

Liquid Hole Multiplier (LHM) - “local dual-phase TPCs”: potential tools for future noble-liquid detectors

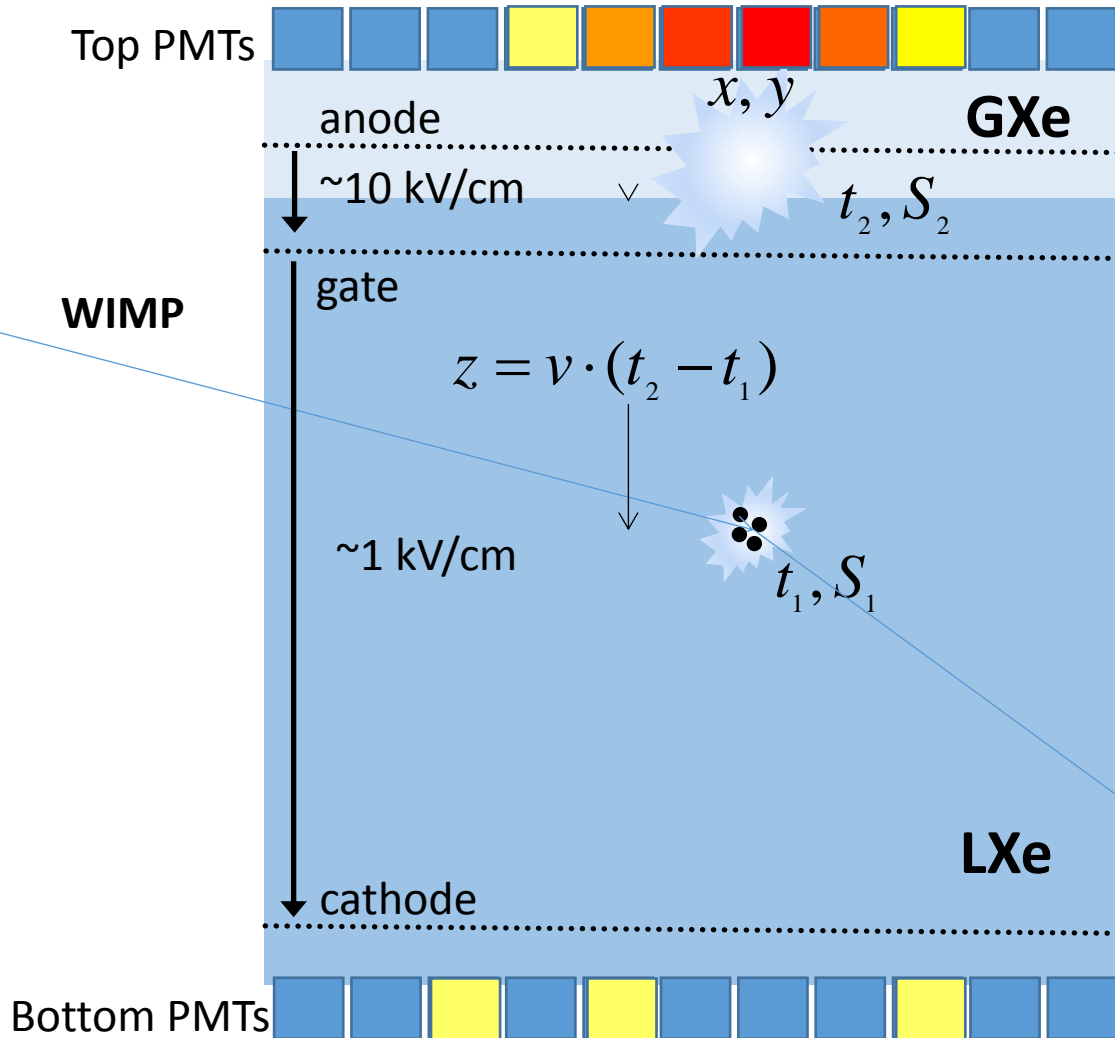
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Research supported by Israel Science Foundation & Israel-Germany Minerva Science Foundation

**Currently at the Engineering Sciences Faculty, Ben Gurion University, Beer Sheva, Israel*

'Classical' dual-phase Time Projection Chamber



Current leading DM **LXe** experiments: **XENON1t**, **PANDA X-II**

Future: **XENONnt**, **LZ** : **few t LXe**

Next decade: & **DARWIN 50 t LXe...**

LAr: Dark Side 20K

See refs in: [Aalbers \(DARWIN\)](#), [JCAP11\(2016\)017](#)

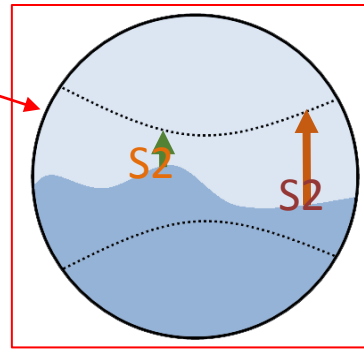
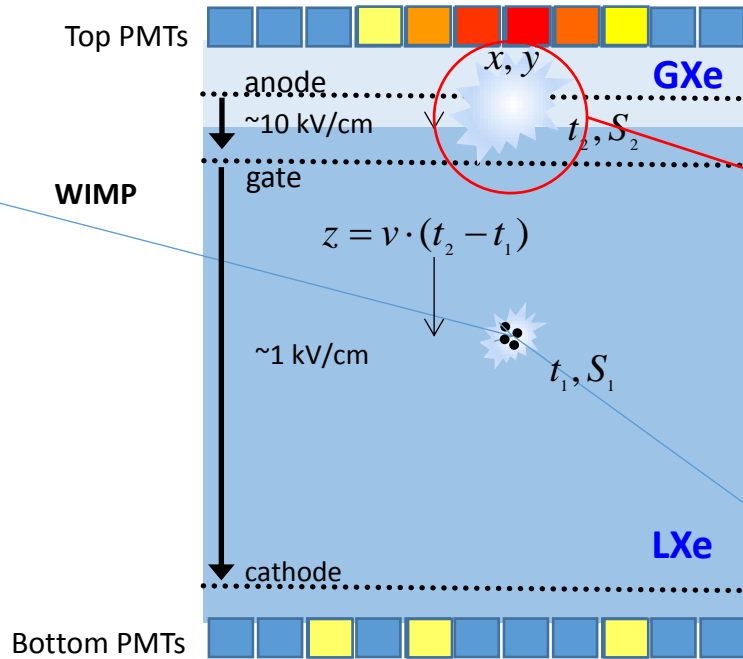
<http://arxiv.org/abs/1606.07001>

- Hit pattern on top PMT array $\rightarrow x, y$
- Time difference $t_2 - t_1 \rightarrow z$
- $S_2/S_1 \rightarrow$ *background discrimination*

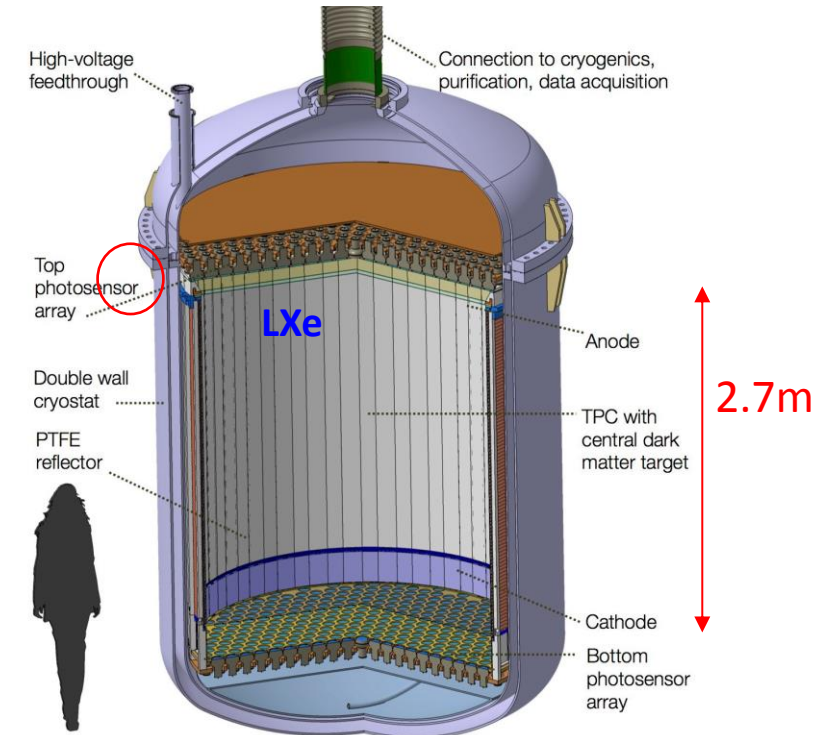
$$\left(\frac{S_2}{S_1} \right)_{\text{nuclear recoil}} \text{ Signal} < \left(\frac{S_2}{S_1} \right)_{\text{electron recoil}} \text{ Background}$$

LARGE dual-phase TPC: technical issues?

concerns regarding S2-signal uniformity in large-diameter (few-meters) dual-phase TPCs



“waves”, parallelism of mesh vs liquid...

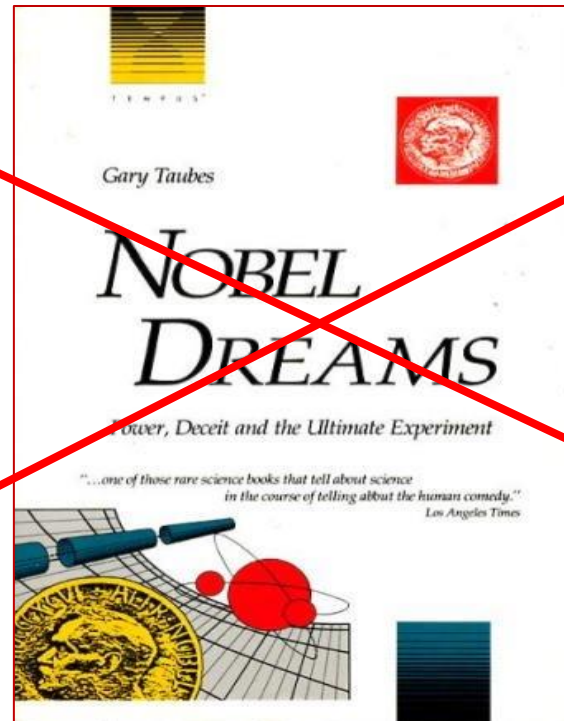


A possible configuration of a **50 t LXe DARWIN** detector. The TPC is surrounded by highly reflective PTFE walls, closed by the cathode and anode electrodes on bottom and top, respectively. Shown is a TPC with 2 photo-sensor arrays made of circular PMTs with 3" diameter. **The final sensor type, however, is not yet defined – being subject to R&D.** [Aalbers \(DARWIN\), JCAP11\(2016\)017 http://arxiv.org/abs/1606.07001](http://arxiv.org/abs/1606.07001)

→ Our goal: Search for a new concept for **S1 & S2** detection in a **single-phase, liquid-only, detector**

Noble (liquid) Dreams

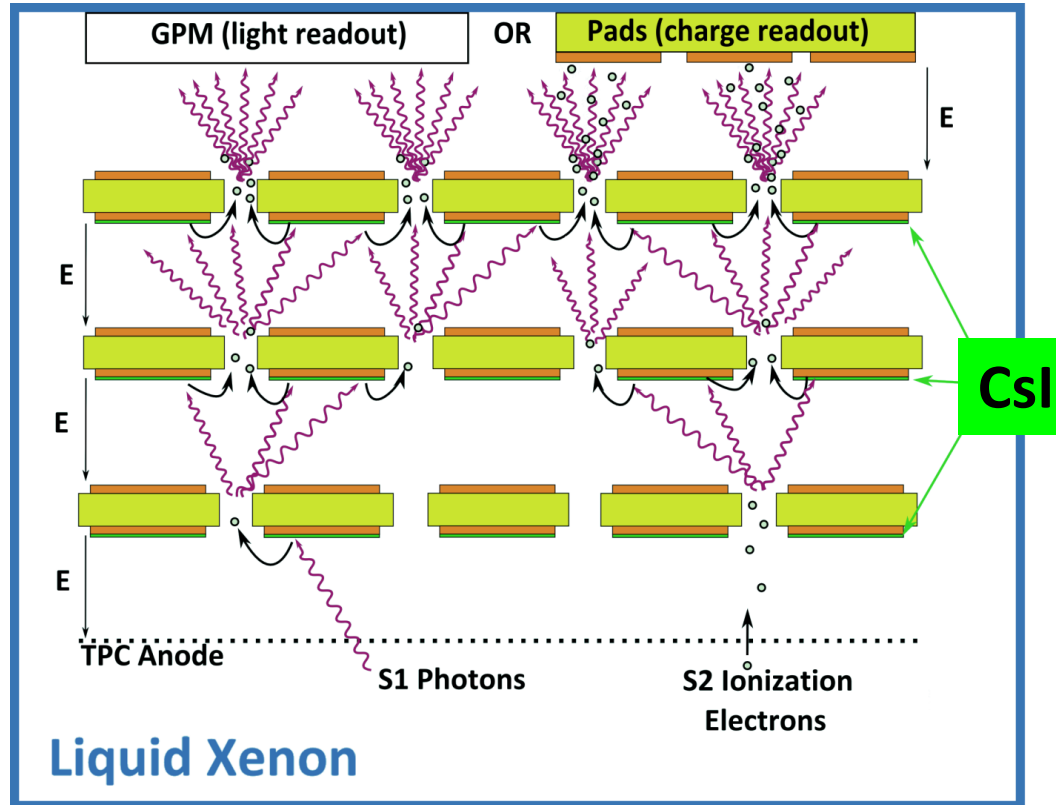
A.B. "Noble Dreams" - TPC2012 Workshop Paris, 2012



Detection solutions for LARGE-VOLUME noble-liquid detectors

Originally proposed: Liquid Hole-Multipliers **LHM** in single-phase LXe

Breskin *J. Phys. Conf. Ser.* **460** (2013) 012020



DREAM:

- Simultaneous detection of **S1** scintillation UV-photons & **S2** ionization electrons by a cascade of CsI-coated THGEM electrodes.
- Electron multiplication via electroluminescence, EL (+ maybe little charge gain) in the holes.
- Optical readout (or maybe charge readout)

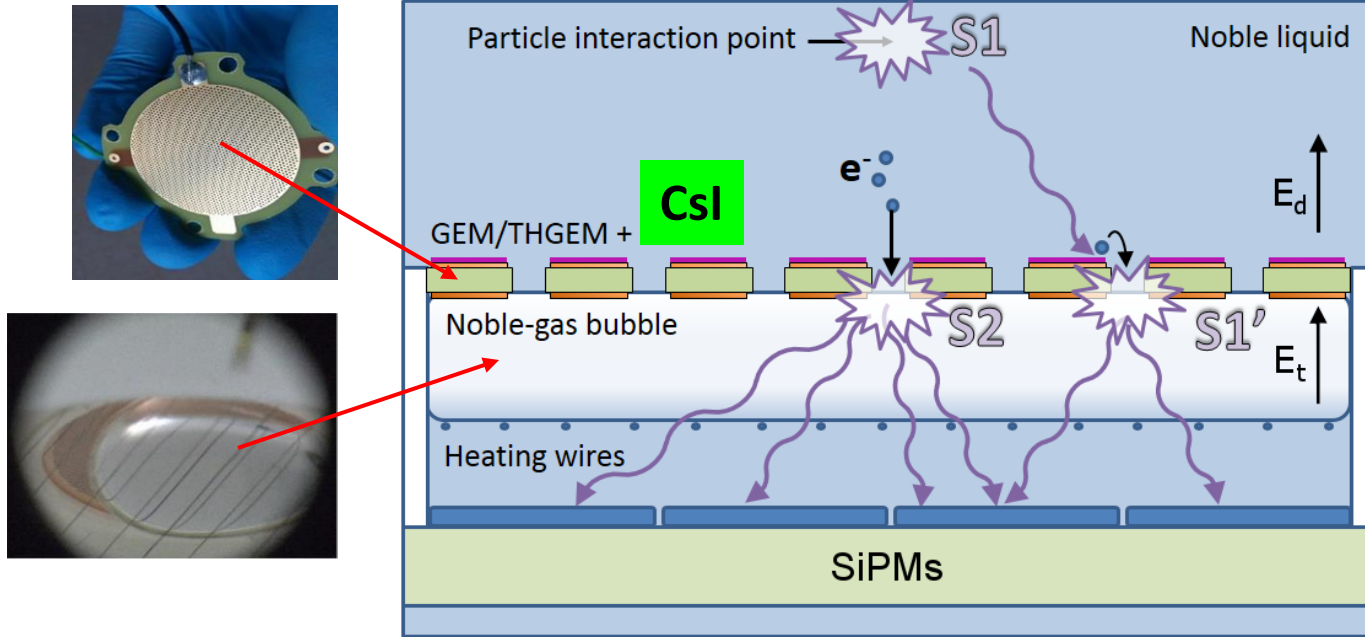
But: LXe prior art:

- Electroluminescence (EL) threshold: ~ 400 kV/cm - on wires
- e-avalanche threshold : ~ 1 MV/cm on wires Doke NIM 1982

→ **Observed large signals!** Arazi 2013 JINST 8 C12004

→ **EL: in gas bubbles** Arazi 2015 JINST 10 P08015

A new concept: Bubble-assisted Liquid Hole Multiplier (LHM)



Precise control of the liquid-gas interface:

- ➔ better S2 resolution
- ➔ potentially better S2/S1-based background discrimination

Reality:

- Perforated electrode (GEM or THGEM) coated on top with a CsI photocathode;
- Heating-wires grid forms a stable bubble underneath, by buoyancy;
- No need for heating after formation;
- A position-sensitive photon detector (e.g. **SiPM** array) is located below;
- Ionization electrons focused into the holes create **EL light** (S2) when crossing the liquid-gas interface into the bubble;
- Primary scintillation (S1) photons impinging on the photocathode release photoelectrons which are focused into the holes and create similar EL signals (S1');
- The lateral coordinates of the EL signals are reconstructed by the photon detector.

Arazi, 2015_JINST 10 P08015

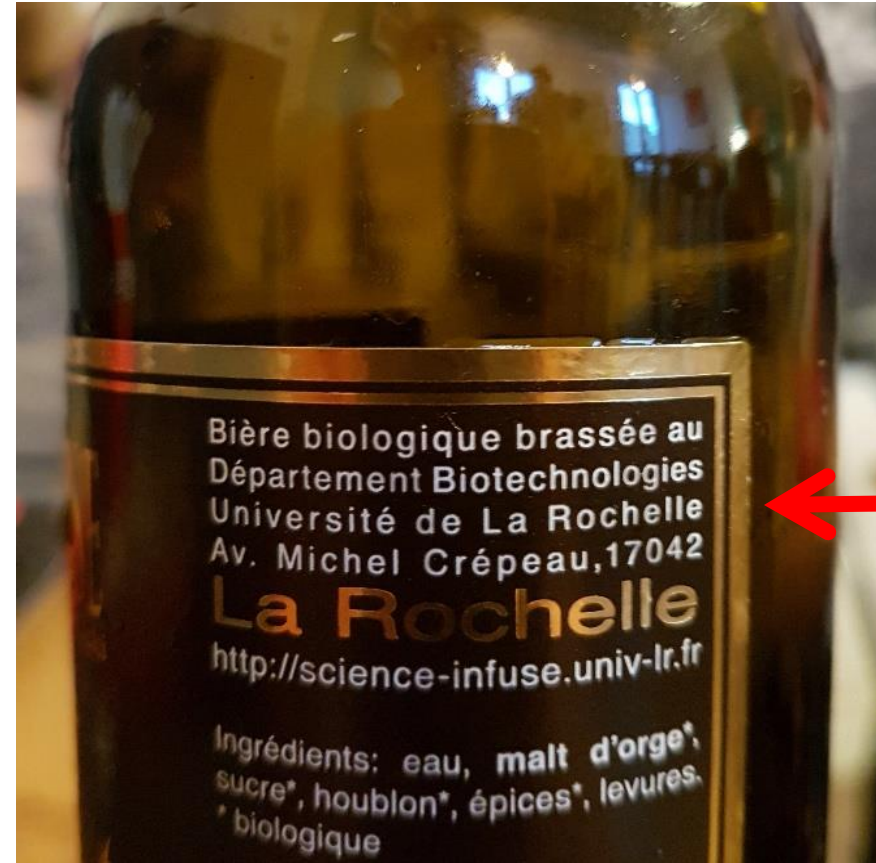
Erdal, 2015 JINST 10, P11002

Erdal, 2019 JINST 14, P01028

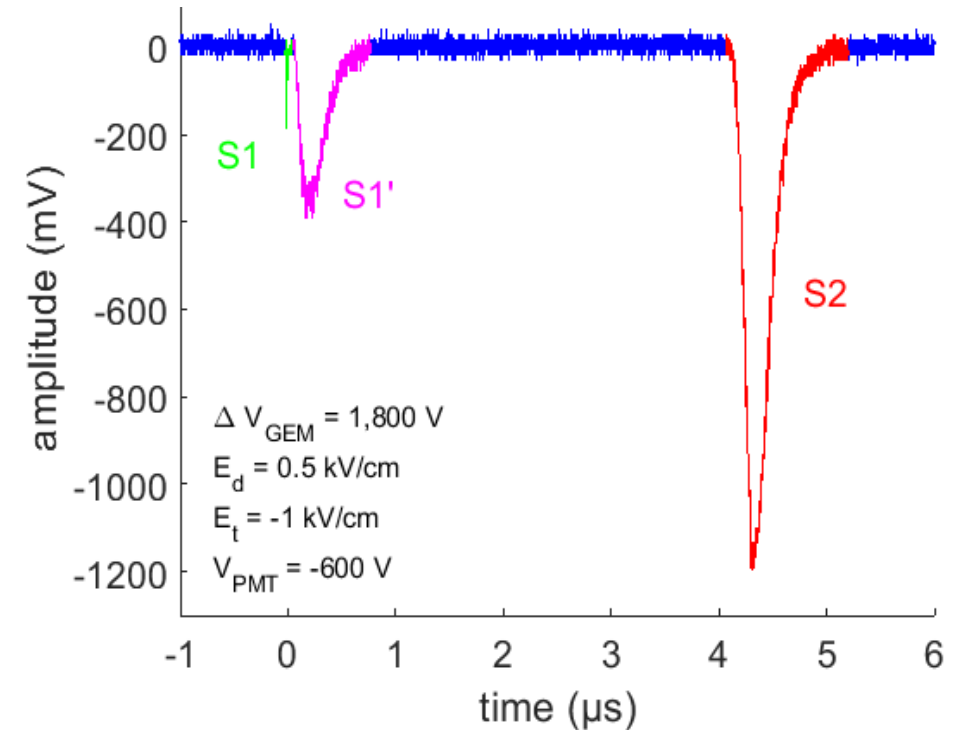
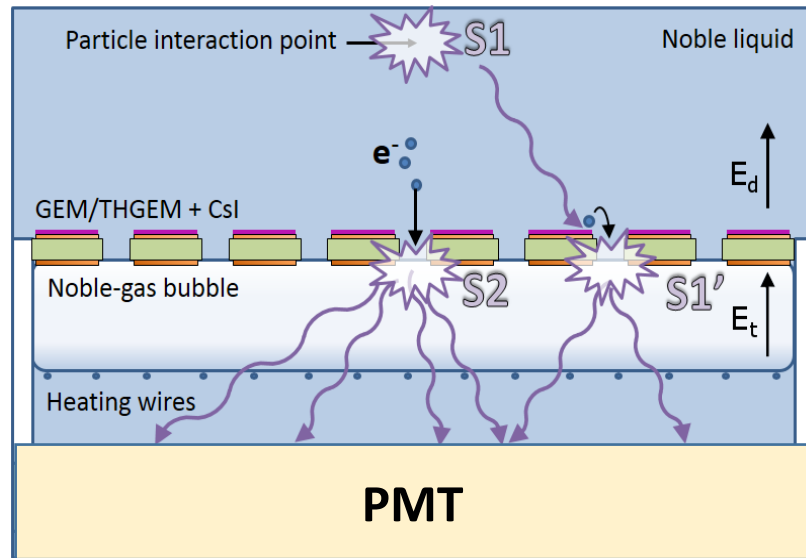
A. Breskin

Competitors in bubble formation: La Rochelle UNIVERSITY!

Science Infuse



Waveform structure



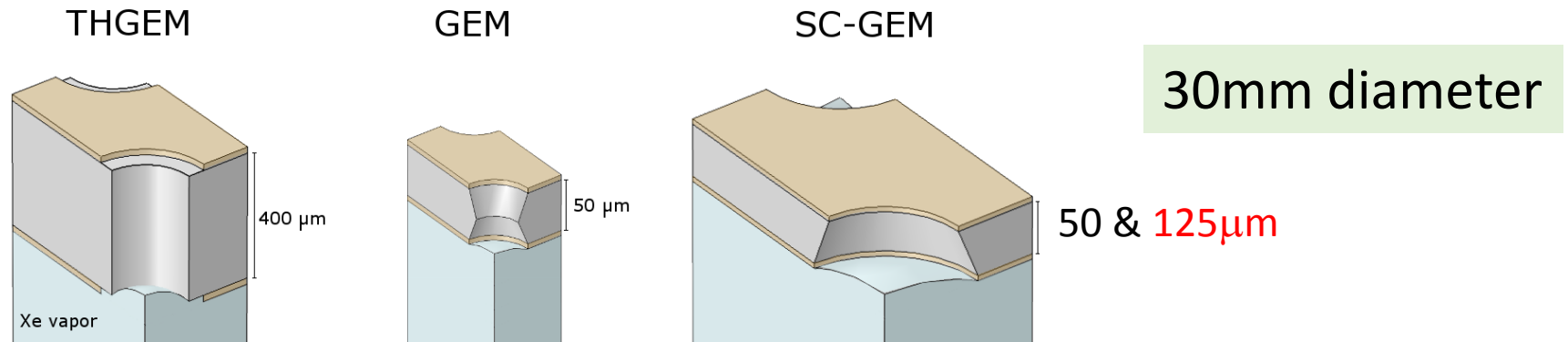
Typical waveform of an alpha-particle event, recorded by a **PMT** below the bubble


S1: primary light passing through holes

S1': EL light from bubble, by photoelectrons emitted from the CsI photocathode

S2: EL light from bubble, by ionization electrons from track

LHM Electrodes investigated



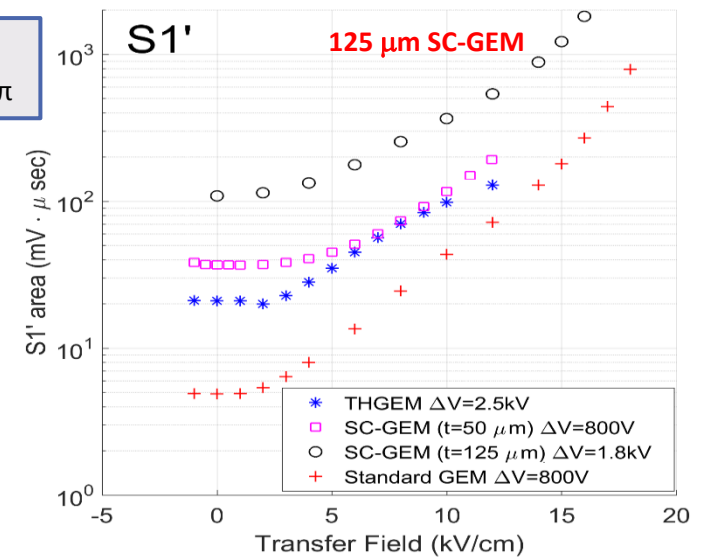
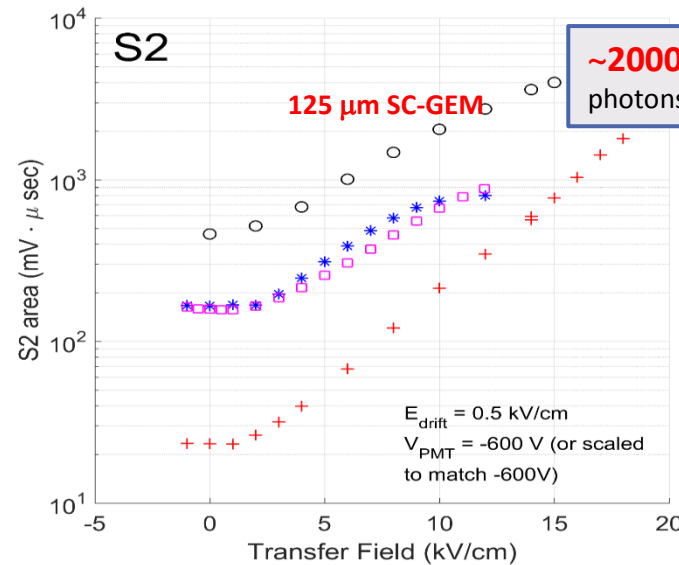
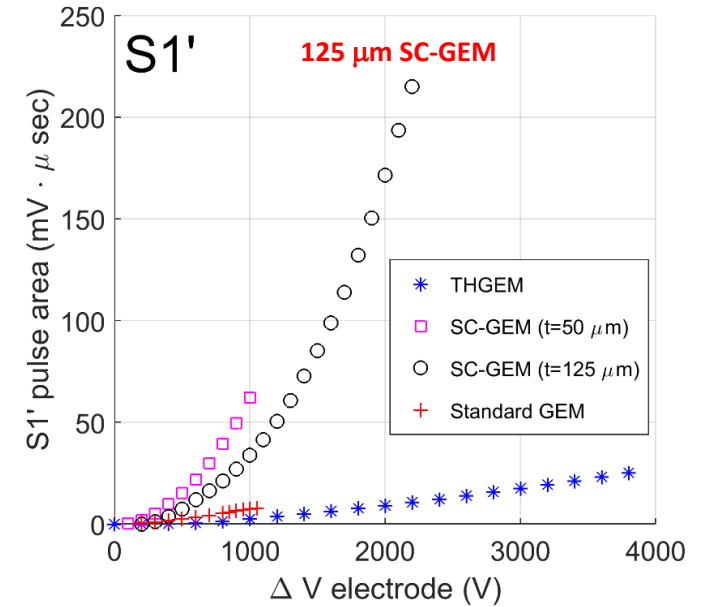
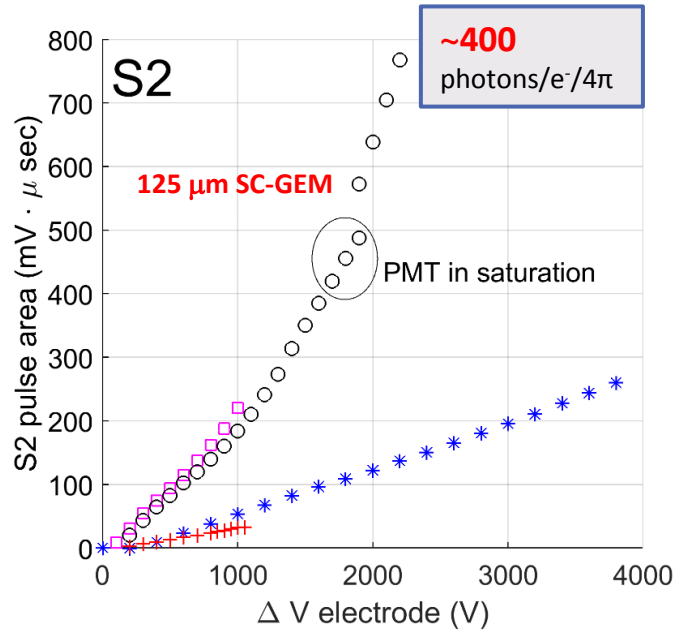
	THGEM	Standard GEM	Single-conical GEM	Single-conical GEM
Insulator	FR4	polyimide	polyimide	polyimide
Thickness	0.4 mm	50 μm	50 μm	125 μm 
Hole diameter(s)	0.3 mm	top/mid/bottom 70/50/70 μm	top/bottom 300/340 μm	top/bottom 300/400 μm
Hole pitch	1 mm	140 μm	600 μm	600 μm
Cu thickness	20 μm	5 μm	5 μm	5 μm
Hole rim	50 μm	--	--	--

Erdal, 2018 *JINST* **13** P12008

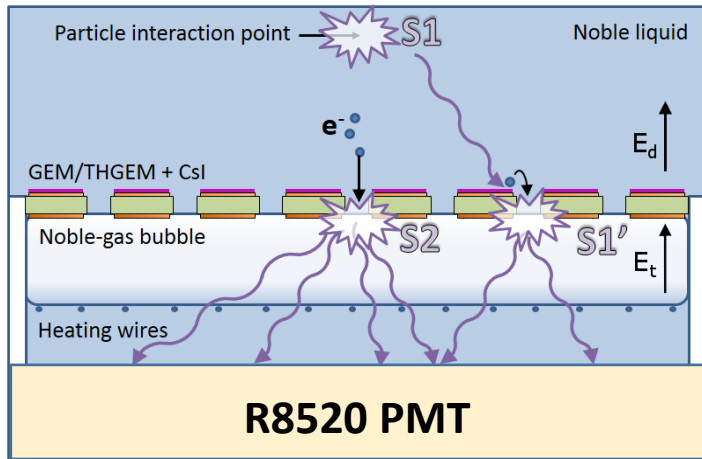
Electroluminescence yield

Primary source of difference of EL-yield between electrodes:
efficiency of electron transfer
 across liquid-gas interface

Intense field across the bubble:
 Up to 5-fold EL yield enhancement

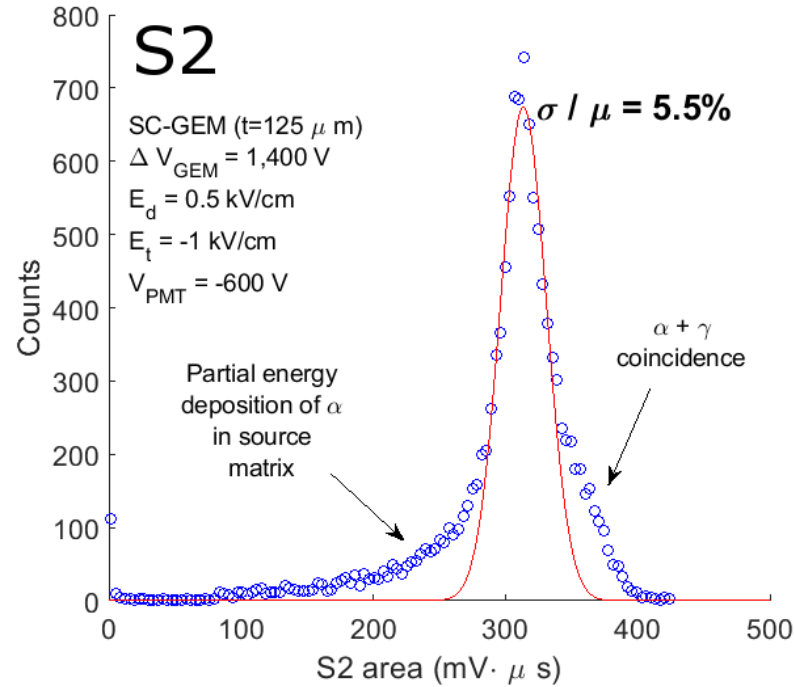


Energy resolution

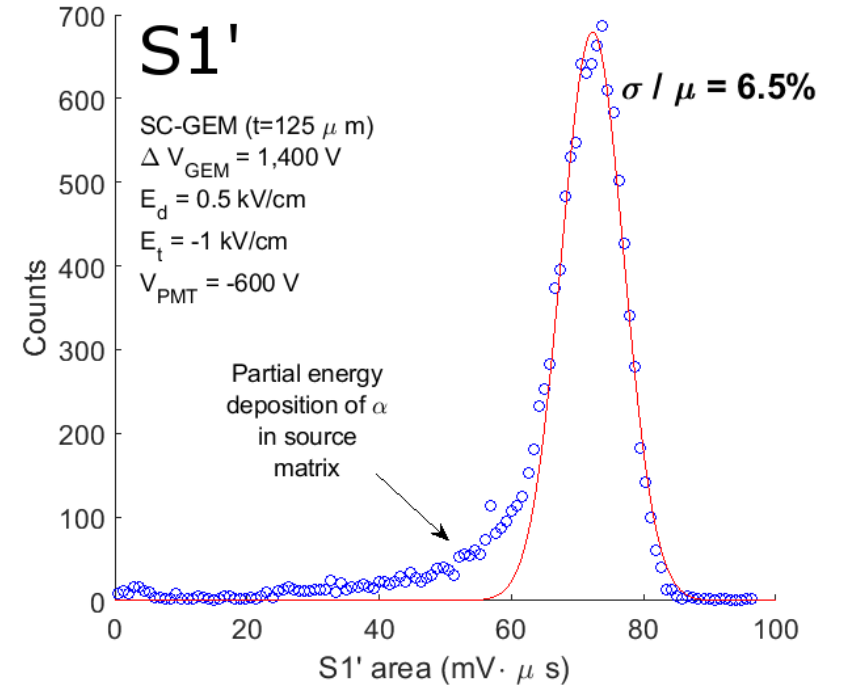


Ionization electrons → EL

Scintillation-induced photons
→ CsI → EL



S2 ~7,000 ionization electrons/event

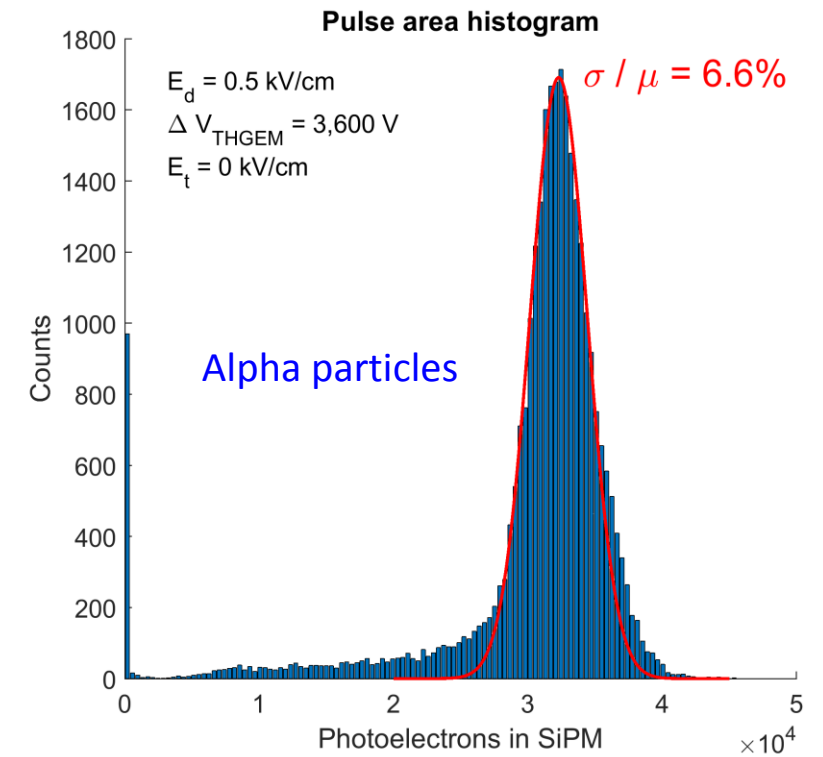
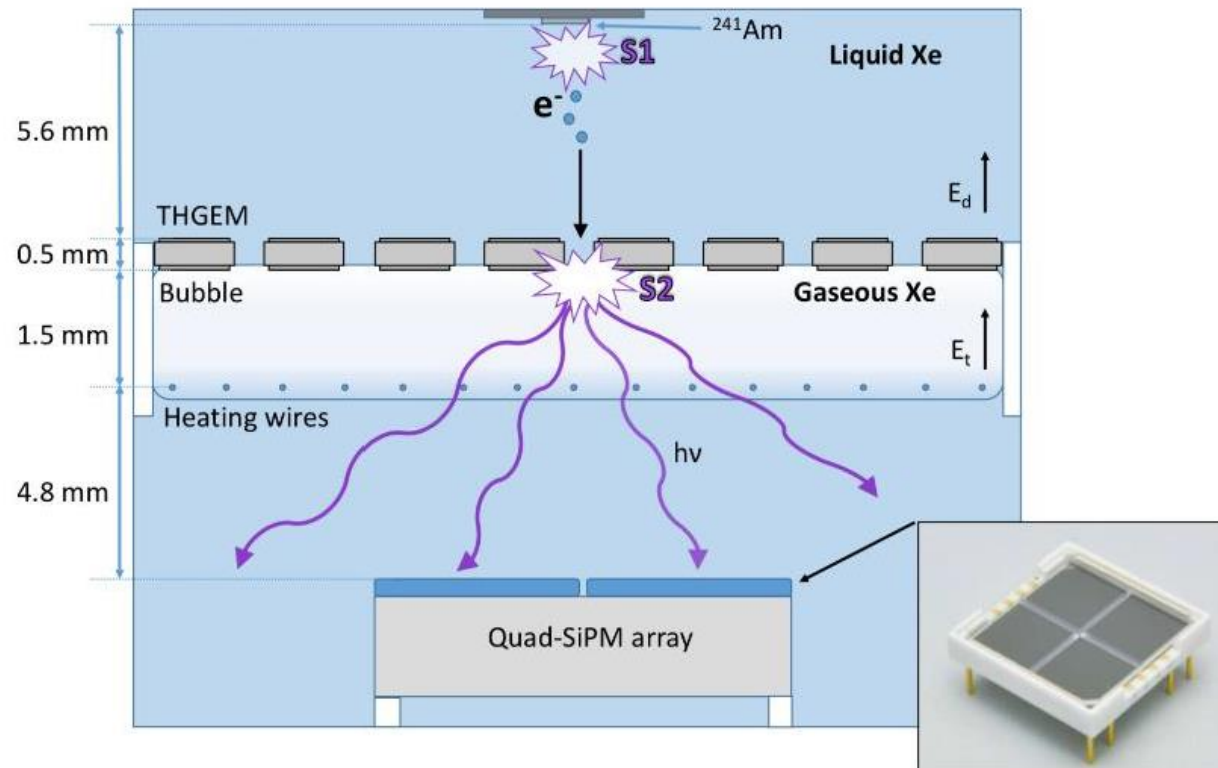


S1 ~1,700 photoelectrons/event

For reference: XENON100 had $\sigma/E \approx 11\%$ for the same number of S2 electrons

BUT: Better resolution expected for these numbers of e's & hv's → possible losses!

Imaging LHM with SiPMs – first results



Hamamatsu VUV4 quad-SiPM array
(4 6x6mm² elements); quartz window

Image reconstruction by center of gravity:
$$\vec{R} = \frac{A \cdot \sum L_i \cdot \vec{r}_i}{\sum L_i}$$

Image of α -particles of ring-shaped ^{241}Am source

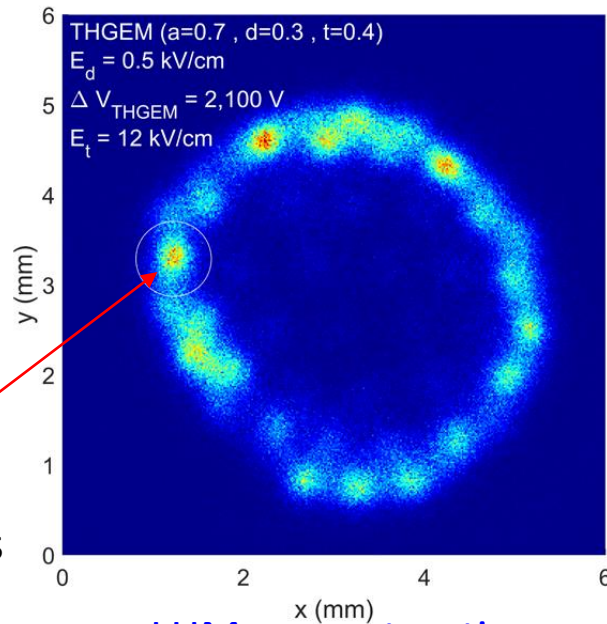
5.5MeV alphas \rightarrow ~ 7000 electrons/event

THGEM:

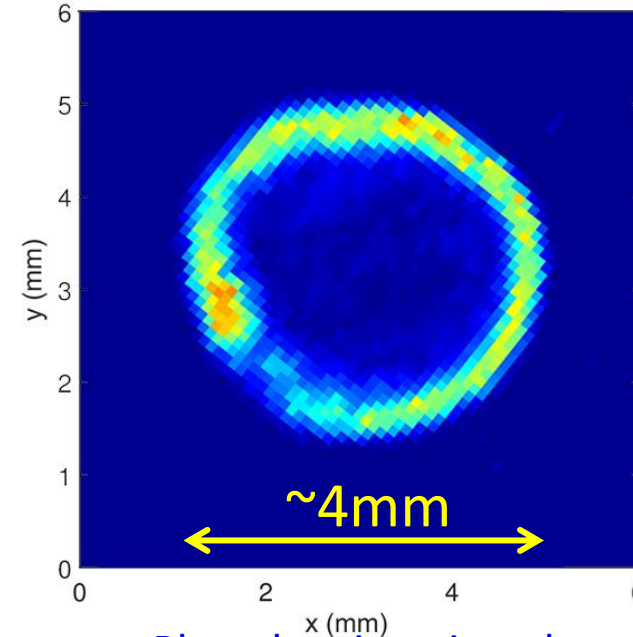
$\Phi 0.3$ holes, 0.7 spaced

α range in LXe: $\sim 40\mu\text{m}$

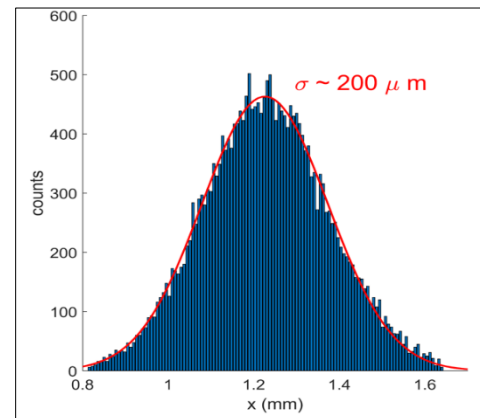
THGEM holes



LHM reconstruction

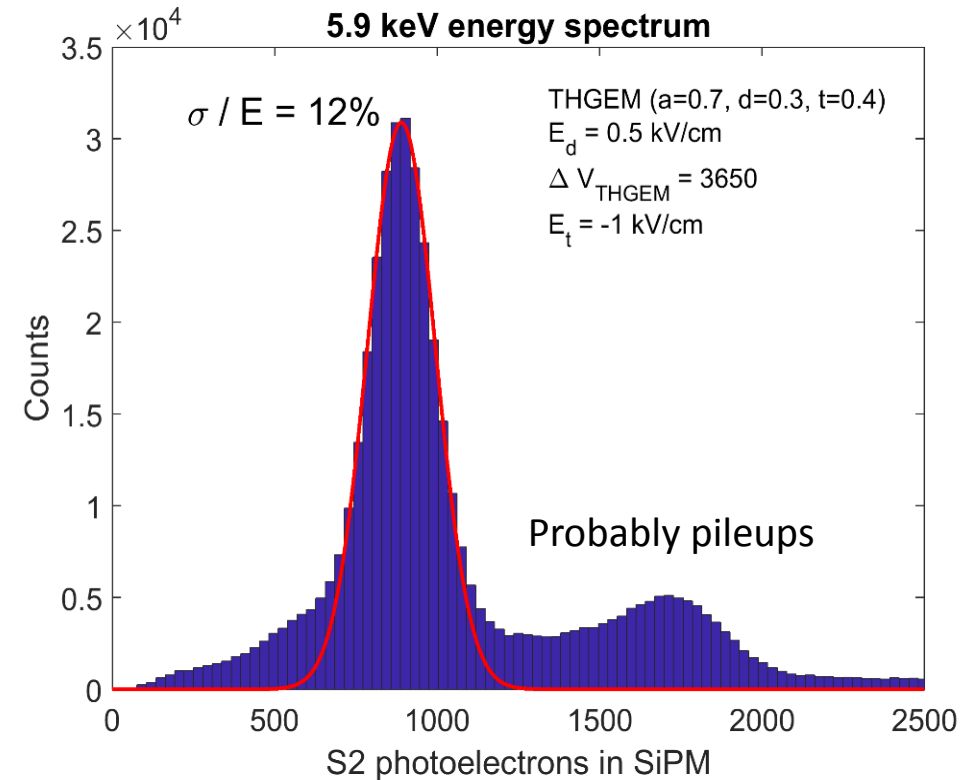
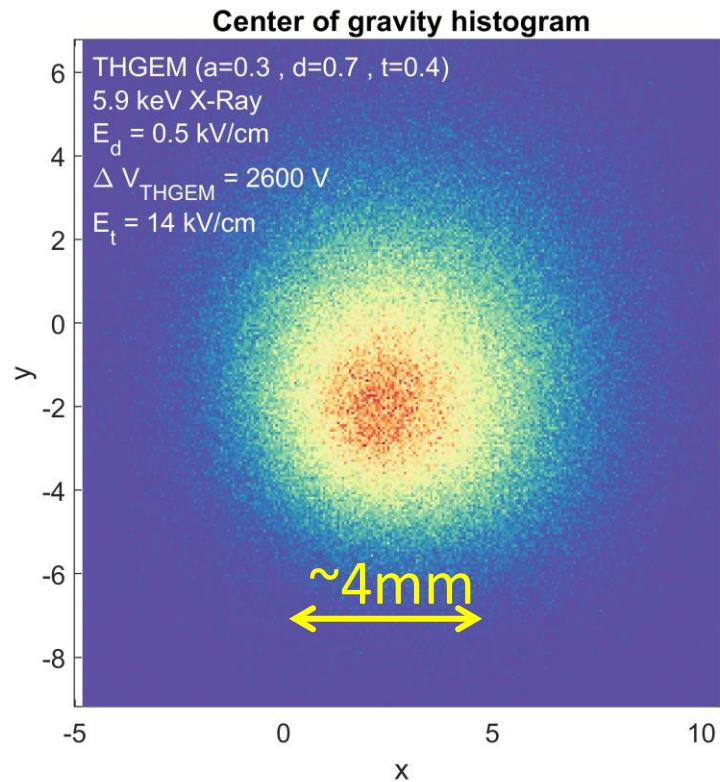


Phosphor-imaging plate



LHM Reconstruction resolution
of THGEM holes: $\sim 200\mu\text{m}$

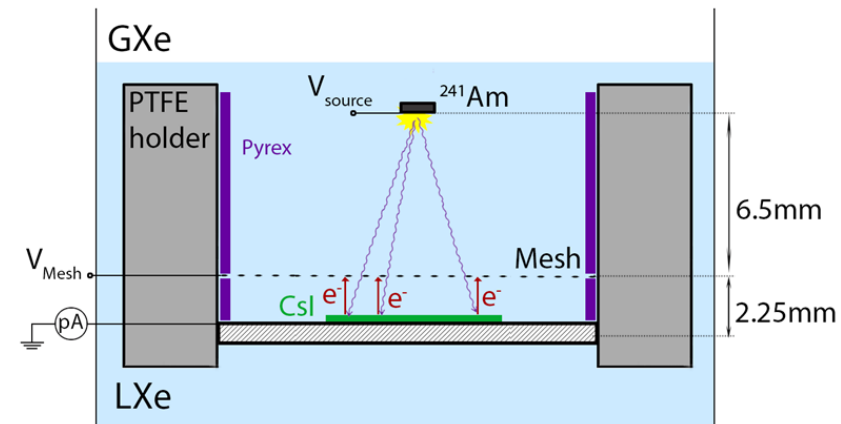
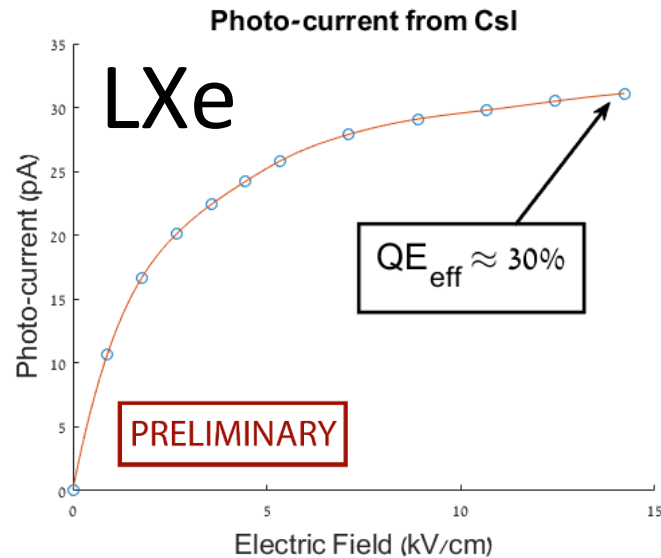
Image and S2 spectrum of a 4mm diameter ^{55}Fe source



5.9 keV x-rays \rightarrow ~200 electrons per event

Photoelectron range in LXe: $\sim 1.5 \mu\text{m}$

Effective CsI Quantum Efficiency in LXe & photon detection efficiency PDE estimates

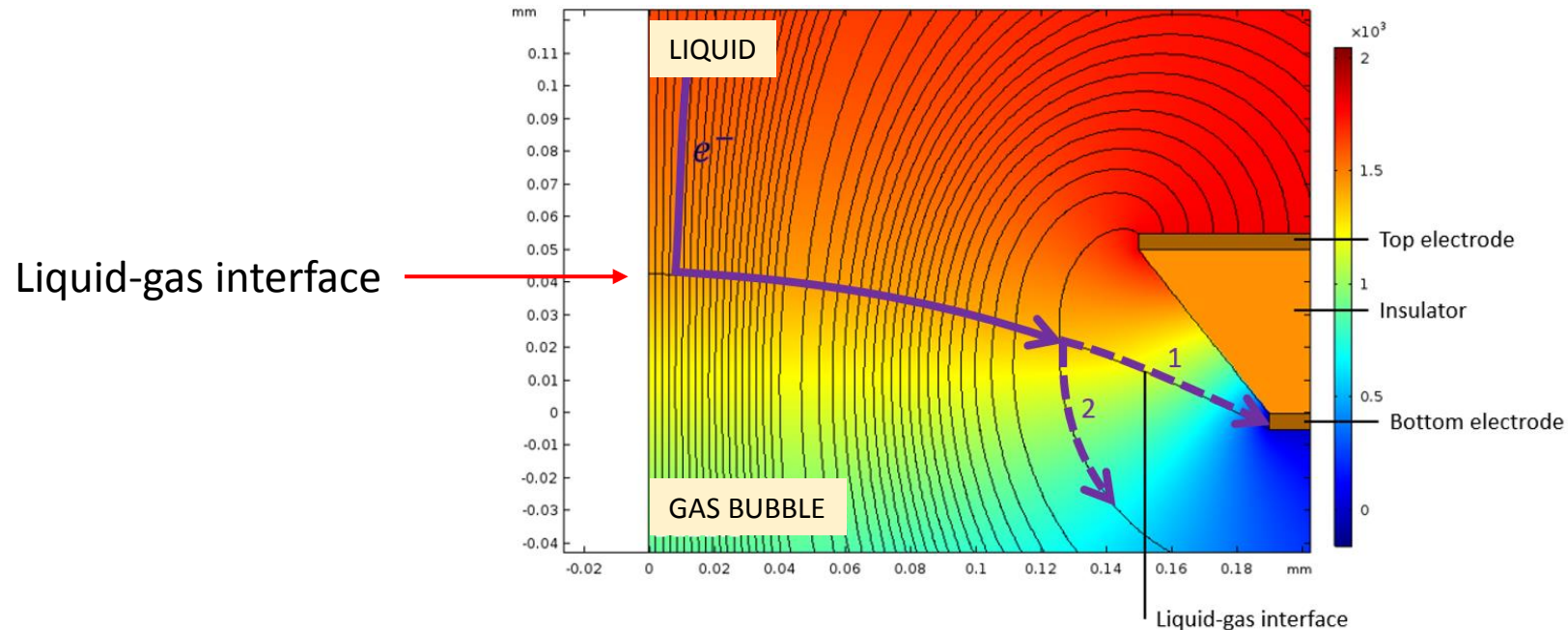


$QE \sim 30\%$ also obtained by Aprile, NIM A338 (1994) 328

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

But so far in LHM: measured PDE ~5%

What limits the PDE?

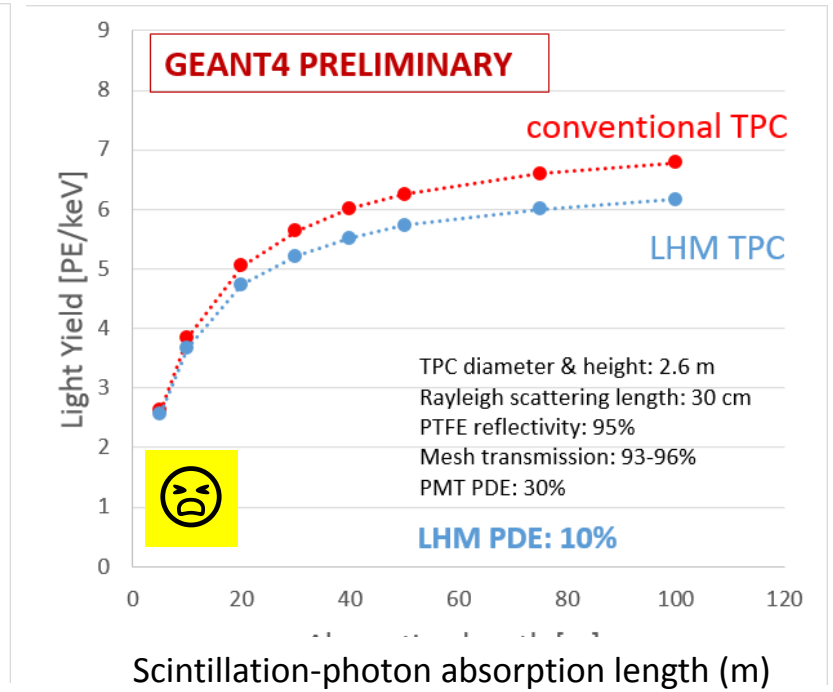
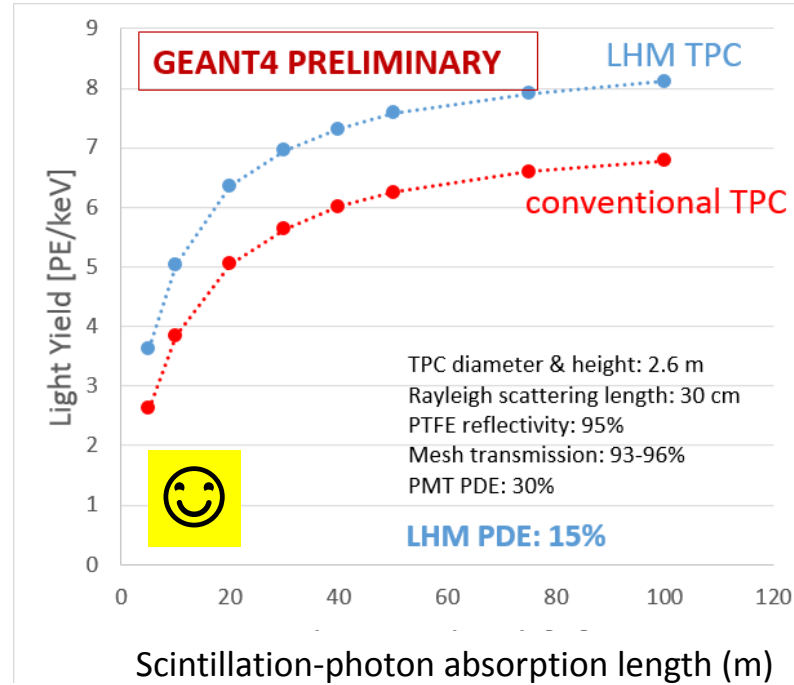
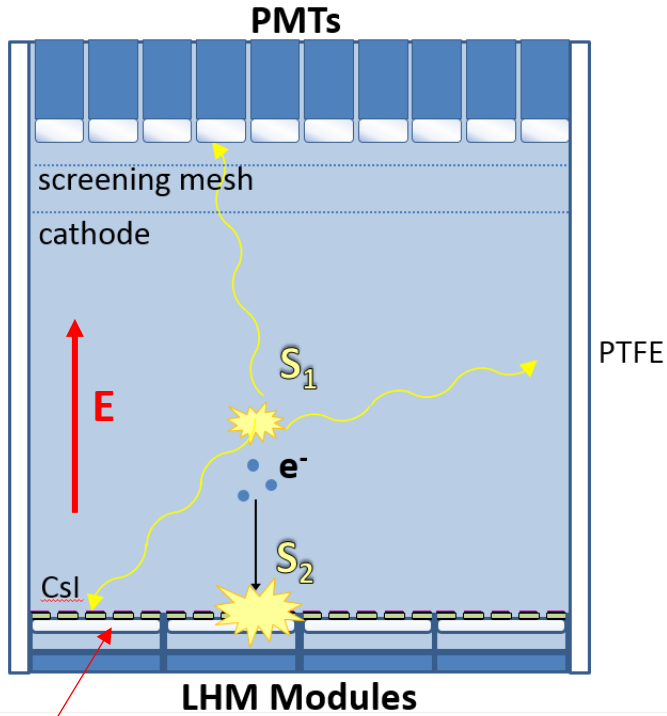


Simulation of electric field lines in the hole with a protruding spherical bubble.
(1) proposed e- trajectory from the liquid, gliding on the liquid-gas interface and reaching the GEM bottom face.
(2) proposed e- trajectory from the liquid, gliding on the interface and tunneling into the vapor phase.

- Electrons must penetrate a potential barrier (0.69 eV)* to cross from liquid-to-bubble.
- **Hypothesis:** bubble curvature + tangential field component → electrons glide towards bottom electrode before tunneling.
- The situation (e.g. curvature) varies with hole-electron geometry.
- There might be an issue related to surface “wetting”.
- Ongoing R&D.

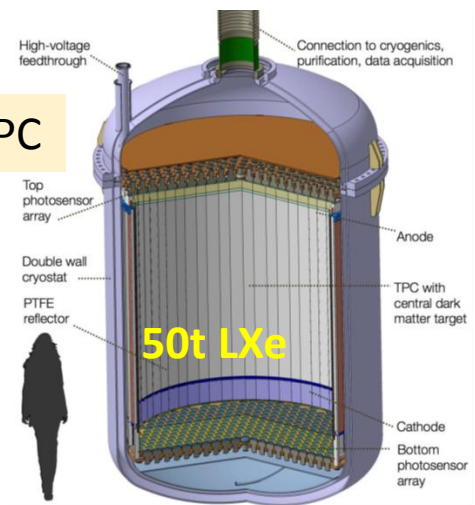
*V. Chepel

LHM-based LXe TPC for DM searches?



Higher S1 light-yield → lower WIMP detection threshold

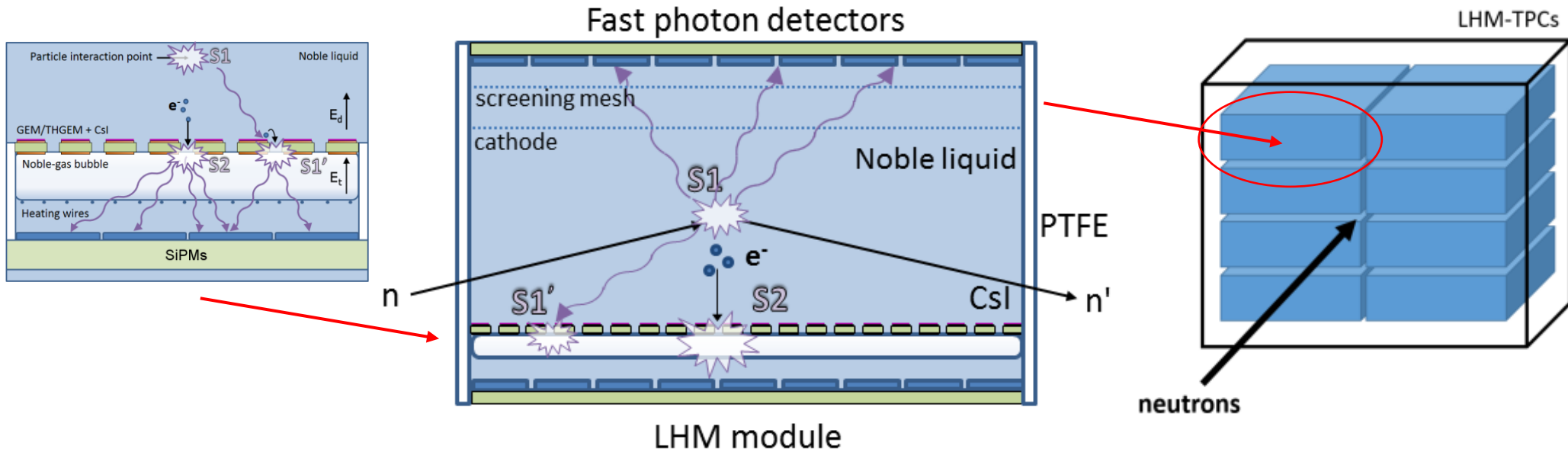
“Local Dual-Phase” TPC



R&D within DARWIN

LAr LHM-TPC for Nucl. Phys. Experiments

example: fast-n detectors for future experiments with Rare Isotope beams
(NSCL and FRIB, with [M. Cortesi et al.](#))



conceptual scheme of an LHM-TPC fast-n detector MODULE.

Large solid-angle “wall” of LHM-TPC neutron-detector MODULES, in single cryostat.

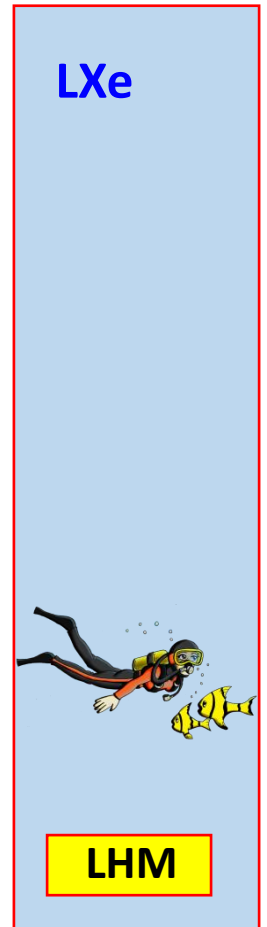
n-efficiency ~ 1 ; ns timing; sub-mm resolution; n- γ discrimination

Summary & Outlook

- LHM: Combined charge and light detection with CsI-coated hole-electrode;
- BEST: Single-Conical GEM (125mm thick)
 - highest photon yields: $\sim 400 - 2000$ photons/e-/ 4π
 - Energy resolution: $\sigma/E \sim 6\%$ for $\sim 7,000$ ionization electrons & ~ 1700 PEs;
 - Good localization : LHM/Quad-SiPM - reconstruction resolution $\sim 0.2\text{mm}$;
 - Current **PDE** $\sim 5\%$ (expected 20%) – probably inefficient e-transfer to bubble.

NEXT:

- Improve PDE: new electrode structures & configurations;
- Model/**understand e-transfer** through liquid-vapor interface;
- Validate 100 – 200 mm diameter LHM/SiPM modules;
- Operate in “**deep sea**” → 2.7m deep DARWIN LXe Demonstrator (Uni. Zr)
- LHM in **LAr** → neutrino physics, Heavy-ion experiments, neutron detectors...



Closing remarks to the younger generation

- Do not take things for granted.
- Detector Physics is flourishing: ever growing demands in many fields.
- The community seeks new ideas.
- Room for **crazy** ones!
- Be courageous: push your own ideas!
- Never get discouraged by criticisms!

GRAND MERCI

to **Paul**, Committee members, Secretaries, Assistants, Caterers...
& presenters!



A la prochaine!