Characterization of the FOOT neutron detectors for nuclear fragmentation measurements at the n_TOF facility

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16th Topical Seminar on Innovative Particle Radiation Detectors – Siena, 25-29/09/2023

FOOT (FragmentatiOn Of Target) goals

Hadrontherapy

Target and Projectile fragmentation

- p, C, O beams @ 200-400 MeV/u

Radiobiology request: to have a more precise Treatment Planning System (**TPS**)

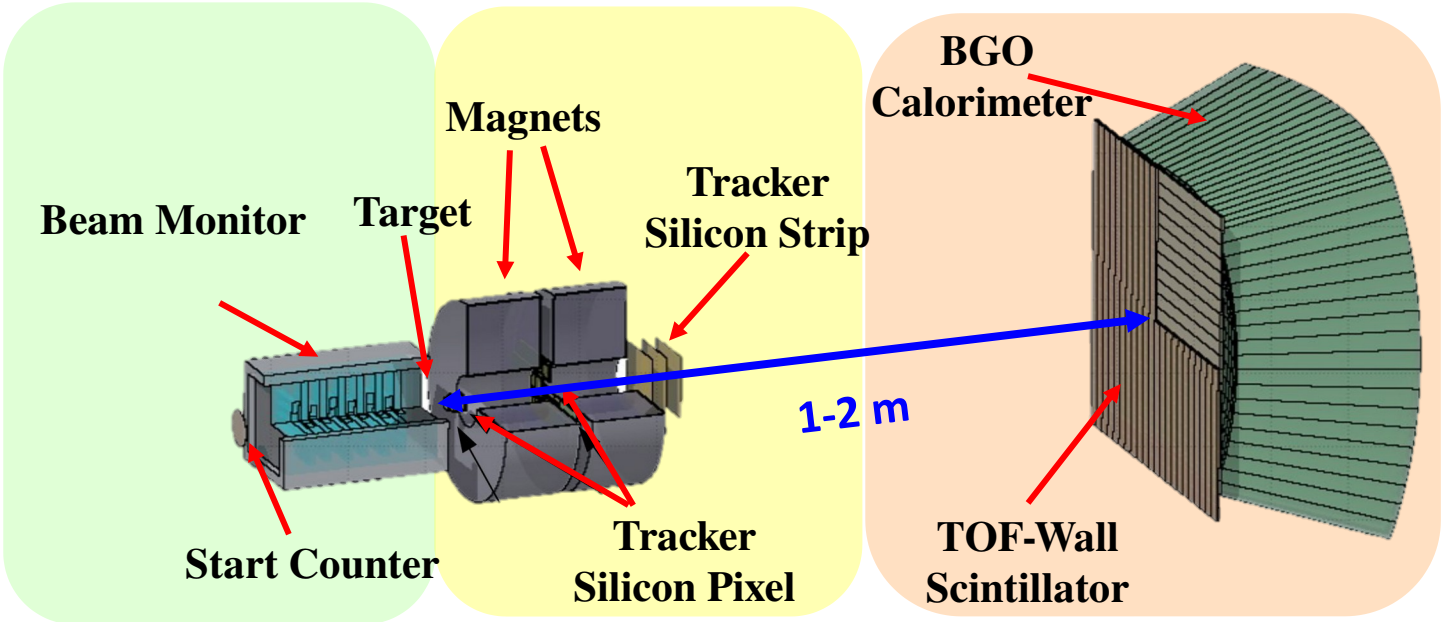
Radioprotection in space

Detailed knowledge of fragmentation processes to **optimize the spacecraft shielding** (long term mission)

- p, He, Li, C, O beams @ 700-800 MeV/u

dσ/dE and dσ/dΩ of fragment production cross sections with 5% precision in direct and inverse kinematics

FOOT setup



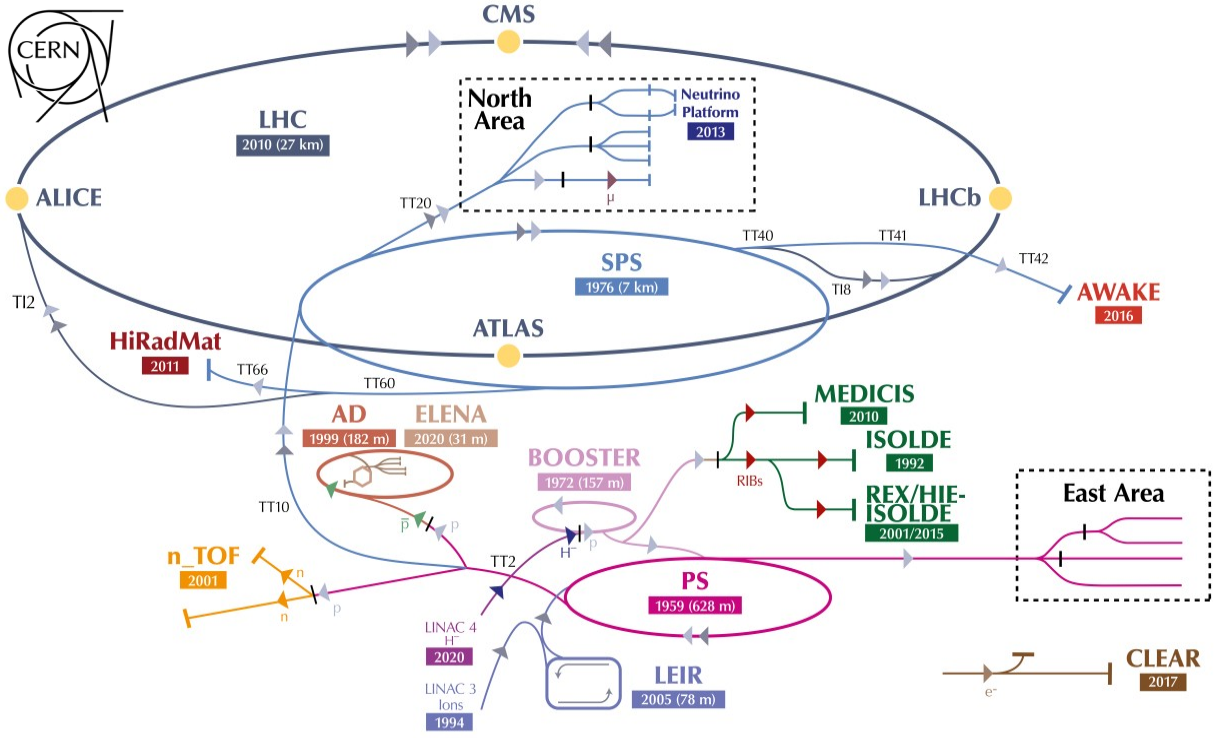
- "Heavy" fragments $3 \leq Z \leq 8$
- First acquisition with full setup in October!

Setup focused on charged particles

⇨

Missing a strategy for neutron detection

n_TOF @ CERN



Pulsed proton beam

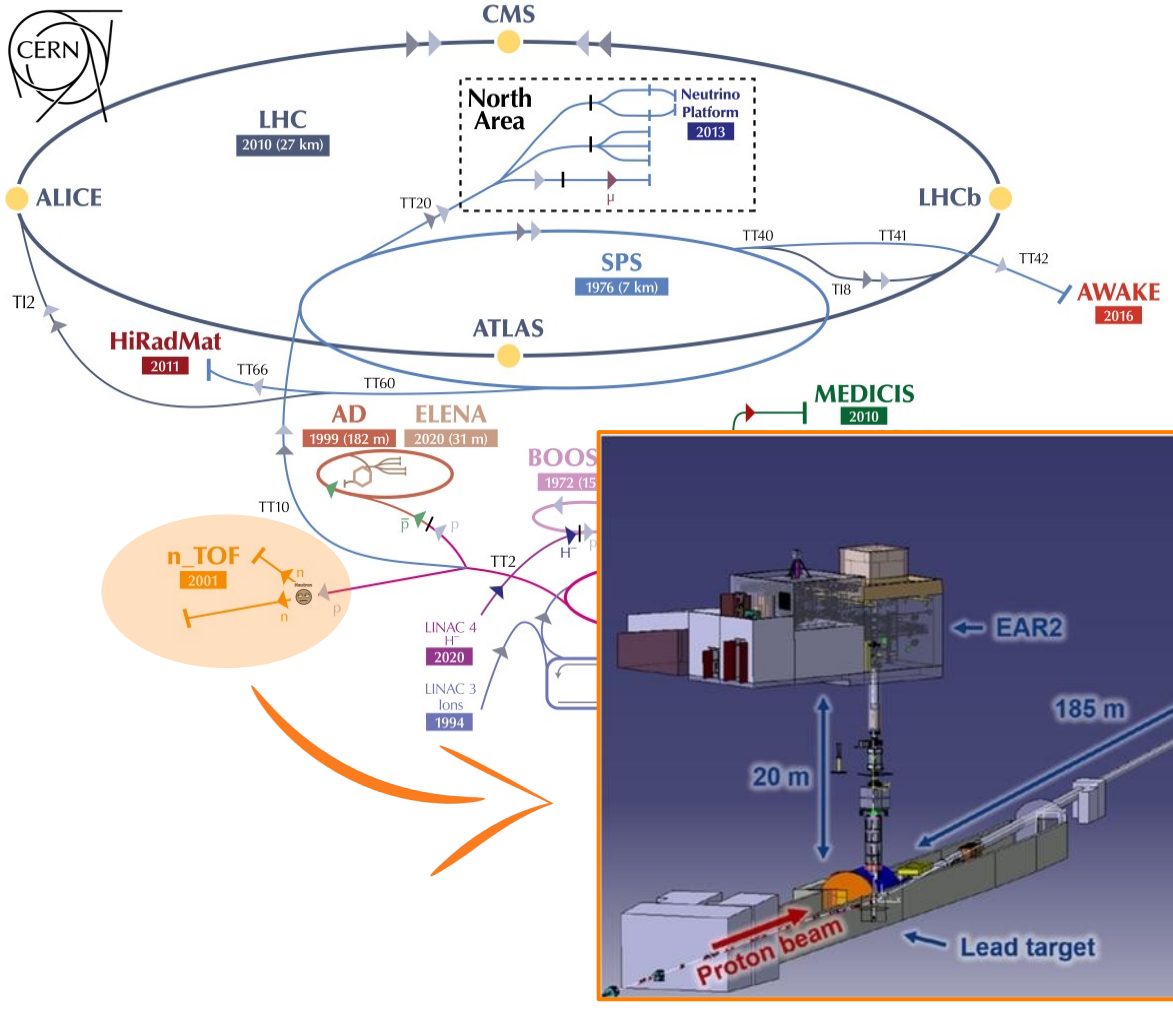
20 GeV/c p from PS

Pb spallation target

Three experimental areas

Time-Of-Flight technique

n_TOF @ CERN



Pulsed proton beam

20 GeV/c p from PS

Pb spallation target

Three experimental areas

Time-Of-Flight technique

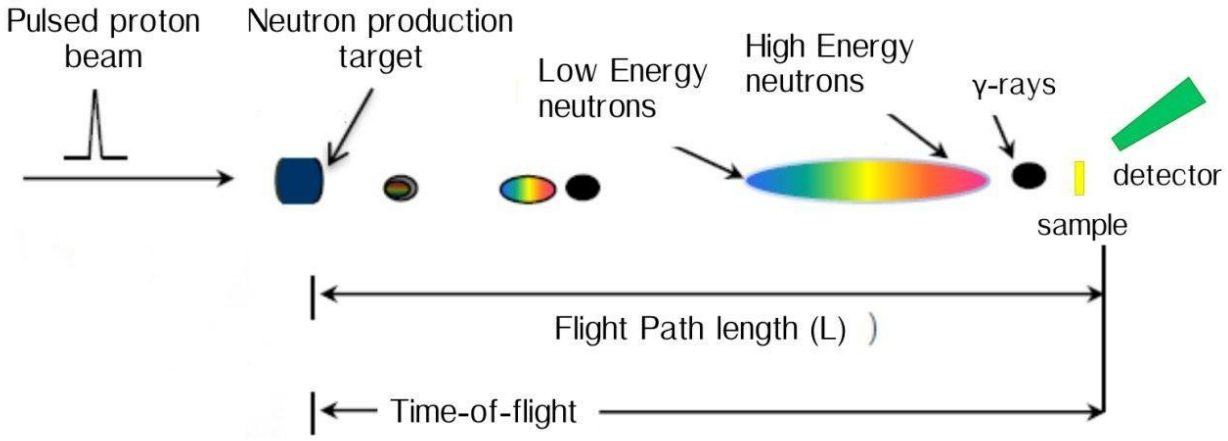
High neutron flux

7×10^{12} p → 10^{15} n

Wide energy range

Thermal – up to 1 GeV

n_TOF @ CERN – Time-Of-Flight technique



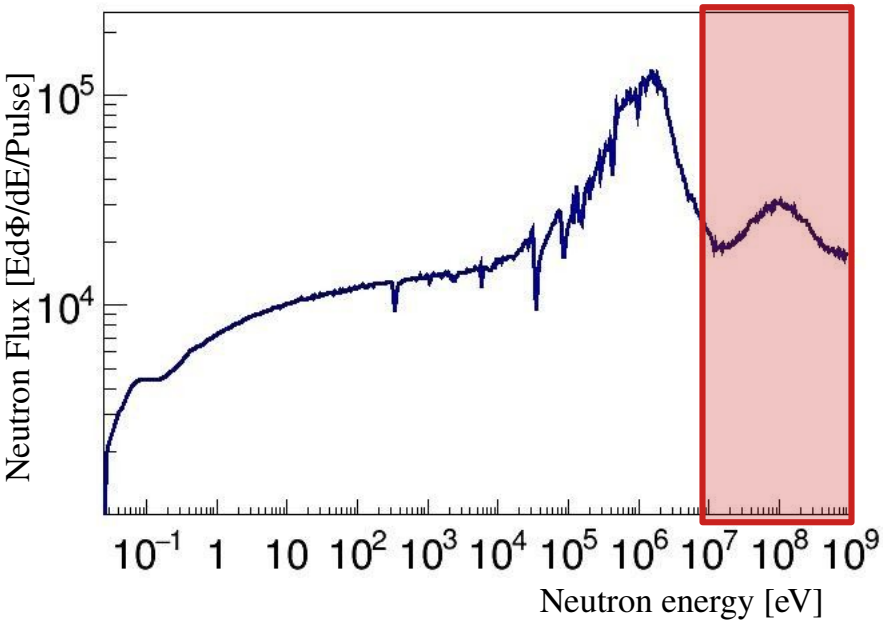
$$\begin{cases} E_k = mc^2(\gamma - 1) \\ \gamma = \sqrt{\left(1 - \frac{L^2}{t^2 c^2}\right)^{-1}} \end{cases} \Rightarrow \frac{\Delta E}{E} \propto \frac{\Delta v}{v} = \sqrt{\frac{\Delta t^2}{t} + \frac{\Delta L^2}{L}}$$

Longer flight path = better resolution!

Extremely good energy resolution

EAR1 →185 m flight path

ΔE/E 10^{-5} - 10^{-3}



FOOT neutron detectors

Phoswich: BGO crystals + EJ232

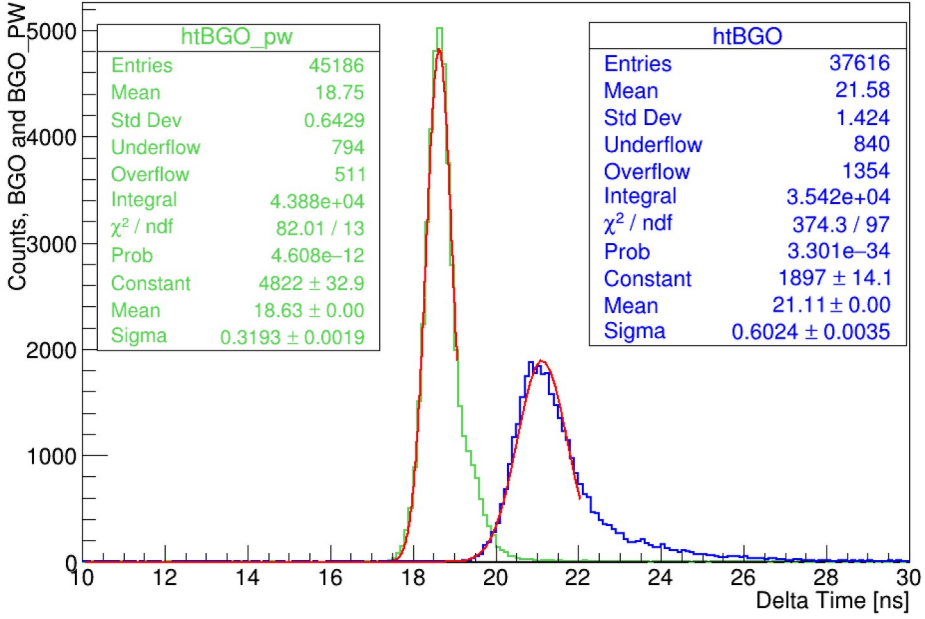
A1: 2.4x2.4 cm^2

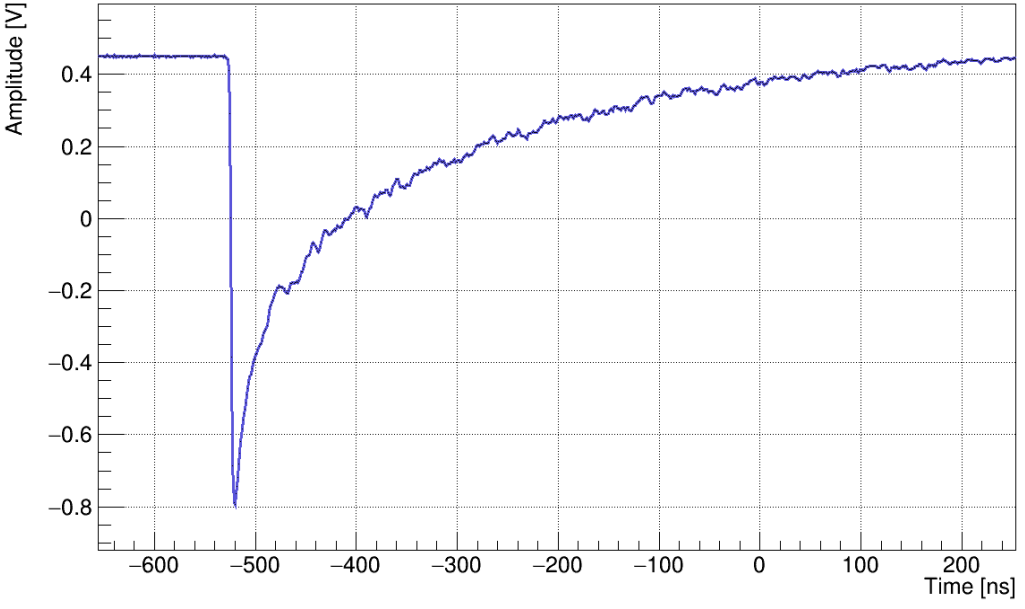
A2: 3.3 x 3.3 cm^2

h: 24 cm

- Particle identification
- Possible Calorimeter upgrade

+ VETO (EJ-204) readout w/ PMT

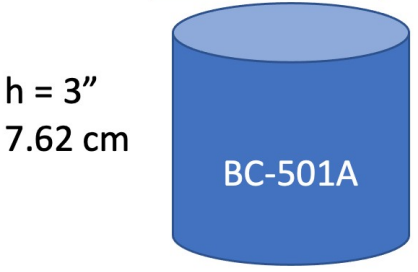




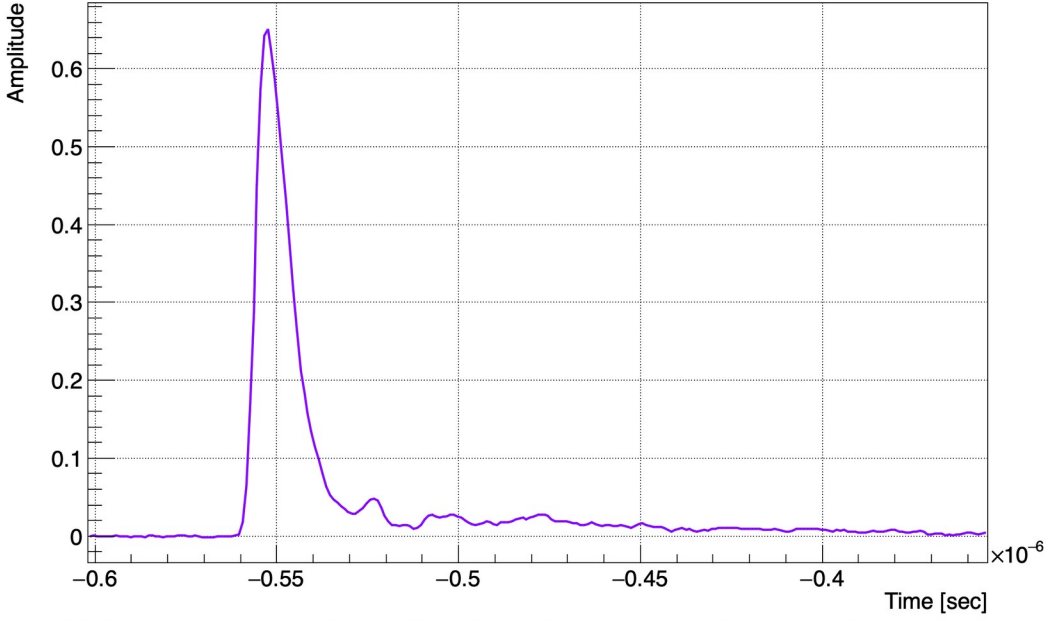
FOOT neutron detectors

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

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



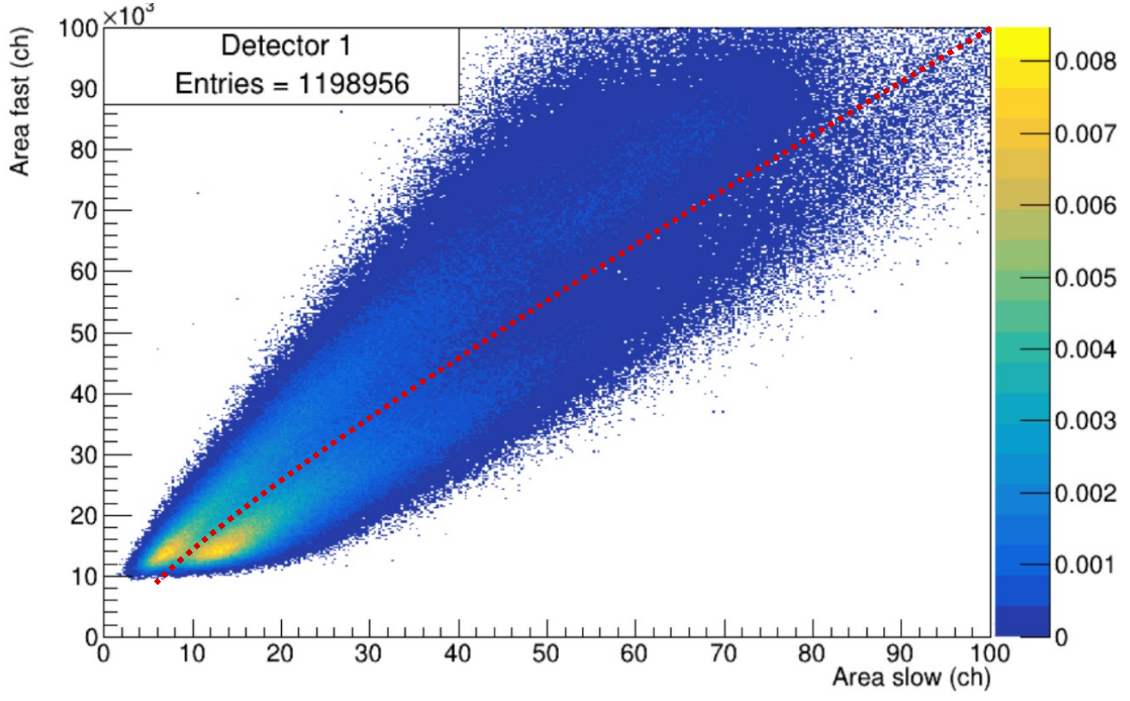
+ VETO (EJ-200)
readout by SiPMs

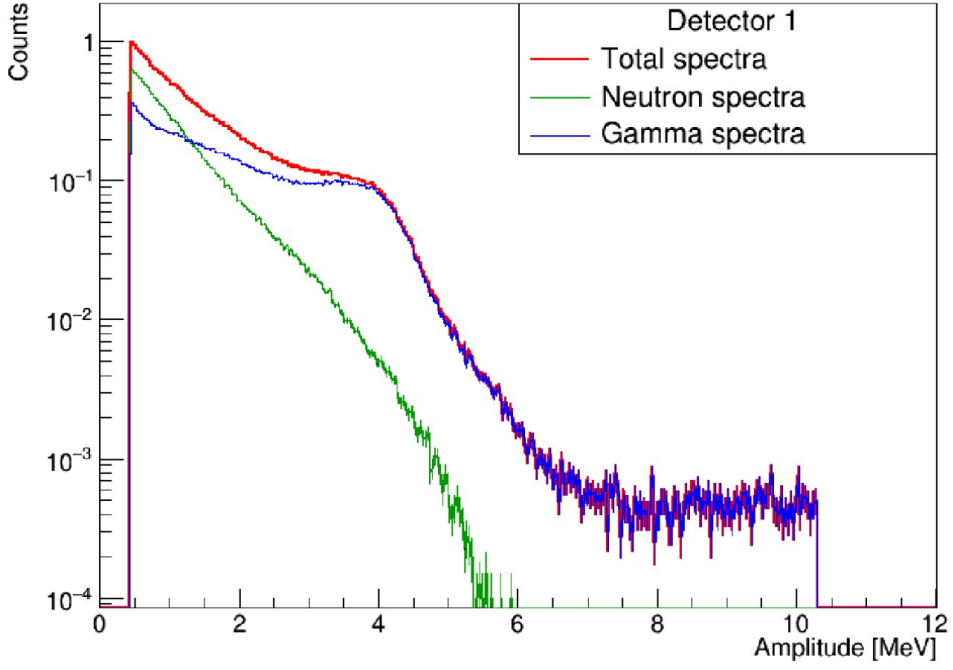


Detector characterization

- Am-Be/^{88}Y source for BC501-A particle identification (n-γ) studies
- **Area fast vs Area slow** of signals for identification

Am-Be

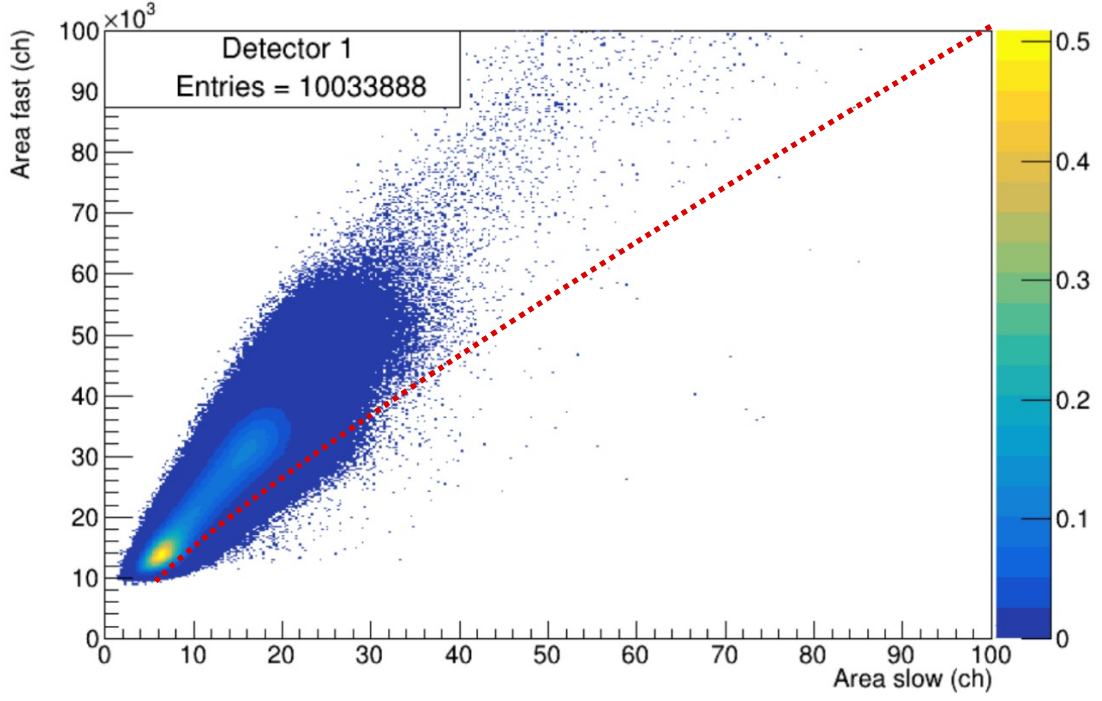


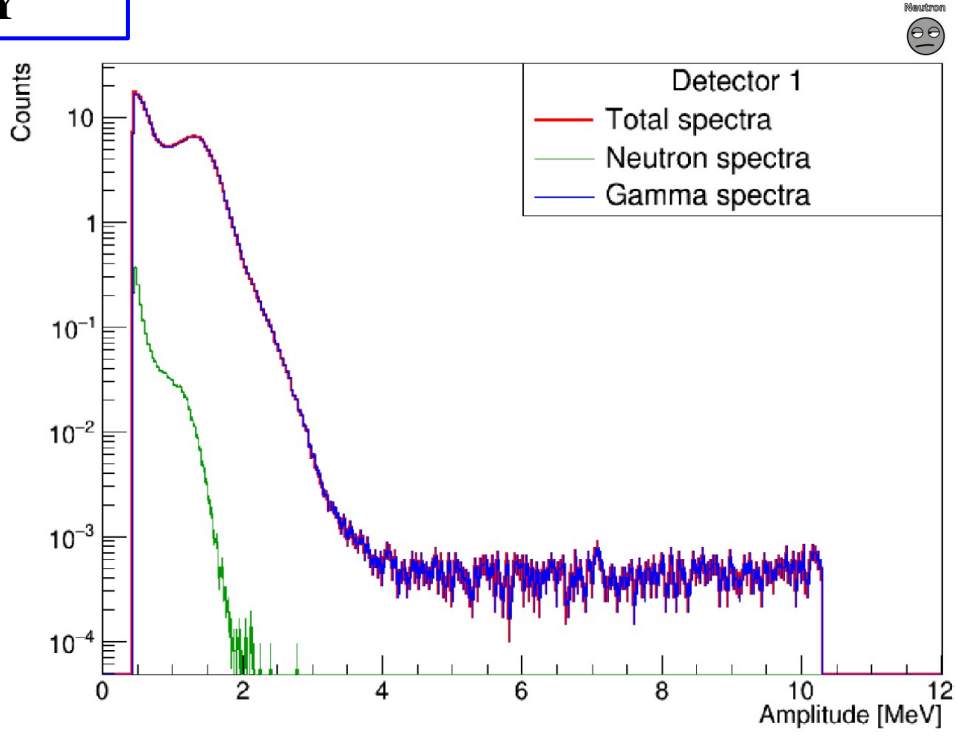


Detector characterization

- Am-Be/^{88}Y source for BC501-A particle identification (n-γ) studies
- **Area fast vs Area slow** of signals for identification

Y





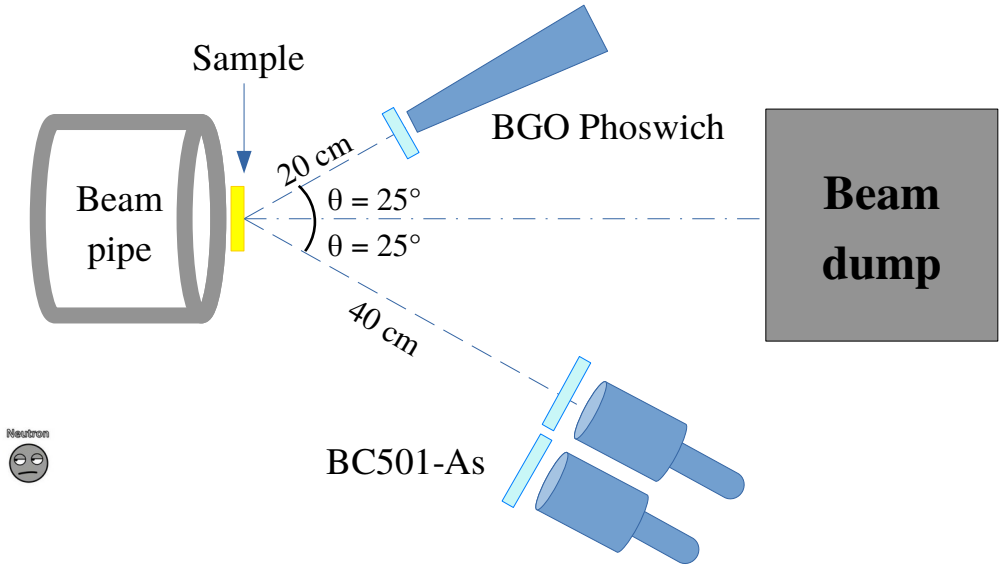
Detector characterization in NEL of EAR1

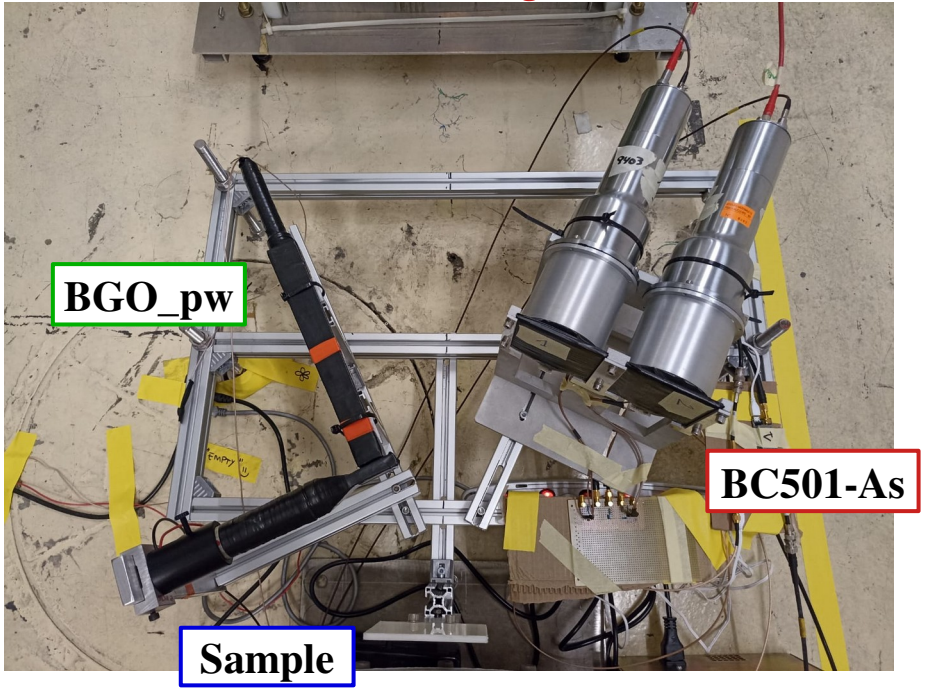
Detection efficiency for high energy neutrons (> 1 MeV)

→ exploit np elastic scattering!

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

Detected neutron | **Incident neutron** | **Scattering angle**

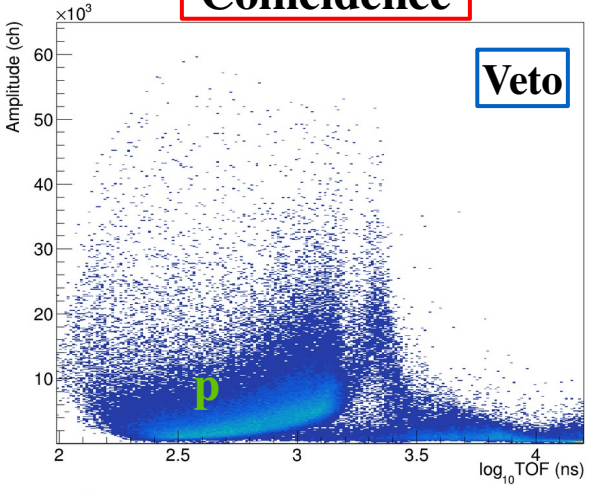


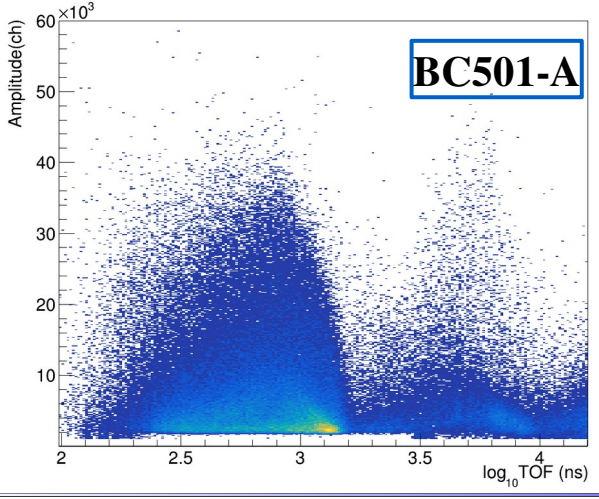


Sample	None	C_2H_4 2 mm	C_2H_4 5 mm	C 1 mm	C 2 mm
Protons [x10^{18}]	1.50	1.83	3.33	3.16	1.42

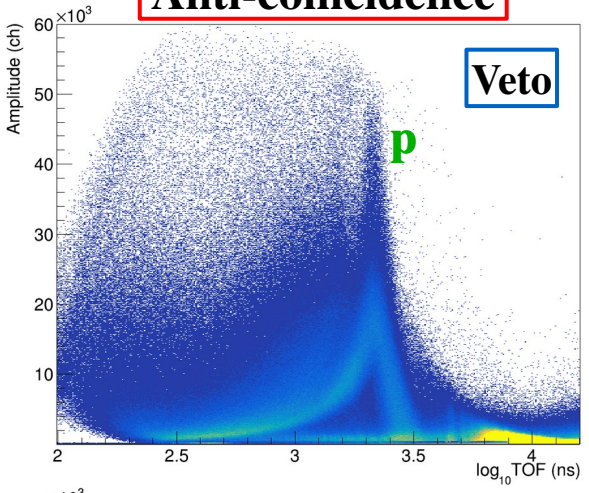
BC-501A coincidence analysis

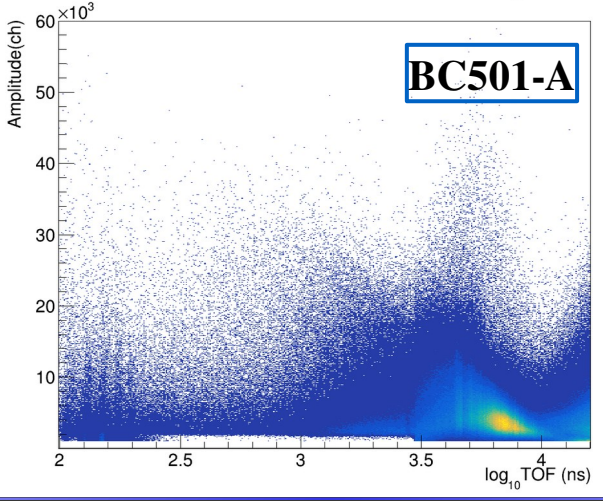
Coincidence

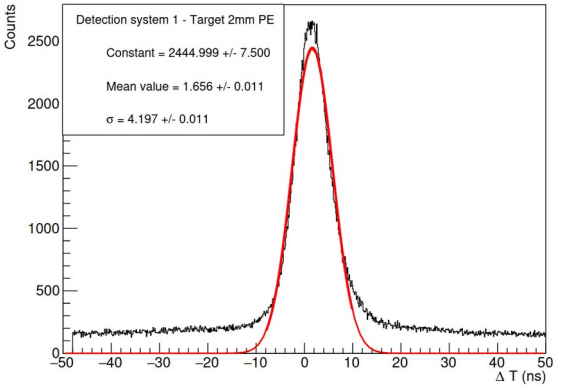




Anti-coincidence





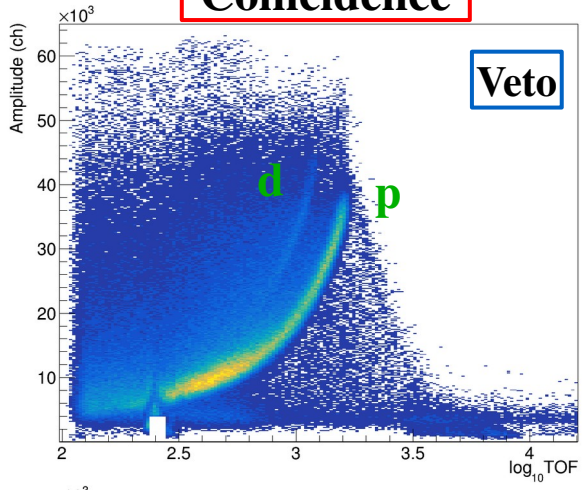


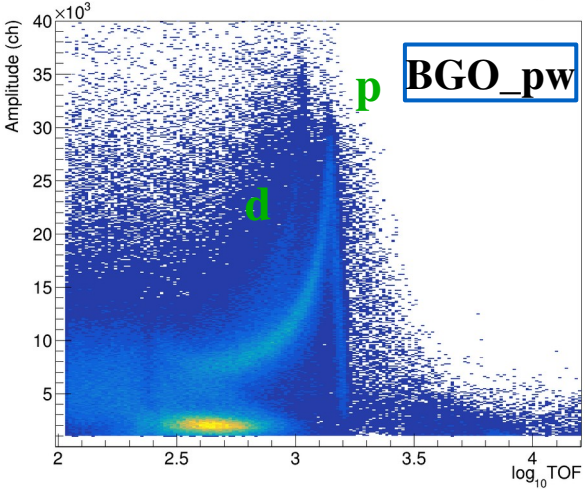
Coincidence analysis routine
→ **divide signals from charged and neutral particles**

- Time coincidence window ± 10 ns
- Energy loss branches from charged particles clearly visible in the veto
- Anticoincidence events currently being carefully studied

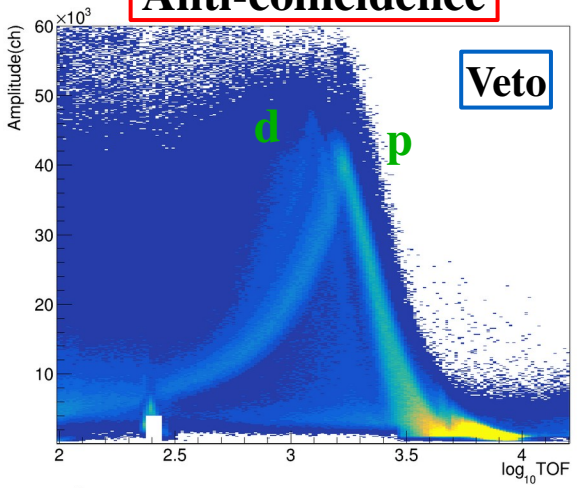
BGO coincidence analysis

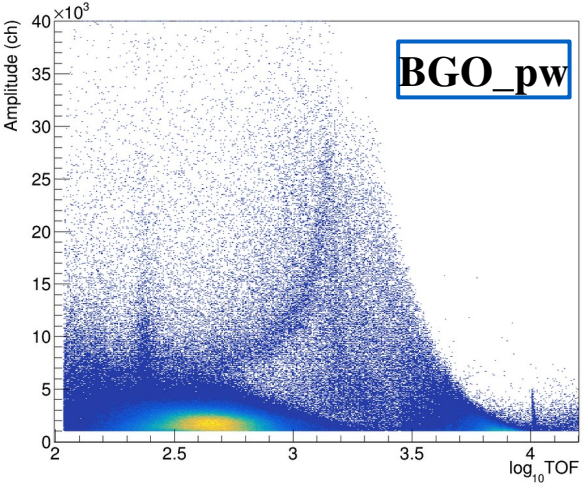
Coincidence

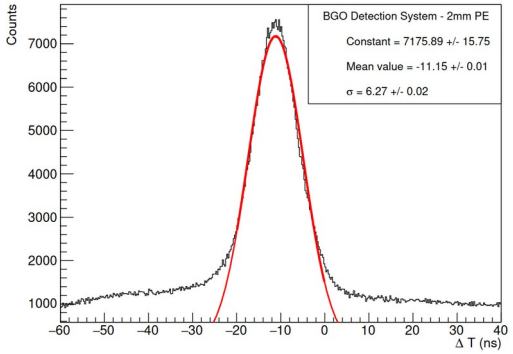




Anti-coincidence







Same coincidence analysis routine

- Time coincidence window ± 12 ns
- Protons and deuterons branches visible
- No fast component in anticoincidences
- n detection efficiency to be evaluated

$$\varepsilon = \frac{n_{\mathrm{n}}}{n_{\mathrm{p}}}$$

Independent of neutron flux

Conclusions

Possible FOOT neutron detectors studied in the NEL of n_TOF EAR1

✔ Functioning veto/detector coincidence selection routine

BC-501A:

✔ Particle discrimination with radioactive sources

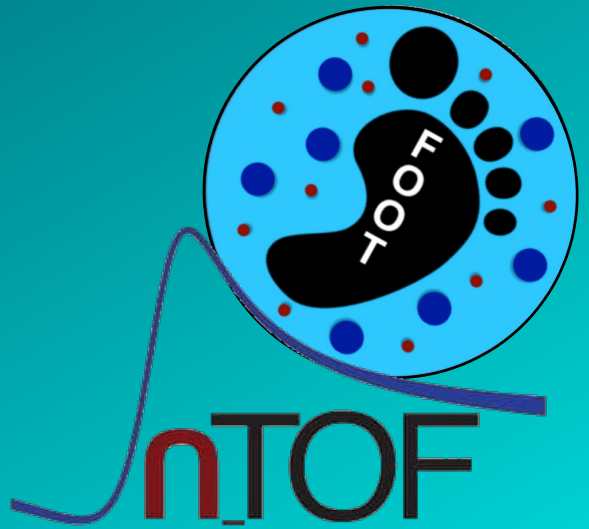
✔ Further studies ongoing for n detection efficiency evaluation

BGO:

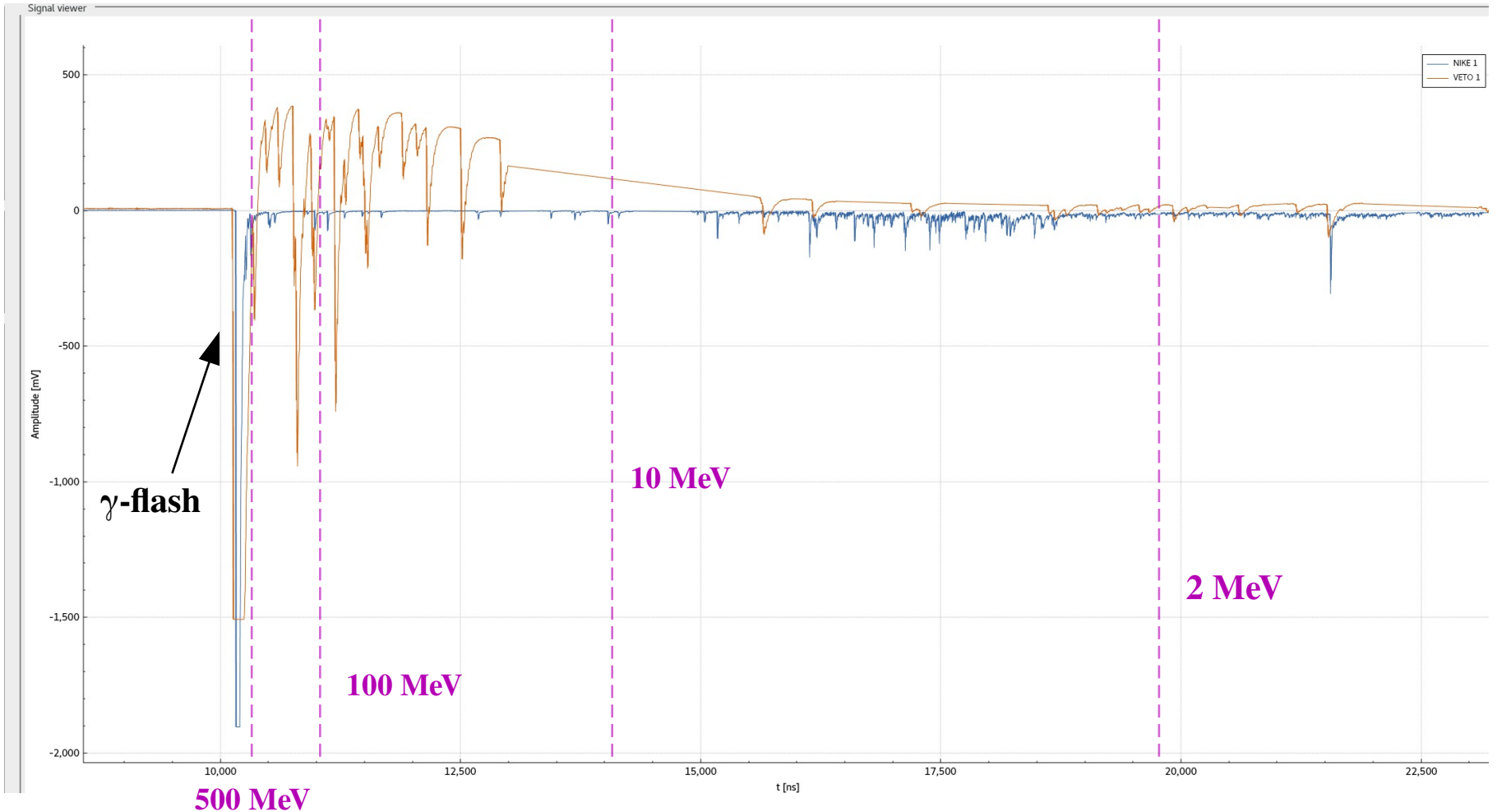
✔ Good reliability of the phoswich system

✔ n detection efficiency to be evaluated using proton and neutron flux

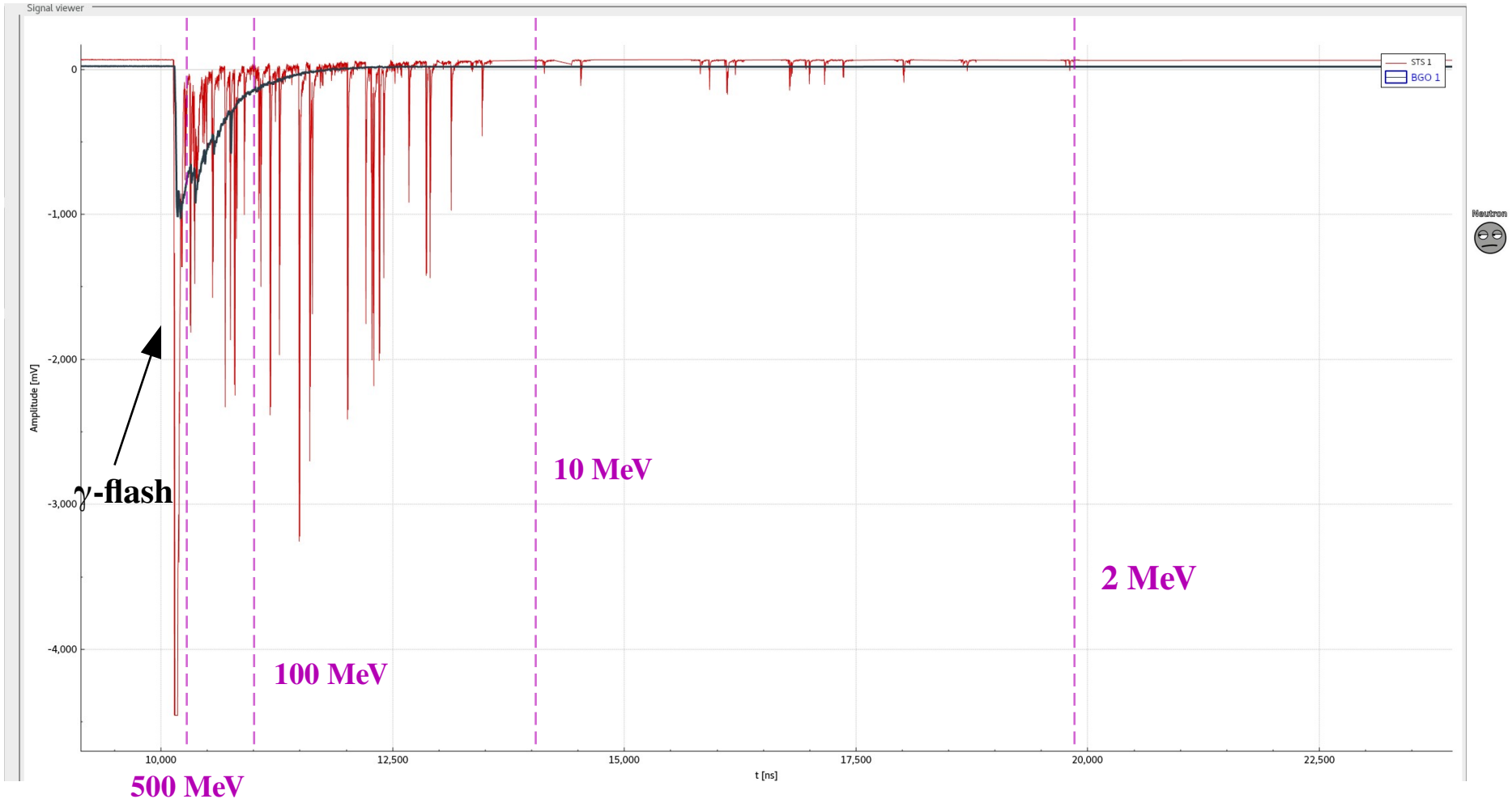
Backup slides



Signals: BC-501A system



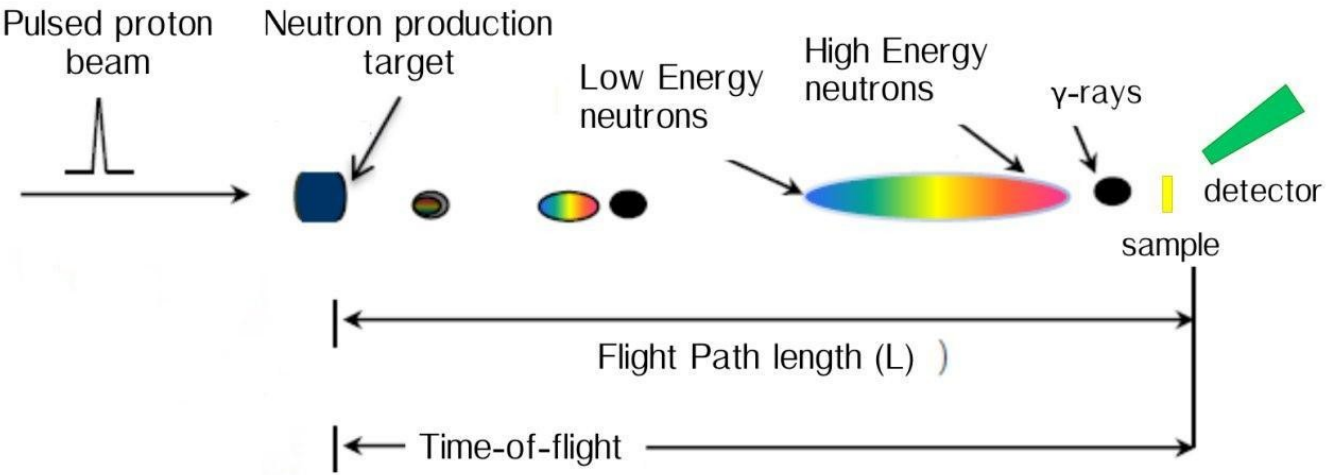
Signals: BGO system



n_TOF @ CERN - TOF - Energy conversion

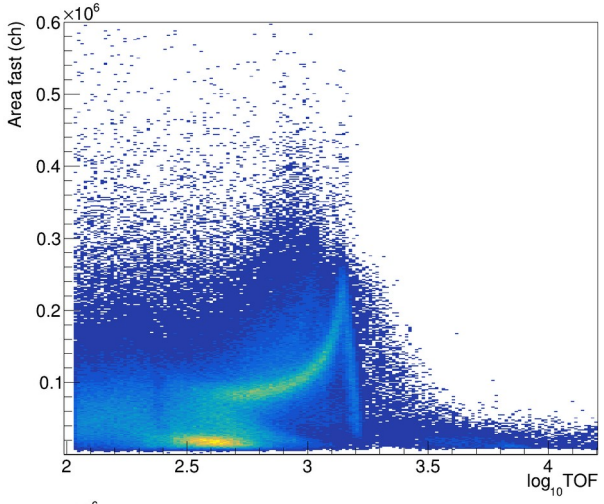
Energy (MeV)	TOF(μs)
1	13.8
10	3.94
50	1.46
100	0.89
150	0.65
200	0.51
250	0.42
300	0.36
400	0.27
500	0.21
1000	0.10

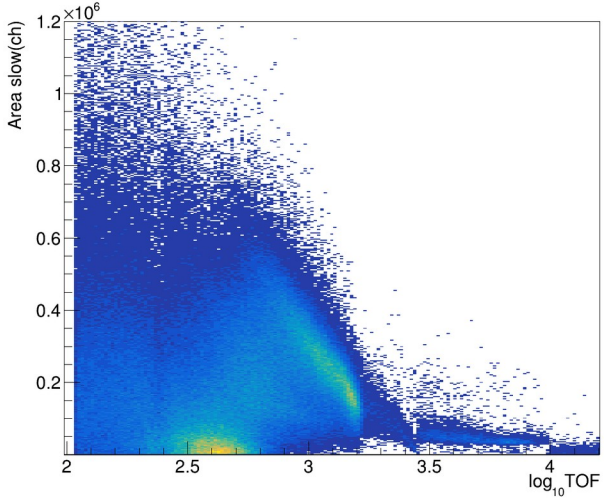
Neutron Escape Line (NEL) of n_TOF EAR1



BGO area fast/slow analysis

Coincidence





Anti-coincidence