

Dark matter directional detection with MIMAC

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Rencontres de Moriond EW 2009

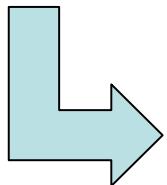
Outline

- Dark matter Directional detection
- The MIMAC project
- The μ TPC detector
- Measurement of the Energy
- Reconstruction of the Track in 3D

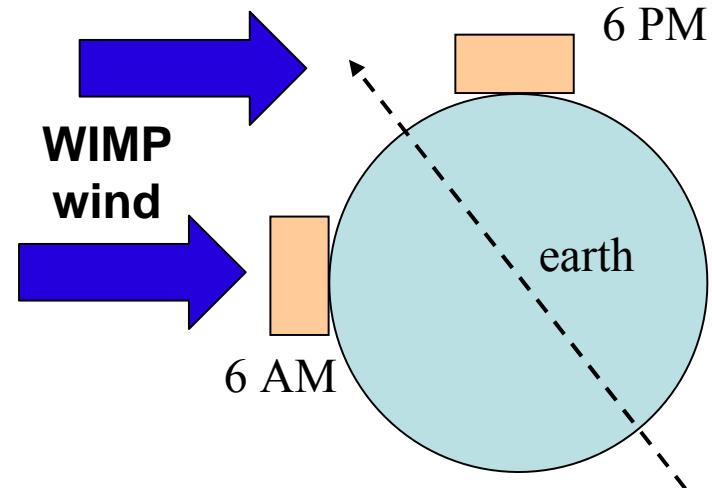
Dark Matter Directional Detection

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.

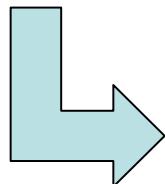


WIMPs events should point towards Cygnus constellation



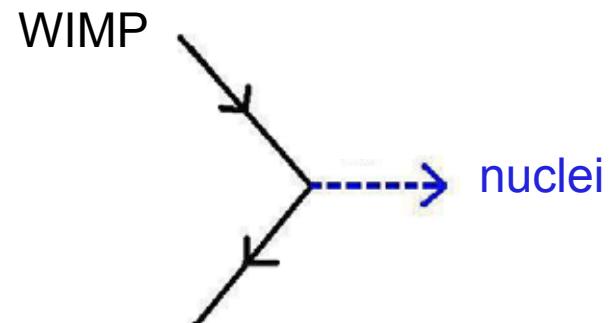
Background can not mimic such genuine events

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

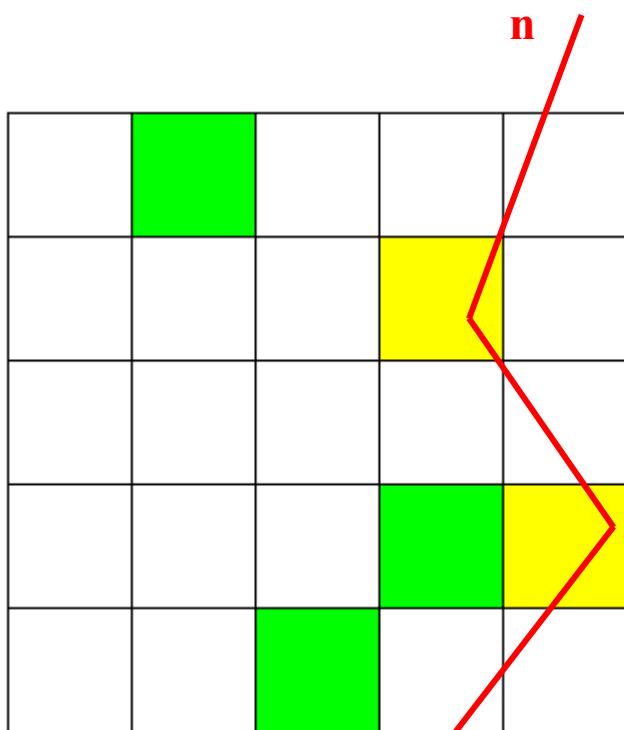


use gaseous detector

Ex: **MIMAC**, DRIFT, DM-TPC ...



The MIMAC project



MIMAC : a multi-chamber detector for DM

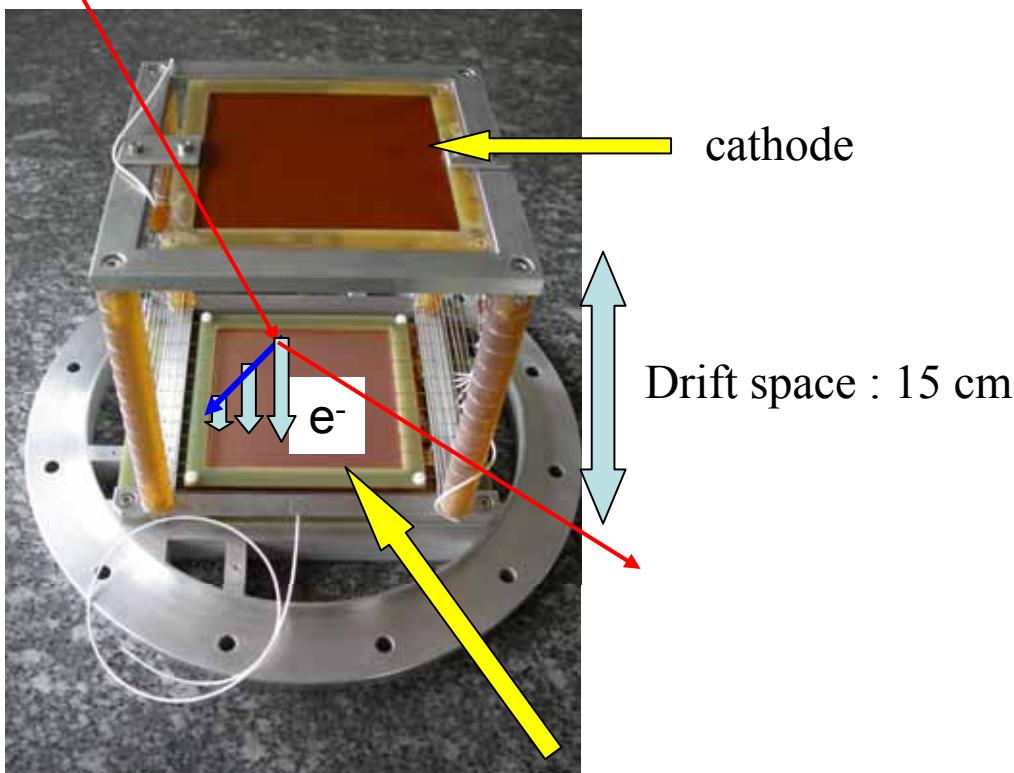
- Matrix of μ TPC chambers
- Micromegas technology (Energy AND Track)
- ${}^3\text{He}$ and CF_4 gas : $\sigma(A)$ dependency
- Spin dependent Interaction (complementarity), interaction with n (He) or p (F)
- Low mass targets allow sensitivity to low mass WIMPs ($M \geq 6 \text{ GeV}$)

Rejection of background events :

- Energy (ionization)
- Track
- Correlation of cells
- Direction (Cygnus), 2nd step of MIMAC

Have to detect low energy Helium ions: $E_{\text{recoil}} < 6 \text{ keV}$

A μ TPC for Dark Matter



Micromegas with pixellized
anode (x,y): 3 cm x 3 cm

Collaboration : CEA Saclay

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

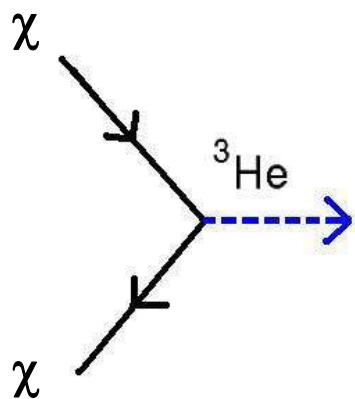
The micromegas offers:

High $\left\{ \begin{array}{l} \text{spatial} \\ \text{time} \\ \text{energy} \end{array} \right\}$ resolution

- ⇒ recoil track projection
- ⇒ energy threshold ~ 1 keV
- ⇒ electron/nuclei discrimination

Energy Measurement $\neq E_{\text{recoil}}$
and
Track Projection \neq 3D Track

Energy measurement : Quenching factor



Recoil energy is shared among :

- Scintillation
- Heat
- **ionization**

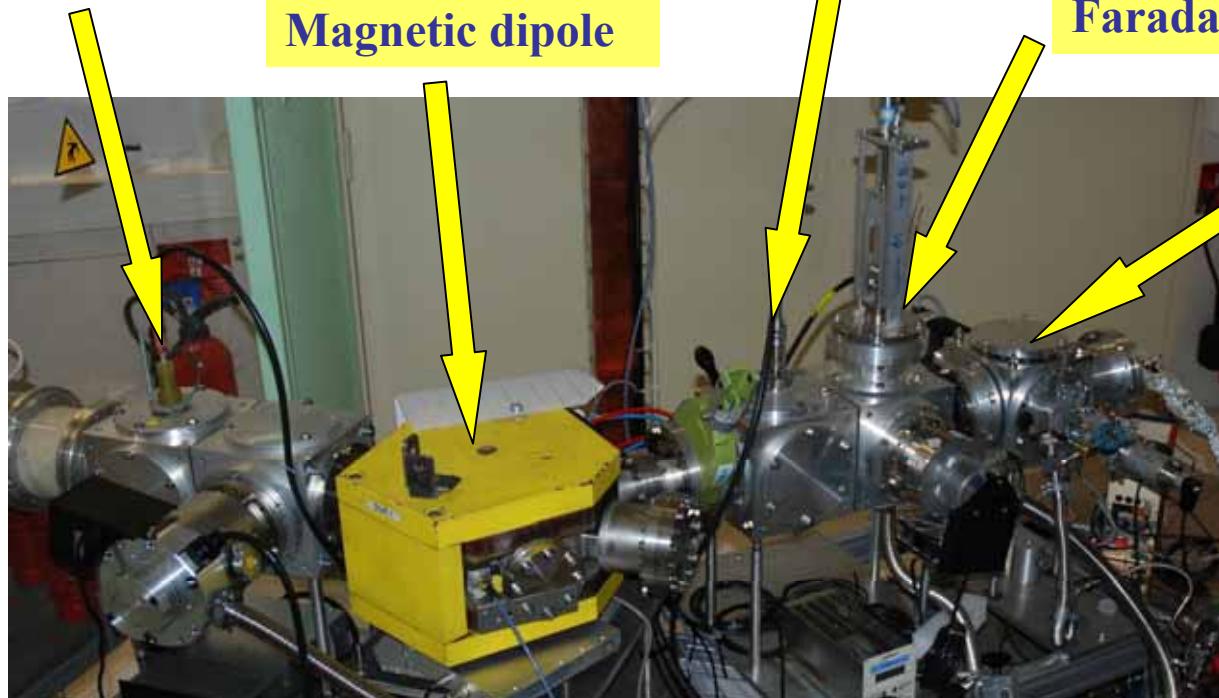
Ionization Quenching factor defined as

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

- 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

Einzel Lens 1

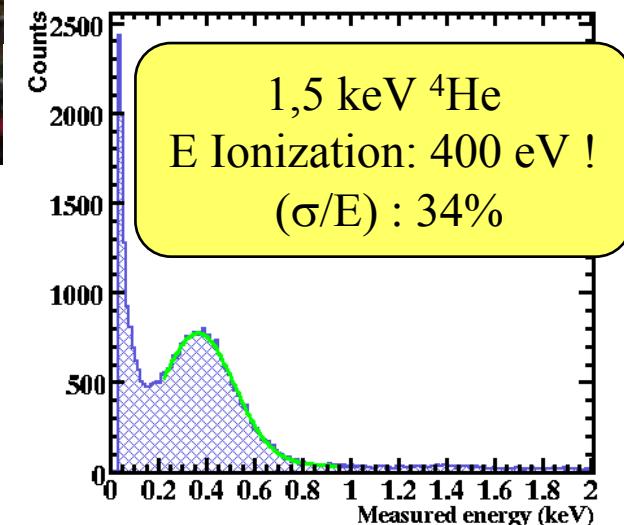


Einzel Lens 2

Faraday Cup

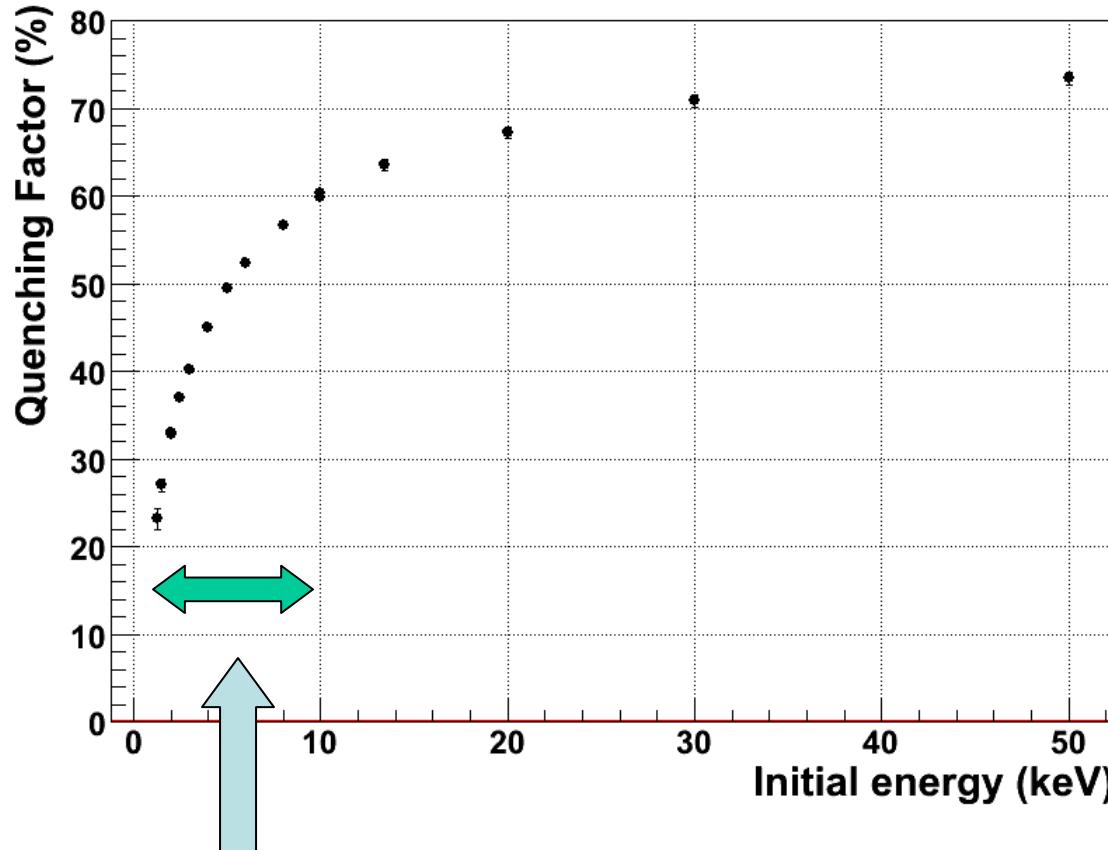
Micromegas μ TPC

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



QF measurement : results

Quenching factor @ 700 mbars

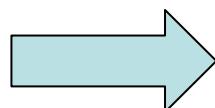


Measurement of ${}^4\text{He}$
in 95% ${}^4\text{He} + 5\%$ C_4H_{10}

- 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

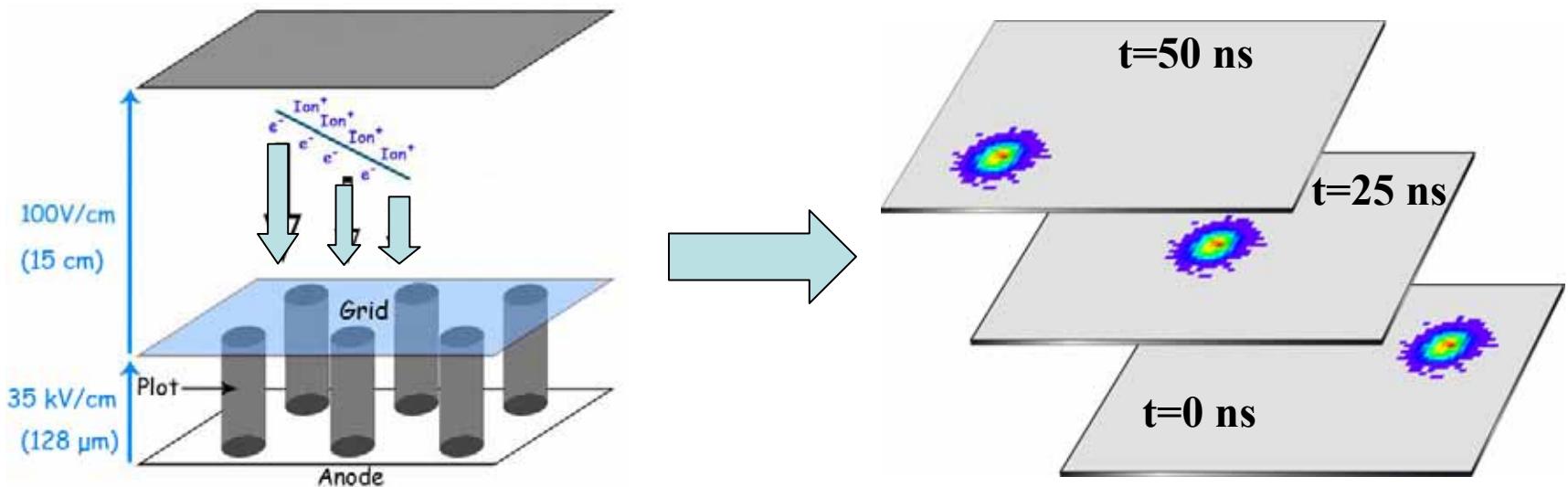
Range of interest for
Dark Matter

D. Santos et al. 2008, arXiv:0810.1137



Access to E_{recoil} of the nuclei

3D Track reconstruction



**Complete electronic system
(ASIC+FPGA+DAQ)**

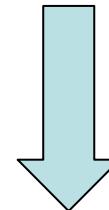
ASIC: 16 strips channels
with mixer & shaper (energy)

FPGA: On-board processing

25 ns scan of the (x,y) anode



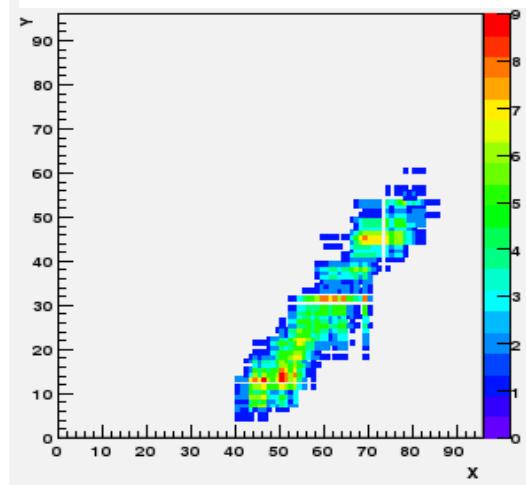
Number of images * Drift velocity
+ 2D projection



**3D Track reconstruction:
L, θ and ϕ**

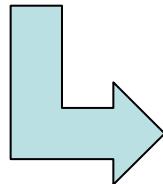
Measured tracks of alpha particle

[View of the anode (X,Y)

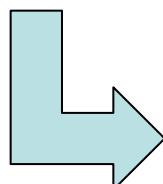


From ^{222}Rn
 $E_\alpha = 5.49 \text{ MeV}$

With the
reconstruction soft

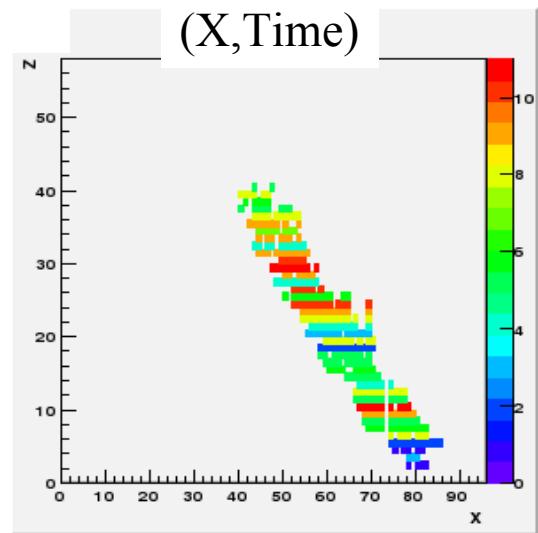


Can ID α tracks

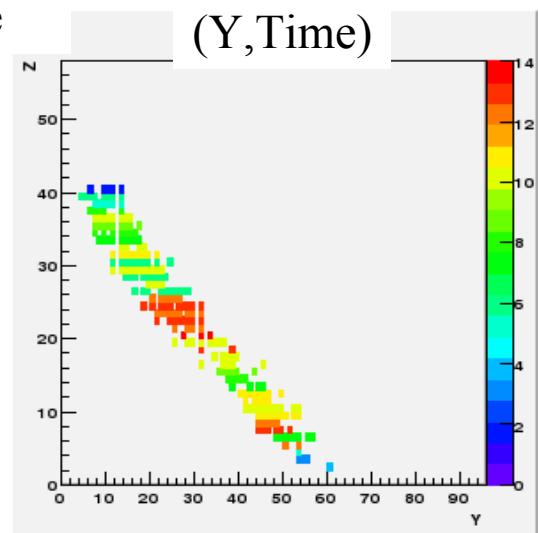


3D Reconstruction works

Time

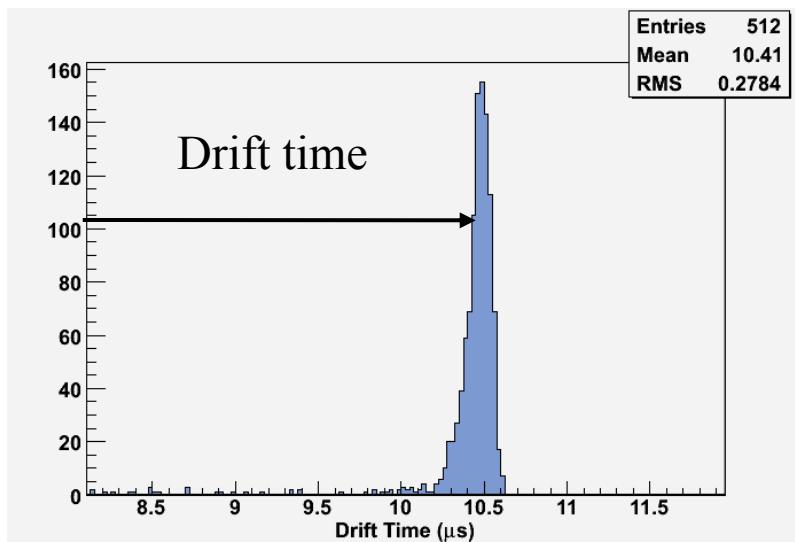
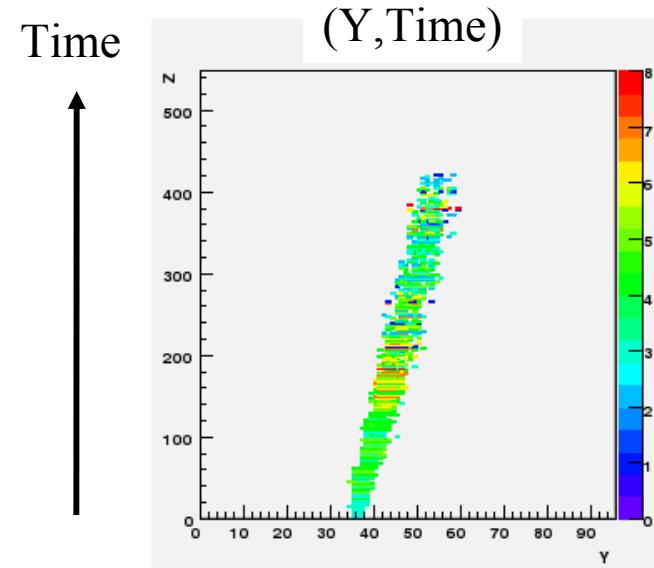
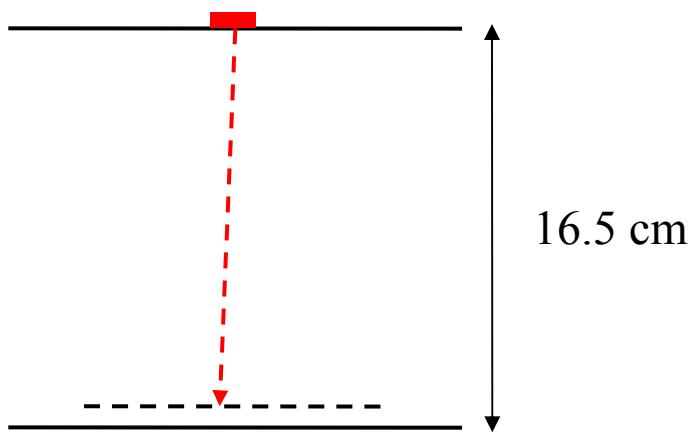


Time



Measurement of drift velocity (NEW !)

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



95% ^4He / 5% C_4H_{10}
Pressure: 360 mbar
Drift field: 180 V/cm
Velocity of 15.85 $\mu\text{m/ns}$

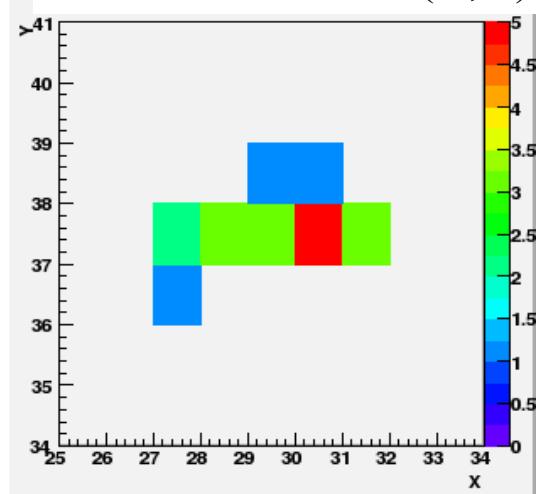
Close to Magboltz value: 15.2 $\mu\text{m/ns}$

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

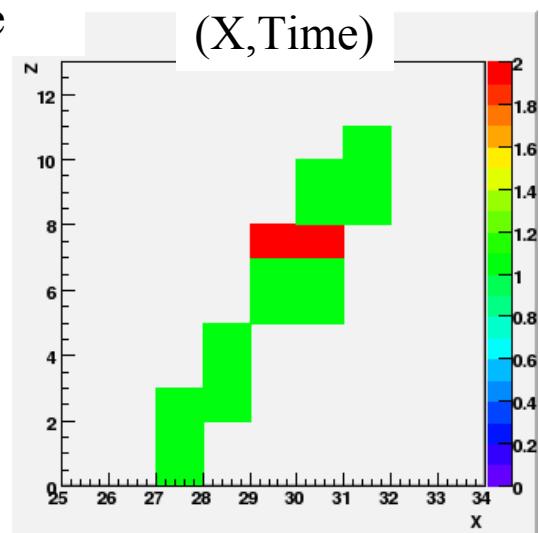
View of the anode (X, Y)



Each pixel is $300 \mu\text{m}$ wide !!

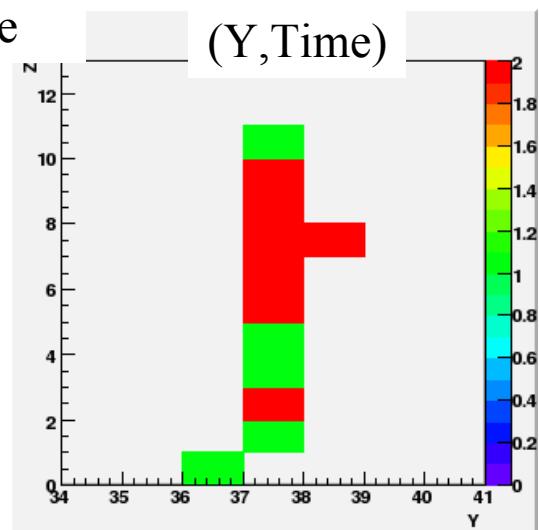
For the first time:
3D track of 5.9 keV electron !!!

Time



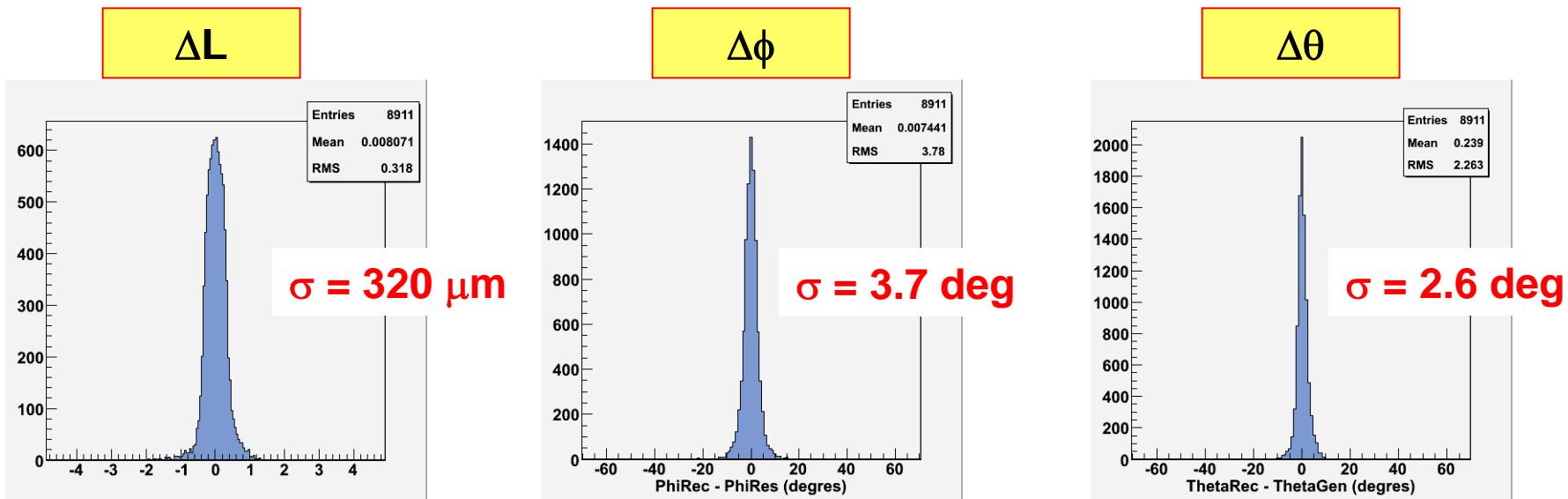
Use the drift velocity predicted by Magboltz

Time



Simulation of track reconstruction

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



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

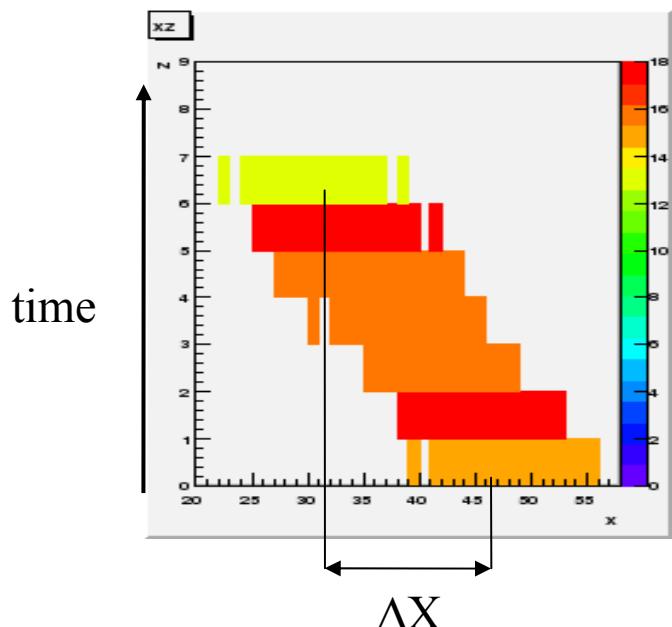
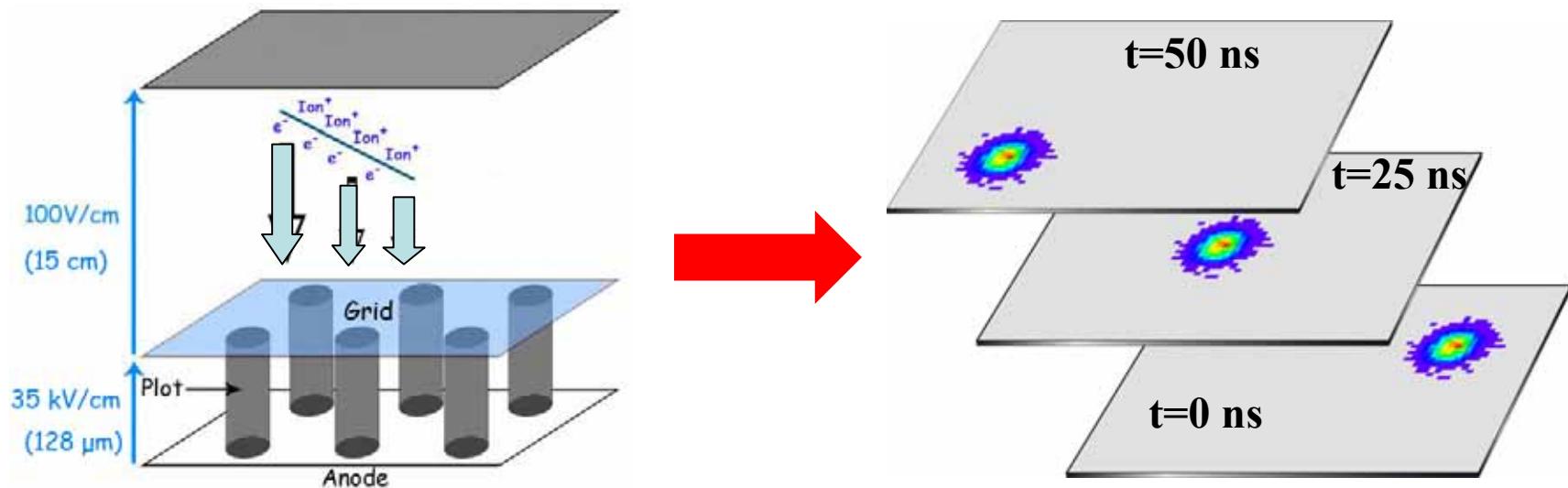
- Electronics : G. Bosson, J-P. Richer
- Gas detector : A. Pellisier
- Data Acquisition: O. Bourrion
- Mechanical Structure : Ch. Fourel
- Ion source : T. Lamy, P. Sole

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

IRSN (Cadarache): L. Lebreton, A. Allaoua

Backup slides

3D Track reconstruction



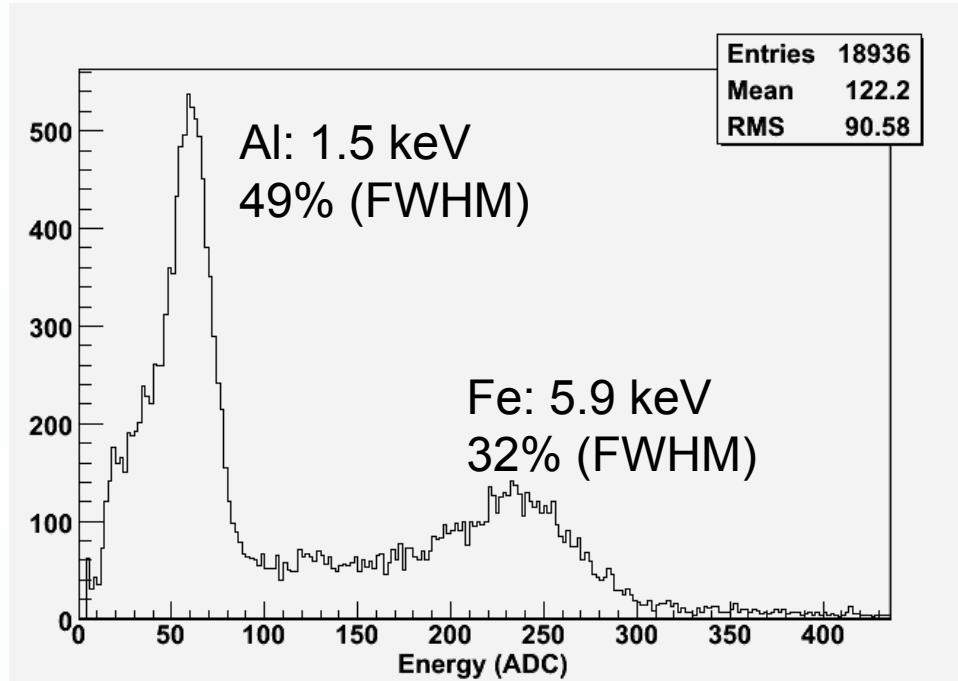
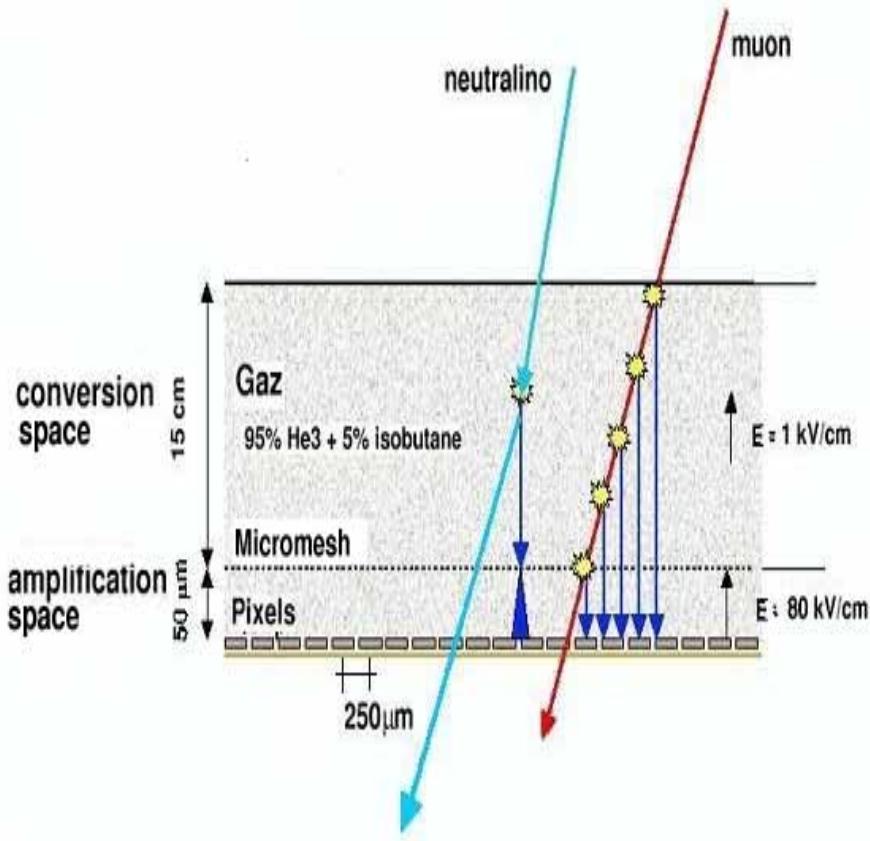
3D track is reconstructed from
25 ns scan of the (x,y) anode

Measure ΔX , ΔY and ΔZ

Knowing the
Drift velocity

L , θ and ϕ

Energy Calibration of Micromegas



Spin contributions to the axial interaction

| Nucleus | Z | Odd nucleon | | $\langle S_p \rangle$ | $\langle S_n \rangle$ |
|-----------------|---|-------------|-----|-----------------------|-----------------------|
| ^3He | 2 | n | 1/2 | -0.05 | 0.49 |
| ^{19}F | 9 | p | 1/2 | 0.44 | -0.11 |

→ Spin dependent Interaction (complementarity)

→ Interaction with n (He) or p (F)

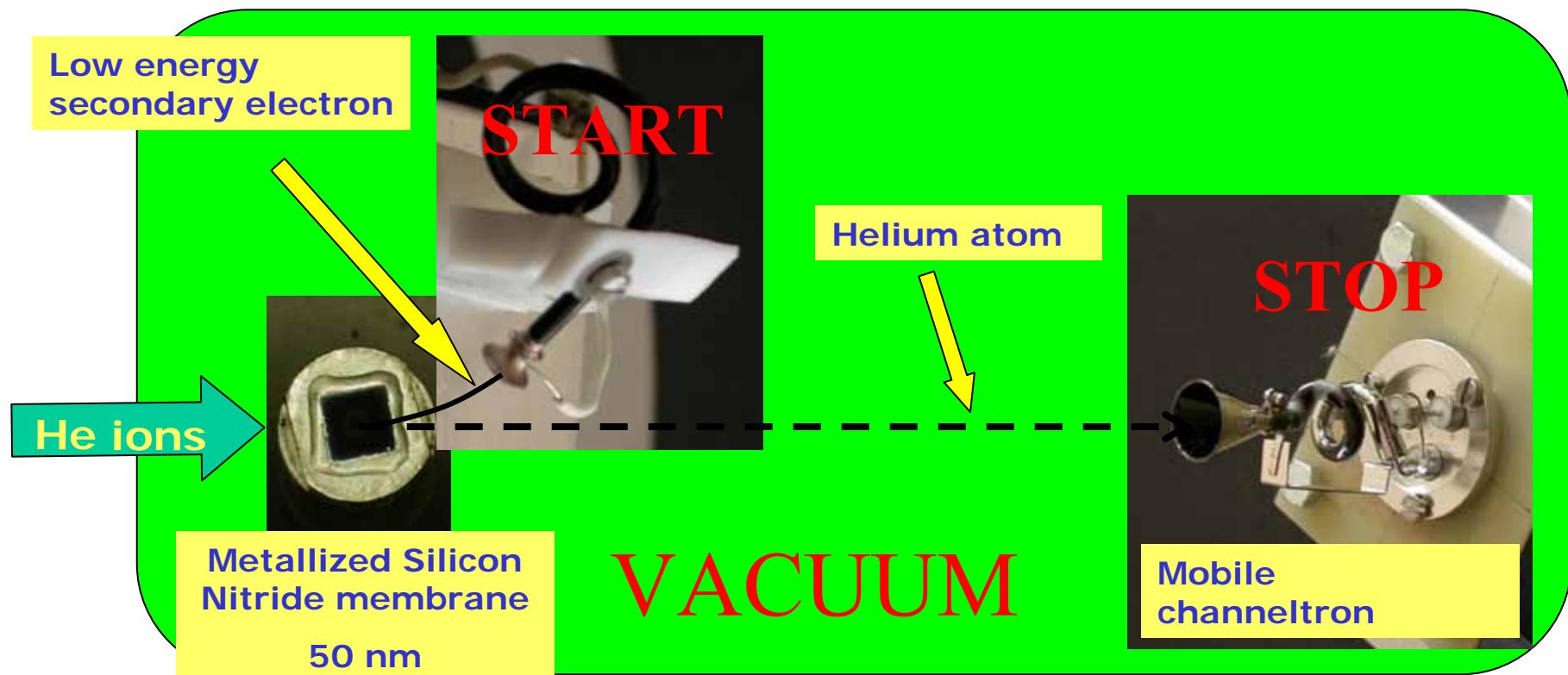
→ Low mass target → Low energy recoils

First phase : focus on low energy Helium ions

$E_{\text{recoil}} < 6 \text{ keV}$

Ion source calibration with Si_3N_4 membrane

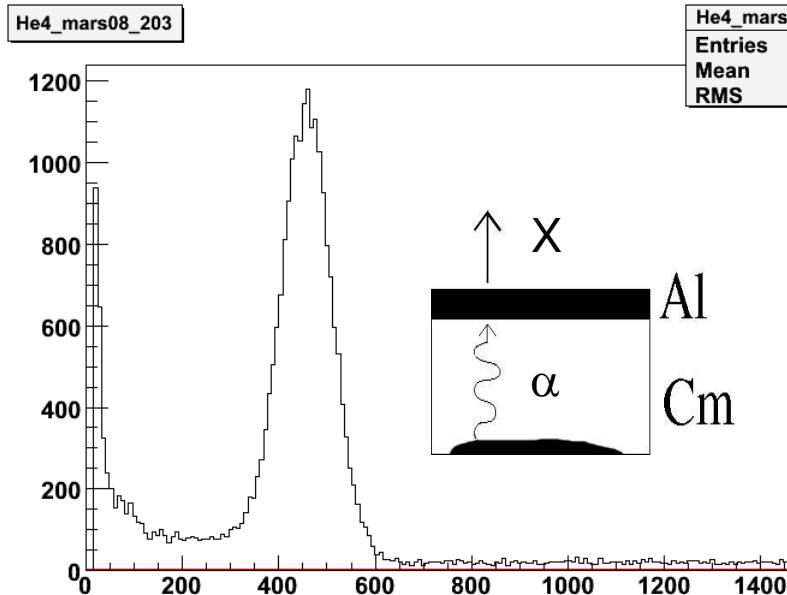
Time of flight under vacuum



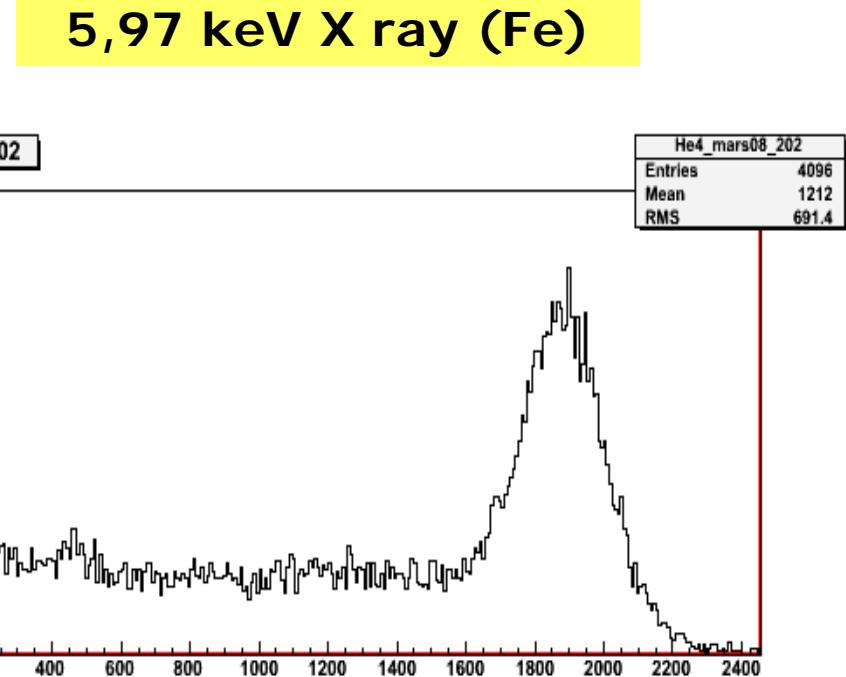
- Neutral atom after the Silicon nitride membrane
- Method : measuring time of flight for 2 positions of the STOP channeltron

QF measurement : calibration

1,486 keV X ray (Al)



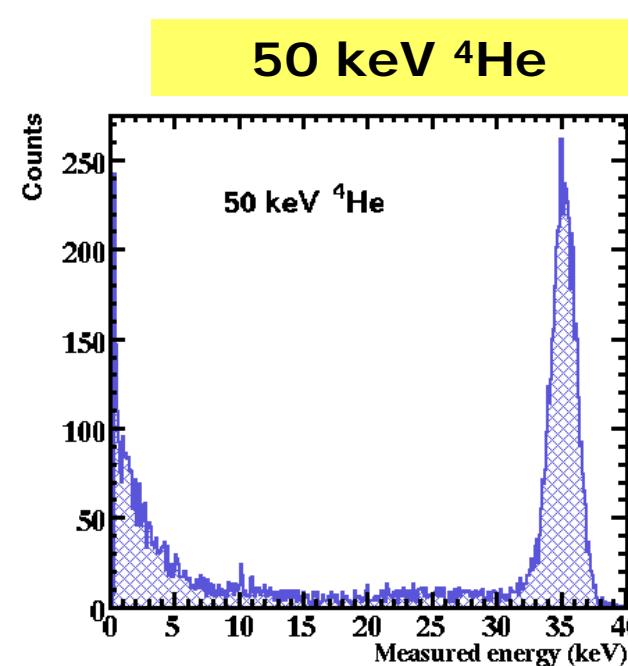
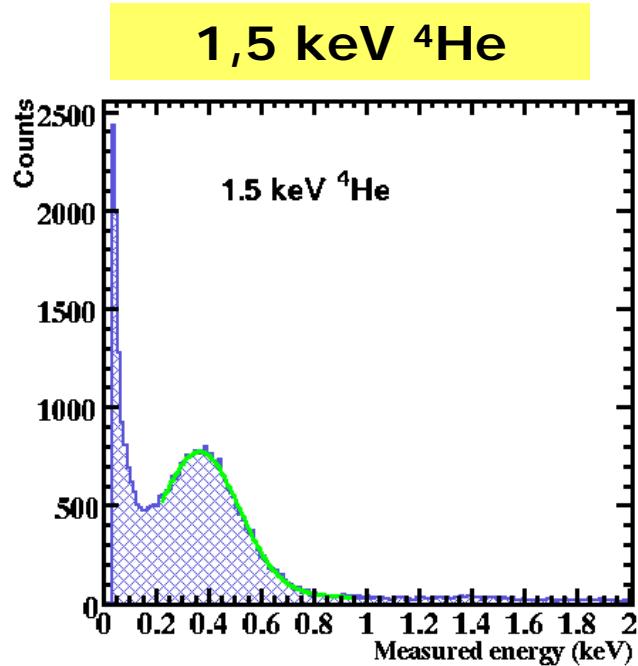
5,97 keV X ray (Fe)



$$\sigma / E \approx 14\%$$

$$\sigma / E \approx 5\%$$

QF measurement : low energy ions



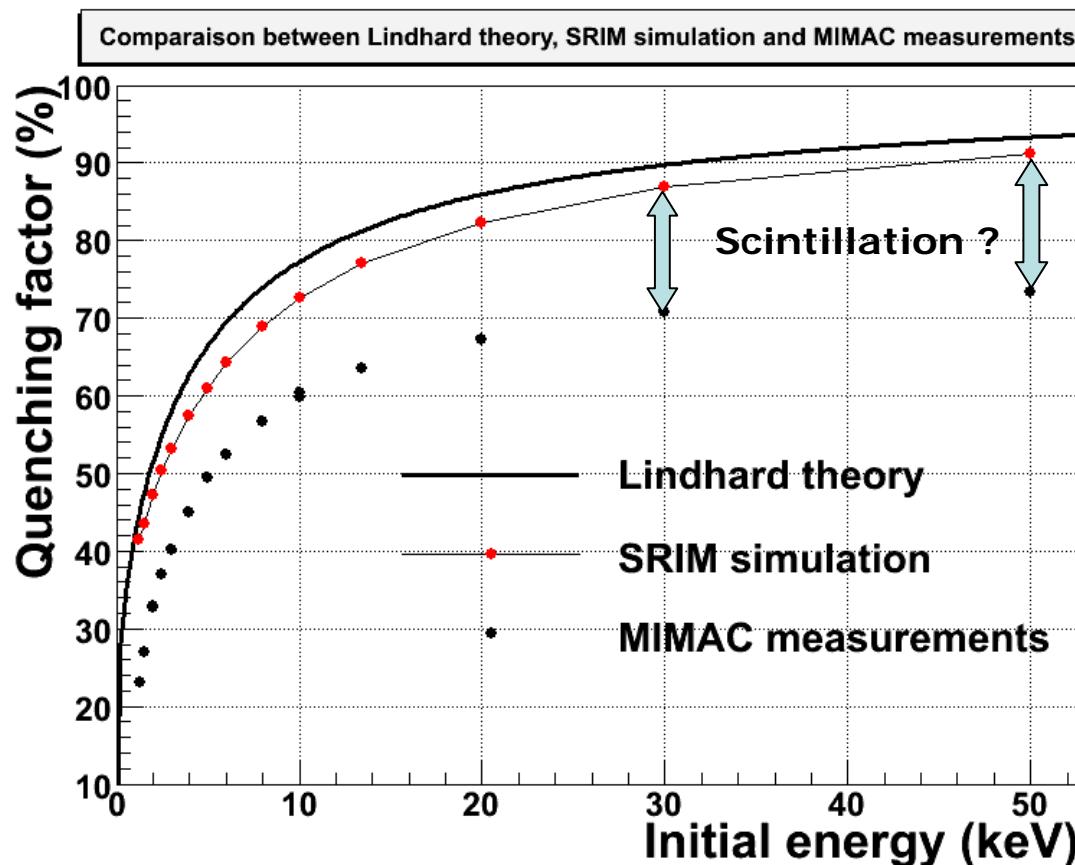
- Ionization energy : 400 eV !
- Energy Resolution (σ/E) : 34%

- Ionization energy : 35,5 keV
- Energy Resolution (σ/E) : 2%



${}^4\text{He}$ from 1 keV to 50 keV

QF measurement : versus Lindhard & SRIM



- Lindhard : pure ${}^4\text{He}$

→ Part of energy given to electrons

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



Δ (SRIM-DATA)

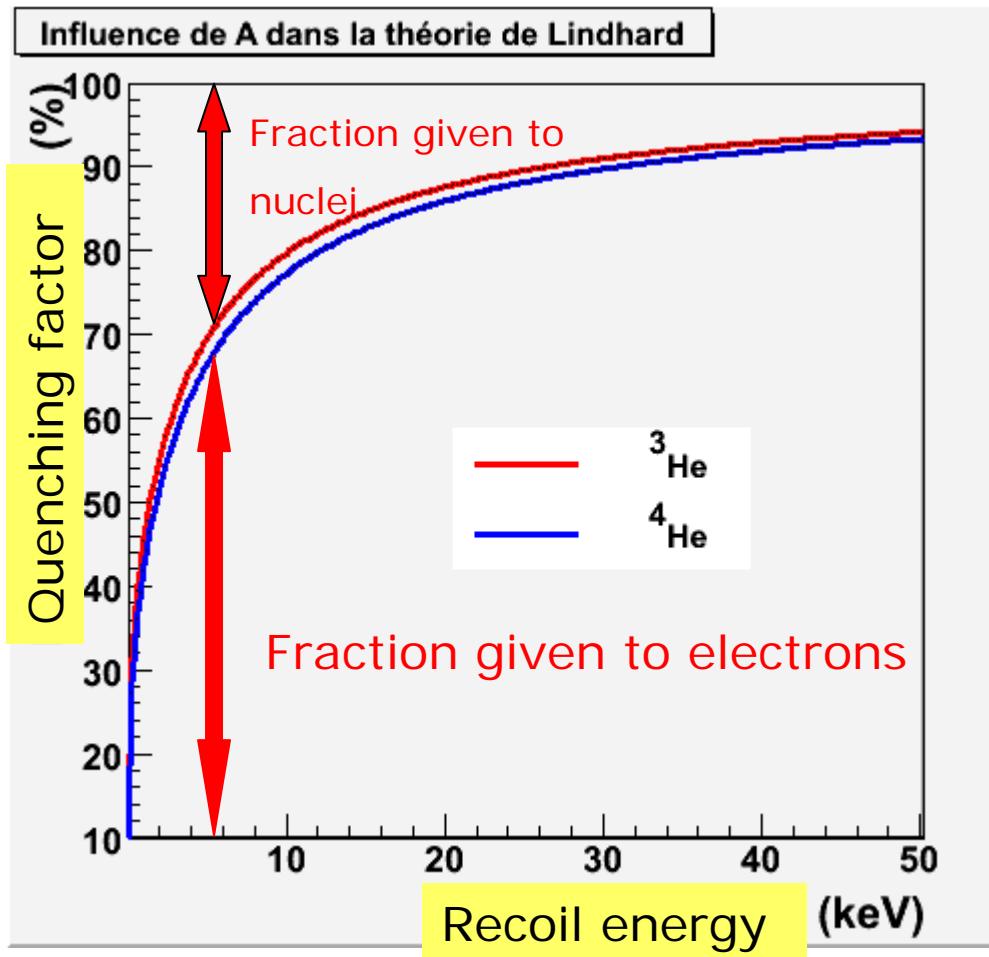
May be assigned to scintillation

D. Santos et al. 2008, arXiv:0810.1137



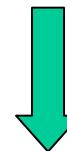
Need to measure He scintillation...

Lindhard prediction for Helium

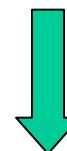


From J. Lindhard (1963)

Lewin & Smith (1996)
parametrization



High Q value for Helium



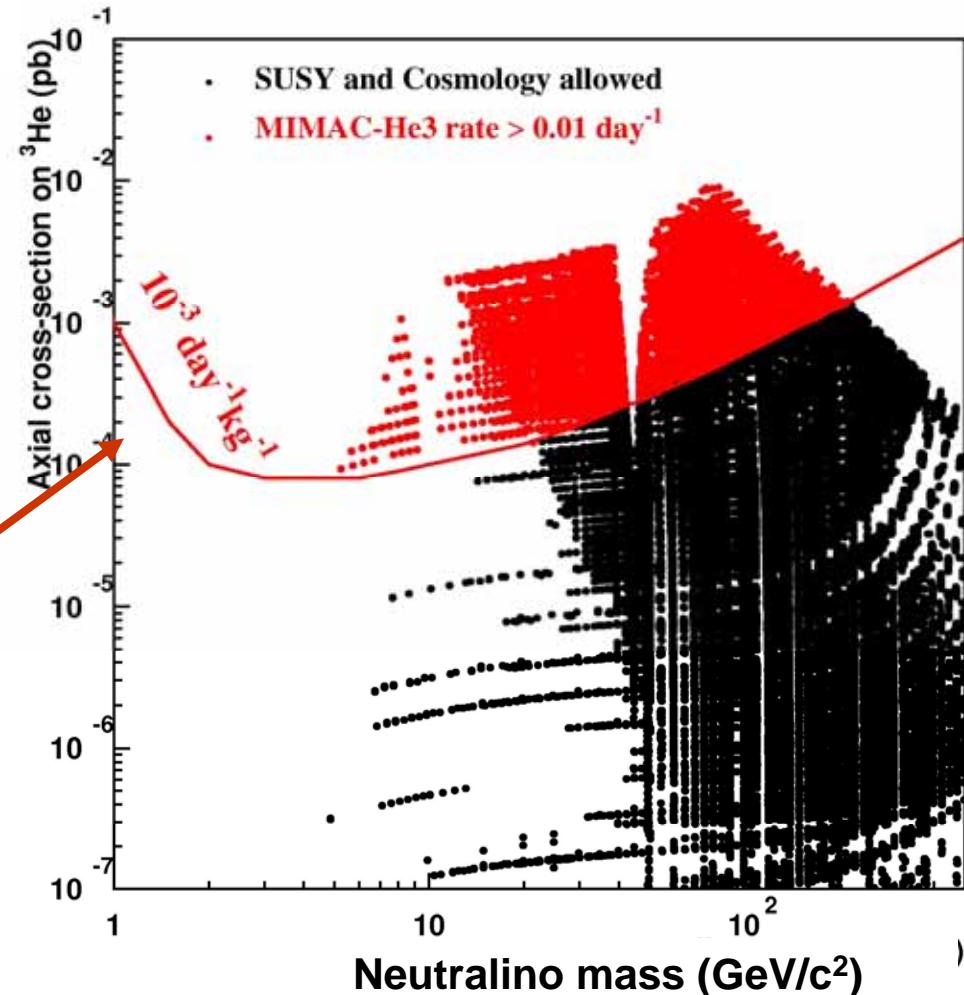
Need to be measured

$Q({}^3\text{He})$ slightly greater than $Q({}^4\text{He})$

Cross section ${}^3\text{He}-\chi$ and event rate in MIMAC-He 3 (10kg)

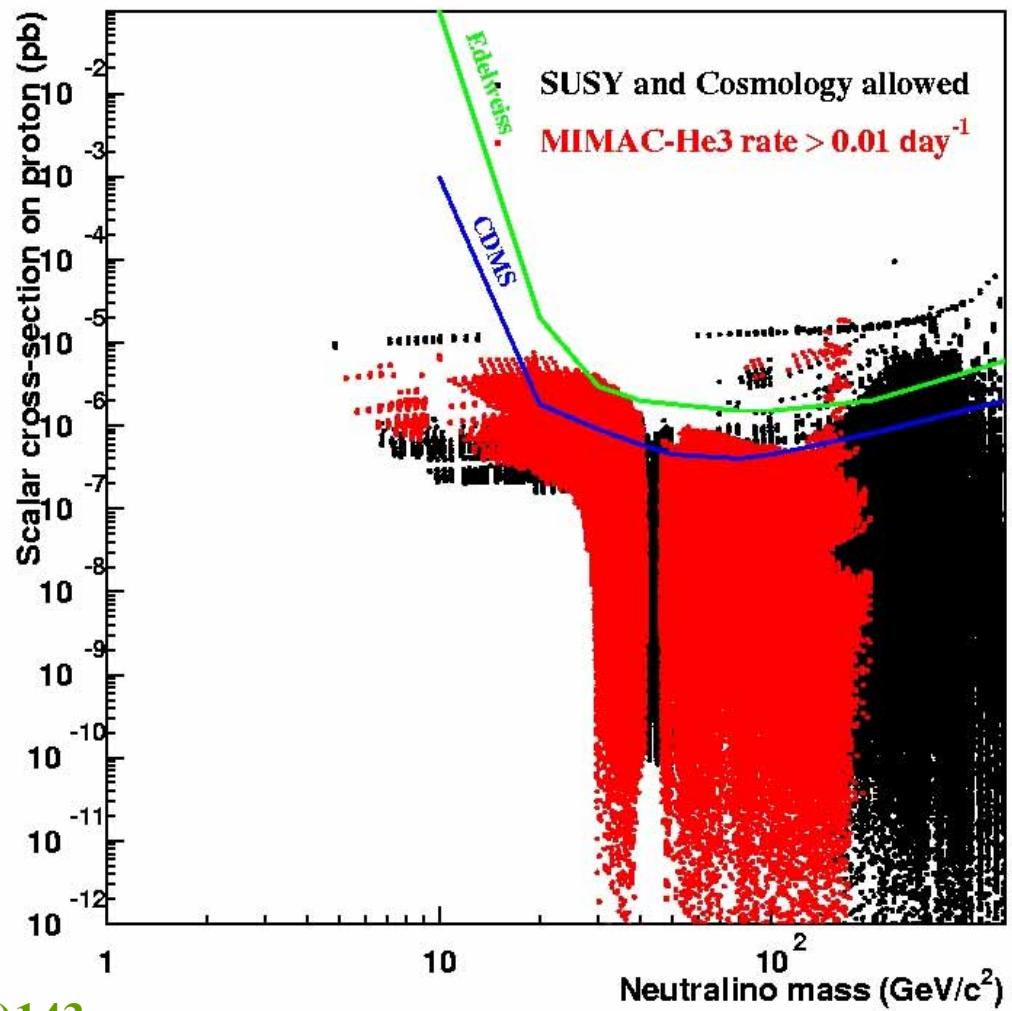
- $0.02 < \Omega_\chi h^2 < 0.15$
- Accelerator constrains

Exclusion curve for
background $10^{-3} \text{ kg}^{-1}\text{jour}^{-1}$



Complementarity with scalar detection

σ_{SD} and σ_{SI}
not correlated

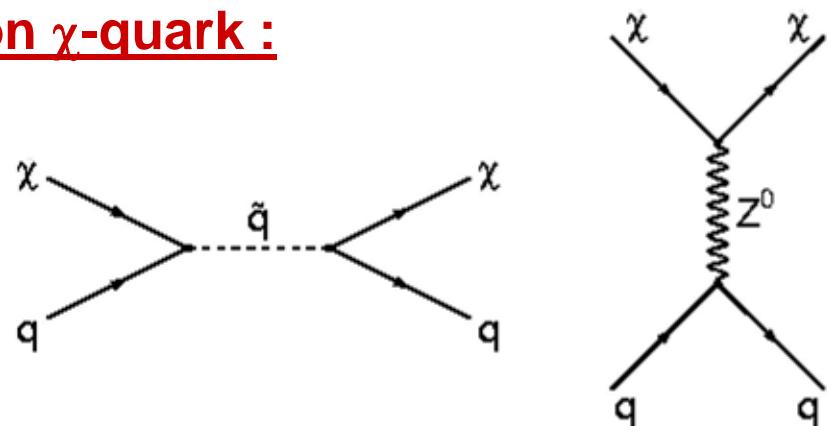


Direct Detection of SUSY particles

Elastic diffusion χ -quark :

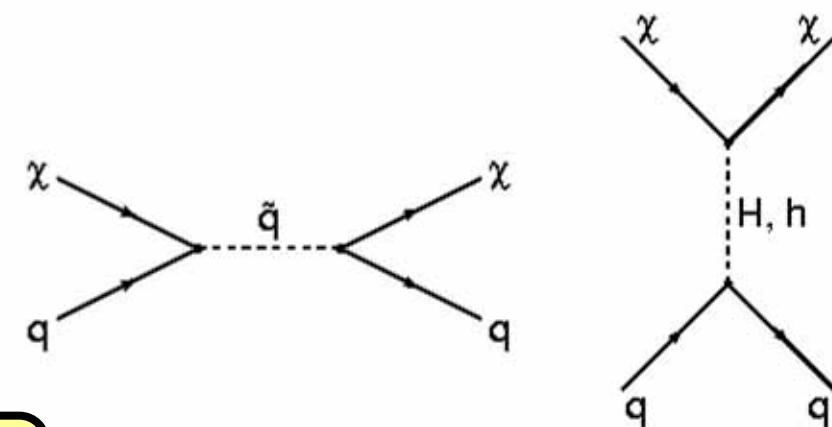
- **spin dependent (axial)**

$$\sigma_{\text{SD}}(^A X) \propto \sigma_{\text{SD}}(p) \times A^2$$



- **spin independent (scalar)**

$$\sigma_{\text{SI}}(^A X) \propto \sigma_{\text{SI}}(p) \times A^4$$



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