MIMAC-He3 : A Micro-TPC Matrix of Chambers of He3 for direct detection of Wimps

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Abstract. The project of a micro-TPC matrix of chambers of ^{3}He for direct detection of non-baryonic dark matter is presented. The privileged properties of ^{3}He are highlighted. The double detection (ionization - projection of tracks) is explained and its rejection evaluated. The potentialities of MIMAC-^{3}He for supersymmetric dark matter search are discussed

1. Introduction

In the last years our work on ^{3}He as a target for detecting WIMPs allowed to confirm its privileged properties for direct detection [1]. These properties can be enumerated as follow :

- its fermionic character opens the axial interaction with fermionic WIMPs as the neutralinos,
- the extremely low Compton cross section reduces by several order of magnitude the natural radioactive background with respect to other targets,
- the high neutron capture cross section gives a clear signature for neutron rejection,
- its light mass allows a higher sensitivity to light WIMP masses than other targets,
- the elastic energy transfer is bounded to a very narrow range of energy (a few keV) offering a high signal to noise ratio.

The extremely low Compton cross section and the possibility to detect events in the keV range ($\leq$5.6 keV) have been demonstrated by the ^{57}Co electron conversion detection recently reported [2]. The detection of 7 keV electrons in the MACHe3 prototype with the source emitting 121 keV γ-rays embedded in the ^{3}He is a clear demonstration of the virtual transparency of this medium to the electromagnetic radiation.

2. Micro-TPC and ionization-track projection

The micro temporal projection chambers with an avalanche amplification using a pixelized anode presents the required features to discriminate electron - recoil events with the double detection of the ionization energy and the track projection onto the anode. In order to get the electron-recoil discrimination, the pressure of the TPC should be such that the electron tracks with an energy less than 6 keV could be well resolved from the recoil ones at the same energy convoluted by the quenching factor. Simulations have been done, as a function of the pressure, for electrons using Geant 4 and for recoils using SRIM. The results are shown on fig. 1.

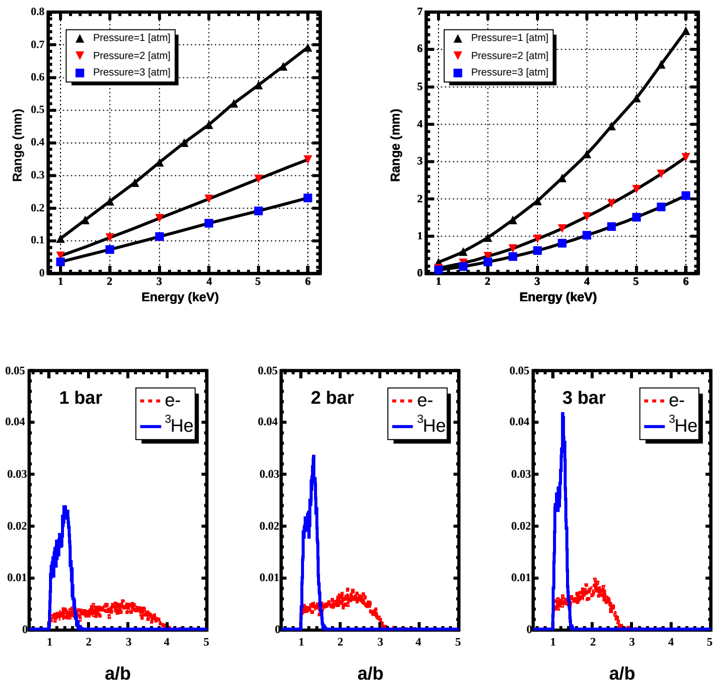

Figure 1. Upper panel : Simulated range vs kinetic energy for ^{3}He (left) and electrons (right), at 3 pressures. Lower panel : Simulated distribution of the ratio a/b at different pressures.

The electrons produced by the primary interactions will drift to the grid in a diffusion process following the well known distribution characterized by a radius of D $\simeq 200\mu\text{m}\sqrt{(}\text{L[cm]})$ where L is the total drift in the chamber up to the grid. This process has been simulated with Garfield and the drift velocities estimated as a function of the pressure and the electric field. A typical value of 26μm/ns is obtained for 1 kV/cm at a pressure of 1 bar. To prevent confusion between electron track projection and recoil ones the total drift length should be limited to L$\simeq$15 cm. It defines the elementary cell of the detector matrix and the simulations performed on the ranges of electrons and recoils suggest that with an anode of 350μm the electron-recoil discrimination required can be obtained. The quenching factor is an important point that should be addressed to quantify the amount of the total recoil energy recovered in the ionization channel. No measurements of the quenching factor (QF) in ^{3}He have been reported. However, an estimation can be obtained applying the Lindhard calculations [3]. The estimated quenching factor given by SRIM for ^{3}He shows up to 70 % of the recoil energy going to the ionization channel for 5 keV ^{3}He recoil.

To measure the QF in ^{3}He at such low energies, we have designed, at the LPSC laboratory, an ion source to accelerate the helium ions before entering to the micro-TPC chamber. They will pass through a thin foil of polypropylene that will neutralize them. The measurement of the energy of the atoms of ^{3}He will be made by a time of flight measurement.

In order to characterize the distribution of pixels on the anode for various trajectories we define the ratio between perpendicular symmetry axis of the pixel distribution (a/b) where a is the larger axis of the distribution. We plot on fig. 1 the simulated distribution of the ratio a/b at different pressures. An isotropic spherical emission of electrons and recoils at L $\sim$ 10 cm from the grid has been injected as the input of the simulation. For the recoils a very concentrated distribution around 1 is expected, and for the electrons a very wide one. The rejection of events using the a/b ratio is a strong function of the energy and the pressure of the chamber, but even at 1 keV and 3 bar only a small number of the total events can be confused.

3. Supersymmetric dark matter search

The potentialities of MIMAC-^{3}He for supersymmetric dark matter search are discussed [4] within the framework of effective MSSM models without gaugino mass unification at the GUT scale. Indeed, the unification constraint can be relaxed with a free parameter R defined by $\mathrm{M}_1 \equiv \mathrm{R}\,\mathrm{M}_2$. In this case, the neutralino $\tilde{\chi}$ can be lighter than the LEP limit obtained in universal scenarii. A large scan of the parameter space has been done with the DarkSUSY code [5] in which the departure from universality ($\mathrm{R} < 0.5$) has been implemented. The complementarity between various detection strategies for spin dependent (SD) interaction have been studied. Figure 2 shows the result in the $(\sigma_{\mathrm{p}}^{\mathrm{SD}}, \sigma_{\mathrm{n}}^{\mathrm{SD}})$ plane in the destructive interference case, for 20 GeV/c^2 neutralinos. Exclusion curves from CRESST, ZEPLIN-I and Edelweiss are presented (see [4] for details). For a given exclusion limit, the excluded region lies outside the two curves.

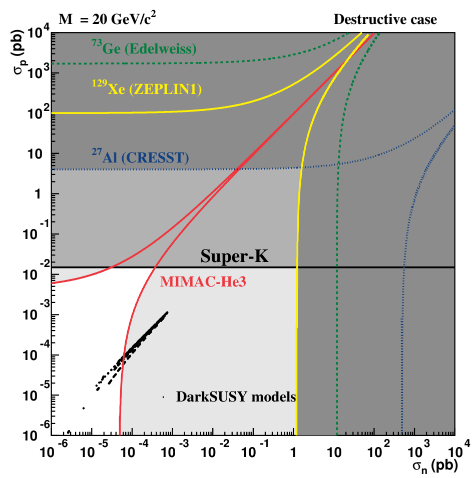

Figure 2. SUSY models satisfying accelerator and cosmological constraints (black points) in the SD cross-section on proton versus neutron plane for 20 GeV/c^2 neutralino.

The current excluded region (dark and medium grey) in this plane is given by the combination of these curves. It also includes the limit from indirect DM detection, from Super-K limit2, which is exclusively sensitive to the SD cross-section on proton. Therefore, this constraint strongly reduces the allowed region with a near orthogonality to neutron based experiments, whereas proton based experiments (CRESST) are well overlapped by Super-K limit. However, SUSY models (black points) neither excluded by accelerator nor cosmological constraints lie well below this limit. The projected exclusion curve for MIMAC-^{3}He is displayed. It can be seen that most of 20 GeV/c^2 neutralinos, escaping from detection of ongoing experiments, would be visible by MIMAC-^{3}He . This study highlights the complementarity of this experiment with most of current spin-independent and spin-dependent experiments : proton based detectors as well as ν telescopes.

4. References

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