PuF project :

^{240}Pu Fission cross section measurement

06/07/2026

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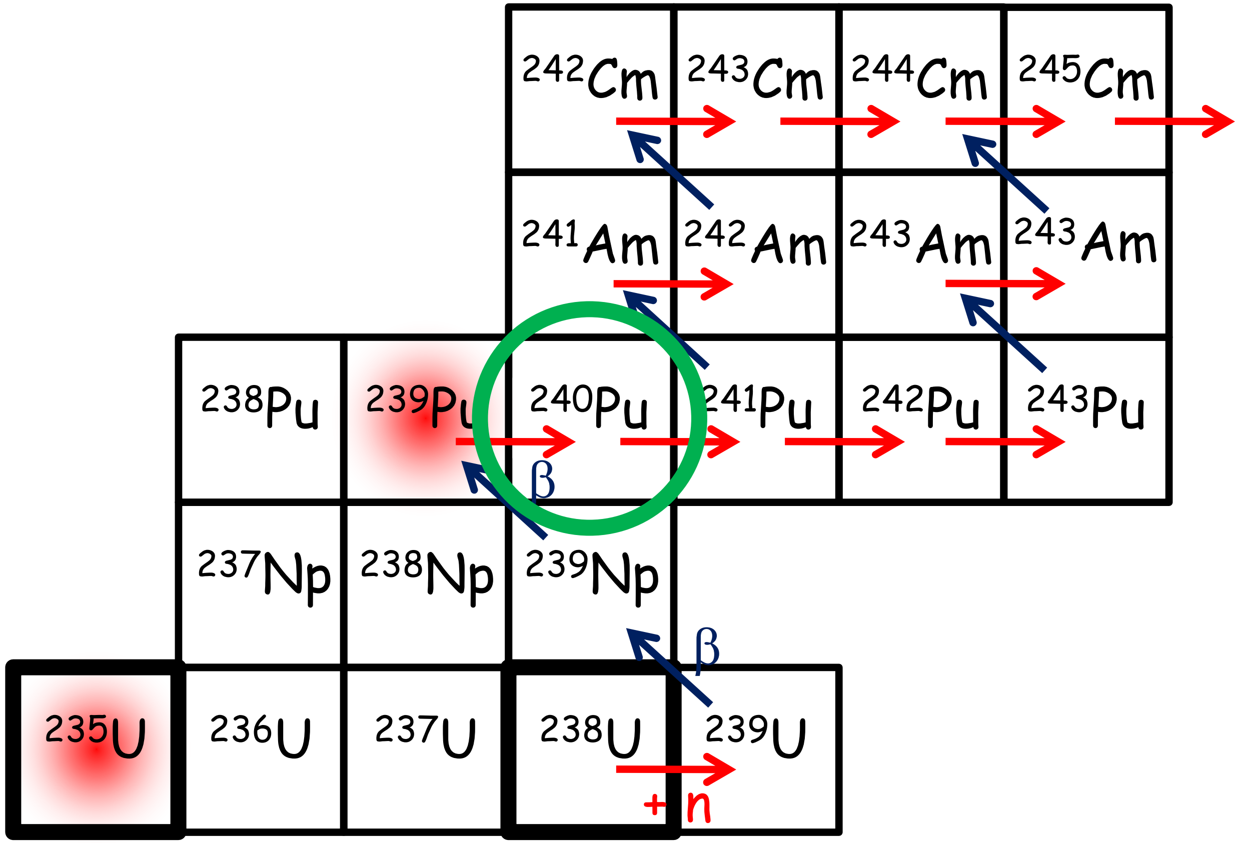
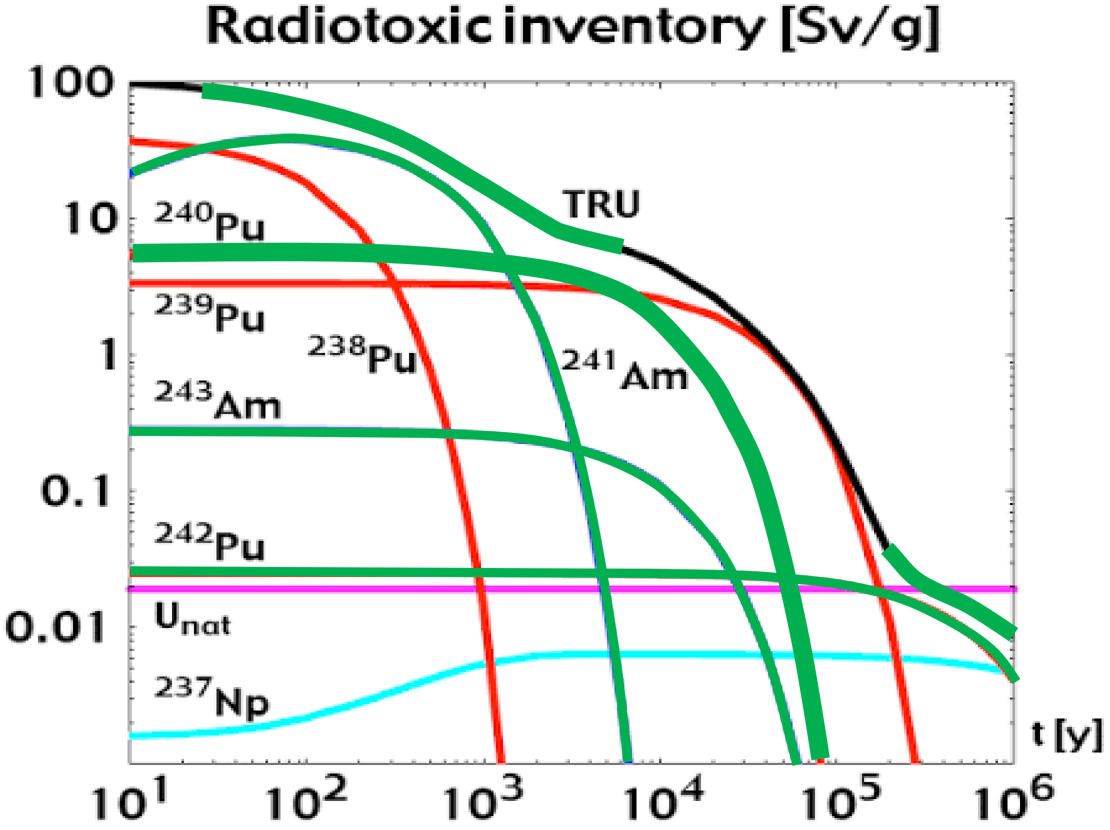
I- Motivations

Main objective

Our goal is to **improve Nuclear Data** needed for simulations (for safety or nuclear waste production)
The Pu isotopes fission cross sections in the MeV region are of particular interest.





P. Mazgaj et al., *Journal of Power Technologies*, *94*(4) (2014)

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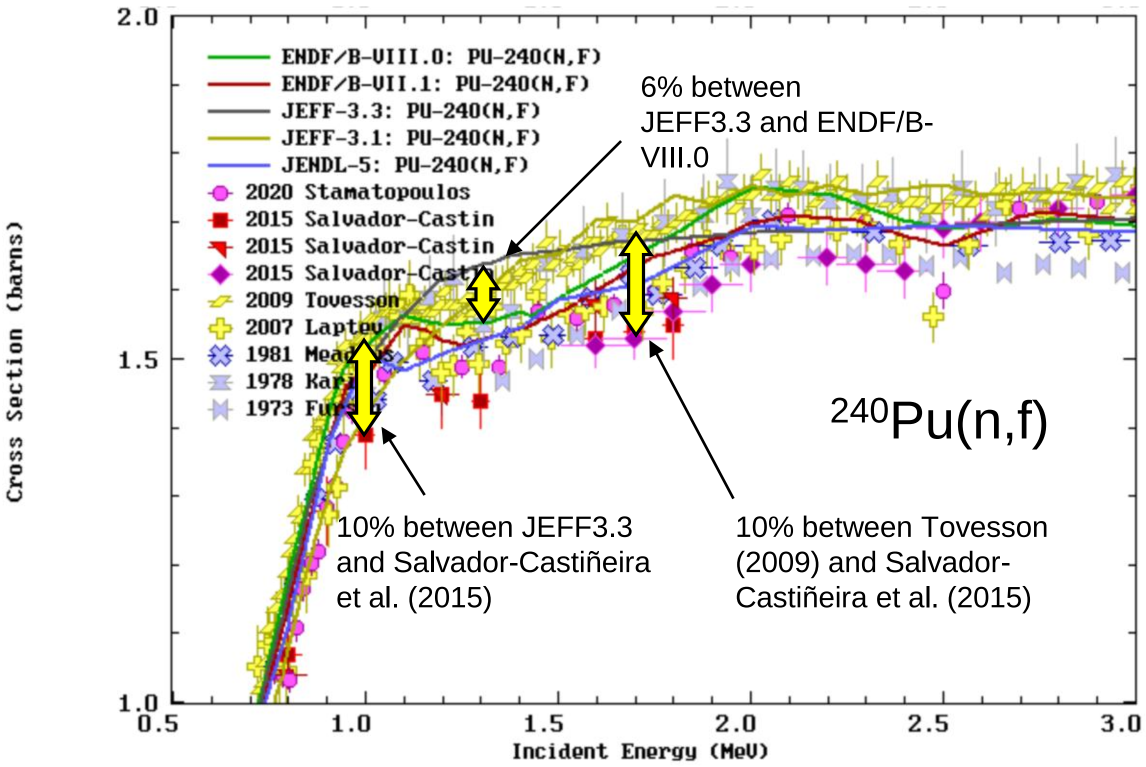

6% between JEFF3.3 and ENDF/B-VIII.0

^{240}Pu(n,f)

10% between JEFF3.3 and Salvador-Castiñeira et al. (2015)

10% between Tovesson (2009) and Salvador-Castiñeira et al. (2015)

Existing data:

- large discrepancies between experimental data (discrepancies larger than error bars)
- large discrepancies between databases (different shapes)

➡ There are uncertainties and uncontrolled biases in the experimental data

HPRL request:
uncertainties of **1.5 – 2 %** in the 0.5 – 1.4 MeV region

➡ Experimental effort needed to tackle this challenge

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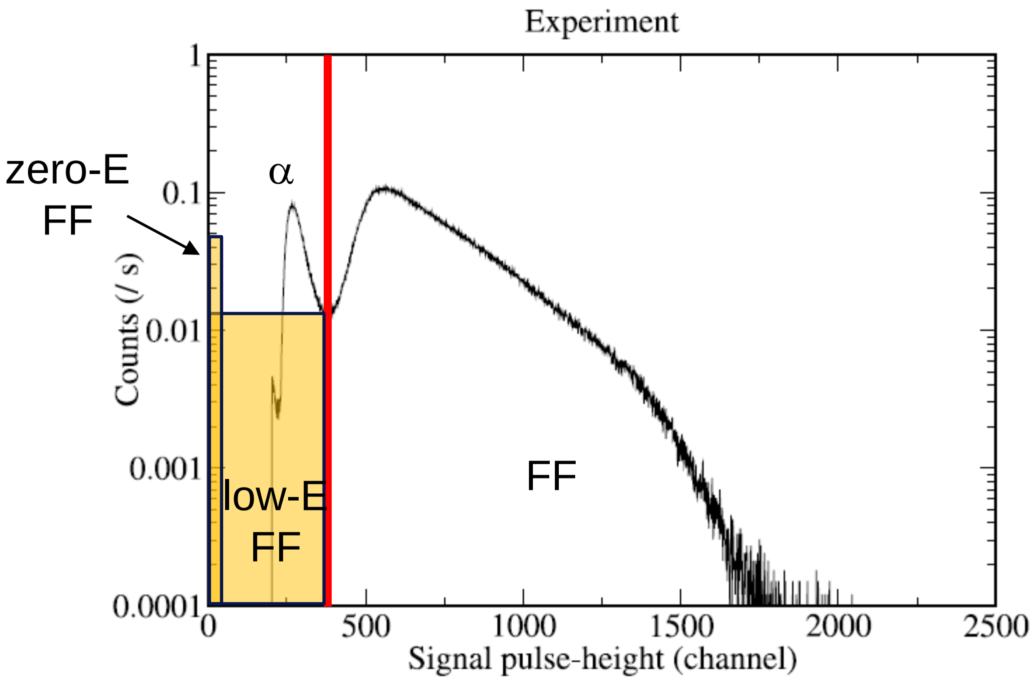
I- Motivations

What can be done ?

Lot of discrepancies between experimental data:

- different experimental technics (Time of Flight, monoenergetic neutrons)
- always the same experimental setup (Fission Chambers)
- “always” the same reference cross section (^{235}U(n,f))



low-E FF:
FF depositing a low energy in the gas

zero-E FF:
FF stopped into the fissile deposit

A fraction of FF are not detected and has to be corrected
(not as simple as it seems => systematic uncertainty)

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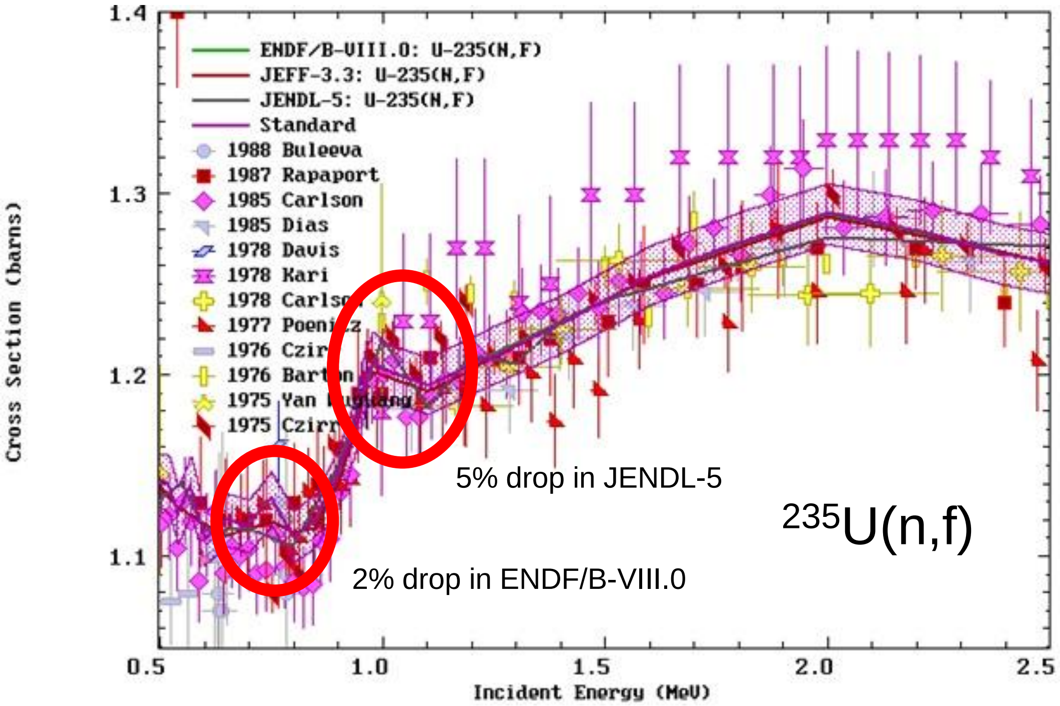

5% drop in JENDL-5

2% drop in ENDF/B-VIII.0

^{235}U(n,f)

- small discrepancies between evaluations
- presence of structures (+9% between 0.85 and 1 MeV)
- standard uncertainty : 1.3 % (has risen from 0.6 % in the last decade)

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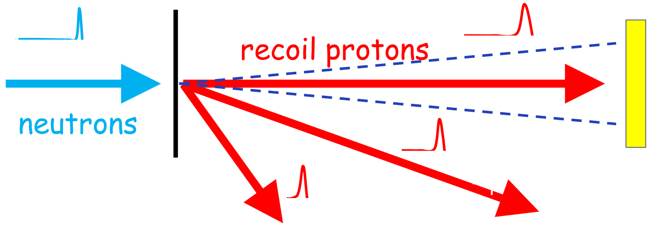
➡ Two different solutions:

- to improve the “classical” experimental setup and methods and track uncertainties and bias :
(ex. much better α-FF discrimination via PSD)

- to perform and independant measurement, by changing everything:
1- use of photovoltaic cells instead of fission chamber
2- use of the ^{1}H(n,n) standard instead of ^{235}U(n,f) one



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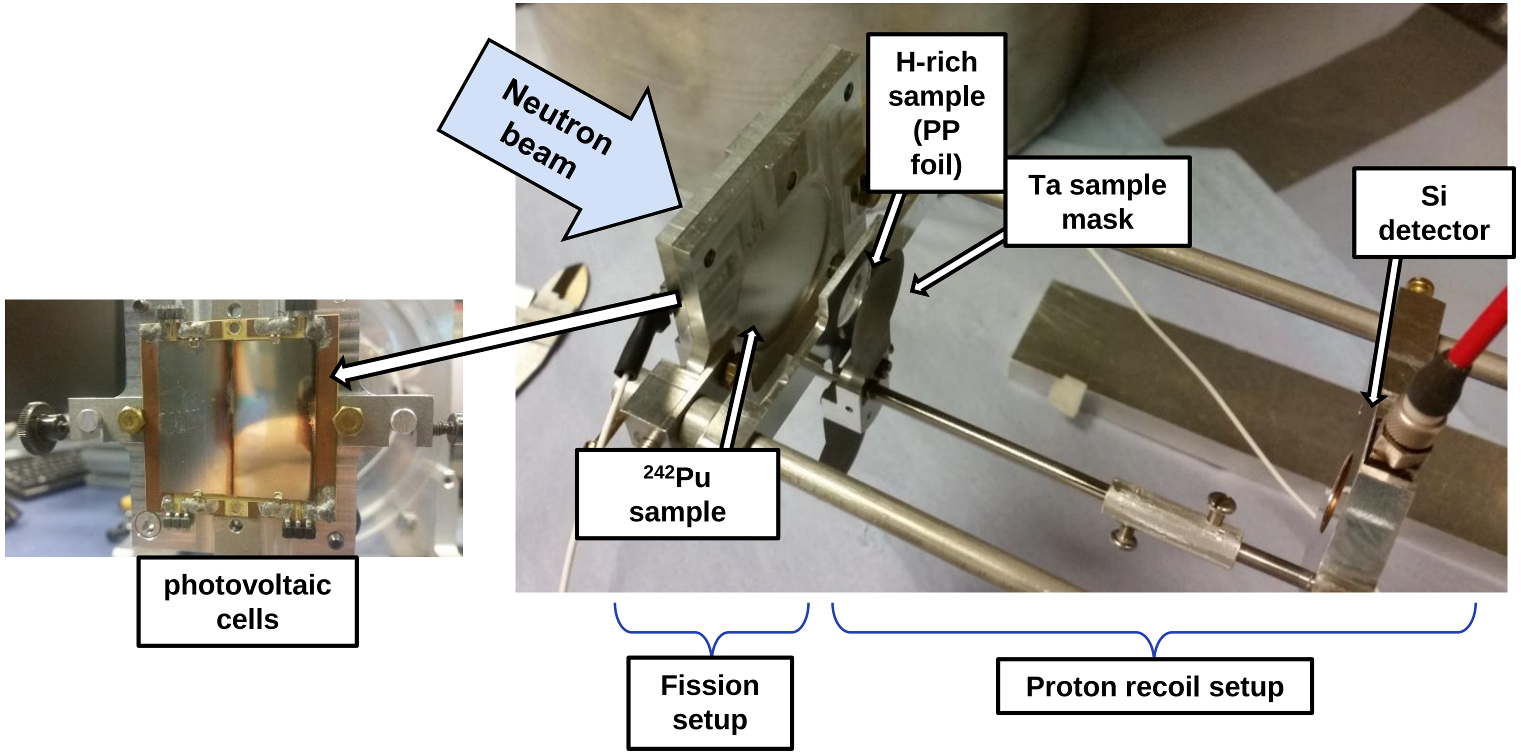
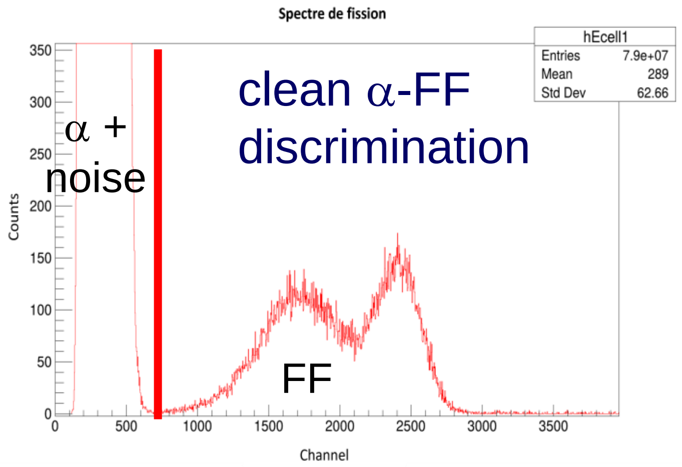
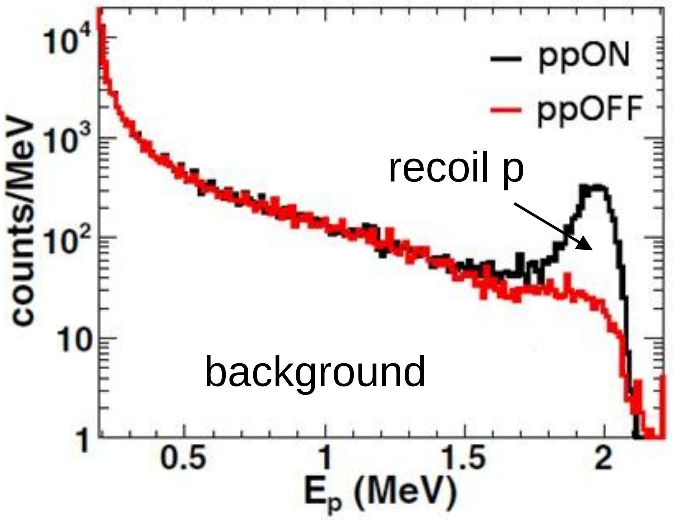
II- Experimental setup and method

Example of the ^{242}Pu(n,f) experiment

A very simple experimental setup!







Better precision for fission, but more “delicate” for flux measurement (proton recoil)

More impact of scattered neutrons (no compensation phenomenon)

II- Experimental setup and method

Cross section measurement

$$\sigma_{242Pu(n,f)} = \frac{\overset{\sim\ \%_{sys}}{\boxed{N_{FF}}}}{\underset{qq\ \%_{sys}}{\boxed{N_p}}} \times \frac{\overset{<\ \%_{sys}}{\varepsilon_p}}{\underset{\sim\ \%_{sys}}{\boxed{\varepsilon_{FF}}}} \times \frac{\overset{<\ \%_{sys}}{\Omega_{PP}}}{\underset{<\ \%_{sys}}{\Omega_{242Pu}}} \times \frac{\overset{qq\ \%_{sys}}{\boxed{N_H}}}{\underset{\text{discarded}}{N_{242Pu}}} \times \overset{<\ \%_{sys}}{\sigma_{H(n,n)}}$$

Each term brings its own uncertainty, but few of them are really **significant**:

- N_H: background correction for scattered neutrons
- N_p: background correction for parasitic proton recoil
- ε_{FF}:
  . $\varepsilon_{geo+intrinsic}$ determined by SF measurement
  . kinematic effects added to ε_{geo} by simulation
- N_H: non-radioactive target, difficult to characterise

An effort has been made to :
- reduce the **uncertainty** on these terms
- track possible **systematic bias**

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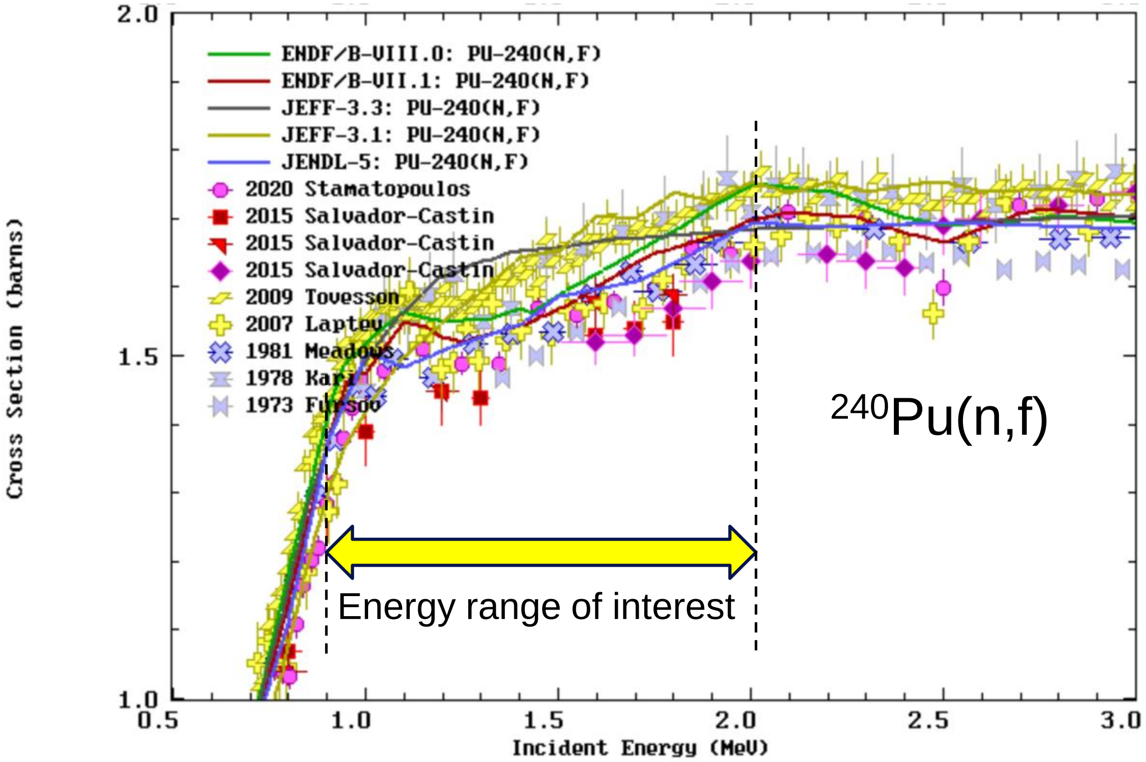
III- The PuF project

Main goal:



New measurement of ^{240}Pu(n,f) between 1 and 2 MeV

Take into account the experience acquired with the ^{242}Pu(n,f) measurement:
- issue with Si contamination
- issue with PP contamination

Project human ressources:

- small fraction of FTE for researcher
- PhD started in late 2025 on the ^{240}Pu(n,f) measurement
  1 year late for the APRENDE beginning,
  but on time for the APRENDE end

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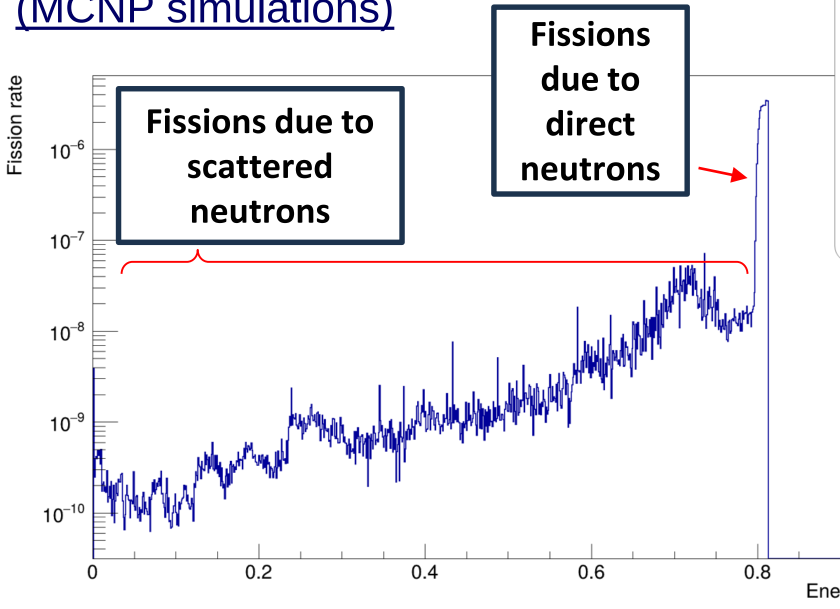
III- The PuF project

^{242}Pu(n,f) analysis as training

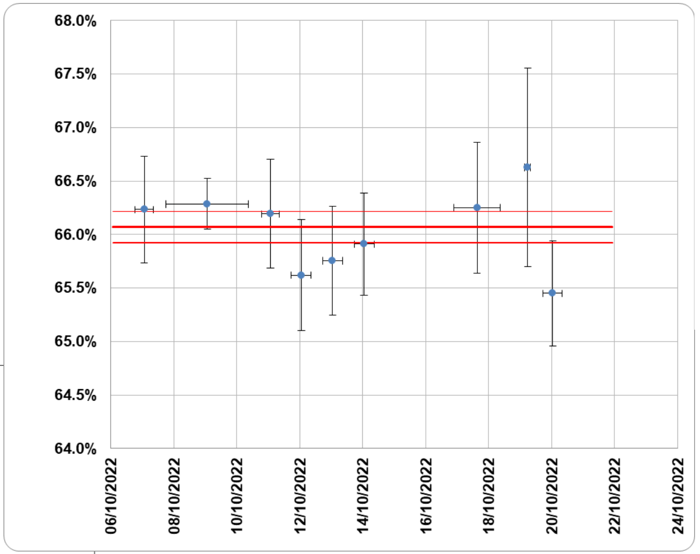
Correction of parasitic fission (MCNP simulations)



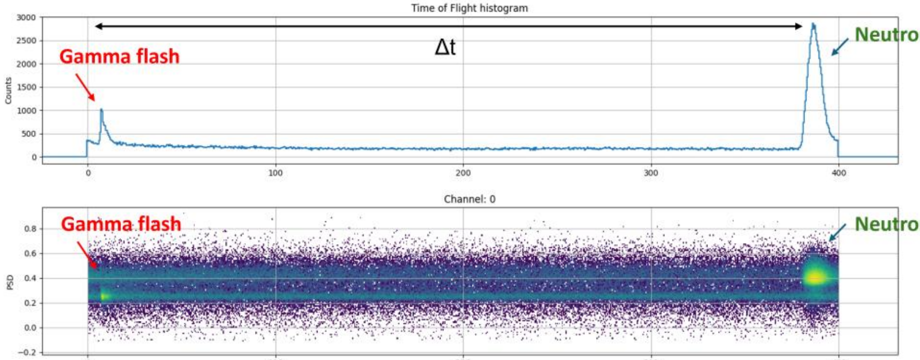
Fissions due to scattered neutrons

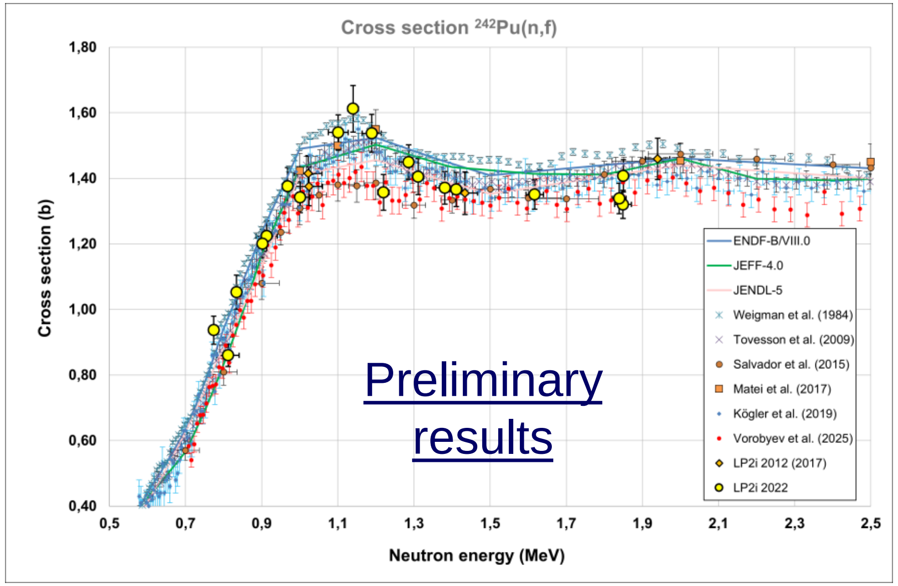
Fissions due to direct neutrons

SF efficiency



Energy re-calibration





Preliminary results

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III- The PuF project

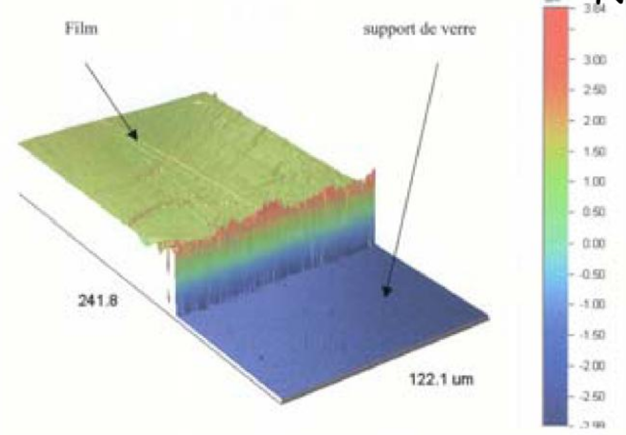
Focus on H atoms quantity:

~~few $\%_{sys}$~~

~ $\%_{sys}$

$$\sigma_{242Pu(n,f)} = \frac{N_{FF}}{N_p} \times \frac{\varepsilon_p}{\varepsilon_{FF}} \times \frac{\Omega_{PP}}{\Omega_{242Pu}} \times \frac{\boxed{N_H}}{N_{242Pu}} \times \sigma_{H(n,n)}$$

The thickness can be measured by interferometry (preferred to the micro-weighing technique)



The polypropylene density is required ! (highly questionable)

The density can be measured using a pycnometer... which uses micro-weighting.

→ use of **micro-weighting** technique to determine the H-content

Procedure:

- cut of a precise area
- 2x2 cm² : small enough to avoid averaging inhomogeneities, large enough to reduce uncertainties (on surface and mass)

What about stoichiometry?

The real stoichiometry can differ from the theoretical one due to the additives used during manufacturing

→ stoichiometry needs to be checked!

2 experiments carried out on the AIFIRA facility
(RBS and ERDA)

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III- The PuF project

Planned experiment:

On the MONNET facility:
- possibility to use ^{3}H target (to cover the energy range of interest)
- Pu targets availability
- ⚠ MONNET is unavailable in 2026 due to building maintenance

Experiment:
- proposal submitted in February and accepted in June 2026
- experiment probably **scheduled in February 2027**

^{240}Pu Target:
- available, albeit with a limited thickness (98 kBq, 95 µg/cm²)
- experimental protocol has to be adapted (long SF measurement prior to the experiment, fewer points measured)

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Conclusions

PuF project:

- measurement of ^{242}Pu(n,f) in the 1-2 MeV energy range
- use of photovoltaic cells and proton recoil technic to change systematics bias
- PhD student since late 2025

Work done:

- training on analysis on ^{242}Pu(n,f) case: scattered neutrons, SF efficiency, kinematic effect simulations, etc.
- experiment on AIFIRA facility to characterise PP film
- proposal submitted and accepted

Work to be done:

- ^{240}Pu(n,f) experiment carried out at the beginning of 2027
- new tests experiments for PP characterisation
- analysis up to beginning of 2028

~~ *Thank you for your attention !* ~~

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Acknowledgment

This scientific program has been funded by several successive European projects

- CHANDA (2013-2017) :

CHANDA
SOLVING CHALLENGES IN NUCLEAR DATA
FOR THE SAFETY OF
EUROPEAN NUCLEAR FACILITIES

- SANDA (2019-2023) :

SANDA

SANDA
Supplying Accurate Nuclear Data for
energy and non-energy Applications

HORIZON2020

- APRENDE (2024-2028) :

APRENDE

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II- What’s new ? Method improvement

H atoms quantity:

~~few $\%_{sys}$~~

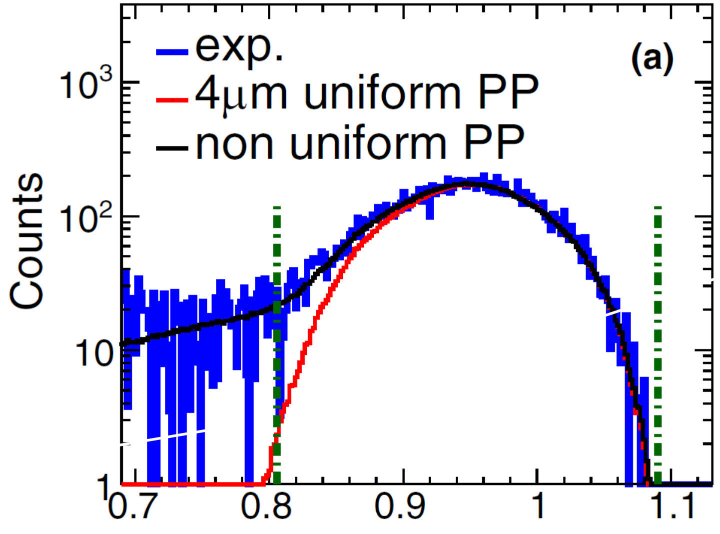
~ $\%_{sys}$

$$\sigma_{242Pu(n,f)} = \frac{N_{FF}}{N_p} \times \frac{\varepsilon_p}{\varepsilon_{FF}} \times \frac{\Omega_{PP}}{\Omega_{242Pu}} \times \frac{N_H}{N_{242Pu}} \times \sigma_{H(n,n)}$$

Is the H-content stable?

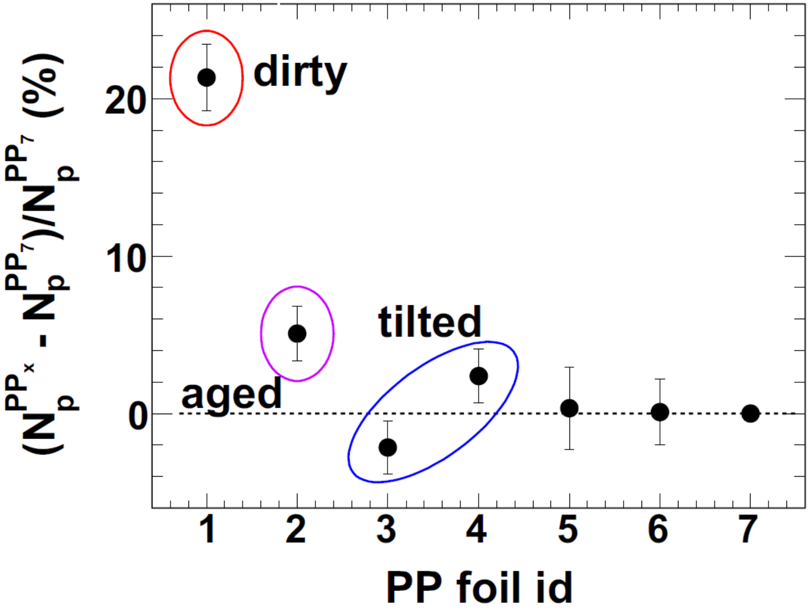
An **evolution** of the H-content has been observed in previous experiment, leading to an **additional proton recoil** contribution.

Quantitative experiment showed up to 20% of additional H-content



proton peak for an ideal radiator

proton emitted by thick H-contamination



This contamination is caused :

- primarily by **oil droplets from oil pumps**
- to a lesser extent by **dust**

It has a stronger effect on thin films (same deposit on less material)

⇒ Oil pumps are banned
Special care is taken to handle the radiators

II- What’s new ? Method improvement

Scattered neutrons:

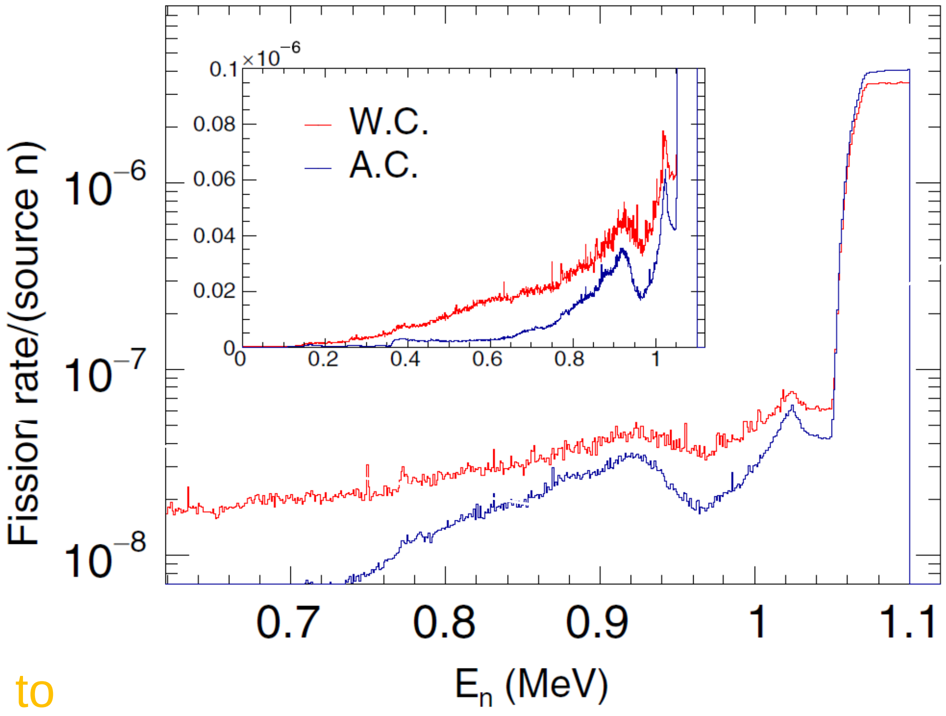
The neutrons emitted by the source may scatter in the surrounding materials before undergoing fission in the target.

The proportion depends on:
- the amount of material (around the production and fissile targets)
- the evolution of σ(n,f)

Scattered neutron contributions:
- to fission: cannot be distinguished from other fission
- to proton recoil: not in the proton peak

$\cancel{0\ \%_{sys}}$ ~ $\%_{sys}$

$$\sigma_{242Pu(n,f)} = \frac{N_{FF}}{N_p} \times \frac{\varepsilon_p}{\varepsilon_{FF}} \times \frac{\Omega_{PP}}{\Omega_{242Pu}} \times \frac{N_H}{N_{242Pu}} \times \sigma_{H(n,n)}$$



fission from scattered neutrons

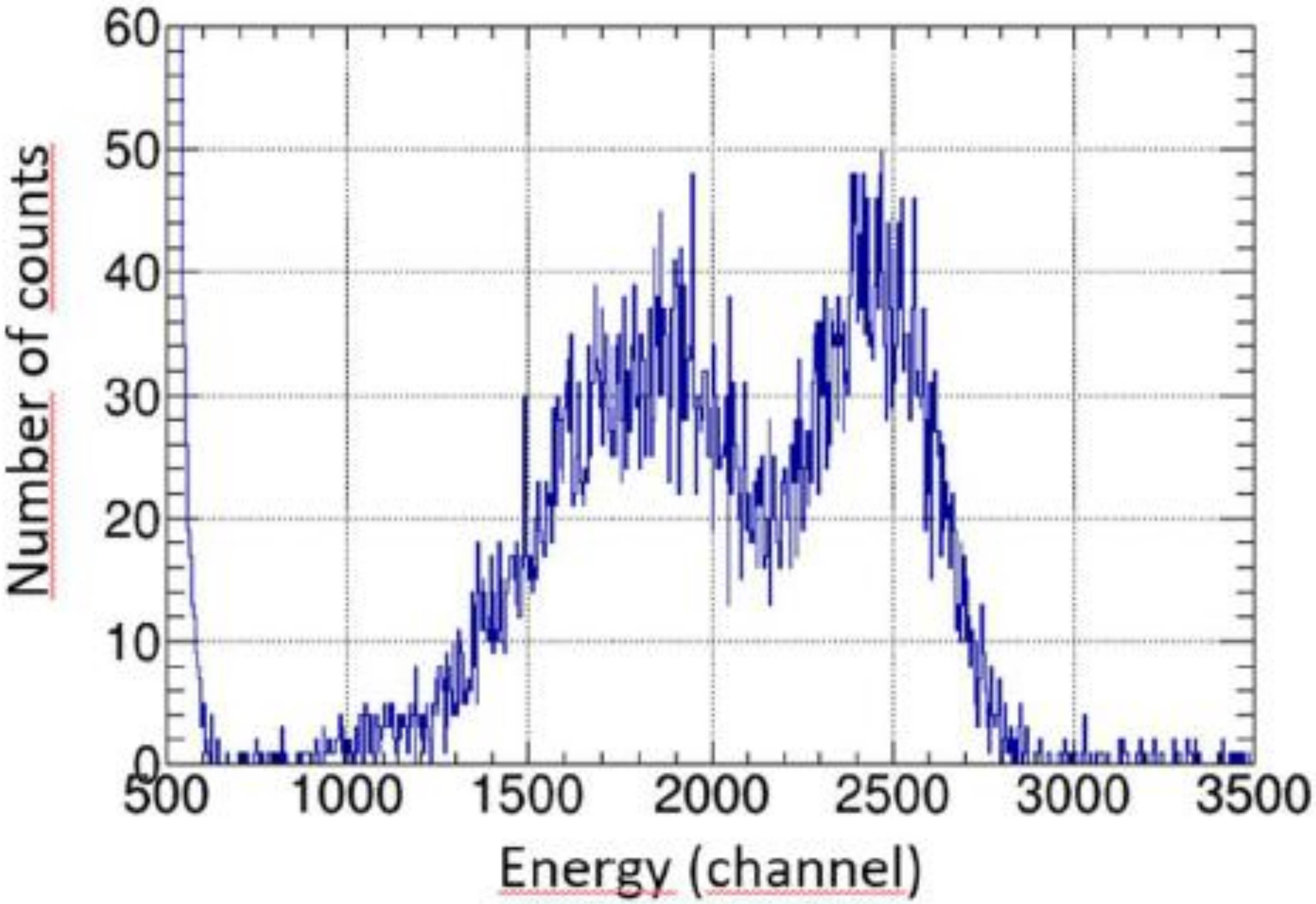
fission from direct neutrons

➡ The **proton recoil technique** is **more sensitive** to scattered neutrons than the fission target reference

Procedure:
- scattered neutron contribution removed via simulations (contribution from 3 to 15% !)

10% uncertainty on the correction factor

Fission vue par les cellules photovoltaïques



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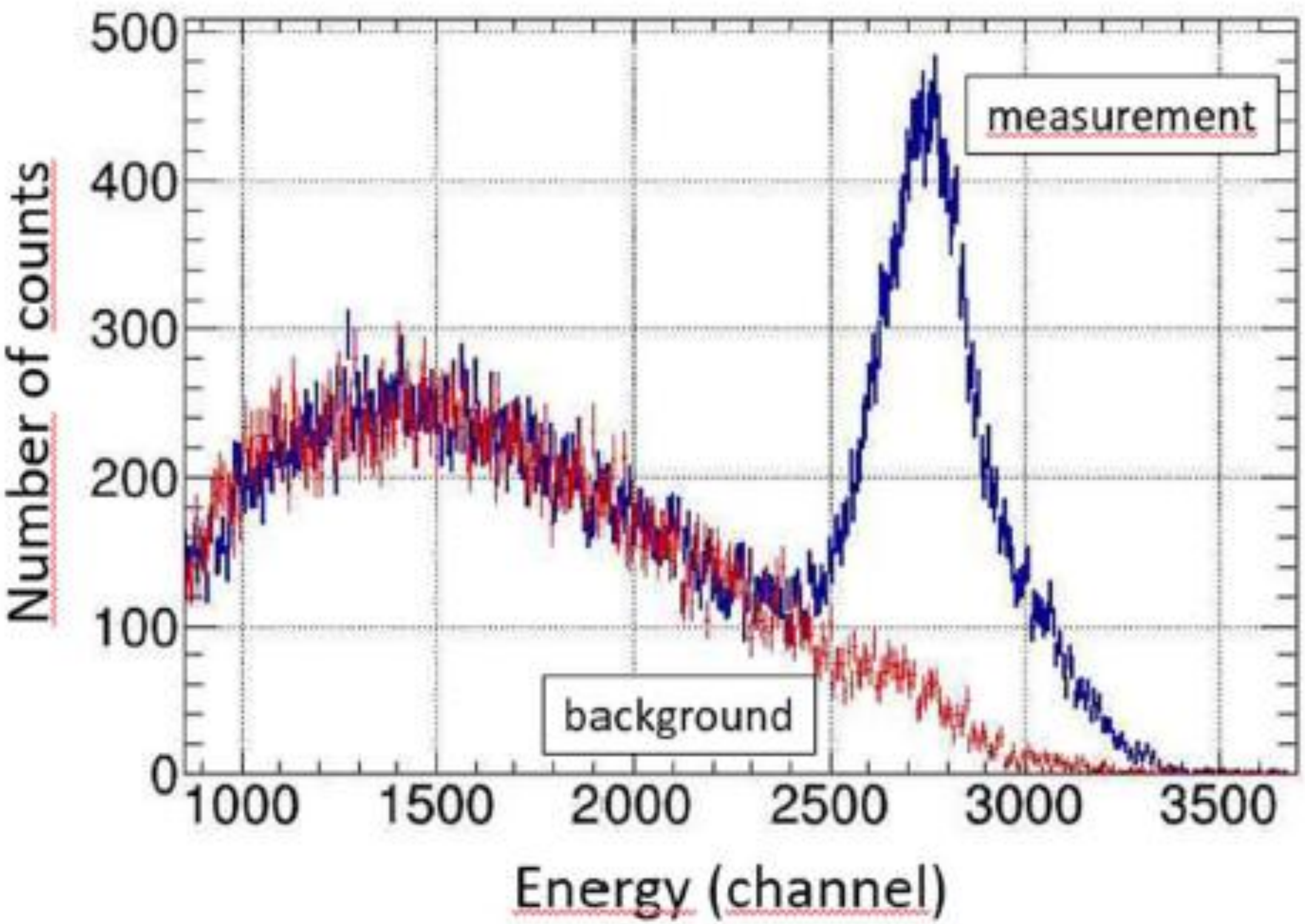
Protons de recul vus par le Si



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