Liquid Hole-Multipliers:
A novel concept for large-volume noble-liquid radiation detectors

Dark-Matter Searches & other rare-event objects

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** With: L. Arazi, H. Landsman, L. Levinson, A. Coimbra et al.*

A. B. ***JPCS*** *460 (2013) 012020*; http://arxiv.org/abs/1303.4365
L. Arazi et al. *2013* ***JINST*** *8 C12004*; http://arxiv.org/abs/1310.4074

Detector up-scaling – PMT Cost and size

- To keep experiments affordable → larger PMTs

  XENON1t: ~250 x 3” dia PMTs (upgrade ~400)

  DARWIN 20t: ~900 x 3” dia PMTs? Or ~500 x 4” dia?

  Post-DARWIN ???

  → sacrifice spatial resolution?

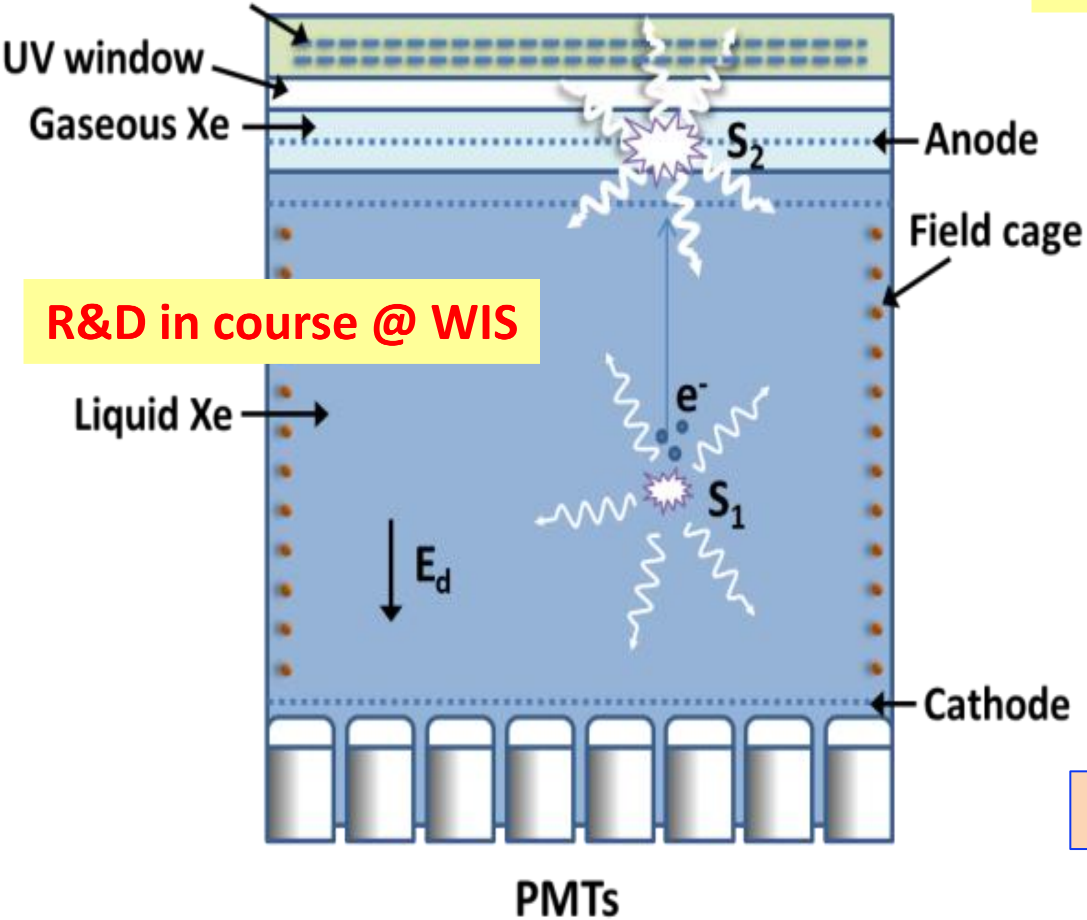
  → sacrifice performance?

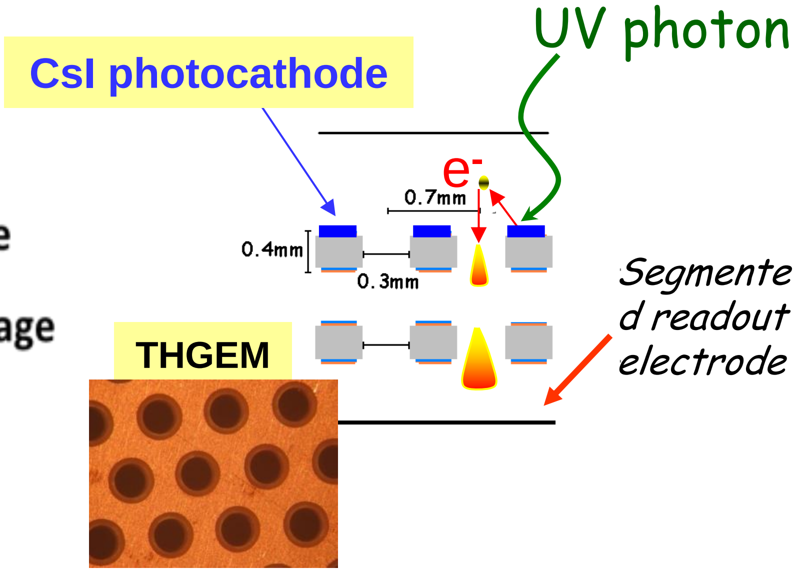
★ Other solutions?

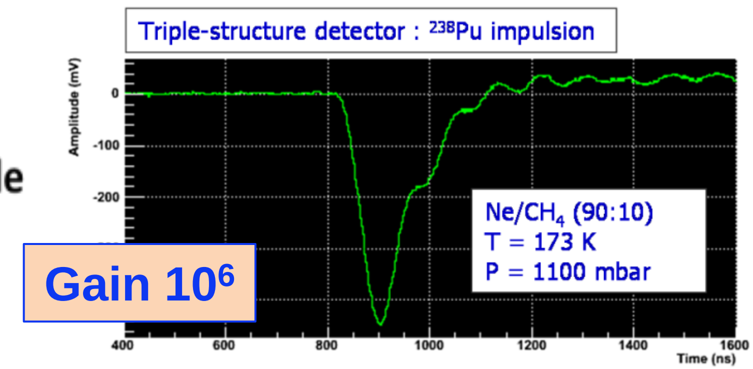
  → Vacuum? Gas? Liquid?

Dual-phase TPC with GPM* S2 sensor

*GPM: Gaseous Photomultiplier





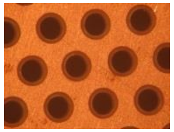


Duval 2011 JINST 6 P04007 ***WIS/SUBATECH***

A proposed concept of a dual-phase DM detector. A large-area Gaseous Photo-Multiplier (**GPM**) (operated with a counting gas) is located in the saturated gas-phase of the TPC; it records, through a UV-window, and localizes the copious electroluminescence S2 photons induced by the drifting ionization electrons extracted from liquid. In this concept, the feeble primary scintillation S1 signals are preferably measured with vacuum-PMTs immersed in LXe.

Why GPMs?

- Large-area coverage at ***significantly reduced cost***



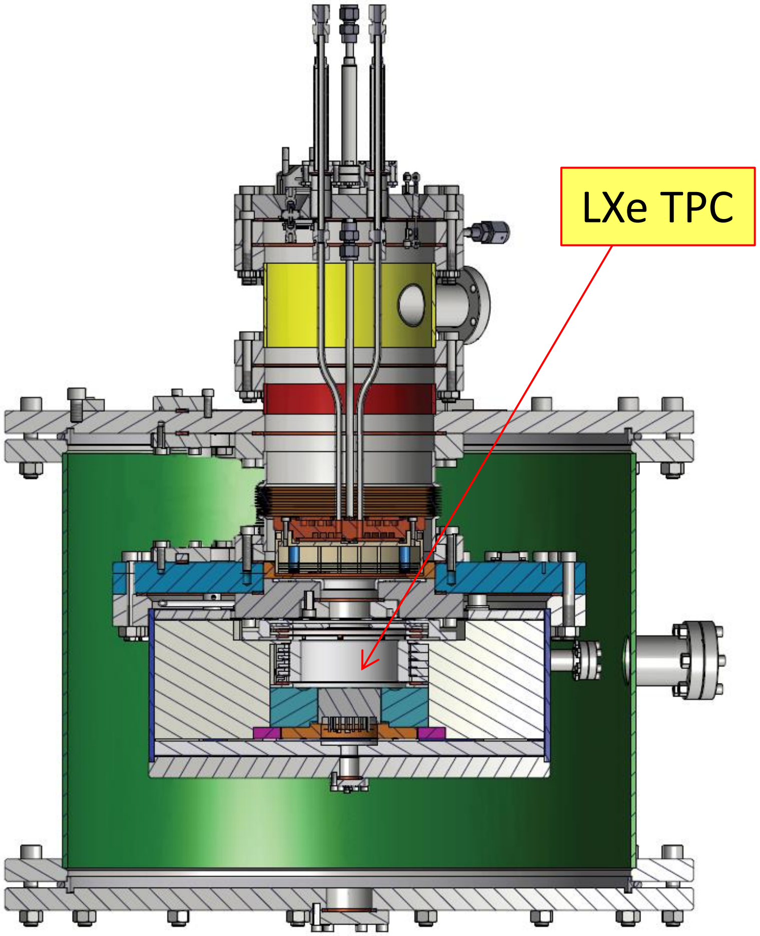
Few K$/sq.m + pixilated hybrid electronics + window/mechanics

- ***Good aspect ratio*** → **similar effective QE** to present PMTs
- ***High pixilation*** → more accurate position reconstruction?

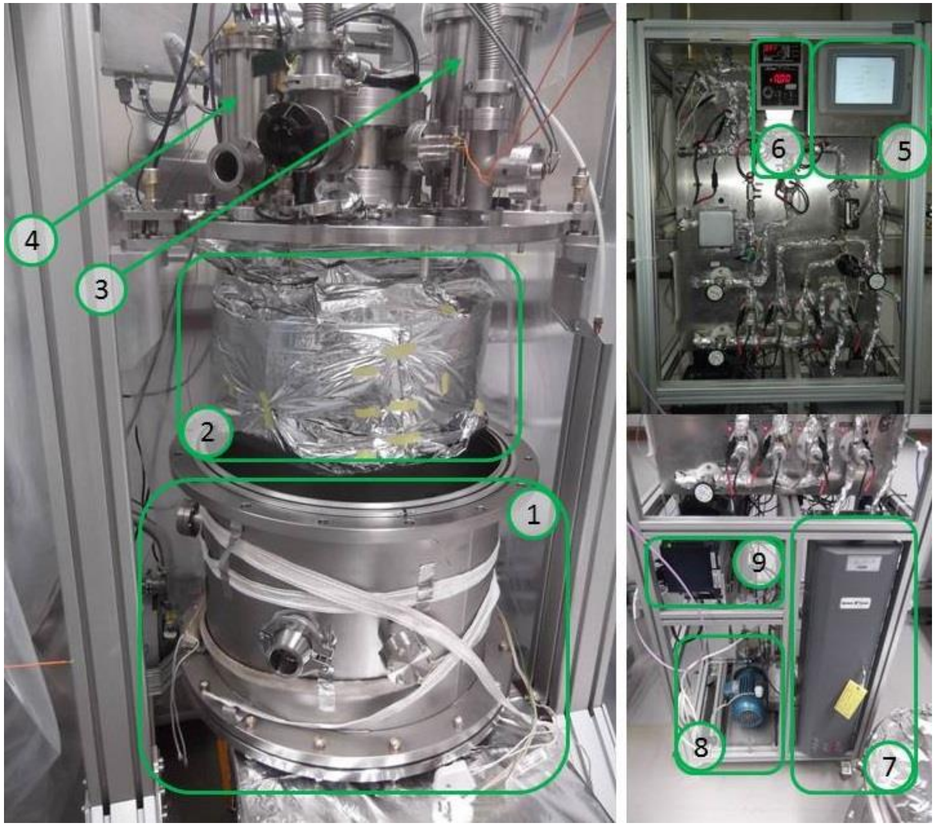
→ improvement in calibration?

→ S2 pattern: better discrimination?

WIS Liquid Xenon (WILiX) R&D facility*

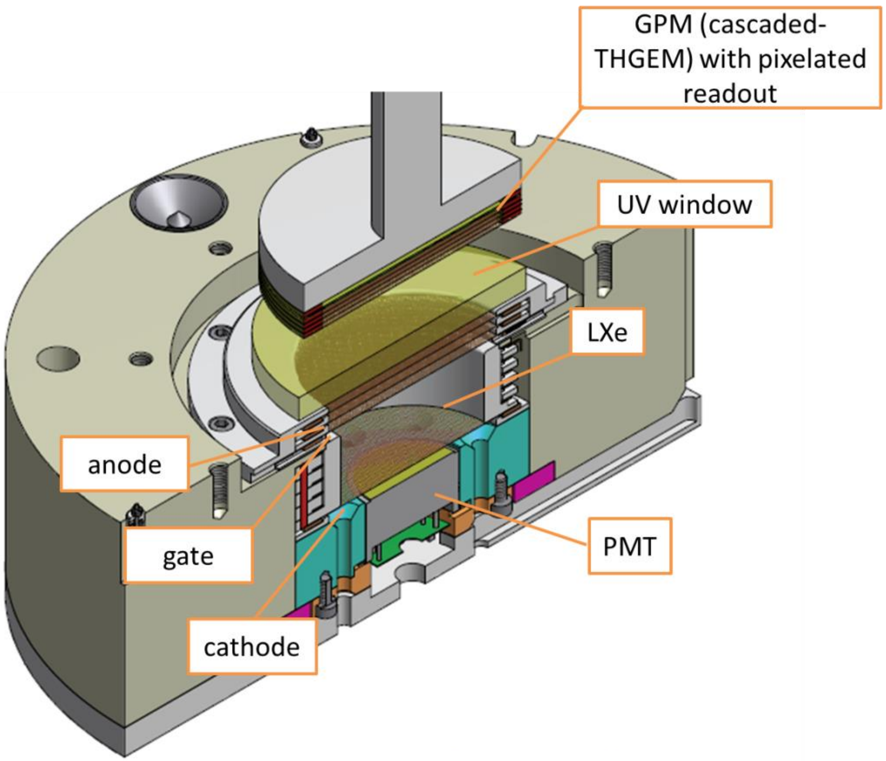


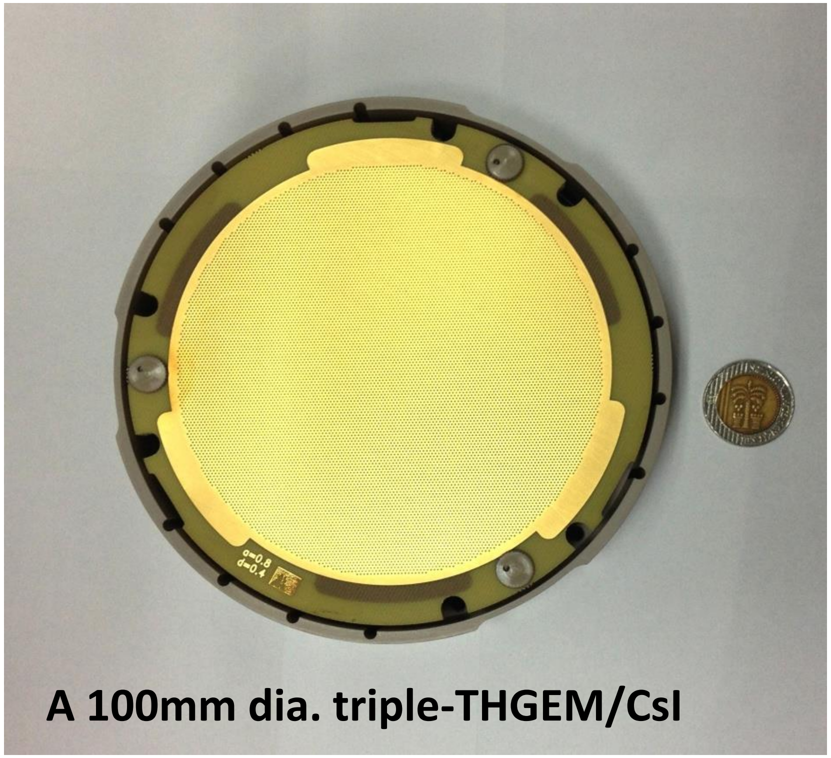
WILiX schematic view



1) Vacuum Chamber, 2) Xenon-TPC Chamber wrapped with super-insulator 3) Heat Exchanger, 4) Xe liquefier, 5-9) Gas-system manifold, control & purification system.

4" GPM proto

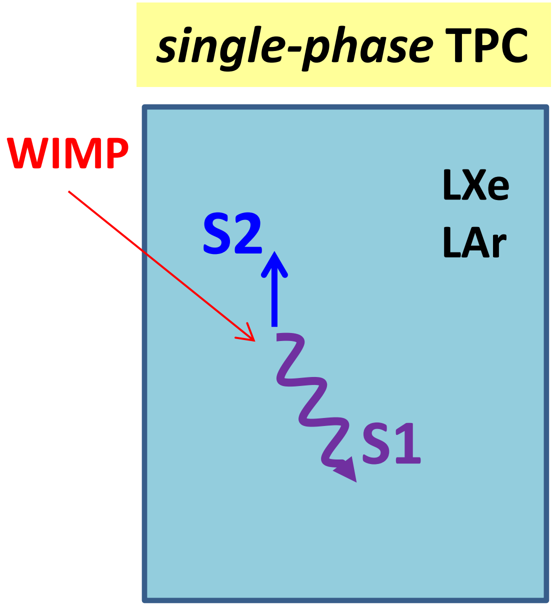




For cryo-GPM see: Duval 2011 JINST 6 P04007

Comparative studies with PMTs

Towards single-phase TPCs?



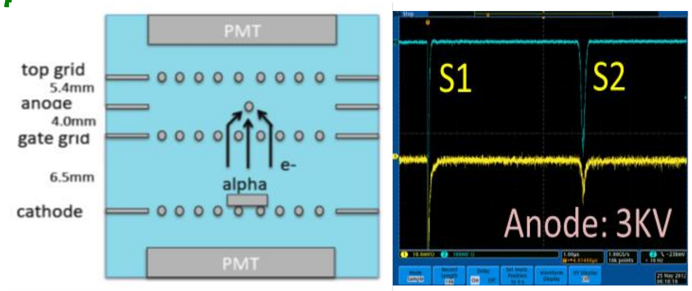
- Technically simpler?
- Sufficient signals?
- Lower thresholds?
- Cheaper?
- Resolutions?
- How to record best scintillation & ionization S1, S2?

Single-phase detector ideas

- **S1 & S2 with UV-PMTs**: S2 from multiplication on wires in liquid.

  *Early works, 70's, on wire multiplication: **T. Doke** Rev. NIM196(1982)87;*

  *recent R&D **E. Aprile, P. Chaguine et al** @ Columbia, private communication* ***to record S2 in LXe***



- **S1 & S2 with Spherical TPC :** S1 p.e. from CsI and S2 electrons multiplied in GEMs in the liquid

  idea only: ***P. Majewski**, LNGS 2006*

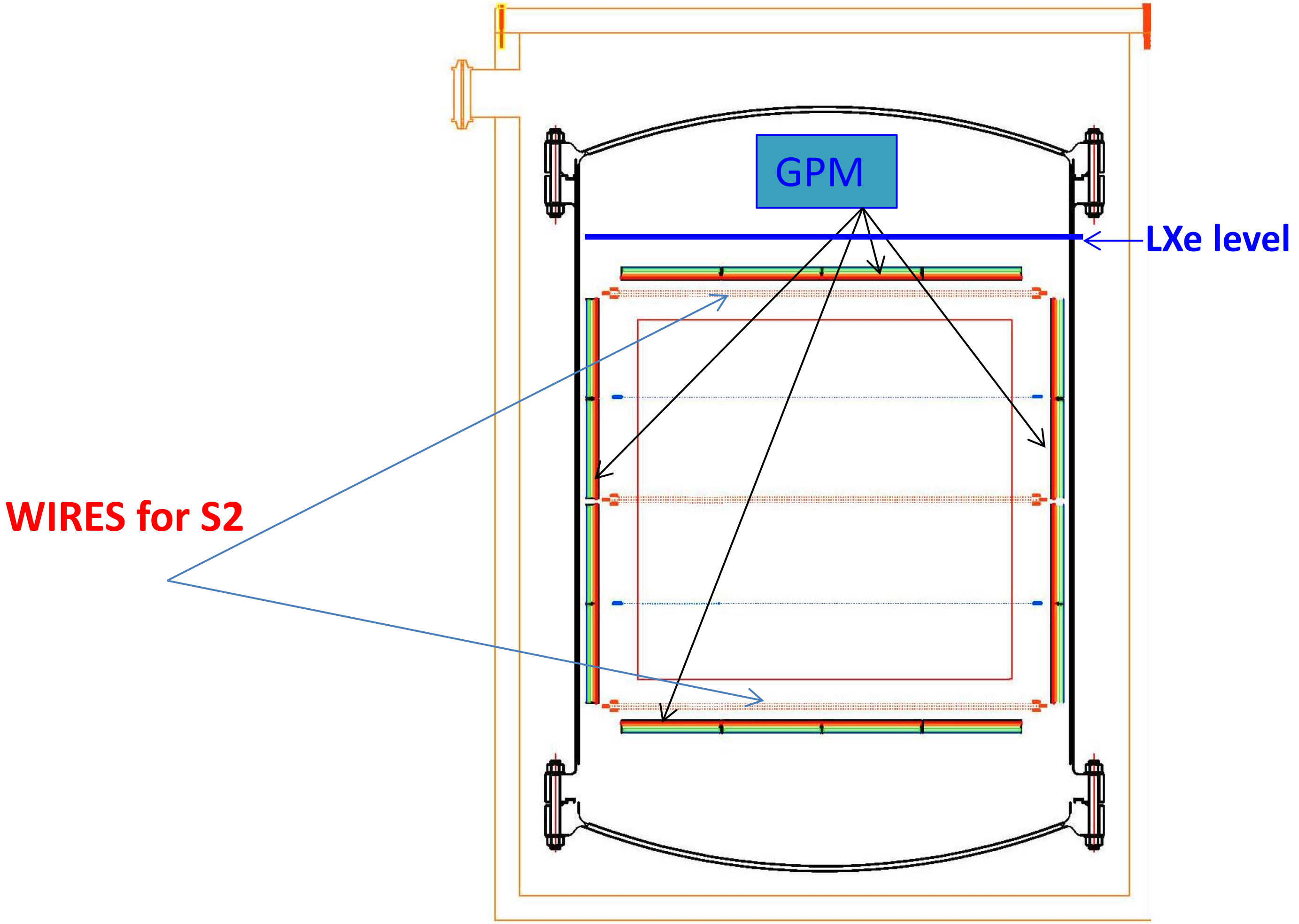
- **S1 & S2 with GPMs:** S2 from multiplication on wires in liquid.

  idea only: ***K. Giboni**, KEK Seminar Nov 2011 & at Zaragoza MPGD2013*

Single-phase option for PANDA

Karl Giboni
KEK Seminar Nov 2011

4π geometry with immersed GPMs

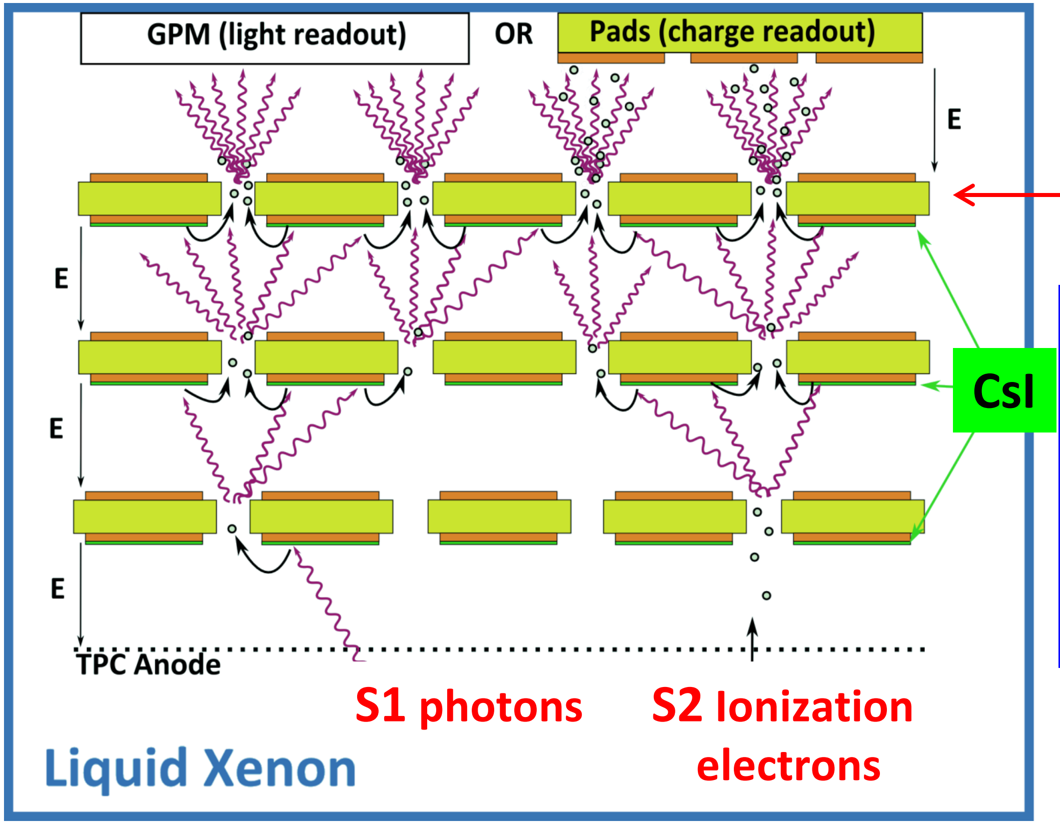


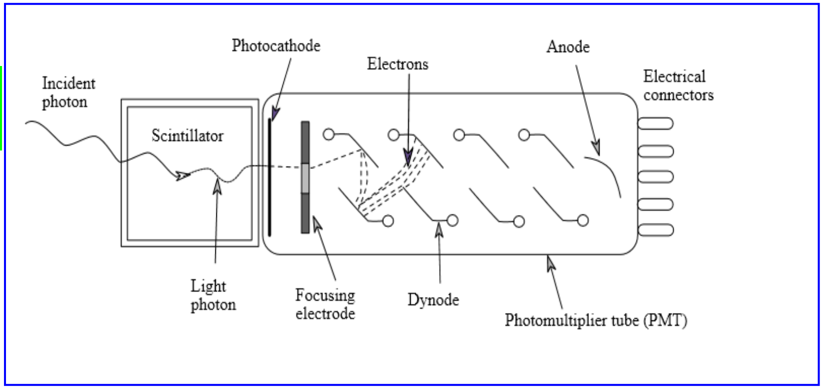
S1 & S2 with a single Liquid Hole-Multiplier LHM

Light amplification in cascaded hole-multipliers immersed in noble LIQUID

A.B. "Noble Dreams", Paris TPC2012 Workshop; arXiv:1303.4365

JPCS 460 (2013) 012020





Similar to electron multiplication on PMT dynodes…

Holes:

- **Small- or no charge-gain**
- **Electroluminescence (optical gain)**

ONE DETECTOR RECORDS BOTH S2 and S1!

LHM: the process

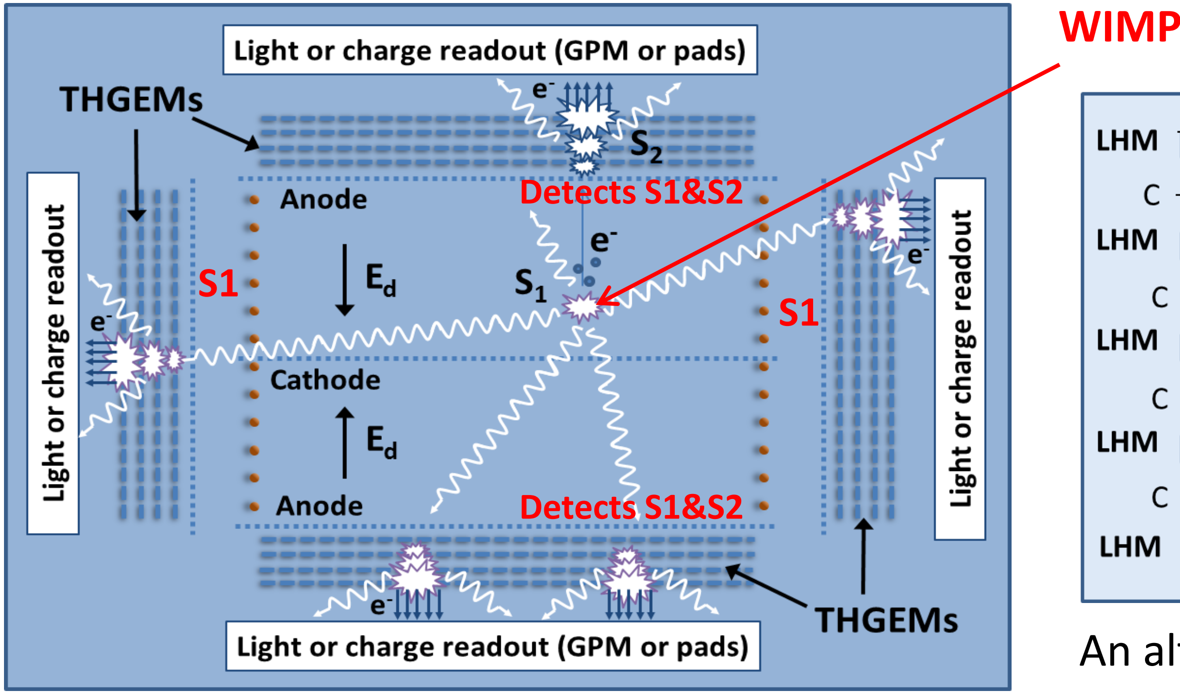
A.B. *Paris TPC2012 Workshop; arXiv:1303.4365*

Modest **charge multiplication + Light-amplification** in sensors **immersed in the noble liquid**, applied to the detection of both scintillation UV-photons **(S1)** and ionization electrons **(S2).**

- **S1** UV-photons impinge on CsI-coated THGEM electrode;
- extracted photoelectrons from CsI are trapped into the holes, where high fields induce electroluminescence (+possibly small charge gain);
- resulting photons are further amplified by a **cascade of CsI-coated THGEMs**.
- Similarly, drifting **S2** ionization electrons are focused into the hole and follow the same amplification path.
- **Prompt S1 and delayed S2** signals are recorded optically by an **immersed GPM** (or PMT, GAPD…) or by **charge collected on pads**.

ONE DETECTOR RECORDS BOTH S2 and S1!

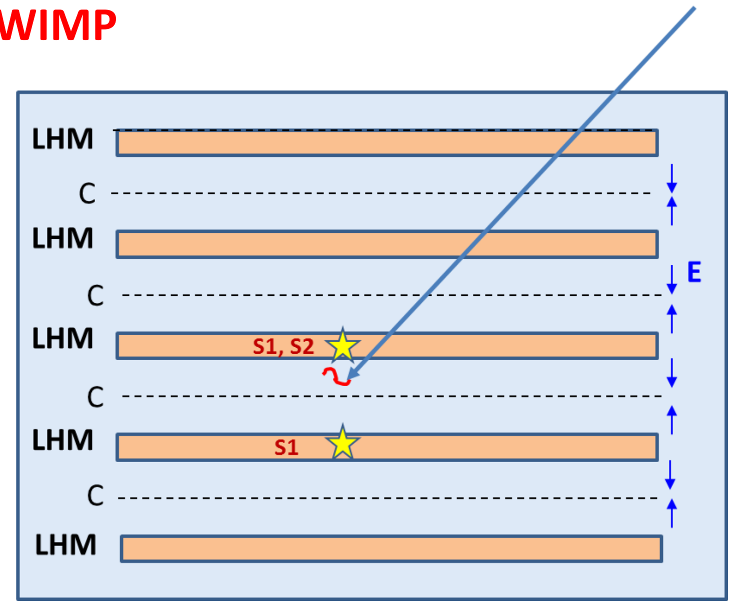
4-π LHM-TPC



A dual-sided single-phase TPC DM detector with top, bottom and side THGEM-LHMs.

The prompt S1 signals: detected with all LHMs.

The S2 signals: recorded with bottom or top LHMs.



An alternative: **a CASCADED-LHM TPC**

Highlights:

- **Higher S1 signals ➔ lower expected detection threshold**
- **Shorter drift lengths➔ lower HV applied & lower e- losses**

Prior Art

- **High QE (25% at 178nm) from CsI photocathodes in LXe**

  Aprile IEEE ICDL 2005, p345

- **Electroluminescence observed in LXe on few-micron diameter WIRES**

  Doke NIM 1982

- **Electroluminescence from THGEM holes in LAr**

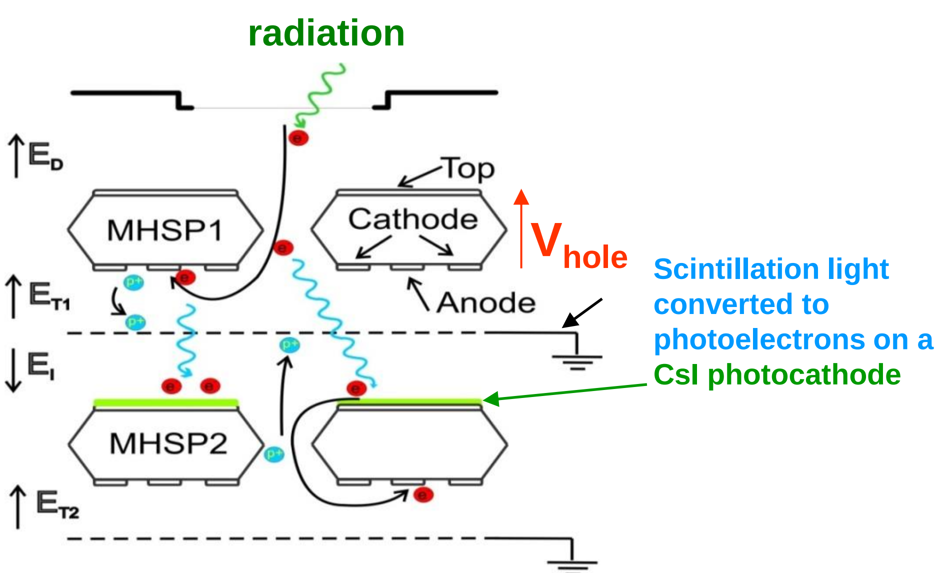
  ~ 500 UV photons/e$^-$ over 4π

  ~ 60kV/cm electroluminescence threshold

  Lightfoot, JINST 2009; similar: Buzulutskov JINST 2012

- **Photon-induced multiplication**

  Veloso, A.B. et al. 2006 JINST 1 P08003



Charge gain In MHSP 1

Photon-induced Charge gain In MHSP 2

RESOLUTION MAINTAINED

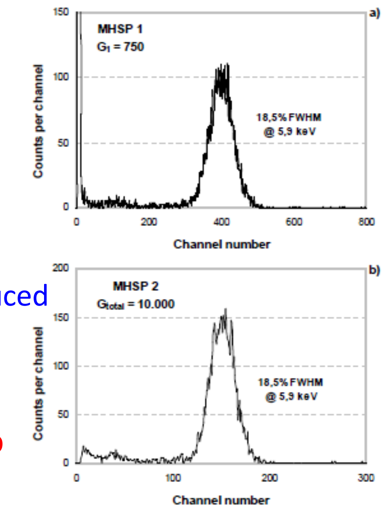
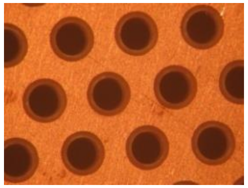
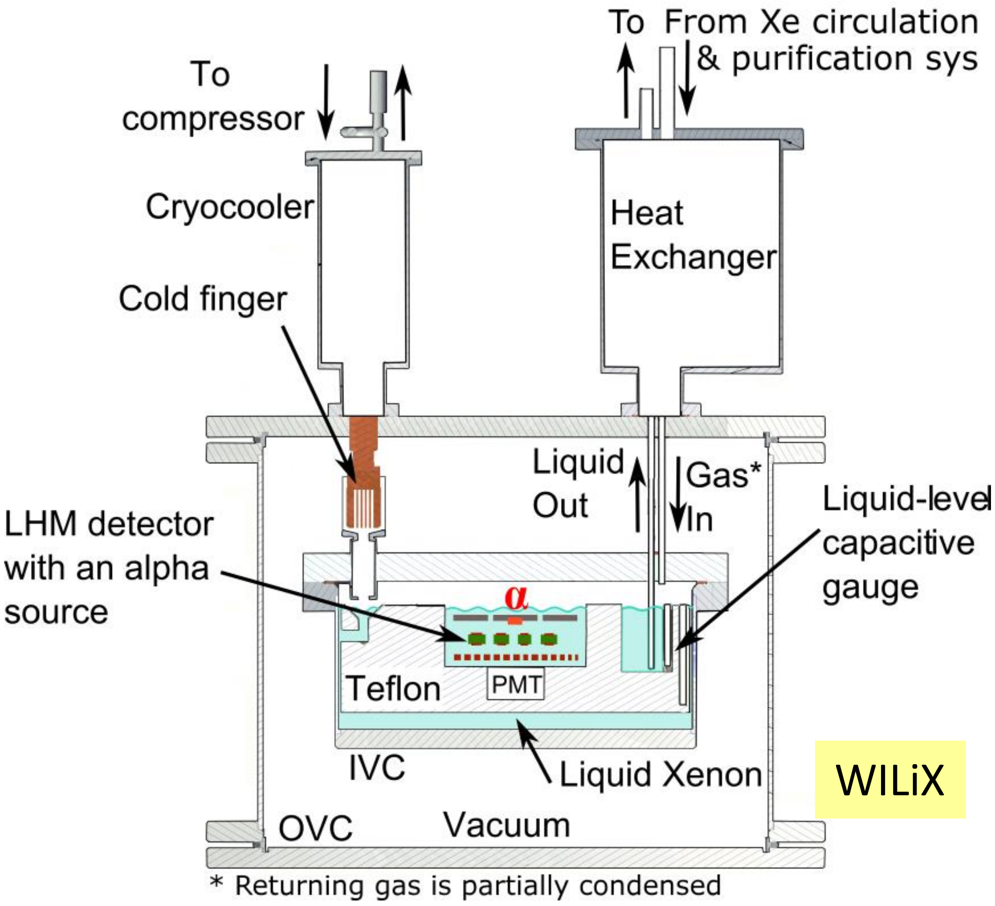


Figure 2. Pulse-height distributions resulting from 5.9 keV x-ray interactions in the drift region of the cascaded detector of figure 1, measured in 1 atm Xe on the anode strips of MHSP1 (*a*) and MHSP2 (*b*).

Photon gain in 1 bar Xe ~ 1000

Setup for testing the LHM

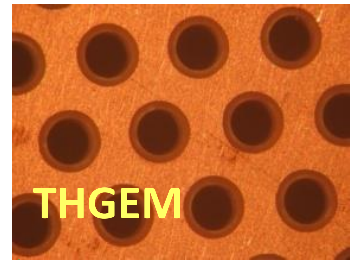


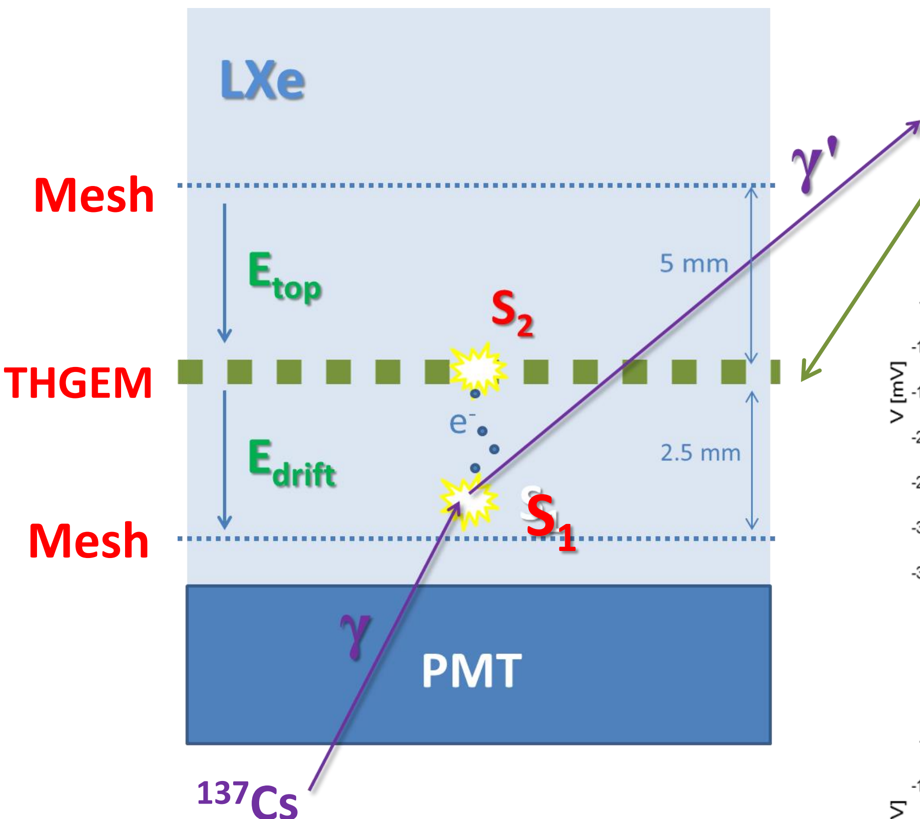


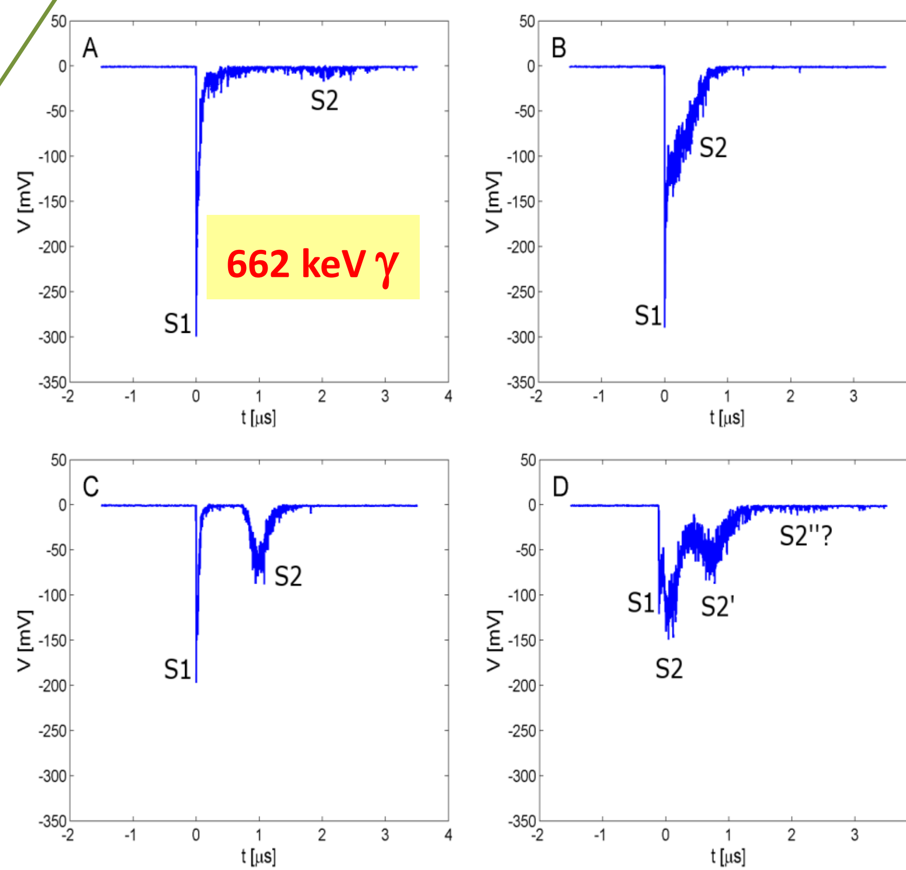
WILiX

Single-THGEM in LXe: Gammas

Thickness 0.4mm





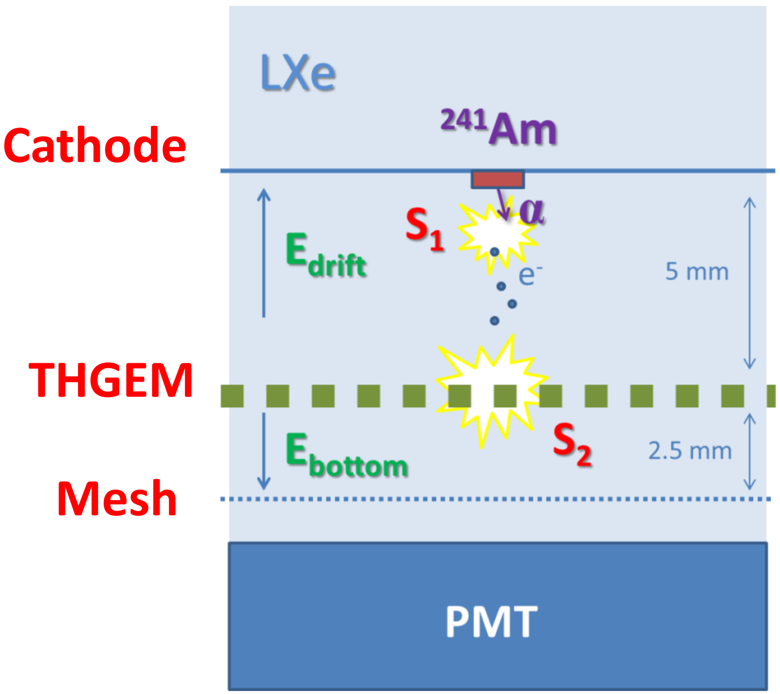


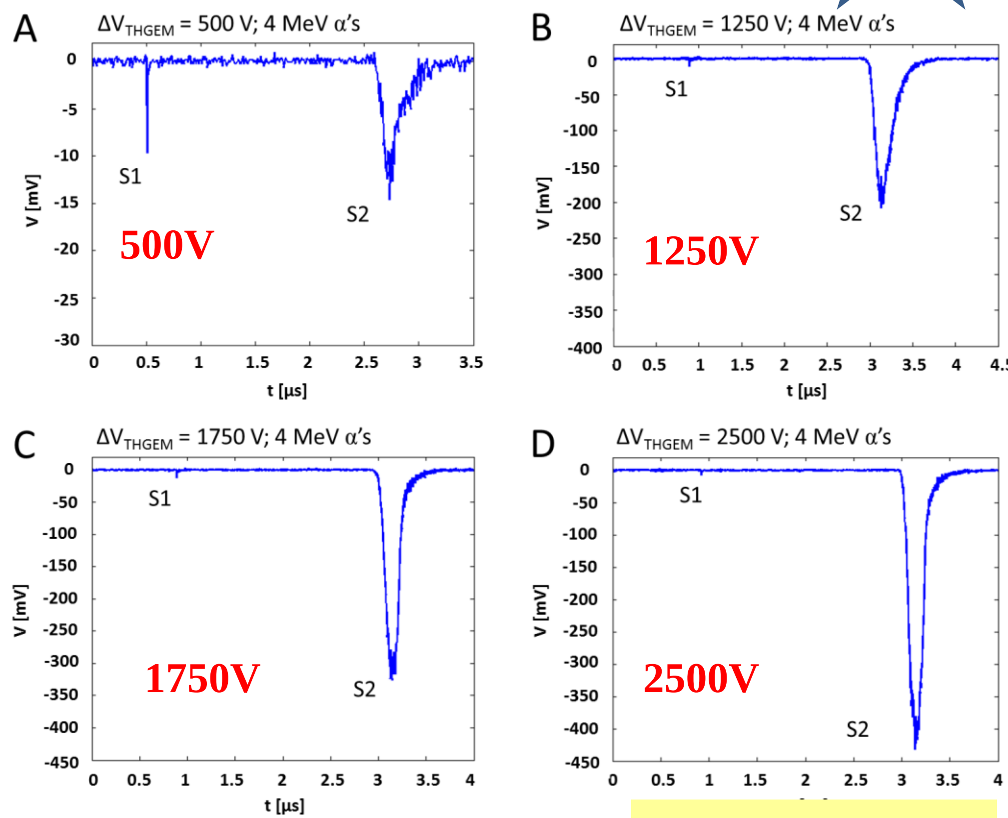
Detects S1 & S2
Hamamatsu R6041-06; 2" dia

L. Arazi et al. 2013 *JINST* 8 C12004

Single-THGEM in LXe: Alphas

~4MeV α





Hamamatsu R6041-06; 2" dia.

Detects ~1% of S1 (through holes) & S2

E_{THGEM}~60kV/cm

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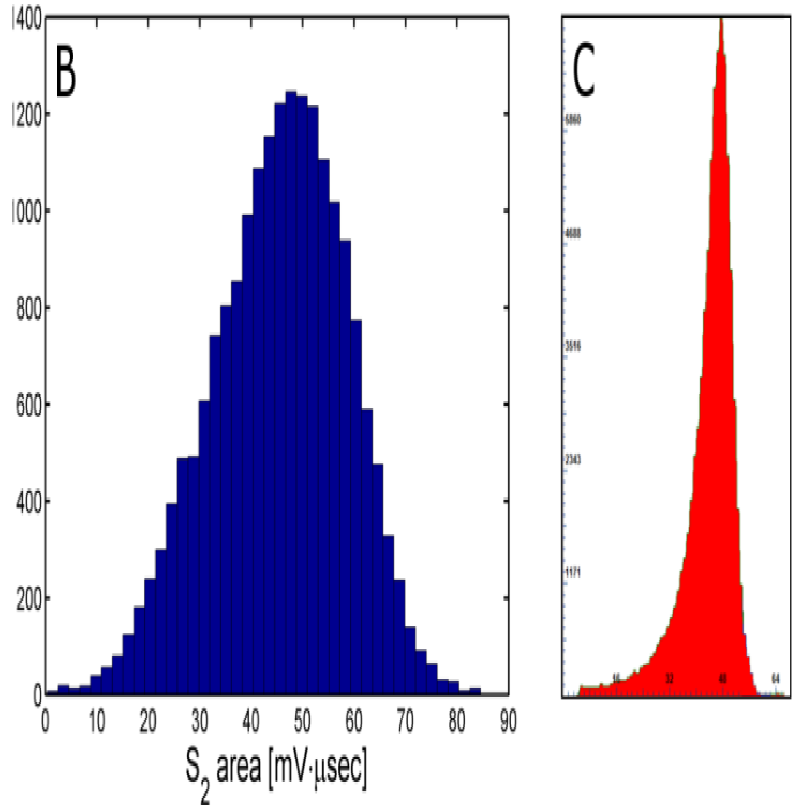
Alpha-induced S2 spectrum in THGEM/LXe

THGEM-emitted S2 (with the PMT)

Alpha source spectrum (SSD)

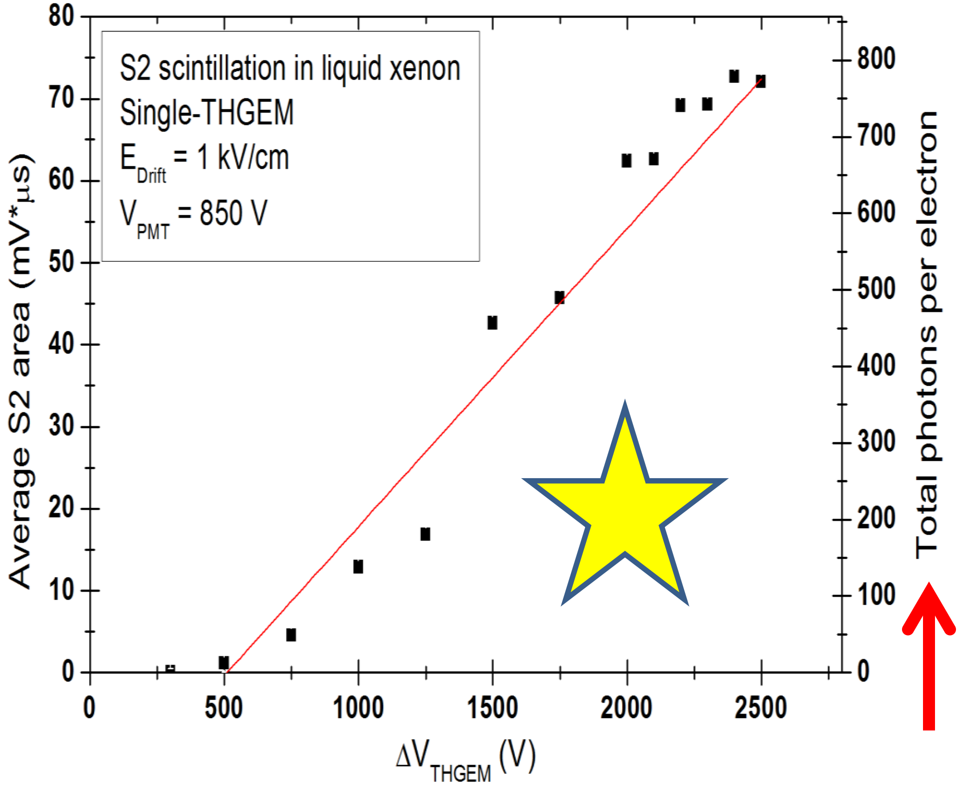


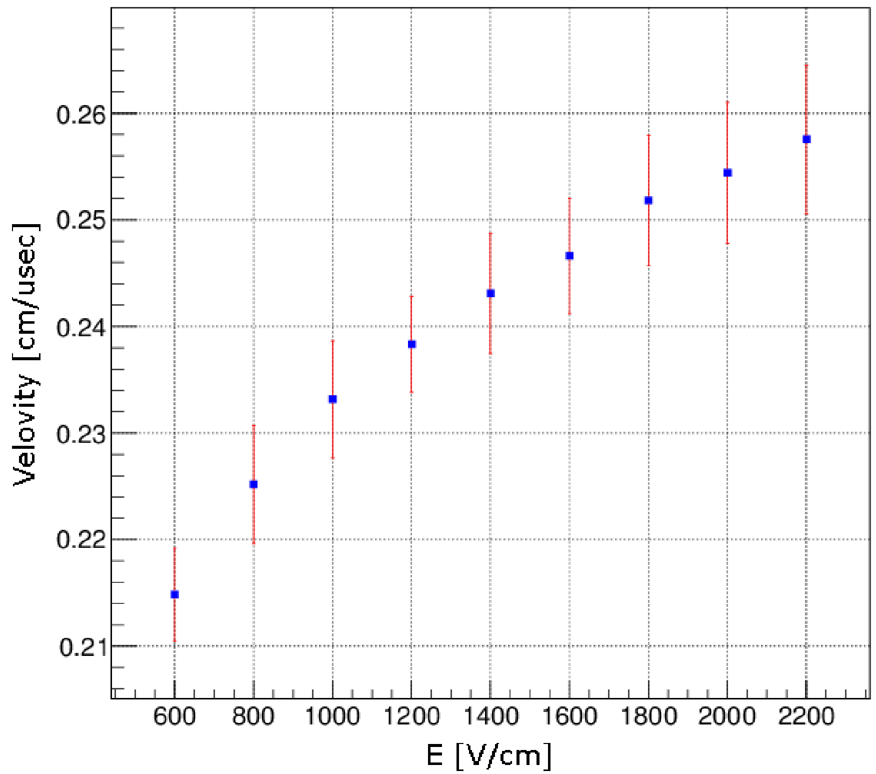
Broadening:

- Non-spectroscopic source
- e^- collection efficiency into holes
- Electron trapping (impurities)
- Geometrical issues…etc.

Photon yield in LXe:
~600 photons/e/4π in a THGEM hole, @ V_{THGEM}=2kV

Photon yield & e- drift velocity in LXe





Photon yield: ~800 photons/e/4π @ 2.5kV

e^- drift velocity: 2.2 mm/μs

L. Arazi et al. 2013 *JINST* 8 C12004

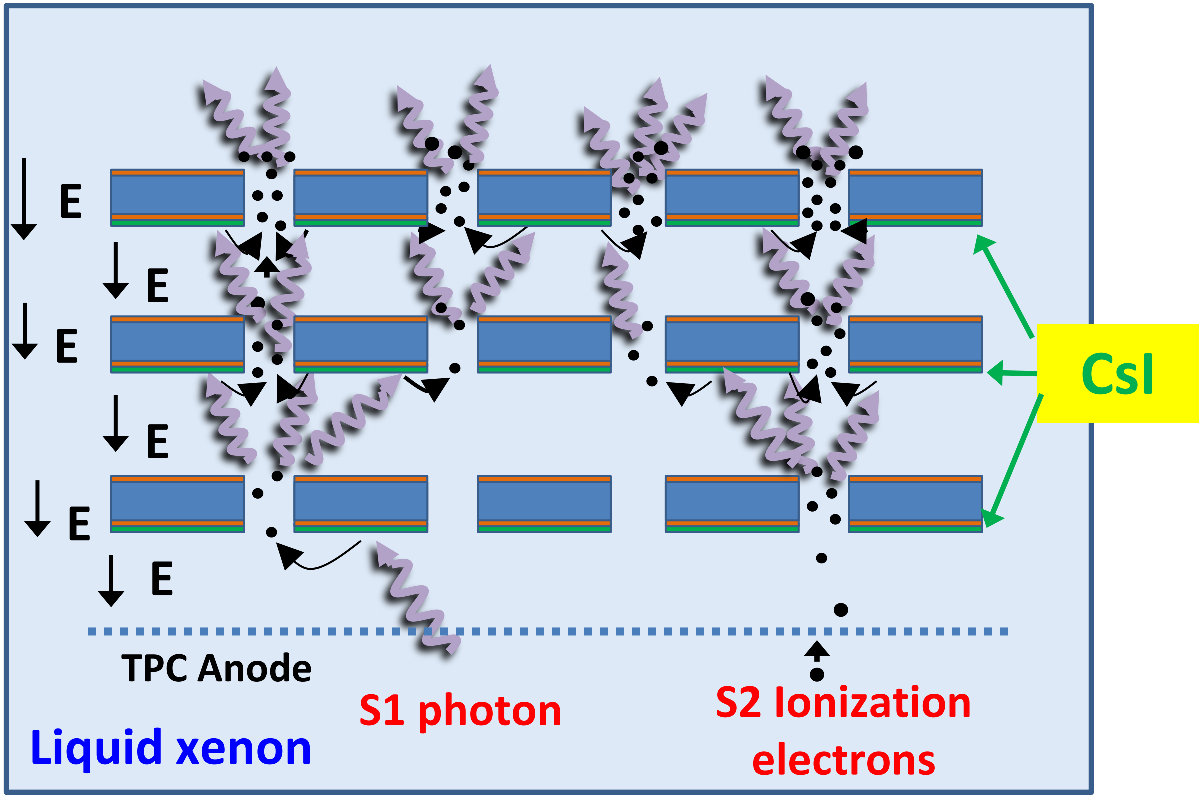
Summary

- A revived interest in LARGE **single-phase** Noble Liquid Detectors
- New concept: **S1** & **S2** recording with immersed **Liquid Hole Multipliers – LHM**
- **First S1 & S2 signals recorded with γ and α in THGEM in LXe**

  ~800 photons/electron/4π @ 2.5kV

- Going ahead with intense R&D

Factors affecting performance



E-values and ratios across the cascaded electrodes + hole geometry:

→p.e. collection efficiency into holes (at the different stages)
→photon gain & number of secondary electrons
→ Energy resolution
→p.e. collection time

To-do List

Present R&D: *(in WILiX + 2^{ed} smaller cryostat)*

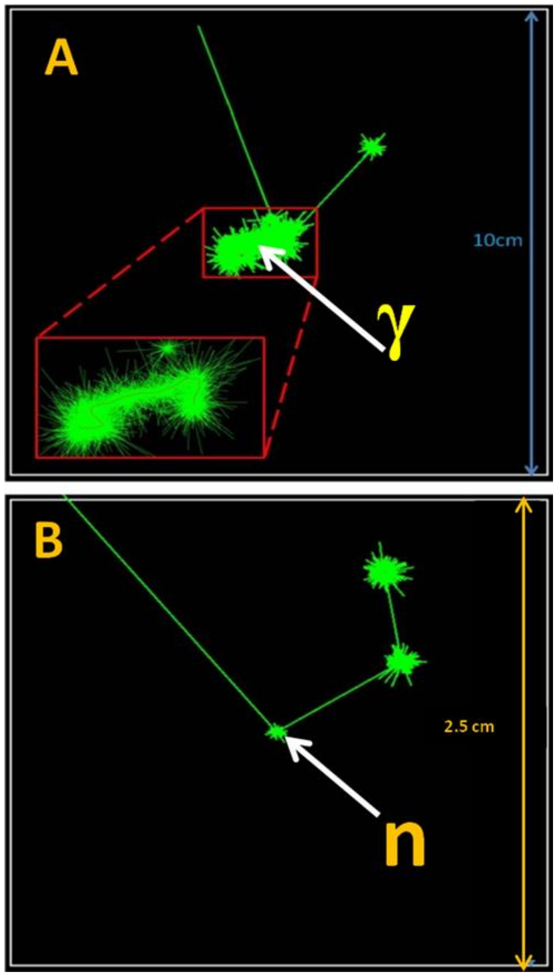
- Purity effects
- THGEM charge & light Gain in LXe vs. hole-geometry
- Substrate material/hole shape
- Electron collection efficiency into holes in liquid phase
- Photon & electron yields in CsI-coated cascaded THGEM
- **Resolutions: E, t**
- Pixilated pad readout (pad counting & p.e. **pattern**)

  → improved E-resolution?; pattern→ improved bkgd discrimination?
- S1/S2 Readout: pads vs. optical (GPM, others)
- Other hole multipliers: GEM, patterned GEM/THGEM….
- Radio-clean electrodes

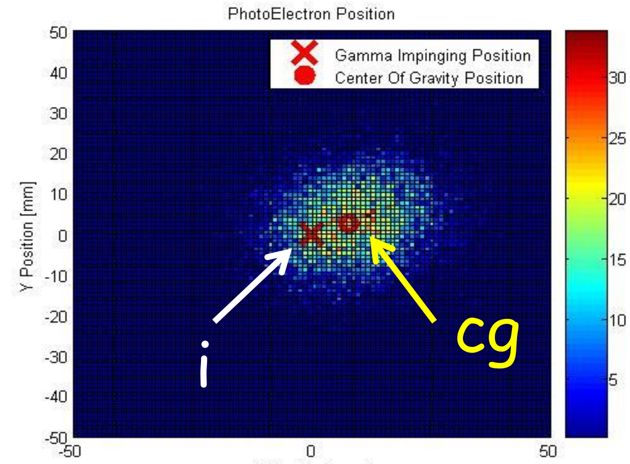
- **→ next DARWIN….**

Radiation patterns – single events

GEANT 4: LXe scintillation detected with a GPM

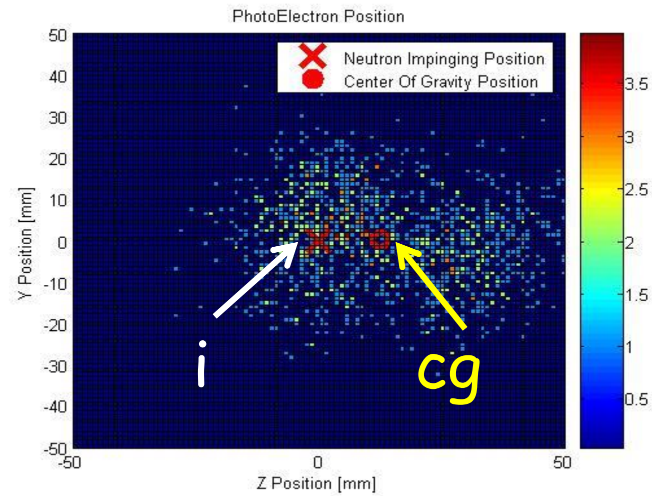


14 MeV Gammas in LXe



Compton electron range

2 MeV Neutrons in LXe



n Scattering

And if all fails….

The Amalfi Bay: a wonderful 2D liquid photon detector…!