

MIMAC at LSM

3D-Directional Direct Dark Matter Detection
with MIMAC

and non - directional with News-G and
Sedine

Daniel Santos

LPSC-Grenoble

on behalf of the MIMAC collaboration



MIMAC (Micro-tpc Matrix of Chambers)

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

- 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

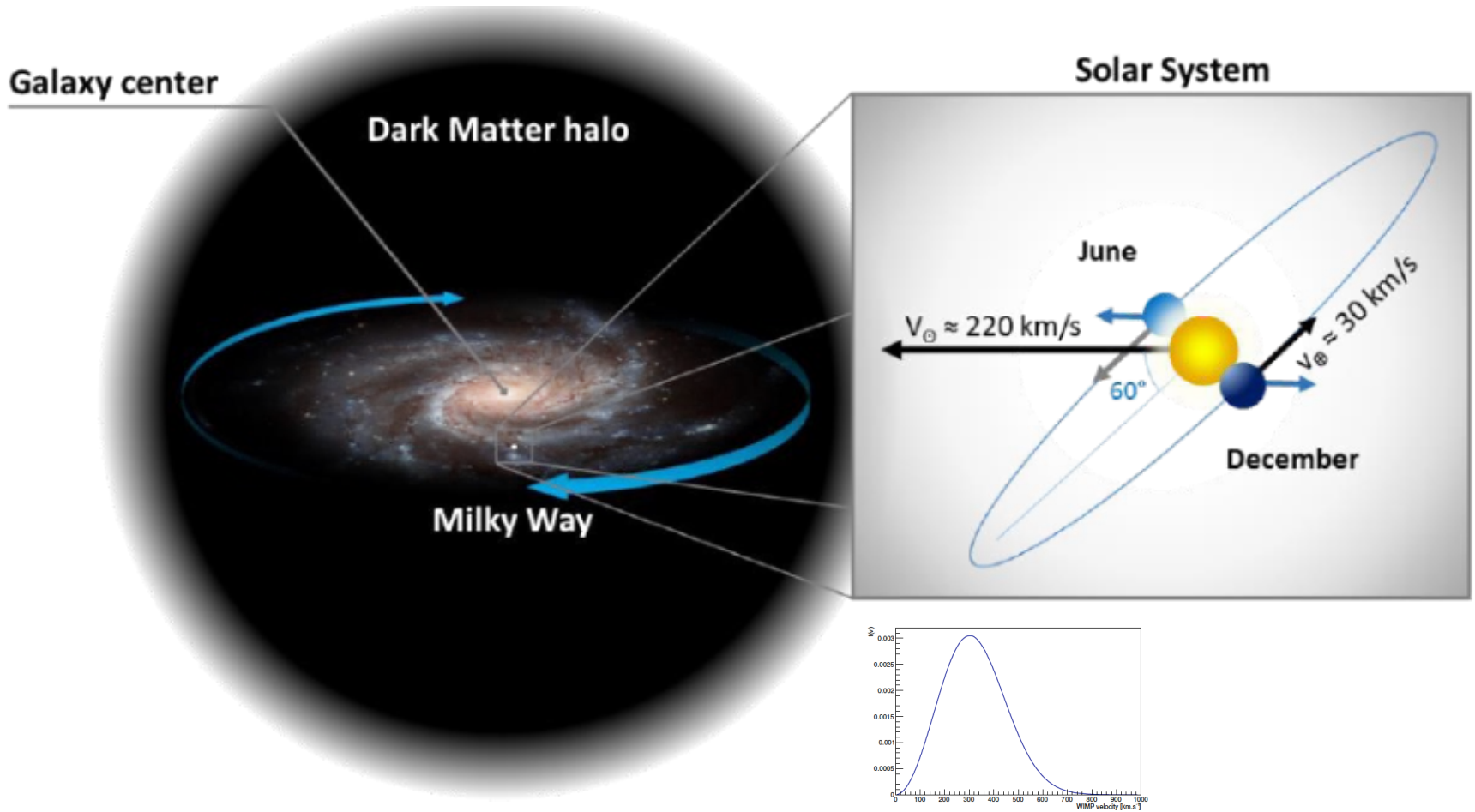
USTC (University of Science and Technology of China, Hefei): Wang Zhiyong

SJTU(Shanghai Jiao tong University): Wang Shaobo, Han Ke, Zhou Ning, Tao Yi

TSINGHUA University (Beijing-China): Yue Qian (China Jinping underground Laboratory (CJPL) director)

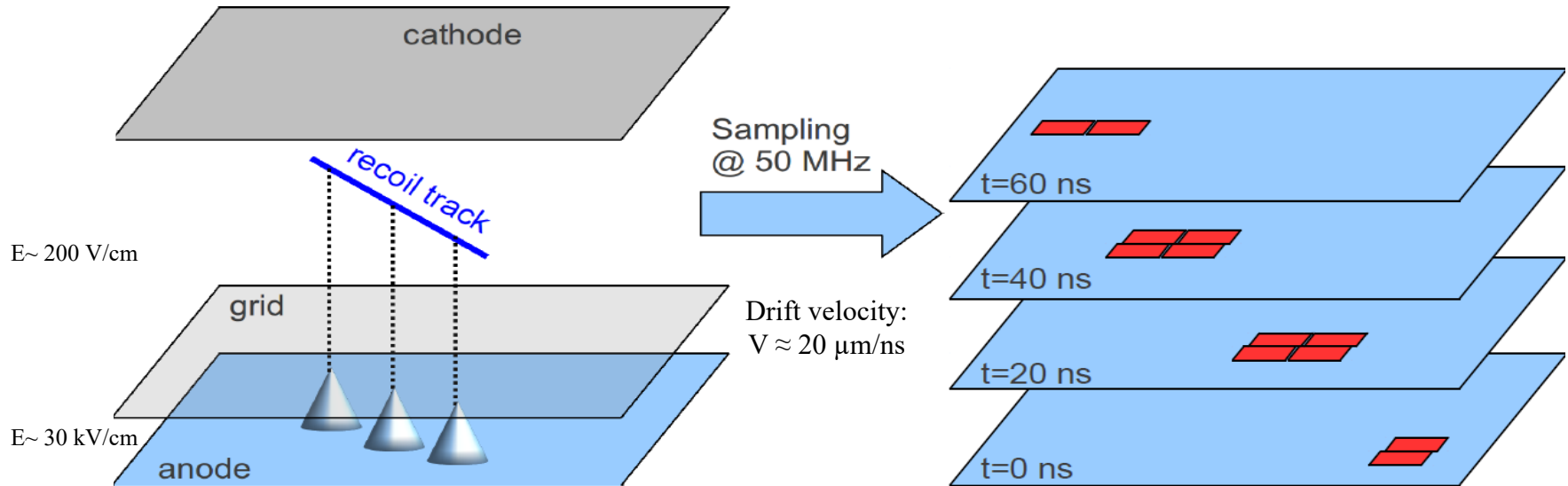
SHAO(Shanghai Astronomical Observatory): Shan Huan Yuan

Directional detection principle



The only signature able to correlate the rare events in a detector to the DM galactic halo !!

MIMAC: Detection strategy



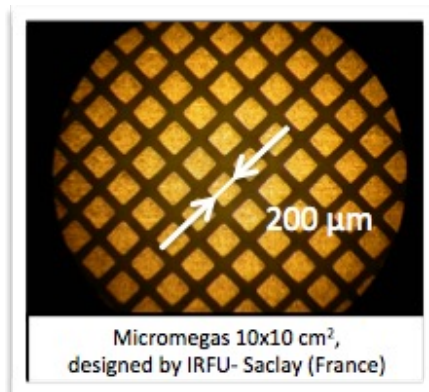
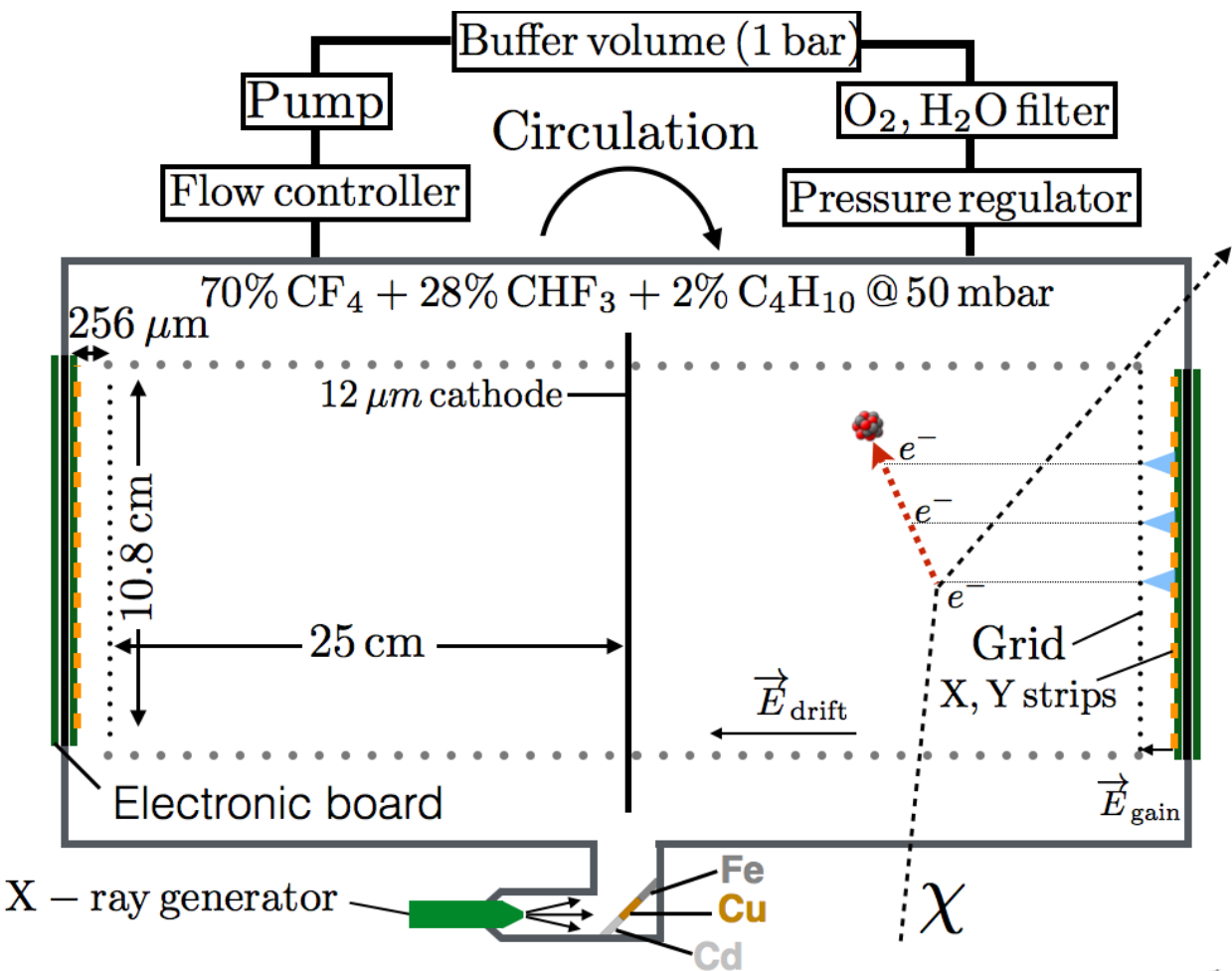
Scheme of a MIMAC μ TPC

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

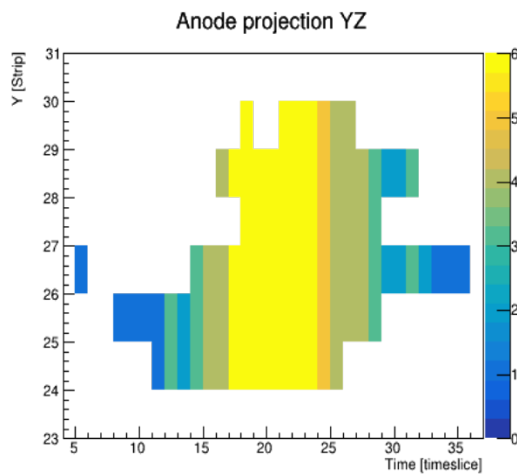
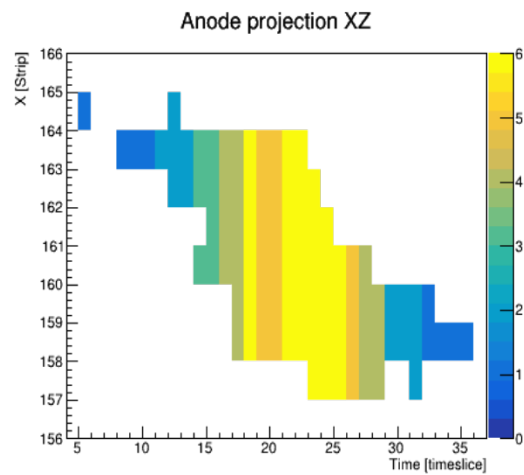
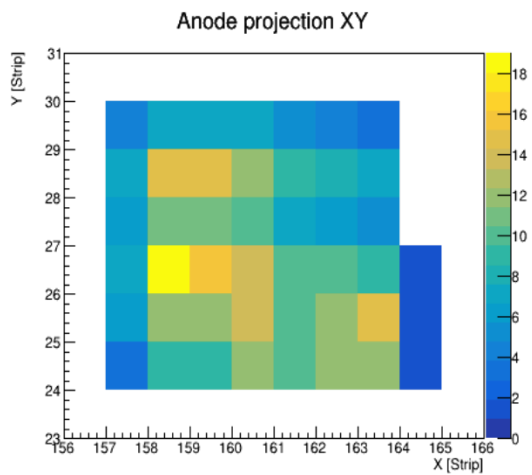
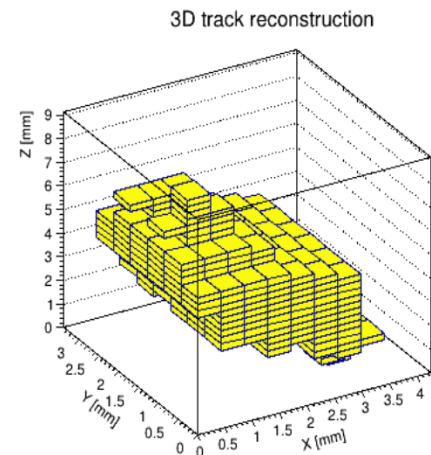
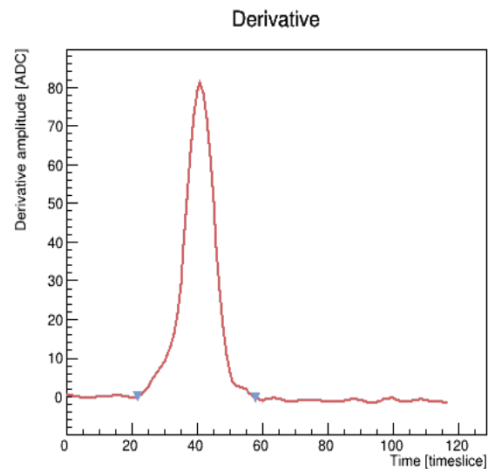
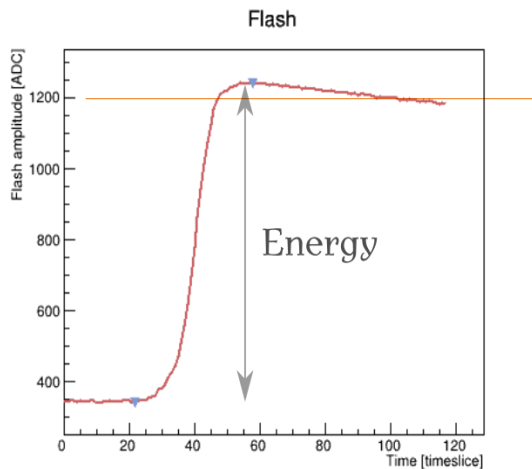
MIMAC-bi-chamber module prototype



MIMAC Target: ^{19}F

- Light WIMP mass
- Axial coupling

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

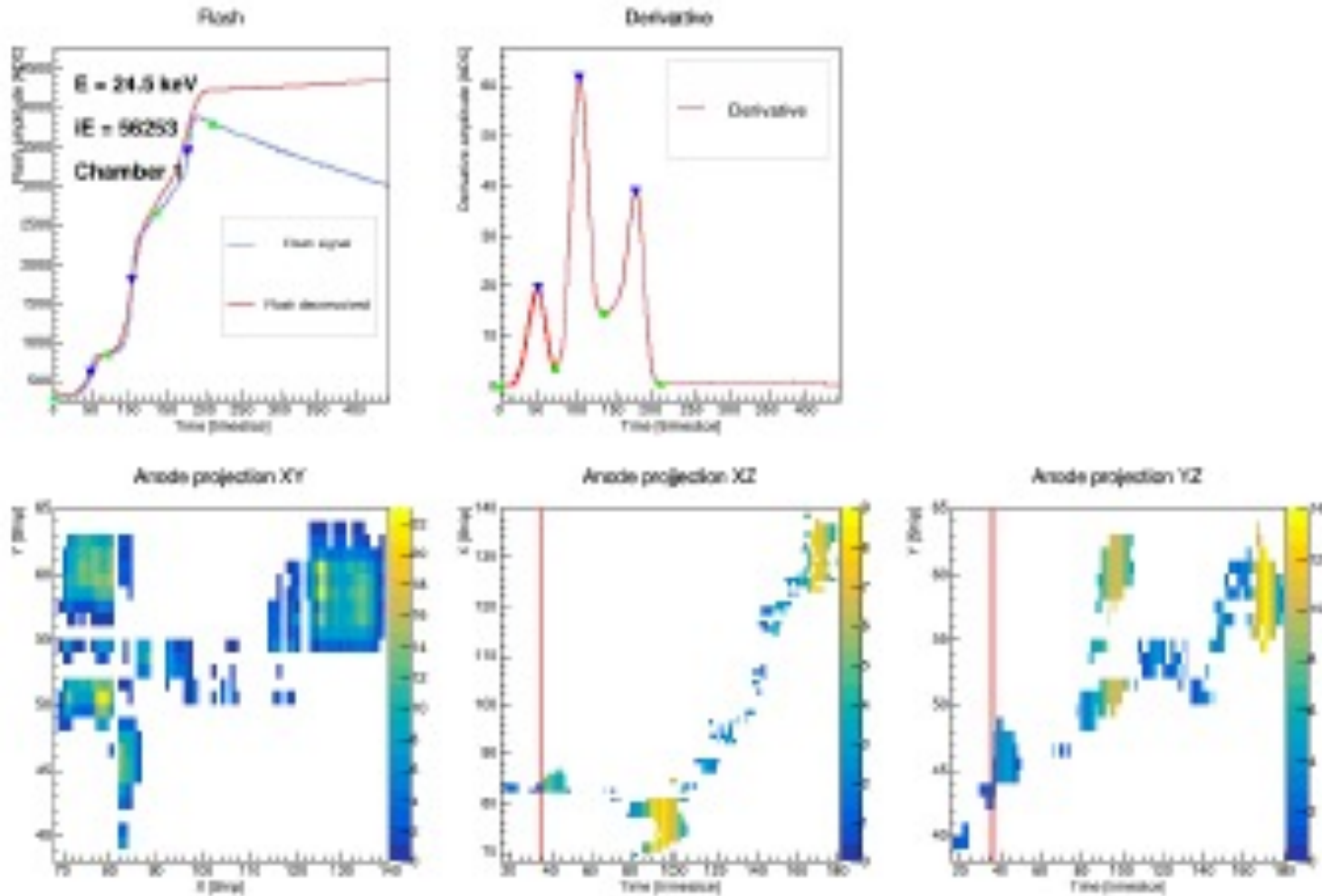


→ Sampling at 50 MHz (20 ns)

5 / 16

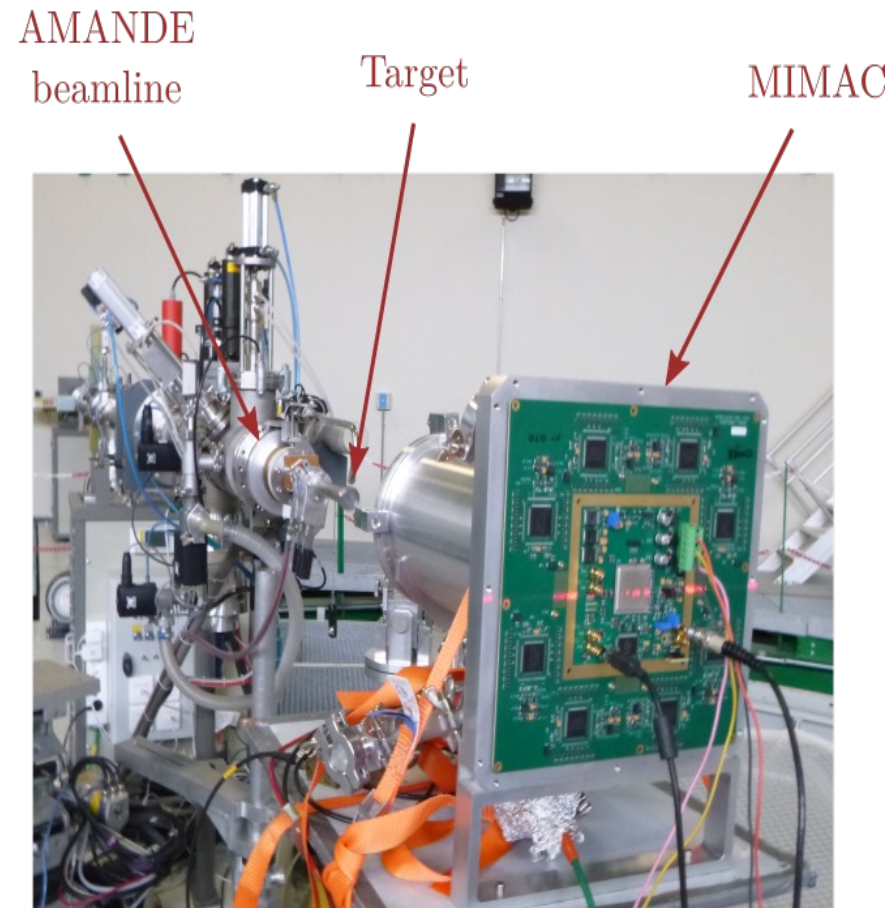
C_4H_{10} + 50% CHF_3 at 30 mbar

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



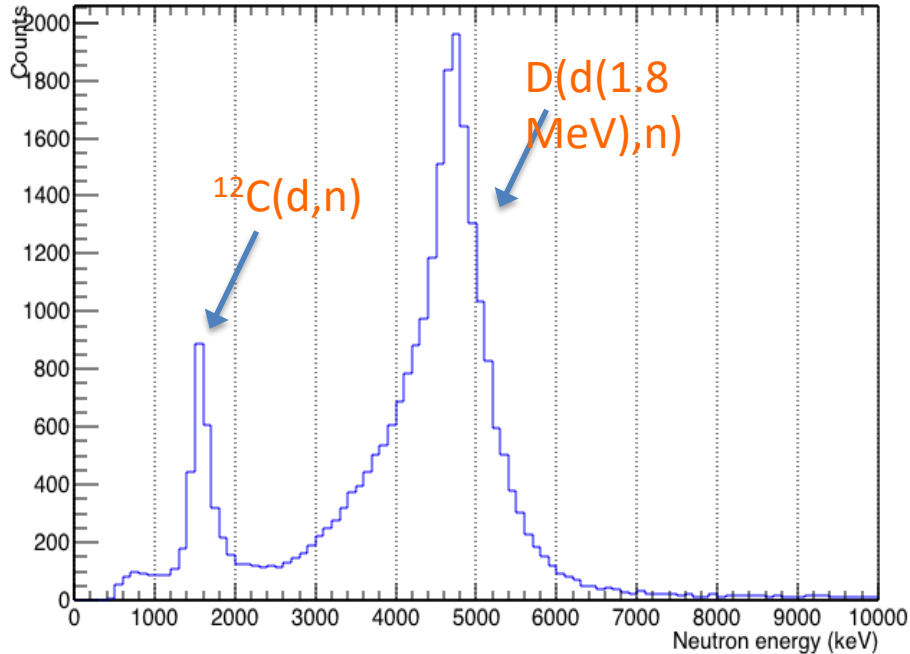
Demonstration of directional detection with mono-energetic neutron fields

- For the low energy range (keV), the AMANDE facility (IRSN-Cadarache) provides mono-energetic neutron fields
- The energy of the mono-energetic neutron field is defined by the angle of **each nuclear recoil** track with respect to the neutron direction



Monoenergetic measurements : detection of target pollution

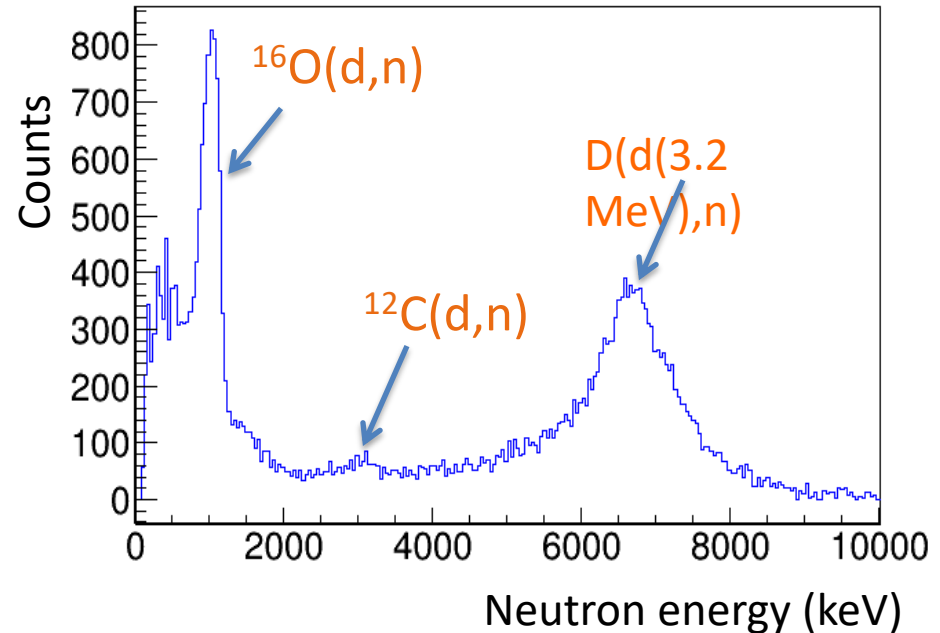
D(d(1.8 MeV,n) : neutrons of 5 MeV



NPL / (UK)

700 mbar He/CO₂ (5%)

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



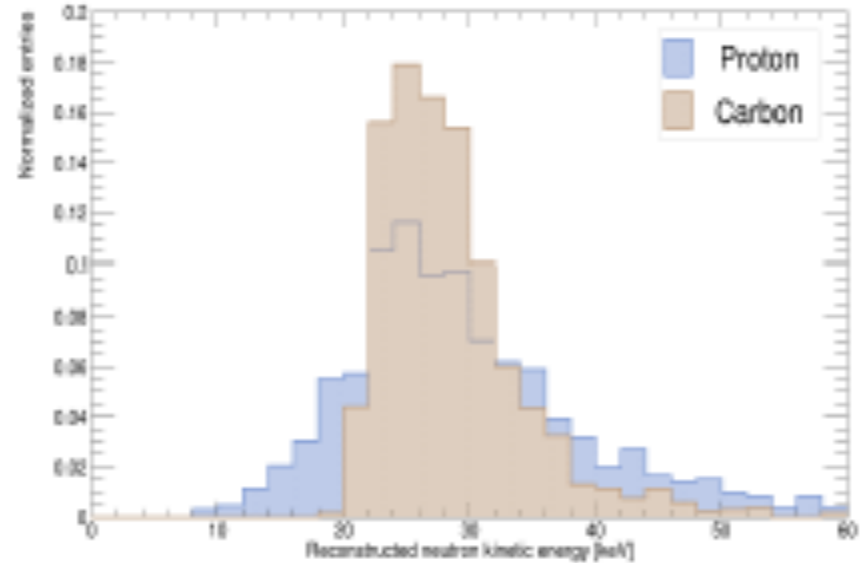
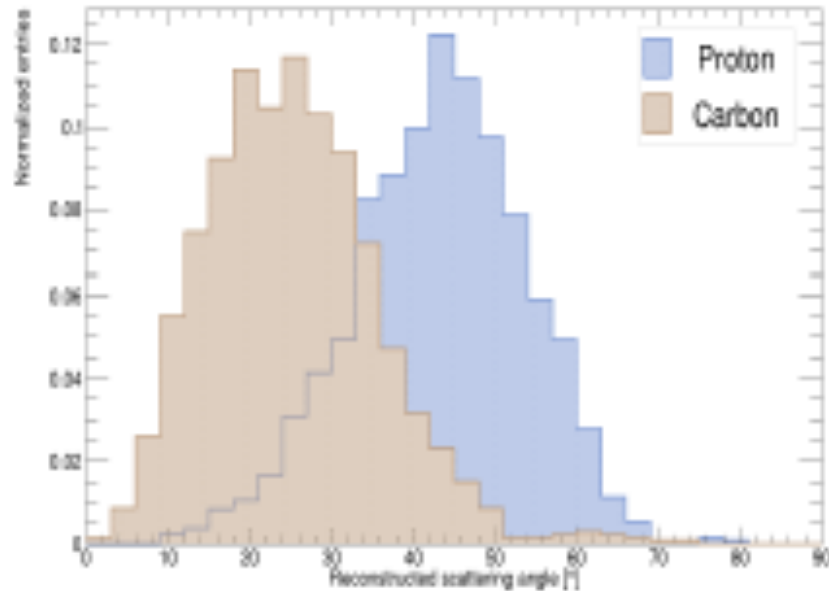
IRSN / AMANDE
(Cadarache)

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

At low energies... 27 keV neutron field

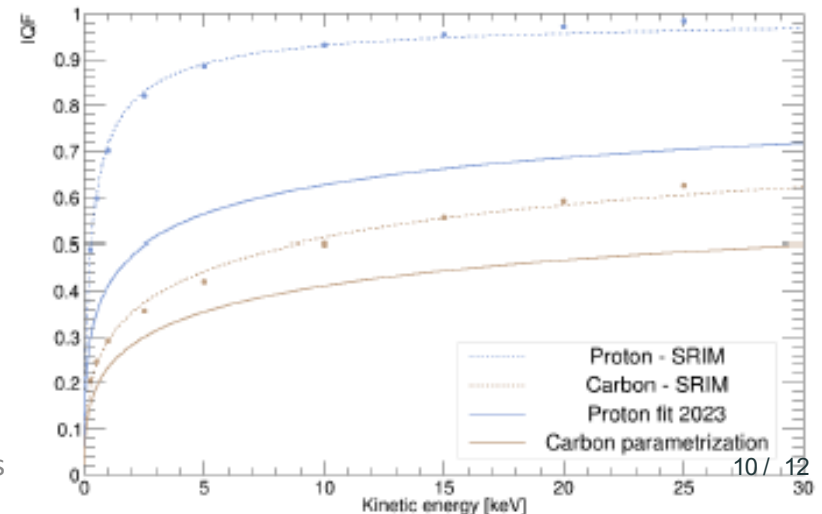
Proton and carbon recoils give the neutron spectra

C. Beaufort et al. (2023, [arXiv:2312.12842](https://arxiv.org/abs/2312.12842))

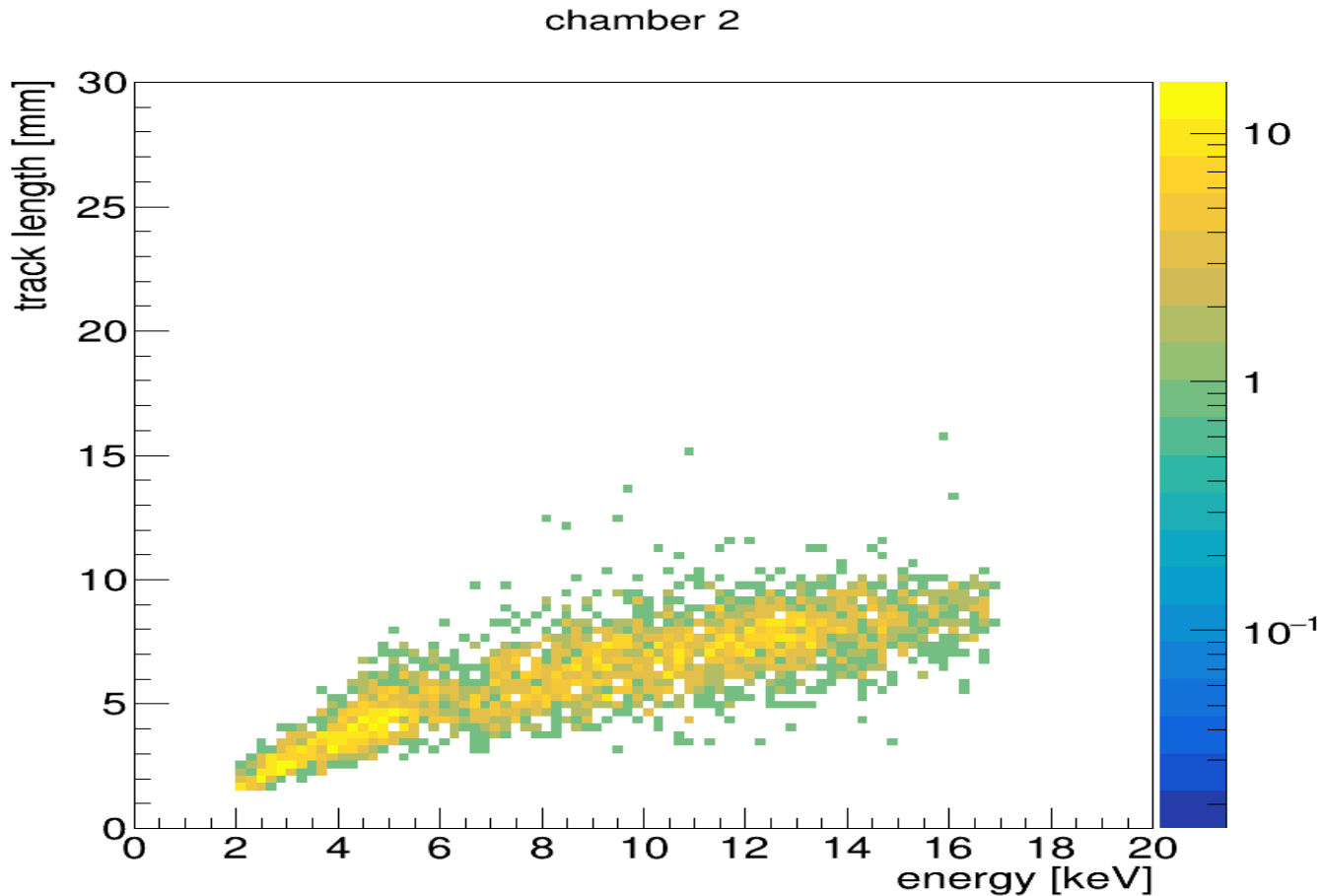


The kinetic energy is reconstructed with :

- the Ionization quenching factor measured by COMIMAC
- understanding the ion contribution to the signal



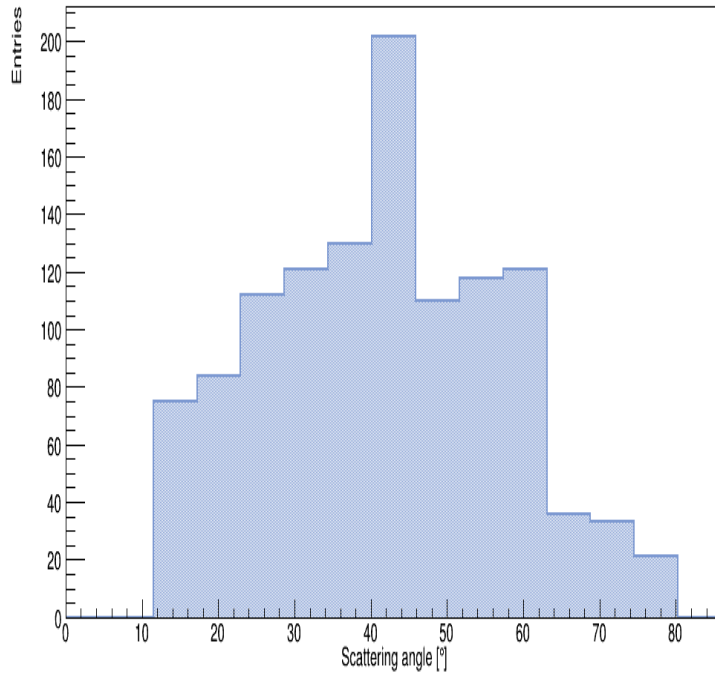
Proton recoil track lengths produced by a mono-energetic neutron field of 27 keV as a function of their ionization energy



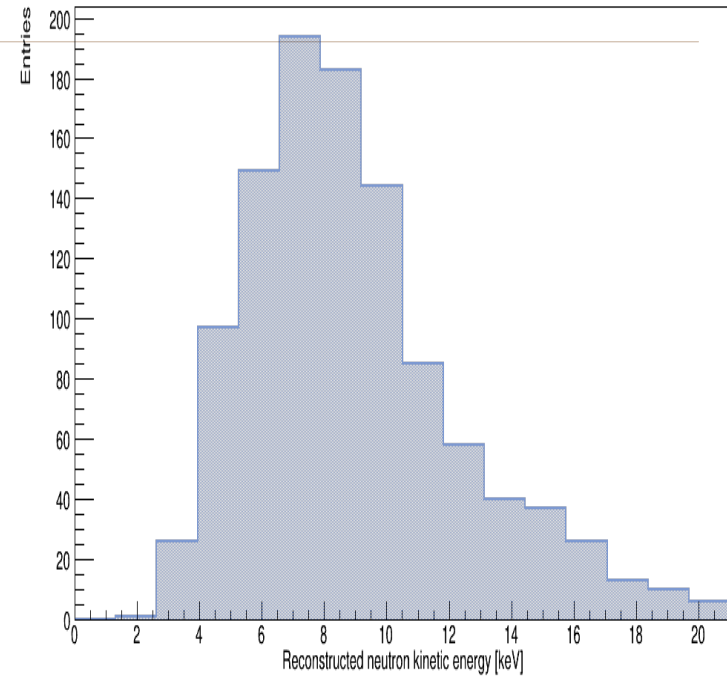
These H⁺ recoils are very useful in characterizing the nuclear recoils searched for DM detection

Mono-energetic neutron field (8 keV)

Neutron spectrum reconstruction from proton recoils



Angular distribution



Reconstructed spectrum

Directional performances at 8 keV:

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

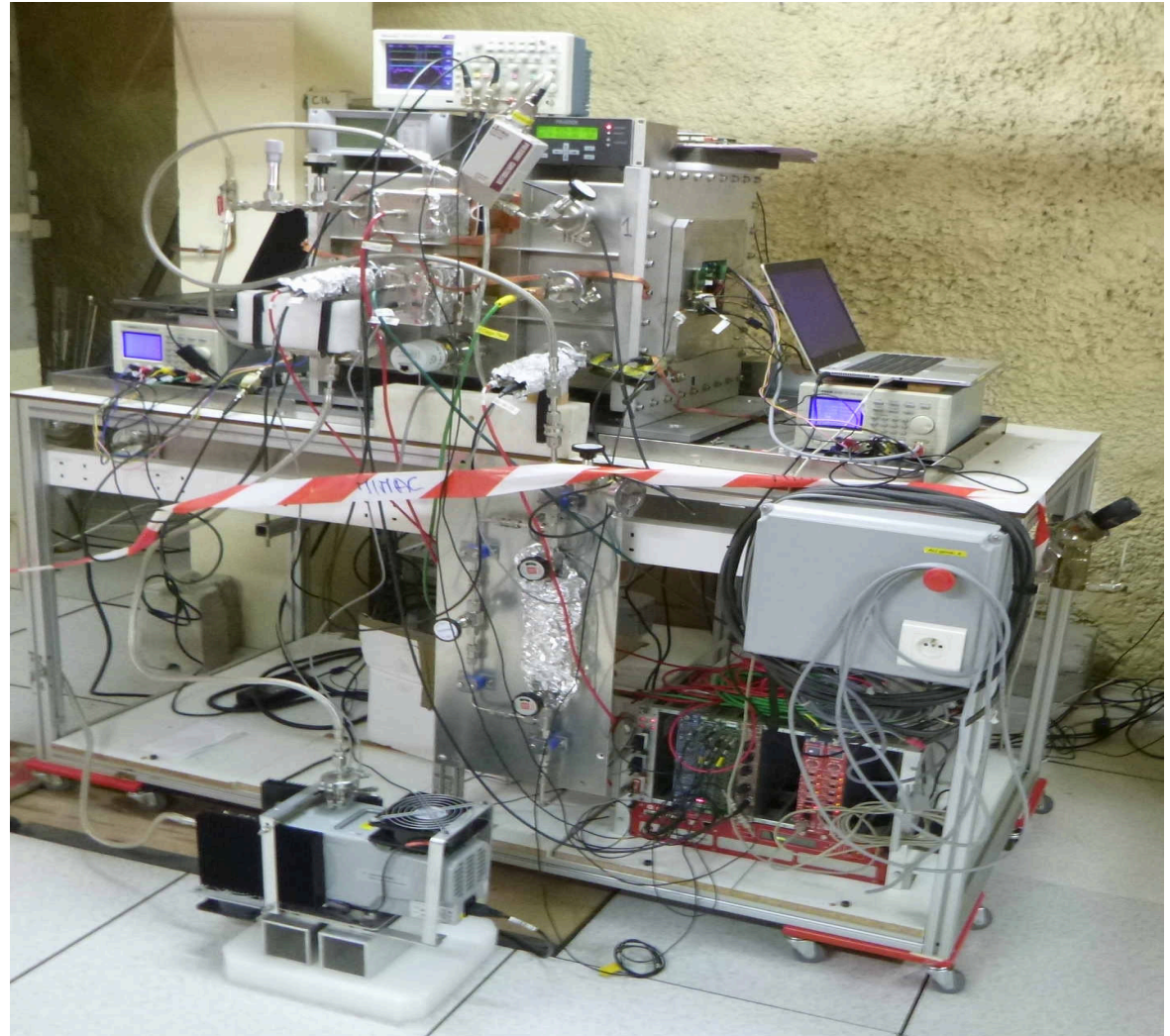
Cyprien Beaufort et al. JCAP08(2022)057

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

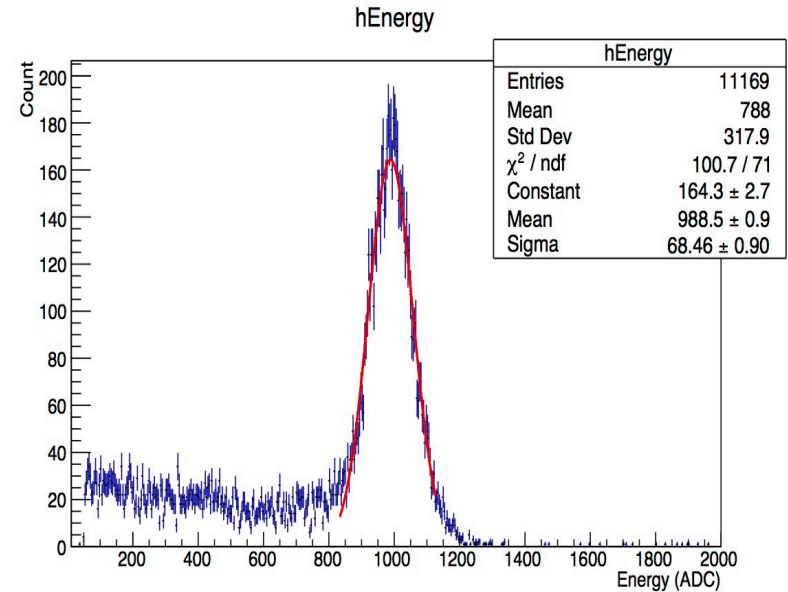
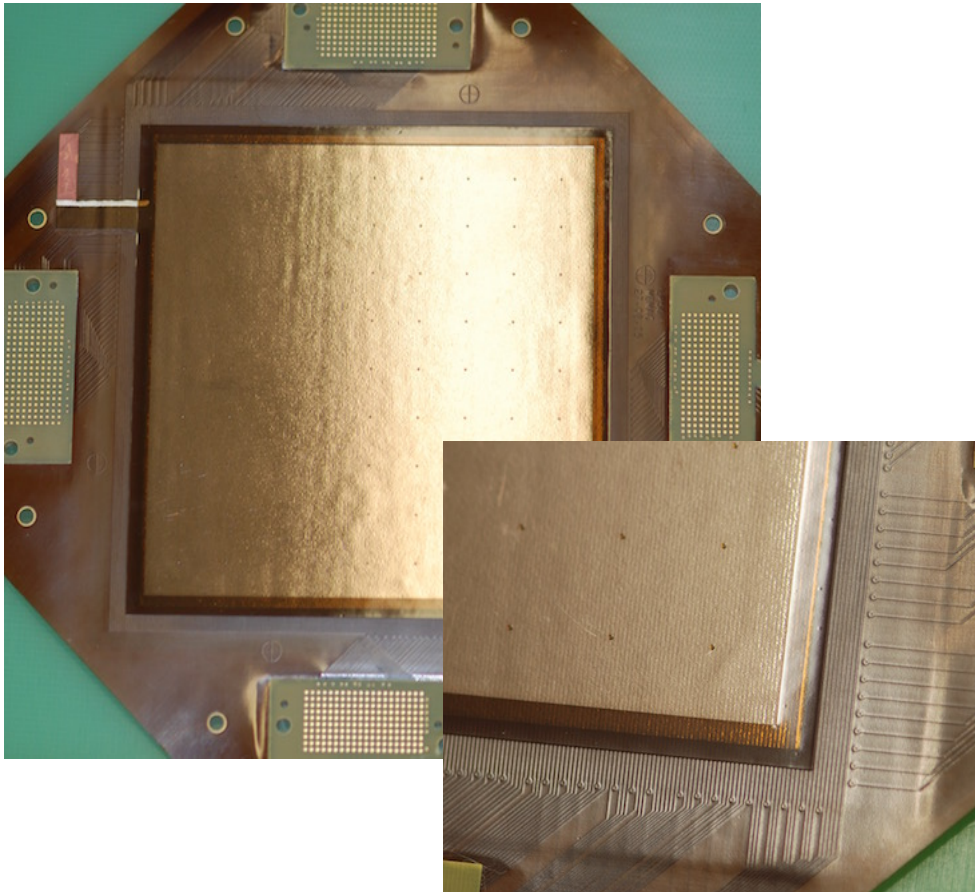
Installed in February 2023

- working at 30 mbar ($C_4H_{10}+50\% CHF_3$)
- Permanent circulating mode
- Remote controlled and commanded
- A periodic calibration by an X-ray generator

MIMAC
at
LSM



New MIMAC low background detector

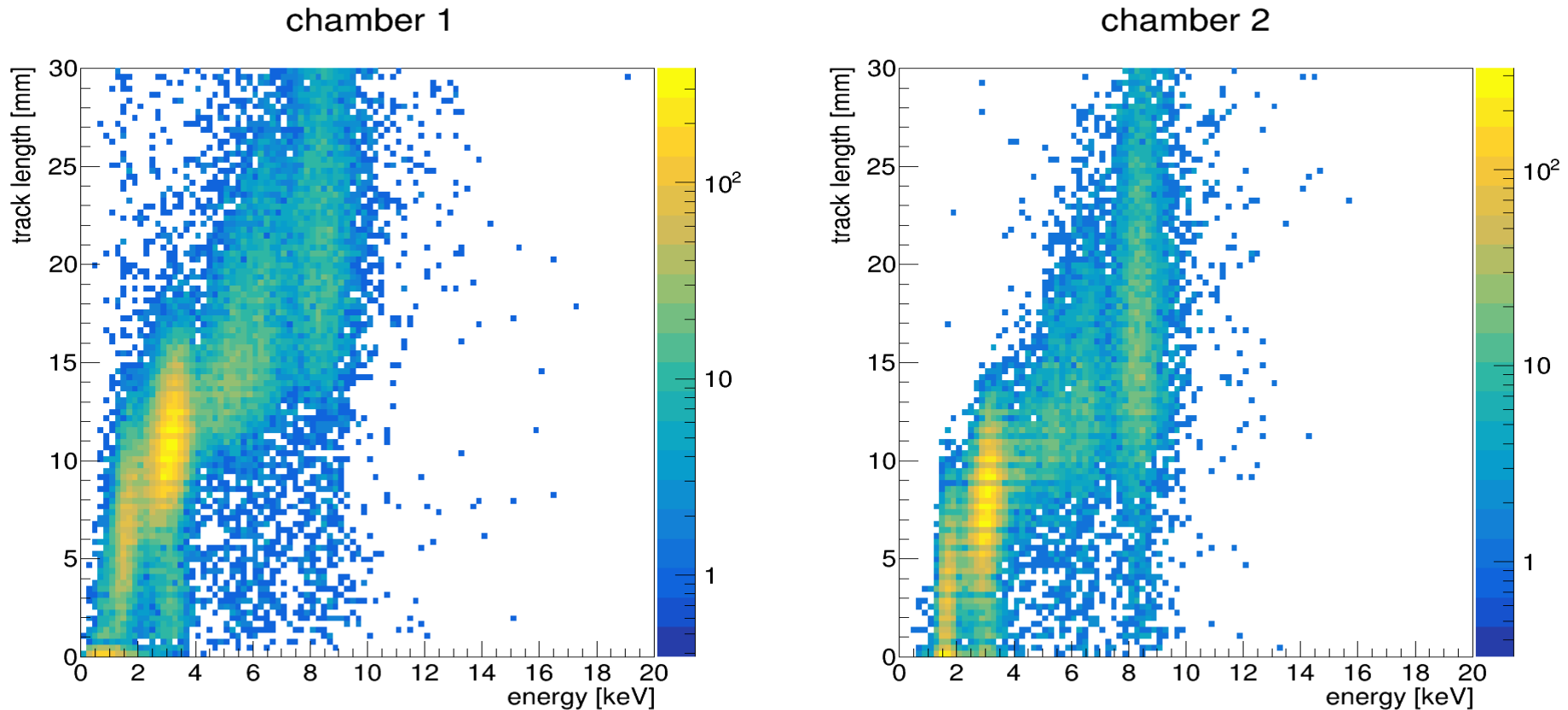


Gaz : MIMAC 50 mbar
HT grille : -560 V
Drift field : -150 V/cm

Kapton micromegas readout
Piralux Pilar

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

Electron track lengths produced by X-rays as a function of their energy



These electron tracks are very useful in the electron vs. nuclear recoil discrimination

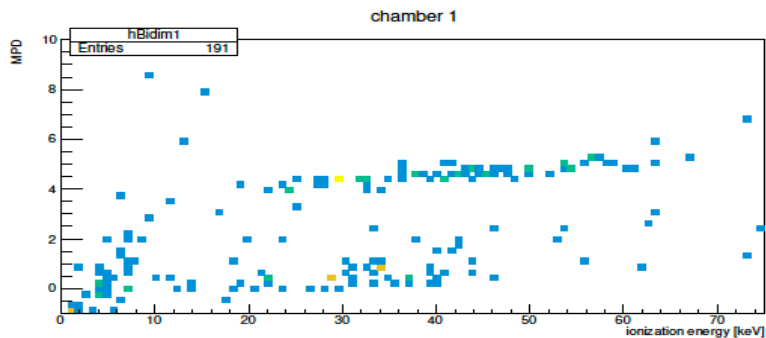
The first physics run of the Bi-chamber in february 2023 at Modane

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

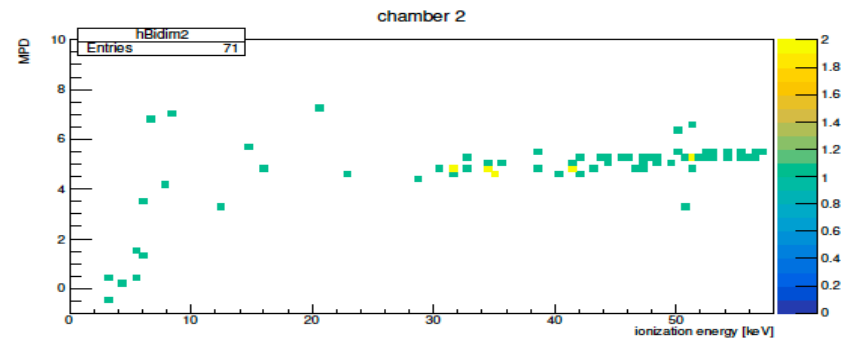
127 h analysed at moderate gain (470 V)

Only recoils after the BDT, mainly from the Rn progeny.

Improvement of the new detector showing very few Rn progeny contributions

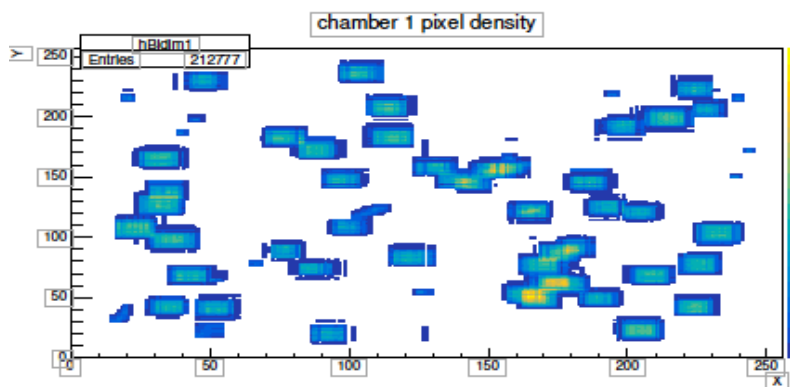


(a) In chamber 1.

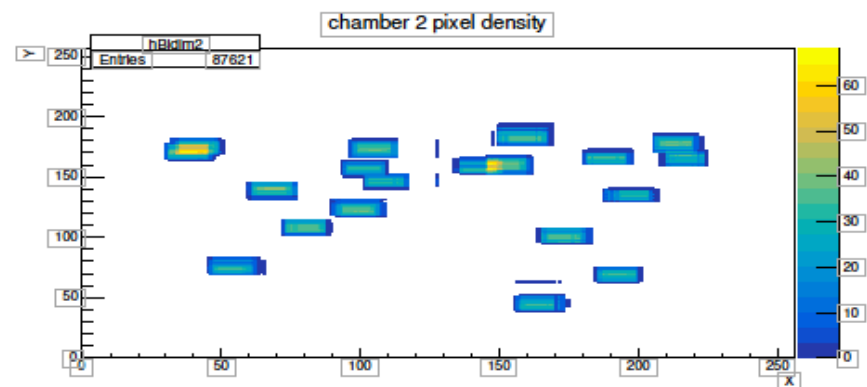


(b) In chamber 2.

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.



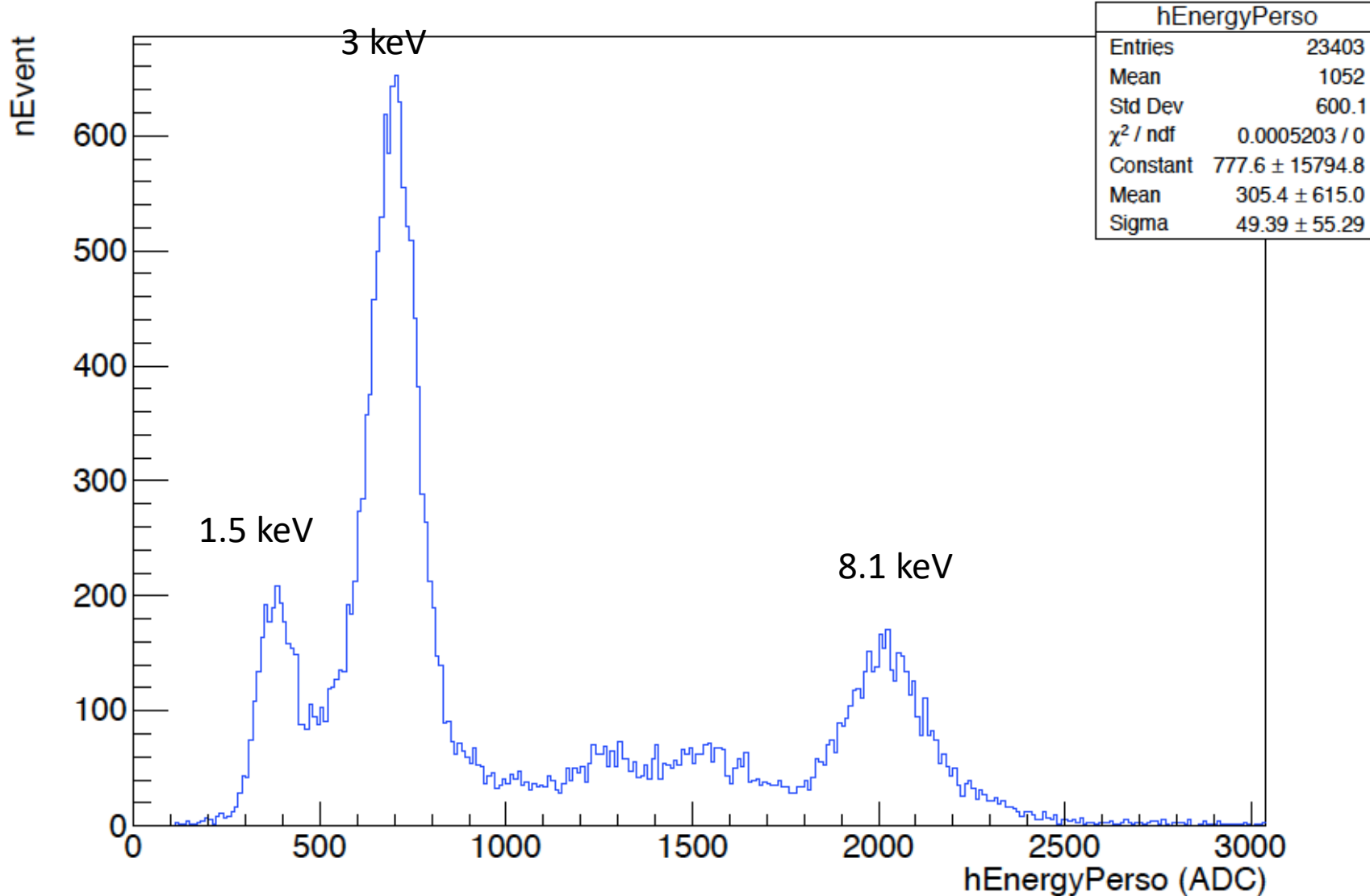
(a) In chamber 1.



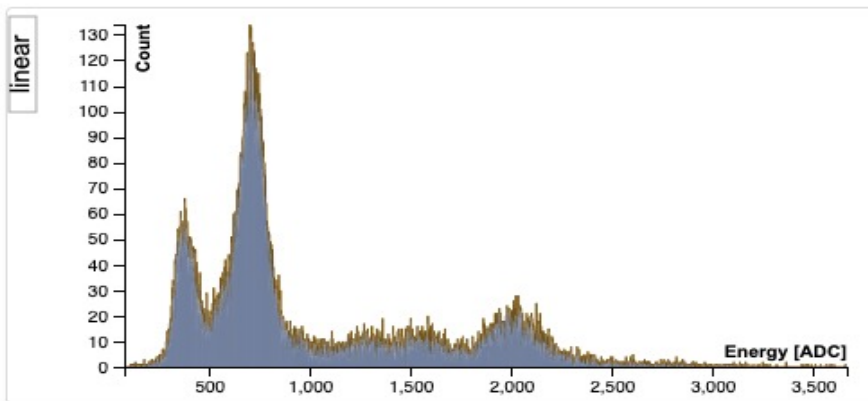
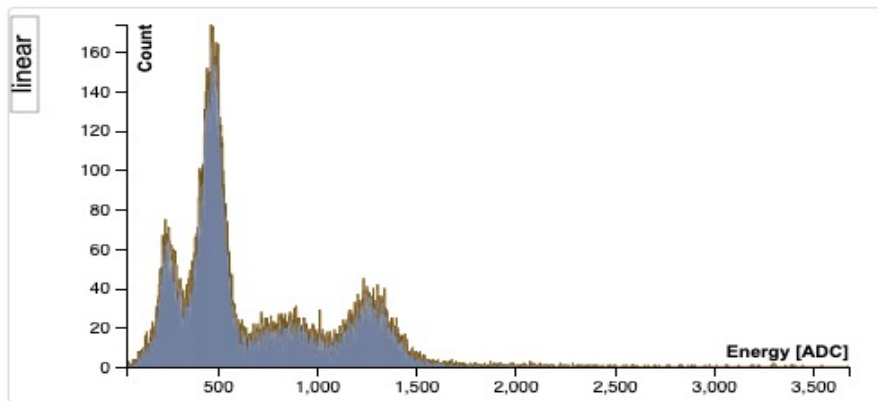
(b) In chamber 2.

X-Y projections of the 3D tracks

X-ray Calibration of the new detector Bi-chamber Module at 500 V, 3000V drift

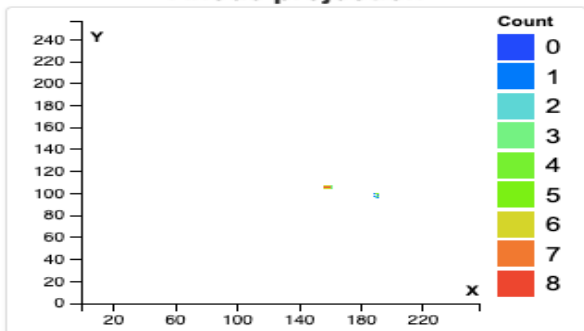


X-ray calibration of both chambers simultaneously

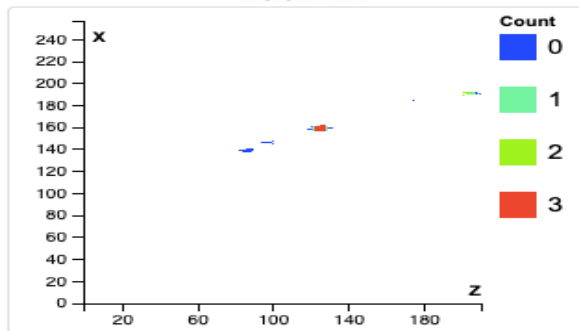


A typical electron event in the chamber 2

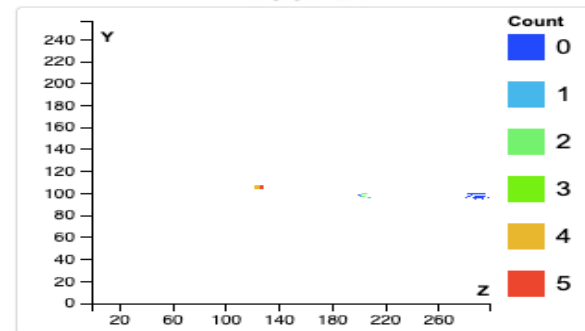
Anode projection



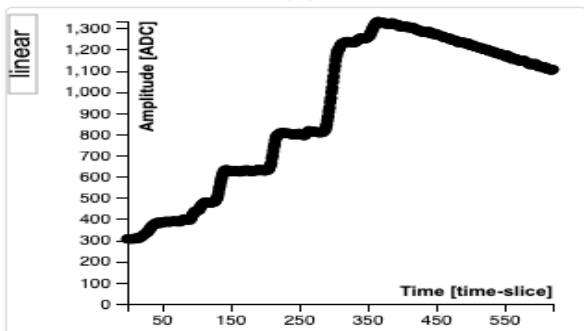
Track ZX



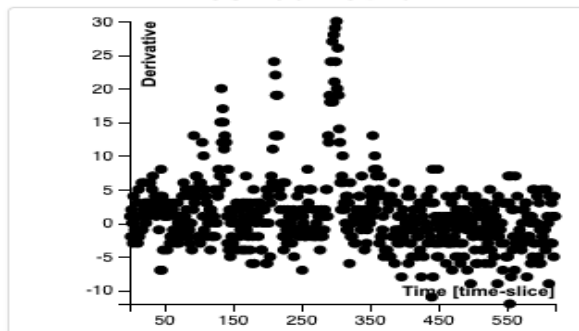
Track ZY



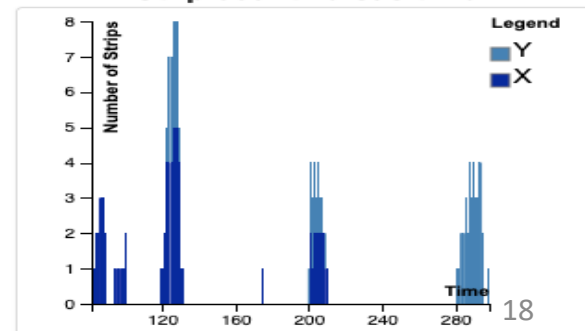
Flash



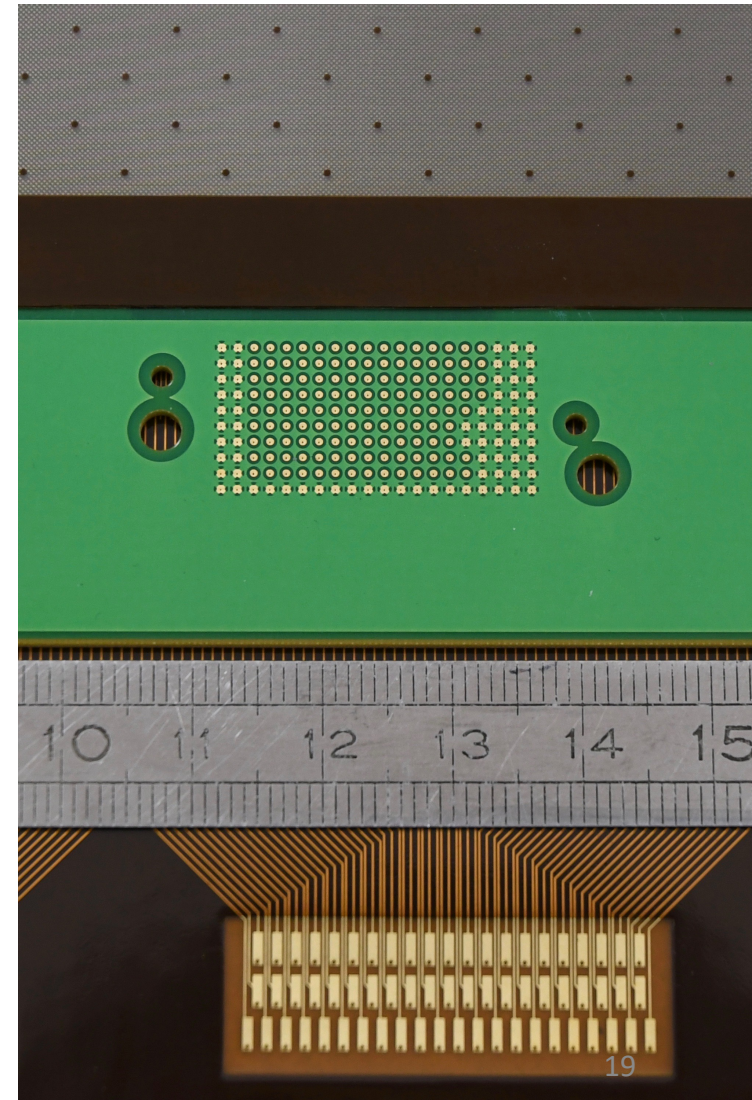
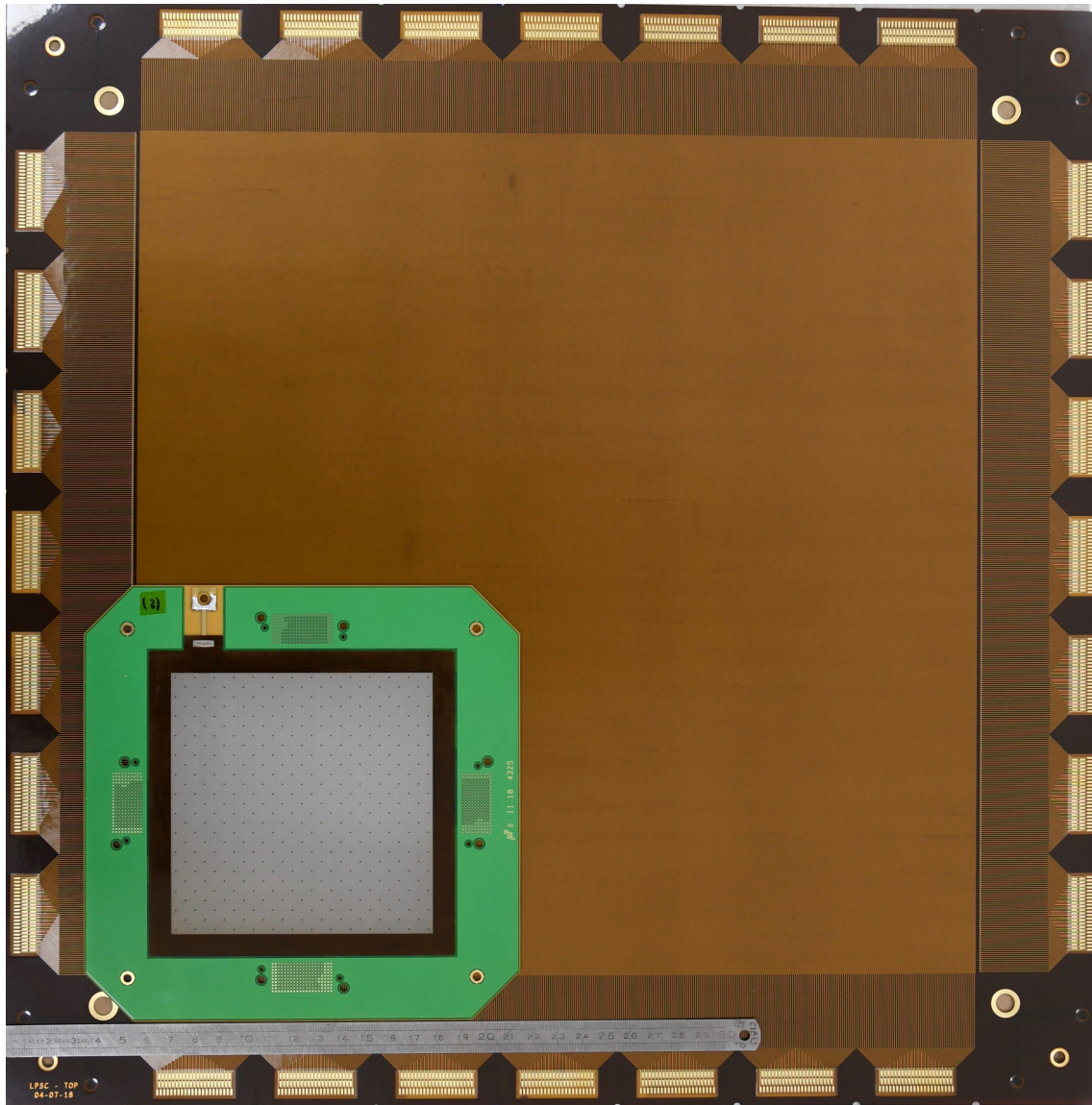
Flash derivative



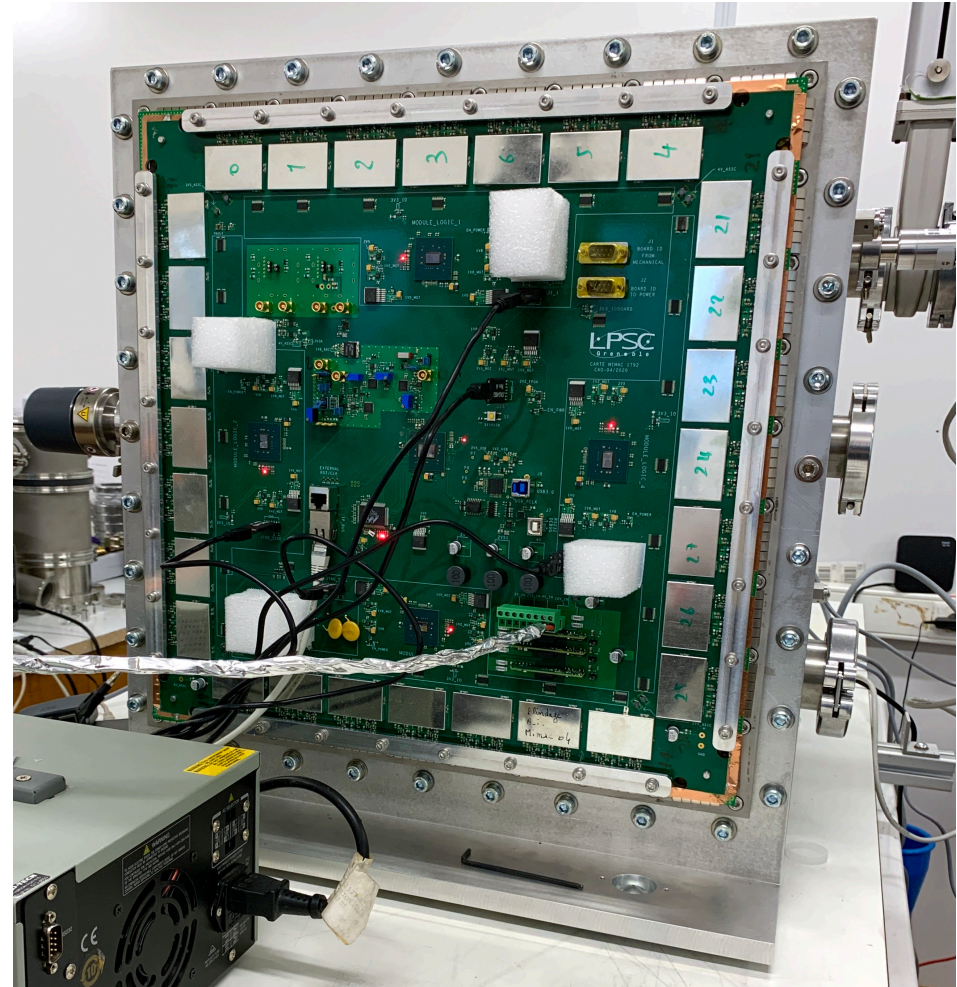
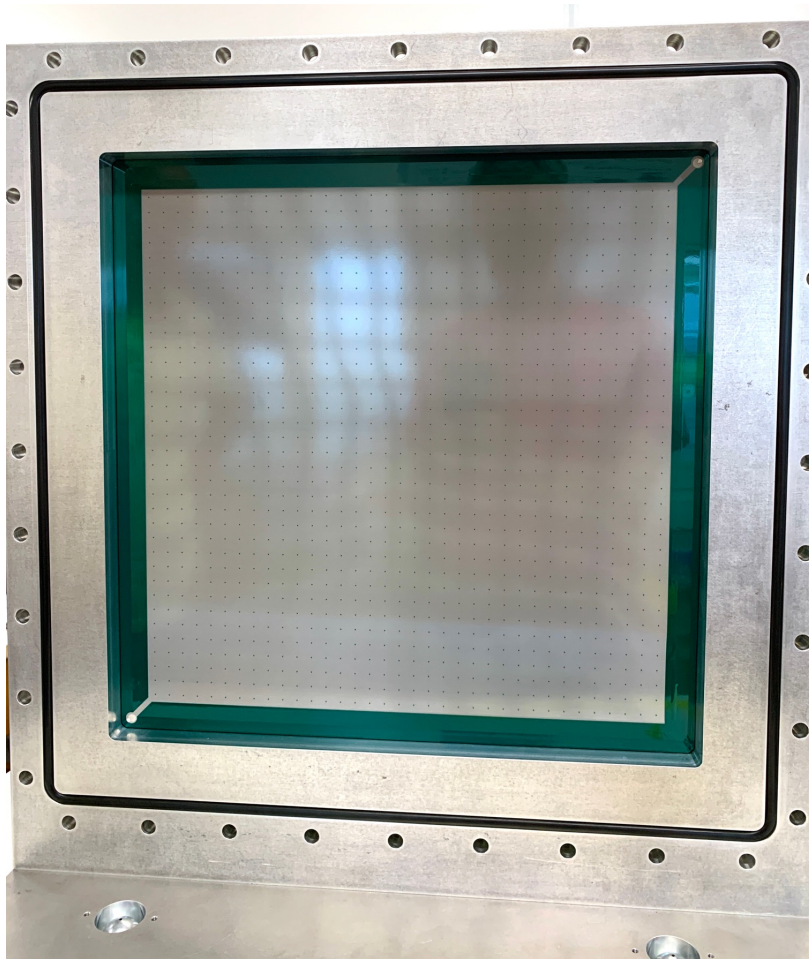
Strip count versus time



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



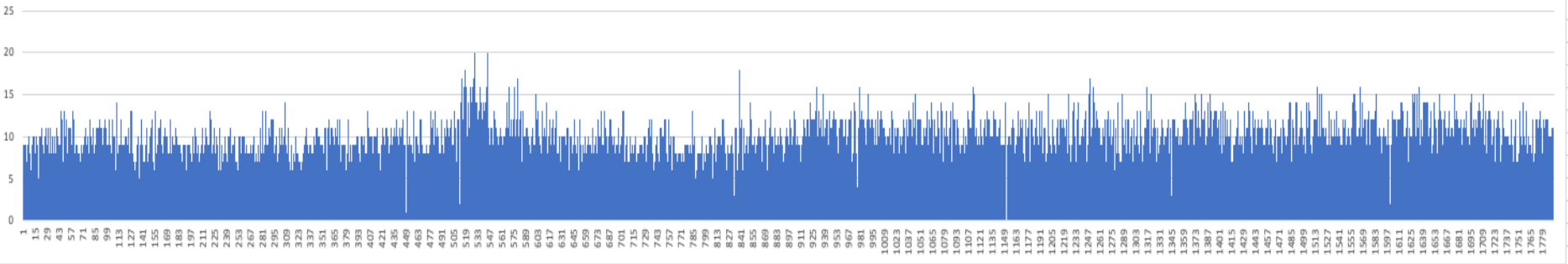
The new detector (35cm side, PCB) is mounted in the bi-chamber at the LPSC-Grenoble



AUTOCALIBRATION OF THE 1792 (896 + 896) CHANNELS

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

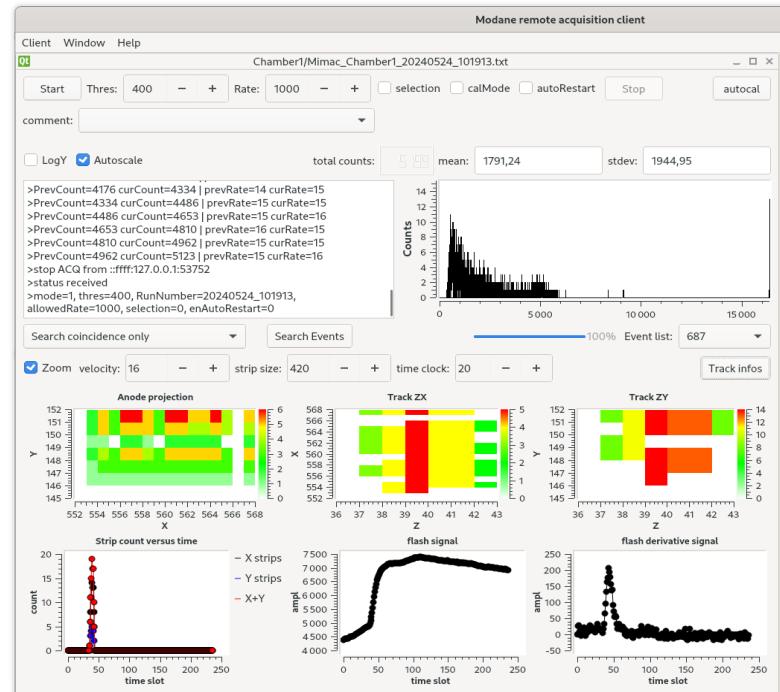
16 mai 2024 Autocal sur la Bichambre



C_4H_{10} (30 mbar)

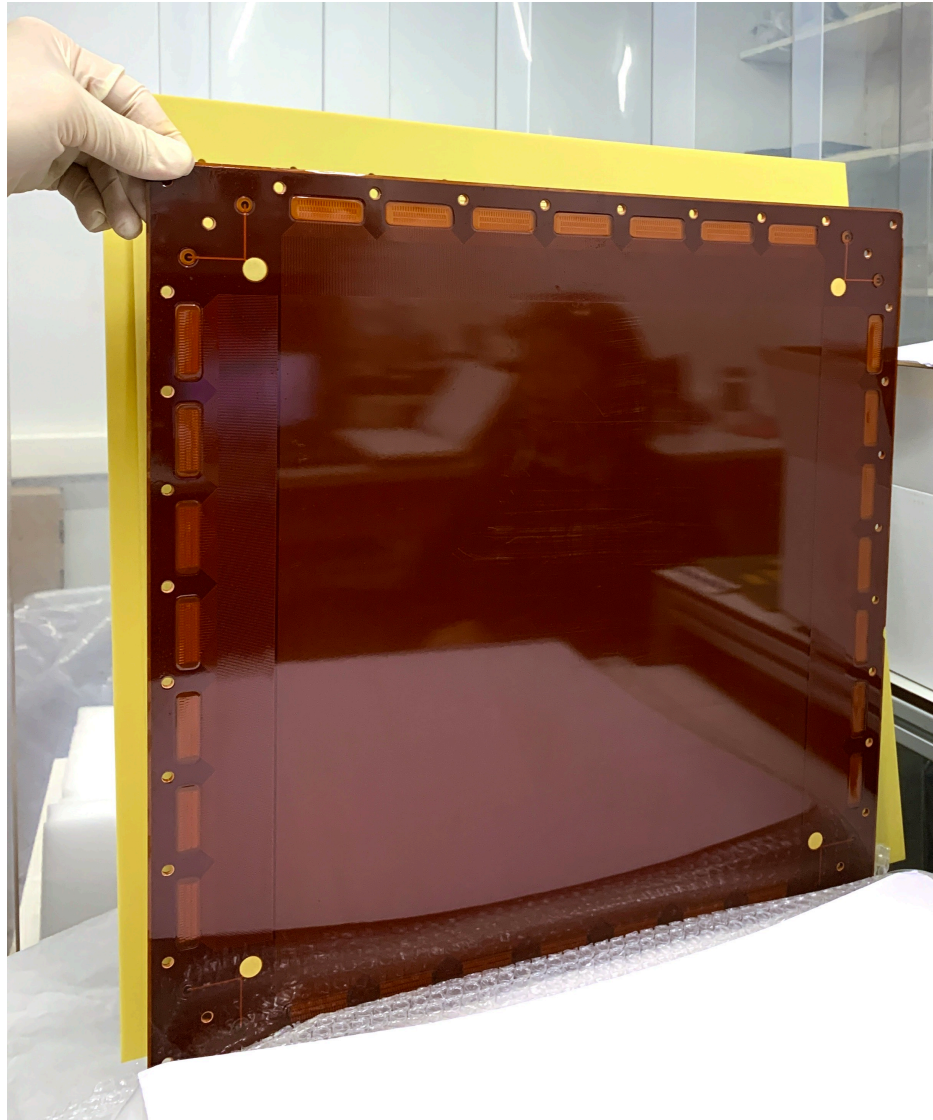
The first events with 3D tracks, of the background at Grenoble (May 24th 2024)

Still many things to improve, but it works !!



Grenoble , May 30th 2024

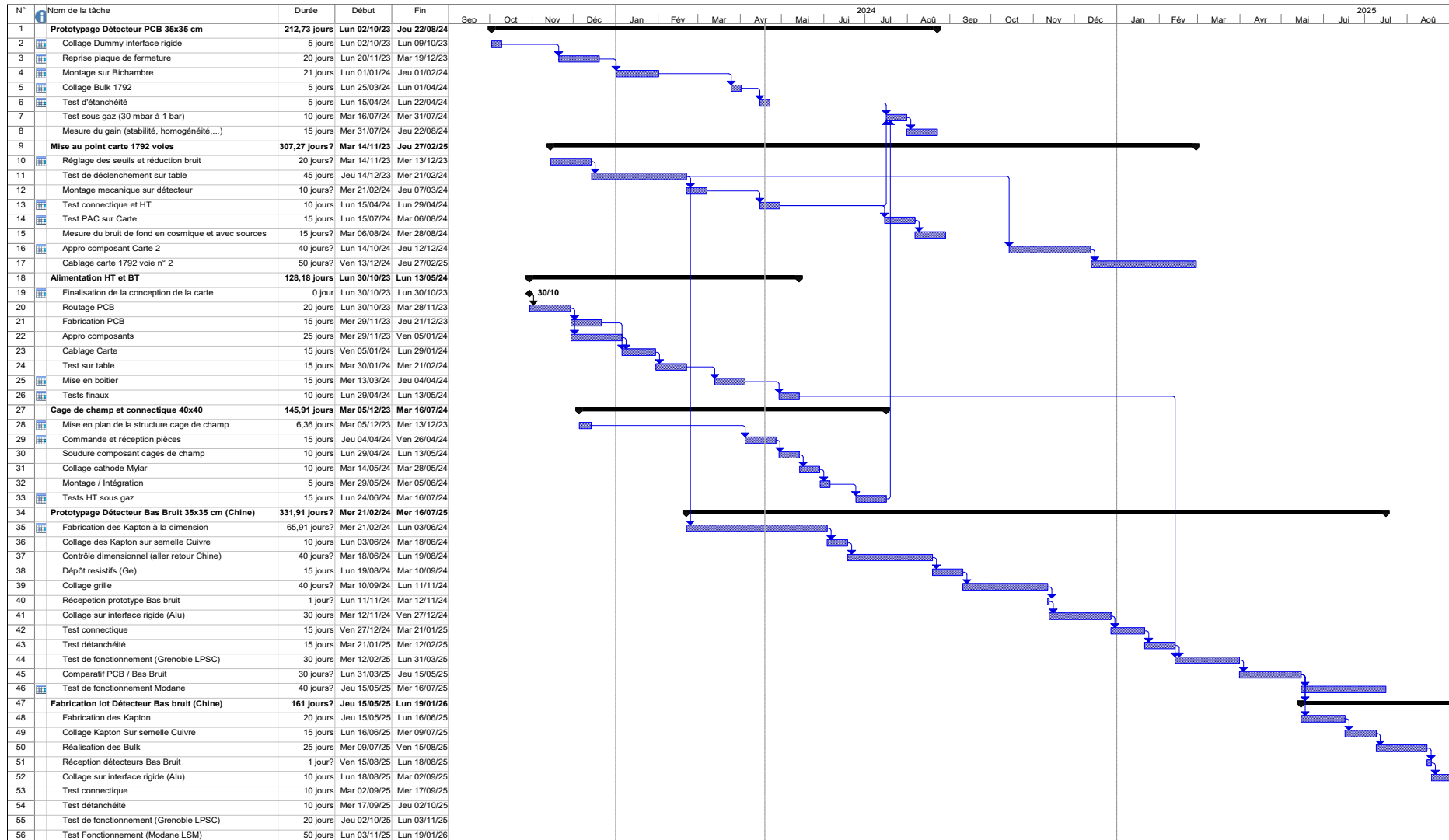
New Micromegas (35cm) on Kapton/Copper made by Chinese USTC (Hefei)



Received on May 28th May 2024
in LPSC-Grenoble



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



Projet : MIMAC2018
Date : Ven 19/04/24

Tâche		Récapitulative de projet		Jalon inactif		Durée uniquement		Fin uniquement		Echéance	
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			

New MIMAC Bi-chamber 35x35x25 cm³

- 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 – 1m³

16 bi-chamber modules (2x 35x35x25 cm³)

New technology anode
35cmx35cm

New electronic board
(1792 channels)

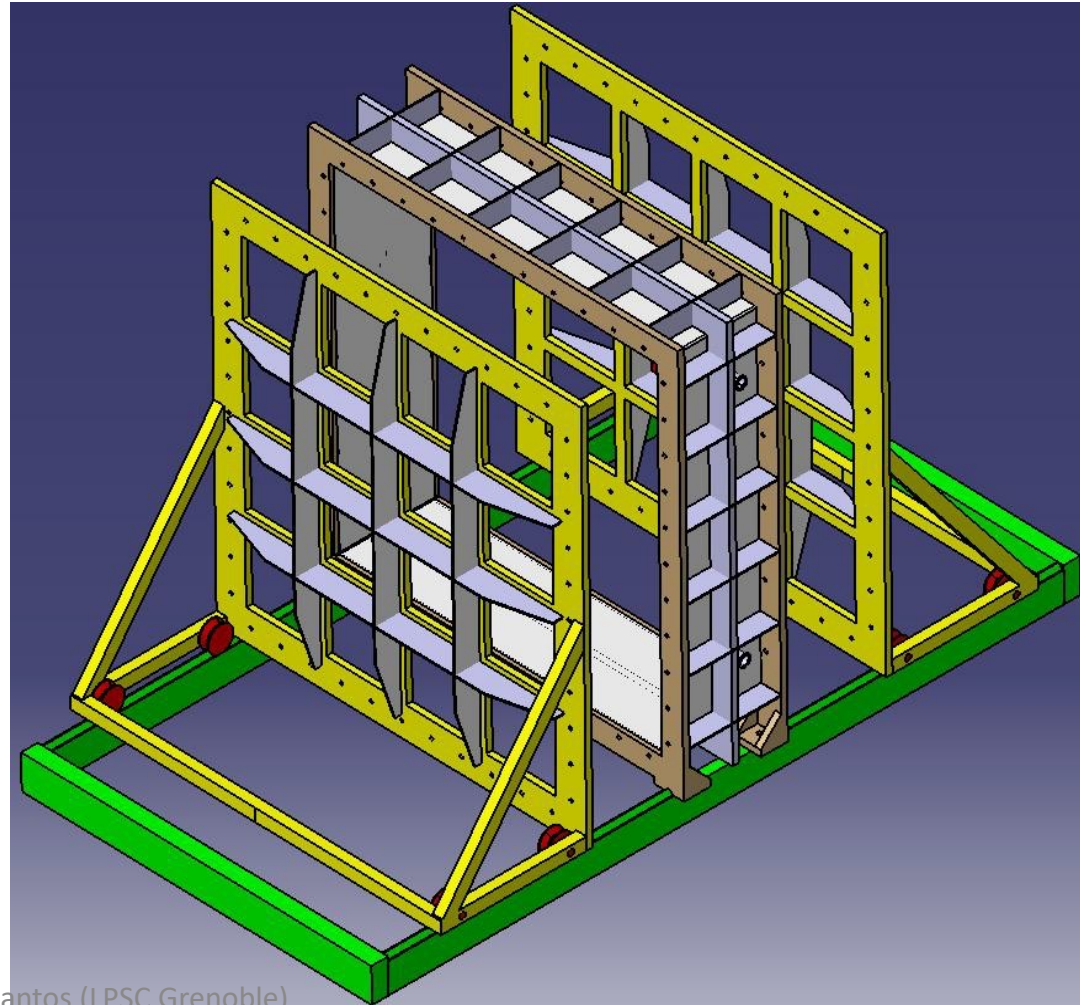
Only one big chamber with
4 field cages inside

First 1 m³ at Modane
by the end of 2027

Pending complementary funding of
200k€

Second 1 m³ at Jinping
by the end of 2028

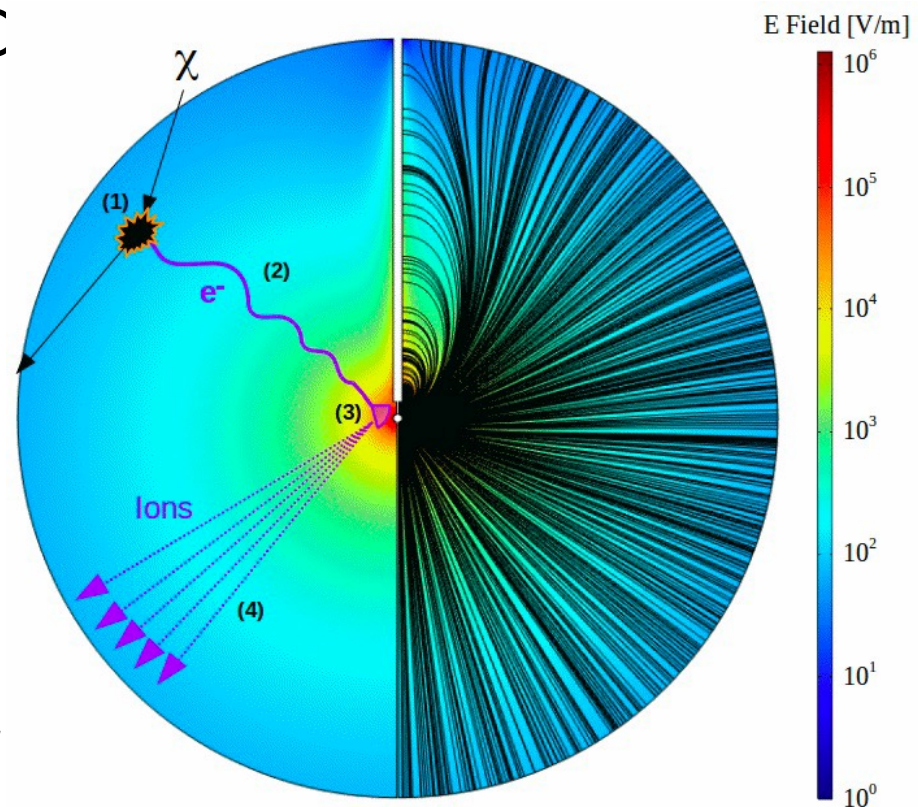
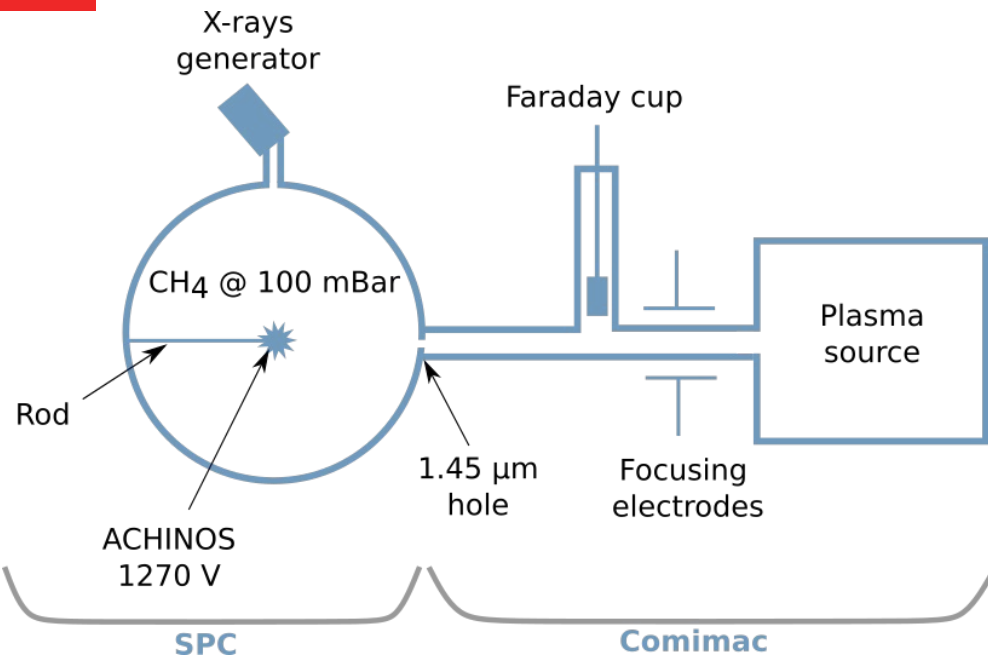
financed by the Chinese partners



NEWS-G (Sedine) at LSM

A. Dastgheibi-Fard, O. Guillaudin, J.F. Muraz and D. Santos
on behalf of NEWS-G collaboration

S30 coupled to COMIMAC



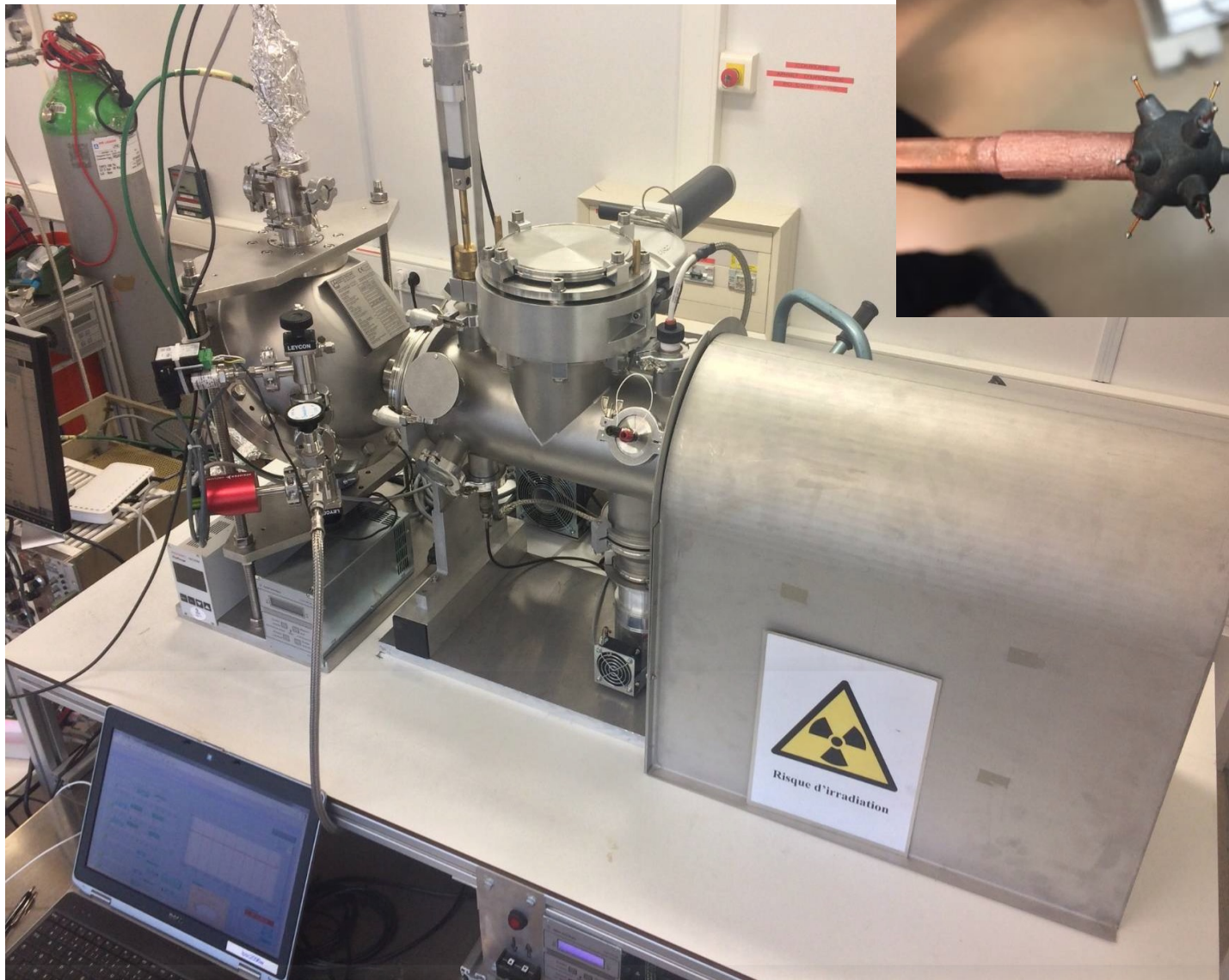
- Table-top particle accelerator
- Send electrons and ions of known kinetic energy
- Interfaced with the detector through a 1.45 μm hole

$$IQF(E_K) = \frac{E^{ioniz}}{E_K} = \frac{f_{calib}(E_{ADU})}{E_K}$$

Ions
Comimac
Electrons



S30 coupled to COMIMAC



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

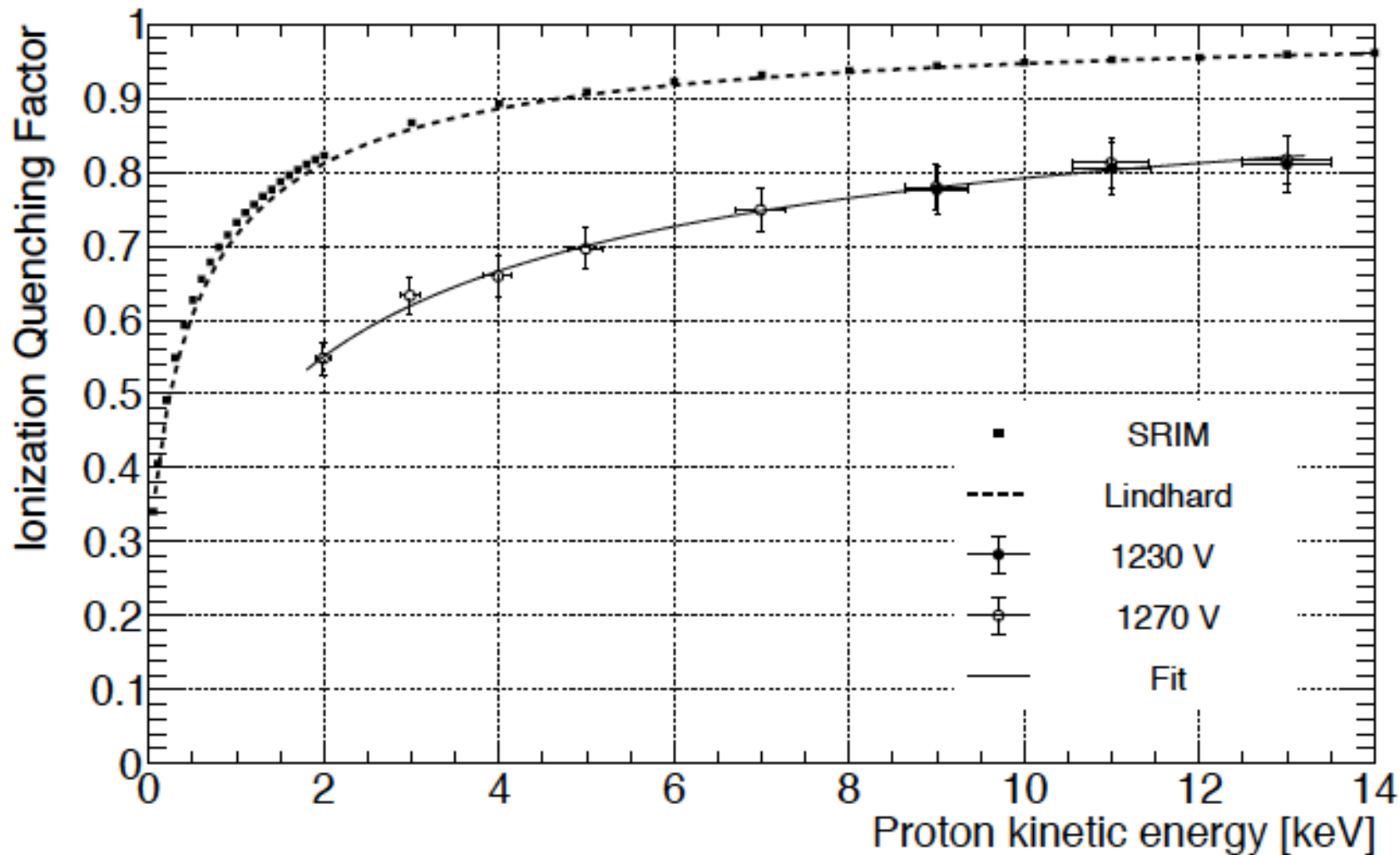


Fig. 9: Ionization Quenching Factor for protons in 100 mbar of methane. The measurements at 1230 V and 1270 V are respectively presented with black dots and white dots. Comparisons with SRIM and with the Lindhard theory are also shown.

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.

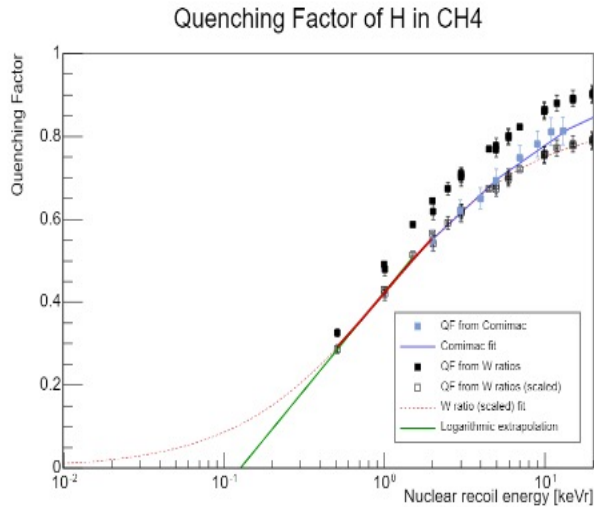


FIG. 1. QF used in this work. From highest to lowest energies, we use the COMIMAC measurement (lavender line [34]), scaled W-value ratios (red line [35]), and a logarithmic extrapolation (green line); the Lindhard-like extrapolation is shown for comparison (dotted red).

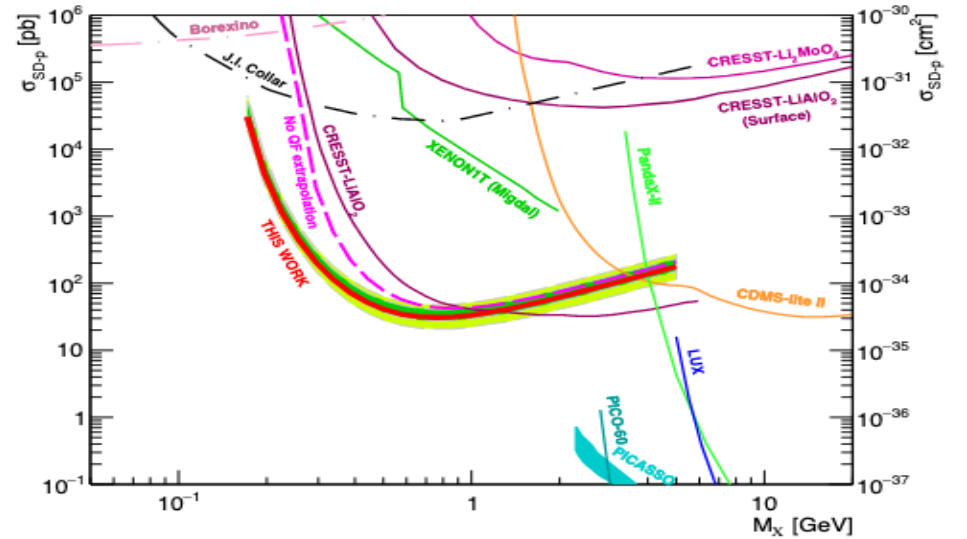
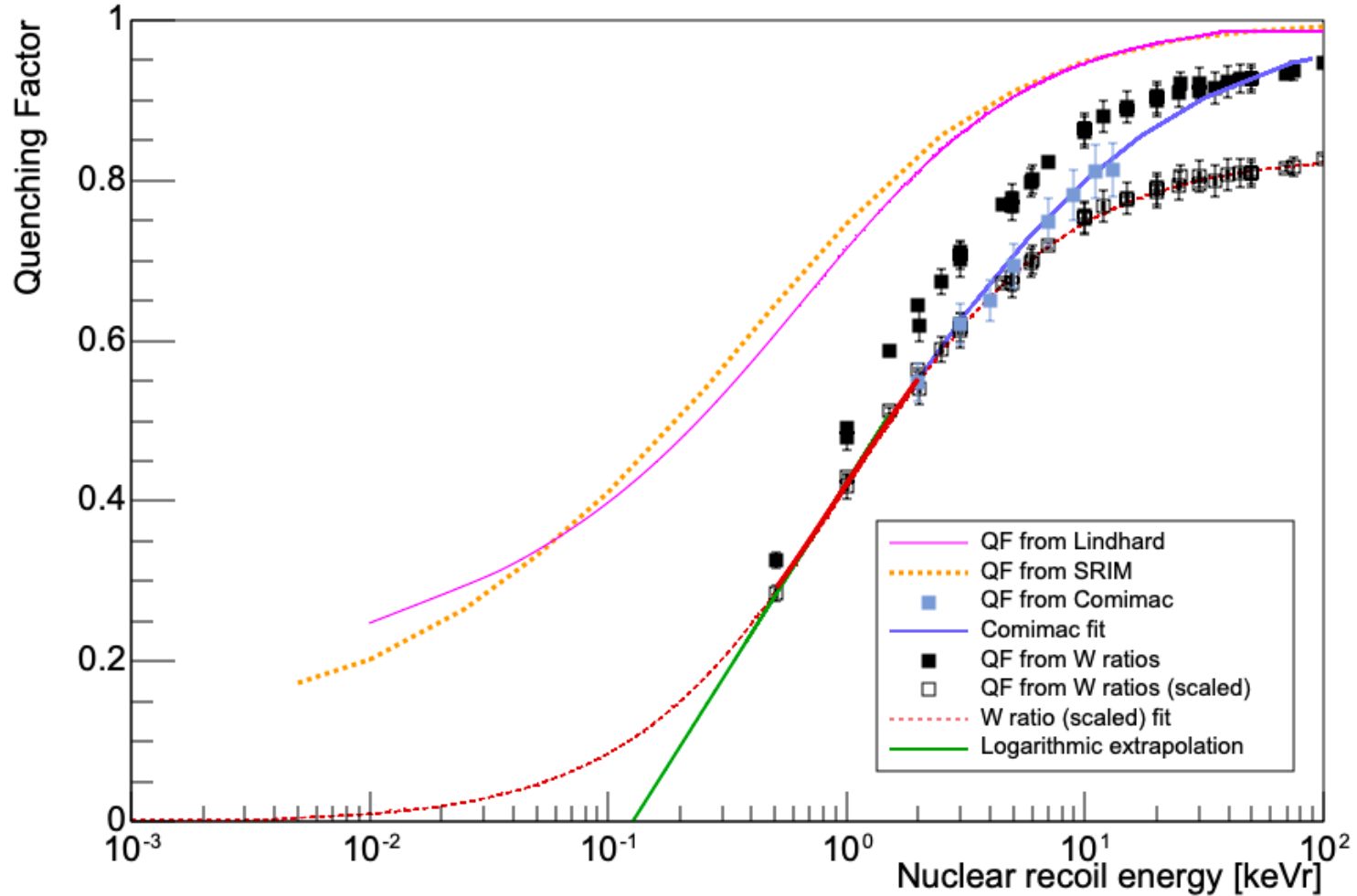


FIG. 3. Exclusion limit on the WIMP–proton spin-dependent cross-section from this work (thick red line) and 1 and 2 σ sensitivity bands (dark and light green shaded areas respectively). The equivalent limit with no quenching factor extrapolation is shown for reference (dashed pink line). Upper limits 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.

Quenching Factor of H in CH4



Sedine at LSM

- Sedine, the first spherical low background detector made with 5N Copper (purity of 99.999%)
- To profit from the work done on NEWS-G (S140) at Modane and Snolab understanding the background and signals in the sphere.
- To profit from the possibility of running an experiment with CH_4 at a pressure of 800 mbar (5.9 times the pressure of S140 run at Modane) and having the IQF measured at Grenoble

We have a nice opportunity to improve the fast exploration of the background for low Wimp masses... even better than present limits

Conclusions

- MIMAC has developed know-how on 3D directional detection from 300 eV up to 15 MeV and even more...600 MeV
- The 10 x 10 cm² Mimac-FastN can become a primary neutron spectrometer discriminating fast and epi-thermal neutrons
- The nuclear recoil directional detection is the observable needed to go beyond the neutrino floor for DM search providing the galactic signature
- The 35 x 35 cm² is the elemental brick to build a big volume directional detector
- The Sedine detector can perform a fast exploration of the low - energy background

A large energy range of neutron fields

50% C₄H₁₀ 50% CHF₃
30 mbar

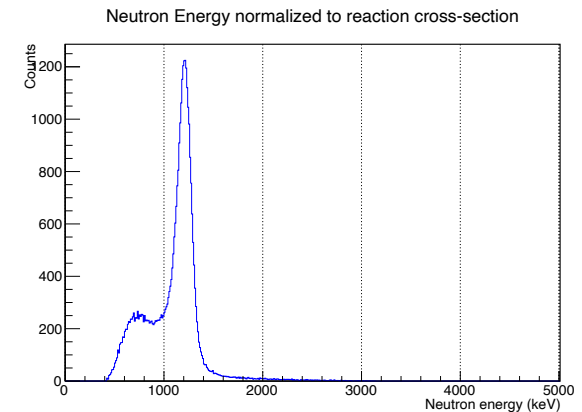
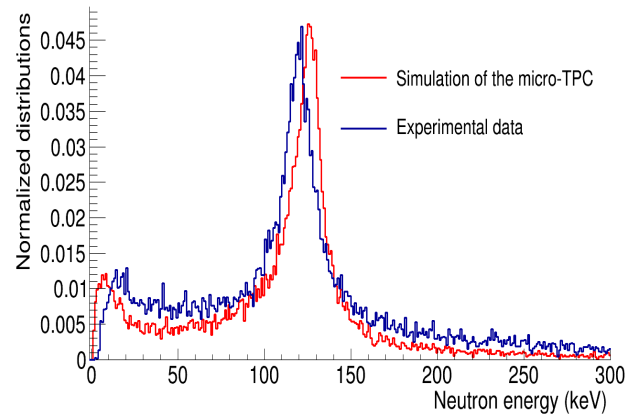
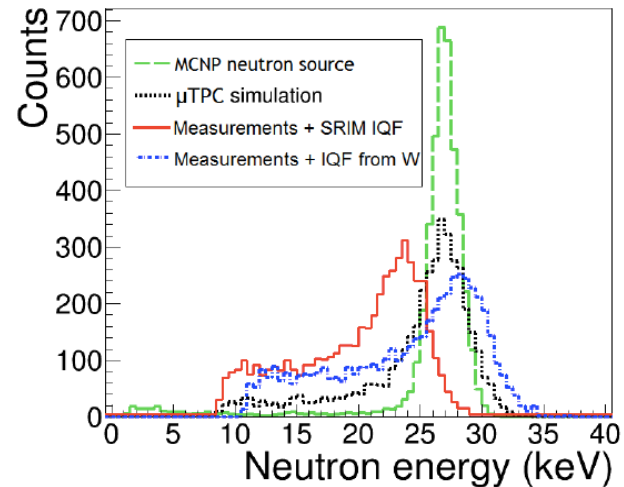
60% C₄H₁₀ 40% CHF₃
50 mbar

95% ⁴He 5% CO₂
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 »

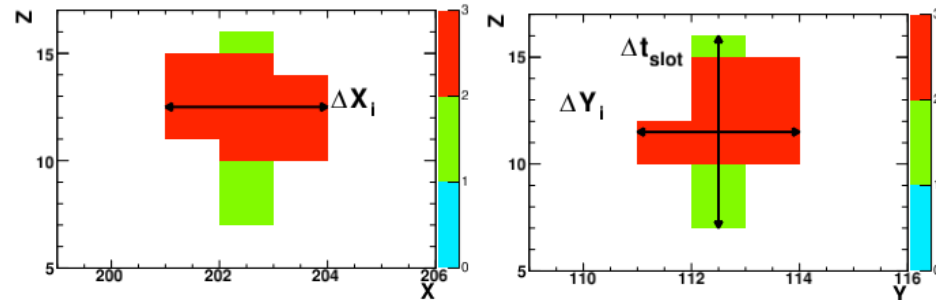
Nuclear Science, IEEE Transactions, 61(2014) 2090

RPR events occur at different positions in the detector...

$z_0 \longleftrightarrow$ Diffusion

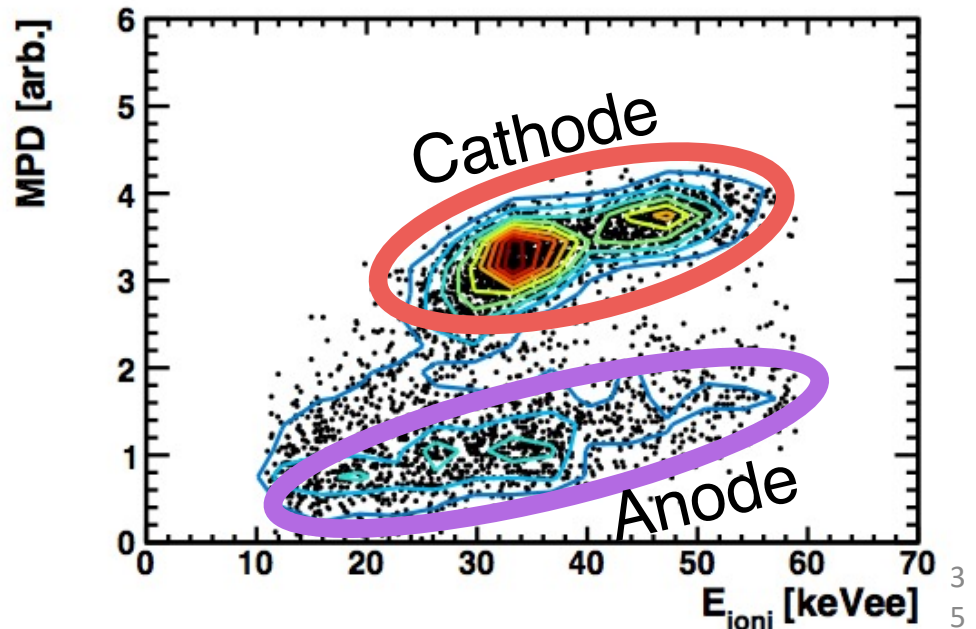
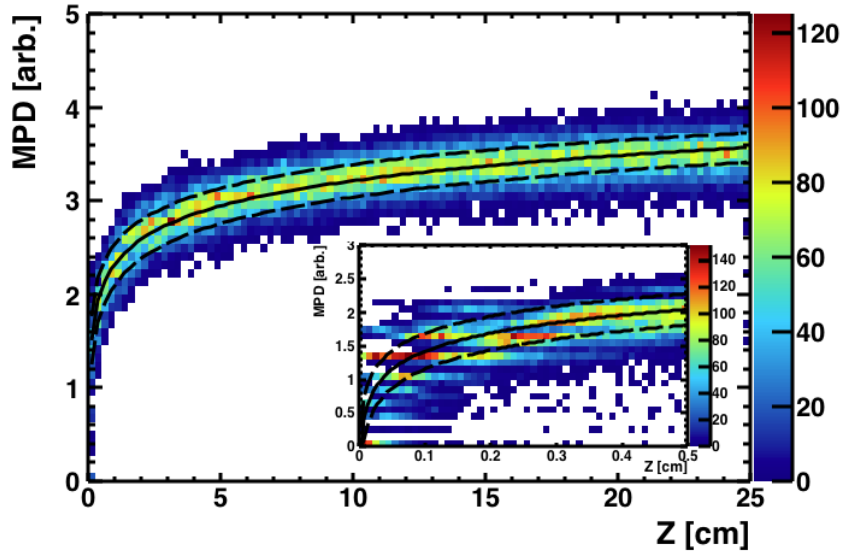
$$\begin{cases} D_T = 237.9 \mu\text{m}/\sqrt{\text{cm}} \\ D_L = 271.5 \mu\text{m}/\sqrt{\text{cm}} \end{cases}$$

« Grid » event



Mean Projected Diffusion:

$$\bar{D} = \ln (\overline{\Delta X} \times \overline{\Delta Y})$$



3D tracks of Rn progeny

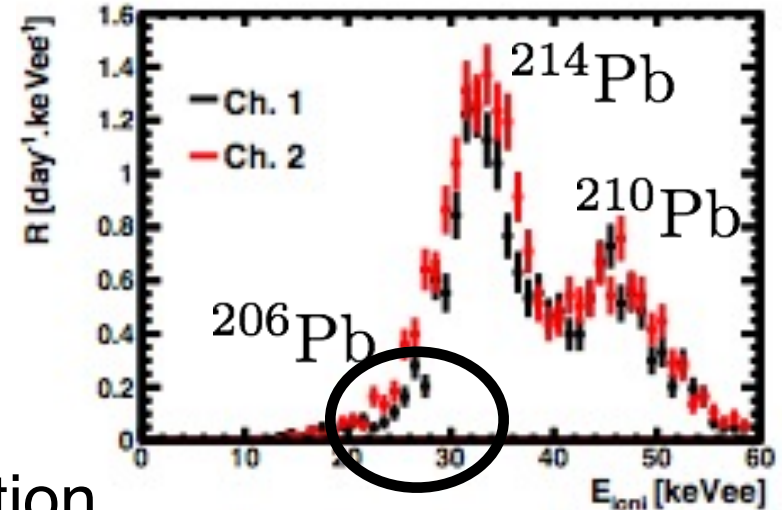
Electron/recoil discrimination

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

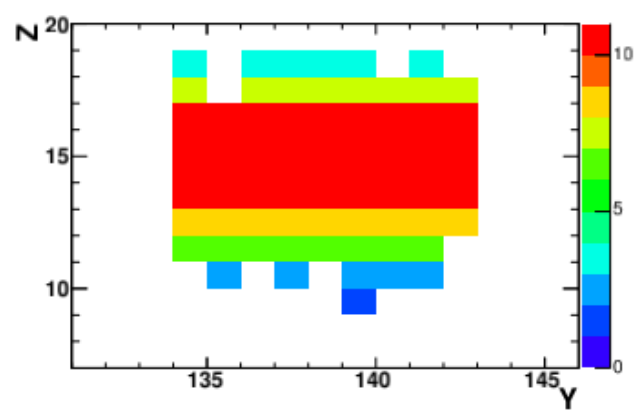
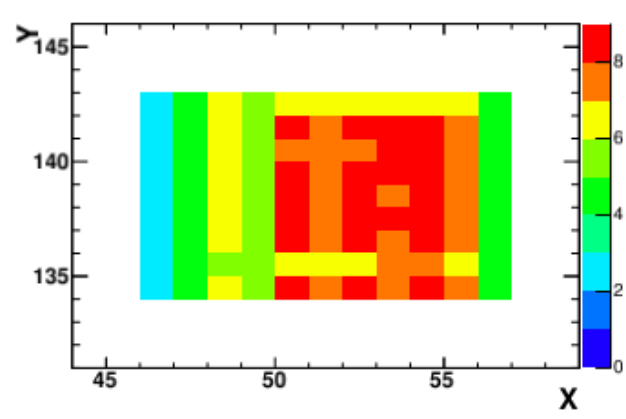
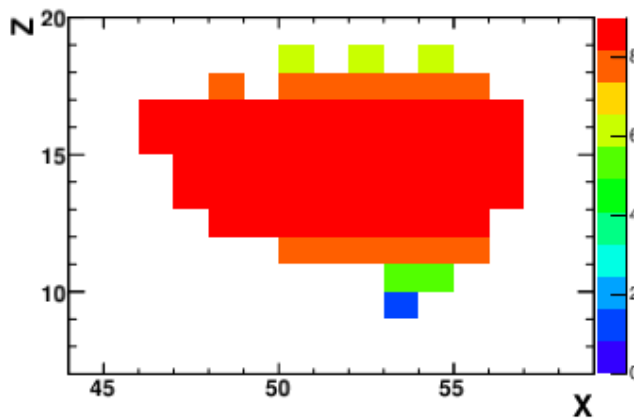
First measurement of 3D nuclear-recoil tracks coming from radon progeny

→ MIMAC detection strategy validation

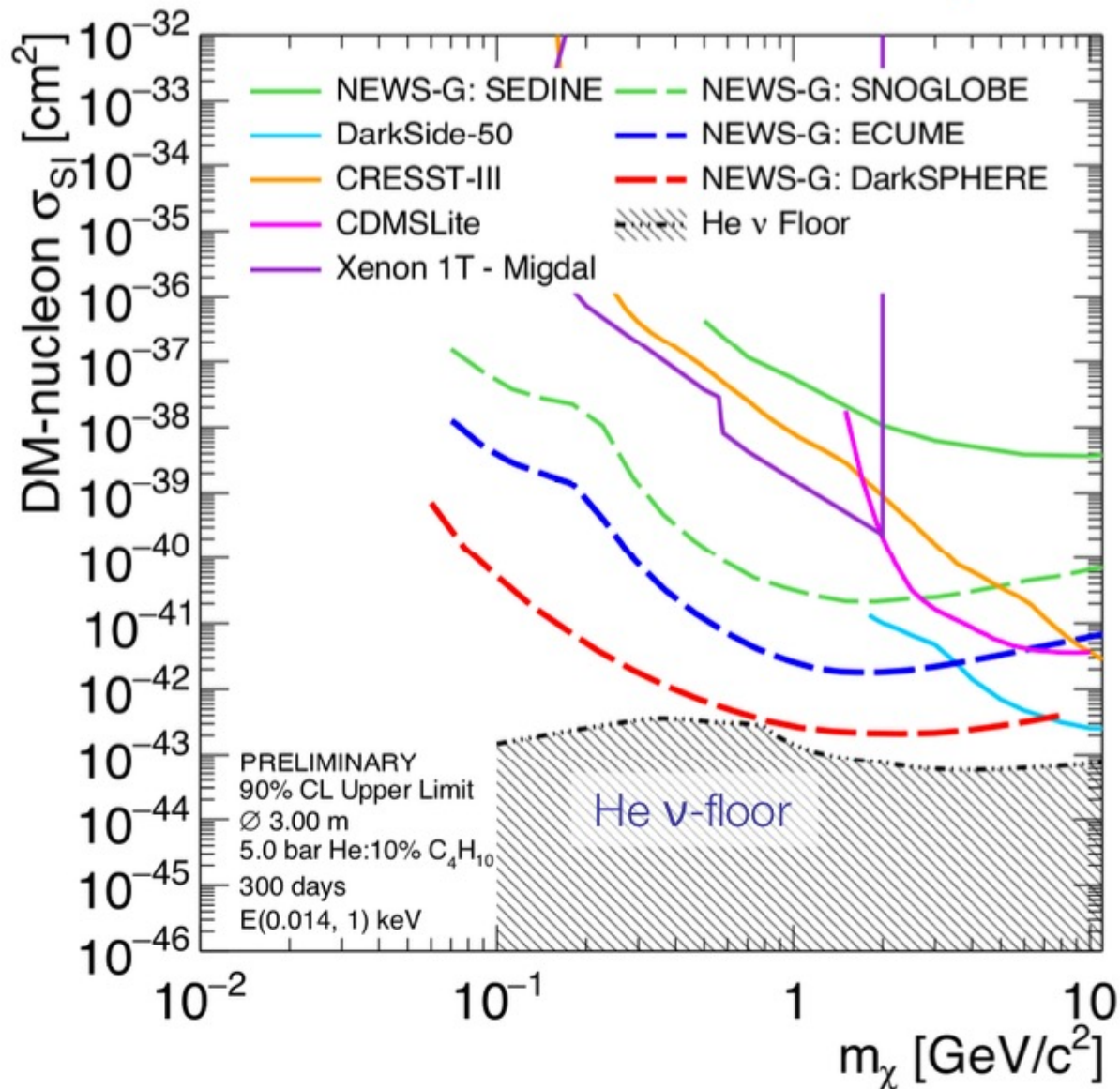
Nuclear recoil spectra



$$R_{206\text{Pb}} \sim 0.25 \text{ day}^{-1} \cdot \text{keVee}^{-1}$$



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



General assumptions:

$F = 0.2$, $\theta = 0.12$,
SRIM quenching factor,
ROI: 14 eV_{ee} - 1 keV_{ee}

NEWS-G SNOLAB:

Ne + 10% CH₄, 1 bar (1.04 kg)
Background: 1.78 dru
Exposure: 20 kg.days
Optimum Interval Method [13]

NEWS-G ECUME:

Ne + 10% CH₄
Background: 0.3 dru
Exposure: 200 kg.days
Optimum Interval Method [13]

DarkSPHERE:

He + 10% C₄H₁₀, 5 bars (26.8 kg)
Background: 0.02 dru
Exposure: 300 days
Binned Likelihood