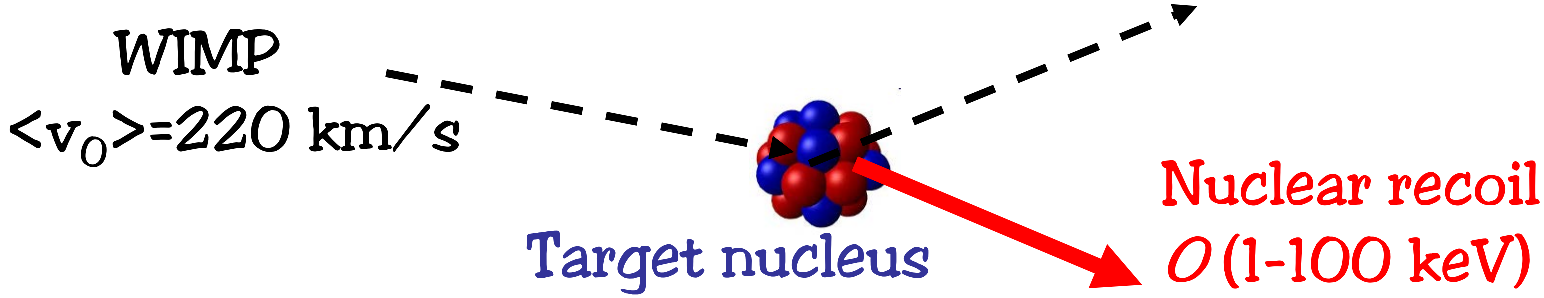
Directional Detection of Dark Matter with MIMAC

Jacob Lamblin,
on behalf of the MIMAC collaboration.
LPSC - Université Joseph Fourier
Grenoble, France

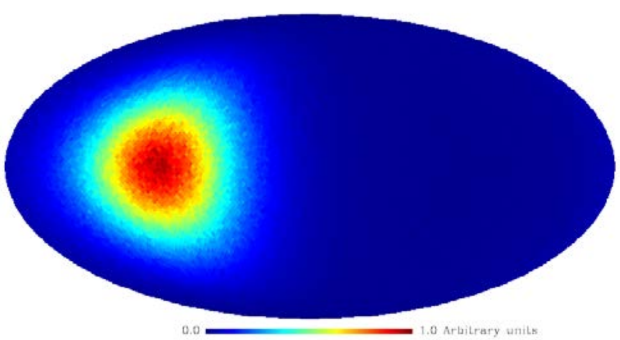
Directional detection



An additional observable: the nuclear recoil direction

D.N. Spergel. Phys. Rev. D. 37 (1988) 1353

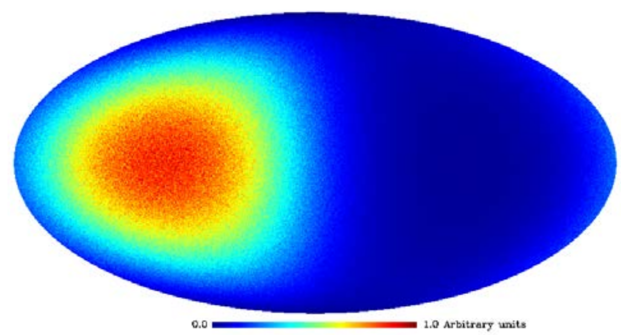
WIMP arrival directions in galactic coordinates



From Cygnus Constellation (l = 90,b = 0)

Angular distribution of nuclear recoils

^{19}F [5-50] keV and $m_{WIMP}=100\ GeV/c^2$



J. Billard et al. Phys. Lett. B. 691 (2010) 156

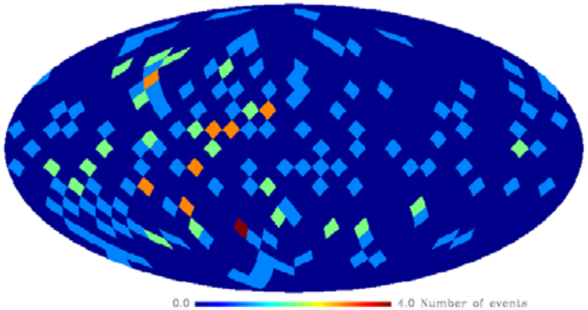
Phenomenology

Interests of the dark matter directional detection compared to the standard direct detection

1) Discovery: an anistropy in the nuclear recoil angular distribution would provide a non-ambiguous signal, even with small numbers of events (background is expected isotropic)

$\mathcal{O}$(10) WIMP events if no background — B. Morgan et al., **Phys. Rev. D 71 (2005)**

$\mathcal{O}$(100) WIMP events if S/B = 1 — J. Billard et al., **Phys. Rev. D 85 (2012)**



100 WIMPs + 100 Bckg

2) Identification: dark matter properties can be constrained from the angular distribution

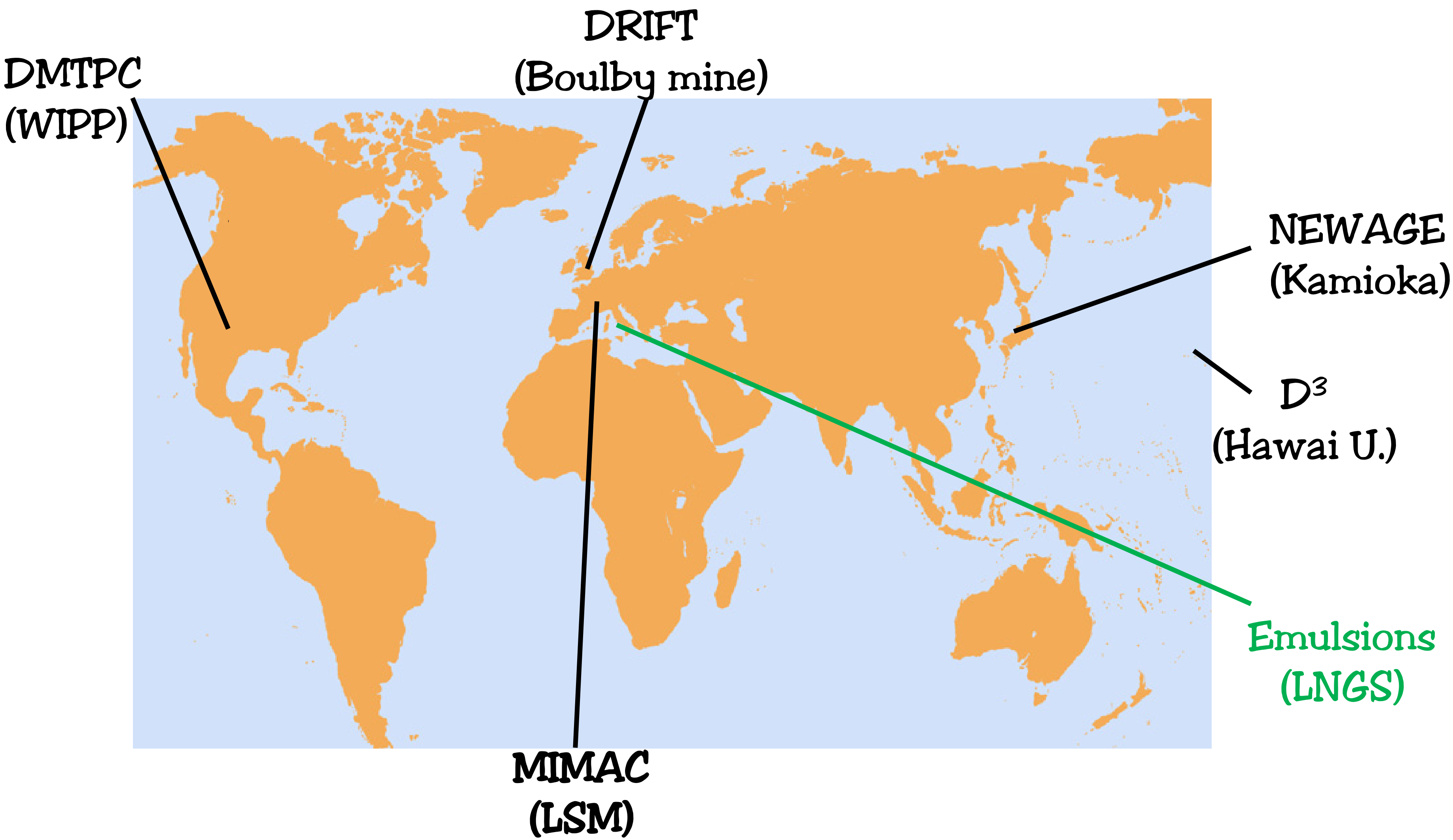
WIMP mass and cross section, Main arrival direction (l , b), Drift velocity dispersion

J. Billard et al., **Phys. Rev. D 83 (2011)**

Current projects

Most of projects use a low pressure gas TPC with CF_4 (^{19}F as target)

See website of Cygnus workshop 2013 for the current status



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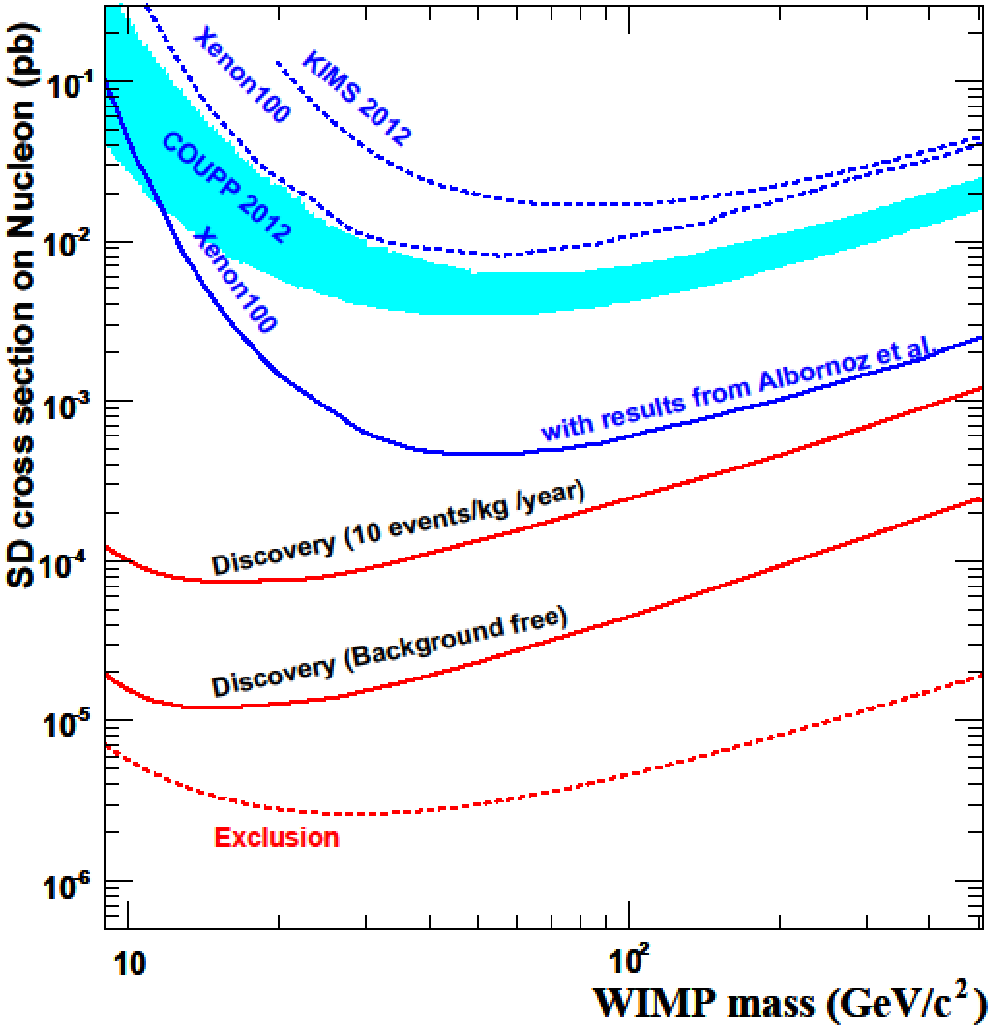
Expected sensitivity

^{19}F as target and low pressure → proton spin-dependent interaction
(could be competitive on SI only at low WIMP mass with a very low energy threshold)



For an exposure of 30 kg.year

D. Albornoz-Vasquez et al., **Phys. Rev. D (2012)**

MSSM + LHC results

→ $\sigma_p/\sigma_n = 1.3$

Some room...
XENON1T might close the window
.... or open the door !

See F. Mayet's talk at Cygnus workshop

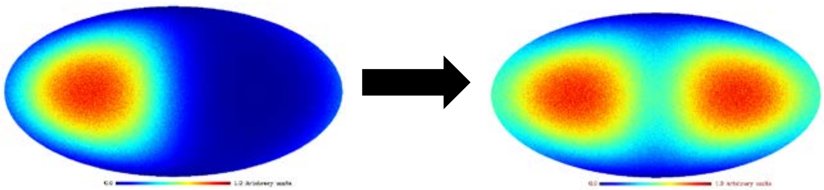
Key parameters for detectors

Energy threshold the lower the better as for the direct detection specially for low mass WIMP.

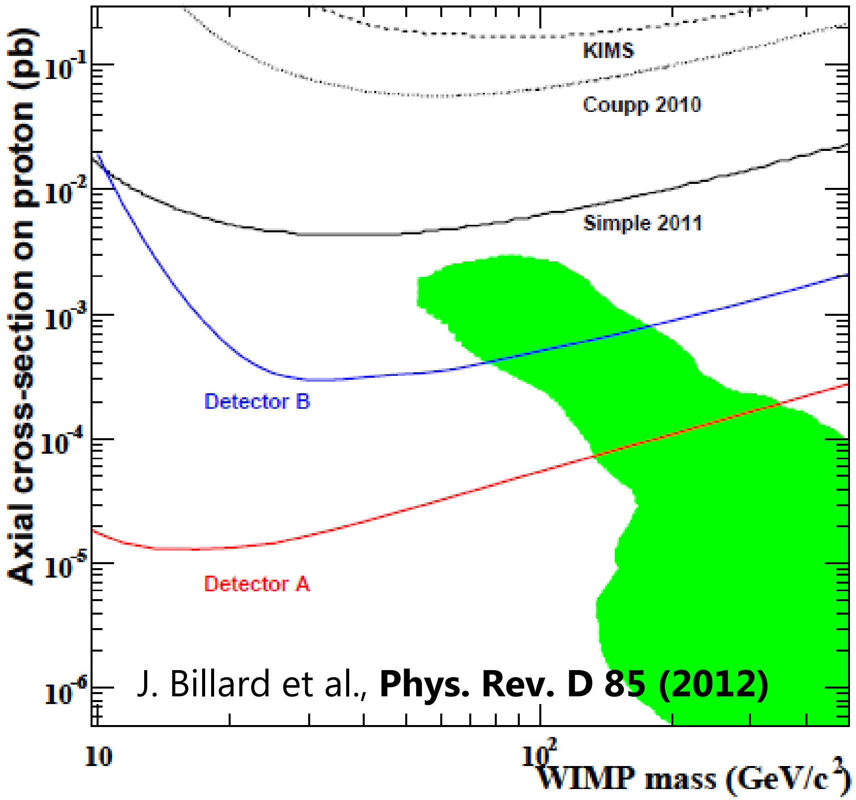
Angular resolution not the most crucial parameter since we look at the nuclear recoil distribution

Sense recognition (head-tail)

not mandatory, we can live without



Discovery sensitivity



Background

	E_{th} [keV]	R_b [evts/kg/year]	σ_γ [°]	ϵ_{HT} [%]
Detector A	5	0	20	100
Detector B	20	10	50	0

The MIMAC project

TPC with micromegas => 3D tracks + energy

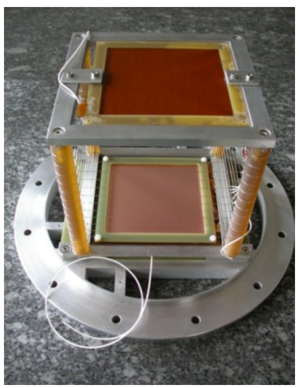
Low pressure 50 mbar (40 torr)

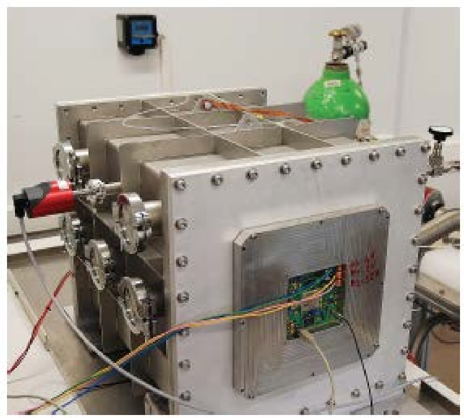
Gas mixture CF_4 (70%) + CHF_3 (28%) + C_4H_{10} (2%) (target = ^{19}F)

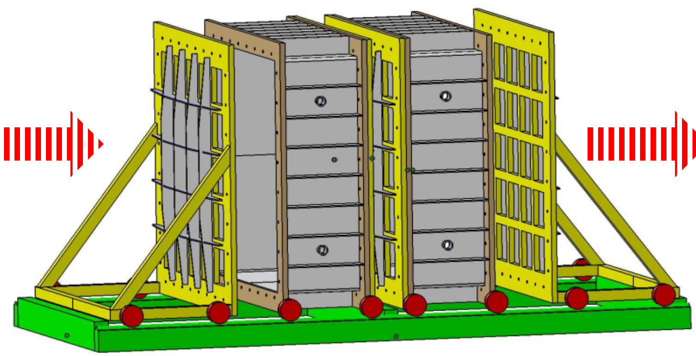
First prototypes
(2007-2011)

Bi-chamber module
5 L = 1 g CF_4

Matrix of bi-chambers
0.5 m^3 = 100 g CF_4







50 m^3
10 kg

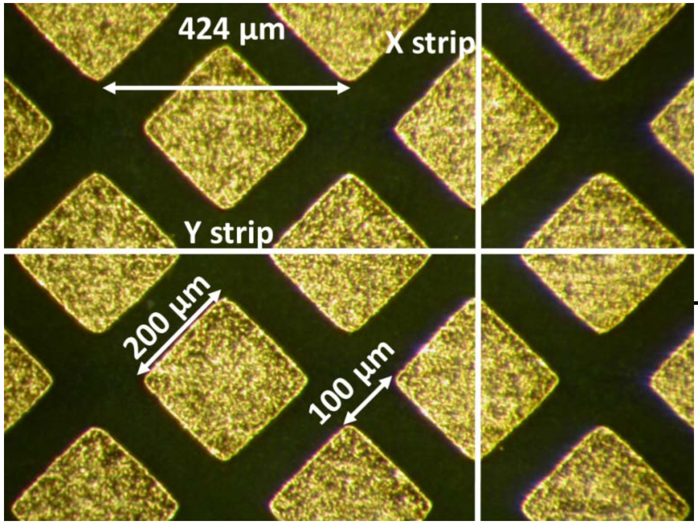
LPSC (Grenoble) G. Bosson, O. Bourrion, Ch. Fourel, O. Guillaudin, J. Lamblin, M. Marton, F. Mayet, J.-F. Muraz, A. Pelissier, J.-P. Richer, Q. Riffard (Ph.D), S. Roudier, D. Santos

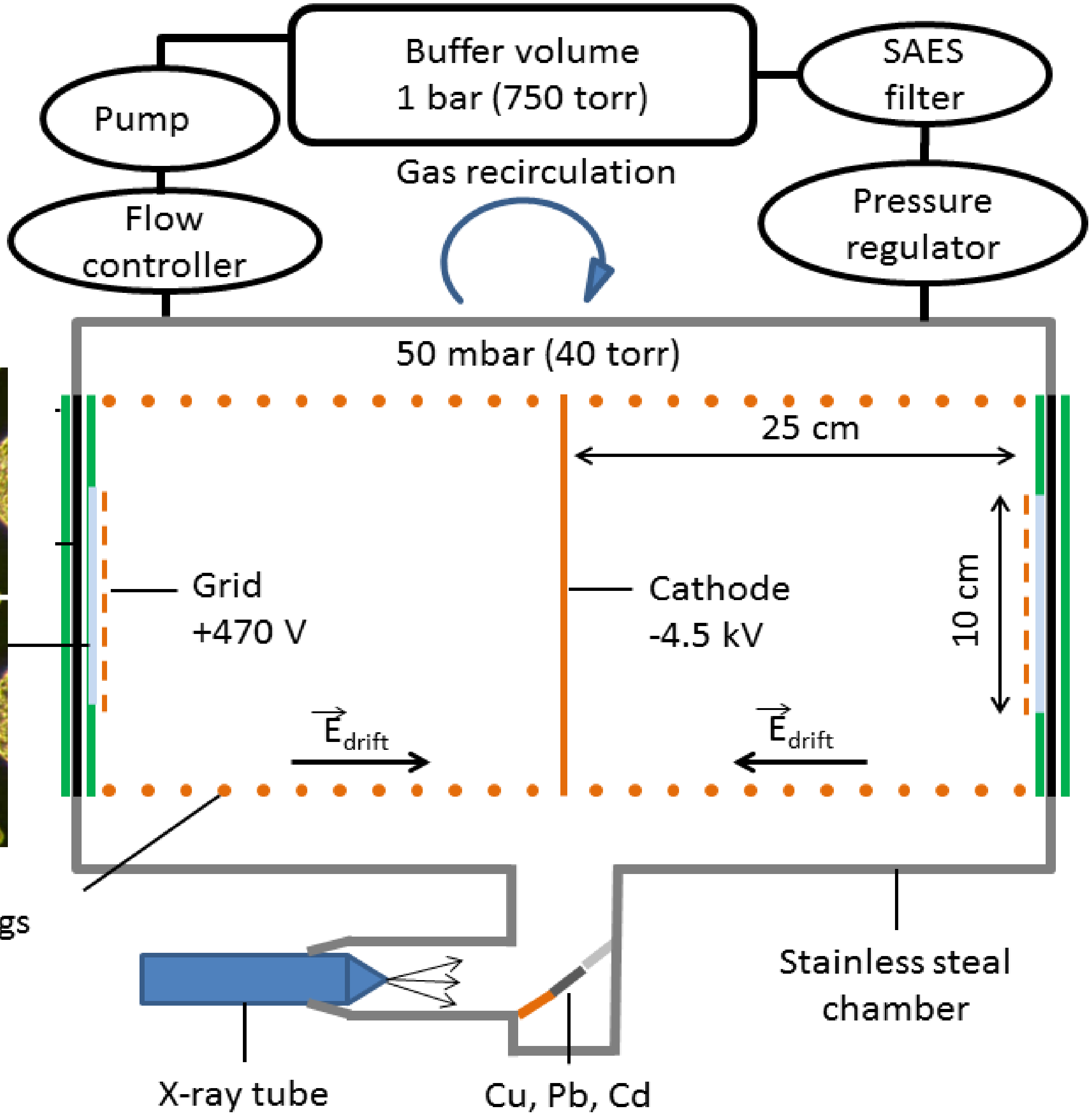
CCPM (Marseille) J. Busto, Ch. Tao, D. Fouchez, J. Brunner

IRSN (Cadarache) L. Lebreton, D. Maire (Ph. D.), J. Médard

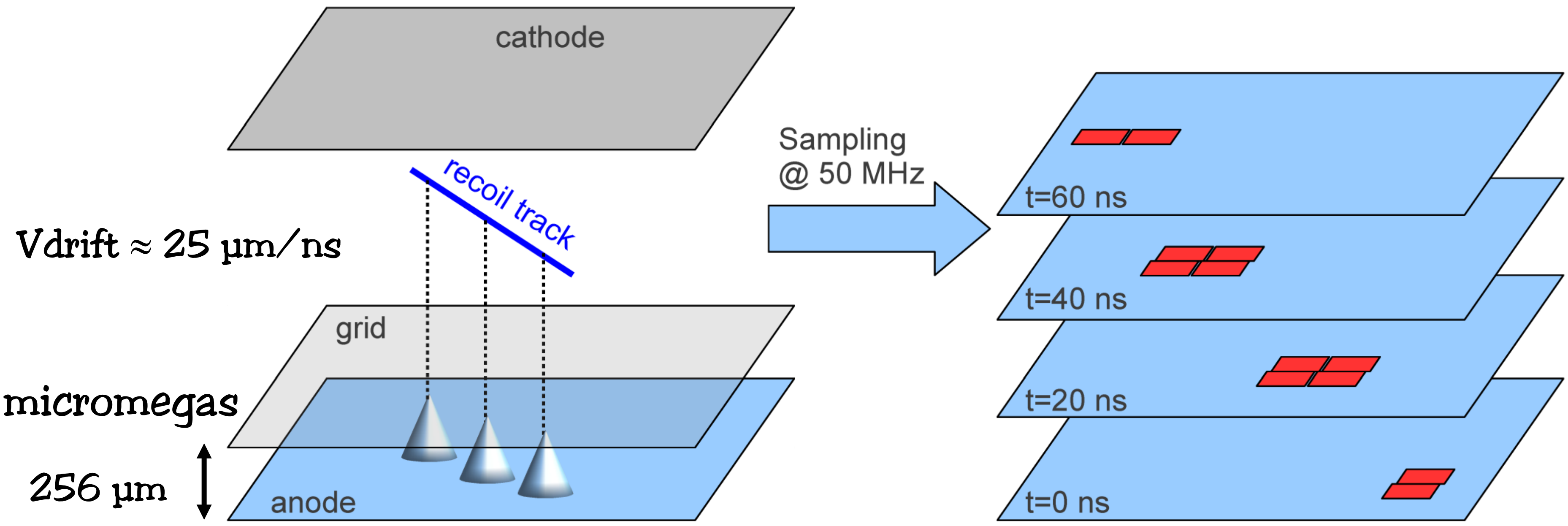
The bi-chamber module

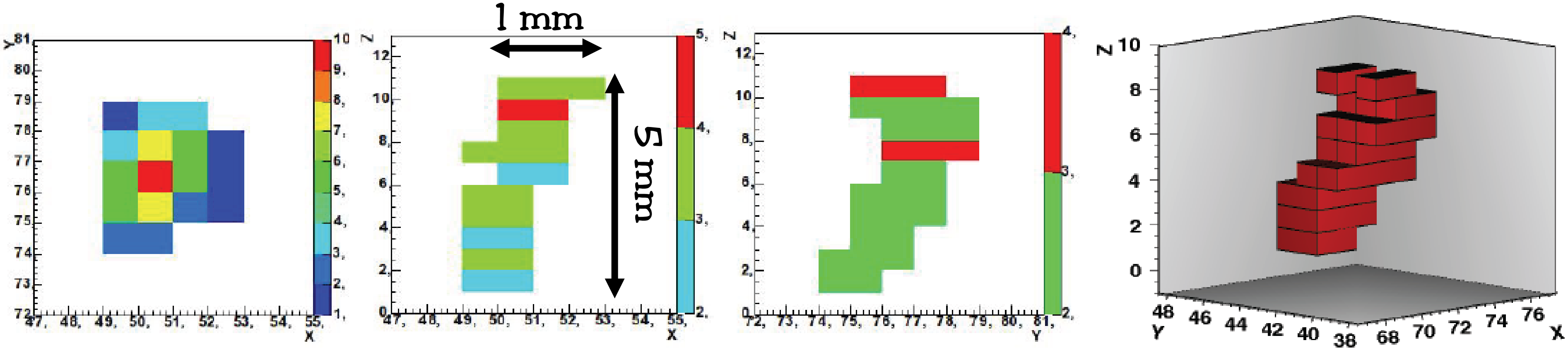
Pixellized micromegas





Track measurement





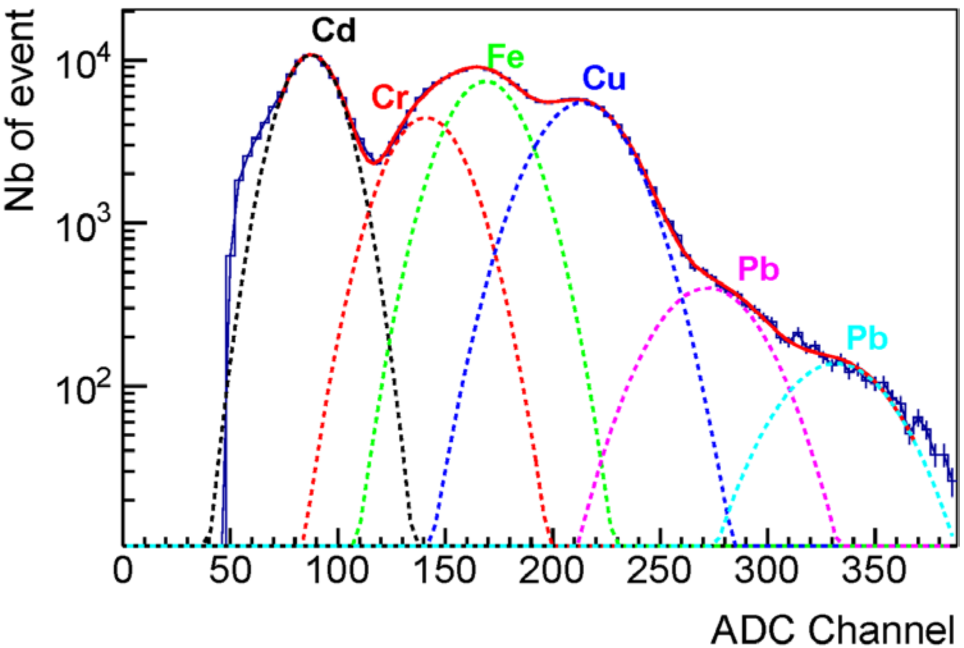
Fluorine recoil candidate ~100 keVnr

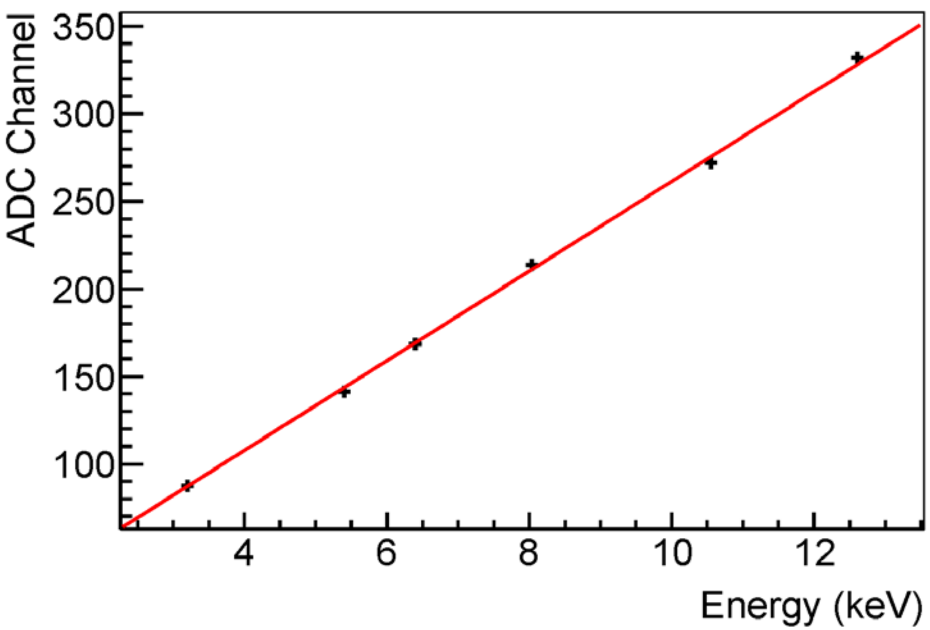
Energy measurement

Ionization energy measured with a charge integrator connected to the grid

Calibration = X-ray fluorescence
- Cd, Cu, Pb (foils),
- Cr, Fe (stainless steal)

=> electronic recoils [3 keV; 12 keV]





Excellent gain linearity

Resolution (σ) ~ 9 % @ 8 keV

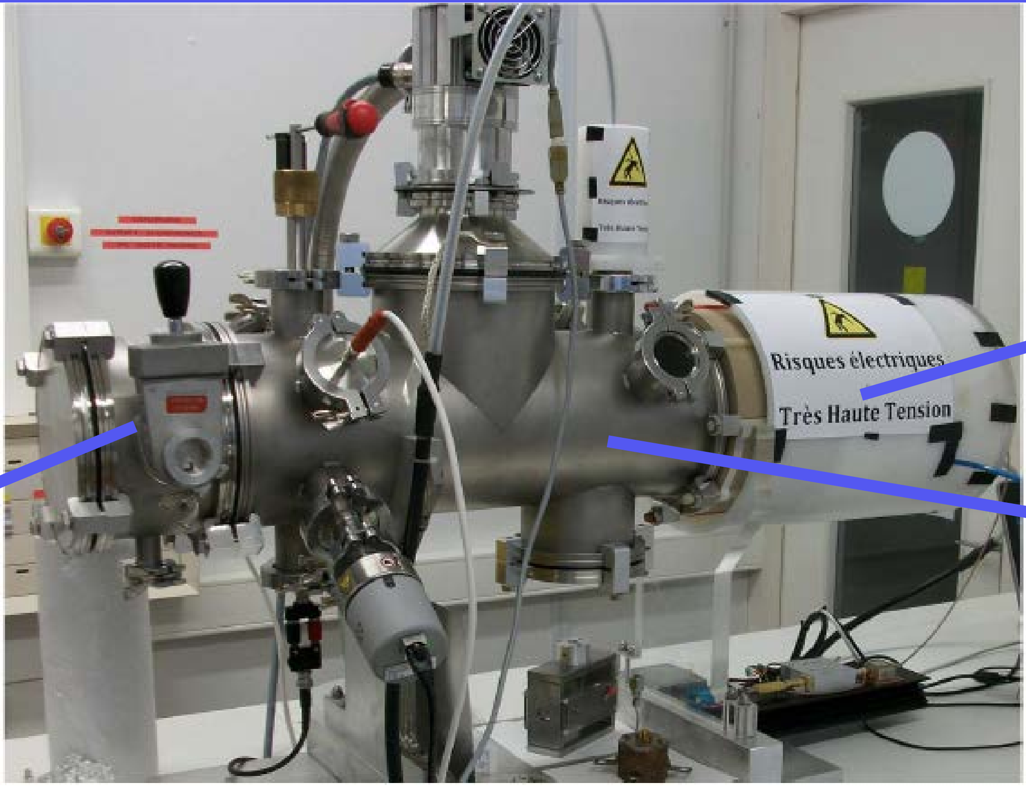
Nuclear recoil energy scale

Preliminary quenching measurements performed at LPSC

[1.25 keVee; 25 keVee]
↔ [5 keVnr; 50 keVnr]

COMIMAC: a new calibration setup

Gas volume with Micromegas



ECR source

Extraction field

Electron and Ion source from 5 keV to 50 keV being developed at LPSC

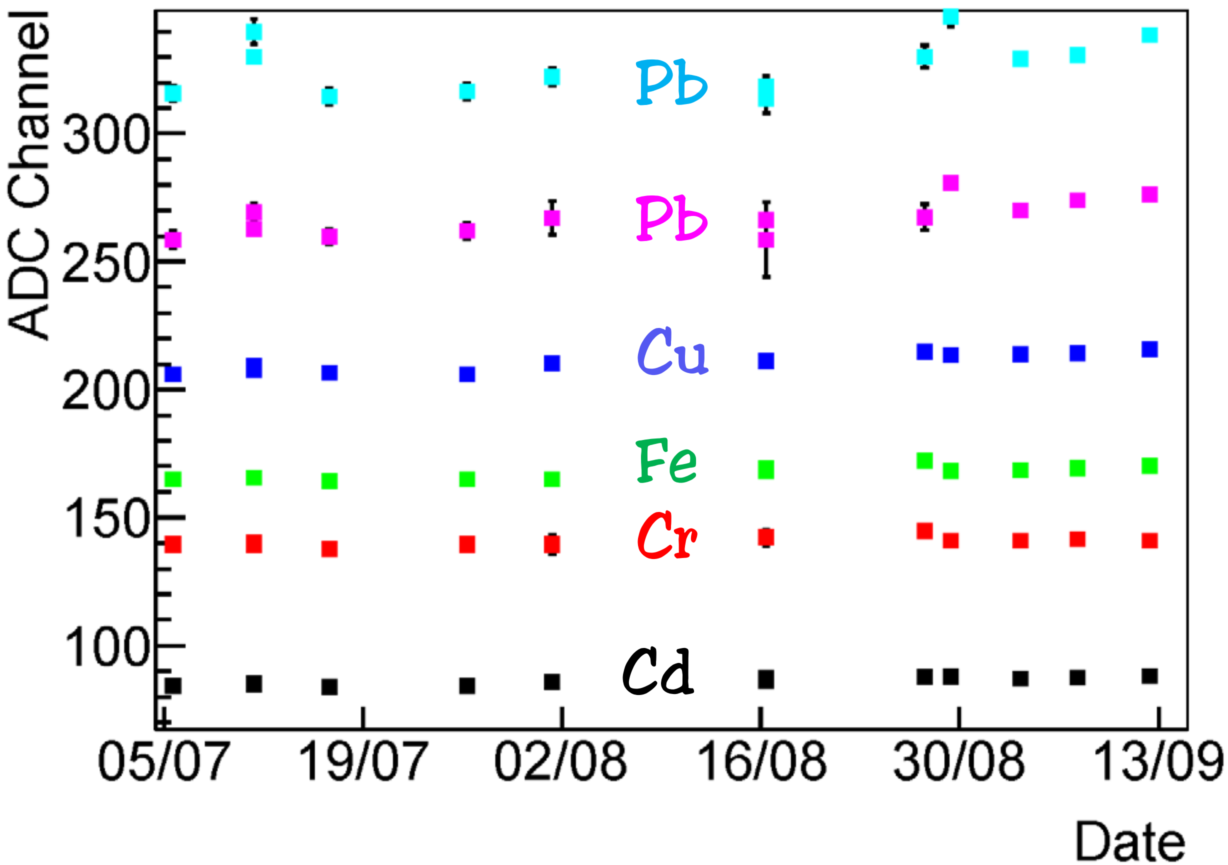
Will be used soon to calibrate the detector (nuclear recoil energy scale) and to characterize the track measurements (efficiency, angular resolution, diffusion)

Background studies

First underground run at LSM during summer 2012.

Remote control and operation.

Calibration peak position



Stable operation during 3 months.

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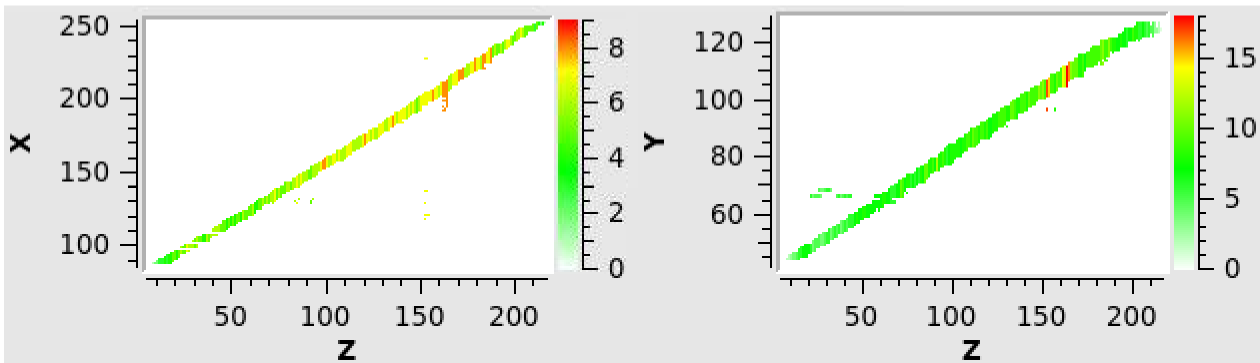
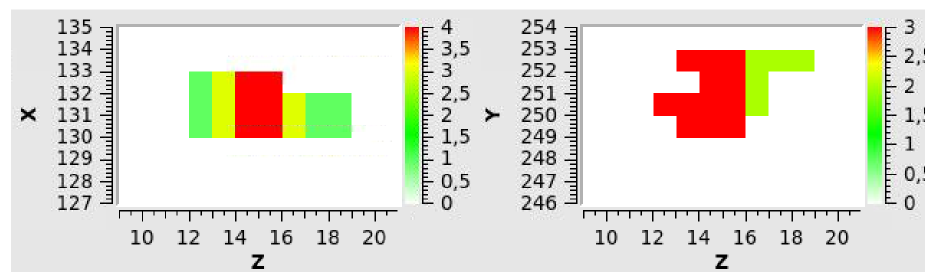
Event discrimination

- Electron = low ionization density => no track or only few pixels
  => long grid signal duration
- Alpha = few MeV => long straight track and energy saturation

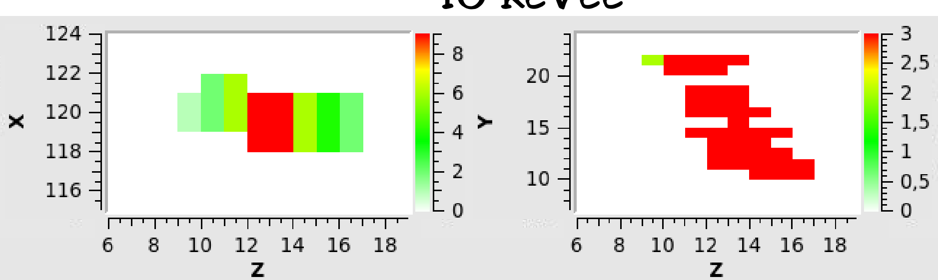


- Nuclear recoils =
  high ionization density
  => small track
  => short grid signal duration

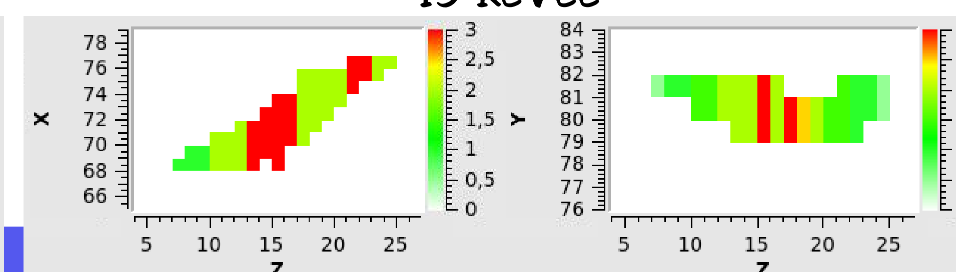
~28 keVee



~40 keVee



~49 keVee

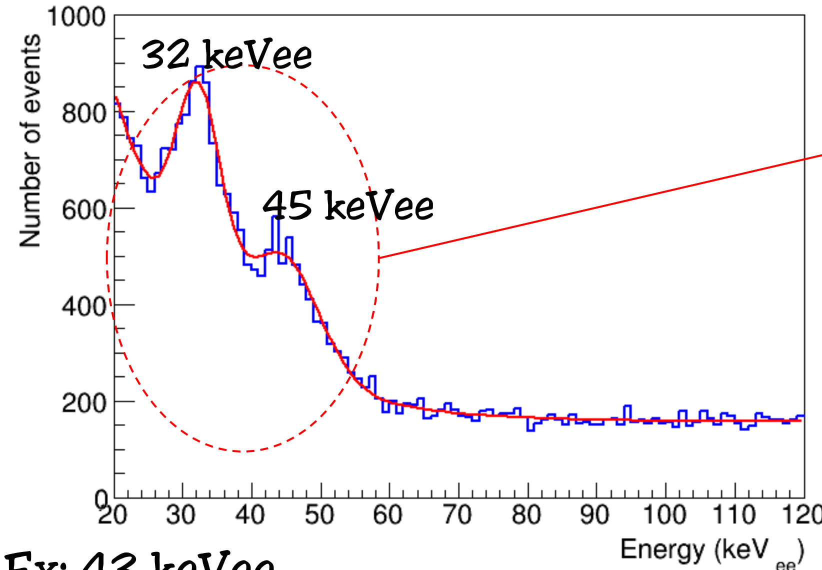


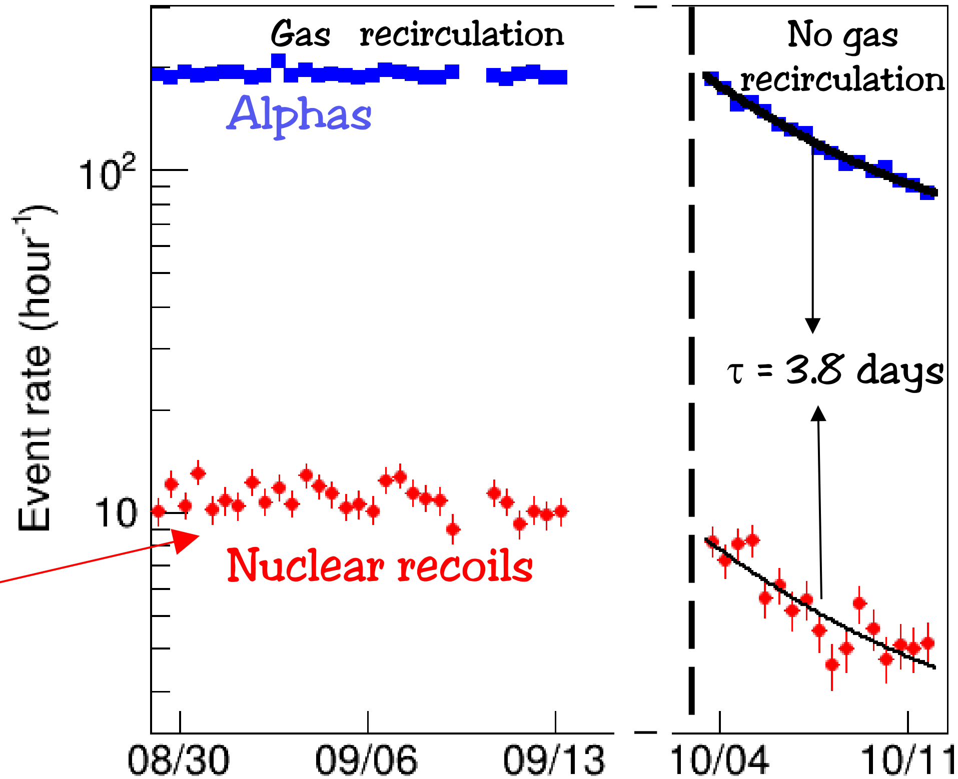
Background origins

~200 alphas per hour:

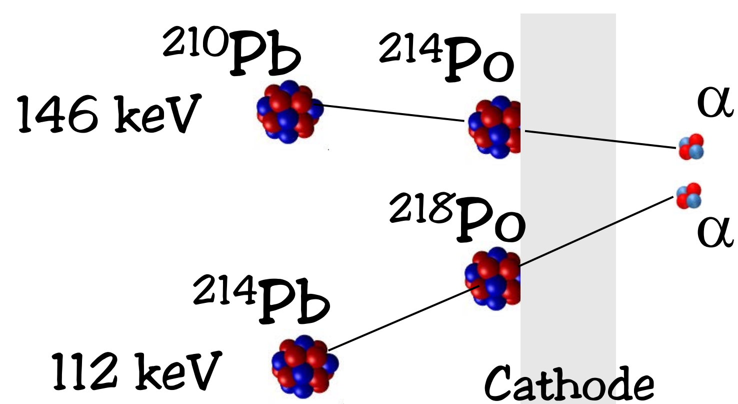
- 2/3 from ^{222}Rn (and its progeny) coming from the gas recirculation system (few 10 mBq/g)
- 1/3 from detector materials (U, Th)

Nuclear recoils: 2 energy peaks



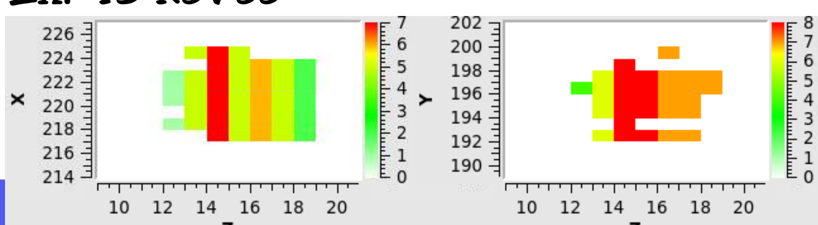


A possible interpretation



Spherical tracks

Ex: 43 keVee



The fight has just started...

Upgrades:

- New pump with a better leak rate => No Radon from the lab
- Time synchronisation of chambers
- New thinner cathode (12 µm)

  => Anti-coincidence to reject nuclear recoils from the cathode
- Faster electronics => Pulse shape analysis of the grid signal

The upgraded detector is going back to LSM this week.

New run will start next week!

Also under study:

- Radon filter
- Material selection
- Track analysis to discriminate fluorine from heavy ions

Summary

- Directional detection could provide a non-ambiguous signature of dark matter.
- Still some room in the parameter space of spin dependent interaction.
- MIMAC = a detector able to measure 3D tracks and energy of nuclear recoils at low energy.
- A detailed characterization of the detector is forthcoming and the background is under study.
- Next step: cubic meter scale.