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Direct detection of light WIMPs with NEWS-G

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NEWS-G (New Experiments With Spheres-Gas) is a direct dark matter detection experiment using Spherical Proportional Counters (SPCs). It uses light noble gases to search for Weakly Interacting Massive Particles (WIMPs) down to the sub-GeV/c^2 mass region. The NEWS-G project builds on the experience gathered with the SEDINE detector, a 60 cm SPC which has been operating for several years at the Laboratoire Souterrain de Modane. The goal is to build a 140 cm diameter SPC using even lower activity materials, and operate it at SNOLAB.

We first introduce the concept of SPC. We then describe performance and calibrations done with a small prototype. Finally, we quickly describe the detector under construction for a deployment at SNOLAB planned in 2019.

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1. Introduction

The Spherical Proportional Counter (SPC) is a novel concept developed in 2006 at the CEA Saclay by I. Giomataris [1]. Its low intrinsic electronic noise in addition to its large amplification allows for a very low energy threshold, down to single electron detection. Their unique characteristics make SPCs competitive detectors for rare event detection applications such as dark matter and neutrino physics. The NEWS-G experiment primarily focuses on the search for light dark matter. The collaboration recently published the first results obtained with a 60 cm diameter SPC, SEDINE, operated at the Laboratoire Souterrain de Modane [2]. These results already exclude at 90% confidence level (C.L.) cross-sections above 4.4×10^{37} cm^2 for a 0.5 GeV/c^2 WIMP.

The competitive constraints are promising for the next phase of the experiment: a 140 cm diameter sphere made of selected radio-pure material and placed inside an enhanced shielding, to be installed at SNOLAB during 2019. In addition to these hardware improvements, the next detector generation will benefit from an intensive study of the electric field and the development of new methods of calibration which greatly improved our understanding of the detector response.

This proceeding will first overview the detector principle. It will show performance improvements on a small prototype, and describe the latest calibration, with sensitivity to single electrons using a solid state laser. Finally, there is a short description of the improved detector that will run at SNOLAB in 2019.

2. Operating principle of the detector

The detector consists of a grounded, metallic spherical vessel filled with gas. The anode is a small ball made of metallic or resistive material, placed at the center of the sphere and supported by a grounded metallic rod, through which the high voltage is applied. In an ideal SPC, the electric field depends on the anode radius r_2, cathode radius r_1, anode voltage V_0 and radial distance r from the anode. t is defined by:

$$E(r) = \frac{V_0}{r^2}\frac{r_2 r_1}{r_1 - r_2} \tag{2.1}$$

The electric field in the detector rapidly decreases with the square of the inverse distance from the center. This configuration divides the detector volume into two regions; the amplification region, less than $1mm$ around the anode, and the drift region. When particles interact in the gas volume, they ionize some gas, inducing the emission of primary electron. Under the influence of the electric field, the primary electrons drift toward the anode at the center of the sphere. The typical drift time varies from μs to ms depending on gas pressure and composition. When primary electrons reach the amplification region, an avalanche is created in the strong electric field. The signal is then induced by the motion of secondary ion away from the anode. Finally, the signal is extracted from the high voltage wire through a capacitor, amplified by a charge amplifier, with time constants from tens to hundreds of μs.

It is possible to extract two main observables from the recorded pulses; theirs amplitudes and rise times. The amplitude is directly dependent on the energy of the deposition. The rise time measures the spatial distribution of the energy deposition. Energy deposition along a track leads to a large rise time caused by the different arrival times of primary electrons. For point like energy depositions, the rise time is related to the diffusion of the primary electron cloud, which is correlated to the drifting distance.

3. Detector calibration and performance

A lot of R&D work has been done to optimise the performance of the detector. Most of it was done using a 30 cm stainless steel sphere with various gas mixtures and conditions.

Anisoptropies of the electric field cause a non-uniformity of the amplification gain. The installation of a secondary electrode helped correct this issue. Figure 1 shows the resulting resolution obtained on the 2.8 keV and 270 eV X-ray peaks from ^{37}Ar inside a sphere prototype. The energy resolution around each peak is close to the theoretical limit from statistical fluctuations of the ionisation process.

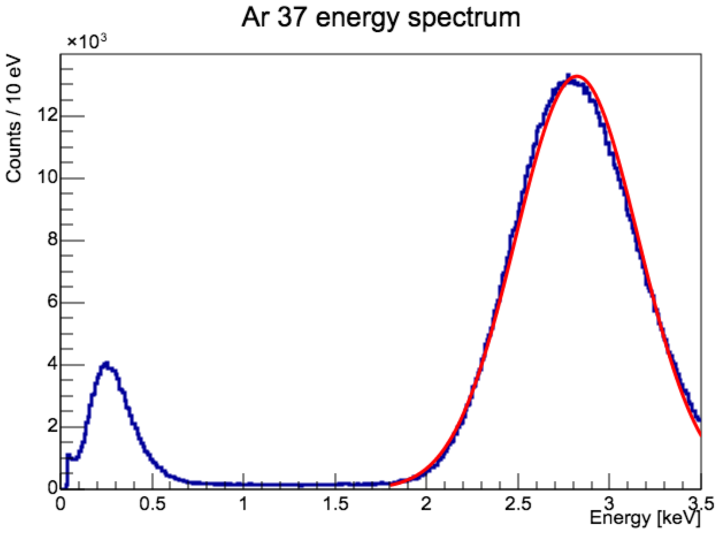

Figure 1: Energy spectrum of ^{37}Ar. The gaussian fit on the $2.82keV$ peak has a resolution of $\sigma/\mu = 12\%$

A 213 nm UV laser is used to further characterize the detector. It allowed to extract single electrons from the inner surface of the sphere. This allows to experimentally measure the fluctuations of the amplification gain of the detector. These fluctuations can be parameterized with the so-called Polya distribution [3]. The 213 nm light beam is splitted and sent through an optic fibre to a photo-detector and inside the sphere. Using the Polya distribution, and the expected Poisson fluctuations of the number of extracted electrons, a fit can be done of data with any number of primary electrons (i.e. laser beam intensity). The linear relationship between these two variables demonstrates the validity of the model. μ is as expected the only parameter of the fit that depends on the intensity of the laser pulses.

This electron counting measurement, combined with radioactive sources, allows to measure the mean number of primary electrons produced in the ionisation process. This laser calibration tool will also be used to continuously monitor the characteristics of the detector during dark matter search experiment. Preliminary measurements show that it can detect variations at the scale of a few seconds for parameters such as drift velocity.

4. Future experiment at SNOLAB

A new detector is under construction to improve sensitivity to dark matter. This will be achieved with:

- a 140 cm (1500 L) sphere made of high purity commercial copper, electroplated with 500 μm pure copper
- a compact lead shield, with 5 cm inner layer of roman lead, and 30 cm of low activity lead
- a 40 cm thick HDPE shield
- an advanced gas system to reduce gas contamination
- an improved calibration scheme, including continuous monitoring with a UV laser

The detector will be tested at Laboratoire Sousterrain de Modane (LSM) in the first half of 2019, and installed at SNOLAB (Sudbury, Canada) later in the year. It will also benefit from extended measurements of the quenching factor for nuclear recoils in neon.

5. Conclusion

SPCs have already shown their potential for dark matter detection with the SEDINE detector. Their performance have since been improved by optimising electric fields. New calibration methods confirm the ability of the detector to measure single electrons, and will allow a more accurate description of the ionisation process. This improved understanding will us allow to reach a greater sensitivity to dark matter particles with an SPC at SNOLAB.

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