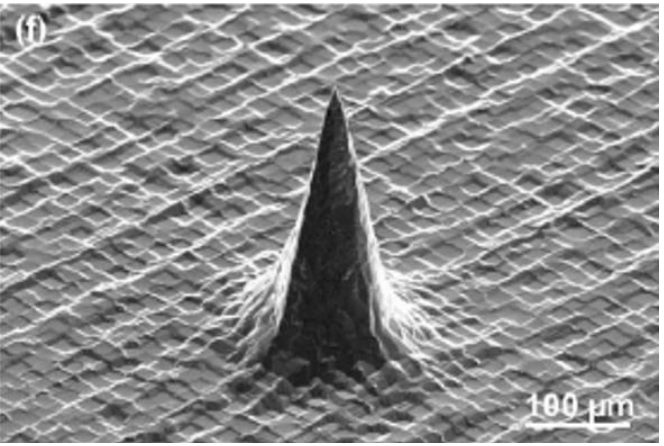
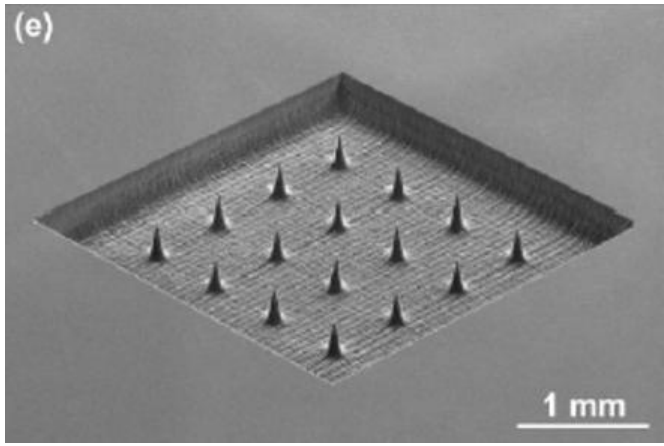


Fea In XE Detector



Romain Gaïor on behalf of the D_RD_34 project

LPNHE
PARIS

I L Λ N C E

Scientific context

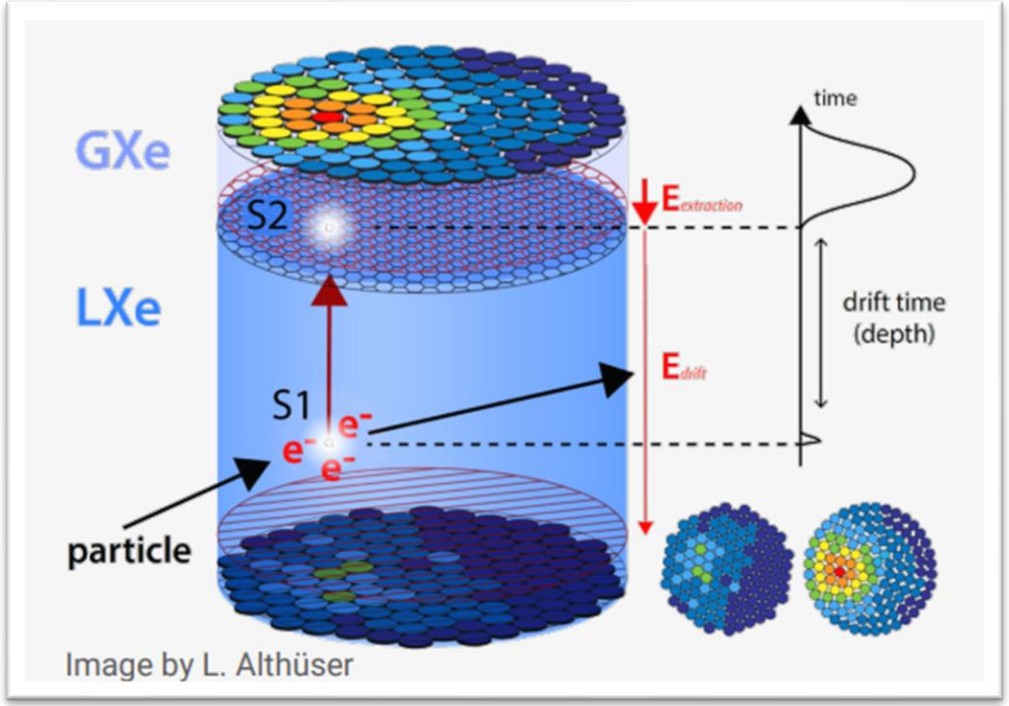
Next generation LXe Experiment (XLZD):
50-100 tons, few meter scale for rare event searches (Dark Matter, neutrinos, 0vBB)

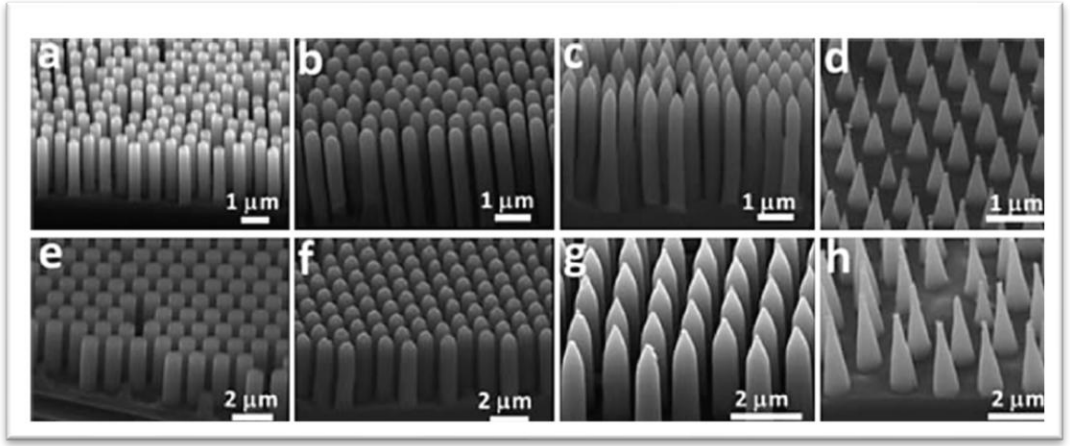
(some)Problematics with large detectors

- Radioactive purity: need for faster purification methods (Radon)
- Electrodes for secondary scintillation: Mechanical issues, resolution, spurious charge

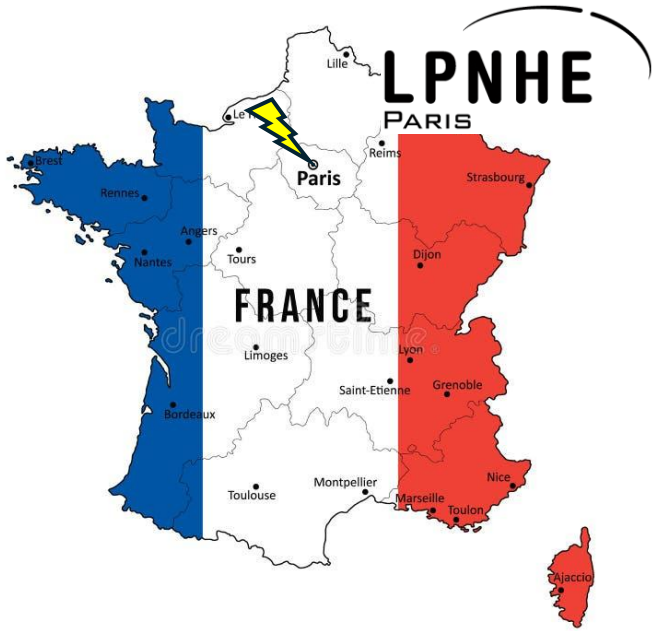
FEA: Microscopic Conductive structure

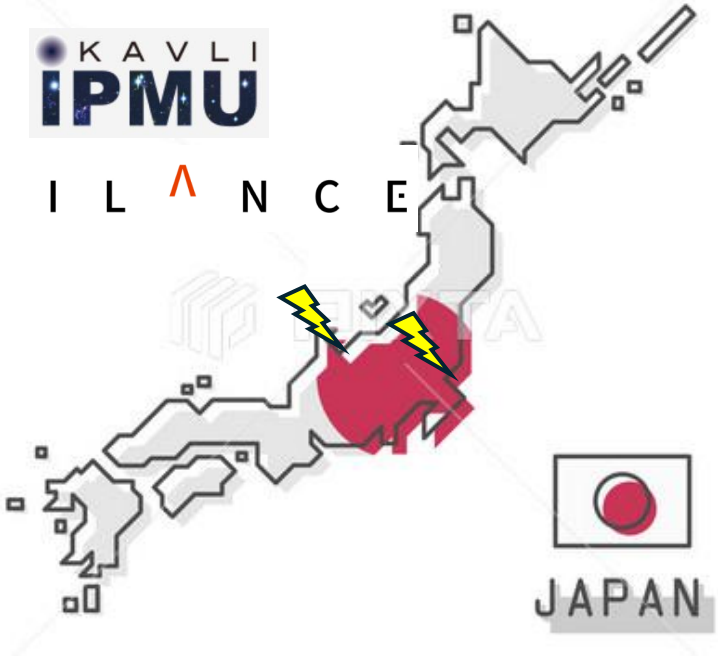
- Large electric field site
- Various shape / material (Cu, Si) / fabrication method
- Used in industry in vacuum





FIXED (D_RD_34) around the world





LPNHE

- Romain GAIOR (now at ILANCE)
- Luca SCOTTO LAVINA
- Yajing XING
- Veronica CAZZOLA

Munster

- Christian WEINHEIMER

OTH Regensburg

- R. SCHREINER
- M. HAUSLADEN

IPMU (Kamioka)

- Kai MARTENS
- Caio ISHIKAWA
- Xiaoxin WANG
- Masaki YAMASHITA (now in Nagoya University)

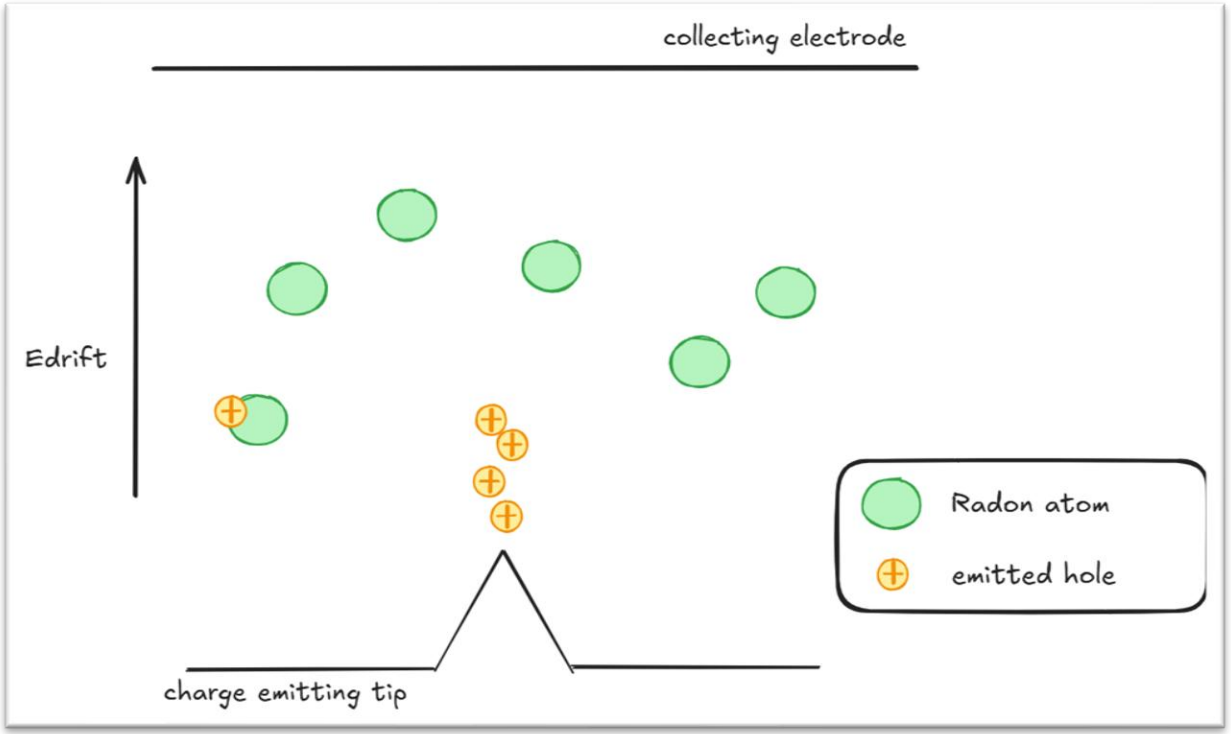
Liquid Xenon Purification

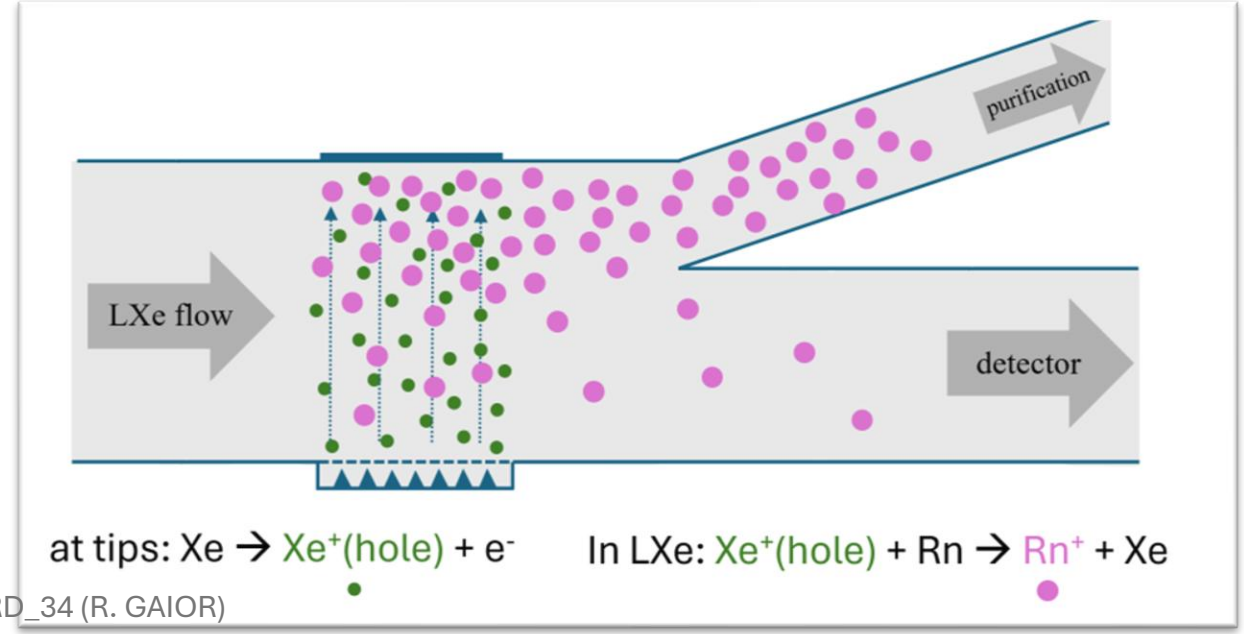
Hole emission in LXe
Large E field (~10MV/cm) at the tip to “emit” hole

Hole attachment time to radon ?
Is the attachment time long enough to drift the Rn over sizeable distance

Stable operation ?
Are we able to operate at very high field (~GV/m)

Work from Caio and Xiaoxin and Kai @ Kamioka
Visit of R.G. in Jan 2026



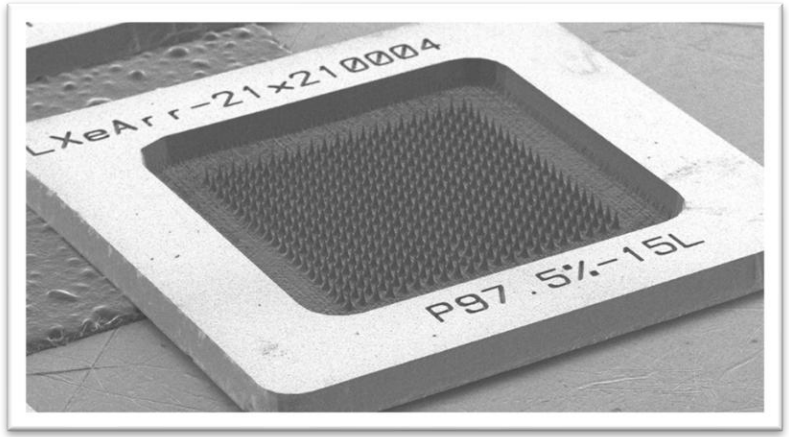


Kamioka setup

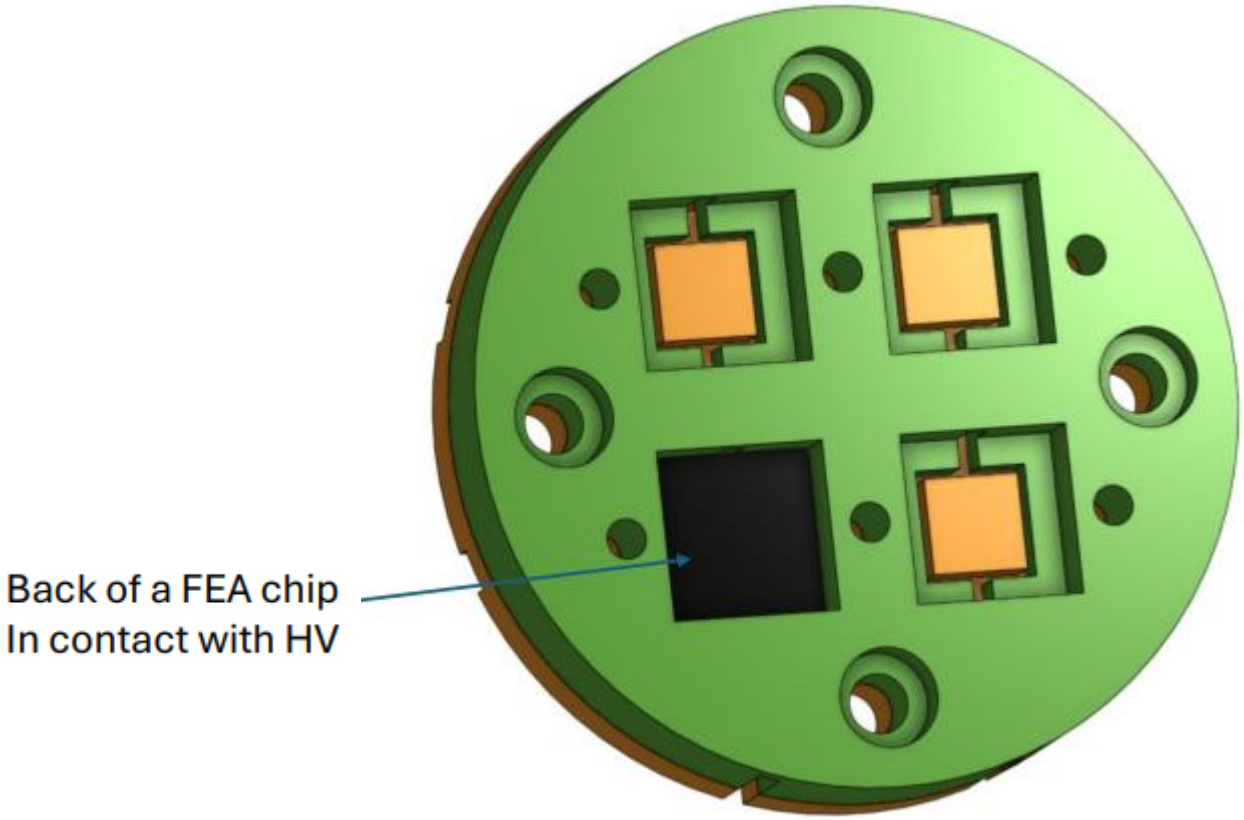
21x21 FEA chip (OTH Regensburg)
Previous data taking with 1 tip/chip

Improved the insulator
Breakthrough found on previous insulator

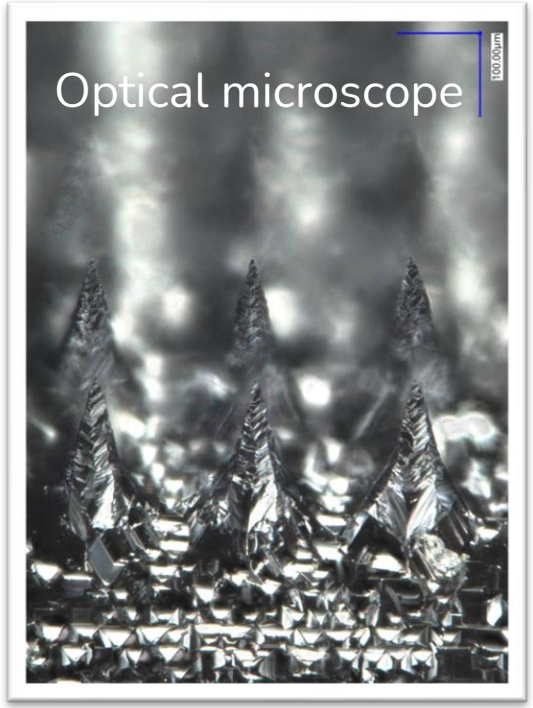
Four chips at the same time



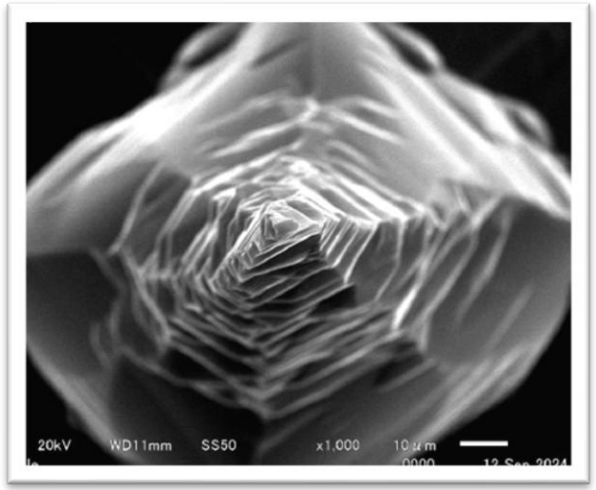
FEA chip 21x21 (doped silicon)



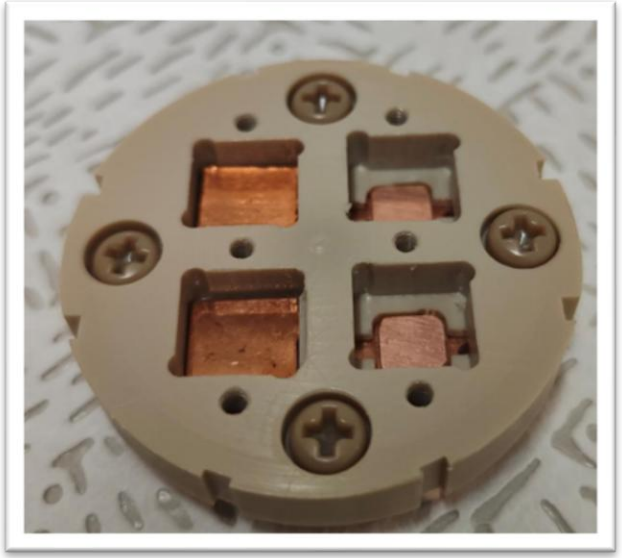
Kamioka setup



Scanning Electron Microscope

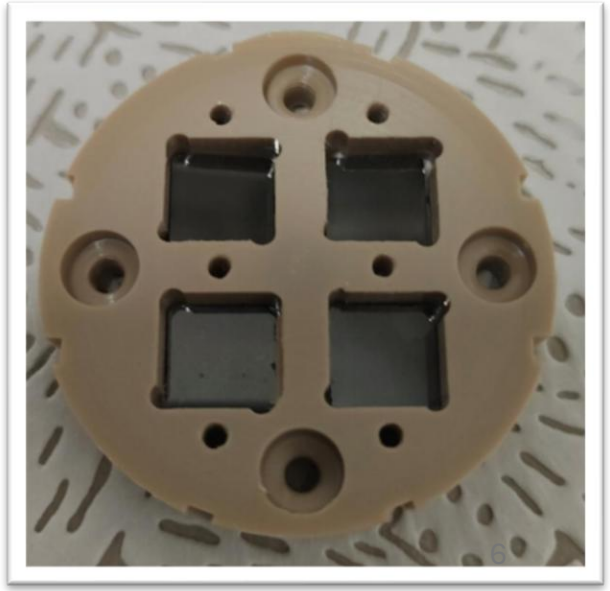


4 FEA chip 21x21 (doped silicon)



Holder for the FEA chips

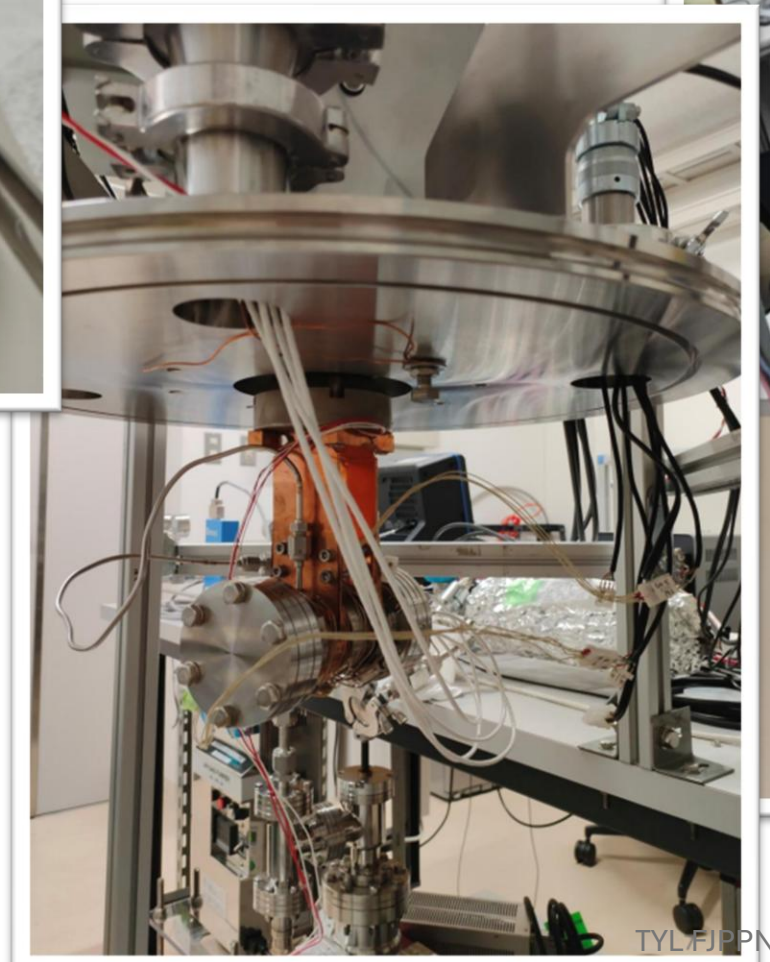
Chips placed in the holder

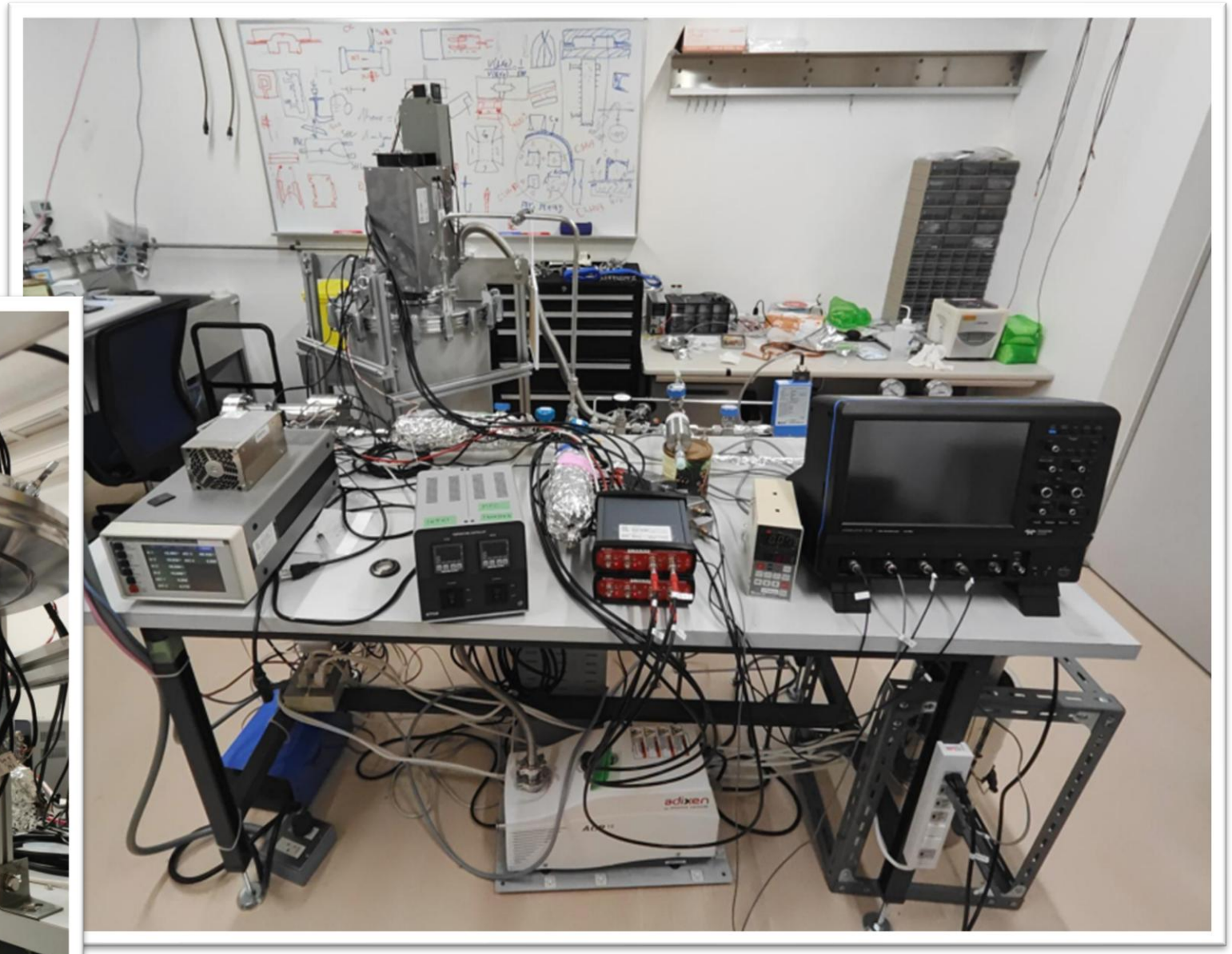


Kamioka setup

Holder inserted in a filler

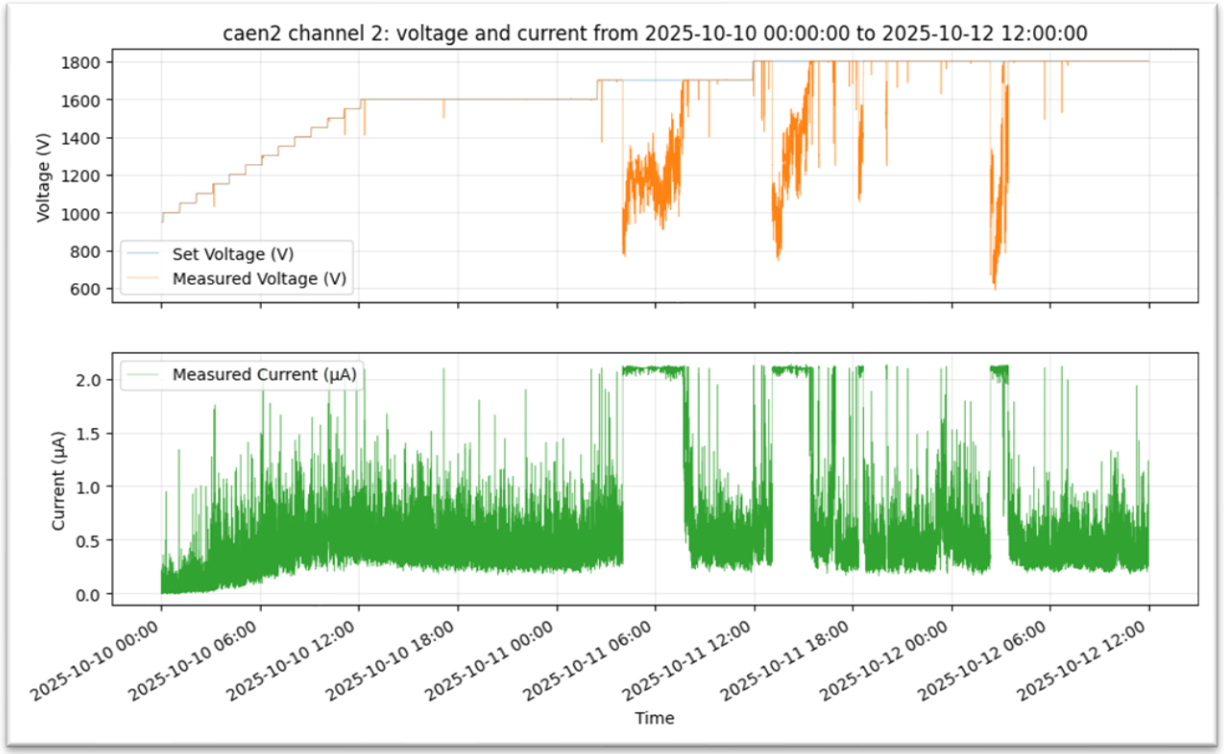
LXe chamber inside a vacuum chamber

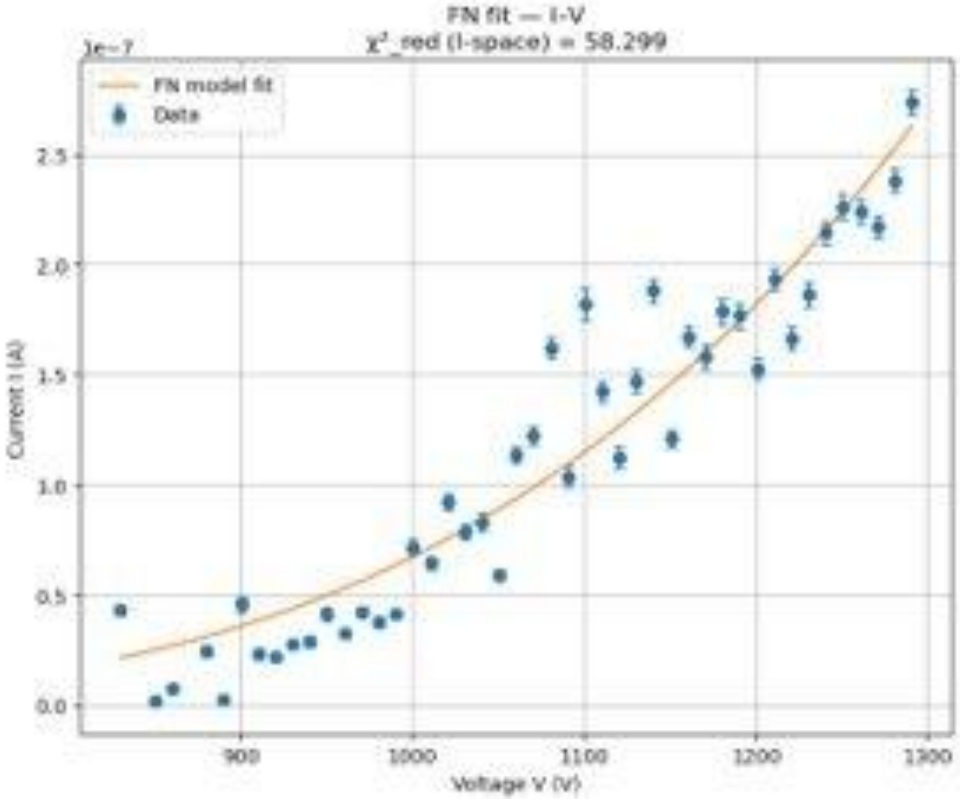




Complete system installed at IPMU lab in Mozumi

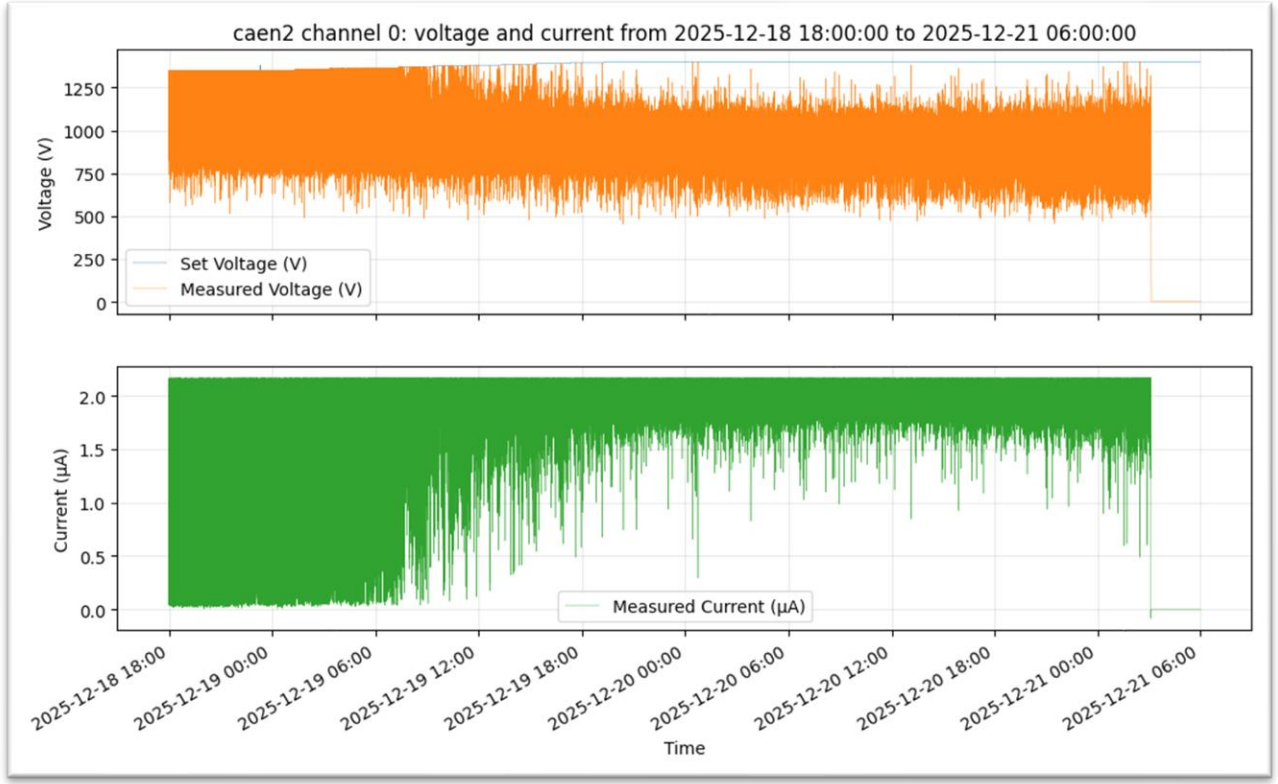
Emission in vacuum

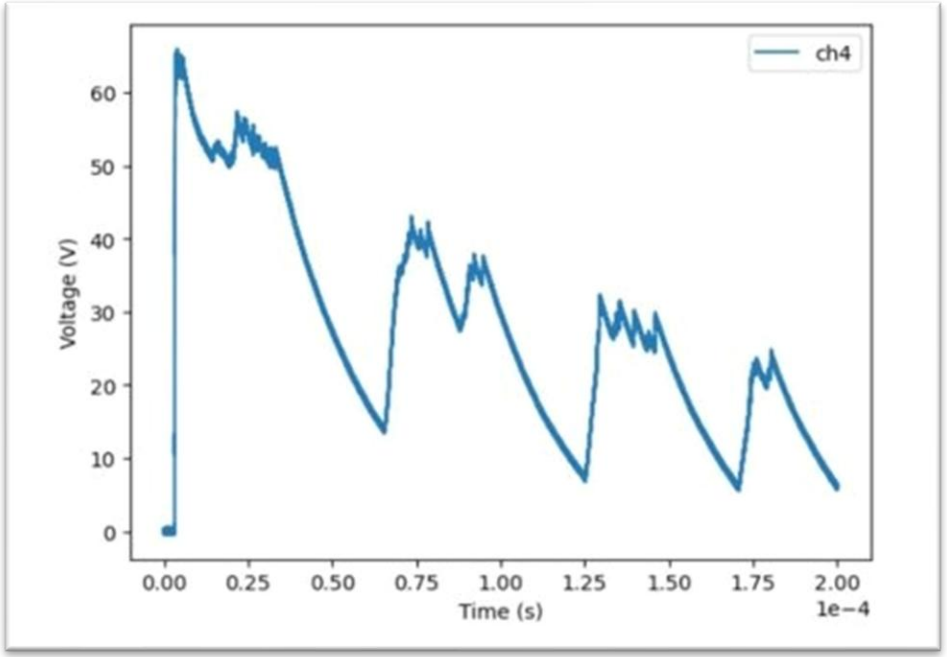




- **Emission in vacuum well controlled**, expected I-V relation
- Allow for the conditioning of the tips
- Average current sometime undergo a sudden change after a spike: possible smoothening of sharpest part of the tip

Emission in Liquid Xenon





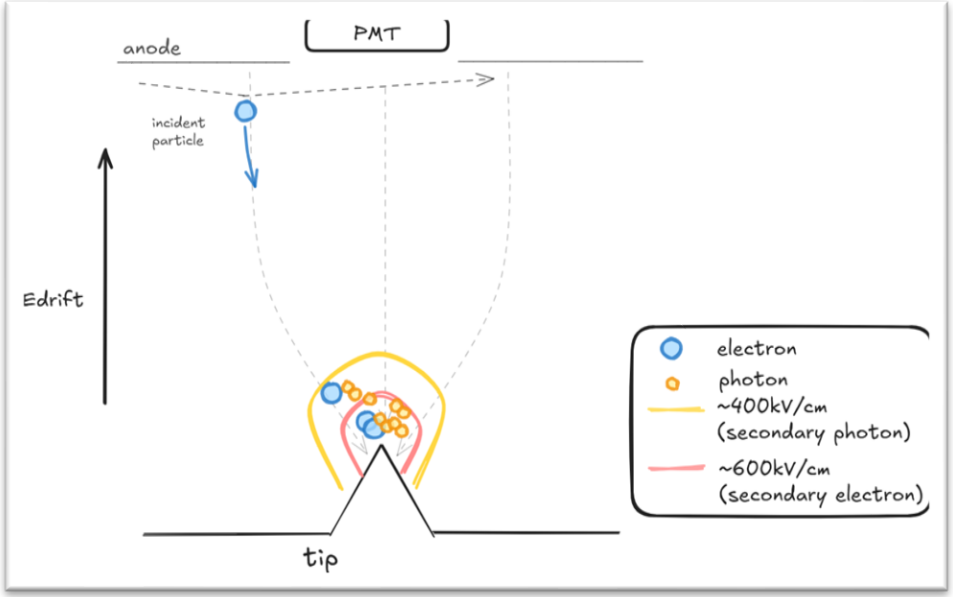
- **Positive and Negative current** in liquid xenon happens in burst/discharge
- Current can be kept constant in average by controlling the frequency of these discharges
- Reproducible behavior
- Will open the chamber and inspect the FEA next month (optical and SEM)

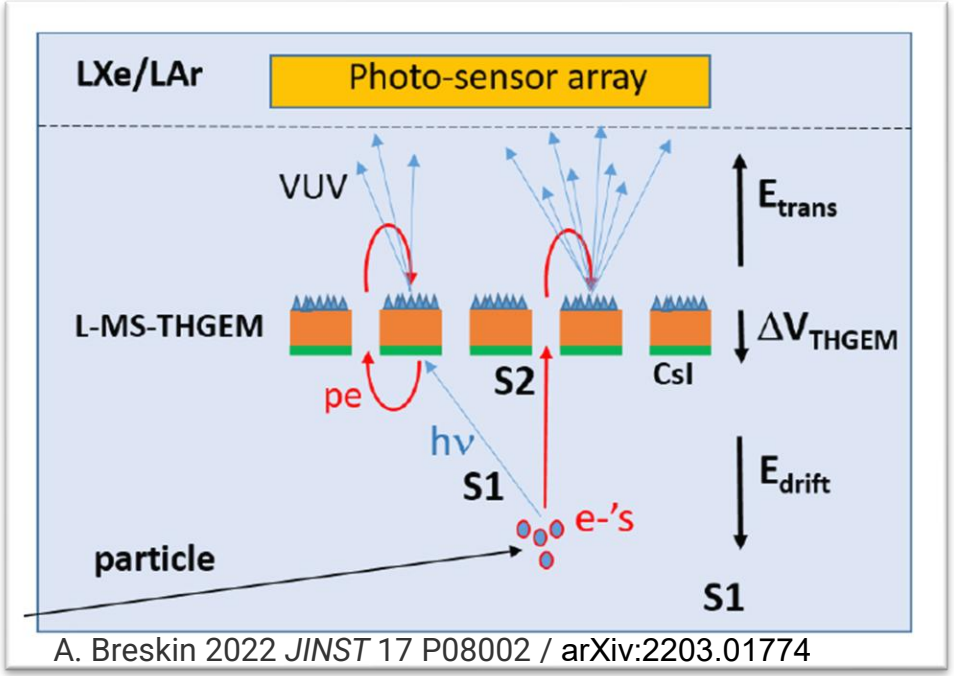
Secondary scintillation in Liquid Xenon

Secondary scintillation
Large E field (~1MV/cm) at the tip to accelerate charges and produce in turn “emit” photon and secondary electrons

Photon yield
Can we produce enough photon to produce a detectable signal (without too many secondary electrons…)

Stable operation ?
Are those device stable ? Can we find a suitable geometry for large TPC





A. Breskin 2022 *JINST* 17 P08002 / arXiv:2203.01774

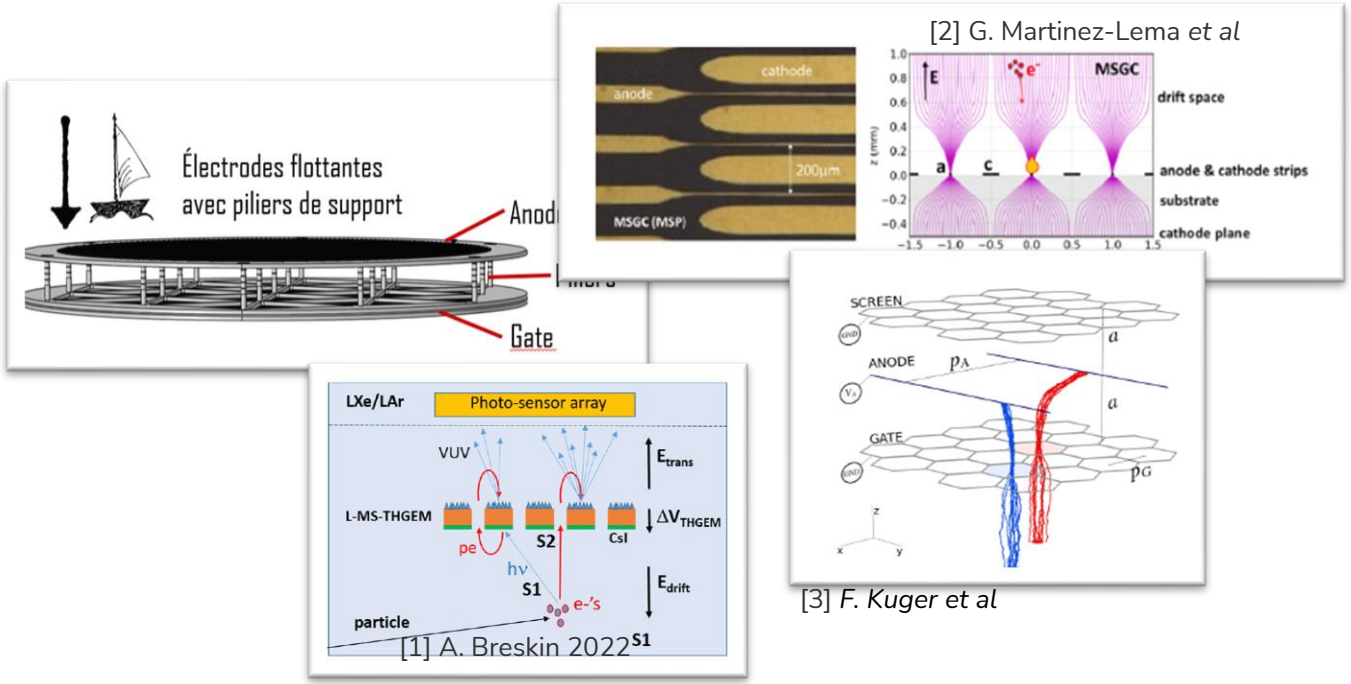
R&D for electrodes in LXe / GXe

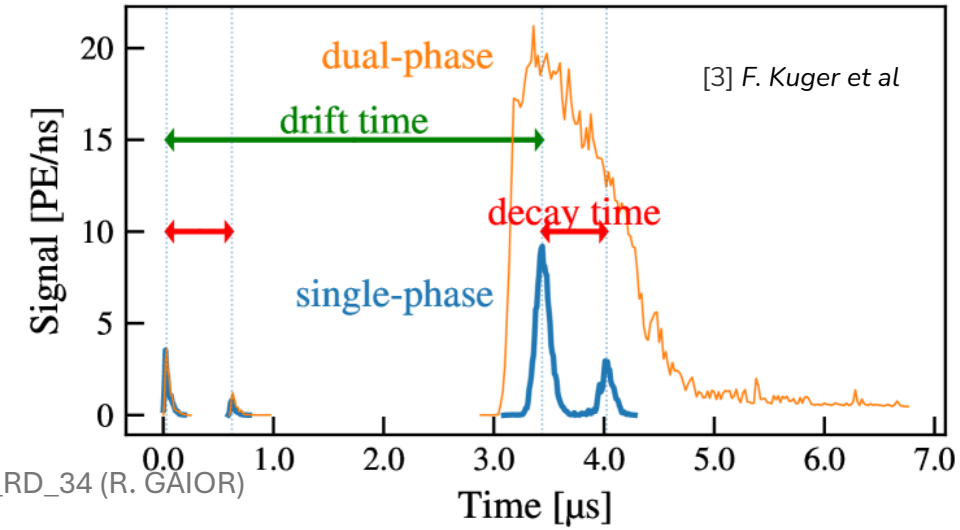
Several R&D to replace double phase paradigm

Rational for a one phase (liquid) solution

- ✓ No liquid - gas interface
- ✓ No electrode sagging
- ✓ No delayed electrons
- ✓ Cleaner S2 signal

- ❑ Large local electric field
- ❑ Not as studied as double phase for rare event searches





[1] A. Breskin 2022 *JINST* 17 P08002 / arXiv:2203.01774
[2] G. Martinez-Lema *et al* 2024 *JINST* 19 P02037
[3] *F. Kuger et al 2022 JINST 17 P03027* arXiv:2405.10687

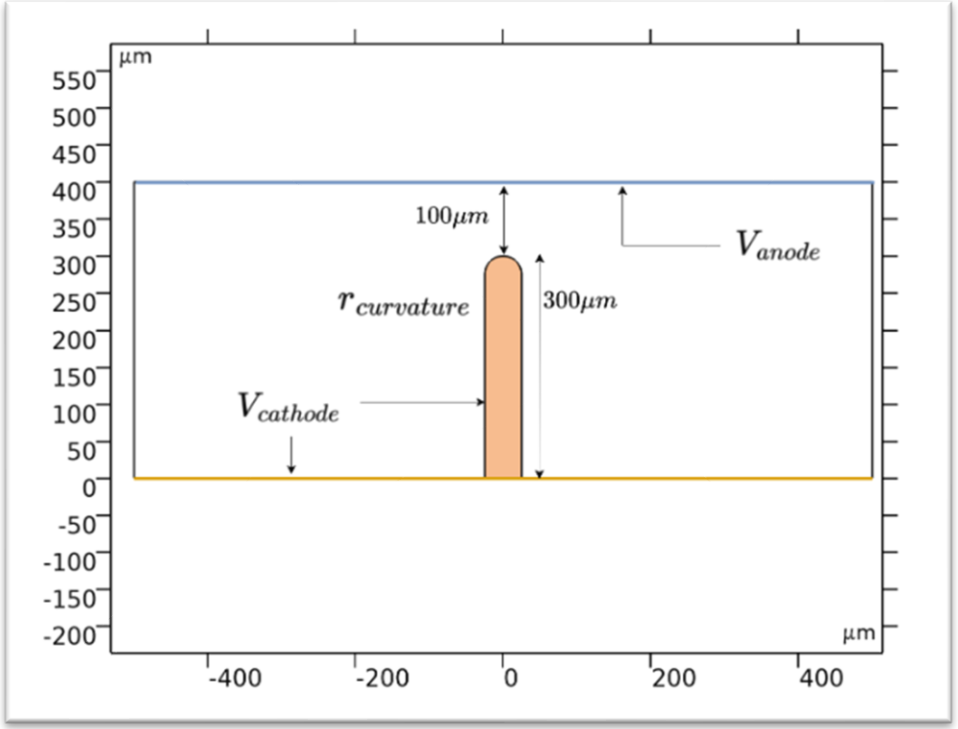
Simulation of secondary scintillation in liquid

Study of the optimal shape

- Baseline design: pillar with counter electrode at 100µm
- Vary geometry and compare photon/electron yield

Simulation procedure

1. E-field simulation (COMSOL)
2. Electron tracking (PyCOMES [1])
3. Emission simulation (Param. From [2])

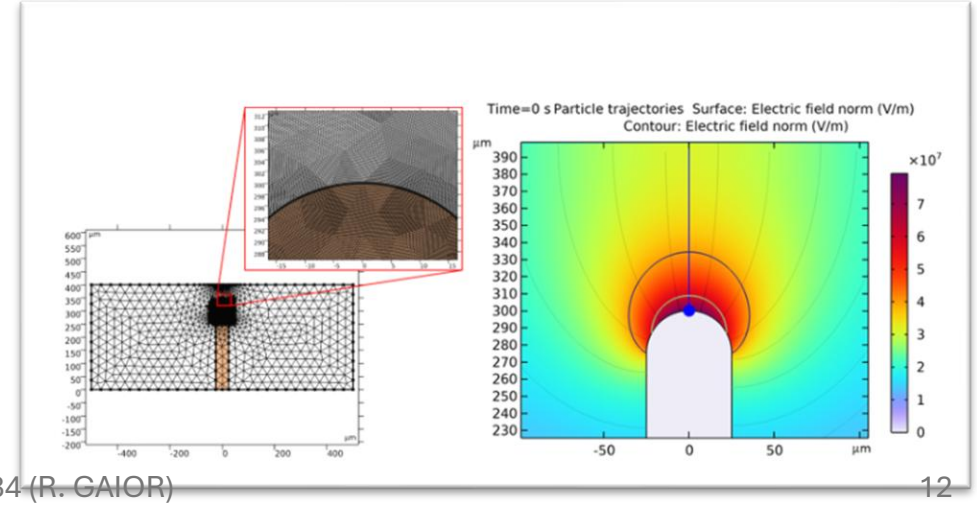


$$\Delta N_e = N_e \theta_0 \exp\left(-\frac{\theta_1}{E(\vec{x}, V_A, d_w) - \theta_2}\right) \Delta\vec{x},$$

$$\Delta N_\gamma = N_e \theta_3 (E(\vec{x}, V_A, d_w) - \theta_4) \Delta\vec{x},$$

$$\theta_2 = 586 \ [kV/cm]$$

$$\theta_4 = 399 \ [kV/cm]$$

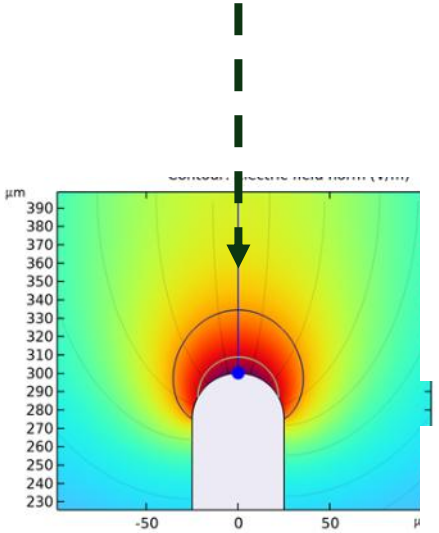


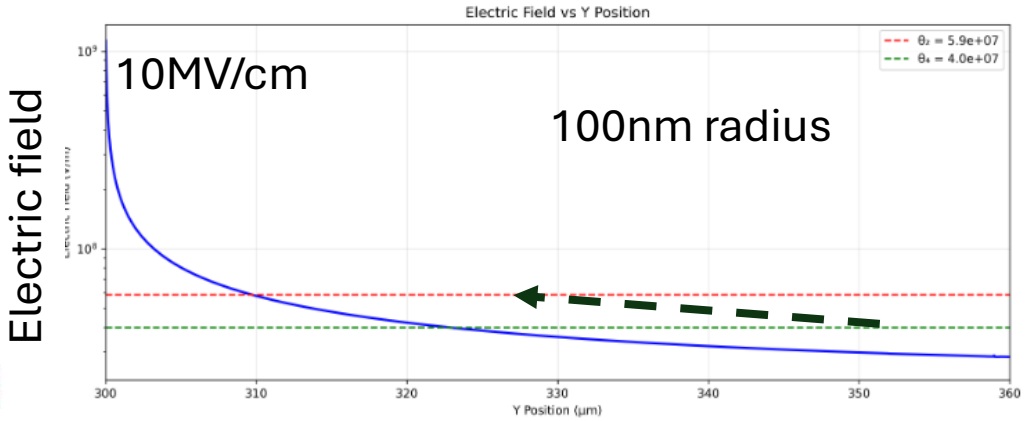
[1] https://github.com/ftoschi/PyCOMes
[2] arXiv:1408.6206v3 / E Aprile *et al* 2014 *JINST* 9 P11012

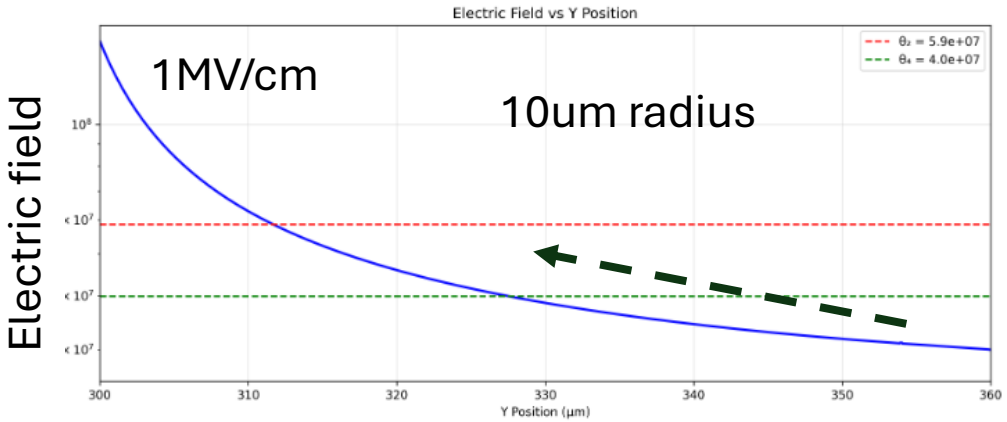
Simulation of secondary scintillation

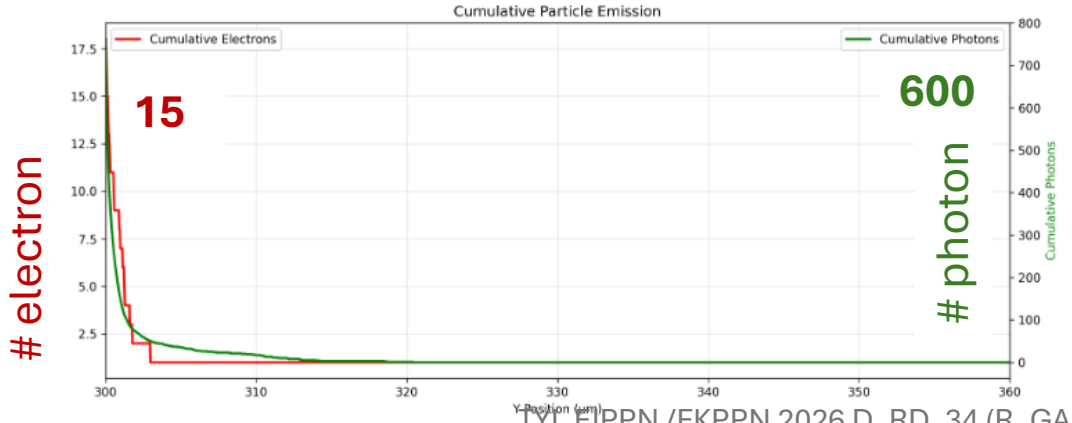
Follow one electron moving toward the tip apex

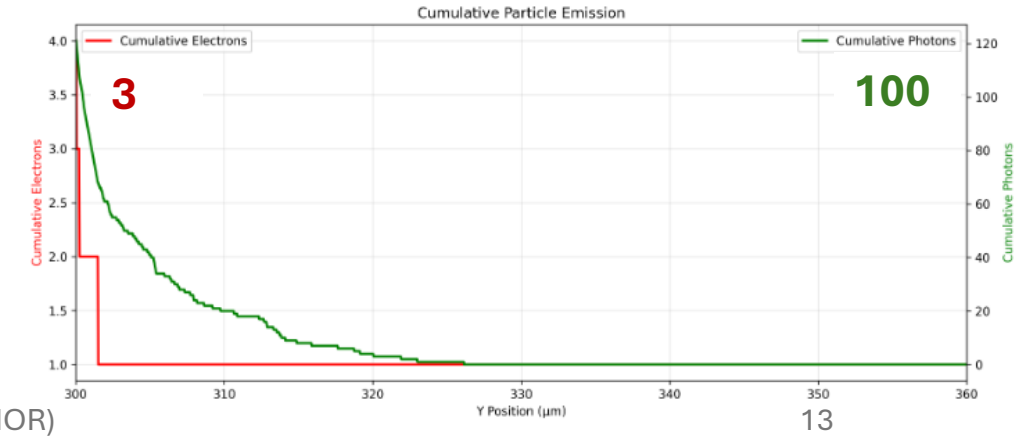
- Photon emission starts from the green line
- Electron emission starts from the red line
- Goal is ~2-3 electron and >100 photons





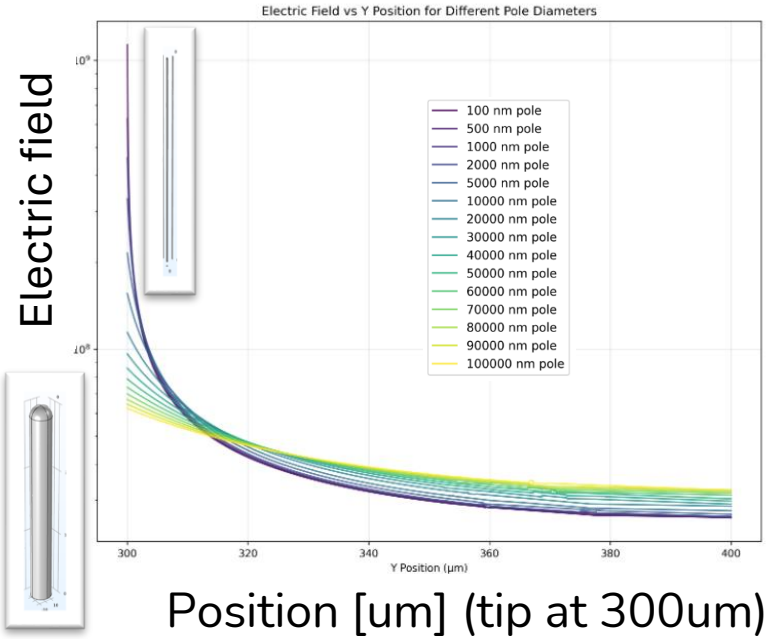




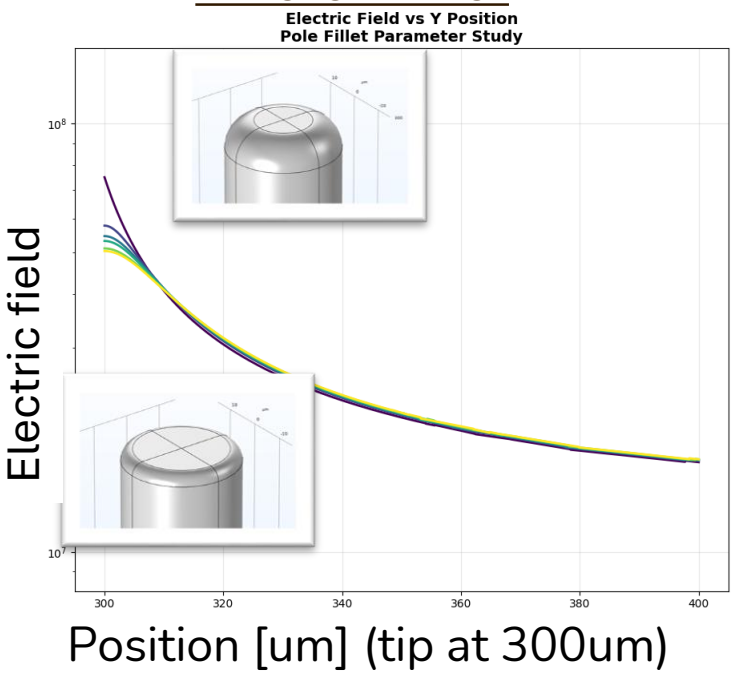


Shape optimization

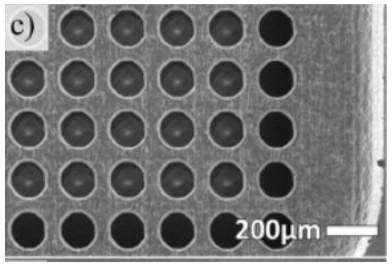
Different radius



Different fillet

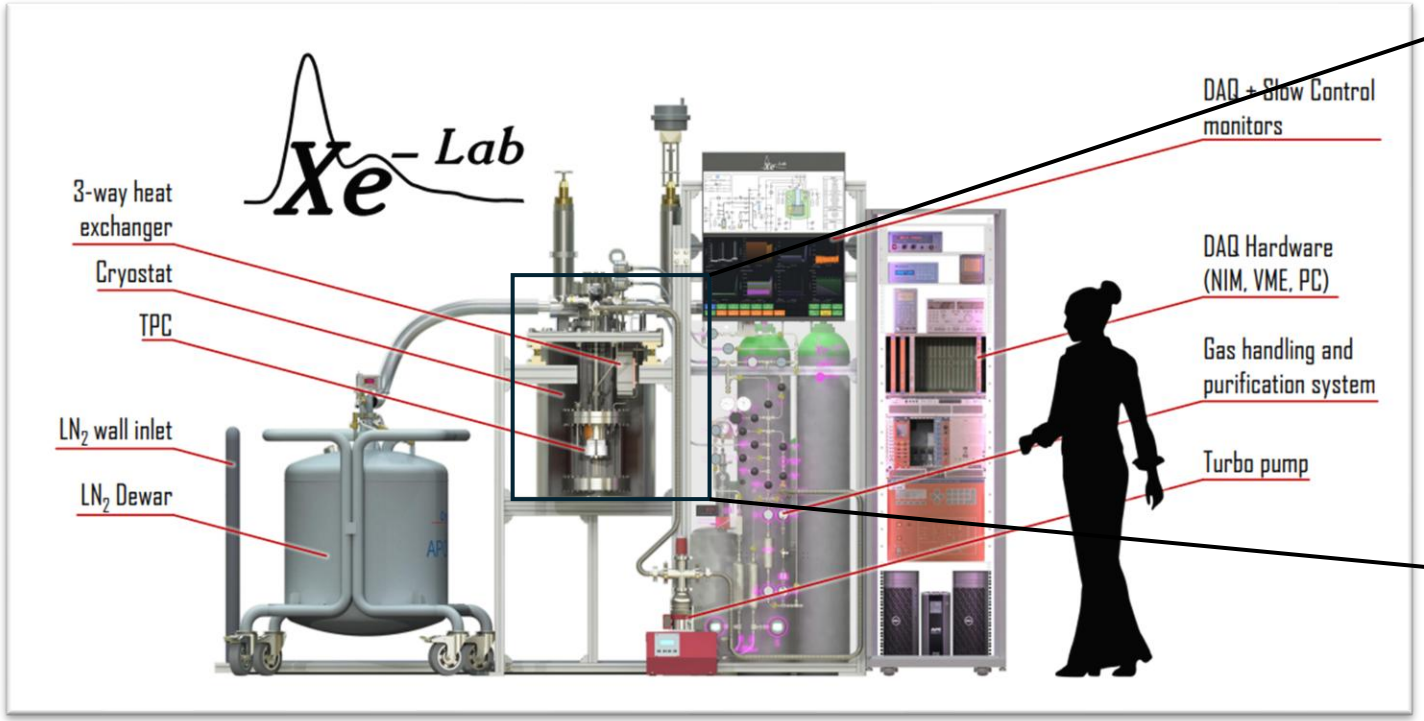


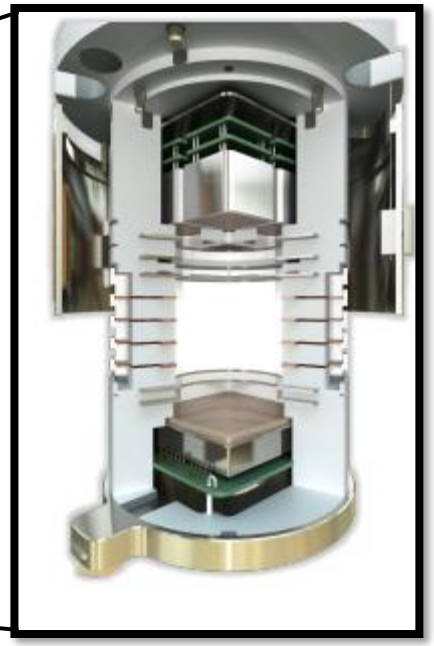
Grid position and shape

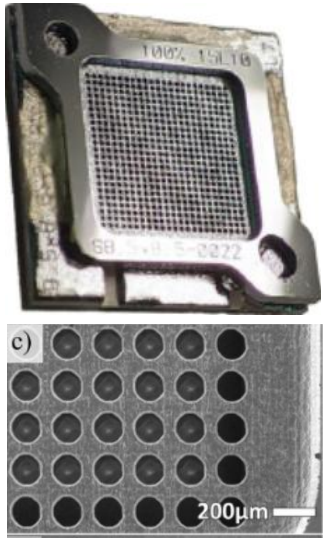


- **Optimisation**: Take advantage of the tip effect without getting too large field
- **Results:** 30µm diameter with aspect ratio of 10 (300µm high) and a flat top is a good candidate
- Final optimization needs to **account for a grid**

Proof of concept design

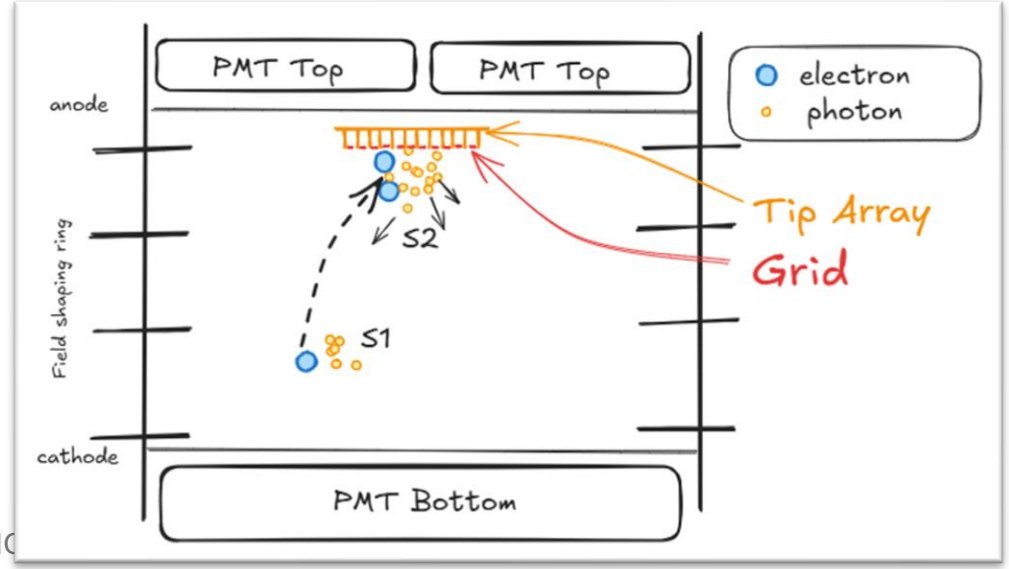




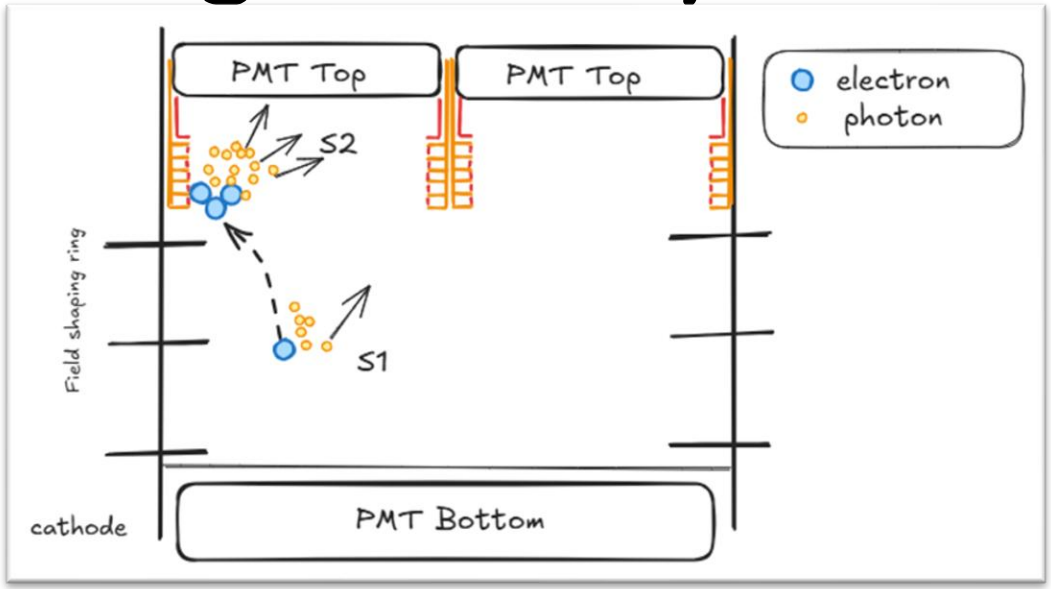


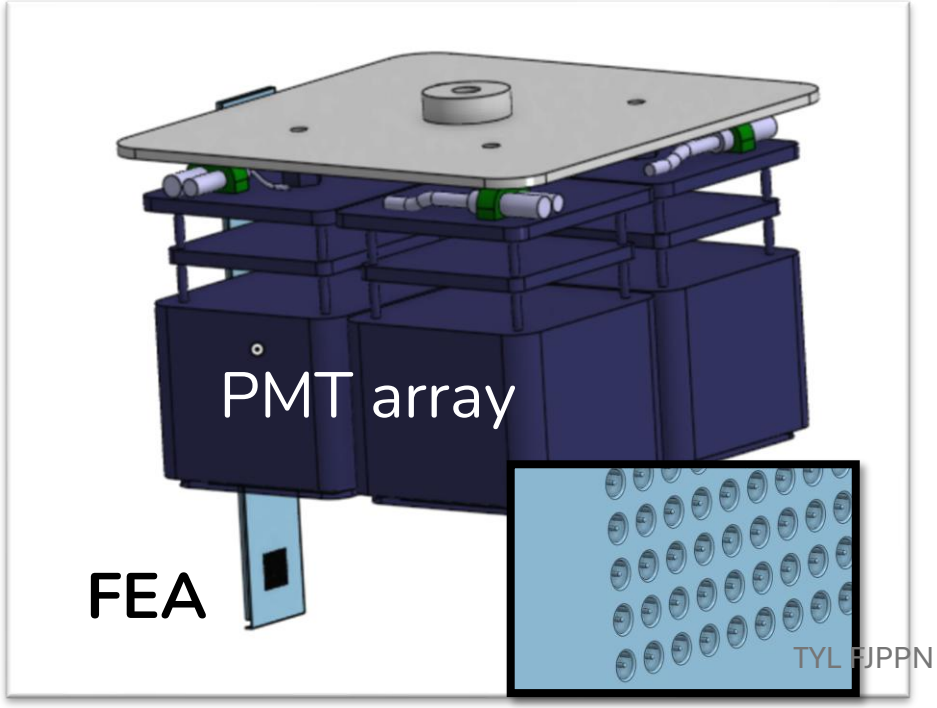
- Xelab @ LPNHE is a Liquid / Gaz Xenon cryogenic platform for electrode development
- Require minimal adaptation: Gate + Anode → FEA + Anode

→ Demonstrate the concept
→ Photon yield measurement system



New geometry idea …

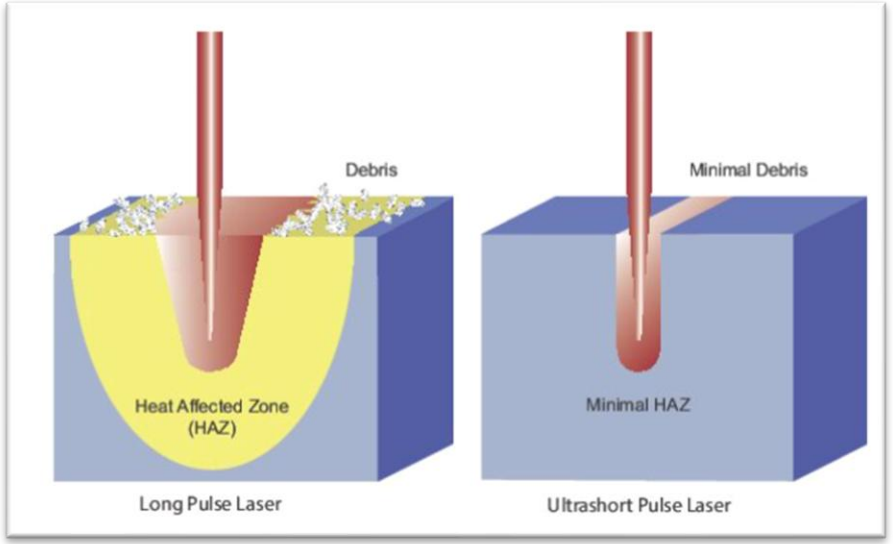




- **Give up the planar electrode**
- **"Individual" amplifier**: 1 or few per PMT
- **Several advantages**
  → Larger transparency: placed in the dead space between PMT
  → Individual device:
    → Easier fabrication
    → Pre calibration
    → Easier replacement
  → Shape optimization
- **reasonable material budget** (can be done in "radio clean" material like Copper, silicon)

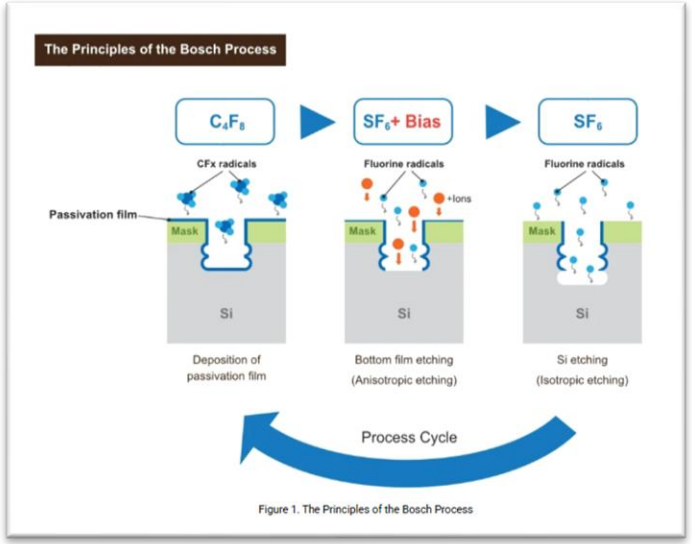
Fabrication options

Laser micromachining



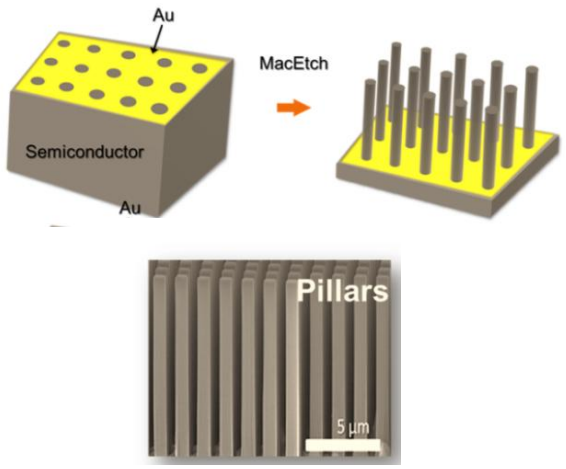
https://www.forter.com.tw/zh-tw/a4-10998-12264/Laser-Micromachining.html

Deep Reactive Ion Etching



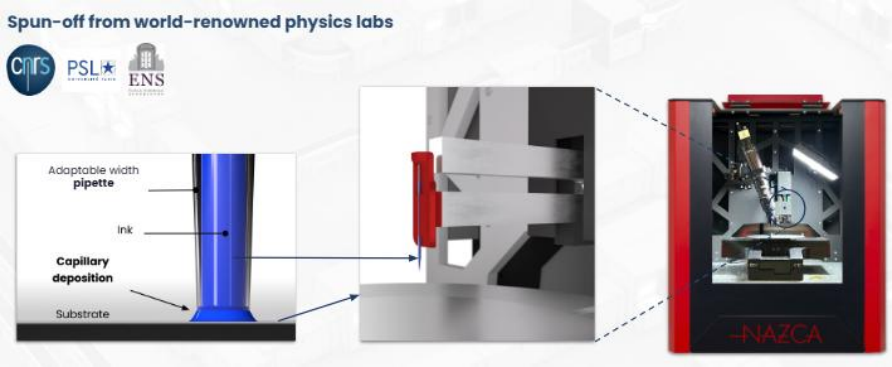
https://www.samcointl.com/news-events/tutorials/what-is-the-bosch-process/

Metal-assisted Chemical Etching



https://sites.utexas.edu/xiulingli/metal-assisted-chemical-etching-macetch/

3D microprinting



https://hummink.com/what-is-microprinting/

- **Can be fabricated with semiconductor fab. technique**
- **Need a smooth surface state**
- **Prototyping friendly**
- **Maybe other options at HPK ?**

Conclusion

- Solid collaboration between France and Japanese team

(now eased by R.G. moving to Japan)

- Some (human and experimental) resources exist

→Help for staff exchange would greatly help

Next steps:

- Conclude about the positive charge emission and design a test with Radon
- Explore fabrication method for secondary scintillation
- Test device in Xelab (LPNHE) or other LXe facility