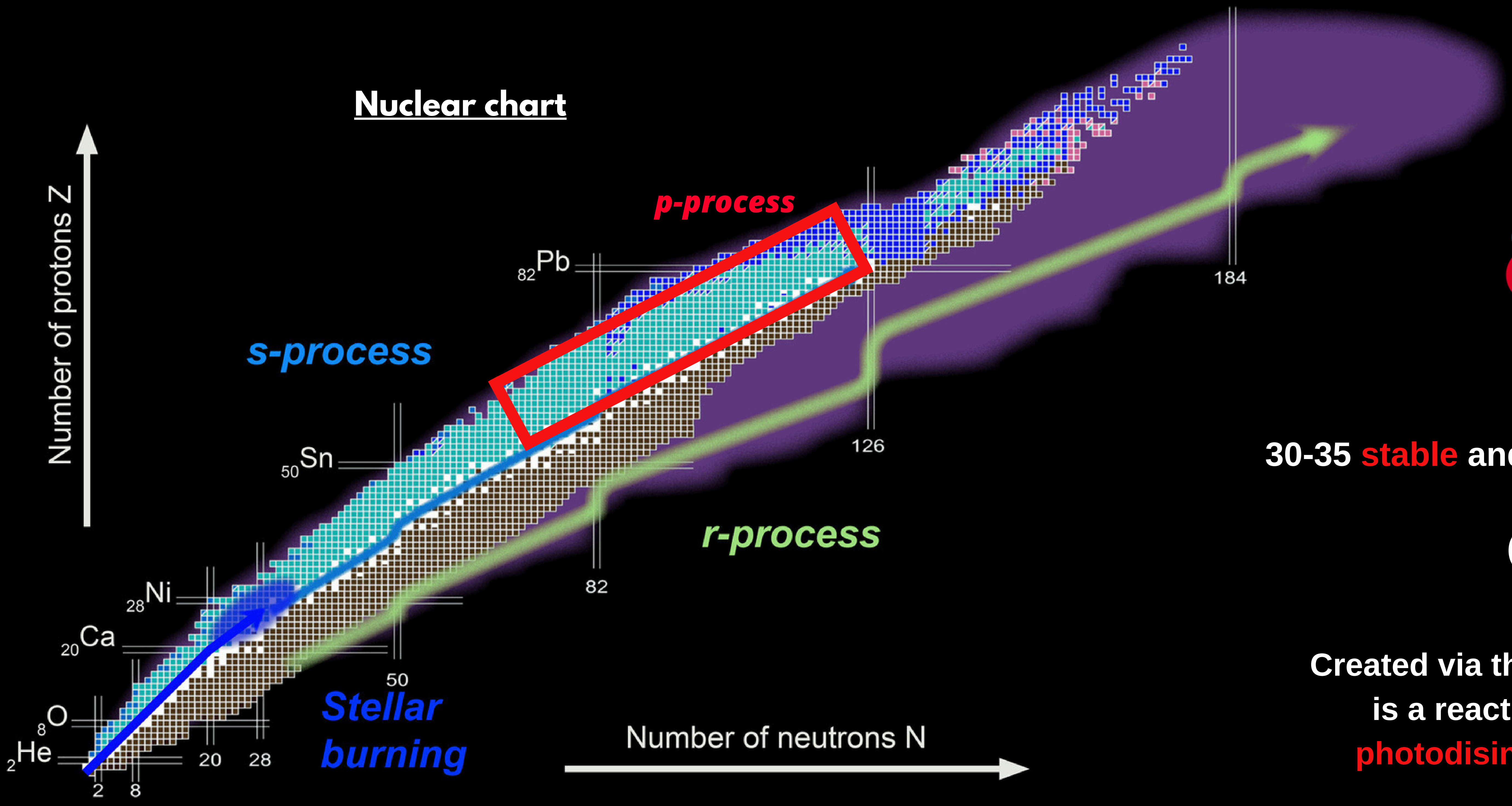
Elastic alpha scattering on Sm: adding experimental data to constrain the α-OMP

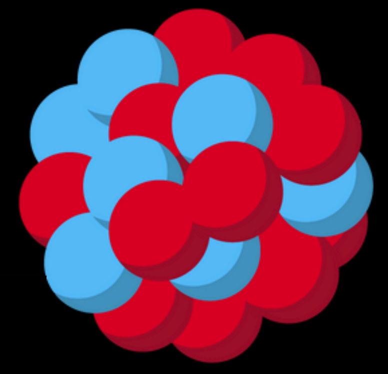
Charles SOTO

PhD Student in Nuclear Matter group: N.Millard-Pinard (PhD supervisor), C.Ducoin (PhD supervisor), O.Stézowski
IP2I Lyon
Collaboration IP2I, IJCLab, GANIL, DEMOKRITOS

PhD days, IP2I Lyon 15 april 2025

P-process

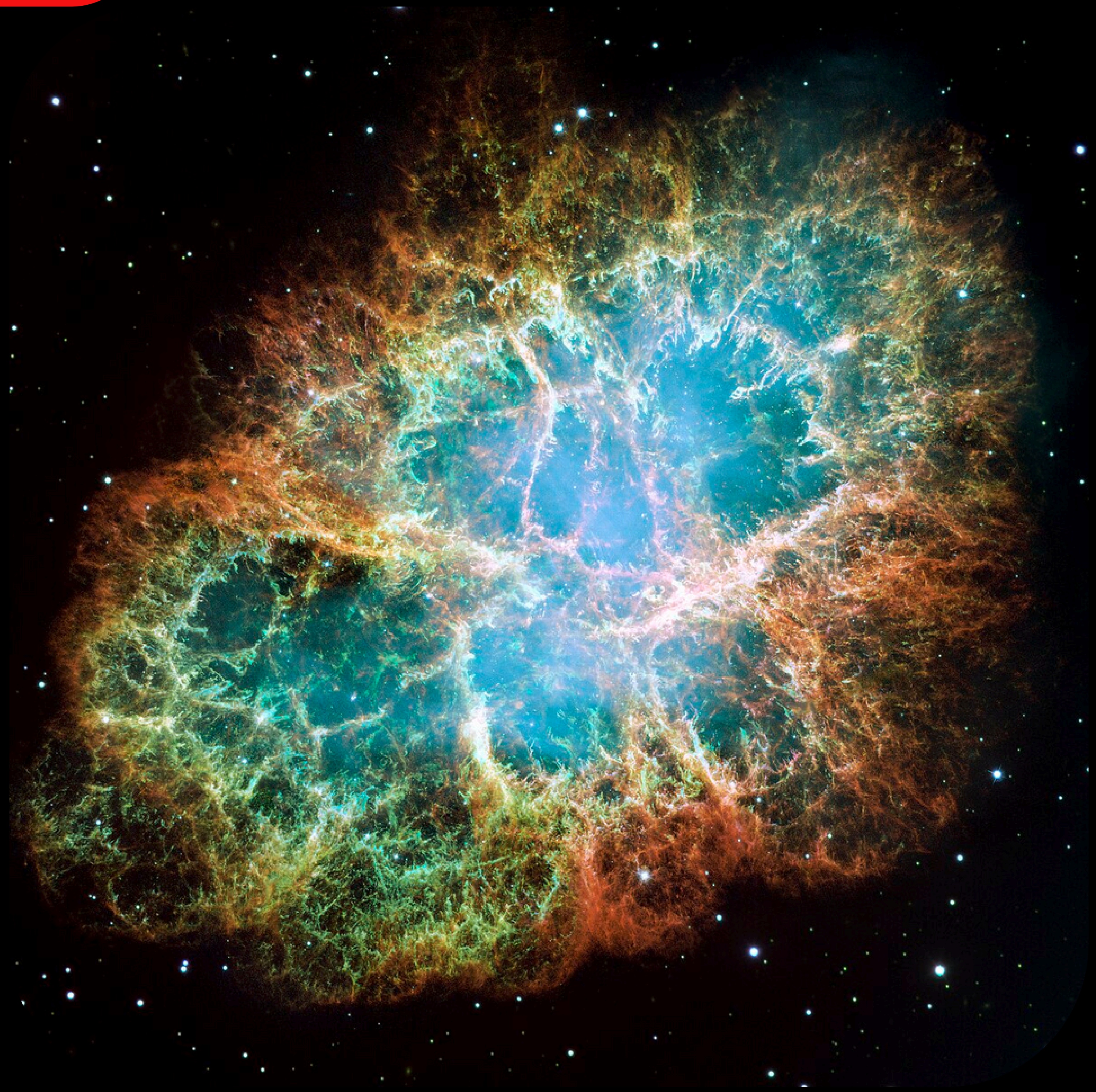




30-35 stable and neutron-deficient nucleus
= P nucleus
(proton rich)

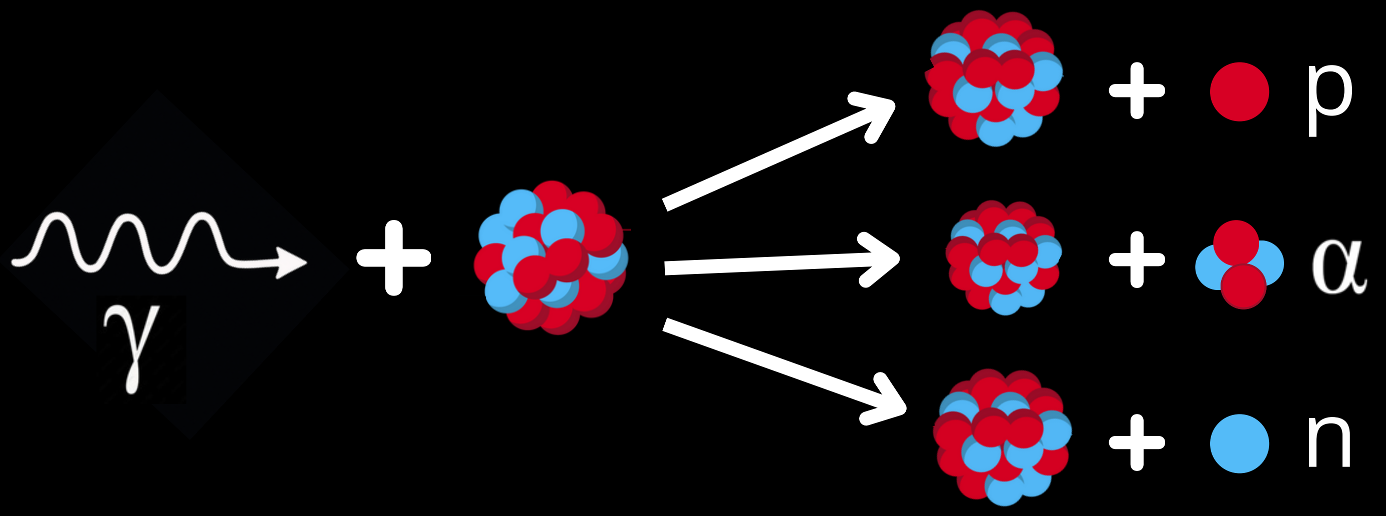
Created via the p-process (main scenario is a reaction network with mainly photodisintegrations (γ,n) , (γ,α)...)

P-process



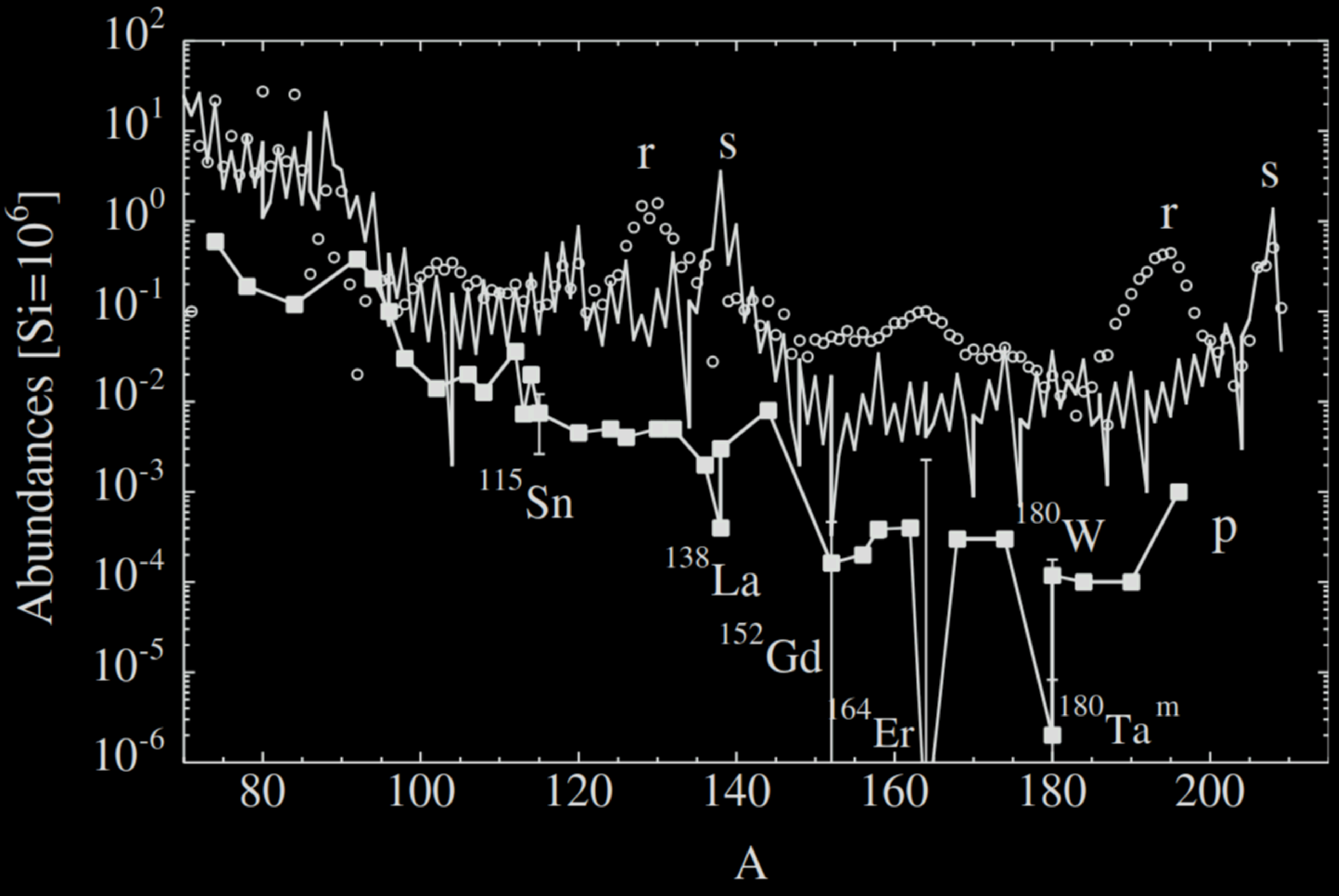
The Crab Nebula is a remanent effect SN 1054.

Astrophysical sites for p process:
CCSN, supernovae Ia, neutrino winds…



Created via the p-process (main scenario is a reaction network with mainly photodisintegrations (γ,n) , (γ,α)…)

The p nuclei



Abundances of the nuclei created by r process (◎), s process (-) and p process (■). The p-process of stellar nucleosynthesis: astrophysics and nuclear physics status M. Arnould, S. Goriely

Compared to their isotopic neighbours, the p nuclei are underproduced

It gives very few clues on the rare astrophysical events that can produce them.

<u>For my thesis:</u>

Focus on the heavier p nuclei (A ≈ 140-200)

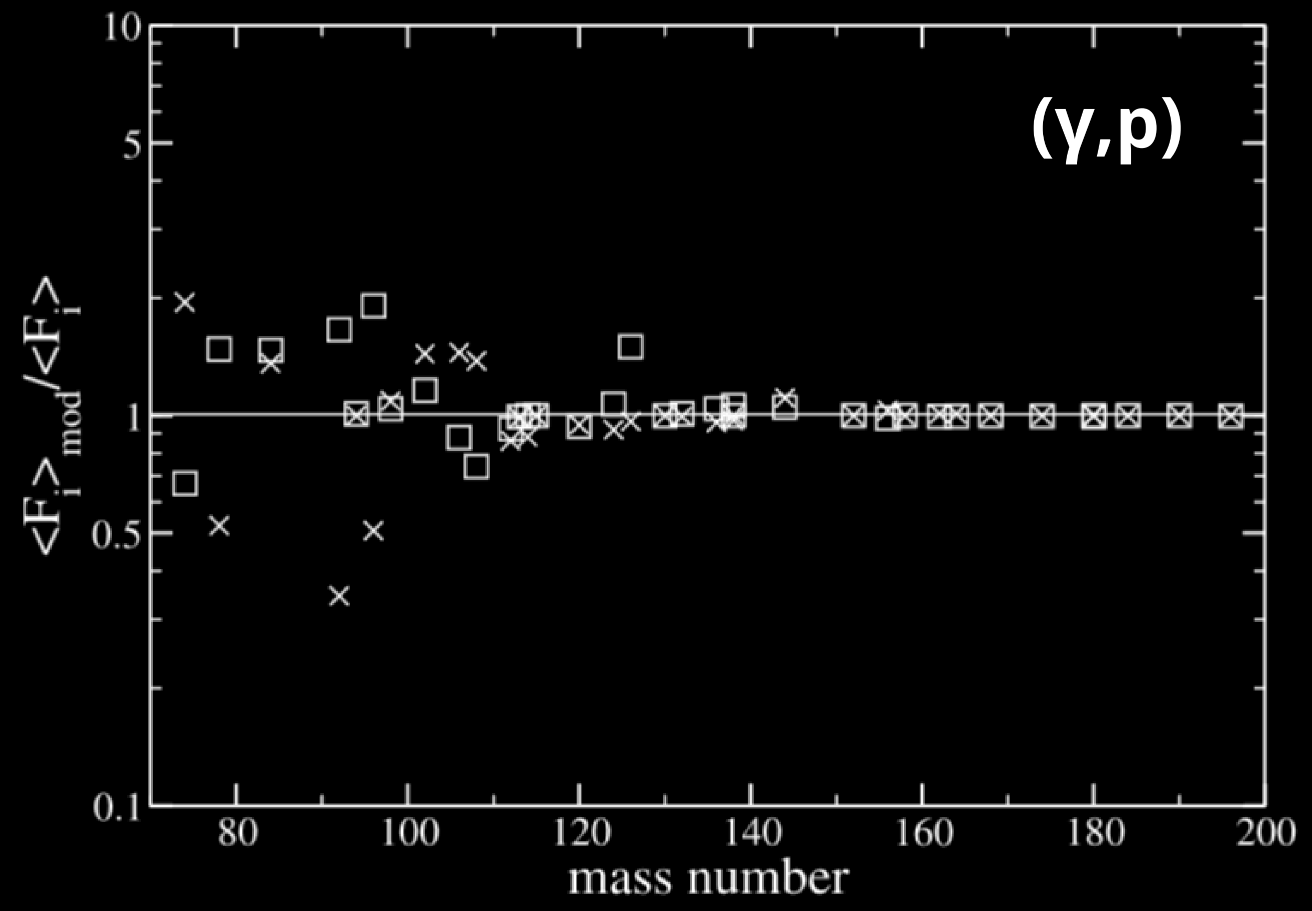
In this region, the (γ,α) reactions are the most crucial

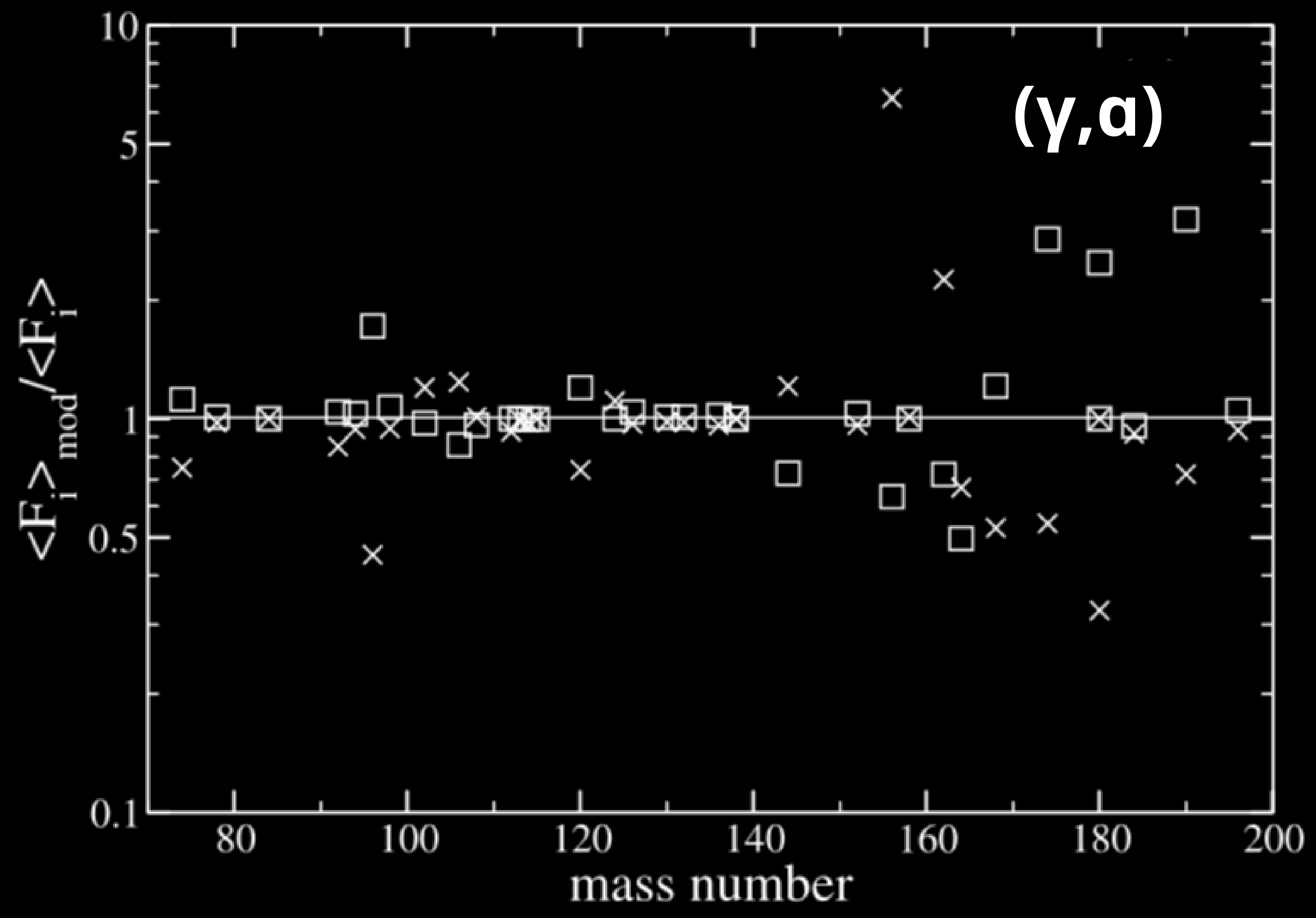
Reactions importance

A lot of the heavy p nuclei are synthetised through (γ,α) reactions, their cross sections and abundances are computed through the HF model.

The final abundances depend a lot on the cross sections of these reactions.

As shown in those figures, the (γ,p) is more important for light p nuclei while (γ,α) is more important for heavy ones.





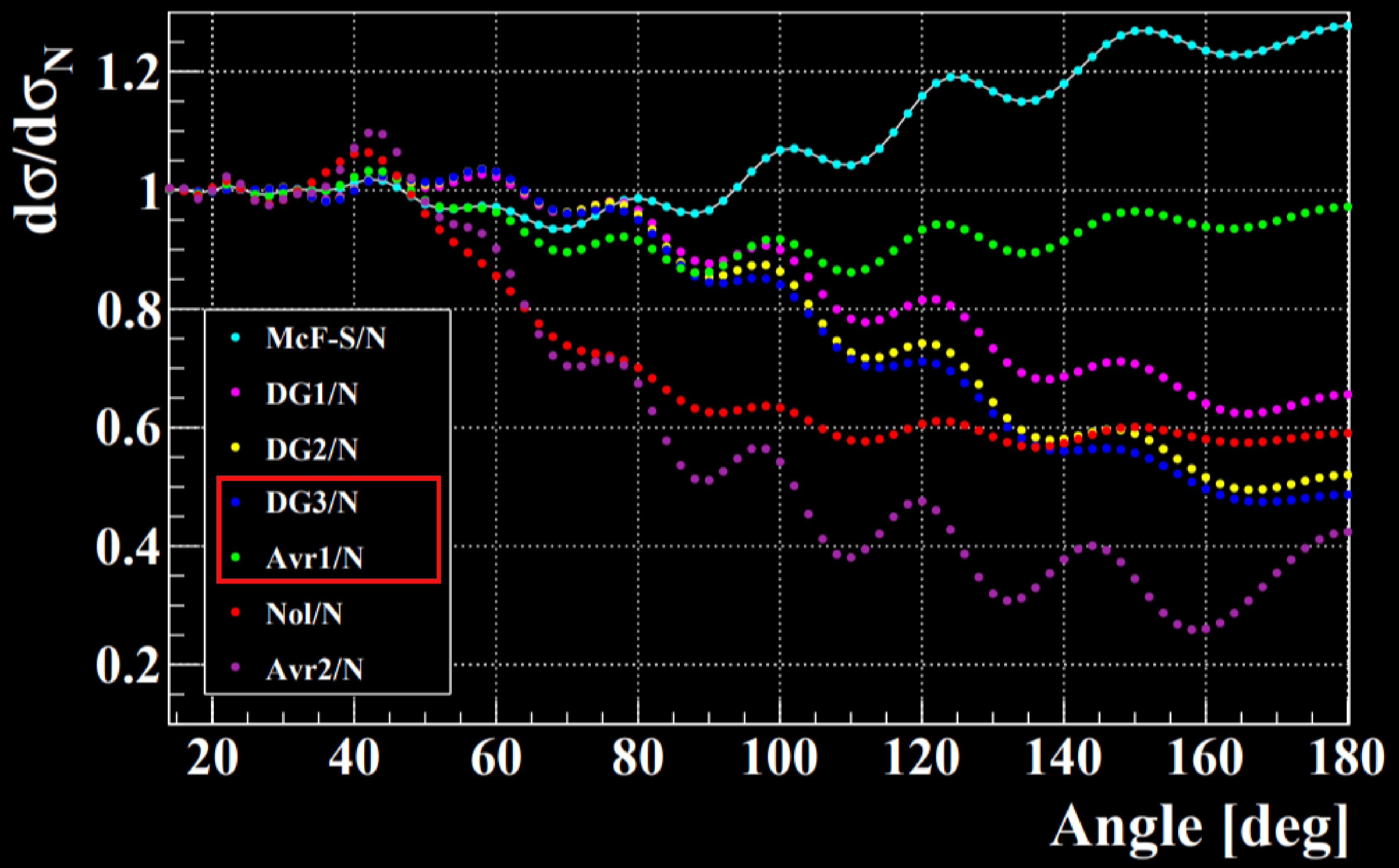
Evolution of the calculated abundances of p nuclei when the reaction rates are multiplied (□) or divided (×) by 3 [W. Rapp et al 2006 ApJ 653 474].

The α-Optical Model Potential

For HF calculations, 3 main ingredients:

- Gamma-Strengh Function
- Nuclear Level Density
- Optical Model Potential

The first two are relatively well known for the heavier region of the p process.
The main uncertainty comes from the OMP.



Calculations of $^{148}Sm(\alpha,\alpha)^{148}Sm$ cross sections at 22MeV using different α-OMP in TALYS (normalized by a reference α-OMP).

More constraints needed on the α-OMP for this region !
The typical way to constrain the OMP is through elastic scattering.

The Samarium

62
Sm
Samarium
150.36

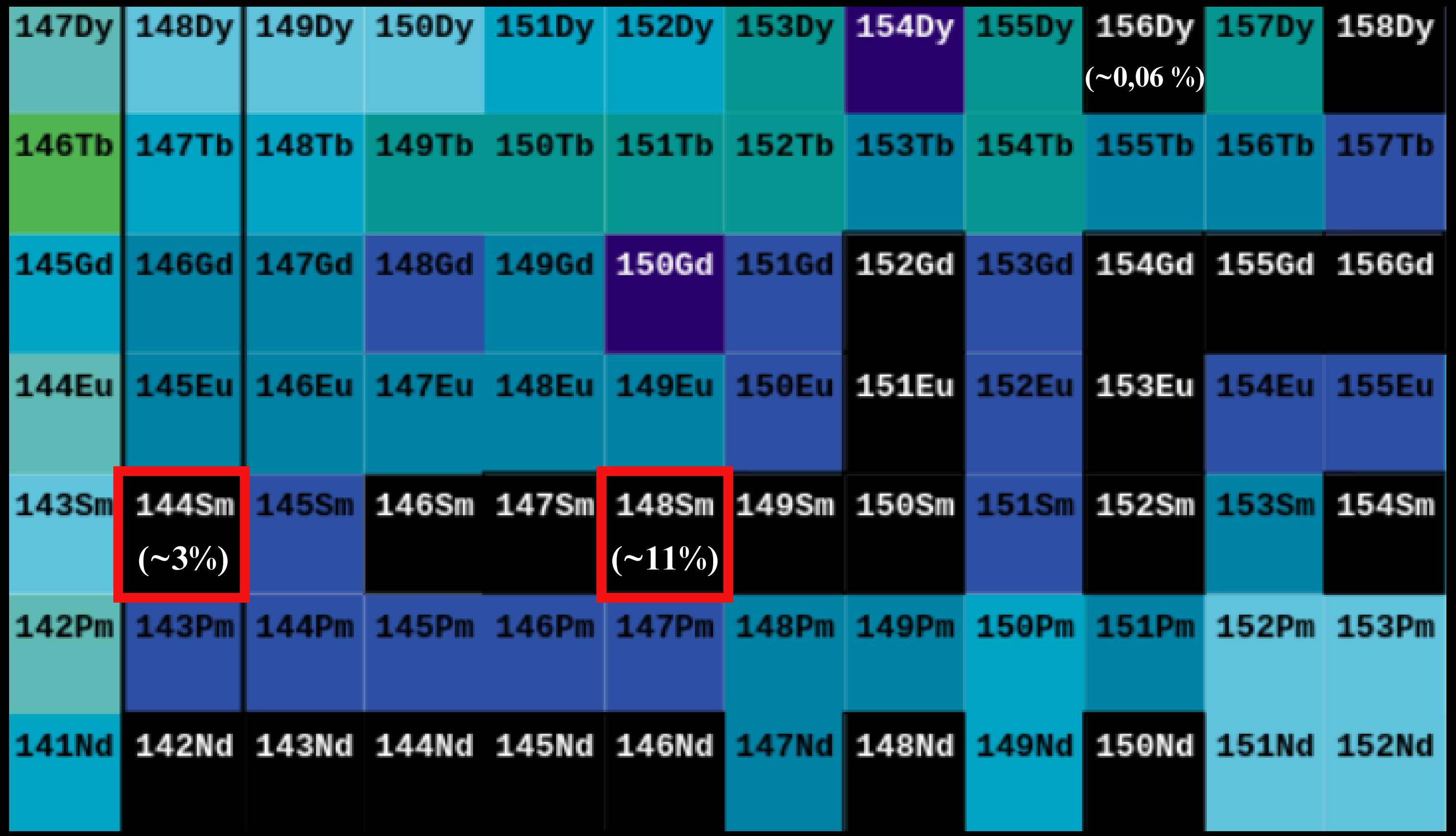
Let's use Samarium !

We are studying 2 Samarium isotopes :

- ^{144}Sm, measured two times through elastic scattering , stable, neutron magic (N=82) and a p nucleus
- ^{148}Sm, has no data available through elastic scattering , stable, non magic

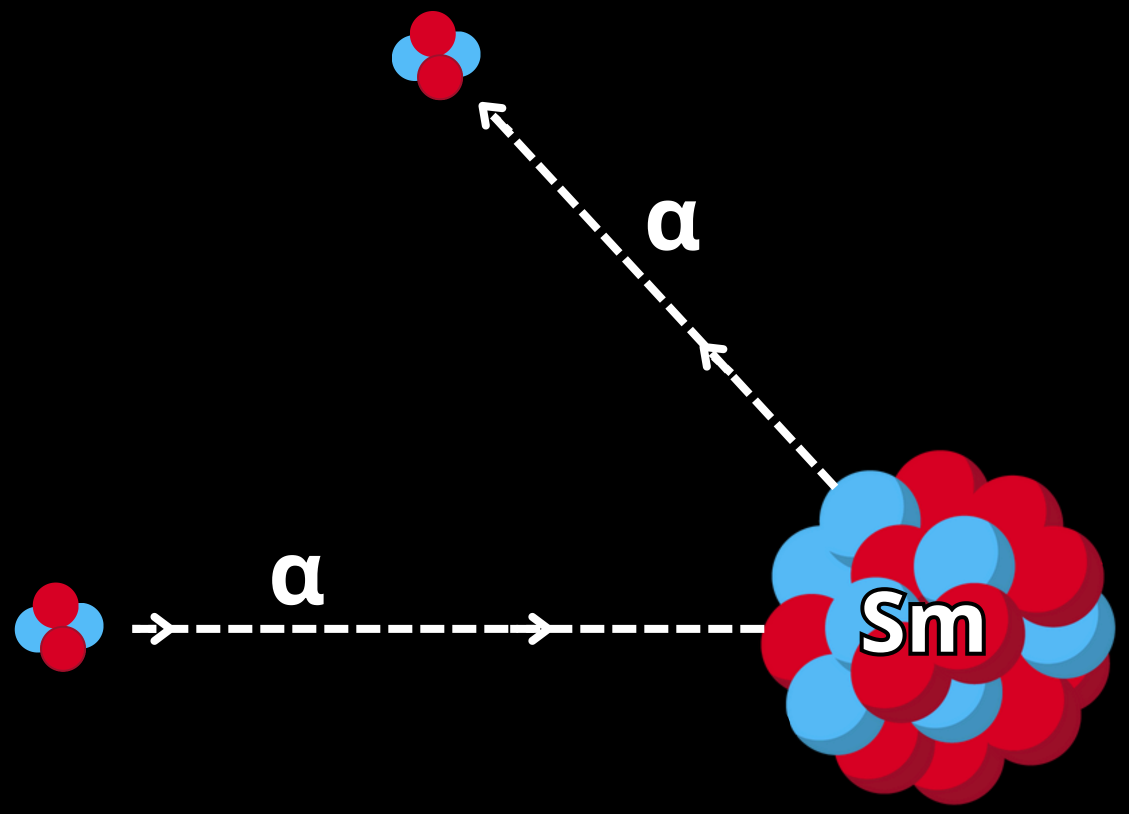
<u>Why Samarium ?</u>

^{144}Sm strongly constrains α-OMP
Good case to study the isotopic dependence
Study of magic *vs* non magic
^{144}Sm is one of the naturally most abundant p nuclei (~3%)
New data through ^{148}Sm
We can compare with the already known case of ^{144}Sm



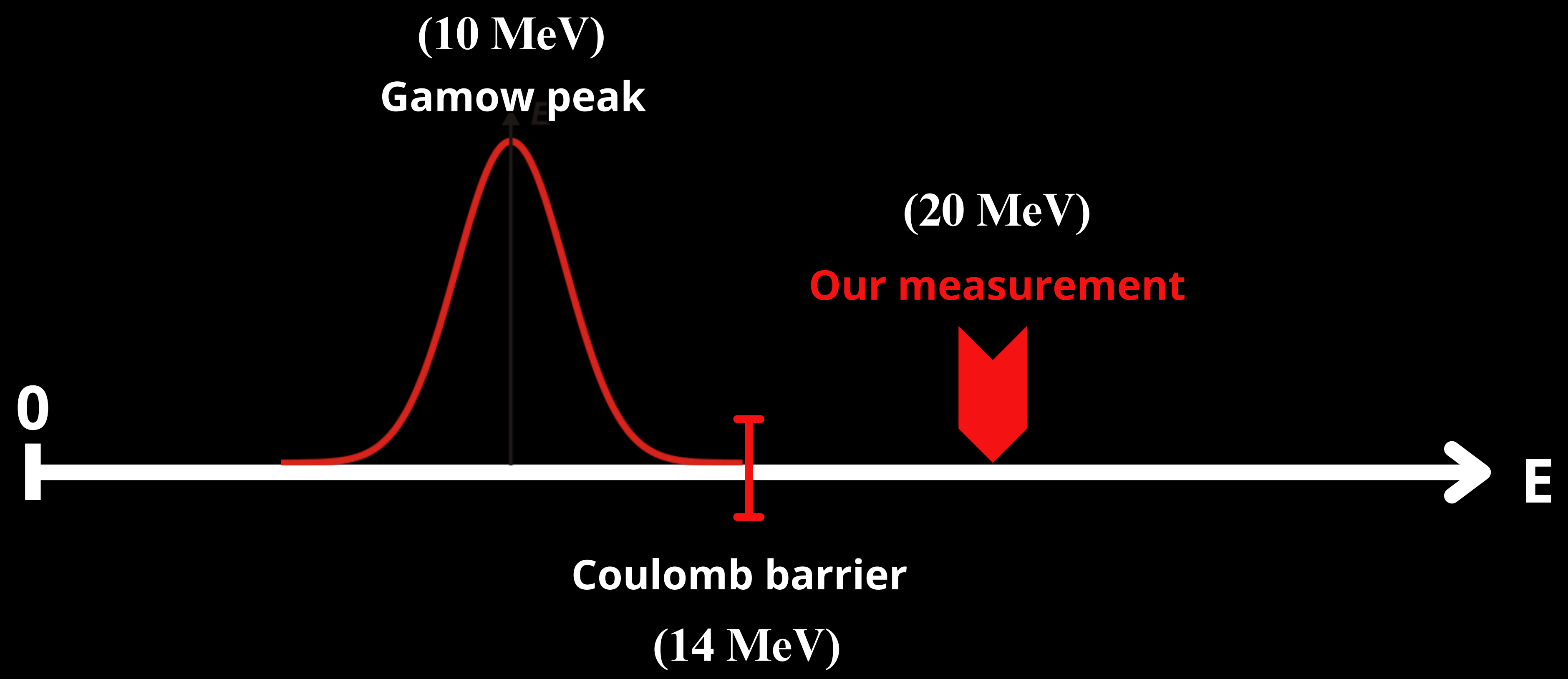
Extract of nuclear chart by NuDat3 centered around the Sm isotopes.

Experiment description



Elastic scattering measurements in order to make a nearly complete angular distribution :

$^{144}Sm(\alpha,\alpha)\ ^{144}Sm$
$^{148}Sm(\alpha,\alpha)\ ^{148}Sm$

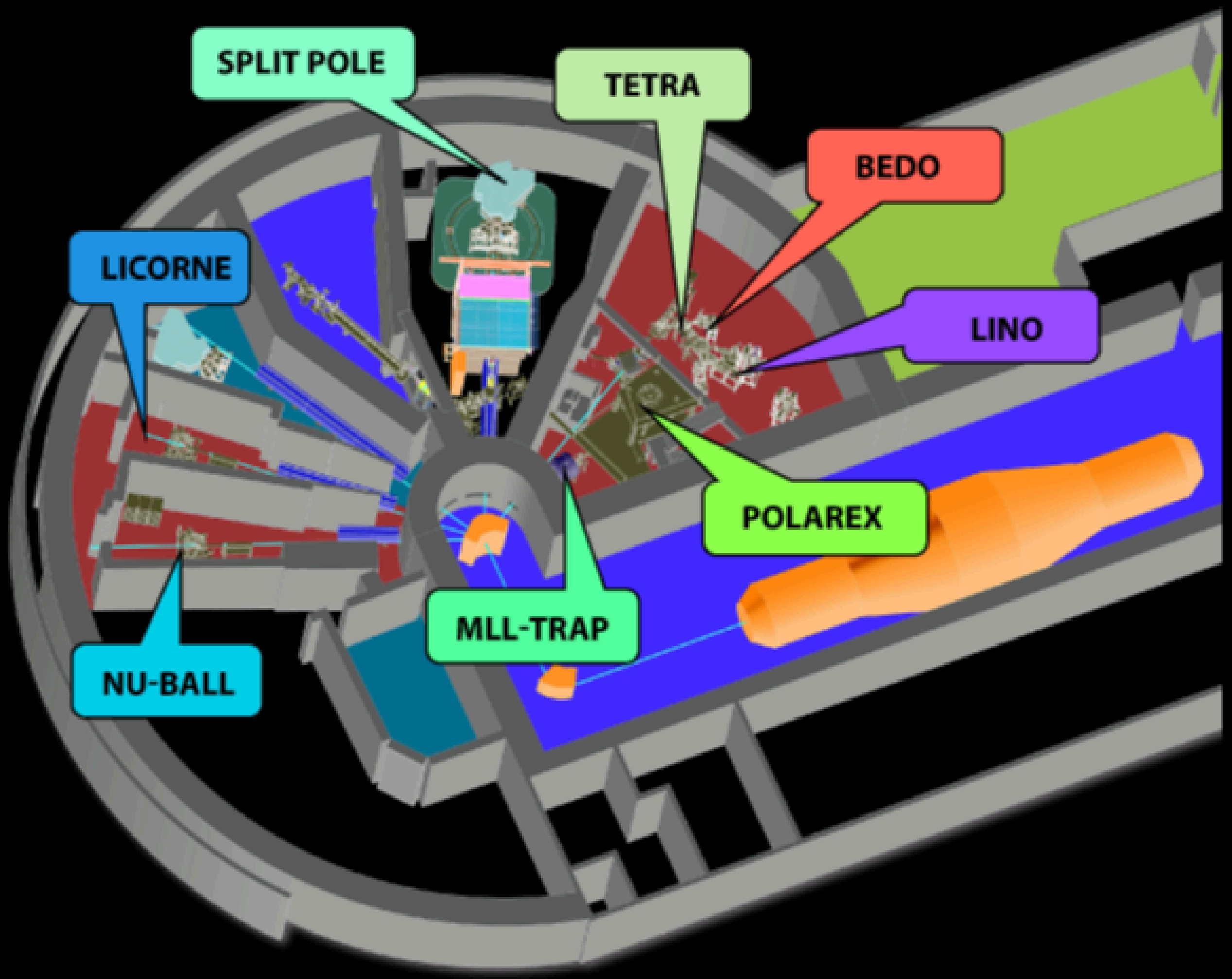


Both at 20 MeV, compromise between:

- Astrophysically relevant (Gamow energy ~ 10 MeV)
- High enough on energy to see effects of nuclear potential (Coulomb barrier ~ 14 MeV).

The collaboration

International collaboration : GANIL, DEMOKRITOS, IJCLab, IP2I

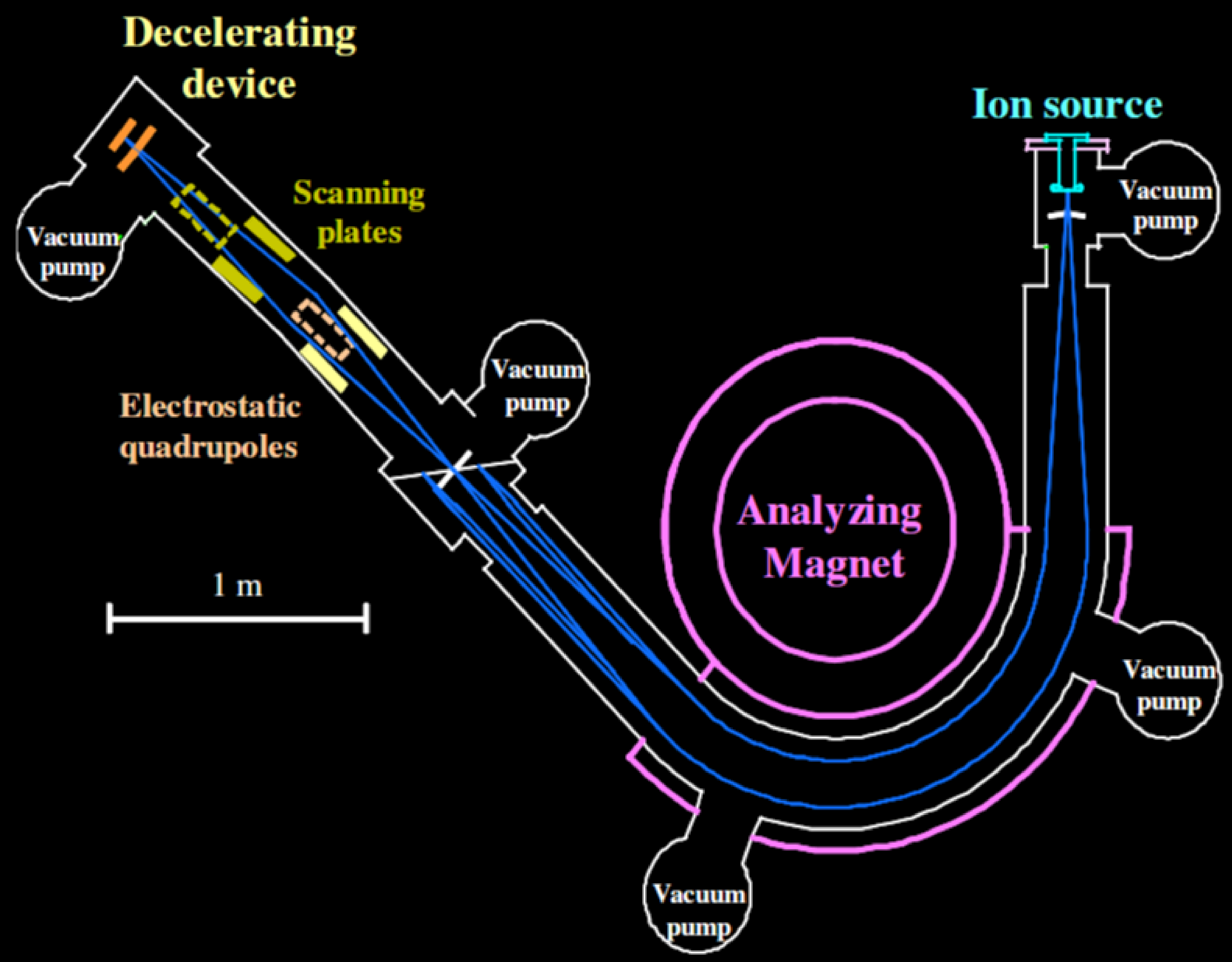


This experiment was made at IJCLab on the ALTO platform in march 2024 using the Tandem accelerator and the SPLIT POLE spectrometer

Targets synthesis

3 targets have been realised :
two ^{148}Sm and one ^{144}Sm,
on carbon backings

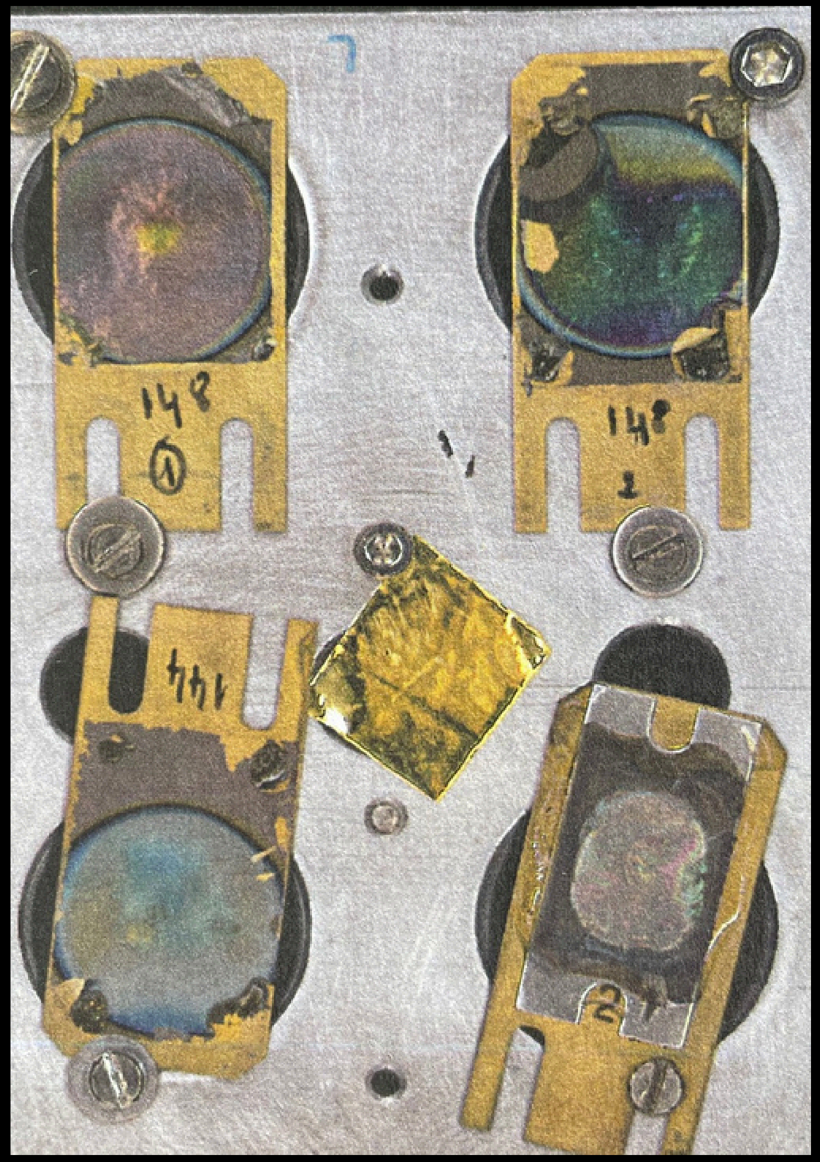
The targets have been realised on the platform SIDONIE at the IJCLab.



Scheme of the SIDONIE electromagnetic isotope separator

SIDONIE is an electromagnetic isotope separator.

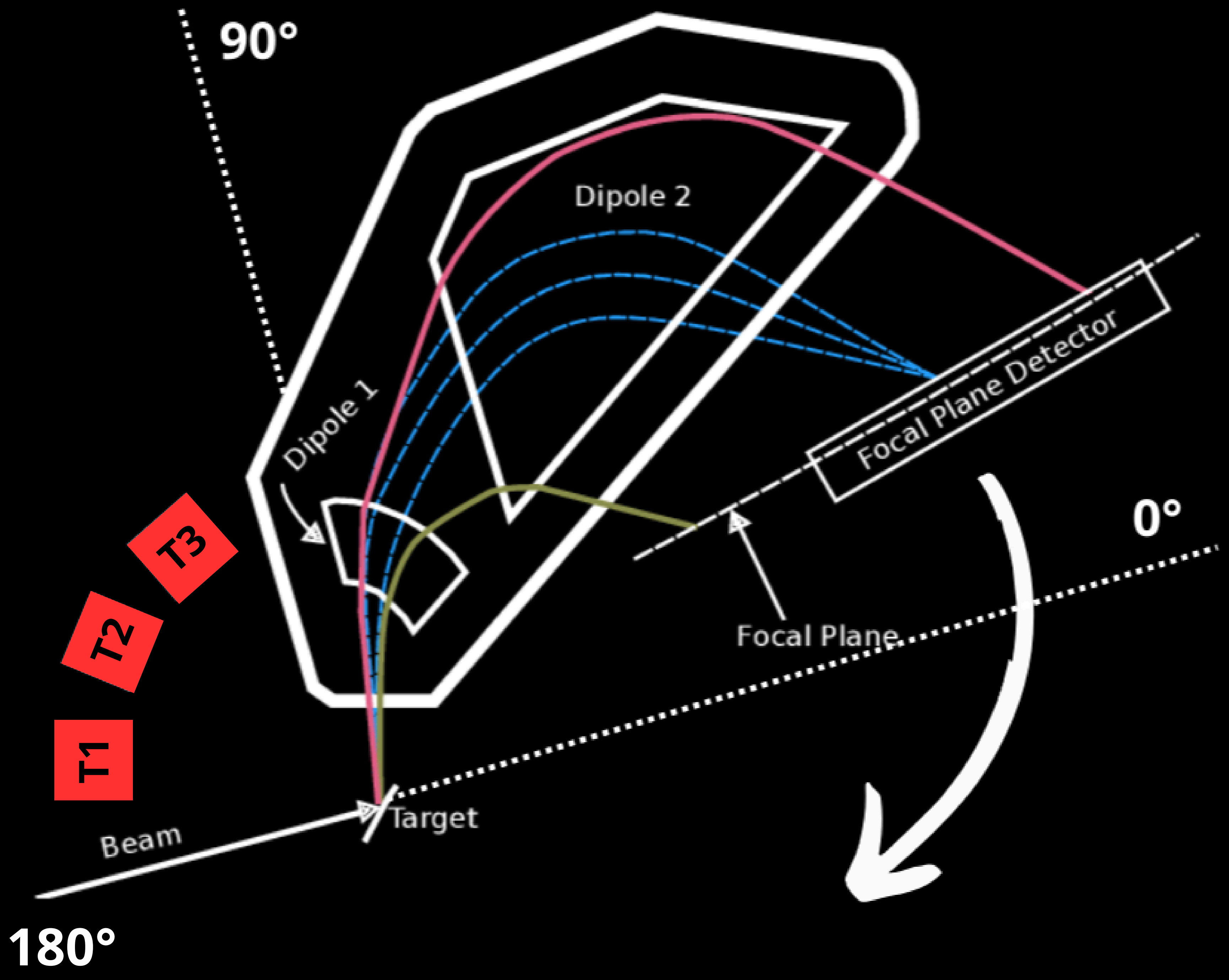
Excellent isotopic purity (~99,99%)



Experimental setup

The Split Pole has been used to measure scattered particles at the forward angles (22°-85°).

For the backward angles, 3 silicon telescopes in ΔE-E configuration have been used up to 145°.

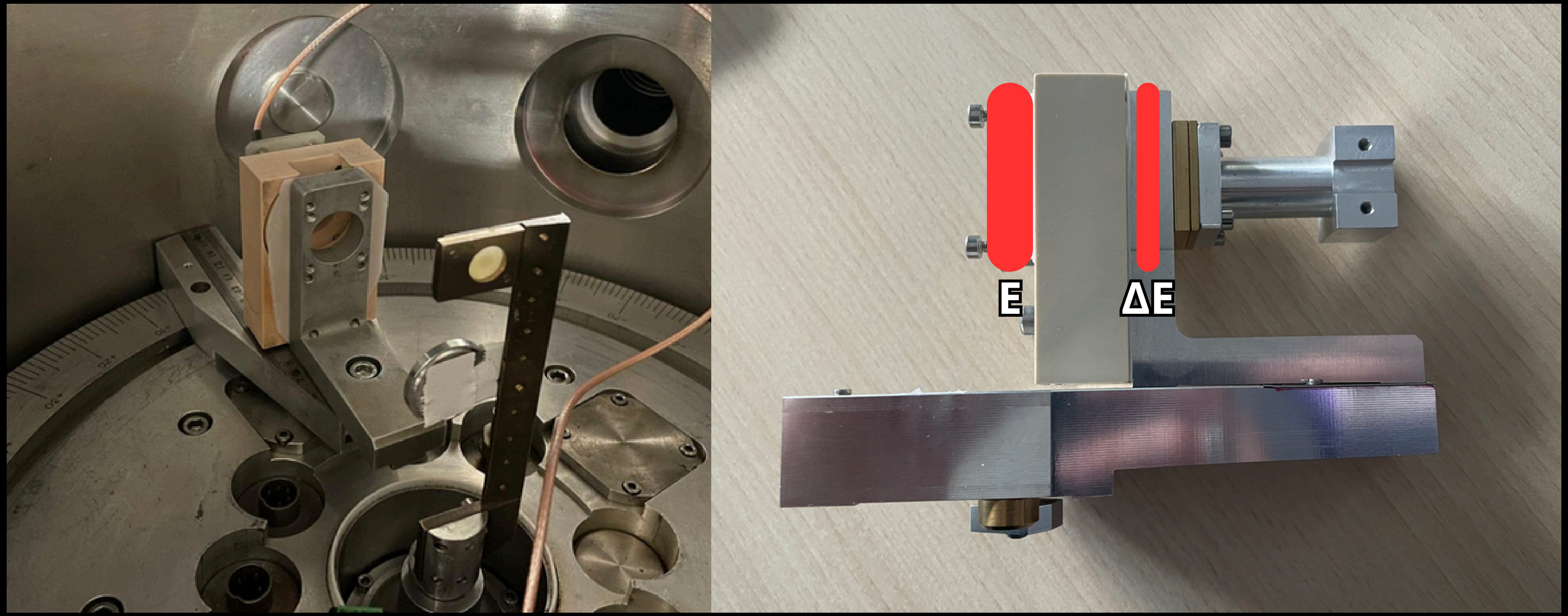


(credit: The Focal-Plane Detector Package on the TUNL Split-Pole Spectrograph, C. Marshall, K. Setoodehnia)

Silicon telescopes

We used **3** sets of **ΔE-E silicon** detectors, purchased for this experiment.

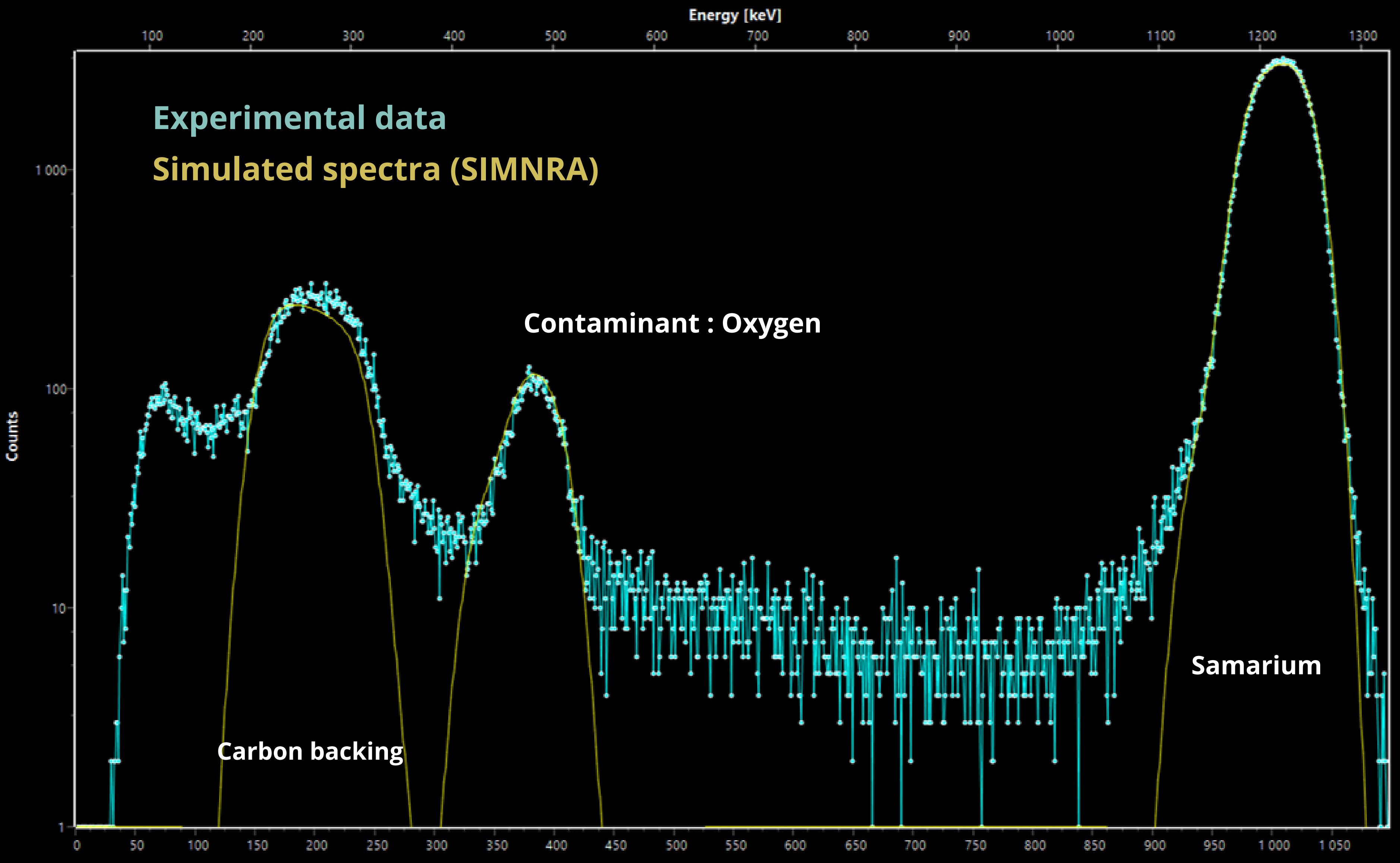
Each ΔE-E couple was mounted onto a **specific mount** with a **2mm collimator**. These mounts were crafted at IP2I.



Characterization at GANIL

- **E** detectors : Thickness = **500 µm** and **1000 µm**, Resolution ~**20 keV**
- **ΔE** detectors : Thickness = **80 µm**, Resolution ~**80 keV**

Rutherford Backscattering Spectrometry (RBS)

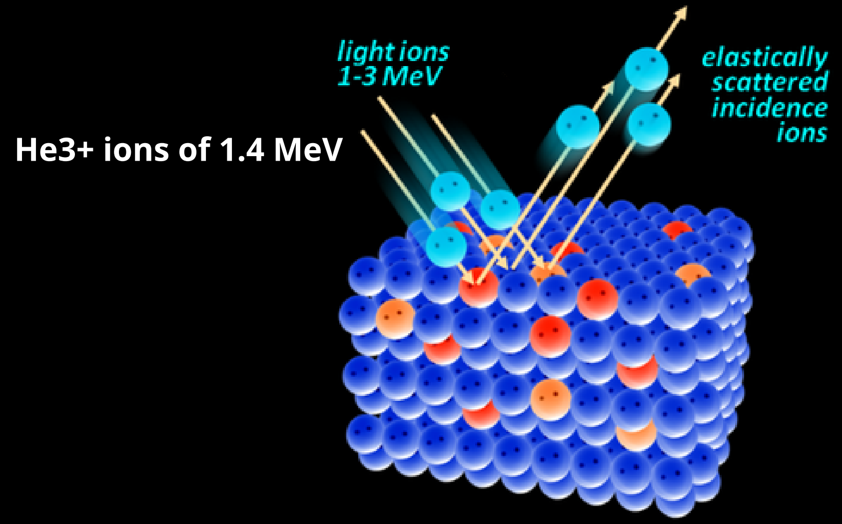


Experimental data of RBS measurement on the ^{144}Sm target, fitted with the software SIMNRA.

To compute the cross sections need to have a precise measurement of the target thickness.

We decided to run an RBS measurement on our targets to characterize them.
This measurement took place at SIDONIE with the team that synthetised them.

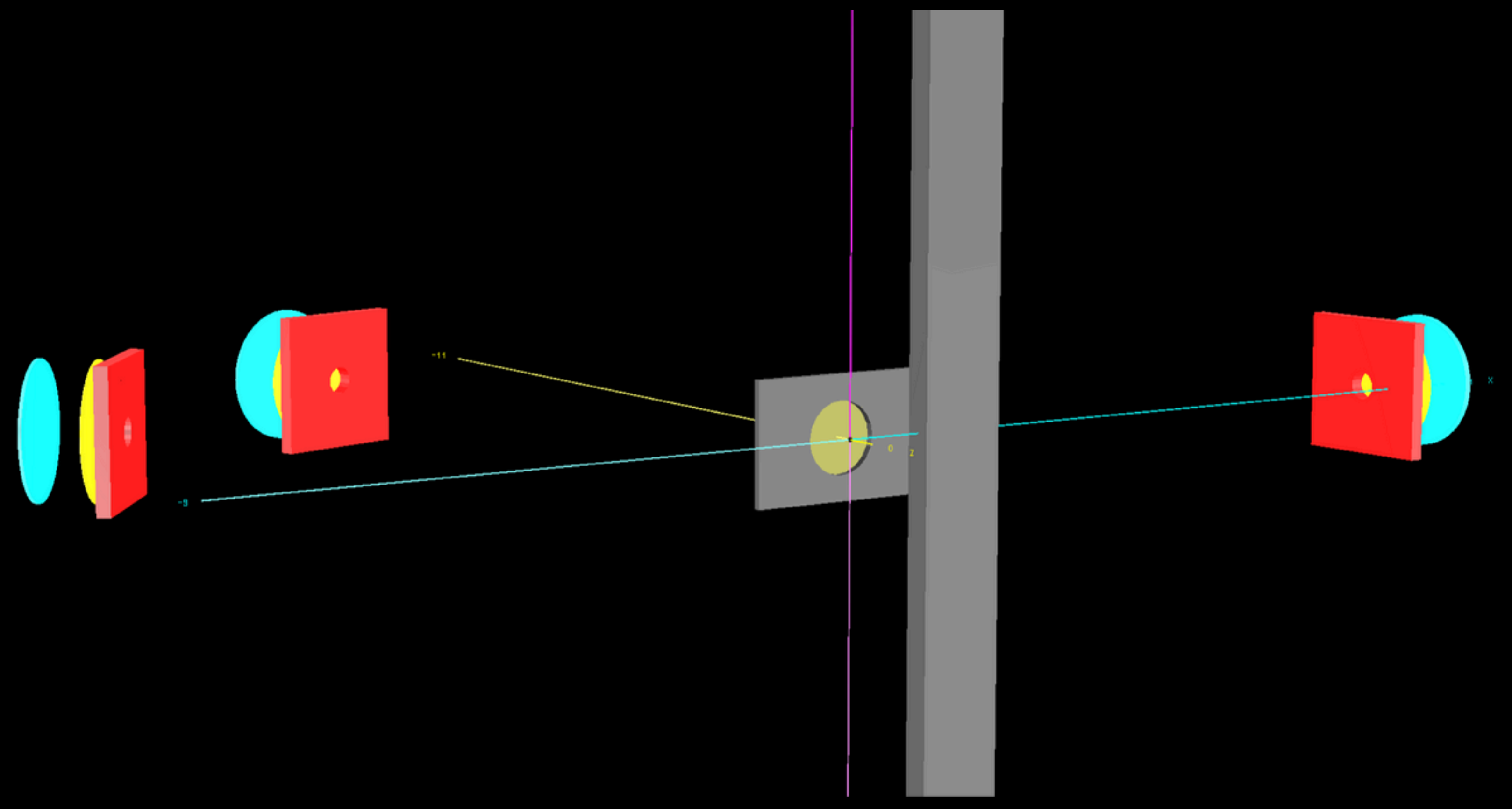
The RBS measurement has been done after our experiment.



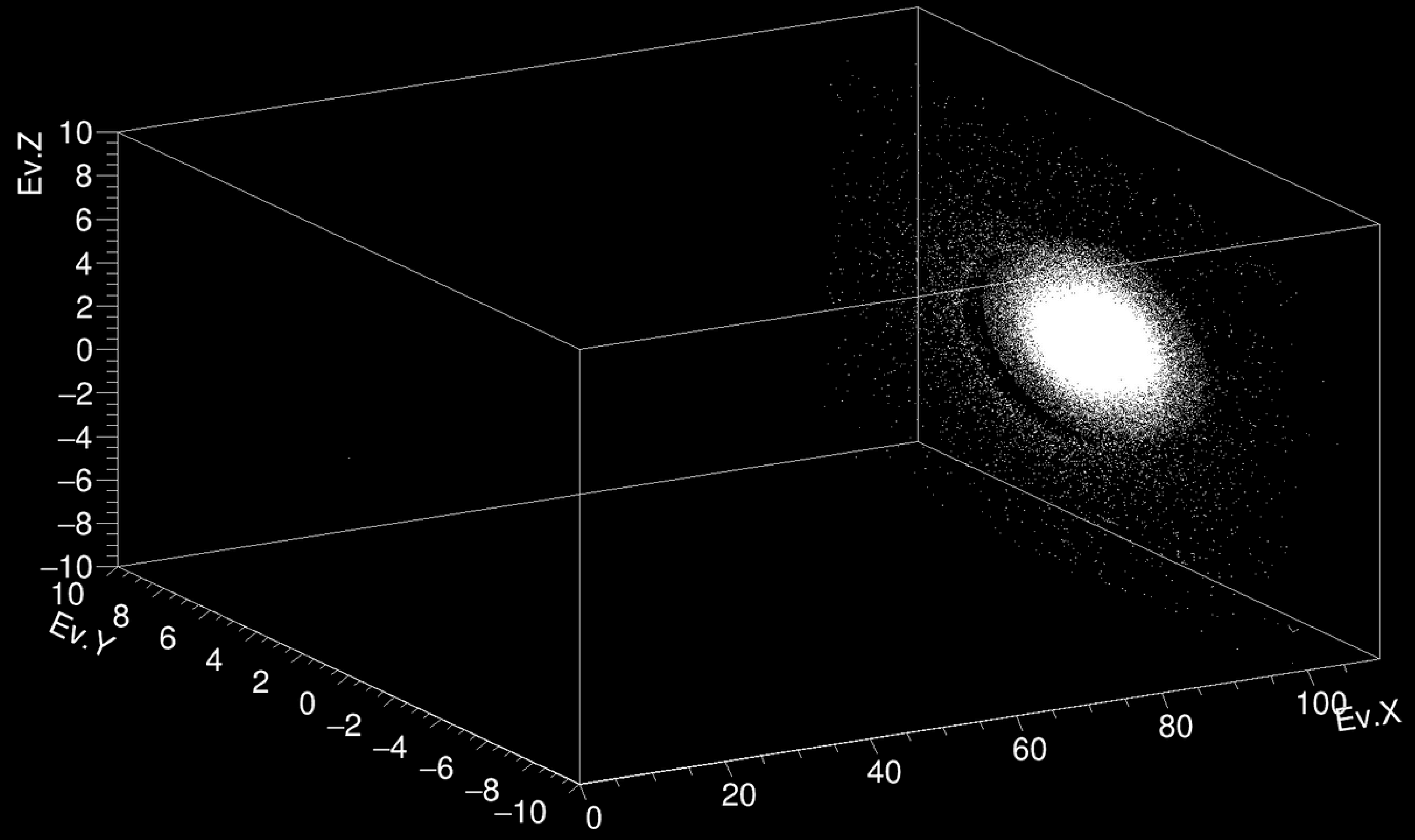
The targets have a samarium content of :
74 µg/cm² for ^{148}Sm
44 µg/cm² for ^{144}Sm

Loss of matter due to auto-pulverization during the synthesis and to the damage that the beam has done to the target.

Simulations



GEANT4 simulations to reproduce the experimental setup

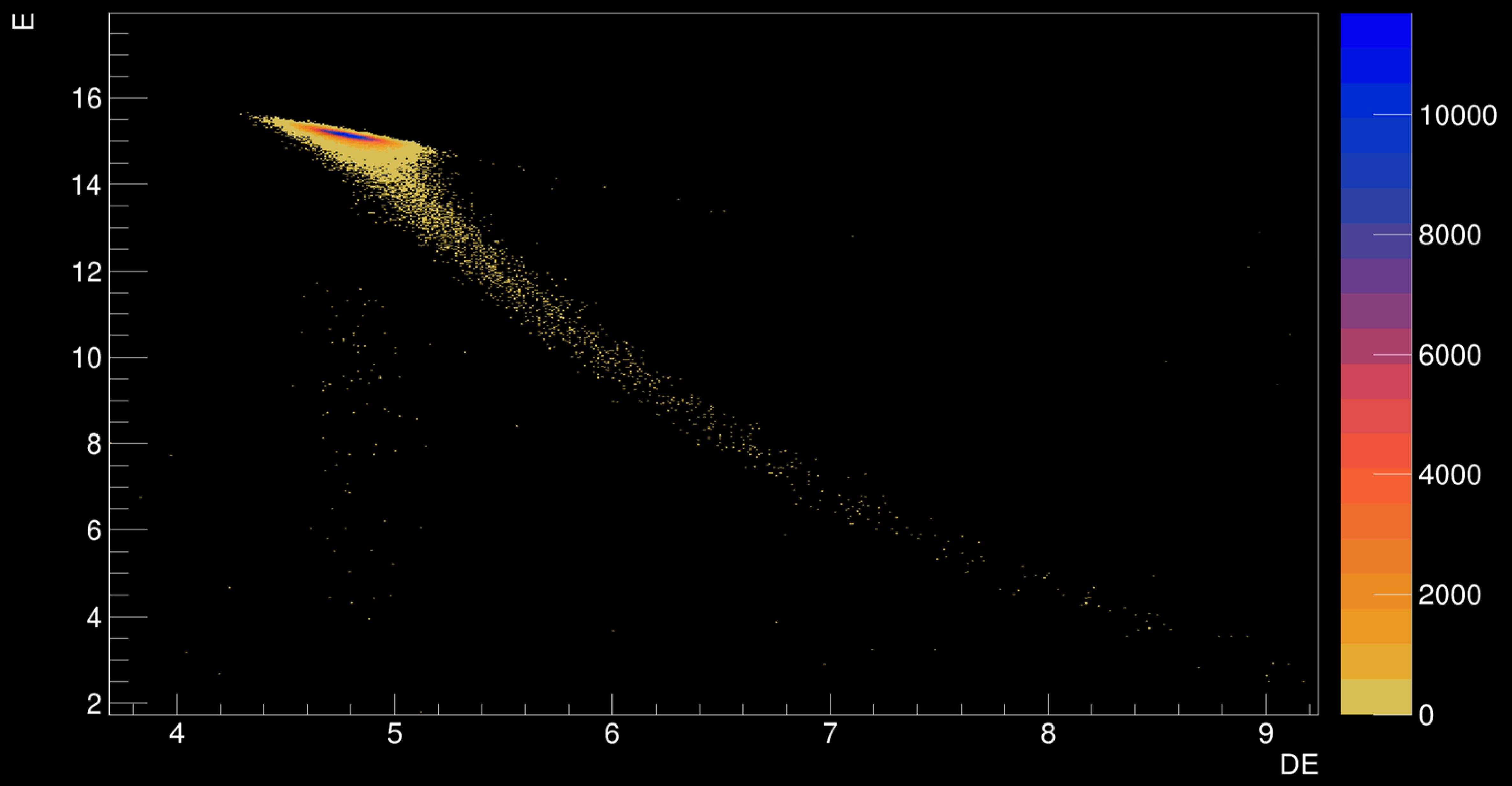


Energy depositions by alphas after the reaction happened,

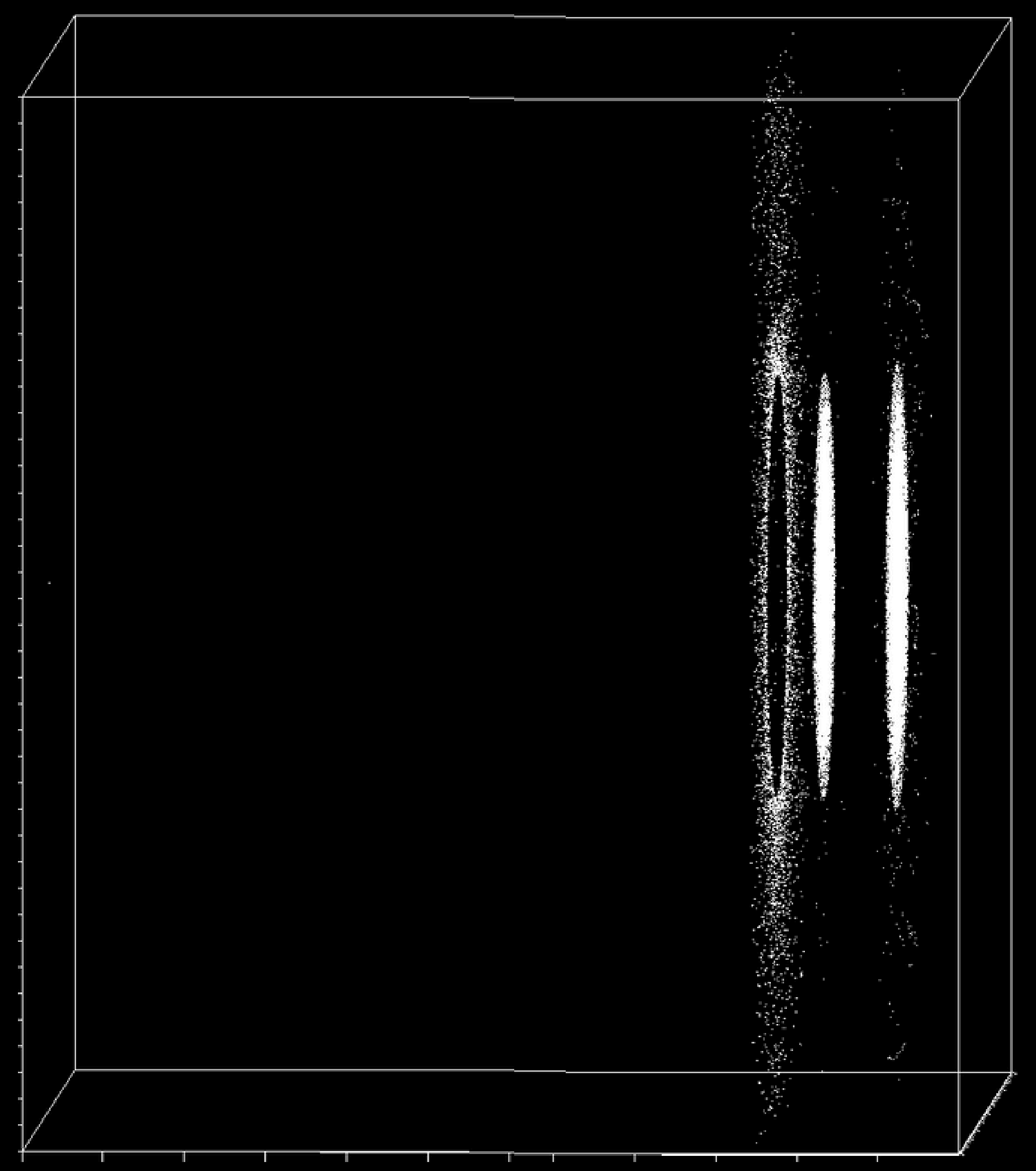
These simulations permitted to deduce the effects of the different materials :
Energy losses, scattering onto surfaces, energy and geometric straggling in the Sm target ...

Simulations

Simulated ΔE-E plot. The energy loss tail is due to the crossing of a thick Sm target.



The straggling in the ΔE ensures that alphas goes into the E

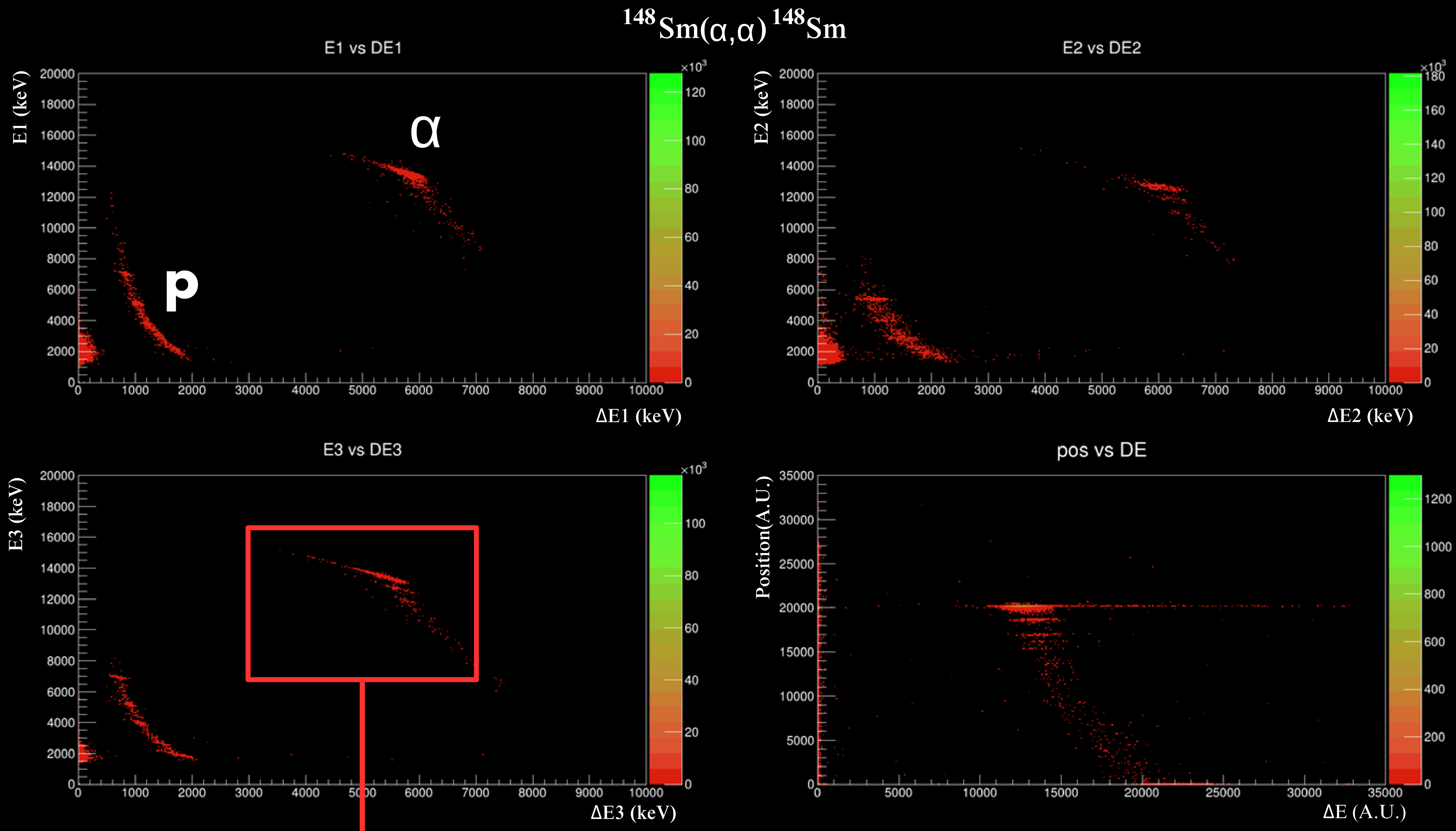


Represents energy loss in the first detector as a function of the energy loss in the second detector,.
The sum is equal to the total energy of the incoming particle (20 MeV for elastic alphas)

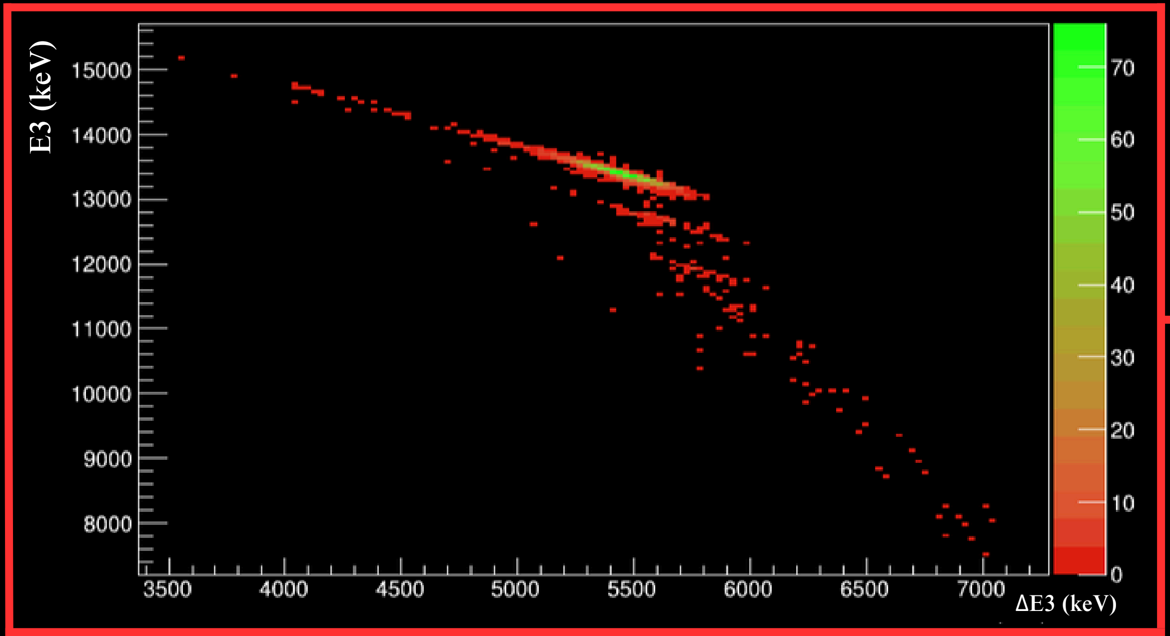
Analysis

This is what our typical **ΔE-E plot** looks like. We can see that the **p** and **α** banana are clearly **separated**.

Contaminants not visible due to the **low cross section** and **low beam intensity**.



ΔE-E plot on all 3 Si telescopes and Split Pole. It shows elastic scattering on ^{148}Sm.



The **elastic scattering** and **1st excited state** are clearly visible.

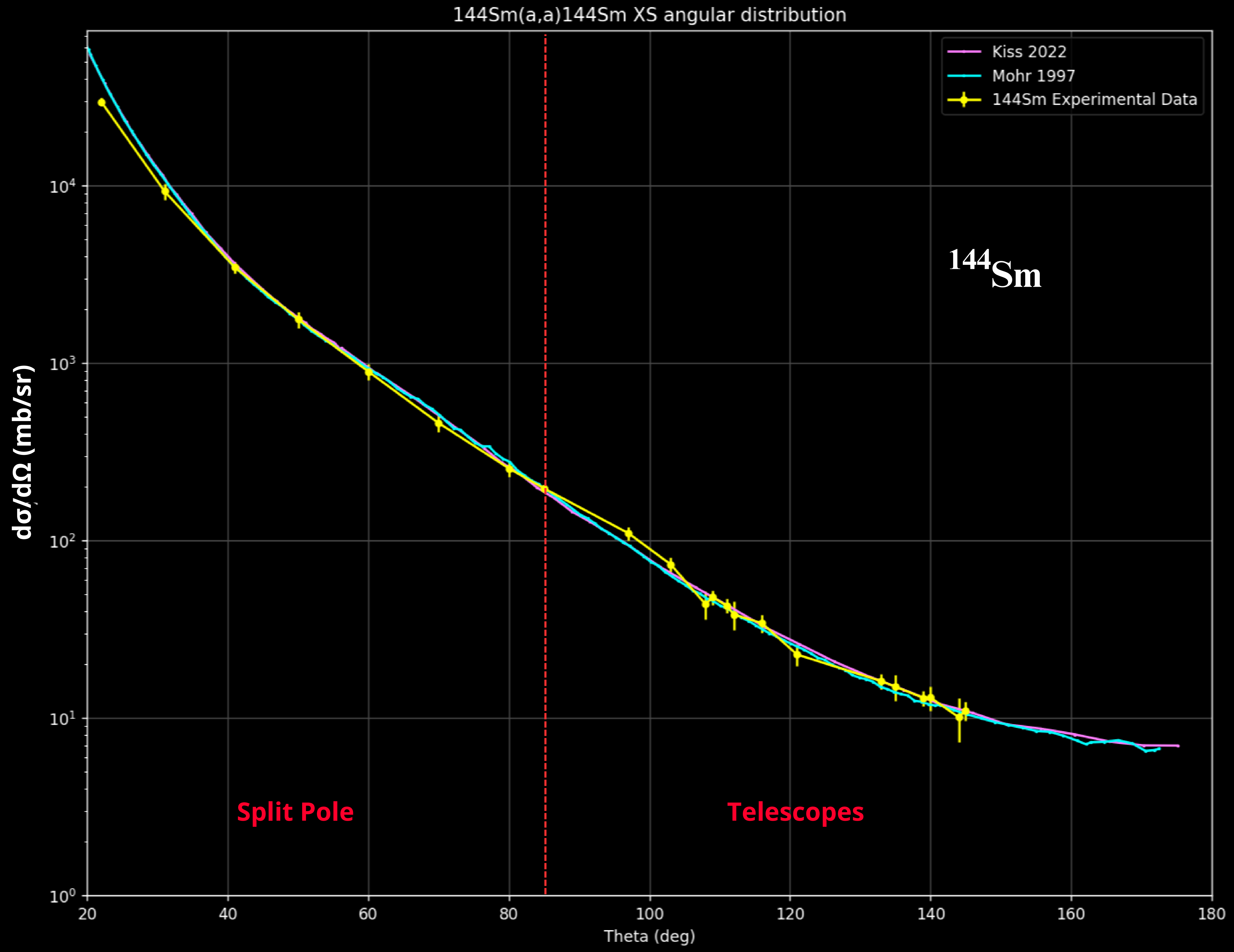
Preliminary results

Preliminary results: angular distribution of **alpha elastic scattering**.

Compared with **literature data** for ^{144}Sm and with **calculations** using **TALYS** and the two α-Optical Model Potentials of **Demetriou** (Omp 5) and **Avrigeanu** (Omp 6) for ^{148}Sm.

They are part of a **new generation** of models, they are now **vastly used** and have been **conceived using** the **^{144}Sm data**.

Main **uncertainty** : **target homogeneity** and hitting point of the beam on the target during the experiment.



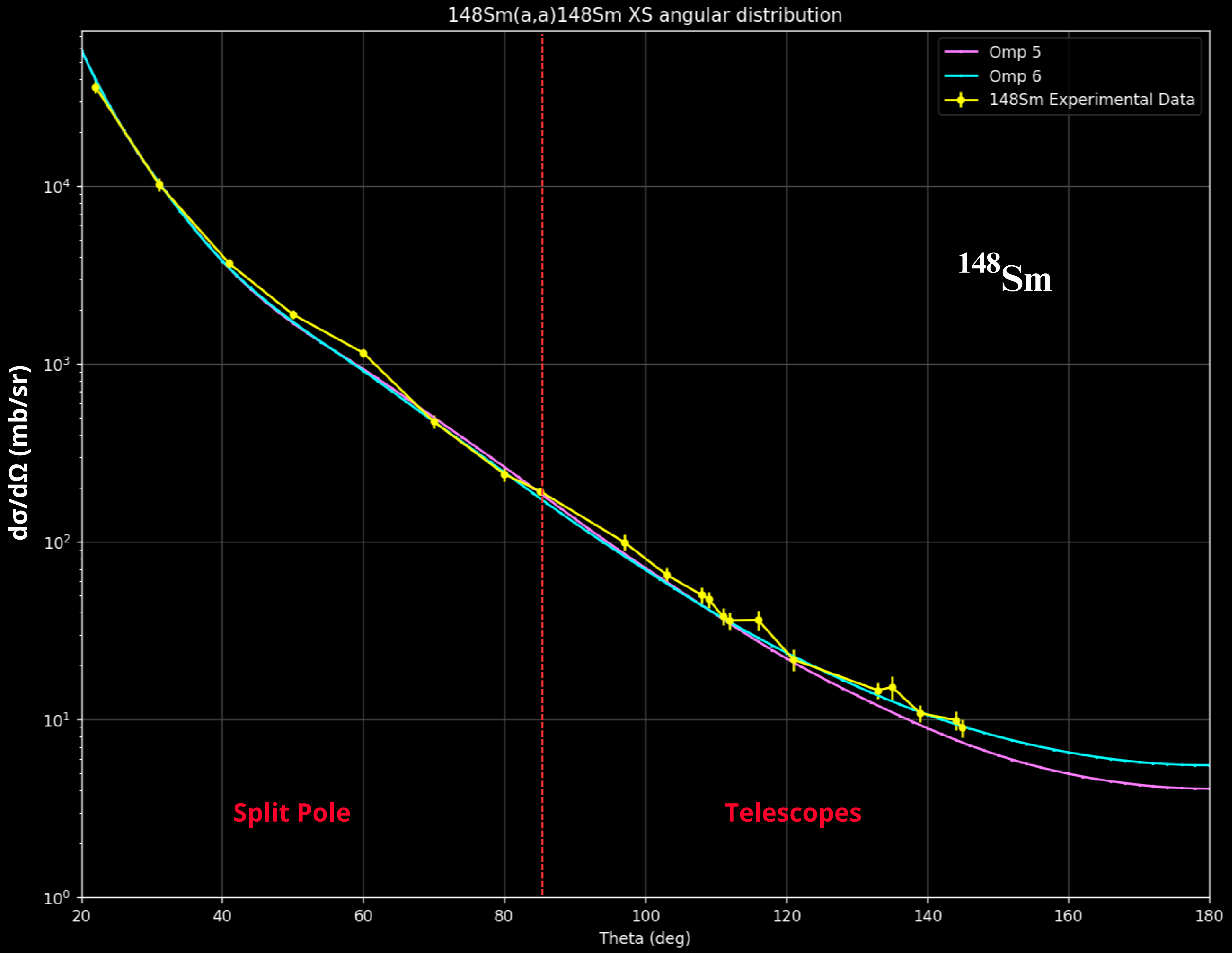
Preliminary results

Preliminary results: angular distribution of **alpha elastic scattering**.

Compared with literature data for ^{144}Sm and with calculations using TALYS and the two α-Optical Model Potentials of Demetriou (Omp 5) and Avrigeanu (Omp 6) for ^{148}Sm.

They are part of a new generation of models, they are now vastly used and have been conceived using the ^{144}Sm data.

Main uncertainty : target homogeneity and hitting point of the beam on the target during the experiment.



Conclusion and perspectives

Alpha elastic-scattering angular distribution for 2 samarium isotopes, ^{144}Sm and ^{148}Sm, at 20 MeV, from 22° to 145°

- Telescopes calibration
- Energy loss and scattering simulations
- Target characterization by RBS
- Preliminary angular distribution

- Study of systematic shifts
- Determine set of parameters on a-OMP
- Study of isotopic and magicity dependence
- Analysis finalisation

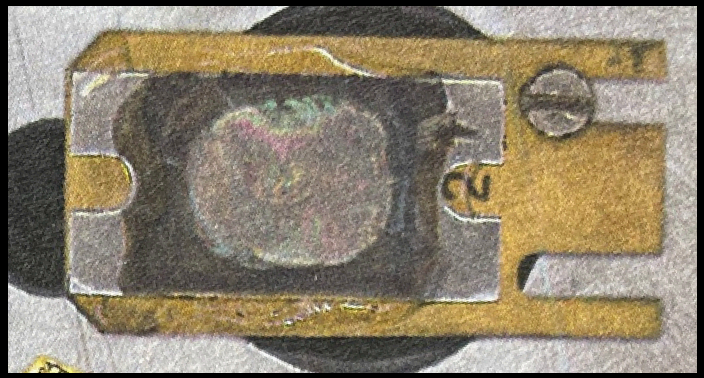
- Study of the energy dependance : very important for the α-OMP
  - Same experiment at 22.5 MeV.
- Study of its influence on the abundance of the p nuclei in this region

Use of 184 W

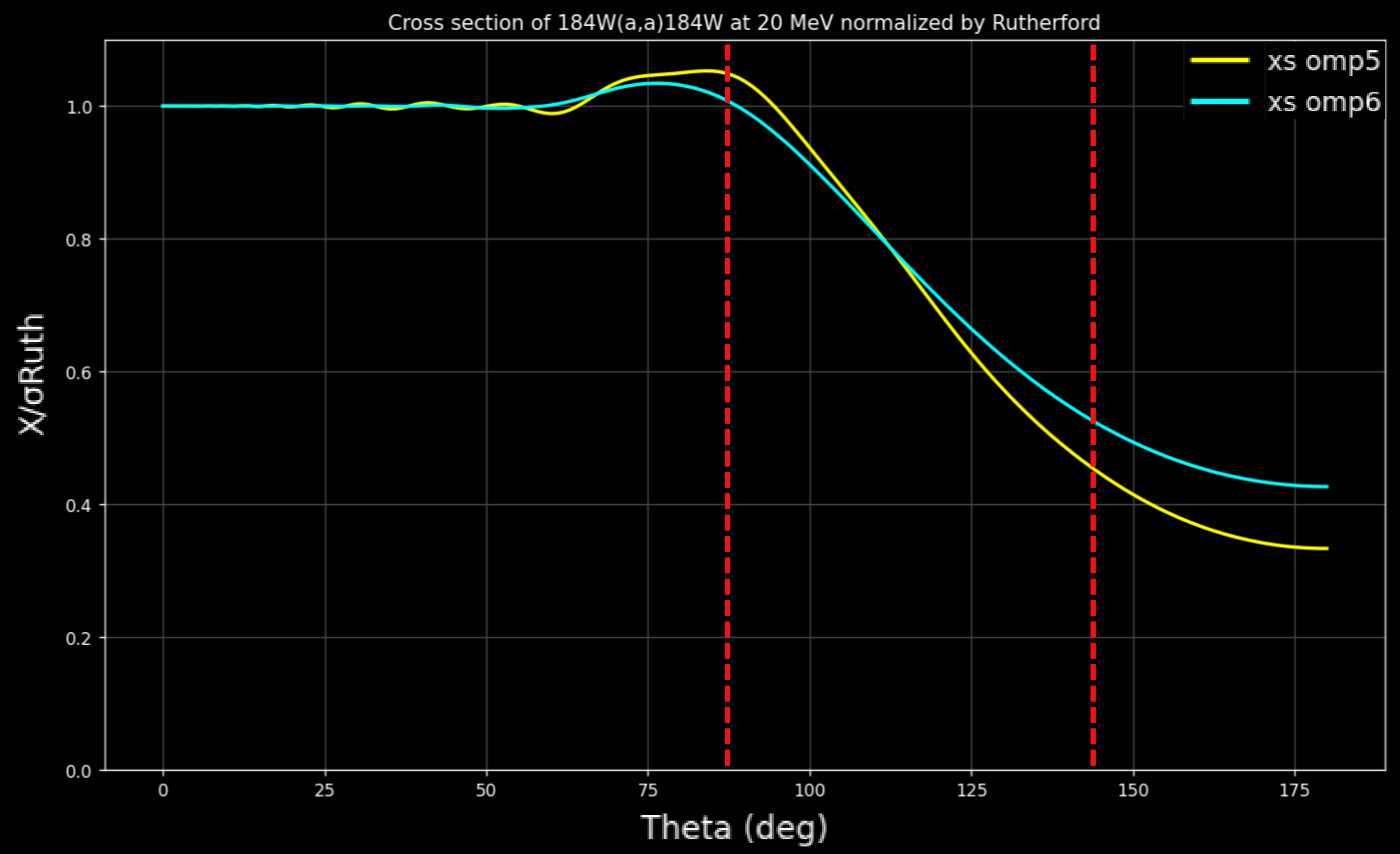
$$\frac{d\sigma}{d\Omega} = \frac{N}{Q \times d\Omega \times \varepsilon}$$

Need to know the solid angle $d\Omega$.
One way to have a precise measurement of it is by using our knowledge of the physics.

We used a ^{184}W target to do elastic scattering. At this energy, $^{184}W(\alpha,\alpha)^{184}W$ is mainly Rutherford, which gives us a pretty good knowledge of the cross section. Using this we can recover the solid angle.



The W target is 159 µg/cm² thick. It has been determined by RBS. At the measured angles, the nuclear potential has an impact on the scattering. We used TALYS with the OMP of Avrigeanu and Demetriou to compute the cross sections.



Cross section of α elastic scattering on W at 20MeV calculated with TALYS, normalized by Rutherford.

The solid angle calculated is then 1.6*10^-4 sr