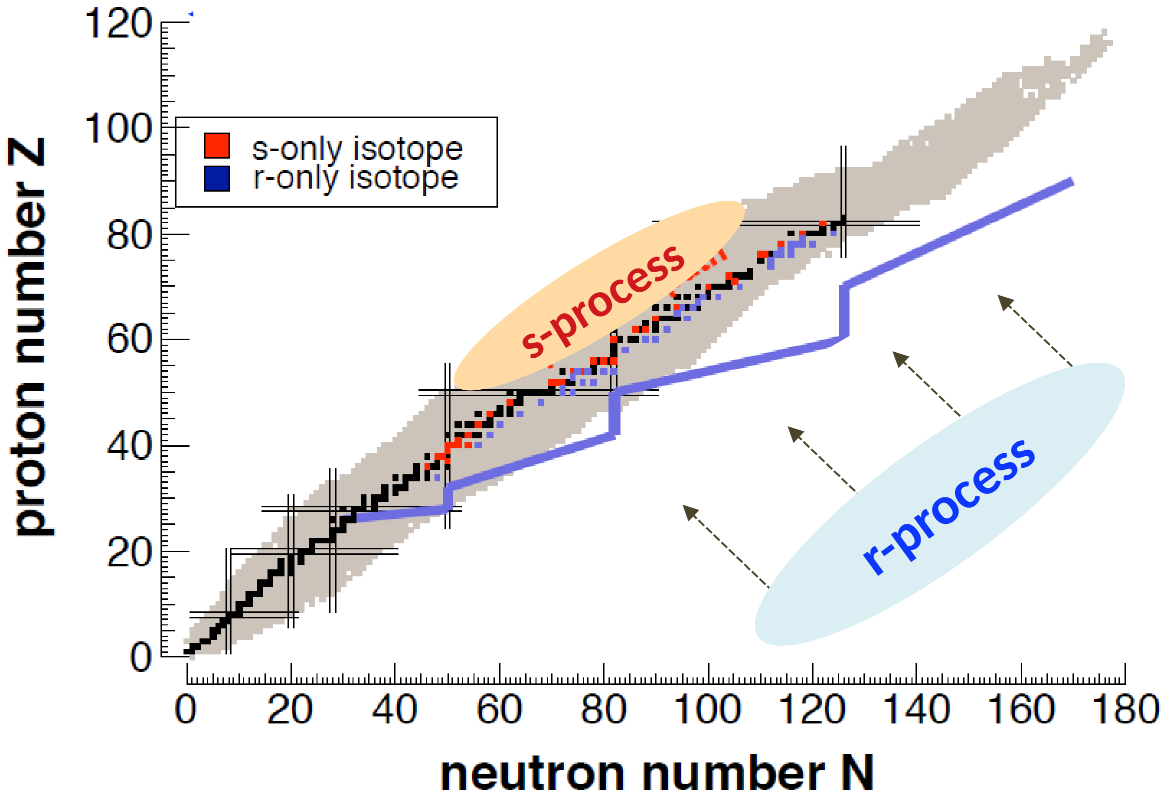
Measurement of $^{140}Ce(n,\gamma)$ cross section at n_TOF

Stellar nucleosynthesis

The heavy elements (Z>26) are produced mostly via neutron captures followed by beta decays.



s-process

- AGB stars
- Capture times >> Decay times
- $N_n = 10^8$ n/cm^3 kT = 0.3-300 keV
- Near the valley of stability

r-process

- Explosive environments
- Capture times << Decay times
- $N_n = 10^{20-30}$ n/cm^3 kT > 100 keV
- Far from stability

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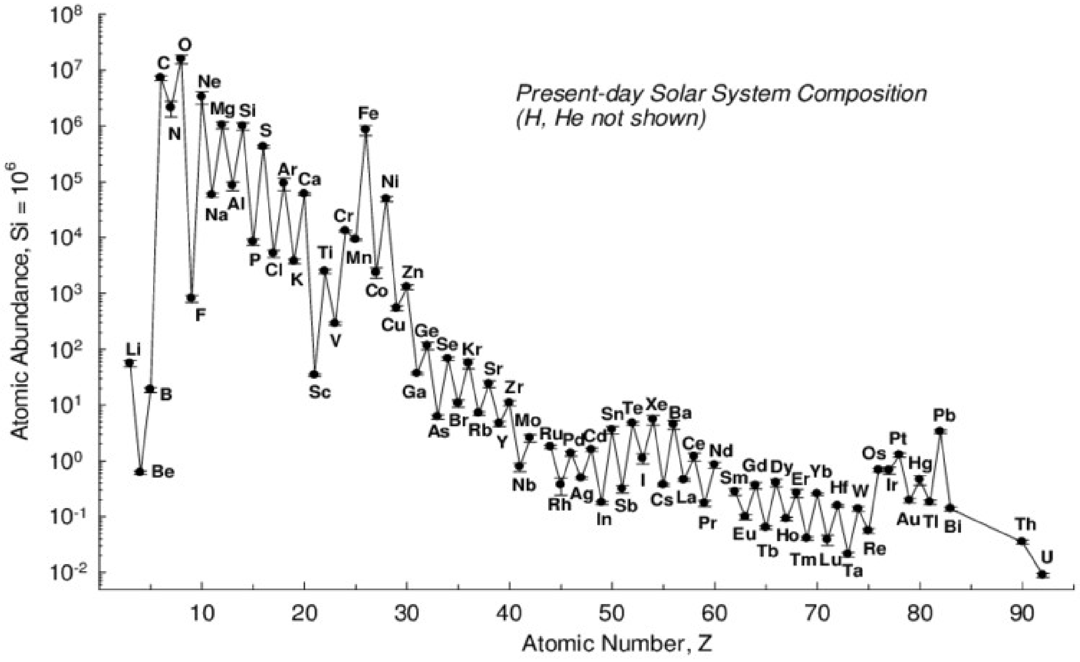

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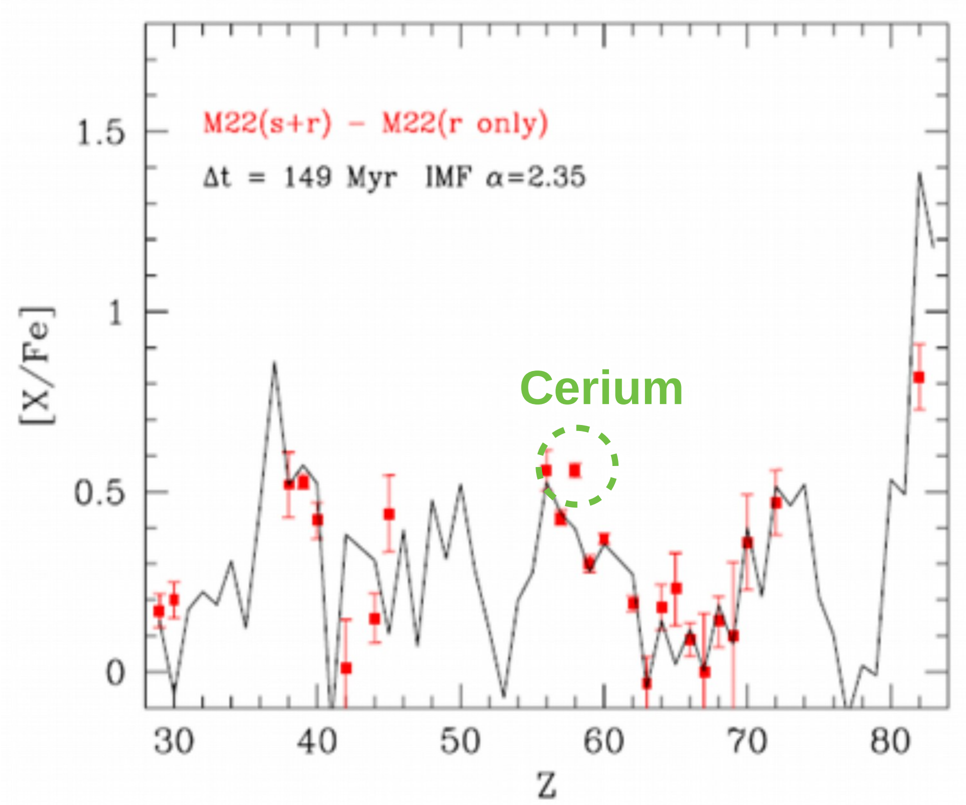
Cerium abundance

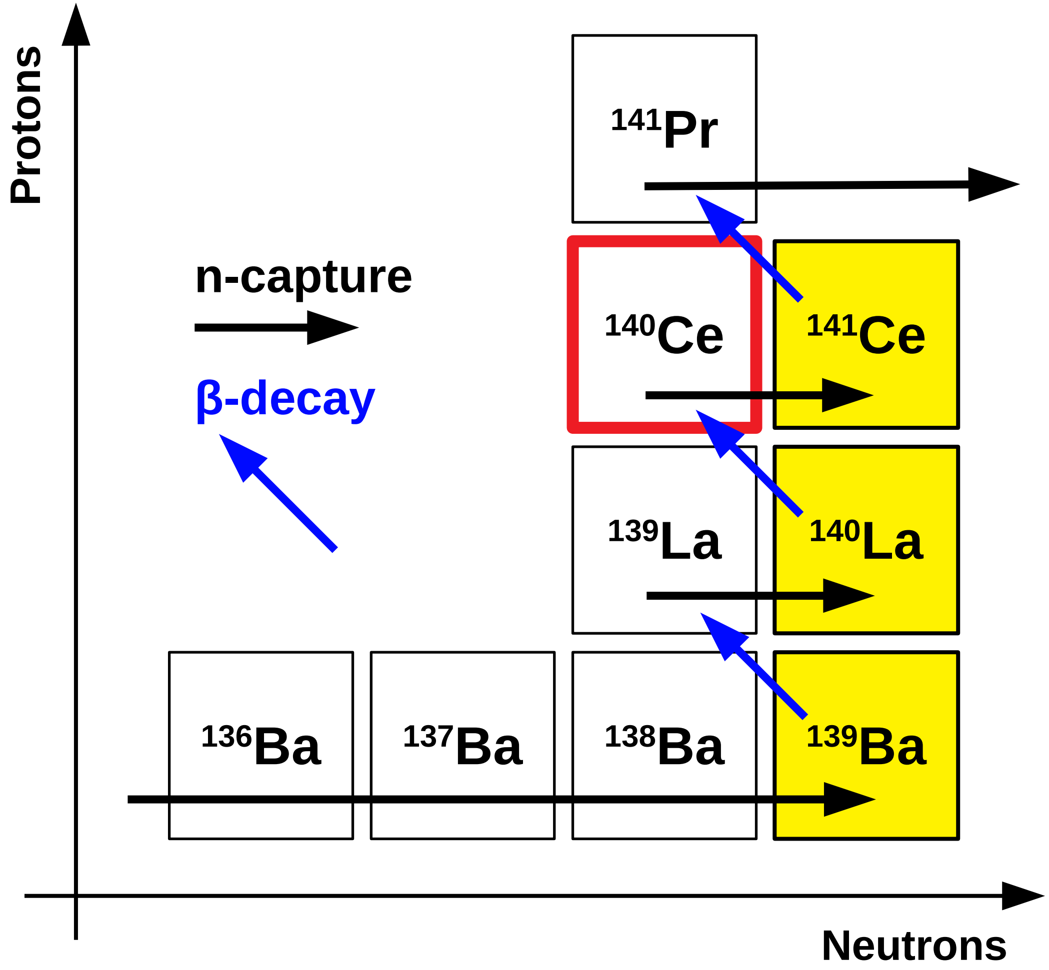


O. Straniero, S. Cristallo, L. Piersanti APJ **785** (2015) 77

Abundance of heavy elements observed in globular cluster M22 compared with a theoretical stellar model.

Almost all the abundances of elements belonging to the second s-process peak (Ba-La-Ce-Nd-Pr) are reproduced except for cerium.

Cerium s-process path



The final cerium abundance strongly depends on ^{140}Ce(n,γ) cross section.

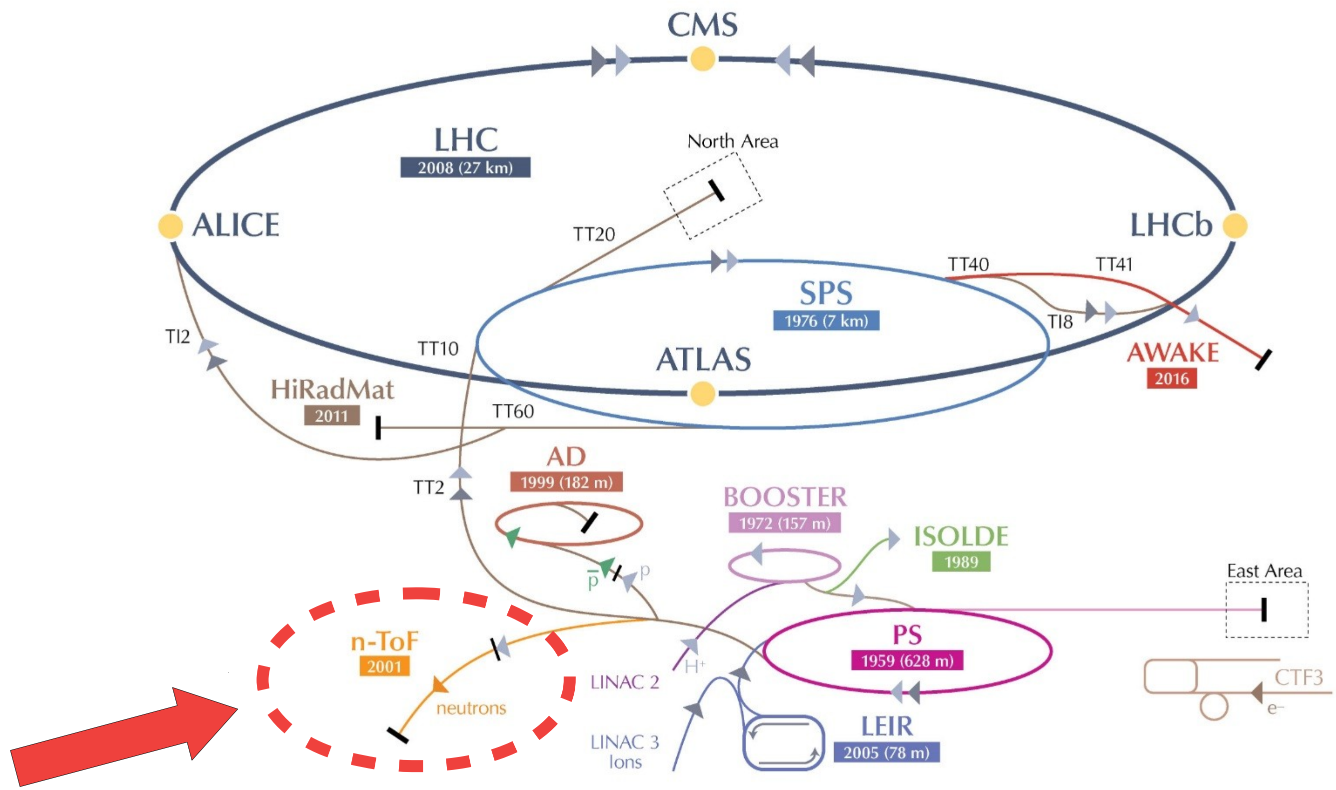
Small cross section (^{140}Ce is a magic nucleus with 82 neutrons) with very few experimental point measured.

The MACS (Maxwellian Averaged Cross Section) is determined by the resonances in keV region.

An accurate measurement of ^{140}Ce(n,γ) cross section has been performed at n_TOF, aiming to obtain high quality data to be included in stellar models.

n_TOF

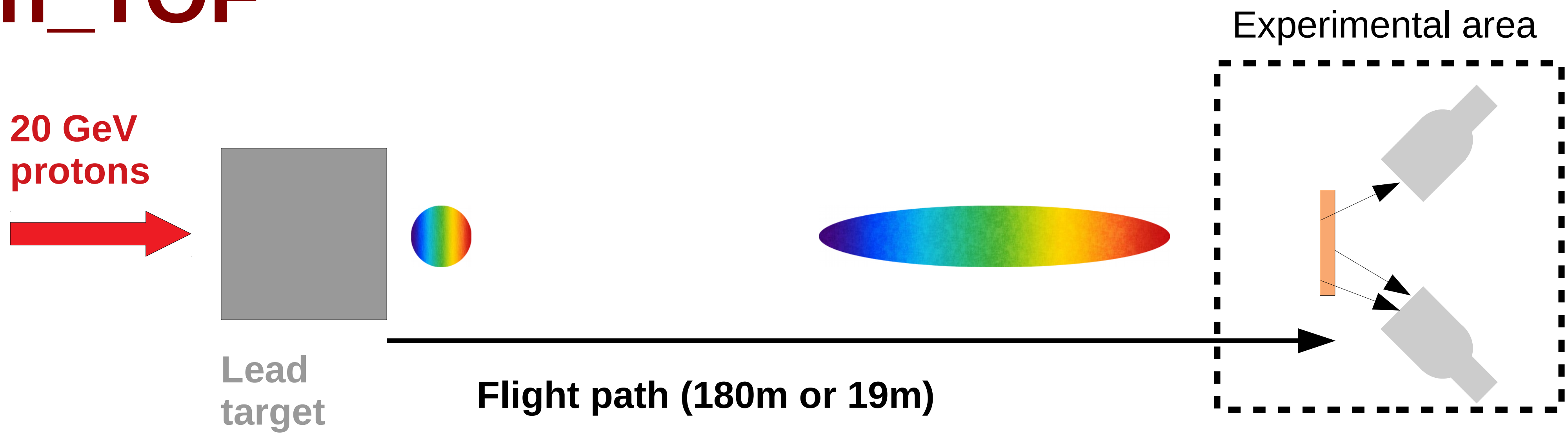
neutron_**T**ime**O**f**F**light



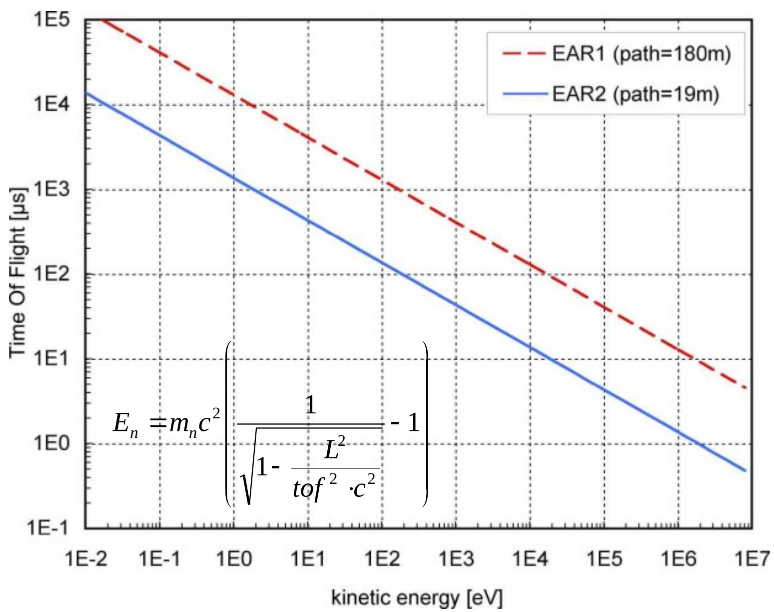
n_TOF is here

n_TOF facility has the **high instantaneous neutron flux**, the **wide energy range** and the **high energy resolution** (around 10^{-4}) and low background needed for this accurate measurement.

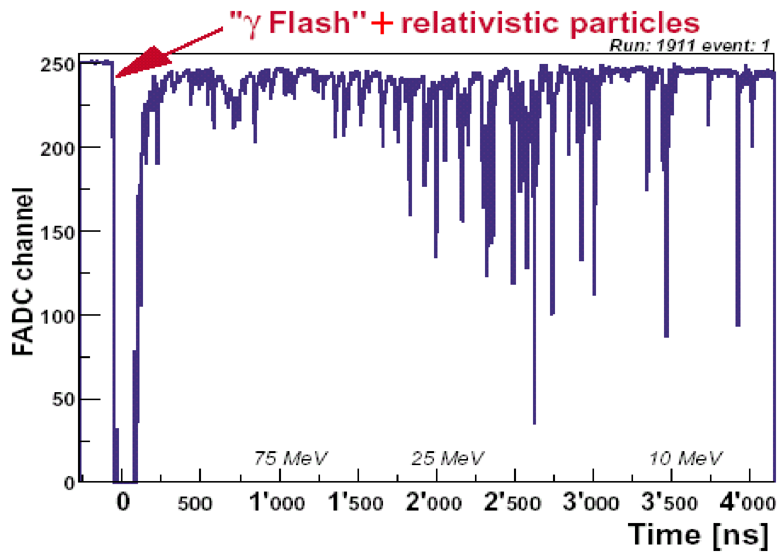
n_TOF



Experimental area
20 GeV
protons
Lead
target
Flight path (180m or 19m)

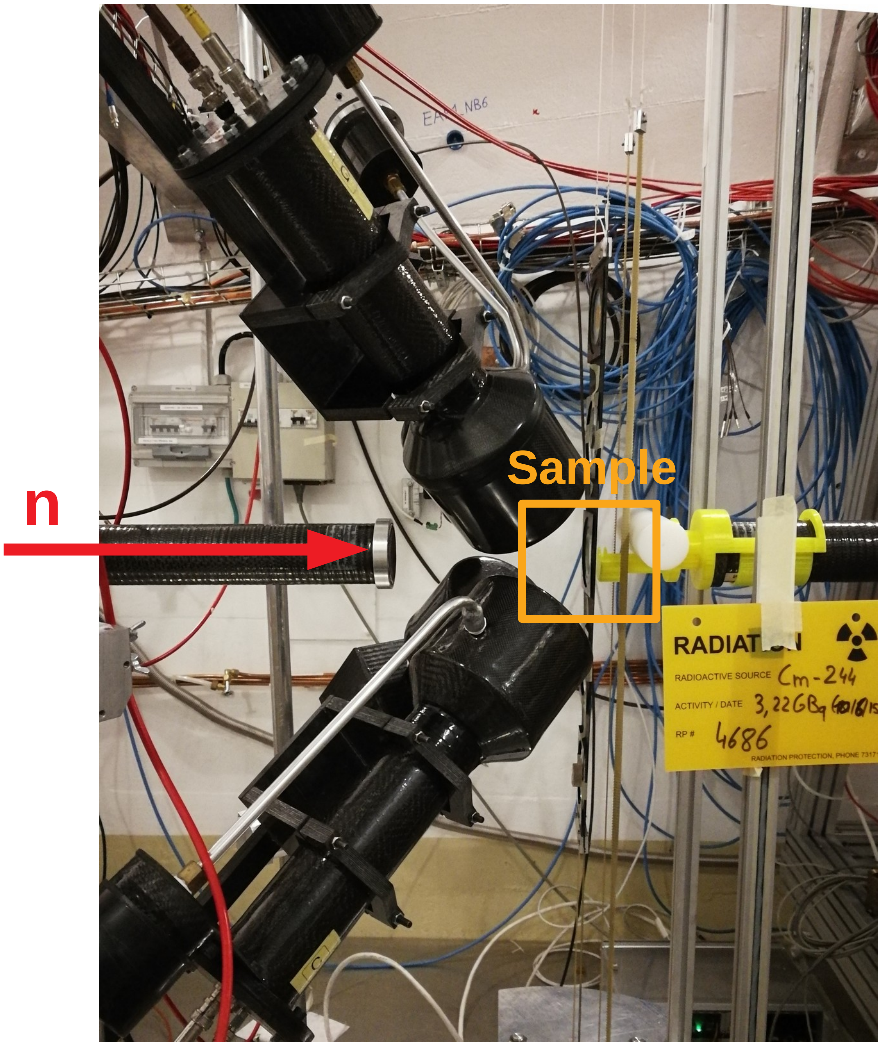


EAR1 (path=180m)
EAR2 (path=19m)
Time Of Flight [µs]
kinetic energy [eV]
1E5
1E4
1E3
1E2
1E1
1E0
1E-1
1E-2
1E-1
1E0
1E1
1E2
1E3
1E4
1E5
1E6
1E7
$E_n = m_n c^2 \left(\frac{1}{\sqrt{1 - \frac{L^2}{tof^2 \cdot c^2}}} - 1 \right)$



"γ Flash" + relativistic particles
Run: 1911 event: 1
FADC channel
250
200
150
100
50
0
75 MeV
25 MeV
10 MeV
0
500
1'000
1'500
2'000
2'500
3'000
3'500
4'000
Time [ns]

Experimental setup



Liquid scintillator detectors containing C_6D_6 used to measure **(n,γ)** reaction cross sections.

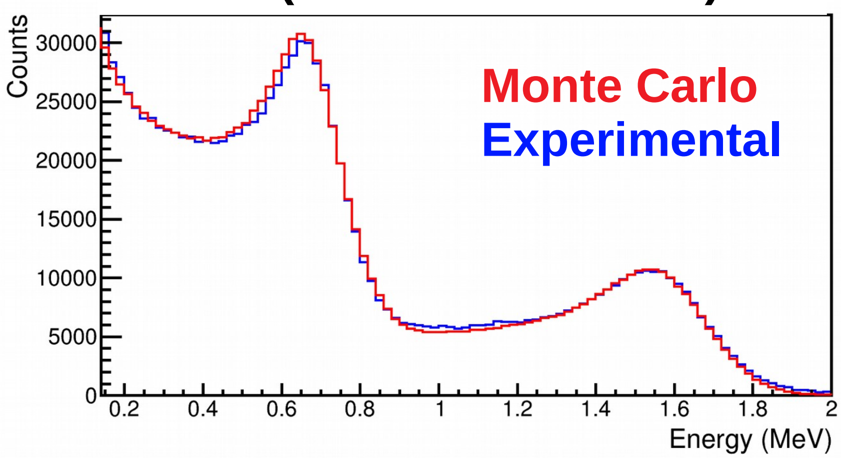
Low neutron sensitivity and background thanks to the carbon fiber structure.

A gold sample is used as reference to normalize the results.

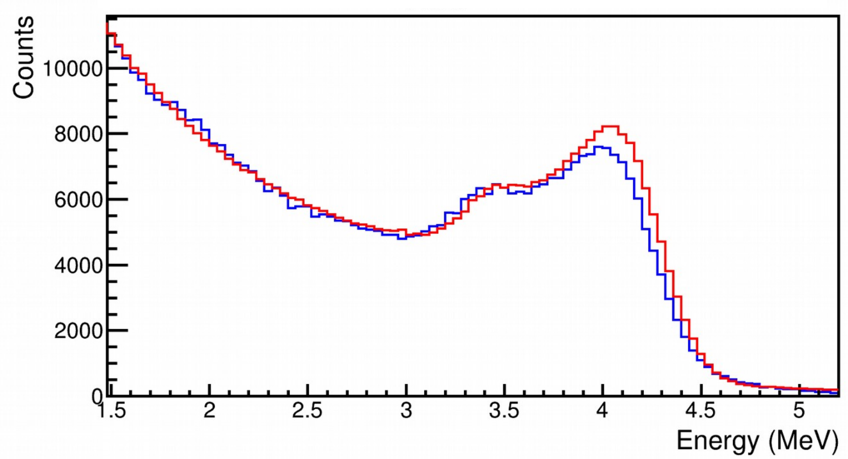
The neutron energy is measured with Time of Flight technique with a **energy resolution of 10^{-4}**.

Calibration and energy spectra

^{88}Y (0.70 and 1.61 MeV)

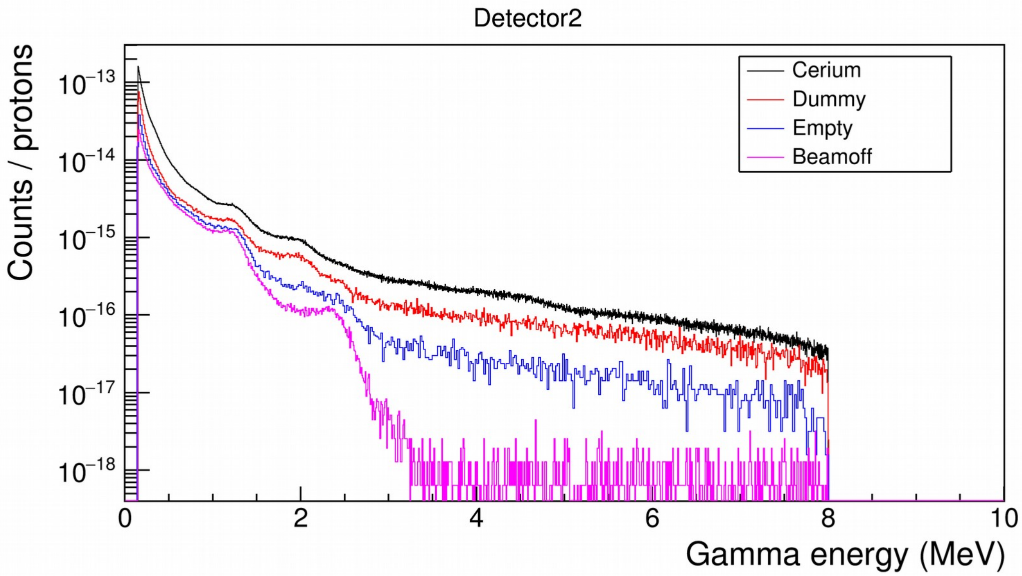


^{241}Am^{9}Be (4.19 MeV)



The **Pulse Height Weight Technique** is used for this analysis, in order to remove the dependence on the cascade decay path.

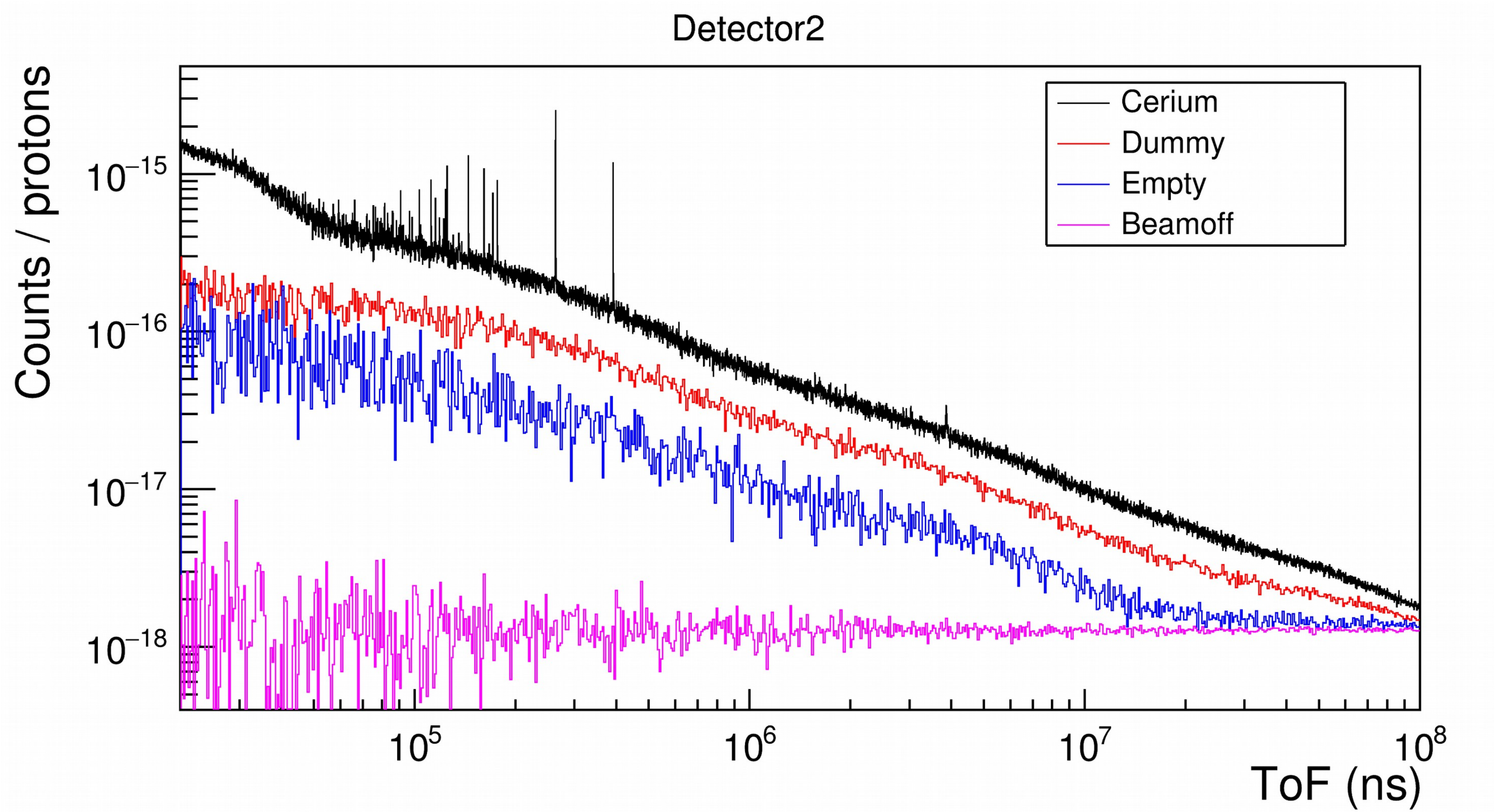
Below the experimental amplitude spectra is compared with the background.



The calibration curve is obtained using 5 Compton Edge of 4 gamma sources:

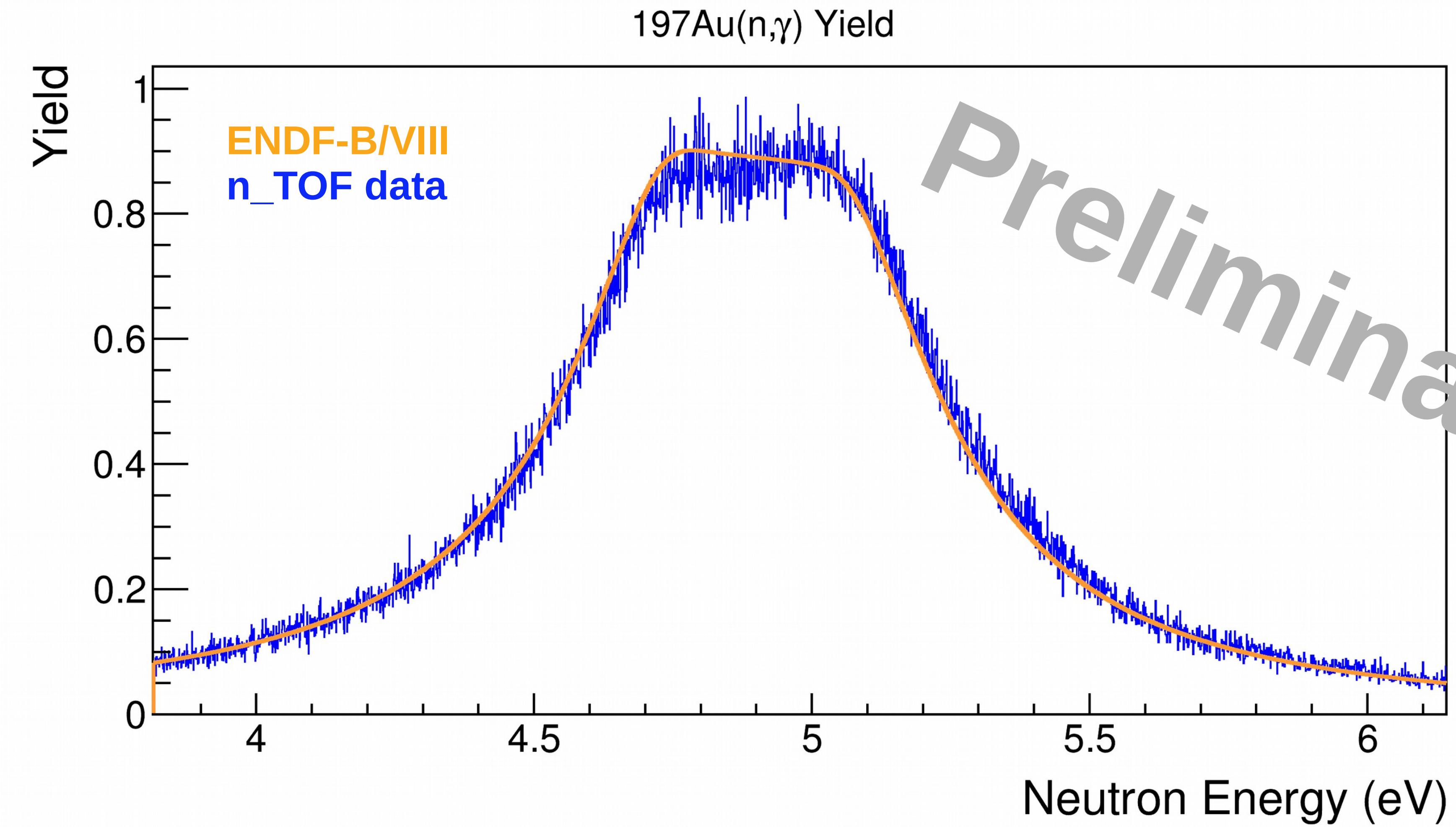
^{137}Cs **^{88}Y** **^{241}Am^{9}Be** **^{244}Cm^{13}C**

Background evaluation



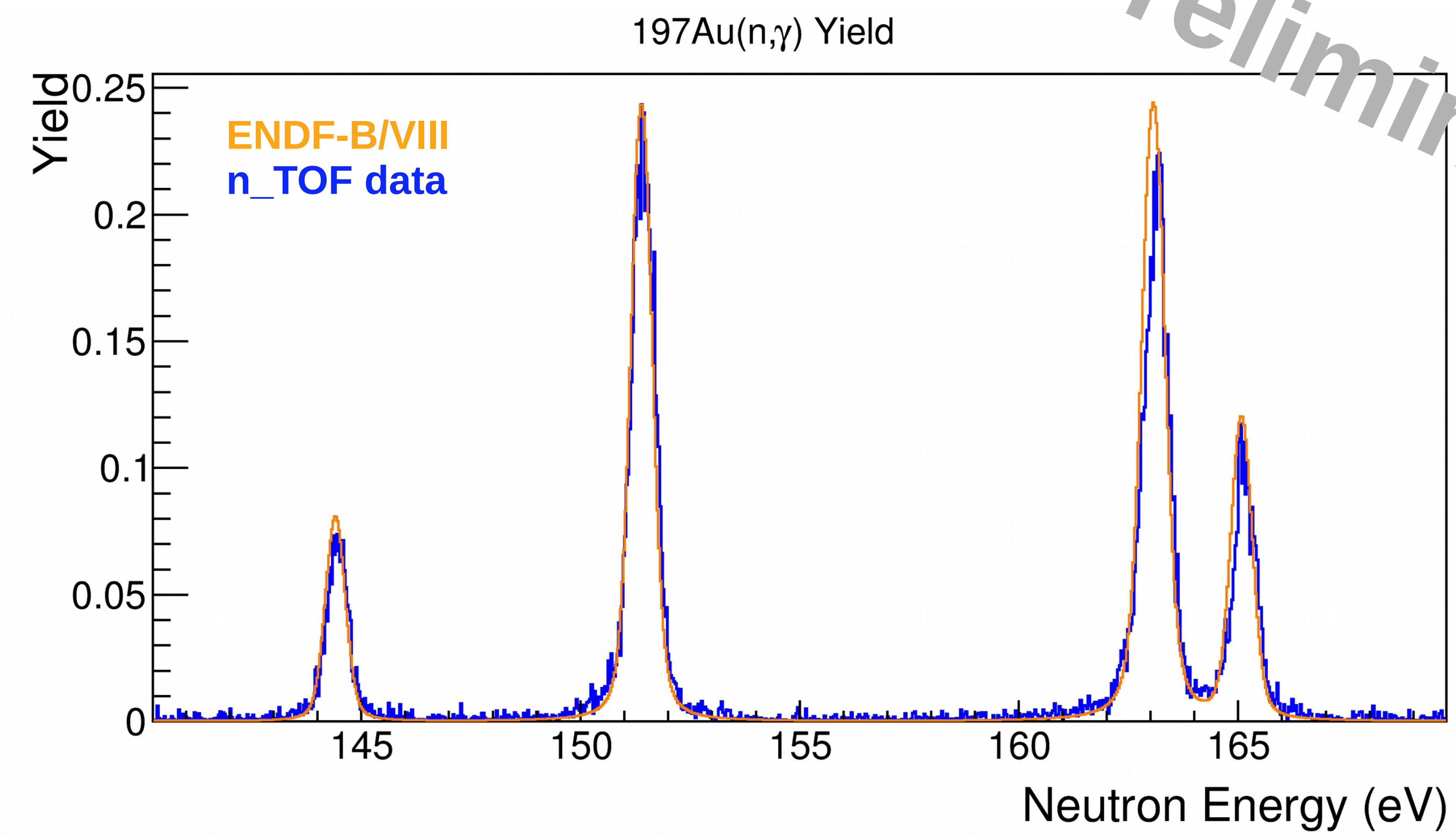
Gold normalization

The saturated resonance at 4.9 eV is well reproduced. It will be used to calculate the beam interceptor factor and normalize cerium data.



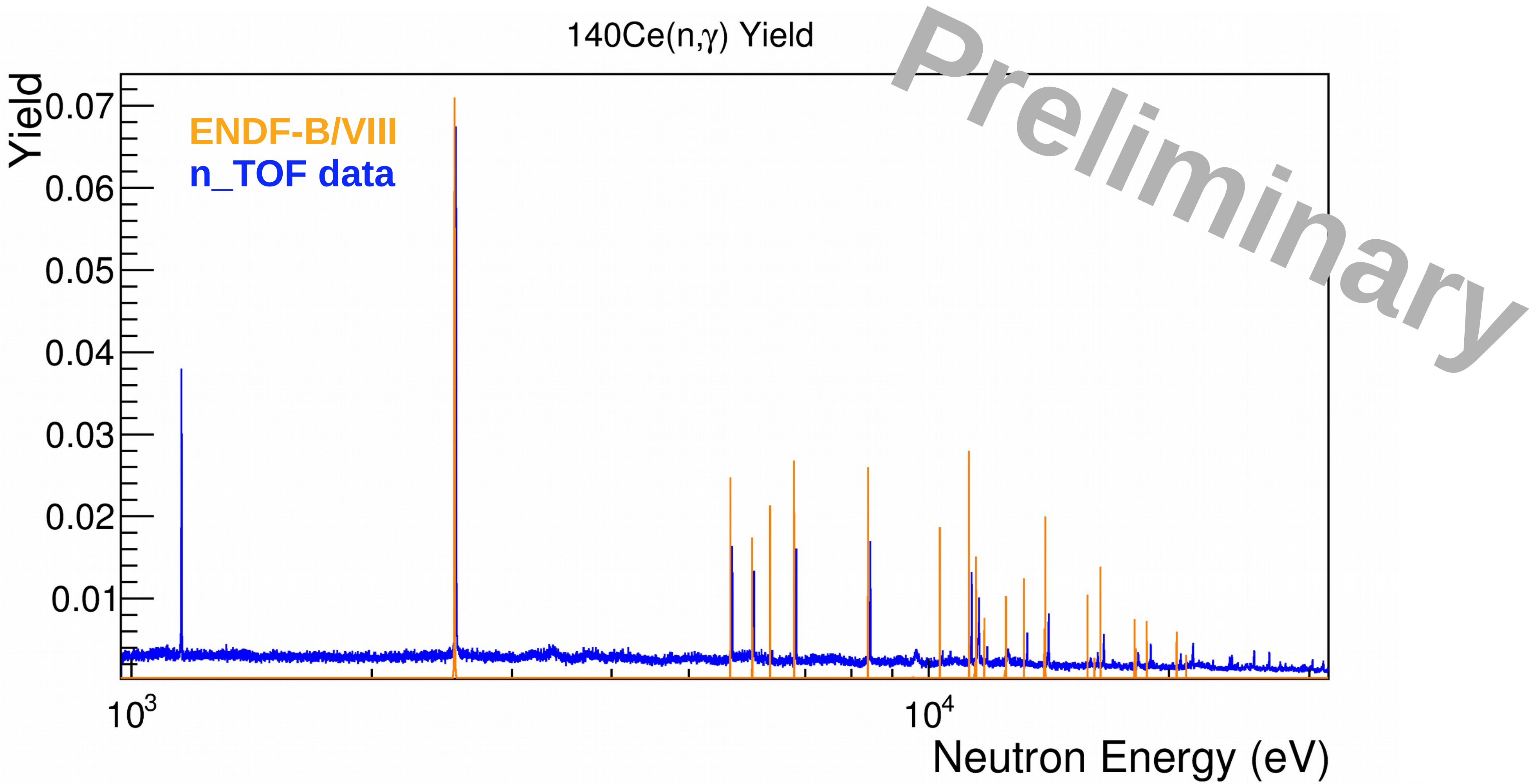
Gold Yield

The gold yield is well reproduced even at higher energy.



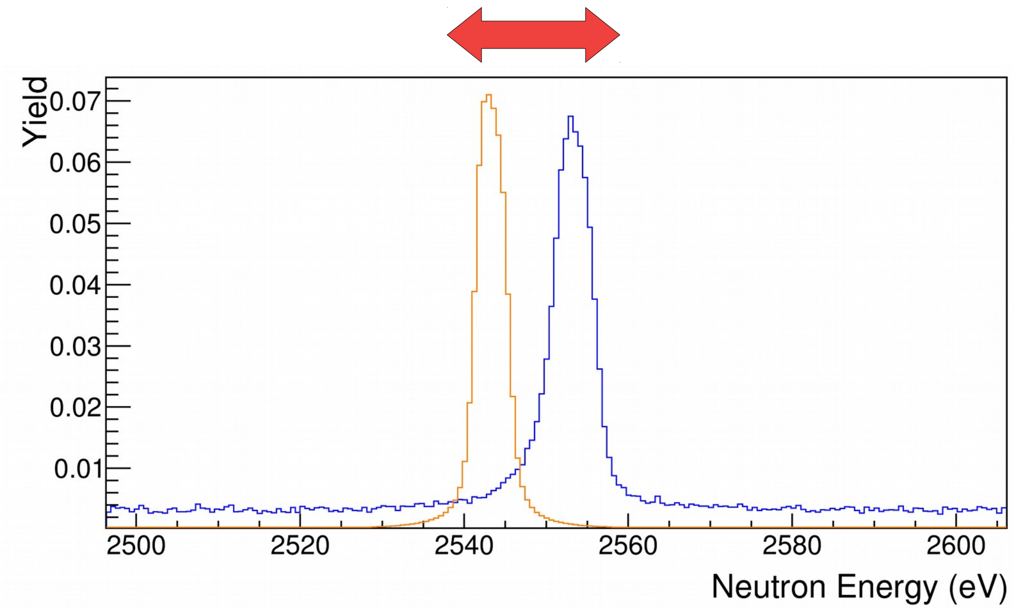
Cerium Yield

Comparison of the experimental and theoretical yield for $^{140}Ce(n,\gamma)$ calculated with ENDF-B/VIII.



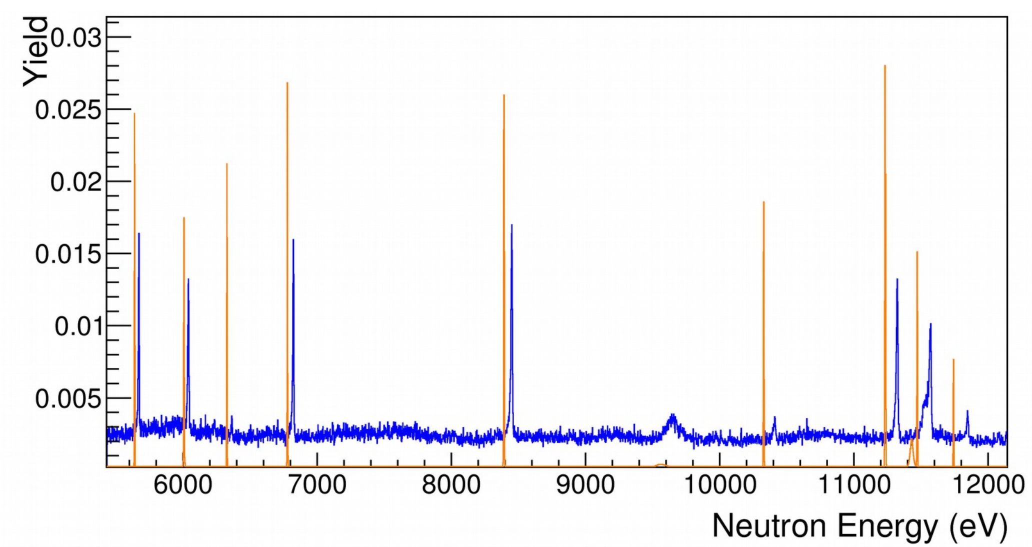
Cerium Yield

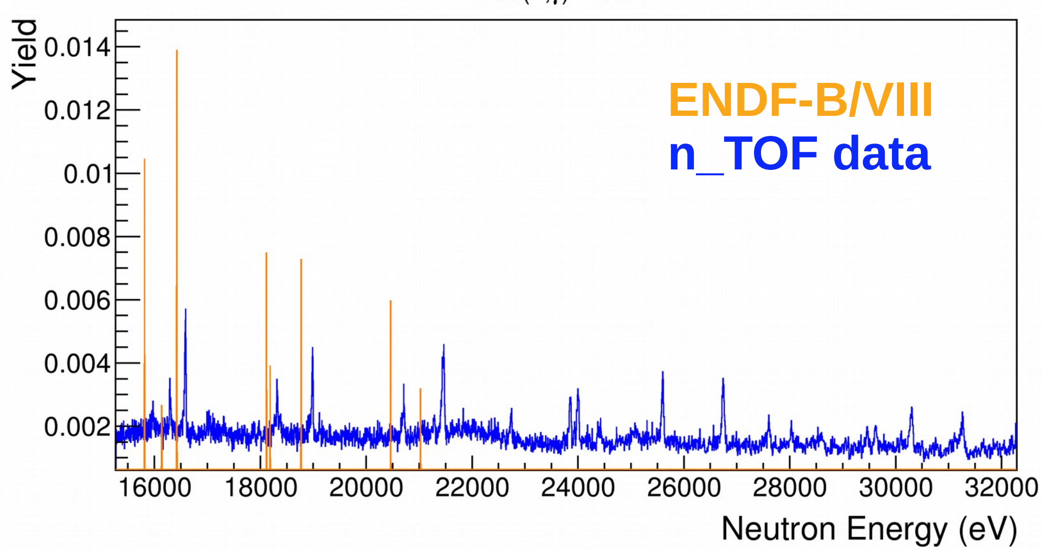
Small shift due to preliminary time-to-energy calibration



Comparison of the experimental and theoretical yield for ^{140}Ce(n,γ) calculated with ENDF-B/VIII.

Preliminary



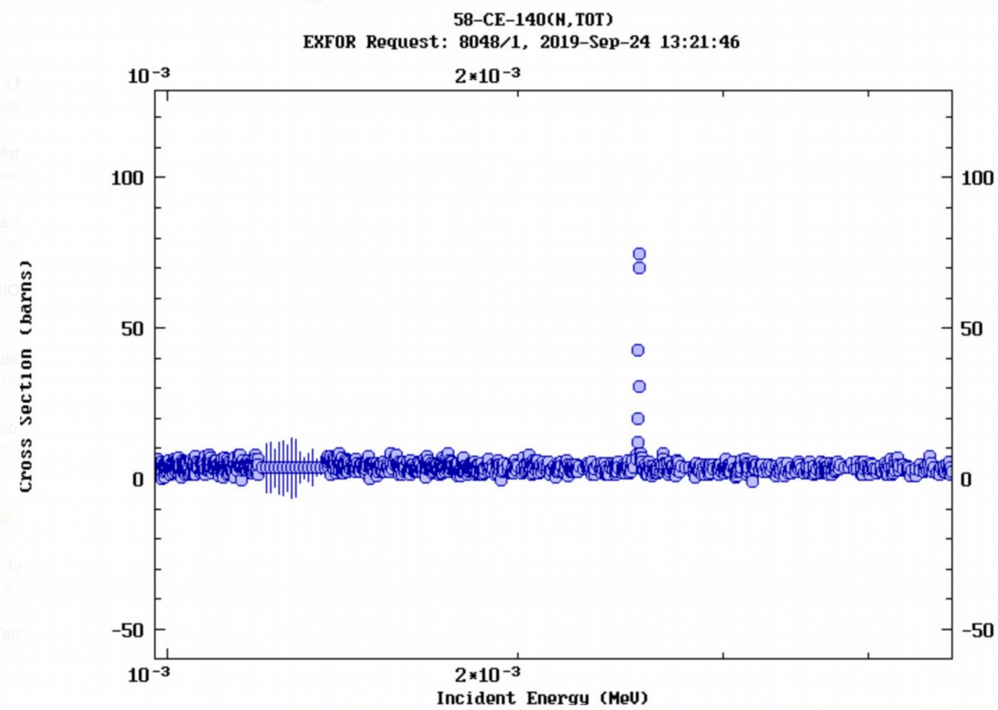


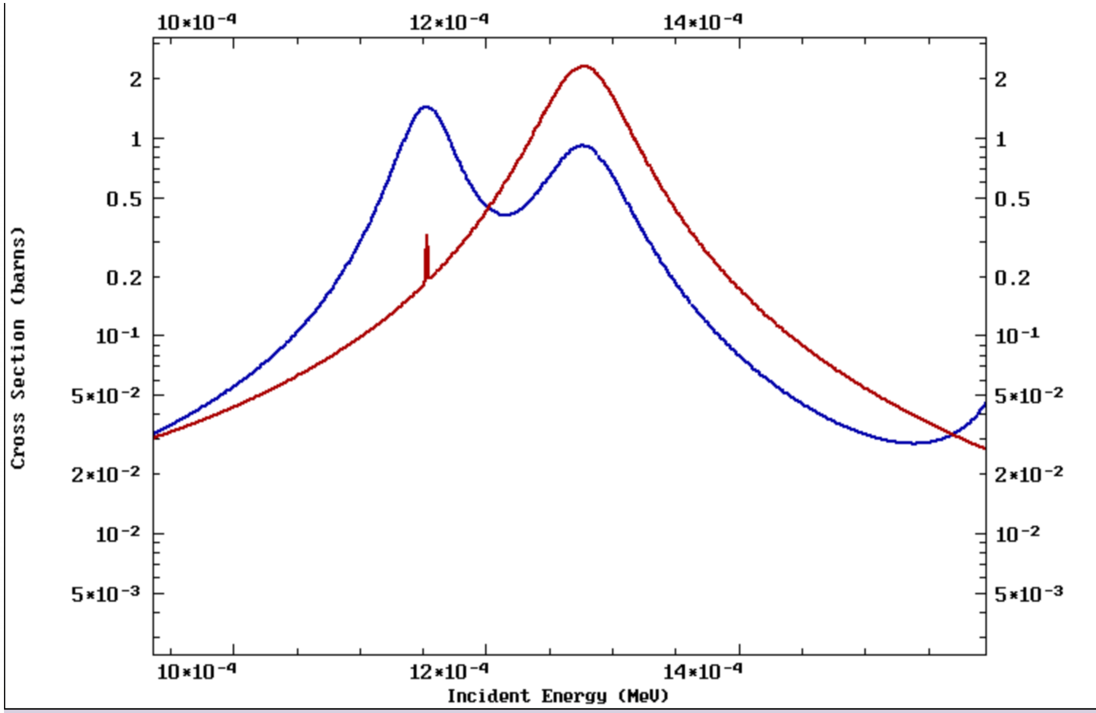
Conclusions

- A measurement of $^{140}Ce(n,\gamma)$ cross has been performed at n_TOF@CERN.
- The collected data seems to be high quality and the background is under control.
- The analysis is still ongoing and the following step will follow:
  - Evaluation of all the background sources and subtraction
  - Include the resolution function and doppler effect
  - Resonance analysis to extract the final cross section

Thank you for your attention

Evaluations and experimental data





^{140}Ce(n,γ)

Ohkubu M., et al.: JAERI-M 93-012 (1993)

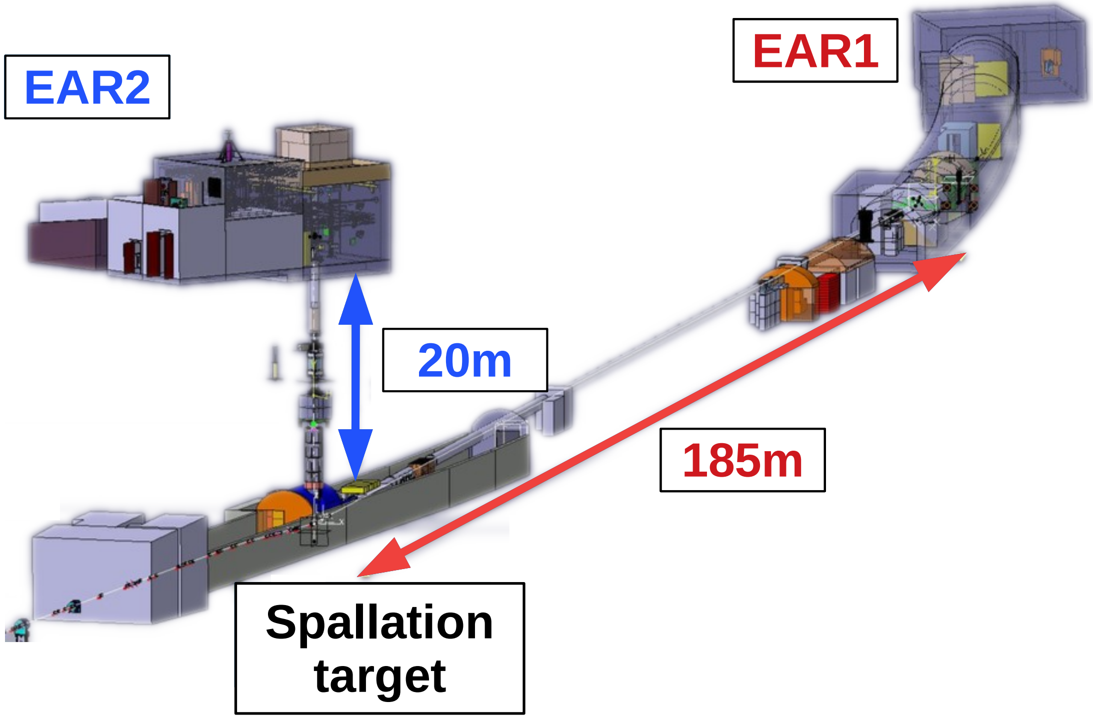
High uncertainty between 1.1 and 1.2 keV

^{142}Ce(n,γ) ENDF-B/VIII

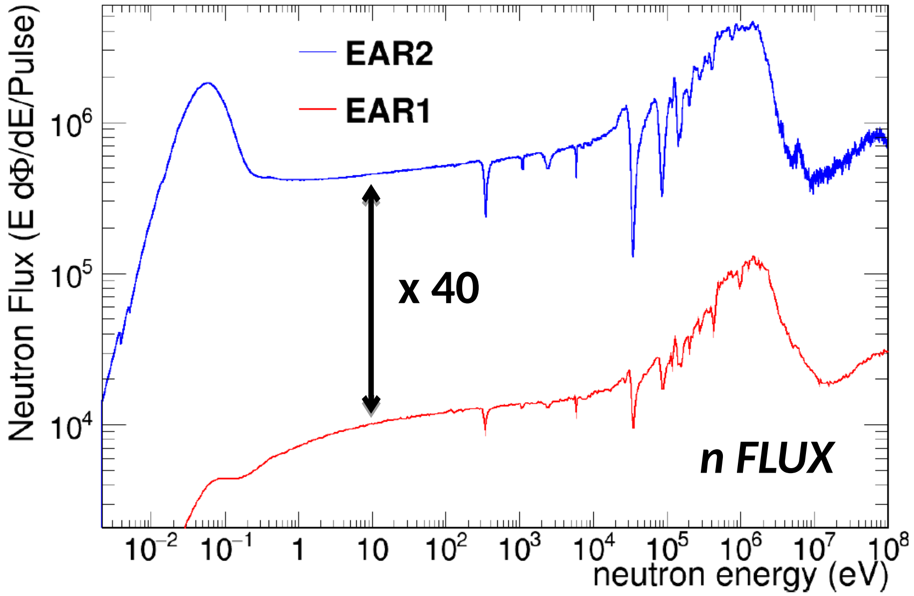
^{142}Ce(n,γ) JENDL4.0

Discrepancies between libraries, resonance at 1.2 keV assigned to ^{142}Ce(n,γ)

n_TOF flux

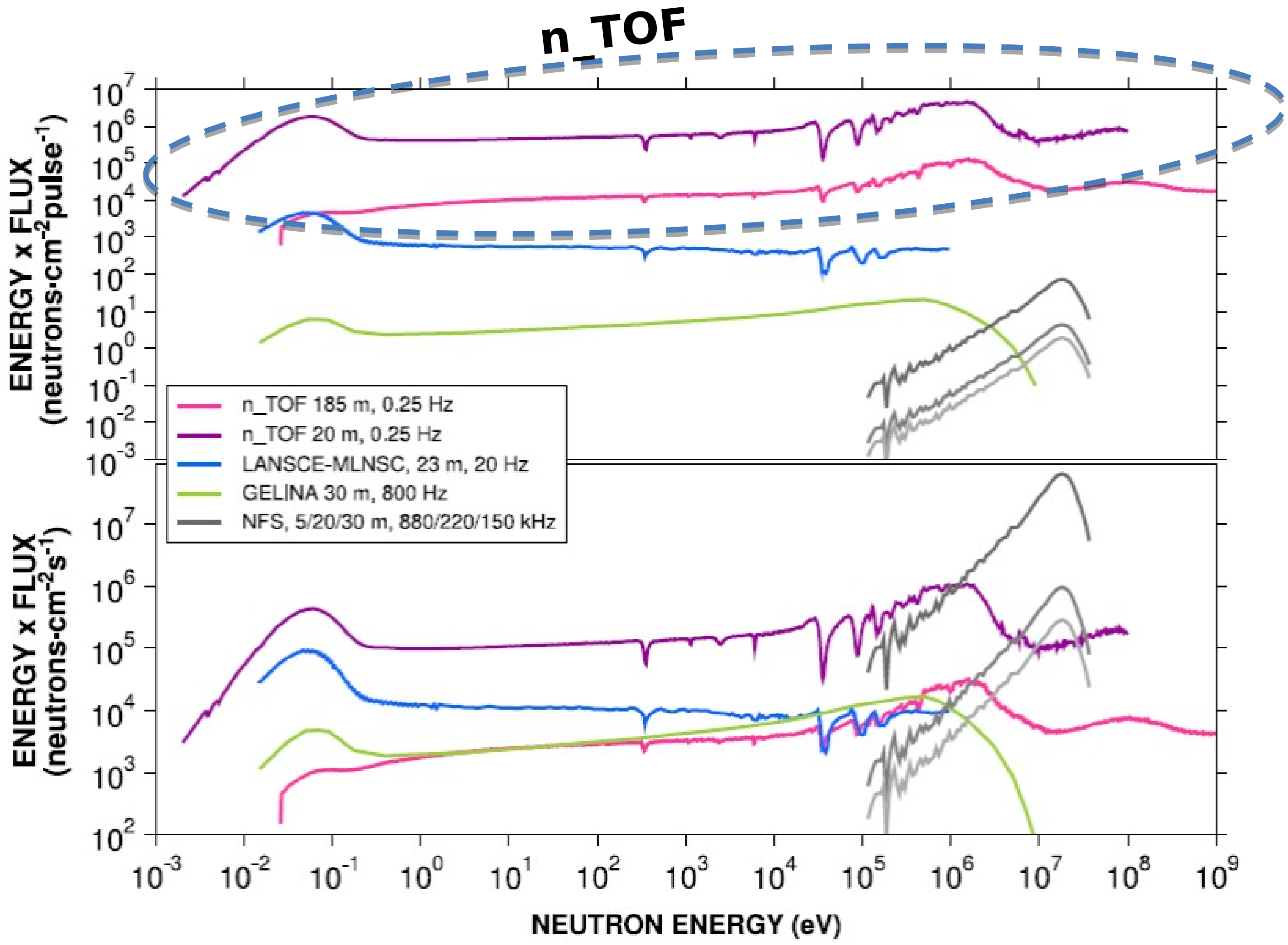


EAR2
EAR1
20m
185m
Spallation target

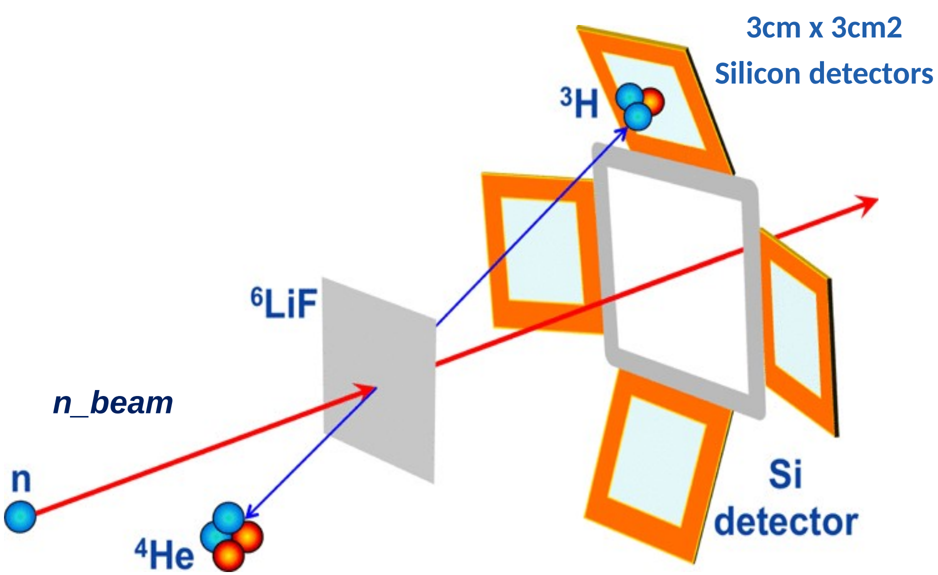


Neutron Flux (E dΦ/dE/Pulse)
EAR2
EAR1
x 40
n FLUX
neutron energy (eV)

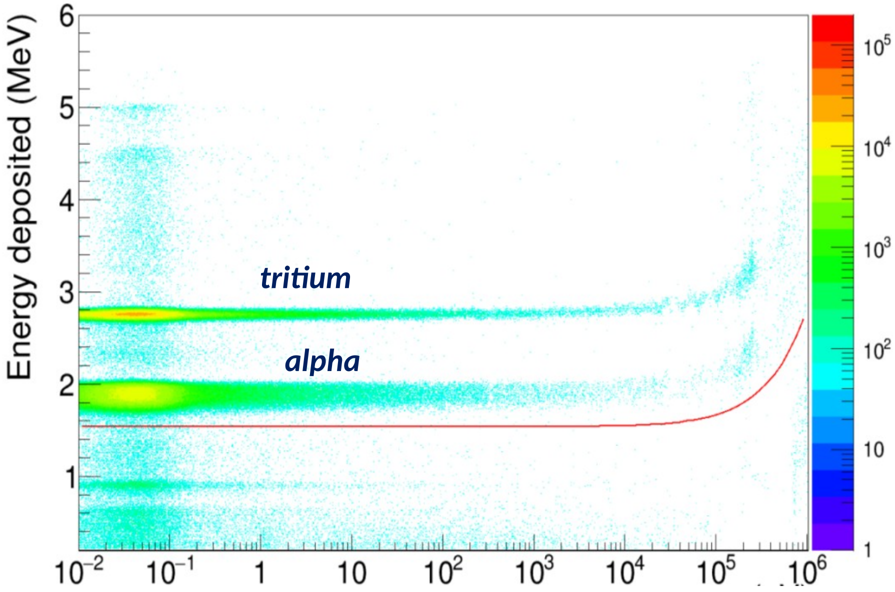
n_TOF flux


n_TOF
ENERGY x FLUX (neutrons·cm^{-2}pulse^{-1})
ENERGY x FLUX (neutrons·cm^{-2}s^{-1})
n_TOF 185 m, 0.25 Hz
n_TOF 20 m, 0.25 Hz
LANSCE-MLNSC, 23 m, 20 Hz
GELINA 30 m, 800 Hz
NFS, 5/20/30 m, 880/220/150 kHz
NEUTRON ENERGY (eV)

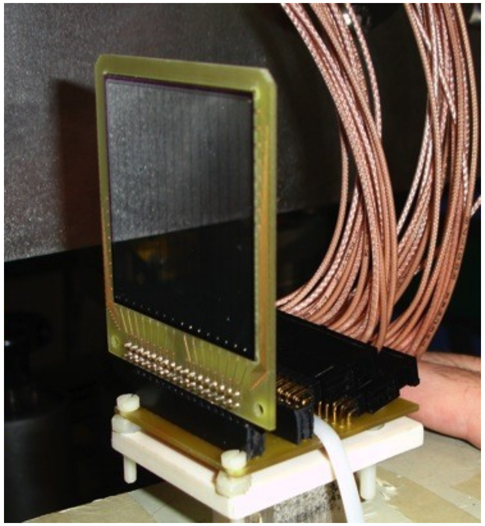
SiMon

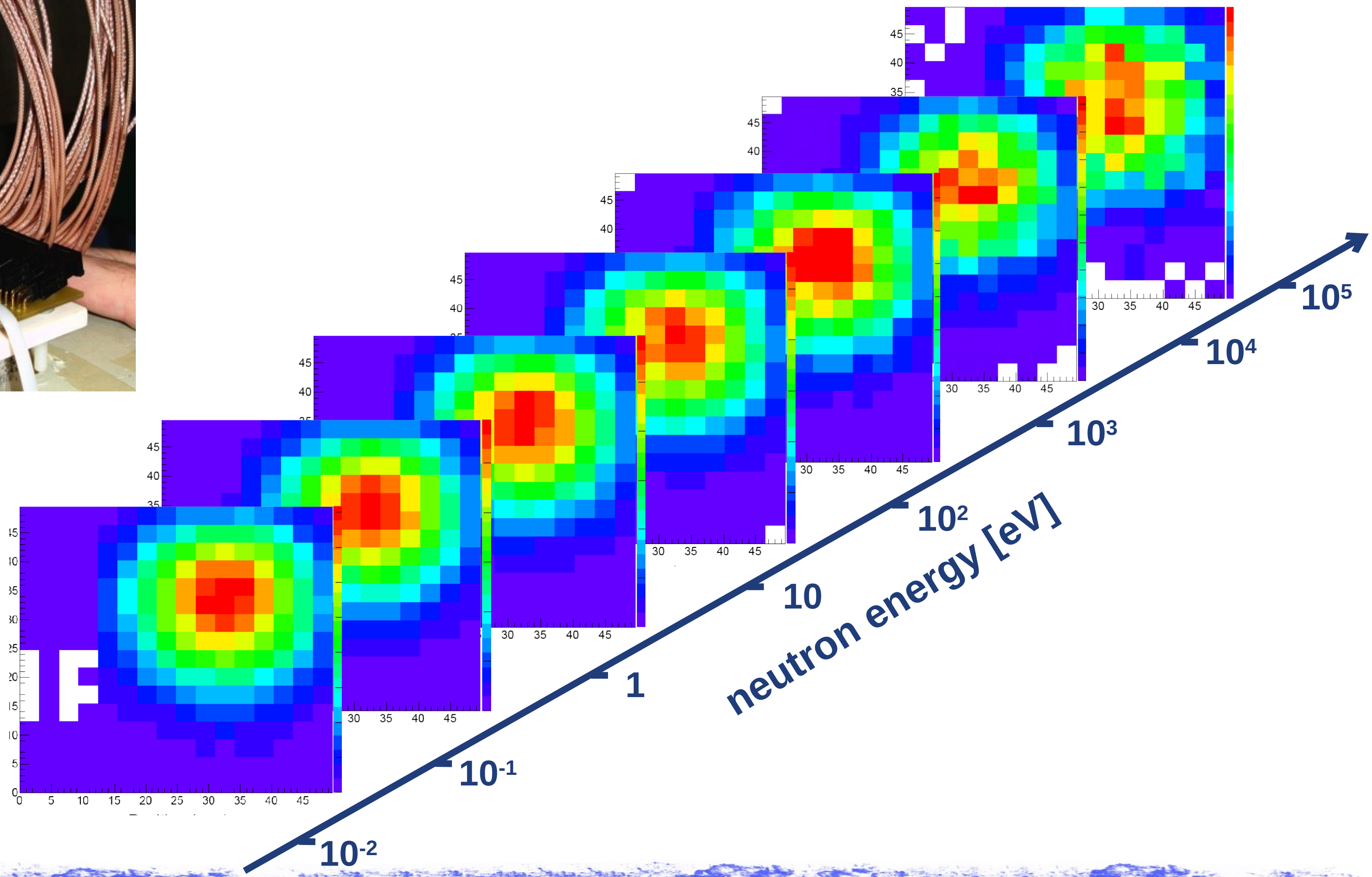

3cm x 3cm2
Silicon detectors
^{3}H
^{6}LiF
n_beam
n
^{4}He
Si
detector


Si
Si
Si
Si

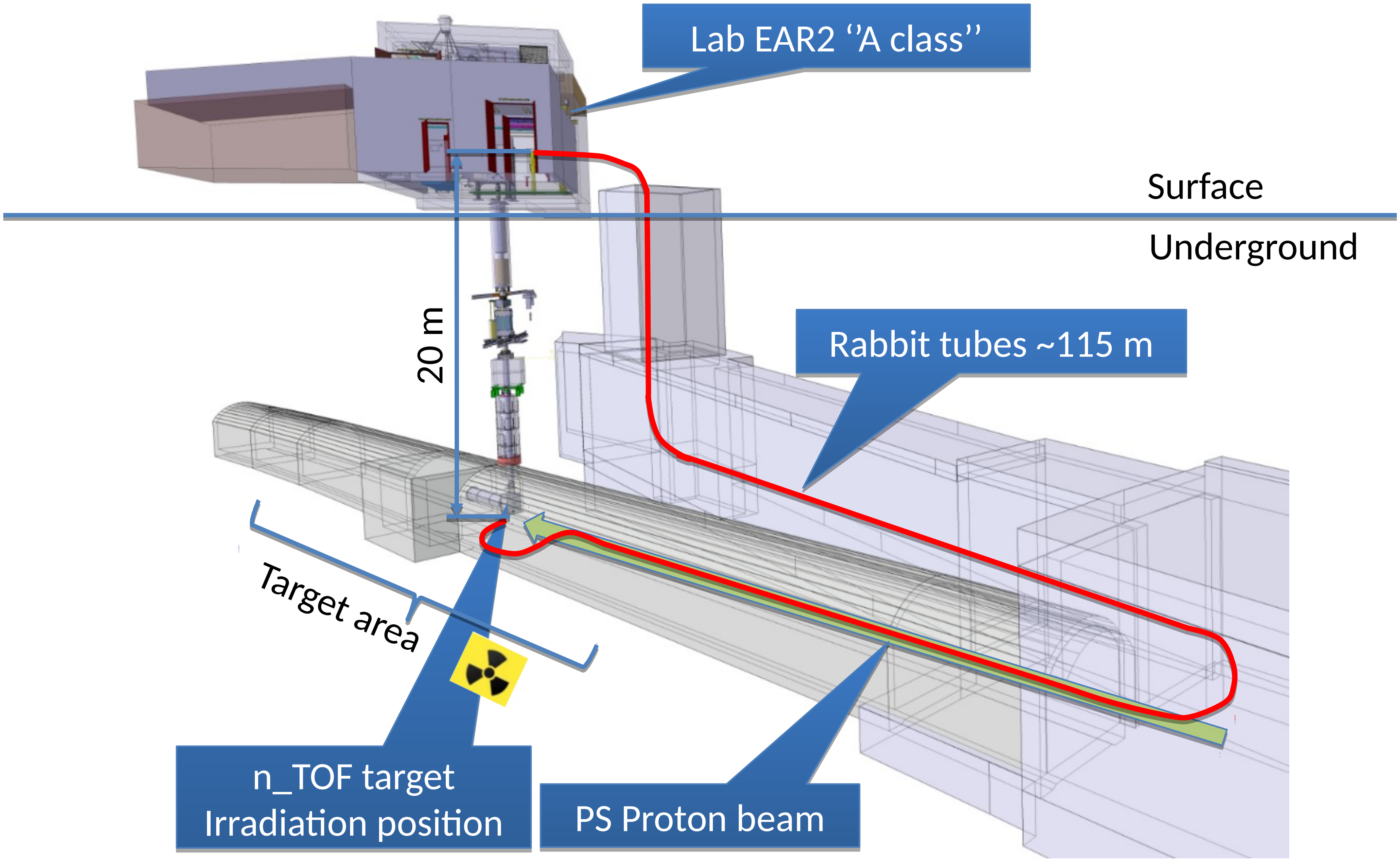

Energy deposited (MeV)
tritium
alpha

Flux profile

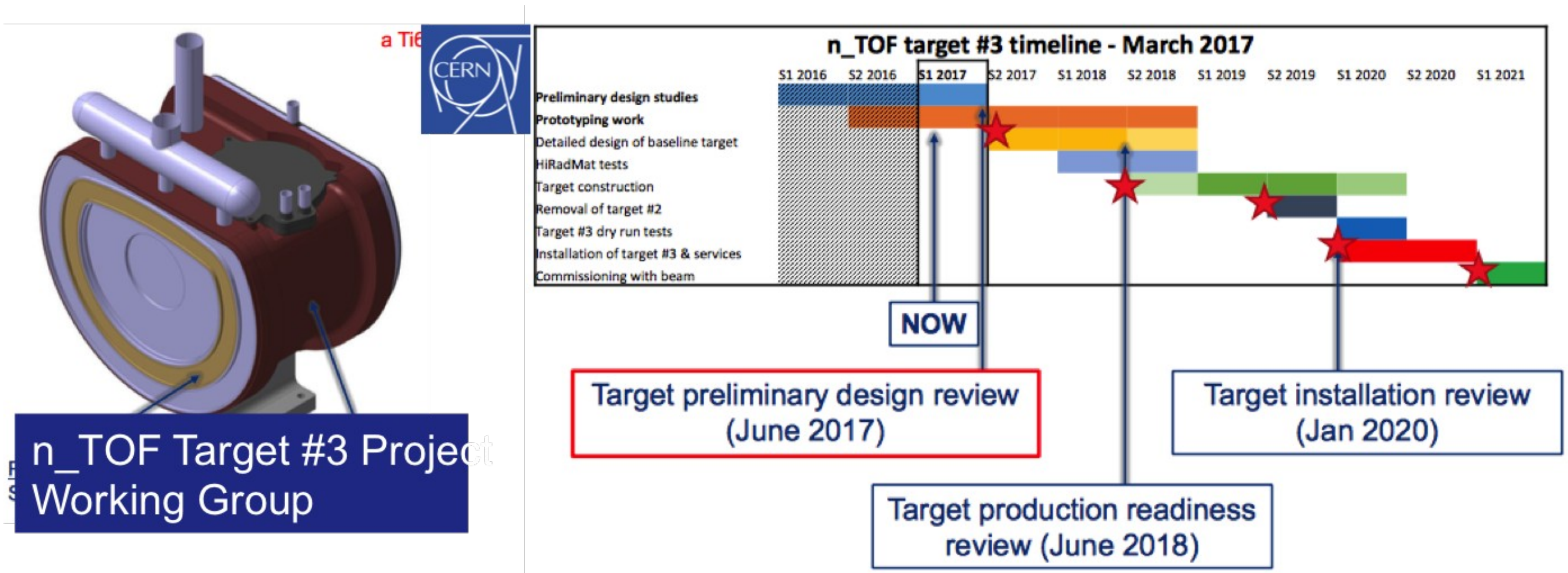




n_TOF Irradiation station

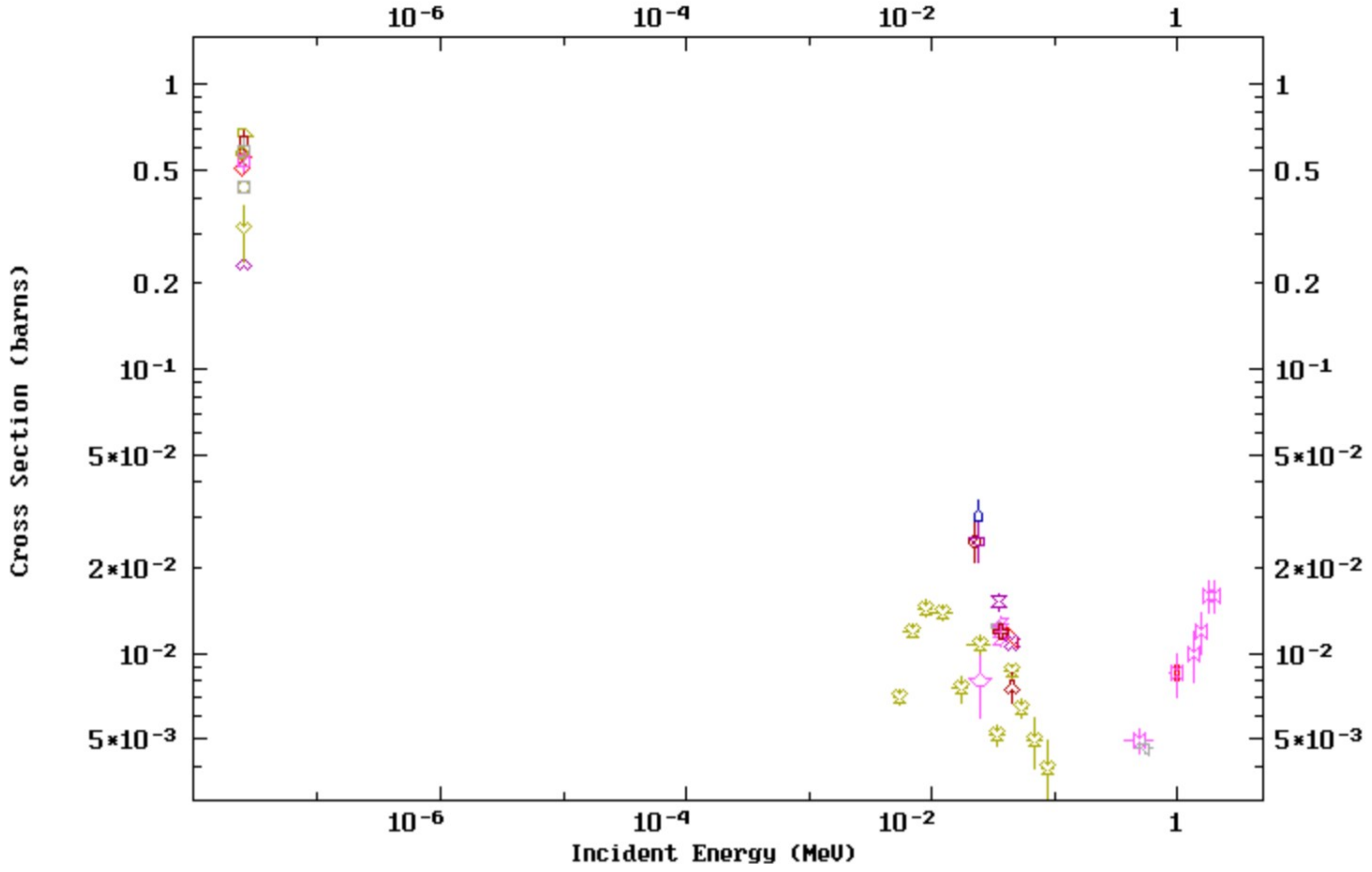


n_TOF status

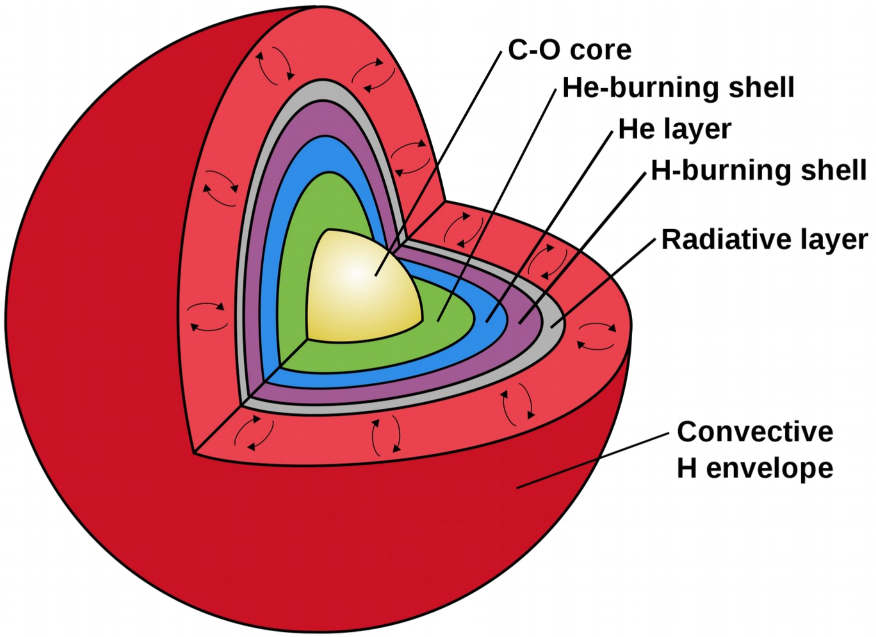


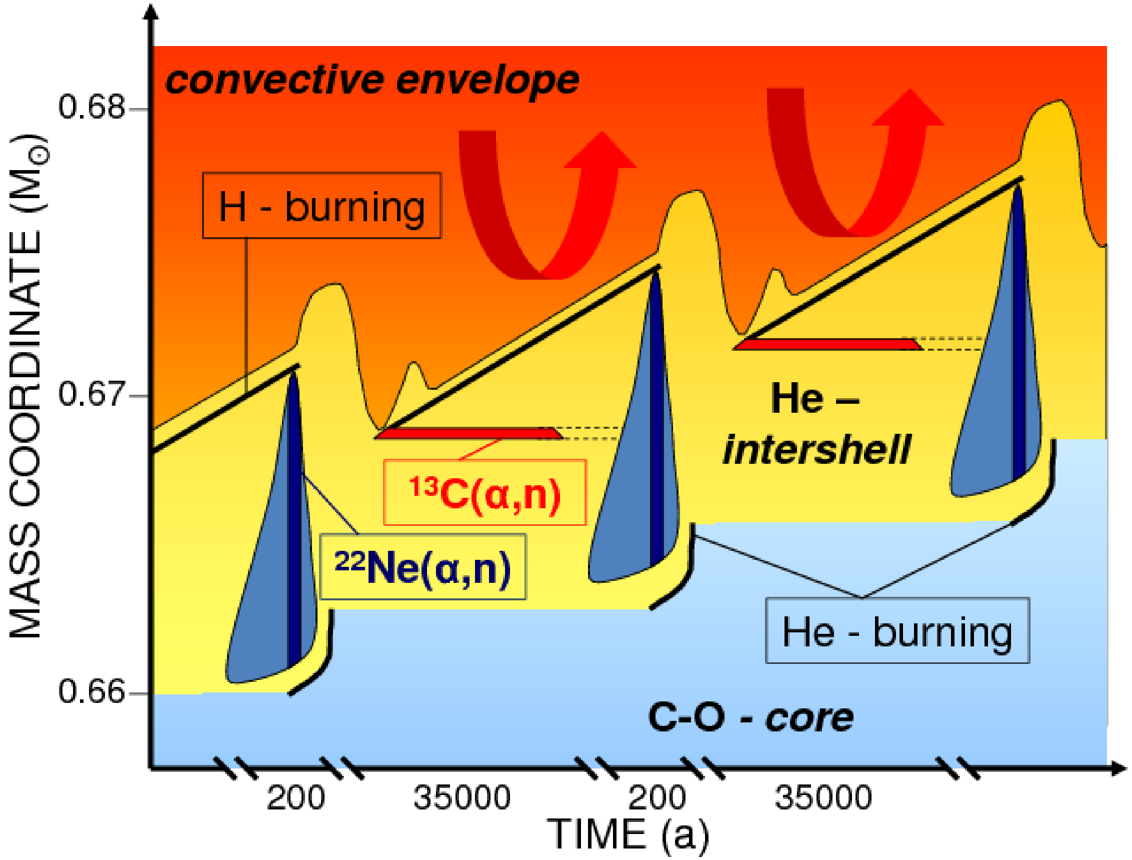
n_TOF Target #3 Project
Working Group
CERN
n_TOF target #3 timeline - March 2017
S1 2016
S2 2016
S1 2017
S2 2017
S1 2018
S2 2018
S1 2019
S2 2019
S1 2020
S2 2020
S1 2021
Preliminary design studies
Prototyping work
Detailed design of baseline target
HiRadMat tests
Target construction
Removal of target #2
Target #3 dry run tests
Installation of target #3 & services
Commissioning with beam
NOW
Target preliminary design review (June 2017)
Target installation review (Jan 2020)
Target production readiness review (June 2018)

Data in EXFOR



AGB structure





Pulse Height Weight Technique

It is used to simplify the analysis **removing the dependence on the cascade decay path**. It requires the use of low efficiency γ detectors with efficiency proportional to the gamma energy. If is met the condition:

$$\varepsilon_{\gamma} = \alpha E_{\gamma}$$

the efficiency for detecting a neutron capture is proportional to the known cascade energy:

$$\varepsilon_{(n,\gamma)} = \sum_{j} \varepsilon_{\gamma_j} = \alpha E_{(n,\gamma)}$$

In our case the direct proportionality is obtained weighting the counts with a function computed via Monte Carlo simulation in GEANT4.

Weighting functions

The weighting functions are computed with a **Monte Carlo simulation in GENT4**, they are a polynomial depending on the gamma energy, detector resolution and the geometry. Below are reported the WF for ^{140}Ce: