Update on FOOT neutron detectors at n_TOF NEL

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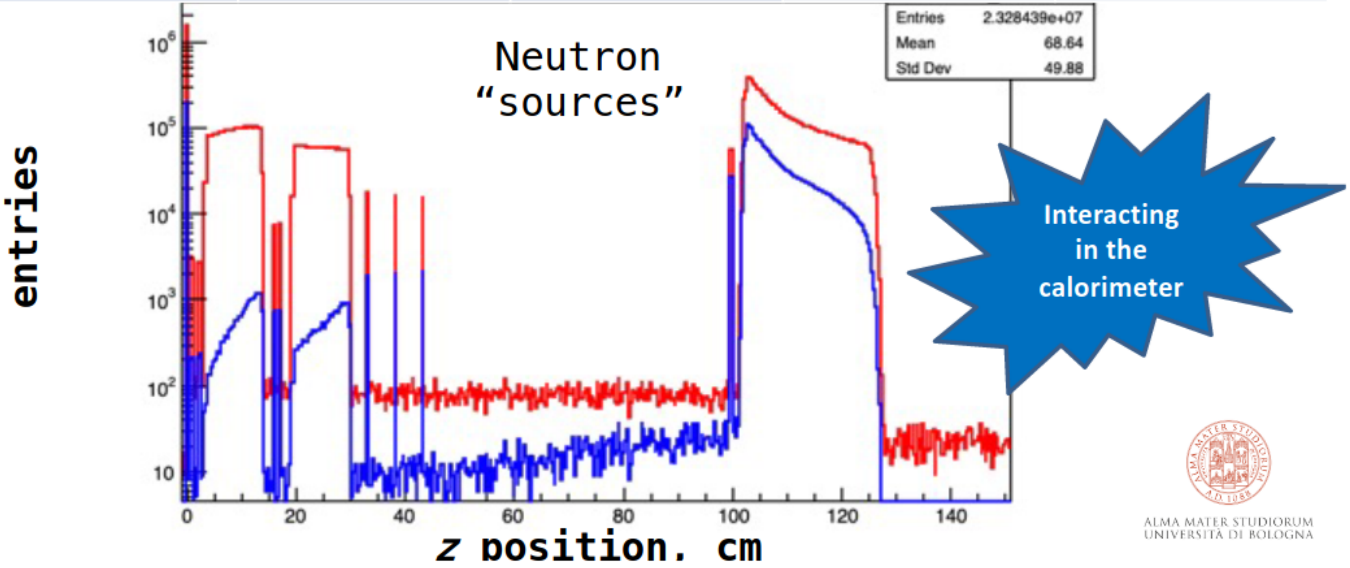
Neutron study from MC - Recap

$^{16}O+C_2H_4$ @200MeV/u (newgeom) statistics: 1.4E6 fragmentations

	Neutrons (10^6) Produced	Neutrons (10^6) interacting Magnets	Neutrons (10^6) towards Calorimeter	Neutrons (10^6) interacting Calorimeter	Neutrons (10^6) arriving to the world
target	3.2	1.3 (40%)	0.6 (20%)	**0.4**	1.4
magnets	6.5			**0.06**	14.8
Cal.	13.3			**3.1**	



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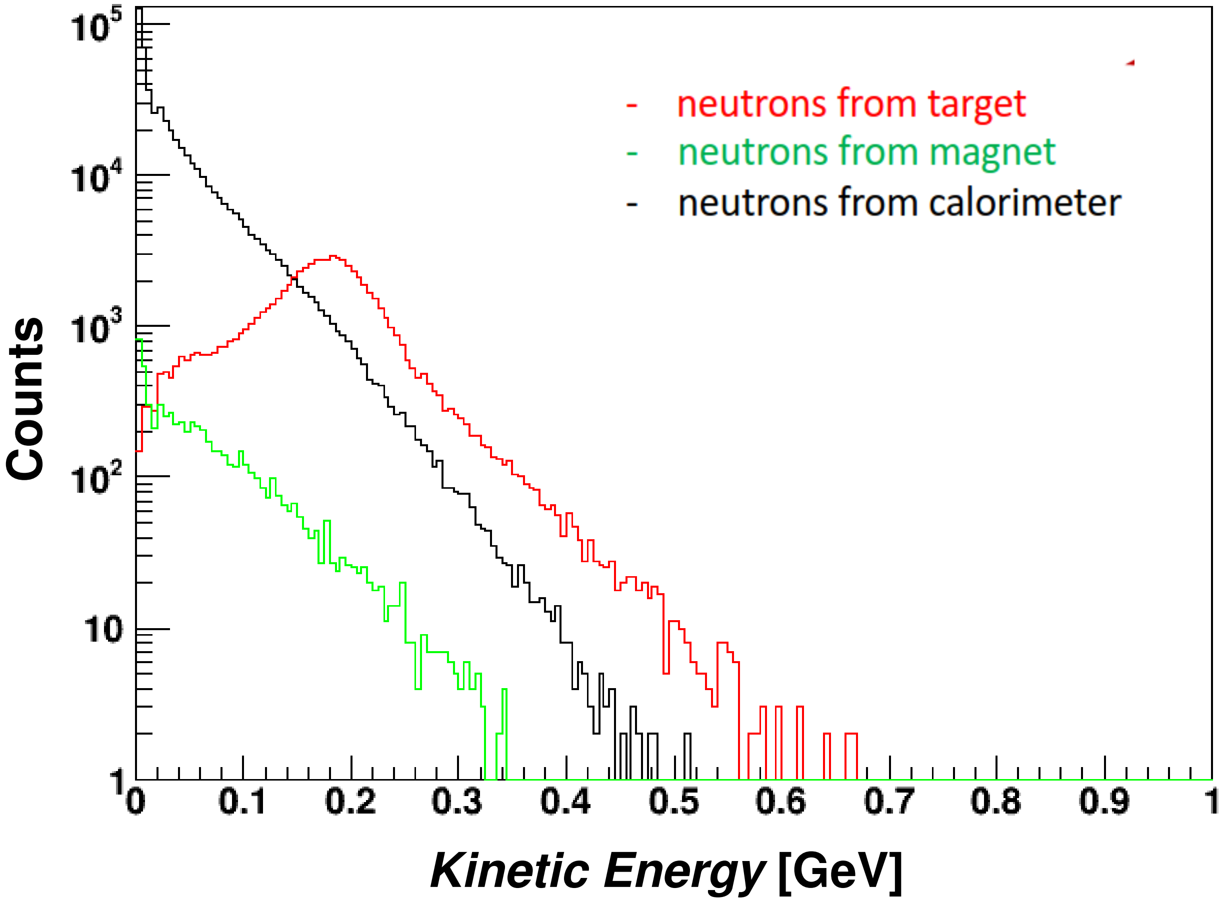
magnets	6.5	**0.06**
Cal.	13.3	**3.1**

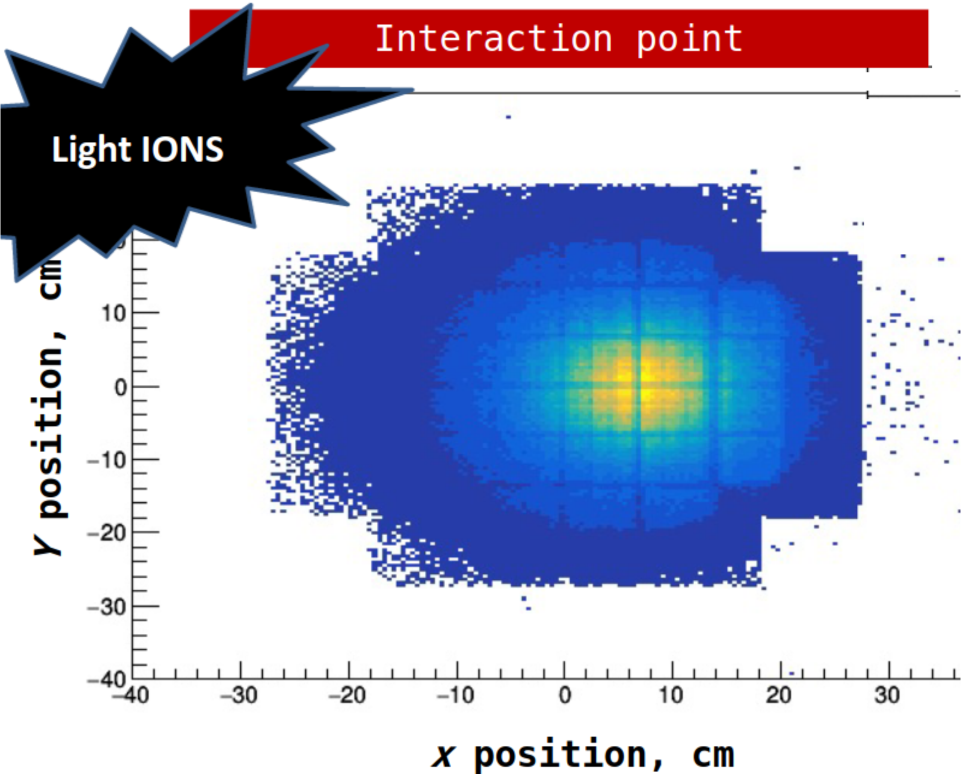
Which information can help to identify neutrons coming from the target?

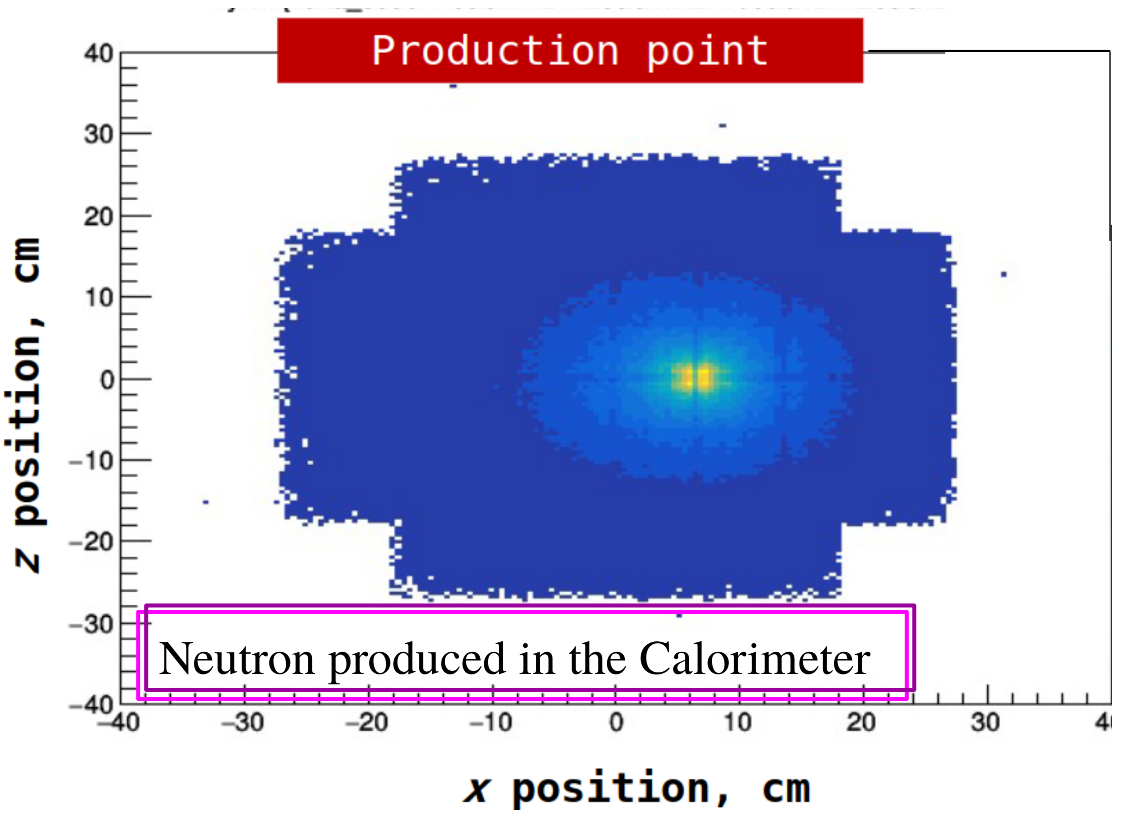


Neutron study from MC - Recap

How to discriminate the neutron from Target and from Calorimeter?

$^{16}O+C_2H_4$ @200MeV/u (newgeom) statistics: 1.4E6 fragmentations





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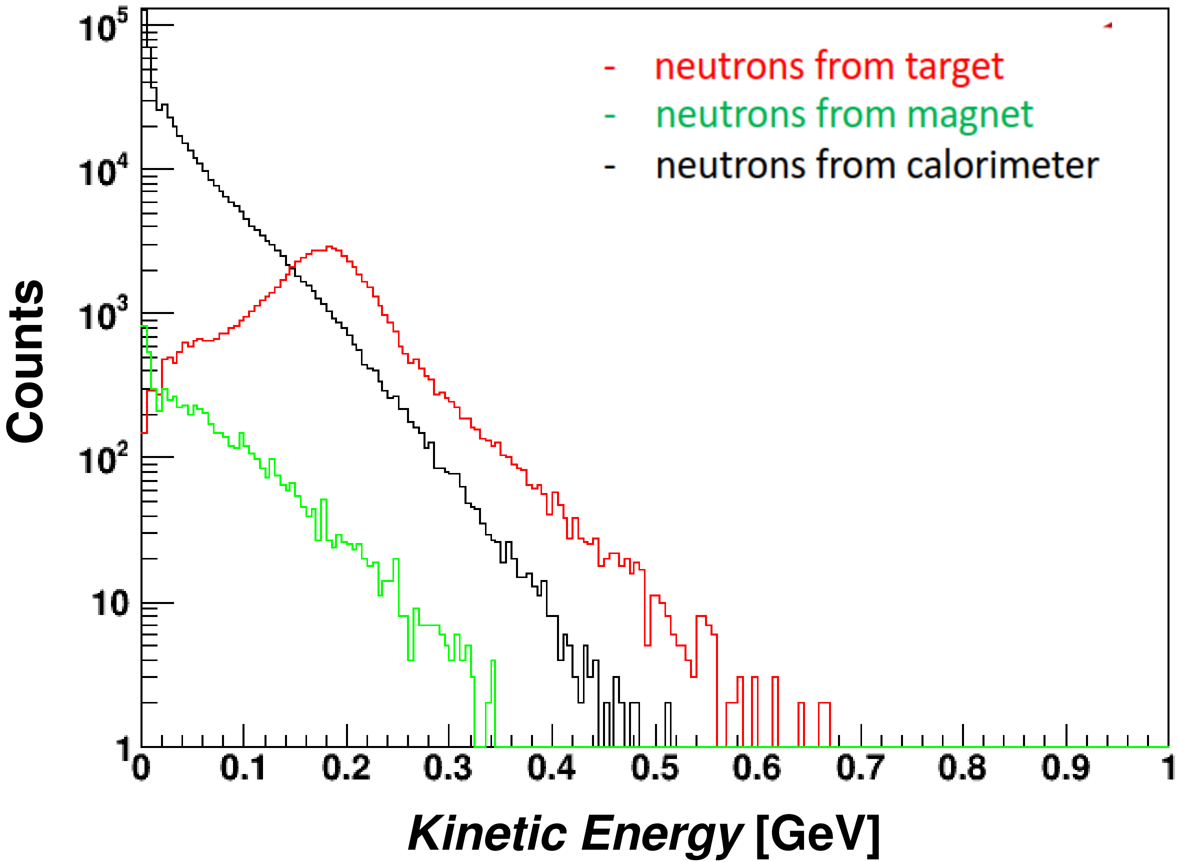

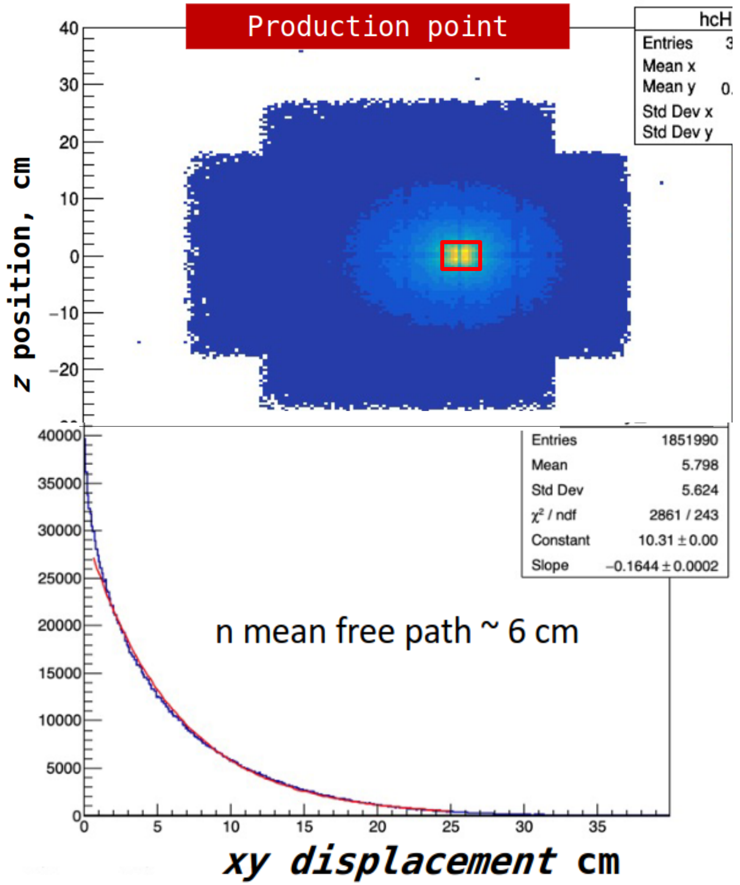

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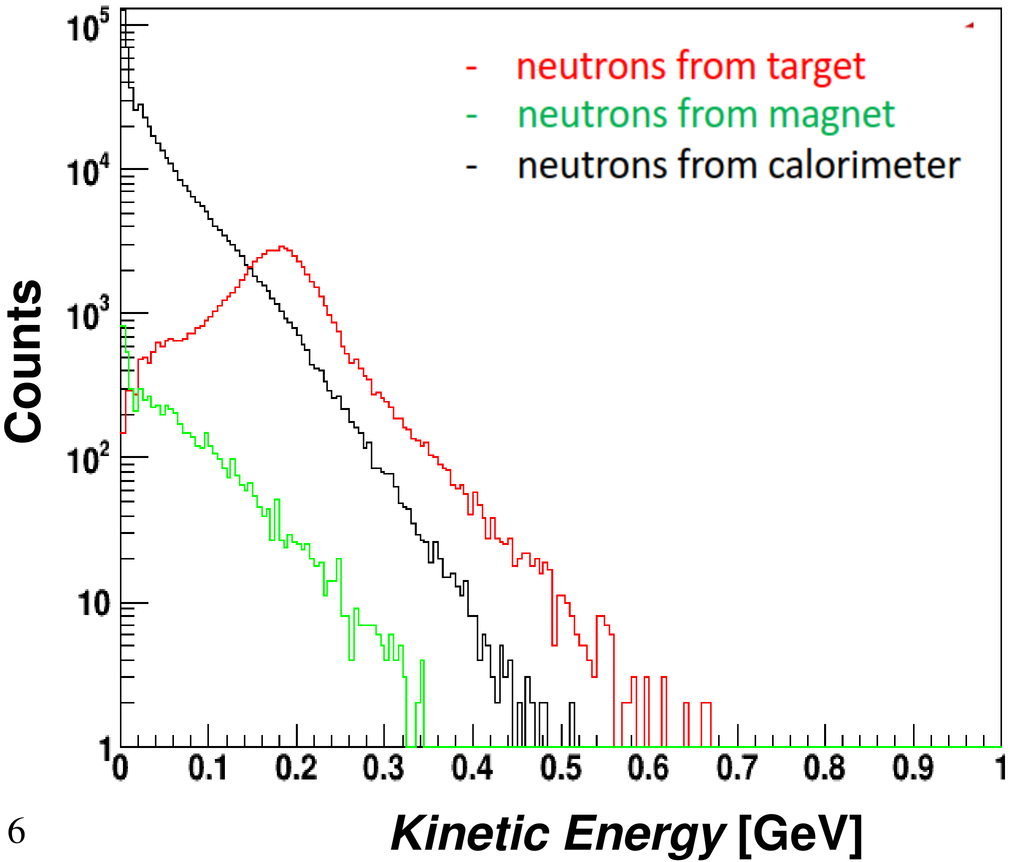

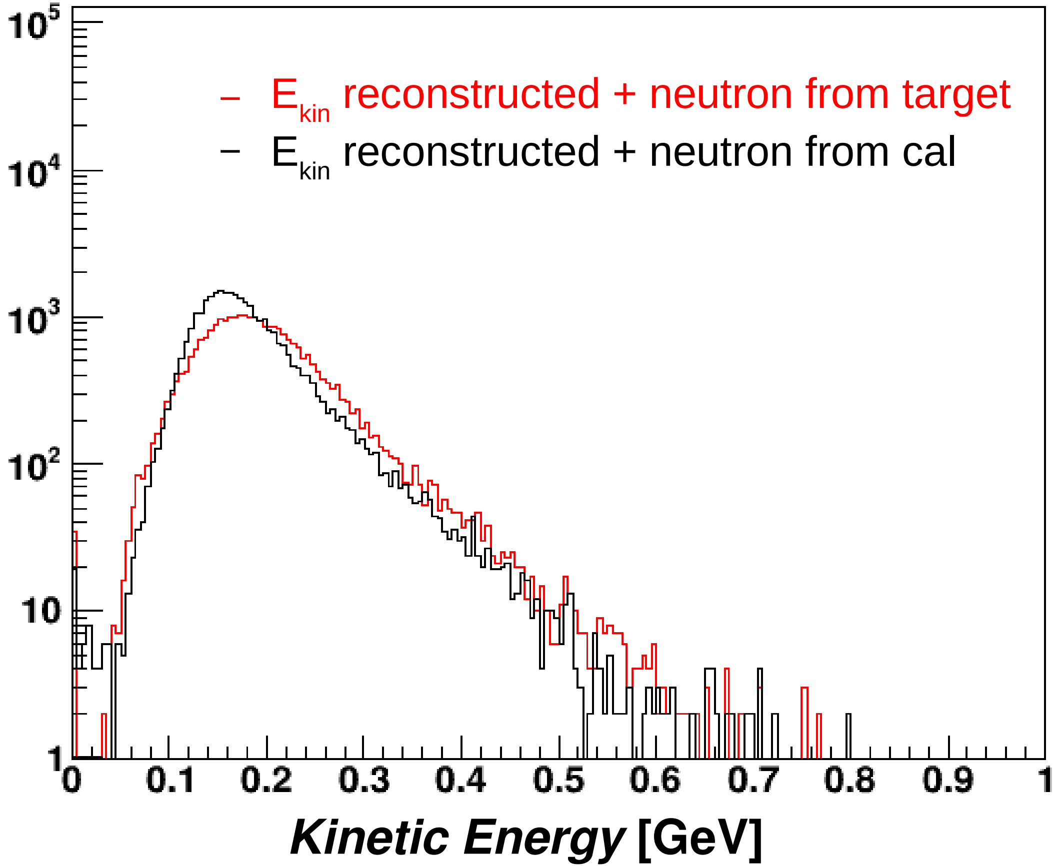

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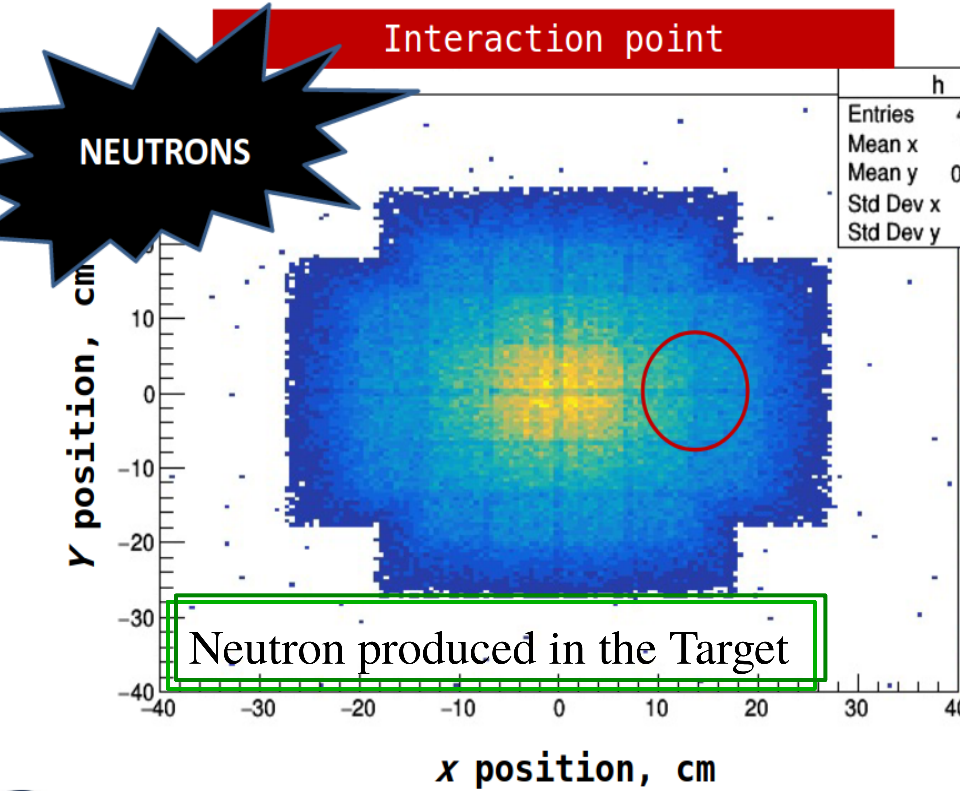

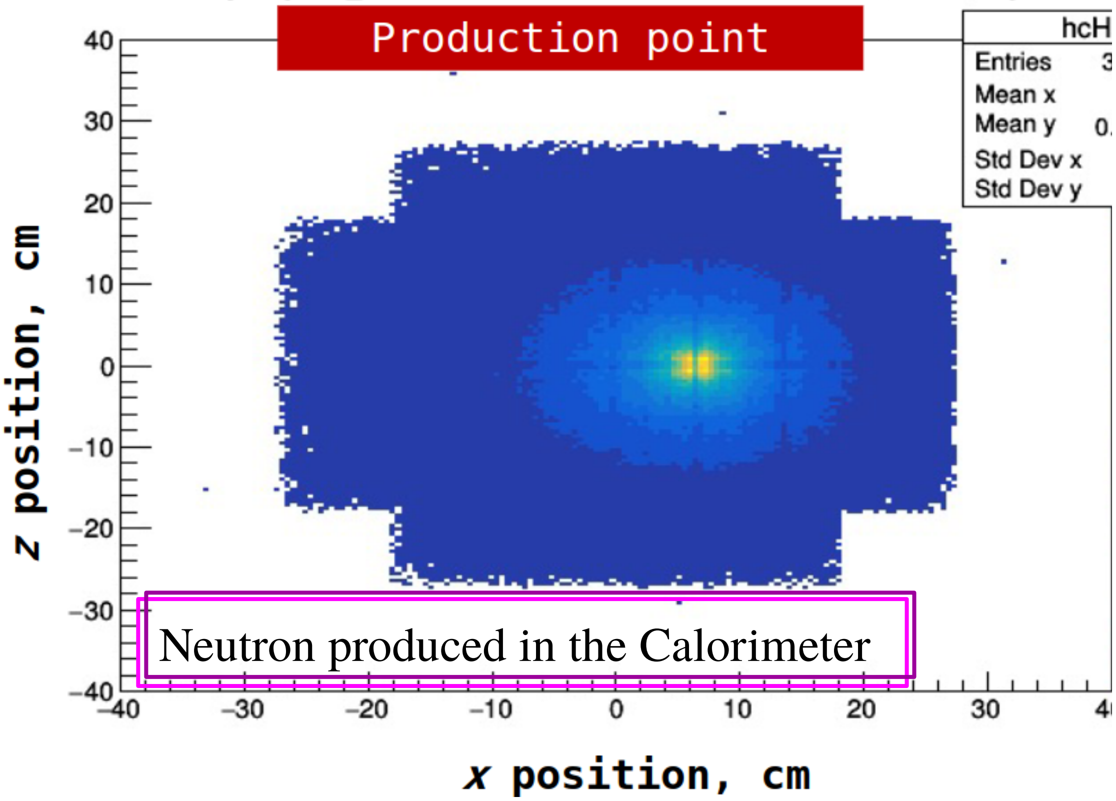

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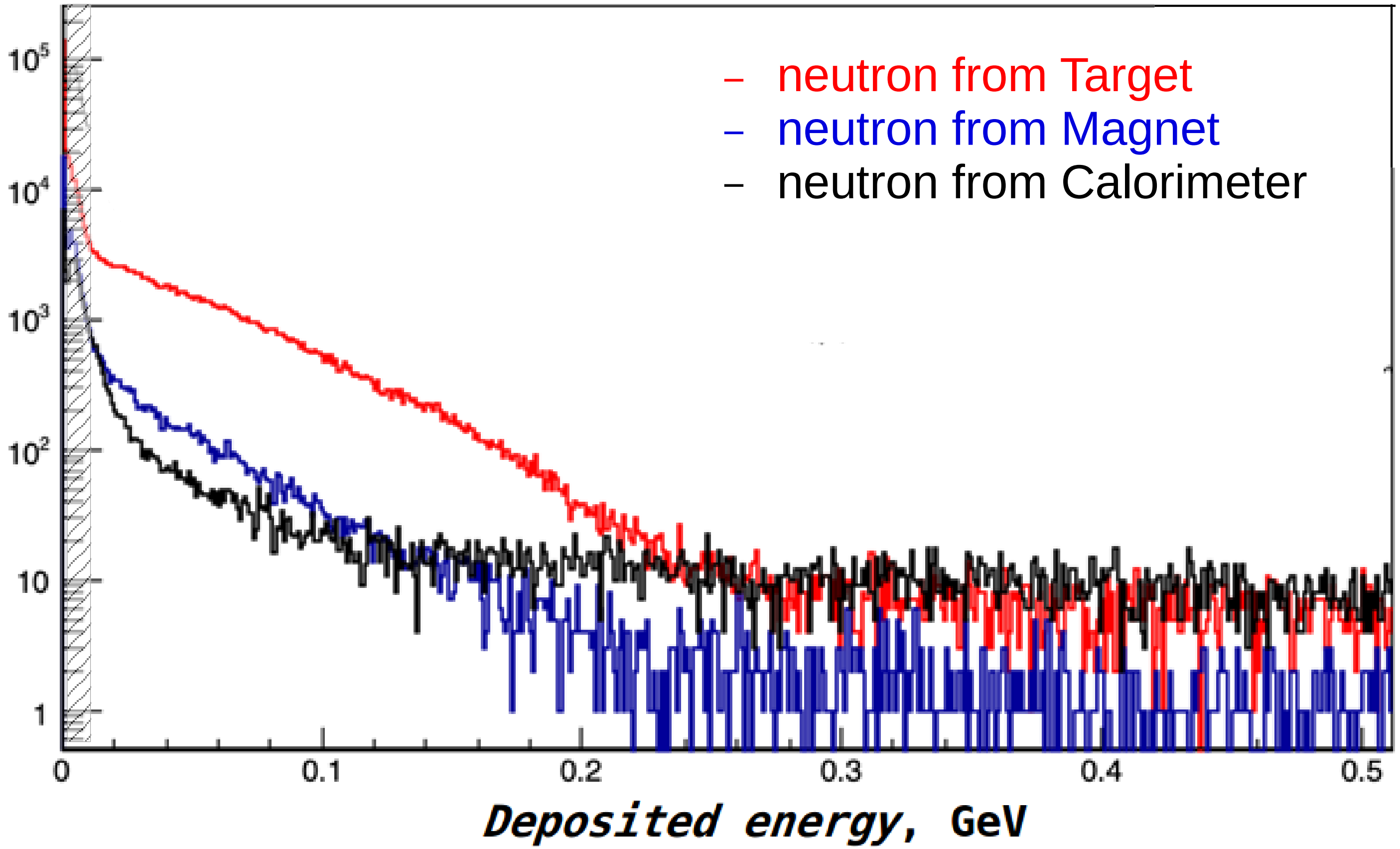


Neutron detectors

Phoswich: BGO crystals + EJ232

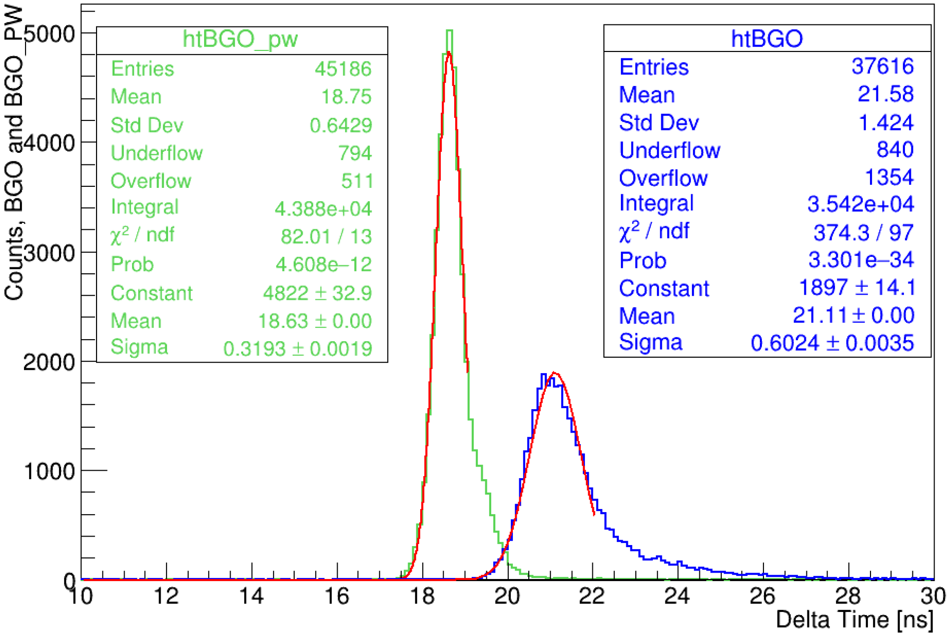
A1: 2.4x2.4 cm^2

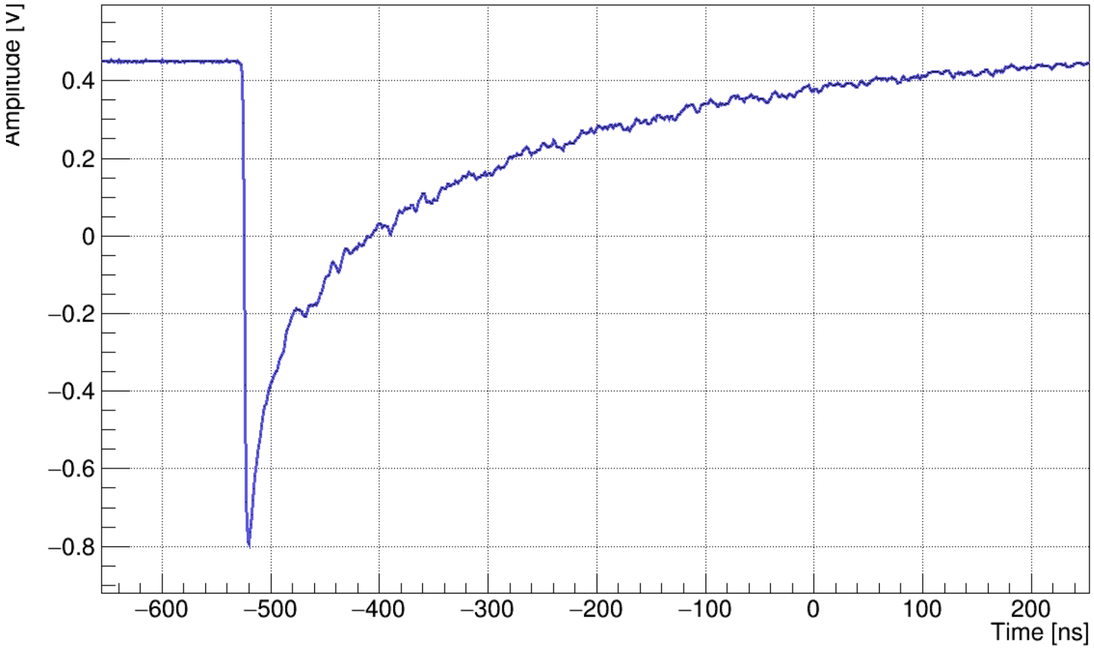
A2: 3.3 x 3.3 cm^2

h: 24 cm

- Particle identification
- Possible Calorimeter upgrade

+ VETO (EJ-204) readout w/ PMT





Neutron detectors

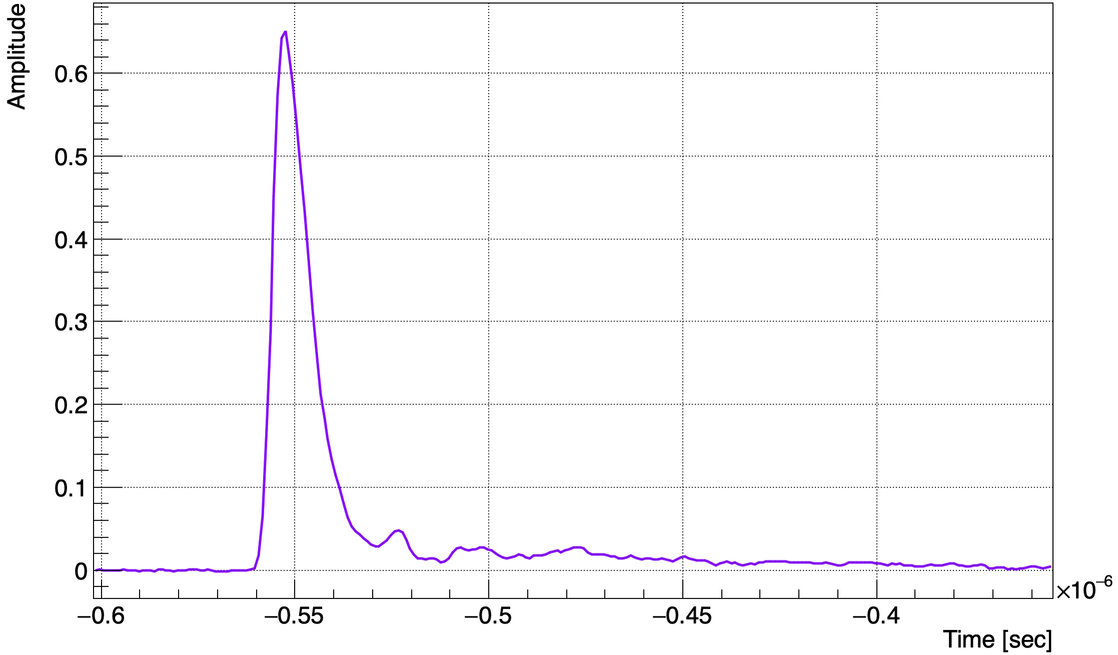
Nike - NE213/BC-501A → liquid scintillator:

- Good time resolution (~3ns RT)
- n/γ discrimination
- Decay Time components 3.16, 32.3 & 270 ns

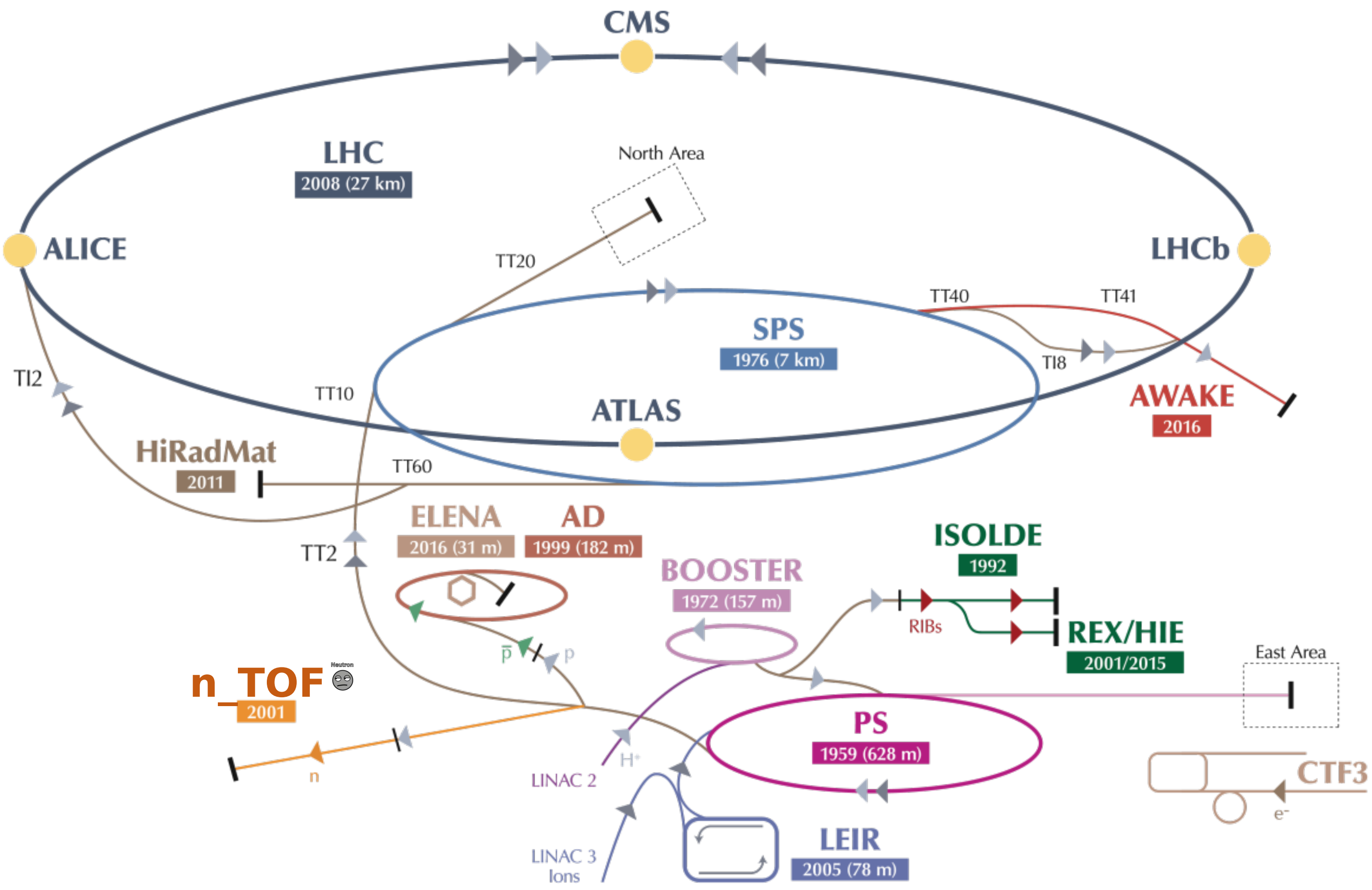
h = 3”
7.62 cm

diametro=3”
7.62 cm

+ VETO (EJ-200)
readout by SiPMs



n_TOF @ CERN



Proton beam

20 GeV/c p from PS

7 ns bunch length

Min. 1.2s btw bunches

Neutron flux @ n_TOF

High neutron flux

$7x10^{12}$ p → 10^{15} n

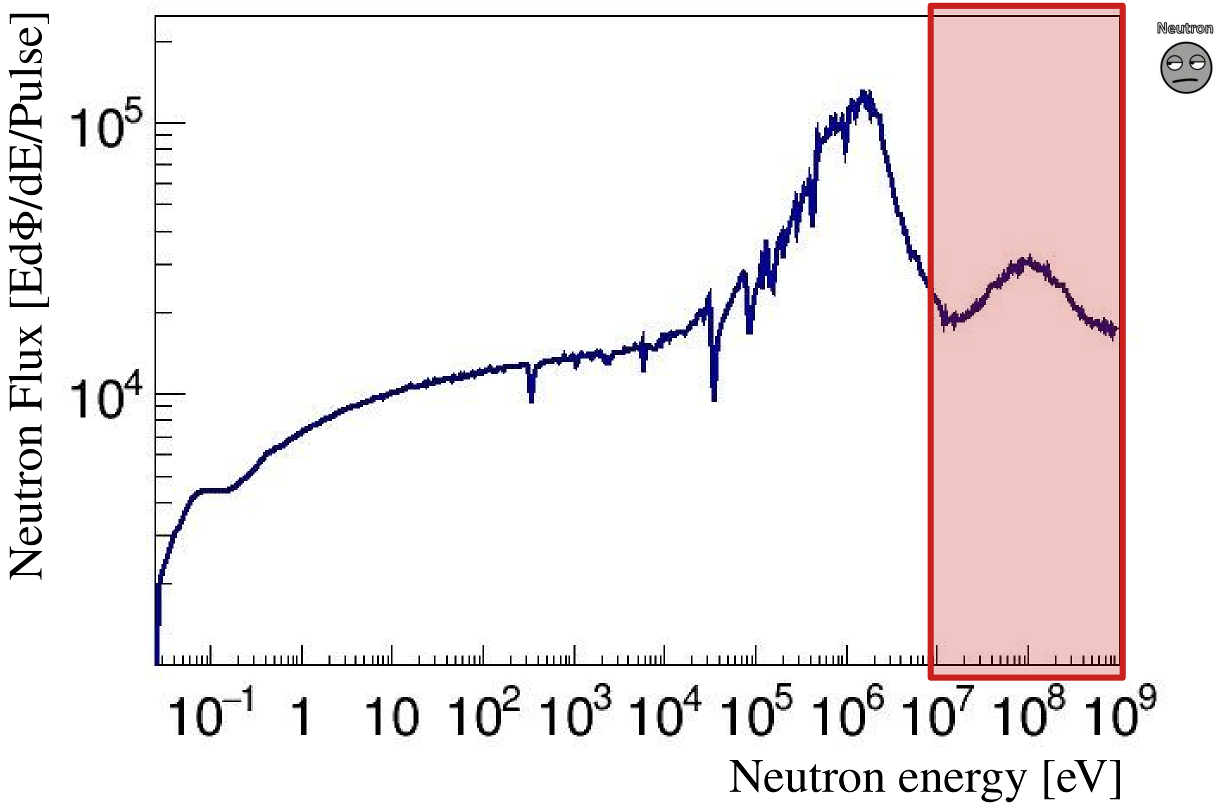
Wide energy range

Thermal – up to 1 GeV

High energy resolution → TOF

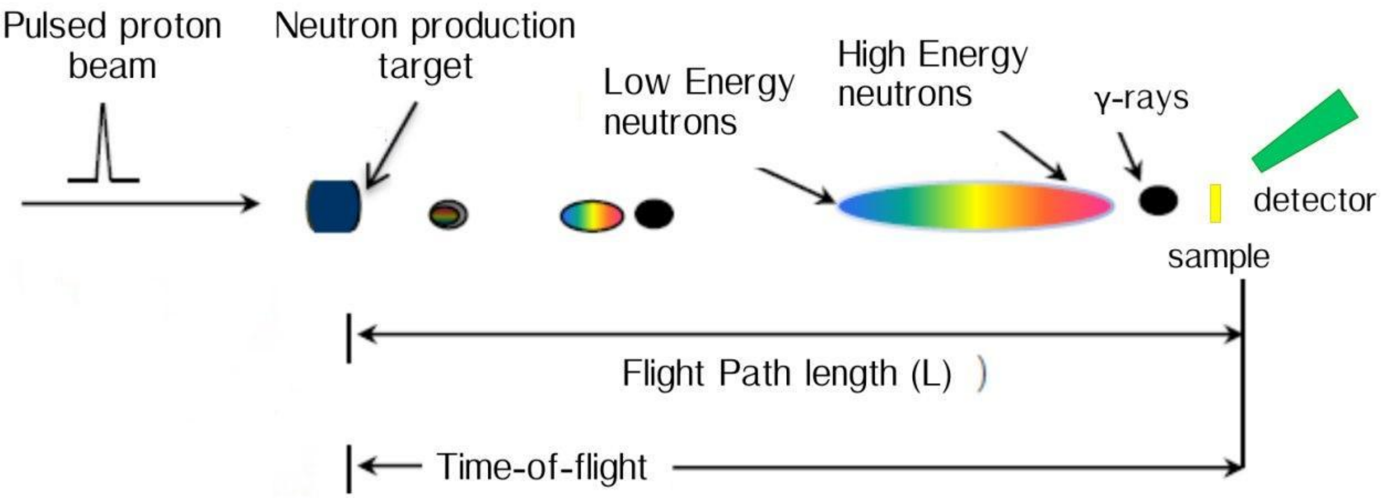
EAR1 →185 m flight path

ΔE/E 10^{-5} - 10^{-3}



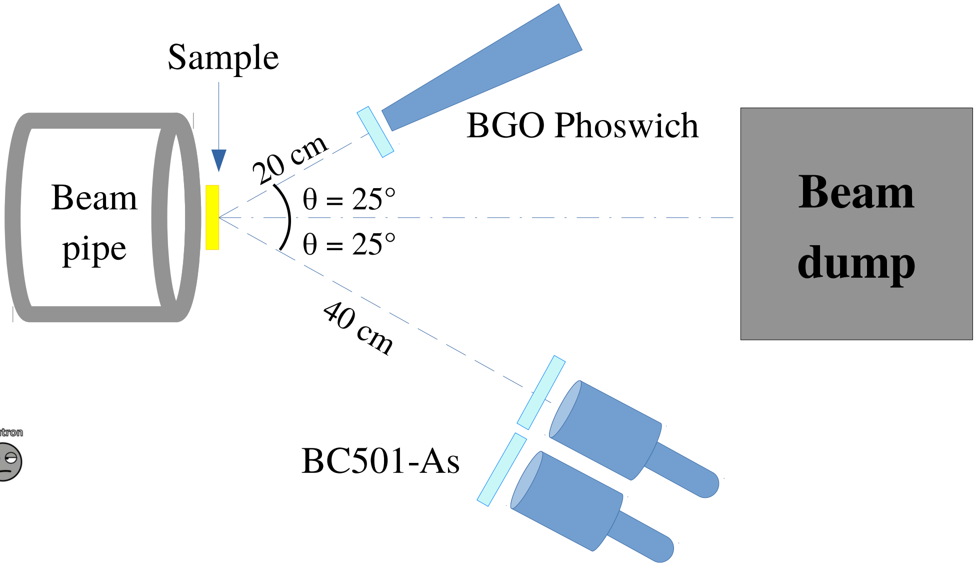
TOF - Energy conversion

Energy (MeV)	TOF(μs)
1	13.8
10	3.94
50	1.46
100	0.89
150	0.65
200	0.51
250	0.42
300	0.36
400	0.27
500	0.21
1000	0.10

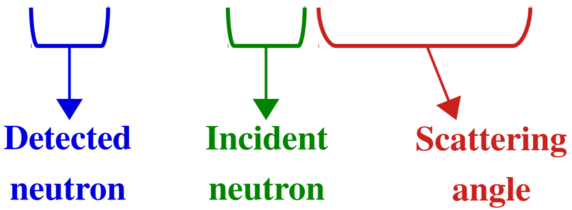


Detector characterization in NEL of EAR1

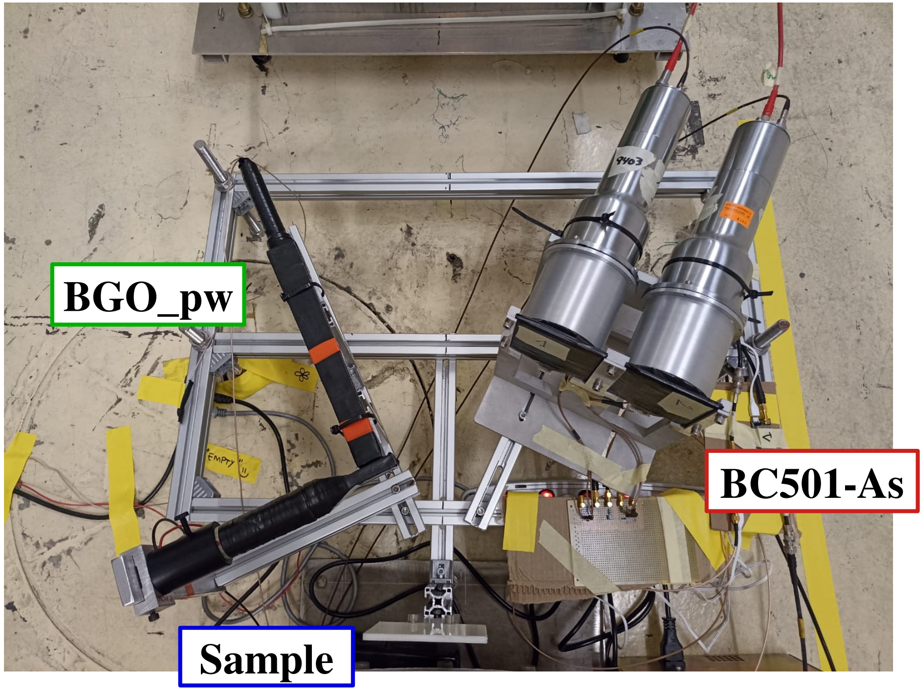
Detection efficiency for high energy neutrons (> 1 MeV)



$$E_n = E'_n cos^2(\theta)$$



Sample	Empty	C_2H_4 2 mm	C_2H_4 5 mm	C 1 mm	C 2 mm
Protons *[x10[18]]*	1.50	1.83	3.33	3.16	1.42



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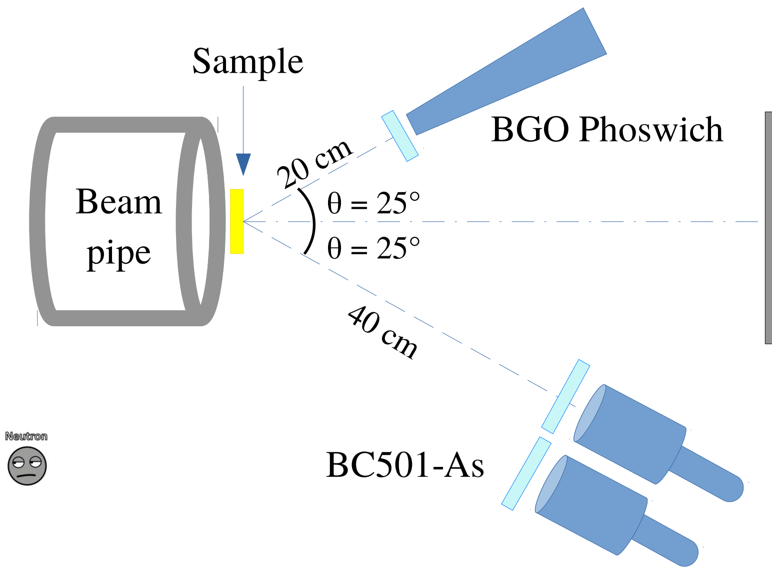

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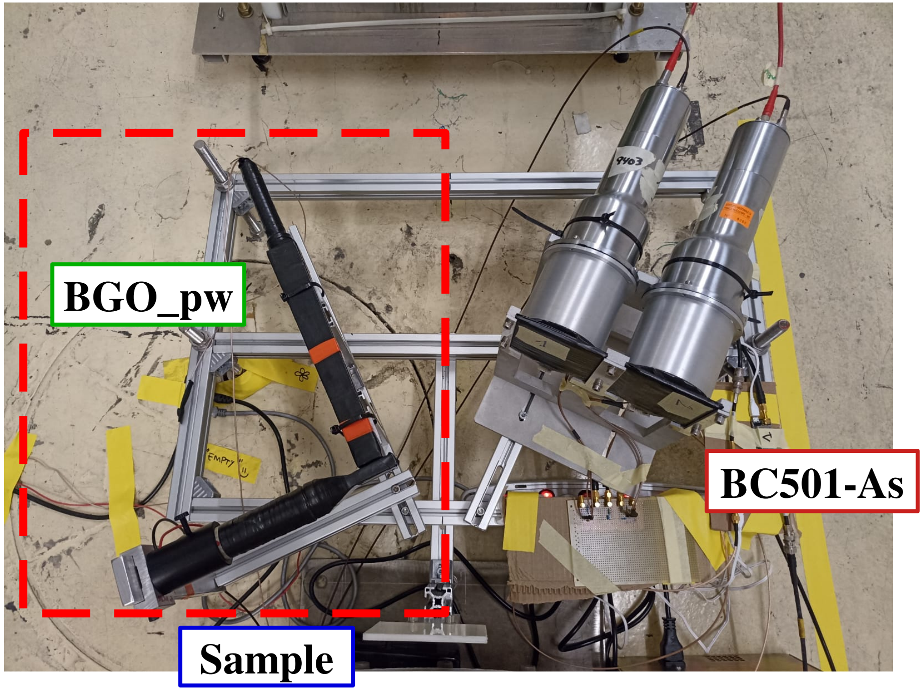
Detected neutron — Incident neutron — Scattering angle



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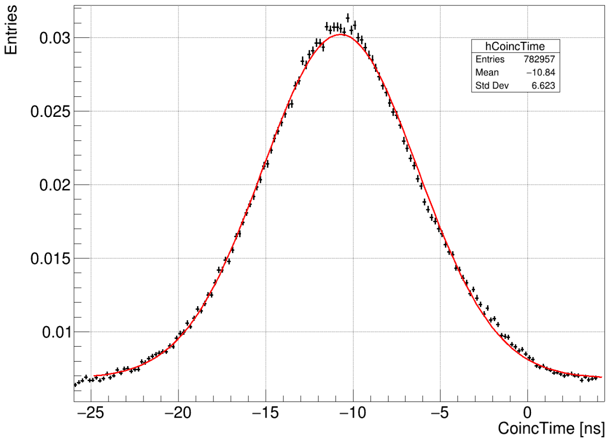
Coincidence analysis

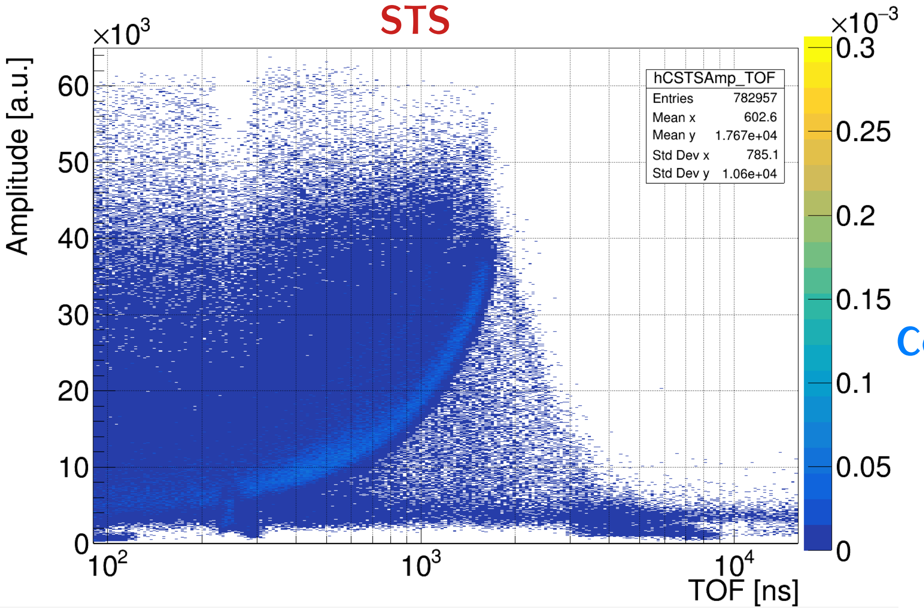
Proton/neutron flux on detector from coincidence/anticoincidence events

→ Identify the coincidence time window

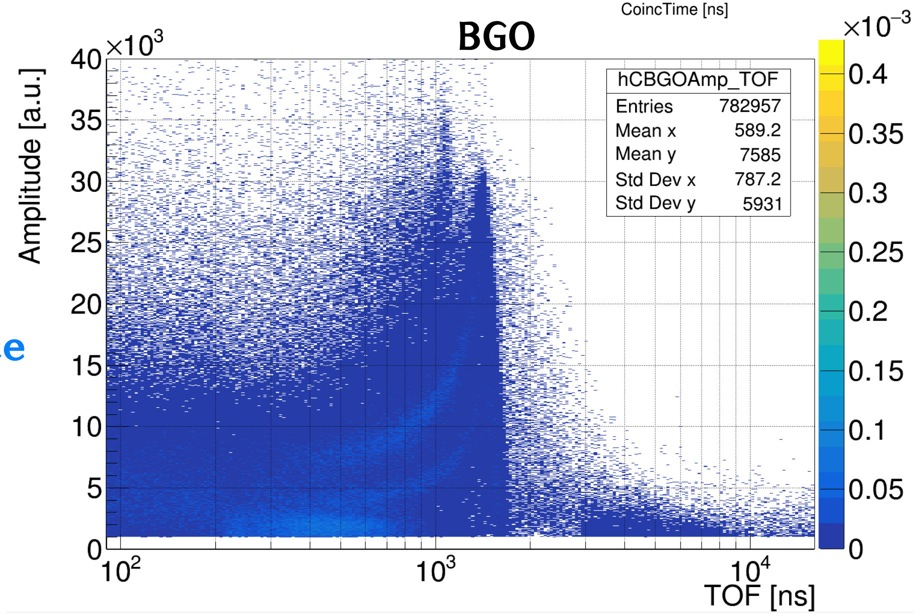
$\sigma(\Delta T_{STS\text{-}BGO}) = 4.5$ ns

→ Coincidence time window set to = ± 15 ns





Coincidence events



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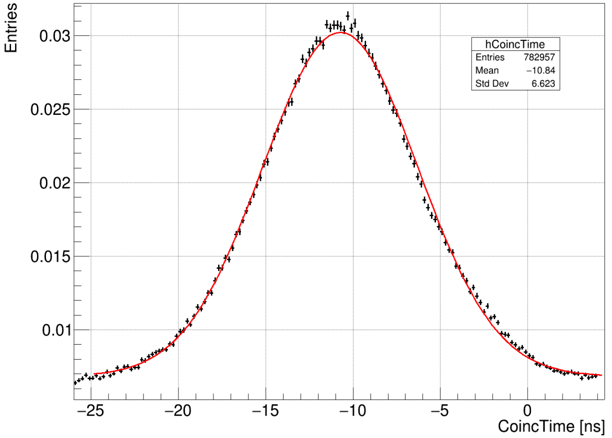

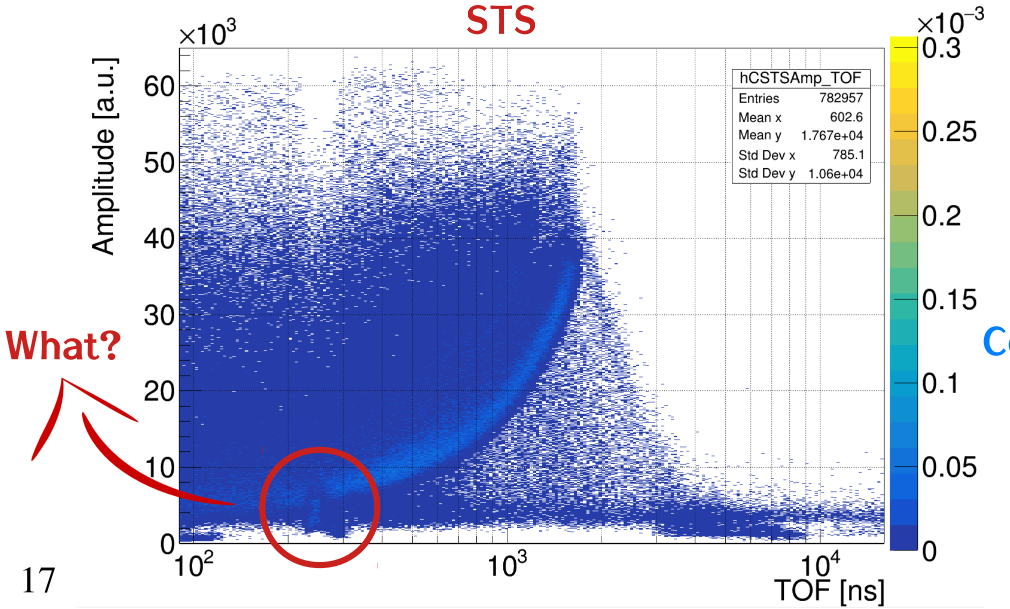

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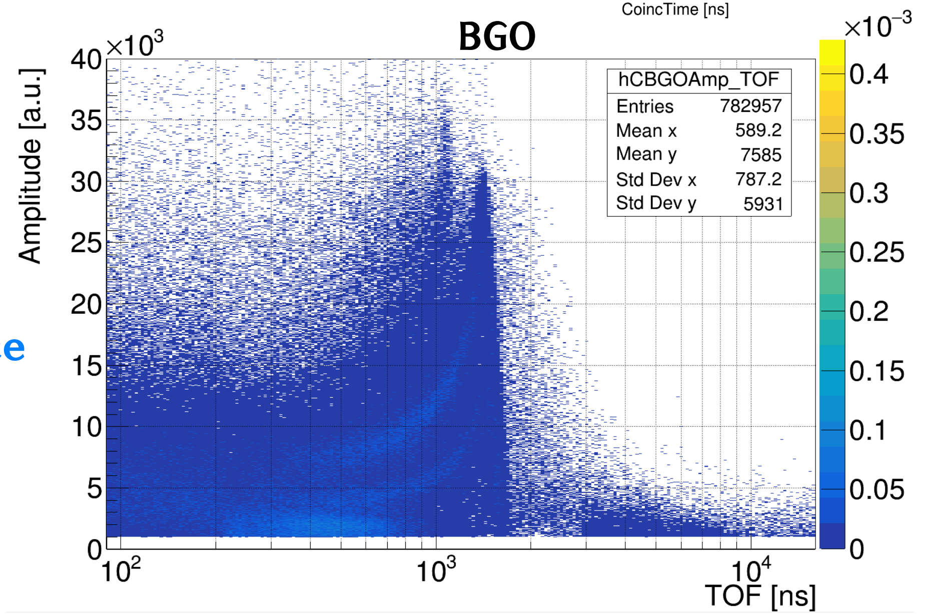
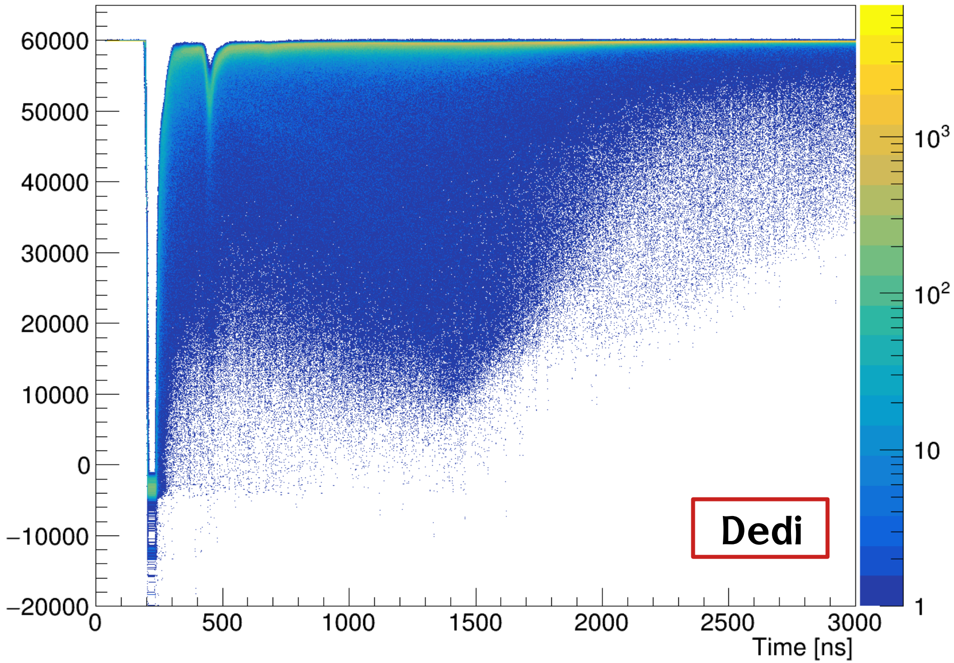
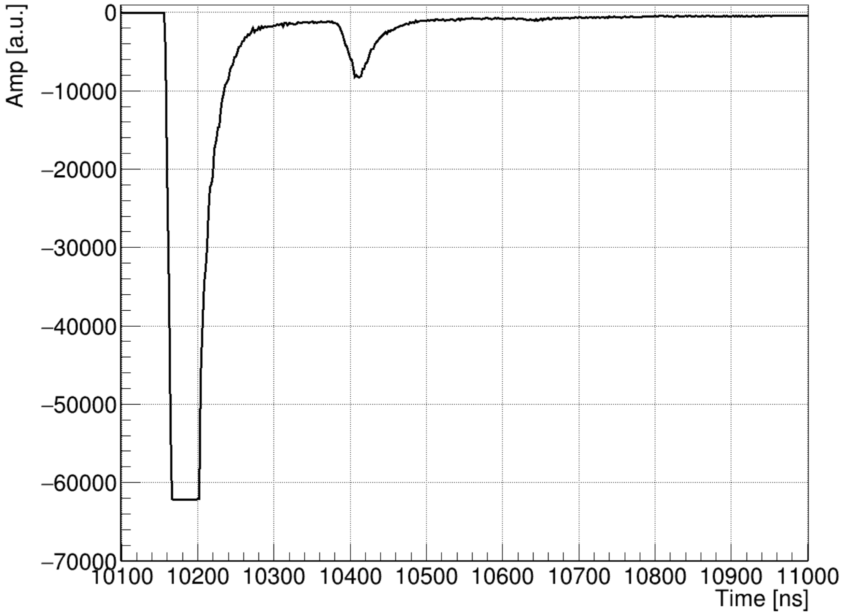


STS PMT after-pulse

Look at the γ-flash shape for the STS

- Sum of 1st movie for each event
- Normalize signals to pulse intensity
- **PMT after-pulse at fixed time after γ-flash!**

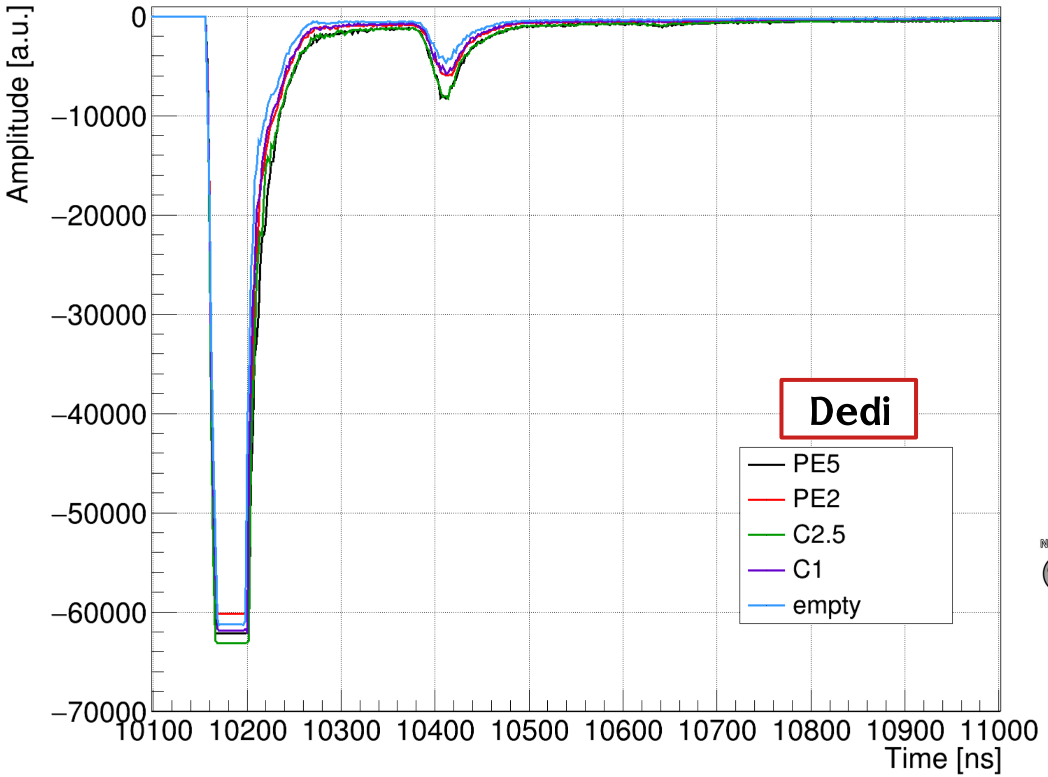


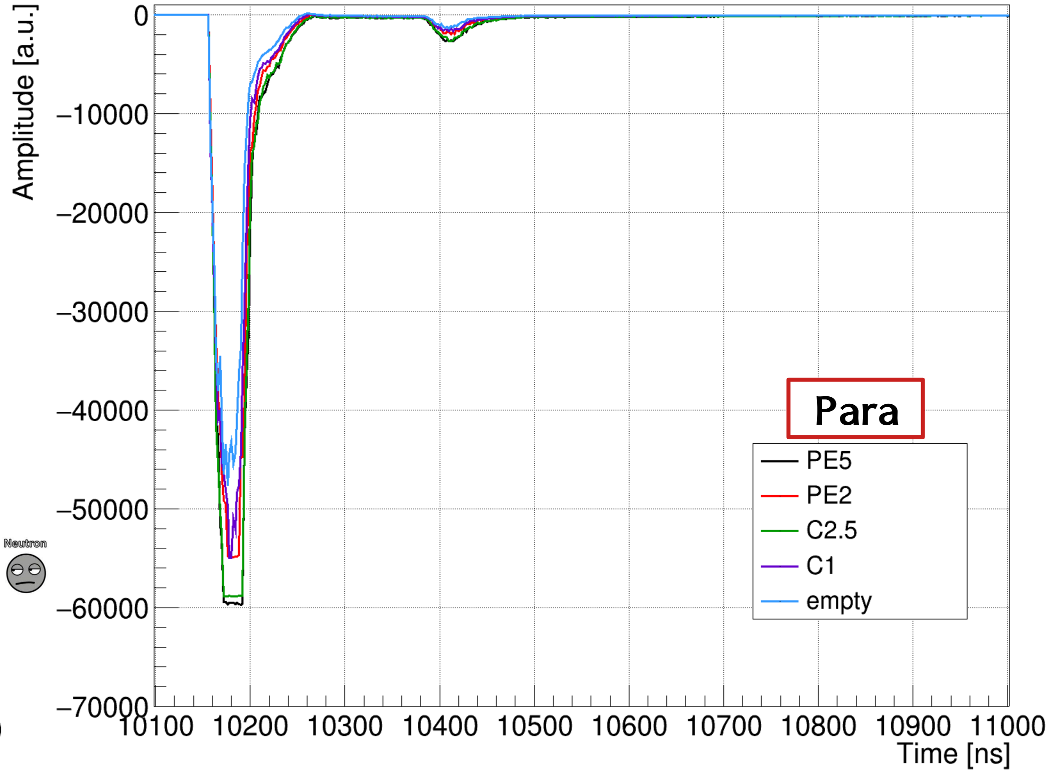


- **Extract γ-flash shape!**
- Use it for baseline subtraction in PSA

STS PMT after-pulse

Check if after-pulse shape is the same for all in-beam samples → ***Not really, but...***





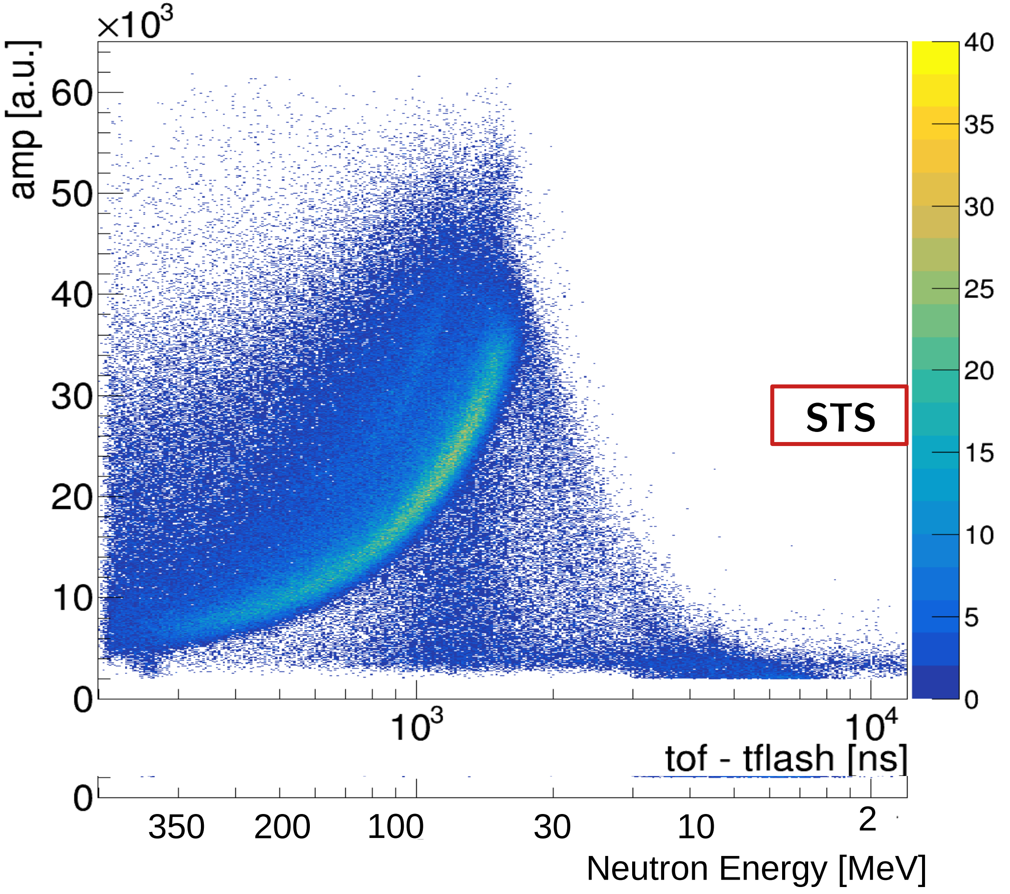
Pulse shapes compatible for samples with the same mass thickness (PE5-C2.5, PE2-C1)

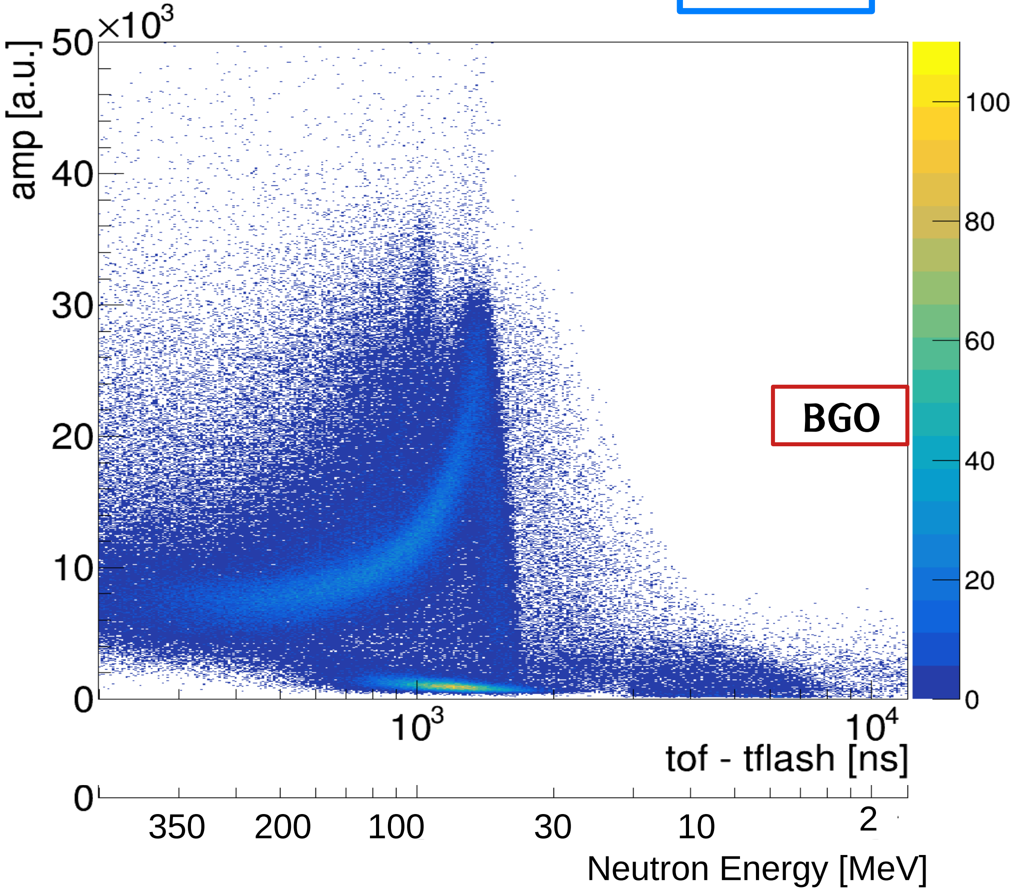
→ 6 different g-flash instead of 10!

Coincidence analysis

Using new PSA in the baseline reconstruction → **PMT afterpulse gone!**

PE 5mm

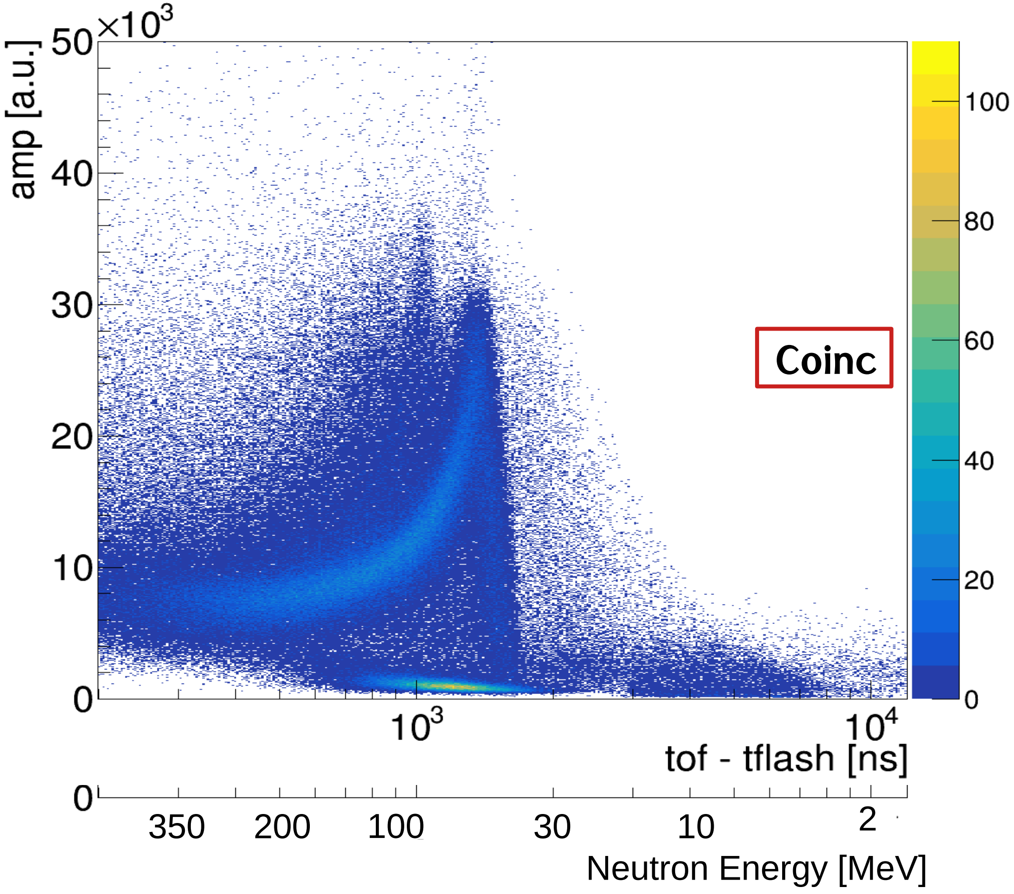


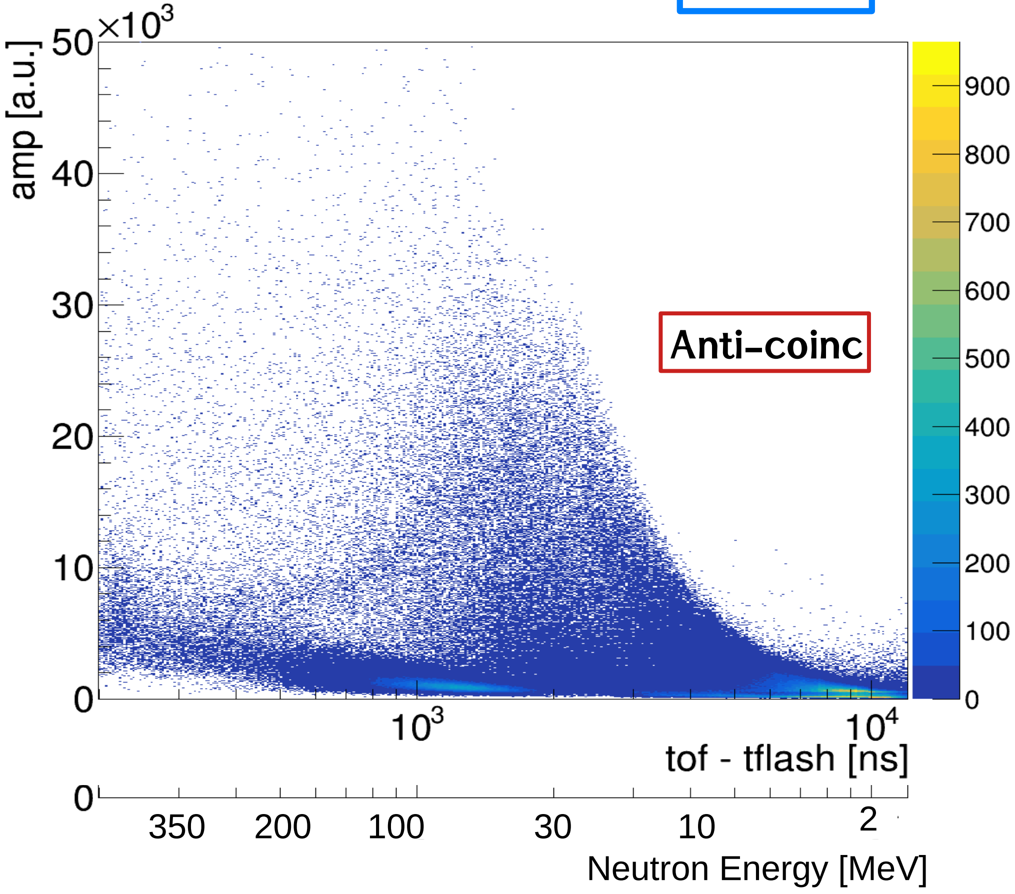


BGO coincidence vs anti-coincidence

PE 5mm

Compare coincidence and anti-coincidence events in BGO





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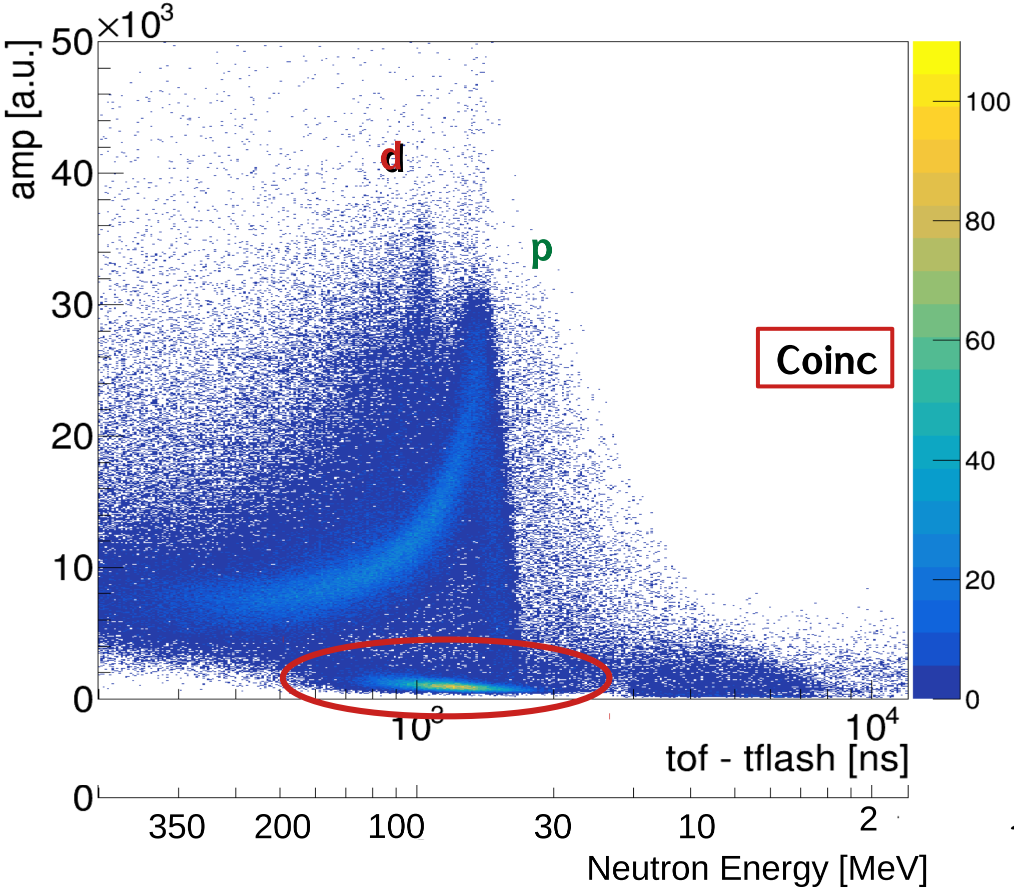
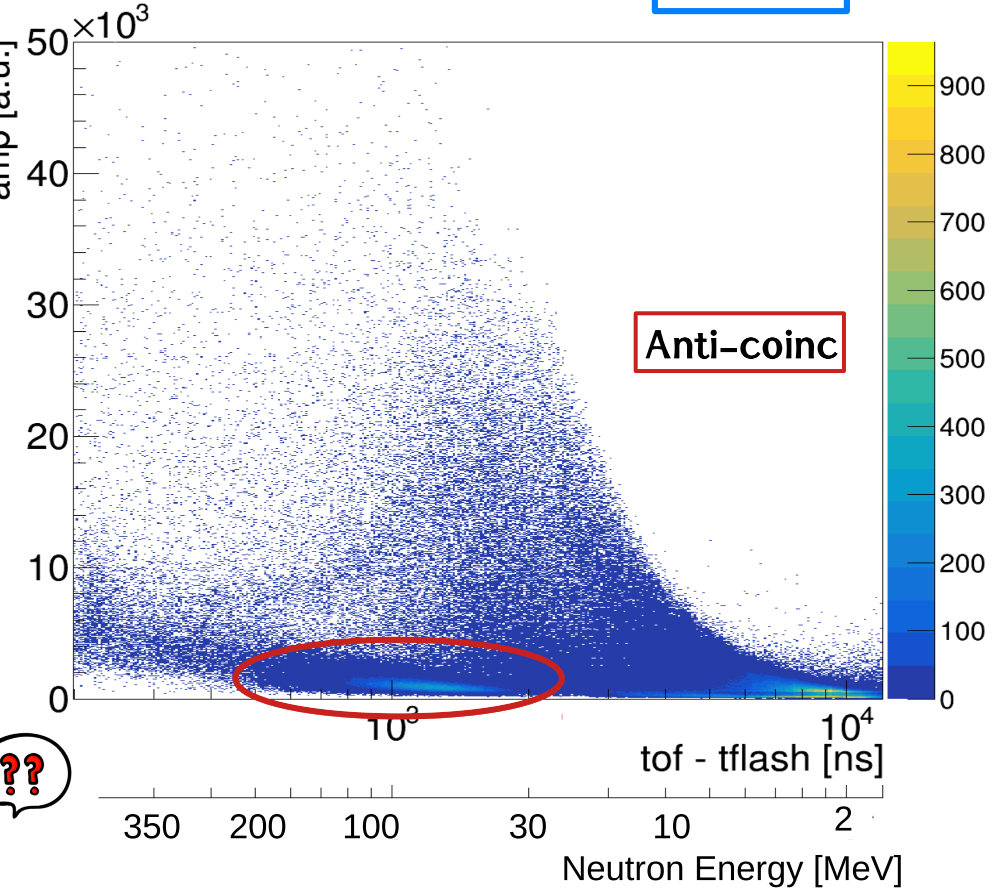
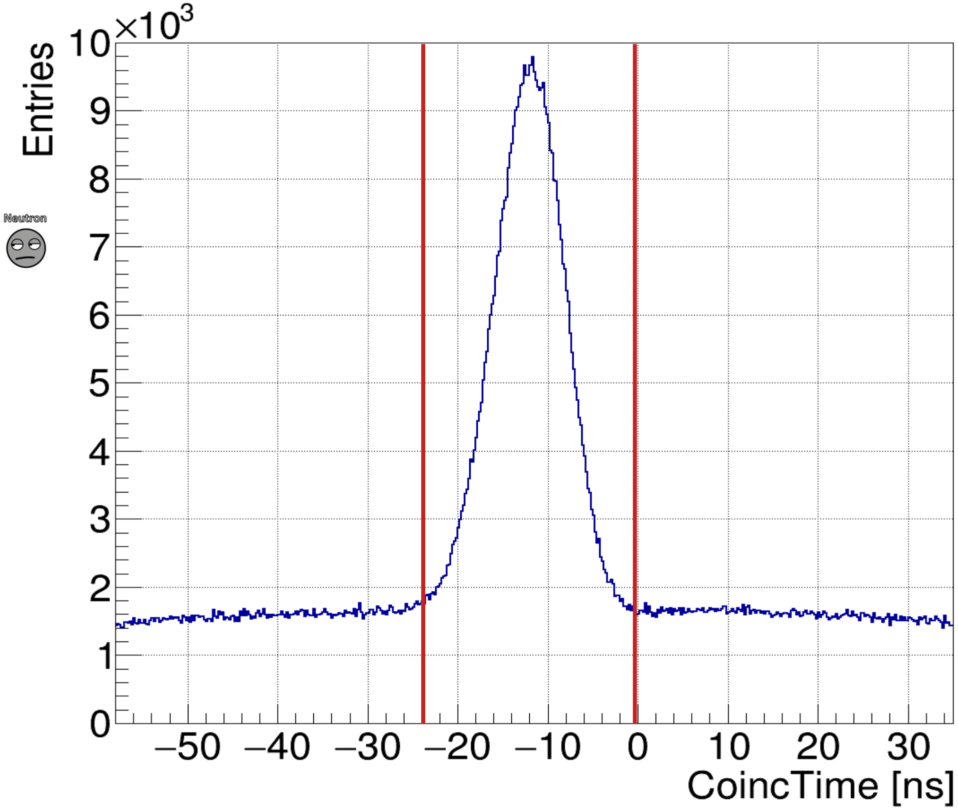
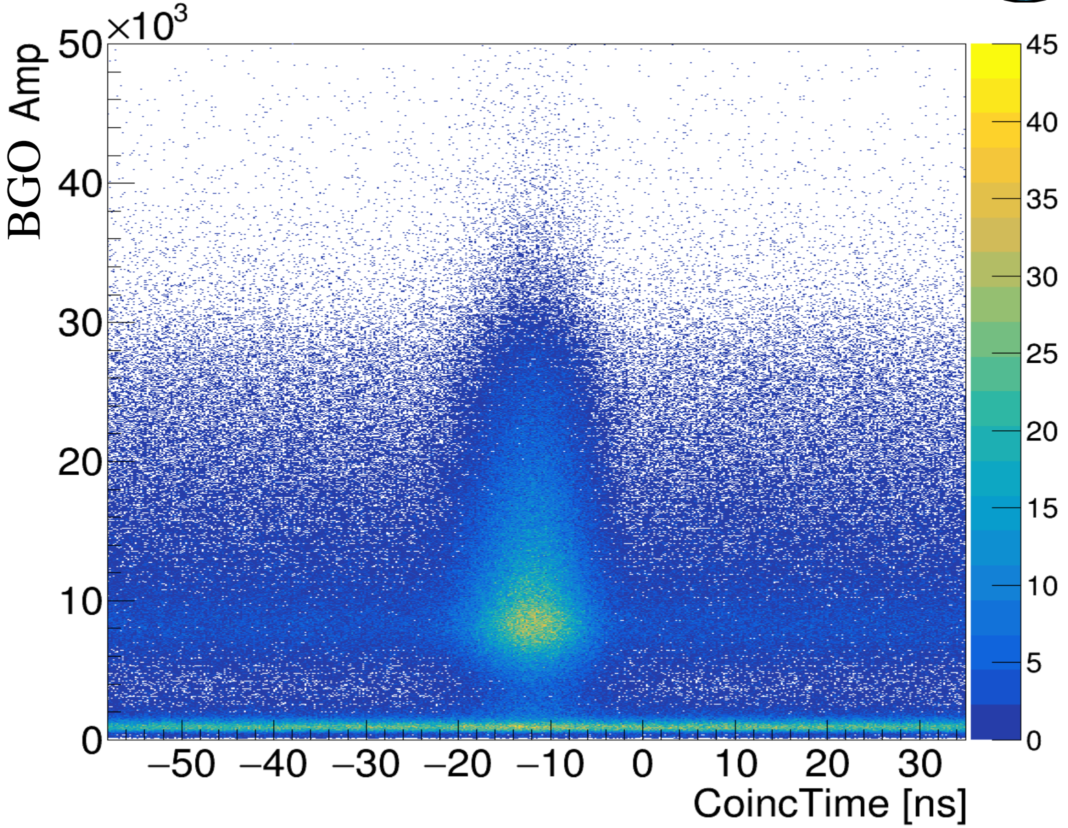




STS-BGO coincidence time window





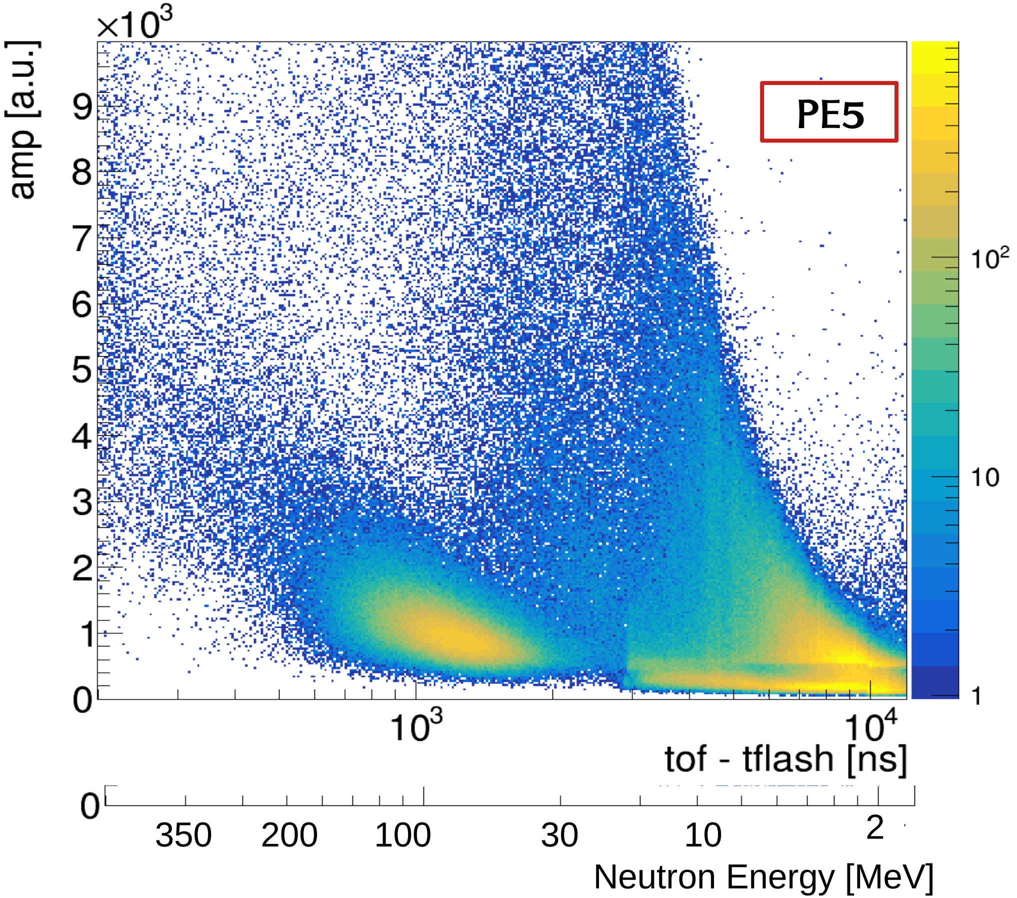
Uniform background of **random coincidence** events

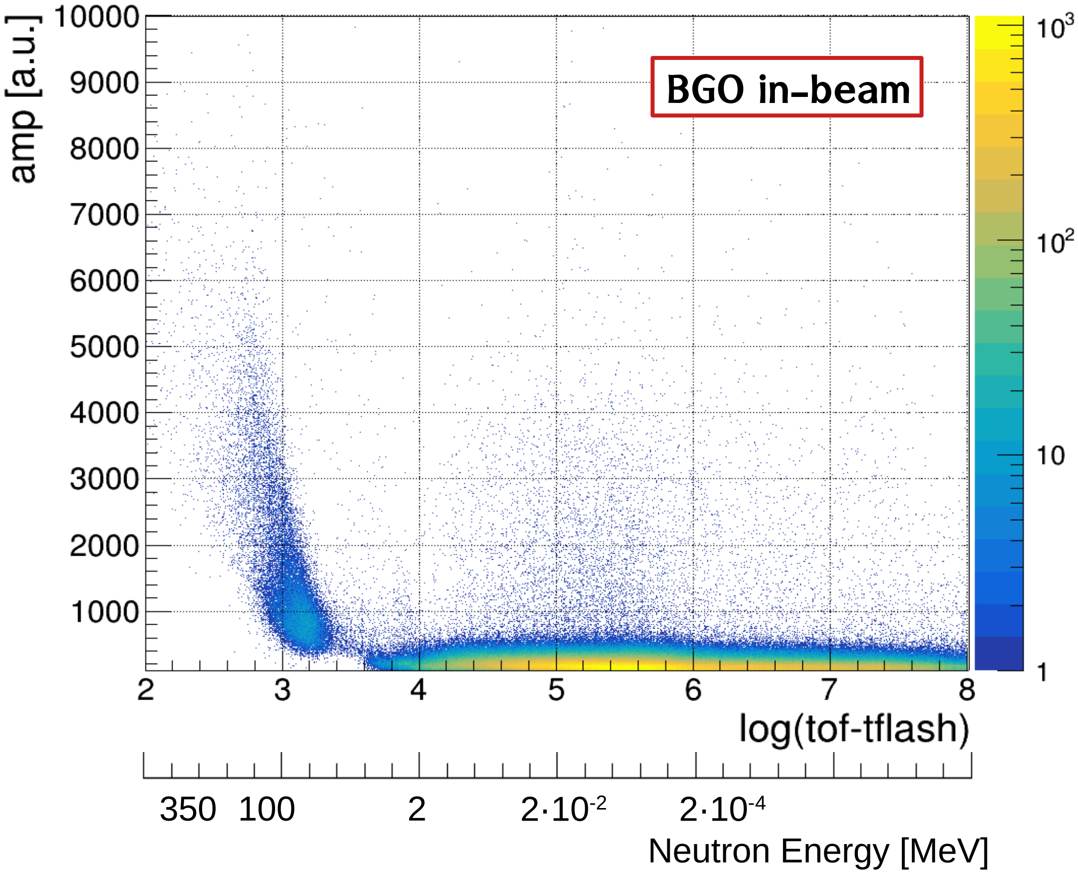
→ Higher geometrical acceptance of STS

→ (n,cp) in the PE sample where particle "dies" in the STS

BGO in beam response

Compare response of BGO w/ PE sample and directly in beam





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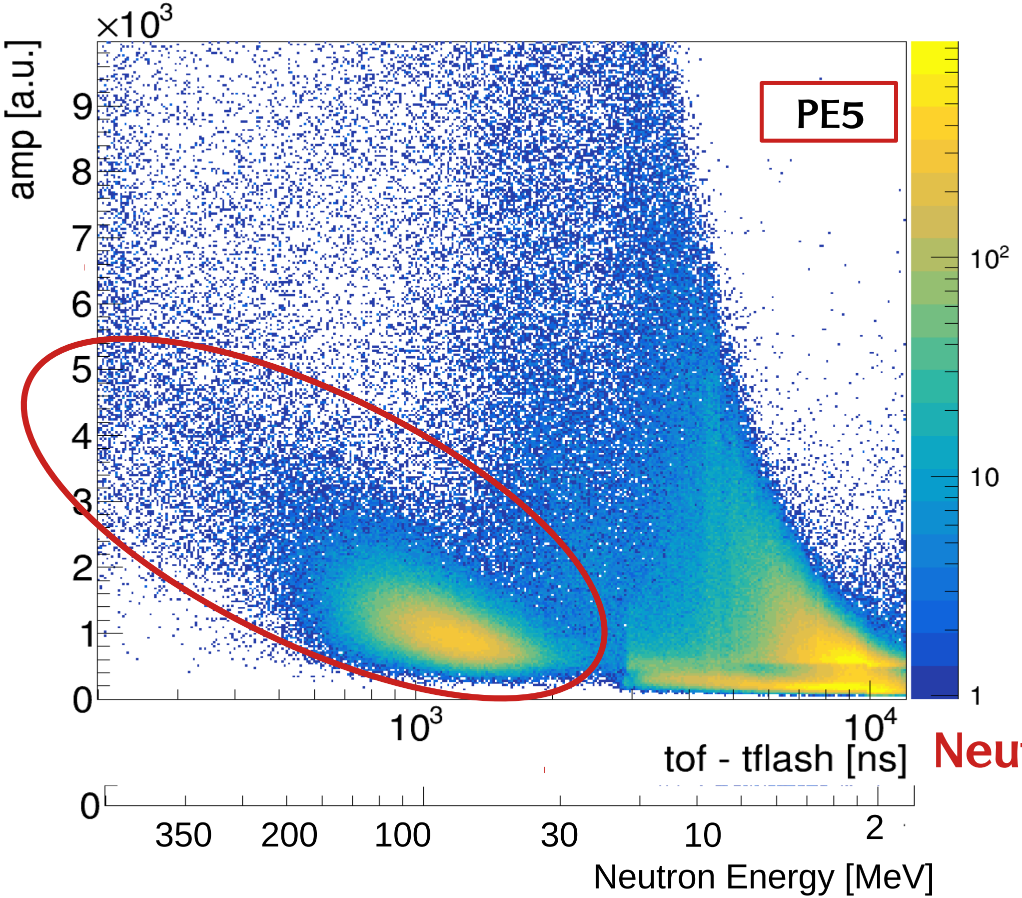
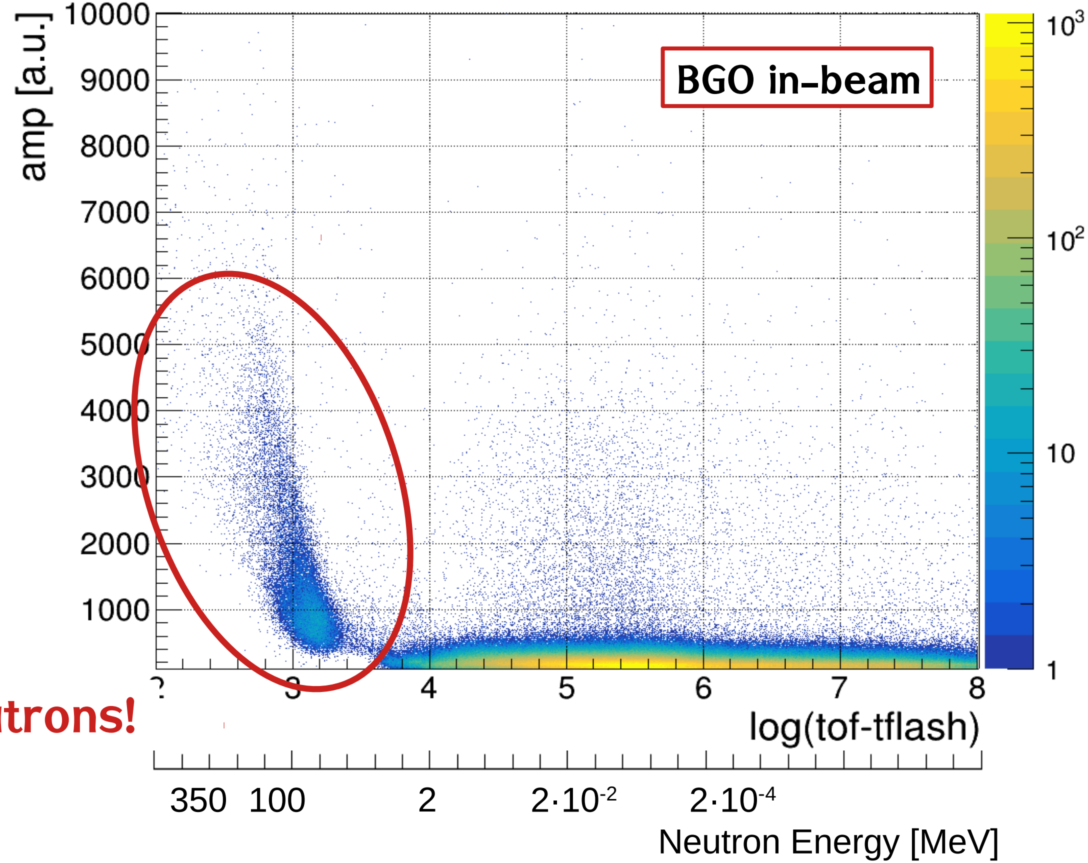


Neutrons!



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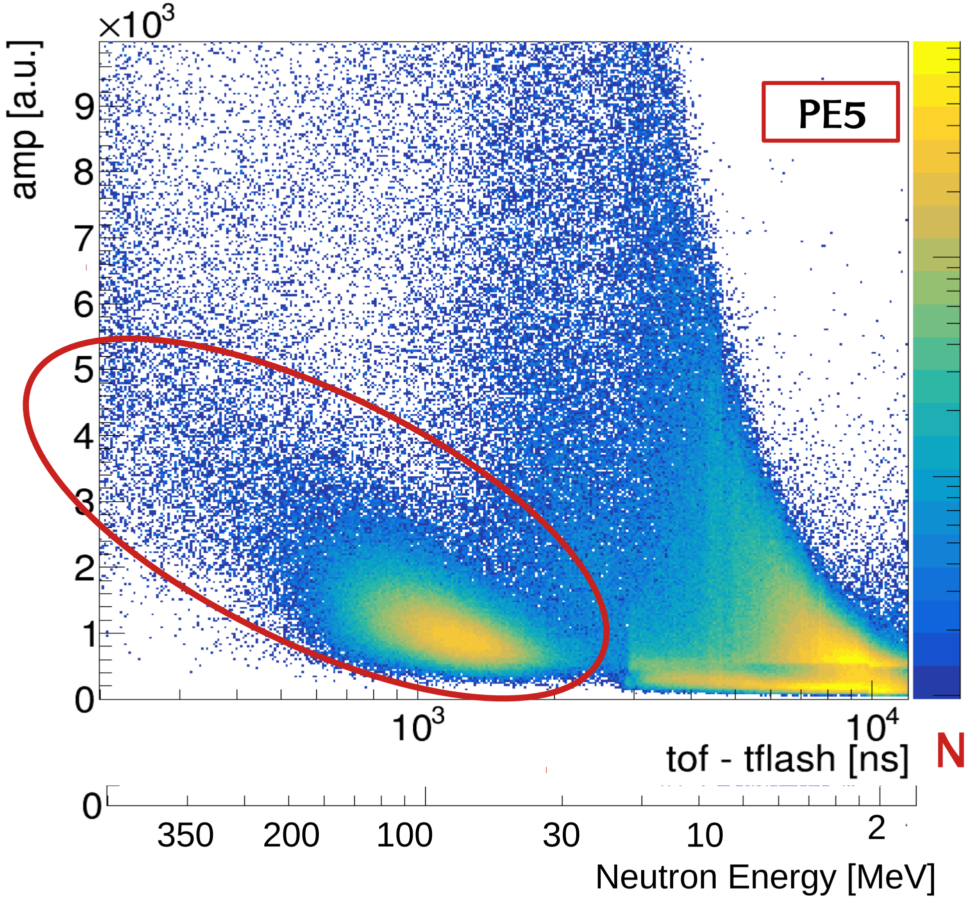

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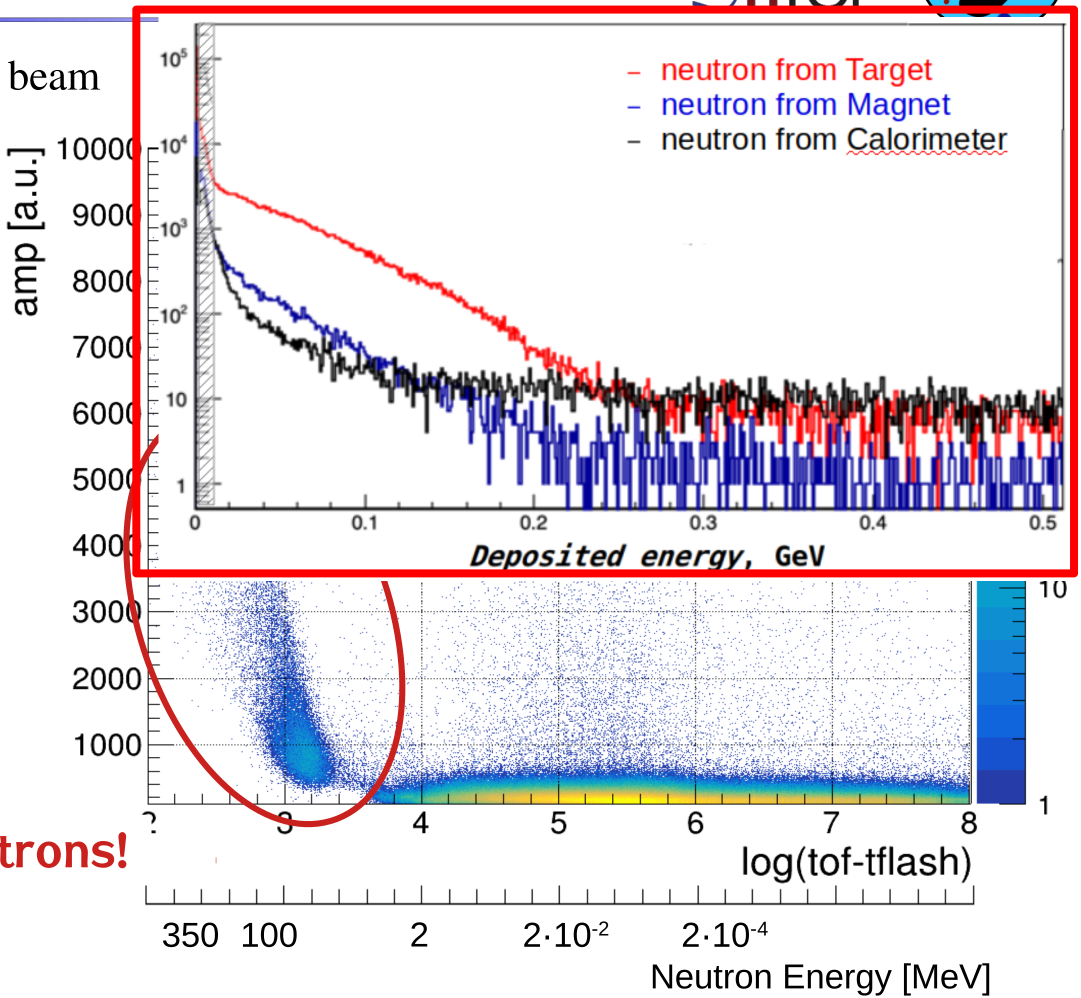


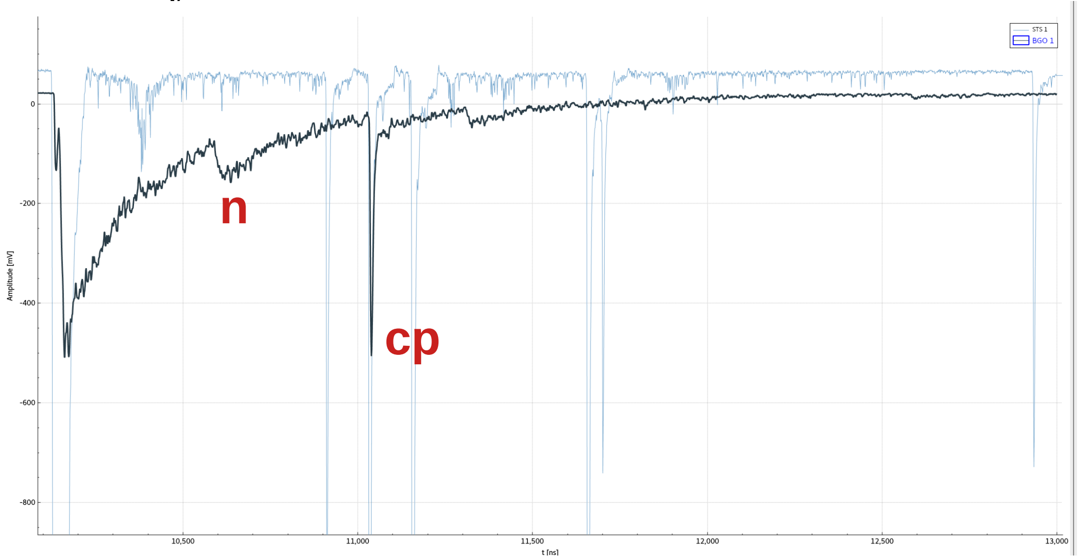
Conclusions

BGO-STS system currently being studied

- ✔ Corrected PMT after-pulse in STS through γ-flash shape fit
- ✔ Identified neutron events in BGO

In progress:

- ✷ *Implement area fast/slow → beta version!*



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In progress:

- *Implement area fast/slow → beta version!*

To do:

- Subtract C contribution
- Evaluate neutron detection efficiency, both in-beam and w/ samples
- Repeat the study with new MC simulations

  \+ constraints to identify neutrons from target

Conclusions

Next n_TOF data taking:

What:

use the actual BGO crystal + BGO in phoswich:

compare the general behavior and neutron sensitivity.

How:

- Place directly in beam to have the precise response

  as a function of the neutron energy →

  if lateral to the neutron beam: ε/ρ

  + think if there is a possible way to have the neutron impinging
  head-on the crystal (SiPM/PMT problems???)

  → general efficiency (taking into account also the neutron-mean free path)

  + configuration closer to FOOT without a scatterer/converter

- If not planned in other data taking:

  En-calibration for protons can be performed with PE converter + TOF technique

Conclusions

Next n_TOF data taking:

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compare the general behavior and neutron sensitivity.

How:

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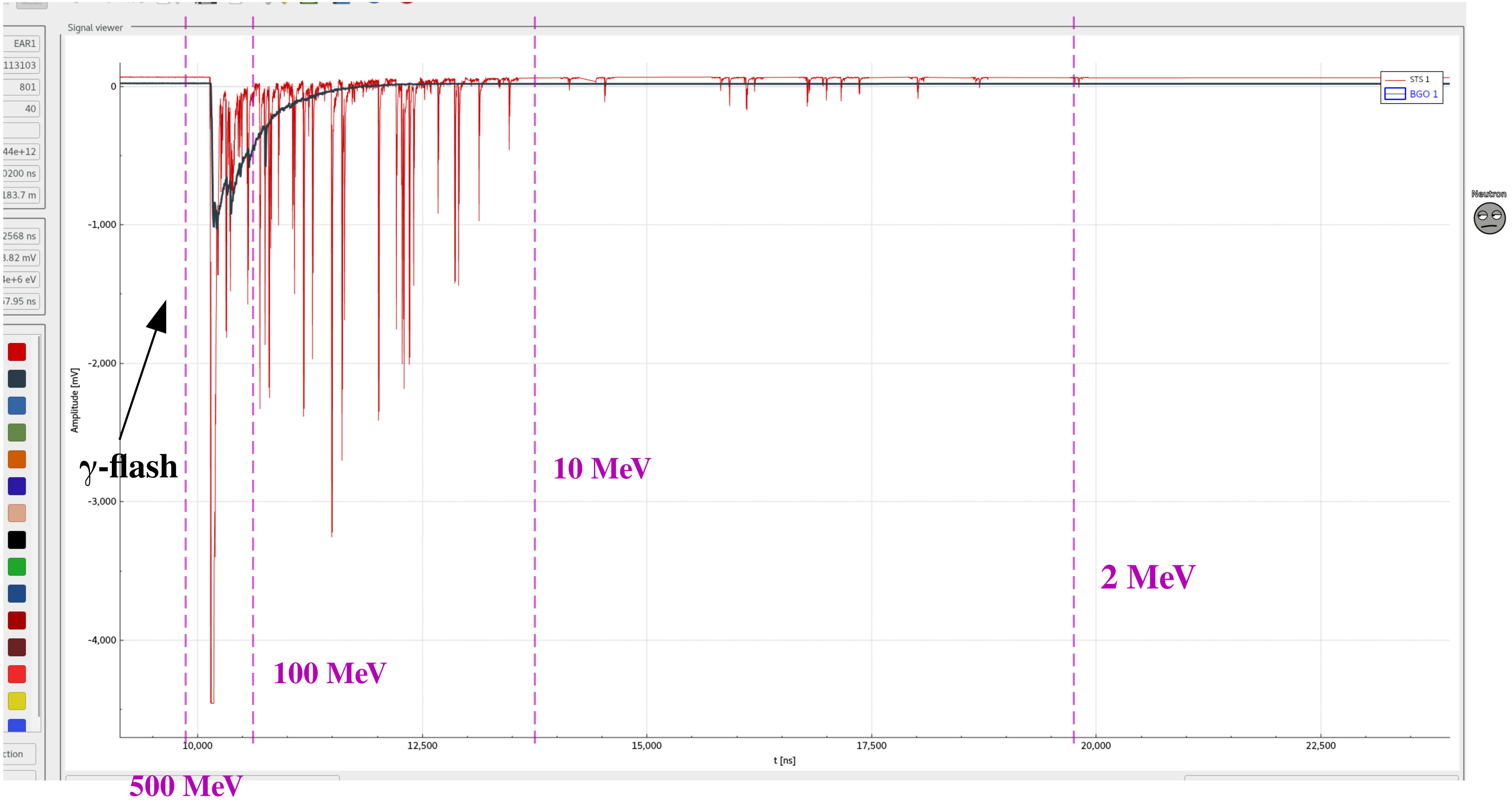
→ general efficiency (taking into account also the neutron-mean free path)
+ configuration closer to FOOT without a scatterer/converter

NB: BGO crystal calibrated (for protons):
in case an En-calibration is needed, it can be performed with PE converter + TOF technique

Thank you for your attention

Backup slides

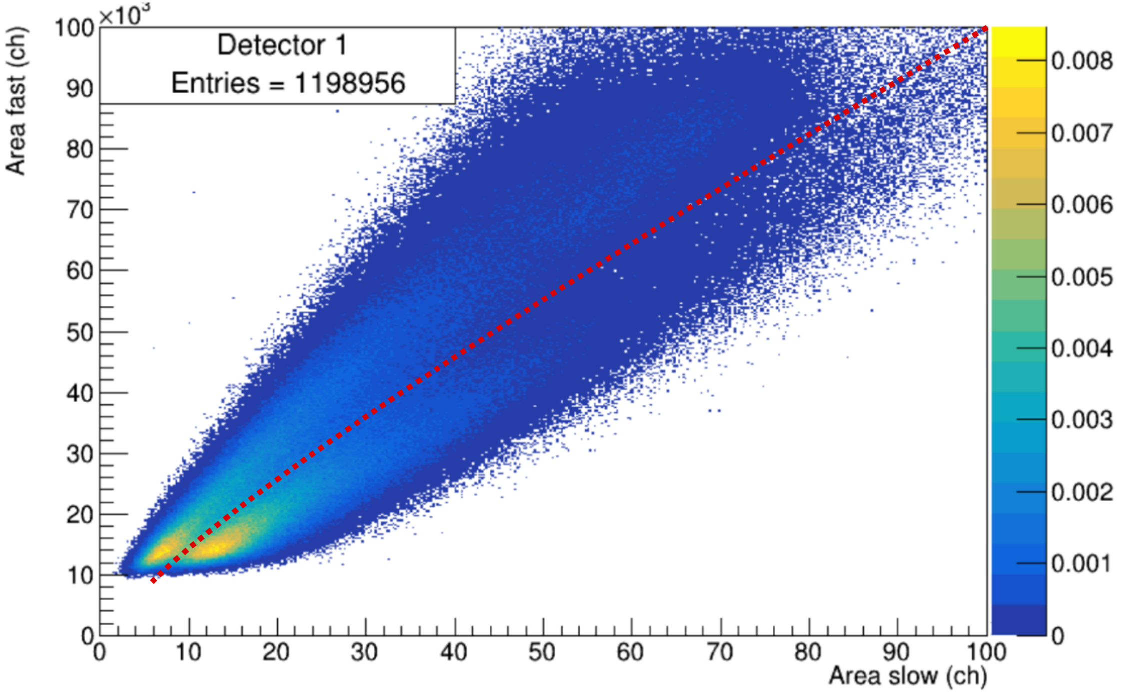
Signals: BGO system

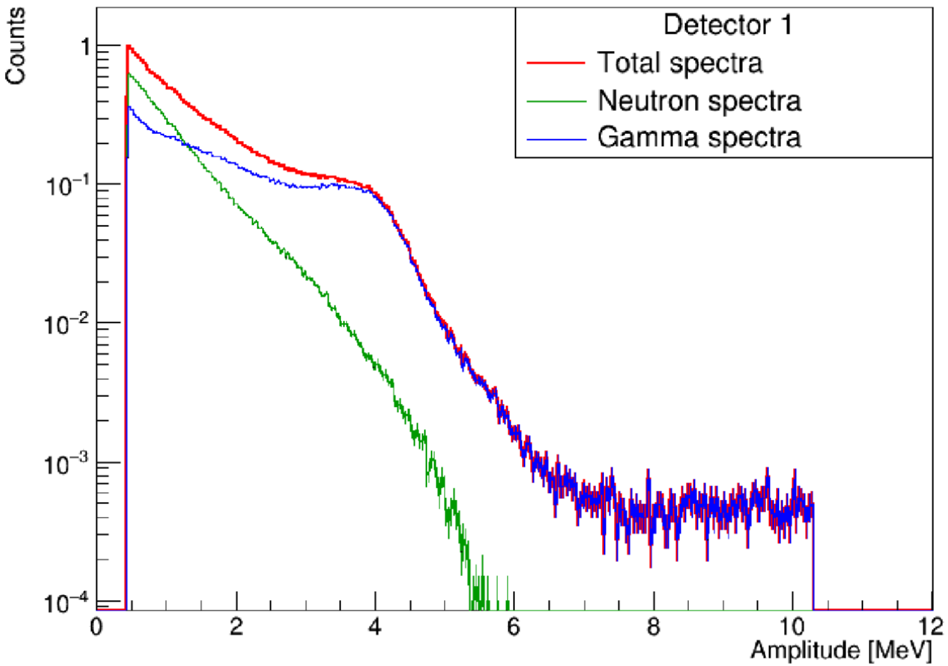


Detector characterization

- Am-Be/^{88}Y source for BC501-A particle identification (n-γ) studies
- **Area fast/slow extraction added to PSA → Many many thanks to Petar!!**

Am-Be





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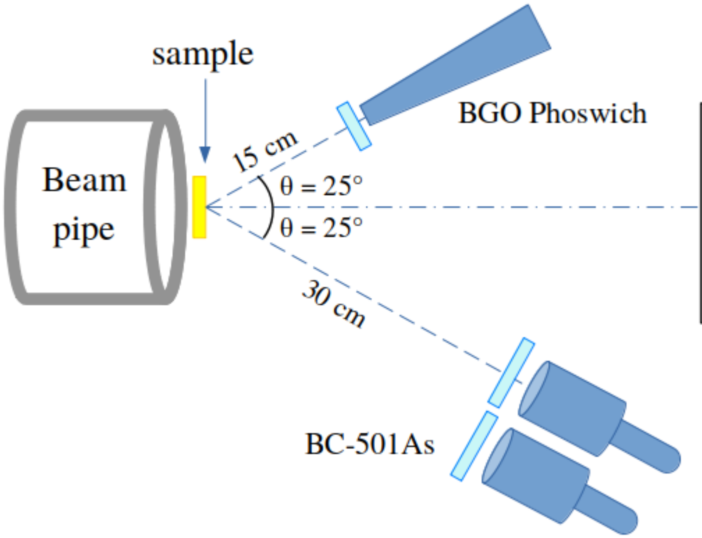
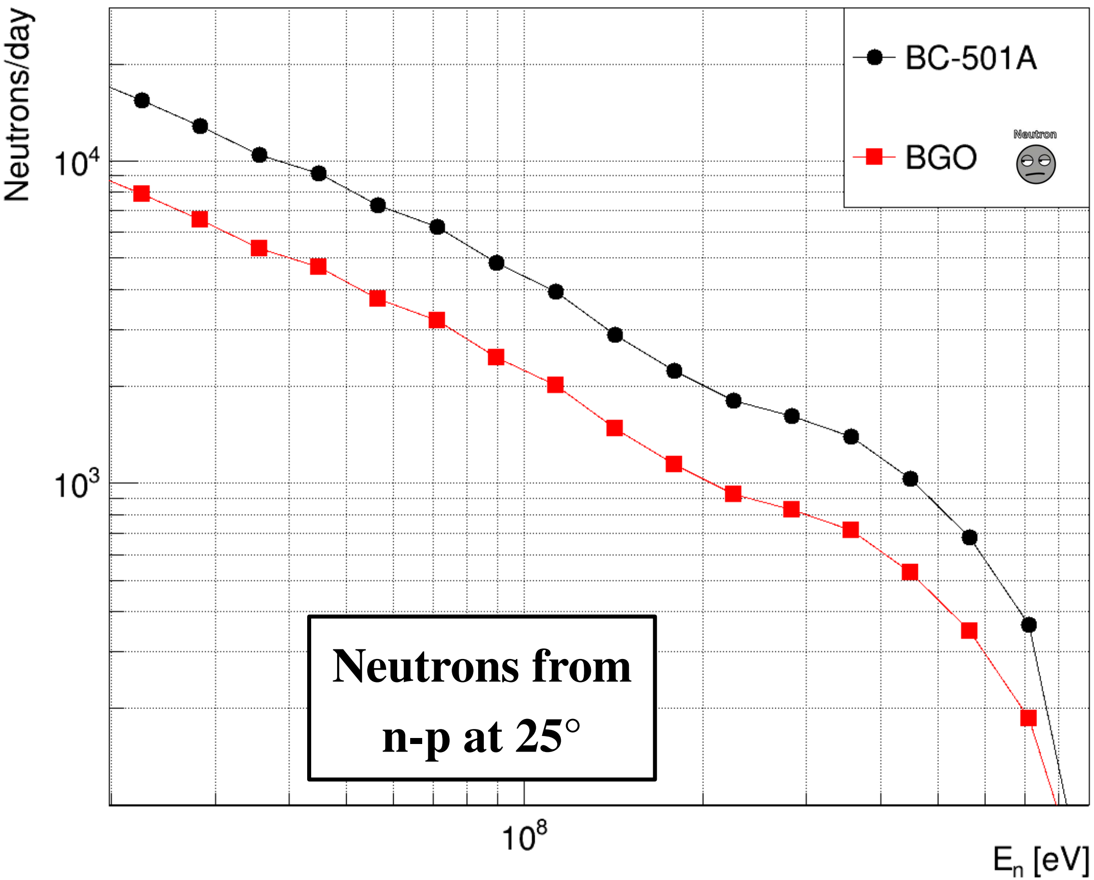


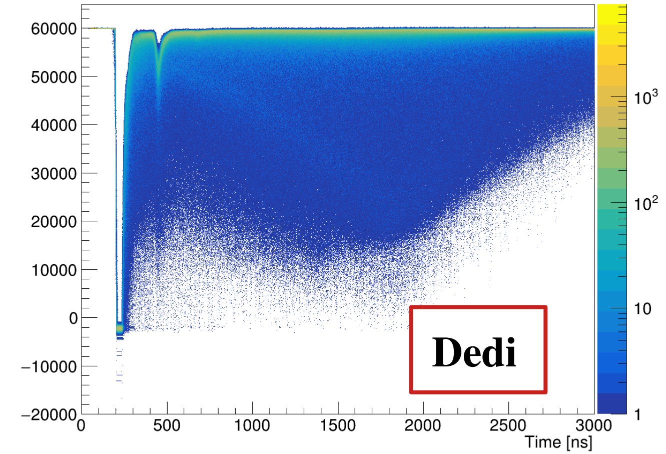
$n_H \approx 0.04$ at/barn
1 bunch every 6 s
10 bins/decade
8-10% energy bin resolution

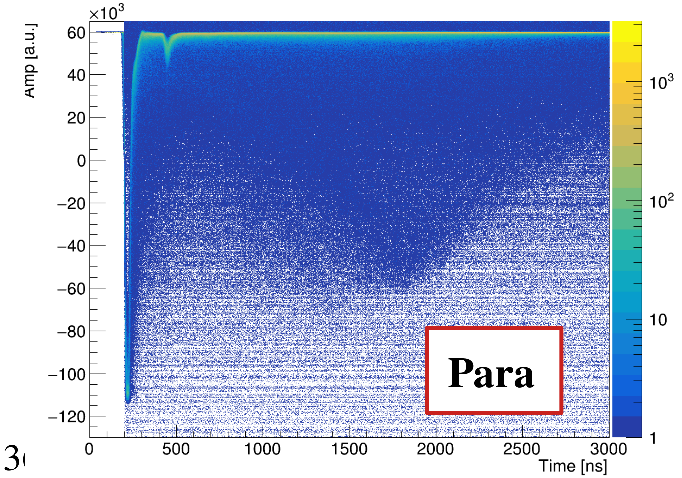
$$E_n = E'_n cos^2(\theta)$$

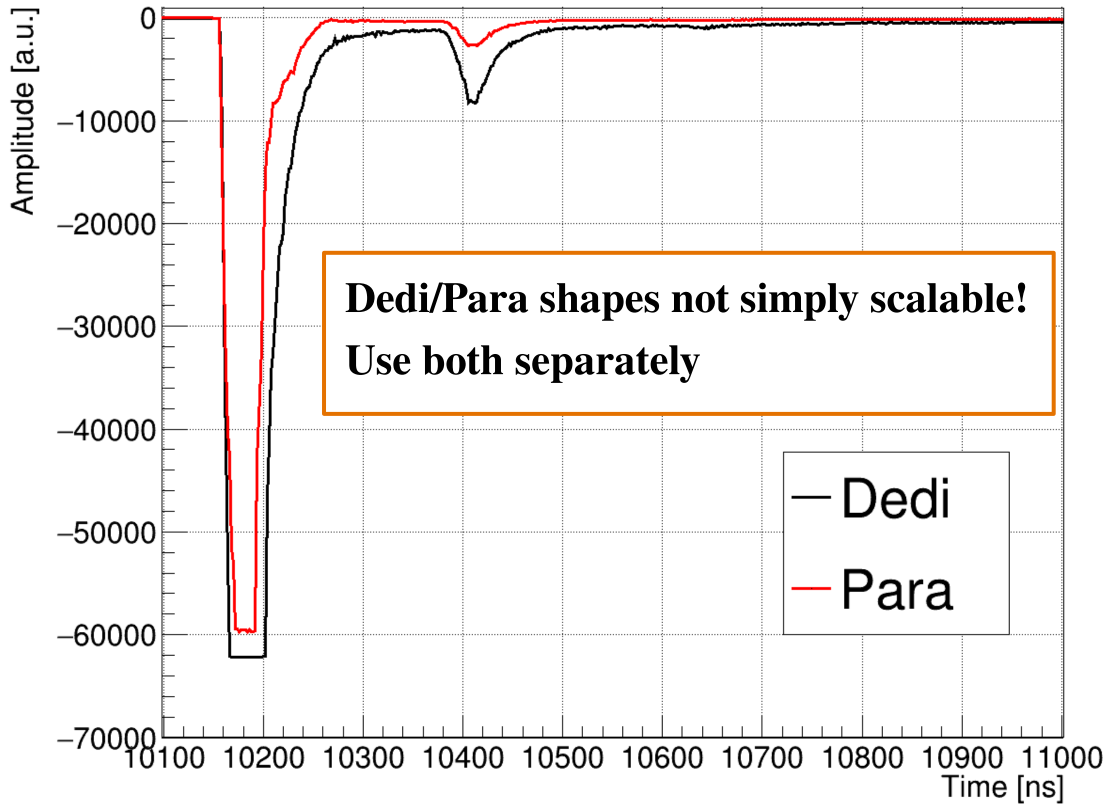


STS PMT after-pulse

Check if after-pulse shape is the same for dedicated and parasitic pulses

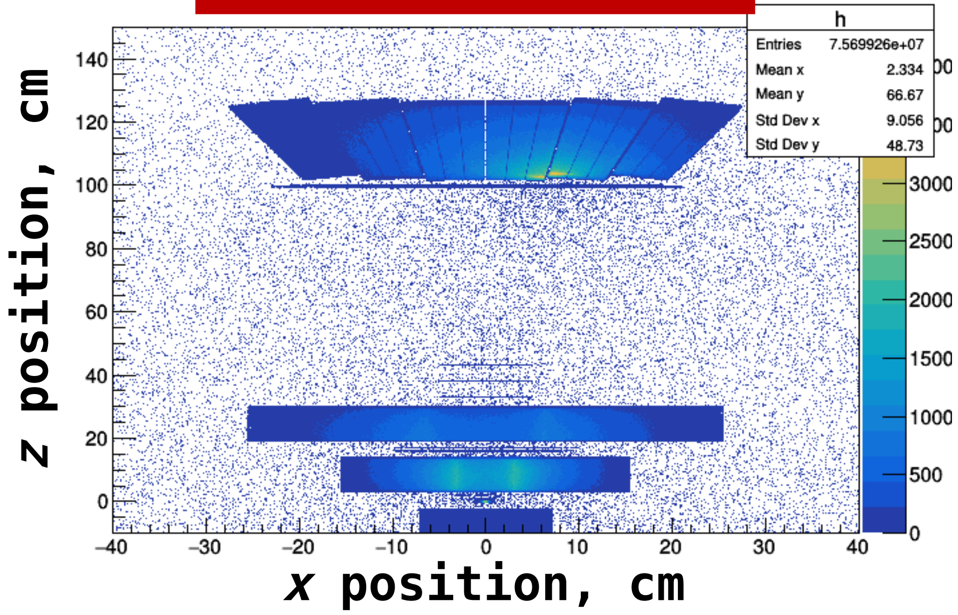


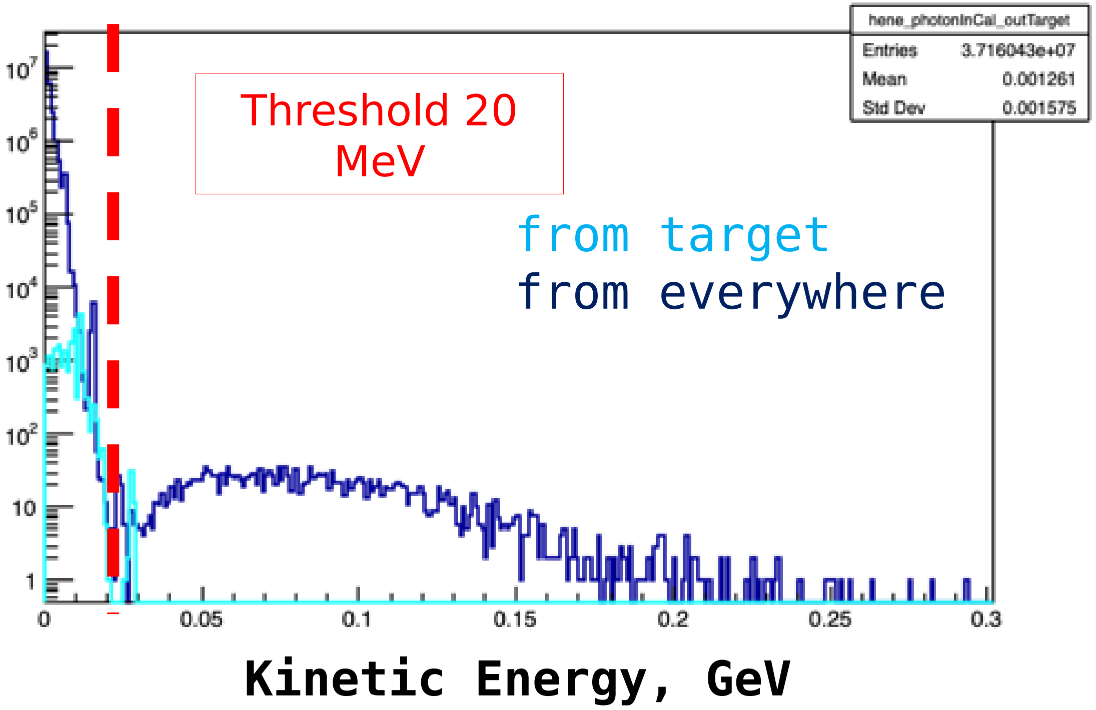




Detecting neutrons with existing setup

75.7x10⁶ γ rays
23.3x10⁶ neutrons





A discrimination level of **20 MeV** makes this **background negligible**