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Status and prospect of NEWS-SNO Experiment

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A novel experiment called NEWS-SNO (News Experiment With Spheres) is setting up at SNO-LAB underground facility to probe low mass Dark Matter particles using a spherical gaseous detector and very light target nuclei such as hydrogen, helium and neon. The concept of spherical gaseous detectors to hunt for Dark Matter was pioneered by I. Giomatris [1] and developed at the laboratoire souterrain de Modane on a 60 cm diameter spherical detector. The analysis and preliminary results of the data collected from this prototype detector are discussed. The expected sensitivity calculated down to 0.7 GeV WIMP mass is quite promising. The attained performance paves the way forward for the larger scale detector to be installed at SNOLAB before the end of 2017. The status and expected sensitivity of the project at SNOLAB are also discussed.

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Introduction

Astronomical and cosmological observations have provided overwhelming evidences for the presence of dark matter in the Universe [2]. The particle nature of dark matter, however, has not yet been resolved and its quest remains among the forefront activities in modern physics [3, 4]. A class of neutral and stable non-baryonic massive particles so-called WIMPs (Weakly Interacting Massive Particles) constitutes the best candidates to date [5]. They are sought for at collider experiments (production), in telescope experiments (indirect detection), and in large underground detectors (direct detection).

NEWS-SNO experiment aims at directly detecting WIMP dark matter candidates using a spherical gaseous detector technique. In principle, ionisation in the gas can be triggered by WIMP induced nuclear recoils, and recorded ionisation signals are proportional to WIMP energy deposition (or WIMP mass). The main advantages of this technique are its event localisation capability, the potential to reach extremely low energy threshold (down to tens of eV) with fairly large target mass and the flexibility to change gas and use light target nuclei to kinematically match very light WIMPs, and thus probe a new and interesting WIMP mass region: 0.1 GeV to 10 GeV. Non finding of heavy WIMP candidates in run I and in first data from run II of the Large Hadron Collider [6, 7] coupled with non discovery of WIMPs above 10 GeV in both indirect and direct detection experiments indubitably suggest to gear searches towards low WIMP masses.

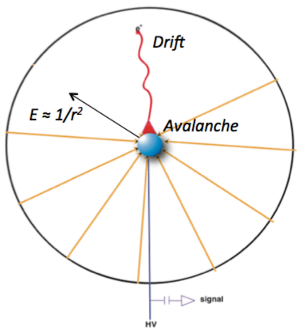

Figure 1: Schematic of the working principle of a spherical gaseous detector

Figure 2: Picture of the prototype SEDINE

1. Detector Set-Up and Operation

A NEWS-SNO detector is comprised of a hollow metallic sphere (made of ultra pure material) filled with gas and enclosing a small spherical ball (so-called sensor) at its center. The sensor is set at high voltage while the spherical vessel is set at ground. This induces a radial electric field E which makes ionisation electrons (produced via energy deposition within the vessel) drift to the sensor and trigger an avalanche in the region of high electric field very close to the sensor [8] (Figure 1). The sensor itself acts as a proportional amplification counter and is read by a single readout channel. The physics of the detection process does not allow for particle-type discrimination since, at high pressure, nuclear recoils and Compton interactions appear both as point like interactions at low energies and cannot be discriminated. However, event localisation discrimination can be performed using the pulse rise time, which is directly related to the diffusion of primary electrons (due to energy deposition), and as such to the radius at which energy is deposited.

The prototype SeDINE (SphEre pour la DetectIon de NEutron), shown in Figure 2, is a 60 cm spherical cavity made of low activity copper (NOSV grade) and containing a 6.35 mm silicon nitrite ball at its center. For the WIMP search run, the cavity was filled with 3100 mbar of Ne+CH_4 (99.3%:0.7 %) and operated in a sealed mode continuously for 42 days for a total exposure of 12.6 kg days. The methane served as a quencher to prevent the destruction of the proportionality of the detector response. The voltage applied to the silicon sensor was carefully selected as 2520 V to produce a high gain without sparks enabling to set a lower trigger threshold of 50 eVee slightly higher than the single ionisation electron energy in neon gas (36 eVee)

The entire detector was surrounded by three layers of passive shielding (8 cm of copper shielding, 10 cm of lead and 30 cm of polyethylene) to mitigate against ambient backgrounds at the laboratoire souterrain de Modane (LSM). LSM as an underground facility provides an overburden rock of 4800 m.w.e to help shield against cosmic rays.

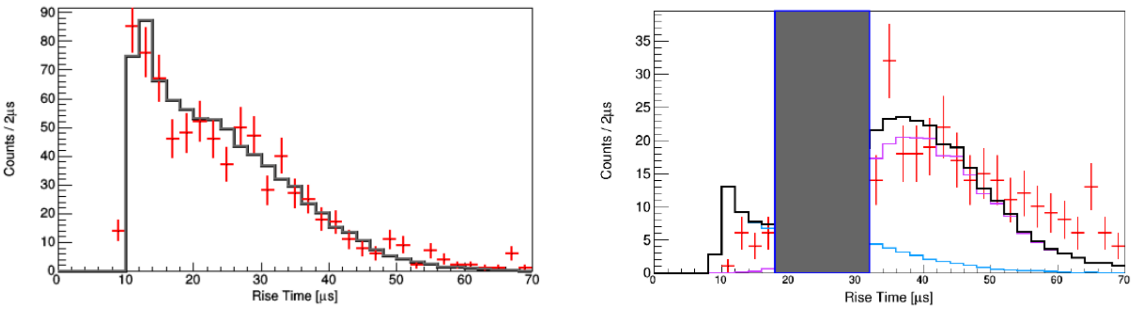

Figure 3: Comparison of the rise time distribution of simulated data and real data in energy window [500 eVee, 750 eVee]. Solid black line represents total simulation and red crosses represent data from AmBe neutron calibration (left) and WIMP search (right). The region of interest in the WIMP search is hidden for this analysis. Purple and cyan lines are contributions from simulated Compton and surface backgrounds (see text).

2. Data Analysis and Expected Sensitivity

Secondary electrons produced during avalanche barely induce a current on the sensor since the avalanche happens very close to the sensor. Positive ions on the other hand, drift a longer distance to reach the grounded spherical shell and thereof, their motion induces a current on the sensor according to the Shockley-Ramo theorem. The recorded pulse signal is a convolution of the ion motion induced current, the diffusion of primary electrons and the pre-amplifier shaping constant (RC) and should consequently be de-convoluted to recover the ionisation charge signal.

Two main analysis variables are extracted from de-convoluted pulses. They are: the pulse energy directly related to the deposited energy and the pulse rise time directly related to the position of the energy deposition. Pulse formation was simulated (assuming an ideal homogeneous electric field) and used to validate the numerical de-convolution methods use in the pulse treatment and to validate the understanding of the physics of the detector. Figure 3 shows an example of the agreement obtained between the simulated and measured pulses in their rise time distribution in a given energy window. Data shown are from a neutron (AmBe) calibration run and a WIMP search run. As can be seen, a good agreement between neutron calibration data and simulation is noticeable while a less good agreement is seen between simulated and measured backgrounds in WIMP search data.

The energy was calibrated via two means. First, by injecting an ^{37}Ar source inside the gas mixture and searching for the two x-rays peaks of 0.28 and 2.6 keV which are decay products of ^{37}Ar via electron capture. Second, by fitting the 8 keV line (due to copper fluorescence) in the WIMP search data. Both energy calibration, shown in Figure 4 and 5 agree within 15 %.

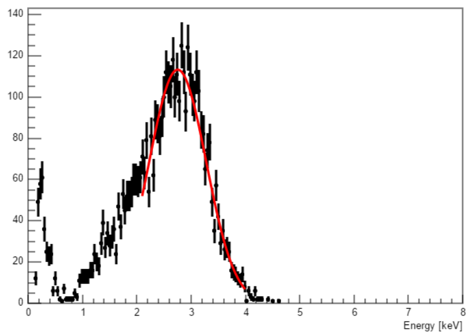

Figure 4: ^{37}Ar X-rays energy calibration

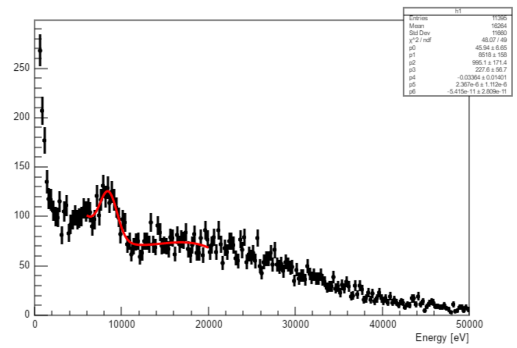

Figure 5: 8 keV copper fluorescence energy calibration

As alluded to above, two background event types were considered in the analysis of the WIMP search data: volume and surface event backgrounds. The former are due to Compton interactions produced by gamma particles originating from the surrounding of the detector and the detector materials. The later are due to ^{210}Po decay products (α, ^{206}Pb) caused by ^{222} Rn contamination on the inner surface of the detector. Figure 6 shows these simulated backgrounds in energy and rise time plane. An energy slice of [500 eVee, 750 eVee] was selected to produce the purple and blue curves shown in Figure 3. The fair agreement seen in Figure 3 for the WIMP search data suggests that this data is mostly a combination of surface and volume event backgrounds. However, it should be noted that the background model needs improvements to reproduce the long rise time tail observed in the data. This work is currently ongoing.

Figure 7 shows data from the WIMP search run in energy and rise time plane. A conservative analysis threshold of 150 eVee is applied for 100% trigger efficiency and the calculated signal cut efficiency is about 85%. Applied analysis cuts mostly remove micro-discharges and spurious pulses. The gray region corresponds to a wide preliminary region of interest (ROI) which is hidden until all the analysis tools are finalized[1]. Demarcated in red is the side band region that was used, together with the knowledge of the probability density functions of the backgrounds to determine their expected density inside the ROI.

While ongoing work to improve the background model is underway in order to perform a likelihood analysis, a Boosted Decision Tree (BDT) analysis was applied to WIMP search data to obtain a conservative limit on WIMP-nucleon interactions. The BDT was trained to define a

[1]Caveat: This is not a blind analysis

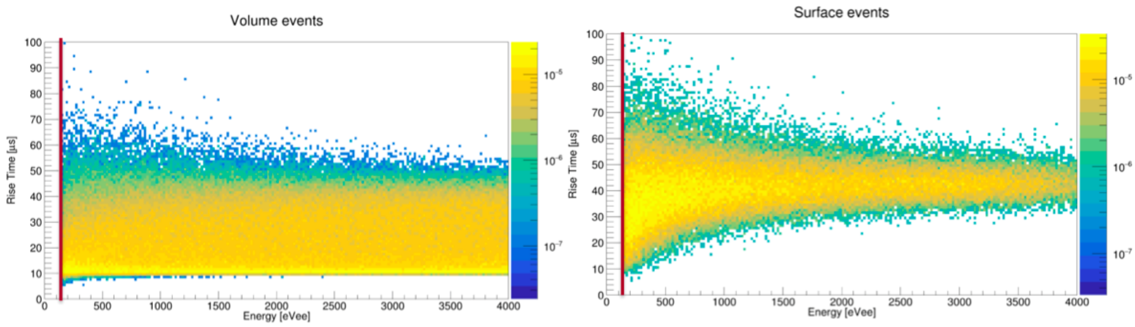

Figure 6: Probability density functions of the two background types in energy and rise time plane. volume events (left) volume events and surface events (right). The red line shows the conservative analysis threshold sets at 150 eVee (see text).

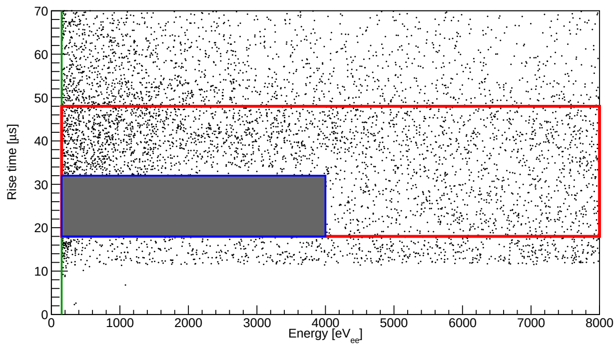

Figure 7: Energy vs rise time distribution from WIMP search data with hidden ROI (gray region) and side band regions in red rectangle. The green line shows the conservative analysis threshold sets at 150 eVee (see text).

fine tuned ROI that optimizes the discrimination between the signal and the backgrounds for each WIMP mass considered. Hundreds of SEDINE like experiments were simulated to account for statistical fluctuations while determining the expected sensitivity. For each simulated data set, an upper limit was set on the WIMP cross section considering all events in the refined ROI as WIMP candidates. Figure 8 shows the expected 1σ and 2σ sensitivity regions obtained using standard assumptions on WIMP kinematics, halo density and assuming calculated quenching factor of neon recoils in neon gas as given by [9]. Quenching factor measurements in neon gas below 1 keV are currently ongoing.

The expected sensitivity of the prototype SEDINE is quite promising: <1 pb at 0.7 GeV WIMP mass.

3. Status of the Project at SNOLAB

At SNOLAB, the detector will be made of a 140 cm spherical vessel molded from C10100 copper (having a few hundreds time less U and Th impurities than NOSV copper used for SEDINE detector). Anticipated target gas are He, Ne and H (via quencher CH4) at variable pressures of up

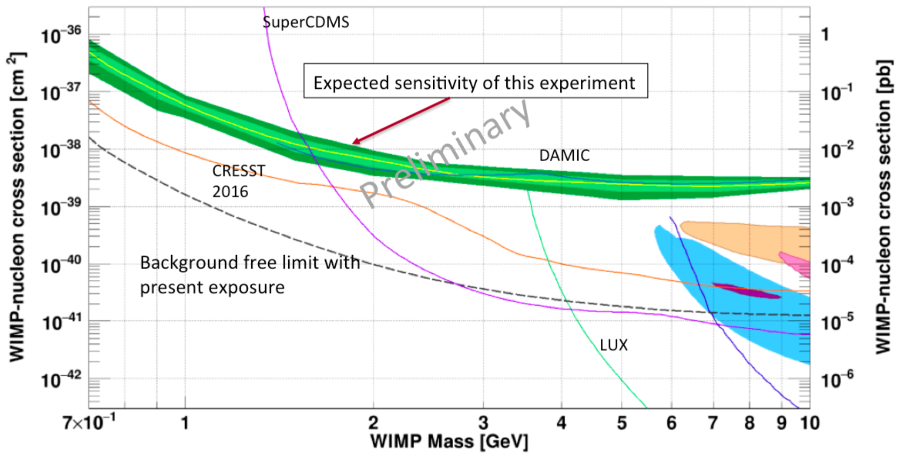

Figure 8: Expected sensitivity of the prototype SEDINE

to 10 bars. The size of the vessel does not have a strong impact on the energy threshold. With anticipated conservative threshold for NEWS-SNO of about 3 electrons, sensitivity to low mass WIMPs can be pushed to around 0.1 Gev with H target. The shielding will consist of 3 cm of archeolog-

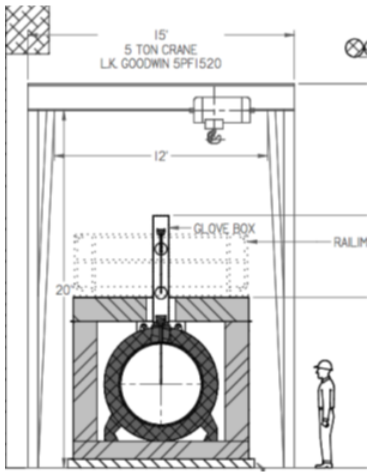

Figure 9: NEWS-SNO Shielding arrangement

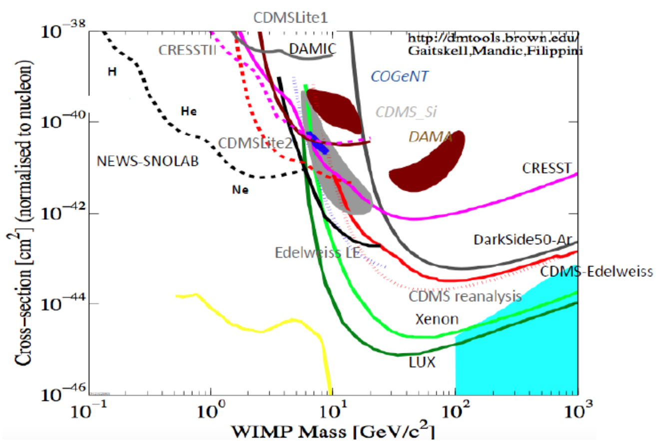

Figure 10: NEWS-SNO anticipated sensitivity

ical lead followed by 22 cm of low activity lead, both enclosed in 40 cm of borated polyethylene arranged as in Figure 9. The combination of the better copper quality, the more homogeneous thickness and more controlled radioactivity of the shields and the anticipated minimisation of internal sphere exposure to radon provides a drastic reduction in backgrounds, allowing to achieve the sensitivity in cross sections shown in Figure 10.

NEWS-SNO project has made substantial progress in the past few months. A site at SNOLAB has been allocated, the design of the detector vessel has been completed and a prototype has been machined and tested for radioactivity. The shielding design has also been completed and is underway for machining. There are a few more technical reviews to be completed at SNOLAB and the construction will start in 2017. It is truly an exciting time as this novel and promising concept of dark matter detection is taking shape.

Acknowledgements

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