Wavelength-shifting optical amplification structures for future Dark Matter searches.

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on behalf of the WLS FAT-GEM work group*

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*see the last slide for complete list of authors

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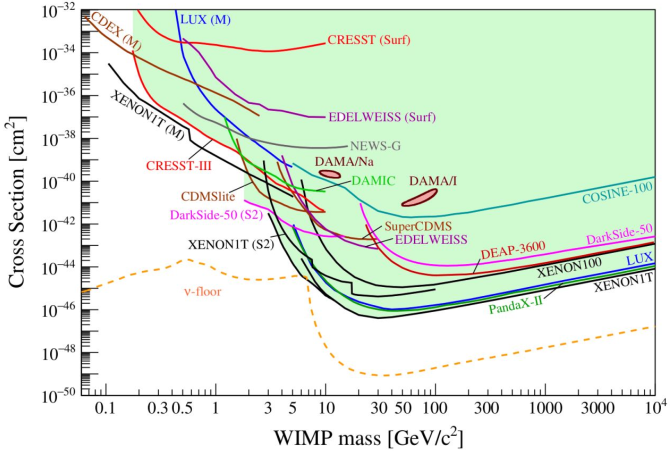
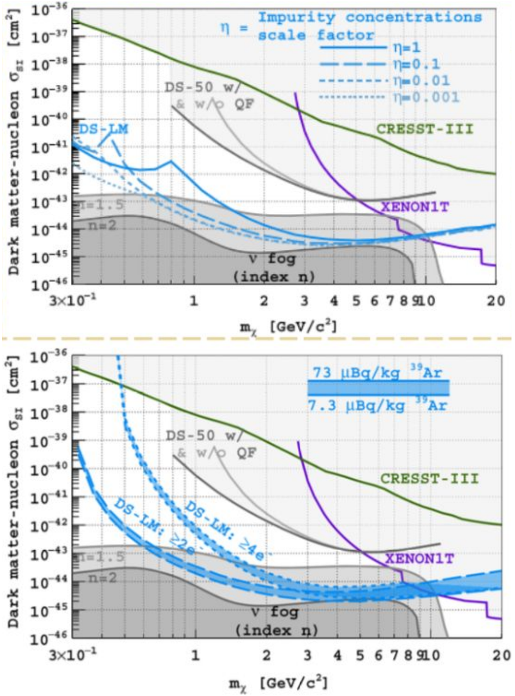
Dark Matter detection challenges

Dual-phase detectors are a preferred choice in **Dark Matter searches** (XENON, LZ, DarkSide). Detection rely on **electroluminescence** mechanism in the gas phase where **large area wire planes or meshes** have been employed so far:

Dark Matter Low-Mass challenges:

- Improving the background rejections
- Lower detection threshold
- Larger exposure (mass x time)





How to tackle this?

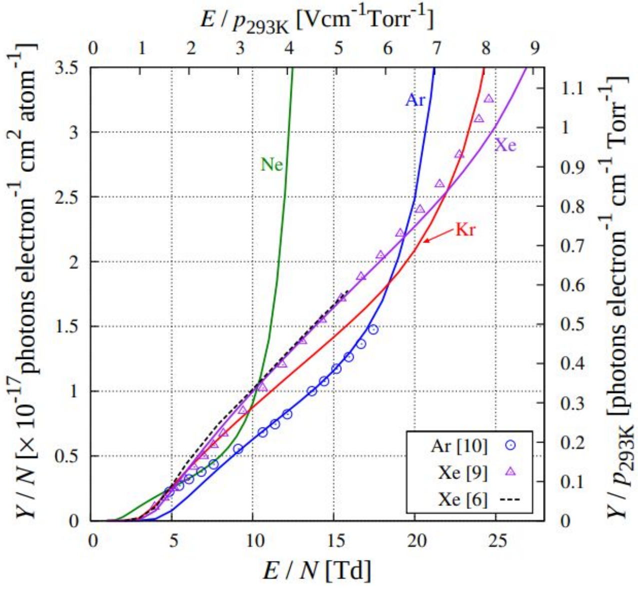
Dark Matter detection challenges

Dual-phase detectors are a preferred choice in **Dark Matter searches** (XENON, LZ, DarkSide). Detection rely on **electroluminescence** mechanism in the gas phase where **large area wire planes or meshes** have been employed so far:

Electroluminescence:

- No charge multiplication.
- No ion feedback.
- Linear response with reduced electrical field.
- Less fluctuations in collected signal compared to charge multiplication.

Excitation and ionization → Deexcitation → **Scintillation** photons are emitted



(C. A. B. Oliveira et al., Phys. Lett. B, 703 (2011) 217-222.)

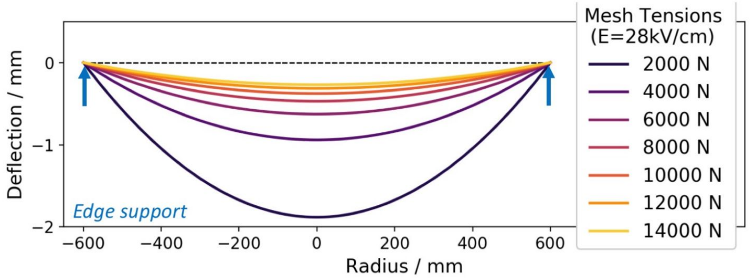
** Ar VUV scintillation not compatible with commercial photosensors

Dark Matter detection challenges

Dual-phase detectors are a preferred choice in **Dark Matter searches** (XENON, LZ, DarkSide). Detection rely on **electroluminescence** mechanism in the gas phase where **large area wire planes or meshes** have been employed so far:

Wires and meshes provide **great energy resolution BUT difficulties to scale up:**

- Loss of tension with time
- Lack of modularity
- No option of direct coupling to solid WLS
- Difficulties at extracting e- from the liquid-gas interface

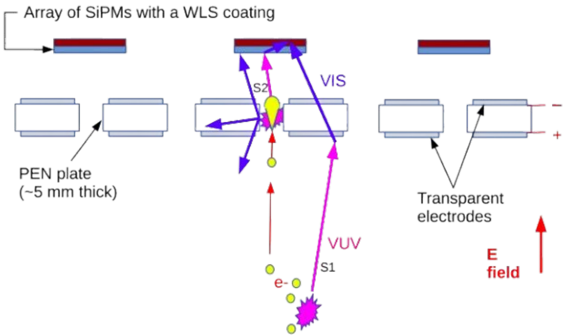


Recent R&D towards novel optical amplification structures…

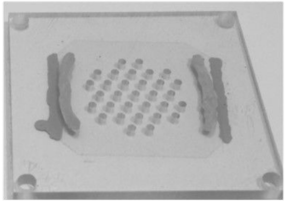
Field Assisted Transparent Gaseous Electroluminescence Multiplier (FAT GEMs)

- Integration with **WLS coatings**
- Modular, **tileable**, and **radiopure**
- Robust mechanical design

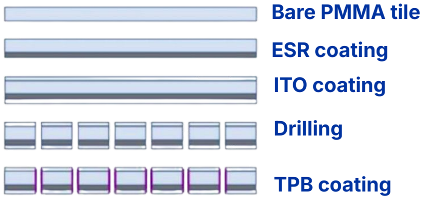
Brief FAT-GEM history



- **HP Xe TPC**
- **Radiopure**
- Translucid



- **Transparent bulk material**
- **PEN as WLS**

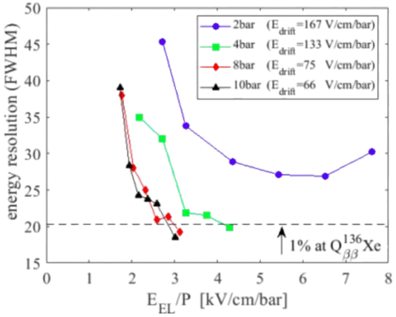


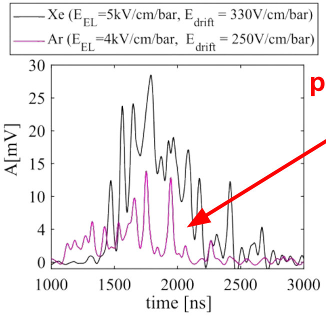
(D. González-Díaz et al., J. Phys. Conf. Ser., 1498 (2020) 012019.)

(M. Kuźniak et al., Eur. Phys. J. C, 81 (2021) 609.)

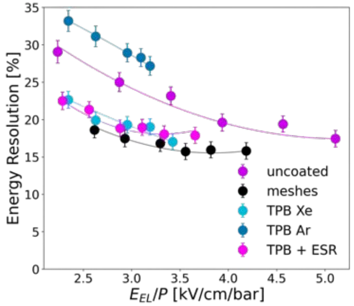
(S. Leardini et al., Sci. Technol. 2 (2024) 1373235.)

2020 — **2021** — **2024** — **Present**



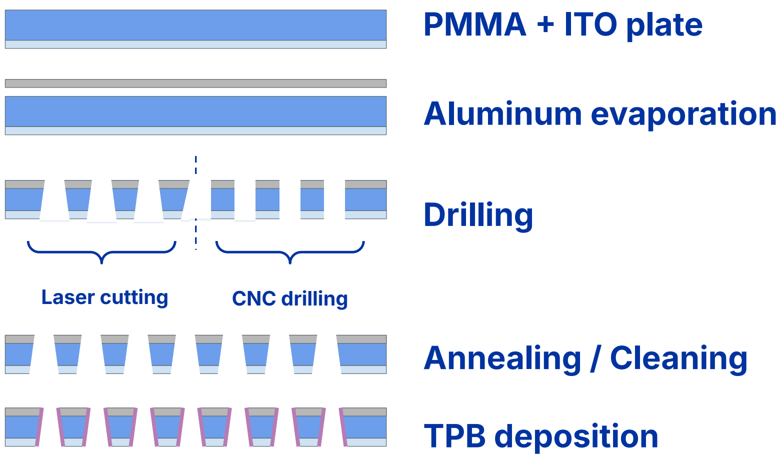


Ar blind photosensor!



New production @AstroCeNT

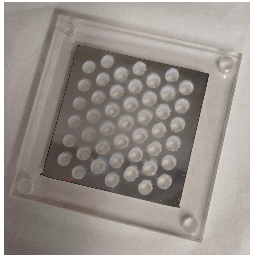
AstroCeNT is carrying out a new production being completely autonomous and developing a manufacturing procedure based on **clean, low radioactive** and **customizable** techniques.



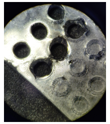
Upgrades from last production:

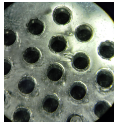
- **Laser cutting** techniques make drilling step **clean** while allowing for a **faster scaling-up**.
  - **Conical holes** potentially having a beneficial impact on light yield.
- **Aluminum electrode** evaporated replacing ESR film.
  - Removes observed charging up keeping reflectivity at similar values.
- Adhesive ITO replaced for **magnetron sputtered ITO**.
  - Higher transparency (from 80% to 90%)

Production @AstroCeNT

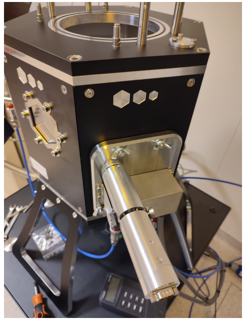


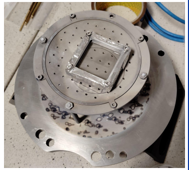
Laser cutting

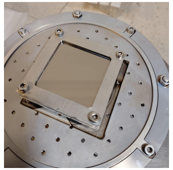




Aluminum evaporation

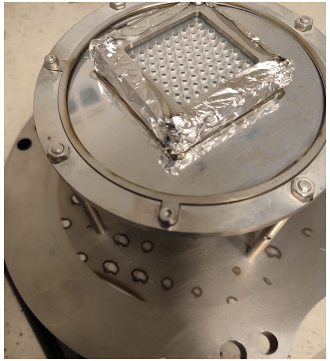




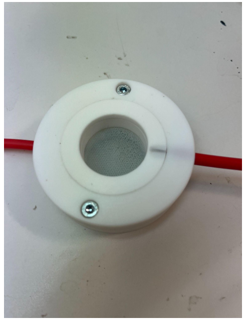


Annealing

WLS evaporation



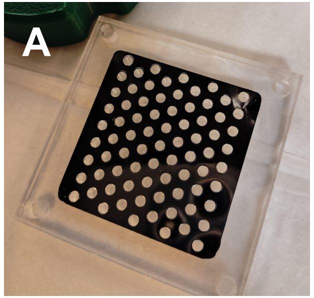
Testing

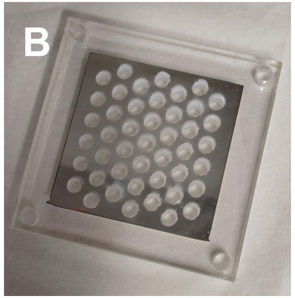


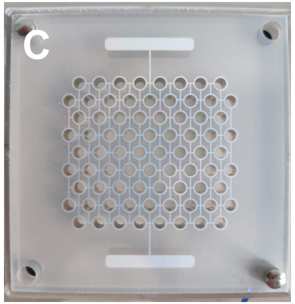
Experimental Campaign

A batch of structures with different configurations was produced and shipped to **IGFAE**, Spain where they were tested during summer.

Structure	Size (cm^2)	Hole diameter (mm)	Pitch (mm)
A	5x5	2	4
B	5x5	3	5
C*	7x7	2	4





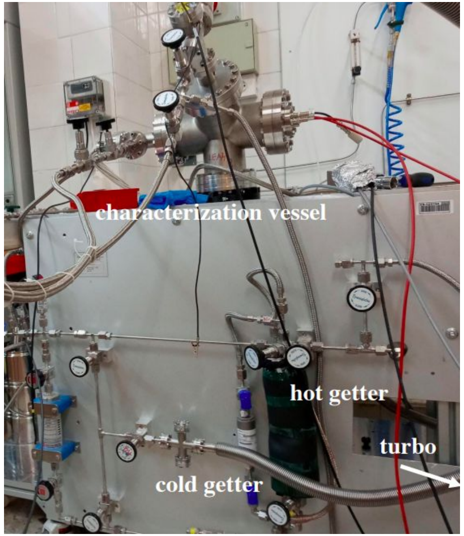


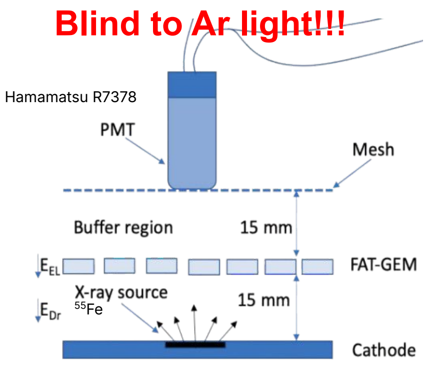
- First step, characterization of these structures before cryogenic tests.

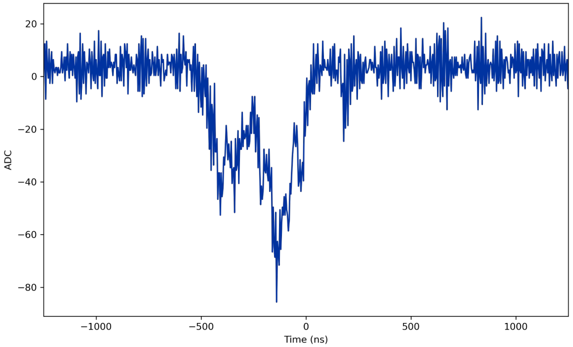
* Produced at CERN workshop

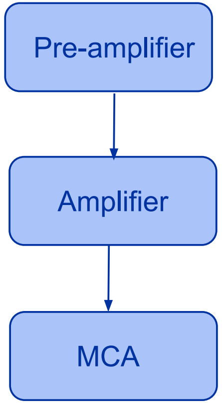
Setup @IGFAE, Spain

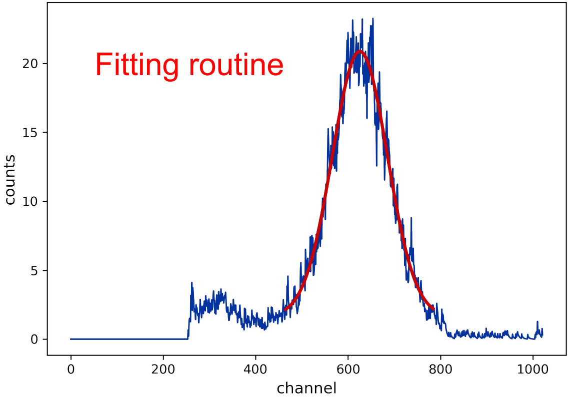
Tests performed in gaseous **Ar** at **4 bar and 293 K → equivalent density to cryogenic operation** (1 bar, 87.5 K)

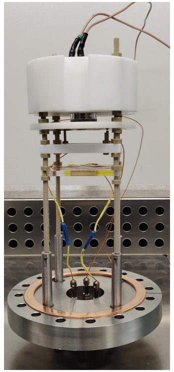




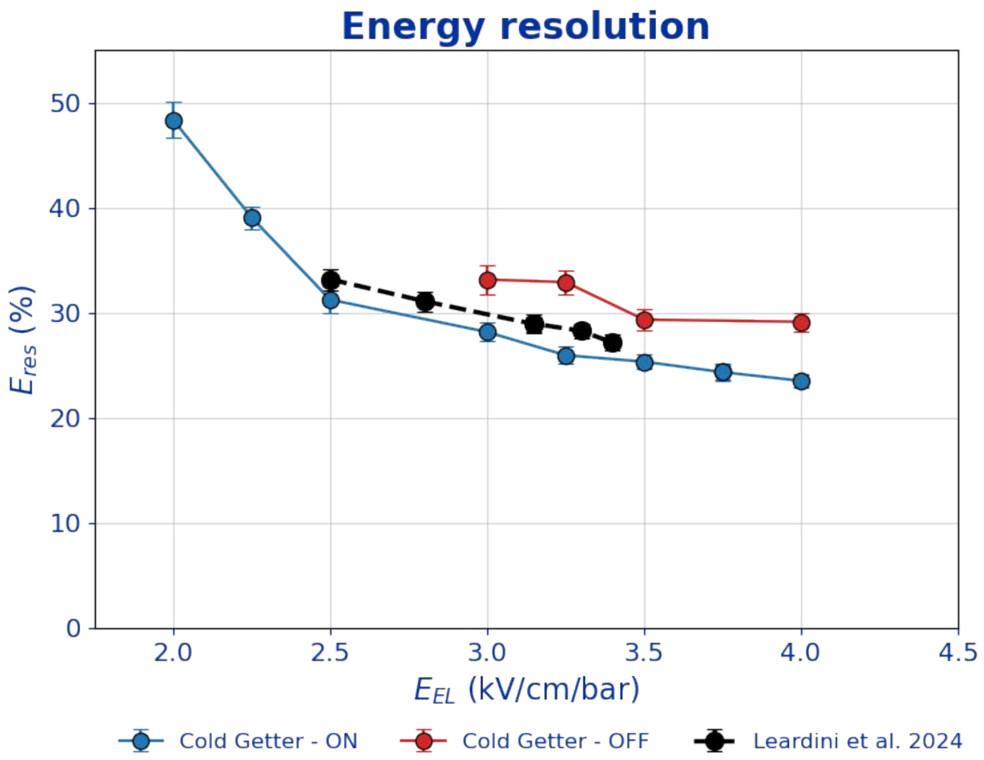




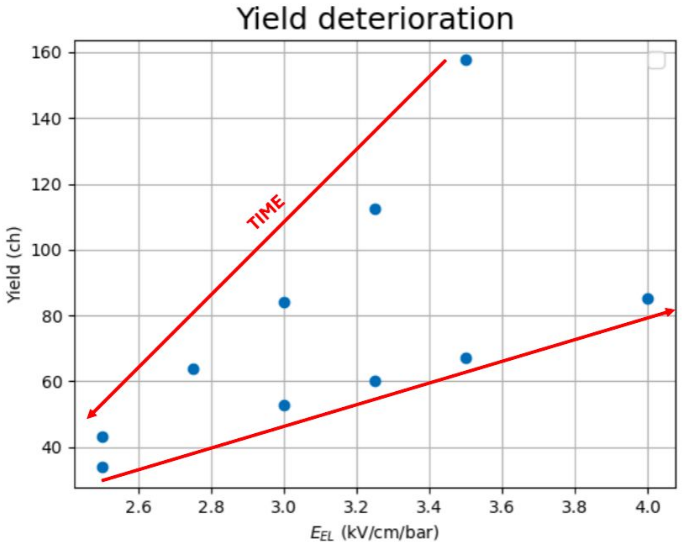




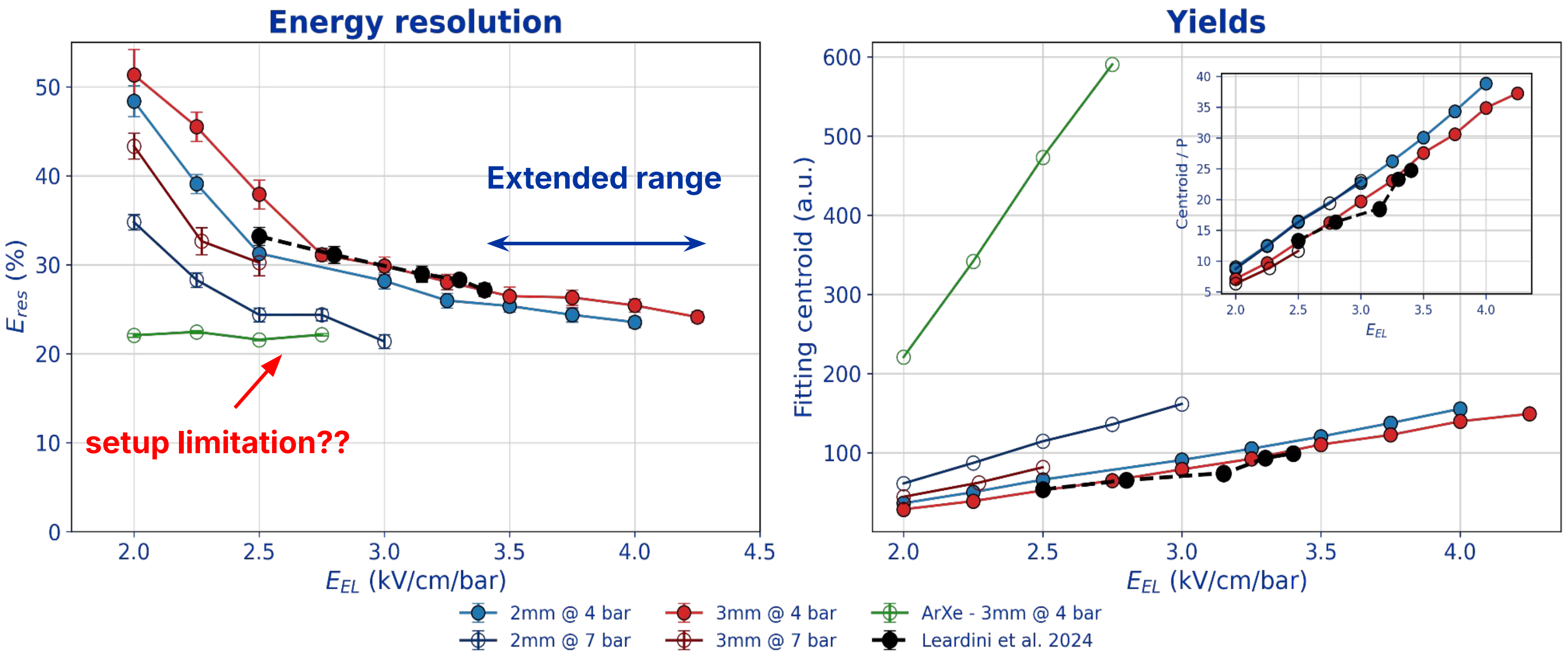
Results (I)



- Fast Ar deterioration was observed.
    - Differences of ~15 min had an impact.
- Need of a purification system: **cold getter**



Results (II)

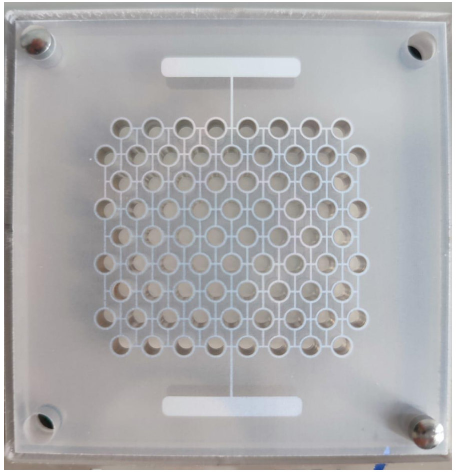


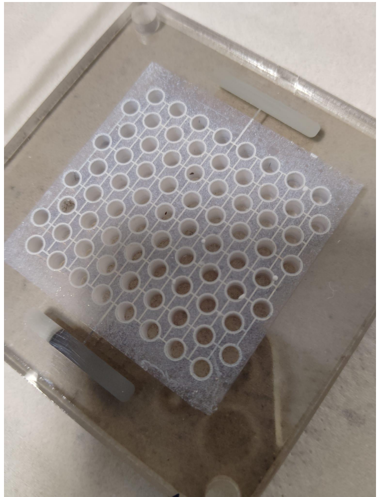
A B

Ongoing Work

Batch of structures produced ar **CERN Workshop** are being tested right now at IGFAE

- **Semi-transparent electrode** allowing for S1 detection
- First tests with 5.5 MeV alpha source
- **Smooth operation**, no strong indication of charging-up from TPB at the FAT-GEM cathode





Ongoing Work

- Batch of structures produced ar CERN Workshop are being tested right now at IGFAE
    - **Semi-transparent electrode** allowing for S1 detection

- New structures produced at AstroCeNT to be tested in Warsaw in **cryogenic conditions** as a first approach to dual-phase applications.

- **Simulations**:
    - Optimize optical response (WLSE and light collection)
    - Understand effects of hole size variations and shapes in detector response.

ArGset @CEZAMAT

S. Choudhary et al 2024 JINST 19 C05019

GSI

IGFAE
Instituto Galego de Física de Altas Enerxías

universidade de aveiro

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CERN

DRD1
Gaseous Detector Technologies

INFN PADOVA
Istituto Nazionale di Fisica Nucleare
Sezione di Padova

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[7]LIBPhys-UC, Department of Physics, University of Coimbra, Portugal.

Conclusions

- Exploring Dark Matter Low-Mass regions requires significant technological developments
- New developments of optical amplification structures will help to tackle these challenges
- Recent success in terms of new production techniques
- Promising results with room for improvement
  - TPB deposition not optimized
- Two batches waiting to be tested:
  - AstroCeNT – cryogenic operation
  - CERN – sensitivity to S1

Thank you!

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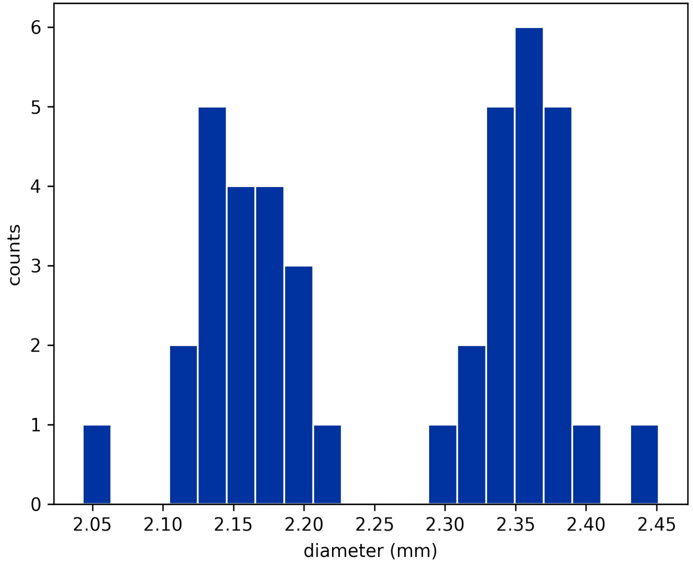
Laser drilling

Hole size characterization



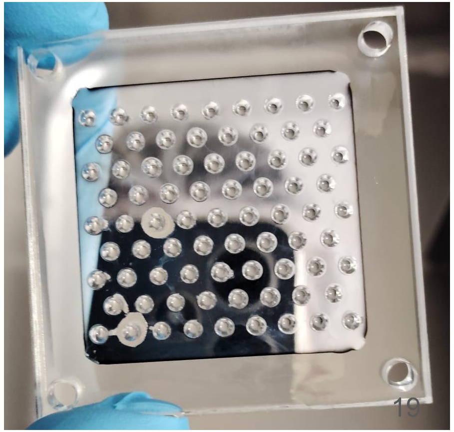
- **Side down:** 2.157 ± 0.034 (mm)
- **Side up:** 2.358 ± 0.026 (mm)

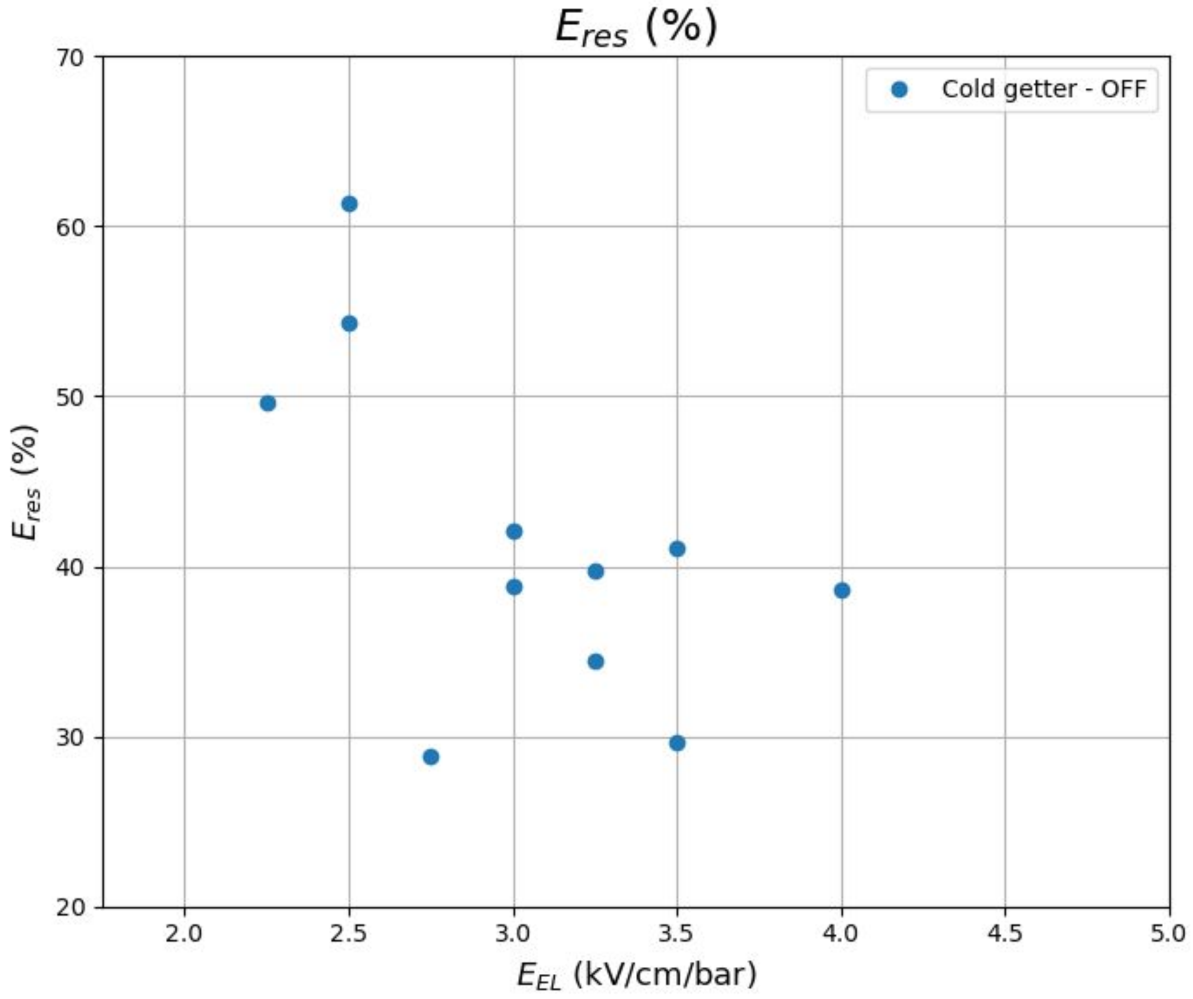
Annealing / Cleaning + TPB deposition

- **Laser drilling** exposes the bulk material to localized high temperatures that produces stress in it. **Annealing** is needed to reduce the stress and recover material properties.

- **CNC drilling** might leave residual oils or other materials in the holes. A cleaning process is needed to reduce impurities.
    - Ultrasonic bath is very aggressive and might end up removing the Aluminum layer.
    - Specific soap and brushes were used.

- **TPB** was deposited in the holes of the structures. However, there might be some uniformities in them.




E_{res} (%)
Cold getter - OFF
70
60
50
40
30
20
2.0
2.5
3.0
3.5
4.0
4.5
5.0
E_{res} (%)
E_{EL} (kV/cm/bar)