Snowmass2021 - Letter of Interest

Search for Low Mass WIMPs with Spherical Proportional Counters

CF Topical Groups: (check all that apply □/■)
■ (CF1) Dark Matter: Particle Like
□ (CF2) Dark Matter: Wavelike
□ (CF3) Dark Matter: Cosmic Probes
□ (CF4) Dark Energy and Cosmic Acceleration: The Modern Universe
□ (CF5) Dark Energy and Cosmic Acceleration: Cosmic Dawn and Before
□ (CF6) Dark Energy and Cosmic Acceleration: Complementarity of Probes and New Facilities
□ (CF7) Cosmic Probes of Fundamental Physics
□ (Other) *[Please specify frontier/topical group]*

IF Topical Groups: (check all that apply □/■)
■ (IF8) Noble Elements

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Collaboration: NEWS-G

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Abstract:

The NEWS-G Collaboration uses spherical proportional counters (SPCs) to search for dark matter particles in the 0.1 - 10 GeV mass range. These low background detectors have single-electron thresholds and are filled with targets of low atomic mass (H, He, Ne) and can be built from ultra-low radioactivity copper. The current phase of the NEWS-G experiment will allow for the exploration of new parameter space in the near future, and the collaboration is proposing DarkSPHERE, the next generation experiment consisting of a 300 cm diameter electroformed copper SPC filled with helium/iso-butane mixture at 5 bar.

1 Current Status

The NEWS-G collaboration searches for low-mass WIMP-like particles using spherical proportional counters (SPCs) filled with gases of light atomic mass [1,2], such as neon, methane, and helium. The Europe/North America collaboration was created in 2014 by Queen's University Canada Excellence Research Chair (CERC) Gilles Gerbier. SEDINE, the first implementation of a low activity SPC, was operated in 2015 to search for dark matter at the Laboratoire Souterrain de Modane (LSM), in France. At the time of publication (2017), the results obtained with the SEDINE detector were the world's most sensitive for very low mass dark matter particles [3]. NEWS-G has now embarked on the next phase of the experiment, a larger SPC made from very-low-activity copper, that will be installed in a compact radiation shield at SNOLAB. Installation at SNOLAB has begun, and first data taking is scheduled for the first half of 2021. The collaboration is planning to replace the current copper spherical vessel with vessels made of copper of increasing radio-purity. The purpose of this letter of interest is to discuss the NEWS-G collaboration plans after the SNOLAB experiment is completed.

The NEWS-G detector consists of a metallic spherical shell, held at ground potential. A small sensor is placed at the center of the sphere at the end of a grounded metallic rod and is held at positive high voltage. The resulting electric field is mostly radial, except near the sensor rod which disturbs the field, and falls as $1/r^2$. The interaction of a particle with the target gas creates the primary ionization, which is then drifted towards the center of the sphere along the electric field lines. As the electrons approach within approximately 1 mm of the sensor, the magnitude of electric field becomes sufficient for the production of secondary ionization. The signal is generated by the ions drifting away from the sensor. The low capacitance of the sensor, which results in low electronic noise, together with the large amplification of the signal, allows for single electron detection and makes the SPC a powerful detector for low energy nuclear recoils. Background events from track-like energy deposits and from radioactive contaminants at the inner surface of the SPC can be discriminated based on the pulse rise-time. The pulse-rise time is correlated to the spatial extent of the energy deposition and to the longitudinal diffusion of the primary ionization which increases for longer drift paths. The current phase of the NEWS-G experiment is a 140-cm ultra-low background (C10100) SPC that is currently being installed at SNOLAB. A novel multi-anode sensor called ACHINOS [4,5] greatly improves the performance of large sized detectors by increasing the magnitude of the electric field at large radii while keeping high gain. The SPC will be placed in a concentric low-radioactivity lead shield, with the innermost 3 cm of lead made from ultra-low ^{210}Pb content archaeological lead. The lead shielding will be enclosed in a stainless-steel envelope that will be continuously flushed with pure nitrogen to mitigate the presence of radon. The detector will then be surrounded by 40-cm of polyethylene to shield against neutrons from the environment. An electroplating method developed by our collaborators at PNNL (USA) was implemented to add 0.5 mm of pure copper to the inside of the hemispheres [6], in order to limit the impact of the ^{210}Pb contamination found in the C10100 copper used to fabricate the SPC [7]. The main background in NEWS-G is expected to come from the ^{210}Pb contamination of the copper in the bulk of the 1.4-metre diameter SPC, more specifically from the bremsstrahlung photons from the beta-decay (end-point 1.2 MeV) of its daughter, ^{210}Bi. For this reason, the NEWS-G collaboration is planning the installation a new high-pressure 60-cm SPC made from ultra-low radioactivity copper to replace the 1.4-metre SPC after the experiment becomes background limited. This next-generation SPC will be fabricated out of 6N copper (purity greater than or equal to 99.9999%) from the Mitsubishi Material Corporation (MMC, Japan). This is the highest purity copper available on the market. The ultimate control on copper backgrounds will be achieved only with the electroforming [8] of a complete spherical shell at SNOLAB with the future ECUME facility (funding secured). The replacement of the C10100 140-cm SPC in the NEWS-G shield at SNOLAB, first with a 6N SPC, and then with an electroformed copper SPC, will effectively unlock the full scientific potential of the NEWS-G experiment at SNOLAB and will allow the exploration of new dark matter interaction parameter

space.

2 Future Plans

The competitive advantage of the spherical proportional counter to search for low-mass dark matter will be maintained if the technology can be scaled to larger exposures, lower backgrounds, and made sensitive to lower WIMP masses. The NEWS-G collaboration aspires to operate a 300 cm diameter SPC made from electroformed copper: DarkSPHERE. A proposed location for the electroforming and detector operation has been at the Boulby underground laboratory. This detector would hold up to 5-bar of helium/iso-butane (10%) mixture, allowing for increased exposure, lower background and a lighter target than the current SNOLAB experiment.

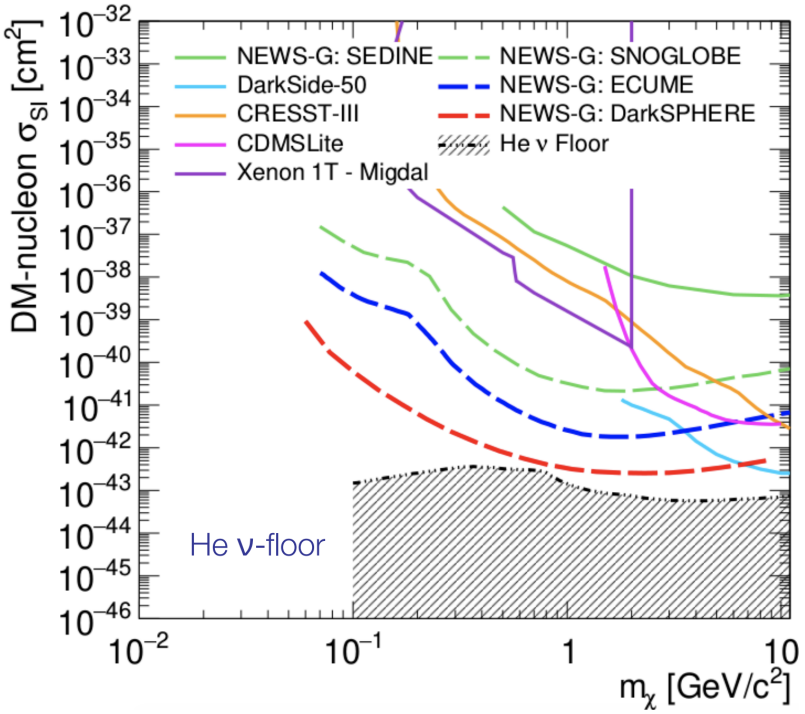

Figure 1: NEWS-G sensitivity projections for the 140 cm SPC at SNOLAB (green dashed line), for NEWS-G at SNOLAB with the electroformed copper vessel (blue dashed line), and proposed electroformed 300 cm diameter SPC at SNOLAB or Boulby (red dashed line), compared with existing limits.

3 Prospects for Directional Measurements

The measurement of the direction of nuclear recoils could allow for the confirmation of a dark matter signal. Using a multi-channel ACHINOS sensor with individual readout for each electrode, a large SPC filled with low pressure gaseous target is a promising technique for the directional measurement of nuclear recoils. Multi-channel readout on ACHINOS is already being used to control the electric field uniformity, and efforts to demonstrate the feasibility of nuclear recoil directional measurements is planned for the feature.

References

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