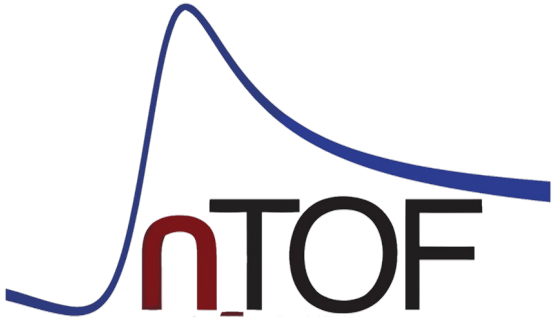


LOI: Characterization of the FOOT neutron detectors for nuclear fragmentation measurements at the n_TOF facility

S. Colombi, A. Manna, C. Massimi, M. Marafini,

N. Patronis, R. Spighi, M. Villa, R. Zarrella

FOOT (FragmentatiOn Of Target) goals

Hadrontherapy

Target and Projectile fragmentation

- dσ/dE and dσ/dΩ with 5% precision of fragment production cross sections in direct/inverse kinematics
- p, C, O beams @ 200-400 MeV/u

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

Radioprotection in space

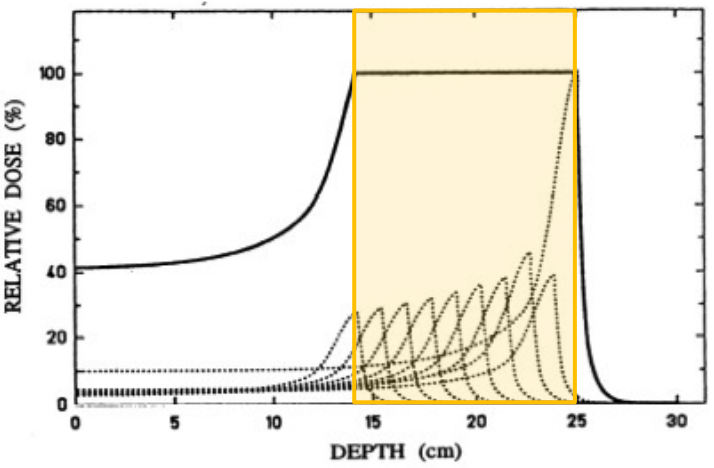
Detailed knowledge of fragmentation processes to **optimize the spacecraft shielding** (long term mission)

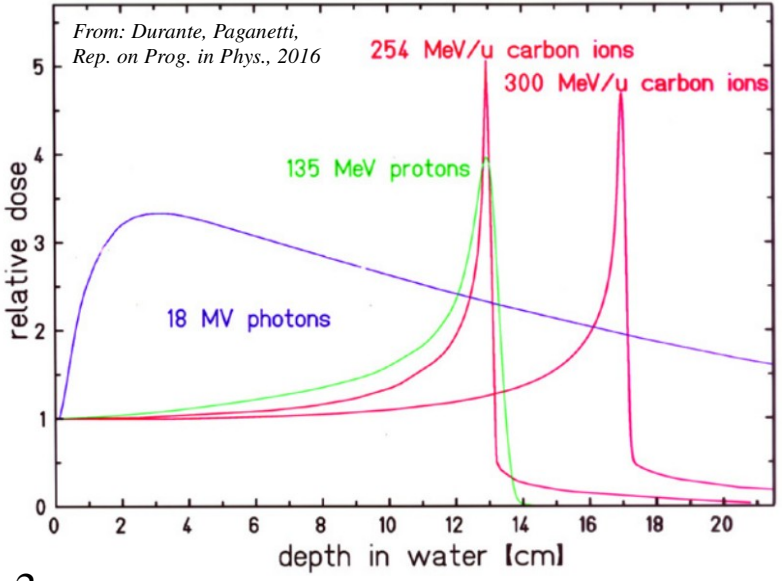
- dσ/dE and dσ/dΩ with 5% precision of the fragment production cross sections in direct/inverse kinematics
- p, He, Li, C, O beams @ 700-800 MeV/u

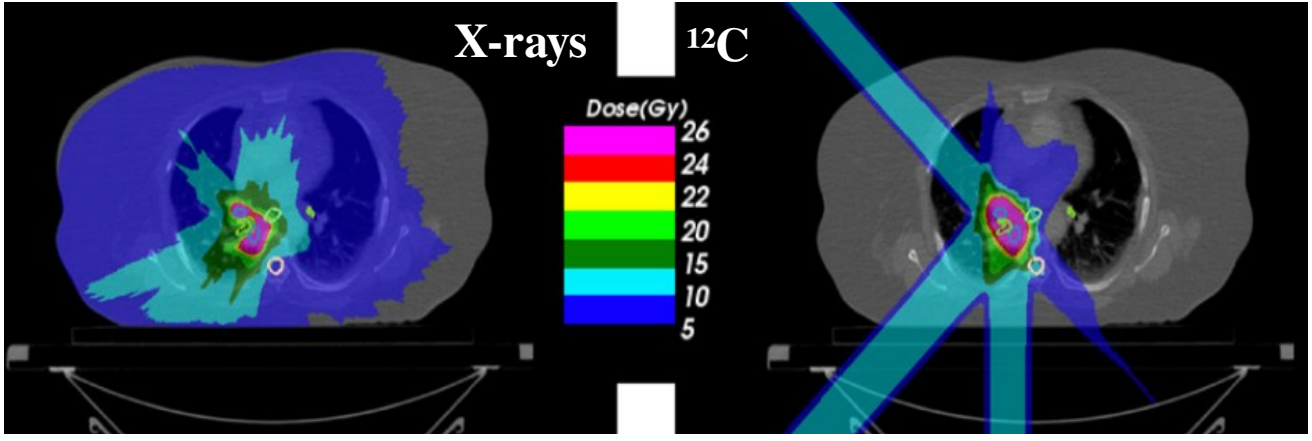
Hadrontherapy vs Radiotherapy

- ✓ Favorable depth-dose profile (Bragg curve)
- ✓ Penetration depends on energy
- ✓ Lower dose/damage outside the tumor

- ✘ MORE expensive than X-rays
- ✘ Nuclear fragmentation





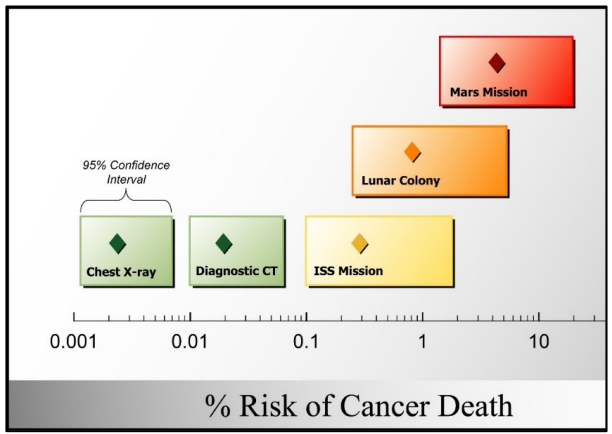


Radioprotection in Space

Mission to Mars!

- Long cruise (~180 days each way)
- Thin atmosphere
- No magnetosphere

No natural protection from radiation!! (GCR + SPE)



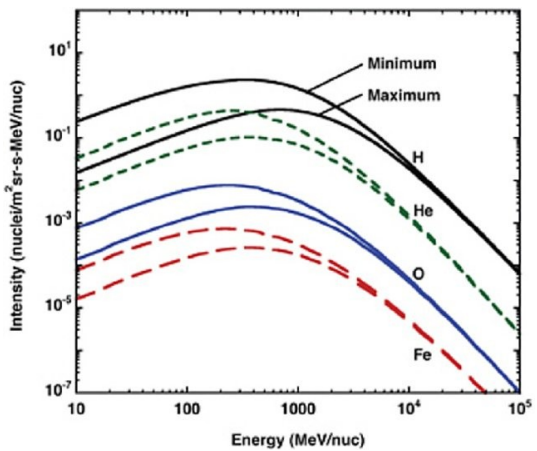
Astronauts need effective shielding!!

Mars mission radiation:
- Travel: 1.8 mSv/day
- On Mars: 0.64 mSv/day

On Earth: 2.64 mSv/year

$Rad_{Mars}/Rad_{Earth} = 280$

1 Sv ~ 3% increase in cancer probability

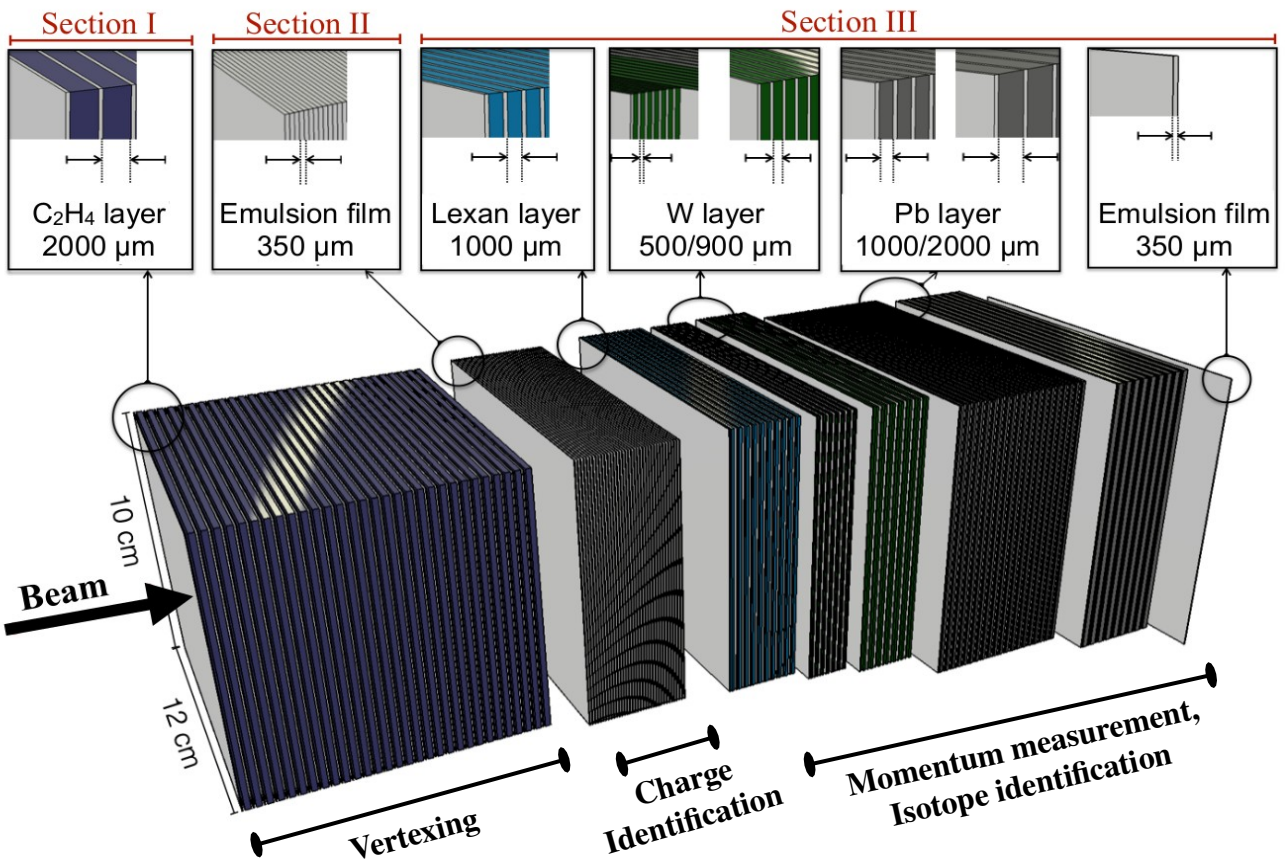


FOOT apparatus: emulsion setup

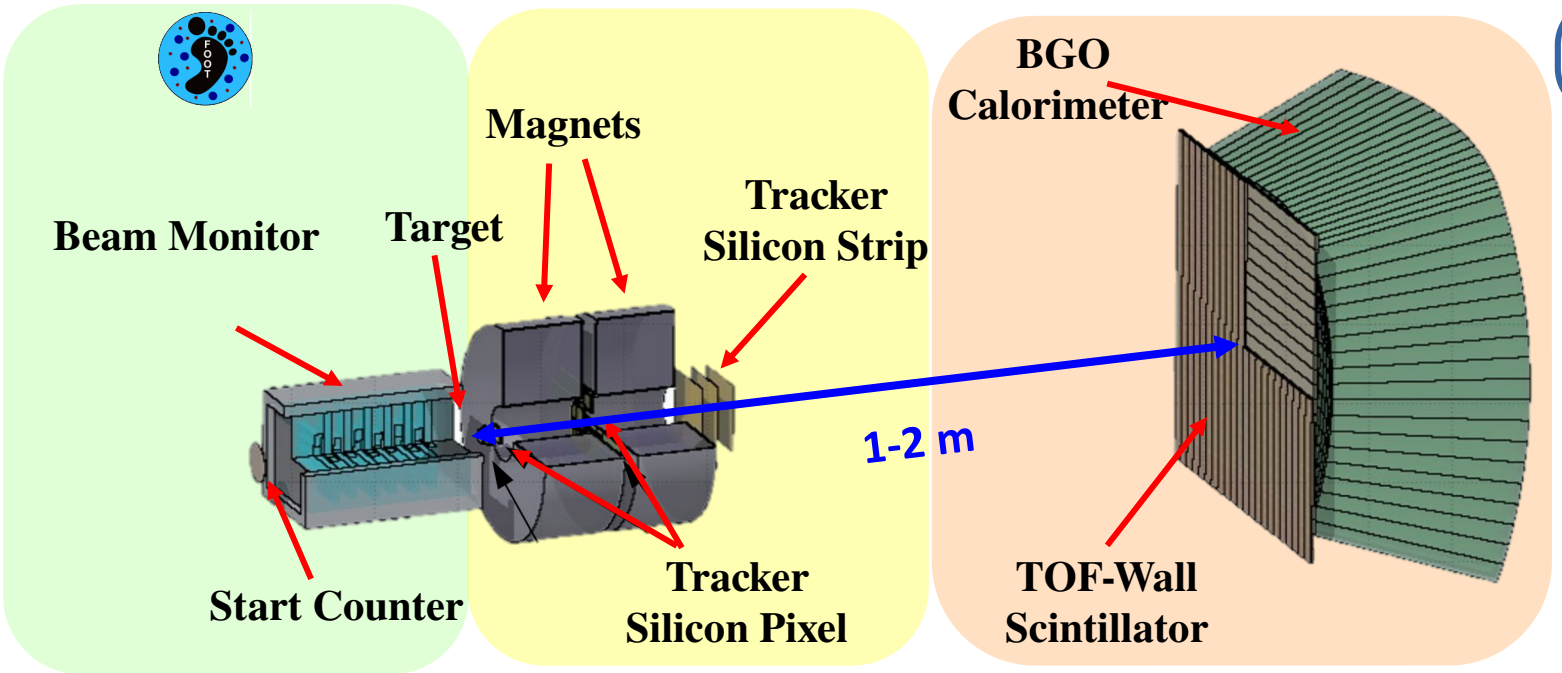
Emulsion Chamber Setup

- **Light fragments** $Z \leq 3$
- **Angular aperture** $\pm 70°$
- Sections:
  I. Emulsions + target
  II. Emulsion layers
  III. Emulsion + passive material

→ **Ready and acquiring data**



FOOT apparatus: electronic setup



Electronic Setup

- **Heavy fragments** $Z \geq 3$
- **Angular aperture** $\pm 10°$

→ **In construction**

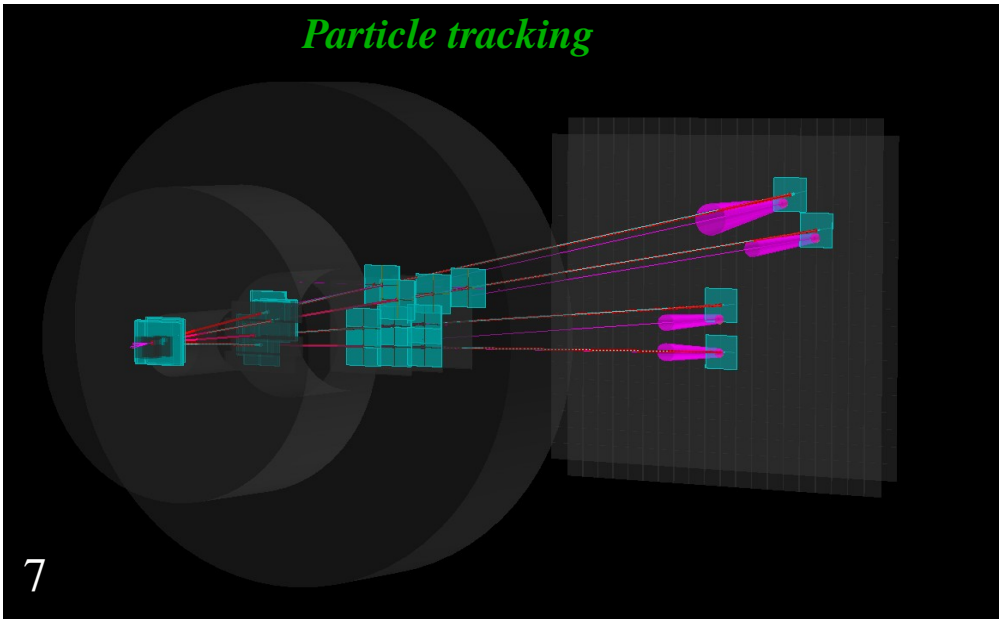
Data acquired w/ partial setup

Particle identification in FOOT

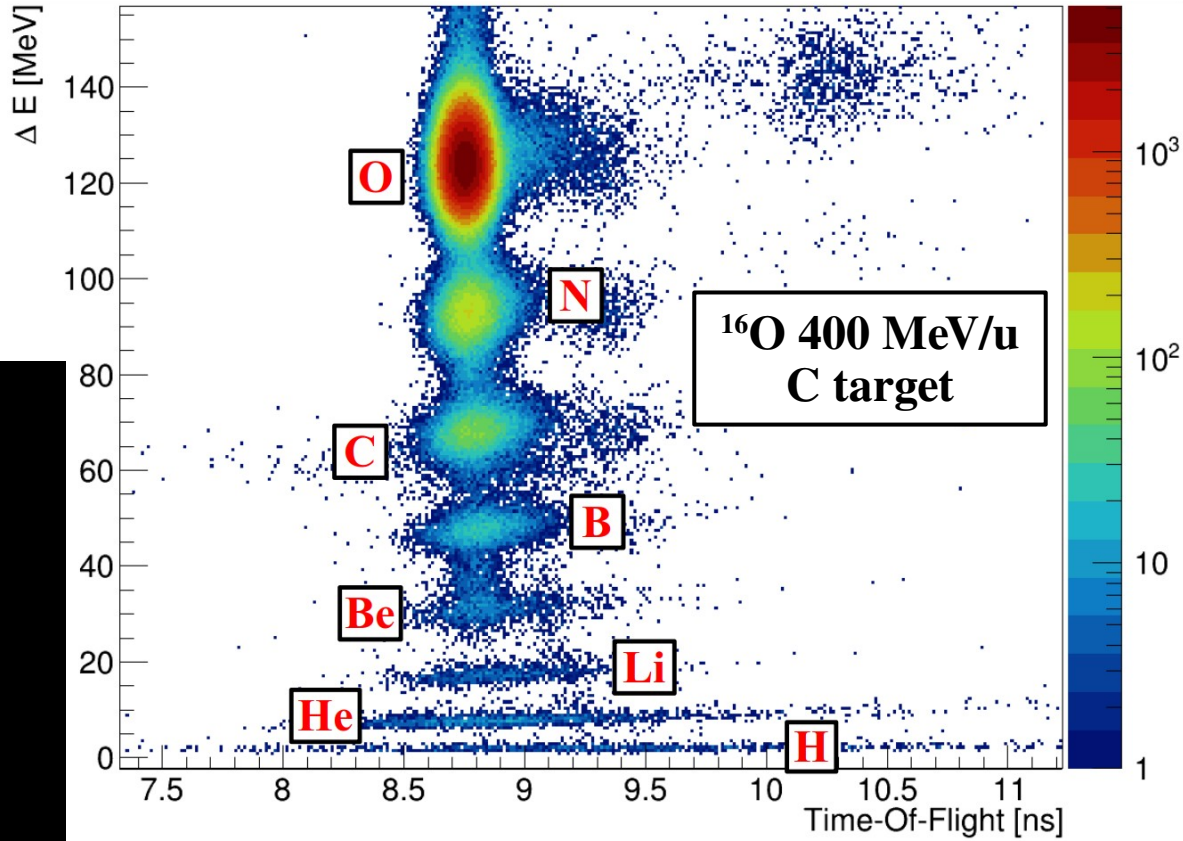
Characterization of charged fragments

- **Charge** (ΔE - TOF)
- **Mass** (E_k – TOF - p)

Particle tracking



Charge identification



But we are still missing something...

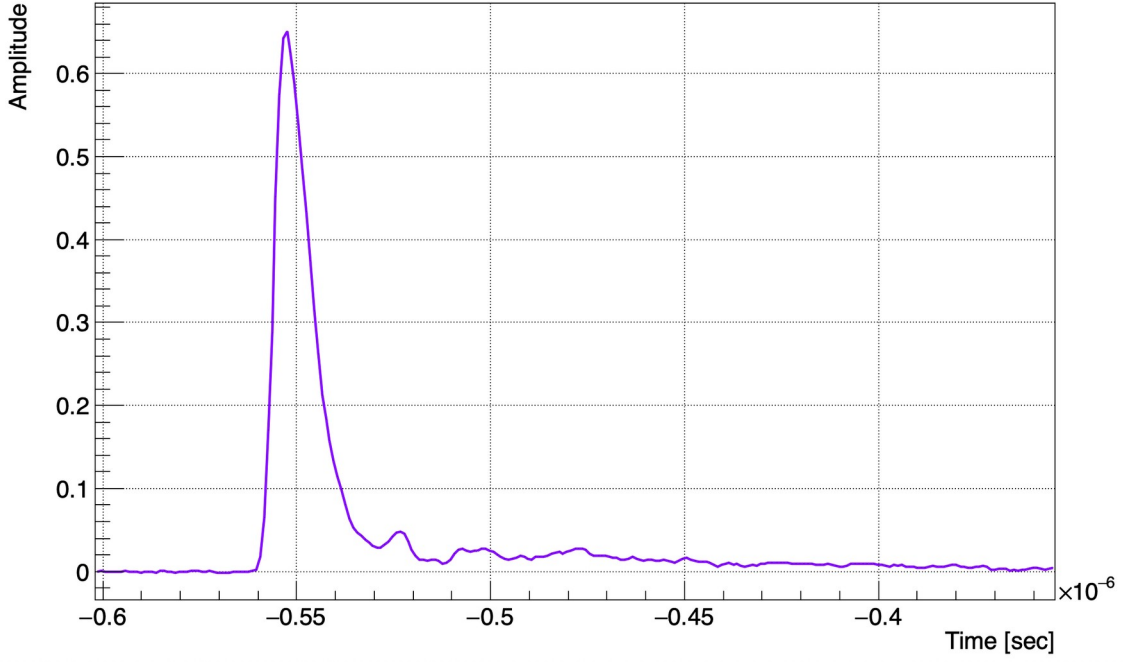
Neutron detectors

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

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

h = 3”
7.62 cm

diametro=3”
7.62 cm



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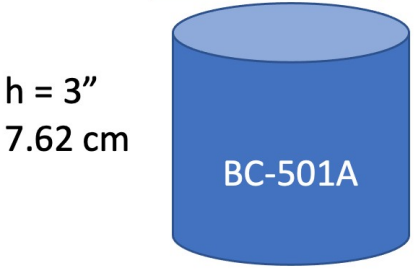
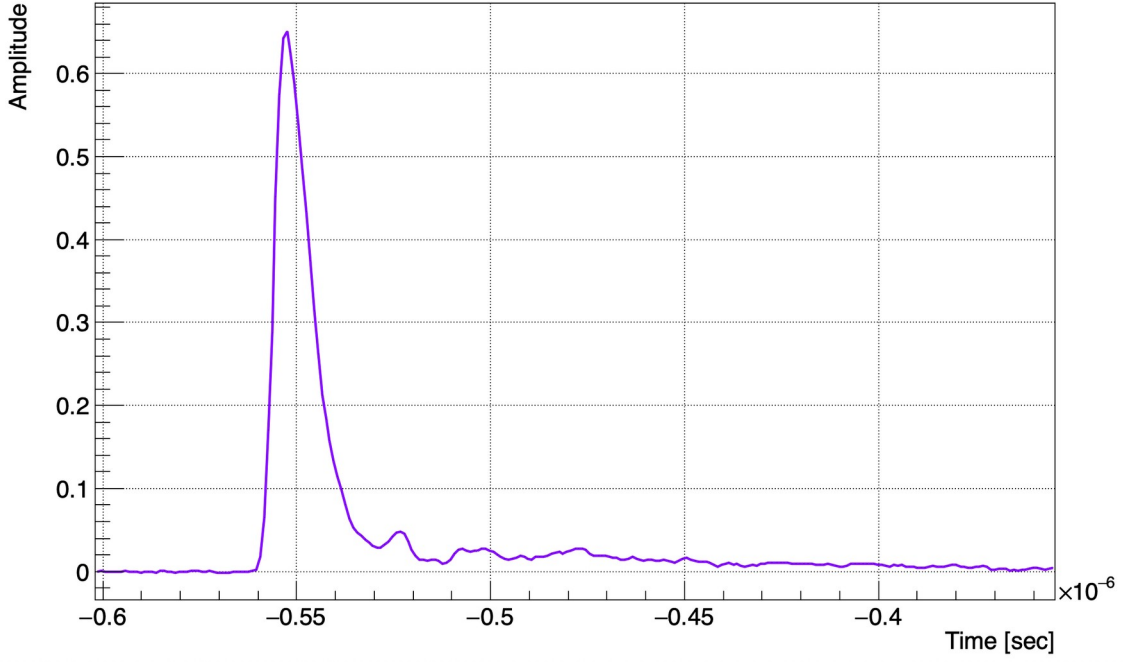


+ VETO (EJ-200)
readout by SiPMs



Neutron detectors

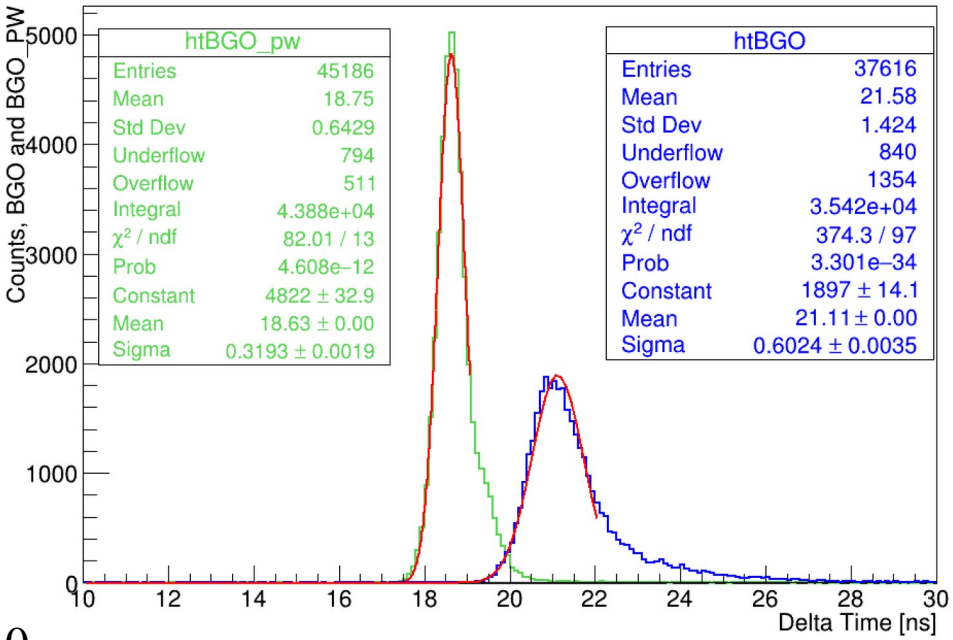
Phoswich: BGO crystals + EJ232

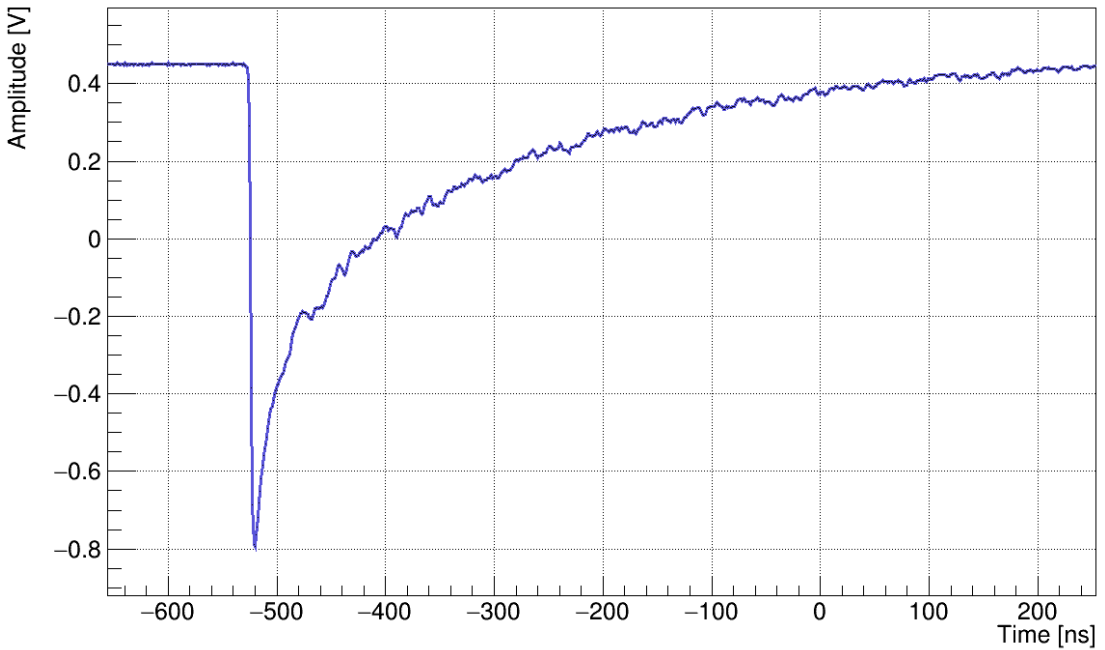
A1: 2.4x2.4 cm^2

A2: 3.3 x 3.3 cm^2

h: 24 cm

- Particle identification
- Possible Calorimeter upgrade





Neutron detectors

Phoswich: BGO crystals + EJ232

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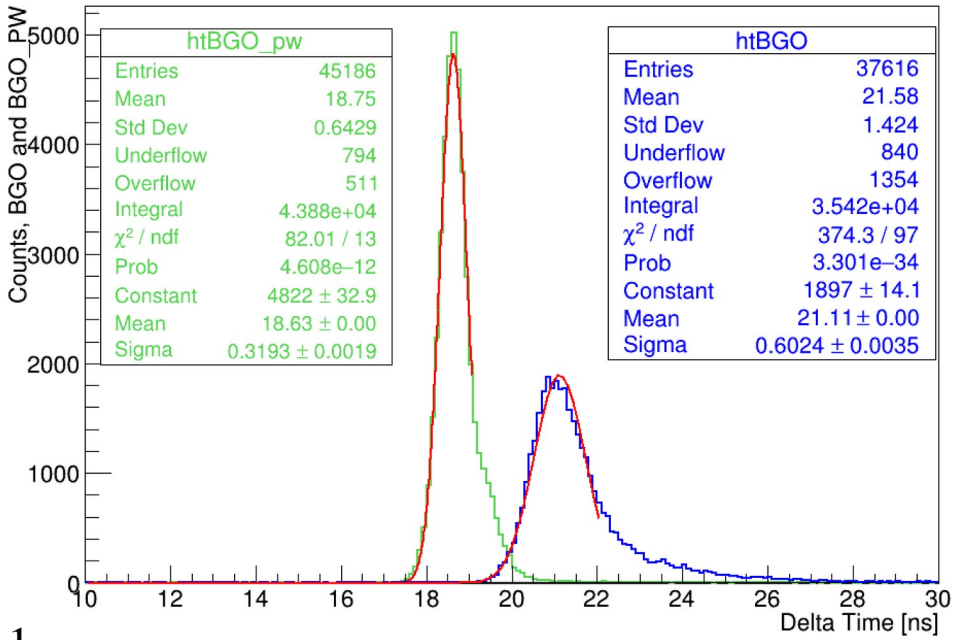
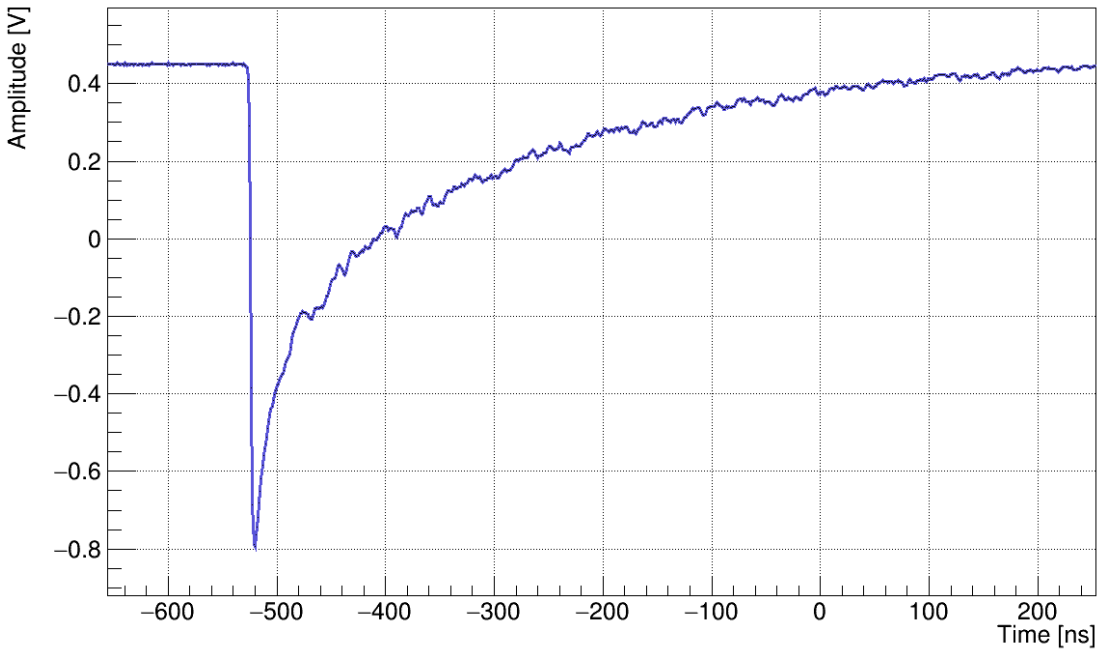
A2: 3.3 x 3.3 cm^2

h: 24 cm

- Particle identification
- Possible Calorimeter upgrade

+ VETO (EJ-204) readout w/ PMT

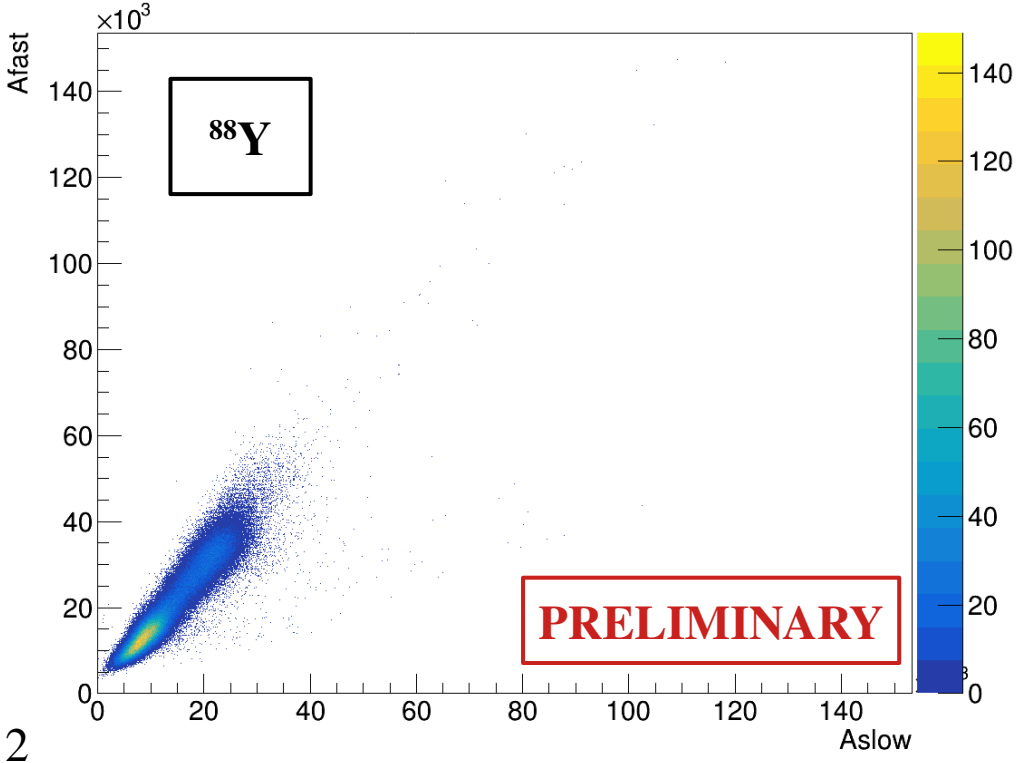


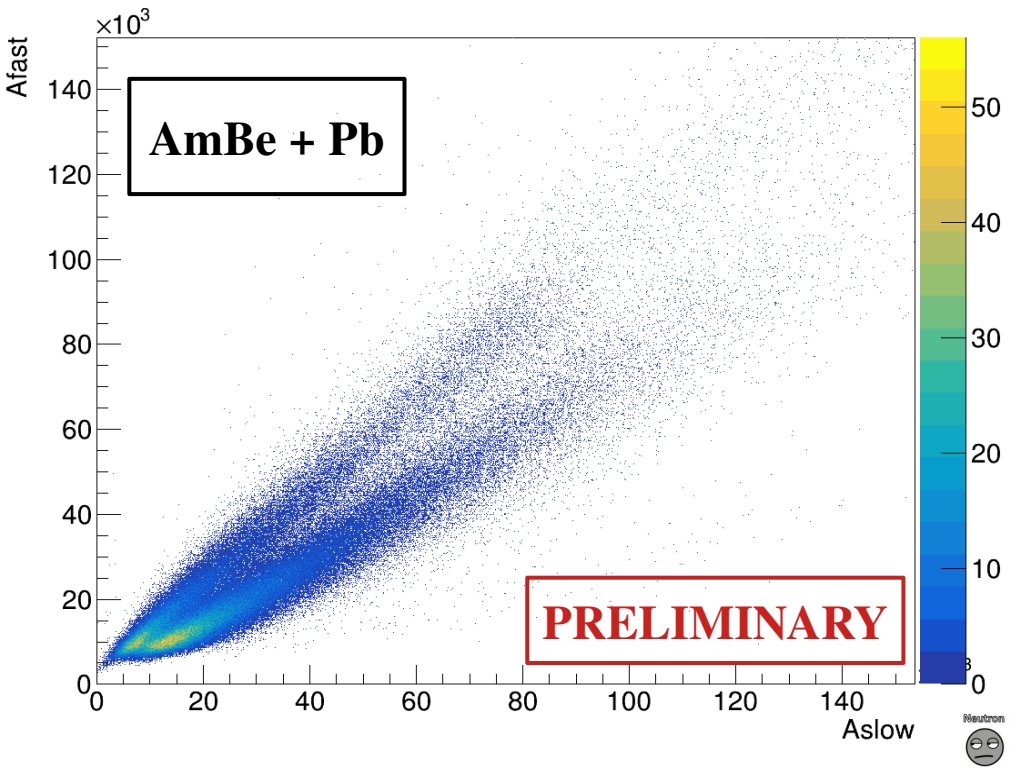


Detector characterization

1) Am-Be/^{88}Y source for preliminary particle identification (n-γ) studies

Until now ⟶ acquired data with NIKEs



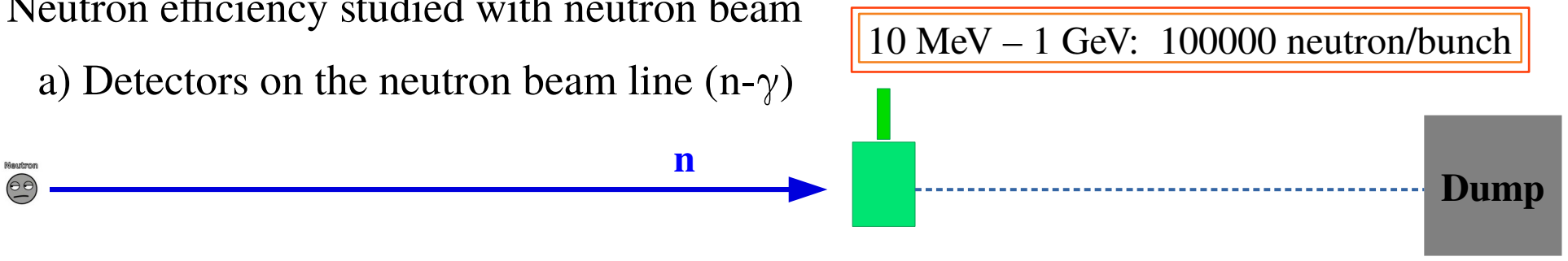


Detector characterization

1) Am-Be/^{88}Y source for preliminary particle identification (n-γ) studies

2) Neutron efficiency studied with neutron beam

   a) Detectors on the neutron beam line (n-γ)



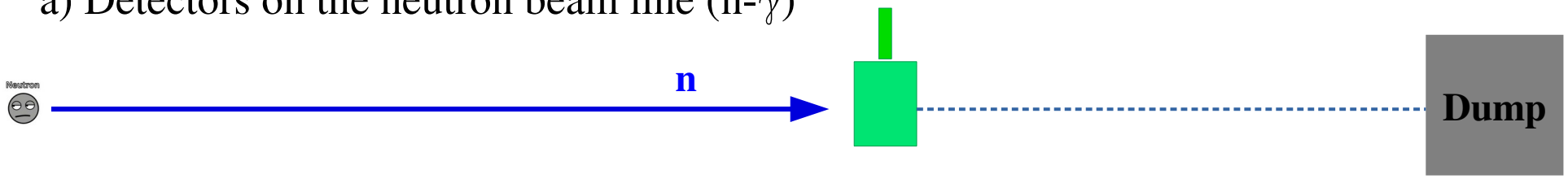
Detector characterization

1) Am-Be/^{88}Y source for preliminary particle identification (n-γ) studies

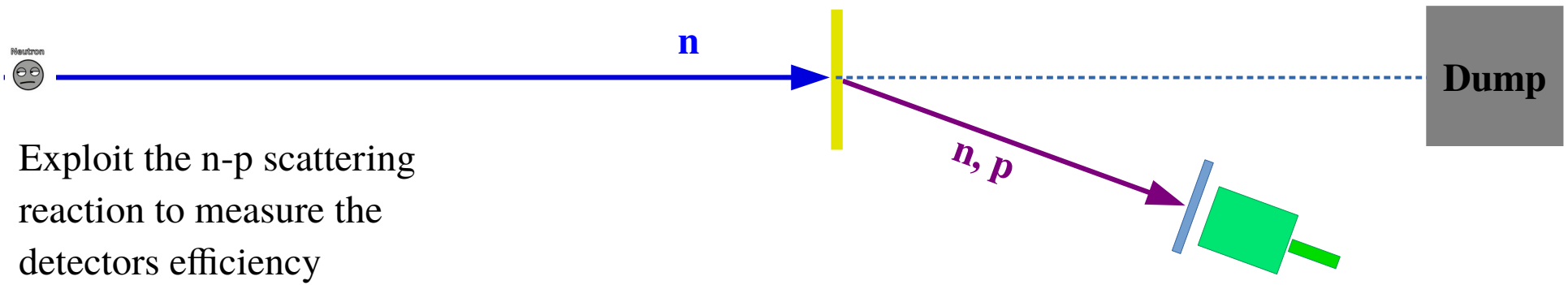
2) Neutron efficiency studied with neutron beam

10 MeV – 1 GeV: 100000 neutron/bunch

a) Detectors on the neutron beam line (n-γ)

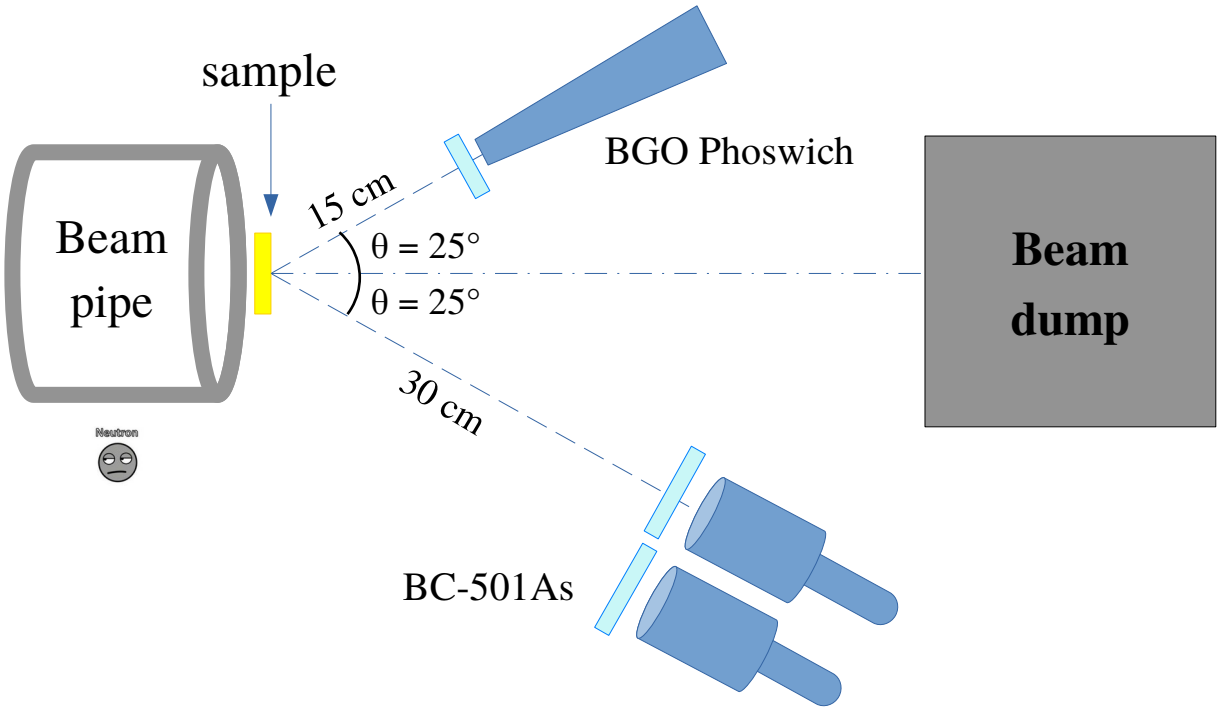


b) PE-C targets on the beam line and detectors (+ vetos) at a fixed angle (20-25°)



Exploit the n-p scattering reaction to measure the detectors efficiency

Detector characterization

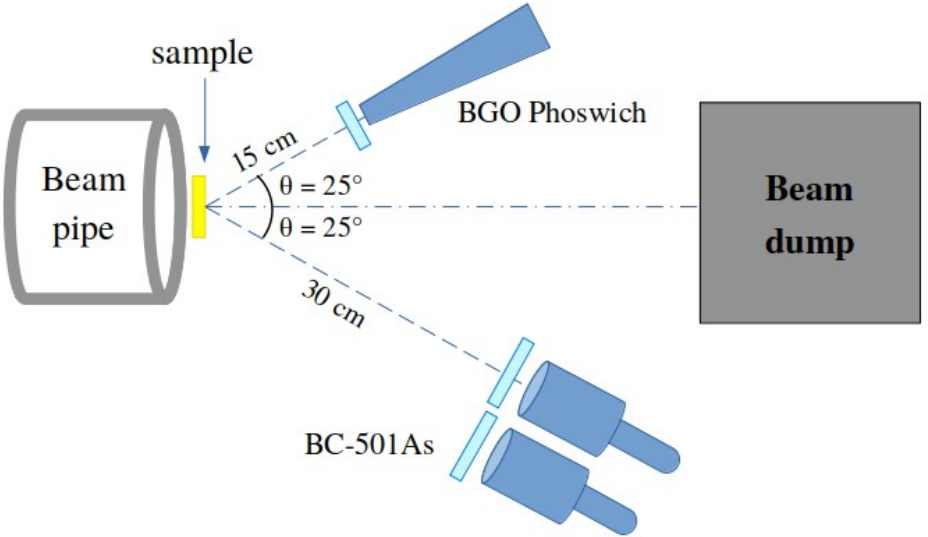


$$E_n = E'_n cos^2(\theta)$$

Detected neutron | **Incident neutron (TOF)** | **Scattering angle**

Detector	***d* [cm]**	**$\delta(cos^2\theta)$ [%]**
NIKE	30	10-13 → ±11
BGO	15	7-8 → ±7

Detector characterization



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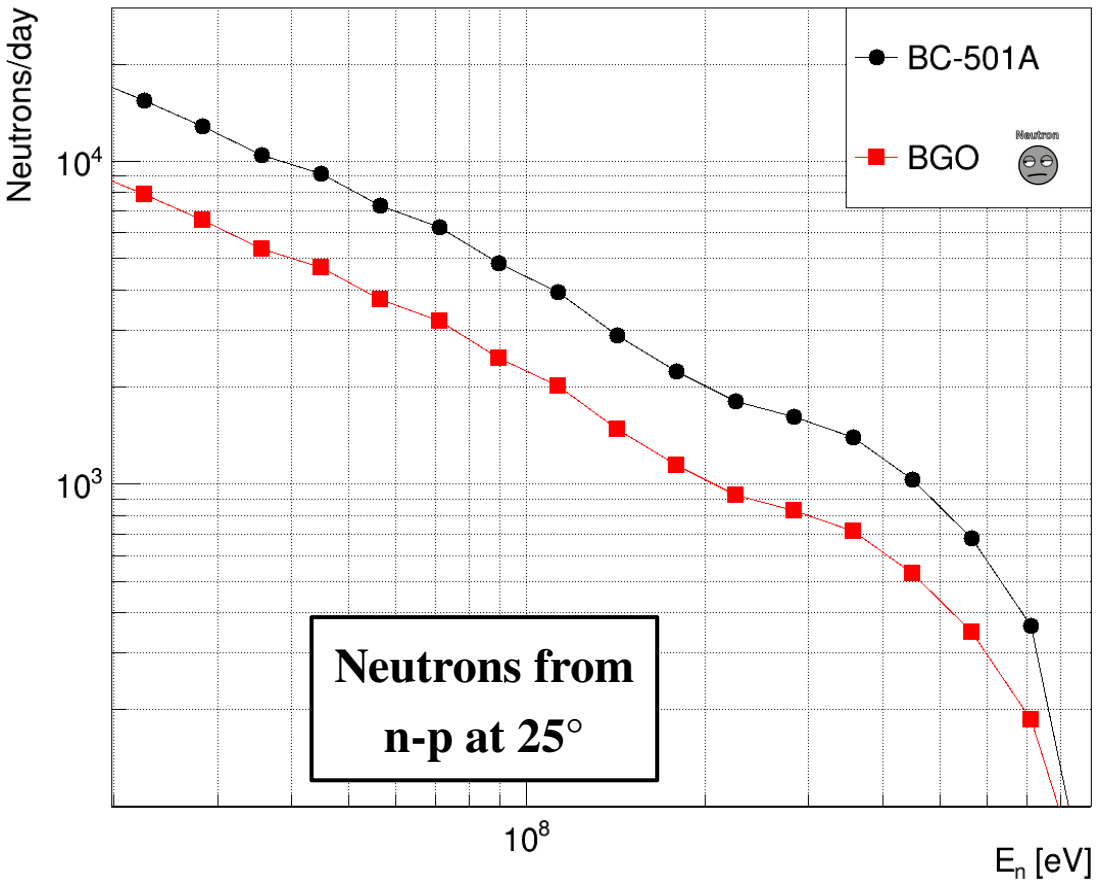


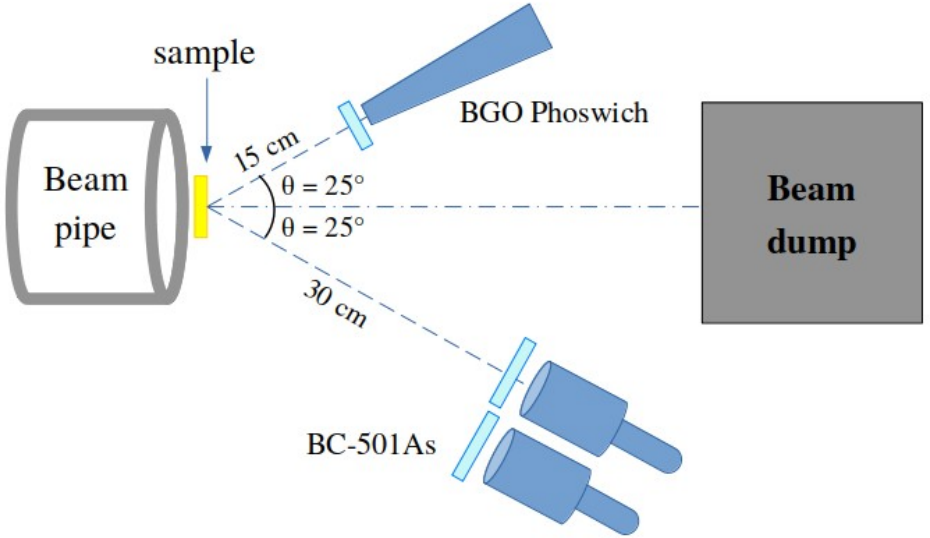
$n_H \approx 0.04$ at/barn

1 bunch every 6 s

10 bins/decade

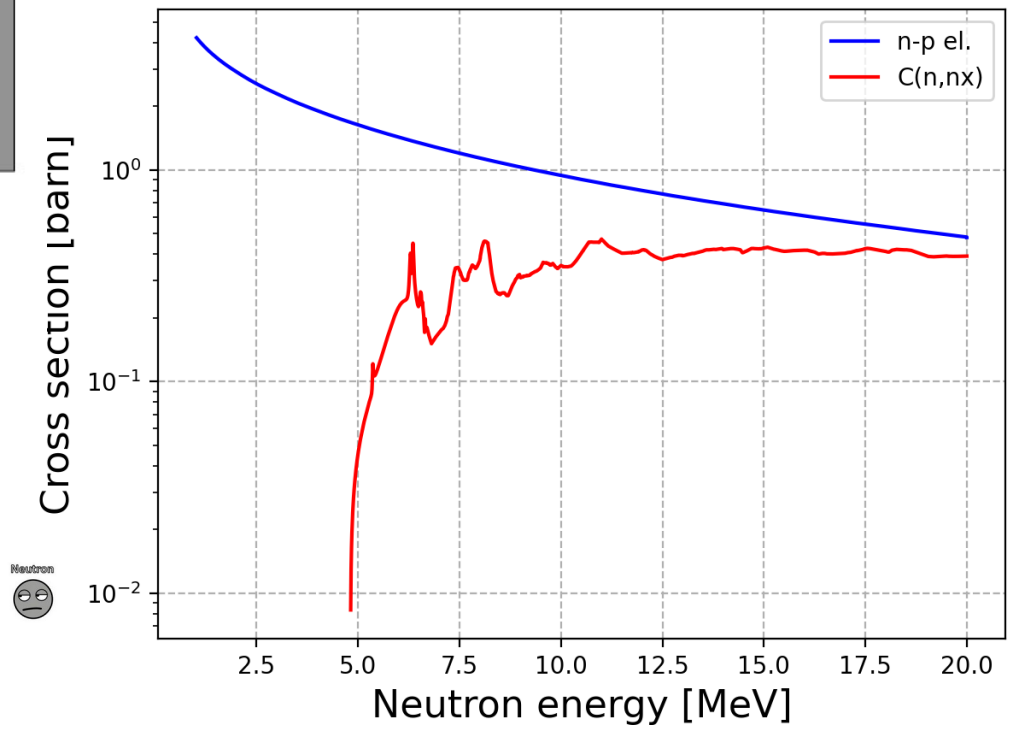
8-10% energy bin resolution

Detector characterization



PROBLEM: PE sample

Need to subtract the C contribution



OBJECTIVE

Neutron detection efficiency with maximum statistical uncertainty at the level of 5%

SOLUTION: 1 month PE 5mm + 1 month C 2.5mm

Conclusions

New FOOT neutron detectors under study at n_TOF

- Particle discrimination capabilities with radioactive sources
- Neutron detection efficiency with neutron beam
- ~ 2 months total acquisition time foreseen
  (1 month PE + 1 month C)
- Measurement performed in parallel with n_TOF physics program
- **No additional protons request needed**

Thank you for your attention