Directional detection with MIMAC

MIcro-tpc MAtrix of Chambers

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Séminaire des doctorants

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Outline

- **Introduction**
- **MIMAC experiment**
- **MIMAC @ Modane**
- **Data analysis results**

Dark Matter evidences

Evidence at large scale

Precision cosmology (CMB, SN Ia, BAO, …)

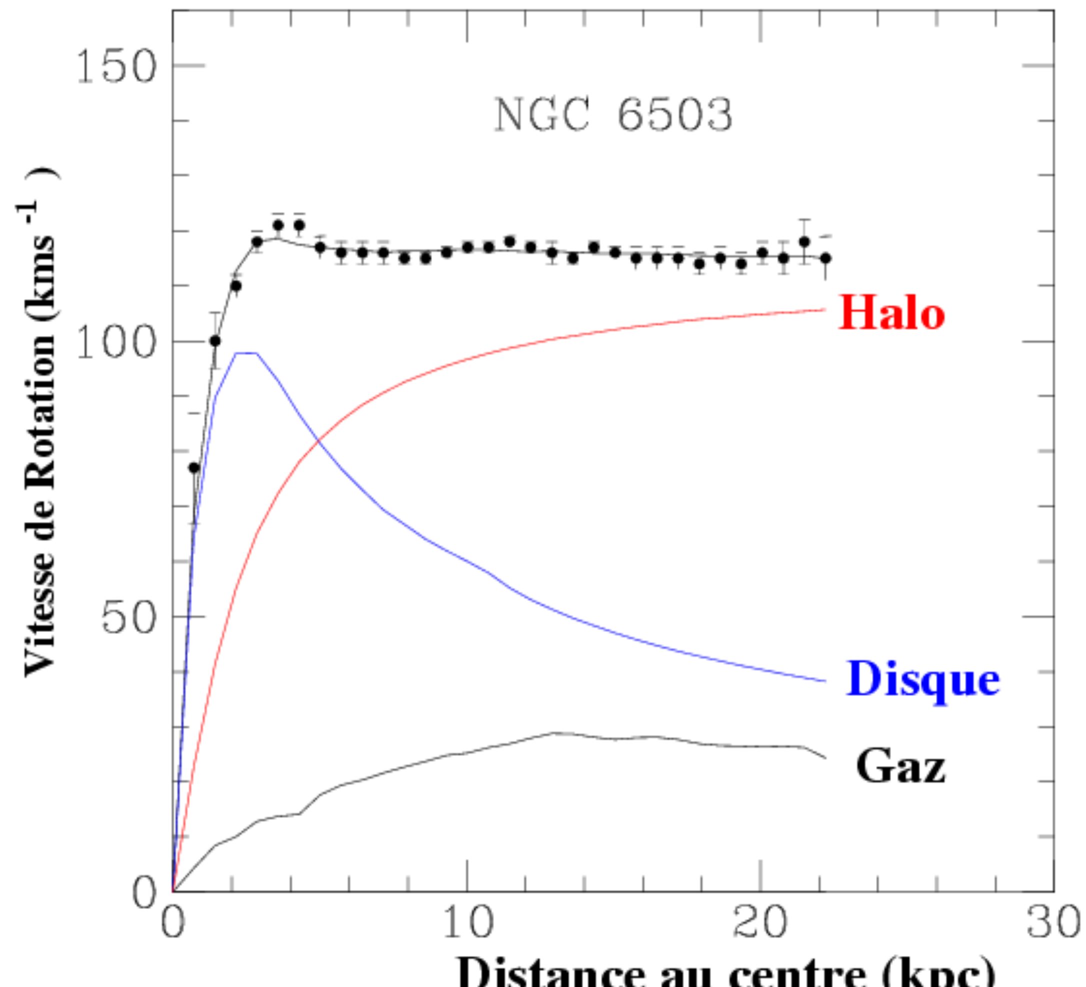
Dark energy	$\Omega_\Lambda = 0.686 \pm 0.020$
Non-baryonic matter	$\Omega_{\mathrm{CDM}} = 0.2640 \pm 0.0068$
Baryonic matter	$\Omega_{\mathrm{b}} = 0.0487 \pm 0.0007$

Planck (Ade *et al.* 2013)

~ 26% of Univers content is non-baryonic dark matter

Local scale

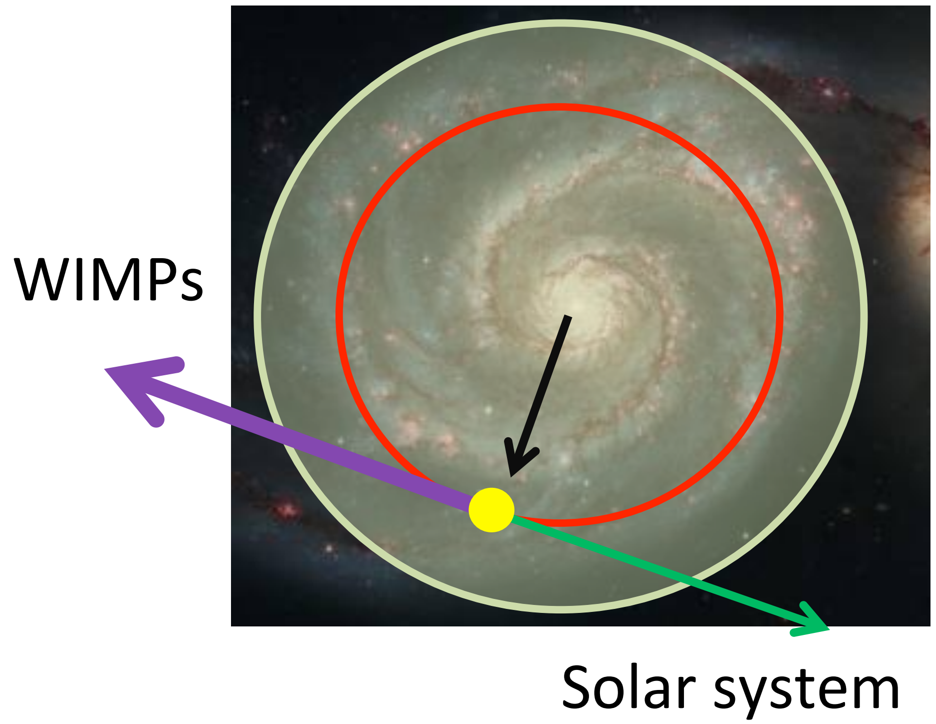
Rotation curves measurement:



From visible mass: Predictions do not correspond to the measurement

Galactic Cold Dark Matter (CDM) halo

Dark Matter candidate



Dark matter halo:

- Surrounding the Milky Way
- Maxwellian velocity distribution $\langle v \rangle \approx 300\,\mathrm{km.s^{-1}}$
- Local density: $\rho_0 = 0.3 \pm 0.1\,\mathrm{GeV.c^{-2}.cm^{-3}}$

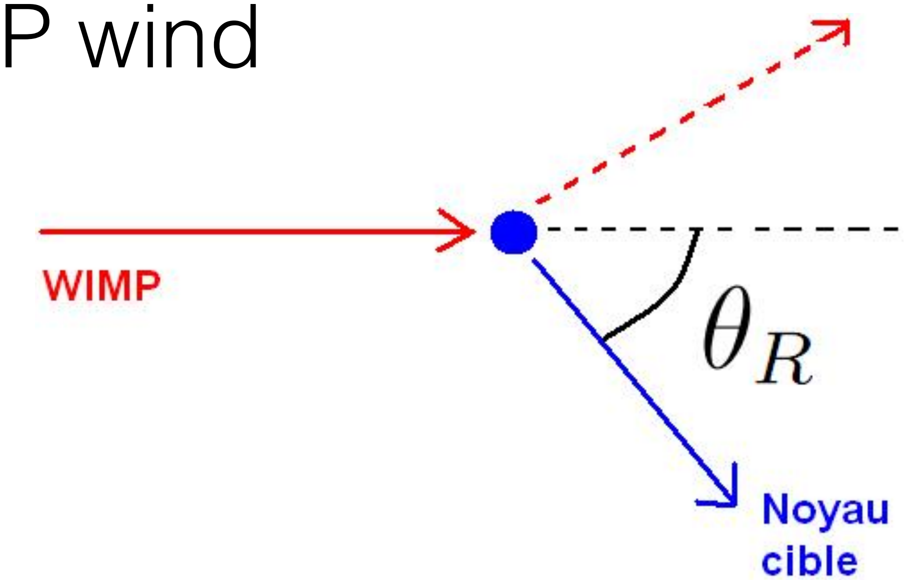
Candidate: WIMP (Weakly Interacting Massive Particle)

- Massive: $\mathrm{GeV/c^2} \; - \; \mathrm{TeV/c^2}$
- Stable
- No electric charge & No color
- Gravitational & weak interaction

WIMP candidate form particle physics (SUSY): Neutralino χ

Direct detection

In the laboratory rest frame: Relative WIMP wind



Elastic diffusion on nucleus

→ Nuclear recoil $E_{\mathrm{kin}} = \mathcal{O}(10\,\mathrm{keV})$

Direct detection principle:

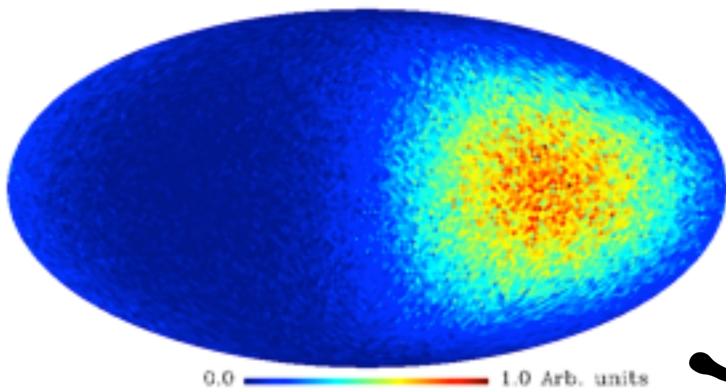
Nuclear recoil **energy** measurement

Ultimate background: Neutron → Same signal as WIMP

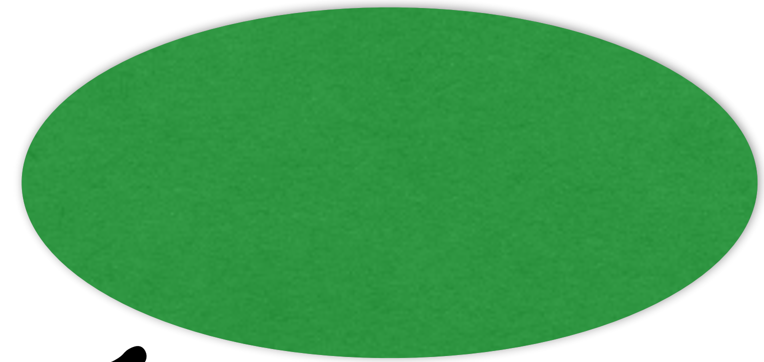
Background discrimination → Directionality

Directional detection

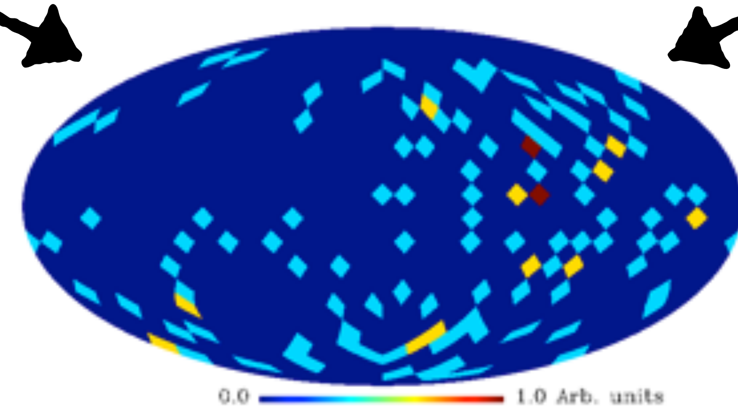
Recoils angular distribution:
Anisotropy



Neutrons angular distribution:
Isotropic



Typical measured recoil angular distribution



Simulation with 100 WIMPs & 100 bkgs

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

J. Billard *et al.*, Phys. Rev. D **85** (2012) 035006

Constraints on WIMP and Halo properties

Directional detection principle:

Measurement of the **energy** and the **track** of the recoils

Directional project in the world

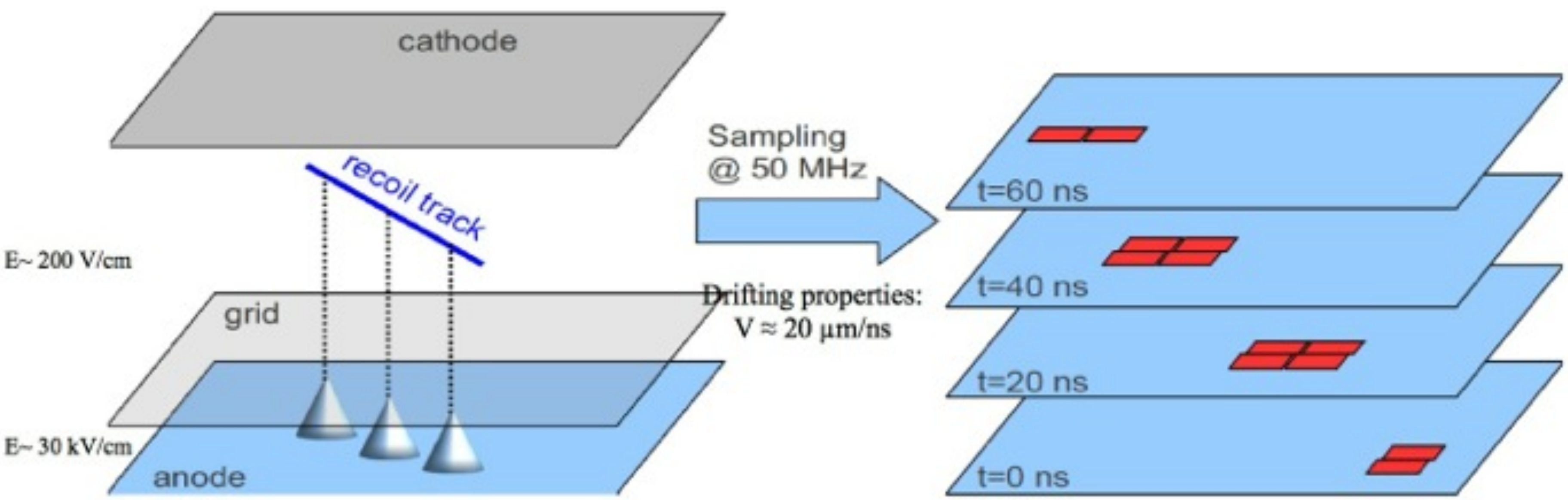
MIMAC detection strategy

MIMAC Target: $^{19}\mathrm{F}$ <— Light nucleus ⟶ Low mass WIMP

& Axial interaction

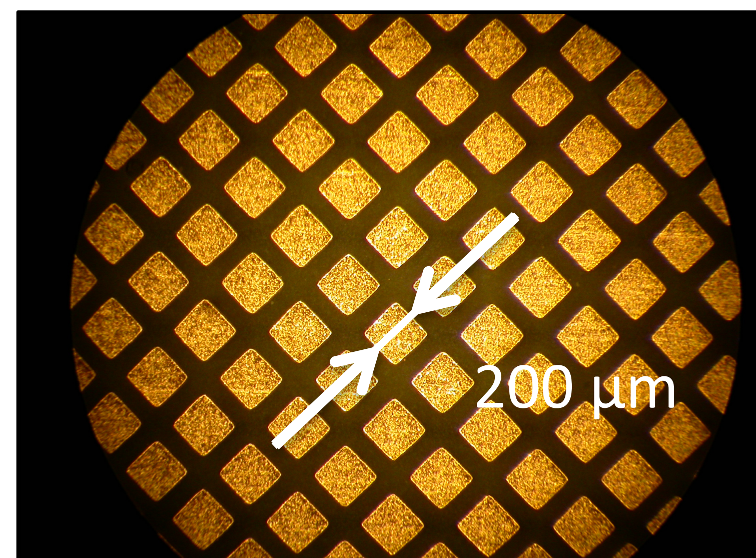
MIMAC detector: µTPC = TPC + Pixelized Micromegas Fast & self-trigger electronic

Sampling:
512 strips @ 50 MHz
$T_{Sampling} = 20ns$



Scheme of a MIMAC µTPC

Evolution of the collected charges on the anode



Micromegas 10x10 cm^2,
designed by IRFU- Saclay (France)

Gas mixture: $70\%\,\mathrm{CF_4} + 28\%\,\mathrm{CHF_3} + 2\%\,\mathrm{C_4H_{10}}\;@\,50\,\mathrm{mbar}$

Ionization quenching factor

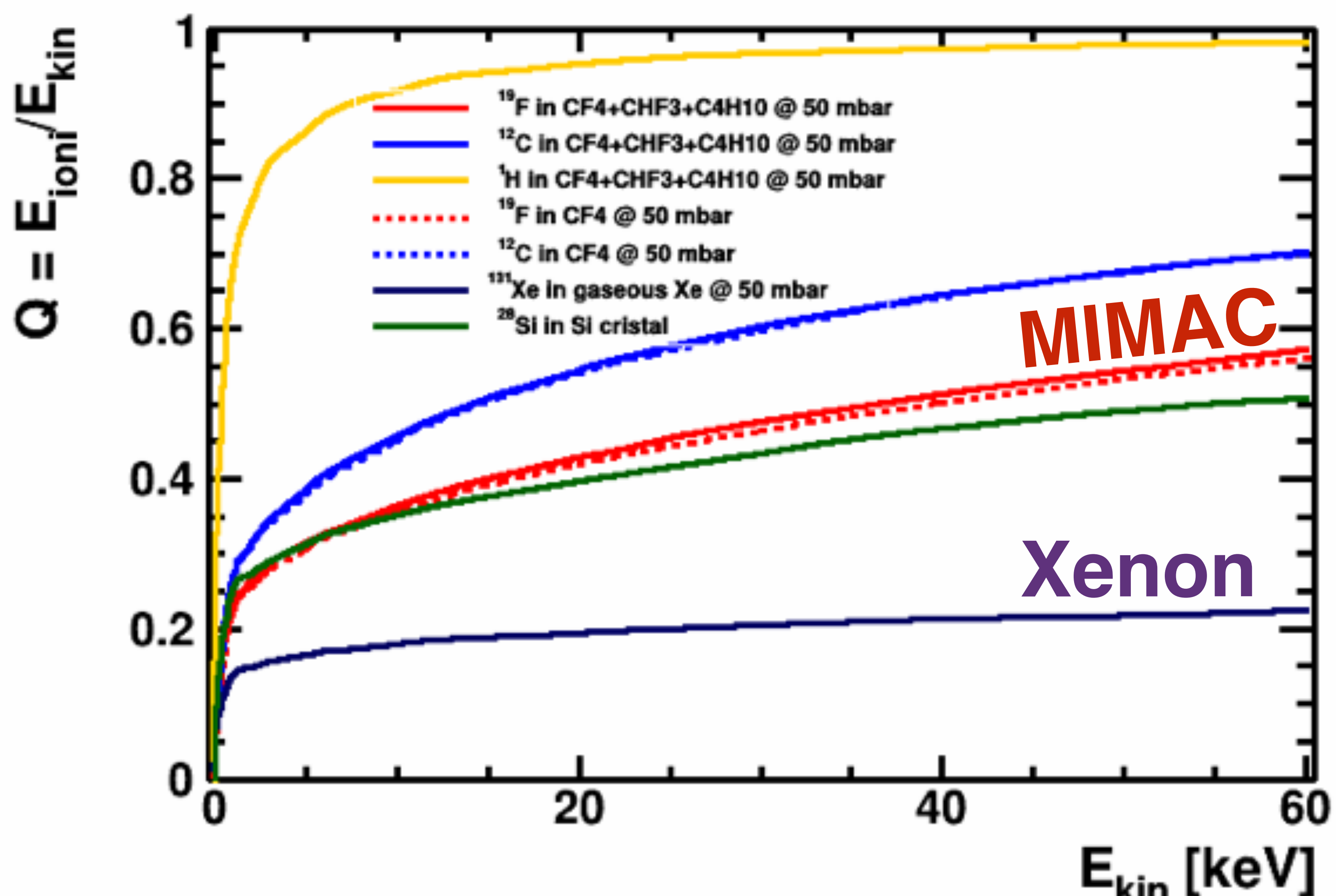
For low energy ion: $E_{\mathrm{kin}} \neq E_{\mathrm{ioni}}$

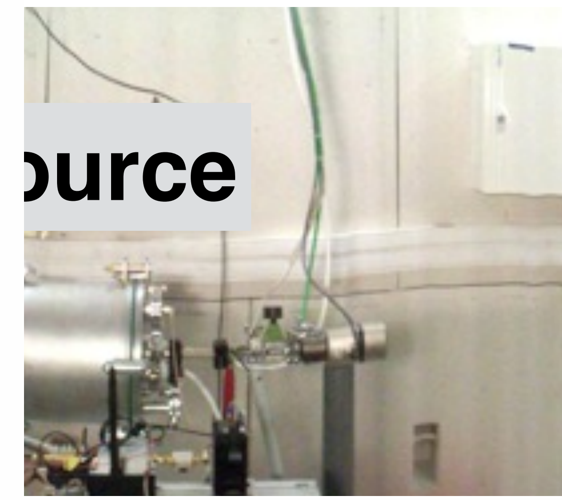
Ionization quenching factor: $Q_{\mathrm{ioni}} = \dfrac{E_{\mathrm{ioni}}}{E_{\mathrm{kin}}}$

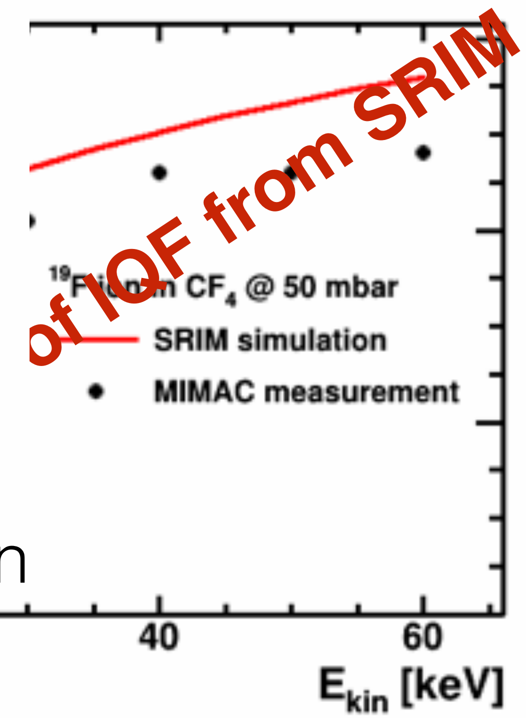
Micro hole ir

$P_{\mathrm{MIMAC}} = 5$

IQF simulation from SRIM







Over-

Important information for kinetic energy reconstruction

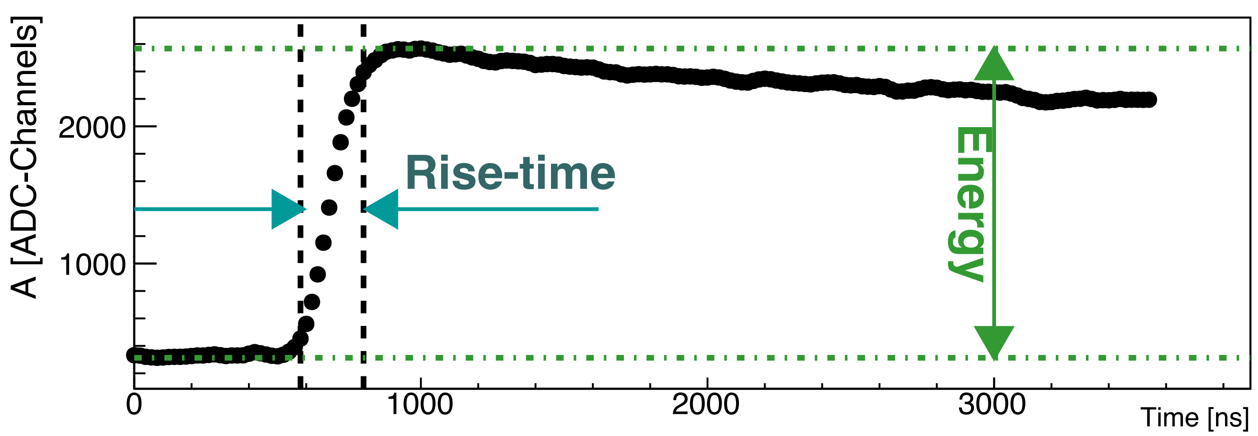
$\overrightarrow{E_{\mathrm{Drift}}}$ → **Measurement needed at low energy**

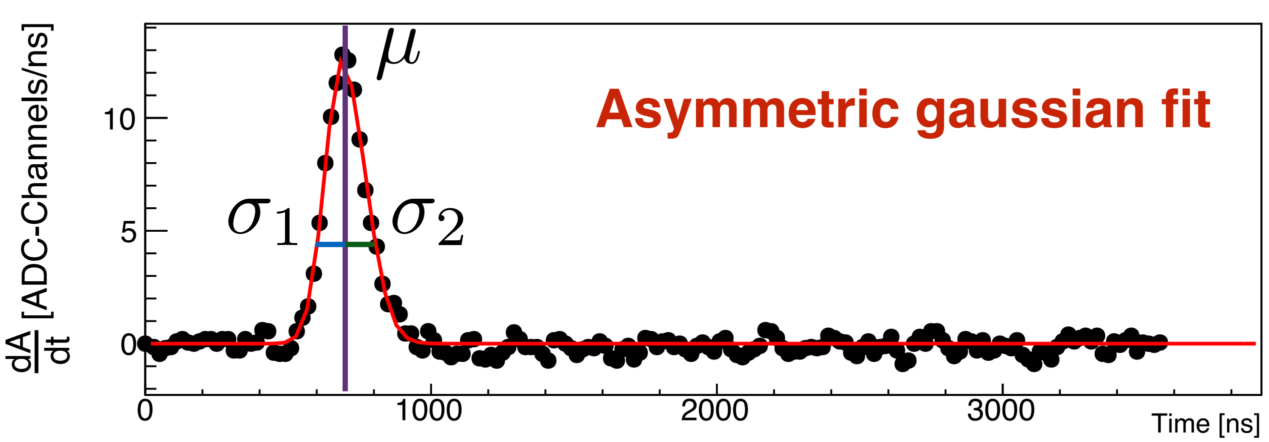
Flash-ADC observables (ionization energy)

Flash-ADC:

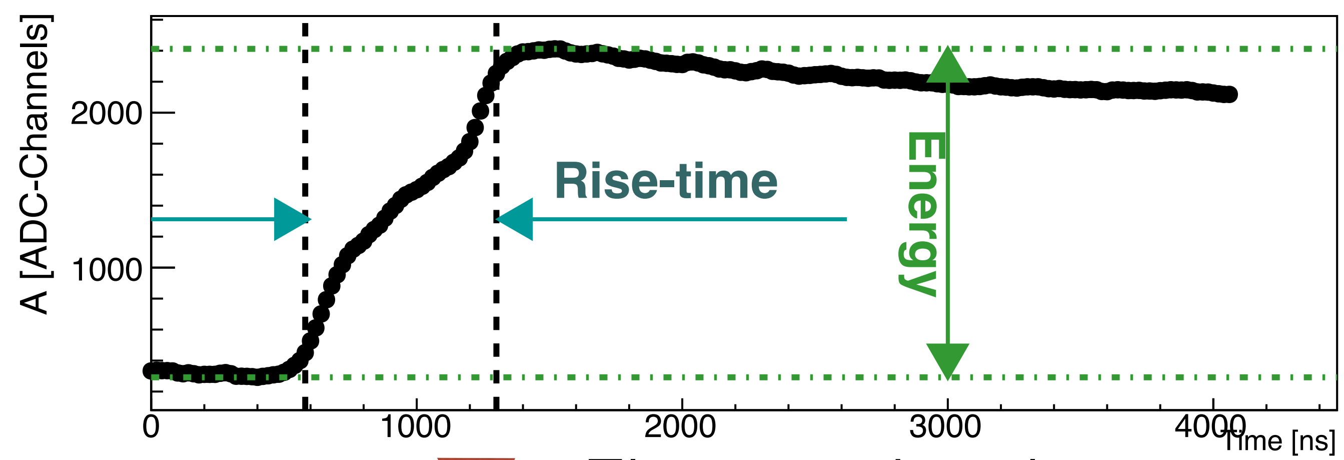
Charge deposition measurement **=** Ionization energy measurement

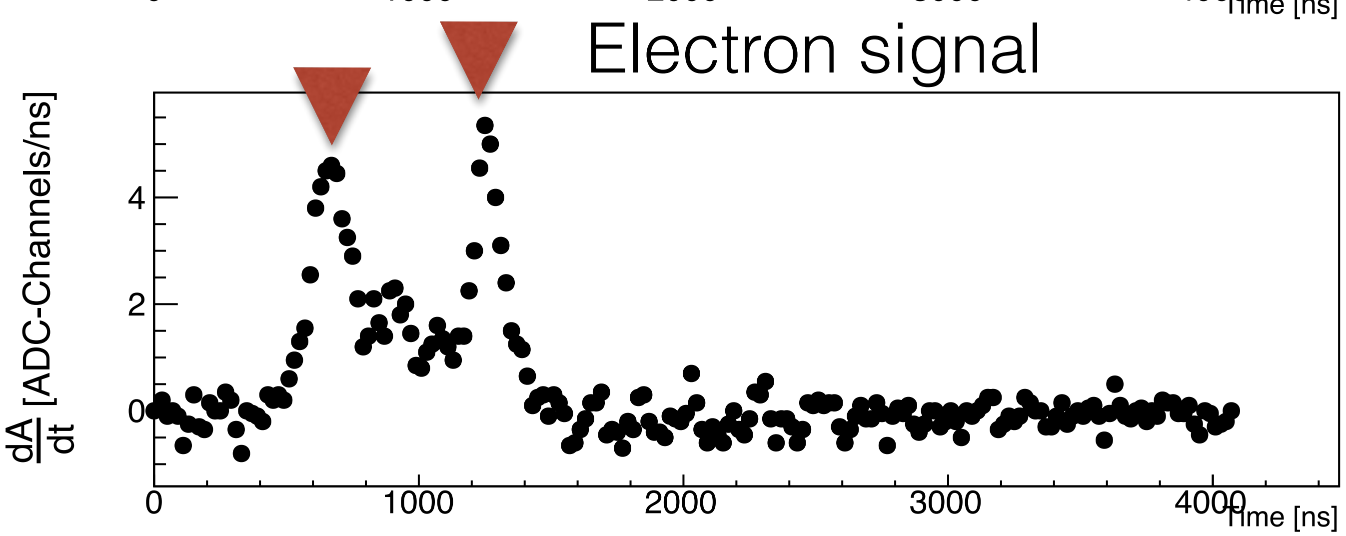
Recoil



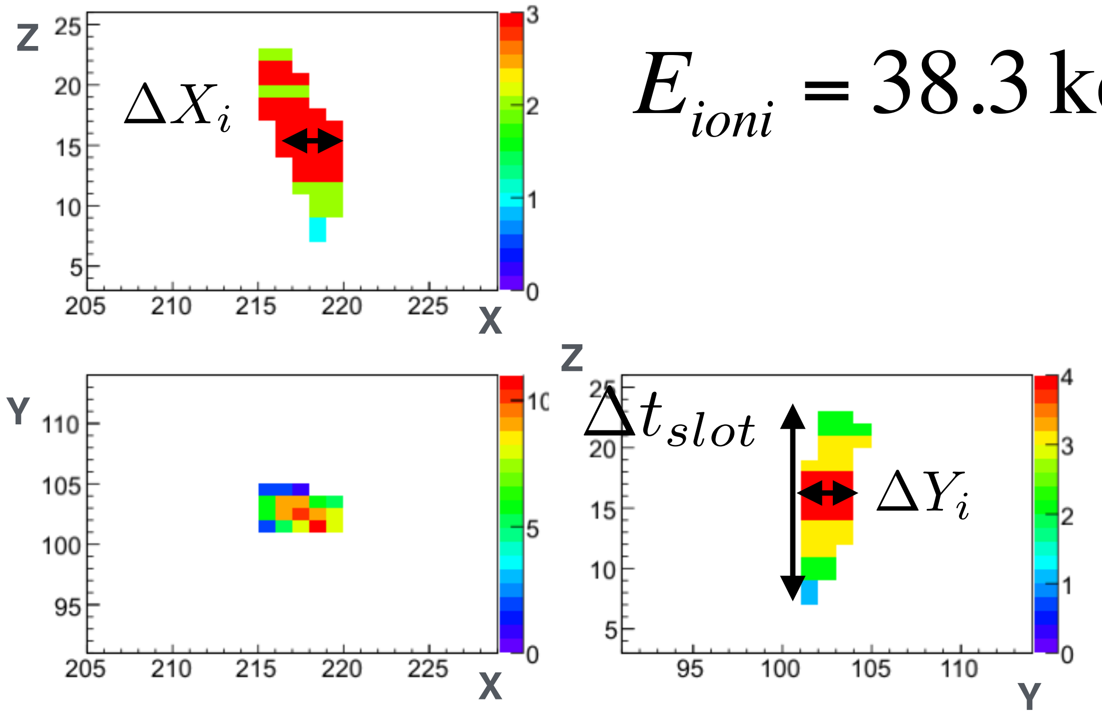


Electron

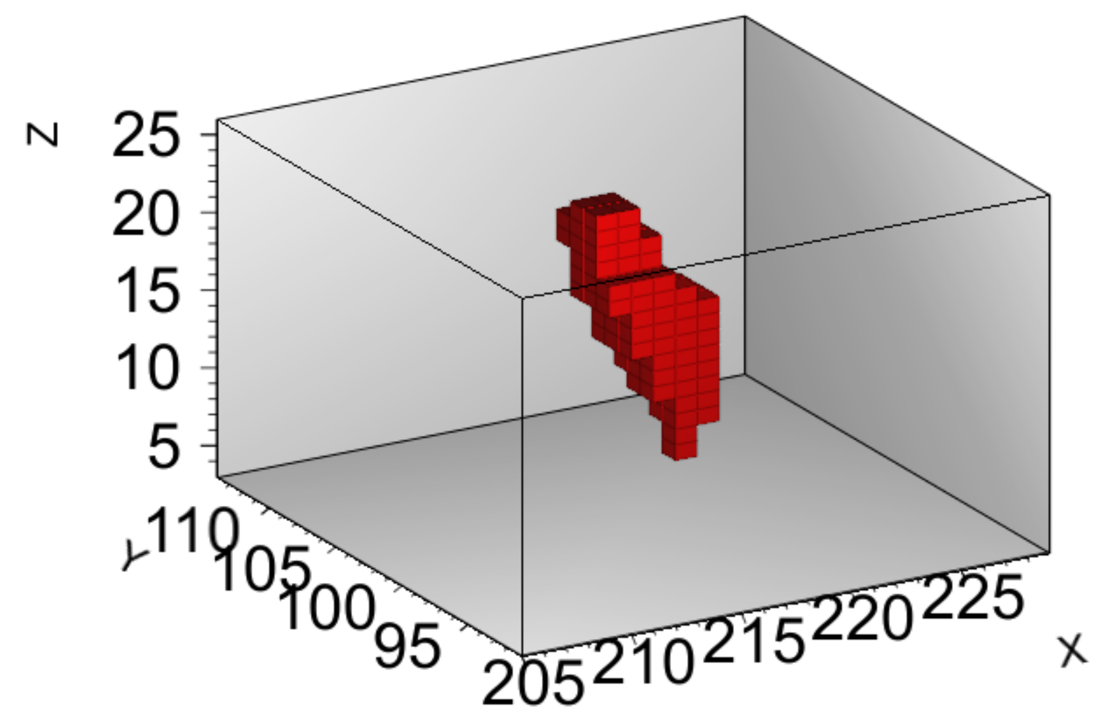




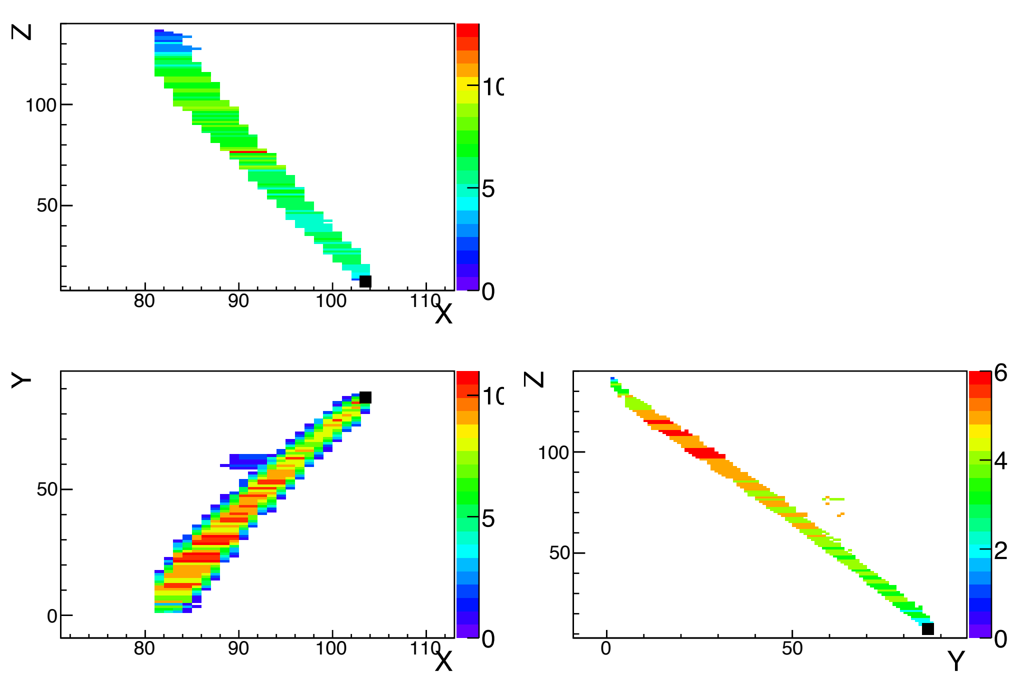
Track observables

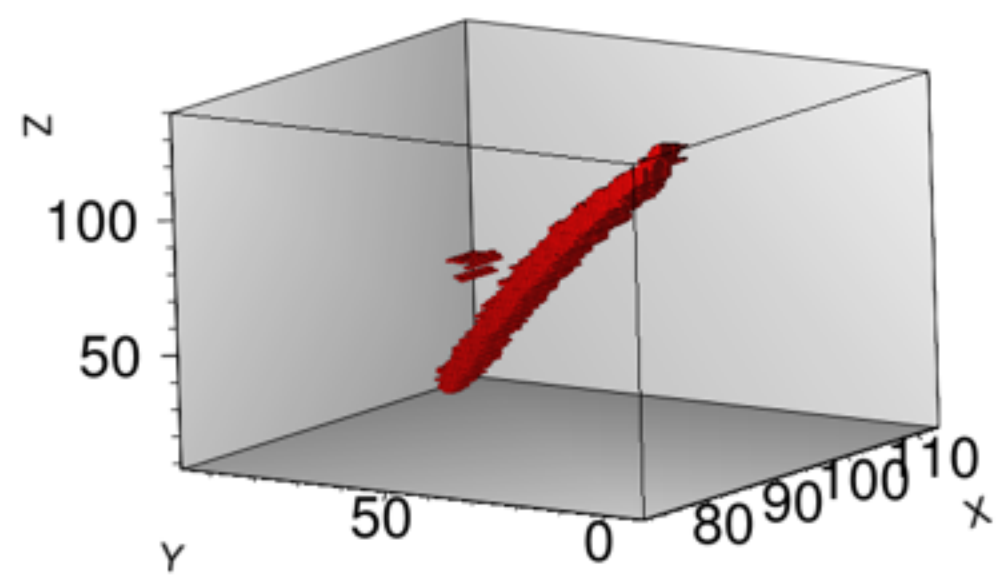


$$E_{ioni} = 38.3\,\mathrm{keV}$$

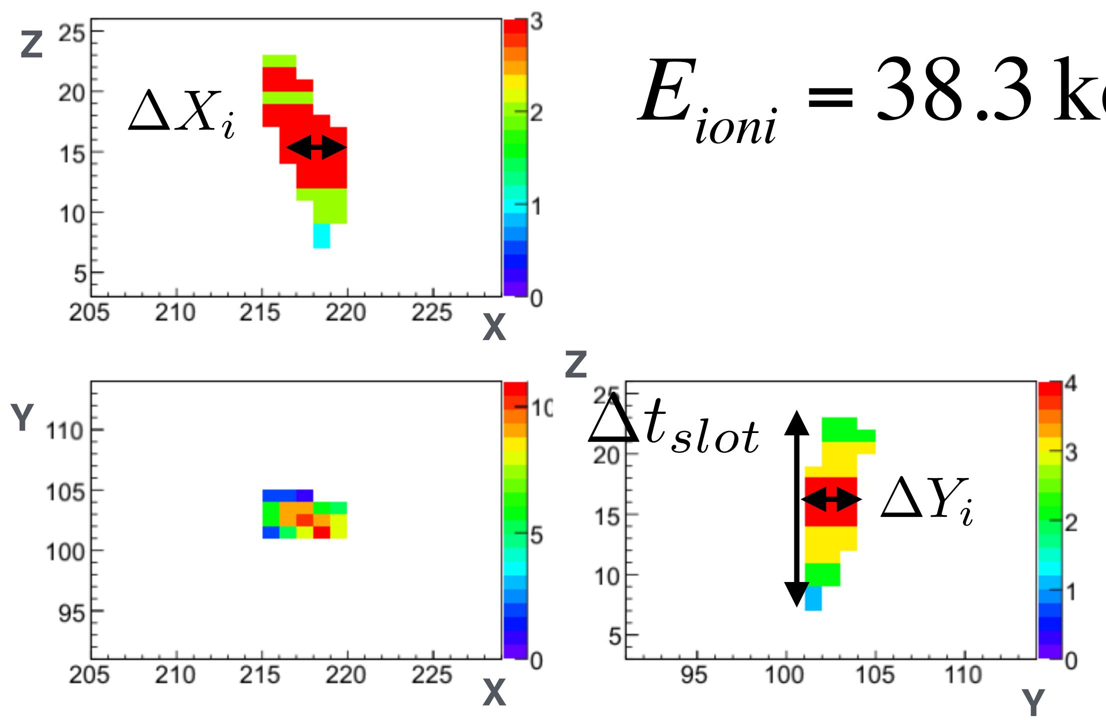


$\alpha - Event$

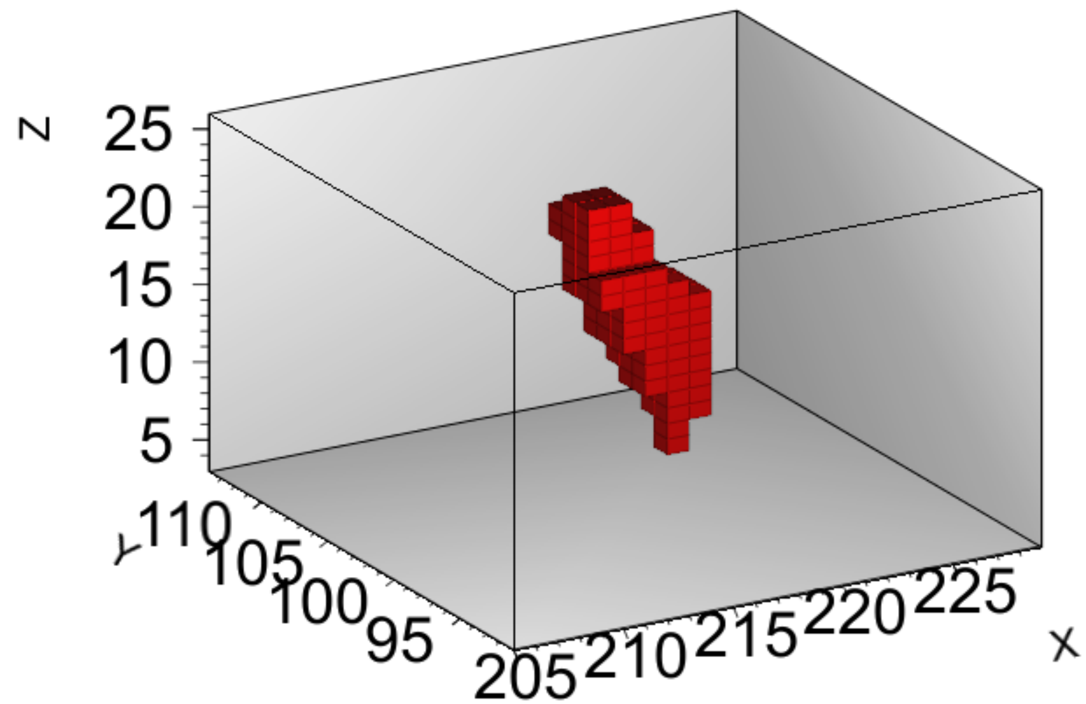




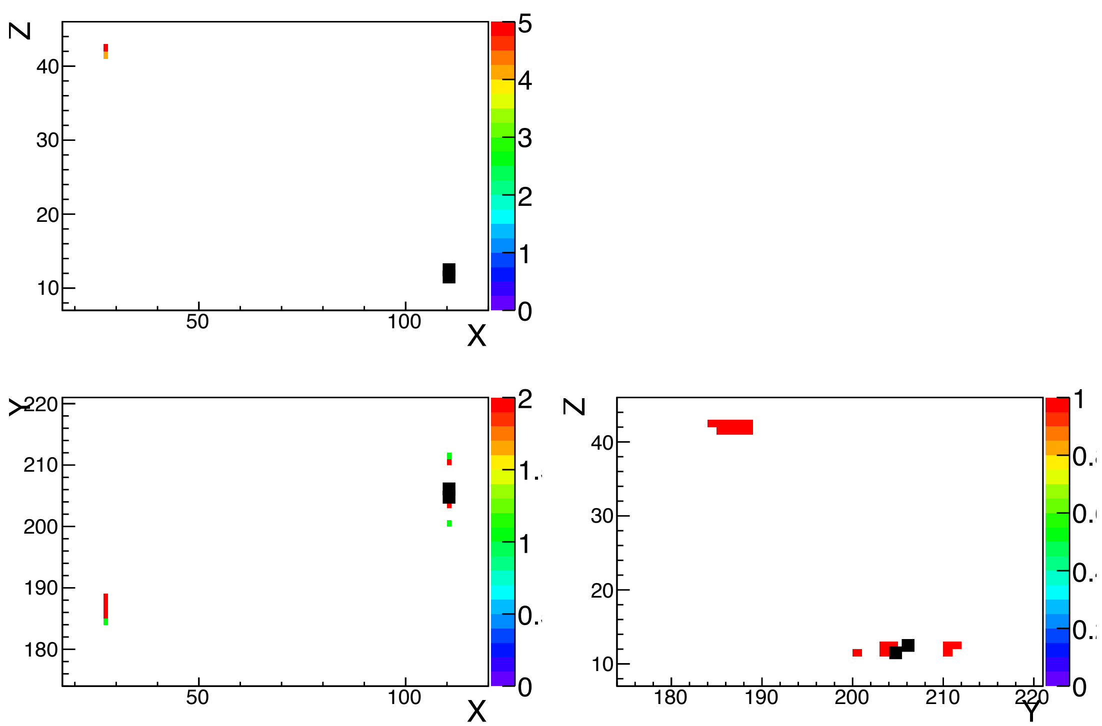
Track observables

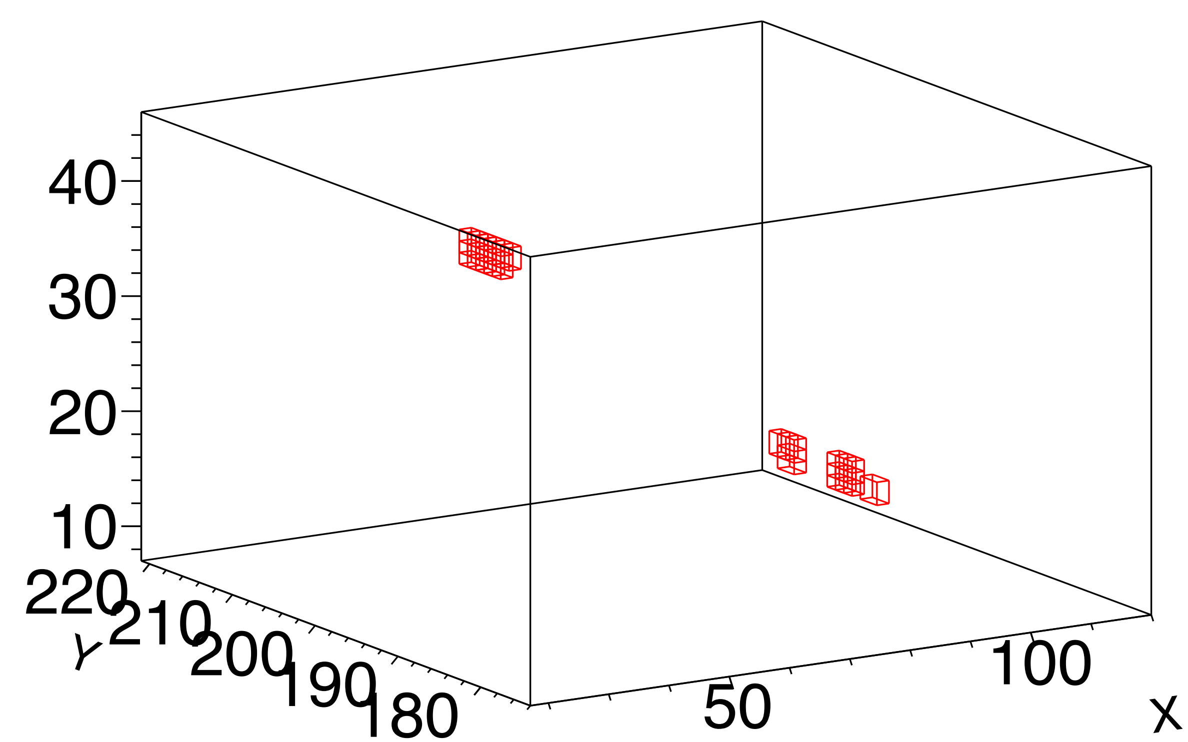


$$E_{ioni} = 38.3\,\text{keV}$$



Electron



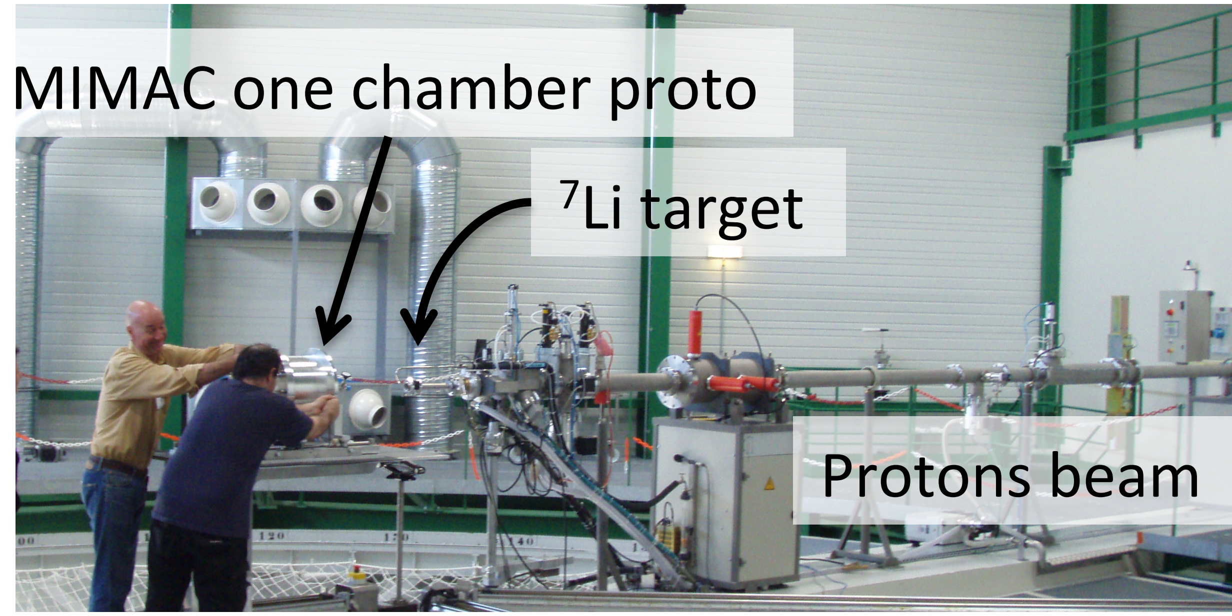


Electron recoil discrimination

@ Amande Facility (IRSN Cadarache):

Neutron field production reaction:

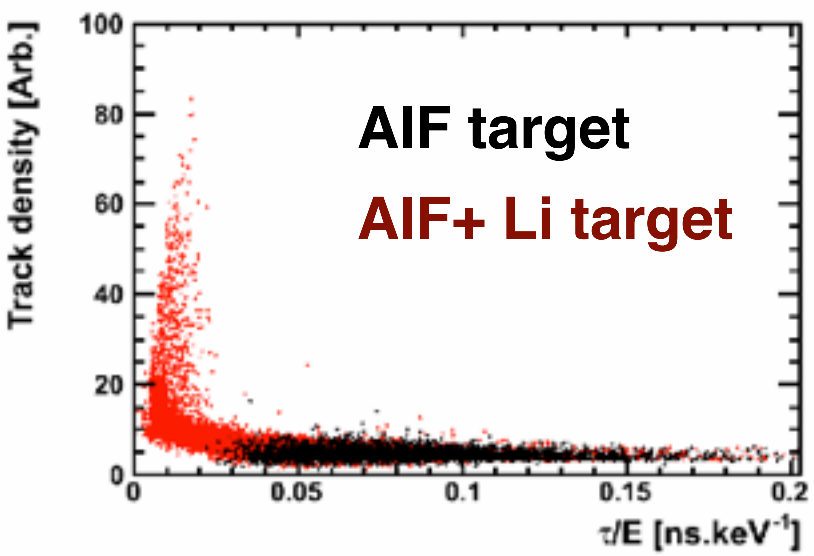
$$^{7}\mathrm{Li(p,n)}^{7}\mathrm{Be}$$

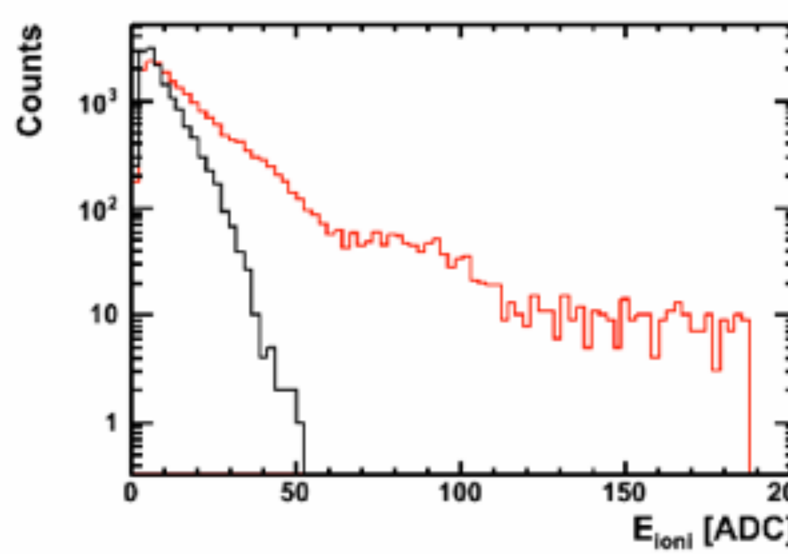


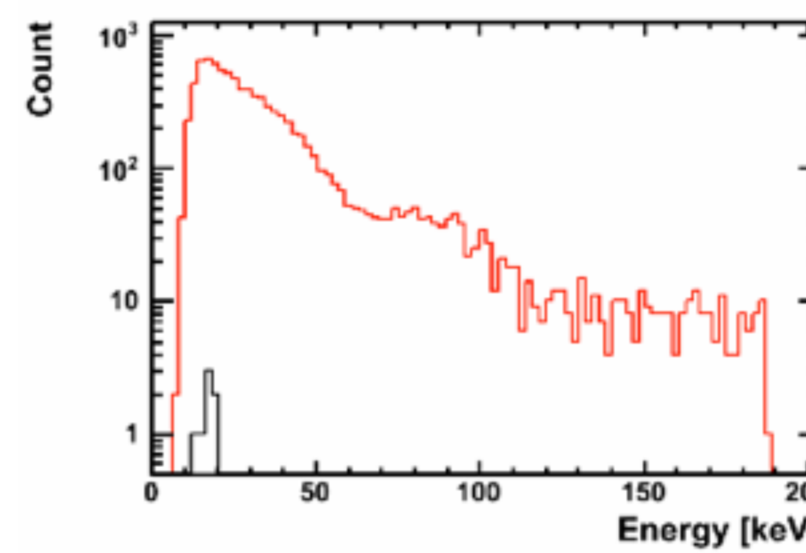
Target : $\mathrm{Al\,F + Li}$

$\gamma - \mathrm{ray}$

Neutrons





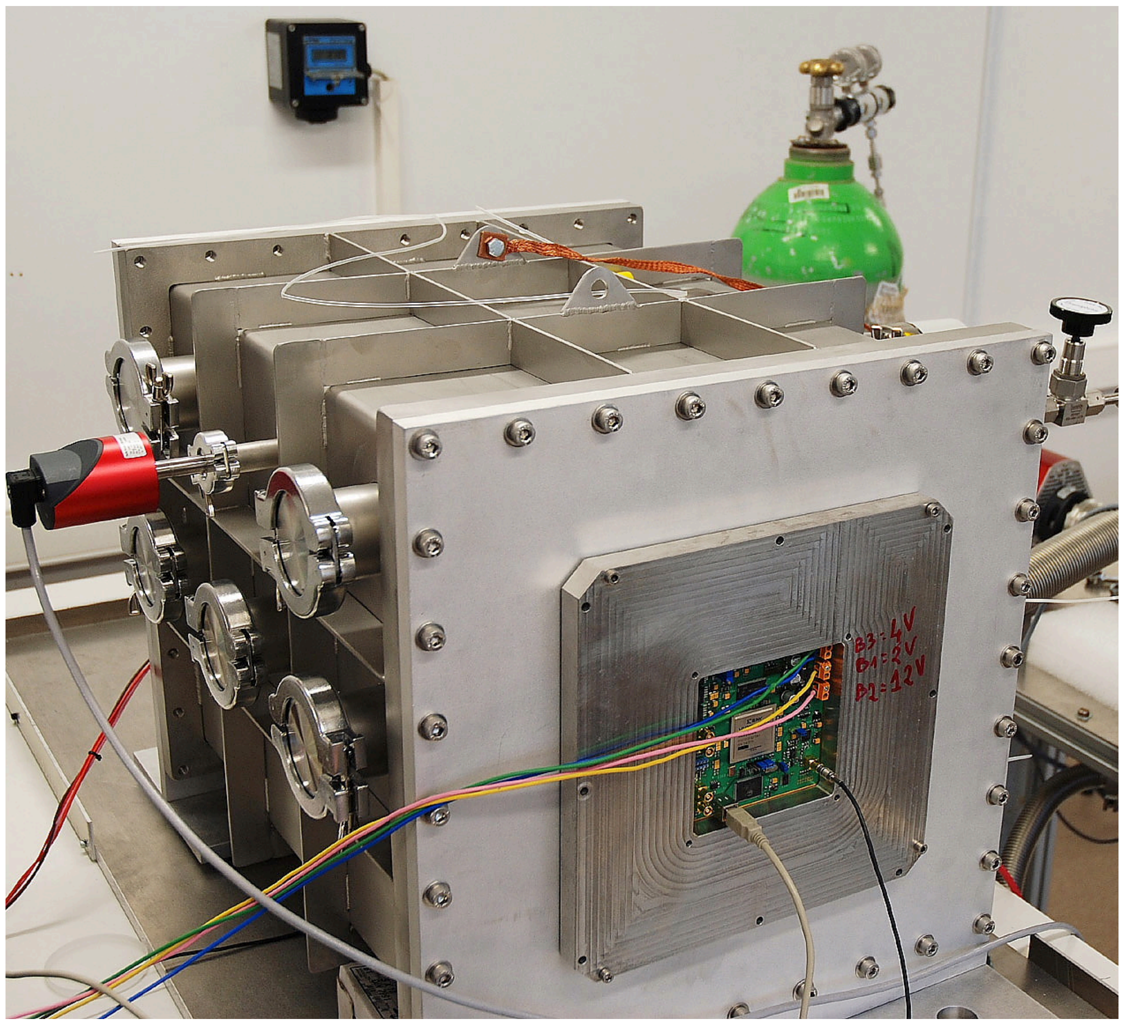


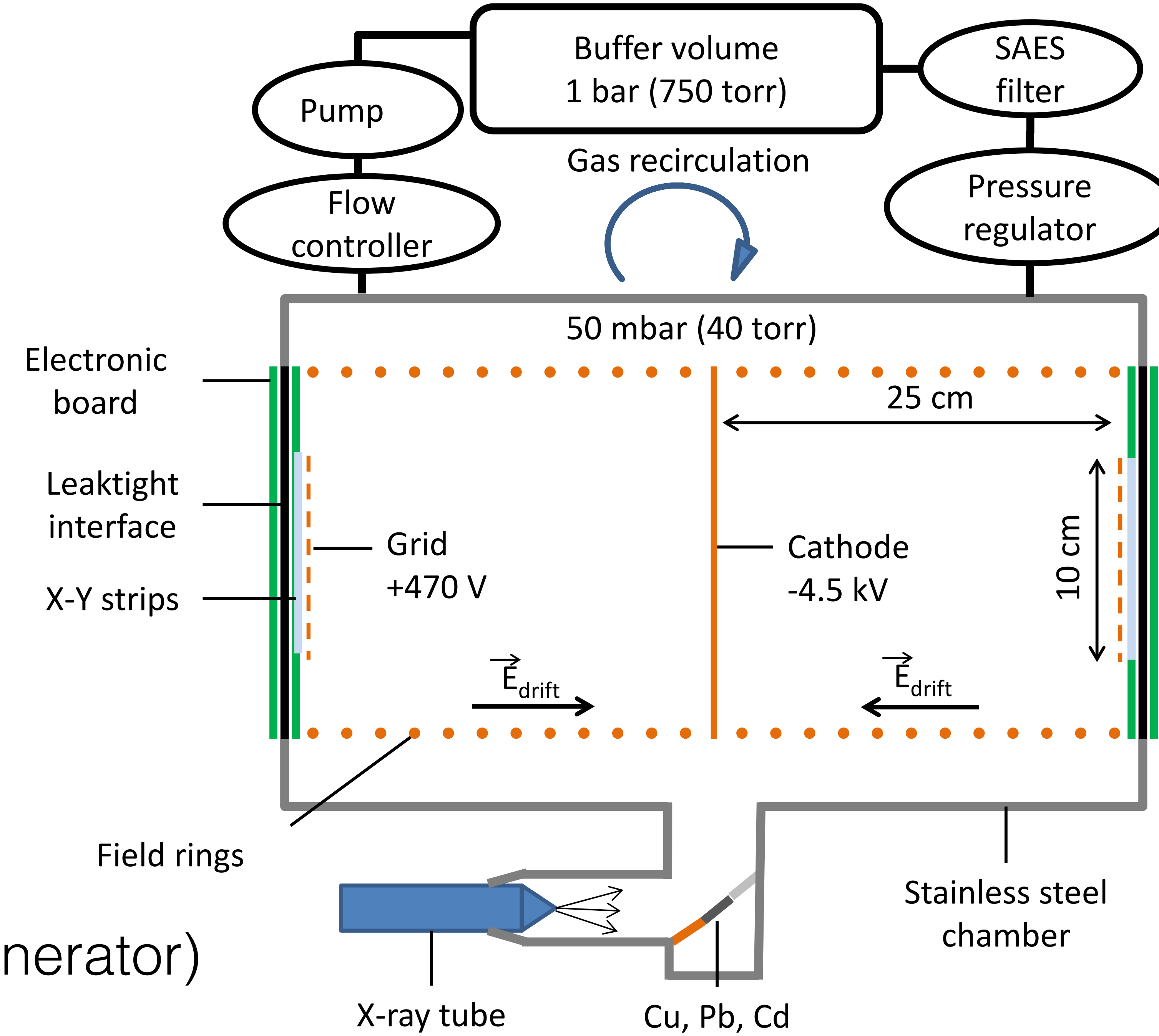
Experiment with and without Li

10^{-5} **electron recoil discrimination**

→ **To apply on 2013-2014 data**

The bi-chamber prototype





Active volume: ~ 6 L
Online calibration: weekly (X-Generator)

Installed at Modane Underground Laboratory (**LSM**) in June 2012

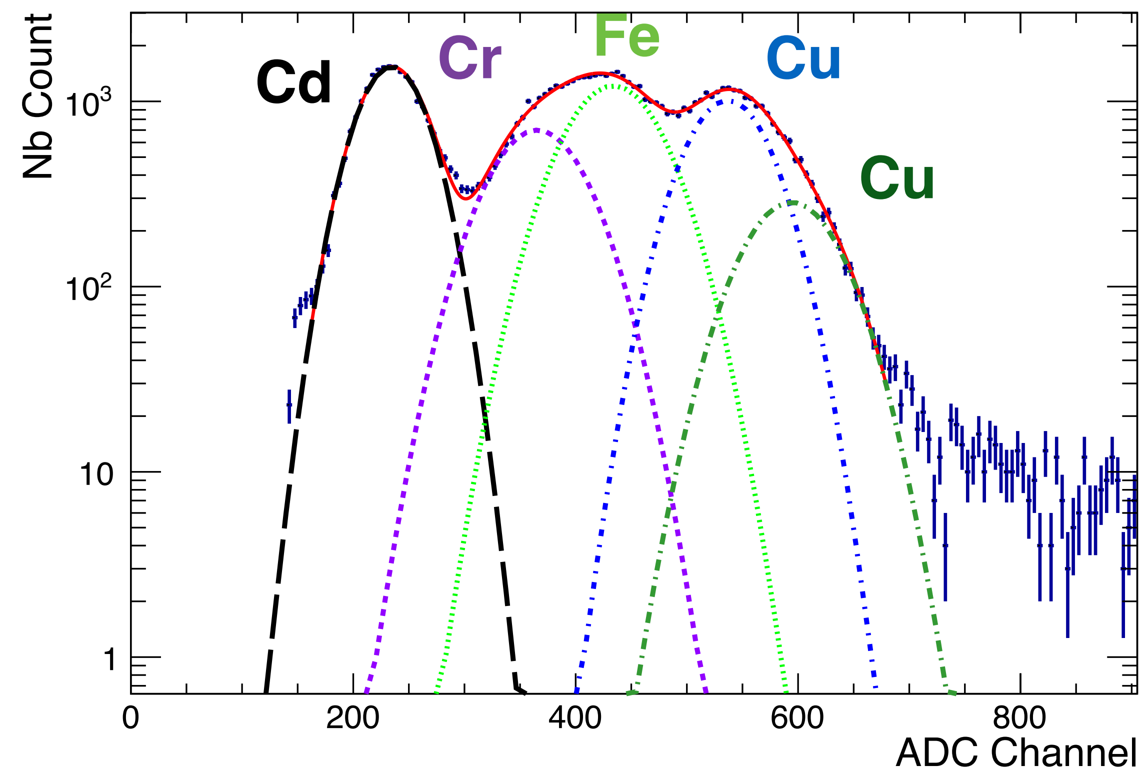
Calibration

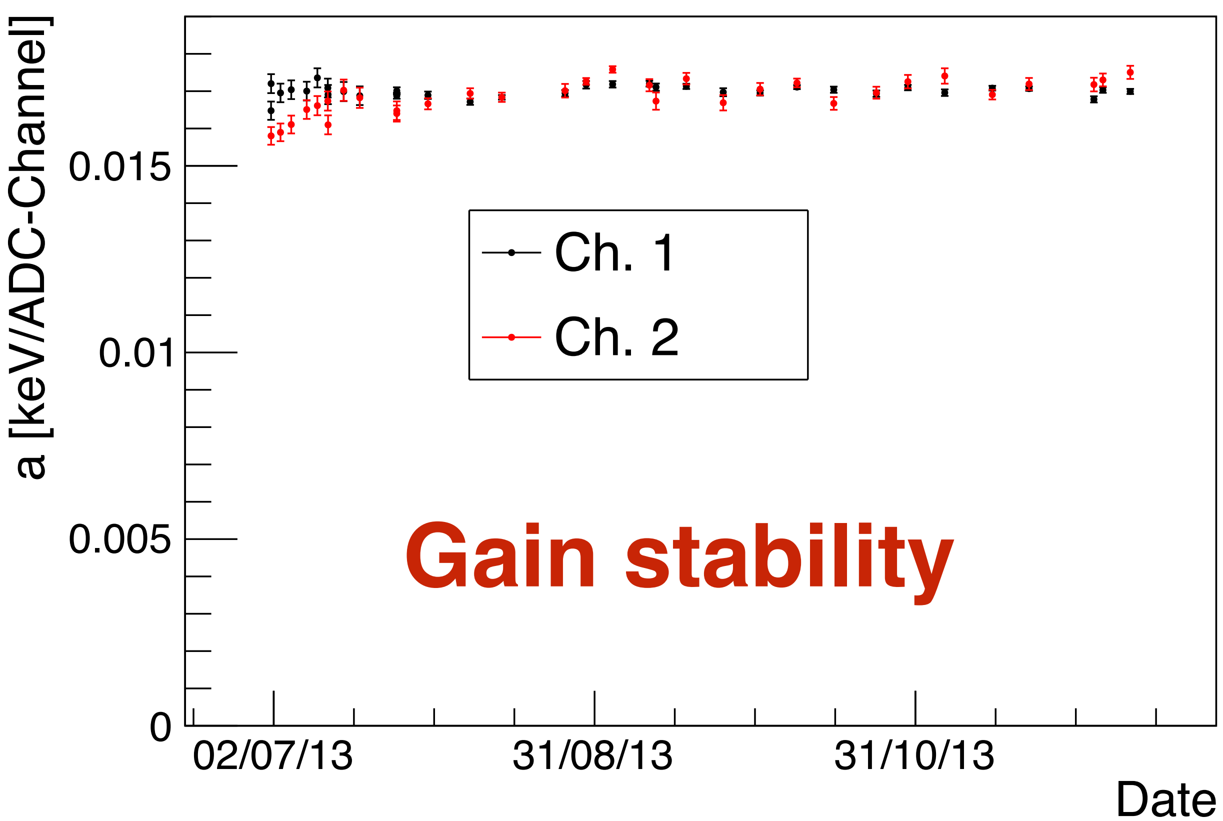
Calibration:

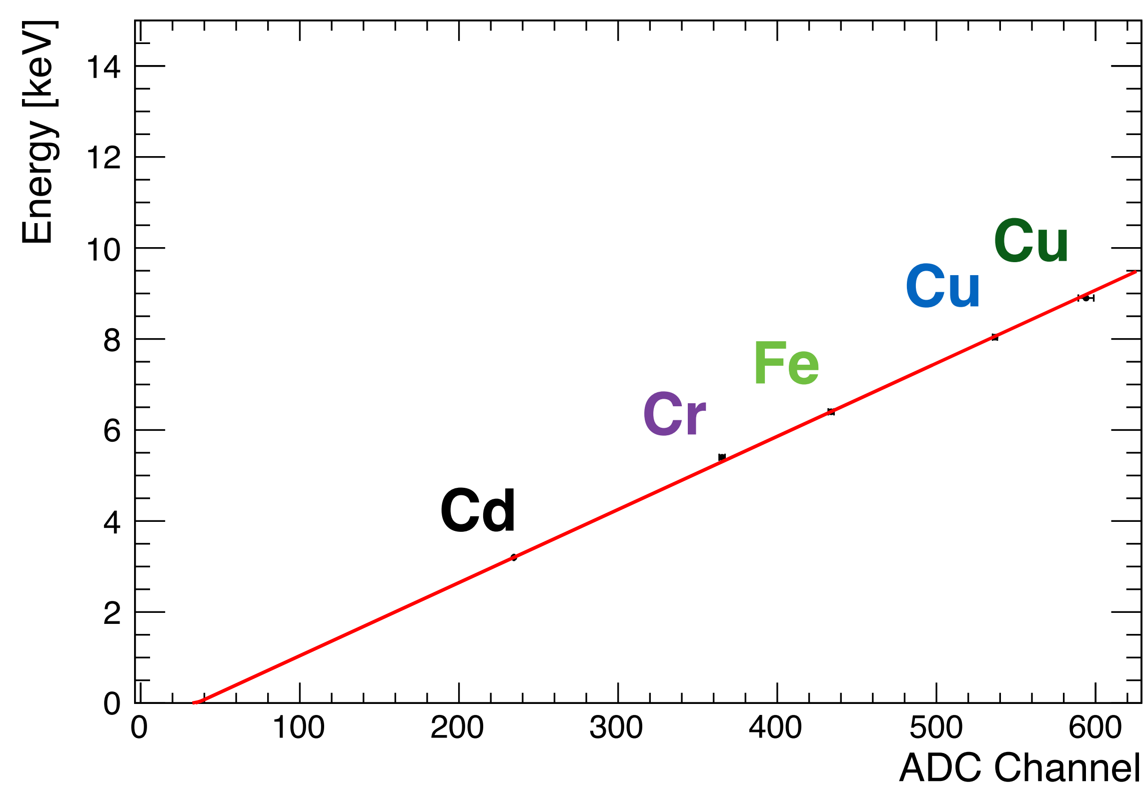
X-ray generator to produce fluorescence photons from metal foils (Cd, Fe, Cu)

Once a week

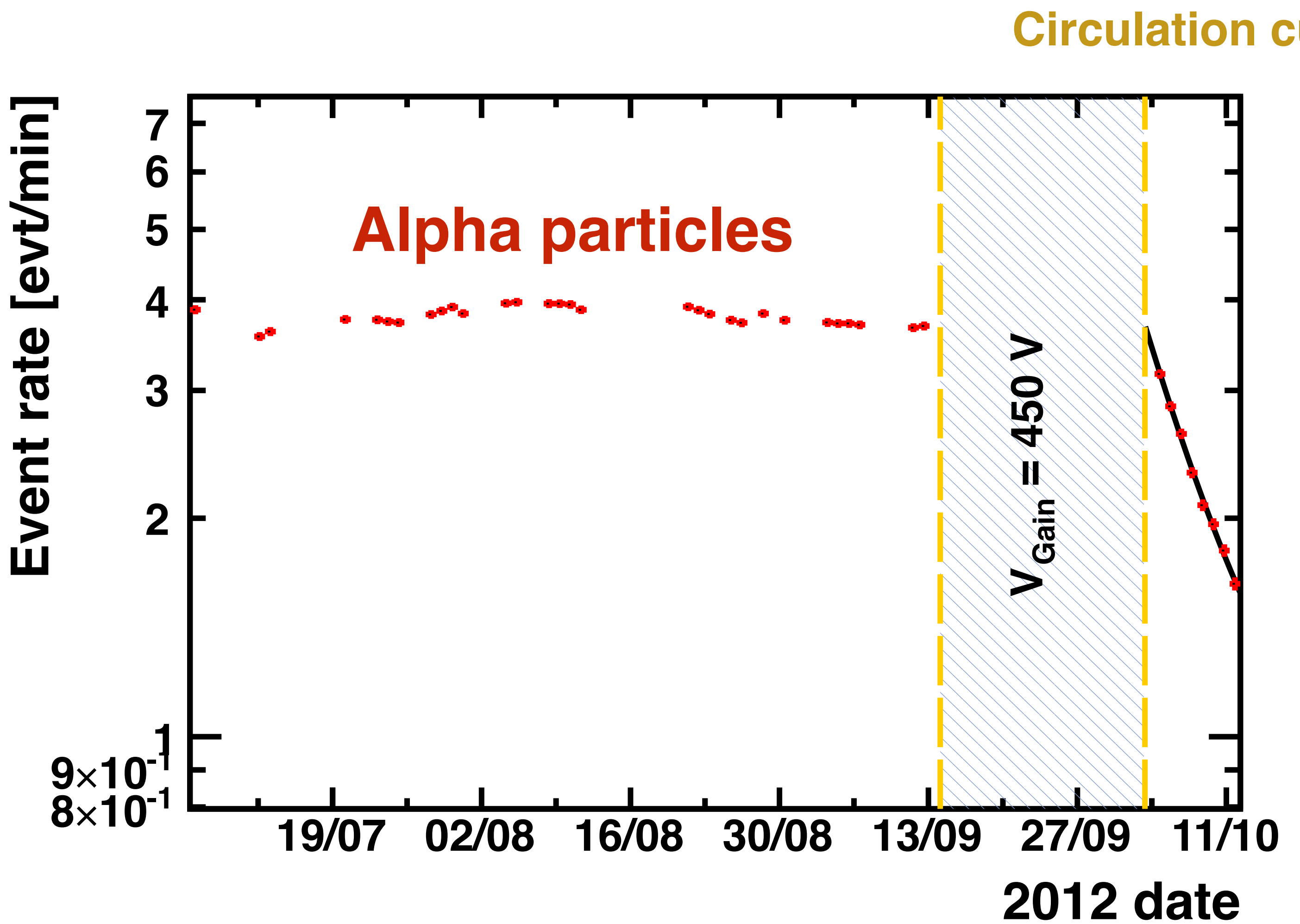
Low energy detector calibration.







2012 results



α-particles rate:

$$R_\alpha \approx 4\,\mathrm{evt/min}$$

Circulation cut
→ Exponential decreasing

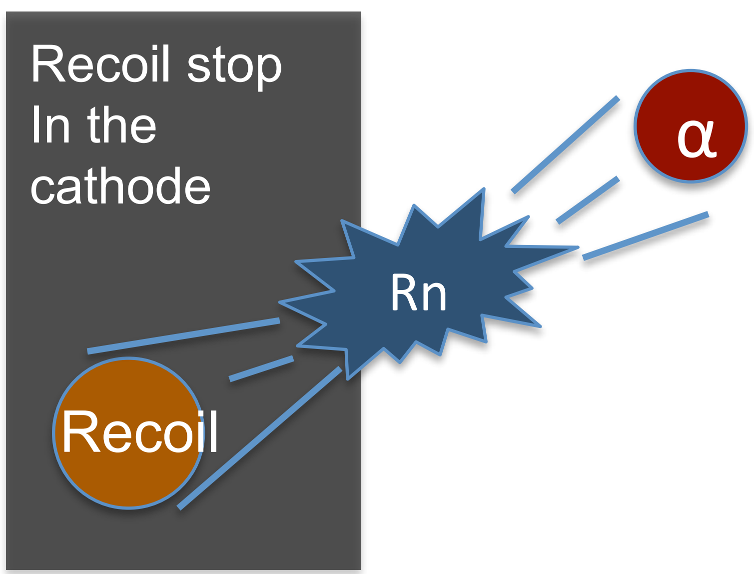
Compatible with the $\alpha-$decay of the $^{222}\mathrm{Rn}$ (3.8 days)

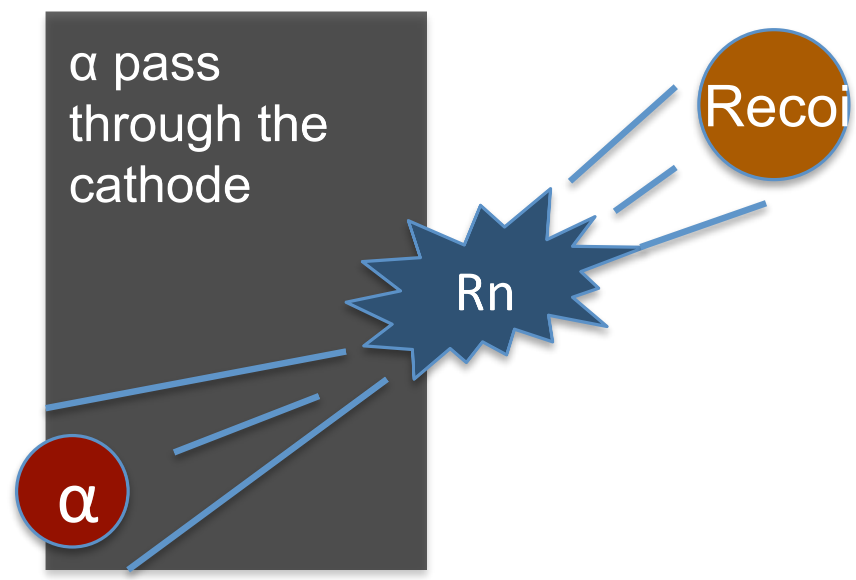
$$(\alpha - \mathrm{decay})$$

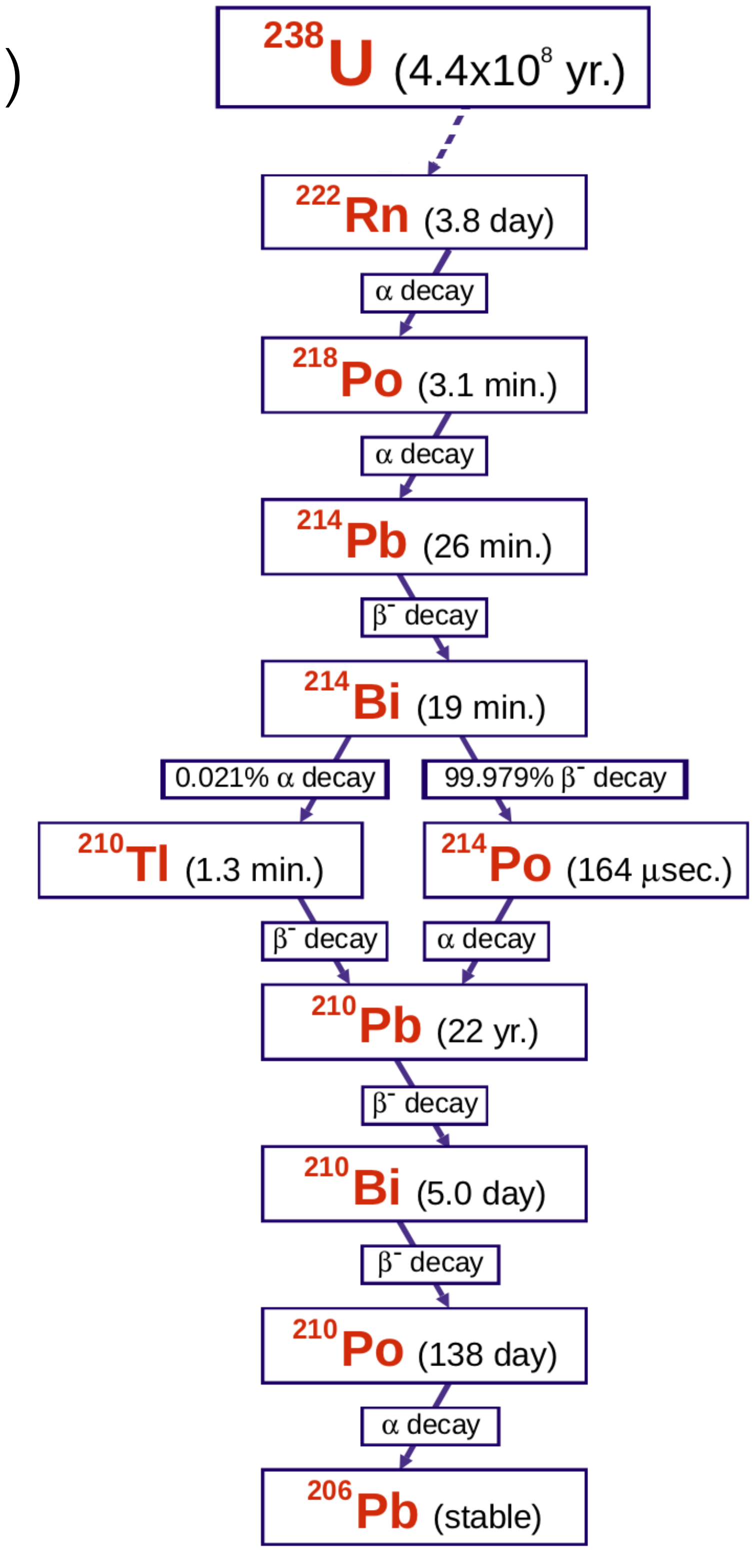
$^{222}\mathrm{Rn}$ from an intrinsic material pollution of $^{238}\mathrm{U}$

Radon progeny

→ 3 alpha decays in the $^{222}\mathrm{Rn}$ chain (cut form $^{210}\mathrm{Pb}$ life time)







$$E^{\alpha}_{kin} \approx 5\,\mathrm{MeV}$$

Flash-ADC saturation

$$E^{recoil}_{kin} \approx 100\,\mathrm{keV}$$

Ionization Quenching

$$E^{recoil}_{ioni} \approx 30\,\mathrm{keV}$$

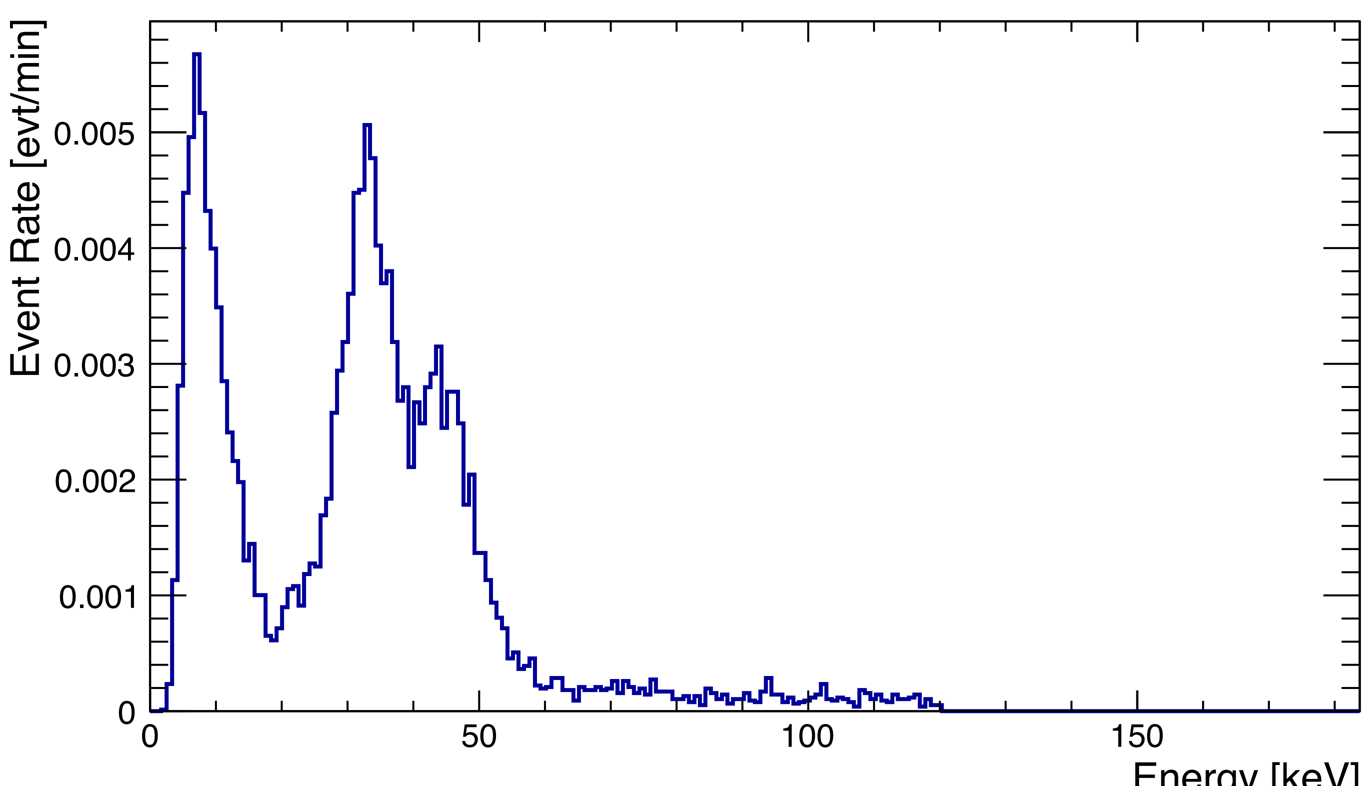
Radon progeny

Noyau père	E_α [MeV]	Noyau fils	E_{Recul} [keV]	Quenching [%]	E_{ioni} [keV]
Issus du ^{222}Rn					
^{222}Rn	5.489	^{218}Po	100.787	37.93	38.23
^{218}Po	6.002	^{214}Pb	112.270	39.10	43.90
^{214}Po	7.687	^{210}Pb	146.525	40.12	58.78

Tree low energy recoils $E_{ioni} \in [38, 59]\,\mathrm{keV}$

(using SRIM IQF estimation)

→ Two peaks expected with $E_{ioni} \in [30, 50]\,\mathrm{keV}$

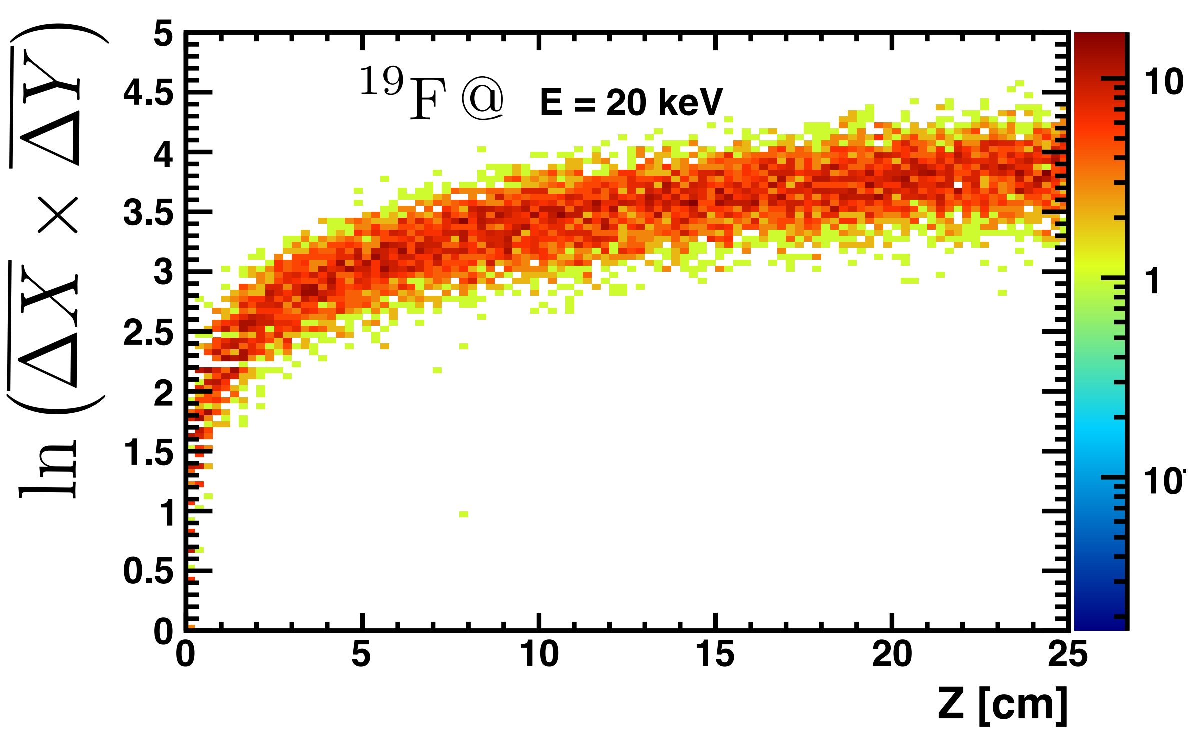


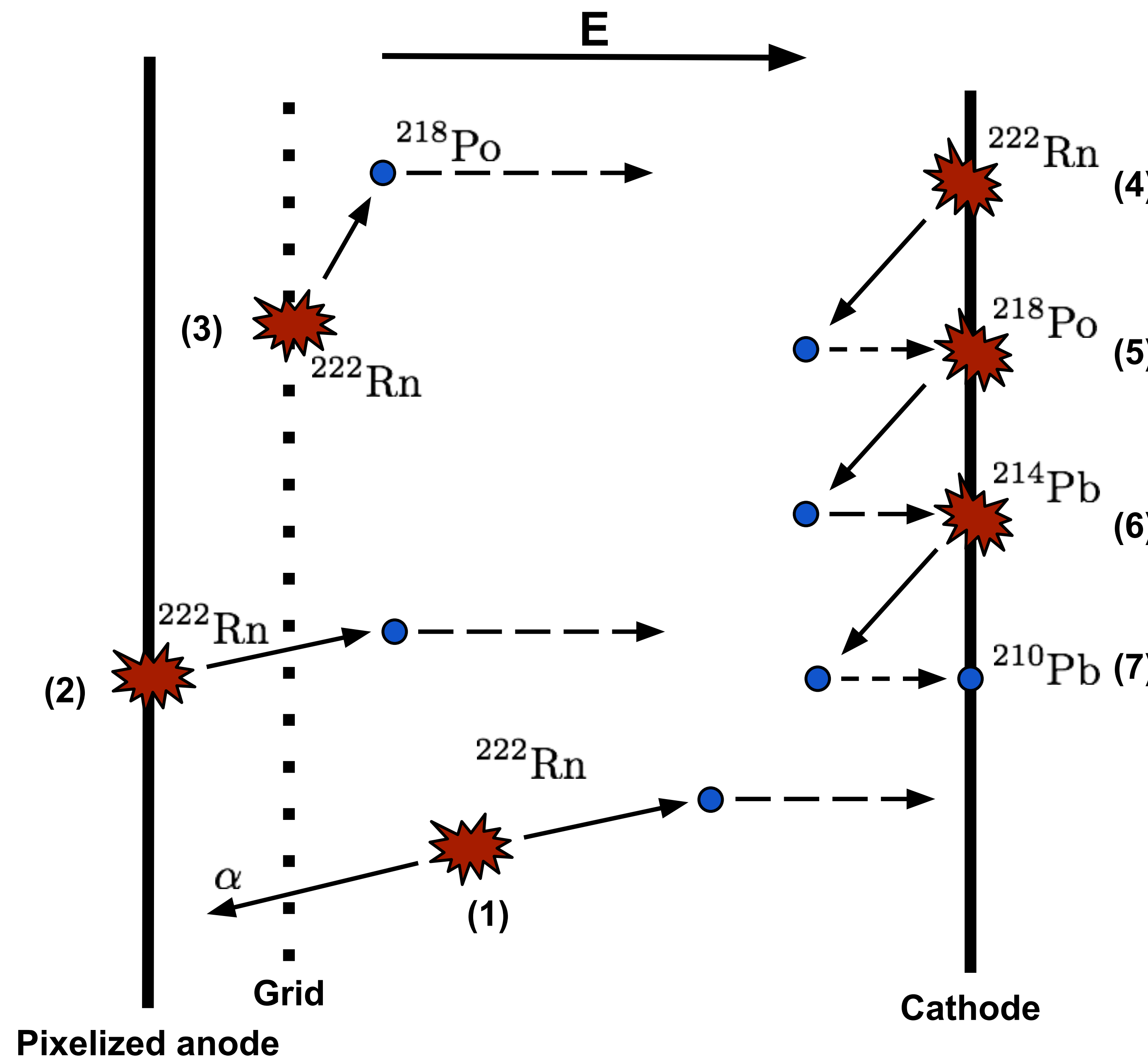
Radon progeny origin

MPD related to the diffusion

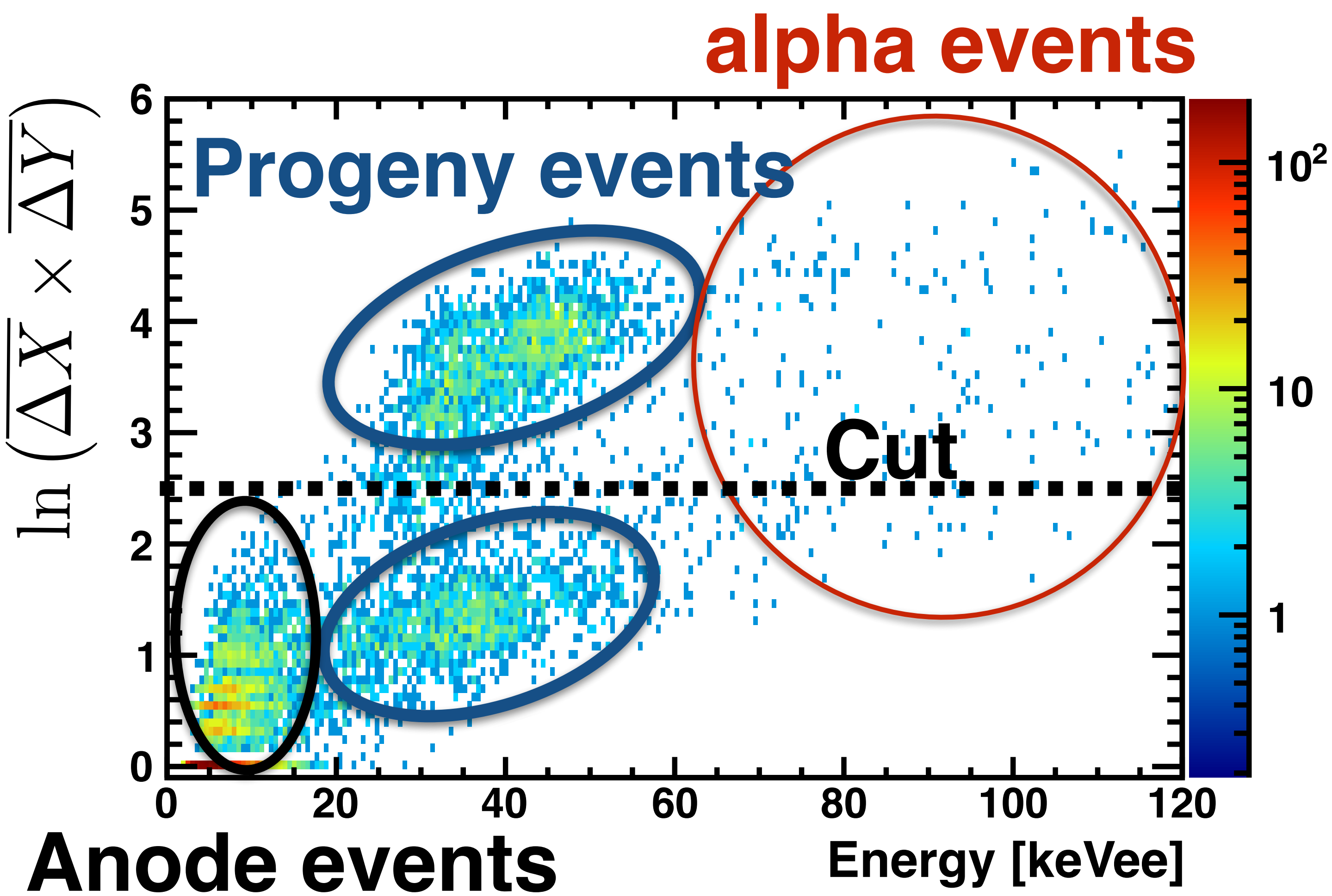
$$\overline{\mathcal{D}} = \ln\left(\overline{\Delta X} \times \overline{\Delta Y}\right)$$

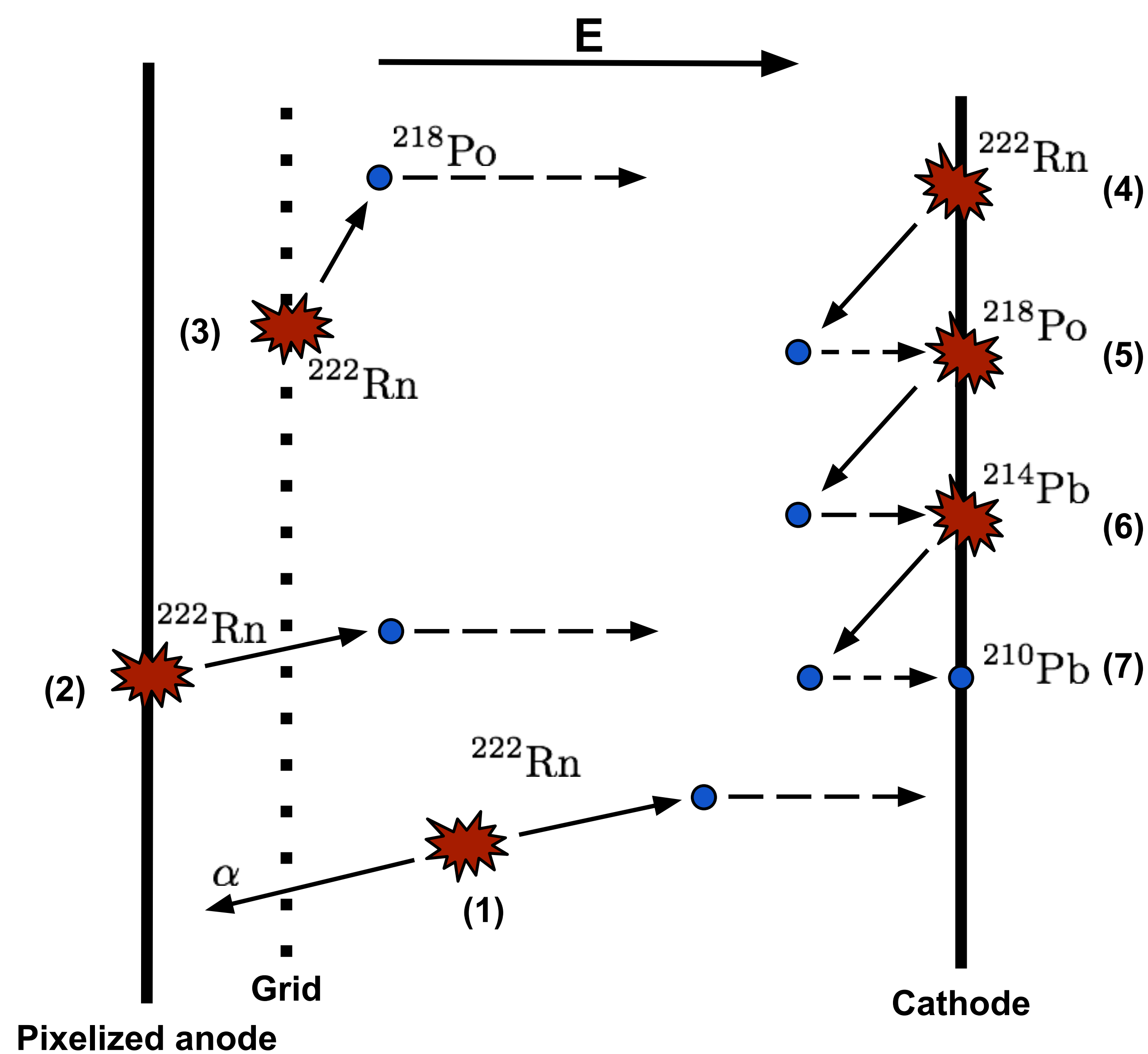
Related to the Z coordinate





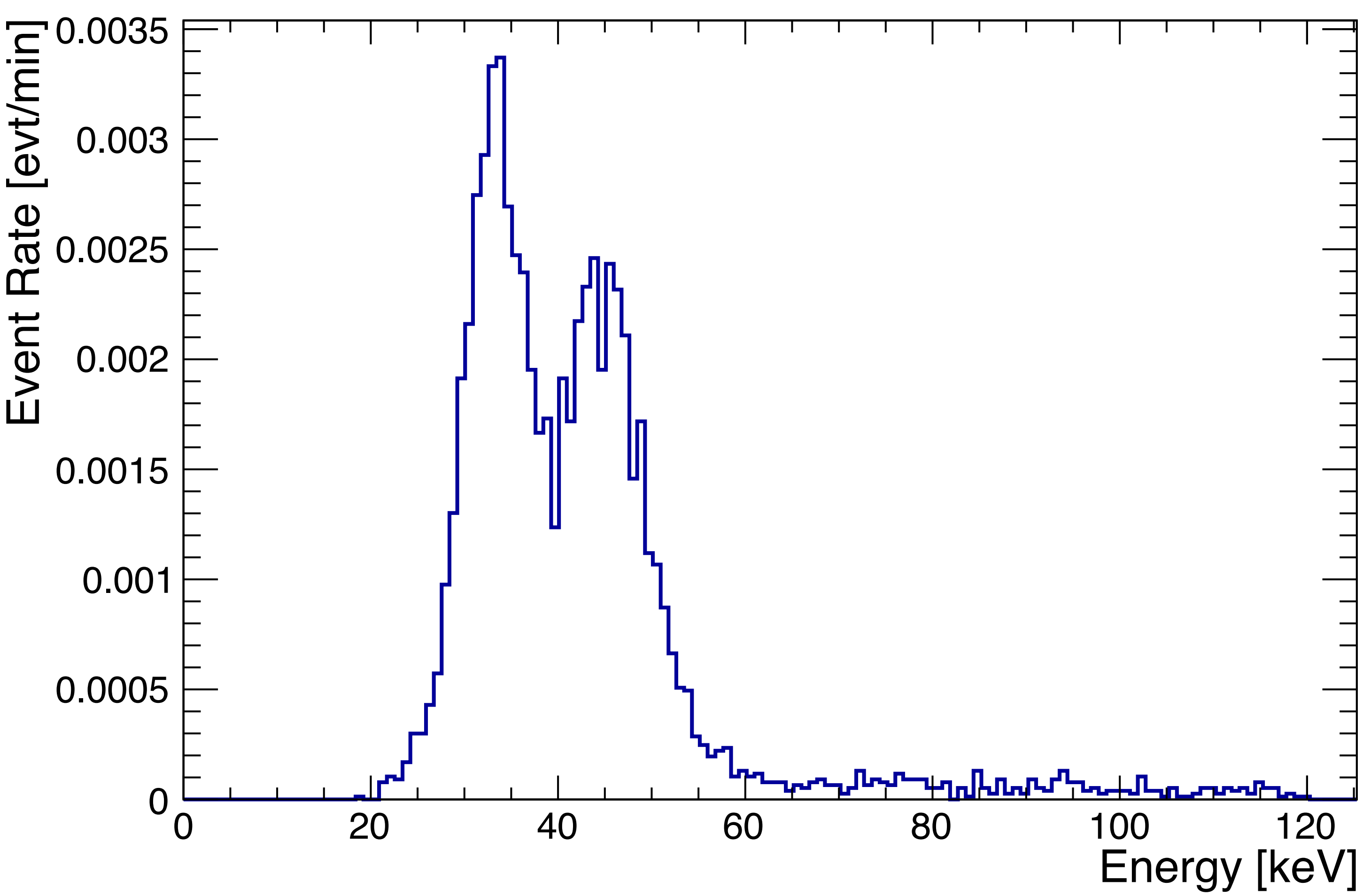
Radon progeny origin

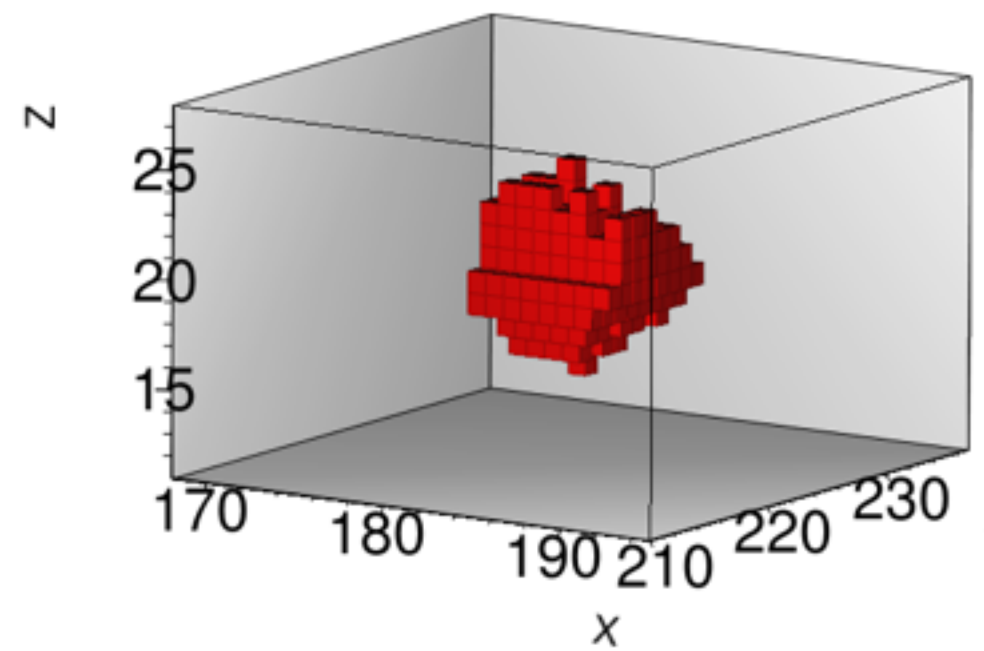


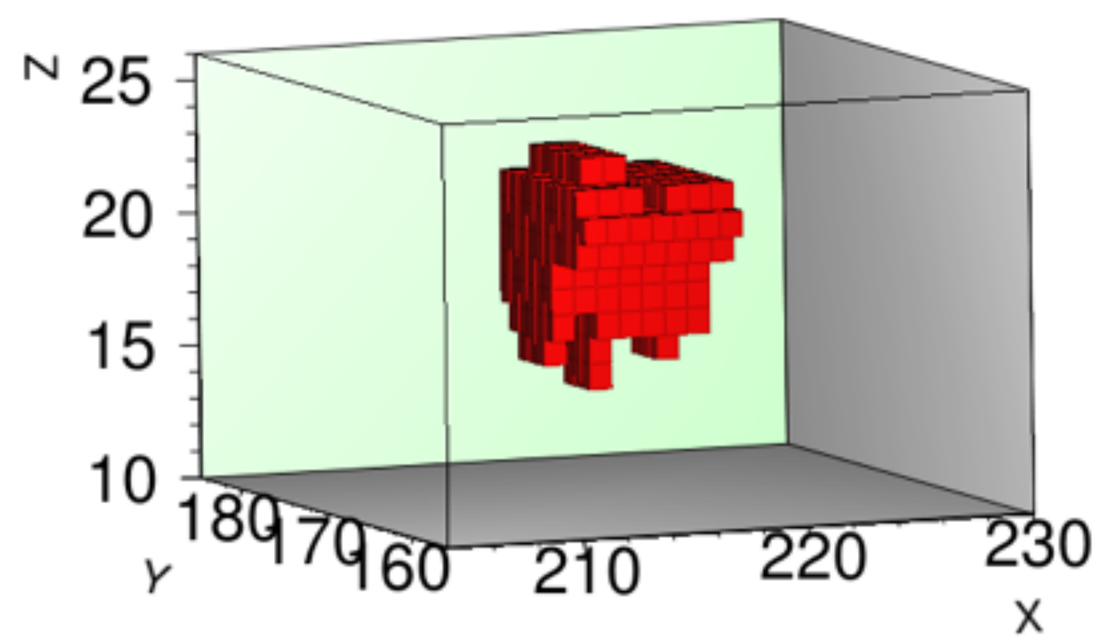


Radon progeny events

First energy spectrum of $^{222}\mathrm{Rn}$ progeny event in a DM search experiment





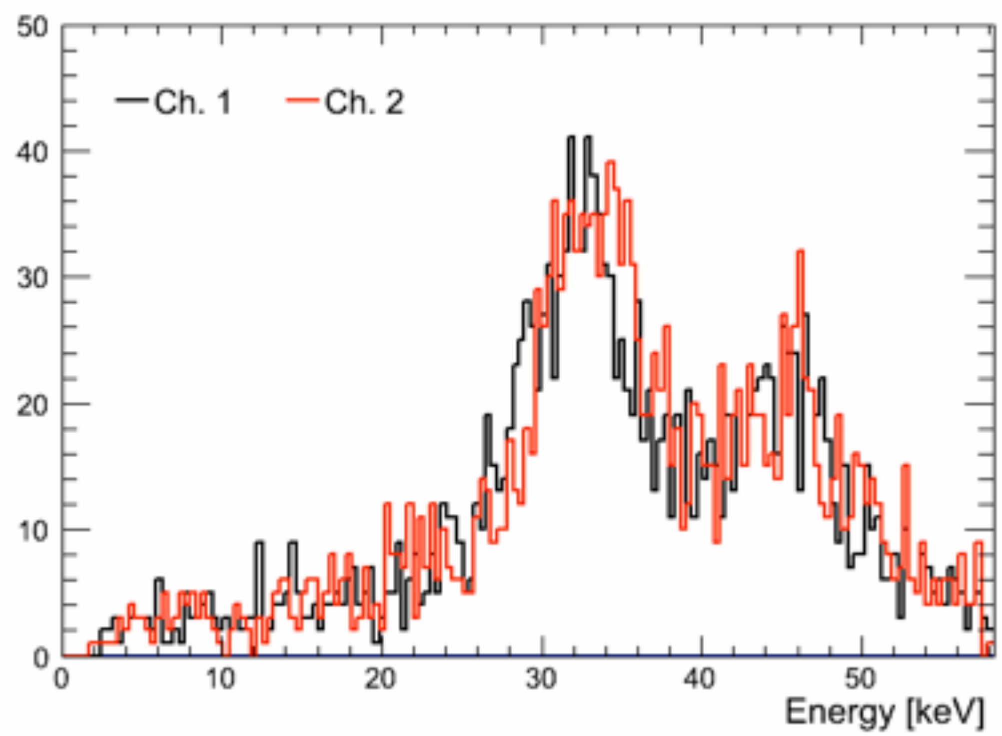


Radon progeny event discrimination

2013 update:

- New cathode (12 μm)
- Chamber electronic synchronisation
- $V_{\mathrm{buffer}} \times 4$
- New circulation pump (no leak)
- New Flash-ADC (rise time 60 ns)

Coincidence between both chambers



Event with track in both chamber

→ Radon progeny @ the cathode

→ **To test on the 2013-2014 run**

Conclusions

Radon progeny:

- **First measurement of the energy and the track of the daughter nuclei**
- Validation of the detection strategy
- Paper in preparation

Electron/Recoil discrimination:

- To apply on the 2013-2014 run
- Improvement using a complete detector simulation & a multivariate analysis

Phenomenology:

- Study of the implication of the LHC Dark Matter search at the LHC (mono-jet / mono-photon) on direct detection
- Paper in preparation

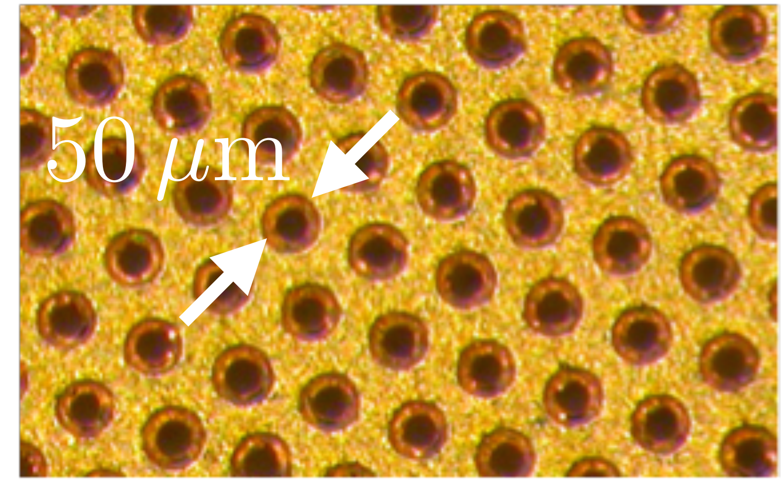
Cathode signal:

- Promising way for the Z fiducialisation
- Experiment in progress

Perspectives

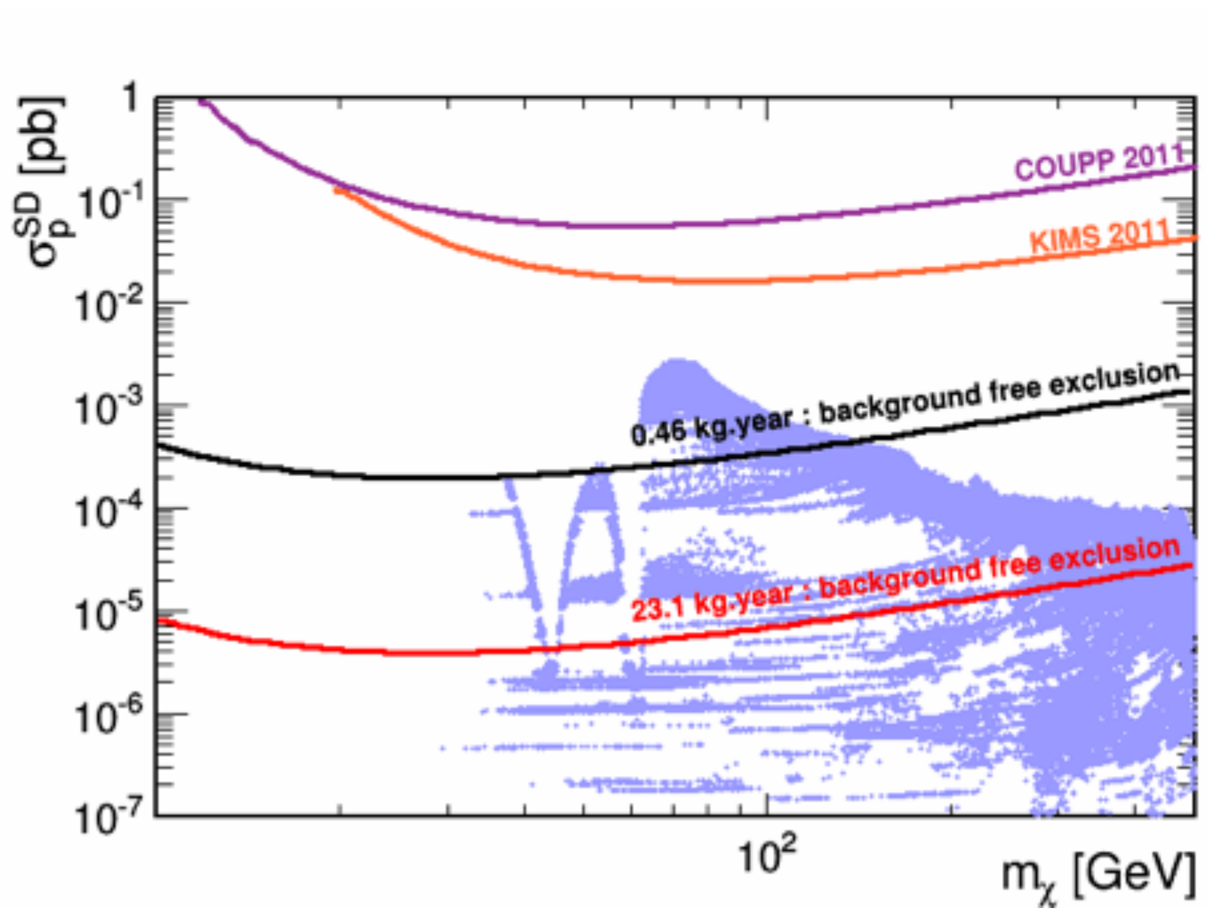
MIMAC future upgrades:

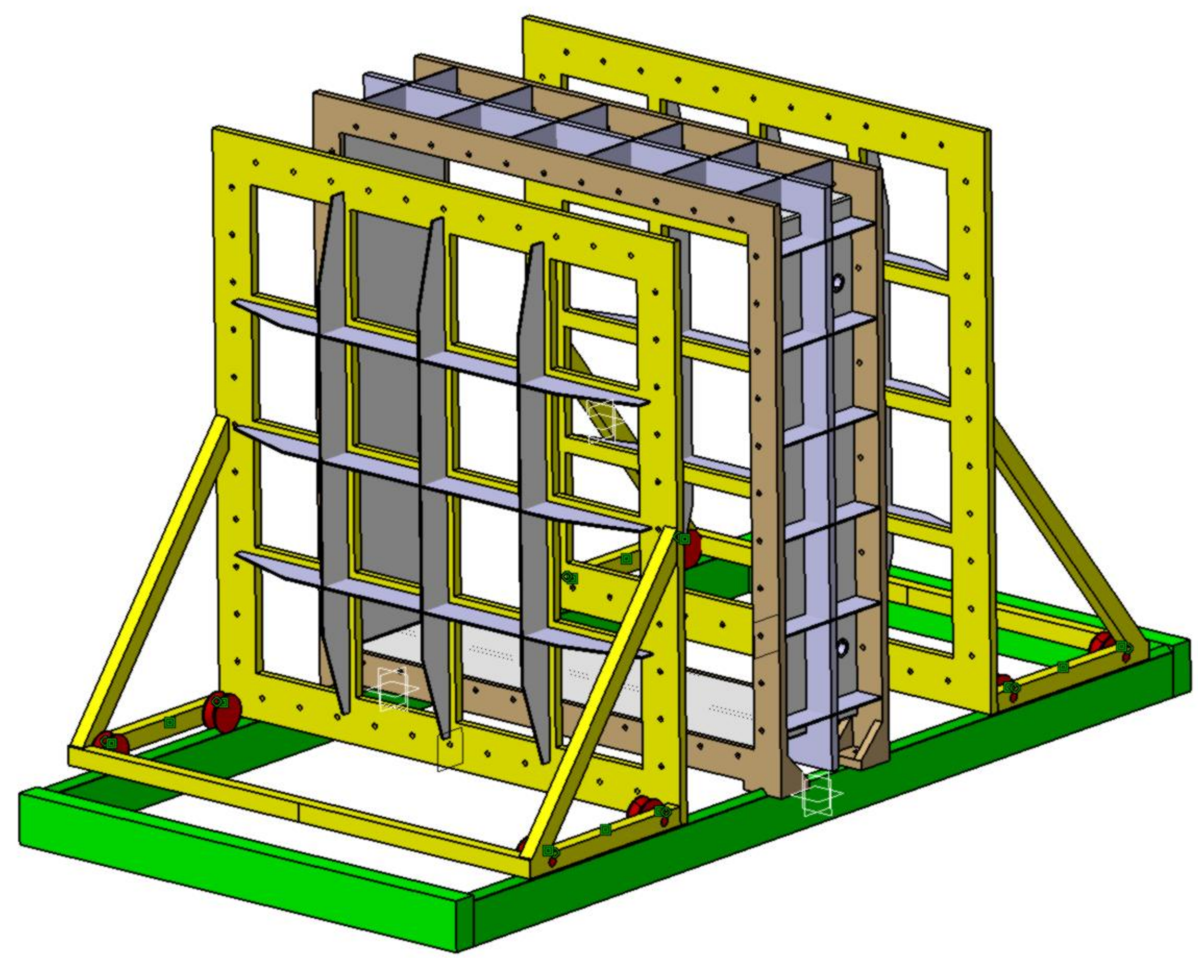
- New 6 μm mylard cathode
- Cathode signal acquisition
- New detector 35x35 with Cu/kapton grid



Demonstrator: 1m3 detector

- 16 bi-chamber modules with 35x35 detector
- Competitive with actual project





MIMAC collaboration

LPSC (Grenoble): F. Mayet , D. Santos
Q. Riffard (Ph.D) (started in October 2012)

Technical Coordination : O. Guillaudin

- Electronics : G. Bosson, O.Bourrion, J-P. Richer
- Gas detector : O. Guillaudin, A. Pellisier
- Data Acquisition: O.Bourrion, T. Descombes
- Mechanical Structure : Ch. Fourel, S. Roudier, M. Marton
- Ion source (quenching) : P. Sortais, J-F. Muraz

Saclay (IRFU): I. Giomataris, E. Ferrer, F.J. Iguaz, J-P. Mols (uM detectors)

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

Neutron facility (AMANDE) :
IRSN (Cadarache): L. Lebreton, D. Maire (Ph. D.)