Rare events searches and gaseous detector developments at CAPA

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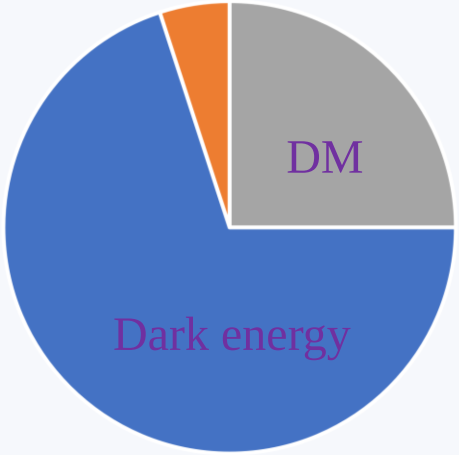
CAPA activites

- CAPA: Centre for Astroparticle and High Energy Physics
- Research lines:
  - **Low background techniques and detector development**
  - Dark matter, axion physics and neutrino physics
  - Lattice gauge theory and field theory applications
  - Standard Model extensions and quantum gravity
  - Observational astrophysics and cosmology



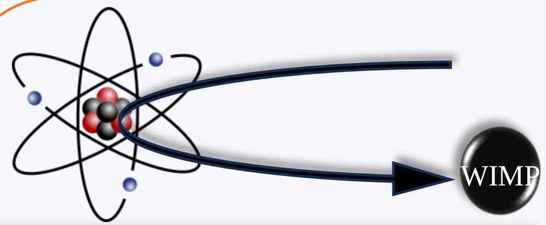
Universe pie

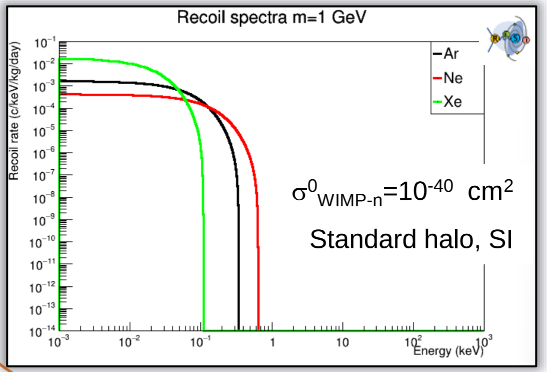
CAPA activites

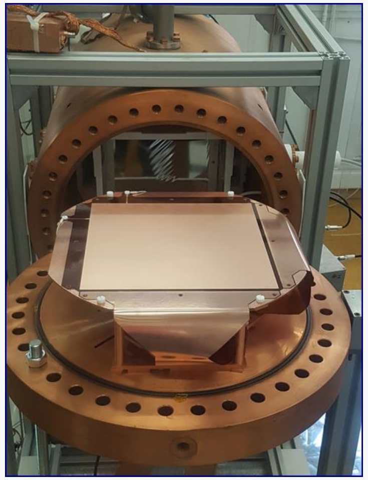
- CAPA: Centre for Astroparticle and High Energy Physics
- Research lines:
  - **Low background techniques and gaseous detector development**

non-gaseous (ANAIS) in Ivan's talk

Low-mass WIMPs



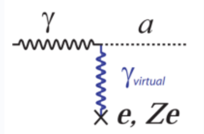


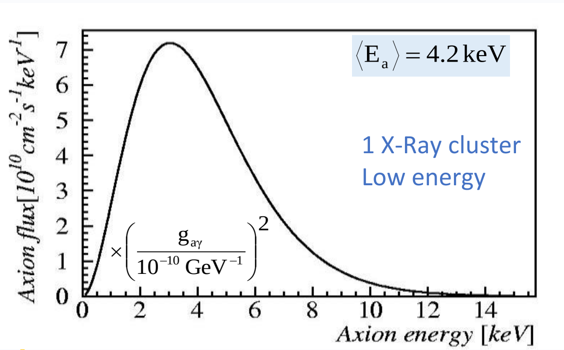


TREX-DM

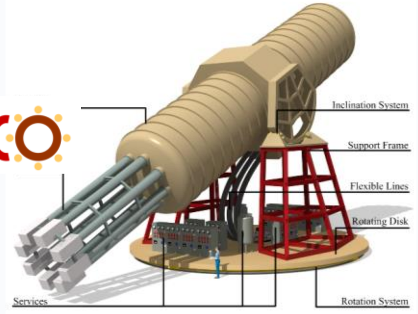
Solar Axions

Primakoff

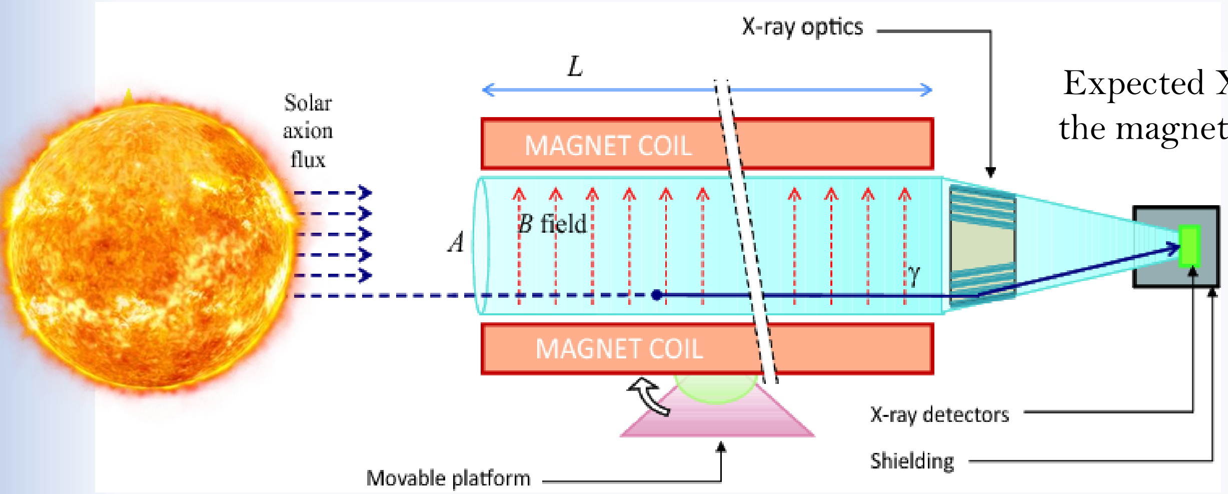




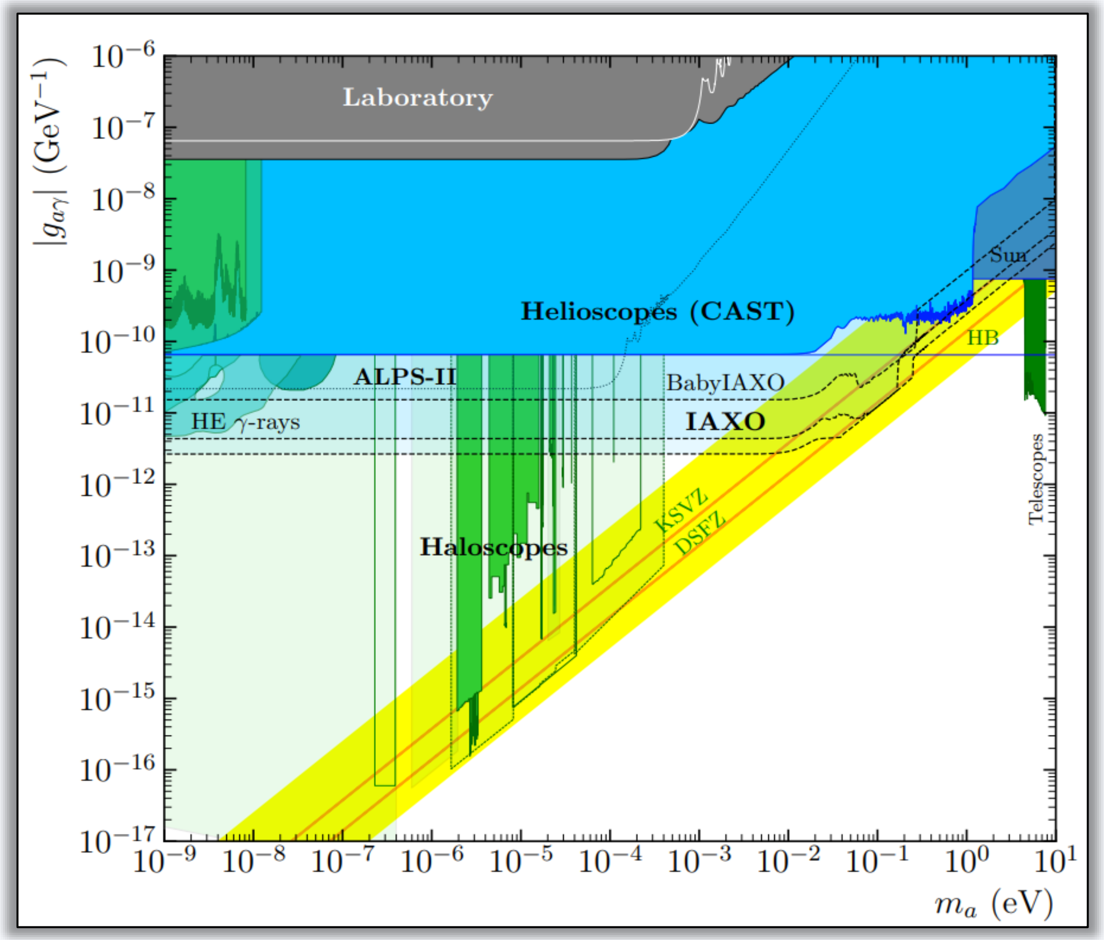
CAST



IAXO helioscope



Expected X-ray excess when the magnet points to the Sun.

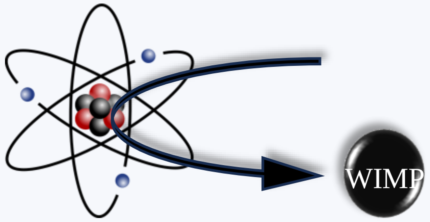


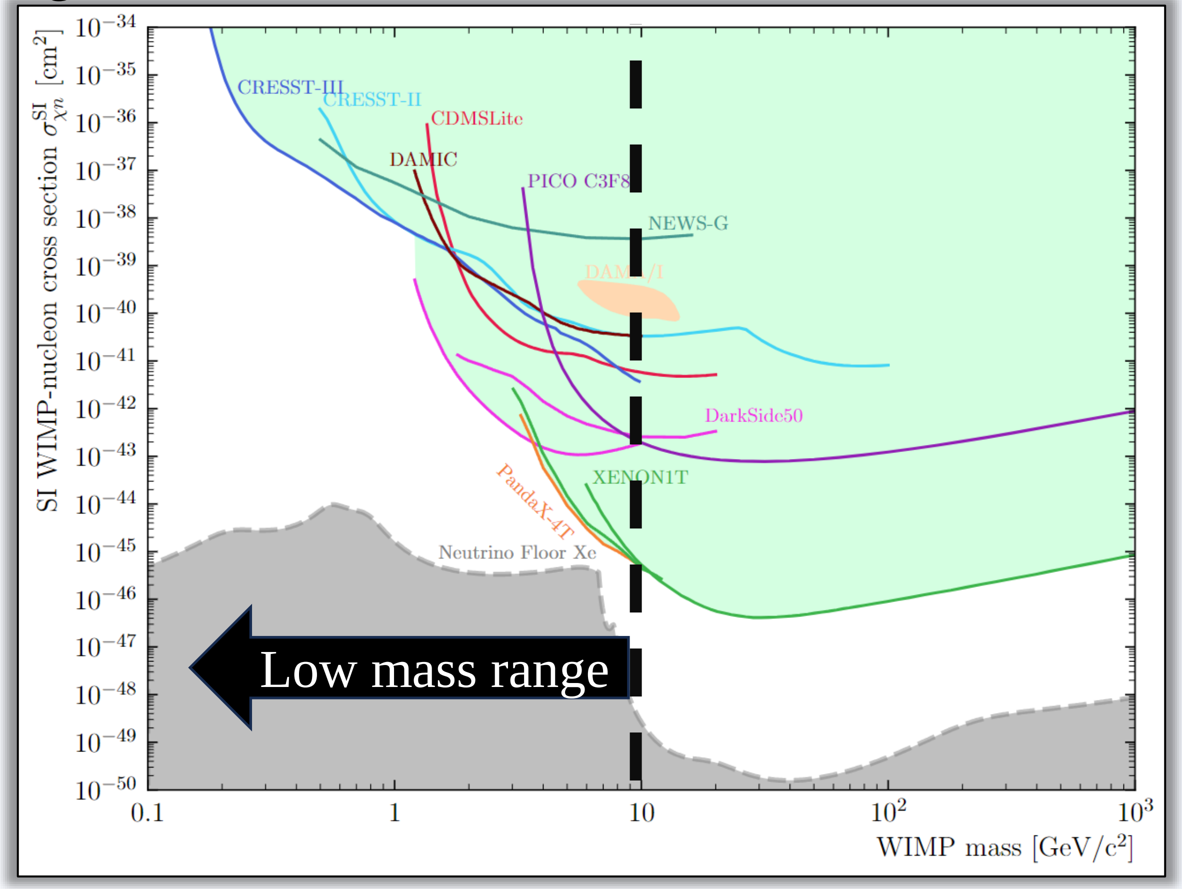
Sensitivity parameters:

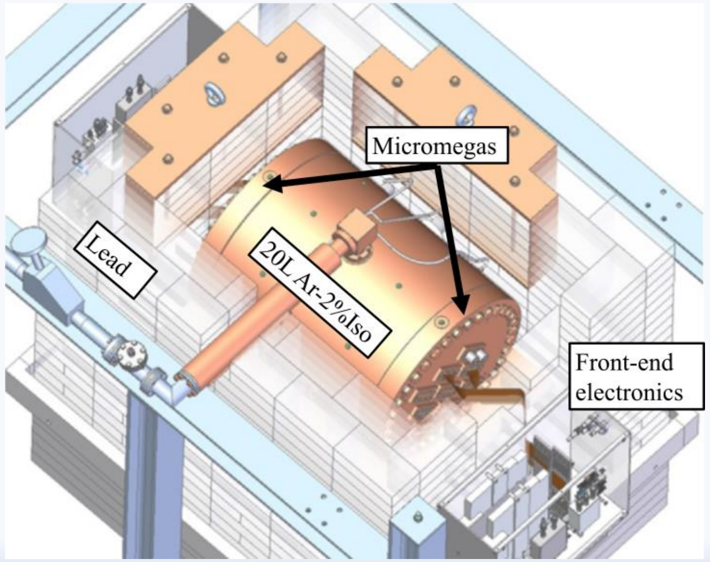
- Magnet
  - Magnetic field
  - Length
- Optics
  - Efficiency
  - Area of the focused spot
- Detector
  - Efficiency
  - Background level
- Time tracking the sun

TREX-DM experiment

- Gaseous TPC of cylindrical copper vessel
  - Active volumen of 20L up to 10bar
  - Copper, lead, polyethylene ceiling&water shielding
- Located at LSC (2400 m.w.e.)
- Goal:
  - Low energy threshold < 1 keV
  - Low background level ~1 (keV kg day)$^{-1}$.

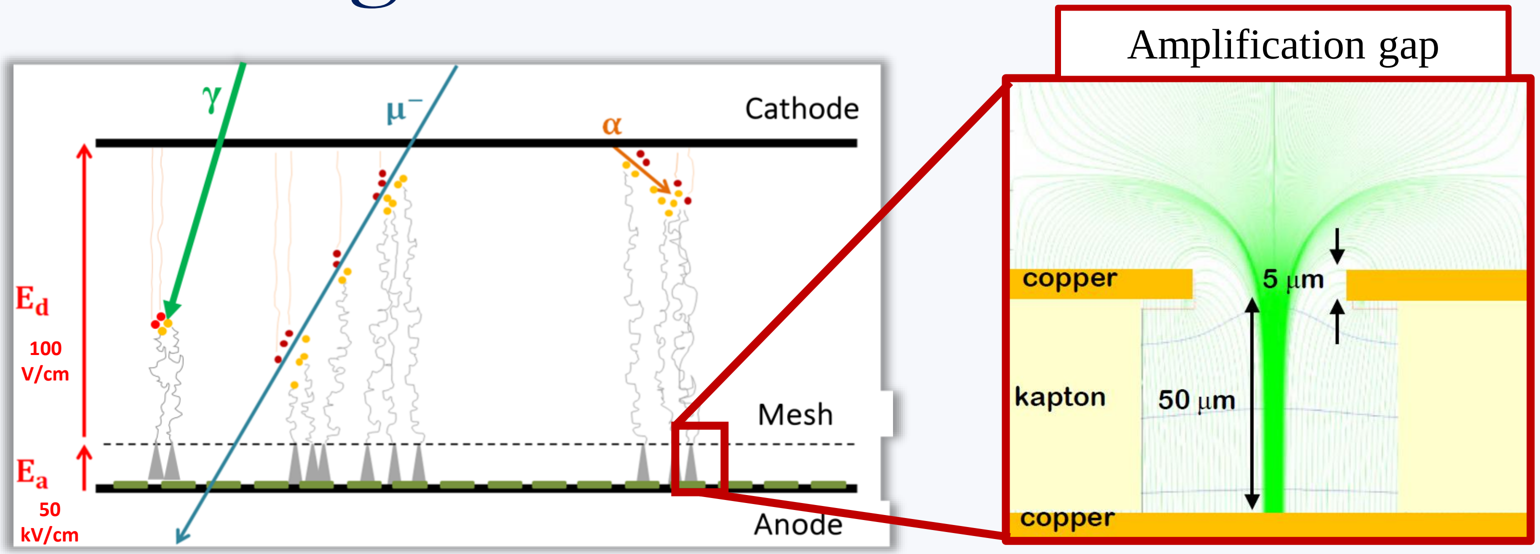




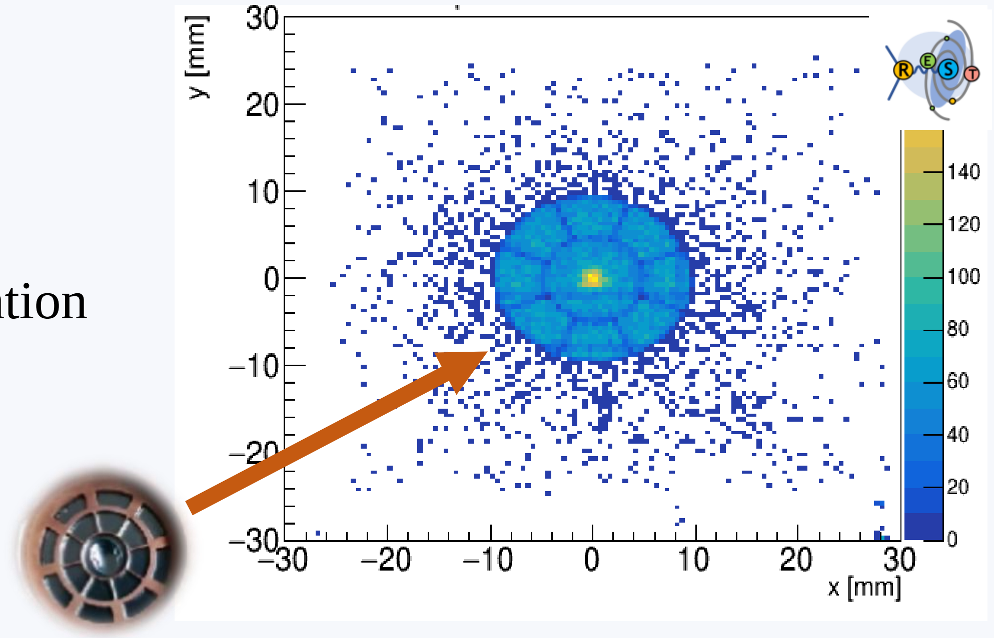


Micromegas detector

- Readout plane for gaseous Time Projection Chamber
- Low intrinsic radioactivity
- Absolute gain 10^3-10^4



- Topological information



IAXO-D Micromegas prototypes for IAXO

IAXO detector prototype

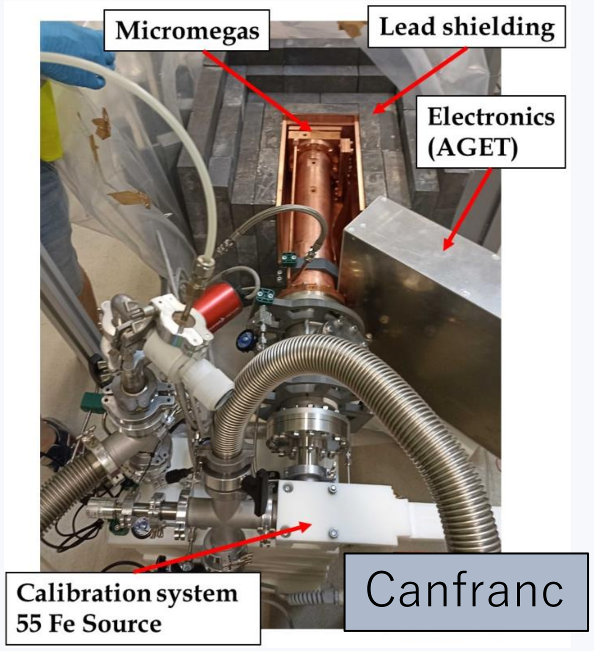
- Ar or Xe + quencher, 1.4 bar, 3cm drift
- Shielding (active & passive)

Goals

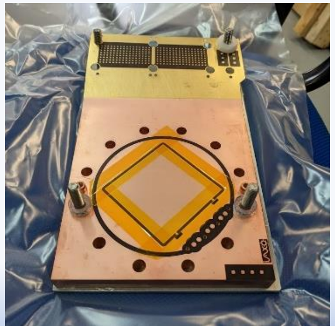
- Background level: 10^{-7}-10^{-8} counts keV^{-1} cm^{-2} s^{-1}
- Energy threshold: ~0.1 keV

Micromegas detector

- Same design as CAST XRT-MM detector
- AGET-based electronics (radiopure version planned)



6cm x 6cm
2x 124 strips
0.475mm width,
0.5mm pitch



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Achieved !!
(preliminary)

Micromegas detector

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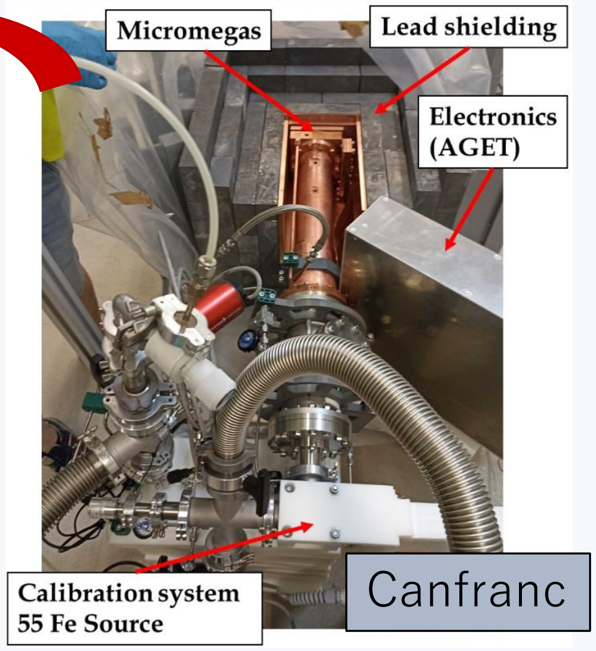

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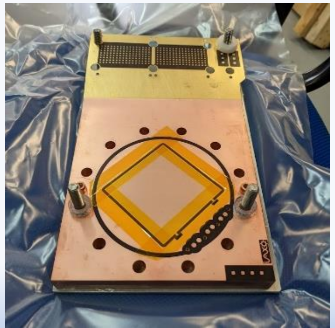
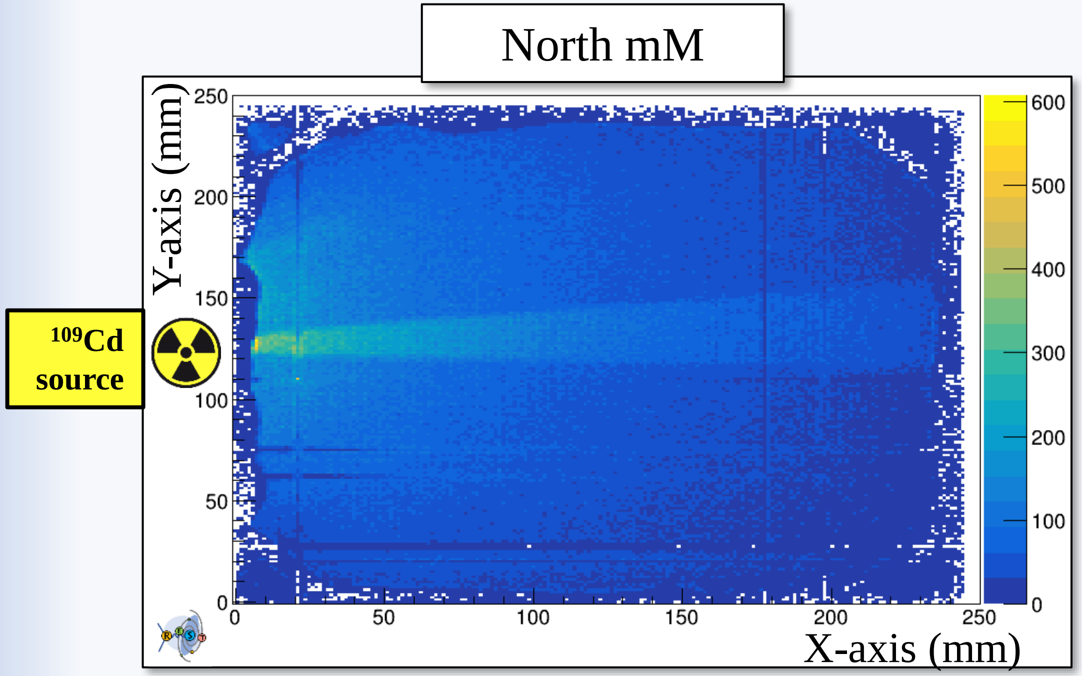
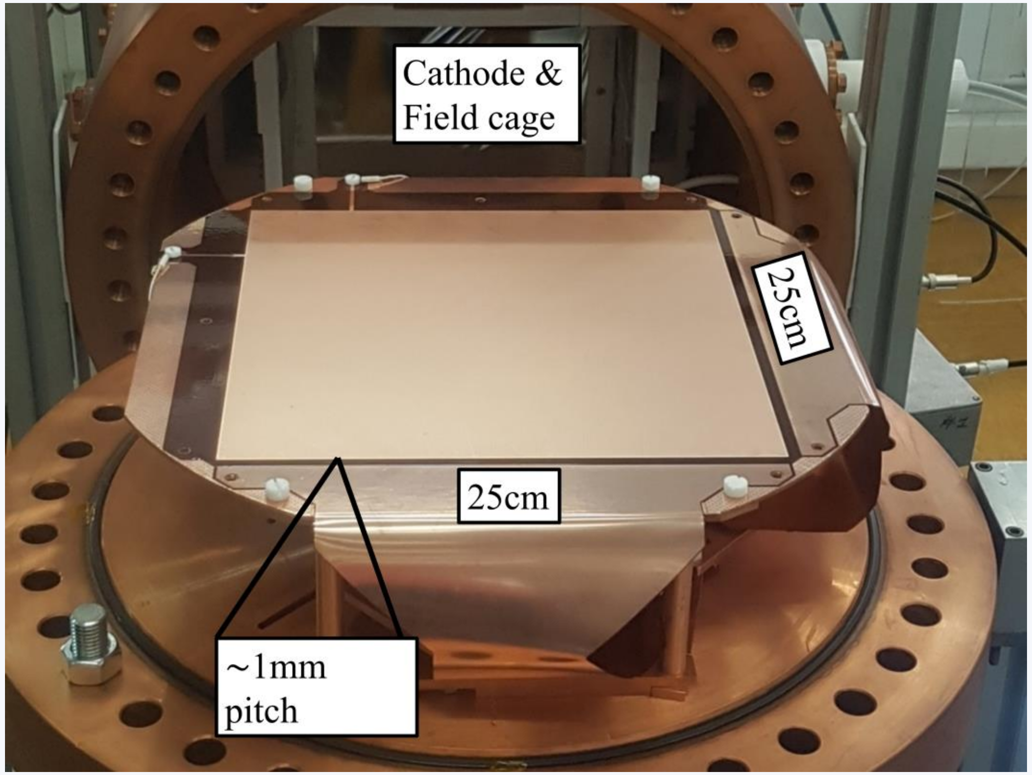


TREX-DM Micromegas

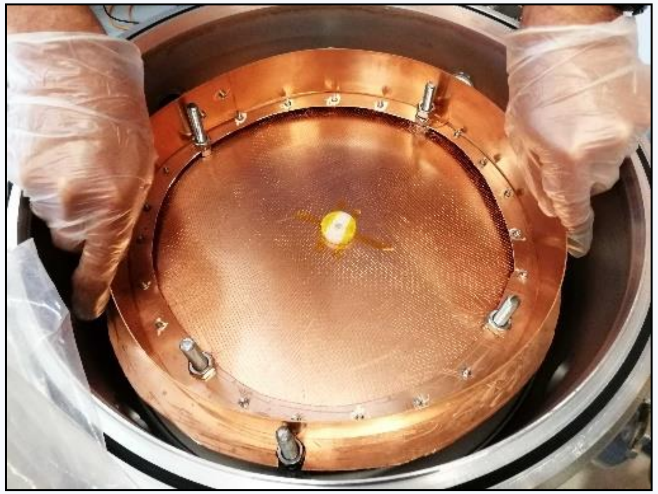
- 1 cathode and 2 readout planes
- Largest surface produced (*micro-bulk*) Micro-Mesh Gaseous Structure (**Micromegas**)
  - 512 channels: 256 X strips, 256 Y strips

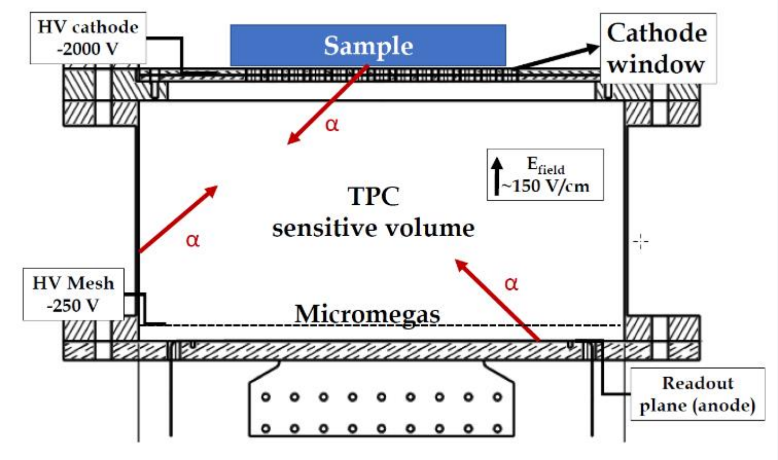




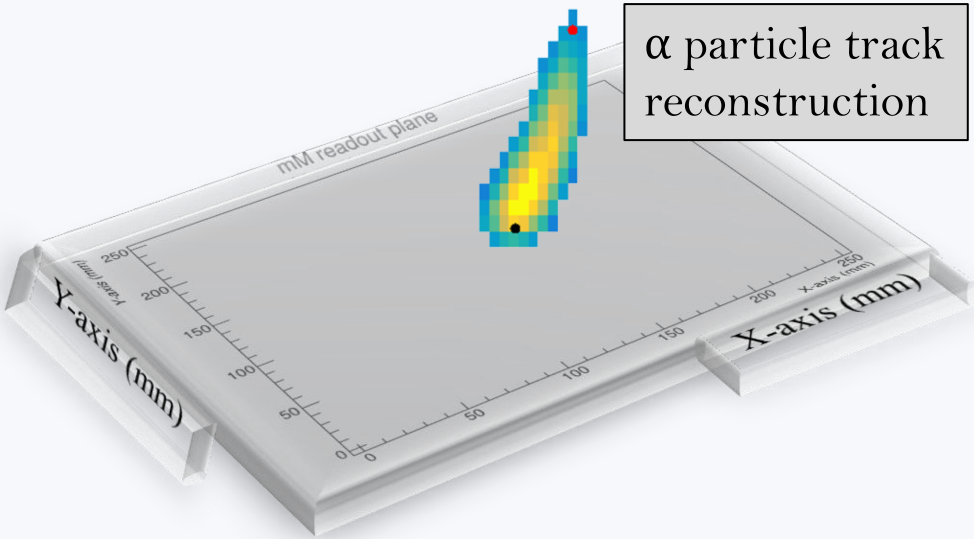
AlphaCAMM (Alpha CAMera Micromegas)

- Gaseous TPC with a segmented mM (25cm x 25cm)
- Measure ^{210}Pb surface contamination of flat samples down to 100 nBq/cm^2
- Track reconstruction (origin and end) allows to identify the alphas coming from the sample



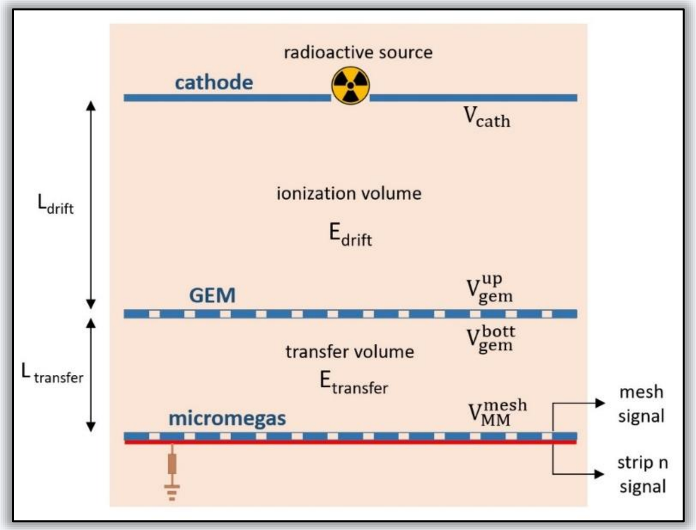


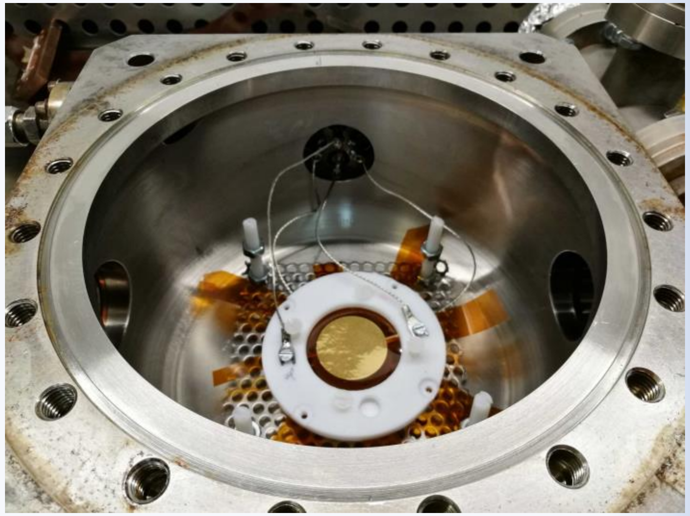
K. Altenmuller et al, 2022 JINST 17 P08035



Micromegas + GEM

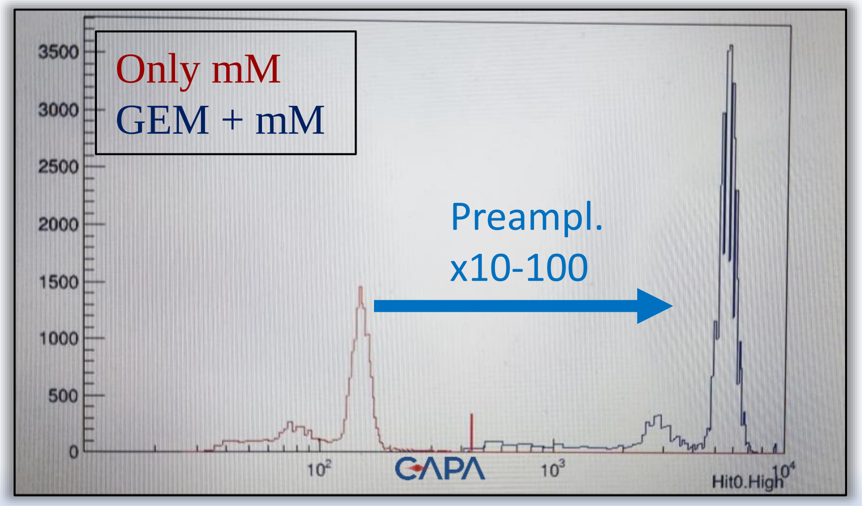
- Improve gain by adding a Gas Electron Multiplier **(GEM)** amplification stage on top of the Micromegas planes
  - ➢ increase signal-to-noise ratio

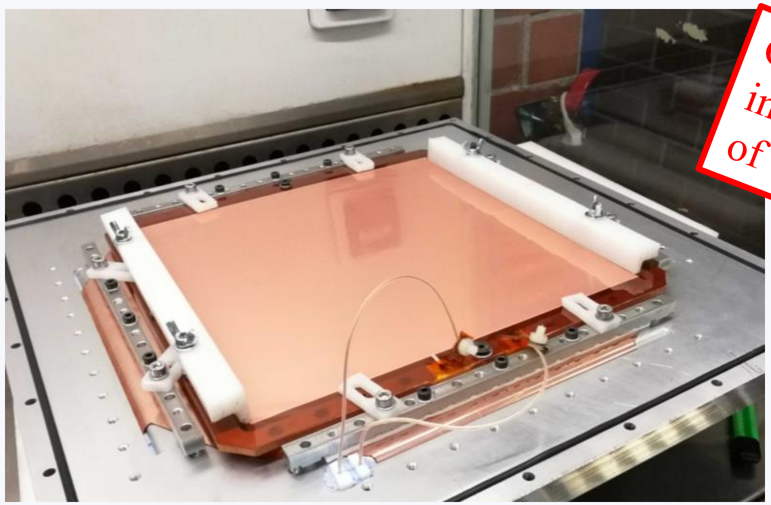




- Preliminary results in test set-up shows x10-100 extra amplification factor

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





GEM already installed at Left side of TREX-DM !!!

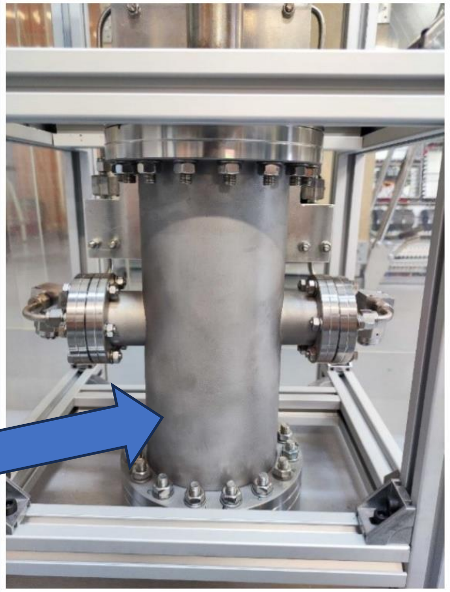
Low energy calibration (^{37}Ar)

- ^{37}Ar: 2.8 keV (90%), 0.27keV (9%)

- Gas source → homogeneous illumination

- Irradiated CaO powder at CNA (Sevilla)
  - 6 hours
  - ~ 1 kBq

40Ca



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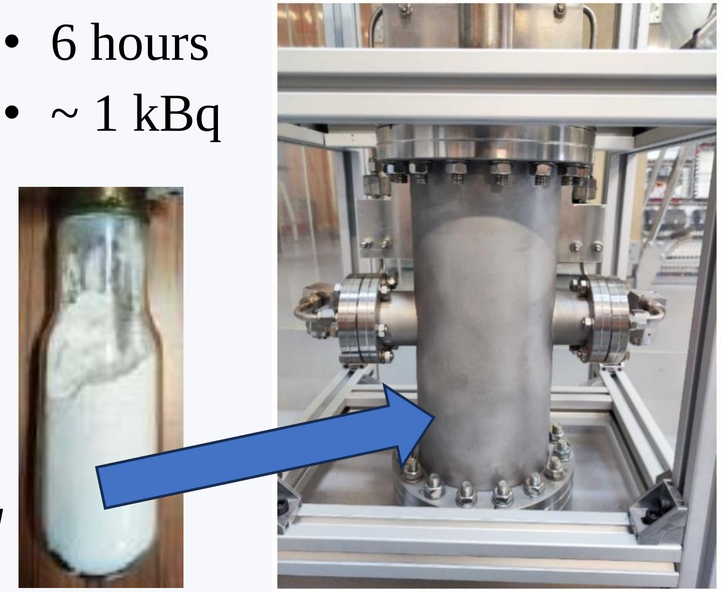
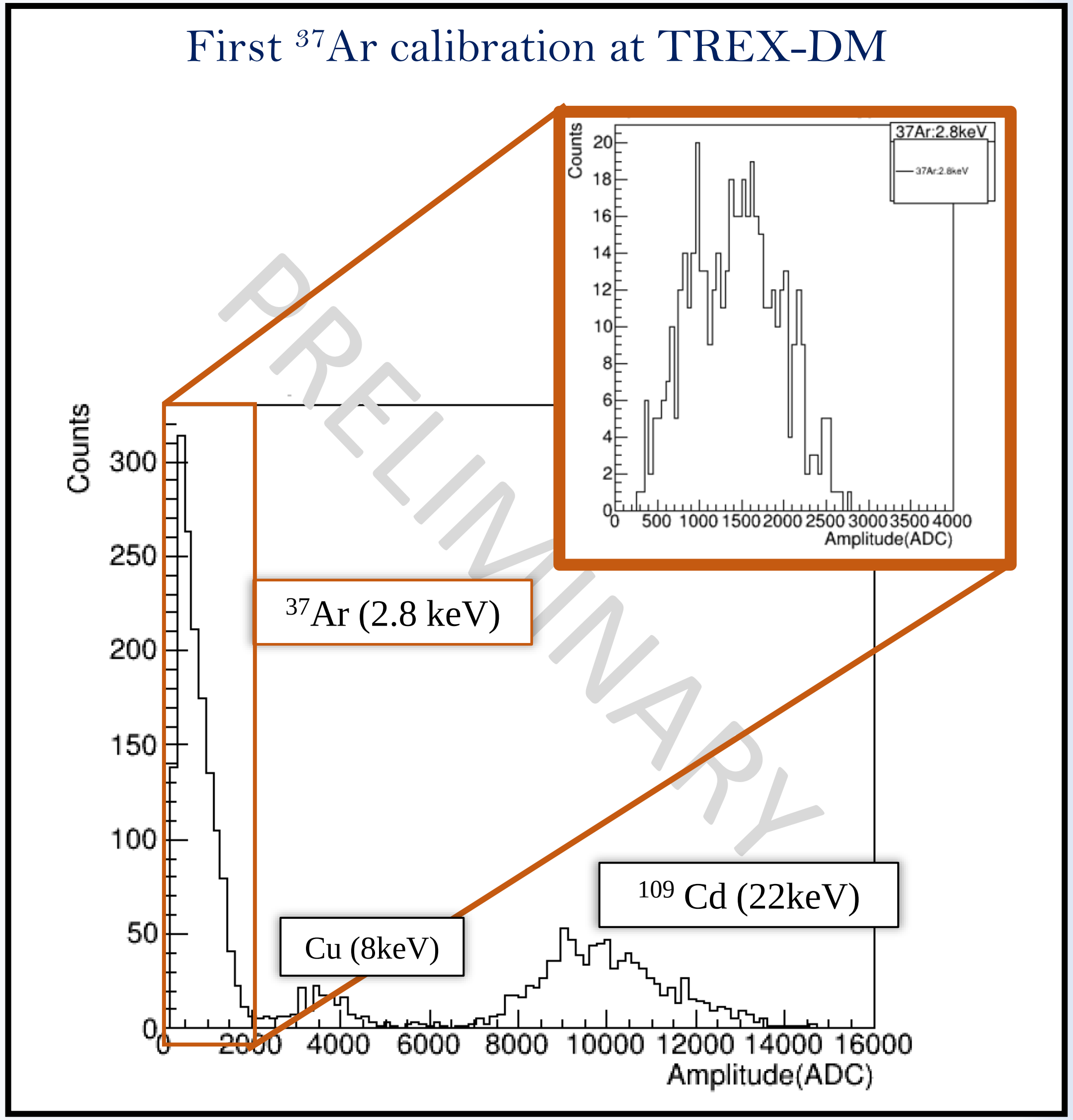




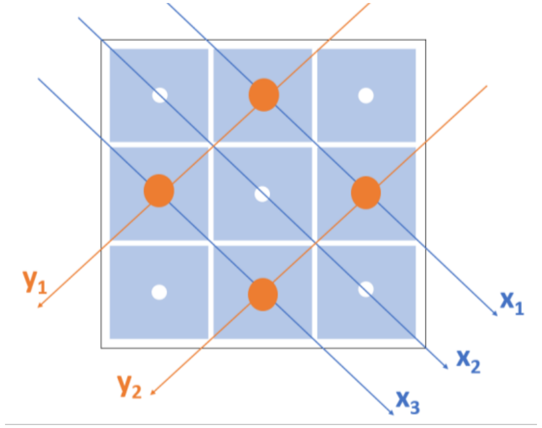
Segmented mesh

✓Simpler construction process

✓Less material budget

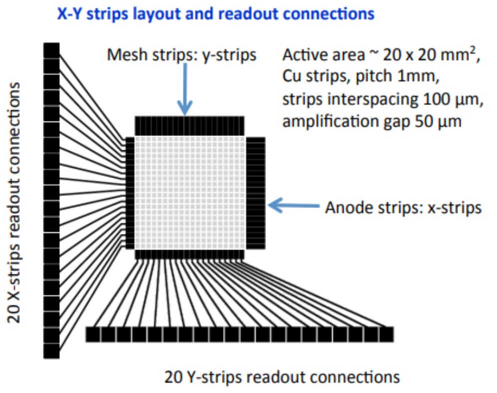
✓Better spatial resolution

❖Dedicated electronics to power the channels of the mesh and read the signal

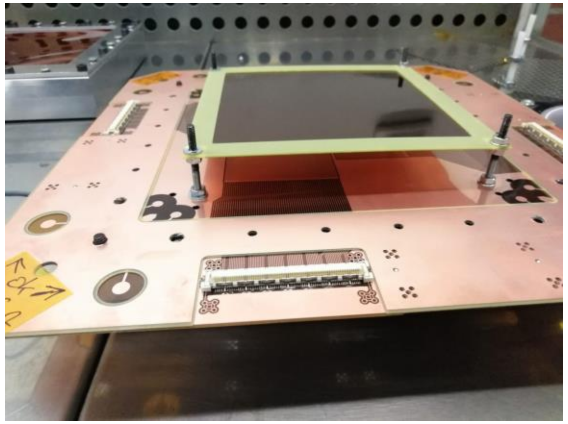


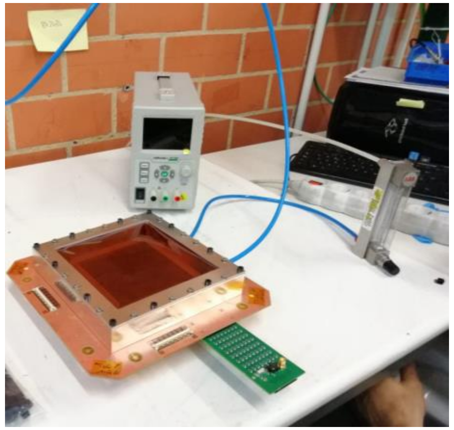
mM (microbulk)

vs.



Segmented mesh (microbulk)

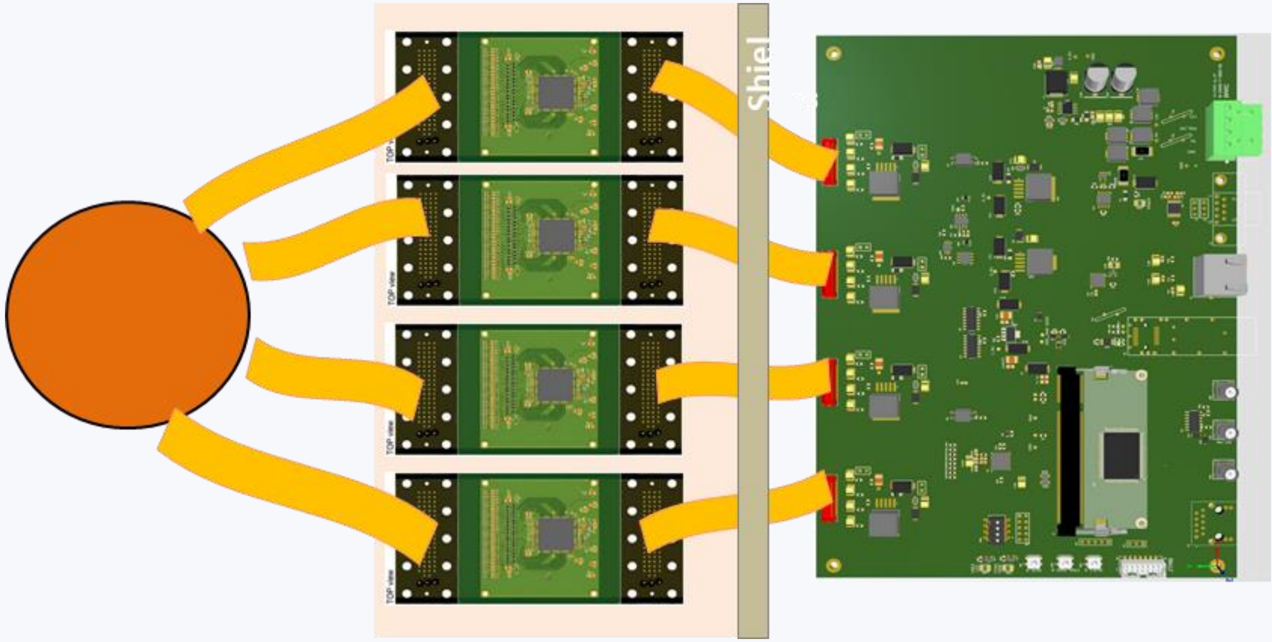


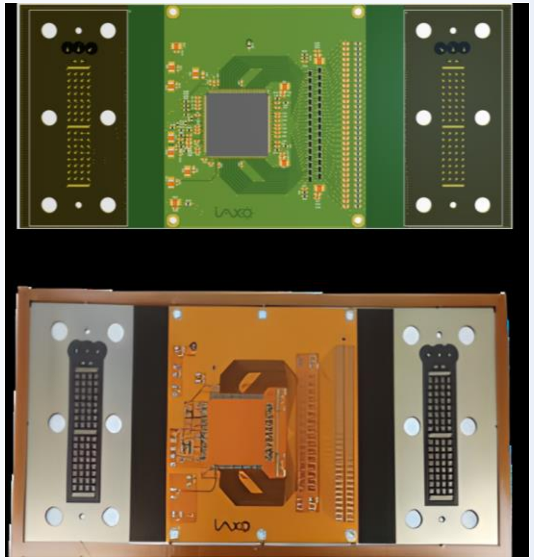


Set up ready for testing

Radiopure electronics

- Usually readout electronics outside the shielding
  - Longer cables, higher noise/threshold
- Development of radiopure FE boards
- Complementes with non-radiopure BE





✓ Limandes mM-FEC

✓ FEC PCB
❖ FEC components

✓ Limandes FEC-BEC

❖ BEC

CAPA

ICCUB Institut de Ciències del Cosmos UNIVERSITAT DE BARCELONA

EXCELENCIA MARÍA DE MAEZTU 2020-2023

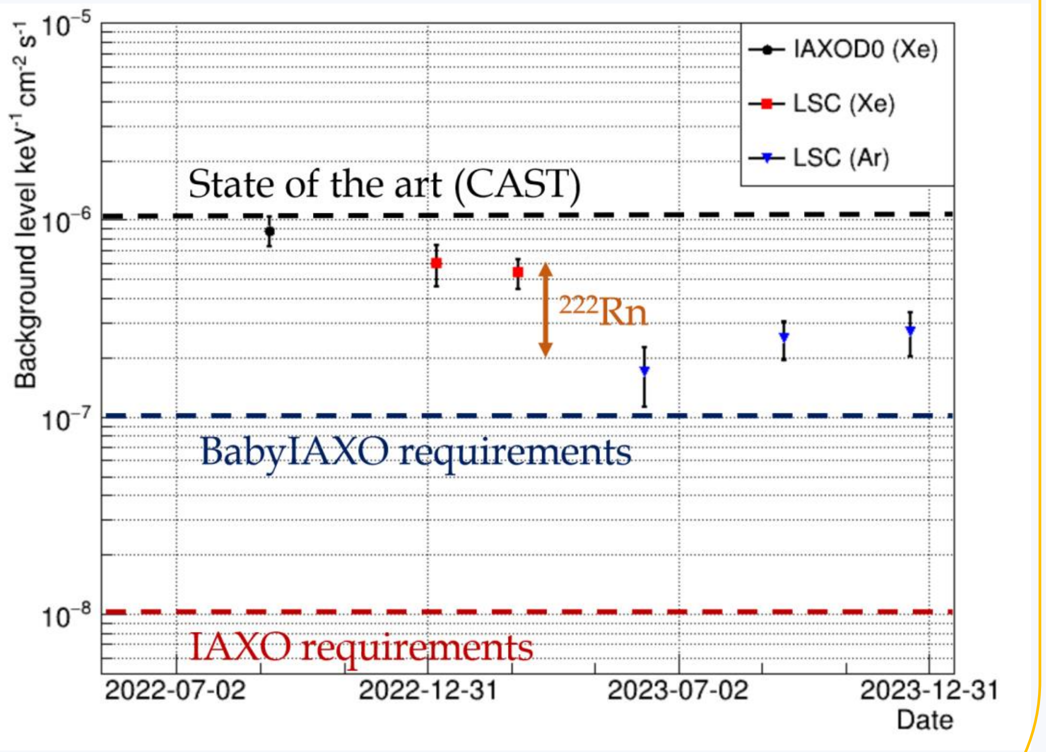
Goals & Milestones

TREX-DM

- GEM installed (one side)
- First ^{37}Ar calibration
- Cathode changed
- AlphaCAMM (non-radiopure) commissioning ongoing

IAXO-D

- Reduced background level at IAXO-D1 (LSC)

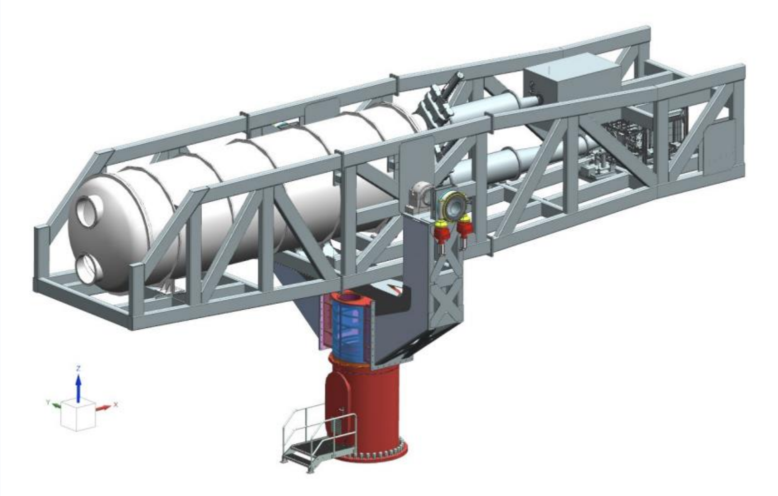


- Radiopure electronics soon

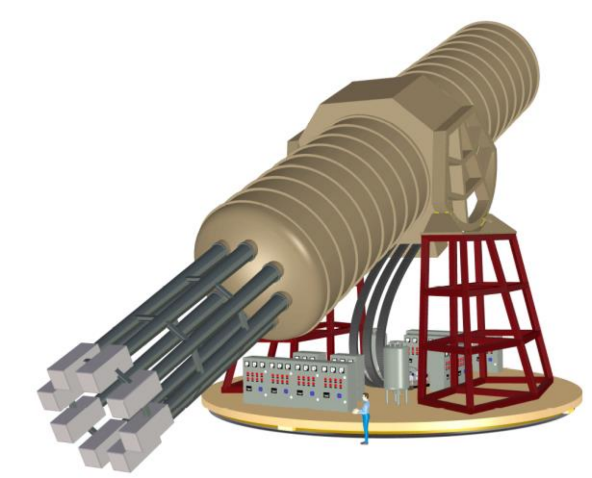
THANKS!

BACK-UP

CAST	
Tracking Time	2 x 1.5h / 24h
Magnetic Field	9 T
Length (B)	9.3 m
# Magnet Bores	1*
$f_M\ [T^2 m^4]$	21



BabyIAXO	
Tracking Time	12h / 24h
Magnetic Field	~ 2 T
Length (B)	9.3 m
# Magnet Bores	2
$f_M\ [T^2 m^4]$	~ 230

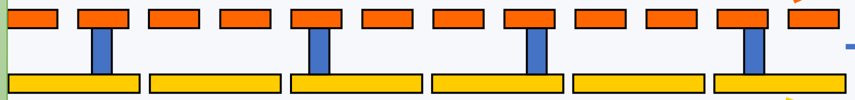


IAXO	
Tracking Time	12h / 24h
Magnetic Field	~ 2.5 T
Length (B)	21 m
# Magnet Bores	8
$f_M\ [T^2 m^4]$	~ 6000

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

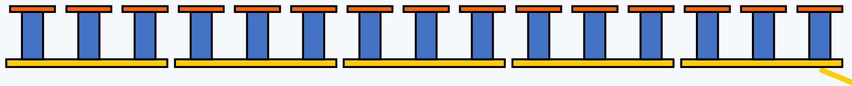
Readout pads

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?

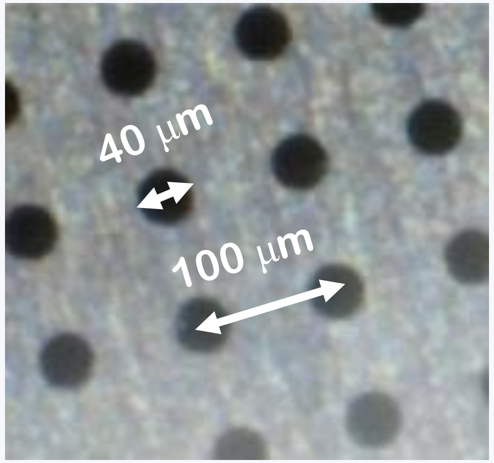
Microfabricated Micromegas

Started development with CNM

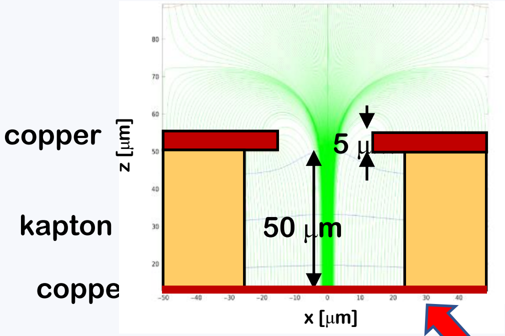
Micromegas structures with Si-wafer microfabrication techniques…
Higher Flexibility & precision in geometrical parameters
Better tailored to application…

Microbulk Micromegas

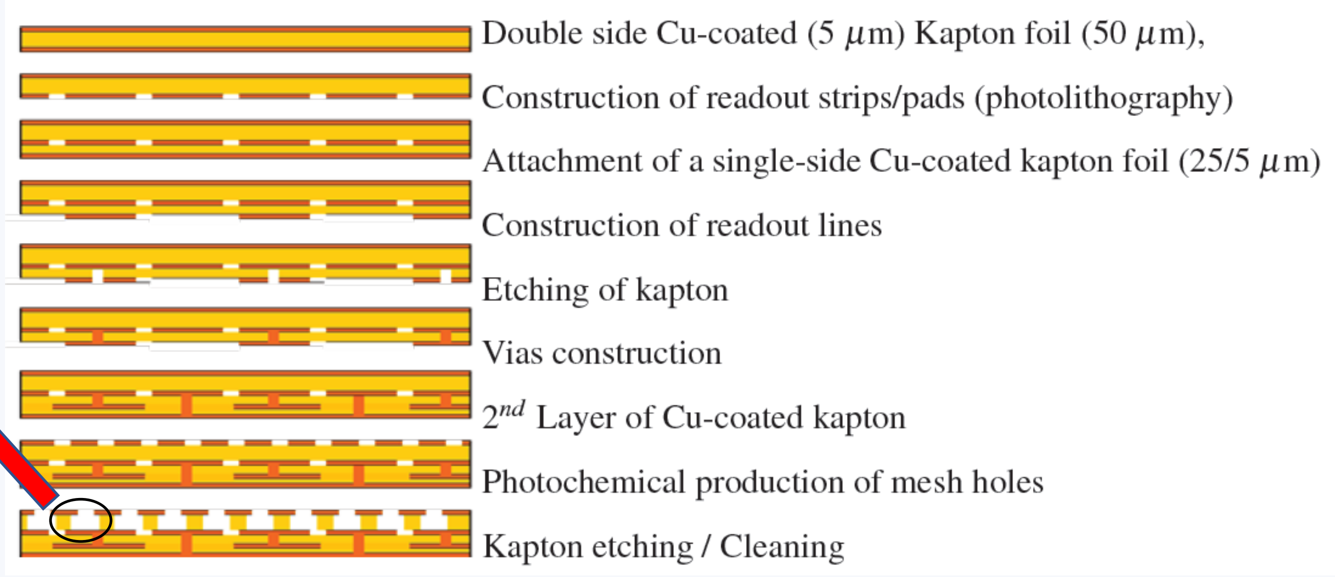
- Made out of copper & polyimide (kapton)
  - potentially very radiopure
- High gap homogeneity
  - good energy resolution
  - Stability/homegeneity in response



Manufactured at Rui de Oliveira's workshop at CERN



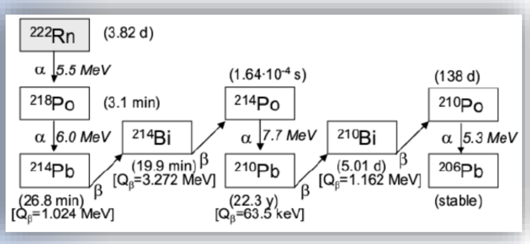
See for details:
JINST 5 (2010) P02001



Credit:
O.Pérez

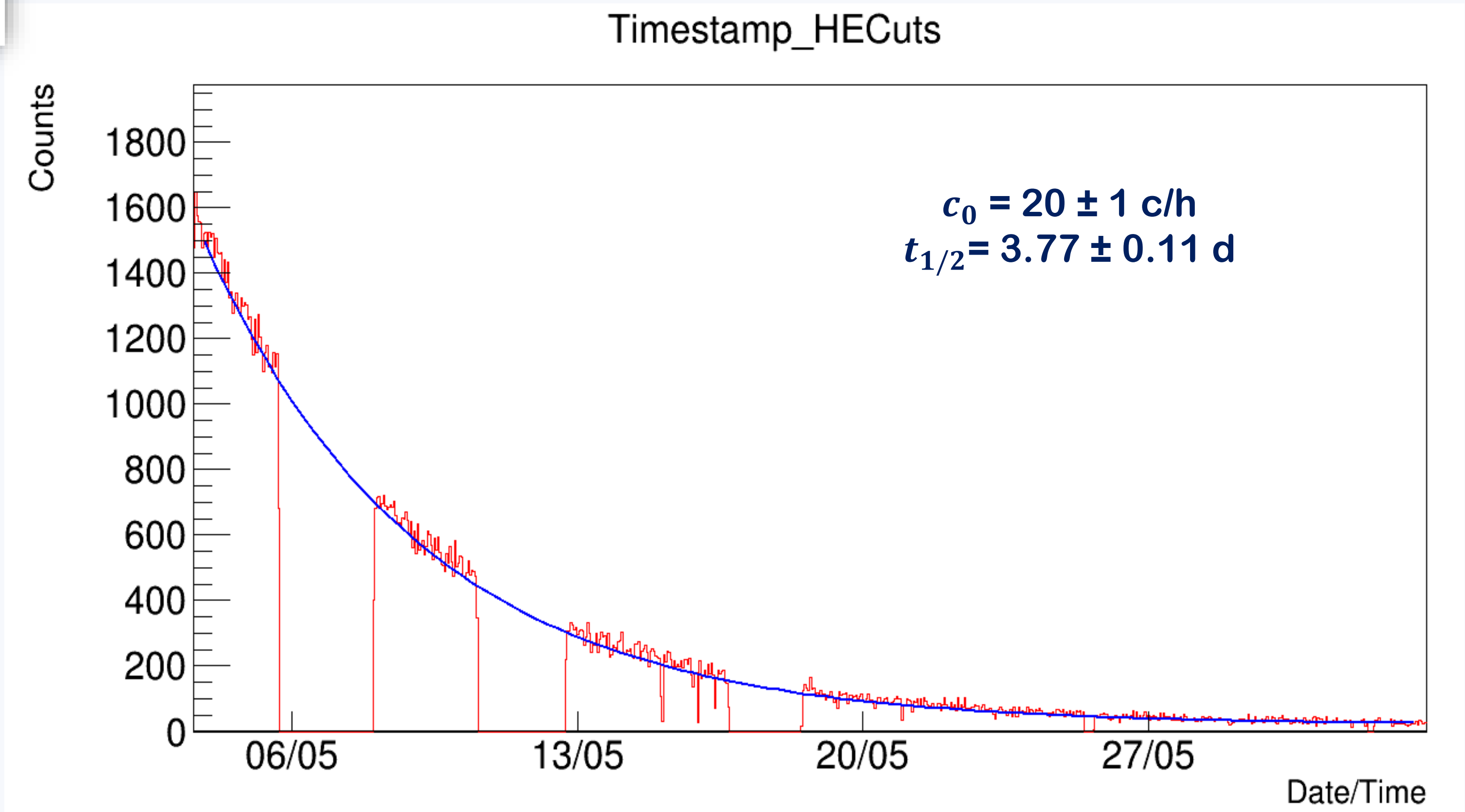
Background status: Rn issue

- **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)

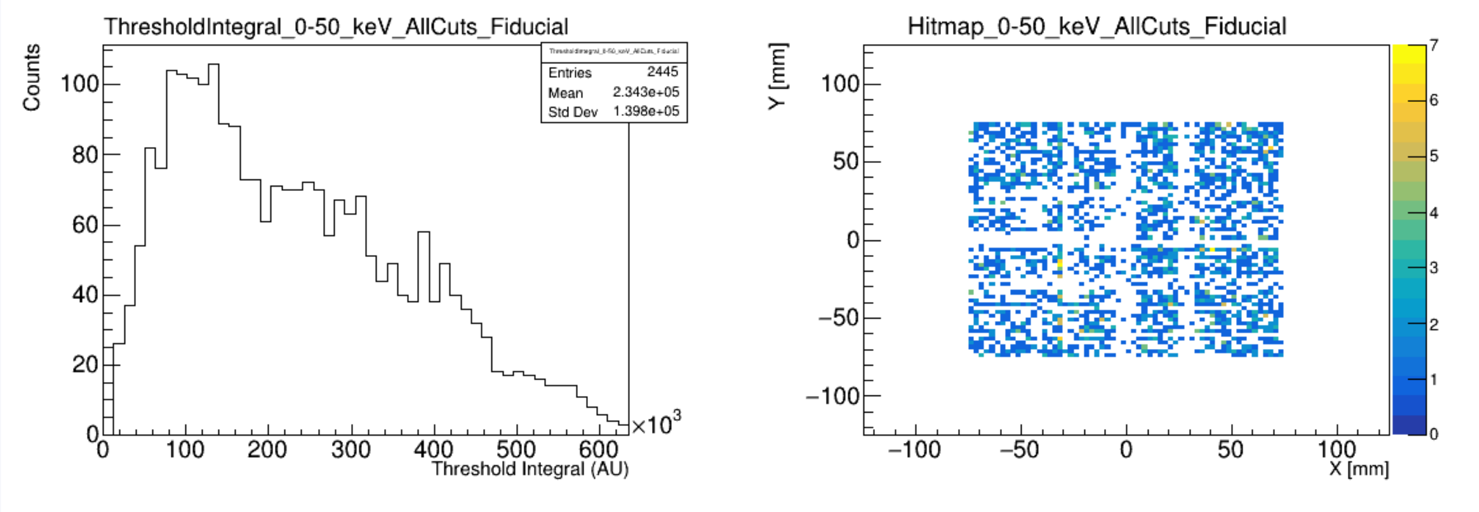
$$c_0 + c_1 e^{-c_3 t}$$



Credit:
O.Pérez

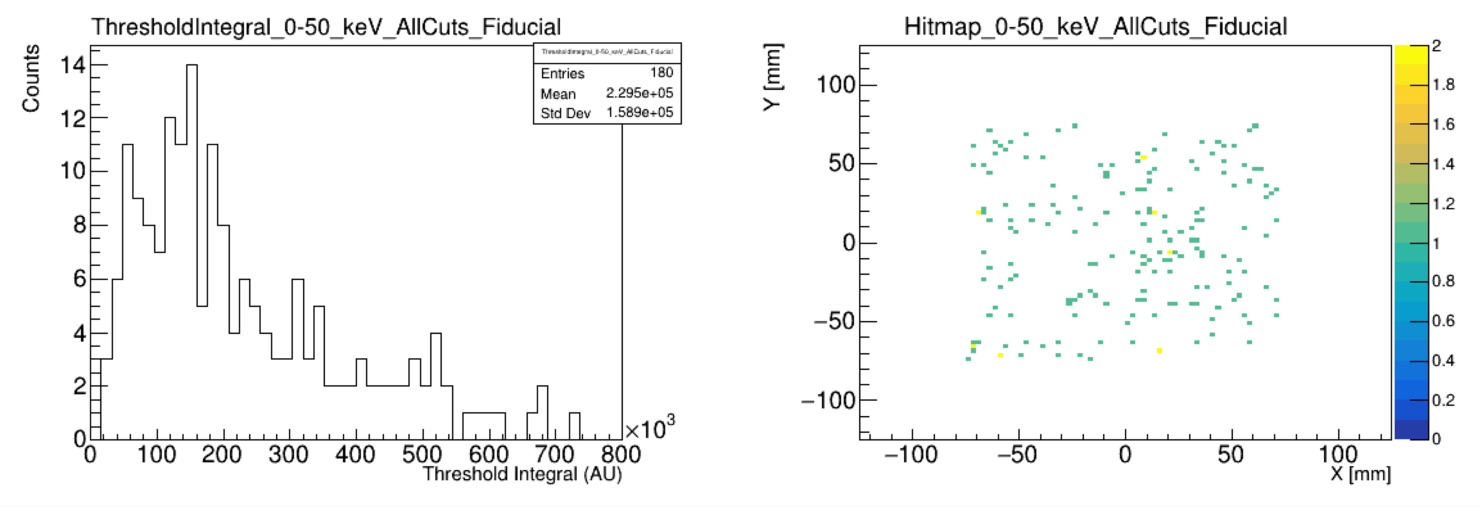
Background status: Rn issue

Background @ low energies



Before Rn decay

0-50 keV → 600 dru



After Rn decay

0-50 keV → 100 dru

Credit:
O.Pérez

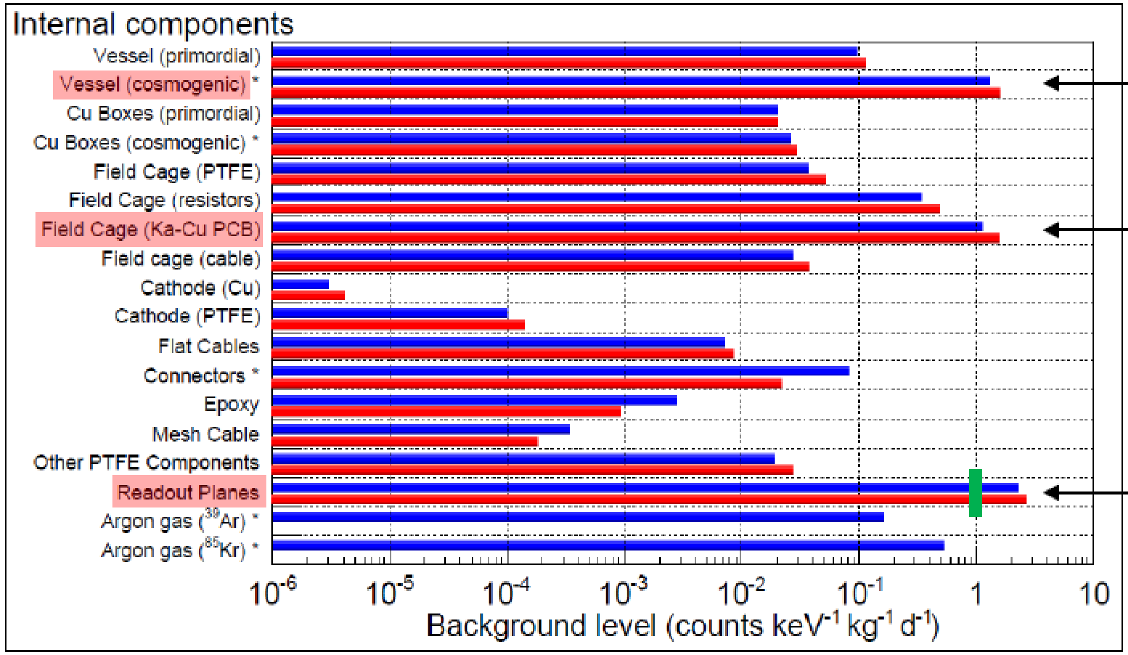
Background status: Rn issue

- **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:
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

2012 JINST 7 P04007

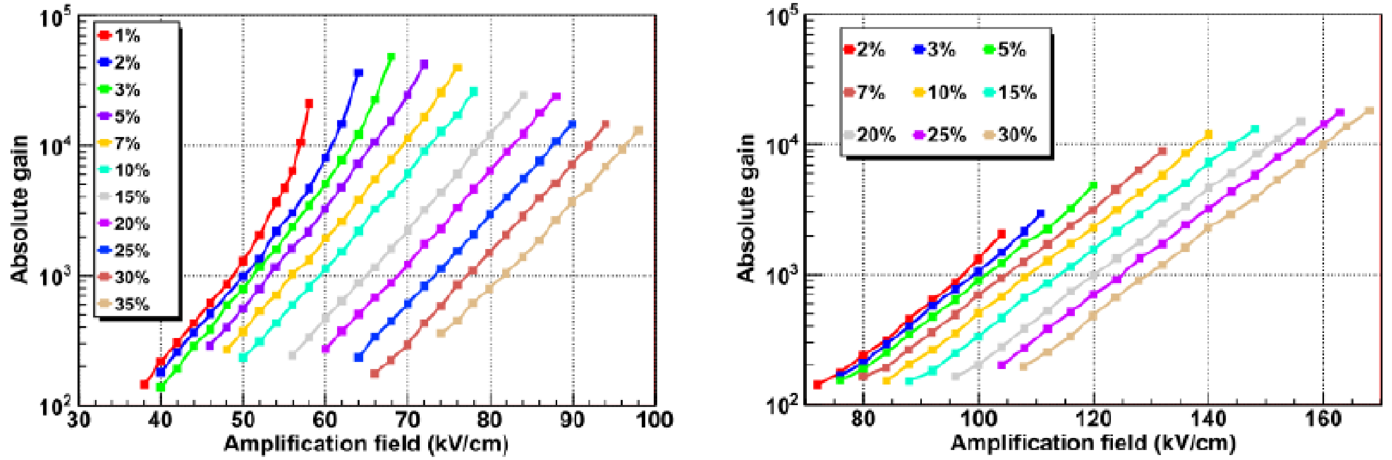


Figure 6. Dependence of the absolute gain with the amplification field for two microbulk detectors with gaps of 50 (left) and 25 μm (right) in argon-isobutane mixtures. The maximum gain of each curve was obtained just before the spark limit. The percentage of each series corresponds to the isobutane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

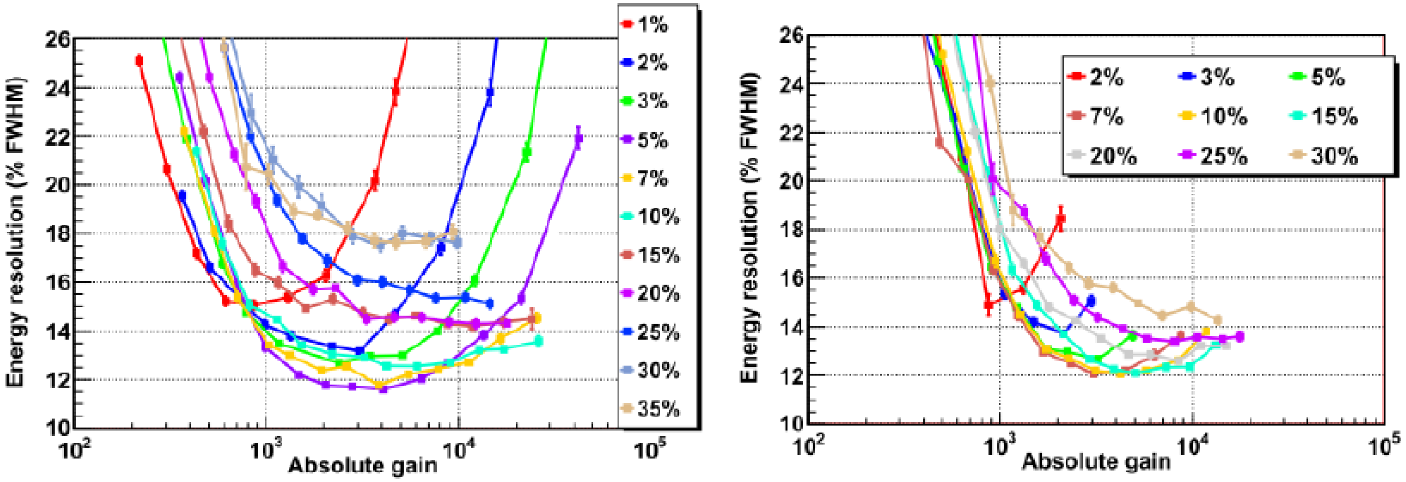


Figure 7. Dependence of the energy resolution with the absolute gain for two detectors of 50 (left) and 25 μm-thickness-gap (right) in argon-isobutane mixtures. The maximum gain of each curve was obtained just before the spark limit. The percentage of each series corresponds to the isobutane concentration.