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)

LPSC (Grenoble) : F. Mayet , D. Santos , C. Grignon (post-doc),
J. Billard (Ph.D)

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

CEA-Saclay (IRFU): I. Giomataris, P. Colas, A. Giganon,
E. Ferrer, J-P. Mols

IRSN (Cadarache): L. Lebreton, C. Golabek

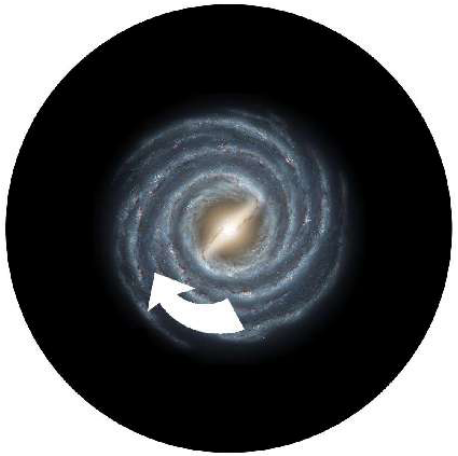
Directional Detection of Dark Matter

Direct detection requires high rejection factor against background, which need to be very precisely understood (radiopurity of materials, neutrons, …)

Directional Detection
gives a clear and unambiguous signature for WIMP

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

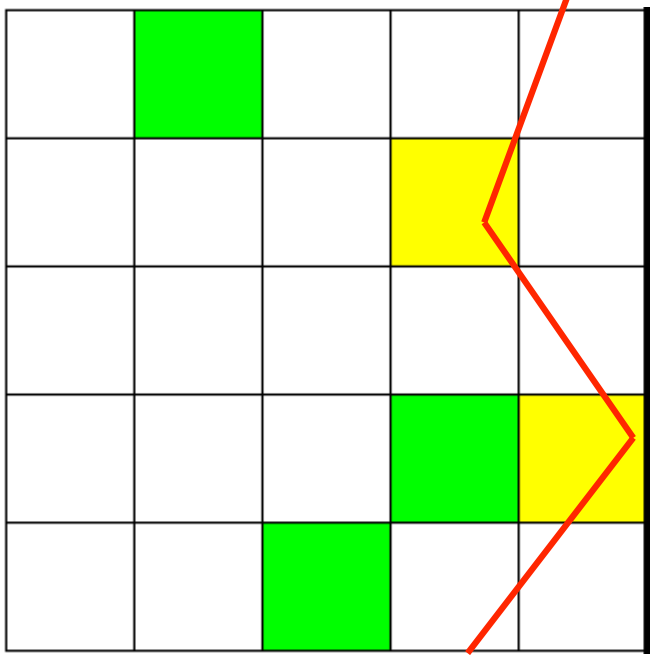
More precisely the Deneb star



Background can not mimic such genuine events

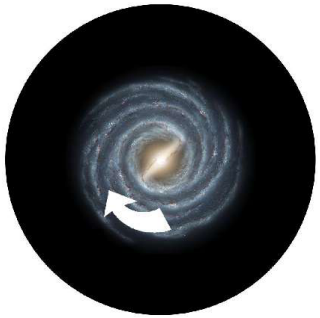
Strategy:
- use direct detection
- reconstruct Energy AND Track of the recoil nuclei
- Prove that the signal "comes from Cygnus"

The MIMAC project



A multi-chamber detector for Dark Matter

- Track-Energy measurements
- Matrix of chambers (correlation)
- µTPC : Micromegas technology
- ^{3}He and CF_4 gaz : $\sigma(A)$ dependancy
- Axial interaction
- Directionnal detector

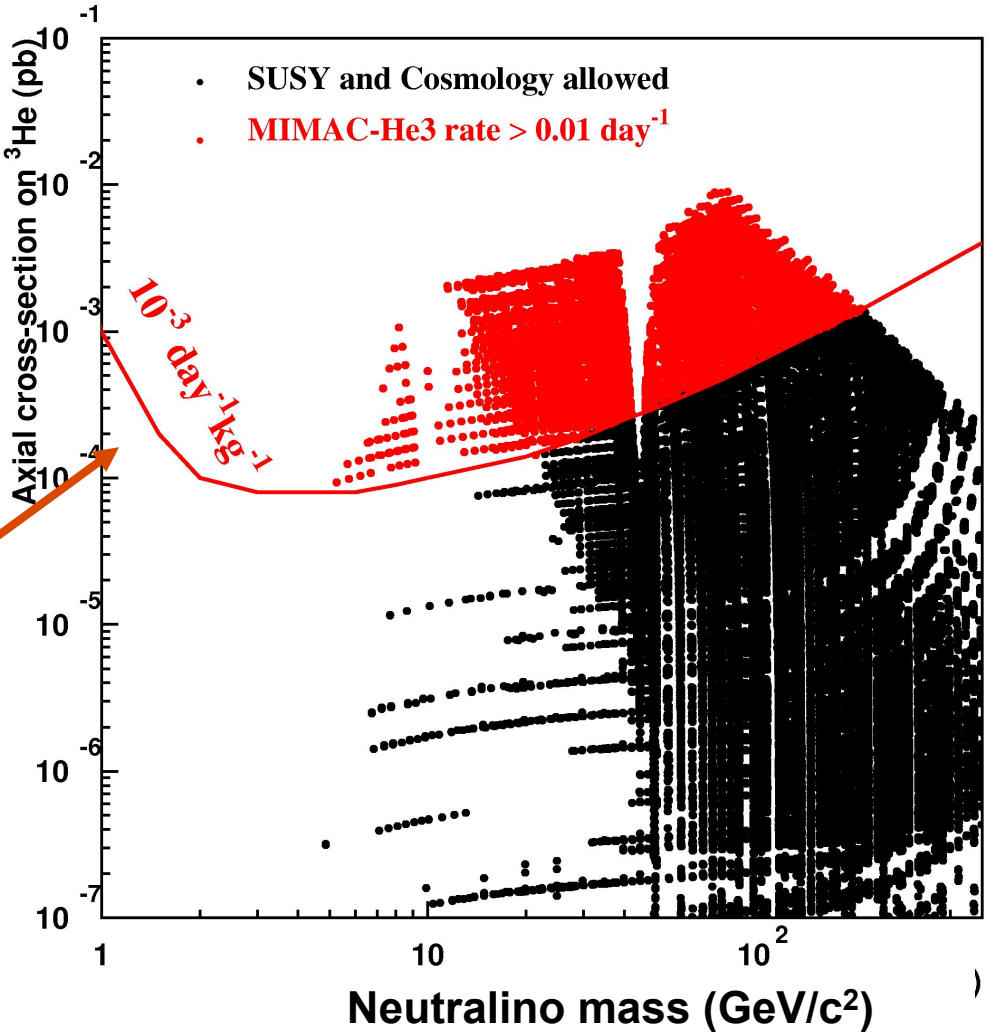


D. Santos (LPSC Grenoble)

Cross section ^{3}He-χ and event rate in MIMAC-He3 (10kg)

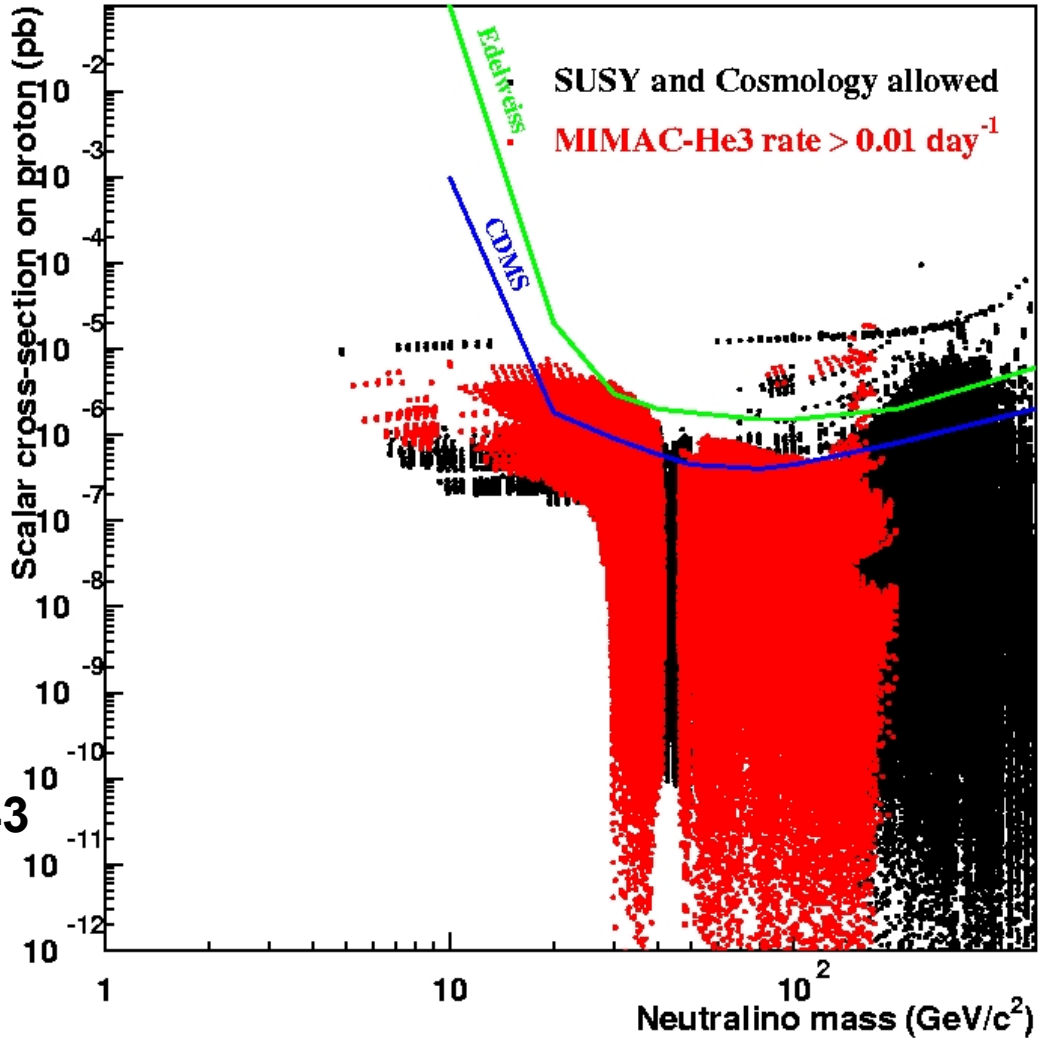
- $0.02 < \Omega_\chi h^2 < 0.15$
- Accelerator constrains

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



Complementarity with scalar detection

σ_{SD} and σ_{SI} not correlated



E. Moulin et al, PLB 614 (2005)143

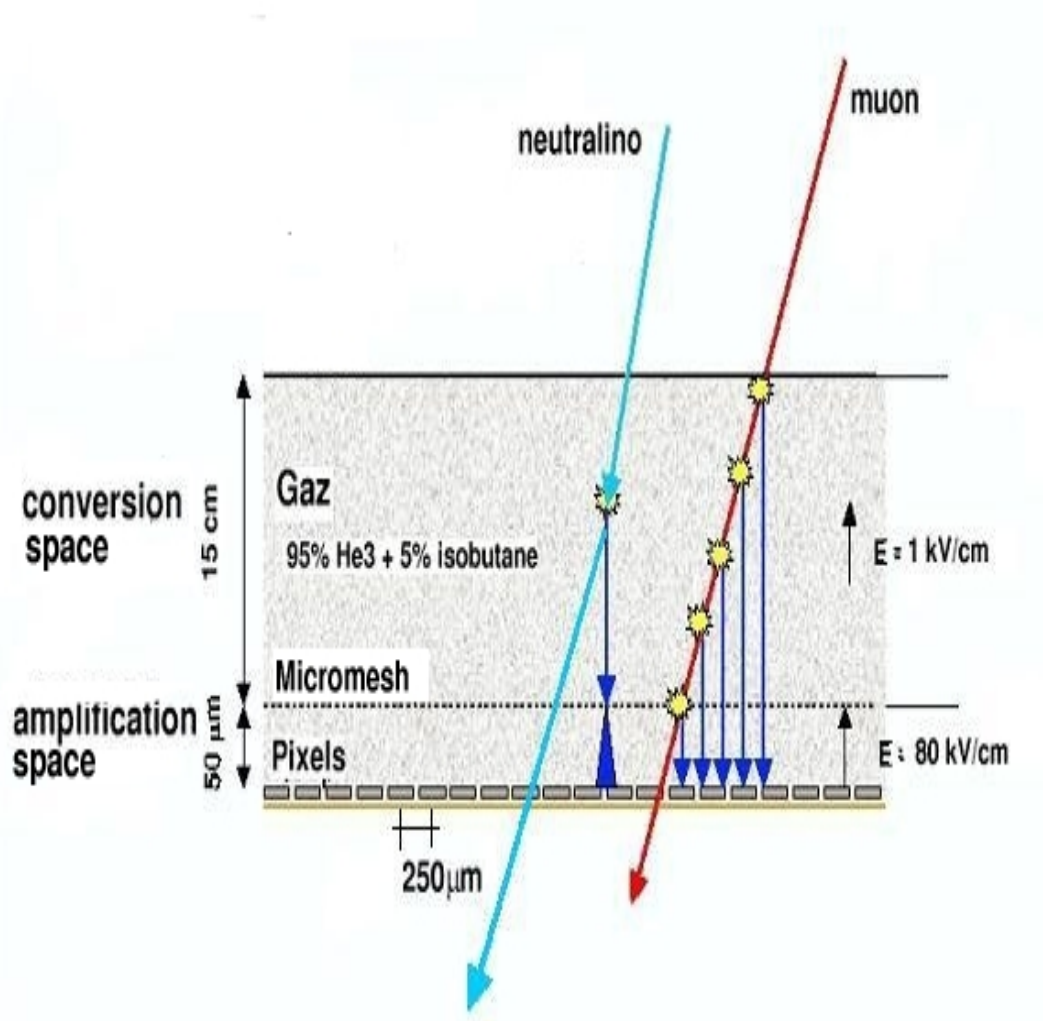
MIMAC:
(Micro-tpc MAtrix of Chambers)

{spatial, temporal, energetic} } resolution

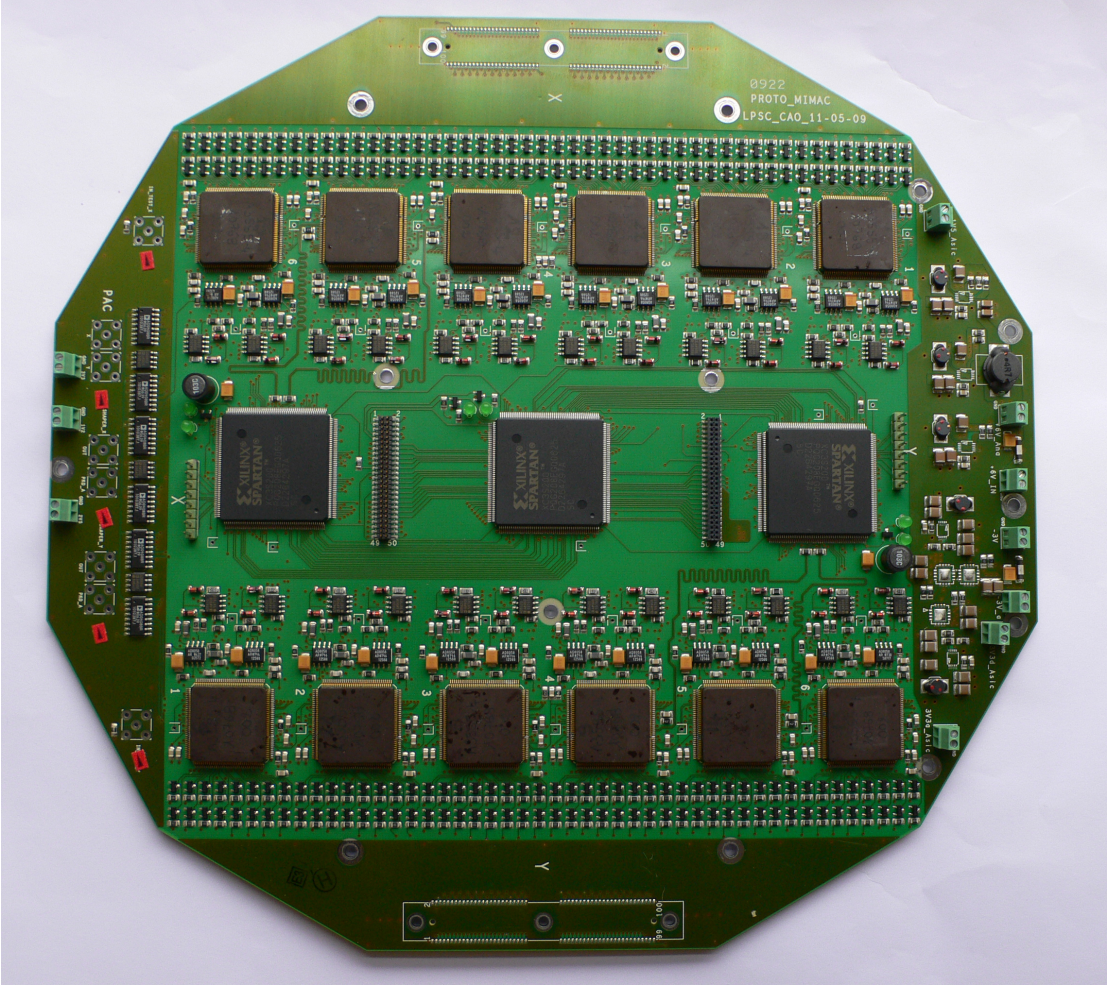
⇒ recoil track

⇒ energy threshold ~ 200eV

⇒ electron/recoil discrimination

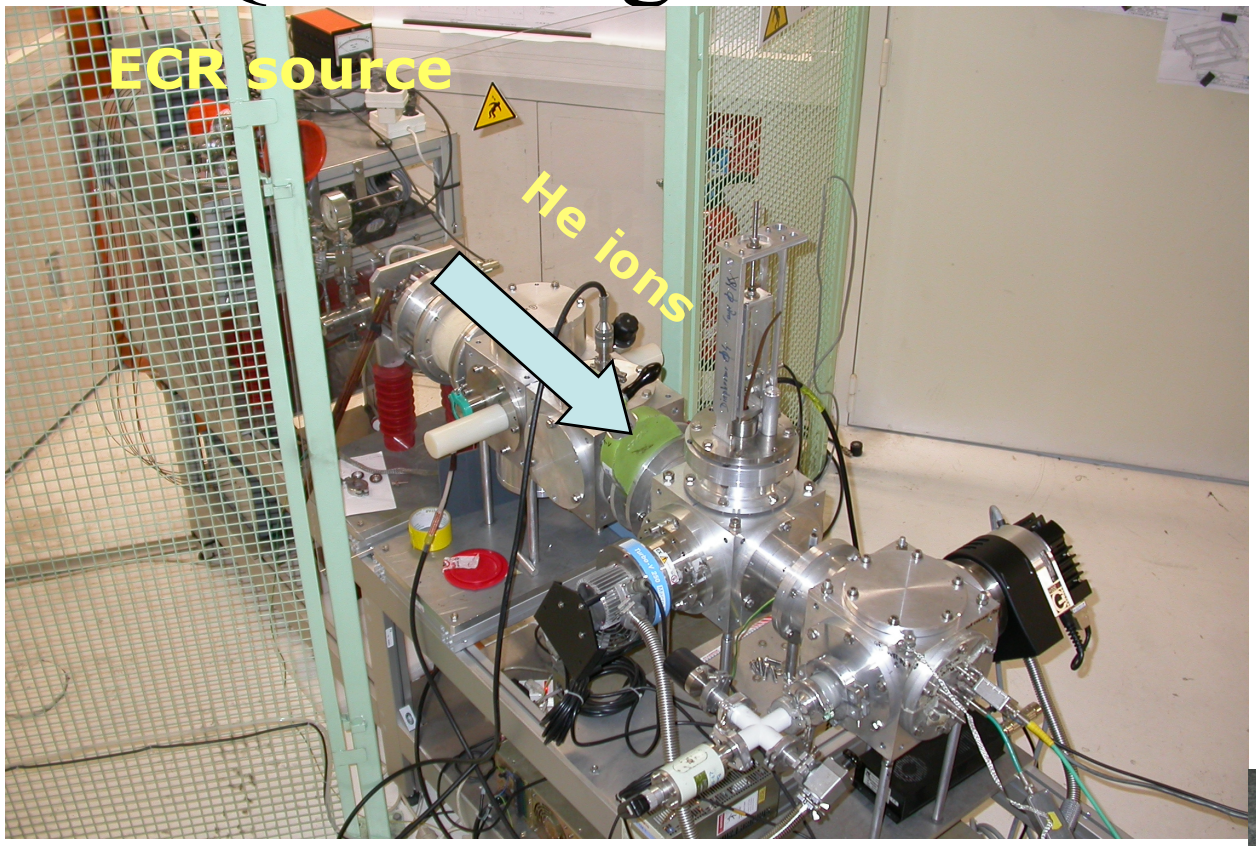


MIMAC chips integrated in the electronics of the prototype



96+96=192 channels
Covering 3x3 cm^2
Autotriggered
Reading it every 25ns

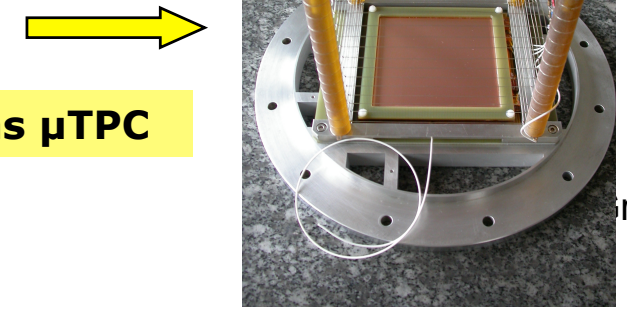
Quenching factor measurement



- **Low energy ion source**

  1 to 50 keV

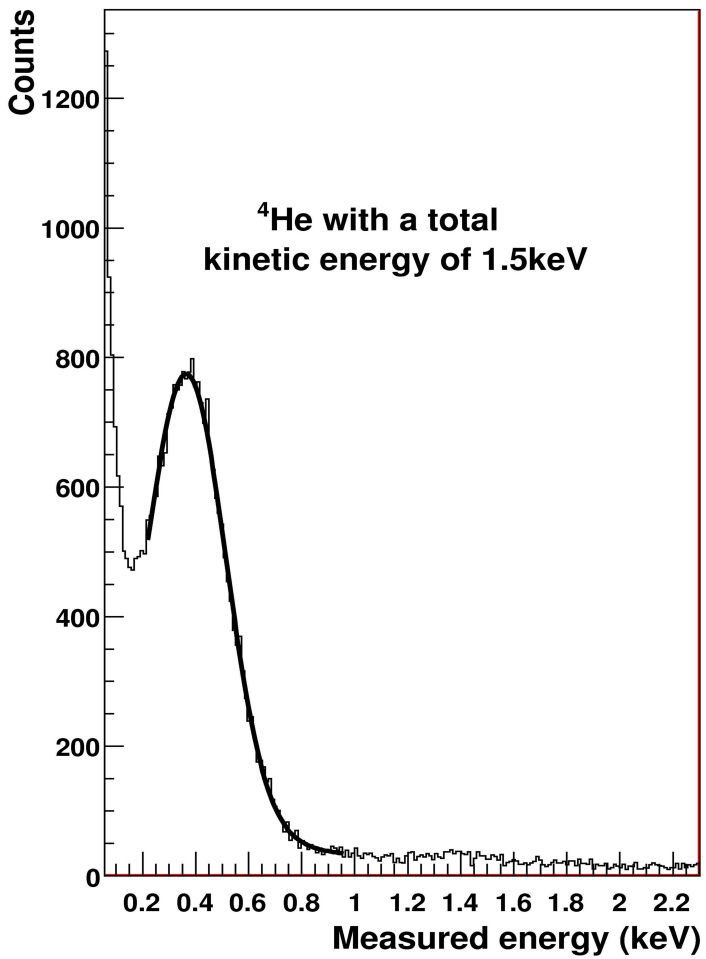
- **Developped @LPSC**

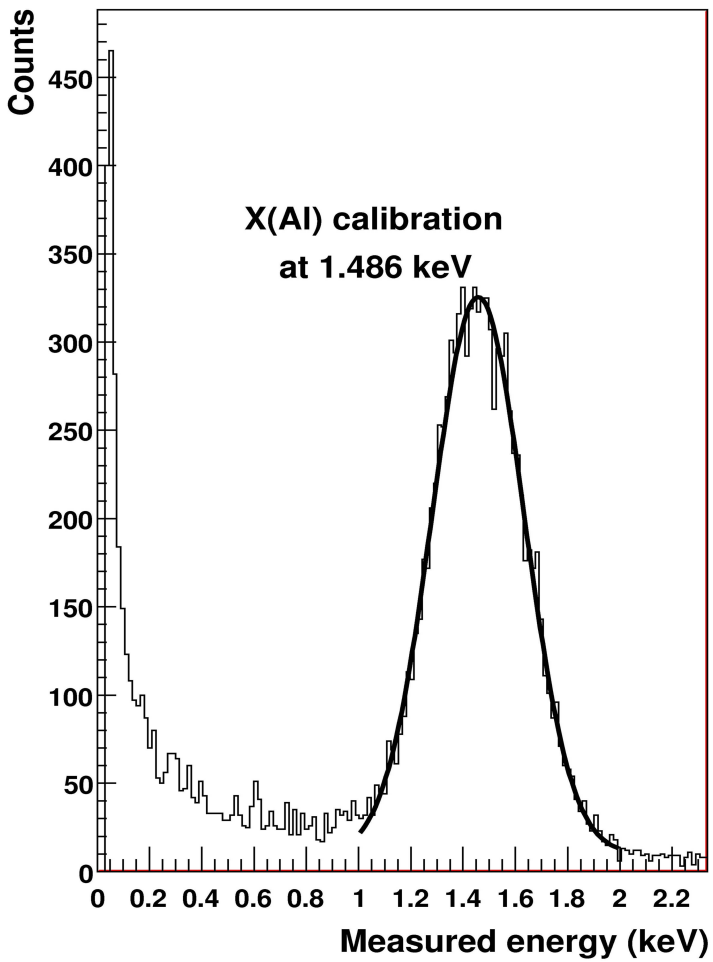


Micromegas µTPC

renoble)

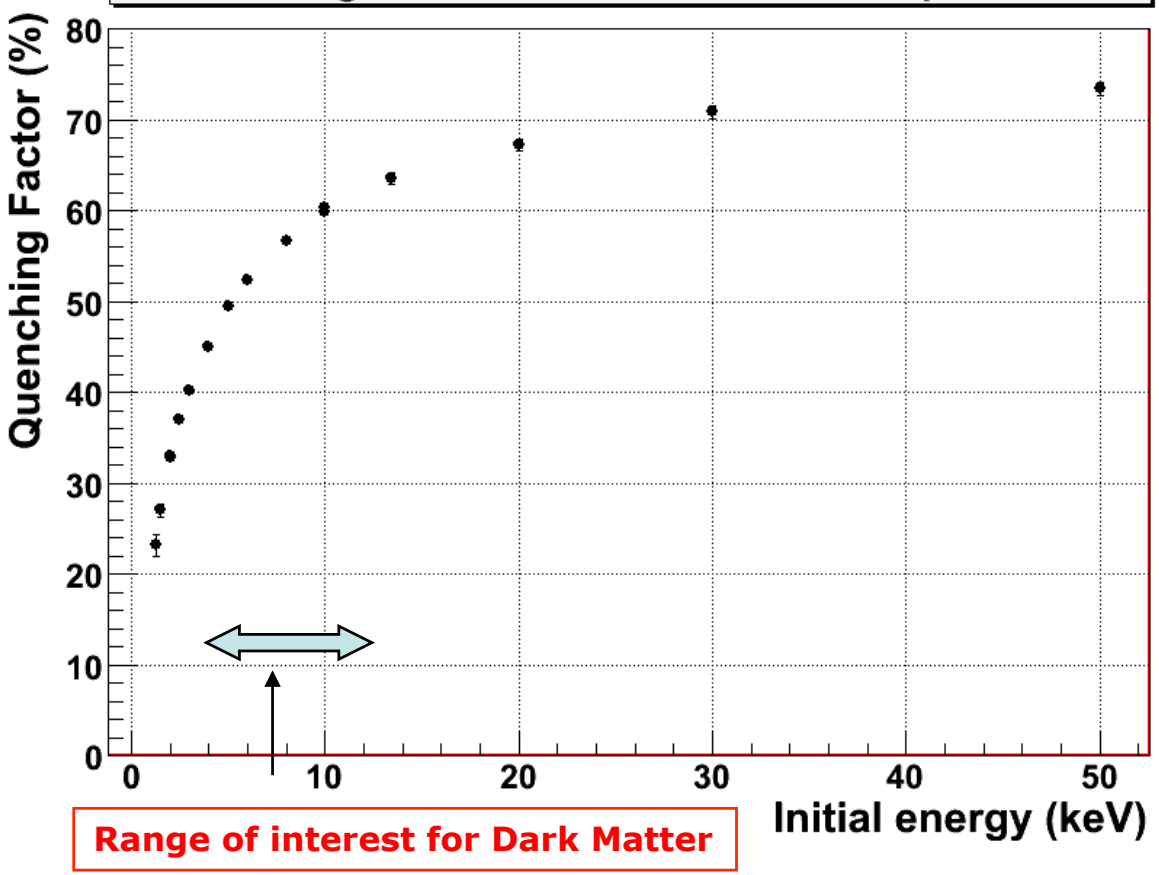
Detection of ^{4}He (recoils) of 1.5 keV !!
(95% ^{4}He + 5% iso) at 700mbars





QF measurement !!

Quenching factor @ 700 mbars



Range of interest for Dark Matter

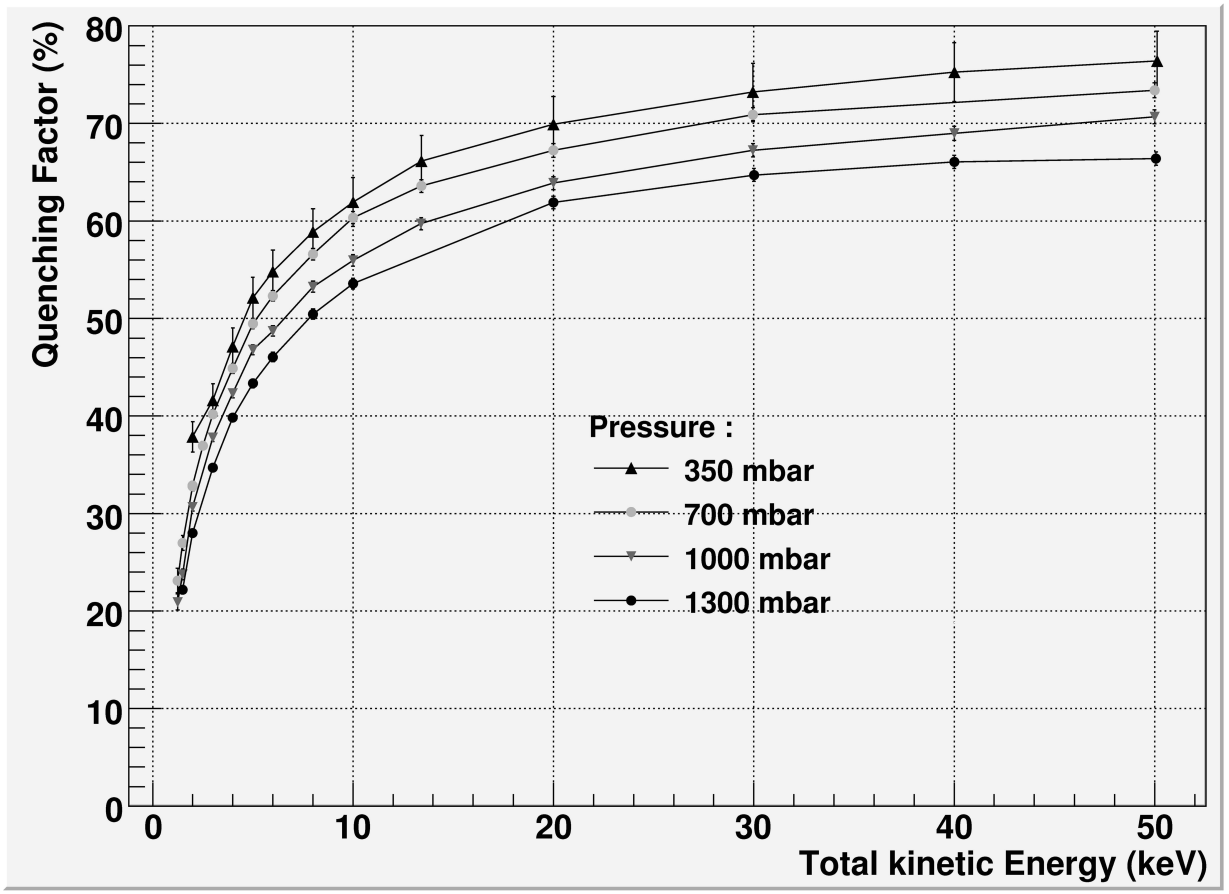
Measurement of ^4He

in 95% ^4He + 5% C_4H_{10}

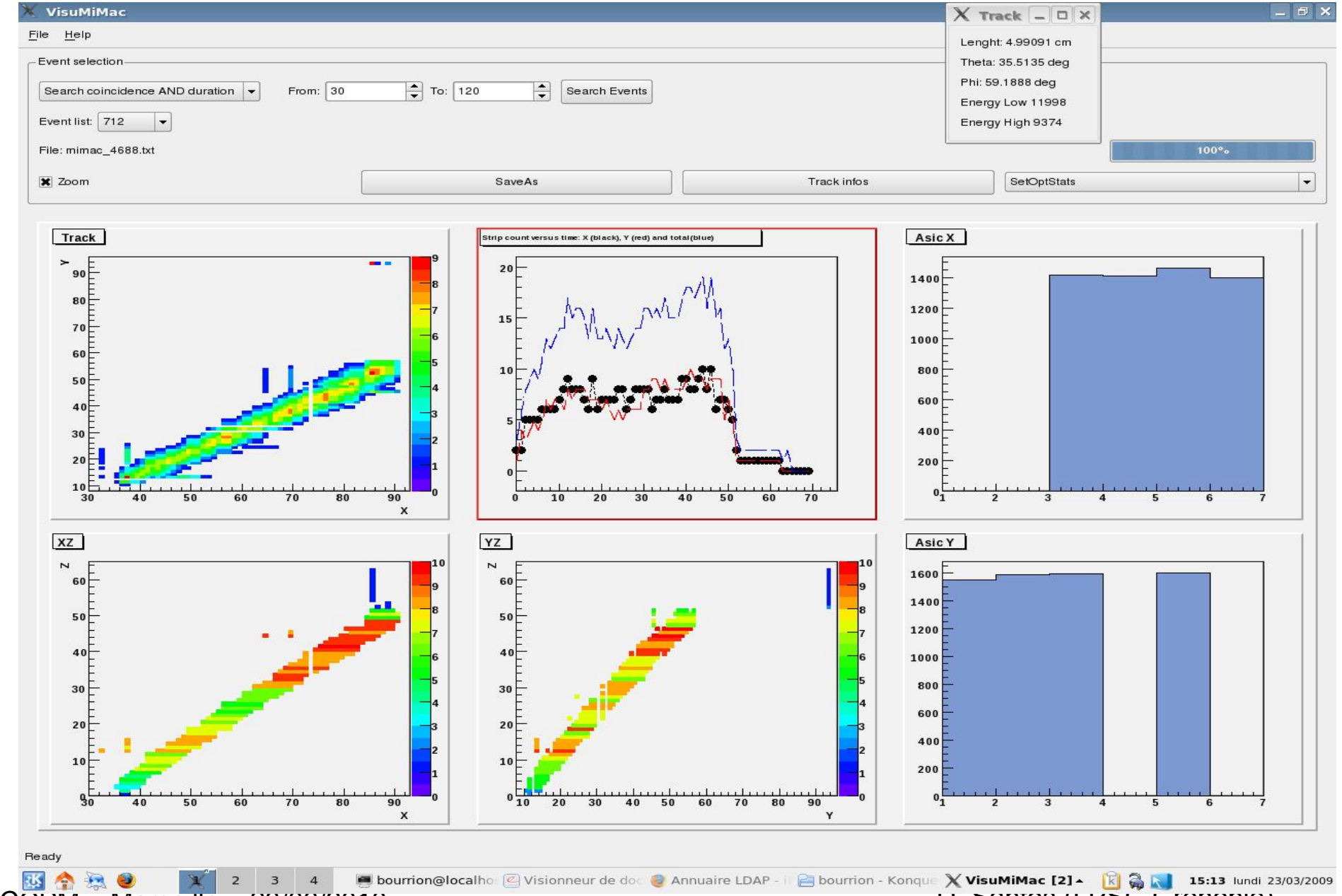
- Threshold :300 eV (ioni.) or 1 keV (recoil)
- The response of this ^4He detector is fully understood from 1 to 50 keV
- Dark Matter range : covered

IQF Measurement of ^{4}He in 95% ^{4}He + 5% C_4H_{10} as a function of the pressure

D. Santos et al. arXiv:astro-ph0810.1137

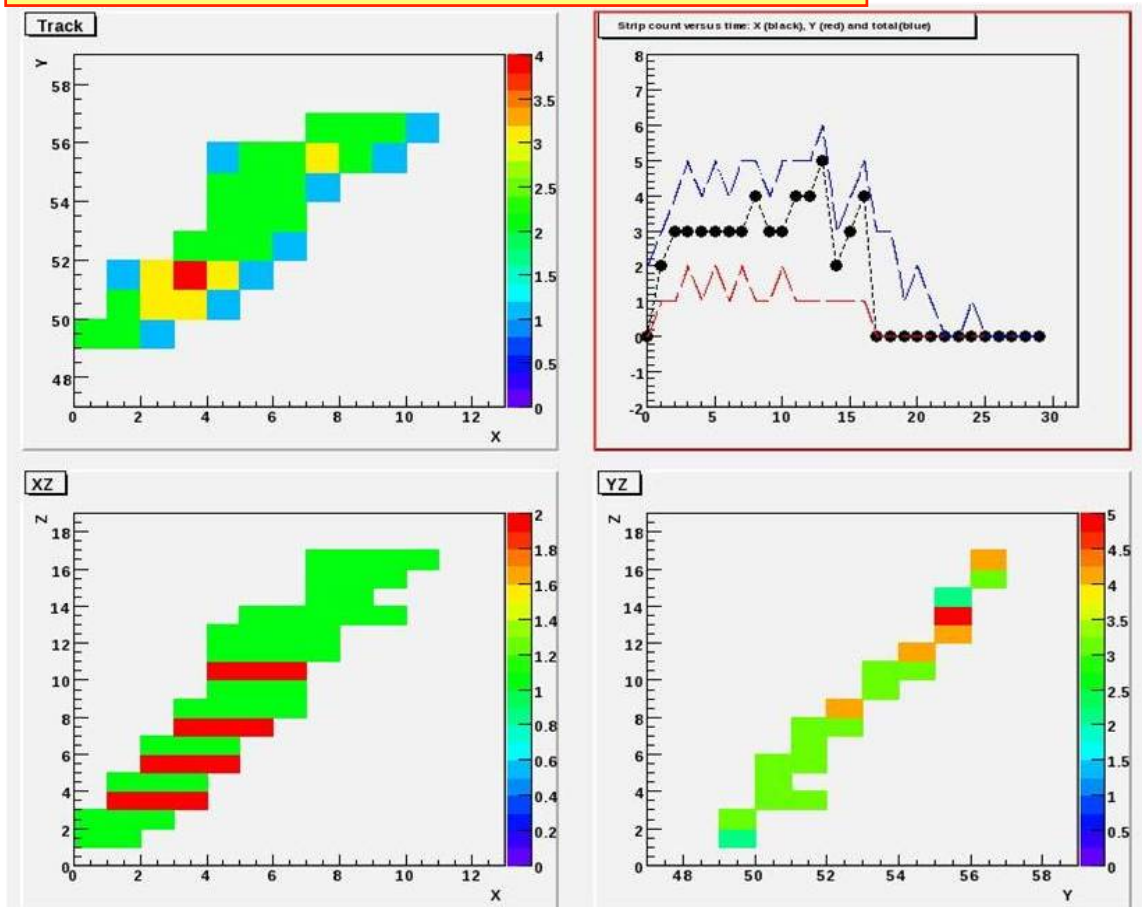


3D track alpha (radioactivity)



3D Track : 5.9 keV electron from ^{55}Fe

MIMAC Event display



With the
3D reconstruction

E=200 V/cm
P=350 mbar
v = 16 µm/ns

Track 45

ϕ = 41.6 deg

Θ = 39.2 deg

L = 8 mm

First 3D track of ~6 keV electron !!

Recoil from 144 keV neutrons

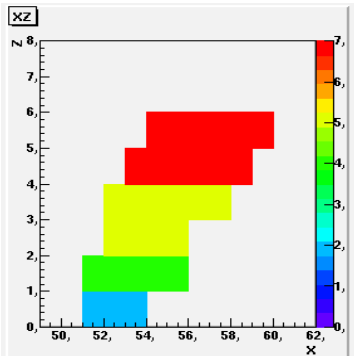
Pure isobutane

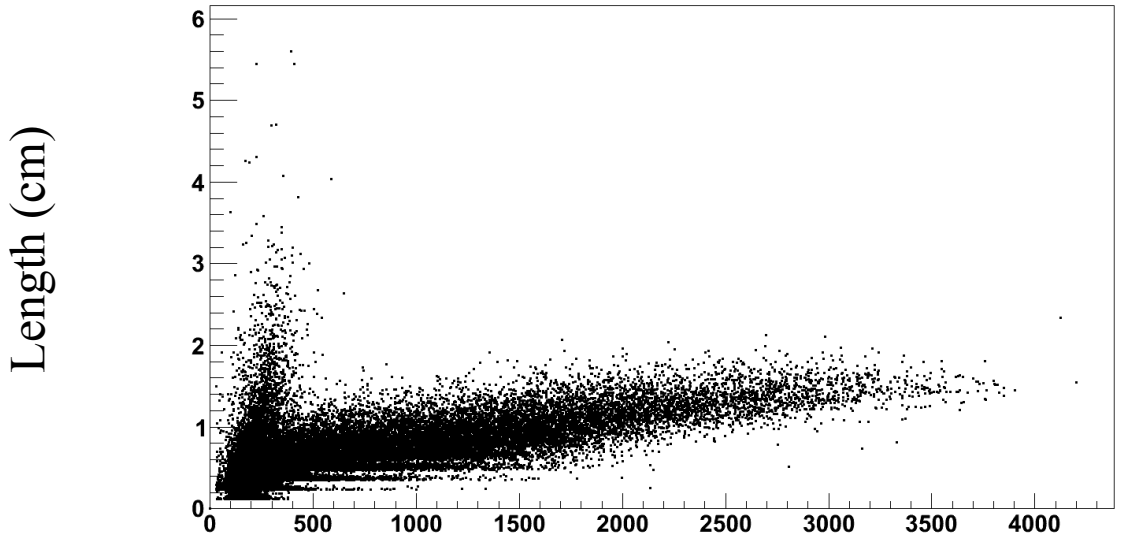
100 mbar

150 V/cm

Amande facility @ IRSN Cadarache

-> Neutron field with energies down to a few keV





- **Possibility to have H as a target**
- **Separate background from recoils**

MIMAC : recoil track measurements

April 2009

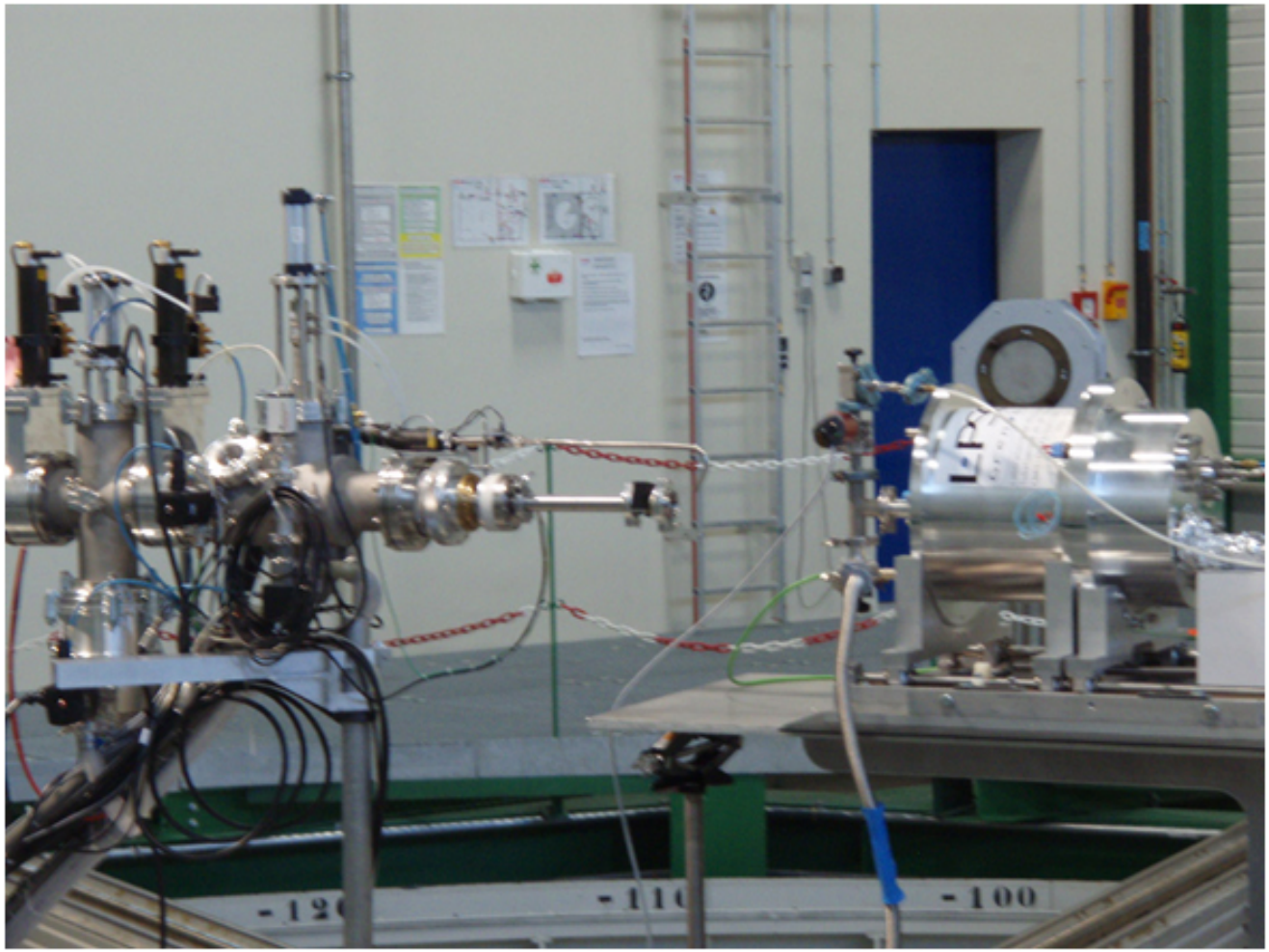
@ IRSN Cadarache

Amande facility :

- Neutron field with energies down to a few keV

D. Santos (LPSC Grenoble)

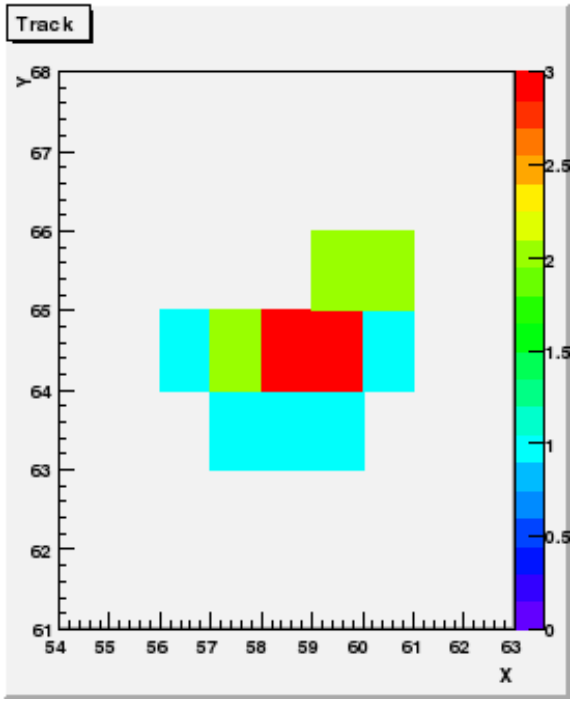
MIMAC prototype at Cadarache (detecting neutrons by nuclear recoil)



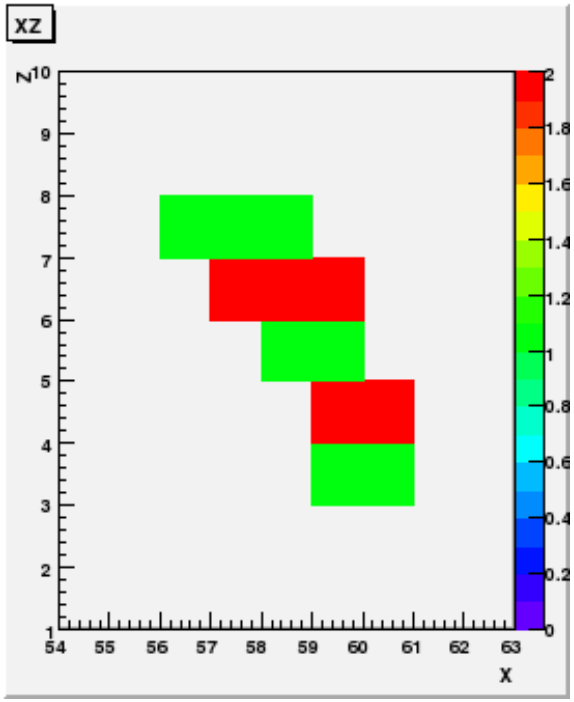
6 keV recoil track (^{4}He) projections

300 mbar (95% of 4He, 5% of $C_4 H_{10}$)

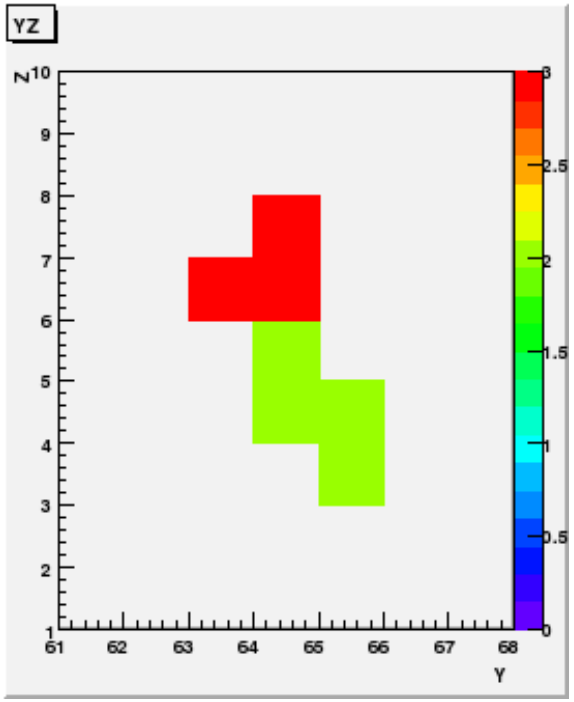
X-Y



X-Z



Y-Z



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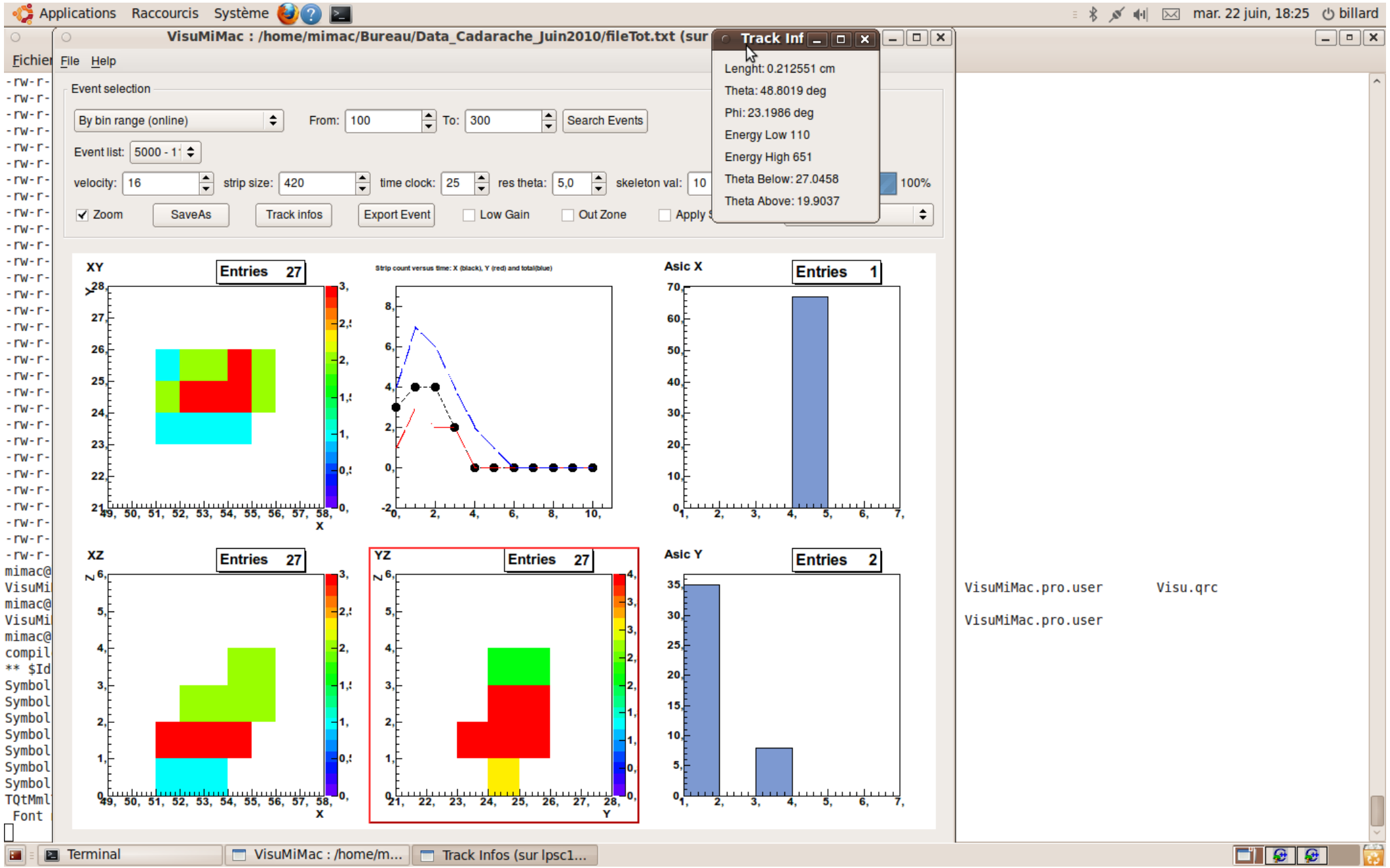
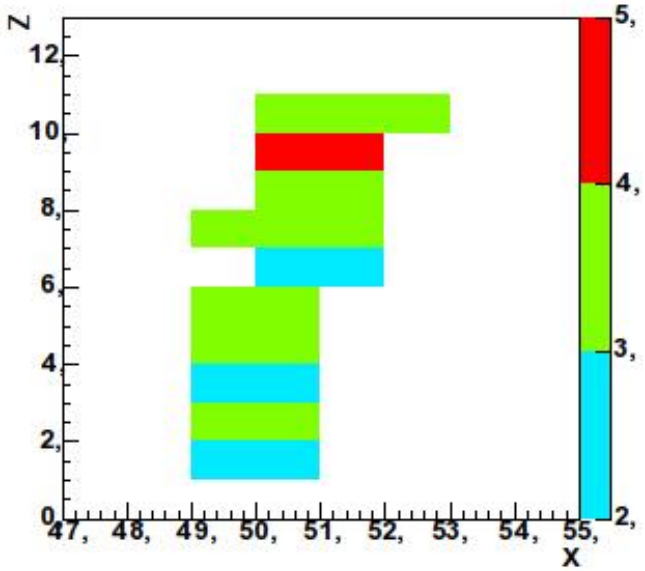
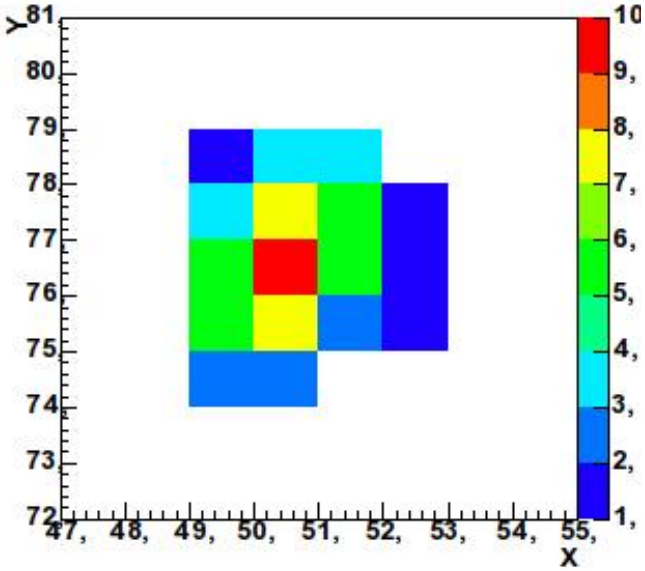
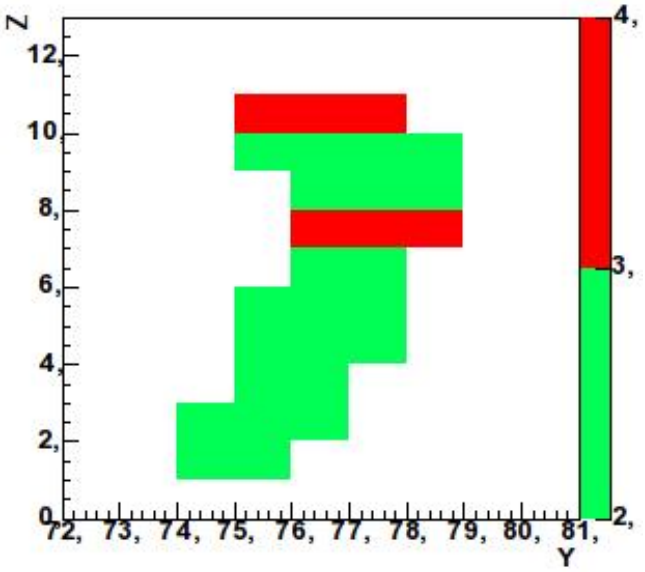
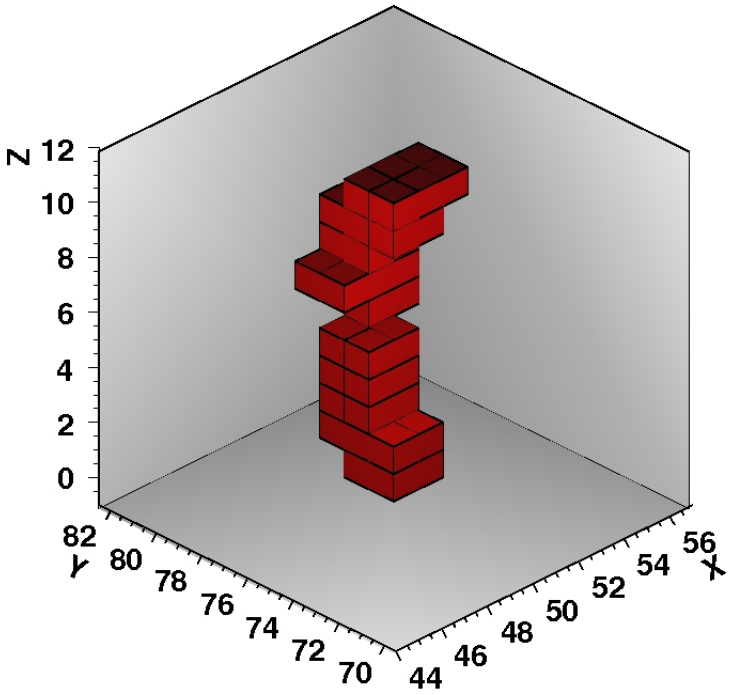

Applications Raccourcis Système
mar. 22 juin, 18:25 billard
VisuMiMac : /home/mimac/Bureau/Data_Cadarache_Juin2010/fileTot.txt (sur
Track Inf
Lenght: 0.212551 cm
Theta: 48.8019 deg
Phi: 23.1986 deg
Energy Low 110
Energy High 651
Theta Below: 27.0458
Theta Above: 19.9037
File Help
Event selection
By bin range (online)
From: 100
To: 300
Search Events
Event list: 5000 - 1
velocity: 16
strip size: 420
time clock: 25
res theta: 5,0
skeleton val: 10
100%
Zoom
SaveAs
Track infos
Export Event
Low Gain
Out Zone
XY
Entries 27
Strip count versus time: X (black), Y (red) and total(blue)
Asic X
Entries 1
XZ
Entries 27
YZ
Entries 27
Asic Y
Entries 2
VisuMiMac.pro.user
Visu.qrc
VisuMiMac.pro.user
Terminal
VisuMiMac : /home/m...
Track Infos (sur lpsc1...





Recul de 19F
(E~40 keV)
dans 50 mbar de
CF4 + CHF3 (30%)

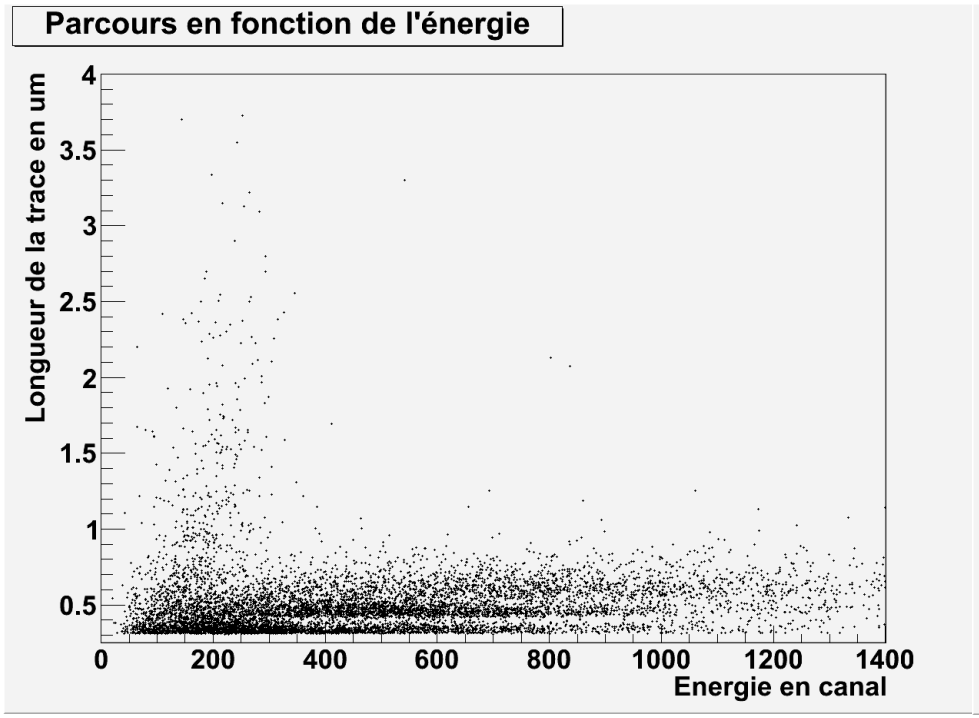


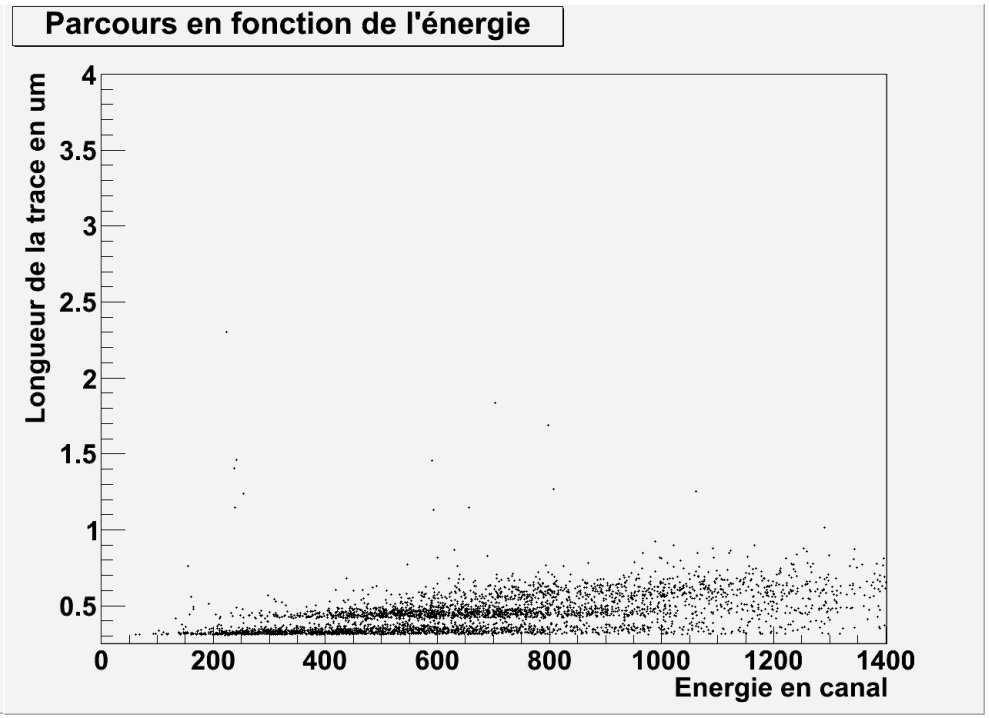


New degree of freedom to discriminate recoils from electrons from 3D tracks

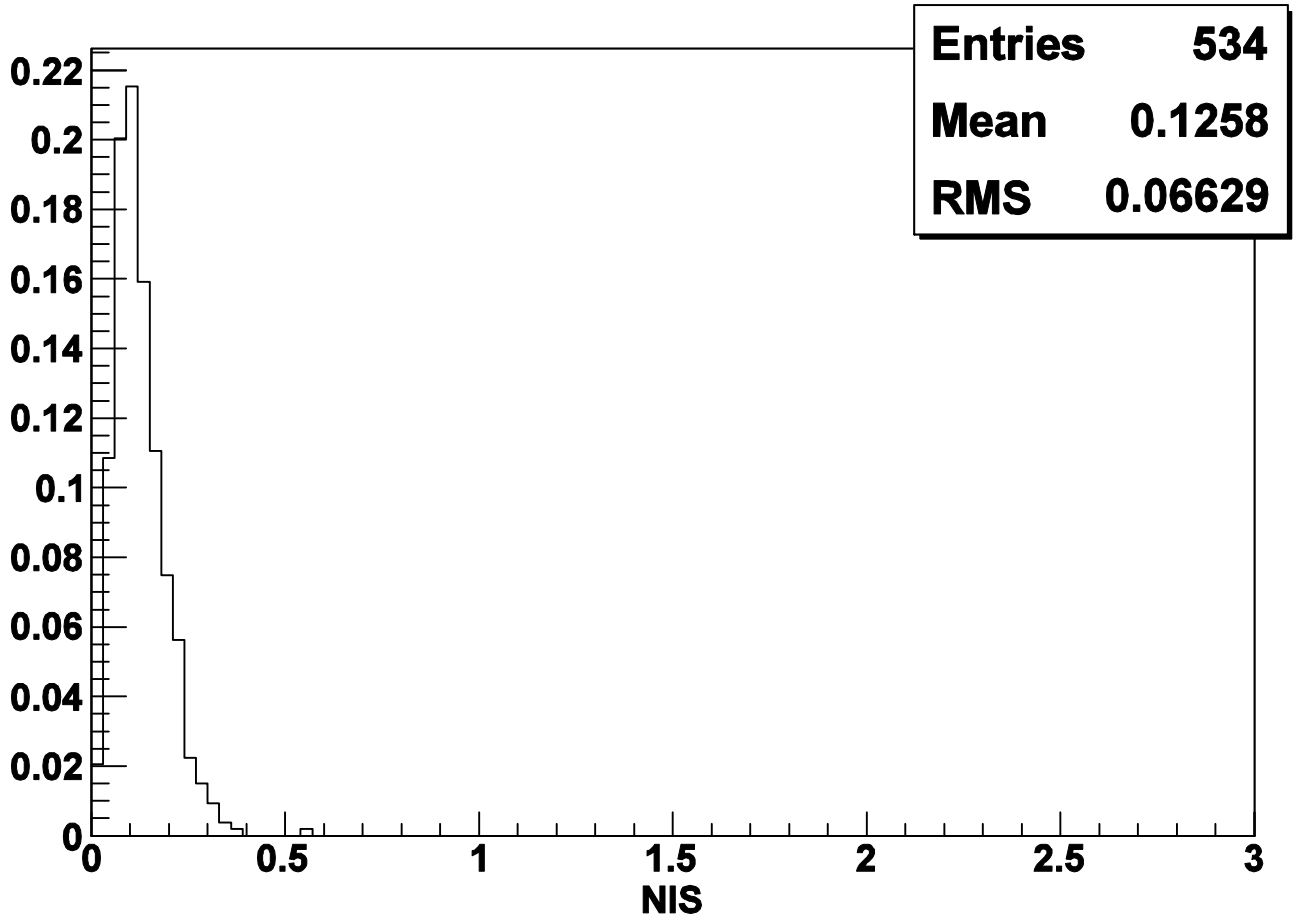
Normalized Integrated Straggling (NIS)

(Sum of partial deflections along the measured track, normalized by its total energy)
(J. Billard et al. (2009) in preparation)

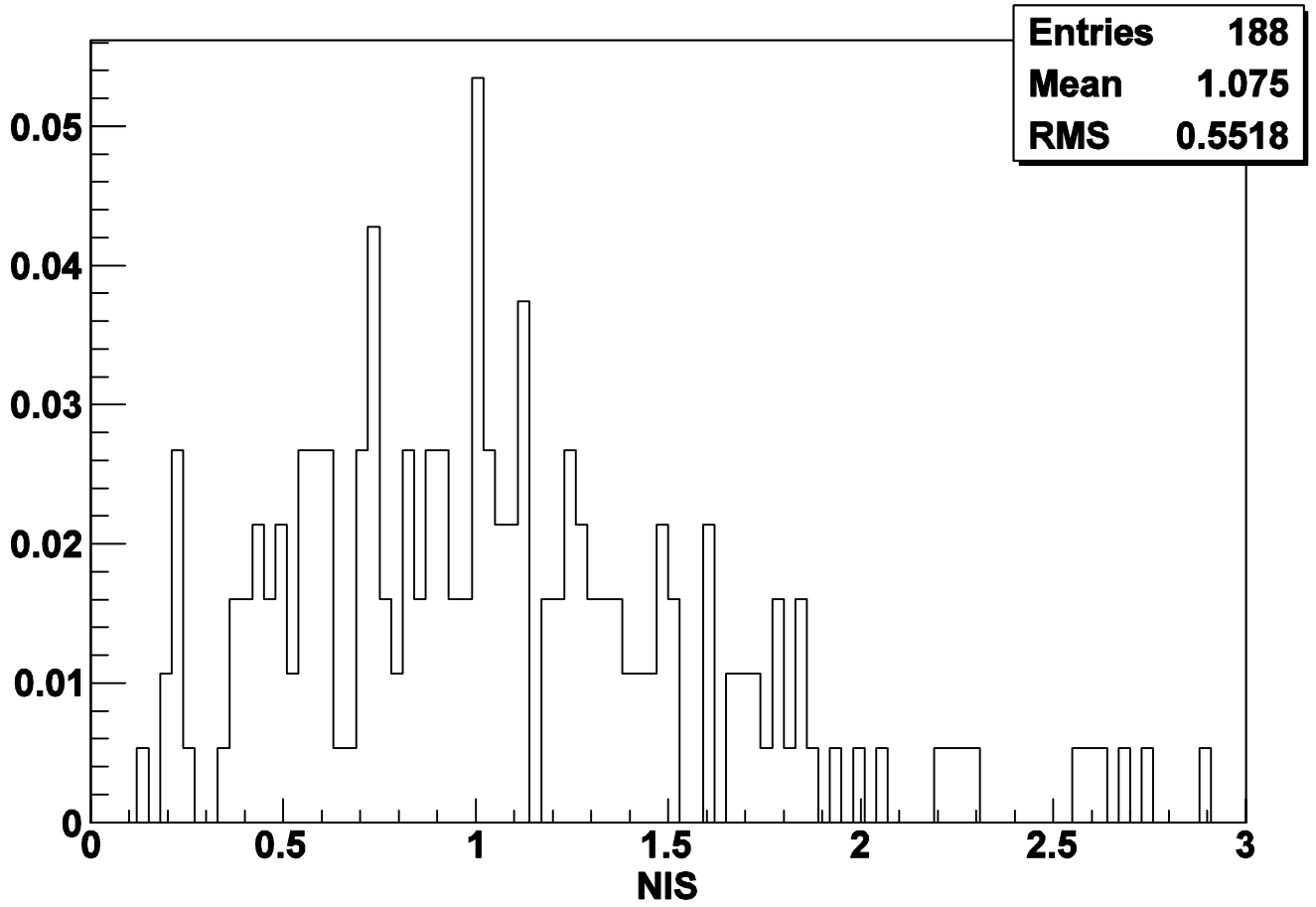




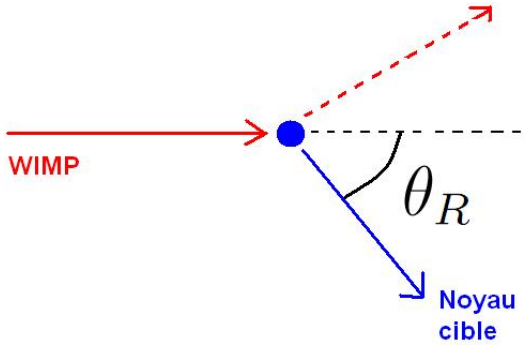
NIS (for recoils)



NIS(for electrons)



La détection directe



Collision élastique d'un WIMP sur un noyau cible du détecteur:

$$E_r = E_{\tilde{\chi}} r \cos^2 \theta_R$$

r : la masse réduite

$$\frac{dR}{dE_r} = \frac{\sigma(E_r)\rho_0}{2m_{\tilde{\chi}} m_r^2} F^2(E_r) \int_{v_{\min}}^{\infty} \frac{f_1(v)}{v} dv$$

Taux d'interaction différentiel en fonction de l'énergie du recul

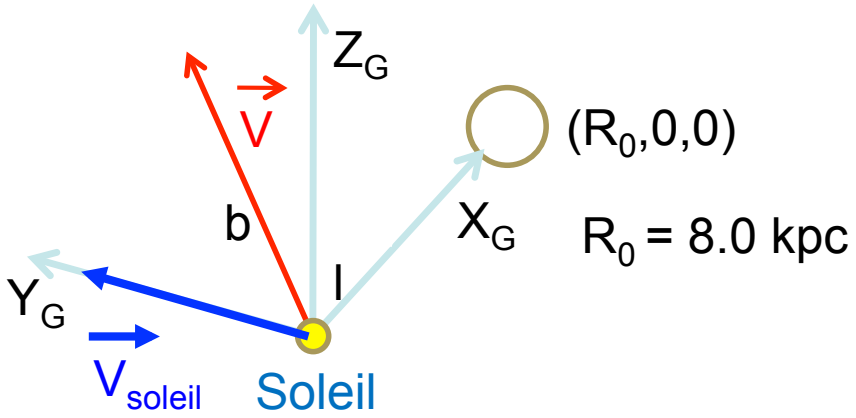
Halo galactique

Physique des particules

Physique Nucléaire

La détection directe

Orbite solaire



$$\vec{V} = V \begin{pmatrix} \cos(l)\cos(b) \\ \sin(l)\cos(b) \\ \sin(b) \end{pmatrix}$$

r: distance au centre galactique

l: longitude galactique

b: latitude galactique

Vitesse tangentielle du soleil:

$$v_\odot = 220 \pm 20 \ \mathrm{km.s^{-1}}$$

Direction: (l = 90, b = 0)

Constellation du Cygne

La détection directe

Les trois modèles de halo isotherme:
- **La sphère isotrope**
- **La sphéroïde oblate**
- **L'ellipsoïde (3 axes différents)**

La dispersion des vitesses est reliée à $V_0(r \to \infty) \approx 220$ km.s^{-1}

$$\sigma_v = v_0/\sqrt{2}$$

$$f(\vec{v}) = \frac{1}{(2\pi\sigma_v)^{3/2}} \exp\left(-\frac{(\vec{v}+\vec{v}_\odot)^2}{2\sigma_v^2}\right)$$

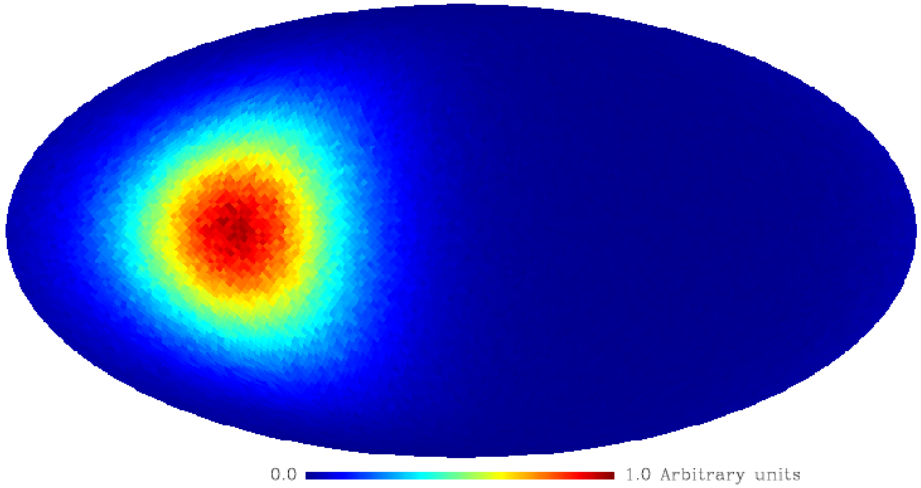
Distribution maxwellienne

Equation de Boltzmann d'un gaz de particules sans collision

$$\frac{\partial f}{\partial t} + \vec{v}.\nabla f - \nabla\Phi.\frac{\partial f}{\partial \vec{v}} = 0$$

Equation de Poisson

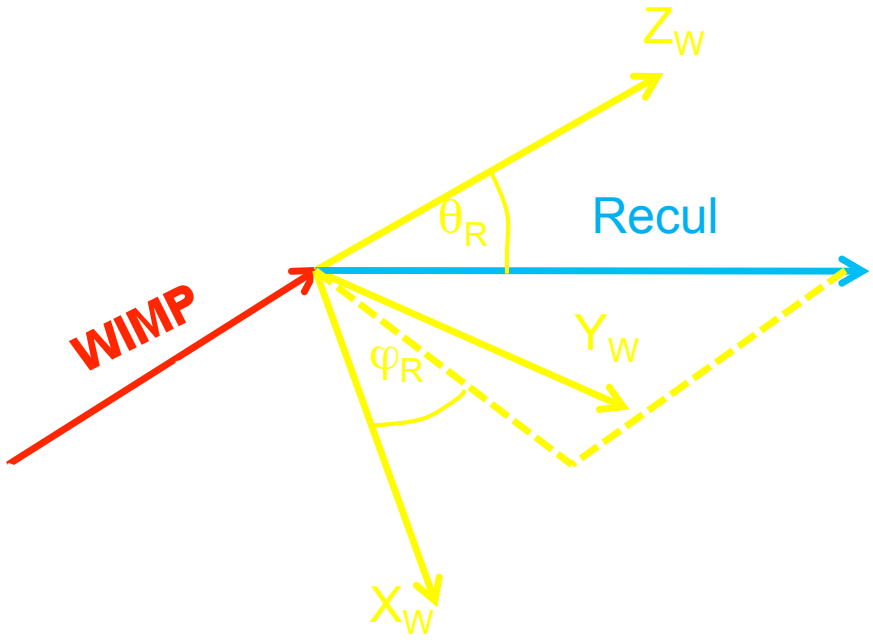
$$\nabla^2\Phi = 4\pi G\rho(\vec{r}) = 4\pi G \int f(\vec{r},\vec{v},t)d^3\vec{v}$$

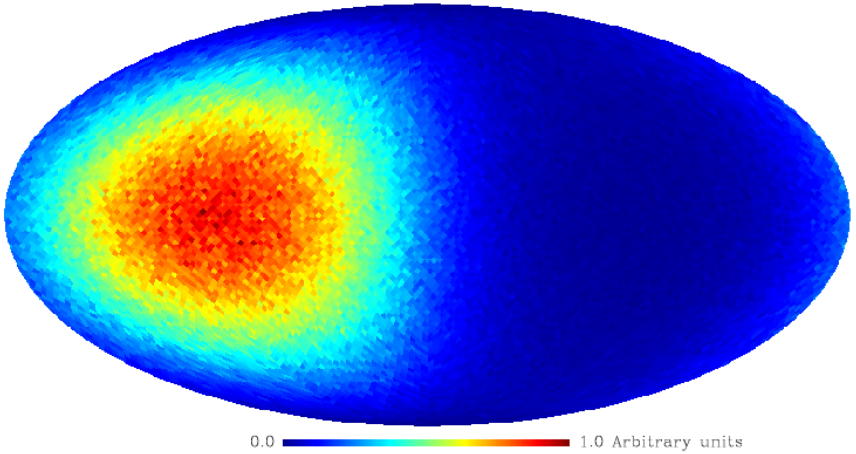


Flux de WIMP dans le référentiel terrestre en coordonnées galactique (HealPix)

I. La détection directe

Simulation des reculs:

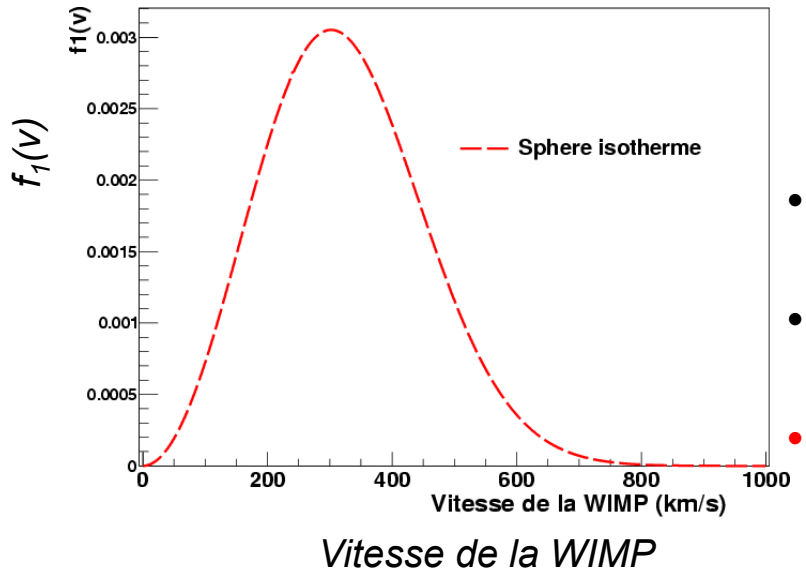




Reculs de WIMP dans le référentiel terrestre en coordonnées galactique (HealPix)

10^8 événements avec E_R = [5,50] keV

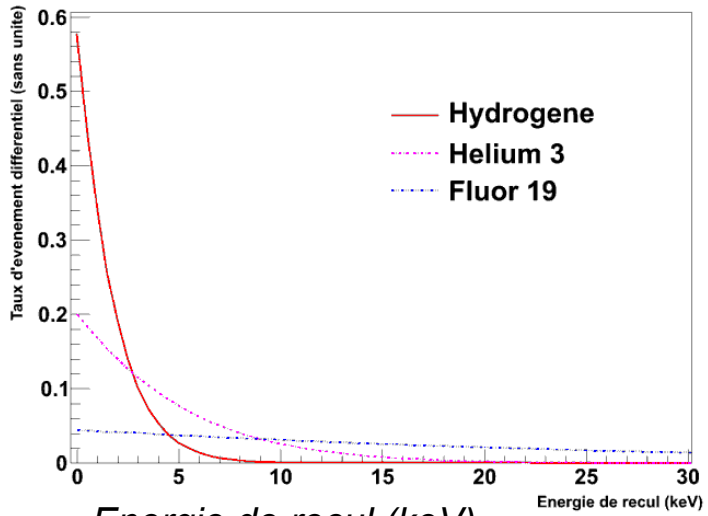
La détection directe



$f_1(v)$

Vitesse de la WIMP

- **Distribution maxwellienne**
- **Vitesse moyenne de 300 km/s**
- **Non relativiste**



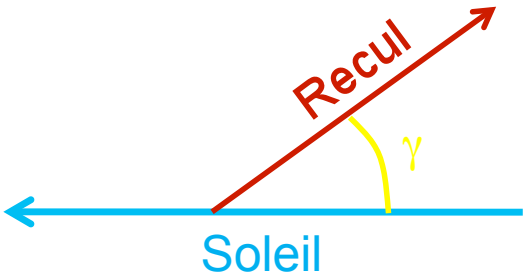
Taux d'evenement

Energie de recul (keV)

Energie de recul de l'ordre du keV

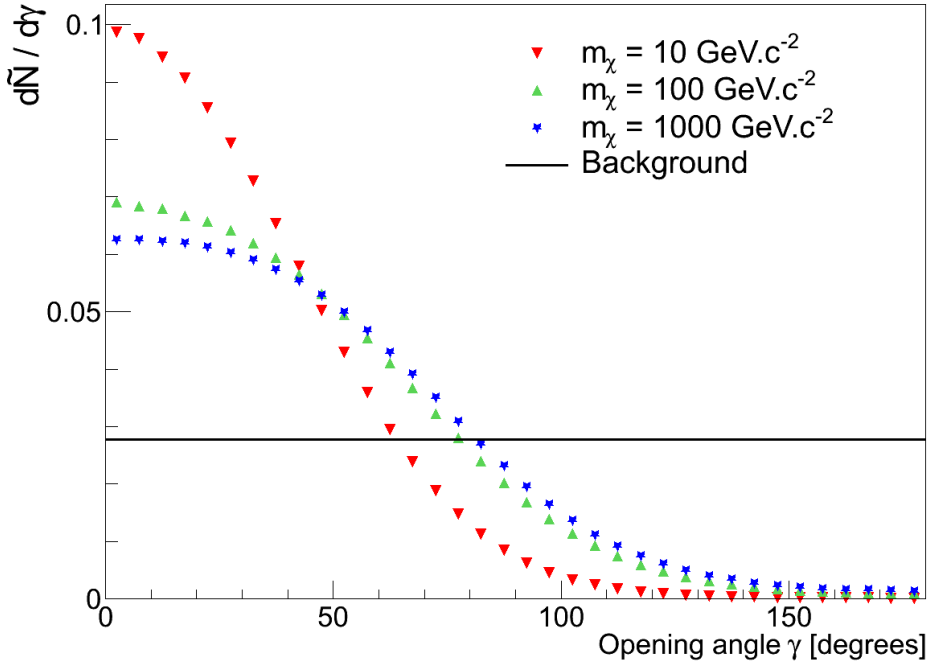
Energie seuil de MIMAC ~ 5 keV (recul) (19F)

Phénoménologie directionnelle



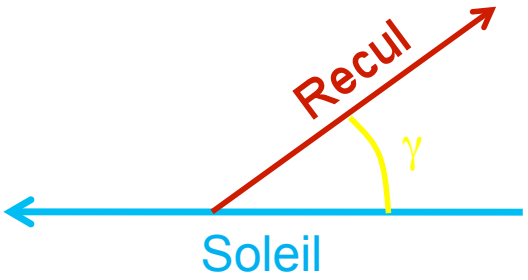
- **Signal plus directionnel pour des masses petites**

- **Quelque soit le masse de la particule WIMP, le signal reste directionnel**



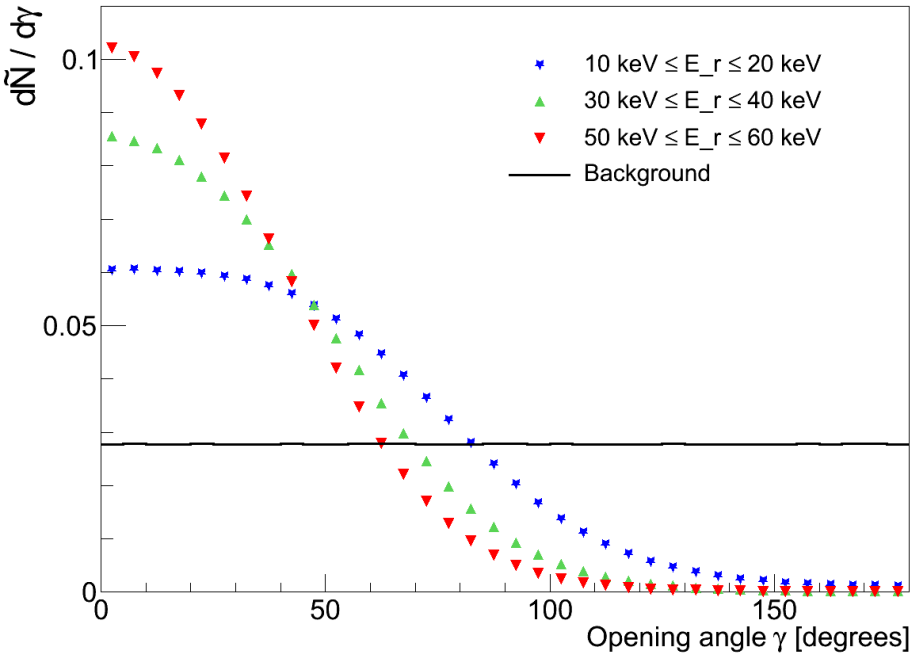
Spectre angulaire normalisé pour du Fluor

Phénoménologie directionnelle



- **Reculs de haute énergie sont plus directionnels, mais moins présents.**

- **Quelque soit la gamme en énergie, le signal reste directionnel**



Spectre angulaire normalisé pour du Fluor

Phénoménologie directionnelle

Méthode de vraisemblance « likelihood », sans priors

C: Distribution théorique du signal WIMP
B: Distribution théorique du bruit de fond (isotrope)
M: Mesure de MIMAC

statistique de Poisson

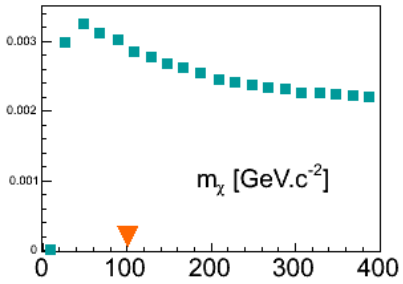
$$\mathscr{L}(m_\chi, \lambda, \ell, b) = \prod_{i=1}^{N_{\rm bins}} P([(1-\lambda)B_i + \lambda S_i(m_\chi; \ell, b)]|M_i)$$

Paramètre de découverte: coordonnées de la source des événements => origine galactique du signal

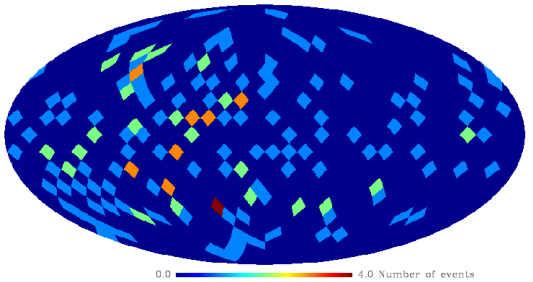
Significance de la découverte: donnée par le paramètre Lambda

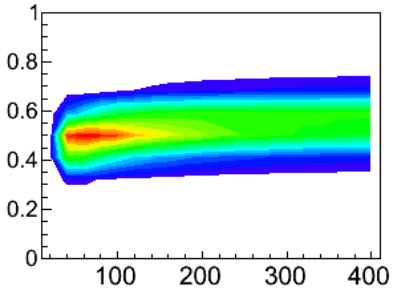
=> fraction du signal WIMP $\lambda = S/(B+S)$

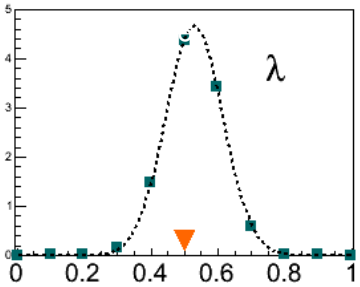
Phénoménologie directionnelle



Input:

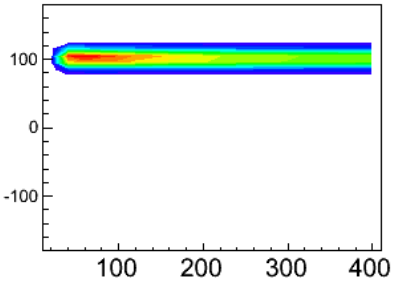


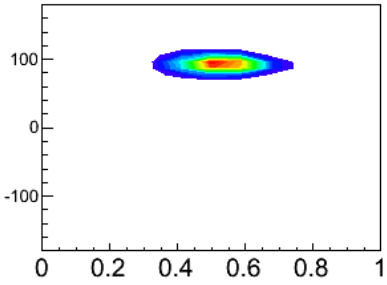


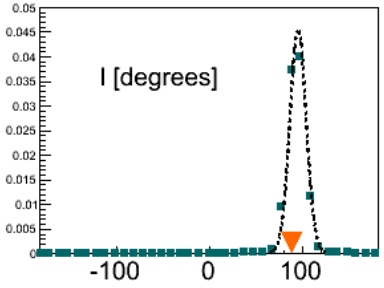


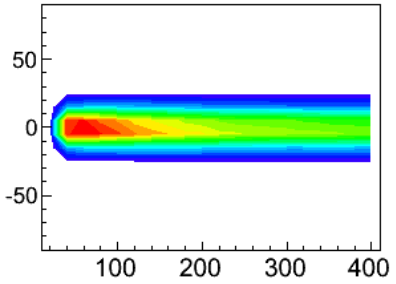
Likelihood analysis

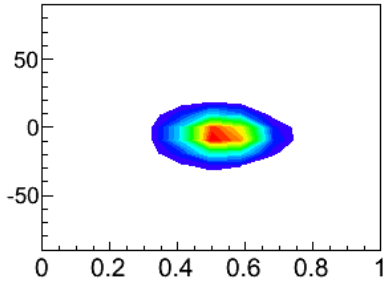
WIMP mass: $m_\chi > 10$ GeV.c^{-2}
WIMP fraction: $\lambda = 0.53 \pm 0.085$ (1σ CL)
Galactic latitude: $l = 95^\circ \pm 10^\circ$ (1σ CL)
Galactic Longitude: $b = -6^\circ \pm 10^\circ$ (1σ CL)

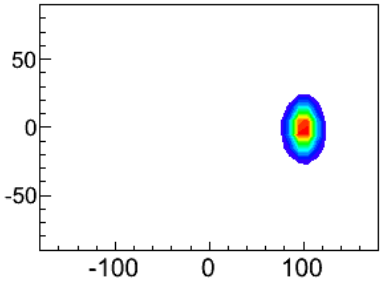


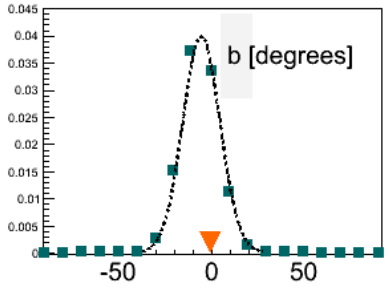












Phénoménologie directionnelle

On reconstruit bien la direction du Cygne à 10° (68% CL)
On obtient Nwimp = 106 ± 15 (68% CL) => Significance = 6,4

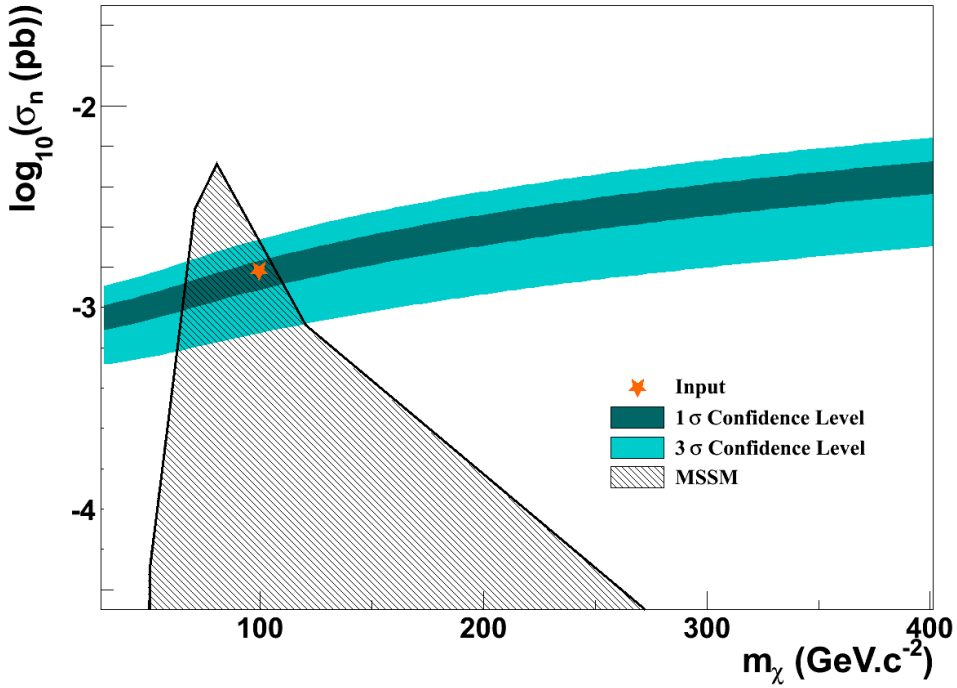
Découverte de la matière noire!

On peut en déduire une contrainte sur le plan

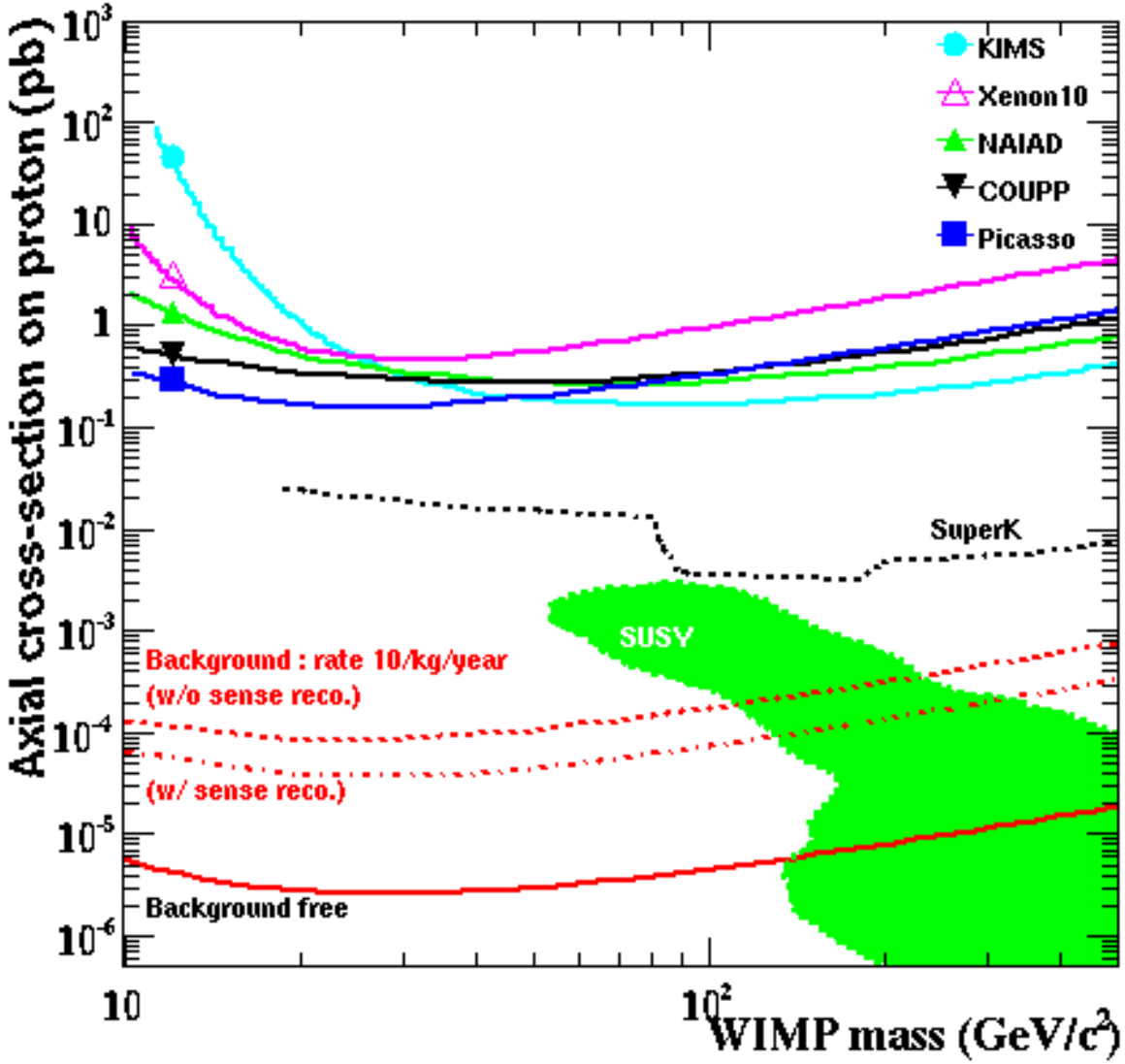
$$(\sigma_n, m_\chi)$$

• La masse n'est pas contrainte, on a juste M>10GeV/c^2

• Lambda est relié à la section efficace



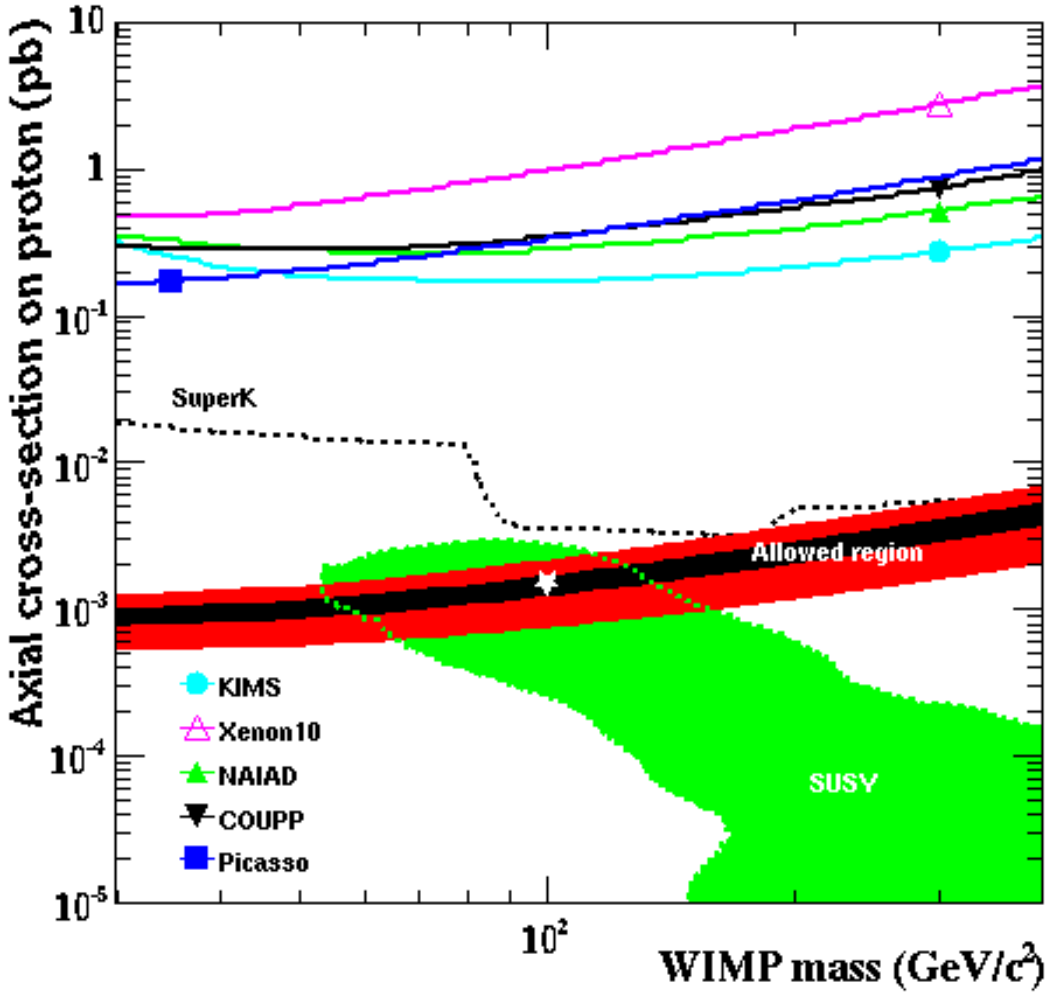
J.Billard, F.Mayet, D.S. (2010,accepted in PLB)



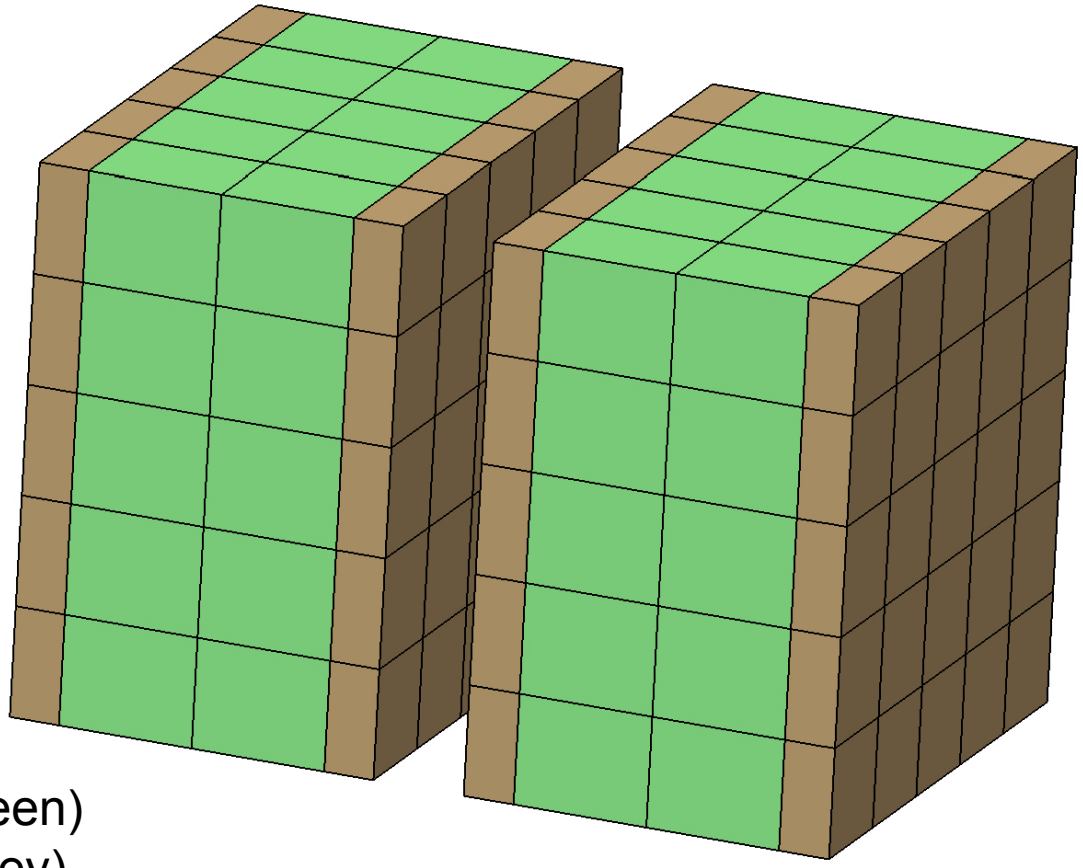
Exclusion plot for directional detection

J.Billard, F.Mayet ,D.S. (2010) submitted to PRD

Discovery plot
(significant number of Wimp events (~50))

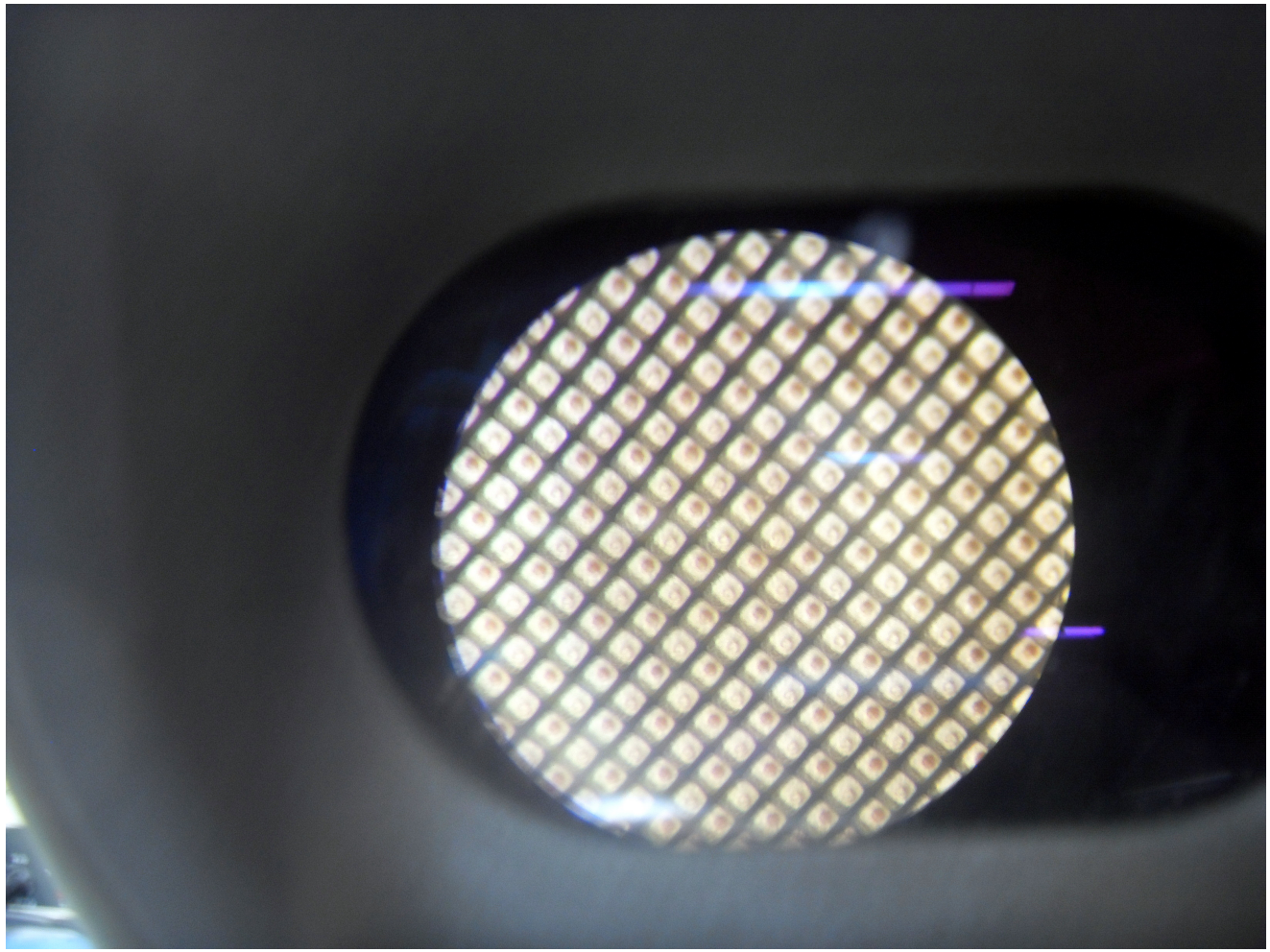


MIMAC unit ($1m^3$)



Chambers (green)
Electronics (grey)

A small part of the 10x10 cm^2 pixelized anode (Saclay-MIMAC)



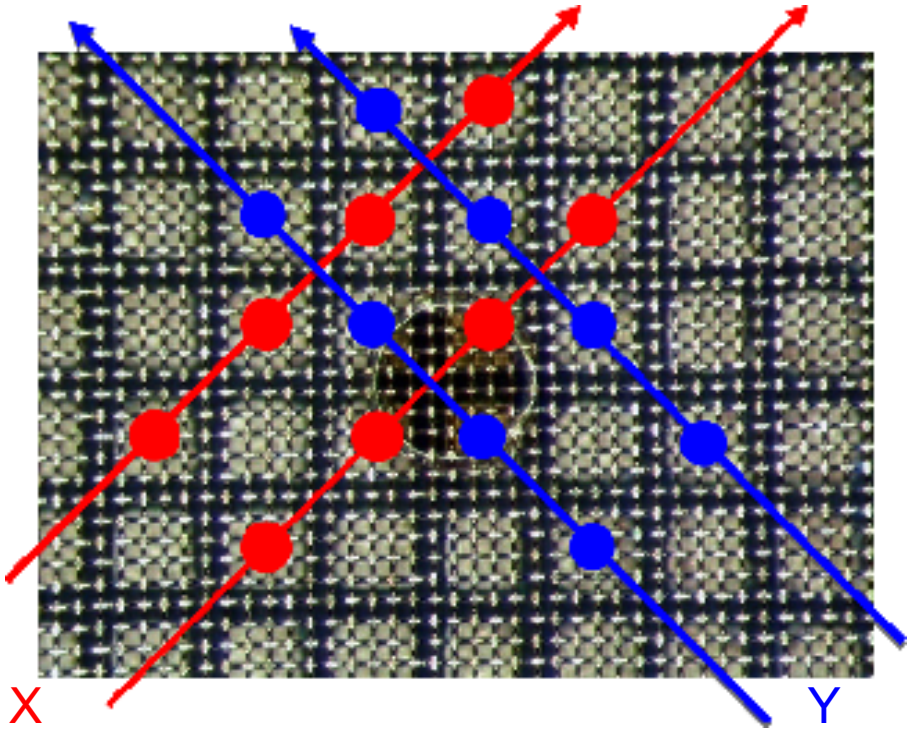
J-P. Mols et al.
October 2009

MIMAC-CYGNUS
(to have 50 evts in 3 years …)

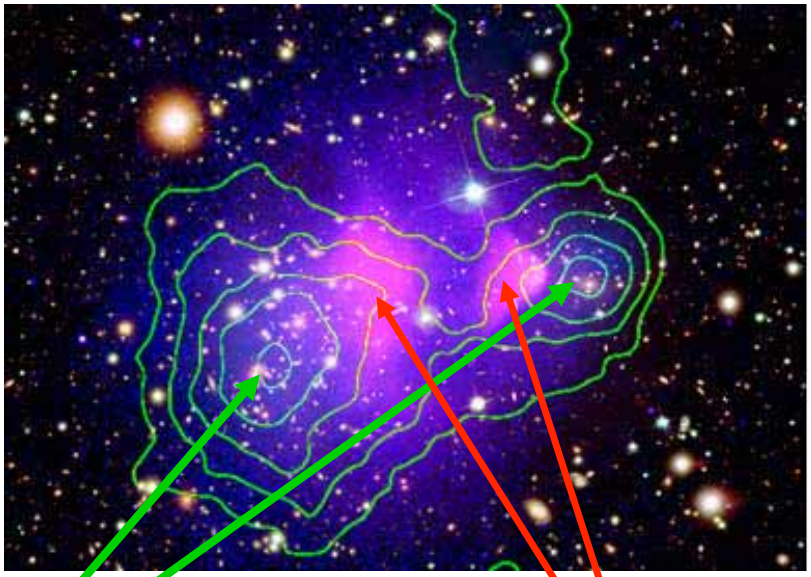
- The number of nuclei in 10 kg of ^{3}He = 3333 N_A
- In CF_4 to have the same number of ^{19}F we need 74 kg
- The axial cross section follows a A^2 dependence (factor 40 wrt ^{3}He)
- We need 50 m^3 of CF_4 at 50mbar
- The tracks of 30 keV ^{19}F are roughly 1mm long at 50mbar.

Possible to have other or alternative target as (^{1}H, ^{3}He, ^{4}He or ^{20}Ne) without change the detector !!

Cablage de l'anode



L’amas du Boulet



Gravite

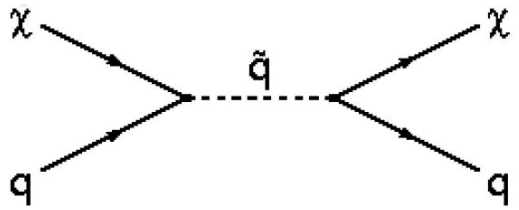
Gaz chauds

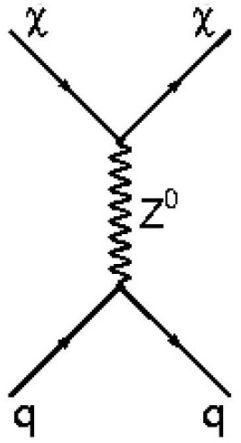
J. Billard

Interaction du neutralino

- **Axiale**

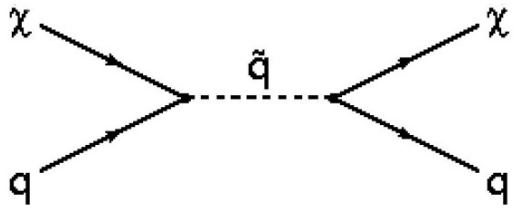
$$\sigma_{SD}(^{A}X) \alpha \sigma_{SD}(p) \times A^2$$

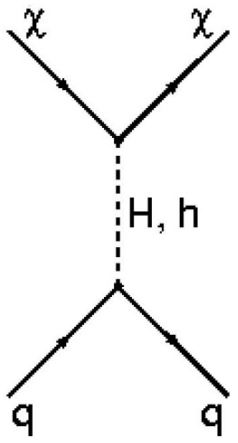




- **Scalaire**

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



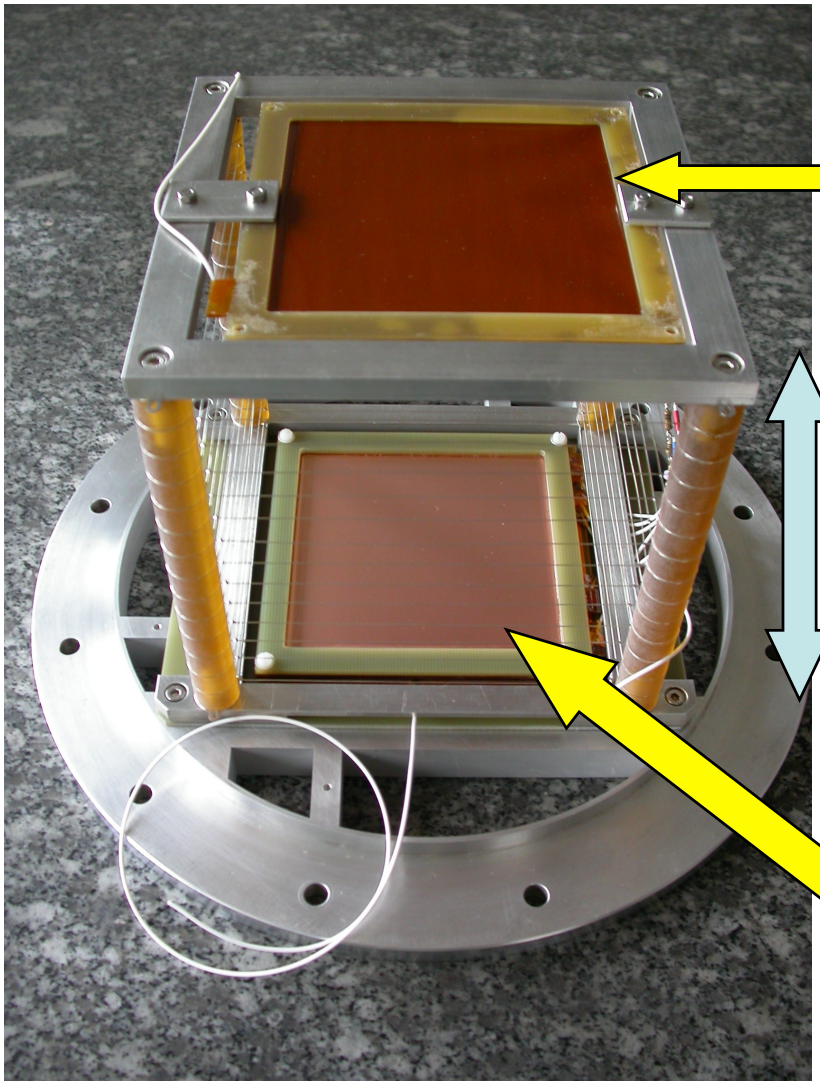


Pour ^{3}He et ^{19}F : $\sigma_{SD} \gg \sigma_{SI}$

Provisional Timetable

- The ANR-MIMAC project has to show the elementary module of the 3D-Matrix working by the end of 2010.
- The CYGNUS design study has as the main purpose to define the 1 m3 by the end of 2012.
- These milestones will give us the design of the 50 m3 detector by 2013.
- The electronic chip necessary to read-out the pixel-anode will be defined by the end of 2010.
- The modular design will give us the possibility to run intermediate volumes during the mounting of the final detector with previous defined phases of extensions.
- The construction of the detector can be done relatively fast having no blocking problems in the design as it has been shown thanks to the ANR-Blanc Project that allow the Saclay and the Grenoble teams work together to define the elementary chamber.

MIMAC : µTPC chamber



cathod

Drift space : 15 cm

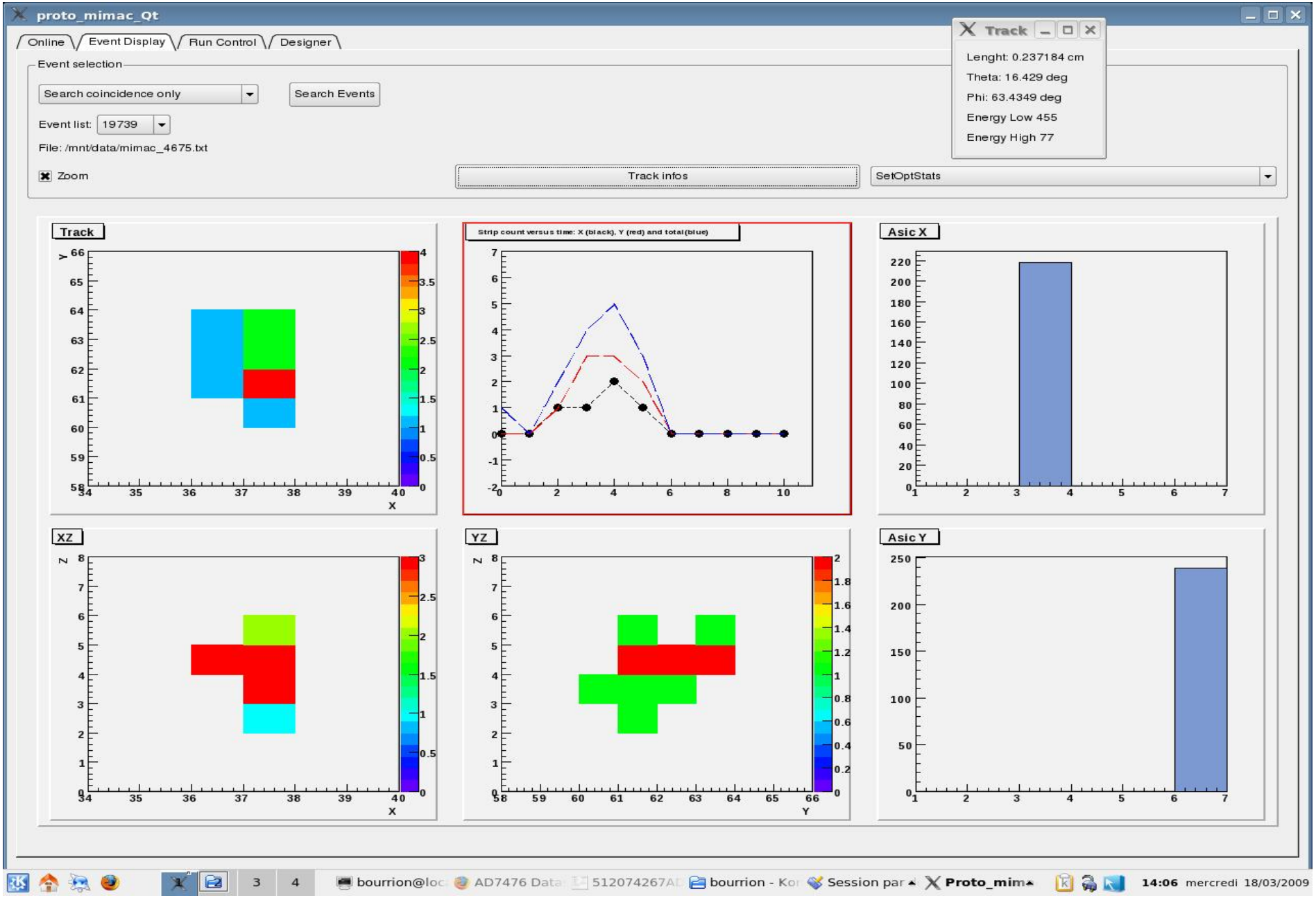
Micromegas

+pixellized anod (x,y)

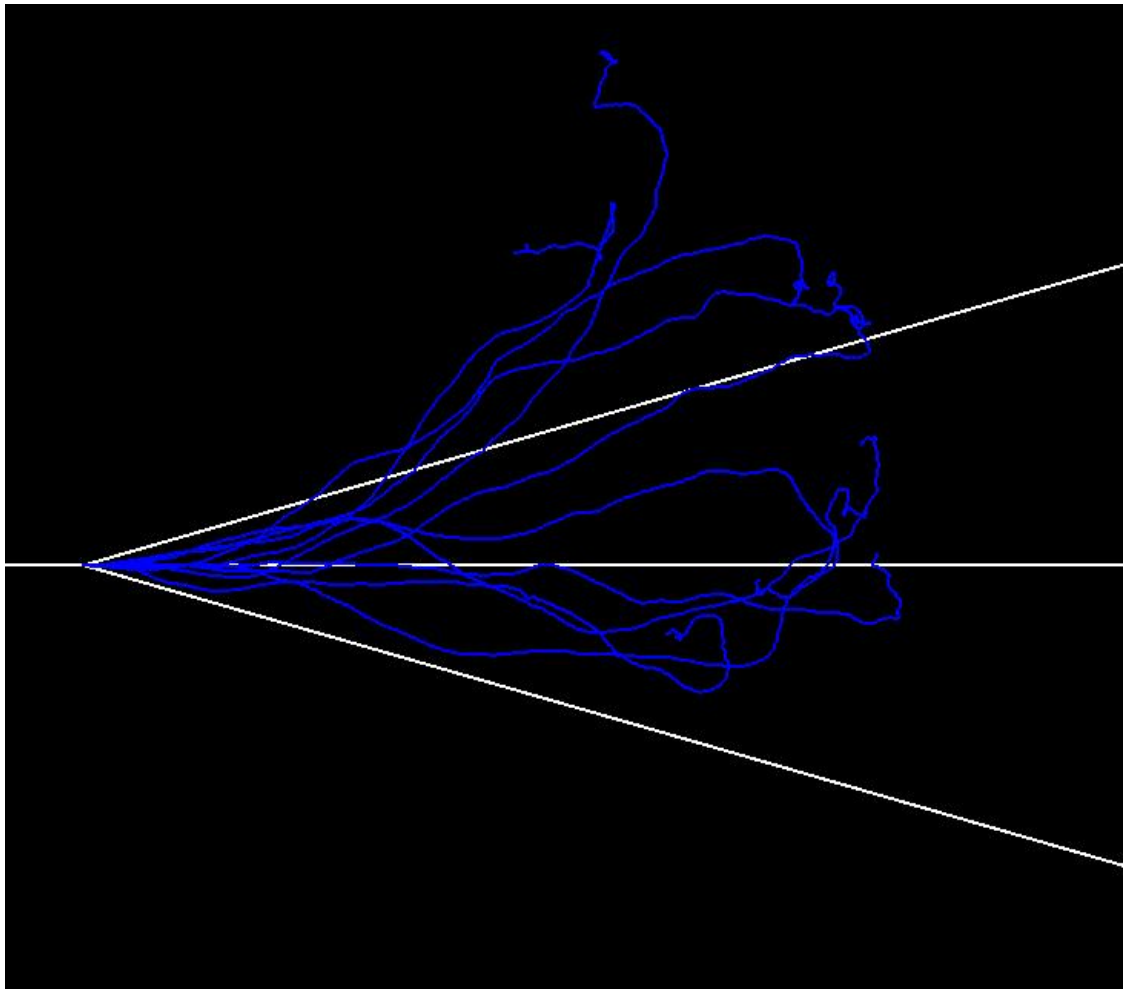
Real size prototype

3D track measurement of an electron (5.9 keV, 350mbar)

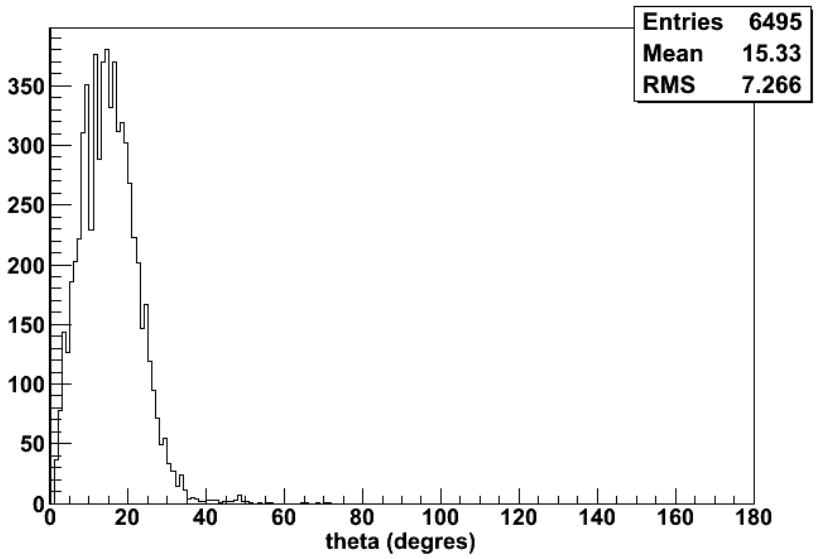
3D track measurement of an electron of 1.5 keV (X(Al))

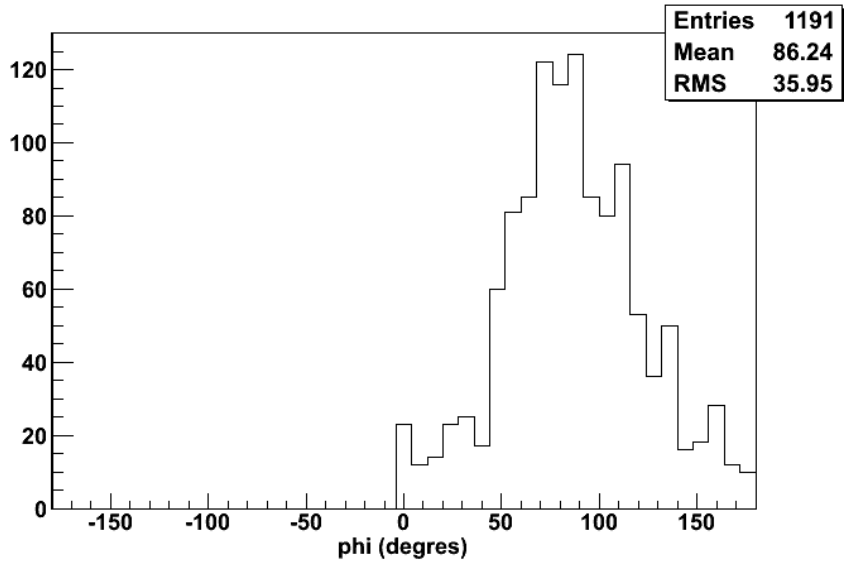


^{4}He (6 keV) in ^{4}He (100mbar)
range ~ 4mm



Directionality of recoils measured in 3D (E ~ 120 keV)





CYGNUS (CosmoloGY with NUclear recoilS)
A large Scale Directional Dark Matter Detector

List of Participants for the ASPERA call (June2009) (alphabetic order) [partner's number]

France
CNRS/IN2P3/UJF/Laboratoire de Physique Subatomique et de Cosmologie de Grenoble (LPSC) [1]
CEA/Saclay/Institut sur les Lois Fondamentales de l'Univers (IRFU) [5]

Germany
University of Technology Darmstadt [4]

Spain
University of Zaragoza [3]

United Kingdom
University of Sheffield [2]
University of Edinbourgh [6]