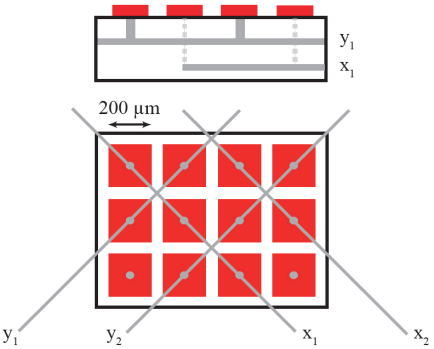
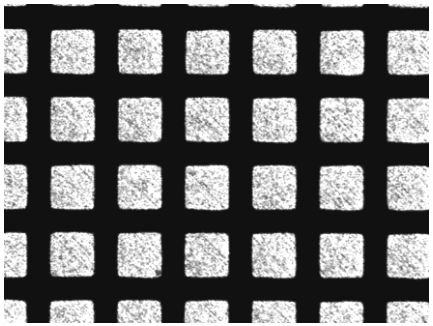
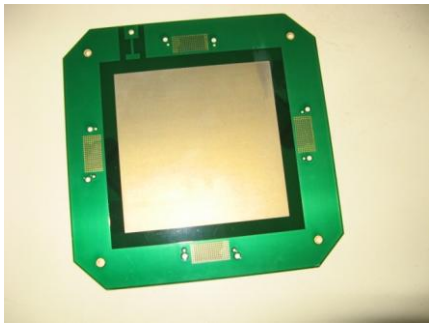
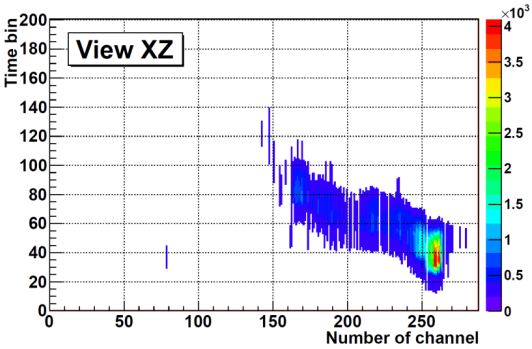
MIMAC: A TPC for directional non baryonic Dark Matter detection









Esther Ferrer Ribas

On behalf of the MIMAC Collaboration

LPSC (Grenoble), CEA/IRFU(Saclay) and IRSN (Cadarache)

IRFU MPGD

6th December 2011

irfu
institut de recherche sur les lois fondamentales de l'univers
saclay

Plan

- Directional Detection of Dark Matter
- Requirements of the MIMAC detector
- R&D and detector characterisation @ Saclay
- Results (Thanks to O. Guillaudin for slides)
    - Low pressure and Quenching factor measurements
    - Track reconstruction with MIMAC dedicated electronics
- Prospects

MIMAC (**MI**cromegas **MA**trix of **C**hambers) Collaboration

Context:

ANR : LPSC (Grenoble), IRFU(SEDI) and IRSN (Cadarache) 2007-2010

- **LPSC** (~320 k€) :
development of dedicated electronics+ daq, simulation, quenching factor mesaurement

- **IRFU/SEDI** (~60 k€) :
detector design and fabrication, electronics interface, characterisation

- **IRSN** (~33 k€) :
neutrons metrology with AMANDE (monoenergetic neutrons neutrons from 2 keV to 19 MeV)

Actors:

- **IRFU/SEDI:** FJ Iguaz, JP Mols, E. Ferrer Ribas, Y. Giomataris
(D. Attié, D. Calvet, P. Colas, F. Druillole, J. Pancin, T. Papaevangelou)

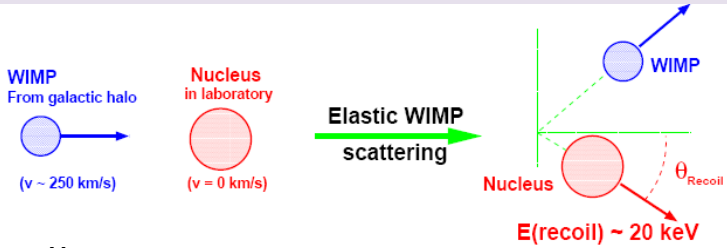
- **LPSC:** J. Billard, J. Lambin, F. Mayet, D. Santos, O. Guillaudin, G. Bosson, JP Richer, A Pellisier, O. Bourrion, Ch. Fourel, T. Lamy, P. Sole

- **IRSN:** C. Golabek, L. Lebreton

- Recently J. Busto and C. Tao **(CPPM Marseille & China)**

Dark Matter search: interest of directionality

Candidates for dark matter:
WIMPS (Weakly Interacting Massive particles), axion, neutrinos

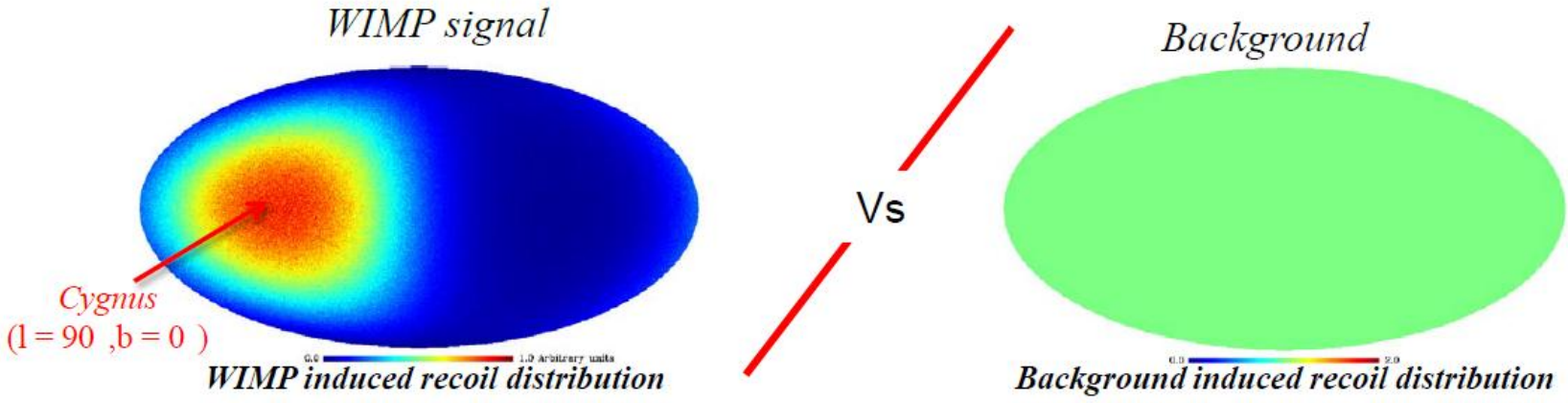


MIMAC Detection strategy:
Detection of WIMPs interaction with standard matter (nuclear recoil)

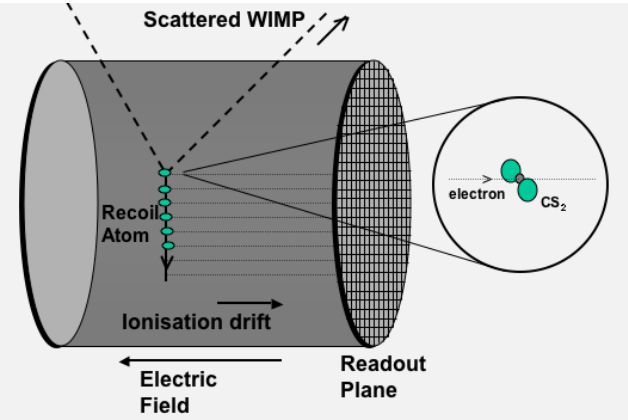
Rate < 1 evt/day/kg of detector
- Need low background
- Need large detector

Ability to measure low recoil energy => low threshold

WIMPS privileged direction Background isotropic
Directionality: clear and unambigous signature from WIMP

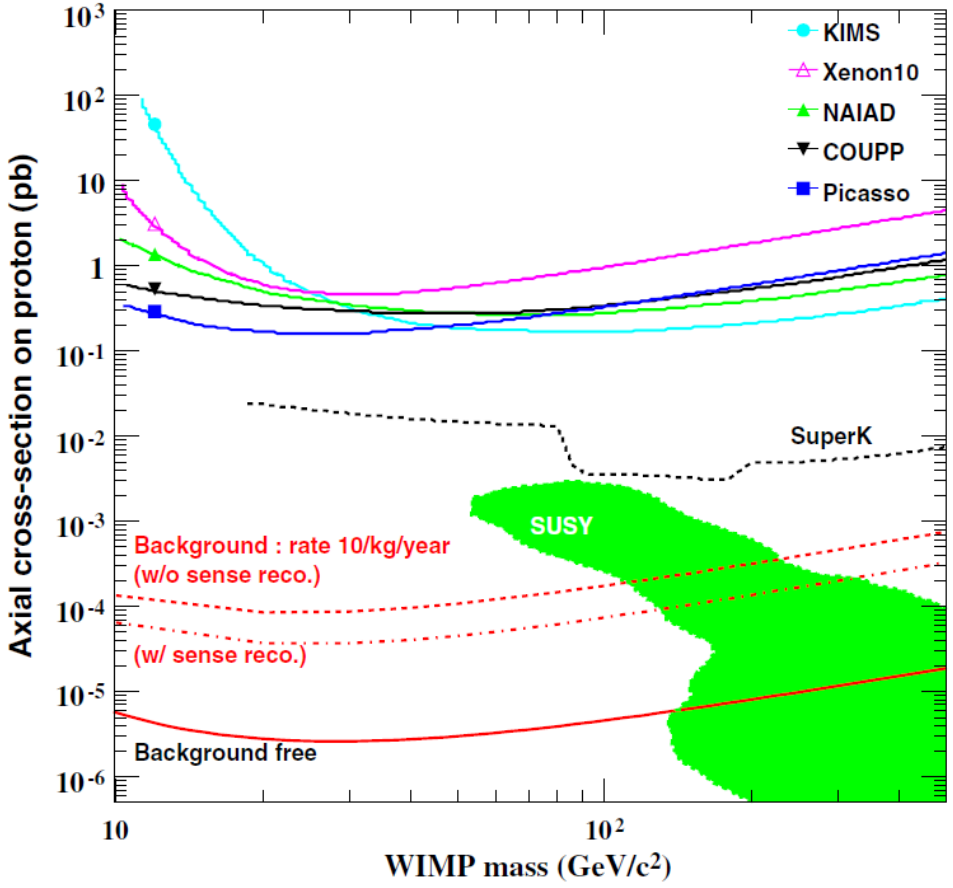


Aims of MIMAC and expected performance



- First step towards a large detector for dark matter
- TPC with Micromegas as the amplification structure
- Reconstruction of the kinematics of the interaction WIMP-nucleus: E + direction+ track parameters
- CF4 @ low pressure

Phys. Rev. D 82, 055011 (2010)



10 kg CF4, 3 years
Recoil energy range (5-10 keV)
Background rate: 10 evts/kg/year

Requirements/Roadmap of the MIMAC detector

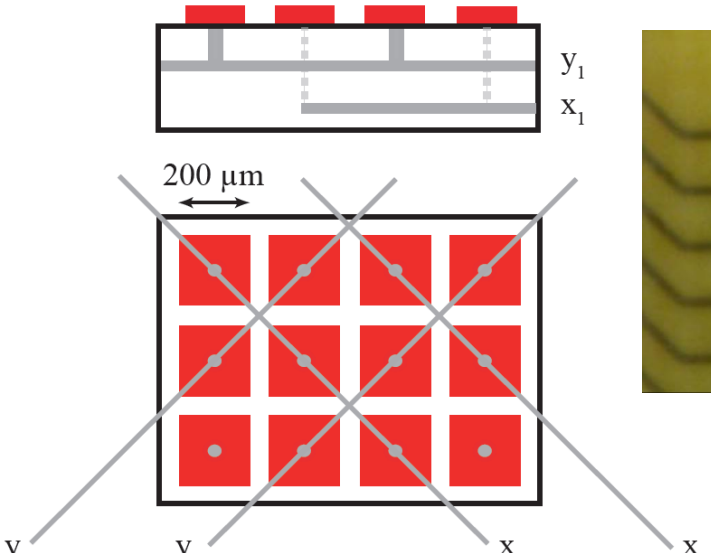
Reconstruction of small tracks (few mm)➔ small pitch

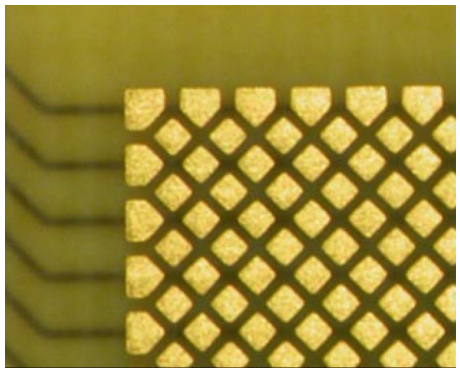
Readout capability for directionality ➔ 2D

Possibility of operation high and low pressure ➔
bulk Micromegas easy to change amplification gaps from 128/256

Bulk Micromegas➔ uniform surface in order to have a good resolution

Small prototype to validate the principle before going to a « realistic » size unit





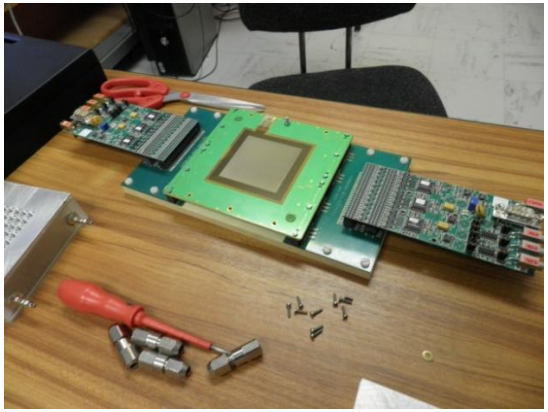
2D « à la CAST »

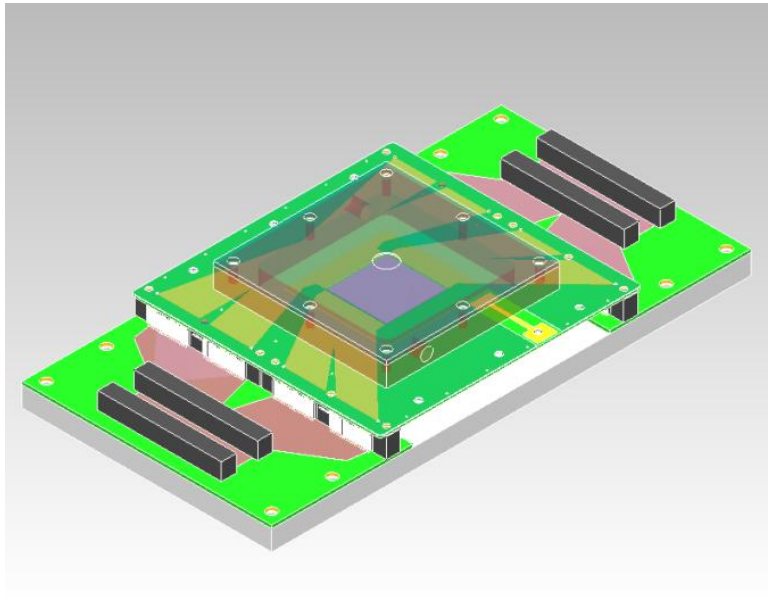
Reduces number of channels with high granularity covering large surfaces

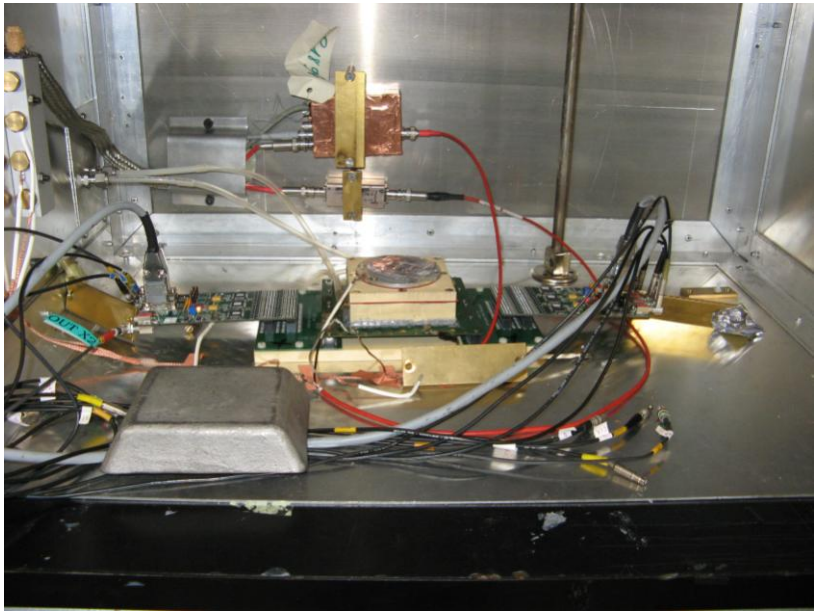
The pixels are at 45° wrt the readout strips

A first small prototype: 3 × 3 cm^2

- 1.6 mm thick PCB 1.6 mm with 200 µm large pixels (200 channels).
- Manufactured by ESPCI.
- Sent to CERN for the bulk process.
- Specific set up for testing in Saclay (gassiplex electronics)

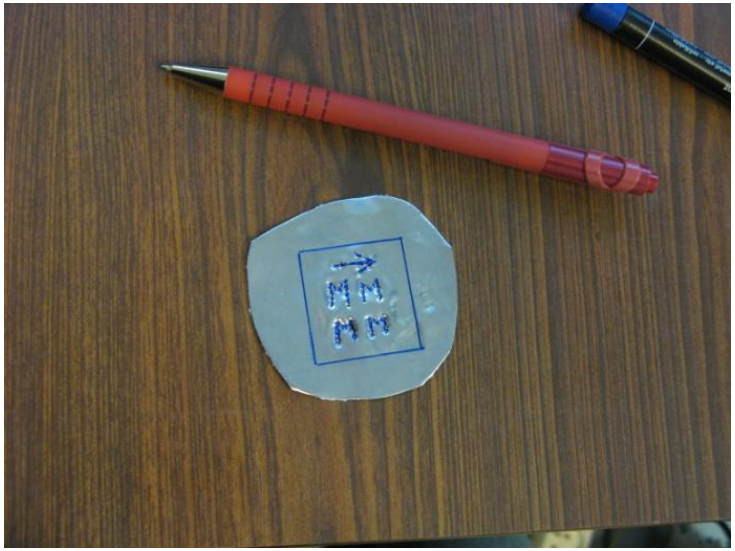


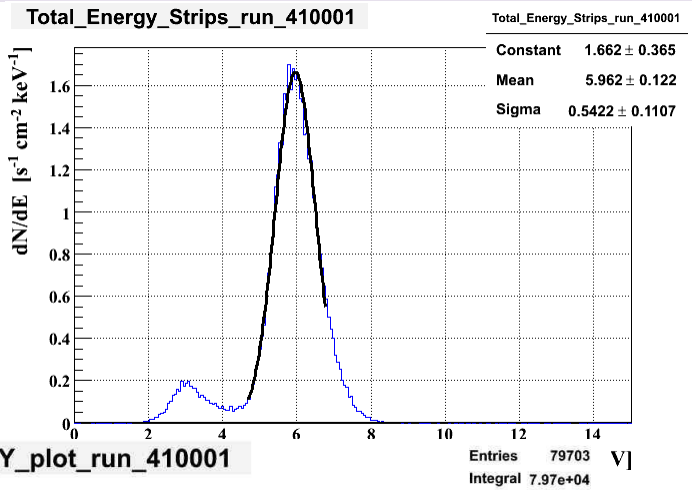


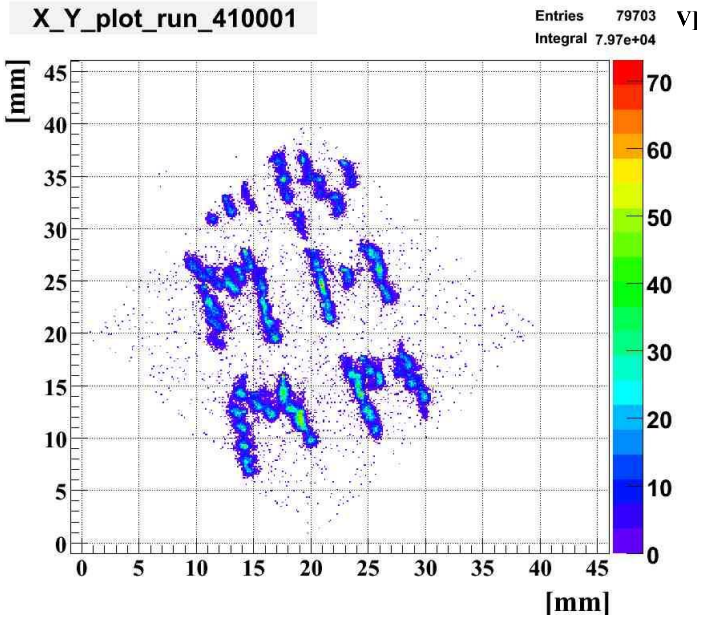


A first small prototype

- Energy resolution: 22% FWHM @ 5.9 keV.
- Improvements for the next prototype:
  - Design of the strips: all the strips do not have the same length
  - Surface homogeneity



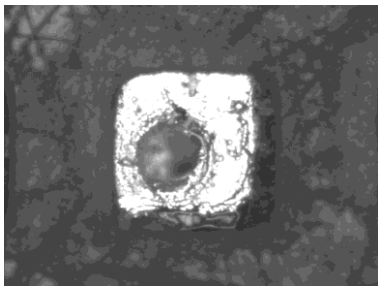


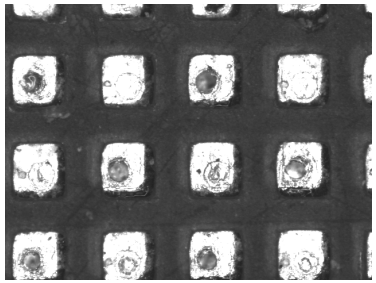


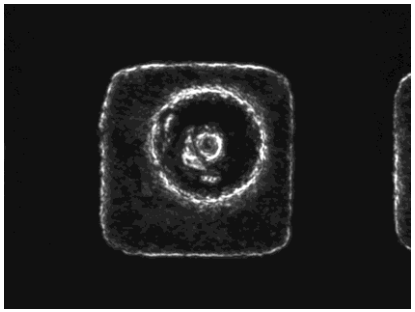
D. Santos et al., MIMAC : A micro-tpc matrix for directional detection of dark matter, [arXiv:1102.3265].

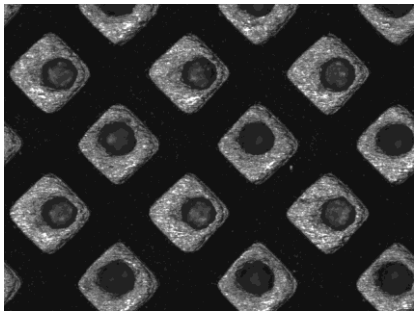
A first small prototype: R&D for the 2D readout plane

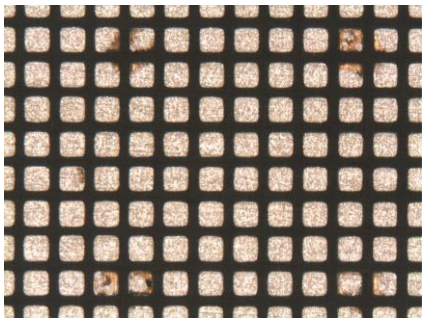
- Filling the vias
- Uniformity of the pixels

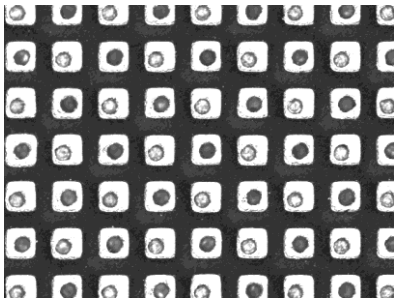


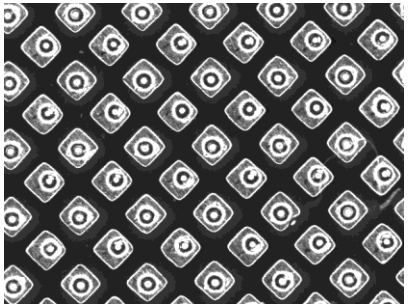










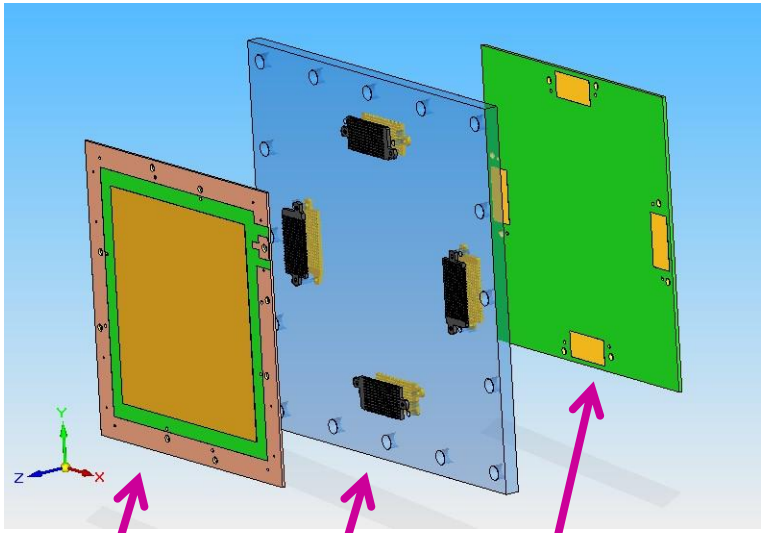


Solution to recover a
uniform surface-silver paint

Going to the 10x10 cm^2: novelties in the design

- A jump in size: 10 x 10 cm^2
- Detector required to stand high pressure and vacuum
- PCB without connectors so that the bulk micromegas can be redone easily
- Electronics close to the detector
- Adaptable to two electronics system (T2K for characterization and MIMAC)

Design of a 10x10 cm^2 prototype

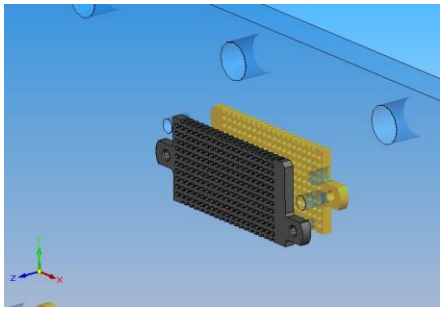


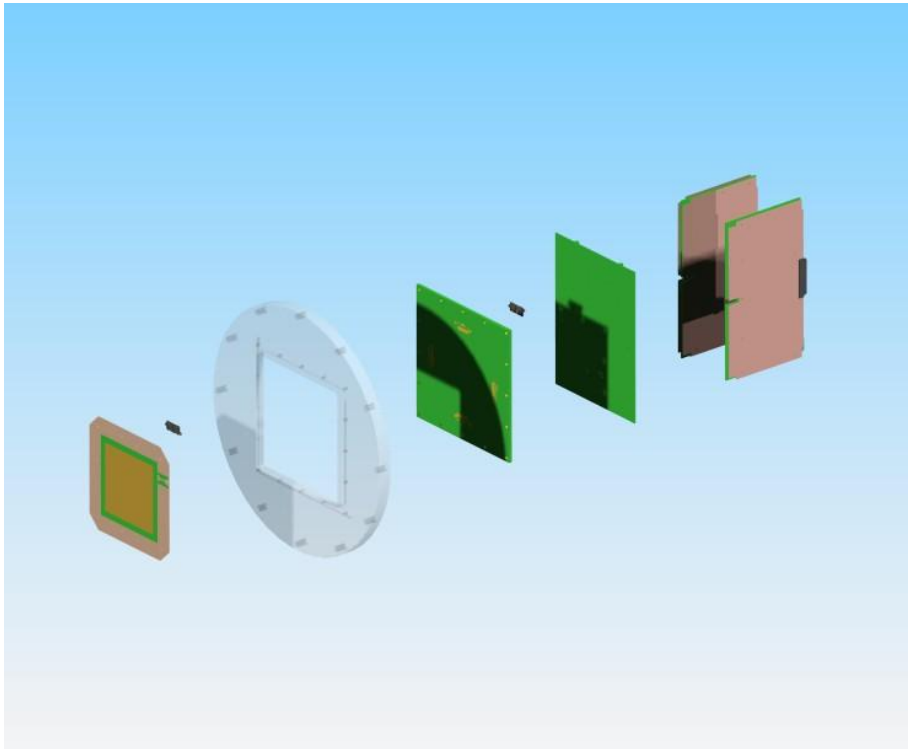
Readout PCB

Leak tight PCB

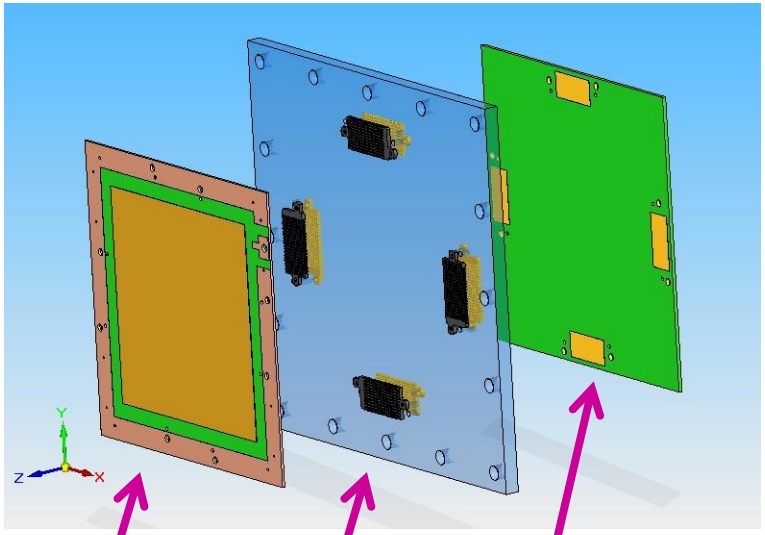
Interface card

SAMTEC connectors (GFZ 200 points)





Design of a 10x10 cm^2 prototype

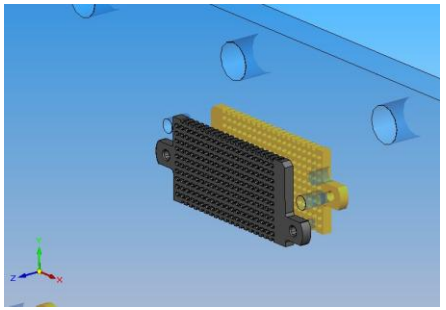


Readout PCB

Leak tight PCB

Interface card

SAMTEC connectors (GFZ 200 points)

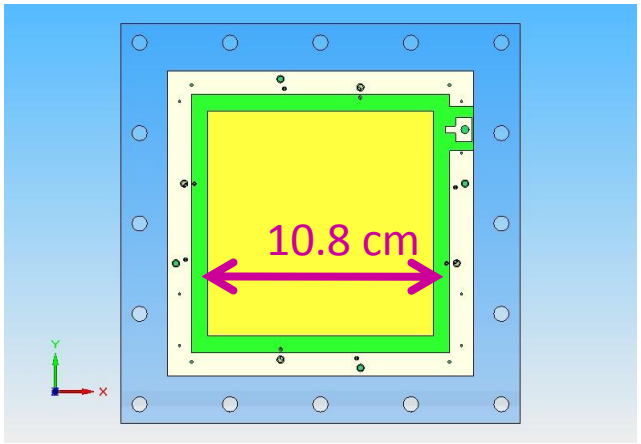


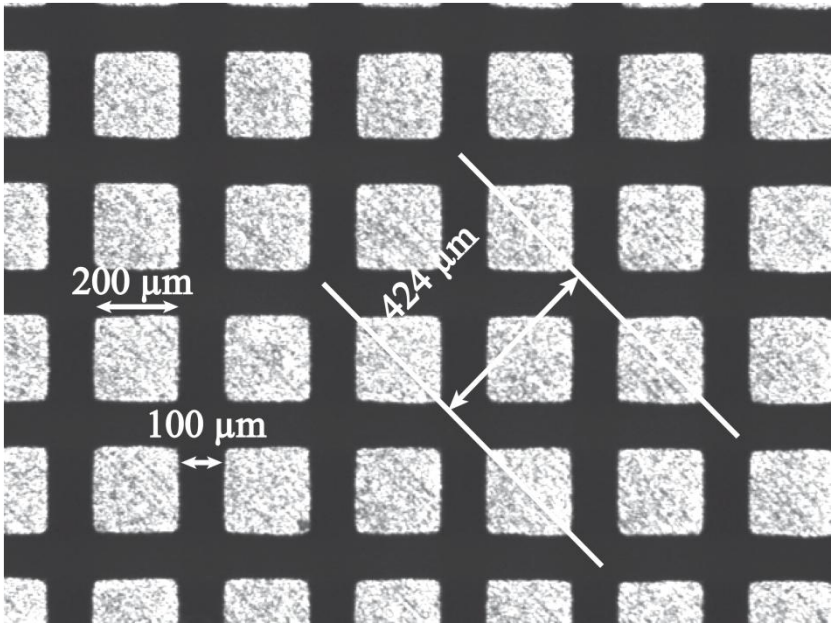
Readout PCB without connectors→ easy for bulking

Leak tight PCB→ 5 mm thick PCB leak tight by metallic vias that have been refilled, connection Between detector and electronics in a reduced space

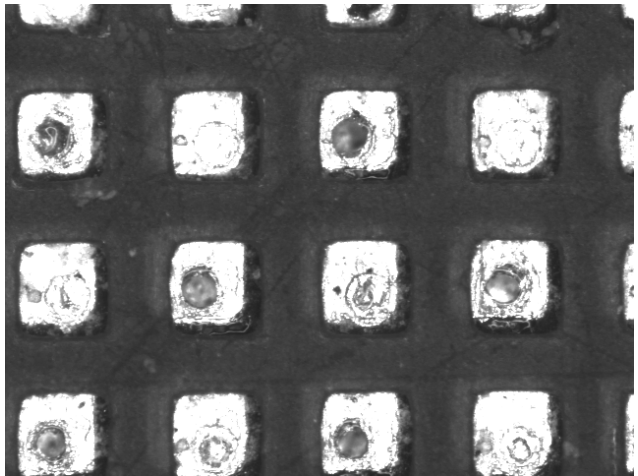
Interface card→ easy transition from one electronic system to another

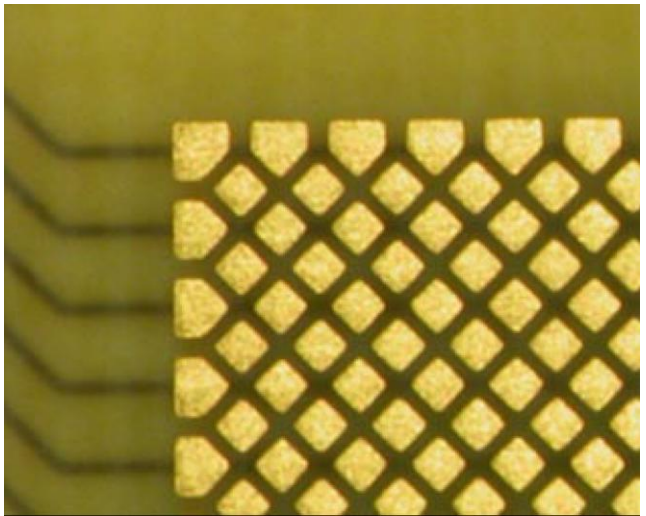
Design of a 10x10 cm^2 prototype





First prototype

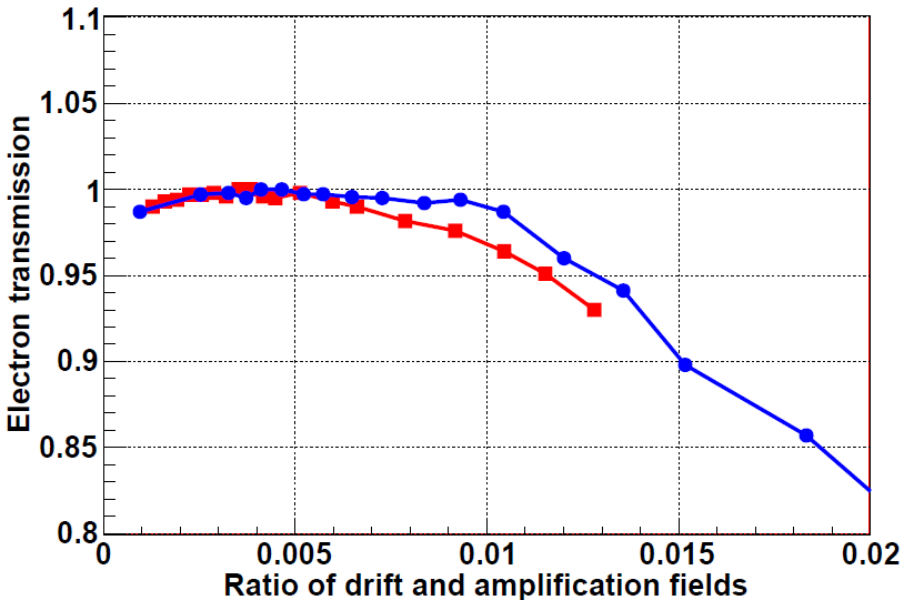




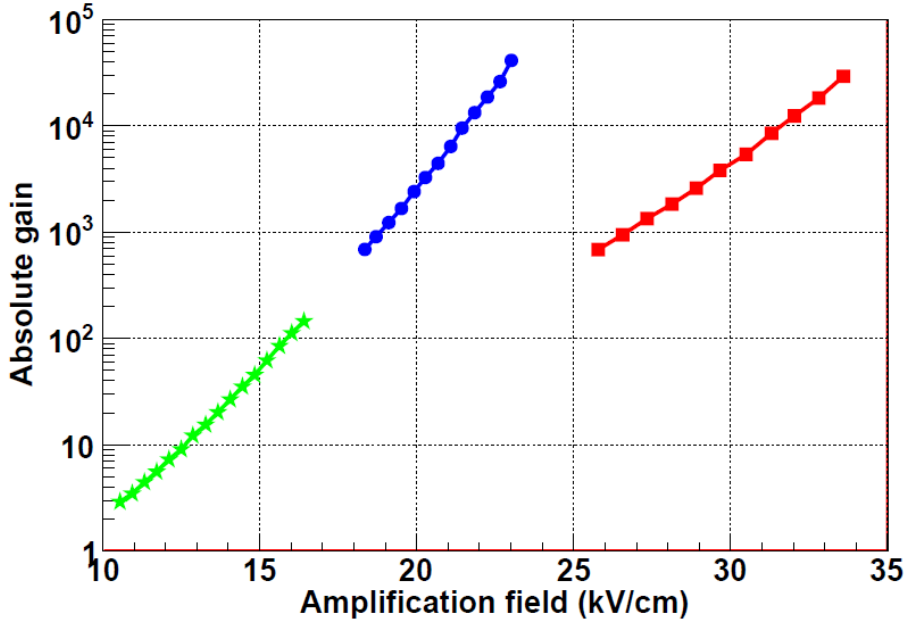
Characterisation of a 10x10 cm^2 prototype

^{55}Fe source in Ar+5%iC4H10
@ atmospheric pressure

Electron transmission



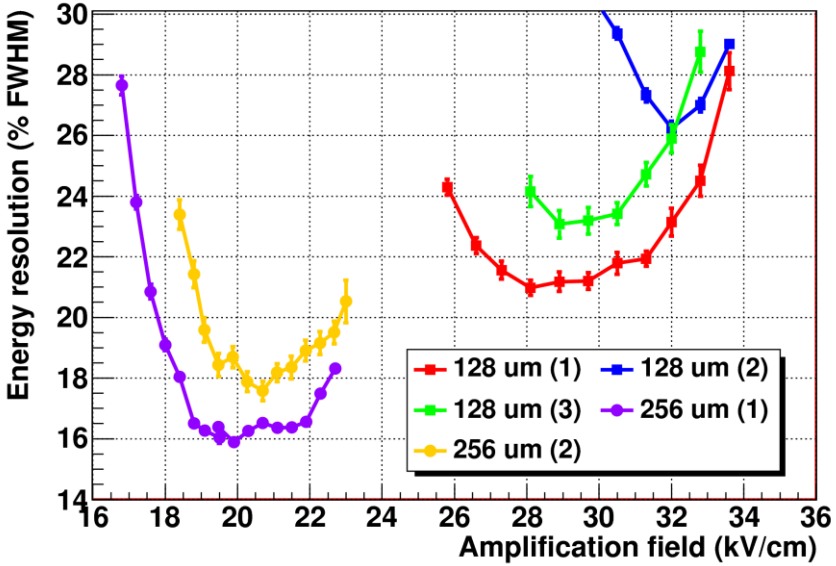
Gain

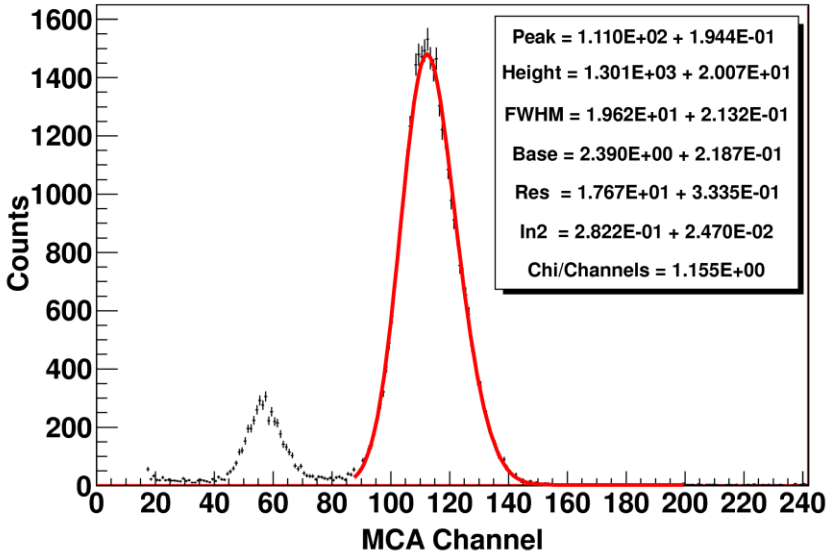


Amplification gap = 256 µm

Amplification gap = 128 µm

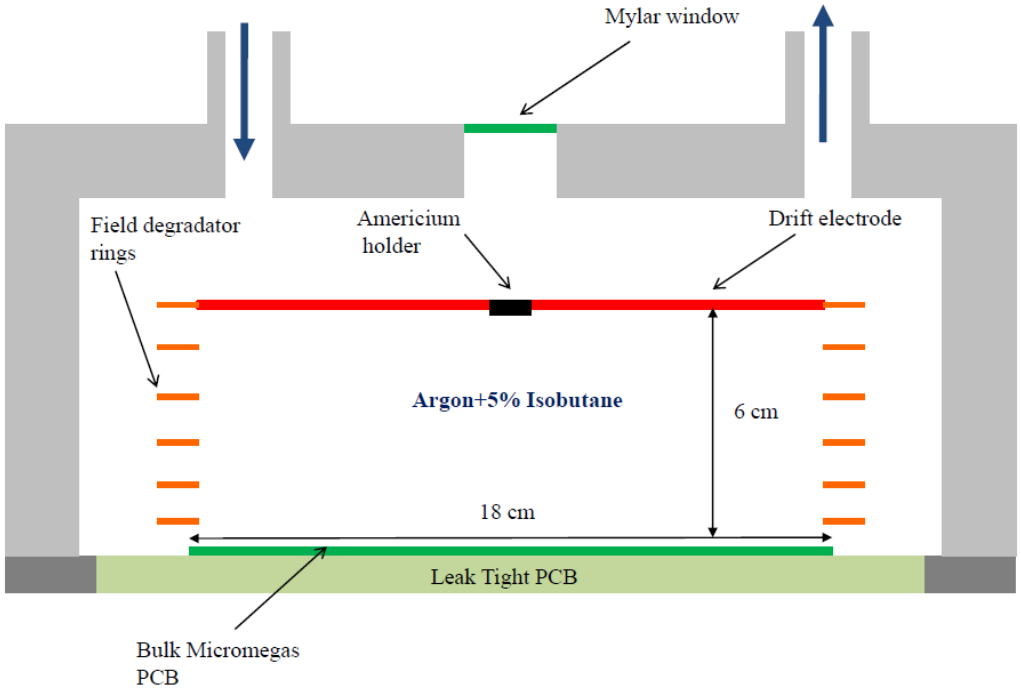
Characterisation of a 10x10 cm^2 prototype

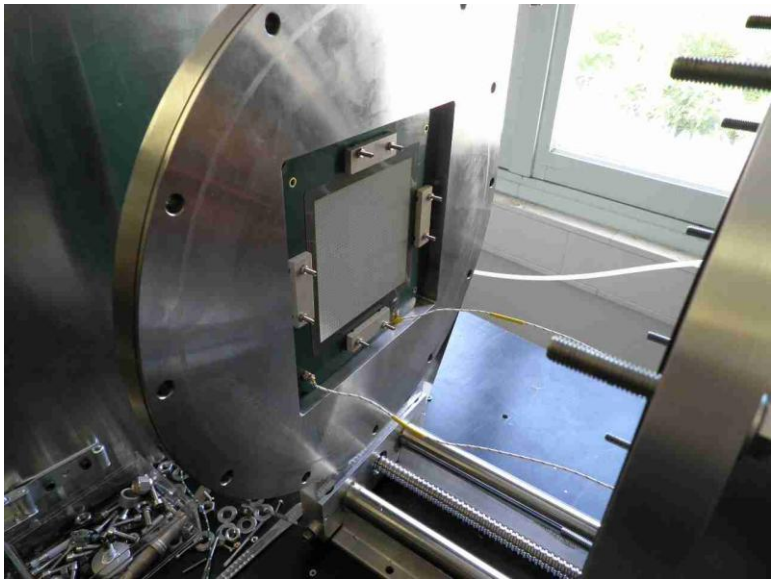




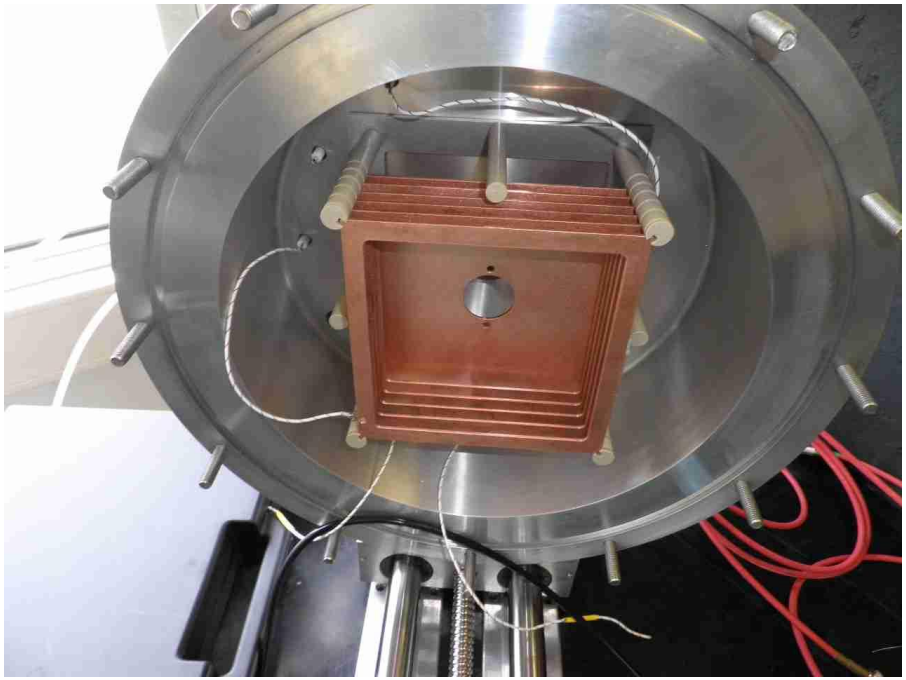
Detector	Num	Lab bulked	Energy Resolution (% FWHM)	
			MCA spectrum	T2K strips
128μm	1	Saclay	21.0 ± 0.3	–
	2	Rui	23.4 ± 0.4	–
	3	Saclay	23.2 ± 0.4	24.1 ± 0.5
256μm	1	Rui	16.0 ± 0.1	–
	2	Rui	17.8 ± 0.3	18.5 ± 0.1

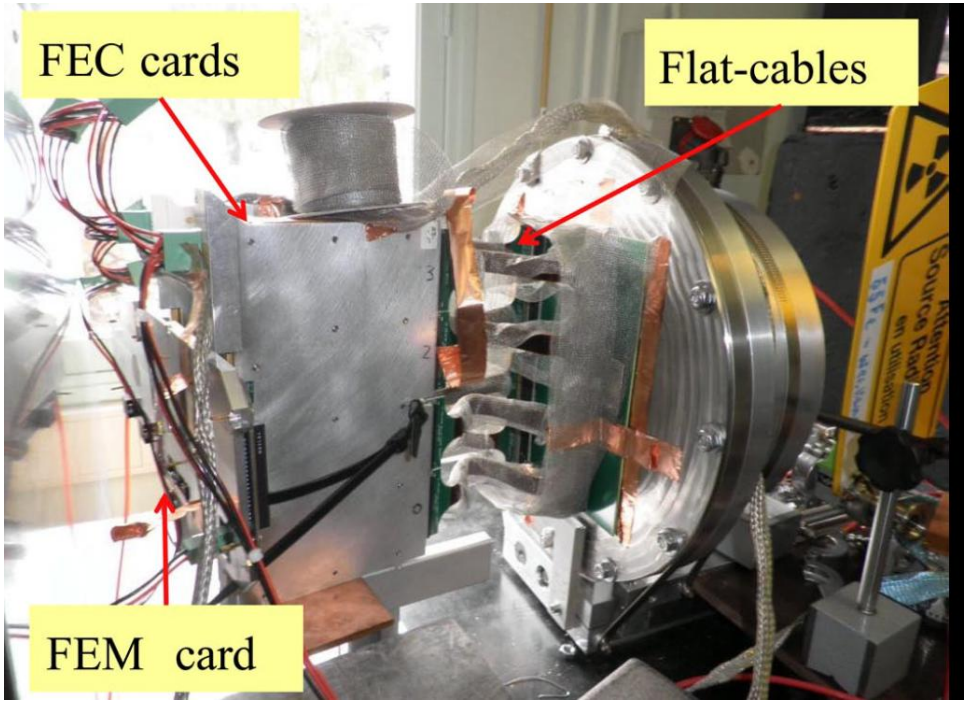
Characterisation of a 10x10 cm^2 prototype: reading the strips with T2K electronics





Characterisation of a 10x10 cm^2 prototype



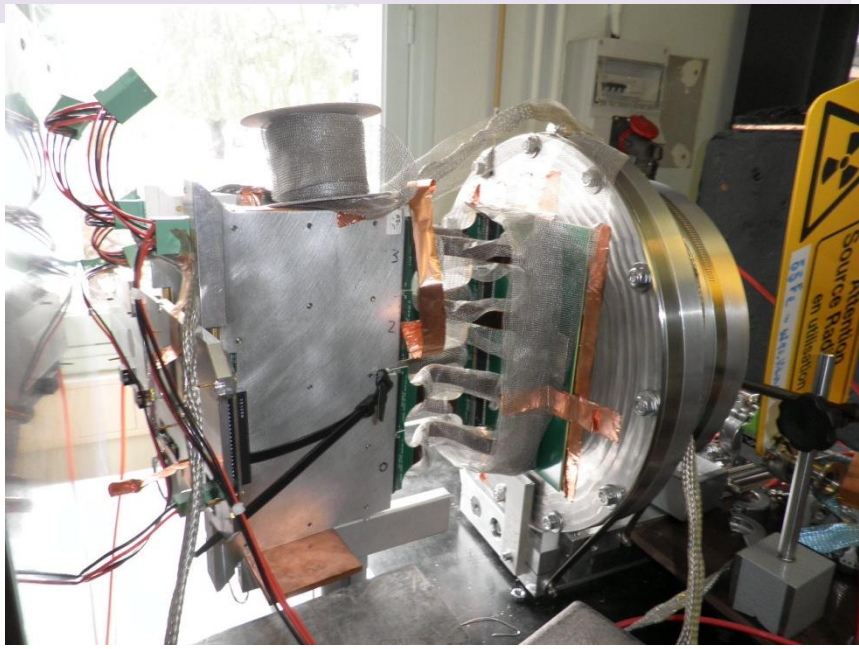


T2K electronics

for validation of the MM planes: no dead strips, readout decoding, general concept

AFTER CHIP

FEC
288 Channels



- 72 channels x 511 analog memory cells
- Sampling rate: 1-50 MHz
- Supports both input signal polarities with 4 Gain ranges
- Programmable peaking time (100 ns-2μs 16 values)
- M.I.P: 12-60 fC, with M.I.P. / noise: 100

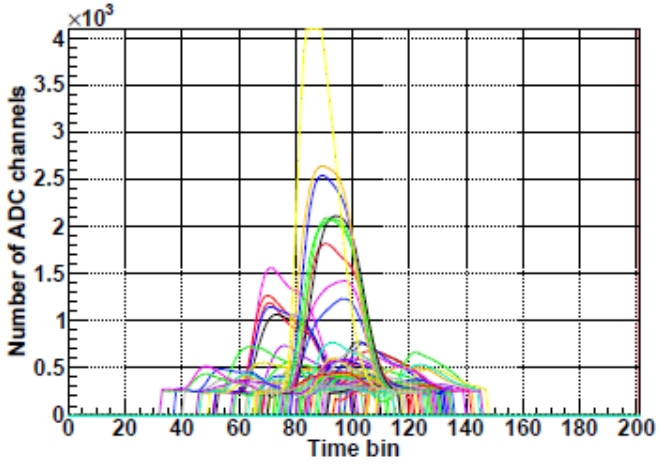
Strip signals are extracted with 8 flat cables to 2 FEC (with 4 AFTER chips to amplify and shape the signals)

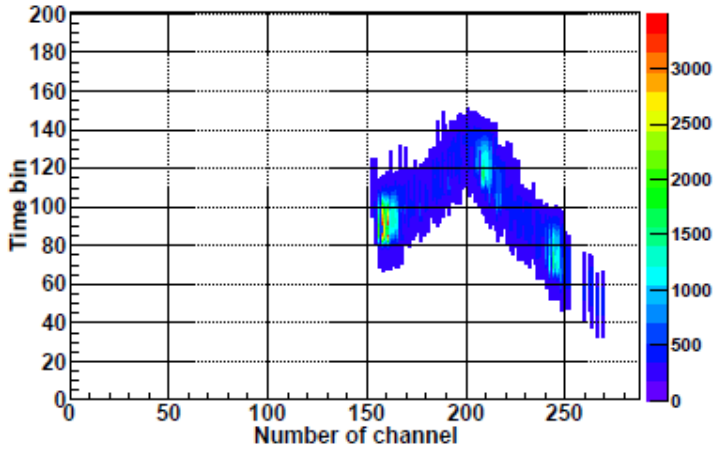
A FEM cards reads the FEC and sends the data to the DAQ system.

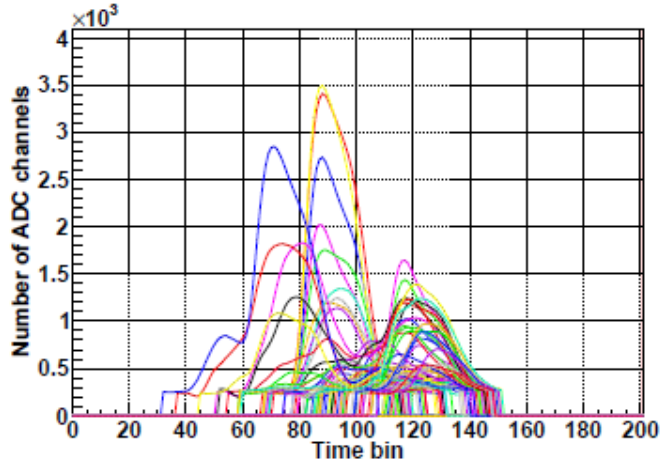
External trigger generated from the mesh amplifier output

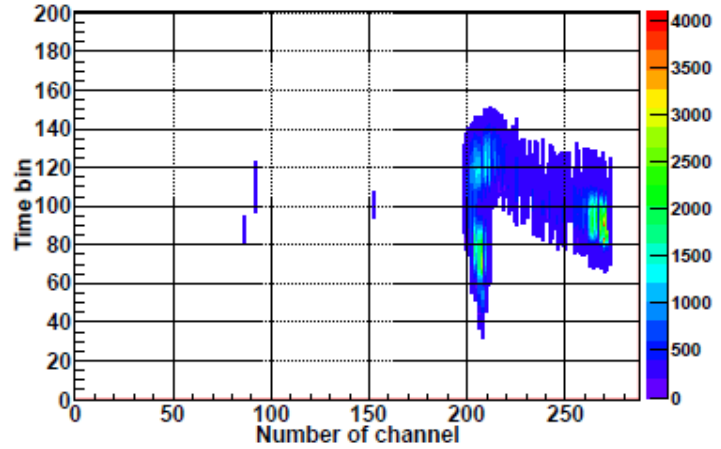
P. Baron et al., AFTER, The Front End ASIC of the T2K Time Projection Chambers Presented at the Topical Workshop on Elctronics for Particle Physics, Paris (France) 21/09/09–25/09/09.

Measuring tracks with T2K electronics





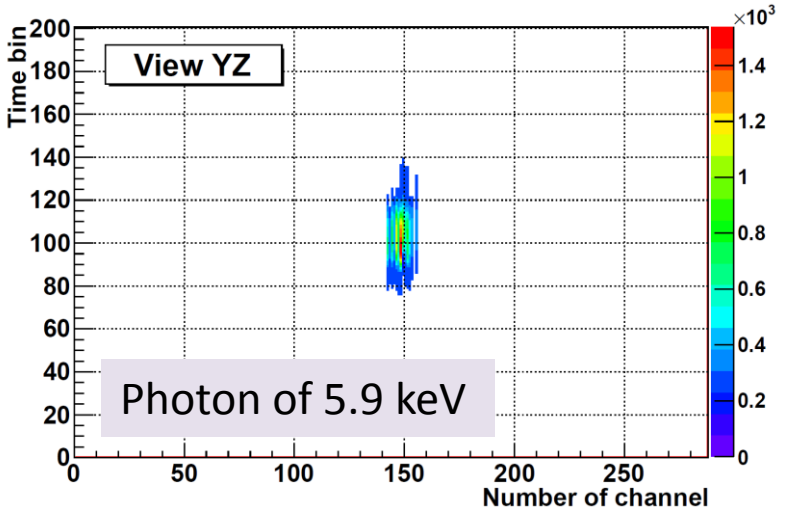


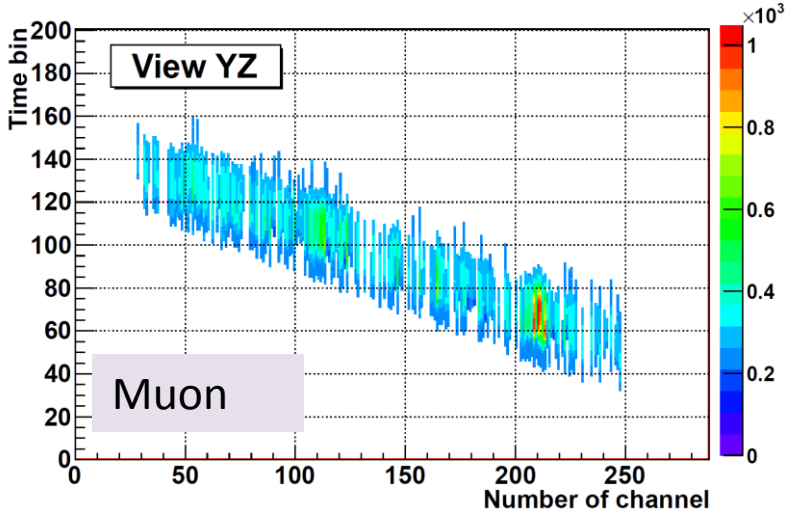


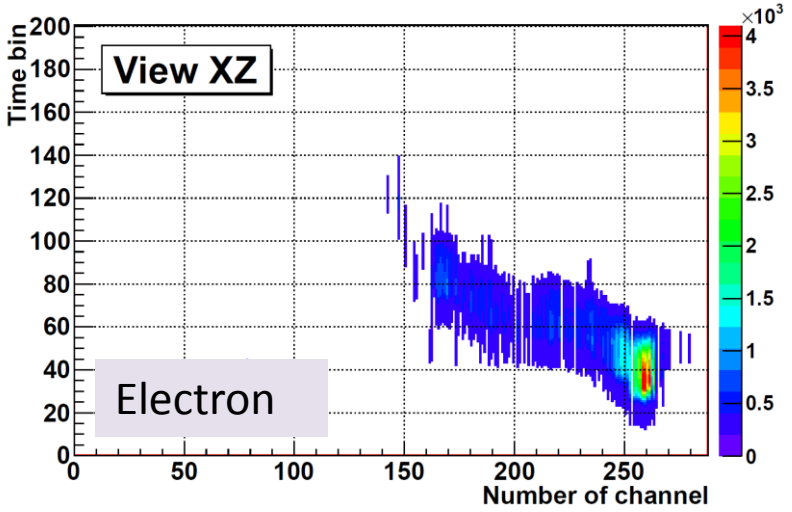
•The XY and YZ projections of each event are reconstructed with the pulse height in each time bin.

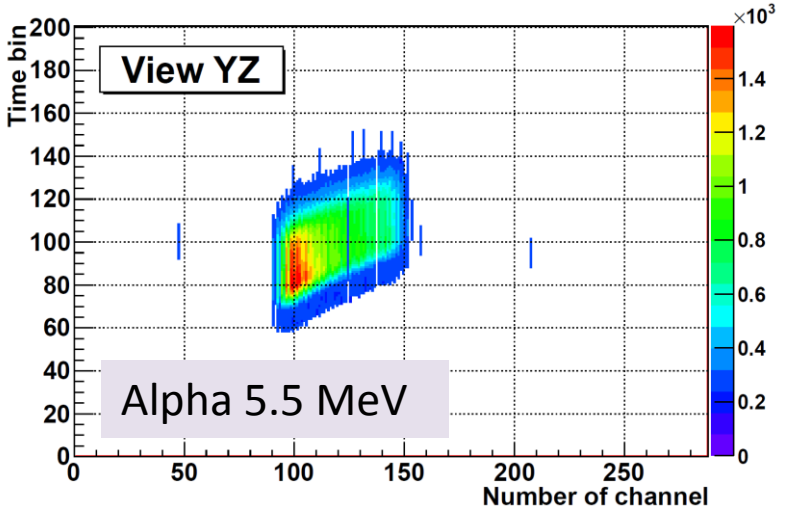
T2K parameters: 50MHz sampling speed, 100 ns shaping time, gain of 120 pF

Micromegas detector developments for MIMAC

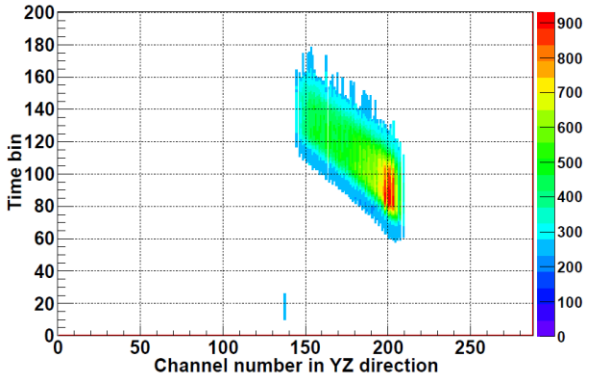




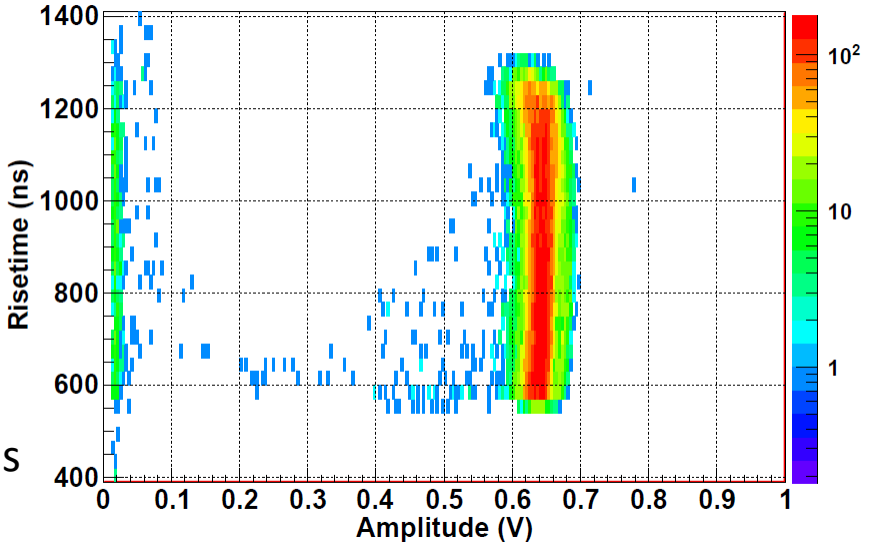




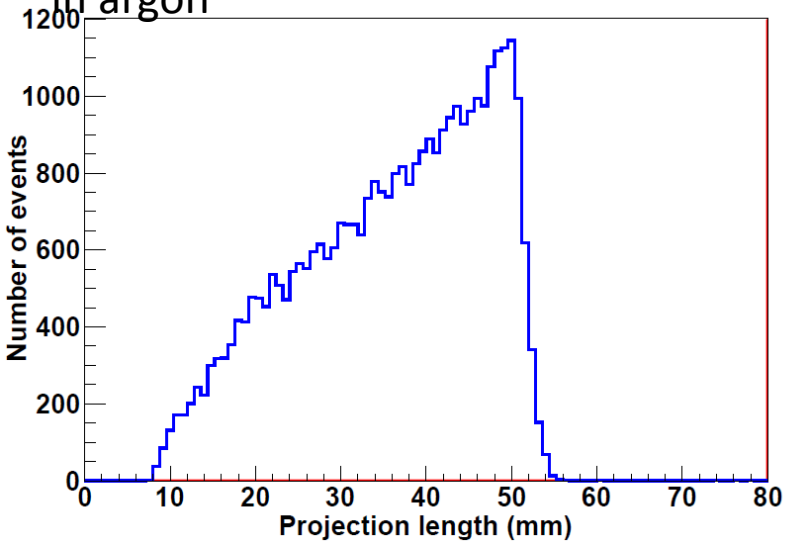
Measuring alpha tracks with T2K electronics

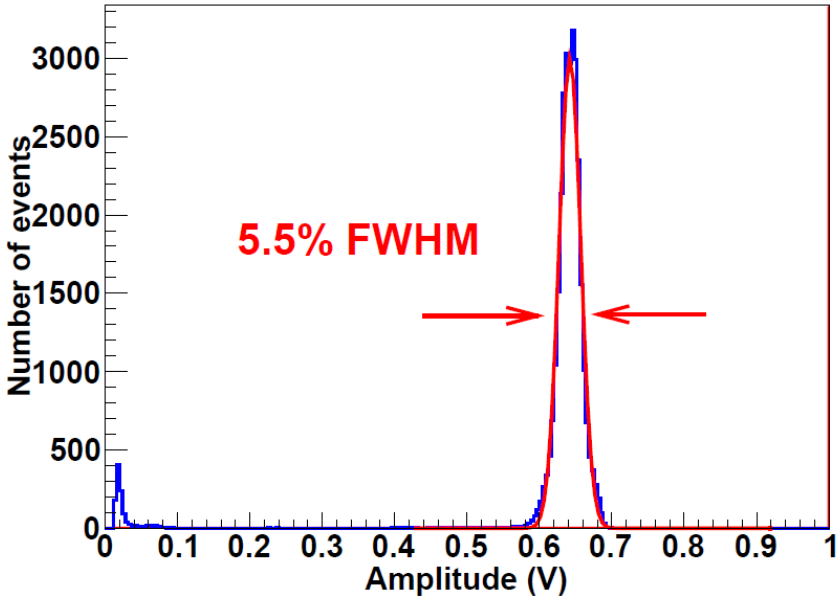


Gain 85, Edrift=70 V/cm



Maximum value matches
well the theoretical length for 5.5 MeV alphas
in argon





F.J Iguaz et al 2011 JINST 6 P07002

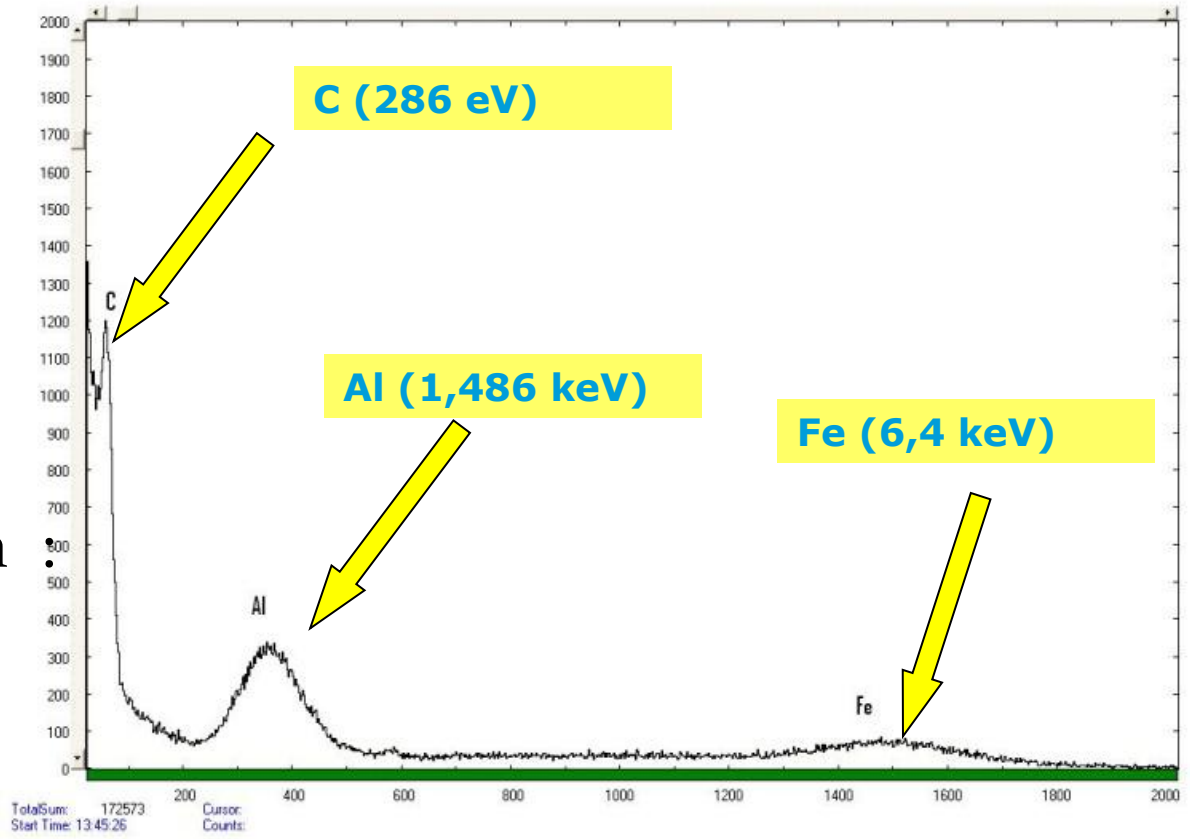
RESULTS

He + 5% Isobutane (350 mbar)
High gain ~ 10^5

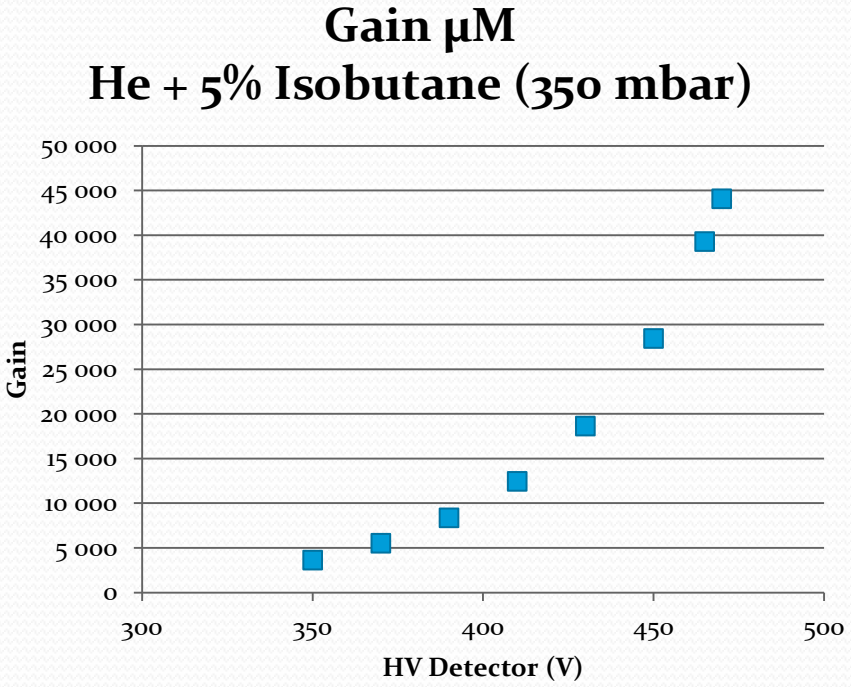
HV = 495 V
Gap : 192 µm

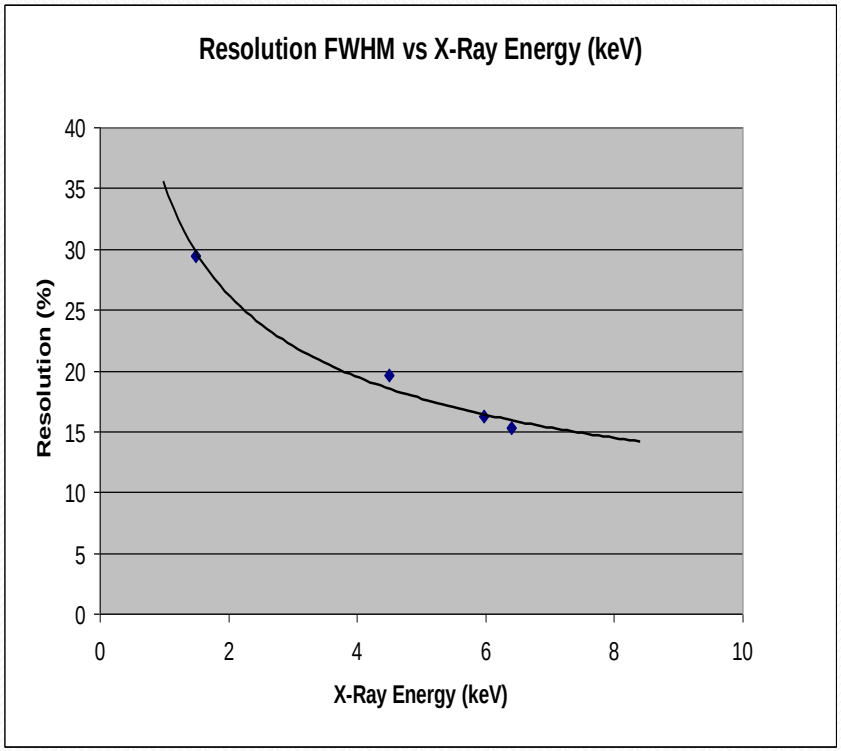
Gain : 10^5
Threshold: 150 eV

X-Rays from Carbon : 286 eV !!!



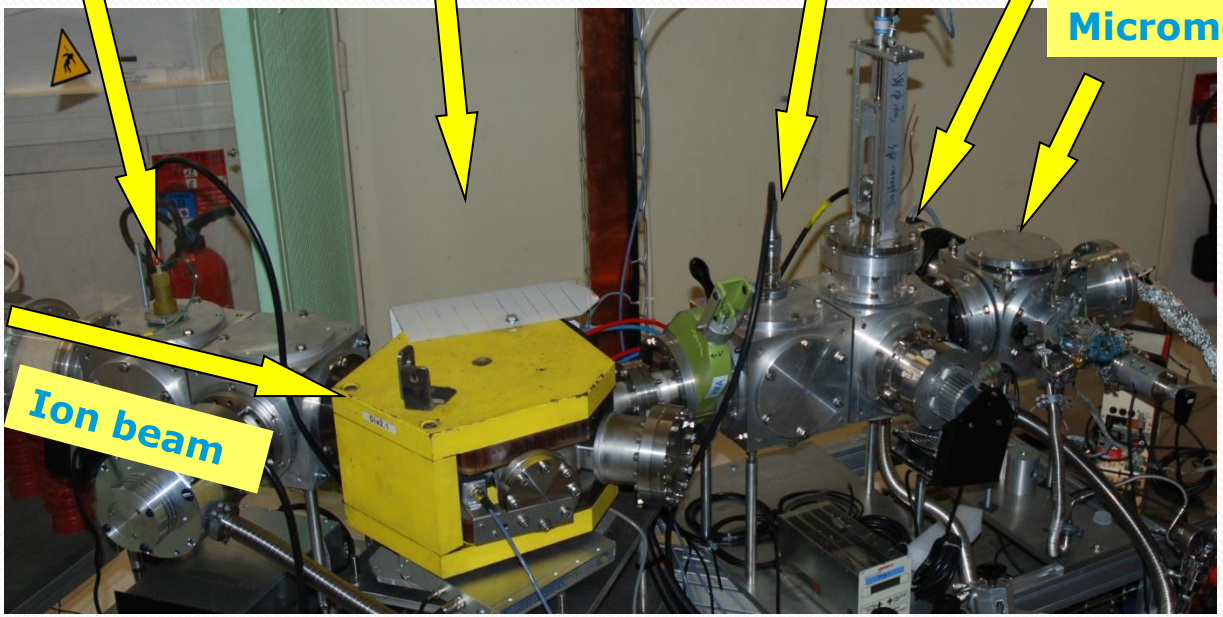
Gain and energy resolution for He + 5% Isobutane (350 mbar)





- Very high gain at low pressure (stable operation)
- Good energy resolution (15 % at 6 keV)
- Detector operated in sealed mode for 1 day after outgazing to 10^{-6} mbar)
- Low gain variation in sealed mode

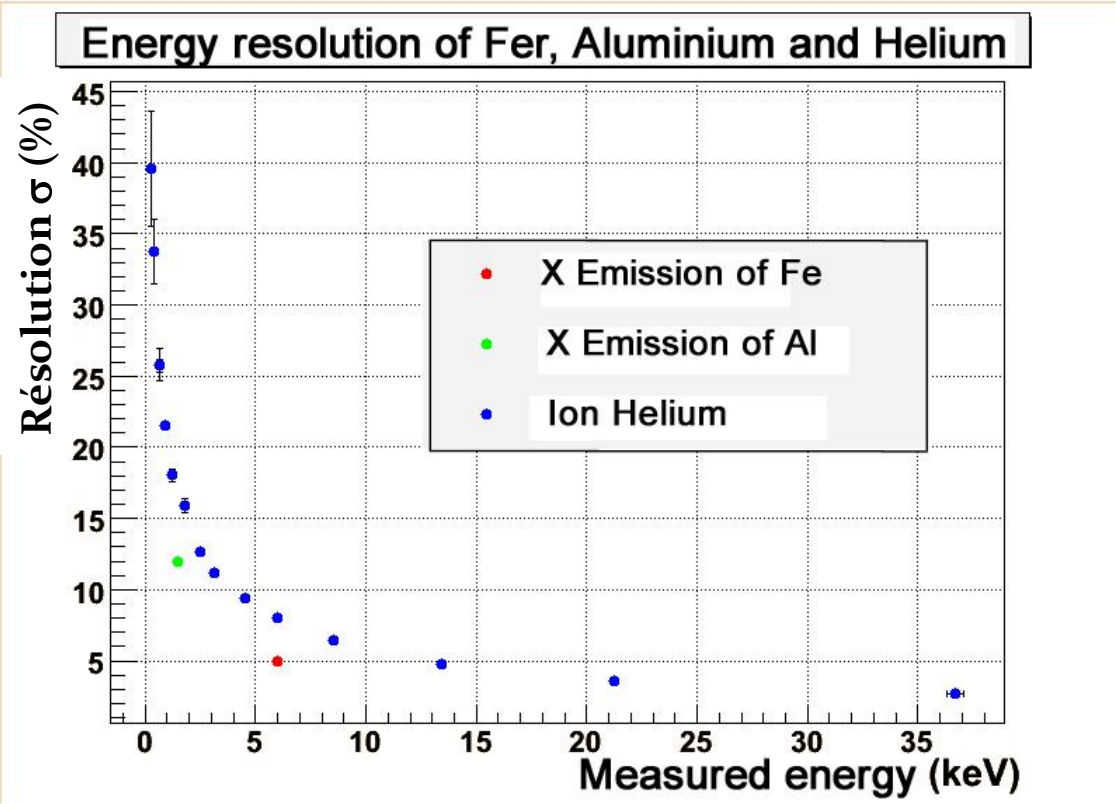
ECR ion source
From 5 to 10 000 ions/s



Ion beam

- p
- ^{3}He
- ^{4}He
- ^{14}N
- ^{12}C
- ^{19}F

Micromegas µTPC : resolution with recoils

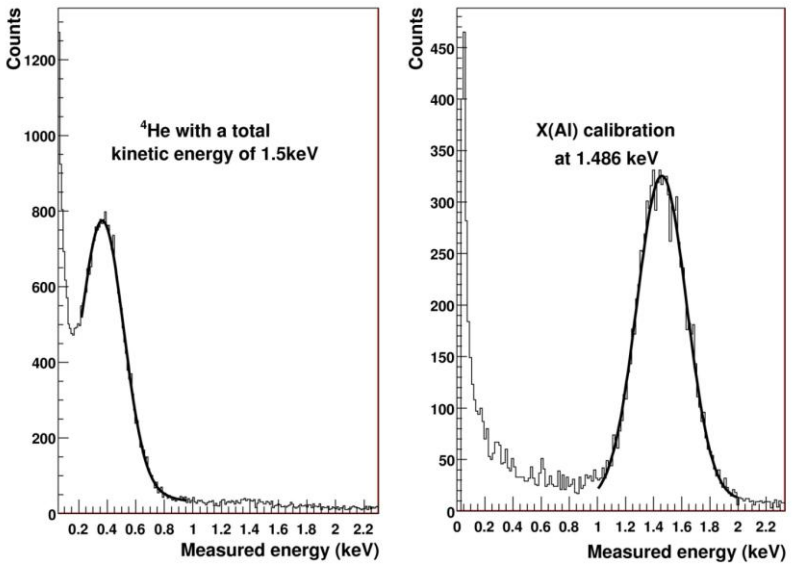


- Energy resolution of Micromegas µTPC has been measured down to 1 keV with ion beam
- Better energy resolution with X-Rays

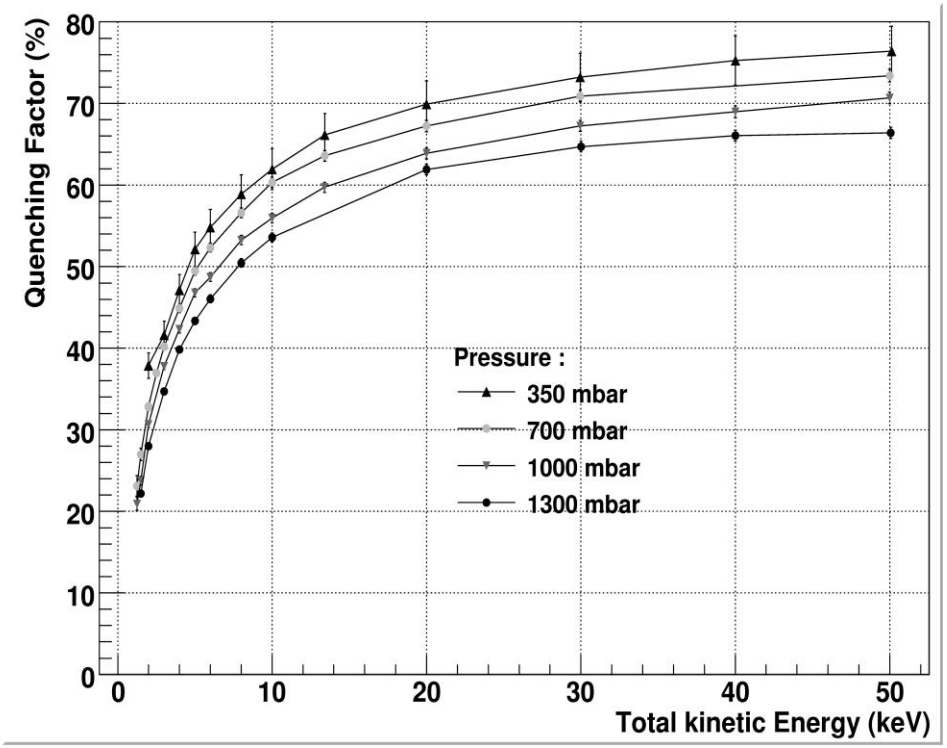
Quenching factor plot

Q.F = E released ionization/ Total Kinetic energy

In the low energy domain measurements do not exist

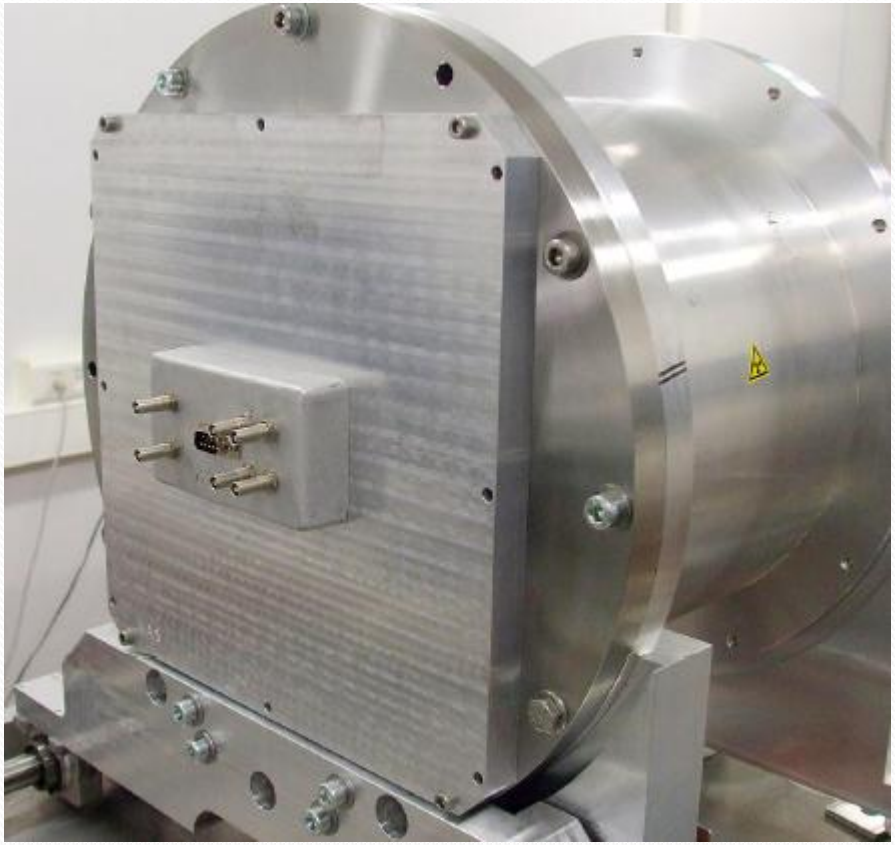


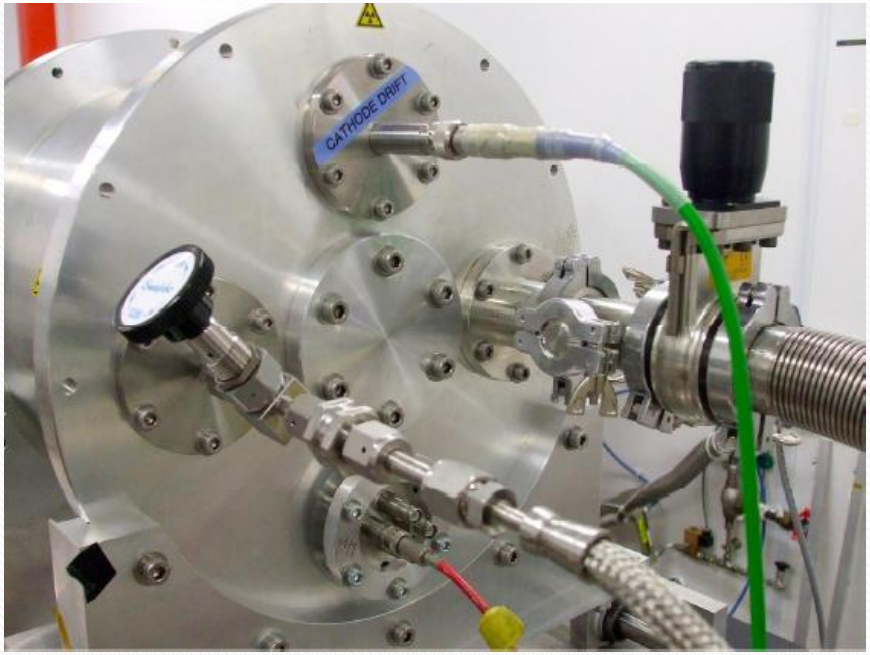
95% ^{4}He + 5% Isobutane at 700 mbar



D. Santos et al., [arXiv:0810.1137]

MIMAC prototype – 10x10x18 cm3

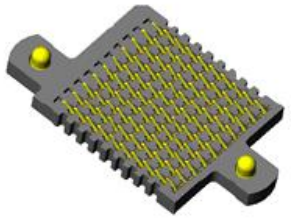




Aluminium Vessel
Pressure from Vacuum to 3 bars
Data : 512 channels via USB

512 channels board overview

Interface connector between board and detector



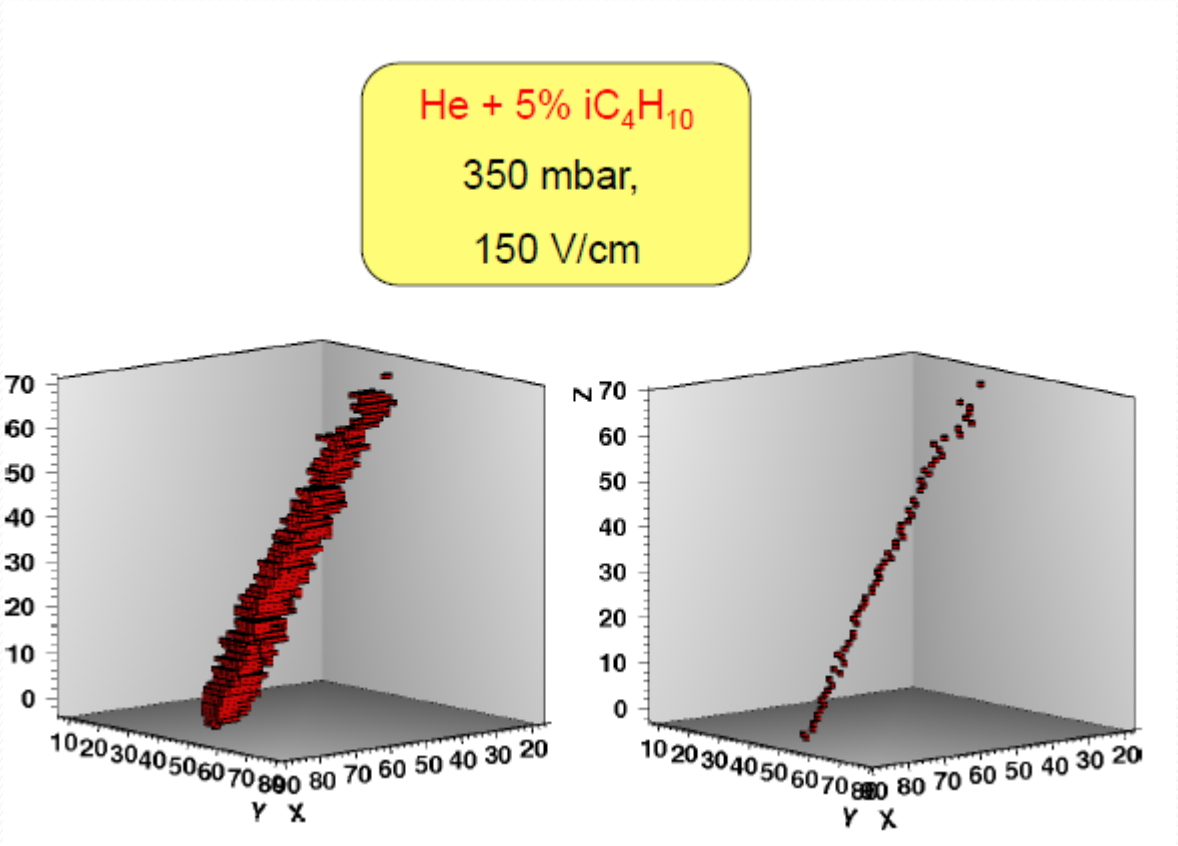
- 25 cm × 25 cm
- FPGA on the back side
- Discharge protection on each input
- 4 V @ 2100 mA
- 2 V @ 480 mA

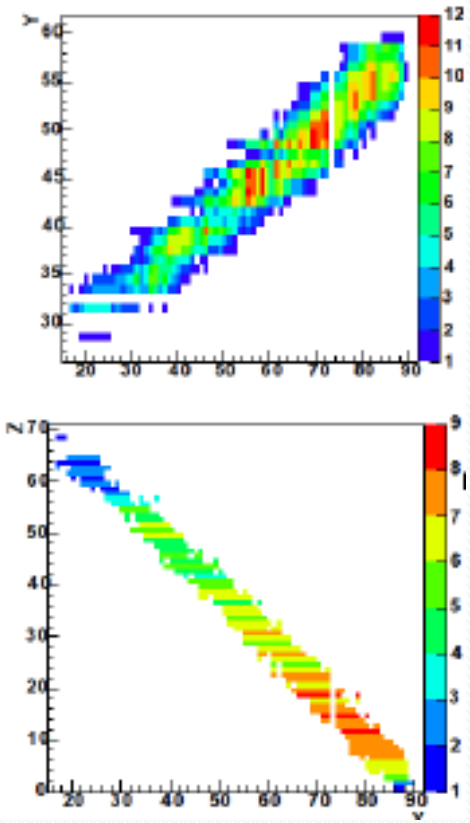
⇒ 9.4 W

- Auto-triggered system
- Grid signal is sampled at 50 MHz to have an **indirect** image of the energy deposit as a function of time
- First level event building done in FPGA
- Readout and slow control performed via a USB interface

3D track : **Alpha 5,5 MeV (222Rn)**

X-Y projection





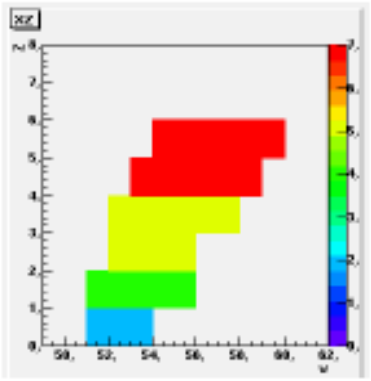
X-Z projection

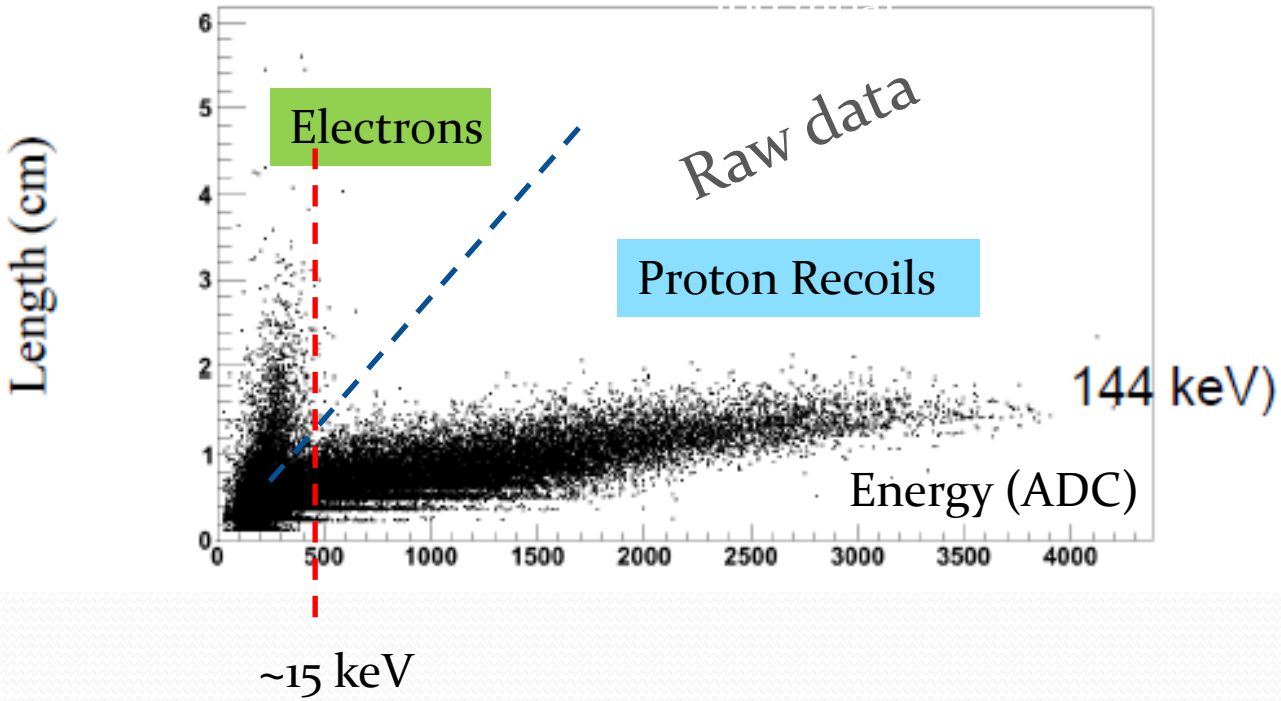
Recoils from 144 keV neutrons

Amande facility @ IRSN Cadarache
-> Monoenergetic neutron field

Isobutane 100 mbar

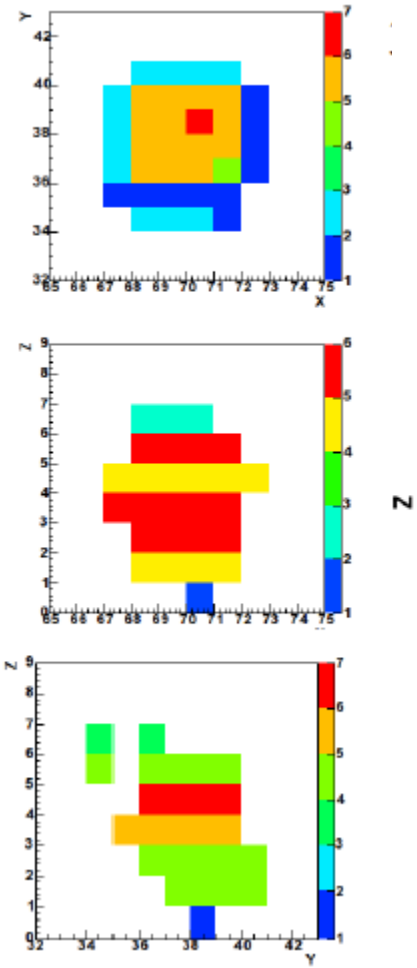
Track / lenght discrimination

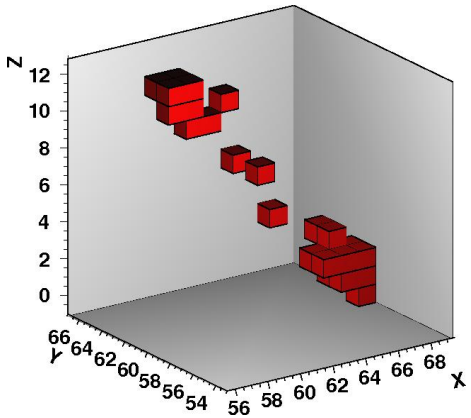




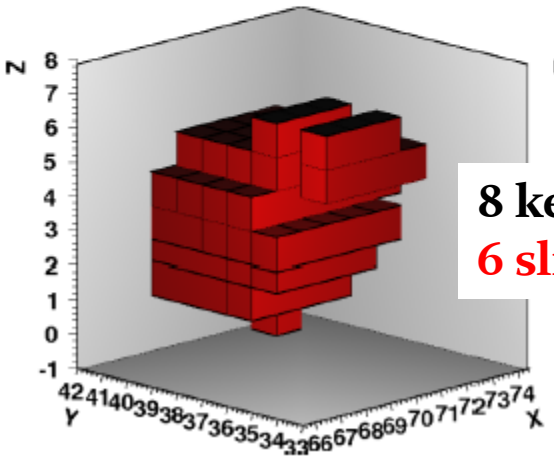
~15 keV

3D Track and discrimination in 350 mbar He + 5% iC4H10

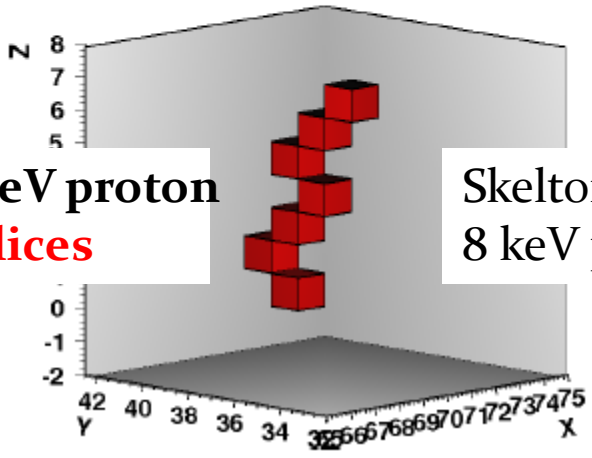




6 keV electron
12 slices

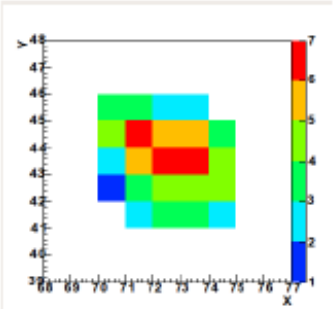


8 keV proton
6 slices



Skelton track
8 keV proton

^{19}F in 70 % CF4 + 30% CHF3

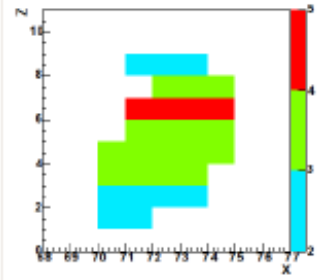


X-Y (anode)

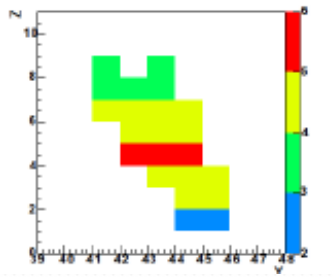
70 % CF_4 + 30% CHF_3

55 mbar,
170 V/cm

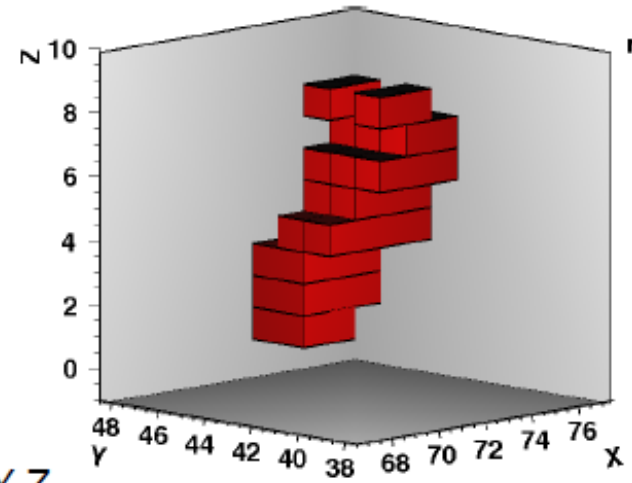
~40 keV (ionization), ~3 mm

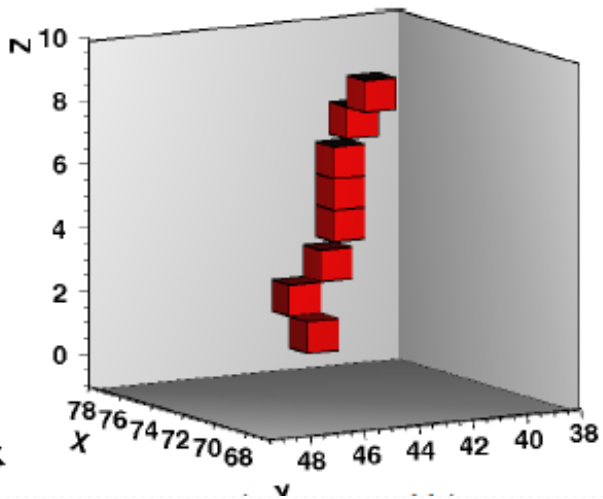


X-Z



Y-Z

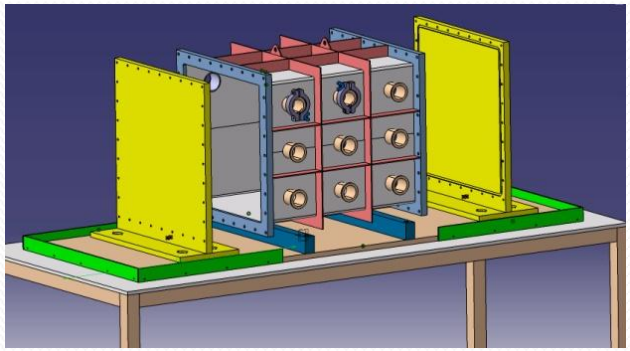




Outlook: short term

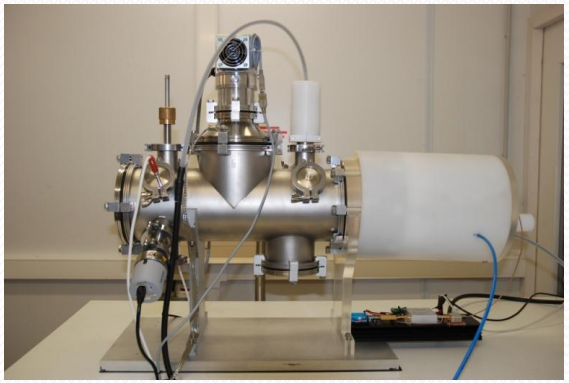
Installation @ Modane

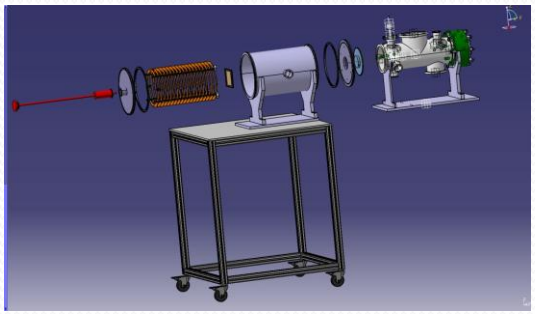
- Bi-chamber module
- 2 TPC : 10x10x25 cm3
- 2 x 512 channels
- February 2012 !



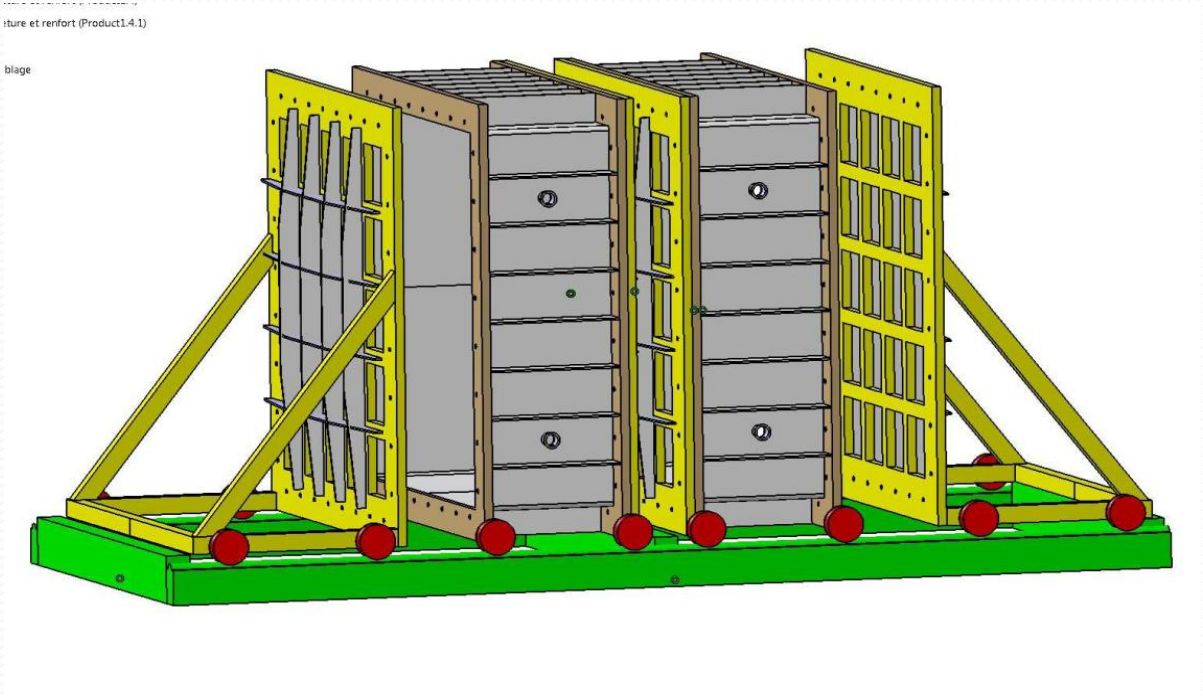
COMIMAC

- Compact / transportable ECR ion source
- First ion beam in October 2011
- Electron beam possible…
- Coupling with µM TPC under design
- Dedicated setup for gaz study :
  - Ion Quenching,
  - Drift velocity,
  - Diffusion, …





Outlook: long term
MIMAC M^3



MIMAC m3

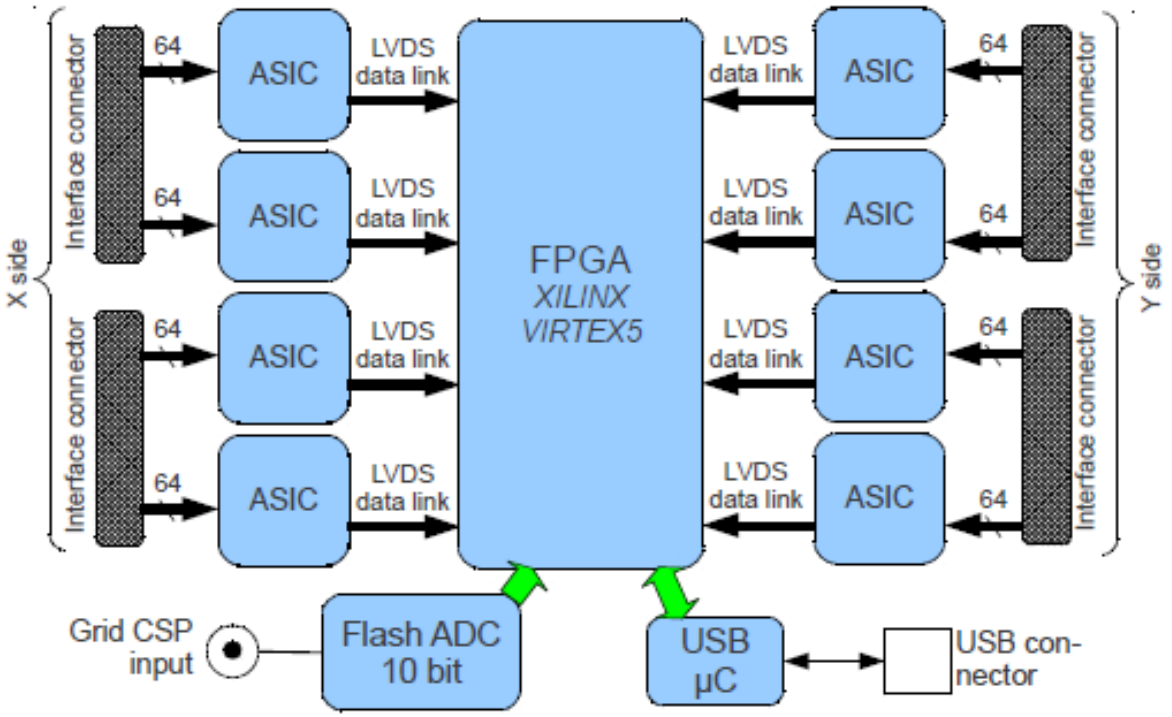
- 4 x 25 micromegas 200x200 mm active area
- 100 x 1024 channels

Conclusions

- Developments on Readout plane and assembly to get a performant detector
- The 10 × 10 cm^2 MIMAC prototype has been characterised
- It has shown good performance: gain, energy resolution and track reconstruction
- The tests with neutrons and with the MIMAC electronics validate fully the prototype.
- Crucial test: accurate measurement of background rejection in Modane and measurement of the intrinsic background of the detector
- Plans for increasing the volume

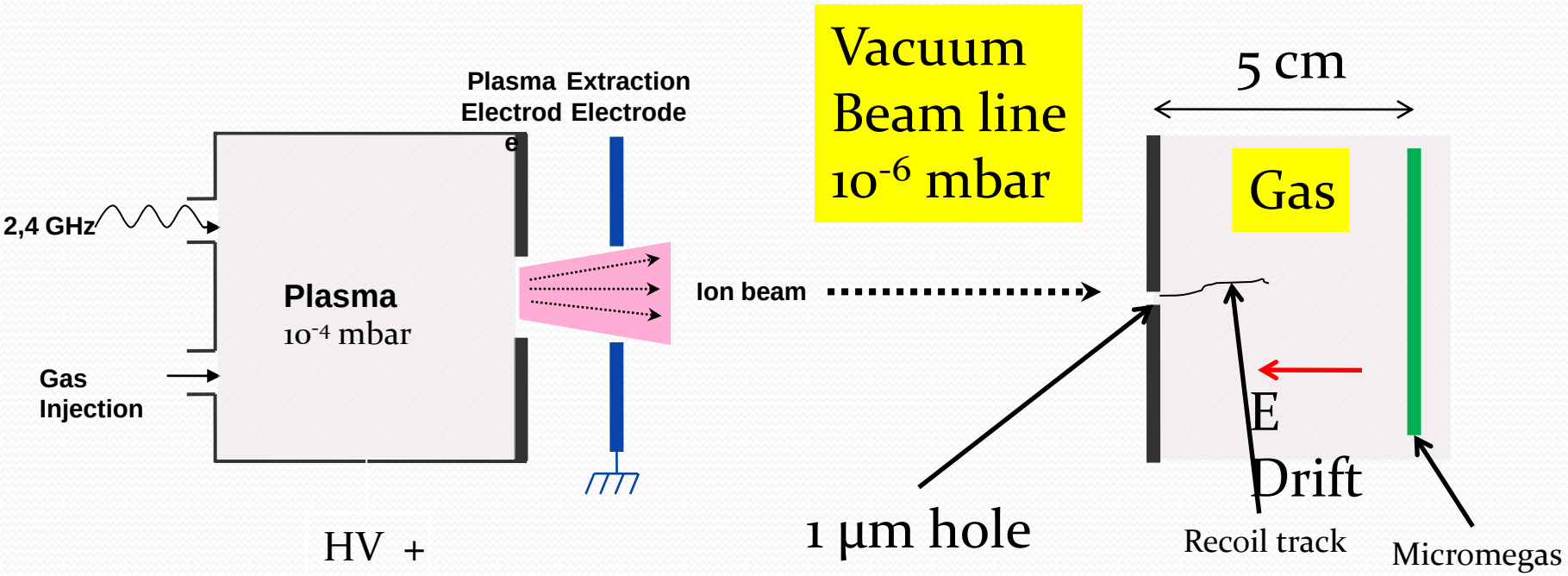
BACK UP

Acquisition board overview



- Auto-triggered system
- Grid signal is sampled at 50 MHz to have an **indirect** image of the energy deposit as a function of time
- First level event building done in FPGA
- Readout and slow control performed via a USB interface

Coupling a ECR ion source to Micromegas chamber



Ions are injected through 1 µm hole inside gas chamber

70 % CF4 + 30% CHF3 + 2 % Iso 50 mbar

Calibration from X rays: 3.05 keV (109Cd) et 5.96 keV (55Fe)