Study of MPGD performance in liquefied noble gases: FHM and microstrip plates

RD51 Common Fund project “Study of MPGD performance in liquefied noble gases”

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Contributors

Institutions:

- LIP – Laboratory of Instrimentation and Expeimental Particle Physics (Portugal)
- WIS – Weizmann Institute of Science (Israel)
- UC (LIBPhys) – University of Coimbra (Portugal)

Also contribution from:

- Bem-Gurion University (Israel)

Contributors:

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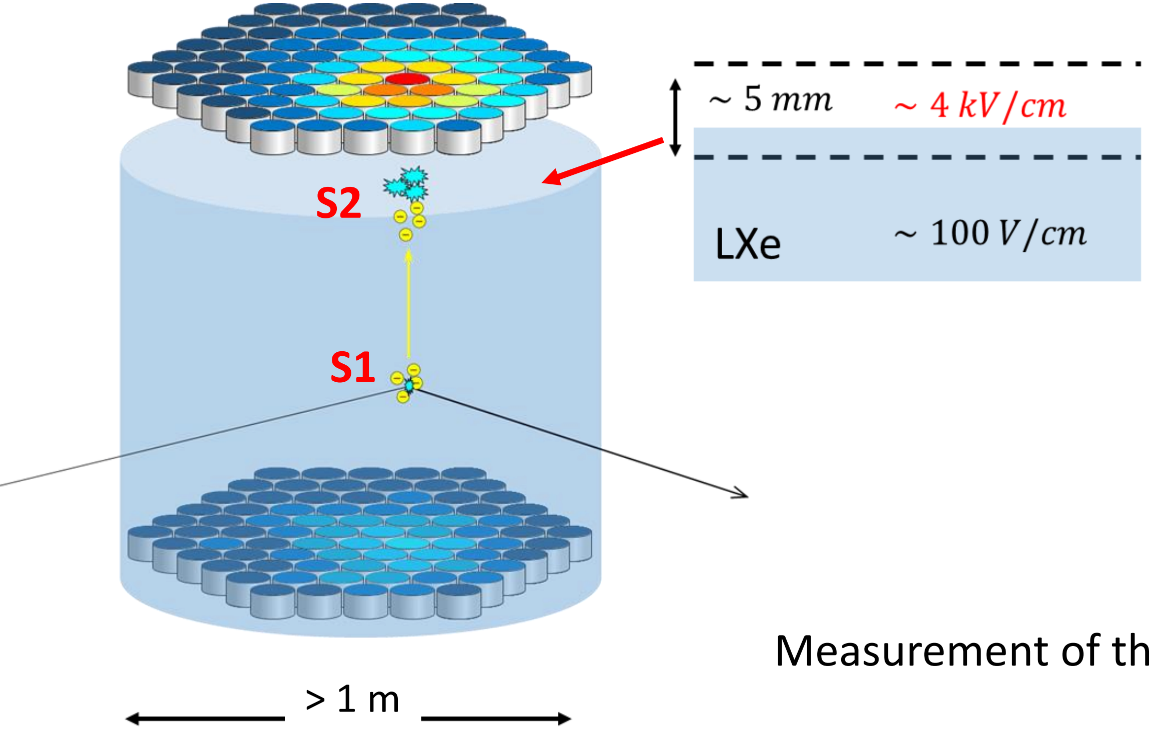
- Amos Breskin
- Gonzalo Martinez Lema
- Arindam Roy
- Vladimir Solovov
- Francisco Neves

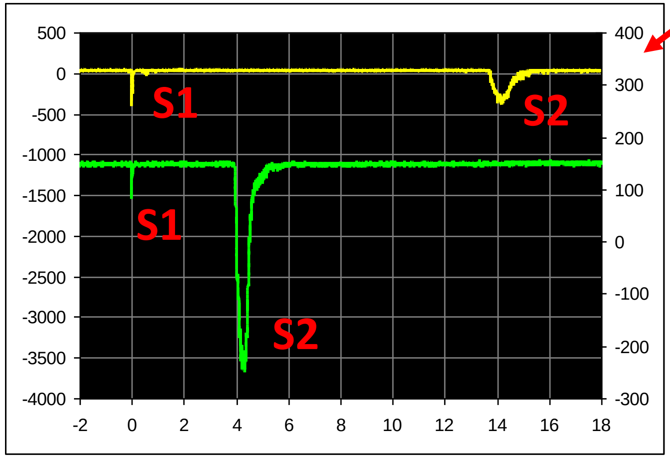
Double-phase liquid noble gas detector

Two-phase liquid detectors are probably the most versatile detectors for low energies and rare events

Typical configuration of a two-phase WIMP detector



WIMP signature



Neutrons (nuclear recoils)

Gammas/electrons

Measurement of the two signals is the basis for e/nuclear recoils discrimination

The threshold is determined by S1 (usually 2 or 3 phe are required in coincidence)

S2 provides energy and position in (x,y) – typically ∼300 ph/e

Motivation

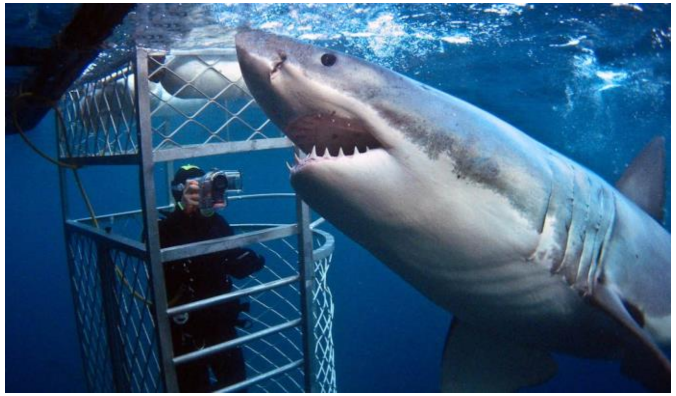
Liquid surface – inconvenient but worth of suffering (at least it was until now)

Problems associated with the surface:

- A strong E field is required for electron extraction → the surface should be between two multiwire electrodes with the distance of ~5 mm between them → **wire sagging matters**
- Under surface charge drift/diffusion
- Possible ripples, acoustic effects, instabilities in a strong E field

The bigger the detector the bigger the problem

Two options: dive or float



“No surface, no problem” – back to single (liquid) phase.

“ We are one”, the electrodes & the surface – floating electrodes:

Outline

1. Double-phase: development of floating electrodes for LXe
2. Single phase: electroluminescence of LXe (LAr) on narrow strips:
   a) Results with a microstrip plate
   b) Results with a VCC – Virtual Cathode Chamber

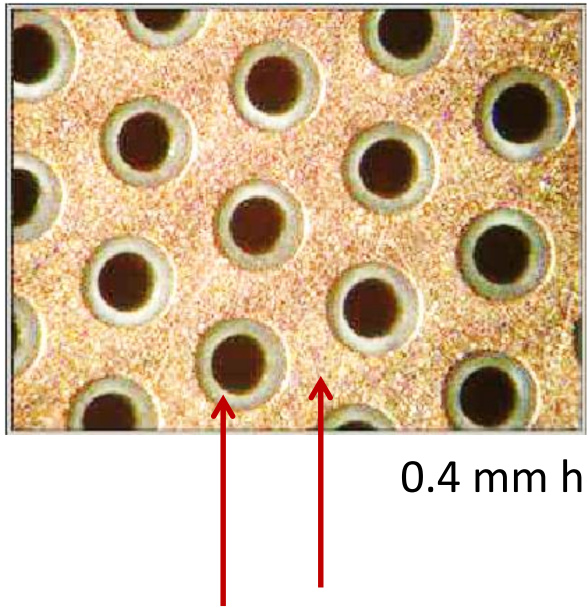
1. Floating electrodes – THGEM

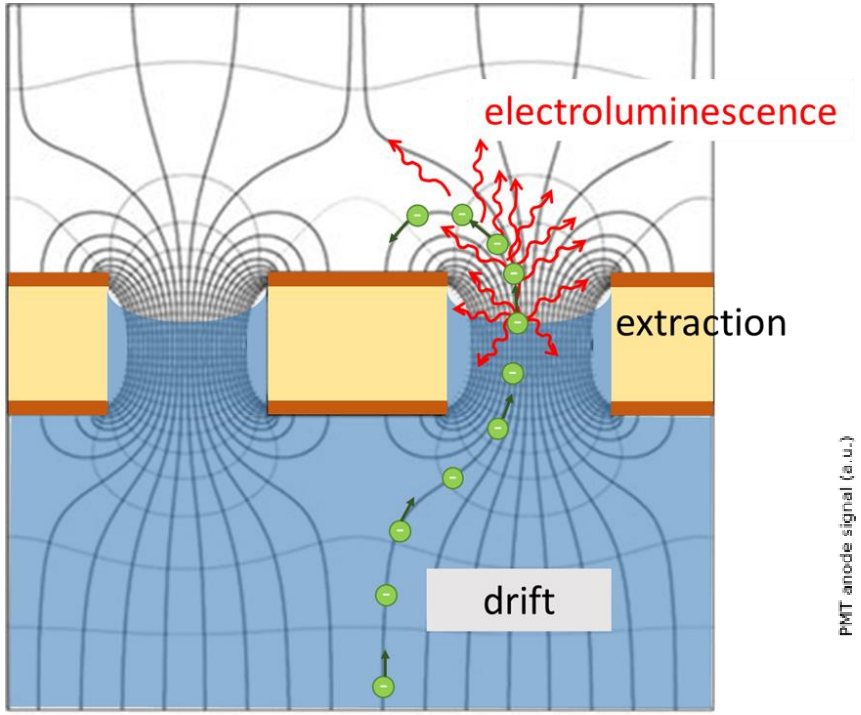
LXe density **2.9** g/cm3

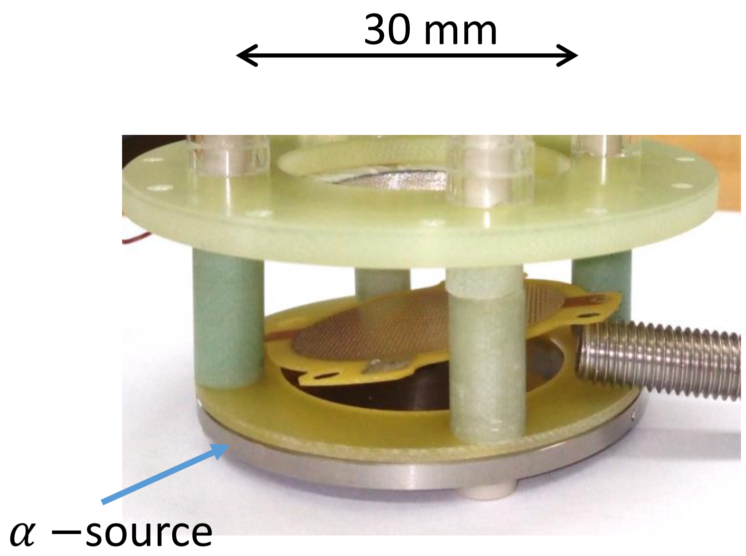
FR4 density **2.0±0.2** g/cm3 - dielectric material used to make THGEM

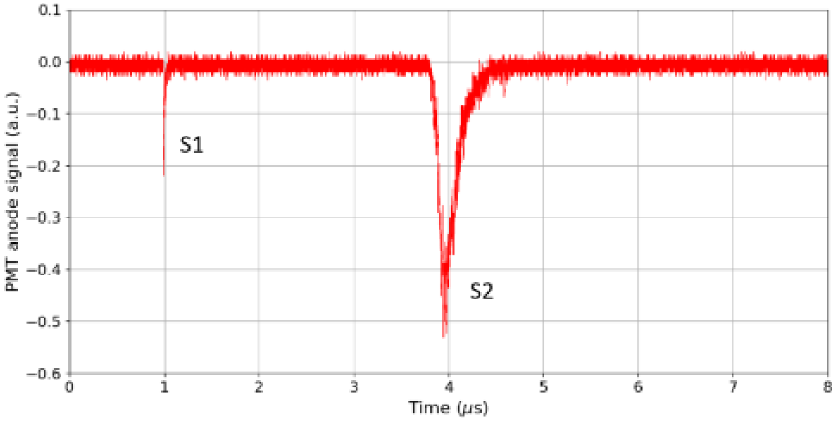
If copper cladding is not too heavy → THGEM **should float** on the surface of LXe

THGEM









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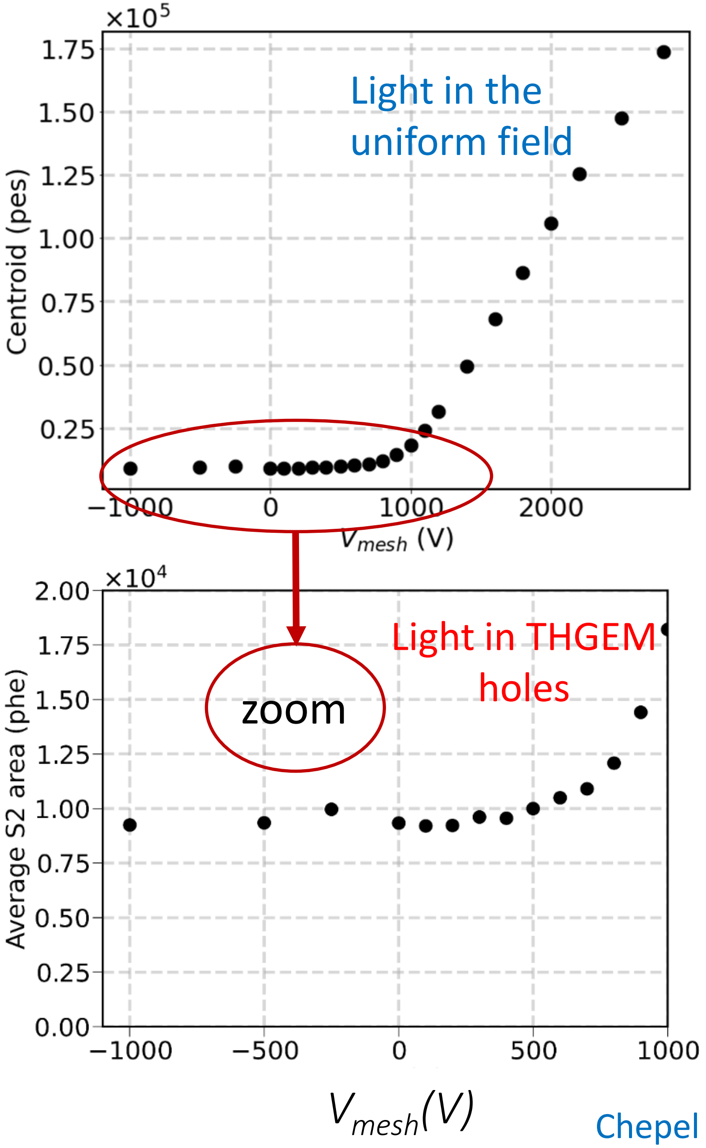
1. Floating electrodes – devil in details



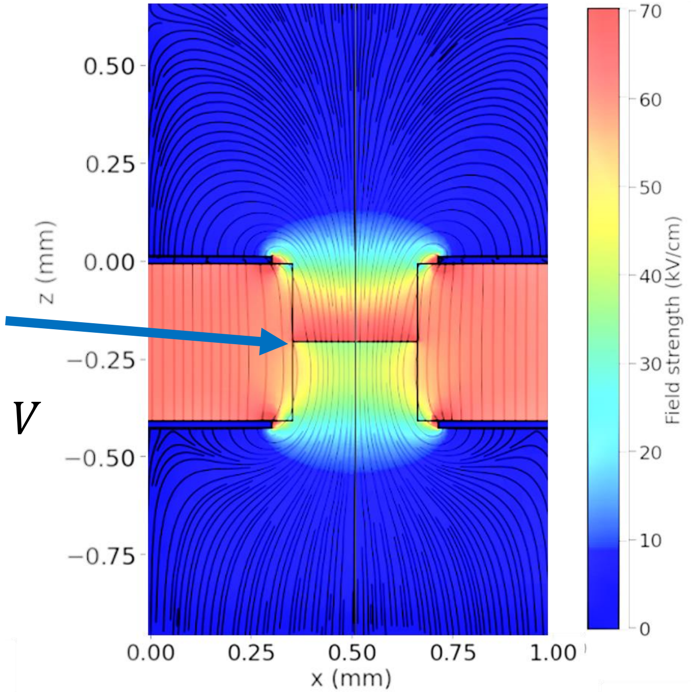
COMSOL:

$$\Delta V_{extr} = 0$$

$$\Delta V_{THGEM} = 2500\ V$$

$$\Delta V_{drift} = 400\ V$$

Assumed LXe level



Fields near the interface:

$$E_{gas} \sim 70\,\frac{kV}{cm}$$

$$E_{liq} \sim 40\,\frac{kV}{cm}$$

Generated in the hole:

$\sim$1 phe/drifting electron

$\sim$20-50 ph/drifting electron in 4π

Not very impressive…

LXe in the hole: is it really like this?

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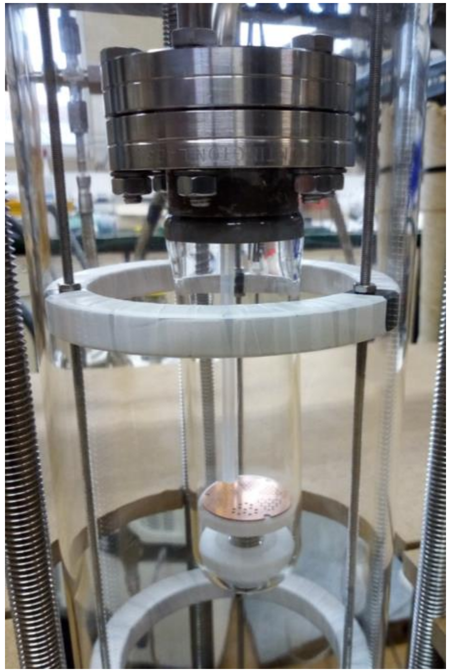
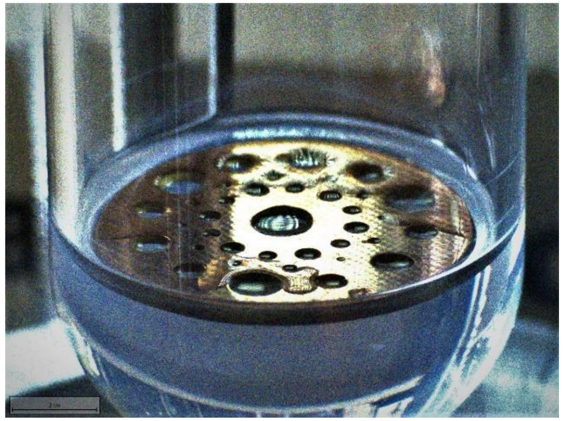
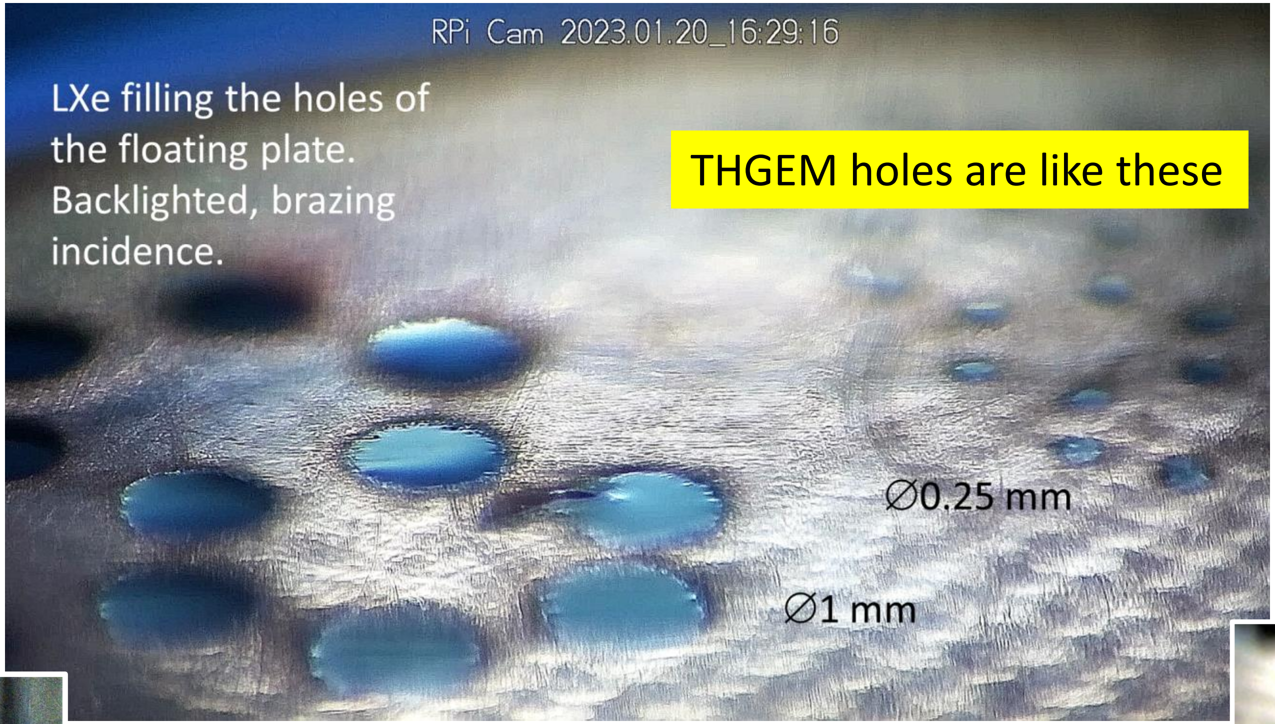
1. Floating electrodes – liquid xenon in the hole







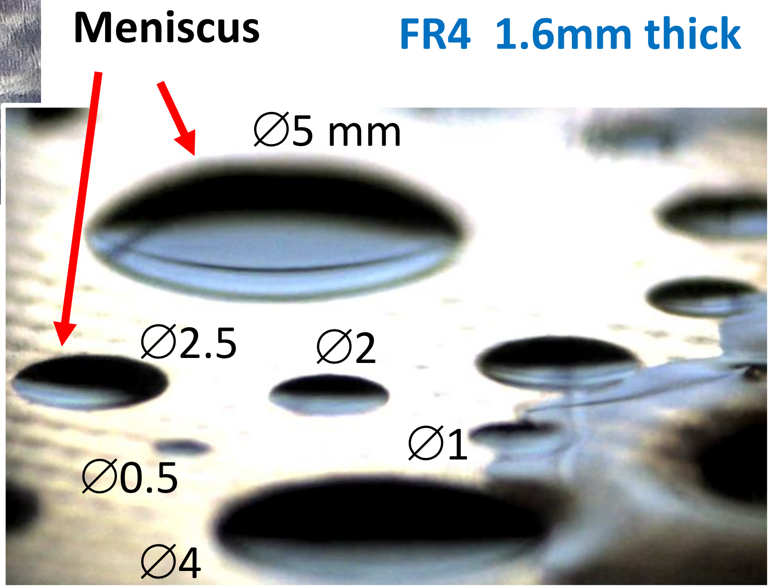
LXe filling the holes of the floating plate. Backlighted, brazing incidence.

THGEM holes are like these

No space for gas in the hole even for ∅1 mm

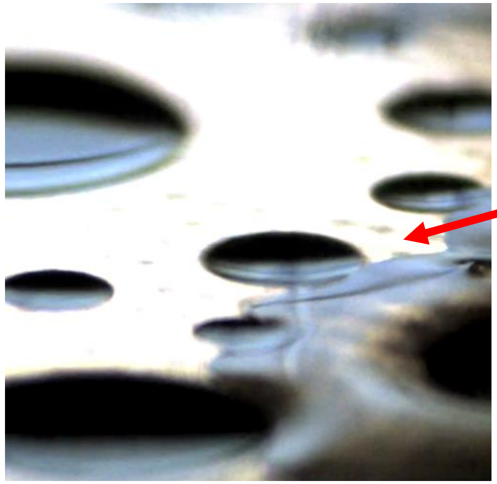
Thicker plate with bigger holes:

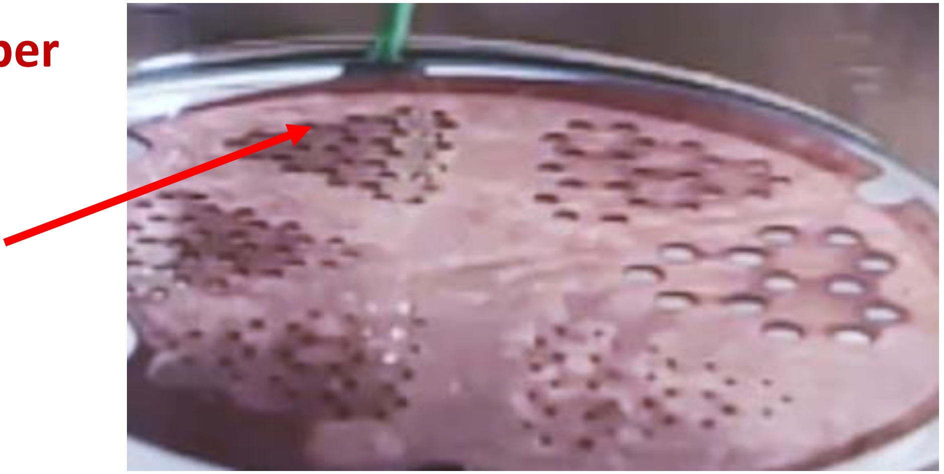
FR4 1.6mm thick



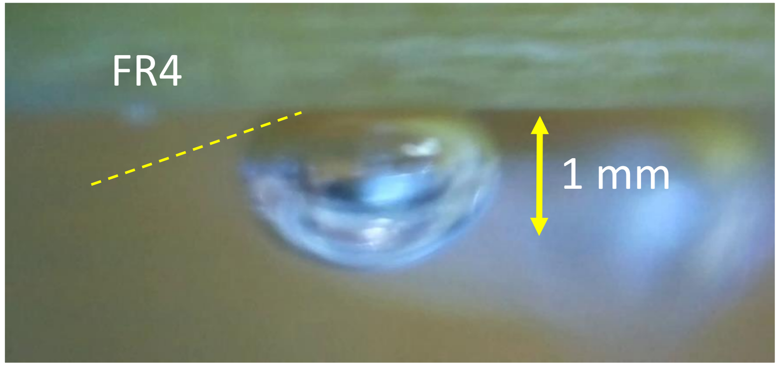
1. Floating electrodes – wettability studies (ongoing)

Wettability of copper

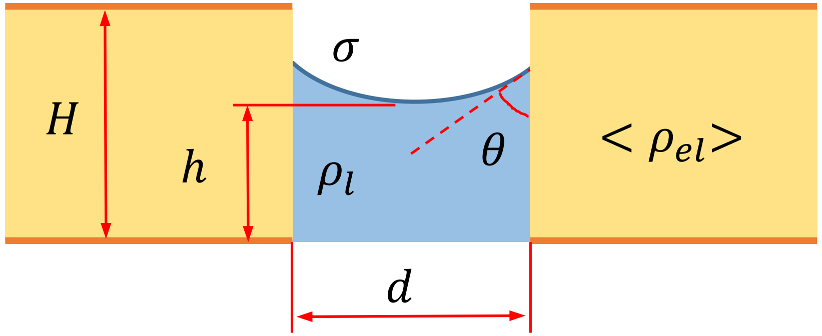




Xe gas bubble in LXe showing high wettability of FR4 by LXe:



Modelling is crucial – contact angle is needed



$$h \approx H\frac{<\rho_{el}>}{\rho_l} + \frac{4\sigma}{\rho_l g d}\cos\theta$$

1. Floating electrodes – remaining questions/further work

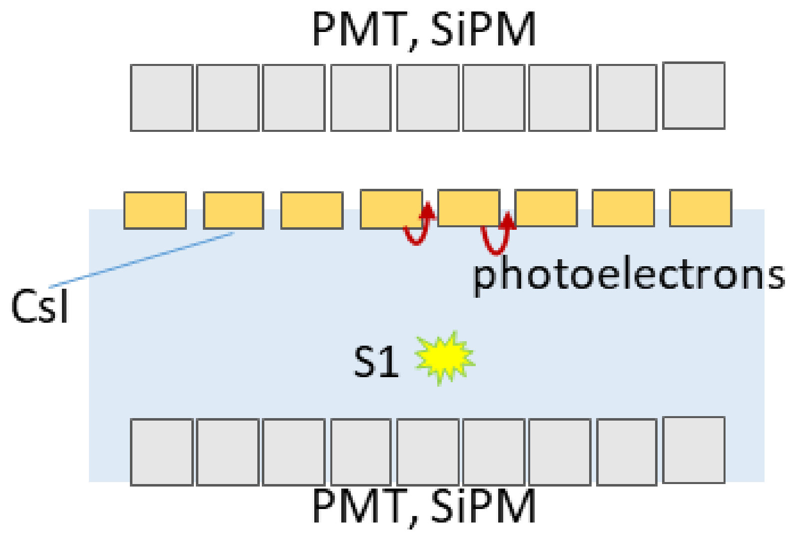
Prove of principle – successful. Open questions:

1. Opacity for VUV (S1 problem) – CsI photocathode? Quartz substrate?
2. Physics – meniscus profile, wettability, field effects, electron transmission efficiency
3. Structure optimization – thicker THGEM? Bigger holes?
4. Works in LAr (1.4 g/cm^3)?

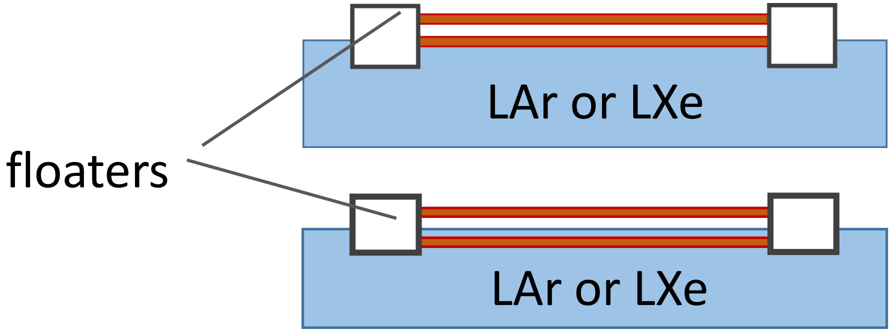
Some plastics do float in LAr, e.g. polycarbonate (1.2 g/cm^3).

The question is whether one can make a THGEM-like electrode from them and put into a cryogenic liquid.

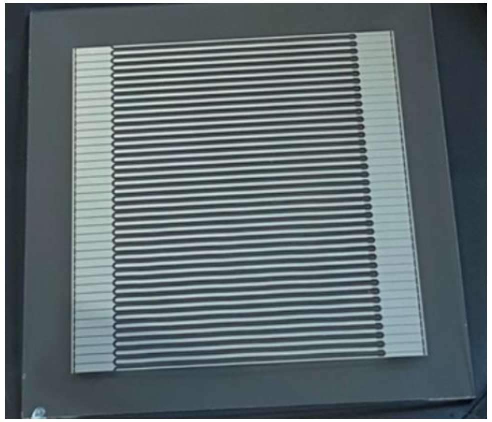
(interest from DUNE; a collaboration with AstroCeNT, Warsaw, is established)



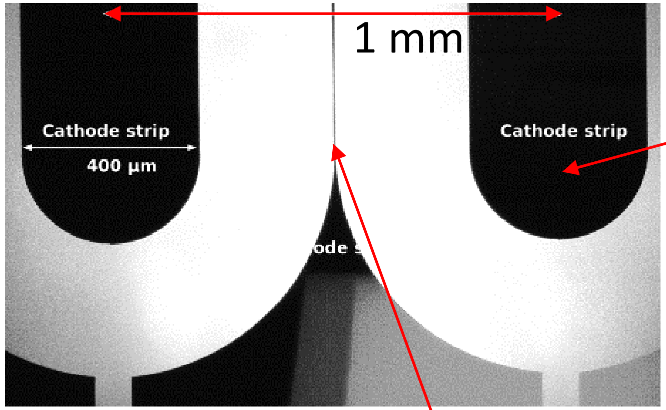
Other possible configurations:



2a. Microstrip plate in LXe (WIS)

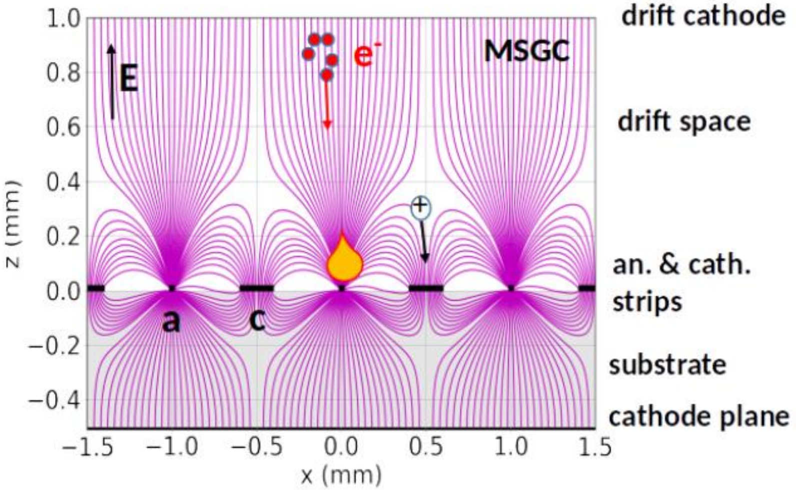


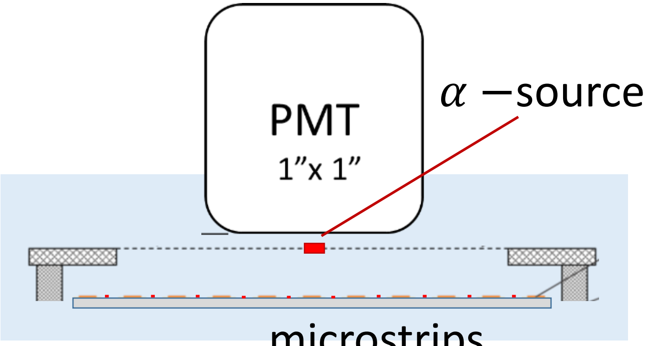
5x5 cm^2 D263 Schott glass
0.5 mm thick
(same as we used to observe electron multiplication in LXe back in 1995)
[Policarpo e. a. NIMA365(1995)568](#)



Cathode 400 μm

Anode 8 μm

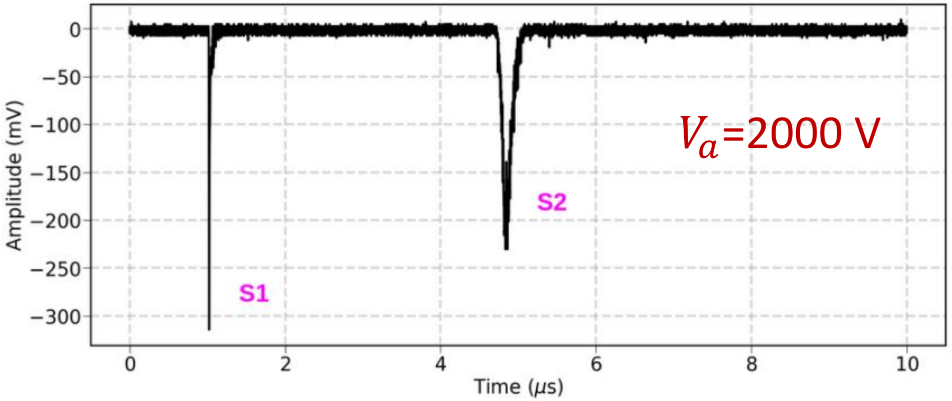




PMT
1”x 1”

α −source

microstrips



V_a=2000 V

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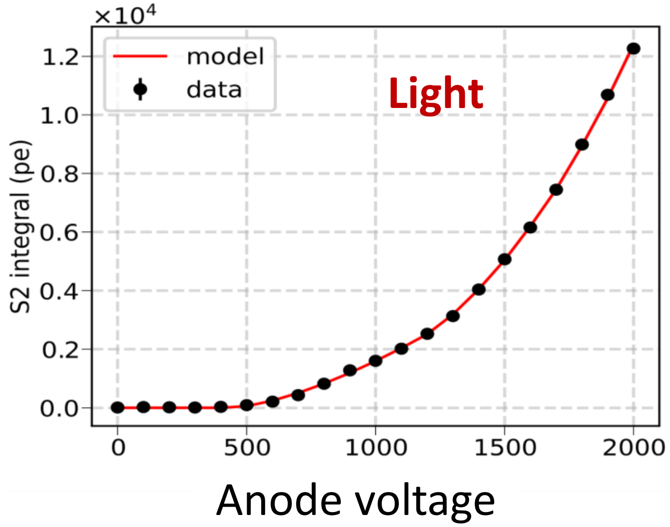
2a. Microstrip plate in LXe (LAr preliminary)

LXe



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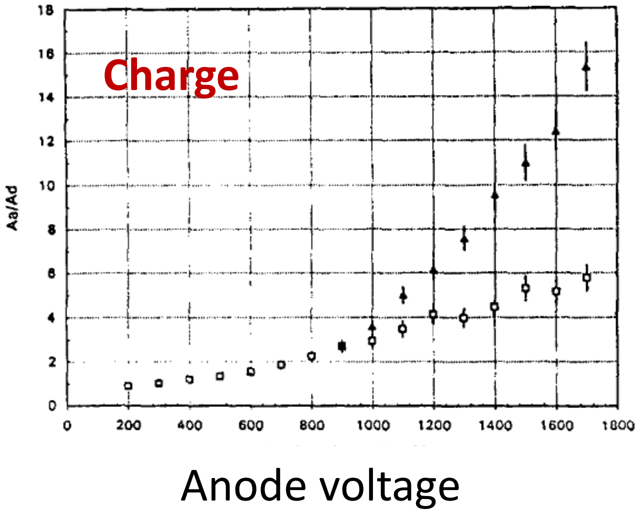
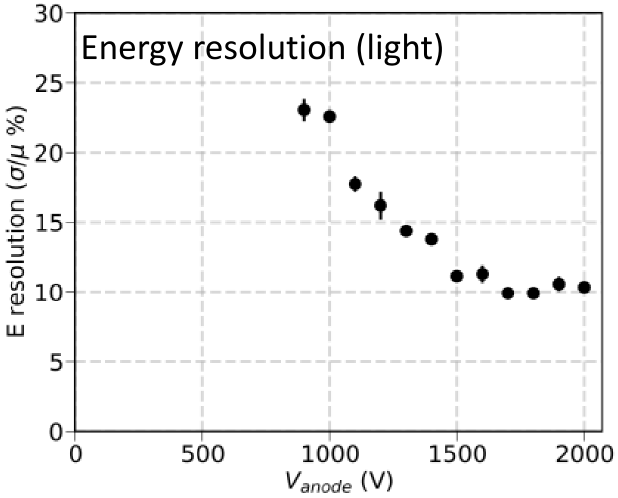


Policarpo e. a. NIMA365(1995)568



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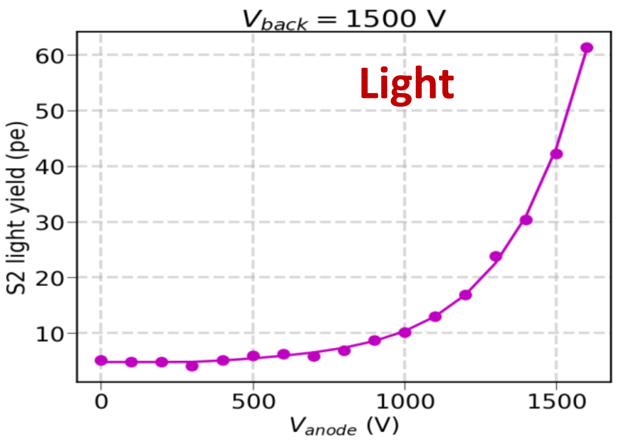
35.5±2.6 VUV phot/drifting e^- in 4π

LAr

preliminary



Same geometry as for LXe (PMT quartz window covered with TPB)

S2 signall by a factor of ~100 smaller

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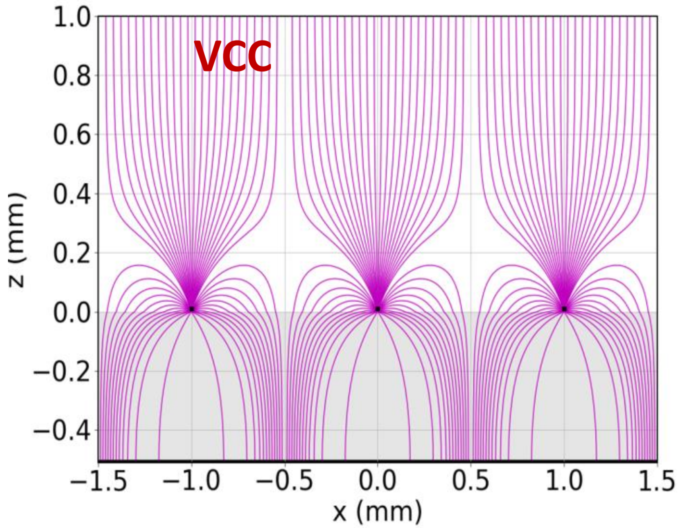
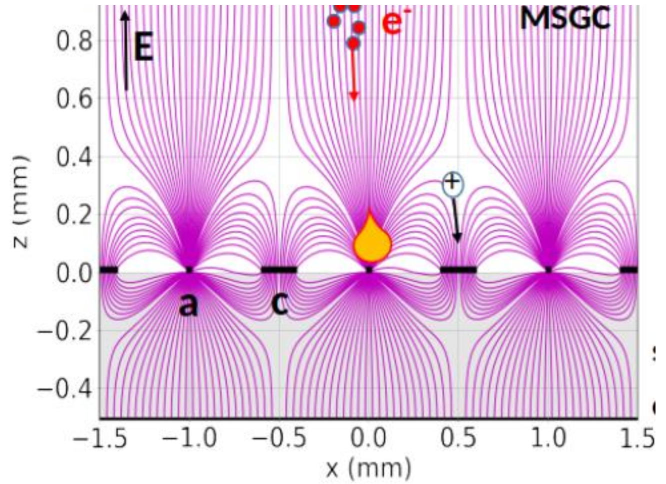
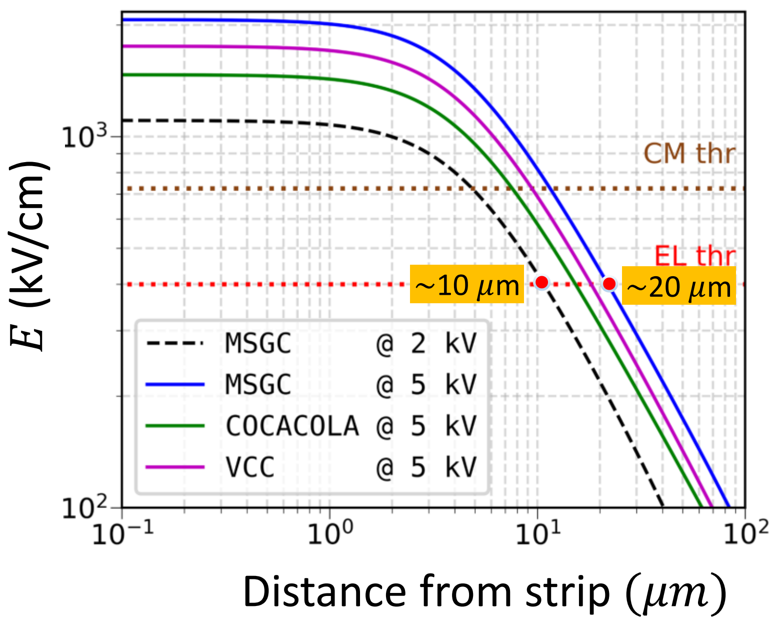
2b. Virtual Cathode Chamber (VCC) vs Microstrip plate

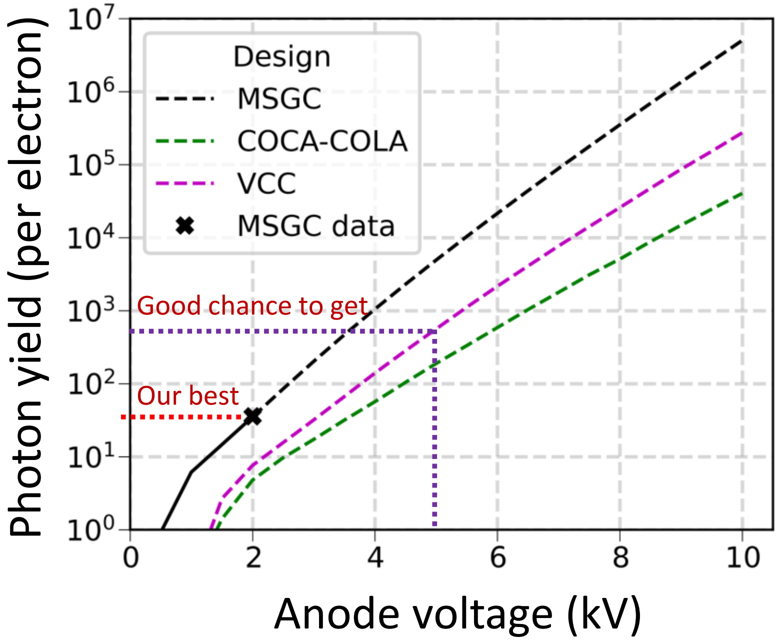
No cathode strips; **the cathode is on the other side of the plate** (Capeans e. a. NIMA400(1997)17)

Computations using $E_{th}(EL) = 412\ kV/cm$
$E_{th}(CM) = 725\ kV/cm$









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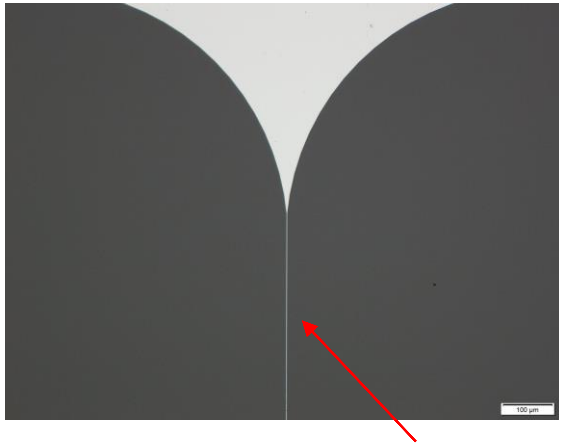
For same voltage, microstrip is better than other configurations

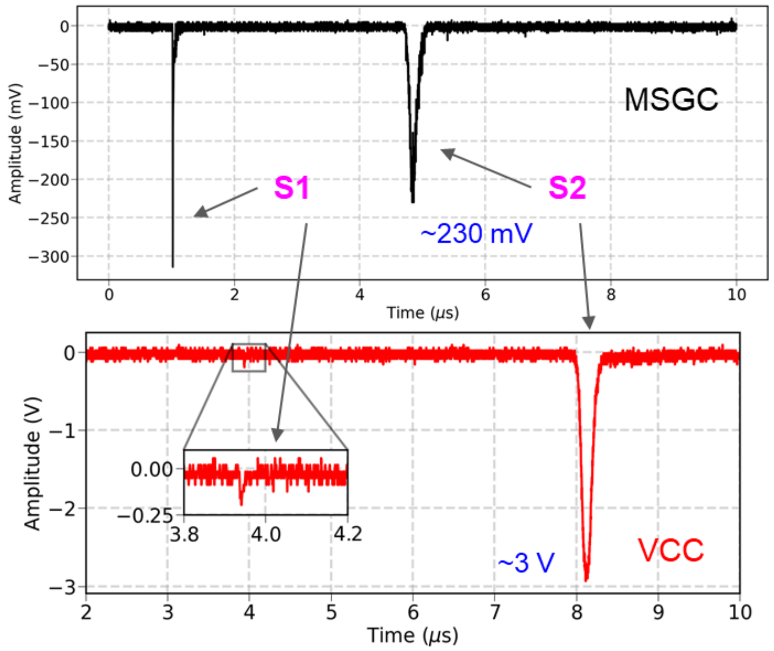
However, higher voltages can be applied to VCC than to a microstrip plate

2b. VCC – results in LXe

Our VCC plate



anode strip (Cr) 2 μm wide

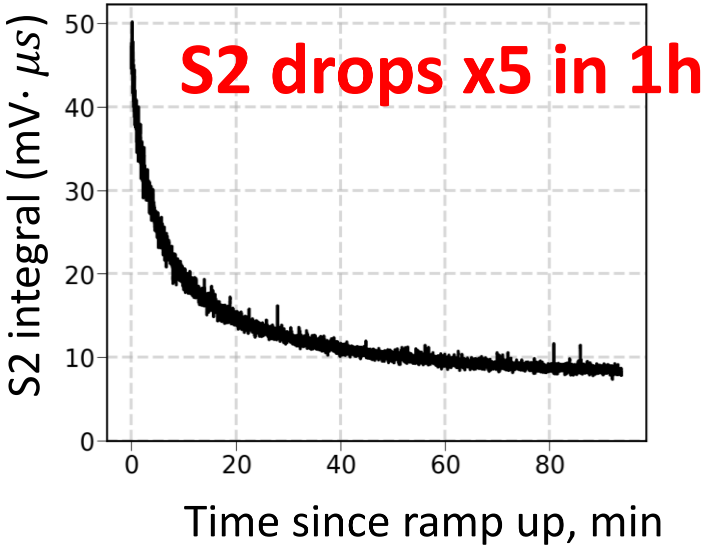


V_{source} = -2.0 kV
$V_{cathode}$ = ground
V_{back} = -2.0 kV
V_{anode} = +1.6 kV

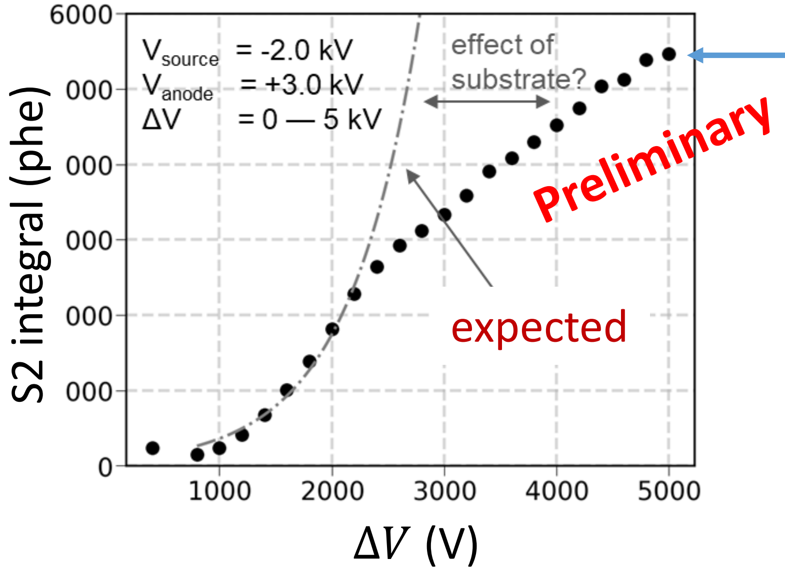
ΔV = 1.6 kV

V_{source} = - 2.0 kV
V_{back} = - 1.75 kV
V_{anode} = +3.25 kV

ΔV = 5.0 kV



S2 drops x5 in 1h



~ 30 photons/drifting e⁻

At more or less stable conditions (in small steps, after waiting a few min)

Max ~ 500 photons/electron observed

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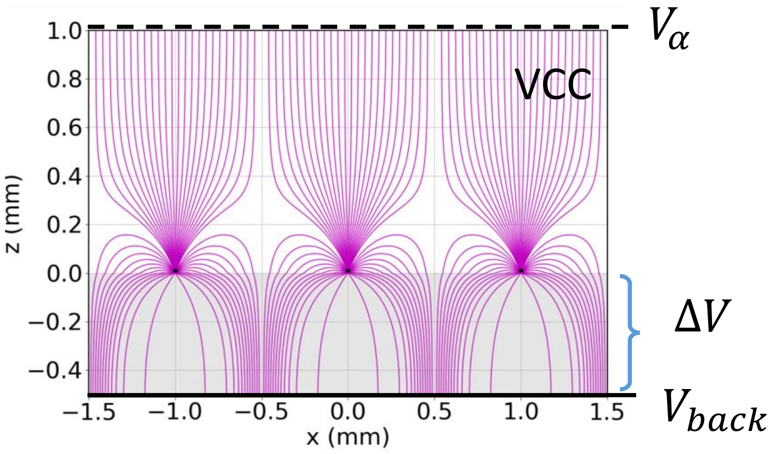
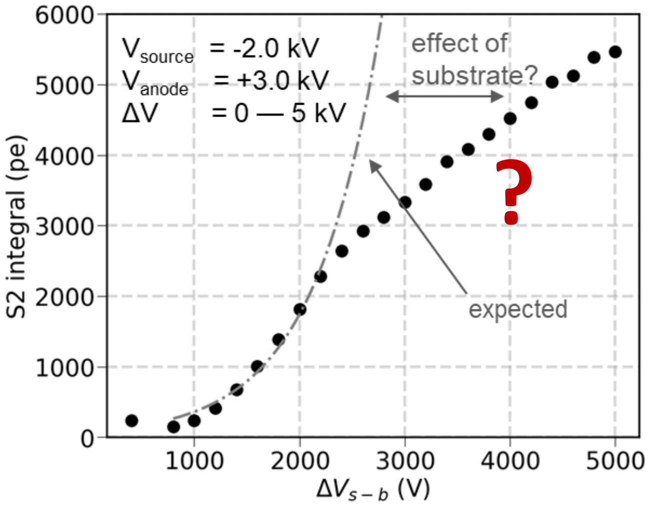
2b. VCC – possible explanations for signal degradation

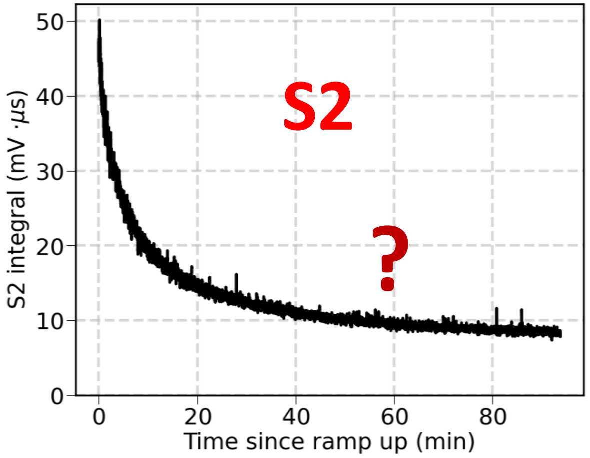




?

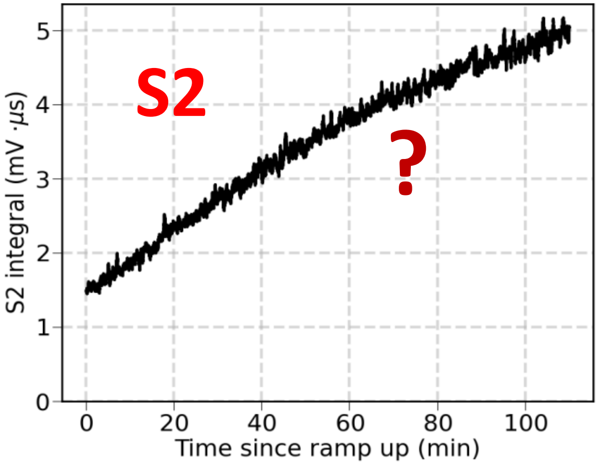
Fixed drift field $(V_\alpha - V_{back} \neq 0)$

$\Delta V = 0 \rightarrow 2\ kV\ (t=0)$



Fixed ΔV

Drift $E = 0 \rightarrow 1.6\,\frac{kV}{cm}\quad (t=0)$



Charging up? – 40 Bq source, $G \lesssim 10$ …

Glass conductivity too low?

($\sim 10^{11}\ \Omega \cdot cm$ at room T, $\times 10^3 - 10^4$ in LXe)

Effect of glass polarization?

Glass – kind of Pestov black glass

One thing is clear – the substrate matters

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2. Microstrips and VCC vs wires

Us: ~ 30 photons/drifting e^- (>500 possible with VCC)

Wires:

~**0.1-0.5** ph/e = “Light/Charge” single wire 4 to 25 μm, up to 5 kV **--** Masuda e.a. 1979

~ **20** ph/e @ ~3.6 kV
100 ph/e @ 5 kV
300+-80 ph/e @ 6.7 kV

10 μm anode wire between two plane multiwire cathodes, 8 mm between them -- Aprile 2014

~ **17 ph/e** @ 3.6 kV **-** single **10 μm** anode wire; cylidrical geometry (wire cathodes) -- Qi e.a. 2023

29 ph/ie @ 4.4 kV -- Tönnies et al 2024

As a footnote: first report on electroluminescence of LXe (in uniform field) – Dolgoshein e.a. 1967

2. Microstrips: what next

Prove of principle – successful.

Advantage - No liquid-gas interface

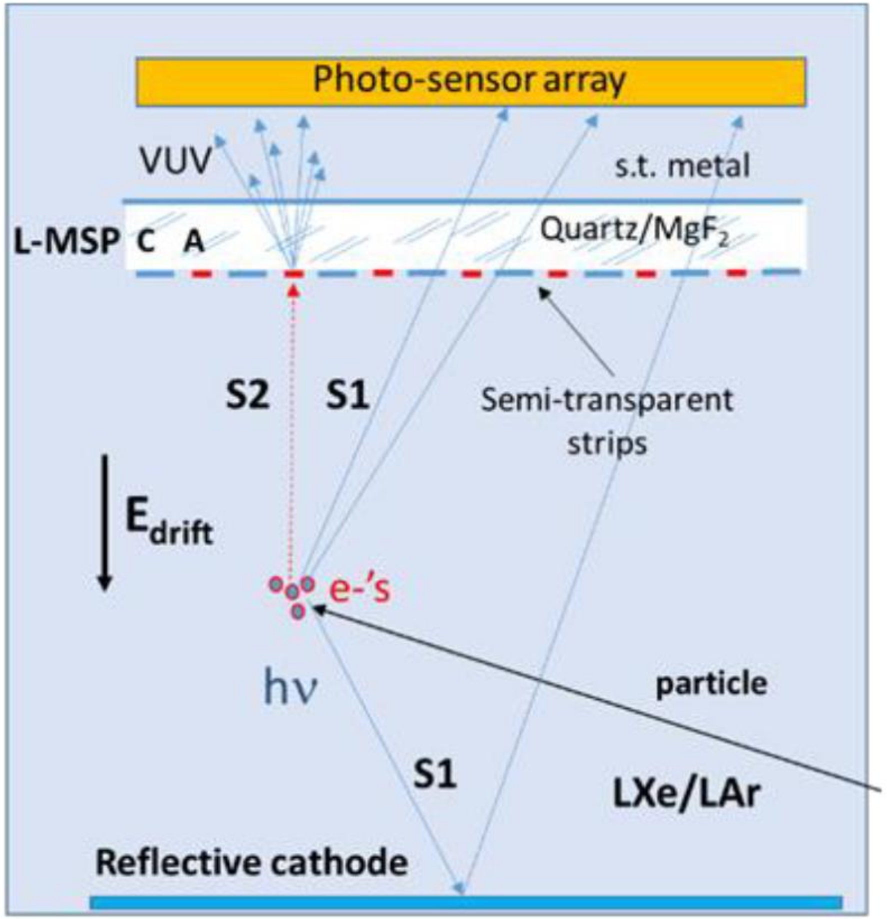
- Reduced instabilities (interface ripples)
- No delayed e^- emission or e^- transfer inefficiency through interface
- No gate-interface-anode alignment problems
- Potential improvement for S2-only events (e.g. lower background)

Drawbacks

- Electric fields ~few 100 kV/cm required for electroluminescence (EL)
- So far, lower light yield than dual-phase detectors (except VCC right after applying the voltage)

Open questions:

1. Substrate polarization/charging up/…? – clarify
2. Would higher conductivity of the substrate help?
3. Is it possible to do on a VUV transparent substrate?
4. Works in LAr ?
5. How do we maximize electroluminescence and avoid charge multiplication?



Breskin JINST 17 (2022) P08002

Conclusions

FHM – prove of principle in LXe successful, structure optimization and material studies are needed; floating in LAr is challenging but interesting

Microstrips and VCC – prove of principle successful in LXe and LAr; light yield in LXe is comparable or higher of that with $\sim 10\ \mu$m wires; signal degradation in time with VCC needs to be understood; much higher ligh yield seems possible

Thank you