Dark matter directional detection with MIMAC

Cyril Grignon

LPSC Grenoble
Université Joseph Fourier - CNRS/IN2P3

Rencontres de Moriond EW 2009
Outline

• Dark matter Directional detection

• The MIMAC project

• The $\mu$TPC detector

• Measurement of the Energy

• Reconstruction of the Track in 3D
Dark Matter Directional Detection

Why? to have a robust signature of WIMP detection

How? The solar system rotates around the center of the Galaxy, through a halo of WIMPs, and towards the Cygnus constellation.

WIMPs events should point towards Cygnus constellation

Background can not mimic such genuine events

Strategy: use direct detection and reconstruct Track AND Energy of the recoil nuclei

use gaseous detector

Ex: MIMAC, DRIFT, DM-TPC …
The MIMAC project

MIMAC: a multi-chamber detector for DM
- Matrix of \( \mu \)TPC chambers
- Micromegas technology (Energy AND Track)
- \(^3\)He and CF\(_4\) gas: \( \sigma(A) \) dependency
- Spin dependent Interaction (complementarity), interaction with n (He) or p (F)
- Low mass targets allow sensitivity to low mass WIMPs (\( M \geq 6 \text{ GeV} \))

Rejected of background events:
- Energy (ionization)
- Track
- Correlation of cells
- Direction (Cygnus), 2\(^{nd}\) step of MIMAC

Have to detect low energy Helium ions: \( E_{\text{recoil}} < 6 \text{ keV} \)
A µTPC for Dark Matter

- Drift space: 15 cm
- Cathode
- Micromegas with pixellized anode (x,y): 3 cm x 3 cm

The micromegas offers:

- High spatial, time, and energy resolution
- Recoil track projection
- Energy threshold ~ 1 keV
- Electron/nuclei discrimination

Collaboration: CEA Saclay

I. Giomataris et al., NIM. A 560 (2006)

Energy Measurement ≠ $E_{\text{recoil}}$
and
Track Projection ≠ 3D Track
Energy measurement : Quenching factor

Recoil energy is shared among:

- Scintillation
- Heat
- Ionization

Ionization Quenching factor defined as

$$Q = \frac{E_{ionization}}{E_{recoil}}$$

- Helium Quenching factor is predicted by Lindhard theory

... but need to be measured!

- Key point for Dark Matter to compute recoil energy
QF measurement: experimental set-up

ECR ion source developed @ LPSC
Low energy ion source 1 to 50 keV
Possibility to separate p, $^3$He, $^4$He, $^{14}$N, $^{19}$F …

1.5 keV $^4$He
E Ionization: 400 eV!
$(\sigma/E): 34\%$
QF measurement : results

- **Quenching factor @ 700 mbars**

- Measurement of $^4\text{He}$ in 95% $^4\text{He} + 5\% \text{C}_4\text{H}_{10}$

  - Threshold: 300 eV (ioni.) or 1 keV (recoil)
  - The response of this $^4\text{He}$ detector is fully understood from 1 to 50 keV
  - Dark Matter range: covered

- **Range of interest for Dark Matter**


- **Access to $E_{\text{recoil}}$ of the nuclei**
3D Track reconstruction

Complete electronic system (ASIC+FPGA+DAQ)

ASIC: 16 strips channels with mixer & shaper (energy)

FPGA: On-board processing

25 ns scan of the (x,y) anode

Number of images * Drift velocity + 2D projection

3D Track reconstruction: L, θ and φ
Measured tracks of alpha particle

From $^{222}\text{Rn}$
$E_\alpha = 5.49 \text{ MeV}$

With the reconstruction soft

Can ID $\alpha$ tracks

3D Reconstruction works
Measurement of drift velocity (NEW !)

$\alpha$ source $^{241}$Am + collimator ($A \sim 1$ Bq)

Time

<table>
<thead>
<tr>
<th>(Y,Time)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
</tr>
</tbody>
</table>

$16.5 \text{ cm}$

95% $^4\text{He}$ / 5% $C_4H_{10}$
Pressure: 360 mbar
Drift field: 180 V/cm

Velocity of $15.85 \mu\text{m/ns}$

Close to Magboltz value: $15.2 \mu\text{m/ns}$

Needed to reconstruct length!
Measured tracks of electrons (preliminary)

- 5.9 keV x-ray from $^{55}$Fe
- Pressure of 600 mbar
- Drift field of 130 V/cm

For the first time:
3D track of 5.9 keV electron !!!

Each pixel is 300 µm wide !!!
Simulation of track reconstruction

• Test of capability of the DAQ and reconstruction algorithm to reconstruct tracks
• Assumed linear trajectory for recoil tracks
• \( V = 26 \, \mu \text{m/ns} \), pitch of 300 microns, \( D = 200 \, \mu \text{m/cm}^{\frac{1}{2}} \)

\[ \Delta L \]
\[ \Delta \phi \]
\[ \Delta \theta \]

\( \sigma = 320 \, \mu \text{m} \)
\( \sigma = 3.7 \, \text{deg} \)
\( \sigma = 2.6 \, \text{deg} \)

Promising angular resolution for directional detection
MIMAC: conclusions and outlooks

- Directional detection offers a robust signature for WIMP detection: we need energy and recoil track of the nuclei

- He Quenching factor has been measured at various pressures
  - Key point for energy measurement

- Energy resolution has been measured down to 1 keV
  - ok for Dark Matter purposes

- First tracks measurements in the detector
  - Alpha used to measure drift velocity
  - Identification of 6 keV electrons, e⁻/nuclei discrimination possible
  - Good for direction detection

Next Step

- Neutrons detection @ IRSN Cadarache, in April 2009
  - neutron beam with an energy down to a few keV (Amande facility)

- Phase I : 1 m³ in 2012
The MIMAC collaboration

LPSC (Grenoble) : D. Santos, F. Mayet, C. Grignon, C. Koumeir

   Technical Coordination : O. Guillaudin
   - Electronics : G. Bosson, J-P. Richer
   - Gas detector : A. Pellisier
   - Data Acquisition: O. Bourrion
   - Mechanical Structure : Ch. Fourel
   - Ion source : T. Lamy, P. Sole

CEA-IRFU (Saclay) : I. Giomataris, P. Colas, E. Ferrer

IRSN (Cadarache): L. Lebreton, A. Allaoua
Backup slides
3D Track reconstruction

3D track is reconstructed from 25 ns scan of the (x,y) anode

Measure \( \Delta X, \Delta Y \) and \( \Delta Z \)

Knowing the Drift velocity

\[ L, \theta \text{ and } \phi \]
Energy Calibration of Micromegas

Al: 1.5 keV
49% (FWHM)

Fe: 5.9 keV
32% (FWHM)
Spin contributions to the axial interaction

<table>
<thead>
<tr>
<th>Nucleus</th>
<th>Z</th>
<th>Odd nucleod</th>
<th>$&lt;S_p&gt;$</th>
<th>$&lt;S_n&gt;$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$^3\text{He}$</td>
<td>2</td>
<td>n</td>
<td>1/2</td>
<td>-0.05</td>
</tr>
<tr>
<td>$^{19}\text{F}$</td>
<td>9</td>
<td>p</td>
<td>1/2</td>
<td>0.44</td>
</tr>
</tbody>
</table>

Spin dependent Interaction (complementarity)

Interaction with n (He) or p (F)

Low mass target → Low energy recoils

First phase: focus on low energy Helium ions

$E_{\text{recoil}} < 6 \text{ keV}$
Ion source calibration with Si$_3$N$_4$ membrane

Time of flight under vacuum

- Neutral atom after the Silicon nitride membrane
- Method: measuring time of flight for 2 positions of the STOP channeltron
QF measurement: calibration

1,486 keV X ray (Al)

\[ \frac{\sigma}{E} \approx 14\% \]

5,97 keV X ray (Fe)

\[ \frac{\sigma}{E} \approx 5\% \]
QF measurement: low energy ions

1.5 keV $^4$He

- Ionization energy: 400 eV!
- Energy Resolution ($\sigma/E$): 34%

50 keV $^4$He

- Ionization energy: 35.5 keV
- Energy Resolution ($\sigma/E$): 2%

$^4$He from 1 keV to 50 keV
QF measurement: versus Lindhard & SRIM

- Lindhard: pure $^4$He
- SRIM: simulation of $^4$He in 95% $^4$He + 5% $C_4H_{10}$

Δ (SRIM-DATA)
May be assigned to scintillation

**Comparaison between Lindhard theory, SRIM simulation and MIMAC measurements**

- Lindhard theory
- SRIM simulation
- MIMAC measurements


Need to measure He scintillation…
Lindhard prediction for Helium

From J. Lindhard (1963)

Lewin & Smith (1996) parametrization

High Q value for Helium

Need to be measured

Q(^3He) slightly greater than Q(^4He)
Cross section $^3$He-$\chi$ and event rate in MIMAC-He$^3$ (10kg)

- $0.02 < \Omega \chi h^2 < 0.15$
- Accelerator constrains

Exclusion curve for background $10^{-3}$ kg$^{-1}$ jour$^{-1}$
Complementarity with scalar detection

$\sigma_{SD}$ and $\sigma_{SI}$ not correlated

E. Moulin et al, PLB 614 (2005)143
Direct Detection of SUSY particles

Elastic diffusion $\chi$-quark:

- spin dependent (axial)
  \[ \sigma_{SD}(AX) \propto \sigma_{SD}(p) \times A^2 \]

- spin independent (scalar)
  \[ \sigma_{SI}(AX) \propto \sigma_{SI}(p) \times A^4 \]

For $^3$He and $^{19}$F: $\sigma_{SD} \gg \sigma_{SI}$