GOBIERNO DE ESPAÑA
MINISTERIO DE CIENCIA, INNOVACIÓN Y UNIVERSIDADES
Financiado por la Unión Europea NextGenerationEU
Plan de Recuperación, Transformación y Resiliencia
GOBIERNO DE ARAGON

High pressure operation of MPGD in CAPA

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Laboratorio Subterráneo de Canfranc

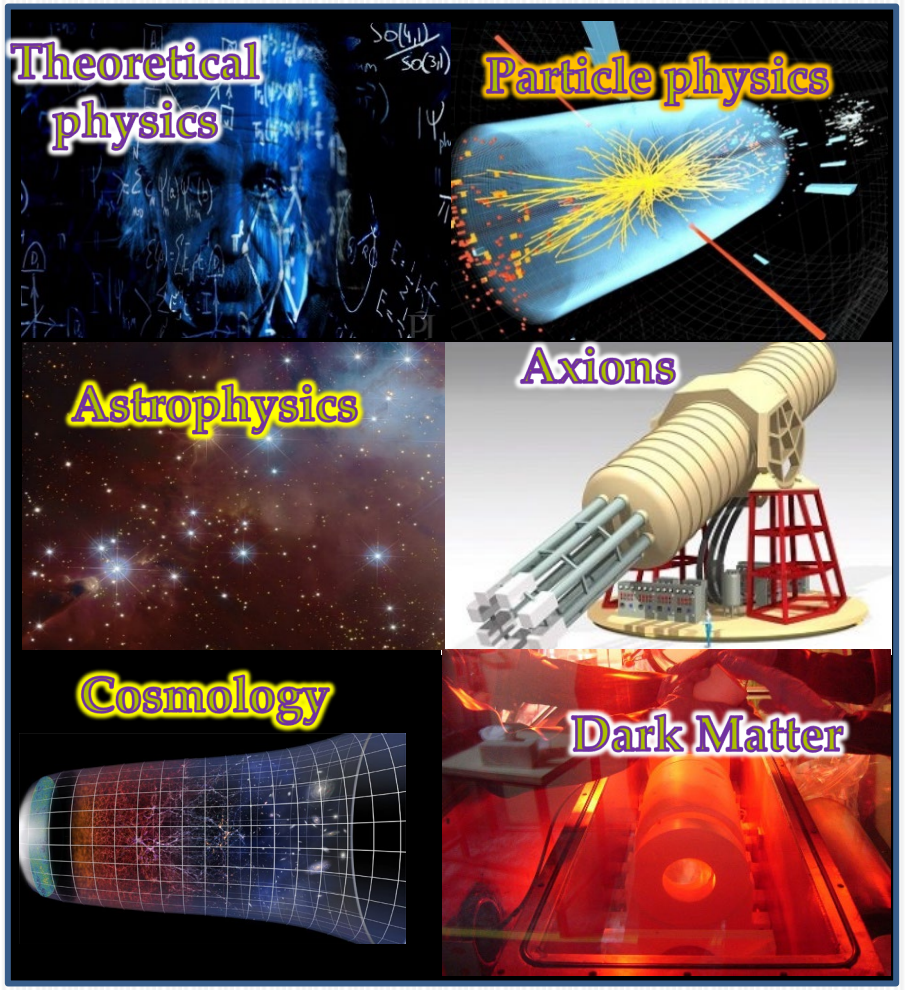
CAPA: Centre for Astroparticle and High Energy Physics

Institute

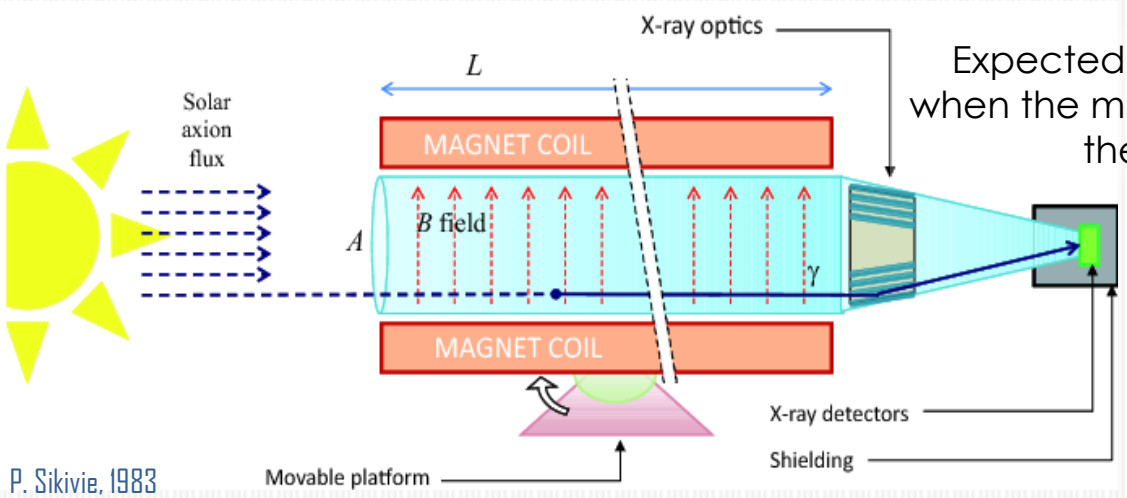
- Research ~~Centre~~ of the University of Zaragoza
- Research Lines:
  - Dark matter, axion physics and neutrino physics
  - Low background techniques and detector development
  - Lattice gauge theory and field theory applications
  - Standard Model extensions and quantum gravity
  - Observational astrophysics and cosmology
- Close Collaboration (experimental) with:
  - CERN, CEA/Saclay, DESY, LSC, CEFCA, ITA, LLNL, NASA, ESA
  - RD-51. DRD1
- Expertise in
  - low-background techniques
  - Gaseous TPC
  - Micromegas detectors
  - **Software related to simulations and data analysis: REST-for-Physics** (https://rest-for-physics.github.io/)
- Applications (mainly) to rare-event searches

...and general R&D in gas readouts

  - Active surface, resistivity, segmentation,...

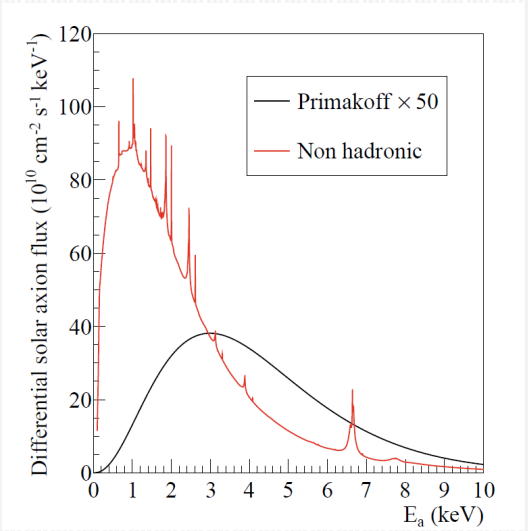


IAXO and BabyIAXO



P. Sikivie, 1983
K. van Bibber, G. Raffelt et al. (1989)

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

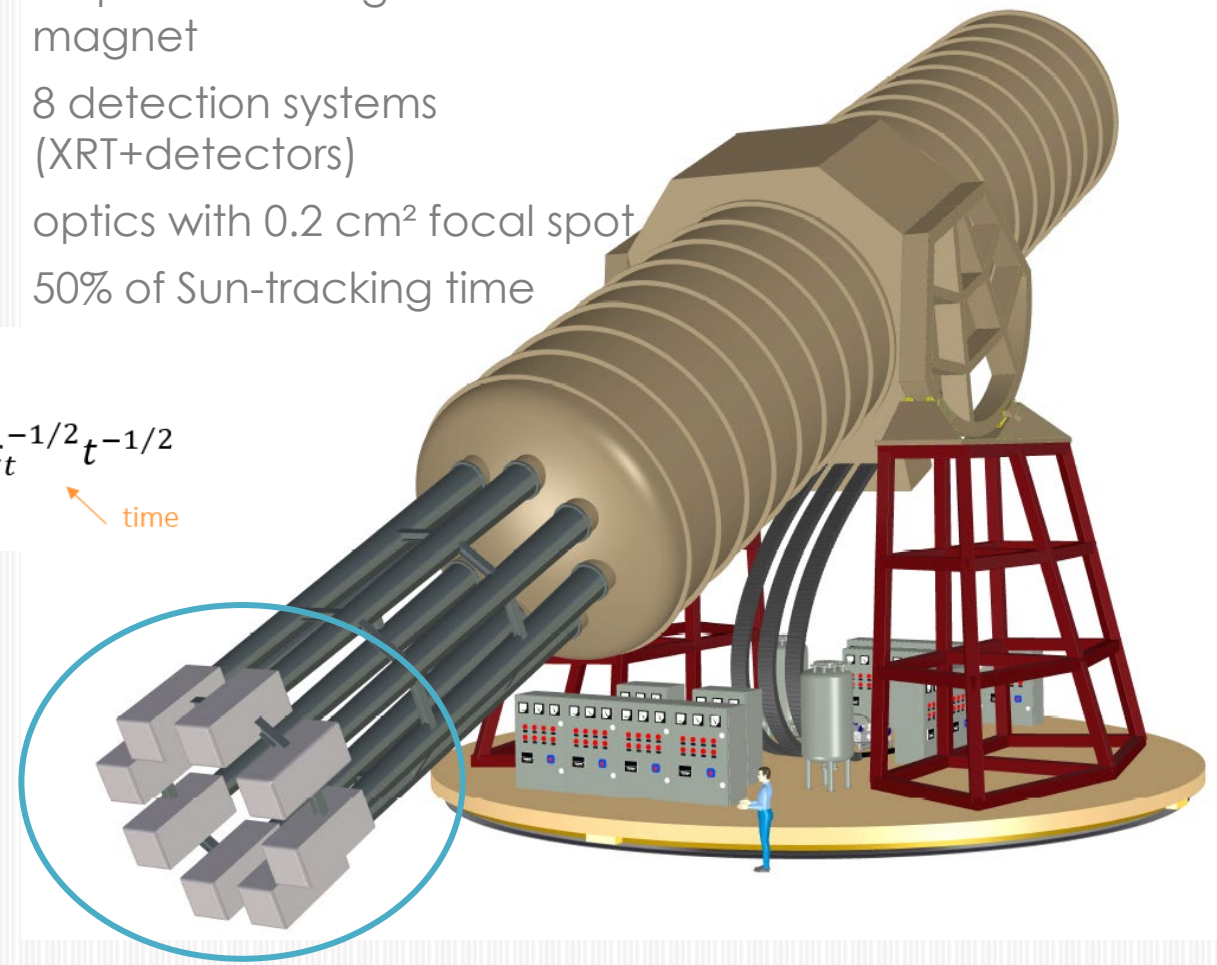


$$g_{a\gamma}^4 \sim B^2 L^2 A \quad \varepsilon_d b^{-1/2} \quad \varepsilon_o \alpha^{-1/2} \quad \varepsilon_t^{-1/2} t^{-1/2}$$

magnet · optics · detectors · time

Figure of Merit (FoM)

- Purpose-built large-scale magnet
- 8 detection systems (XRT+detectors)
- optics with 0.2 cm² focal spot
- 50% of Sun-tracking time

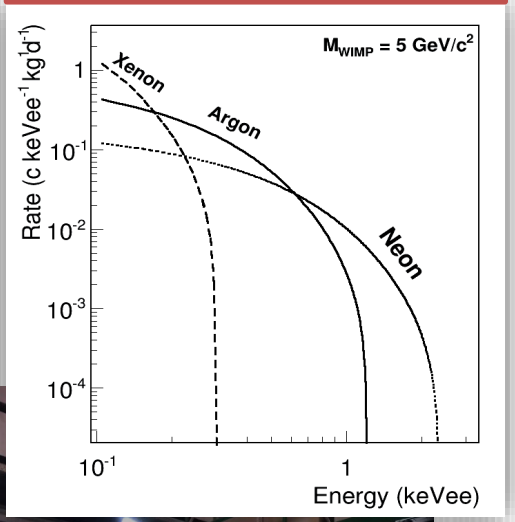


TREX-DM (TPC for Rare Event eXperiments-Dark Matter)

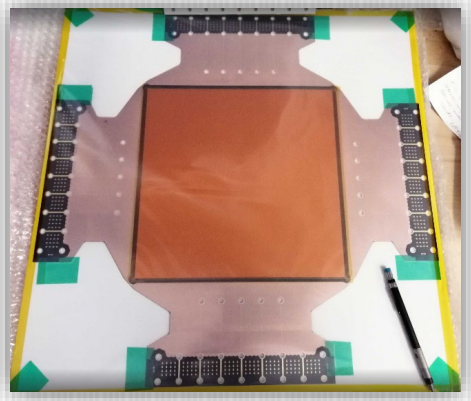
- **A Micromegas TPC for light WIMPs at the LSC**
- ~20 l of pressurized gas (~0.16 kg Ne at 10 bar)
- microbulk Micromegas and AGET-based electronics.
- **Goals:** low energy threshold (< 1 keV)
  low background level (~1/keV/kg/day)
- NOT focused in directionality → operation at high P

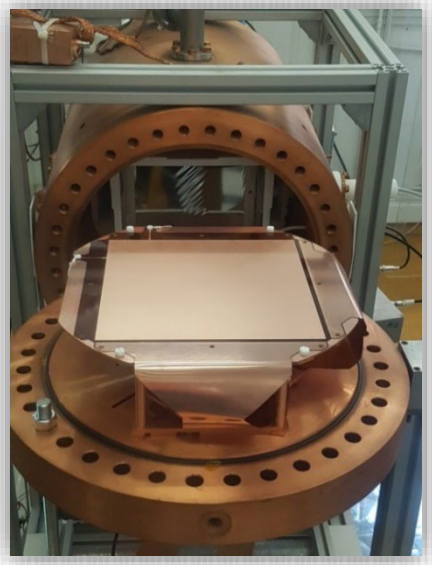
Potential to be sensitive to low-mass WIMPs (0.1-10 GeV/c^2) beyond current bounds

The lighter the target, the more sensitive to low mass

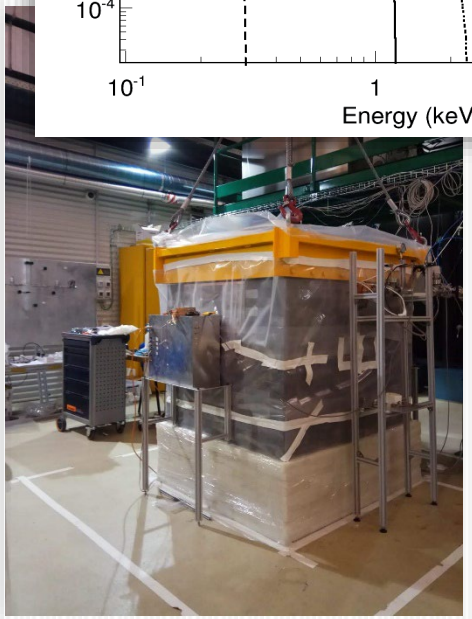


YouTube





H=0.5 m, D=0.5 m
Central cathode



Experiments and R&D

Requirements/Similarities

- Relatively high gain
  - Energy range of interest: 0.1-20keV
- Low background
  - Radioactivity issues
  - Background discrimination techniques
    - Good detector response characterization
    - Event topology (appropriately segmented anode, software efforts,…)
- Low energy threshold
  - Sensitivity enhancement (appropriate trigger, DAQ electronics, …)

Differences

- Active area
- Operating pressure
  - High pressure (up to 10bar) to accumulate target mass
  - Energy threshold differences
- Operating gas optimization
  - Target differs because of Physics
    - Low-mass WIMPs: Ne, Ar with 10%Iso
    - Solar axions: Xe-based mixture

Low-Background levels

Low-backgrounds…

- Background components of our experiments:
  - Cosmic rays : γ, neutrons
  - Radiation and particles from environment
    - Radioactivity in materials (primordial, cosmogenic, anthropogenic):
      - 232Th, 238U, 40K, 60Co, 210Pb, … 39Ar!

→ α, β, γ — internal / external

  - **Radon 222Rn**

→ α, γ + Outgassing, daughters plate-out on surfaces

  - Neutrons:
    - radiogenic: fission, (a,n) reactions in rock,
    - cosmogenic: induced by muons

(n,γ) capture; inelastic scattering → γ, …

elastic scattering → WIMP-like recoils!

Mitigation:

Underground operation
Passive and active shielding
Radiopurity control
Background discrimination techniques

➢ Attempts of creating single public repositories of radiopurity measurements

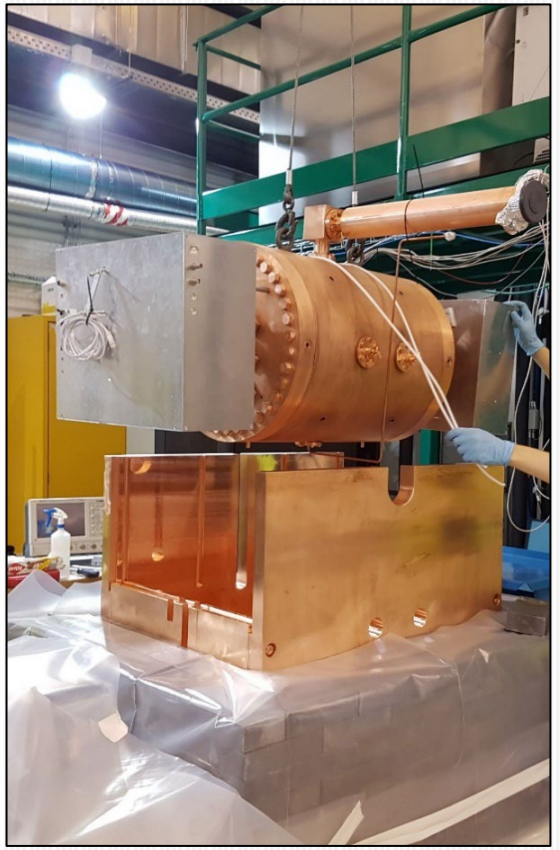
Radiopurity.org: https://www.radiopurity.org

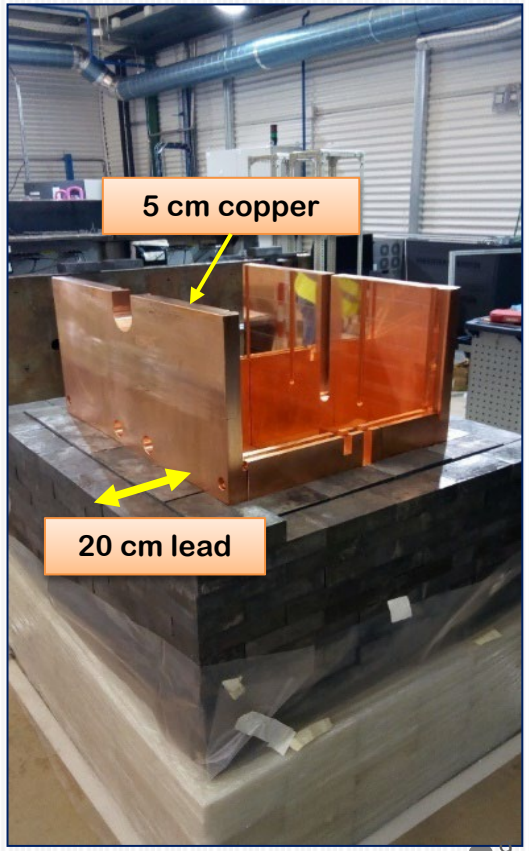
J.C. Loach et al., Nucl. Instrum. Meth. A 839 (2016)

Adapted from : S. Cebrian, *Symposium on Large TPCs, 13th December 2023*

Background levels: Shielding

- 5 cm copper + 20 cm lead
- DAQ electronics outside the shielding
- N2 or Rn-free air is flushed into the plastic cover
- Neutron shielding in place (80%)
  polyethylene ceiling + water tanks

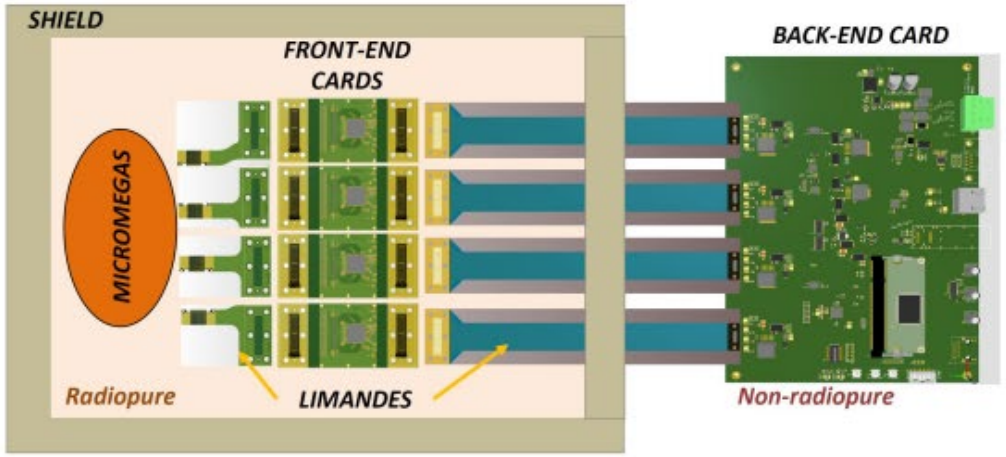


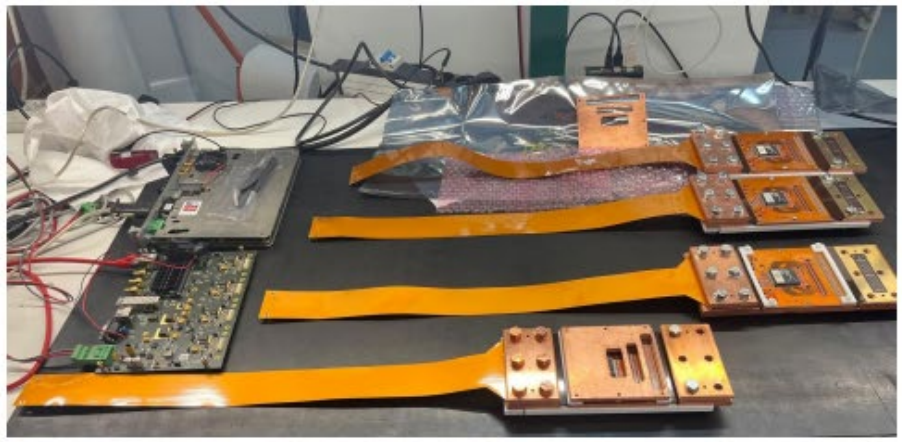


Radiopure electronics

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

Front End, 4 cards withSTAGE and flat cables to connect to Back End





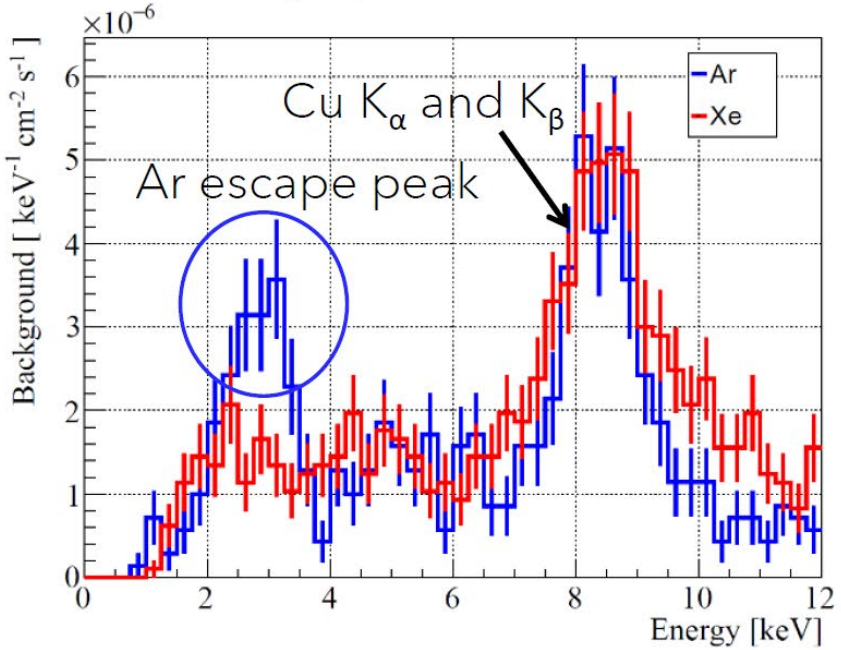
Being installed in the lab prototype during this week

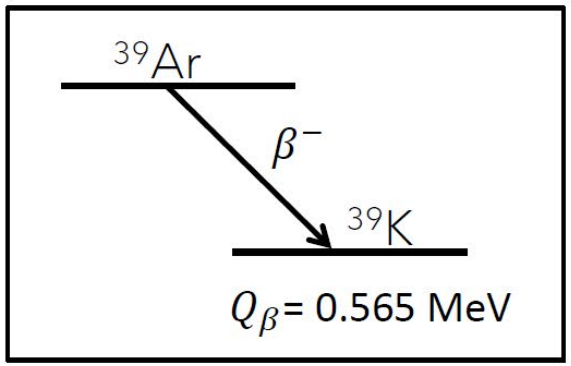
39Ar and Rn: (Baby)IAXO prototype in LSC

Goals

- Study of intrinsic background
- Optimization of the performance with different gas mixtures:
  Ar+Isobutane and Xe+Ne+Isobutane
  - From simulations: intrinsic background in Ar limited by ^{39}Ar
  - Ar escape peak at 3 keV

Requires recirculation





Altenmüller, K., et al. "New upper limit on the axion-photon coupling with an extended CAST run with a Xe-based micromegas detector." *Physical Review Letters* 133.22 (2024): 221005.

Slide from M. Jiménez

Purifiers: Rn in TREX-DM

- Recirculation:

  gas through purifiers, which emanate Rn
- Several options used:
  - Agilent (for O2 and **H2O**)
  - SAES MicroTorr (O2 and H2O)
  - 5Å molecular sieve
  - Custom-made O2+H2O+Rn filter (developed by U. Birmingham)
  - Activated carbon filters
- For the moment, best results with open-loop low-flow
- On-going search for possible solutions:
  - Currently preparing tests with new material

  (silver-zeolites, Ag-ETS-10) to reproduce results in:

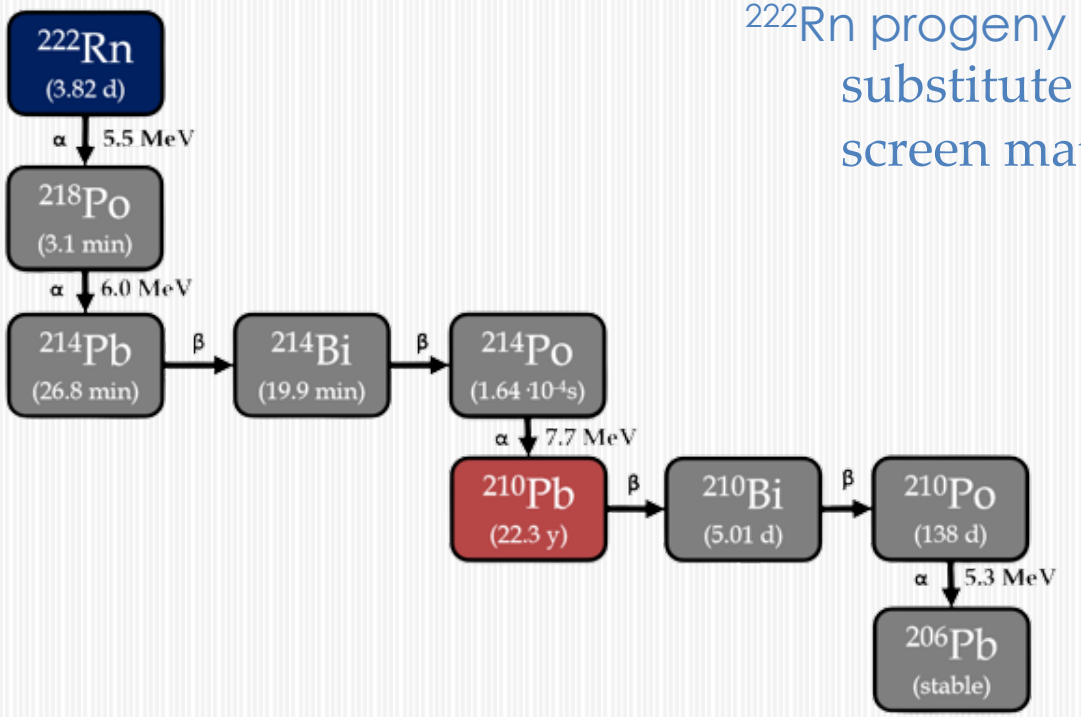
  https://doi.org/10.48550/arXiv.2505.07979

Ag-ETS-10

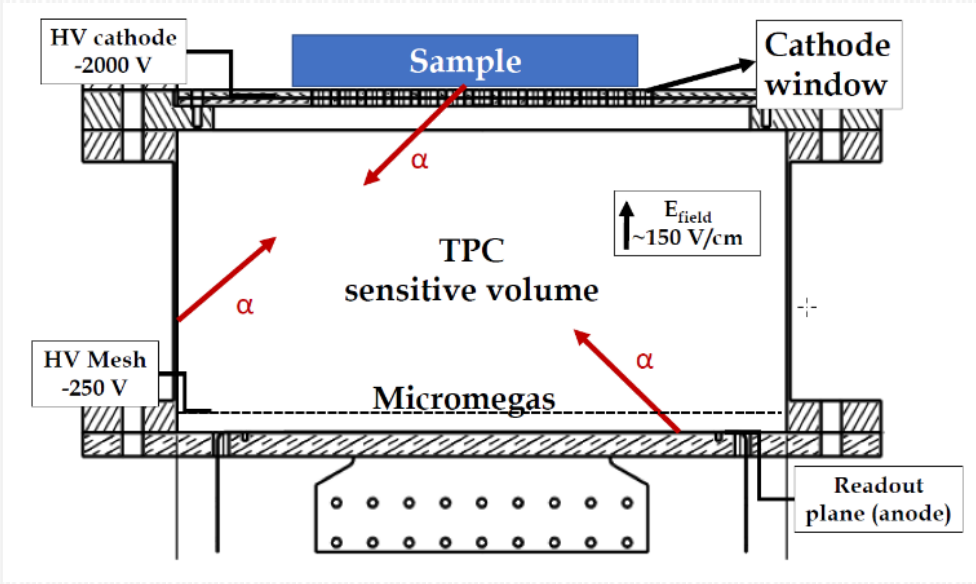
Agilent Filters

Background: Rn levels

- Background level
  - Switched from sealed mode to open loop: 600dru to 100dru (dru = $keV^{-1}\,kg^{-1}\,day^{-1}$)



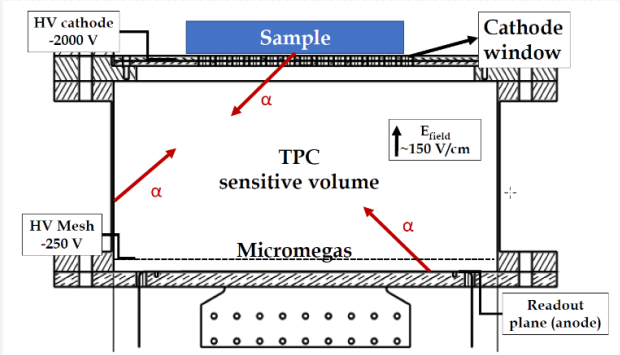
^{222}Rn progeny contamination on mylar cathode surface
substitute cathode
screen material for alpha surface contamination



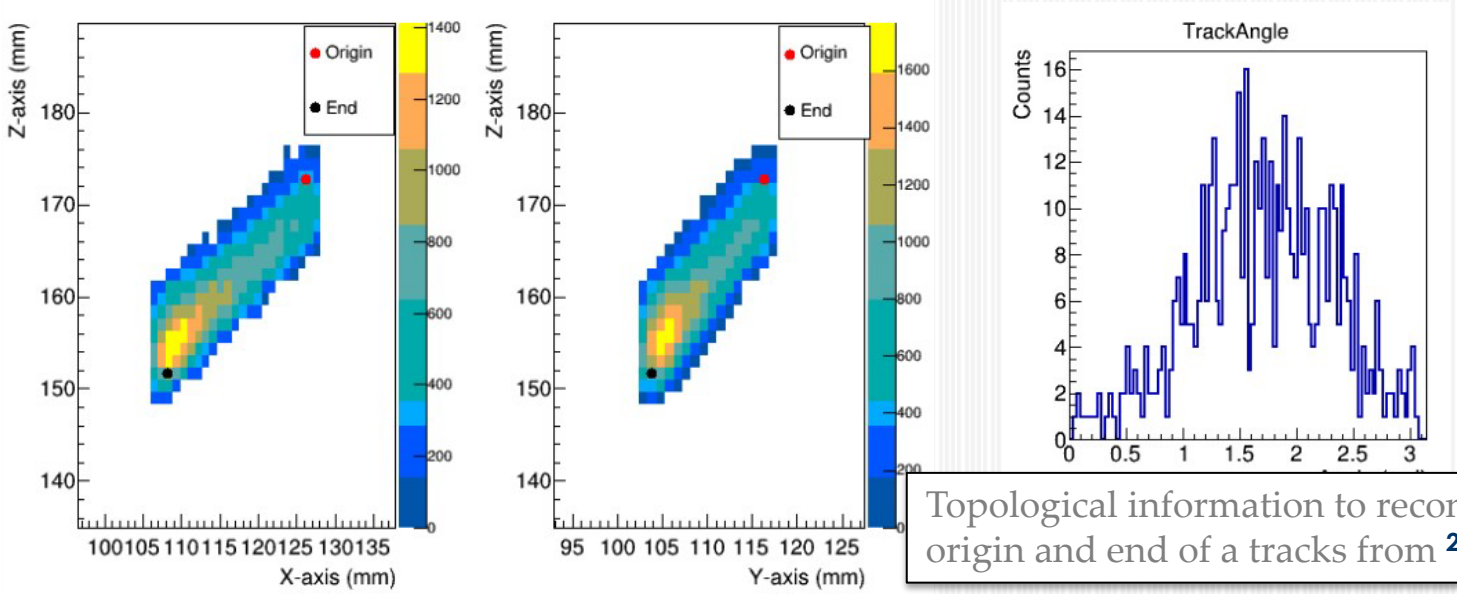
AlphaCAMM (Alpha CAMera Micromegas)

- 'Spin-off' of TREX-DM: gaseous chamber with a segmented mM (25cm x 25cm) to measure ^{210}Pb surface contamination of flat samples down to 100 nBq/cm^2

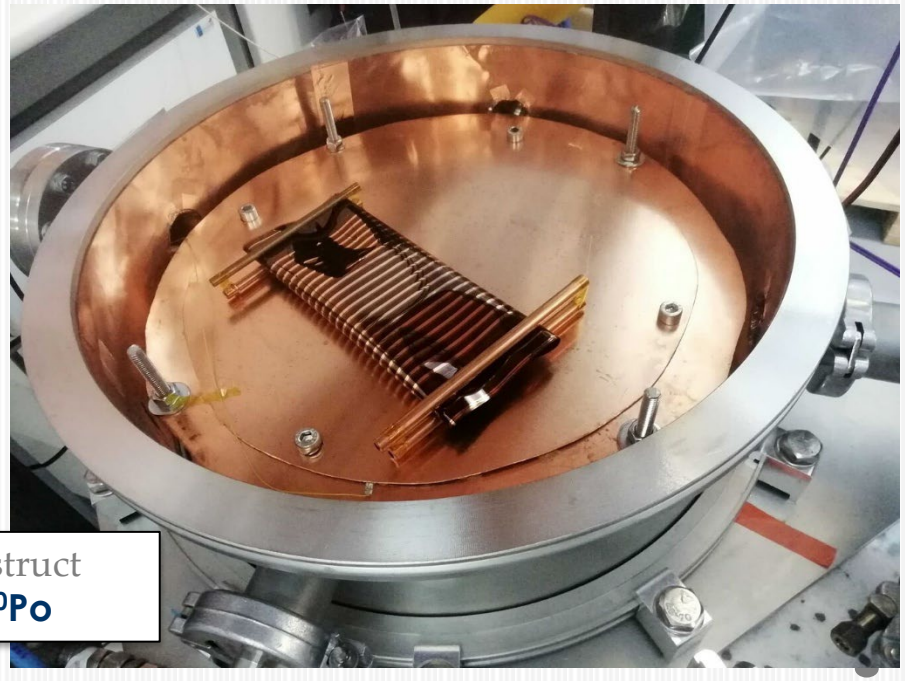
K. Altenmuller et al, 2022 JINST 17 P08035



Measurements of materials of interest already started:
aluminised mylar, 'clean' copper wires, copper-clad kapton, copper strips on kapton…

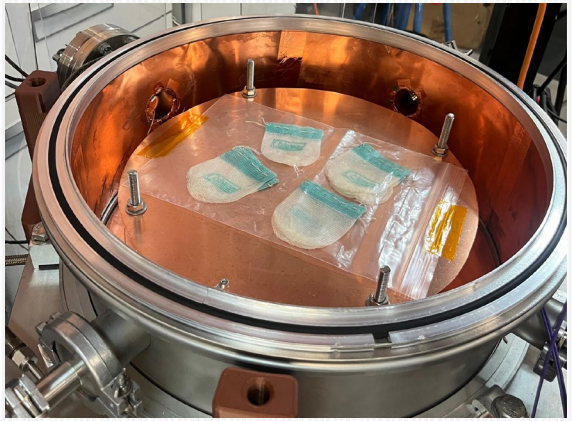


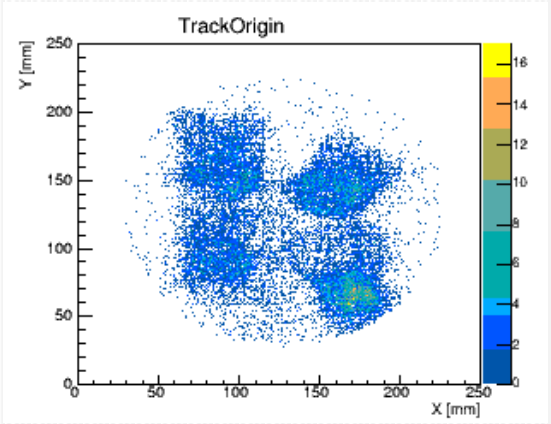
Topological information to reconstruct origin and end of a tracks from ^{210}Po

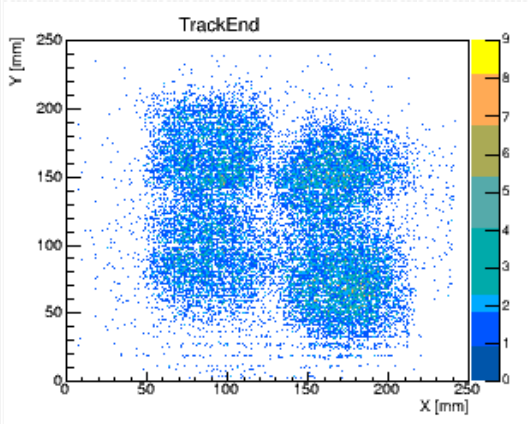


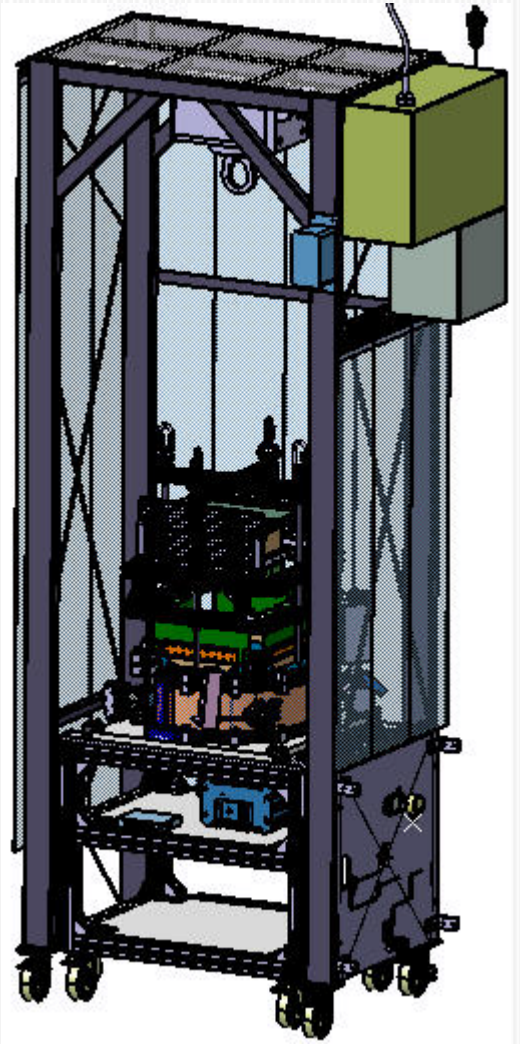
AlphaCAMM (Alpha CAMera Micromegas)

- Stand-alone facility for measurements
  - Open to anyone interested









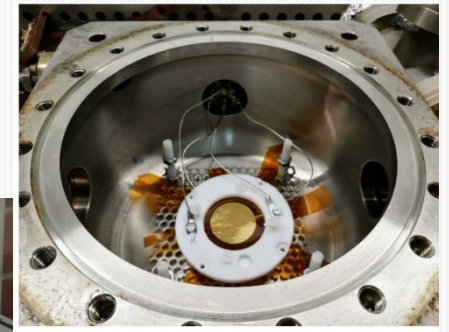
Low-energy threshold

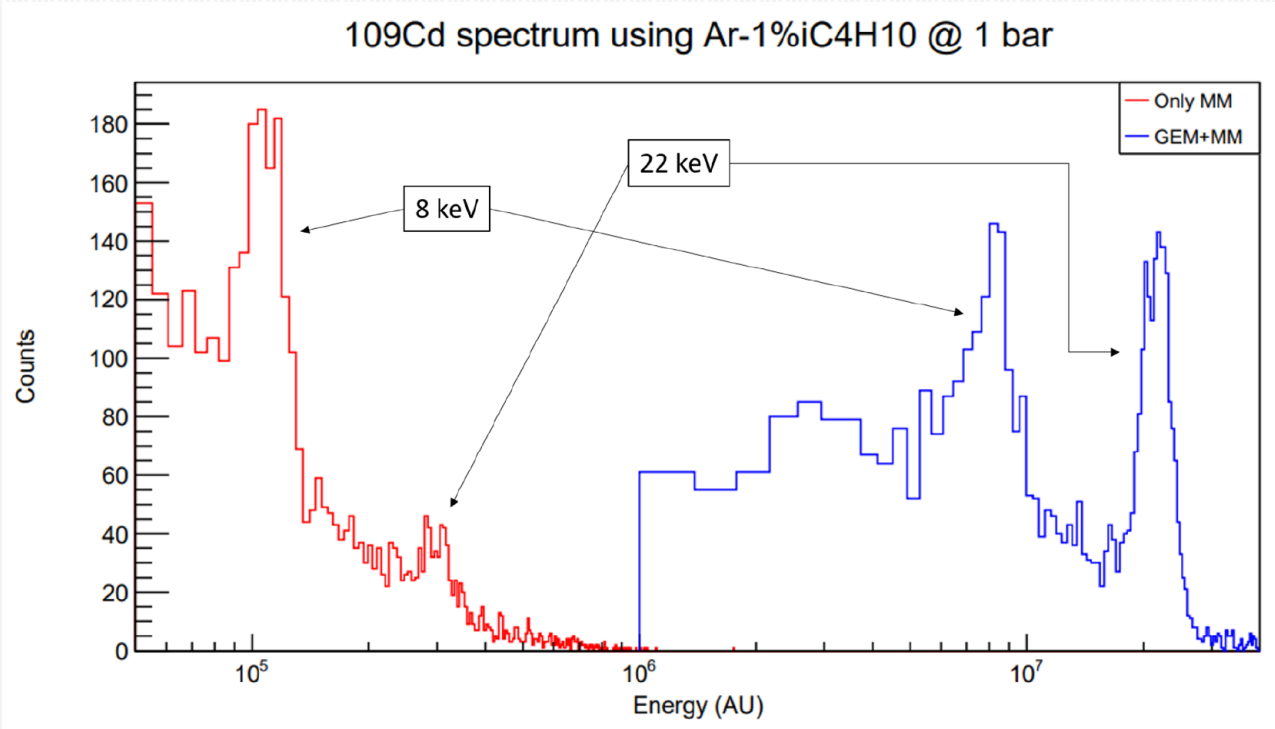
Lower threshold: GEM-MM

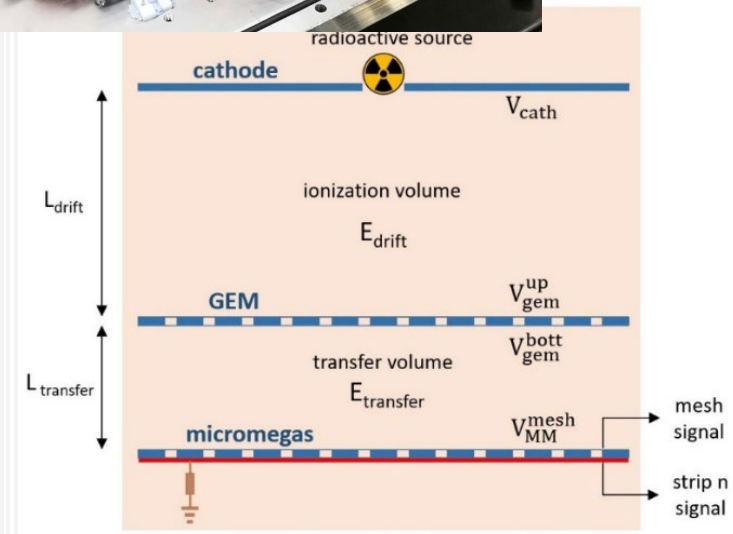
- Energy threshold
  - preamplification volume with a GEM on top of a mM

factors would allow very low energy threshold (even single e-)

- Big microbulk mM @1bar (x80)
- Small microbulk mM @1-10bar (x90 to x20)



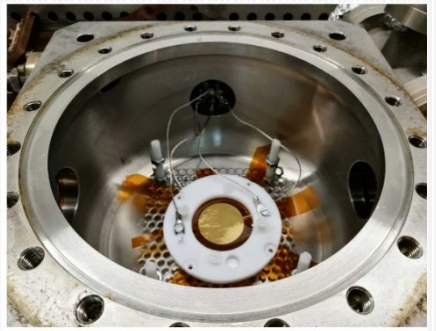


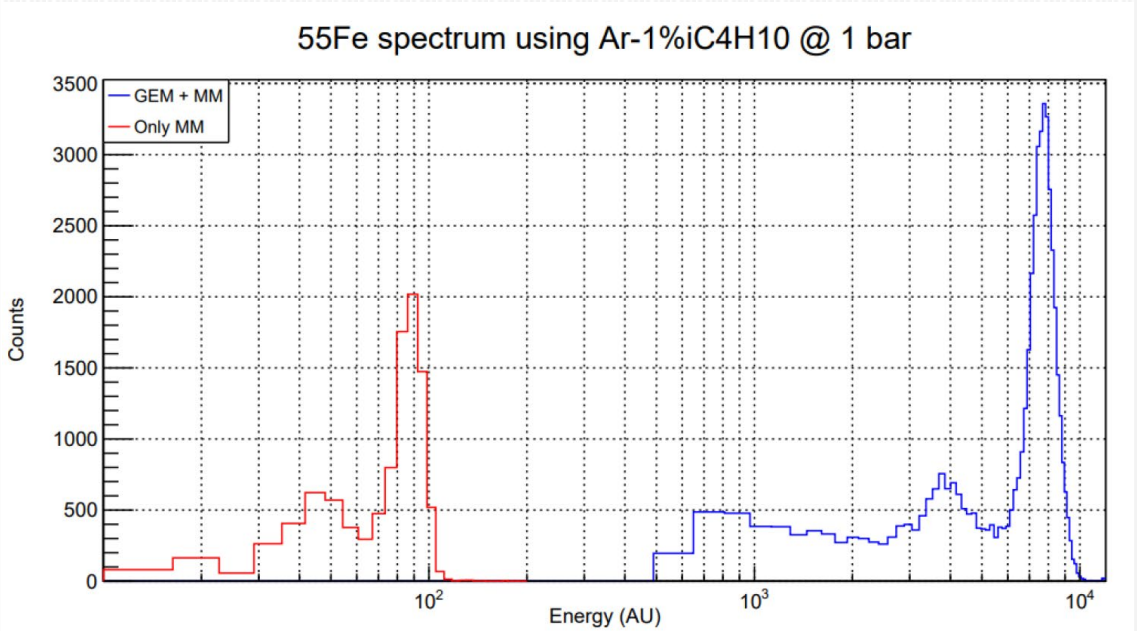


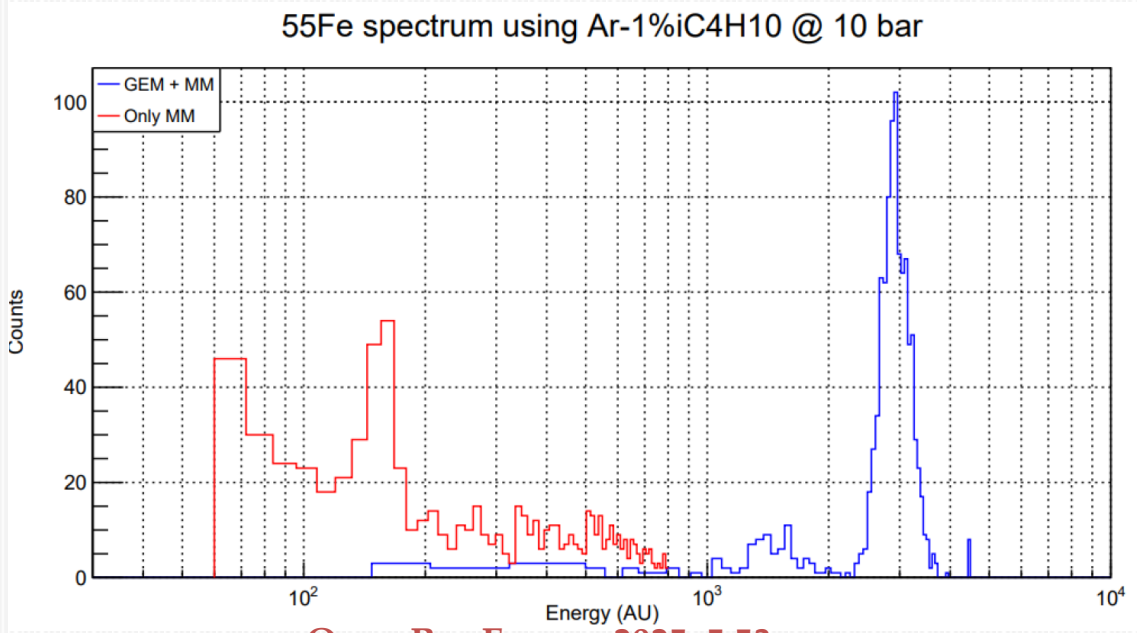
Open Res Europe 2025, 5:53
arXiv: 2412.19864 [physics.ins-det]

GEM-MM operation: different pressures

Pressure (bar)	V_{mesh} (V) (GEM + MM system)	V_{GEM} (V) (GEM + MM system)	Preamp. factor	V_{mesh} (V) (only-MM system)	GEM effective extra gain factor
1	305	310	-	315	90
4	390	410	70	400	50
10	535	550	21	540	19
1	290	285	85	293	80







Open Res Europe 2025, 5:53
arXiv: 2412.19864 [physics.ins-det]

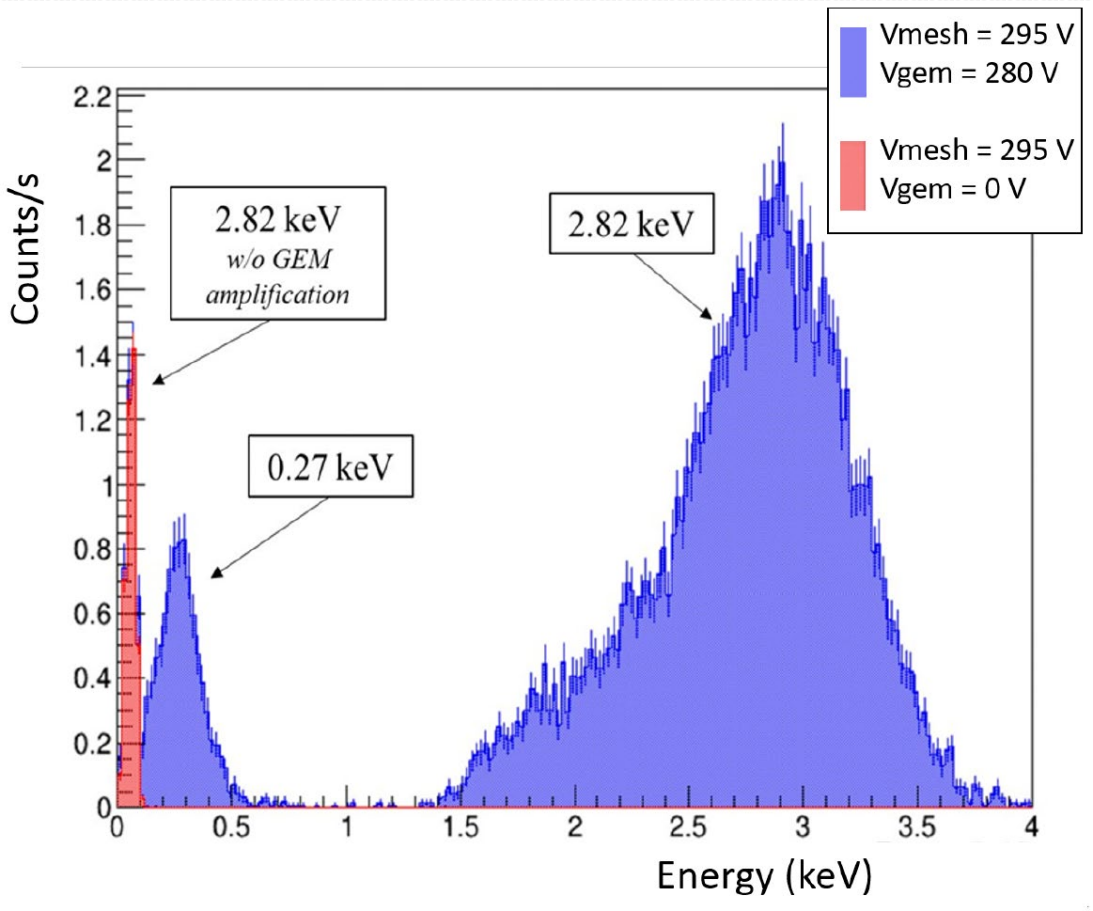
Low energy, volume calibrations

Gas source: distribution in all volumen, homogeneous calibration of the readout plane.

37Ar: 2.8 keV (90%), 0.27keV (9%)

- Irradiated CaO powder at HiSPANoS

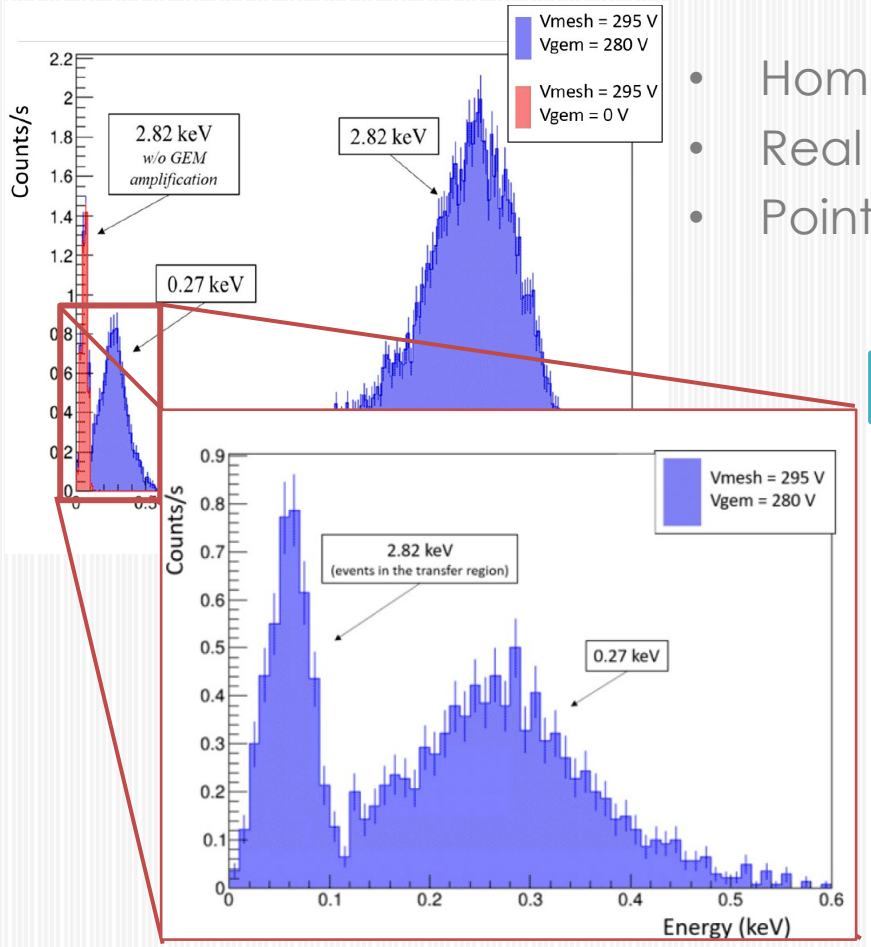
40CaO



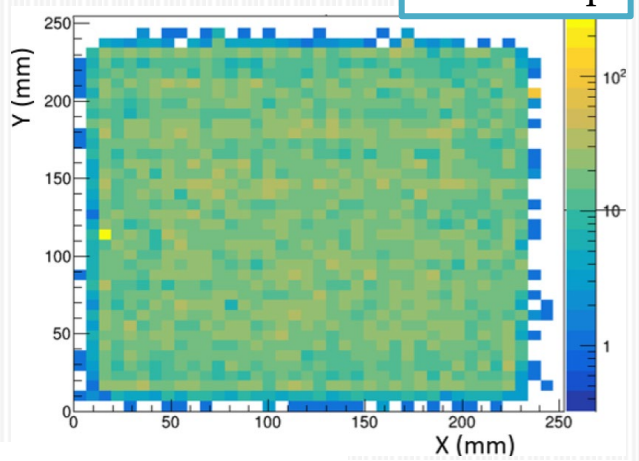
publication in preparation
PhD thesis of Ó. Pérez Lázaro, arXiv:2507.02172 [physics.ins-det]

37Ar calibrations

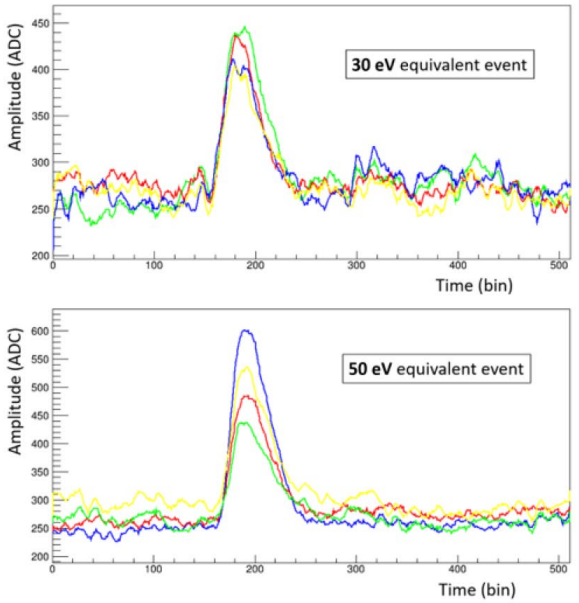
- Homogeneous illumination and response
- Real signals of sub-100eV events
- Point to $O(10)$ eV threshold



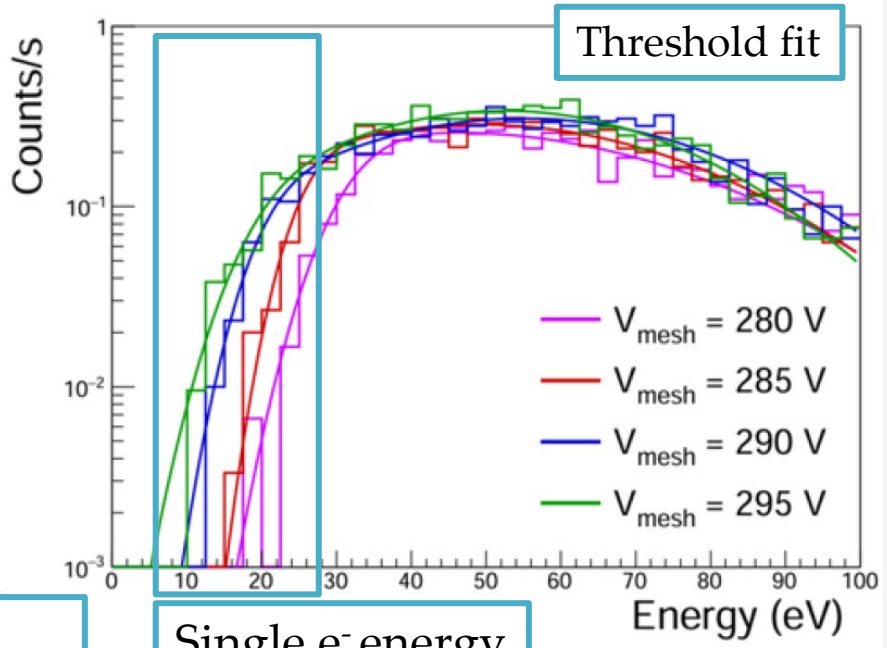
2D hitmap



Examples of low-energy events



Threshold fit



a window to uncharted territory for this kind of detectors

Single e⁻ energy

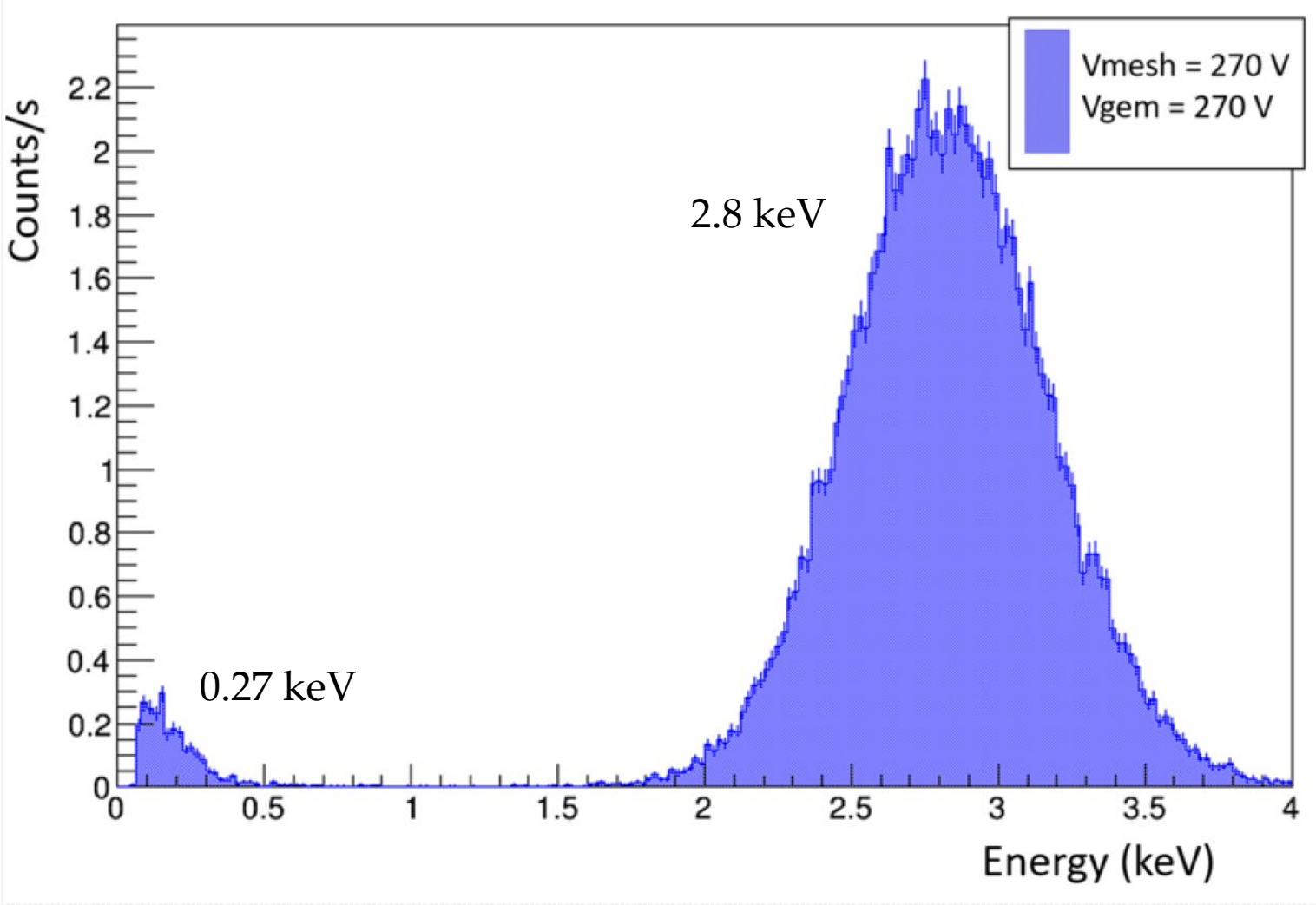
37Ar calibration, nominal gain

Threshold still clearly ~200eV

Some loss of linearity…?

Need for multiple low/energy calibration points

Also of interest:
83mKr:
30keV, 7.6keV, 2.1keV, 1,8keV

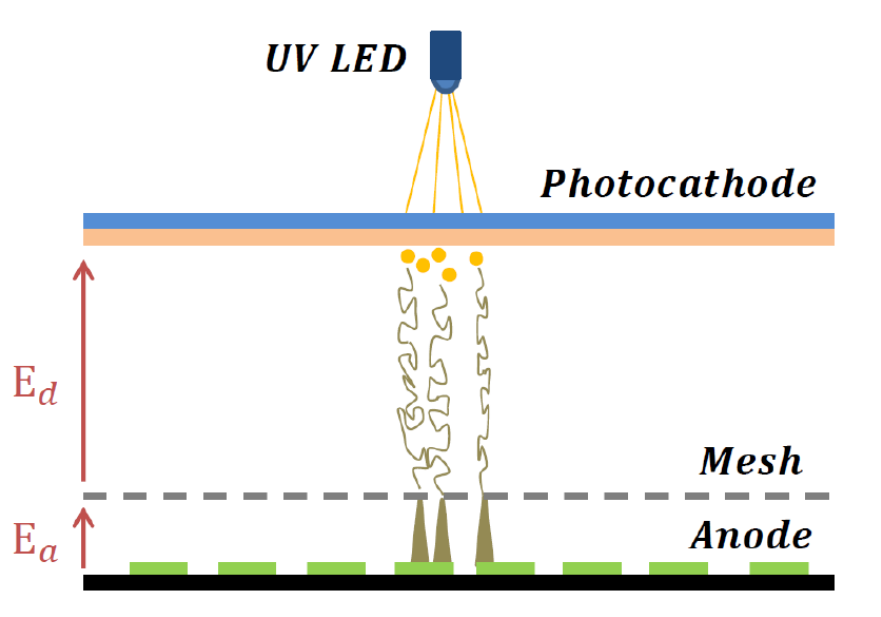


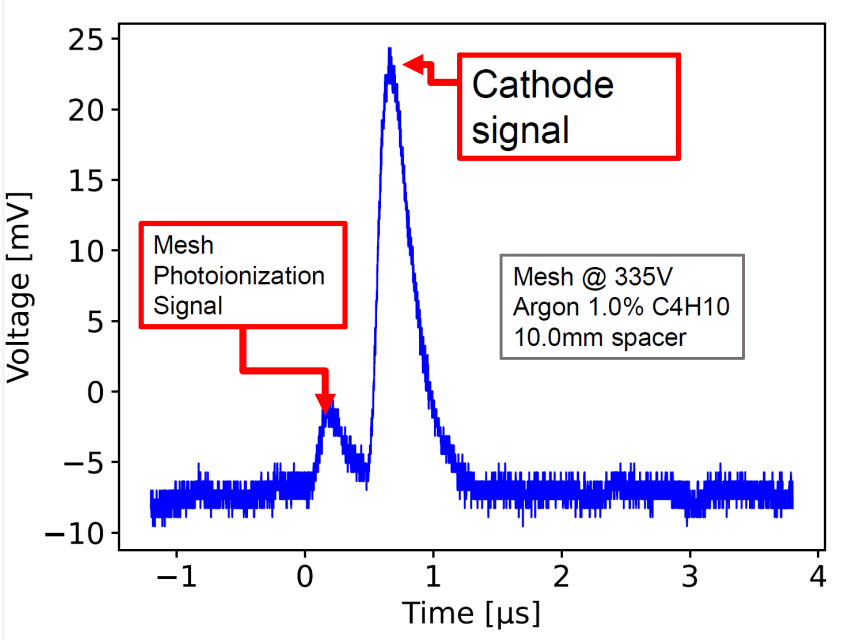
General R&D

General R&D

- A facility for gas drift velocity characterisation
  - T0 from the source
  - ToA of photocathode electrons

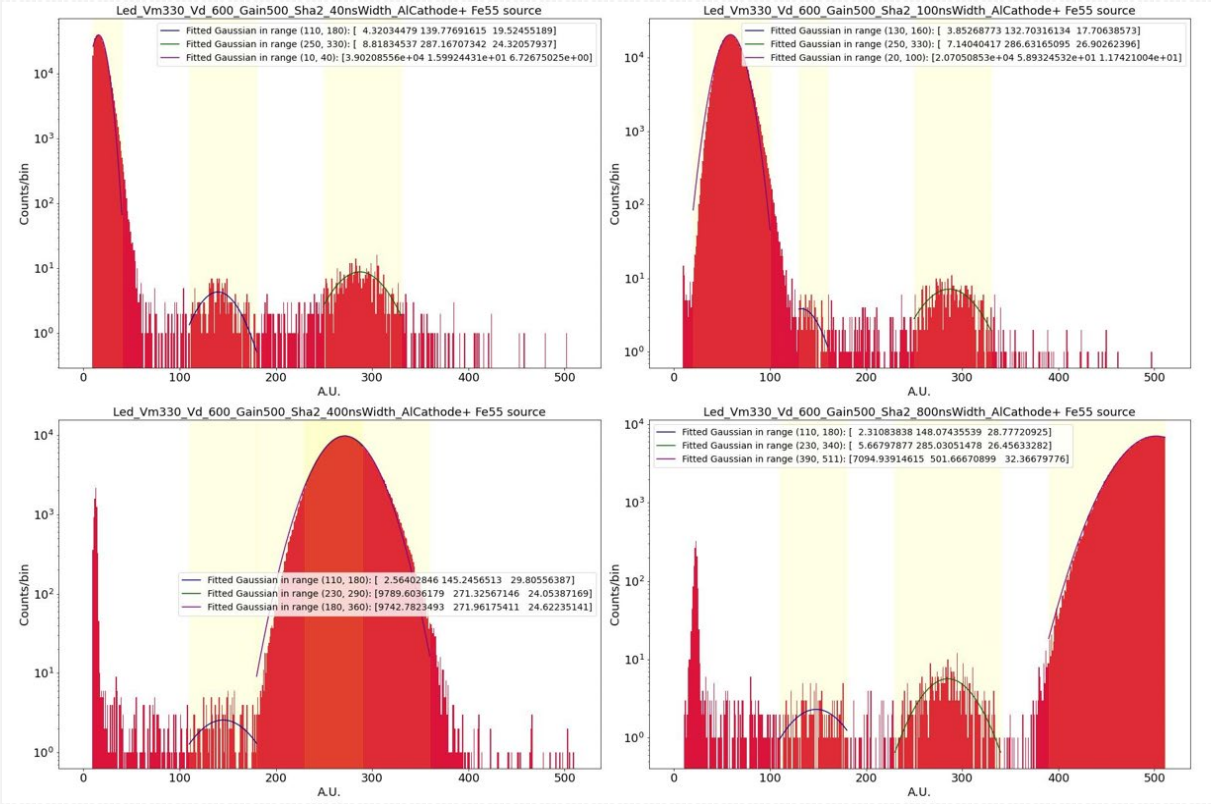
At CEA/Saclay





General R&D

- Variable energy calibration method: study the energy threshold limits
  - Down to single electron calibration



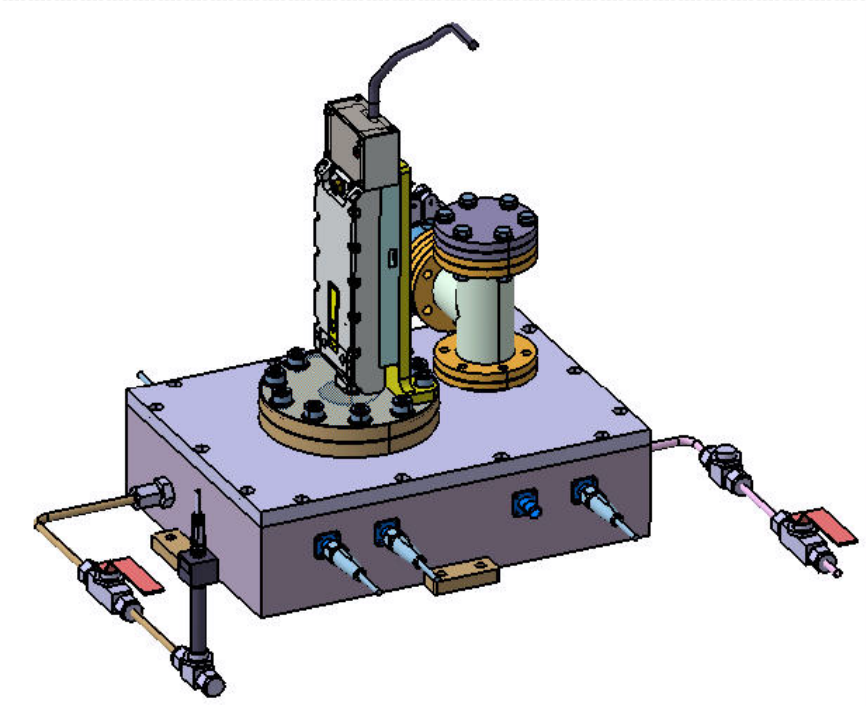
PhD thesis of D. Díez Ibáñez

General R&D

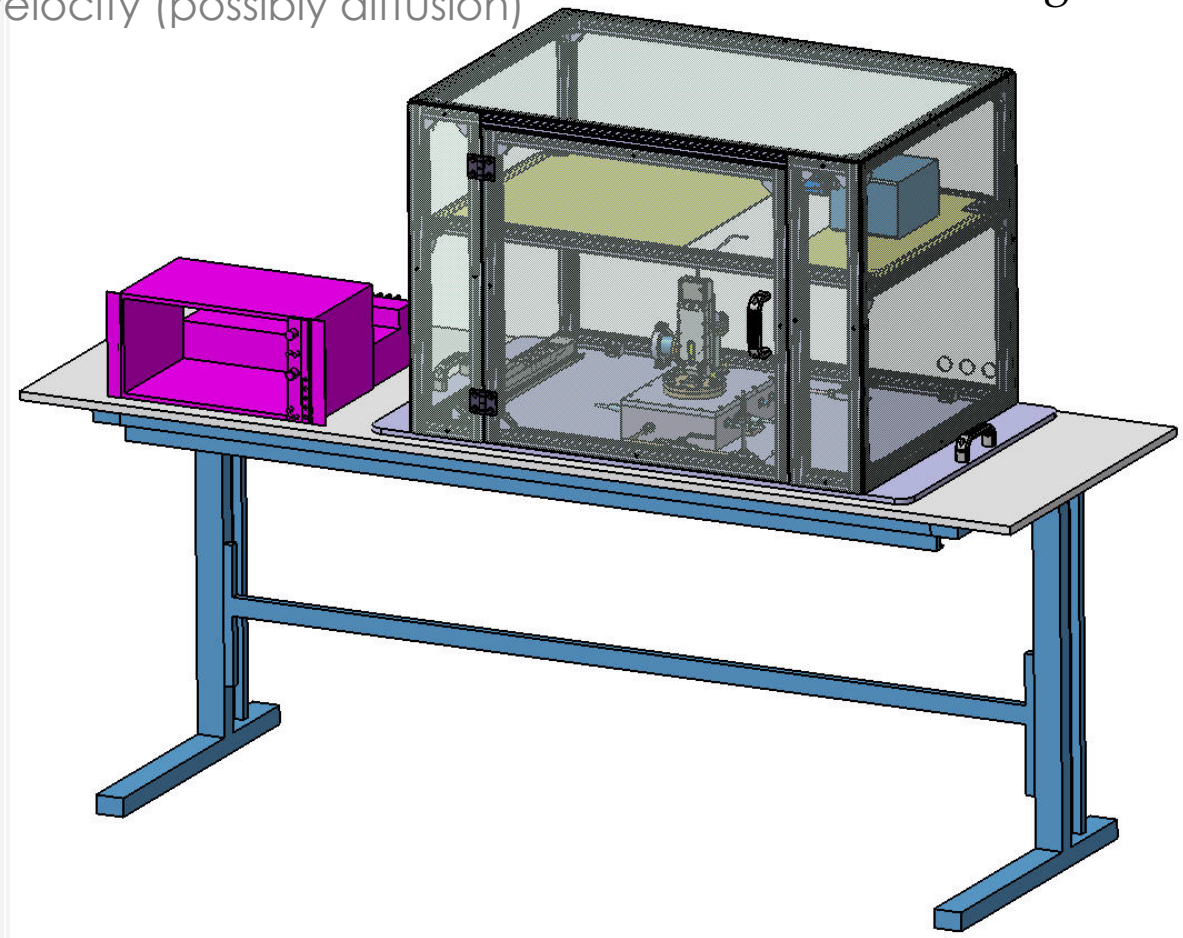
- A facility for gas studies

for energy calibration, spatial resolution and gas drift velocity (possibly diffusion)

  - Laser purchased
  - Cabin material on the way



Offered at the discussions for the nextAIDA through WG3



General R&D

- Resistive microbulk Micromegas
  - Should allow safer operation at higher gains
  - For the moment, radioactivity measurements are not Good
    - Active R&D with MPT@CERN
  - Batch of small detectors to characterize should arrive in the next days

At MPT/CERN
tests at 500V ok
checks at 700V pending

Comments

Although driven by our primary interests in baby(IAXO) and TREX-DM

- Baby(IAXO) optimizes all parameters for the most sensitive Helioscope
- TREX-DM offers a technology that can be very sensitive to low-mass WIMPs

Open detector challenges being addressed: Mostly encompassed in DRD1

- Improve the radiopurity of detectors of this type in order to reduce their intrinsic background
- Improve the energy threshold of detection (by improving operational gain and/or EM noise)
- Improve general robustness of detector, technical design choices, novel gas mixtures and operation points, etc. to facilitate future implementations: scaling-up to larger detector sizes, handling large readout granularity, etc

- **Busy past has shown the way to… a busy future ahead**
- **Continuous R&D gives birth to 'spin-off' projects of great interest**
  - AlphaCAMM for Alpha Surface contamination
  - Laser setup for gas characterisation even at HP

Dziękuję