Could MPGDs revolutionize noble-liquid detectors? *

Amos Breskin

מכון ויצמן למדע
WEIZMANN INSTITUTE OF SCIENCE

Remark: three other talks on ***dual-phase*** novelties by **Chepel, Roy & Tesi**

* for more details:
http://arxiv.org/abs/2203.01774
https://doi.org/10.1088/1748-0221/17/08/P08002

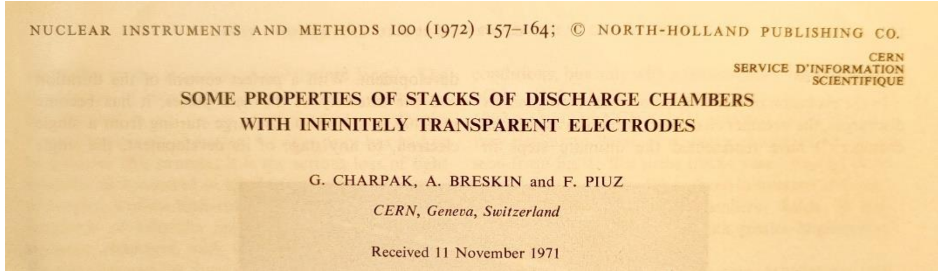
Talk dedicated to my friend

Francois Piuz 1937-2022

One of the leading Detector Physicists of my generation

Last project: CsI-RICH of LHC-ALICE

50 years ago…


NUCLEAR INSTRUMENTS AND METHODS 100 (1972) 157–164; © NORTH-HOLLAND PUBLISHING CO.

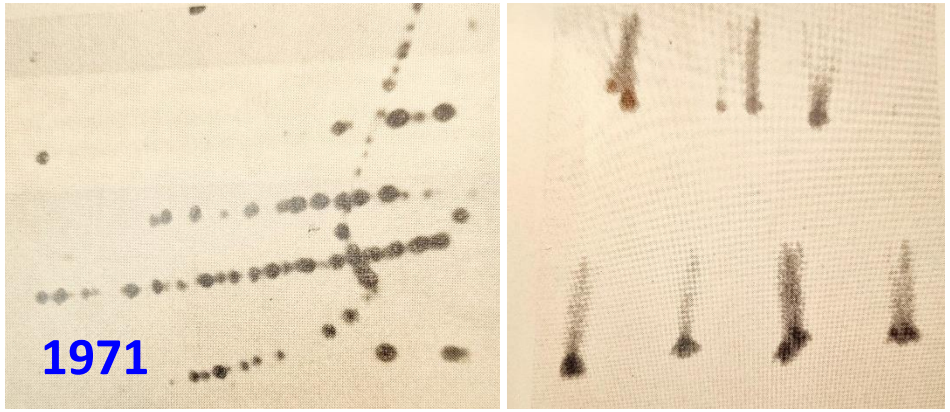
CERN
SERVICE D'INFORMATION
SCIENTIFIQUE

SOME PROPERTIES OF STACKS OF DISCHARGE CHAMBERS
WITH INFINITELY TRANSPARENT ELECTRODES

G. CHARPAK, A. BRESKIN and F. PIUZ

CERN, Geneva, Switzerland

Received 11 November 1971



2019 *Symphonie pour platane et pinceaux*

Amos Breskin 2019

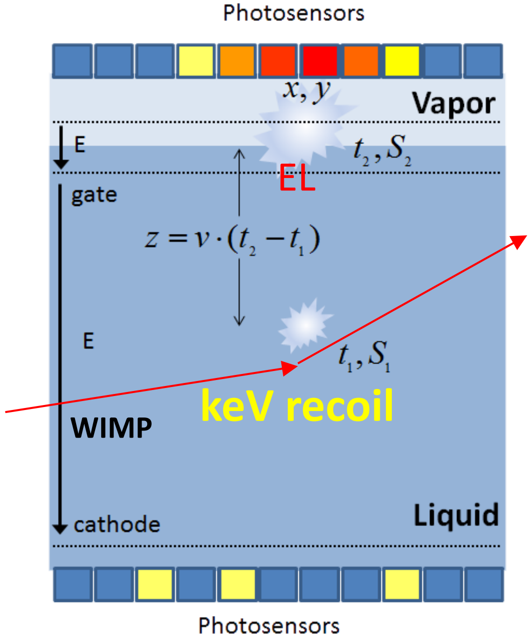
Francois Piuz 2004

3 years ago…

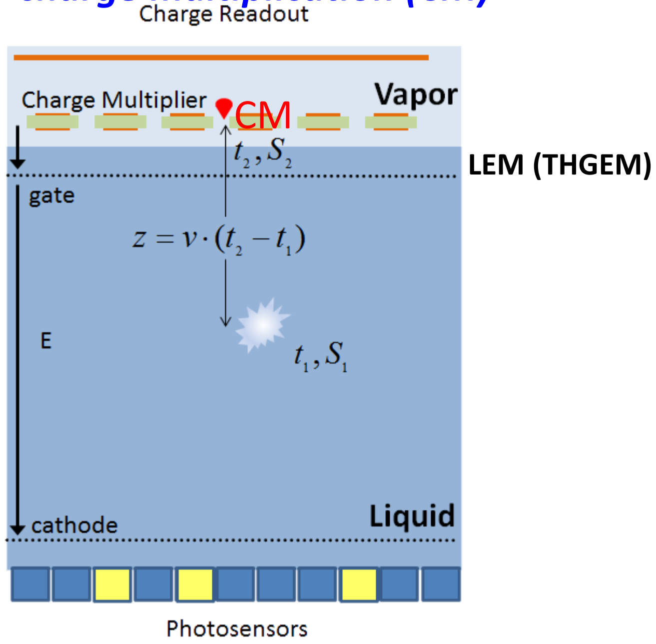
Noble-liquid TPCs: current status
DM, Neutrino Physics

S1- scintillation: Time stamp/threshold
S2- EL/CM: charge & 2D

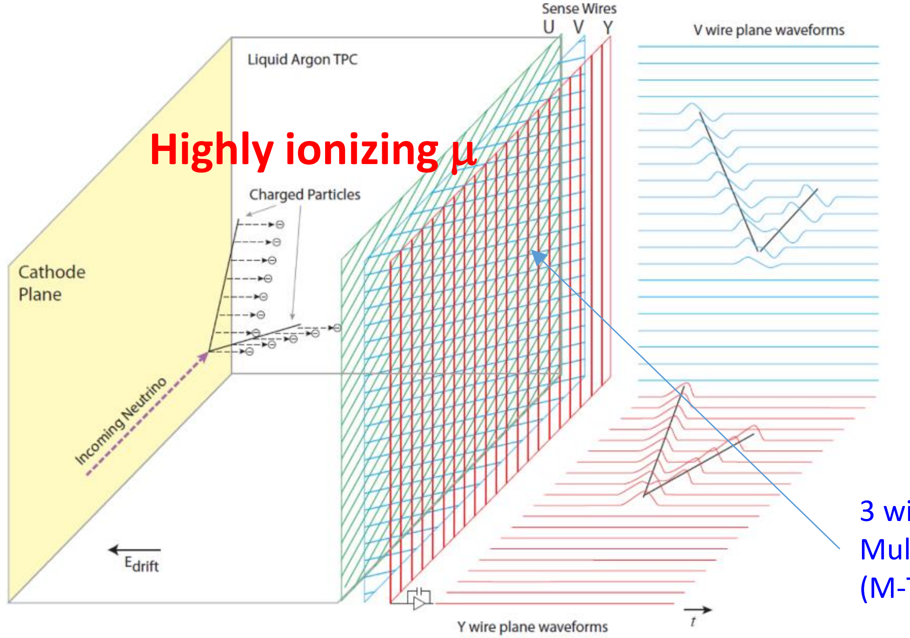
Dual-phase
electroluminescence (EL)



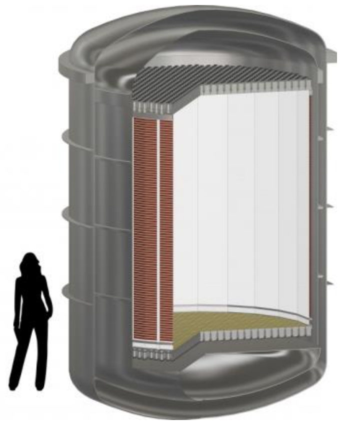
Dual-phase
charge multiplication (CM)



Single-phase
Charge collection



3 wire planes or
Multilayer perforated PCB
(M-THGEM-like)



Energy deposited in liquid. Primary scintillation detected by PMTs, SiPM. Charges extracted to gas + **multiplied** by electroluminescence or by avalanche.
XENON, LUX, PNDA X,

Future 50-ton LXe – DARWIN/XLZD
Dark-matter search

Energy deposited in liquid. Primary scintillation detected by photon detectors. Charges detected in liquid by wires (or multilayer perforated electrodes), **without multiplication**

Future 68-Kton LAr
DUNE
Neutrino physics

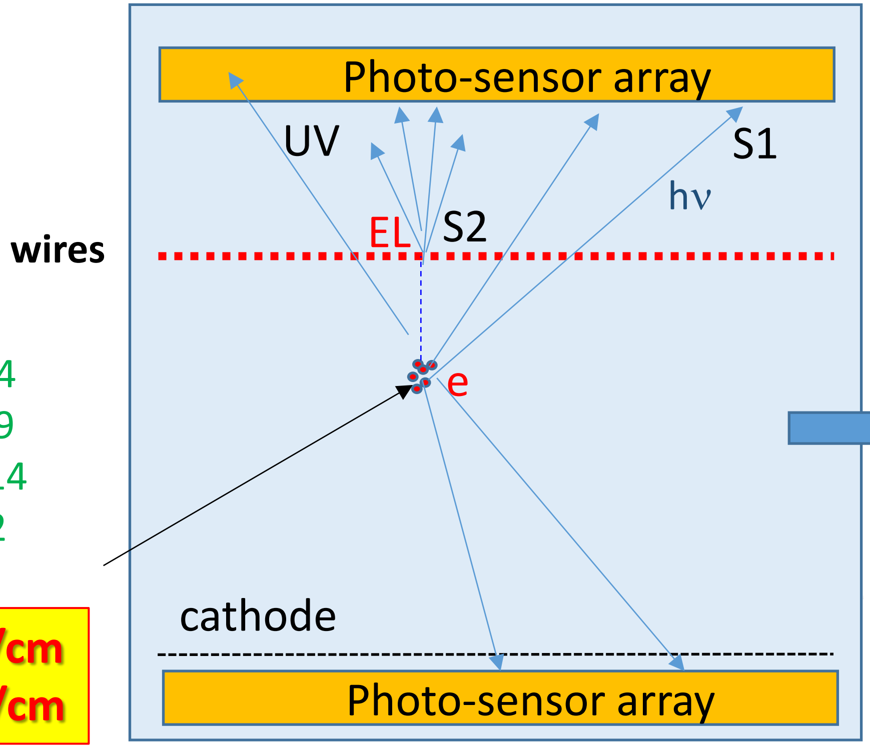
Single-phase: from wires to microstructures - e^-

~50 years of Wires in LXe:

Derenzo PRA 1974
Masuda NIM 1979
* Aprile JINST 2014
Brown JINST 2022

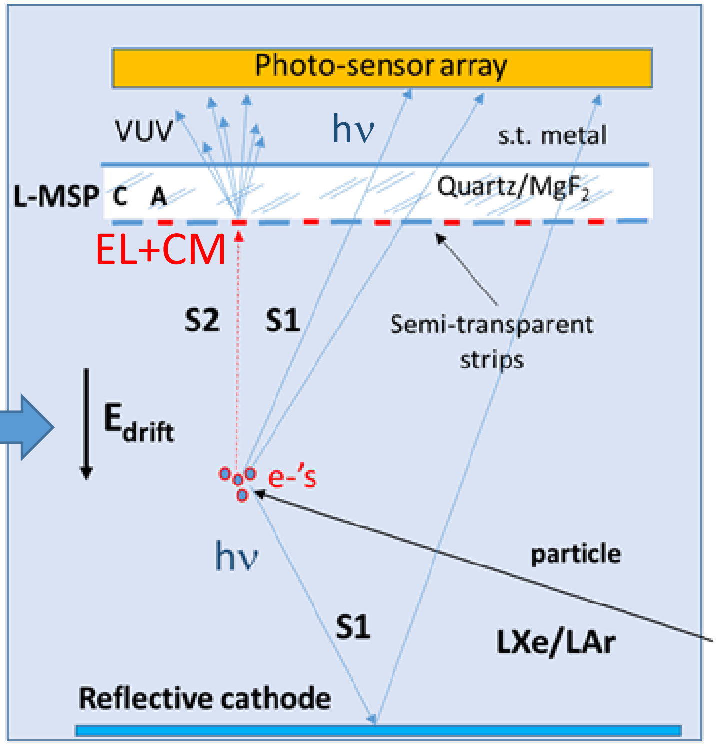
* EL th. ~400kV/cm
CM th. ~700kV/cm

Wires



wires sagging, staggering

Microstructures



SiPM, SPAD…

Modular Microstrip plates & more!

L-MSGC/LXe: gain 10
Policarpo et al. NIMA 1995

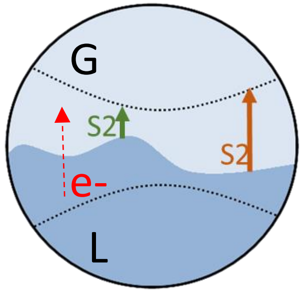
- MSP formed on VUV-transparent substrate, with thin Ni or Cr electrodes.
- **L-MSP**: MSGC, COCA COLA, VCC …
- Charges deposited in liquid, undergo electroluminescence (EL) & small charge multiplication (CM) @ high field near the **anode strips**.
- The effective light-emission region depends on the MSP type, & potentials applied to the MSP electrodes – recorded by photo-sensors.

Why new concepts?

Dual-phase:

Current expected problems with large-area TPCs, that affect resolution & efficiency:

- liquid-gas interface instabilities - spontaneous electron emission, gas gap variations,
- electron extraction efficiency from liquid to gas,
- limited avalanche gain in noble gases.
- Mechanical issues



Single-phase:

- No multiplication
- High threshold
- Only suits highly ionizing events

Multiplication in single-phase liquid:

➔**Lower detection thresholds**

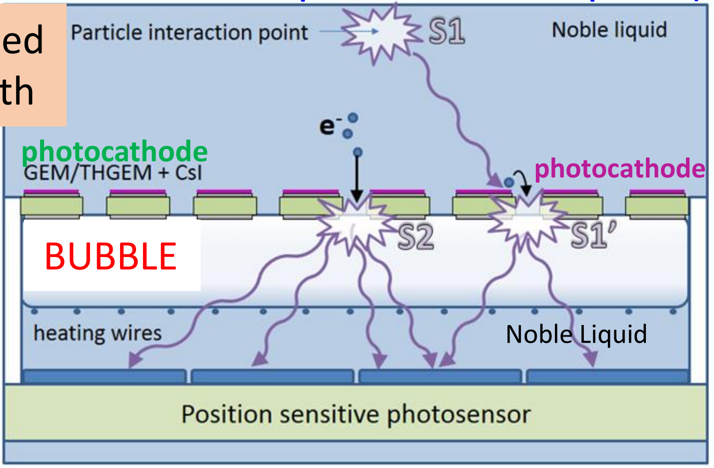
➔**May Pave the way to novel DM detectors**

NOVEL DUAL-PHASE DETECTOR CONCEPTS

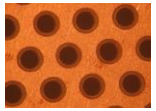
"local dual-phase":

Bubble-assisted Liquid Hole Multiplier (LHM)

Discussed in length



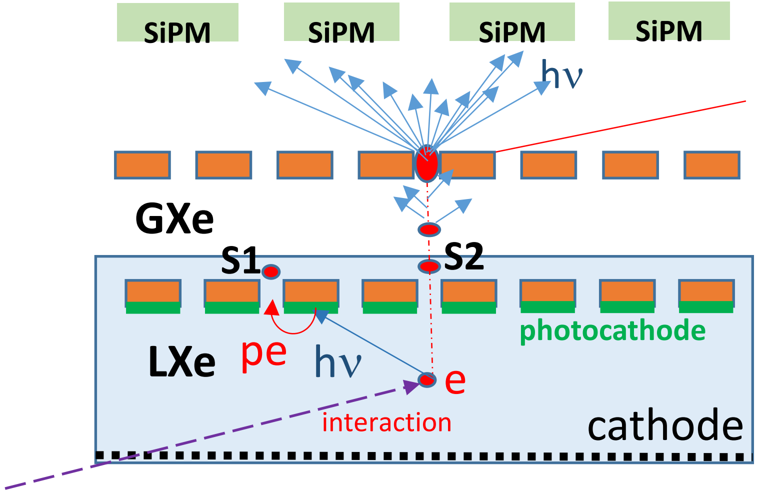
GEM/THGEM



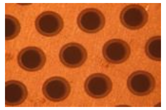
https://doi.org/10.1088/1748-0221/13/12/P12008

Bubble-less Liquid Hole Multiplier (LHM)

ROY talk



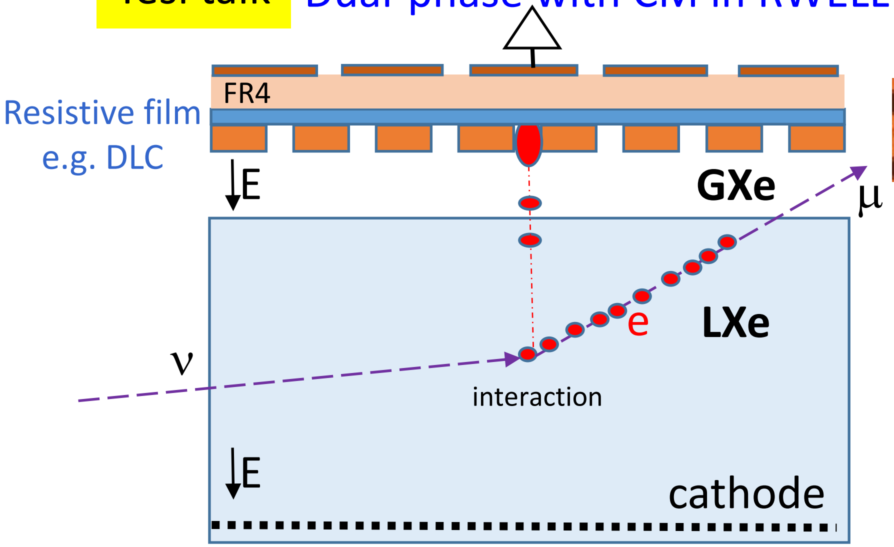
GEM/THGEM



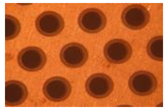
https://events.camk.edu.pl/event/47/contributions/377/attachments/126/281/LIDINE-2022%20The%20Bubble-Free%20Liquid%20Hole-Multiplier-v2.pdf

Dual-phase with CM in RWELL

Tesi talk

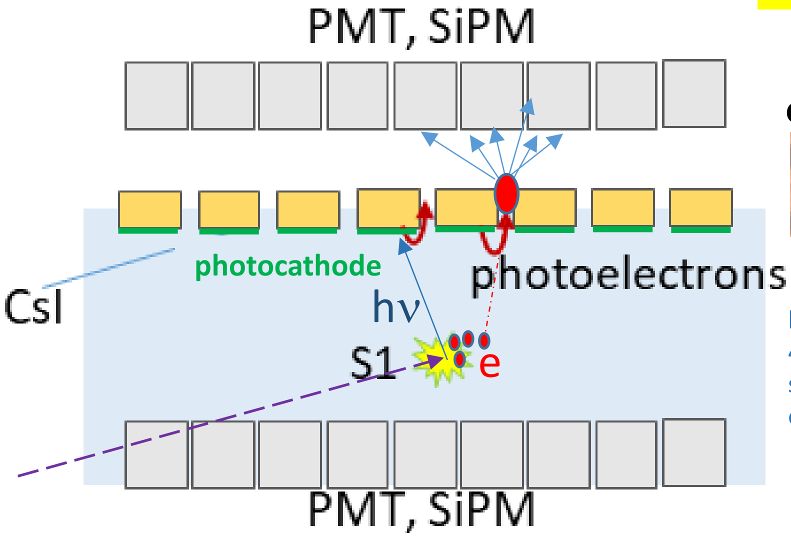


THWELL

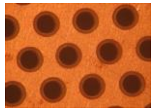


Floating Hole Multiplier (FHM)

Chepel talk



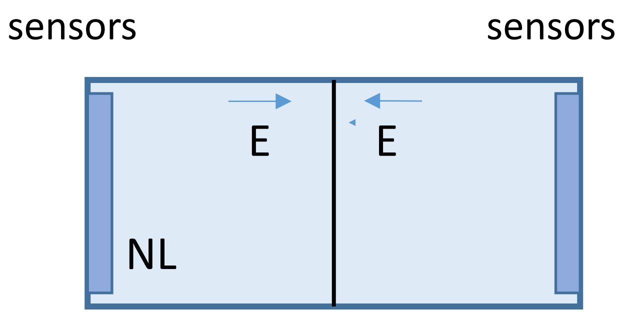
Floating GEM/THGEM



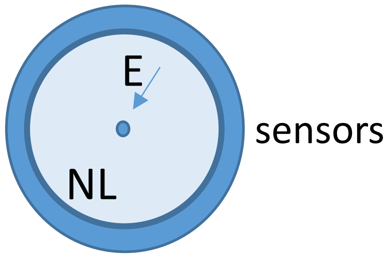
https://events.camk.edu.pl/event/47/contributions/379/attachments/122/275/LIDINE2022_Chepel_presentation%20.pdf

Why single phase?

- To overcome liquid-gas **interface problems** in large dual-phase detectors:
- Only single-phase can be **“face-to-face”** and **“horizontal”:**
  ➔ Half of HV for equal field; avoids effects of sporadic bubbles



- “**Radial** geometry” possible



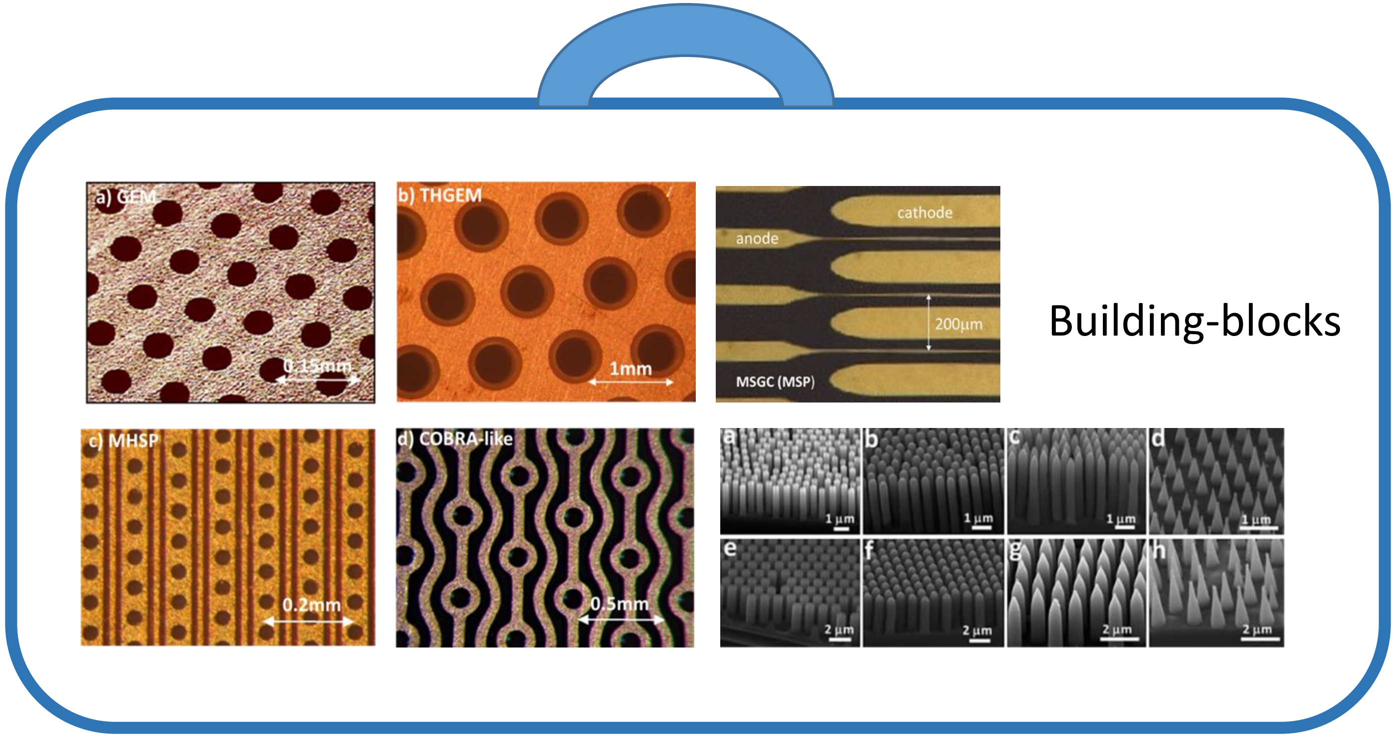
- New concepts: potentially “cheaper” photo-sensors; lower detection thresholds
  ➔ impact on the “physics”

SINGLE-PHASE LIQUID-MPGD TPC CONCEPTS

Goal:

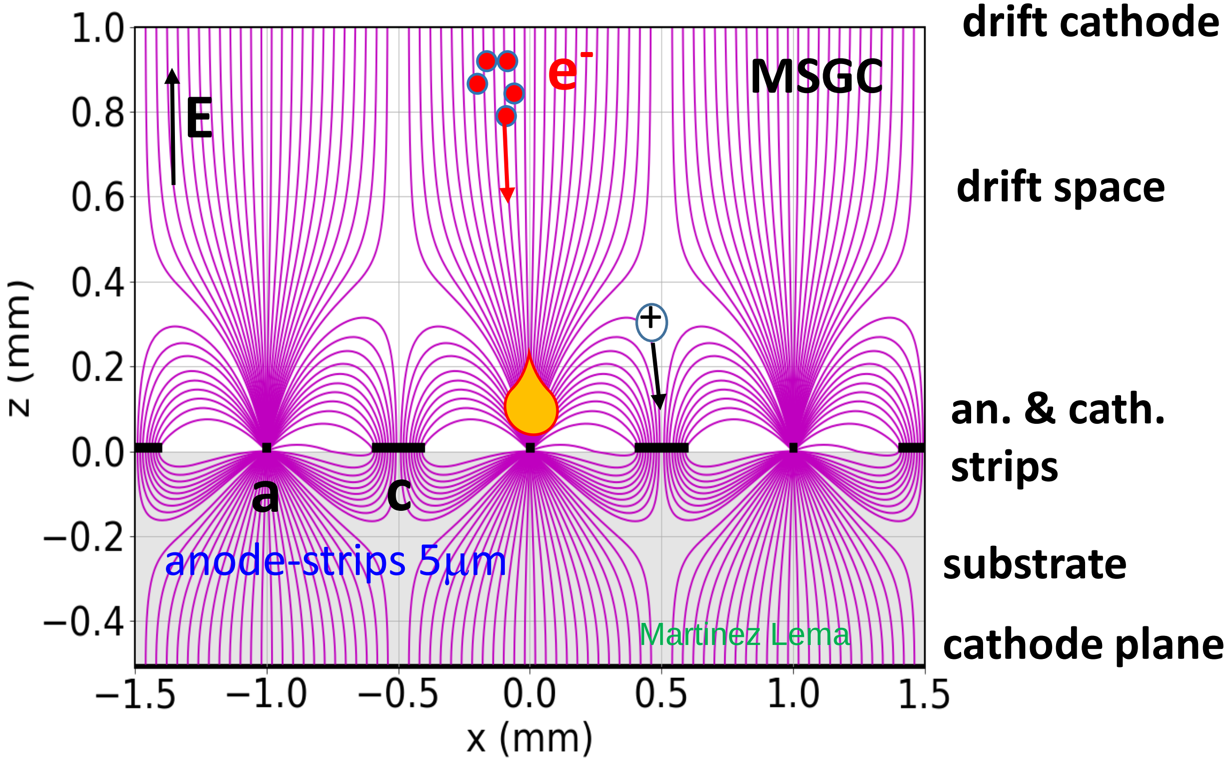
Devise robust noble-liquid MPGD multiplier configurations for detecting both: e^- & UV-photons

Tool Box:



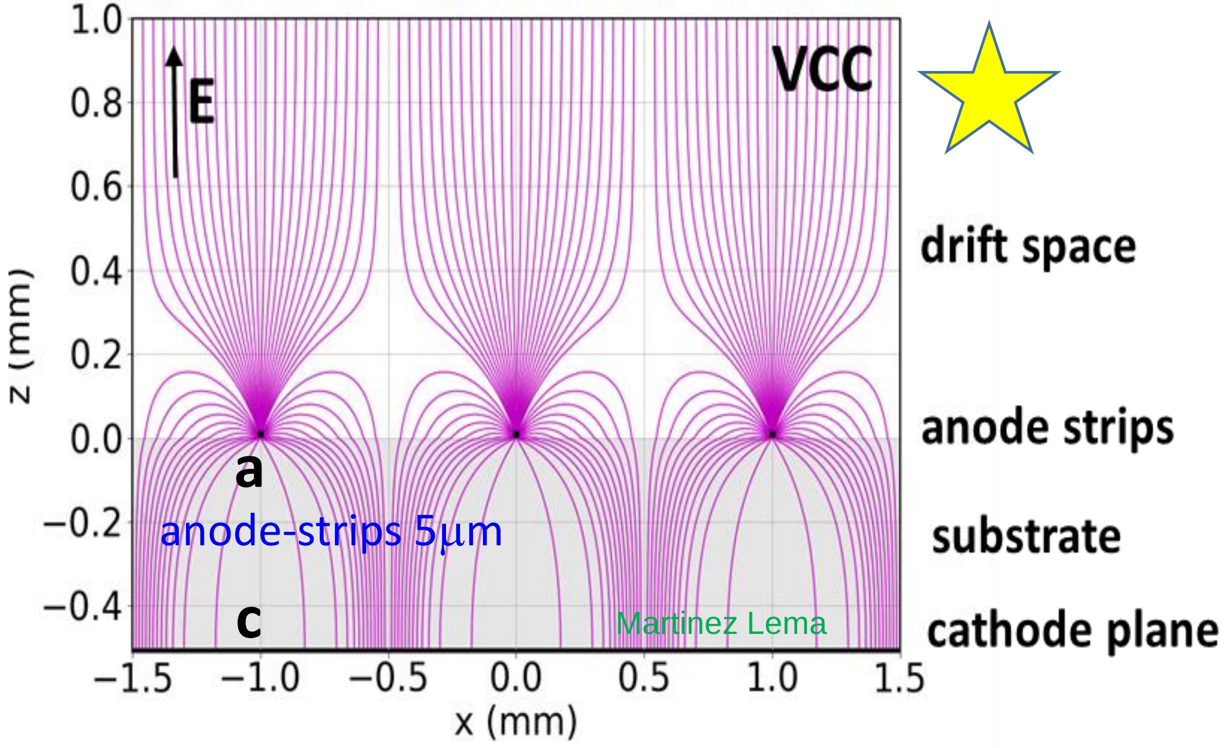
MSPs: MSGC & VCC

Microstrip Gas Chamber Oed 1988



Weakness: sparks a-c limit HV

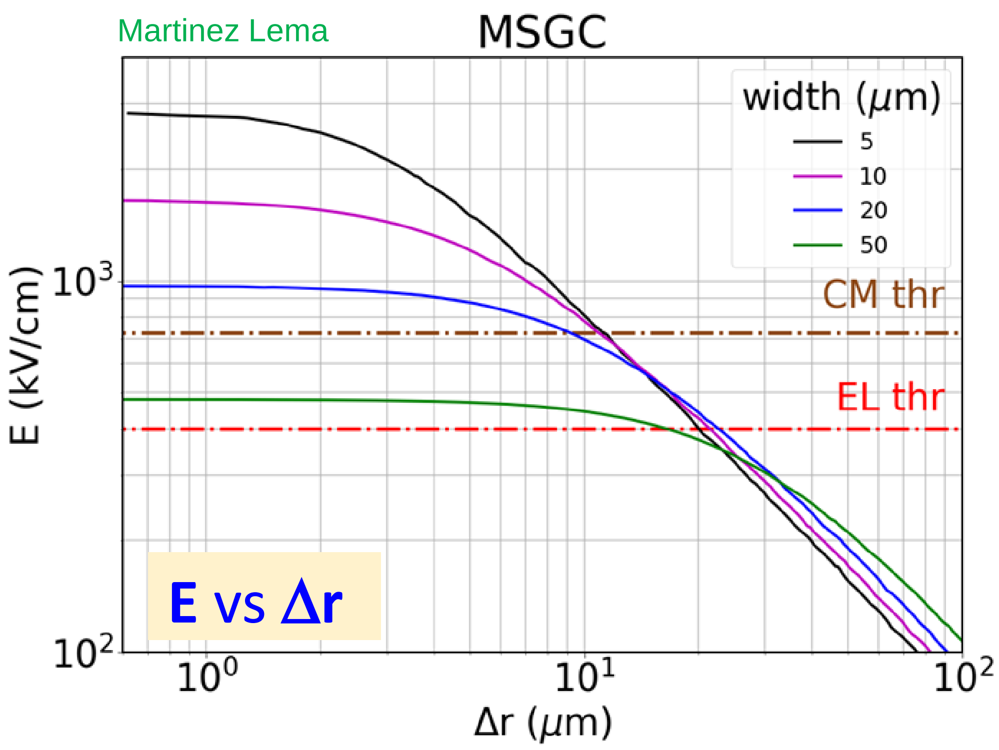
Virtual Cathode Chamber Capeans 1997

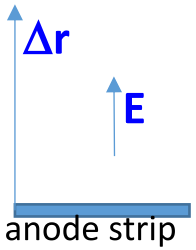


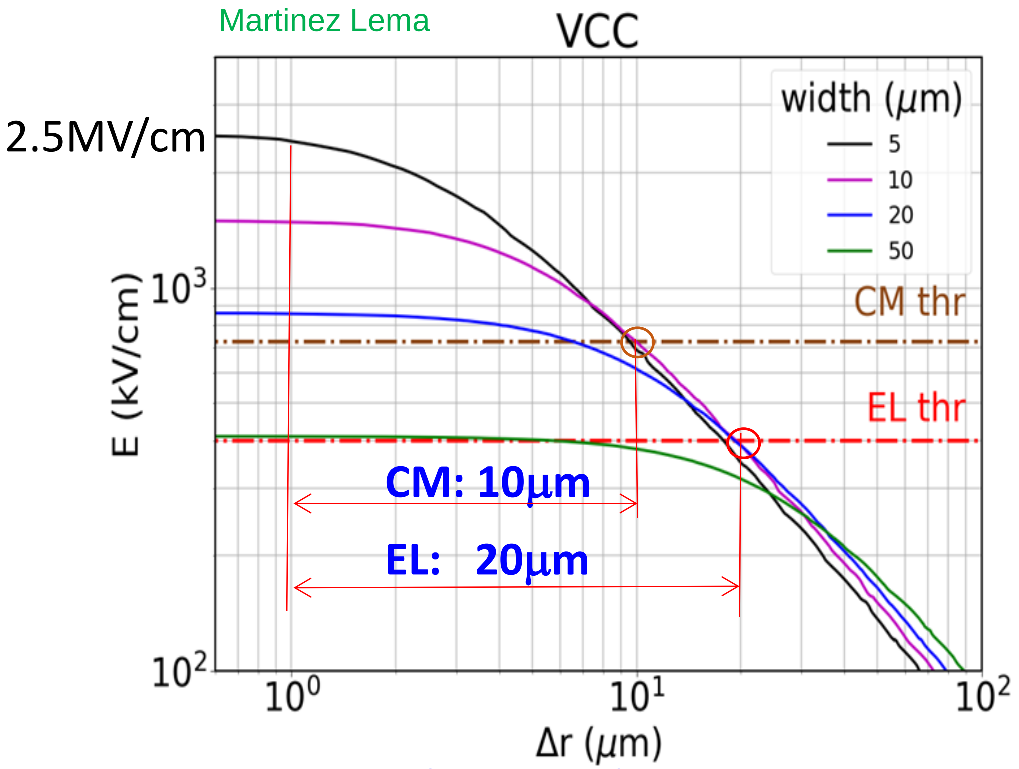
Benefit: spark-less.
The substrate separates strips from cathode plane

Field-line simulations: substrate 0.5mm; anode-strips 5μm; cathode-strips 200μm; drift-gap=1.9mm; strip pitch=1mm. Potentials: V_a=5KV; V_c=0; backplane: V_b=0; drift: V_d=-300V.

Simulated E vs distance from anode strip: MSGC vs VCC







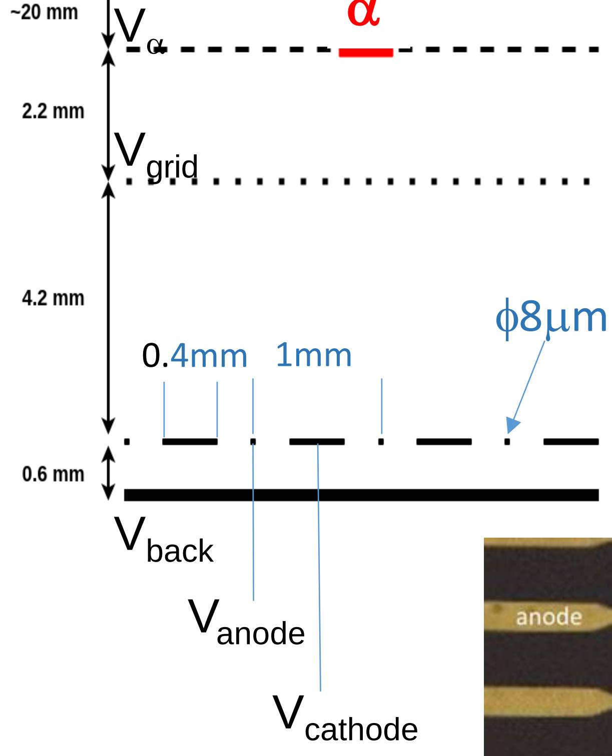
<u>crossing EL threshold</u> **~ 20μm from strip surface.** <u>Avalanche threshold</u> **~10μm from surface.** (thresholds: **Aprile 2014**)

E vs distance from strip: substrate 0.5mm; anode-strips 5-50μm; cathode-strips 200μm; drift-gap=1.9mm; strip pitch=1mm. Potentials: V_a=5KV; V_c=0; backplane: V_b=0; drift: V_d=-300V.

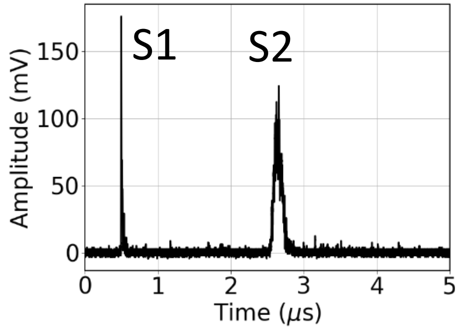
MSGC & VCC: similar results for **E** vs **Δr**: @ **5-10μm** anode strips, for **V_a= 5kV*** ***(5 kV not applicable in MSGC ➔ sparks)**
VCC: anode <u>strips insulated from cathode plane</u> ➔ V_a (VCC) certainly > V_a (MSGC) !!!

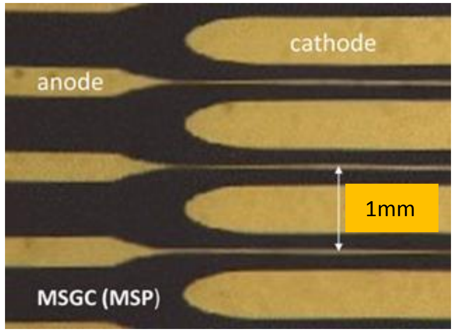
MSGC - Preliminary results

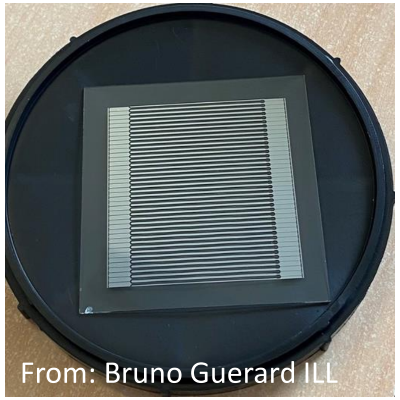
Setup



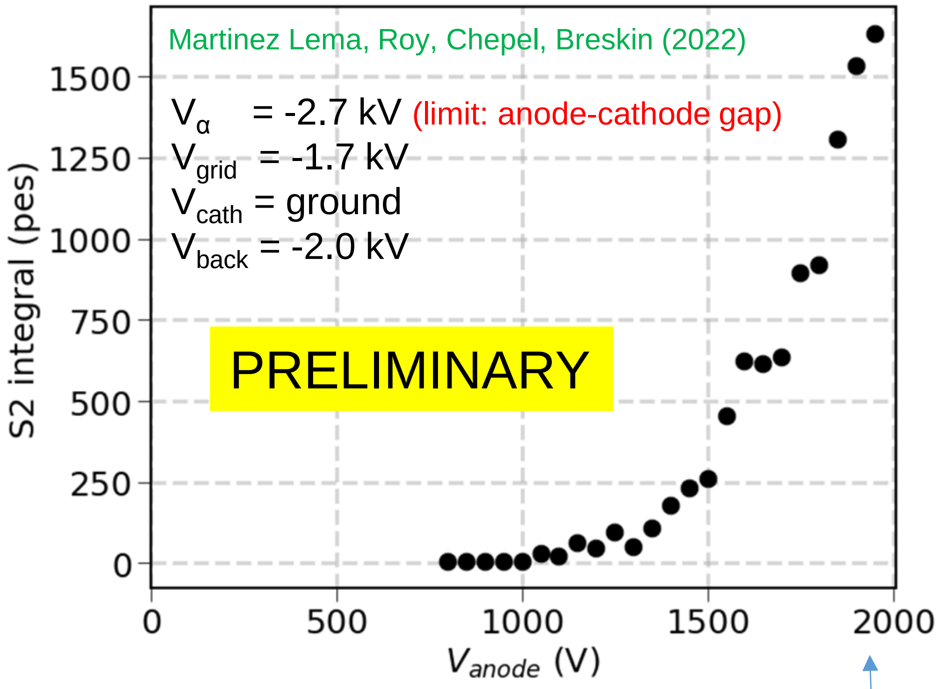
Single event







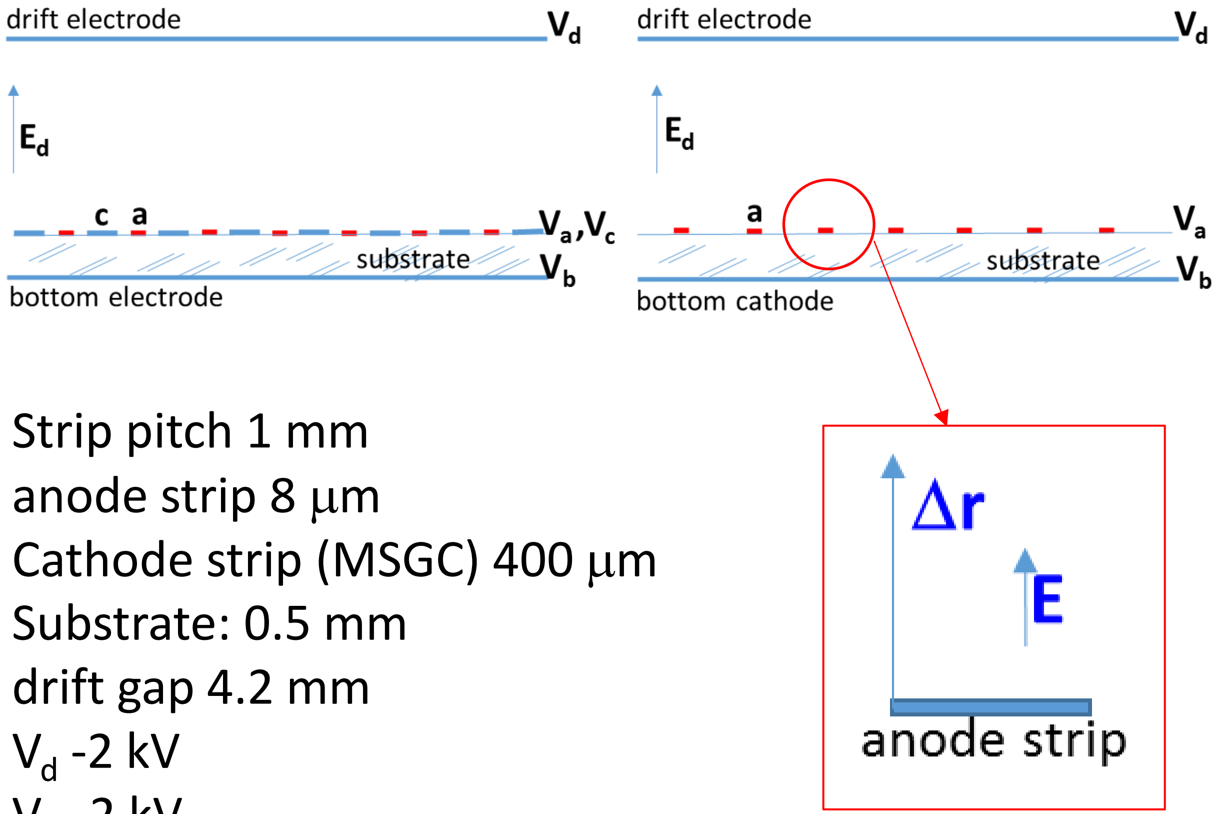
Average of S2 spectrum vs V_{anode}



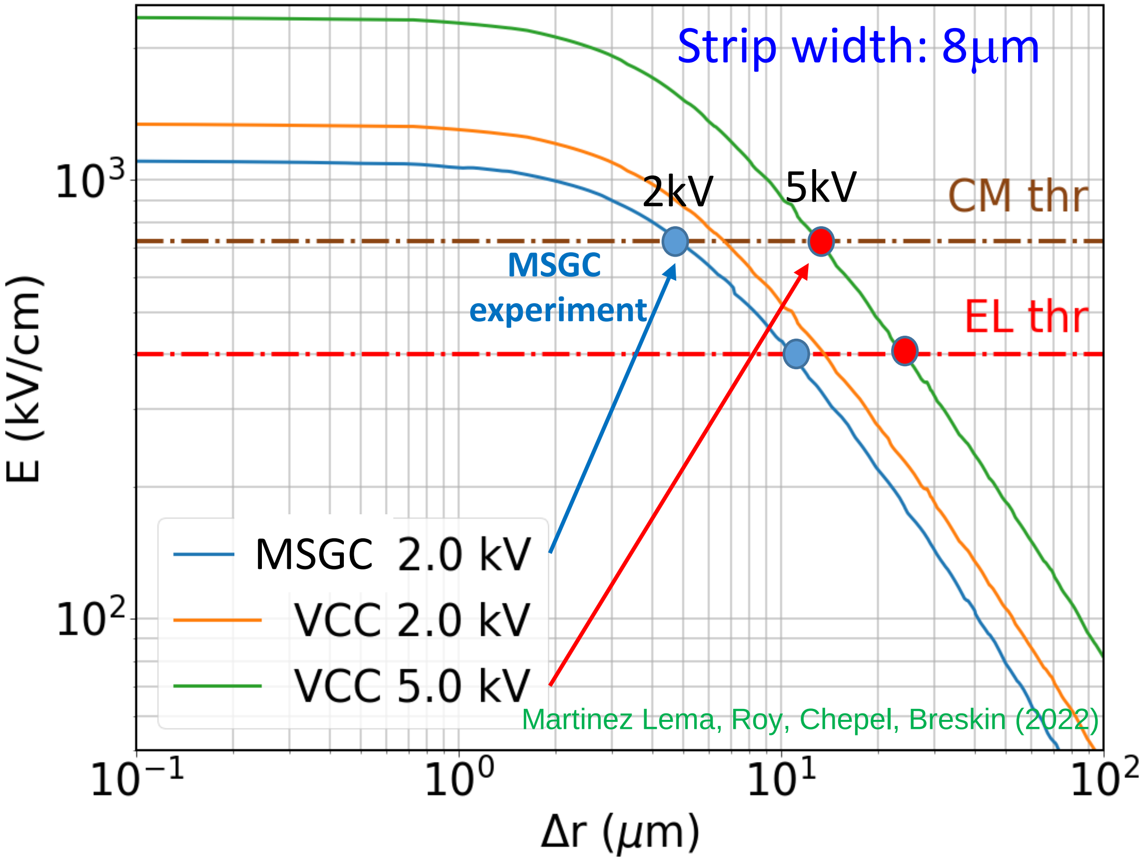
Ω ~ 6 %
T ~ 90%
QE ~ 40%
Q_{total} (α) ~ 1 fC
Y ~ 10 photons/e
@ 2.7 kV

Charge gain ~ 4
With α

MSP Simulations - EL & CM onset vs distance from strip - vs V_a

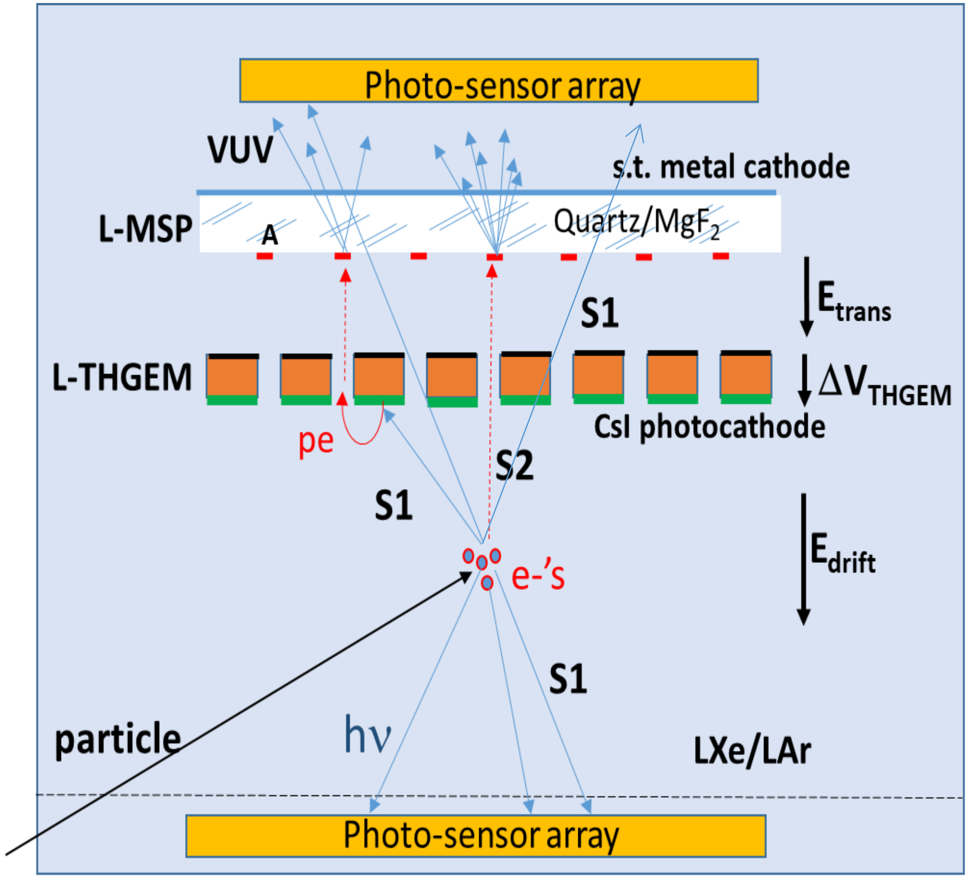


Strip pitch 1 mm
anode strip 8 μm
Cathode strip (MSGC) 400 μm
Substrate: 0.5 mm
drift gap 4.2 mm
V_d -2 kV
V_b -2 kV
V_c (in MSGC) 0 V
V_a variable



MSGC: V_a@2kV: CM starts ~4.8 μm; EL ~11 μm
VCC: V_a@5kV: CM starts ~**15 μm; EL ~25 μm**

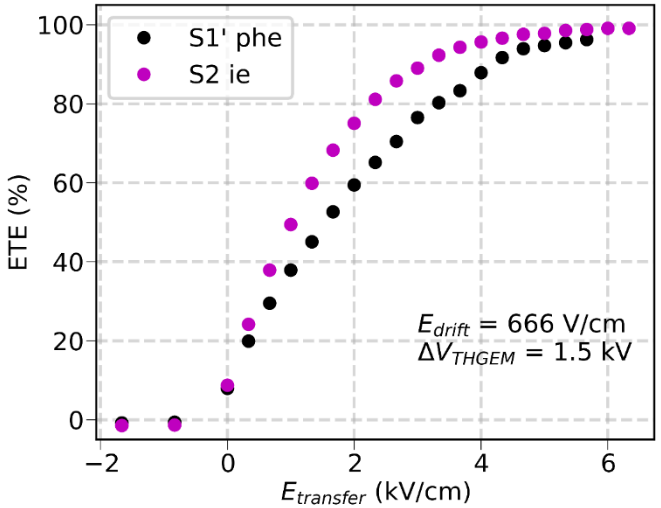
Single-phase with cascaded THGEM + MSP ➔ S1 & S2



- 2-stage TPC with CsI-coated **L-THEM + L-MSP.** here **L-VCC** with S.T. Cr\Ni strips on VUV- substrate.
- **S2 e$^-$ & S1 UV-pe$^-$** collected into L-THGEM holes & <u>efficiently</u>* transferred to the L-VCC.
- VUV photons emitted by **EL + small avalanche** near strips, are detected through the substrate, by top photo-sensors.
- Other fraction of S1 photons – are detected by bottom photo-sensors or reflected by a mirror-cathode to the CsI.
- Option: top L-THGEM surface can be reflective or coated with a WLS (➔ visible-range photo-sensors, glass substrate).

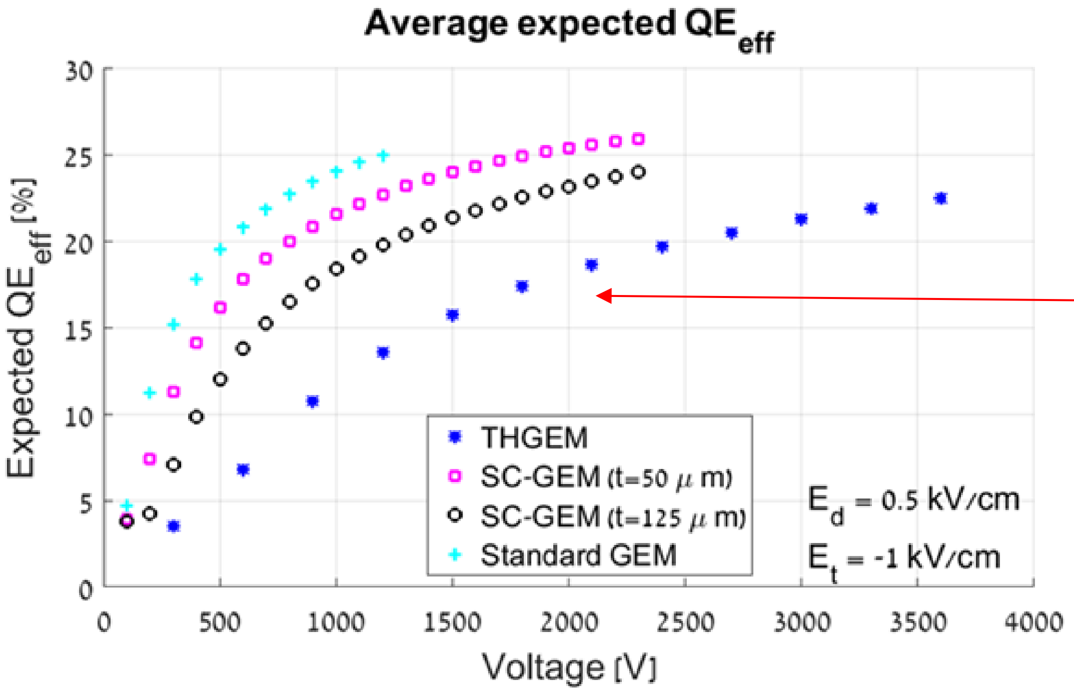
* Experimental Transfer Efficiency of e$^-$ and pe$^-$ through THGEM holes in LXe.

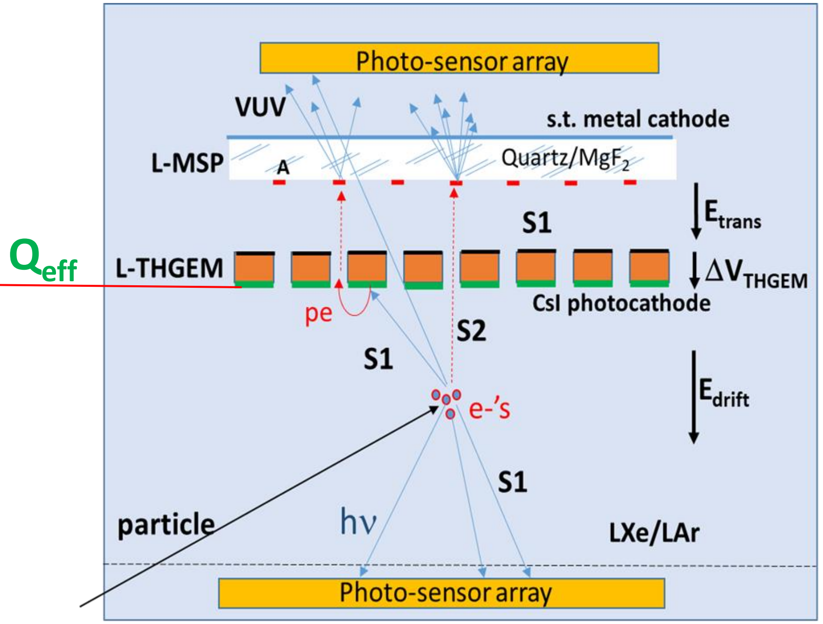
Talk by ROY



Effective quantum efficiency Q_{eff} of CsI in LXe

GEM, SC-GEM, THGEM

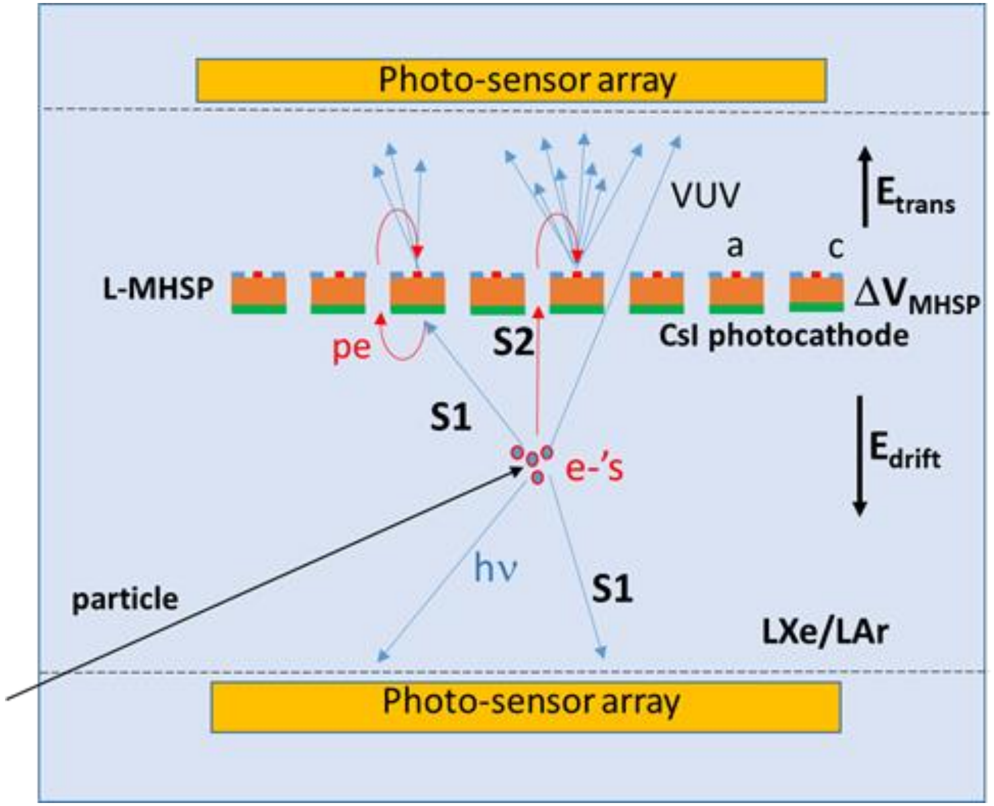


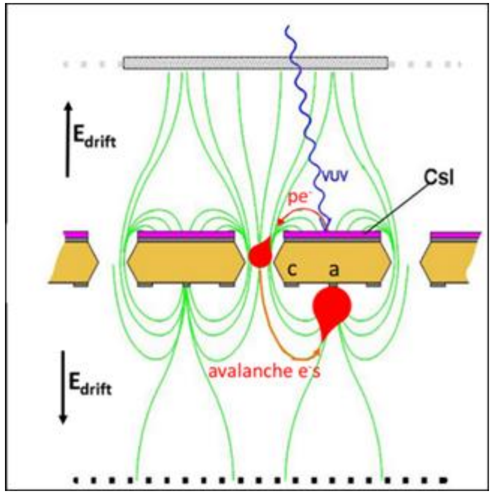


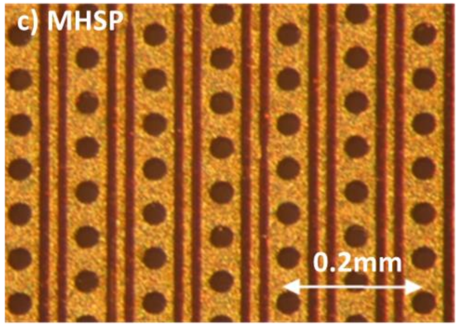
ERDAL 2021 https://jinst.sissa.it/jinst/theses/2021_JINST_TH_002.jsp

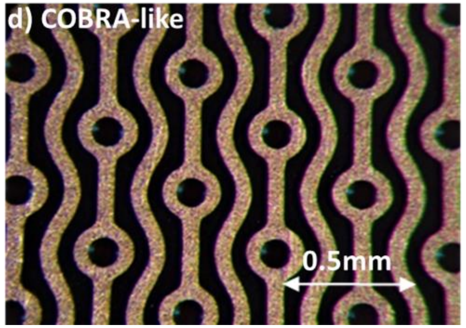
Expected average QE_{eff} in LXe across the entire surface of an electrode, as a function of voltage across the electrode. They were computed (using COMSOL®) for different perforated electrodes; electric field values: E_d=0.5 kV/cm and E_t=-1 kV/cm.

Single-phase with single Micro Hole & Strip Plate (MHSP)







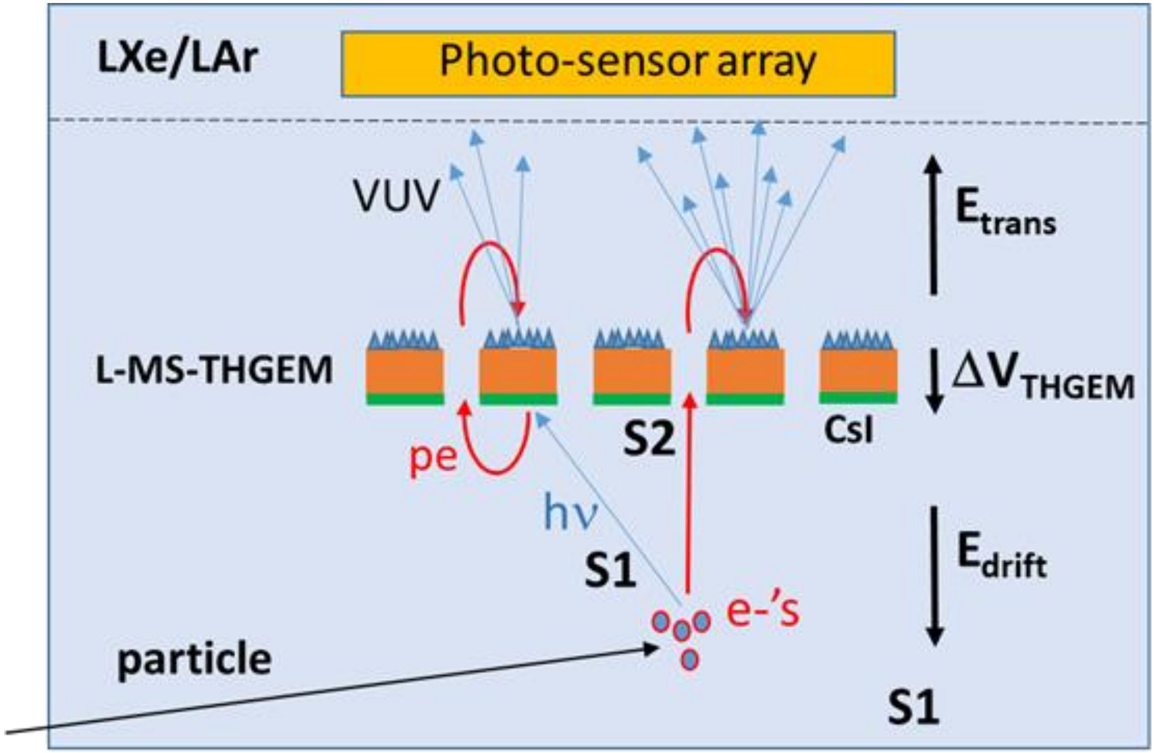


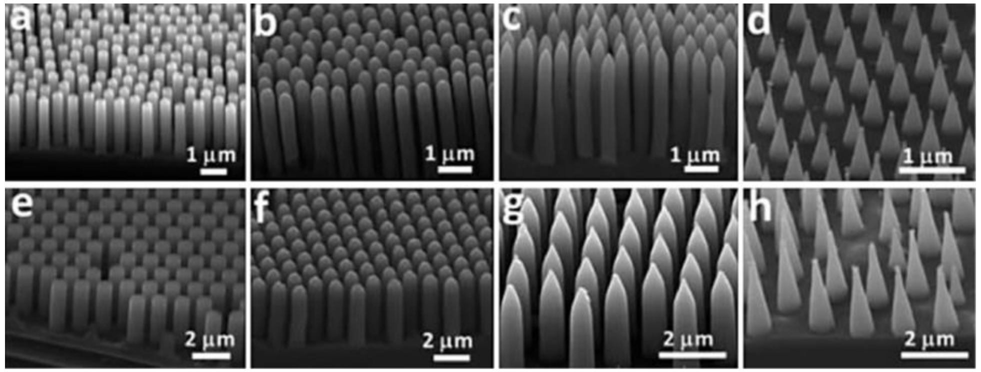
MHSP: Veloso, Rev Sci. Instr. 71, 2371 (2000)
https://doi.org/10.1063/1.1150623

Current technologies ➔ few-μm strips possible

- A single-phase TPC with (here) a CsI-coated **L-MHSP**.
- Both S2 e- & VUV photoelectrons are collected into the L-MHSP holes, drift to MHSP anode strips.
- VUV photons by EL + small avalanche near strips, are detected by the top photo-sensors.
- Other fraction of S1 photons - detected by bottom photo-sensors.

Single-phase with Micro-structured electrode



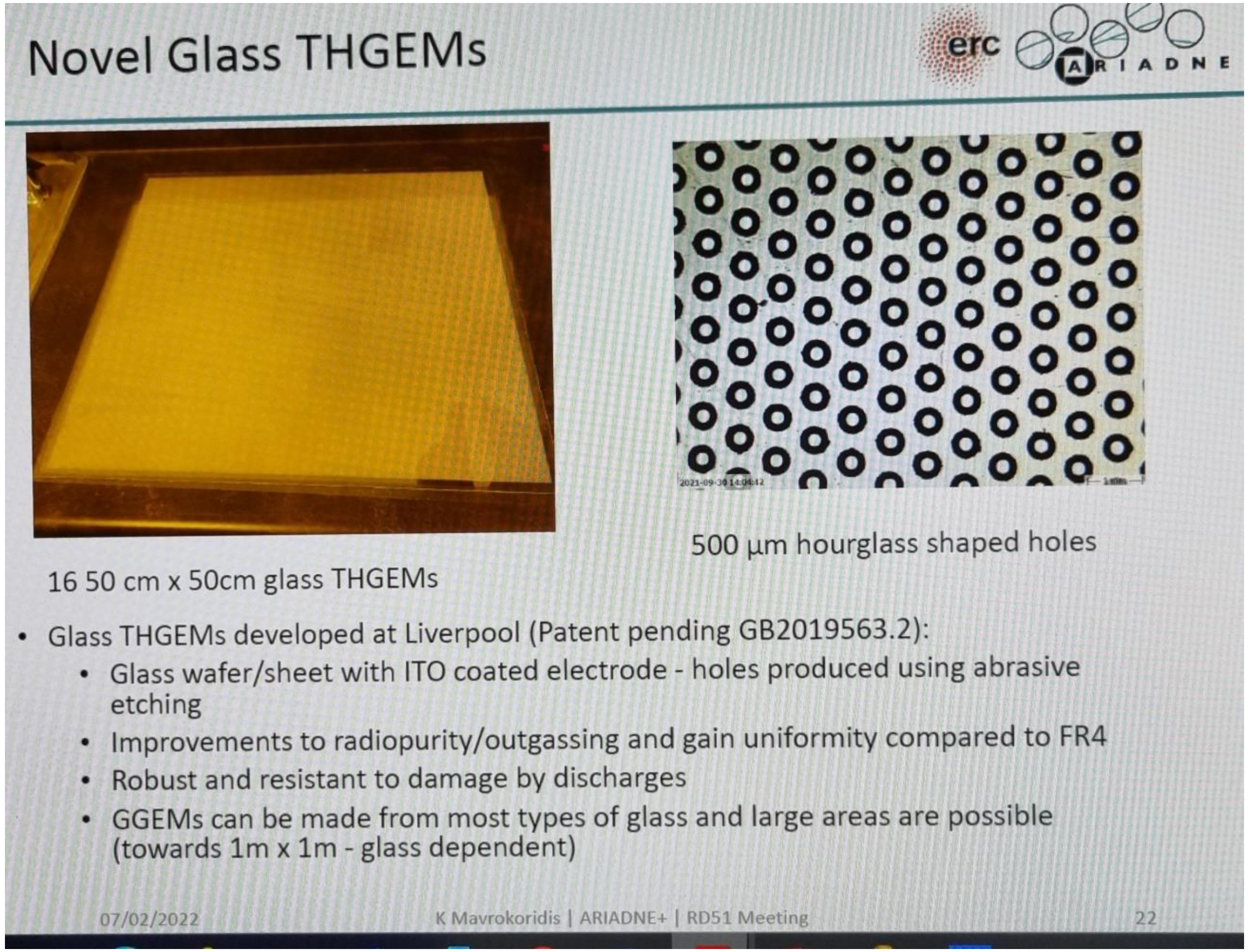


Hao Lin https://doi.org/10.1039/C3TA11889D

- A single-phase TPC with a Liquid micro-structured THGEM multiplier (**L-MS-THGEM**) coated with CsI. Both S2 ionization electrons and S1 VUV photoelectrons are collected into the holes, drift across the THGEM electrode, towards the micro-structured top surface.
- VUV photons emitted by EL + small avalanche at the vicinity of the "anode tips", are detected by the top photo-sensors.
- Other fraction of S1 photons are detected by bottom photo-sensors (or mirror)

Can we form large-size patterned electrodes?

ARIADNE LAr TPC with optical readout. **50x50cm² glass THGEM (GTHGEM)**



Lowe et al. Appl. Sci. **2021**, 11(20), 9450; https://doi.org/10.3390/app11209450

- So far, borofloat 33 glass and fused silica glass electrodes (the latter of *higher radio purity*) produced by abrasive formation of sub-mm holes.
- Electrode surfaces coated by resistive ITO film;
- Can be patterned, by laser techniques – e.g. to form **COBRA-like patterns**.
- Thin anode strips and other metallic patterns currently formed in industry: inkjet & photolithographic techniques. (few-micron thin strips on relatively large areas (up to 24"x 24") already formed on a variety of substrate materials.

See refs in https://doi.org/10.1088/1748-0221/17/08/P08002

Could MPGDs revolutionize noble-liquid detectors?

Single-phase TPCs:

- *Many open questions…*
- *Simulations & exp. R&D on MSPs configurations (LAr, LXe)*
- *R&D on nanostructures*
- *R&D on stability of VUV-photocathodes in noble liquids*
- *Technologies: radio-clean materials, production methods, modularity…*

Dual-phase TPCs:

Talks by CHEPEL, ROY, TESI

e & photon multiplier & photo-sensor module

Open to collaborations!
Students and postdocs welcome!

Some projects currently supported by RD51 Common Fund

Thank you