

Low-mass WIMP detection with TREX-DM

Álvaro Ezquerro Sastre

on behalf of TREX-DM team

aezquerro@unizar.es



Universidad
Zaragoza



Laboratorio Subterráneo de Canfranc

What is TREX-DM??

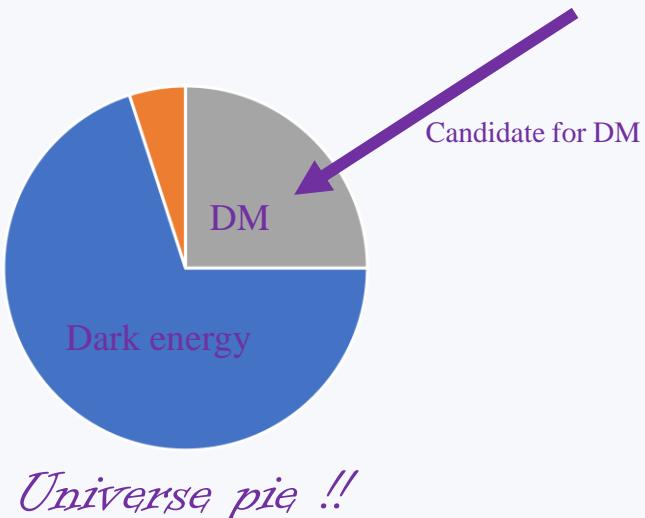
Particle detector aiming for
direct detection of WIMPs

What is a WIMP?

Guess what chart comes here...

What is TREX-DM??

Particle detector aiming for
direct detection of WIMPs



How?

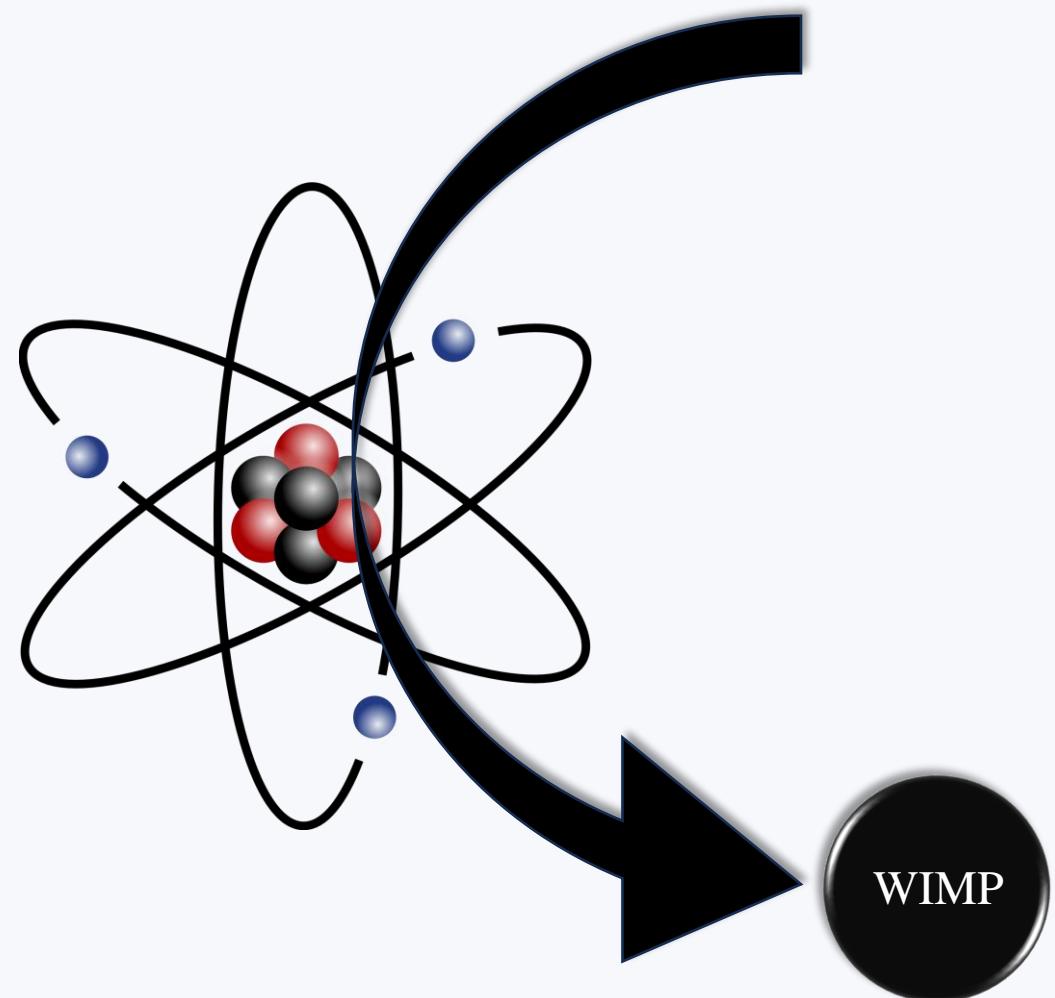
- Interaction: Spin Independent Nuclear Recoil

$$\frac{d\sigma}{dE_R} = \frac{m_N}{2\mu^2 v^2} \sigma_0 F_H^2(E_R)$$

- With our detector target material

atomic mass (number of nucleons) A

Exposure = $M_{det} \cdot T$



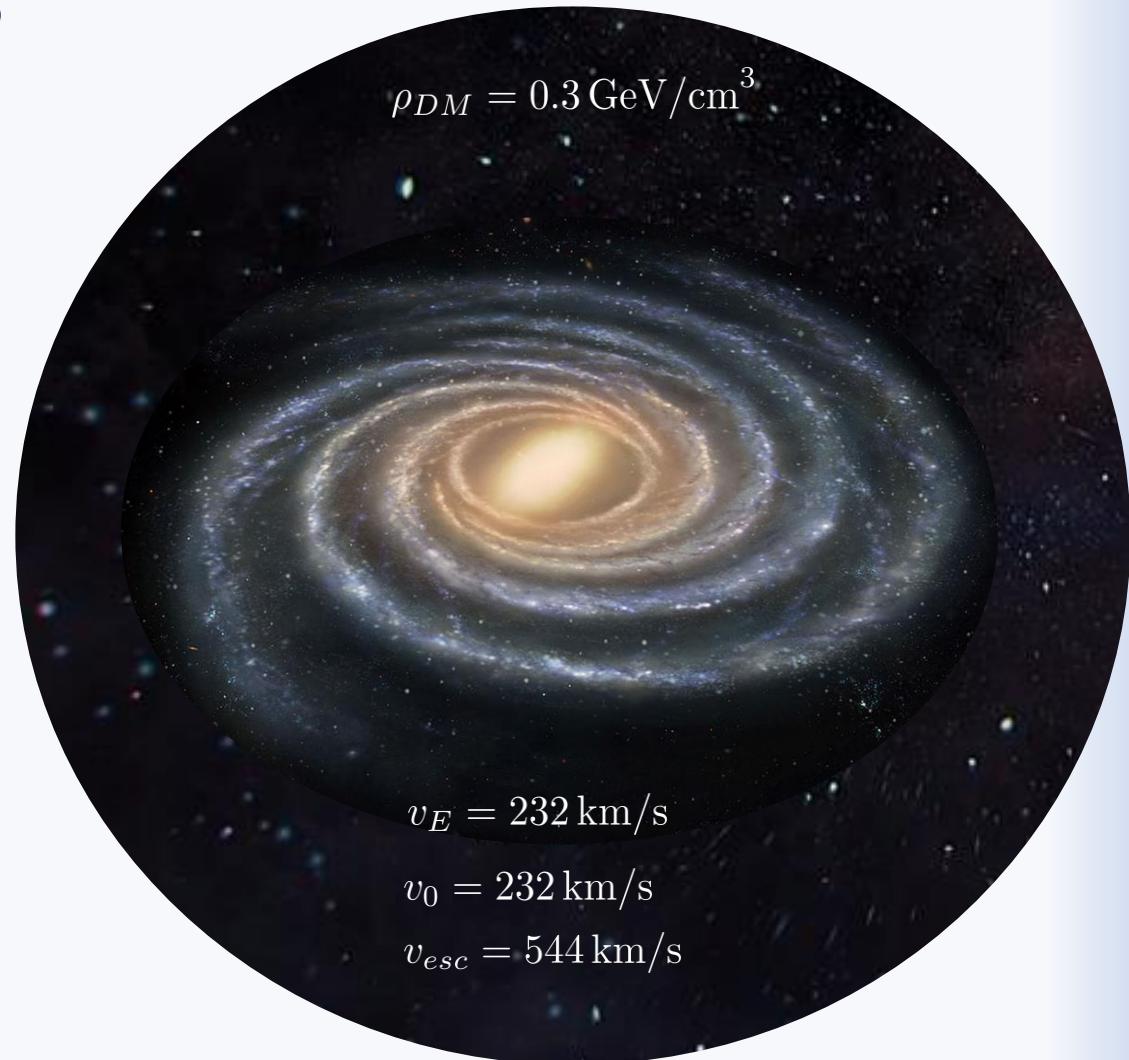
How?

- Interaction: Spin Independent Nuclear Recoil

$$\frac{d\sigma}{dE_R} = \frac{m_N}{2\mu^2 v^2} \sigma_0 F_H^2(E_R)$$

- With our detector target material
atomic mass (number of nucleons) A
 $\text{Exposure} = M_{det} \cdot T$
- Of WIMPs from Milky Way Halo

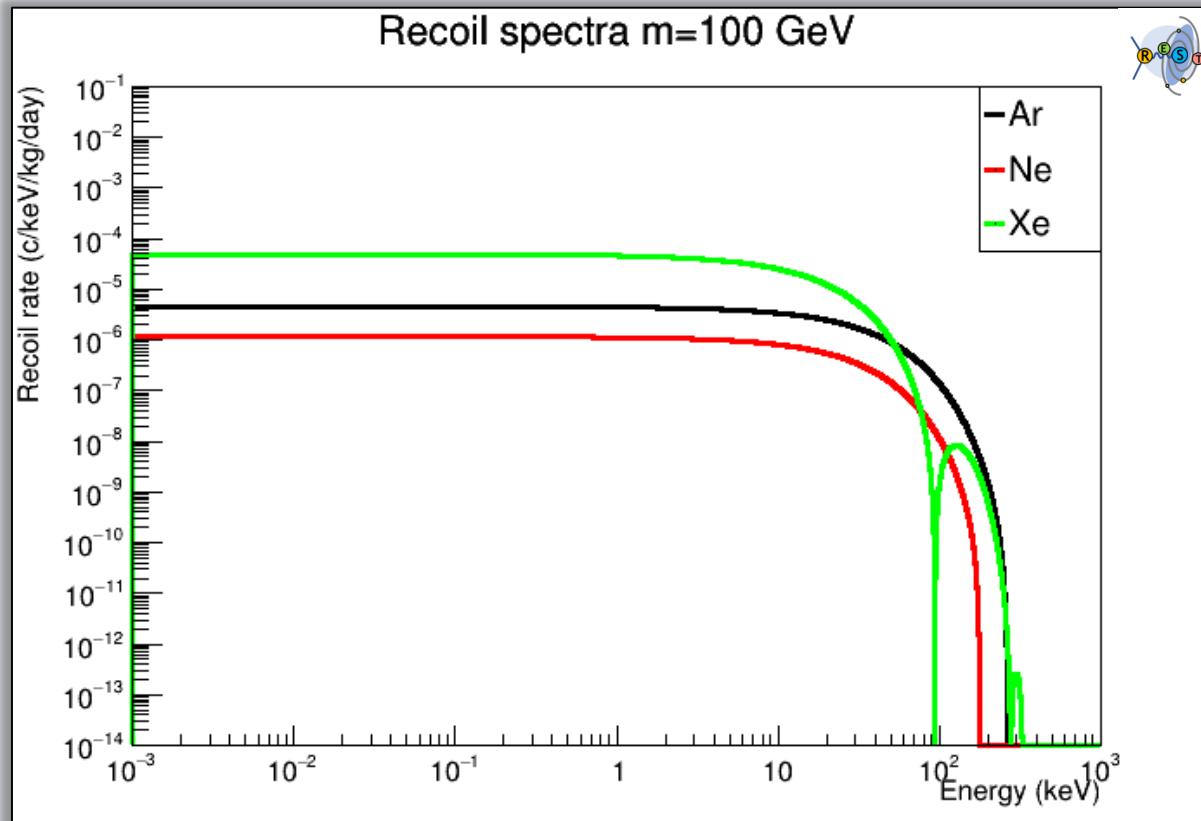
$$f(\vec{v}, \vec{v_E}) \propto \exp\left(-\frac{(\vec{v} + \vec{v_E})^2}{v_0^2}\right) \quad \text{from } v_{min}^2 = \frac{E_R m_N}{2\mu^2} \text{ to } v_{esc}$$



Baxter, D et al. Recommended conventions for reporting results from direct dark matter searches. Eur. Phys. J. C 81, 907 (2021).

Rate

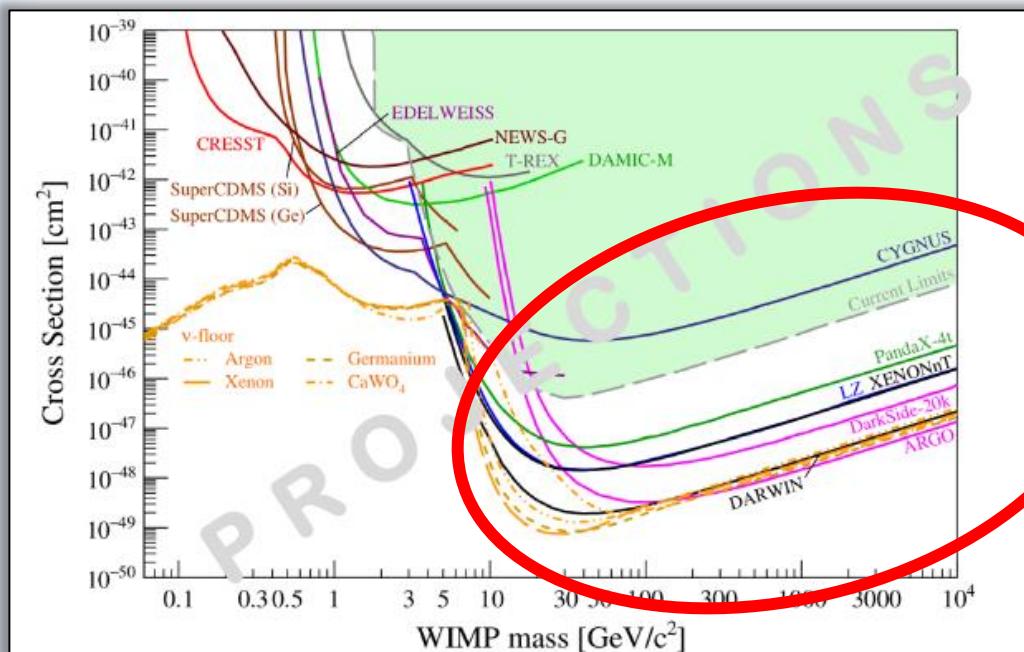
$$\frac{dR}{dE_R} = \frac{\rho_\chi}{2\mu^2 m_\chi} \sigma_0 F_H^2(E_R) \int_{v_{min}}^{v_{esc}} \frac{f(\vec{v}, \vec{v}_E)}{v} d^3v$$



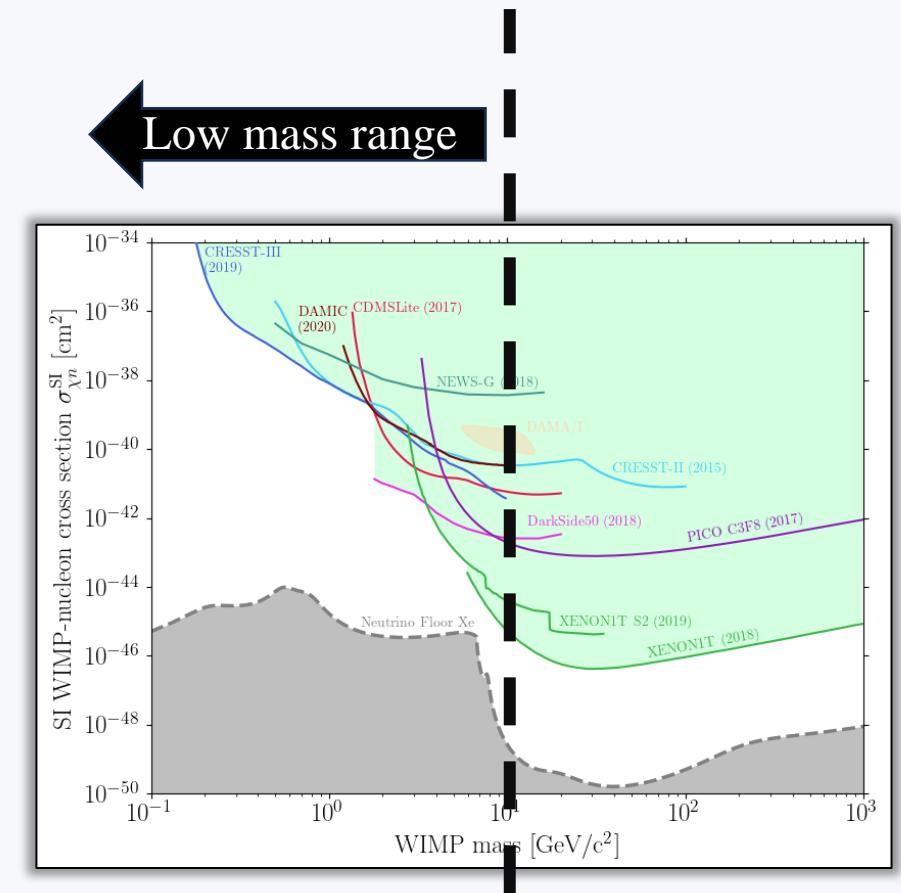
$\sim 1-100$ c/kg/year !!!

Goal of TREX-DM

- Spin independent nuclear recoil
(σ_{SI} , WIMP mass)
- Direct detection of WIMPs (dark matter)
 - Low masses $< 10 \text{ GeV}/c^2$

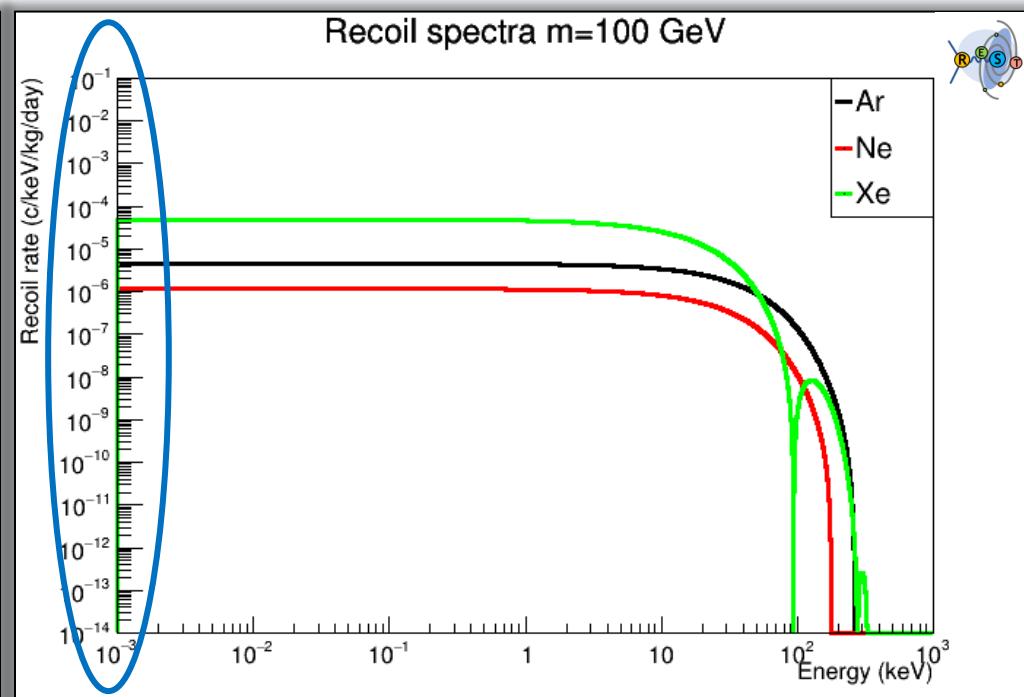
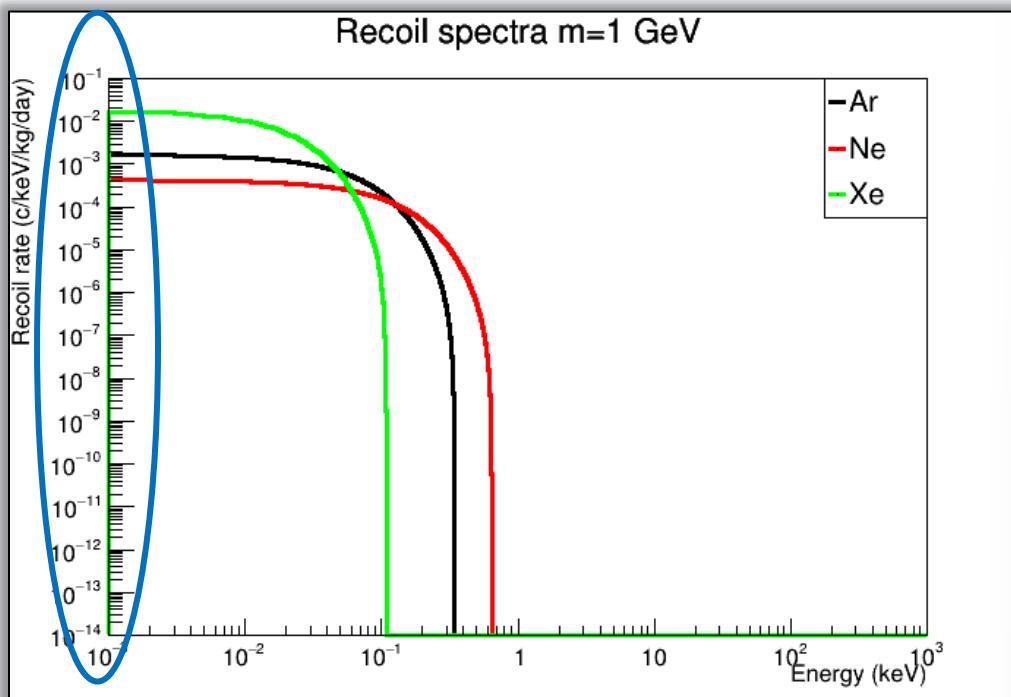


A. Ezquerro - Saturnalia 2023



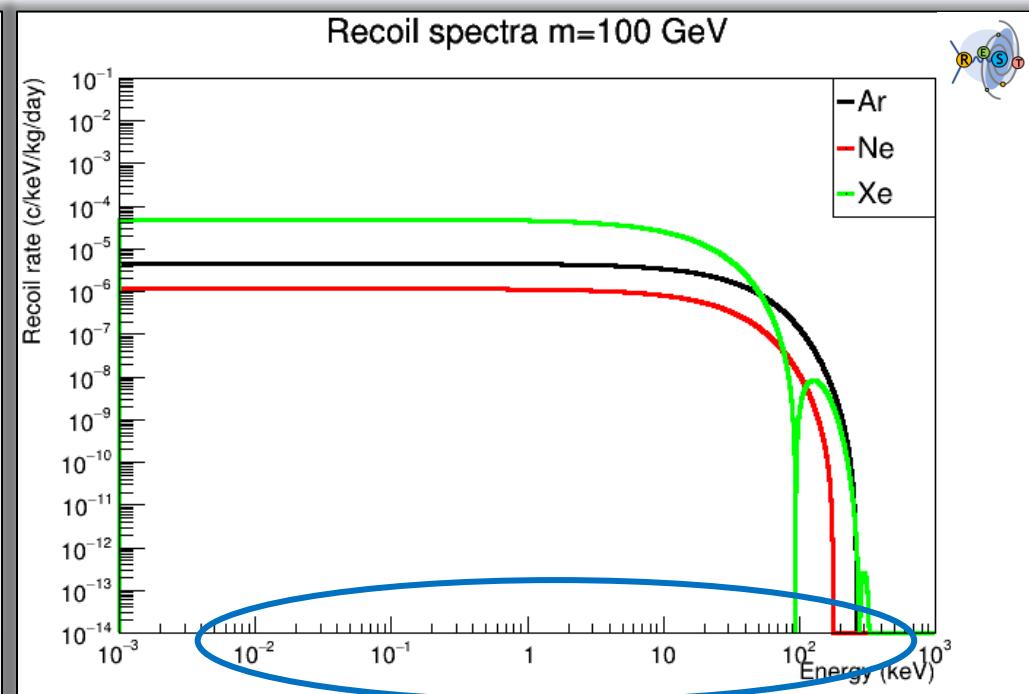
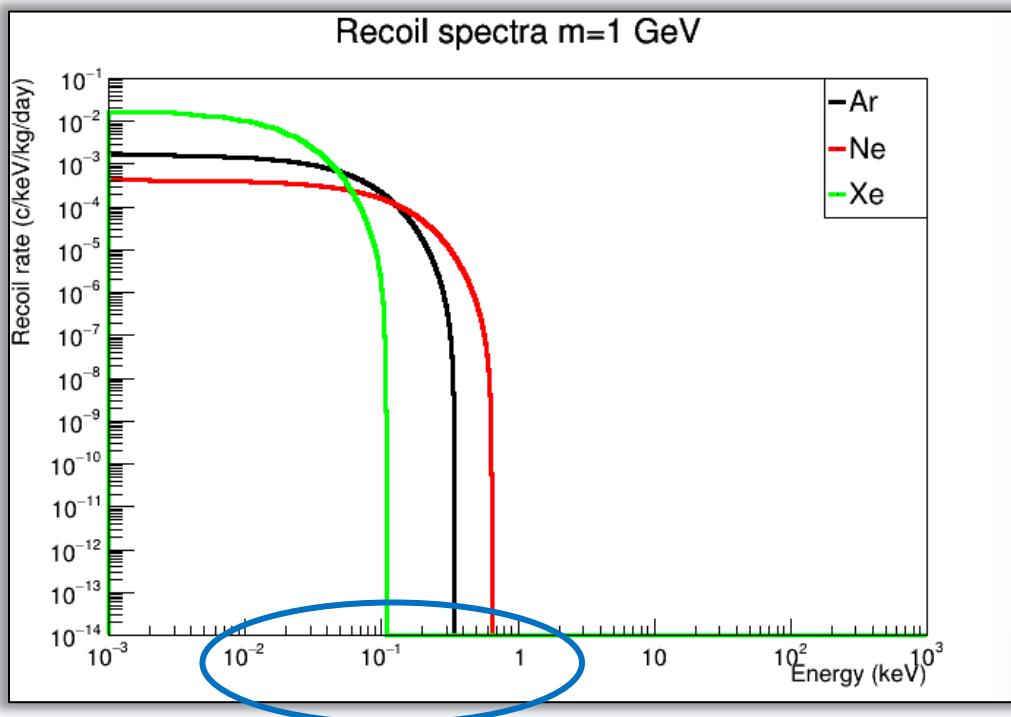
Challenges

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



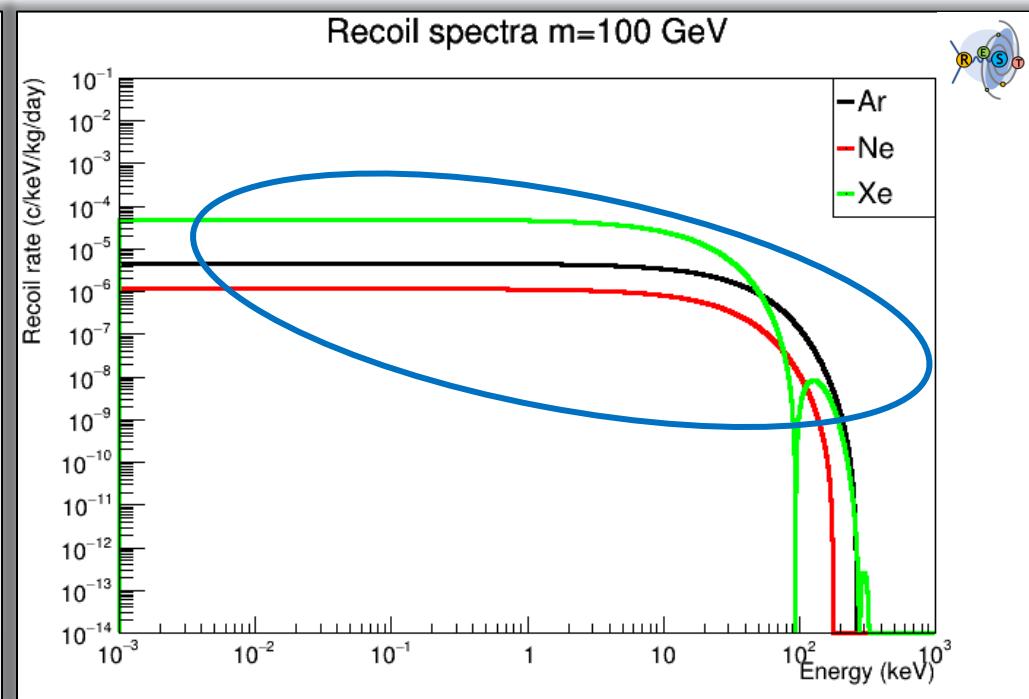
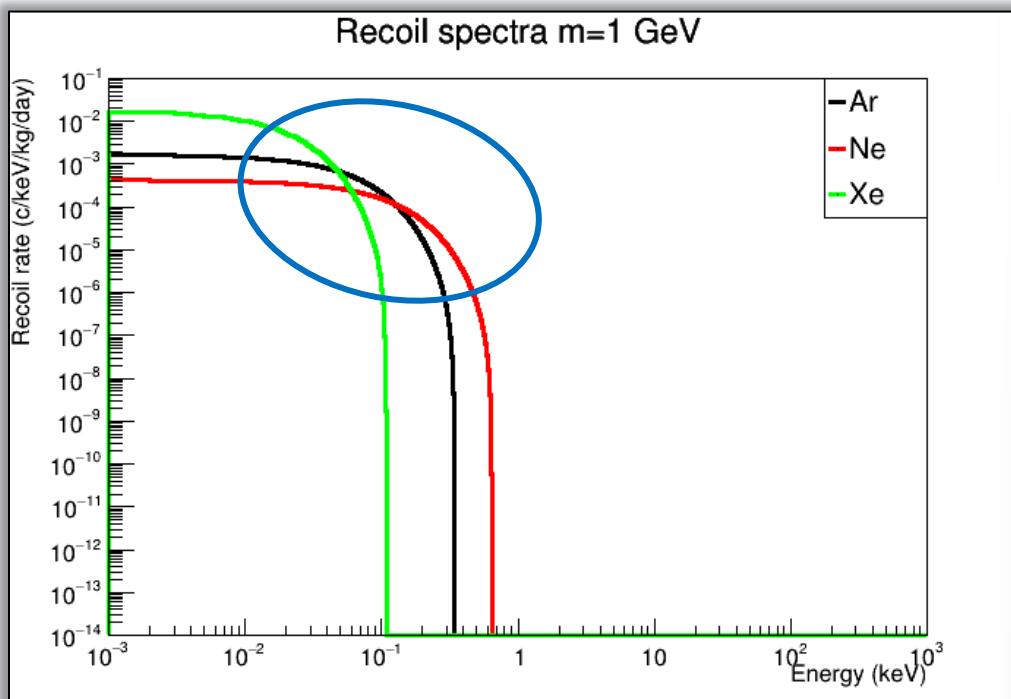
Challenges

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Challenges

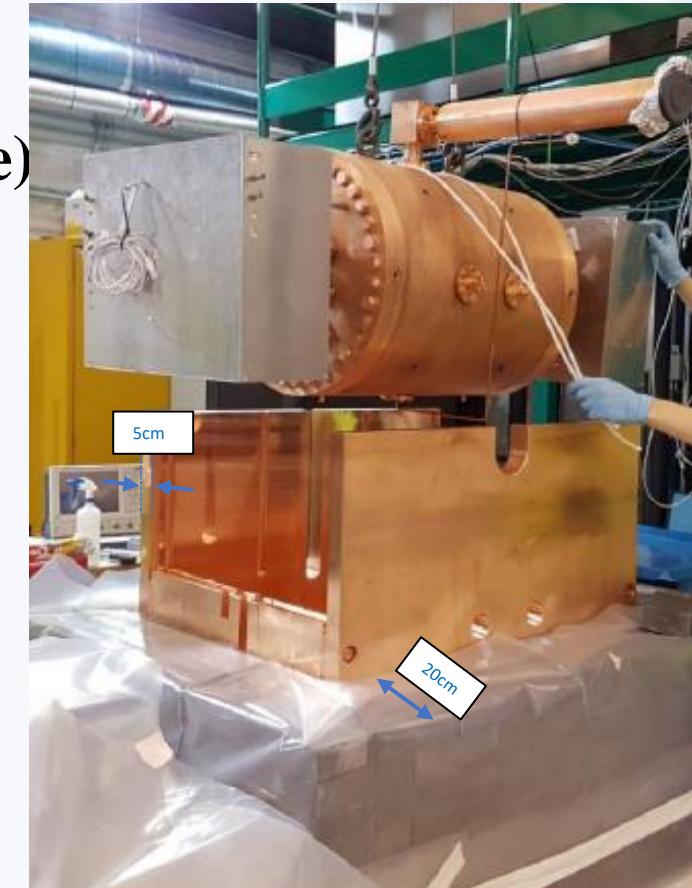
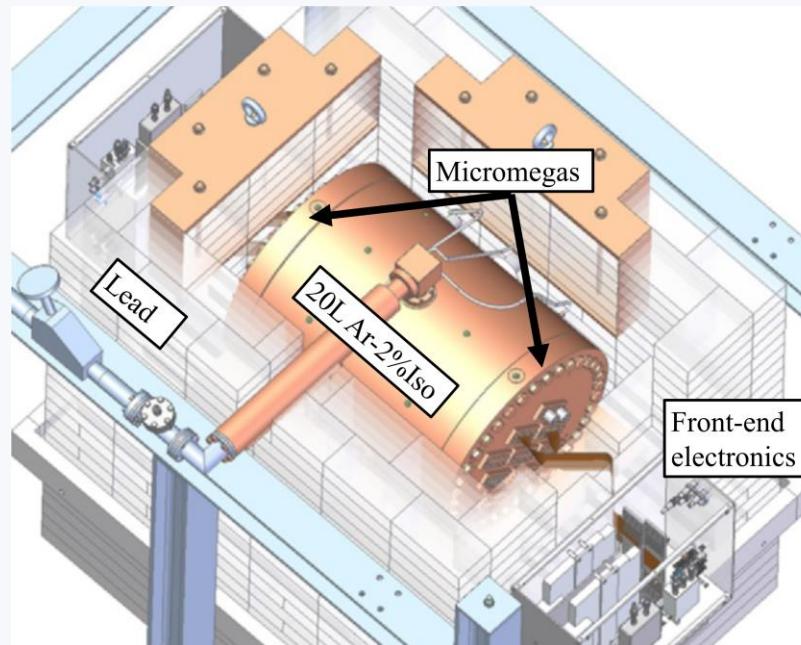
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TREX-DM specifications

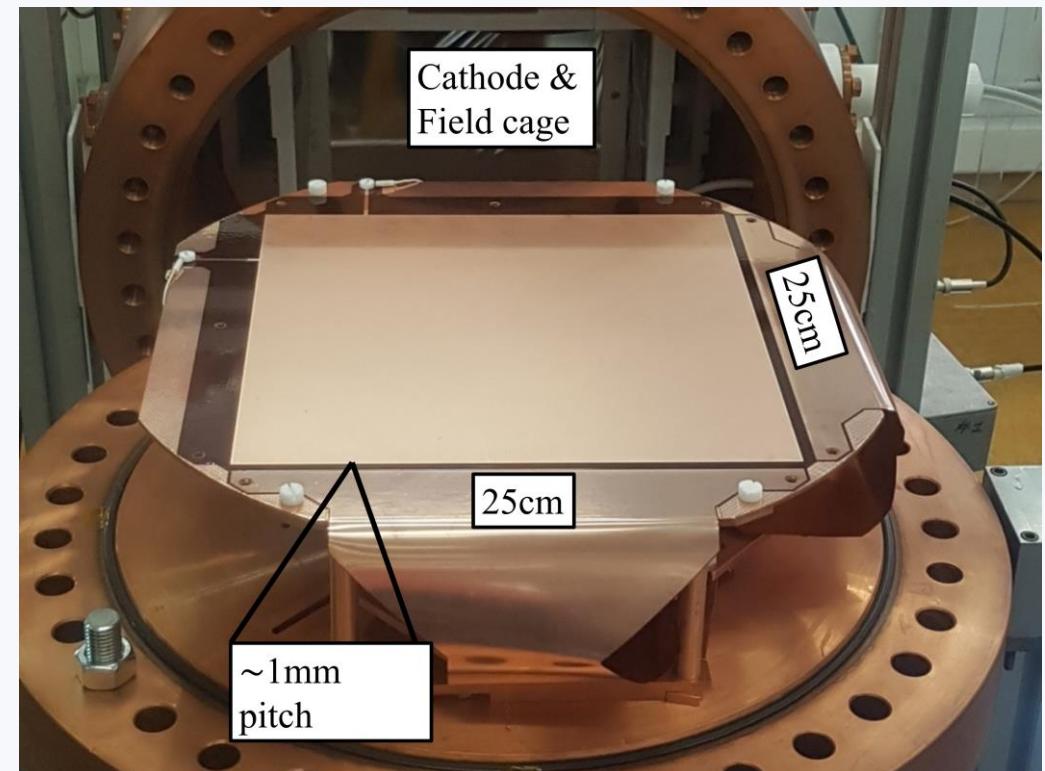
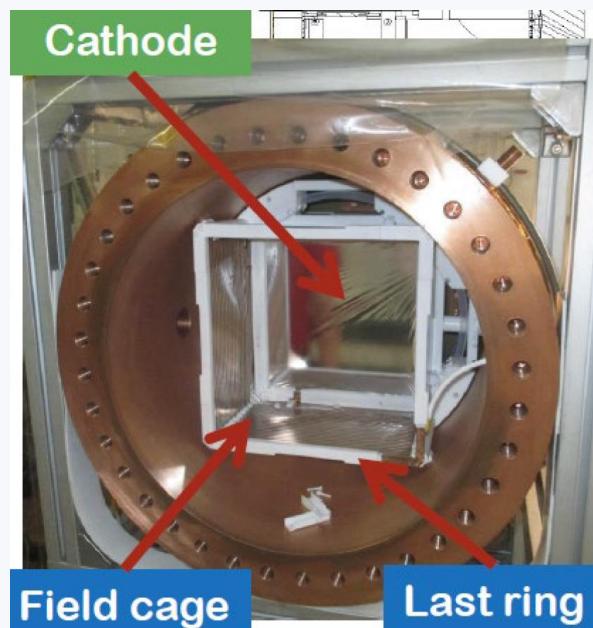
Iguaz, F.J., Garza, J.G., Aznar, F. et al. TREX-DM: a low-background Micromegas-based TPC for low-mass WIMP detection. *Eur. Phys. J. C* **76**, 529 (2016). <https://doi.org/10.1140/epjc/s10052-016-4372-6>

- Gaseous TPC of cylindrical copper vessel
- Active volume 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.)



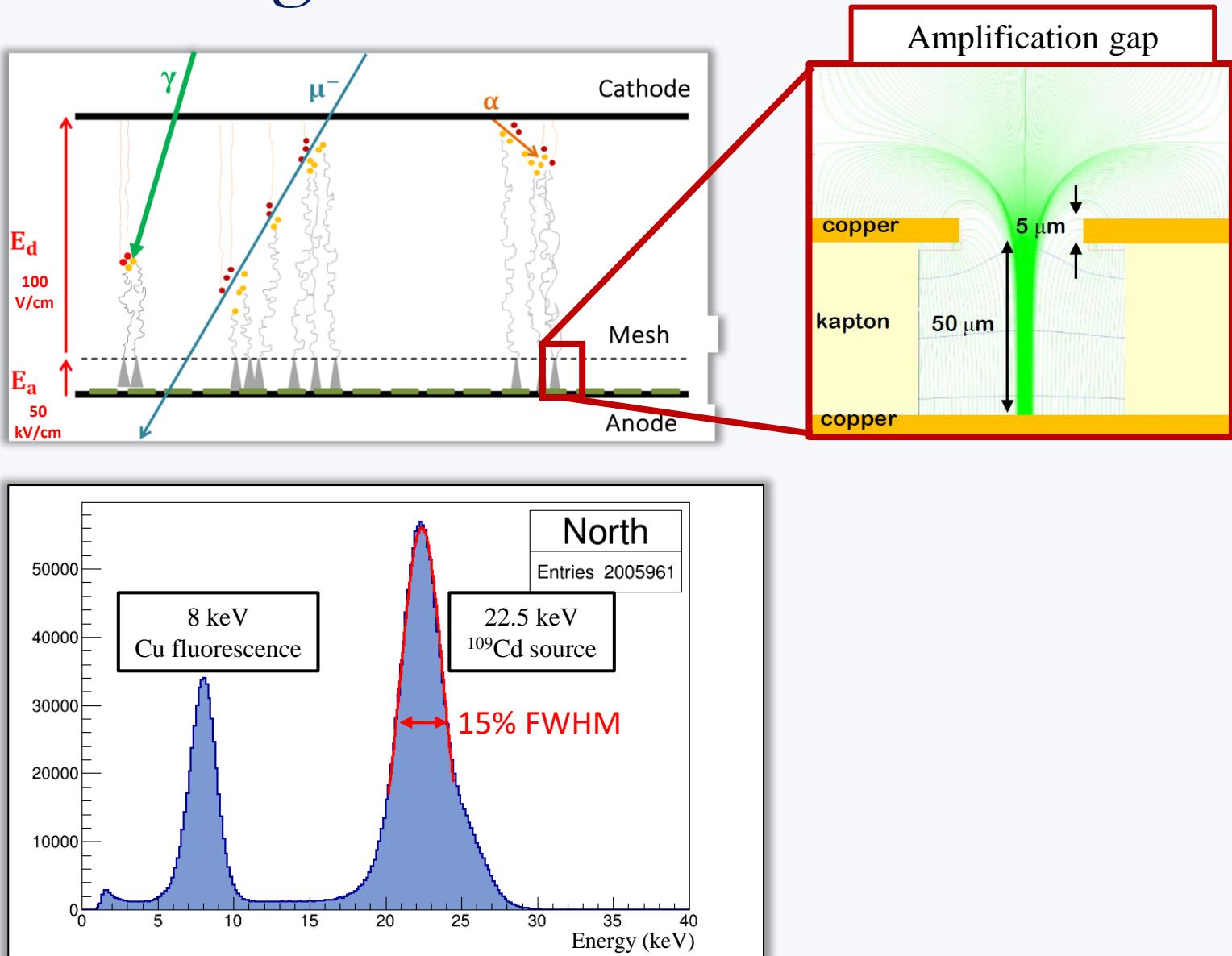
TREX-DM specifications

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



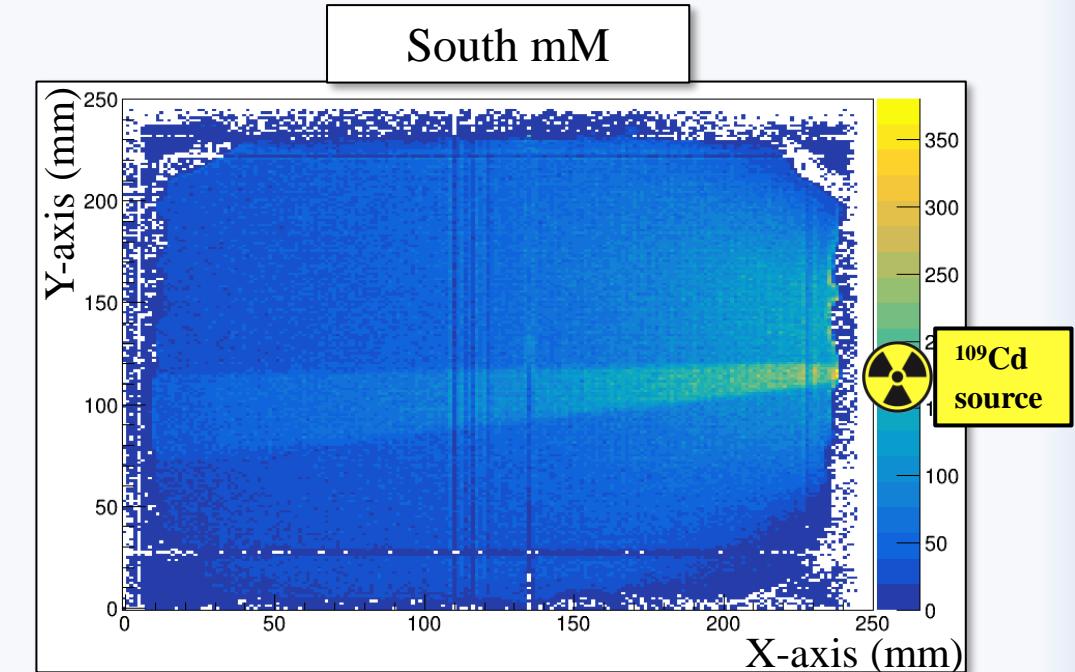
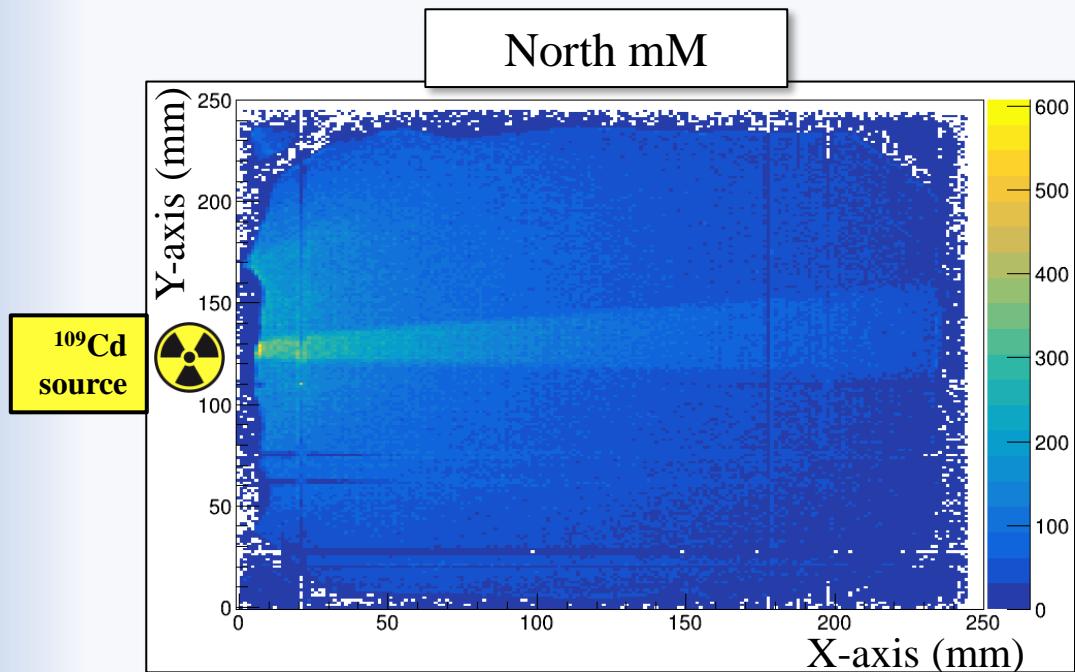
Micromegas detector

- Working principle of TPC with mM
- Low intrinsic radioactivity
- Absolute gain 10^3 - 10^4



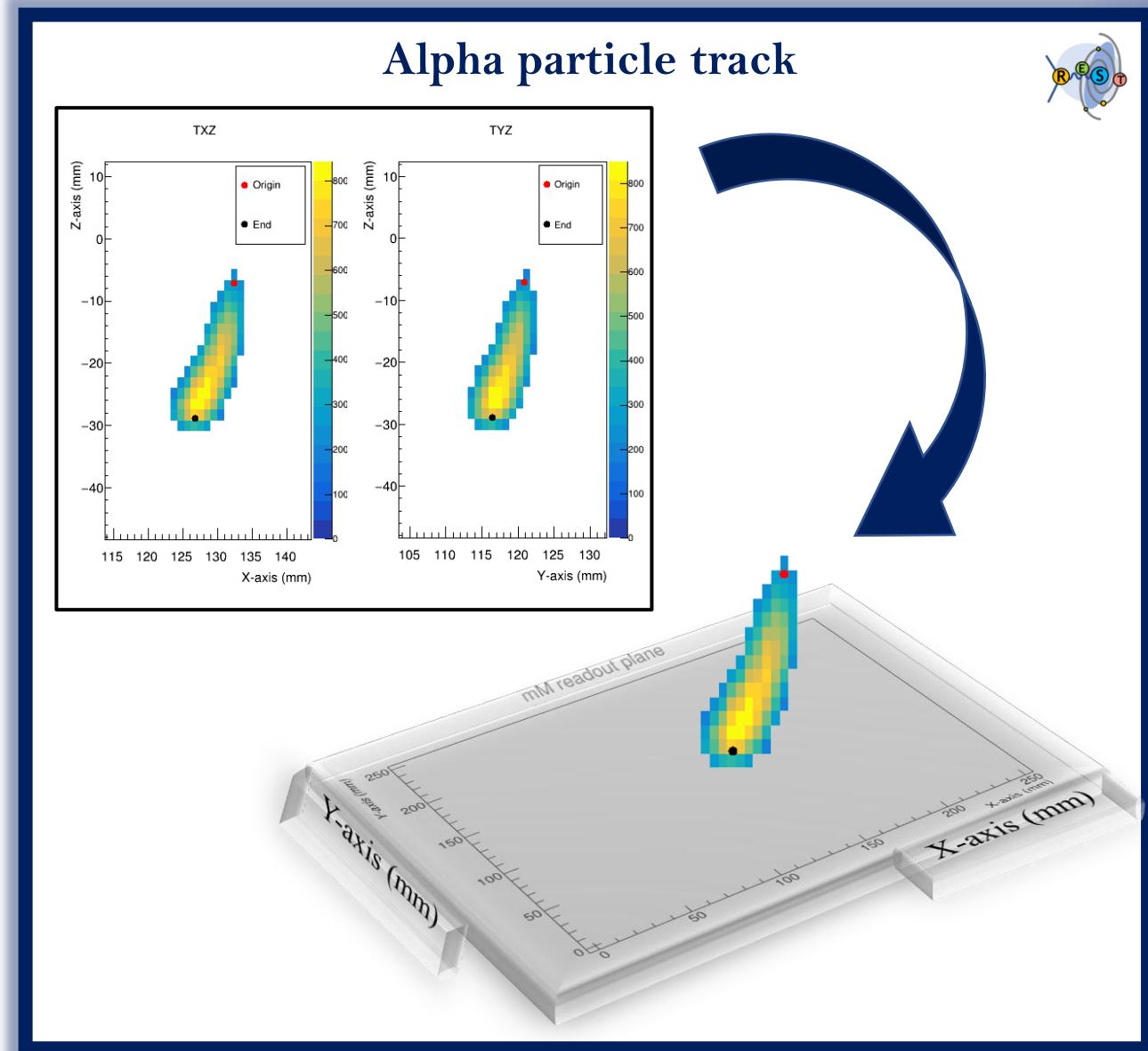
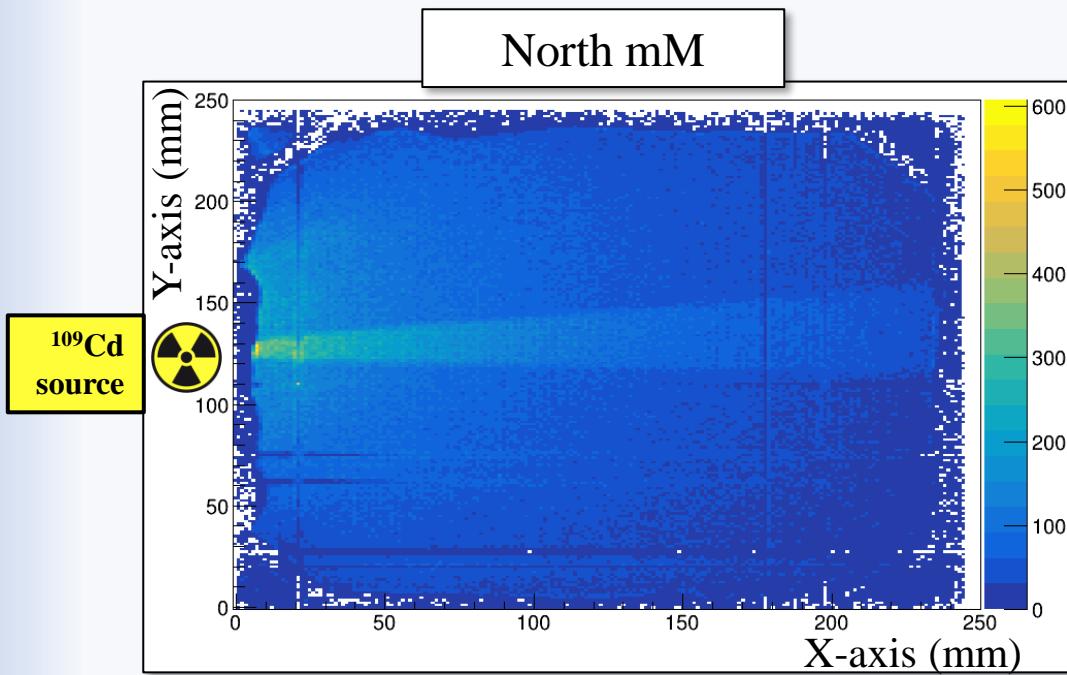
Micromegas detector

- Topological information
➤ background discrimination



Micromegas detector

- Topological information
➤ background discrimination

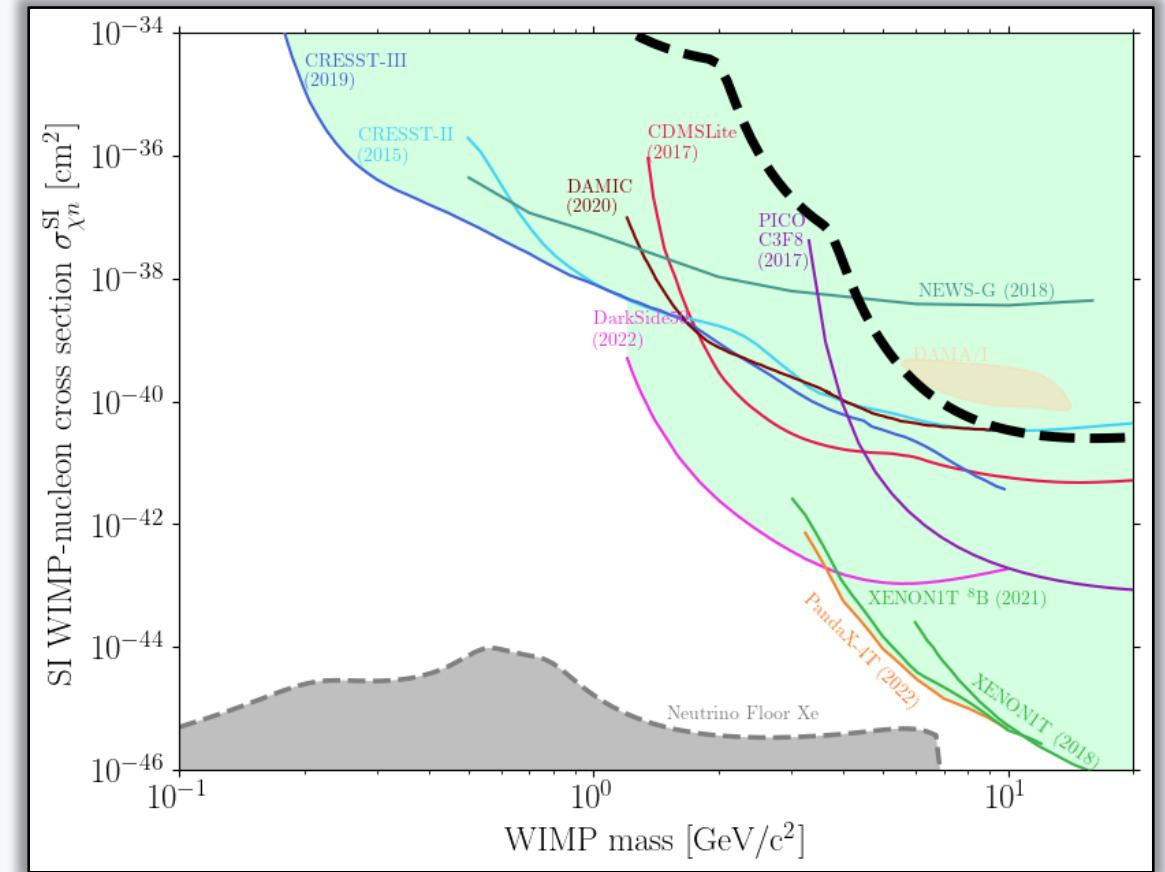


State of art

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

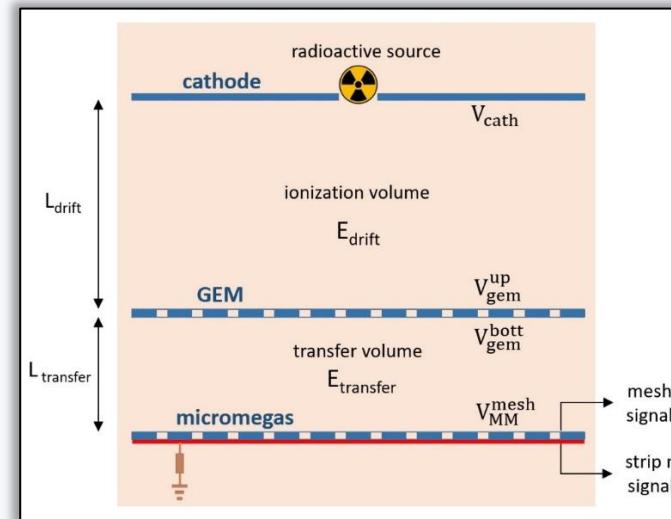
(dru = keV $^{-1}$ kg $^{-1}$ day $^{-1}$)

Exposure 0.32 kg y

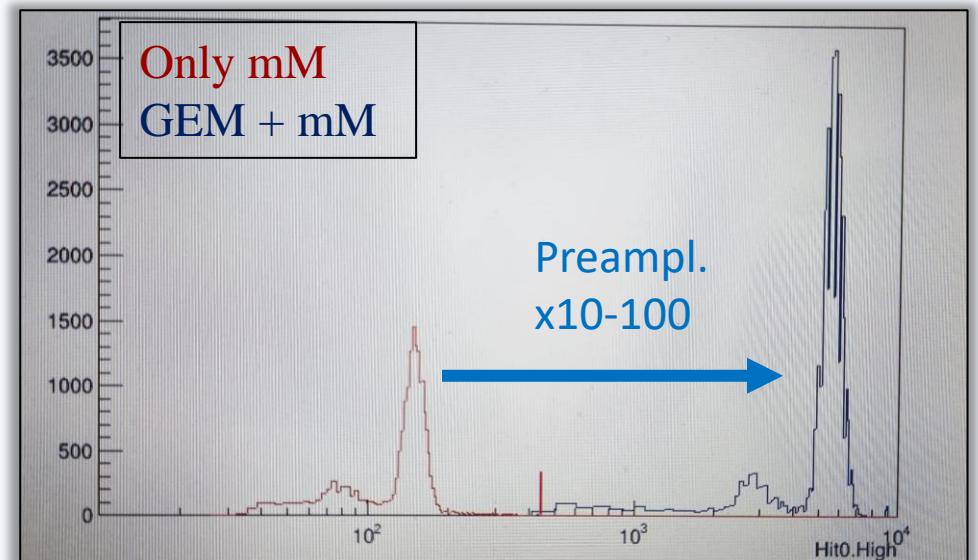


Improving energy threshold

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



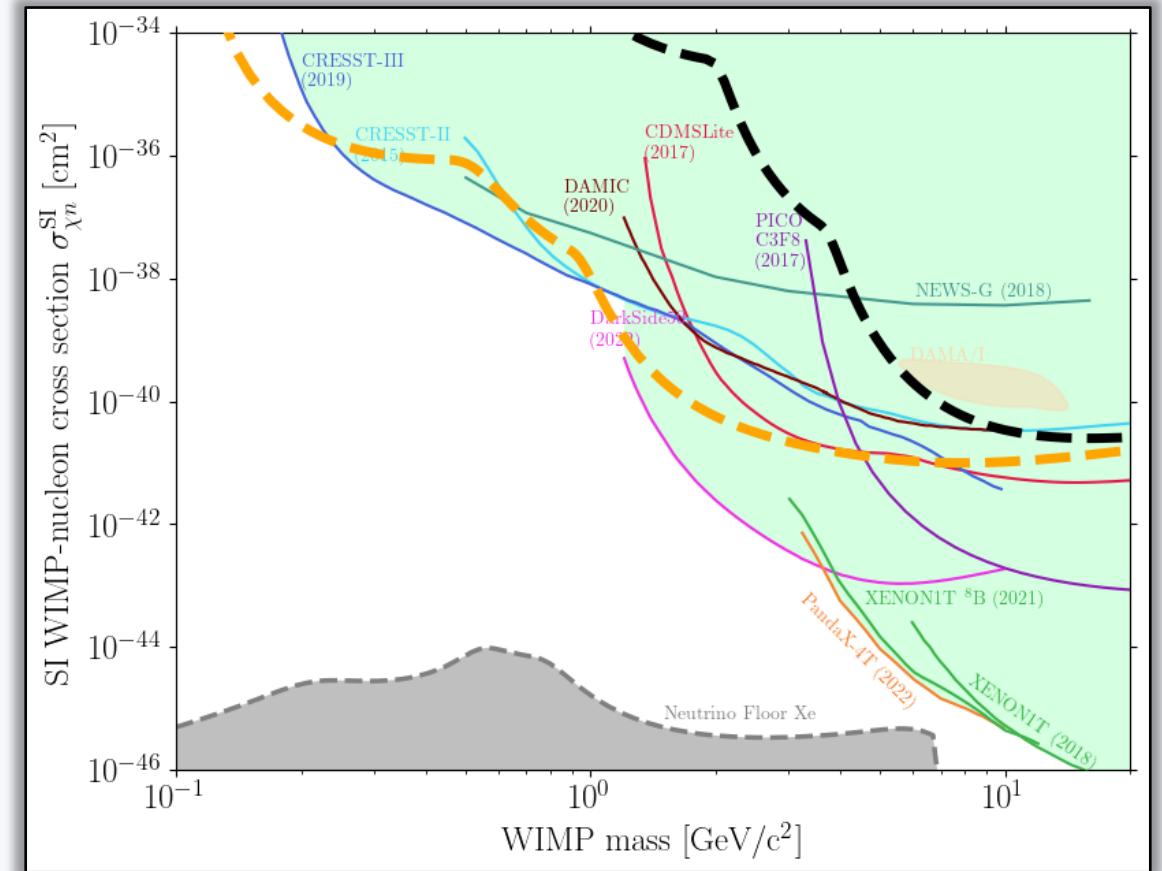
- Preliminary results in test set-up shows x10-100 extra amplification factor
→ E_{thr} lowered down to single electron (20 eV_{ee})



Sensitivity prospects

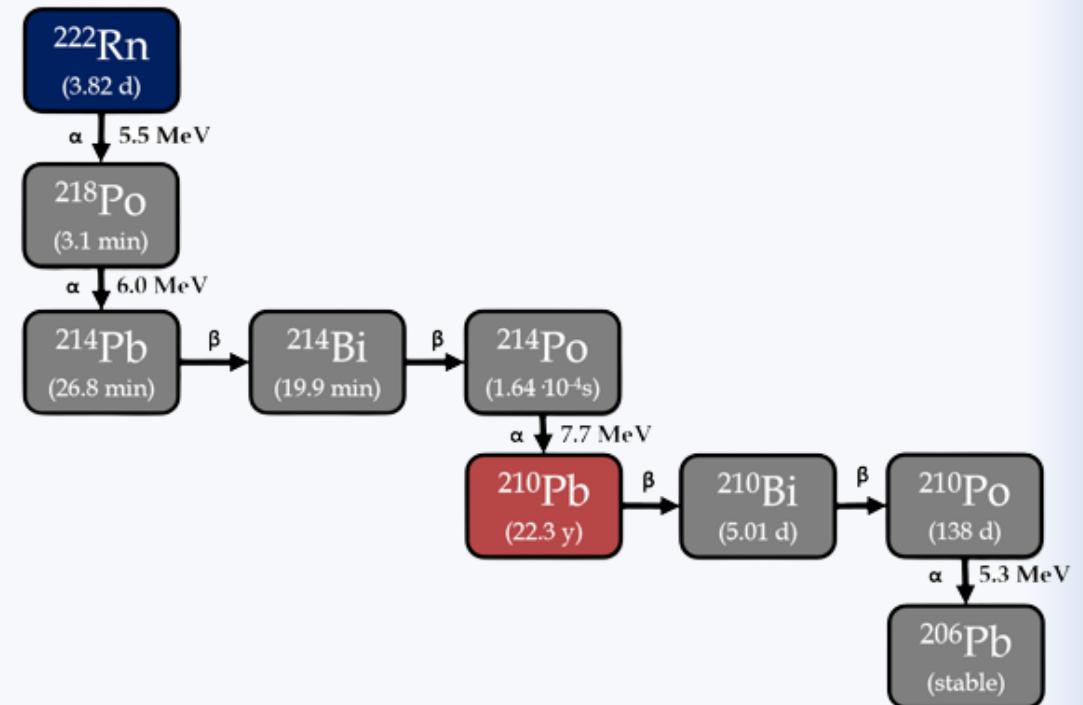
	E_{th} (eV _{ee})	B(dru)	Gas
Z	1000	100	Ar-1%Iso
A	50	100	Ar-1%Iso

Exposure 0.32 kg y



Improving background

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



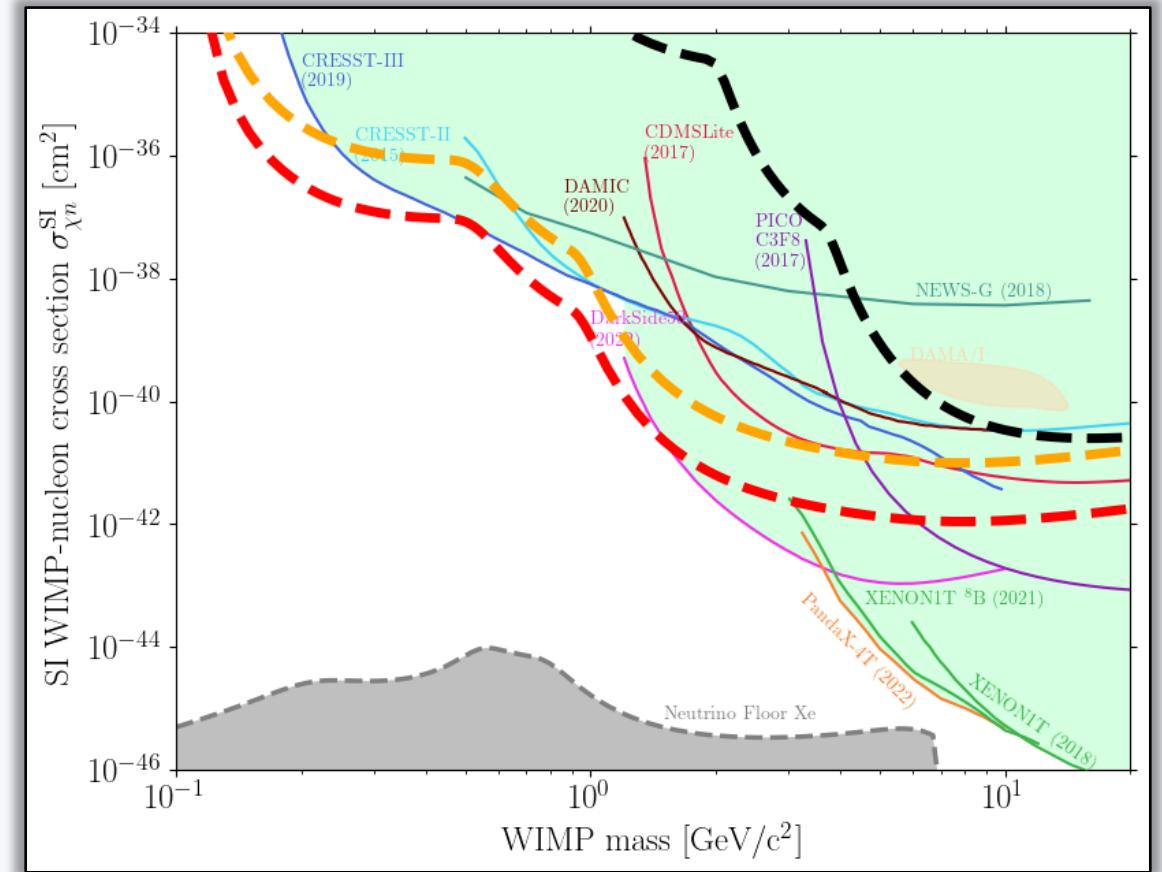
- II. Plans to install a more radiopure cathode in the coming months

➤ 1-10 dru

Sensitivity prospects

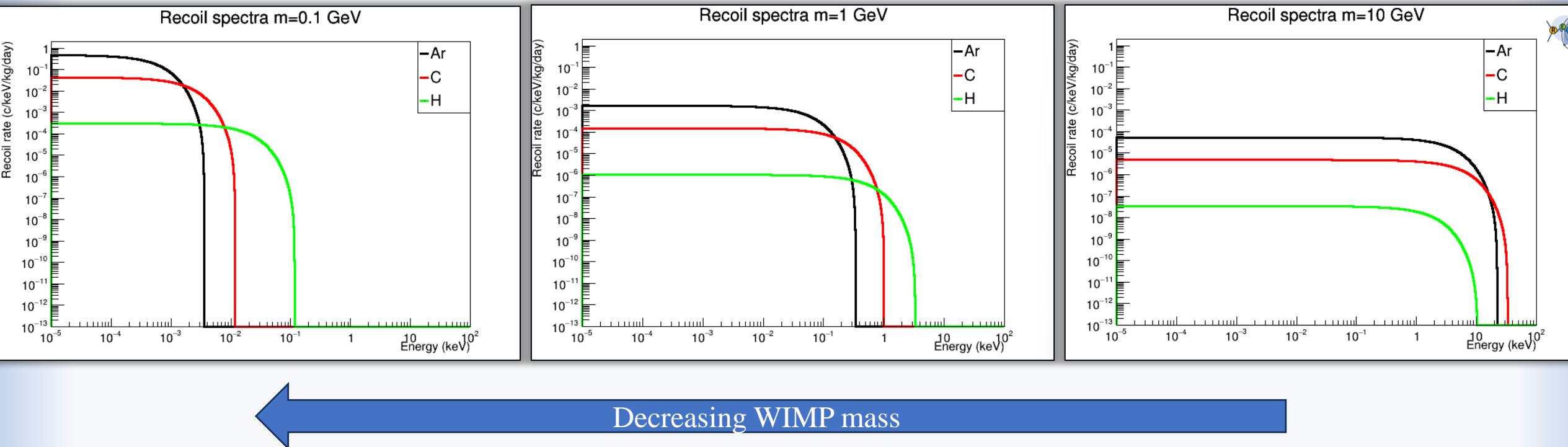
	E_{th} (eV $_{ee}$)	B(dru)	Gas
Z	1000	100	Ar-1%Iso
A	50	100	Ar-1%Iso
B	50	1	Ar-1%Iso

Exposure 0.32 kg y



Increasing quencher in gas

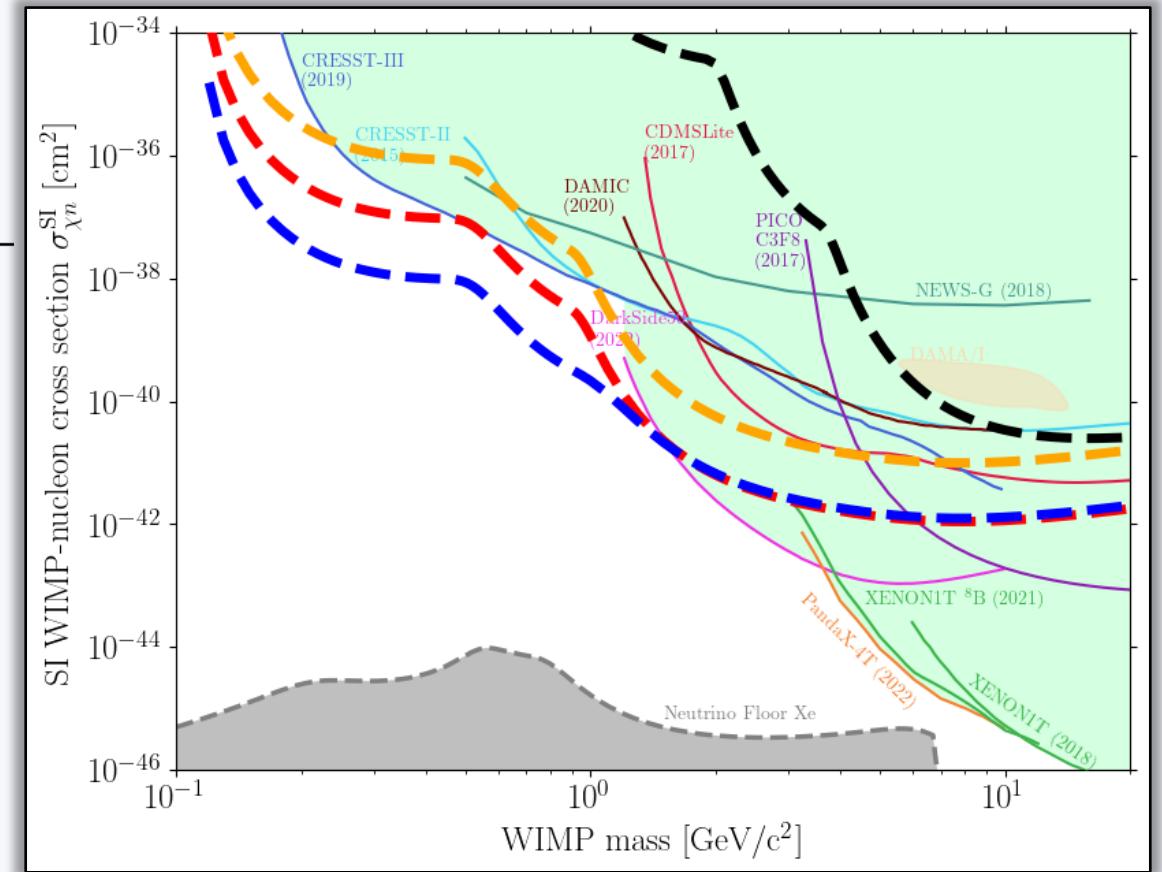
- For low-mass WIMPs, the lighter the better!



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

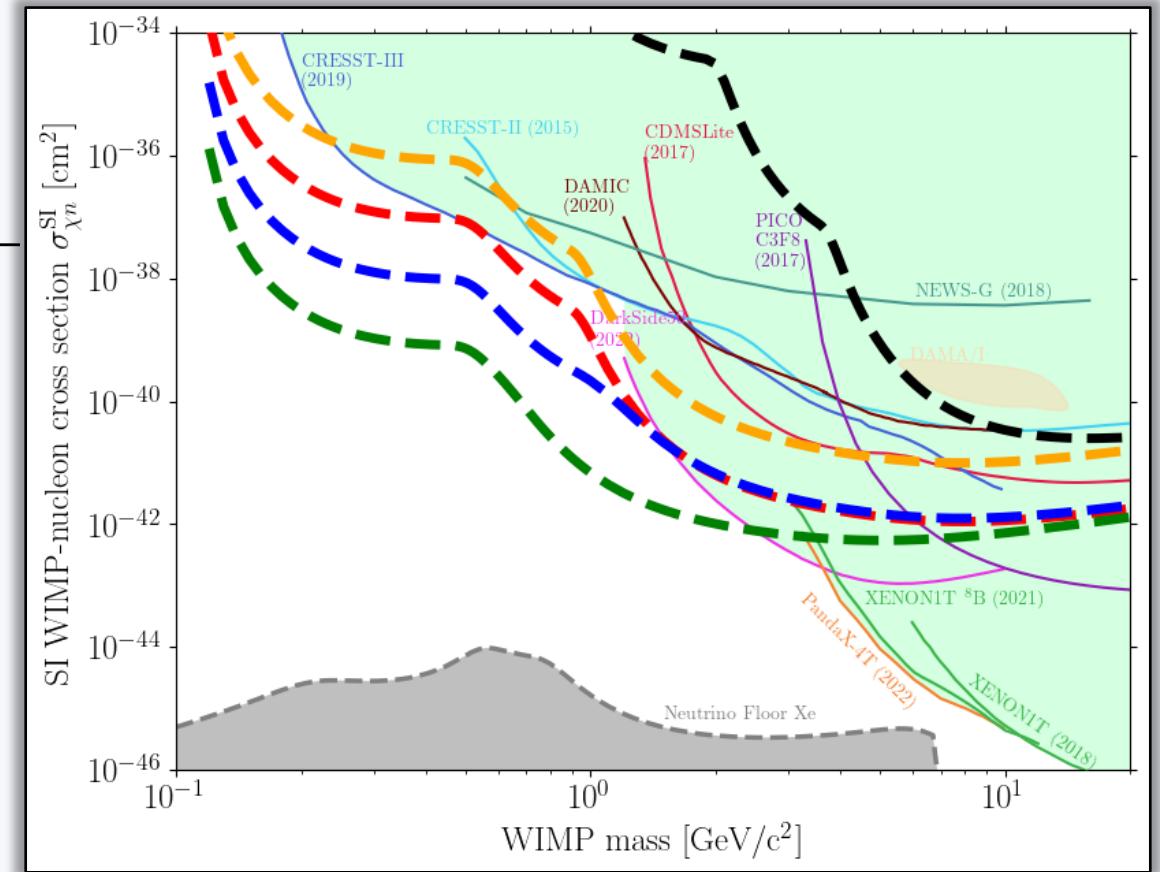


Sensitivity prospects

	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

THANKS!



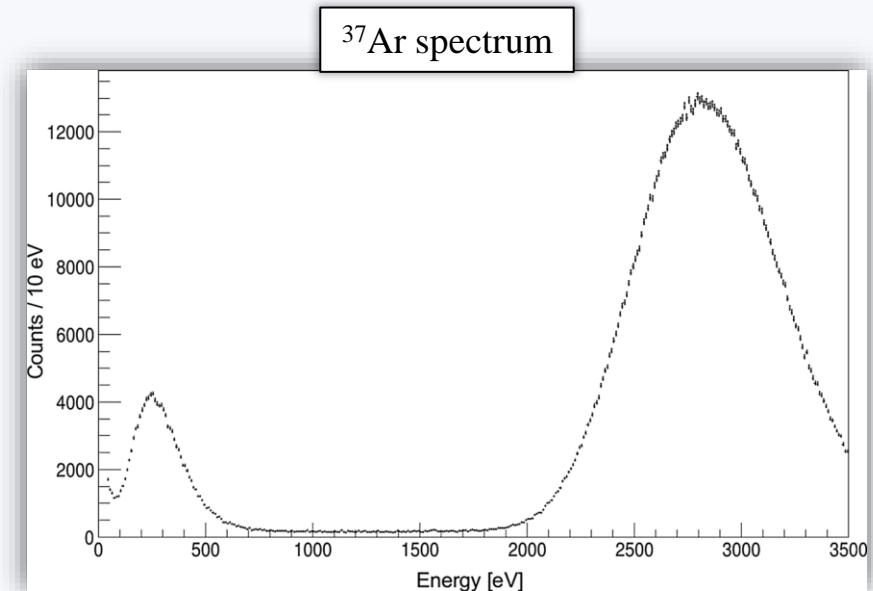
**Installation of new
micromegas**



BACK-UP

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)



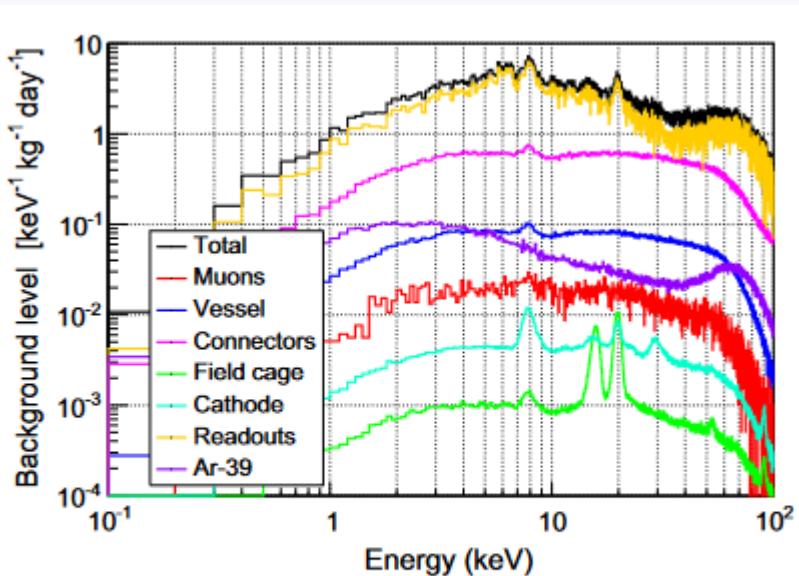


Fig. 20 Simulated background spectrum expected in TREX-DM experiment (*black line*) during a physics run at LSC if operated in Ar+2%*i*C₄H₁₀ (*left*) or Ne+2%*i*C₄H₁₀ at 10 bar. The contribution of

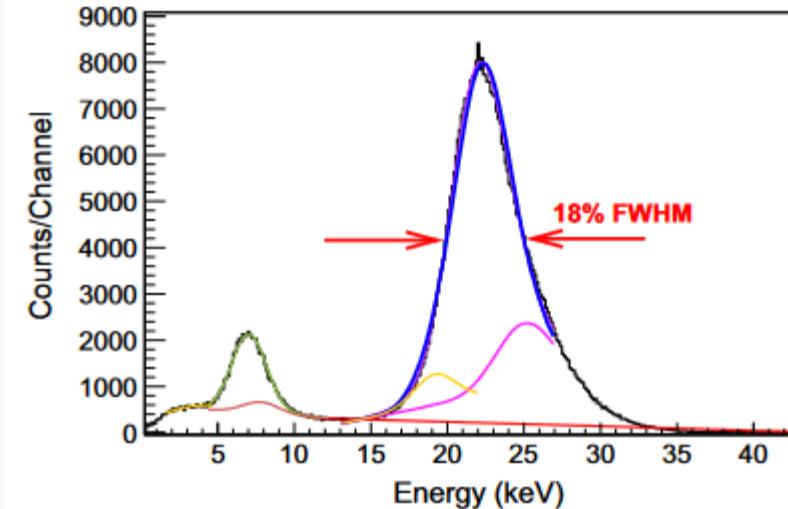


Fig. 6 Energy spectrum generated by the mesh signals when one of the Micromegas readouts is irradiated by a ¹⁰⁹Cd source in Ar+2%*i*C₄H₁₀ at 2 bar. The spectral parameters are defined through an iterative multi-Gaussian fit corresponding to the K_α (22.1 keV, *blue line*) and K_β (24.9 keV, *magenta 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)

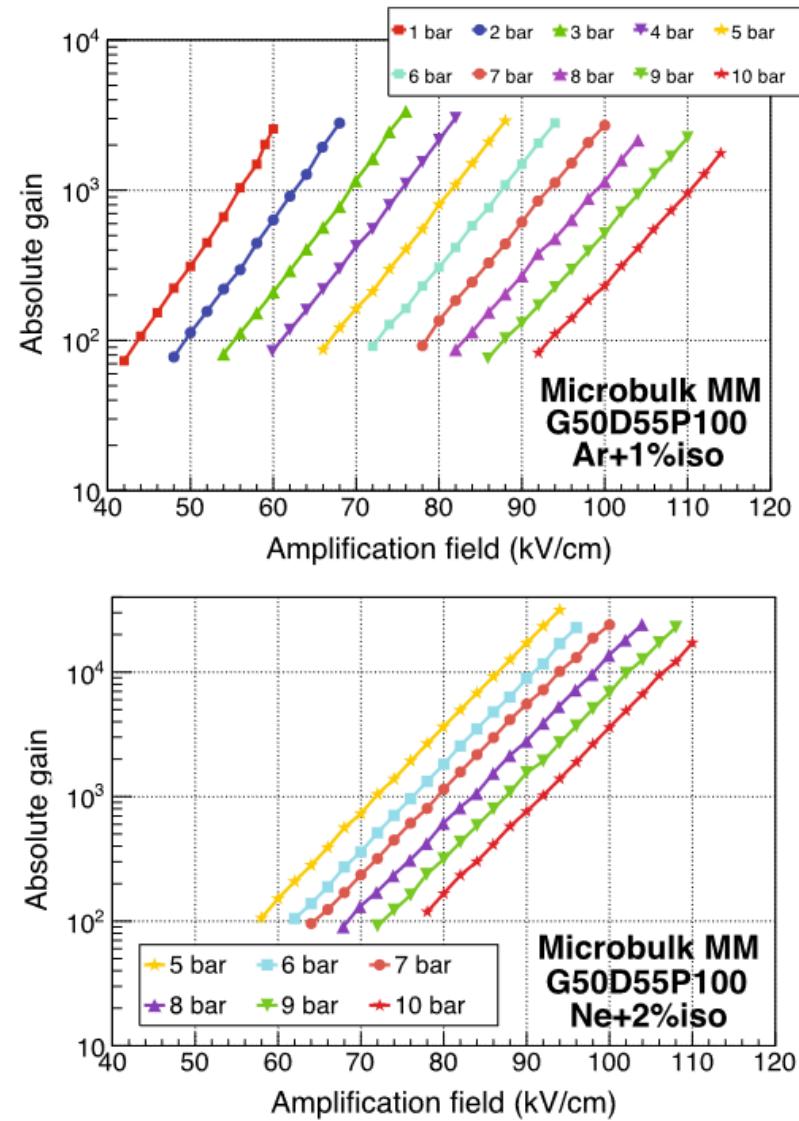
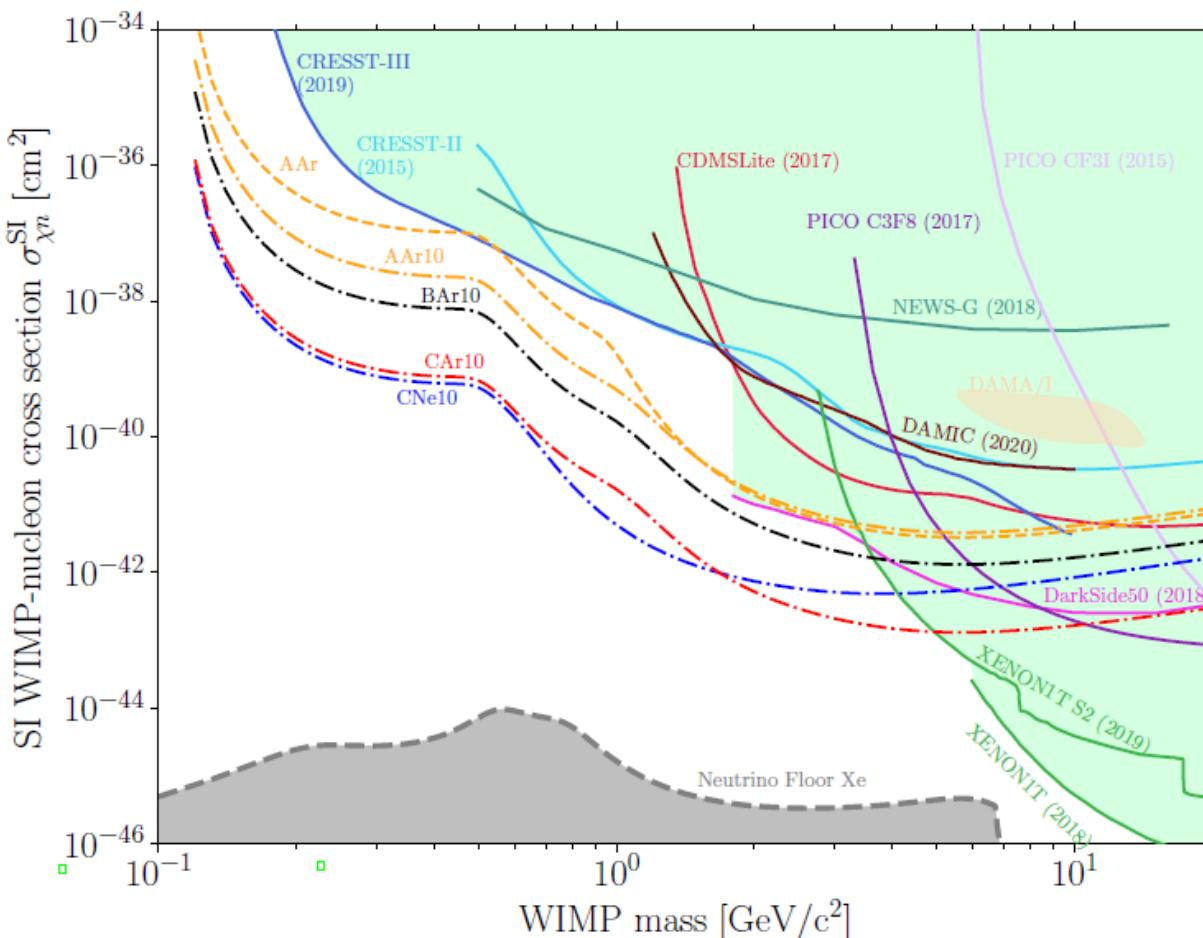


Fig. 4 Gain curves obtained in the characterization of microbulk Micromegas with Ar (top) and Ne (bottom) mixtures using a ^{109}Cd source. Curves for different pressures up to 10 bar are shown

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>

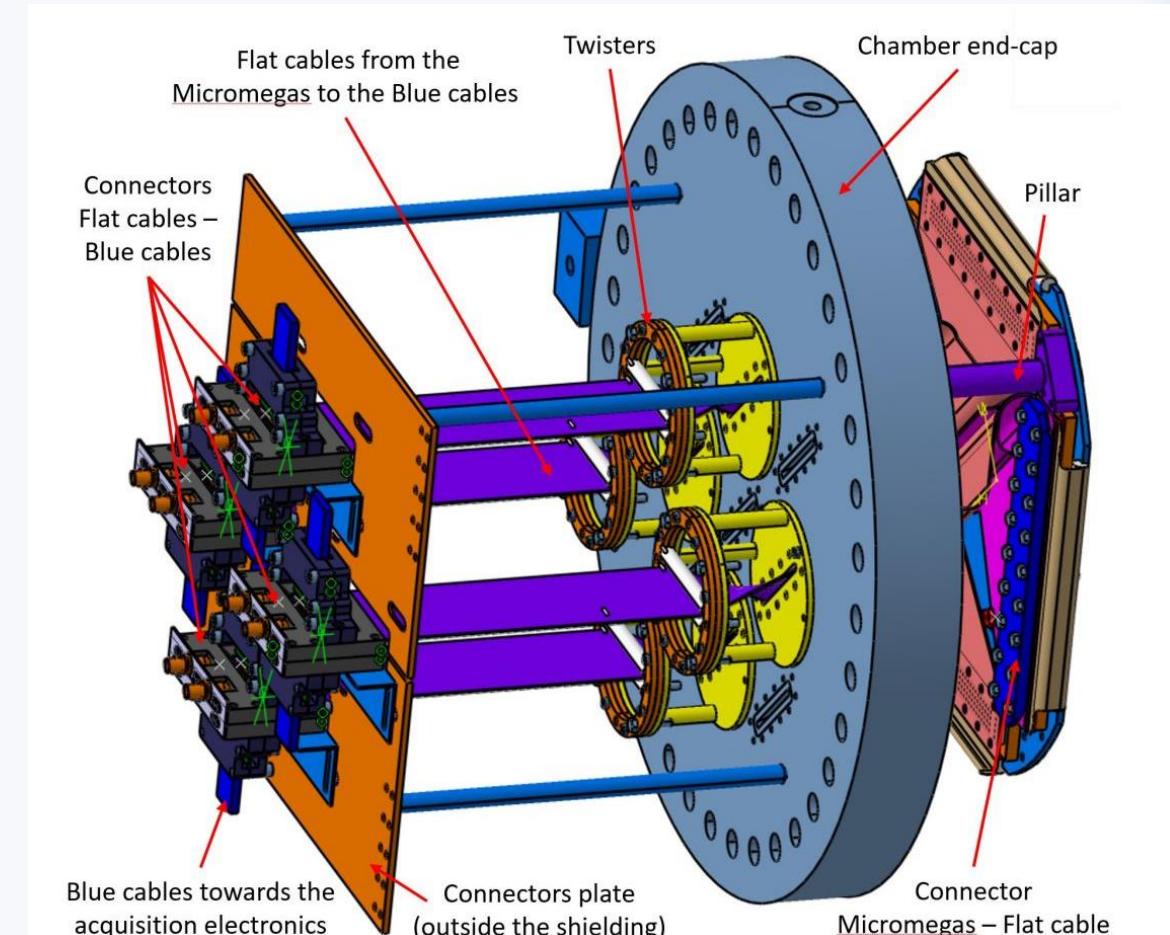
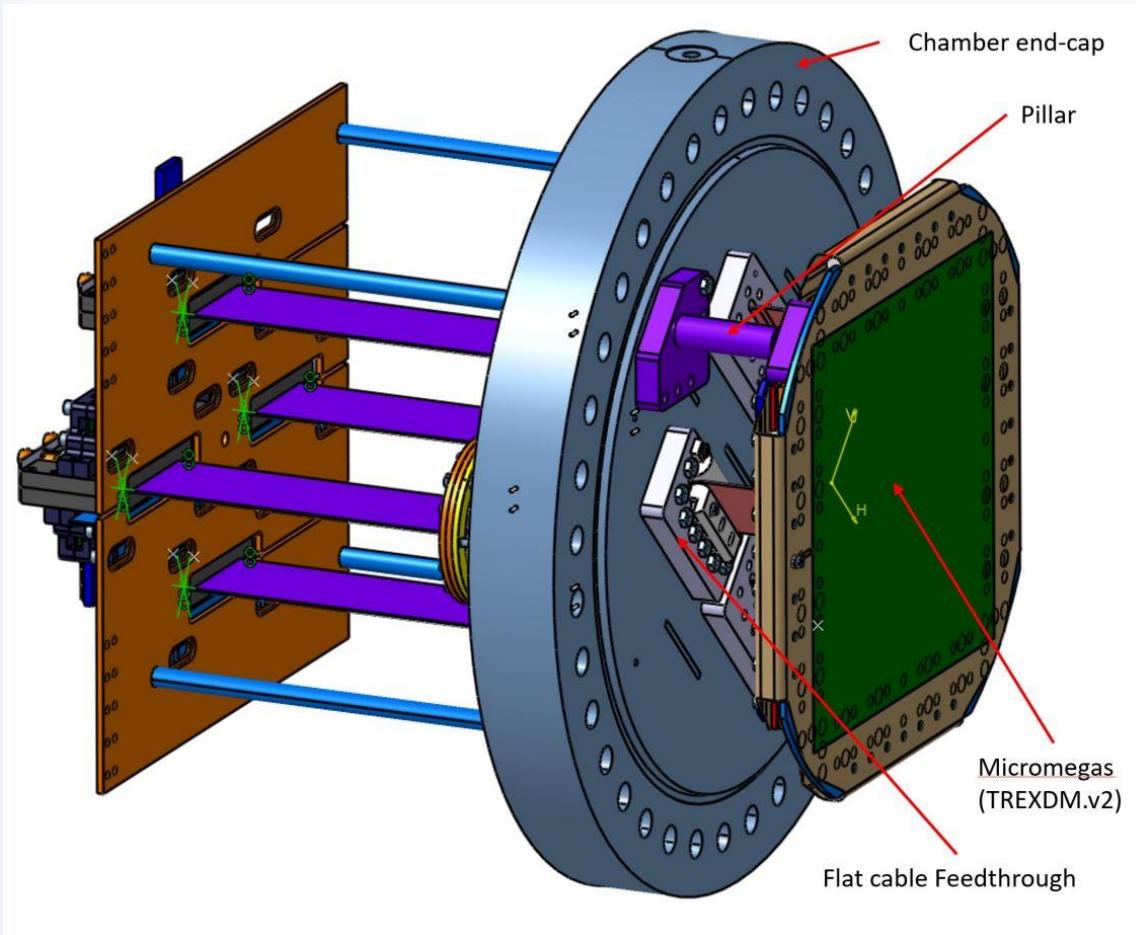
Projected sensitivity

	E_{th} (keV)	B($\text{keV}^{-1}\text{kg}^{-1}\text{d}^{-1}$)	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

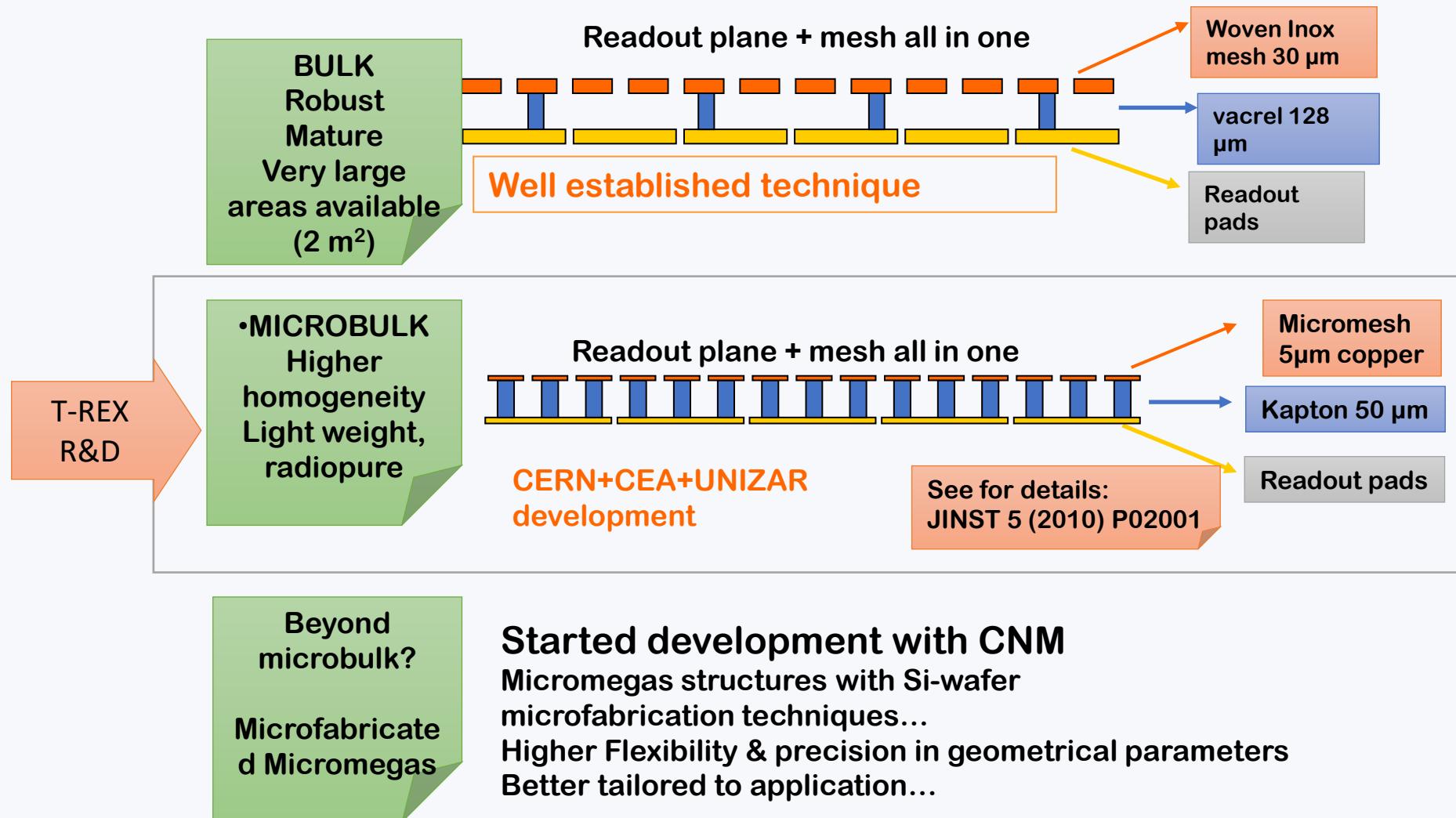


Credit:

H. Mirallas



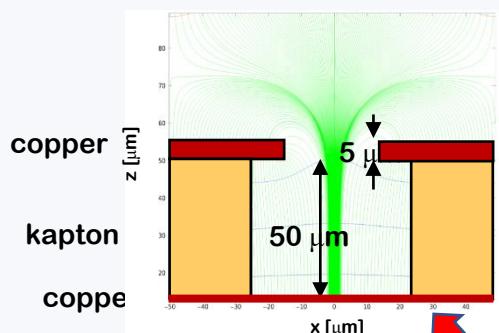
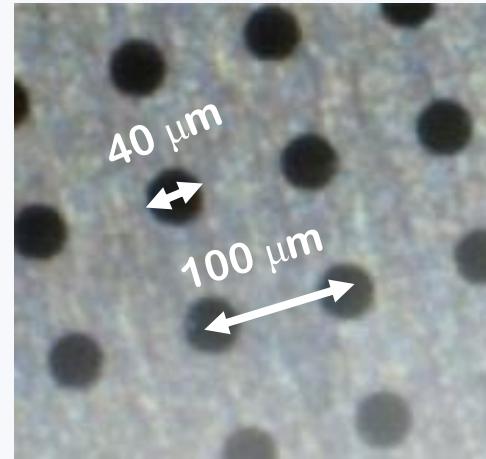
Micromegas readouts



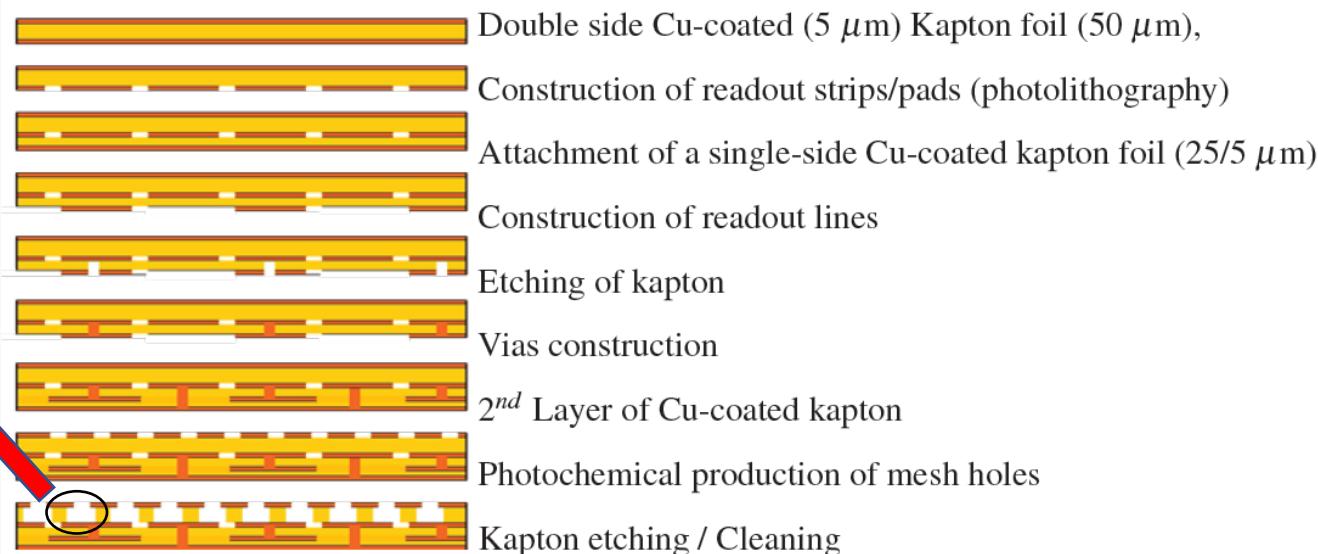
Microbulk Micromegas

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

Manufactured at Rui
de Oliveira's
workshop at CERN



See for details:
JINST 5 (2010) P02001



Background status: Rn issue

Filters in the gas system

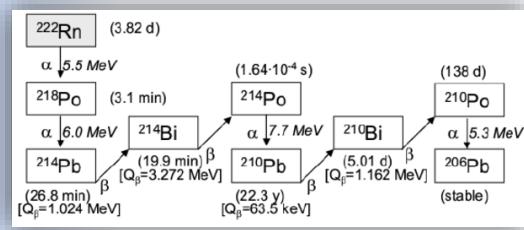


Left: H₂O; right: O₂



Background status: Rn issue

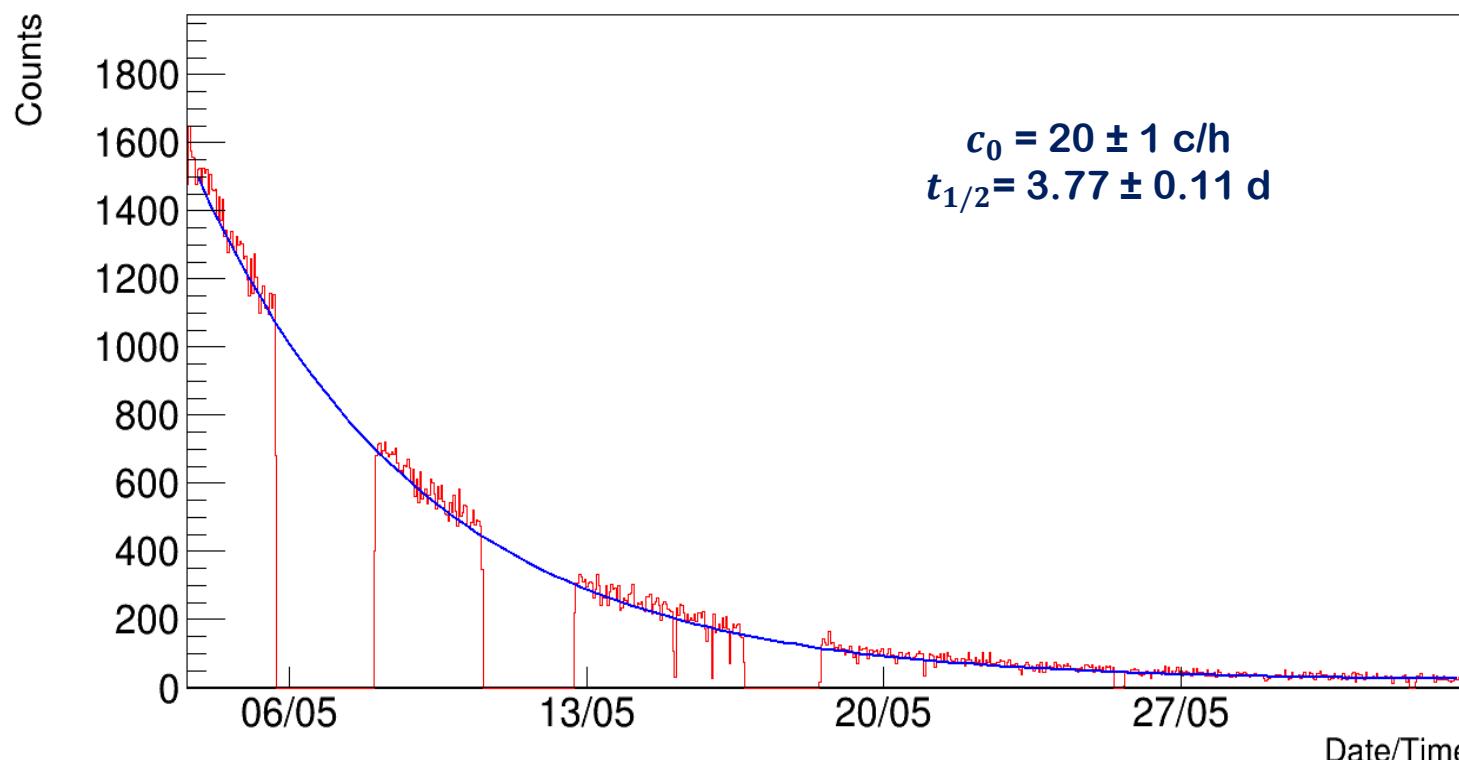
- LE and HE runs during 1 month in seal mode
- They supported the hypothesis of Rn + constant component: decrease in alpha rate and background rate in 0-50 keV after cuts



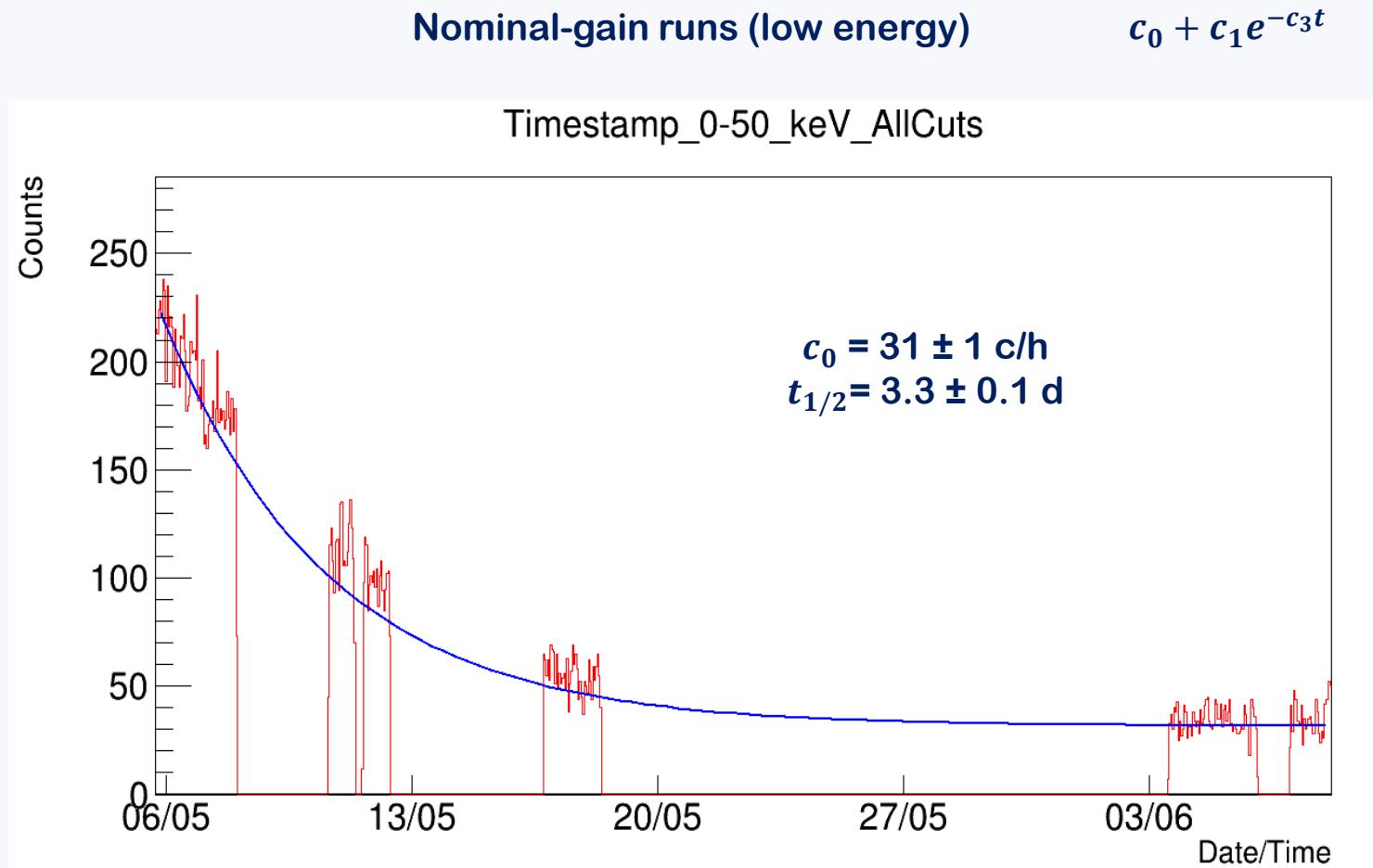
Low-gain runs (alphas)

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

Timestamp_HECuts

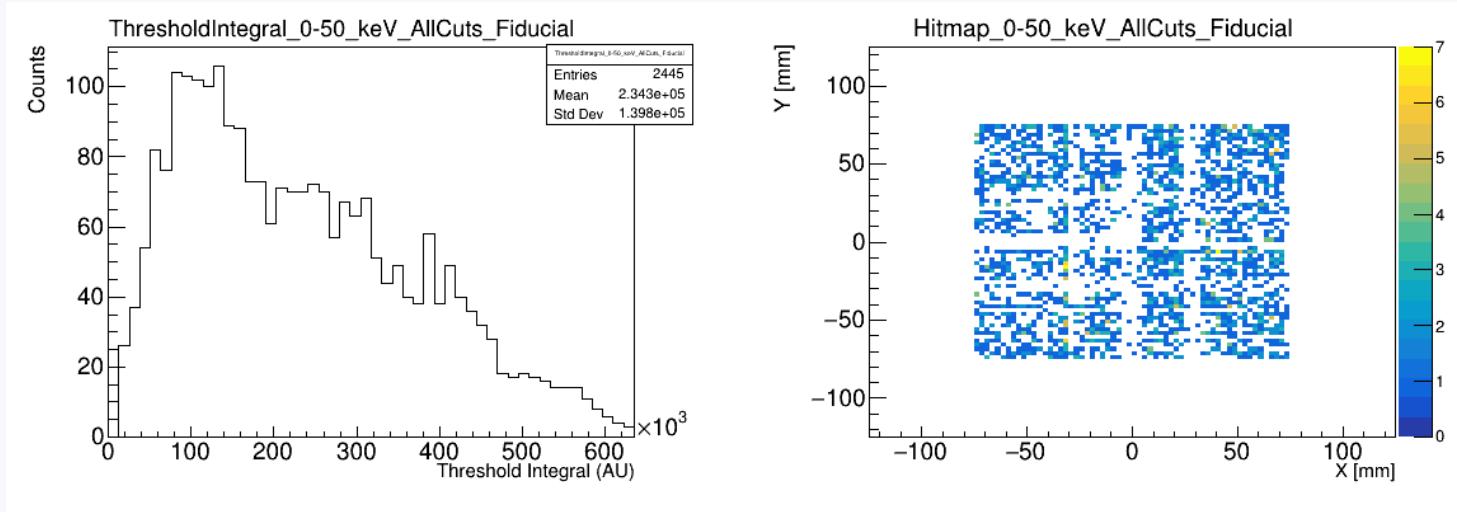


Background status: Rn issue

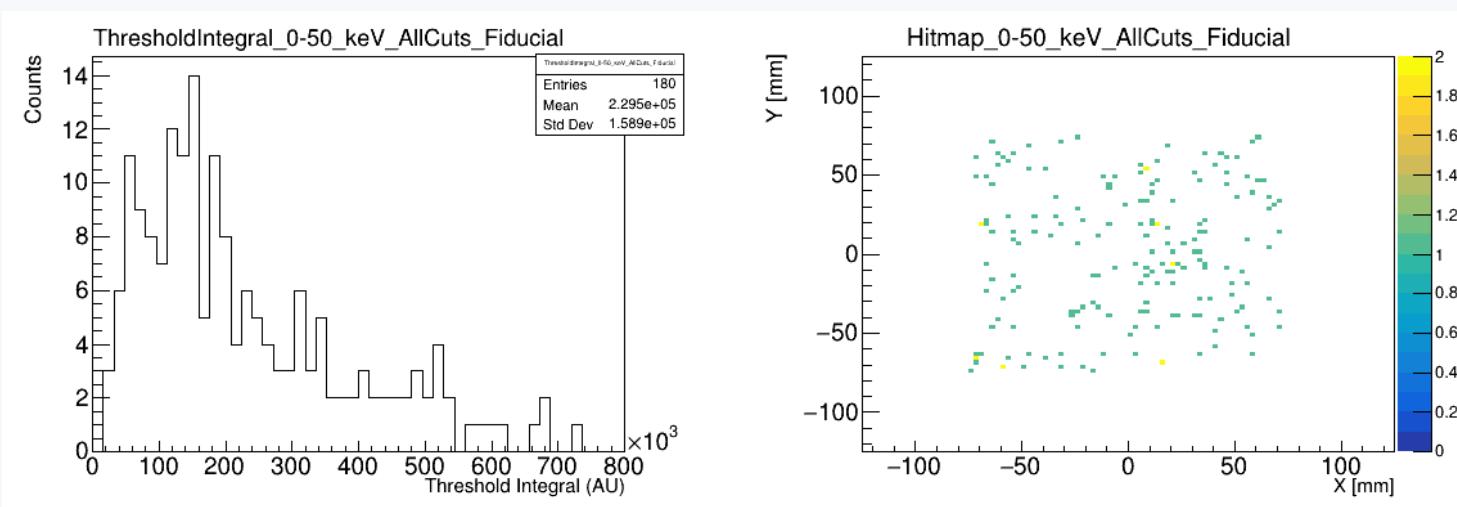


Background status: Rn issue

Background @ low energies



Before Rn decay
 $0\text{-}50 \text{ keV} \rightarrow 600 \text{ dru}$

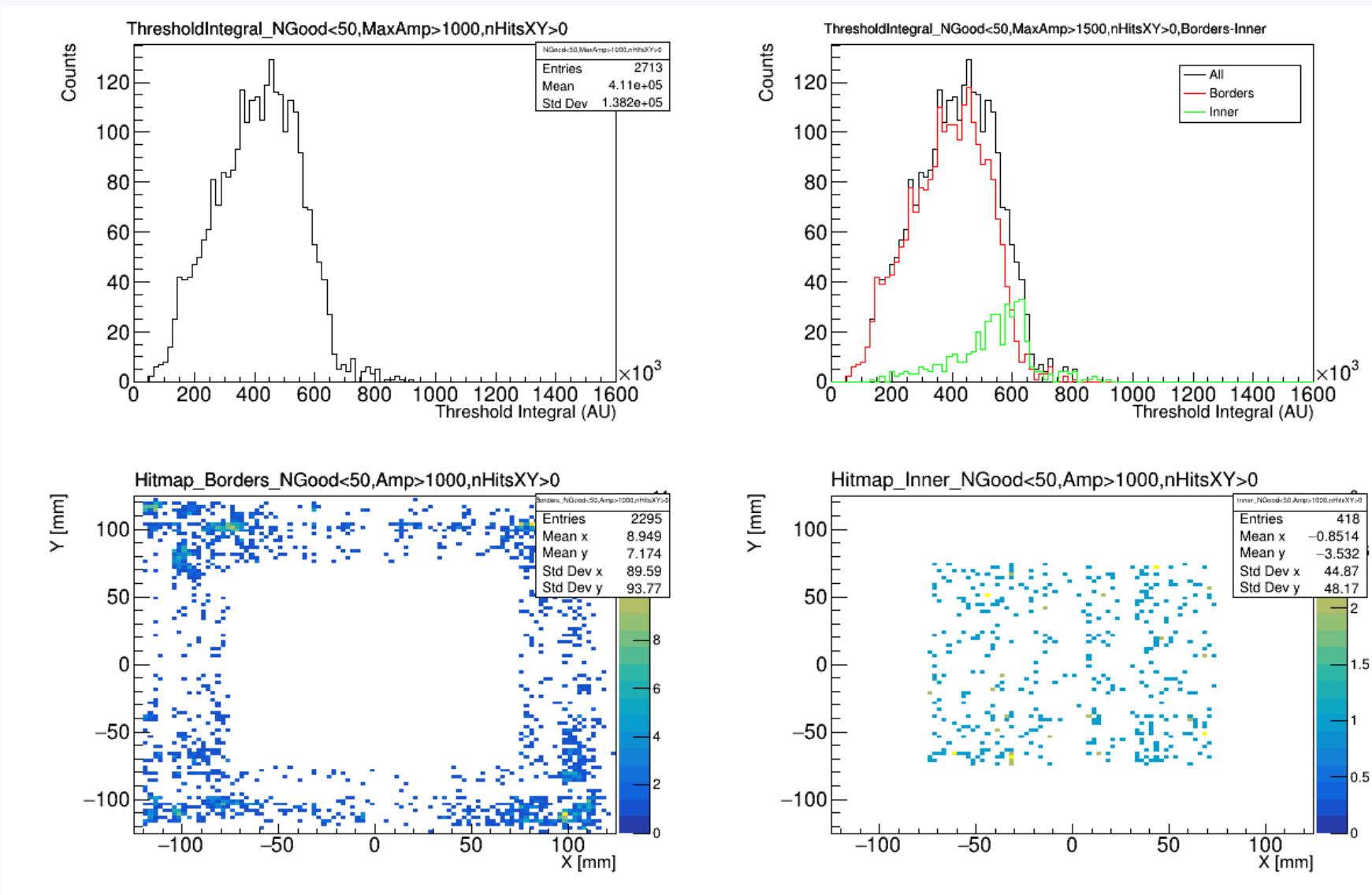


After Rn decay
 $0\text{-}50 \text{ keV} \rightarrow 100 \text{ dru}$

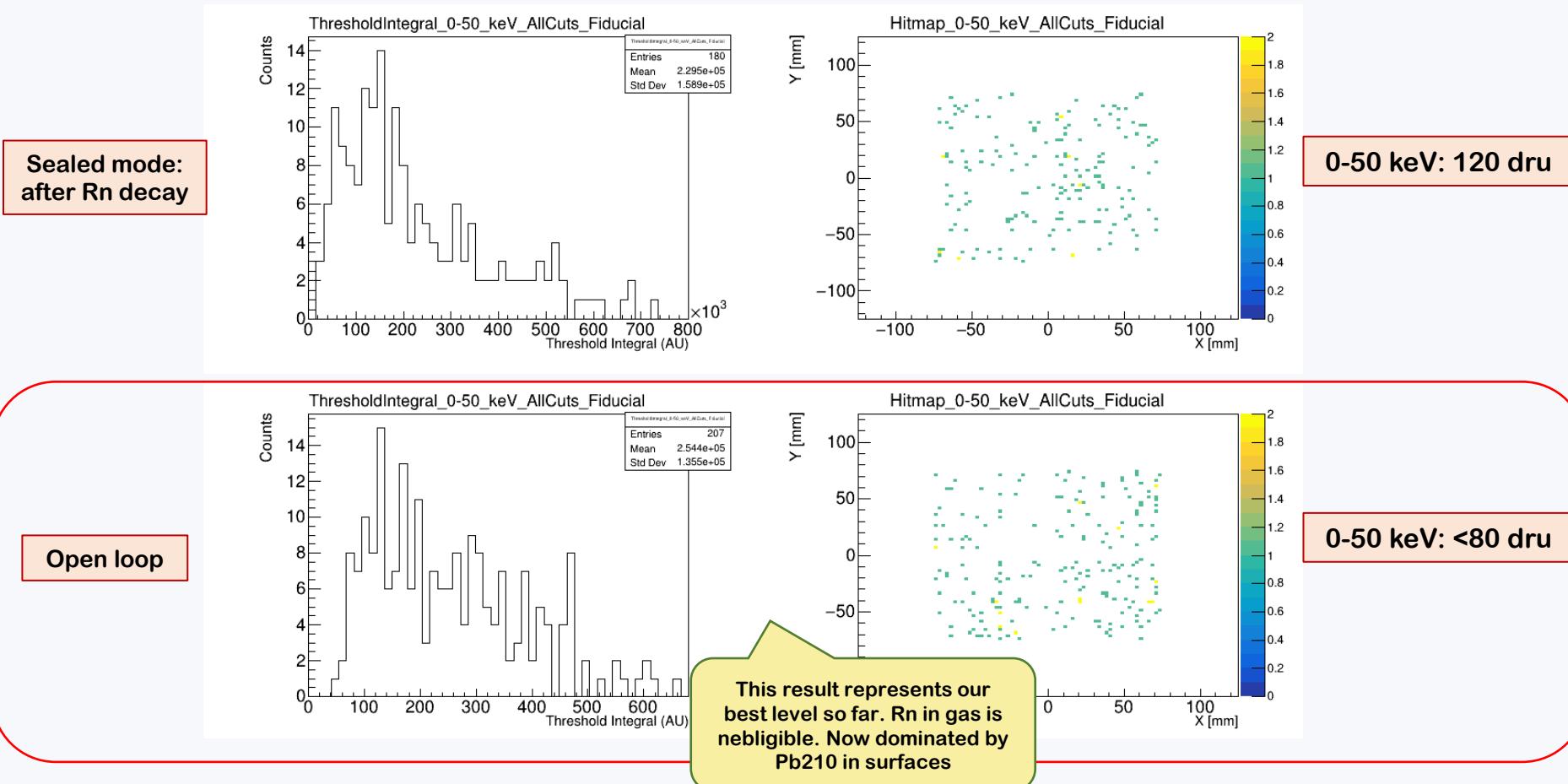
Background status: Rn issue

- 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

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

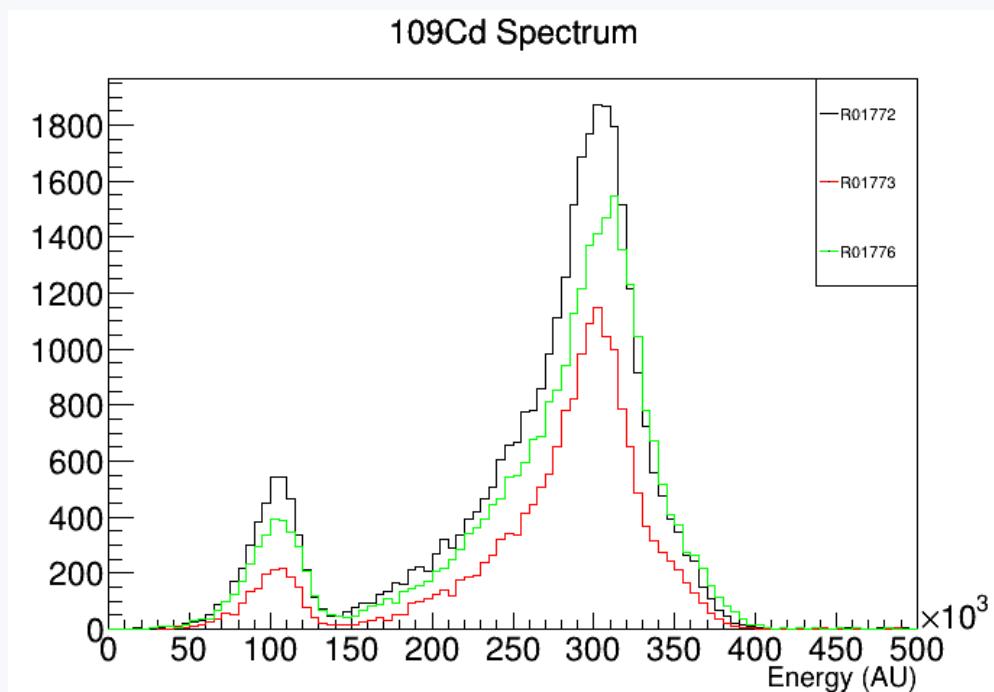


Background level comparison: seal mode in June 2021 vs. open loop



Flow optimisation in open loop: ^{109}Cd calibrations

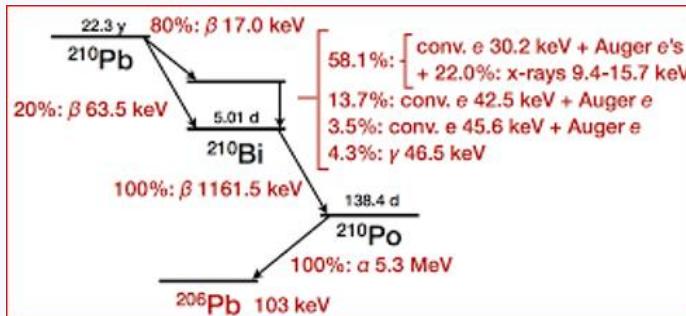
0.9 ln/h \Rightarrow one renovation every 11.5 days



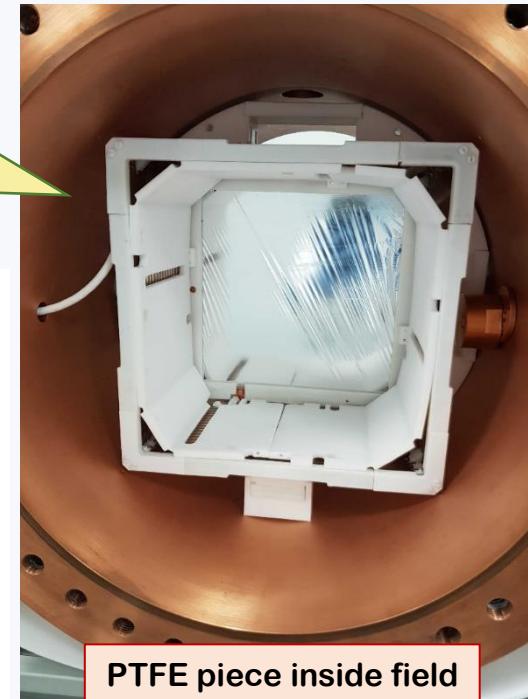
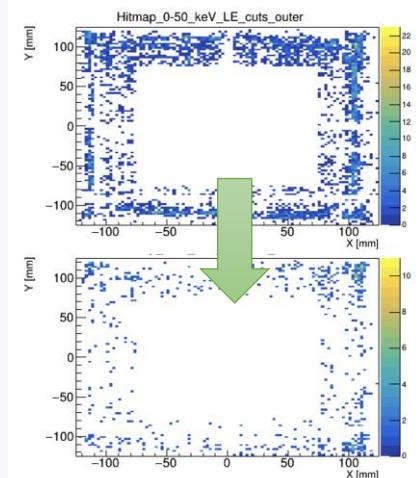
Calibrations after 0, 1 and 2 weeks at 0.9 ln/h \Rightarrow gas is clean with this flow

Surface alphas (Rn progeny)

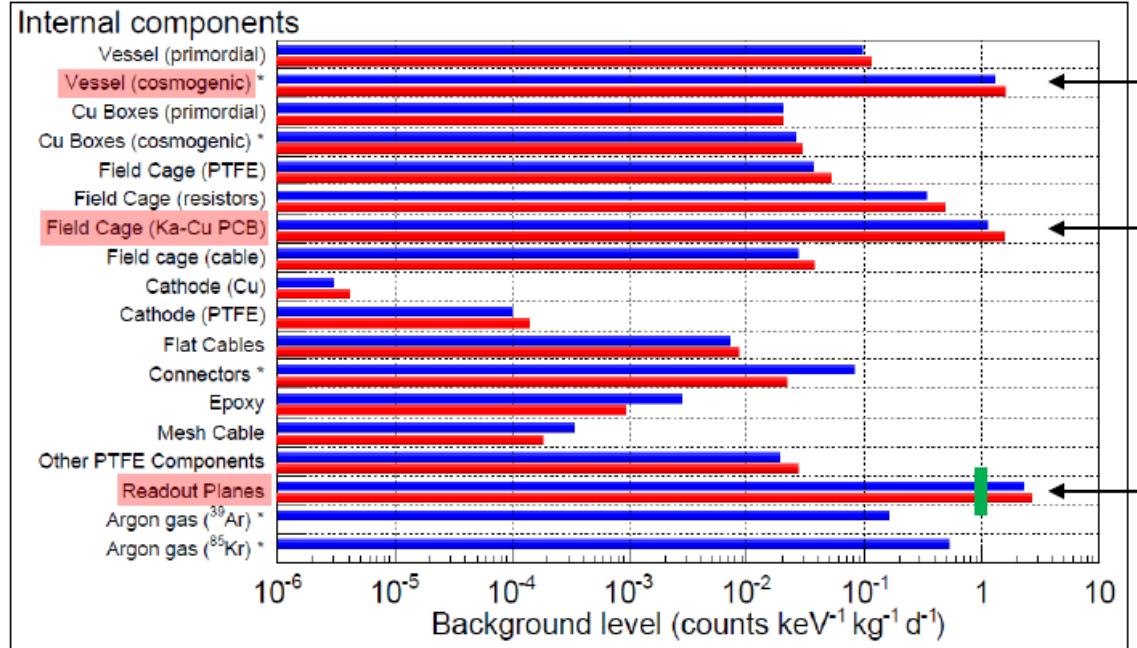
- Rn progeny (Pb210) attached to surfaces (from past exposure) produces alpha events, but also LE events (in similar proportion)



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



Challenges: Background level reduction



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

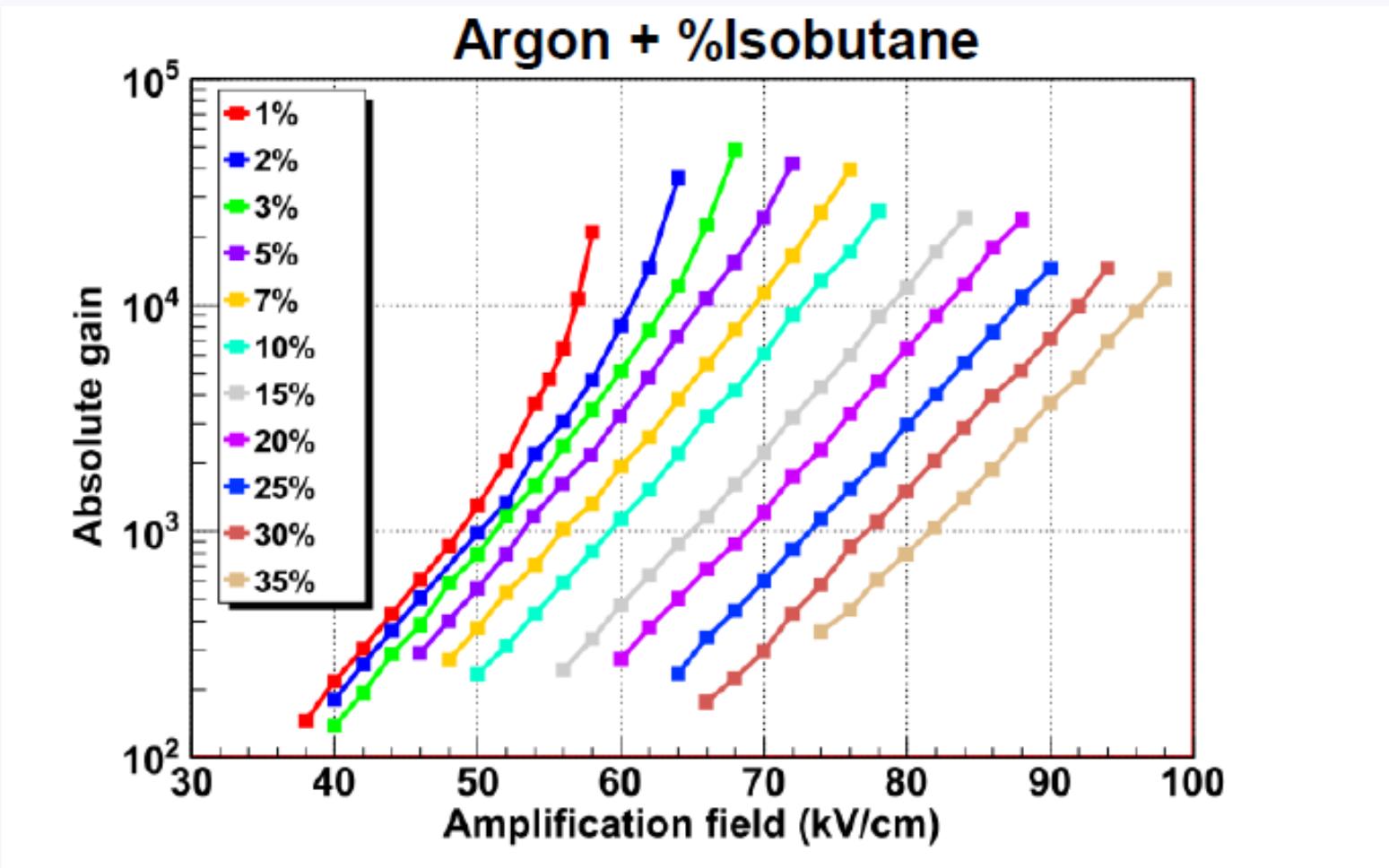
New design on going.

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



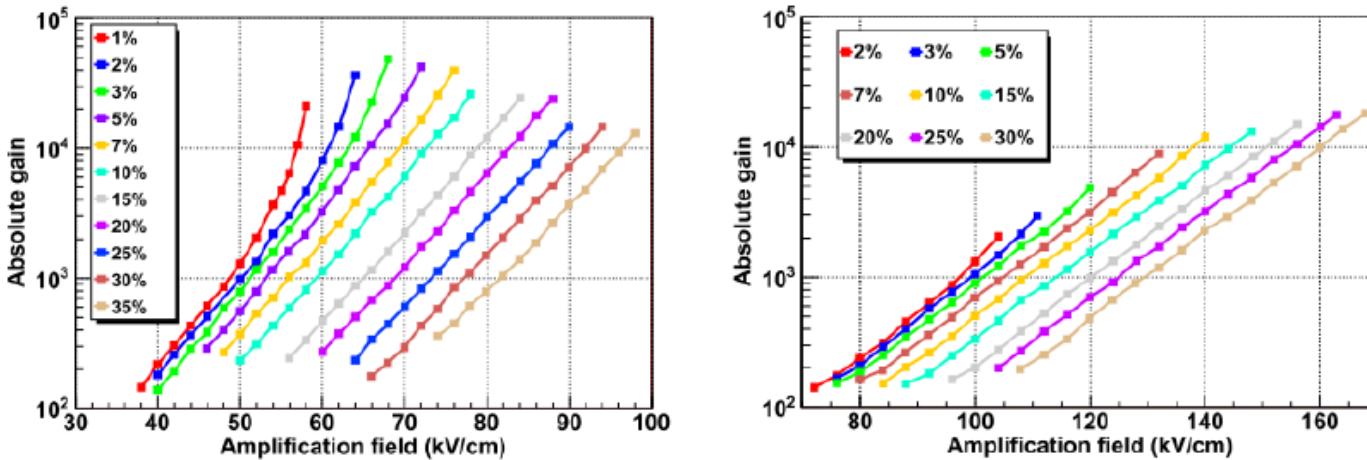


Figure 6. Dependence of the absolute gain with the amplification field for two microbulk detectors with gaps of 50 (left) and 25 μm (right) in argon-isobutane mixtures. The maximum gain of each curve was obtained just before the spark limit. The percentage of each series corresponds to the isobutane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

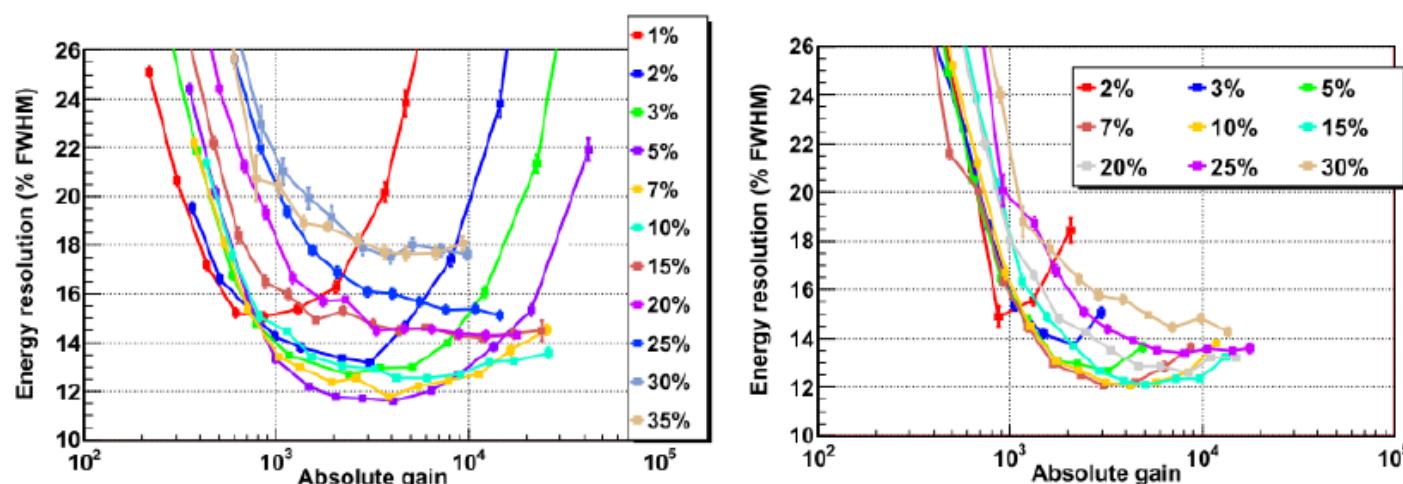


Figure 7. Dependence of the energy resolution with the absolute gain for two detectors of 50 (left) and 25 μm -thickness-gap (right) in argon-isobutane mixtures. The maximum gain of each curve was obtained just before the spark limit. The percentage of each series corresponds to the isobutane concentration.