NEWS-G: Search for Light Dark Matter with a Spherical Proportional Counter

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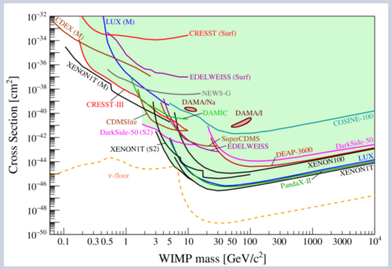
PANIC 2021

1. Introduction

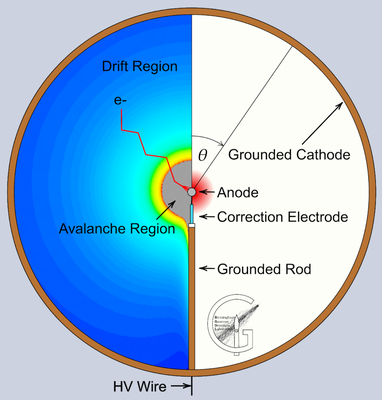


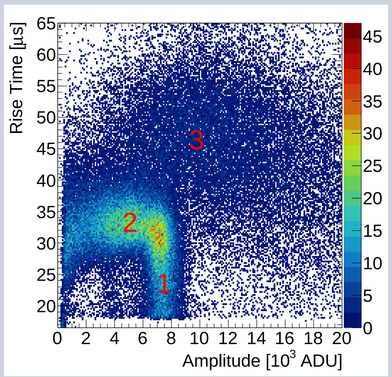
The absence of conclusive direct evidence for Dark Matter (DM) particles and emerging theoretical models have driven searches for lower mass candidates, which, due to the requirements of a low mass target and a low energy threshold, remain mostly unexplored [1]. The New Experiments With Spheres (NEWS- G) collaboration [2] is utilising the Spherical Proportional Counter (SPC) to search for DM in the 0.1 GeV to a few GeV mass range.

2. Spherical Proportional Counters

The SPC [3], is simple and robust gaseous detector, well suited to various applications, ranging from fast neutron spectroscopy to direct DM searches. Key advantages are:

- Low capacitance ($\mathcal{O}$(0.1 pF)), independent of cathode radius
- Single-channel read-out, in simplest form
- Stable operation at high gains
- Fiducialisation and background suppression from pulse-shape characteristics (below)
- Variable gas mixture and pressure



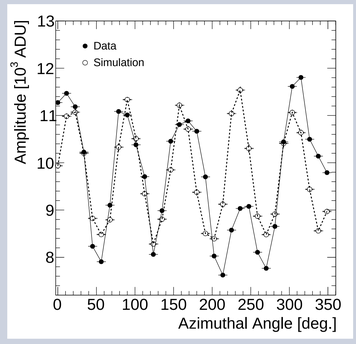


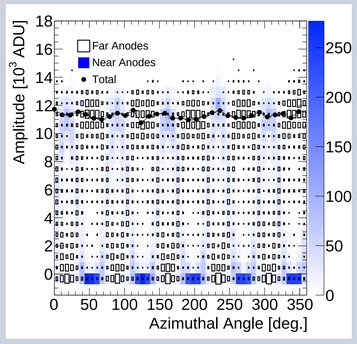
Pulse rise time versus amplitude in an 30 cm diameter SPC filled with 1.3 bar He:Ar:CH_4 (51.7%:46%:2.3%) and ^{55}Fe source inside the detector. The three distinct populations are (1) 5.9 keV photons interacting in the gas volume, (2) interactions near the cathode, and (3) cosmic muon interactions. Pulse-shape discrimination enables background suppression and fiducialisation.

3. Read-out Instrumentation

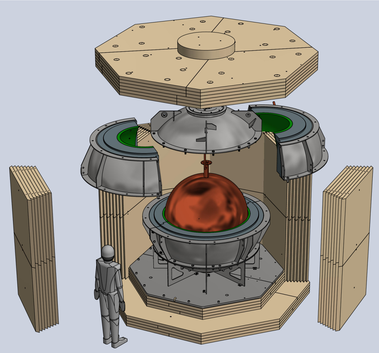
Conventional read-out uses a single spherical anode at the detector's centre. However, in this case, drift and avalanche fields are coupled, limiting detector size, operating pressure and stability. ACHINOS (right) overcomes this by using multiple anodes at a fixed radius from the detector centre, decoupling the drift and avalanche fields, and allowing higher electric fields [4].

Developments in terms of construction precision and operational stability have been achieved using Diamond-Like Carbon (DLC) coated additive manufactured materials. Extensive simulation and experimental testing have been performed to study ACHINOS (below).





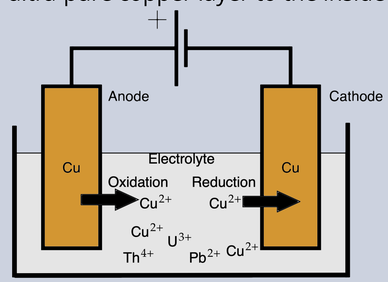
4. NEWS-G DM Searches



First results were obtained with SEDINE, a 60 cm diameter SPC operated in the Laboratoire Souterrain de Modane (LSM), and placed the first exclusion limits on a 0.5 GeV mass DM candidate with $\sigma_{\mathrm{SI}} = 4.4 \times 10^{-37}\mathrm{cm}^2$ [2]. A 140 cm detector, SNOGLOBE, constructed using 4N copper with an electroplated internal layer to suppress background, was recently installed SNOLAB, Canada (left).

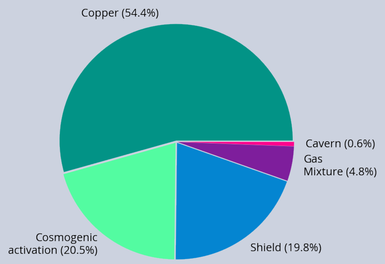
5. Ultra-Pure Copper Electroforming

Copper is a common choice for detector materials due to its commercial availability at high purities, relatively low cost and ability to make pressure vessels. However, during commercial manufacturing processes, 222Rn progeny can be introduced to the bulk. Alpha spectroscopy assay of 4N copper used by NEWS-G indicates a contamination of 29^{+8+9}_{-8-3} mBqkg^{-1} [6]. A method for producing copper with suppressed contamination is potentiostatic electroforming (Fig. 8), which exploits the relatively high reduction potential of copper (Table 1). This was used to apply a 500 μm ultra-pure copper layer to the inside of SNOGLOBE.



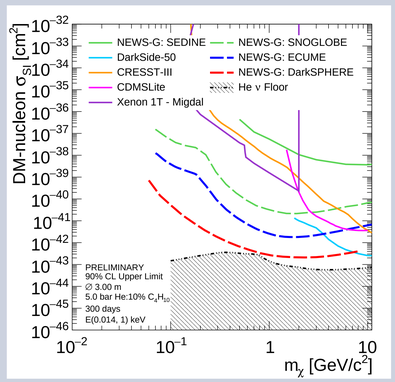
Reductants		Oxidants	E^o (V)	
$Cu^{2+} + 2e^-$	$\rightleftharpoons$	Cu	+0.34	[5]
$Pb^{2+} + 2e^-$	$\rightleftharpoons$	Pb	-0.13	[6]
$U^{3+} + 3e^-$	$\rightleftharpoons$	U	-1.80	[7]
$Th^{4+} + 4e^-$	$\rightleftharpoons$	Th	-1.90	[7]
$K^+ + e^-$	$\rightleftharpoons$	K	-2.93	[8]

6. Fully Electroformed Detectors



(Left) The dominant backgrounds for SNOGLOBE. Building on the electroforming experience developed with SNOGLOBE, a fully-underground electroformed 140 cm diameter detector, ECUME, will be produced in SNOLAB. A prototype is currently under construction.

An underground fully electroformed 3 m diameter detector, DarkSPHERE, is currently being designed with a water-based shielding to reduce this background component to the experiment. Boulby Underground Laboratory, UK, is a potential host. The projected sensitivity of current and future NEWS-G detectors are shown in the Figure to the right.



7. References

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