Laser-based production of GEM-like structures for cryogenic applications

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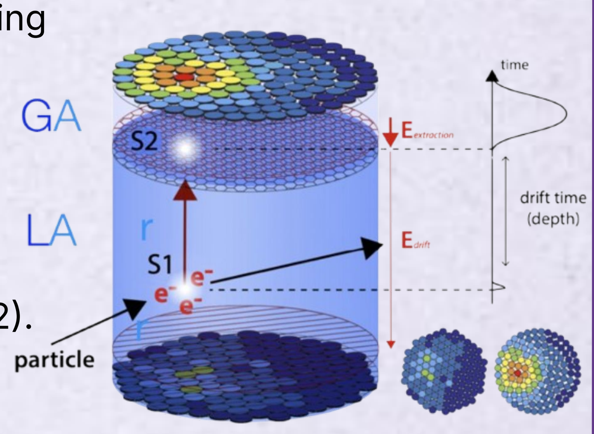
Introduction

- Dual-phase Time Projection Chambers (TPCs) are the leading technology for dark matter direct detection (LZ, XENONnT, DarkSide-50) and neutrino physics (DUNE).
- Particle interactions in the liquid produces a prompt scintillation signal (S1). The ionisation electrons from this interaction drift to the liquid–gas interface, where electroluminescence (EL) generates a secondary signal (S2).
- Next-generation detectors aim for tens-of-tonne target masses → EL amplification must scale to square-meter areas.

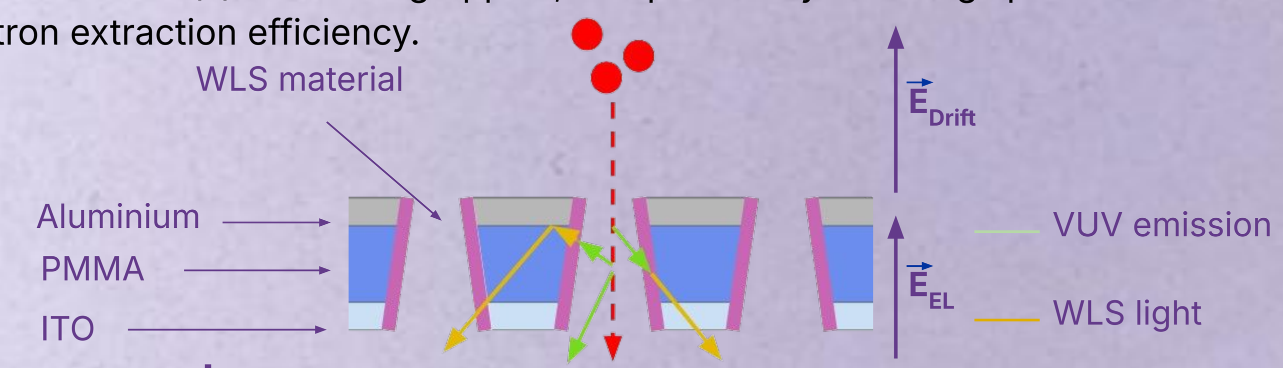


Key challenges:
- Standard meshes/wire planes sag/deform when scaled up, causing non-uniform EL fields
- Common photosensors have low sensitivity to argon's VUV emission (128 nm).
- Liquid-gas interface effects (ripples, spurious electron emission) affect signal quality.

Solution:
- Field Assisted Transparent Gaseous Electroluminescence Multipliers (FAT-GEMs)
– a mechanically robust, low-radioactivity, scalable alternative to meshes.

FAT-GEM

- Based on MPGD technology, but much thicker (mm-scale) than standard GEMs:
  a. Extra thickness → larger EL-gap → higher EL yield, less charge multiplication
- Bulk material (PMMA) is radiopure; its rigidity reduces sag/deformation, keeping EL fields uniform.
- Holes coated with a wavelength shifting material (WLS), TPB, to convert VUV photons (peaked at 128 nm) into visible light (~420 nm), matching standard photosensor sensitivity
- Simple/low-cost production → easily tileable for large-area coverage.
- EL field is confined to hole(s): containing ripples; and potentially reducing spurious electron emission & improving electron extraction efficiency.

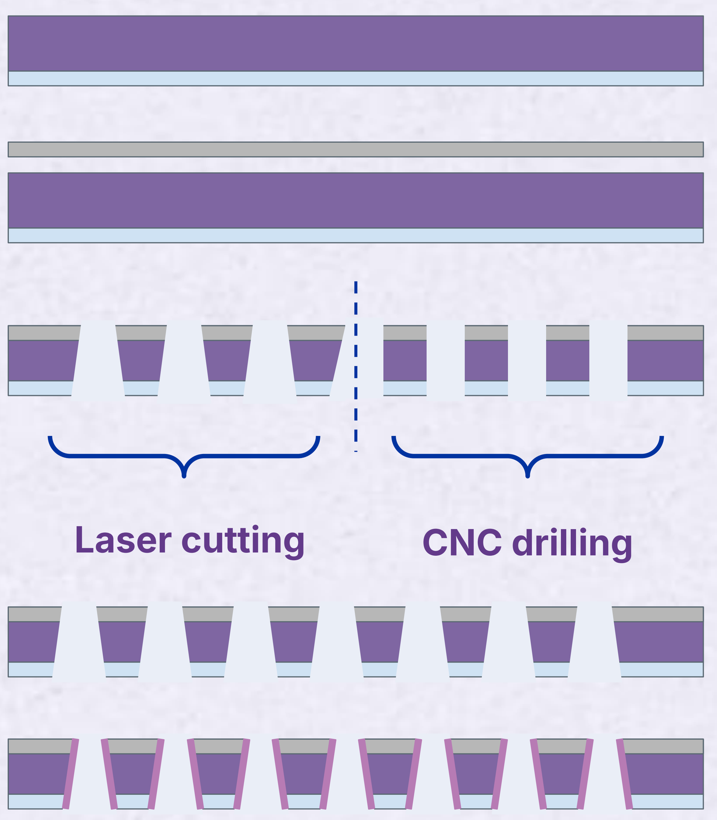


Production upgrades:

FAT-GEMs with WLS capabilities have been fabricated and characterised previously [2,3]. Here we introduce some manufacturing upgrades to improve performance in pure Ar and at cryogenic conditions

- **Remove ESR + ITO adhesive layers** → Aluminium directly deposited into the PMMA plate.
  - Transparency improved (**80% → 90%**, 420 nm)
- Use of **clean and scalable technique** (laser drilling)

Manufacturing process



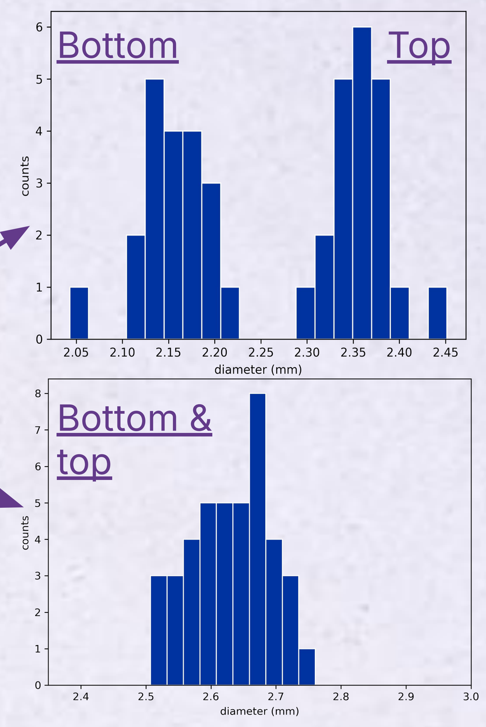
1) PMMA + ITO plate

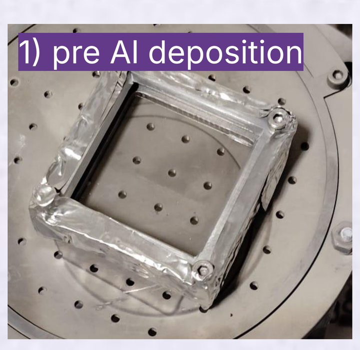
2) Aluminium deposition

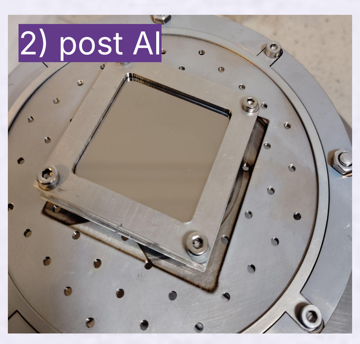
3) Drilling — Laser cutting / CNC drilling

4) Annealing / Cleaning

5) TPB deposition



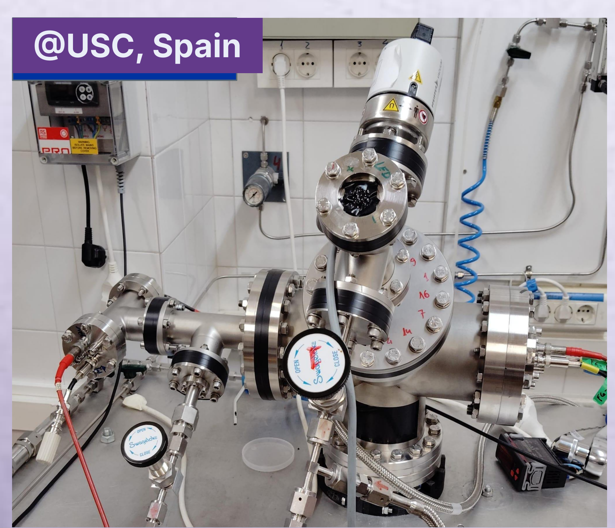


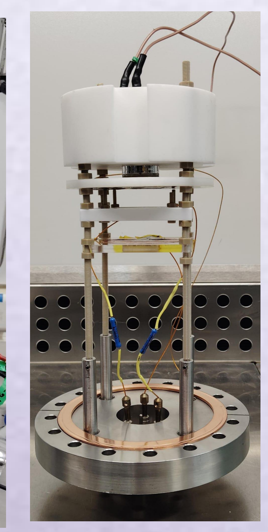


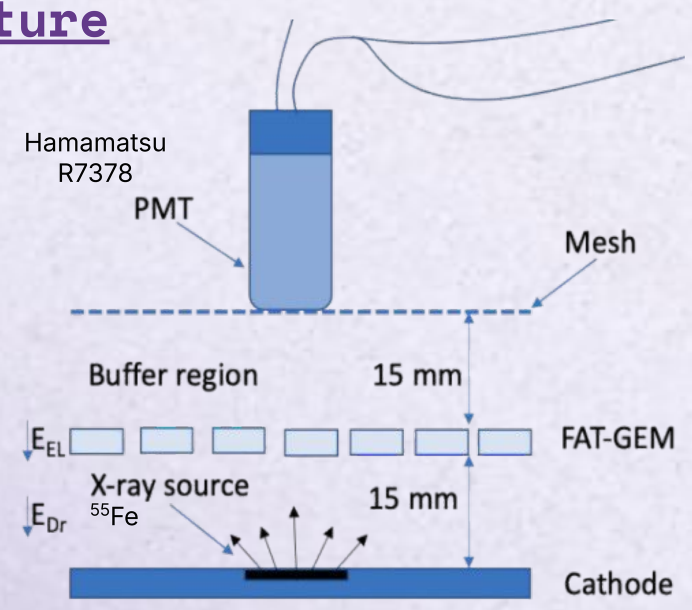
1. **Sample preparation**: ITO-coated PMMA plates cut to size, ultrasonically cleaned, dried, and edge-masked.
2. **Aluminium evaporation:** A vacuum evaporator is used to deposit a ~300 nm layer of Al to act as a **reflective electrode** to improve light collection efficiency.
3. **Drilling**: Hole pattern production could be done in two ways
   a. **Laser cutting.**
   b. **CNC mechanical drilling.**
4. **Annealing / Cleaning:**
   a. **Laser-cut samples:** High temperatures during cutting degrade some material properties. A thermal treatment (annealing) is performed afterward to restore them.
   b. **Mechanically drilled samples:** No thermal treatment needed, but residual oils are left in the holes. These are removed with a dedicated detergent.
5. **TPB deposition:** Tetraphenyl butadiene (TPB) is evaporated onto the hole walls to produce a ~1.5 µm thick coating.
6. **Cleaning and packaging:** Residues removed by air-brush, electrodes checked for resistivity, and structures inspected under microscope before being vacuum-packed with desiccant for shipping.

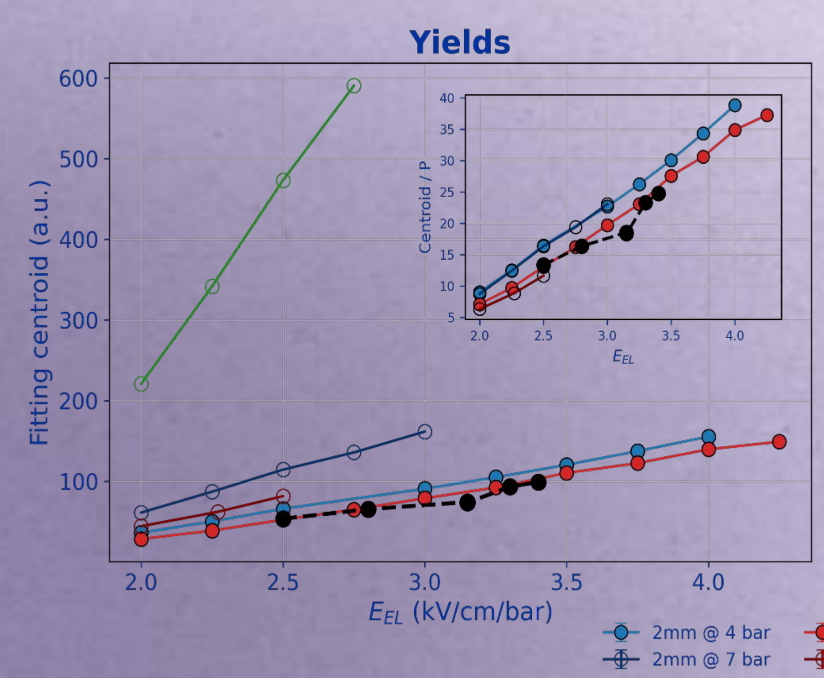
Testing

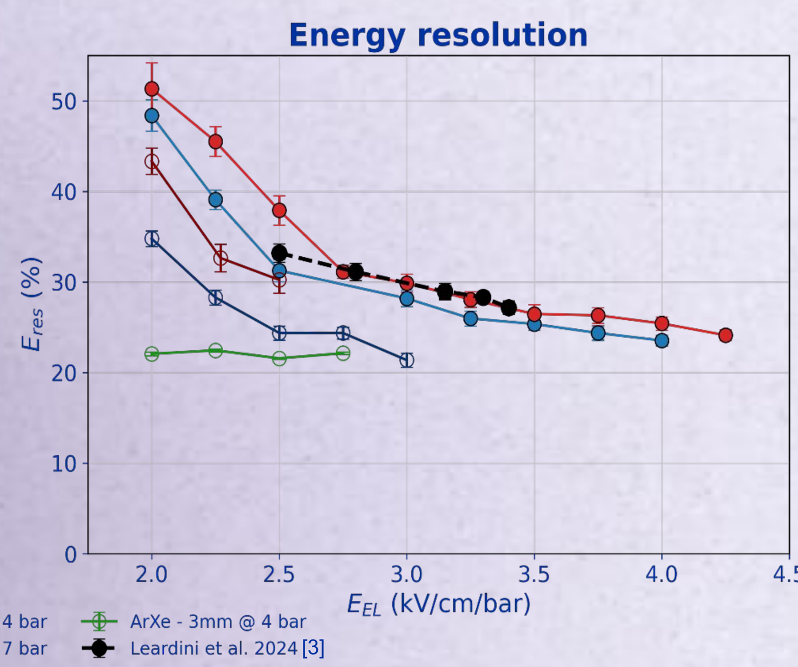
Characterisation at room temperature



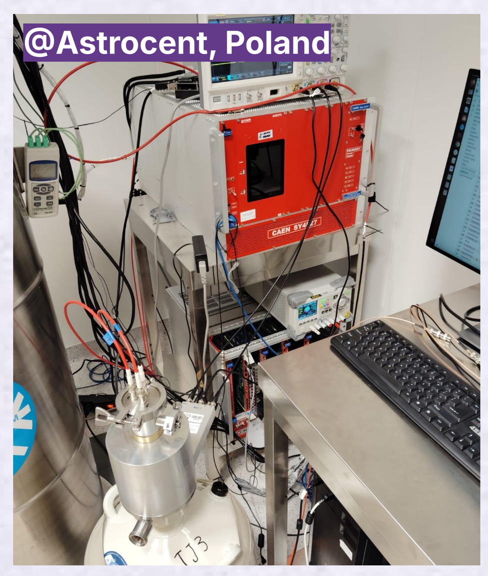


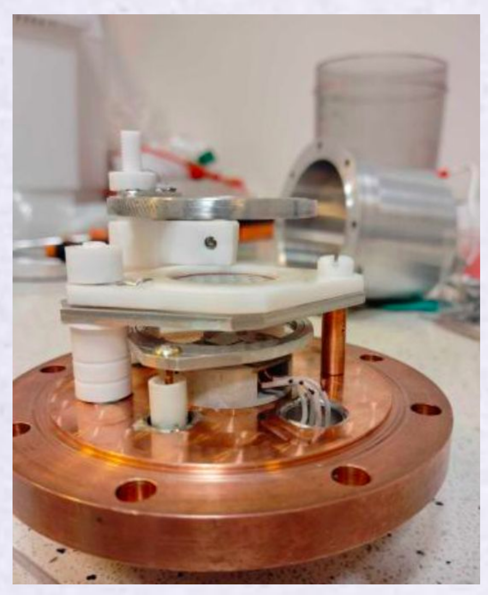


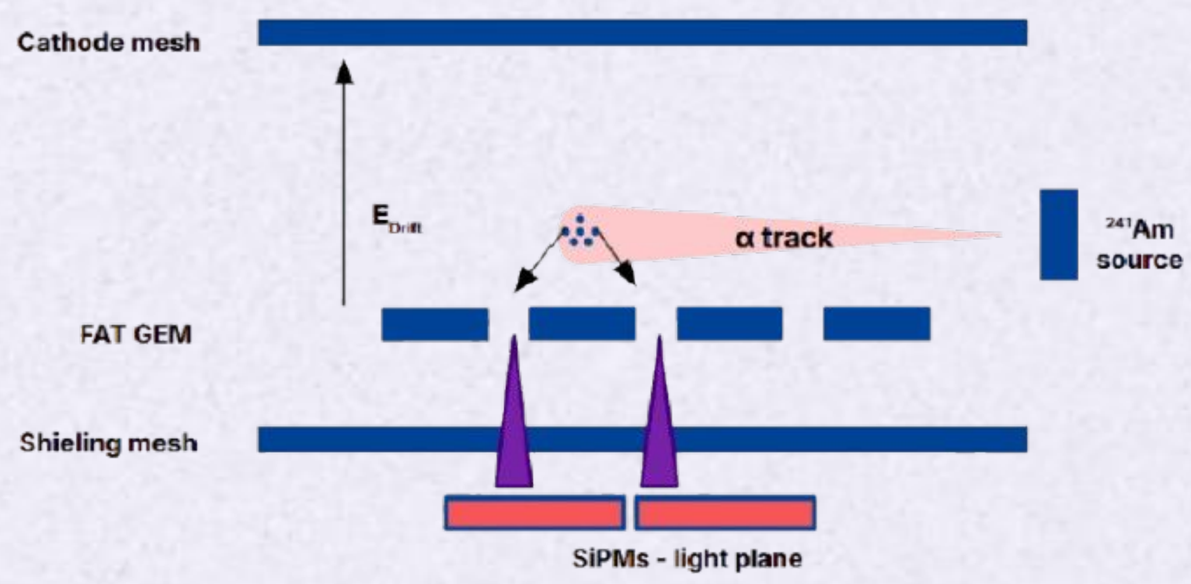


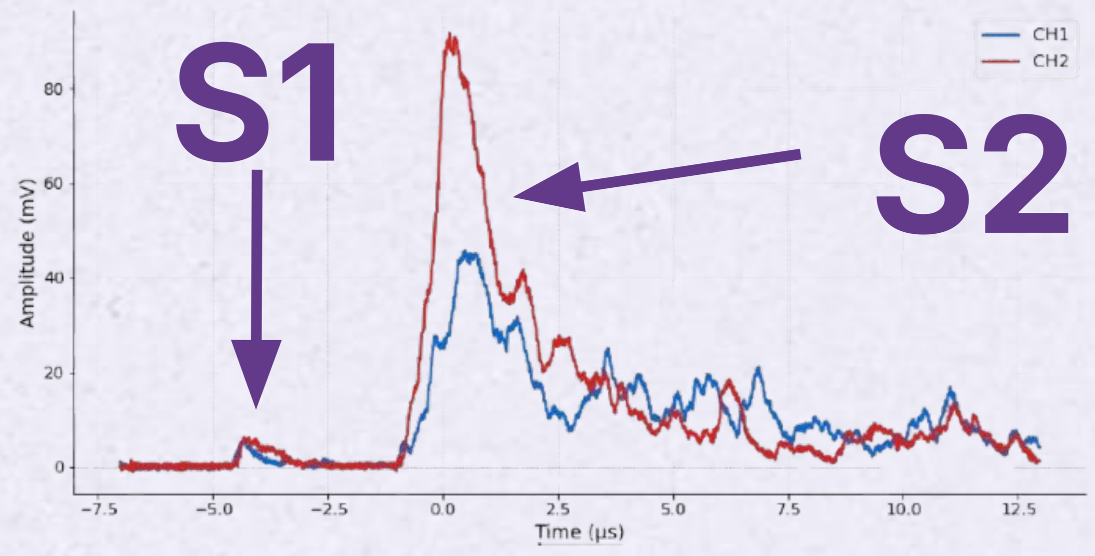


Characterisation at cryogenic temperatures







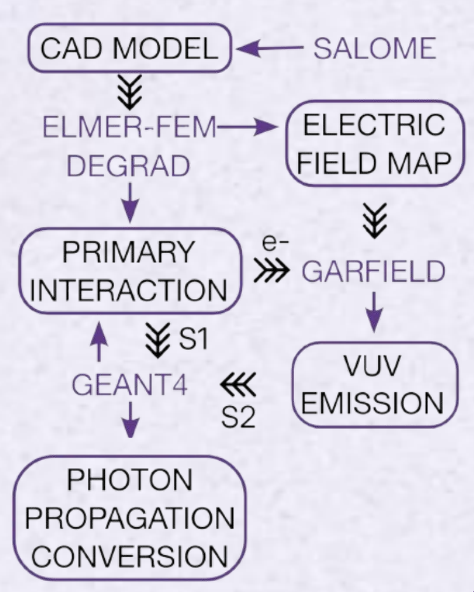


Conclusions

- First batch of FAT-GEMs produced at Astrocent facilities:
  - **Improved performance in Ar (20% higher light yield! [3]).**
  - Intrinsically radiopure & scalable materials.
  - Use of clean and minimally invasive techniques: **laser drilling**.
  - Minimises gas-liquid interface effects (confined to hole-size).
  - Potential to improve electron extraction efficiency.
- Promising technology:
  - Cryogenic operation and floating capability
  - Customisable solution:
    - bulk, electrode, wls materials, shape, hole configuration.

Future Work

- Continued testing of the setup at cryogenic temperatures with other sources (e.g, 55Fe).
- Development of a **full simulation framework** to optimise hole geometries
- Installation & operation in a dual-phase TPC



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