MIMAC
MIcro-tpc MAtrix of Chambers
A Large TPC for directional non baryonic Dark Matter detection

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MIMAC:
(MIcro-tpc MAtrix of Chambers)

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J. Billard (Ph.D) (leaving in July 2012), Q. Riffard (Ph.D)

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- Electronics: G. Bosson, O. Bourrion, J-P. Richer
- Gas detector: O. Guillaudin, A. Pellisier
- Data Acquisition: O. Bourrion
- Mechanical Structure: Ch. Fourel, M. Marton
- Ion source: P. Sortais, J-F. Muraz, J. Médard

Joining:

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

Neutron facility (AMANDE):

IRSN (Cadarache): L. Lebreton, D. Maire (Ph. D.)

IDM2012 – Chicago (USA) – July 24th 2012

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The MIMAC project

A low pressure multi-chamber detector

- Energy and 3D Track measurements
- Matrix of chambers (correlation)
- $\mu$TPC : Micromegas technology
- CF$_4$, CHF$_3$, and $^1$H : $\sigma$(A) dependancy
- Axial interaction
- Directionnal detector

Bi-chamber module
2 x (11x11x25 cm$^3$)

Strateg: 
- direct detection
- Energy AND 3D-Track of the recoil nuclei
- Prove that the signal “comes from Cygnus”
MIMAC: Detection strategy

Scheme of a MIMAC µTPC

Evolution of the collected charges on the anode

Measurement of the ionization energy: Charge integrator connected to the grid

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Ionization Quenching Facility at LPSC-Grenoble

- Low energy ion source
  1 to 50 keV
- Developed @LPSC
Ionization Quenching Measurements:
5keV $^{19}$F Recoil in 60 mbar
40mbar CF4+16.8mbar CHF3+1.2 mbar Isobutane

Recoil: $^{19}$F 5 keV
$E_i = 1.19$ keV
$Q=0.238$
Threshold: 400 eV

Ion beam

Gas

E Drift
Ionization Quenching Factor for Fluorine in pure CF4 at 50 mbar (preliminary results)

Fluorine in CF4 at 50 mbar

He in He + 5% C4H10 at 350 mbar
MIMAC 100x100 mm²(v2)
(designed by IRFU- Saclay (France))
New MIMAC electronics (512 channels)

Entirely developed (ASICs included) by the MIMAC team at the LPSC-Grenoble (France)
MIMAC: Performance at low energies

3 keV ($^{109}$Cd)

5.9 keV ($^{55}$Fe)

CF$_4$ + 28% CHF$_3$

(+2% C$_4$H$_{10}$)

50 mbar

Fluorine candidate

@ 50 keV ionization

Produced with a monochromatic neutron field (AMANDE)

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MIMAC : nuclear recoil track measurements

April 2009
@ IRSN Cadarache
and May 16th, 2011 !!

Amande facility :
• Neutron field with energies down to a few keV
Recoils from 144 keV neutrons

Amande facility @ IRSN Cadarache
-> Neutron field with energies down to a few keV

- Possibility to have H as a target
- Background discrimination from recoils

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Normalized Integrated Straggling (NIS)
(a new degree of freedom for e-recoil discrimination)
(The addition of partial deflections along the measured track, normalized by its total (ionization) energy)

\[ \text{NIS} = \frac{\sum (\Delta \theta_i)}{E} \]

Summed over all the time samples of a track
MIMAC (bi-chamber module) at Modane Underground Laboratory (France) since June 22nd 2012 working at 50 mbar (CF$_4$ + 30% CHF$_3$) in a permanent circulating mode.

Laboratoire Sousterrain de Modane (LSM) IN2P3 (CNRS) – CEA FRANCE
Calibration – Chamber2- Cd-(Cr-Fe)-Cu
(binding energy of $^{19}\text{F} \sim 0.7$ keV)

Energy (ADC channel)

<table>
<thead>
<tr>
<th>h_Energy_s1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Entries: 51307</td>
</tr>
<tr>
<td>Mean: 148.7</td>
</tr>
<tr>
<td>RMS: 55.17</td>
</tr>
</tbody>
</table>

2.5 keV
5.7 keV
7.3 keV
Gain stability (Peak_channel vs. time(days)) in Chamber1(X-ray generator)
2.5 keV (blue), 5.7 keV (red), 7.3 keV (green) (June 22\textsuperscript{nd} to July 3\textsuperscript{rd} with different conditions)
An alpha particle crossing the detector
An alpha particle crossing the detector
A recoil event (~ 34 keVee)
A recoil event (\(\sim 40\) keVee)
A recoil event ($\sim 28$ keVee)
Phenomenology: **Discovery**

Proof of discovery: **Signal pointing toward the Cygnus constellation**

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

**Strong correlation** with the direction of the Constellation Cygnus even with a large background contamination

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The eight parameters are strongly constrained with only one directional data set.

### WIMP mass Vs cross section

**Masse**

<table>
<thead>
<tr>
<th>$m_\chi$ (GeV/c²)</th>
<th>$\log_{10}(\sigma_n)$ (pb)</th>
<th>$\ell_\odot$ (°)</th>
<th>$b_\odot$ (°)</th>
</tr>
</thead>
<tbody>
<tr>
<td>50</td>
<td>-3</td>
<td>90</td>
<td>0</td>
</tr>
<tr>
<td>51.8$^{+5.6}_{-19.4}$</td>
<td>-3.01$^{+0.05}_{-0.08}$</td>
<td>92.9$^{+2.5}_{-2.5}$</td>
<td>2.0$^{+2.5}_{-2.5}$</td>
</tr>
</tbody>
</table>

### Section efficace

<table>
<thead>
<tr>
<th>$\sigma_x$ (km.s⁻¹)</th>
<th>$\sigma_y$ (km.s⁻¹)</th>
<th>$\sigma_z$ (km.s⁻¹)</th>
<th>$\beta$</th>
<th>$R_b$ (kg⁻¹.year⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>155</td>
<td>155</td>
<td>155</td>
<td>0</td>
<td>10</td>
</tr>
<tr>
<td>158$^{+15}_{-17}$</td>
<td>164$^{+27}_{-26}$</td>
<td>145$^{+14}_{-17}$</td>
<td>-0.073$^{+0.29}_{-0.18}$</td>
<td>10.97 ± 1.2</td>
</tr>
</tbody>
</table>

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Discovery at 3\(\sigma\) with BKG (300)

- Even with a large number of background events, discovery is still possible
- Only low number of WIMP events are required at low masses

\(\rightarrow\) A discovery (>3\(\sigma\)@90%CL) with BKG is possible down to \(10^{-3}\)-\(10^{-4}\) pb

MIMAC Phenomenology: Discovery

Estimation of the discovery potential

MIMAC characteristics
- 10 kg CF
- DAQ: 3 years
- Recoil energy range [5, 50] keV

\(\rightarrow\) With BKG (300)
\(\rightarrow\) Without BKG

\(\rightarrow\) Only low number of WIMP events are required at low masses

D. Albornoz-Vasquez et al., PRD 85

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D. Santos (LPSC Grenoble)
MIMAC – $1m^3$
Conclusions:

i) **MIMAC** bi-chamber module is running at Modane Underground Laboratory since June 22\textsuperscript{nd} 2012.

ii) For the first time 3D nuclear recoil tracks are available between 1keVee and 100 keVee to characterize fast neutron background.

iii) New degrees of freedom are available to discriminate electrons from nuclear recoils to improve the DM search for.

iv) The directional detection at low energies is possible!

v) A lot of work to be done…You are all welcome!
MIMAC : Dark Matter discovery/exclusion

- **discovery** ($5\sigma$) 
  Up to $10^{-4}$ pb

- **exclusion**
  Up to $10^{-6}$ pb

Simulated data
- 30 kg.year CF$_4$
- Recoil energy [5, 50] keV
- Angular resolution : 15°

J. Billard et al., PLB 2010
J. Billard et al., PRD 2010