
Measurement of the $^{235}\text{U}(\text{n},\text{f})$ cross section relative to n-p scattering up to 1 GeV

A. Manna for the n_TOF Collaboration

International Conference on Nuclear Data for Science and Technology

Beijing – May 19-24, 2019



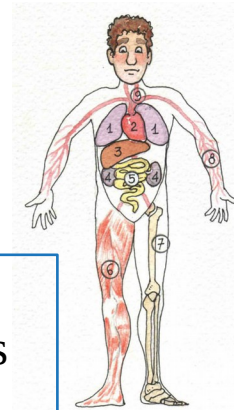
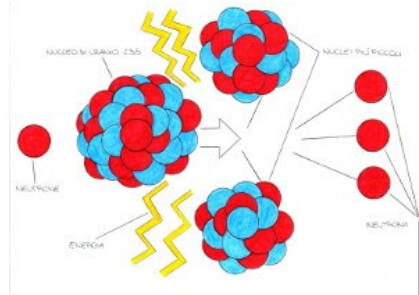
Motivations



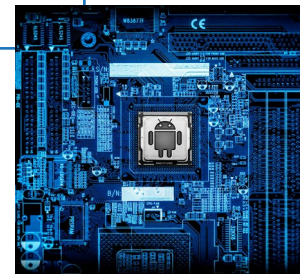
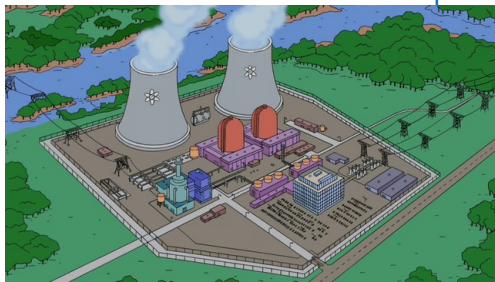
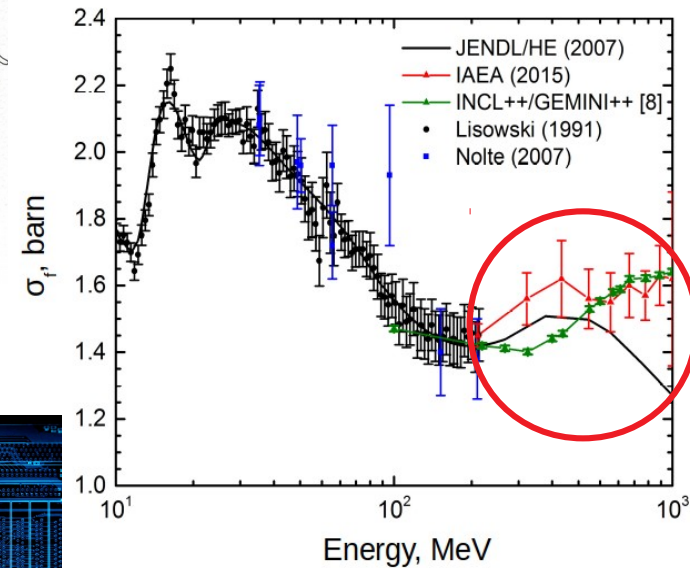
INDC International Nuclear Data Committee

“...Our analysis indicates that the new absolute measurements of the neutron induced fission cross section (e.g. relative to n-p scattering) on Uranium, Bismuth, Lead and Plutonium have the highest priority in establishing neutron induced fission reaction standard above 200 MeV...”

(INDC(NDS)-0681 Distr. ST/J/G/NM, IAEA 2015)

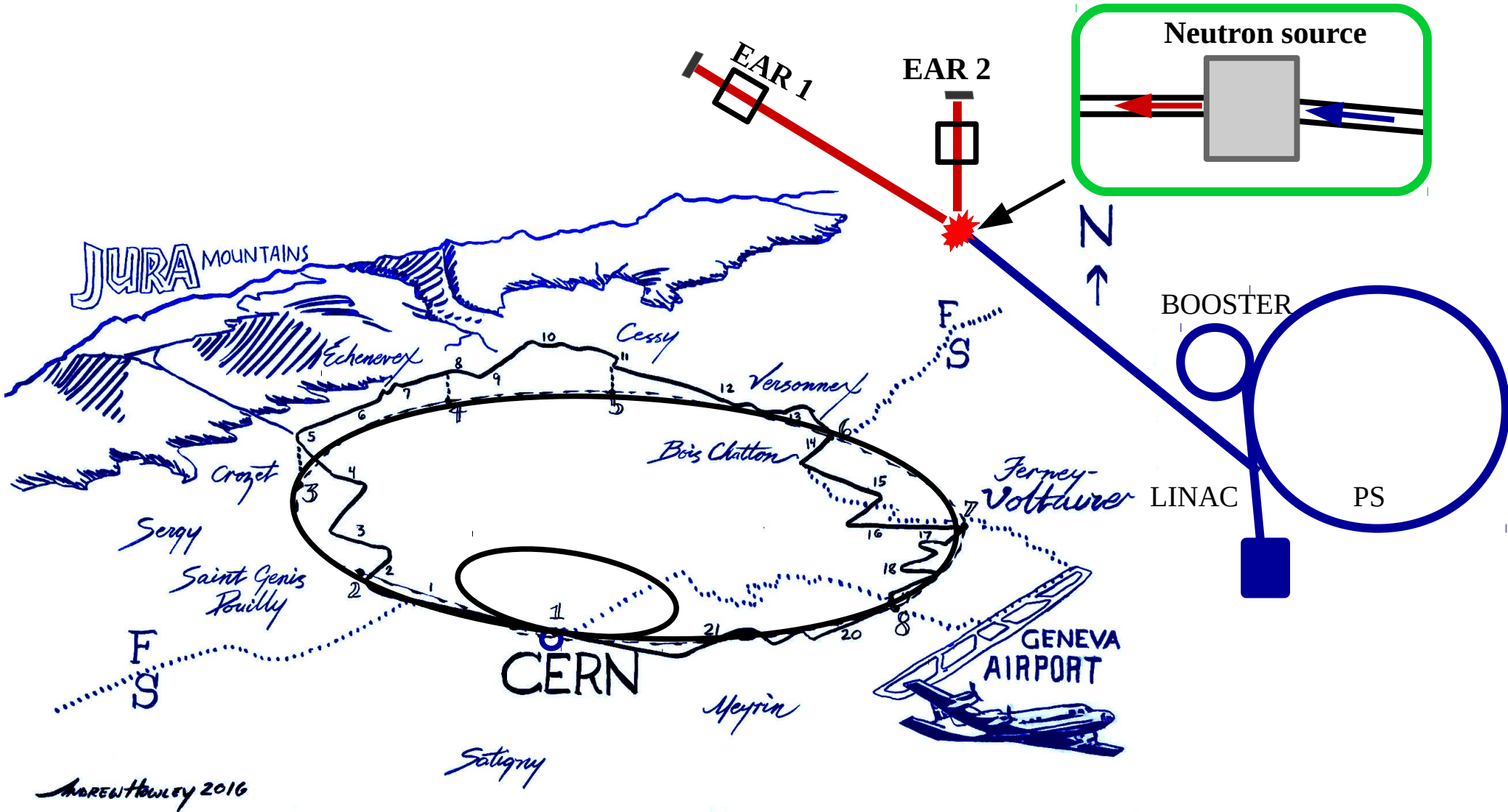


$^{235}\text{U}(n,f)$ is one of the most significant cross-section standards at 0.025 eV and [0.15-200] MeV **BUT** there are **no experimental data above 200 MeV**, despite its importance



The n_TOF facility

neutron Time Of Flight



ANDREW HAWLEY 2016



The n_TOF facility

neutron Time Of Flight

High energy resolution

Time of Flight (ToF) technique

with a long flight path:

185 m @ EAR 1

20 m @ EAR 2

$$\Delta E/E \sim 10^{-5} - 10^{-3}$$

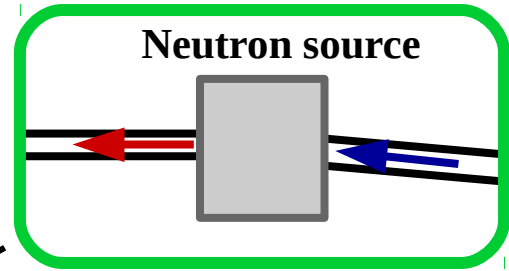
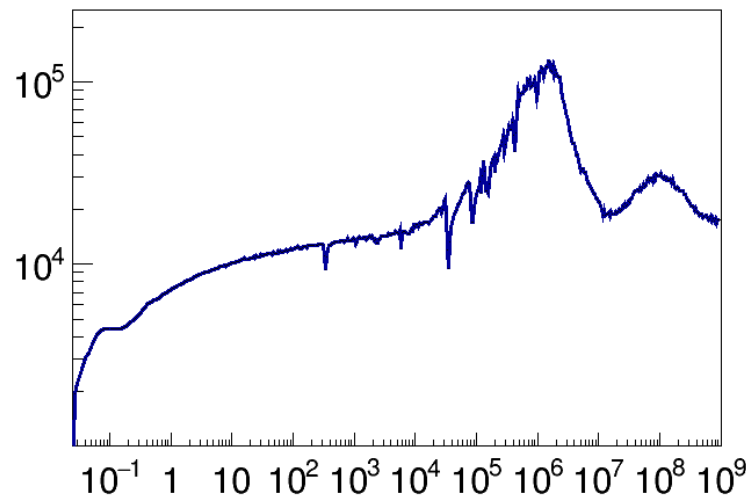
High neutron flux & wide energy range

Spallation reaction

$7 \cdot 10^{12}$ protons,
20 GeV/c momentum

+

1.3 ton Pb Target



BOOSTER

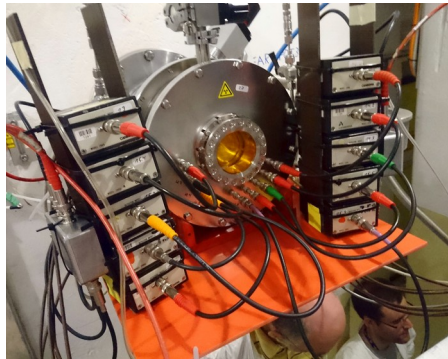
LINAC

PS

Experimental setup

^{235}U fission reaction

Fission fragment



Parallel Plate
Ionization Chamber
(IC)

└─► Ambient gas pressure

Neutron energy:
0.025 eV - 200 MeV



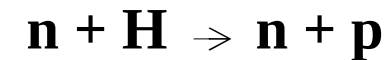
Parallel Plate
Avalanche Counter
(PPAC)

└─► Low gas pressure
~ 4 mbar

Neutron energy:
0.025 eV - 1 GeV

Neutron flux

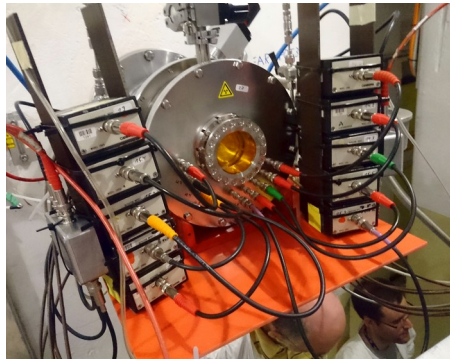
Elastic scattering



Experimental setup

^{235}U fission reaction

Fission fragment



Parallel Plate
Ionization Chamber
(IC)

→ Atmospheric pressure

Neutron energy:
0,025 eV - 200 MeV



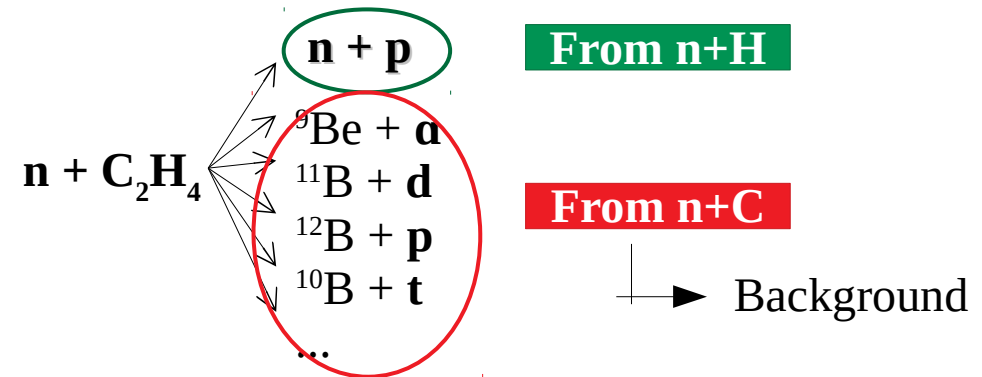
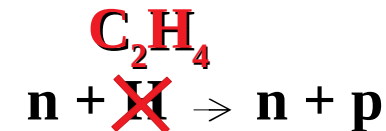
Parallel Plate
Avalanche Counter
(PPAC)

→ Low gas pressure
~ 4 mbar

Neutron energy:
0,025 eV - 1 GeV

Neutron flux

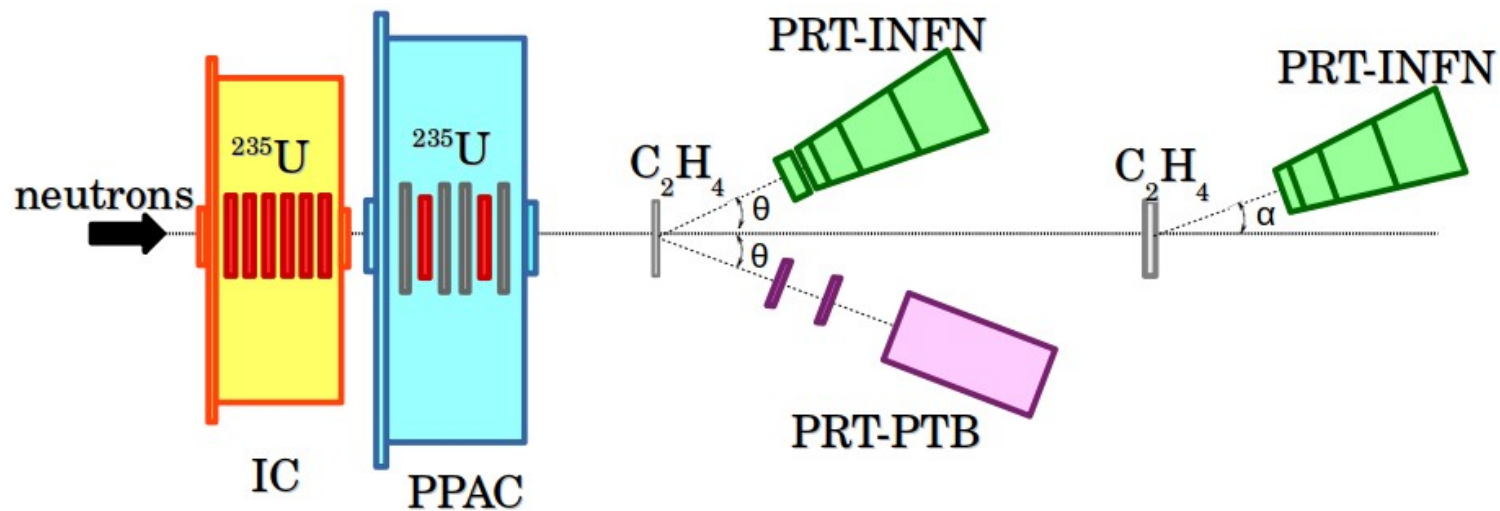
Elastic scattering



A Proton Recoil Telescope

can discriminate the different emitted particles

Experimental setup



^{235}U fission reaction

Fission fragment

IC

4 double sided U (99.93% ^{235}U) = 32,660 mg

PPAC

2 samples U (92.7% ^{235}U) = 28 mg

Neutron flux

Elastic scattering

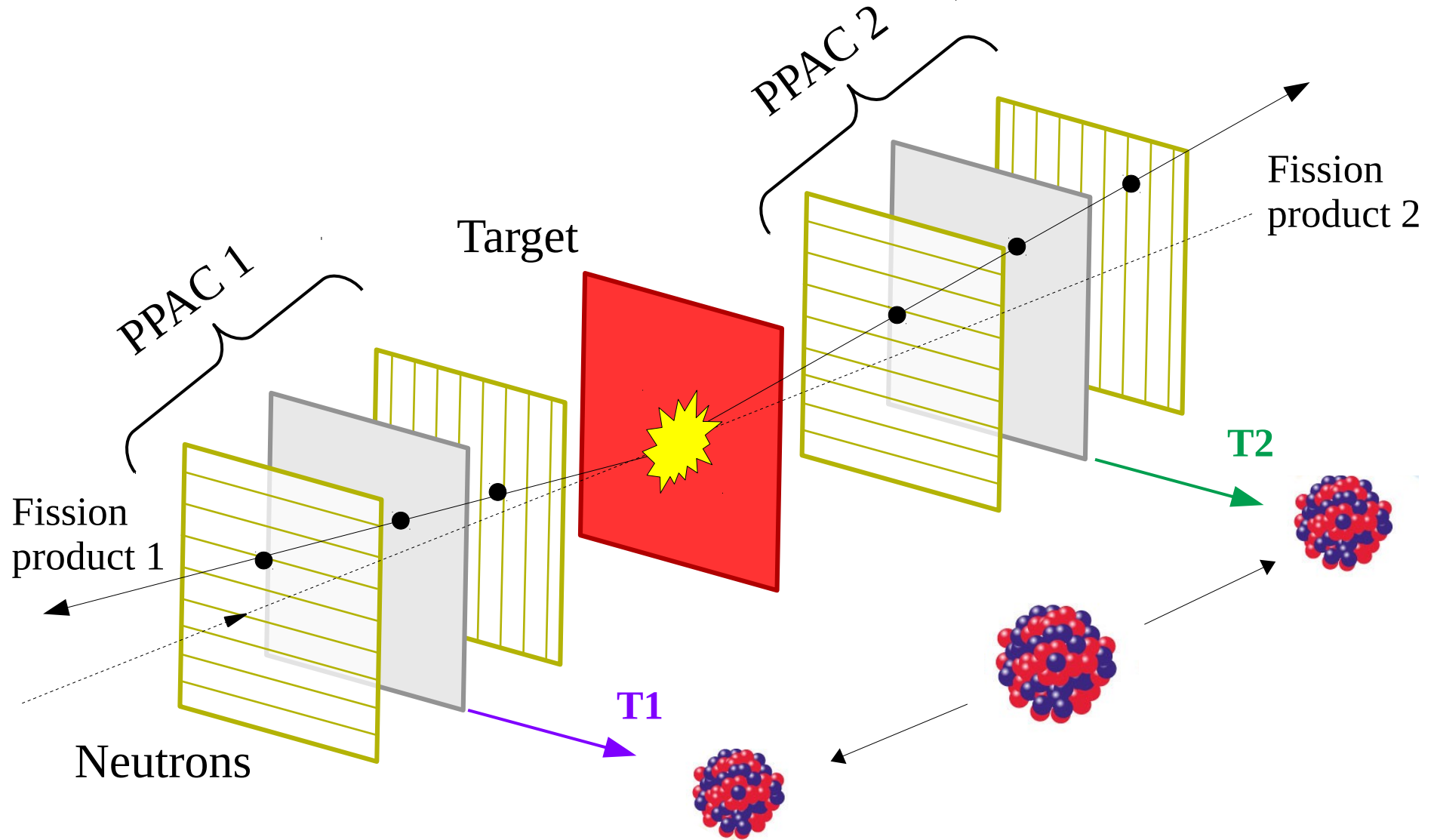
3 Proton Recoil Telescopes

located out of the neutron beam

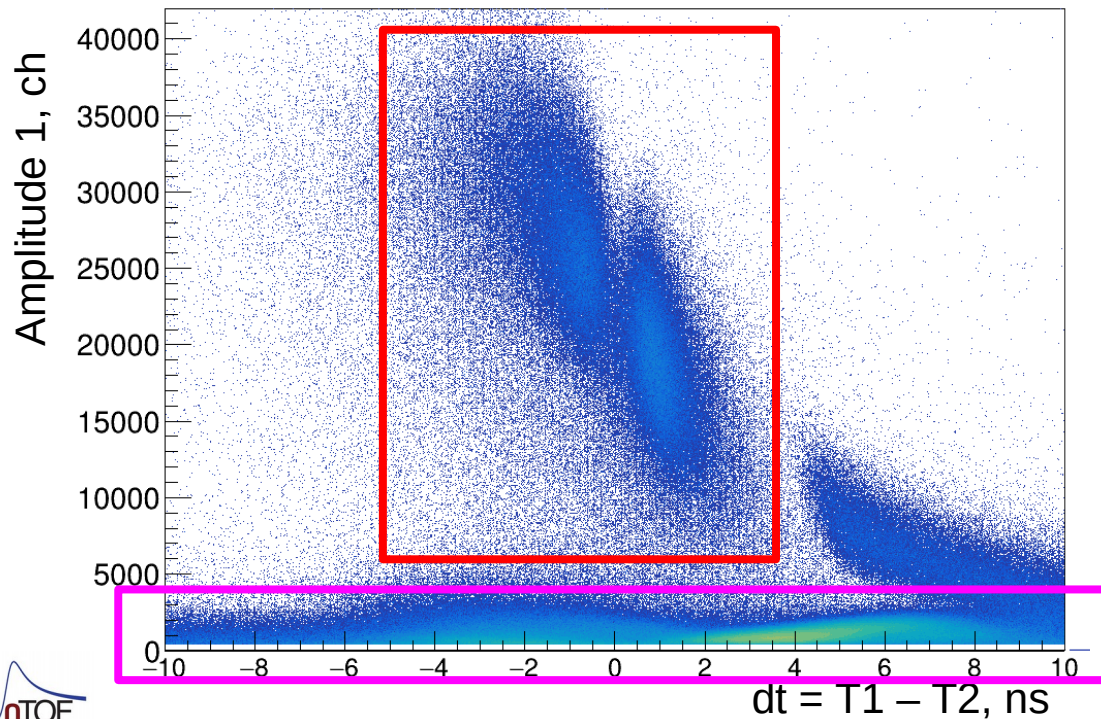
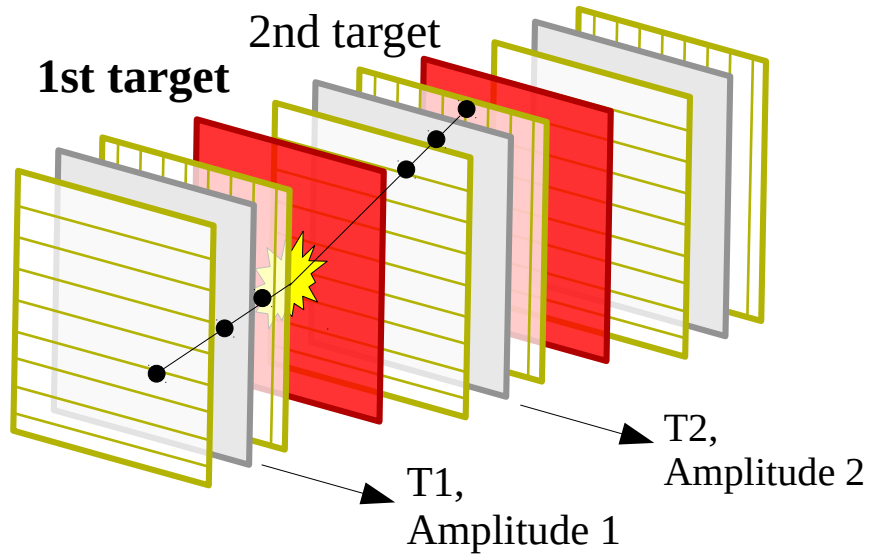
- 2 @ 25° pointing at
a Polyethylene: 1/2/5 mm thick

- 1 @ 20° pointing
a Polyethylene: 5 mm thick

PPACs



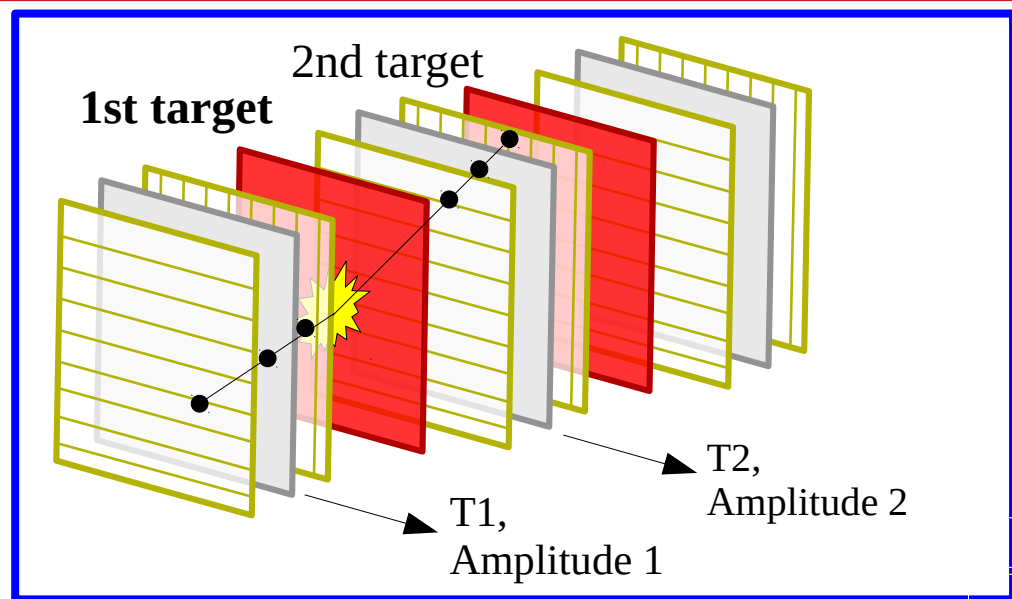
Coincidences between fragments



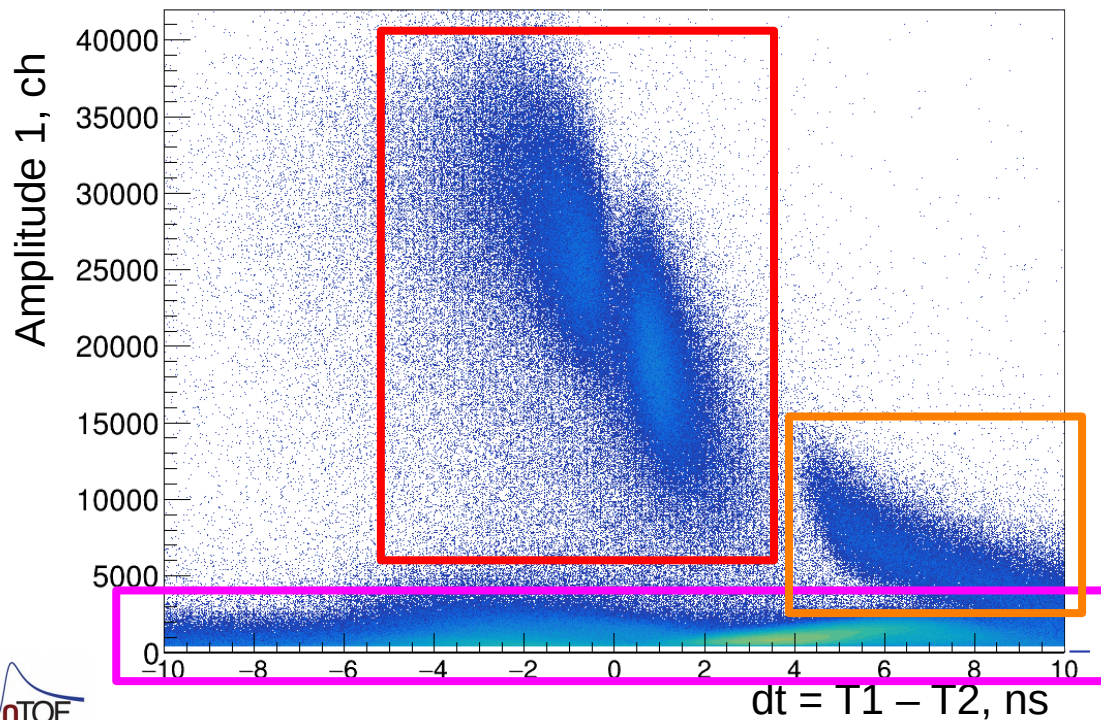
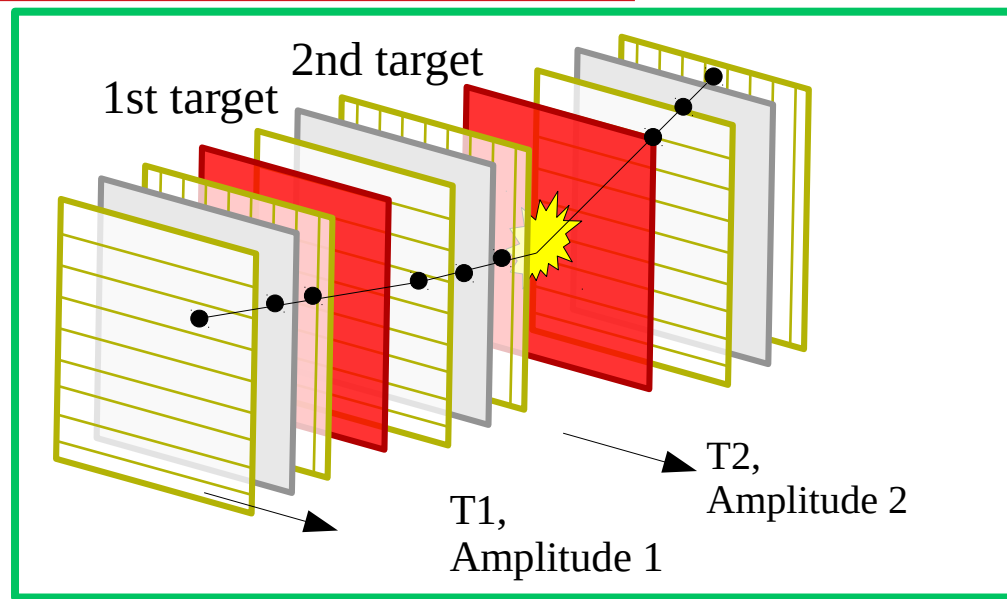
**FF from
1st ^{235}U**

**α from
2nd ^{235}U**

Coincidences between fragments



+

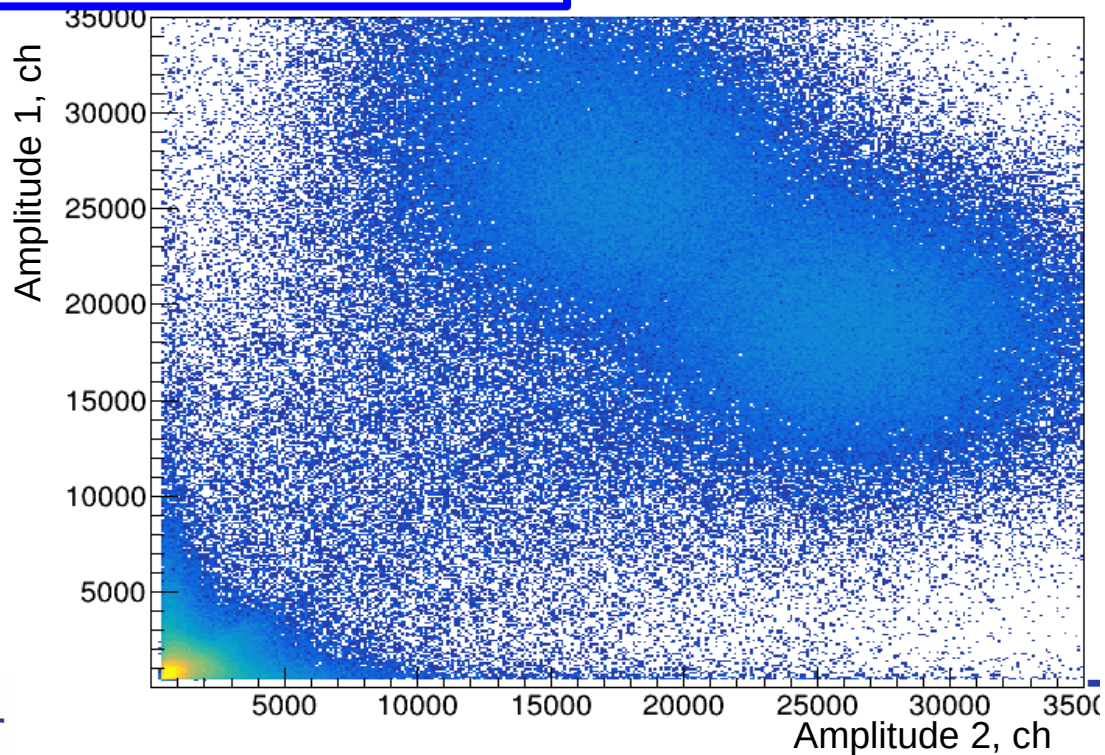
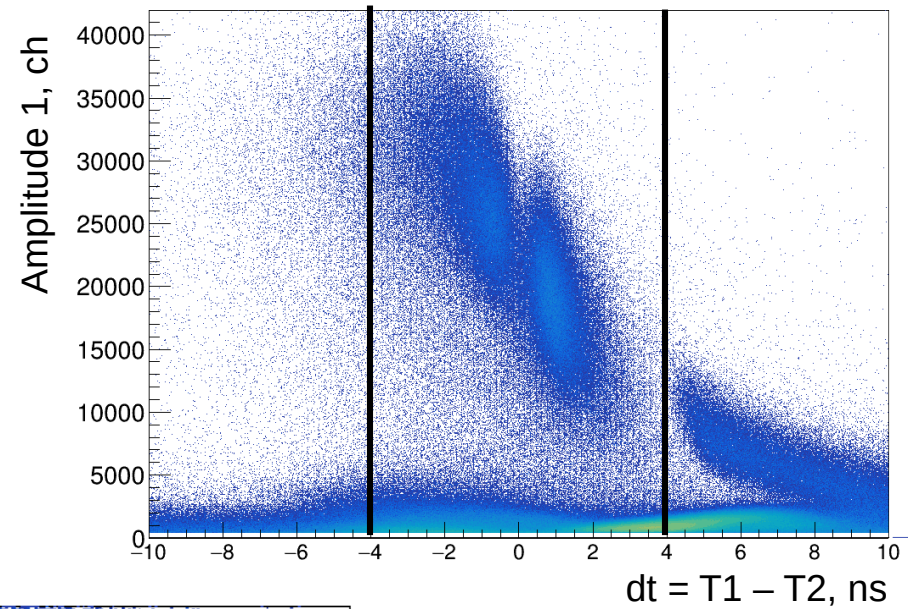
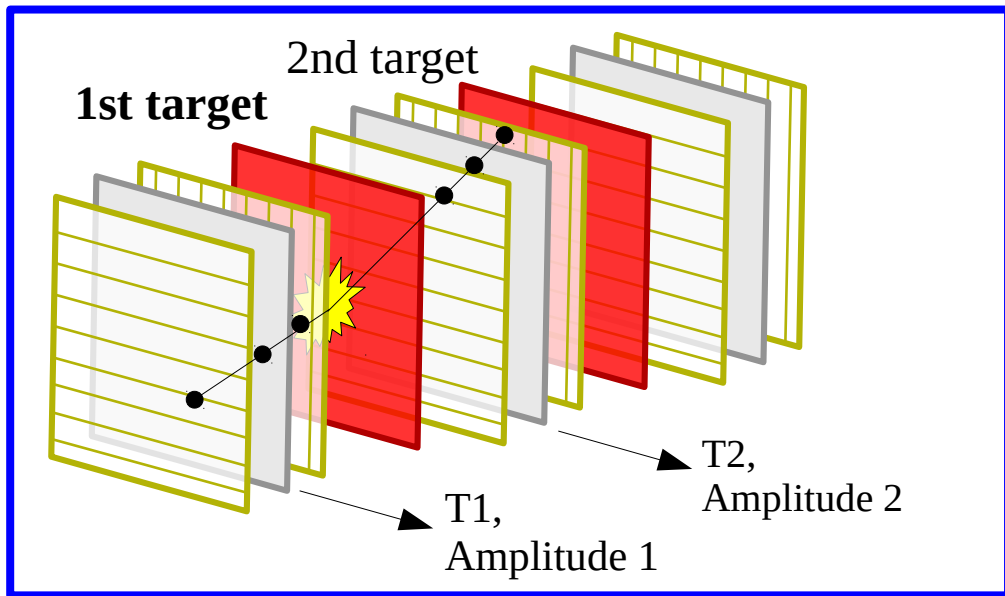


FF from
2nd ^{235}U

FF from
1st ^{235}U

α from
2nd ^{235}U

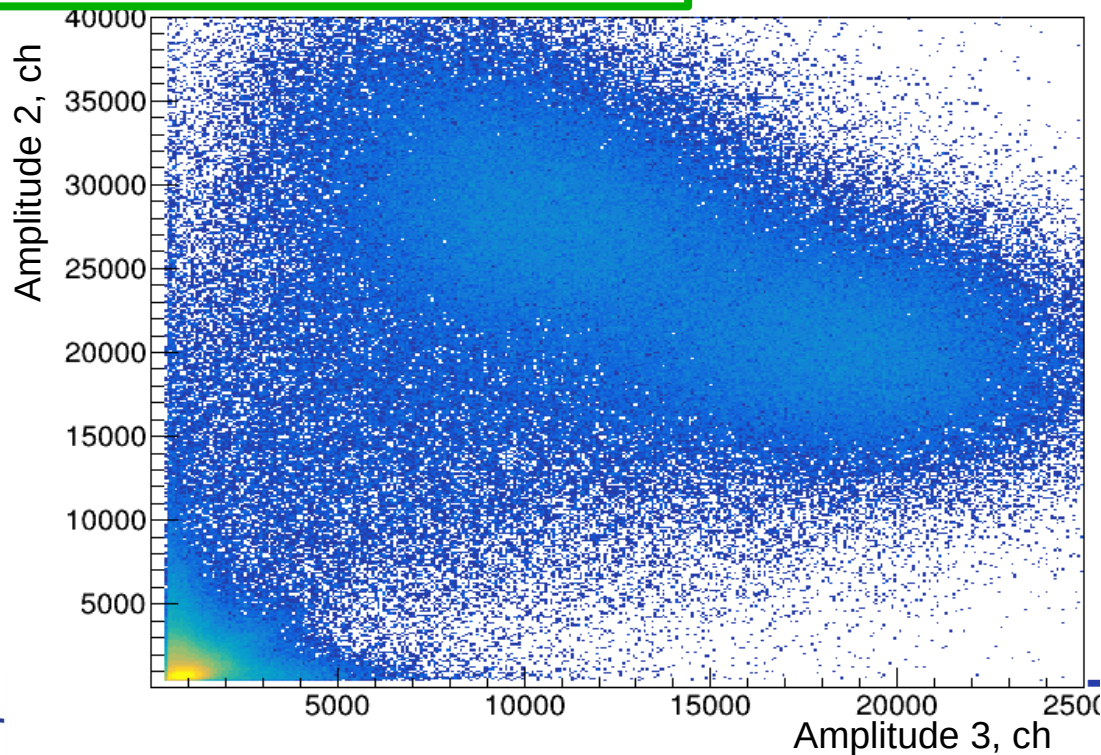
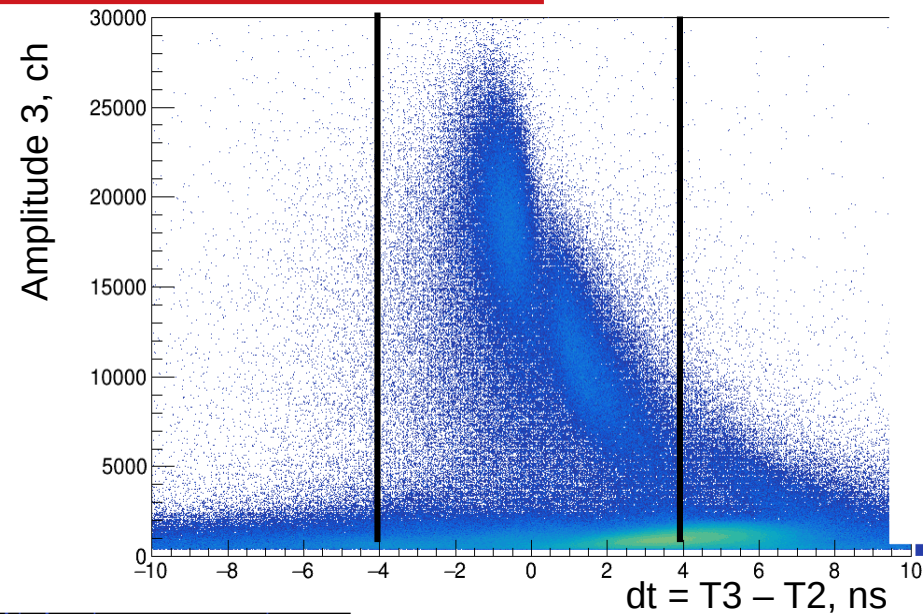
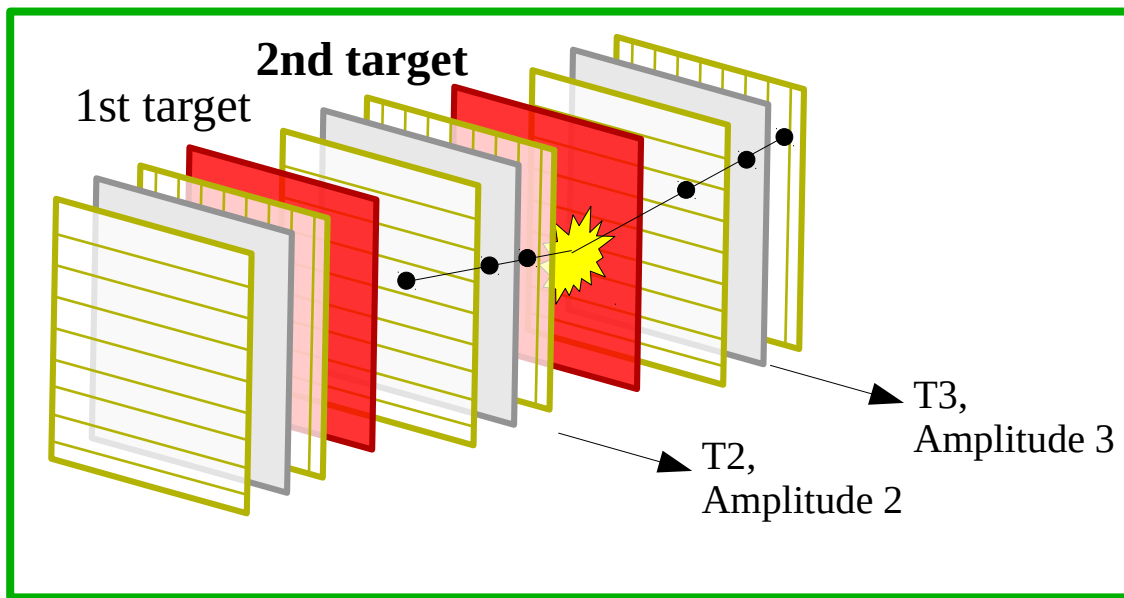
Coincidences between fragments



FF from
1st ^{235}U

FF from
2nd ^{235}U

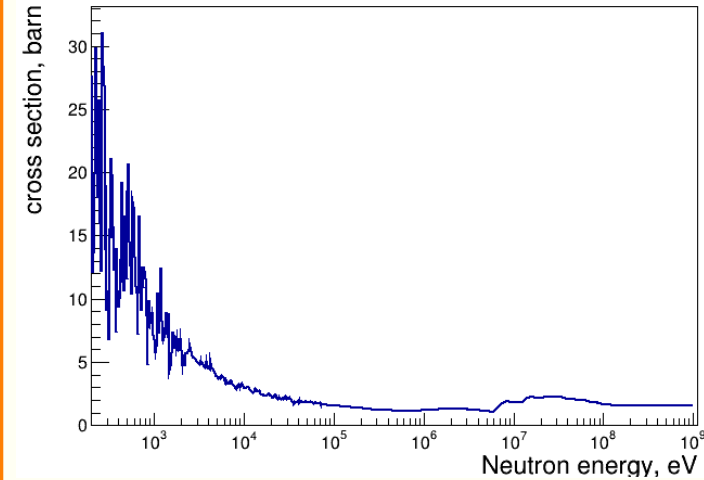
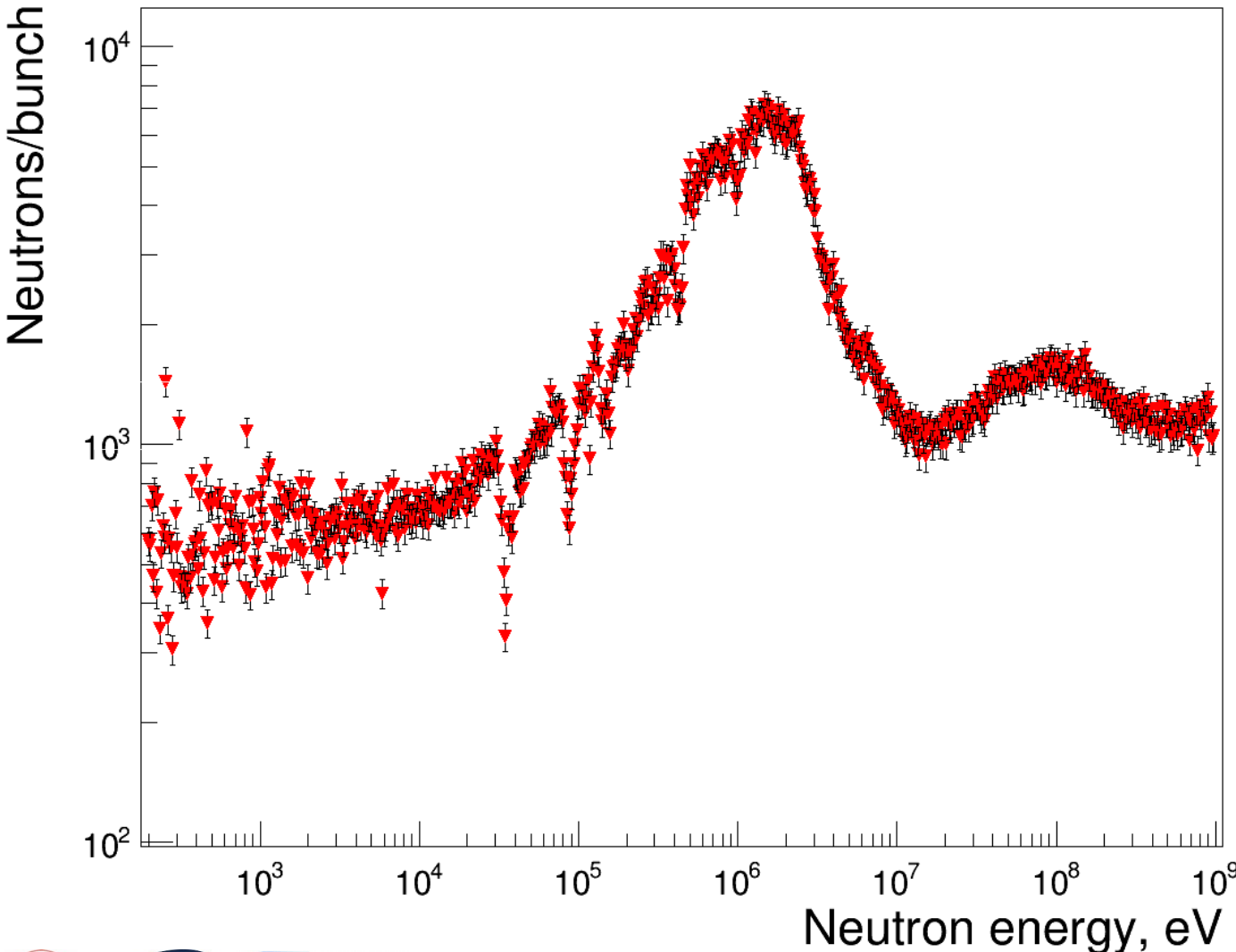
Coincidences between fragments



FF from
1st ^{235}U

FF from
2nd ^{235}U

Flux with PPAC



^{235}U :

th-10 MeV ENDF/B-VIII
(10 – 200) MeV IAEA
>200 MeV constant

^{238}U :

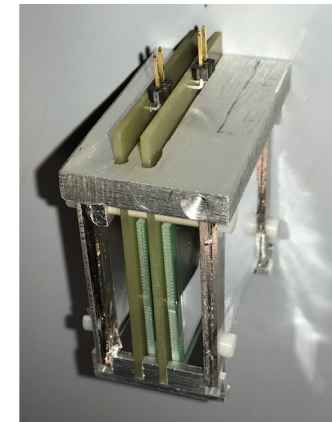
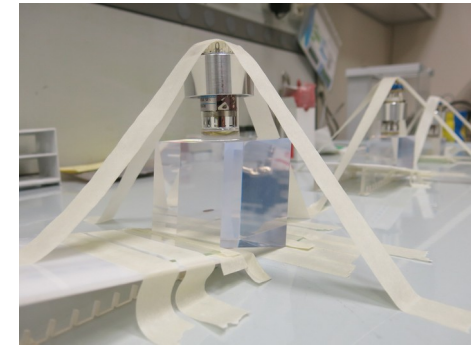
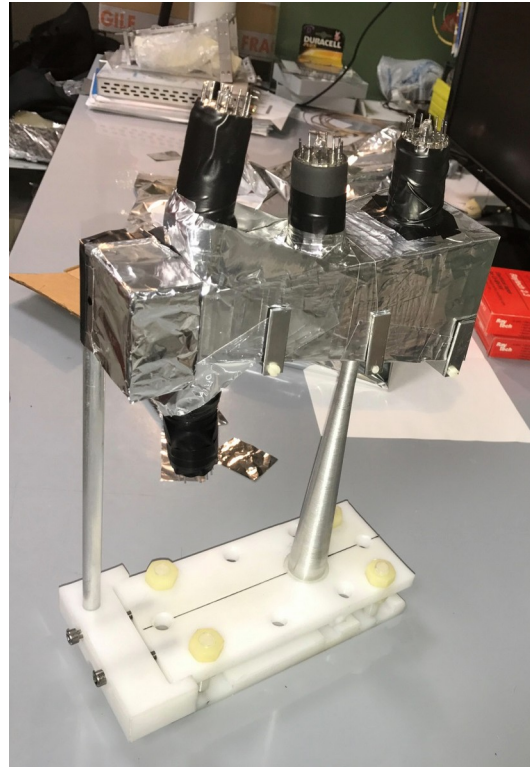
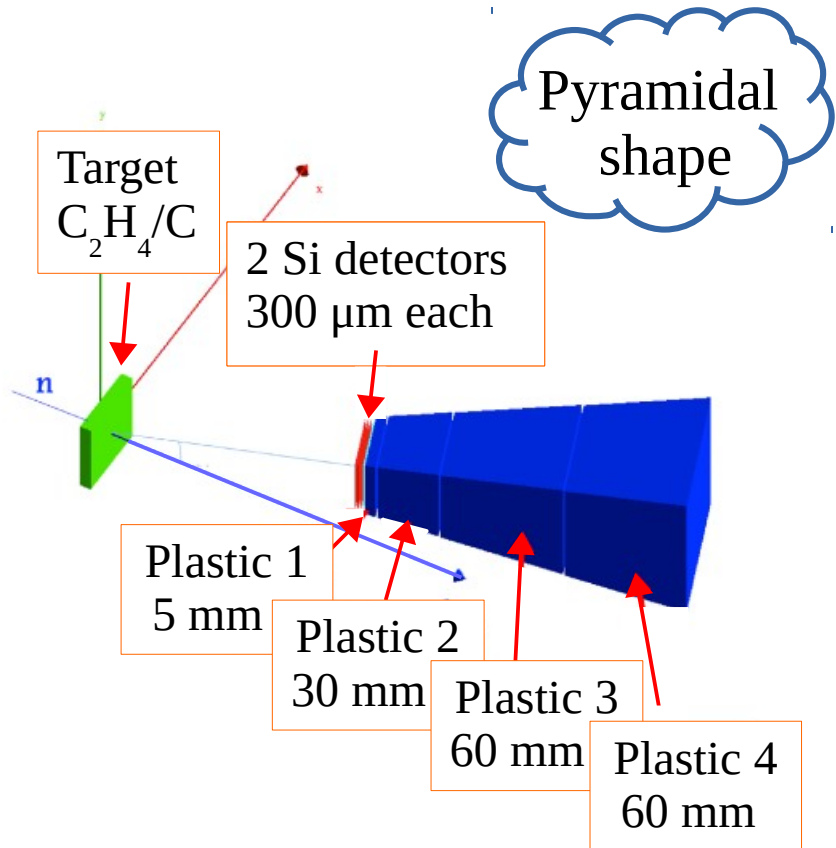
(6.283%)

th-200 MeV IAEA
>200 MeV constant

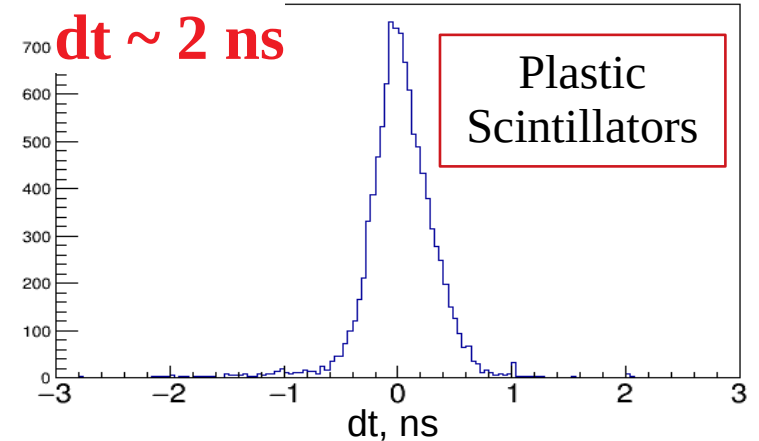
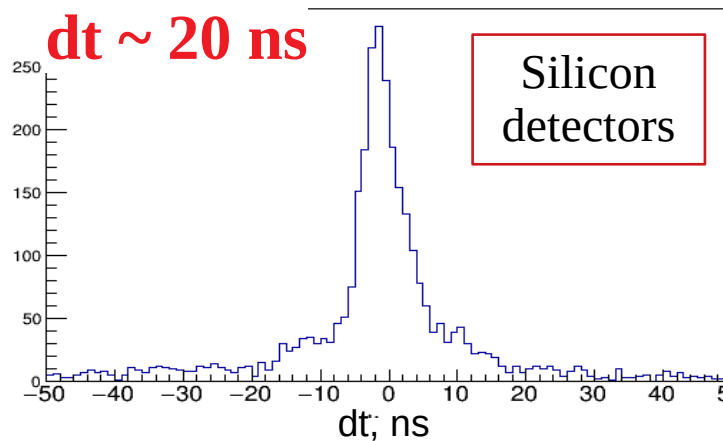
$^{234}\text{U} + ^{236}\text{U}$: (0.7472% + 0.2696%)

th-30 MeV ENDF/B-VIII
>30 MeV interpolation with
 ^{235}U and ^{238}U

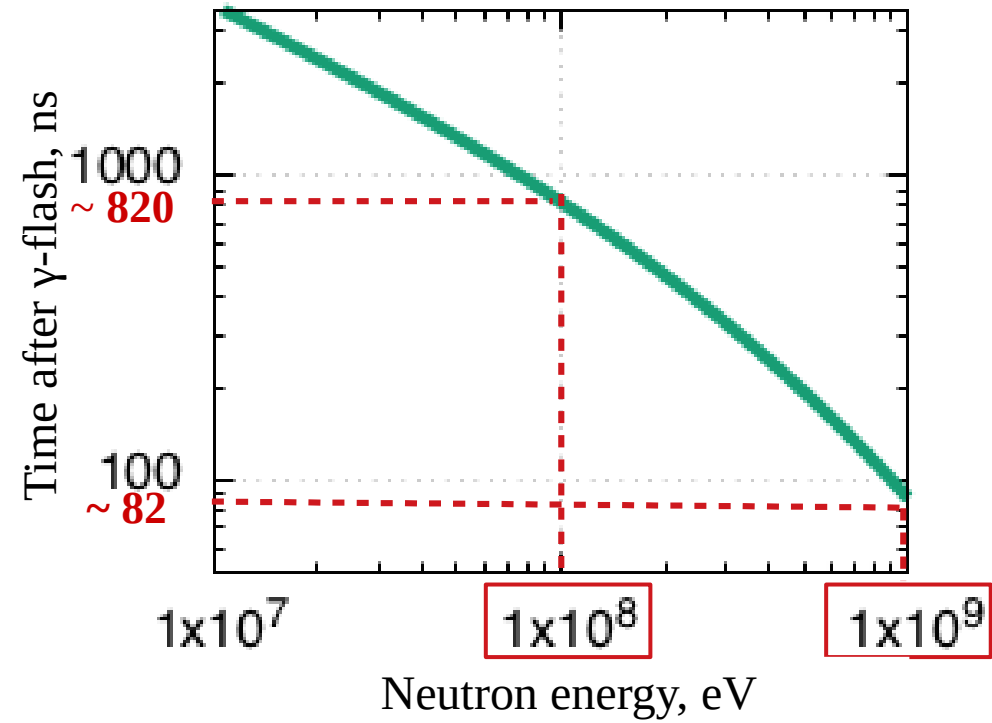
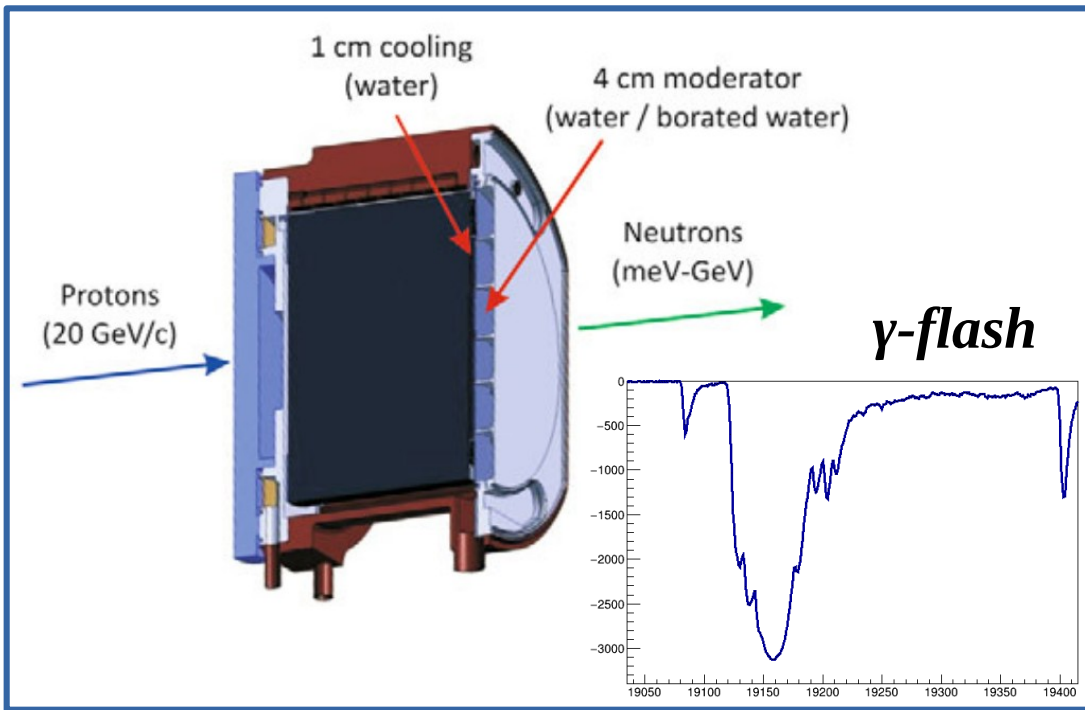
A Proton Recoil Telescope



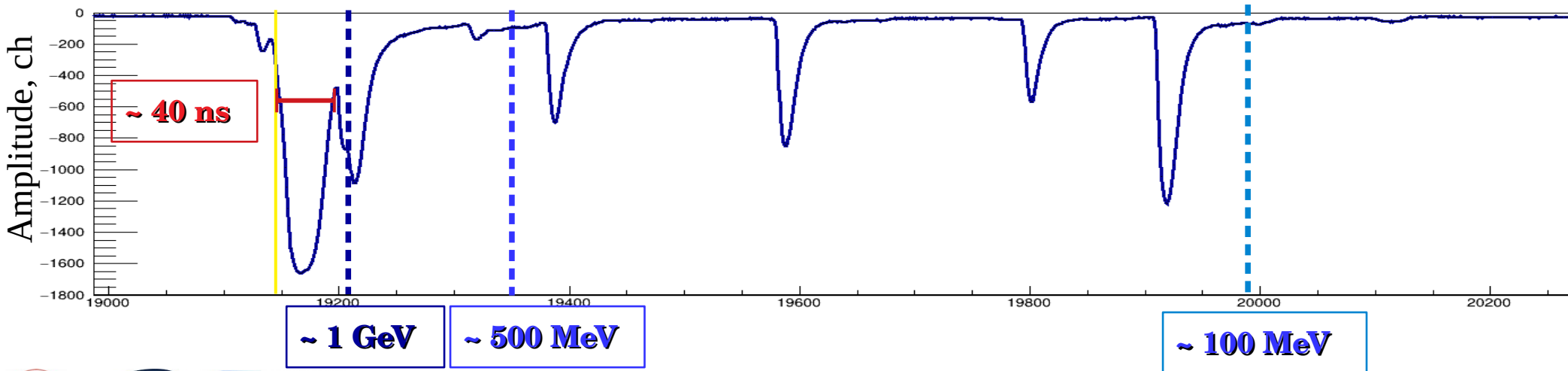
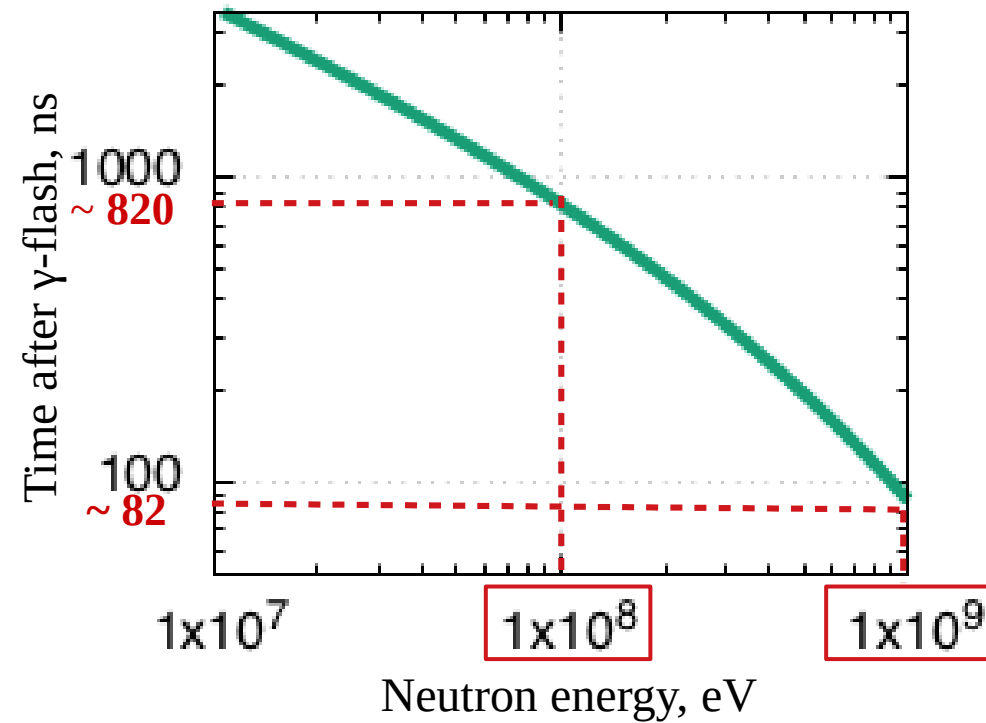
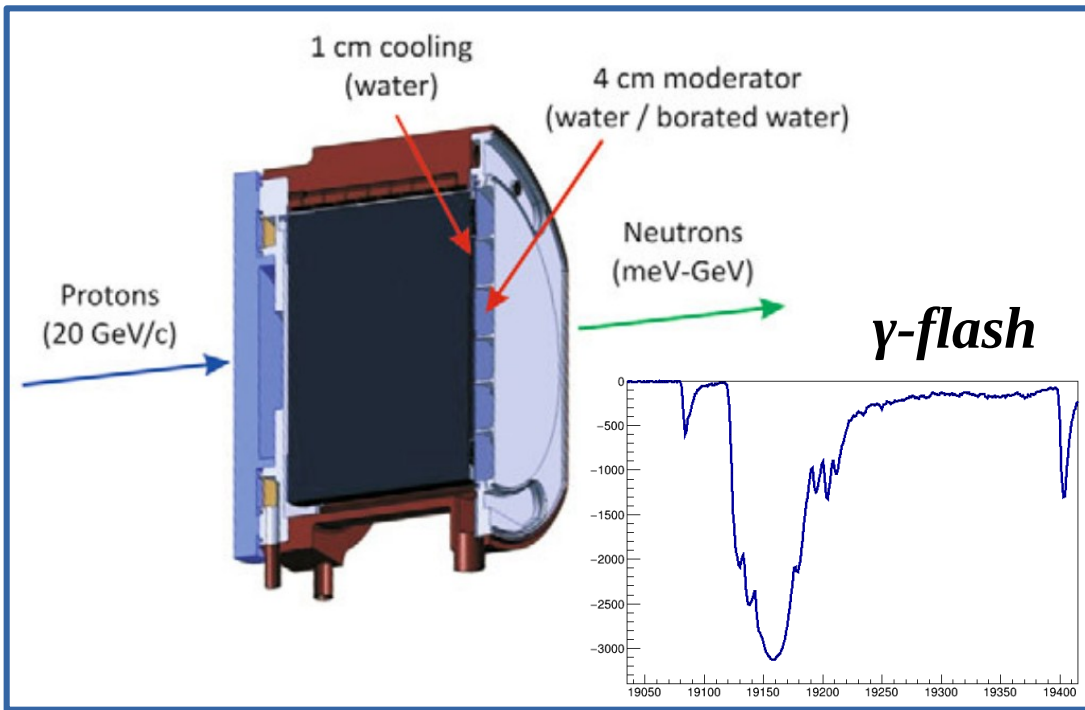
Timing properties:



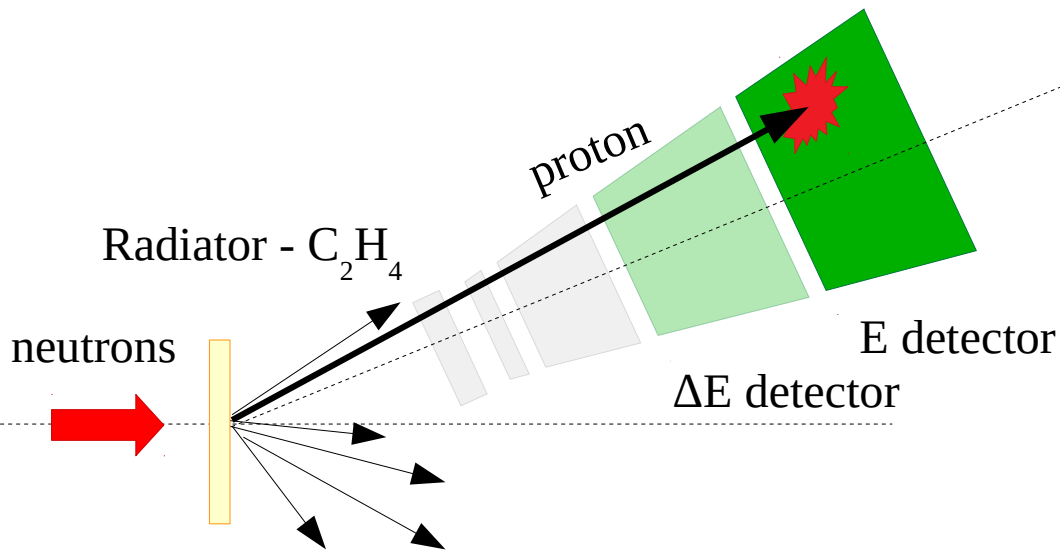
PRT - Response to the γ -flash



PRT - Response to the γ -flash



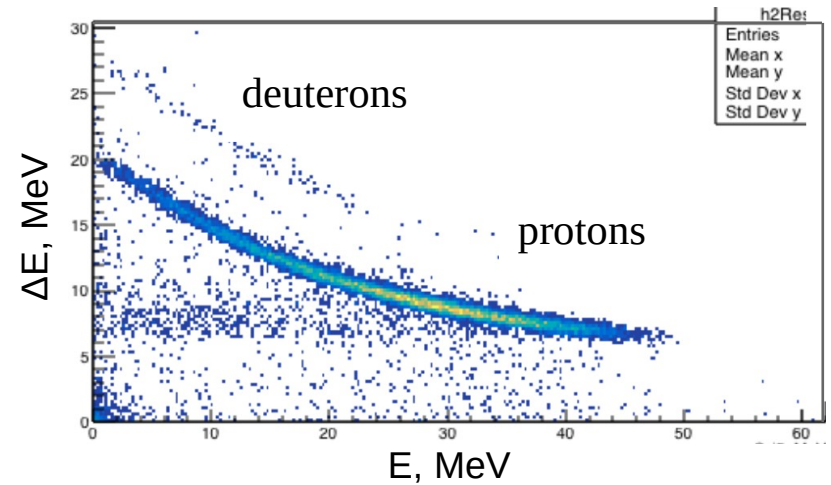
$\Delta E - E$ Matrix



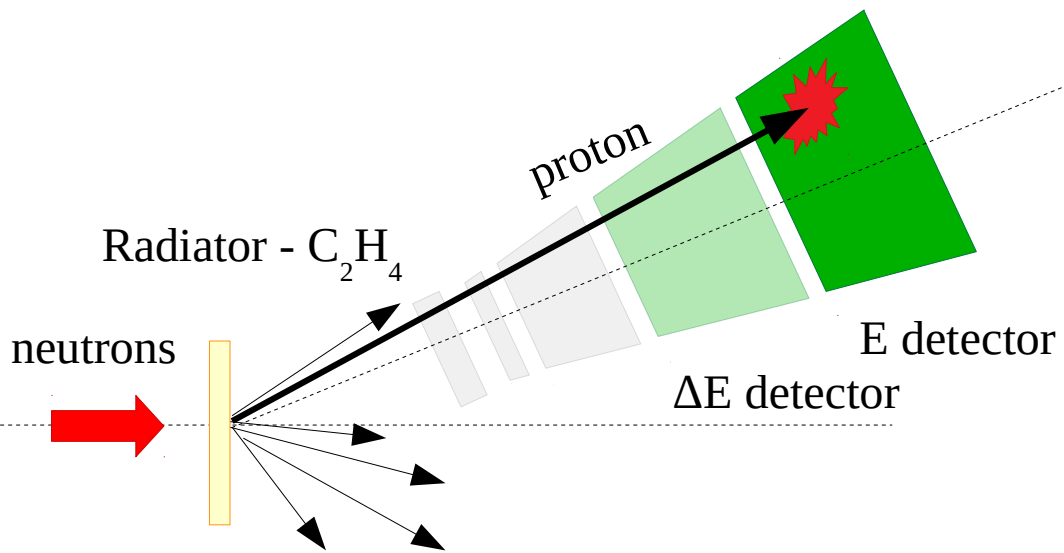
$$\Delta E \cdot E \propto k \cdot z^2 \cdot M$$

k : material absorption properties

M, E, z : interacting particle properties



Pulse Reconstruction



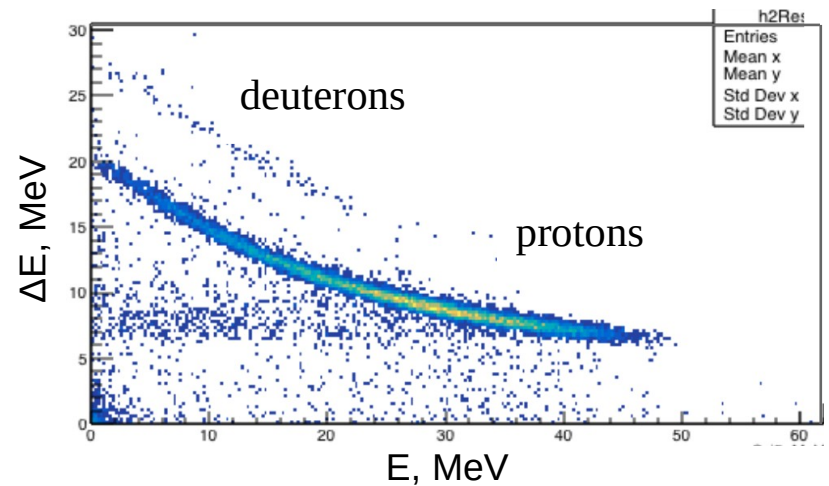
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k : material absorption properties

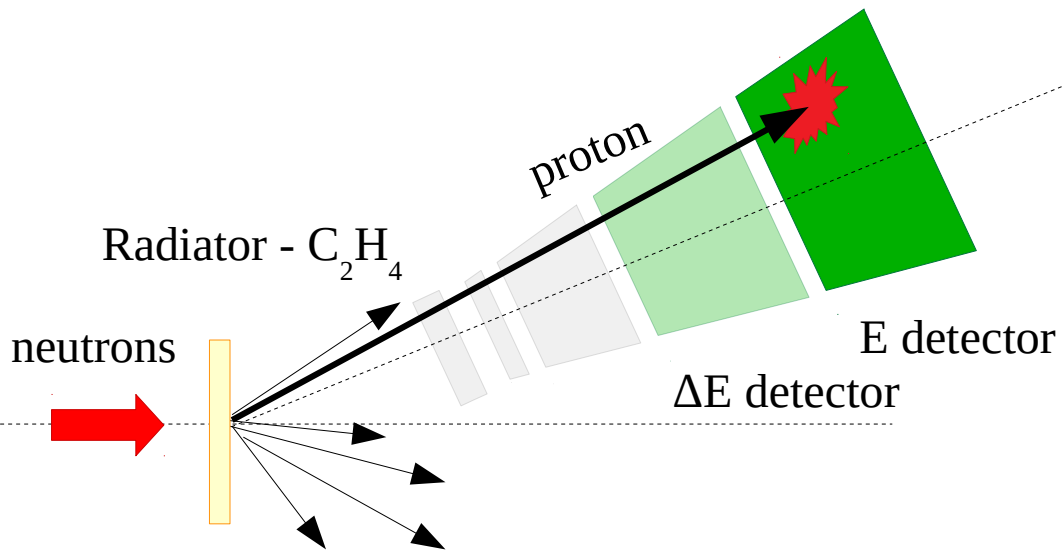
M, E, z : interacting particle properties

Deposited energy range in the Plastic Scintillators:

- 1st: 1-20 MeV
- 2nd: 1-50 MeV
- 3rd & 4th: 1-70 MeV



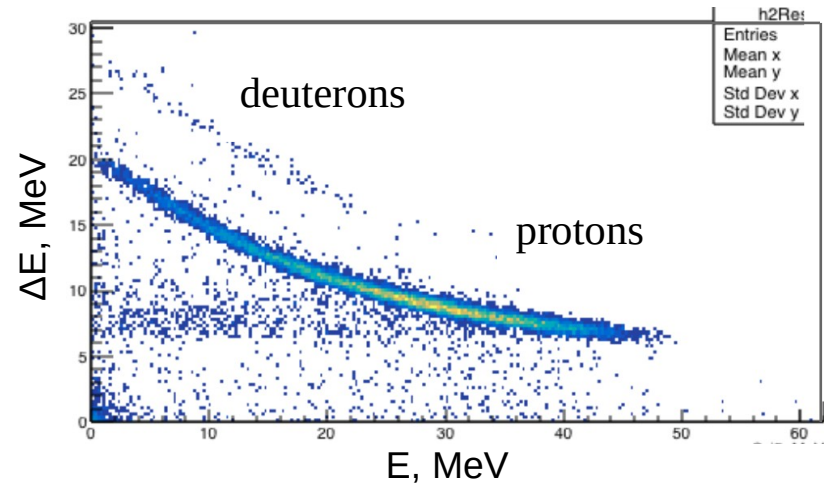
Pulse Reconstruction



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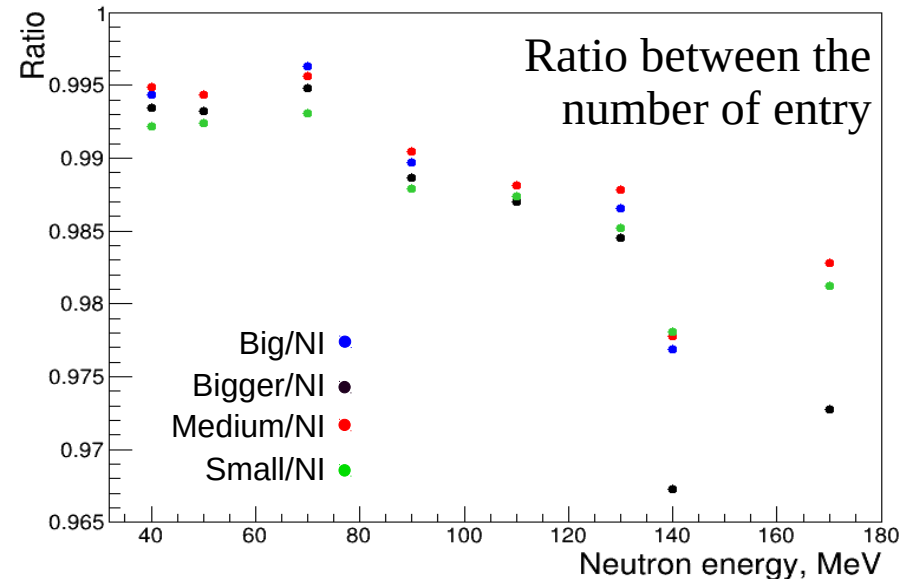
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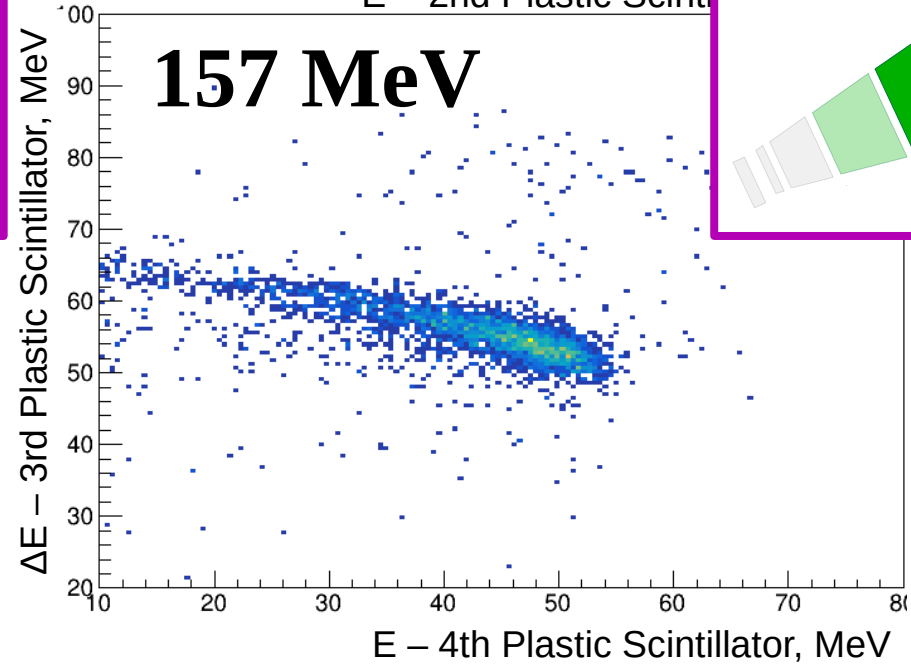
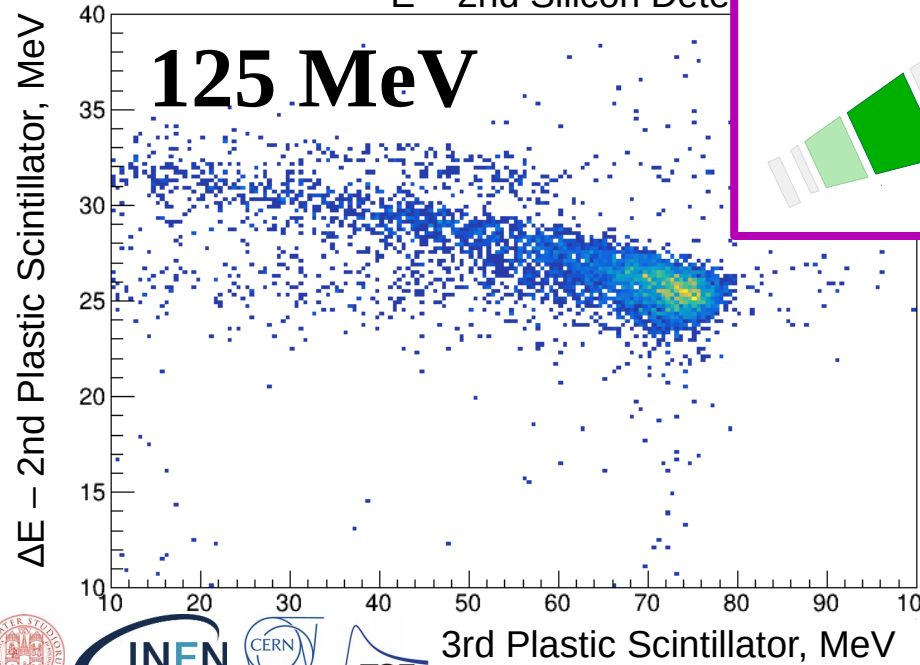
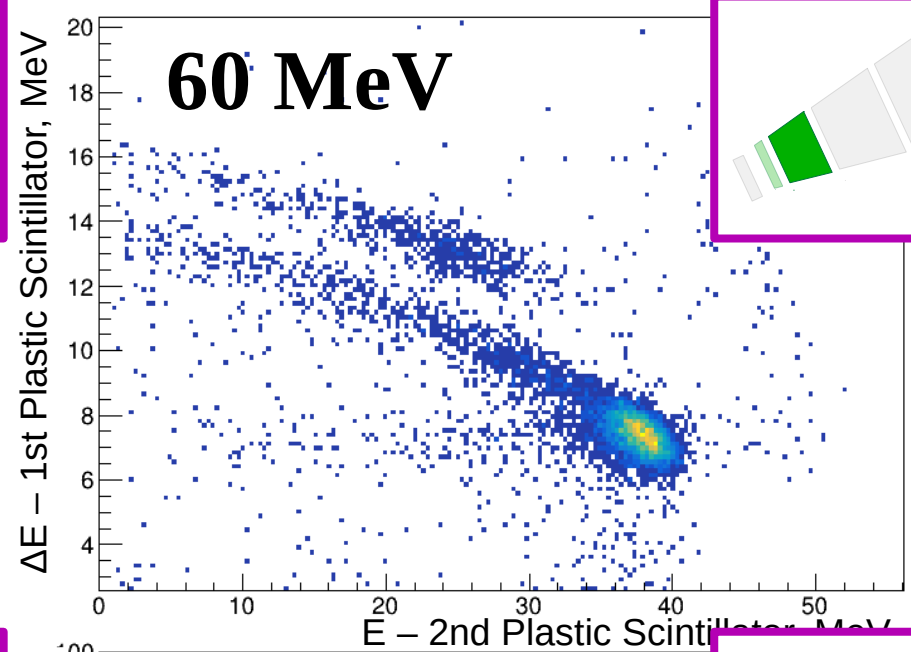
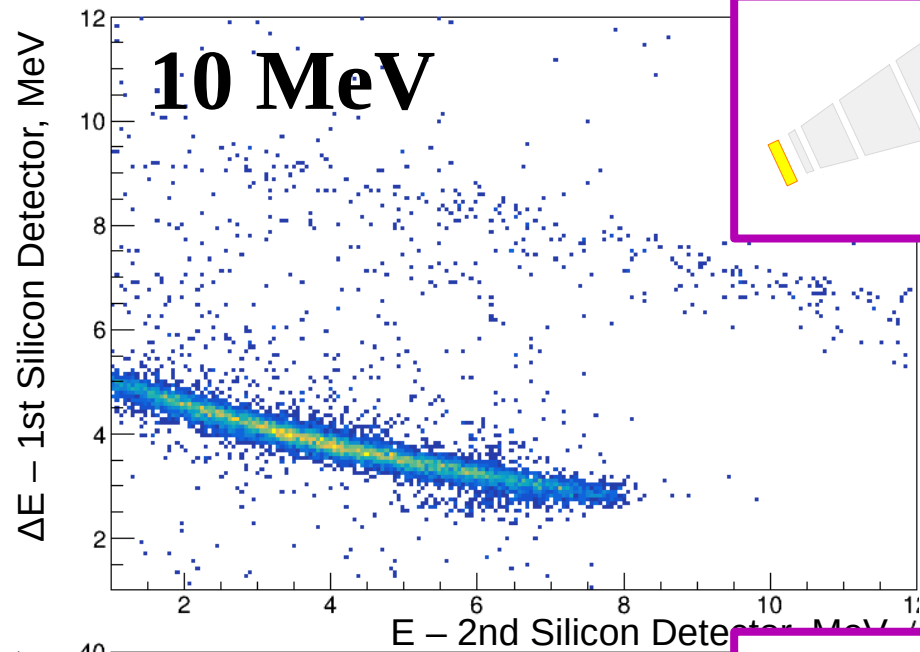
Numerical Integration

Fit with different shapes

- “Bigger” Signal
- “Medium” Signal
- “Small” Signal
- “Big” Signal



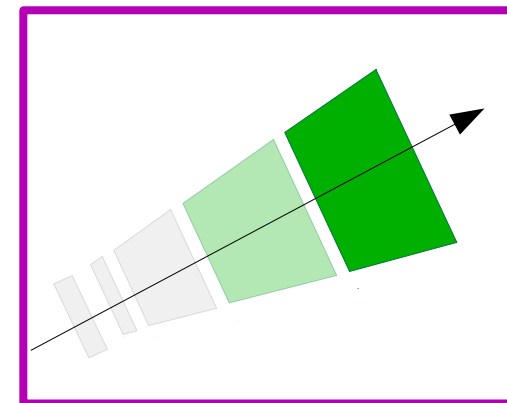
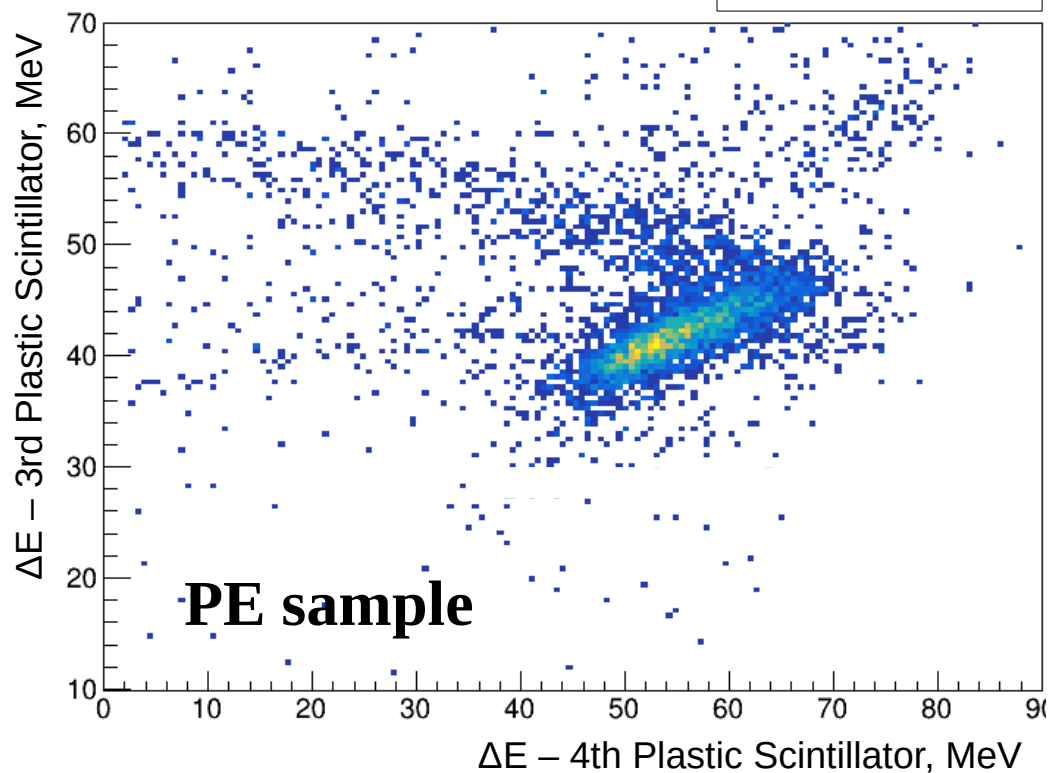
$\Delta E - E$ Matrix



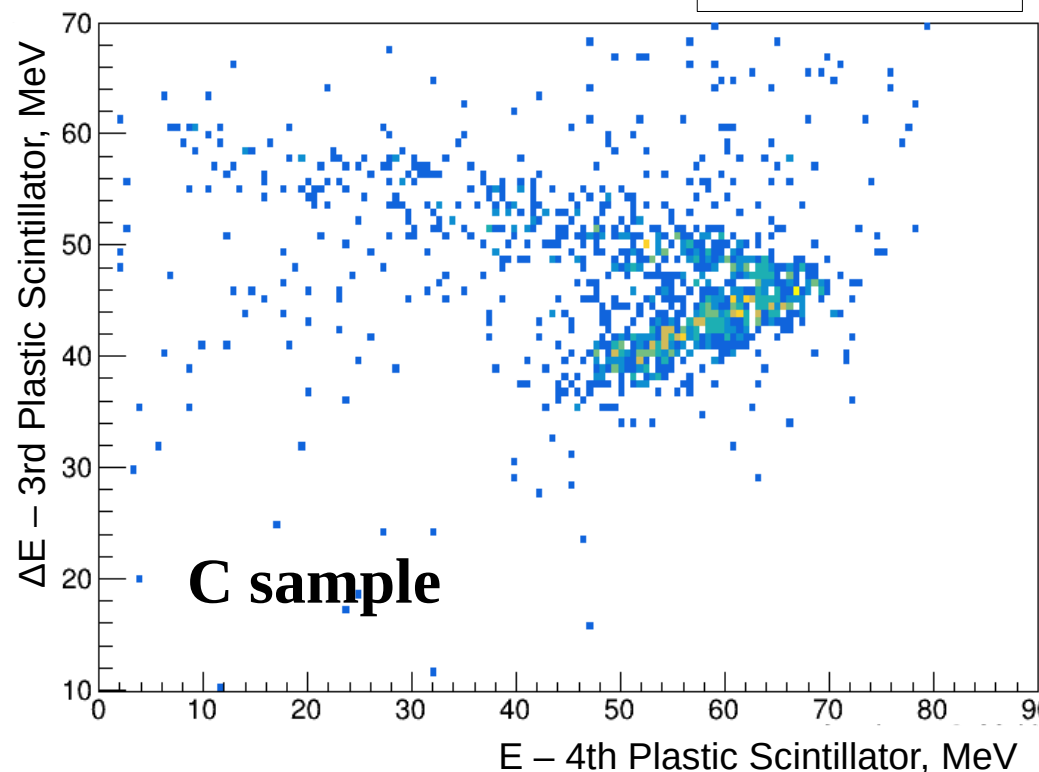
$\Delta E - E$ Matrix

200 MeV

Entries: 4841



Entries: 2486

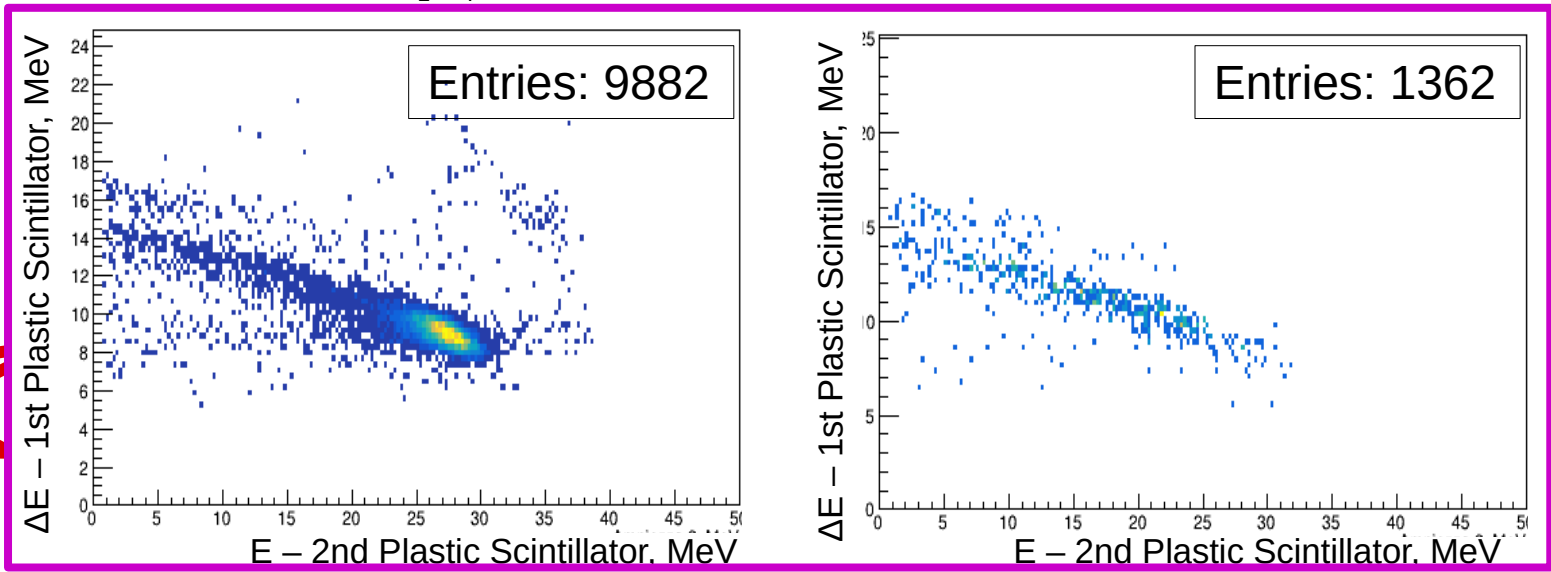


Extraction of the neutron flux



DATA

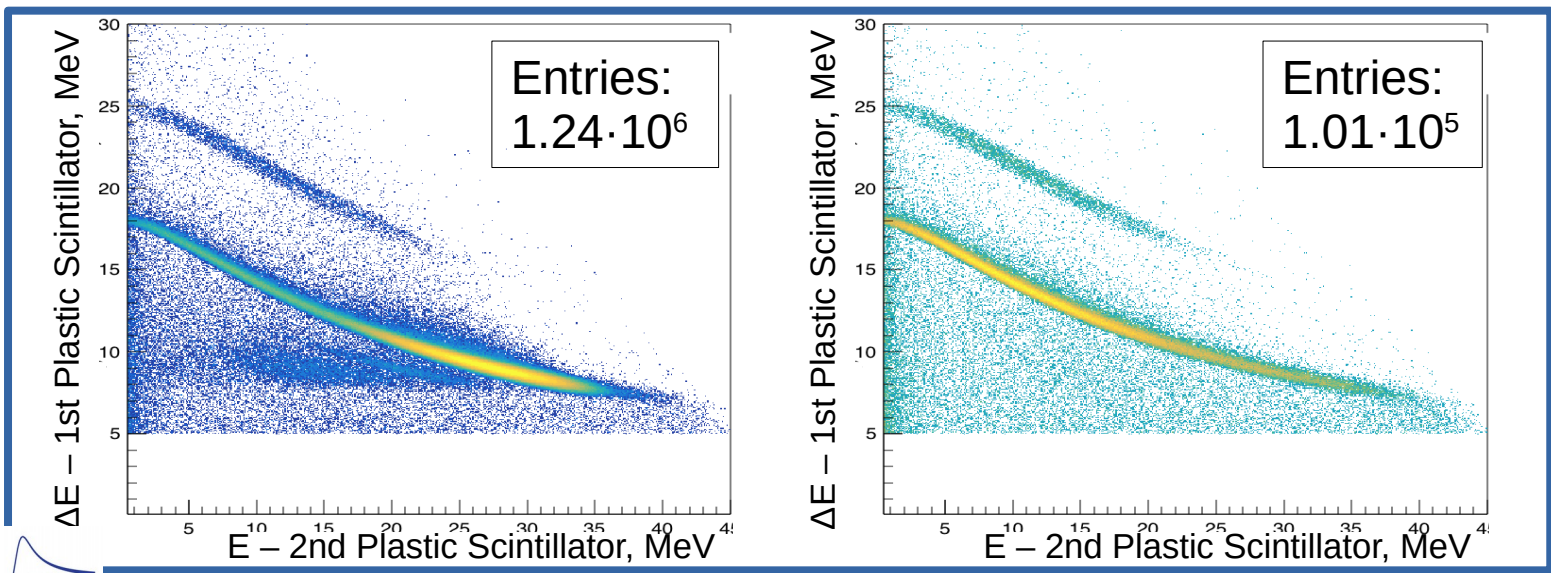
50 MeV



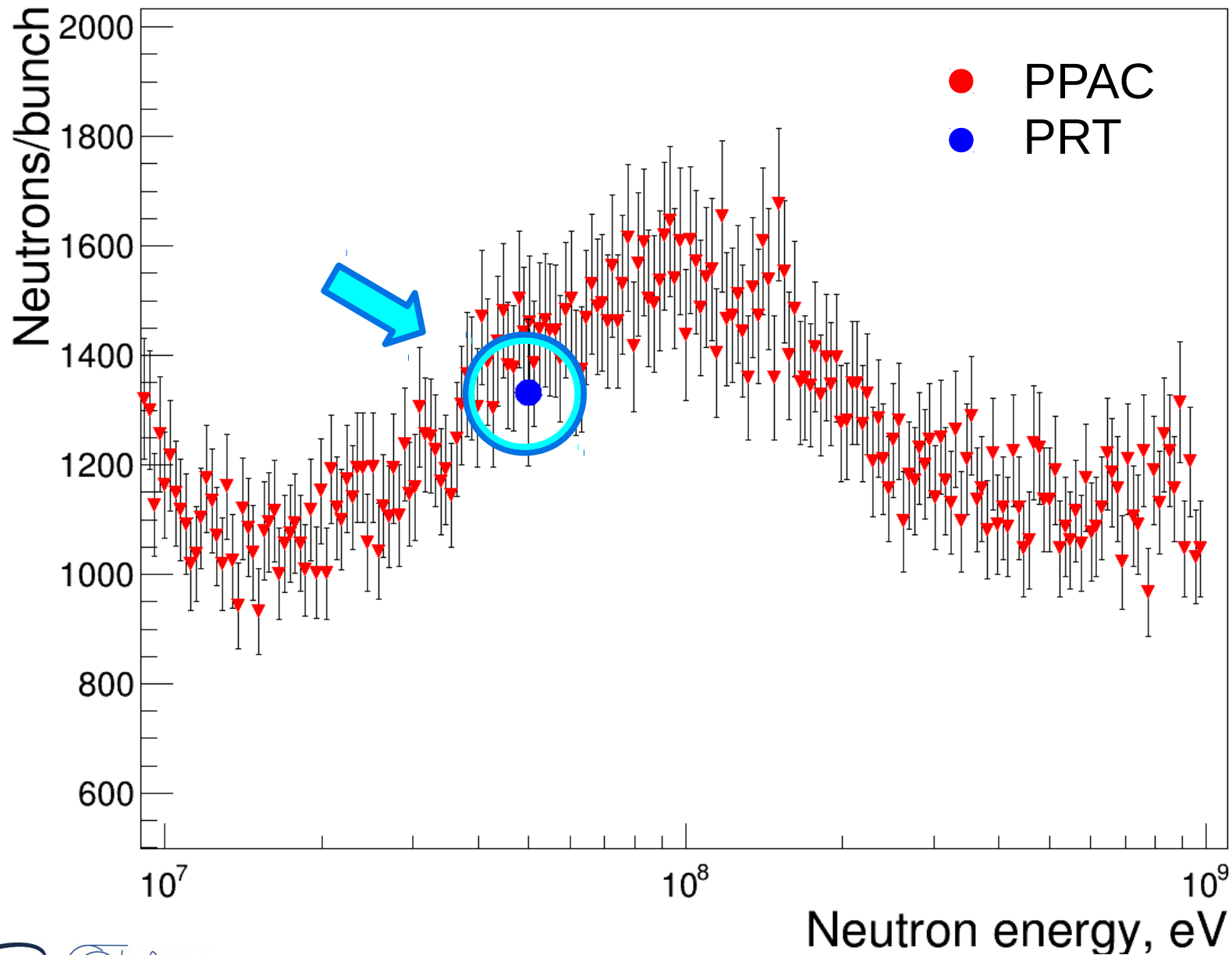
MC Simulation

#n = $5.12 \cdot 10^{10}$

see **Nicholas Terranova's** talk R247



Flux PPAC with PRT point



Conclusions

- ◆ Demanding measurement:
 - experimental setup → Neutron Flux
 - beam time
- ◆ Large effort for the MC simulation → ϵ

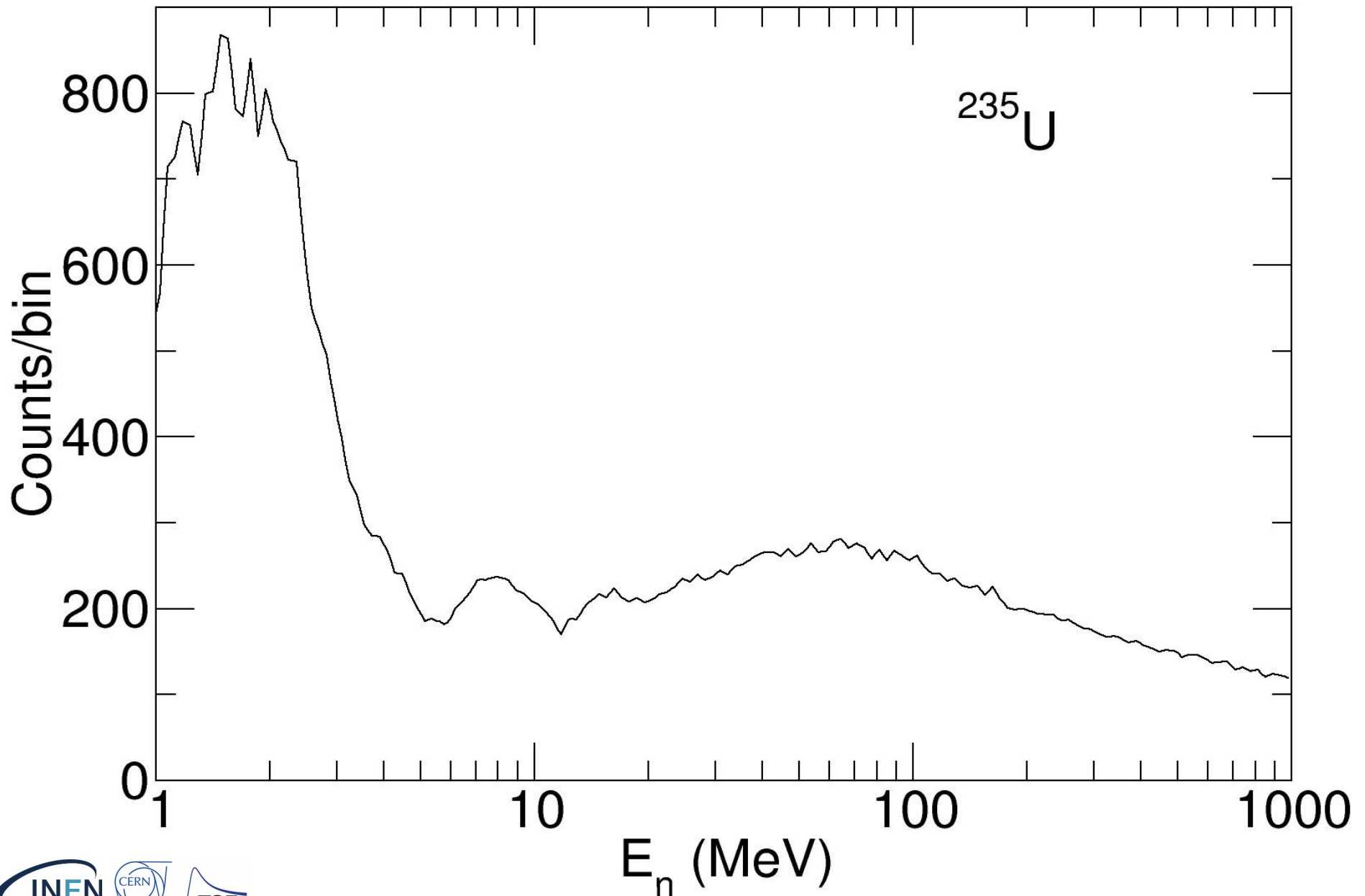
NEXT STEPS:

- ◆ Extract the n_TOF flux up to 1 GeV with the Proton Recoil Telescopes
- ◆ Count the fission fragments → $^{235}\text{U}(n,f)$ from 10 MeV to 1 GeV
- ◆ Evaluation of systematic uncertainties → Comparison with PTB

BACKUP

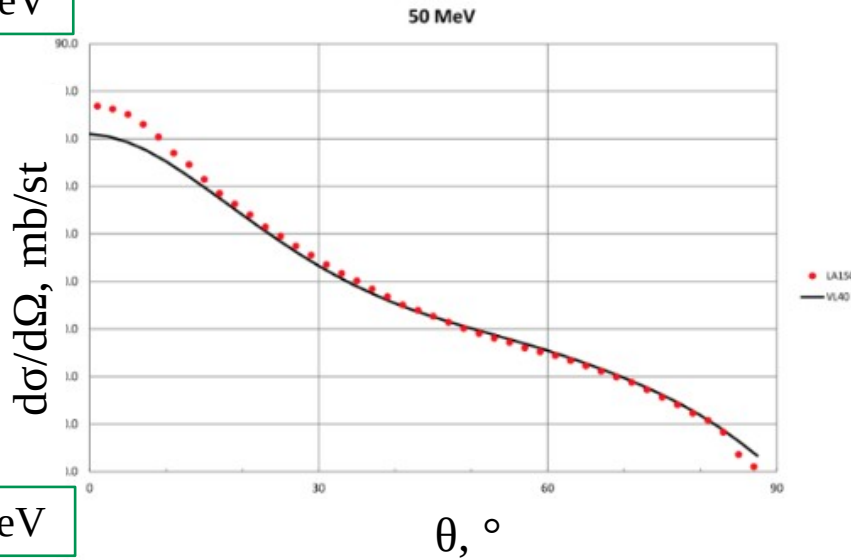


$^{235}\text{U}(\text{n},\text{f})$ counts

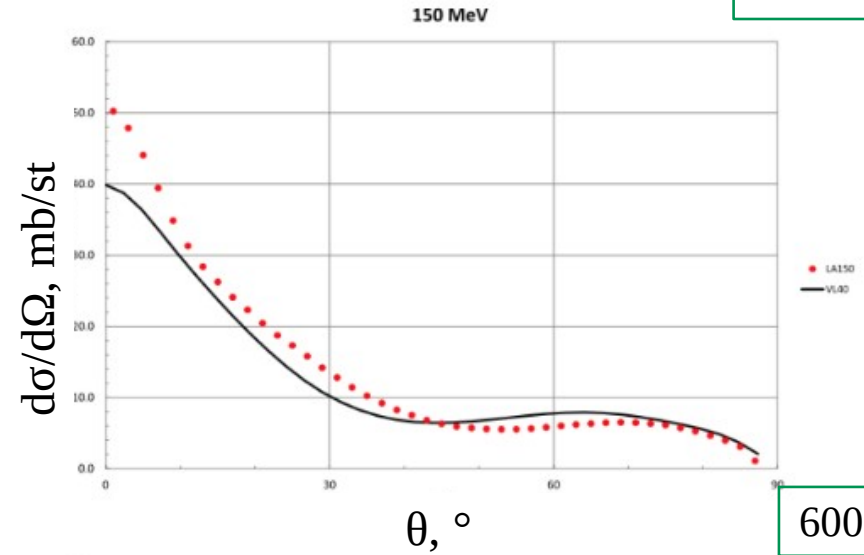


n-p scattering cross section

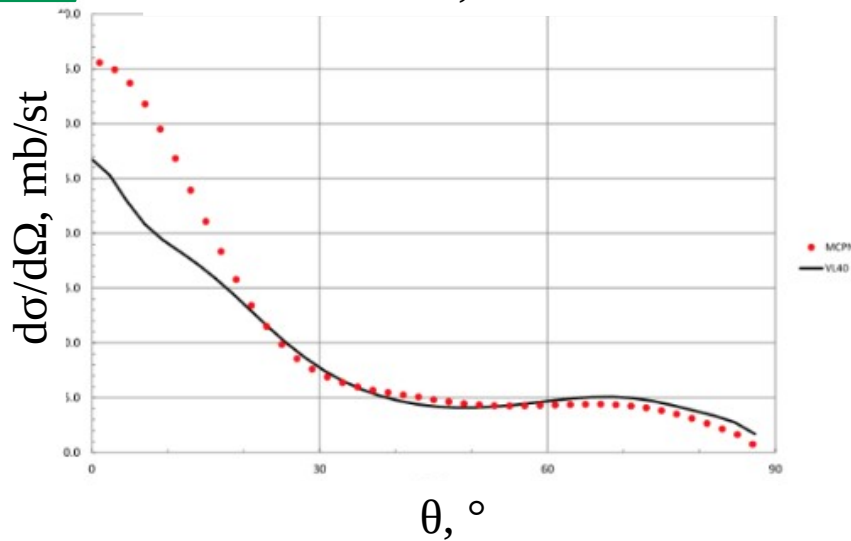
50 MeV



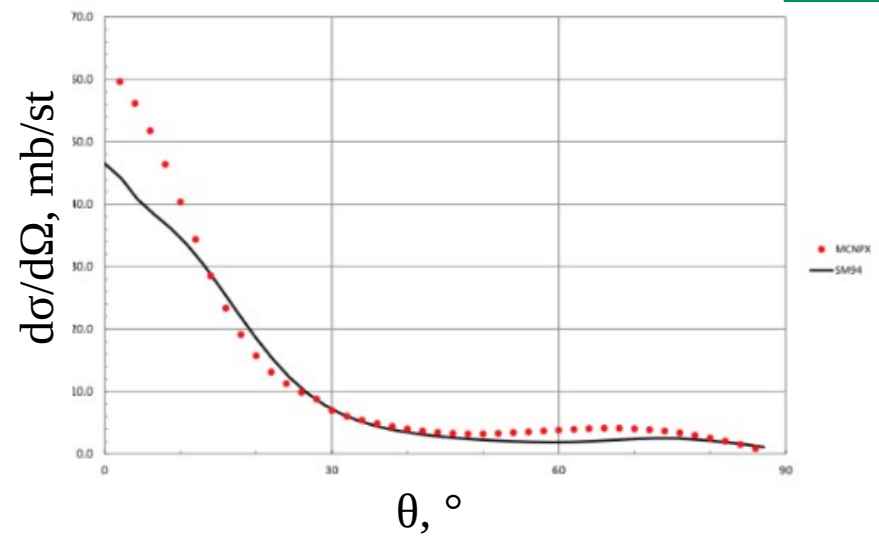
150 MeV



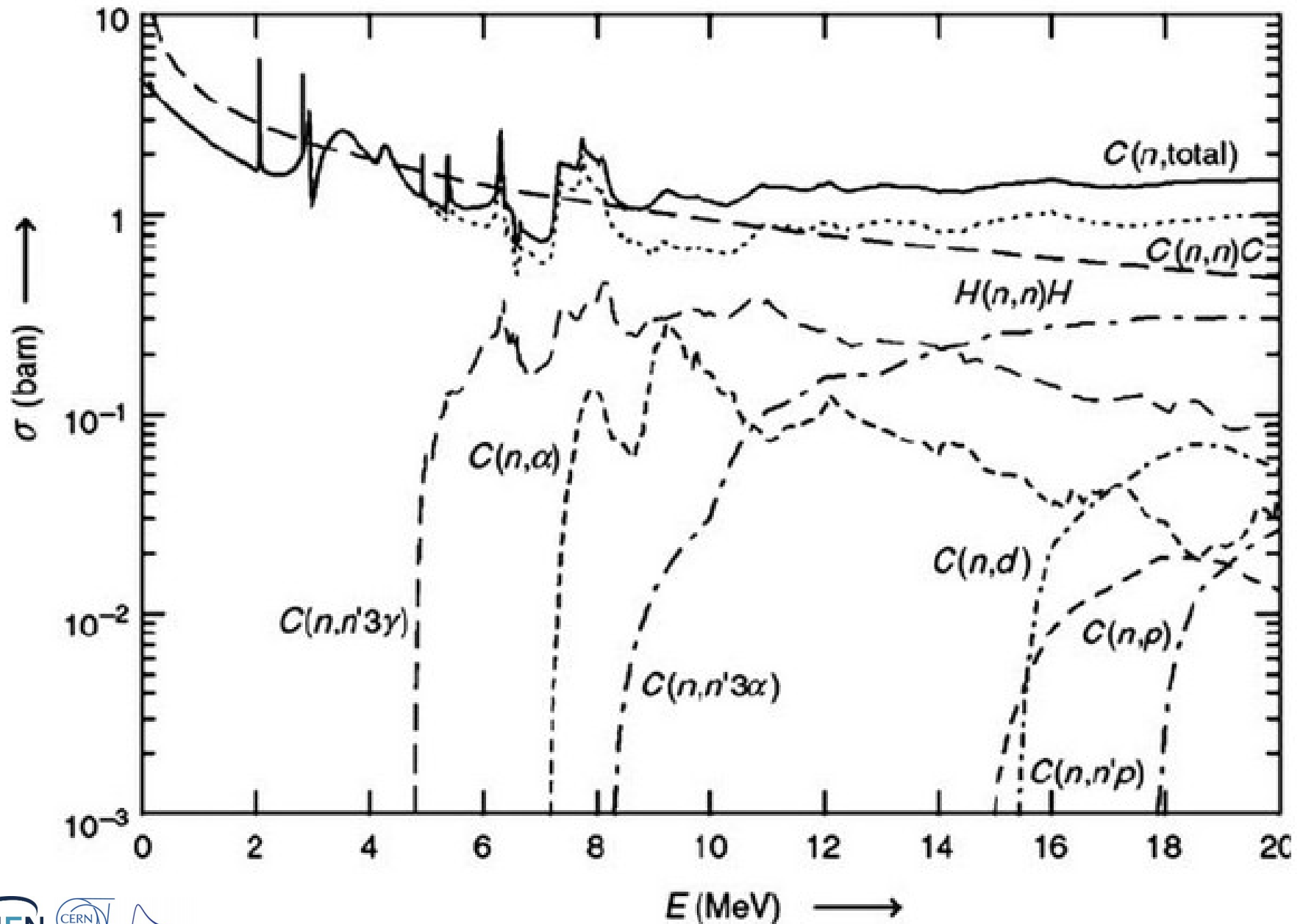
300 MeV



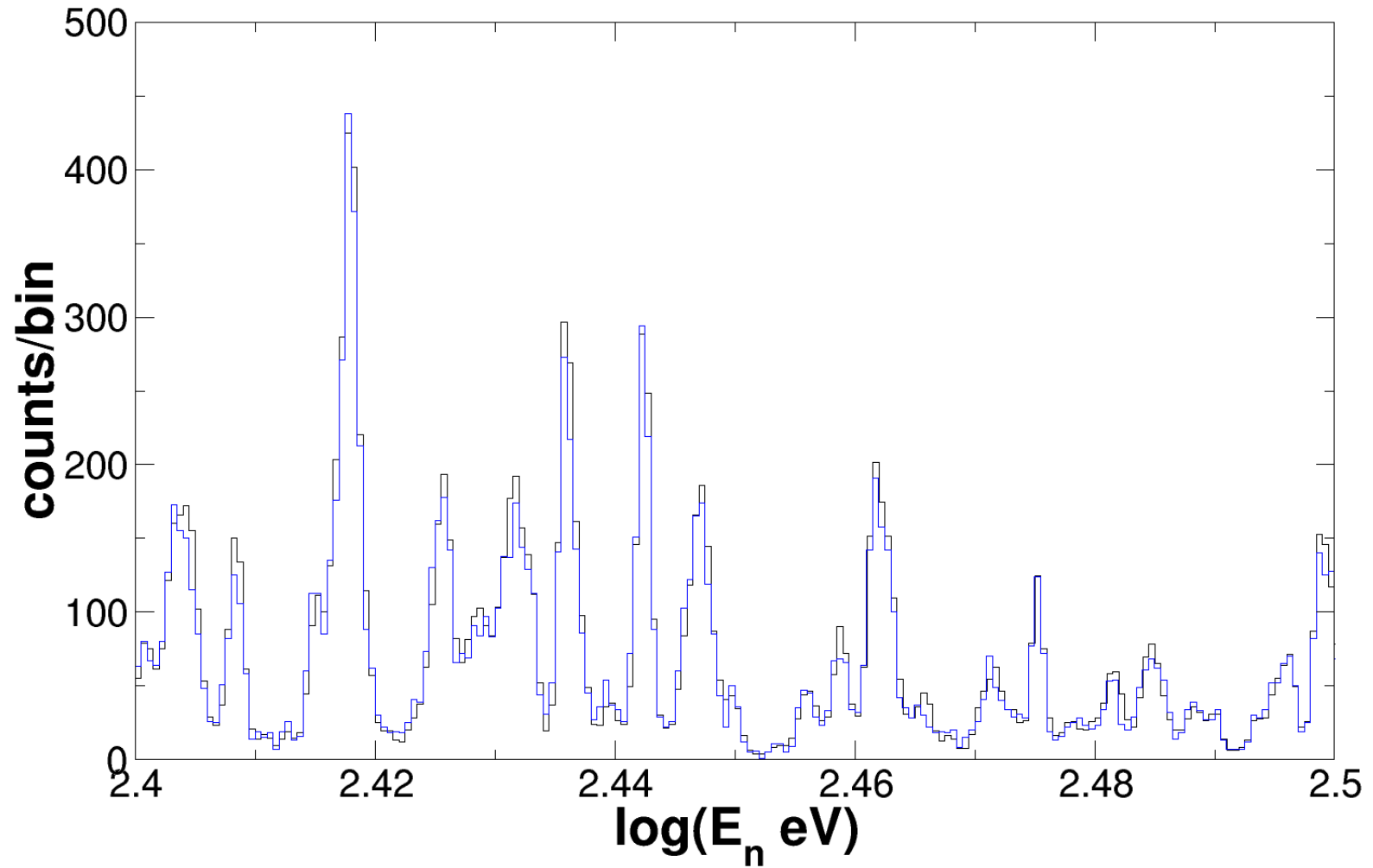
600 MeV



n-C scattering cross section

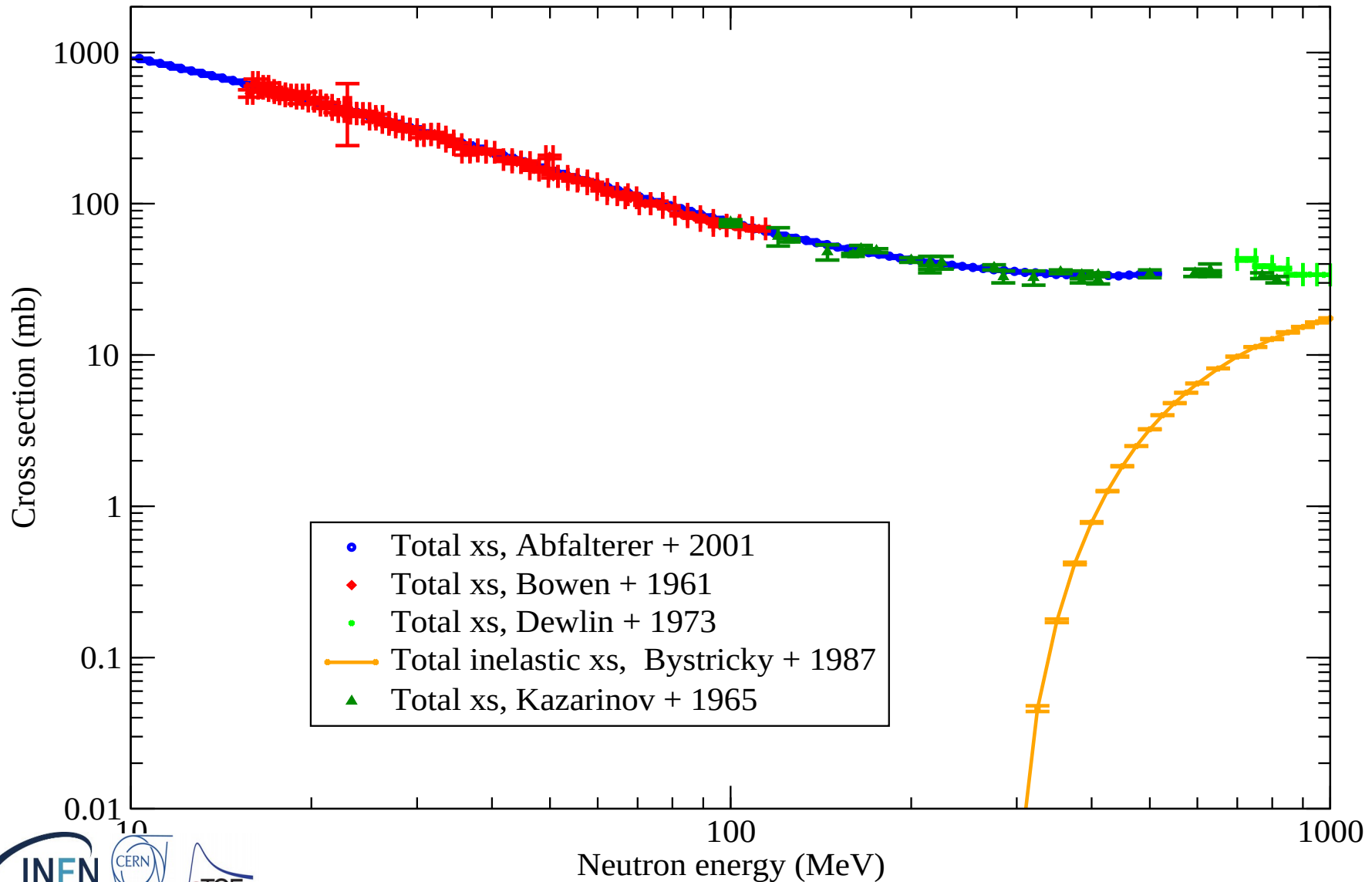


Resonances of ^{235}U



n-p scattering cross section

n-p scattering cross section



Pulse Reconstruction

