Advances with the Bubble-Free Liquid Hole-Multiplier

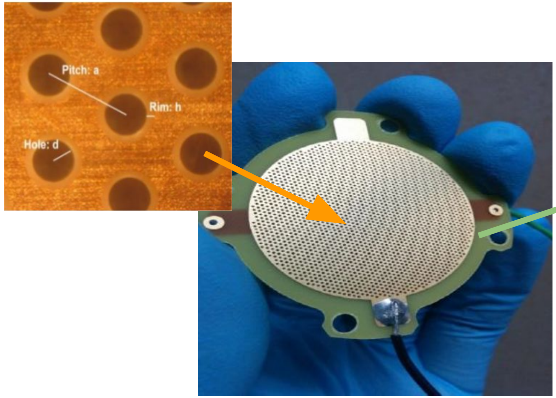
A dual-phase LHM concept for scintillation- and electroluminiscence-photon detectors

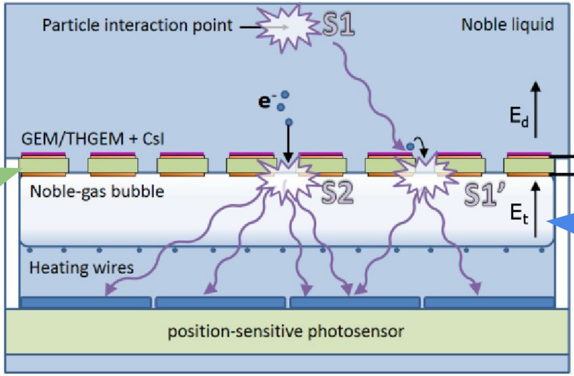
G. Martínez Lema[1,2]
A. Roy[1,2]
A. Breskin[2]
L. Arazi[1]

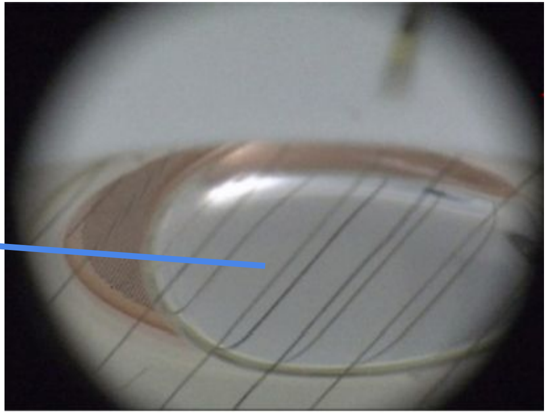
[1] Ben Gurion University of the Negev
[2] Weizmann Institute of Science

The bubble-assisted LHM (BA-LHM)

- CsI-coated perforated electrode (GEM, THGEM, other) immersed in LAr/LXe
- GAr/GXe bubble trapped underneath
- Electrons focused into the holes produce EL signal
  - S1-induced photoelectrons generated by CsI (**S1’**)
  - S2 ionization electrons

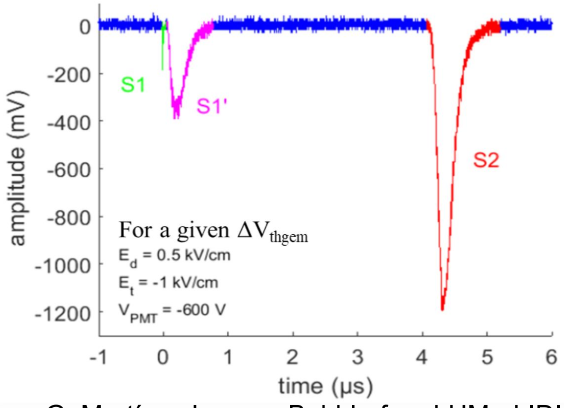


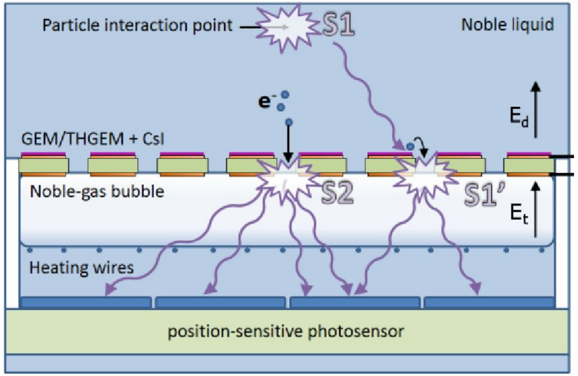




The bubble-assisted LHM (BA-LHM)

- Light pulses detected by photosensors below
- Stable L-G interface => good energy resolution (σ/E ~ 6% for 5.5 MeV α's)
- Accurate position reconstruction (~0.2 mm)





Main publications

Arazi et al., 2015_JINST 10 P08015
Arazi et al., NIM A 845 (2017) 218
Erdal et al., 2019 JINST 14, P01028
Erdal et al., 2018 JINST 13 P12008
Erdal et al., 2019 JINST 14 P11021

Quantum efficiency of CsI in LXe

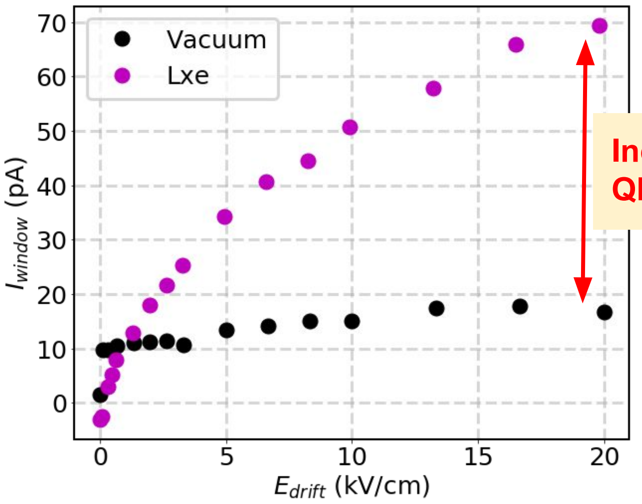
- **QE_{LXe} ~ 30%** > QE_{vac}
- Original measurement by

  E. Aprile et al., NIM A 338 (1994) 328-335

- Reproduced by us

  Erdal et al. LIDINE 2019

  Roy et al. LIDINE 2021



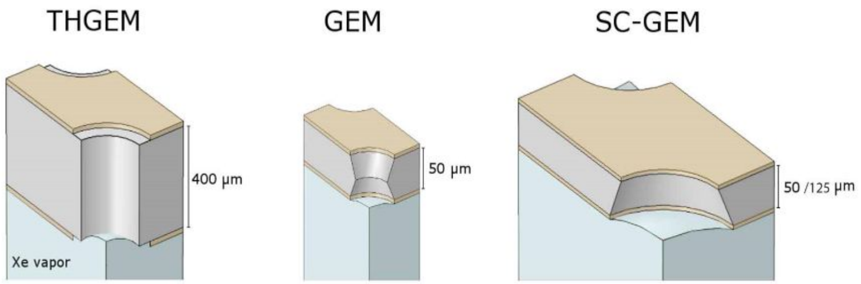
Increased QE_{eff} by ~x3.5

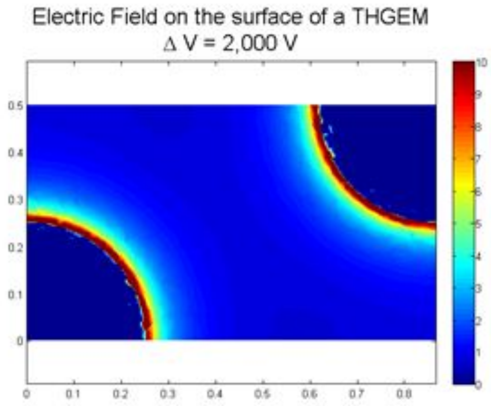
G. Martínez Lema
RD-51 miniweek 02/2022

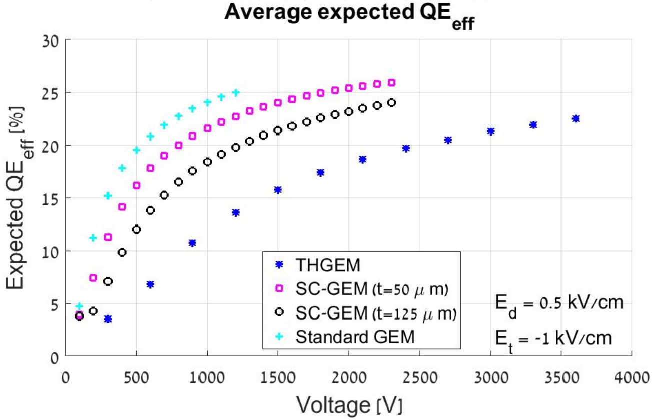
* Higher QE attributed to a change in the work function due to polarization of the medium

BA-LHM: Photon detection efficiency (PDE)

- PDE estimated from COMSOL + measured QE vs E in LXe
  - **Expected ~18 % for THGEM ~25 % for SC-GEM**
  - **Measured ~1 % for THGEM ~3.5% for SC-GEM**
- Main hypothesis →Low e^- transfer efficiency across the bubble interface



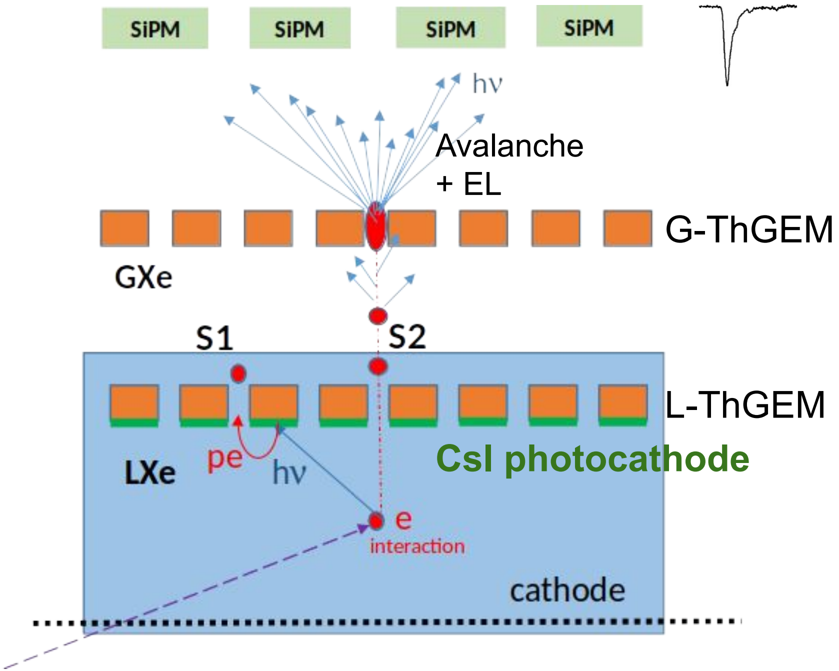




[Erdal et al 2018 JINST 13 P12008](#)
[E. Erdal, 2021 JINST TH 002](#)

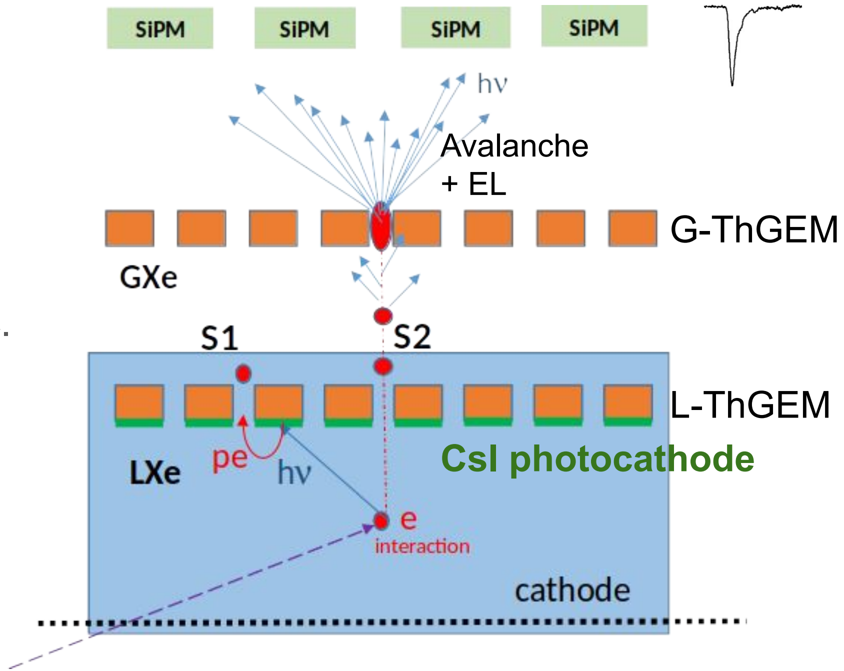
Bubble-free LHM (BF-LHM)

- L-G interface moved away from the electrode
- Two electrodes
    - L-THGEM: fully immersed and coated with CsI on the bottom for **VUV detection**
    - G-THGEM: kept in gas phase. **Avalanche + EL amplification in holes**
- Ionization electrons & photoelectrons transfered efficiently through L-THGEM holes into gas
- Strong extraction field between the electrodes
    - **Known** high extraction efficiency into gas
- Avalanche + EL light collected by photosensors on top



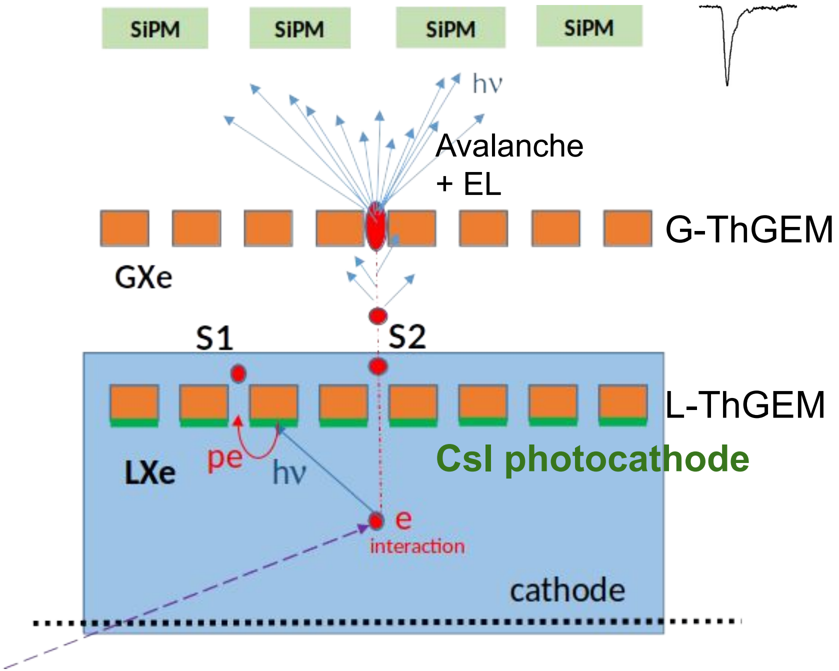
Bubble-free LHM: Advantages

- Flat L-G interface
  - Expected **high PDE** @ 175 nm
- Single photons induce large signals
  - Dark counts negligible → SiPMs, CMOS, etc.
- Light yield ***localized*** to the G-THGEM holes
  - Variations on the Liq-Gas interface not a concern
  - Fast signals
- Good expected position resolution



Bubble-free LHM: Status

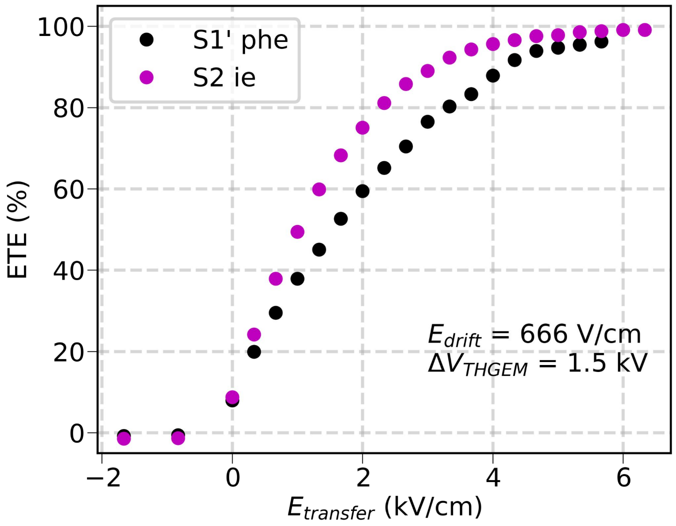
- Demonstrated a **high electron transfer efficiency** across the L-THGEM RD-51 miniweek 02/2022
    - Photoelectrons and ionization electrons
- Measured a **higher PDE** relative to the bubble-assisted LHM (this talk)
- Observed **large and fast EL signals** (this talk)

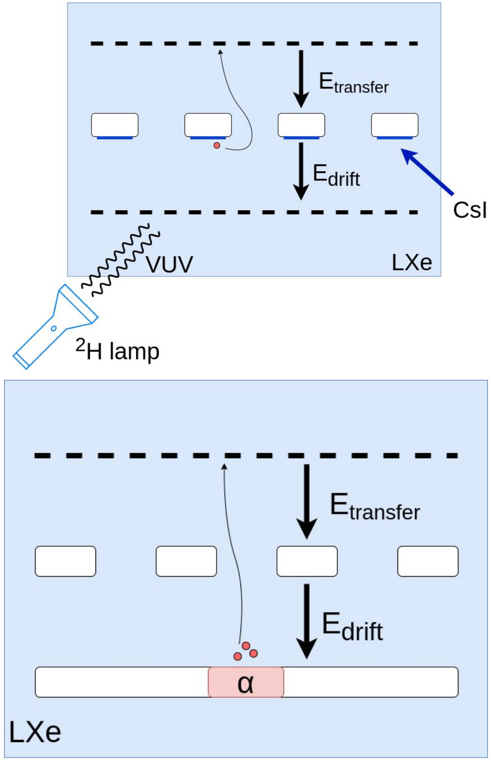


Preliminary results

Electron transfer efficiency across the L-THGEM

- **High transfer efficiency** for both S1'-like photoelectrons and S2 ionization electrons

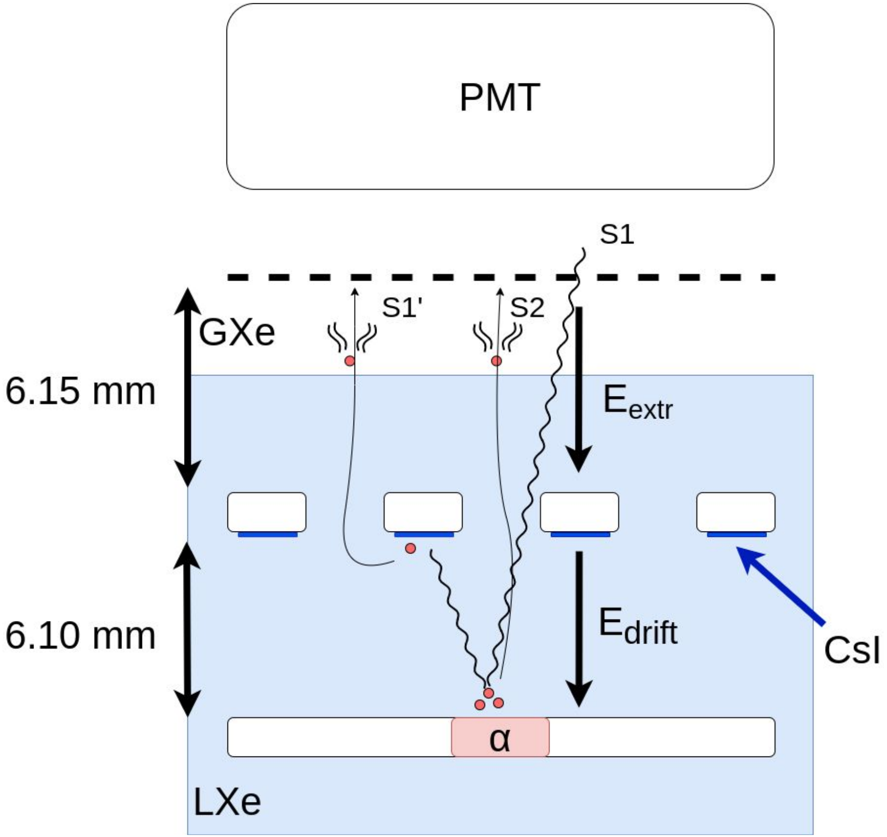




A simplified setup: dual-phase with single-THGEM

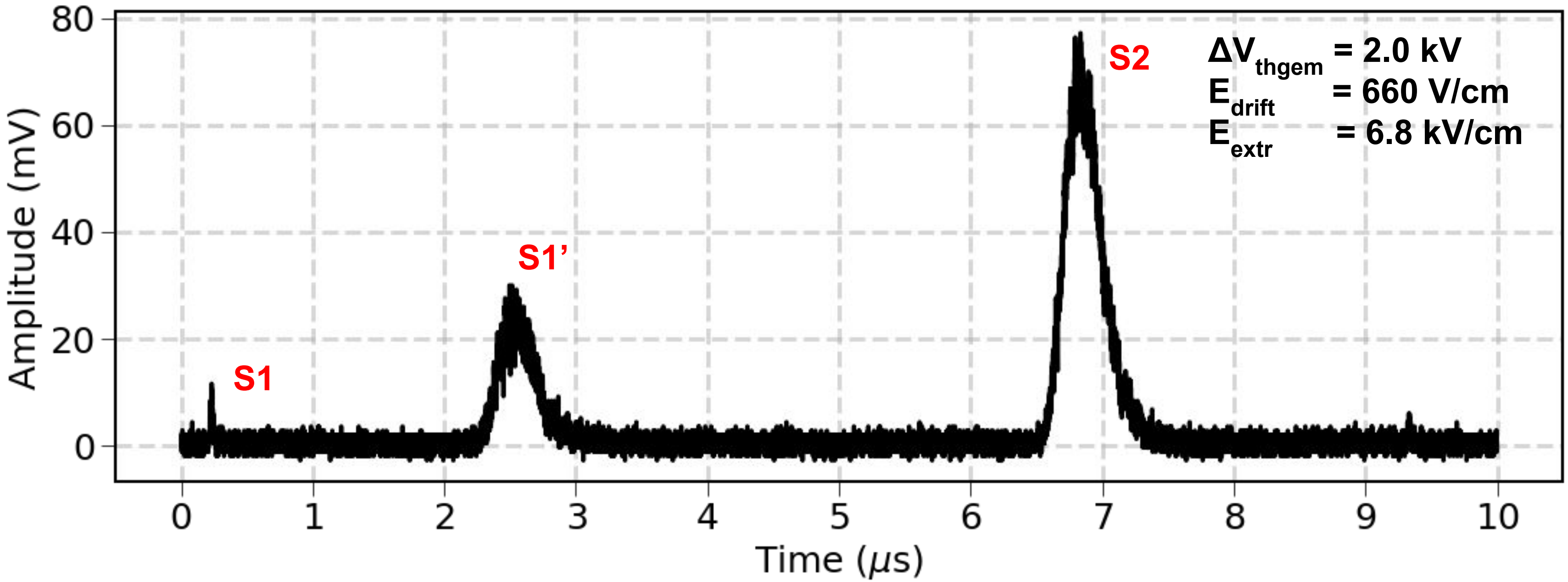
- Simple dual phase setup
- L-THGEM immersed and coated with CsI for VUV detection
- Mesh in the gas phase to create an extraction field
    - **EL amplification** in the gap
- Aimed to measure PDE

THGEM parameters
0.3 mm hole ∅
50 μm rim
0.7 mm pitch
0.4 mm thickness
20 mm ∅ CsI spot



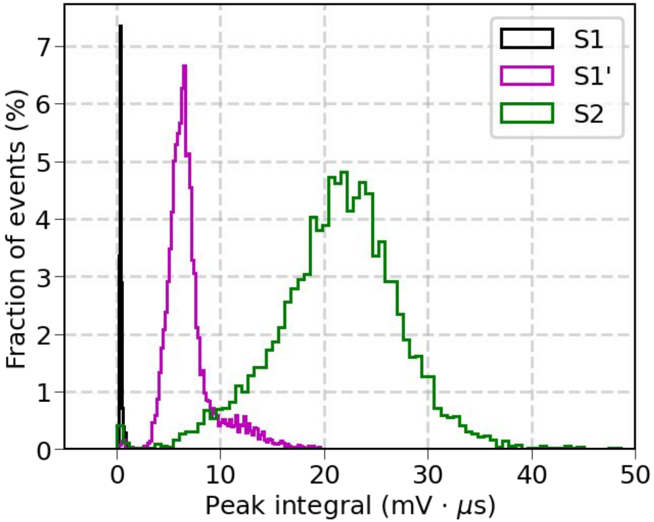
Example waveform

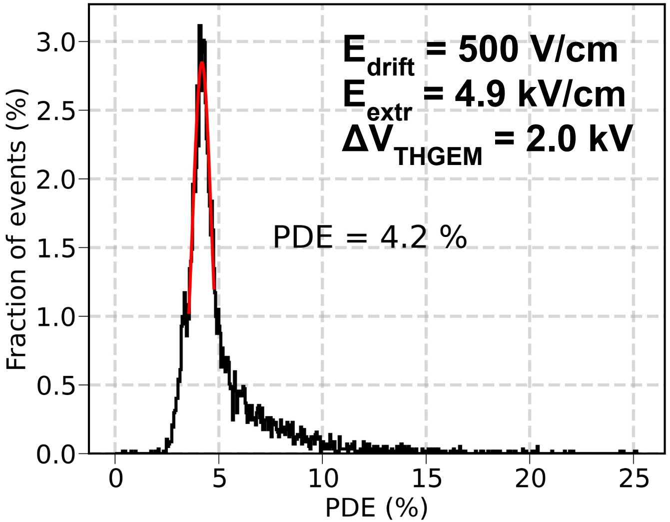
- A typical waveform produced by an ^{241}Am **α** interaction



PDE measurement

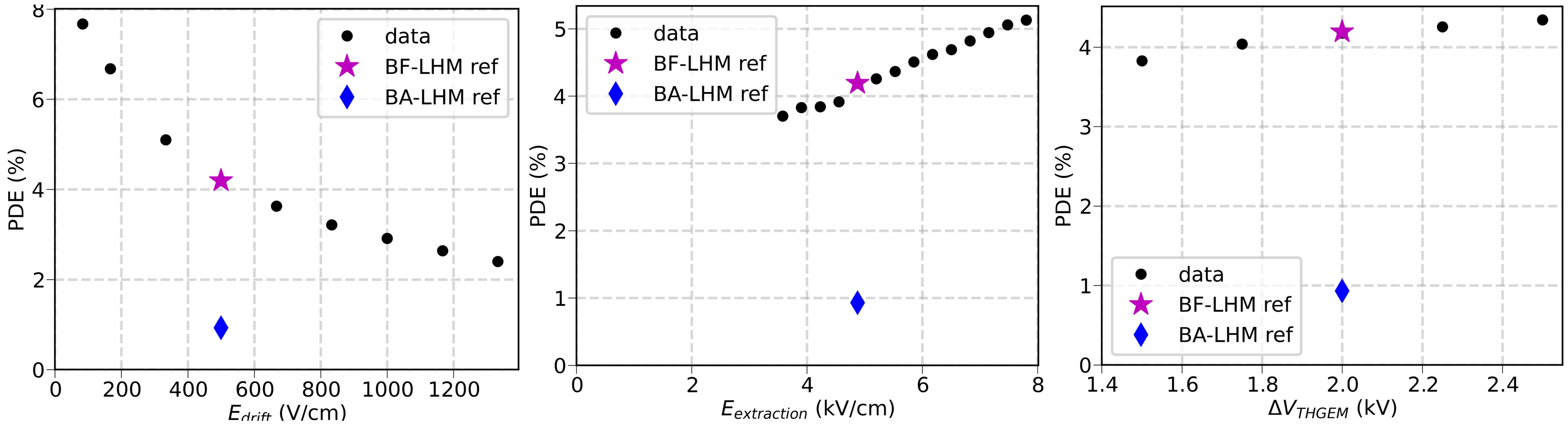
- PDE measurement based on the ratio of S1' and S2 signal strengths 2021 JINST TH 002
- Similar voltage configuration to bubble-assisted LHM
- BA-LHM PDE ~ 0.9%
- Observed a PDE increase of ~x4.7 in the BF-LHM





PDE optimization

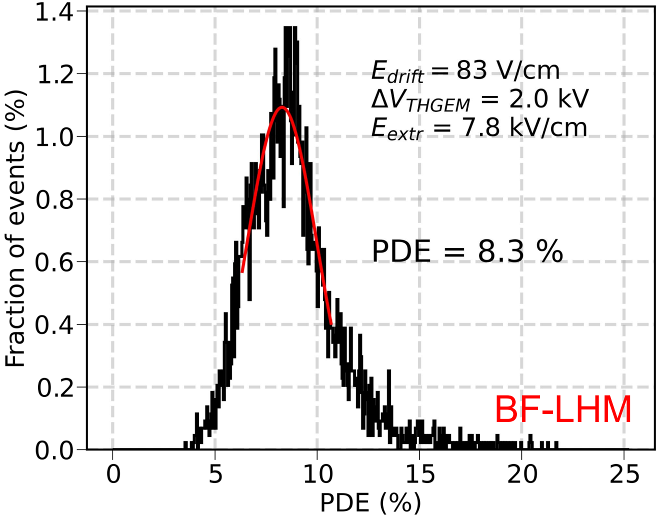
- With the current configuration the PDE can be improved by
  - Lowering the drift field → decrease of e⁻ backscattering
  - Increasing the extraction field → electron loss to the top face of the THGEM
  - Increasing ΔV_{THGEM} → greater effective QE of the photocathode

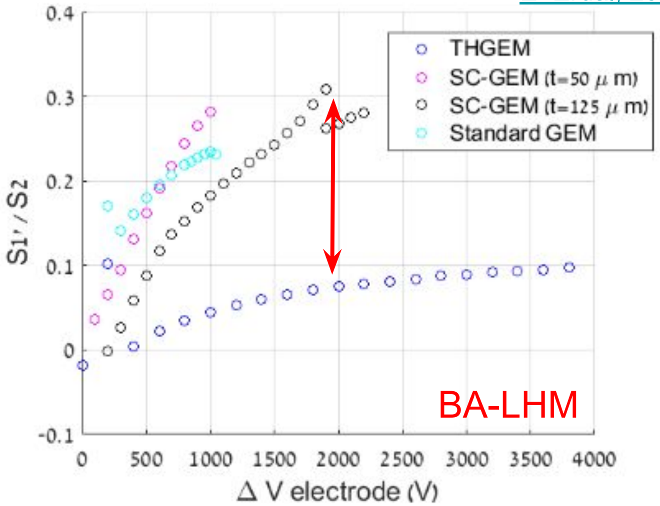


Optimal PDE

- With a more optimal field configuration, we measure a **PDE of 8.3%**
- A higher PDE can be achieved with SC-GEMs
    - We expect a **PDE in excess of 20 %** for a BF-LHM with SC-GEMs

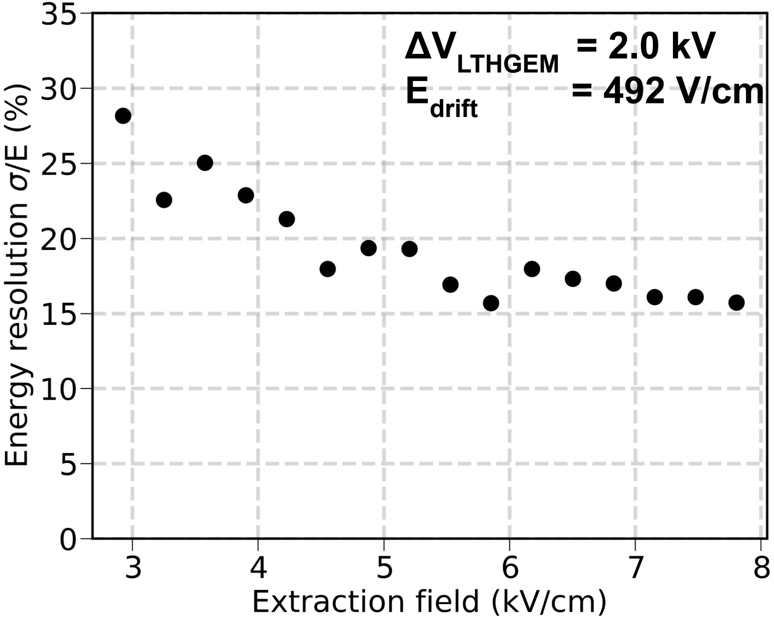
E. Erdal, 2021 JINST TH 002





Energy resolution

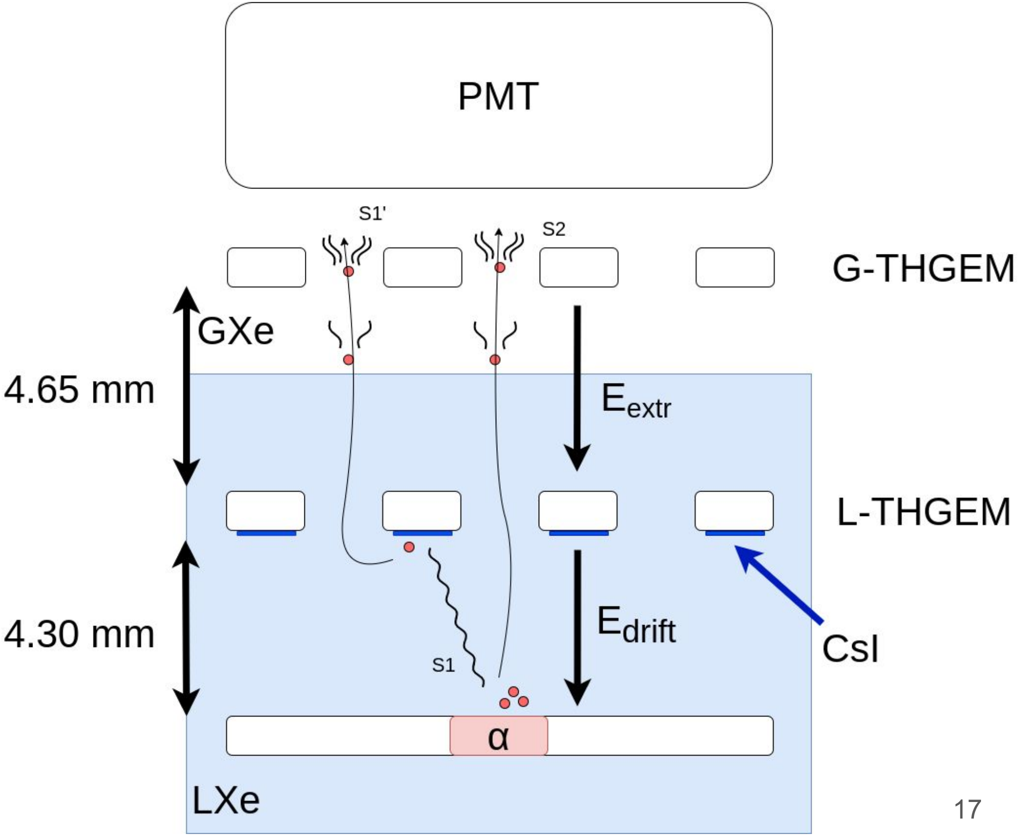
- Energy resolution for S2 signals worse than expected (~10%)
  - Under investigation (interface instabilities?)



Double-THGEM configuration

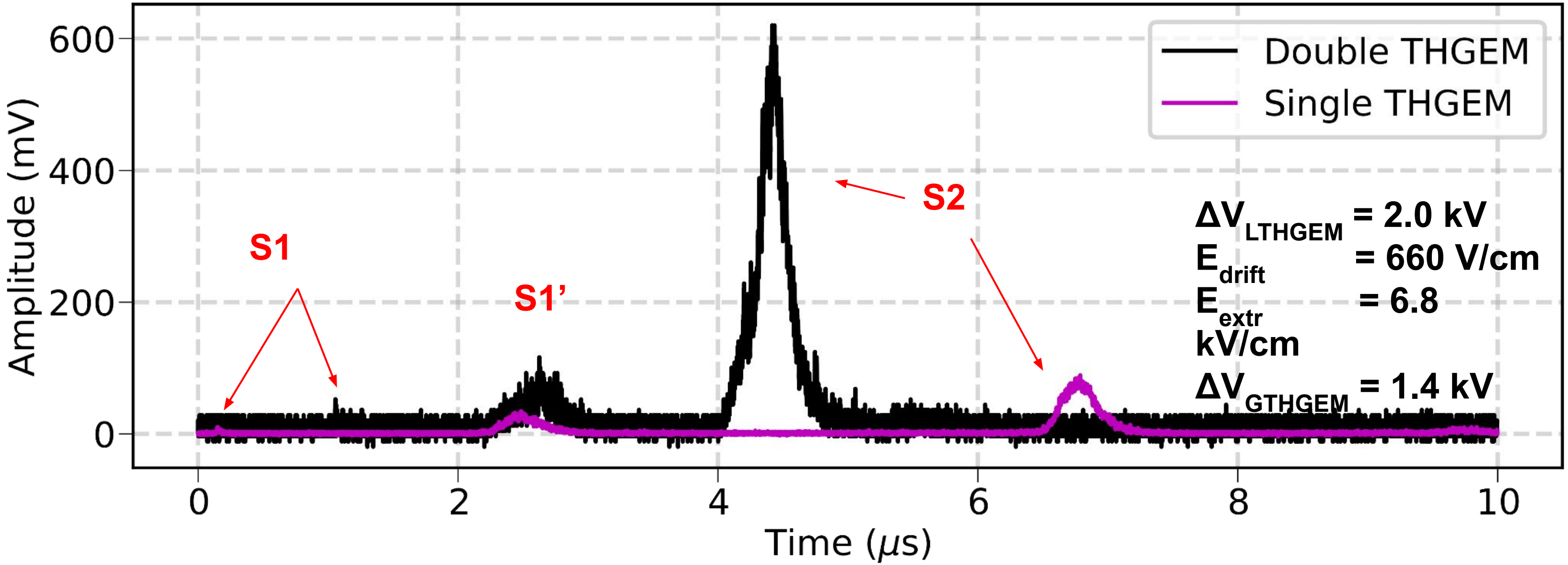
- L-THGEM immersed in LXe and coated with CsI for VUV detection
- G-THGEM in gas phase for **EL stability**
- Identical THGEM electrodes

THGEM parameters
0.3 mm hole ∅
50 µm rim
0.7 mm pitch
0.4 mm thickness
20 mm ∅ CsI spot



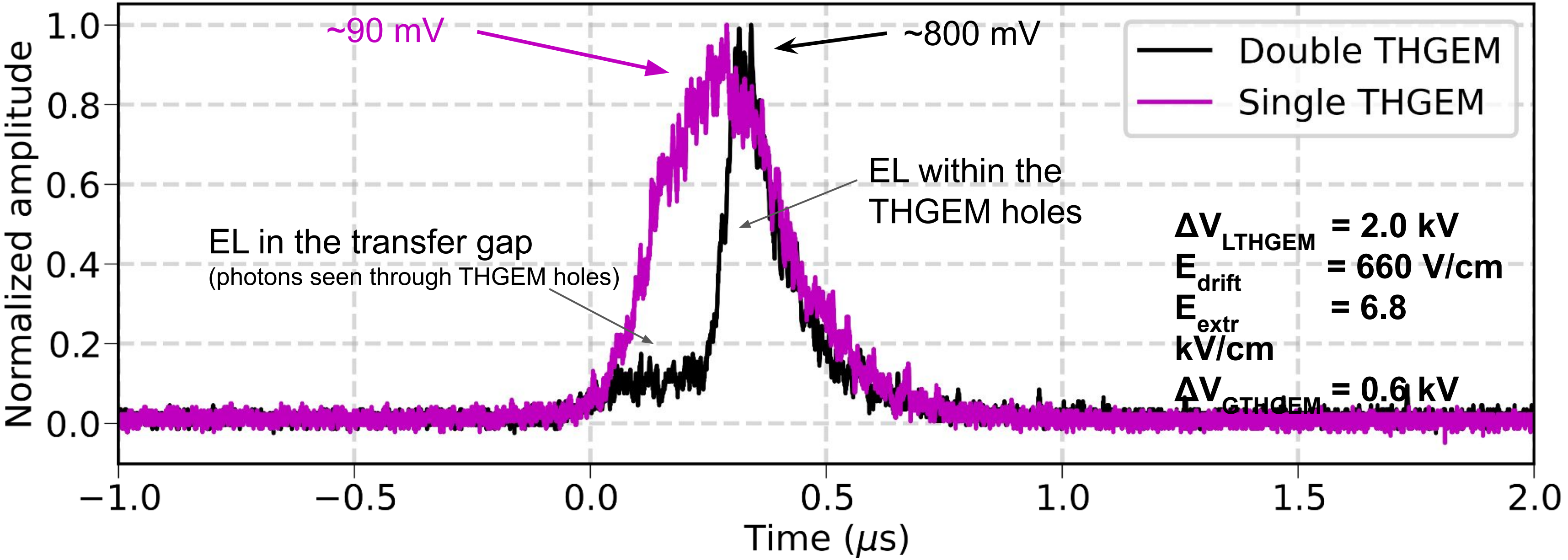
Example waveform: single-THGEM vs double-THGEM

- **Higher EL yield** than with the single-THGEM configuration under similar conditions



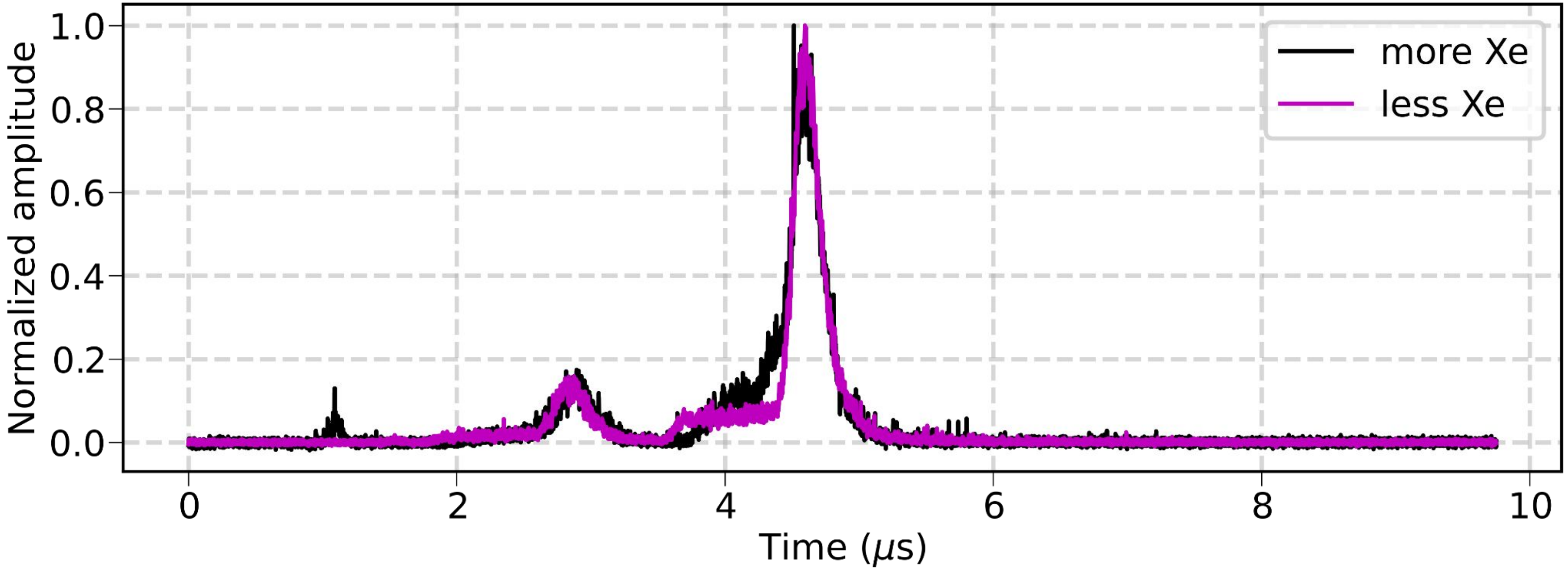
S2 width comparison: single THGEM vs double THGEM

- **Faster S2 signals** under the appropriate voltage configuration



Variations in the liquid-gas interface

- Liquid level changes, but EL happens mostly within the THGEM holes

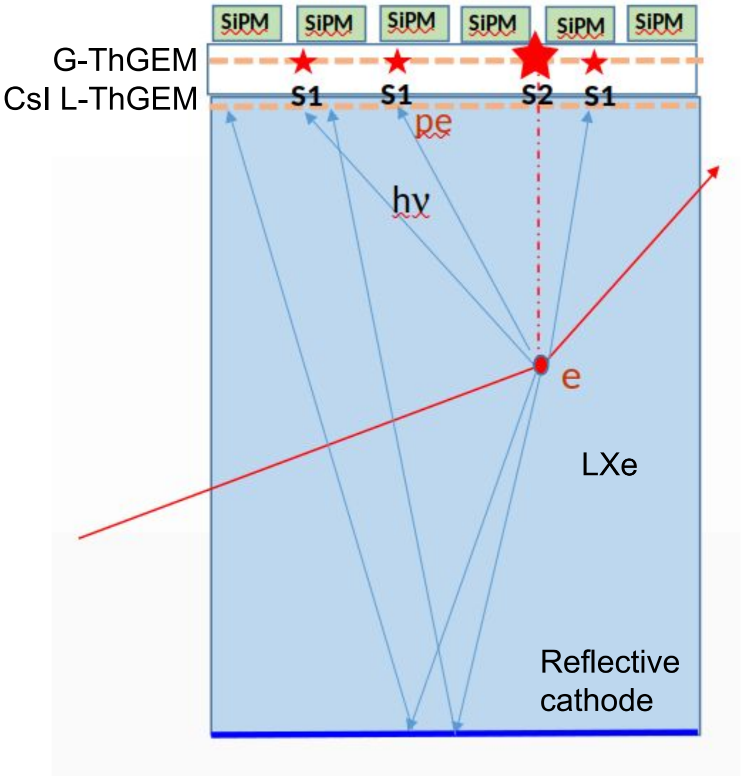


Next steps

- Study energy resolution with double-thgem setup
- Compare different GEM structures
    - SC-GEM known to provide better PDE
- Measure absolute PDE in dual-phase configuration

Outlook: a potential dual-phase LHM TPC for Dark Matter

- **High PDE**
- **Unambiguous detection of single-photon S1s**
    - Dark counts are no longer a determining factor
    - Lower detection threshold
    - Possible to use SiPMs or CMOS-SPAD
- EL + avalanche light localized to the G-THGEM holes
    - Fluctuations on the **L-G interface not critical**
    - **Fast signals**
- No need for grid or meshes in the active volume
    - Improved S1 light collection efficiency
- No need for PMTs
    - Better radiopurity
    - No wasted LXe in the buffer region

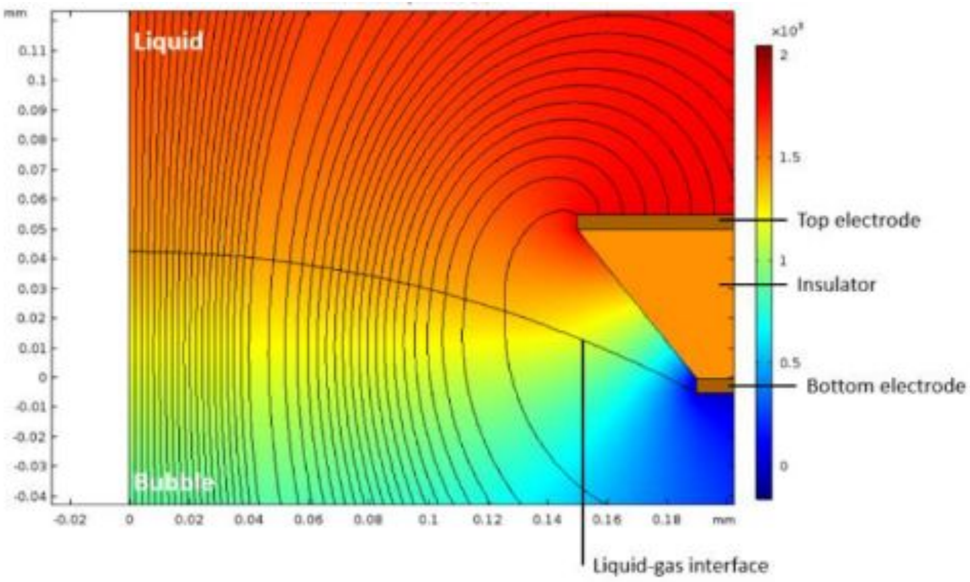


Thank you for your attention

Backup

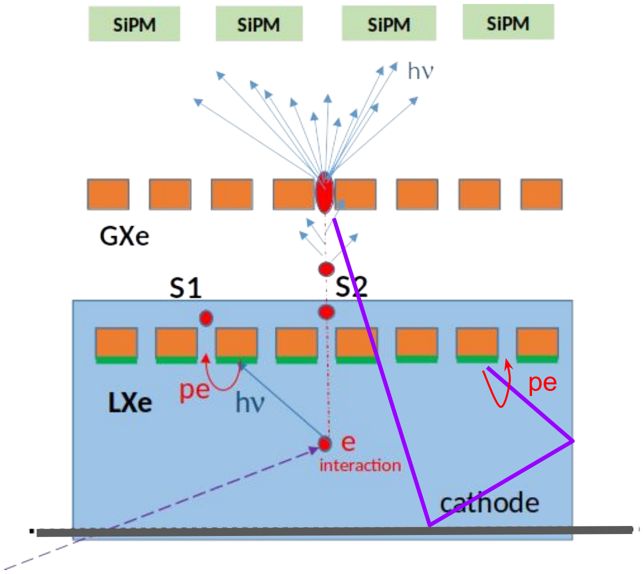
Low PDE: why?

- Main hypothesis: low e^- transfer efficiency across the bubble interface
    - e^- stuck and lost to the wall
- Ongoing efforts to understand this effect
    - Bubble physics (A. Tesi etal 2021 JINST 16 P09003)
- A dual-phase configuration seems more adequate



Photon feedback

- We haven't observed a significant amount of photon feedback
- More detailed studies to come

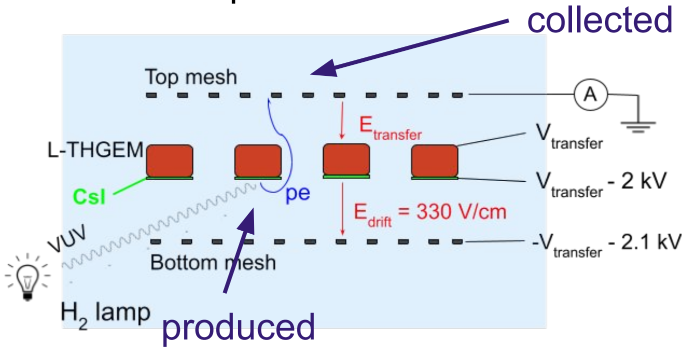


Methodology

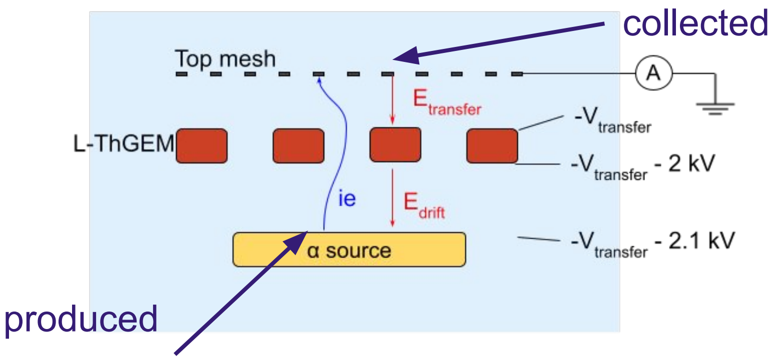
- Measure current on different electrodes
    - Each electrode is measured separately
- Transmission efficiency defined as

$$\varepsilon = \frac{I_{collected}}{I_{produced}}$$

S1 photoelectrons

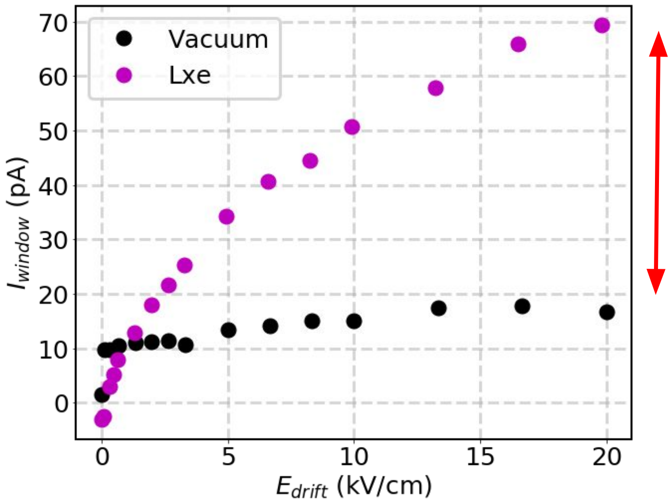


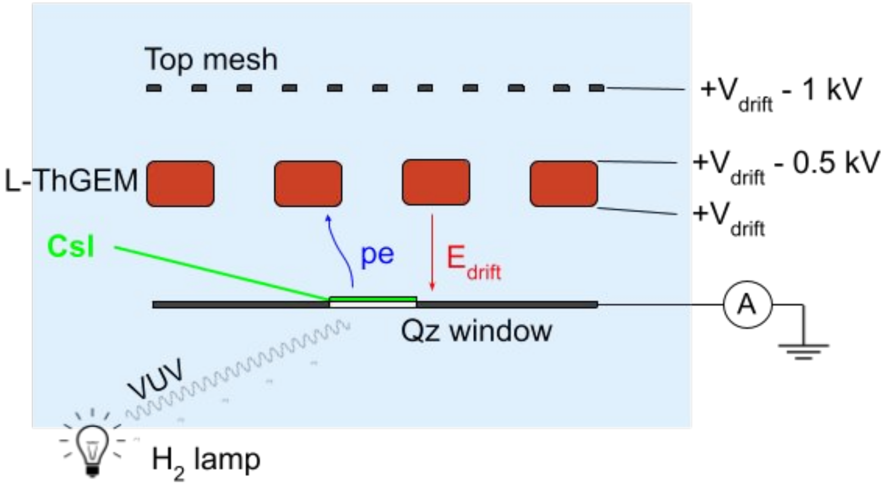
S2 ionization electrons



Photoelectron extraction efficiency

- Photoelectrons are extracted from a CsI-coated window illuminated by a H_2 lamp and collected on the bottom side of the L-ThGEM
- $QE_{LXe} > QE_{vac}$

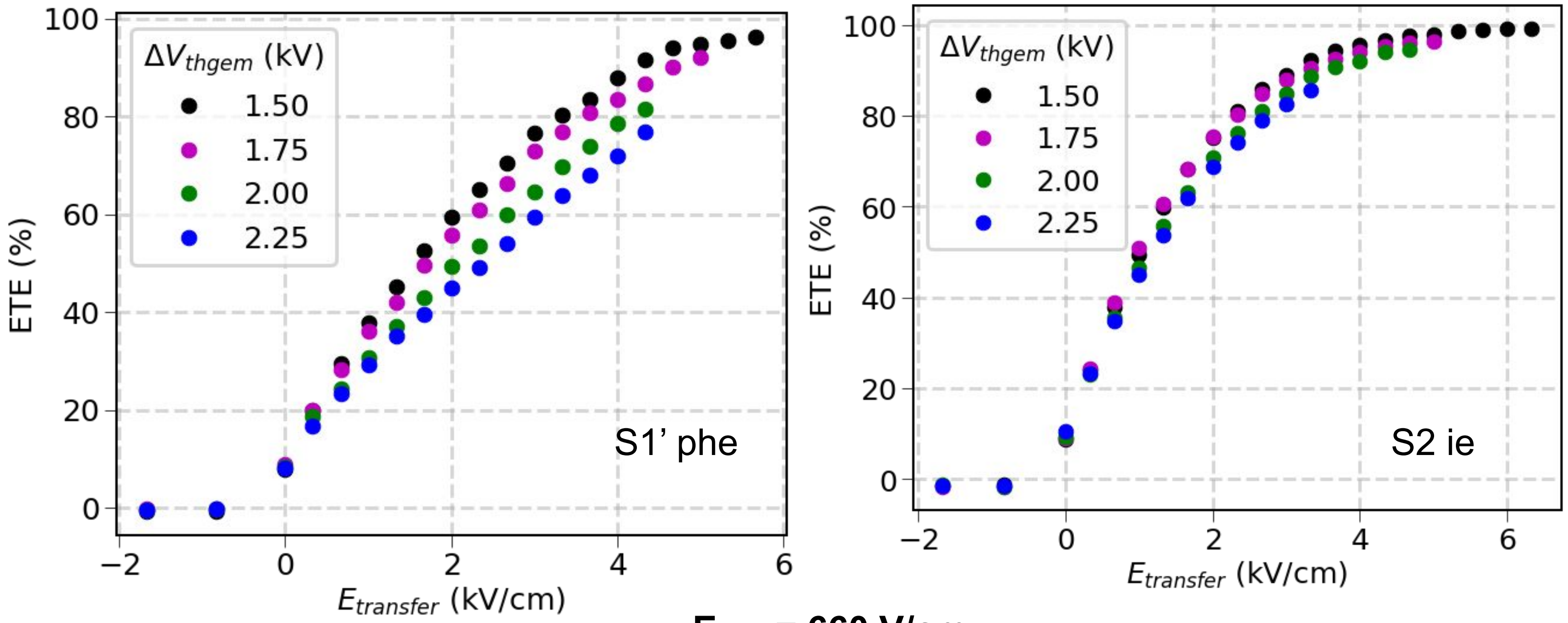




LXe: increased QE_{eff} by ~x3.5

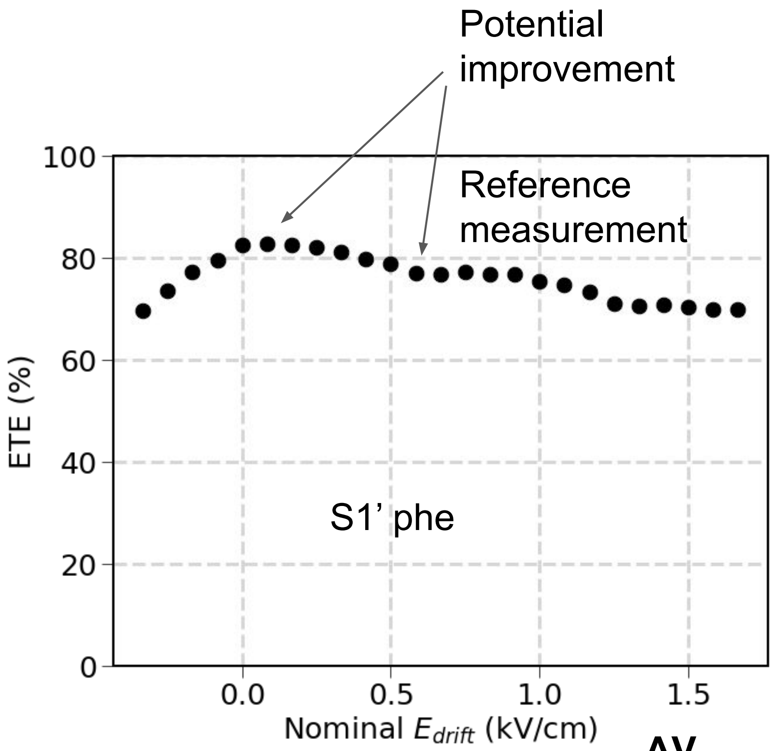
Reproduction of the results by
[E. Aprile et al., NIM A 338 (1994) 328-335]

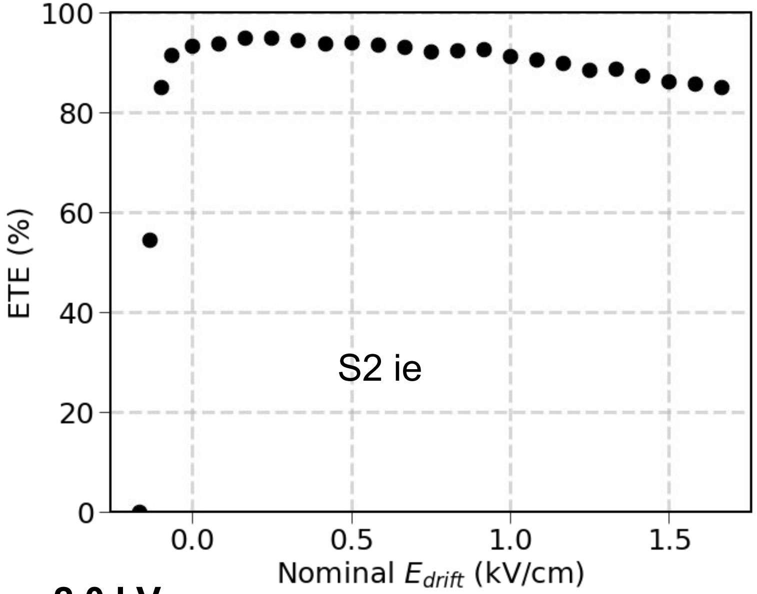
ETE vs ΔV_{THGEM}



E_{drift} = 660 V/cm

ETE vs Edrift

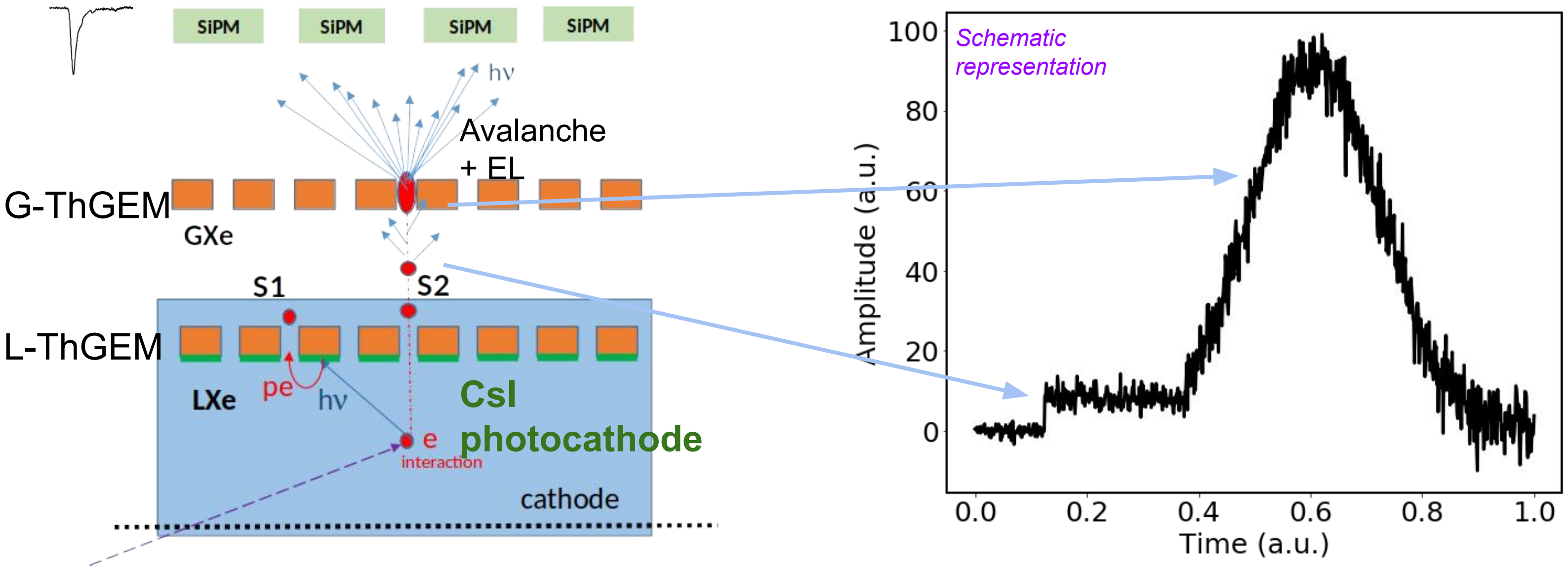




ΔV_{THGEM} = 2.0 kV
E_{extr} = 4.0 kV/cm

EL amplification prior to G-ThGEM crossing

- Some EL light would be produced before crossing the G-ThGEM
  - Most of it will be blocked by the electrode
  - Its effect needs to be studied



PDE

$$PDE = \frac{N_{pe}^{transferred}}{N_{\gamma}^{PC}}$$

effective light yield:
photons detected per electron in LXe

$$S1' = N_{pe}^{transferred} \cdot Y^{eff}$$

$$S2 = N_{e}^{transferred} \cdot Y^{eff}$$

$$N_{\gamma}^{PC} = \frac{E}{W_{sc}} \cdot f_{refl} \cdot \frac{\Omega^{PC}}{4\pi}$$

$$N_{e}^{transferred} = \frac{E}{W_i} \cdot R \cdot \varepsilon_{S2}$$

from literature

$$PDE = \frac{W_{sc}}{W_i} \cdot \frac{R}{f_{refl} \cdot \frac{\Omega^{PC}}{4\pi}} \cdot \varepsilon_{S2} \cdot \frac{S1'}{S2}$$

measured by us