Development of a Transportable Neutron Imager For Localization of Radioactive Sources

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Abstract

Detecting radioactive hotspots presents a challenge for the nuclear industry and security applications, such as waste management, decommissioning, radiation protection, and the response to nuclear accidents. In this study, we present a prototype of gamma-neutron imager utilizing a 12 × 12 plastic scintillator (PS) pixel matrix, with each pixel measuring 3.6 mm × 3.6 mm × 3.6 mm and coupled to an ArrayC-30035-144P SiPM from SensL. The light response of each pixel is separated by 0.6 mm of PTFE wall. The electronic readout includes the SiPM, connected to the diode-coupled charge division readout system from AiT. We utilized a rank 7 MURA coded mask, comprising two layers: 1 mm of lead and 1 cm thick polyethylene, with a surface area of 11.4 cm × 11.4 cm. The prototype has a field of view (FoV) of 68°. Additionally, all components were assembled within a polyethylene camera housing measuring 17 cm × 14 cm × 9 cm.

We performed Geant4 simulations to determine the optical parameters of the scintillator, explore quenching mechanics, and examine neutron interactions within our scintillator. Additionally, we conducted experiments on the prototype using a proton beam at the Cyrcé facility at IPHC. In this presentation, we will discuss the simulation and experimental results.

Neutron Imager Prototype

The neutron imager prototype consists of:

- Two rank 7 MURA coded aperture; 1 cm thick polyethylene and 1 mm thick lead
- Triple discriminant PS (89.02% C, 7.21% H, 2.53% N, 1.06% O, 0.053% Li)
- ArrayC-30035-144P SiPM;
- AB4 electronic readout.

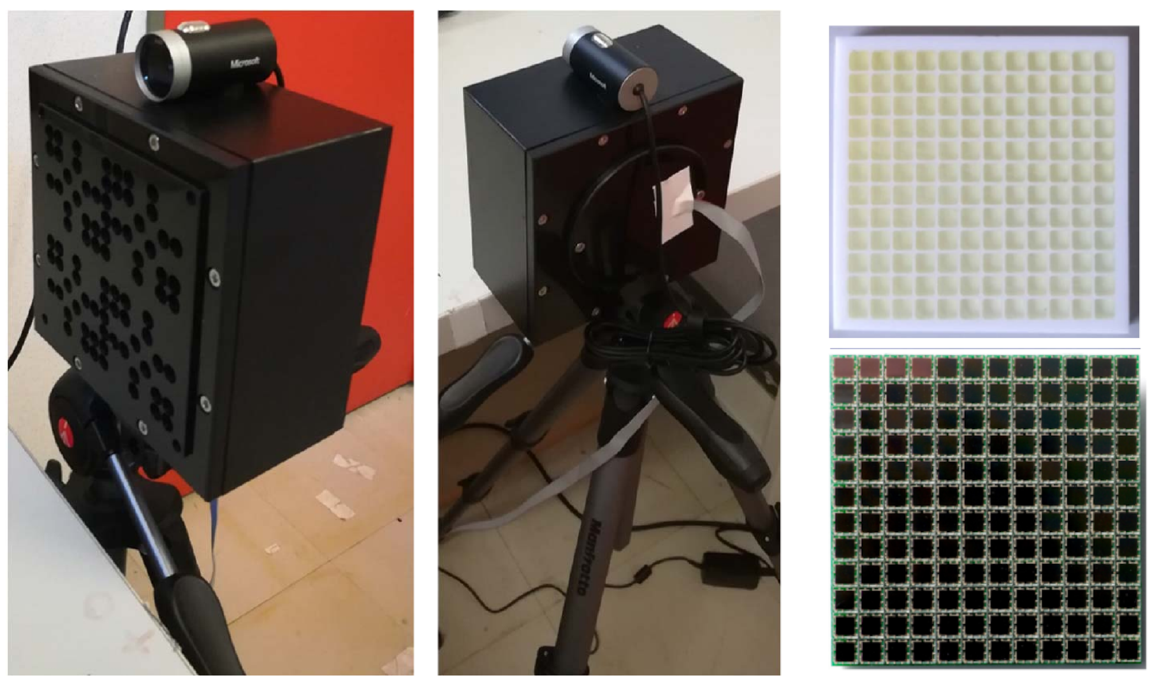

Figure 1. Left: Prototype of the neutron imager based on pixelated PS and coded aperture. Right top: 12 ×12 PS pixels cover by PTFE, Right bottom: SensL SiPM sensor array (ArrayC-30035-144P) [1]

Research objectives

The present study investigates the following objectives:

- **Objective 1:** Monte Carlo simulations to investigate the neutron interactions within the PS and determine the scintillator parameters.
- **Objective 2:** Tests on the prototype to determine the spatial resolution, energy calibration for the pixels, and the validation of the simulations.

Monte Carlo Simulations

Monte Carlo-based simulation toolkit, Geant4 [2], was employed for the simulation studies. Geant4 offers a wide range of physics processes and models. We utilized the `NeutronHP` physics list for neutron (<20MeV) transportation model:

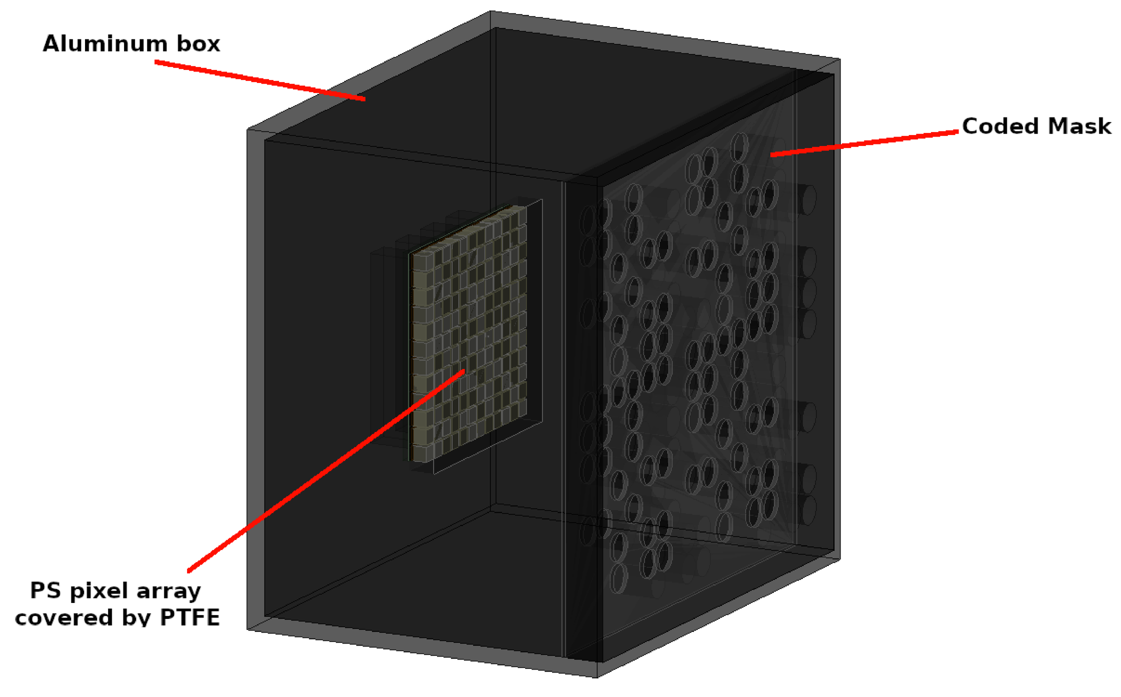

Figure 2. The drawing of Geant4 mass model of the prototype used in the simulations.

Scintillator Parameters

Table 1 presents the parameters used in the simulations for the PS.

Table 1. Scintillator parameters that are used in the simulations

Refractive Index	Scintillation Yield (photons/MeV)	Rise Time (ns)	Decay Time (ns)	Birk's Constant (mm/MeV)
1.57	3800	5	750	0.137

Thermal Neutron Interaction

Addition of ^6Li ensures that the PS exhibits triple pulse shape discrimination due to the capture of the thermal neutron by ^6Li via the reaction $^6Li(\alpha, n)^3$H.

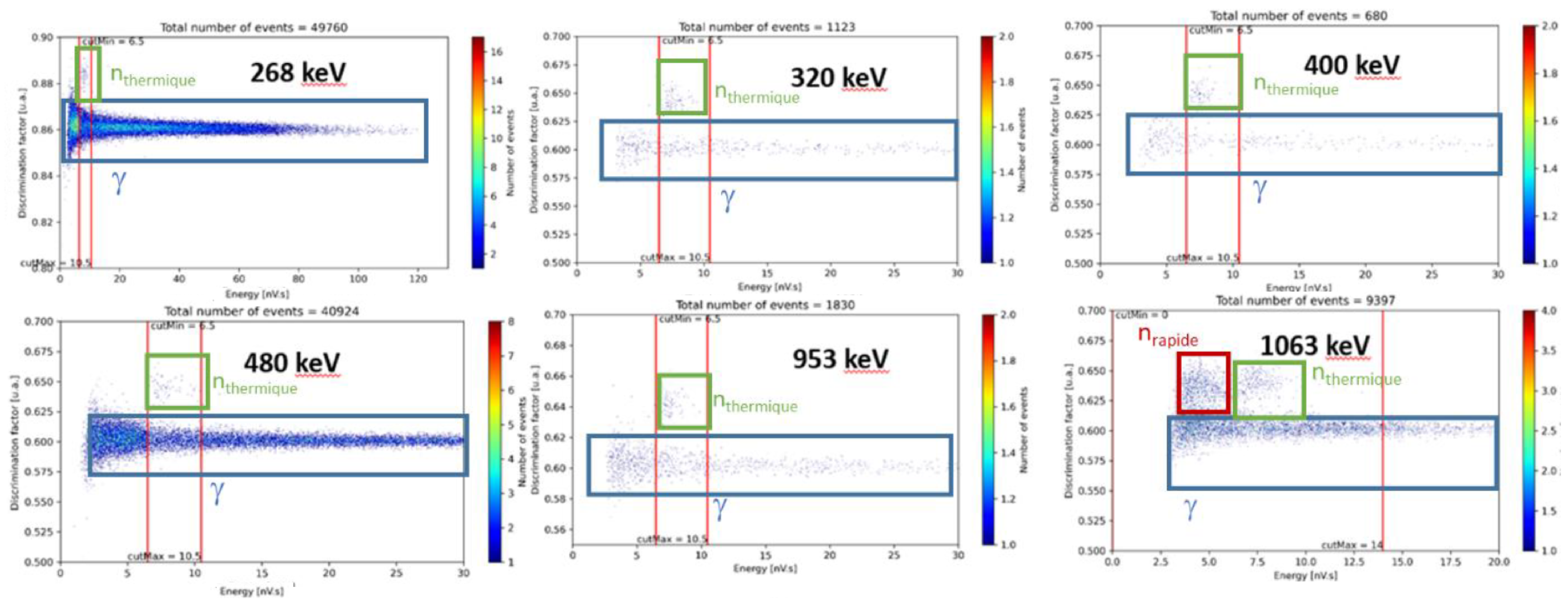

Figure 3. Two-dimensional histograms presenting the distribution of the discrimination factor (Qtail/Qtot) as a function of energy for the neutron energy range incidents between 268 and 1063 keV. These data are obtained with the triple scintillator discriminant [3].

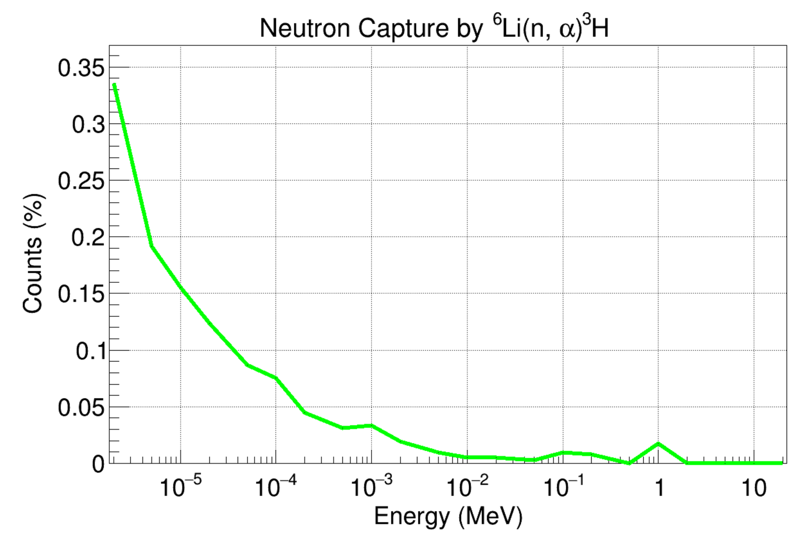

Figure 4. Neutron capture events by ^6Li in simulation. `NeutronHP` physics list used in the simulation.

Experiments

We performed experiments at the Cyrcé facility to calibrate the energy response of our prototype using proton beams with various energies and to investigate its spatial resolution capabilities by varying beam sizes.

Spatial Resolution

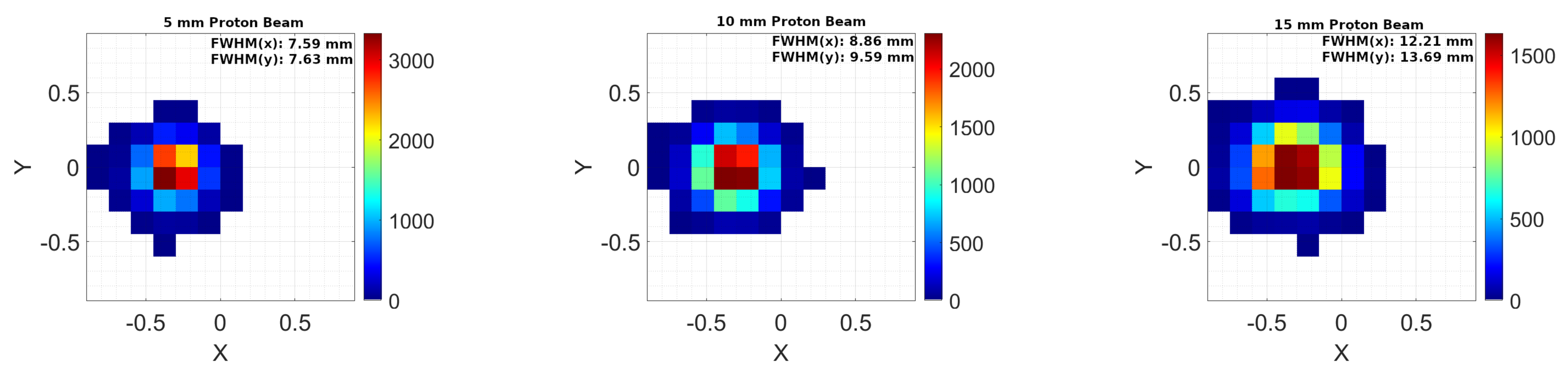

Figure 5. Pixel maps for beam sizes of 5 mm, 10 mm, and 15 mm, arranged from left to right.

Energy Response Calibration of the Prototype

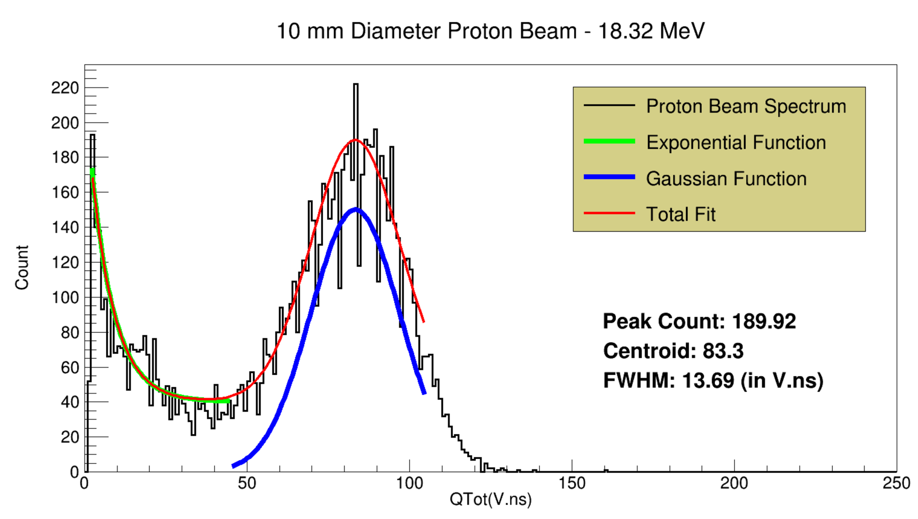

Figure 6. 10 mm diamater proton beam binned total charge ($V \times ns$) spectrum and illustration of the corresponding fit models.

We employed exponential and Gaussian functions to model the spectra derived from all experiments. The energy calibration was conducted using Equation 1, where parameters A and B were determined as follows: A is 0.065 for edge pixels, 0.067 for middle pixels, while B takes on 12.73 for edge pixels and 11.85 for middle pixels.

$$E(MeV) = A + B \times Q_{Tot}(V \times ns) \quad (1)$$

Conclusions

- Conducted a simulation study to determine the PS parameters and elucidate the nature of neutron interactions with our scintillator.
- Performed energy calibration and spatial resolution determination
- As future work, planning to reconstruct a detailed model of the detector response and spectrum in simulations, taking into account SiPM parameters (dark noise, after-pulsing, and cross-talk) as well as electronic noise effects.

References

[1] C. Lynde et al., Demonstration of coded-aperture fast-neutron imaging based on Timepix detector, NIM-A 954:161373, and 2020 Symposium on Radiation Measurements Applications XVII.

[2] S. Agostinelli et al., Geant4—a simulation toolkit, and NIM-A 506:250-303 2003.

[3] Aya Kanj and Development of a transportable neutron spectro-imager with high detection sensitivity 2024 Université Paris-Saclay.

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