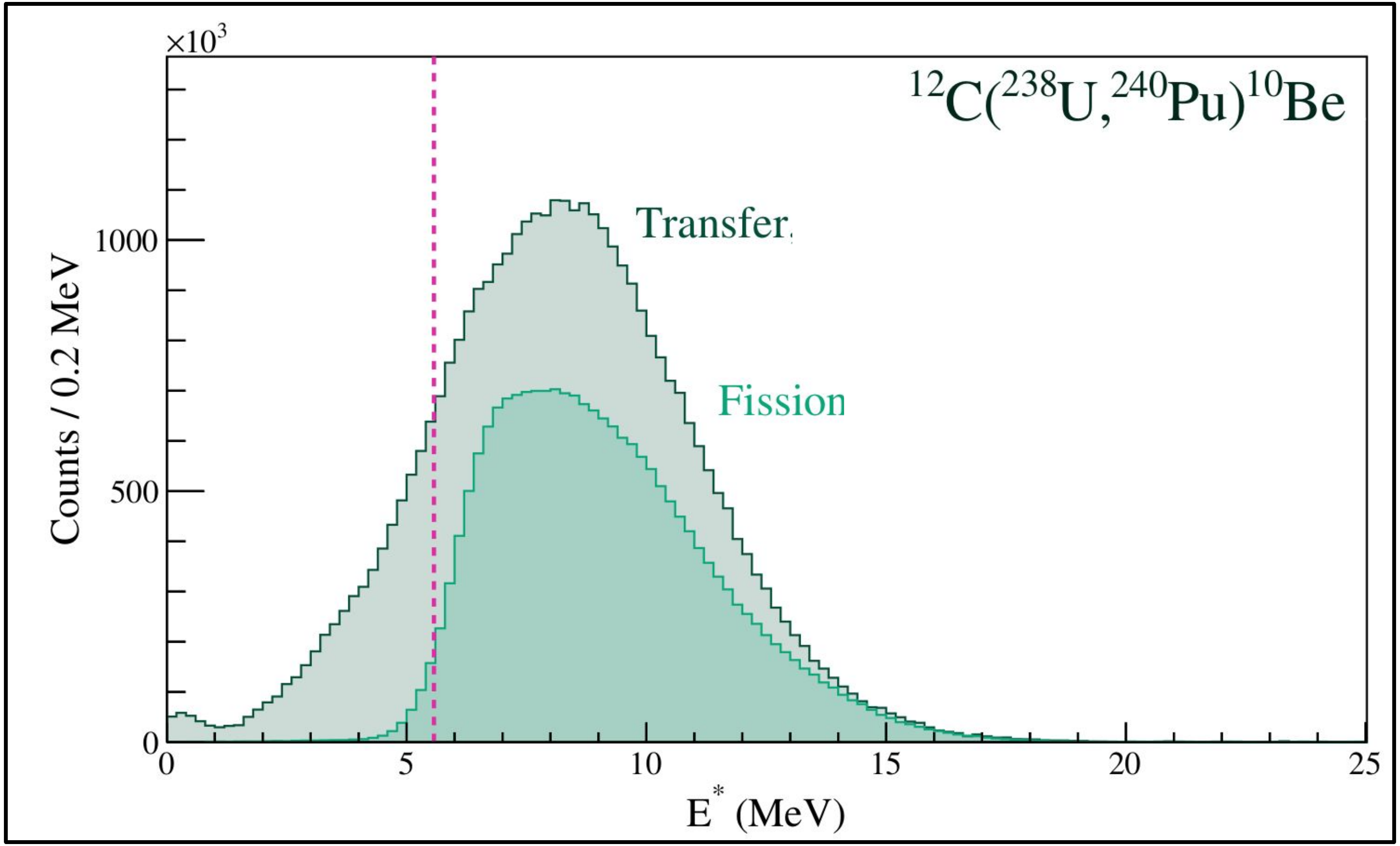
Excitation energy Resolution



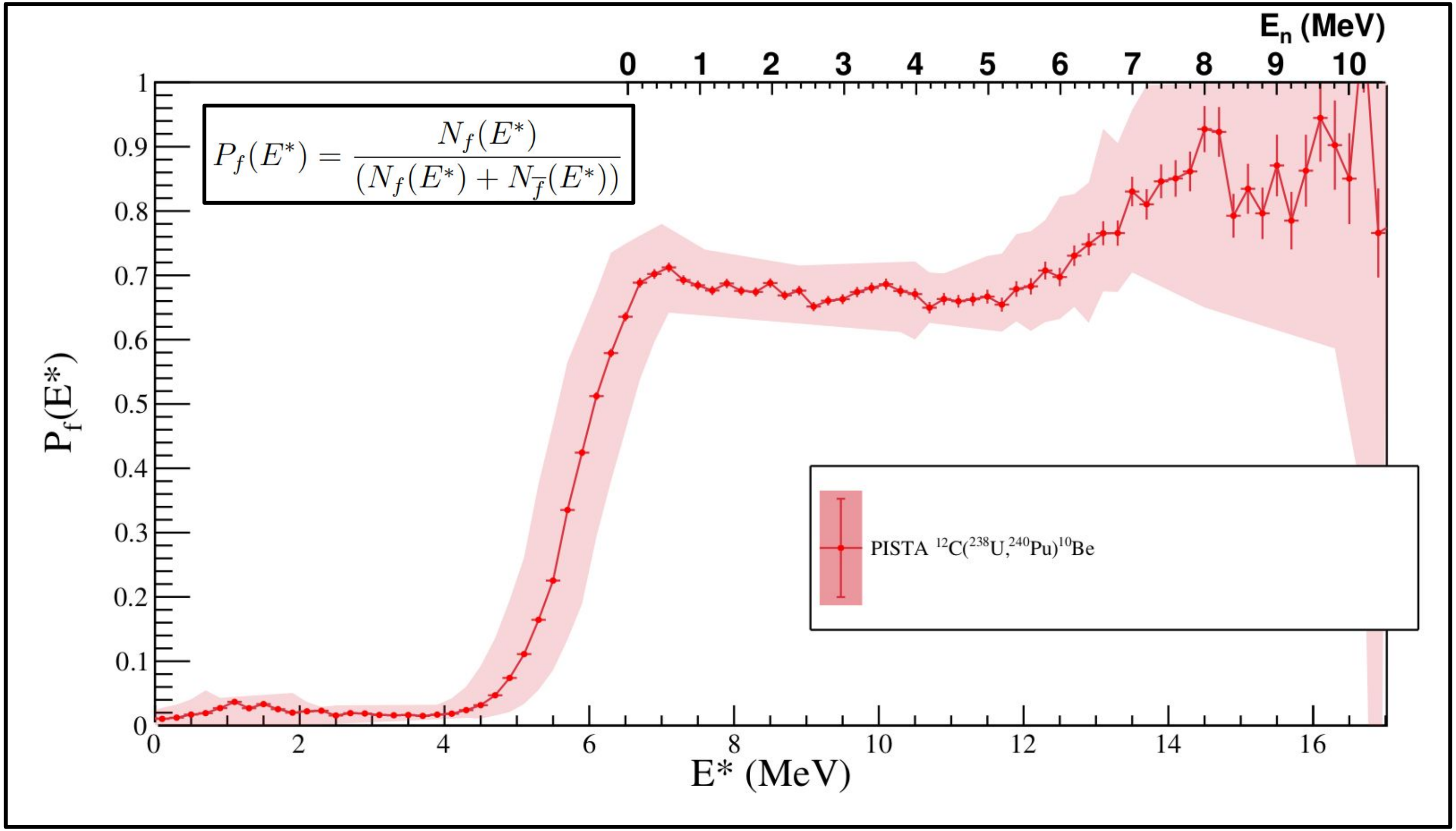
E* energy Spectrum



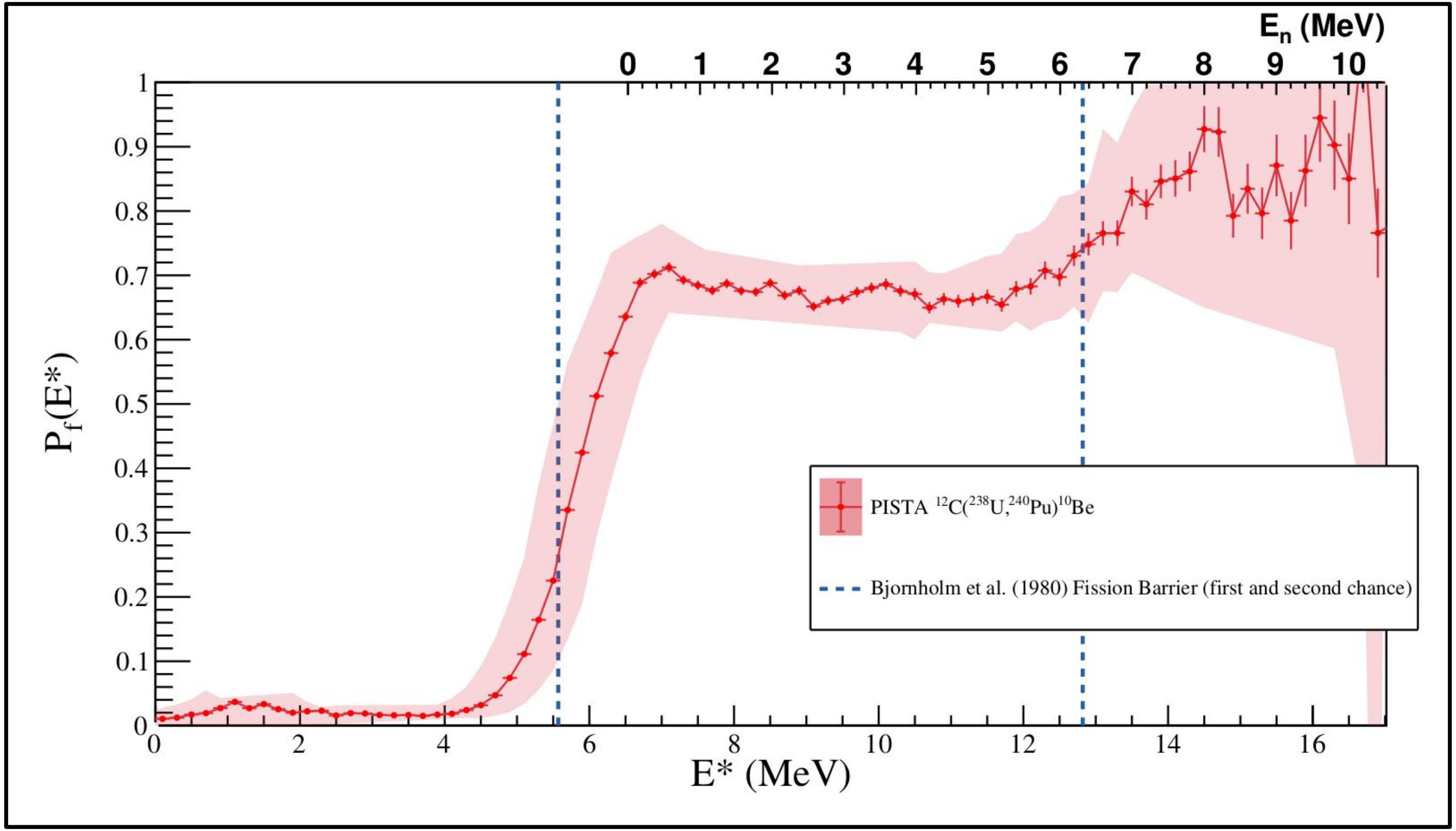
E* energy Spectrum



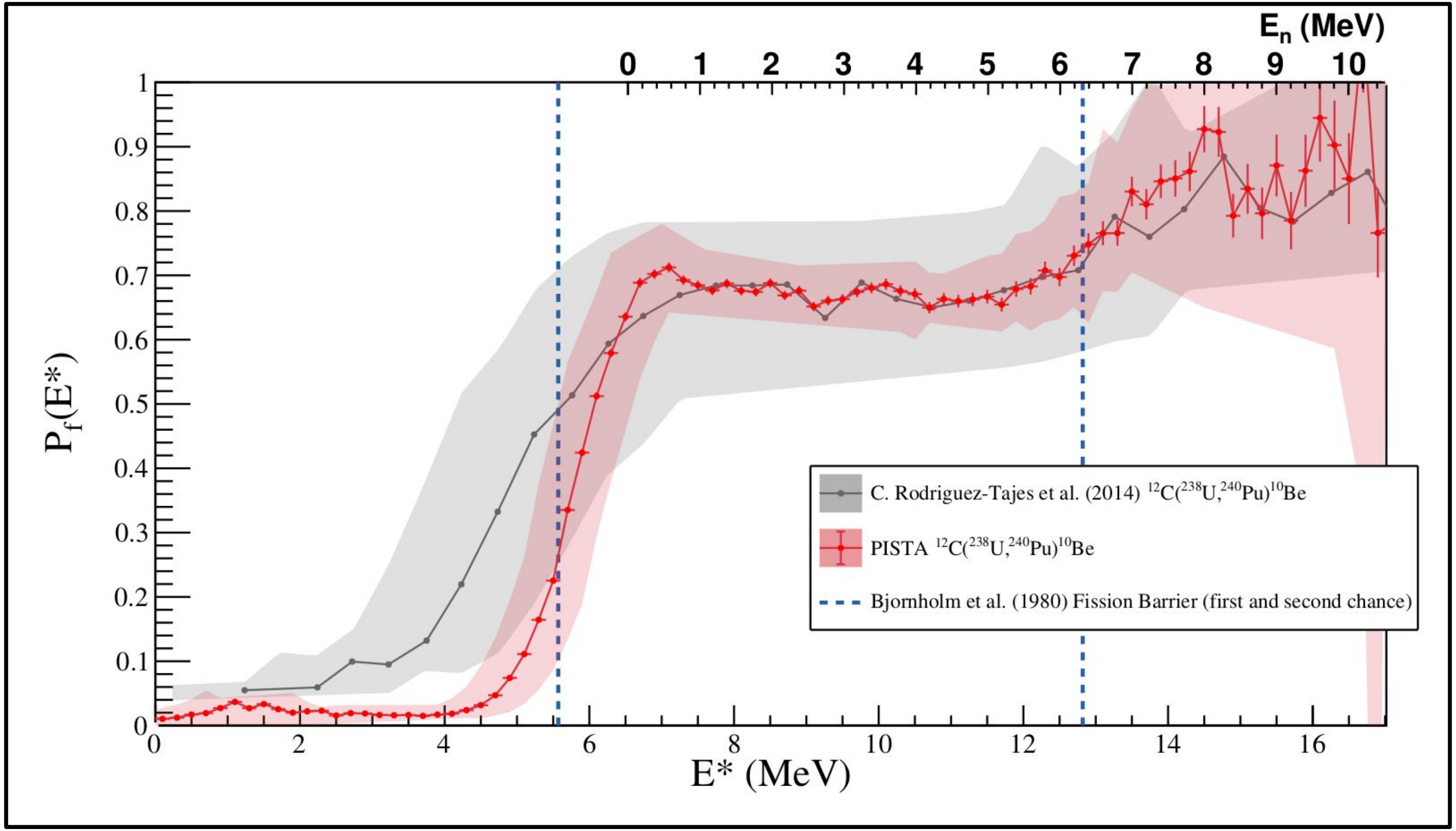
Fission Probability



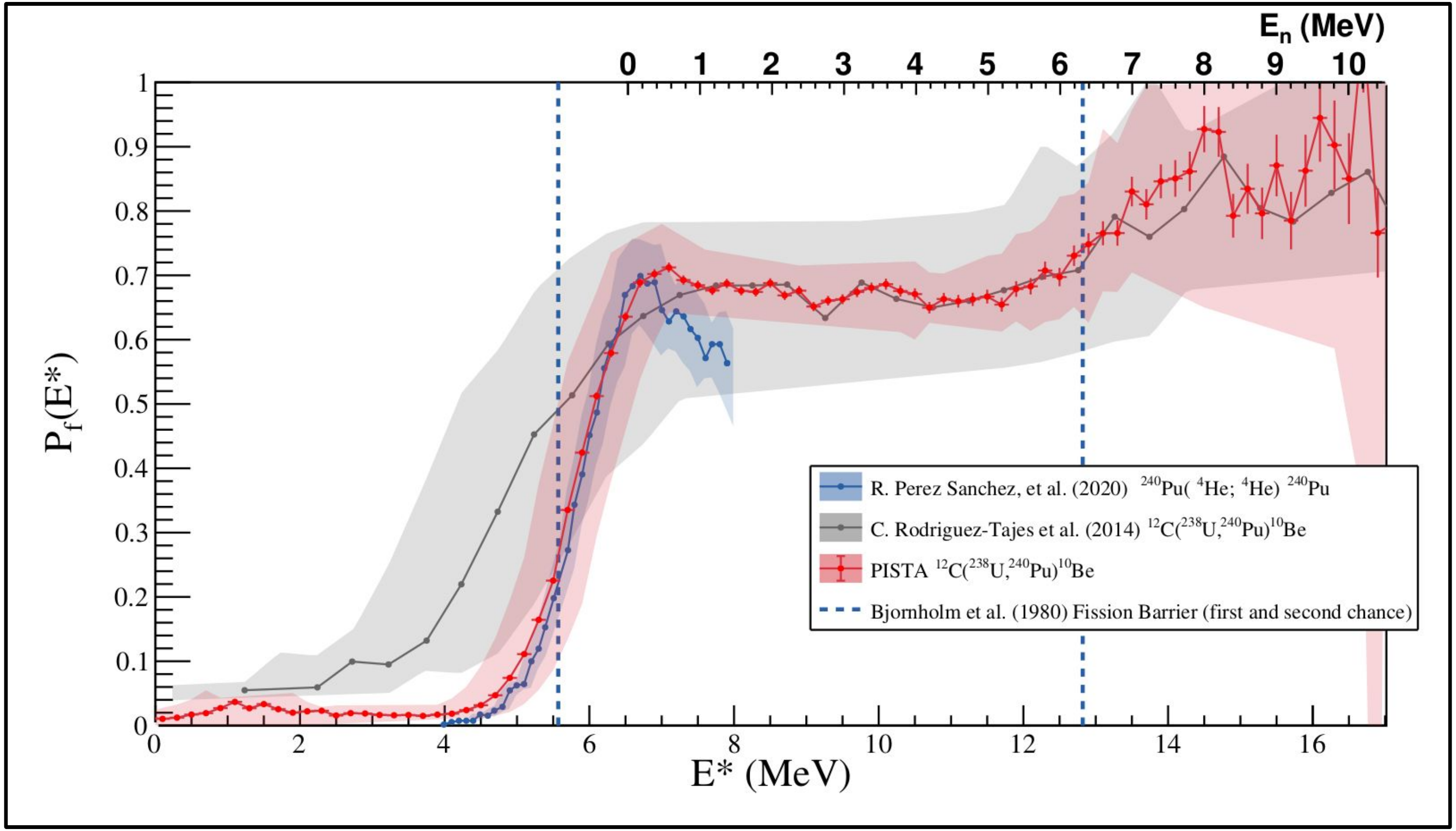
Fission Probability



Fission Probability

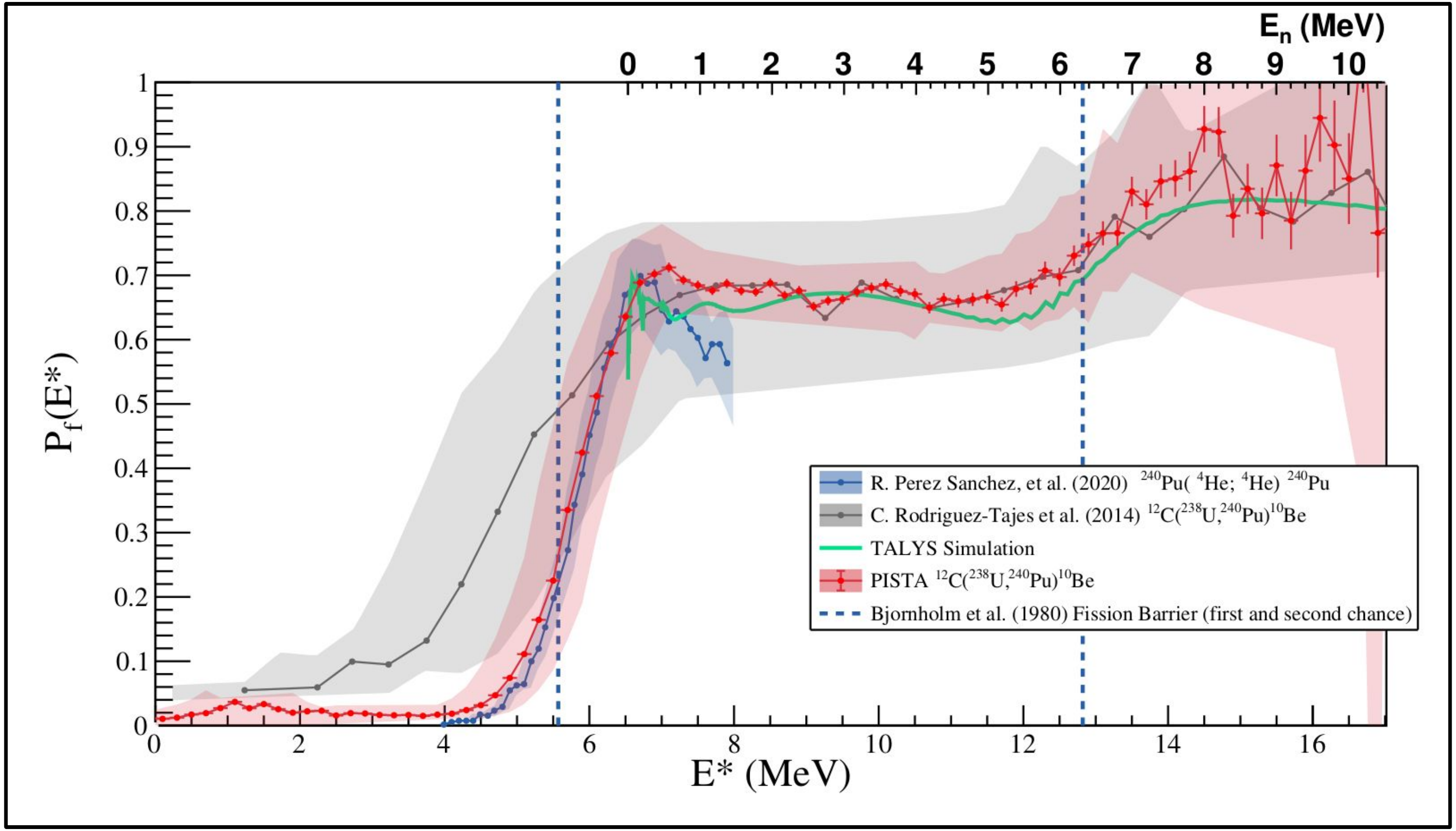


Fission Probability

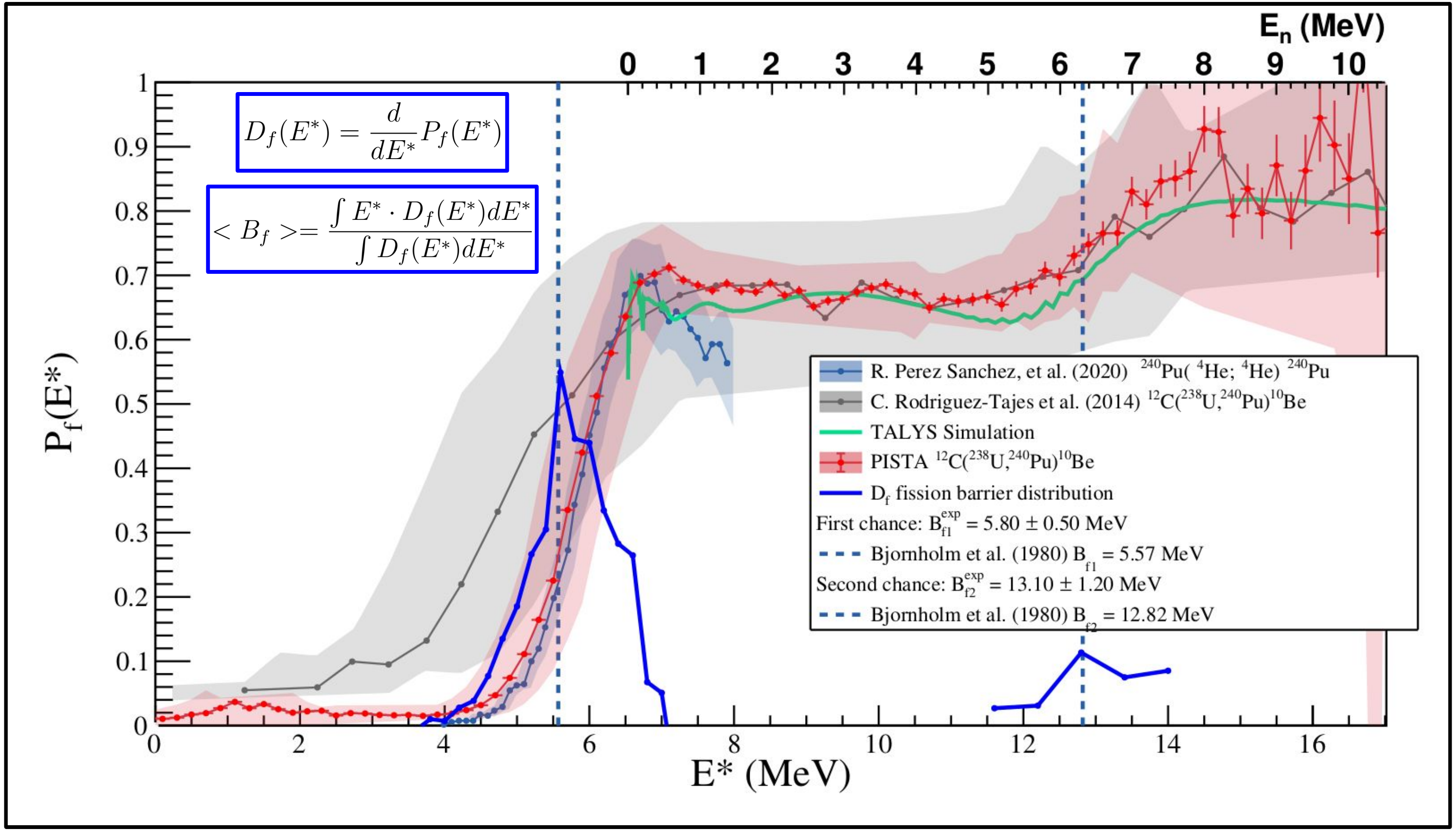


P. Romain, B. Morillon and H. Duatre. Nuclear Data Sheets, 131:222–258, 2016. Special Issue on Nuclear Reaction Data

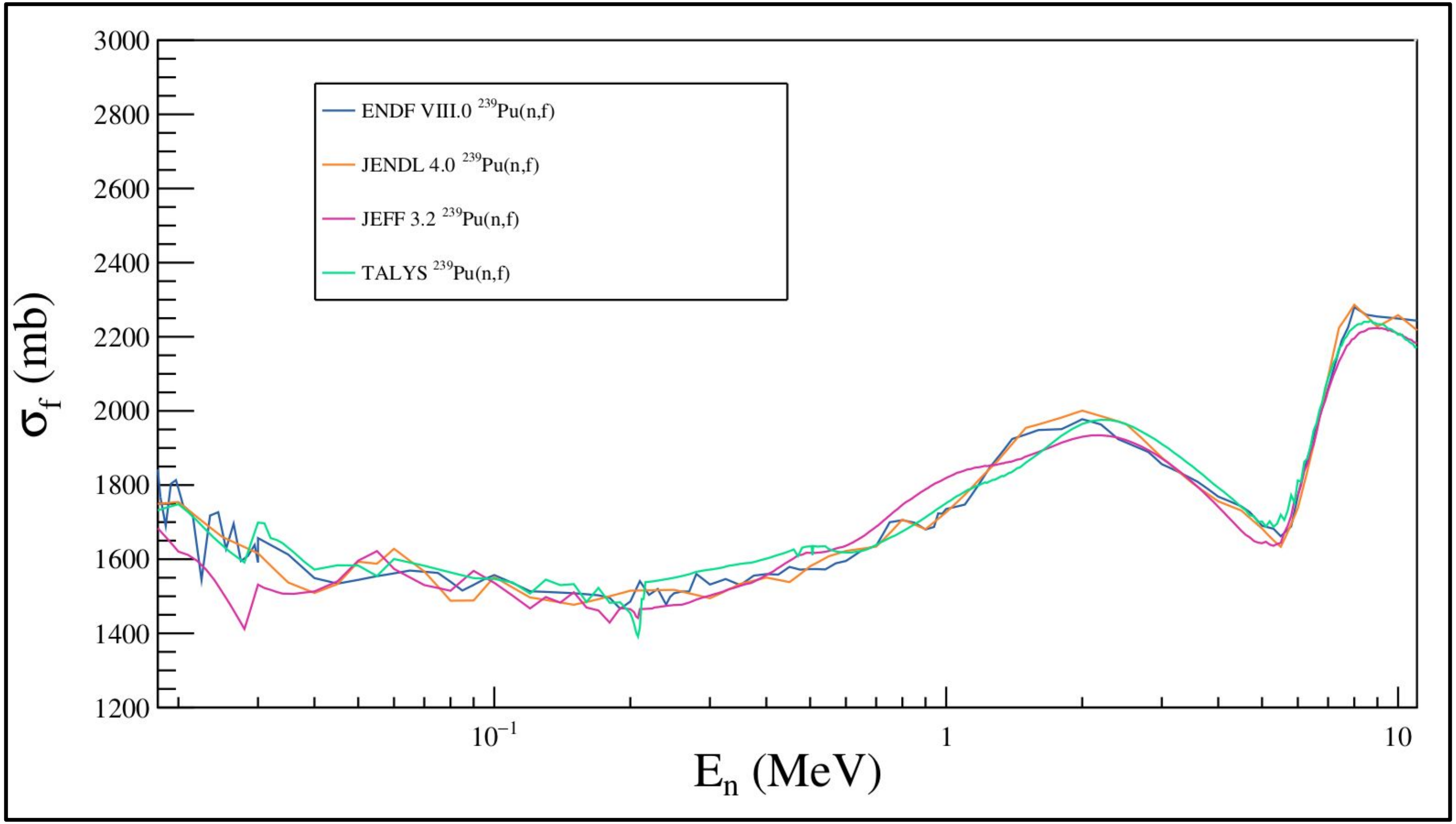
Fission Probability



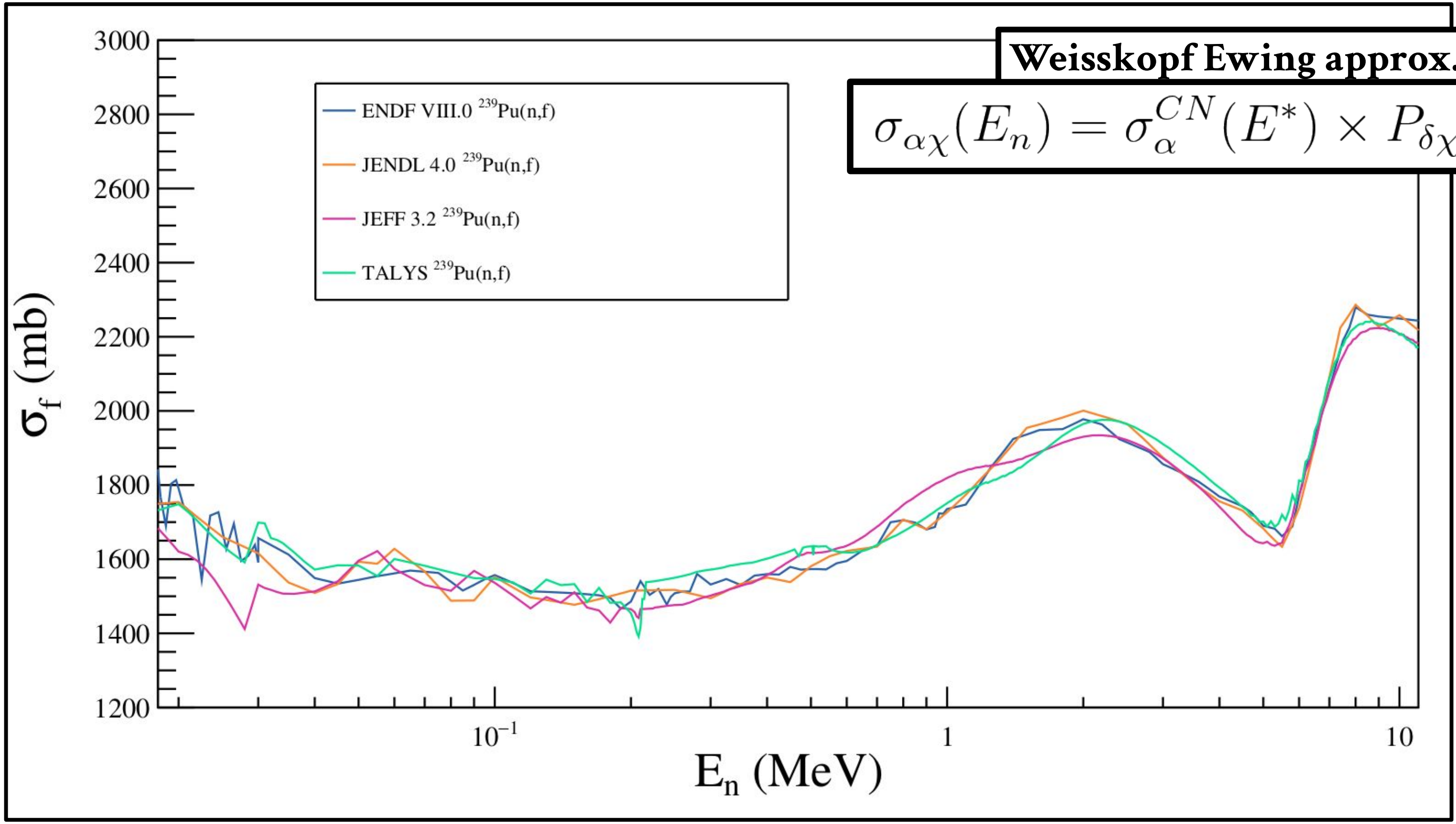
Fission Probability



Fission Cross section Indirect Measurement



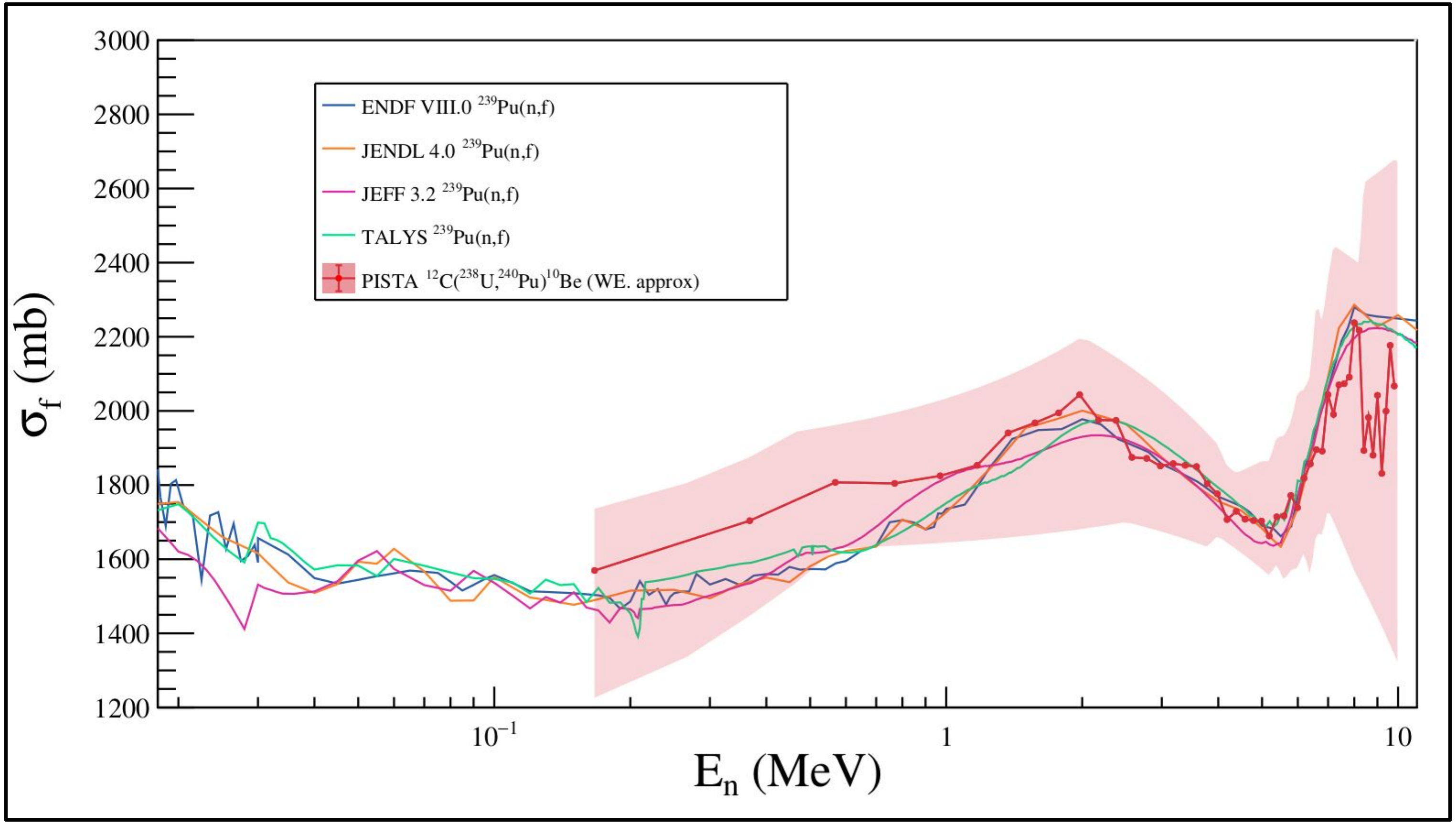
Fission Cross section Indirect Measurement



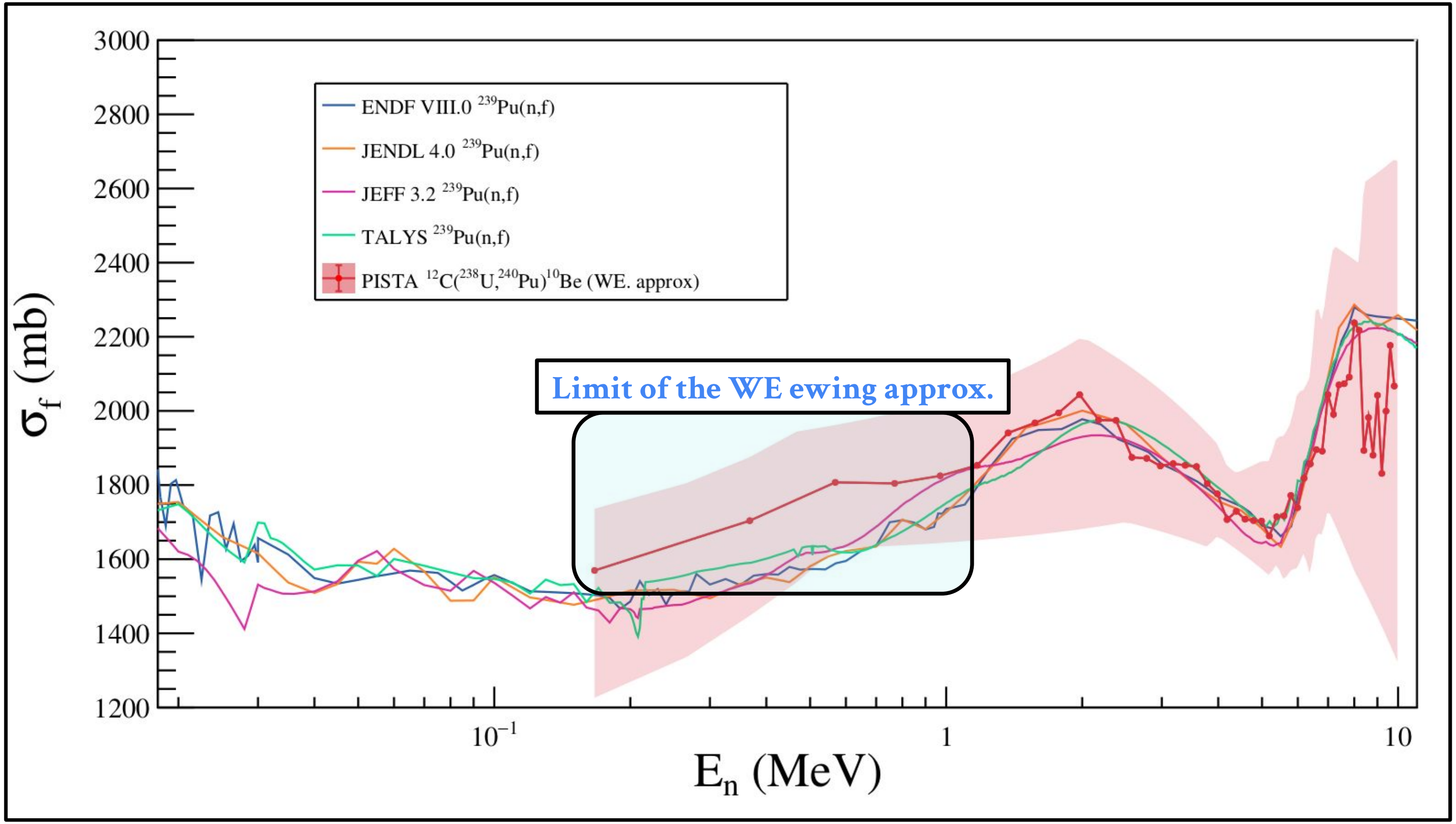
Weisskopf Ewing approx.

$$\sigma_{\alpha\chi}(E_n) = \sigma_{\alpha}^{CN}(E^*) \times P_{\delta\chi}(E^*)$$

Fission Cross section Indirect Measurement



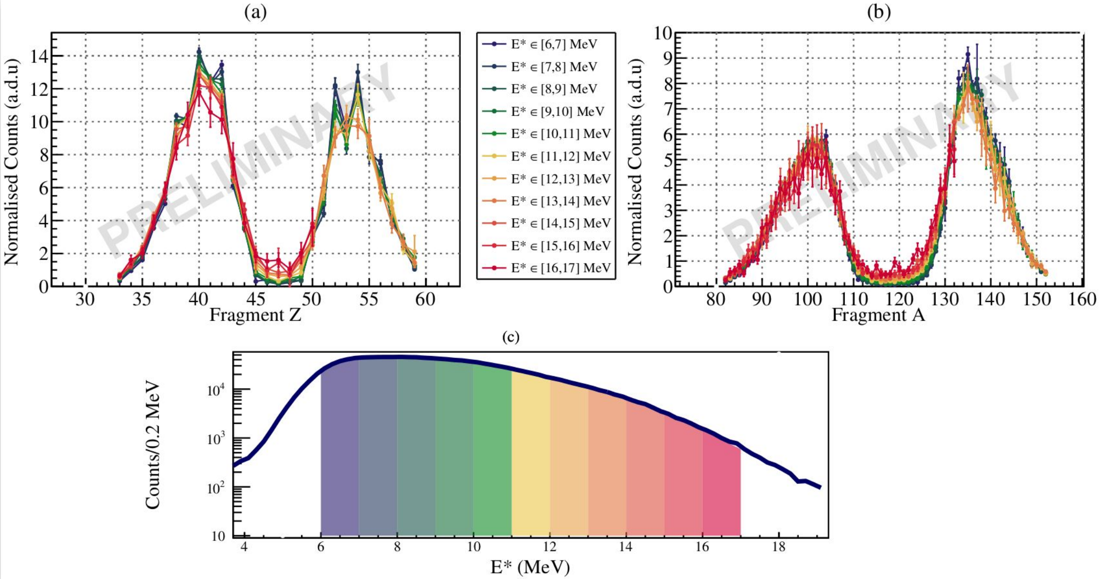
Perspectives / Fission Cross section Indirect Measurement



Summary and perspectives

- First used in the **E850 campaign** (June last year & April this year), **PISTA** combines inverse kinematics with multi-nucleon transfer, enabling simultaneous study of multiple fissioning systems with isotopic characterization of fragments and **precise identification of the fissioning system** in (A,Z) and its excitation energy.
  ($\sigma(E^*)$ = 520 keV / FWHM(PId) = 1.1 %)

- Early results, **extend the scope of fission studies at VAMOS**, including applications to **surrogate methods studies**



Next VAMOS présentations

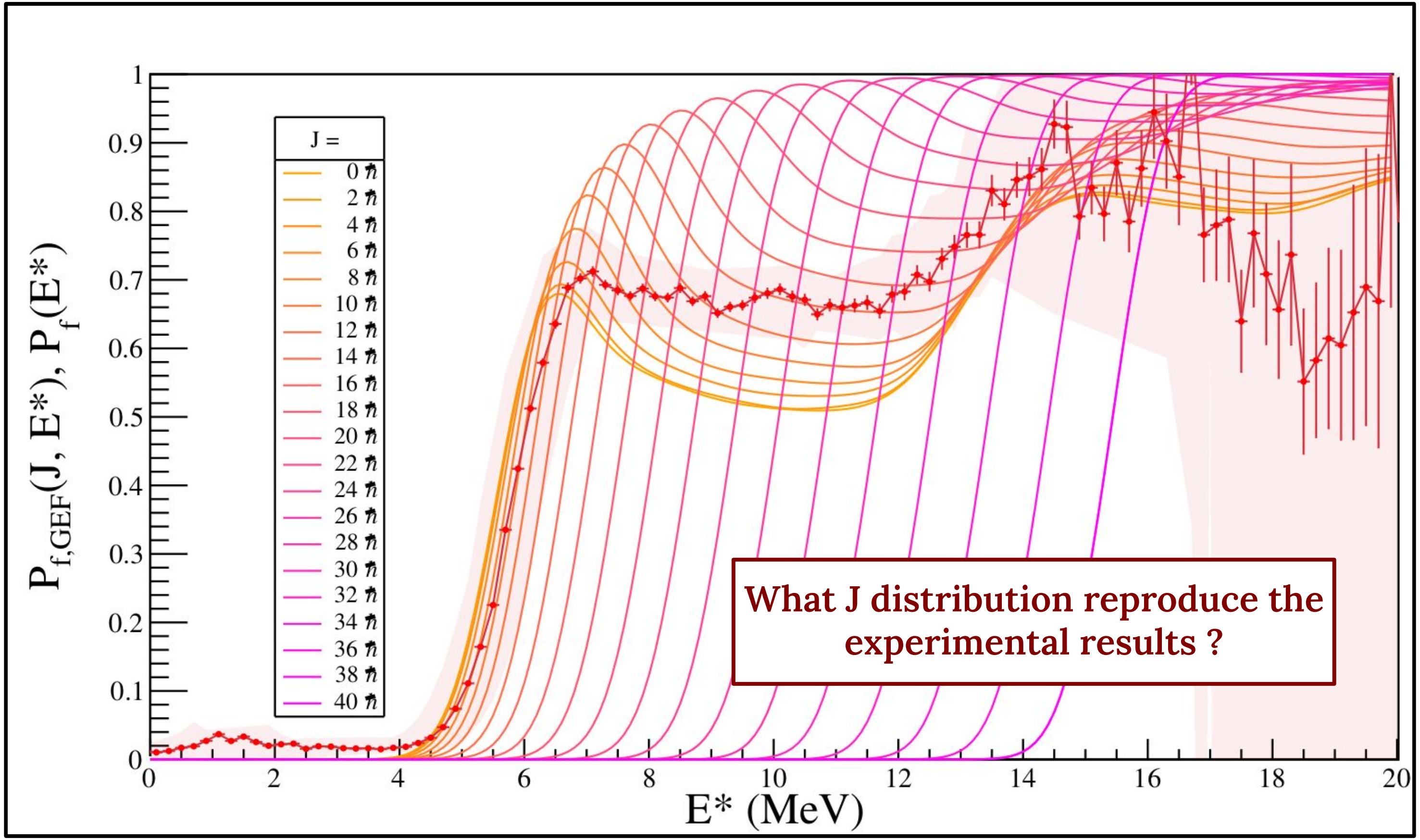
Indu Jangid “just after me” 23/09
Room Inspire 3

Alex Cobo Zarzuelo 23/09 18:05
Room Inspire 2

Theodore Efremov. 23/09 18:25
Room Inspire 2

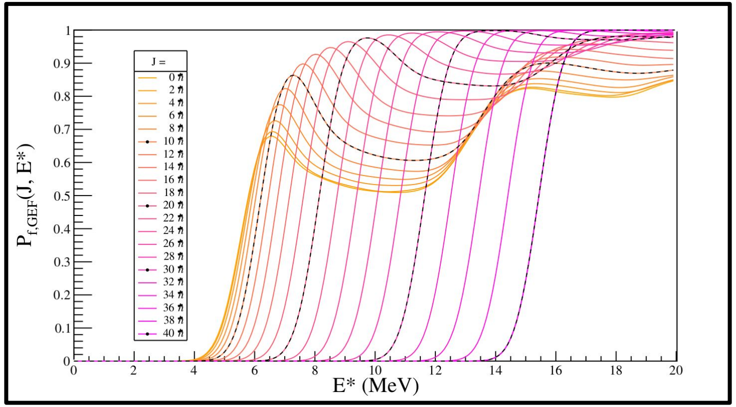
Alexis Francheteau *Poster Session*

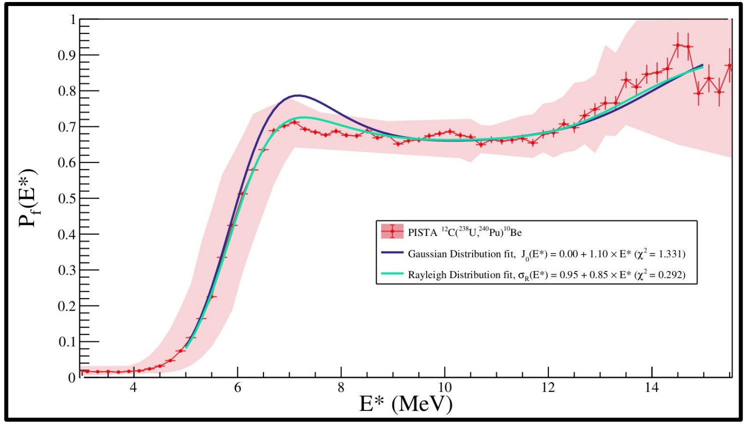
Fission Probability Comparison with GEF



What J distribution reproduce the experimental results ?

Fissionning System Angular Momentum Inference



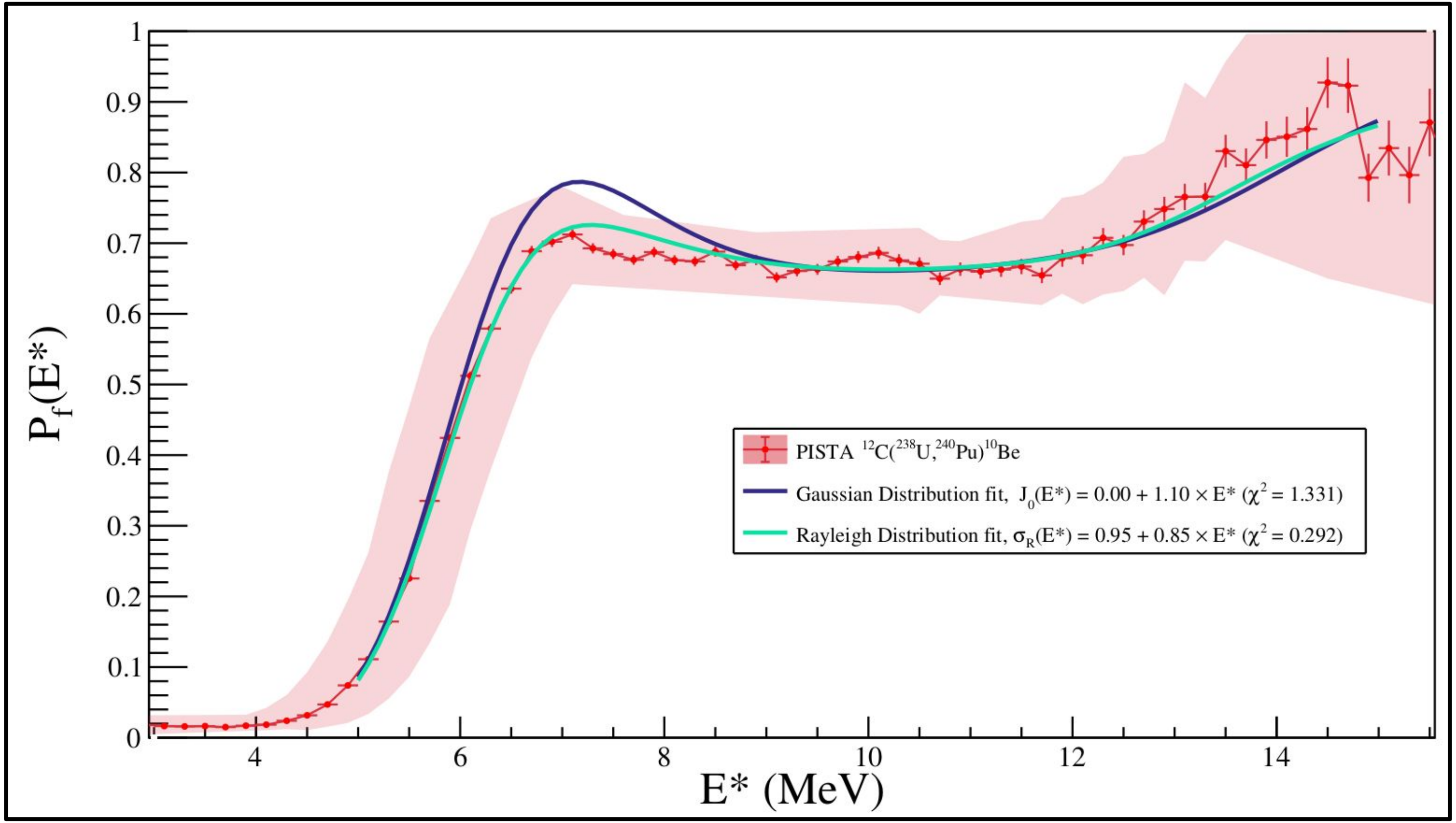


$$P_{\Re}(J) = \frac{(2J+1)}{2 \cdot \sigma_{\Re}^2} \cdot \exp\left(-\frac{(J+1/2)^2}{2 \cdot \sigma_{\Re}^2}\right)$$

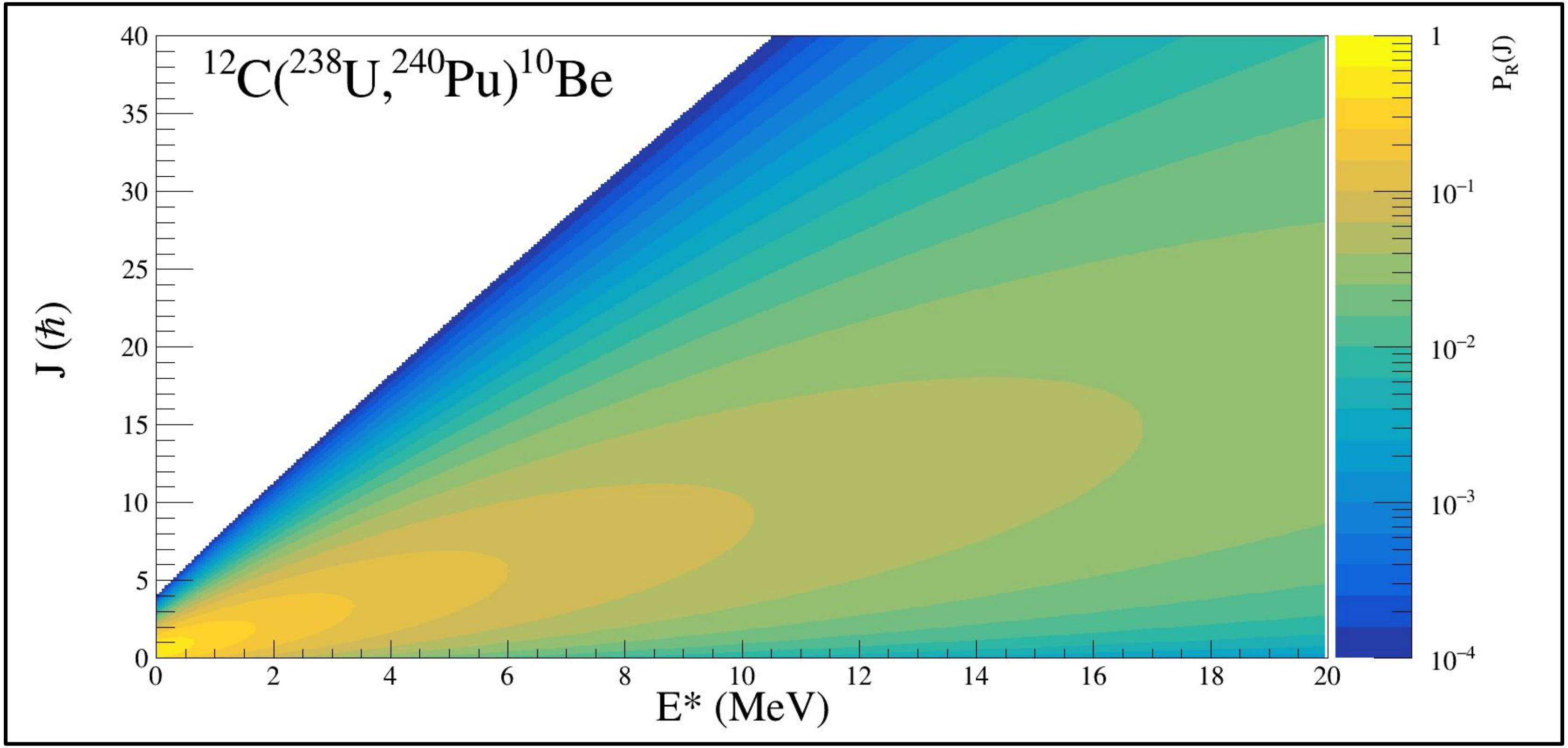
$$\sigma_{\Re}(E^*) = a_{\Re} \cdot E^* + b_{\Re}$$

$$\chi^2 = \int_{E_{min}}^{E_{max}} \left[P_f(E^*) - \sum_{J=0}^{40} P_{\Re}(J, E^*) \cdot P_{f,GEF}(E^*|J)\right]^2 dE^*$$

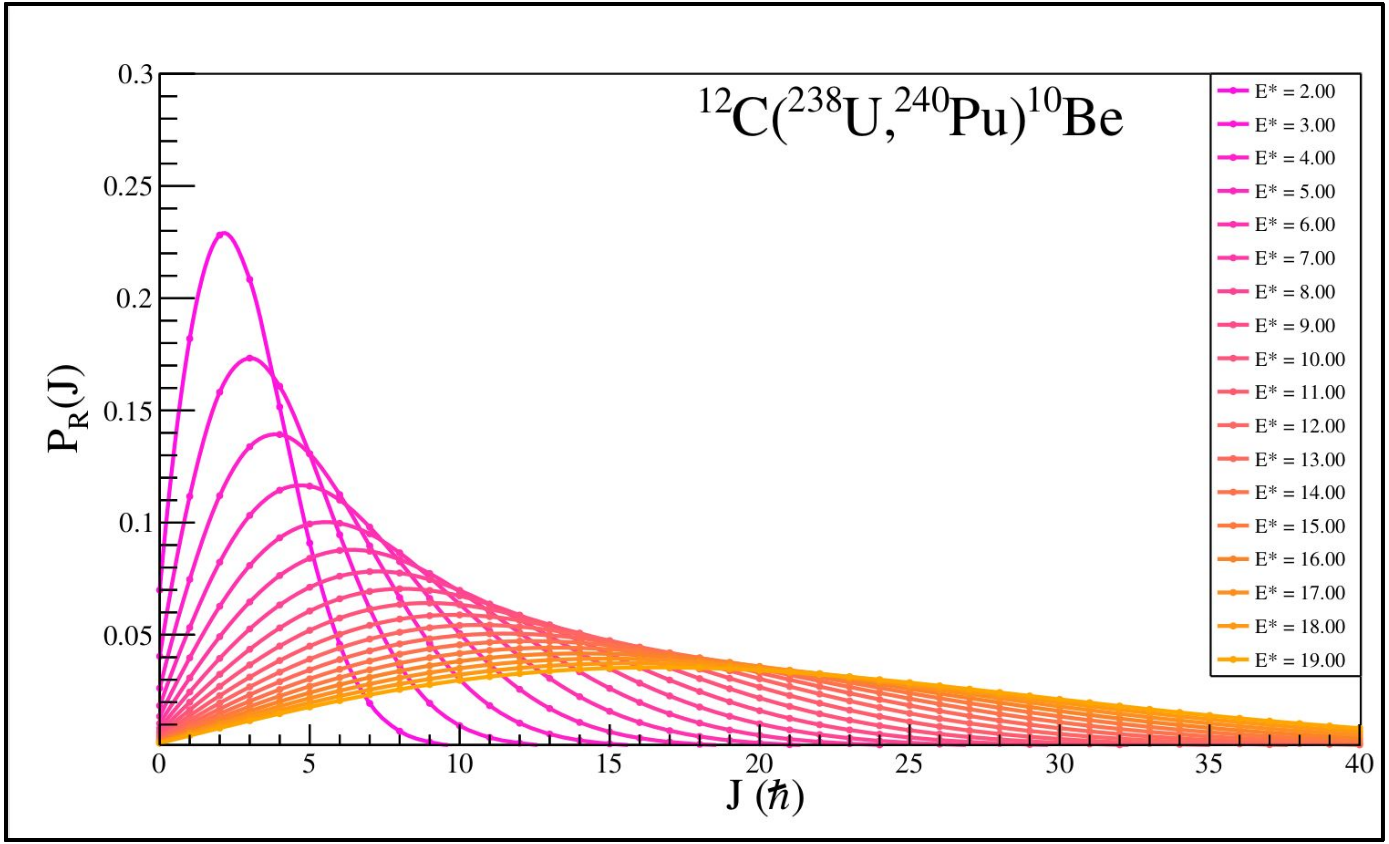
Fissionning System Angular Momentum Inference



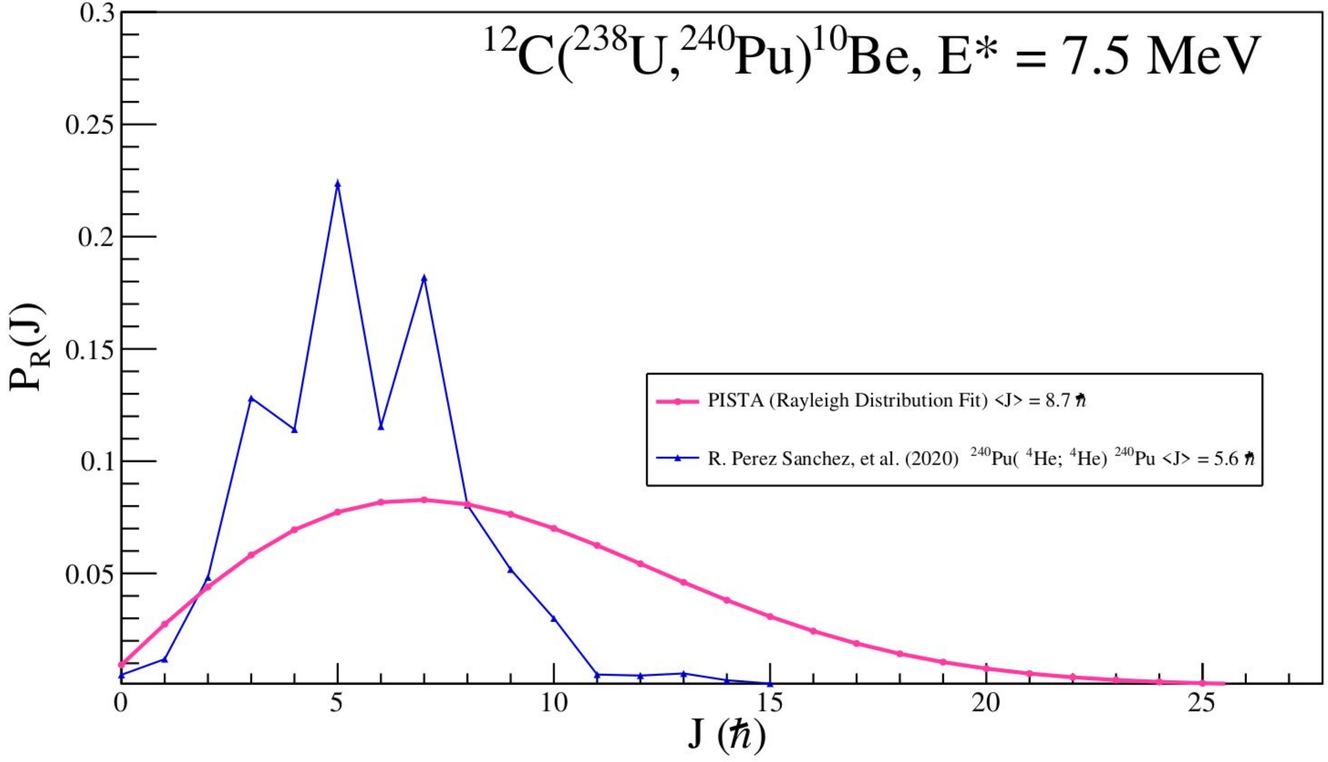
Fissionning System Angular Momentum Inference

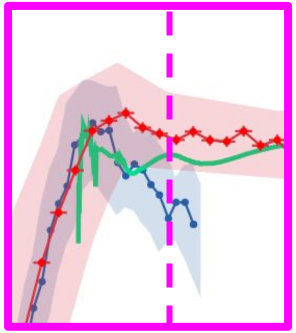


Fissionning System Angular Momentum Inference

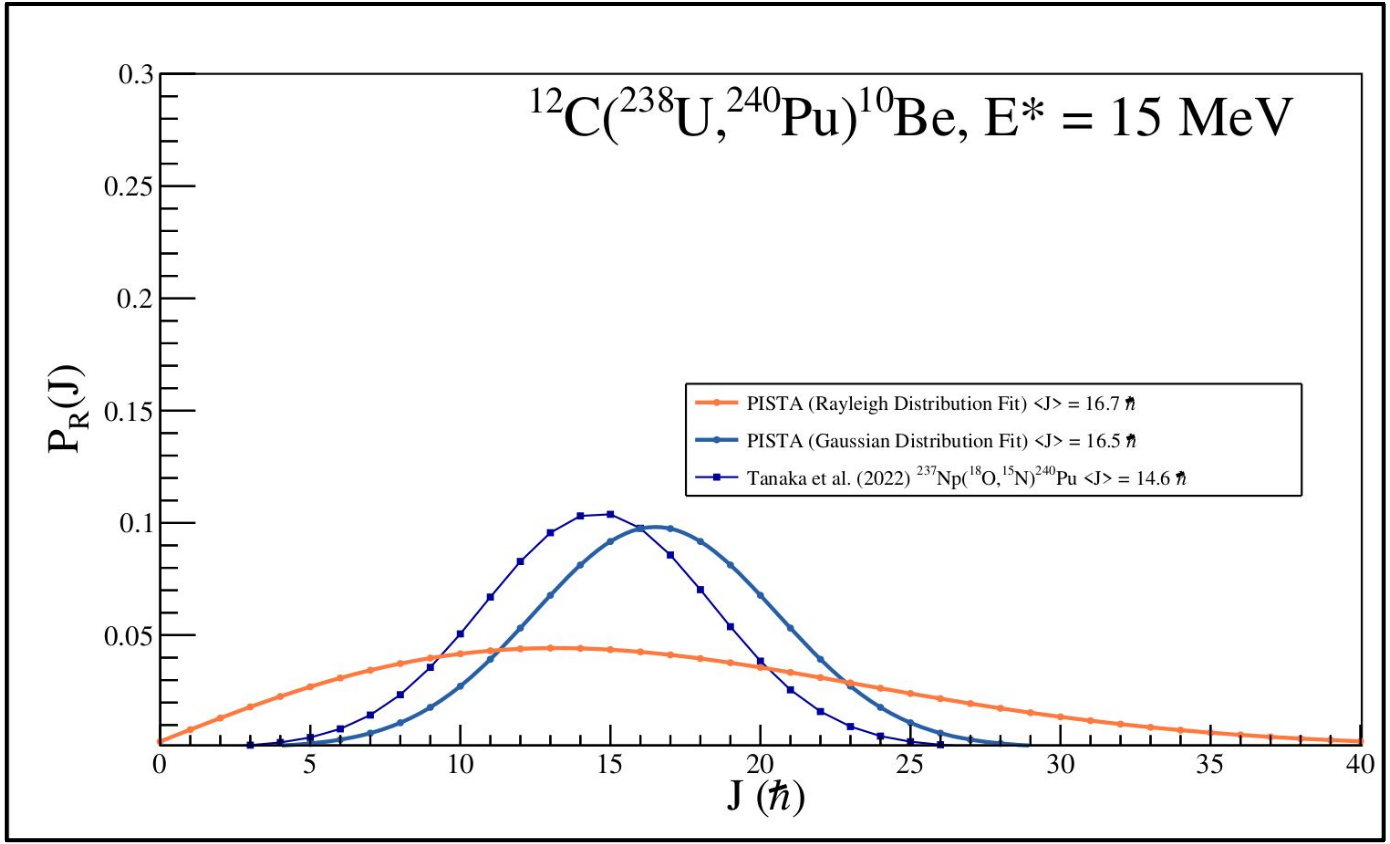


Fissionning System Angular Momentum Inference

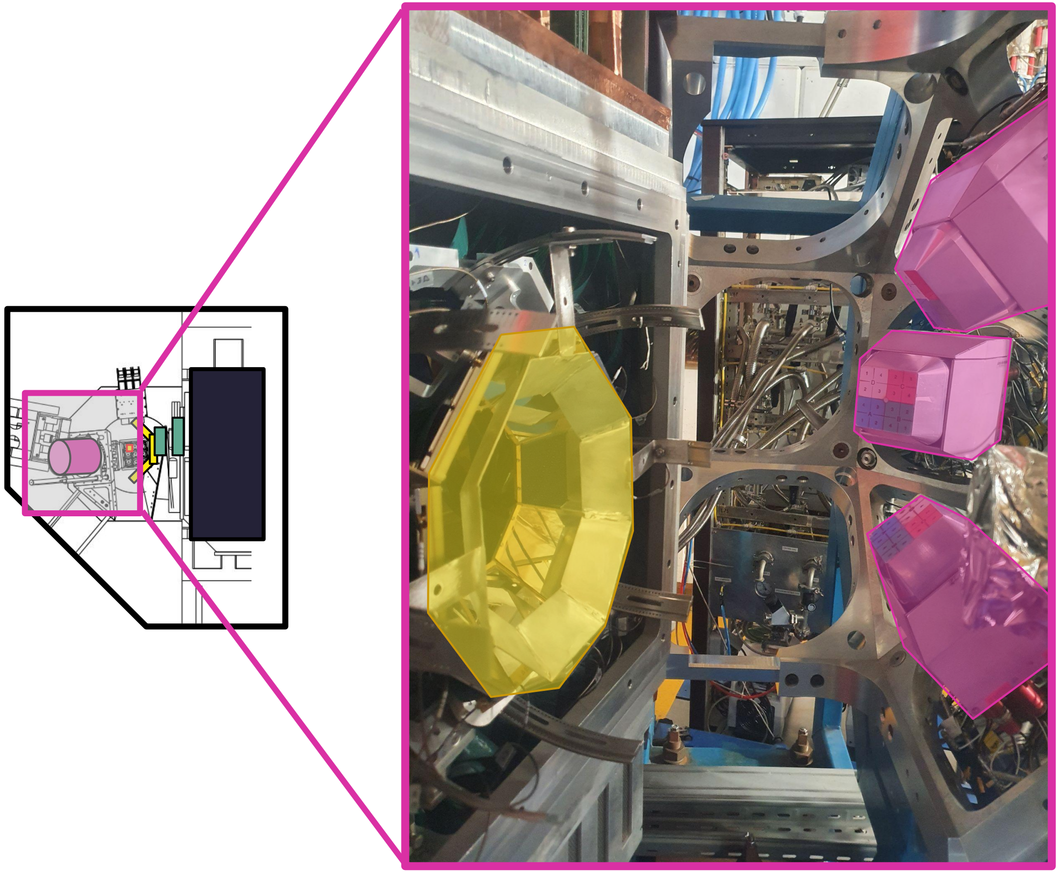




Fissionning System Angular Momentum Inference

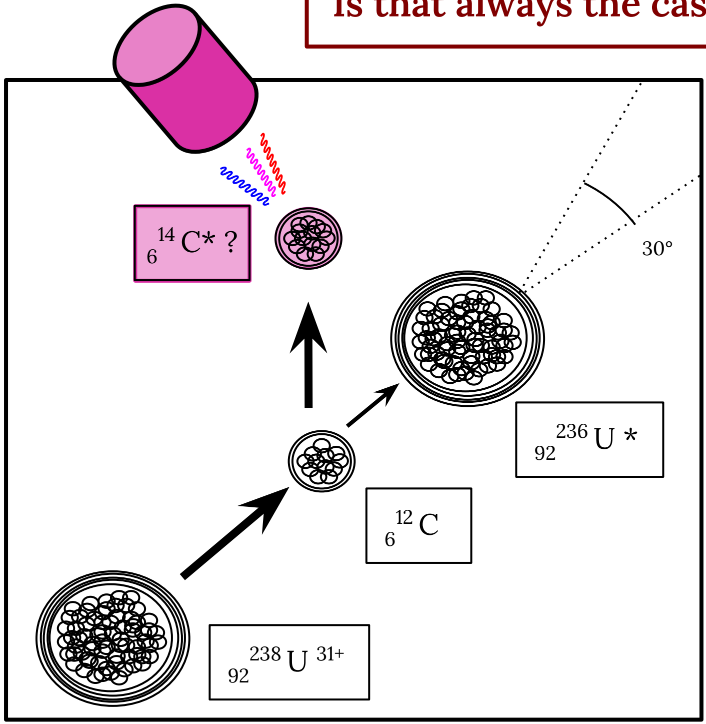


Excitation of the Target-Like



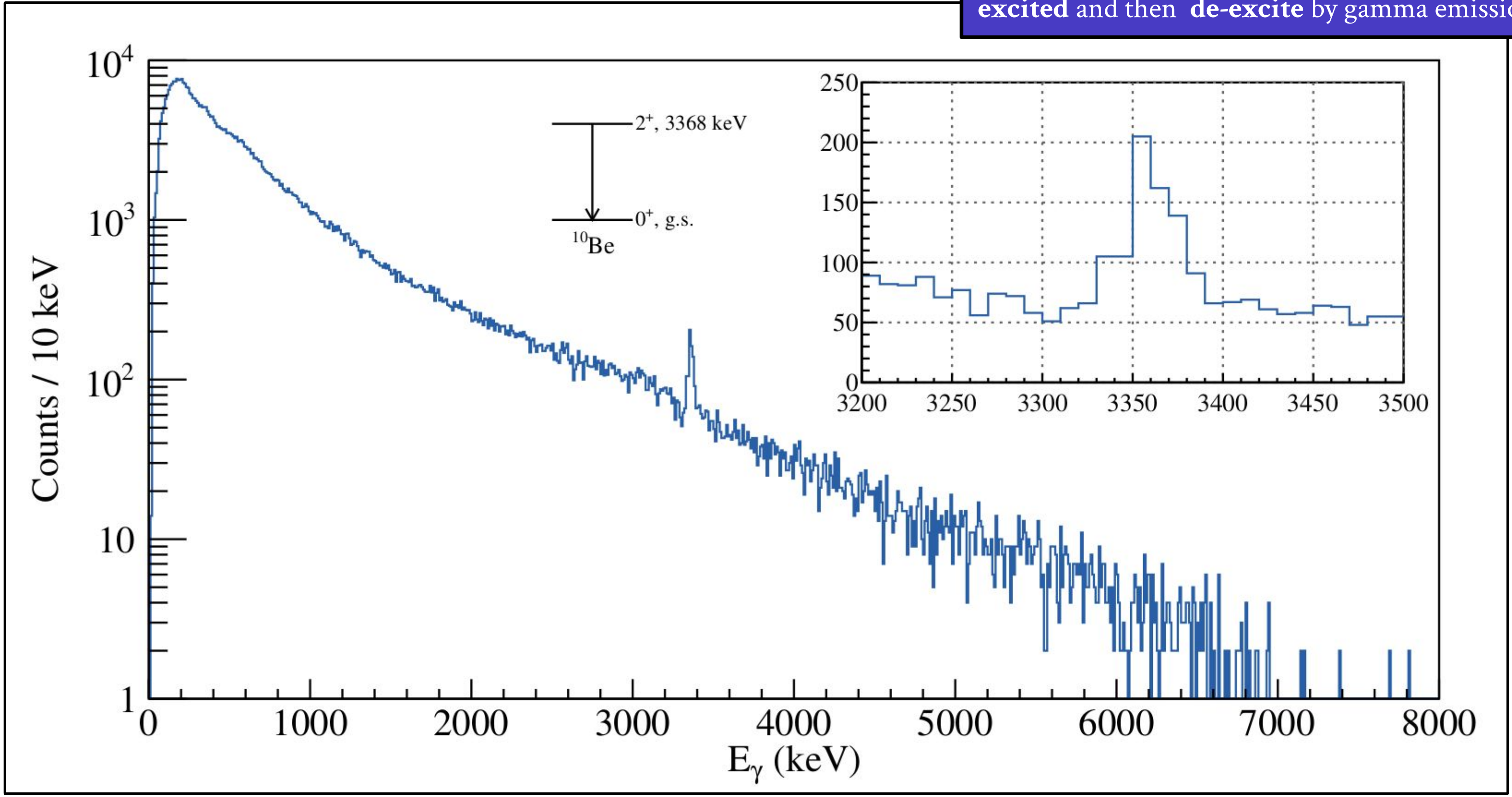
Assuming [...] that the target-like nucleus **is not excited** after the interaction we have ...

Is that always the case?

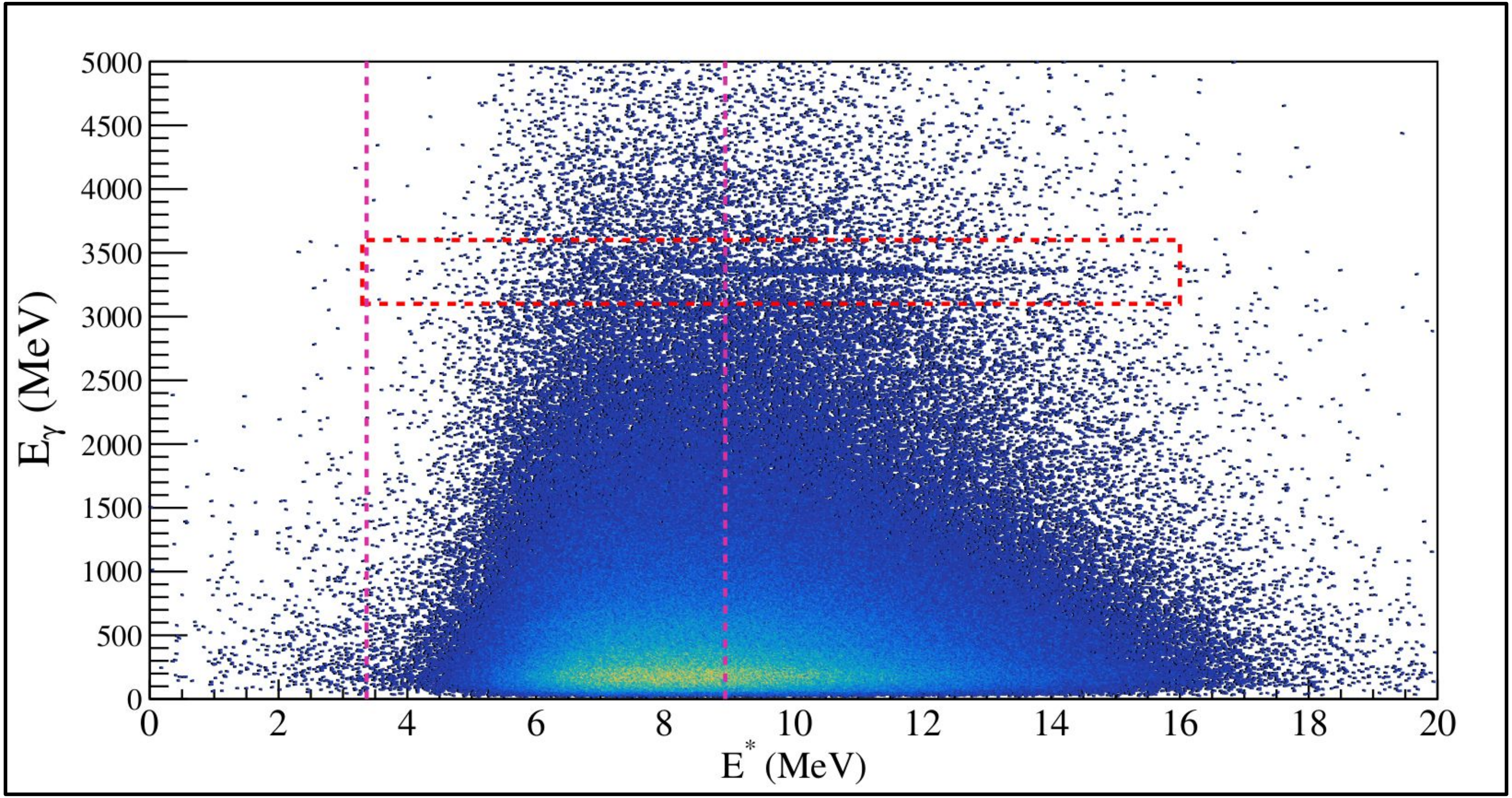


Excitation of the Target-Like

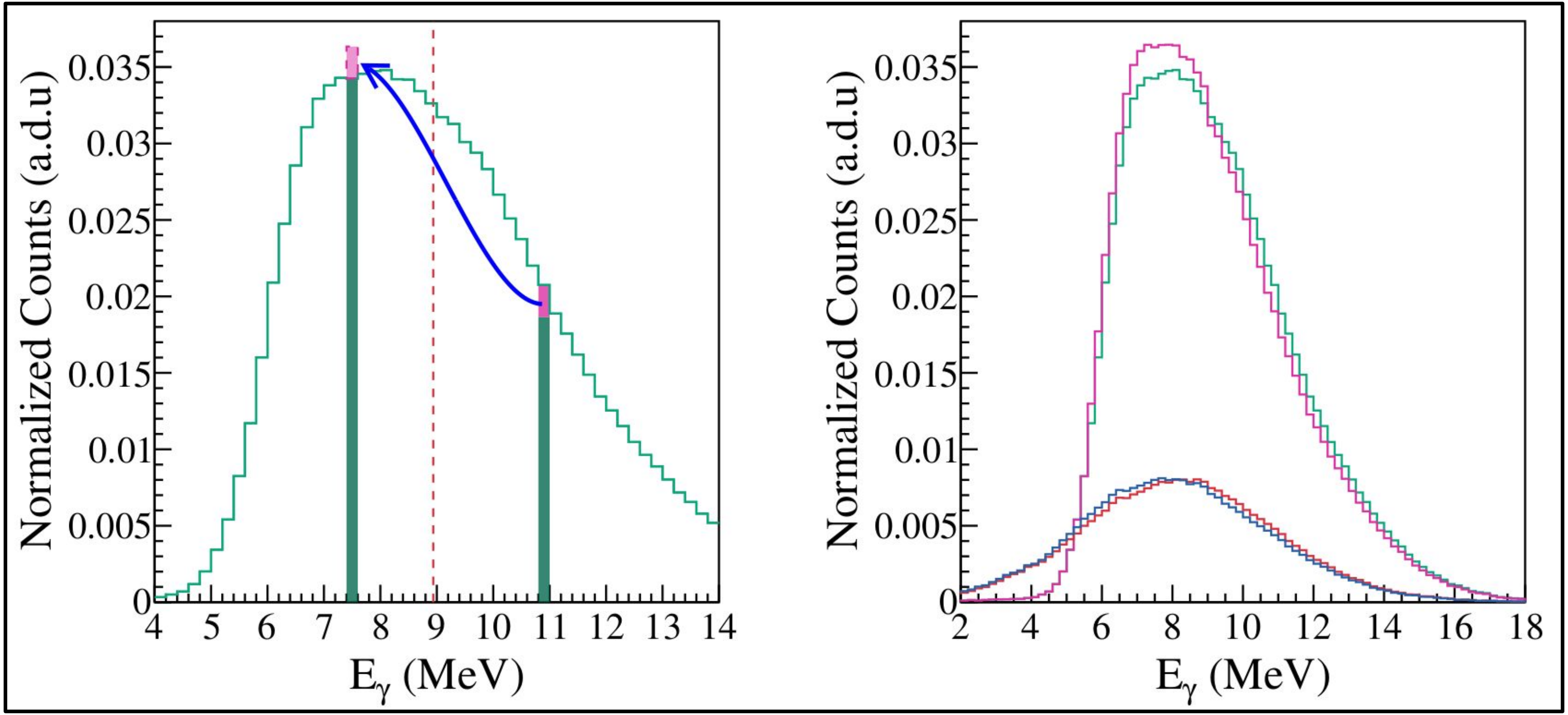
Assuming that the target-like nucleus **has been excited** and then **de-excite** by gamma emission



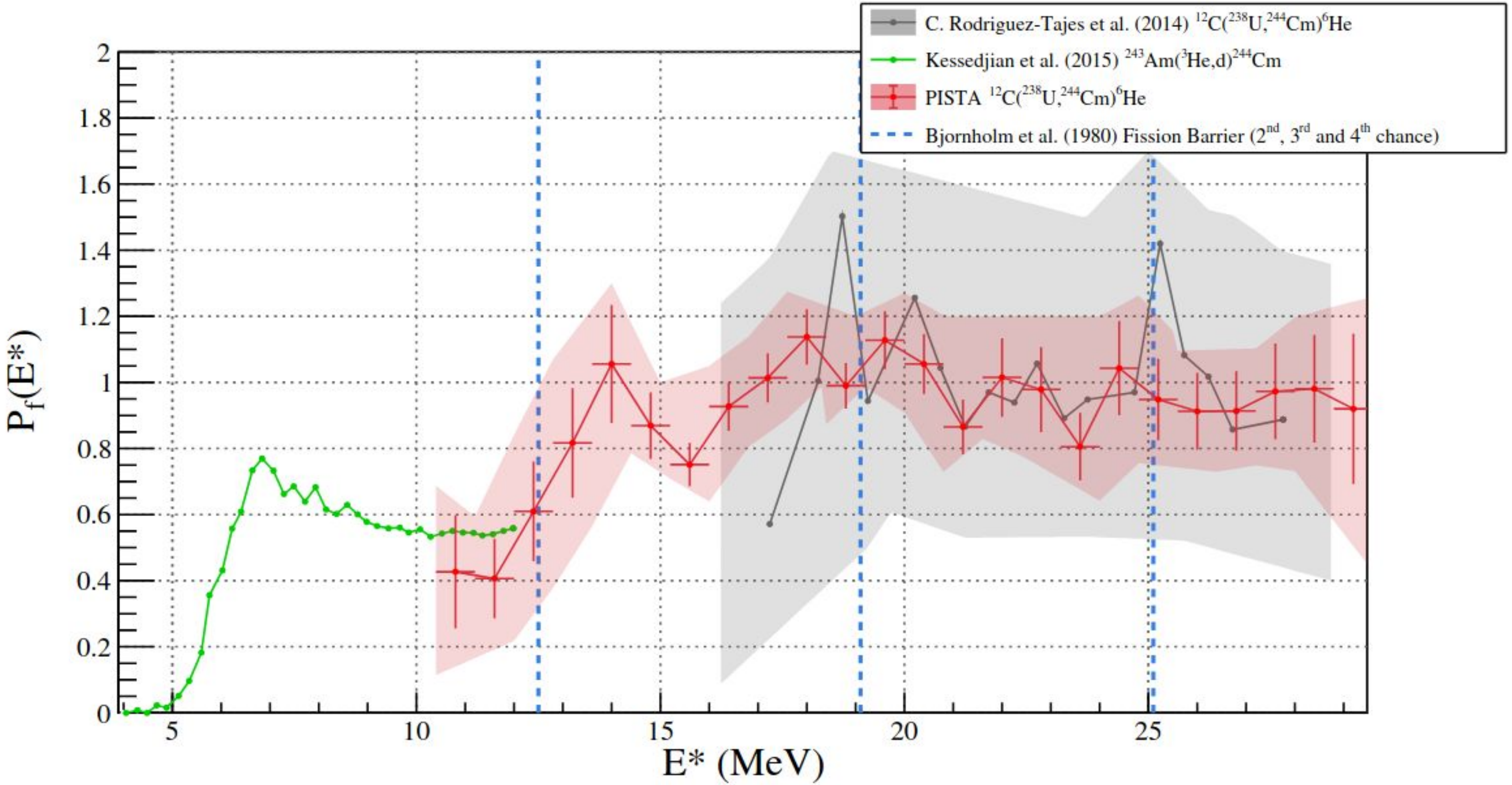
Excitation of the Target-Like



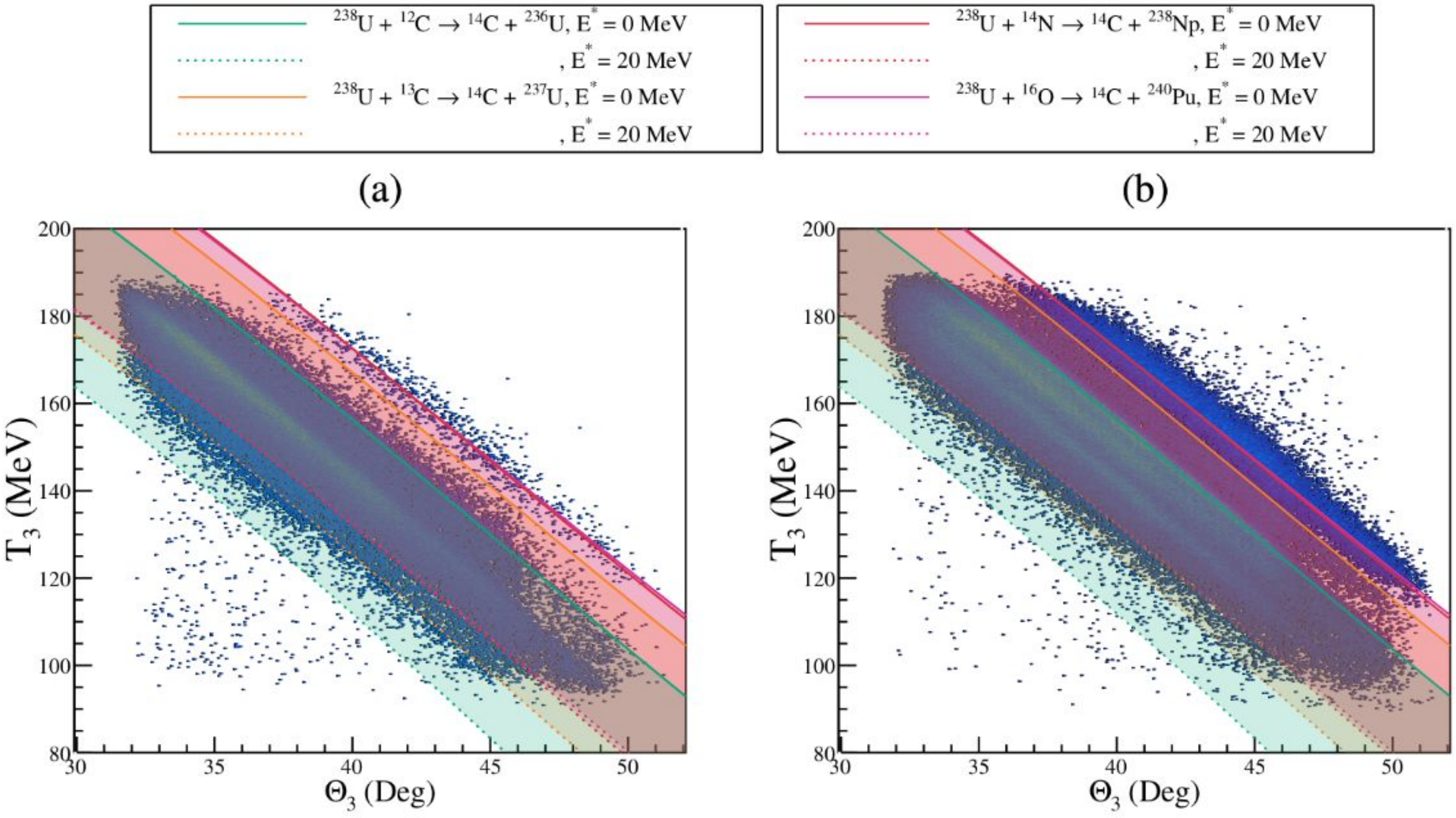
Excitation of the Target-Like



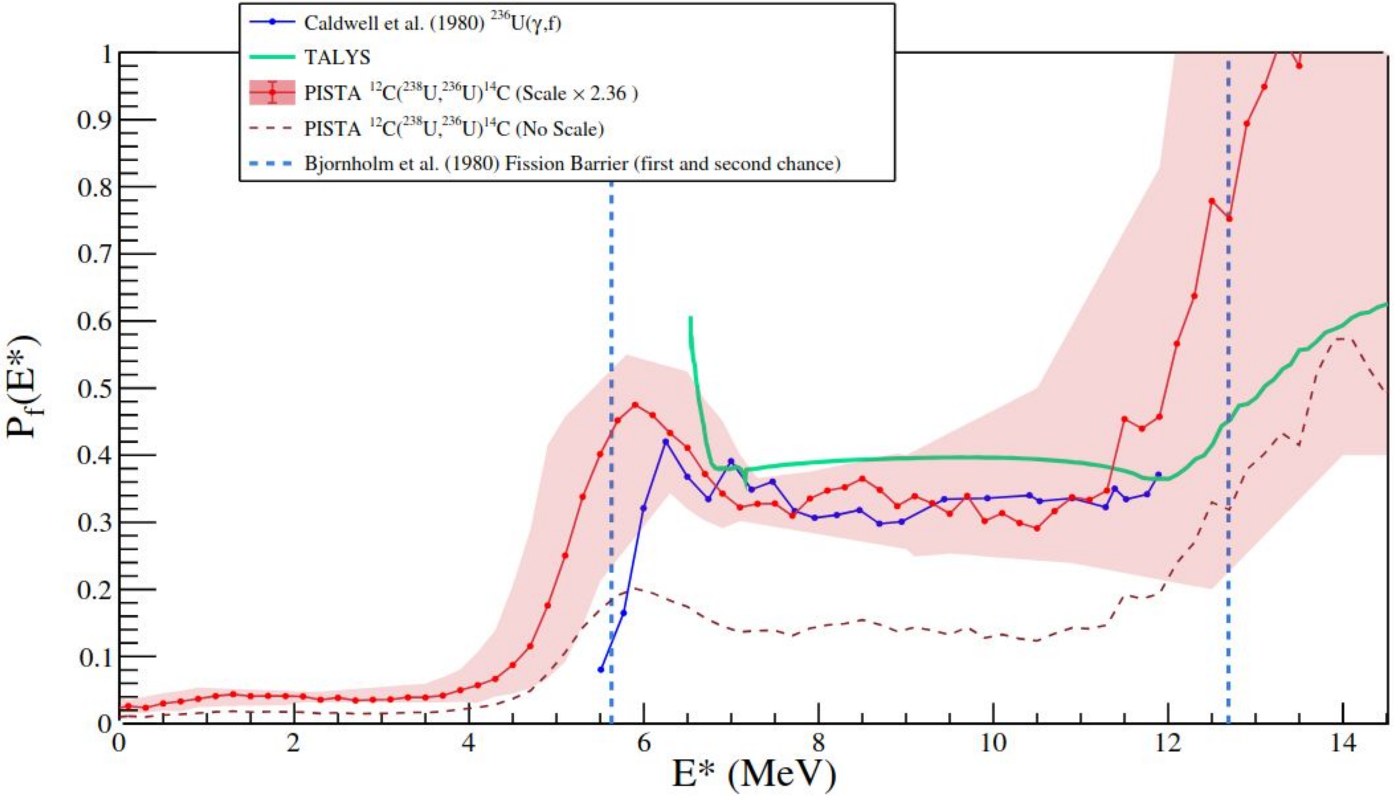
other channels ...



other channels ...



other channels ...



other channels ...