MIMAC

MIcro-tpc MAtrix of Chambers

A Large TPC for Directional Dark Matter detection

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(LPSC-Grenoble)

(Université Grenoble-Alpes -CNRS/IN2P3)

MIMAC (MIcro-tpc MAtrix of Chambers)

LPSC (Grenoble) : D. Santos, F.Naraghi , N. Sauzet (CDD)

-Technical Coordination, Gas circulation and detectors : **O. Guillaudin**

- Electronics : **G. Bosson, J. Bouvier, J.L. Bouly, L.Gallin-Martel, F. Rarbi**
- Data Acquisition: **T. Descombes**
- Mechanical Structure : **J. Giraud**
- COMIMAC (quenching) **:** **J-F. Muraz**

IRFU (Saclay): P. Colas, I. Giomataris

CCPM (Marseille): C. Tao, J. Busto

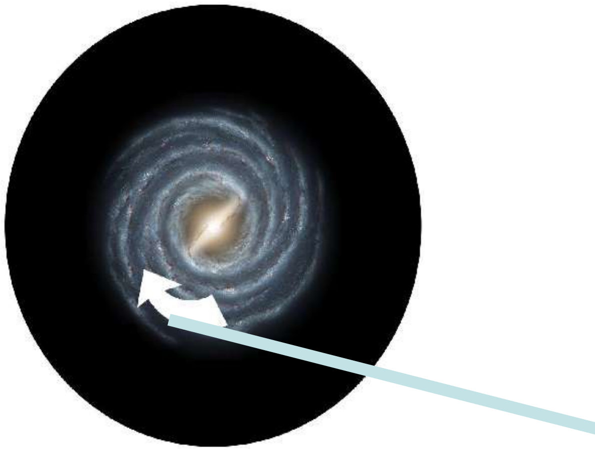
Tsinghua University (Beijing-China): C. Tao, I. Moric (post-doc), Y. Tao (Ph.D)

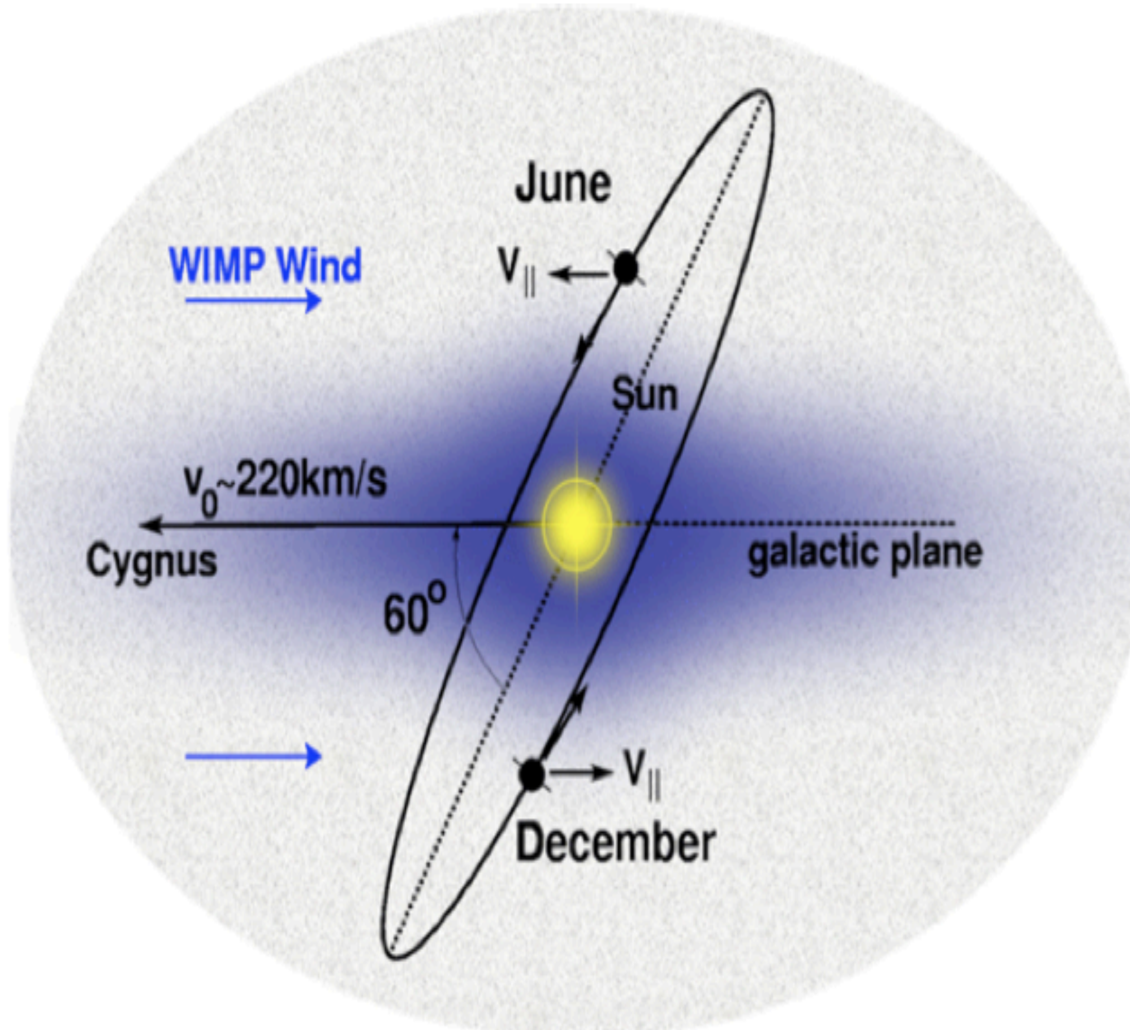
Prototype hosted in **IHEP (Beijing-China)**: **ZhiminWang , Changgen Yang**

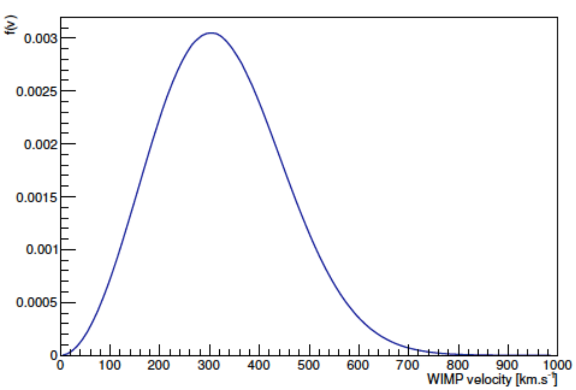
Neutron facility (AMANDE) :

IRSN (Cadarache): V. Lacoste, B. Tampon (Ph. D.)

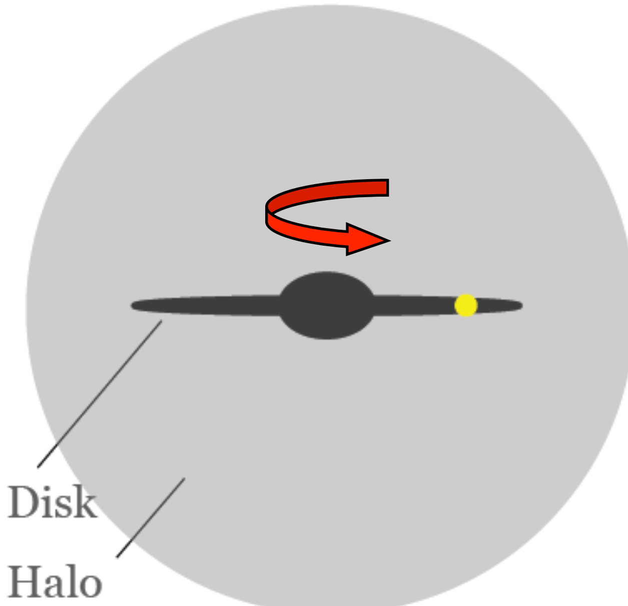
Directional detection: principle

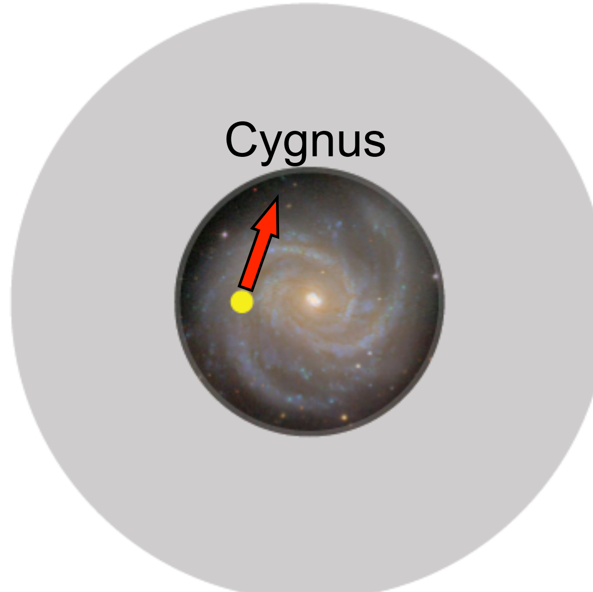






Directional detection : principle



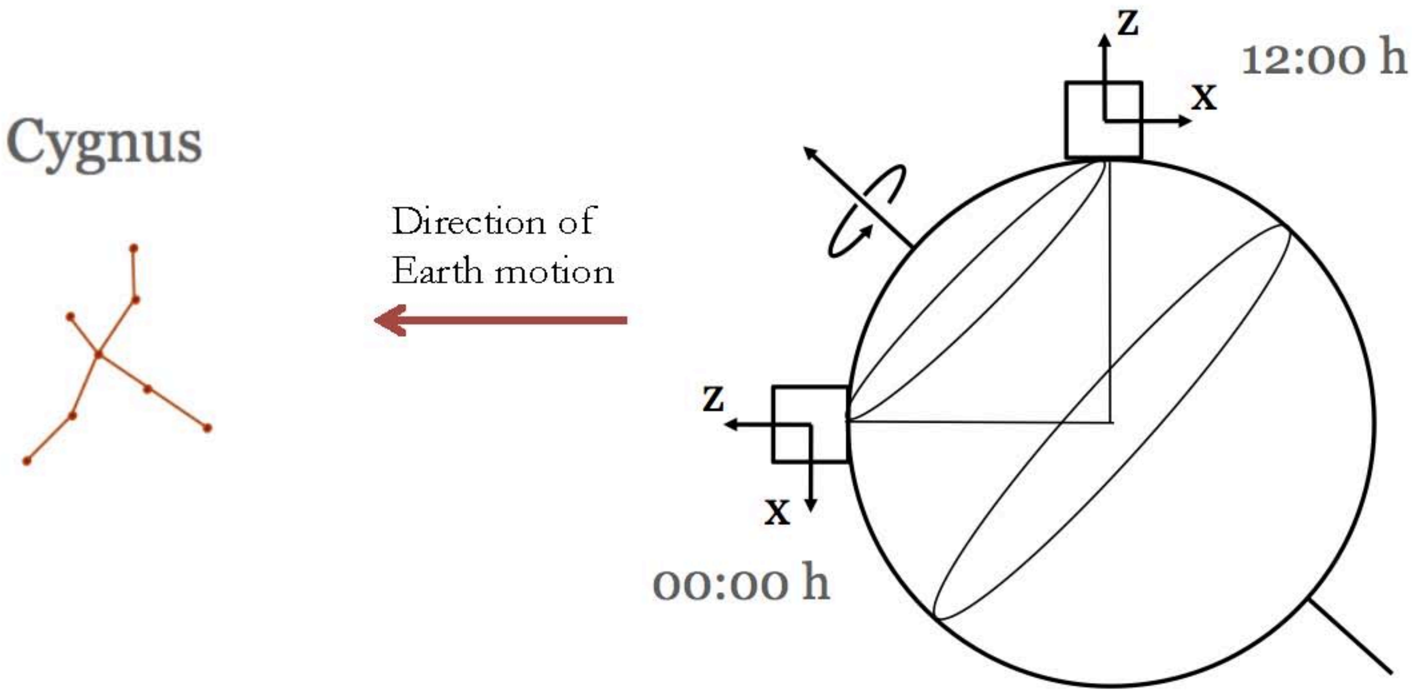


$<V_{rot}> \sim 220$ km/s

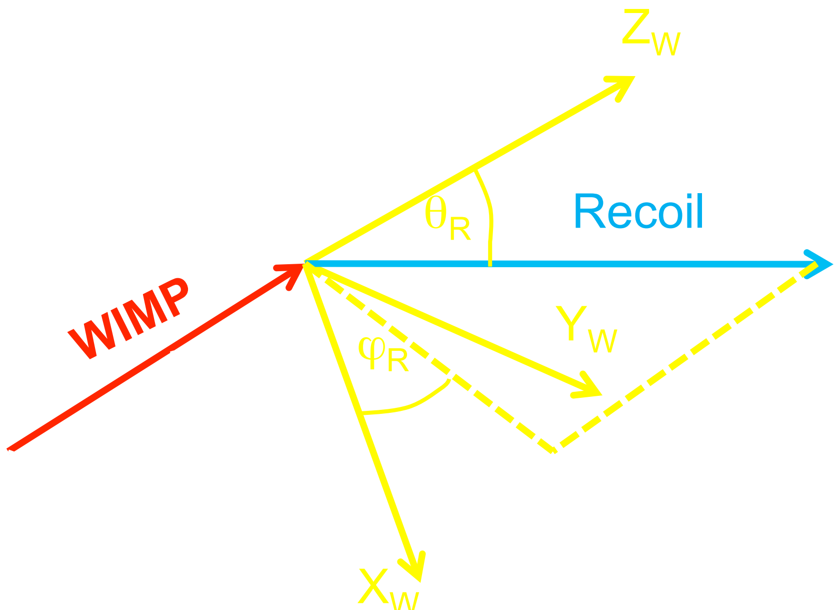
The signature, the only one (!), able to correlate the events in a detector to the galactic halo !!

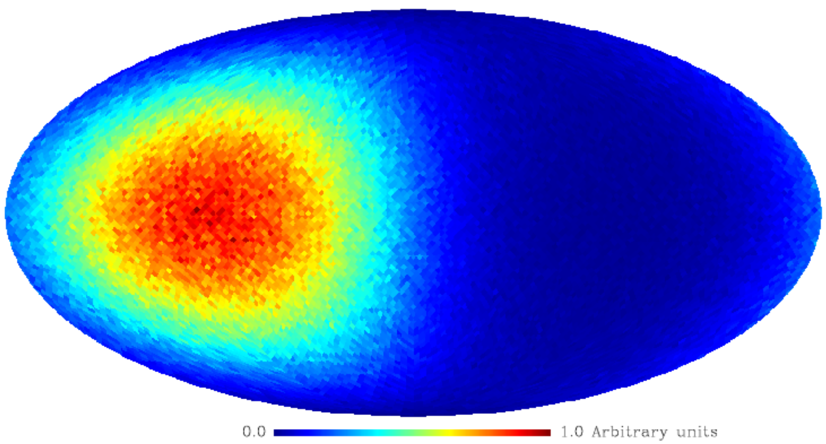
Angular modulation of WIMP flux

Modulation is sidereal (tied to stars) not diurnal (tied to Sun)



There are many "angles" for nuclear recoils…

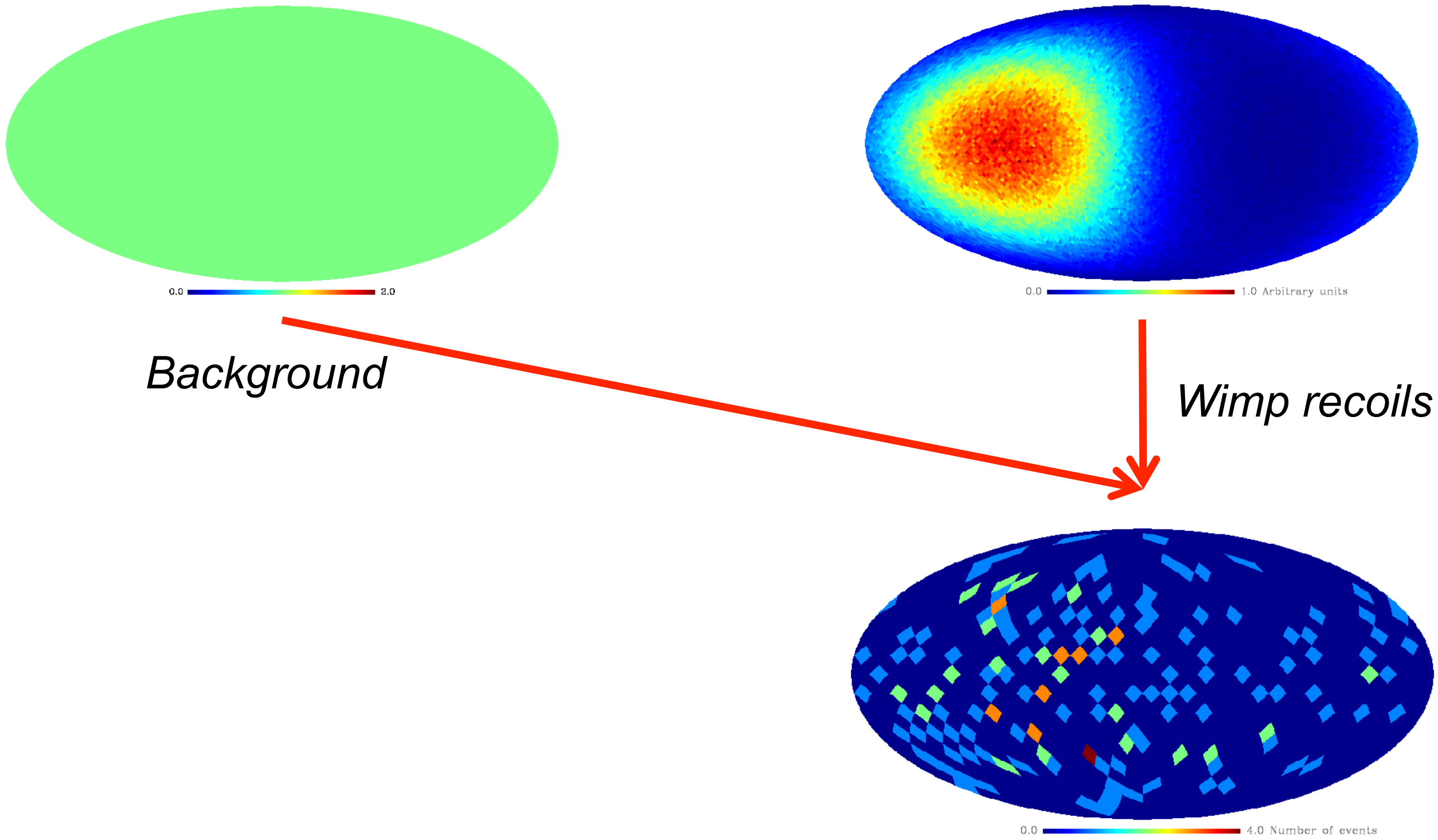




Map of recoils in galactic coordinates (HealPix)

10^8 Events with E_R = [5,50] keV

100 WIMP evts + 100 Background evts

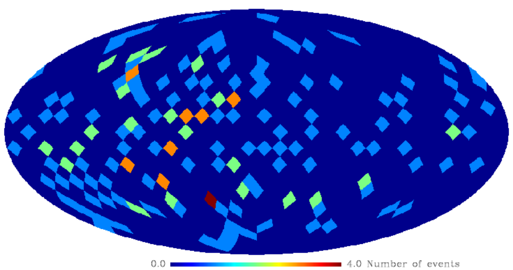


Phenomenology: Discovery

J. Billard *et al.*, PLB 2010
J. Billard *et al.*, arXiv:1110.6079

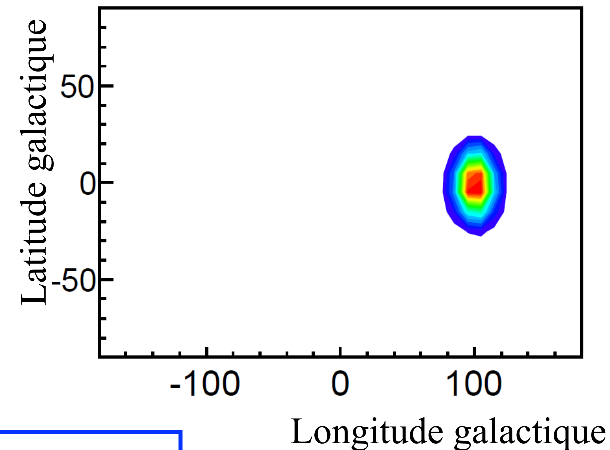
Proof of discovery: **Signal pointing toward the Cygnus constellation**

Blind likelihood analysis in order to establish the galactic origin of the signal



100 WIMP + 100 BKG

$$\mathscr{L}(\ell, b, m_\chi, \lambda)$$



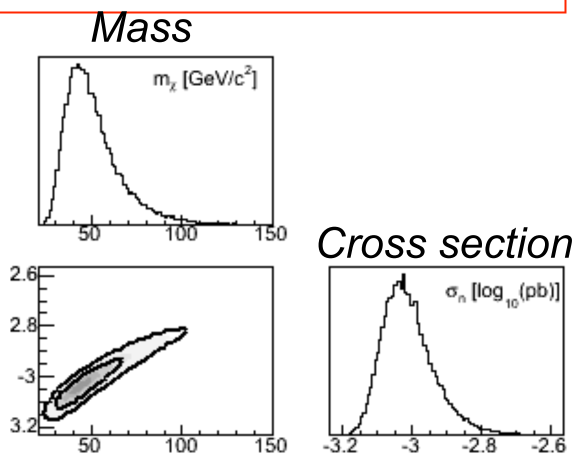
Strong correlation with the direction of the Constellation Cygnus **even with a large background contamination**

Directional Detection : identification

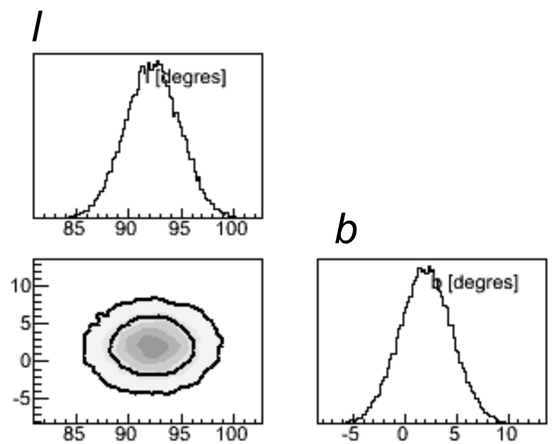
J. Billard *et al.*, PRD 2011

8 parameters simultaneouly constrained by only one 3D experiment

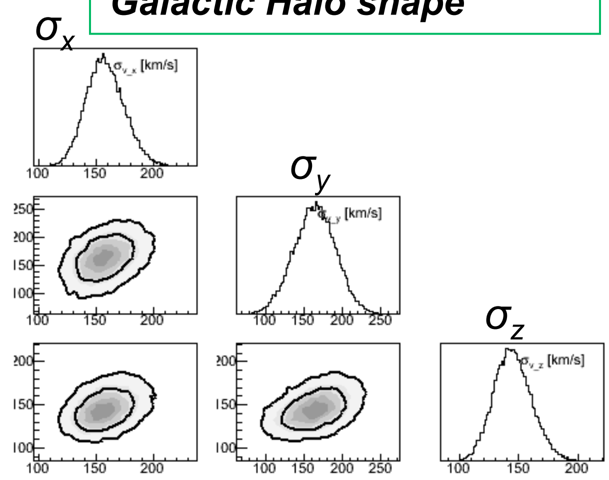
Mass – cross section



Dark Matter signature



Galactic Halo shape

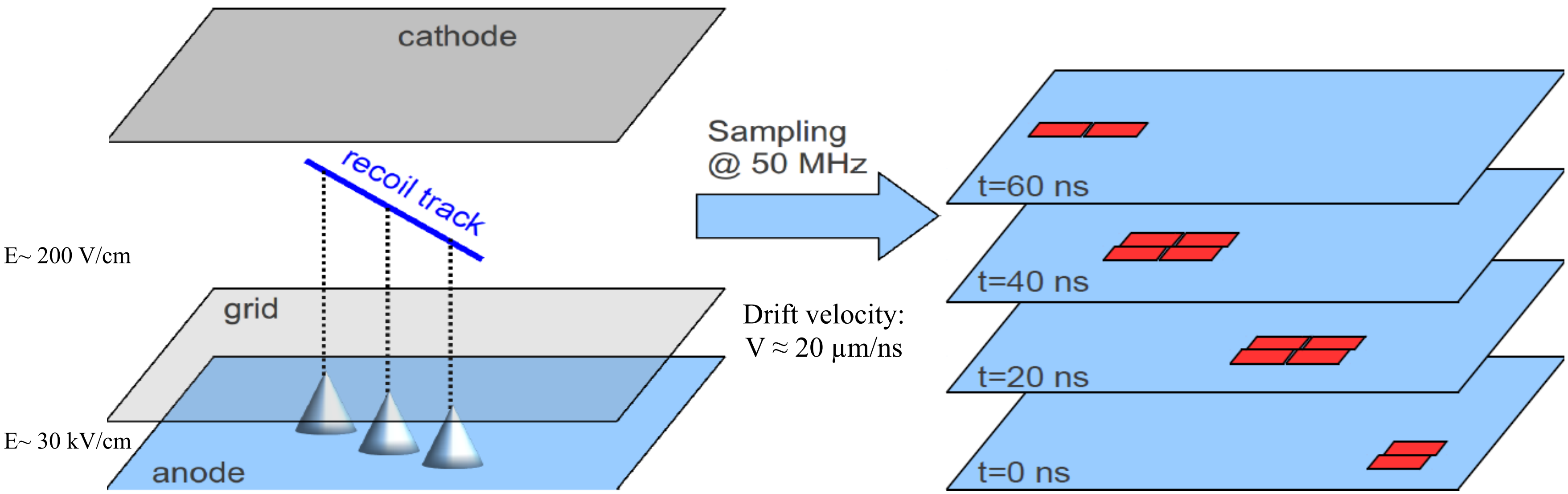


	m_χ (GeV/c^2)	$\log_{10}(\sigma_n$ (pb))	$\ell_\odot$ (°)	$b_\odot$ (°)	σ_x (km.s^{-1})	σ_y (km.s^{-1})	σ_z (km.s^{-1})	β	R_b (kg^{-1}year^{-1})
Input	50	-3	90	0	155	155	155	0	10
Output	$51.8^{+5.6}_{-19.4}$	$-3.01^{+0.05}_{-0.08}$	$92.2^{+2.5}_{-2.5}$	$2.0^{+2.5}_{-2.5}$	158^{+15}_{-17}	164^{+27}_{-26}	145^{+14}_{-17}	$-0.073^{+0.29}_{-0.18}$	10.97 ± 1.2

Directional experiments around the world

CYGNUS 2017- International Workshop
Xichang, Sichuan (CHINA) – June 13th- 15th 2017

MIMAC: Detection strategy

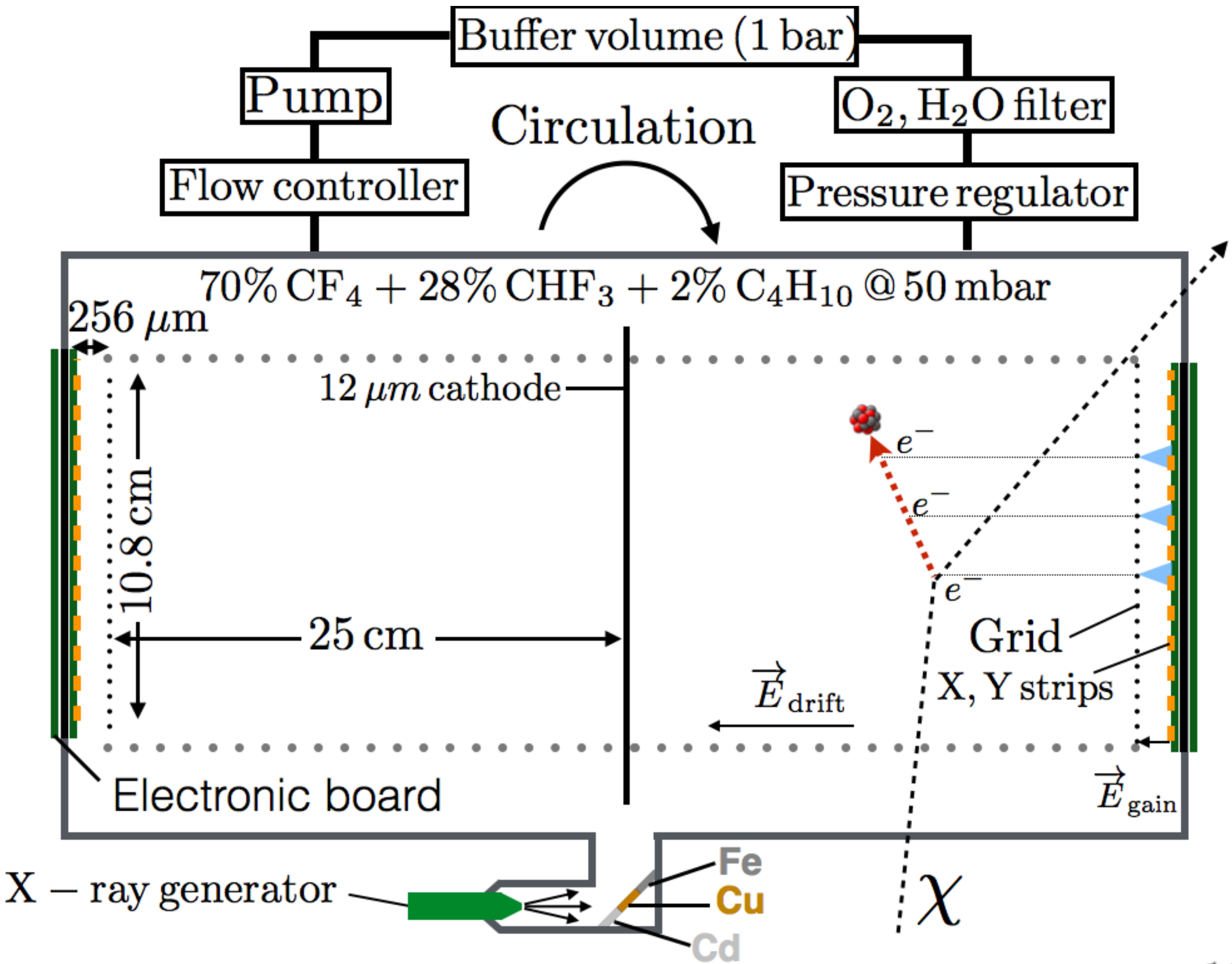


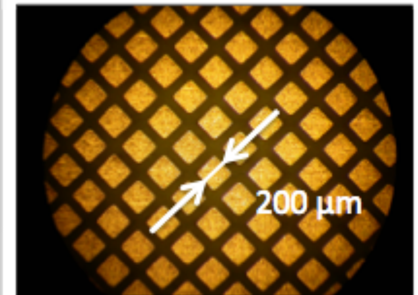
Scheme of a MIMAC µTPC *Evolution of the collected charges on the anode*

Measurement of the ionization energy:

Charge integrator connected to the mesh coupled to a FADC sampled at 50 MHz

MIMAC-bi-chamber module prototype





Micromegas 10x10 cm², designed by IRFU- Saclay (France)

MIMAC Target: ^{19}F

- Light WIMP mass
- Axial coupling

MIMAC (bi-chamber module)at Modane Underground Laboratory (France)
since June 22nd 2012.
Upgraded in June 2013, and
in June 2014.

-working at 50 mbar
(CF_4+28% CHF_3 + 2% C_4H_{10})

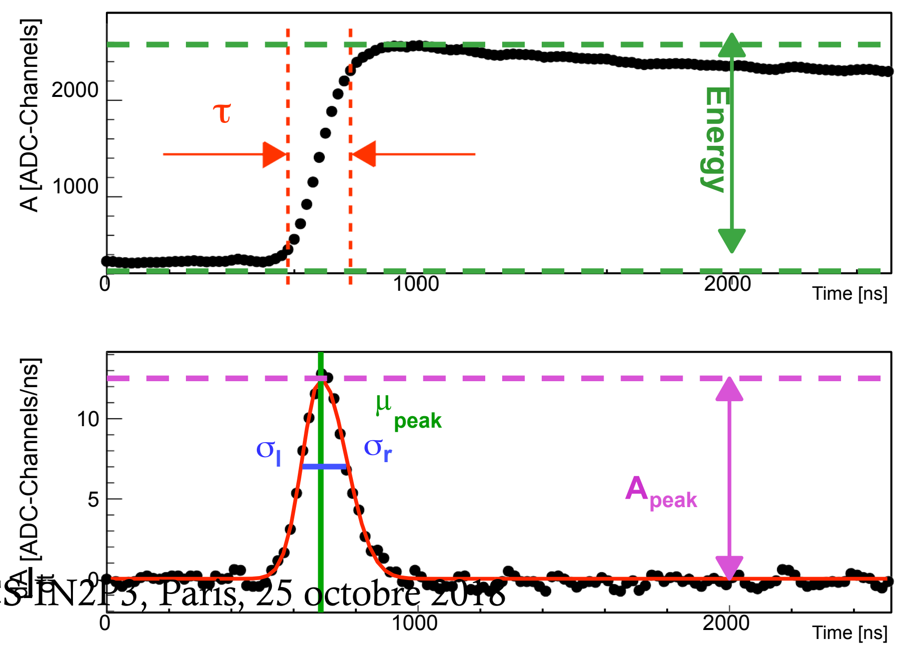
-in a permanent circulating mode
-Remote controlled
and commanded
-Calibration control twice per week

Many thanks to LSM staff

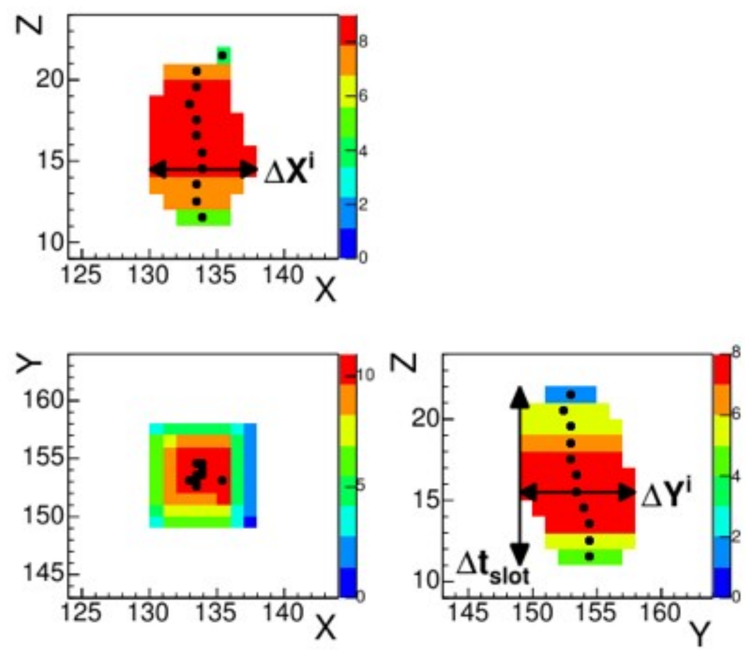
MIMAC readout

Dedicated fast electronics (self-triggered)
Based on the MIMAC chip (64 channels)

preamplifier signal + FADC: Energy



3D - track



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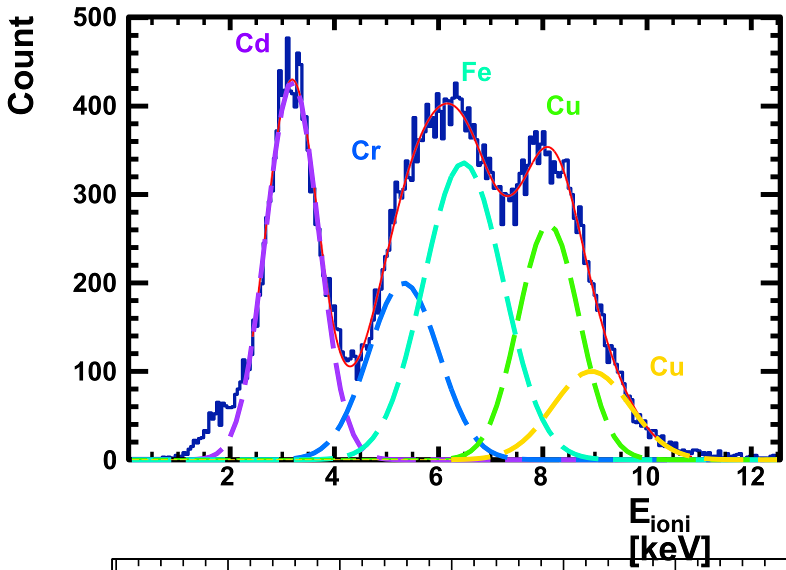
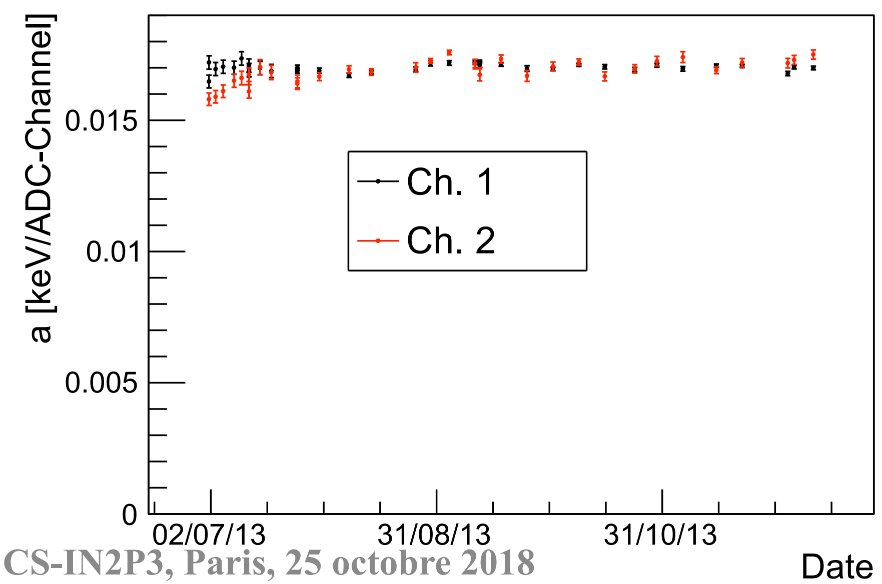
Detector calibration
(not at the maximum gain!)

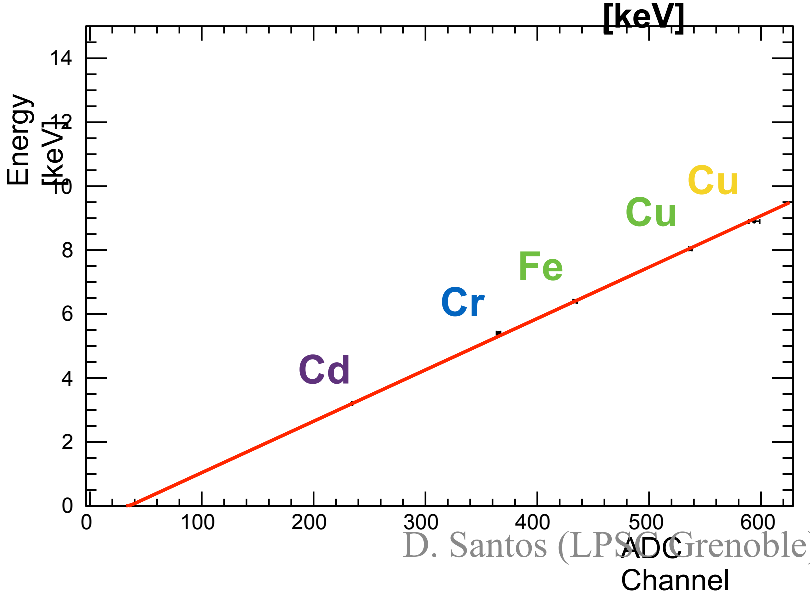
Calibration: (once a week)

X-ray generator producing fluorescence photons from Cd, Fe, Cu foils.
Threshold ~ 1 keV

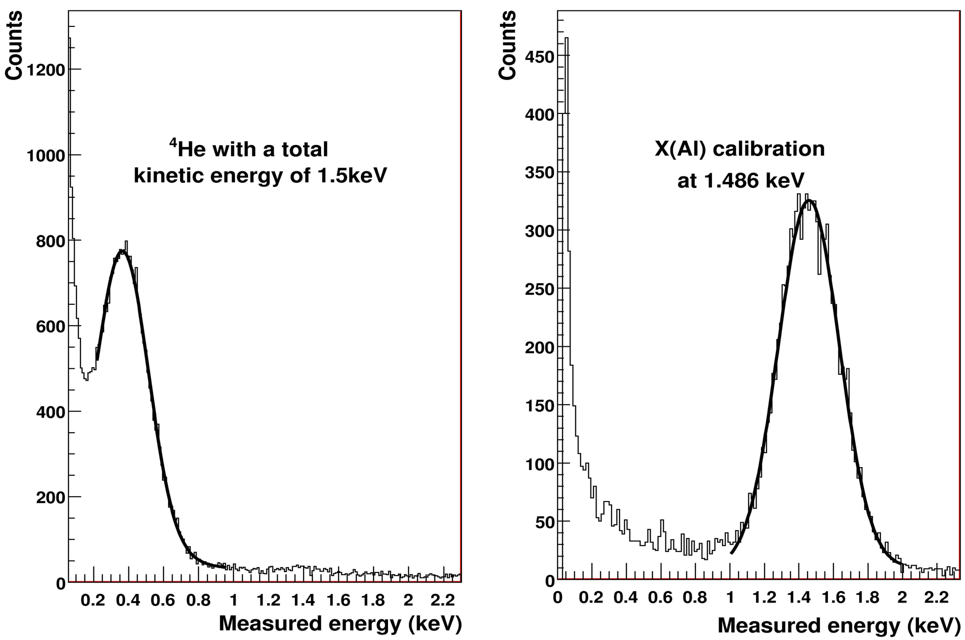
Circulation system:
Excelent Gain stability in time

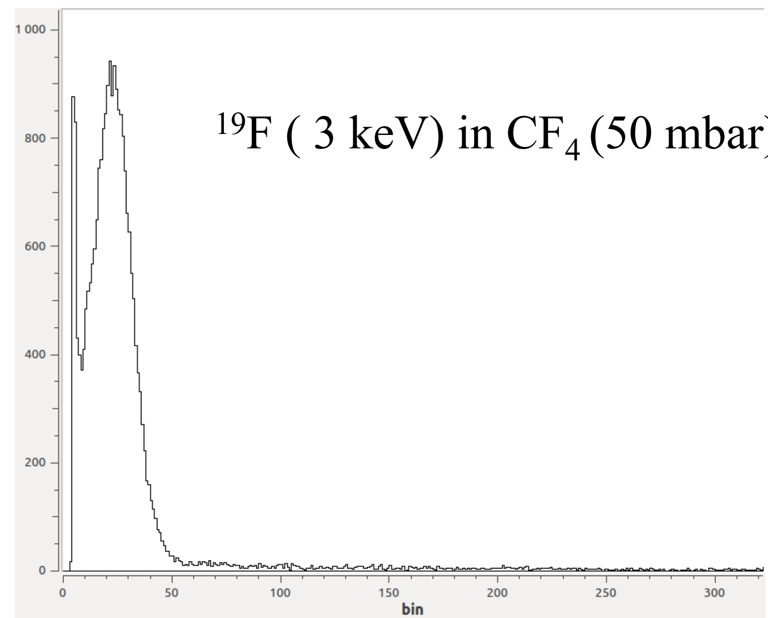






Ionization Quenching Factor Measurements at LPSC-Grenoble

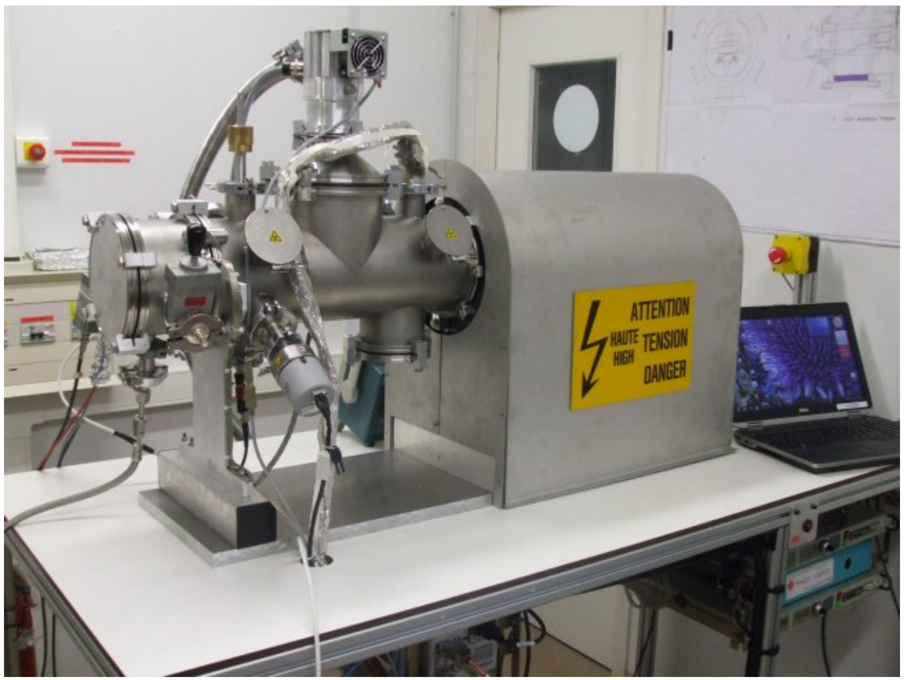


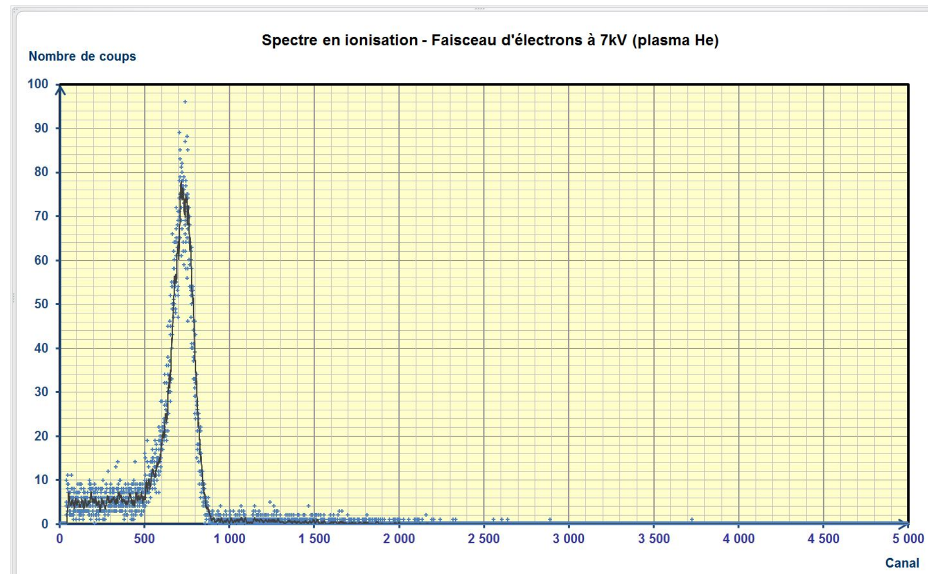


^{19}F (3 keV) in CF_4 (50 mbar)

Portable Quenching Facility (COMIMAC)

(Electrons and Nuclei of known energies)

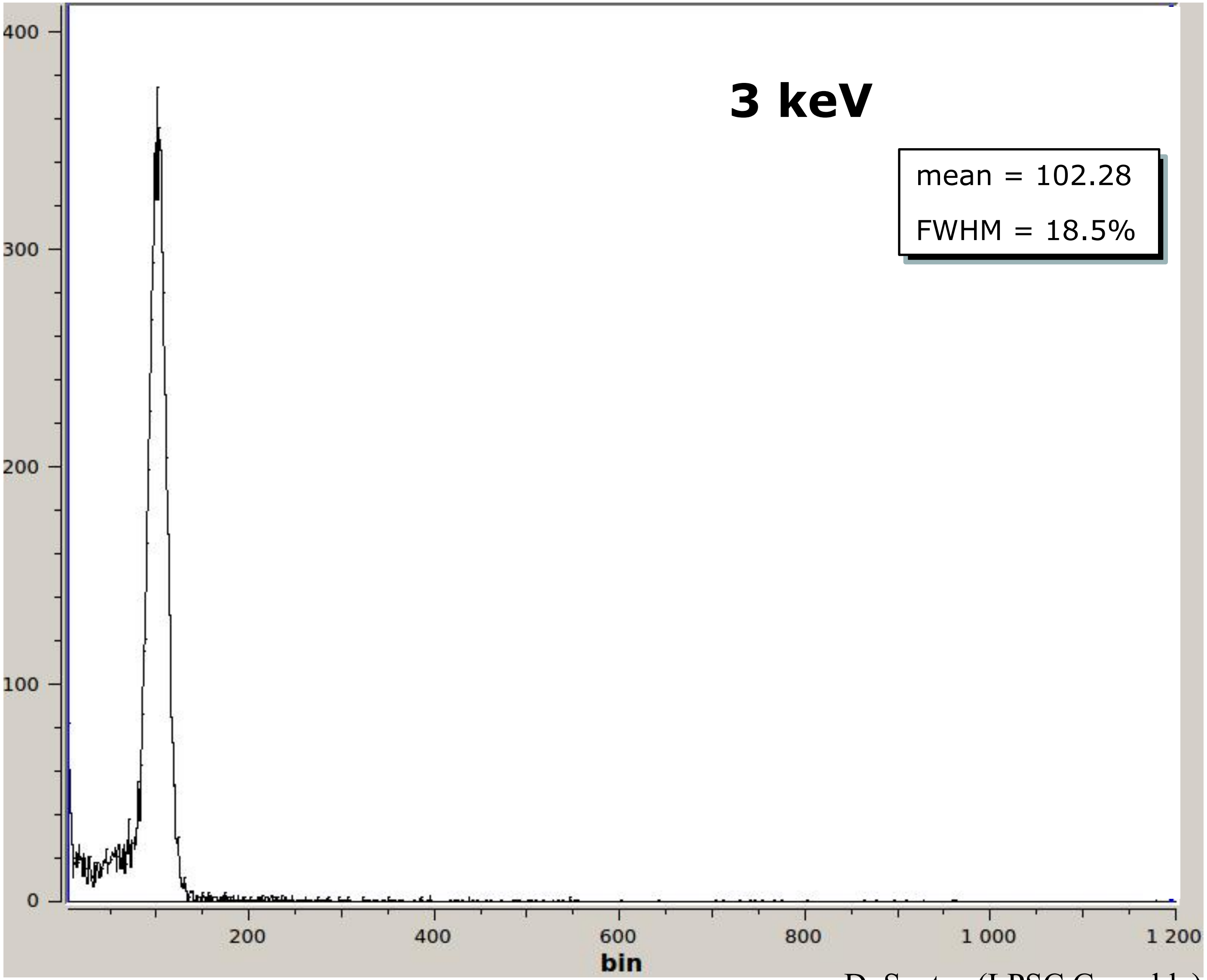




Electrons of 7 keV

In a gas detector the IQF depends strongly on the quality of the gas.
The IQF needs to be measured periodically (in-situ) in a long term run experiment.

Electrons Performance



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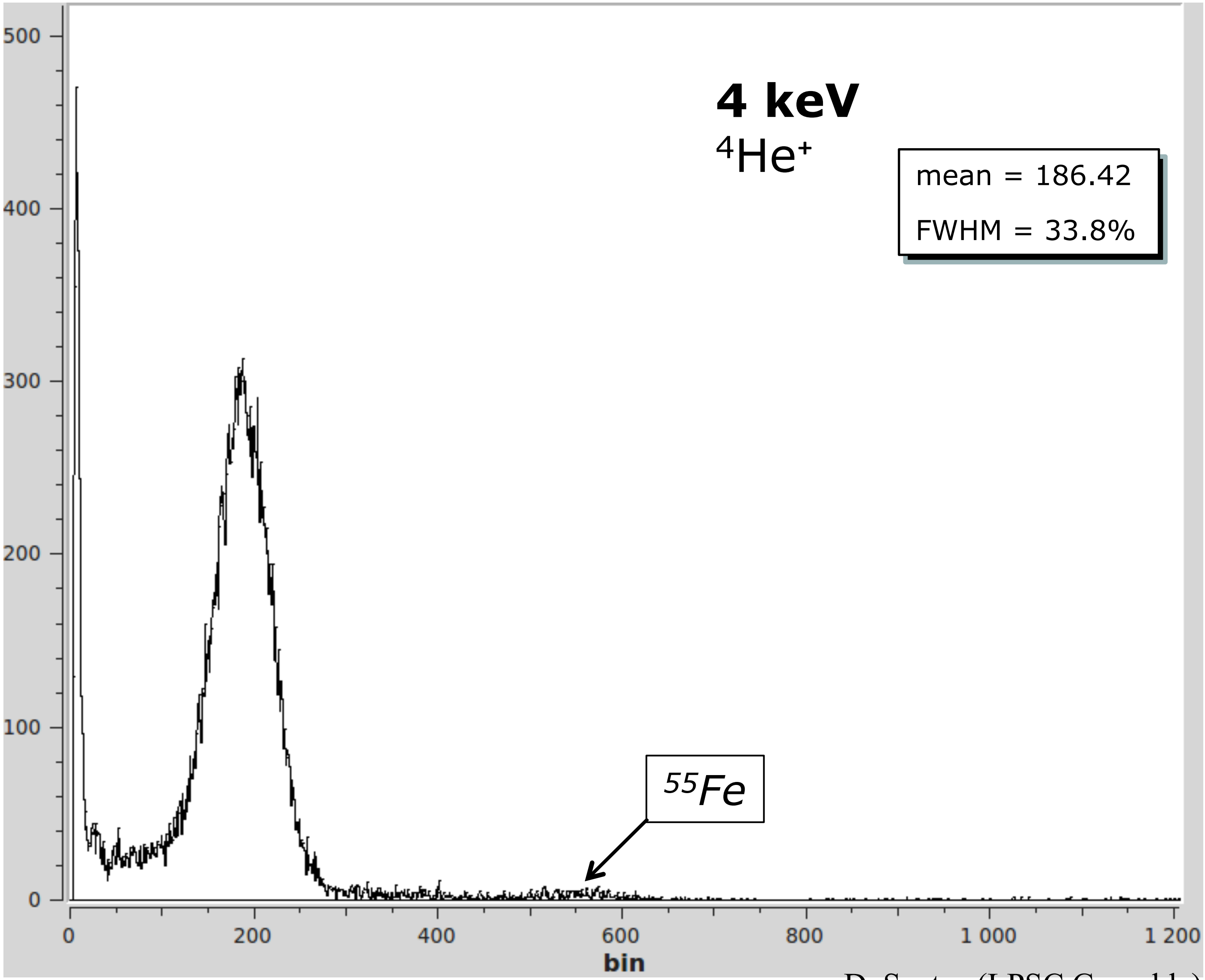
Ions Performance



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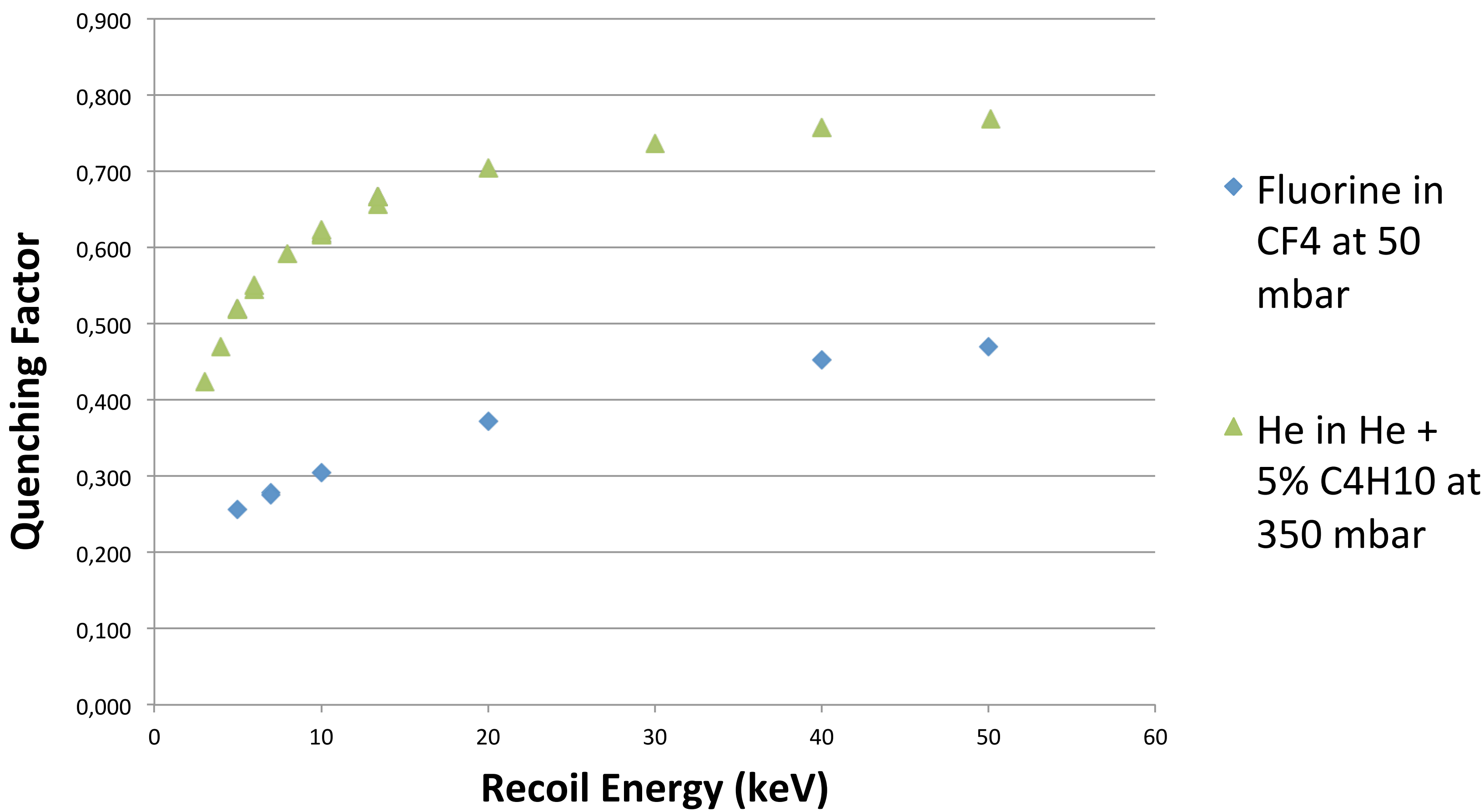
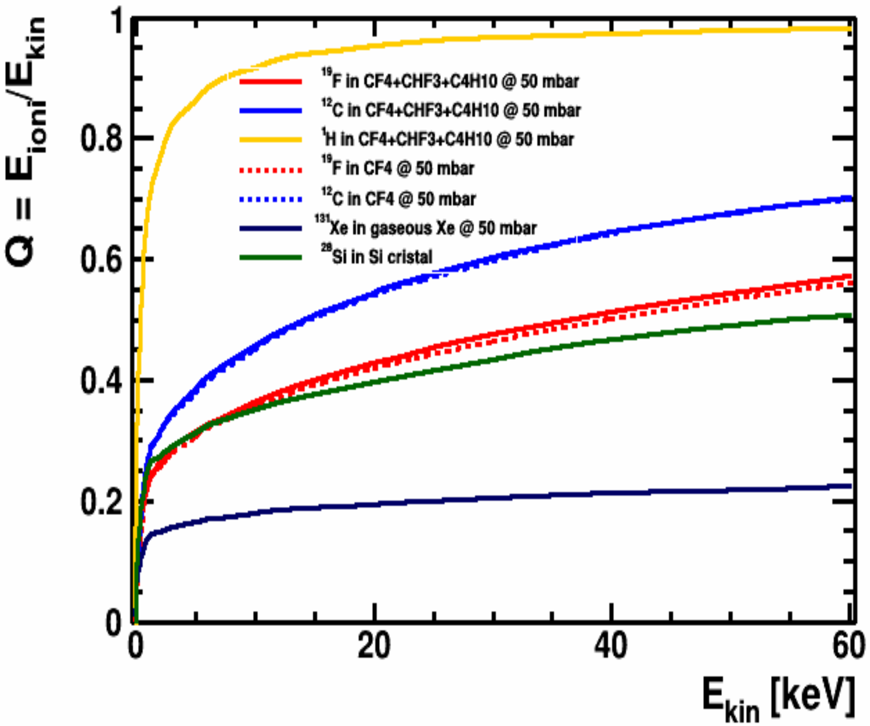
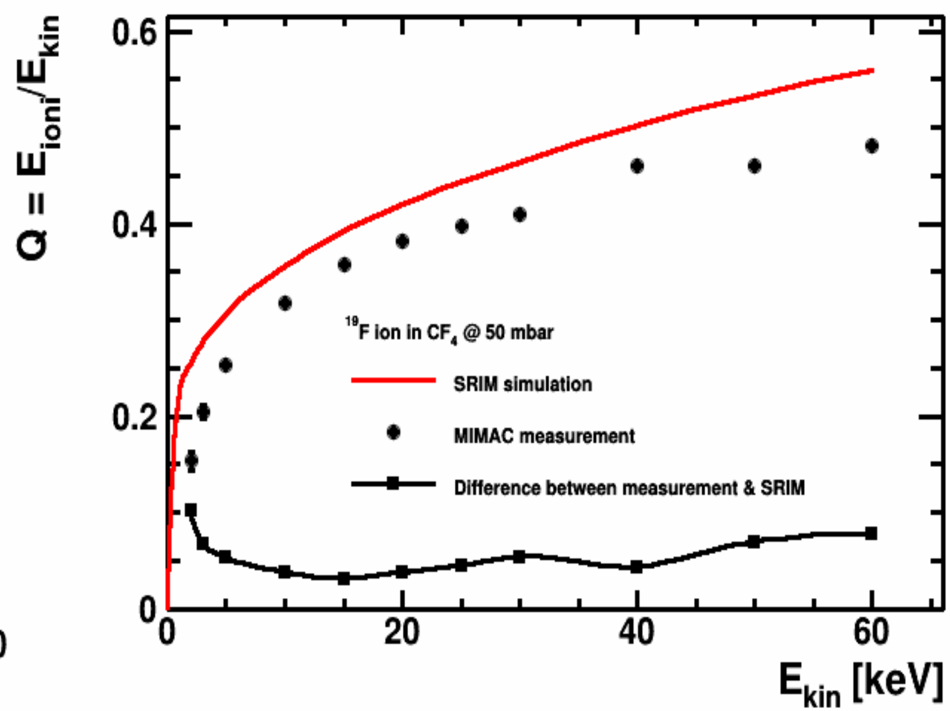
Ionization Quenching Factor for Fluorine in pure CF4 at 50 mbar



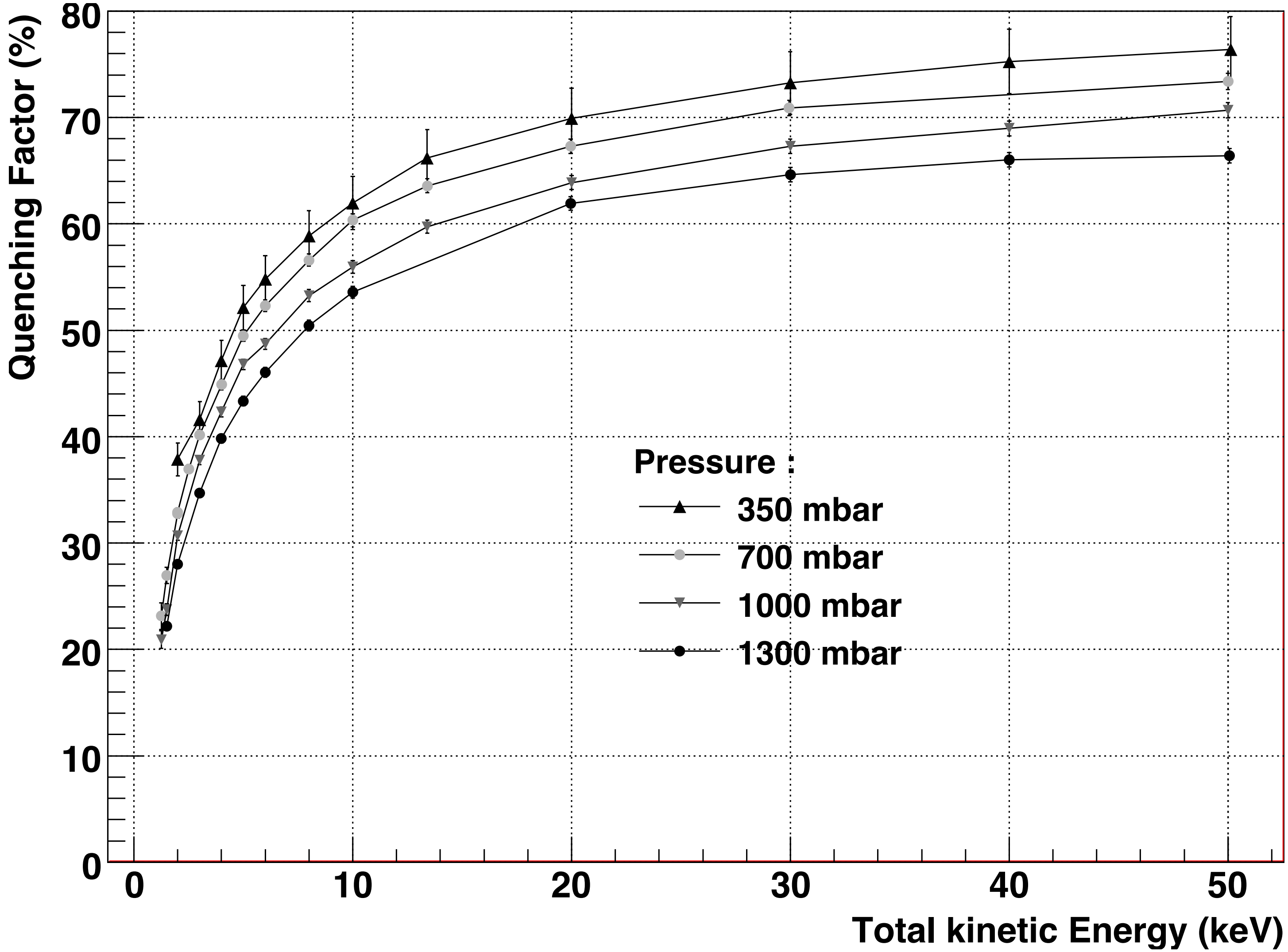
Ionization Quenching Factors

Simulations and Measurements (LPSC)

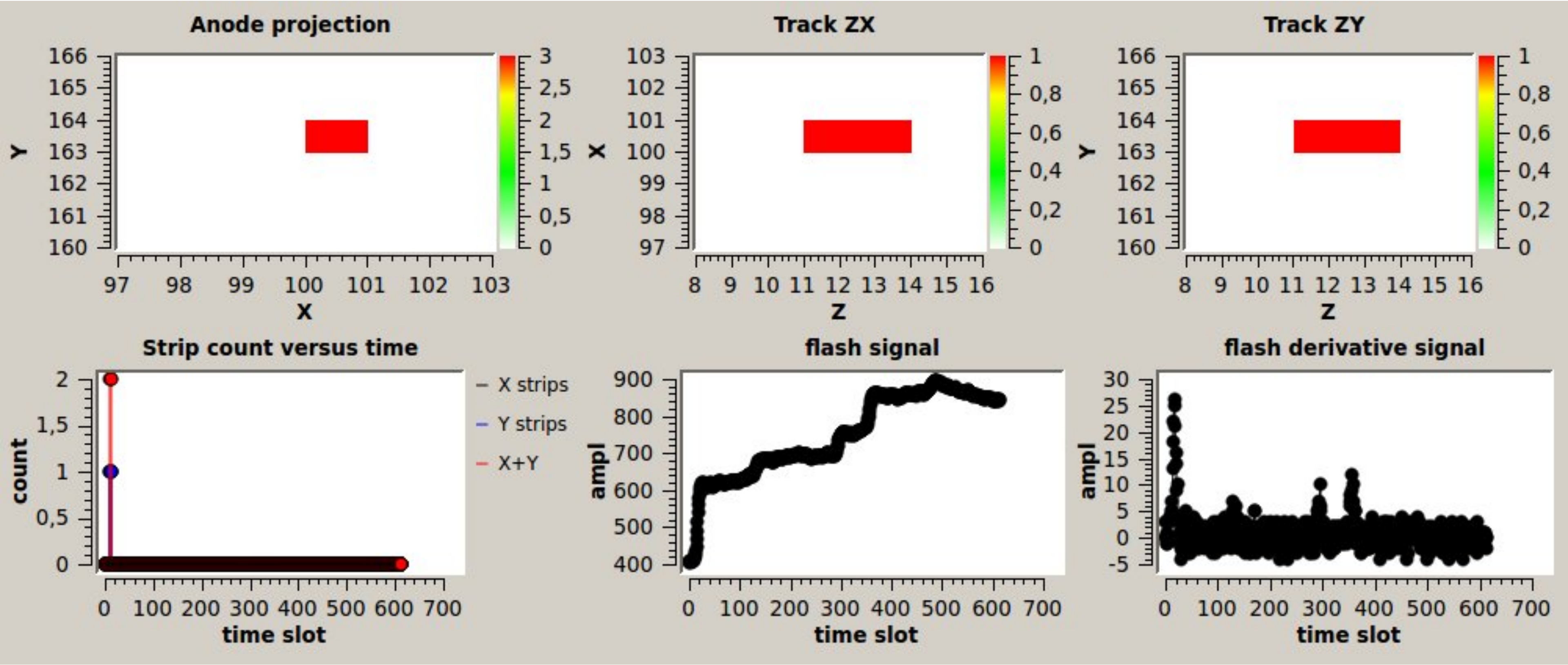




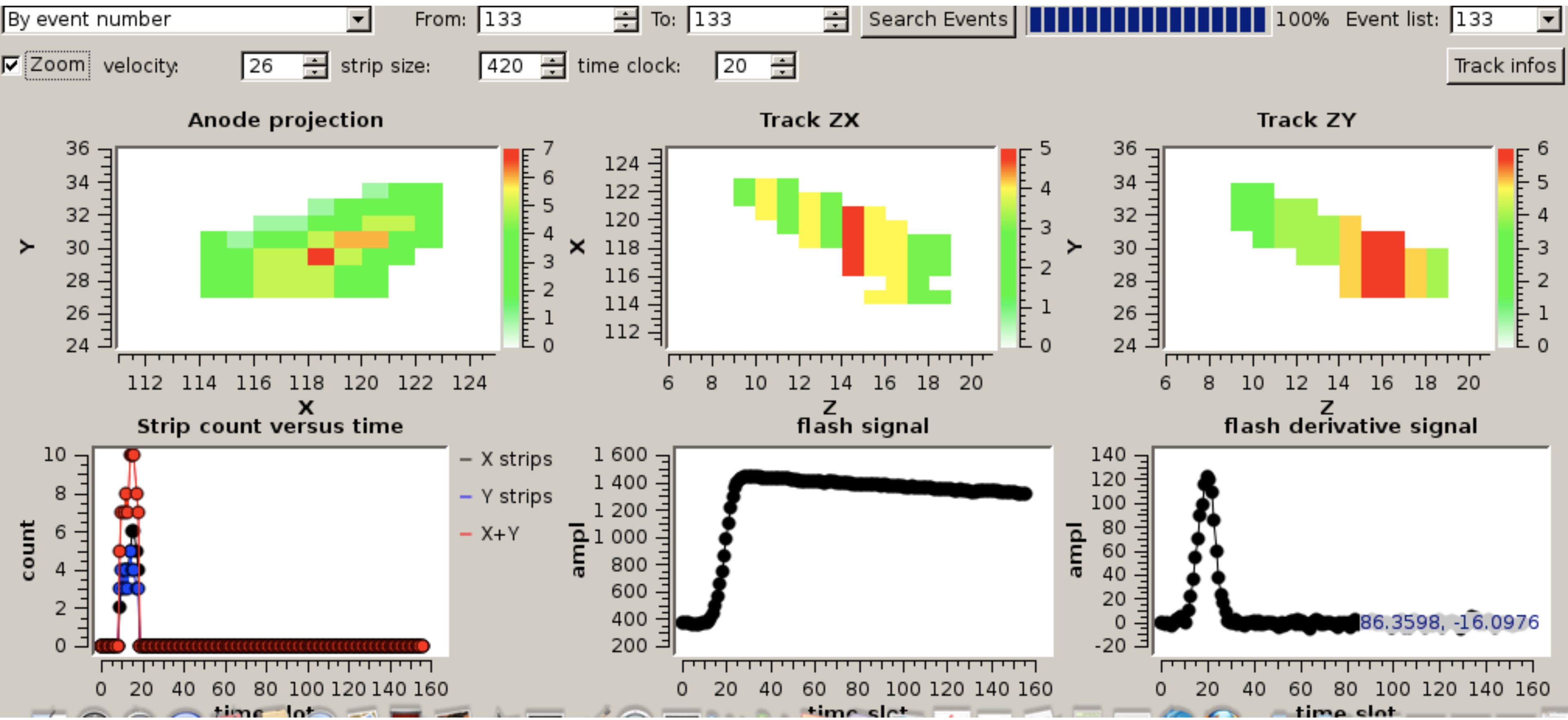
IQF in ^4He + 5% isobutane for different pressures!!



An Electron event (18 keV)

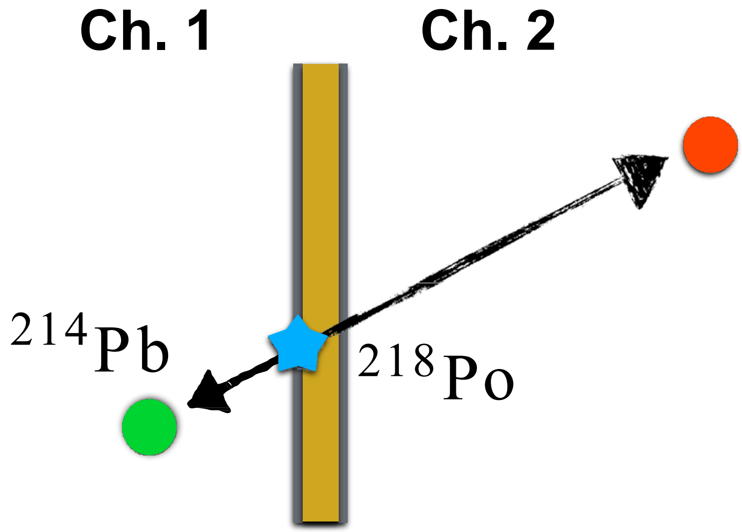


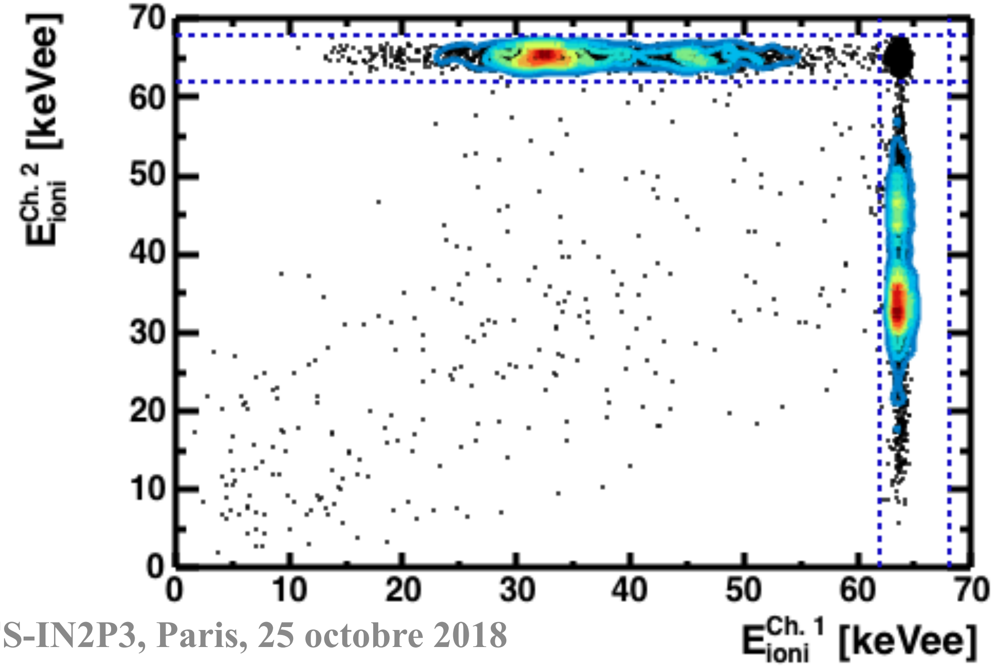
A “recoil event” (~ 34 keVee)



RPR: « In coincidence » events

Chamber coincidences:

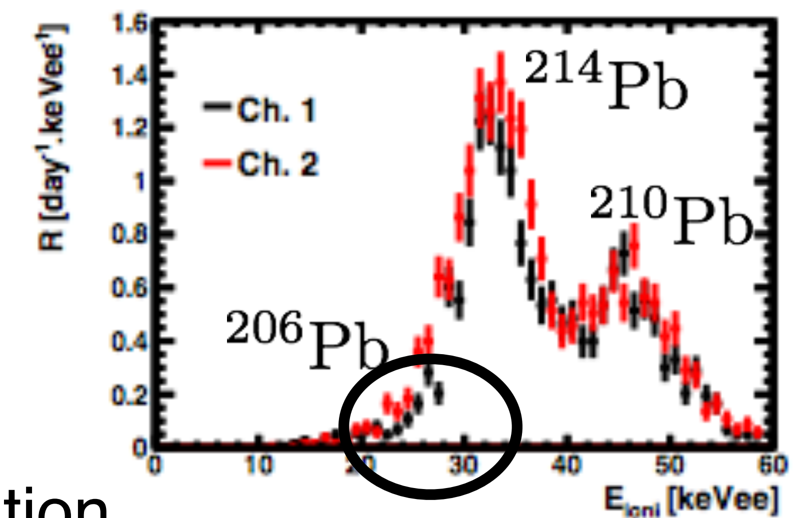




3D tracks from nuclear recoil of radon progeny detection

First detection of 3D tracks of Rn progeny

Nuclear recoil spectra



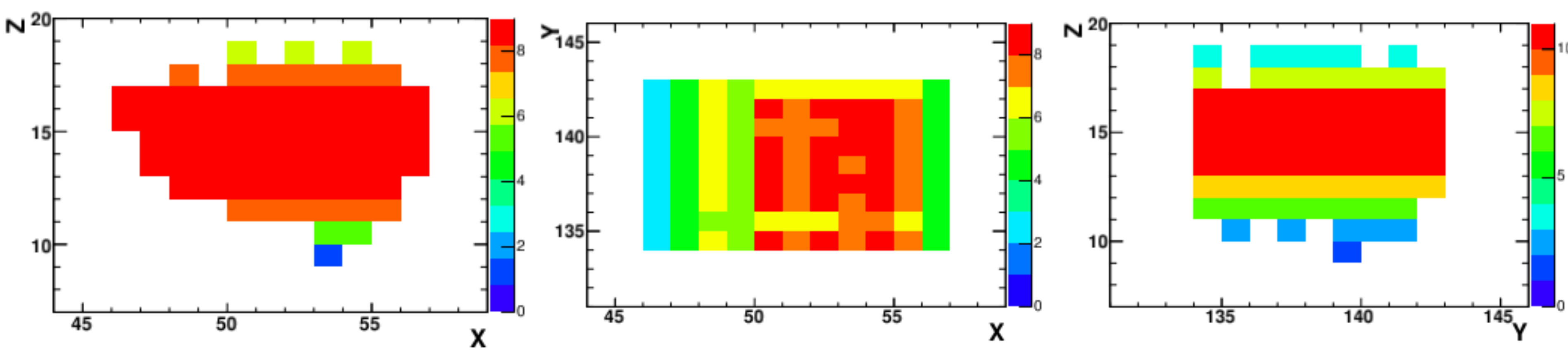
$R_{^{206}\mathrm{Pb}} \sim 0.25\,\mathrm{day}^{-1}.\mathrm{keVee}^{-1}$

Electron/recoil discrimination

Mesure: $\begin{cases} E_{ioni}(^{214}\mathrm{Pb}) = 32.90 \pm 0.16\,\mathrm{keVee} \\ E_{ioni}(^{210}\mathrm{Pb}) = 45.60 \pm 0.29\,\mathrm{keVee} \end{cases}$

First measurement of 3D nuclear-recoil tracks coming from radon progeny

⟶ MIMAC detection strategy validation

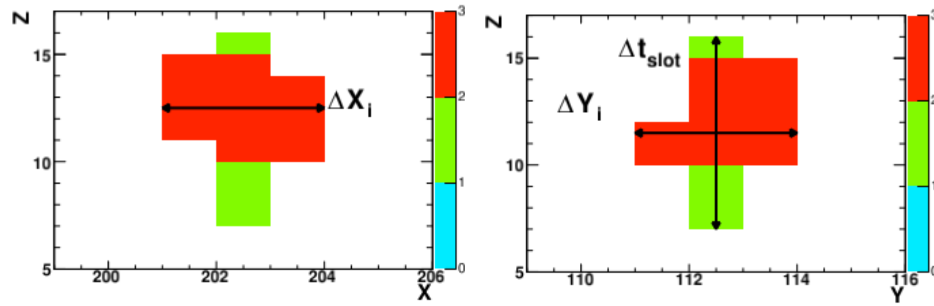


RPR events occur at different positions in the detector…

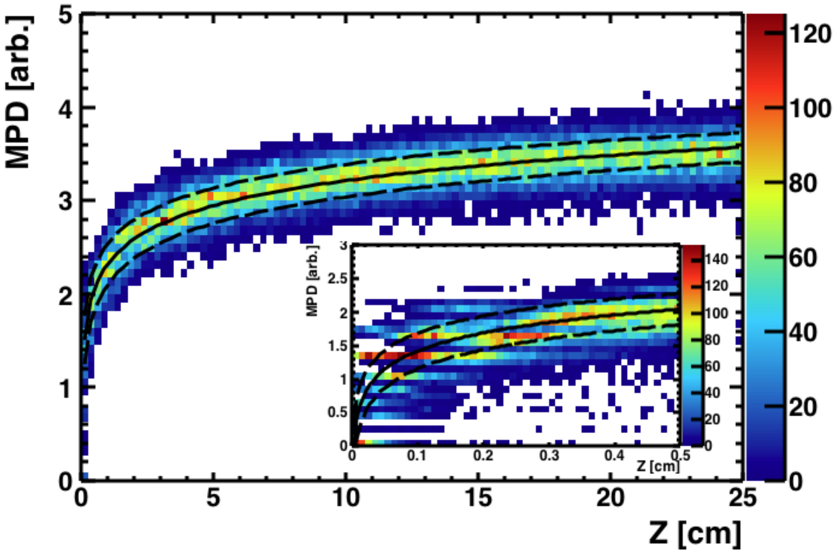
$$z_0 \longleftrightarrow \text{Diffusion}$$

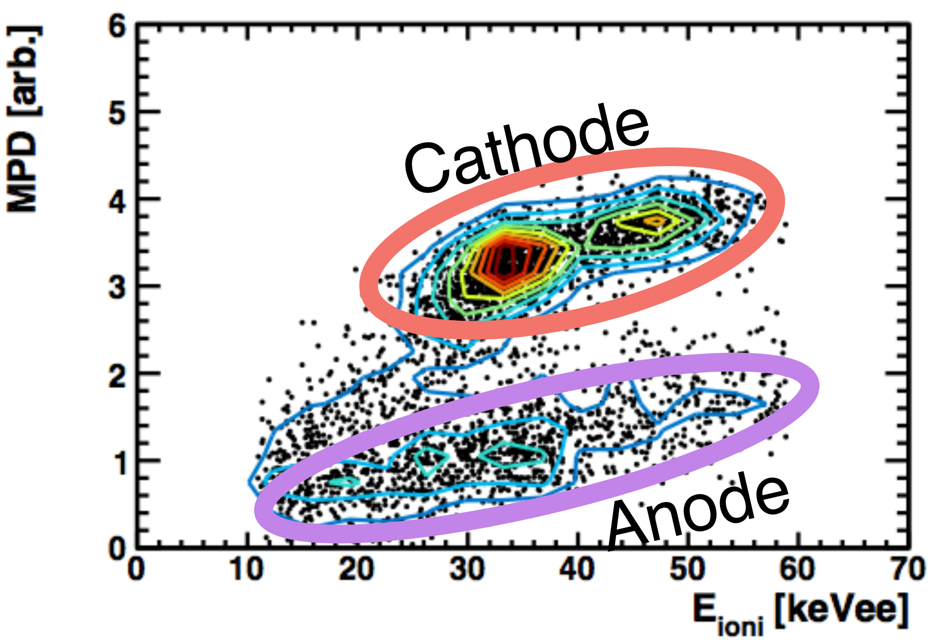
$$\begin{cases} D_T = 237.9\,\mu\text{m}/\sqrt{\text{cm}} \\ D_L = 271.5\,\mu\text{m}/\sqrt{\text{cm}} \end{cases}$$

« Anode » event

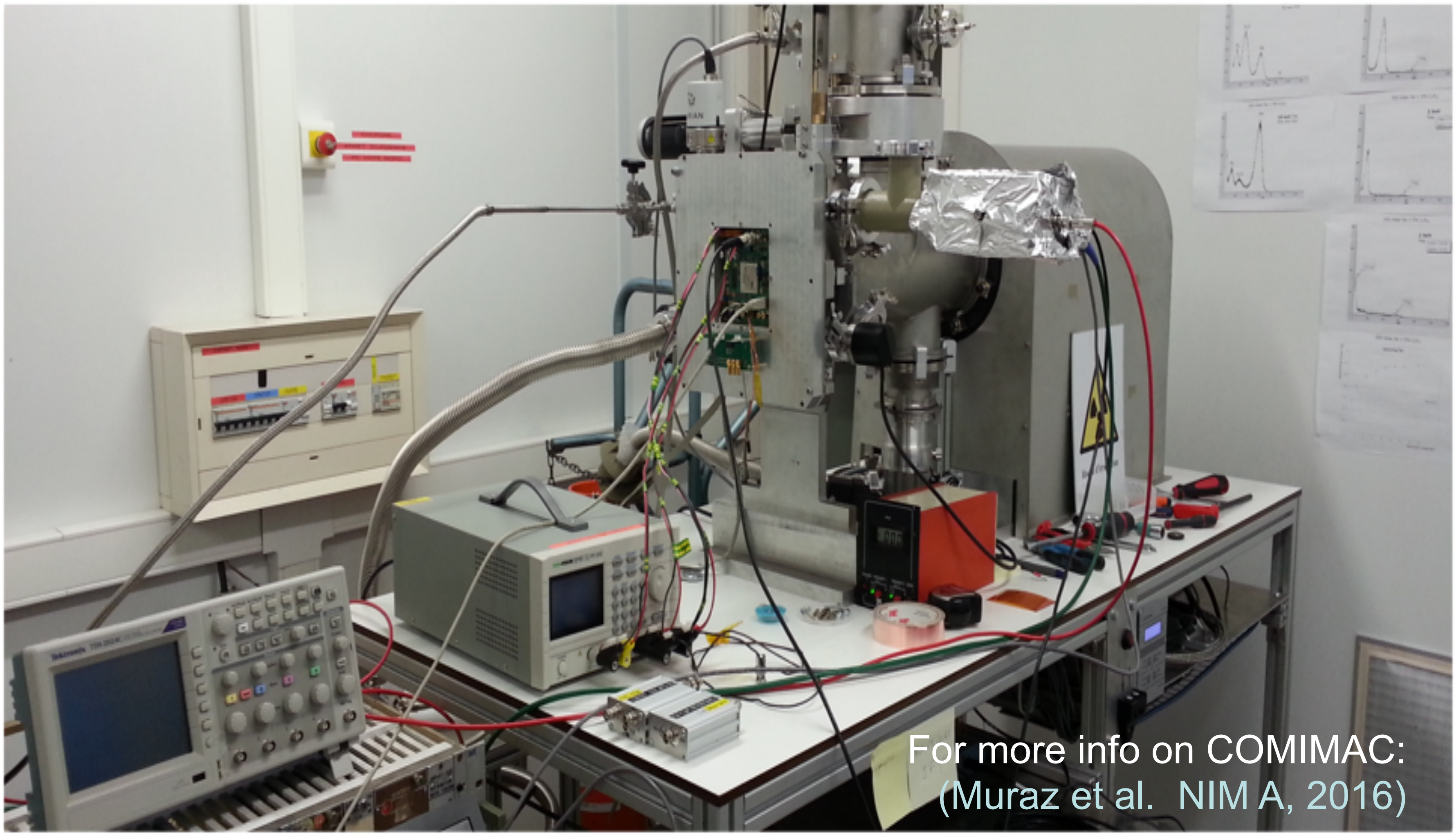


Mean Projected Diffusion: $\overline{\mathcal{D}} = \ln\left(\overline{\Delta X} \times \overline{\Delta Y}\right)$



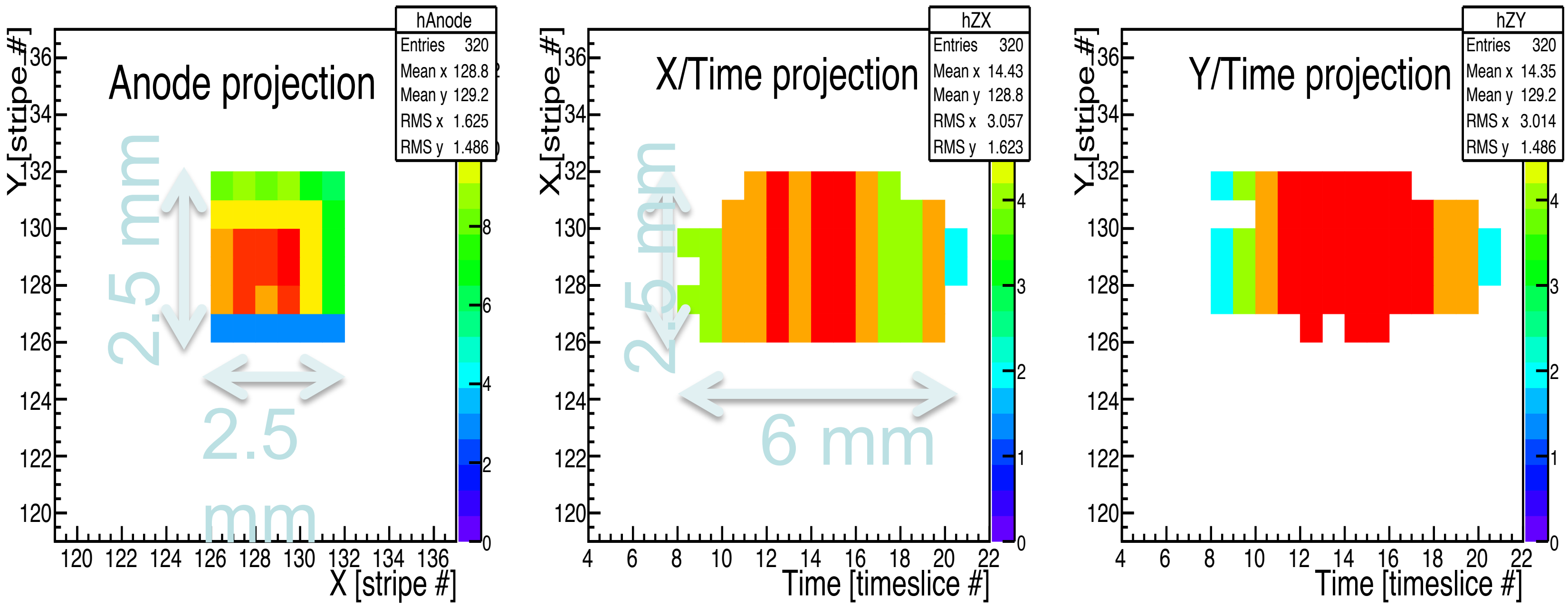


First controlled Fluorine tracks, using COMIMAC



COMIMAC: first measurements on controlled tracks of Fluorine

25 keV (kinetic) Fluorine → ~ 9 keVee



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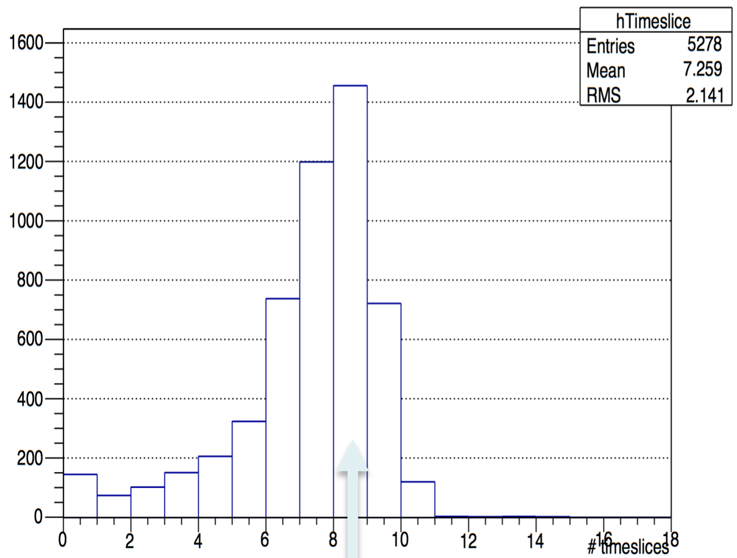
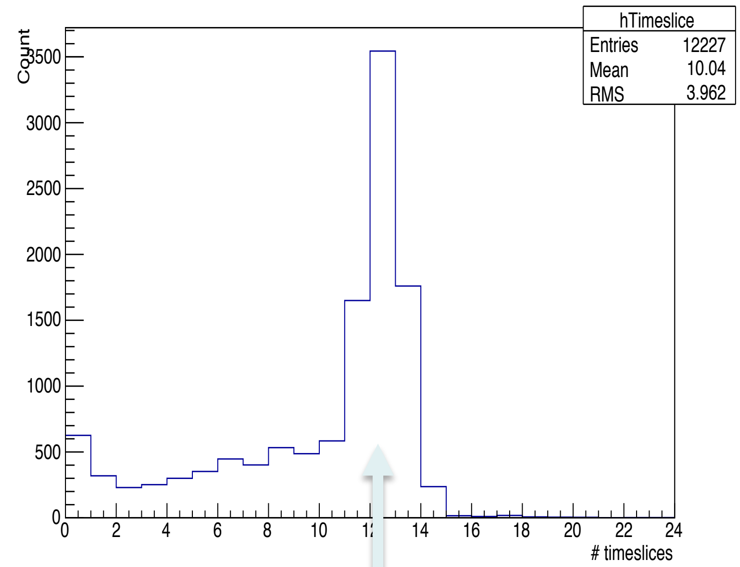
COMIMAC: first controlled tracks of ^{19}F

8 keV kinetic → 2 keVee

25 keV kinetic → 9 keVee





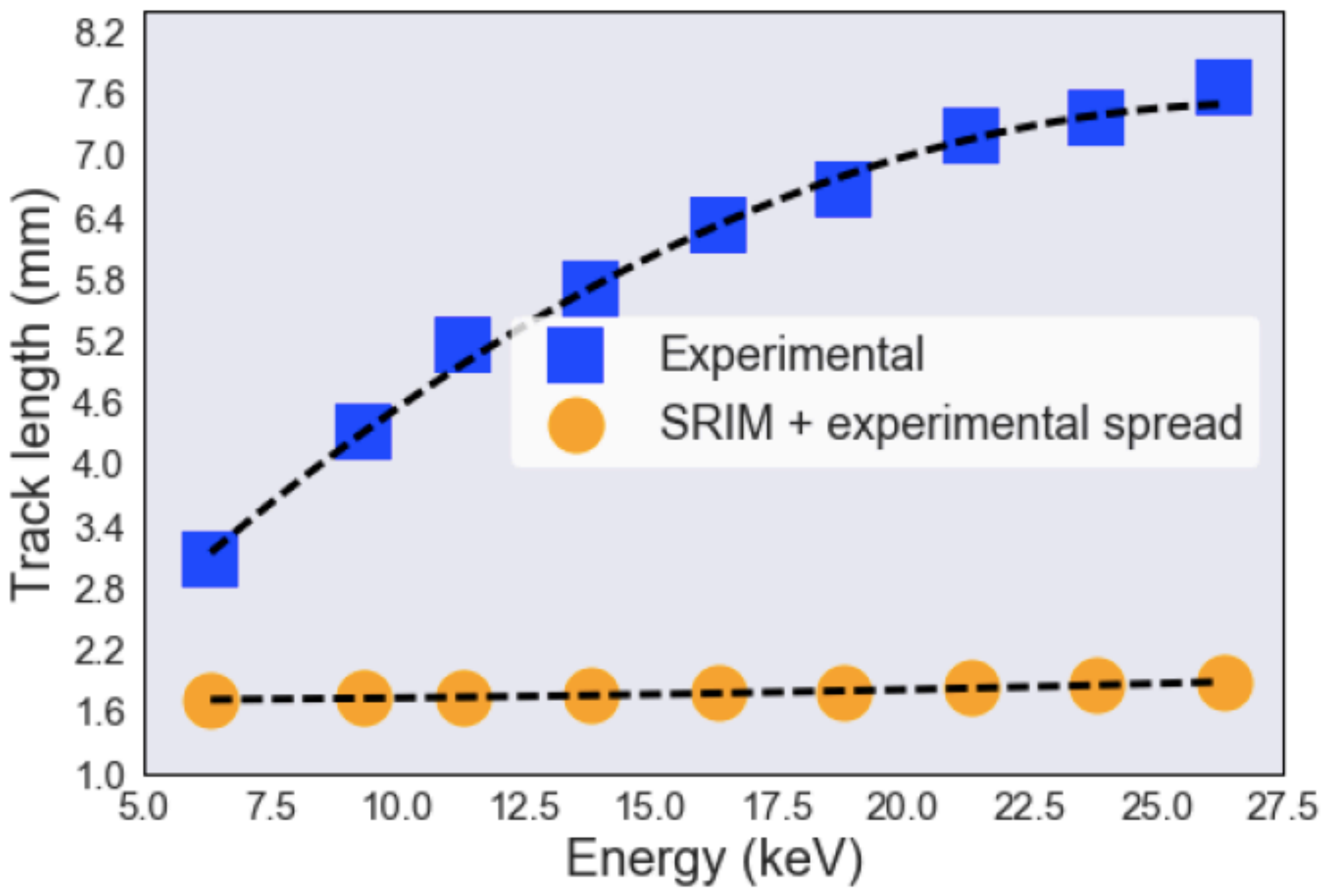
8 timeslices
* 20 ns/timeslices
* 23.5 µm/ns
= 3.8 mm

12 timeslices
* 20 ns/timeslice
* 23.5 µm/ns
= 5.8 mm

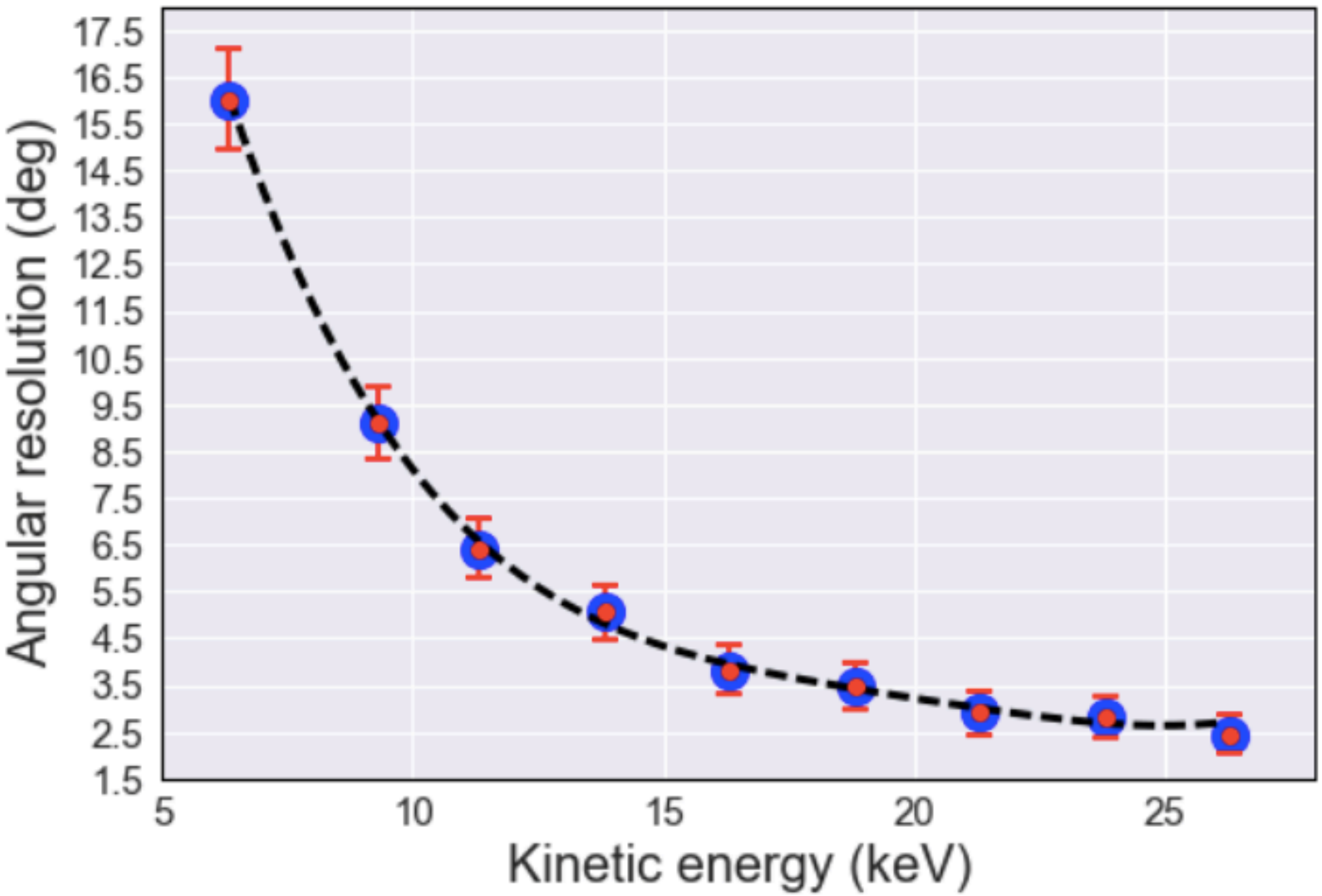
I. Moric, Y. Tao et al. (in preparation)

3D-Track Length Measured and Simulated

(I. Moric, Y. Tao, N. Sauzet, DS. et al. 2018)

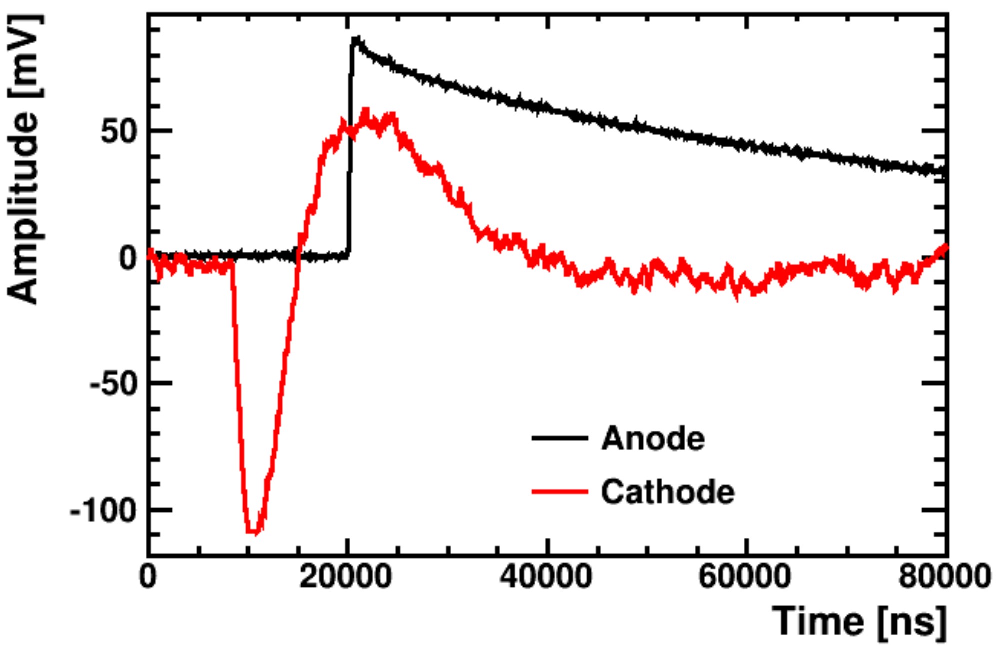


Angular resolution measured with COMIMAC
(^{19}F ions at known kinetic energies)
(I. Moric, Y. Tao et al. 2018)



Cathode Signal to place the 3D-track

- The cathode signal is produced by the primary electrons. It is produced before the anode signal produced by the avalanche.



Measurement in a MIMAC chamber of an alpha passing through the active volume parallel to the cathode at 10 cm distance.

MIMAC-Cathode Signal measurements

C. Couturier, Q. Riffard, N. Sauzet, O. Guillaudin, F. Naraghi, and D. Santos.
Journal of Instrumentation, 12(11):P11020, 2017.

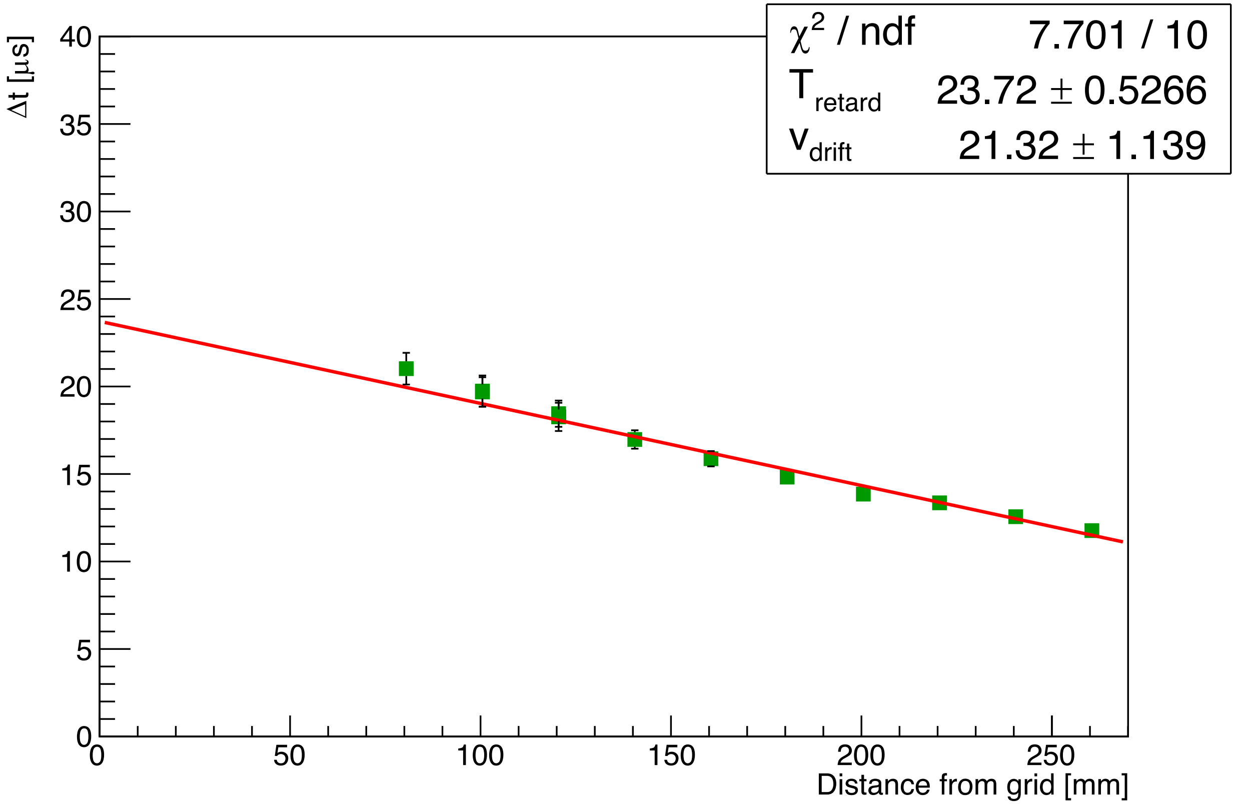
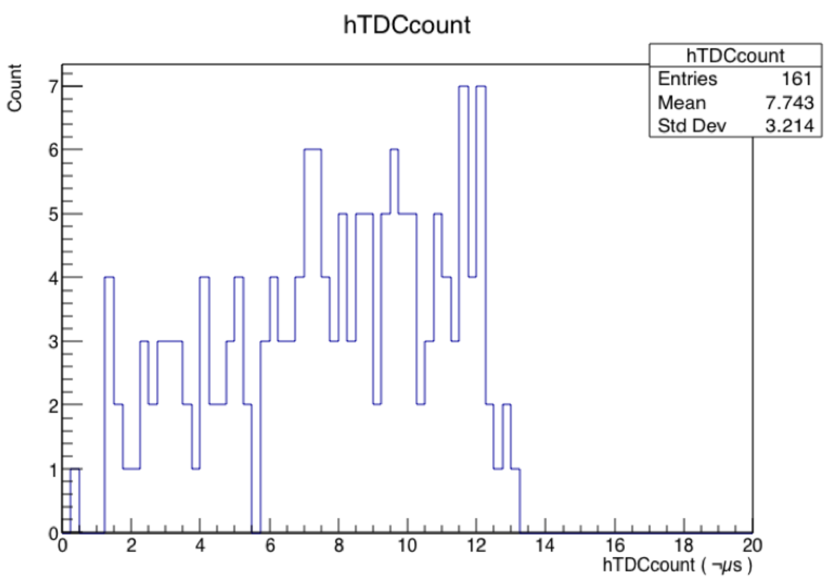


Figure 4. Measure of the time differences (TAC) between the grid signal and the delayed cathode signal in the "START Grid" configuration, as a function of the distance of the α source from the anode (green points) ; error bars correspond to the standard deviation of the mean. A linear fit of these points is superimposed in red and provides the values of the drift velocity and the additional delay.

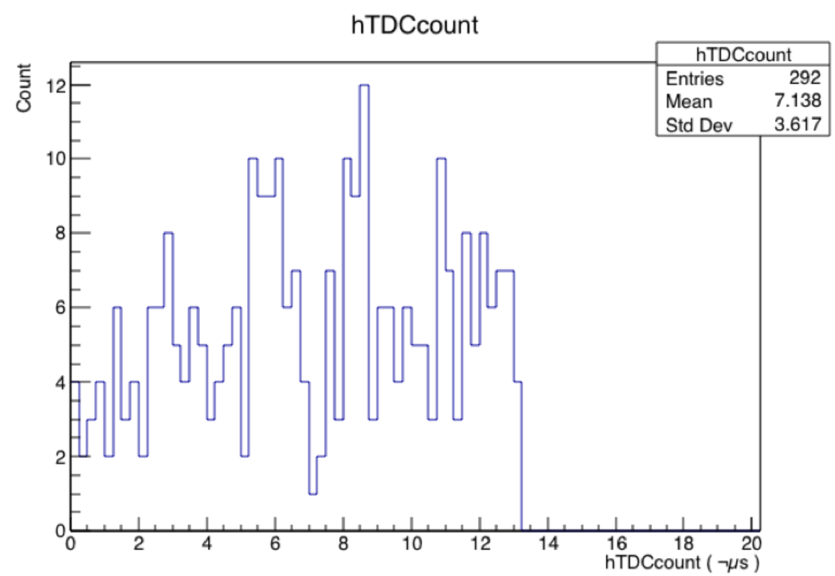
First Cathode Signals from the MIMAC bichamber background

(O. Guillaudin et al. October 2018)

Chamber 1

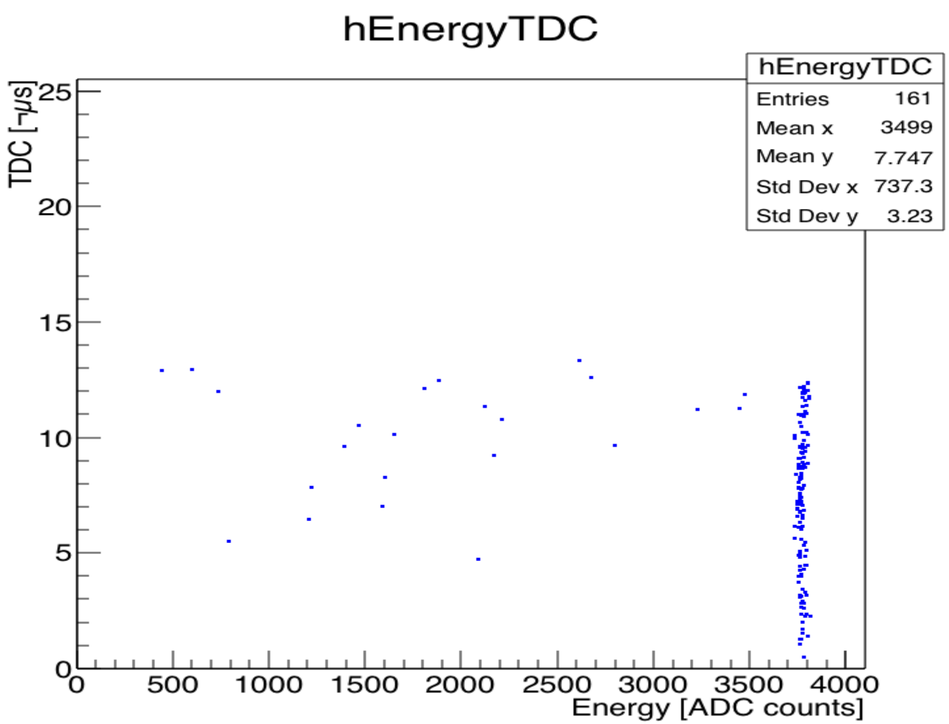


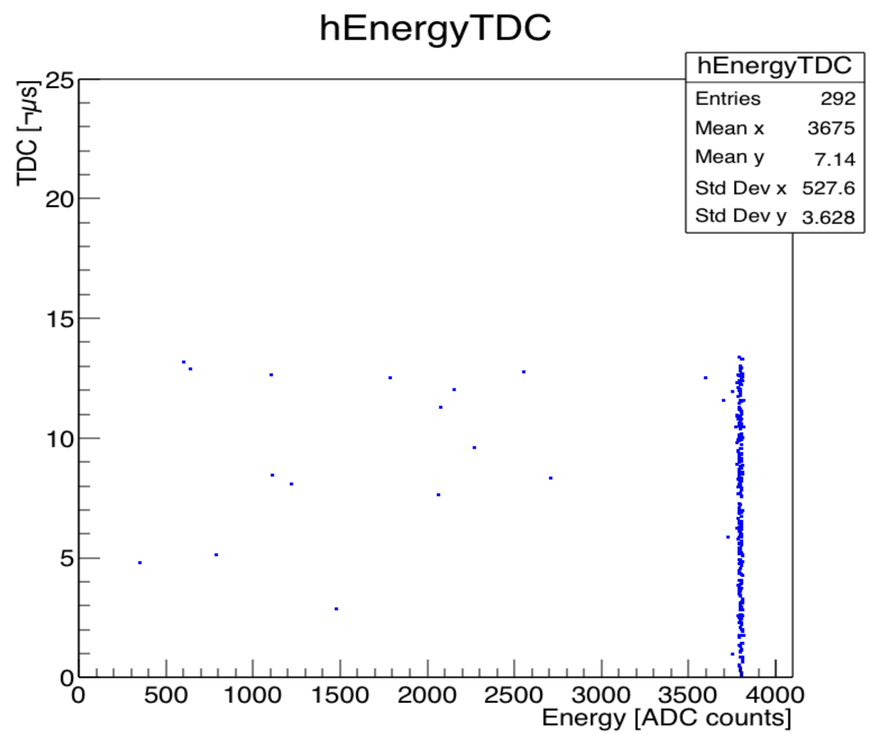
Chamber 2



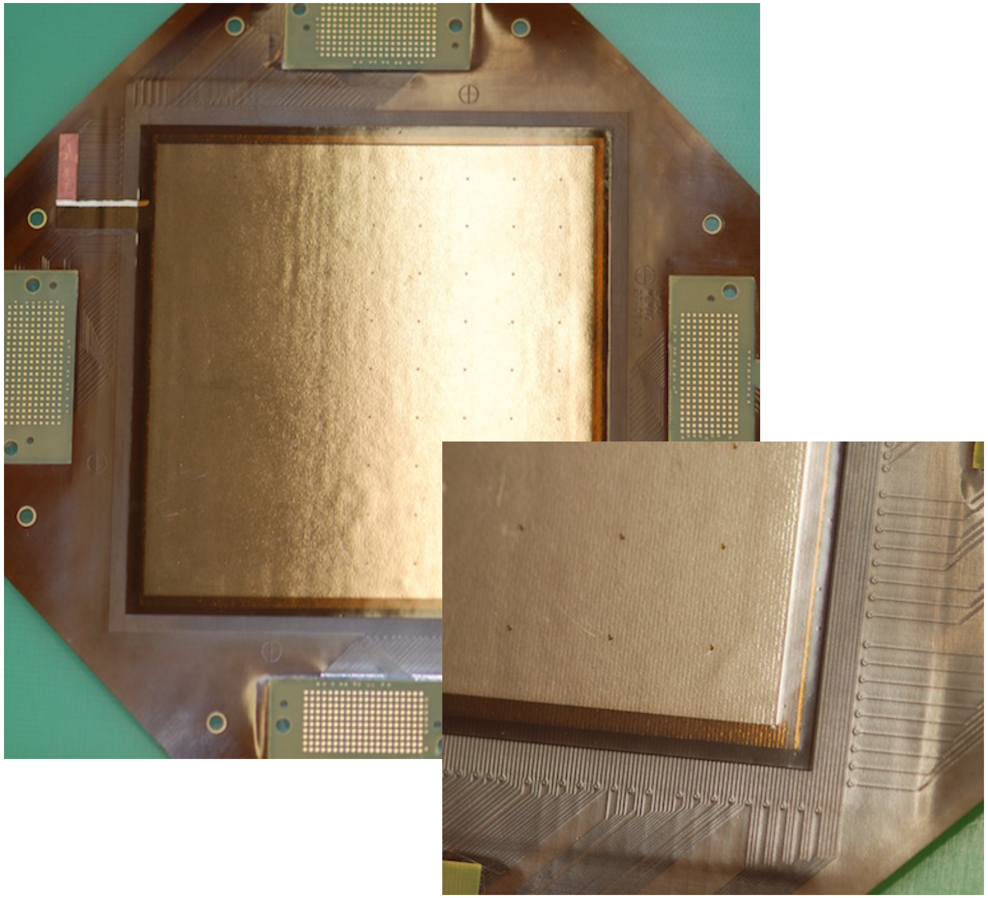
Measuring the time between the “event production” and the avalanche signal !!
Covering the 26 cm drift distance (13 us x 20 um/ns) !!

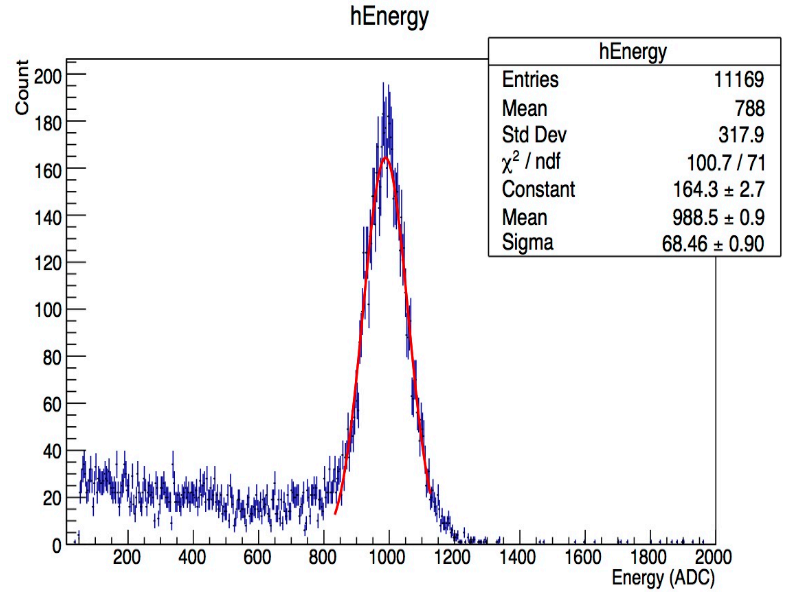
Ionization Energy distribution of the events recorded with the Cathode Signal





New MIMAC low background detector 10 cm x 10 cm



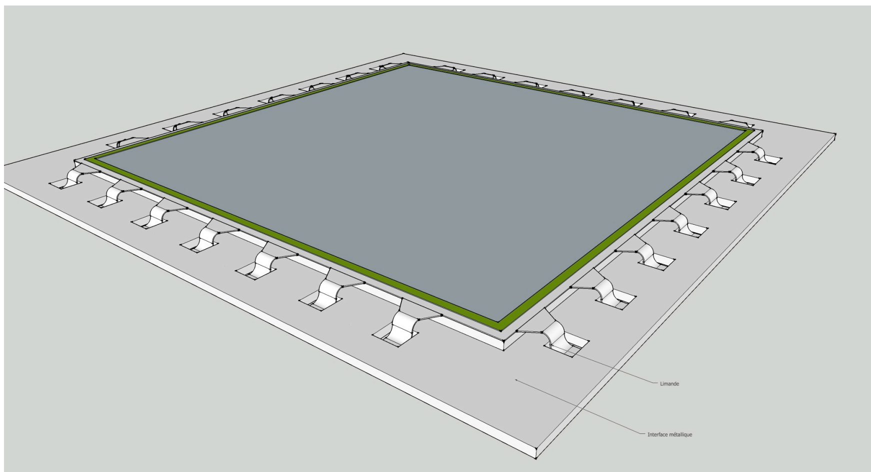


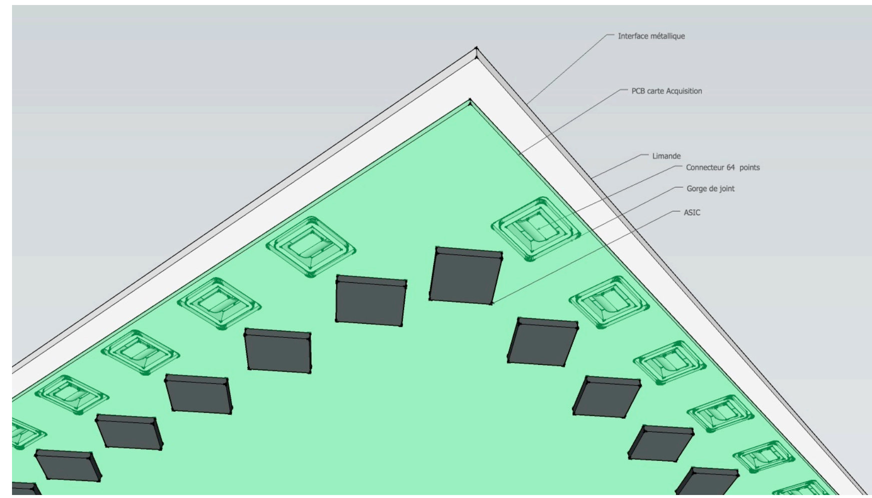
Gaz : MIMAC 50 mbar
HT grille : -560 V
Drift field : -150 V/cm

Kapton micromegas readout
Piralux Pilar

16,3 % FWHM (6 keV)
Gain ~25 000
Energy threshold <1 keV

New 35 x 35 cm^2 low background detector design
(1792 channels, 28 ASICs) (O. Guillaudin et al.)



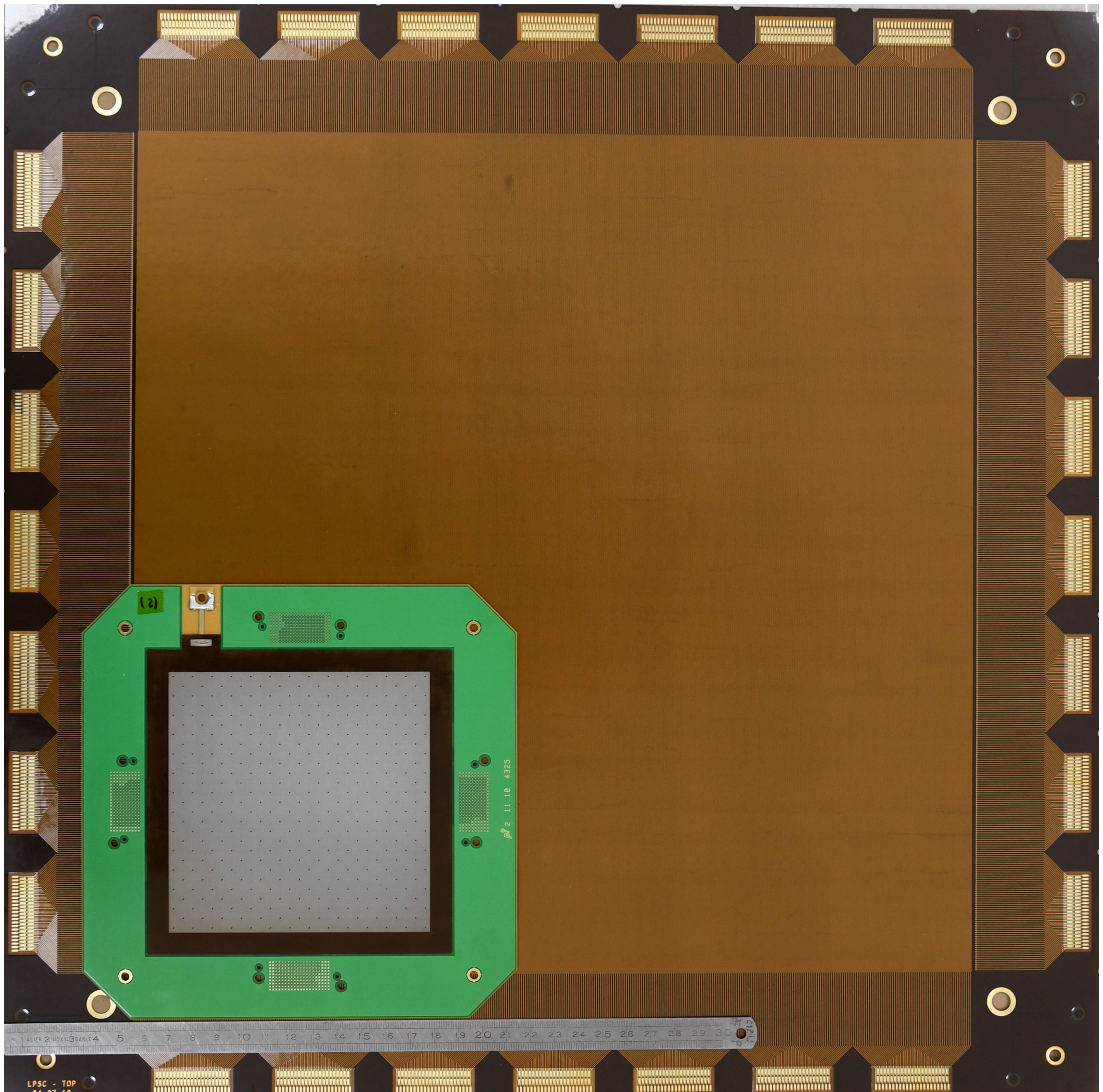


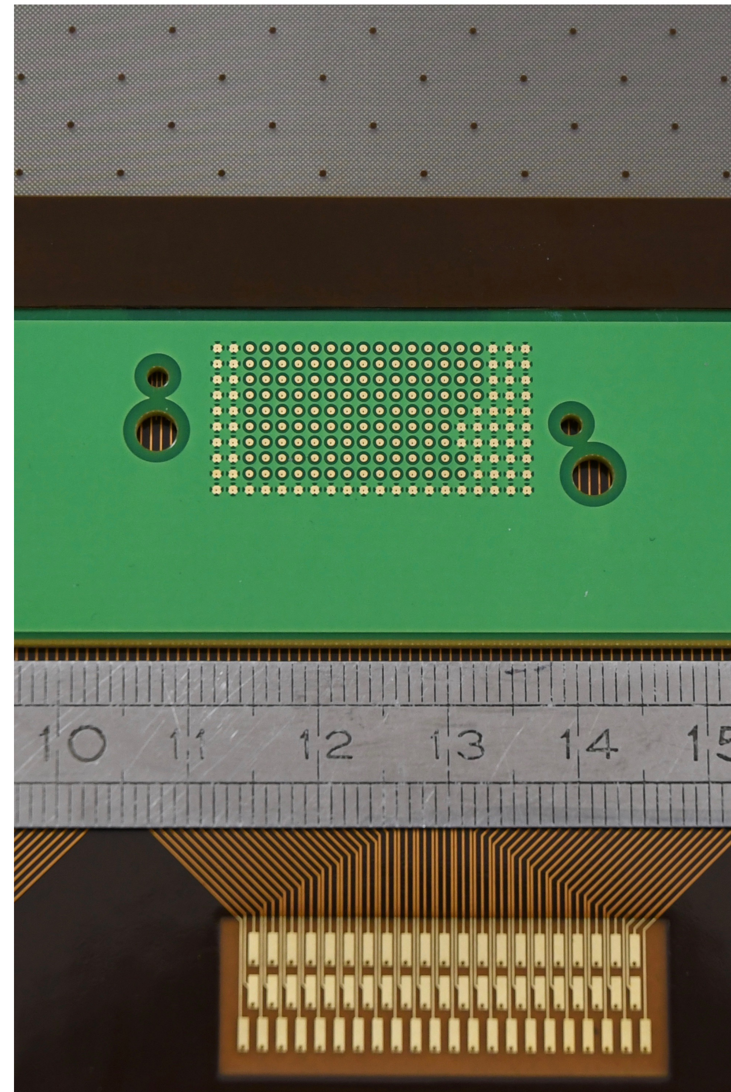
Left: Top view of the new detector design using kapton and plexiglass instead of PCB.

Right: Bottom view, showing the ASICs distribution to minimize the length of the connections.

The ASIC-MIMAC technology should be upgraded (0.35 to 0.13 um) :
6 month study for the "electronics" team of the LPSC

The new 35 cm "new technology" MIMAC detector compared to the old one





Les réalisations techniques envisagées sont :

1) Nouveau module bi-chambre bas-bruit pour les détecteurs 35 cm (voir tableau 1)

Comprenant :
Nouveau détecteur bas-bruit (35 cm x 35 cm) avec la technologie DLC
(Diamond Layer Coating) (étude et fabrication en interne)

Nouvelle interface acquisition-détecteur (étude et fabrication en interne)

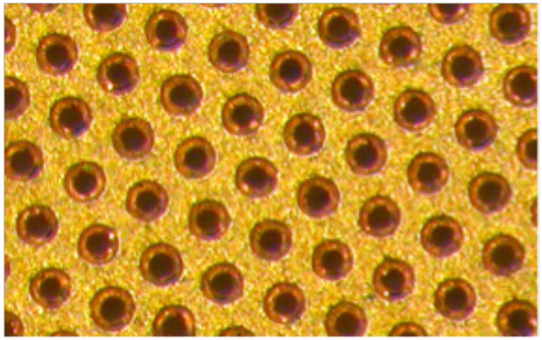
Nouvelle carte d'acquisition 1792 voies (28 ASICs)
Intégration de nouveaux connecteurs.

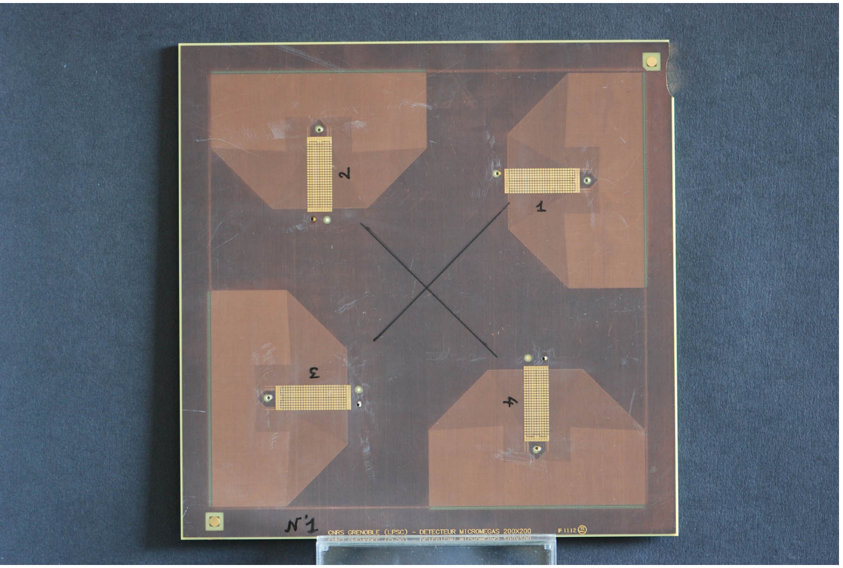
Nouvelle Cage du Champ (en plexiglas et kapton cuivré)
(étude et fabrication en interne)

Filtrage du Rn (en collaboration avec le CPPM-Marseille)

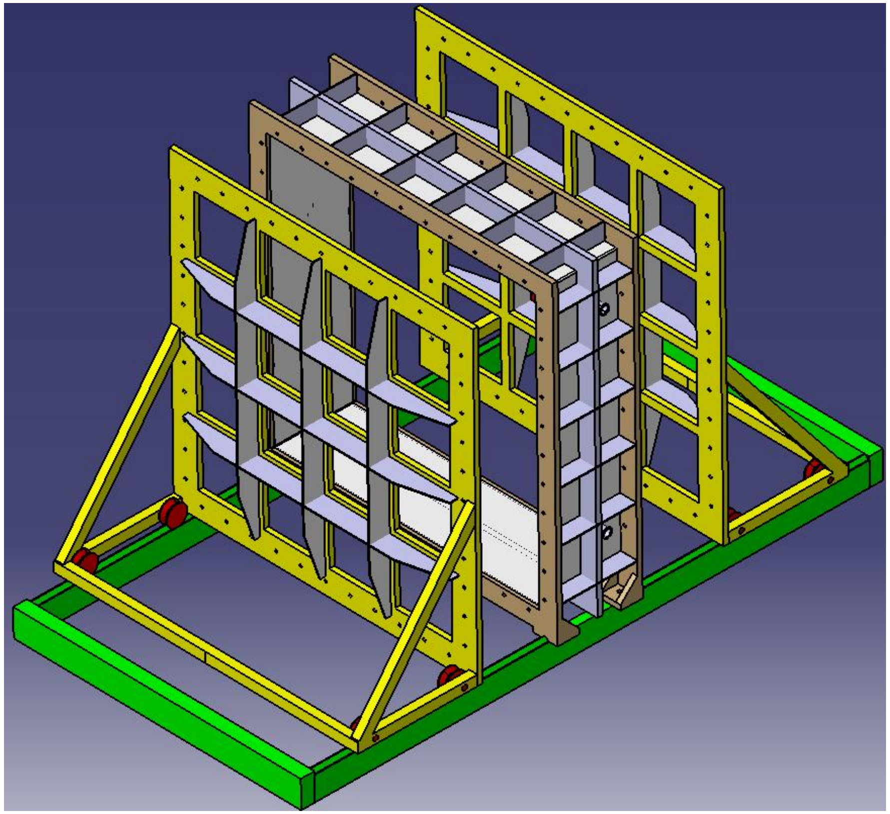
MIMAC – 1m^3 = 16 bi-chamber modules (2x 35x35x26 cm^3)

i) New technology anode 35cmx35cm
ii) Stretched thin (12 um) grid at 512um.
iii) New electronic board (1792 channels)
iv) Only one big chamber





New 20cmx20cm pixellized anode (1024 channels)



Analyse “SWOT”

Forces :
MIMAC a bénéficié d’un développement « maison (IN2P3)»
La capacité de mesurer de très faibles énergies en ionisation et de reconstruire des traces de longueur sub-millimétrique.
La possibilité de développer des détecteurs MPGD bas bruit.
Nous maitrisons le savoir-faire : détecteur, électronique et mesure du facteur de quenching en ionisation.
L’accès et la proximité au LSM (Laboratoire Souterrain de Modane).

Faiblesses :
Les équipes de physiciens du LPSC et du CPPM sont sous-dimensionnées.
Une autre équipe intéressée à participer serait souhaitable !

Opportunités :
Notre stratégie de détection et technologie MIMAC sont pour l’instant celles qui permettent le seuil le plus bas avec la mesure de traces en 3D.
Valorisation de la technologie dans le domaine de la mesure neutronique.

Menaces :
Les particules de matière sombre pourraient être d’une masse inférieure à 500 MeV/c^2.

Conclusions

- A new directional detector of nuclear recoils **at low energies (E > 100 eV)** has been developed giving a lot of flexibility on targets, pressure, energy range…

- New observables are available to discriminate electrons from nuclear recoils to improve the DM search for and to cope with « non zero » background.

- Angular resolution and directional studies of 3D tracks have been performed experimentally with COMIMAC showing large discrepancies wrt simulations!

- **The 1 m^3 will be the validation of a new generation of a large DM high definition detector including directionality (a needed signature for DM discovery)**

- **The « large volume » needed for Dark Matter detection could be possible to get it by an array in different underground laboratories !**

We need to help the Grenoble and Marseille teams to keep the know-how and succeed