Gas Detectors for Dark Matter, Nuclear Recoil or Electron Detection

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Overview

- What is a gas detector in general ? Some of them…
- Why gas detectors for DM or Neutron detection
- Ionization Calibration Measurements
- Non directional detector (high pressure ~ 10 bar):
    - NEWS-G
- Directional Detectors (low pressure ~50 mbar) :
    - DRIFT, DMTPC, NEWAGE, MIMAC
- Electron-recoil discrimination and Radon progeny
- Angular Resolution Measurements
- Conclusions

What is a gas detector in general?

- An active volume where the **primary ionization electrons** will be drifted to the amplification region (directly or carried by “negative ions”) by means of a **Electric field (E)** :
  - Drift velocity: $\mathbf{v_{drift}}$**= f (E, gas mixture, pressure)**
  - Active Volume Geometry: spherical, cylindrical, cubic

- An **avalanche** region where the multiplication of primary electrons takes place:
  - Multi Wires (DRIFT)
  - An isolated electrode (spherical) (NEWS-G)
  - A micro-pattern device: Micro-Pic (NEWAGE)
    Micromegas (Bulk) (MIMAC)

Some definitions… to describe a gas detector

- **Gas mixture** = A +x% B (the gas **quencher**)
- $e^- + A \rightarrow e^- + A^+ + e^-$ (the **Townsend ionization**…on which the **avalanche** will be built)
- $e^- + A \rightarrow e^- + A^m$ (metastable atomic state)

  if the $E(A^m) > E_I(B)$: $A^m + B \rightarrow A + B^+ + e^-$

- $e^- + A \rightarrow e^- + A^*$ (excited atomic state)

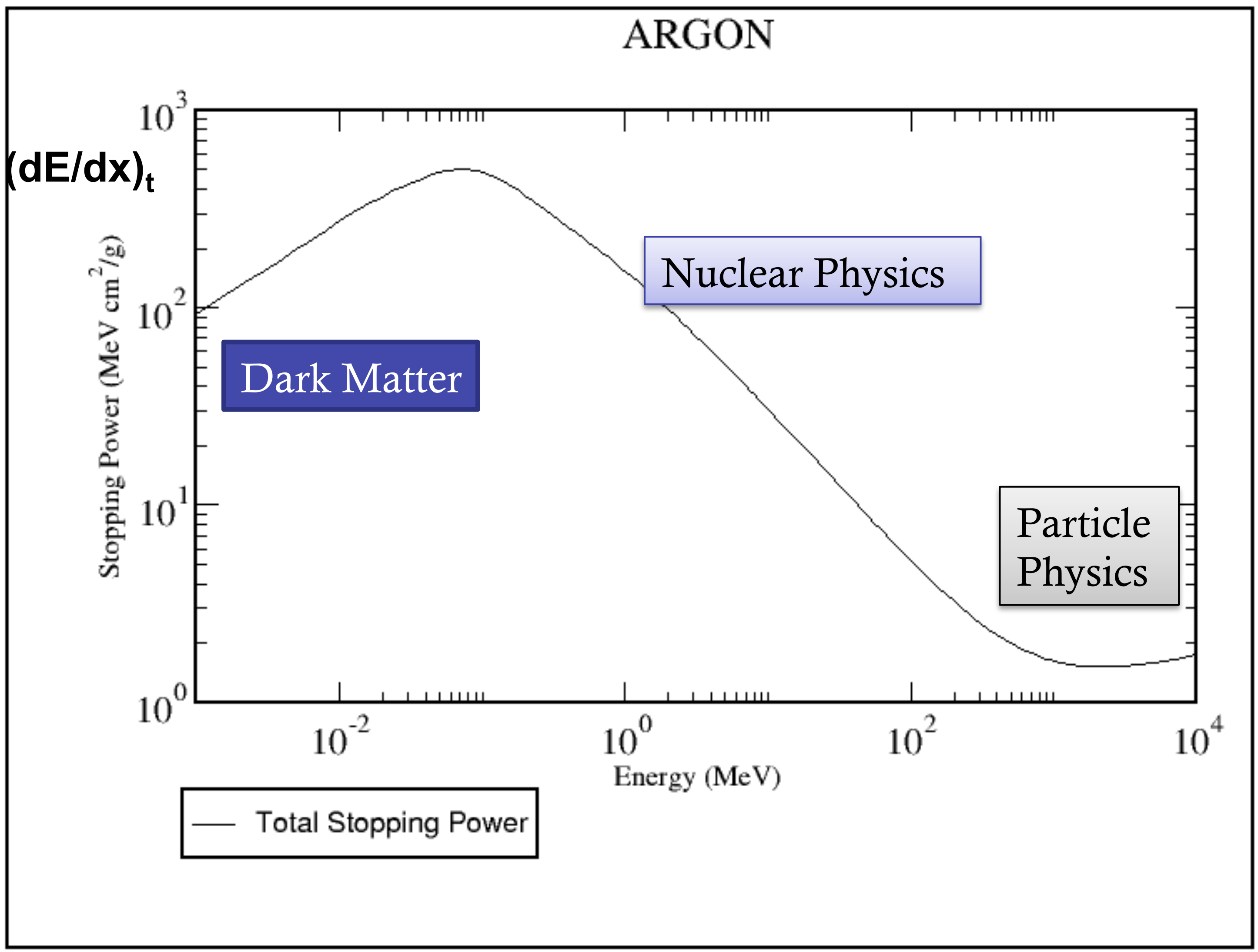
  if the $E(A^*) > E_I(B)$: $A^* + B \rightarrow A + B^+ + e^-$

called the **Penning** transfers !

Recombination (e^- - ion) : the electron recombined in an atom

Attachment : $AX + e^- \rightarrow AX^-$ (the electron is attached to a molecule…)

PSTAR : Stopping Power and Range Tables for Protons



Some numbers to keep in mind…

Properties of several gases used in proportional counters (from different sources, see the bibliography for this section). Energy loss and ion pairs per unit length are given at atmospheric pressure for minimum ionizing particles

Gas	Z	A	δ (g/cm³)	E_{ex}	E_i (eV)	I_0 (eV)	W_i	dE/dx (MeV/g cm⁻²)	dE/dx (keV/cm)	n_p (i.p./cm) a)	n_T (i.p./cm) a)
H_2	2	2	8.38×10^{-5}	10.8	15.9	15.4	37	4.03	0.34	5.2	9.2
He	2	4	1.66×10^{-4}	19.8	24.5	24.6	41	1.94	0.32	5.9	7.8
N_2	14	28	1.17×10^{-3}	8.1	16.7	15.5	35	1.68	1.96	(10)	56
O_2	16	32	1.33×10^{-3}	7.9	12.8	12.2	31	1.69	2.26	22	73
Ne	10	20.2	8.39×10^{-4}	16.6	21.5	21.6	36	1.68	1.41	12	39
Ar	18	39.9	1.66×10^{-3}	11.6	15.7	15.8	26	1.47	2.44	29.4	94
Kr	36	83.8	3.49×10^{-3}	10.0	13.9	14.0	24	1.32	4.60	(22)	192
Xe	54	131.3	5.49×10^{-3}	8.4	12.1	12.1	22	1.23	6.76	44	307
CO_2	22	44	1.86×10^{-3}	5.2	13.7	13.7	33	1.62	3.01	(34)	91
CH_4	10	16	6.70×10^{-4}		15.2	13.1	28	2.21	1.48	16	53
C_4H_{10}	34	58	2.42×10^{-3}		10.6	10.8	23	1.86	4.50	(46)	195

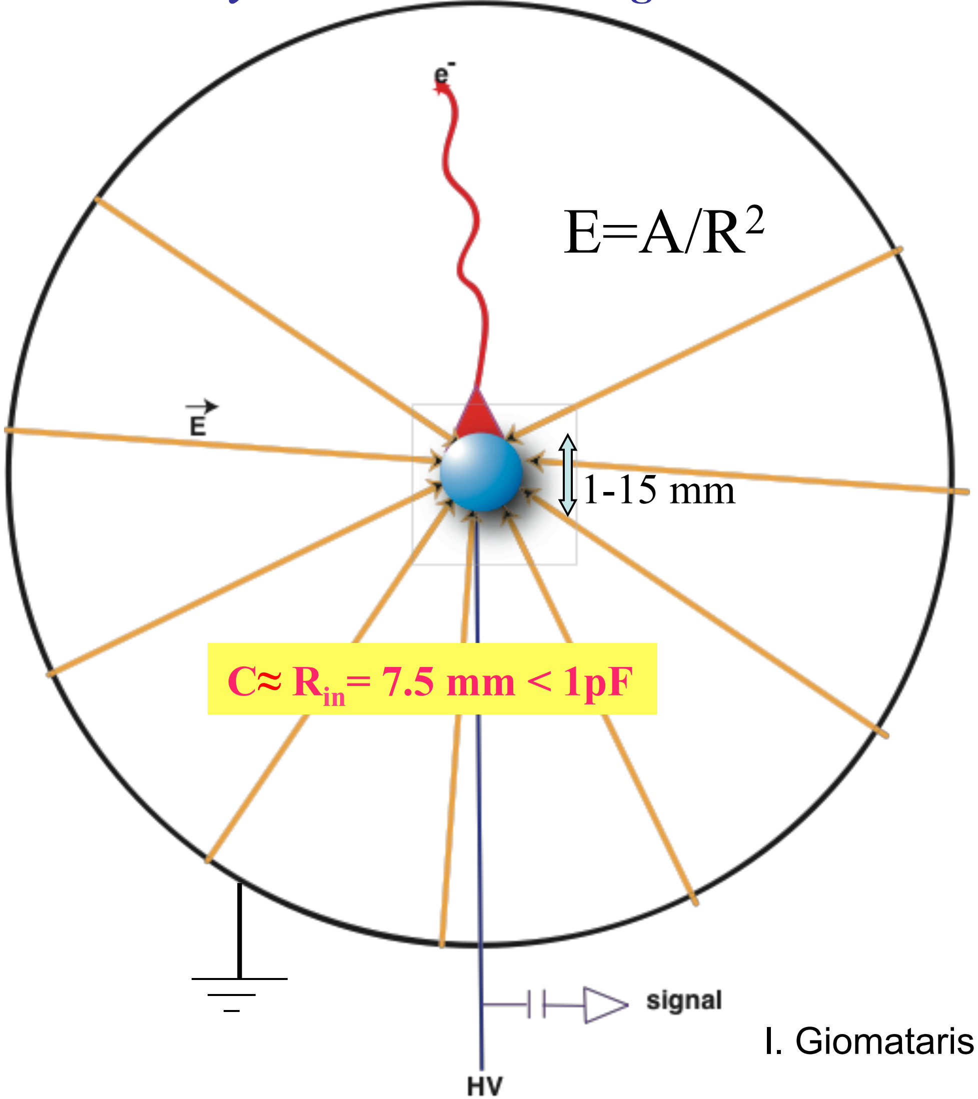
a) i.p. = ion pairs

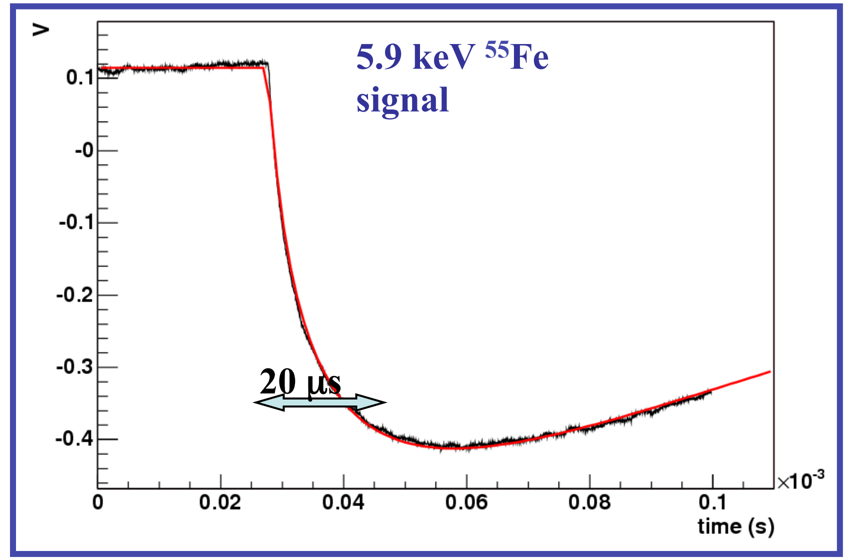
F. Sauli, (1977, CERN)

Radial TPC with spherical proportional counter read-out

Saclay-Thessaloniki-Saragoza

A Novel large-volume Spherical Detector with Proportional Amplification read-out, I. Giomataris *et al.*, JINST 3:P09007,2008

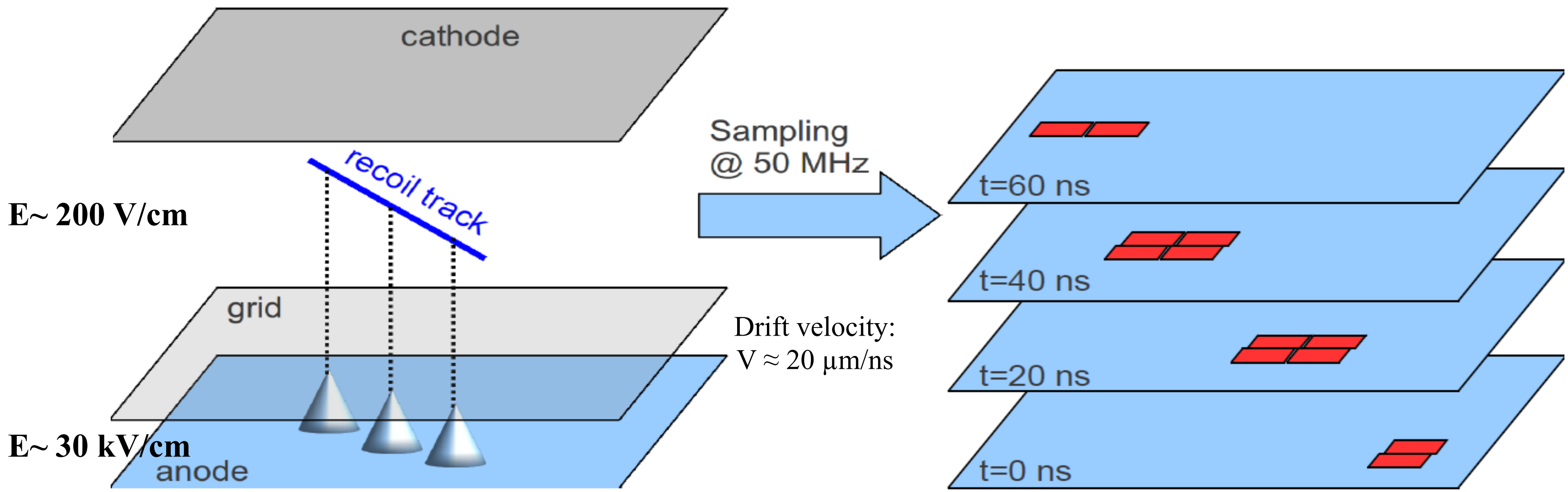




I. Giomataris (2008)

- Simple and cheap
- Large volume
- single read-out
- Robustness
- Good energy resolution
- Low energy threshold
- Efficient fiducial cut

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

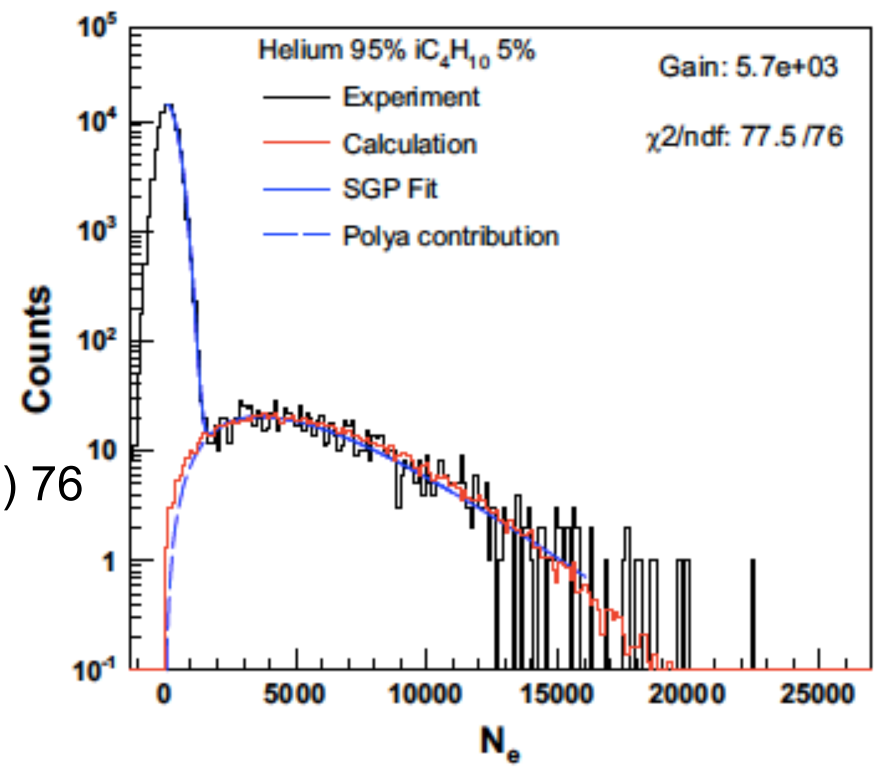
Distribution of Number of electrons (N_e) produced in Avalanches (Polya distribution)

$$P(N_e) = \frac{(1+\theta)^{1+\theta}}{\Gamma(1+\theta)} \left(\frac{N_e}{\overline{N_e}}\right)^{\theta} \exp\left[-(1+\theta)\frac{N_e}{\overline{N_e}}\right]$$

$$f = \left(\frac{\sigma_{N_e}}{\overline{N_e}}\right)^2 = \frac{1}{1+\theta}$$

Single Electron Response (SER) Measurements

T. Zerguerras et al. NIMA772 (2015) 76



Gain of a Gas detector =
< Number of e⁻ produced in an avalanche per primary e⁻ >

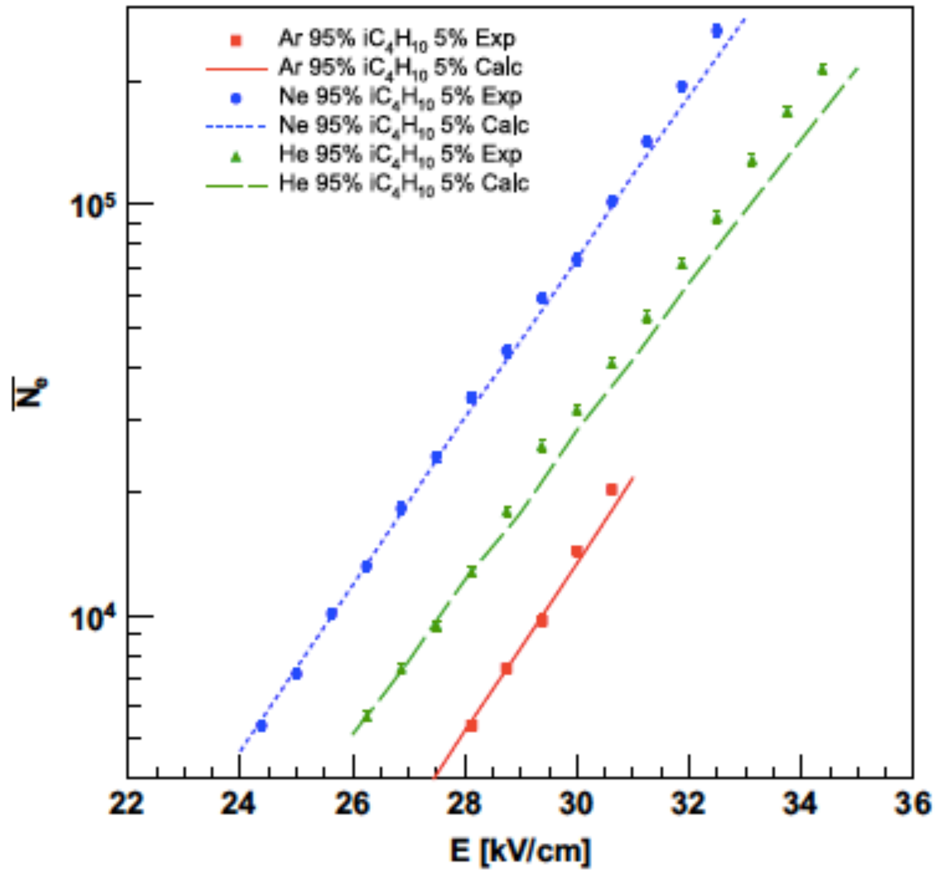
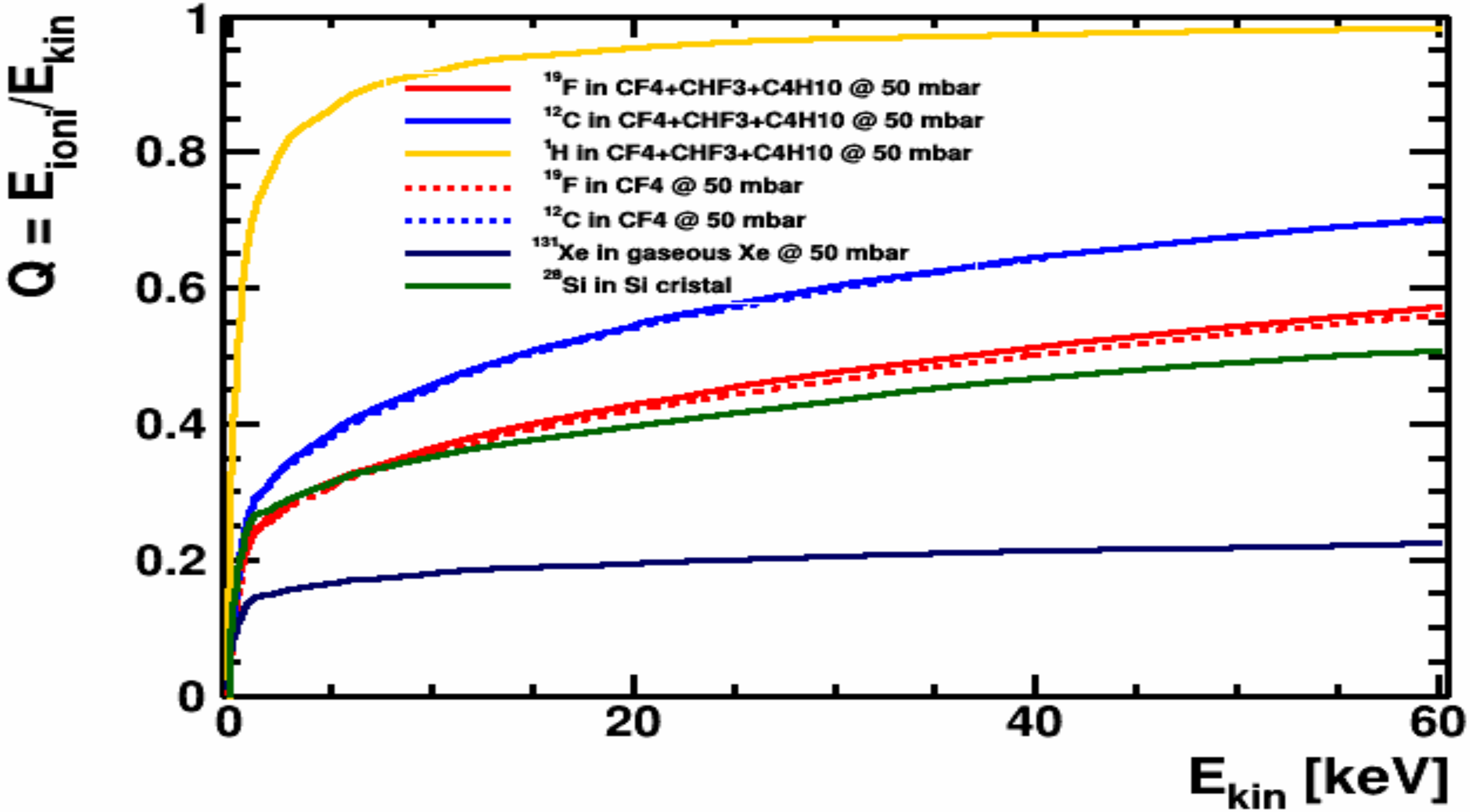


Fig. 6. Experimental mean gains $\overline{N_e}$ as a function of the amplification field E compared with the Monte-Carlo simulations for the argon, neon and helium gas mixtures.

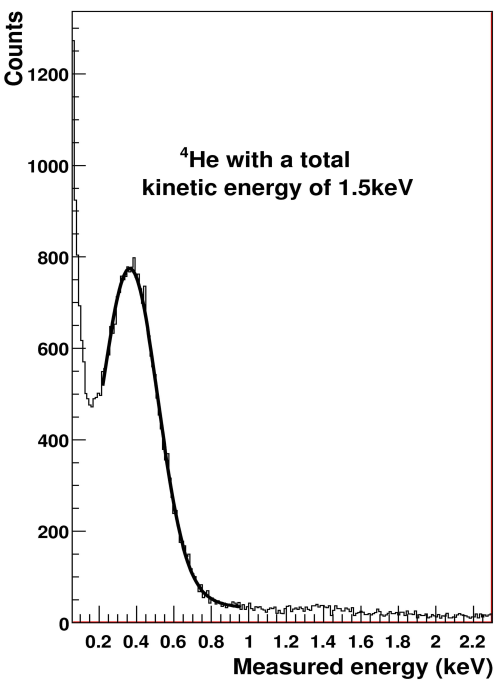
T. Zerguerras et al.
NIMA772 (2015) 76

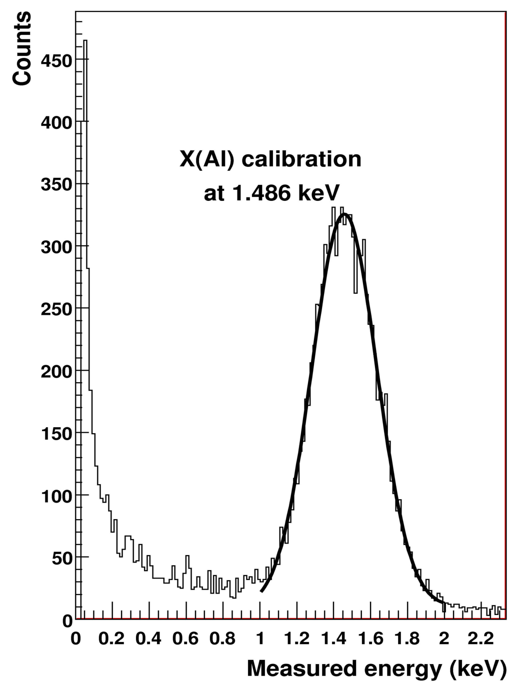
Ionization Quenching Factors

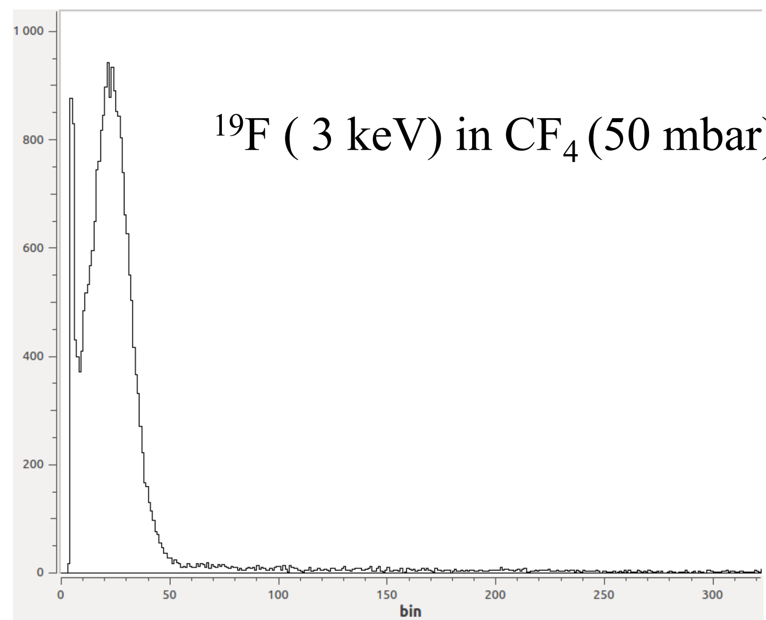
SRIM-Simulations (LPSC)



Ionization Quenching Factor Measurements at LPSC-Grenoble





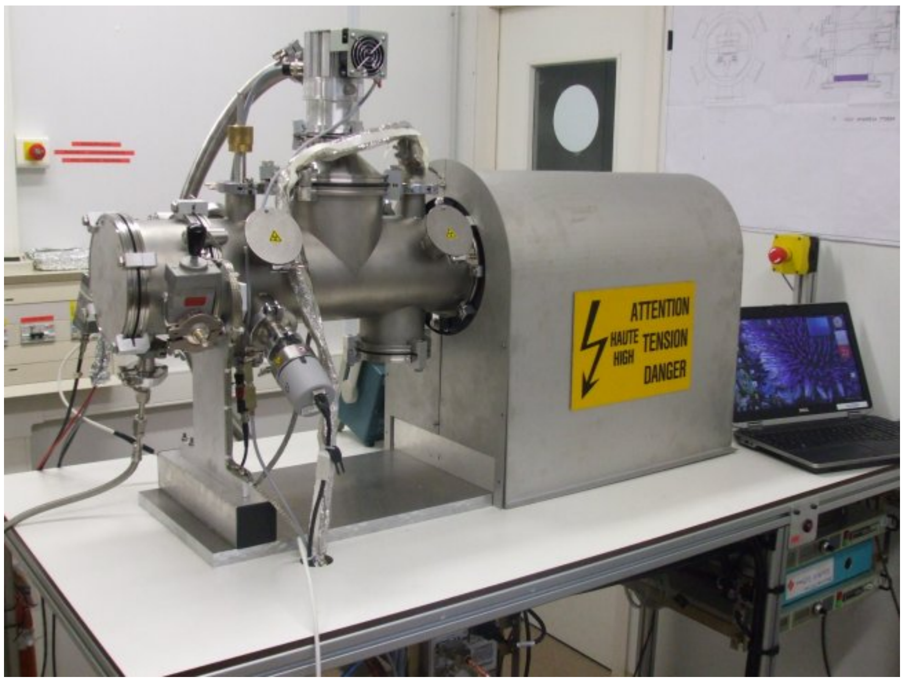


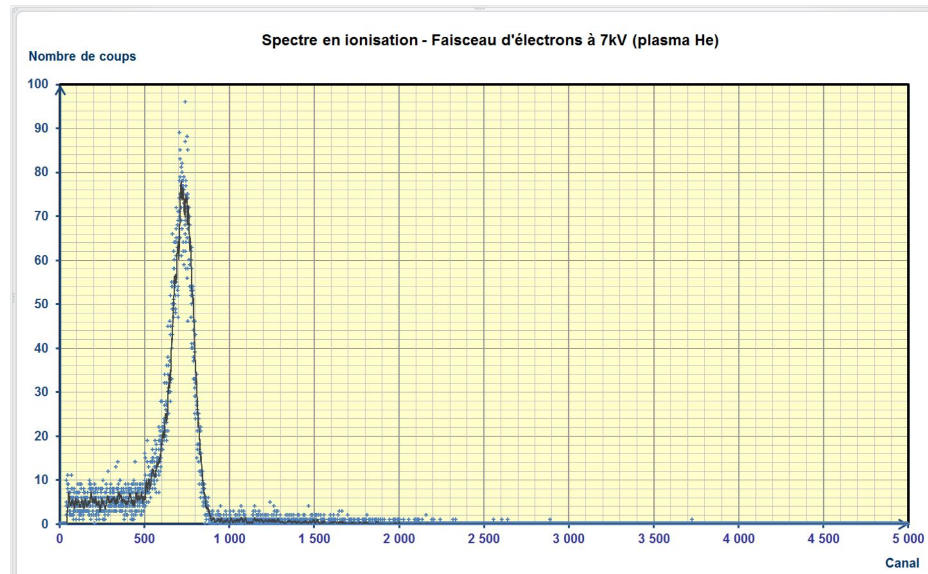
^{19}F (3 keV) in CF_4 (50 mbar)

D. Santos (LPSC Grenoble)

Portable Quenching Facility (COMIMAC)

(Electrons and Nuclei of known kinetic energies)

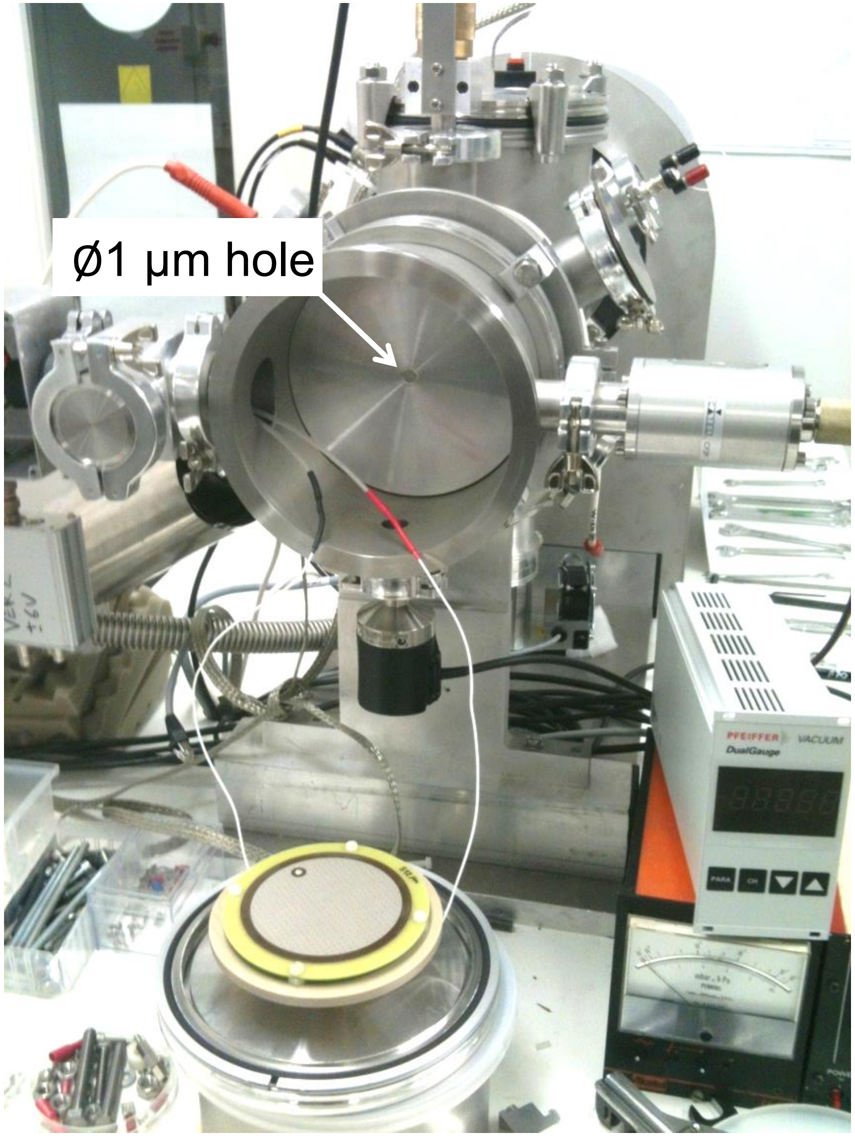




Electrons of 7 keV

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.

COMIMAC@LPSC



Setup:

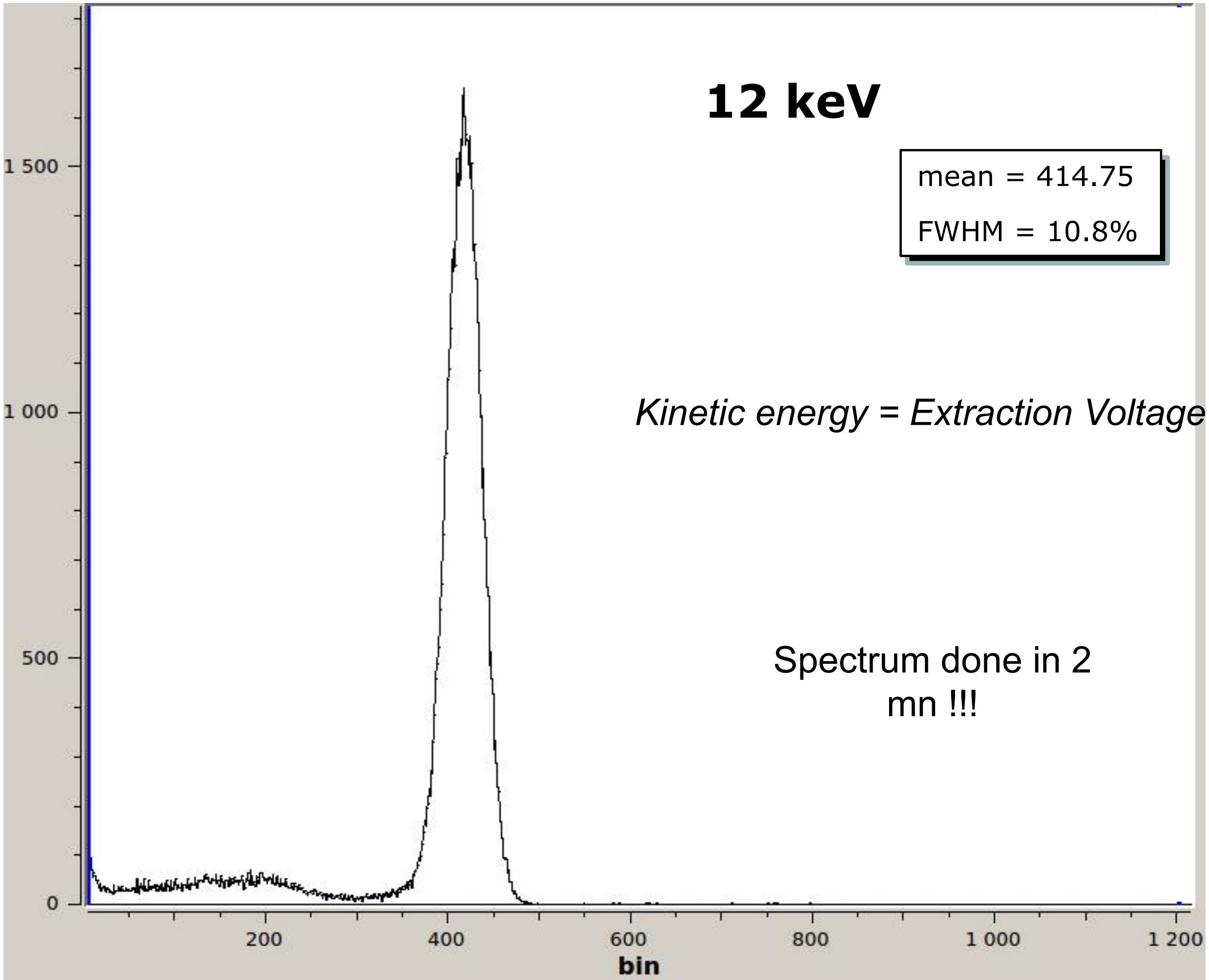
- Chamber volume : 2 liters
- 128, 256 or 512 µm micromegas
  (Ø 60 mm, bulked @ CERN)

Electrons Performance

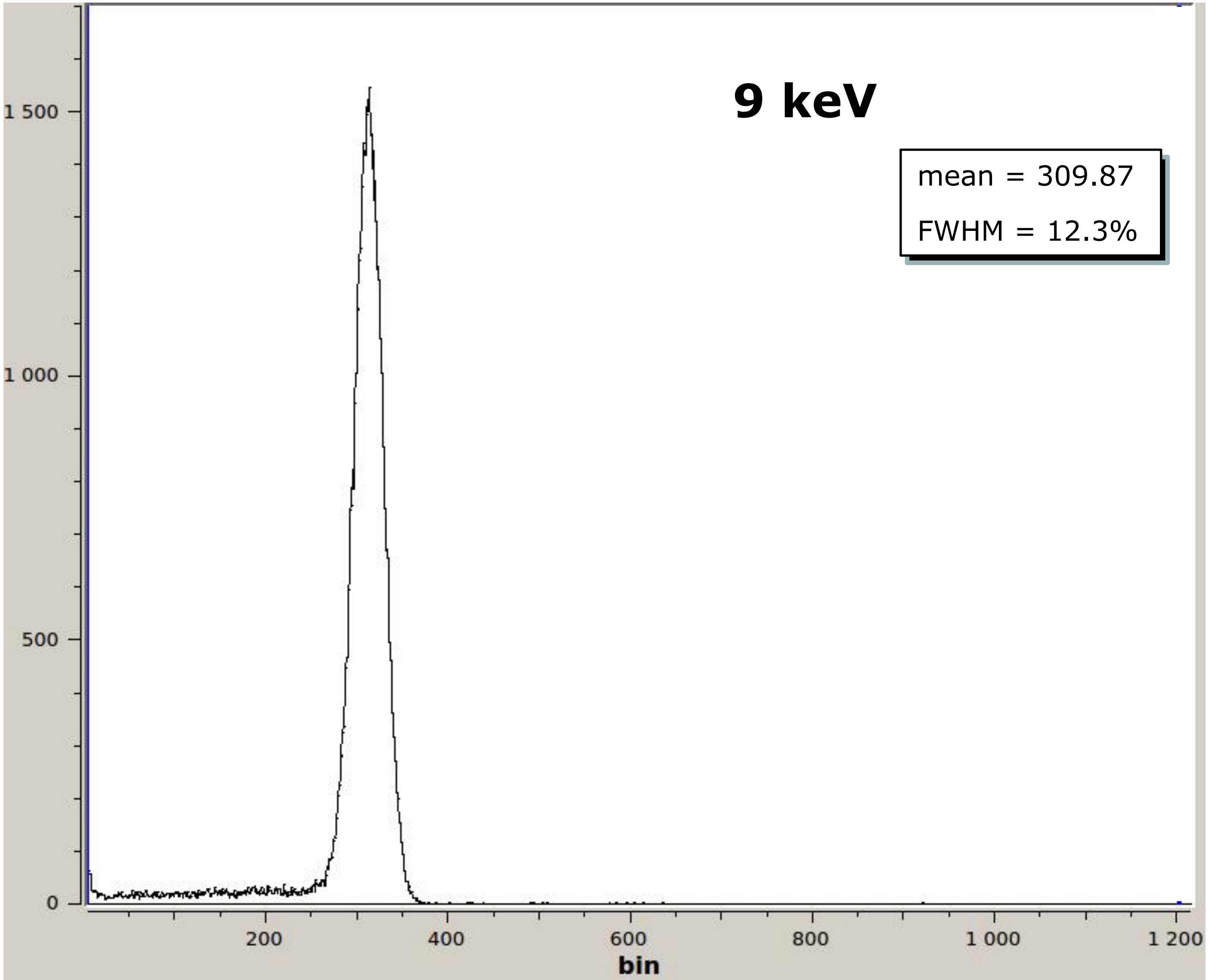
<u>Set up :</u>

- Electrons extracted from Nitrogen plasma in the source *(I=20 nA)*
- Gas : He + 5% C_4H_{10}
- Pressure : 700 mbar
- µmegas : 256 µm
- Drift distance : 60 mm
- Drift E field : 108 V/cm
- Gain : 471 V *(Grid : 650 V, Anode : 1 121 V)*
- Energies : 1.5 – 3 - 5.96 – 9 - 12 keV

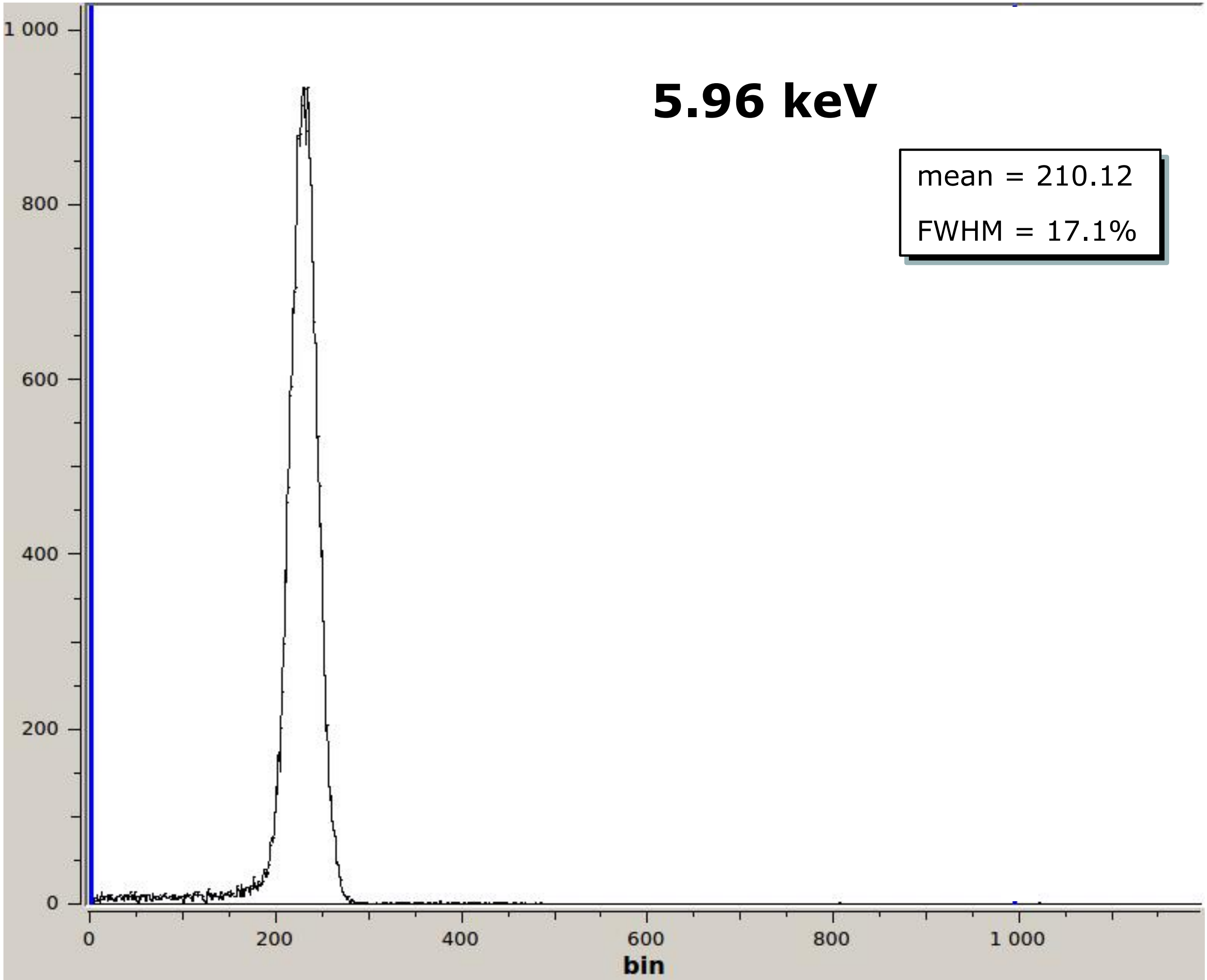
Electrons Performance



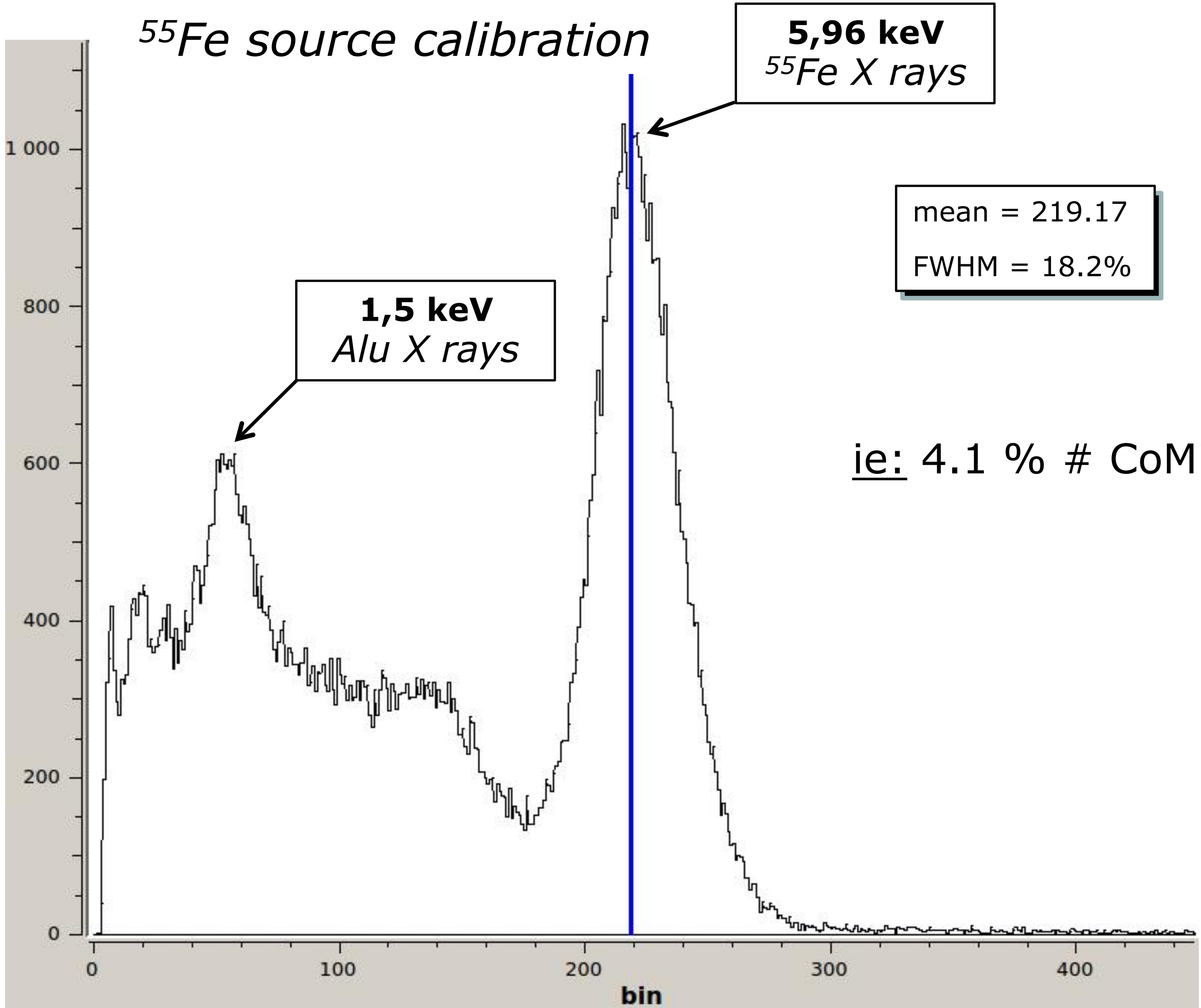
Electrons Performance



Electrons Performance

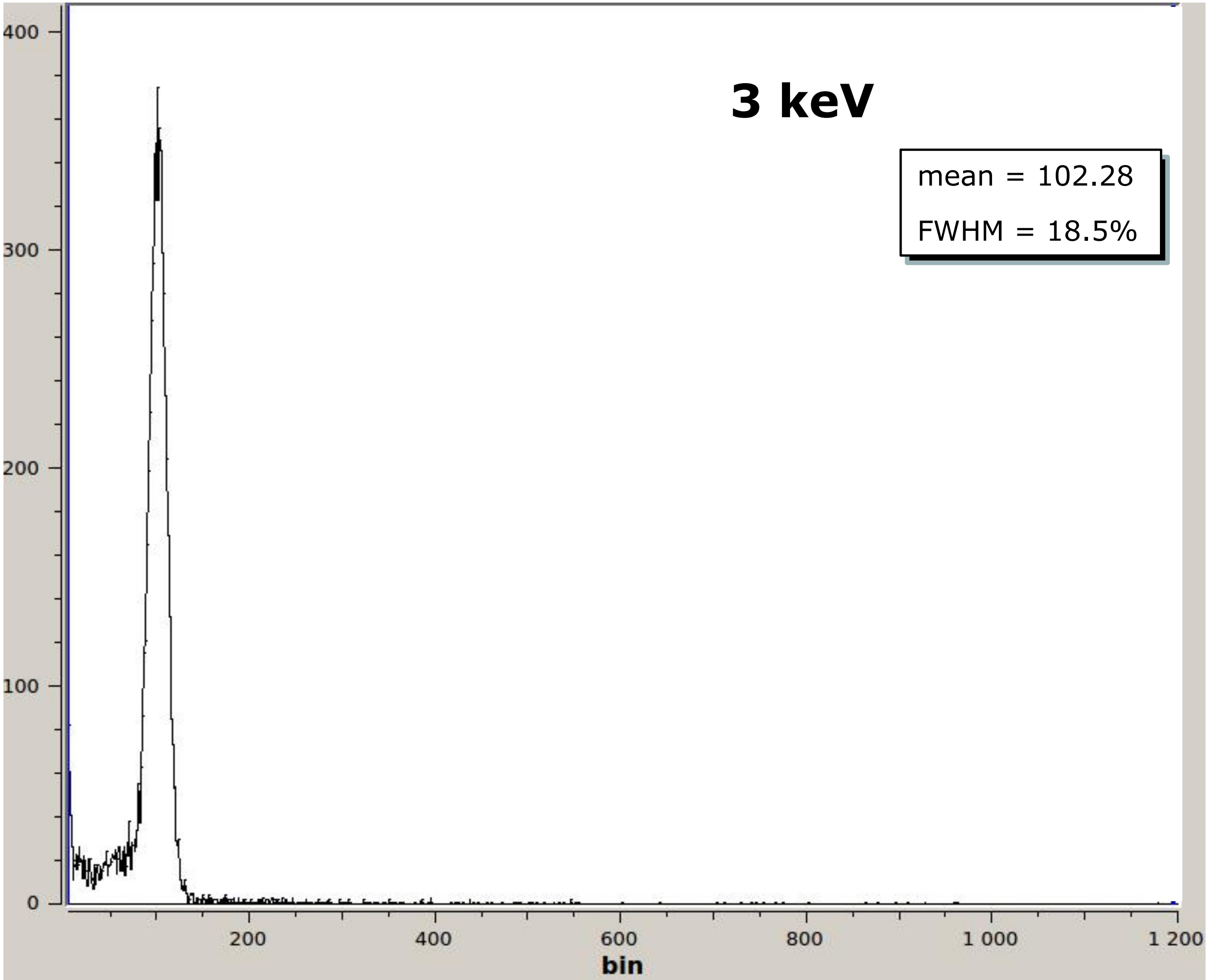


Electrons Performance

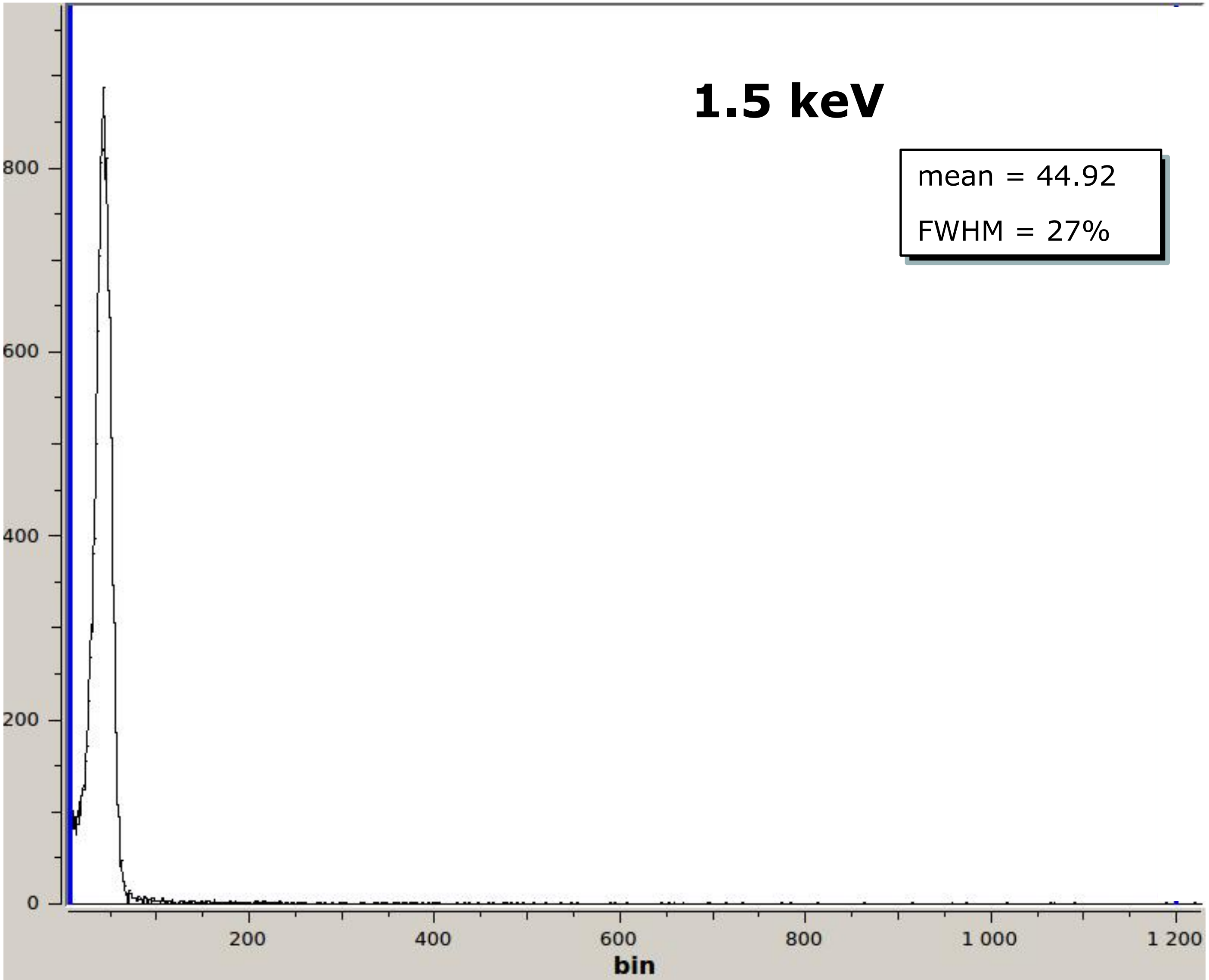


ie: 4.1 % # CoMimac

Electrons Performance

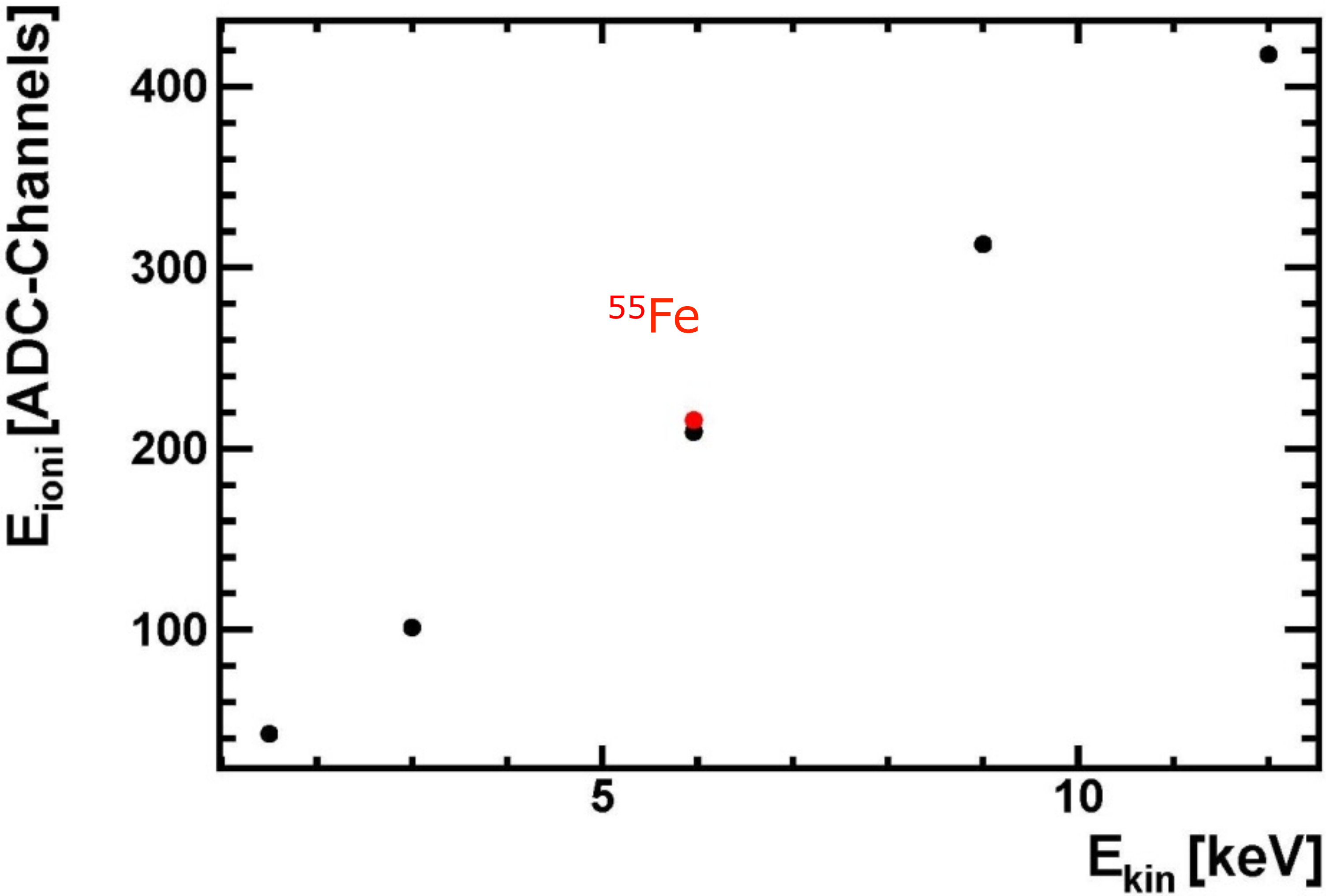


Electrons Performance

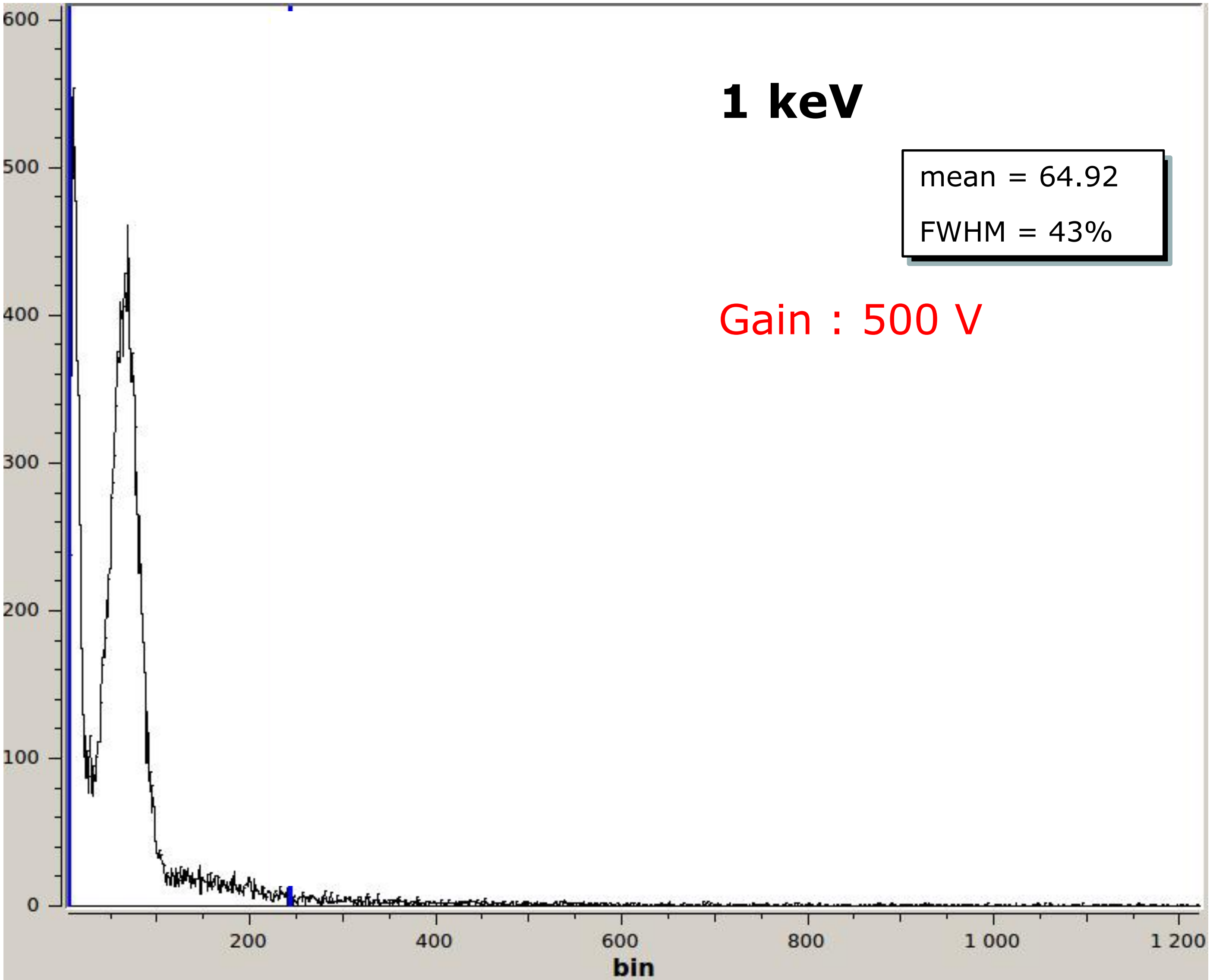


Electrons Performance

Electron Linearity response



Electrons Performance

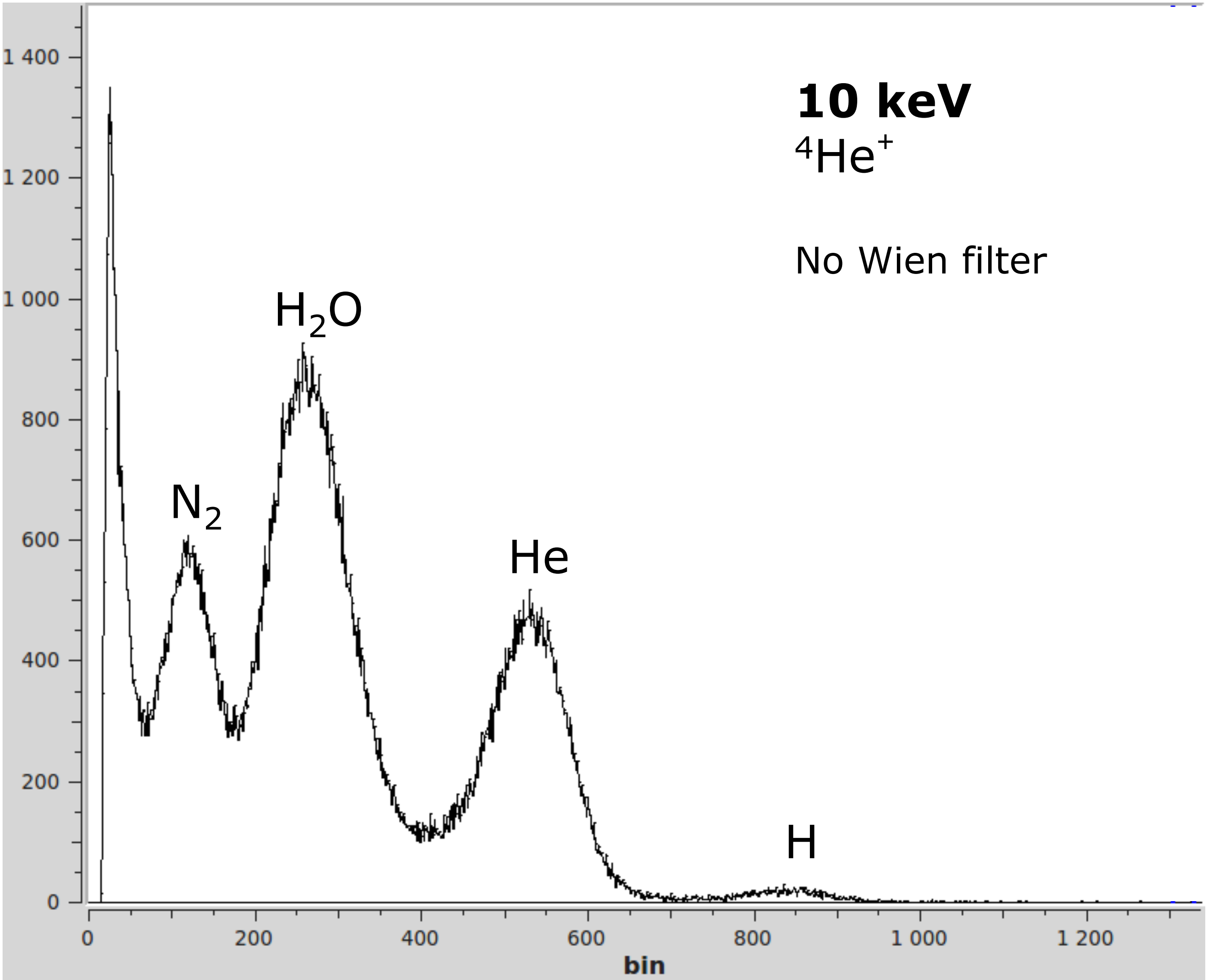


Ions Performance

Set up :

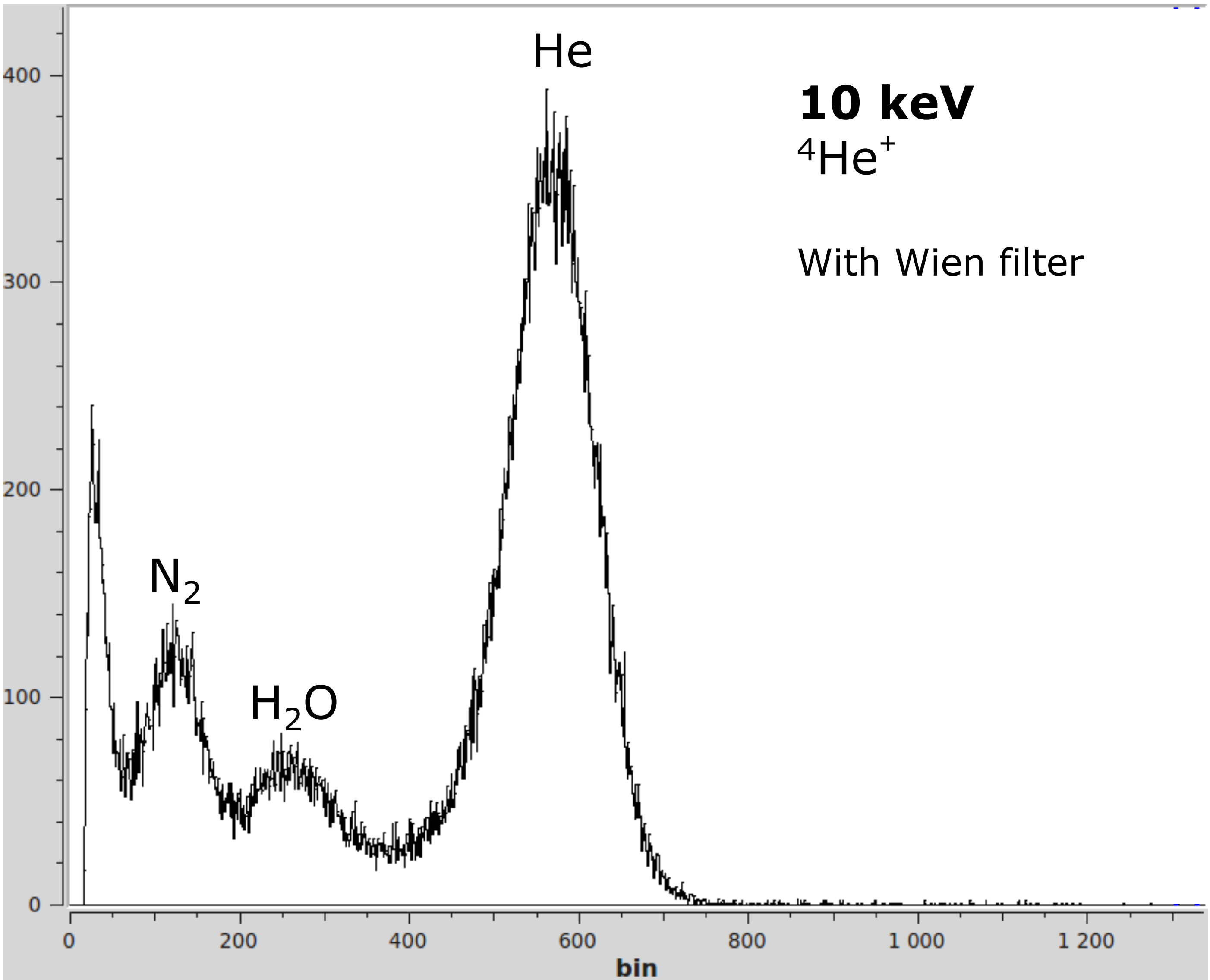
- Ions : $^4He^+$
- Gas : He + 5% C_4H_{10}
- Pressure : 350 mbar
- µmegas : 256 µm
- Drift distance : 60 mm
- Drift E field : 166 V/cm
- Gain : 460 V *(Grid : 1000 V, Anode : 1 460 V)*
- Energies : 1 – 2 - 4 – 6 – 8 - 10 – 12 - 15 keV

Wien Filter

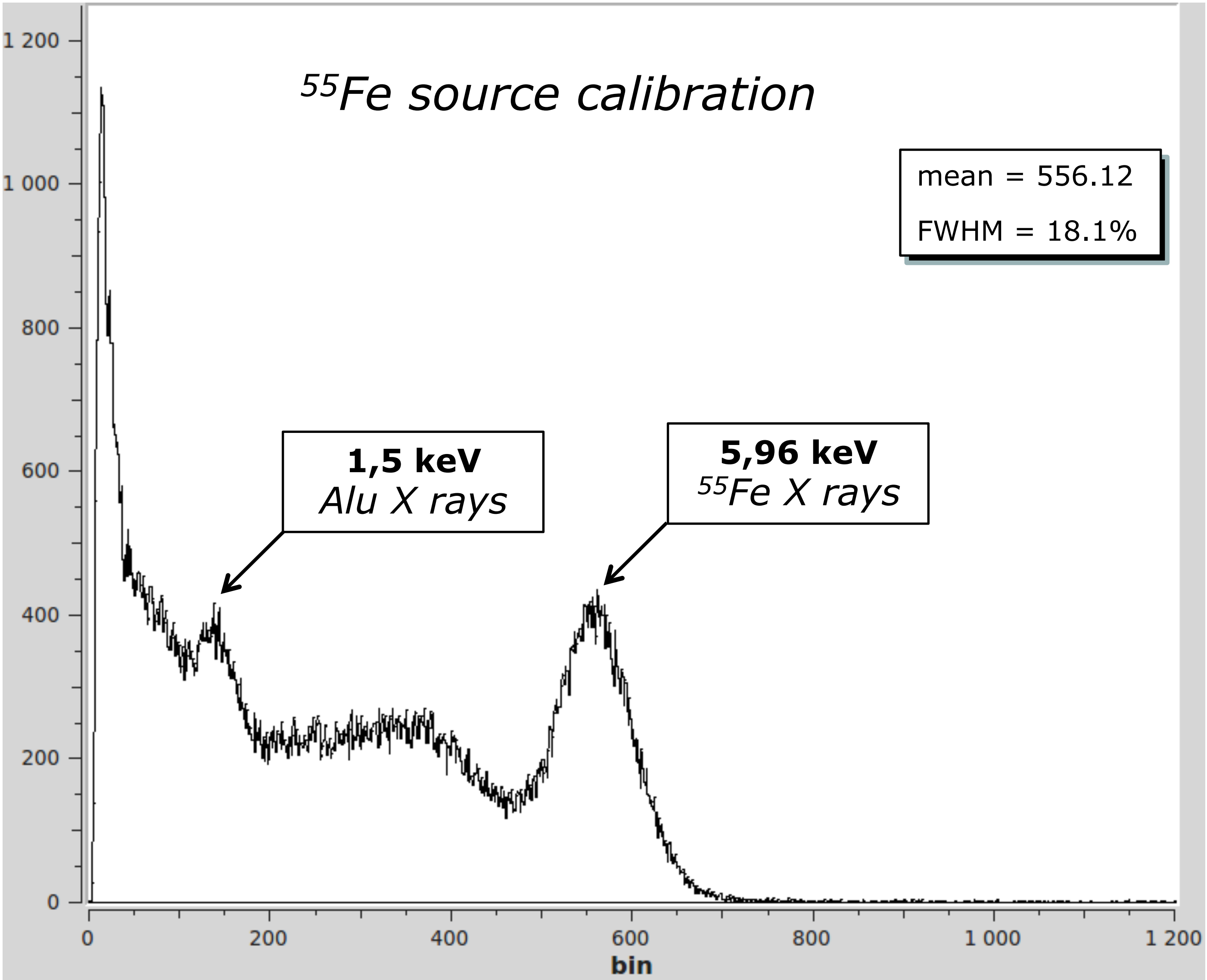


10 keV
$^4He^+$
No Wien filter
H_2O
N_2
He
H
1 400
1 200
1 000
800
600
400
200
0
0
200
400
600
800
1 000
1 200
bin

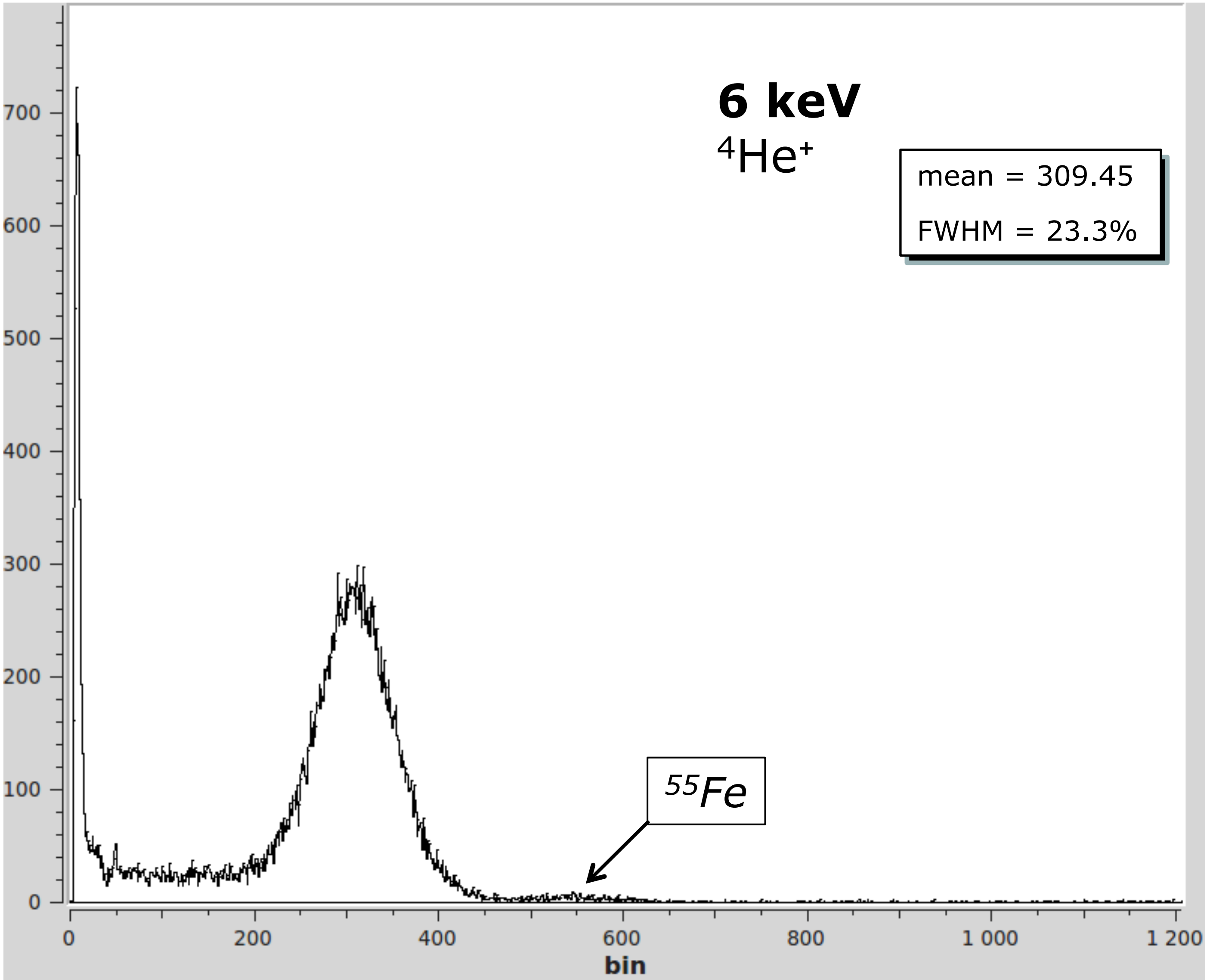
Wien Filter


He
10 keV
$^4He^+$
With Wien filter
N_2
H_2O
400
300
200
100
0
0
200
400
600
800
1 000
1 200
bin

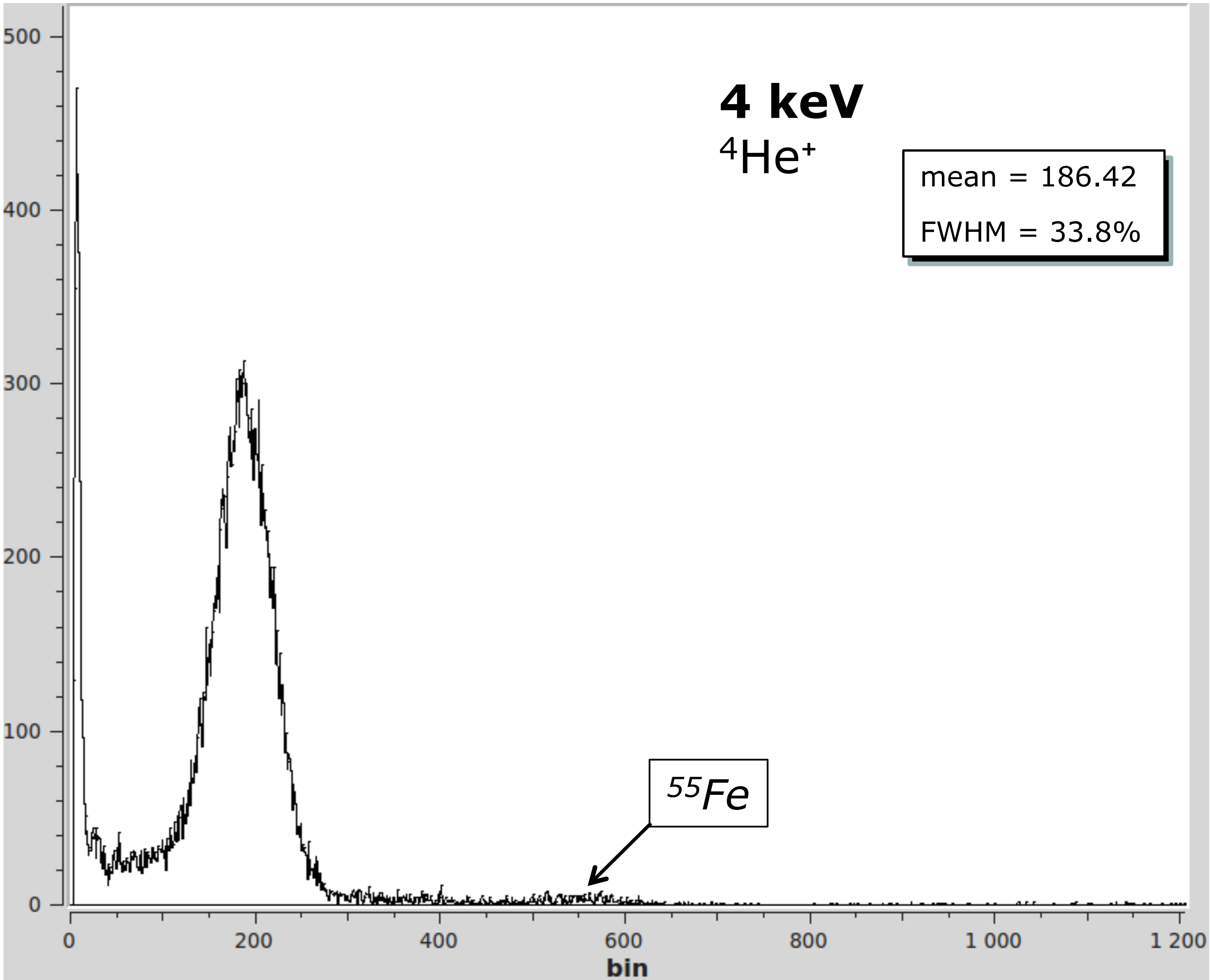
Ions Performance



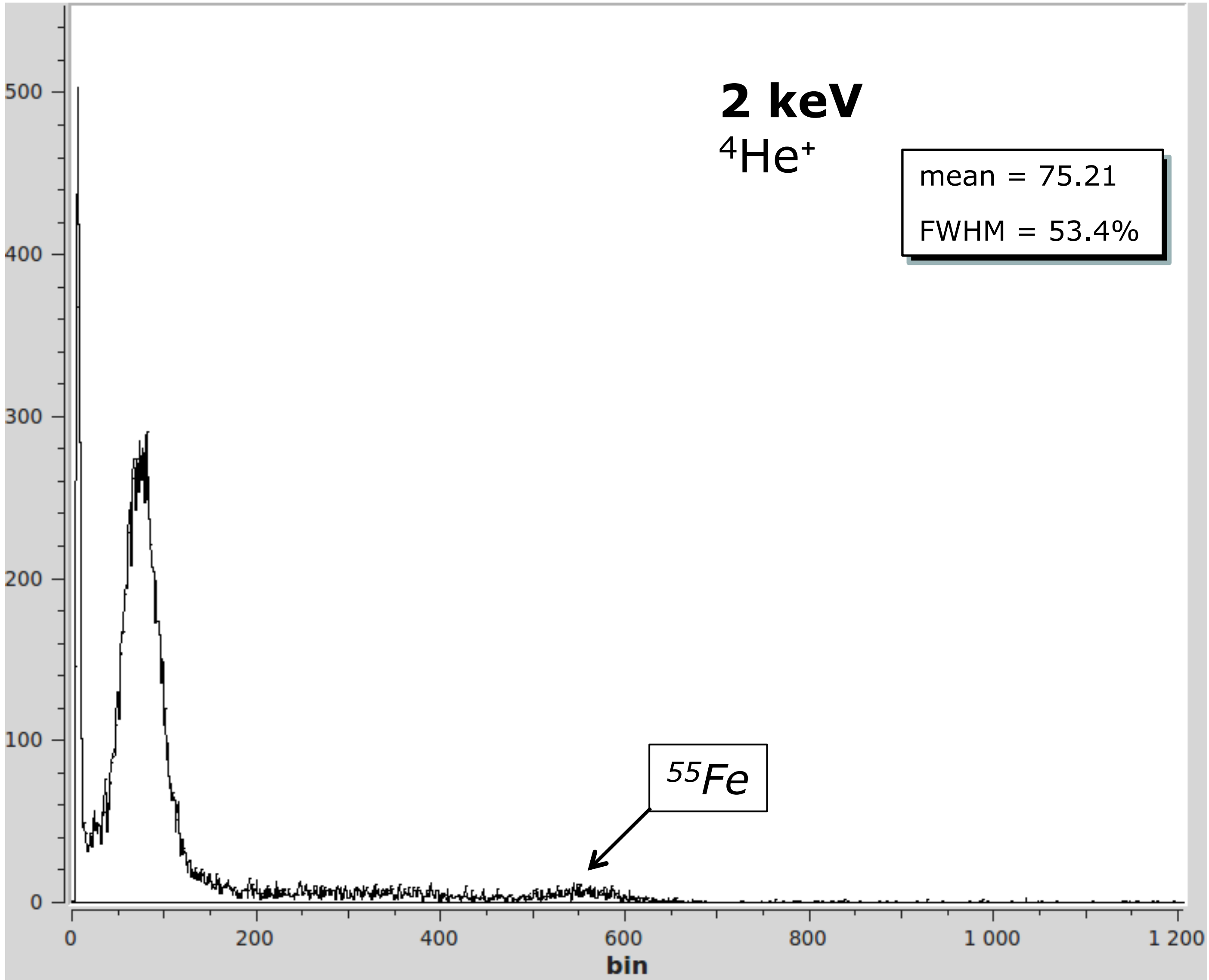
Ions Performance



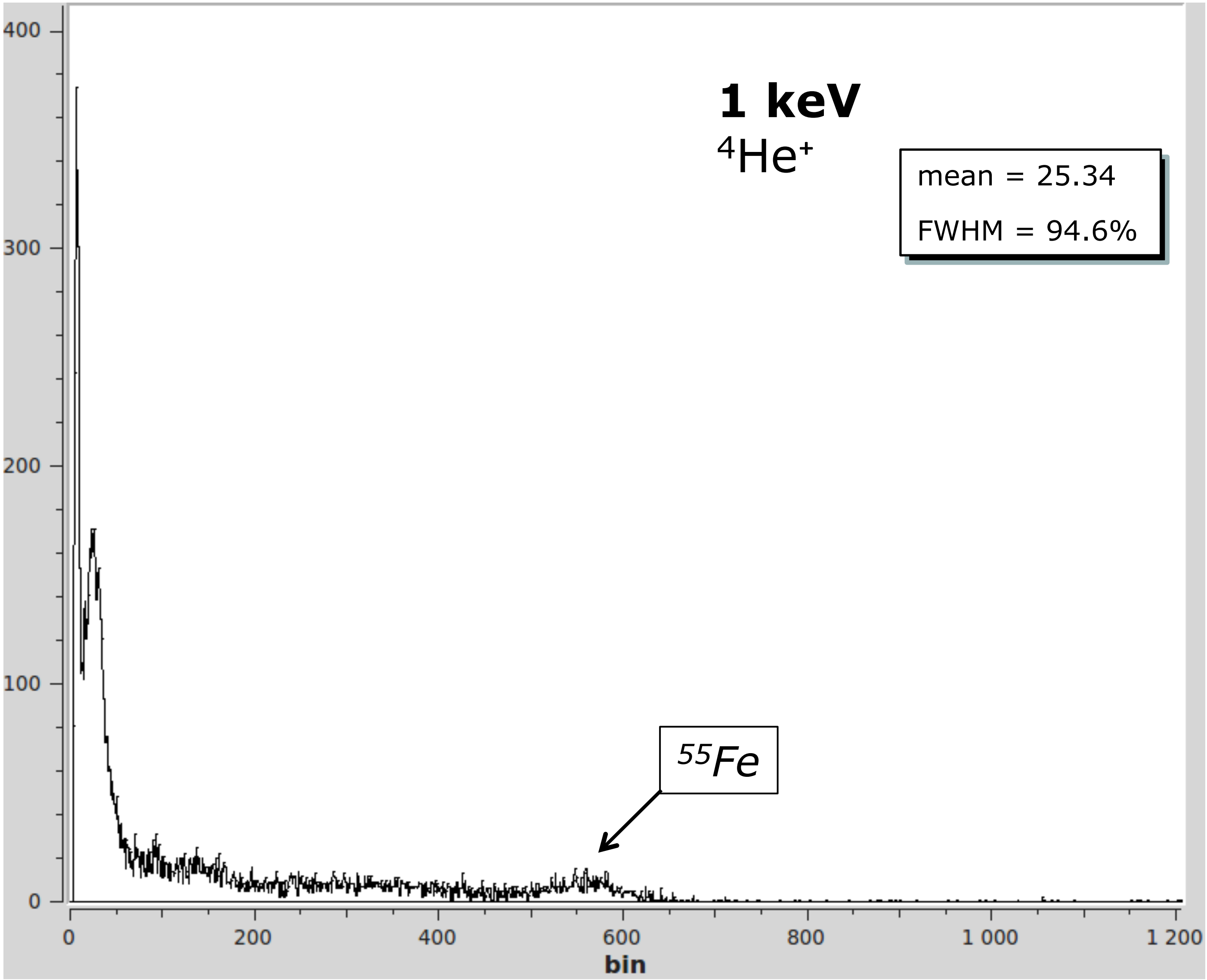
Ions Performance



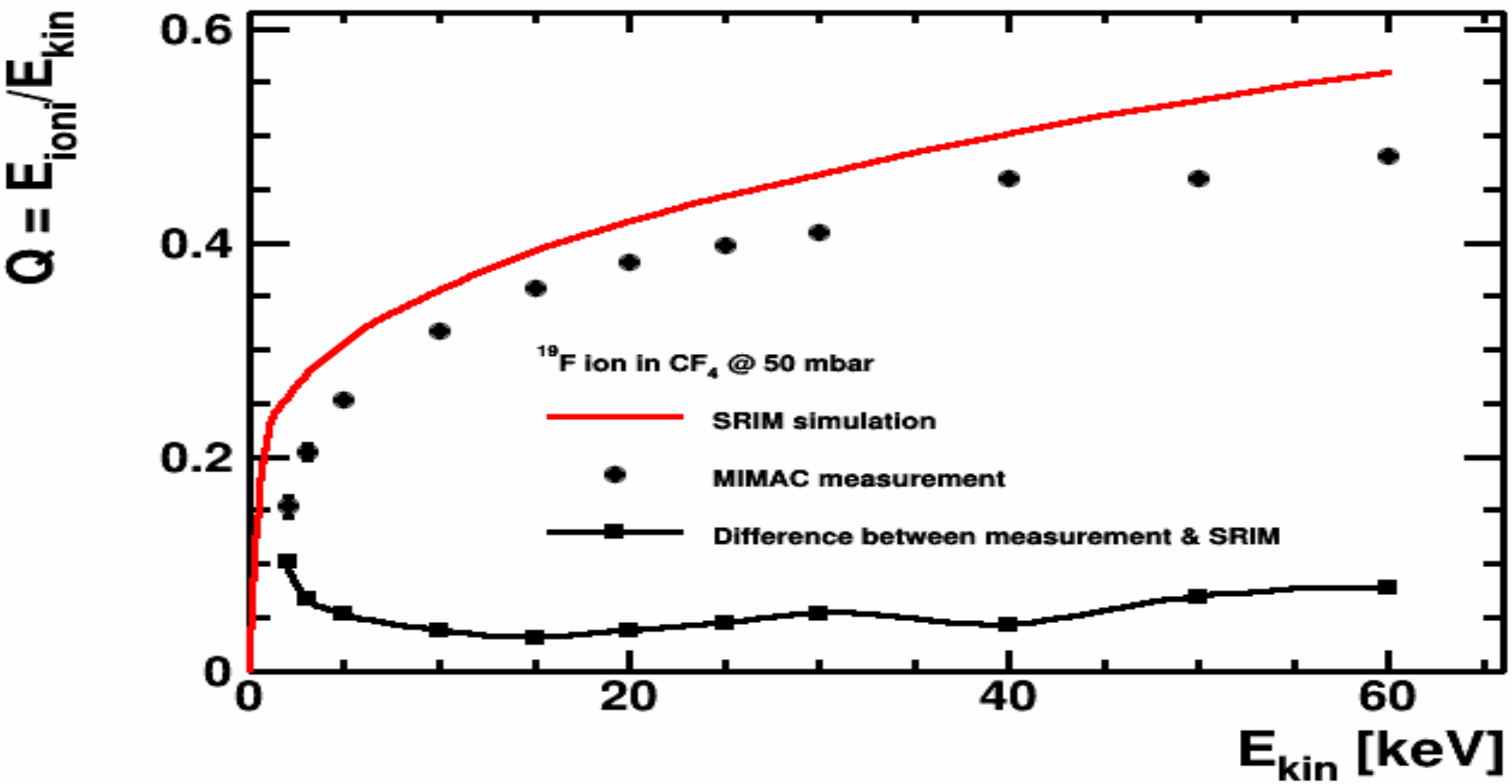
Ions Performance



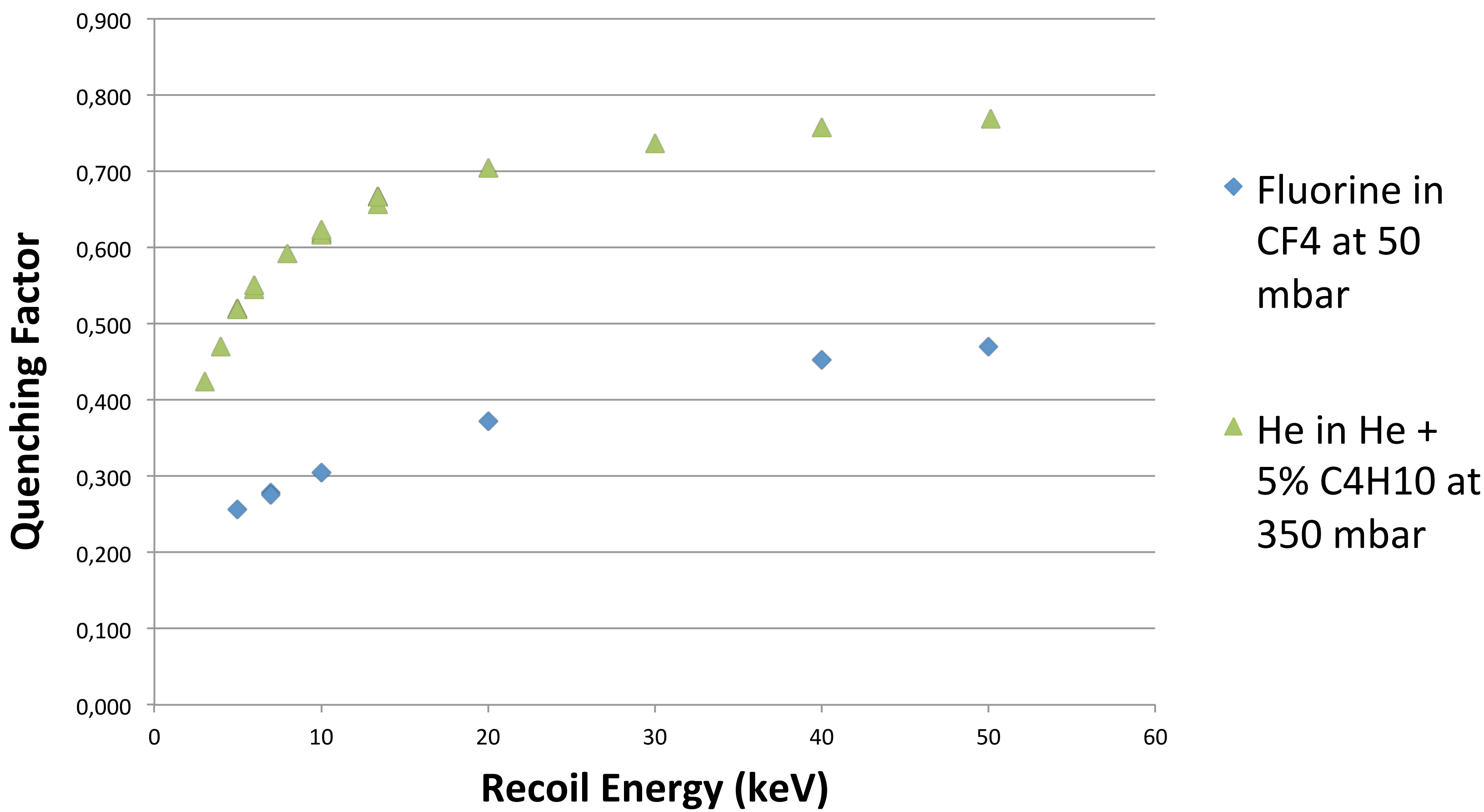
Ions Performance



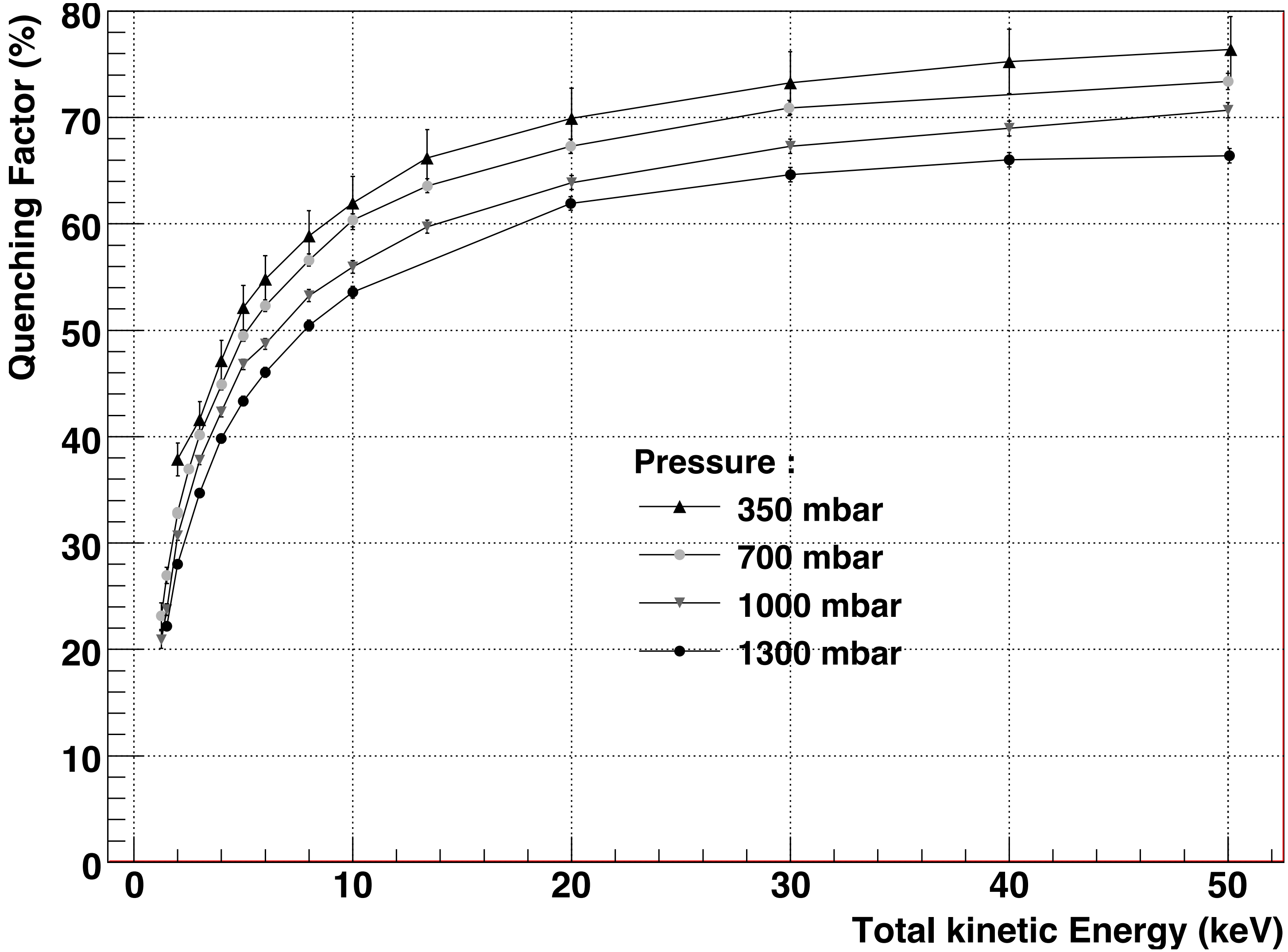
^{19}F - IQF Measurements compared with SRIM-Simulations !



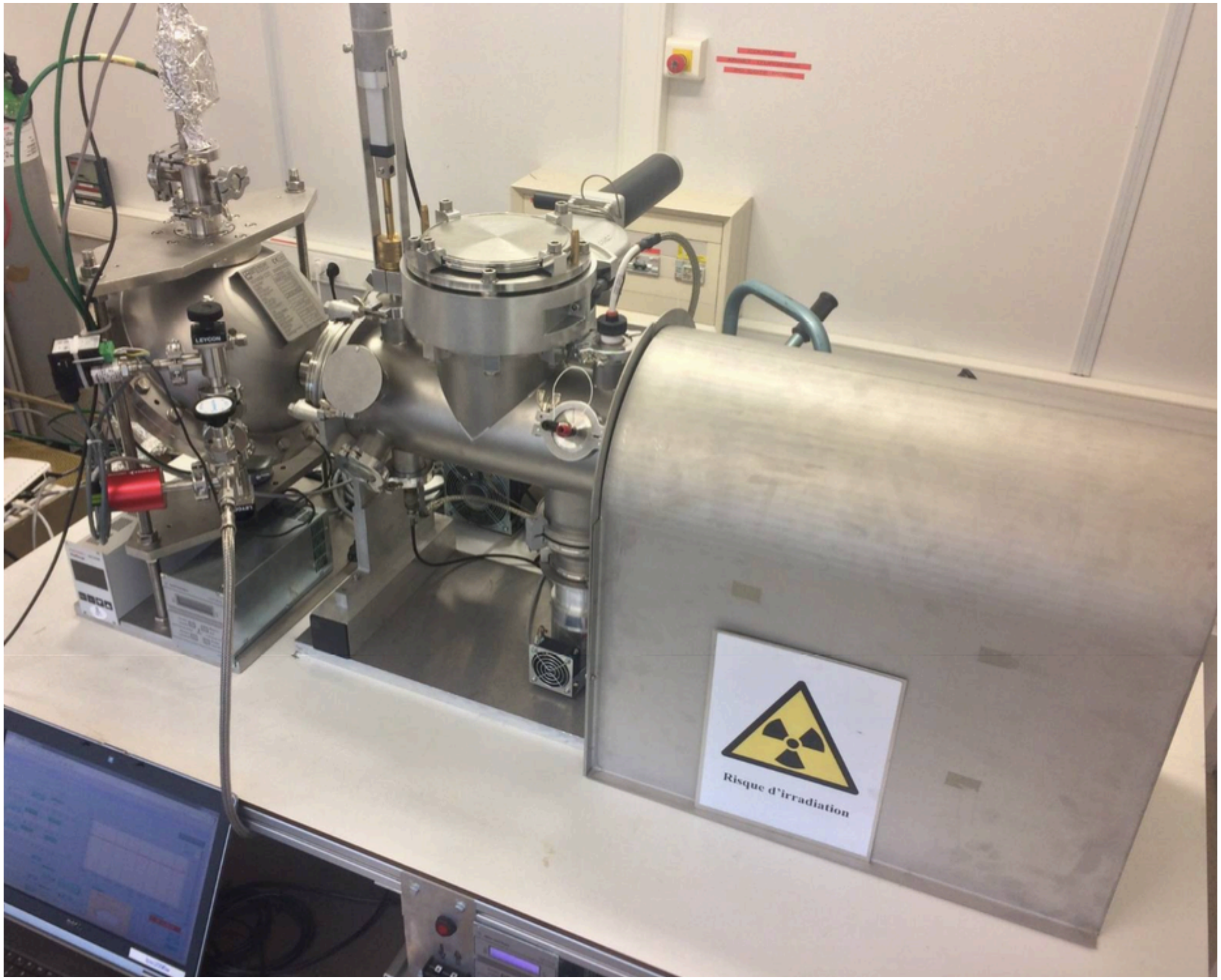
Ionization Quenching Factor for Fluorine in pure CF4 at 50 mbar



IQF in $^4He + 5\% C_4H_{10}$ for different pressures!!



Ionization Quenching Factor Measurements in the frame of NEWS-G (up to 10 bars…) with COMIMAC in Grenoble (France)



D. Santos (LPSC Grenoble)

Why Gas Detector for DM detection
(ionization, scintillation and tracks)

i) Flexibility to change the nucleus **target**:

^{1}H, ^{3}He, ^{4}He, ^{19}F, ^{20}Ne, ^{40}Ar, ^{129,130}Xe

Optimizing the momentum transfer !!

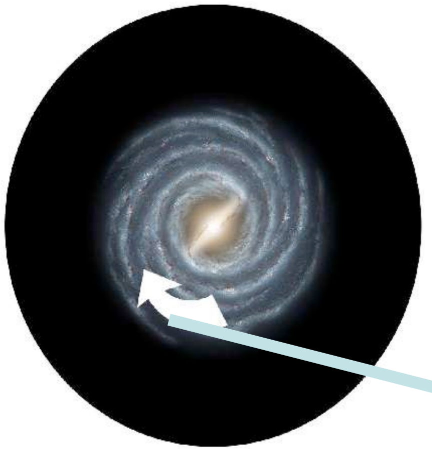
ii) Access to very low threshold in **ionization energy** (sub-keV) by low capacitance and high gains

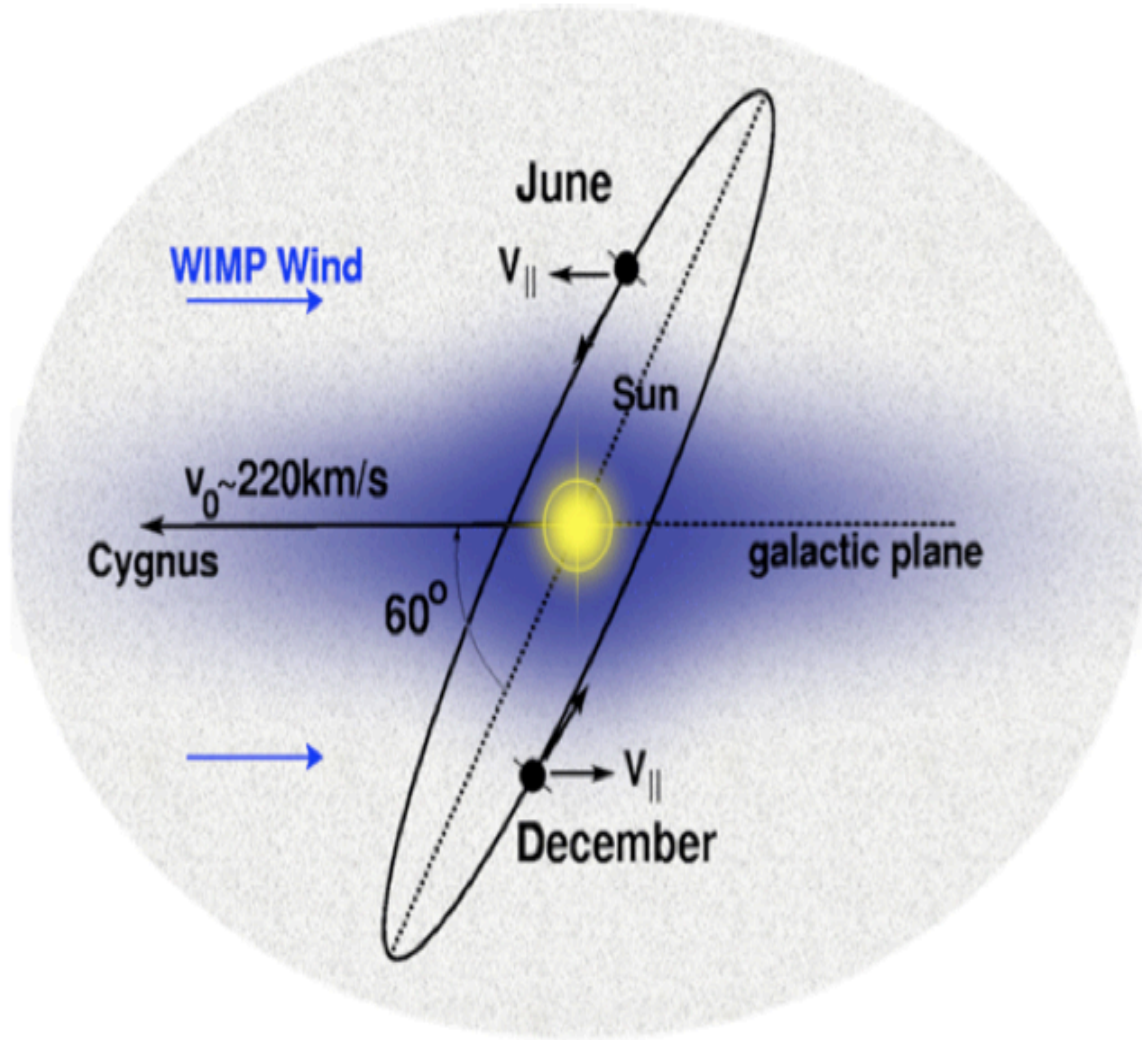
iii) Flexibility to change **pressure** ($N_{evts} \sim N_{nuclei}$)

iv) Opening the **directional** signature (1D, 2D and 3D **tracks**)

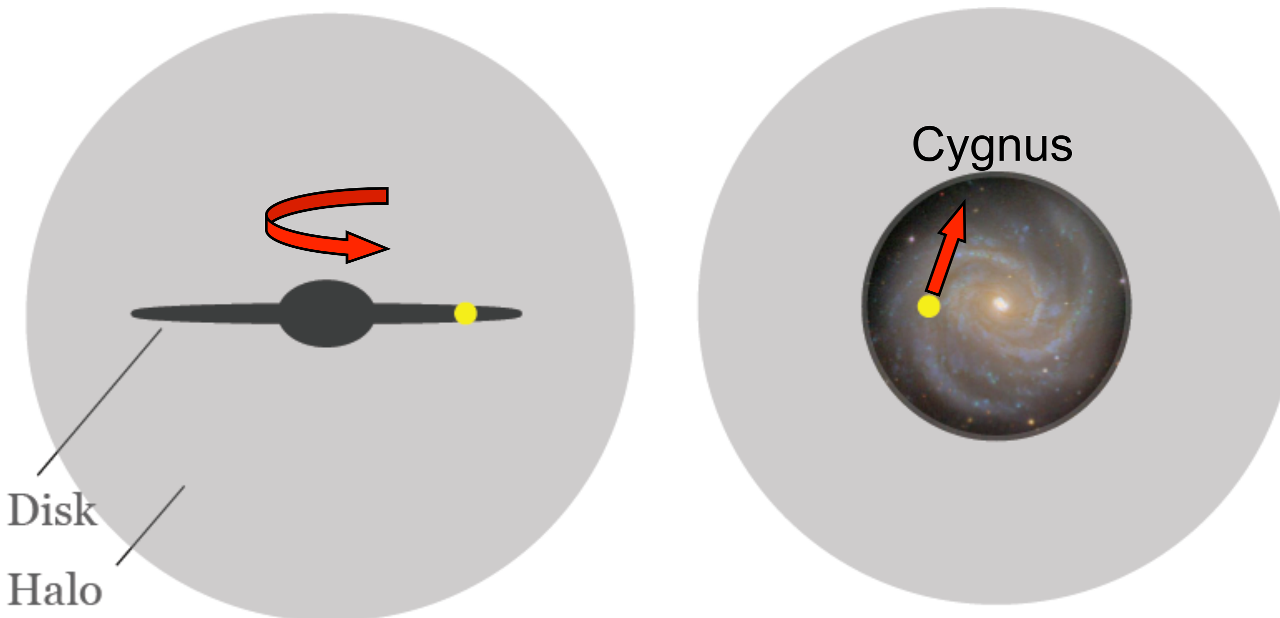
v) Allowing to cope with **neutron background** events

Directional detection: principle





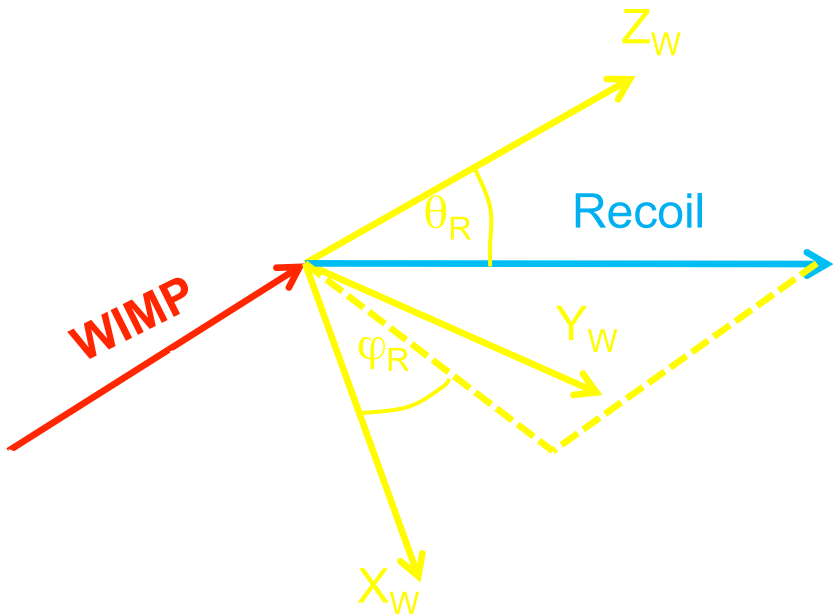
Directional detection : principle

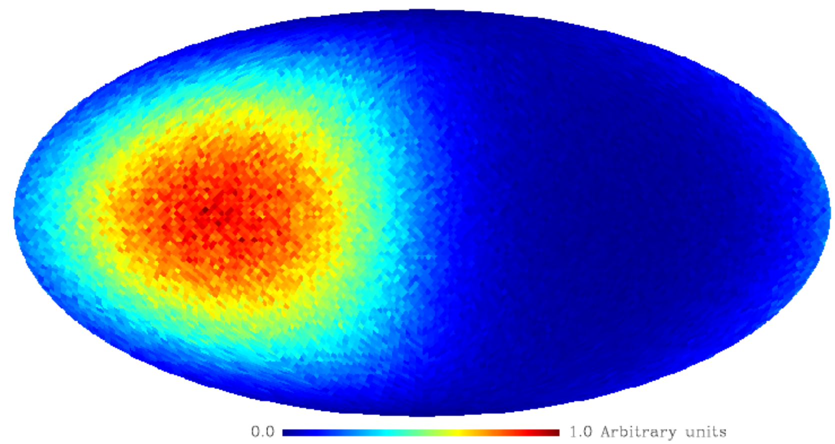


$<V_{rot}> \sim 220$ km/s

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

There are many "angles" for nuclear recoils…

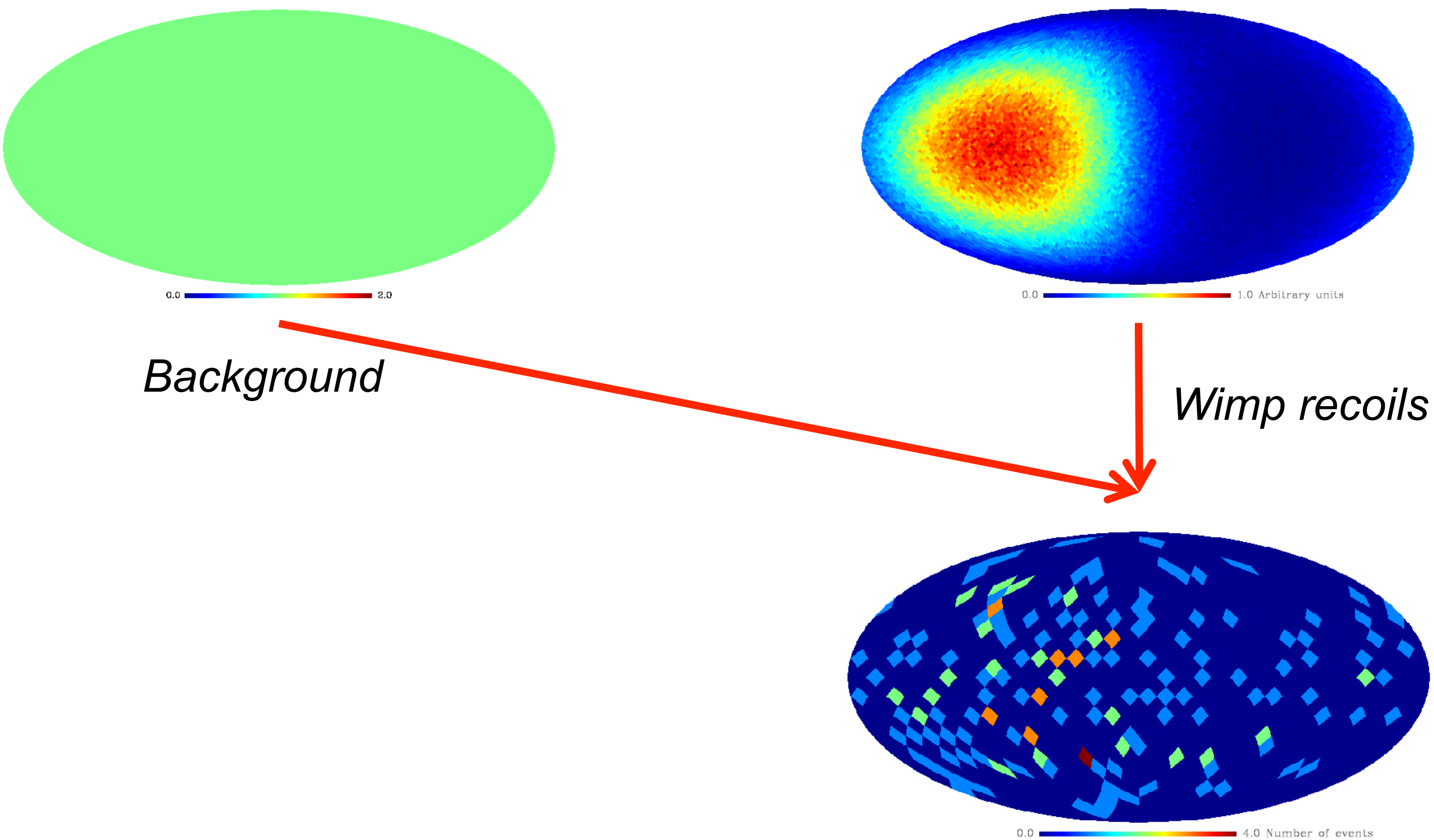




Map of recoils in galactic coordinates (HealPix)

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

100 WIMP evts + 100 Background evts

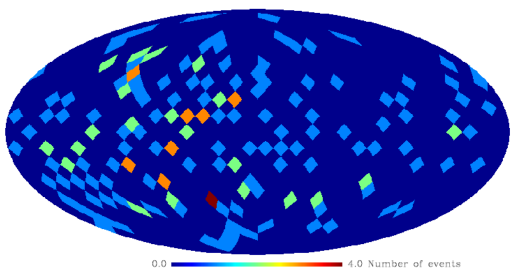


Phenomenology: Discovery

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

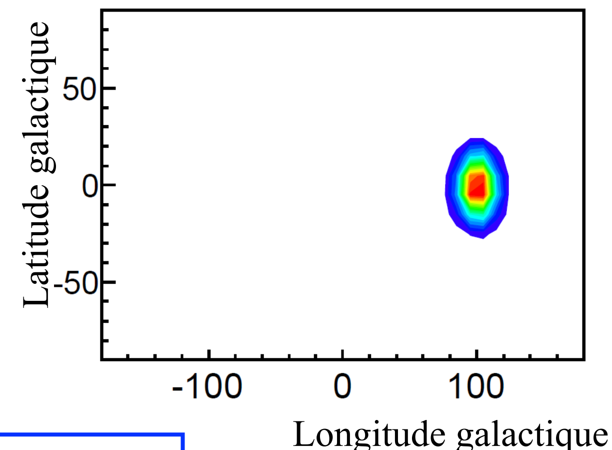
Proof of discovery: **Signal pointing toward the Cygnus constellation**

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



100 WIMP + 100 BKG

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

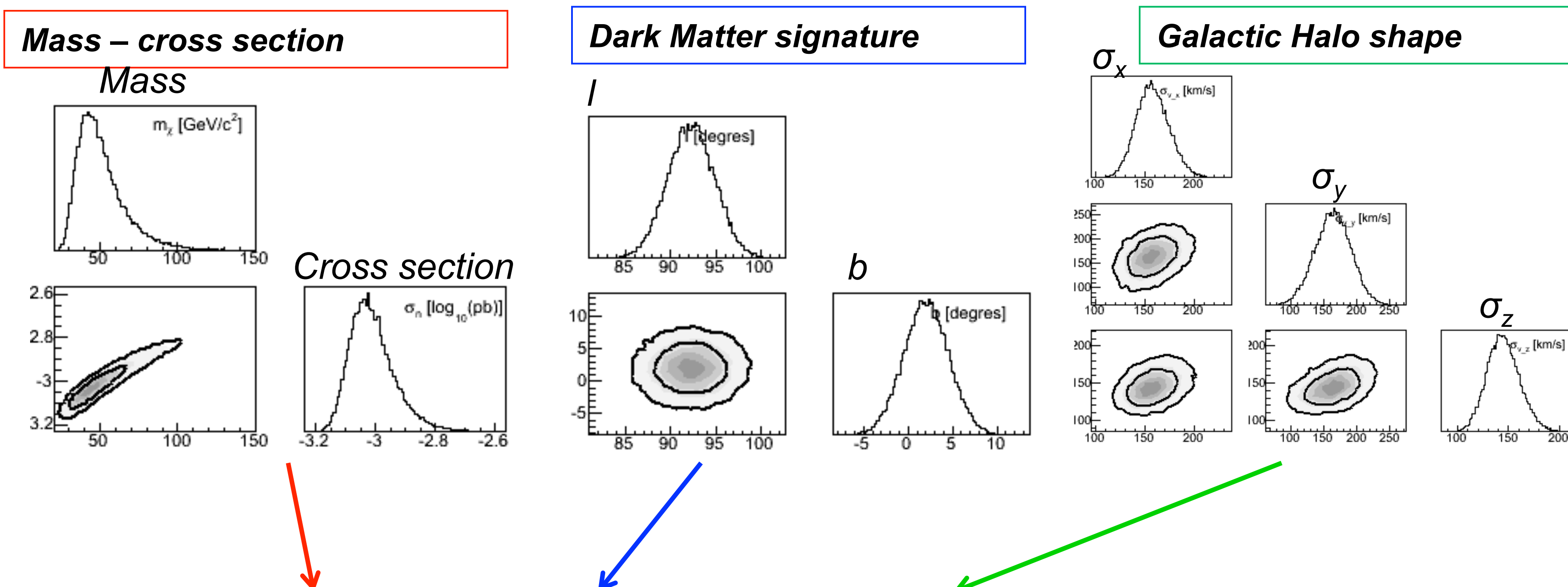


Strong correlation with the direction of the Constellation Cygnus **even with a large background contamination**

Directional Detection : identification

J. Billard *et al.*, PRD 2011

8 parameters simultaneouly constrained by only one 3D experiment



	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

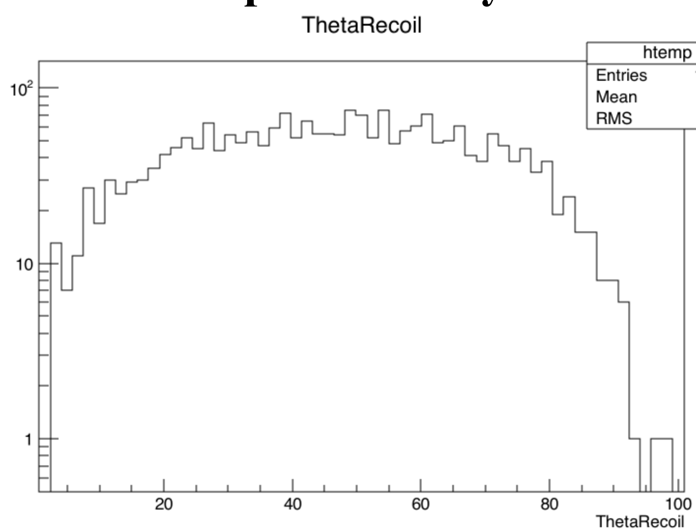
There are many angles to measure in 3D! 1D and 2D are not enough !

^{19}F recoils (E_{kin}= 1-110 keV)

Angular distribution in the laboratory (with respect to the neutron direction)

Produced by neutrons of 565 keV

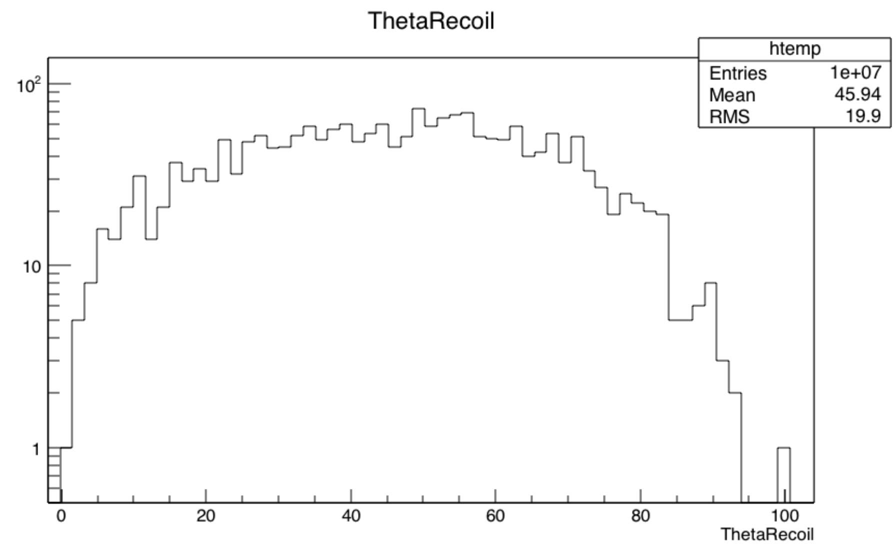
Validated experimentally at Cadarache !!



^{19}F recoils (E_{kin}= 1- 40 keV)

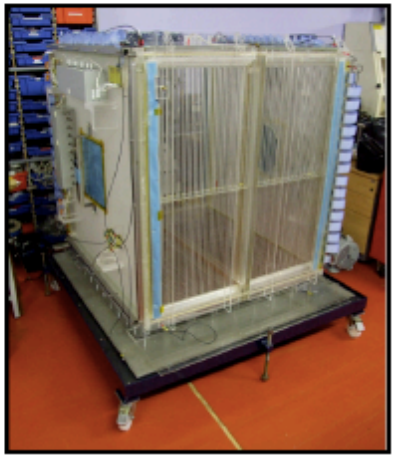
Angular distribution in the laboratory

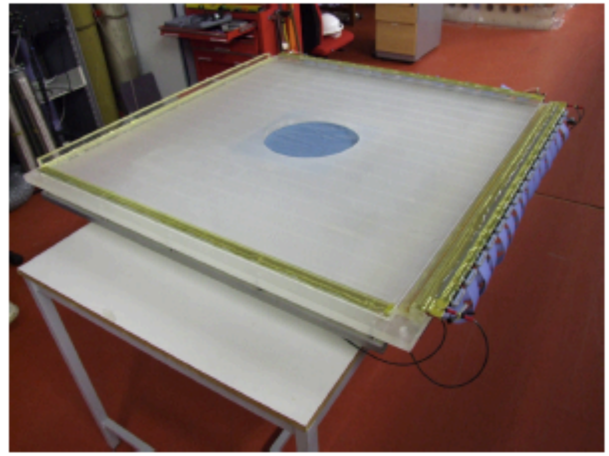
Produced by neutrons of 200 keV



Geant4 simulations (N. Sauzet, DS)

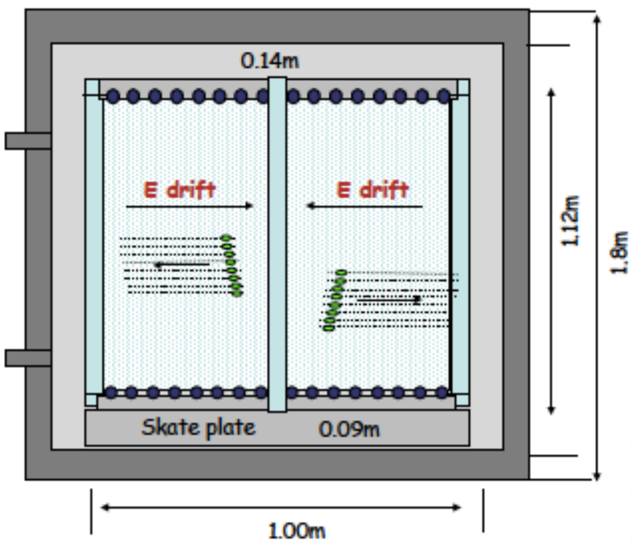
DRIFT Basics

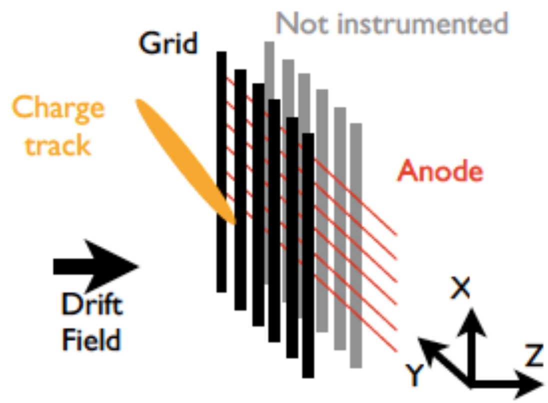


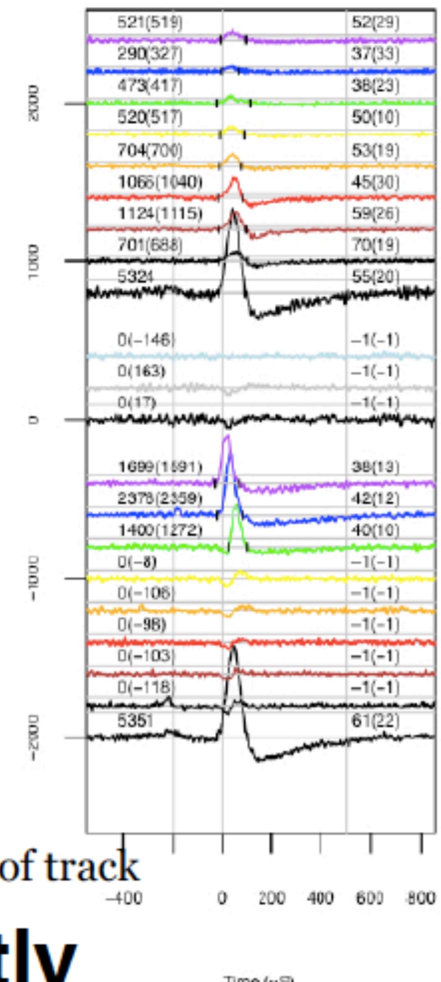


Directional Recoil Identification From Tracks (DRIFT)

DRIFT IIa, b, c, d, e





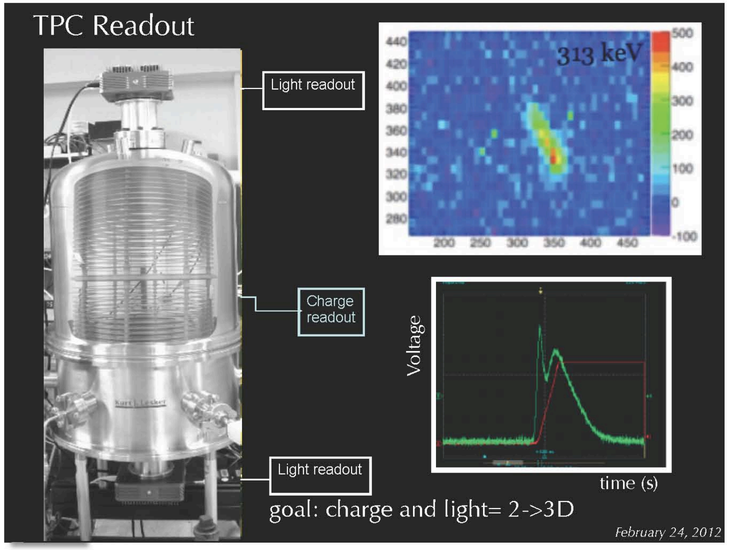


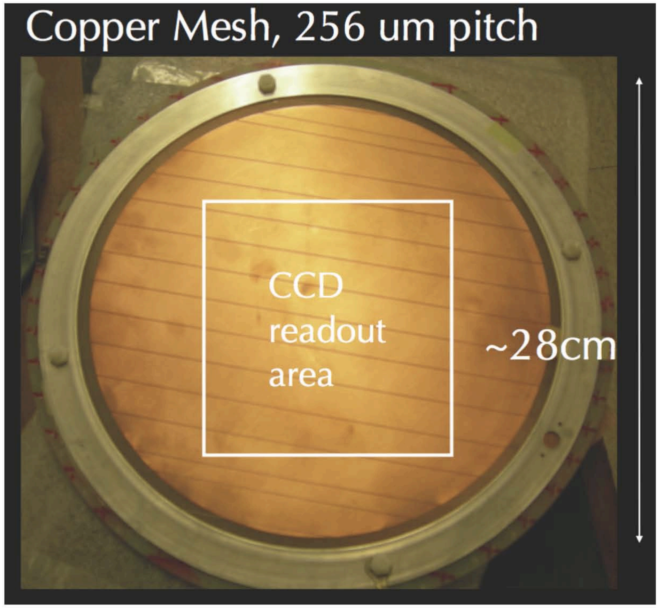
ΔX: Number of anode wires crossed
ΔY: Progression across grid wires
ΔZ: Drift time between start and end of track

Significant advances recently

DM-TPC – Dark Matter TPC

Started = 2007, US
Underground in WIPP, USA in 2011
Current operating detector = DMTPC 10 liter
Technology = TPC with micromegas + light and charge readout





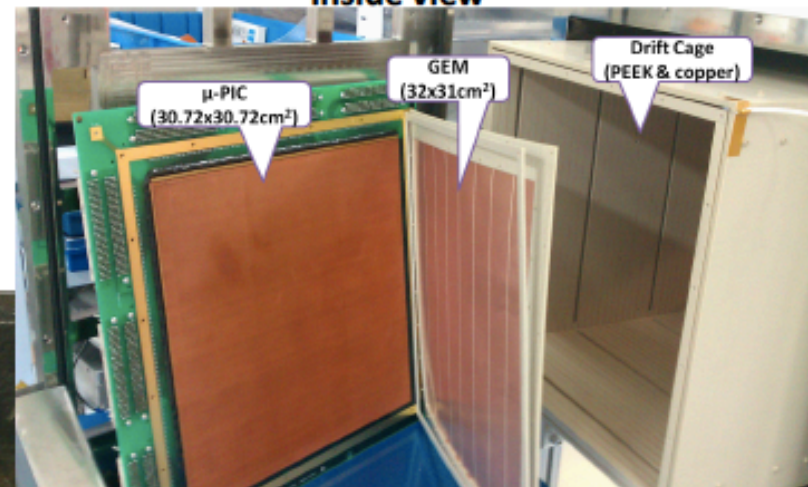
xyz resolution = 0.256 mm & absolute in xy, Δz coming
Target = CF_4 @ 75 Torr
Fiducial volume = 9.18 liters
F mass = 2.85 g
Limit setting threshold = 80 keVr

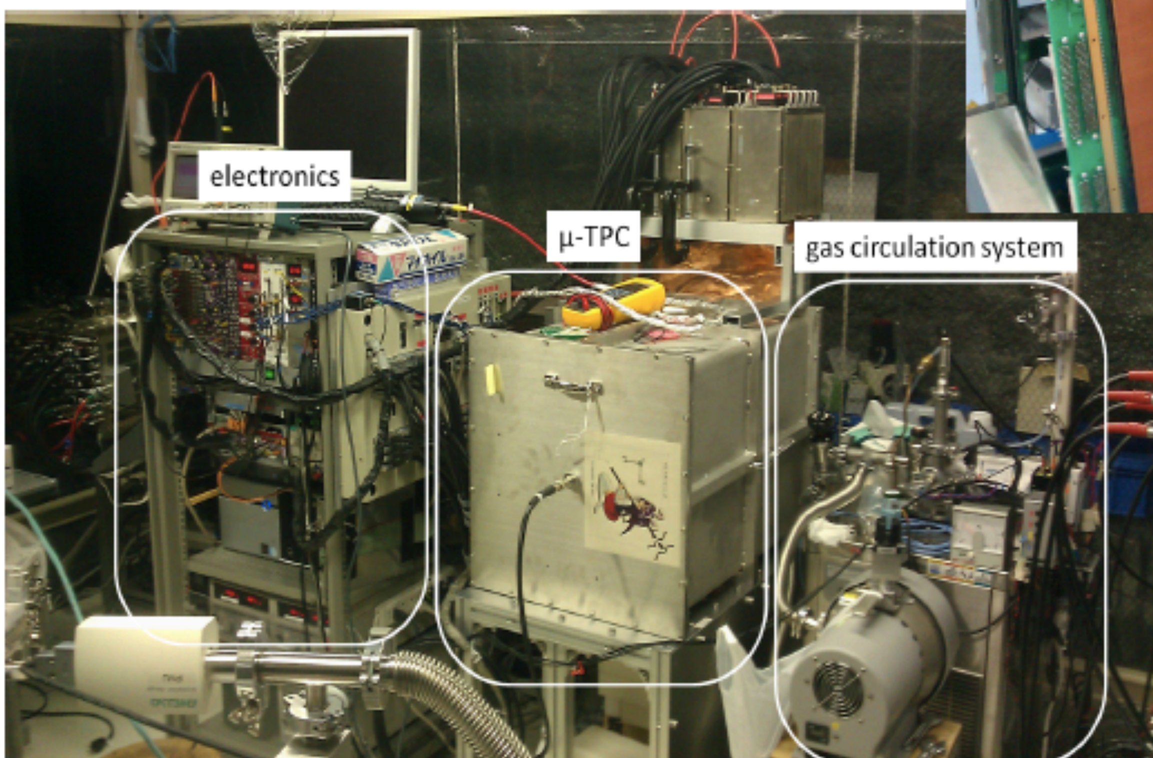
These values are probably out of date
See more on DMTPC website

NEWAGE-0.3b' Detector

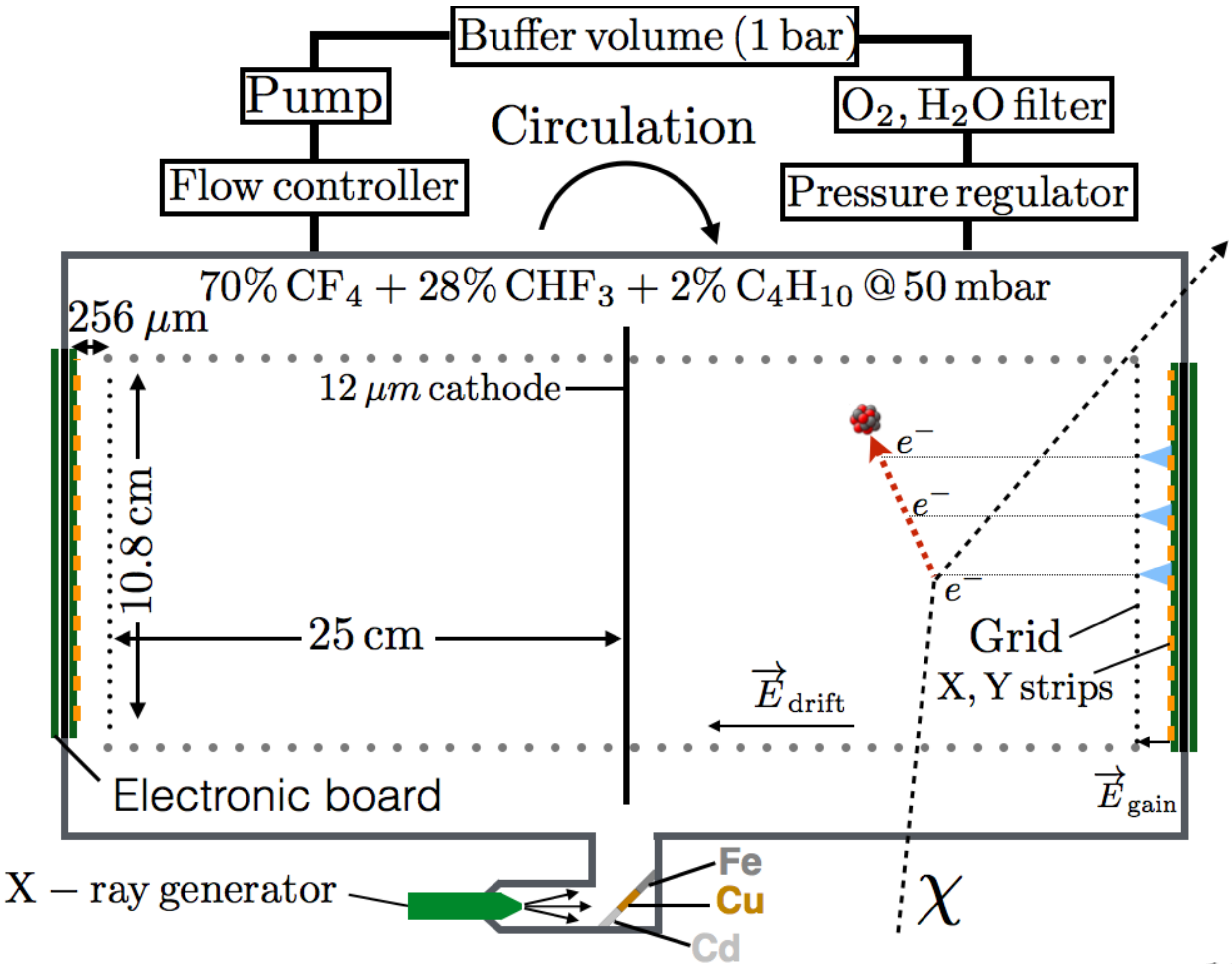
- Detection Volume: 31 × 31 × 41cm^3
- Gas: CF_4 at 76Torr (50keVee threshold)
- Gas circulation system with cooled charcoal
- Installed in Kamioka Laboratory

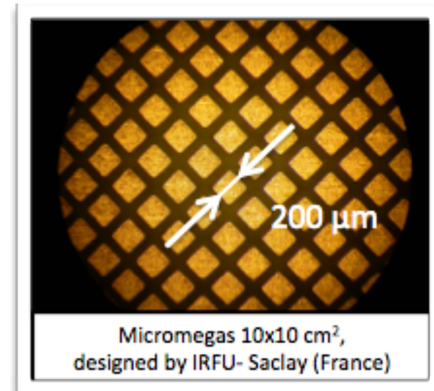
Inside view





MIMAC-bi-chamber module prototype





MIMAC Target: ^{19}F

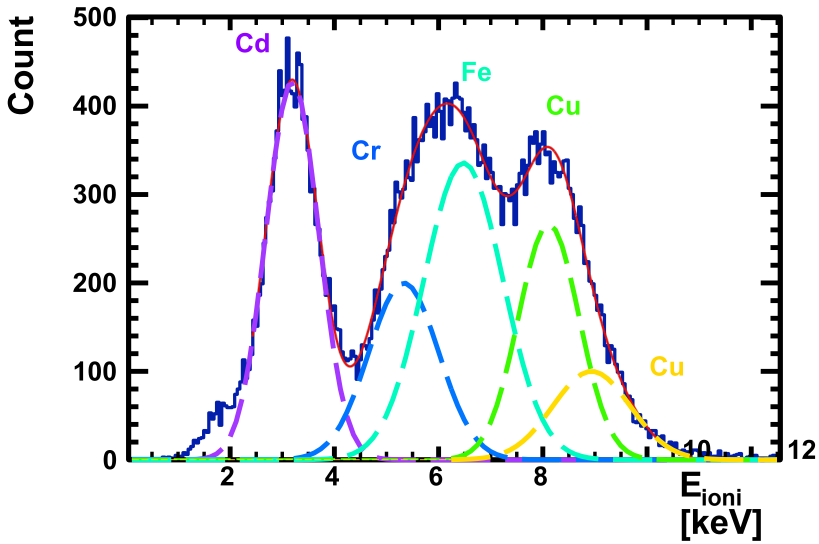
- Light WIMP mass
- Axial coupling

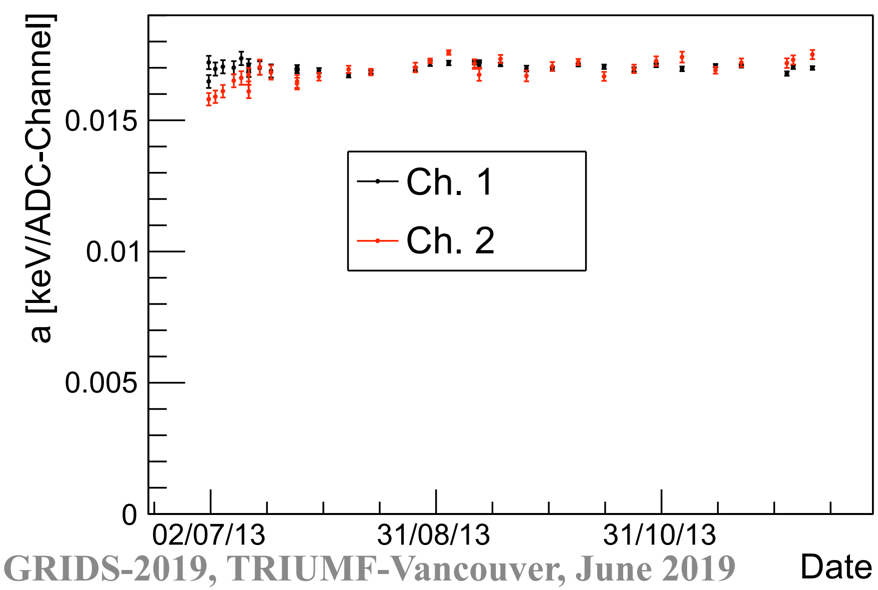
In any case one needs to measure the ionization released by the particles in the active volume

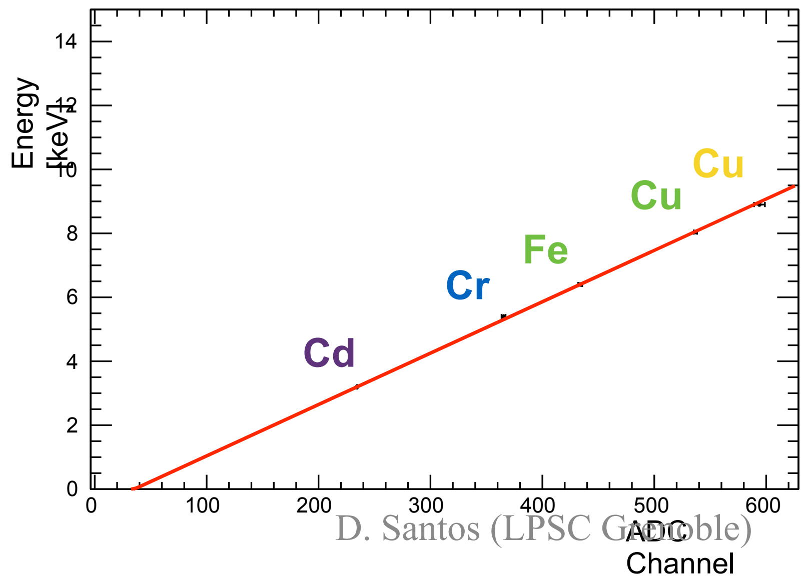
Example of calibration (MIMAC)

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

Circulation system:
Excelent Gain stability in time



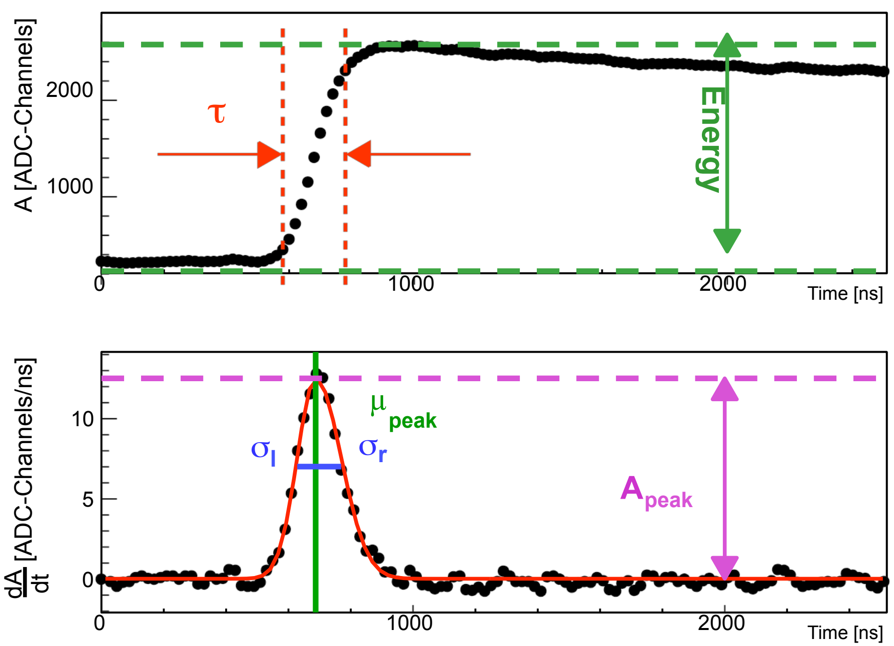




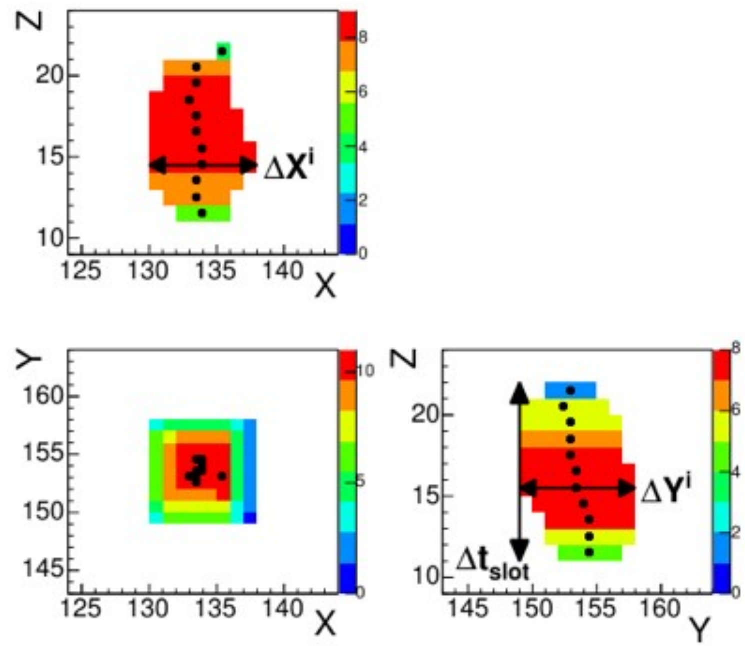
MIMAC readout

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

preamplifier signal + FADC: Energy



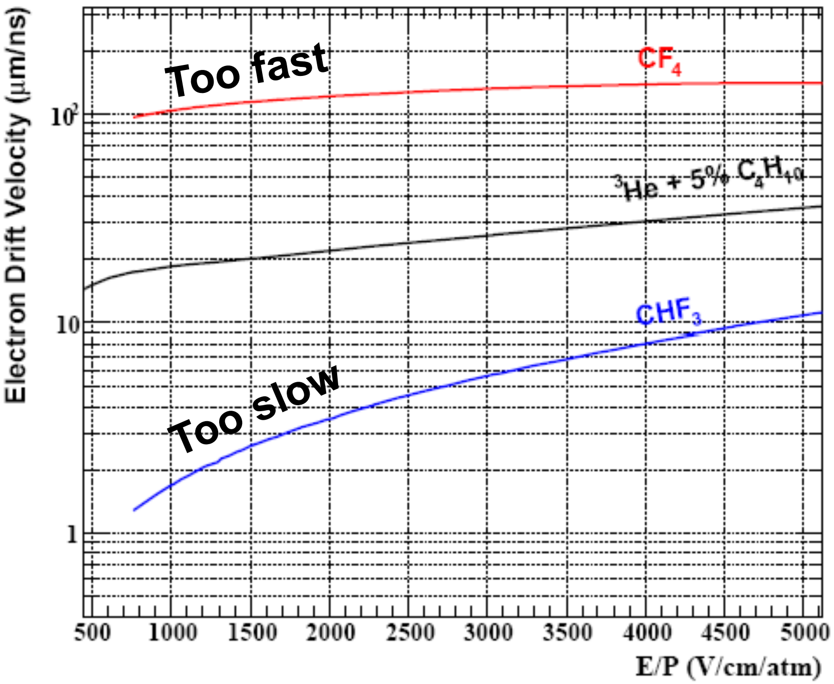
3D - track

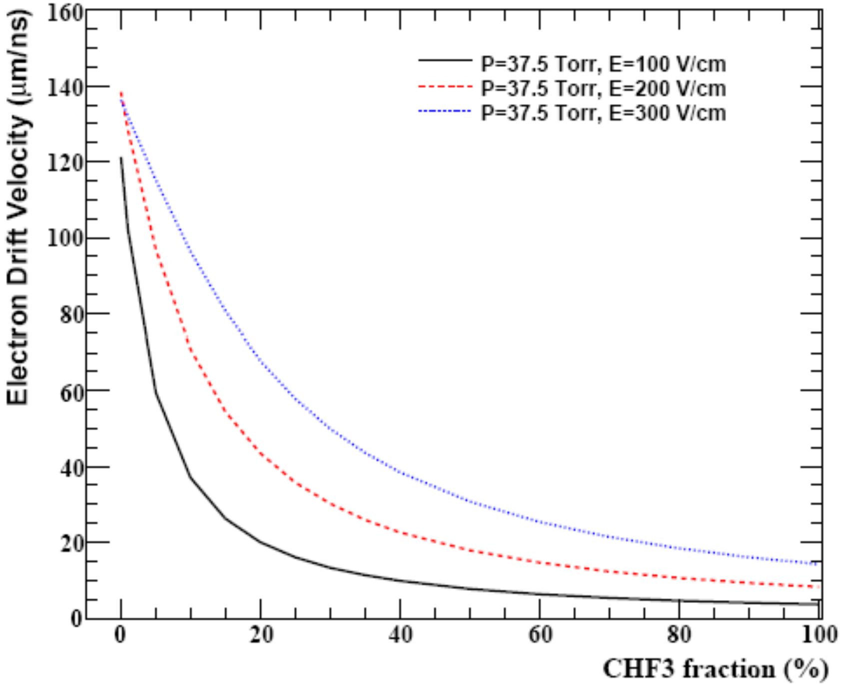


D. Santos (LPSC Grenoble)

3D Tracks: Drift velocity

Magboltz Simulation





- New mixed gas MIMAC target : CF_4 + x% CHF_3 (x=30)

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

Nuclear recoil calibration with neutrons

Neutron monochromatic field:

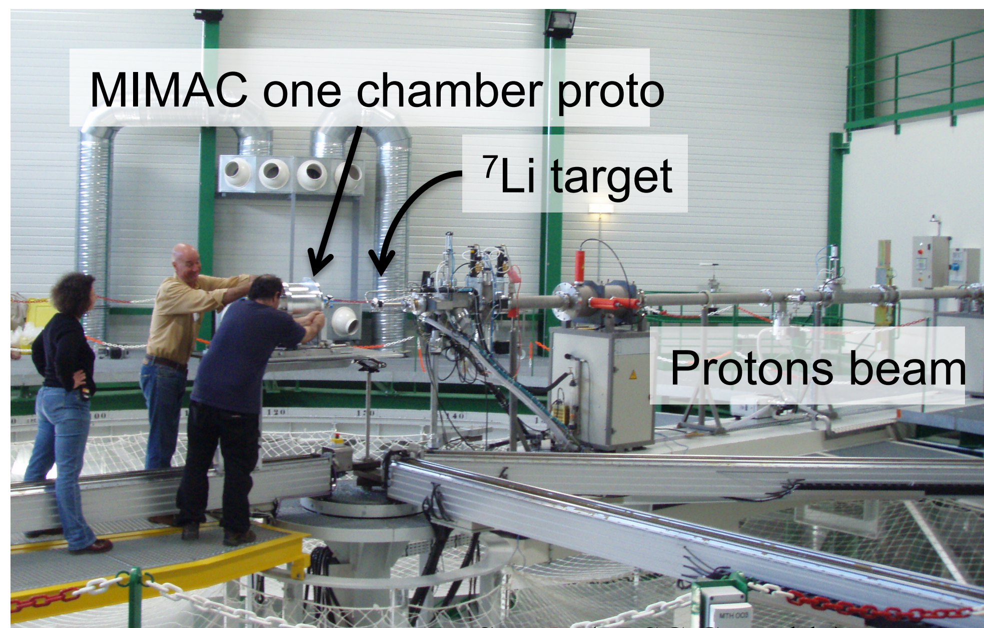
AMANDE facility at IRSN of Cadarache

- **Neutrons with a well defined energy from resonances of ^{7}Li by a (p,n) reaction**

$$E_{Recoil} = 4\frac{m_n m_R}{(m_n + m_R)^2} E_{neutron} \cos^2\theta$$

Electron Calibration:

^{55}Fe (5.9 keV) and ^{109}Cd (3.1 keV) sources

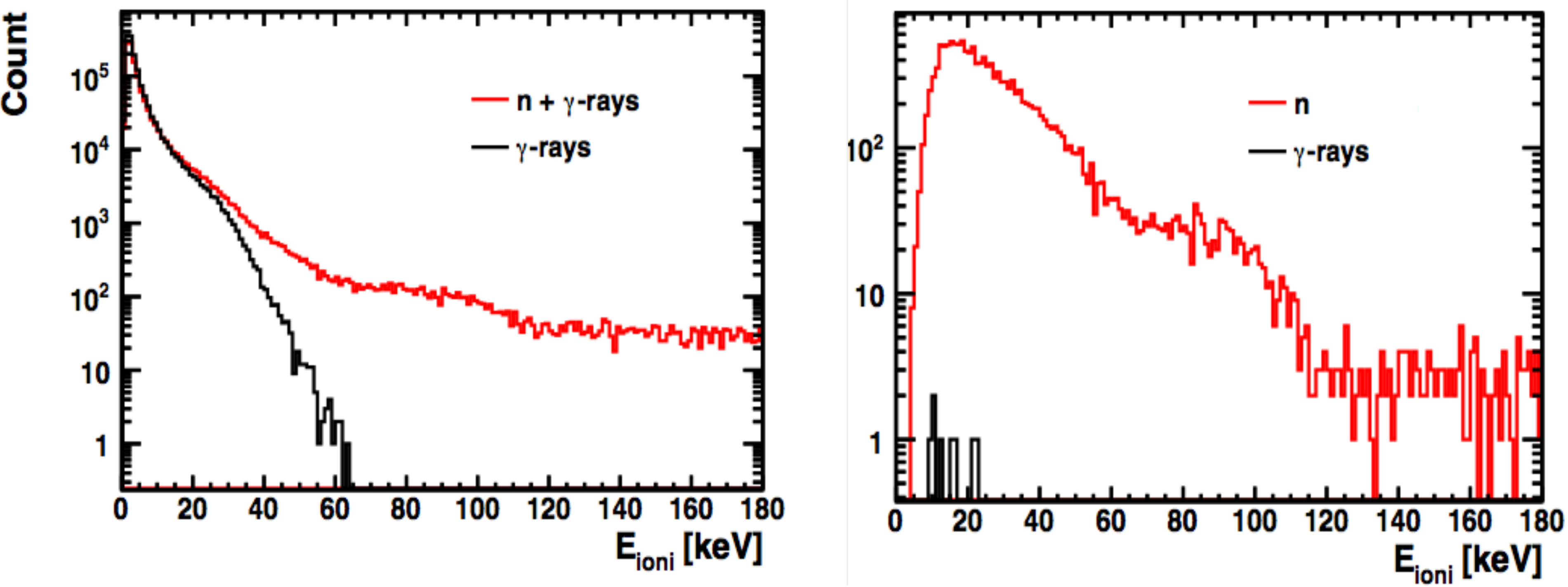


Electron-recoil Discrimination

^{7}Li (p,n (565 keV)) nuclear reaction

Neutrons ⟶ F , C, H, nuclear recoils

$\gamma - \text{rays}$ ⟶ Electrons

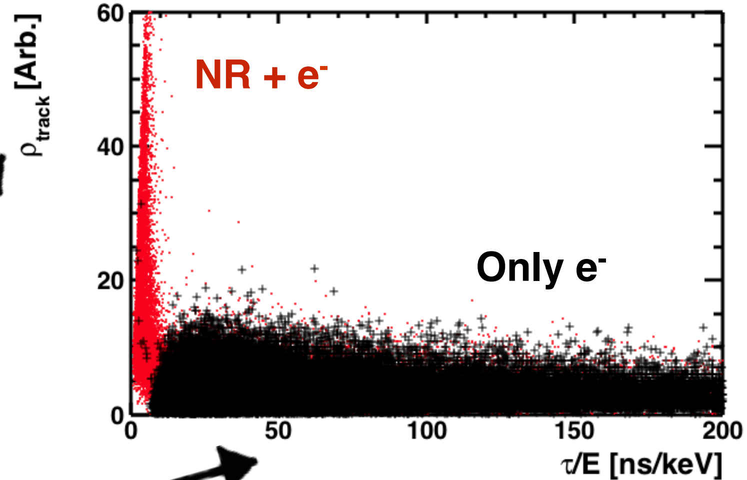


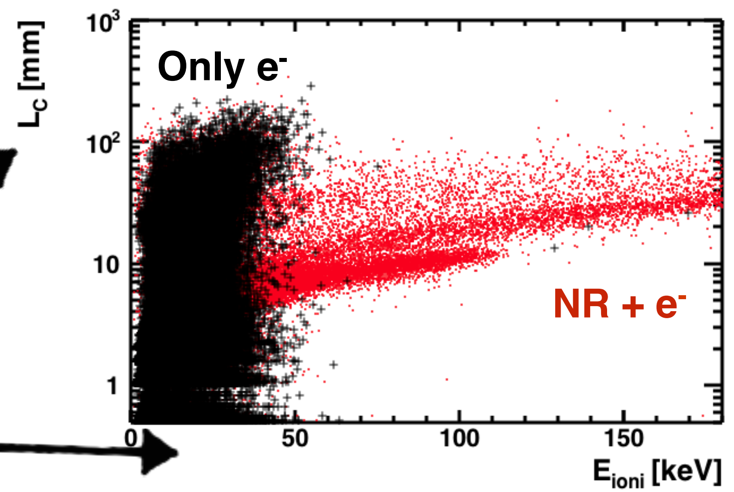
$N_{acpt}/N_{tot} = 1.1 \times 10^{-5}$ electron integrated rejection

22 observables built using the MIMAC readout…. and more …
(Q. Riffard et al. arXiv: 1602.01738 (2016))

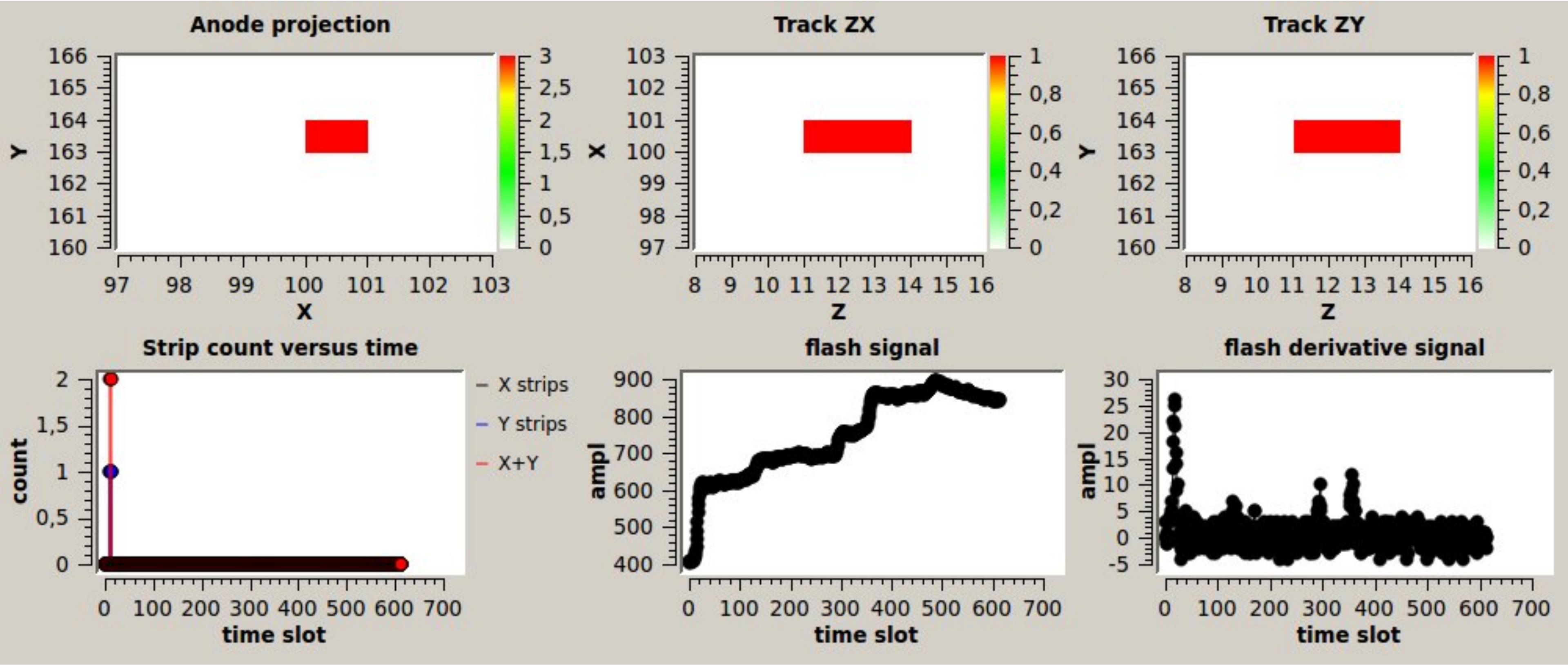
Variable	Type
Minimals	
$S[0]$	Pulse-shape
Track is outside	Track
Clustering	Track
$\Delta X > 1$ or $\Delta Y > 1$	Track
Discriminanting	
N_{Coinc}	Track
$\rho_{track}/\Delta t_{slot}$	Track
N_{Strip}	Track
A_{peak}	Pulse-shape
ρ_{track}	Track
NIS	Track
τ	Pulse-shape
t_{slot}^{start}	Track
Δt_{slot}	Track
$t_{start}^{pulse} - t_{slot}^{start}$	Both
χ^2_{peak}	Pulse-shape
σ_{Long}	Track
μ_{peak}	Pulse-shape
τ/E_{ioni}	Pulse-shape
L_C	Track
$V(\Delta X \Delta Y)$	Track
E_{ioni}	Pulse-shape
$\sigma^{(1)}_{Trans} - \sigma^{(2)}_{Trans}$	Track

With fast neutrons



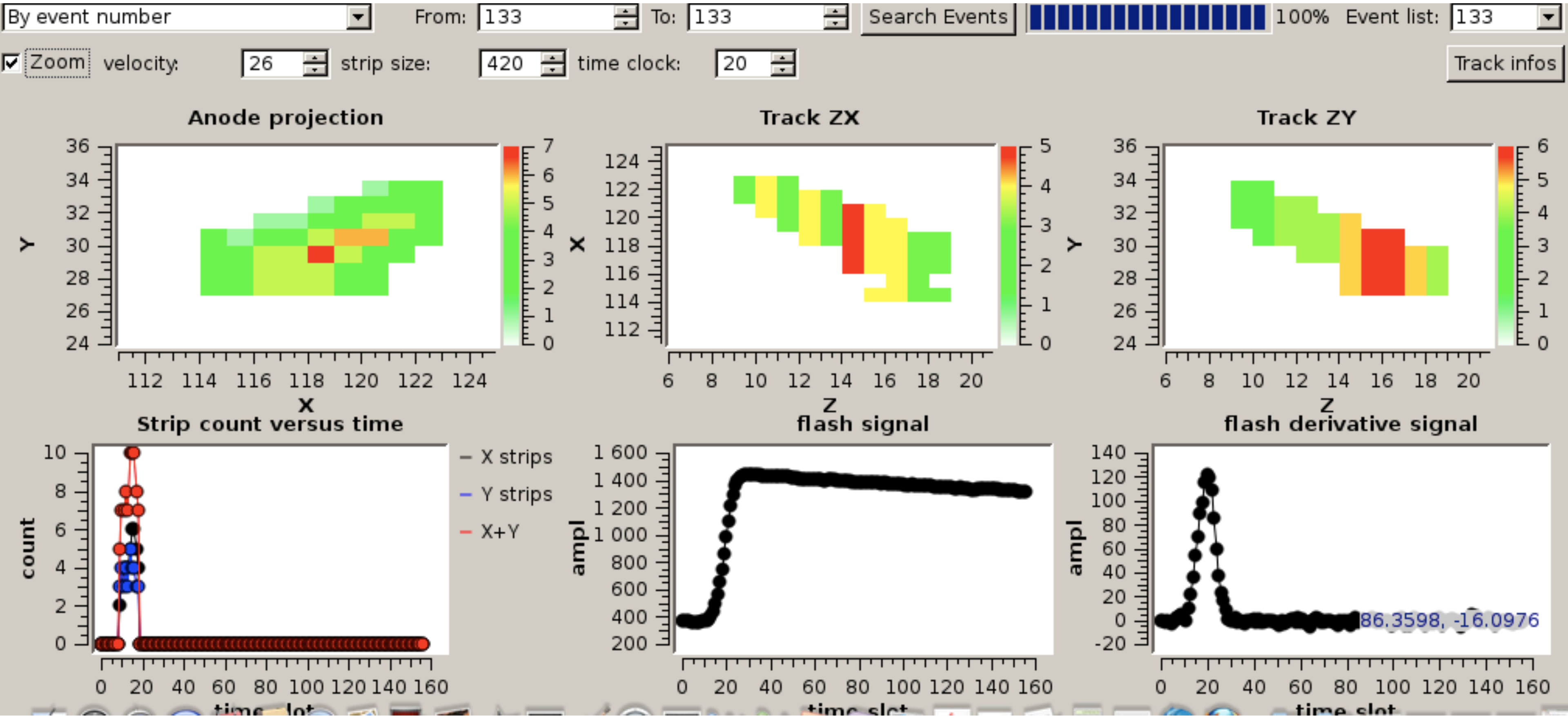


An Electron event (18 keV)



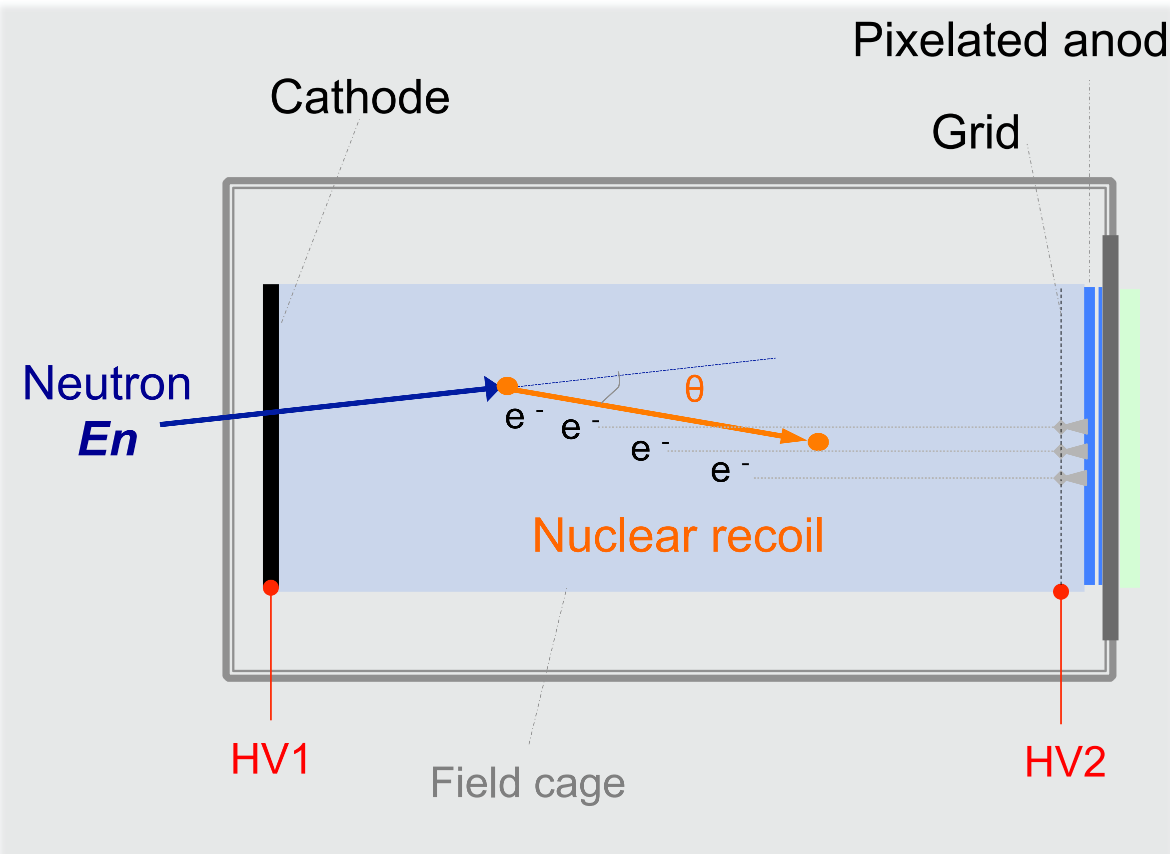
D. Santos (LPSC Grenoble)

A “recoil event” (~ 34 keVee)

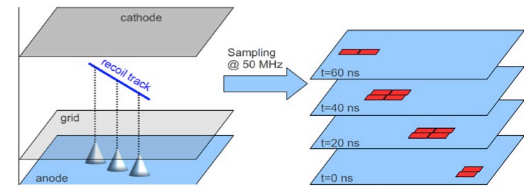


D. Santos (LPSC Grenoble)

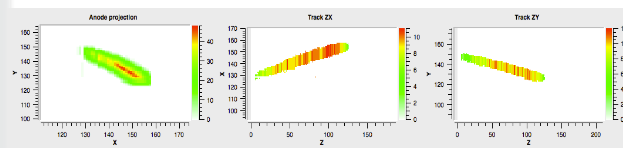
MIMAC-FASTn operation principle



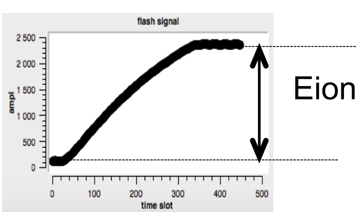
25 ns sampling :



3D recoil track → θ



Energy deposited in ionization :



From **θ**, **E_{ion}**, and the **IQF**,

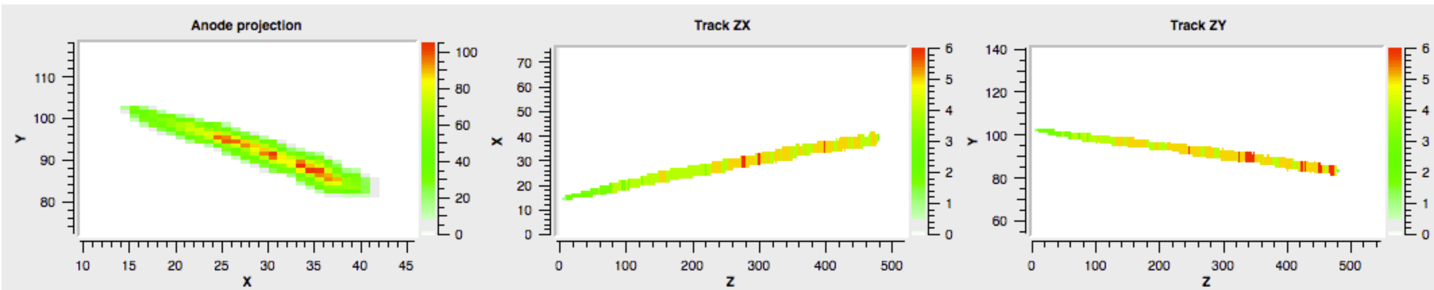
*we get the neutron energy **En***

^{4}He nuclear recoil / electron discrimination

A ^{4}He nuclear recoil track

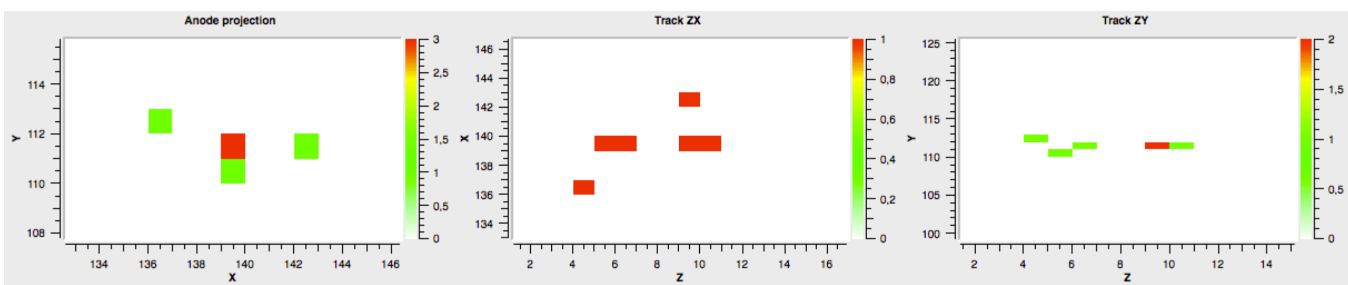
2.9 MeV kinetic

Measurements at CERF facility (CERN high energy Reference Field)



A muon track

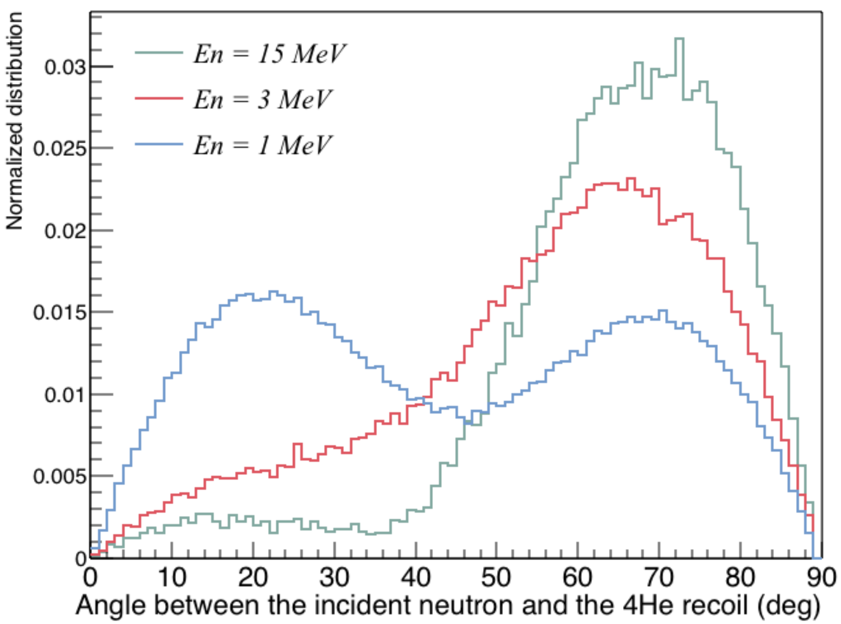
90 keV



Specificity for high neutron energies, above 5 MeV

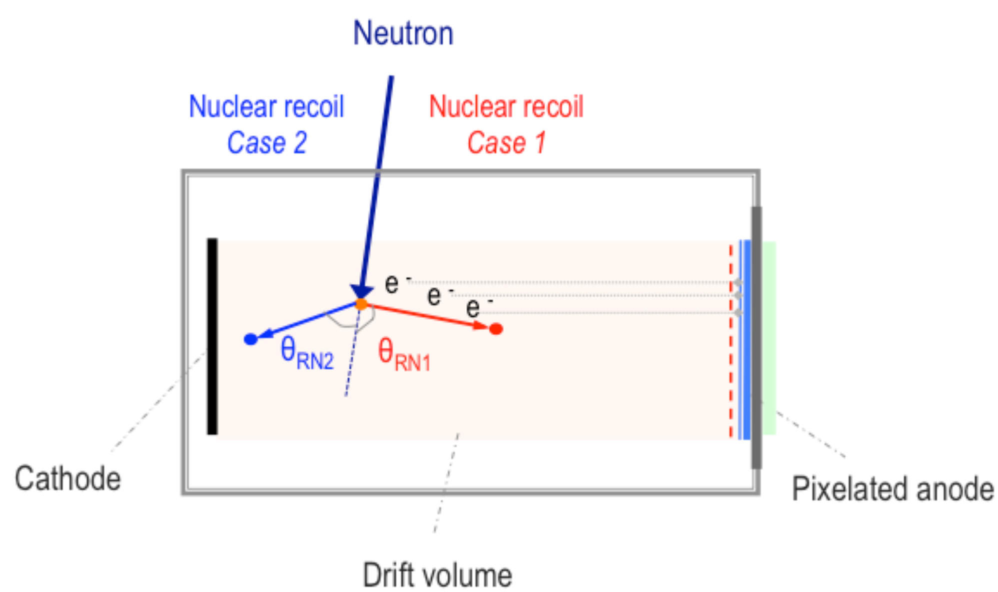
GEANT4 simulation

Angular distributions of ^4He recoils, resulting from elastic diffusions with neutrons :



Read-out strategy patented for high energy neutron spectroscopy

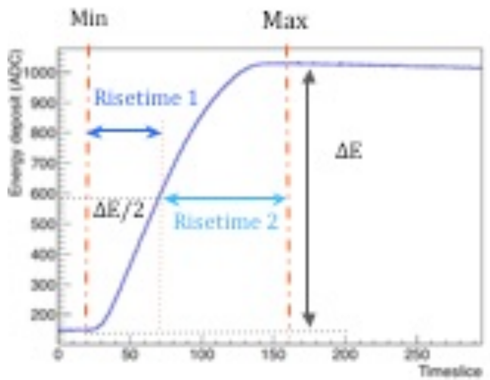
Measurement configuration above 5 MeV :
perpendicular to the detector axis

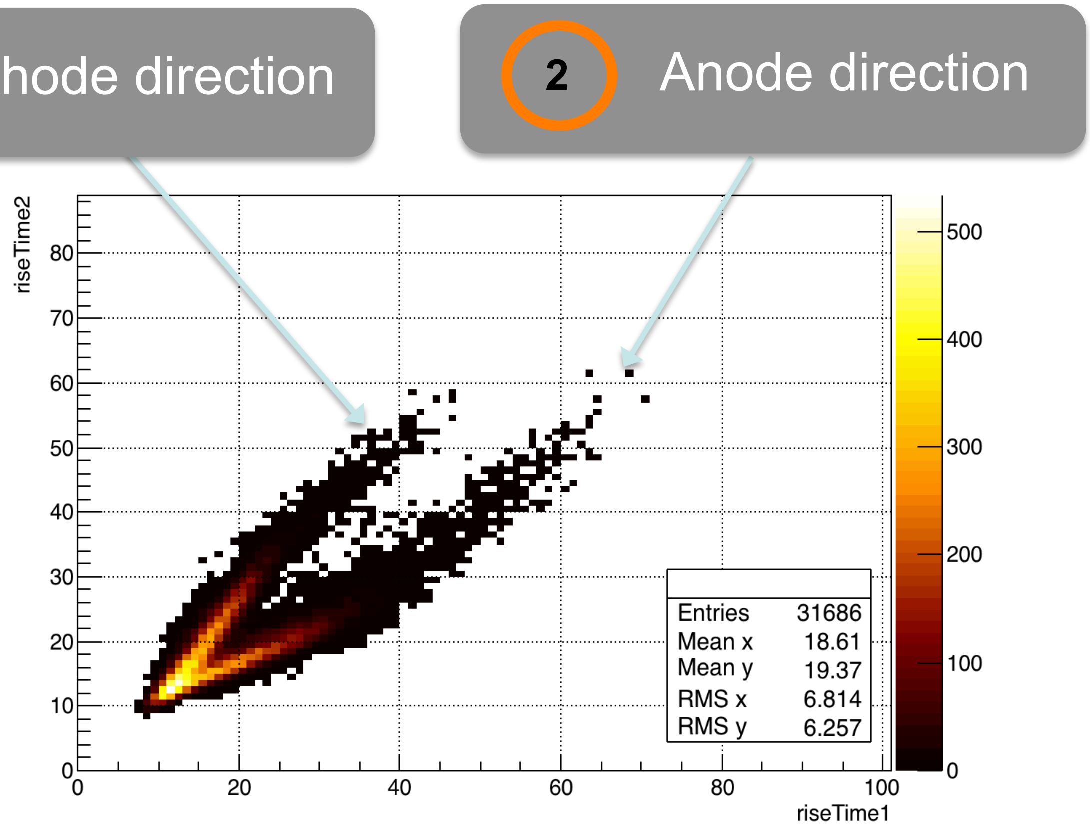


Direction of ^{4}He recoil tracks : head-tail signature

Detector perpendicular to the beam direction

Analysis from the charge deposit profile on the grid :





The track direction is essential for the definition of the interaction point

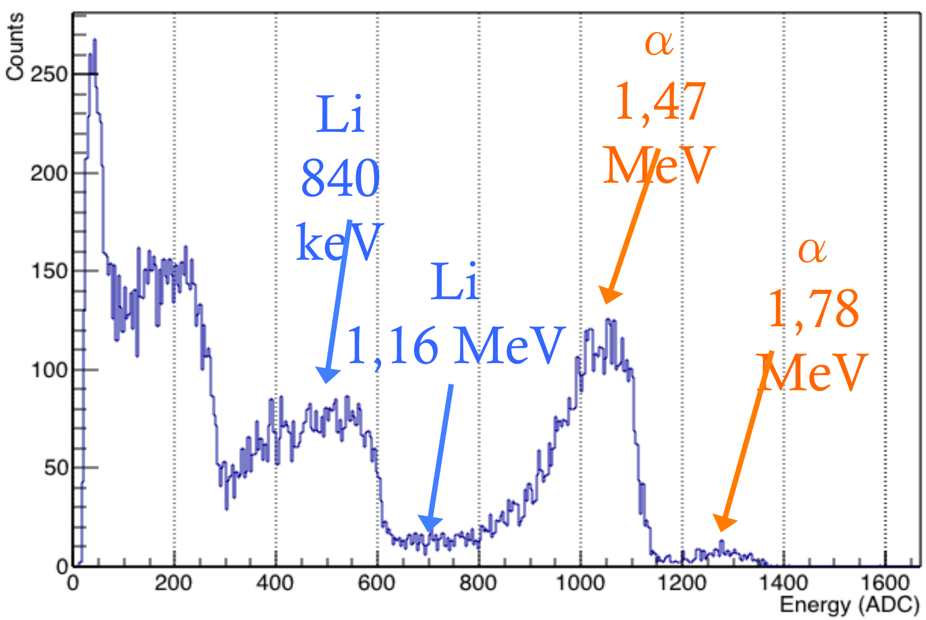
IRSN /AMANDE (Cadarache)

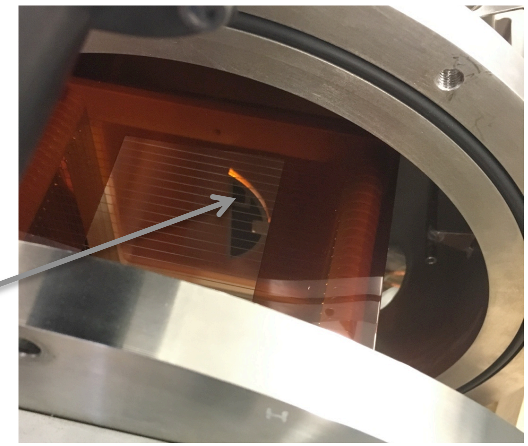
^{3}H(p(3357 keV),n)

Monoenergetic neutrons of 2.5 MeV

Energy calibration of the Flash-ADC

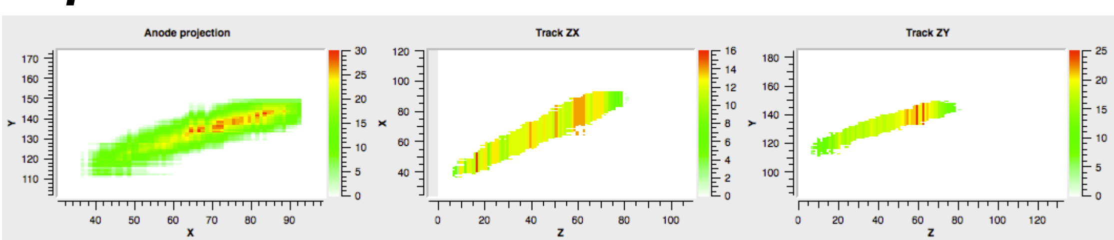
Detection of α and ^{7}Li, resulting from thermal neutron capture on a B_4C layer



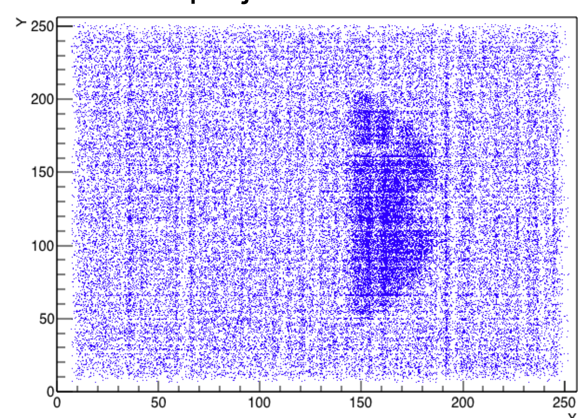


B_4C layer

Alpha track

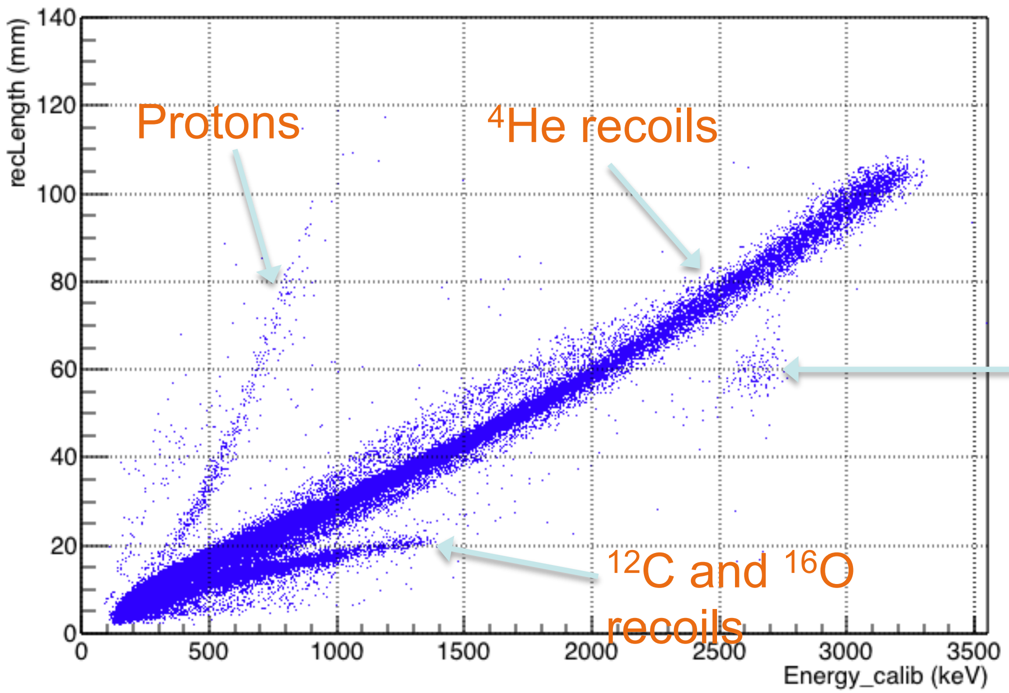


Anode projection : track start



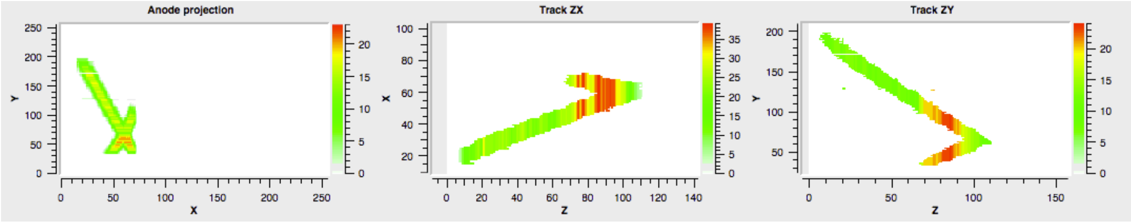
Selection of ^{4}He nuclear recoils : D(d(1.8 MeV),n)

Discrimination from protons, ^{12}C, ^{16}O, and (n,α) reactions



700 mbar He/CO_2 (5%)

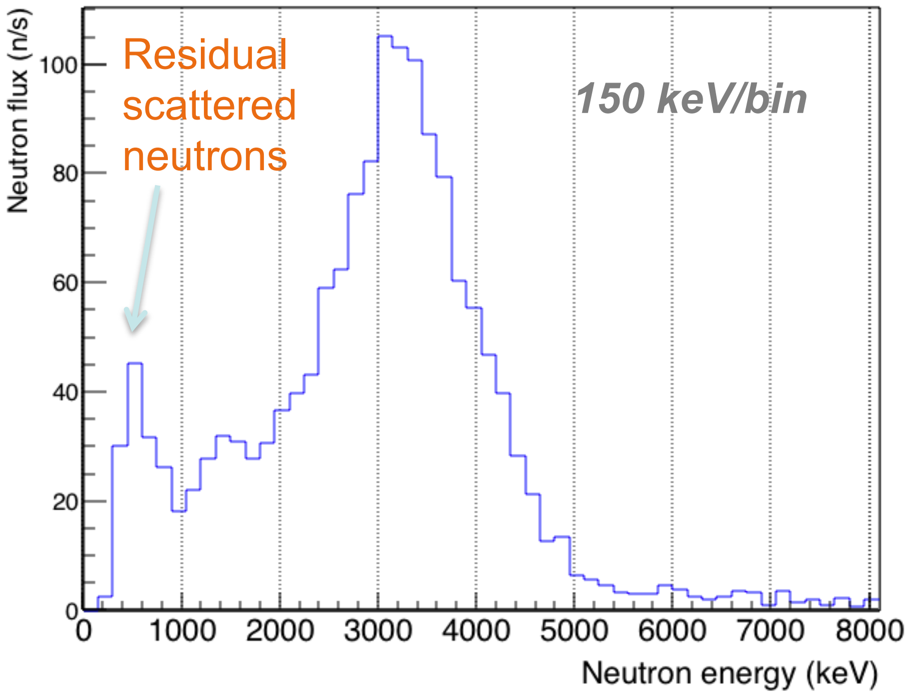
^{16}O(n,α)^{13}C

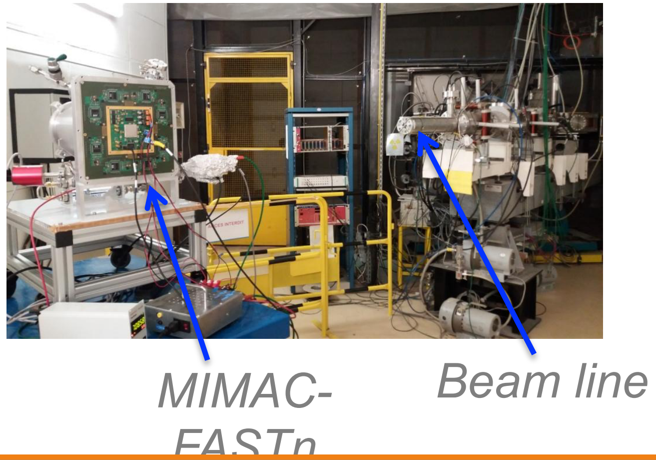


IRSN / AMANDE (Cadarache)

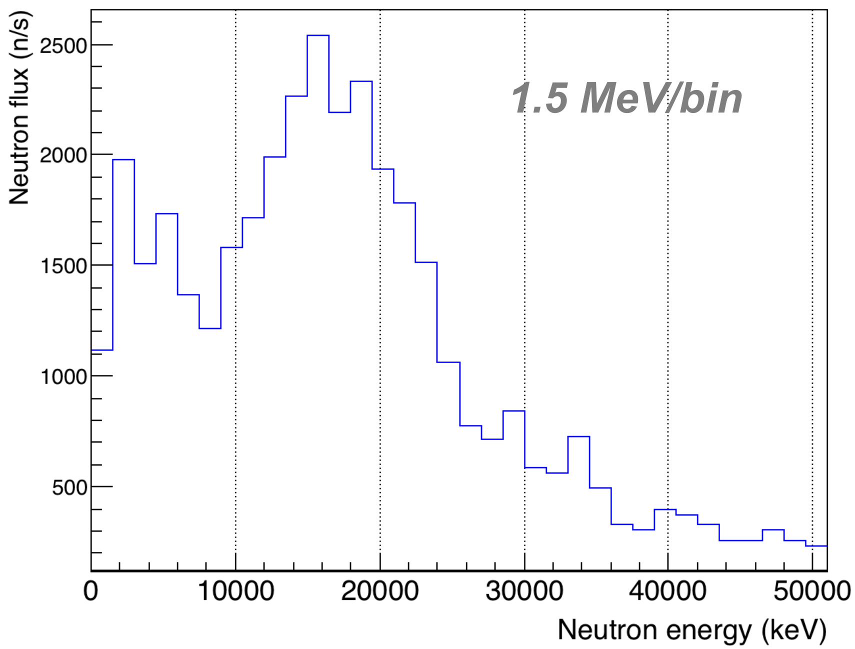
Monoenergetic measurement with neutrons of 3.1 MeV and 15 MeV on GENESIS (LPSC)

D(d(220 keV),n)
Parallel configuration





T(d(220 keV),n)
Perpendicular configuration



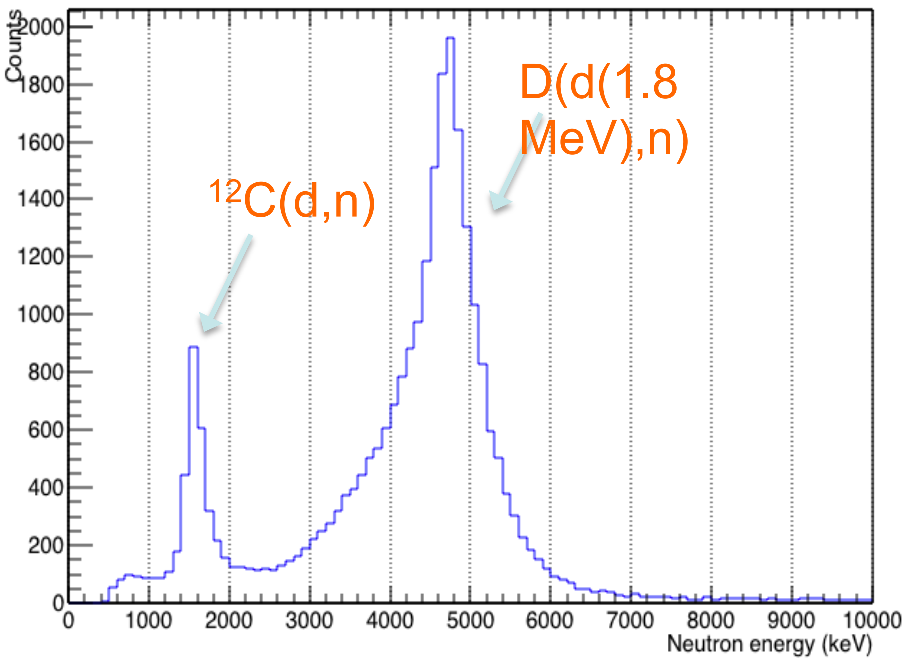
700 mbar He/CO_2 (5%)

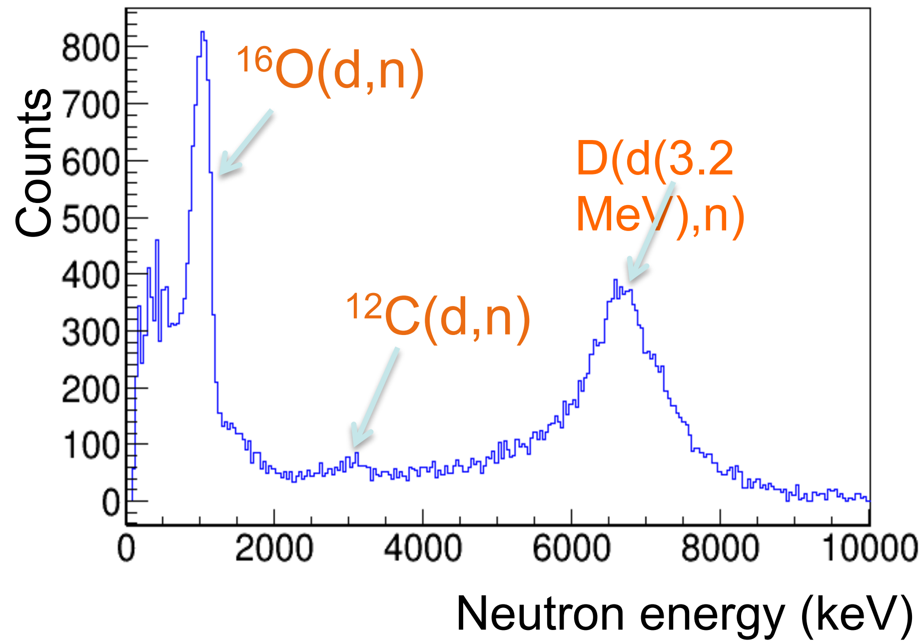
Paper to be submitted

Monoenergetic measurements : detection of target pollution

D(d(1.8 MeV,n) : neutrons of 5 MeV

D(d(3.2 MeV,n) : neutrons of 6.5 MeV





NPL /(UK)

IRSN / AMANDE (Cadarache)

700 mbar He/CO_2 (5%)

Paper to be submitted

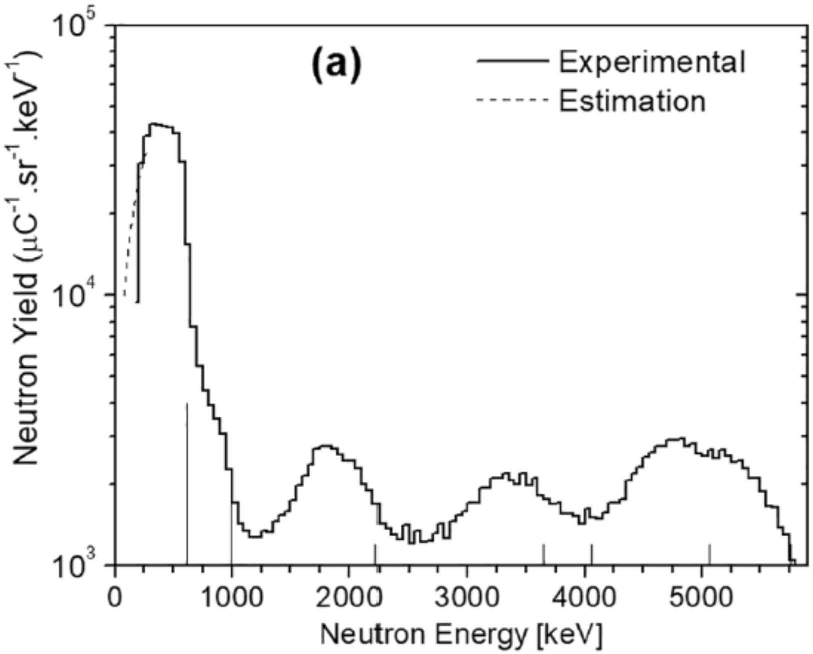
Polyenergetic measurement with $^{9}Be(d(1.45\ MeV),n)$

Angular distribution

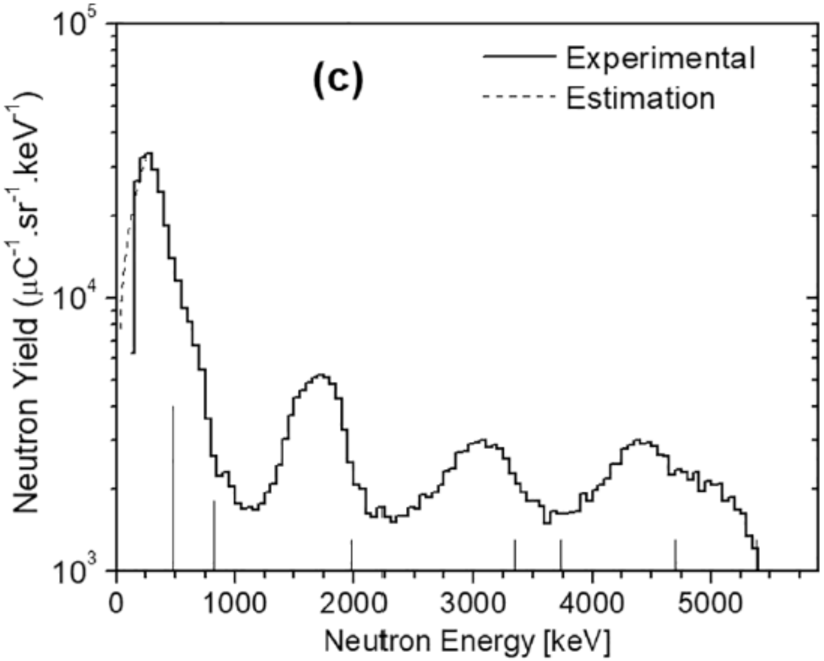
INFN LNL (Legnaro - Italy)

700 mbar He/CO_2 (5%)

Spectrum measured at **0 deg**



Spectrum measured at **60 deg**

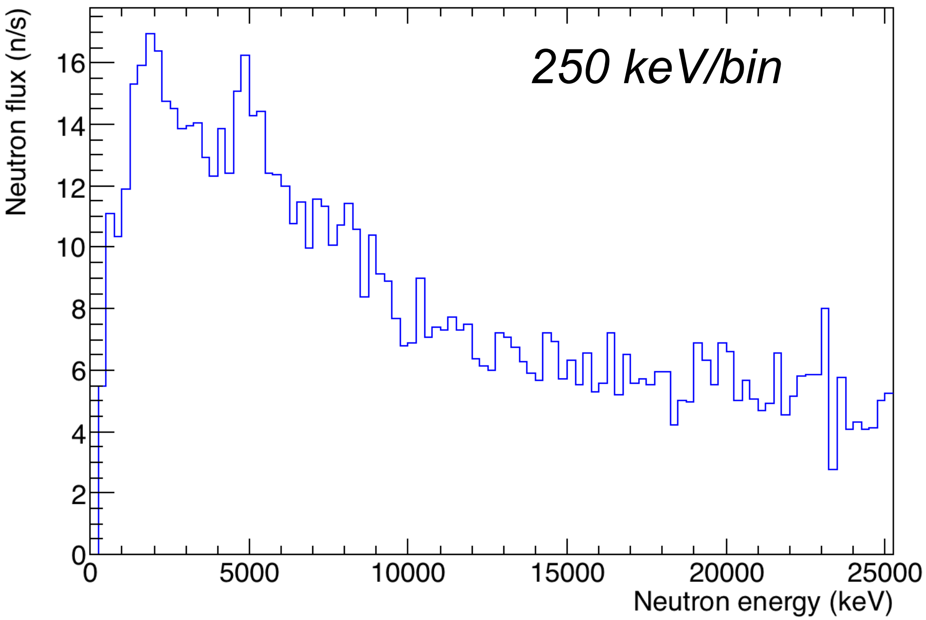


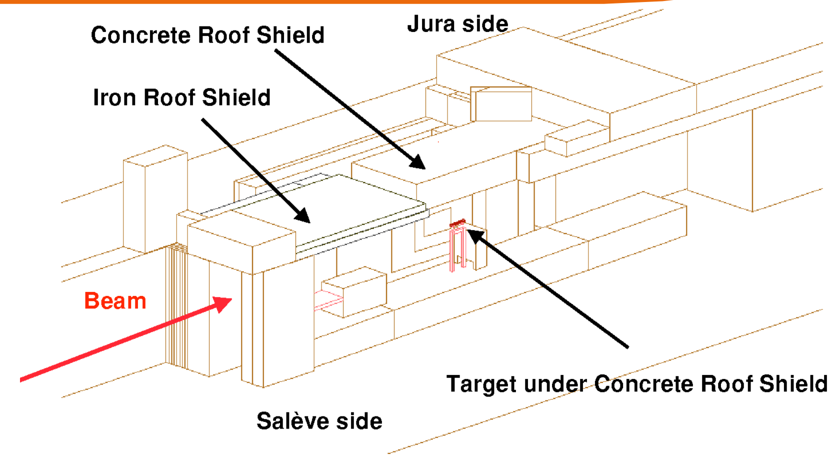
M.E. Capoulat, N.Sauzet *et al.*
« Neutron spectrometry of the $^{9}Be(d(1.45\ MeV),n)^{10}B$ reaction for accelerator-based BNCT »
NIM B, vol. 445, pp. 57-62, 2019

Exploration up to 200 MeV : measurement at CERF

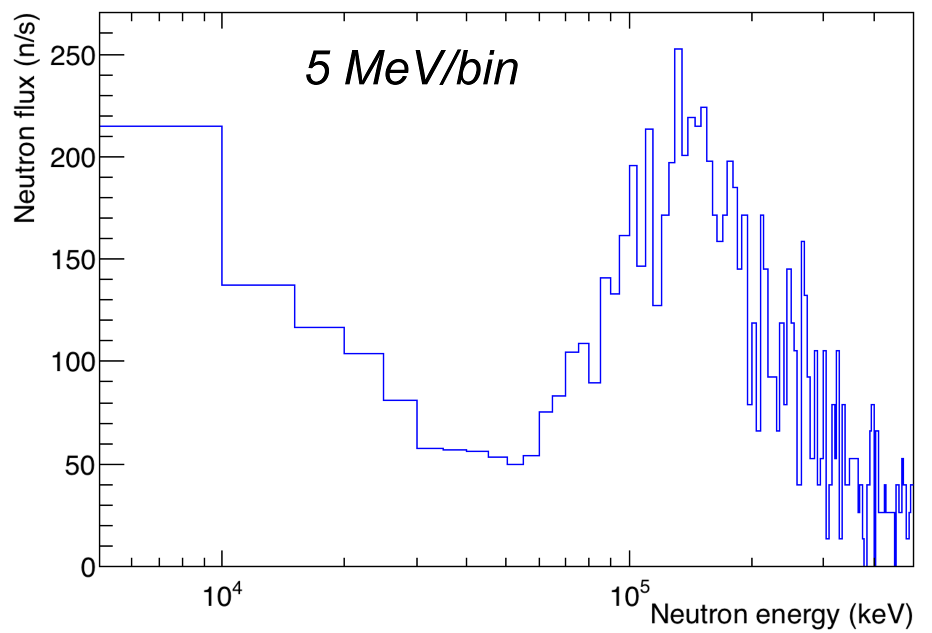
Perpendicular configuration

Below 25 MeV :





Above 100 MeV :



1.2 bars

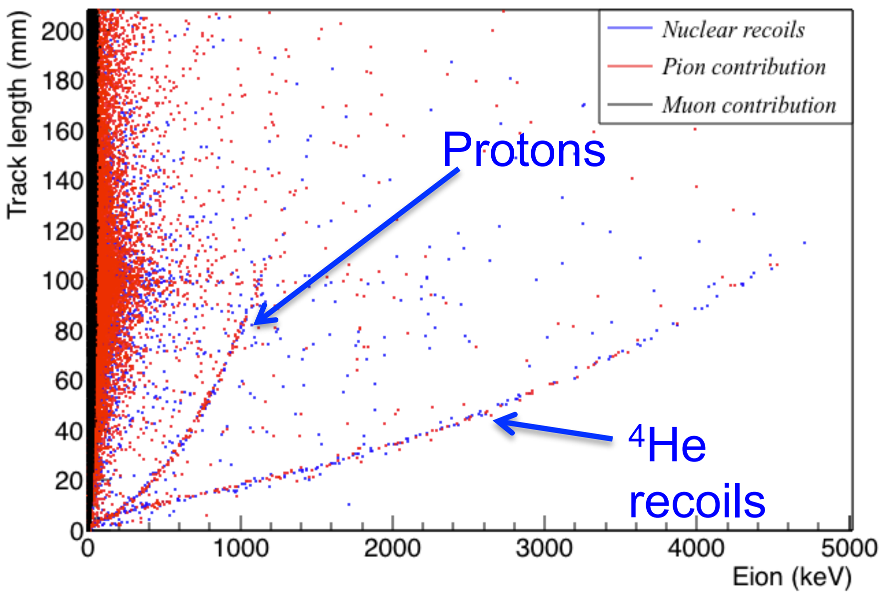
He/CO_2 (5%)

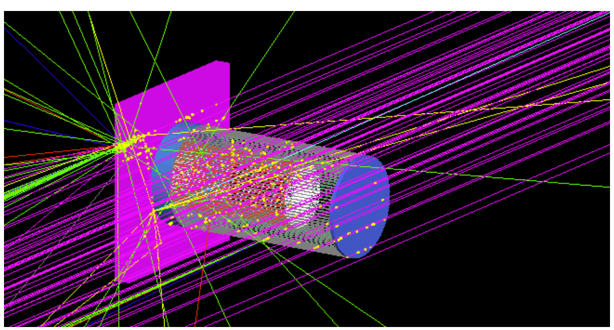
Preliminary results

Exploration up to 200 MeV : measurement at CERF
Discrimination of muons and pions

1 GEANT4 simulation

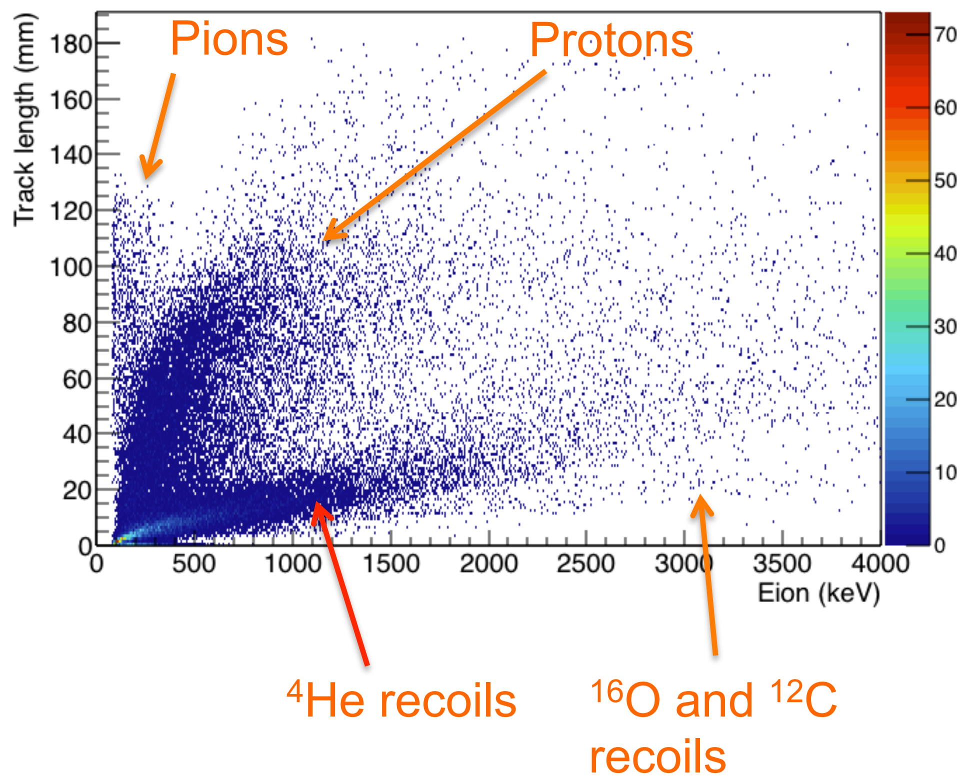
CERF facility (neutrons, muons, pions)





2 Measurement with Mimac-FastN

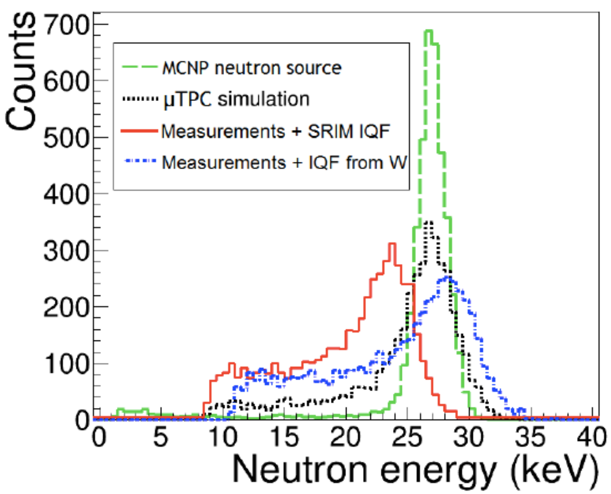
CERF facility : ^{63}Cu(p(120 GeV),n)



A large energy adjustable range

50% C_4H_{10} 50% CHF_3 30 mbar

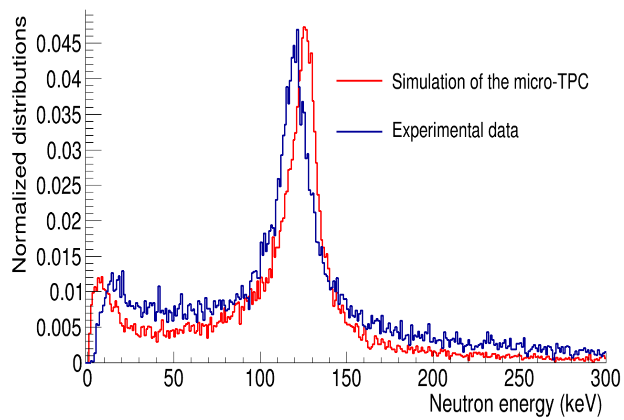
E_n=27 keV



D. Maire *et al.*
« Neutron energy reconstruction and fluence determination at 27 keV with the LNE-IRSN-MIMAC µ-TPC recoil detector »
IEEE Transactions on Nuclear Science, 63(3) : 1934-1941, June 2016

60% C_4H_{10} 40% CHF_3 50 mbar

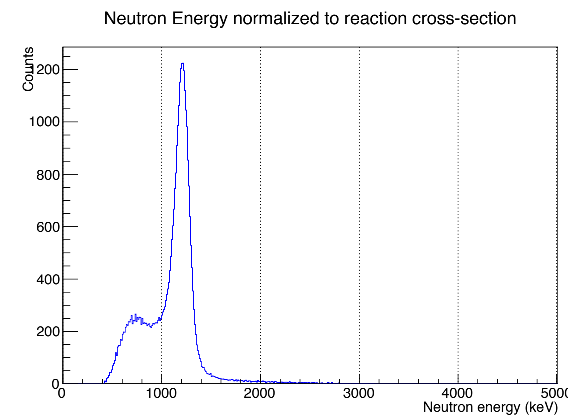
E_n=127 keV



D. Maire *et al.*
« First measurement of a 127 KeV neutron field with a µ-TPC spectrometer »
Nuclear Science, IEEE Transactions, 61(2014) 2090

95% ^4He 5% CO_2 700 mbar

E_n=1.2 MeV



Paper to be submitted

Radon Progeny

^{222}Rn chain:

- 4 β-decays

→ Electron event (background)

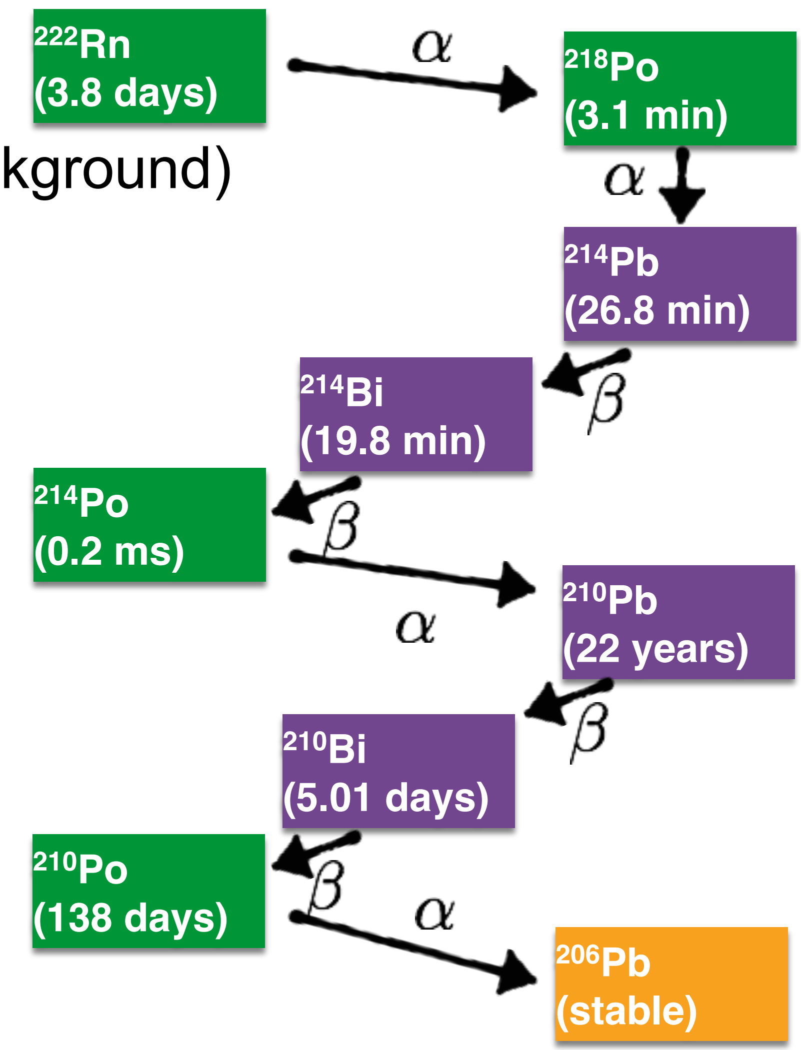
- 4 α-decays

→ α-particle emission: $E_\alpha \sim 5\,\mathrm{MeV}$ → Saturation

→ Daughter nucleus recoil (surface event):

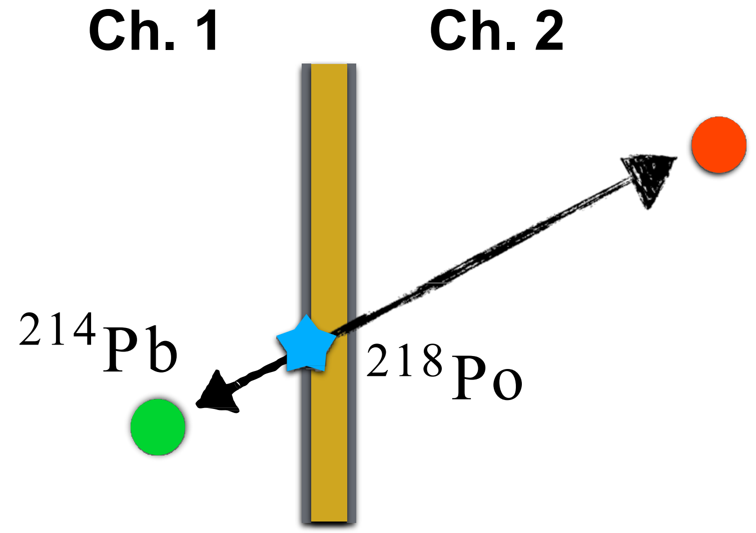
Parent	Daughter	E^{kin}_{recoil} [keV]	E^{ioni}_{recoil} [keV]
^{222}Rn	^{218}Po	100.8	38.23
^{218}Po	^{214}Pb	112.3	43.90
^{214}Po	^{210}Pb	146.5	58.78
^{210}Po	^{206}Pb	103.1	39.95

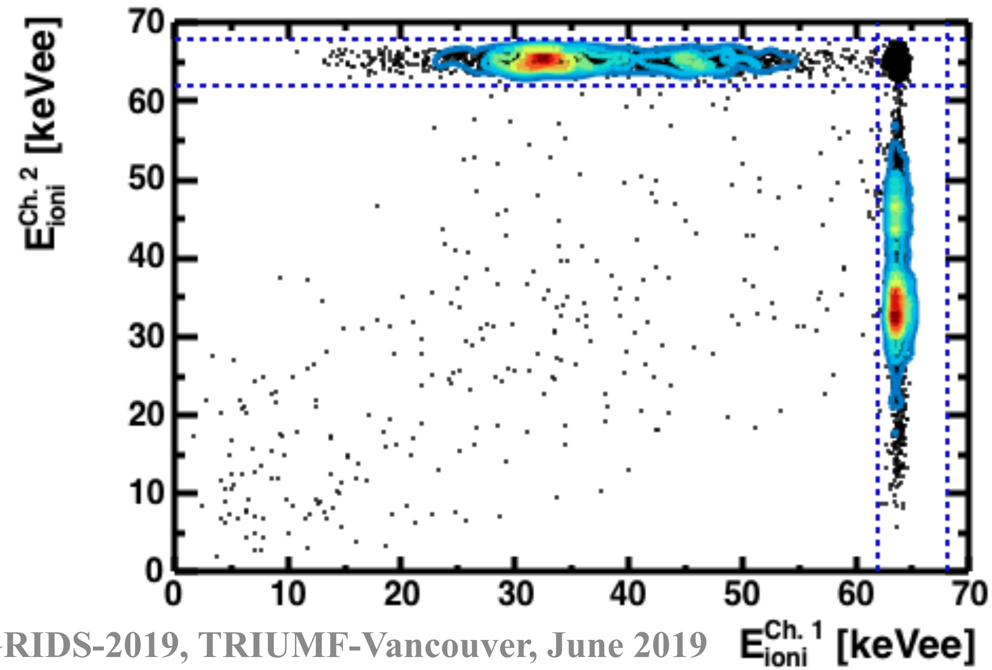
Simulation (SRIM)



RPR: « In coincidence » events

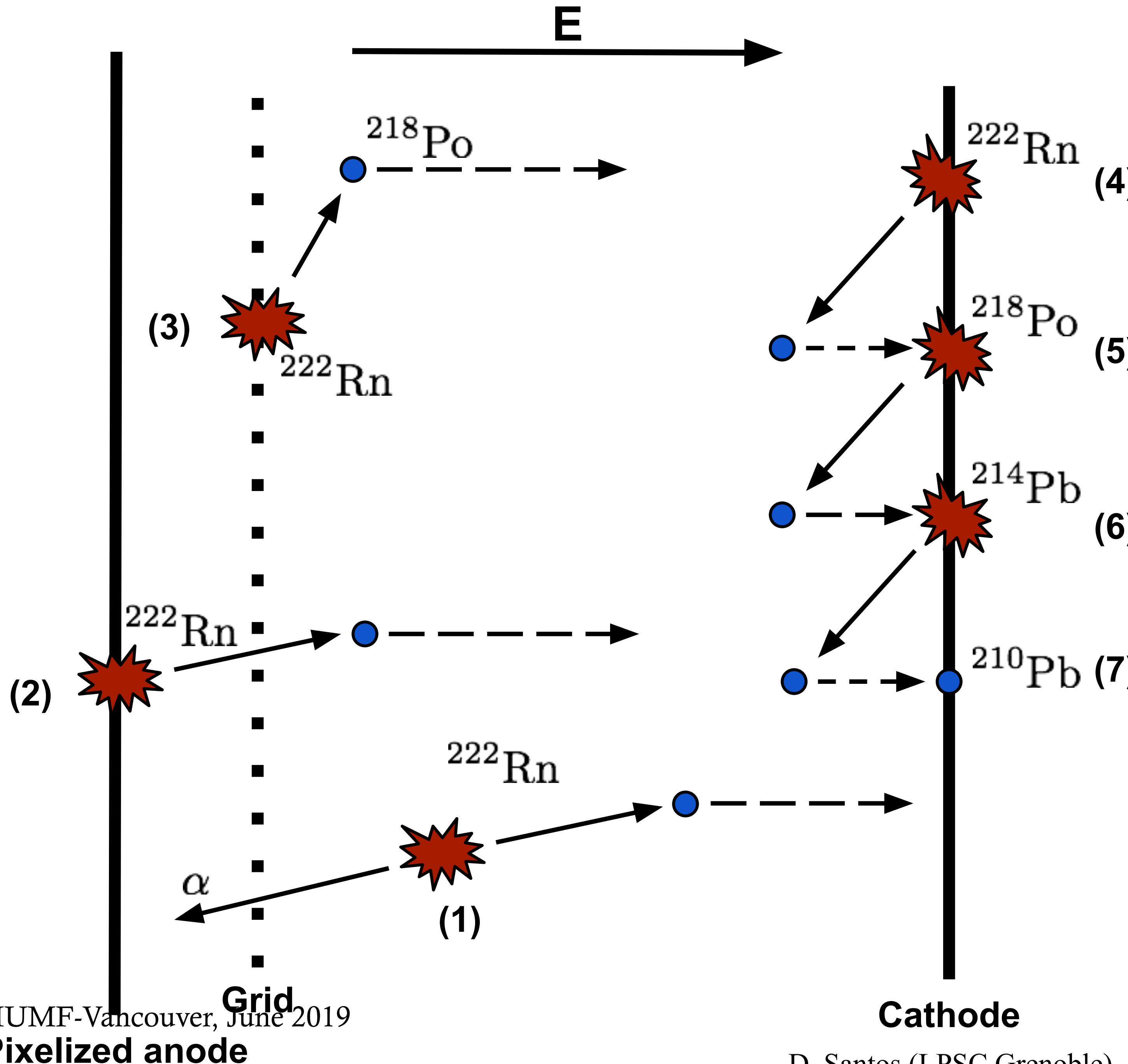
Chamber coincidences:





3D tracks from nuclear recoil of radon progeny detection

D. Santos (LPSC Grenoble)


E
^{218}Po
^{222}Rn
(4)
(3)
^{222}Rn
^{218}Po
(5)
^{214}Pb
(6)
^{222}Rn
^{210}Pb (7)
(2)
^{222}Rn
α
(1)
Grid
Pixelized anode
Cathode

First detection of 3D tracks of Rn progeny

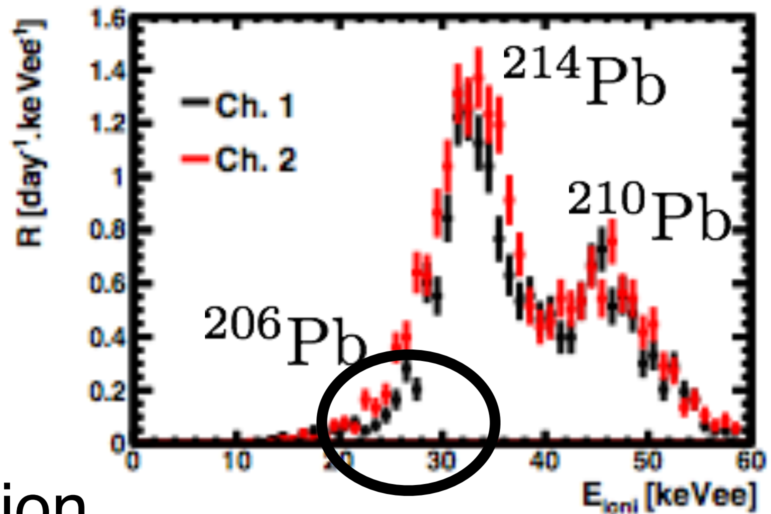
Electron/recoil discrimination

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

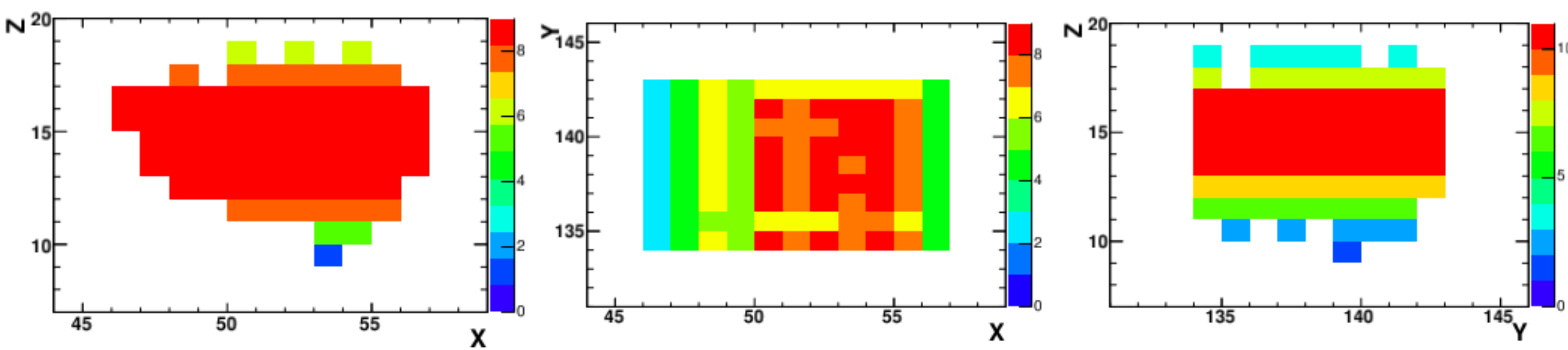
First measurement of 3D nuclear-recoil tracks coming from radon progeny

→ MIMAC detection strategy validation

Nuclear recoil spectra



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

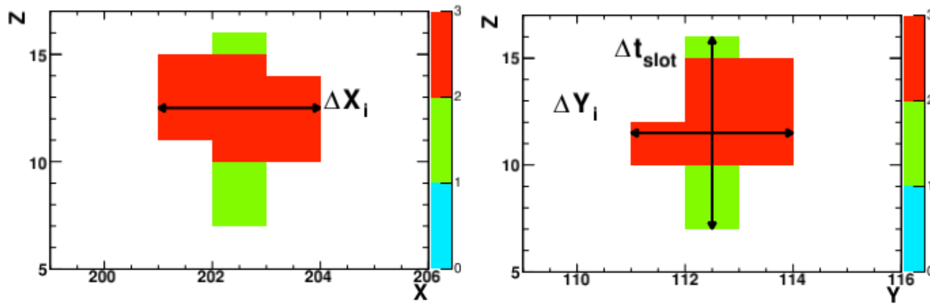


RPR events occur at different positions in the detector…

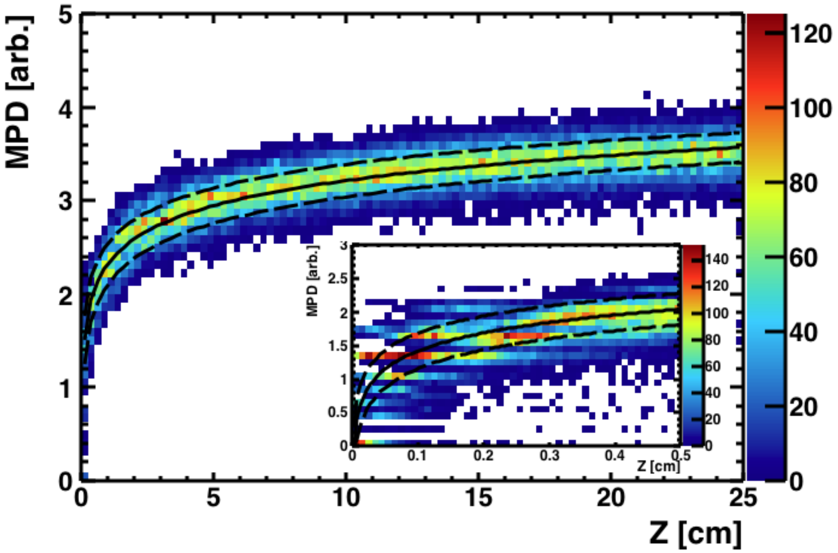
$$z_0 \longleftrightarrow \text{Diffusion}$$

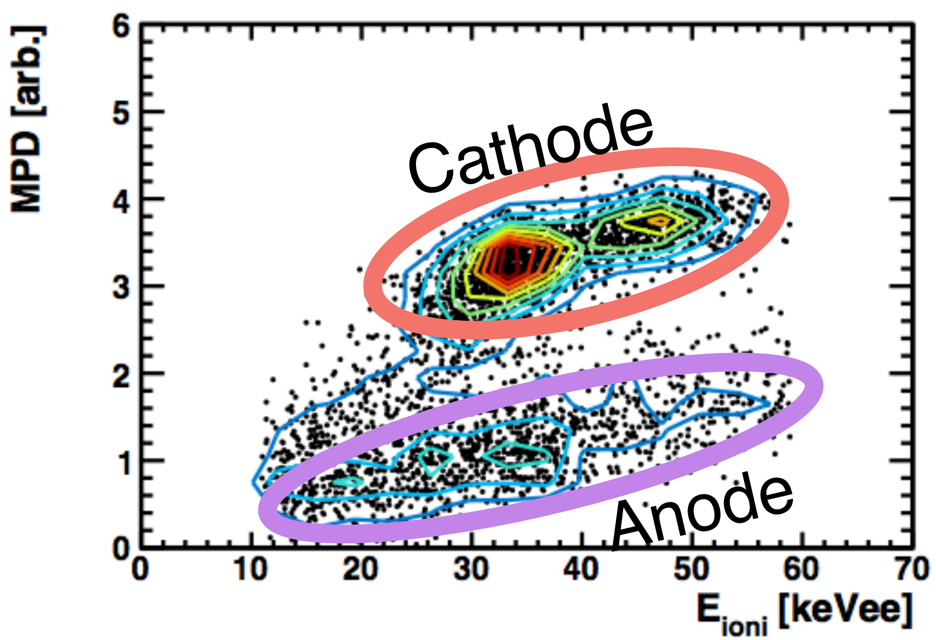
$$\begin{cases} D_T = 237.9\,\mu\text{m}/\sqrt{\text{cm}} \\ D_L = 271.5\,\mu\text{m}/\sqrt{\text{cm}} \end{cases}$$

« Anode » event



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

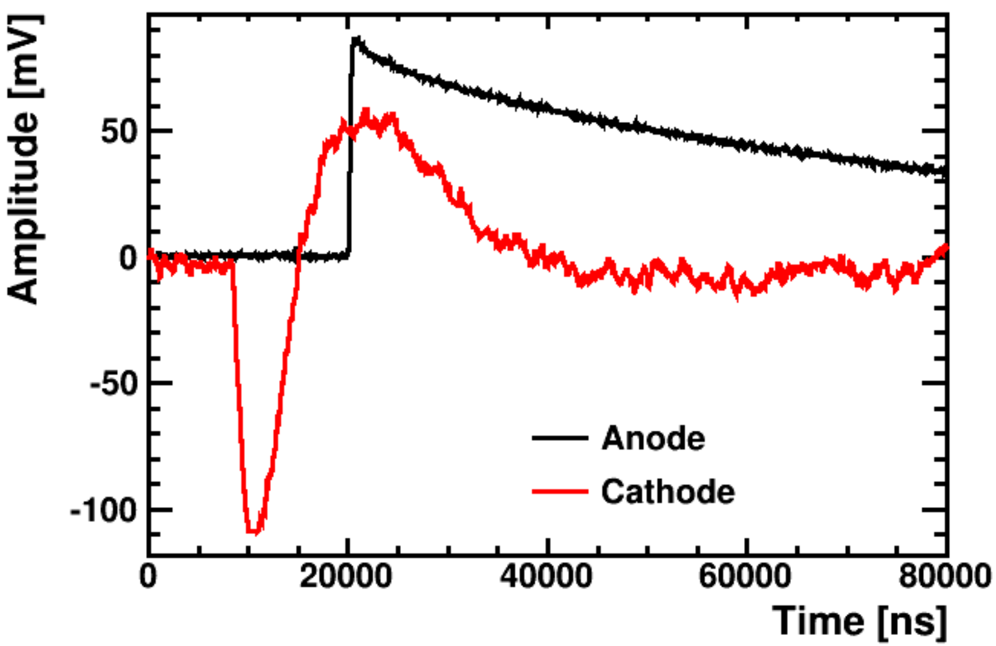




Cathode Signal to place the 3D-track

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

(C. Couturier,Q. Riffard, N. Sauzet et al. (2017))



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 giving the **drift velocity** of primary electrons !!

(C. Couturier, Q. Riffard, N. Sauzet et al. 2017)

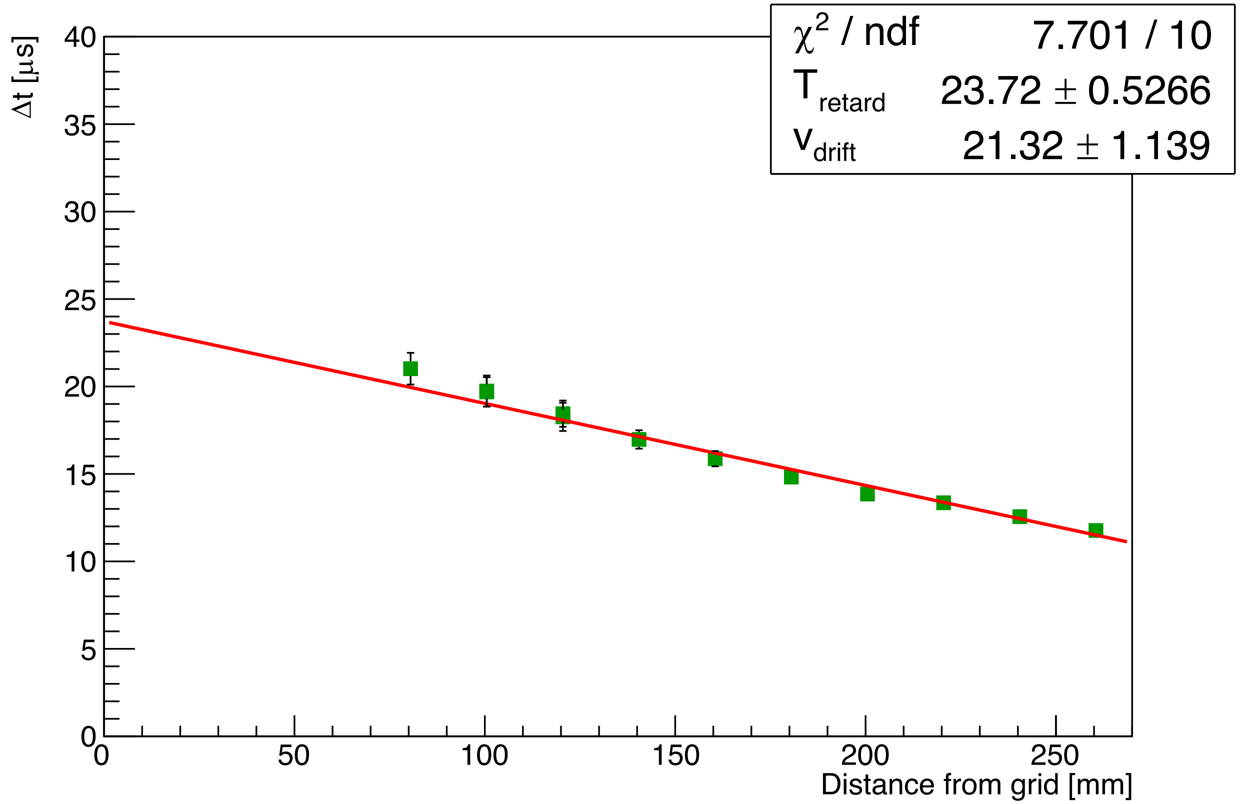
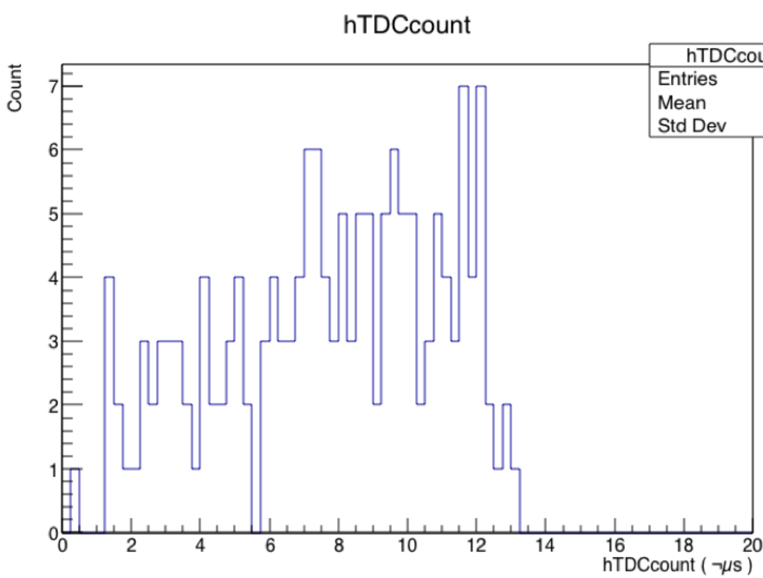


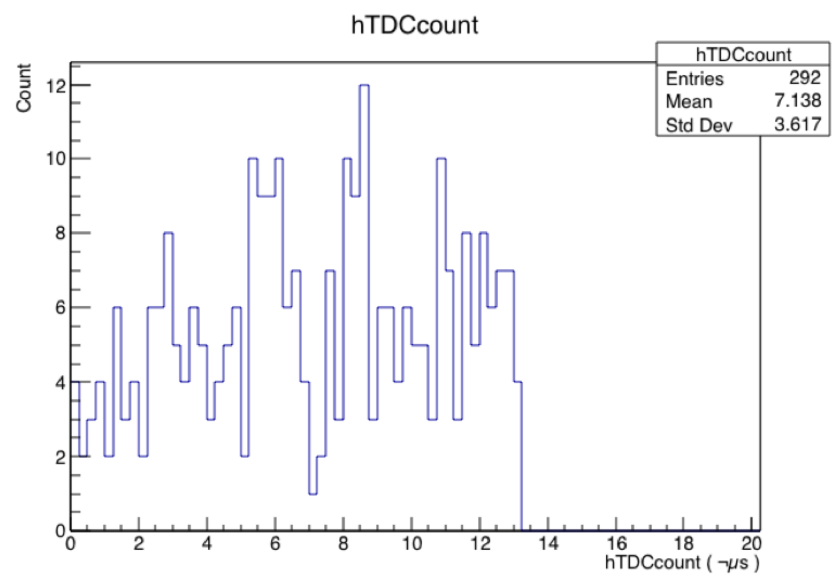
Figure 4. Measure of the time differences (TAC) between the grid signal and the delayed cathode signal in the "START Grid" configuration, as a function of the distance of the α source from the anode (green points) ; error bars correspond to the standard deviation of the mean. A linear fit of these points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

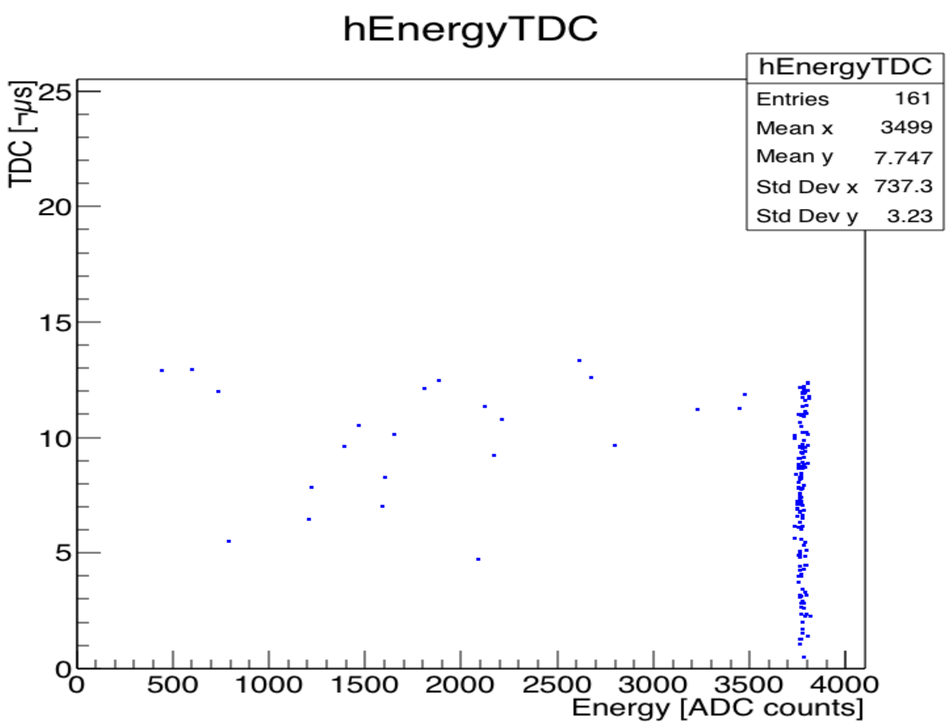


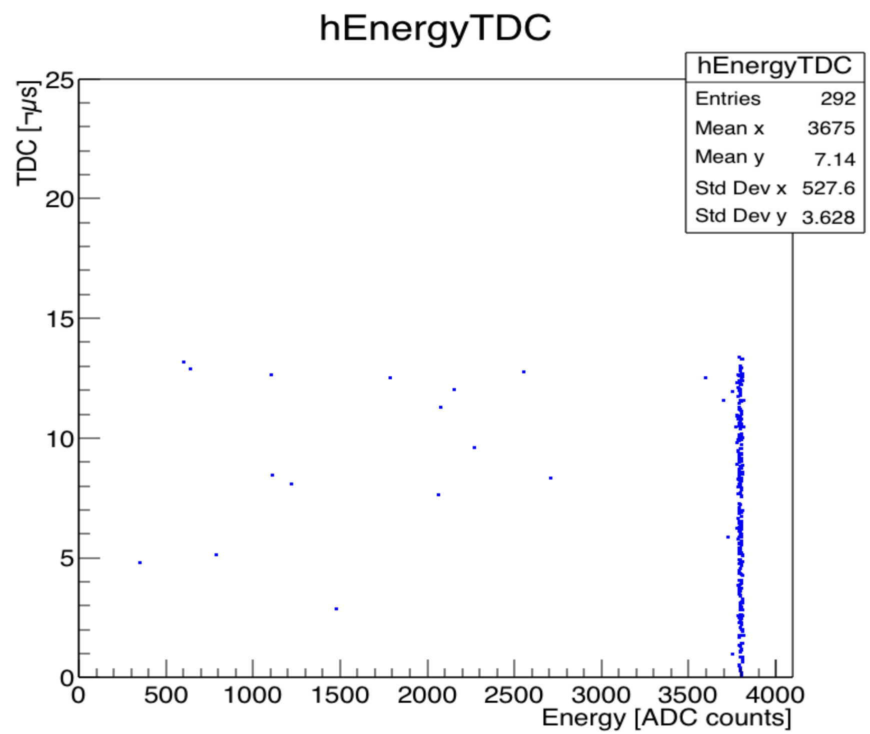
Chamber 2



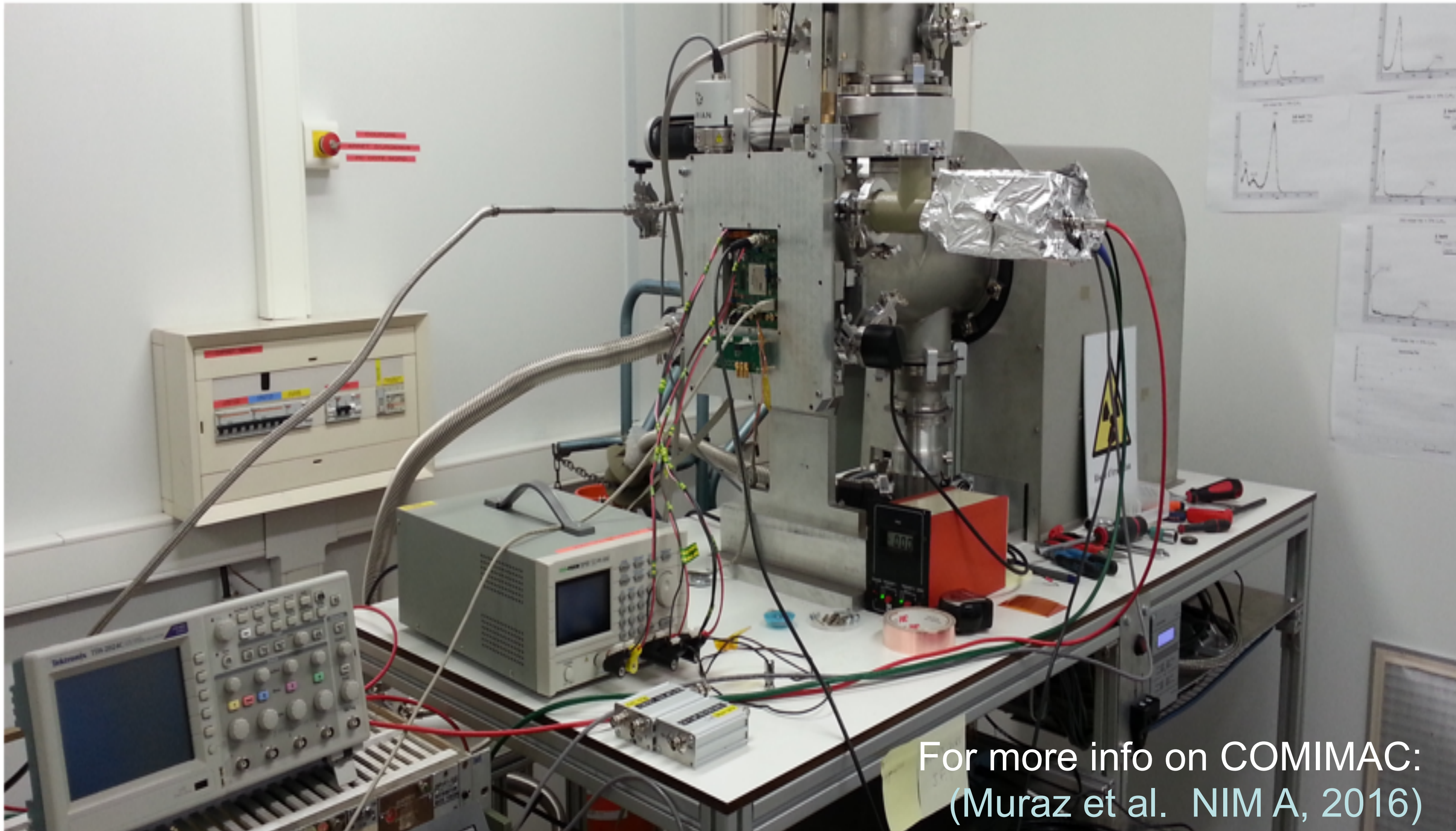
Measuring the time between the "event production" and the avalanche signal !!
Covering the 26 cm drift distance (13 us x 20 um/ns) !!

Ionization Energy distribution of the events recorded with the Cathode Signal



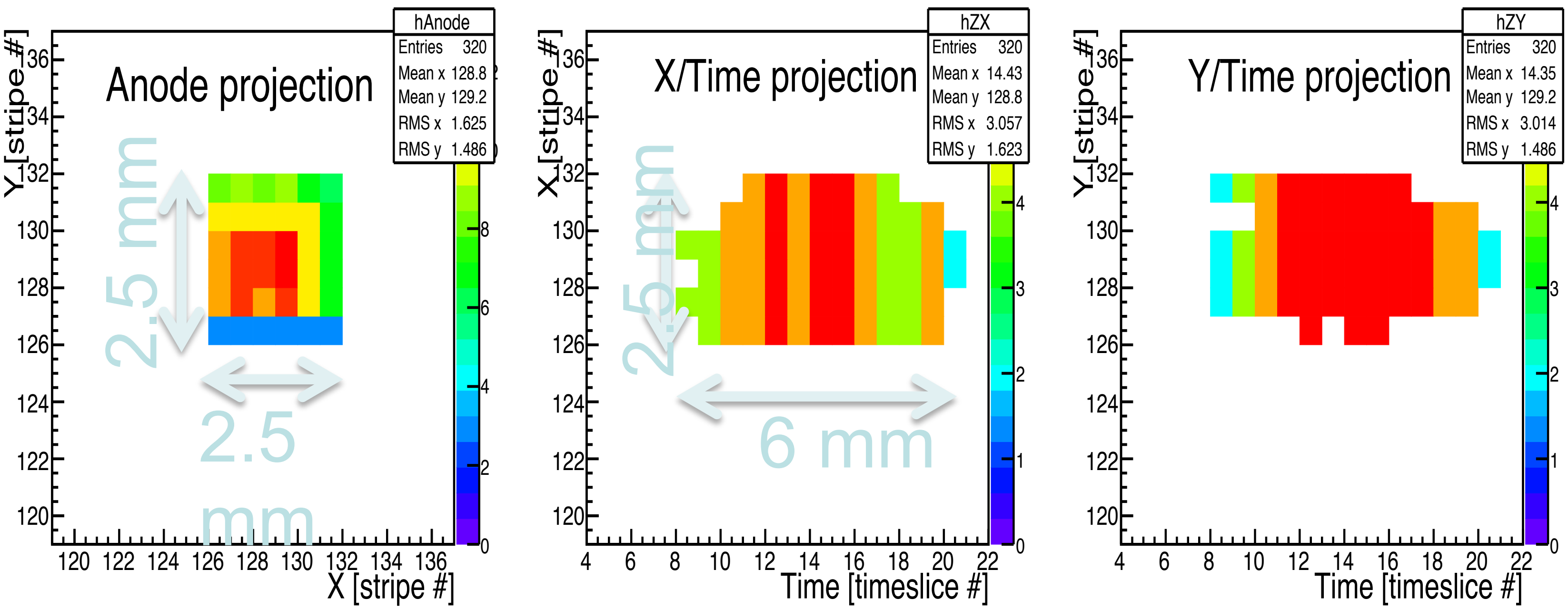


First controlled Fluorine tracks, using COMIMAC



COMIMAC: first measurements on controlled tracks of Fluorine

25 keV (kinetic) Fluorine → ~ 9 keVee



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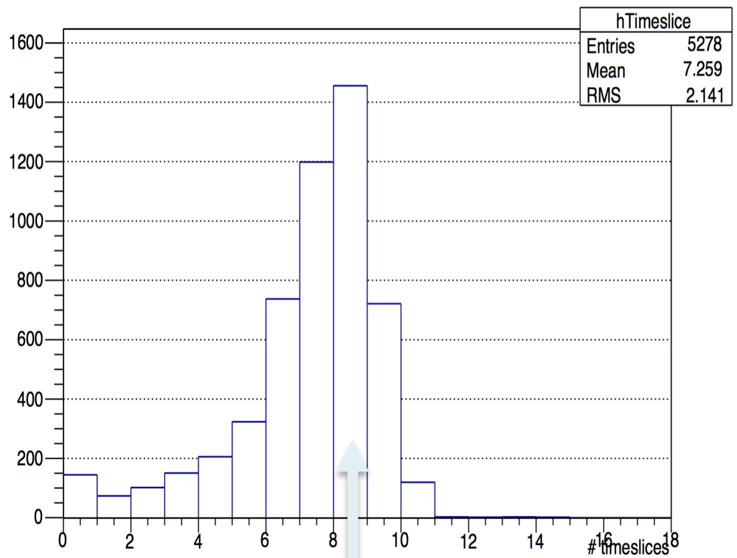
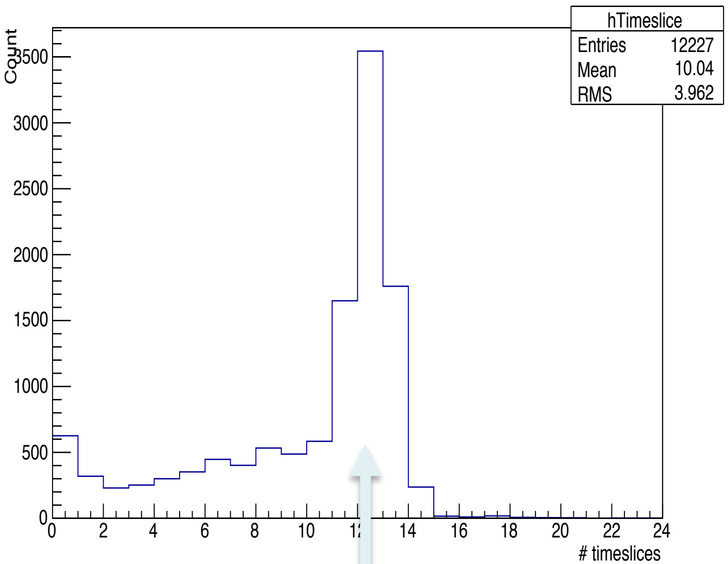
COMIMAC: first controlled tracks of ^{19}F

8 keV kinetic → 2 keVee

25 keV kinetic → 9 keVee



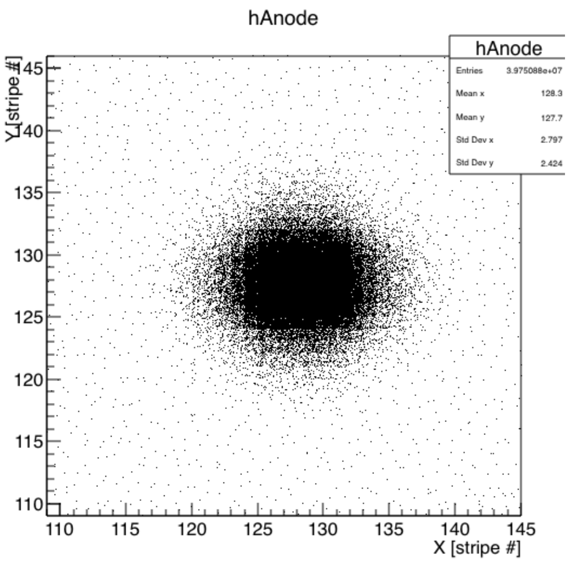


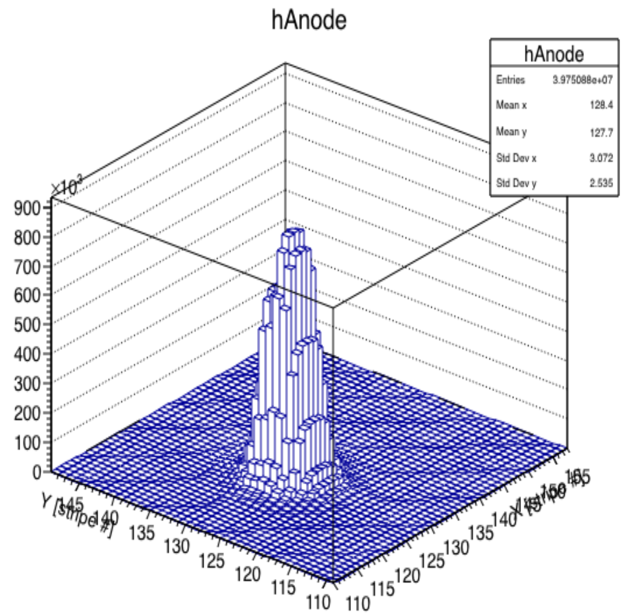
8 timeslices
* 20 ns/timeslices
* 23.5 µm/ns
= 3.8 mm

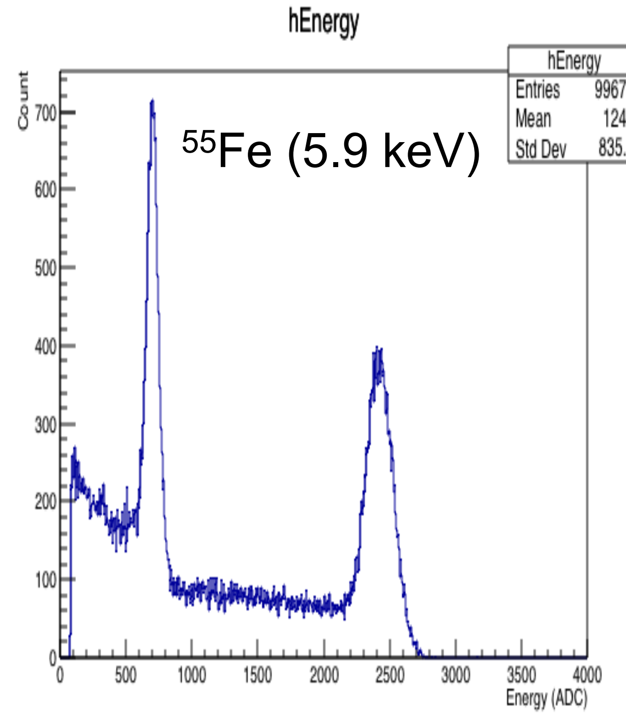
12 timeslices
* 20 ns/timeslices
* 23.5 µm/ns
= 5.8 mm

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

Protons (25 keV (kinetic))



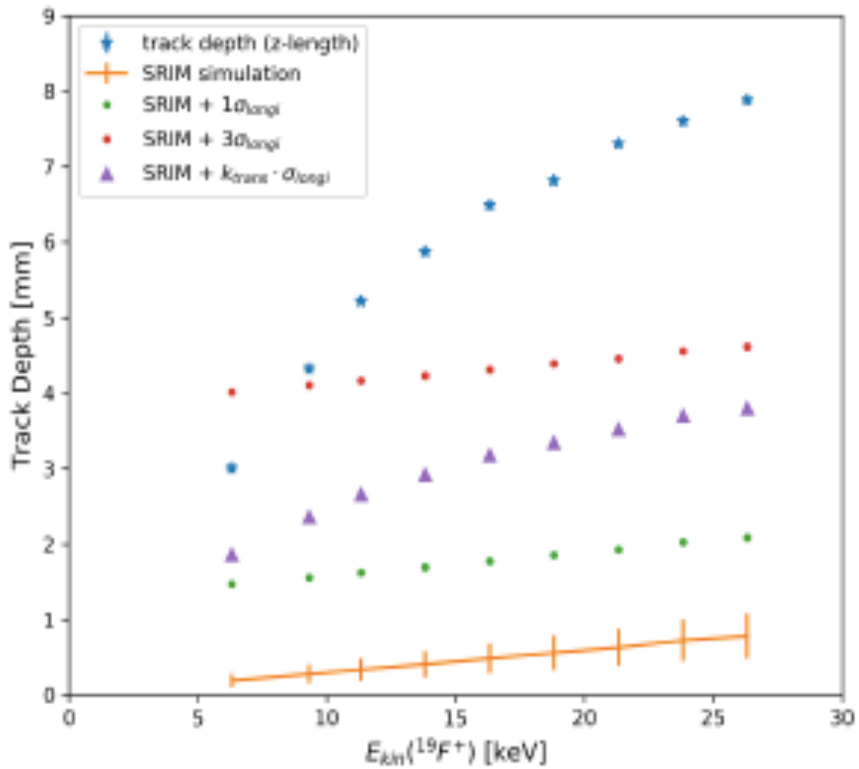




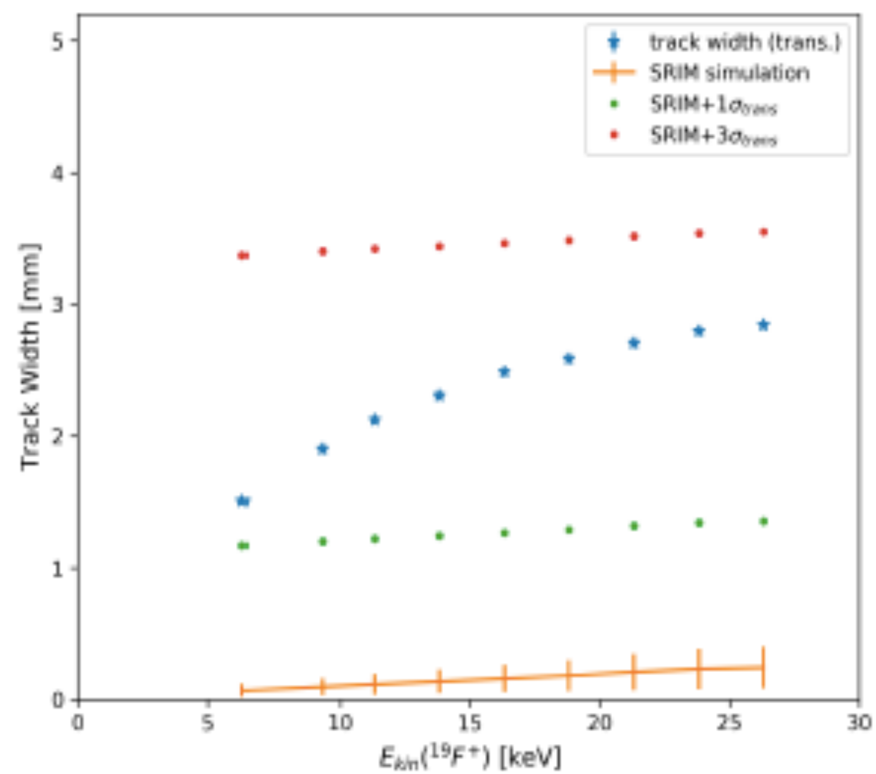
Track "Lengths" measured with COMIMAC

(Y. Tao, I. Moric, et al. (arXiv1903.02159)

(important differences with respect to the SRIM simulations !)



(a) Track depth comparison



(b) Track width comparison

Angular resolution measured with COMIMAC (^{19}F ions at known kinetic energies) (Y. Tao, I. Moric, et al. (arXiv1903.02159)

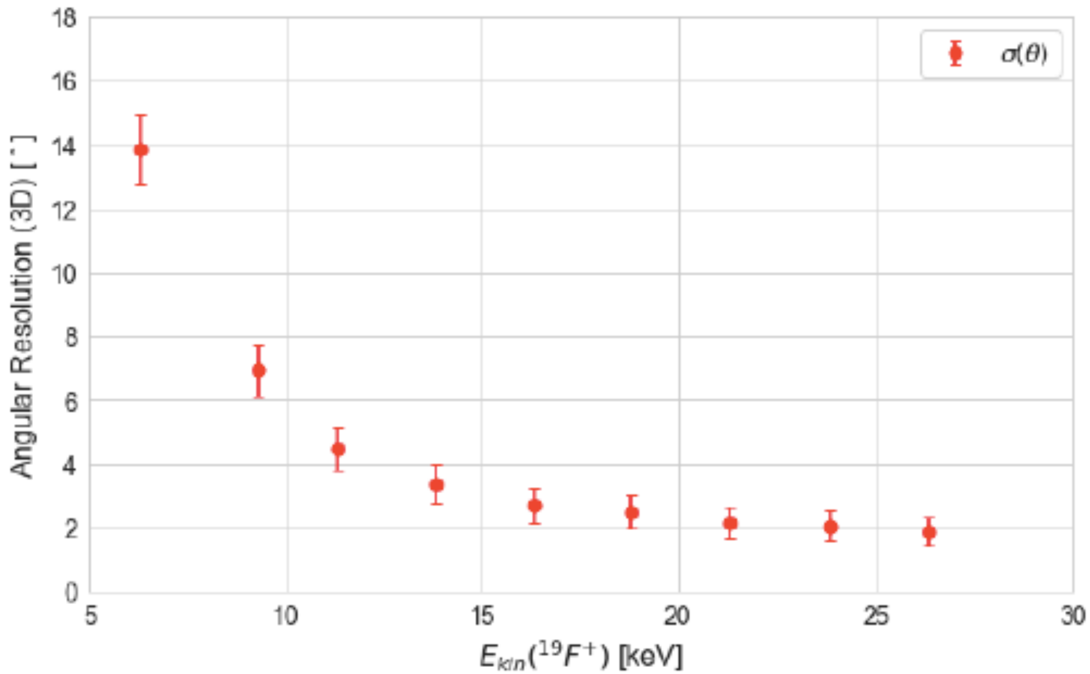
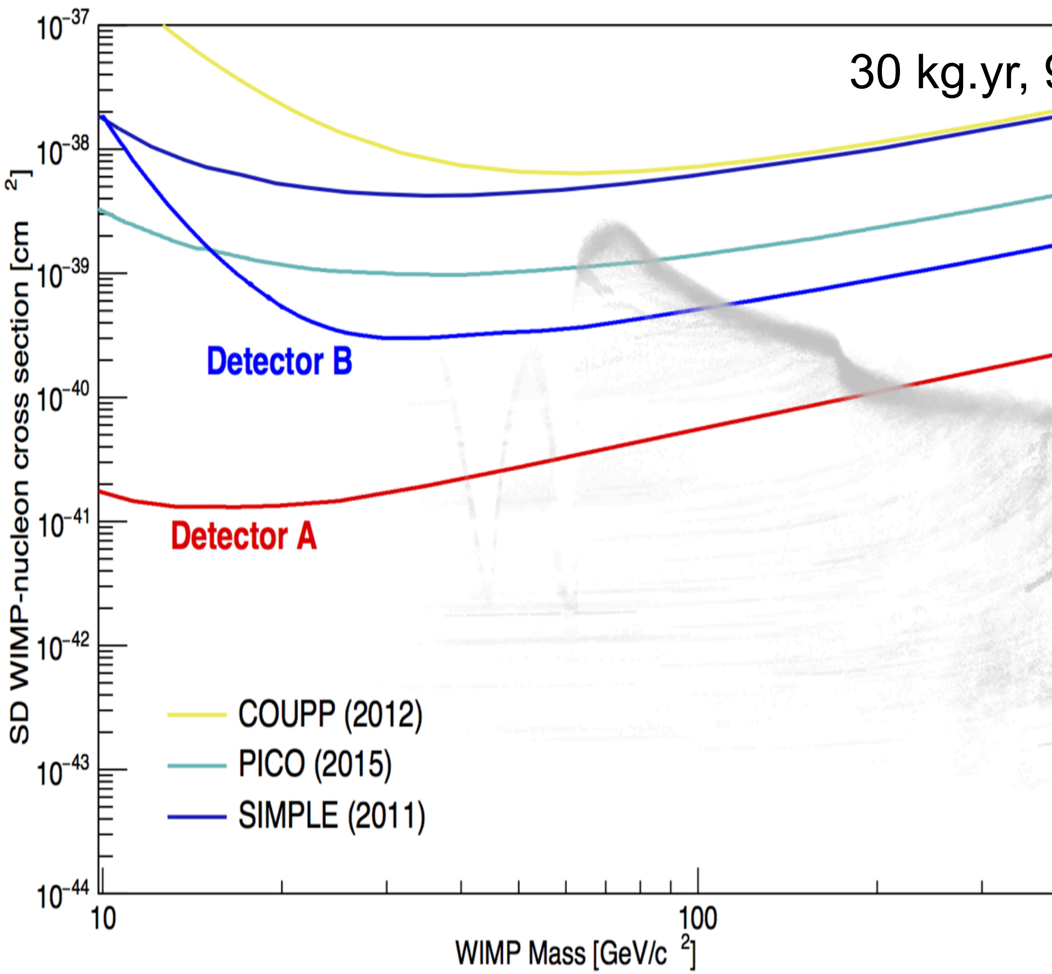


Figure 8. MIMAC angular resolution as a function of ^{19}F ion kinetic energy. At lower energies, the ion tracks are shorter and have more straggling resulting in worse angular resolution and bigger error bars. The angular resolution is better than 20° down to a kinetic energy of 6.3 keV, and is below 10° for a kinetic energy of 9.3 keV. Error bars are derived from the pixel strips pitch and reconstructed track length as described in the text.

MIMAC-Exclusion limits



30 kg.yr, 90% CL lower limits

A: 5 keV (threshold)
no background
3D track with head-tail
angular resolution 20°

B: 20 keV
background= 10evt/kg yr
angular resolution 50°
3D with no head-tail

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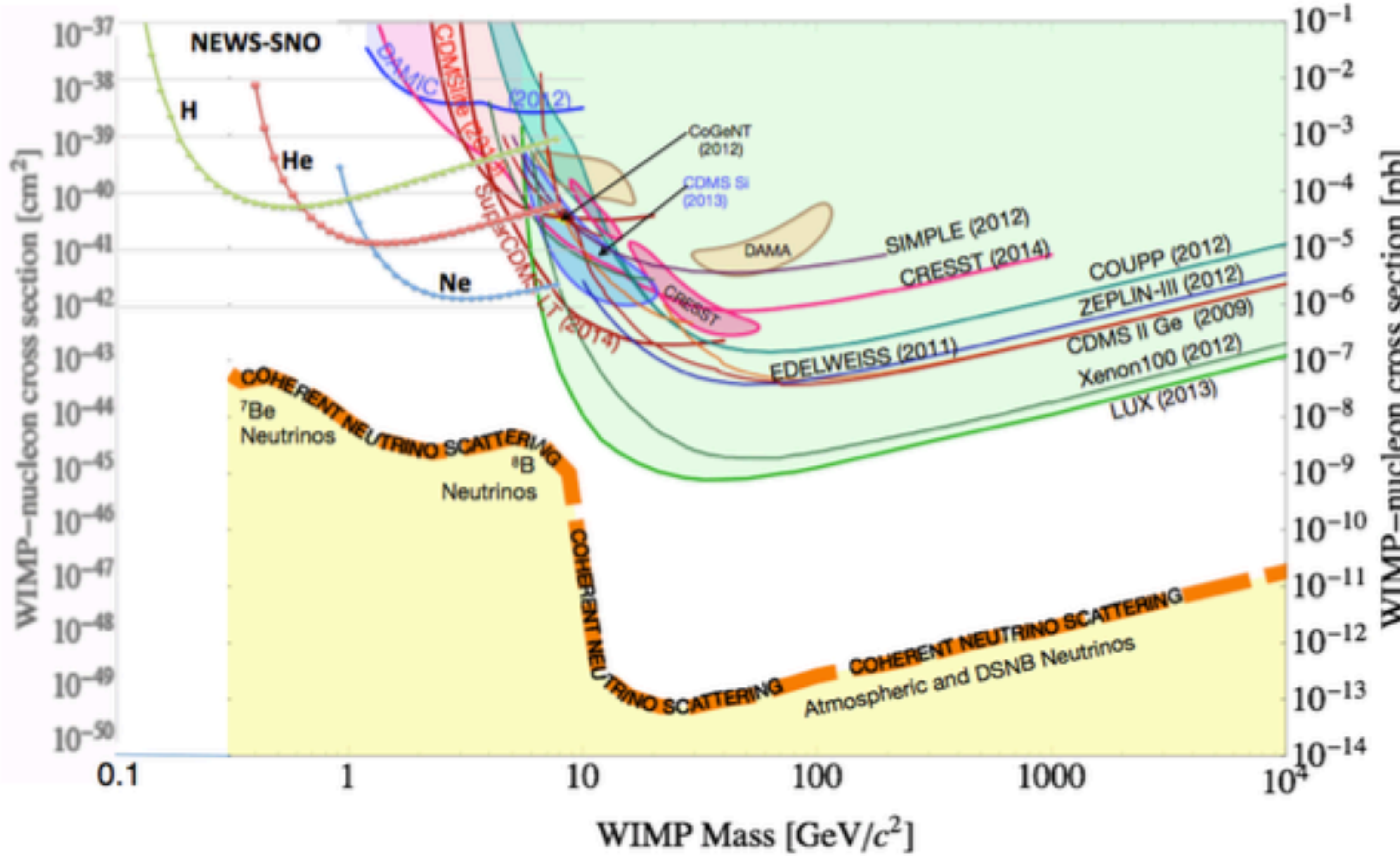
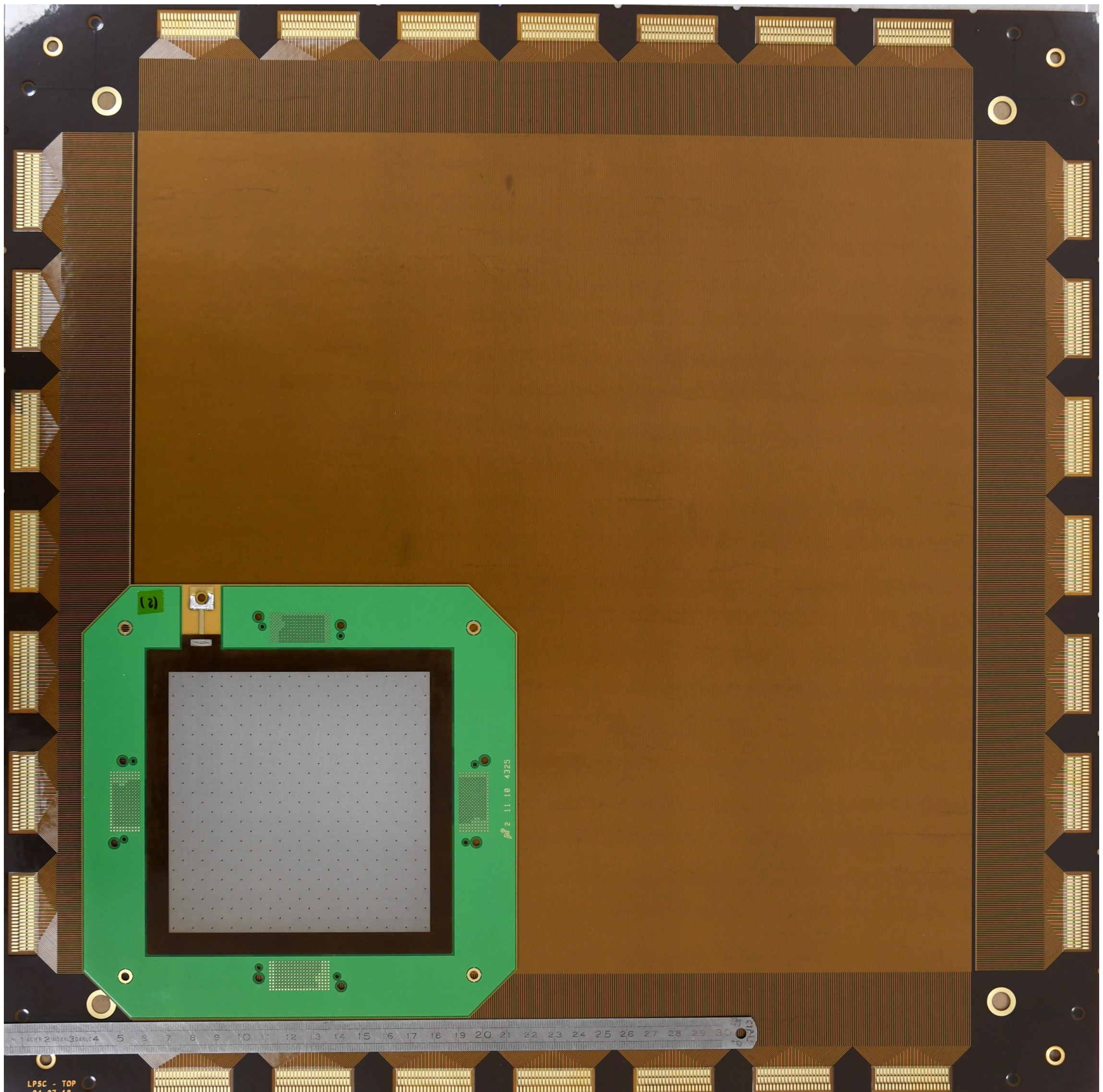
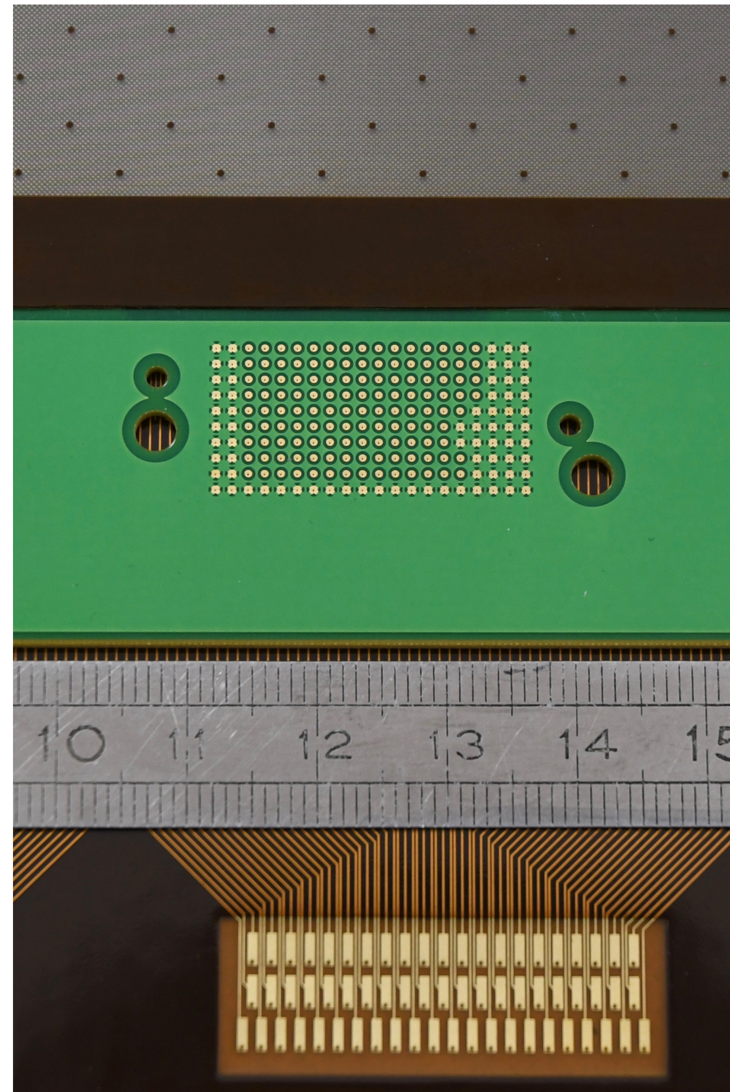
WIMP Light Mass window
MIMAC- NEWS complementarity

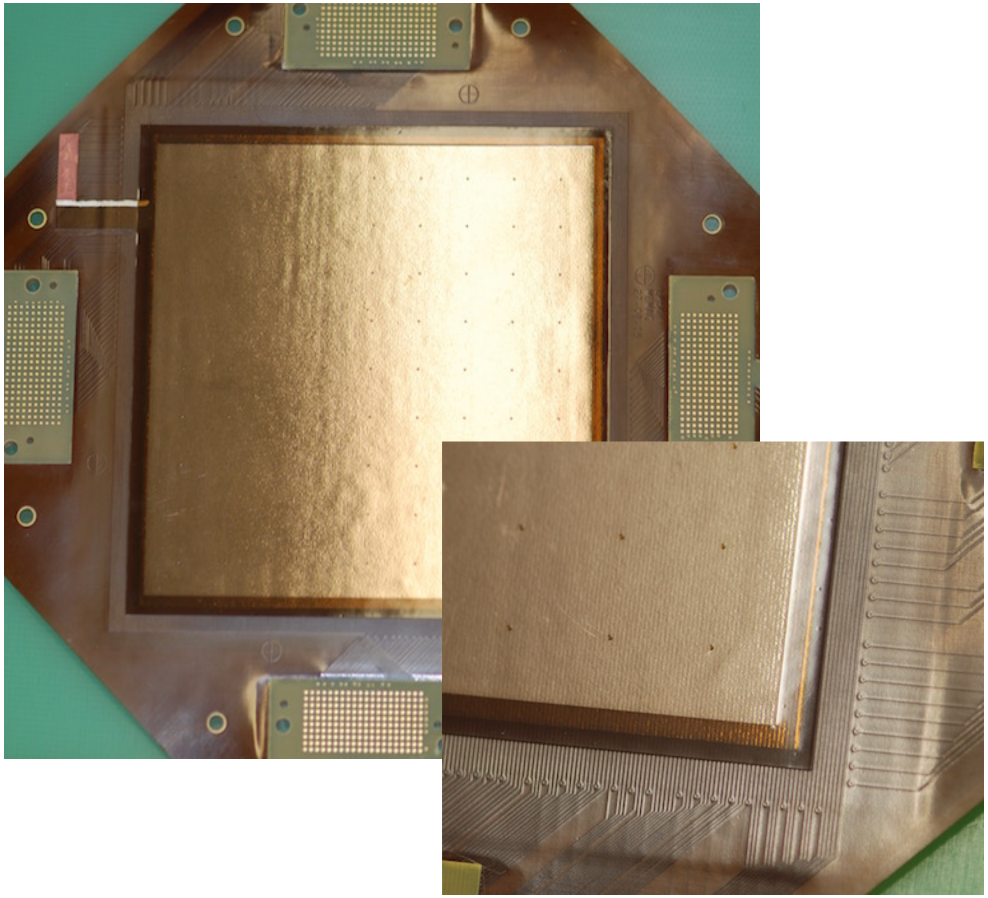


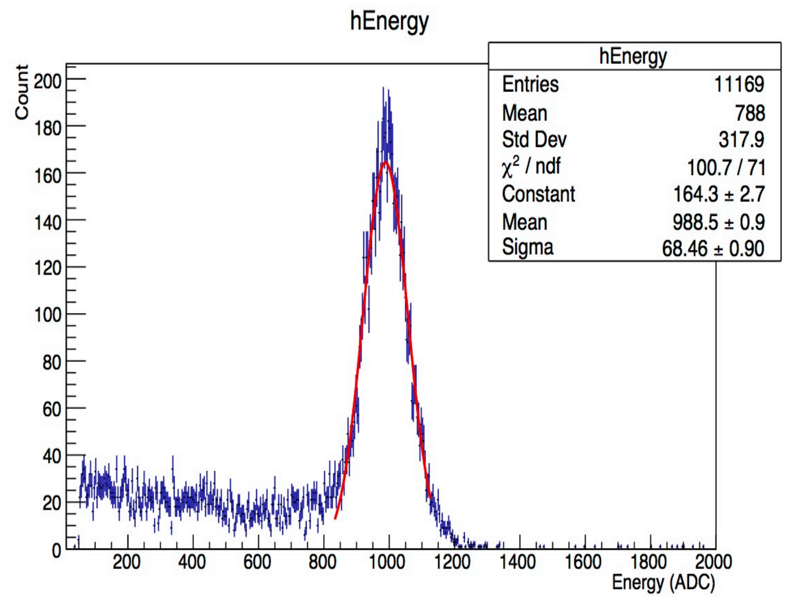
The new 35 cm “new technology” MIMAC detector compared to the old one





New MIMAC low background detector
10 cm x 10 cm





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

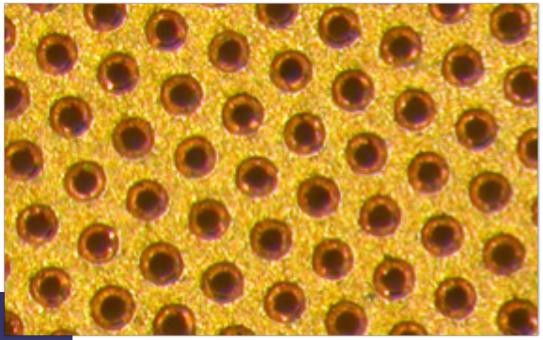
Kapton micromegas readout
Piralux Pilar

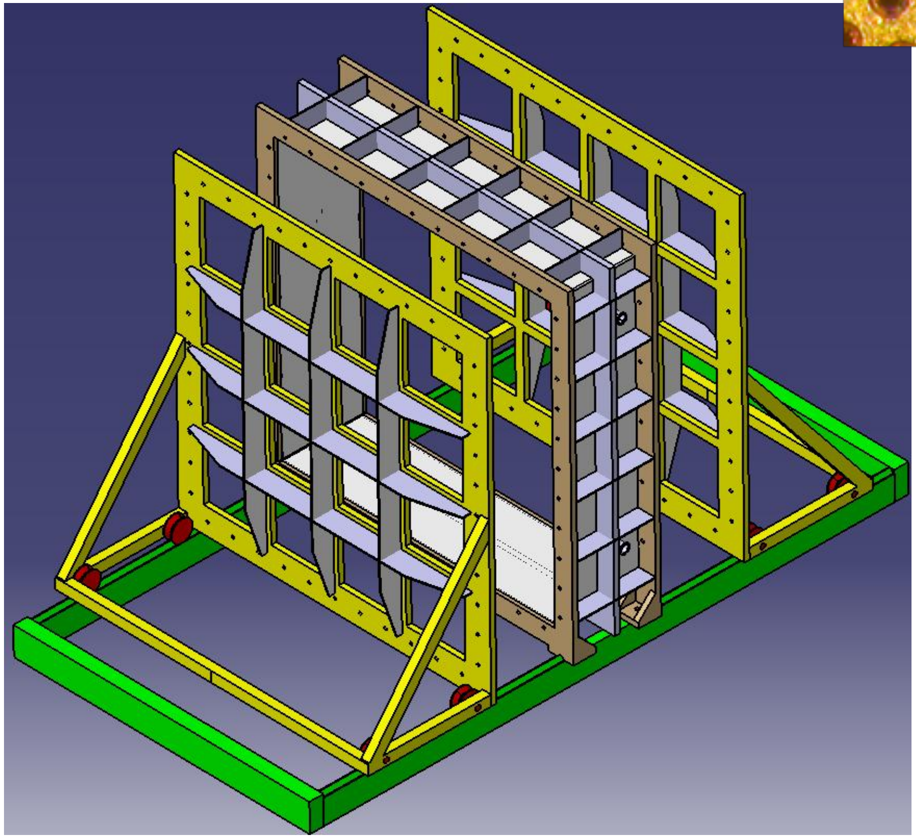
16,3 % FWHM (6 keV)
Gain ~25 000
Energy threshold <1 keV

D. Santos (LPSC Grenoble)

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





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Conclusions

- **Gas detectors** open new possibilities in the DM research, Neutron spectroscopy and other fields…
- New directional detectors of nuclear recoils at low energies have been developed giving a lot of flexibility on targets, pressure, energy range…
- Ionization quenching factor measurements have been determined experimentally and they can be checked in-situ.
- 3D nuclear recoil tracks from Rn progeny have been observed and can be used for calibration and monitoring.
- New degrees of freedom are available to discriminate electrons from nuclear recoils.
- Angular resolution and directional studies of 3D tracks are now possible with COMIMAC.
- **The 1 m^3 will be the validation of a new generation of a large DM high definition DIRECTIONAL detector (a needed signature for DM discovery)**
- **Large active volumes with a high 3D spatial resolution will open new windows to observe Nature !**

TPC directional detectors

	DRIFT	MIMAC	NEWAGE	DMTPC
	Boulby	Modane	Kamioka	SNOLAB
Gas mix	73%CS_2 +25%CF_4 +2%O_2	70%CF_4 +28%CHF_3 +2%C_4H_{10}	CF_4	CF_4
Current volume	800 L	6 L	37 L	1000 L
Drift	ion, 50 cm	e−, 25 cm	e−, 41 cm	e−, 27 cm
Threshold (keVee)	20	1	50	20
Readout	Multi-Wire Proportional Counters	Micromegas	micro-pixel chamber +GEM	CCD

Adapted from Mayet et al. [arXiv:1602.03781]