Directional detection with MIMAC
Micro-tpc MAtrix of Chambers

Status and perspectives

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**Directional detection**

**Directional Detection of Dark Matter (DM):**

- **DM expected signal**
- **Uniform expected background**
- **$E_{Recoil} \in [5,50] \text{ keV}$**

**Expected measurement, 100 evts signal, 100 evt bkg**

**Proof of the detection:**

Signal pointing toward Constellation Cygnus

**Profile likelihood Analysis**

**Proof of discovery:**

Signal pointing toward the Cygnus constellation

Blind likelihood analysis in order to establish the galactic origin of the signal

**Significant correlation**

With the direction of the Constellation Cygnus even with a large background contamination

**Phenomenology:**

Discovery

D. Santos (LPSC Grenoble)

LTPC Conference - Paris - December 17th 2012

MIMAC detection strategy

**Sampling:**
512 channels @ 50 MHz
\( T_{\text{Sample}} = 20 \text{ ns} \)

**Ionization energy:**
Measured with a charge integrator from to the grid

**3D-Track:**
- \( Z \) coordinate from drift velocity (measured)
- \( X,Y \) coordinates from the strips of pixels
  \( \rightarrow \) To get \((l, b)\) coordinates

J. Billard, F. Mayet and D. Santos, JCAP **04** (2012) 006
Gas mixture and pressure

Gas mixture @ 50 mbar:

\[ 70\% \text{ CF}_4 + 28\% \text{ CHF}_3 + 2\% \text{ C}_4\text{H}_{10} \]

70 \% CF\textsubscript{4}:
- \textsuperscript{19}F: target for DM detection

28 \% CH\textsubscript{3}:
- Reduce the drift velocity

2 \% C\textsubscript{4}H\textsubscript{10}:
- Increase the detector gain
- Quencher

Electrons drift velocity:
\[ v_{\text{drift}} = 26 \mu m/\text{ns}^{-1} \]
Ionization Quenching measurement

Ionization Quenching Factor (IQF):

\[ Q_{\text{ion}} = \frac{E_{\text{recoil}} (E_{\text{kin}})}{E_{\text{recoil}} (E_{\text{kin}})} \]

**SRIM:** Overestimation of the IQF
→ Require a measurement

**Ionization Quenching Facility at LPSC-Grenoble**
- Low energy ion source 1 to 50 keV
- Developed @LPSC
**MIMAC validation with neutrons**

“a WIMP signal simulator”

**Neutron field:** AMANDE facility at IRSN (Cadarache)

- Neutrons with a well defined energy from resonances of $^7\text{Li}$ by the reaction $^7\text{Li}(p,n)$
- Monochromatic neutron fields

Neutron will produce nuclear recoils in the active volume with energies:

$$E_{\text{Recoil}} = 4 \frac{m_n m_R}{(m_n + m_R)^2} E_{\text{neutron}} \cos^2 \theta$$

Different end-points for different nuclei

$\theta$: diffusion angle in laboratory referential

**Calibration:**

$^{55}\text{Fe}$ (5.9 keV) and $^{109}\text{Cd}$ (3.1 keV) sources
Measurement of the ionization energy and the track length

Max neutron energies at $0^\circ$: $E_n(0^\circ) = 565 \text{ keV}$

- Fluorine end-point $\times Q_{ion}$
- Carbon end-point $\times Q_{ion}$
- Proton branch
- (Fluorine + Carbon) branch
- (Fluorine + Carbon + Proton)
Recoil tracks measurement

$E_{\text{ioni}} = 38.3 \text{ keV}$

$E_{\text{ioni}} = 12.1 \text{ keV}$
MIMAC bi-chamber prototype

- Two mirror detectors sharing the same cathode → 2 x 512 electronic channels
- Active volume = 2x(25x11x11) cm³ ~ 5L
- Filled with a gas mixture of 70% CF₄ + 28% CHF₃ + 2% C₄H₁₀ at 50 mbar
- Gas circulation system with O₂ filter
- On-line calibration system with a X-ray generator
- Installed at Modane Underground Laboratory (LSM) in June 2012
MIMAC at the LSM: Calibration

Calibration:

• X-ray generator to produce fluorescence photons from metal foils (Cd, Fe, Cu, Pb)
• Twice a week

Low energy detector calibration.

Many thanks to LSM staff

LTPC Conference- Paris - December 17th 2012
D. Santos (LPSC Grenoble)
MIMAC at the LSM: Calibration

Calibration:
• X-ray generator to produce fluorescence photons from metal foils (Cd, Fe, Cu, Pb)
• Twice a week low energy detector calibration.

Gain stability: (Tiny variation of peaks position in time)

→ Stable quality of the gas mixture

![Graph showing gain stability over time](image-url)
Event Rate: about 5 evt/min, without any cuts

October 3rd: Gas system circulation shutdown → Exponential decreasing of the event rate

Radon pollution Expected

Cathode surface events:

Recoil stop
In the cathode

α pass through the cathode

Recoil

α
Rn

Recoil

α
Rn
MIMAC bi-chamber prototype at the LSM: Radon pollution

**Event Rate:** about 5 evt/min, without any cuts

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**Radon pollution Expected**

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**Cathode surface events:**

Recoil stop
In the cathode

α pass through the cathode

No problems for discrimination

Time & spatial correlation between the two chambers

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18/03/13

Quentin Riffard - Moriond 2013
Low energy recoils:

<table>
<thead>
<tr>
<th>Recoil</th>
<th>Recoil Energy [keV]</th>
<th>Ionization Quenching factor (SRIM) [%]</th>
<th>Ionization Energy (SRIM) [keV]</th>
<th>Ionization Energy measured [keV]</th>
</tr>
</thead>
<tbody>
<tr>
<td>$^{218}\text{Po}$</td>
<td>100.79</td>
<td>37.93</td>
<td>38.23</td>
<td>32.43</td>
</tr>
<tr>
<td>$^{214}\text{Pb}$</td>
<td>112.27</td>
<td>39.10</td>
<td>43.90</td>
<td>34.56</td>
</tr>
<tr>
<td>$^{210}\text{Pb}$</td>
<td>146.52</td>
<td>40.12</td>
<td>58.78</td>
<td>46.04</td>
</tr>
</tbody>
</table>

Analysis using MIMAC observables

Each event in the histogram has an associated track

Fit:
- 3 Gaussian distributions $\rightarrow ^{222}\text{Rn Progeny}$
- 1 constant $\rightarrow \alpha$-particles from the other chamber passing through the cathode
Recoil track at 34 keV

By event number
From: 133  To: 133
Search Events
100% Event list: 133

Anode projection
Track ZX
Track ZY

Strip count versus time

- X strips
- Y strips
- X+Y

Flash signal

Flash derivative signal

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Next step: MIMAC – 1m$^3$

MIMAC demonstrator for DM search

- 50 bi-chamber modules (20x20x25 cm$^3$) split up into two big chambers (25 modules each)
- New technology anode 20cmx20cm (piggy-back) (already tested in 10cmx10cm)
- New electronic card (1024 channels)
Phenomenology: Discovery

Exposure:
30 kg.an CF$_4$

Recoil energy range:
[5, 50] keV

Focusing on the axial interaction

Discovery at 3σ with 90 % CL :
- With 300 background events
- Without background events

Conclusions:
A discovery (>3σ @90%CL) with BKG is possible down to 10-3-10-4 pb
Conclusions

- Measurement of recoil 3D-tracks with tenths keV ionization energy and a few millimetres length
- Correlation between the two chambers to discriminate α-particles from the cathode
- Measurement for the first time of tracks of recoils coming from the Radon progeny and their energies

Next step: The 1 m$^3$ demonstrator
The MIMAC collaboration

**LPSC (Grenoble):** J. Lamblin, F. Mayet, D. Santos
J. Billard (Ph.D) (left in July 2012), Q. Riffard (Ph.D) (started in October 2012)

Technical Coordination: O. Guillaudin
- Electronics: G. Bosson, O. Bourrion, J-P. Richer
- Gas detector: O. Guillaudin, A. Pellisier
- Data Acquisition: O. Bourrion
- Mechanical Structure: Ch. Fourel, S. Roudier, M. Marton
- Ion source (quenching): P. Sortais, J-F. Muraz

**Saclay (IRFU):** I. Giomataris, E. Ferrer, F.J. Iguaz, J-P. Mols (uM detectors)

**CCPM (Marseille):** J. Busto, Ch. Tao, D. Fouchez, J. Brunner (Radon filtering)

Neutron facility (AMANDE):

**IRSN (Cadarache):** L. Lebreton, D. Maire (Ph. D.), J. Médard (CDD-1year)