FAT-GEM detectors for operation in noble elements

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European Union ASTROCENT
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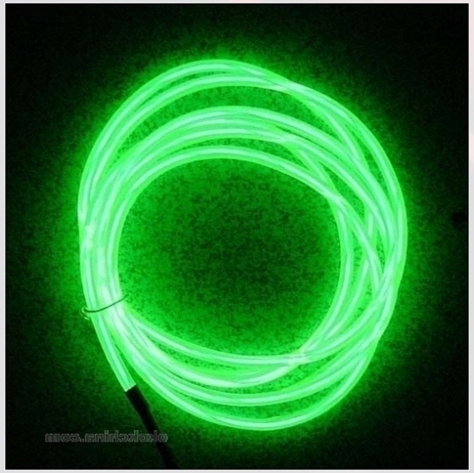
Introduction: electroluminescence



- Introduced by Conde and Policarpo in 1967
- No avalanche multiplication, no ions
- Linear response
- Much less fluctuations in the collected signal than avalanche multiplication
- Optical gains up to 1000s, yet far from the discharge region
- No ion feedback
- Widely used for DM direct detection and neutrino physics, more recently

State – of – art

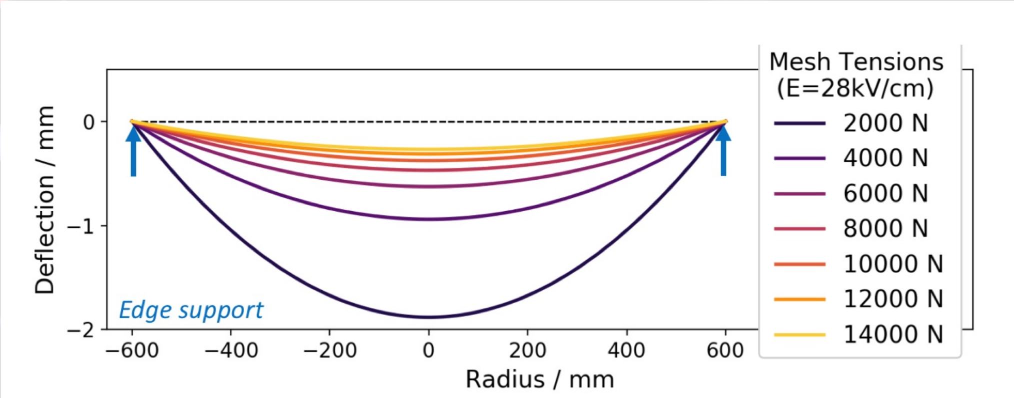
- Meshes (woven, calendered, electroformed, or set as an array of wires) are widely used as secondary scintillation structures in the field of rare event searches
- Excellent energy resolution and ability to detect single-electrons
- Difficult scalability

Loss of tension

mesh-stretching on large areas is complicated

vulnerability to weak points

lack of modularity complicates testing



Rogers et al., 2018 *JINST* **13** P10002

State – of – art

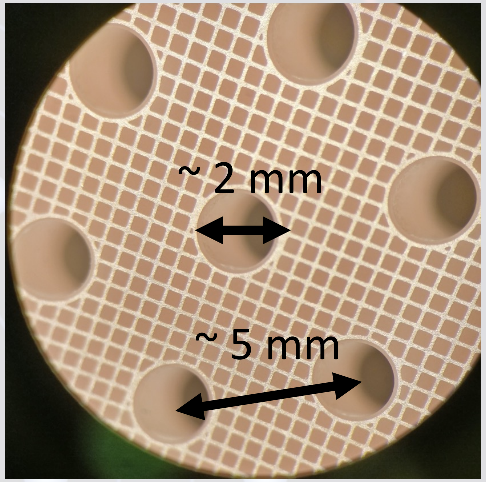
IDEA -> FAT-GEMs

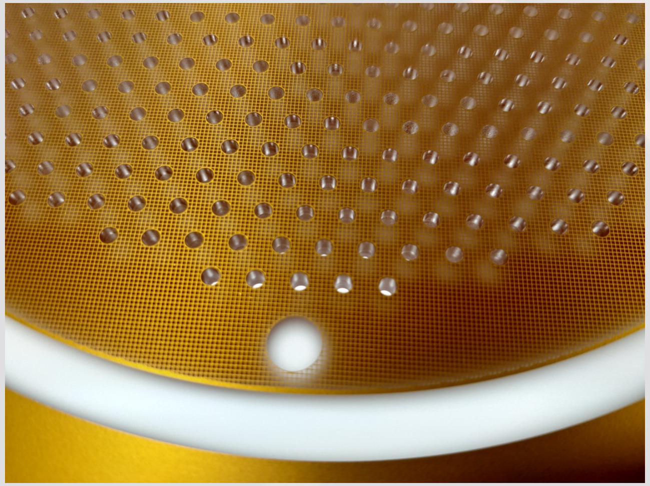
(Field-Assisted Transparent Gaseous Electroluminescence Multiplier)

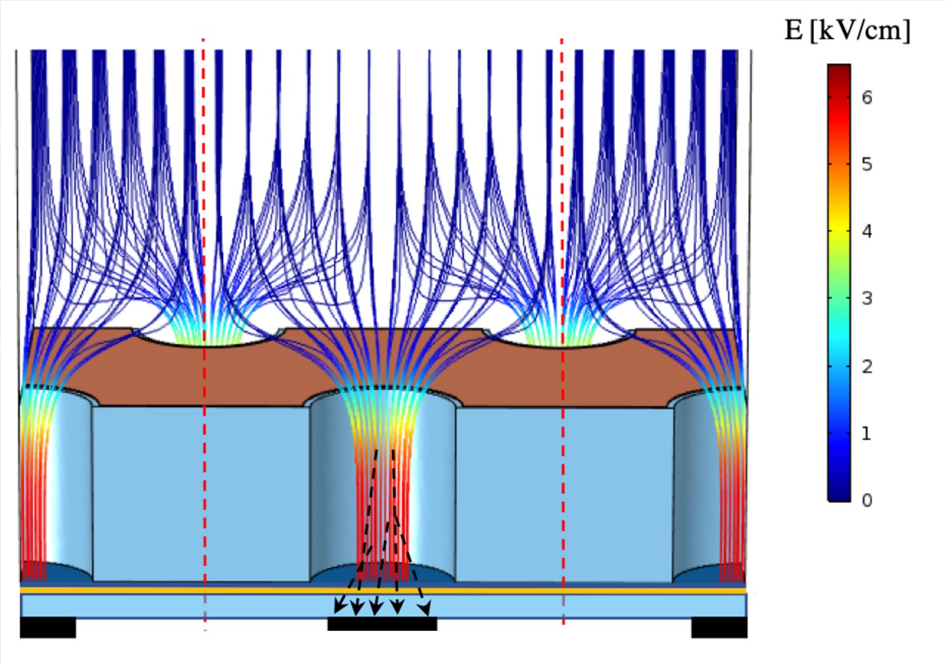
- Scalable
- Radiopure
- Transparent to scintillation

- Similar version but with opaque substrate (Teflon) developed @AXEL

(Ban et al., Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment, Volume 875, 2017, Pages 185-192)



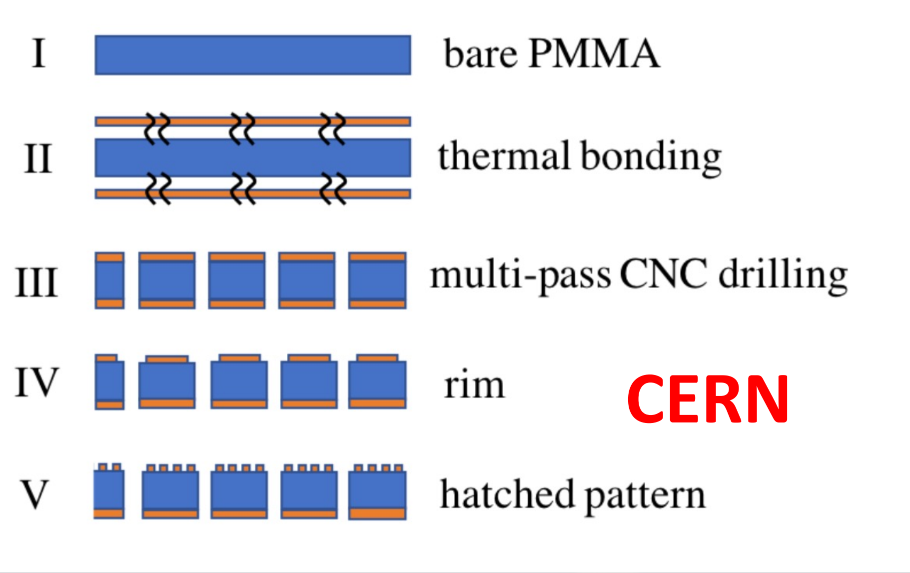




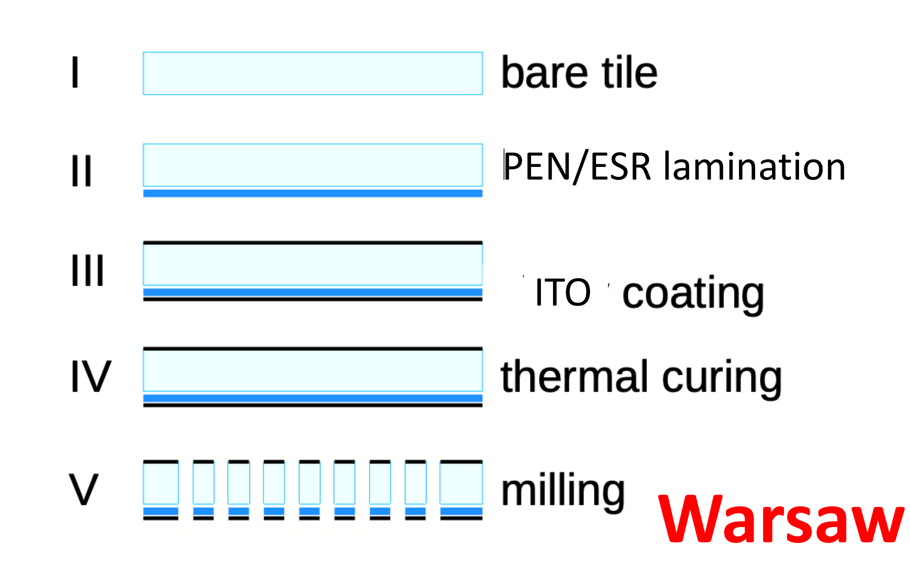
Saa et al., journal of synchrotron radiation, 2021, Volume 28, Part 5

How it’s made

- Fabricated at CERN and at AstroCeNT/CAMK PAN (Poland)
- Bulk made of PMMA (Polymethyl methacrylate) or PEN (polyethylene naphtalate)
- Thermally bonded electrodes / ITO coating
- Area up to 50 cm x 50 cm at least (easily tiled)
- Thickness = 5 mm (!)
  (important for high electroluminescence yields)



D. González-Díaz et al 2020 J. Phys.: Conf. Ser. 1498 012019



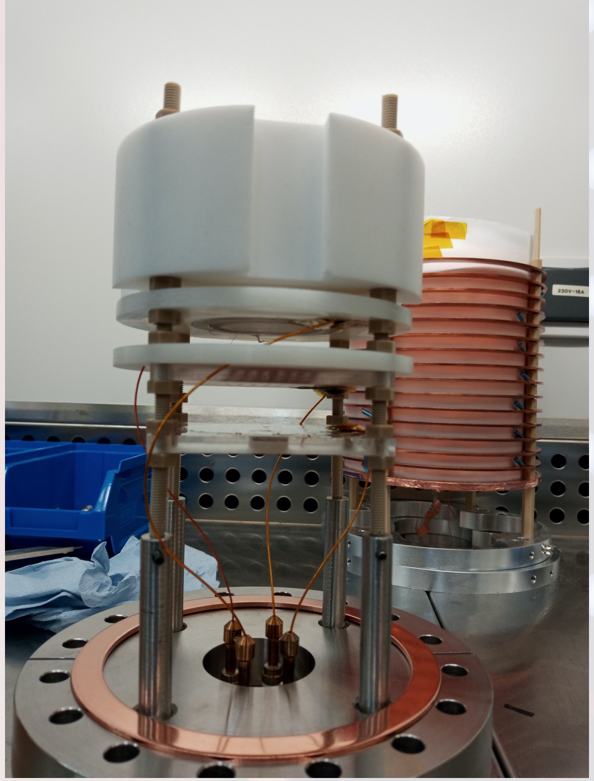
Kuzniak et al., The European Physical Journal C volume 81, Article number: 609 (2021)

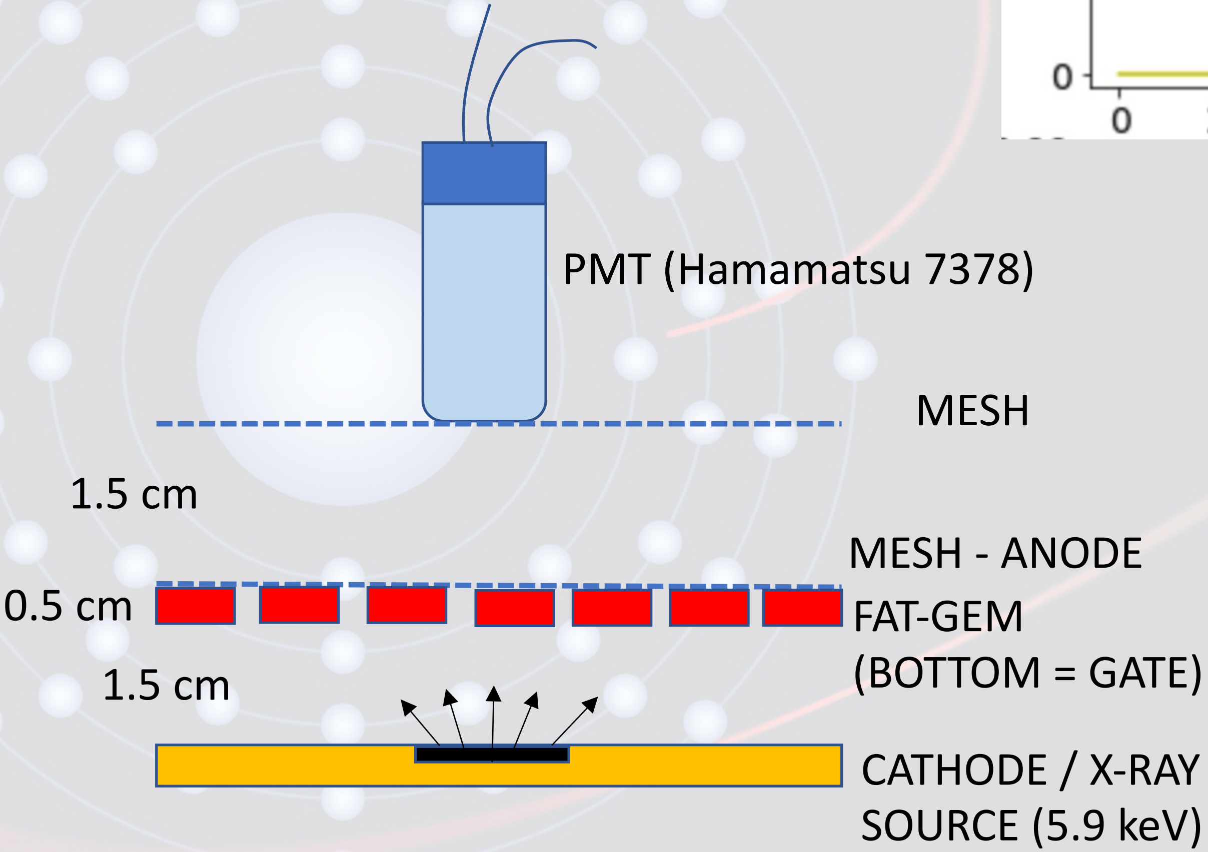
Radiopurity

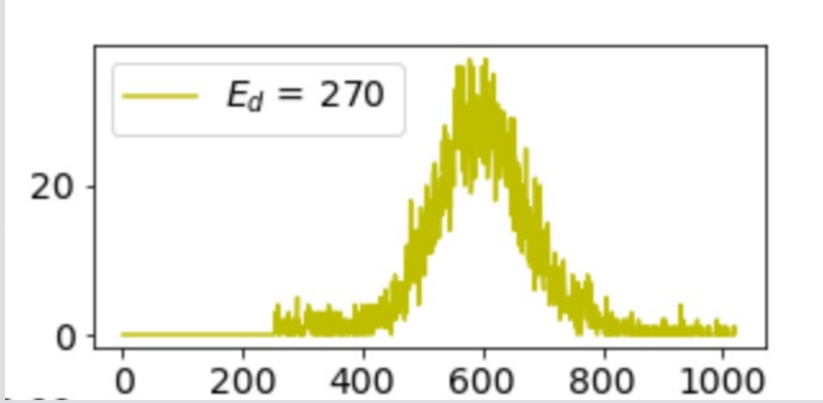
- Radiopurity of FAT-GEM studied at Canfranc Underground Laboratory (thanks to I. Catalin Bandac and S. Cebrián)
- No isotope was detected in 47.7 days!

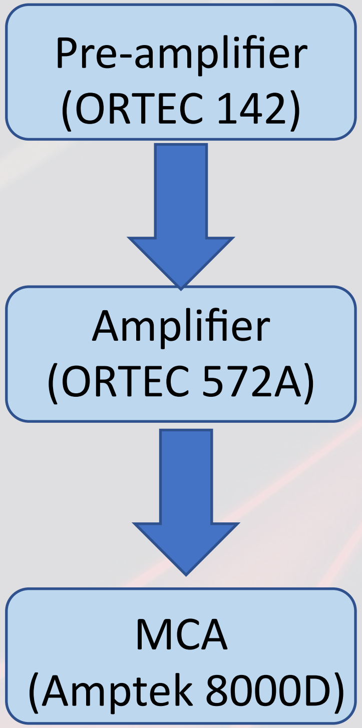
	Acrylic (mBq/kg)	FAT GEM (mBq/cm^2)
U-238/Pa-234m	<340	<0.741
U-238/Pb-214	<2.8	<0.006
U-238/Bi-214	<2.3	<0.007
Th-232/Ac-228	<8.8	<0.021
Th-232/Pb-212	<2.9	<0.007
Th-232/Tl-208	<6.3	<0.014
U-235/U-235	<1.9	<0.006
K-40	<17	<0.036
Co-60	<0.74	<0.002
Cs-137	<1.1	<0.002

Setup - detail









1st part:
non-VUV transparent structures

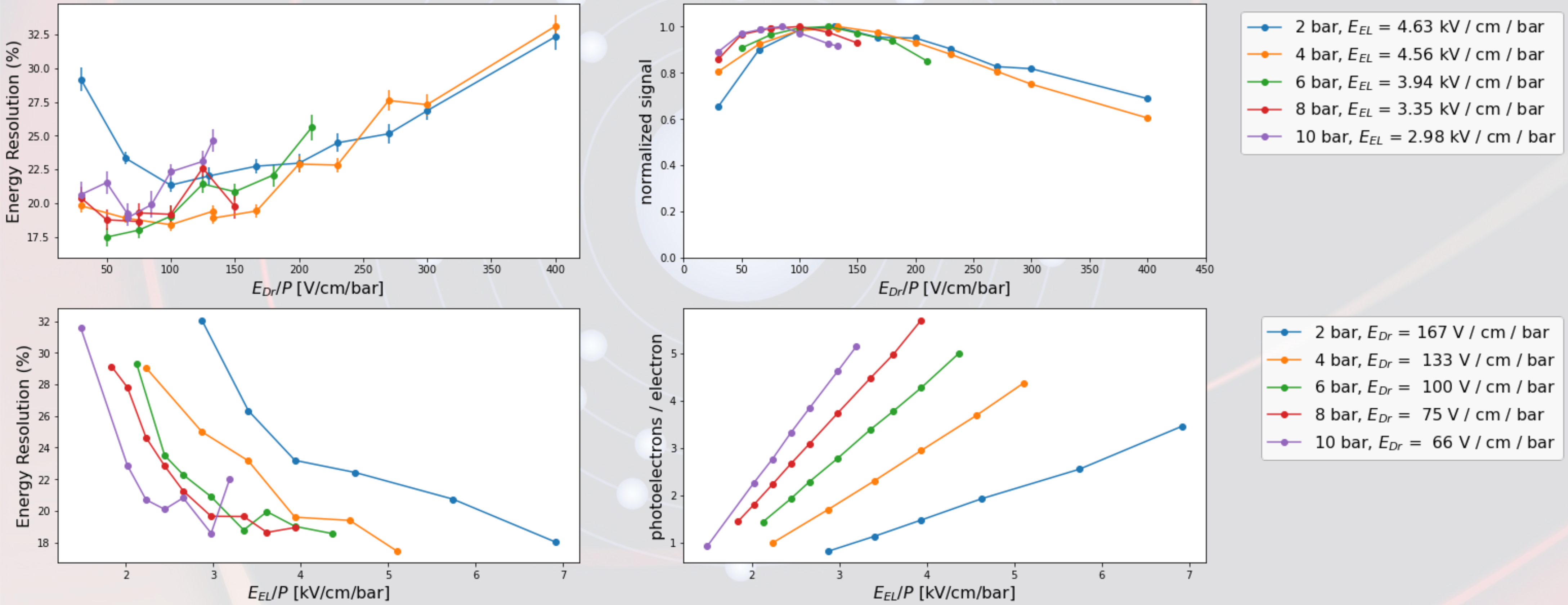
Experimental campaign

- Data taken with 2, 4, 6, 8 and 10 bar of Xenon, 5.9 keV Fe source

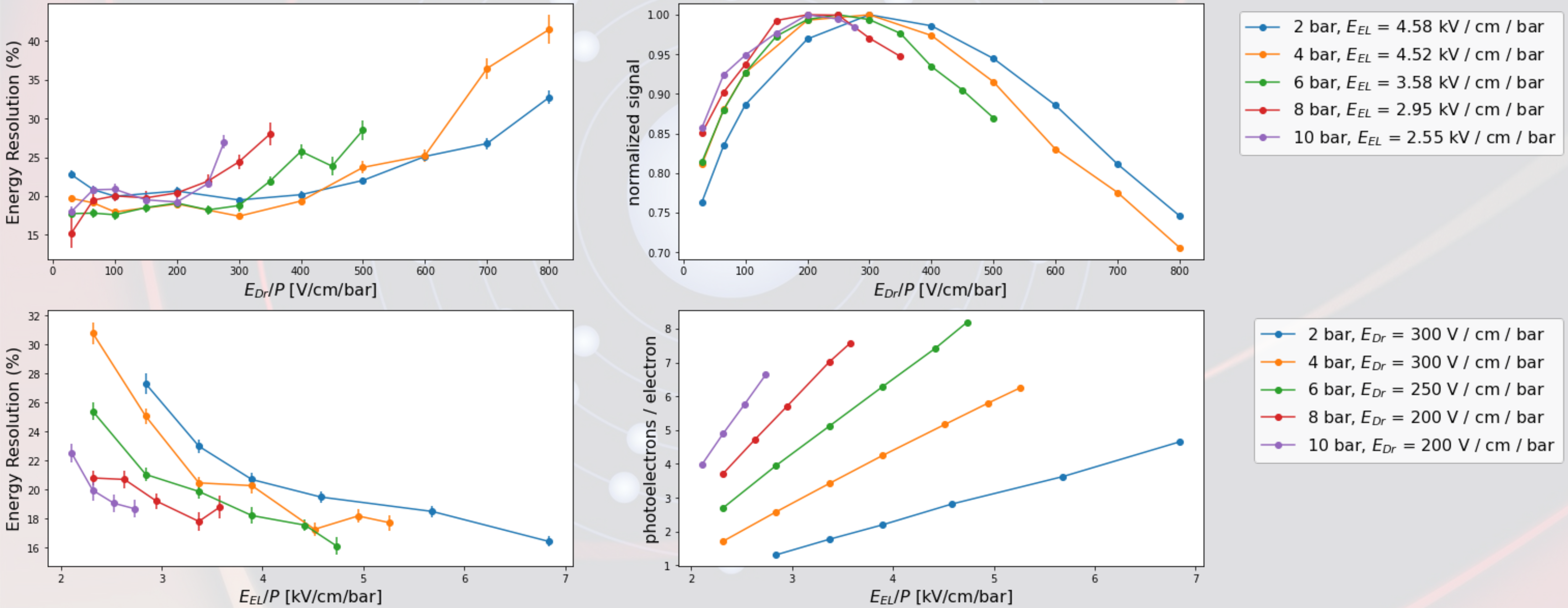
- Structures studied:
  - 2 mm hole, 5 mm pitch
  - 3 mm hole, 5 mm pitch
  - 4 mm hole, 6 mm pitch

- Procedure:
  - scan of drift field with a fixed electroluminescence field (E_{EL})
  - find the optimal drift field (E_{Dr})
  - scan of E_{EL}

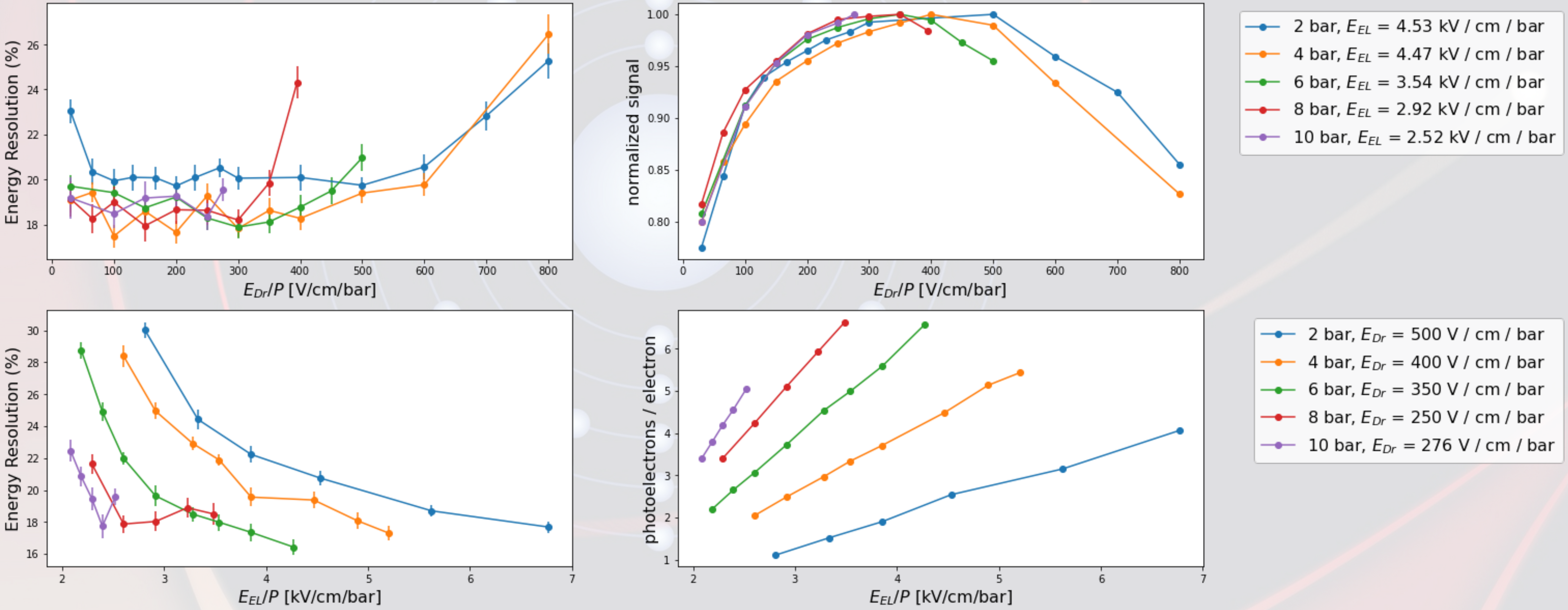
2 mm hole structure



3 mm hole structure

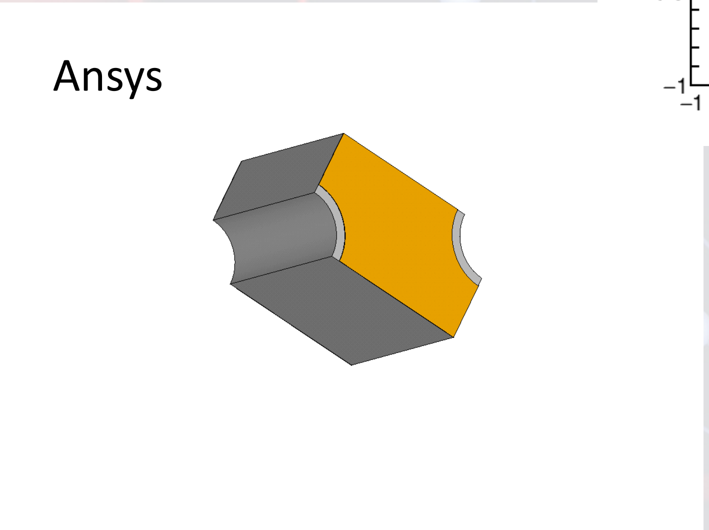


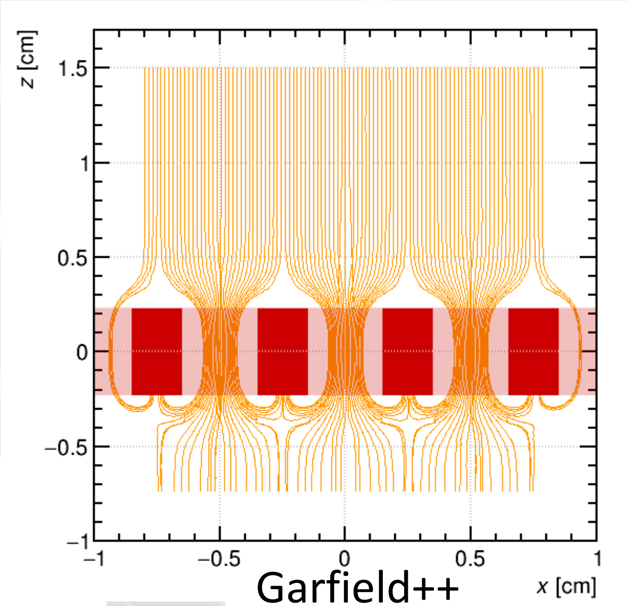
4 mm hole structure



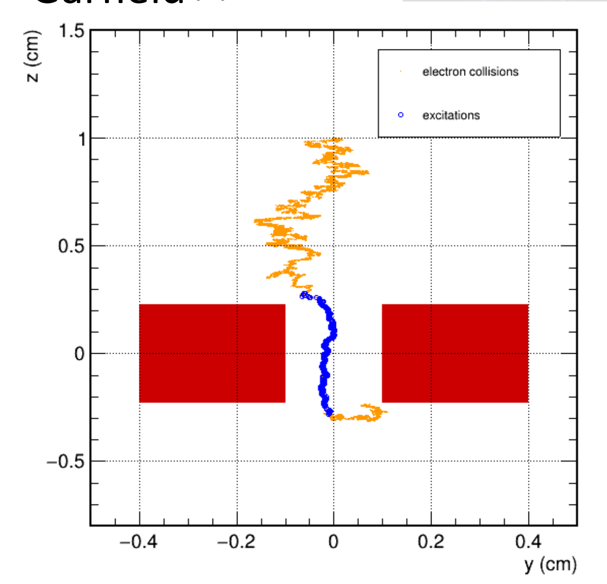
Simulations

- Field lines with Ansys
- Simulated excited states in Garfield++
- Geometrical + quantum efficiency with Geant4

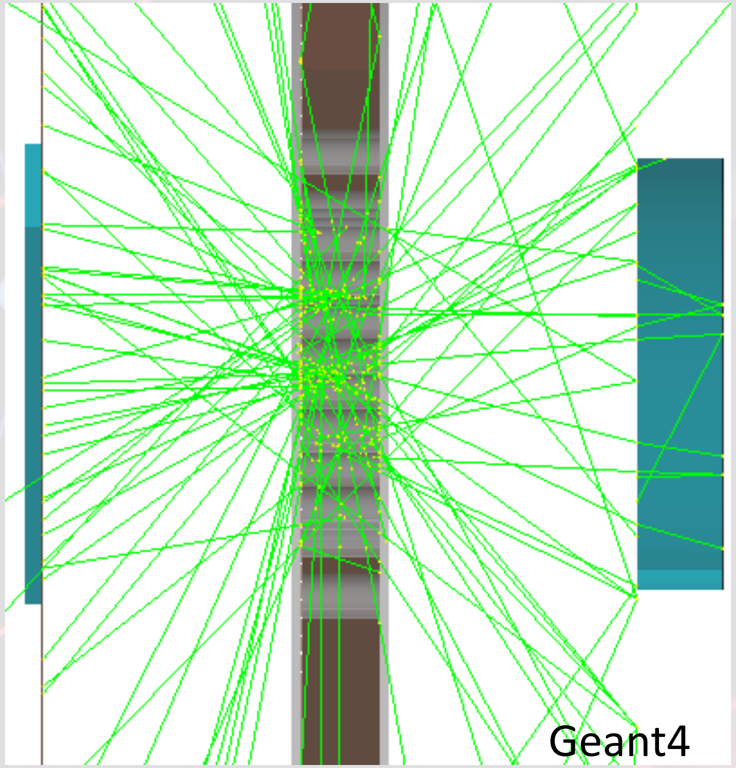




Garfield++



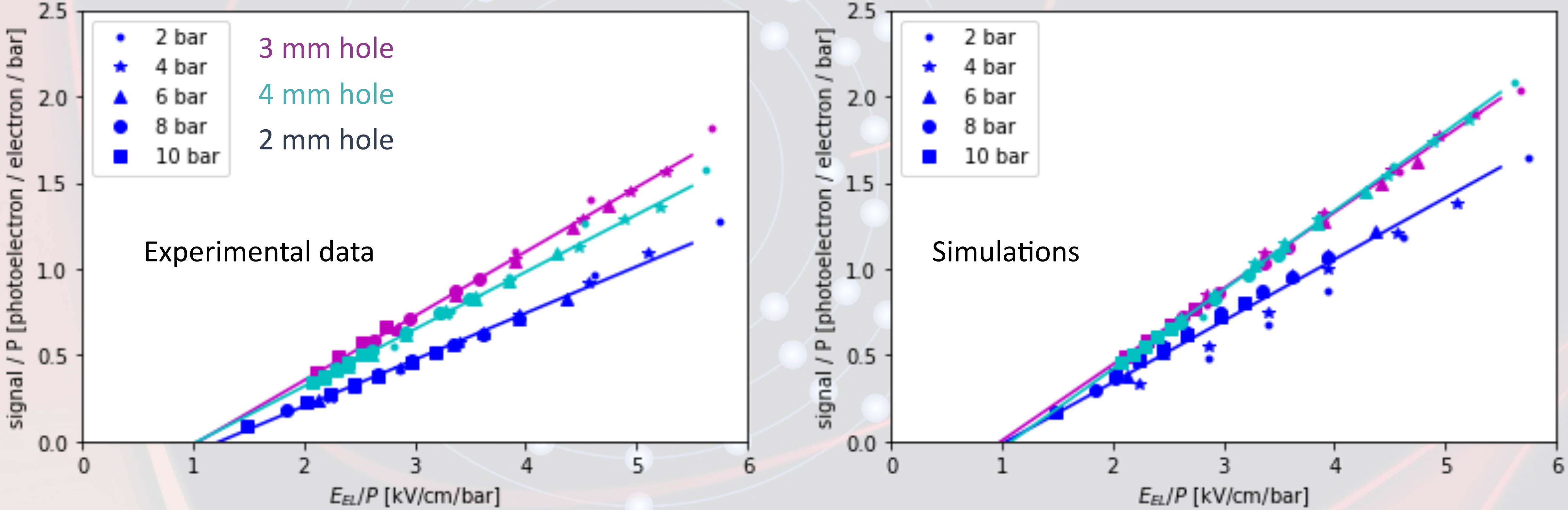
PMT



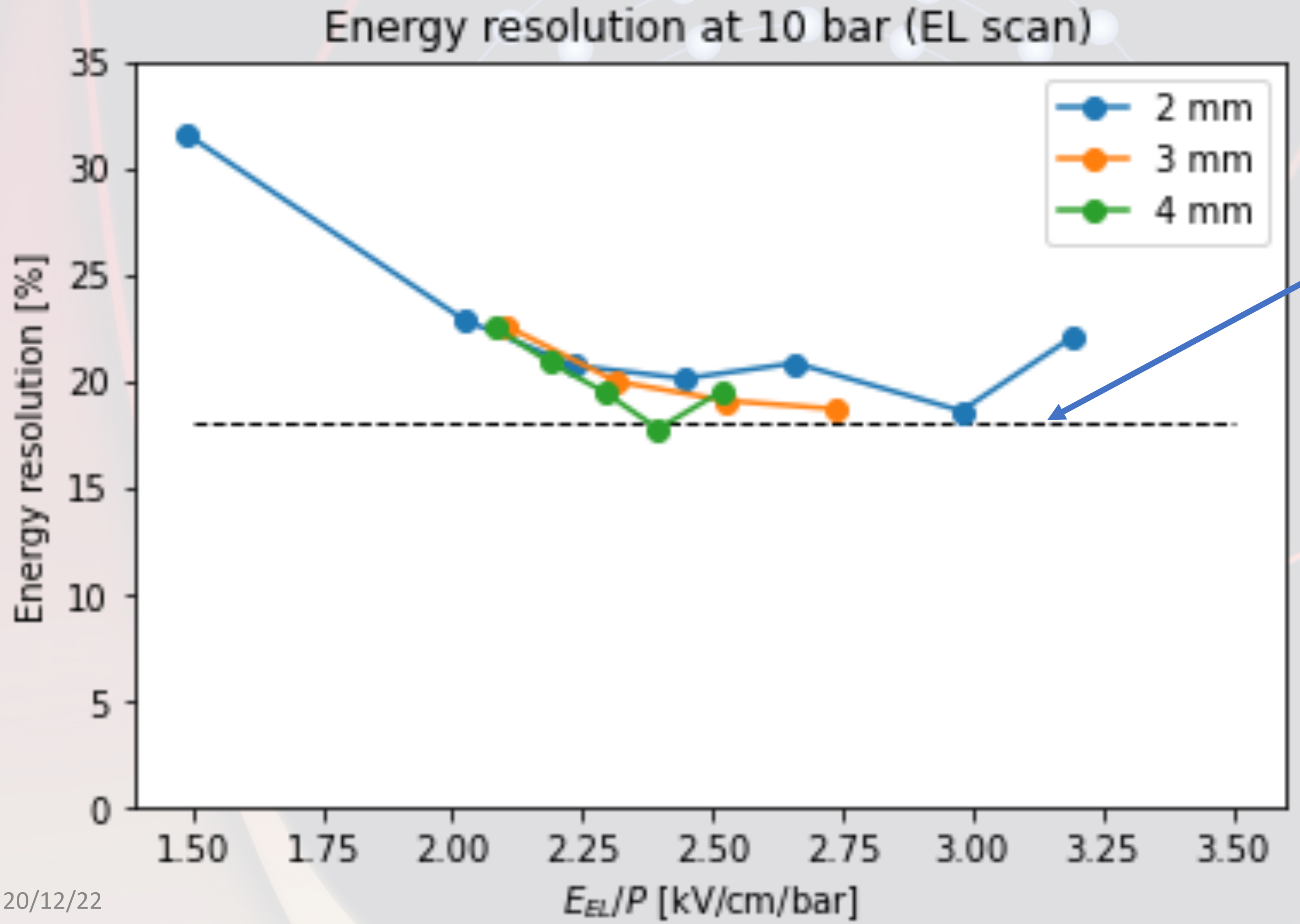
CATHODE

FAT-GEM

All in a nutshell (P-scaled plots)



EL energy resolution – all structures



Best FAT-GEM ER 18% at 10 bar

Extrapolated @2615 keV -> 0.85%

ER achieved for neutrinoless double beta decay experiment
0.91 ± 0.12% @ 2615 keV
(Renner et al., *J. High Energ. Phys.* **2019,** 230)

Energy resolution suspected to be limited by PM afterpulsing
A new PM will be installed soon

2nd part: VUV-transparent structures

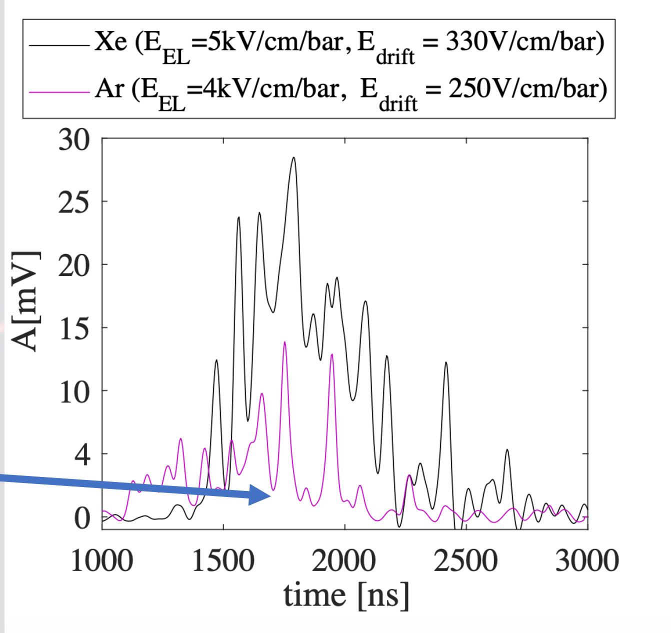
VUV-transparent FAT-GEMs

- PMMA itself not transparent to VUV

perforated PEN

TPB inside the holes

Observed S2 waveform in Argon – PMT not sensitive to 128 nm! -> hints of WLS



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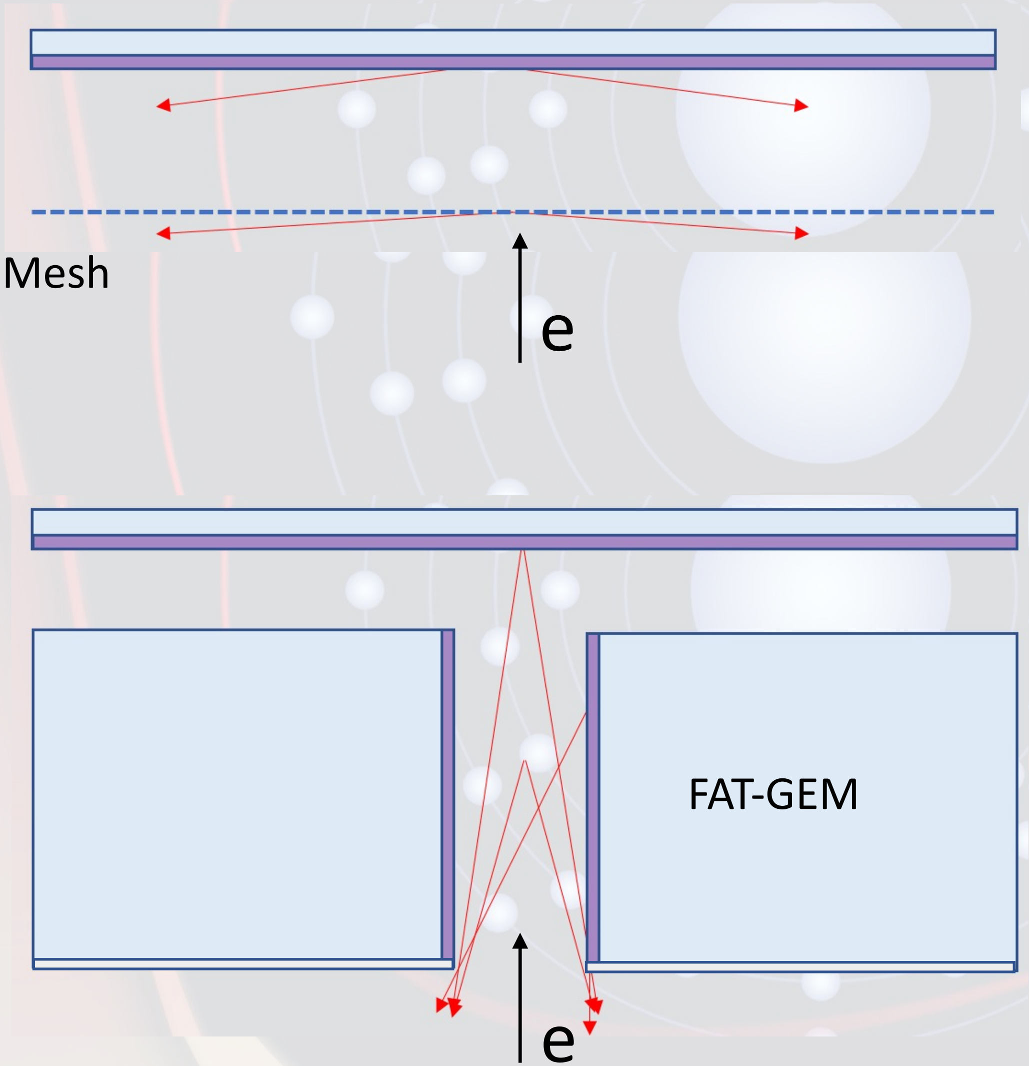
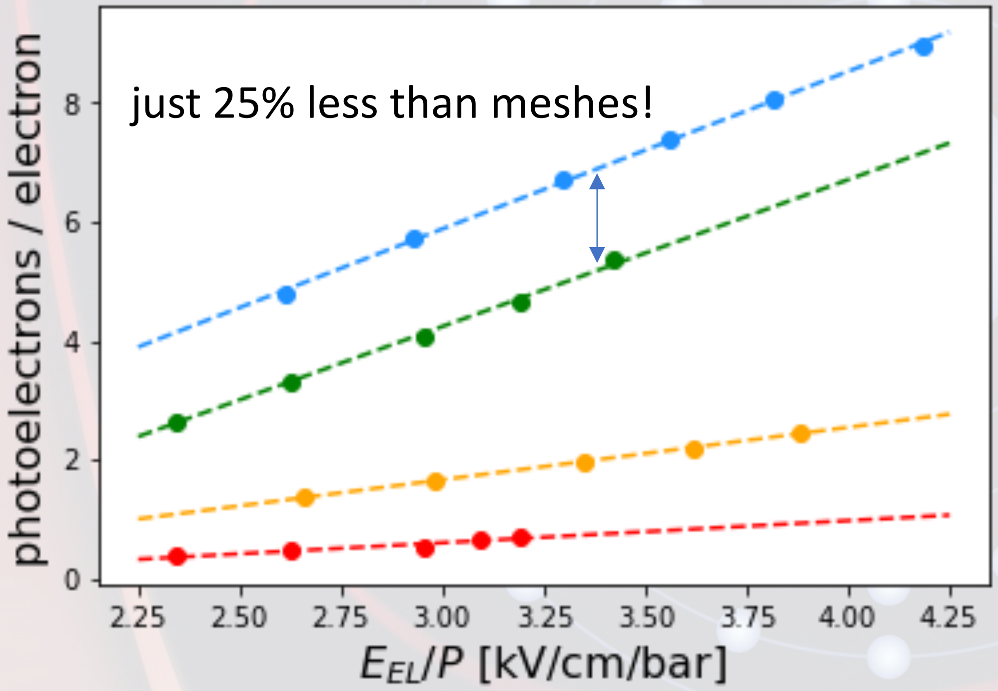
FAT-GEM vs mesh

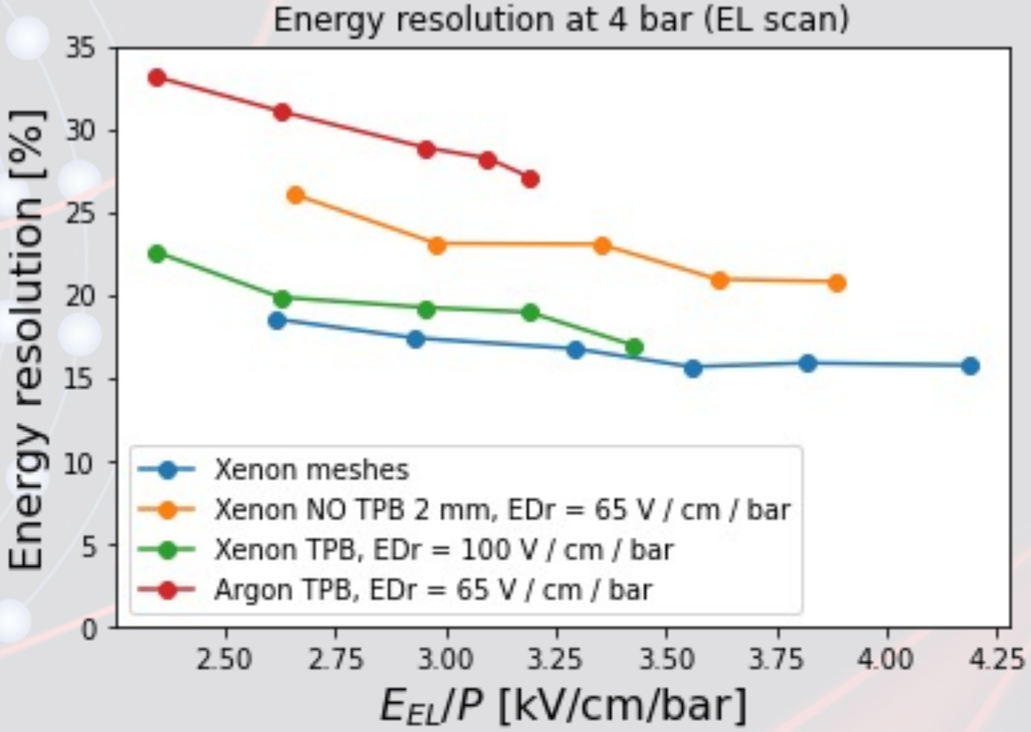


- FAT-GEM holes with TPB coating -> light collection x1.8 with respect to mesh configuration

- Reflector layer -> improves light collection x2.9 with respect to mesh configuration (according to Geant4 simulations)

Results from structures with TPB-coated holes (4 bar)





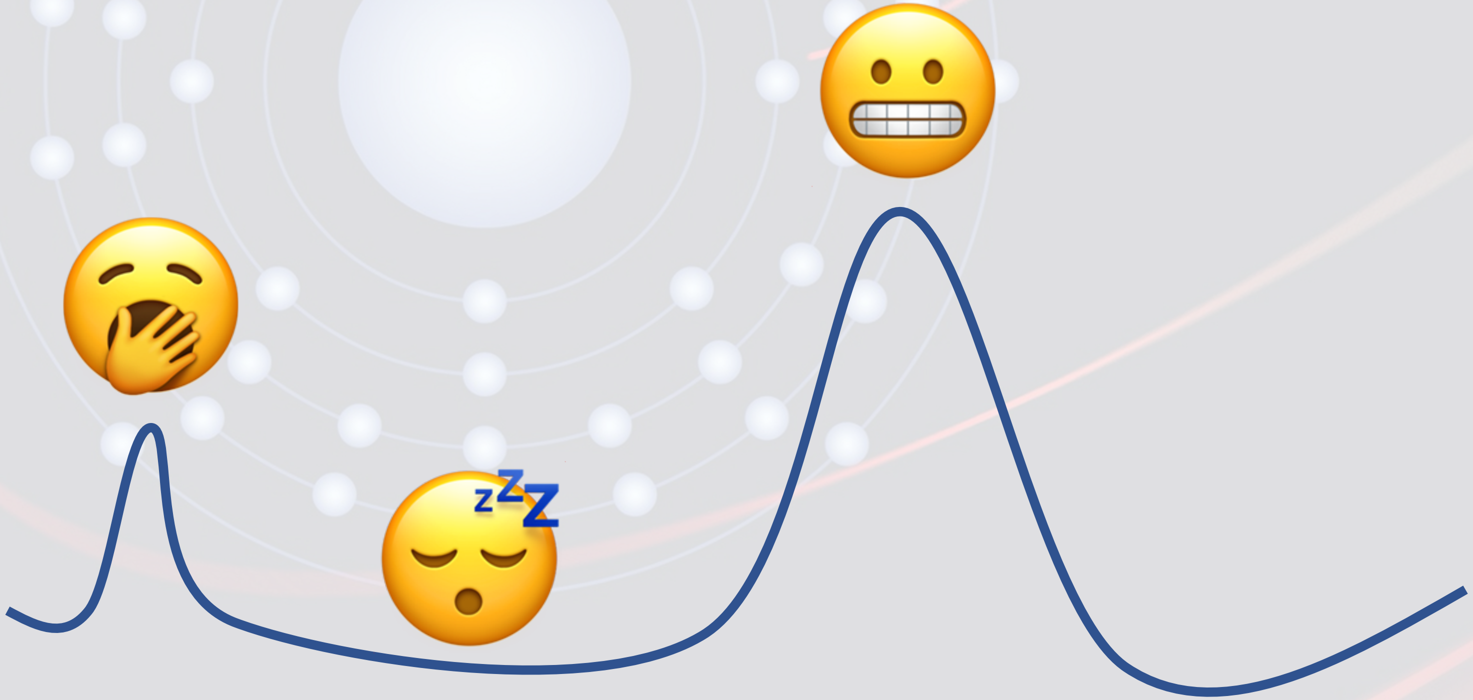
- WLSE of TPB estimated from simulations ~ 50% (preliminary)
- Optical transparency of ITO we used ~75%

-> room for improvement!

Conclusions and outlook

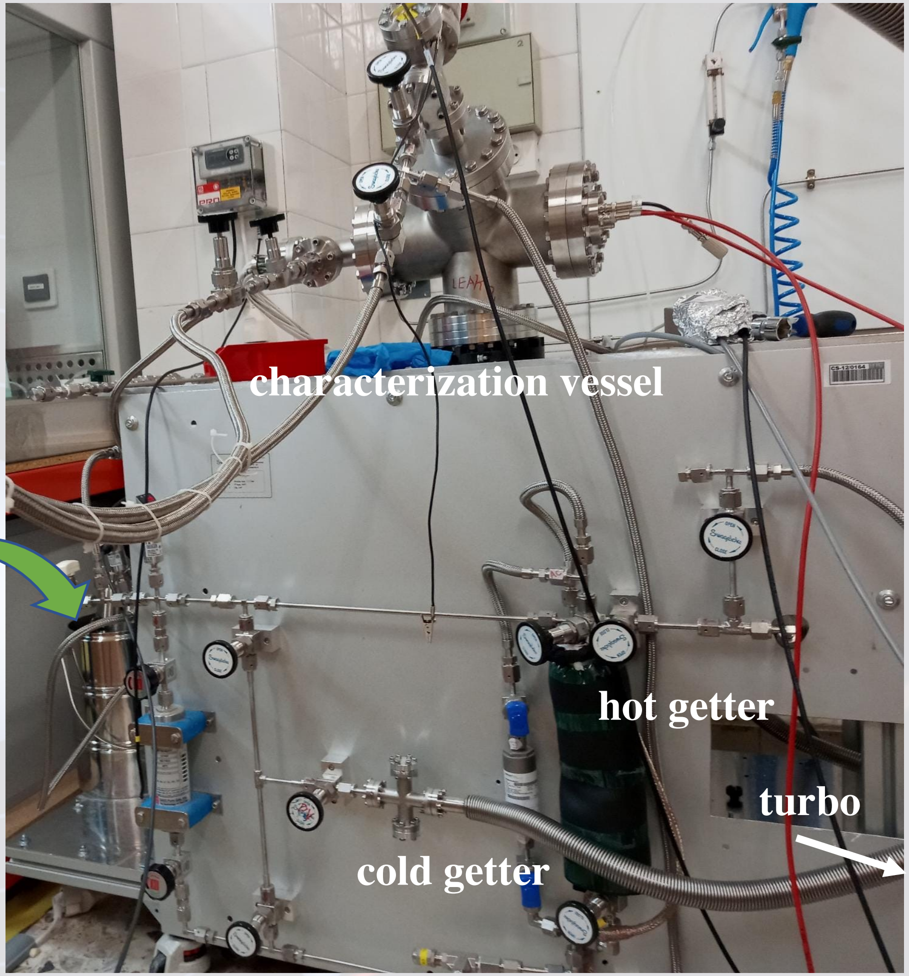
- FATGEMs are promising radiopure and scalable structures for electroluminescence – based noble gas detectors
- Testing different structures, we were able to reach (and slightly exceed) the energy resolution scale of neutrinoless double beta decay experiments
- Recent success at evaporating the TPB inside the holes at AstroCeNT. The structure shows wavelength-shifiting, making it possible to observe Ar scintillation with a conventional fused-silica PM and enhancing the detection efficiency for Xe
- The observed scintillation yields are within 25% of those achievable with meshes
- Room for optimization by using ESR, improving the TPB coating and ITO transparency seems possible. Stay tuned!

Thanks for your attention!

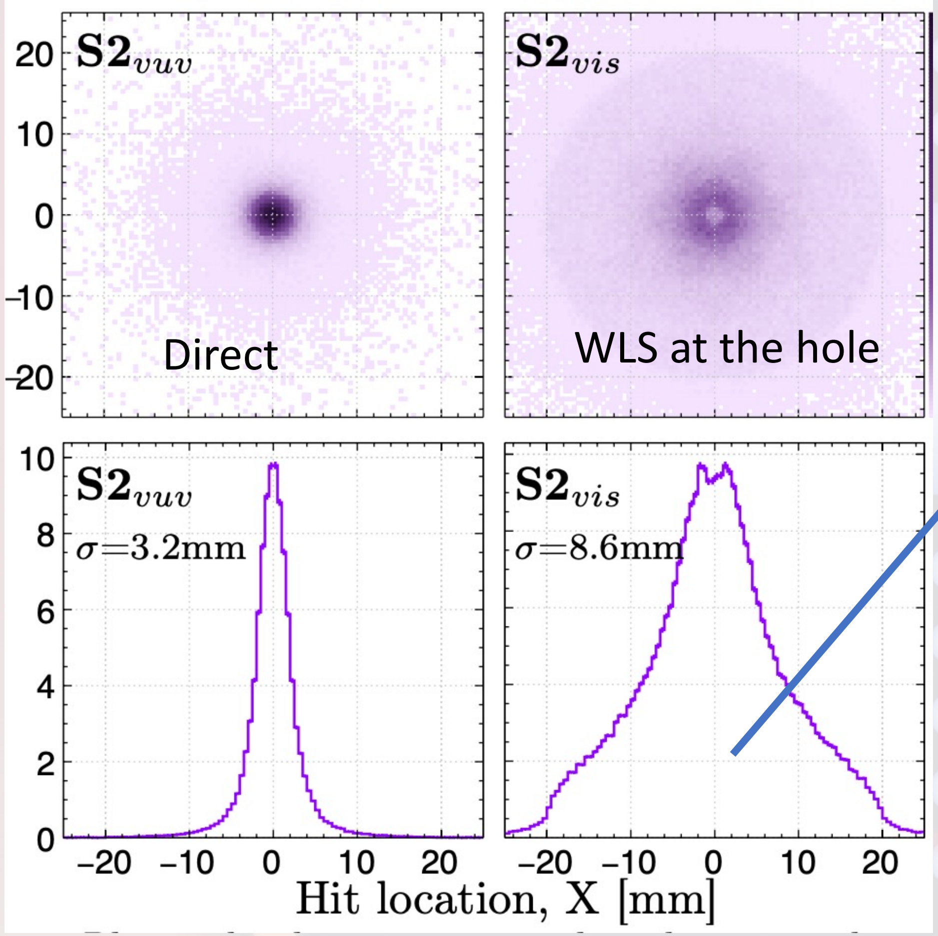


Appendix

Setup - overview



PSF Geant4 simulations



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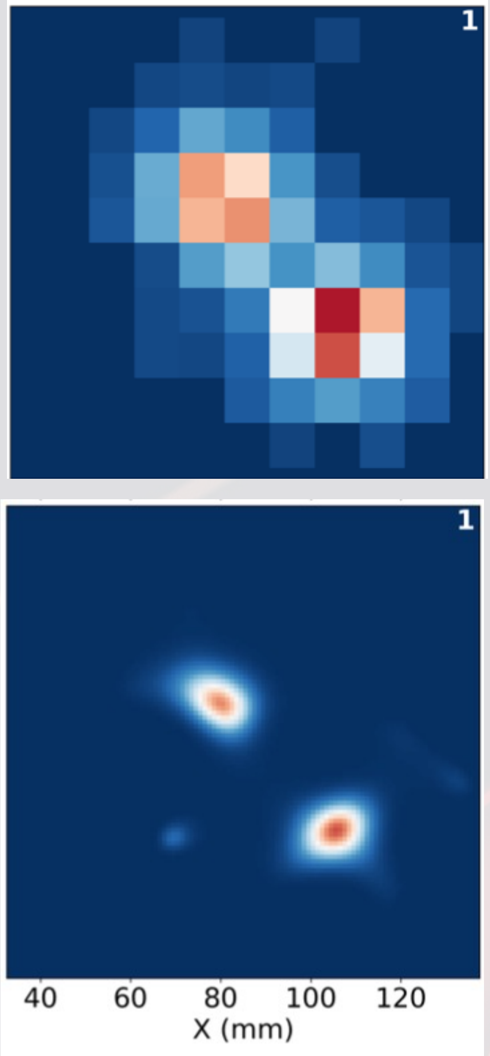
PSF of order
10 mm-σ can be
deconvoluted



(A. Simón *et al* 2022 *JINST* **17** C01014)