Dark Matter Directional Detection

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With contributions from Dan Snowden-Ift and James Battat slides
At the galaxy cluster scale...

(1E0657-558)  \[ Z = 0.296 \]

Collision de l’amas du Boulet
(D. Clowe et al. 2006)

Total mass profiles  Baryonic Matter

Non-baryonic matter is 6 times more important than baryonic one...
Directional detection: principle

\[ <V_{\text{rot}} > \sim 220 \text{ km/s} \]

« A wind of WIMPS coming from the Cygnus constellation »

The signature able to correlate the events found to the galactic halo!
Solar System's orbit

Galactic coordinates

V_WIMP

Z_G

X_G

b

Y_G

V_{SS}

Solar System

WIMP signal

Cygnus Constellation (l = 90°, b = 0°)

After collision

WIMP signal expected

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Moriond-VHEPU, March 14th 2013
Map of recoils in galactic coordinates (HealPix)

$10^8$ Events with $E_R = [5,50]$ keV
Angular modulation of WIMP flux

Modulation is sidereal (tied to stars) not diurnal (tied to Sun)
100 WIMP evts + 100 Background evts
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
Directional experiments around the world

- DRIFT (Boulby)
- Emulsions (Gran Sasso)
- NEWAGE (Kamioka)
- DMTPC (WIPP)
- MIMAC (Modane)

Running in an Underground Laboratory
“The case for a directional dark matter detector and the status of current experiments”

International Journal of Modern Physics A

112 authors from both theory and experiment
DRIFT – Directional Recoil Identification From Tracks

Started = 1998, US/UK
Underground in Boulby, England in 2001
Current operating detector = DRIFT-IIId
Technology = Negative ion TPC with
MWPC wire readout

xyz resolution = 2 mm, ~<2mm, 0.2 mm,
no absolute
Target = 30 Torr CS$_2$ + 10 Torr CF$_4$
Fiducial volume = 800 liters
F mass = 33.3 g
Limit setting threshold = 50 keVr
DM-TPC – Dark Matter TPC

Started = 2007, US
Underground in WIPP, USA in 2011
Current operating detector = DMTPC
10 liter
Technology = TPC with micromegas + light and charge readout

xyz resolution = 0.256 mm &
absolute in xy, Δz coming
Target = CF₄ @ 75 Torr
Fiducial volume = 9.18 liters
F mass = 2.85 g
Limit setting threshold = 80 keVr
DMTPC

10L

4Shooter (20L)

DMTPCino (1 m³)

Underground at WIPP

At MIT

Funded by NSF+DoE

James Battat  Bryn Mawr College

D. Santos (LPSC-Grenoble)
NEWAGE  
Started 2002, Japan  
(KOBE university)  
(New generation WIMP search with an advanced gaseous tracker experiment)

30 cm x 30 x 31 cm³, 400 μm pitch

30 cm μPIC  
(Toshiba)

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Nuclear Emulsion

Started = 2010, Japan
Underground in LNGS, Italy
Current operating detector = Prototype
Technology = Fine grained nuclear emulsion + expansion + microscope readout
Spatial resolution = 100 nm

Target = C(NO), Br, Ag
Thresholds = C - 40 keV, Br - 170 keV, Ag - 200 keV in principle
Interaction = Target is SI, but Br and Ag have spin.
Detector mass of prototype - we will make several g detector
**MIMAC**
MIcro-tpc MAtrix of Chambers
(started 2005 – France)

**Strategy:**
- Matrix of micro-TPC
- Directional detection (energy and 3D track)
- Multi-targets (1H, $^3$He, $^{19}$F) ---> $\sigma(A)$
- Axial interaction
- $^3$He, CH$_4$, C$_4$H$_{10}$, CF$_4$

- TPC low pressure (~50 mbar)
- Pixellized Micromegas (Saclay) coupled to a LPSC fast and self-triggered electronics

**Rejection based on:**
- Energy and 3D-track : e-/nuclei
- Correlation of $\mu$TPCs (neutrons)

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Ionization Quenching Measurements:
5keV $^{19}$F Recoil in 60 mbar
40mbar CF$_4$+16.8mbar CHF$_3$+1.2 mbar Isobutane

Recoil: $^{19}$F 5 keV
$E_i = 1.19$ keV
$Q=0.238$
Threshold: 400 eV
Recoil of 19F $(E_{\text{ion}} \sim 40 \text{ keV})$ in 50 mbar of CF4 + CHF3 (30%)

Q. Riffard’s talk on MIMAC, tomorrow! for more details
**MIMAC** (bi-chamber module) at Modane Underground Laboratory (France) since June 22nd 2012

- working at 50 mbar
  
  \( \text{CF}_4 + 28\% \text{ CHF}_3 + 2\% \text{ C}_4\text{H}_{10} \)

- in a permanent circulating mode
- Remote controlled and commanded
- Calibration control twice per week

Many thanks to LSM staff
An alpha particle crossing the detector
(as an illustration of the MIMAC observables)

D. Santos (LPSC-Grenoble)
« MIMAC – observables »

• Ionization energy (+ quenching factor)
• Track length and 3D track
• NIS (Normalized Integrated Straggling)
  
  Low energy electron/recoil discrimination for directional Dark Matter detection, J.Billard et al. (JCAP 07(2012) 020

• Delta T= (Flash-ADC time – Time slots) [20ns] = f(drift)
• dE/dx asymmetry as a function of t
• Track topology (number of holes)

Quentin Riffard’s talk tomorrow (March 15th) for more details
Total event rate at Modane in Chamber2 (threshold 1 keVee, at 470V) (no cuts !) (validation of the source of alphas (Rn))

Event rate

Stop of circulation October 3rd 2012
Calibration – Chamber2 (at Modane) fluorescence of Cd-(Cr-Fe)-Cu

Energy (ADC channel)

- 3.2 keV
- 6.4 keV
- 8.1 keV

<table>
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<th>h_Energy_s1</th>
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<td>Entries</td>
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<tr>
<td>Mean</td>
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<td>RMS</td>
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(preliminary analysis): A “recoil event” (~ 34 keVee)

D. Santos (LPSC-Grenoble)

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Nuclear Recoils produced by the $^{222}$Rn chain decay (without alpha detection)

$E_{\text{kin}}(^{218}\text{Po}) \sim 100$ keV

$E_{\text{ion}} \sim 38$ keV ($Q_{\text{ion}}$ from SRIM)

$L_{\text{track}} \sim 700$ um
Spectrum of nuclear recoil tracks detected at Modane (coming from the $^{222}$Rn chain decay, surface events) and the alpha particles through the cathode…

Q. Riffard’s talk on MIMAC, tomorrow! For more details
MIMAC – $1m^3 = 50$ bi-chambers ($20\times20\times25\;\text{cm}^3$)

i) New technology anode $20\times20\text{cm}$ or bigger (piggy-back) (already tested in $10\times10\text{cm}$)

ii) New electronic card (1024 channels)

iii) Only two big chambers (25 bi-chambers each in the case of $20\times20\;\text{cm}^2$ anode)

New $20\times20\text{cm}$ pixellized anode
Directional Dark Matter: discovery/exclusion

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

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

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

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

Estimation of the discovery potential

MIMAC characteristics
- 10 kg CF₄
- DAQ: 3 years
- Recoil energy range [5, 50] keV

Discovery at 3σ

\[ \text{With BKG (300)} \]
\[ \text{Without BKG} \]

\[ \rightarrow \text{Even with a large number of background events, discovery is still possible} \]
\[ \rightarrow \text{Only low number of WIMP events are required at low masses} \]

\[ \rightarrow \text{A discovery (>3σ@90%CL) with BKG is possible down to 10^{-3}-10^{-4} pb} \]
Mass – cross section

Dark Matter signature

Galactic Halo shape

8 parameters simultaneously constrained by only one experiment

Directional Detection: identification

J. Billard et al., PRD 2011

Moriond-VHEPU, March 14th 2013

D. Santos (LPSC-Grenoble)
2007 – Boulby, England  
2009 – MIT, Boston, USA  
2011 – Aussois, France  
2013 – Toyama, Japan  

http://ppwww.phys.sci.kobe-u.ac.jp/~newage/cygnus2013/
How big is a 1 tonne directional detector?

14 m x 14 m x 14 m directional dark matter detector

Mini-BooNE  MINOS  SNO  Super-Kamiokande