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

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Introduction

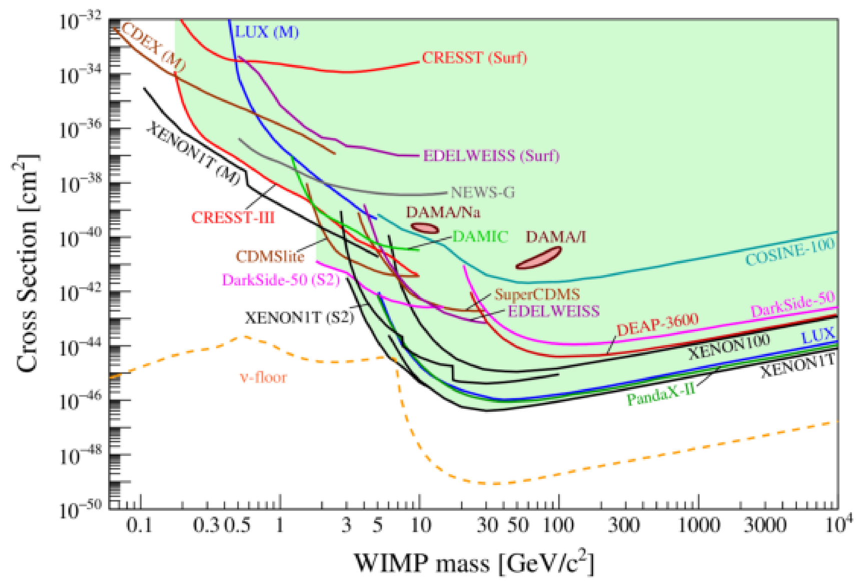

Figure 1: Current best exclusion limits for direct DM searches [1].

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 (Fig. 1). The New Experiments With Spheres (NEWS-G) collaboration [2, 3] is utilising the Spherical Proportional Counter (SPC) to search for DM in the 0.1 GeV to a few GeV mass range.

Spherical Proportional Counters

The SPC [4] (Fig. 2), 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 ($\mathcal{O}(0.1\ \mathrm{pF})$), independent of cathode radius
- Single-channel read-out, in simplest form
- Stable operation at high gains
- Fiducialisation and background suppression from pulse-shape characteristics (Fig. 3)
- Variable gas mixture and pressure

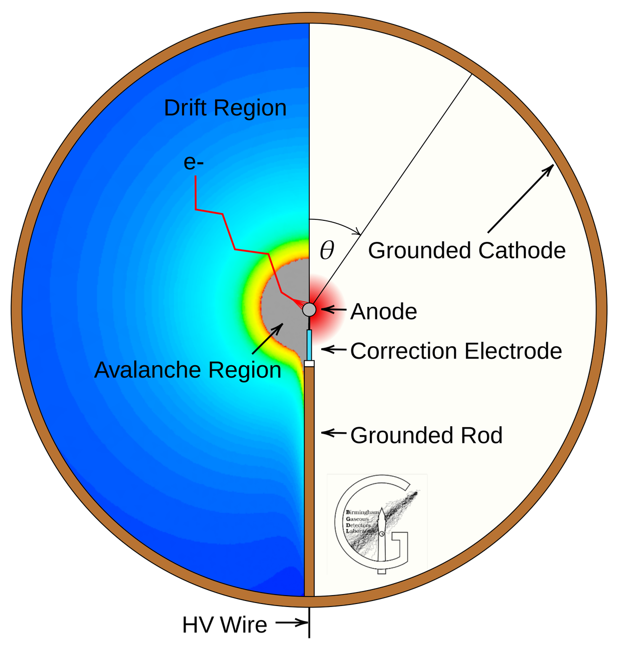

Figure 2: Spherical proportional counter principle of operation.

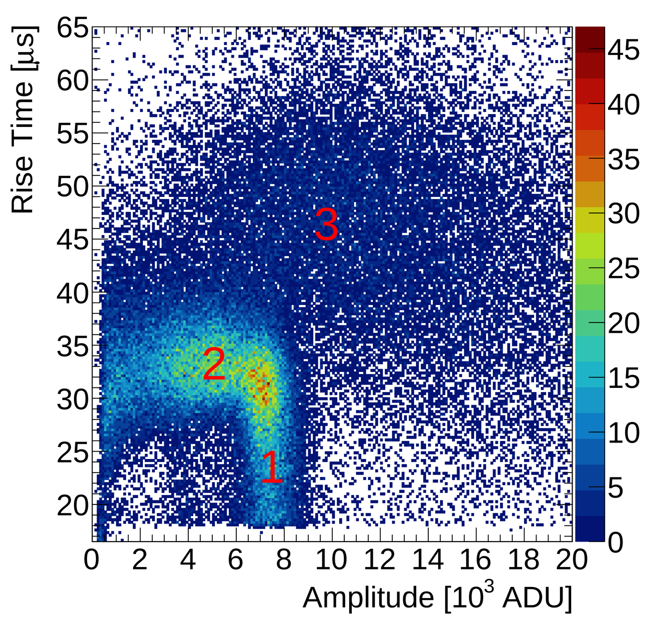

Figure 3: Pulse rise time versus amplitude in an 30 cm-diameter SPC filled with 1.3 bar He:Ar:CH_4 (51.7%:46%:2.3%) and ^{55}Fe source inside detector. The three distinct populations are (1) 5.9 keV photons interacting in the gas volume, (2) interactions near the cathode, and (3) cosmic muon interactions.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

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 (Fig. 4) 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 (Fig. 5 left) [5]. 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 (Fig. 5 centre and right).

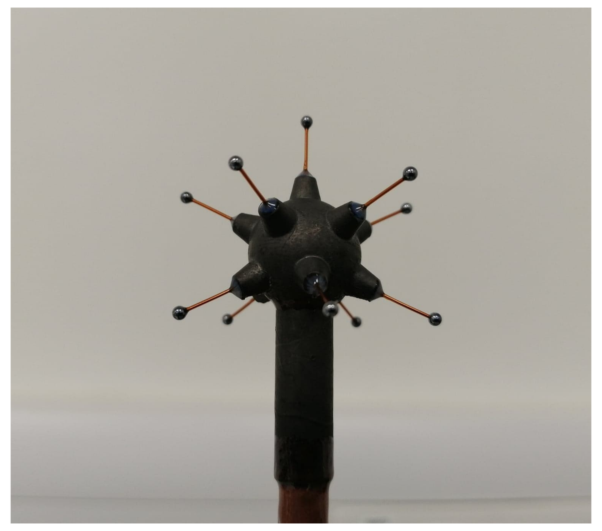

Figure 4: A multi-anode read-out structure, ACHINOS, with 11 1-mm anodes

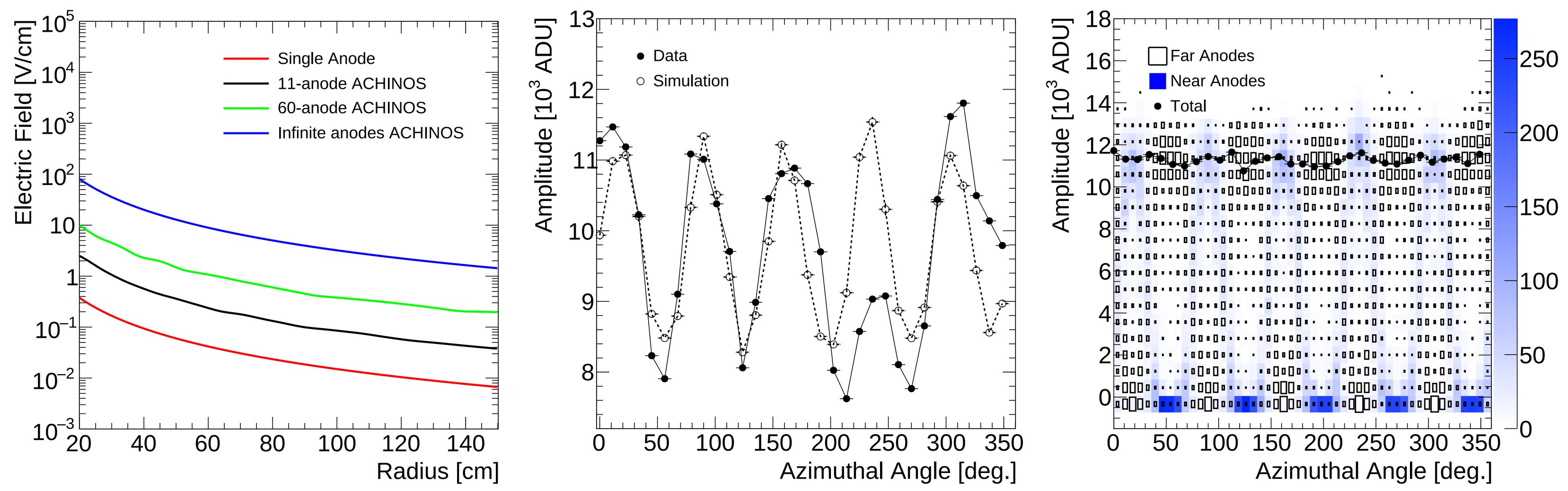

Figure 5: Left: Electric field magnitude comparison between read-out systems. Centre and right: ACHINOS

NEWS-G DM Searches

Figure 6: SEDINE detector in LSM.

First results were obtained with SEDINE(Fig. 6), 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 $\sigma_{\mathrm{SI}} = 4.4\times10^{-37}\ \mathrm{cm}^2$ [2]. A 140 cm detector, SNOGLOBE, constructed using 4N copper with an electroplated internal layer to suppress background, was recently installed SNOLAB, Canada (Fig. 7).

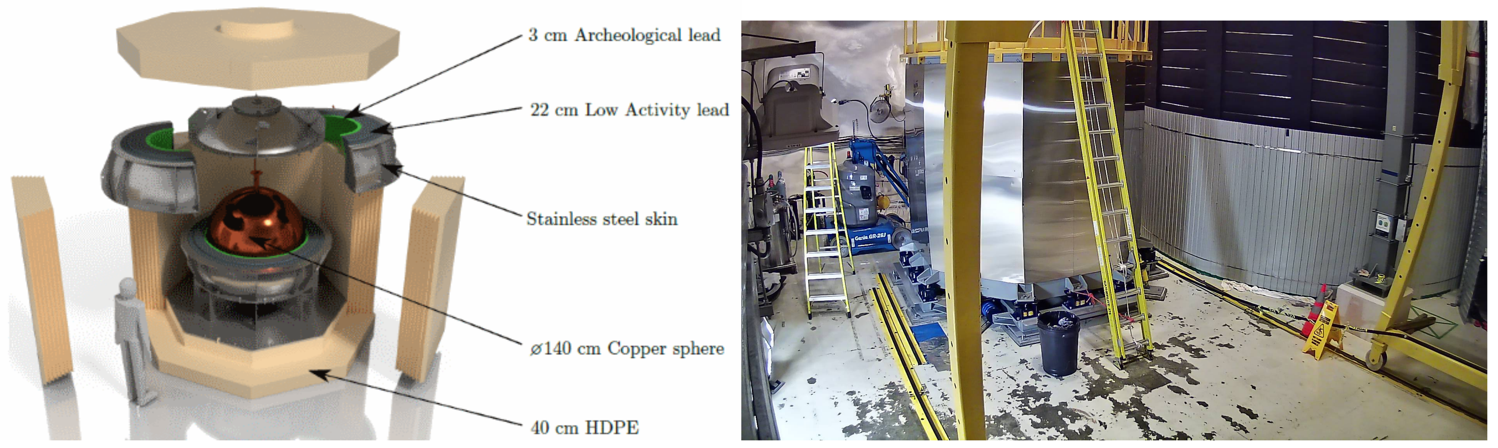

Figure 7: Design and construction of SNOGLOBE and its shielding.

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, ^{222}Rn progeny can be introduced to the bulk. Alpha spectroscopy assay of 4N copper used by NEWS-G indicates a contamination of $29^{+8+9}_{-8-3}\ \mathrm{mBq\,kg^{-1}}$ [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.

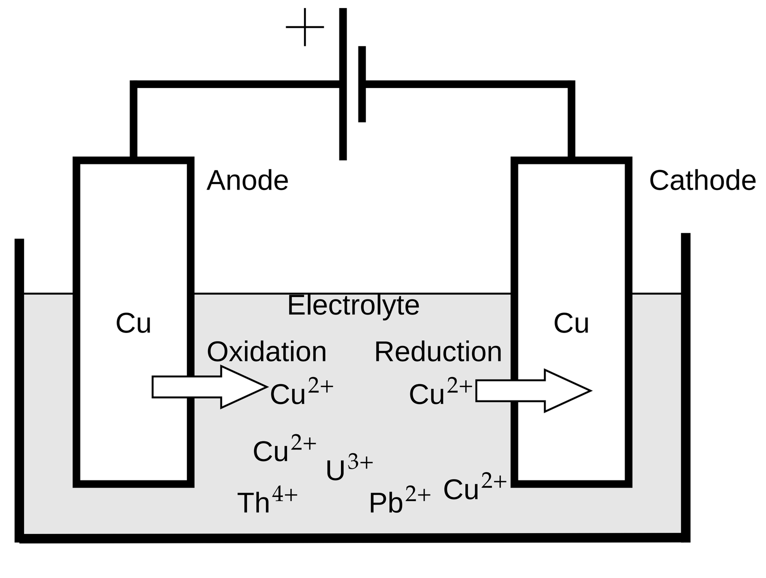

Figure 8: Schematic of potentiostatic electroforming.

Table 1: Reduction potential for copper and possible radiocontaminants.

Reductants		Oxidants	E^0 (V)	
$Cu^{2+} + 2e^-$	$\leftrightharpoons$	Cu	$+0.34$	[7]
$Pb^{2+} + 2e^-$	$\leftrightharpoons$	Pb	-0.13	[8]
$U^{3+} + 3e^-$	$\leftrightharpoons$	U	-1.80	[9]
$Th^{4+} + 4e^-$	$\leftrightharpoons$	Th	-1.90	[9]
$K^+ + e^-$	$\leftrightharpoons$	K	-2.93	[10]

Fully Electroformed Detectors

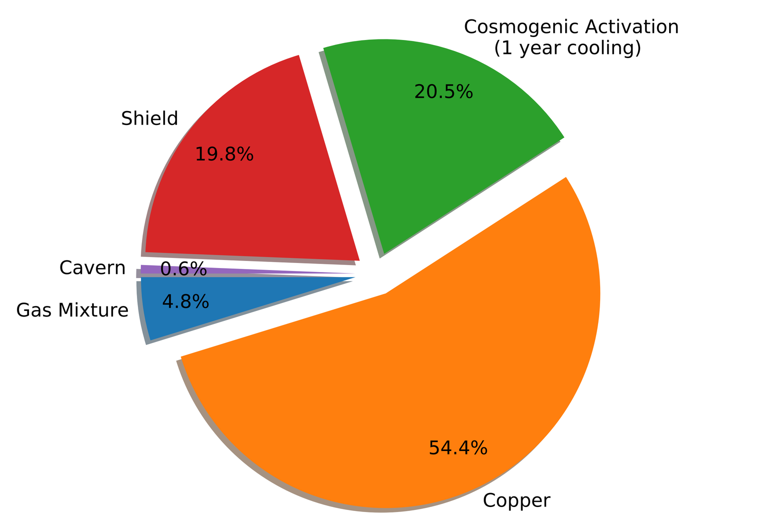

Figure 9: Background contributions for SNOGLOBE.

The dominant backgrounds for SNOGLOBE are shown in Fig. 9. 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 Fig. 10.

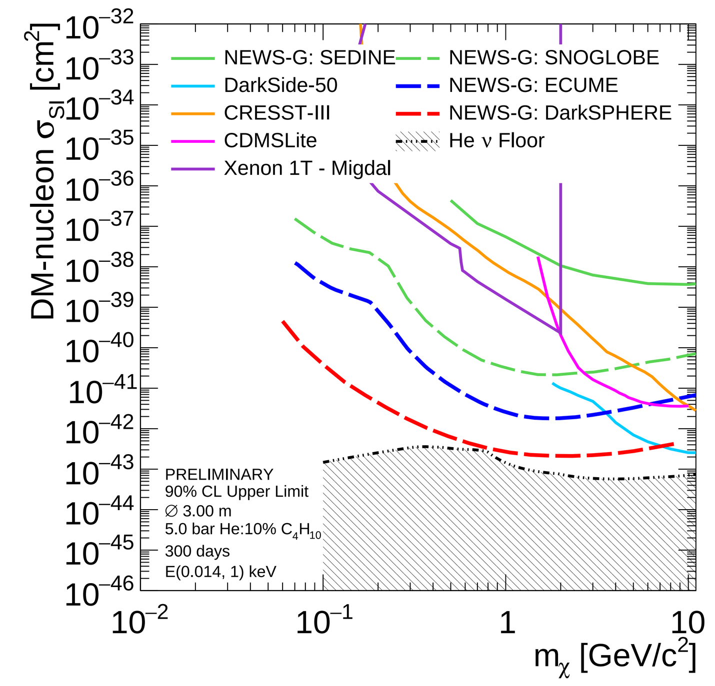

Figure 10: Projected 90% confidence level upper limit for SI DM-nuleon interactions for SNOGLOBE, ECUME and DarkSPHERE.

References

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