Detector Development for Dark Matter Searches

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I am a doctoral researcher in the research group led by Prof. Konstantinos Nikolopoulos at the Institute for Experimental Physics, University of Hamburg. I began my PhD in August 2024 and have now completed two years into my doctoral research.

Our research group is involved in Higgs physics analysis with the CMS detector, as well as detector R&D and experiments for dark matter and rare event searches (NEWS-G, IAXO, DarkSide-20k, and MIGDAL collaborations). My work is related to the dark matter part of the group. One of the main focuses is the potential of light dark matter detection down to the sub-GeV range by employing Spherical Proportional Counters (SPC), a gaseous detector suitable for direct light dark matter searches as a part of the NEWS-G collaboration.

To better understand the detector's response, our group is working on the design and realisation of a neutron scattering experiment involving the SPC and a backing detector (see Fig.1). In this context, we are also investigating the use of plastic scintillators read out with Silicon Photomultipliers (SiPMs) as a backing detector.

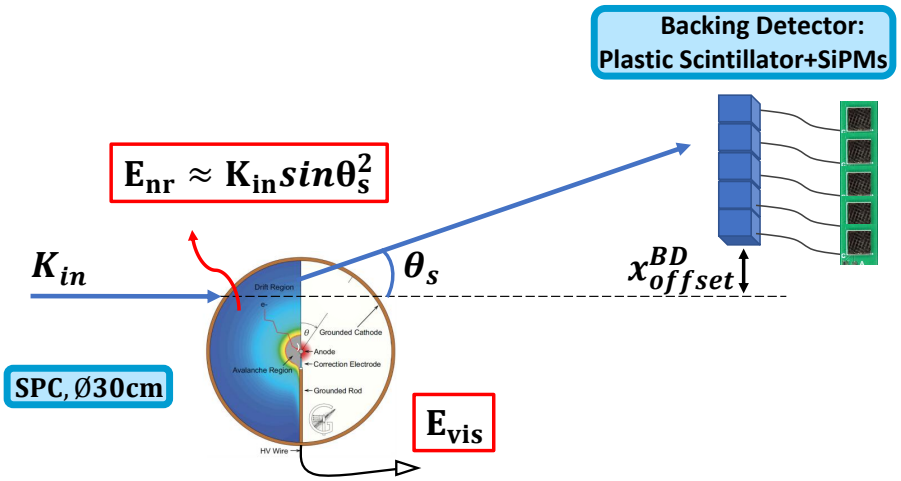

Figure 1: Schematic layout of a neutron scattering experiment involving the SPC and plastic scintillators read out with SiPMs serving as a backing detector.

The main focus of this project is to measure the Ionization Quenching Factor (IQF) for different gases and neutron kinetic energies, defined as the ratio of the "visible" to the kinetic energy of the nuclear recoil: IQF(E_{nr})=E_{vis}/E_{nr}, where $E_{vis} < E_{nr}$.

I have participated in a neutron test-beam campaign hosted in the NCSR "Demokritos" facility in Athens where data were taken for a range of neutron energies with a ⌀30cm SPC. Another neutron test-beam campaign is foreseen by the end of 2026 where the primary goal will be to observe correlations between the SPC and a backing detector.

For this purpose, Geant4 simulations were developed to model the geometry and scattering kinematics of the neutron scattering setup involving the SPC and plastic scintillators. The aim of these simulations was to optimise the geometrical layout, taking into account the range of accessible nuclear recoil energies in the SPC ($E_{nr} \approx K_{in} \sin^2 \theta_s$) and the expected coincidence signal rate relative to background, as well as the expected uncertainty on E_{nr} introduced by the positioning and dimensions of the setup's components.

To this cause, characterisation measurements of commercially available SiPMs were conducted. Key performance parameters like dark noise and cross-talk probability were measured for a range of applied voltages and temperatures from room temperature to $-85°$C. Moreover, radiation hardness measurements have been carried out in the NCSR "Demokritos" facility for a range of fluences from 2×10^9 to 1.1×10^{10} $\mathrm{n_{eq}/cm^2}$.

Finally, characterisation measurements with cosmic muons were conducted to study the response of plastic scintillators read out with SiPMs. The experimental setup and the scintillation light processes were implemented in Geant4 simulations. Scintillator performance parameters such as transmittance, reflectivity and light-yield were tuned by a data-driven comparison with the simulations.