A prototype of a directional detector for non-baryonic dark matter search: MIMAC (Micro-TPC Matrix of Chambers)

Cyril Grignon

LPSC Grenoble
Université Joseph Fourier - CNRS/IN2P3

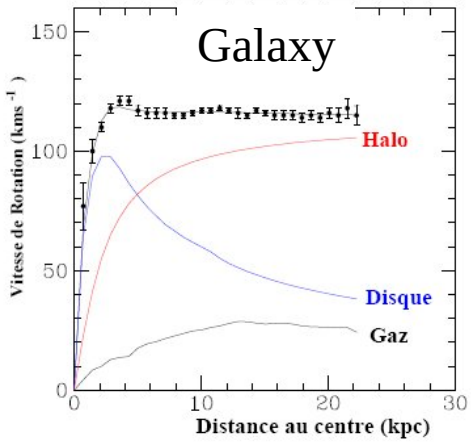
MPGD 2009, 12-15 June 2009, Kolympari

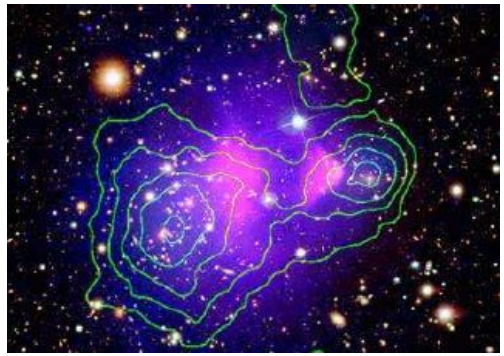
Outline

- Dark matter and Directional detection
- The MIMAC project and the µTPC
- Measurement of the Energy
- The pixellized micromegas and the MIMAC electronic
- Reconstruction of the Track in 3D

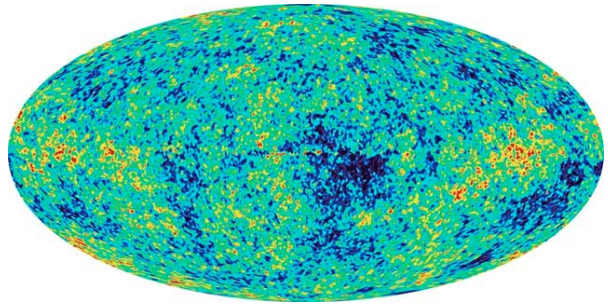
Dark Matter

Dark Matter is present at all scales in the universe …





clusters



CMB

Density of the universe:
74.2 % : dark energy
4.4 % : baryonic matter
21.4 % : dark matter

Natural candidate arise from SUSY: neutralino

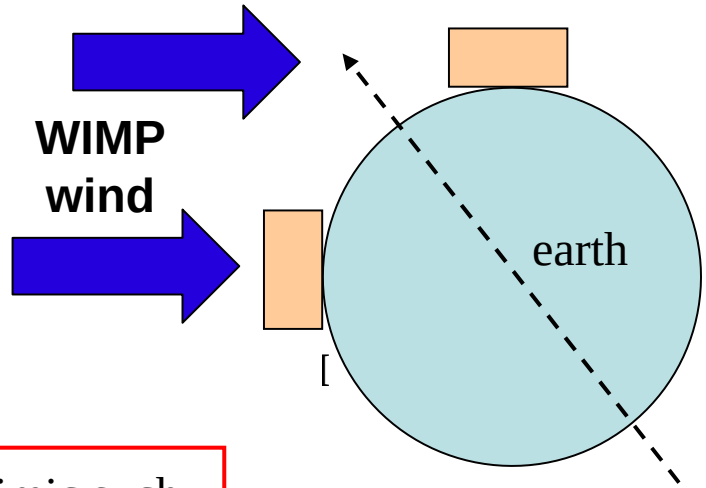
Direct detection through the scattering on a nuclei: 10-50 keV nuclear recoil

Main challenge: separate WIMP signal from background radioactivity (α,β,γ,μ,n ..)

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.

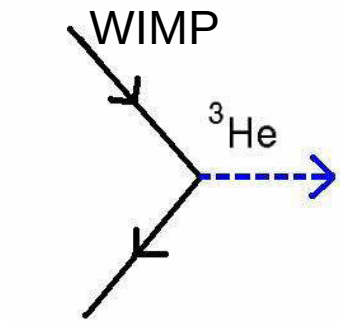


WIMPs events should point towards Cygnus constellation

Background can not mimic such genuine events

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

use gaseous detector

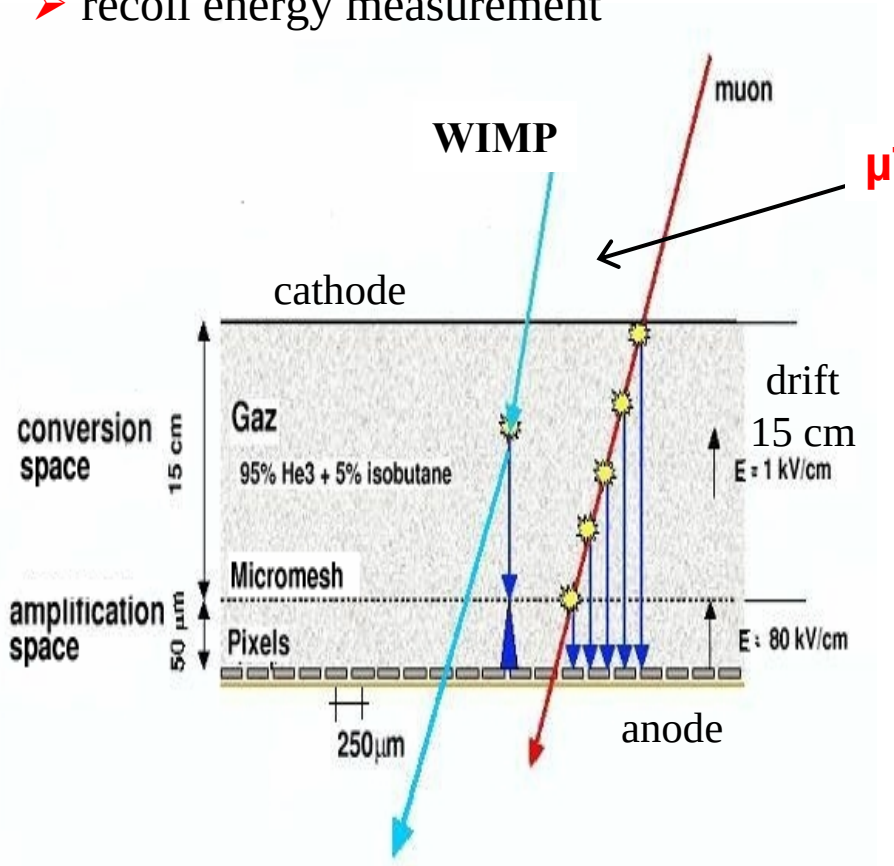


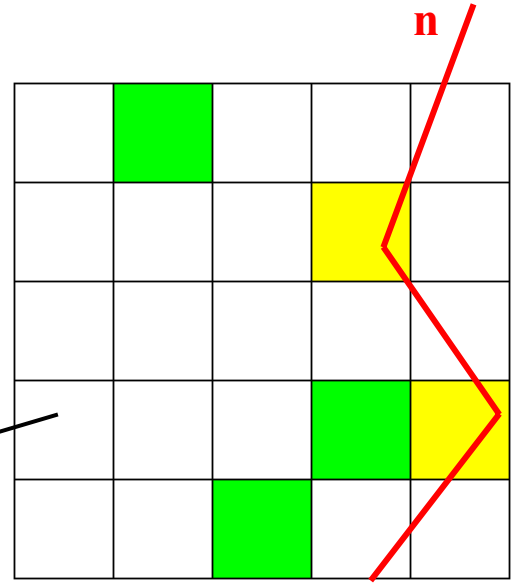
Need to measure (E,L, Θ, ϕ)

Ex: **MIMAC**, DRIFT, DM-TPC …

MIMAC

Strategy:
- direct detection of nuclei recoil
- 3D track reconstruction
- recoil energy measurement



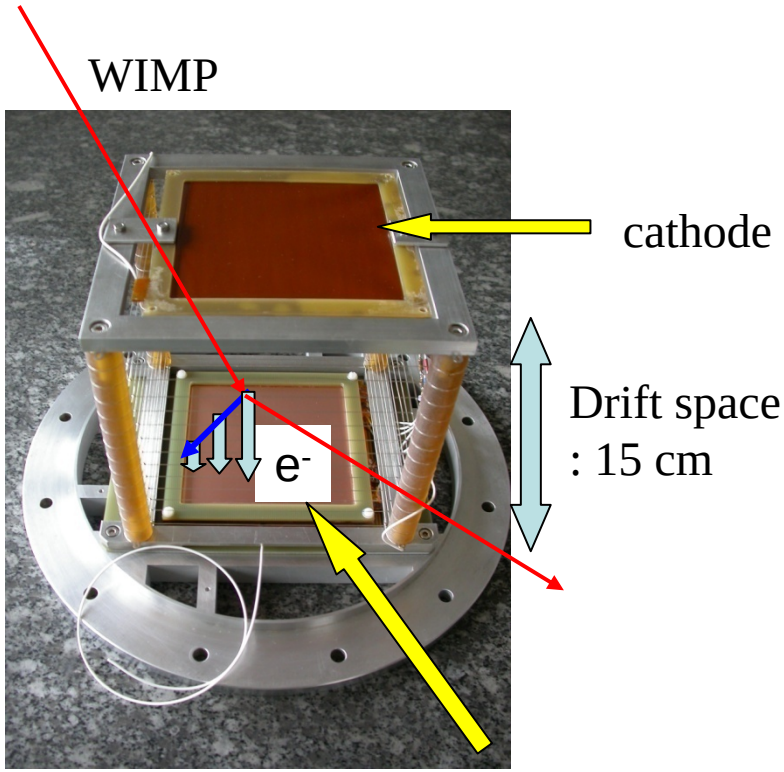


Principle:
- matrix of gaseous µTPC
- low mass, targets at low pressure :
  ^3He, CH_4,C_4H_{10},CF_4 : few mm tracks
- low energy recoil :10 keV

Background rejections based on:
- energy and track : e-/nuclei
- correlation of µTPC (neutrons)
- direction

Have to precisely measure recoil Energy and to reconstruct the 3D track of the nuclei

The micromegas µTPC prototype



Bulk micromegas with pixellized anode (x,y): 3 cm x 3 cm

The micromegas offers:

High { energy, time, spatial } resolution

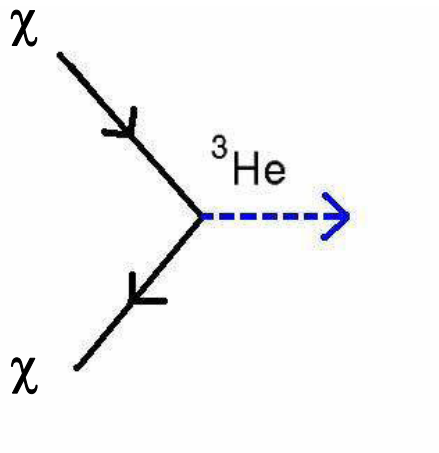
- Recoil track reconstruction
- Energy threshold 1 keV
- Electron/nuclei discrimination

Collaboration : CEA Saclay

Measured Energy ≠ E_{recoil}

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

Energy measurement : Quenching factor



Recoil energy is shared among :

- Scintillation
- Heat
- **ionization**

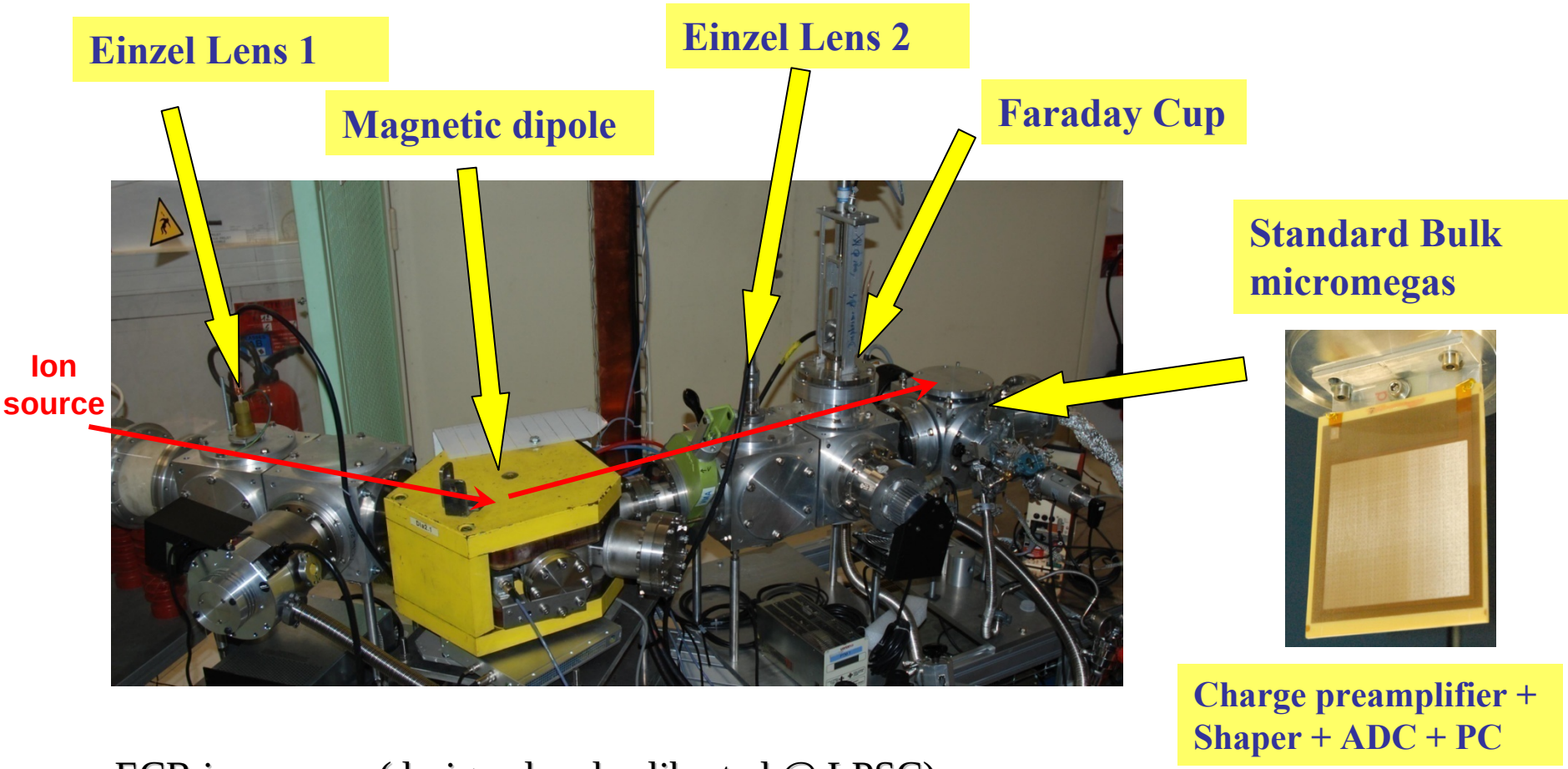
Ionization Quenching factor defined as $$Q = \frac{E_{ionization}}{E_{recoil}}$$

- Helium Quenching factor is predicted by Lindhard theory

… but need to be measured for mixtures !

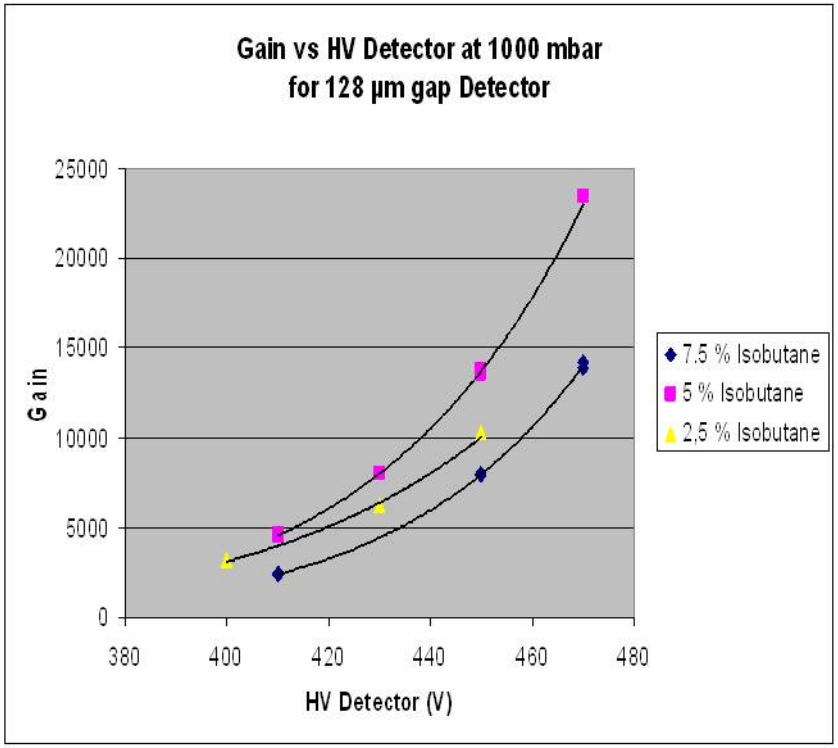
- Key point for Dark Matter to compute recoil energy

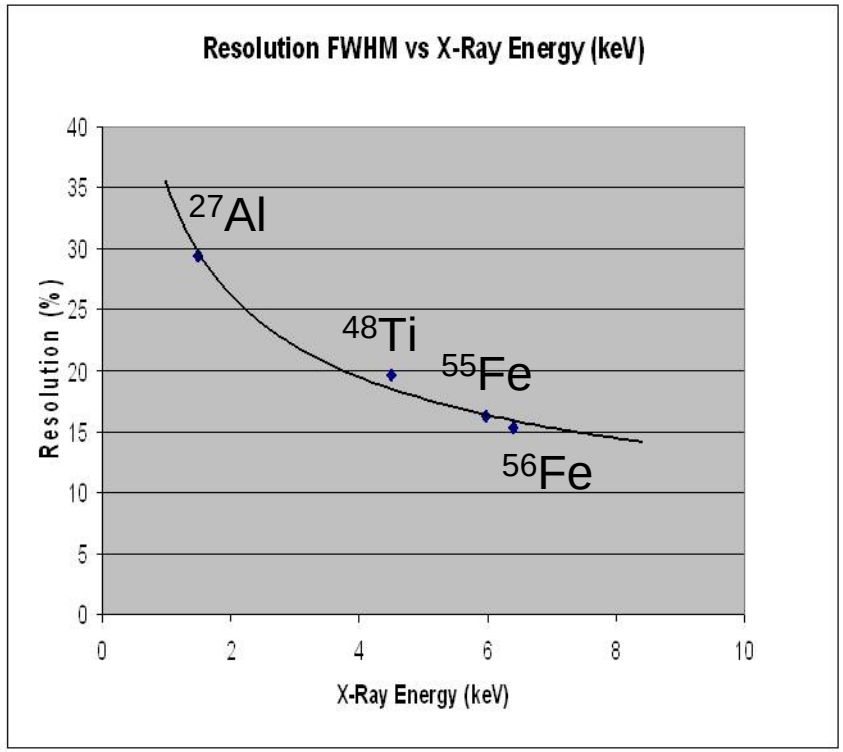
QF measurement : experimental set-up



ECR ion source (designed and calibrated @ LPSC)
Low energy ion source **1 to 50 keV**
Possibility to produce p, ^{3}He, ^{4}He, ^{19}F
Bulk calibrated with radioactive sources or fluorescence

Micromegas gain and energy resolution





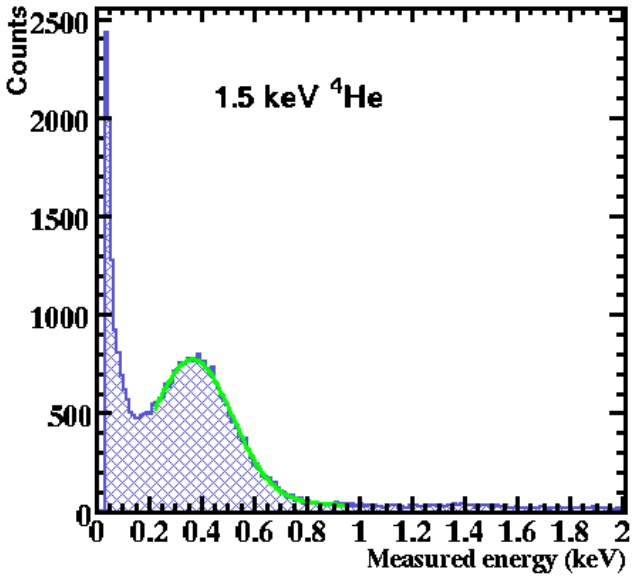
Enough gain for given electronic threshold

Typical working gain : 10 000

Resolution of 15.3 % @ 6.4 keV

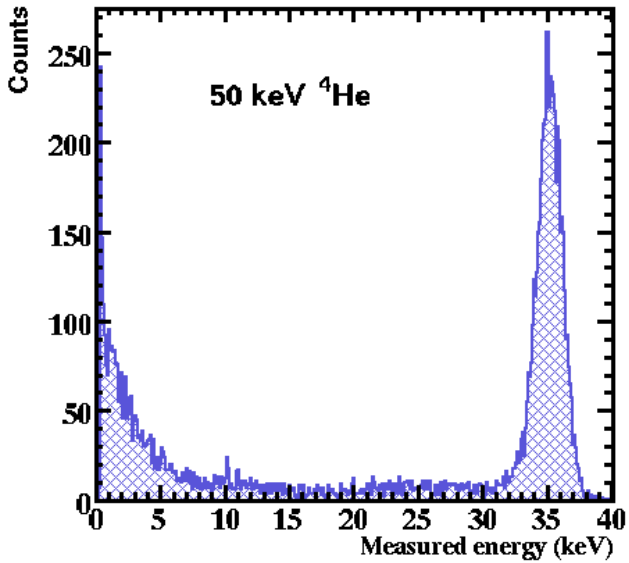
QF measurement : low energy ions

1,5 keV ^{4}He



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

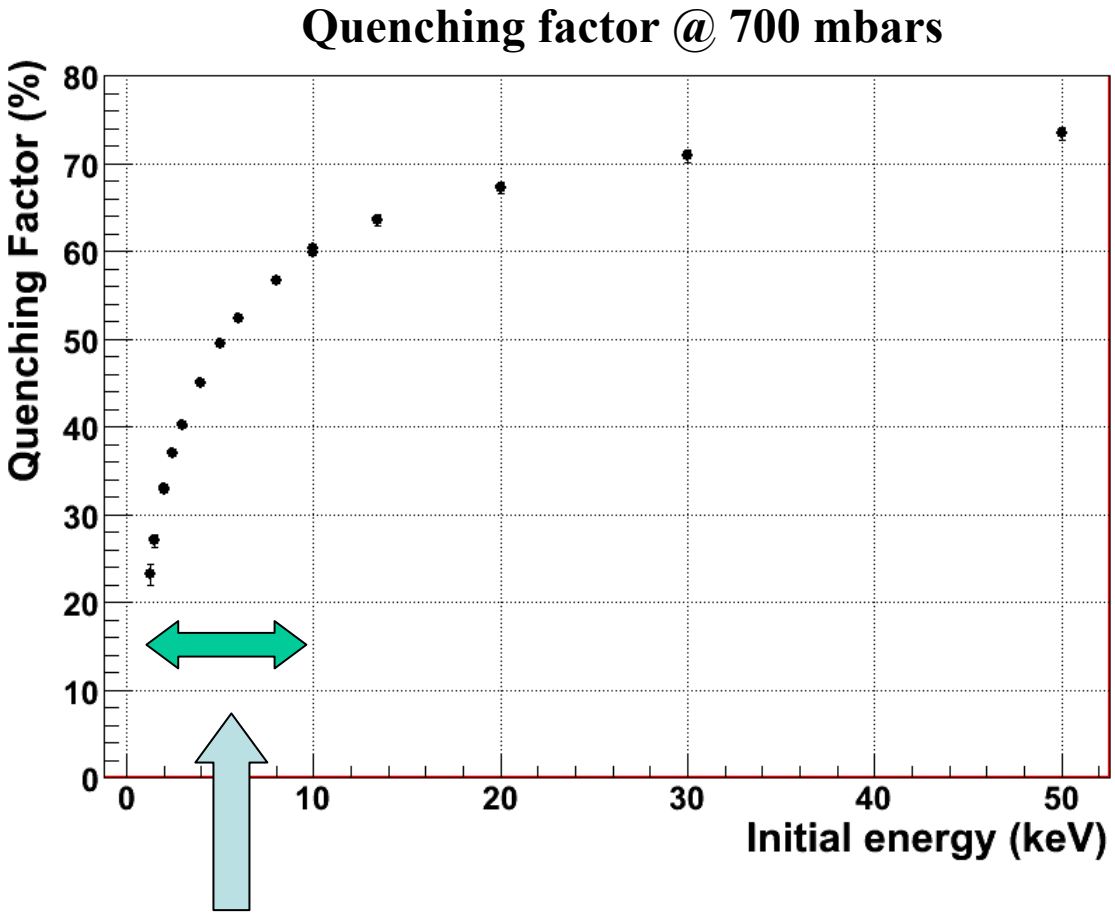
50 keV ^{4}He



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

^{4}He from 1 keV to 50 keV

QF measurement : results



Range of interest for Dark Matter

Measurement of ^{4}He

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

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

D. Santos et al. 2008, arXiv:0810.1137

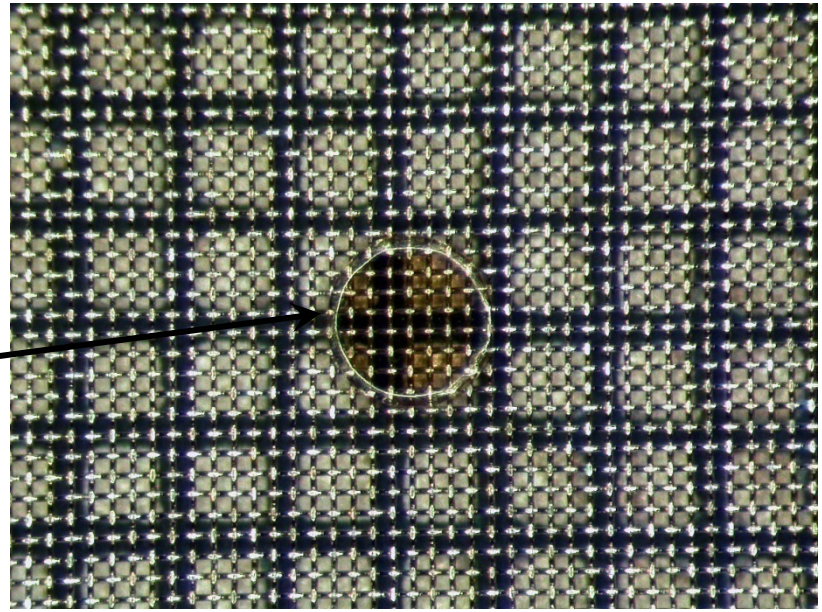
Access to E_{recoil} of the nuclei

Pixellized Micromegas prototype 3 x 3 cm^2

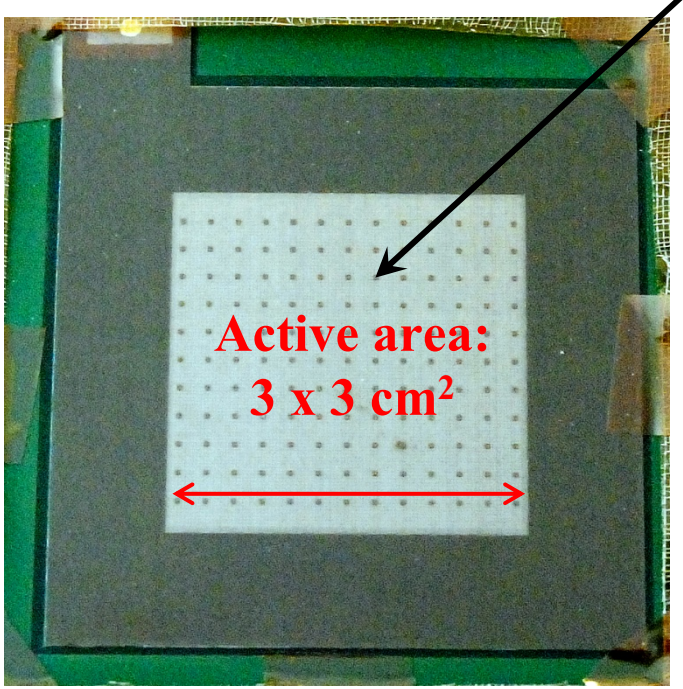
Weaved micro-mesh in steel

325 LPI, 25 µm thick

128 µm amplification gap



Pillar



96 strips for X and 96 strips for Y

2D readout (X and Y) 400 µm pitch

~ 400 µm spatial resolution in X and Y

And the 3D ??

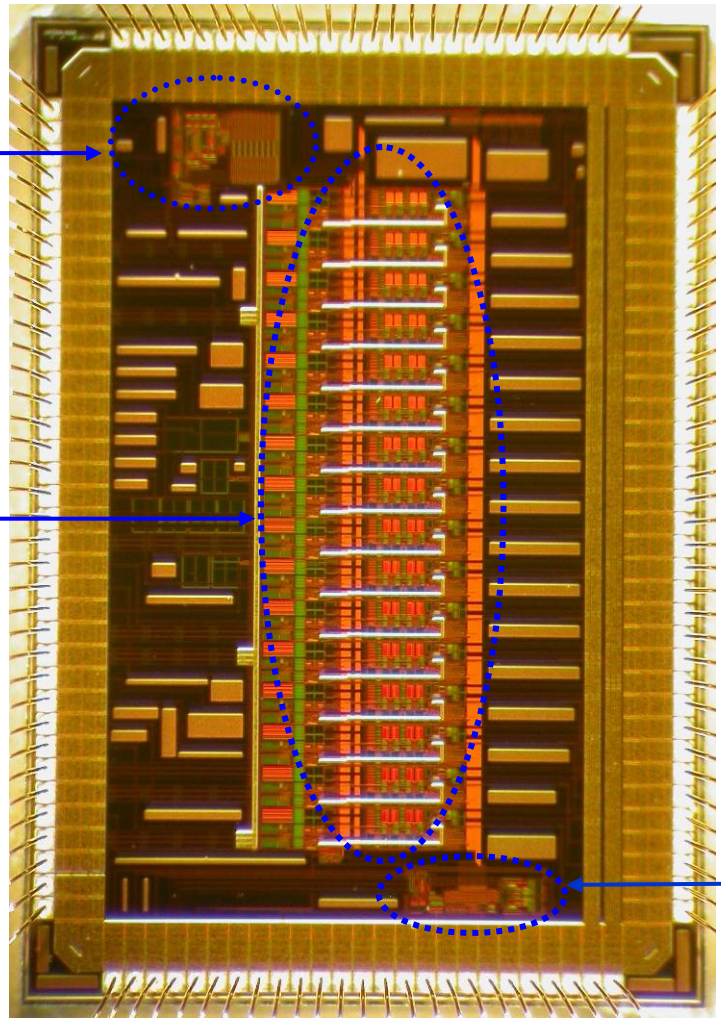
MIMAC Chip designed at LPSC

Self-triggered electronic for Anode sampling @ 40 MHz

Mixer & shaper
→ Energy

16 anode « pixel » channels

Charge sensitive preamplifiers
+
Current comparators
+
5 bit DACs



Austriamicrosystems
BiCMOS-SiGe 0.35 µm

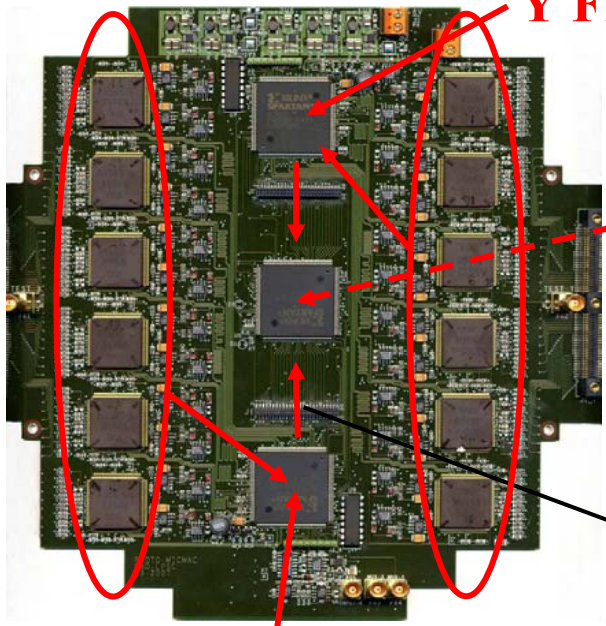
3250µm x 4700µm
[area ~ 15 mm^2]

Serializer (Position)

First version running, next version under design (64 channels ASIC)

Electronic board and DAQ

The **X and Y-FPGA** process, concentrate and time sort data for each side



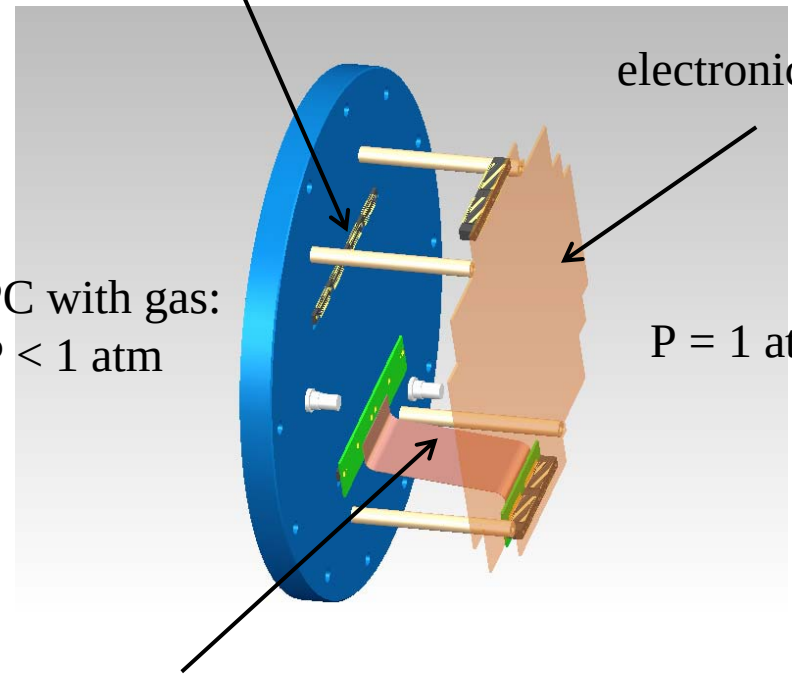
Central FPGA performs the same between X and Y

The **acquisition station** extracts the data event by event and store them on disk

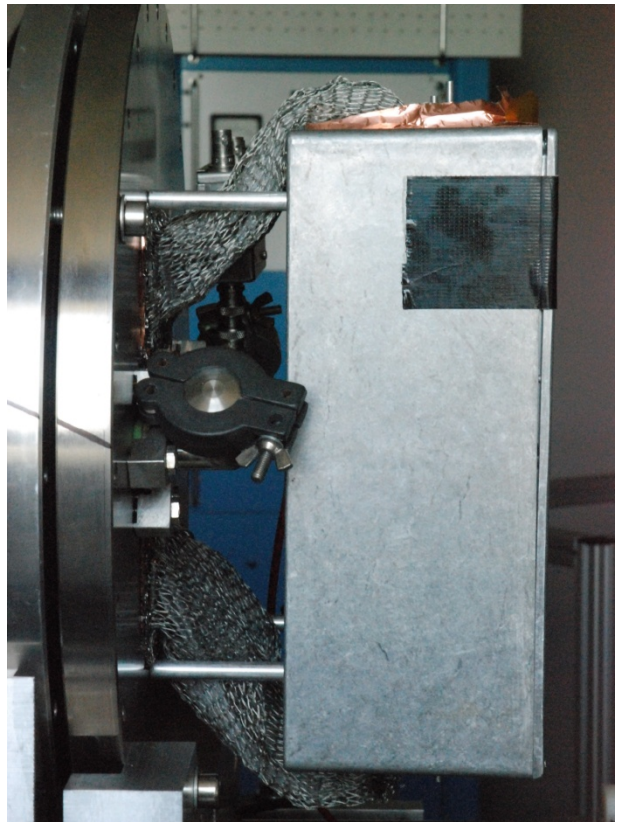
Ethernet microcontroller forwards the data via a TCP socket server to the acquisition station

Electronic board outside the gas vessel

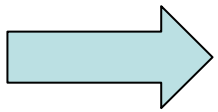
High density seal connector (CEA patent)



electromagnetic shielding for electronic board

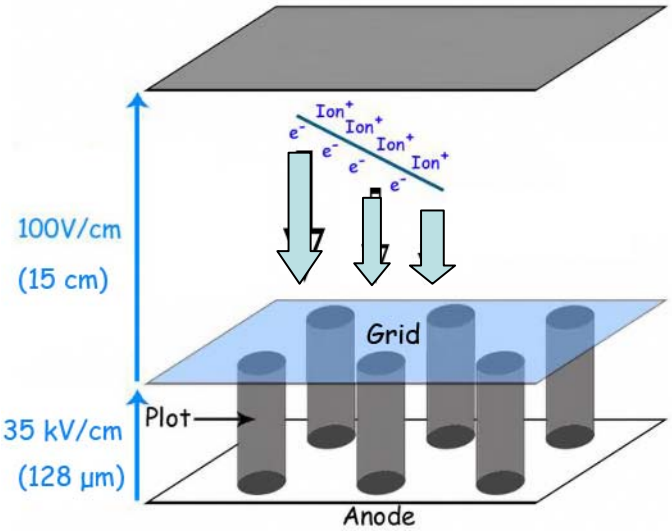


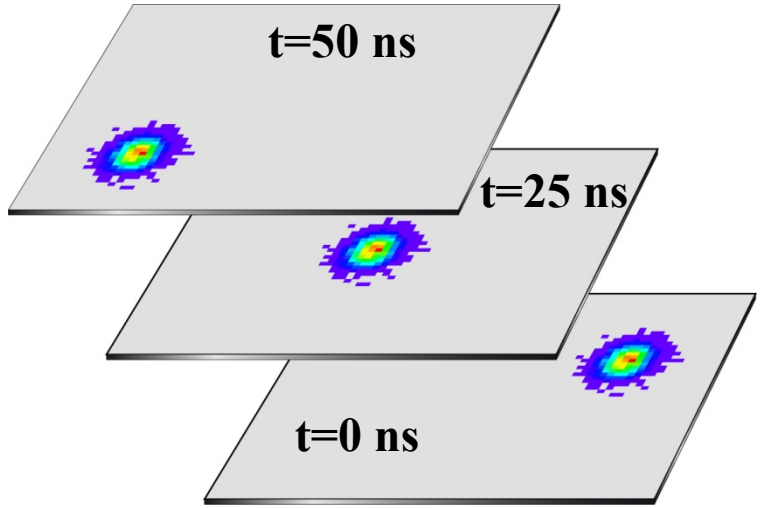
From CAD view …



… to reality

3D Track reconstruction





Complete electronic system (ASIC+FPGA+DAQ)

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

FPGA: On-board processing

Each 25 ns scan of the (x,y) anode

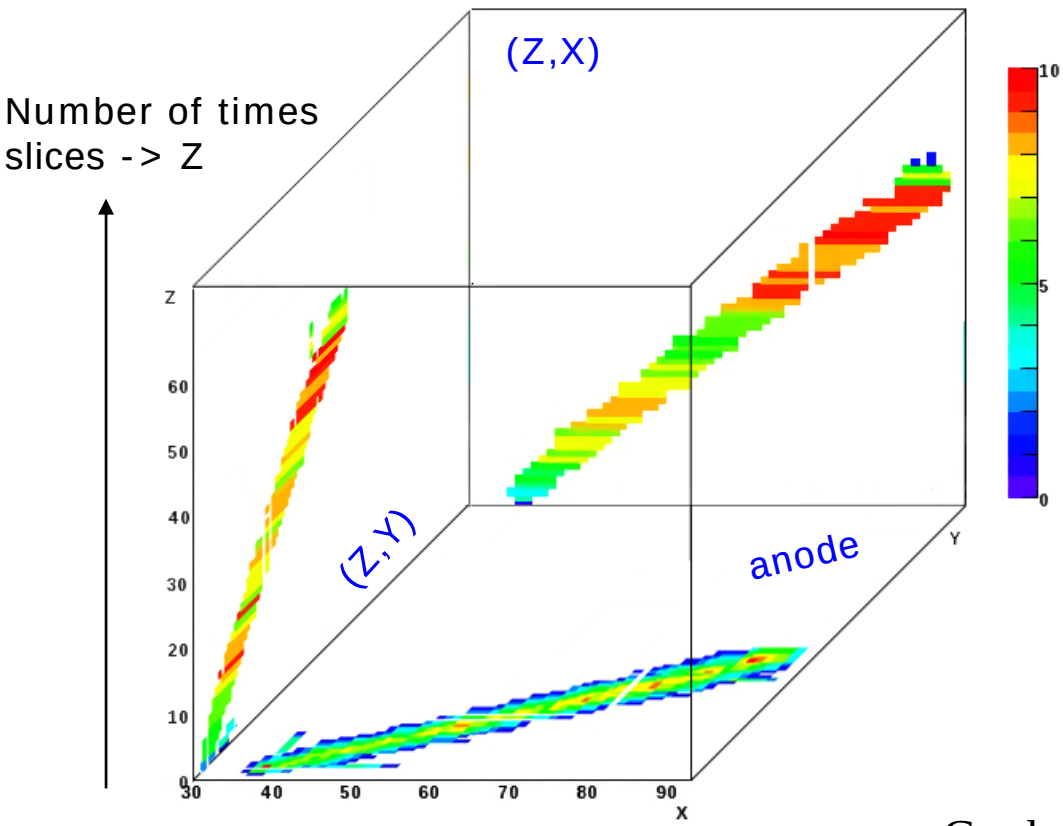
Number of images * Drift velocity + 2D projection

3D Track reconstruction:

L, θ and ϕ

3D Track : 5.5 MeV α from ^{222}Rn

DATA



With the
3D reconstruction

Track 354

ϕ = 59.2 deg

Θ = 35.5 deg

L = 4.99 cm

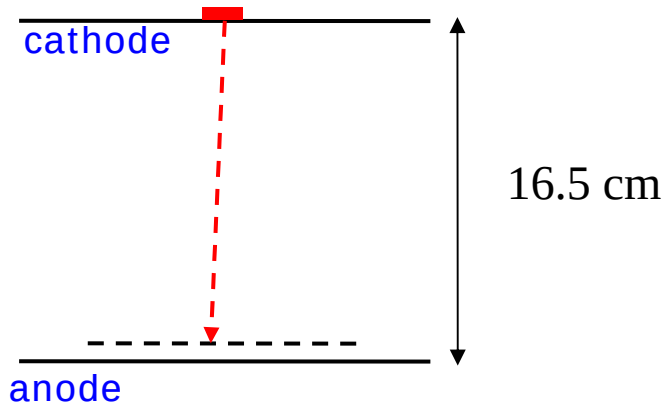
Go through the detection volume

Only a part of the total alpha track

Measurement of electron drift velocity

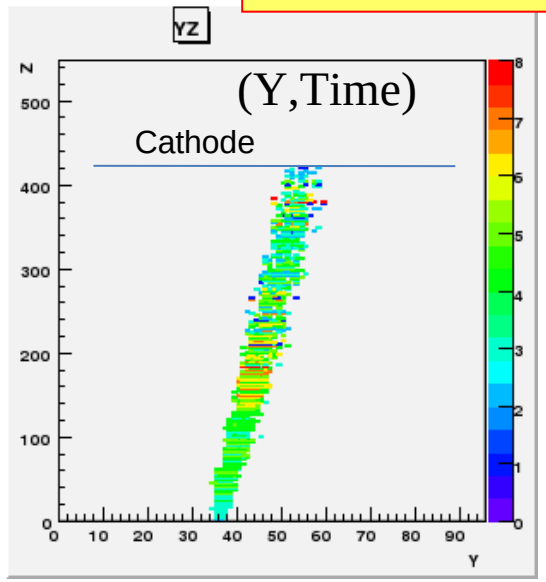
DATA

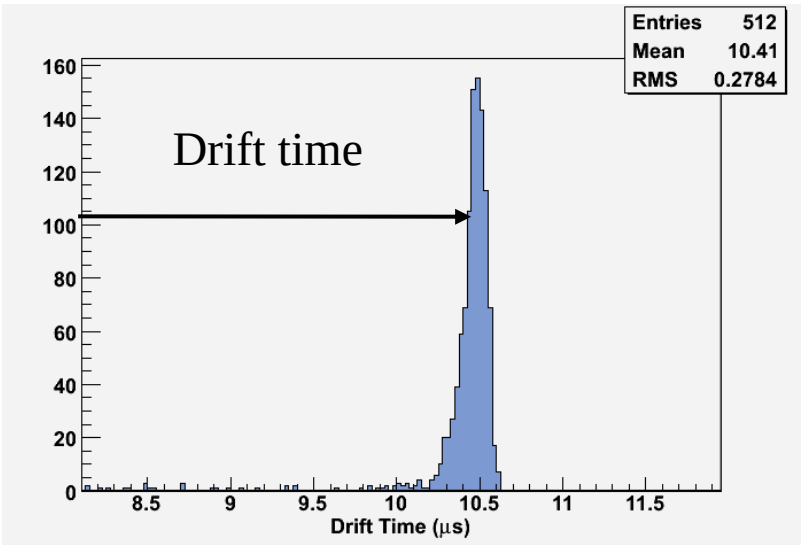
α source ^{241}Am + collimator (A ~ 1 Bq)

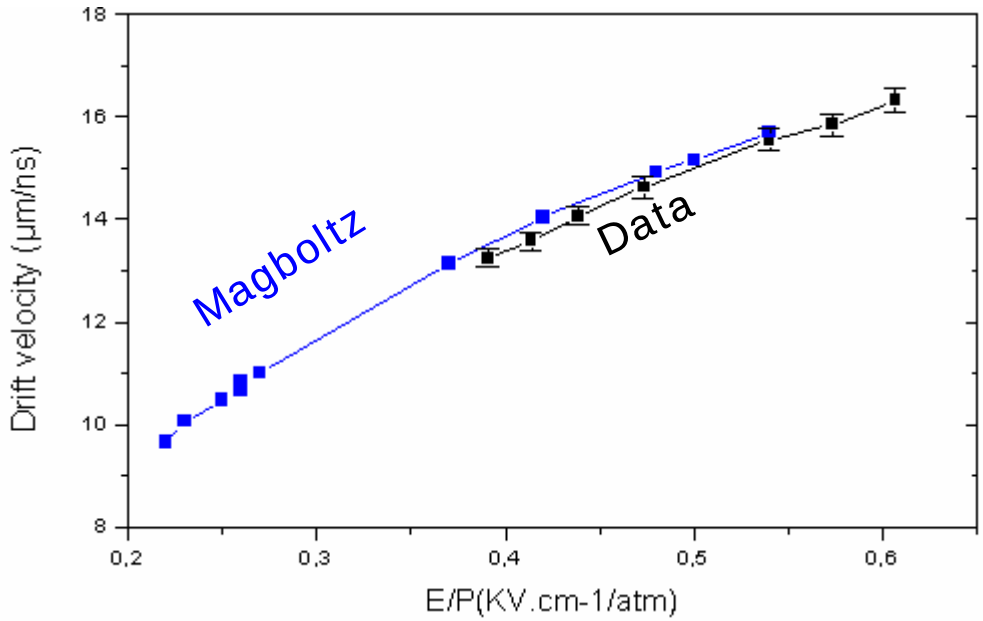


Drift Time

(~10 µs)

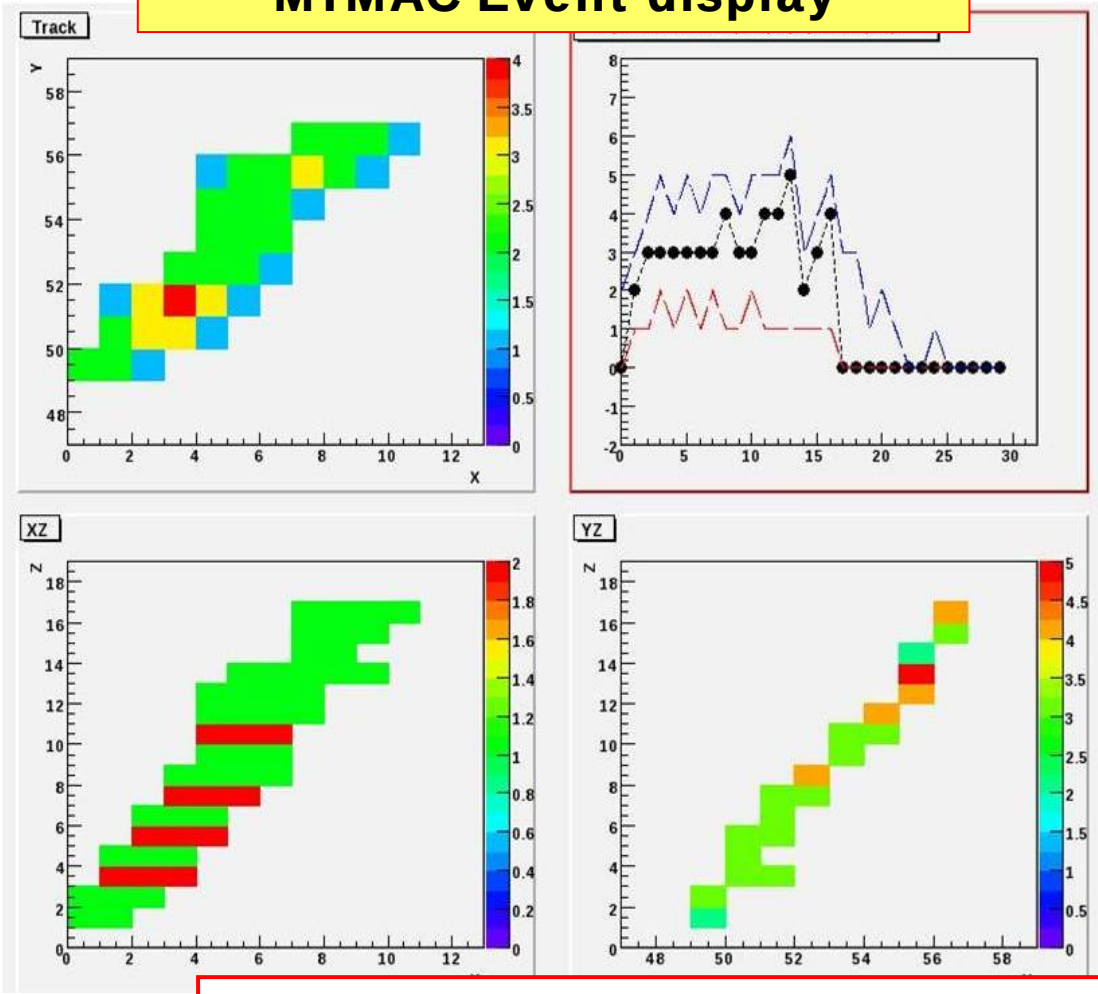






3D Track : 5.9 keV electron from ^{55}Fe

MIMAC Event display



$^{4}He+5\%$ Iso
E=200 V/cm
P=350 mbar
v = 16 µm/ns

DATA

With the
3D reconstruction

Track 45

ϕ = 41.6 deg

Θ = 34.2 deg

L = 7.5 mm

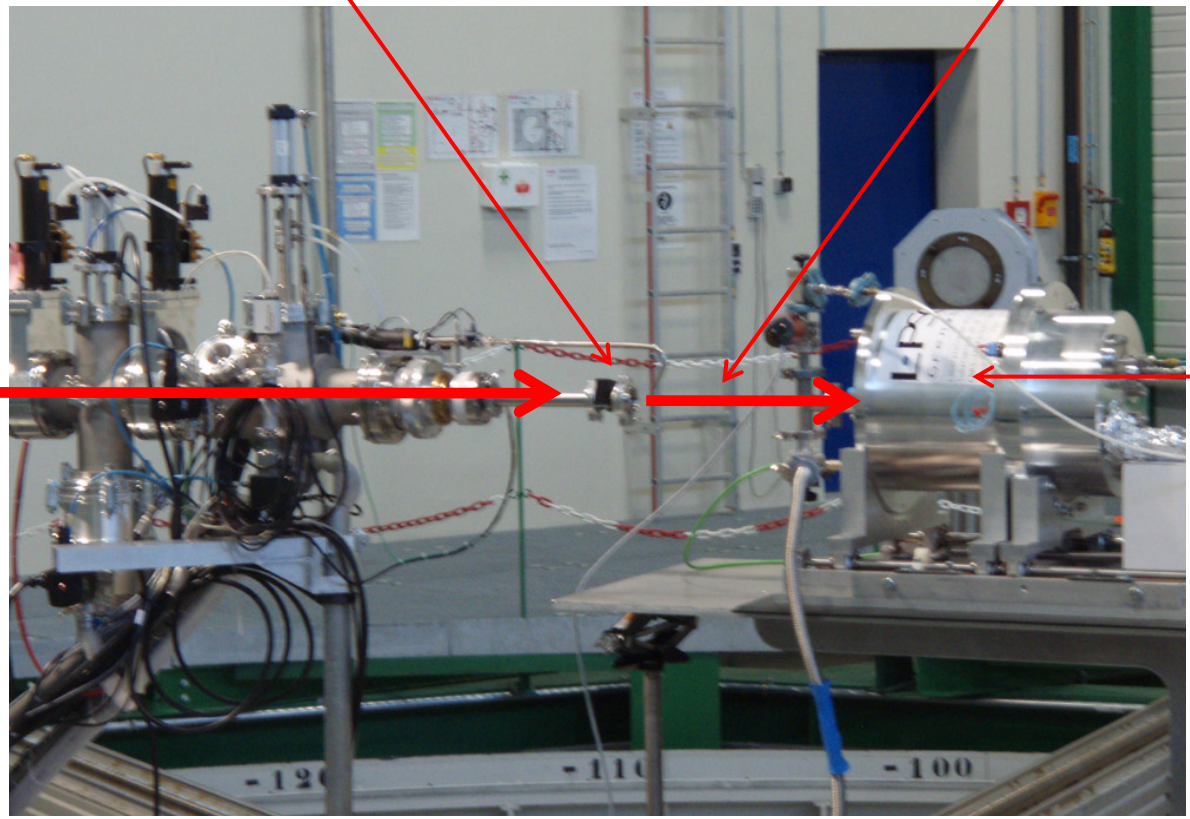
First 3D track of ~6 keV electron !!
… typical of a background event for Dark Matter

Amande neutron source : IRSN facility @ Cadarache

Target:
Sc for 8.2 keV n
LiOH for 144 keV n

neutron beam

Proton or
deuton beam

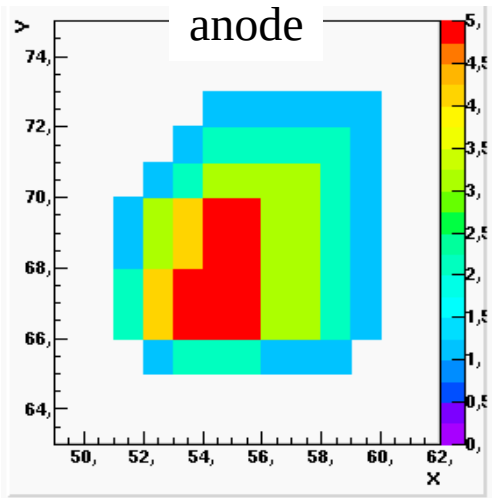


prototype with
pixellized bulk
micromegas

Simple to use

Recoil from 144 keV neutrons

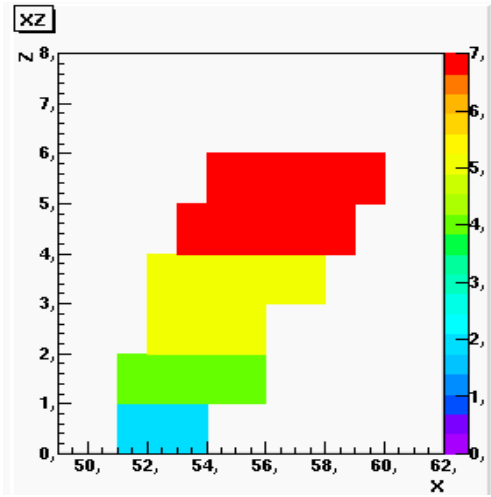
DATA



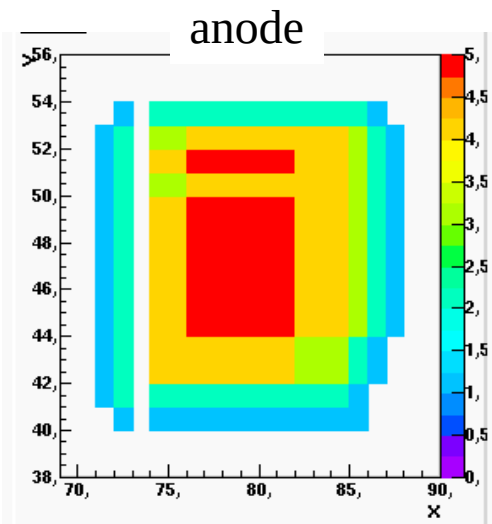
100 % iC_4H_{10}

100 mbar,

150 V/cm



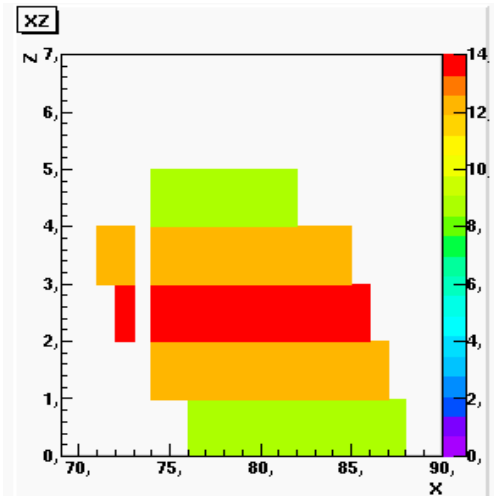
Possible to reconstruct recoils of p @ low pressure in methane and isobutane



100 % CH_4

150 mbar,

120 V/cm



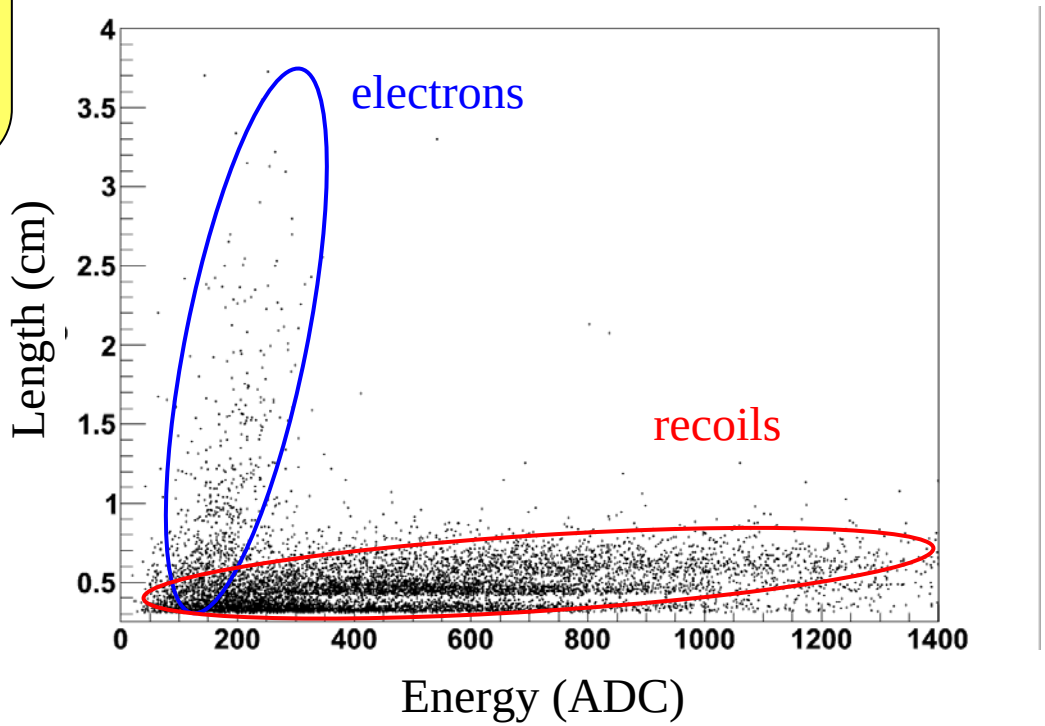
Recoil from 144 keV neutrons

Obtained with pure isobutane

100 mbar

150 V/cm

Preliminary results!



DATA

Muons do not trigger the DAQ ⇒ under electronic threshold

Separate background from recoils

MIMAC: conclusions and outlooks

- Precise measurement of the energy recoil in He down to 1 keV
- Development of a dedicated ASIC to reconstruct a 3D track of a recoil
- Alpha tracks used to measure drift velocity
- First tracks of a 5.9 keV electron at low pressure
- Reconstruction of 144 keV recoils

Discrimination recoil / electrons possible

Next Steps

- Bulk micromegas with a higher gap (256 µm) for low pressure (< 300 mbar)
- New ASIC in October 2009
- New pixellized micromegas (10 x 10 cm^2) end of 2009
- 4 modules (20 x 20 cm^2) at the end of 2010

Long term: dark matter astronomy

The MIMAC collaboration

LPSC (Grenoble) :

G. Bernard, J. Billard, C. Grignon, C. Koumeir, F. Mayet, D. Santos

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

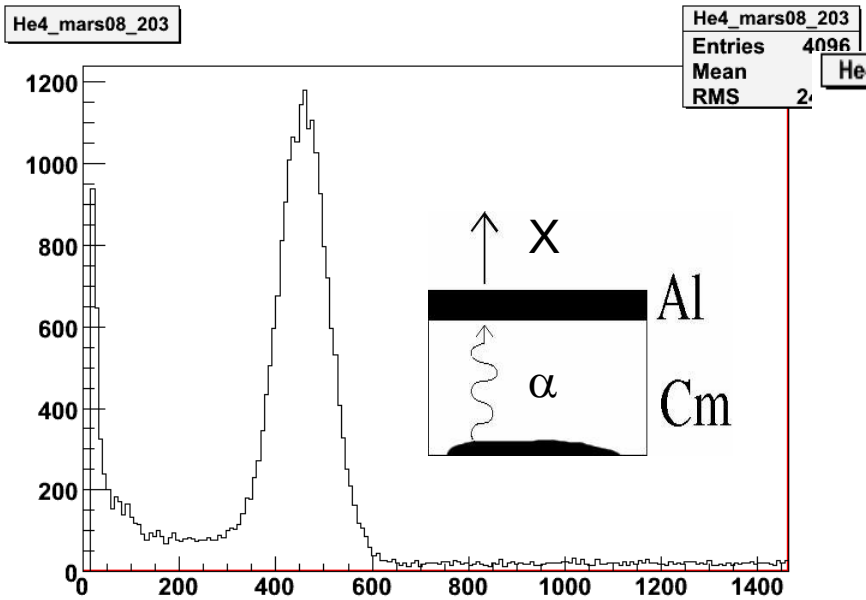
CEA-IRFU (Saclay) : I. Giomataris, P. Colas, E. Ferrer

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

Backup slides

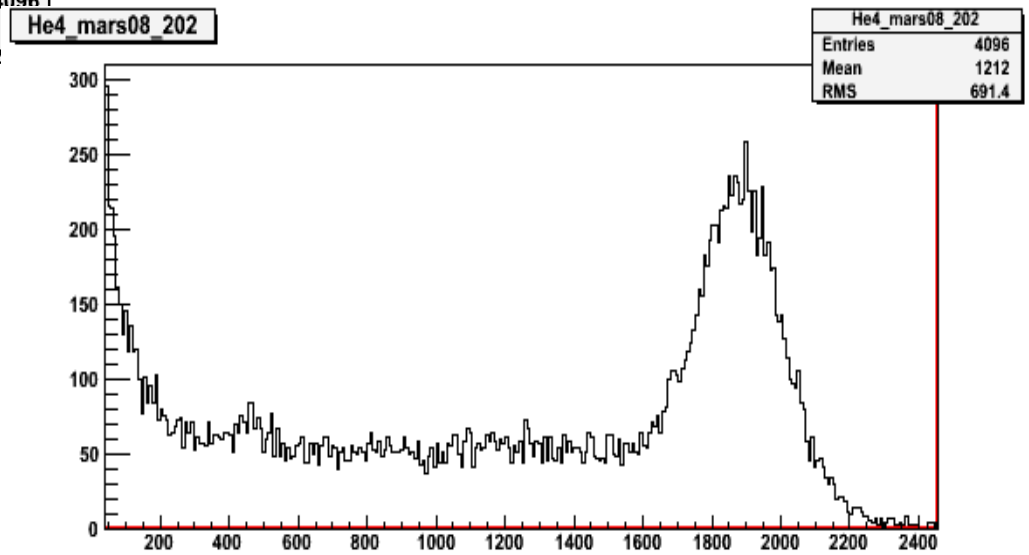
QF measurement : calibration

1,486 keV X ray (Al)



$\sigma / E \approx 14\%$

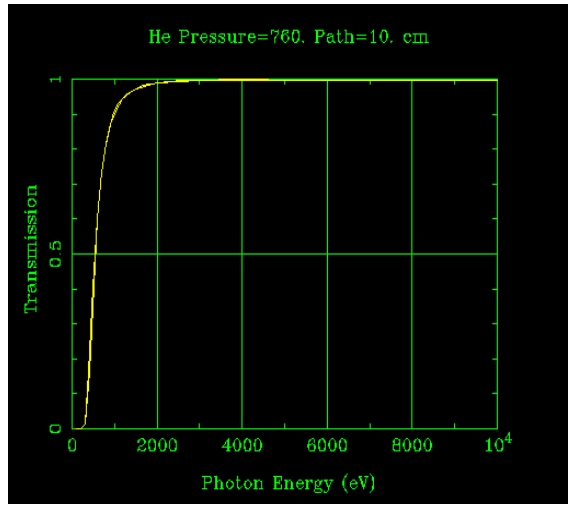
5,97 keV X ray (Fe)

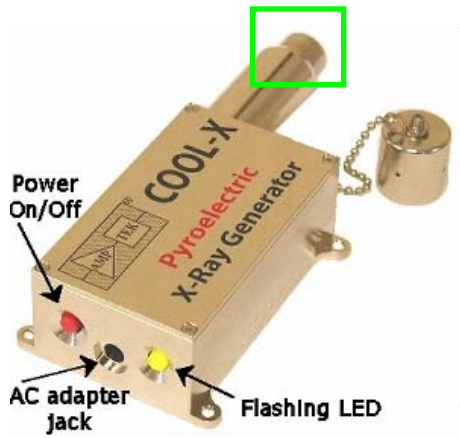


$\sigma / E \approx 5\%$

Calibration with Helium / Isobutane mixture

- Classical radioactive source :
  - 55Fe (5.97 keV)
- Helium transparency for X > 2 keV
  - High flux source (multicell detector!)
- Production of fluorescence X-Rays on different targets with a Miniature X-Ray Generator (inside chamber)
  - Peak X-ray flux equivalent to a 2 mCi source (during few sec)
  - Target and X-ray
    - Al : 1.486 keV
    - Ti : 4.504 keV
    - Fe : 6.4 keV
    - Cu : 8.1 keV

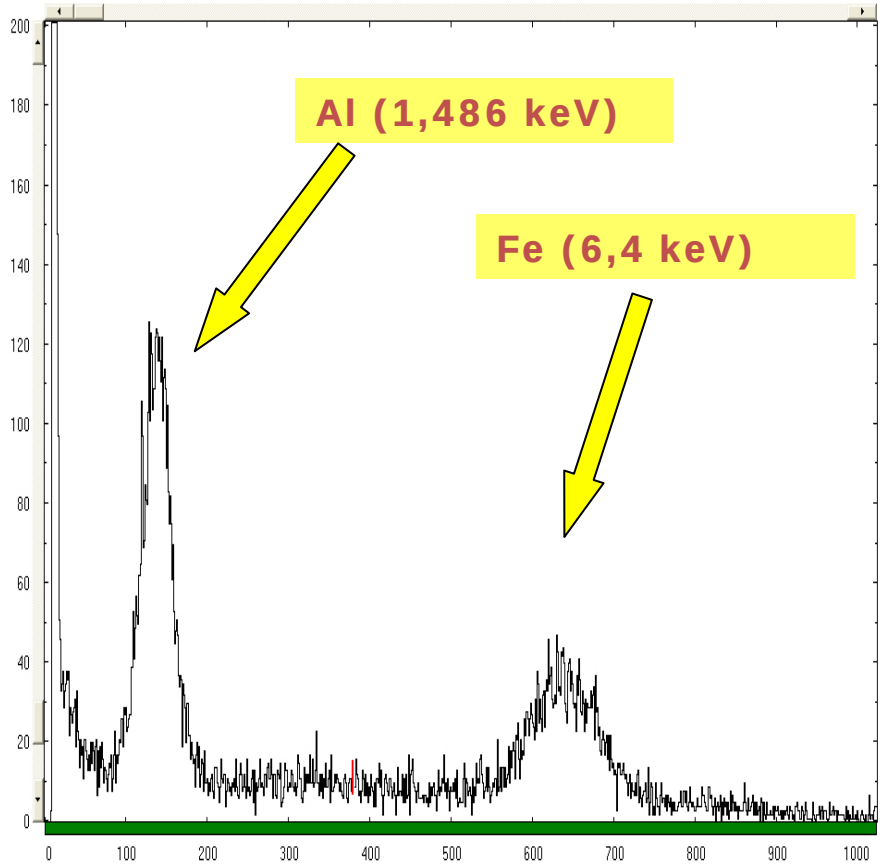




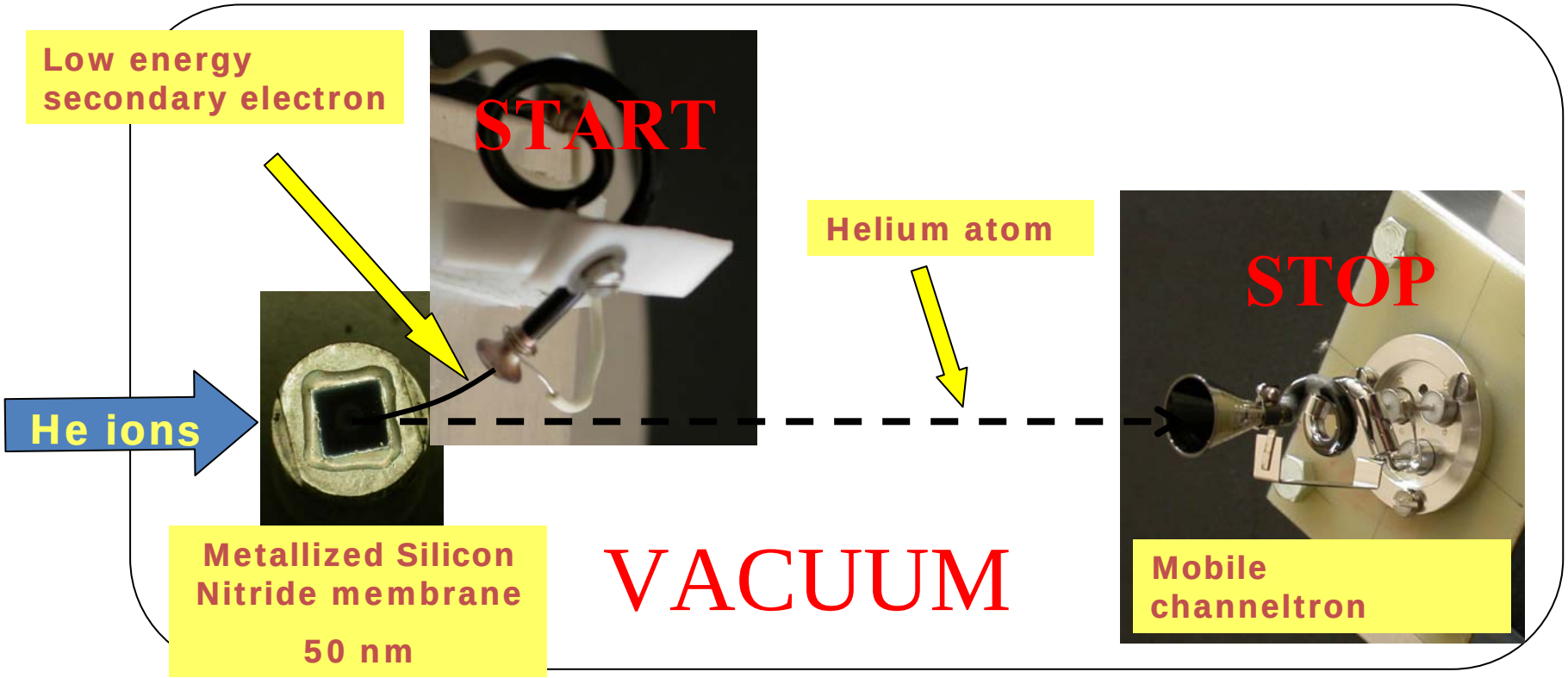
Multi-Target Spectrum

- Target : Aluminium + Iron
- 1000 mbar Helium + 5% Isobutane
- E Drift = 130 V/cm
- HV Detector = 430 V

- Gain = 1,1 10^4
- Energy Resolution FWHM
  - Aluminium 1,486 keV = 29,4 %
  - Iron 6,4 keV = 15,3 %



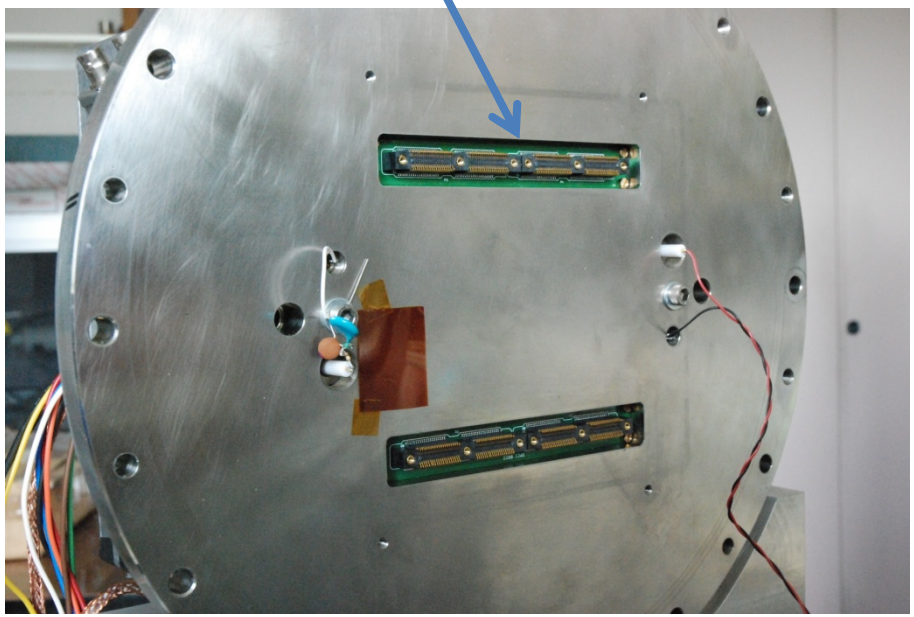
Ion source calibration with Si_3N_4 membrane time of flight under vacuum



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

Connectors and contacts

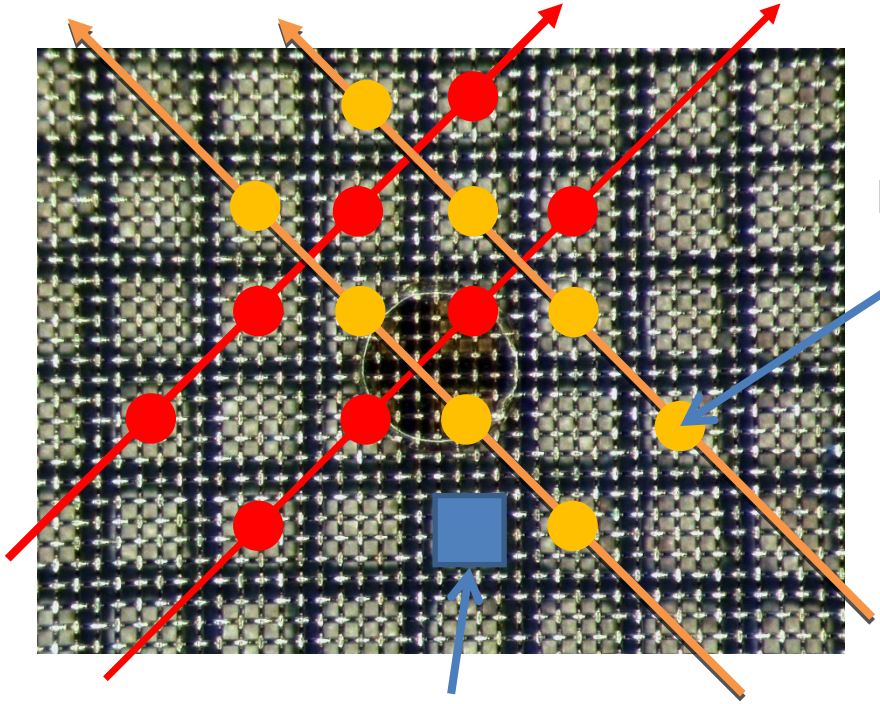
High density connector



Dectector back side

2D readout circuit and pillar

can be readout from the 2 ends of the circuit



Micro via

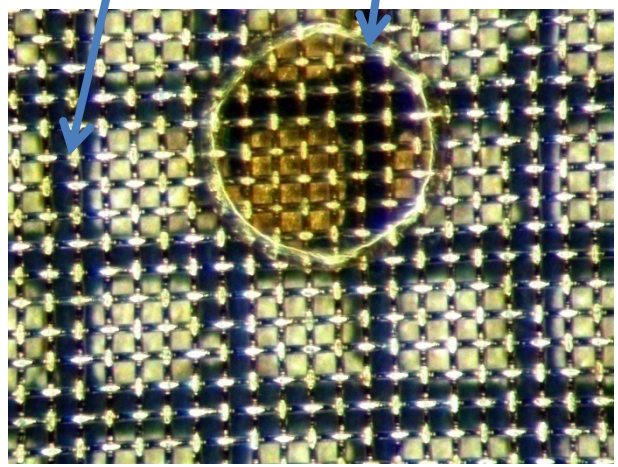
420 µm pitch
X Strips

Pixel
(200x200 µm)

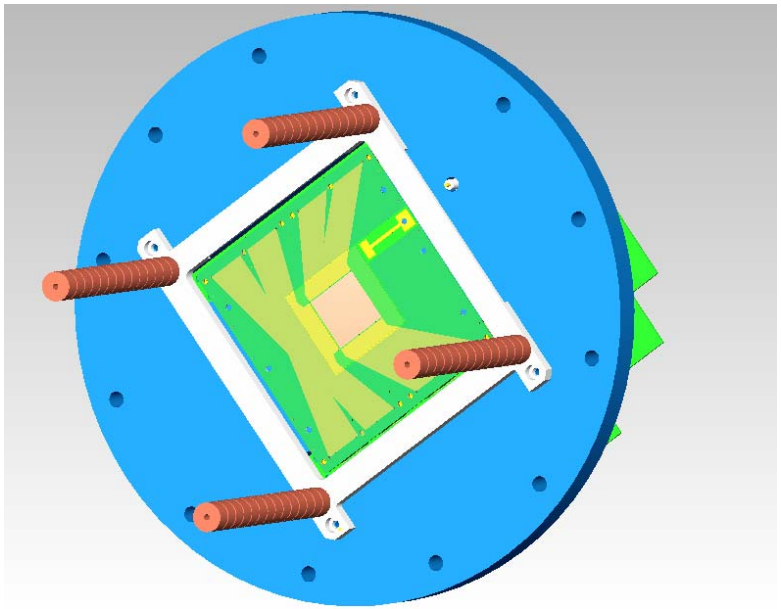
420 µm pitch
Y Strips

Pillar

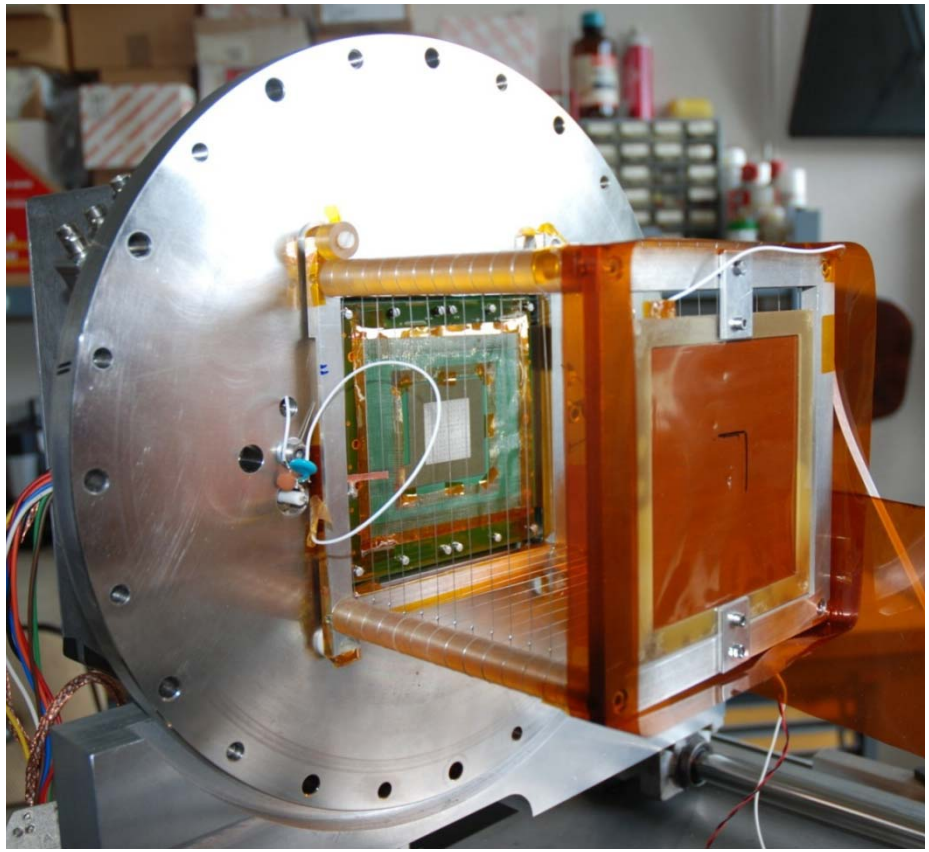
Mesh



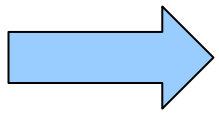
Inside view of the detector



Inside field cage



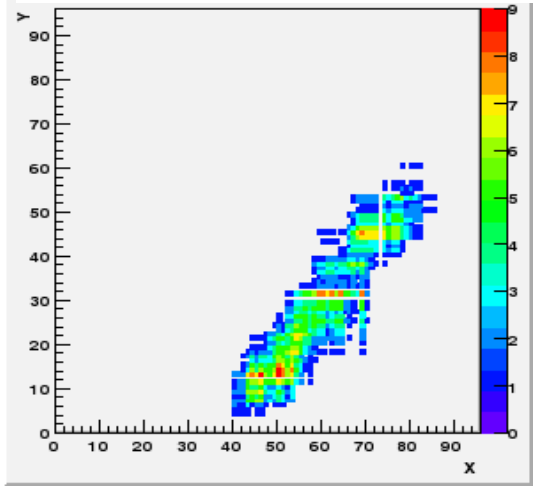
From CAD view …



… to reality

Measured tracks of alpha particle

View of the anode (X,Y)



From ^{222}Rn
E_α = 5.49 MeV

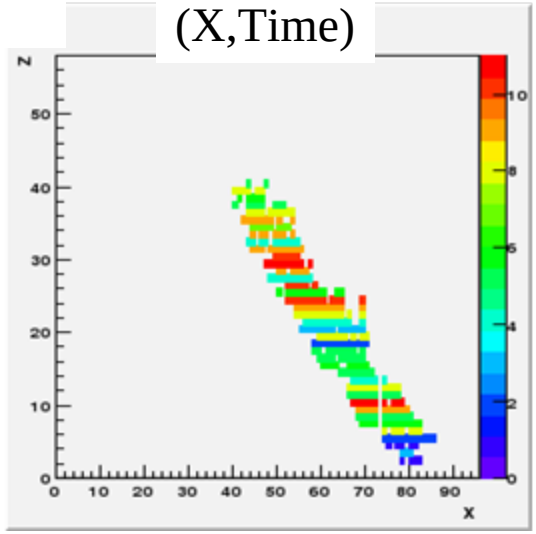
With the reconstruction soft

Can ID α tracks

3D Reconstruction works

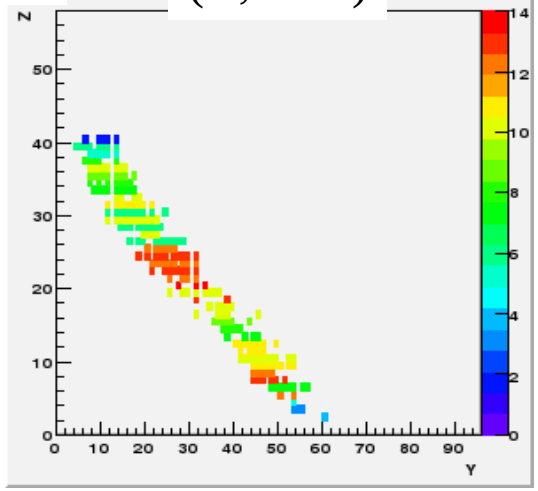
Time

(X,Time)



Time

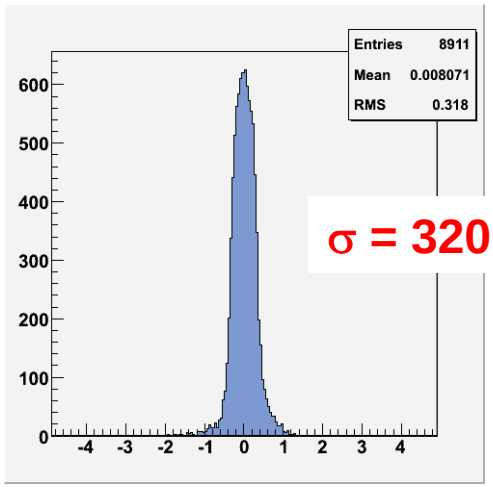
(Y,Time)



Simulation of track reconstruction

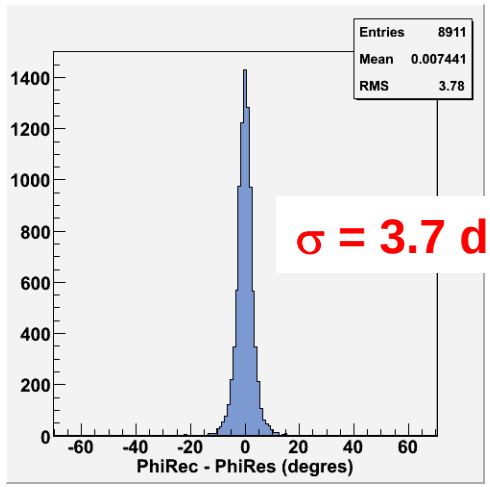
- Test of capability of the DAQ and reconstruction algorithm to reconstruct tracks
- Assumed linear trajectory for recoil tracks
- V = 26 μm/ns, pitch of 400 microns, D = 200 μm/cm½
- for track length between 1 mm to 1 cm

ΔL



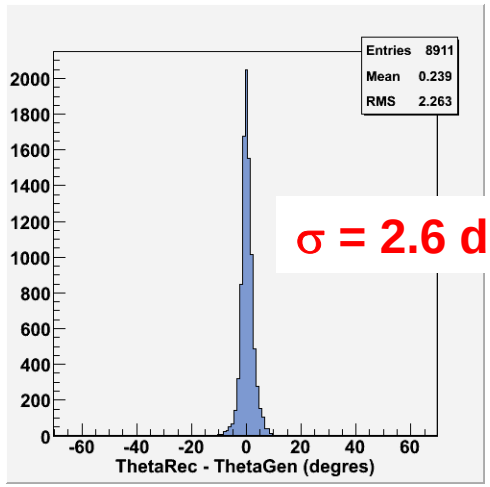
σ = 320 μm

Δϕ



σ = 3.7 deg

Δθ



σ = 2.6 deg

Promising angular resolution for directional detection