MIMAC
MIcro-TPC MAtrix of Chambers
for Directional Dark Matter detection

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FCPPL/N, June 2024, Bordeaux

on behalf of the MIMAC collaboration

MIMAC Collaboration

LPSC (Grenoble) : D. Santos, F. Naraghi, C. Beaufort

- SDI : **O. Guillaudin, N. Sauzet**
- Electronics : **O. Bourrion, C. Hoarau, E. Lagorio**
- Data Acquisition: **T. Descombes**
- COMIMAC (quenching) **: J-F. Muraz**

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

IRSN- LMDN (Cadarache): M. Petit, T. Vinchon (neutron spectroscopy)

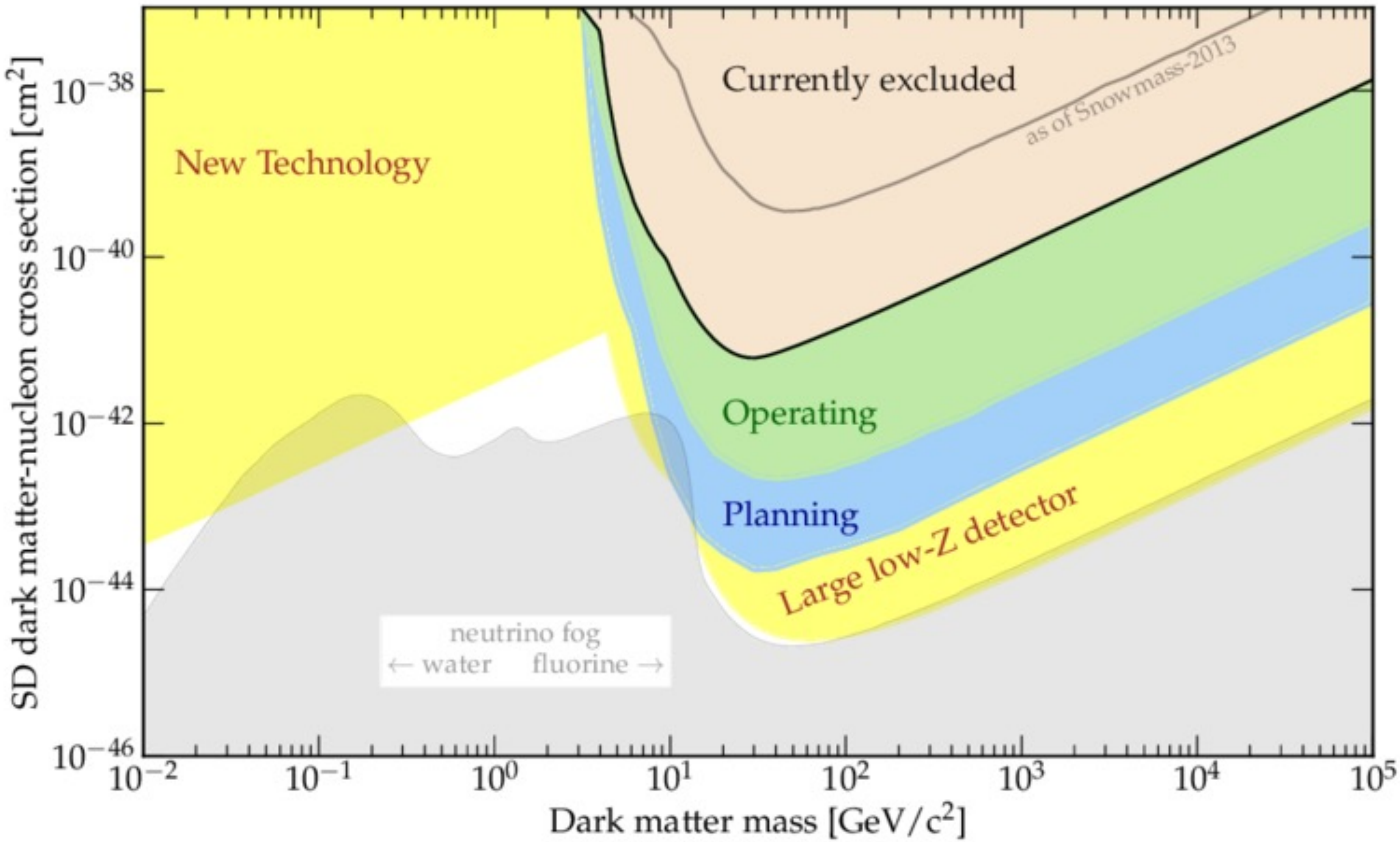
IHEP (Beijing-China): Wang Zhimin, (Yang Changgen)
USTC (University of Science and Technology of China, Hefei): Wang Zhiyong et al
SJTU(Shanghai Jiao tong University): Wang Shaobo, Han Ke, Zhou Ning, Tao Yi
TSINGHUA University (Beijing-China): Yue Qian director
(China JinPing underground Laboratory, CJPL)
SHAO(Shanghai Astronomical Observatory): Shan Huan Yuan

Also partnership with the NEWS gaseous sphere collaboration

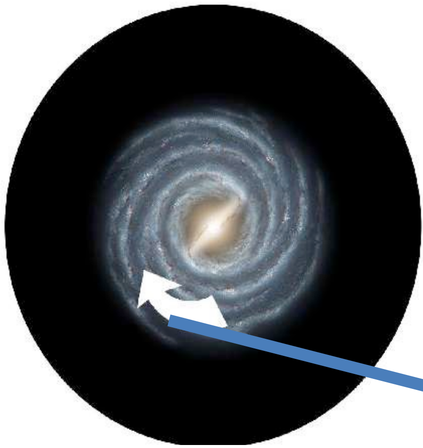
Dark Matter direct detection

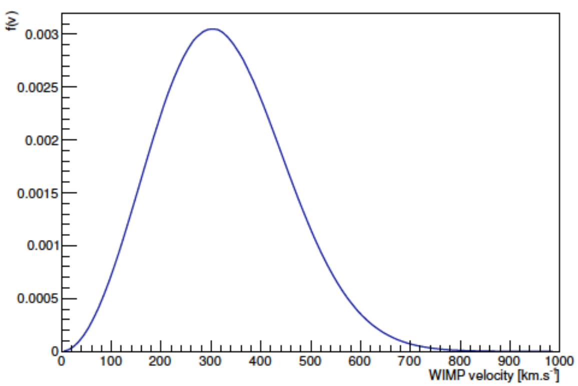
DOI:10.48550/arXiv.2209.07426

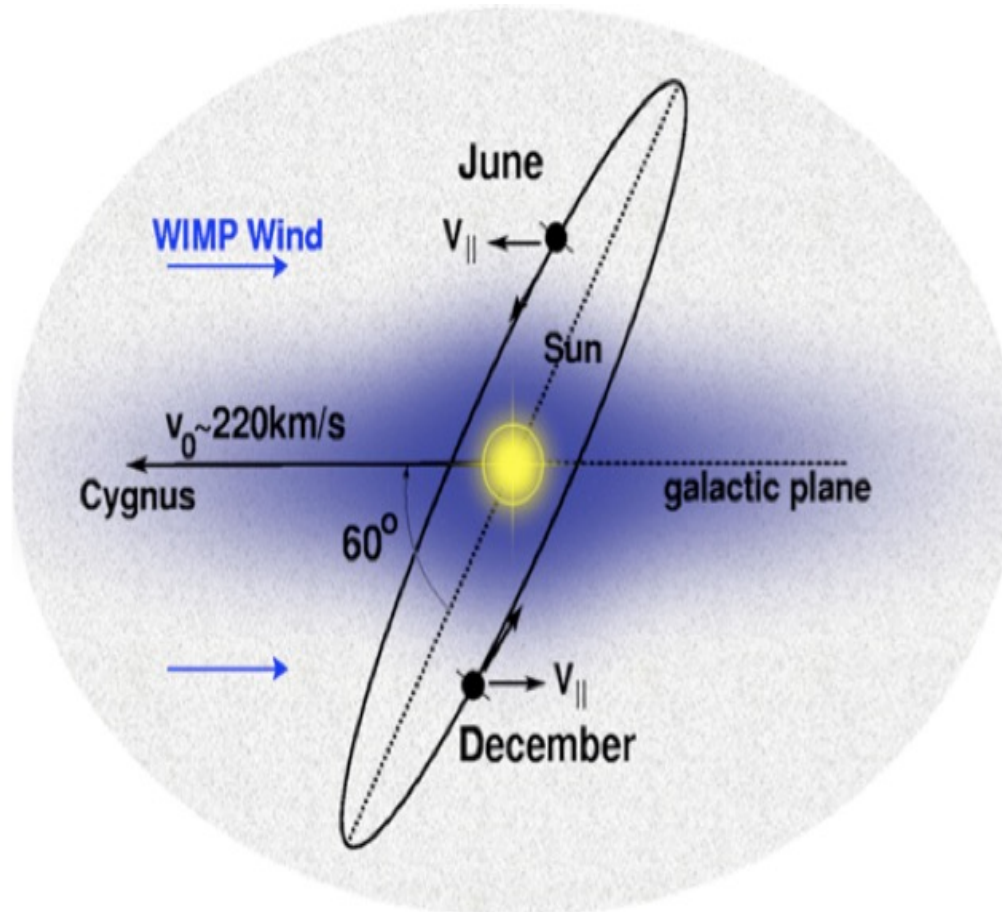
Report of the Topical Group on Particle Dark Matter for Snowmass 2021



Directional detection: principle







Signature: correlate the rare events in a detector to the galactic halo !!

Dark matter detection with hydrogen proportional counters

G. Gerbier, J. Rich, M. Spiro, C. Tao

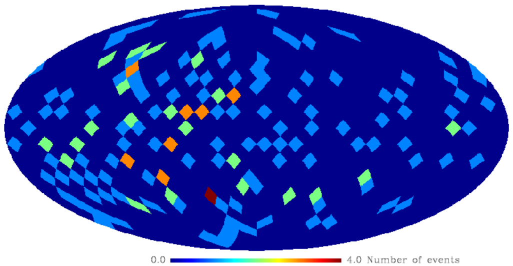
Nuclear Physics B - Proceedings Supplements Vol 13, 1990, Pages 207-208

Phenomenology: Discovery

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

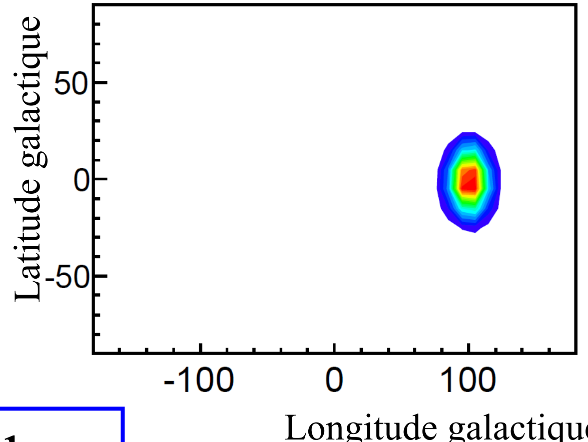
Proof of discovery: **Signal pointing toward the Cygnus constellation**

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



100 WIMP + 100 BKG

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



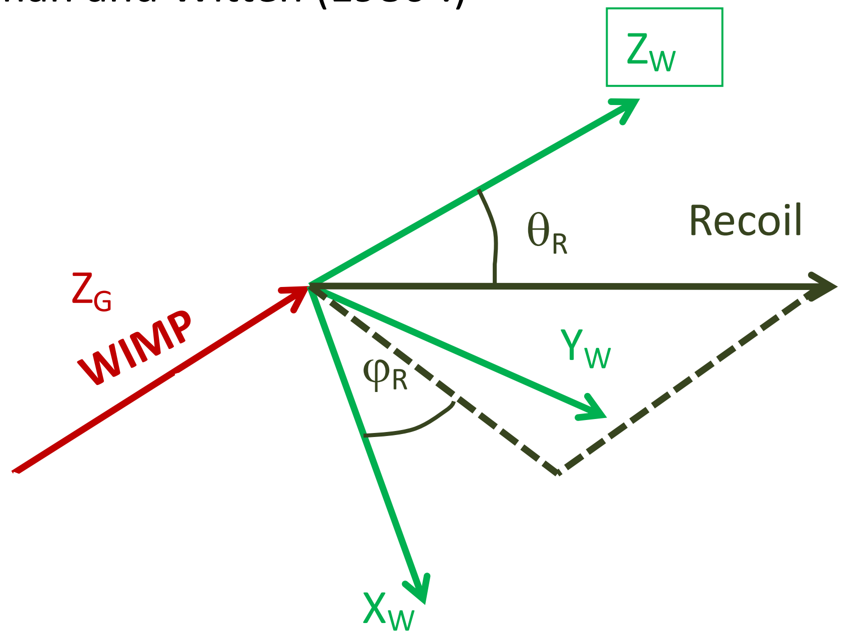
Strong correlation with the direction of the Constellation Cygnus **even with a large background contamination**

Need better than 20° angular resolution

3D tracks are needed…

WIMP produce nuclear recoils

Goodman and Witten (1986 !)



J. Billard *et al.*, PLB 2010
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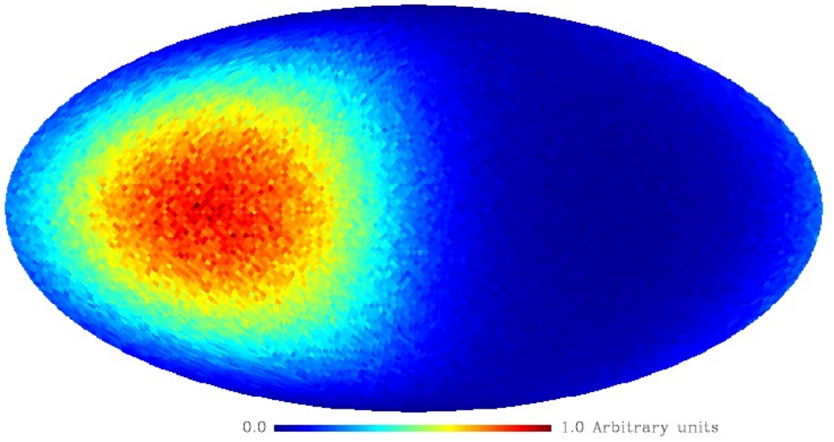
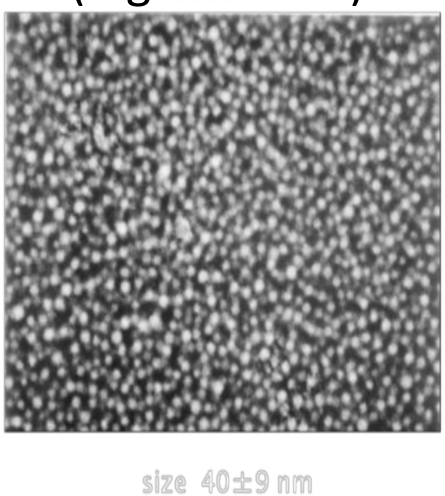


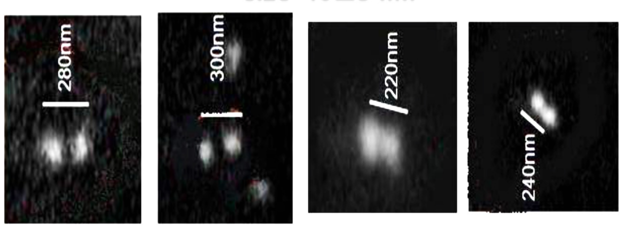
Map of recoils in galactic coordinates (HealPix)

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

Directional detection: comparison of some strategies

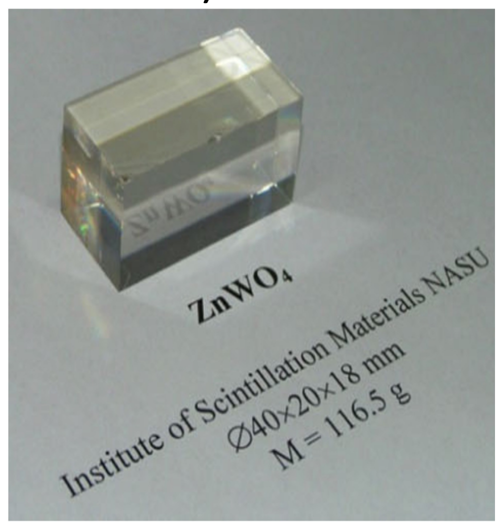
- Emulsion layers target = C (low masses), Ar, Br, Kr (high masses)





D'Ambrosio et al. 2014

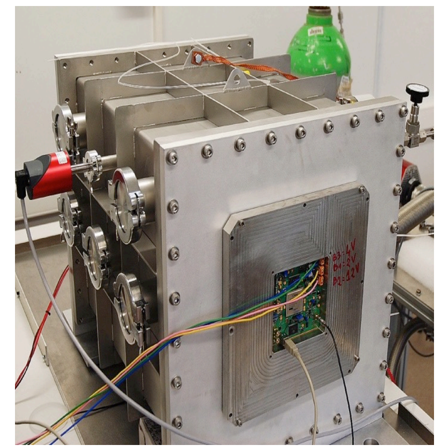
- Anisotropic crystals target = O (low masses), Zn, W (high masses)

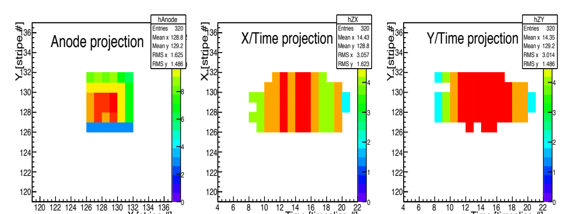


No tracks ; only statistical distributions (!)

Capella et al. 2013

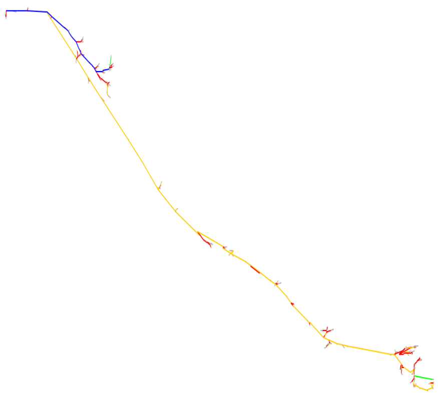
- Low pressure TPCs target = F





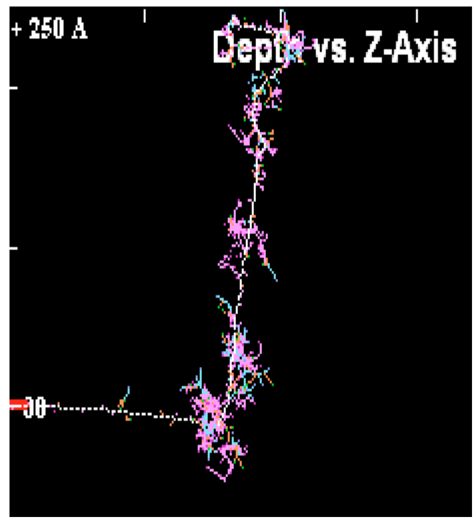
Directional detection: comparison of some strategies

- Emulsion



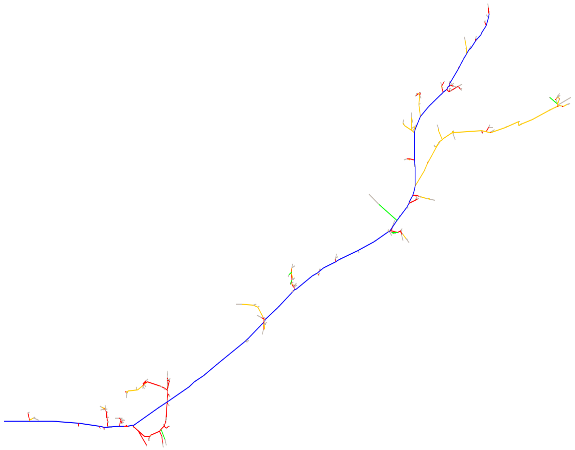
~100 nm

- Anisotropic crystals



~10 nm

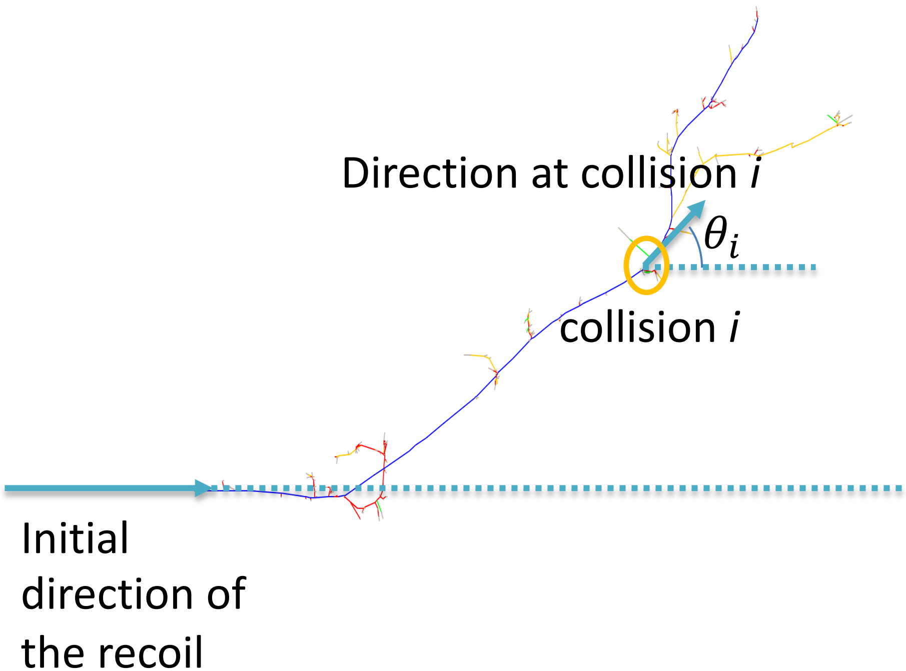
- Low pressure TPCs



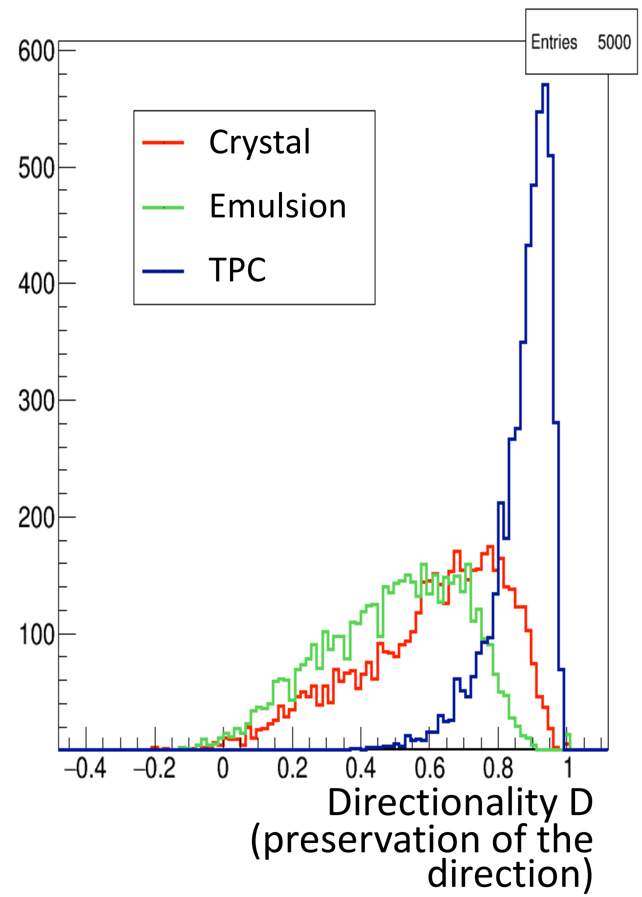
~1 mm
(10^5 times longer !!)

SRIM simulations

Directional detection: Directionality 'D'



$$D = \frac{\langle \cos(\theta)\cdot E\rangle_{track}}{\langle E\rangle_{track}} = \frac{\sum_{i=0}^{N_{collisions}} \cos(\theta_i)\cdot E_i}{\sum_{i=0}^{N_{collisions}} E_i} = \frac{\sum_i \cos(\theta_i)\cdot E_i}{N_{collisions}\cdot\langle E\rangle_{track}}$$



For more information on the comparison:
Couturier et al.

TPC directional detectors

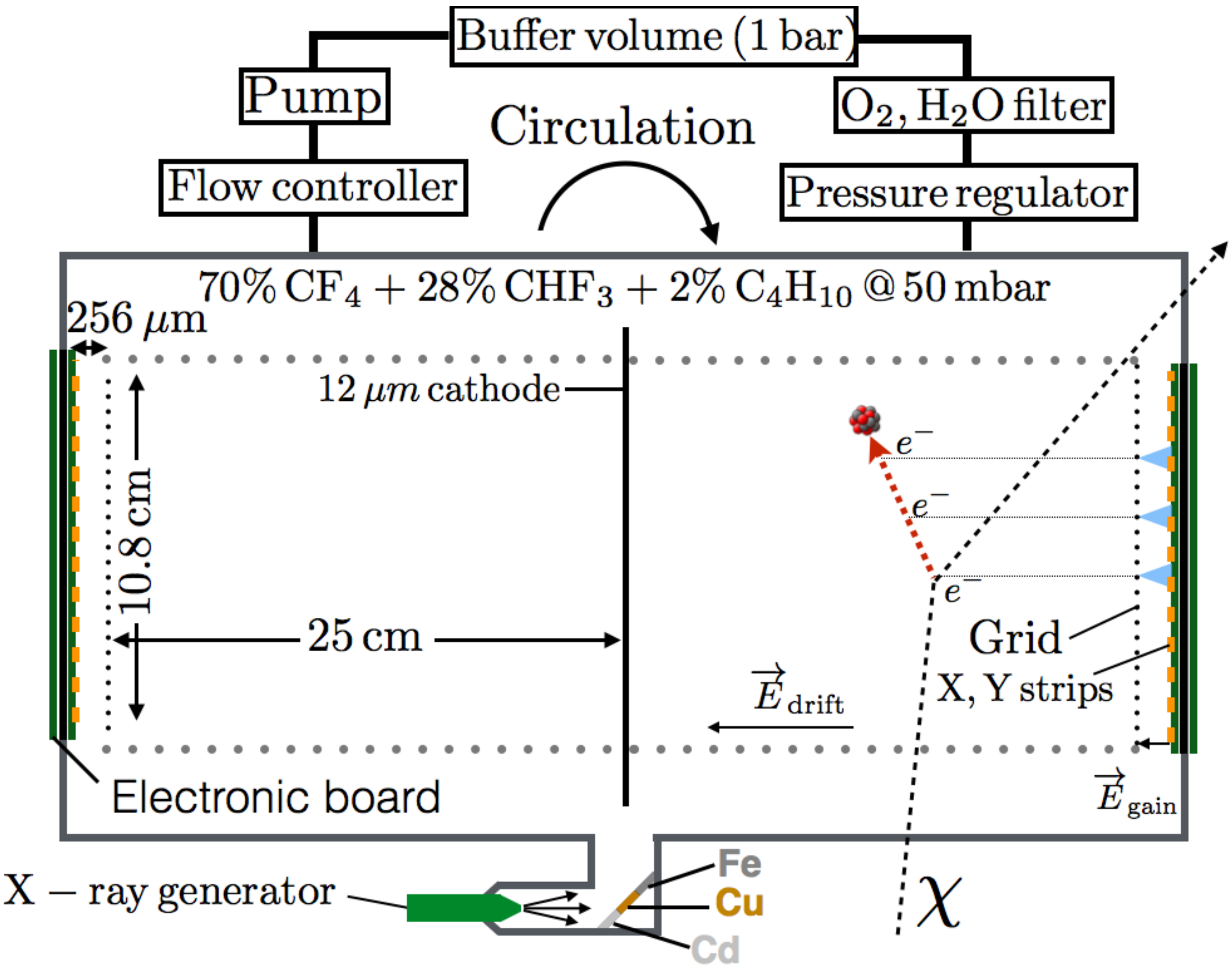
Adapted from Mayet et al. [arXiv:1602.03781]

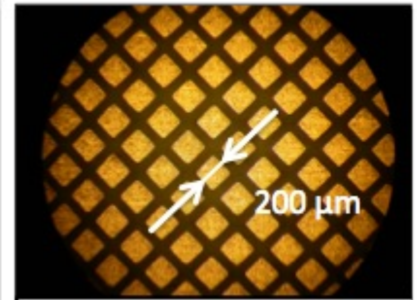
	DRIFT	MIMAC	NEWAGE	DMTPC
	Boulby	Modane	Kamioka	SNOLAB
Gas mix	73%CS2 +25%CF4 +2%O2	70%CF4 +28%CHF3 +2%C4H10	CF4	CF4
Current volume	800 L	6 L	37 L	1000 L
Drift	ion, 50 cm	e−, 25 cm	e−, 41 cm	e−, 27 cm
Threshold (keVee)	20	1	50	20
Readout	Multi-Wire Proportional Counters	Micromegas	micro-pixel chamber +GEM	CCD

+ Cygno collaboration : GEM ionization+ scintillation.
From ORANGE (0.1l) to LIME (50l)prototypes

Only MIMAC has shown tracks (for many years)!

MIMAC bi-chamber module prototype



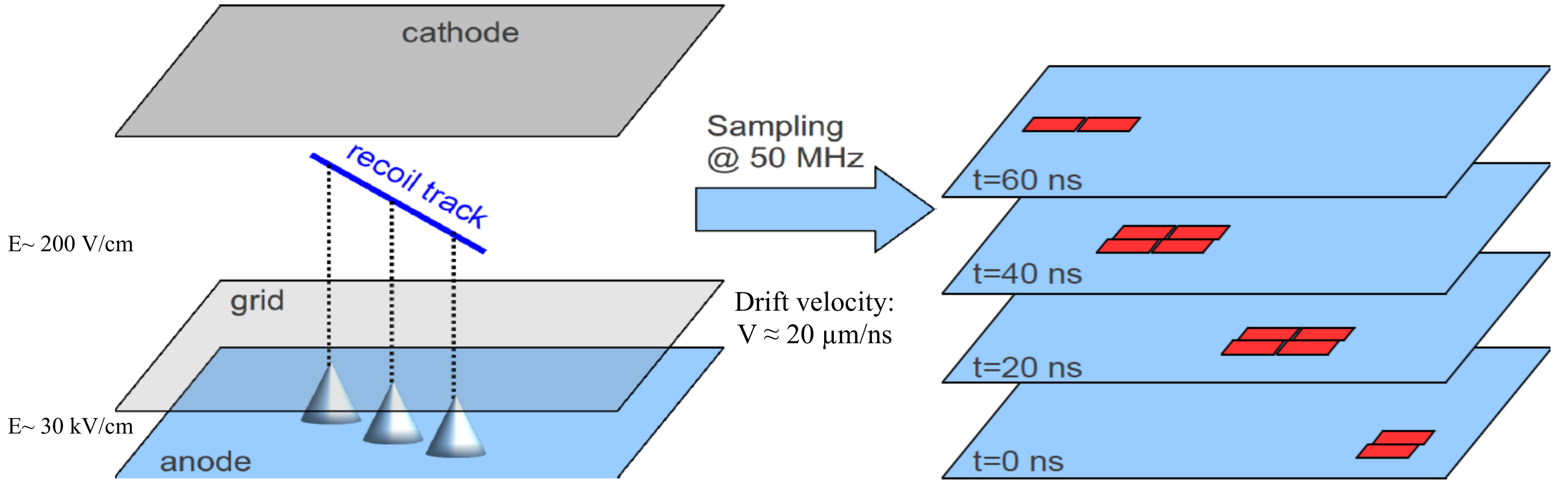


Micromegas 10x10 cm², designed by IRFU- Saclay (France)

MIMAC Targets: ^{19}**F , H**

- **Light WIMP mass**
- **Axial coupling**

MIMAC detector



Evolution of the collected charges on the anode

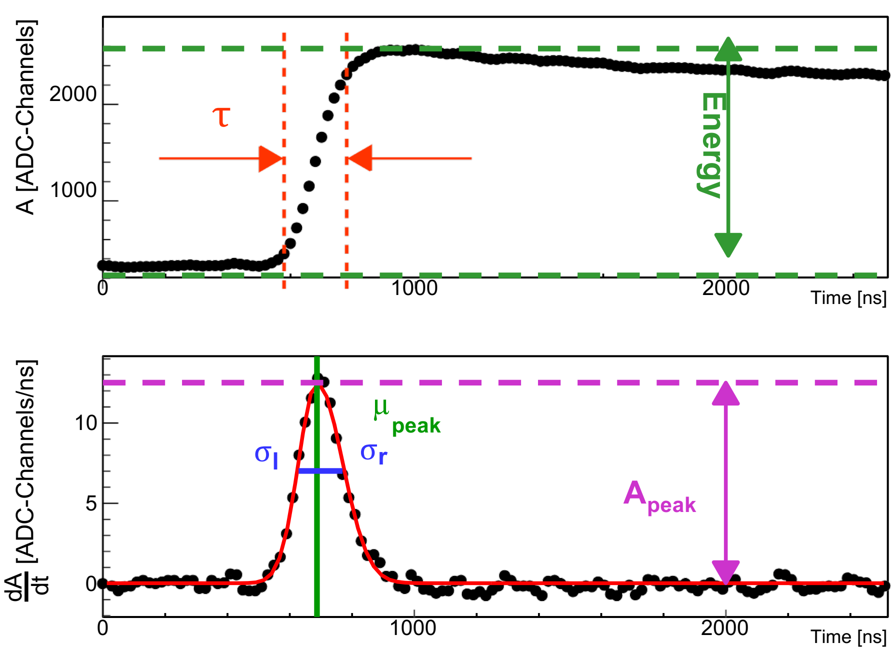
Measurement of the ionization energy :

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

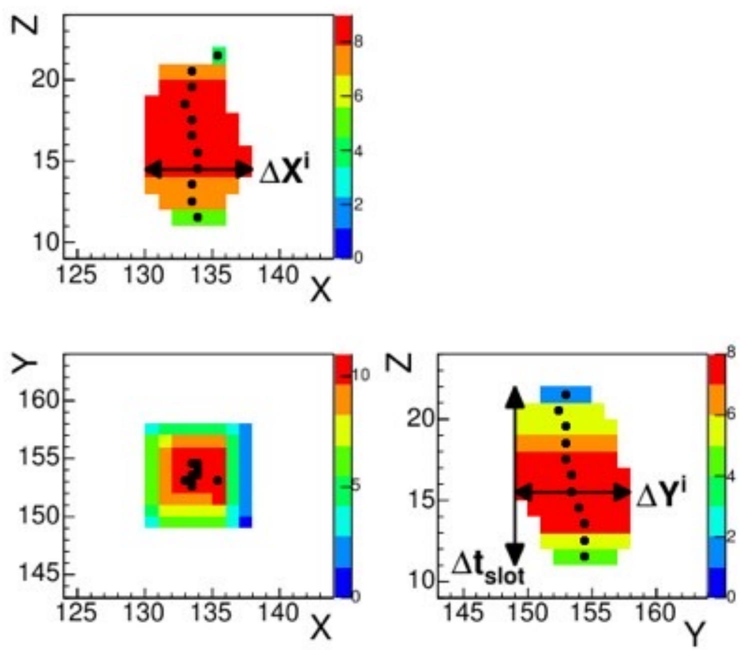
MIMAC readout

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

preamplifier signal + FADC: Energy



3D - track



MIMAC : different detectors and measurements

- **Different prototypes:**

  - 10x10 cm bi-chambers in LPSC Grenoble and LSM

  - 10x10 cm in IHEP/Tsinghua

  - 35x35 cm in LPSC

- **Many different measurements:**

  - measurements of **quenching factors** for reconstructing nuclear recoil energies with a dedicated **COMIMAC** set-up

  - Different gaz, different pressures

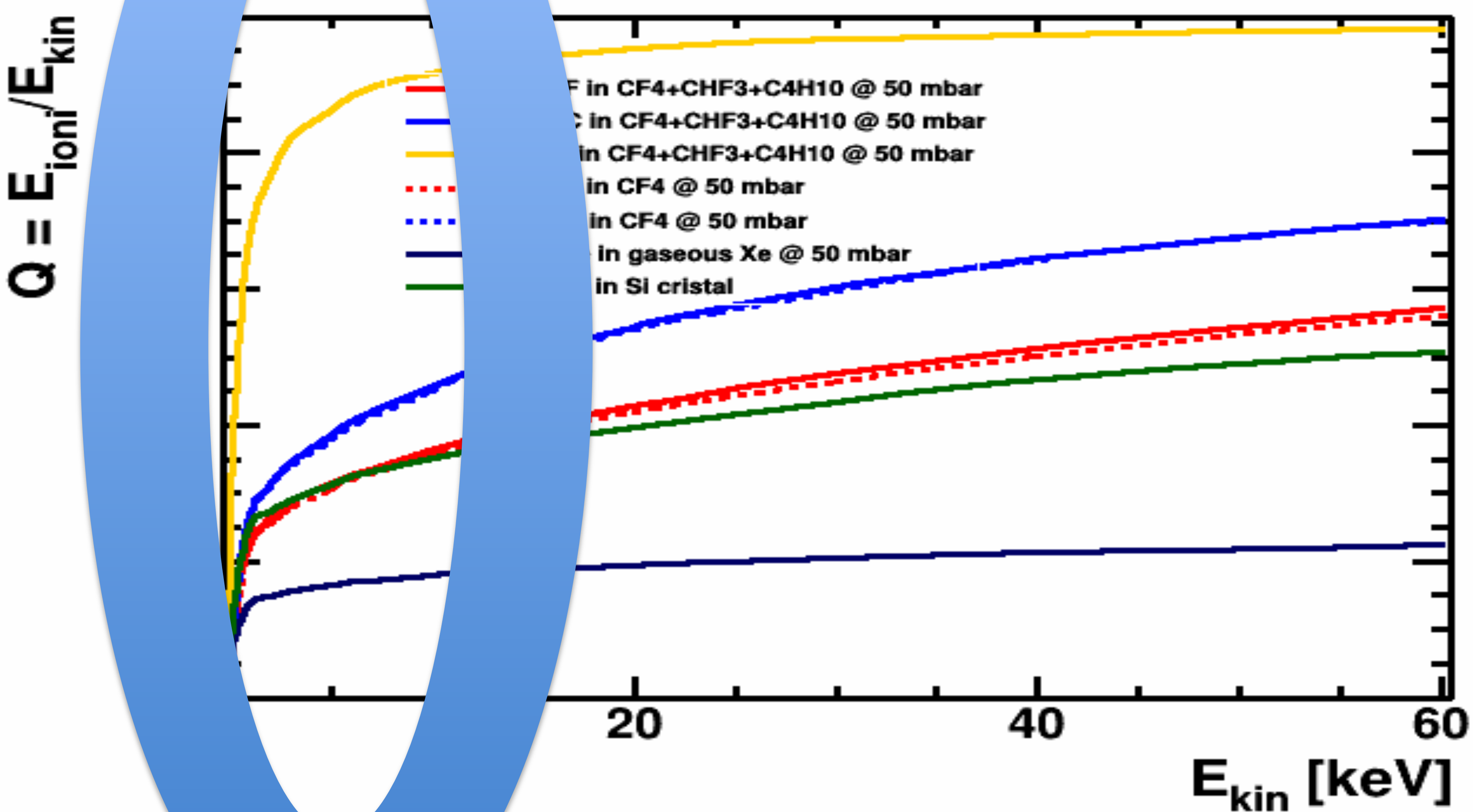
  - electron/ X-ray measurements for calibrations/monitoring and understanding **background discrimination**

  - neutron fields with different energies to demonstrate nuclear recoil reconstruction capability

  - **3D reconstruction** with an additional cathode signal

  - DM searches in LSM

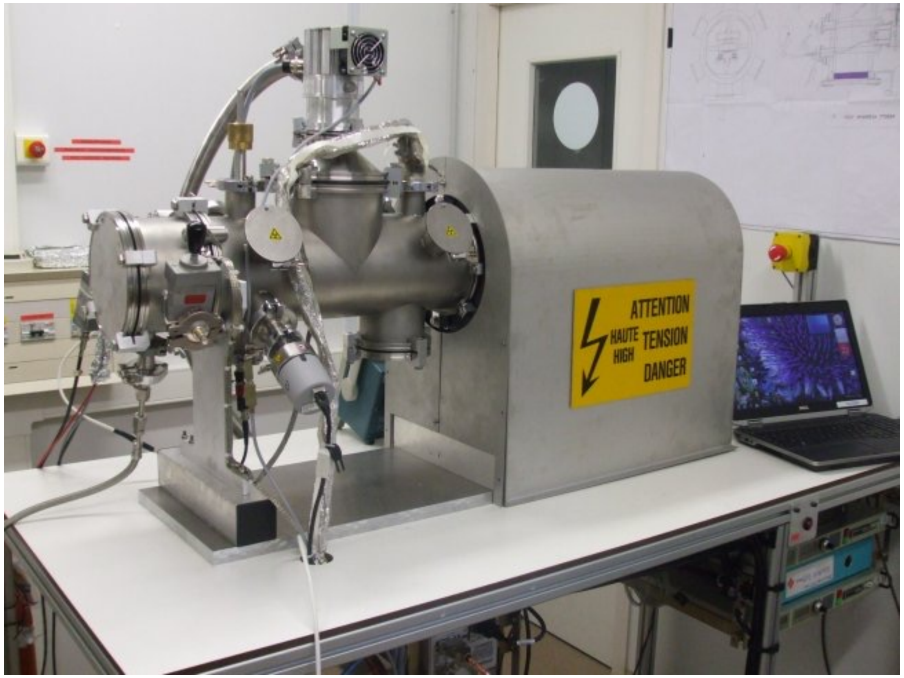
ation Quenching Factors

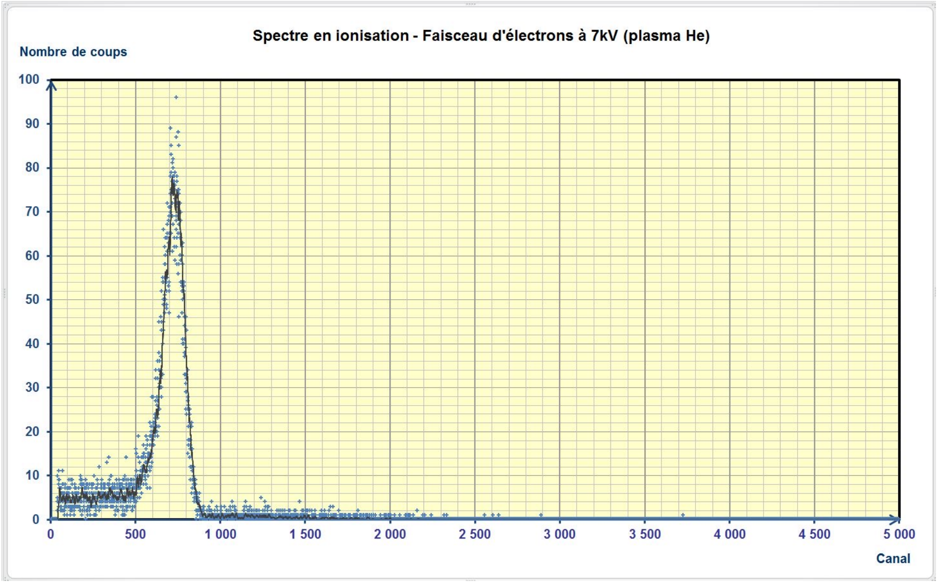


SRIM-Simulations (LPSC)

Portable Quenching Facility (COMIMAC)

Electrons and Nuclei of known energies



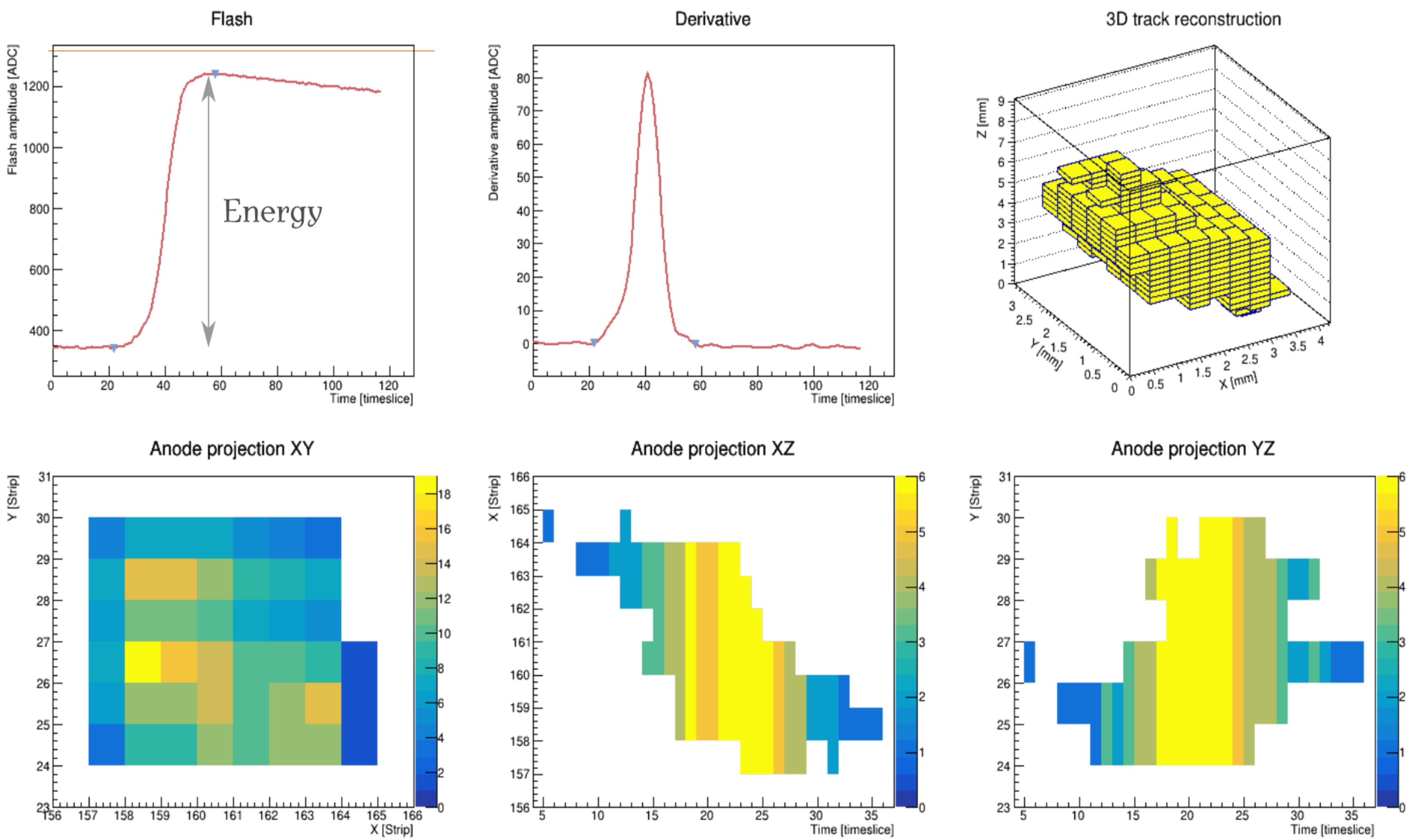


Electrons of 7 keV

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.

COMIMAC paper : Muraz et al. NIM A, 2016

Example of a proton recoil of 6 keV_{ee} (8.6 keV_{nr})



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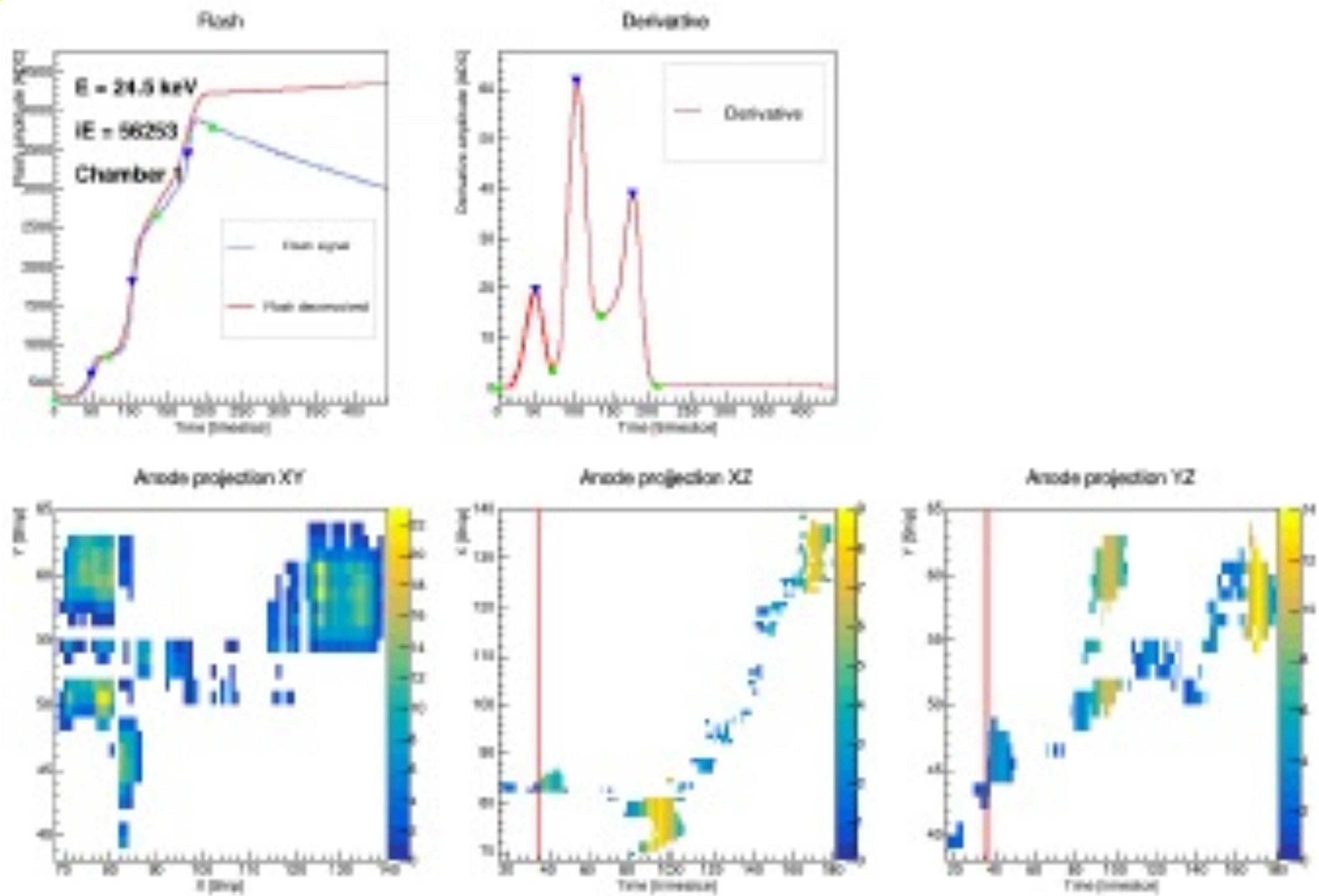
--→ Sampling at 50 MHz (20 ns)

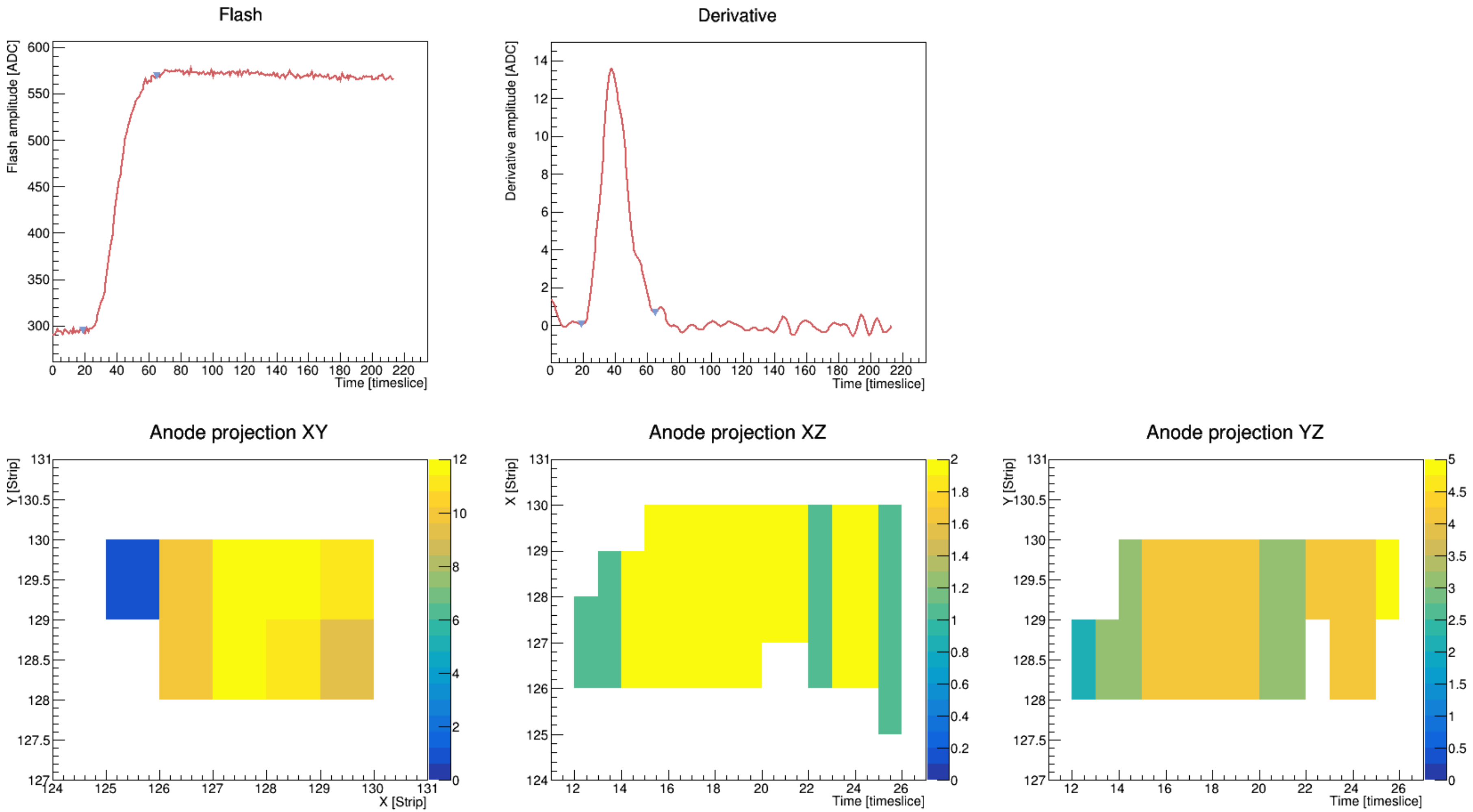
with C_4H_{10} +. 50% CHF_3 at 30 mbar

Event display of an « electron event» with a total measured ionization energy of 24.5 keV, with a secondary electron



150 eV 3D- electron track produced by COMIMAC

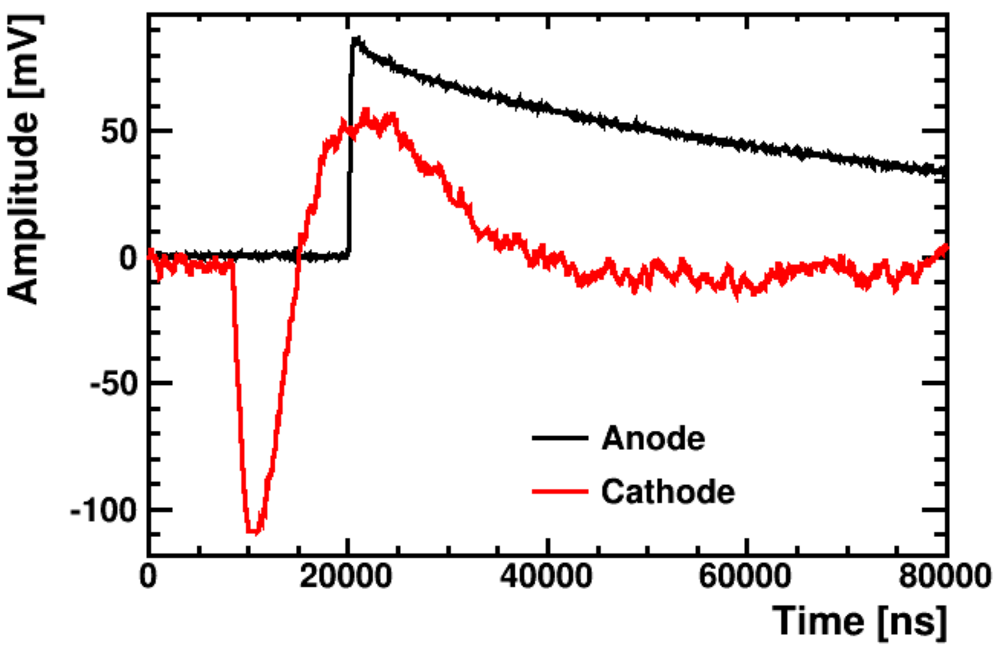
detected by one MIMAC chamber
(C_4H_{10}+50% CHF_3) at 30 mbar



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)

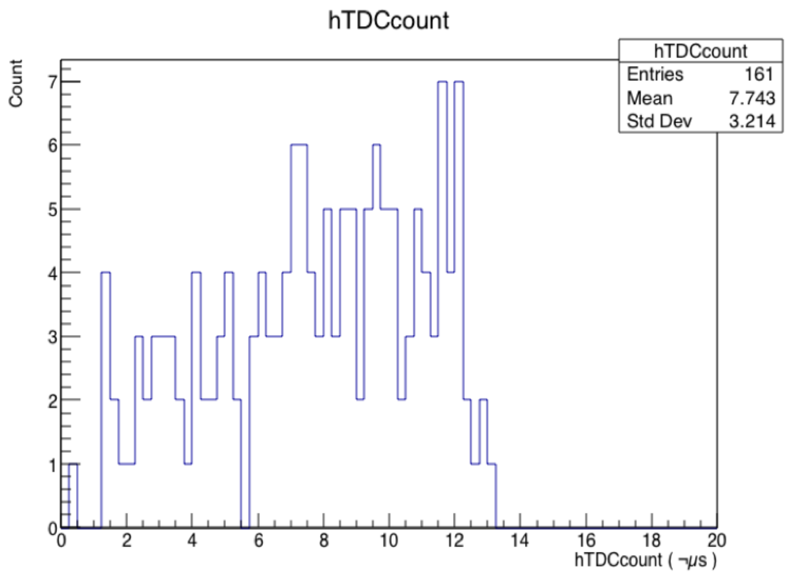


Measurement in a MIMAC chamber of an alpha passing through the active volume parallel to the cathode at 10 cm distance.

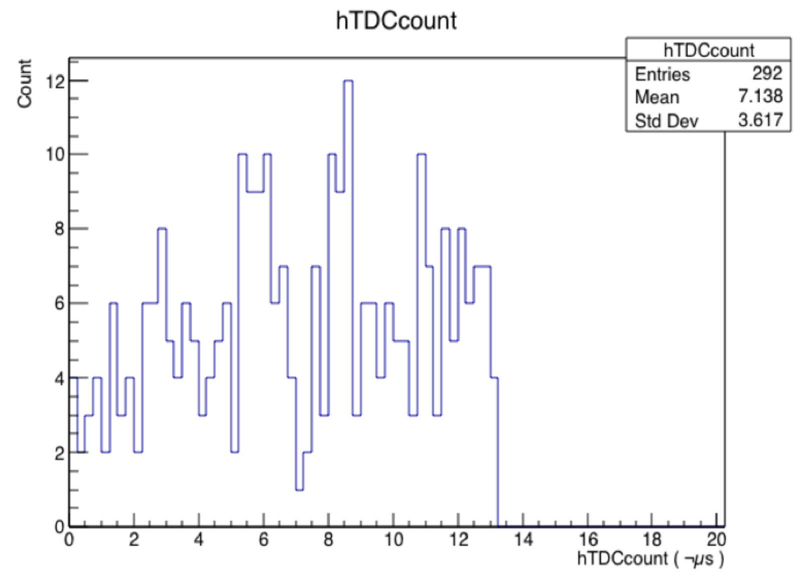
First Cathode Signals from the MIMAC bichamber background

O. Guillaudin, D.S. et al.

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) !!

MIMAC-Cathode Signal measurements

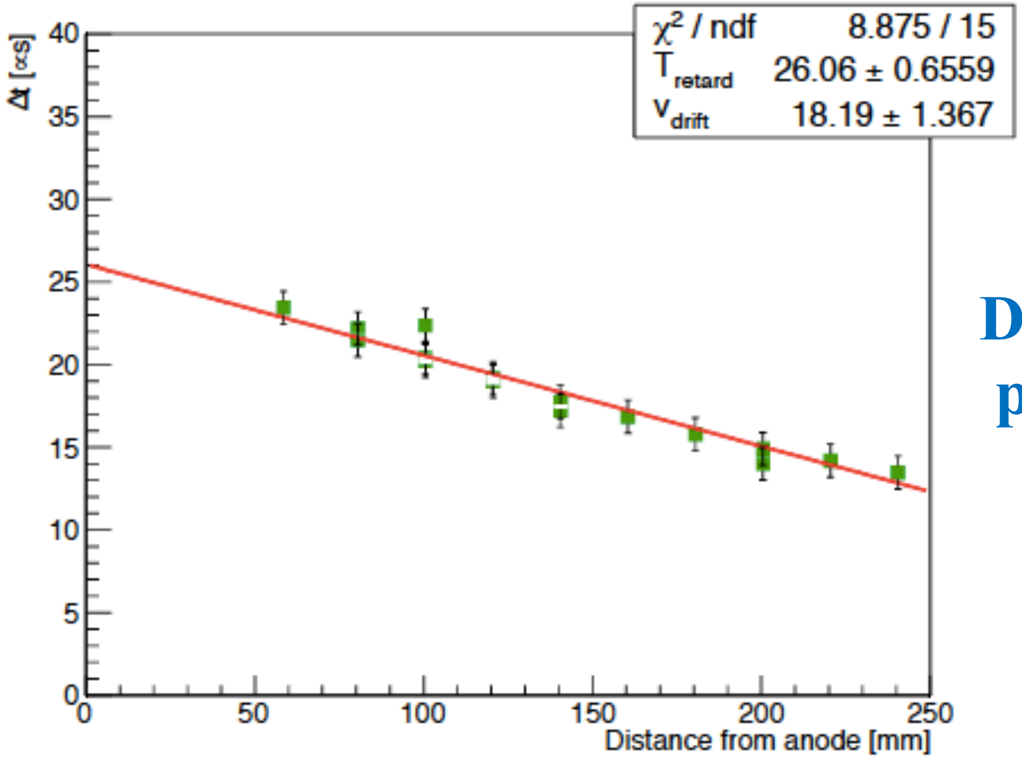


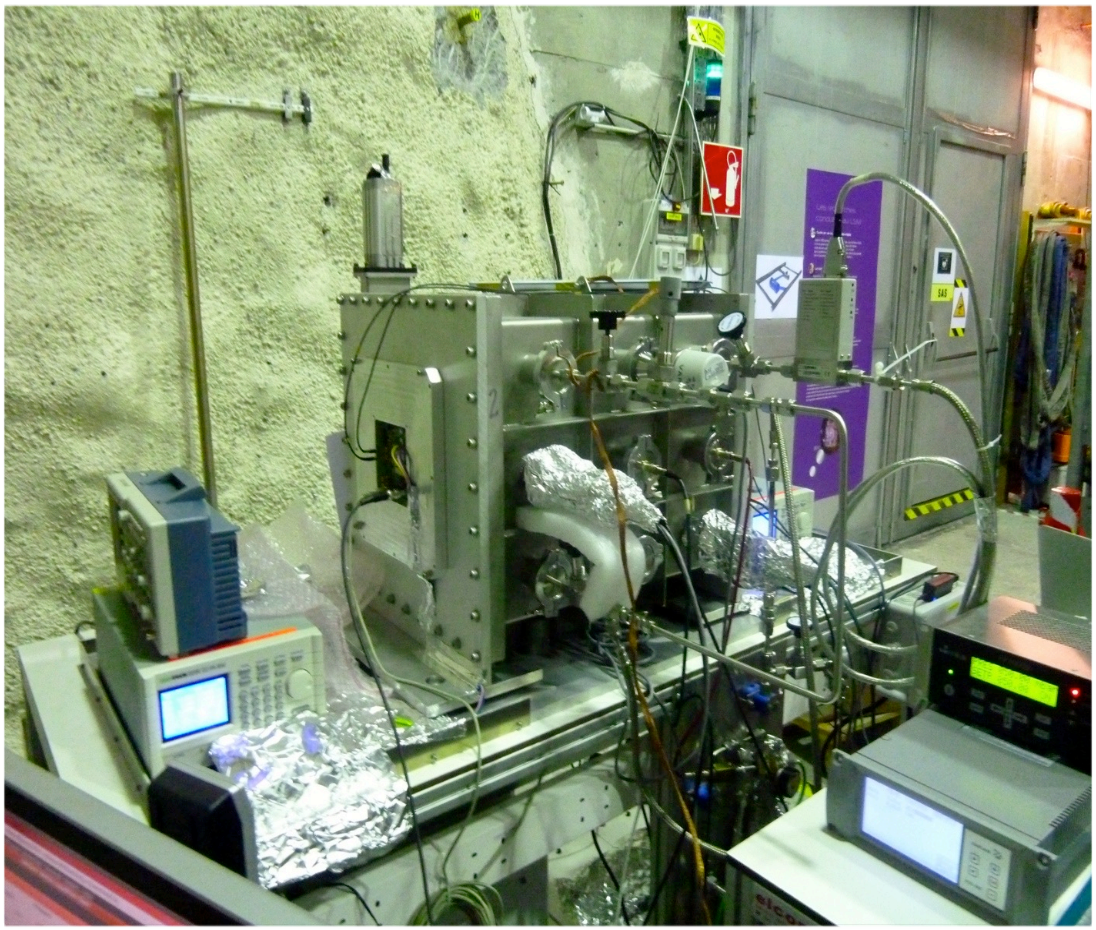
Figure 4. Measure of the time differences (TAC) between the grid signal and the delayed cathode signal in the "START Grid" configuration, as a function of the distance of the α source from the anode (green points) ; error bars correspond to the standard deviation of the mean. A linear fit of these points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

Drift velocity of primary electrons !!

MIMAC (bi-chamber module) at Modane Underground Laboratory

(LSM France)

First installation June 22nd 2012



Upgraded June 2013, and
June 2014 till February 2018

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

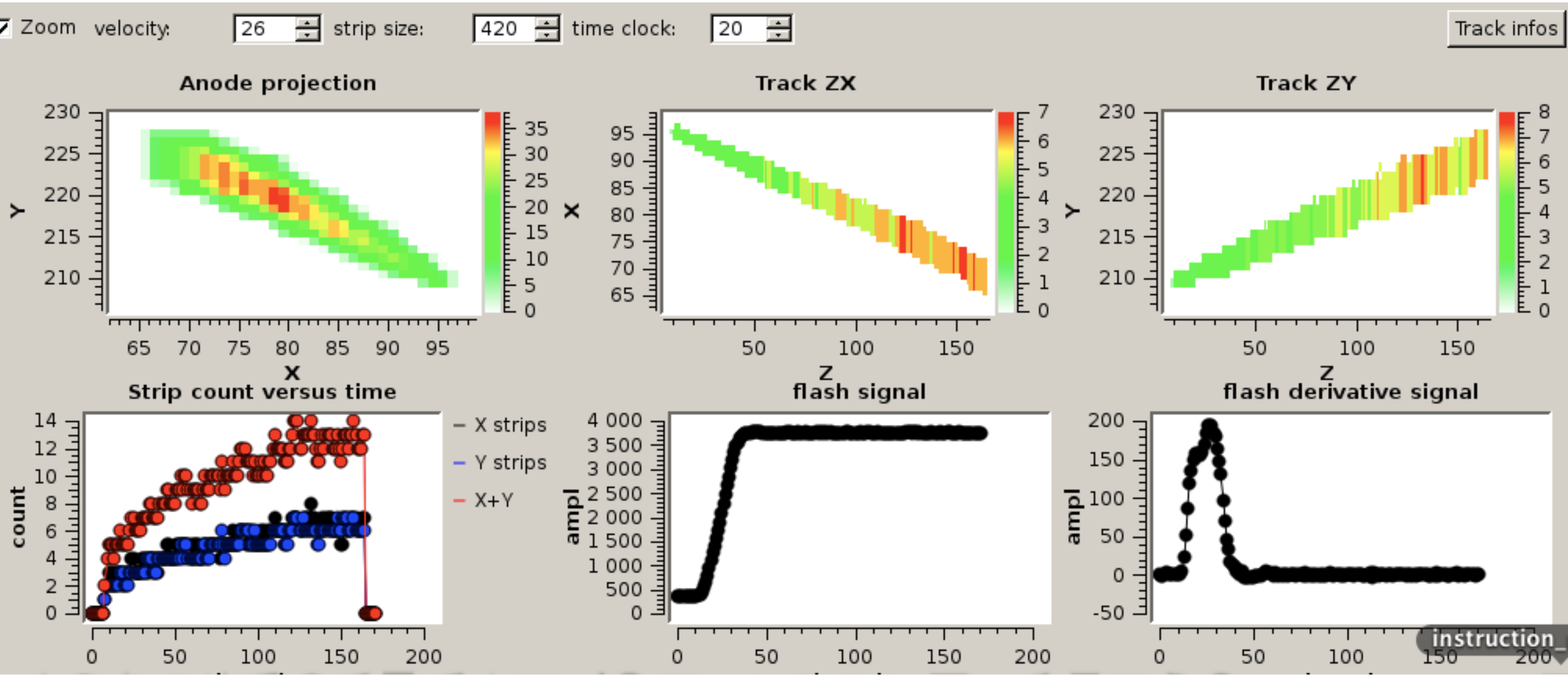
-in a permanent circulating mode
-Remote control
-Calibration control twice per week

- Since then upgraded with new detectors and with the Cathode signal.
- Reinstalled at LSM in 09/22

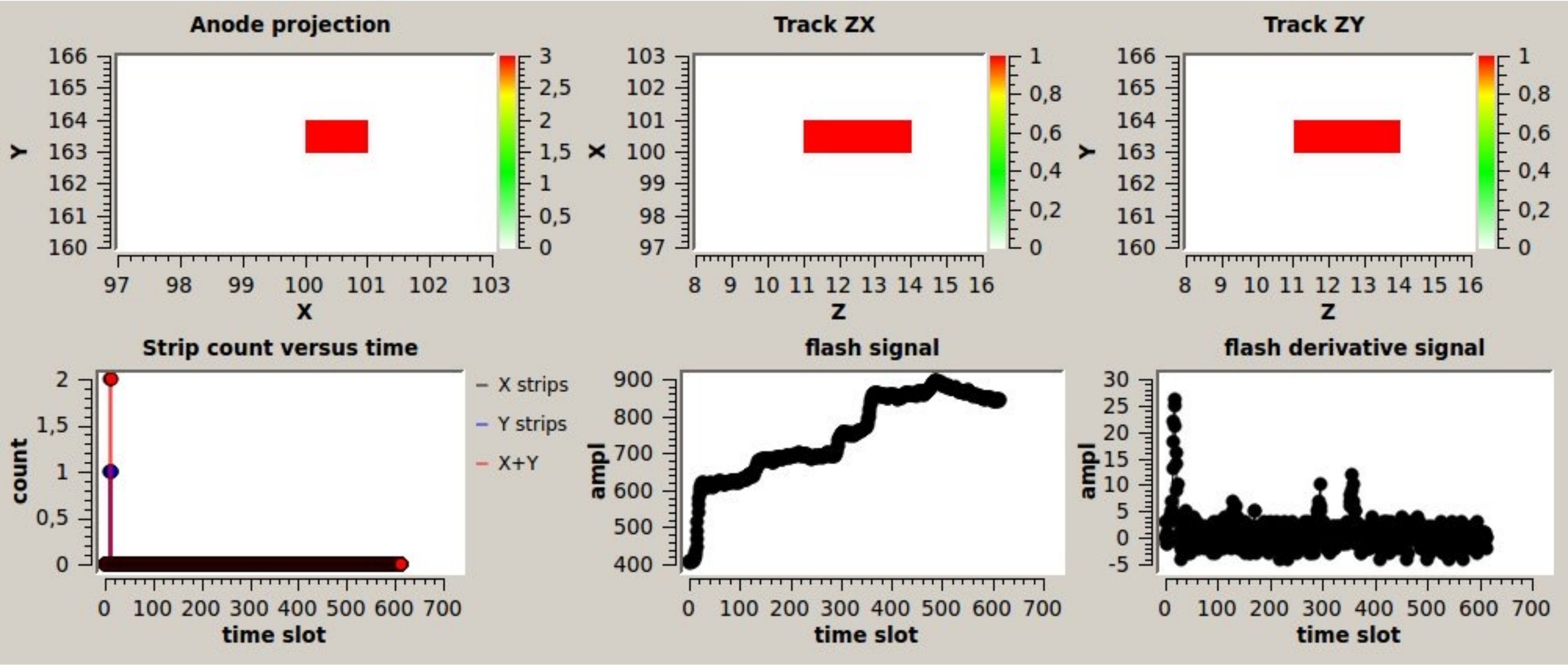
An alpha particle crossing the detector

(as an illustration of the MIMAC observables)

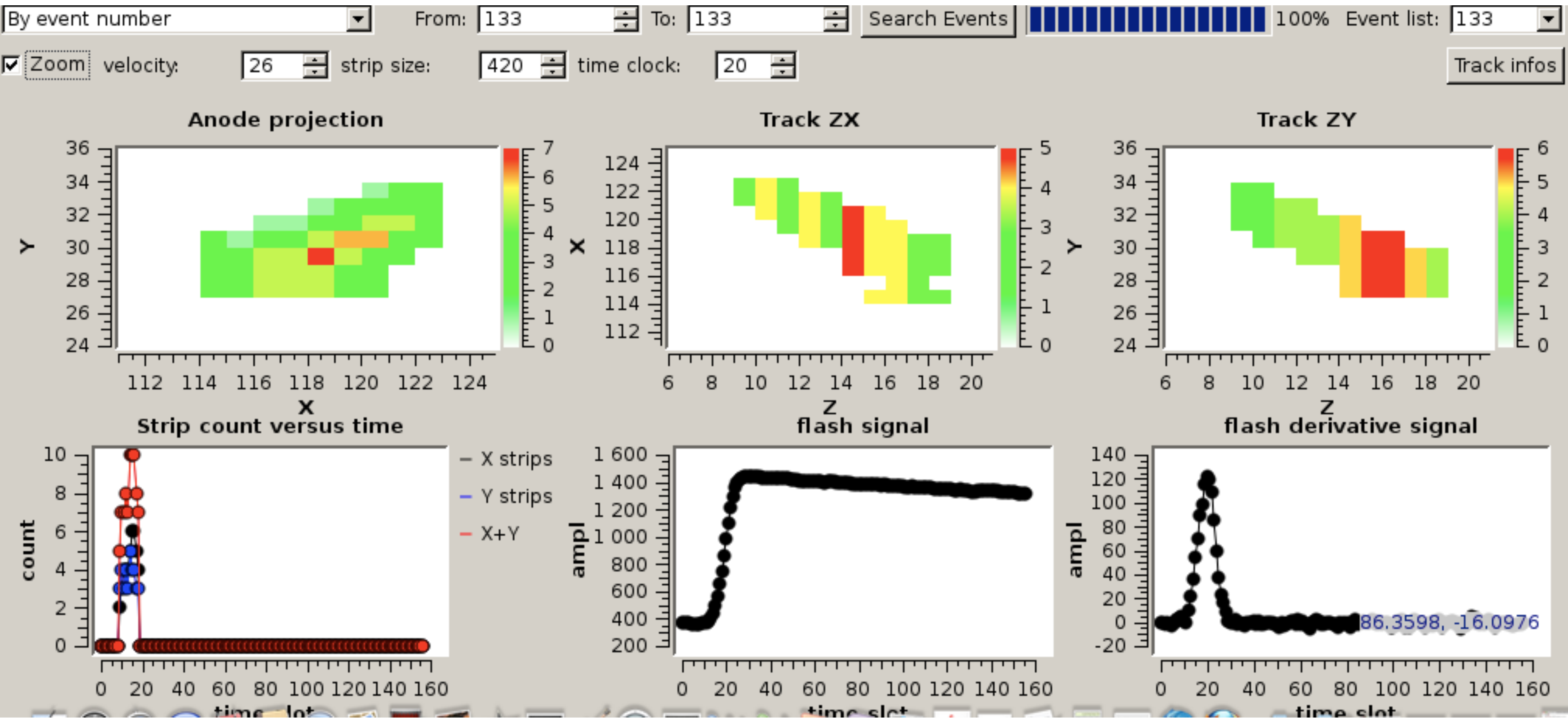
X-Y (anode) | X-Z(t) | Y-Z(t)



An Electron event (18 keV)



A “very interesting recoil event” (~ 34 keVee)



Radon Progeny

^{222}Rn chain:

- 4 β decays

  → Electron event (background)

- 4 α decays

  → α -particle emission:

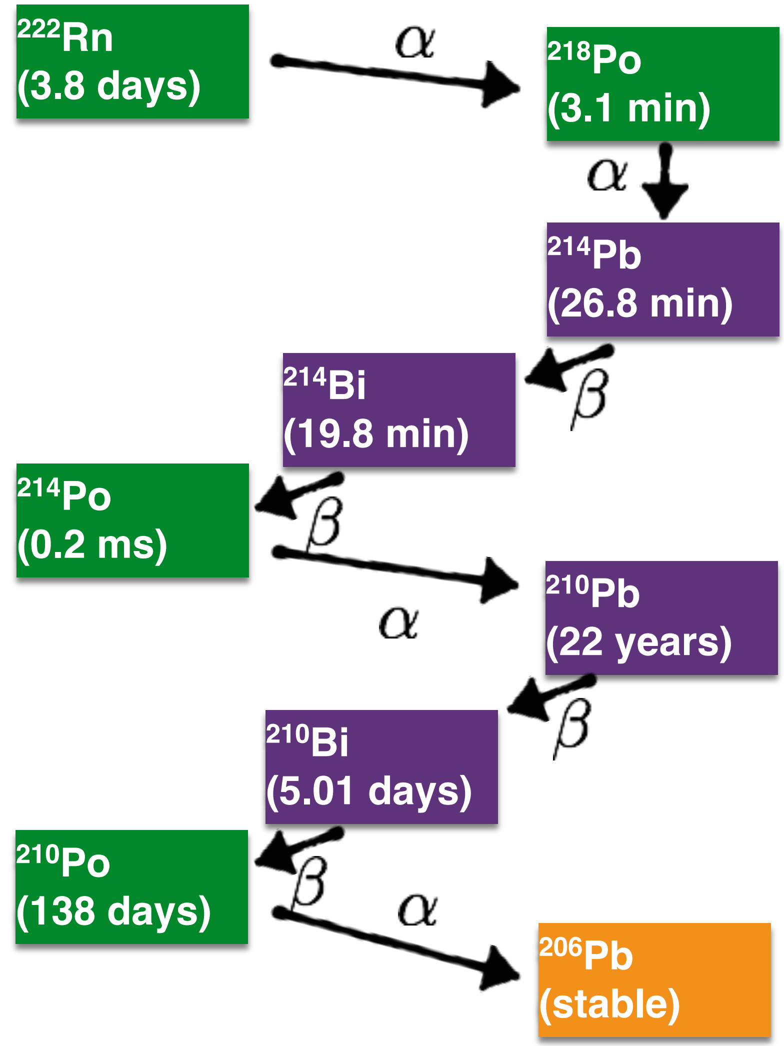
  $E_\alpha \sim 5\,\mathrm{MeV}$ → Saturation

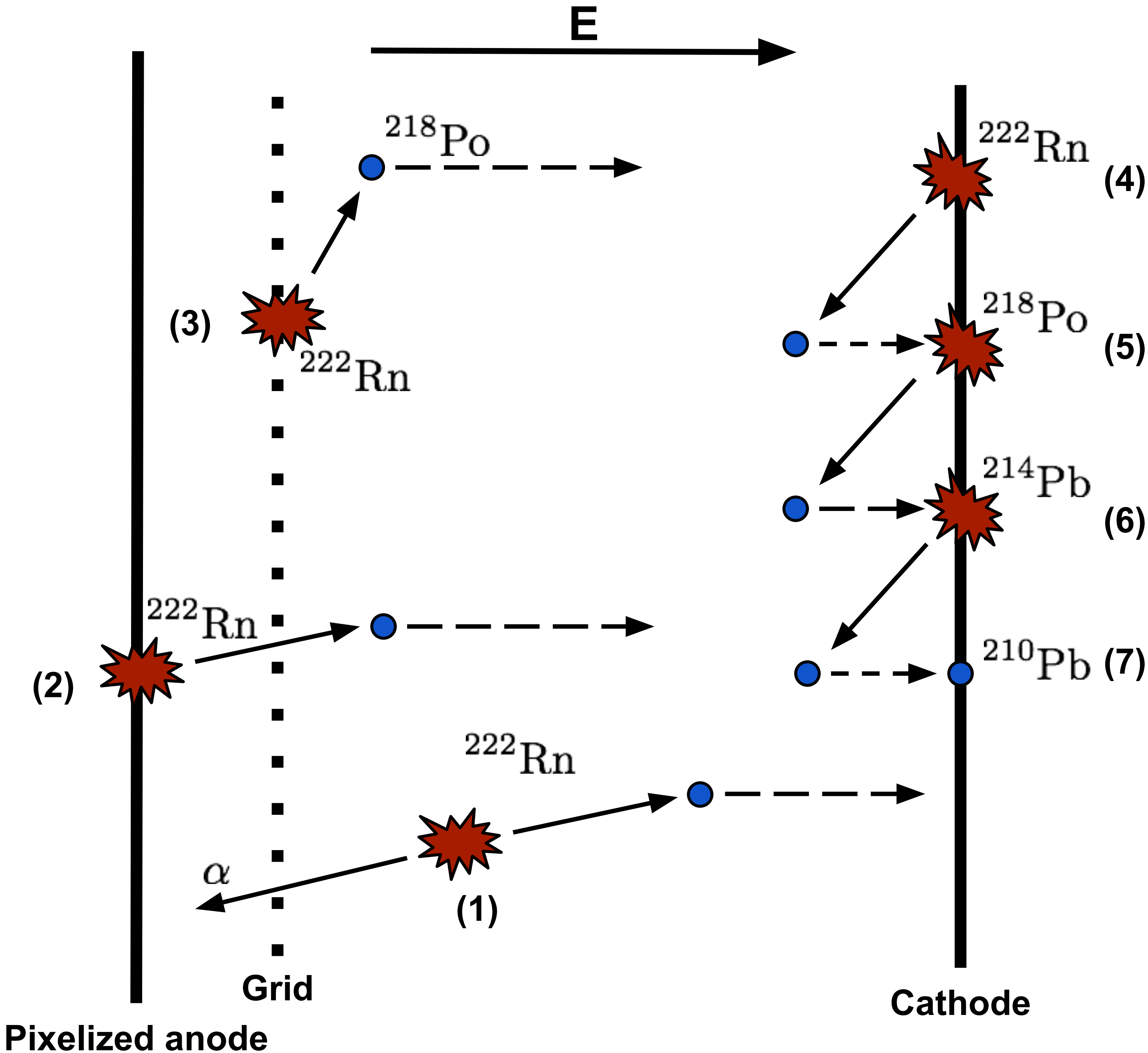
  → Daughter nucleus recoil

  (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)

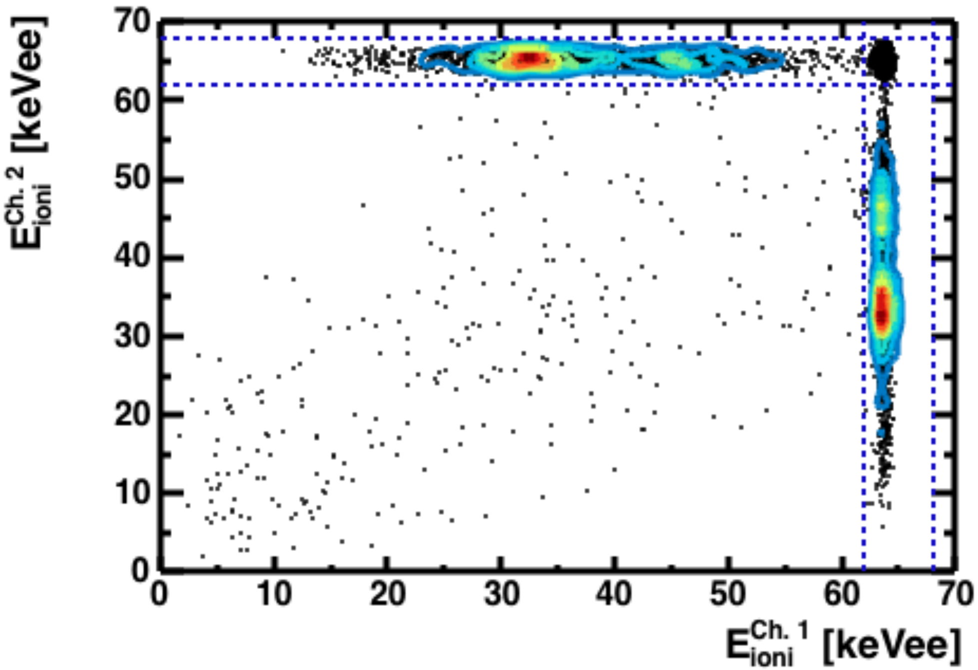


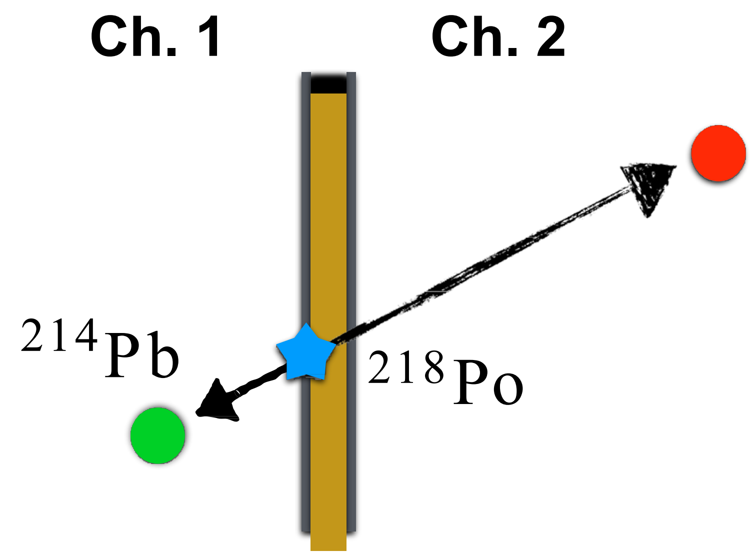


E
^{218}Po
^{222}Rn
(4)
(3)
^{222}Rn
^{218}Po
(5)
^{214}Pb
(6)
^{222}Rn
(2)
^{210}Pb (7)
^{222}Rn
α
(1)
Grid
Cathode
Pixelized anode

RPR: « In coincidence » events

Chamber coincidences:





3D tracks from nuclear recoil of radon progeny detection

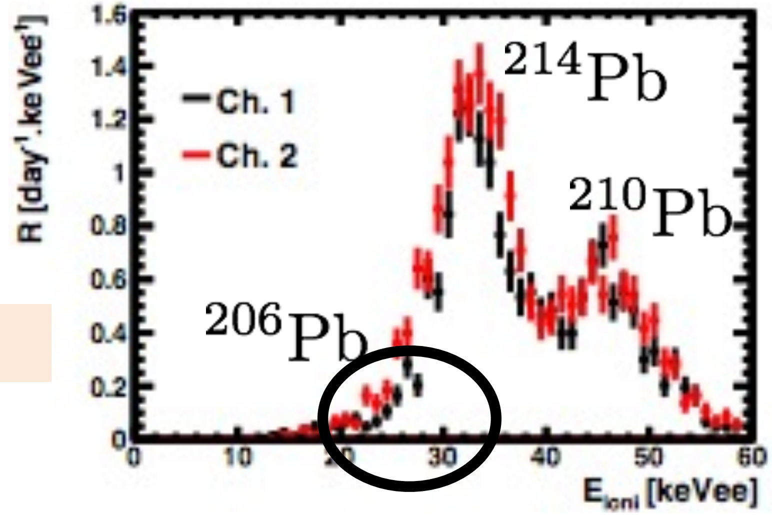
First detection of 3D tracks of Rn progeny

Electron/recoil discrimination

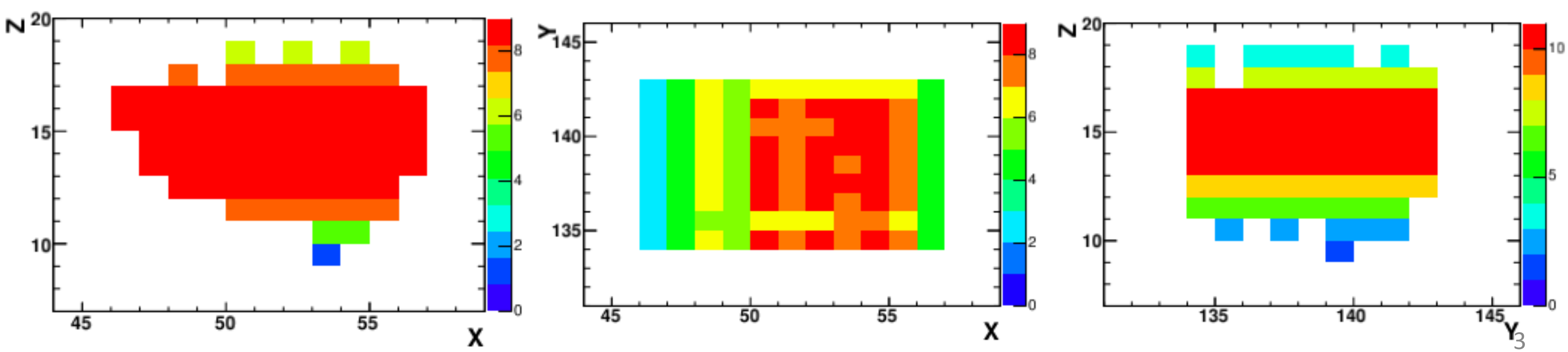
Measure:
$$\begin{cases} E_{ioni}(^{214}\mathrm{Pb}) = 32.90 \pm 0.16\,\mathrm{keVee} \\ E_{ioni}(^{210}\mathrm{Pb}) = 45.60 \pm 0.29\,\mathrm{keVee} \end{cases}$$

➔ MIMAC detection strategy validated

Nuclear recoil spectra



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

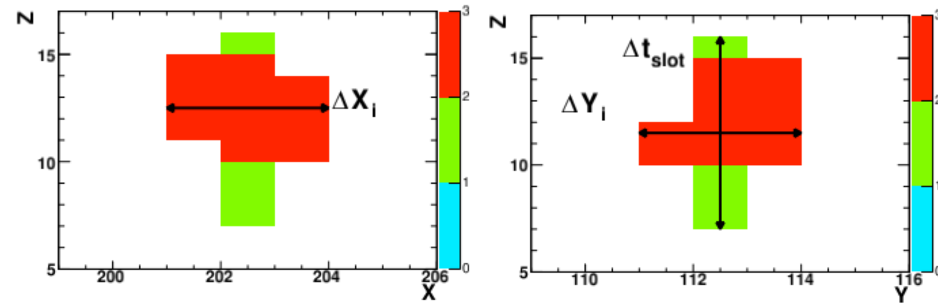


RPR events in the detector

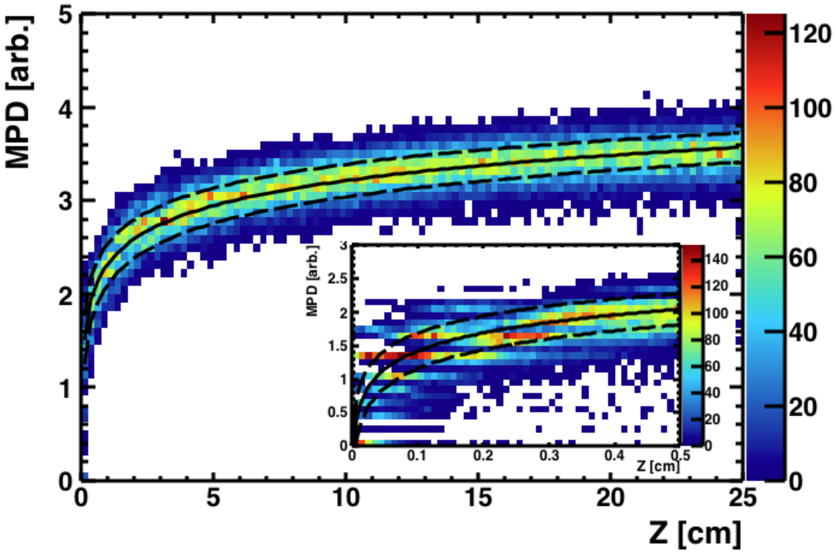
$$z_0 \longleftrightarrow \text{Diffusion}$$

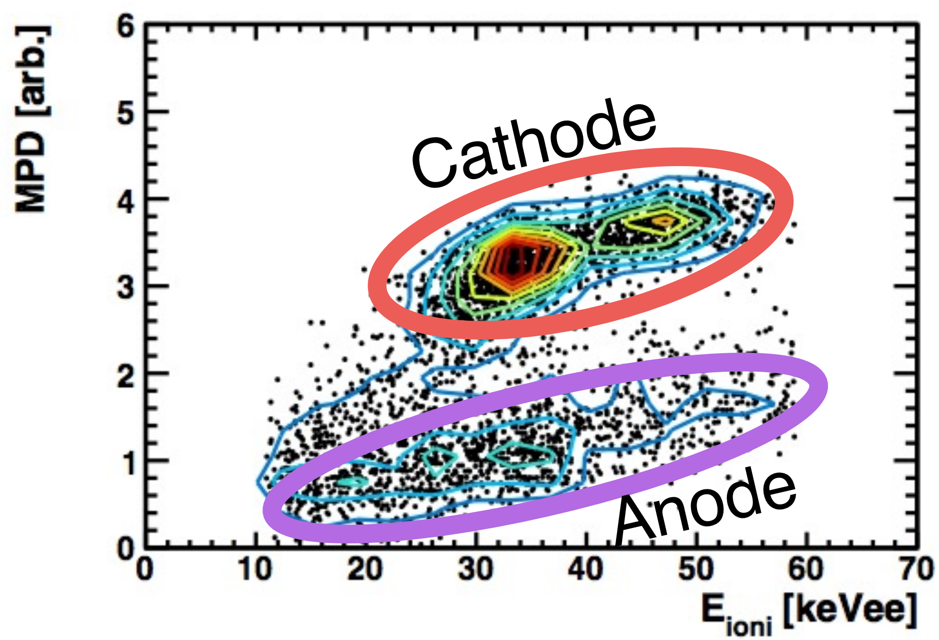
$$\begin{cases} D_T = 237.9\,\mu\text{m}/\sqrt{\text{cm}} \\ D_L = 271.5\,\mu\text{m}/\sqrt{\text{cm}} \end{cases}$$

« Grid » event



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

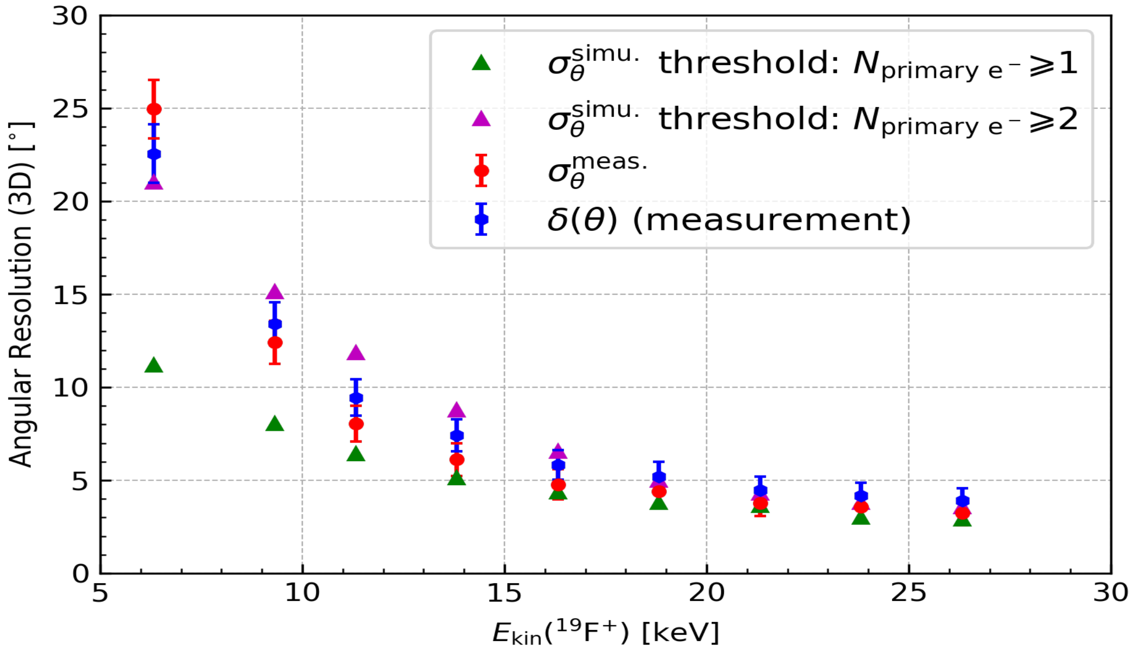




Directionality issues

Directionality at high gain

Measured and simulated angular resolution at 0° with F beam
Tao Yi et al. 2018



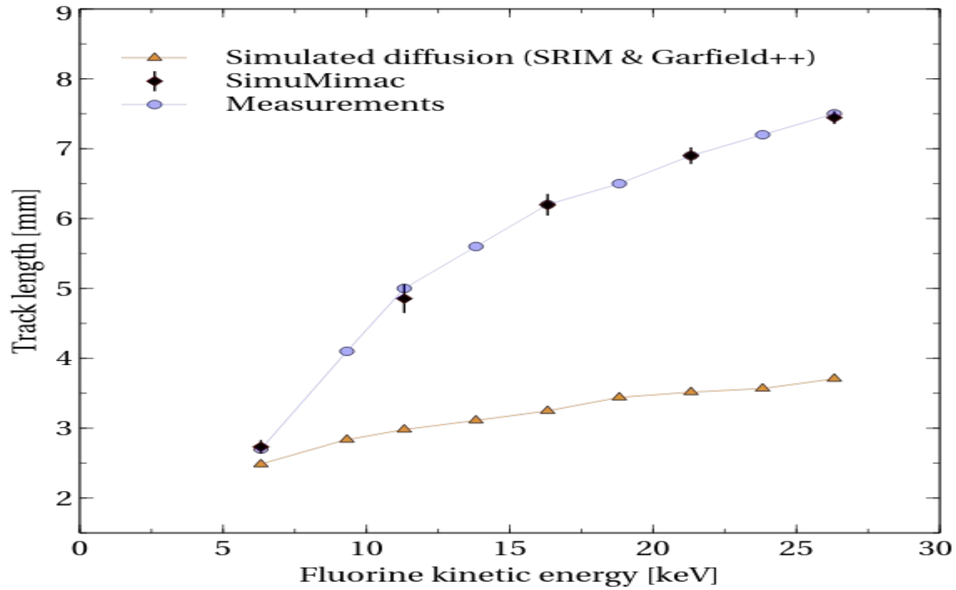
Measured angular resolution below 10° at E_{kin}>10 keV

⇒ **Twice better than requirements** for a directional detector (Billard *et al.*, 1110.6079)

Directionality at high gain

At high-gain, **measurements and simulations used to strongly disagree**

Measured and simulated fluorine track lengths.



C.Beaufort 2021, **SimuMimac** a simulation tool based on SRIM and Garfield++ to model the physics of the detector from the primary electron cloud to the signal formation

- SimuMimac agrees with the measurements
- Main difference with standard simulation code:

takes into account the current induced by the motion of the ions

Directionality at high gain

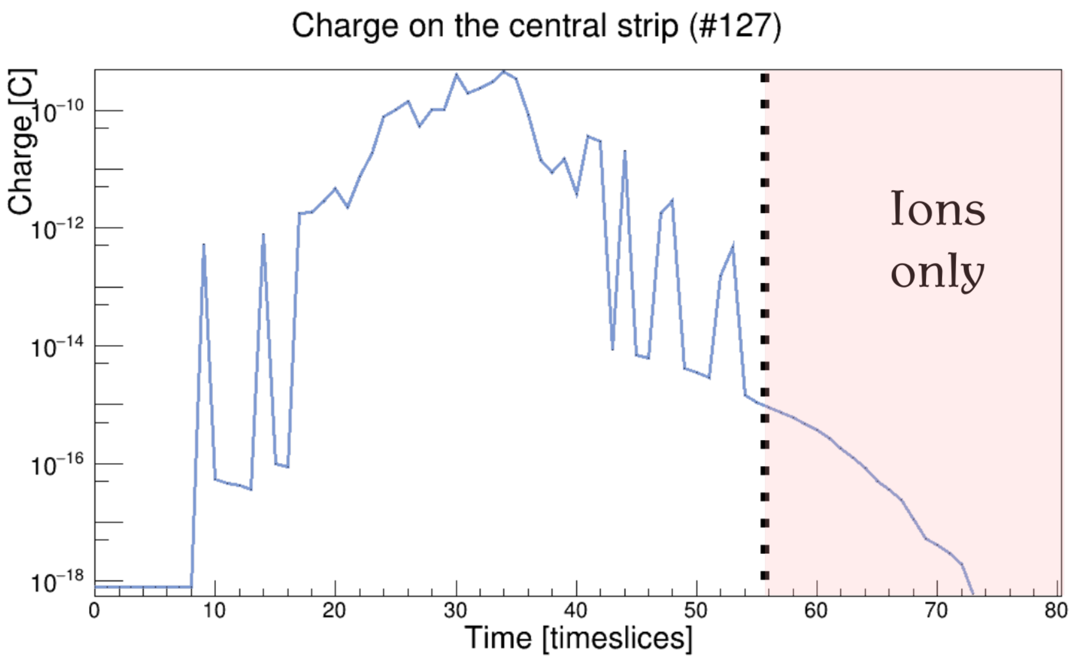
- Current induced by the charges (*Ramo-Shockley theorem*):

$$i(t) = \sum_{k=i,e} q_k \mathbf{E}_{w,k} \cdot \mathbf{v}_k \text{ with } \mathbf{v}_e \sim 10^3 \mathbf{v}_i$$

- Ions induce smaller currents than electrons but they remain longer in the gap

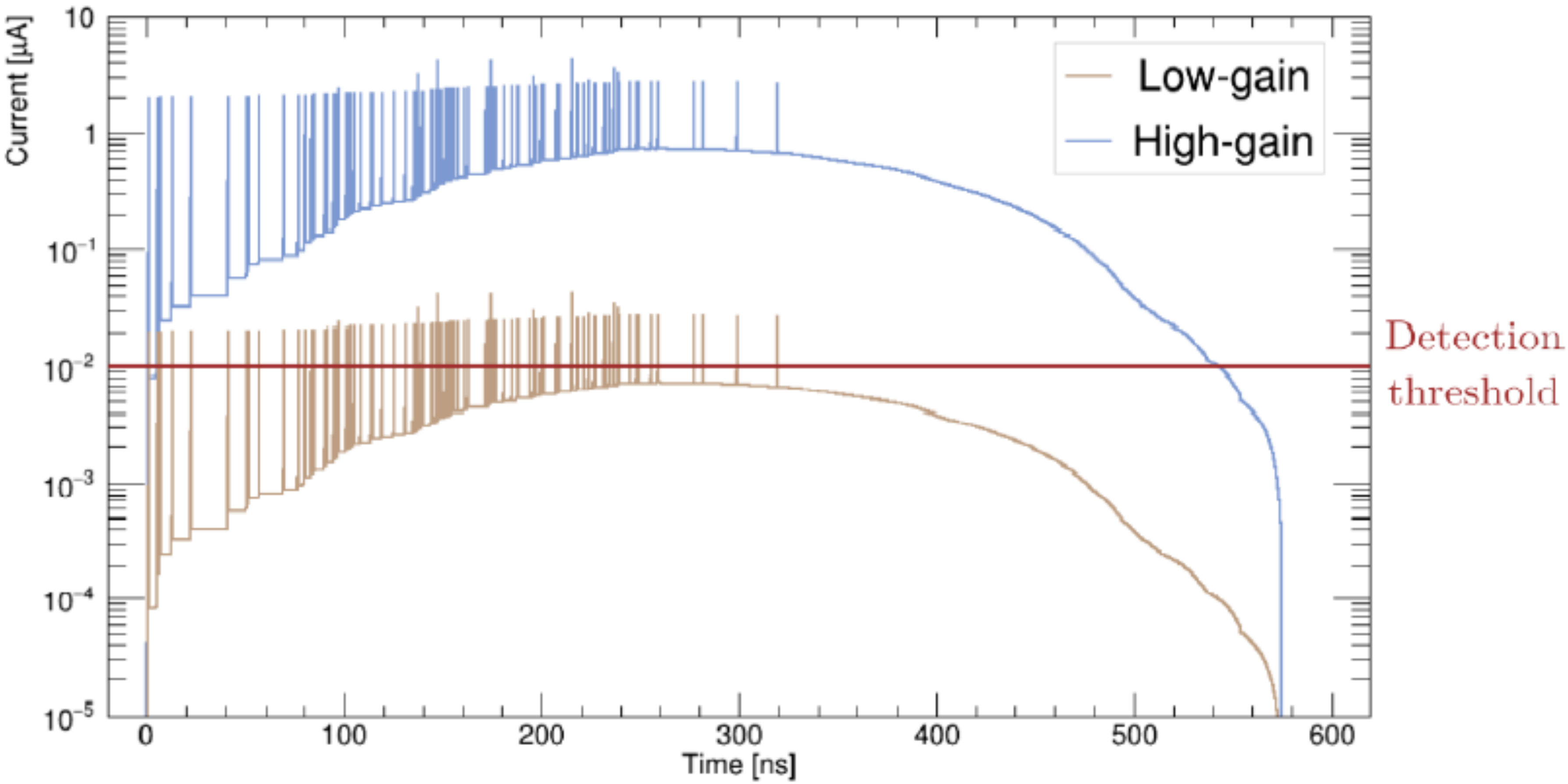
- At large gain, the ionic contribution
  - is non-negligible
  - **elongates the signal**

SimuMimac



Signal contributions at high-gain

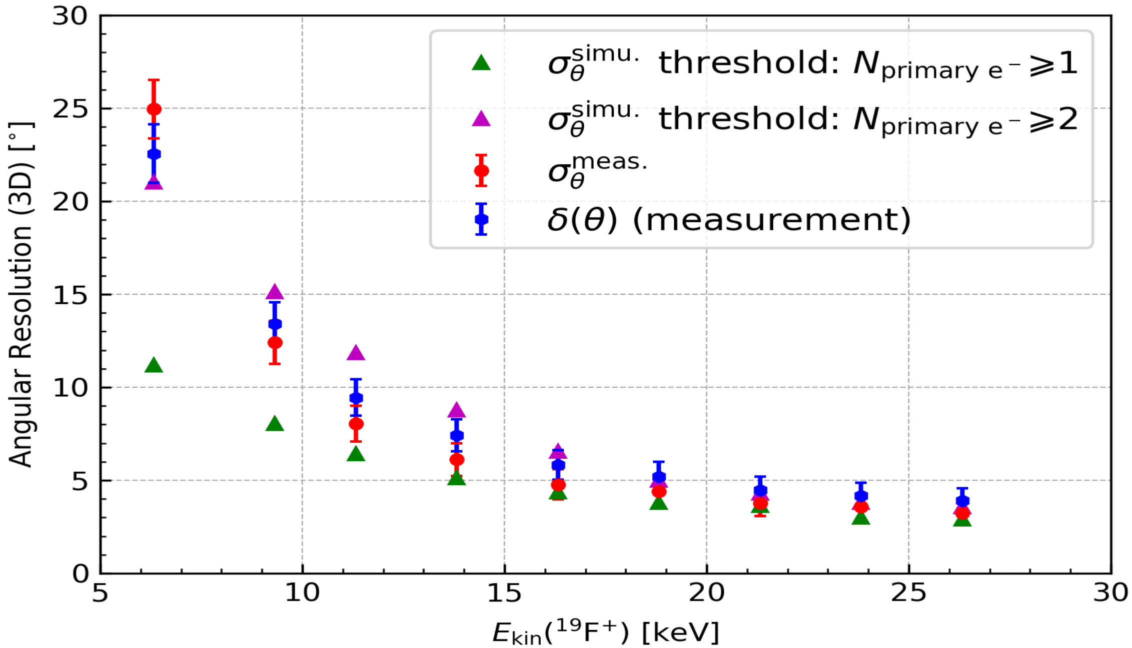
with primary electrons and secondary ions
Cyprien Beaufort et al., arxiv 2112.12469



Tracks longer, and higher detection efficiency!

Directionality at high gain

Measured and simulated angular resolution at 0° with F beam
Tao Yi et al. 2018



Measured angular resolution below 10° at E_{kin}>10 keV

⇒ **Twice better than requirements** for a directional detector (Billard *et al.*, 1110.6079)

0° was the beam test configuration,
the resolution must now be determined at any angle

Nuclear recoil calibration with neutrons

Neutron monochromatic field:

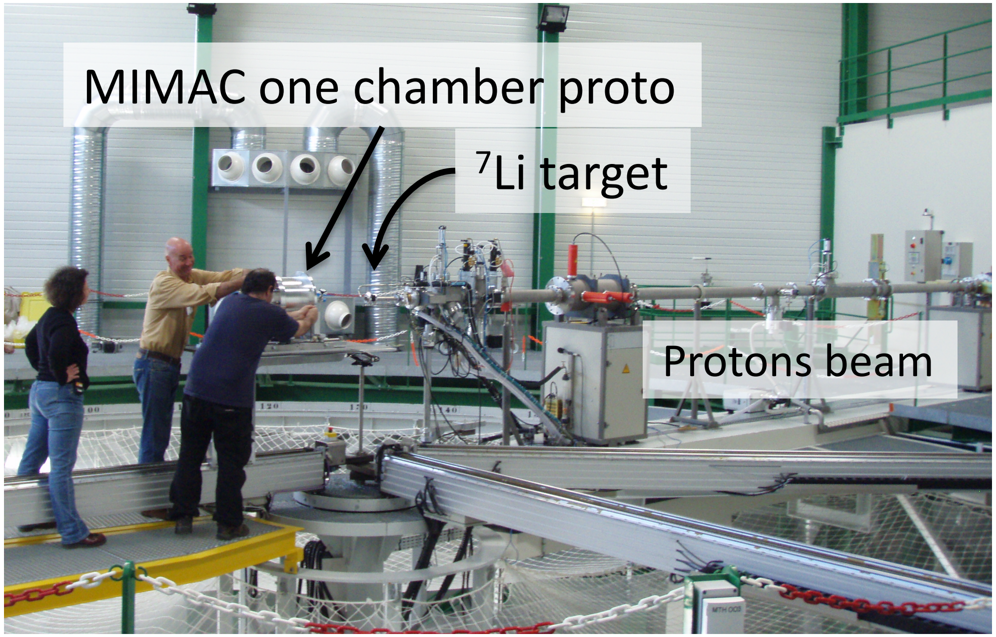
AMANDE facility at IRSN of Cadarache

- **Neutrons with a well defined energy from resonances of nuclear reaction**

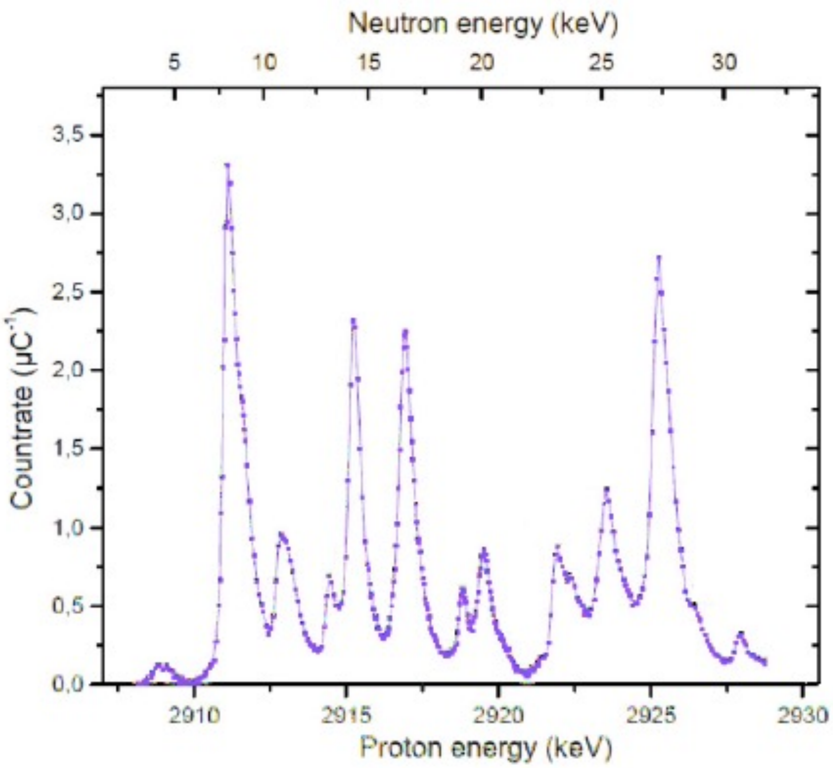
$$E_{\mathrm{Re}coil} = 4\frac{m_n m_R}{(m_n + m_R)^2} E_{neutron} \cos^2\theta$$

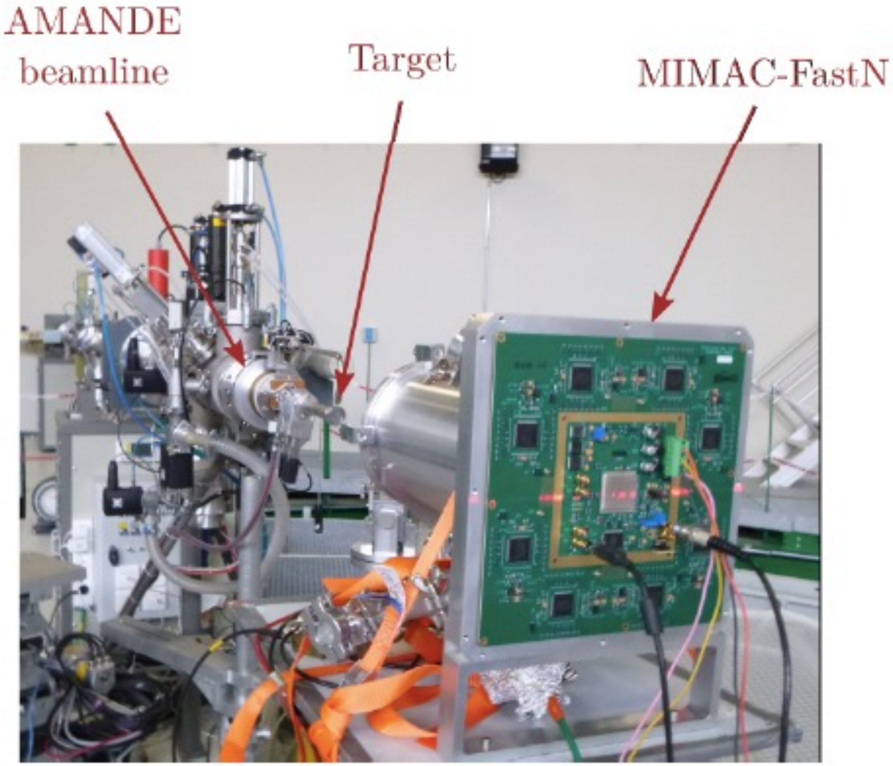
Electron Calibration:

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



Low energy (8 and 27 keV) mono-energetic neutron detection

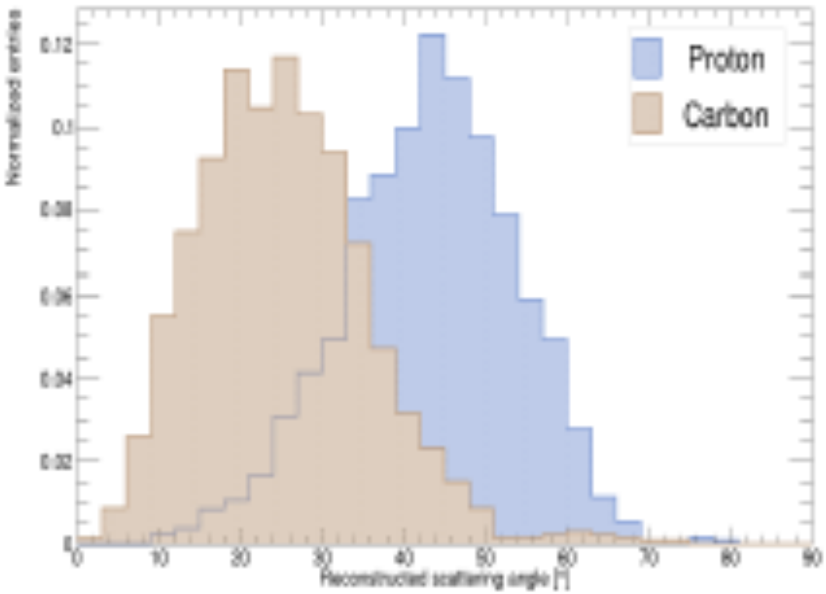




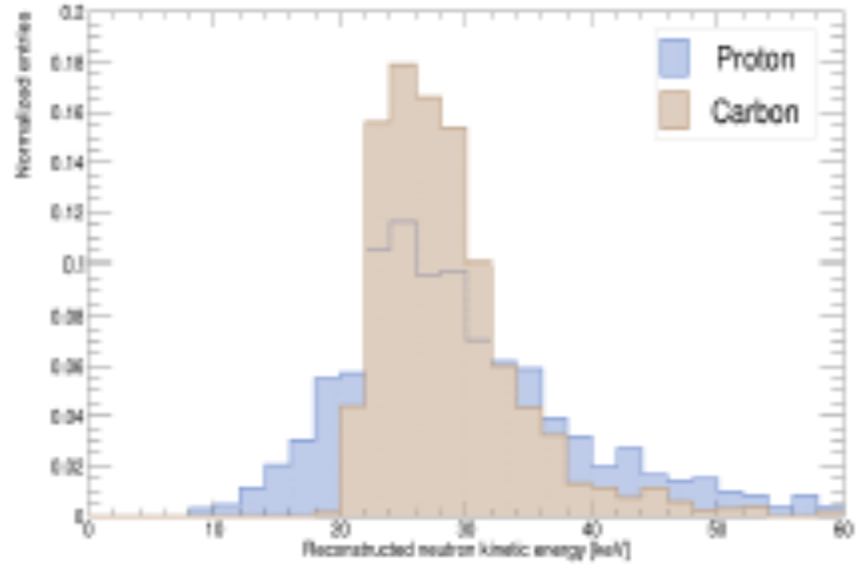
$^{45}Sc(p,n)$ neutron resonances

27 keV neutron field
Proton and carbon recoils give the neutron spectra

C. Beaufort et al. (2023, arXiv:2312.12842)



Reconstructed angle

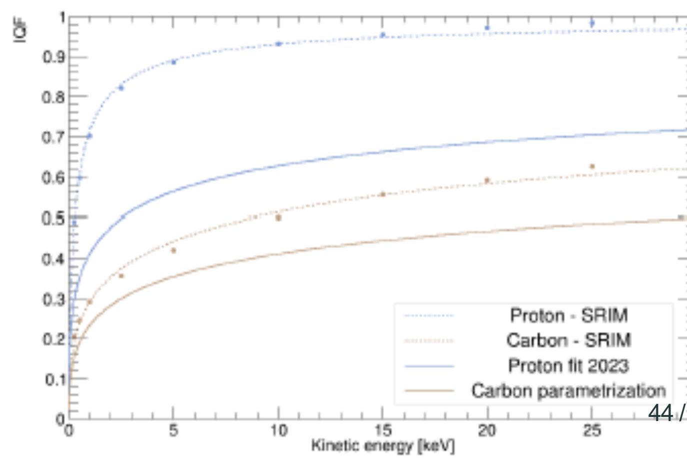


Reconstructed energy

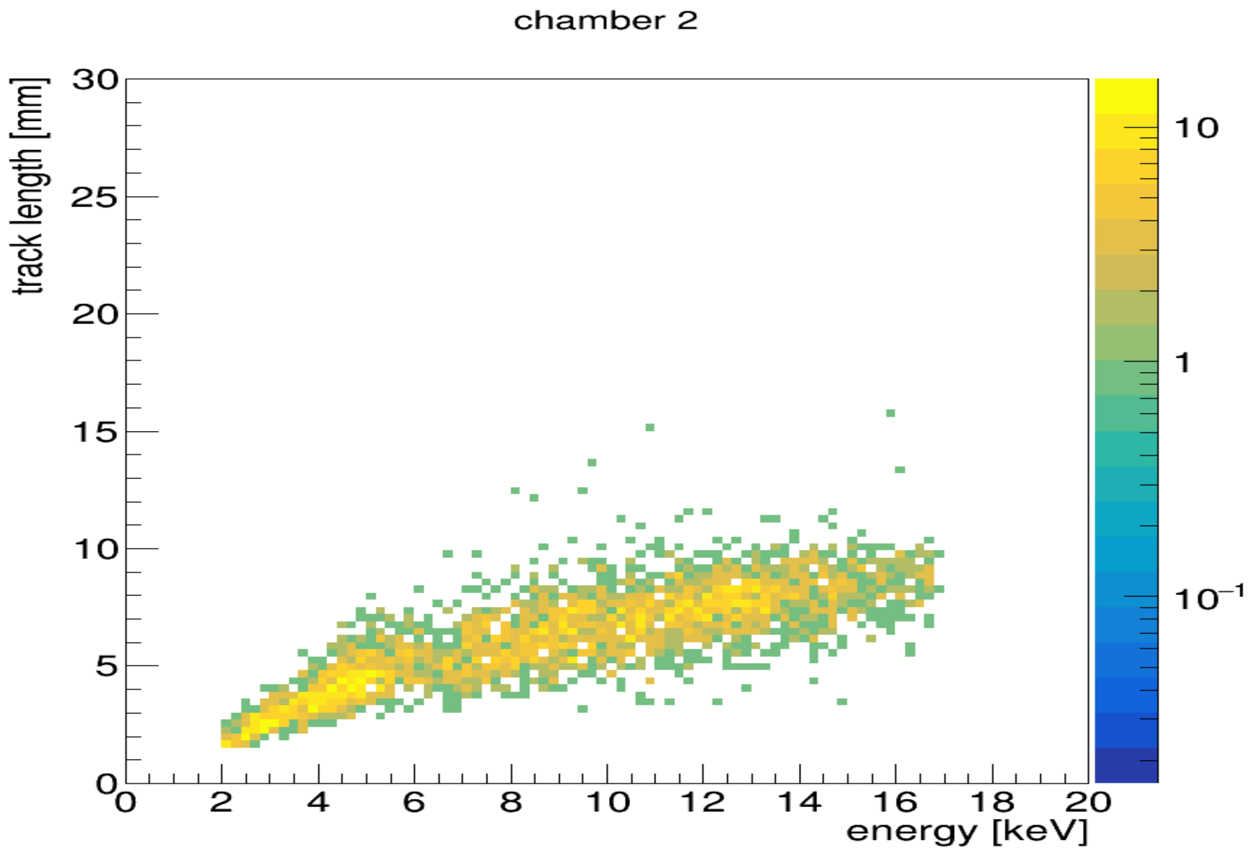
The kinetic energy and angles are reconstructed with :

- the Ionization quenching factor measured by COMIMAC

- understanding the ion contribution to the signal

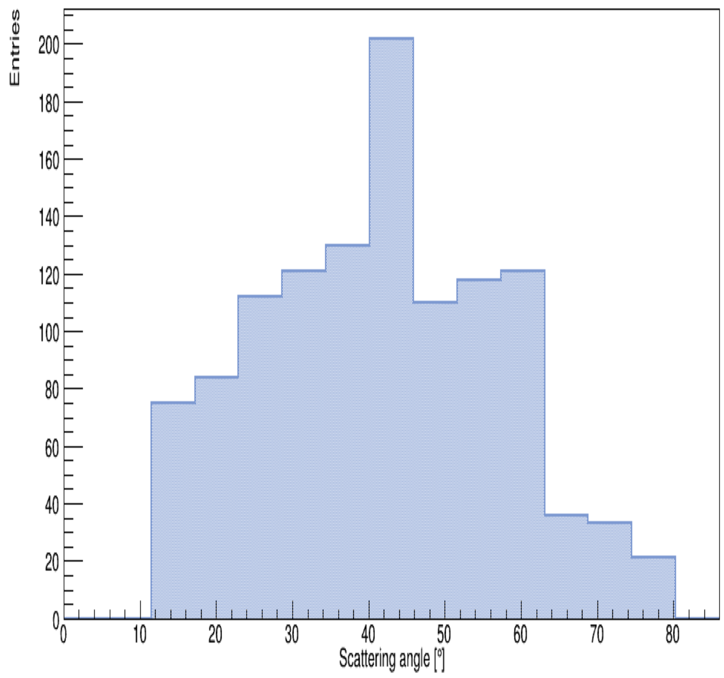


Mono energetic neutron field of 27 keV : reconstructed proton track length vs ionization energy

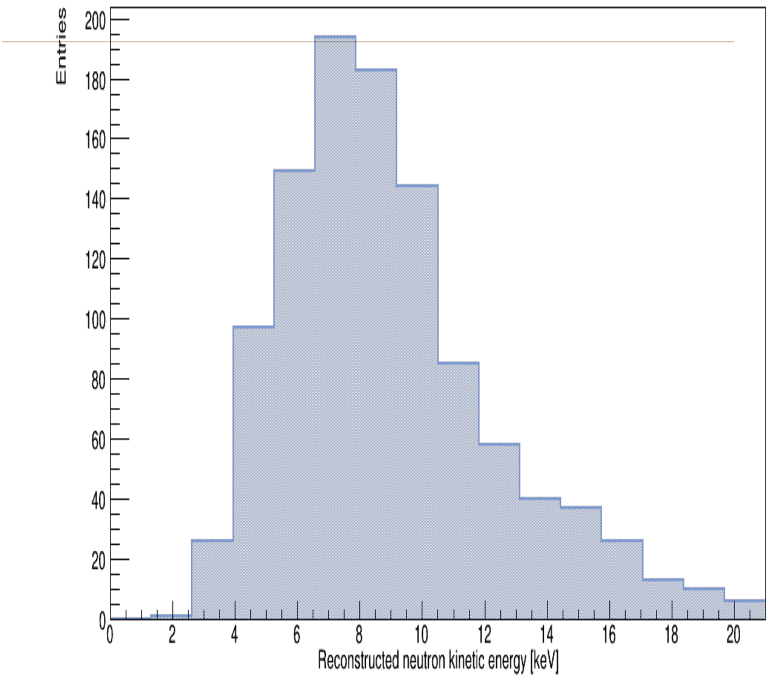


H^+ recoils very useful for low mass WIMP search

Mono-energetic neutron field of 8 keV reconstruction with proton recoils



Angular distribution



Energy spectrum

Directional performances at 8 keV:

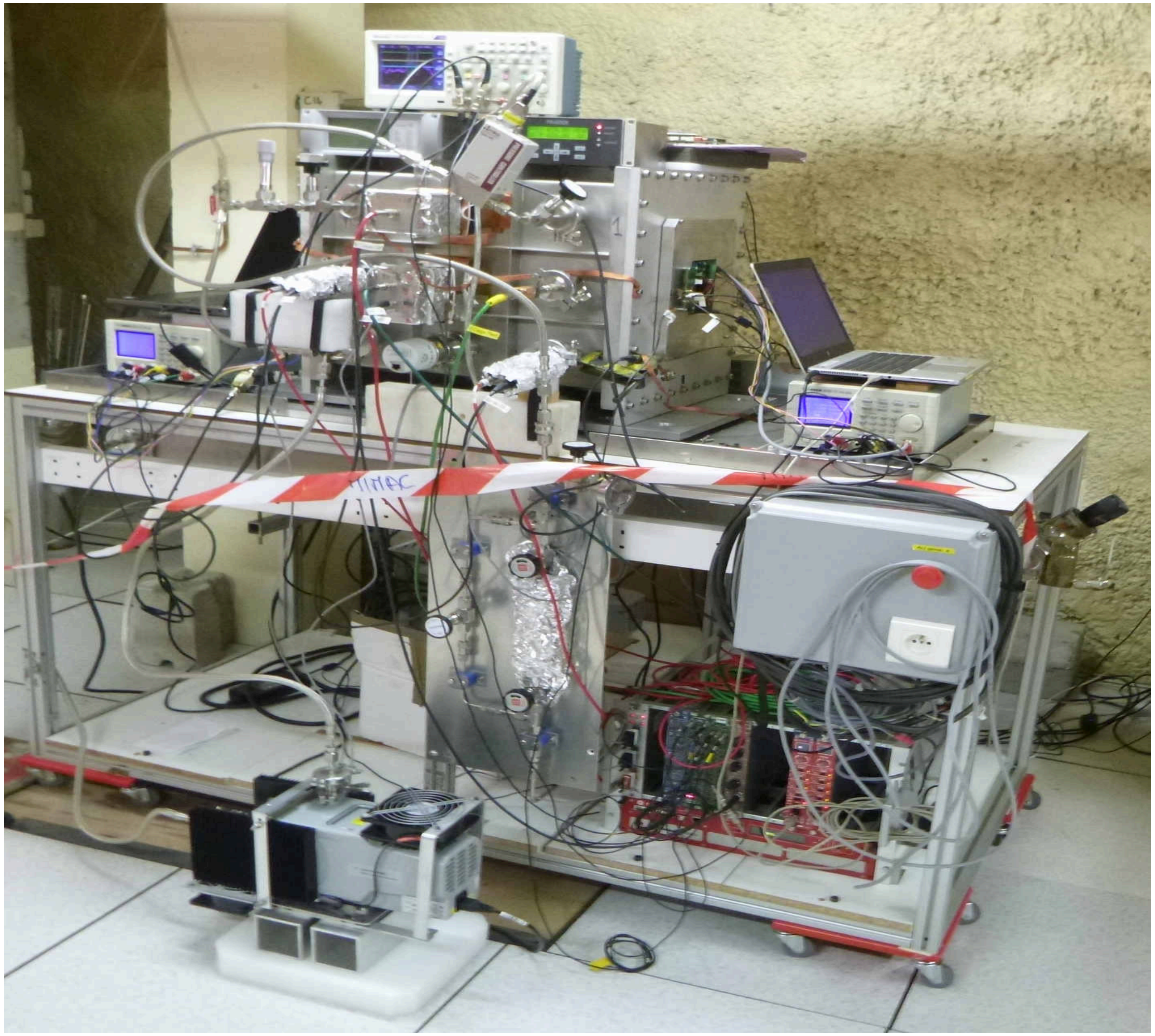
- Energy reconstructed agrees within 4.0%
- Angular resolution better than 15°

Cyprien Beaufort et al., JCAP08(2022)057

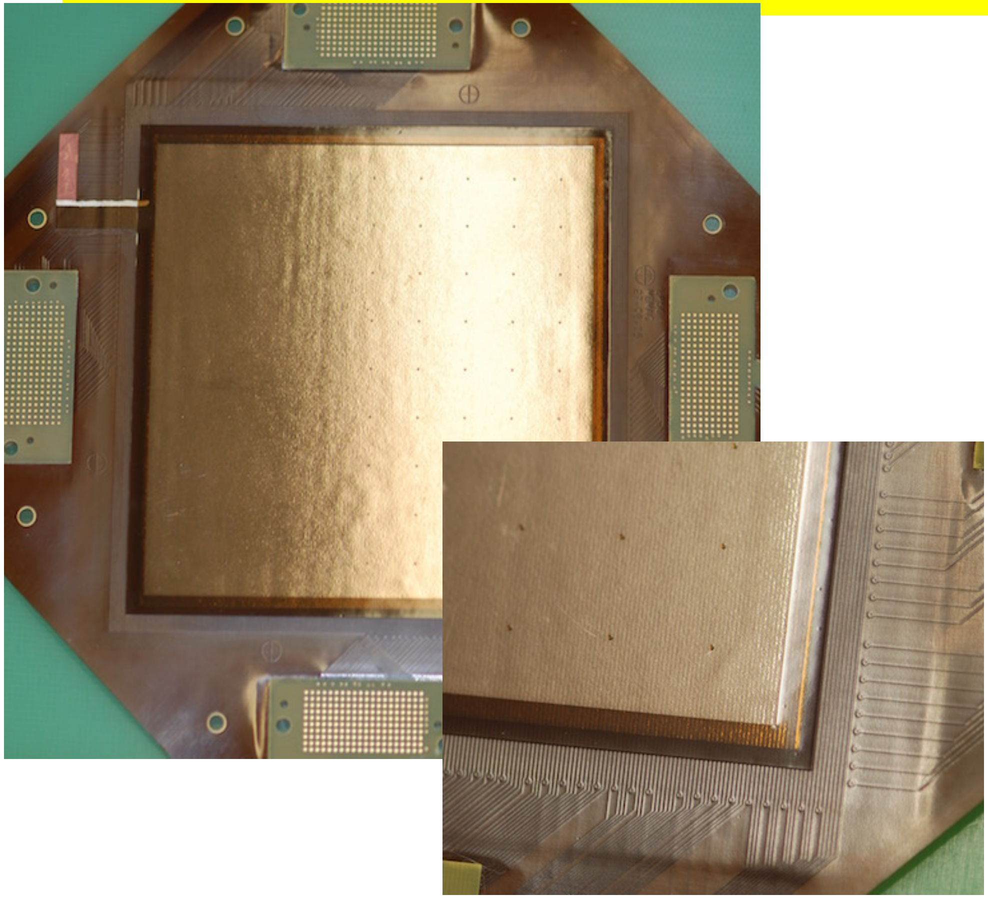
MIMAC at LSM

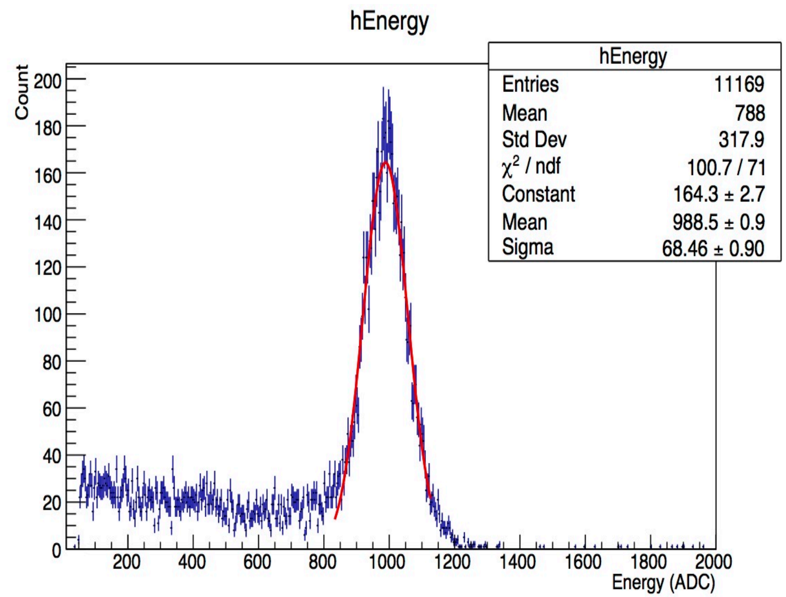
Bi-chamber-512 module
(with the Cathode Signal and the new low background 10 cm detectors)
Installed in February 2023

- 30 mbar (C_4H_{10}+50% CHF_3)
-Permanent circulating mode
-Remote controlled
- Periodic calibration with an X-ray generator



New MIMAC low background detector



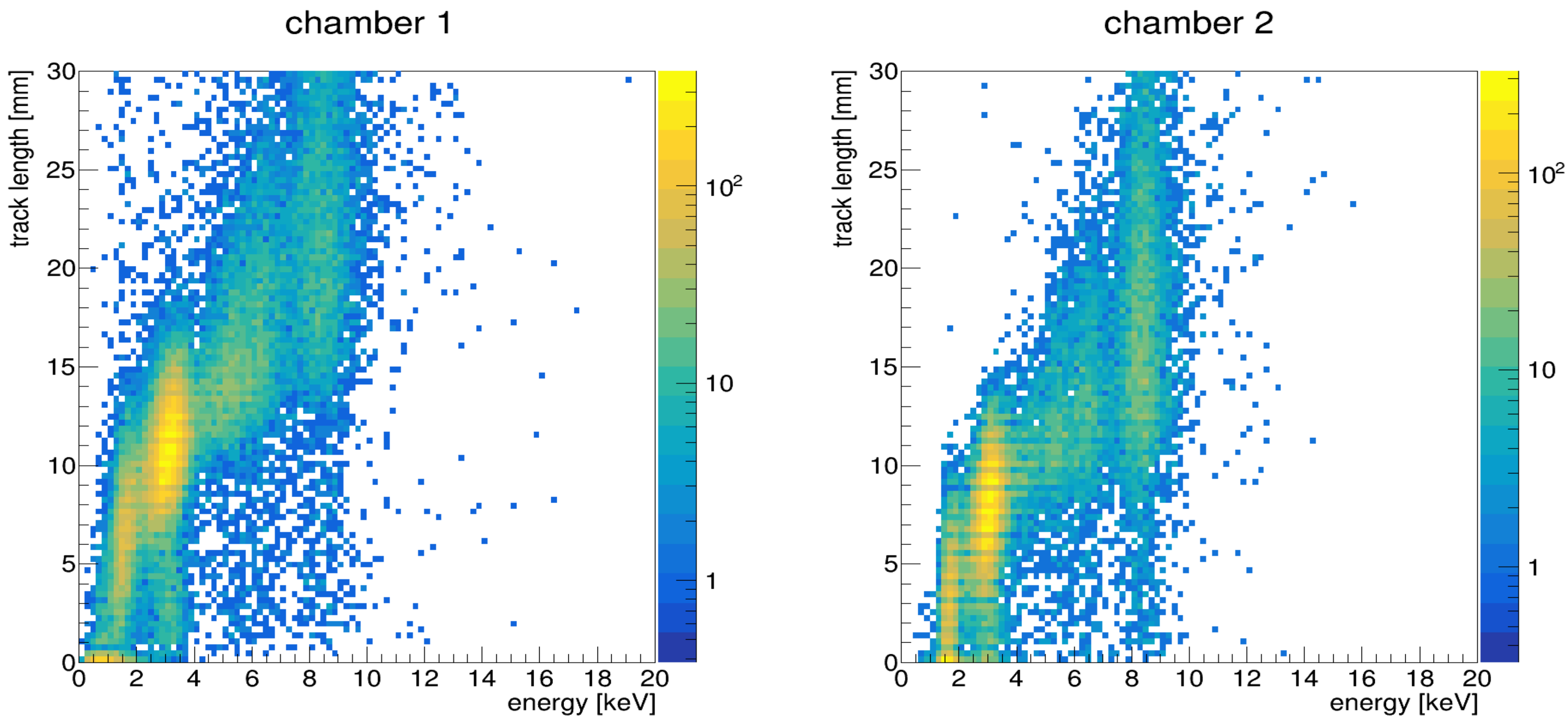


Kapton micromegas readout
Piralux Pilar

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

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

X-rays: Electron track length vs energy

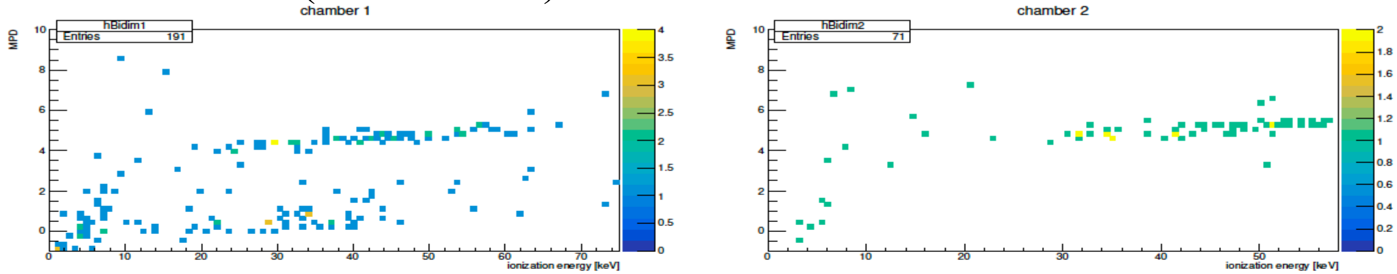


Understanding electron tracks are very useful for electron vs. nuclear recoil discrimination

Bi-chamber in Modane LSM

First run of February 2023 with 127 h analysed at moderate gain (470 V)

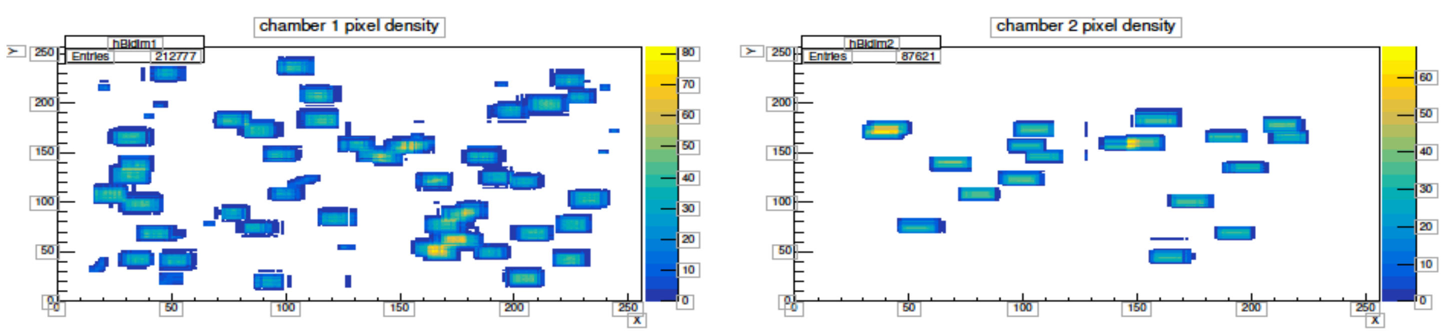
Chamber 1(old detector) Chamber 2 (new detector)



(a) In chamber 1. **(b)** In chamber 2.

Figure 7.16.: MPD as a function of the energy in the background selection using the BDT at Modane, from runs with a gain covering an energy range of up to 70 keV.

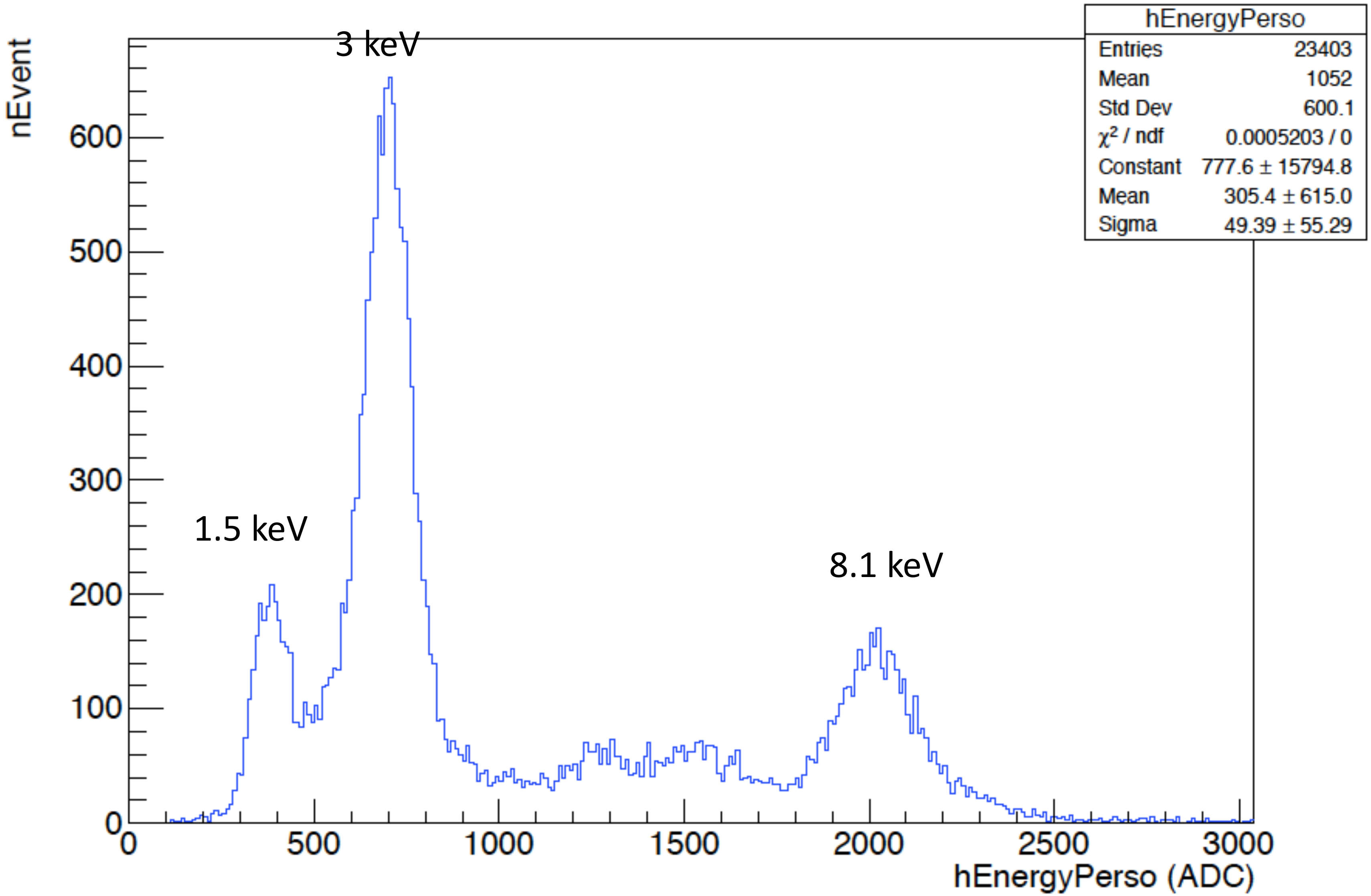
X-Y projections of the 3D tracks



(a) In chamber 1. **(b)** In chamber 2.

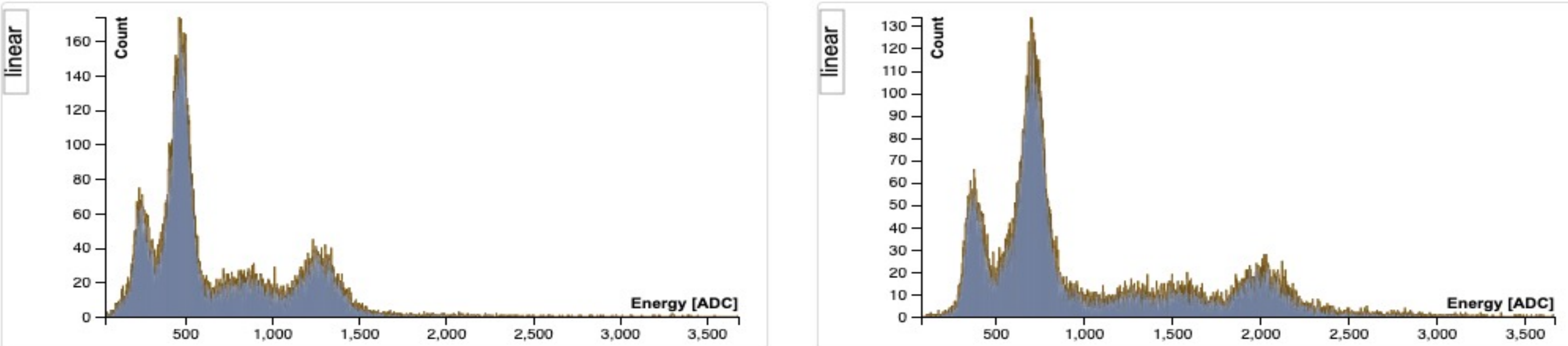
- Only recoils after the BDT, mainly from the Rn progeny.
- Improvement of the new detector showing very few Rn progeny contributions

X-ray Calibration of the new detector Bi-chamber Module

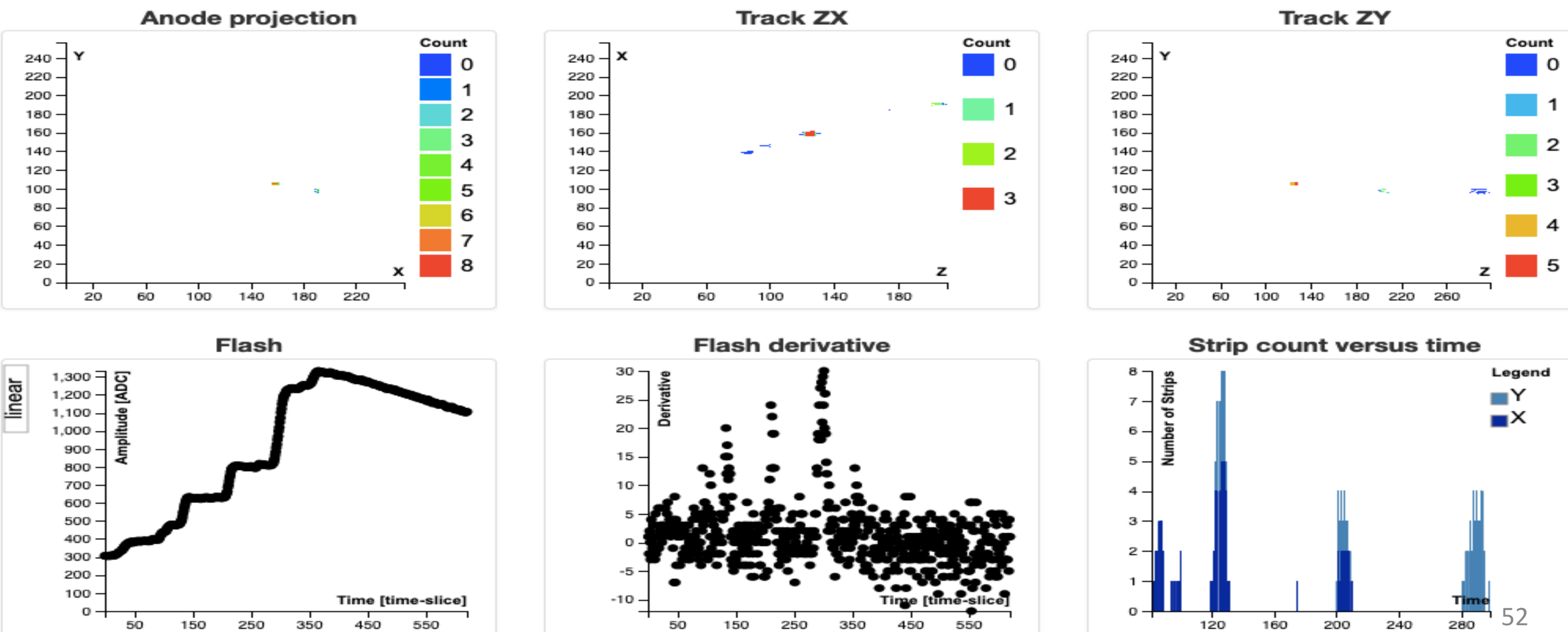


500 V, 3000V drift

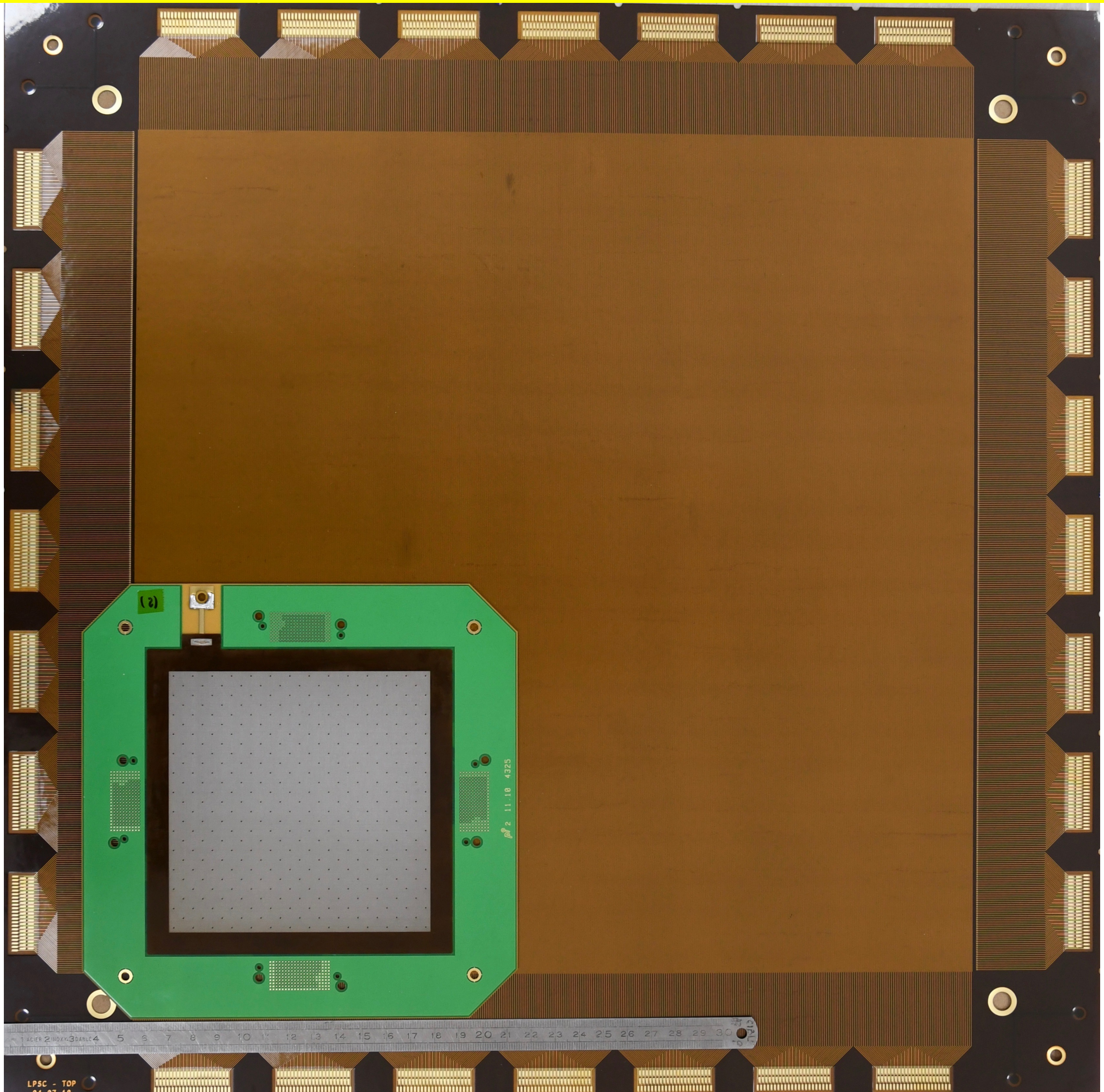
X-ray calibration of both chambers simultaneously

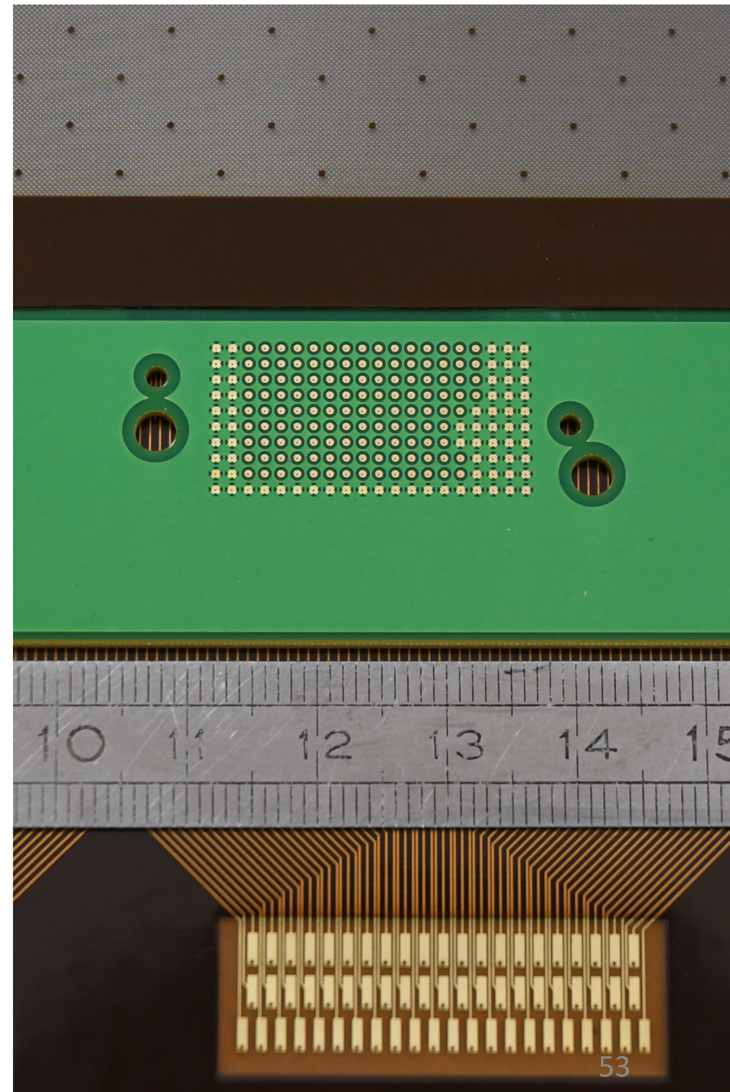


A typical electron event in chamber 2

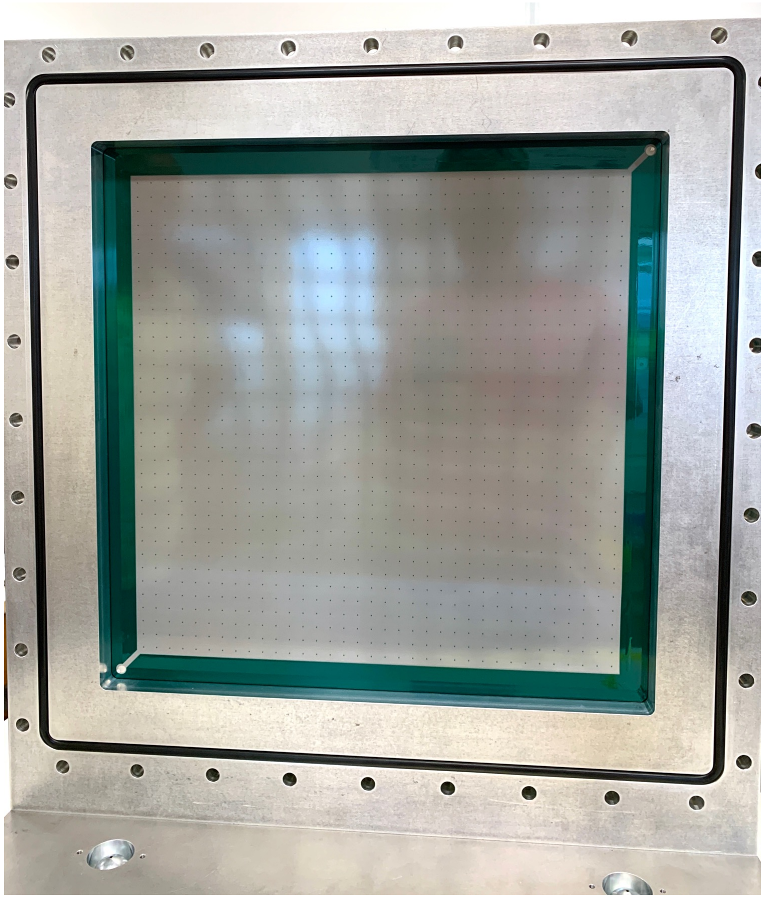


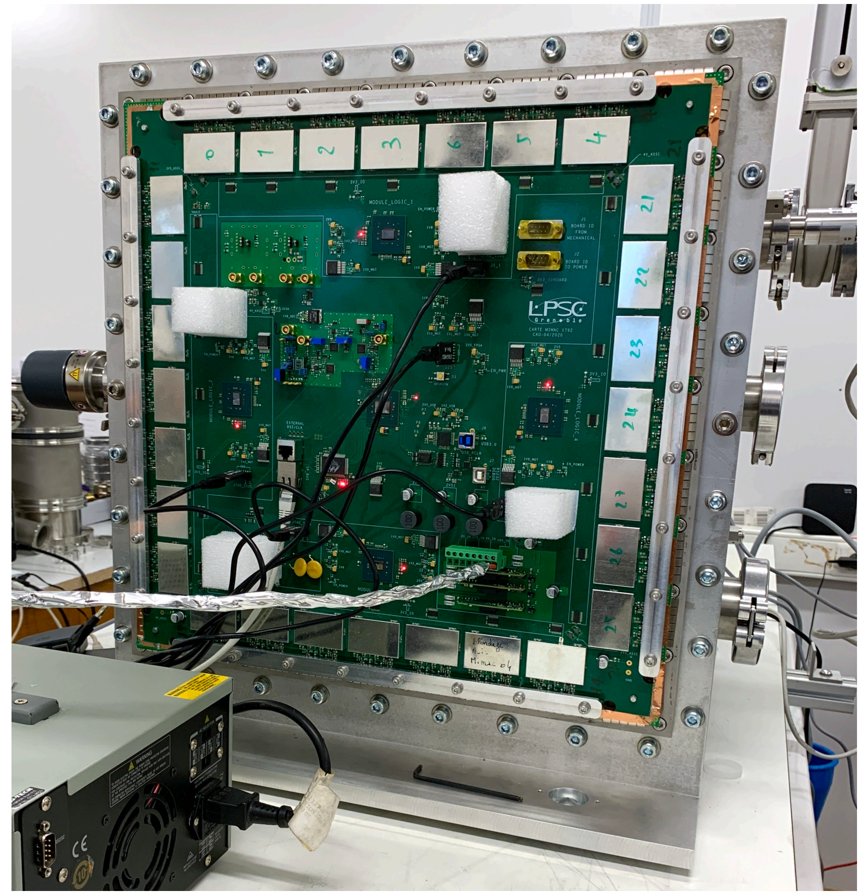
35 cm MIMAC detector compared to the old 10 cm





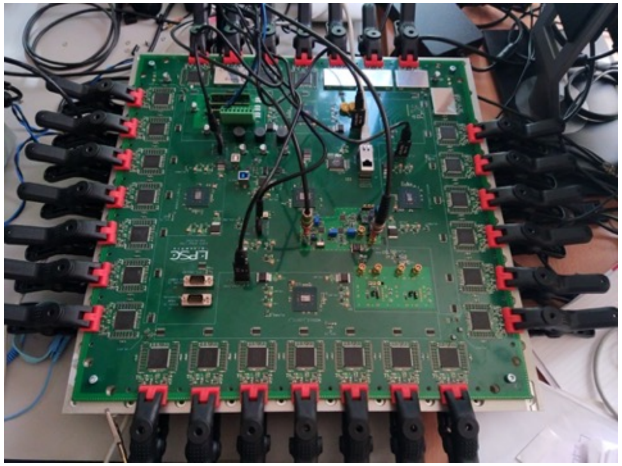
35x35 cm (PCB) in the bi-chamber at LPSC-Grenoble



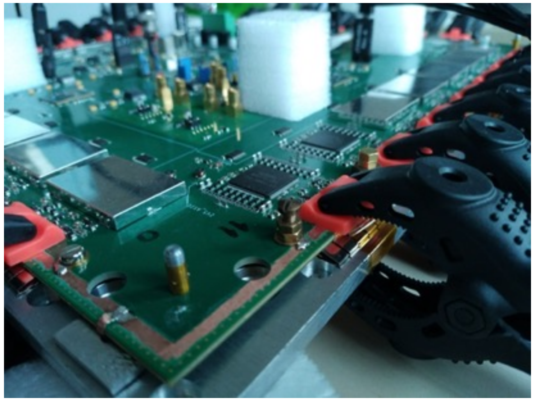


TRAVAUX RÉALISÉS

Fonctionnement de la carte électronique sur table seule	✓
Couplage de la carte électronique avec le détecteur 35 x 35 cm, sur table	✓

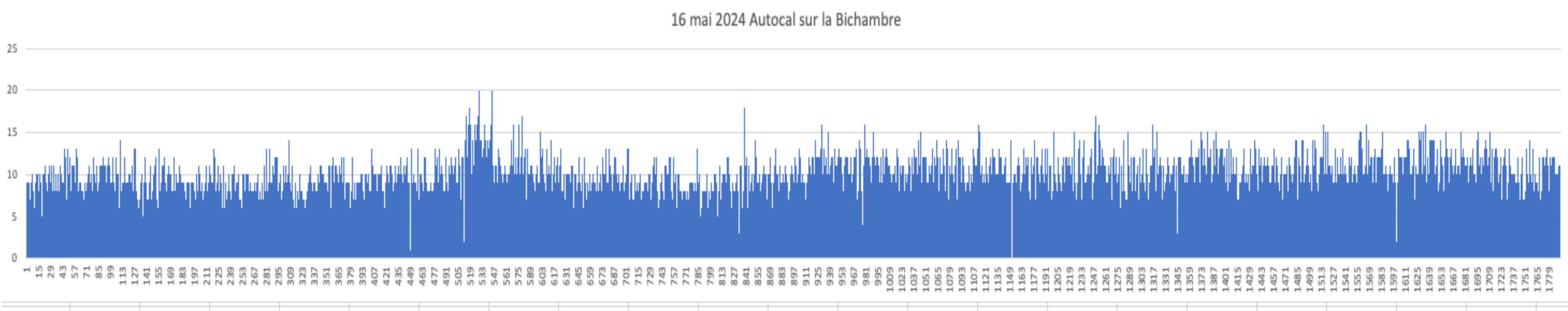


- Synchronisation des ASIC et des FPGA,
- Programmation des FPGA,
- Soft de reconstruction des pistes (nouveau routage carte+détecteur),
- Adaptation soft d’acquisition pour tests, et intégration protocole Ethernet,
- Résolution de problématiques CEM (blindages, conductivité entre les masses,…)
- Caractérisation du bruit électronique intrinsèque,
- Tests de déclenchement sur événement simulé.



AUTOCALIBRATION OF THE 1792 (896 + 896) CHANNELS

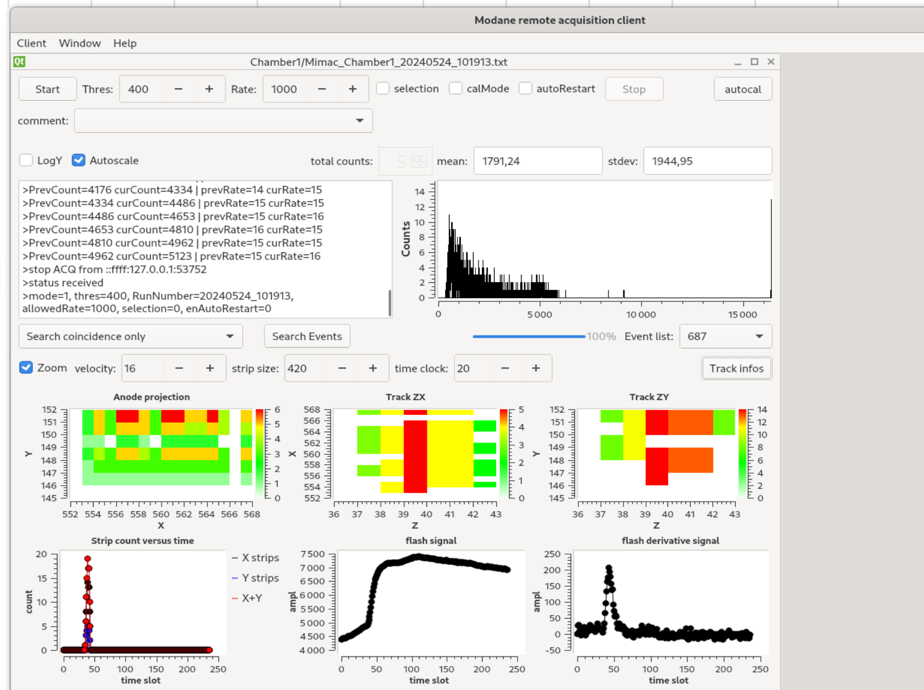
1792 threshold values from the autocalibration defined by the intrinsic electronic noise on each strip.



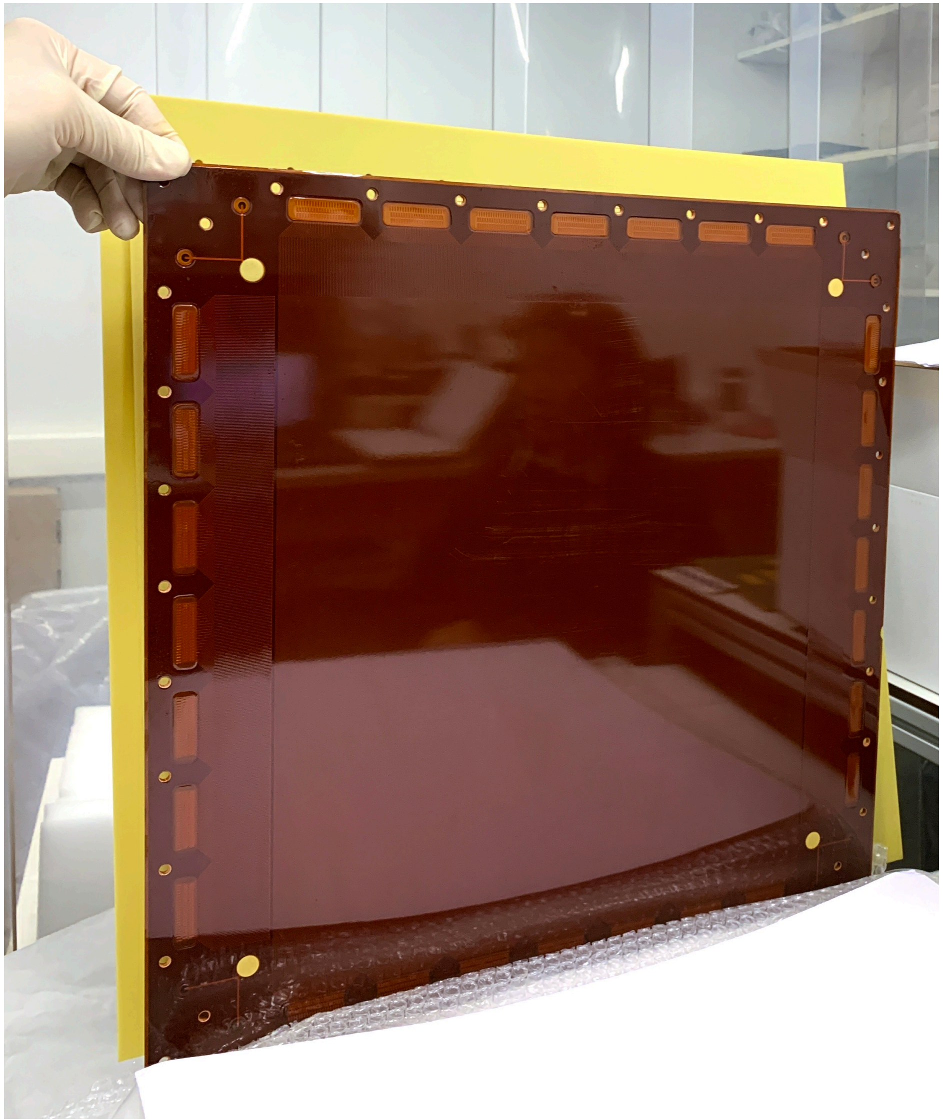
C_4H_{10} (30 mbar)

The first events with 3D tracks, of the background at LPSC Grenoble (May 24th 2024)

Still many things to improve, but it works !!



New Micromegas (35cm) on Kapton/Copper made by Chinese USTC (Hefei)



Received on May 28th May 2024 in LPSC-Grenoble

New MIMAC Bi-chamber 35x35x25 cm^3

- Installation at Modane November 2024 with the PCB version (1 chamber) and with the same gas system as the 10 cm Bi-chamber module

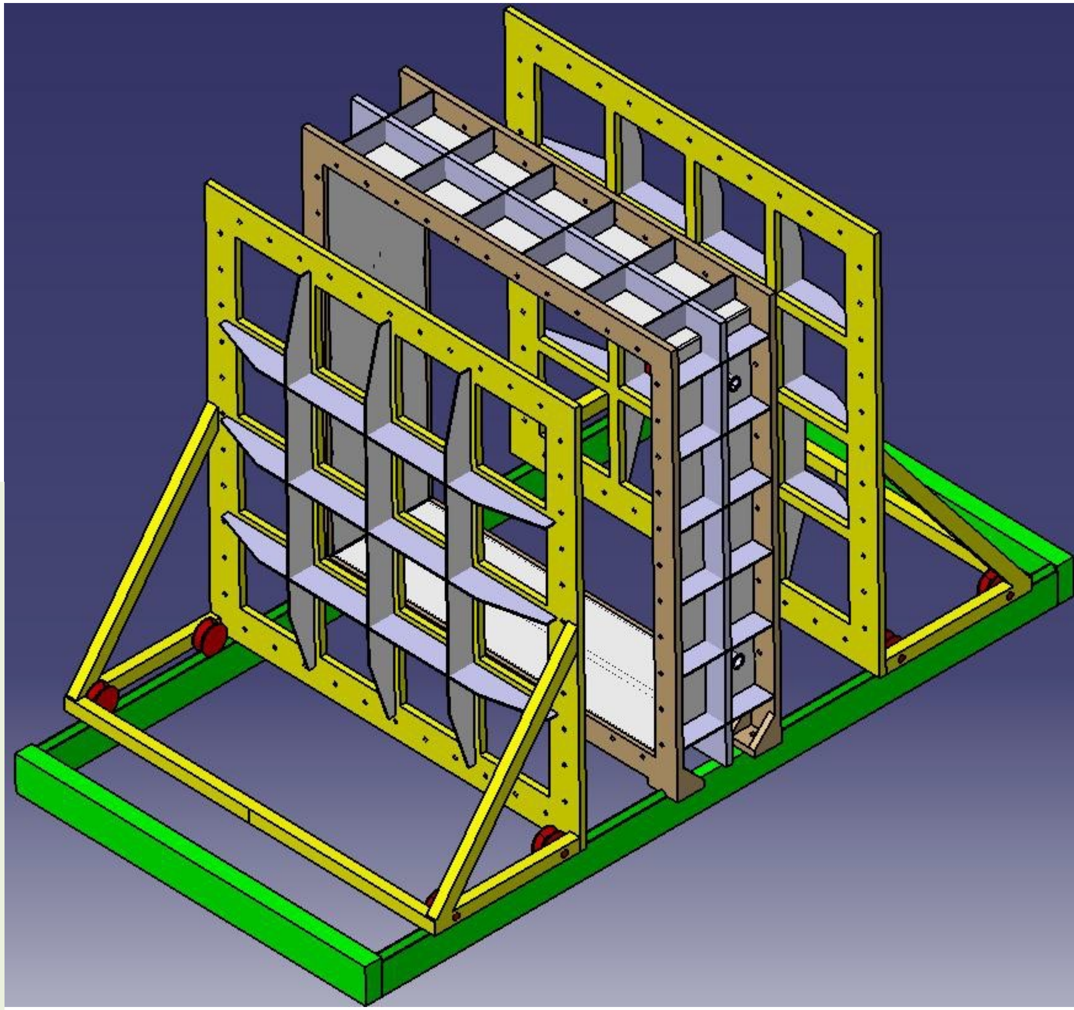
- Run background without lead shielding

- Installation at Modane with the new low background (Kapton/Copper) micromegas in September 2025

The future… MIMAC – 1m^3

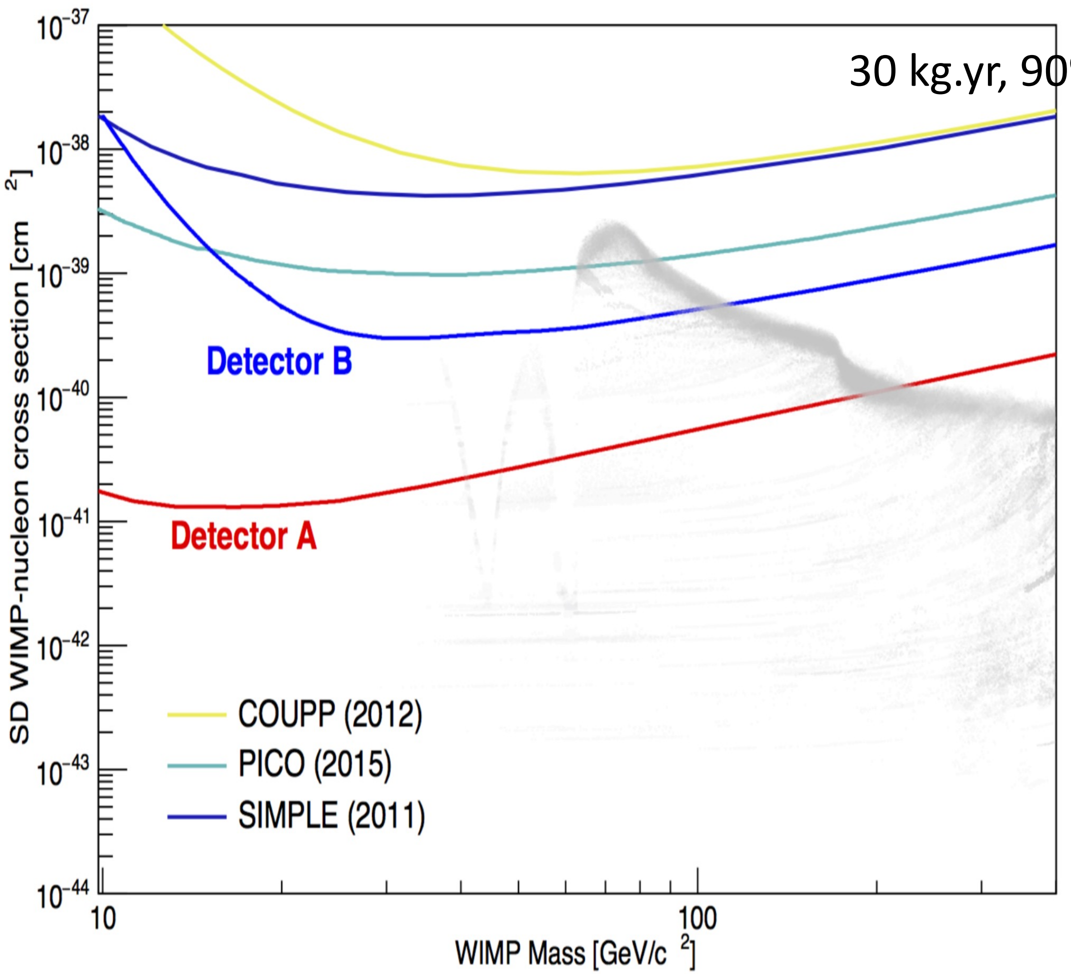
16 bi-chamber modules (2x 35x35x25 cm^3)

- New technology anode 35cmx35cm
- New electronic board (1792 channels)
- Only one big chamber with 4 field cages inside



- First 1 m^3 at Modane by the end of 2027 Pending complementary funding of 200k€
- Second 1 m^3 at Jinping by the end of 2028 financed by the Chinese partners

MIMAC- SD Exclusion limits



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

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

SD still potential for discovery!!

Dark matter results from NEWS-G at the LSM with a methane target

(NEWS-G Collaboration)

(Dated: March 12, 2024)

The NEWS-G direct detection experiment uses Spherical Proportional Counters (SPCs) to search for low mass WIMP-like dark matter. New results are reported using a new 135 cm-diameter SPC, from a 10 day physics campaign carried out at the Laboratoire Souterrain de Modane (LSM). 114 g of methane gas were used, providing sensitivity to low-mass dark matter, particularly for a spin-dependent coupling with protons. Leading constraints are presented for this coupling in the WIMP mass range 0.17 to 1.2 GeV/c^2, with an excluded cross section of 30.9 pb for a WIMP mass of 0.76 GeV/c^2. These results show promise for the upcoming operation of this detector at SNOLAB.

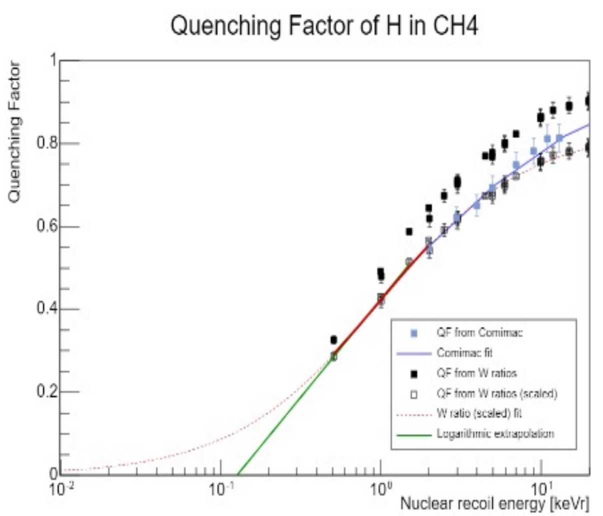


FIG. 1. QF used in this work. From highest to lowest energies, we use the COMIMAC measurement (lavender line [34]), scaled W-value ratios (red line [35]), and a logarithmic extrapolation (green line); the Lindhard-like extrapolation is shown for comparison (dotted red).

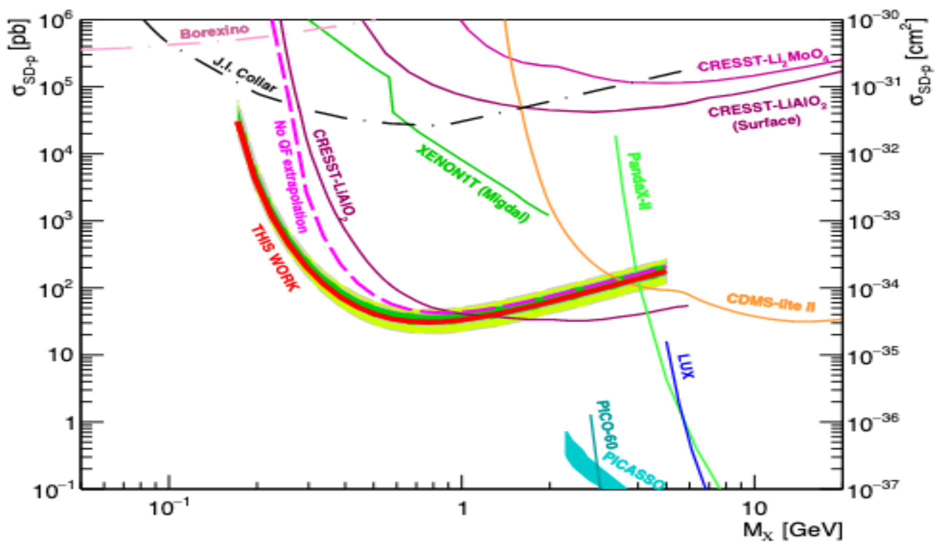
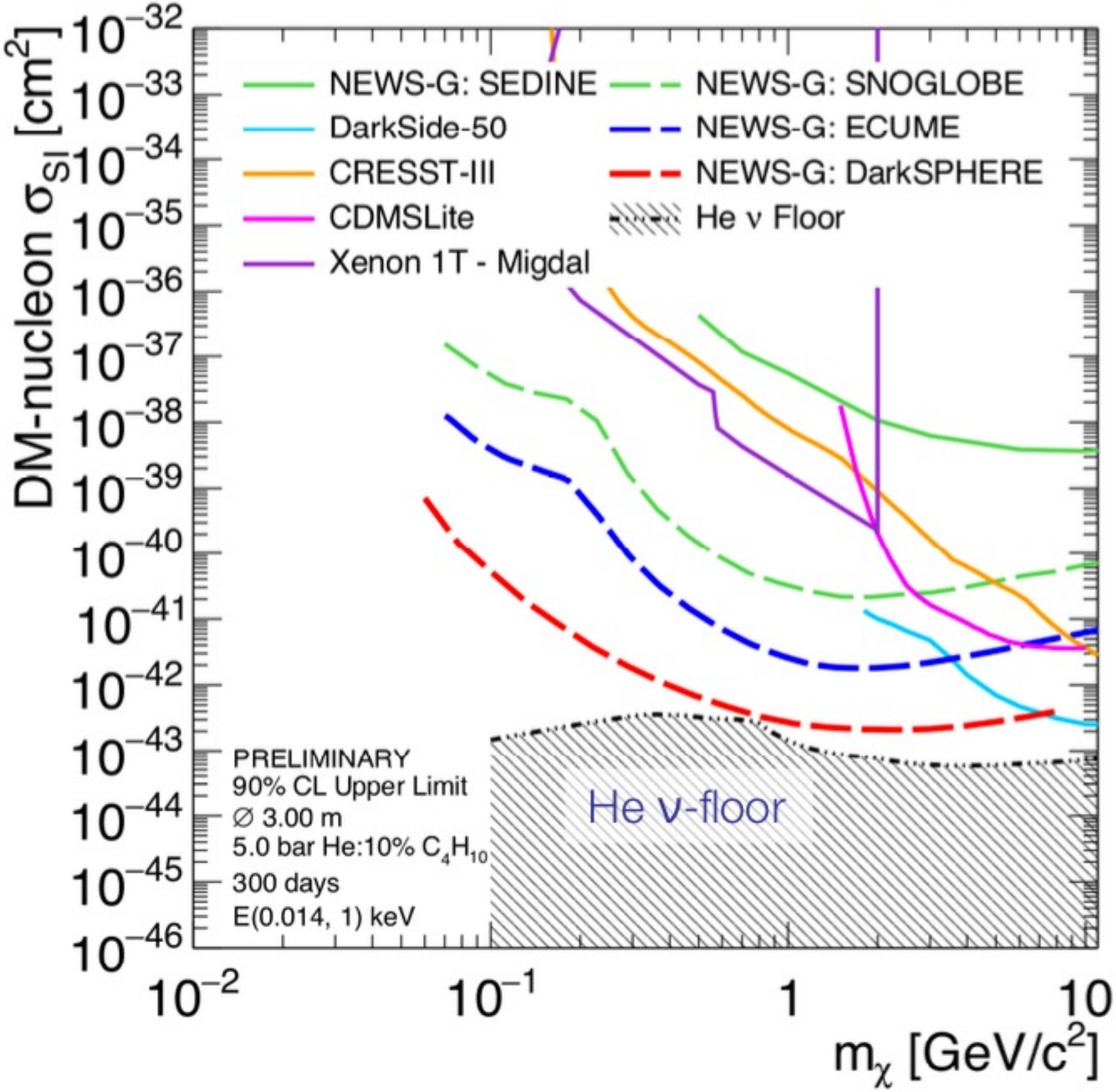


FIG. 3. Exclusion limit on the WIMP–proton spin-dependent cross-section from this work (thick red line) and 1 and 2σ sensitivity bands (dark and light green shaded areas respectively). The equivalent limit with no quenching factor extrapolation is shown for reference (dashed pink line). Upper limits from CDMS-lite [46], CRESST-III [47–49], LUX [50], PANDAX-II [51], XENON-1T (Migdal) [52], PICASSO [53], PICO-60 [54], J.I. Collar [55] and Borexino [56] are also shown.

NEWS-G will produce increasingly radio-pure, scaled-up detectors over the next 5+ years



General assumptions:
F= 0.2, θ = 0.12,
SRIM quenching factor,
ROI: 14 eV_{ee} - 1 keV_{ee}

NEWS-G SNOLAB:
Ne + 10% CH_4, 1 bar (1.04 kg)
Background: 1.78 dru
Exposure: 20 kg.days
Optimum Interval Method [13]

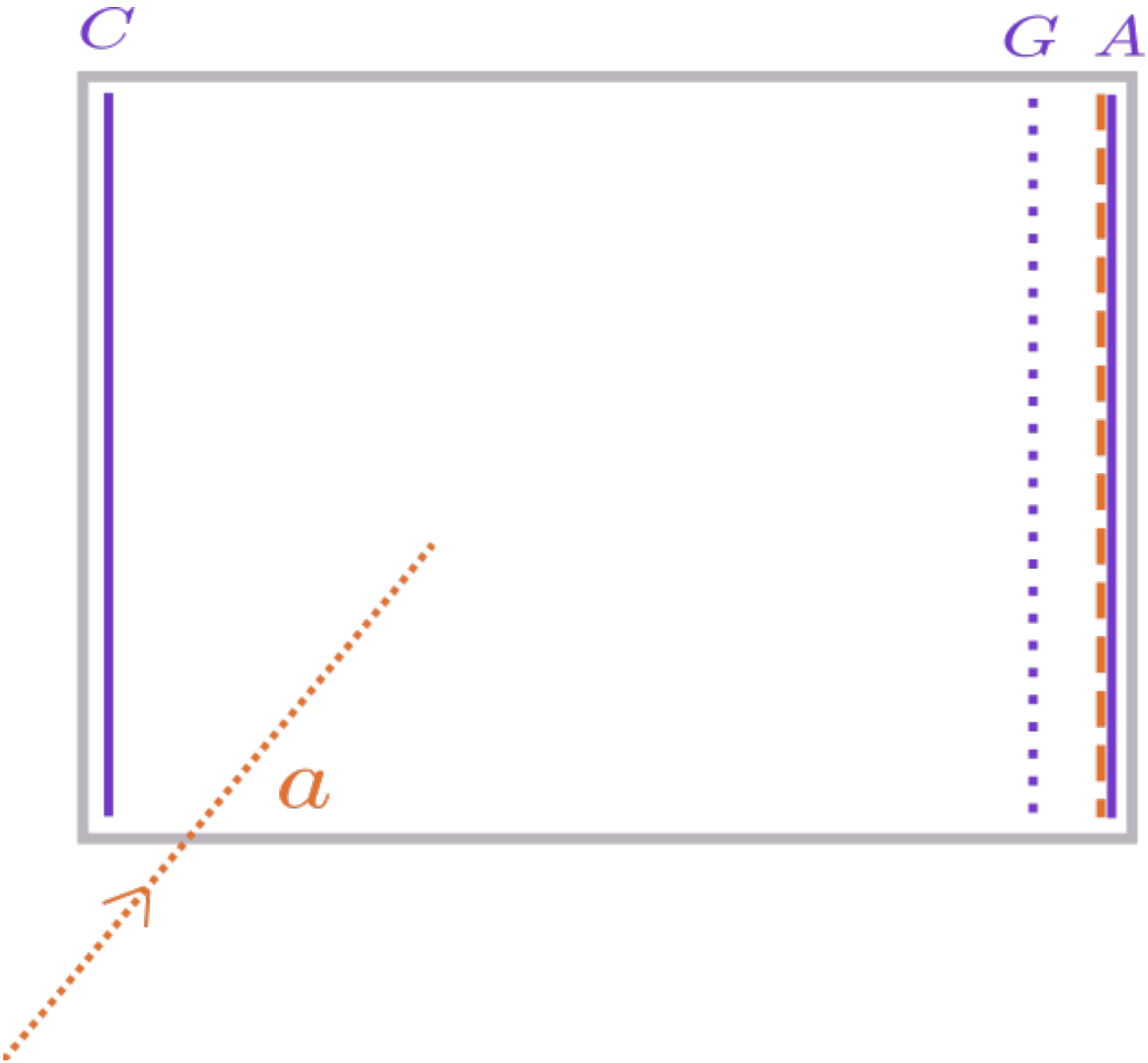
NEWS-G ECUME:
Ne + 10% CH_4
Background: 0.3 dru
Exposure: 200 kg.days
Optimum Interval Method [13]

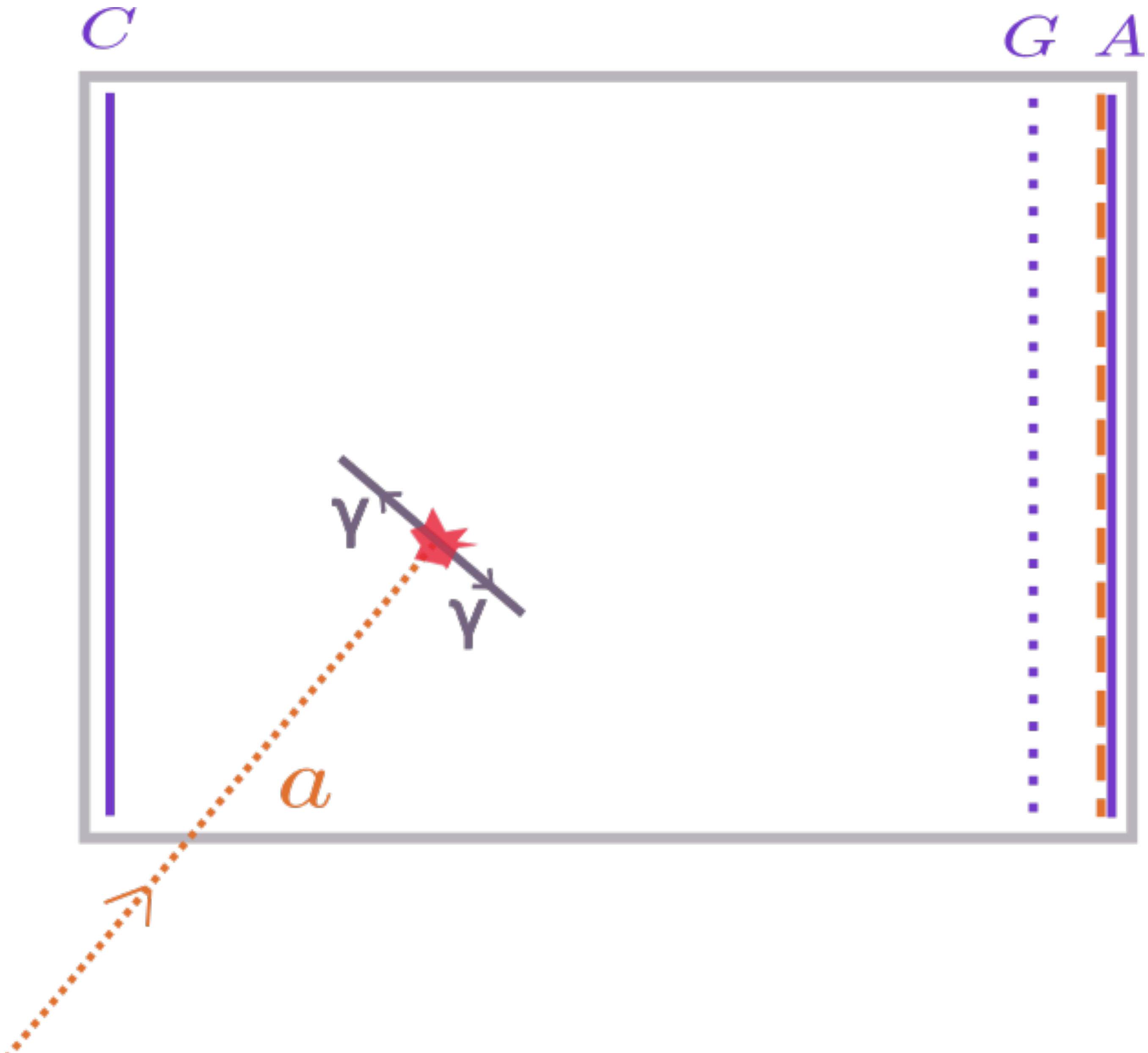
DarkSPHERE:
He + 10% C_4H_{10}, 5 bars (26.8 kg)
Background: 0.02 dru
Exposure: 300 days
Binned Likelihood

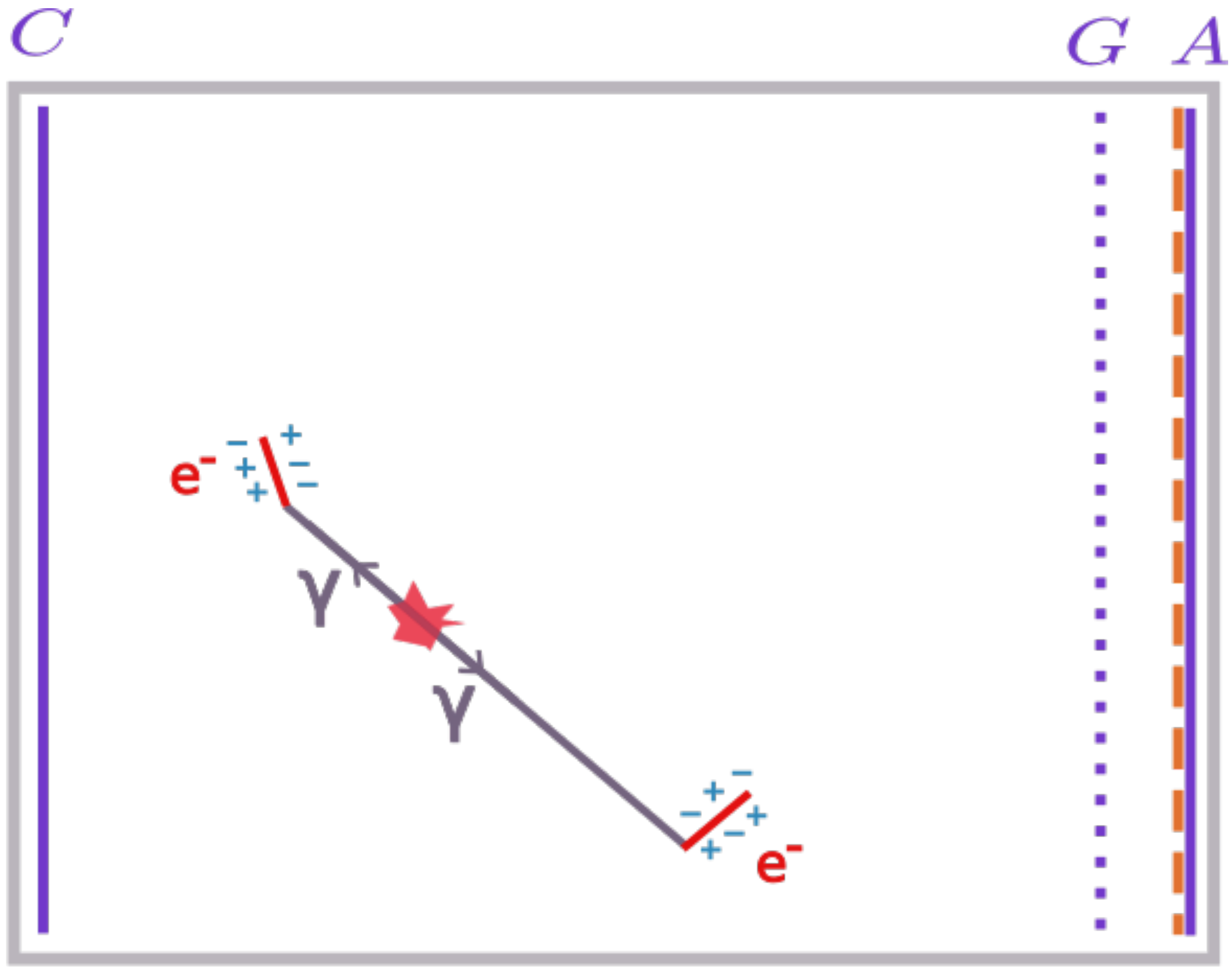
Conclusions

- MIMAC has developed know-how on 3D directional detection
- The nuclear recoil directional detection is the observable needed to go beyond the neutrino floor for DM search and provides a galactic signature
- The 35 x 35 cm^2 is the elemental brick to build a big volume directional detector
- The first stages: a 1m^3 detector in LSM and CJPL

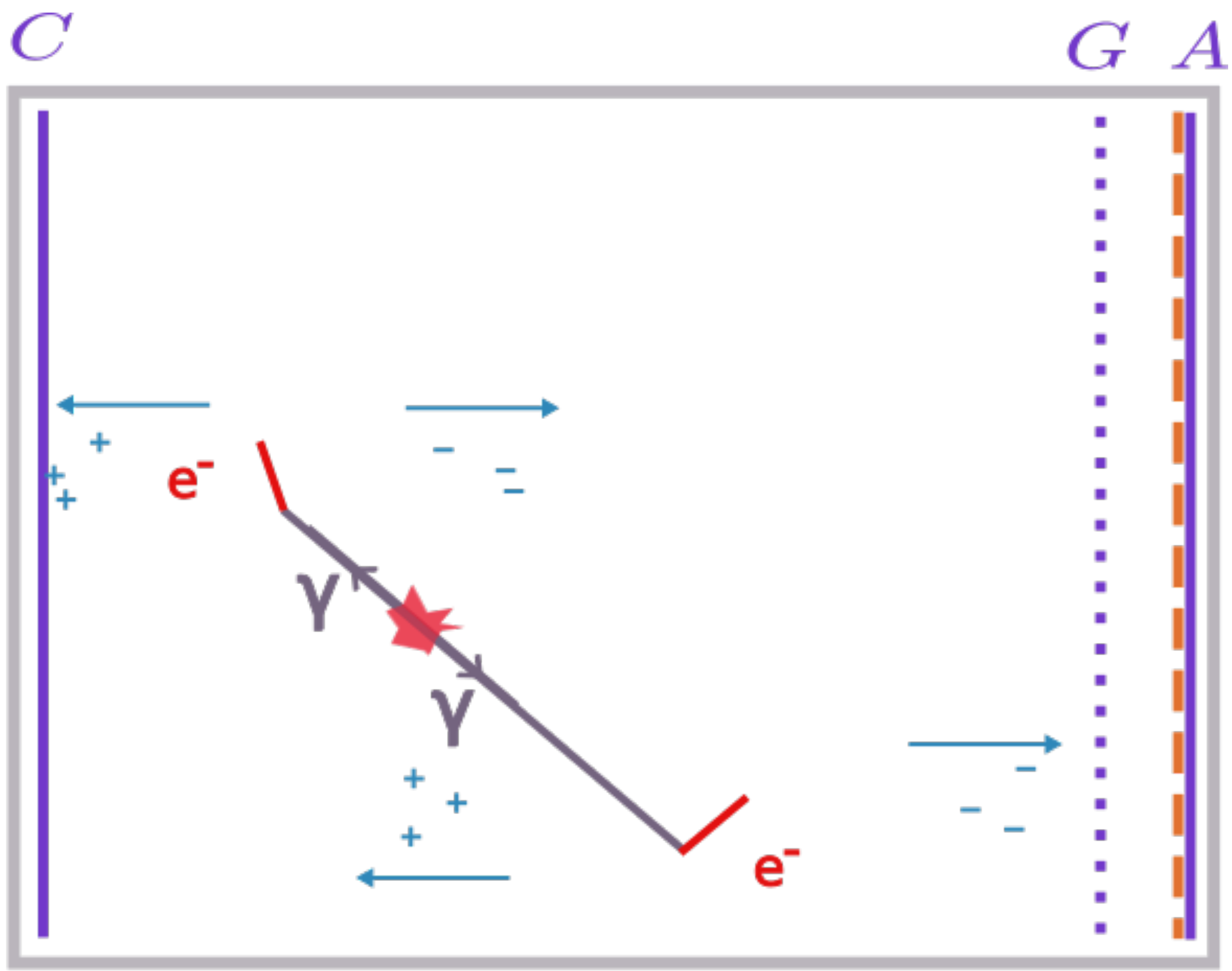
- The 10 x 10 cm^2 Mimac-FastN can become a primary neutron spectrometer discriminating fast and epi-thermal neutrons
- MIMAC can also be an axion-like particle detector


C
G
A
a

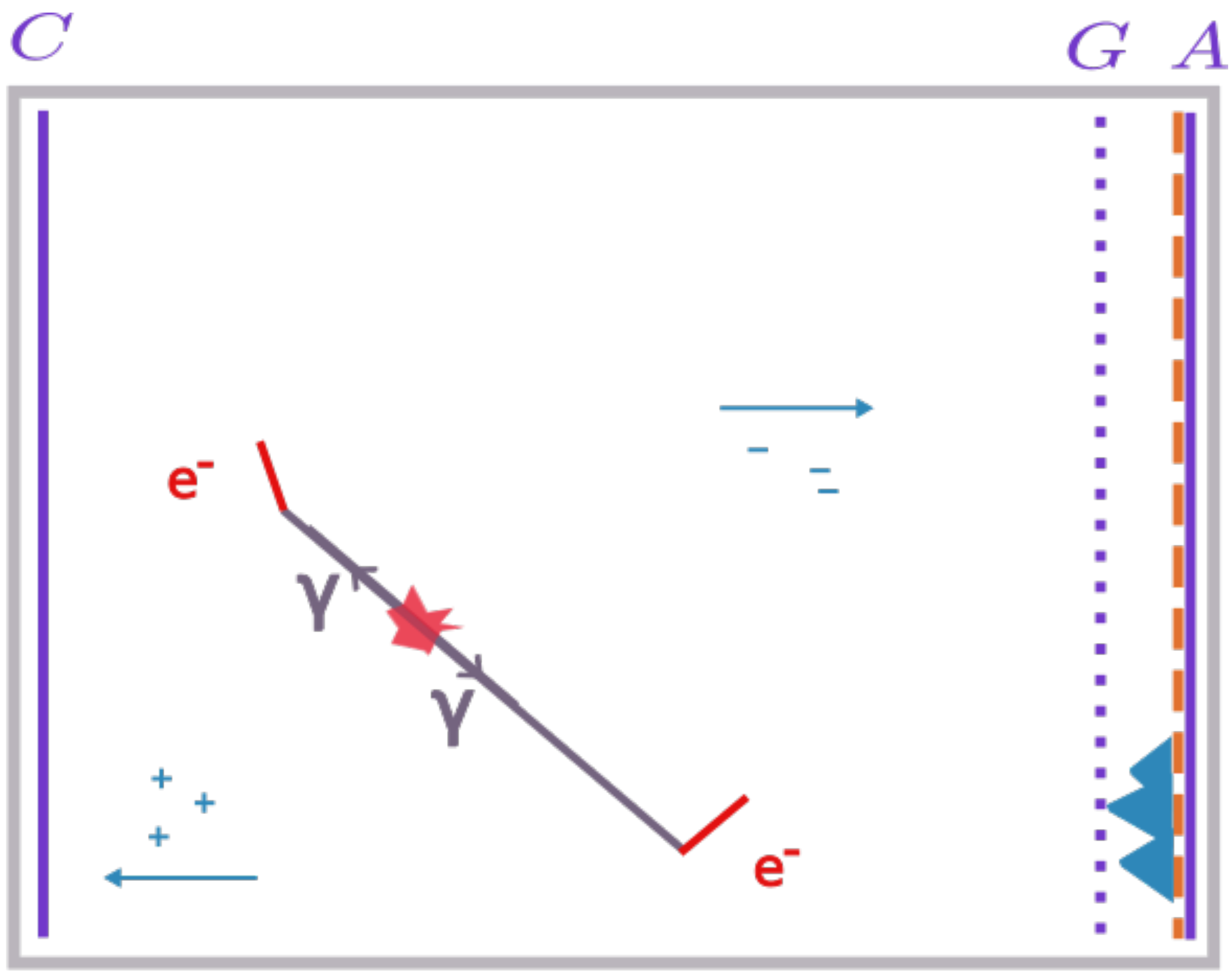

C
G
A
γ
γ
a

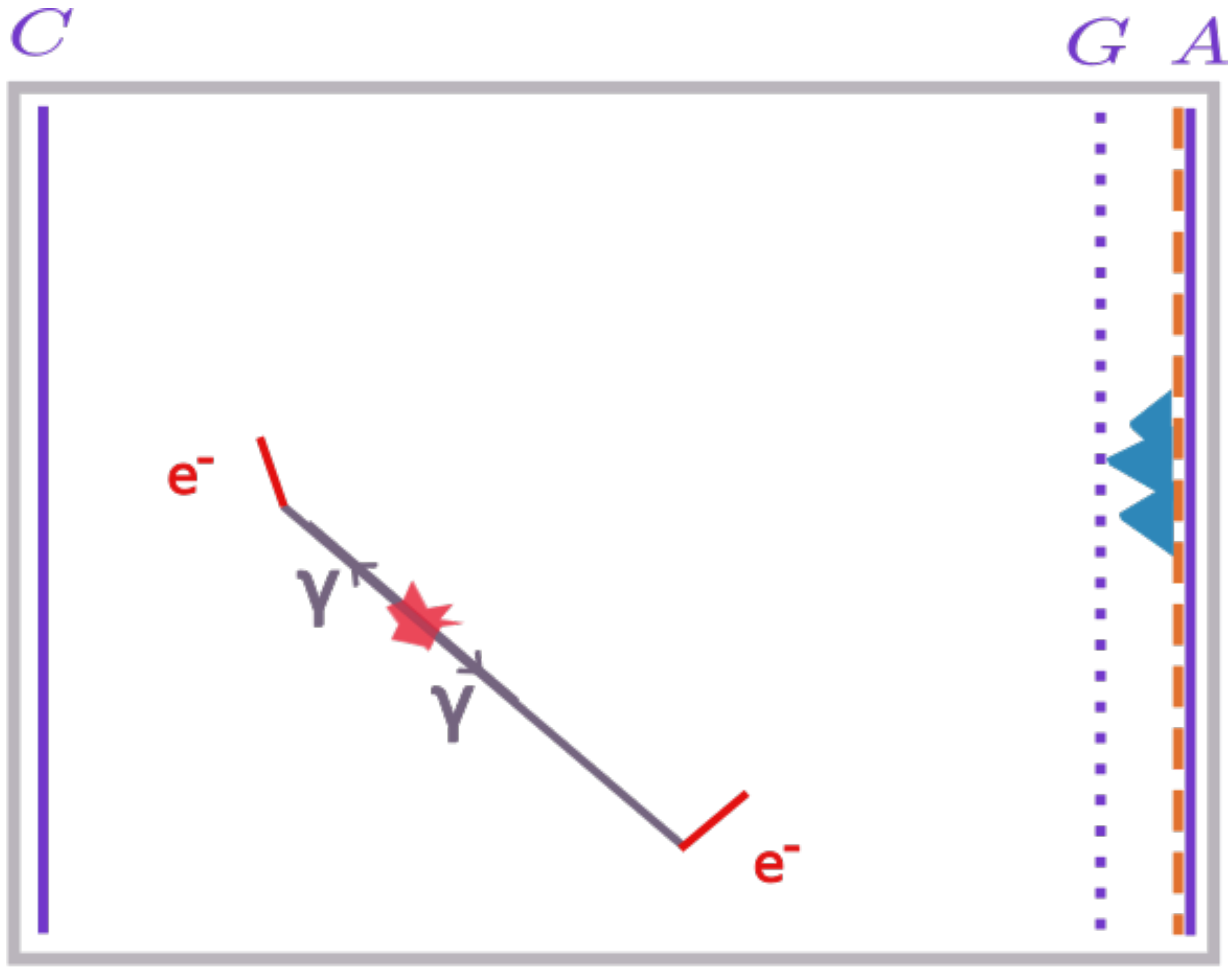


C
G
A
e-
γ
γ
e-



C
G
A
e-
γ
γ
e-


C
G
A
e-
γ
γ
e-

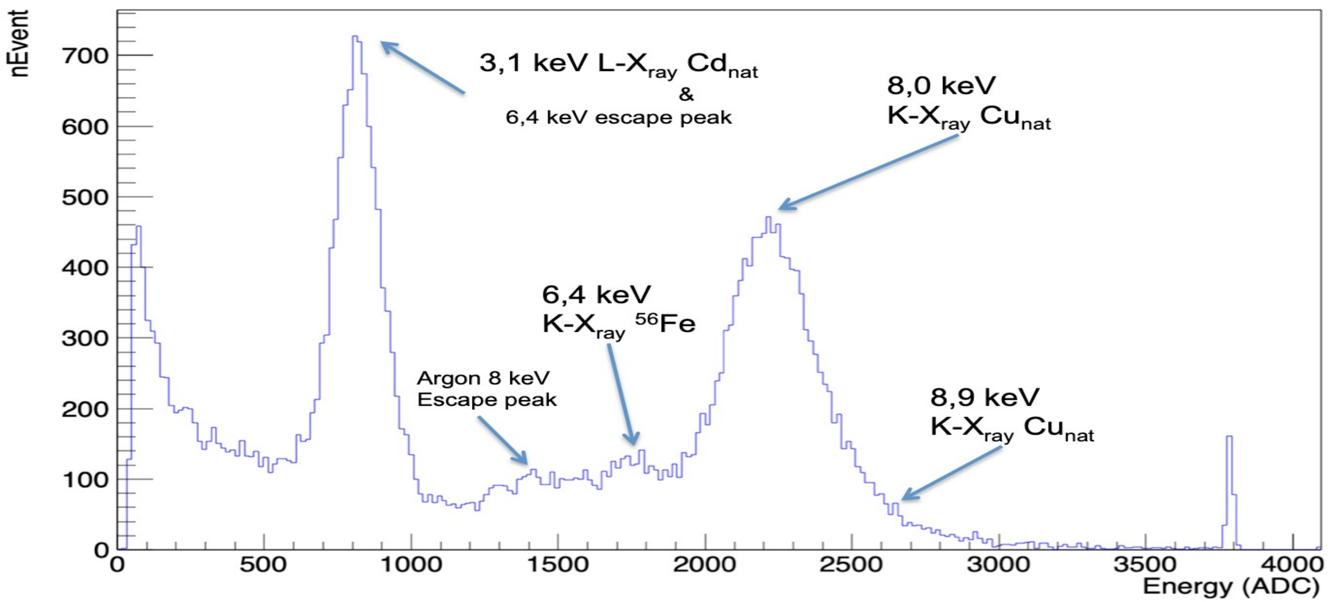


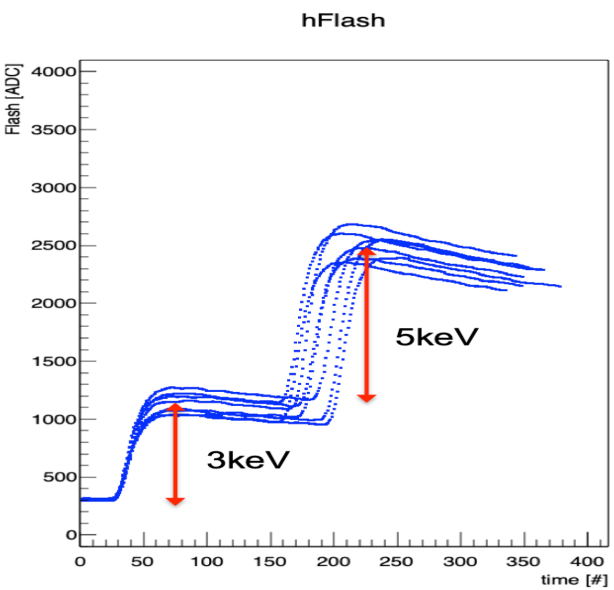
C
G
A
e-
γ
γ
e-

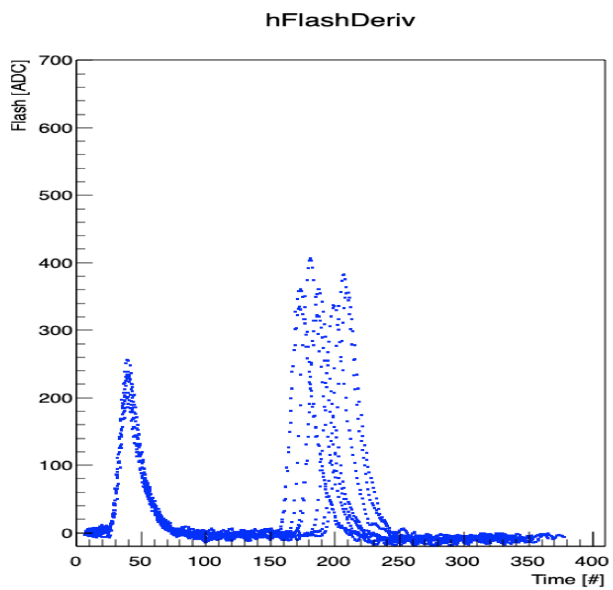
Calibration

Fluorescence X-ray

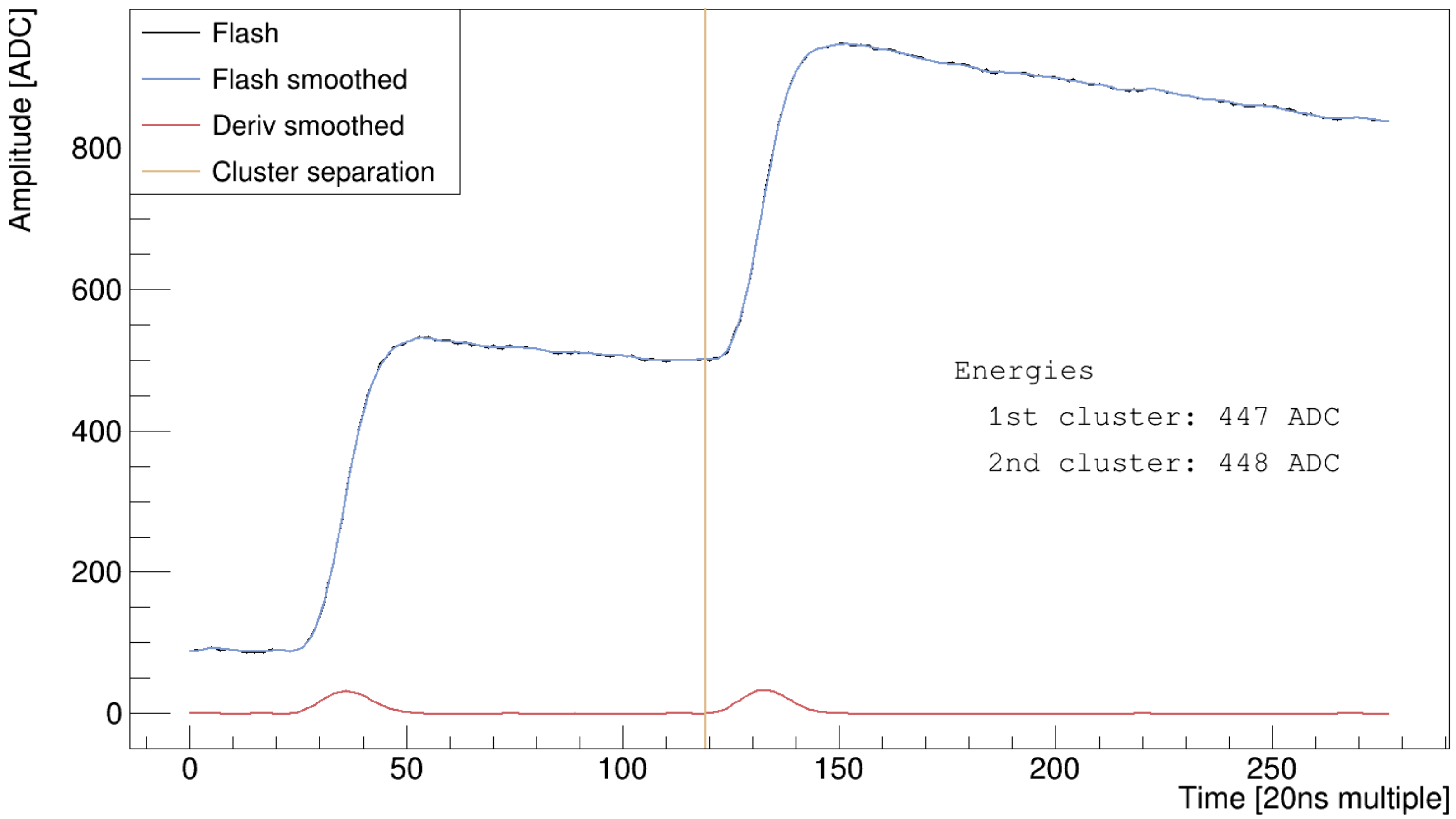
$^{40}Ar + 5\% \ C_4H_{10}$

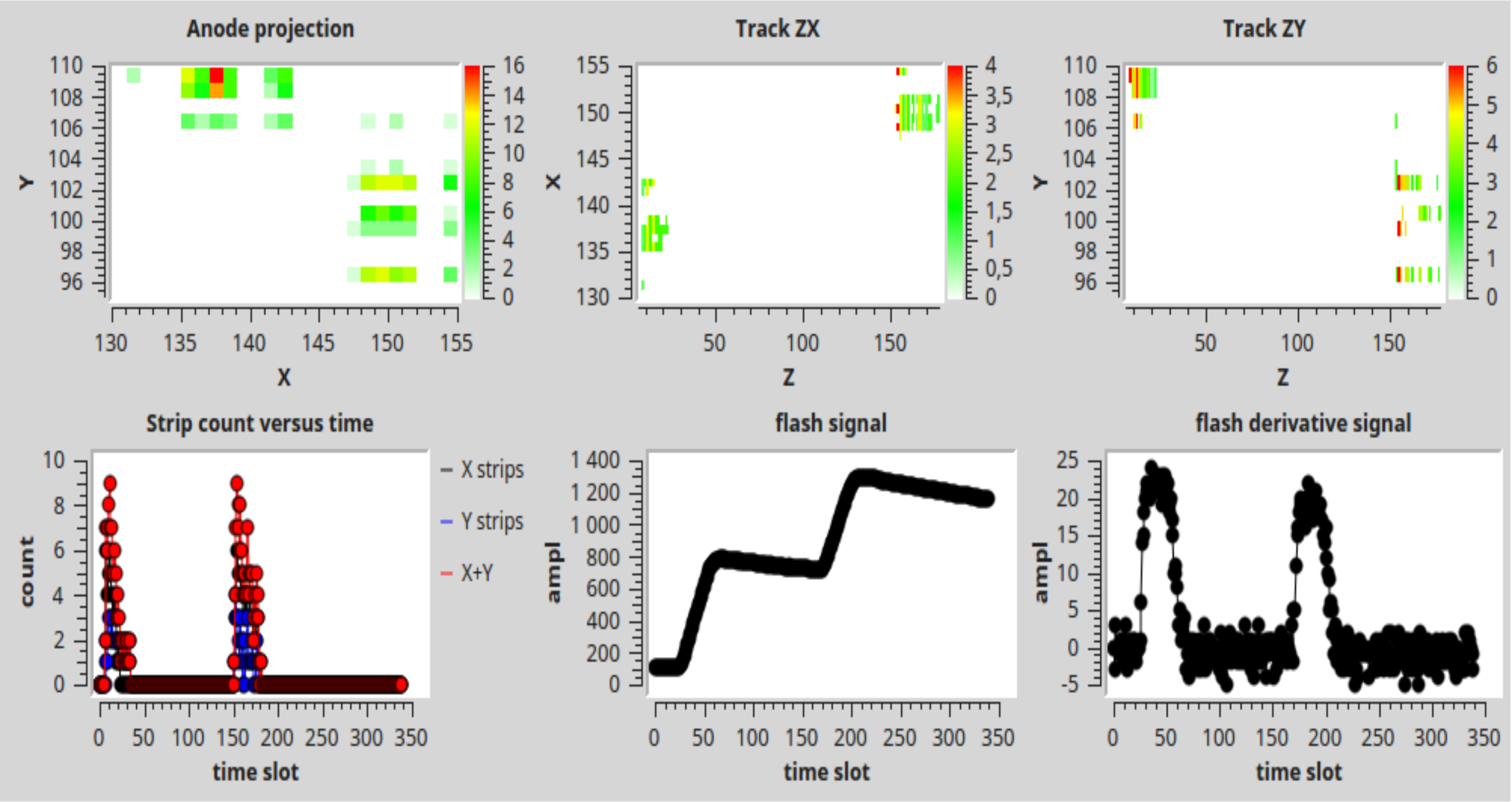






Two e$^-$ (4 keV) sent by COMIMAC (in less than 2 us)





Anode projection
Track ZX
Track ZY
Strip count versus time
X strips
Y strips
X+Y
count
time slot
flash signal
ampl
flash derivative signal

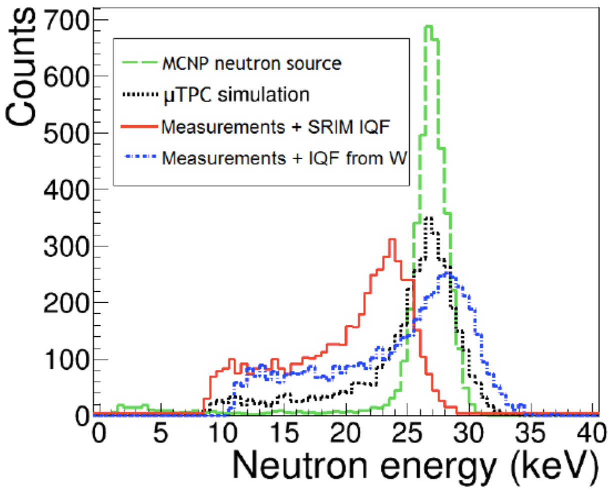
Thank you for your attention!

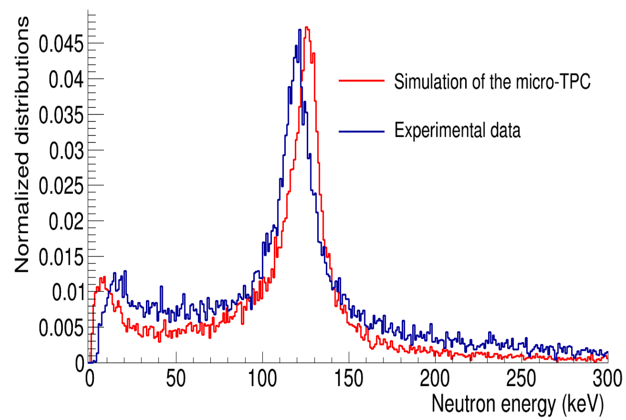
Merci !

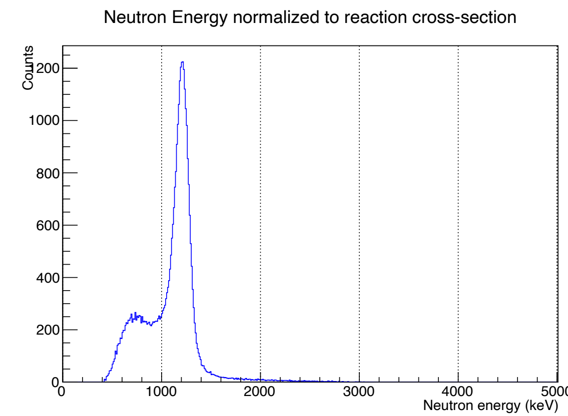
谢谢！

A large energy range of neutron fields

50% C_4H_{10} 50% CHF_3 30 mbar	60% C_4H_{10} 40% CHF_3 50 mbar	95% ^4He 5% CO_2 700 mbar
E_n=27 keV	***E_n=127 keV***	***E_n=1.2 MeV***







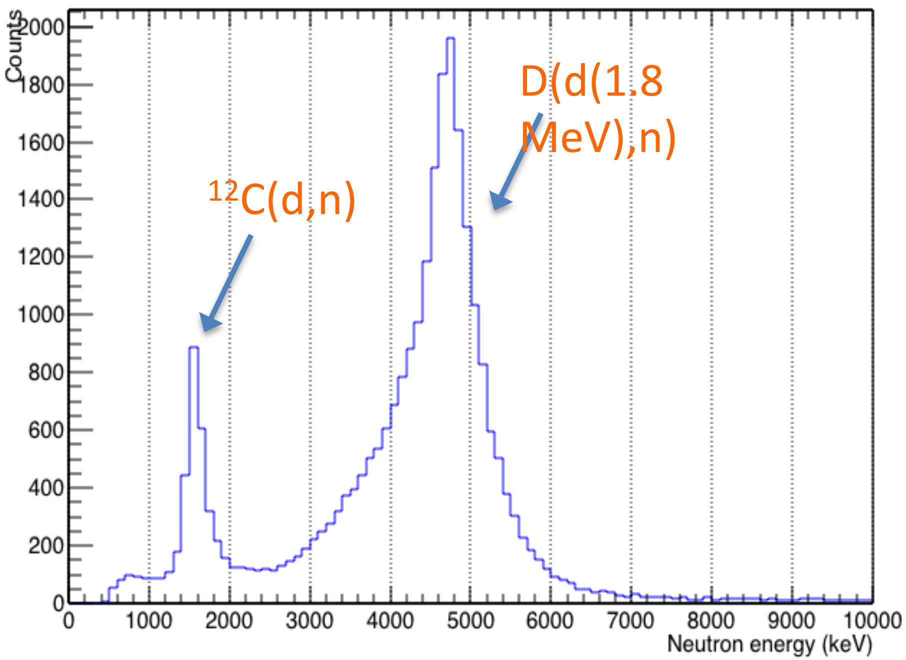
D. Maire *et al.*
« Neutron energy reconstruction and fluence determination at 27 keV with the LNE-IRSN-MIMAC µ-TPC recoil detector »
IEEE Transactions on Nuclear Science, 63(3) : 1934-1941, June 2016

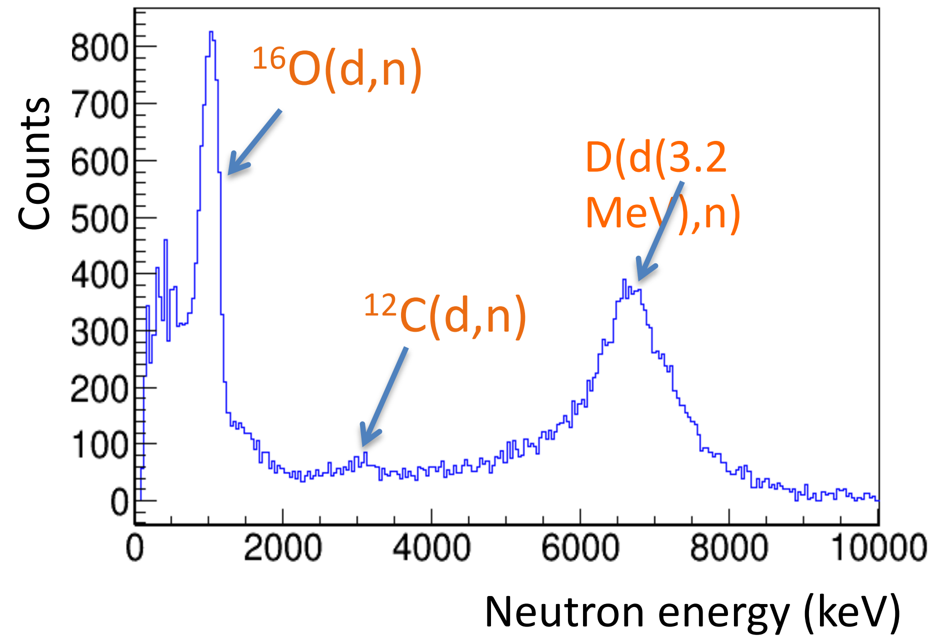
D. Maire *et al.*
« First measurement of a 127 KeV neutron field with a µ-TPC spectrometer »
Nuclear Science, IEEE Transactions, 61(2014) 2090

Measurements of monoenergetic neutrons

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

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





NPL /(UK)

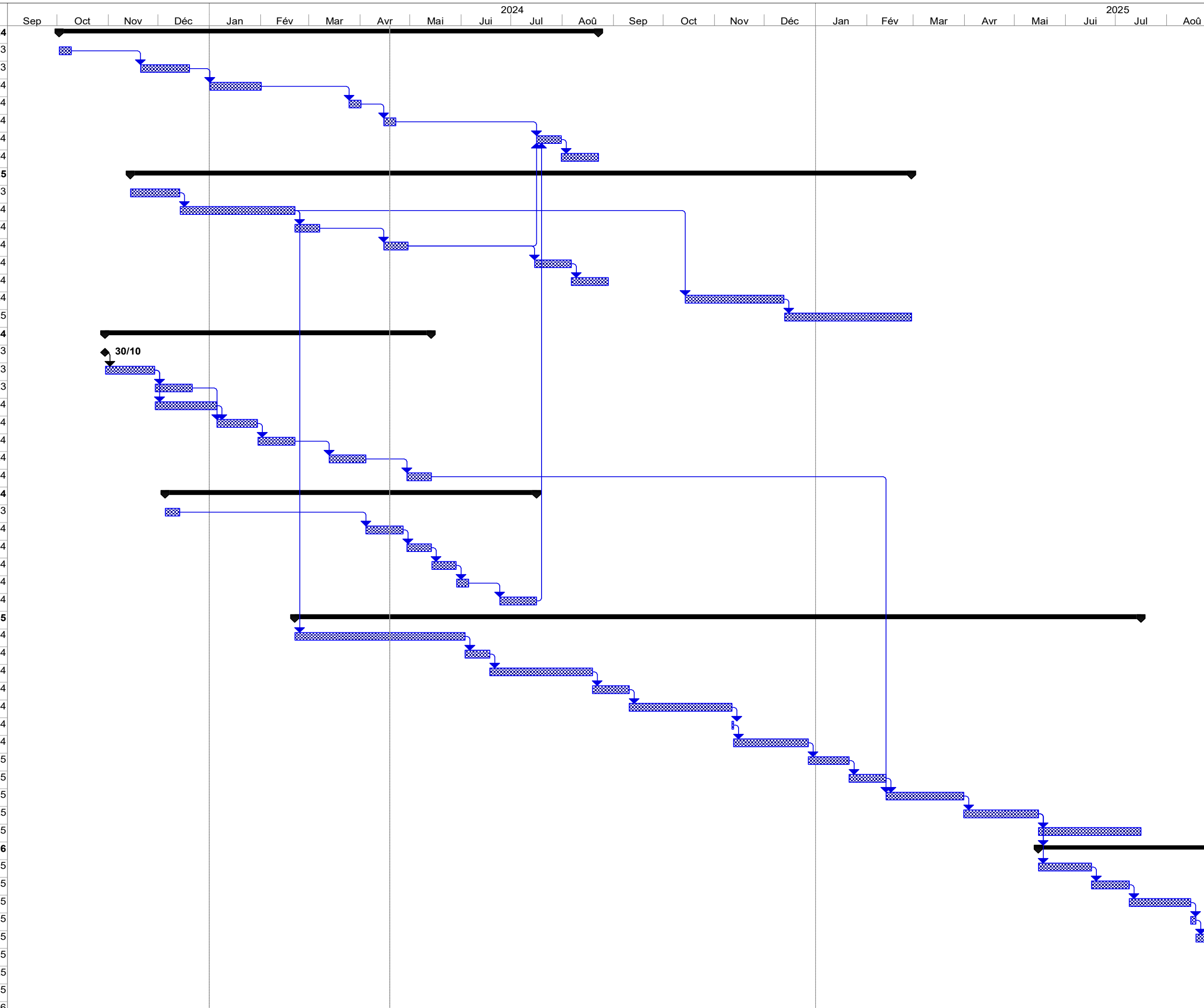
700 mbar He/CO_2 (5%)

IRSN / AMANDE (Cadarache)

Fast neutron spectroscopy from 1 MeV up to 15 MeV with Mimac-FastN, a mobile and directional fast neutron spectrometer, N. Sauzet , D. Santos, O. Guillaudin, G. Bosson, J. Bouvier, T. Descombes, M. Marton, J.F. Muraz, NIM A 965 (2020) 163799

The different tasks foreseen in the next two years between the LPSC and the Chinese partners.

N°	Nom de la tâche	Durée	Début	Fin
1	**Prototypage Détecteur PCB 35x35 cm**	**212,73 jours**	**Lun 02/10/23**	**Jeu 22/08/24**
2	Collage Dummy interface rigide	5 jours	Lun 02/10/23	Lun 09/10/23
3	Reprise plaque de fermeture	20 jours	Lun 20/11/23	Mar 19/12/23
4	Montage sur Bichambre	21 jours	Lun 01/01/24	Jeu 01/02/24
5	Collage Bulk 1792	5 jours	Lun 25/03/24	Lun 01/04/24
6	Test d'étanchéité	5 jours	Lun 15/04/24	Lun 22/04/24
7	Test sous gaz (30 mbar à 1 bar)	10 jours	Mar 16/07/24	Mer 31/07/24
8	Mesure du gain (stabilité, homogénéité,...)	15 jours	Mer 31/07/24	Jeu 22/08/24
9	**Mise au point carte 1792 voies**	**307,27 jours?**	**Mar 14/11/23**	**Jeu 27/02/25**
10	Réglage des seuils et réduction bruit	20 jours?	Mar 14/11/23	Mer 13/12/23
11	Test de déclenchement sur table	45 jours	Jeu 14/12/23	Mer 21/02/24
12	Montage mecanique sur détecteur	10 jours?	Mer 21/02/24	Jeu 07/03/24
13	Test connectique et HT	10 jours	Lun 15/04/24	Lun 29/04/24
14	Test PAC sur Carte	15 jours	Lun 15/07/24	Mar 06/08/24
15	Mesure du bruit de fond en cosmique et avec sources	15 jours?	Mar 06/08/24	Mer 28/08/24
16	Appro composant Carte 2	40 jours?	Lun 14/10/24	Jeu 12/12/24
17	Cablage carte 1792 voie n° 2	50 jours?	Ven 13/12/24	Jeu 27/02/25
18	**Alimentation HT et BT**	**128,18 jours**	**Lun 30/10/23**	**Lun 13/05/24**
19	Finalisation de la conception de la carte	0 jour	Lun 30/10/23	Lun 30/10/23
20	Routage PCB	20 jours	Lun 30/10/23	Mar 28/11/23
21	Fabrication PCB	15 jours	Mer 29/11/23	Jeu 21/12/23
22	Appro composants	25 jours	Mer 29/11/23	Ven 05/01/24
23	Cablage Carte	15 jours	Ven 05/01/24	Lun 29/01/24
24	Test sur table	15 jours	Mar 30/01/24	Mer 21/02/24
25	Mise en boitier	15 jours	Mer 13/03/24	Jeu 04/04/24
26	Tests finaux	10 jours	Lun 29/04/24	Lun 13/05/24
27	**Cage de champ et connectique 40x40**	**145,91 jours**	**Mar 05/12/23**	**Mar 16/07/24**
28	Mise en plan de la structure cage de champ	6,36 jours	Mar 05/12/23	Mer 13/12/23
29	Commande et réception pièces	15 jours	Jeu 04/04/24	Ven 26/04/24
30	Soudure composant cages de champ	10 jours	Lun 29/04/24	Lun 13/05/24
31	Collage cathode Mylar	10 jours	Mar 14/05/24	Mar 28/05/24
32	Montage / Intégration	5 jours	Mer 29/05/24	Mer 05/06/24
33	Tests HT sous gaz	15 jours	Lun 24/06/24	Mar 16/07/24
34	**Prototypage Détecteur Bas Bruit 35x35 cm (Chine)**	**331,91 jours?**	**Mer 21/02/24**	**Mer 16/07/25**
35	Fabrication des Kapton à la dimension	65,91 jours?	Mer 21/02/24	Lun 03/06/24
36	Collage des Kapton sur semelle Cuivre	10 jours	Lun 03/06/24	Mar 18/06/24
37	Contrôle dimensionnel (aller retour Chine)	40 jours?	Mar 18/06/24	Lun 19/08/24
38	Dépôt resistifs (Ge)	15 jours	Lun 19/08/24	Mar 10/09/24
39	Collage grille	40 jours?	Mar 10/09/24	Lun 11/11/24
40	Récepetion prototype Bas bruit	1 jour?	Lun 11/11/24	Mar 12/11/24
41	Collage sur interface rigide (Alu)	30 jours	Mar 12/11/24	Ven 27/12/24
42	Test connectique	15 jours	Ven 27/12/24	Mar 21/01/25
43	Test détanchéité	15 jours	Mar 21/01/25	Mer 12/02/25
44	Test de fonctionnement (Grenoble LPSC)	30 jours	Mer 12/02/25	Lun 31/03/25
45	Comparatif PCB / Bas Bruit	30 jours?	Lun 31/03/25	Jeu 15/05/25
46	Test de fonctionnement Modane	40 jours?	Jeu 15/05/25	Mer 16/07/25
47	**Fabrication lot Détecteur Bas bruit (Chine)**	**161 jours?**	**Jeu 15/05/25**	**Lun 19/01/26**
48	Fabrication des Kapton	20 jours	Jeu 15/05/25	Lun 16/06/25
49	Collage Kapton Sur semelle Cuivre	15 jours	Lun 16/06/25	Mer 09/07/25
50	Réalisation des Bulk	25 jours	Mer 09/07/25	Ven 15/08/25
51	Réception détecteurs Bas Bruit	1 jour?	Ven 15/08/25	Lun 18/08/25
52	Collage sur interface rigide (Alu)	10 jours	Lun 18/08/25	Mar 02/09/25
53	Test connectique	10 jours	Mar 02/09/25	Mer 17/09/25
54	Test détanchéité	10 jours	Mer 17/09/25	Jeu 02/10/25
55	Test de fonctionnement (Grenoble LPSC)	20 jours	Jeu 02/10/25	Lun 03/11/25
56	Test Fonctionnement (Modane LSM)	50 jours	Lun 03/11/25	Lun 19/01/26



Projet : MIMAC2018
Date : Ven 19/04/24

Tâche	Récapitulative de projet	Jalon inactif	Durée uniquement	Fin uniquement	Échéance
Fractionnement	Tâches externes	Jalon inactif	Report récapitulatif manuel	Tâches externes	
Jalon	Jalons externes	Récapitulatif inactif	Récapitulatif manuel	Jalons externes	
Récapitulative	Tâche inactive	Tâche manuelle	Début uniquement	Avancement	

Ionization Quenching Factor Measurements with COMIMAC (NEWS-G collaboration, arXiv 2201.09566, published in ERJ-C)

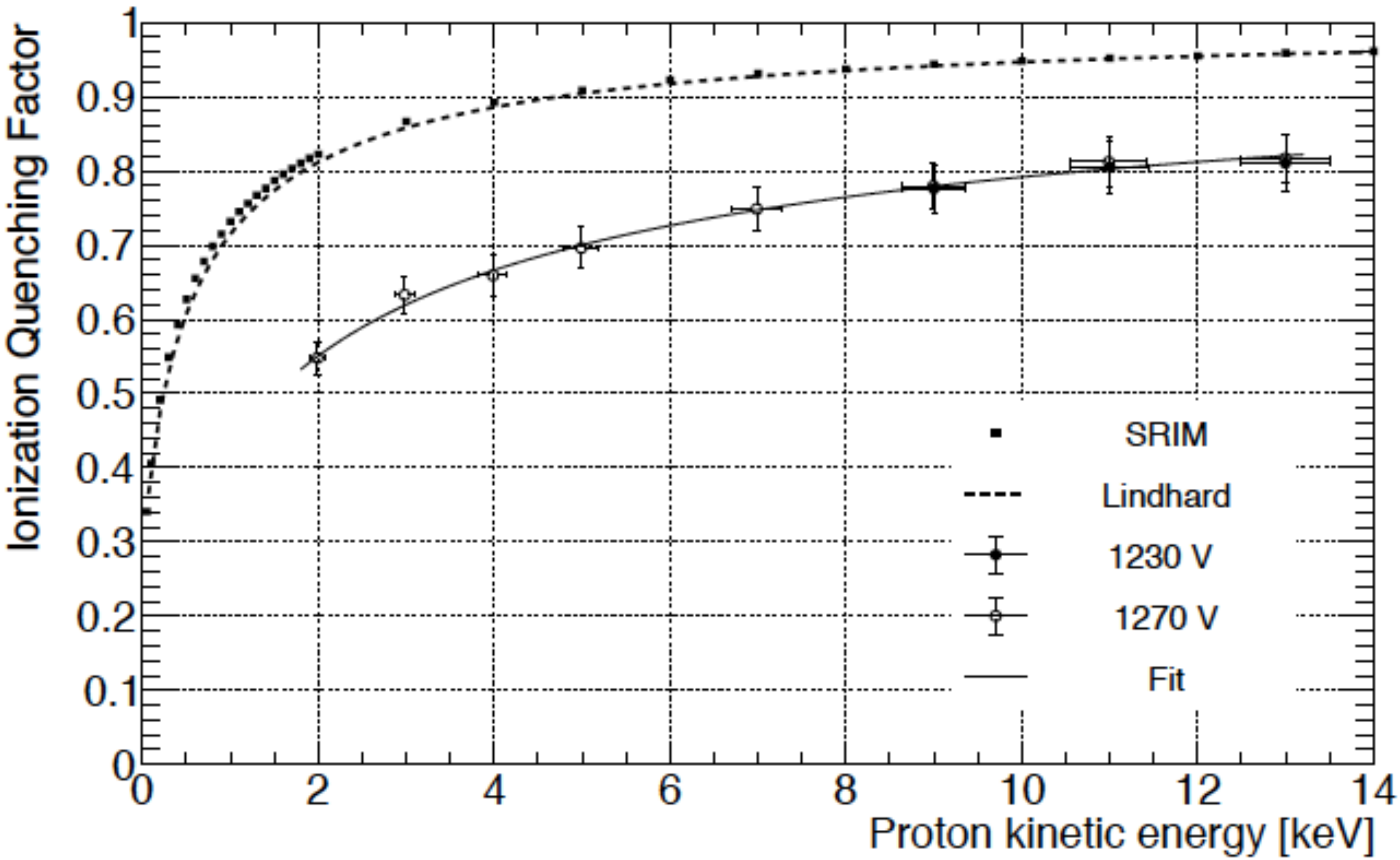
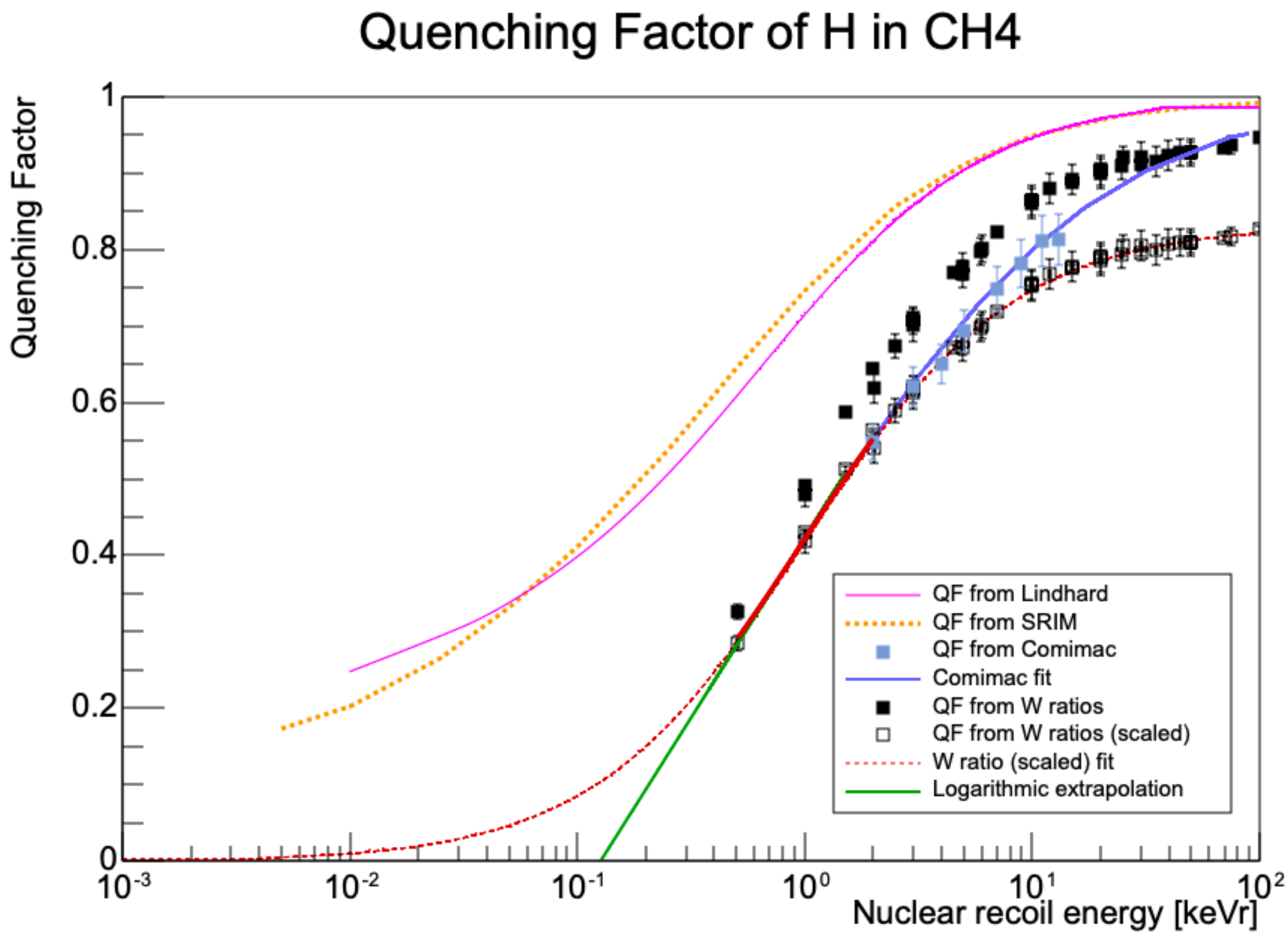


Fig. 9: Ionization Quenching Factor for protons in 100 mbar of methane. The measurements at 1230 V and 1270 V are respectively presented with black dots and white dots. Comparisons with SRIM and with the Lindhard theory are also shown.


Quenching Factor of H in CH4
Quenching Factor
1
0.8
0.6
0.4
0.2
0
10^{-3}
10^{-2}
10^{-1}
10^{0}
10^{1}
10^{2}
Nuclear recoil energy [keVr]
QF from Lindhard
QF from SRIM
QF from Comimac
Comimac fit
QF from W ratios
QF from W ratios (scaled)
W ratio (scaled) fit
Logarithmic extrapolation