Workshop on Technologies & applied research at the future Valencian Proton-Therapy facility

Measurement with pure $LaCl_3$ crystal for Range Monitoring in Proton Therapy.

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Motivation

- Proton Therapy has emerged as a promising technique for cancer treatment.

-There is uncertainty in the proton Range.

-To avoid this, proton treatment plans are designed with safety margins that don't allow the maximum potential of the technique.

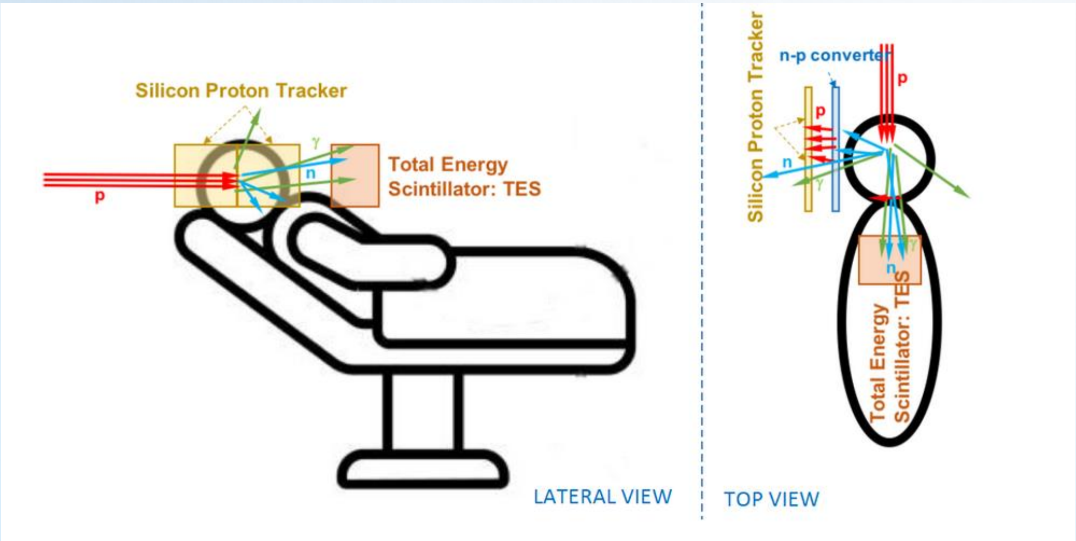
Solutions approaches:

1. **Take images with protons:** Direct RSP map [1]
2. **Verify the proton range online:** Detection of scattered particles (normally γ) [2]

[1] K.S. Ytre-Hauge, et al., Sci Rep 9, 2011 (2019)
[2] F. Hueso-Gonzalez and T. Bortfeld, IEEE Trans Radiat Plasma Med. Sci. 4, p. 170 (2020)

PRIDE project (Proton Range and Imaging Device)

We aim at the integration of a proton tomography **(pCT)** scanner and a range verification detector for proton therapy **(pRV)** within the same device.



- A position-sensitive plastic scintillator that acts as n-p converter; Two Double-Sided Silicon-Strip Detectors for the detection of lateral scattered neutrons and protons. [1]

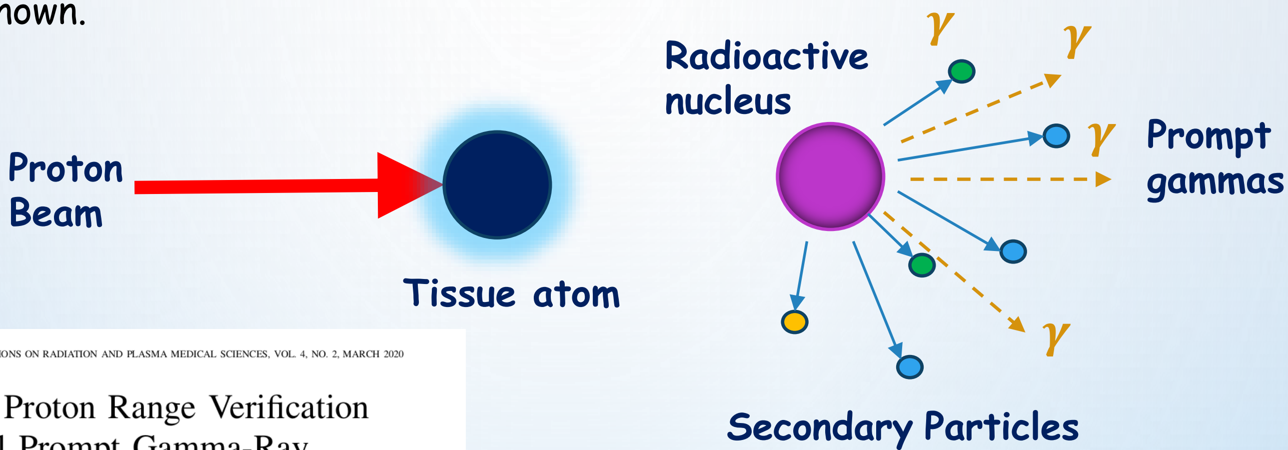
Amanda Nerio – IEM group

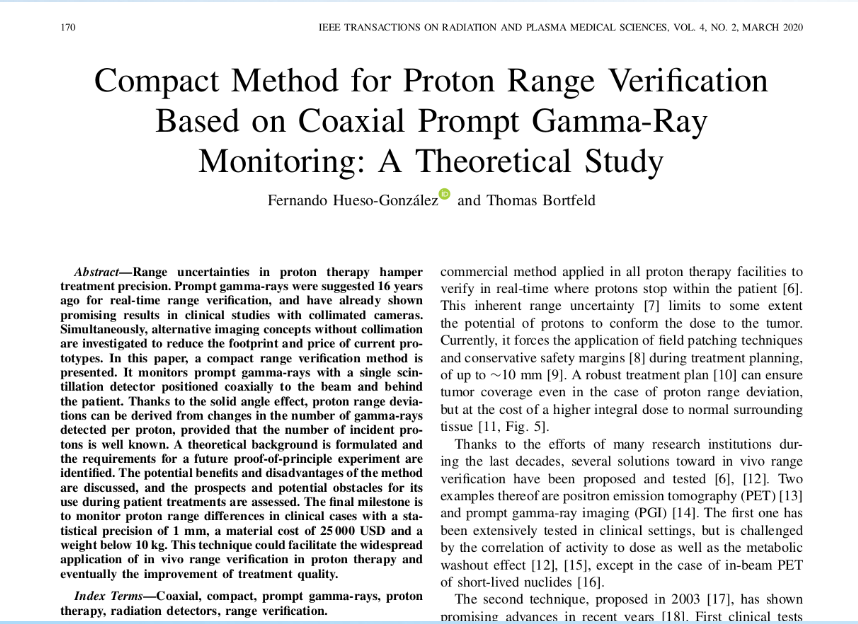
- Scintillator crystal, with excellent neutron-gamma discrimination, in coaxial configuration [2]

[1] K.S. Ytre-Hauge, et al., Sci Rep 9, 2011 (2019)
[2] F. Hueso-Gonzalez and T. Bortfeld, IEEE Trans Radiat Plasma Med. Sci. 4, p. 170 (2020)

What do we want to measure?

Thanks to the effect of the solid angle, the change in the range of the protons can generate a variation in the **number of gamma rays** detected per proton, as long as the number of incident protons is well known.





Compact Method for Proton Range Verification Based on Coaxial Prompt Gamma-Ray Monitoring: A Theoretical Study

Fernando Hueso-González and Thomas Bortfeld

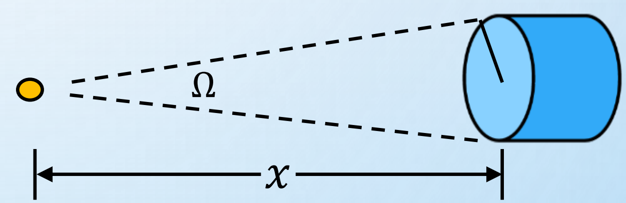
***Abstract*—Range uncertainties in proton therapy hamper treatment precision. Prompt gamma-rays were suggested 16 years ago for real-time range verification, and have already shown promising results in clinical studies with collimated cameras. Simultaneously, alternative imaging concepts without collimation are investigated to reduce the footprint and price of current prototypes. In this paper, a compact range verification method is presented. It monitors prompt gamma-rays with a single scintillation detector positioned coaxially to the beam and behind the patient. Thanks to the solid angle effect, proton range deviations can be derived from changes in the number of gamma-rays detected per proton, provided that the number of incident protons is well known. A theoretical background is formulated and the requirements for a future proof-of-principle experiment are identified. The potential benefits and disadvantages of the method are discussed, and the prospects and potential obstacles for its use during patient treatments are assessed. The final milestone is to monitor proton range differences in clinical cases with a statistical precision of 1 mm, a material cost of 25 000 USD and a weight below 10 kg. This technique could facilitate the widespread application of in vivo range verification in proton therapy and eventually the improvement of treatment quality.**

***Index Terms*—Coaxial, compact, prompt gamma-rays, proton therapy, radiation detectors, range verification.**

commercial method applied in all proton therapy facilities to verify in real-time where protons stop within the patient [6]. This inherent range uncertainty [7] limits to some extent the potential of protons to conform the dose to the tumor. Currently, it forces the application of field patching techniques and conservative safety margins [8] during treatment planning, of up to ~10 mm [9]. A robust treatment plan [10] can ensure tumor coverage even in the case of proton range deviation, but at the cost of a higher integral dose to normal surrounding tissue [11, Fig. 5].

Thanks to the efforts of many research institutions during the last decades, several solutions toward in vivo range verification have been proposed and tested [6], [12]. Two examples thereof are positron emission tomography (PET) [13] and prompt gamma-ray imaging (PGI) [14]. The first one has been extensively tested in clinical settings, but is challenged by the correlation of activity to dose as well as the metabolic washout effect [12], [15], except in the case of in-beam PET of short-lived nuclides [16].

The second technique, proposed in 2003 [17], has shown promising advances in recent years [18]. First clinical tests



Fernando Hueso will provide a more in-depth explanation of the method later today.

F. Hueso-Gonzalez and T. Bortfeld, IEEE Trans Radiat Plasma Med. Sci. 4, p. 170 (2020)

What do we want to measure?

We want to follow the same approach but making use of the simultaneous detection of γ-rays and neutrons.

Why γ-rays and neutrons?

Independent measurements and lower neutron background

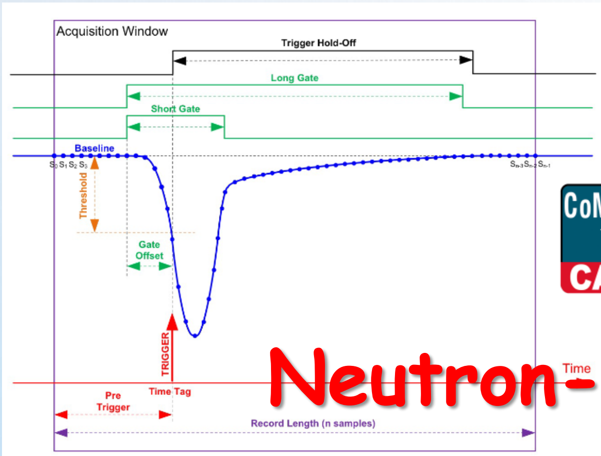
Therefore, we need a scintillating crystal, in coaxial configuration, with a good Pulse-Shape Discrimination (PSD) of γ-rays and neutrons.

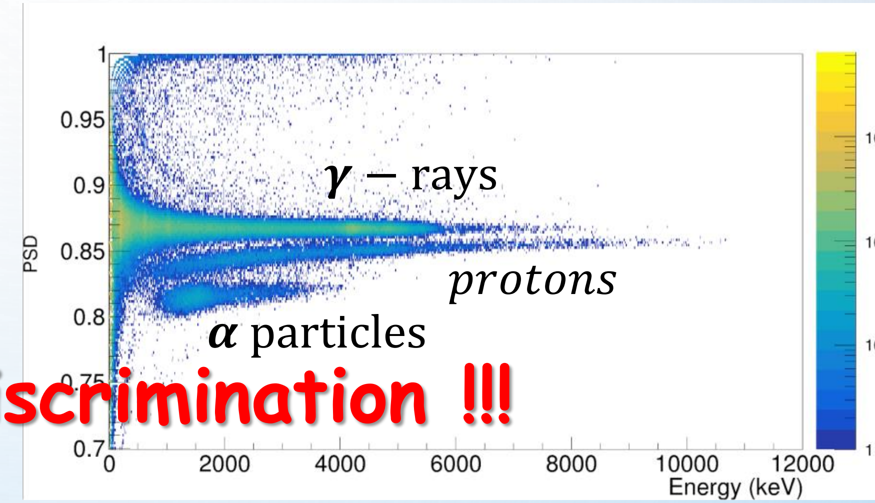
(PSD) Pulse Shape Discrimination

$$\boldsymbol{PSD} = \frac{Q_{LG} - Q_{SG}}{Q_{Lg}}$$

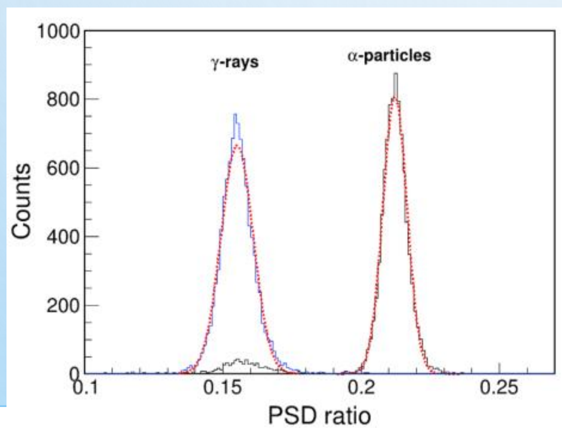
$\boldsymbol{Q_{LG}}$ *charge acumulate in Long Gate*

$\boldsymbol{Q_{SG}}$ *charge acumulate in Short Gate*





Neutron-γ discrimination !!!



$$\mathrm{FOM} = \frac{|P_\alpha - P_\gamma|}{FWHM_\alpha + FWHM_\gamma}.$$

$$FOM > 1.5$$

P. Vuong, H. Kim et al., Nuclear Engineering and Technology 53, p. 3784 (2021)

Possible Candidates

- **CLYC** $(Cs_2\ Li\ Y\ Cl_6{:}\,Ce)$

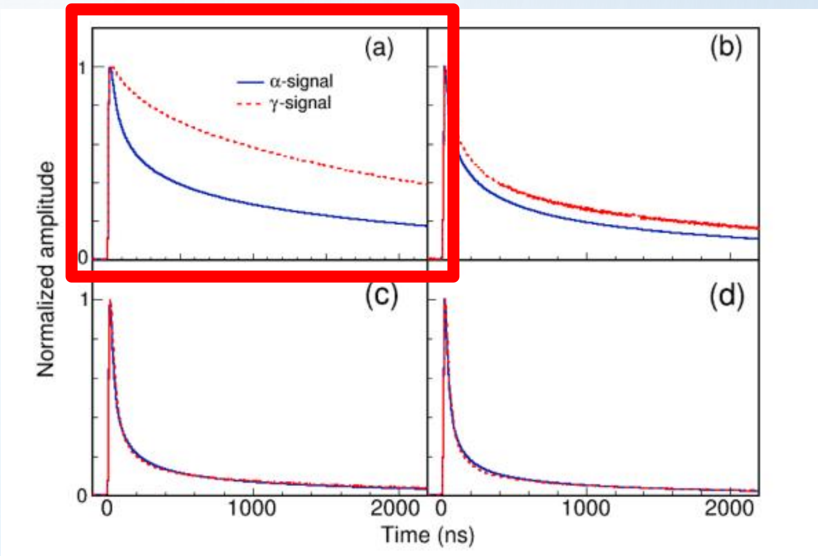
35Cl(n,p)35S
35Cl(n,a)32P

Whit a good PSD capability neutron-γ but cannot discriminate the reaction products within the crystal. It's better for slow neutrons

- $\boldsymbol{LaCl_3{:}\,Ce}$

The best **FOM** values were estimated to be 2.5, 1.8, 0.9, and 0.8 for pure, 0.01%, 0.05%, and 0.1% Ce-doped LaCl3 crystals, respectively.

Decreasing Ce concentration produces a better PSD discrimination.

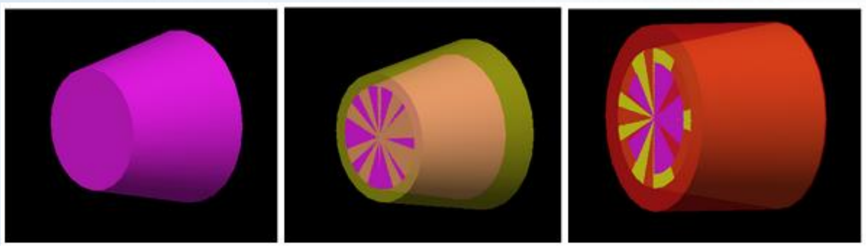


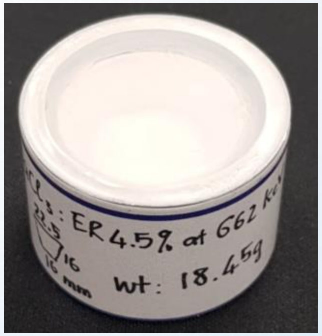
(a) Pure **(b)** 0.01% **(c)** 0.05% **(d)** 0.1% Ce Doped LaCl3 crystals

P. Vuong, H. Kim et al., Nuclear Engineering and Technology 53, p. 3784 (2021)

Pure LaCl3

We have used a **non-commercial** pure LaCl3 scintillator with excellent neutron-gamma discrimination, provided by our collaborators Phan Quoc Vuong and Hongjoo Kim from the Department of Physics at Kyungpook National University (South Korea).



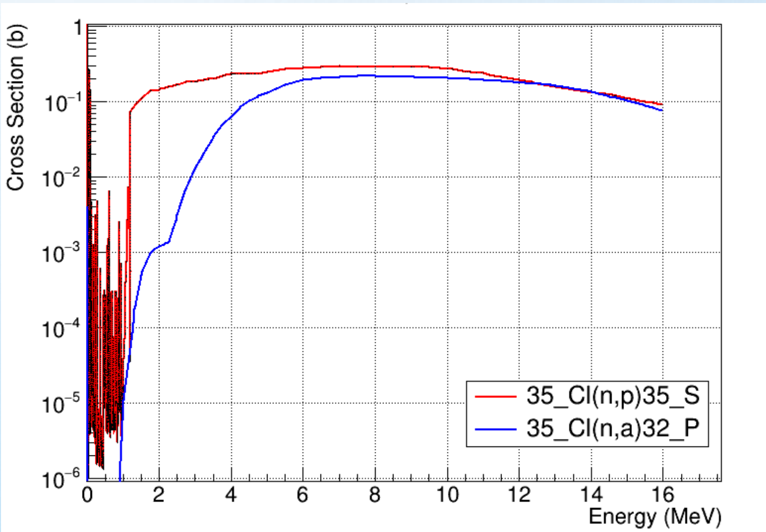


KYUNGPOOK NATIONAL UNIVERSITY

Truncated conical shape.
- 16 mm high.
- 16 mm smallest diameter.
- 22.5 mm largest diameter

Density 3.84 g/cm3
Light yield 34000 photons/MeV

Resolution 4.0% FWHM a 662 keV



P. Vuong, H. Kim et al., Nuclear Engineering and Technology 53, p. 3784 (2021)

Setup

- Target of CsI
  Proton Beam 10 MeV

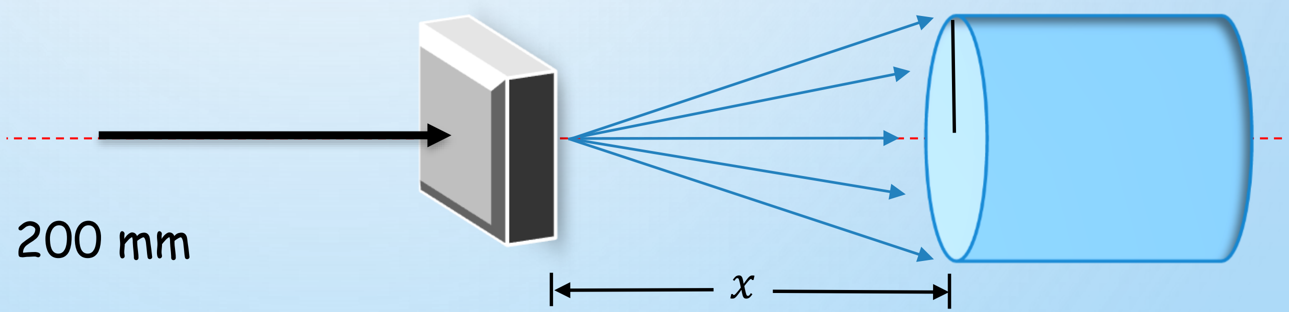
$$p + {}^{127}_{\cdot}I \rightarrow {}^{127}_{\cdot}Xe + n$$

- Target of 9Be

$$a + {}^{9}_{\cdot}Be \rightarrow {}^{12}_{\cdot}C + n$$

Alphas 4 MeV
HV: -1100

PMT: R1924-100 Hamamatsu
Long gate: 16 us
Short gate: 0.4 us

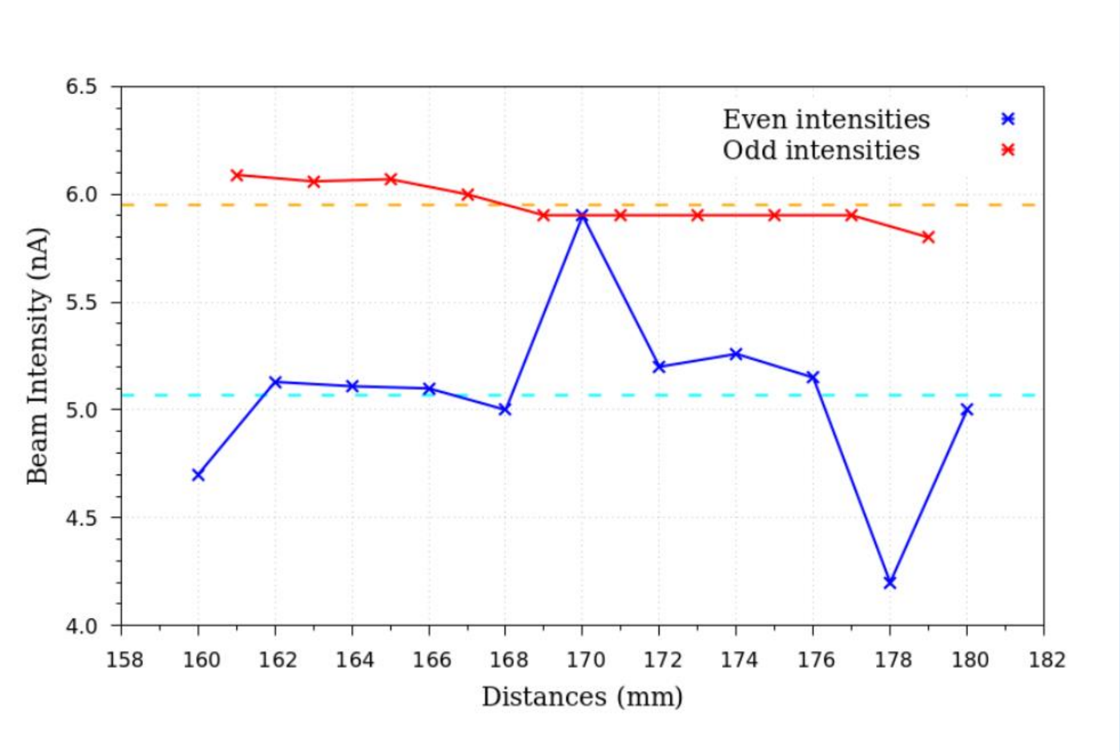


Distances: 185, 190, 195, 200 mm
Time: 600 s

Preliminary Analysis

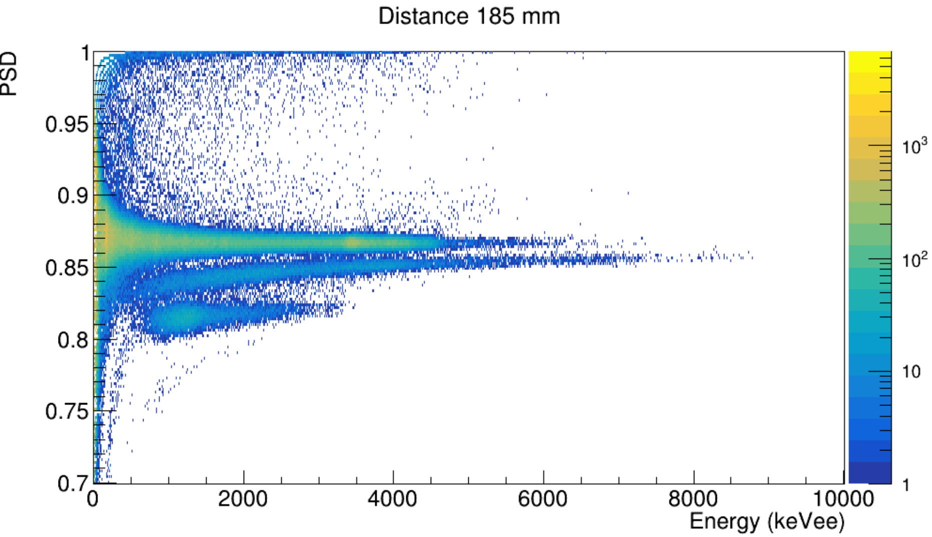
Feb - 2023

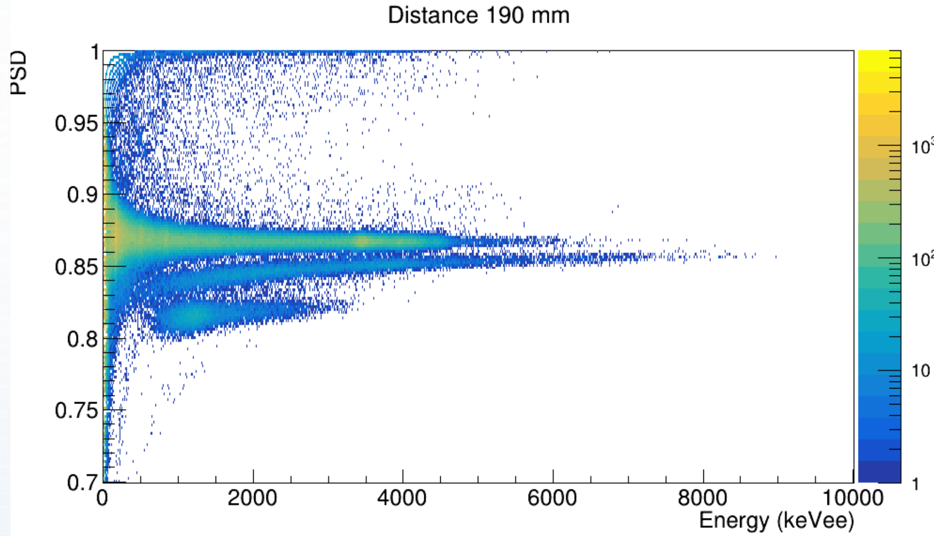
Certain factors directly affected the outcomes. Specifically, the instability in beam intensity during the measurements and the need to turn the beam on and off to reposition the target significantly impacted the results.

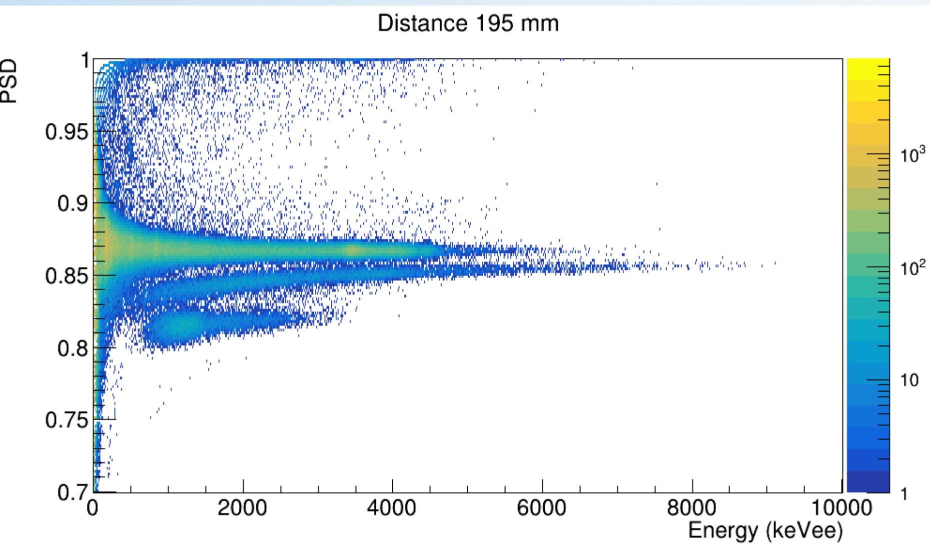


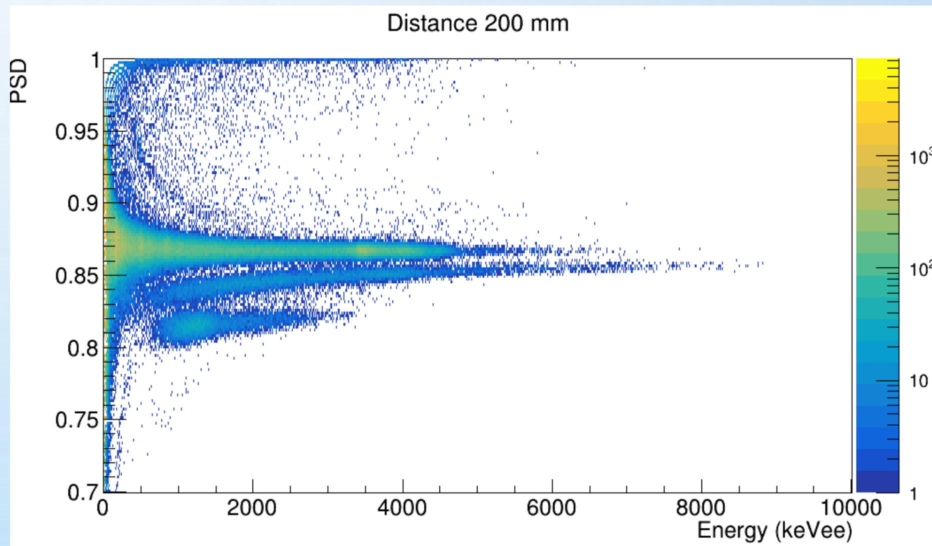
Jun 2023

PSD

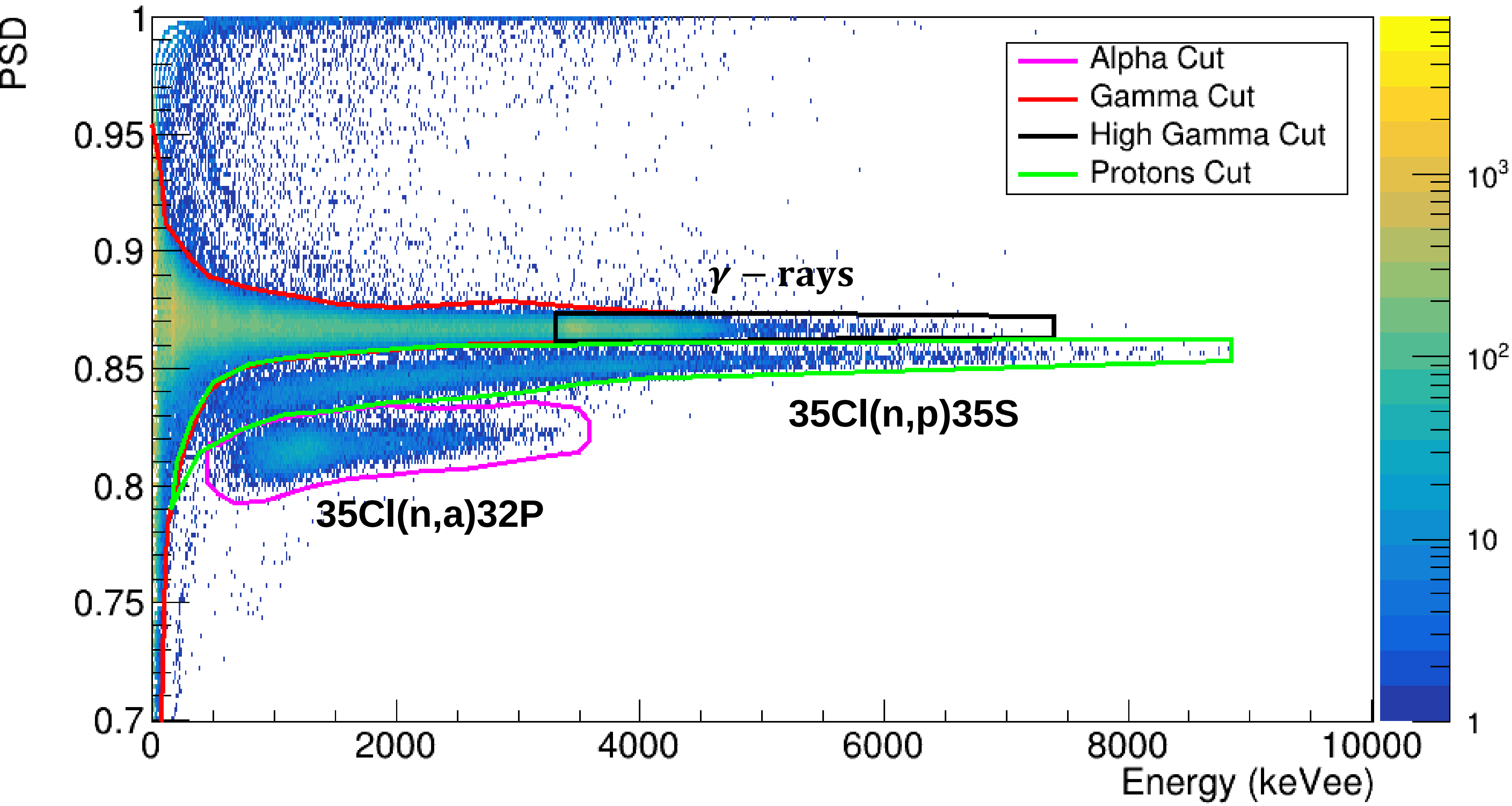

Distance 185 mm
PSD
1
0.95
0.9
0.85
0.8
0.75
0.7
0
2000
4000
6000
8000
10000
Energy (keVee)
10^3
10^2
10
1


Distance 190 mm
PSD
1
0.95
0.9
0.85
0.8
0.75
0.7
0
2000
4000
6000
8000
10000
Energy (keVee)
10^3
10^2
10
1


Distance 195 mm
PSD
1
0.95
0.9
0.85
0.8
0.75
0.7
0
2000
4000
6000
8000
10000
Energy (keVee)
10^3
10^2
10
1

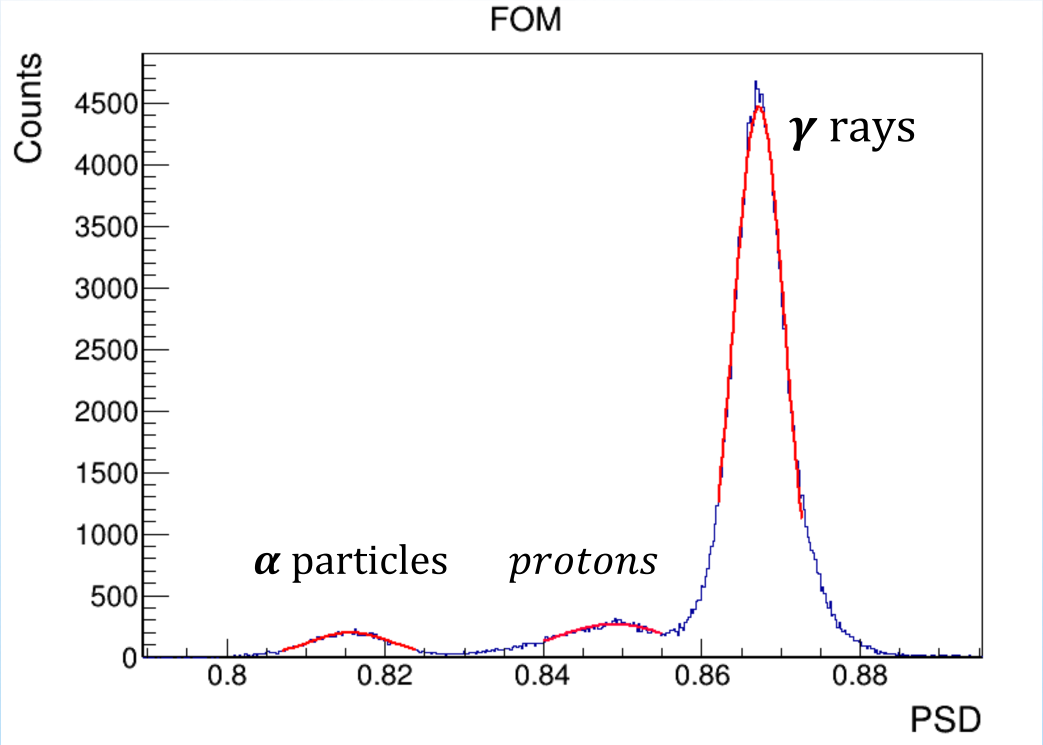

Distance 200 mm
PSD
1
0.95
0.9
0.85
0.8
0.75
0.7
0
2000
4000
6000
8000
10000
Energy (keVee)
10^3
10^2
10
1

-PSD


PSD
1
0.95
0.9
0.85
0.8
0.75
0.7
0
2000
4000
6000
8000
10000
Energy (keVee)
Alpha Cut
Gamma Cut
High Gamma Cut
Protons Cut
γ – rays
35Cl(n,p)35S
35Cl(n,a)32P
10^3
10^2
10
1

-FOM

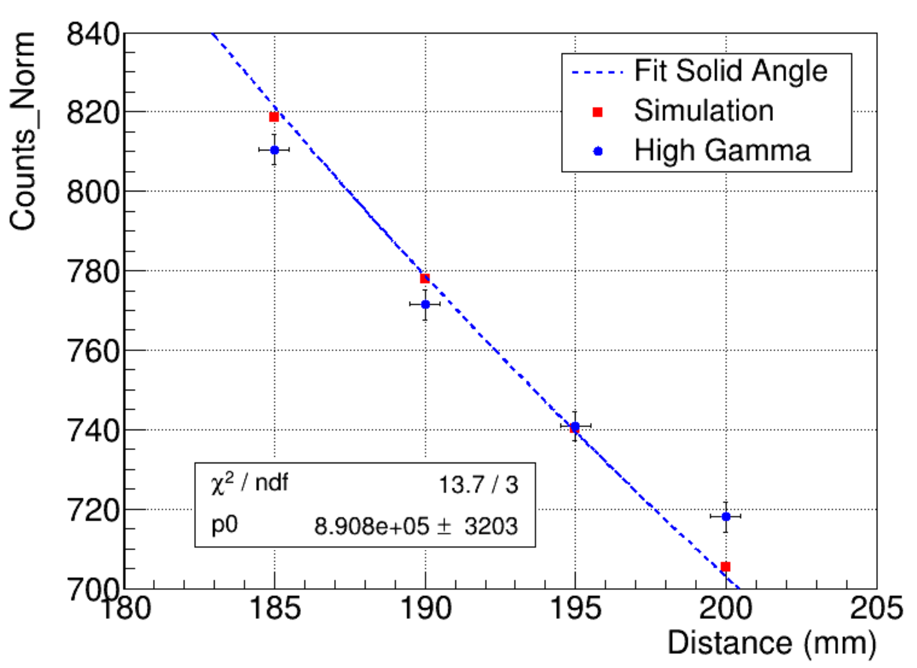
Distance (mm)	FOM (γ,α)	FOM (γ,p)	FOM (p,a)
185	2.60	0.75	1.15
190	2.52	0.76	1.13
195	2.61	0.74	1.13
200	2.57	0.74	1.12

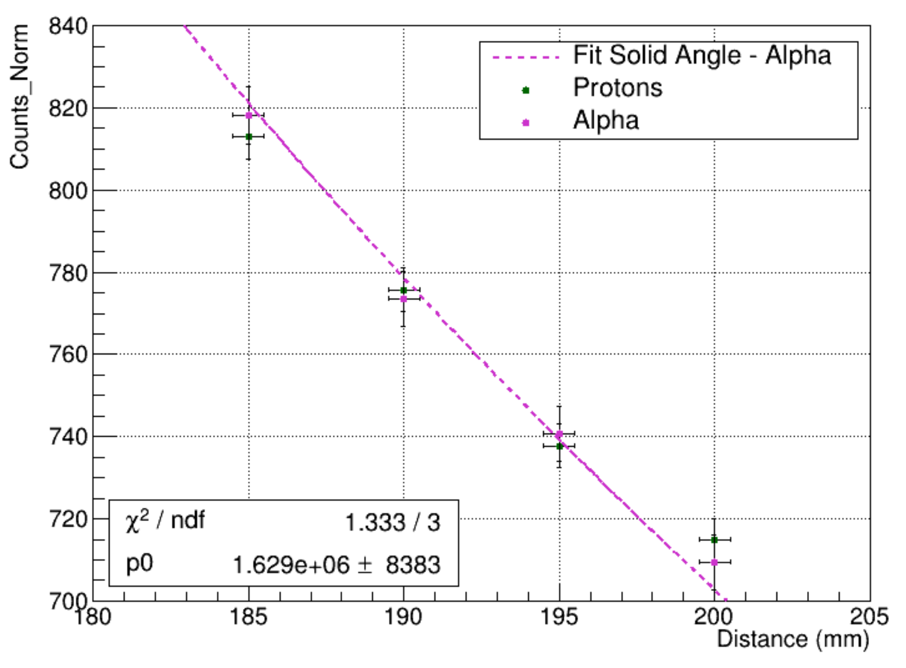


-Sensitivity

Distance (mm)	Counts Alpha	Counts total gammas	Counts protons	Counts High Gamma
185	256	11766	405	810
190	242	11356	386	771
195	232	10957	368	741
200	222	10652	356	718

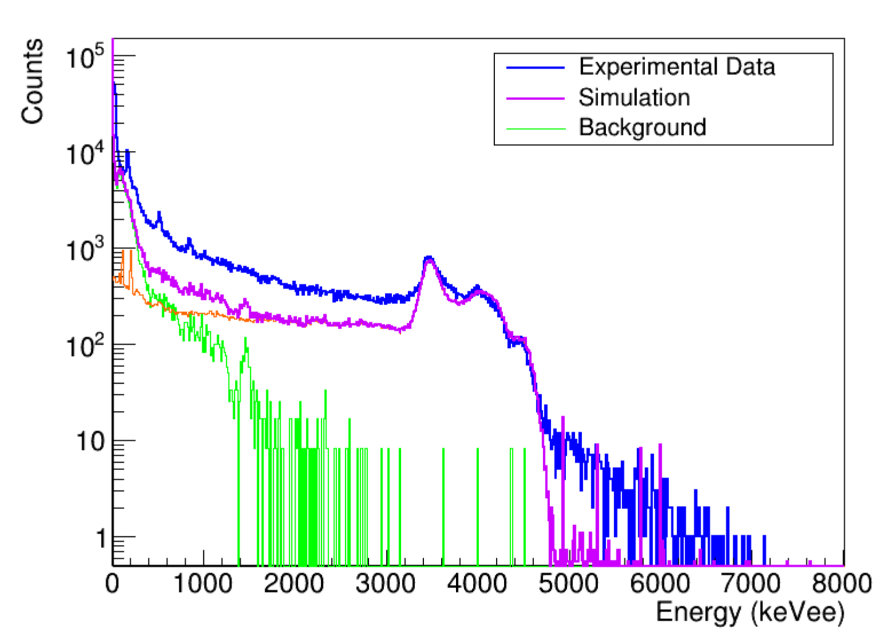
$$\frac{\Omega}{4\pi} = \frac{p0}{2} \cdot \left(1 - \frac{x}{\sqrt{x^2 + r^2}}\right)$$



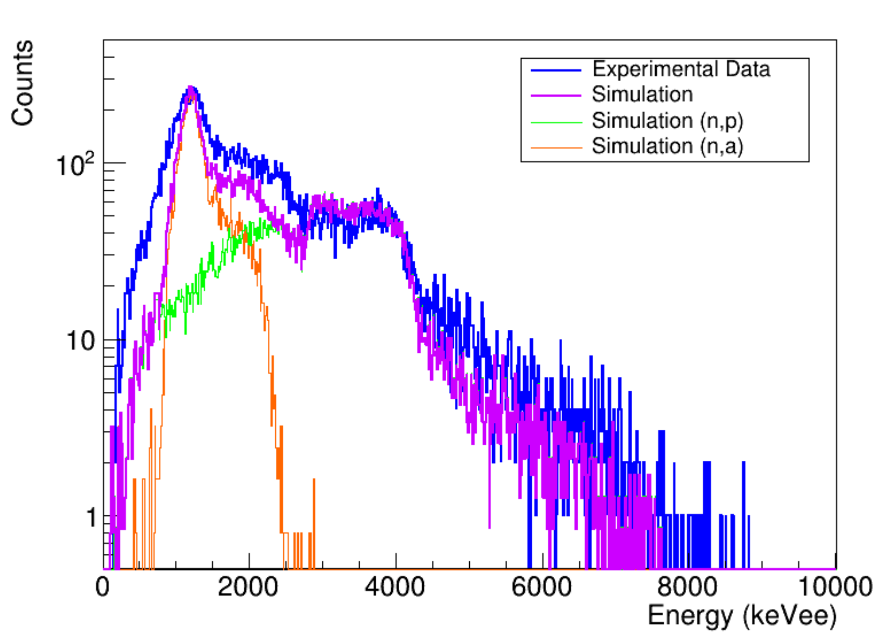


-Simulation results

γ rays



Neutrons



Summary

Pure LaCl3 is a good candidate for gamma and neutron discrimination, it presents a good PSD capacity, practical for neutron spectroscopy.

As a first sensitivity test, it presents encouraging results in the adjustment to the theoretical model, however, it is a measure that does not have the realistic conditions of a proton therapy facility.

The **PRIDE project** will carry out the first scope verification test. A measurement is planned at the Krakow CCB facility, with different basic phantoms, changing the beam energies between 80 - 125 MeV and so that the Bragg peak moves between 5 and 10 cm in 20 steps of 2.5 mm. With this measurement we plan to test the range-verification capabilities of our coaxial LaCl3 detector and the pixelated plastic + DSSD tracker.

THANKS

TO THE AUDIENCE AND TO WHO HAVE ORGANIZED THIS EVENT

Contact us

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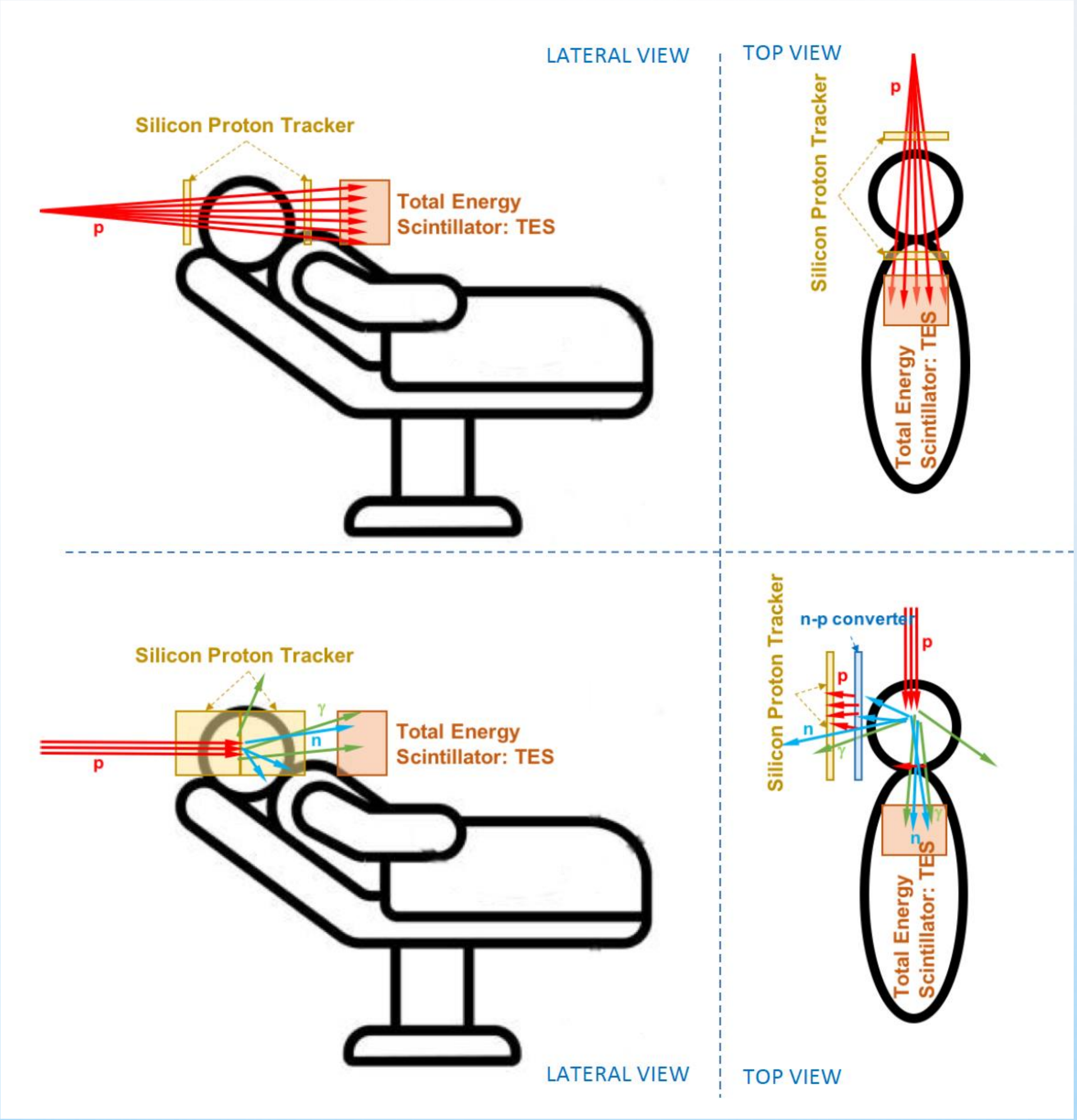
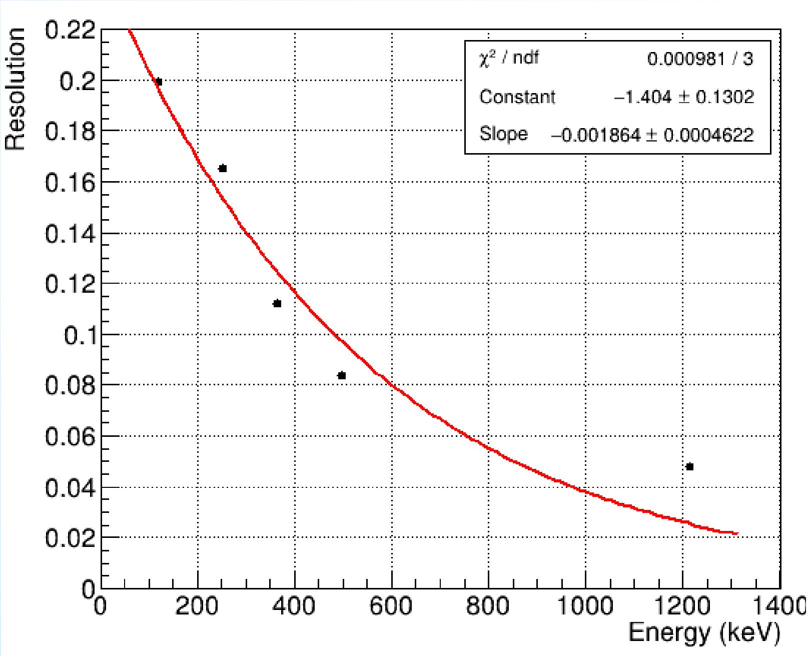
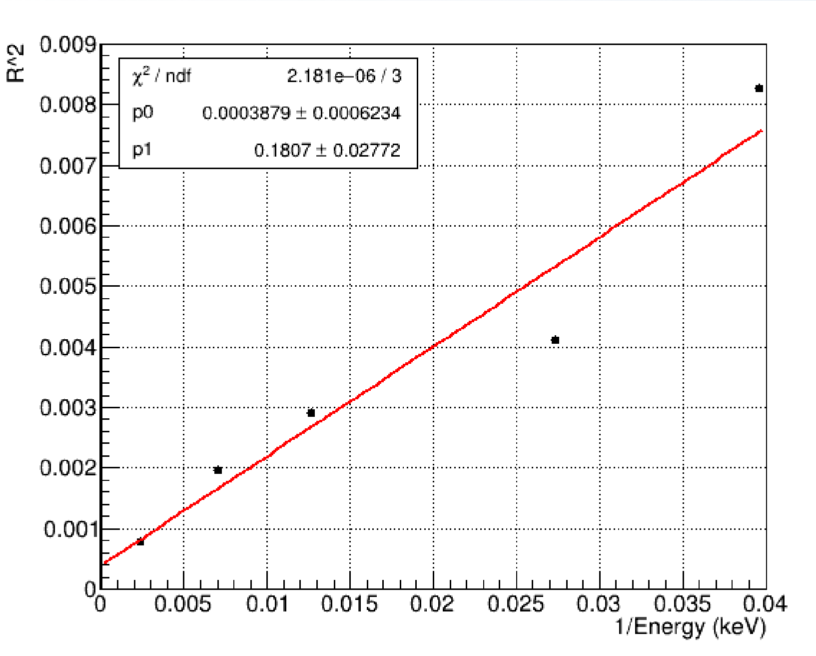
Backup



LATERAL VIEW
TOP VIEW
Silicon Proton Tracker
p
Total Energy
Scintillator: TES
Silicon Proton Tracker
p
Total Energy
Scintillator: TES
Silicon Proton Tracker
γ
n
p
Total Energy
Scintillator: TES
Silicon Proton Tracker
n-p converter
p
p
n
γ
γ
n
Total Energy
Scintillator: TES
LATERAL VIEW
TOP VIEW

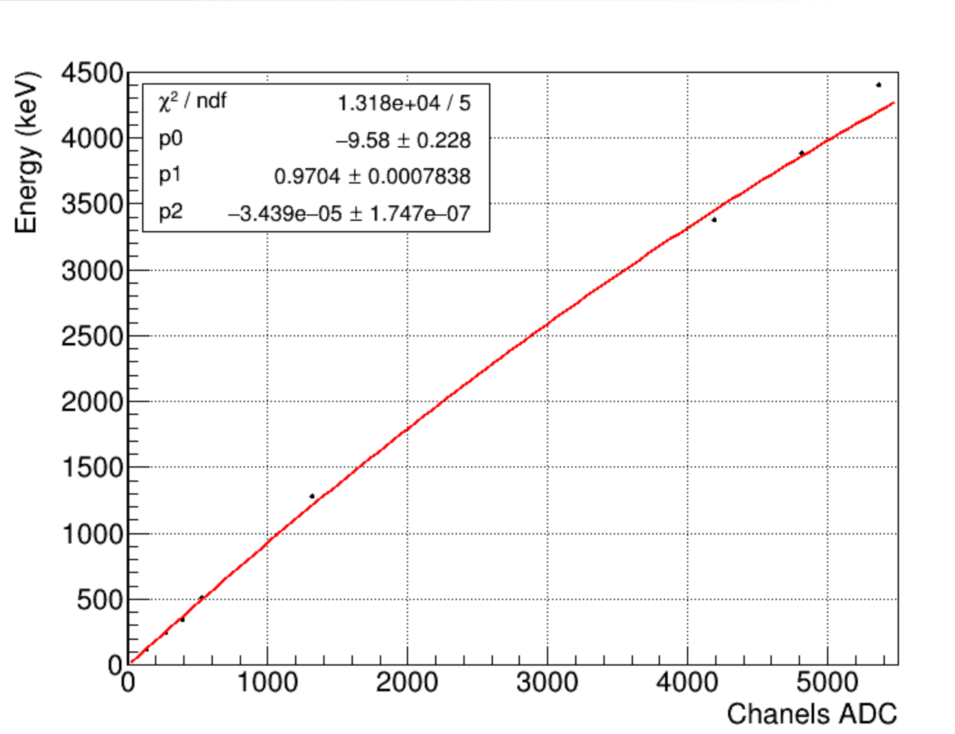
Resolution CMAM – Jun 2023

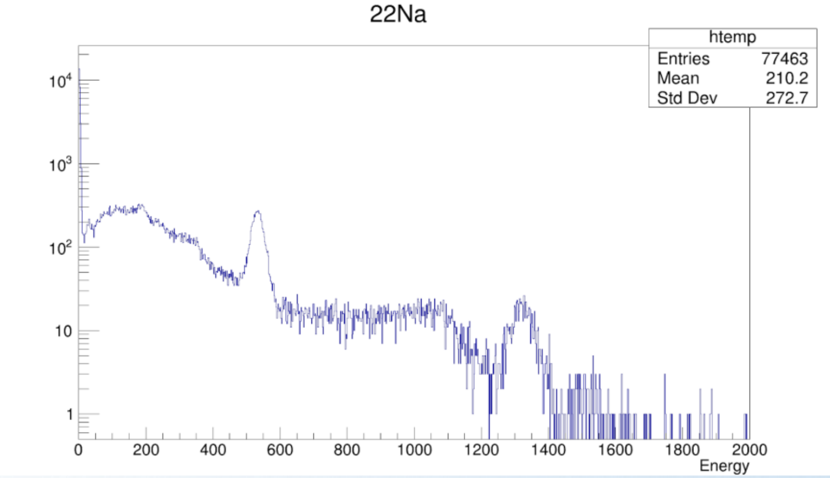


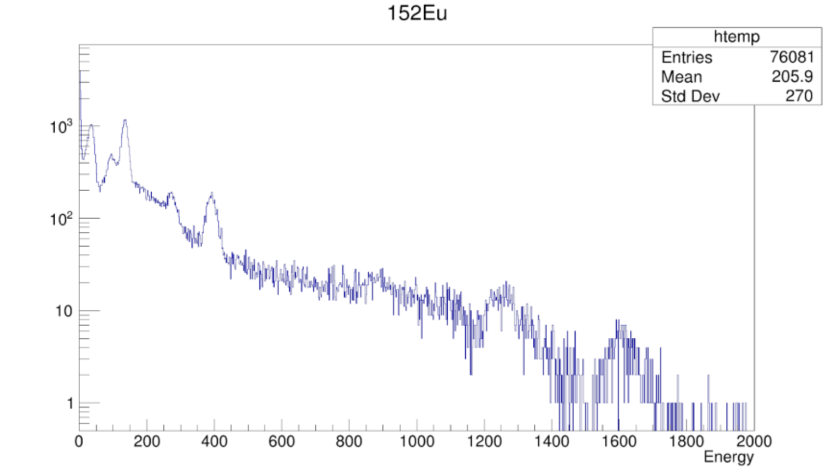


Calibration

Na22 - Eu152



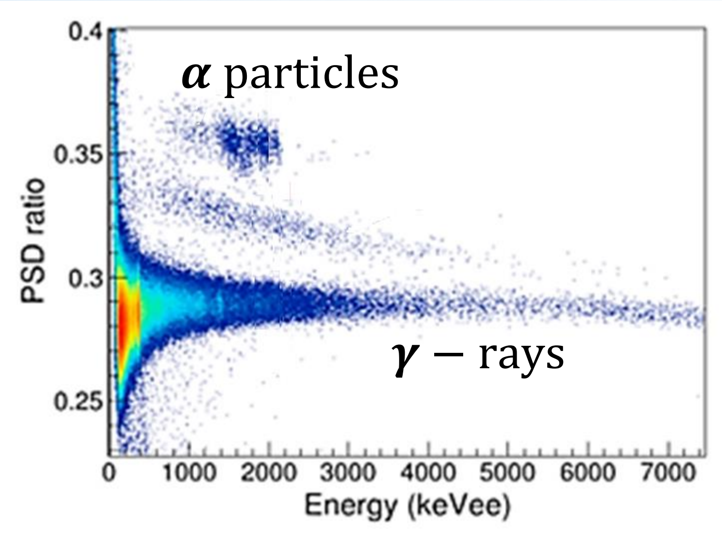


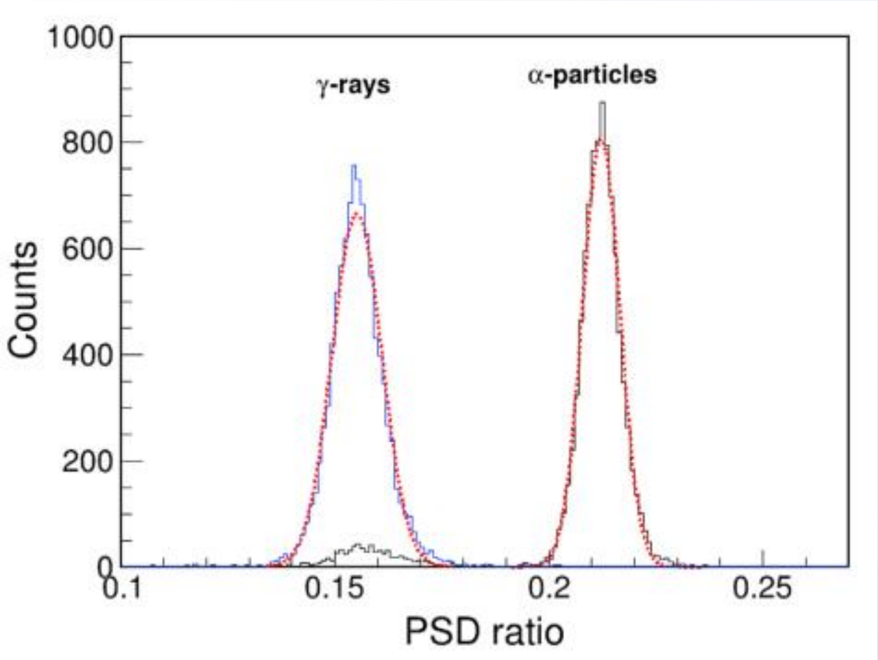


(FOM) Figure Of Merit

Parameter that shows the separation power between alpha and gamma signals.

$$\mathrm{FOM} = \frac{|P_\alpha - P_\gamma|}{FWHM_\alpha + FWHM_\gamma}.$$





[Vuong2021]

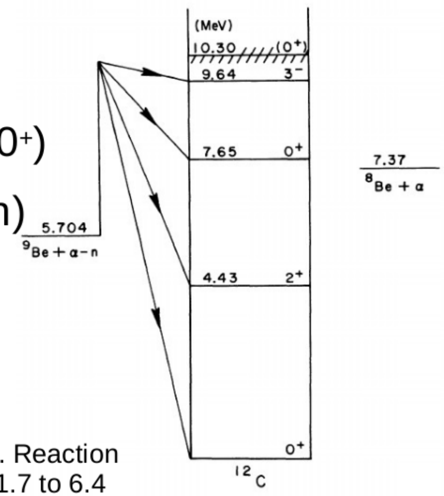
[Vuong2021]

Reactions target 9Be Alphas 4 MeV

9Be(alpha,n)12C has 3 possible channels:

- N0: Ground State (No gamma)
- N1: Excited State 4.43 MeV (Gamma)
- N2: Excited State 7.65 MeV (No Gamma $0^+ \rightarrow 0^+$)
- N3: Excited State 9.64 MeV (Gamma, too high)

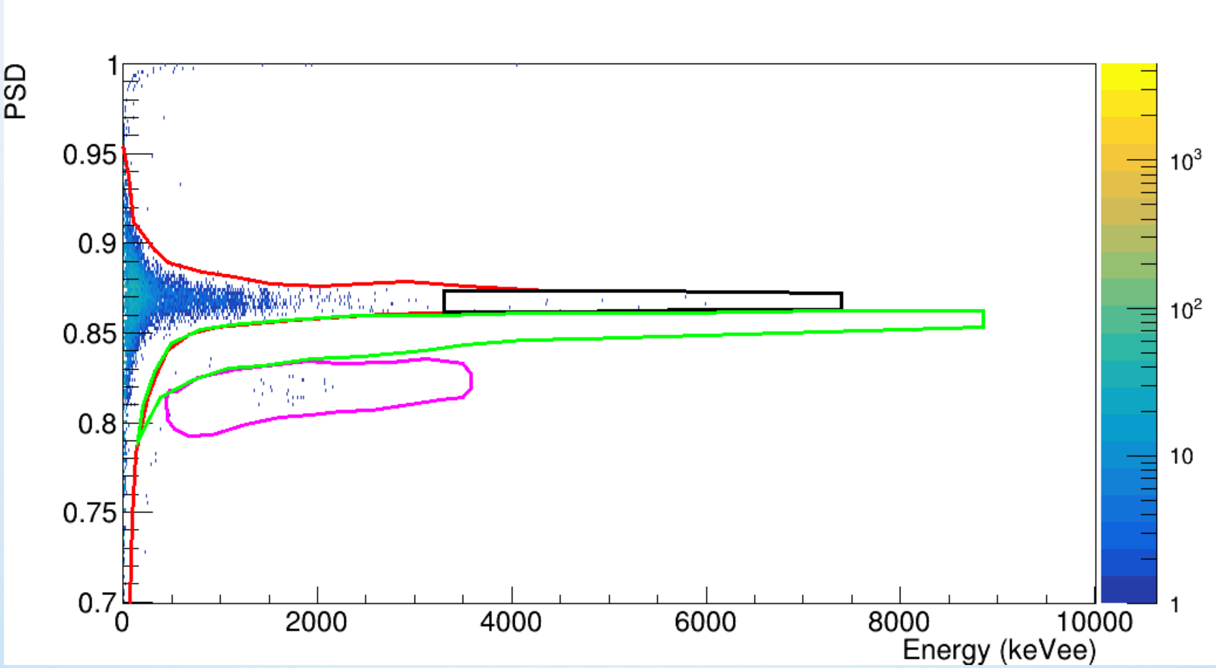
We must maximize N1 production!



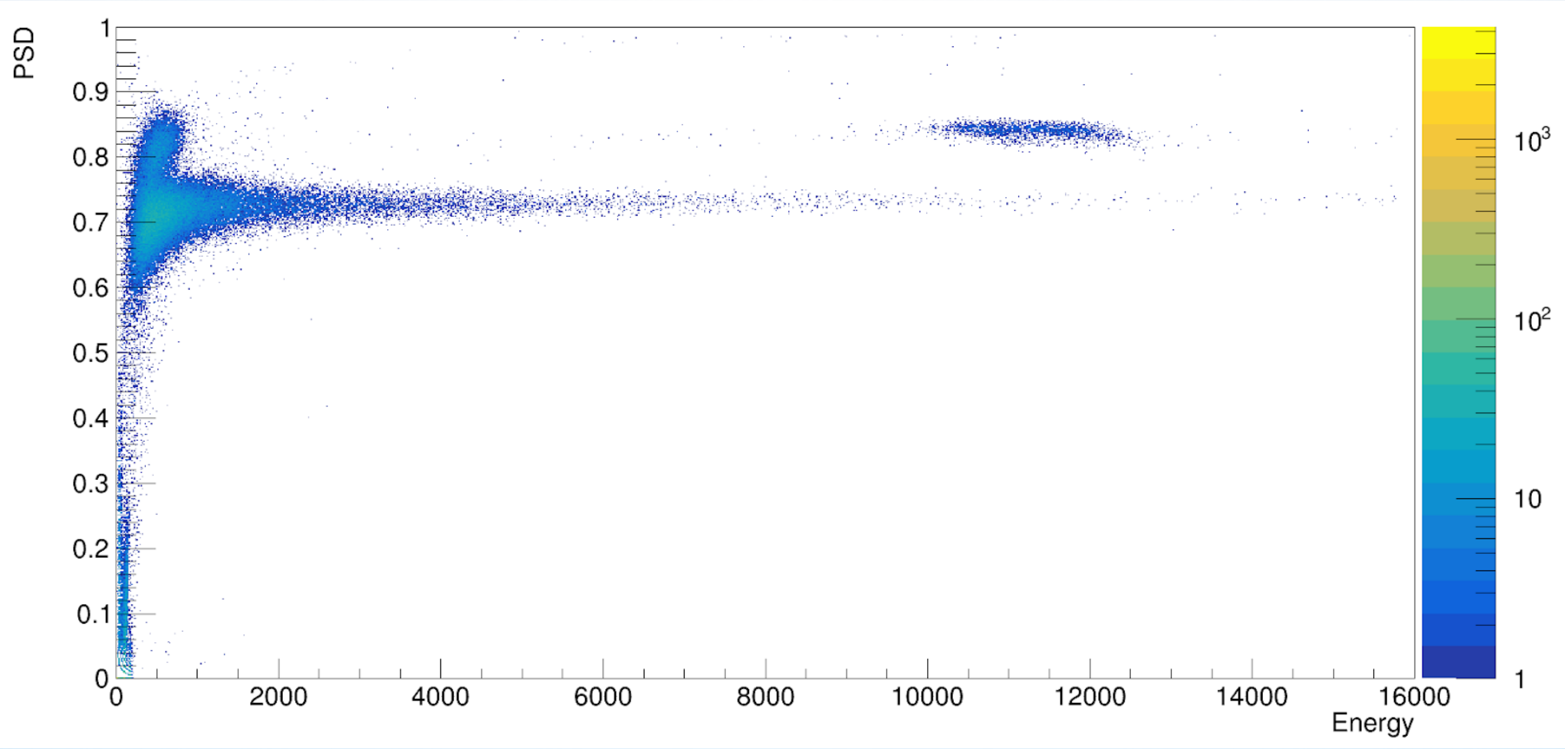
A. W. Obst et al. Reaction Be(o,n) C from 1.7 to 6.4 MeV

FIG. 1. Energy-level diagram for ^{12}C.

PSD background – CMAM Jun 2023



PSD CLYC – Test IFIC



PSD CMAM – Feb 2023