Low-mass WIMP detection with TREX-DM

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on behalf of TREX-DM team

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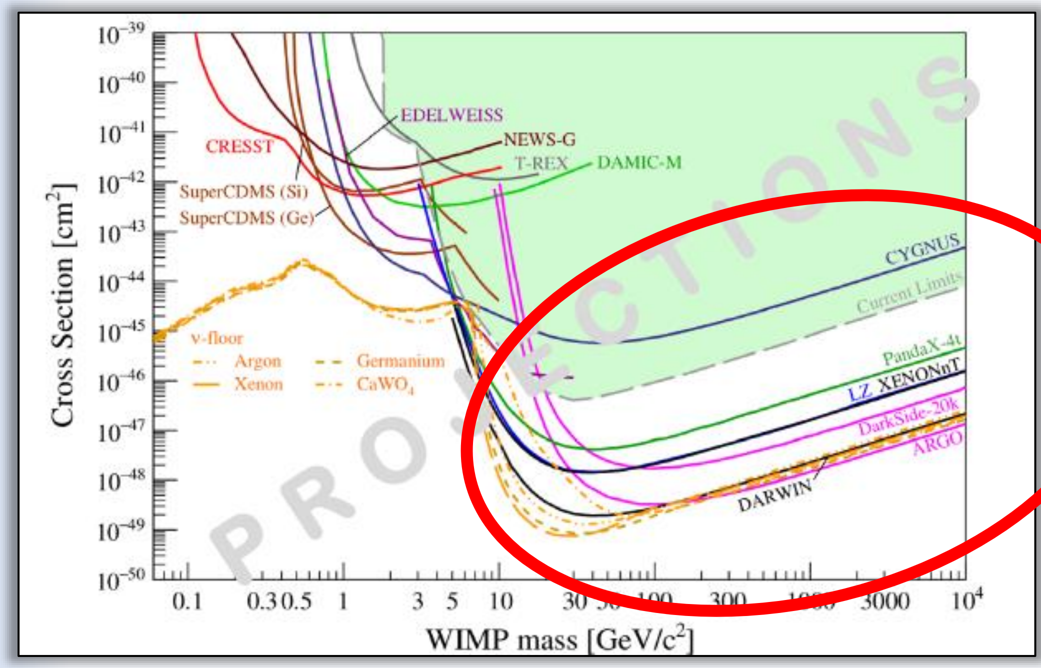
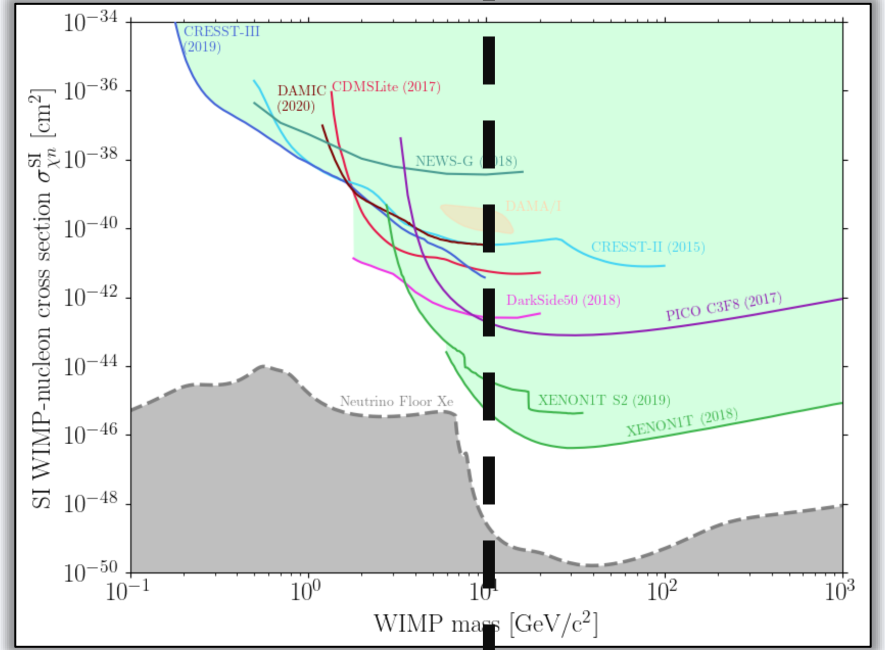
Goal

- Direct detection of WIMPs (dark matter)
  - Low masses <10 GeV/c^2
- Spin independent nuclear recoil

Low mass range

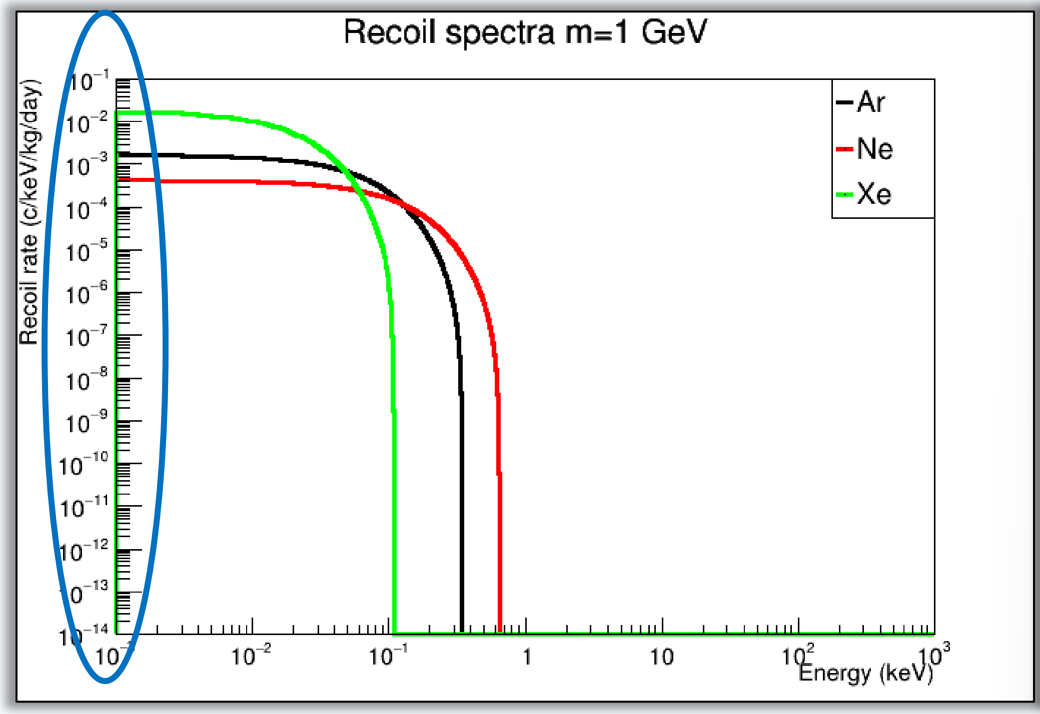


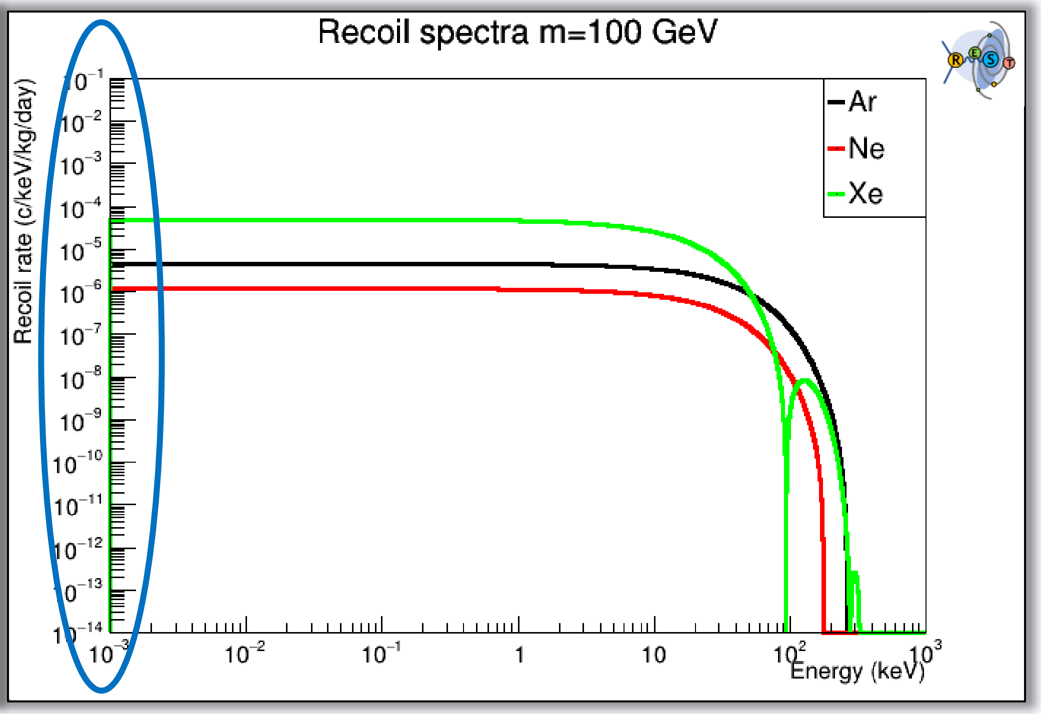
Projected to reach neutrino fog in high mass soon!



Challenges

- Low-mass WIMP detection requires:
  - low background
  - high exposure (mass × time)
  - low energy threshold
  - light nuclei targets





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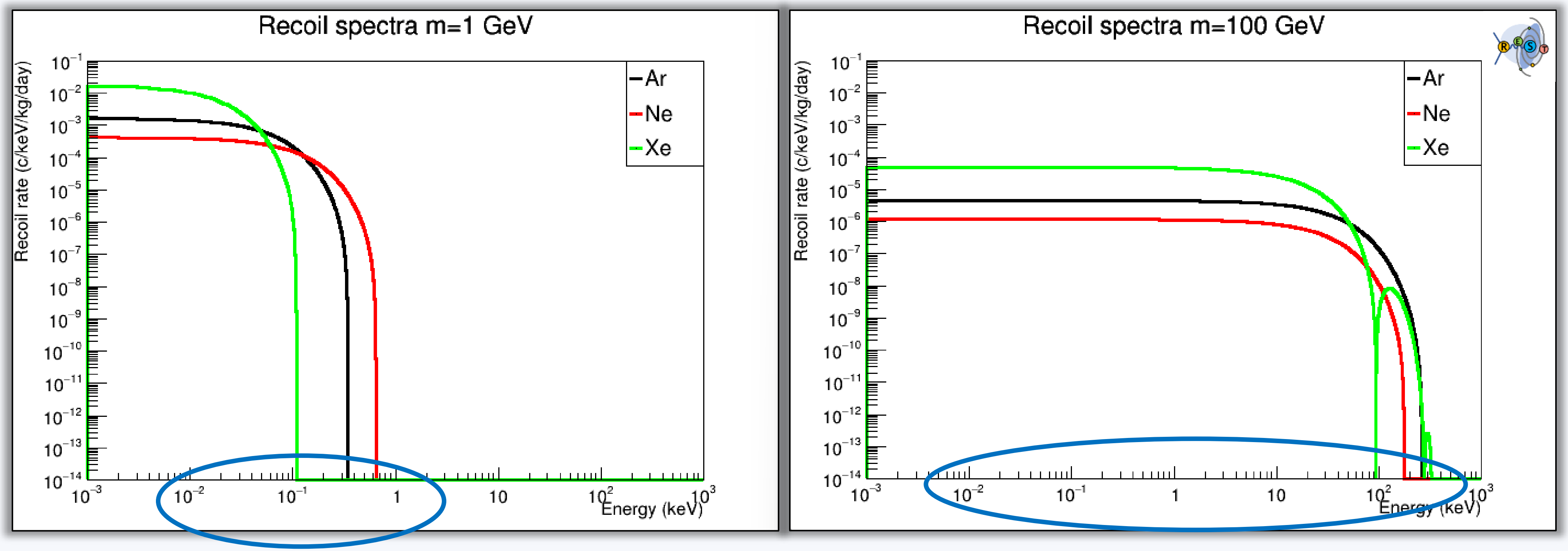

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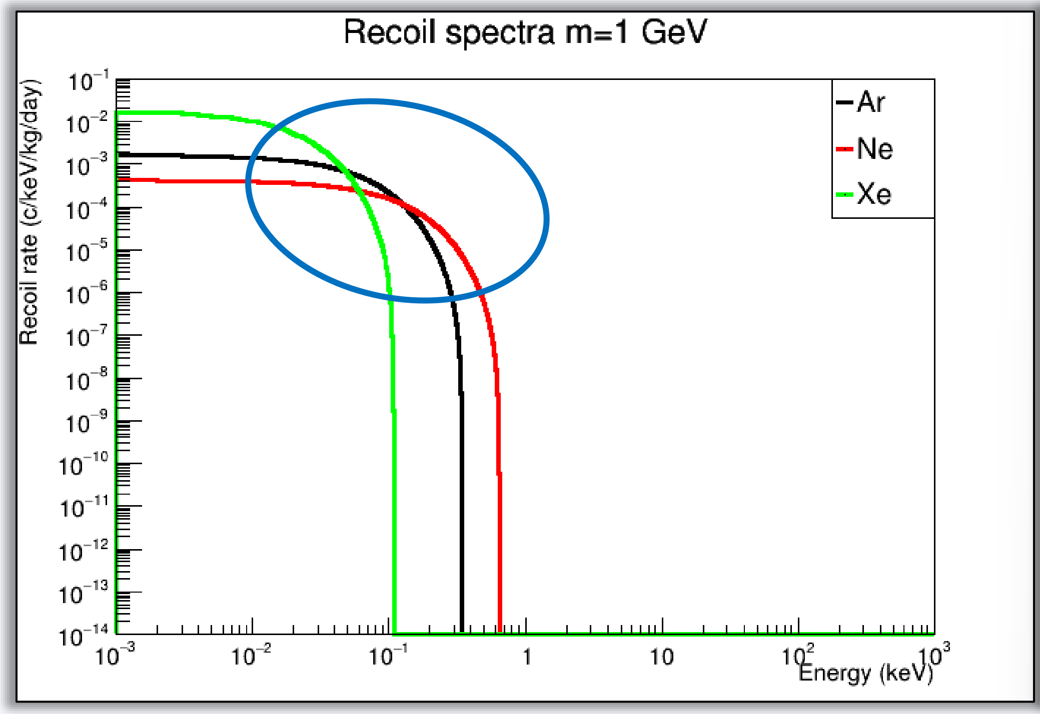
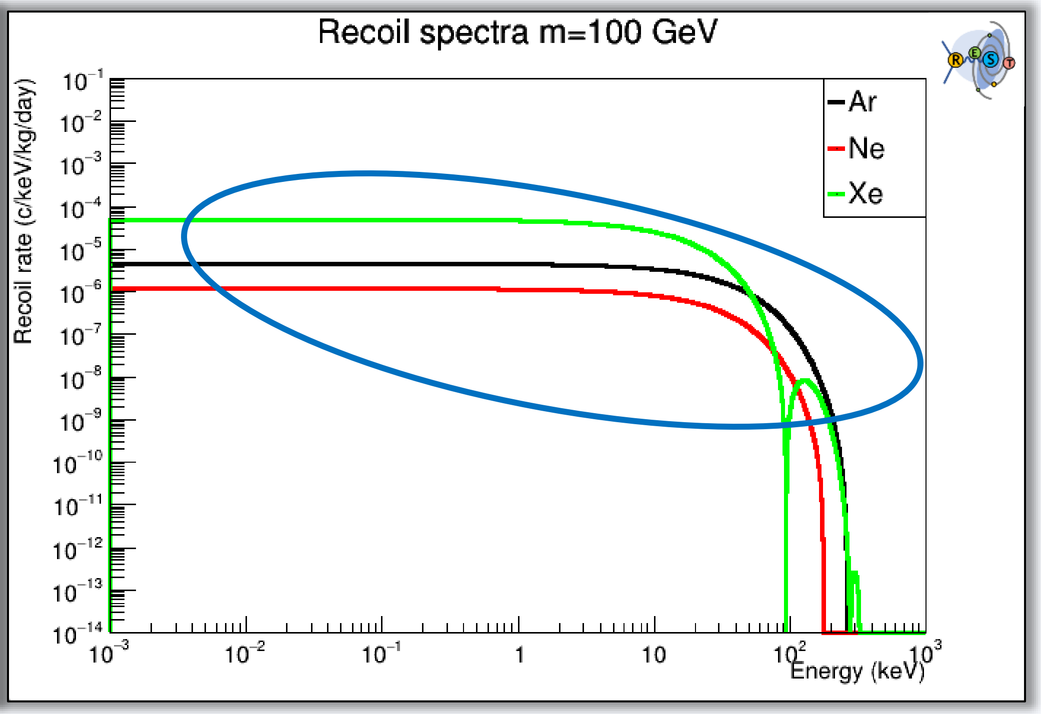
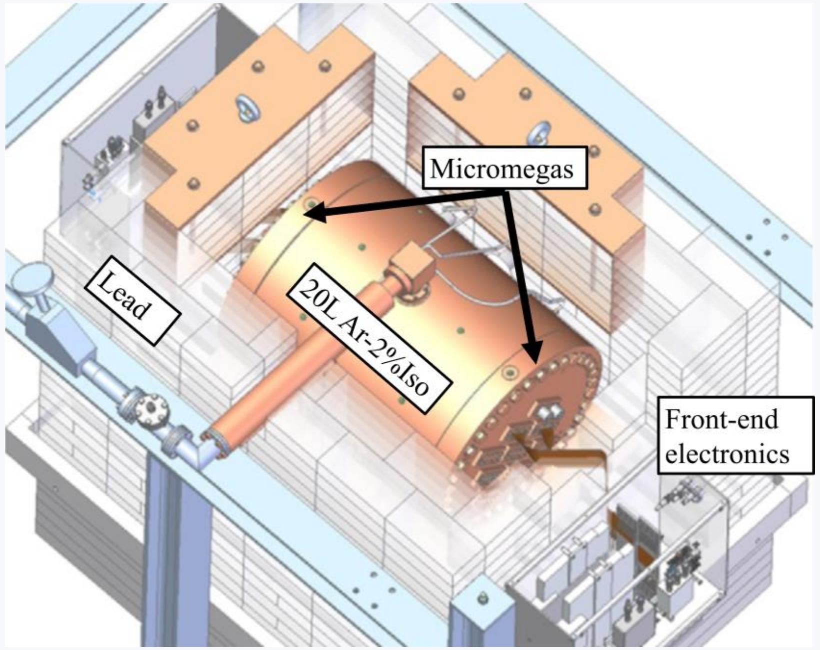


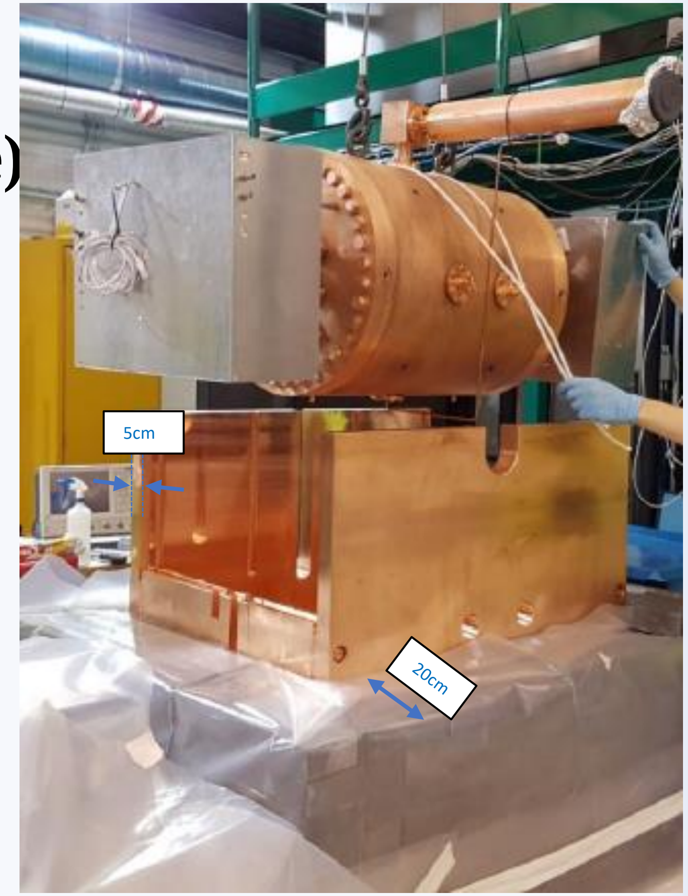


TREX-DM specifications

*Iguaz, F.J., Garza, J.G., Aznar, F. et al. TREX-DM: a low-background Micromegas-based TPC for low-mass WIMP detection. Eur. Phys. J. C **76**, 529 (2016). https://doi.org/10.1140/epjc/s10052-016-4372-6*

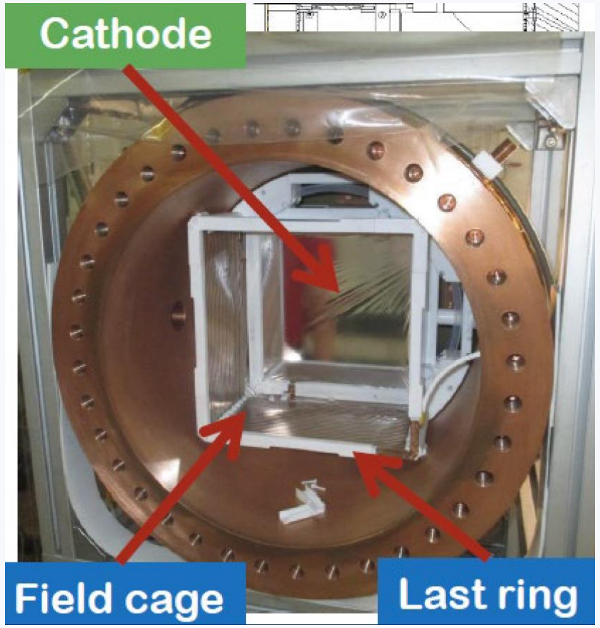
- Gaseous TPC of cylindrical copper vessel
- Active volumen of 20L up to 10bar (**~0.32 kg Ar** or **~0.16 kg Ne**)
- Shielding
  - 5cm copper + 20cm lead walls
  - Polyethylene ceiling + water
- Located at LSC (2400 m.w.e.)

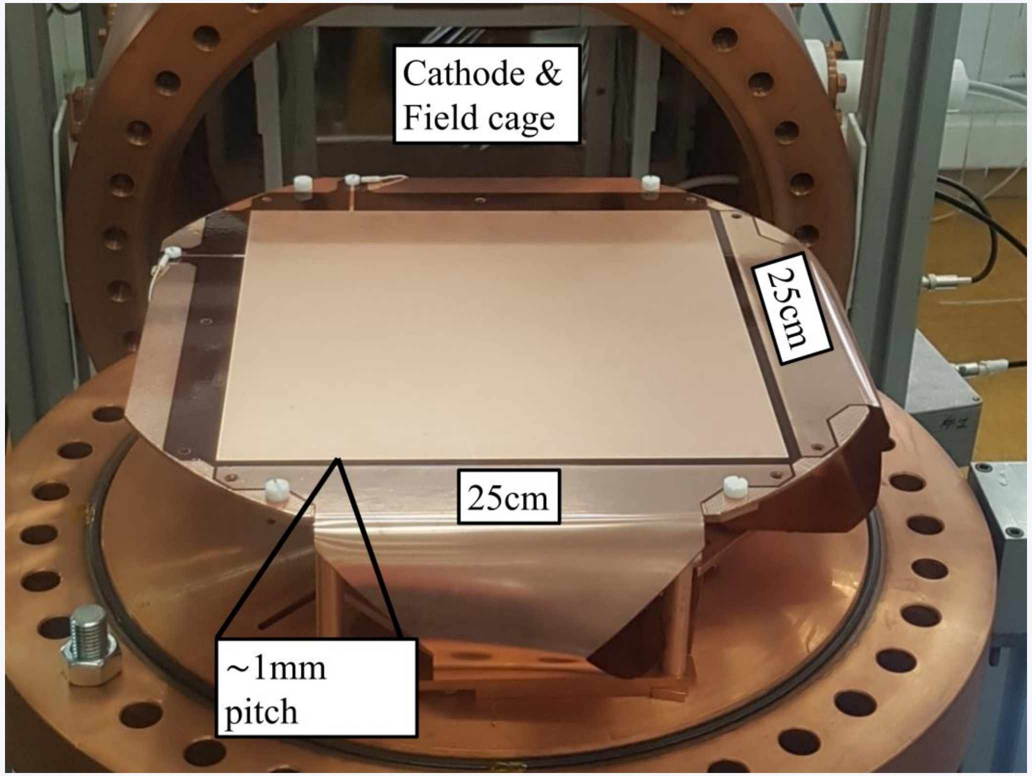




TREX-DM specifications

- 1 cathode and 2 readout planes
- Largest surface produced (*micro-bulk*) Micro-Mesh Gaseous Structure (**Micromegas**)
  - 512 channels: 256 X strips, 256 Y strips



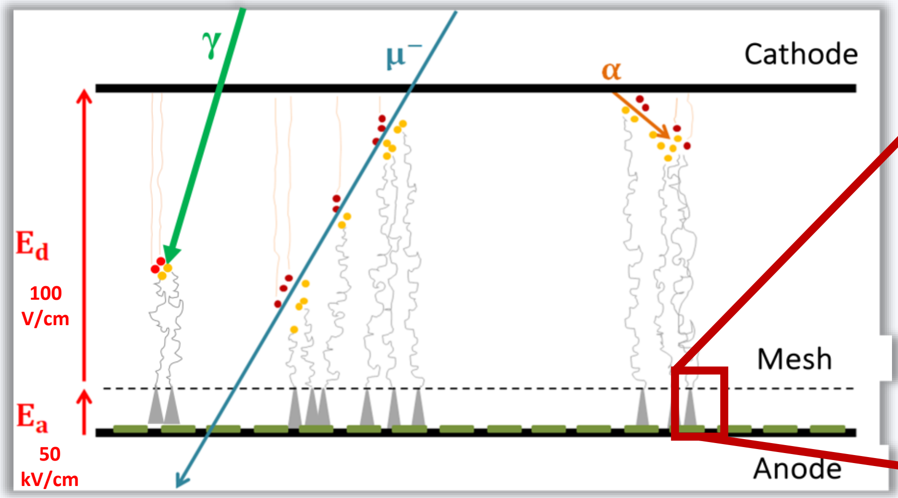


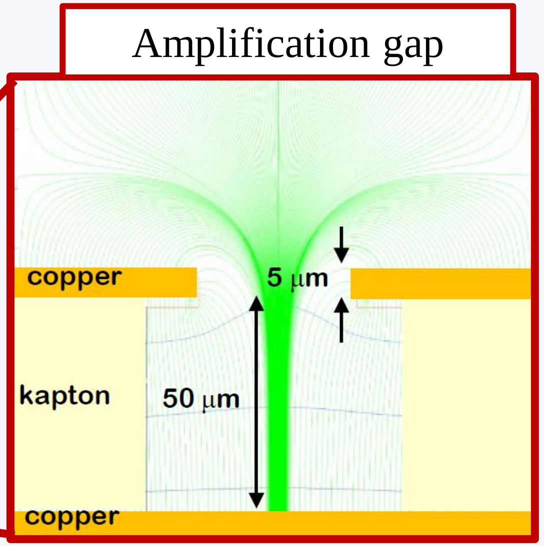
Micromegas detector

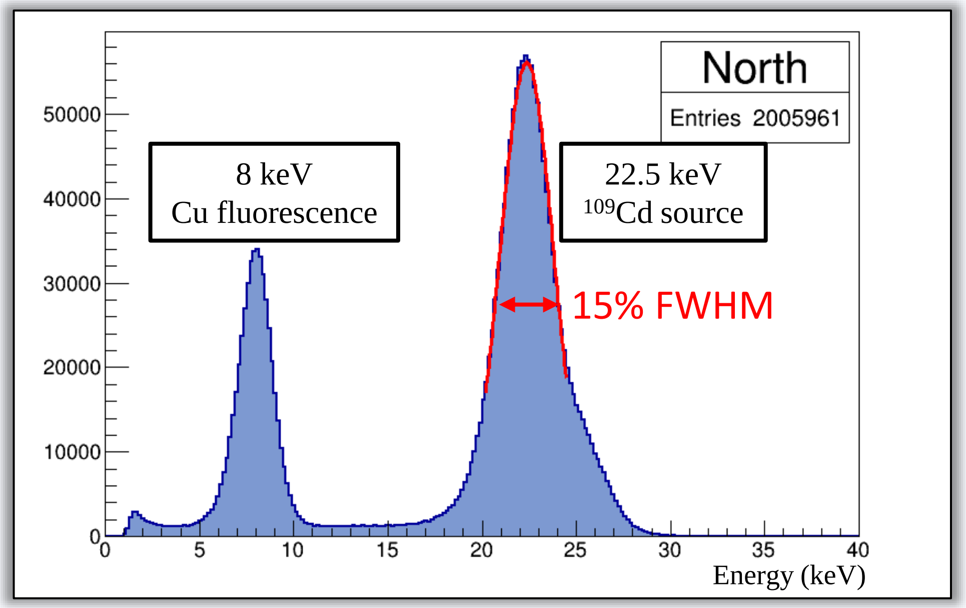
- Working principle of TPC with mM

- Low intrinsic radioactivity

- Absolute gain 10^3-10^4

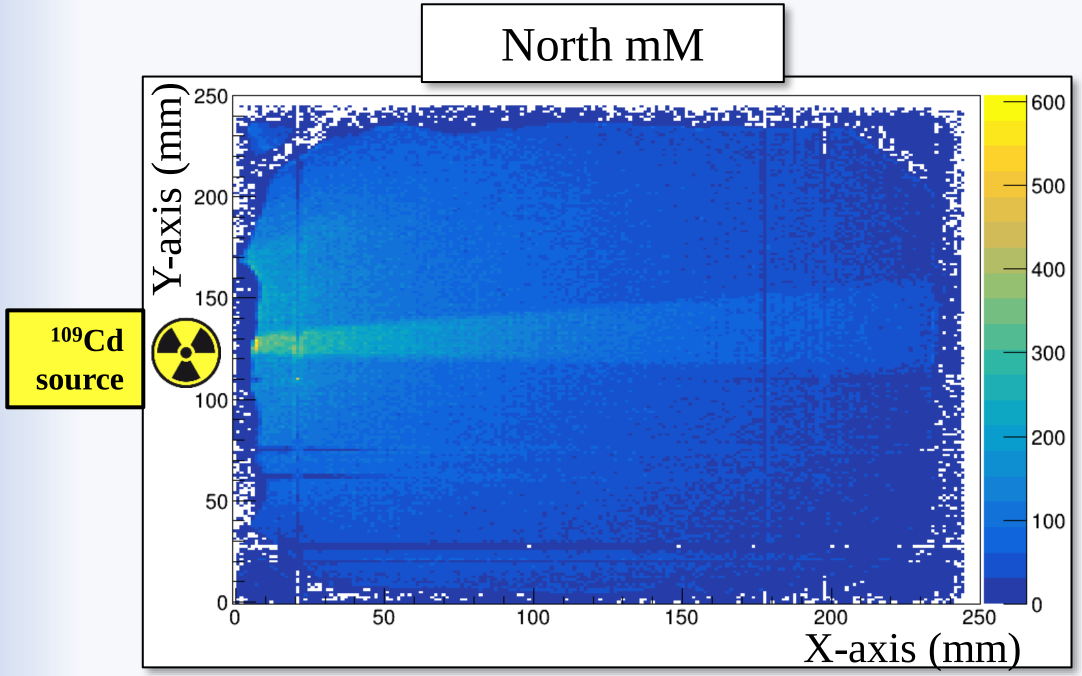


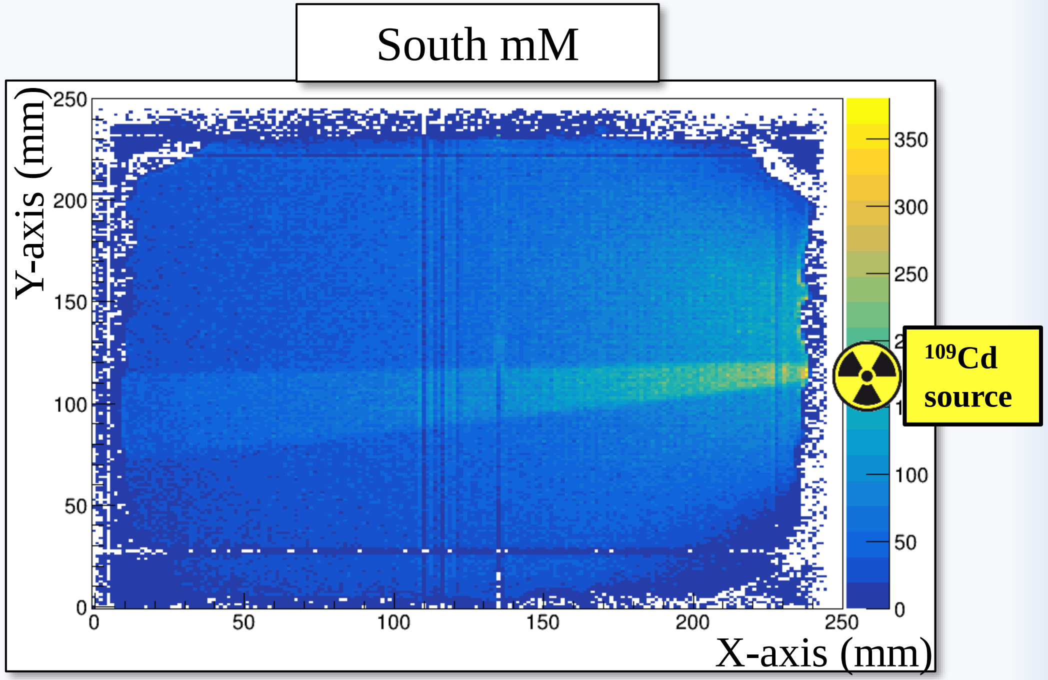




Micromegas detector

- Topological information
  - ➢background discrimination





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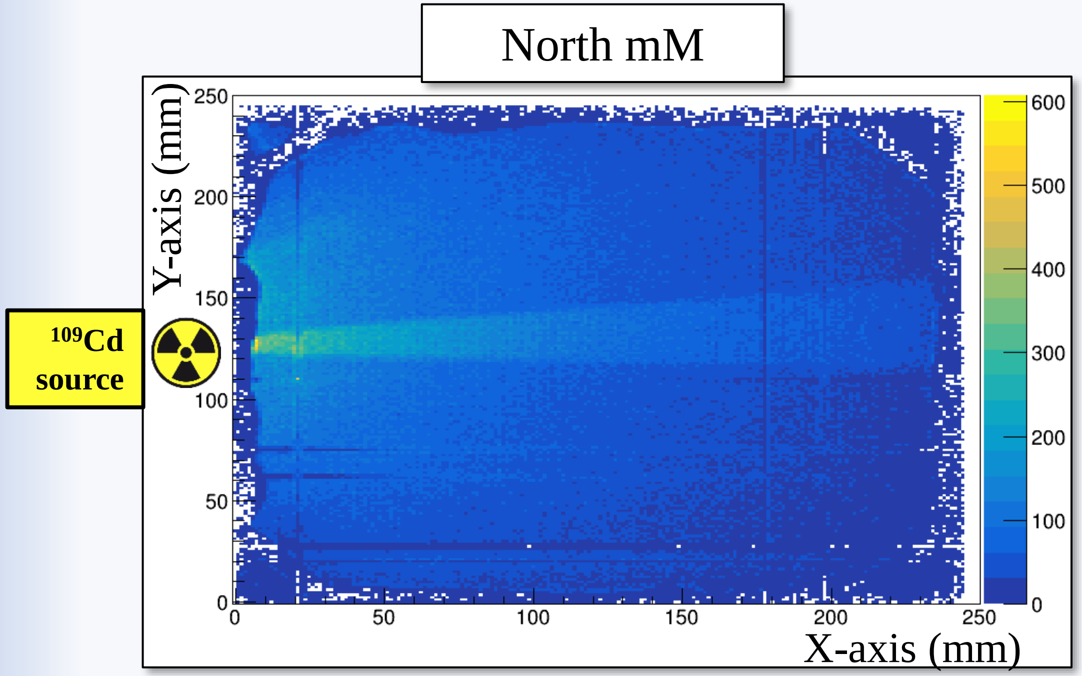
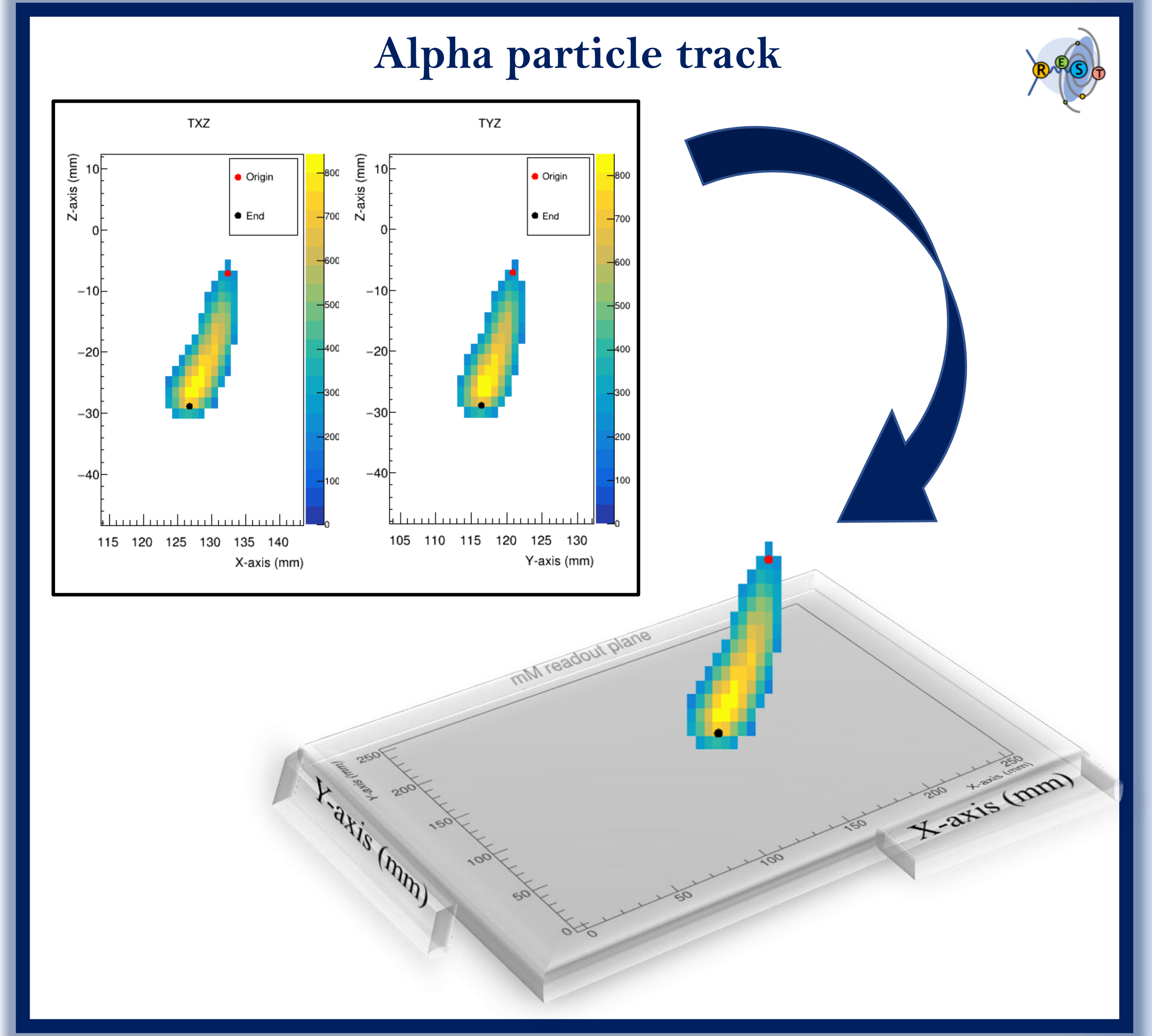




Low energy calibration

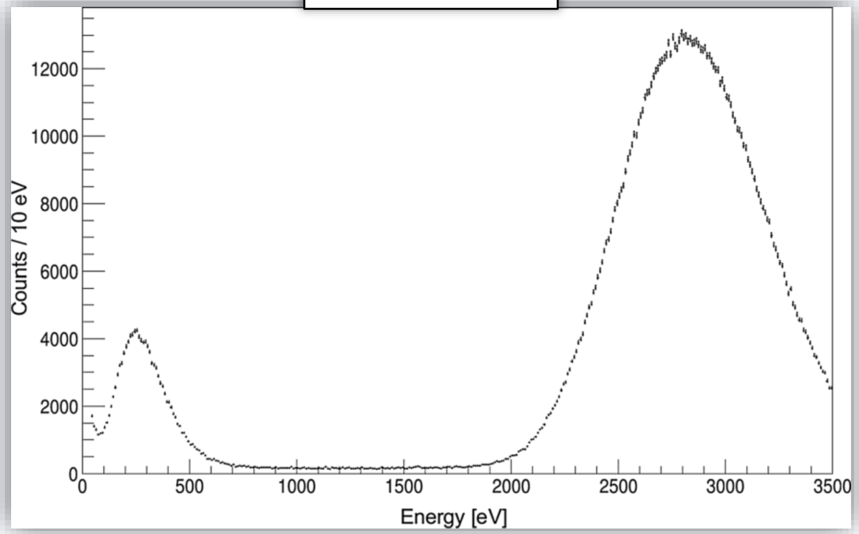
- Currently two ^{109}Cd source are used

- ^{37}Ar
  - 2.82 keV (K shell, probability 0.90)
  - 0.27 keV (L shell, probability 0.09)
  - Used in XENON1T and NEWS-G

- Gas source → homogeneous illumination

- By ^{40}Ca irradiation with fast neutrons (AmBe source)

^{37}Ar spectrum

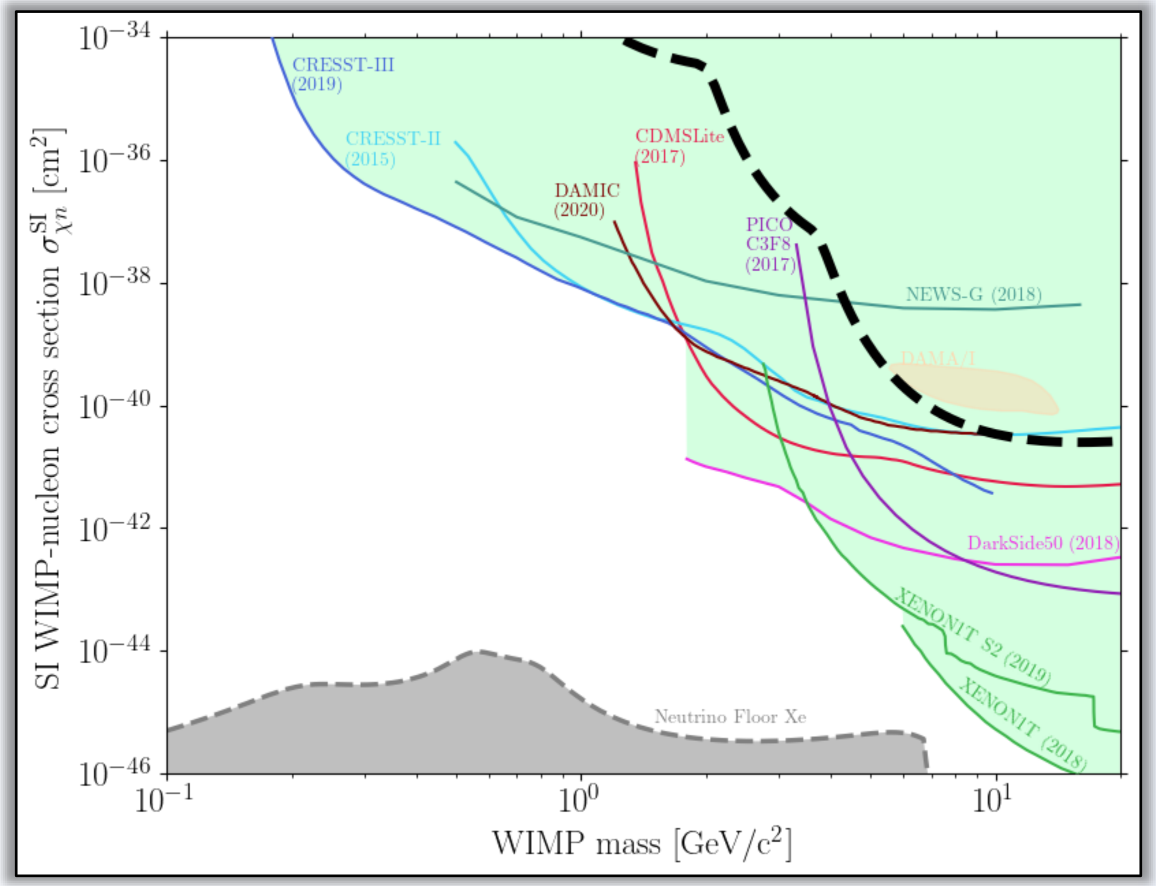


State of art

	E_{th} (eV_{ee})	B(dru)	Gas
Z	1000	100	Ar-1%Iso

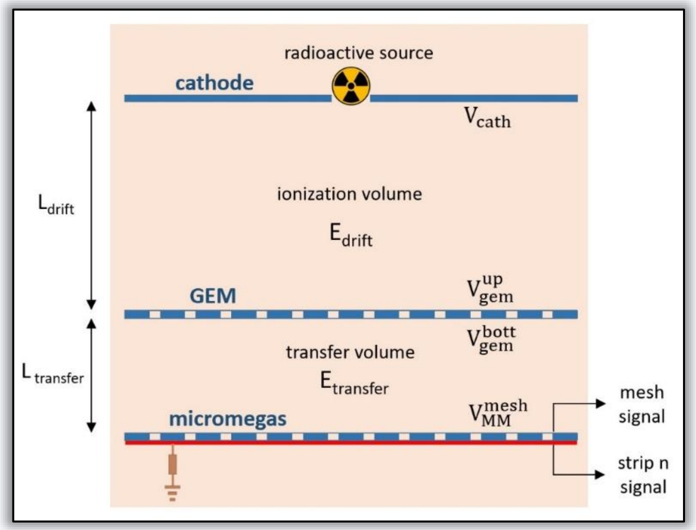
(dru = keV^{-1} kg^{-1} day^{-1})

Exposure 0.32 kg y



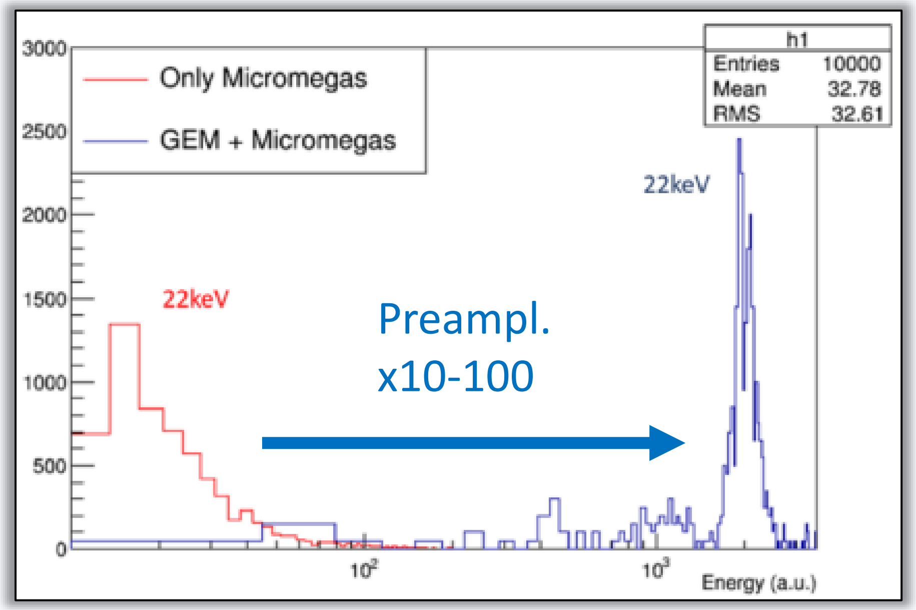
Improving energy threshold

- Improve gain by adding a Gas Electron Multiplier **(GEM)** amplification stage on top of the Micromegas planes
  - ➢ increase signal-to-noise ratio



- Preliminary results in test set-up shows x10-100 extra amplification factor

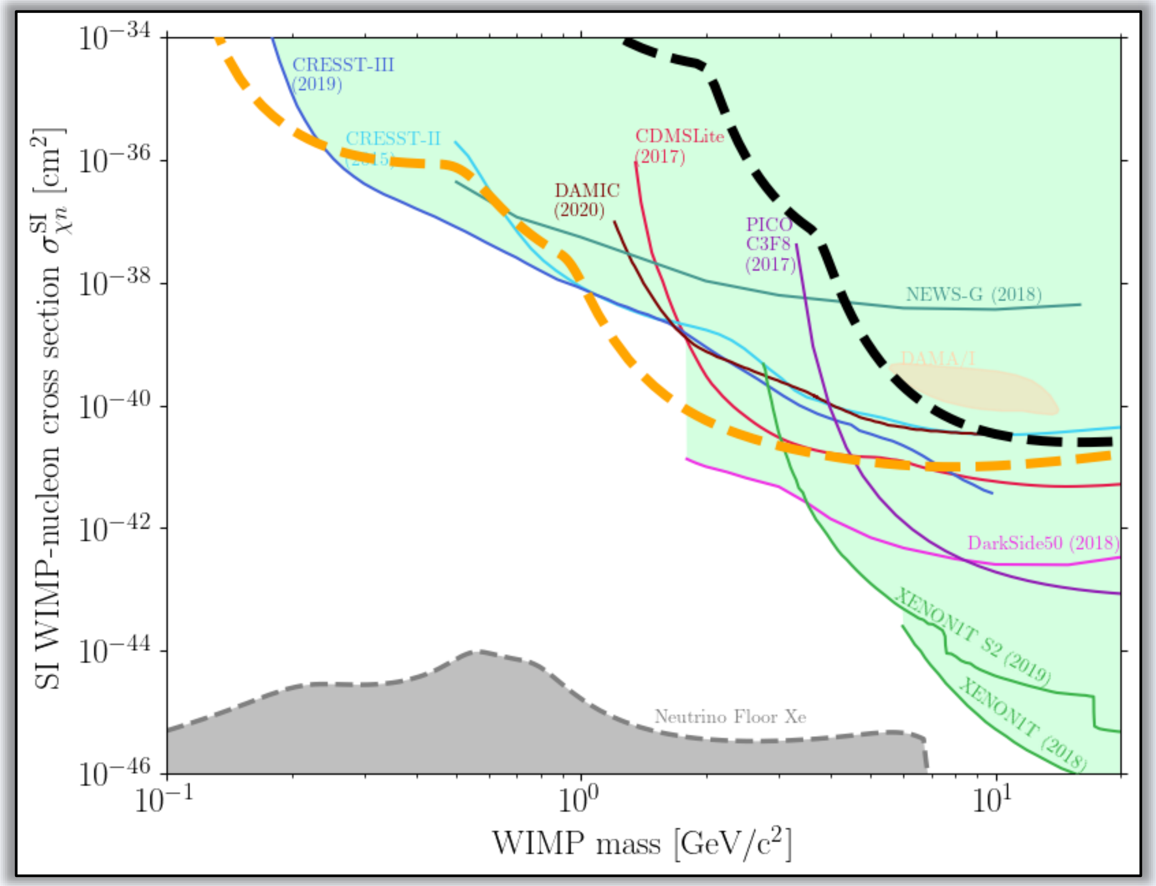
→ E_{thr} lowered down to single electron (20 eV_{ee})



Sensitivity prospects

	E_{th} (eV$_{ee}$)	B(dru)	Gas
Z	1000	100	Ar-1%Iso
A	50	100	Ar-1%Iso

Exposure 0.32 kg y



Improving background

2019 – Commissioning & Ne data-taking

I. Ne data-taking with H_2O & O_2 filters and recirculating

II. Background dominated by ^{222}Rn

- 600 c keV^{-1} kg^{-1} day^{-1} (= dru)

III. Solution: open-loop operation

- 100 dru (x10-100 higher than background model)

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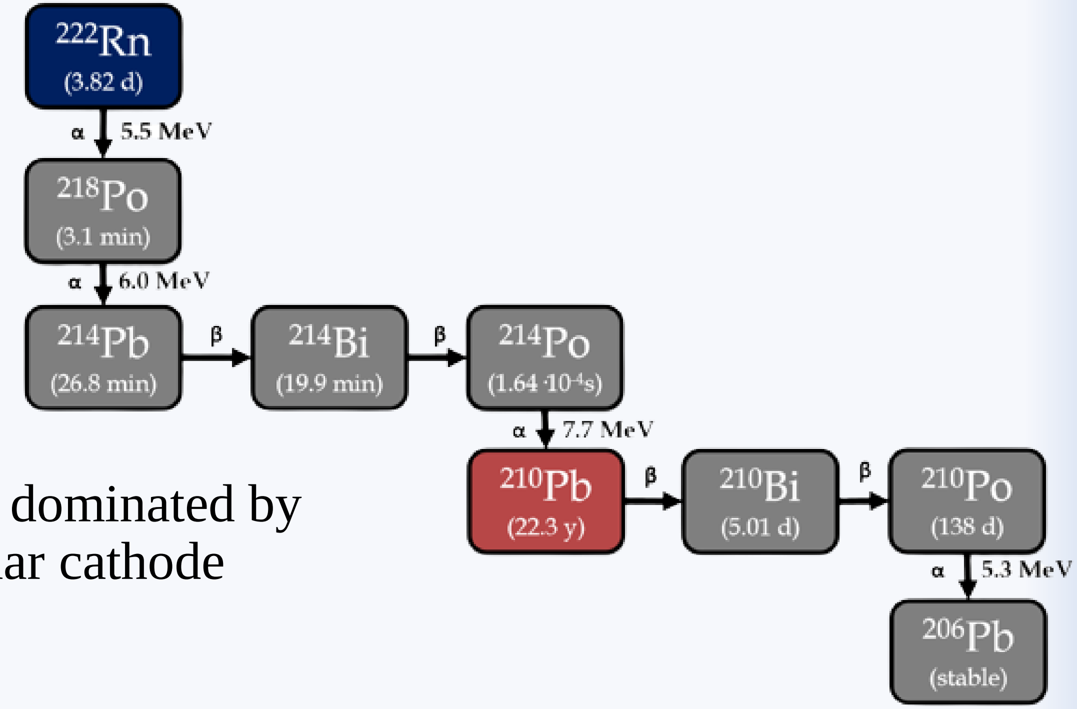

2022 – New & cleaner micromegas installed

IV. Alpha measurements shows this background is dominated by ^{222}Rn progeny (^{210}Pb) on the surface of the mylar cathode

Improving background

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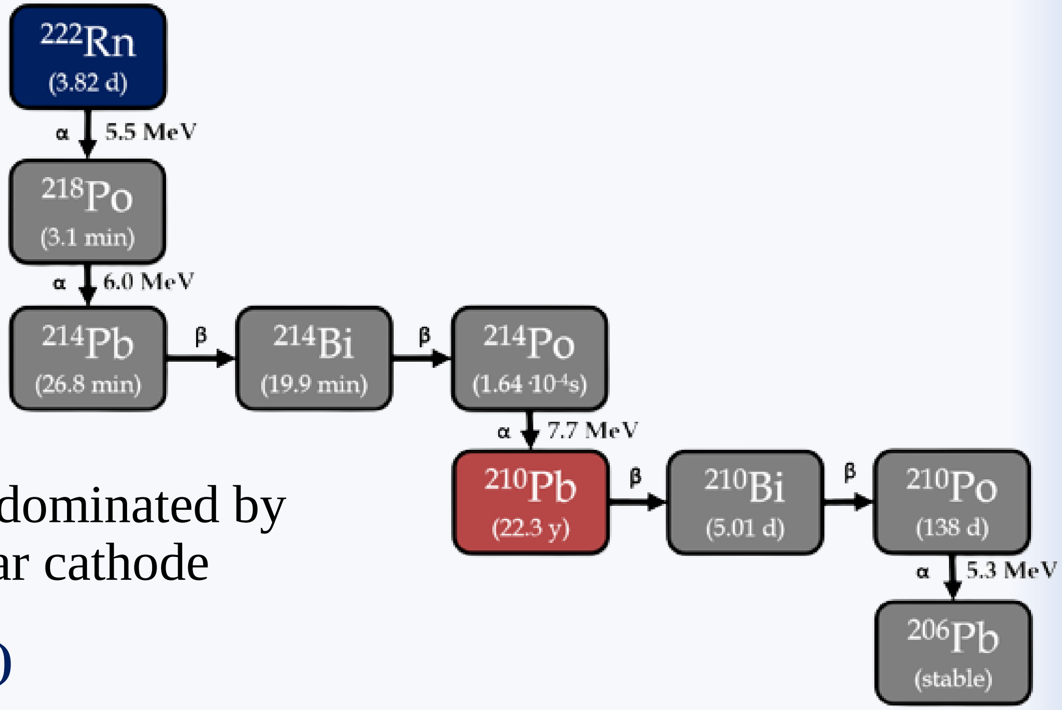


2022 – New & cleaner micromegas installed

IV. Alpha measurements shows this background is dominated by ^{222}Rn progeny (^{210}Pb) on the surface of the mylar cathode

2023 – Relocation & Ne not available anymore (change to Ar)

V. Plans to install a more radiopure cathode in the coming months

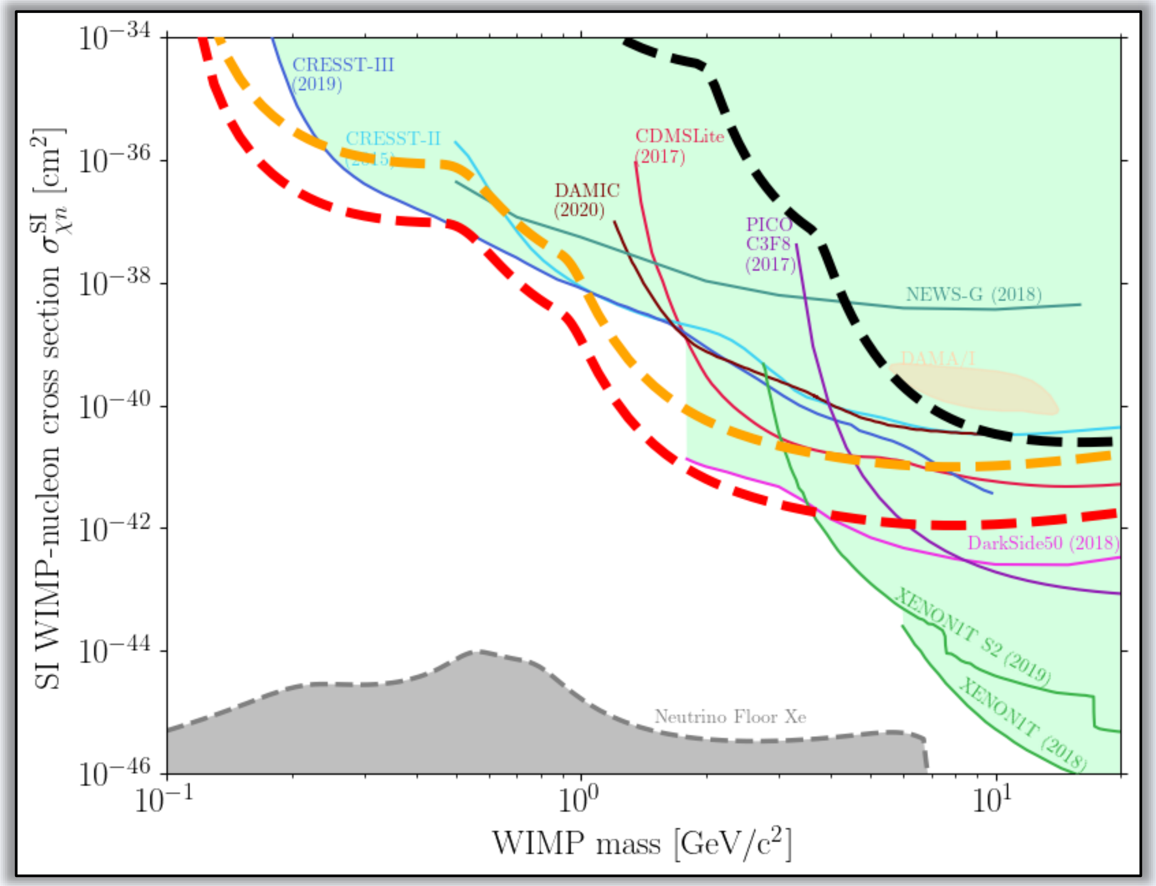
2024

- ➢ 1-10 dru

Sensitivity prospects

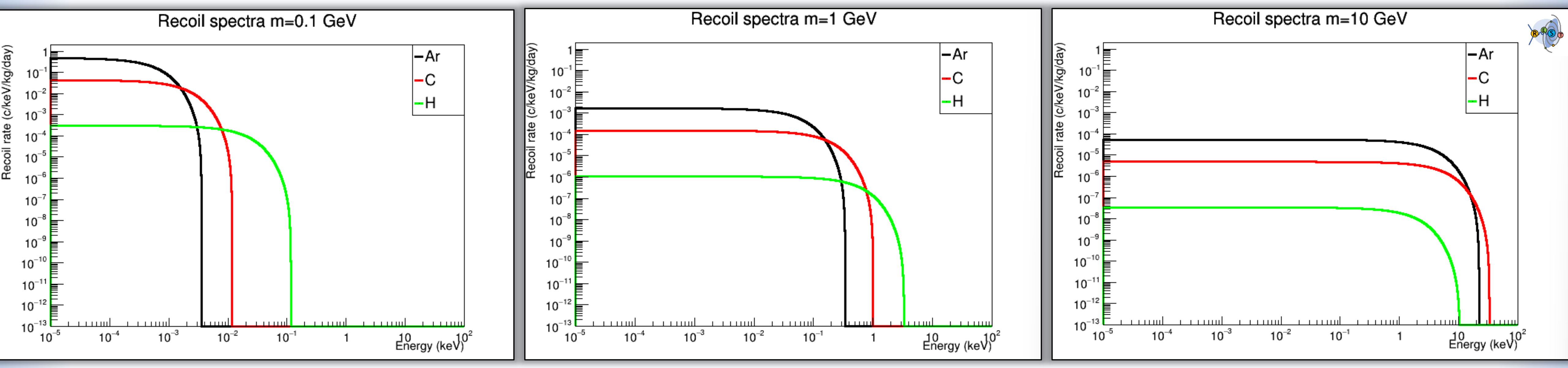
	E_{th} (eV$_{ee}$)	B(dru)	Gas
Z	1000	100	Ar-1%Iso
A	50	100	Ar-1%Iso
B	50	1	Ar-1%Iso

Exposure 0.32 kg y



Increasing quencher in gas

- For low-mass WIMPs, the lighter the better

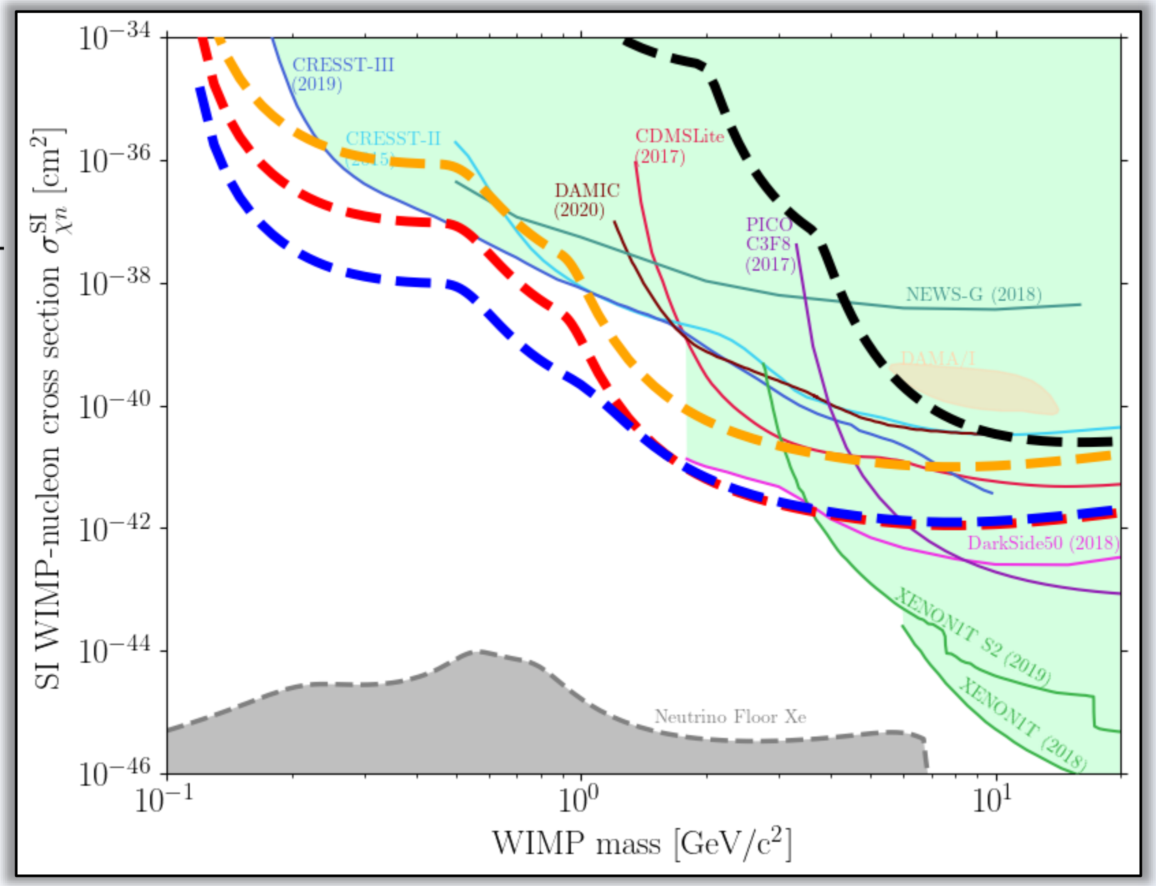


Decreasing WIMP mass

Sensitivity prospects

	E_{th} (eV_{ee})	B(dru)	Gas
Z	1000	100	Ar-1%Iso
A	50	100	Ar-1%Iso
B	50	1	Ar-1%Iso
C	50	1	Ar-10%Iso

Exposure 0.32 kg y

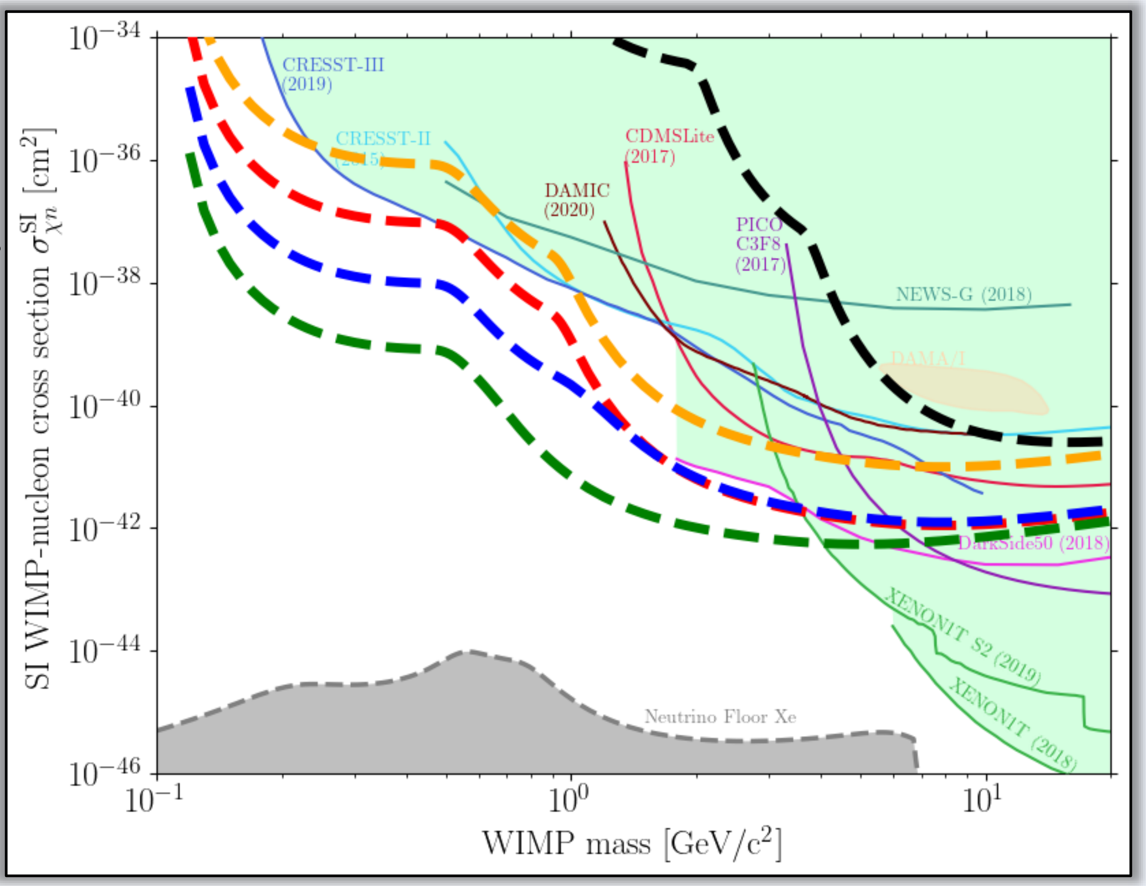


Sensitivity prospects

	E_{th} (eV_{ee})	B(dru)	Gas
Z	1000	100	Ar-1%Iso
A	50	100	Ar-1%Iso
B	50	1	Ar-1%Iso
C	50	1	Ar-10%Iso
*D	50	0.1	Ne-10%Iso

Exposure 0.32 kg y

*Exposure 1.6 kg y



Summary

- TREX-DM is the only (non-directional) experiment with Micromegas technology searching for (low-mass) WIMPs
    - ➢ High radiopurity
    - ➢ Topology information → background & noise discrimination

- Upgrades planned to be implemented in the near future
    I. GEM pre-amplification & low-energy calibration
    II. Cleaner materials (cathode)
    III. More isobutane

Installation of new micromegas

YouTube

BACK-UP

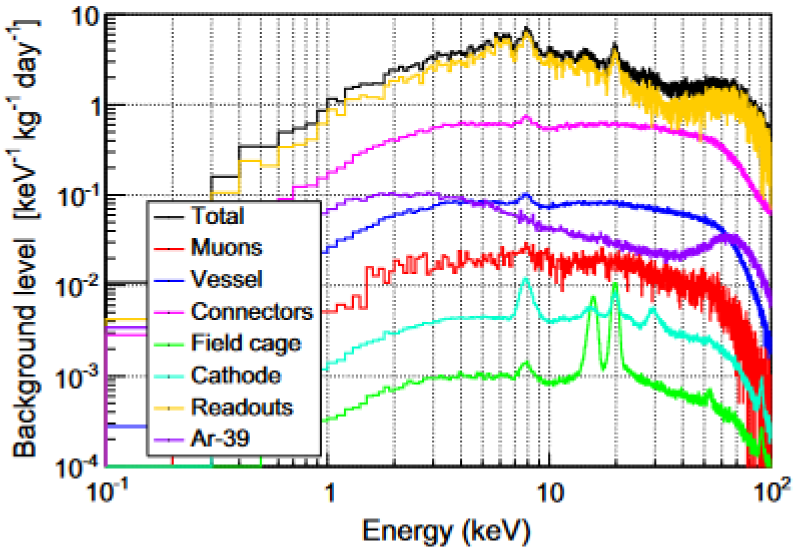


Fig. 20 Simulated background spectrum expected in TREX-DM experiment (*black line*) during a physics run at LSC if operated in $Ar+2\%iC_4H_{10}$ (*left*) or $Ne+2\%iC_4H_{10}$ at 10 bar. The contribution of

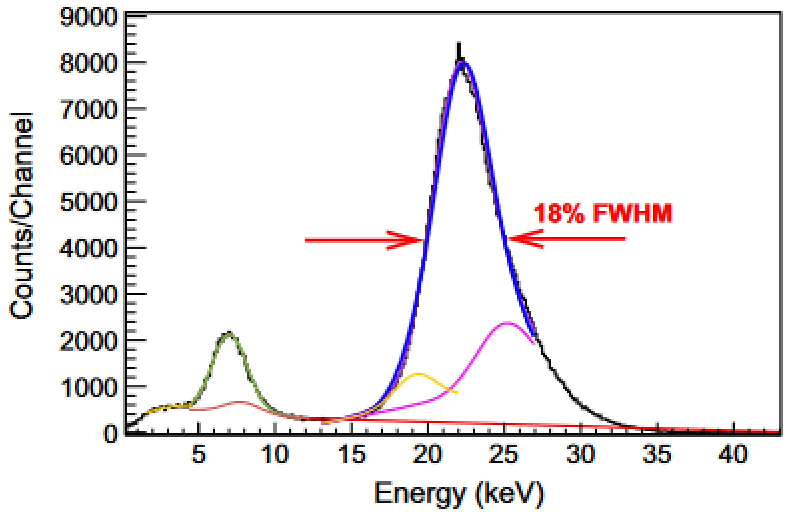


Fig. 6 Energy spectrum generated by the mesh signals when one of the Micromegas readouts is irradiated by a ^{109}Cd source in $Ar+2\%iC_4H_{10}$ at 2 bar. The spectral parameters are defined through an iterative multi-Gaussian fit corresponding to the K_α (22.1 keV, *blue line*) and K_β (24.9 keV, *magenta line*) emission lines of the source and their escape peaks (located at 19.1 and 21.9 keV, *orange line*). The fluorescence lines of iron (at 6.4 keV, emitted from the mesh) and copper (8 keV, from the vessel or the field cage strips) are also present (*green* and *brown lines*, respectively)

Iguaz, F.J., Garza, J.G., Aznar, F. *et al.* TREX-DM: a low-background Micromegas-based TPC for low-mass WIMP detection. *Eur. Phys. J. C* **76**, 529 (2016). https://doi.org/10.1140/epjc/s10052-016-4372-6

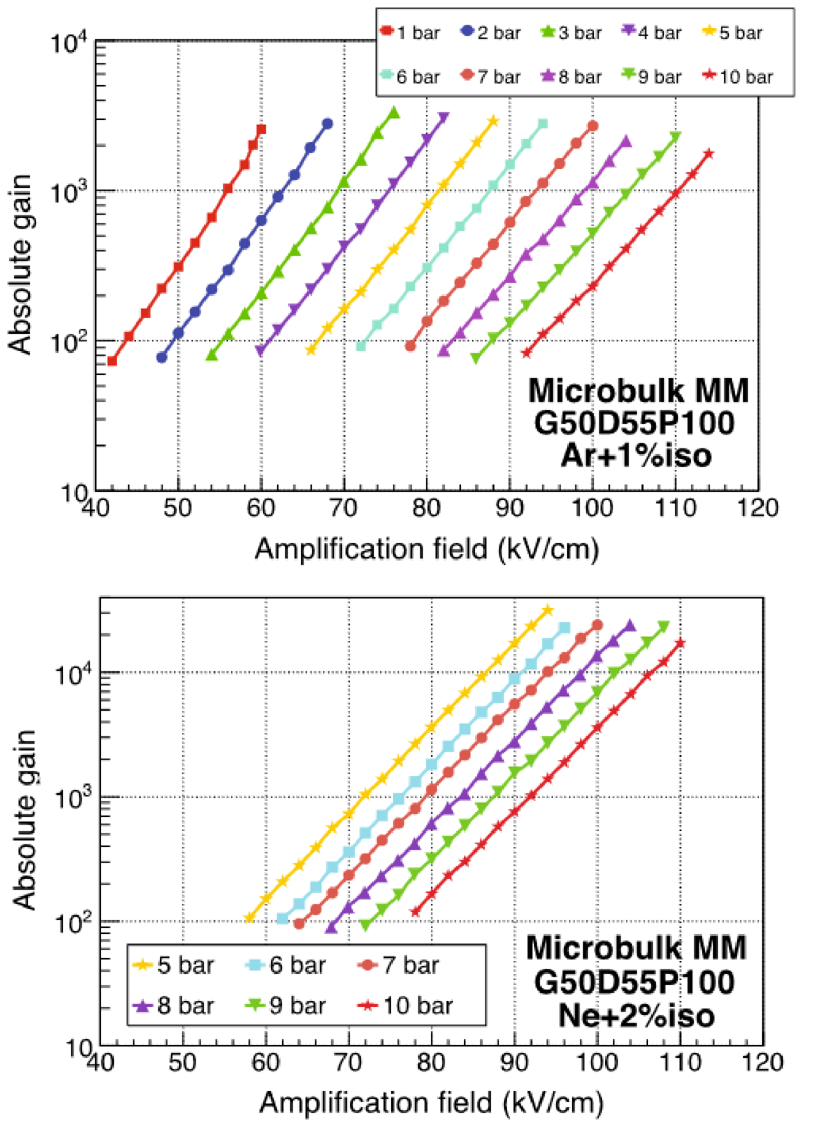
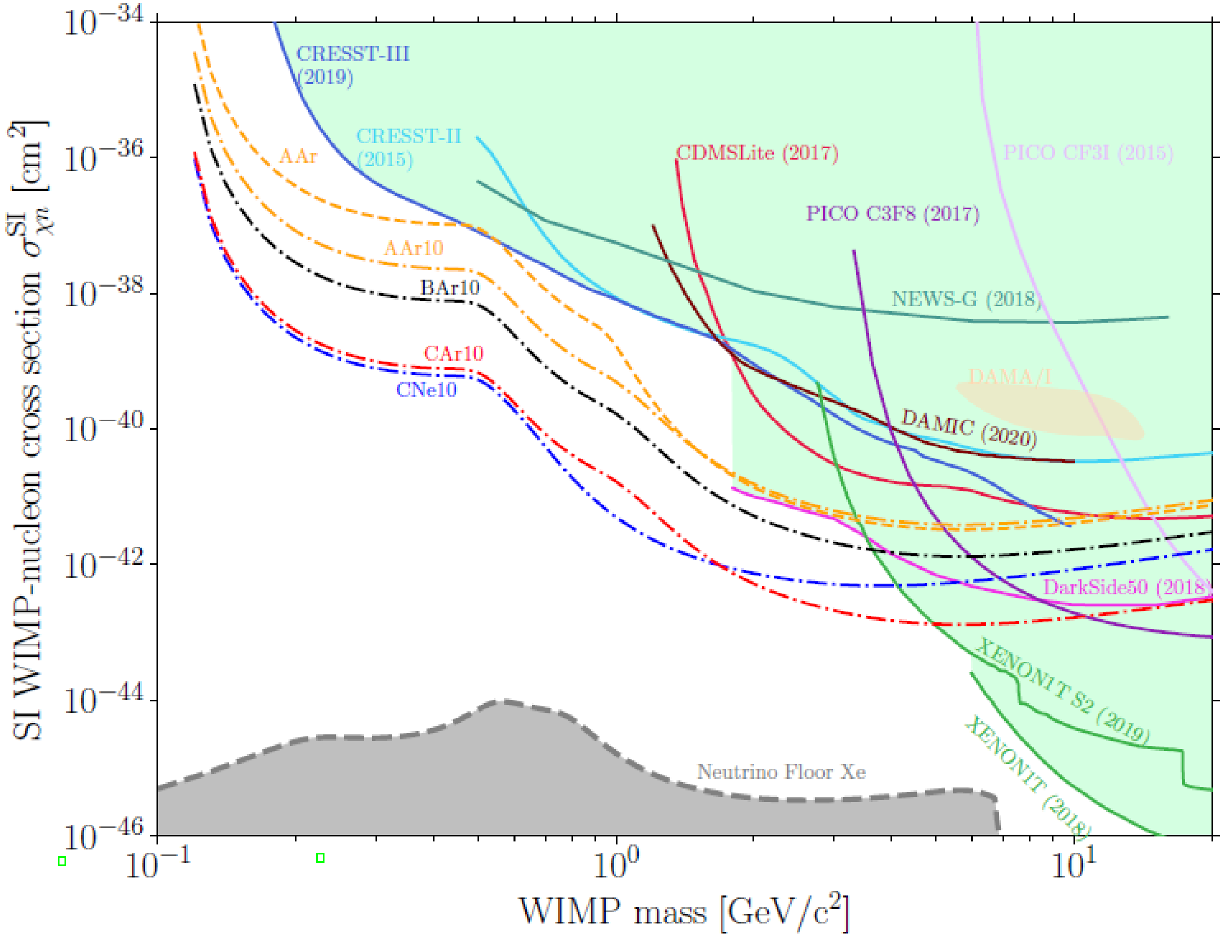


Fig. 4 Gain curves obtained in the characterization of microbulk Micromegas with Ar (top) and Ne (bottom) mixtures using a ^{109}Cd source. Curves for different pressures up to 10 bar are shown

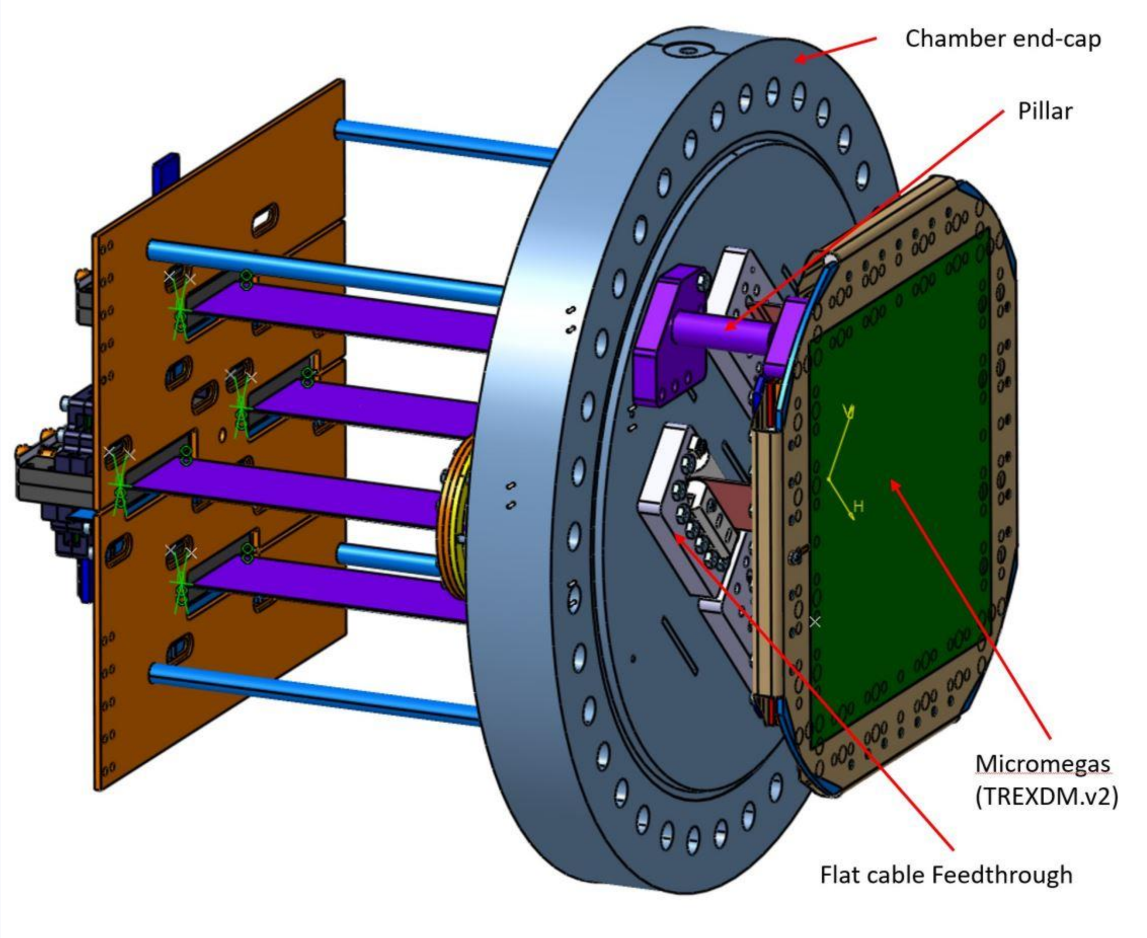
Castel, J., Cebrián, S., Coarasa, I. *et al.* Background assessment for the TREX dark matter experiment. *Eur. Phys. J. C* **79**, 782 (2019). https://doi.org/10.1140/epjc/s10052-019-7282-6

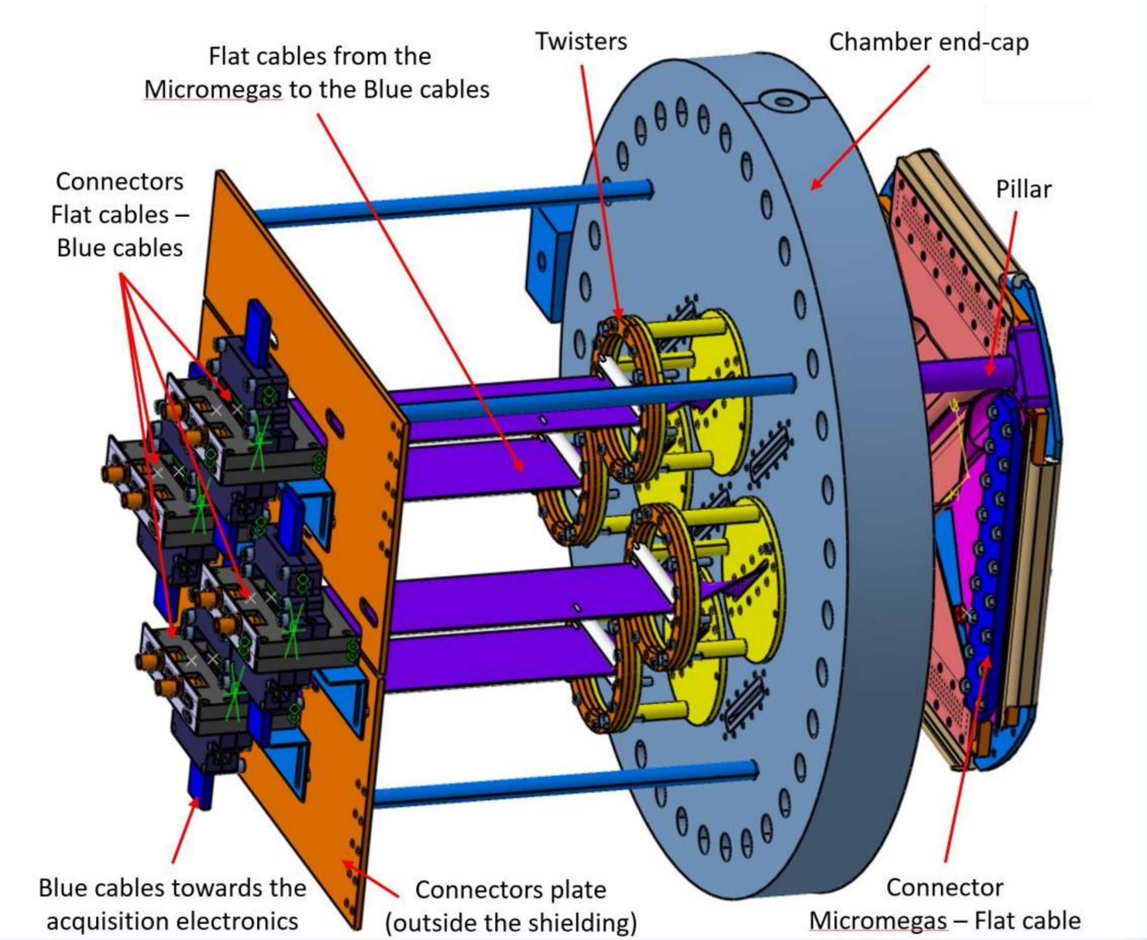
Projected sensitivity

	E_{th} (keV)	B(keV^{-1}kg^{-1}d^{-1})	Exp (kg y)	Gas
AAr	0.05	10	0.58	Ar-2%Iso
AAr10	0.05	10	0.52	Ar-10%Iso
BAr10	0.05	1	0.52	Ar-10%Iso
CAr10	0.05	0.1	5.2	Ar-10%Iso
CNe10	0.05	0.1	3	Ne-10%Iso



Credit:
H. Mirallas

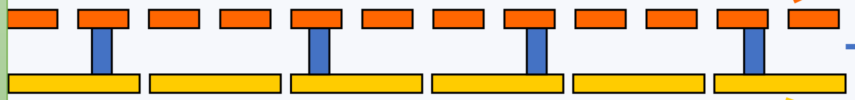




Micromegas readouts

BULK
Robust
Mature
Very large areas available
(2 m^2)

Readout plane + mesh all in one



Woven Inox mesh 30 µm

vacrel 128 µm

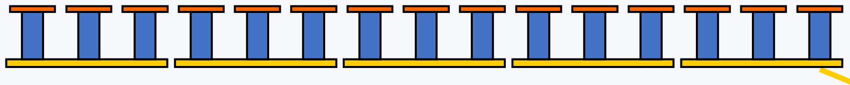
Readout pads

Well established technique

T-REX R&D

•MICROBULK
Higher homogeneity
Light weight, radiopure

Readout plane + mesh all in one



Micromesh 5µm copper

Kapton 50 µm

Readout pads

CERN+CEA+UNIZAR development

See for details:
JINST 5 (2010) P02001

Beyond microbulk?

Microfabricated Micromegas

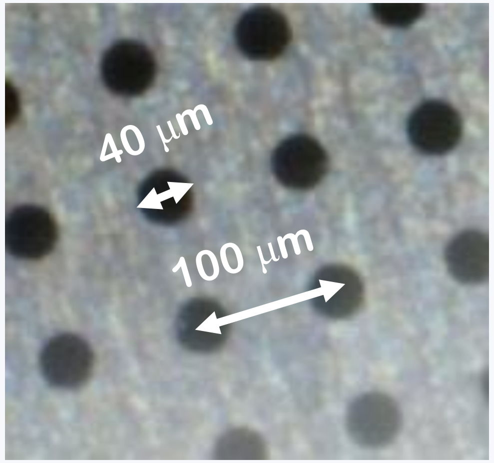
Started development with CNM

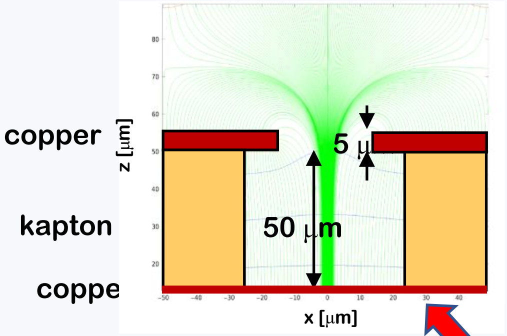
Micromegas structures with Si-wafer microfabrication techniques…
Higher Flexibility & precision in geometrical parameters
Better tailored to application…

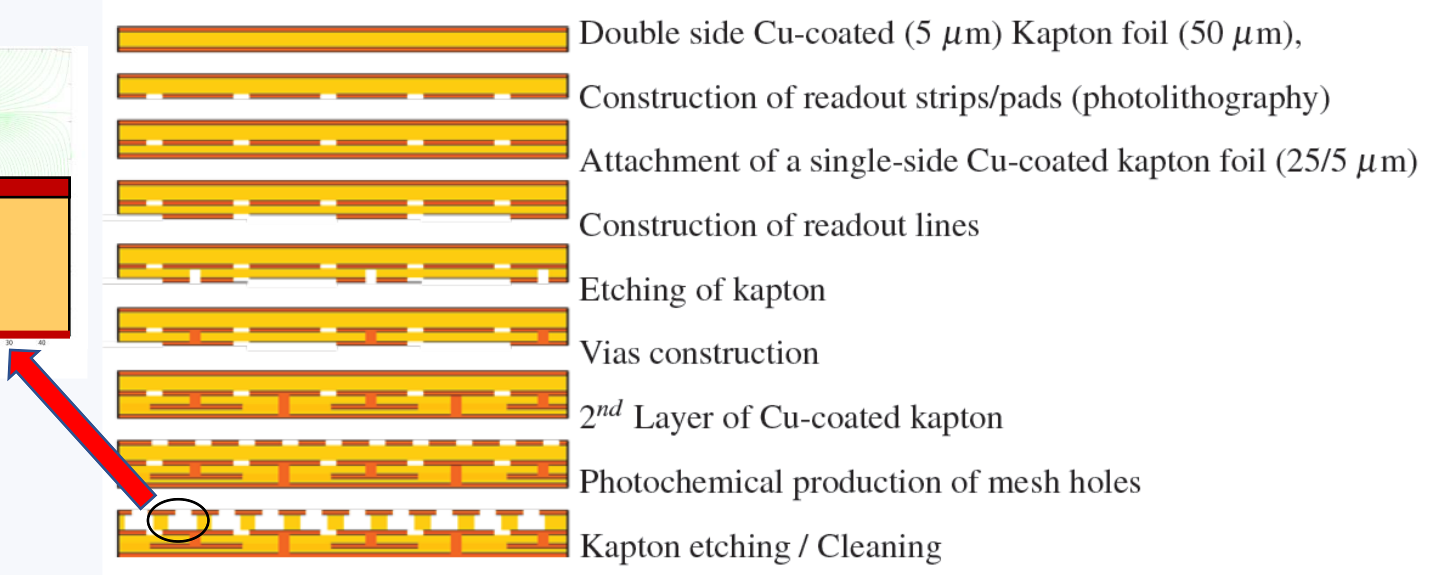
Microbulk Micromegas

- Made out of copper & polyimide (kapton)
  - potentially very radiopure
- High gap homogeneity
  - good energy resolution
  - Stability/homegeneity in response

Manufactured at Rui de Oliveira's workshop at CERN







See for details:
JINST 5 (2010) P02001

Credit:
O.Pérez

Background status: Rn issue

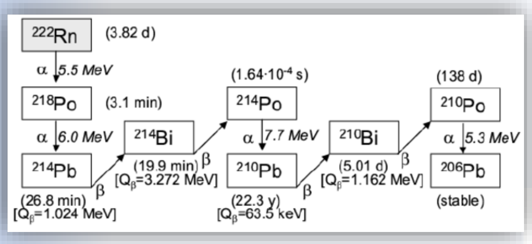
Filters in the gas system

Left: H_2O; right: O_2

Credit:
O.Pérez

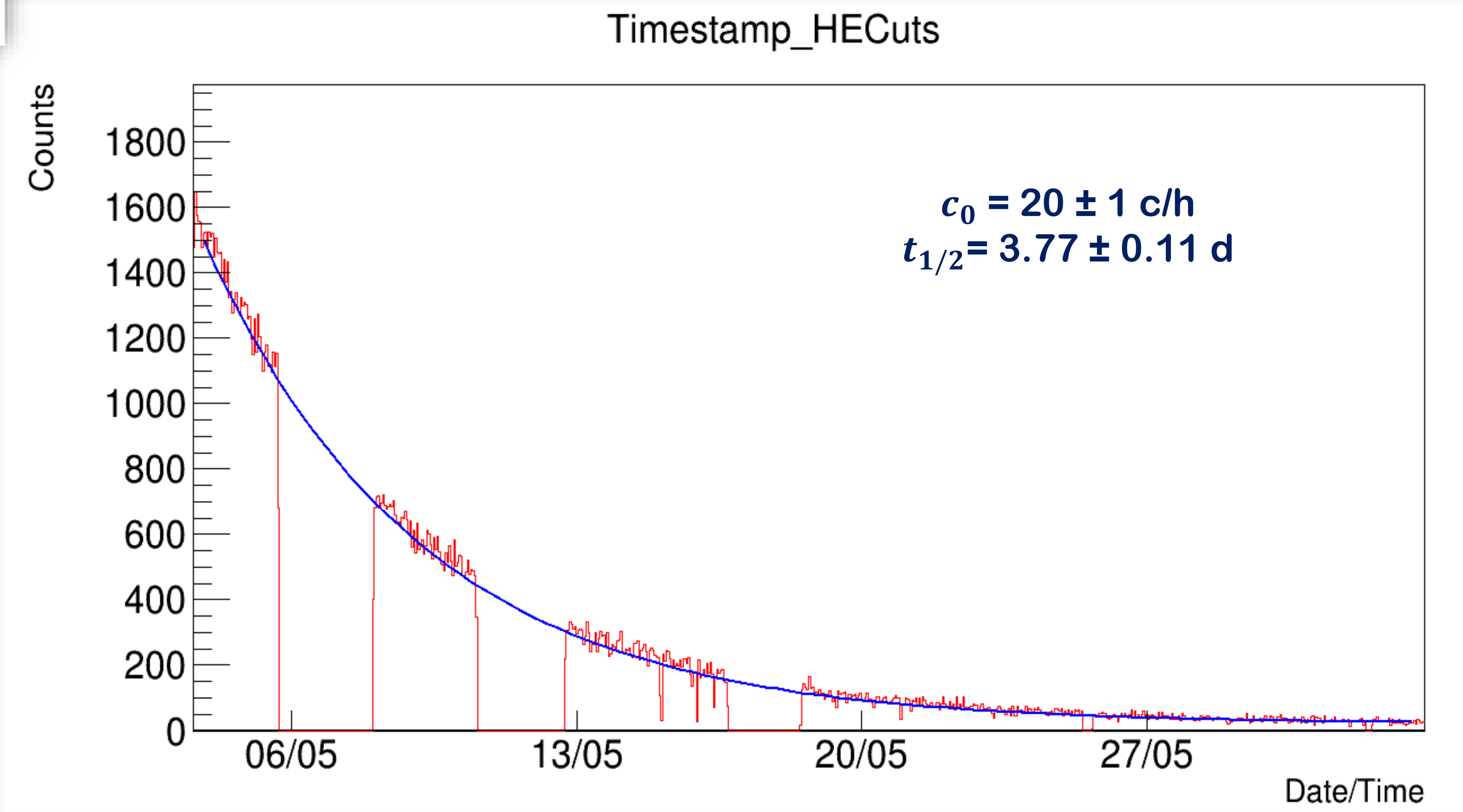
Background status: Rn issue

- **LE and HE runs during 1 month in seal mode**
- **They supported the hypothesis of Rn + constant component: decrease in alpha rate and background rate in 0-50 keV after cuts**



Low-gain runs (alphas)

$c_0 + c_1 e^{-c_3 t}$

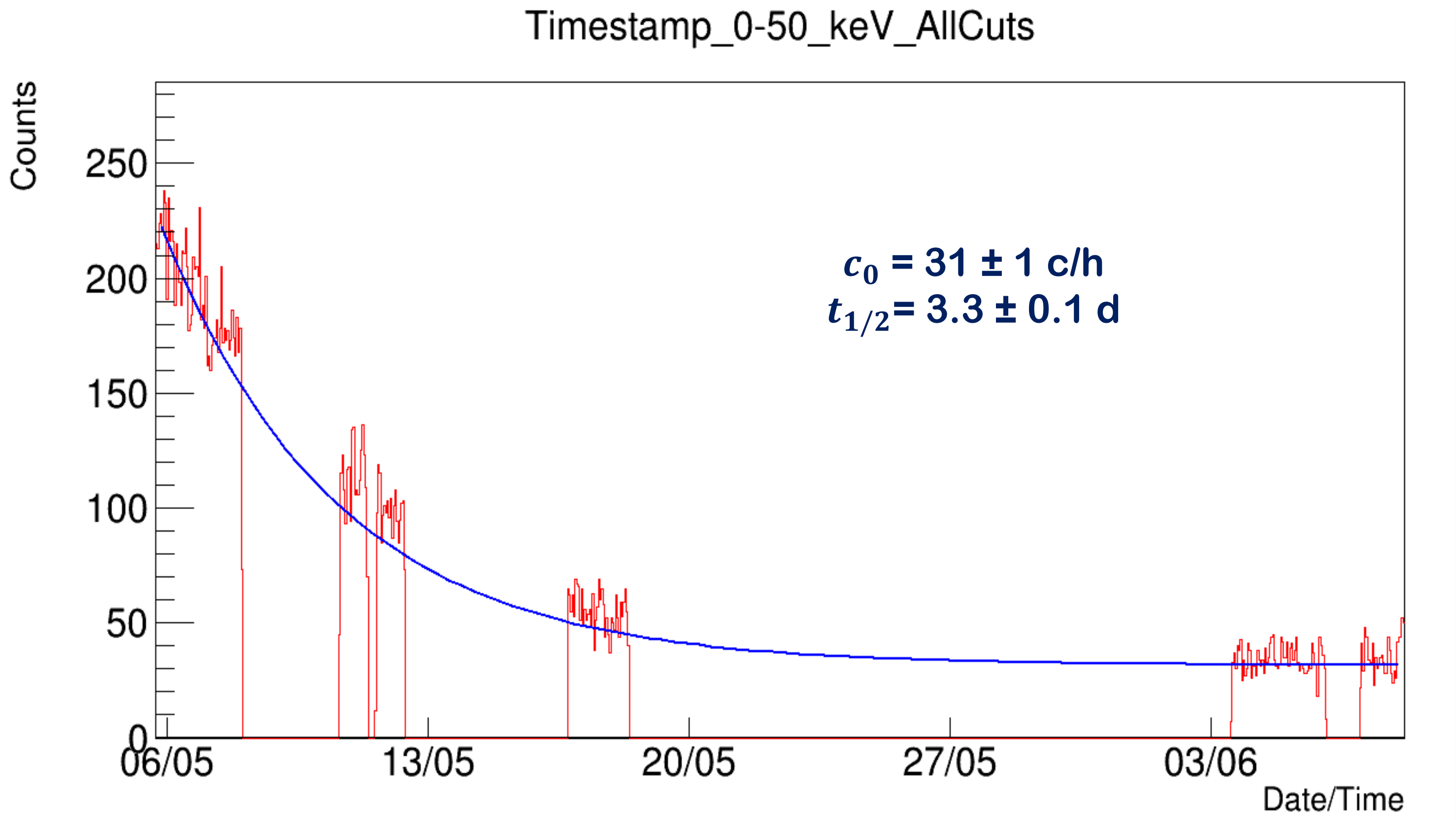


Credit:
O.Pérez

Background status: Rn issue

Nominal-gain runs (low energy)

$c_0 + c_1 e^{-c_3 t}$

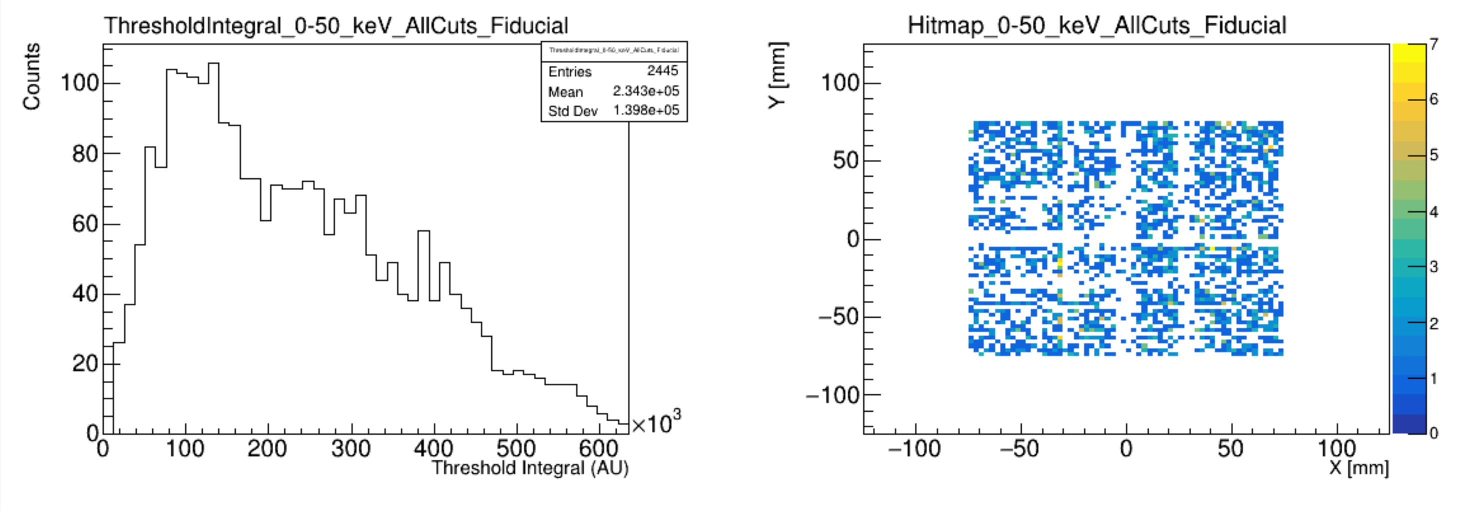


c_0 = 31 ± 1 c/h
$t_{1/2}$= 3.3 ± 0.1 d

Credit:
O.Pérez

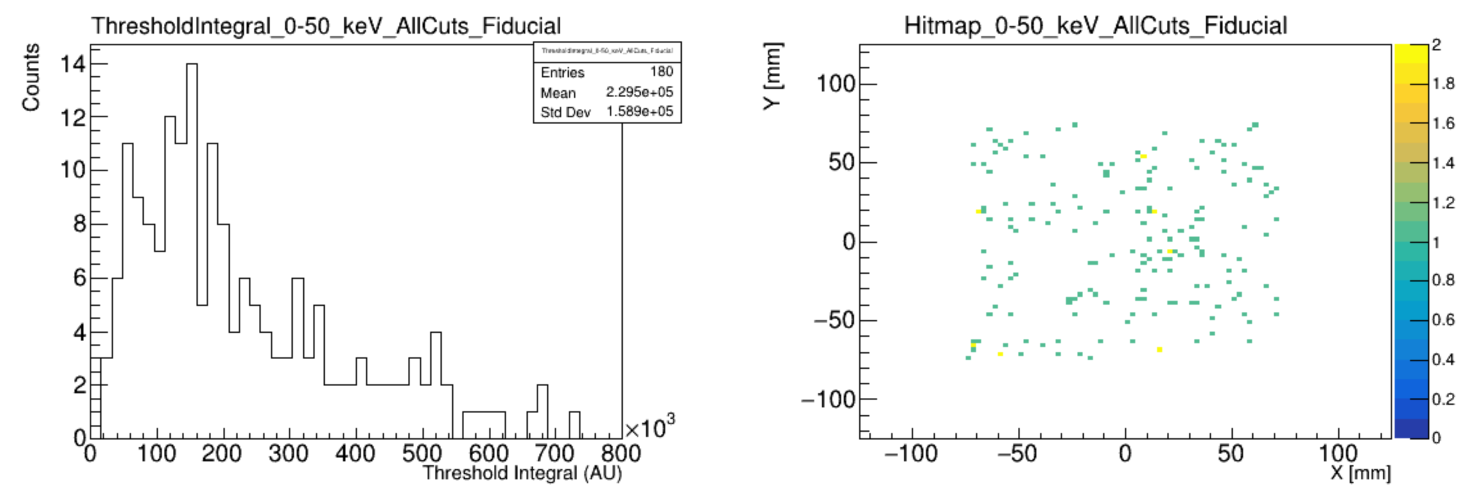
Background status: Rn issue

Background @ low energies



Before Rn decay

0-50 keV → 600 dru



After Rn decay

0-50 keV → 100 dru

Credit:
O.Pérez

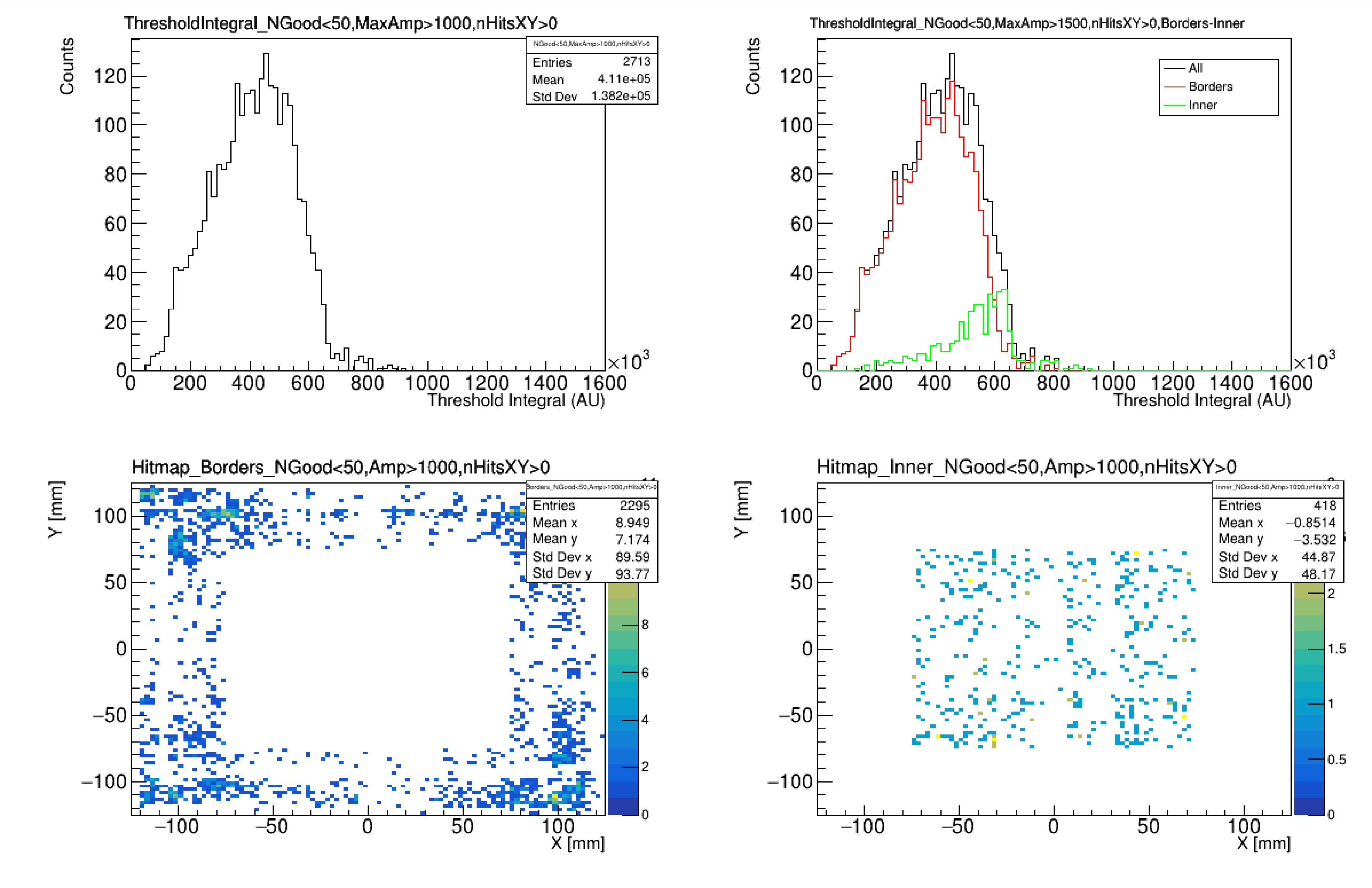
Background status: Rn issue

- **Internally emanated Radon is the main source of background (removing it takes us from ~600 dru down to ~100 dru in the 0-50 keV range)**
  - **A lot of effort put into removing it from the system:**
    - **Trying with several commercial filters**
    - **Testing 5Å molecular sieves (we found out they do trap Rn, but emanate more than Agilent filters, best commercial filters we have)**
    - **Testing a custom-made O2+H2O filter developed by the University of Birmingham with low-emanation materials (ongoing collaboration with NEWS-G)**
    - **Testing activated carbon filters**
    - **Open-loop operation bypassing the filters and the recirculation pump**

- **Rn progeny surface contamination may well be responsible for the rest of background not accounted for in our background model**
  - **A program to identify alpha surface contaminations + its mitigation is ongoing**

Credit:
O.Pérez

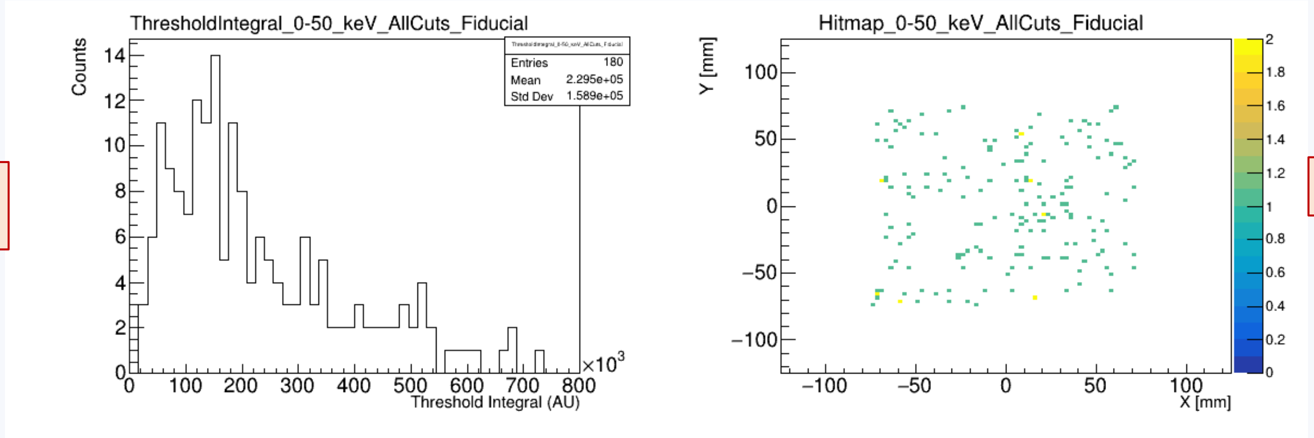
Open loop: no longer a Rn spectrum, only surface contamination



Credit:
O.Pérez

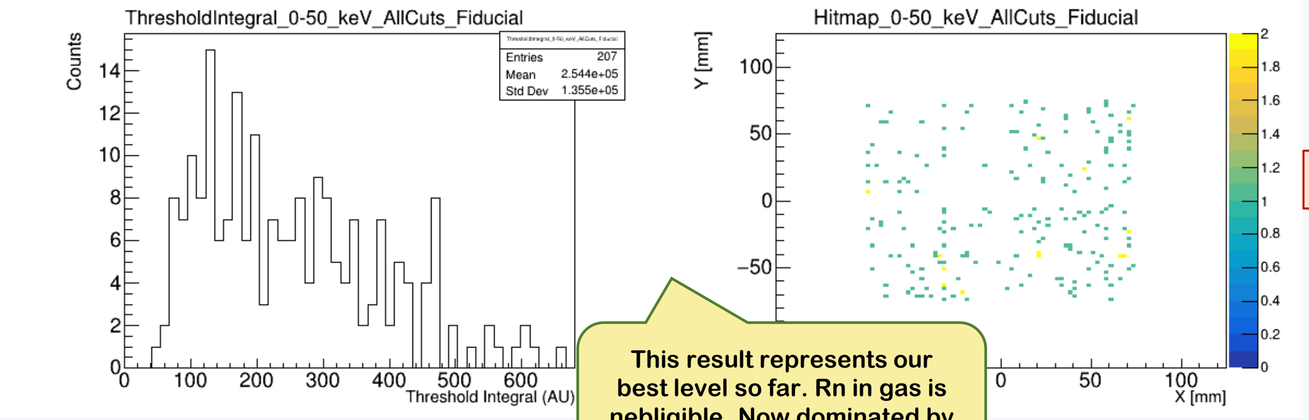
Background level comparison: seal mode in June 2021 vs. open loop

Sealed mode: after Rn decay



0-50 keV: 120 dru

Open loop



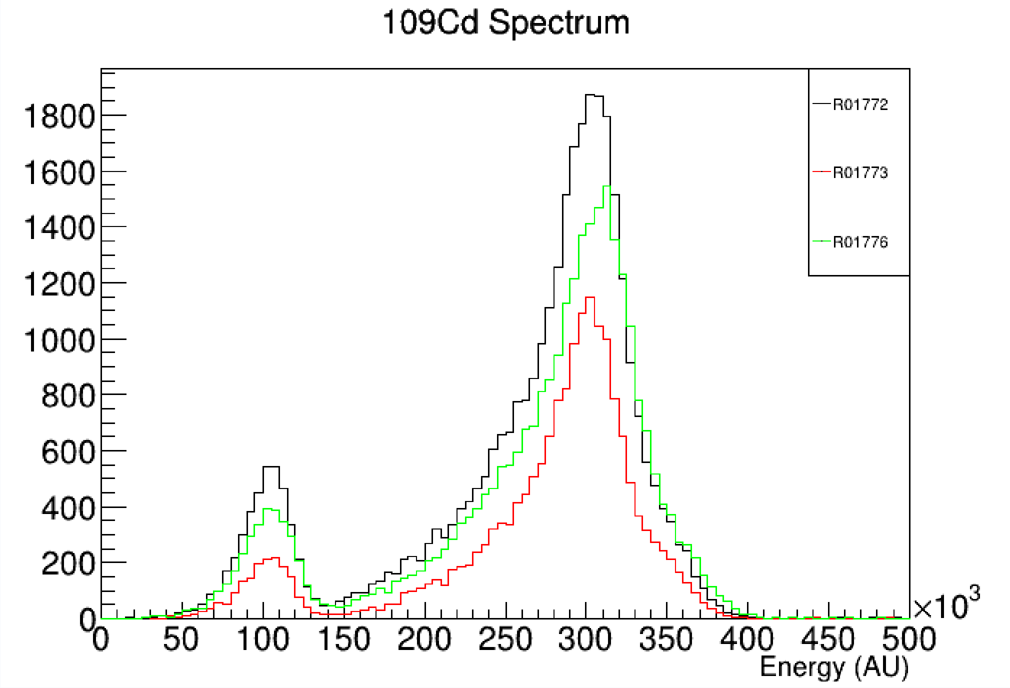
0-50 keV: <80 dru

This result represents our best level so far. Rn in gas is nebligible. Now dominated by Pb210 in surfaces

Credit:
O.Pérez

Flow optimisation in open loop: 109Cd calibrations

0.9 ln/h ⟹ one renovation every 11.5 days

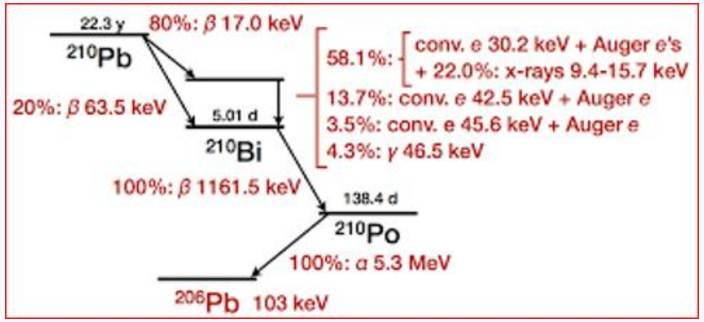


Calibrations after 0, 1 and 2 weeks at 0.9 ln/h ⟹ gas is clean with this flow

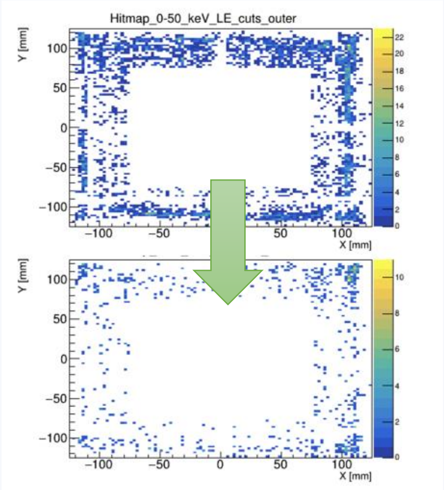
Credit:
O.Pérez

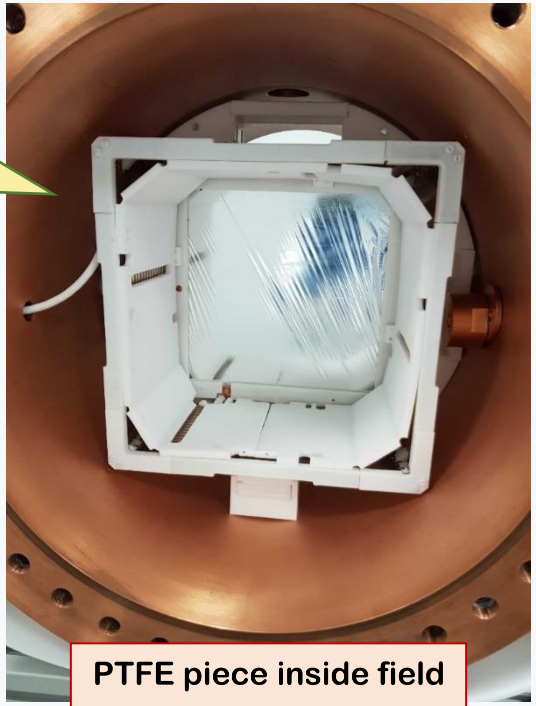
Surface alphas (Rn progeny)

- **Rn progeny (Pb210) attached to surfaces (from past exposure) produces alpha events, but also LE events (in similar proportion)**



Reminder: machining of the Teflon walls led to reduction of both HE and LE background counts in the outer region

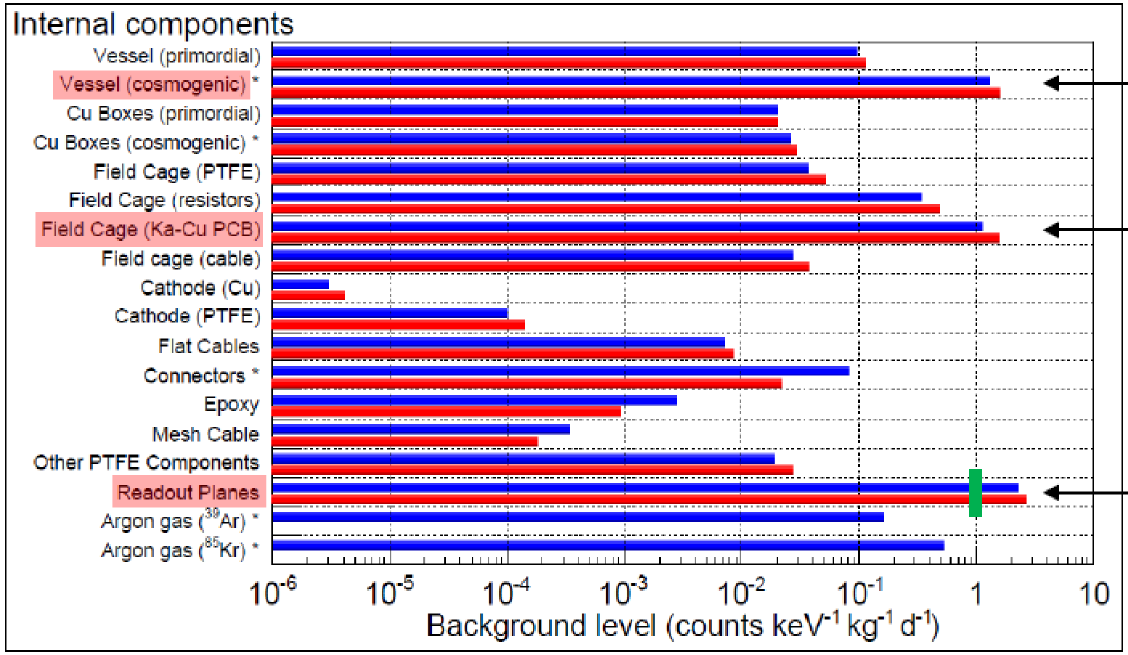




PTFE piece inside field cage

Credit:
H. Mirallas

Challenges: Background level reduction



Next step once the background is dominated by the vessel activation.

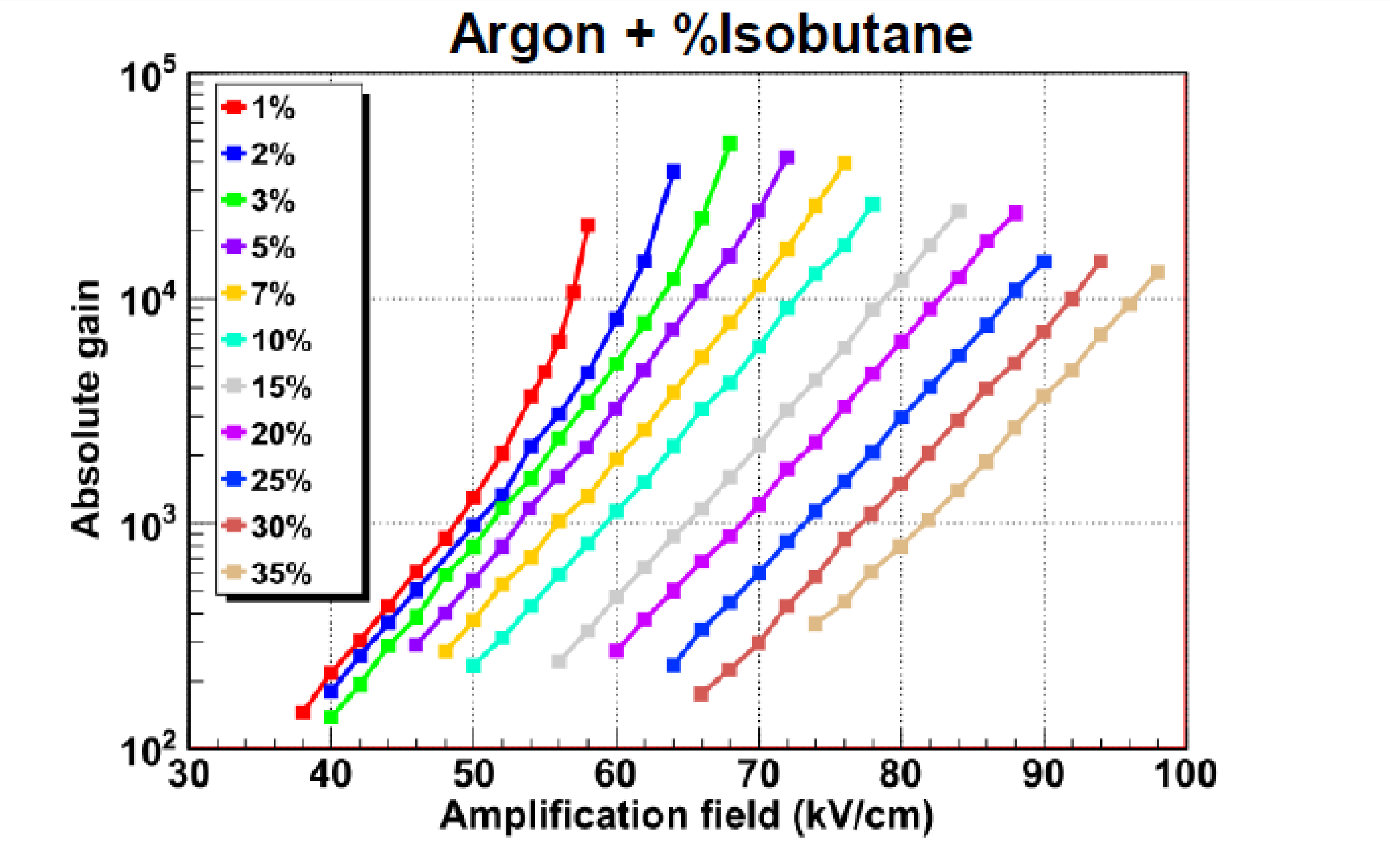
New design on going.

Factor ~ 3 of contamination reduction respect to the previous Micromegas.

Main challenges in radio-purity of materials:

- Search of clean commercial materials. Large screening programs
- Synthesize clean materials.
- Control of processes in companies
- Storage in controlled environments

- More isobutane → higher voltages



2012 JINST 7 P04007

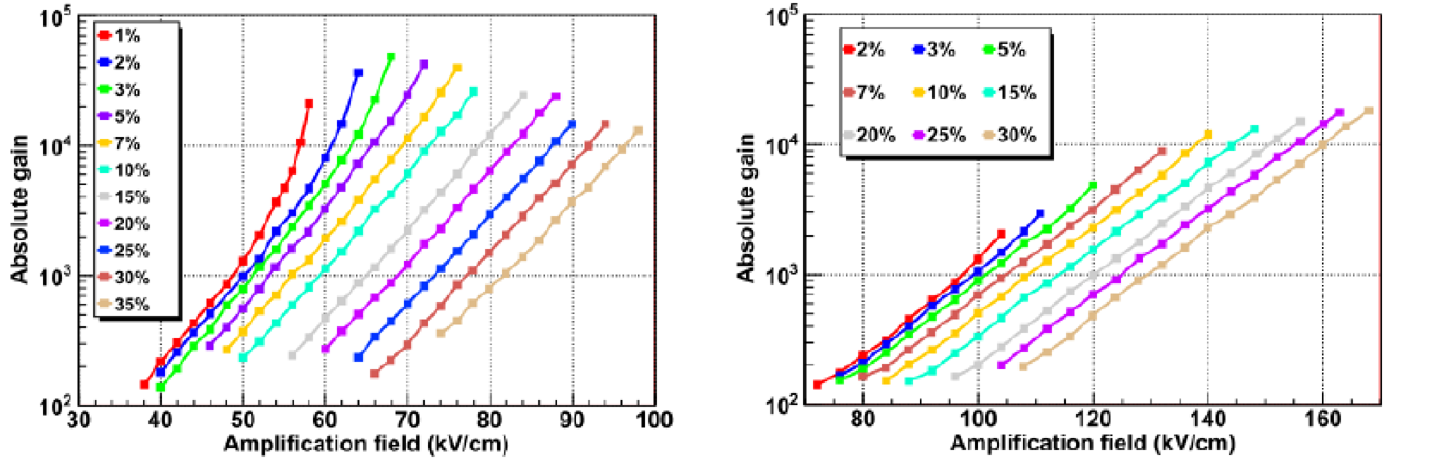


Figure 6. Dependence of the absolute gain with the amplification field for two microbulk detectors with gaps of 50 (left) and 25 μm (right) in argon-isobutane mixtures. The maximum gain of each curve was obtained just before the spark limit. The percentage of each series corresponds to the isobutane concentration.

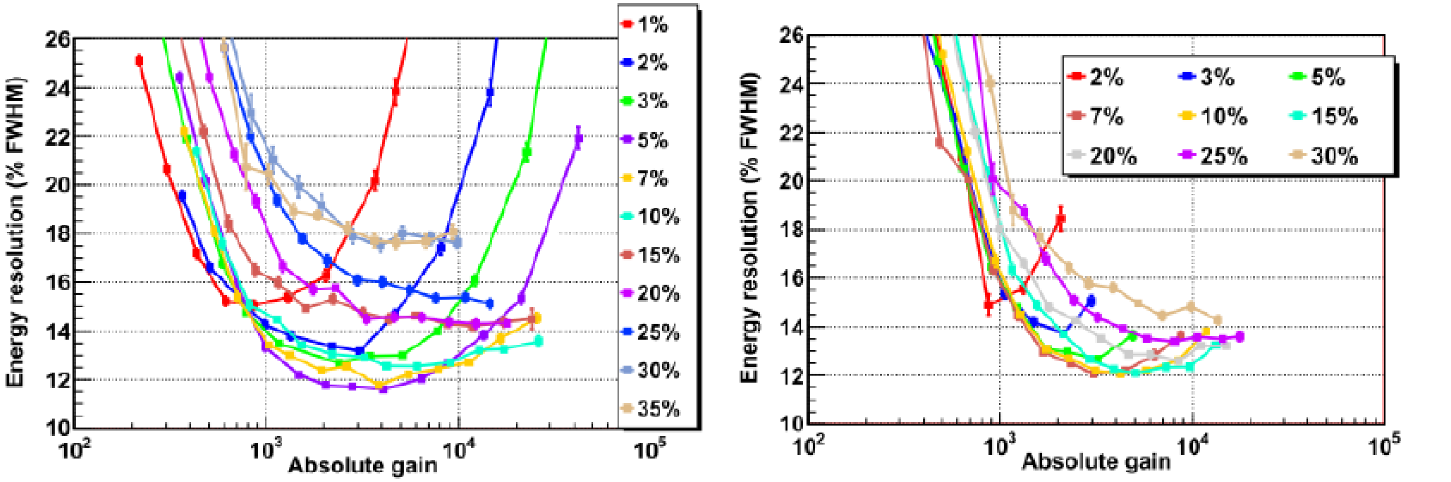


Figure 7. Dependence of the energy resolution with the absolute gain for two detectors of 50 (left) and 25 μm-thickness-gap (right) in argon-isobutane mixtures. The maximum gain of each curve was obtained just before the spark limit. The percentage of each series corresponds to the isobutane concentration.

Micromegas detector

- Topological information
  - ➢background discrimination

North mM