Floating Hole Multiplier – a novel concept for dual-phase noble liquid detectors

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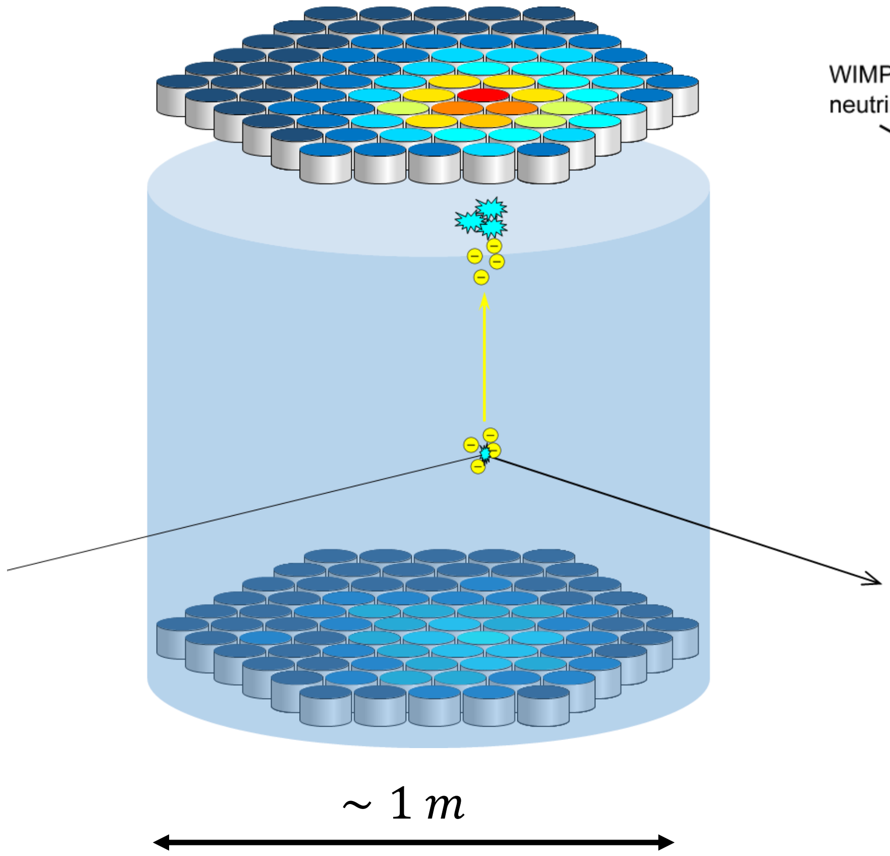
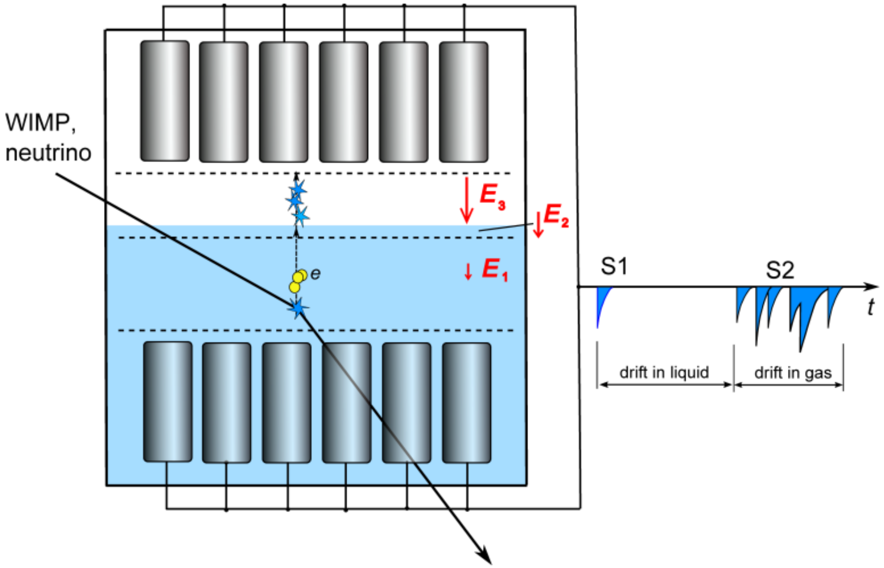
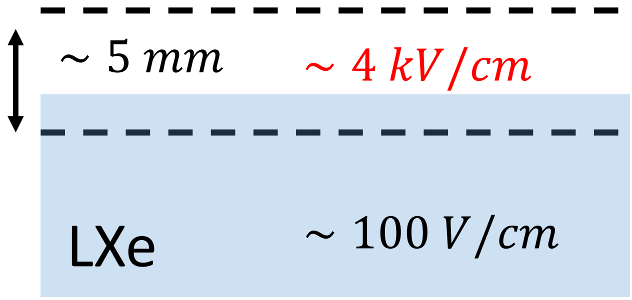
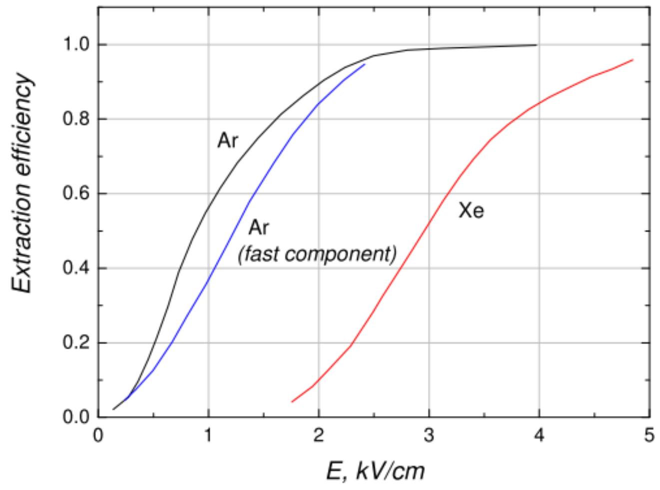
Generally accepted configuration of a 2-phase detector (for DM search, at least)







Electron emission efficiency *vs* E



Motivation

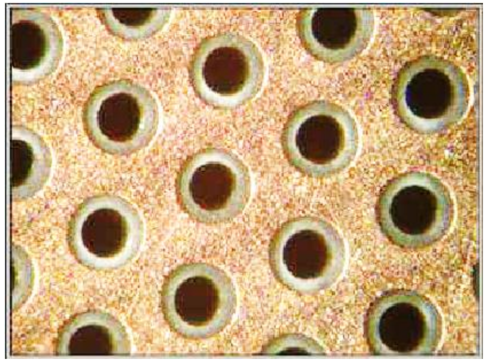
Liquid surface is inconvenient but the benefits were worth of suffering (until now, at least).

There is a number of problems associated with it both of physical and technical nature:

- The liquid-gas interface must be in a strong *E* field for efficient electron extraction; present solution – parallel multiwire electrodes at ~5 mm → wire sagging; **worse for bigger detectors**
- Insufficient field → electron trapping under the surface
- Charge drift/diffusion under the surface,
- Ripples, acoustic effects, instabilities in strong *E* field
- These effects can contribute to spontaneous single electron emission from the liquid

If we still in love with 2-phases – what can we do?

- **How do we gain a better control of what is happening on the surface?**
- Ideally, one would like to separate the two phases with, say, a membrane transparent for light and electrons but not for Xe or Ar atoms.
- Big question – what this membrane might be?
- The liquid phase and the gas should be in thermal equilibrium (in the region of their contact, at least) → problem of gas condensation above the membrane and bubble formation in the liquid
- Maybe, holes for electrons? → GEM, THGEM, etc
- How do we control the liquid level precisely to have liquid below and gas above it?



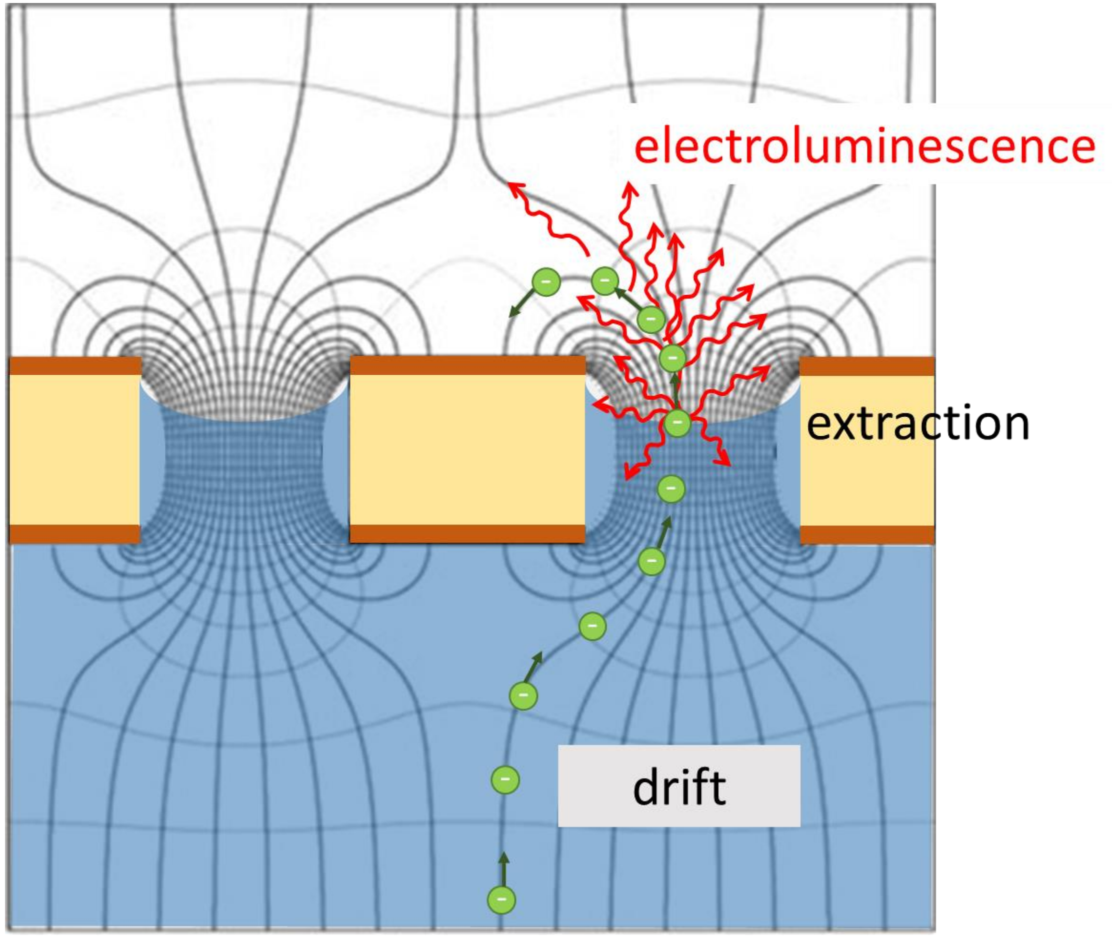
Go natural, let it float !

The idea

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



How do we know that the liquid interface will stay between the two copper electrodes?

How do we know the liquid will enter the hole?

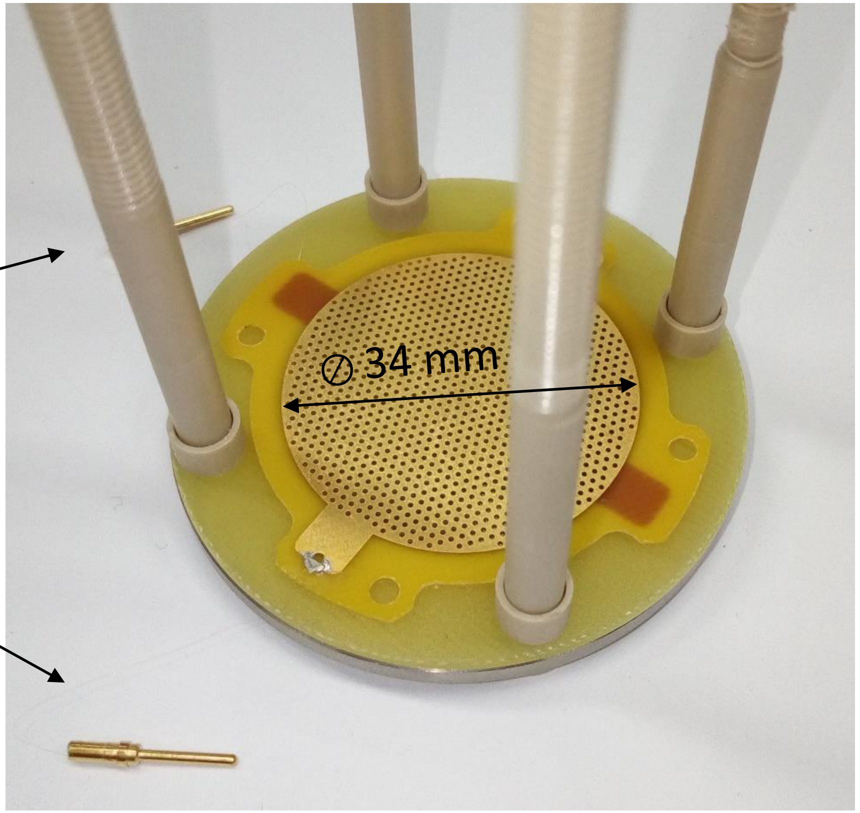
How do we know that the liquid will not spill over THGEM?

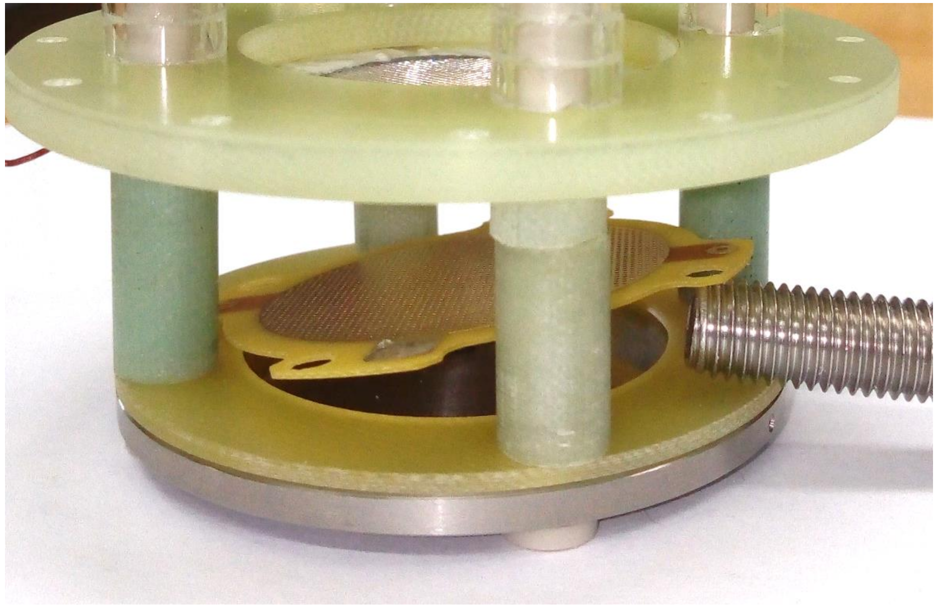
How do we know what is liquid surface profile in the hole?

Too many questions… Just try it!

Experimental setup

Two 20 μm wires connected to the two TGEM electrodes

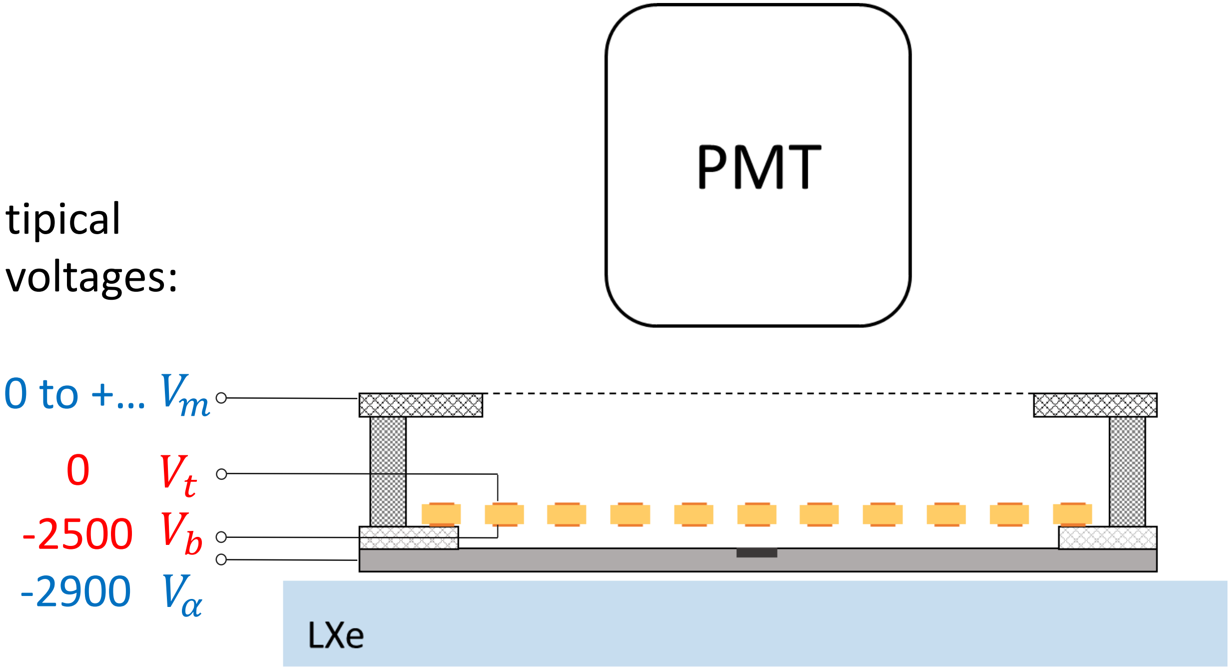




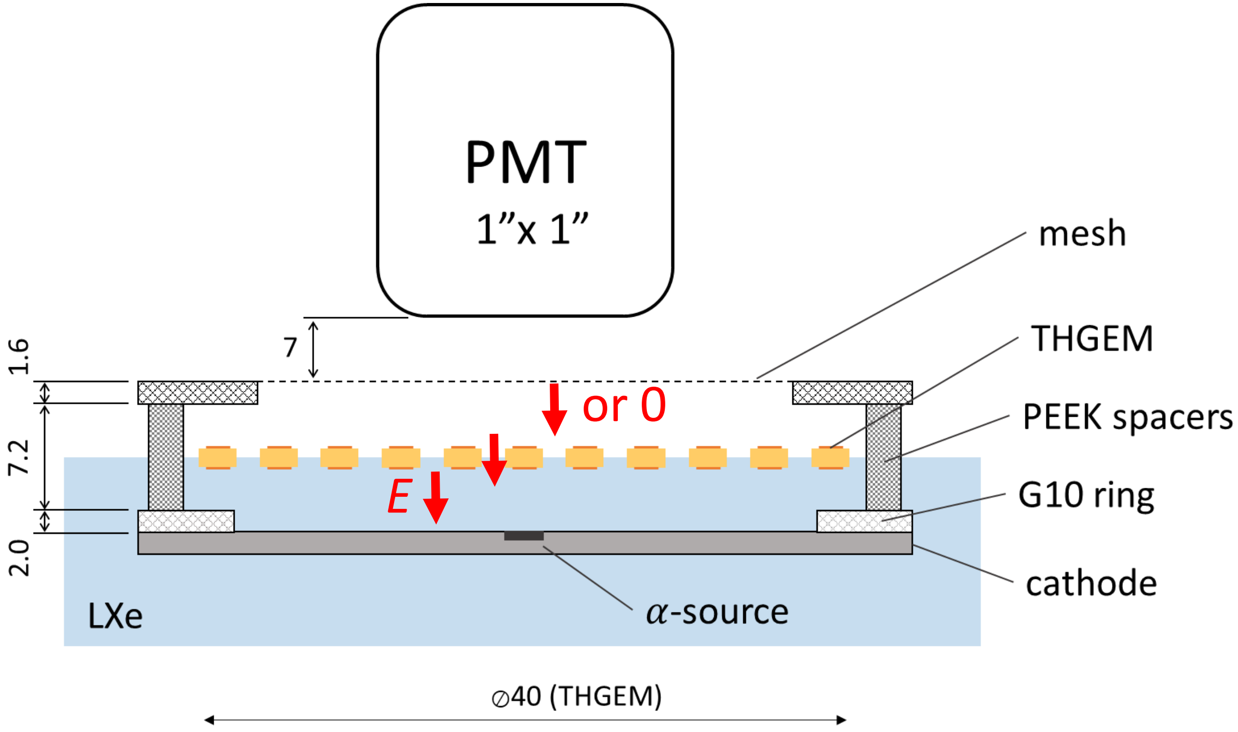
THGEM:
0.4 mm thick
0.3 mm holes, 0.1 mm rim
1.0 mm pitch

Experimental setup – voltages

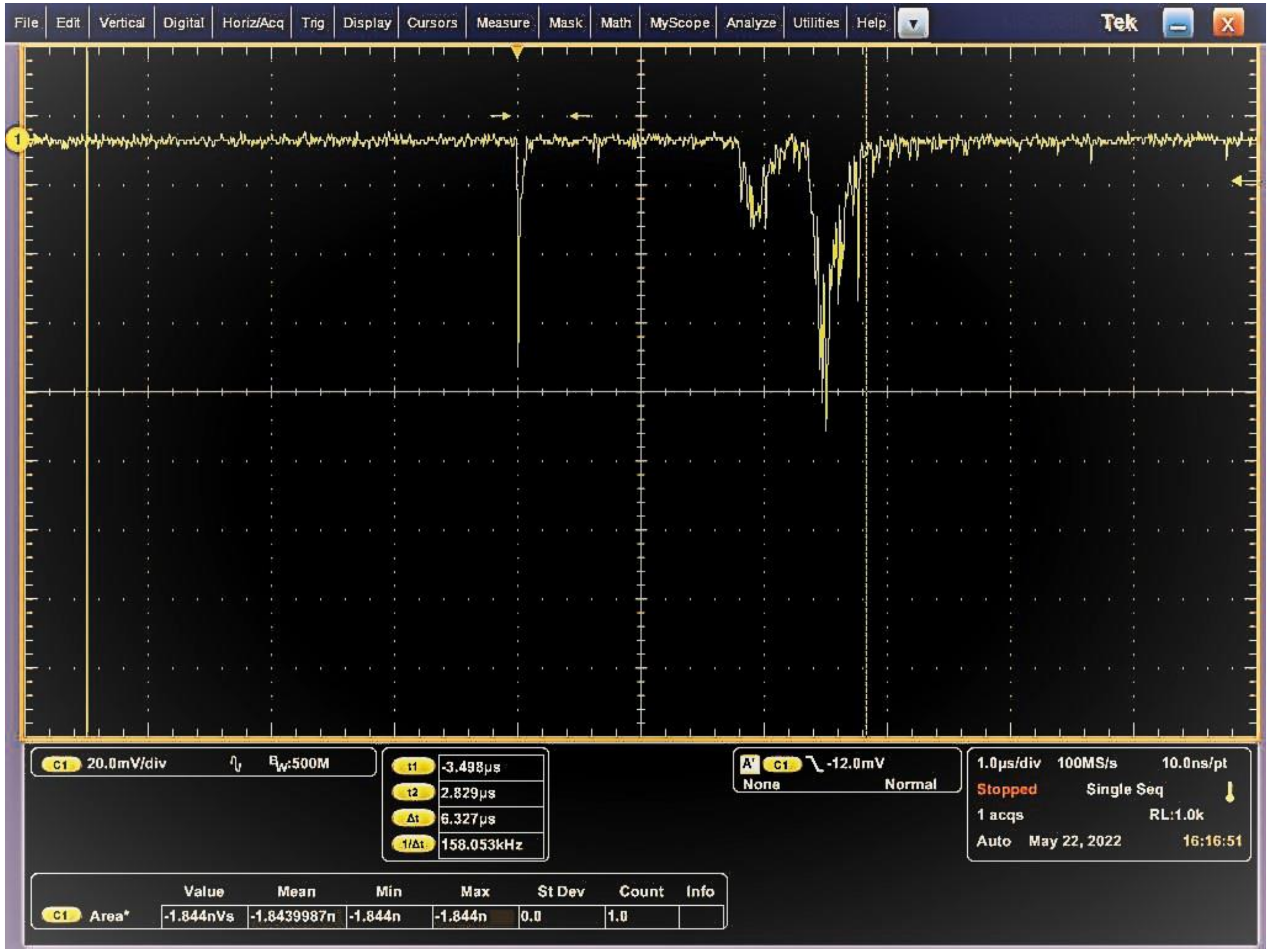
THGEM position with LXe below the cathode



Floating THGEM



See something?

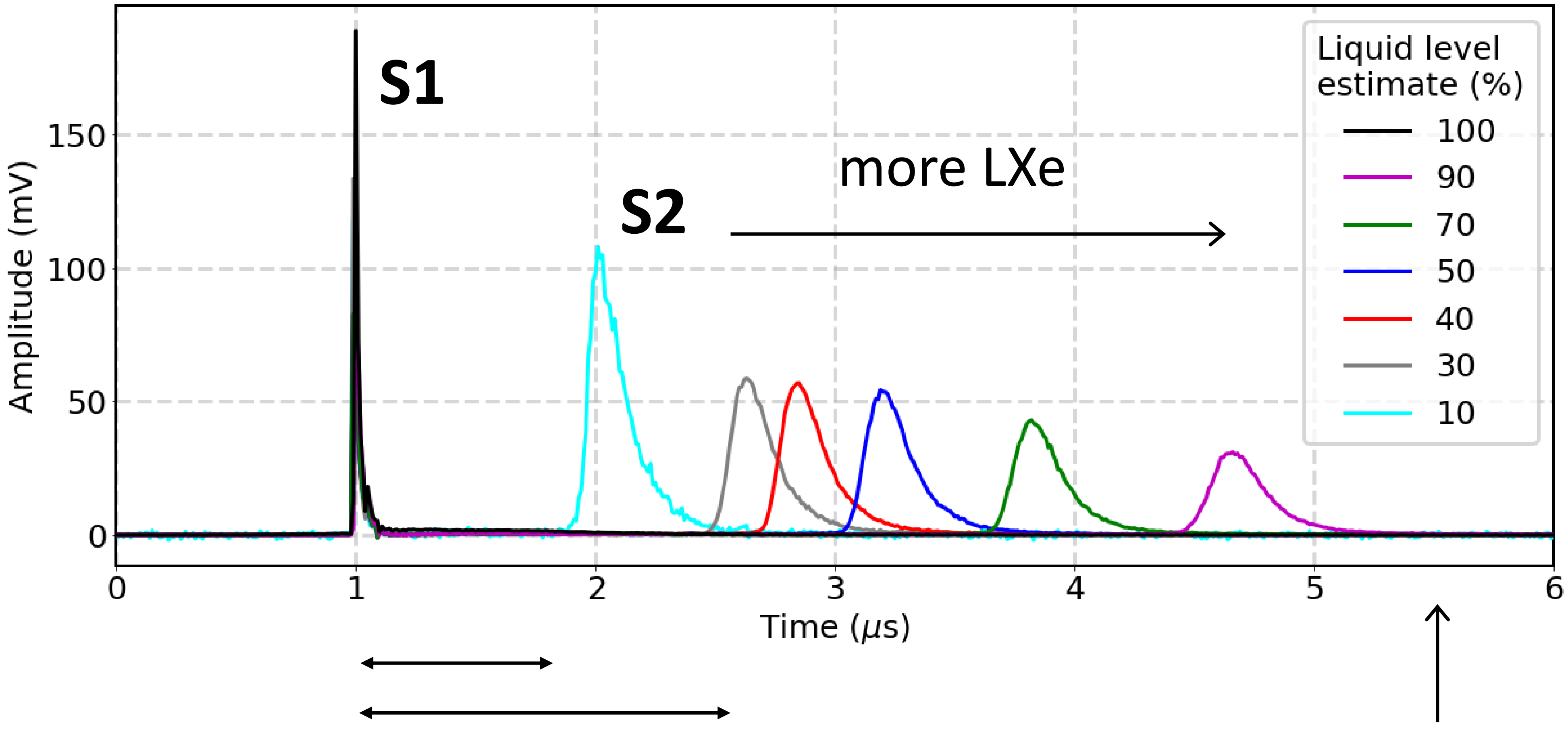


PMT signal

$$\Delta V_{\mathrm{drift}} = 400\ \mathrm{V}$$
$$\Delta V_{THGEM} = 2500\ \mathrm{V}$$
$$\Delta V_{extr} = 0$$

Estimated liquid thickness 6.8 mm

PMT waveforms for different liquid levels



Drift time in the liquid

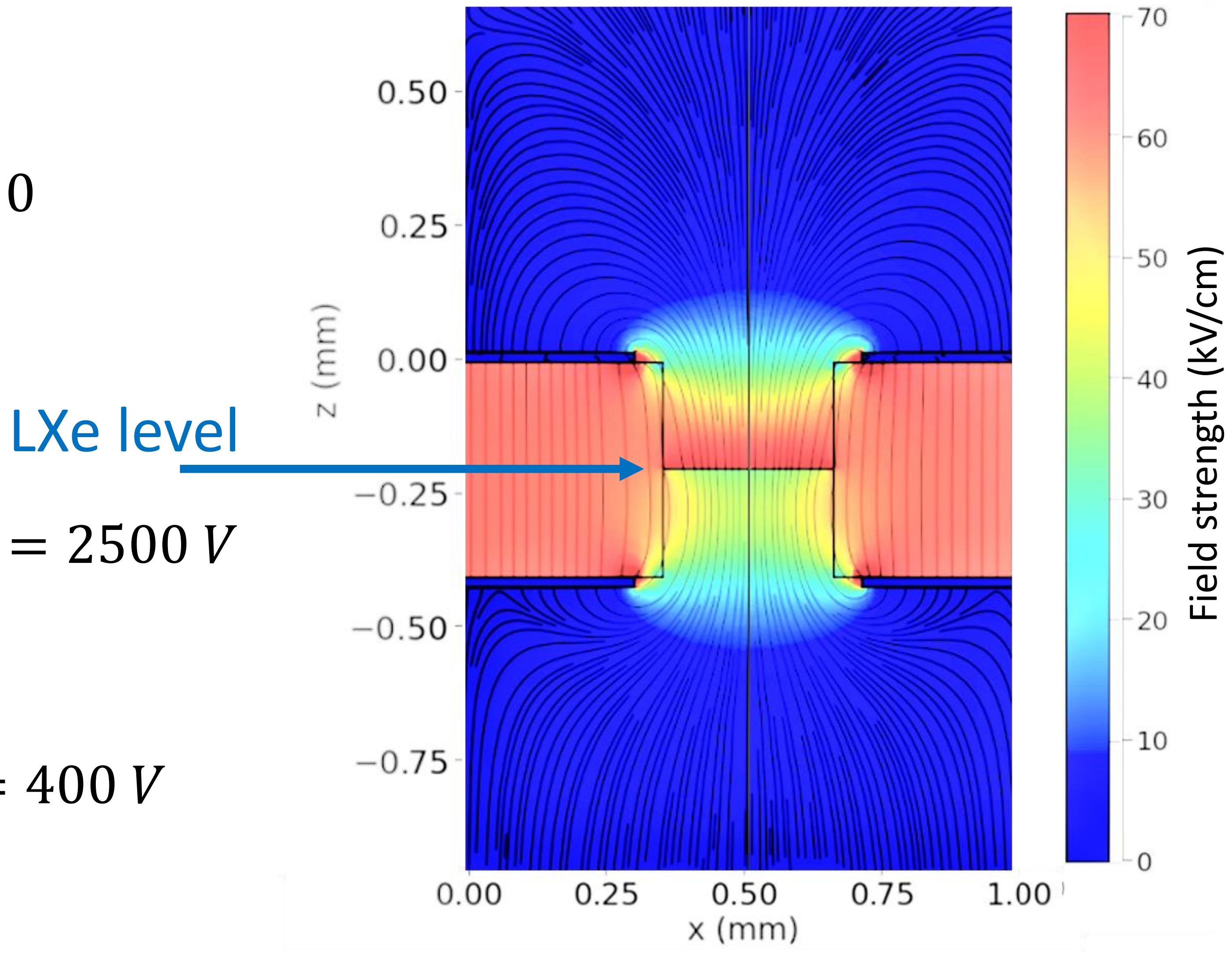
No S2 for fully covered THGEM

Field computation (COMSOL)

$\Delta V_{extr} = 0$

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

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



Fields near the interface:

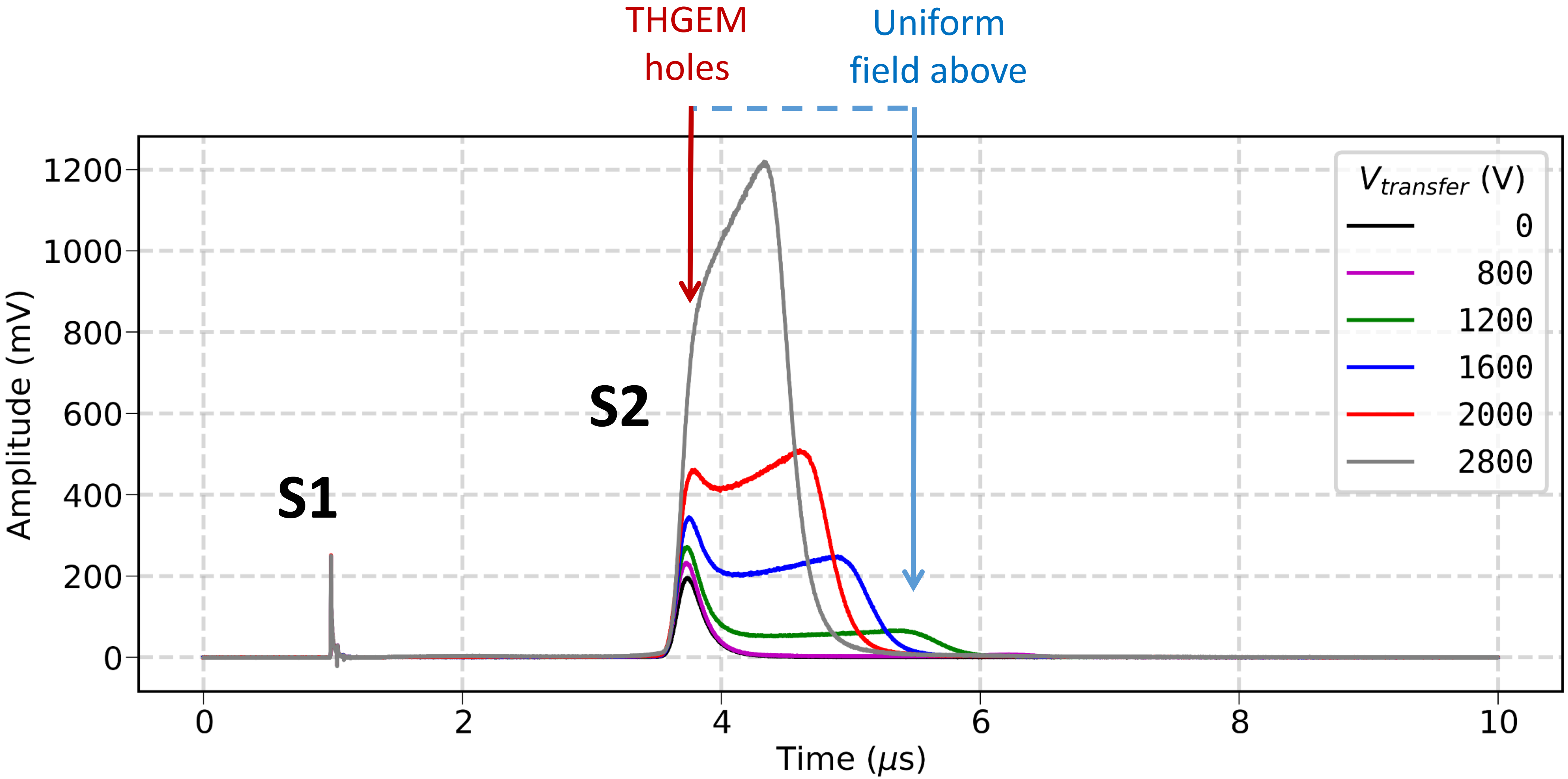
$$E_{gas} \sim 70\,\frac{kV}{cm}$$

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

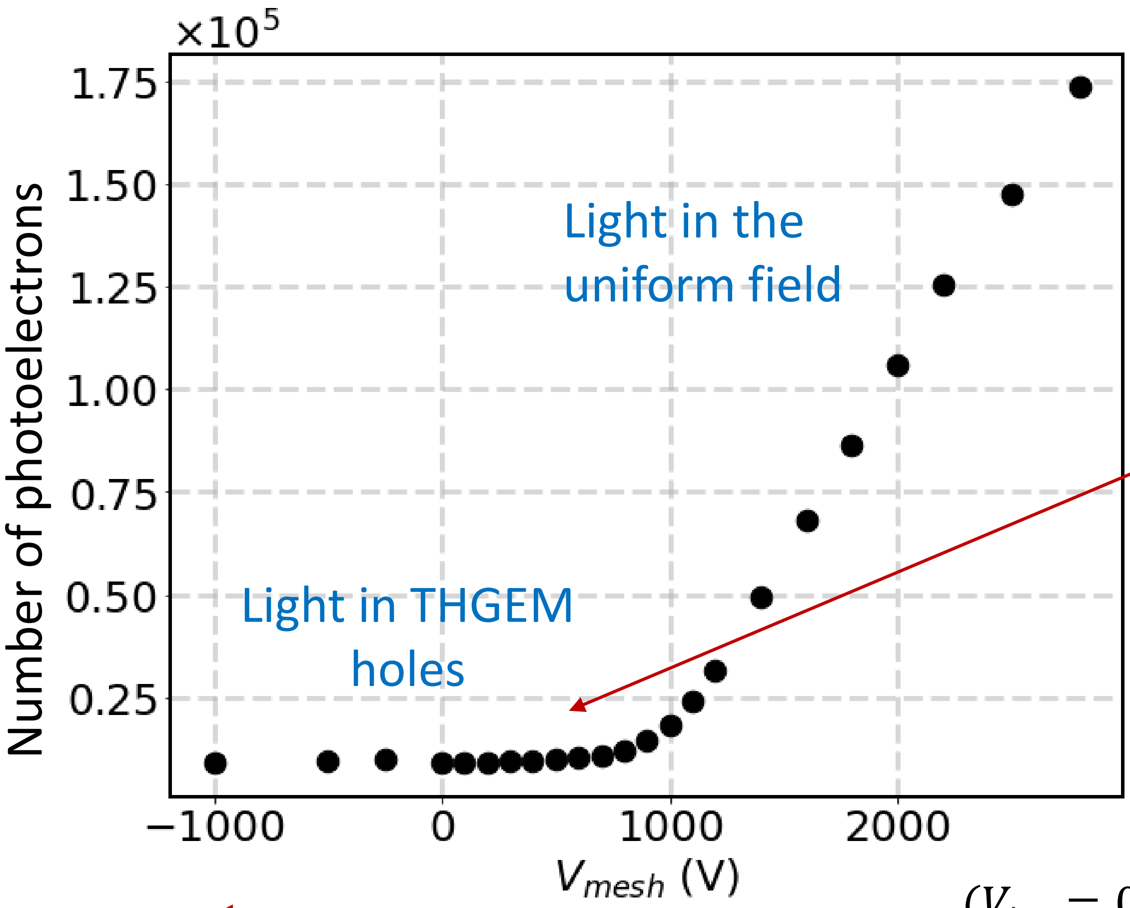
Too weak to generate electroluminescence in liquid xenon

($\sim 400\,\frac{kV}{cm}$ is needed)

Waveform evolution with field above THGEM



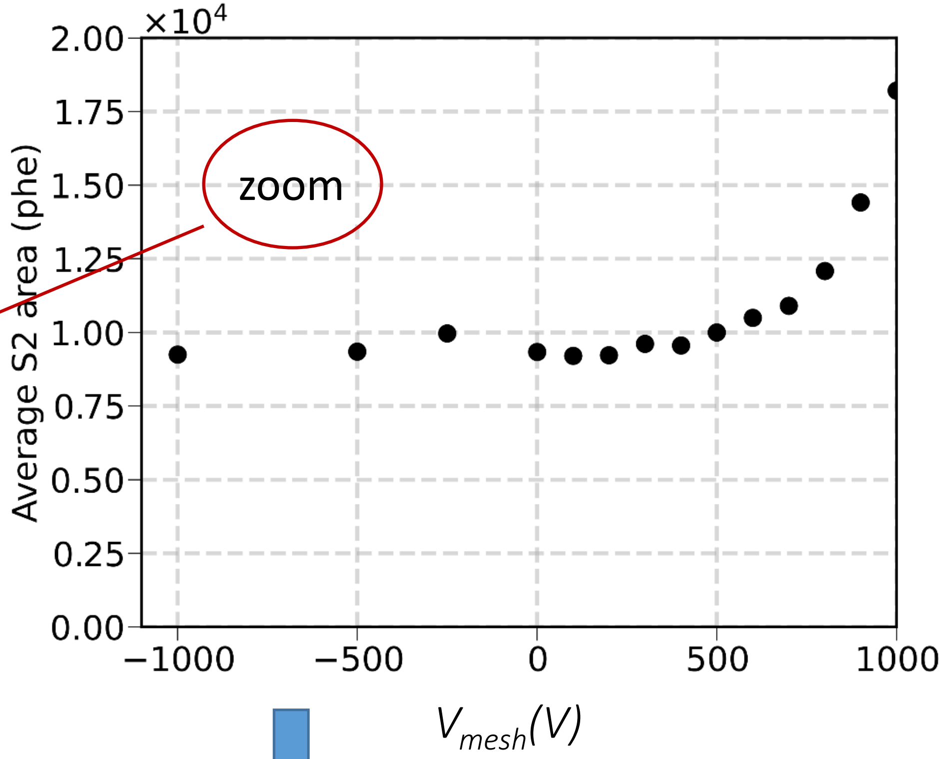
S2 area as function of the field above THGEM



$(V_{top} = 0)$

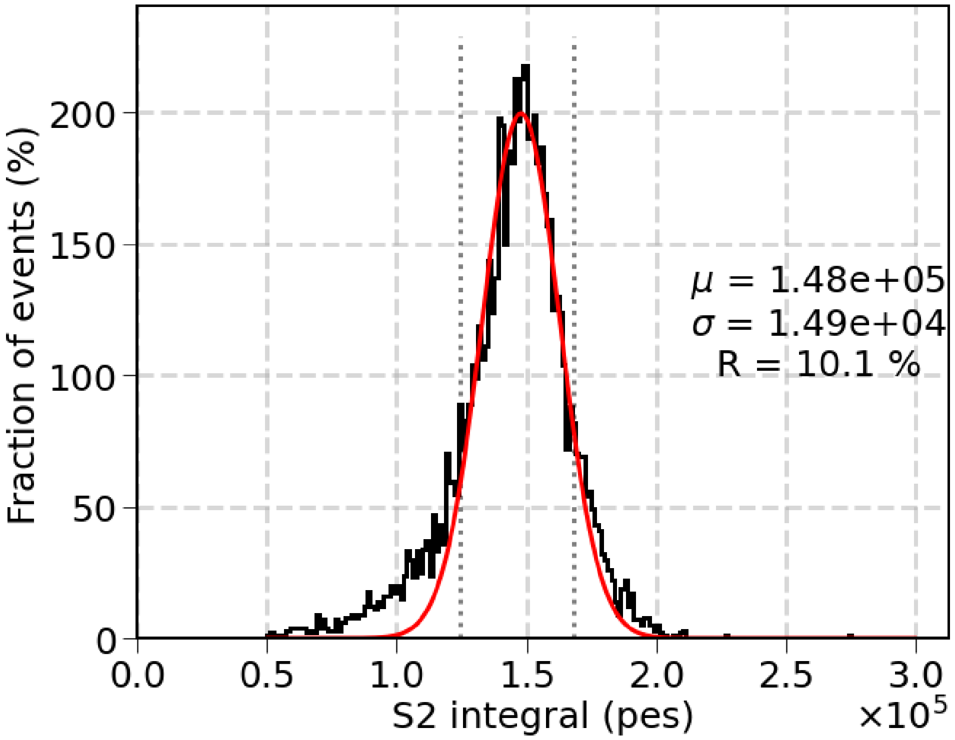
Reversed extraction field

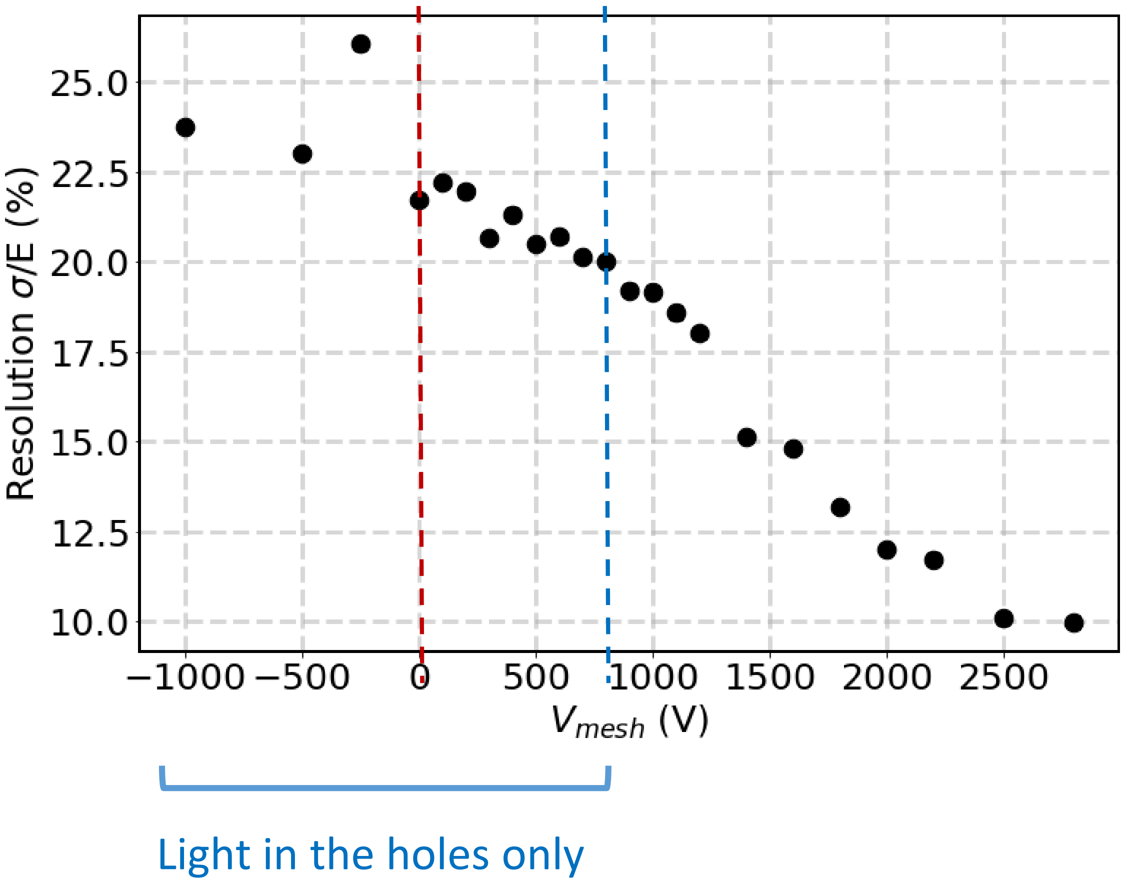
~20x more light above THGEM than in the holes



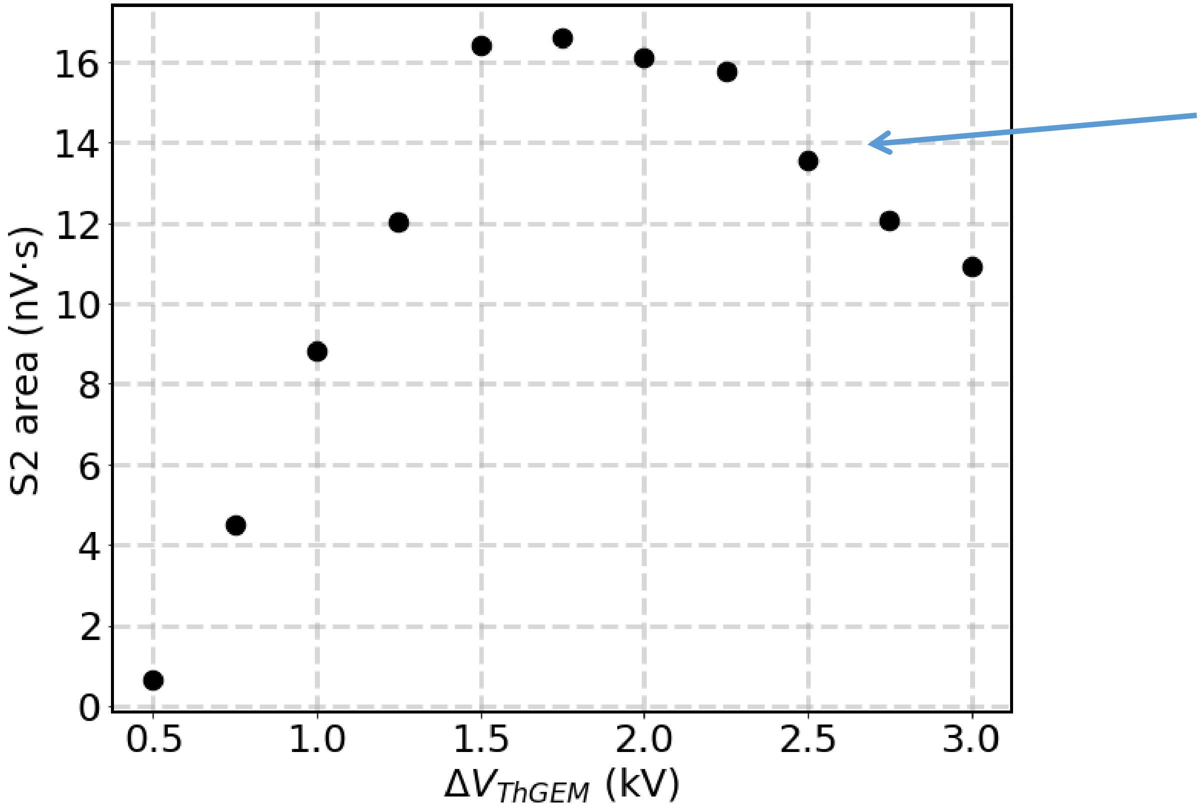
Most of the light is produced in the holes and not in their vicinity

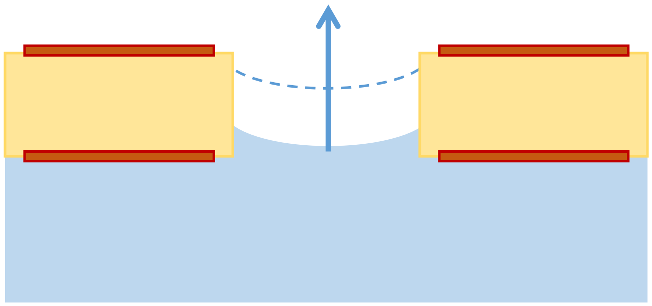
S2 area – resolution





S2 area as function of voltage across THGEM – dielectric retraction?



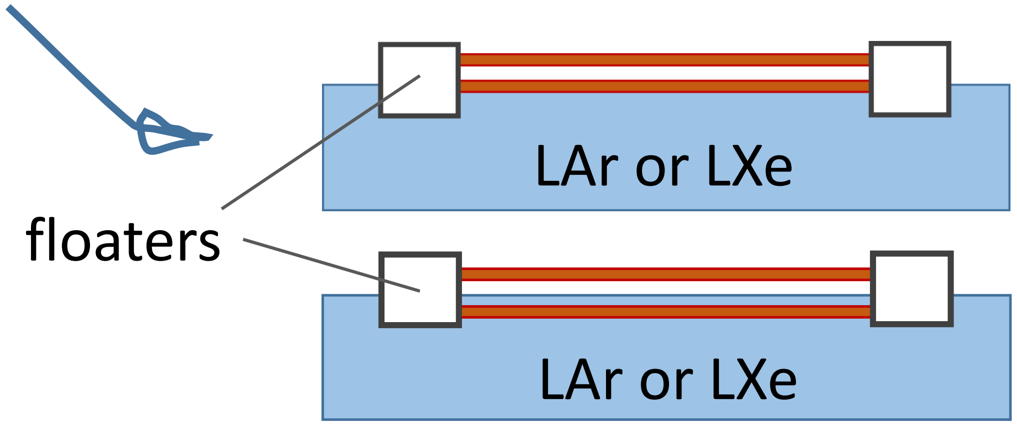


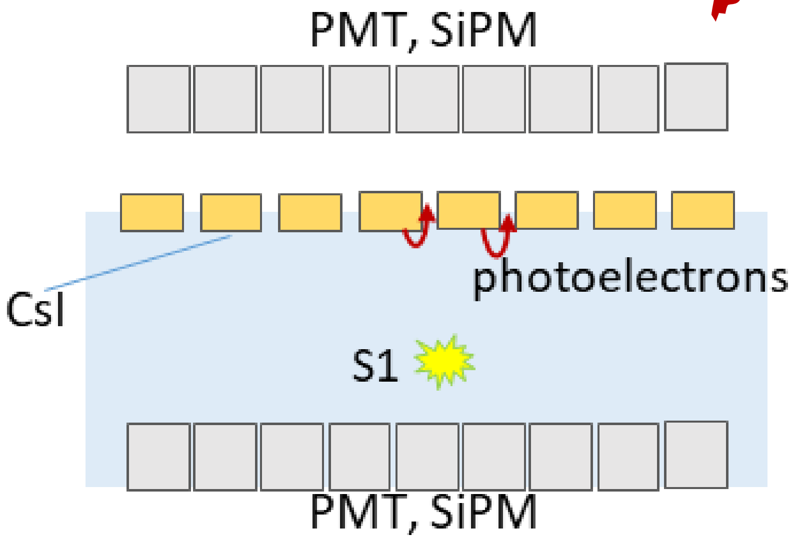
Benefits

1. Significantly smaller free liquid surface – reduced probability of any kind of surface instabilities (ripples, waves, microexplosions, etc.)
2. Electron drift/diffusion under the surface – eliminated or made local (within the hole pitch)
3. High electron extraction probability thanks to high field at the interface (unreachable in uniform field)
4. Positive ion feedback (if any) – likely to end up at the floating electrode
5. **Result – reduced single electron noise**
6. Parallelism between gate and extraction electrodes – guaranteed for any dimensions
7. No sagging
8. No need for fine detector levelling and liquid level control

Remaining questions/futher work

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





Conclusions

1. Prove of principle – successful
2. Next – study details – physics and optimization
3. There is more to floating …