Neutron spectroscopy with a nitrogen-filled large-volume spherical proportional counter at high pressure

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Introduction

A dedicated, precise, and in-situ measurement of the neutron flux in underground laboratories is of paramount importance for many direct dark matter search experiments, as neutron-induced background can mimic the standard dark matter signal. Two Spherical Proportional Counters (SPC), [1], are installed and operated at the University of Birmingham (UoB) and the Boulby Underground Laboratory, aiming to provide detailed measurements on fast neutrons. This method is a safe, inexpensive, effective, and reliable alternative to ^{3}He based detectors.

SPC instrumentation and recent advancements

The SPC is a novel gaseous detector with several advantages including low capacitance. The layout and the principle of operation are presented in (Fig. 1, left). The electric field intensity depends on the distance from the centre as $1/r^2$, separating the volume to a drift and an amplification region.

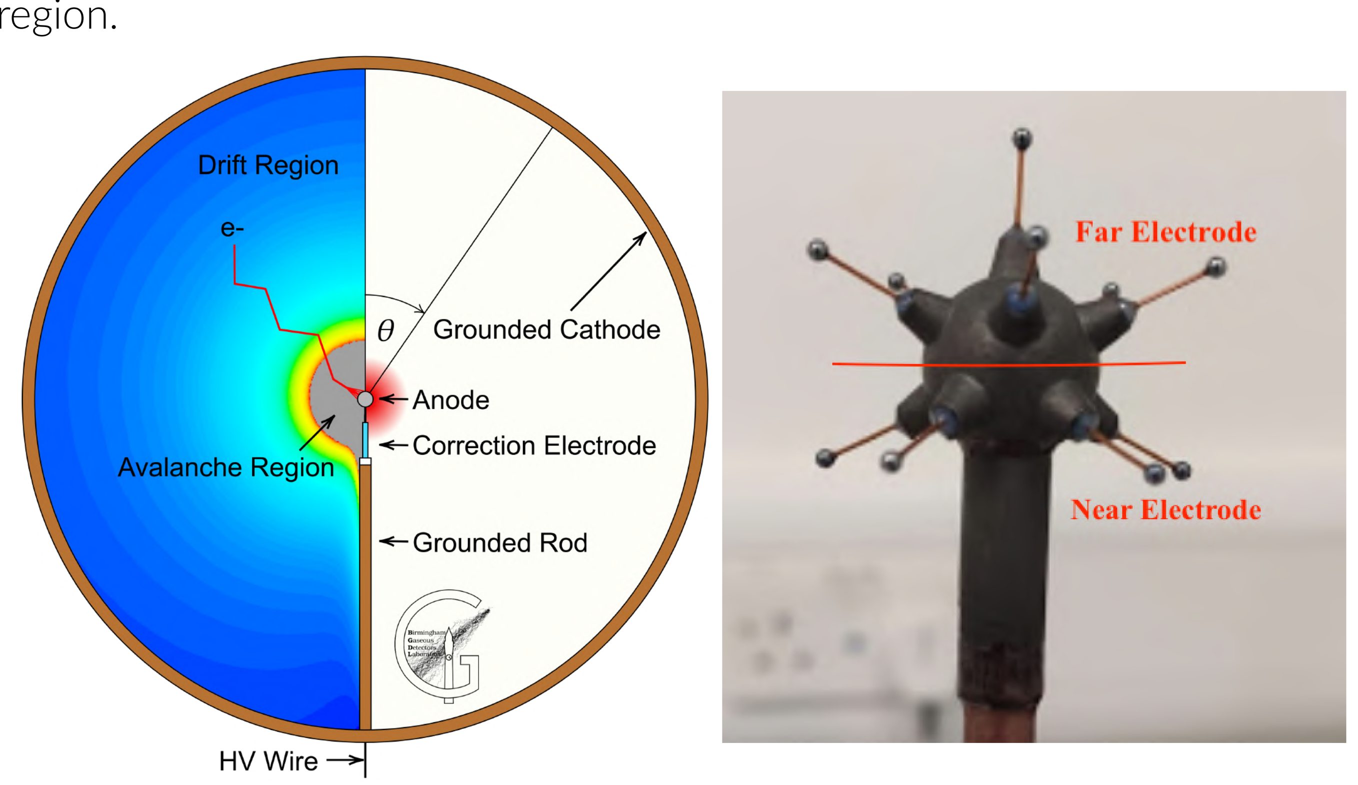

Figure 1. A schematic of the spherical proportional counter and the generation of avalanche from a primary electron (left). The two electrodes (near and far) multi-anode read-out structure (right).

For large detectors or high pressure operation, the small ratio of the electric field to the gas pressure (E/P) increases the probability for electron attachment and recombination. This challenge is tackled with the use of a multi-ball sensor, called ACHINOS [2]. Such a structure (Fig. 1, right) comprises several smaller anodes in fixed radius from the centre, arranged in a regular pattern.

Neutron measurements with SPC

The SPC filled with a N_2 based gas mixture, exploit the

$$^{14}N + n \rightarrow {}^{14}C + p + 625\,keV,$$
$$^{14}N + n \rightarrow {}^{11}B + \alpha - 159\,keV$$

processes [3]. Given the large volume of SPC, the capability of operation in high pressure and the high atomic number of N_2 (compared to ^{3}He) makes the detector efficient for fast neutron detection and sensitive to thermal neutrons as well (Fig. 2). Incorporating the sensor developments in the SPC instrumentation, an 11-anodes ACHINOS sensor with anode diameter at 1 mm is installed in the 30 cm diameter SPC available in UoB, filled with N_2 up to 2 bar pressure.
An ^{241}Am^{9}Be neutron source is placed inside the graphite stack (Fig. 3, left). Neutrons from the source thermalise through interactions in the graphite. From dedicated simulations it is estimated that each neutron emitted from the source has a $\approx 5 \times 10^{-3}$ probability as shown in Fig. 3 (right).

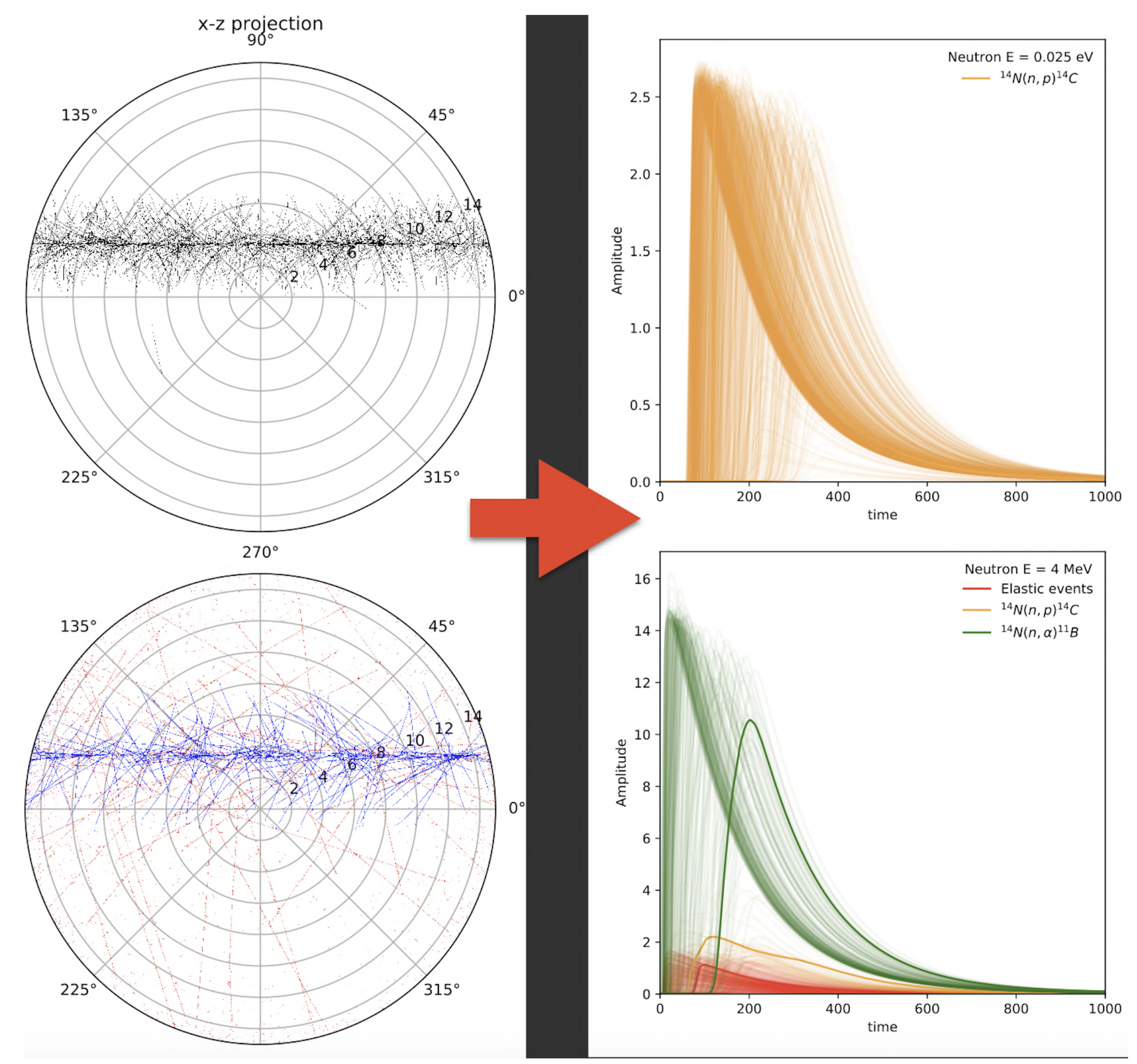

Figure 2. Simulated neutron tracks (left) and the obtained pulses (right) in the SPC for thermal (top) and fast neutrons (down).

Measurements results

Thermal and fast neutron measurements performed with the SPC, in a variety of anode voltages with 1.5 bar N_2 gas filling (Fig. 4). A neutron detection efficiency of $\approx 3.7 \times 10^{-4}$ is measured. The feasibility of detector operation with 2 bar N_2 gas filling is demonstrated in Fig. 5.

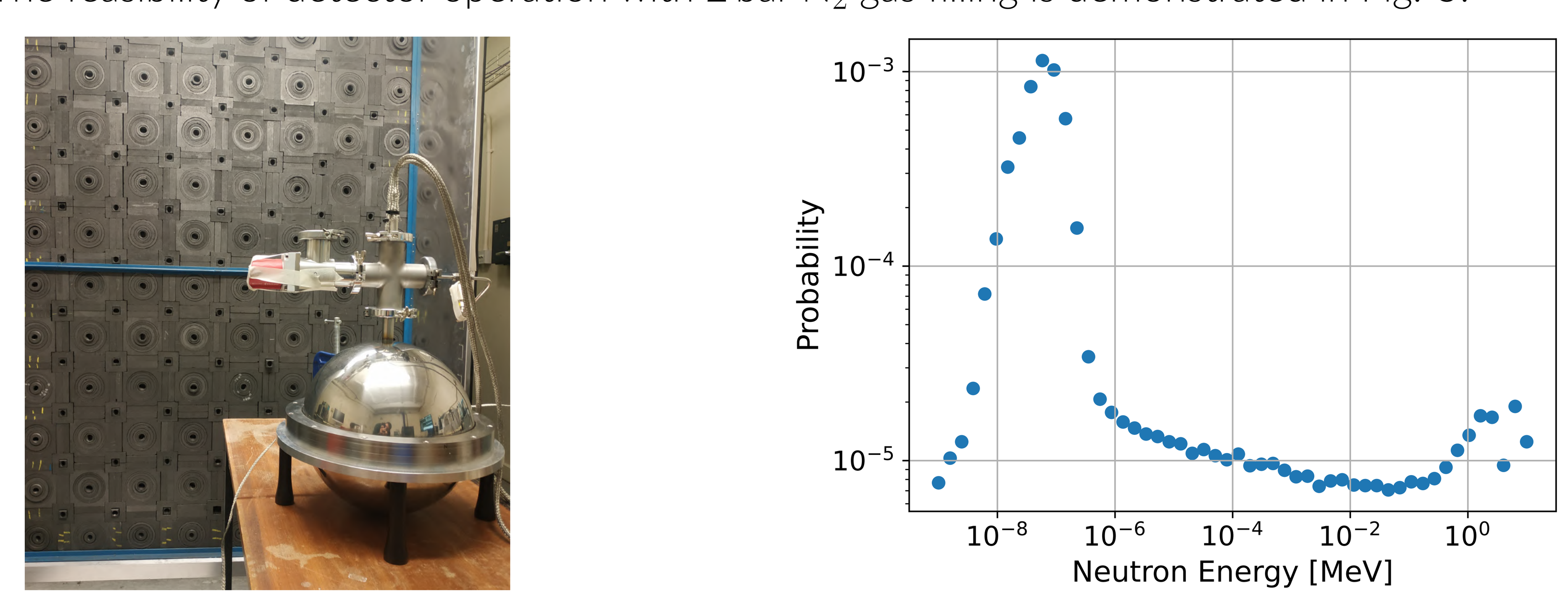

Figure 3. Thermalised neutrons from ^{241}Am^{9}Be, detected with a nitrogen-filled SPC operated at 2 bar (left). The probability for a neutron from the source to reach the detector volume, as a function of its energy in the detector volume (right).

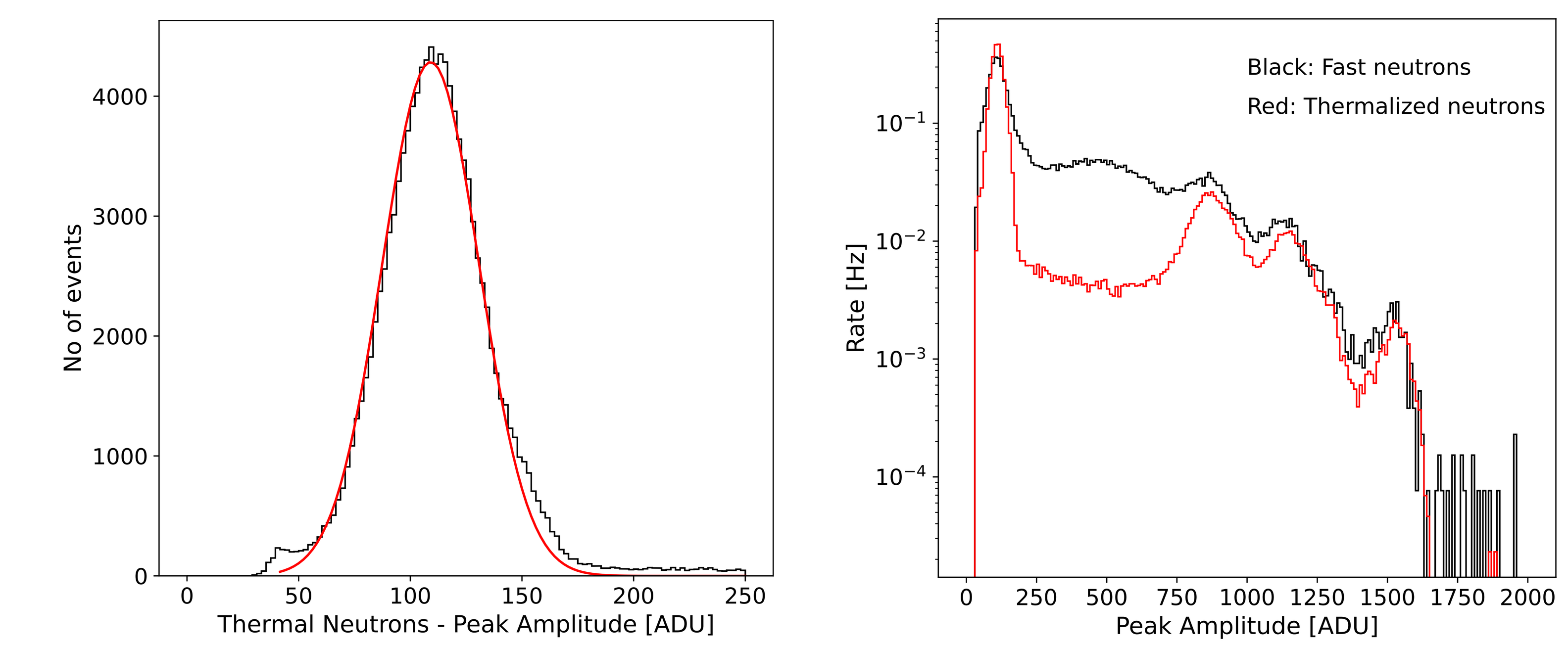

Figure 4. Data at 1.5 bar N_2 and 4.5 kV anode voltage: (Left) The thermal neutrons peak amplitude distrubution after applying pulse shape quality criteria.The peak corresponds to the 625 keV recoil energy with 20.7% energy resolution. (Right) Comparison of thermal (red) and fast (black) neutrons energy spectrum. Rn decay chain alphas are present and used for energy calibration.

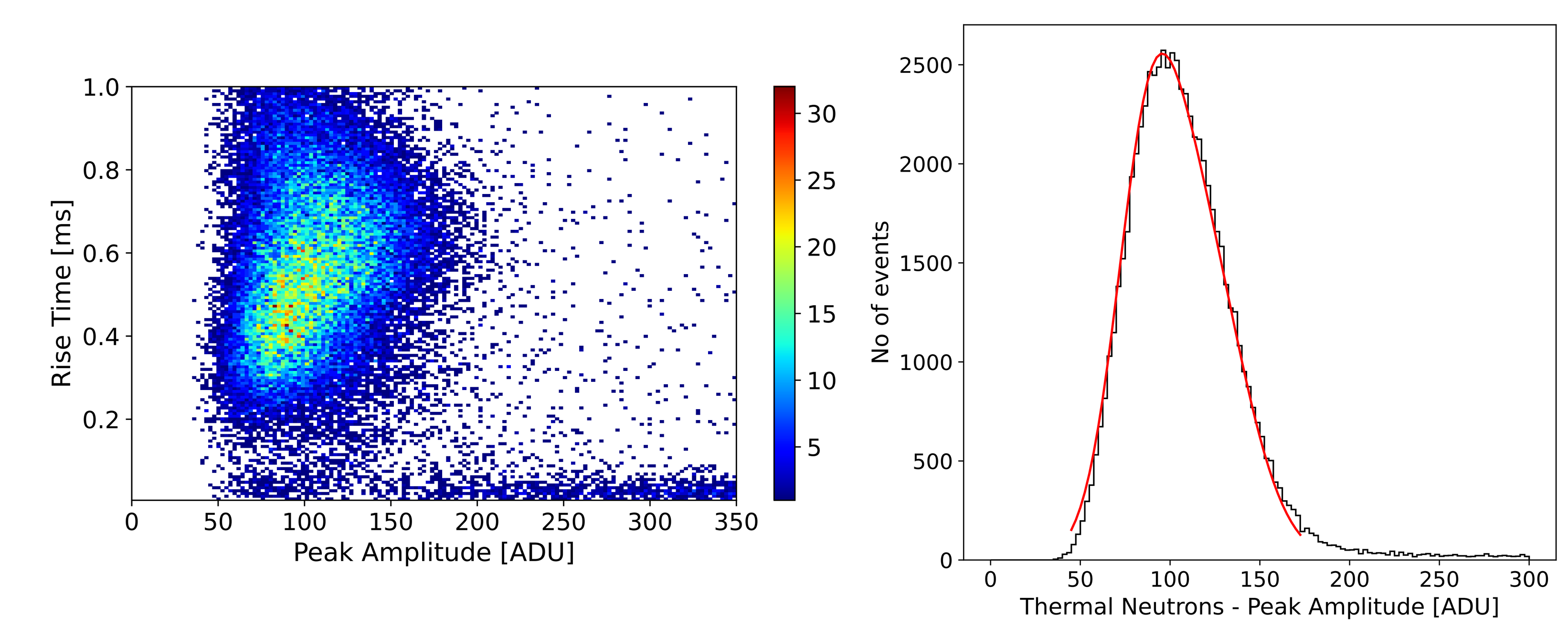

Figure 5. Data at 2 bar N_2 and 4.95 kV anode voltage: (Left) Rise time vs peak Amplitude. (Right) Thermal neutrons peak amplitude distribution. The peak corresponds to the 625 kV recoil energy with 17.3% energy resolution.

Conclusions

The capability of the SPC in neutron detection when operating with N_2 gas filling at pressure up to 2 bar is demonstrated using fast neutrons and neutrons thermalised by the graphite stack at UoB. Further measurements are planned to be conducted at the Boulby Underground Laboratory.

Acknowledgments

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References

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