PROCEEDINGS OF SCIENCE

Latest results from the NEWS-G dark matter experiment

Jean-Marie Coquillat[a,*] **on behalf of the NEWS-G collaboration**

[a] *Department of Physics, Engineering Physics & Astronomy, Queen's University, 64 Bader Lane, Kingston, Ontario, K7L 3N6, Canada*

E-mail: jeanmarie.coquillat@queensu.ca

In the Fall of 2019, the NEWS-G experiment used its latest detector, a 140 cm diameter Spherical Proportional Counter (SPC) to search for low-mass dark matter at the Laboratoire souterrain de Modane (LSM) in France. The detector has then been moved to SNOLAB in Canada and has taken data since the Fall of 2022. SPCs are metallic spheres filled with gas, with a high-voltage anode at the centre that attracts and amplifies ionization charges from atomic recoils. Having the sphere filled with pure methane, hydrogen was used as the target to produce new limits on the proton spin-dependent cross-section around masses of 1 GeV.

This paper first introduces the NEWS-G experiment and describes the commissioning at the LSM with the shielding used, the SPC detection principle and the new multi-anode sensor. It then focuses on the calibrations using a UV laser and ^{37}Ar, as well as the background discrimination methods to remove α-particle induced events and spurious pulses. Then, it presents the profile likelihood ratio method that was used to derive constraints on WIMP mass and cross-section. Finally, it describes the status of the recent data taken at SNOLAB and mentions future projects.

XVIII International Conference on Topics in Astroparticle and Underground Physics 2023
28 August - 1st September 2023
University of Vienna, Vienna, Austria

*Speaker

PoS(TAUP2023)042

1. Introduction

In the last century, from galactic rotation curves to the fits of the cosmic microwave background, there has been ample evidence for the existence of an invisible collisionless mass inside of galaxies, called dark matter [1]. Since no definite dark matter candidate exists within the Standard Model, multiple particles have been proposed to explain its nature. One of them is weakly interacting massive particles (WIMPs). Many experiments have searched for direct detection of WIMPs but none have conclusively succeeded yet. The lack of discovery motivates searches at lower masses, where excluded cross-sections are not as constrained. The NEWS-G experiment aims to use spherical proportional counters (SPCs) to probe for low-mass WIMPs.

2. The NEWS-G detector

2.1 Spherical proportional counters

An SPC is a metallic sphere filled with gas with a central high-voltage anode supported by a grounded rod and producing (to first approximation) a radial electric field. If a particle interacts with an atom in the gas, the recoil may have enough energy to ionize the gas. The electrons then drift towards the centre where they undergo a Townsend avalanche. The drifting secondary ions induce a current in the sensor which is converted into a digital signal. The detection mechanism is illustrated in Figure 1.

The NEWS-G experiment produced dark matter limits in 2017 from the SEDINE detector, a copper sphere of 60 cm in diameter [2]. The newest NEWS-G detector is S140, a sphere of 135 cm in diameter which took data in 2019 with methane at the LSM and has since then been moved to SNOLAB where it now takes data.

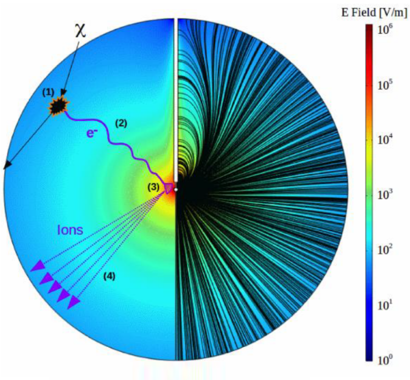

Figure 1: Left: SPC detection principle of a WIMP. Right: Electric field lines inside an SPC.

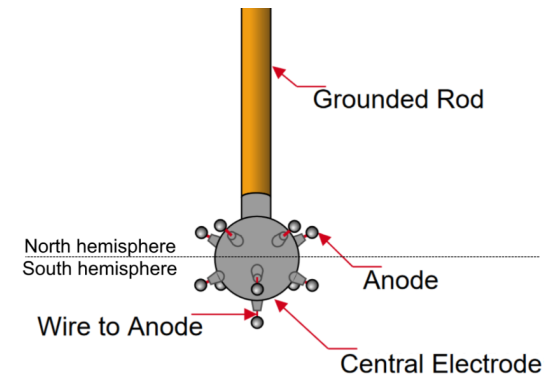

Figure 2: Schema of an achinos sensor.

2.2 The S140 detector

The S140 sphere is made of C10100 copper, with the inner surface covered with 0.5 mm of electroformed ultra-pure copper [3]. Layers of water, lead and archaeological lead shield the detector [4]. In total, 10 days of physics data were taken with 135 mbar of methane, i.e. 0.12

kg·days, before the whole detector (minus the water shield which was replaced by polyethylene) was shipped to SNOLAB.

S140 uses a multi-anode sensor called an achinos (shown in Figure 2) to keep the electric field strong far from the centre while enabling high gain close to the anodes [5, 6]. The achinos sensor comprises 11 equidistant anodes (plus the supporting rod) divided into two electrical channels: the north channel for the five anodes closest to the rod and the south channel for the six remaining ones. Due to the effect of the rod on the electric field, two-thirds of the volume leads to the south channel anodes. Also, a positive signal in one channel will induce a smaller negative signal in the other channel because of the Shockley-Ramo theorem.

2.3 Calibration of the detector

One of the main calibration methods is an ultraviolet laser. The laser sends light through an optic fibre which goes towards the sphere's inner surface, where it produces electrons due to the photoelectric effect. The optic fibre also diverts half of the light to a photodetector so that the laser events can be tagged. This gives a population of surface events that can be used for single-electron response calibrations, monitoring of the detector and electron drift time measurements [7].

The other primary calibration source is ^{37}Ar. The radioactive gas has two major energy peaks at 270 eV and 2.8 keV. Since it diffuses throughout the entire volume of the detector, it gives an example of volume events and enables energy calibration.

Other necessary calibrations are the W-values, calculated from literature measurements [8], and the quenching factor, measured at the COMIMAC facility [9].

3. Analysis of the LSM S140 data

3.1 α-particle-induced background

One of the main sources of background in the data taken at the LSM came from 0.028 Hz of surface α-particle events, primarily due to ^{210}Po contamination [10]. α particles ionize a large amount of gas, creating a space charge from all the secondary ions. This results in a sudden drop in the electron drift time, lasting approximately 10 seconds until the ions reach the sphere's surface. In parallel, α events also cause a sudden surge in the rate of events by inducing a high number of low-energy events for approximately five seconds. Although this mechanism is not completely understood, evidence suggests it is related to the amount of impurities in the gas mixture. Both effects are shown in Figure 3. Rejection of α-induced events was done by removing 5 seconds after each α, which were identified by the width of saturated events or their effect on the event baseline and rate. This removed 95% of the selected background while keeping 86% of the total time.

3.2 Pulse shape discrimination

In the data collected at the LSM, multiple spurious pulses were also present. Two main methods can discriminate against those. First, the spurious pulses tend to either be measurably spikier or wider than real events created by an electron avalanche. The other method is to look at the inverted induced pulse on the opposite channel, which does not occur for the spurious pulses. With those discrimination methods, approximately 95% of the spurious pulses can be removed while keeping 77% of the physical events [10].

PoS(TAUP2023)042

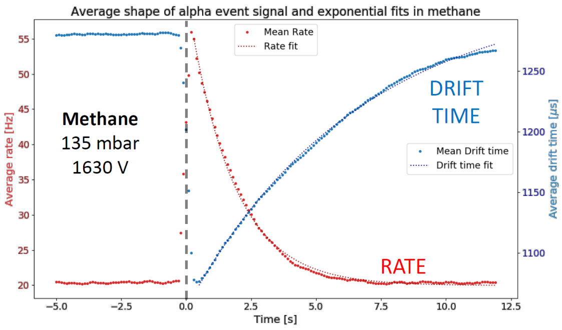

Figure 3: Average electron drift time (in blue) and total rate of events (in red) before and after an α event in S140 at the LSM with exponential fits.

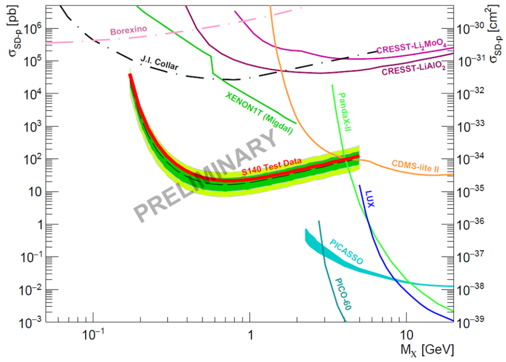

Figure 4: Preliminary LSM S140 test data limits in methane from 2022 [11].

3.3 Preliminary WIMP limits

After all selection cuts, the number of electrons per event is counted by a peak-finding algorithm. The time separation between the first and last peak indicates the radial position of the event, due to surface events experiencing more diffusion than volume events. Single-peak events have been excluded from the final analysis since their time separation is undetermined. 27% of the full data was set aside as a test to build the analysis, while the rest was kept blind. Profile likelihood fits were made for the 2, 3 and 4-peak data, with fits on surface background, coincidences and WIMP signal contributions. No significant WIMP signal was detected in the test data. This gives the strongest constraints for the spin-dependent WIMP-proton interaction in the 0.2-1 GeV/c^2 mass range [11].

4. Future of NEWS-G

4.1 SNOLAB

The S140 detector is currently taking data at SNOLAB, where there are many improvements compared to the data taken at the LSM. The neon mixture runs taken in early 2023 have no spurious pulses, better gas purity and less noise than the LSM data. There is also now the possibility of triggering independently on the north, south and photodetector channels on any run, and the low energy background has been reduced by 1-2 orders of magnitude compared to the LSM. Other improvements are planned, like a second etching of the inner surface and installing a new gas purifier and a radon trap.

4.2 Other projects

Two next-generation NEWS-G detectors are under consideration. One of them is ECuME, a copper sphere fully electroformed underground that would have the same size as S140 and also stay in SNOLAB. A 30 cm prototype is being built at the Pacific Northwest National Laboratory. The second planned detector would be DARKSPHERE, another fully electroformed sphere of 3m in diameter that would stay in the Boulby Underground Laboratory using a water shield [12].

Furthermore, the NEWS-G^3 (or G3) project at Queen's University aims to detect coherent elastic neutrino-nucleus scattering (CEνNS) at nuclear reactors. The shield is already built with layers of lead, polyethylene, copper and muon veto. It is now subject to testing and calibration.

5. Conclusion

In conclusion, in the search for dark matter, spherical proportional counters and the NEWS-G experiment are well suited to probe for low-mass WIMPs. After the test data was taken in methane at the LSM with the S140 detector, NEWS-G produced the world-leading proton-WIMP spin-dependent limits for WIMPs between 0.2 and 1 GeV/c^2. The blind portion of the same data will soon surpass these limits. Many improvements in SNOLAB and potential future detectors also mean the possibility of probing for even lower cross-sections of low-mass dark matter.

References

[1] G. Bertone and D. Hooper, *History of dark matter*, Rev. Mod. Phys. **90** (2018) 045002.

[2] Q. Arnaud, D. Asner et al., *First results from the NEWS-G direct dark matter search experiment at the LSM*, Astroparticle Physics **97** (2018) 54.

[3] L. Balogh, C. Beaufort et al., *Copper electroplating for background suppression in the NEWS-G experiment*, Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment **988** (2021) 164844.

[4] L. Balogh, C. Beaufort et al., *The NEWS-G detector at SNOLAB*, Journal of Instrumentation **18** (2023) T02005.

[5] A. Giganon, I. Giomataris et al., *A multiball read-out for the spherical proportional counter*, Journal of Instrumentation **12** (2017) P12031.

[6] I. Giomataris, M. Gros et al., *A resistive ACHINOS multi-anode structure with DLC coating for spherical proportional counters*, Journal of Instrumentation **15** (2020) P11023.

[7] Q. Arnaud, J.-P. Bard et al., *Precision laser-based measurements of the single electron response of spherical proportional counters for the NEWS-G light dark matter search experiment*, Phys. Rev. D **99** (2019) 102003.

[8] I. Katsioulas, P. Knights et al., *Ionisation quenching factors from W-values in pure gases for rare event searches*, Astroparticle Physics **141** (2022) 102707.

[9] L. Balogh, C. Beaufort et al., *Measurements of the ionization efficiency of protons in methane*, The European Physical Journal C **82** (2022) 1114.

[10] J.-M. Coquillat, *Calibration and background data analysis in the scope of the NEWS-G dark matter experiment*, Master's thesis, Queen's University, 2021.

[11] F.A.V. de Sola Fernandez, *Search for light WIMP recoils on methane with NEWS-G*, in *14th International Conference on Identification of Dark Matter*, SciPost Physics Proceedings, 2022.

[12] L. Balogh, C. Beaufort et al., *DarkSPHERE: Exploring light dark matter with a spherical proportional counter electroformed underground at the Boulby Underground Laboratory*, 2023.

PoS(TAUP2023)042