Search for low-mass WIMPs with Spherical Detectors : NEWS-LSM and NEWS-SNO

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The technique of spherical gaseous detectors has been used for the first time in the Laboratoire Souterrain de Modane to search for WIMP signal. Some details on the used 60 cm diameter detector, operating conditions and preliminary results are given. Thanks to a low energy threshold of 150 eV and the use of Neon target, anticipated sensitivity has been calculated for WIMP masses as low as 0.7 GeV with a Boosted Decision Tree method. Final analysis of this data set is under way. A larger size detector of 140 cm diameter to be installed in SNOLAB is currently under design and planned to be operated end 2017.

1 Introduction

Dark matter is now clearly an essential ingredient of our understanding of the Universe. Its nature is still unknown but -massive- neutral particles, non relativistic at decoupling time, are a generic class of well motivated candidates. Recent -non-findings at LHC [1] and failure from direct detection experiments to find any candidate at masses above 10 GeV [2]suggest that the search should be extended, in particular to low mass. On the other hand, several new theoretical approaches (dark sector, asymmetric dark matter, U-boson, generalized effective theory ...) open the way to candidates with lower mass and/or more complex couplings than the traditional spin (in)dependent ones [3].

The proposed gaseous spherical detector technique, initiated by I Giomataris [4], benefits from two key features: 1) access to extremely low threshold -10's of eV- with sizeable amounts of target mass, few 10's of g to 10's of kg, 2) the so called kinematical match between target (A of nuclei) and projectile (Dark Matter particles) mass by the use of light A targets such as He or H nuclei. Energy transfer is optimized for similar mass of target and projectile, allowing to probe the 0.1 to 1 GeV mass range.

A 60 cm diameter prototype detector has been operated successfully with Ne gas at 3 bars. The next sections describe the used setup, operating conditions and first analysis of data obtained at the Laboratoire Souterrain de Modane (LSM).

2 Experimental set-up at LSM and Operating conditions

The detector consists of a spherical metallic vessel and a small metallic ball located at the center of the vessel. The ball is maintained in the center of the sphere by a rod and is set at high

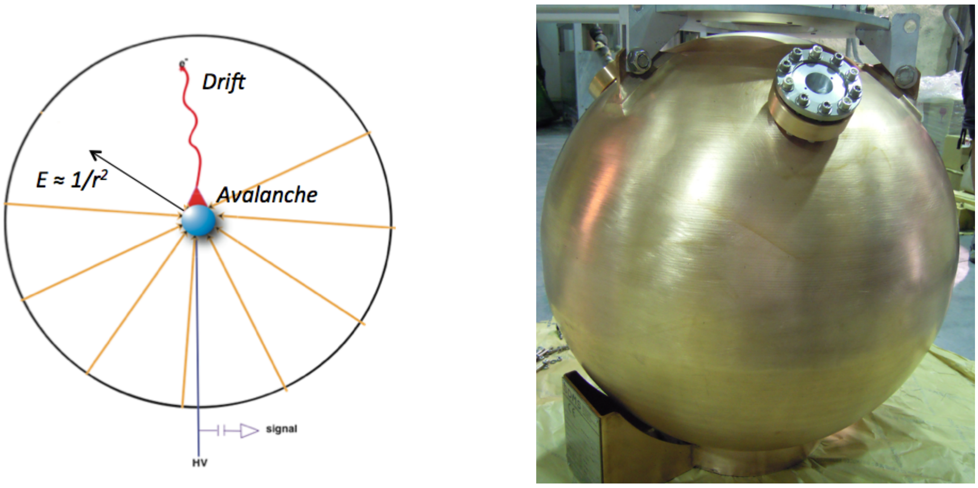

Figure 1: a left) Principle of spherical gas detector - b right) 60cm prototype made of low activity Copper

voltage. The configuration of the electric field, typically varying as $1/r^2$, allows the electrons to drift to the central sensor in low field regions constituting most of the volume, while they trigger an avalanche within few mm around the sensor (Figure 1a). The amplification capability combined with the very low capacitance of the sensor allows to reach single ionization electron sensitivity [5].

At high pressure, nuclear recoils and compton interactions appear both as point like interactions at low energies and cannot be discriminated. However fiducial information can be obtained by measuring the rise time of the pulse, directly linked to the diffusion of primary electrons, thus to the radius at which occurred the interaction.

The present results have been obtained with the SEDINE prototype, a 60 cm spherical detector made of ultra pure copper (Figure 1b). The sphere was installed underground, in the LSM under a rock thickness of 4800 mwe, and protected from external radiations by shields made of, from inside to outside, 8 cm of copper, 10 cm of lead and 30 cm of Polyethylene.

A simple sensor was designed, consisting of a 6.35 mm silicon ball, set to high voltage, to which is welded a 380 micron diameter insulated wire, inside a copper rod at ground.

The sphere was filled with a mixture of Neon and CH_4 in the proportions 99.3/0.7 at a total pressure of 3100 mb. The central ball was set at 2520 V, allowing a sufficient gain to set the acquistion threshold level equivalent to 50 eVee (electron equivalent) energy, that is around a single primary ionisation electron.

The detector was run in sealed mode for 42 days without interruption.

3 Data analysis and expected sensitivity

The acquired pulse shape is a convolution of the arrival time dispersion of the primary ionization electrons, of the current induced by the ions drifting away and of the transfer function of the amplifier.

Numerical unconvolution methods have been applied to the data pulses to obtain the two

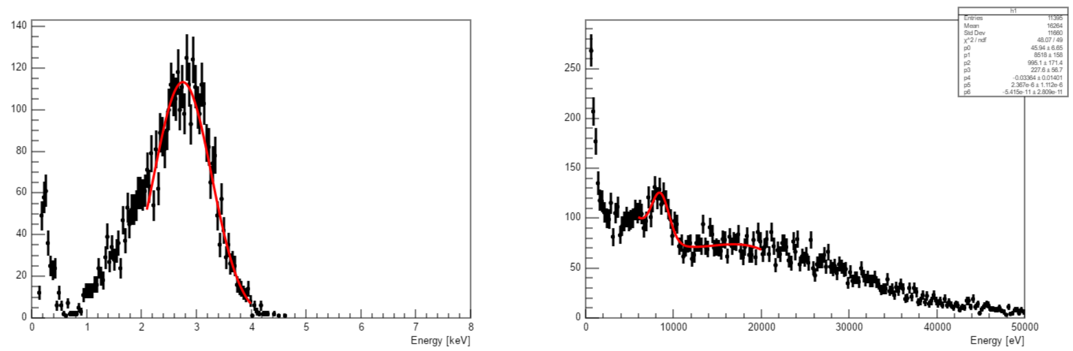

Figure 2: a left) Ar37 calibration b right) Data run with 8 keV induced by copper fluorescence

main parameters used in the analysis described later : the deposited energy and the risetime of the pulse, related to the radius at which occured the interaction.

Simulation of pulses based on physics and electronic described above allowed to validate the pulse uncovolution method. Energy calibration has been performed down to energies of 200 eV thanks to the use of an ^{37}Ar source, which electron capture decay induces X rays at 2.8 and 0.26 keV. The spectrum shown on Figure 2a shows indeed the expected features. The energy spectrum of the dark matter search run exhibits a line at 8 keV induced by copper fluorescence allowing to cross check the calibration with ^{37}Ar (Figure 2b).

The anticipated background interactions occuring in the detector have two main origins, on one hand compton / photoelectric interactions occuring in the volume induced by gamma rays coming from the materials of the detector and outside the detector and on the other hand particles originating from the surface of the detector, expected from Radon daughther deposits, mostly ^{210}Pb decays, beta/X rays, ^{210}Po alphas and associated ^{206}Pb nuclear recoils.

Rise time distribution of these two populations are expected to be very different. Full simulation of the pulses have been performed for volume and surface interactions and their rise time vs energy scatter plots are shown on Figure 3a and 3b.

Futhermore, to calibrate experimentally the response of the detectors to volume events and their risetime distribution, an Am-Be neutron source was used in situ, to produce point like energy deposition all over the volume.

The Figure 4a shows the measured rise time distribution in a typical energy window of 500 to 750 eV together with the simulated distribution of volume point like energy deposition in a simplified spherical symmetry for the electric field. Indeed, there is good agreement between data and model.

For the present analysis, a conservative analysis threshold of 150 eVee has been chosen.

Cuts were applied on the shape of the recorded pulse to remove microdischarges and spurious electronic pulses. The corresponding signal efficiency was measured from nuclear recoil sample.

Events recorded during the WIMP search run are shown in the rise time vs energy plane on Figure 4b. The comparison of Figures 4b 3a and 3b suggests that the data from WIMP search run are mostly a combination of surface and volume events. The shaded region corresponds to our wide preliminary region of interest (ROI) to search for WIMP's. The region highlighted in red is the side band region that is used, together with the probability density functions of the main backgrounds, to determine the expected population inside the ROI. A Boosted Decision

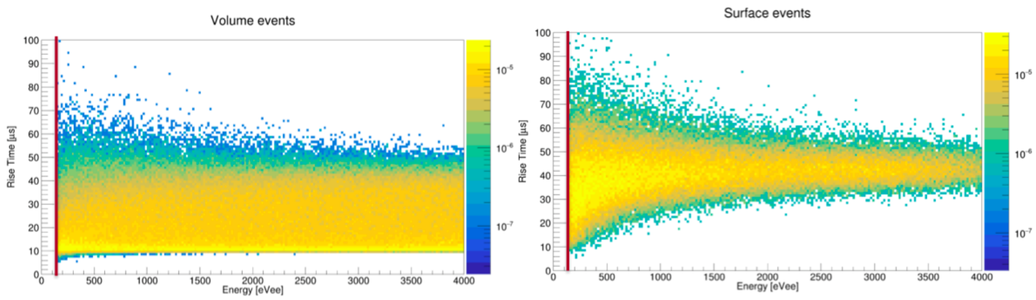

Figure 3: Probability density functions in the risetime vs energy plane of volume events (left) and surface events (right).

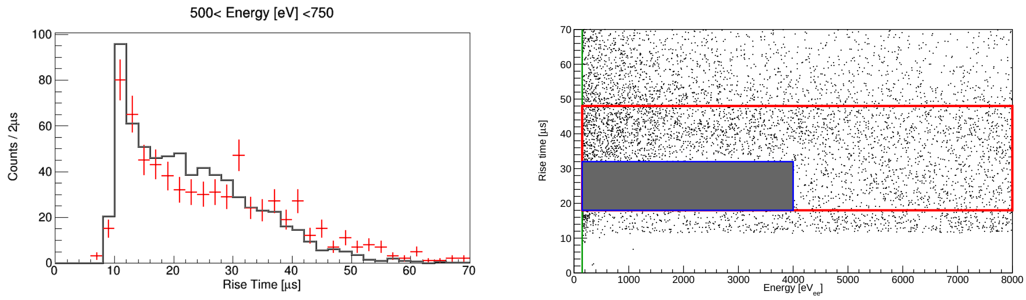

Figure 4: a left) Rise time distribution of events from neutron run calibration (red cross) together with simulated distribution in the 500-750 eV region. b) rise time vs energy distribution from WIMP search data with ROI (shaded) and side band (red rectangle) regions (see text).

Tree was trained in order to define a fine tuned ROI that optimizes the signal/background discrimination for each considered WIMP mass.

To determine the expected sensitivity, hundreds of NEWS-LSM Neon experiments are simulated to account for statistical fluctuations. 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, using standard assumptions on WIMP velocities, halo density, and calculated quenching factor of Neon recoils in Neon gas [6]. On Figure 6 are shown the expected 1σ (resp 2σ) sensitivity regions in light green (dark green).

Final analysis of the data is under way.

Quenching factors in Neon and Helium gas are being currently measured in the subkeV region using ion beams provided by a facility of the collaboration.

4 NEWS-SNO

The NEWS-SNO project builds up on the knowledge acquired with the operation of the 60 cm prototype in LSM. It will consist of a 140 cm sphere inserted in a shell of 25 cm archeological and low activity lead shield, itself protected by a 40 cm thick polyethylene shield, to be installed

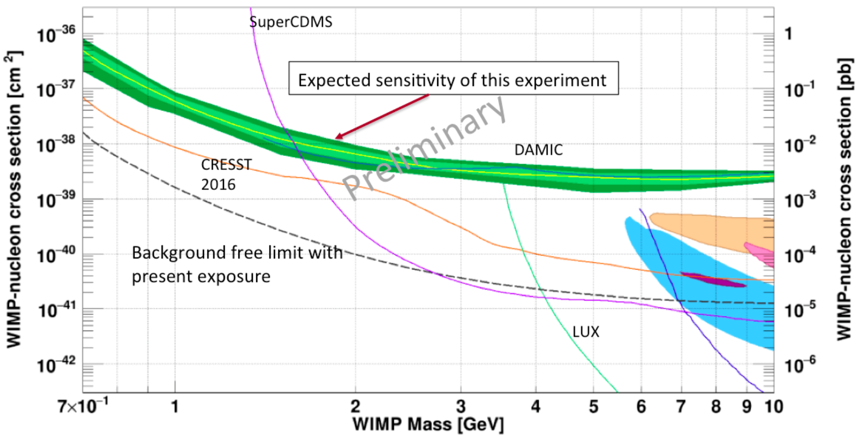

Figure 5: Expected sensitivity of the present search with Neon nucleus

in SNOLAB by end 2017. Space in SNOLAB has been assigned, design of the whole project is completed and TDR phase is ongoing.

Among major improvements, selection of extremely low activity copper (in the range of few μBq/kg of U and Th impurities) and dedicated handling to avoid radon entering the detector at any time will insure significant reductions of the backgrounds levels, both in surface and volume, relative to the above results, and allow sensitivity to Nucleon-WIMP cross section down to 10^{-44} cm^2. Use of H and He targets will allow to reach WIMP mass sensitivity down to 0.1 GeV. Details on set up and expected performances can be found in reference [7].

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