# First observation of electroluminescence in liquid xenon within THGEM holes:

# towards novel Liquid Hole-Multipliers

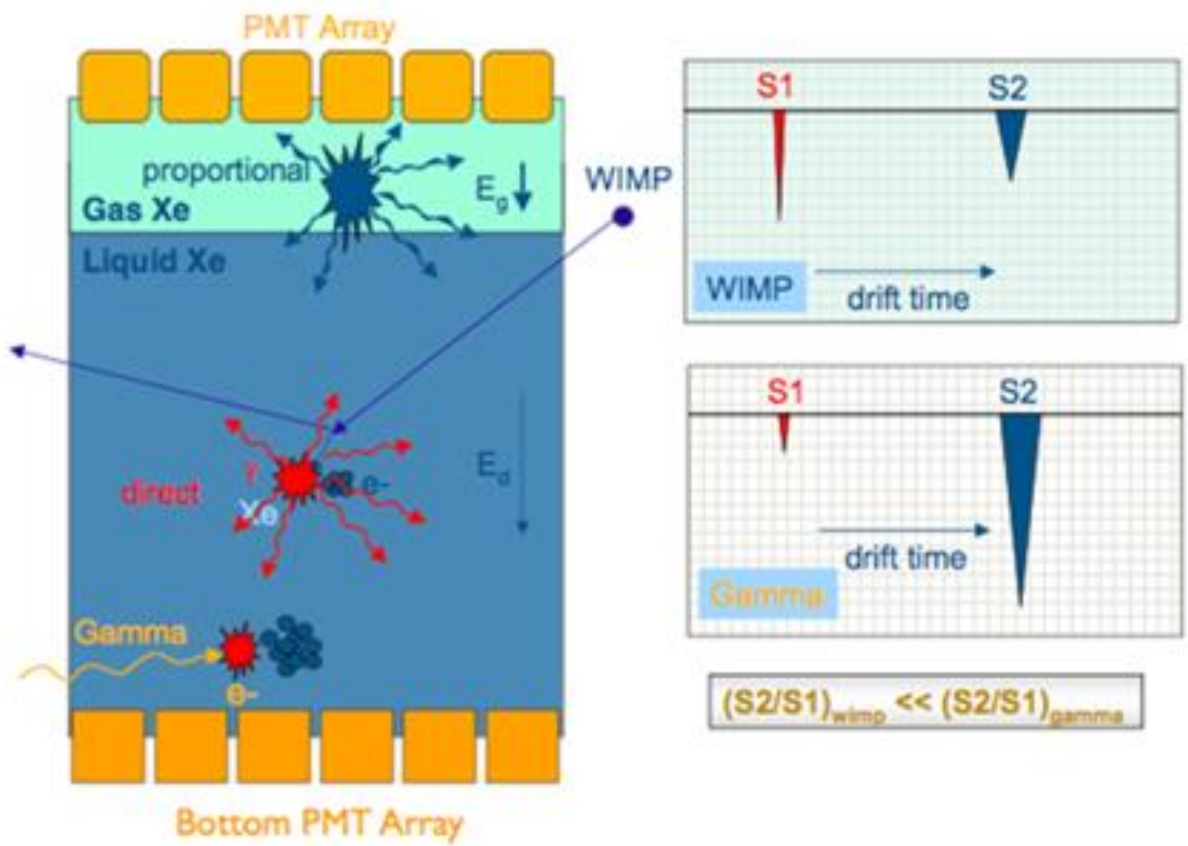
**L. Arazi, A. Breskin, A. Coimbra*,**

**R. Itay, H. Landsman, M. Rappaport, D. Vartsky**

*Weizmann Institute of Science*

* *On leave from Coimbra Univ.*

# CLASSICAL DUAL-PHASE NOBLE-LIQUID TPC



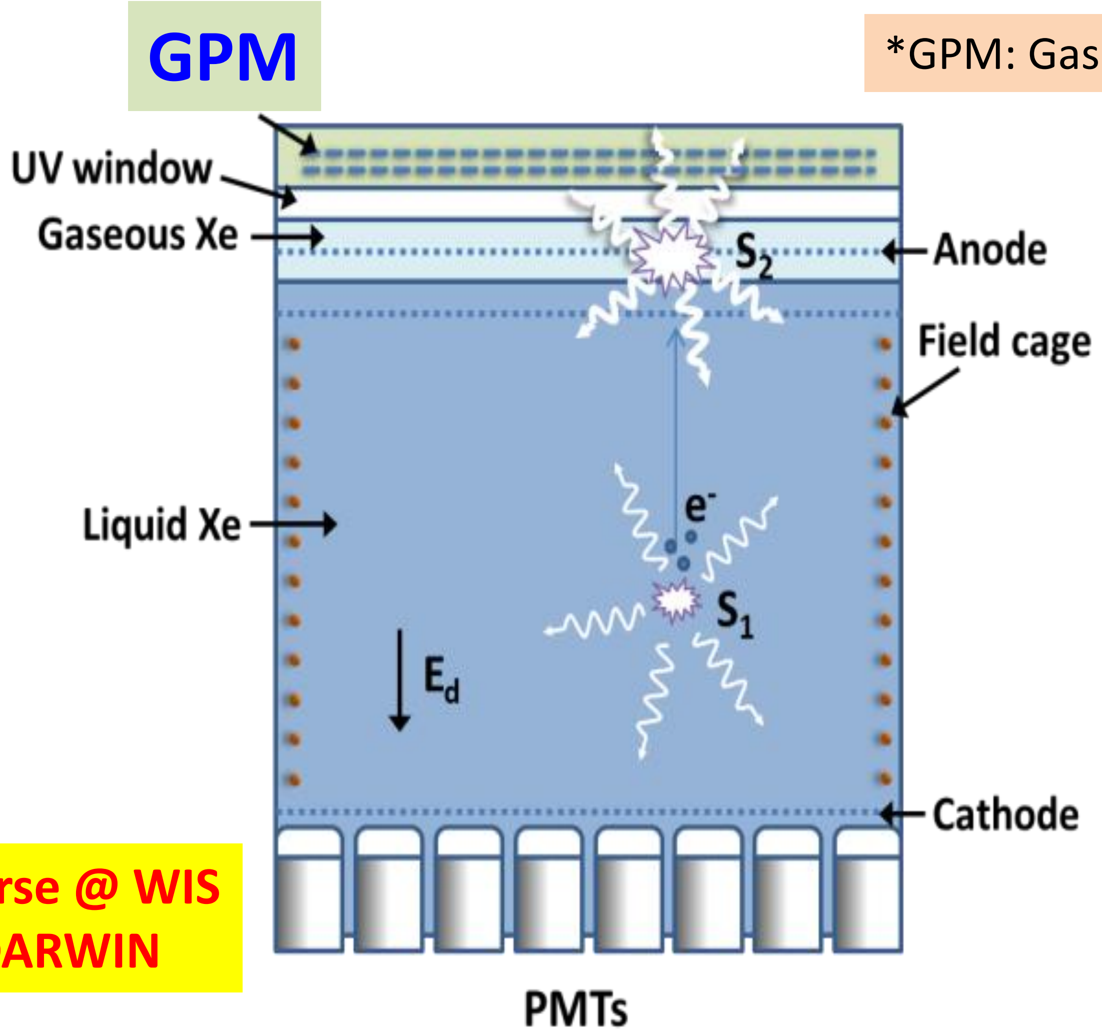

**Present:**
**XENON100, ZEPLIN, LUX….**
**Under design:**
**XENON1ton**

**Future:**
**MULTI-TON (e.g. Darwin):**
- **COST**
- **STABILITY**
- **THRESHOLD**

***A two-phase TPC***. *WIMPs interact with noble liquid; primary scintillation (S1) is detected by bottom PMTs immersed in liquid. Ionization-electrons from the liquid are extracted under electric fields ($E_d$, and $E_g$) into the saturated-vapor above liquid; they induce electroluminescence in the gas phase – detected with the top PMTs (S2). The ratio S2/S1 provides means for discriminating gamma background from WIMPs recoils, due to the different scintillation-to-ionization ratio of nuclear and electronic recoils.*

# Dual-phase TPC with GPM* S2 sensor

*GPM: Gaseous Photomultiplier

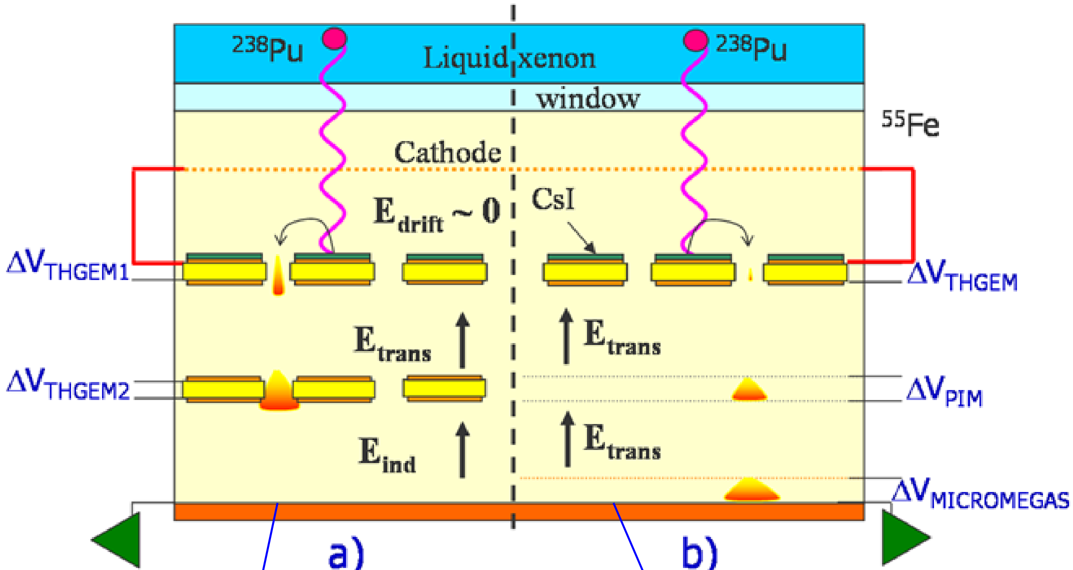


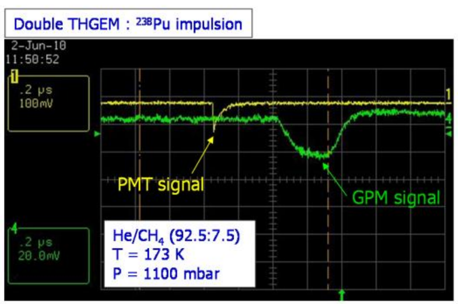

**R&D in course @ WIS**
**Within DARWIN**

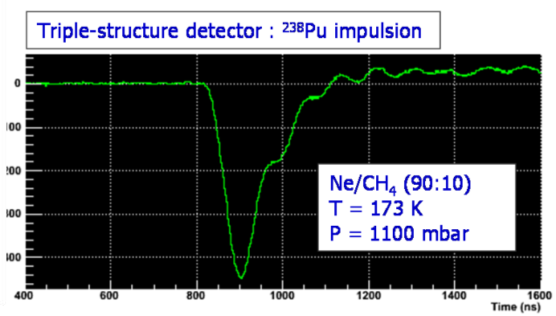
A proposed concept of a dual-phase DM detector. A large-area Gaseous Photo-Multiplier (**GPM**) (operated with a counting gas) is located in the saturated gas-phase of the TPC; it records, through a UV-window, and localizes the copious electroluminescence S2 photons induced by the drifting ionization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

# Nantes/Weizmann

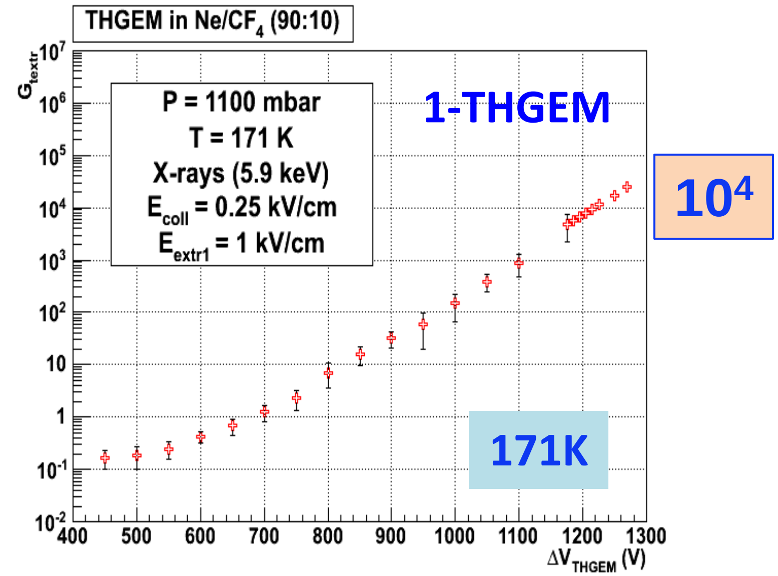
# LXe-TPC/GPM

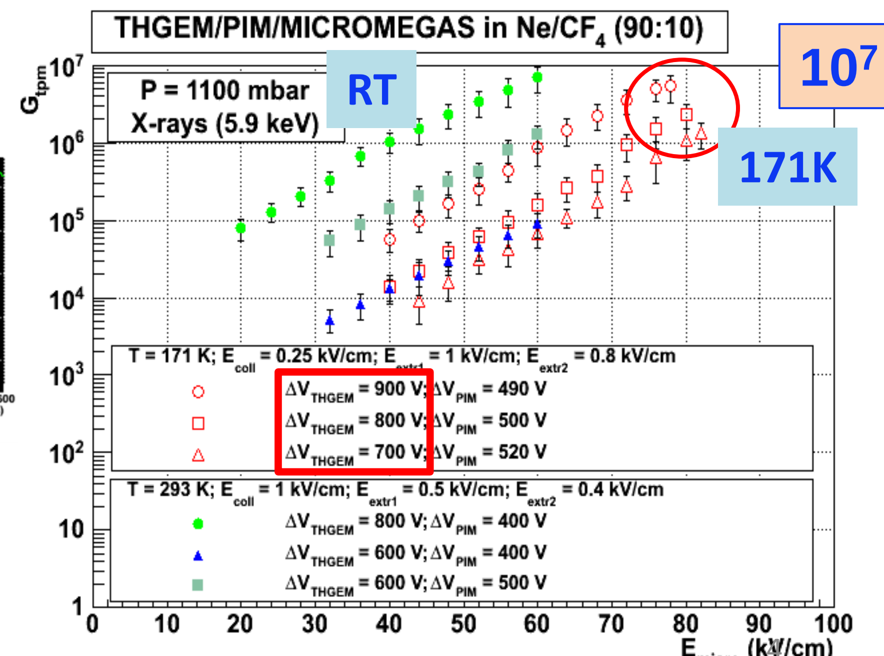



173K, 1100mbar

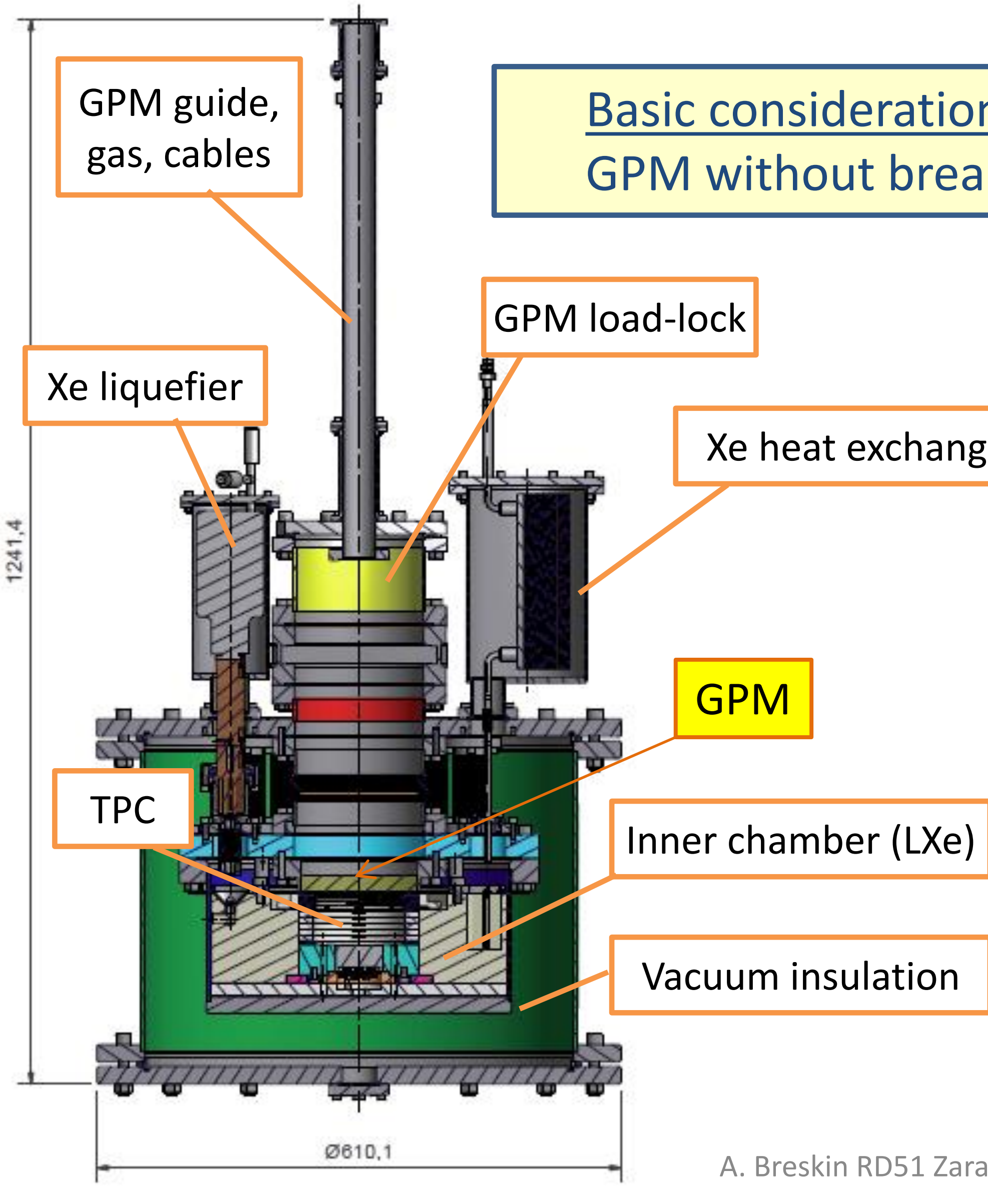


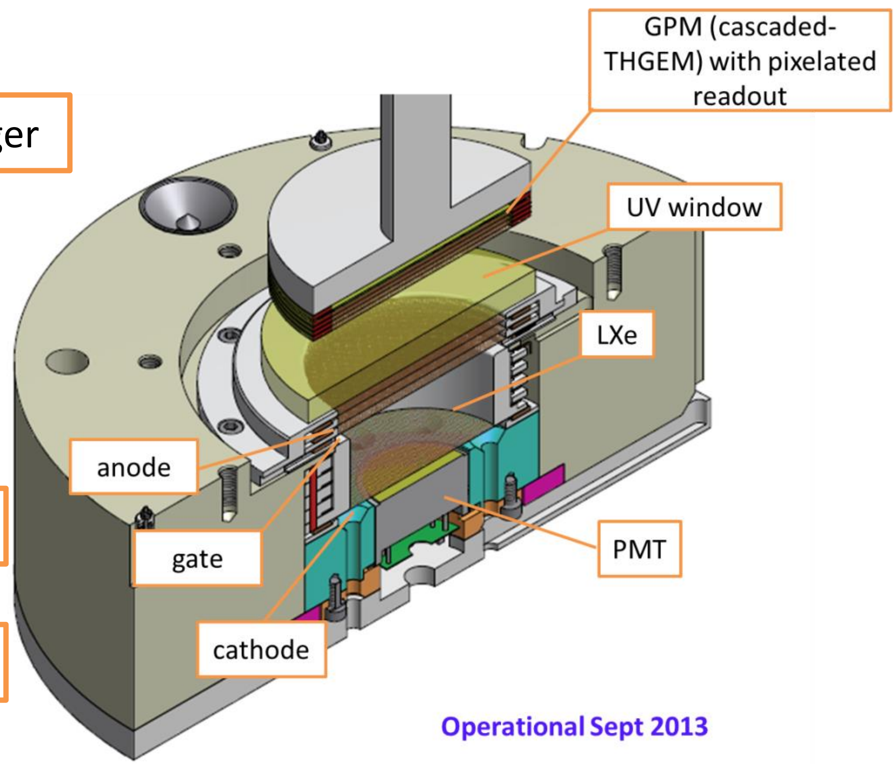




Duval 2011 JINST 6 P04007

# WIS Liquid Xenon (WILiX) R&D facility

Basic consideration: allow frequent modifications in GPM without breaking the LXe equilibrium state




Operational Sept 2013

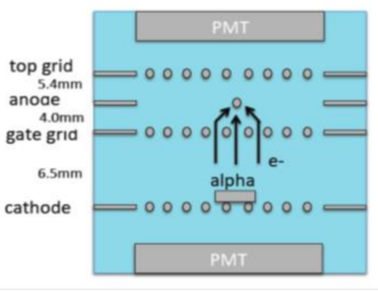
# Towards single-phase TPCs?

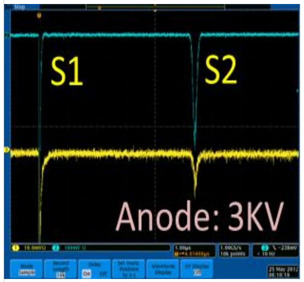
- Technically simpler?
- Sufficient signals?
- Lower thresholds?
- Cheaper?
- Resolutions?
- How to record best scintillation & ionization S1, S2?

# 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(1082)87;*
  *recent R&D **E. Aprile** @ Columbia private communication 2012*




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

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

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

  idea: ***K. Giboni**, KEK Seminar Nov 2011*

**S1 & S2 with cascaded Liquid Hole-Multipliers (LHM):** S1 & S2 multiplication in **CsI-coated cascaded THGEMs** (or GEMs, MHSPs etc.).

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

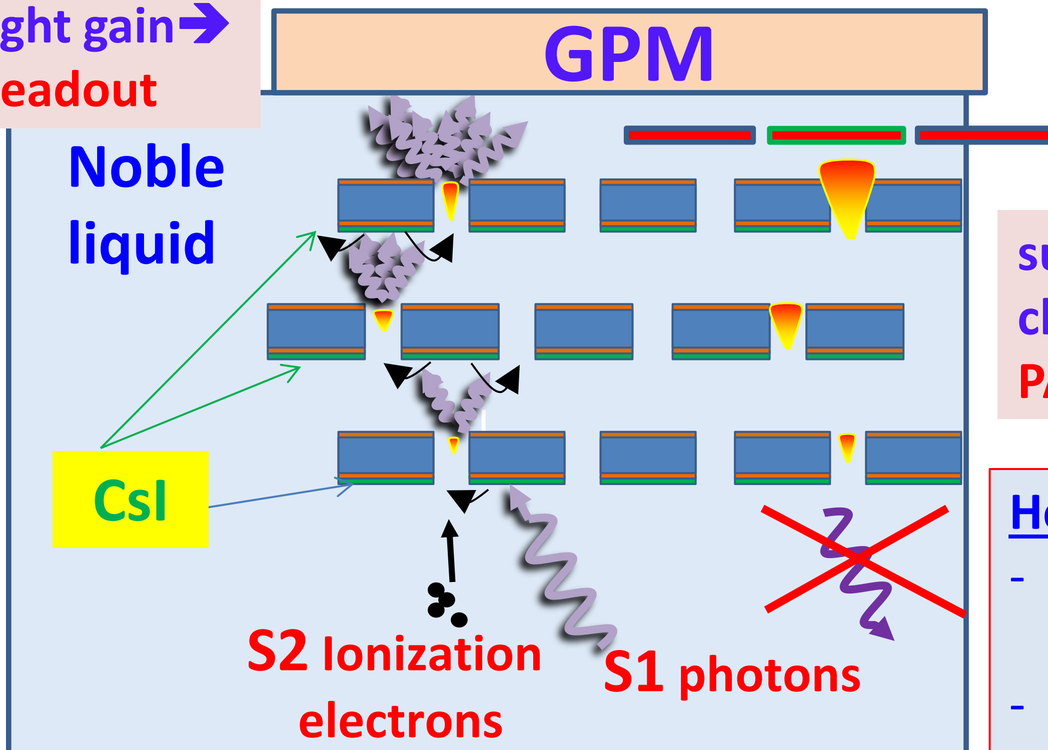
**R&D LHM/LXe - in course**

# S1 & S2 with single Liquid Hole-Multiplier LHM

## Light amplification in cascaded hole-multipliers in the LIQUID

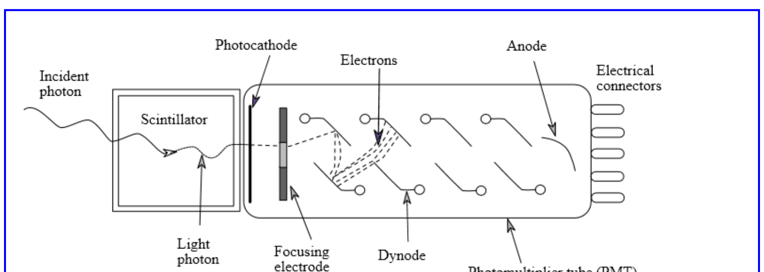
*A.B. Paris TPC2012 Workshop; arXiv:1303.4365*

High light gain → GPM readout




sufficient charge → PAD readout

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




Similar to PMT dynodes…

Feedback-photons from final avalanche or/and electroluminescence BLOCKED by the cascade

# LHM: the process

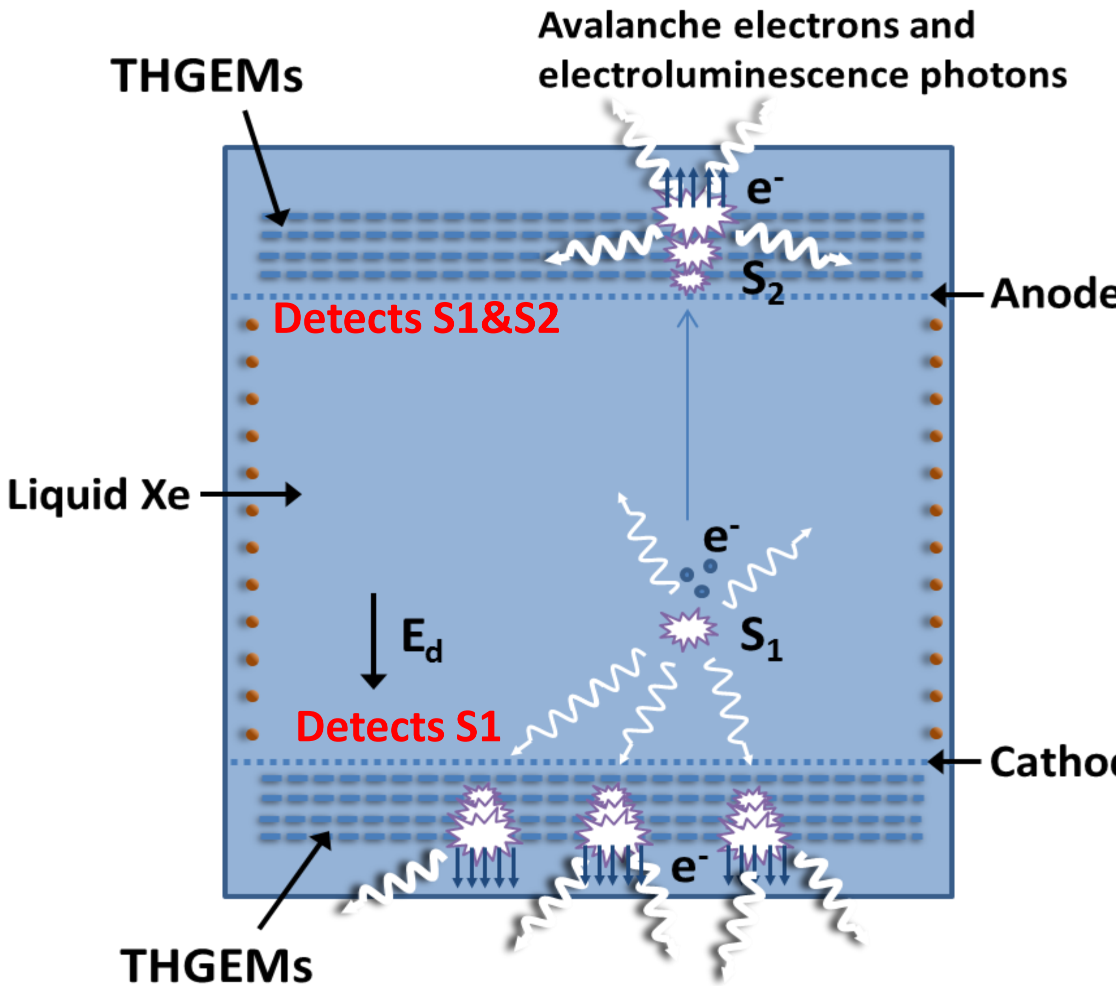
*__A.B.__ Paris TPC2012 Workshop; arXiv:1303.4365*

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!**

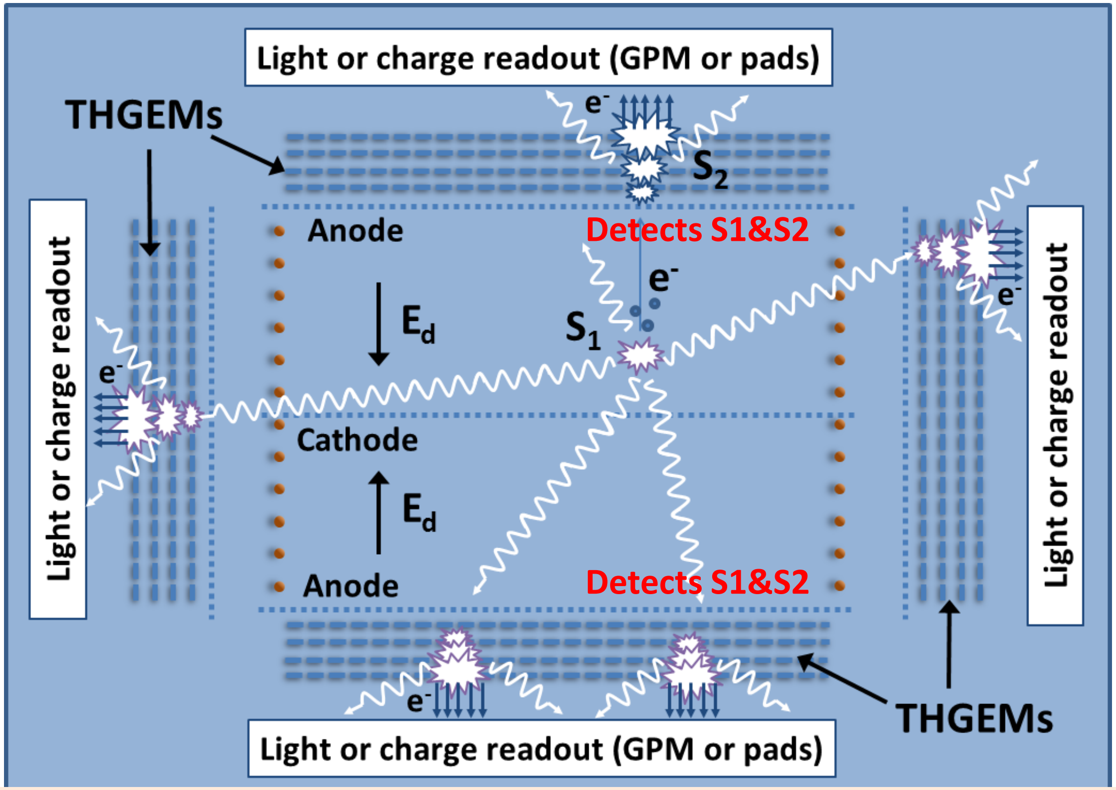
# LHM-TPC




**A single-phase TPC DM detector with THGEM-LHMs.**

The prompt S1 (scintillation) and the S2 (after ionization-electrons drift) signals are recorded with immersed CsI-coated cascaded-THGEMs at bottom and top.

# 4-π LHM-TPC

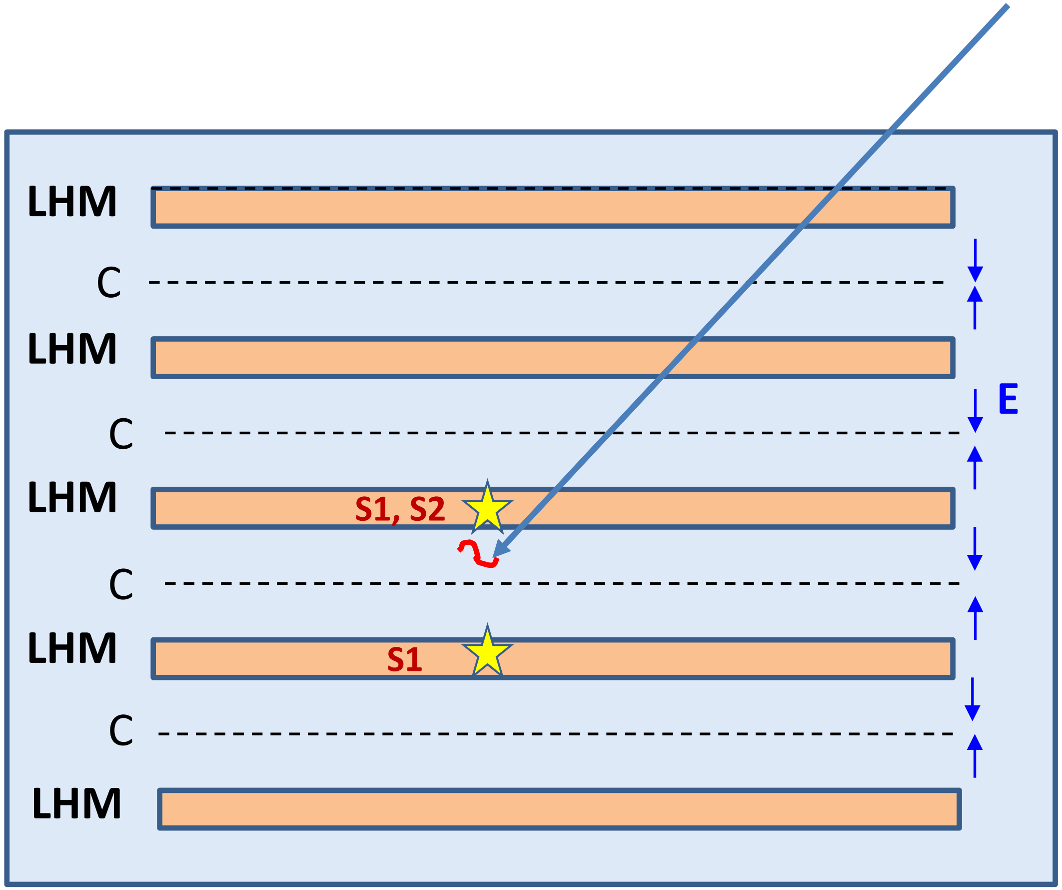



**A dual-sided single-phase TPC DM detector with top, bottom and side THGEM-LHMs.**
The prompt S1 scintillation signals are detected with all LHMs. The S2 signals are recorded with bottom and top LHMs.

**Highlights:**

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

# A CSCADED LHM-TPC



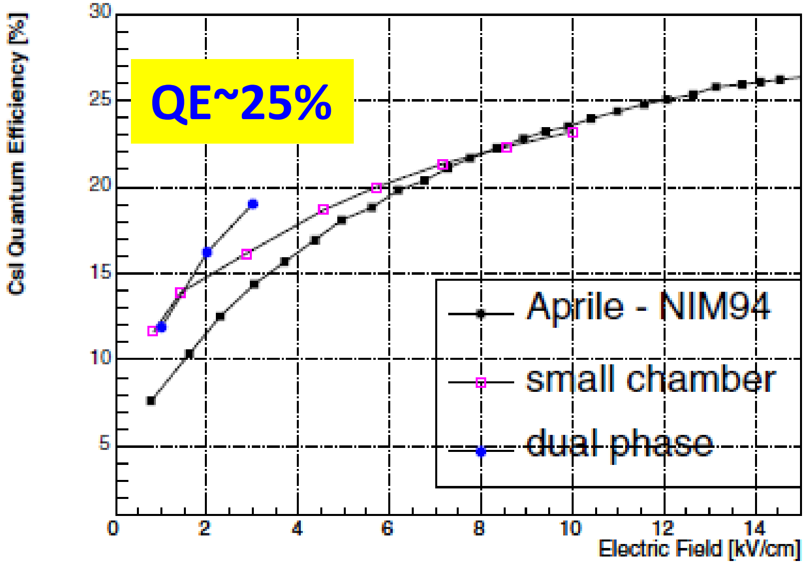

**LOW HV for large-volume**

**Relaxed electron lifetime**

**Need: low radioactivity and pad-readout**

# "Prior Art"

## High QE from CsI in LXe



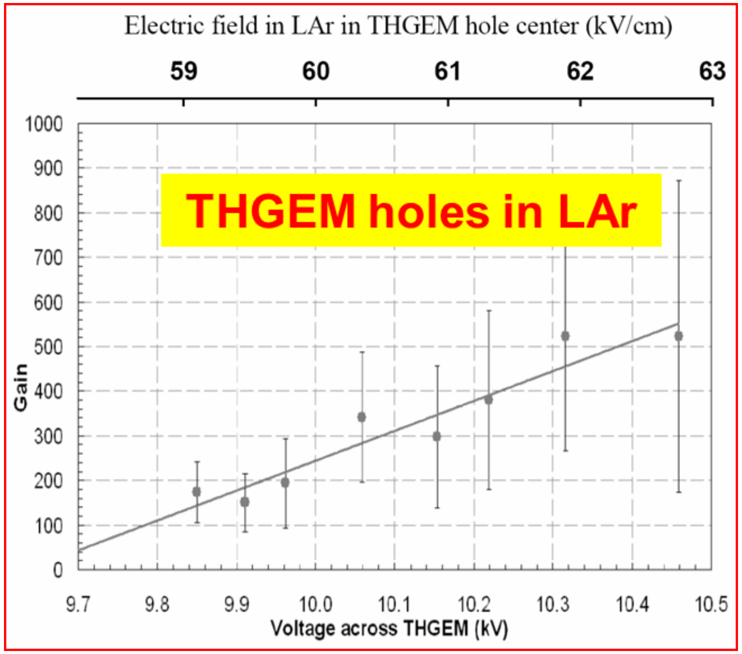

Aprile IEEE ICDL 2005, p345

## Data in LXe with thin wires

- **Electroluminescence threshold: ~400 kV/cm on wires**
- **e-avalanche threshold : ~1 MV/cm on wires**
  Doke NIM 1982
- **Maximum charge gain measured 200-400 on wires, strips, spikes…**

## Electroluminescence from THGEM holes in LAr

- **~500 UV photons/$e^-$ over $4\pi$**
  **measured with gAPD/WLS**
  Lightfoot, JINST 2009
- **~60kV/cm electroluminescence threshold confirmed in THGEM/LAr**
  Buzulutskov JINST 2012

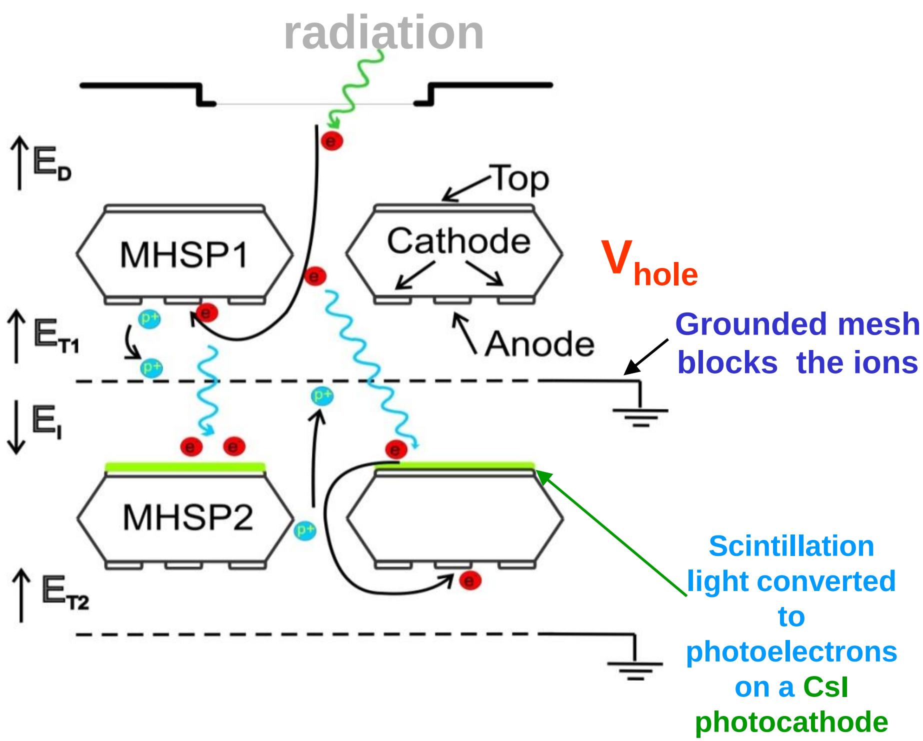



**But: LAr purity unknown**

# An Optical ion Gate

**Aveiro/Coimbra/Weizmann**

- Radiation-induced electrons are multiplied in a first element
- Avalanche-induced photons create photoelectrons on a CsI-coated multiplier
- The photoelectrons continue the amplification process in the second element
- No transfer of electrons or ions between elements: NO ION BACKFLOW
- Avalanche-ions from first elements: blocked with a patterned electrode
- For higher gains, the second element can be followed by additional ones




Charge gain
In MHSP 1

Photon-induced
Charge gain
In MHSP 2
**RESOLUTION MAINTAINED**

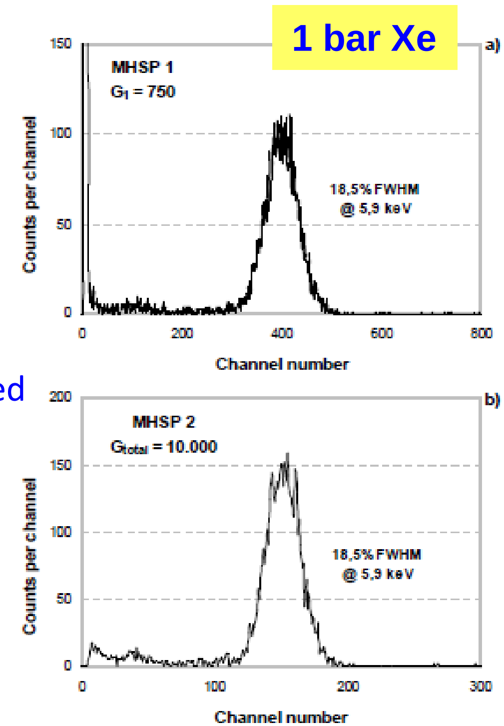
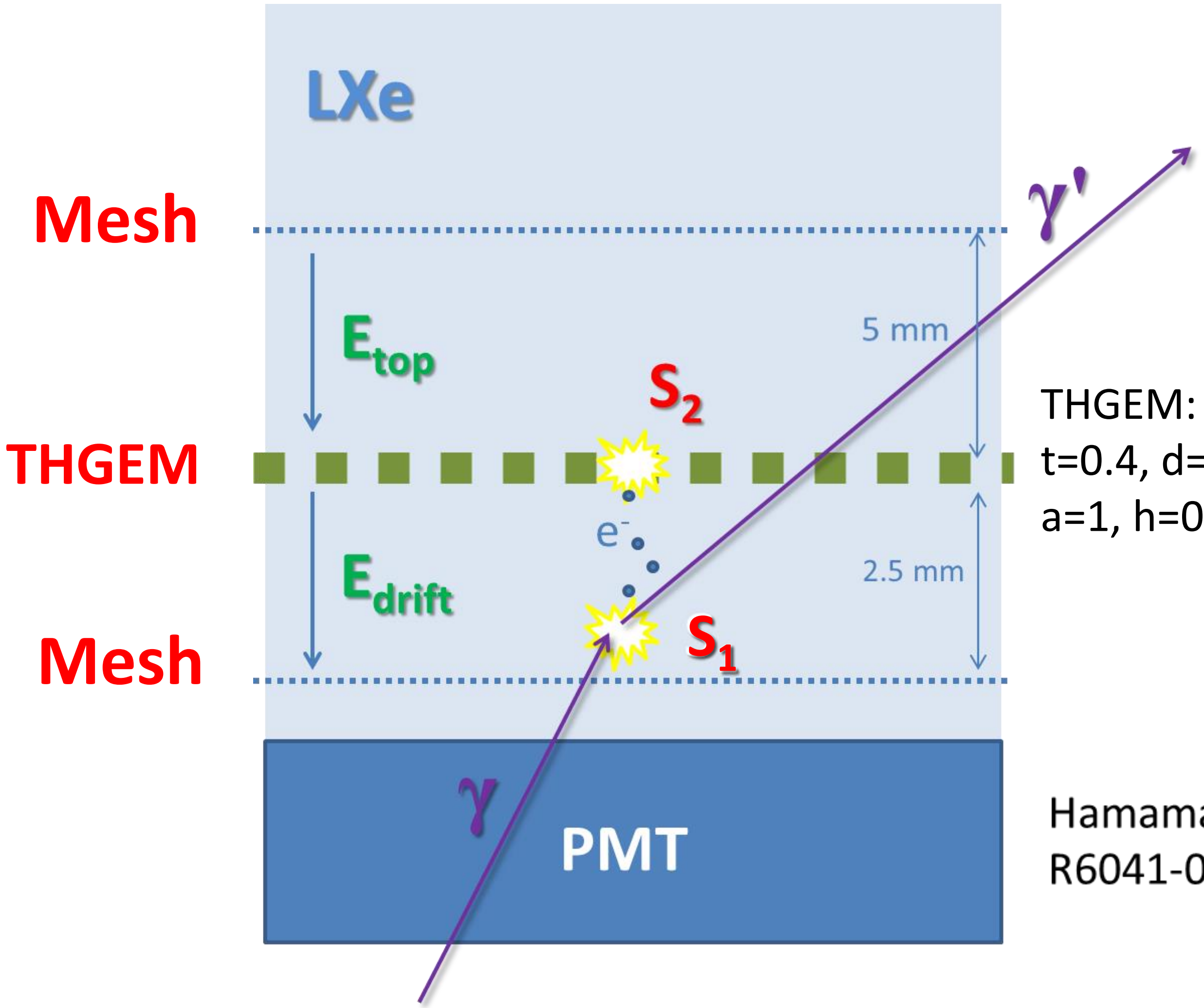



Figure 2. Pulse-height distributions resulting from 5.9 keV x-ray interactions in the drift region of the cascaded detector of figure 1, measured in 1 atm Xe on the anode strips of MHSP1 (*a*) and MHSP2 (*b*).

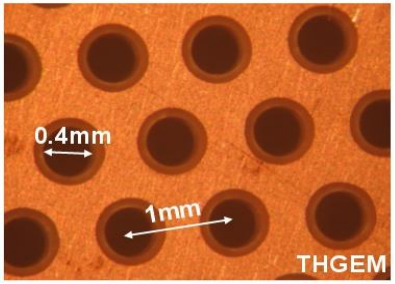
**VELOSO et al. 2006 *JINST* 1 P08003**
**Similar idea**
**Buzulutskov & Bondar**
**2006 JINST 1 P08006**

**Photon gain in 1 bar Xe ~ 1000**
IEEE TRANs NS, VOL. 56, NO. 3, JUNE 2009

# Single-THGEM in LXe: Gammas setup




Thickness 0.4mm

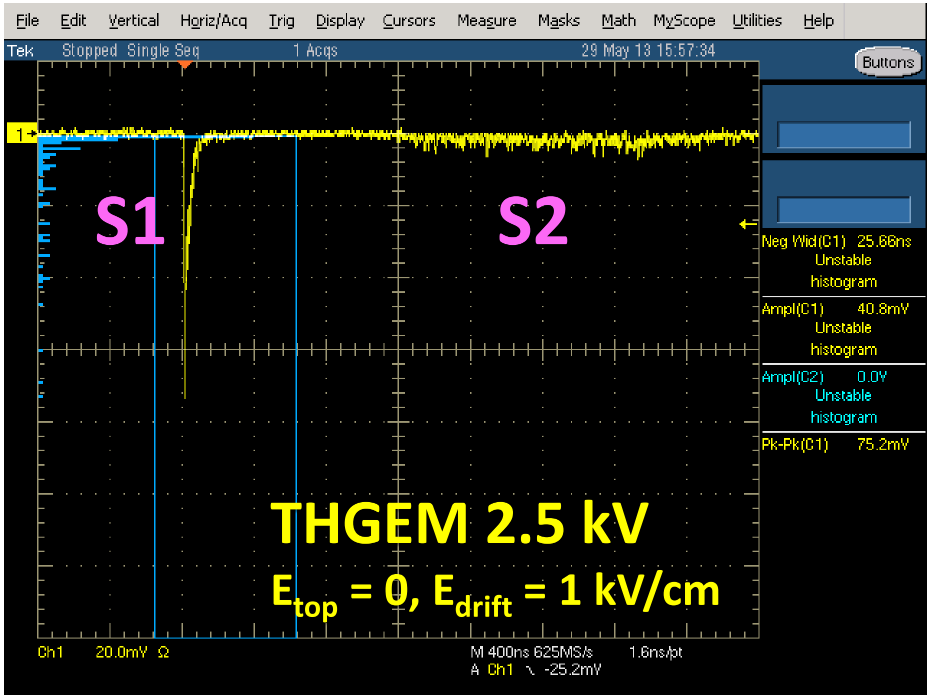


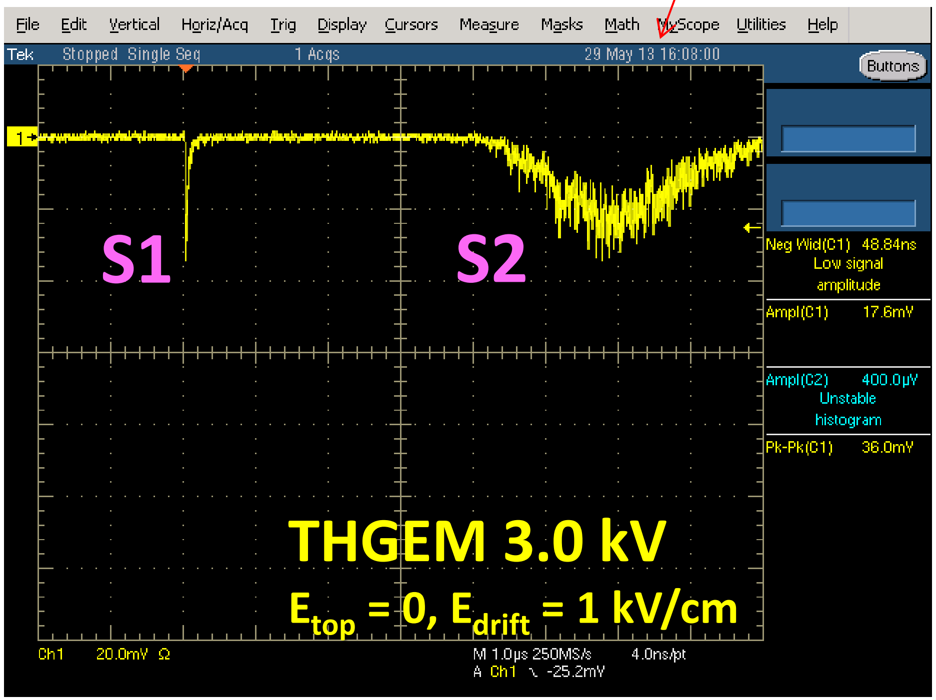

THGEM:
t=0.4, d=0.3,
a=1, h=0.1

Hamamatsu
R6041-06 2”dia

# THGEM immersed in LXe: First electroluminescence events - Gammas

May 29 2013



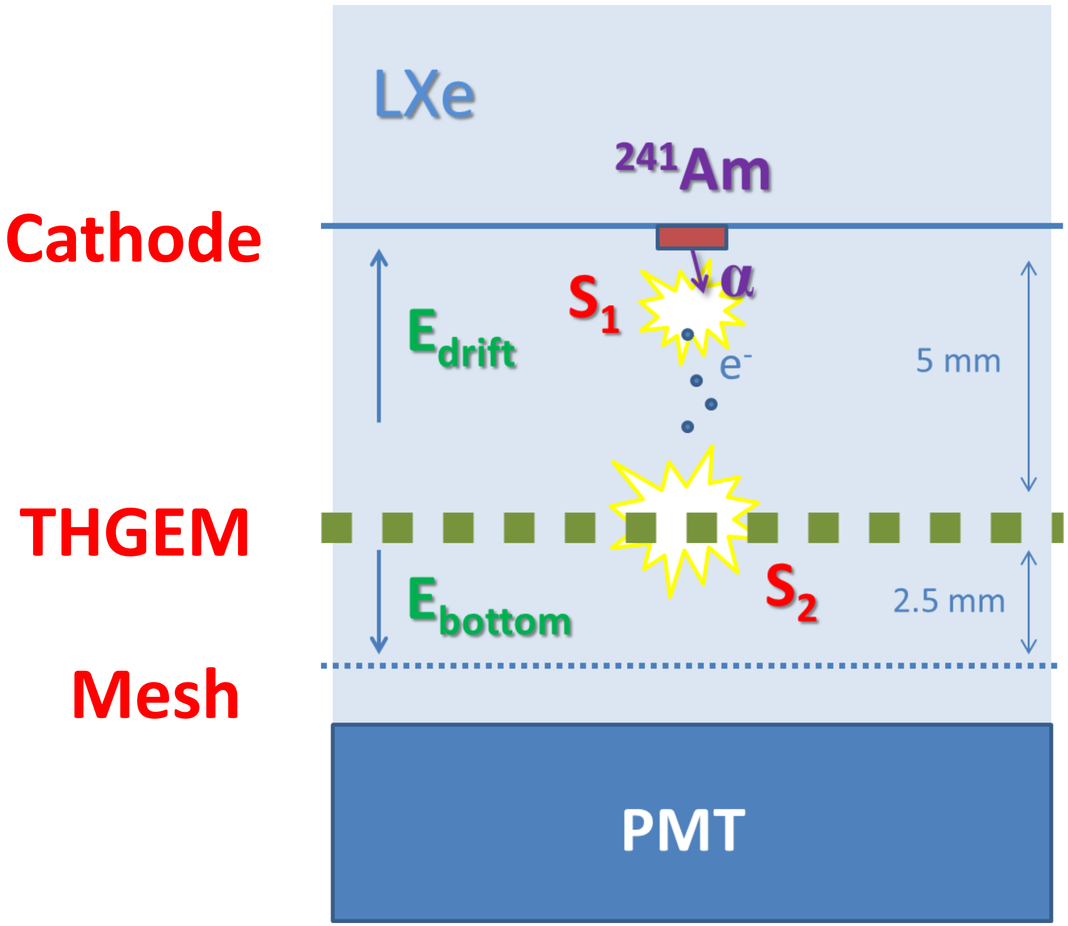




THGEM: t=0.4, d=0.3, a=1, h=0.1

$E_{THGEM}$~70kV/cm

LXe purity unknown

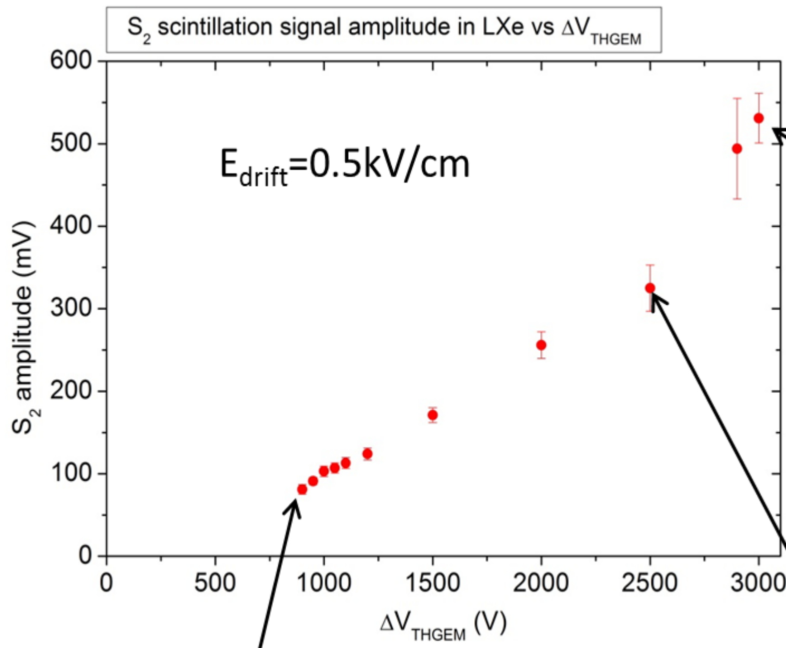
# Single-THGEM in LXe: Alphas setup

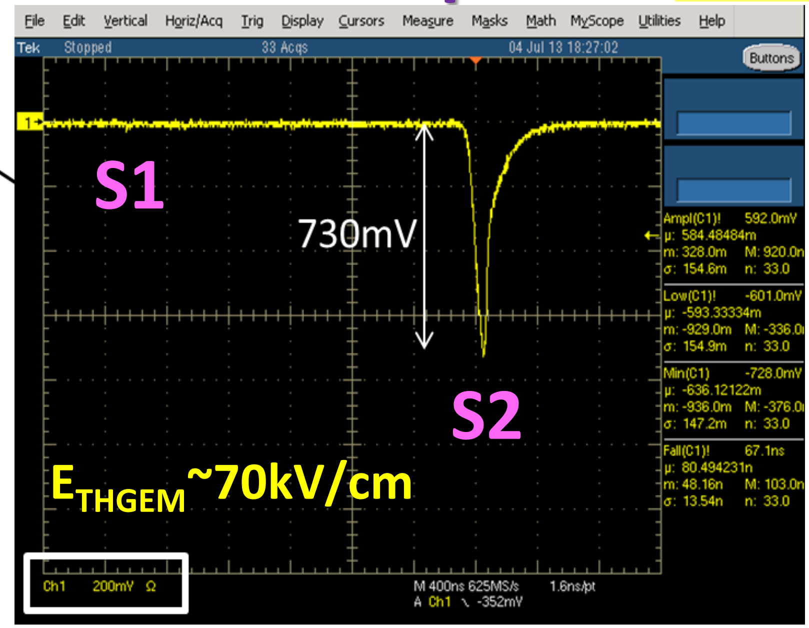


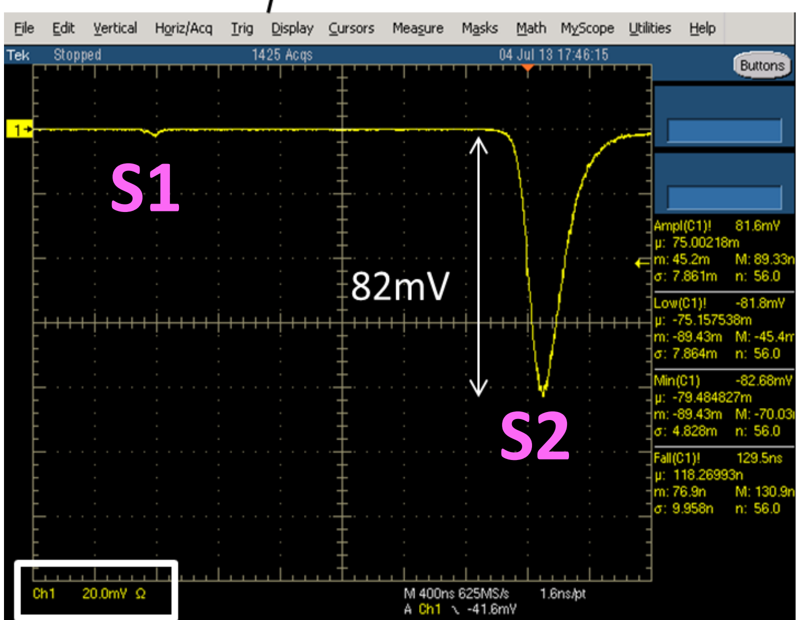

Hamamatsu
R6041-06 2” dia

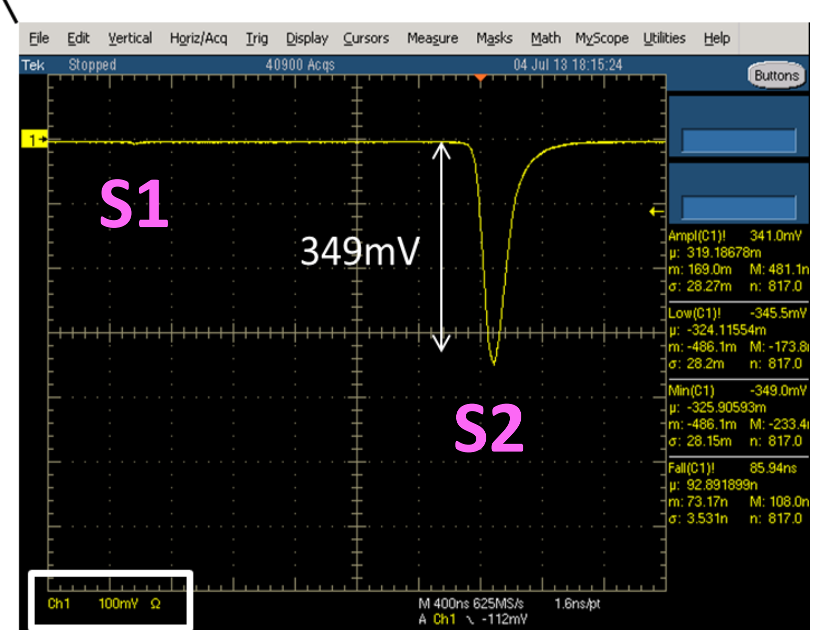
# THGEM immersed in LXe: Alphas

July 4, 2013




LXe purity unknown

# Summary & To-do list

- A revived interest in **single-phase** Noble Liquid Detectors for large-volume systems.
- A new concept proposed: scintillation (S1) & ionization (S2) recording with **single** immersed **Liquid Hole Multipliers – LHM**
- **First S1 & S2 signals recorded with $\gamma$ and $\alpha$ in THGEM in LXe** (unknown purity)
- Applications beyond DM searches!

**Concept needs validation:**

- Purity effects
- THGEM charge & light Gain in LXe vs. hole-geometry
- Electron collection efficiency into holes in liquid phase
- Photon & electron yields in CsI-coated cascaded THGEM
- Resolutions: E, t
- Feedback suppression
- S1/S2 Readout: pads vs. optical (GPM, others)
- Radio-clean electrodes

**Intense R&D in course on both GPM & LHM**

**Wonderful opportunities for the younger generation!**