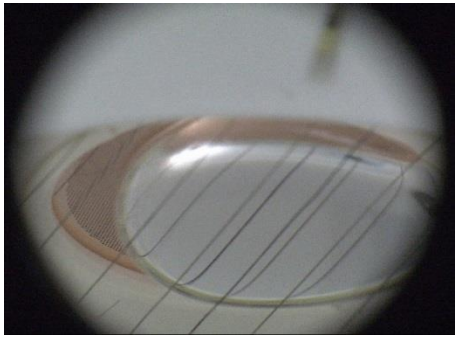
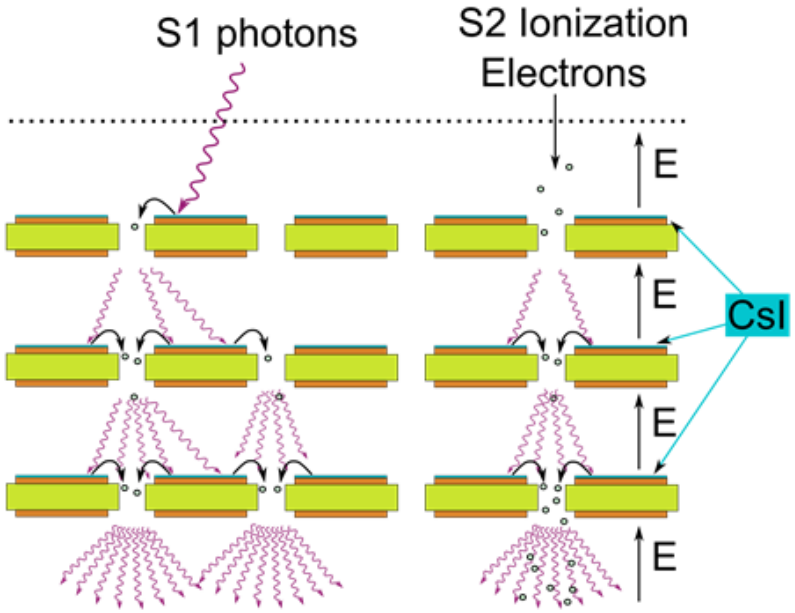
Recent advances with bubble-assisted Liquid Hole Multipliers

L. ARAZI, E. ERDAL, Y. KOROTINSKY, M. L. RAPPAPORT, A. ROY, S. SHCHEMELININ, D. VARTSKY, AND A. BRESKIN



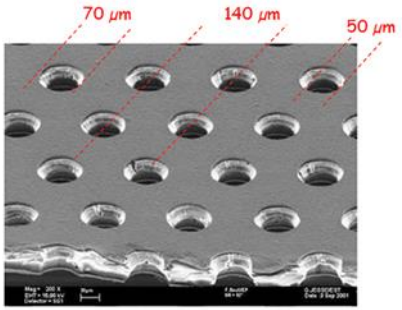
RD51 mini-week, December 12 2016, CERN

Amos' original dream

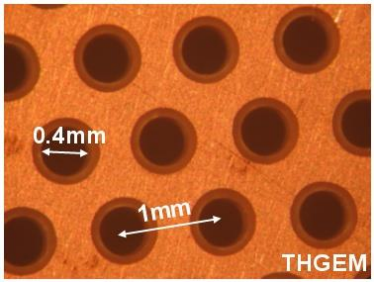


Photosensors (PMTs, SiPMs, GPMs)

Liquid xenon



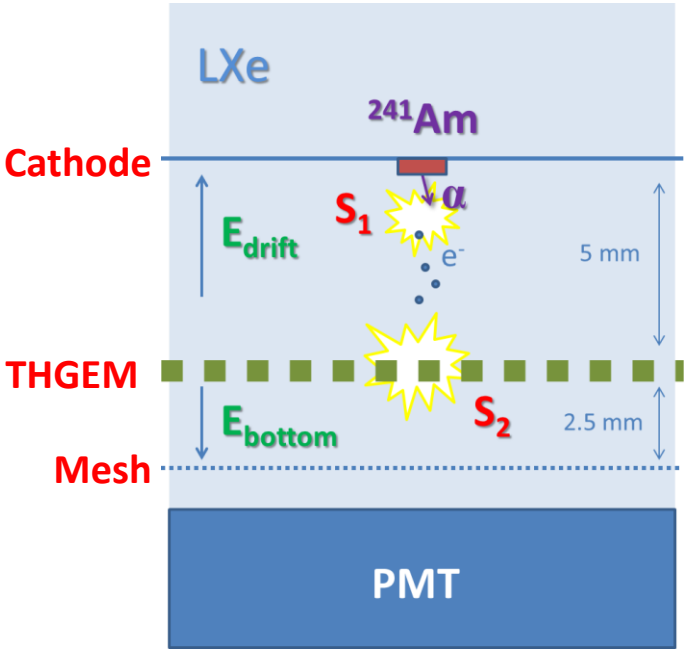
GEM

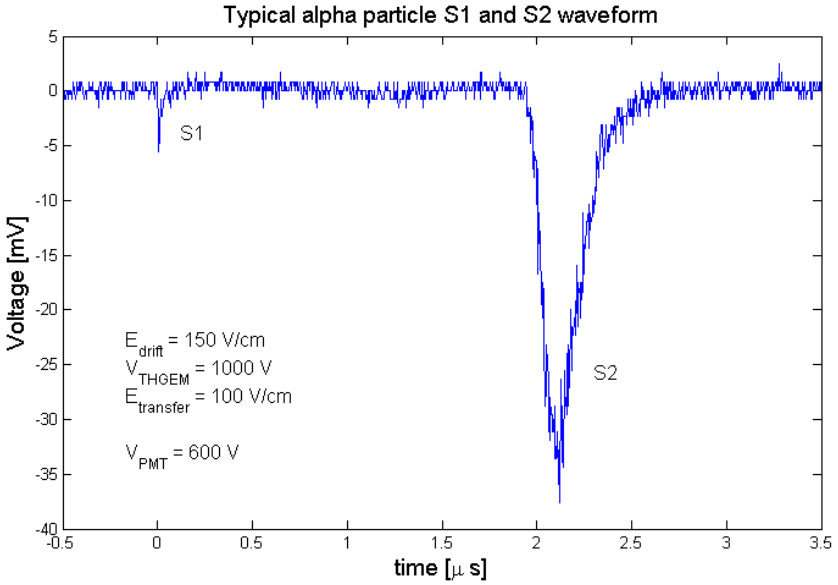


Thick GEM (THGEM)

A. Breskin J. Phys. Conf. Ser. 460 (2013) 012020 arXiv:1303.4365

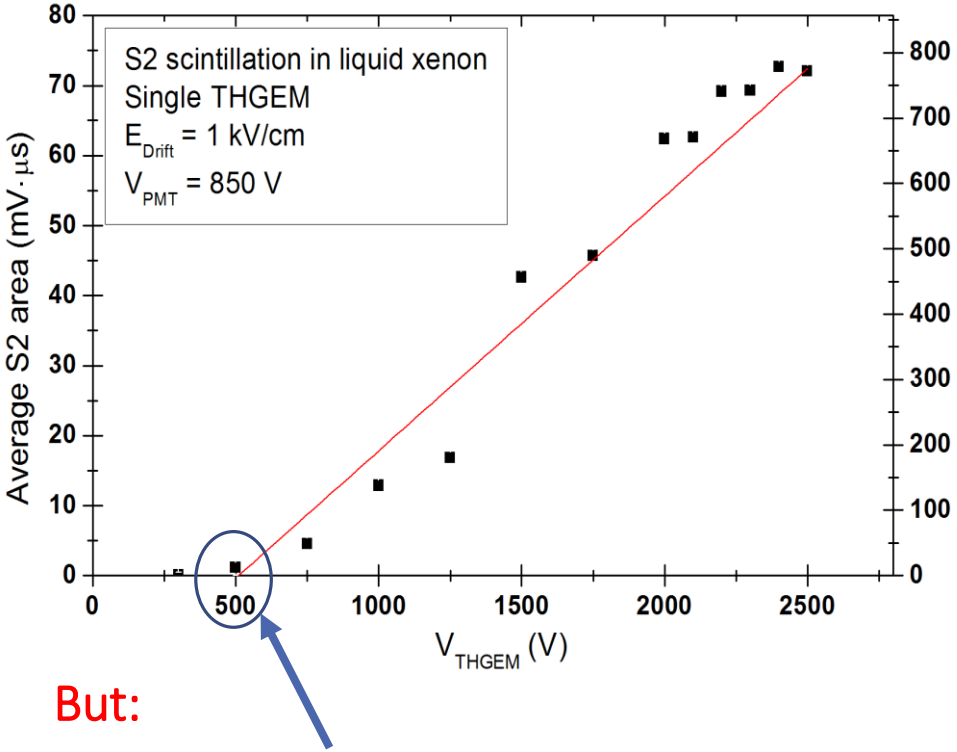
Can we generate S2 in the holes of an immersed THGEM?



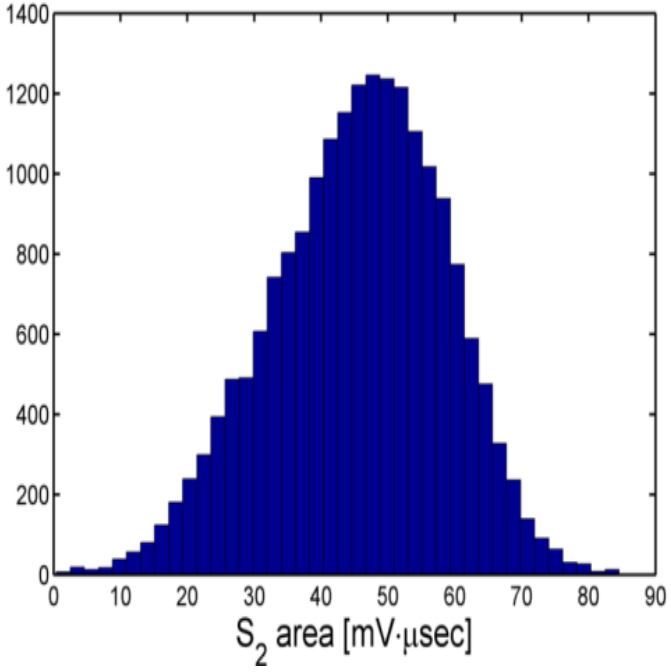


L. Arazi *et al.* 2013 *JINST* **8** C12004, arXiv:1310.4074

YES WE CAN!



S2 spectrum



But:

Field lower by ~100 than threshold for thin wires

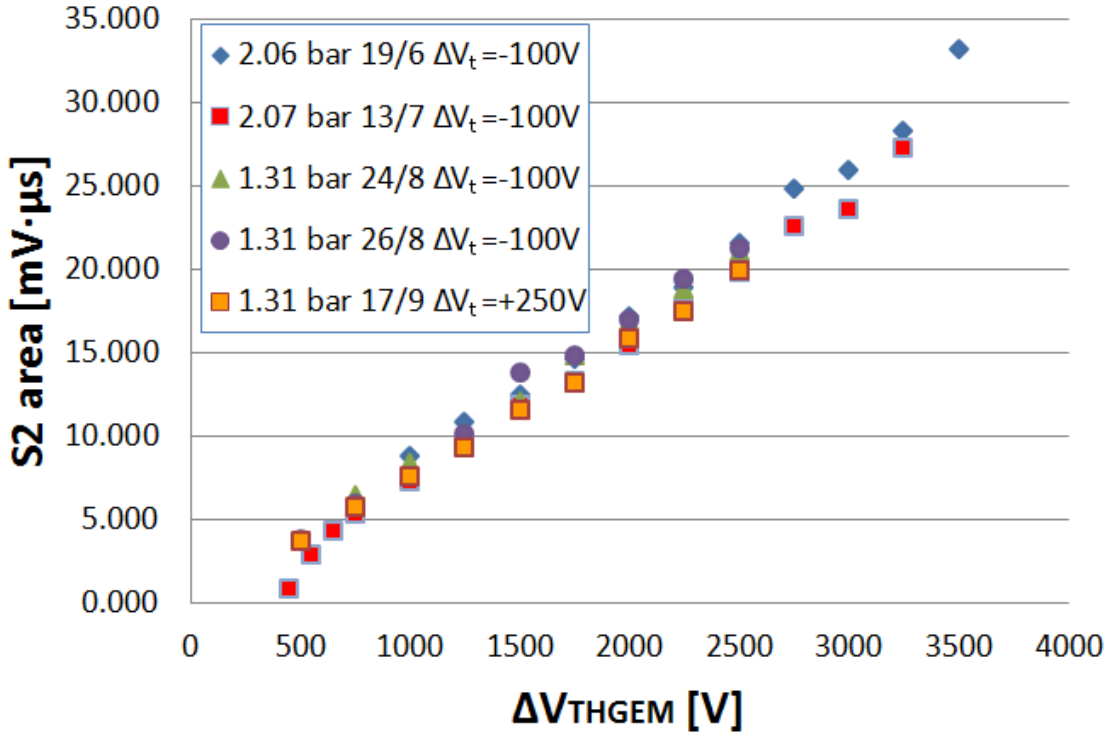
S2 disappears when the pressure abruptly increases & reappears when it drops back

The only plausible explanation: S2 in bubble!

L. Arazi *et al.*, JINST 10 (2015) P08015, arXiv:1505.02316

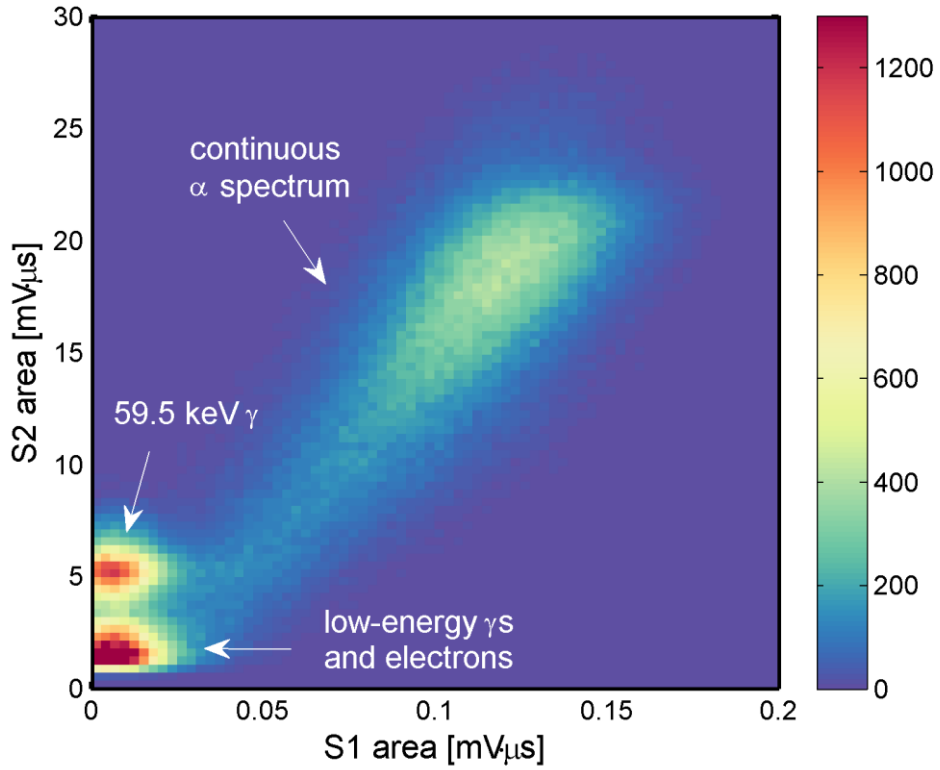
This was embarrassing…

But:
Repeatable results over months of operation



L. Arazi et al. 2015 JINST 10 P08015, arXiv:1505.02316

And excellent energy resolution…

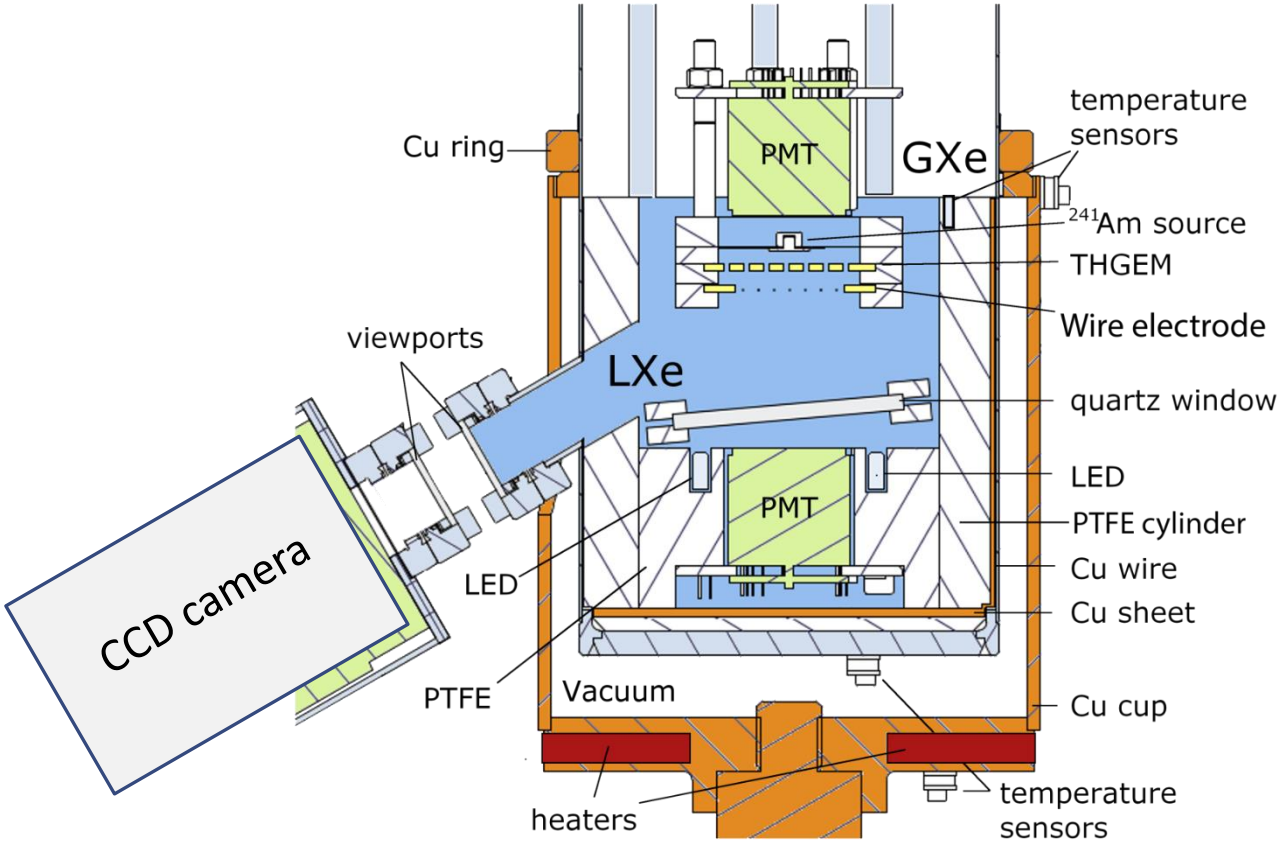


L. Arazi et al. 2015 JINST 10 P08015, arXiv:1505.02316

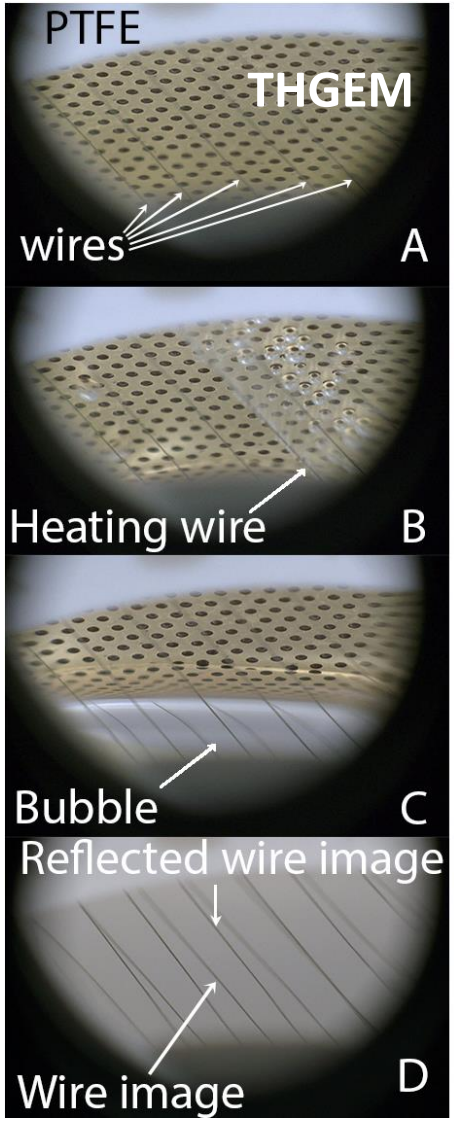
Birth of the:

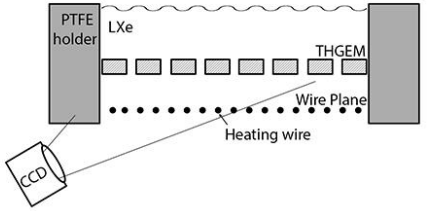
BUBBLE-ASSISTED LIQUID HOLE-MULTIPLIER

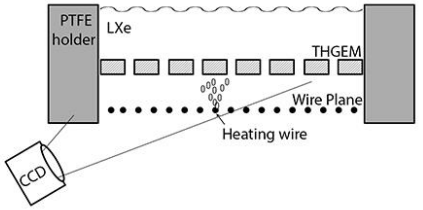
Seeing is believing

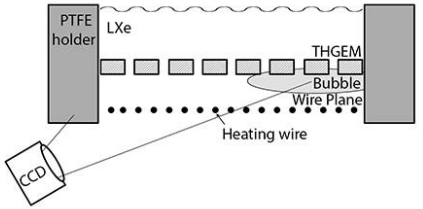


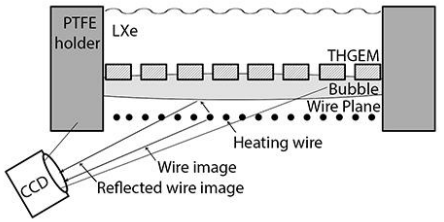
And bubbles… there are!









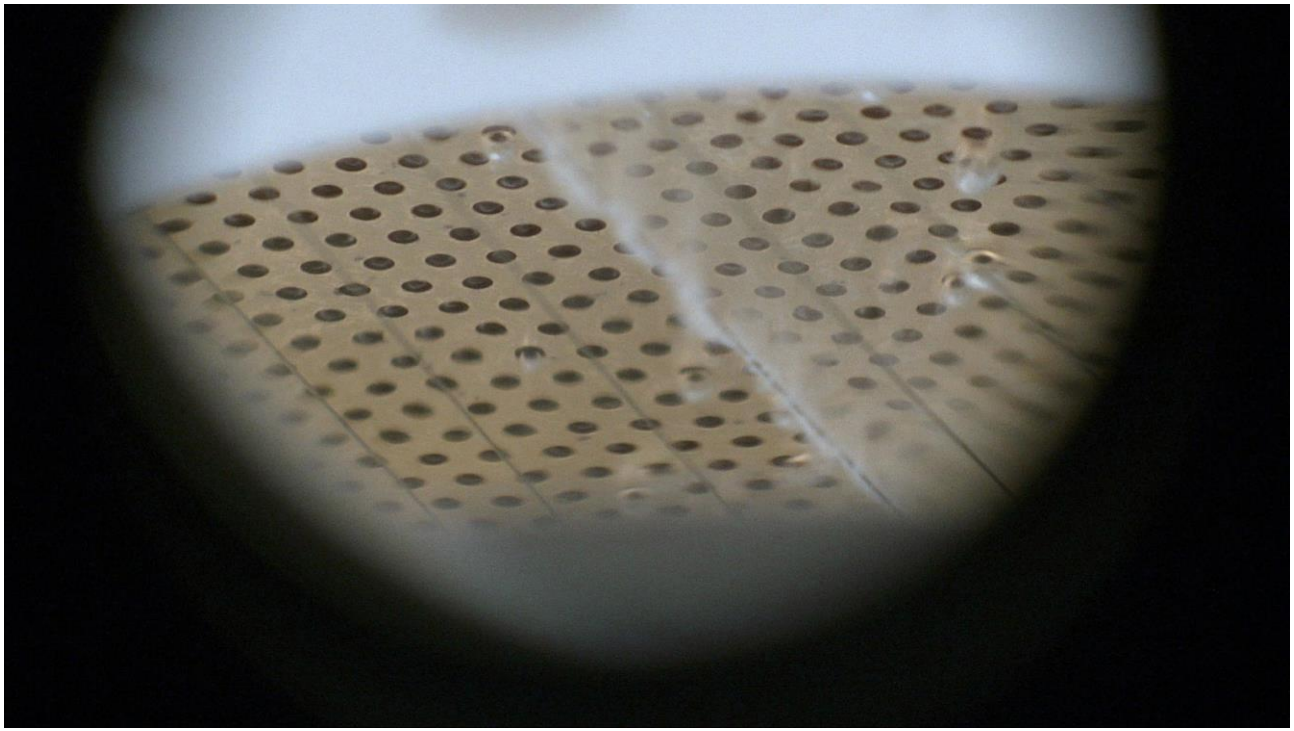


S2 seen only in the presence of a bubble

E. Erdal *et al.* 2015 JINST **10** P11002, arXiv:1509.02354

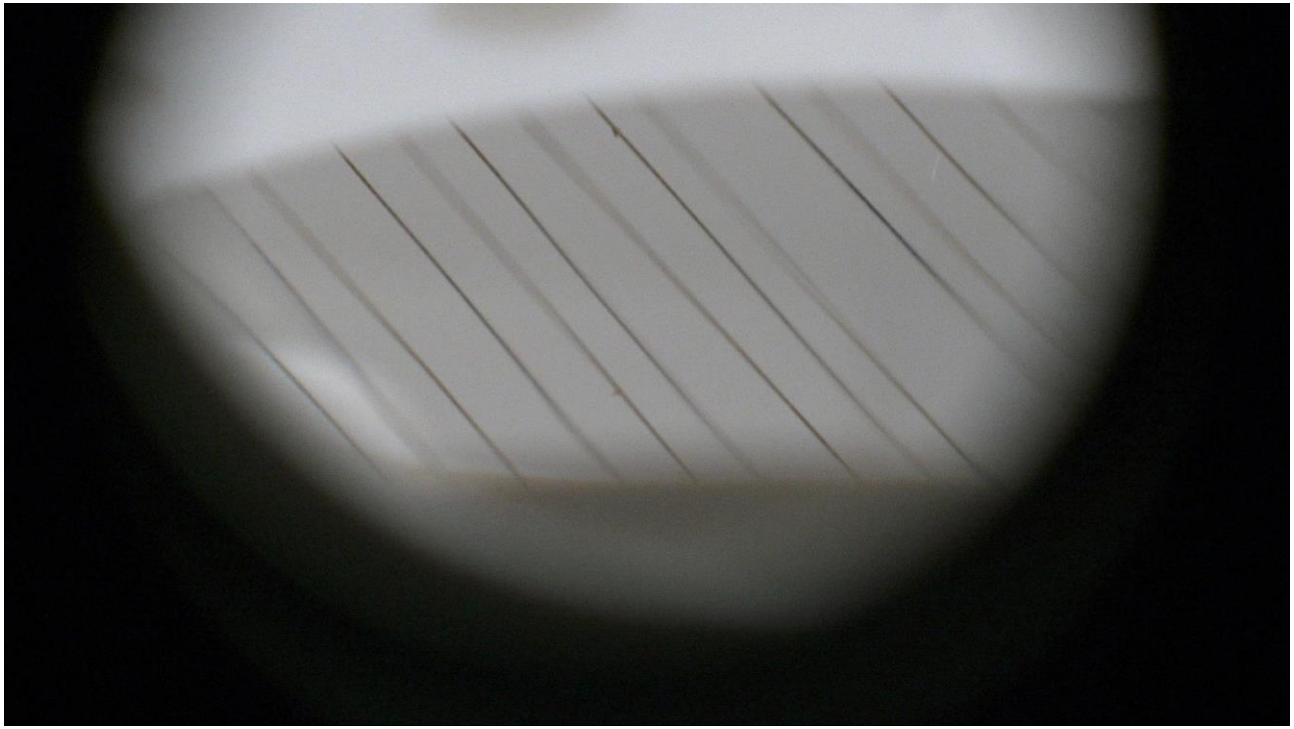
Bubble formation

Use heating wire to generate bubble ‘on demand’



Bubble in steady state

Once formed, the bubble remains stable (indefinitely?)

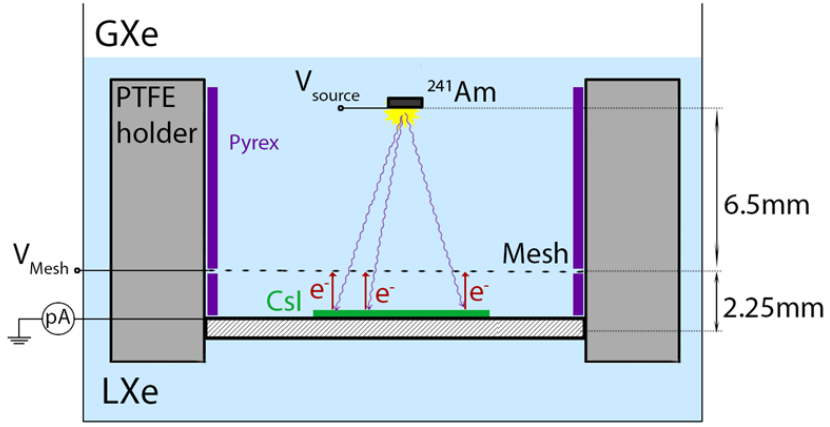


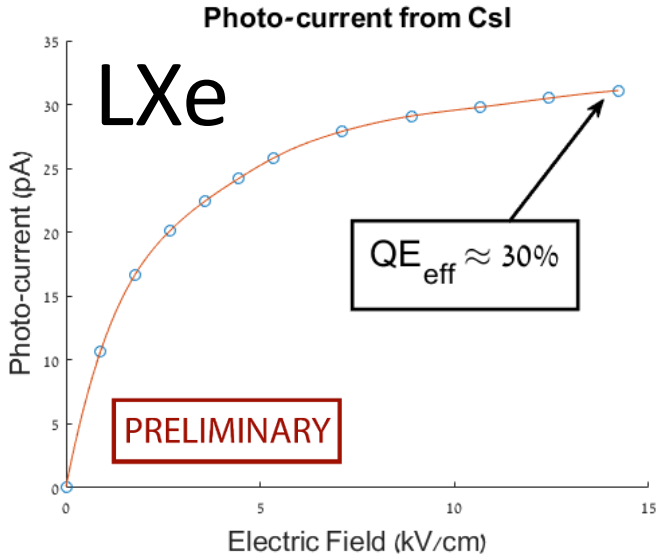
Where do bubbles come from?

Comparative study of different LHM electrodes

COMBINED RESPONSE TO IONIZATION ELECTRONS AND PRIMARY SCINTILLATION PHOTONS

Before we begin:
Effective CsI Quantum Efficiency in LXe and

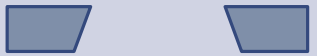




QE~30% also obtained by E. Aprile et al NIM A338 (1994) 328

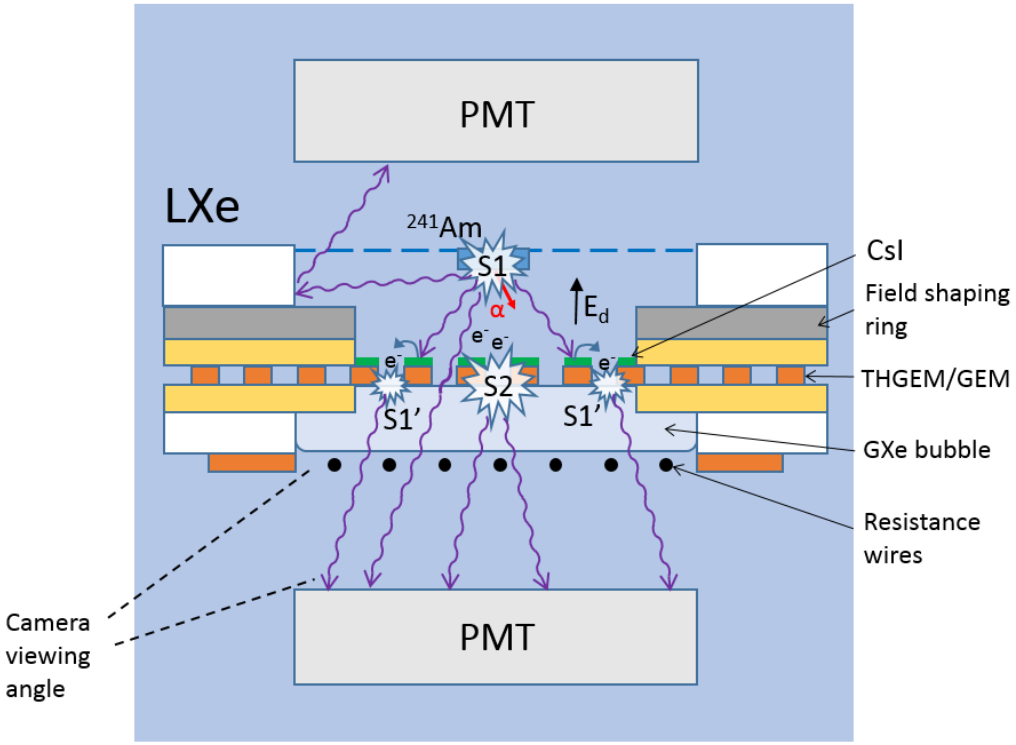
→ GEM-LHM at 1300 V: theoretical PDE >20% (assuming full PE collection)

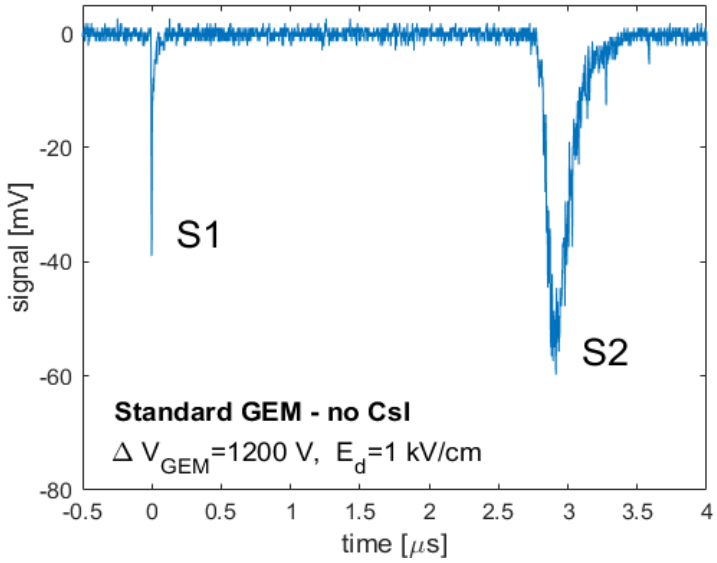
Electrodes tested

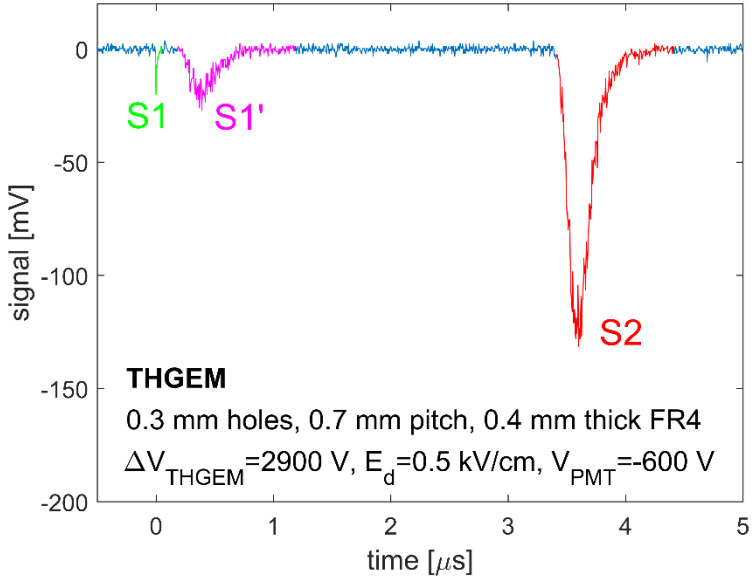
	THGEM	Standard GEM	Single-conical GEM
Insulator	FR4	Kapton	Kapton
Thickness	0.4 mm	50 µm	50 µm
Hole shape			
Hole diameter	0.3 mm	70/50/70 µm	150/190 µm
Hole pitch	0.7 mm	140 µm	300 µm

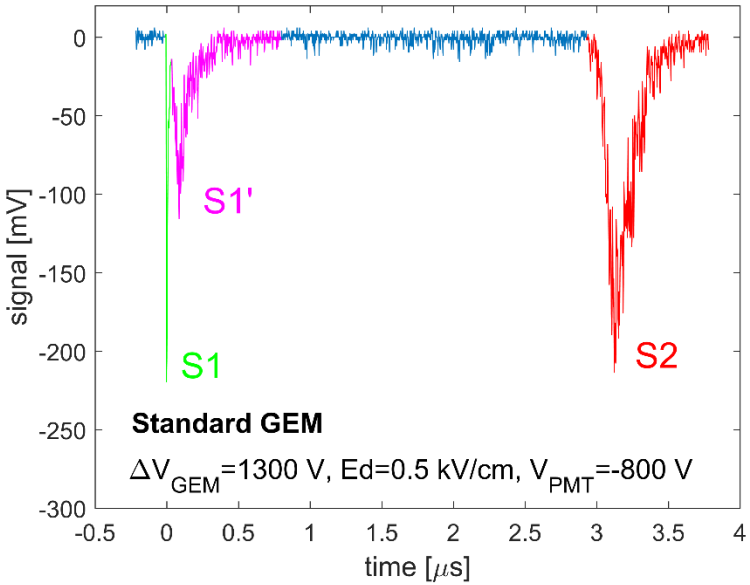
Most promising results

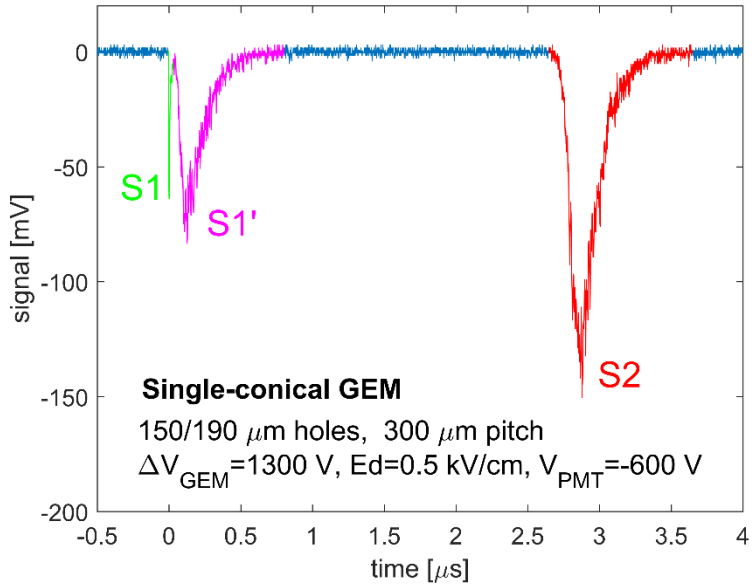
Experimental setup



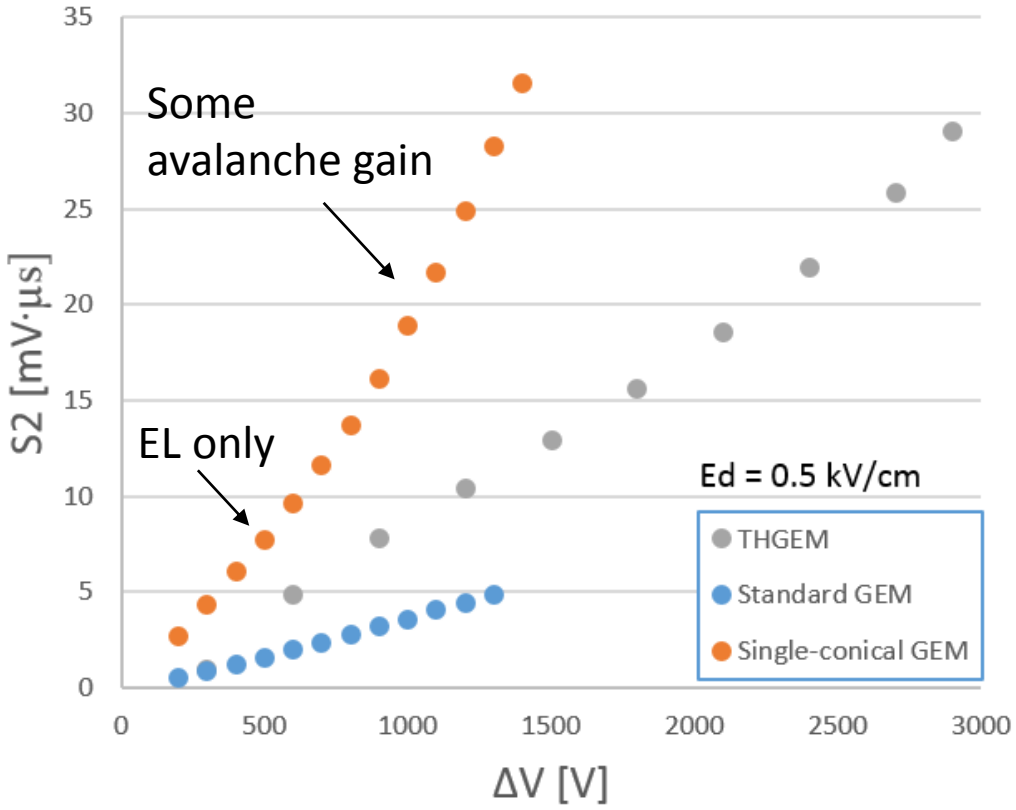

S1
S2
Standard GEM - no CsI
Δ V_GEM=1200 V, E_d=1 kV/cm
signal [mV]
time [μs]


S1
S1'
S2
THGEM
0.3 mm holes, 0.7 mm pitch, 0.4 mm thick FR4
ΔV_THGEM=2900 V, E_d=0.5 kV/cm, V_PMT=-600 V
signal [mV]
time [μs]

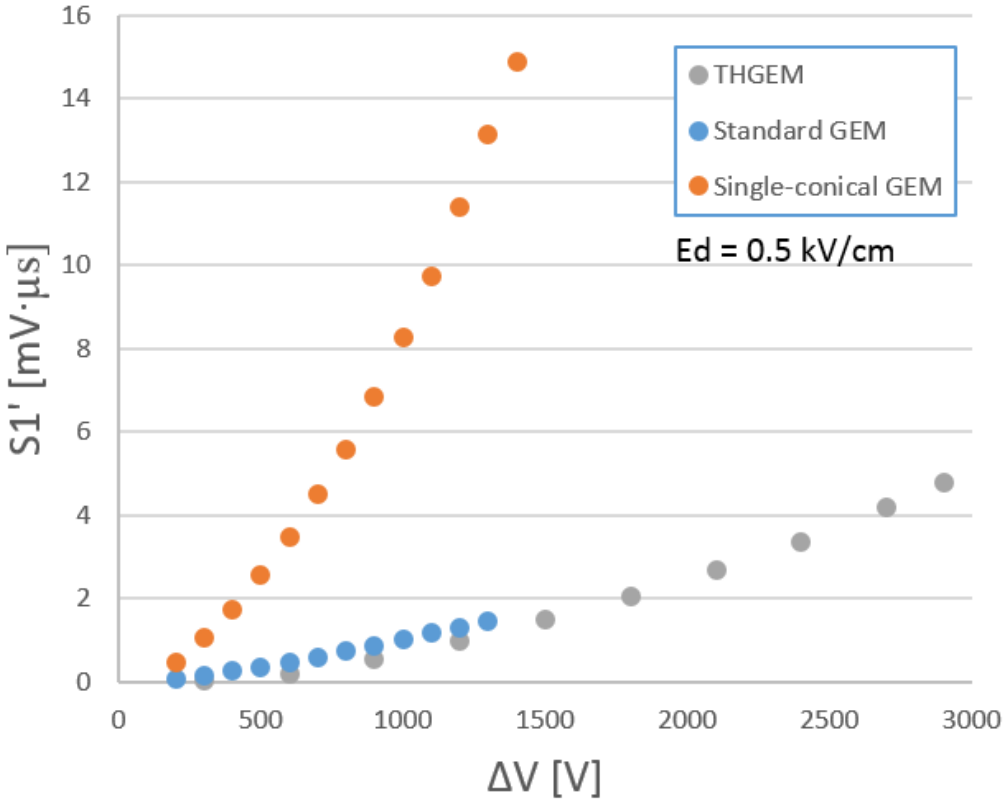

S1'
S1
S2
Standard GEM
ΔV_GEM=1300 V, Ed=0.5 kV/cm, V_PMT=-800 V
signal [mV]
time [μs]


S1
S1'
S2
Single-conical GEM
150/190 μm holes, 300 μm pitch
ΔV_GEM=1300 V, Ed=0.5 kV/cm, V_PMT=-600 V
signal [mV]
time [μs]

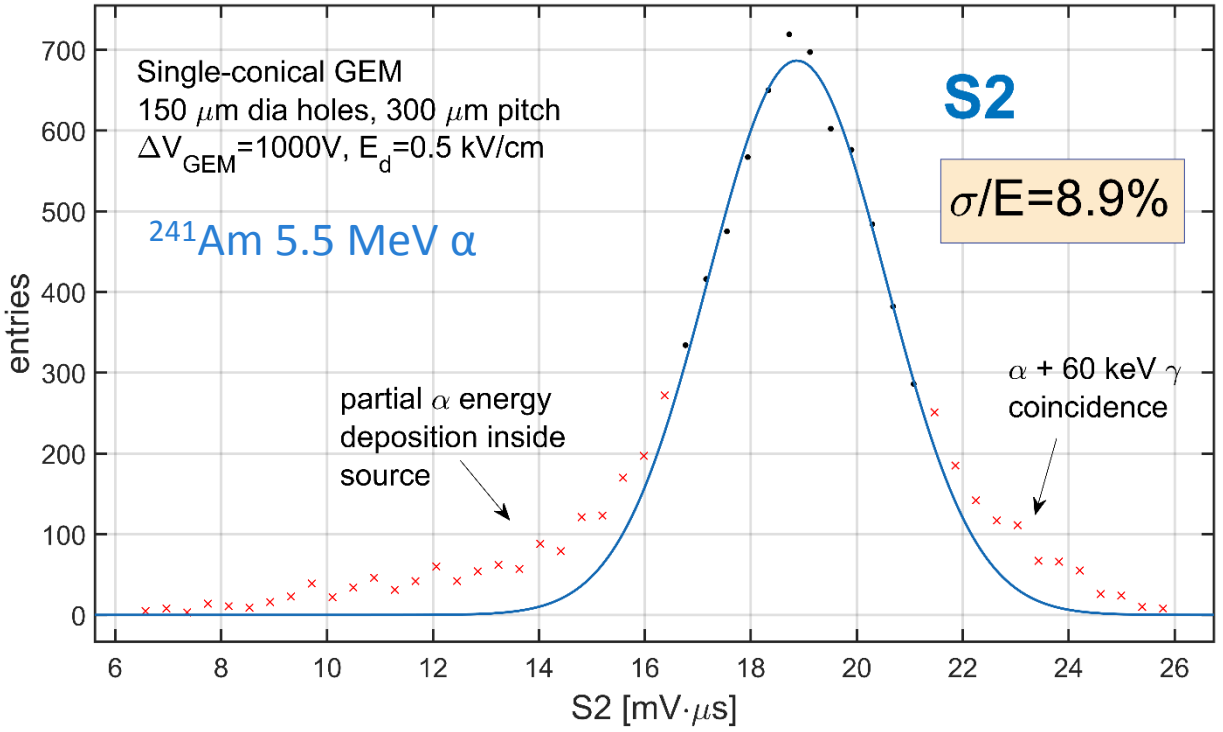
S2 vs. voltage



S1’ vs. voltage

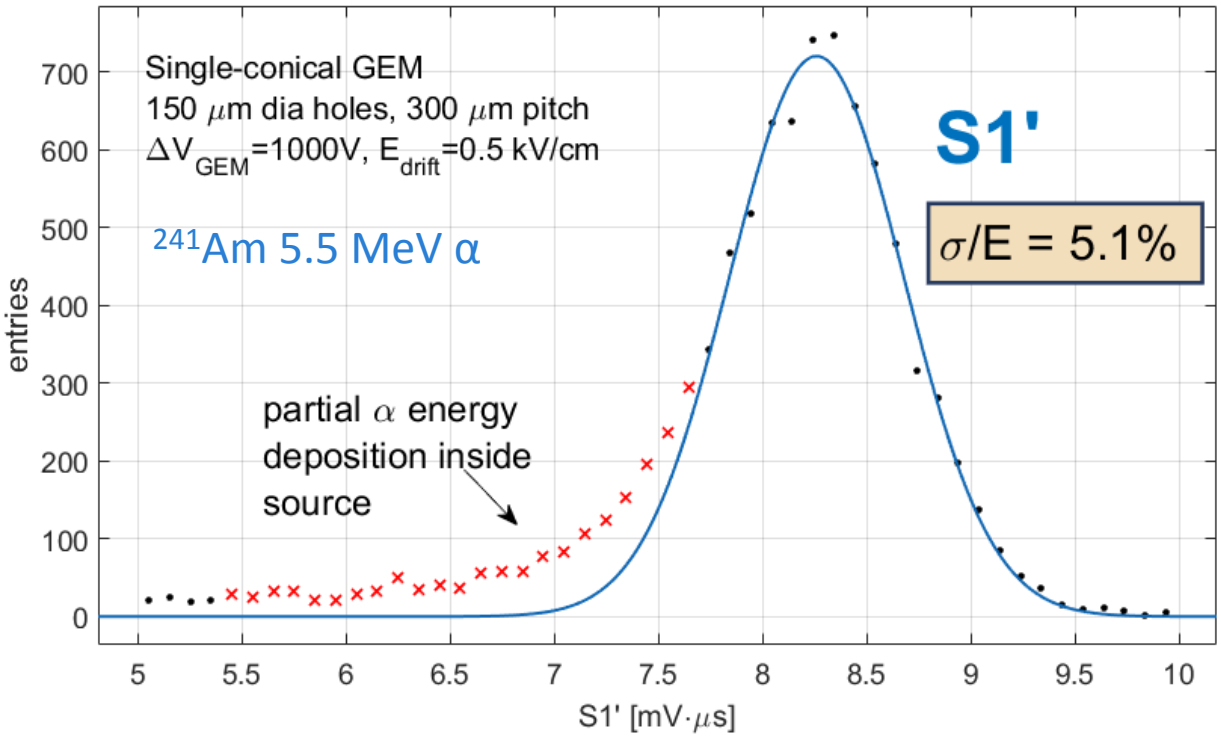


Single-conical GEM: S2 spectrum



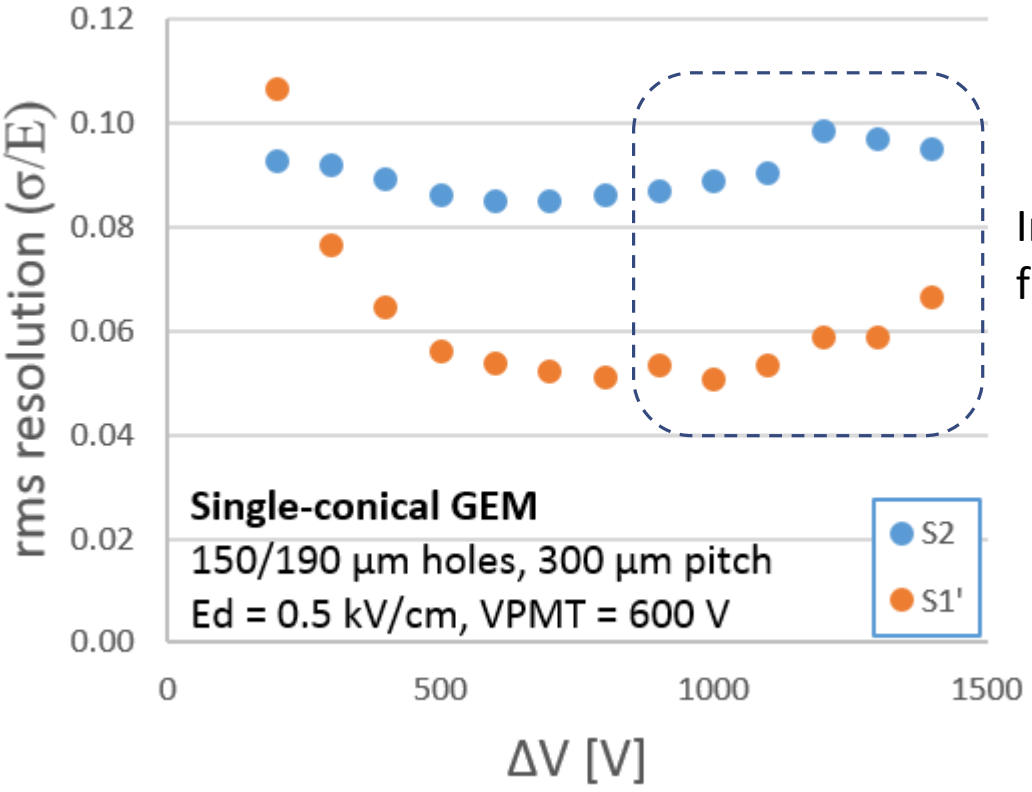
~9,000 electrons

Single-conical GEM: S1’ spectrum



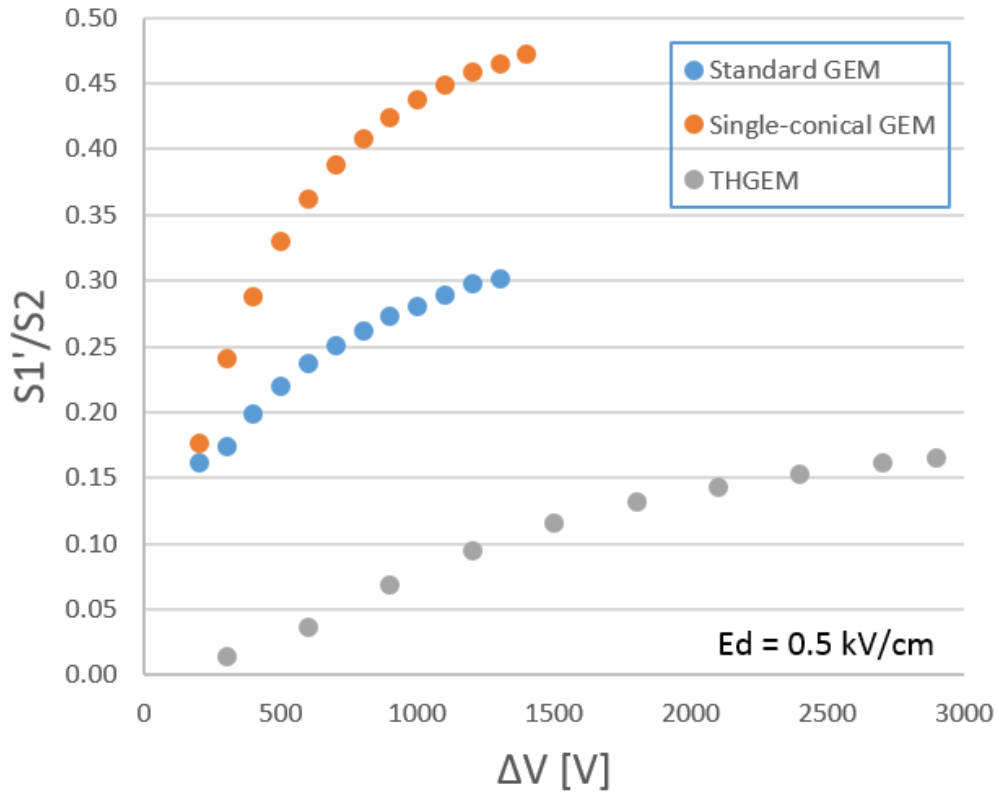
~4,000 photoelectrons (PEs)

Single-conical GEM: S1’ and S2 rms resolution



Increasing gain fluctuation?

S1’/S2 vs. voltage & PDE estimate

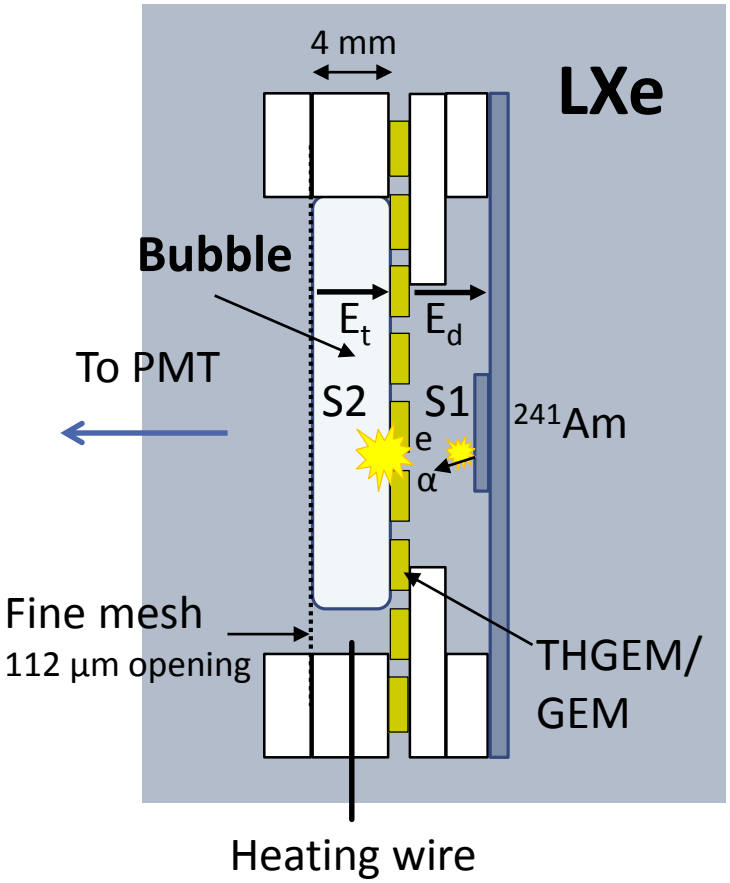


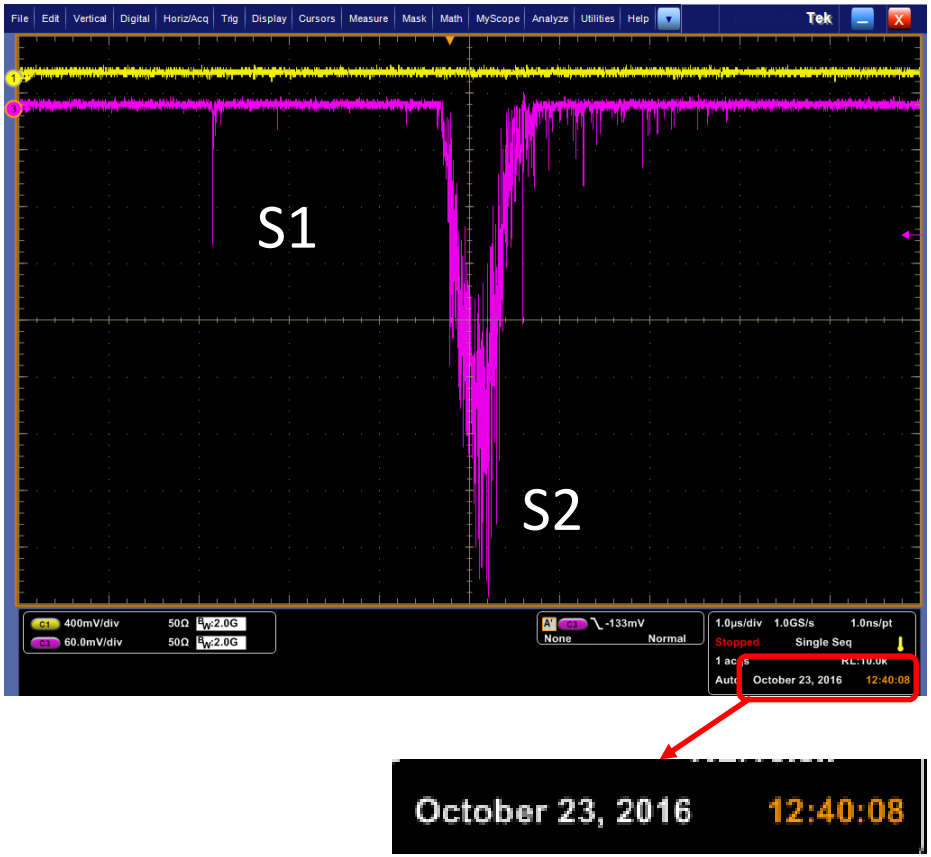
Very preliminary estimate from S1’/S2 for the single-conical GEM at 1300 V:

$$PDE \approx (8.3 \pm 1.9)\%$$

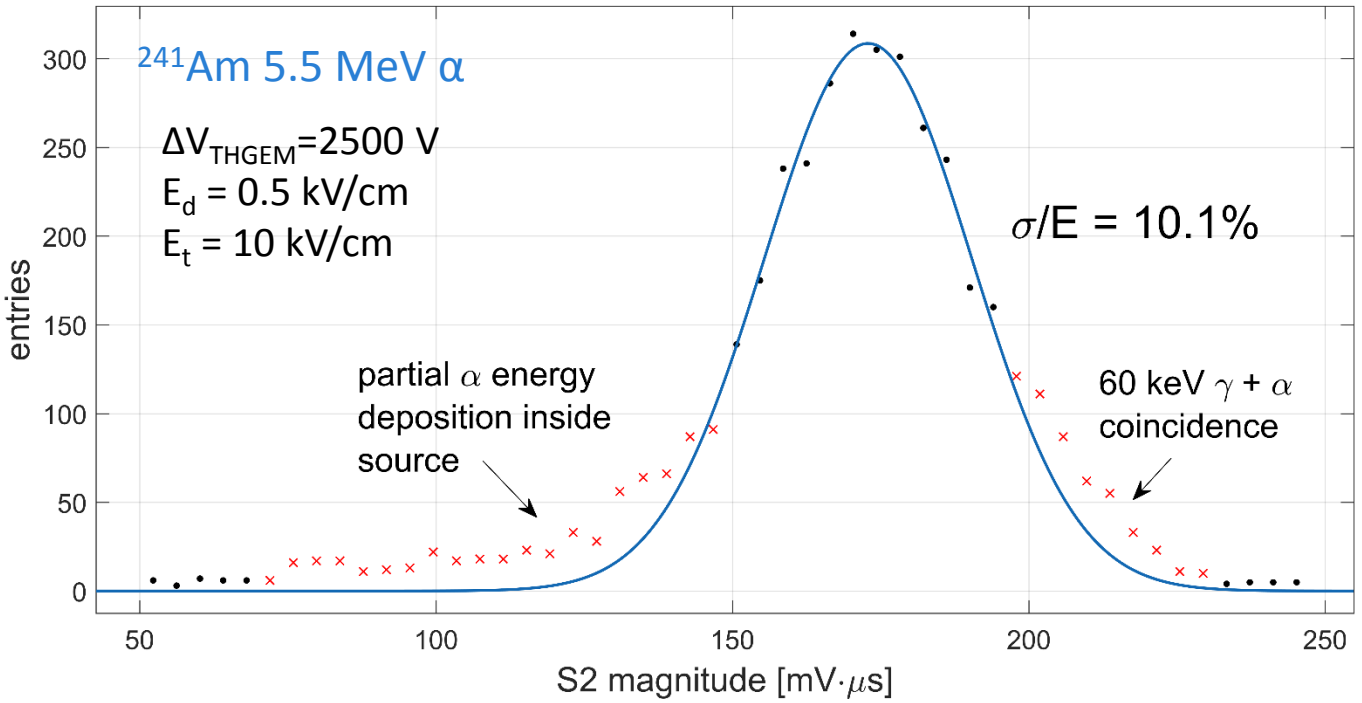
Main challenge: photoelectron collection into GEM holes – ongoing studies

Vertical bubbles – first results!

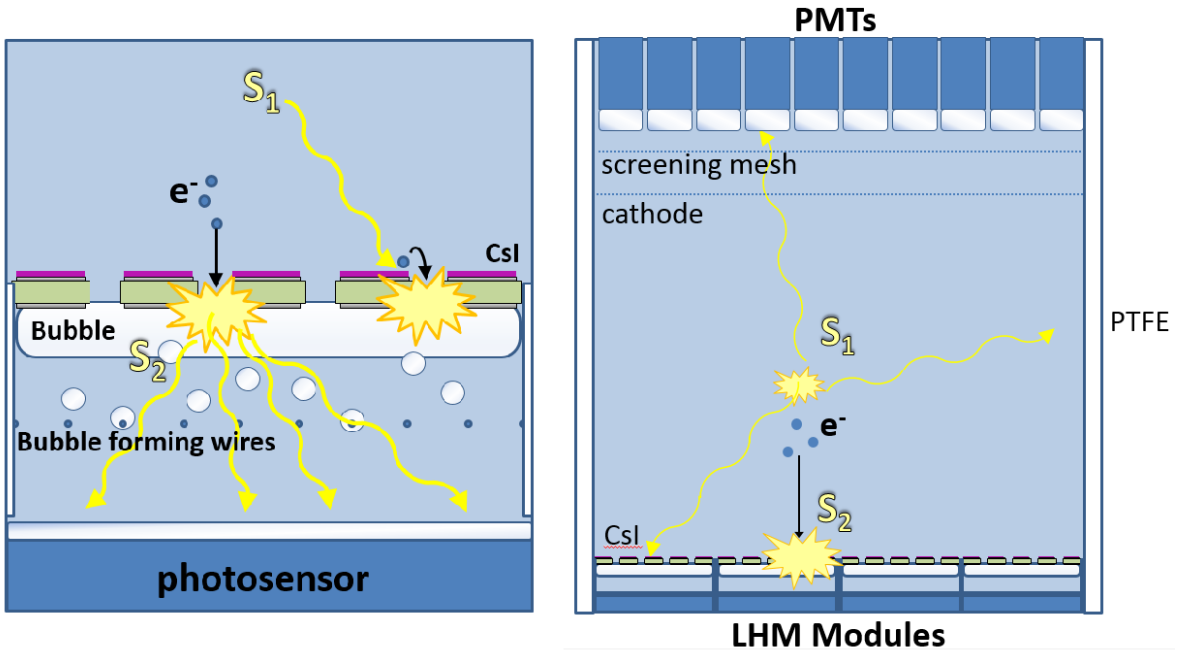




Vertical bubbles – first results!



Dreaming ahead:
Bubble-assisted local dual-phase TPC



- Controlled liquid-gas interface at precise location → high S2 resolution
- Down to only 2 meshes, interface outside sensitive volume → higher light yield

Effect of LHM on light yield: 2.6 m diameter/height LXe TPC

Conventional TPC

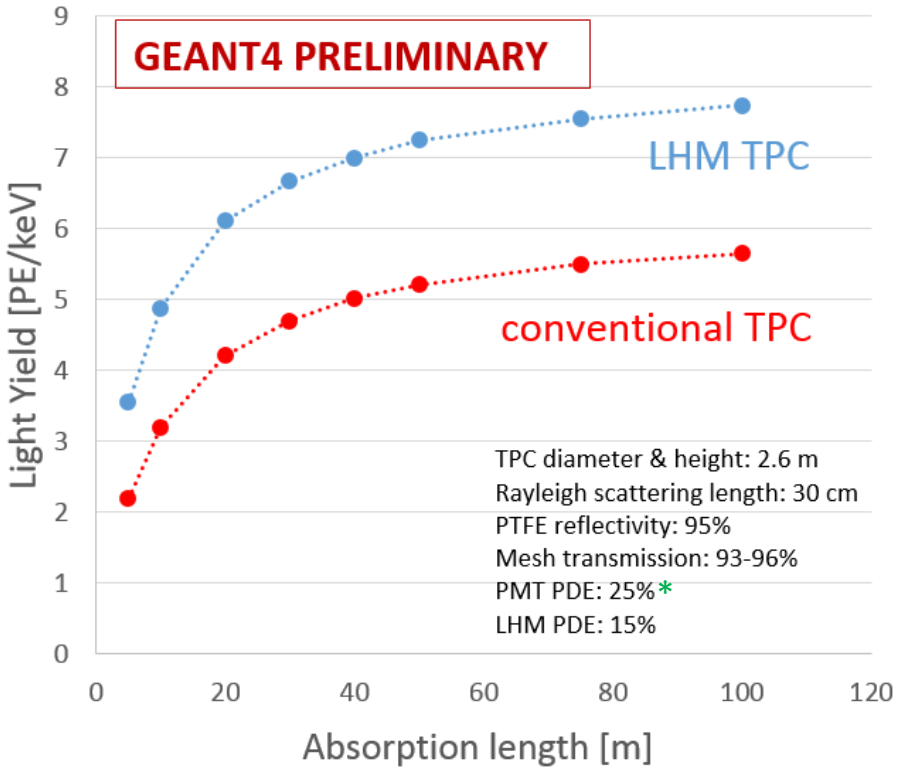
- Top/bottom PMTs
- 5 meshes
- Liquid/gas interface inside sensitive volume

LHM TPC

- Top: PMTs
- Bottom: LHMs
- 2 meshes (cathode, screening)
- Interface outside sensitive volume

Uniform photon staring points, isotropic

Light Yield: number of PEs detected per keV for 122 keV gamma at zero field



* C. H. Faham *et al.* JINST 10 (2015) P09010, arXiv:1506.08748

Summary and outlook

- Demonstrated controlled bubble formation and long term stability
- S1' & S2 energy resolution (for a small prototype) surpasses that of existing dark matter experiments
- Both ionization electrons and primary photons detected for the same voltage configuration
- A single electron creates a flash of >200 photons
- LHM signals can be read out by PMTs, GPMs, or SiPMs (SiPM DCR not an issue)
- PDE optimization studies underway (with high expectations)
- Dream: cover large areas with LHM modules, with potentially **significant improvement of sensitivity & background rejection** in multi-ton *bubble-assisted local-dual-phase LXe DM TPCs*
- Next: large LHM modules, vertical orientation, LAr
- Study applicability to other fields (e.g., neutrino physics)