

Dark matter directional detection with MIMAC

C. Grignon¹, J. Billard¹, G. Bosson¹, O. Bourrion¹, O. Guillaudin¹, C. Koumeir¹, F. Mayet¹,
D. Santos¹, P. Colas², E. Ferrer², I. Giomataris²

¹ *LPSC, Université Joseph Fourier Grenoble 1, CNRS/IN2P3, Institut Polytechnique de Grenoble, 53
avenue des Martyrs, 38026 Grenoble, France*

² *IRFU/DSM/CEA, CE Saclay, 91191 Gif-sur-Yvette cedex, France*

MiMac is a project of micro-TPC matrix of gaseous (³He, CF₄) chambers for direct detection of non-baryonic dark matter. Measurement of both track and ionization energy will allow the electron-recoil discrimination, while access to the directionality of the tracks will open a unique way to distinguish a genuine WIMP signal from any background. First reconstructed tracks of 5.9 keV electrons are presented as a proof of concept.

1 Introduction

Nowadays, there is a strong evidence in favor of a dark matter dominated Universe : locally, from the rotation curves of spiral galaxies¹ or the Bullet cluster² and on the largest scales, from cosmological observations^{3,4}. Most of the matter in the Universe consists of cold non-baryonic dark matter (CDM), the leading candidate for this class of yet undiscovered particles (WIMP) being the lightest supersymmetric particle. In various supersymmetric scenarii (SUSY), this neutral and colorless particle is the lightest neutralino $\tilde{\chi}$.

In order to detect this particle, tremendous experimental efforts on a host of techniques have been made. Whatever the detection technique used, ultimately, the problem is to distinguish a genuine WIMP event from backgrounds (mainly neutrons and γ -rays). The most promising strategy is to search for a favored incoming direction for the WIMP signal, the sun's velocity vector being oriented towards the Cygnus constellation^{5,6}. Several projects aiming at directional detection of Dark Matter are being developped^{7,8,9,10}.

Gaseous μ TPC detectors present the privileged features of being able to reconstruct the track of the recoil following the interaction, thus allowing to access both the energy and the track properties (length and direction). Although a precise measurement of the energy of the recoil is the starting point of any background discrimination, the 3D reconstruction of the track is necessary to do some dark matter directional detection.

2 The MIMAC project

The MIMAC project is a multi-chamber detector for Dark Matter search. The idea is to measure both track and ionization with a matrix of micromegas μ TPC filled with ³He and CF₄. The use of these two gases is motivated by their privileged features for dark matter search. In particular, a detector made of such targets will be sensitive to the spin-dependent interaction, leading to a natural complementarity with existing detectors mainly sensitive to scalar interaction, in various

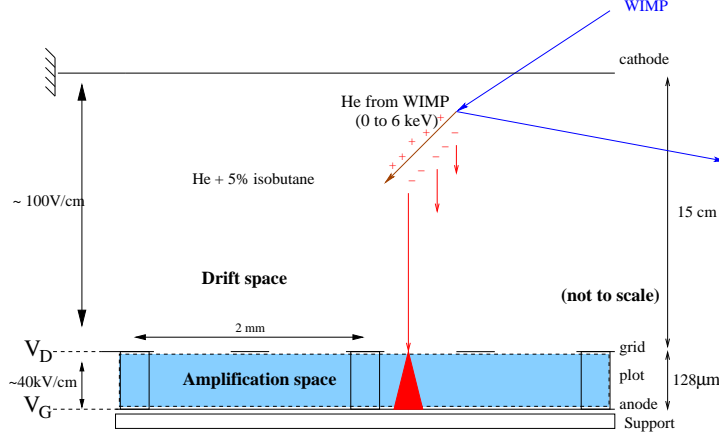


Figure 1: Sketch of the Micromegas μ TPC used for the Quenching factor measurement (not to scale).

SUSY models, e.g. non-universal SUSY^{11,12}. Using both ^3He and CF_4 in a patchy matrix of μ TPC opens the possibility to compare rates for two atomic masses, and to study neutralino interaction separately with neutron and proton as the main contribution to the spin content of these nuclei. With low mass targets, the challenge is to measure low energy recoils, below 6 keV for Helium, by means of ionization measurements, and to reconstruct the 3 dimensional track of the nuclei during low pressure operation of the MIMAC detector. Combining these two informations will open the possibility to discriminate neutralino signal and background on the basis of track features and directionality.

3 Measurement of the ionisation quenching factor

In order to distinguish signal from background, it is essential to precisely measure the energy of the recoil. This energy is released in the detection medium and is shared among three different processes: ionization, scintillation and heat. The fraction of energy given to electrons is defined as the ionization quenching factor (IQF) and has been estimated theoretically¹³ and parametrized by¹⁴, but has never been measured at low energy in helium gas, due to ionization threshold of detectors and experimental constraints.

As described in^{15,16,17}, we designed an Electron Cyclotron Resonance Ion Source, able to produced various ions (proton, ^3He , ^4He , ^{19}F) with an energy from 1 keV to 50 keV. We successfully measured the IQF in helium at low energies, and reached an energy threshold below 1 keV, which is a key point for Dark Matter detectors, since it is needed to evaluate the nucleus recoil energy and hence the WIMP kinematics.

4 Track reconstruction in 3D

The second step of a dark matter project aiming at directional detection is to show the possibility to reconstruct a 3D track. This is a key point as the required exposure is decreased by an order of magnitude between 2D read-out and 3D read-out⁶.

To perform this 3D reconstruction, we chose to use a segmented anode of a micromegas detector^{18,19} in order to collect the electrons produced by the recoil. As pictured on the figure 2, the electrons move towards the grid in the drift space and are projected on the anode thus allowing to access information on x and y coordinates. The third coordinate is obtained by sampling the anode every 25 ns and by using the knowledge of the drift velocity of the electrons.

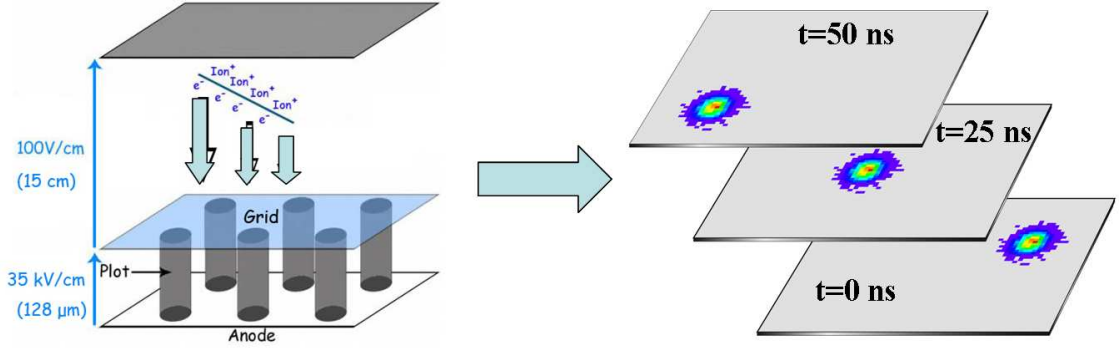


Figure 2: Track reconstruction in MIMAC. The anode is scanned every 25 ns and the 3D track is reconstructed, knowing the drift velocity, from the serie of images of the anode.

In order to perform this 40 MHz sampling of each $200 \mu\text{m}$ strip of the anode, we developed a complete electronic system²⁰ including 16 channels ASICs with a mixer and shaper for energy measurement, a FPGA with on-board processing and DAQ. We also developed a simulation software to test both the capability of the DAQ to reconstruct tracks and the reconstruction algorithm itself. For a realistic detector combined to our electronic, we show that the 3D track reconstruction can be achieved with a rather good resolution, of 0.3mm on the track length and below 4° on θ and ϕ , assuming a linear trajectory for the recoil ion²¹.

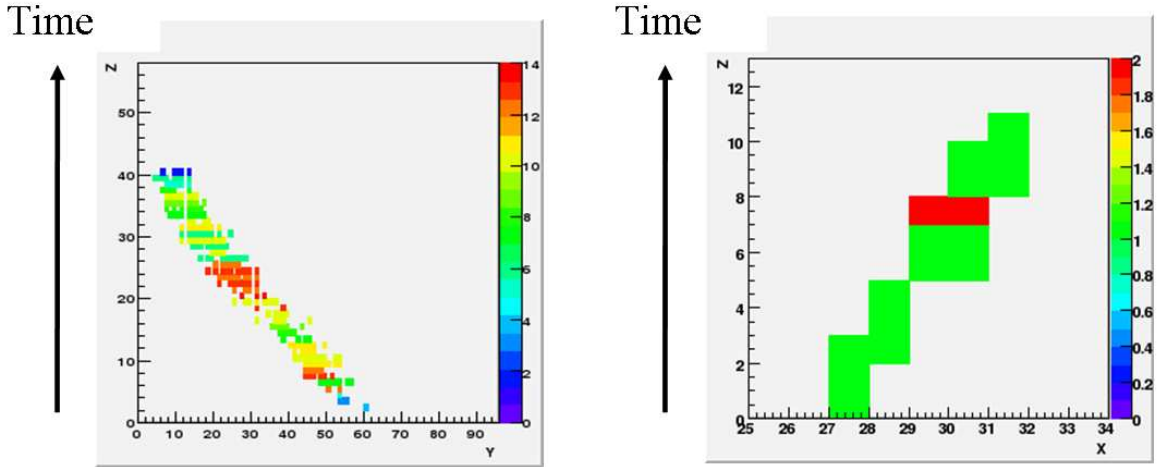


Figure 3: Reconstructed track of a 5.59 MeV α from radon impurities (left) and reconstructed track of a 5.9 keV electron projected on the XZ plane (right)

The first track reconstruction have been obtained with 5.59 MeV α from Radon impurities. Figure 3 presents a projection on a xz plane of an α 3D track obtained at 800 mbar in a Helium + 5 % isobutane mixture. This can be taken as a proof of the principle of track reconstruction strategy chosen for this project. Furthermore, we were able to use a sealed alpha source to measure the drift velocity of electrons at a specific E/P value²².

We were also able to reconstruct, for the first time, electron tracks with an energy of 5.9 keV (see figure 3), at 600 mbar. This highlight the possibility to separate electron event from nuclear recoil, even at very low energy.

5 Conclusion

Directional detection offers a robust signature for WIMP detection as long as we have access to the energy and recoil track of the nuclei. The MIMAC experiment has shown a precise measurement of the recoil energy of ions down to 1 keV as well as the ionisation quenching factor of He at this energy range.

Furthermore, we developed a complete electronic system and a dedicated algorithm in order to reconstruct precisely the recoil track in 3 dimensions. We were able to reconstruct alpha tracks in the prototype, due to ^{222}Rn , which can be used to prove the capability of the detector to reconstruct tracks. Finally, we reconstructed for the first time a 5.9 keV electron track in our prototype, which is a key point for background discrimination in a dark matter detection experiment.

The test of the detector will be performed this year with at the Amande facility with a neutron beam of a few keV, in order to check the capability of the MIMAC project to reconstruct low energy tracks.

References

1. V. C. Rubin *et al.*, arXiv:9904050 (1999).
2. D. Clowe *et al.*, *Astrophys. J.*, 648 L109 (2006).
3. E. Komatsu *et al.*, arXiv:0803.0547 (2008).
4. M. Tristram *et al.*, *Astron. Astrophys.* **436** 785 (2005).
5. D. N. Spergel, *Phys. Rev. D* **37**, 1353 (1988).
6. A. M. Green & B. Morgan, *Astropart. Phys.* **27**, 142 (2007).
7. G. J. Alner *et al.*, *Nucl. Instrum. Methods A* **555**, 173 (2005).
8. G. Sciolla *et al.*, arXiv:0806.2673 (2008).
9. D. Santos *et al.*, arXiv:astro-ph/0701230 (2006).
10. J. I. Collar & Y. Giomataris, *Nucl. Instrum. Methods A* **471**, 254 (2000).
11. F. Mayet *et al.*, *Phys. Lett. B* **538**, 257 (2002).
12. E. Moulin *et al.*, *Phys. Lett. B* **614**, 143 (2005).
13. J. Lindhard *et al.*, *Mat. Fys. Medd. K. Dan. Vidensk. Selsk.* **33** (1963) 1-42.
14. J. D. Lewin & P. F. Smith, *Astropart. Physics* **6** (1996) 87-112.
15. D. Santos, F. Mayet, O. Guillaudin *et al.*, arXiv:0810.1137 .
16. O. Guillaudin *et al.*, Proc. of the 4th symposium on large TPCs for low energy rare event detection, Paris, Dec. 2008, *Journal of Physics: Conference Series*.
17. F. Mayet *et al.*, Proc. of the 4th symposium on large TPCs for low energy rare event detection, Paris, Dec. 2008, *Journal of Physics: Conference Series*.
18. I. Giomataris *et al.*, *Nucl. Instrum. Methods A* **376**, 29 (1996) .
19. I. Giomataris *et al.*, *Nucl. Instrum. Methods A* **560**, 405 (2006).
20. J.P. Richer *et al.*, in preparation.
21. C. Grignon *et al.*, in preparation.
22. C. Koumeir *et al.*, in preparation.