New *Single-Phase* Concepts: S1 & S2*

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Remark: see two talks on ***dual-phase*** novelties by **Chepel** and **Martinez Lema**

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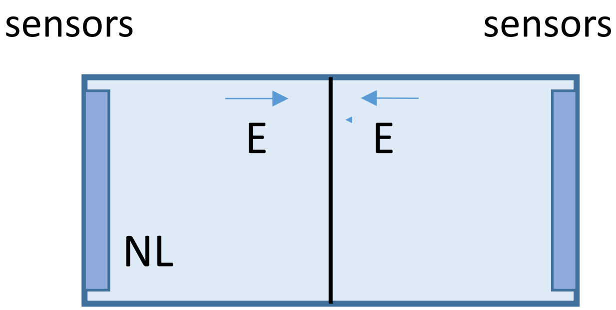
* http://arxiv.org/abs/2203.01774
https://doi.org/10.1088/1748-0221/17/08/P08002

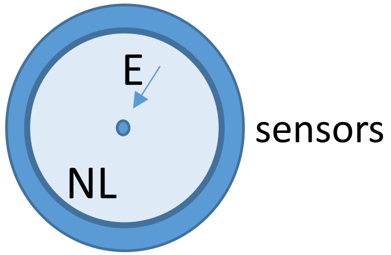
Why single phase?

- To overcome current expected problems with large dual-phase dets':
  ➔ liquid-gas interface instabilities, gas gap variations, electron extraction efficiency

- Only single-phase can be **"face-to-face"** and **"horizontal"**:
  ➔ Half of HV for equal field; avoids effects of sporadic bubbles



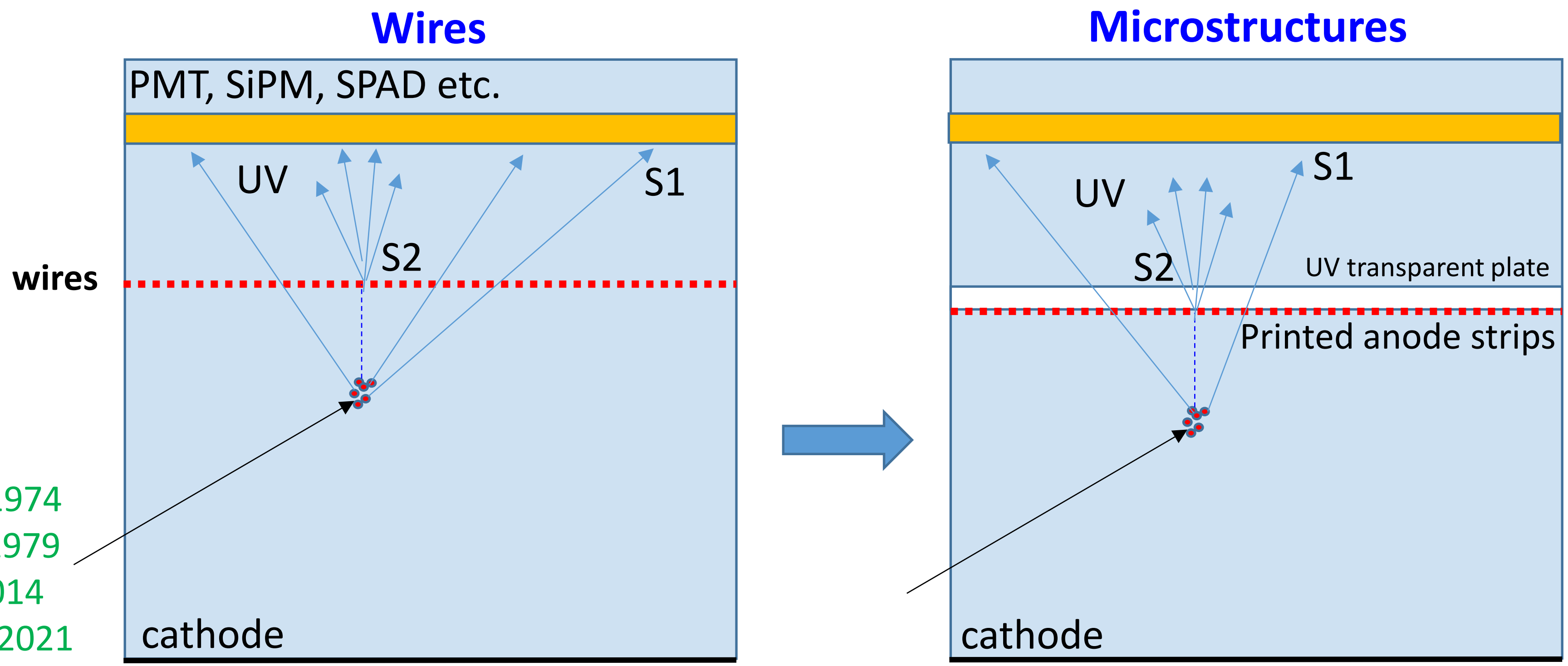
- "**Radial** geometry" possible



- New concepts, technologies:
  Expected: High photo-yields (also for S1)
  ➔ reduced dark-current issues ➔ "cheaper" photo-sensors (SiPM, CMOS…)
  ➔ lower detection thresholds

From wires to microstructures

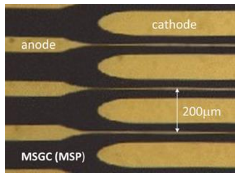
Examples: here multiplier senses **S2 ONLY: EL & charge multiplication (CM)**



Wires in LXe:

Derenzo PRA 1974
Masuda NIM 1979
Aprile JINST 2014
Brown LIDINE 2021

Microstrip plates & more!



Oed 1988

MSP LXe: CM~10

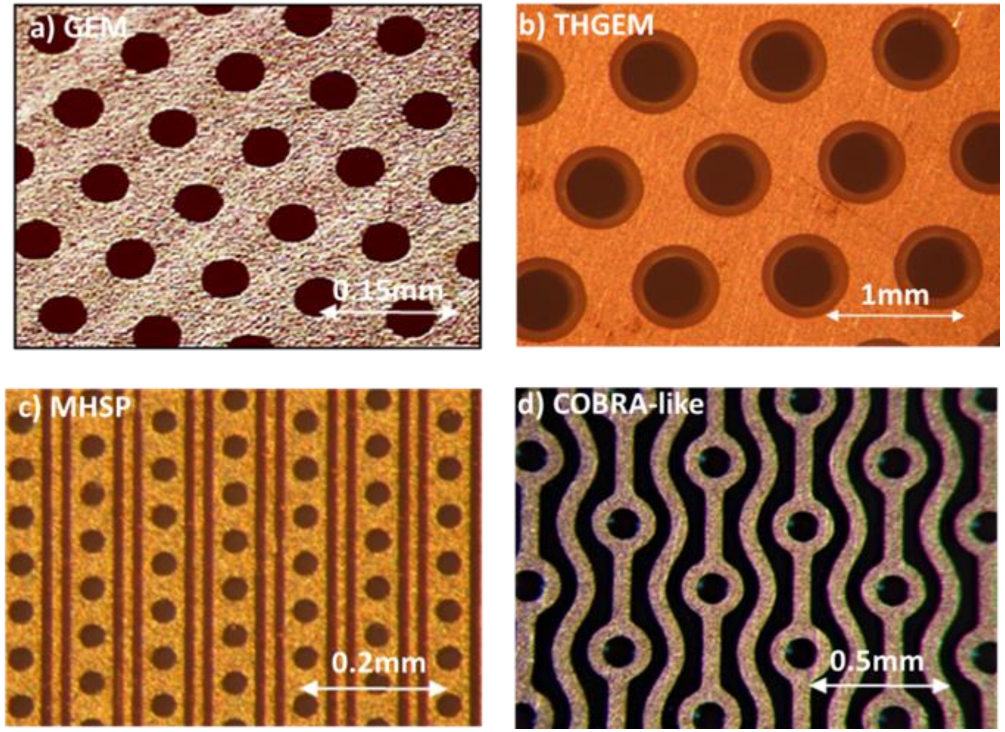
Policarpo et al. NIMA 1995

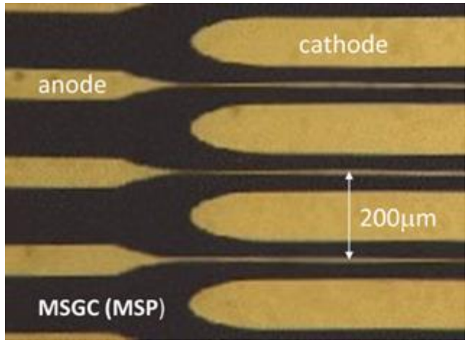
<u>Goals</u>: - Devise other solutions than EL/CM (**S2**) on wires (sagging, staggering)

- Search for robust **<u>S2-e⁻ & S1-photon</u>** recording modules

General idea:
Micro-Patterned & Nanostructured electrodes

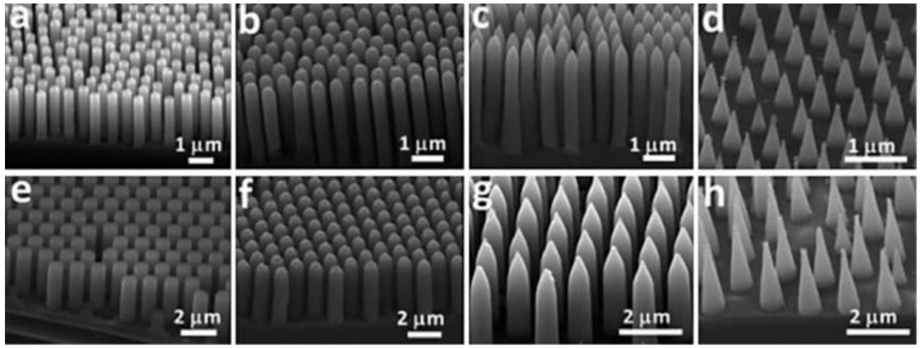
Make use of known and yet unknown electrodes to reach high photoyields:



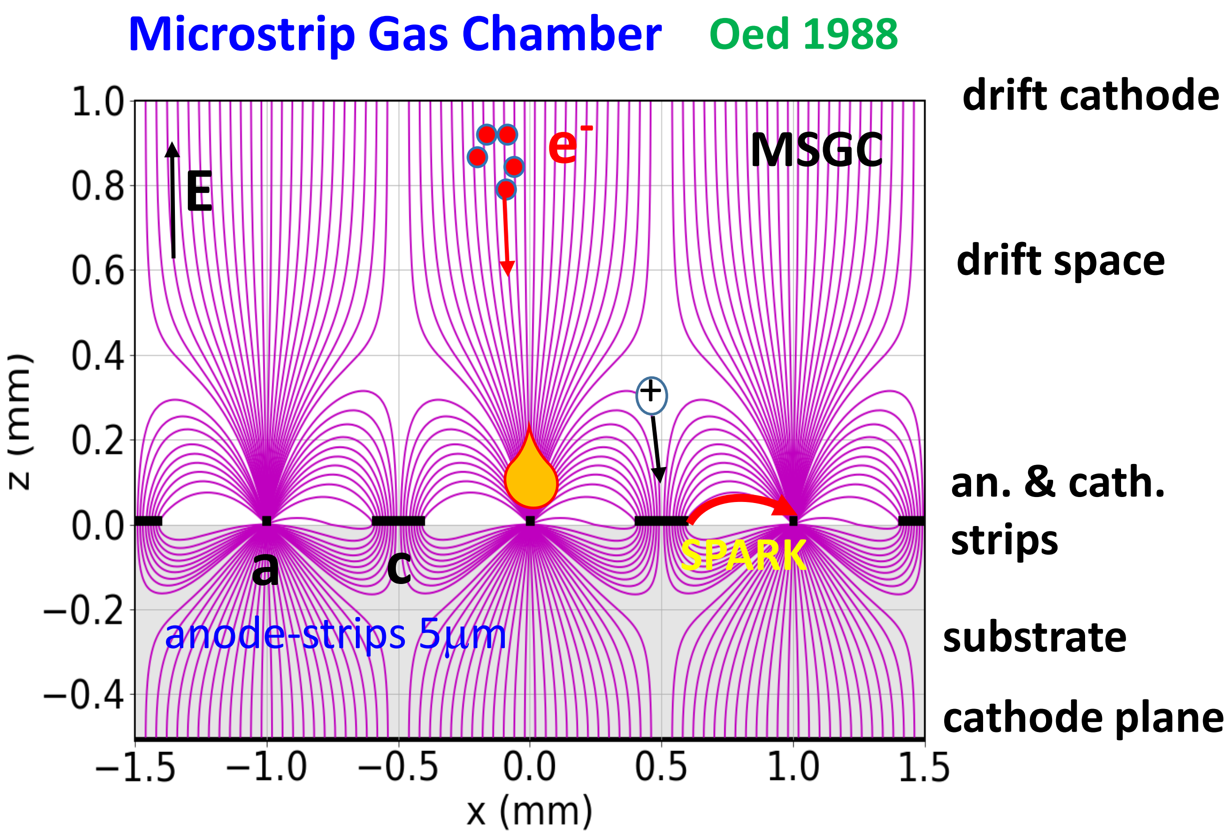


SEM images of highly regular: ***nanopillar, nanorod, nanopencil & nanocone Si arrays****,*

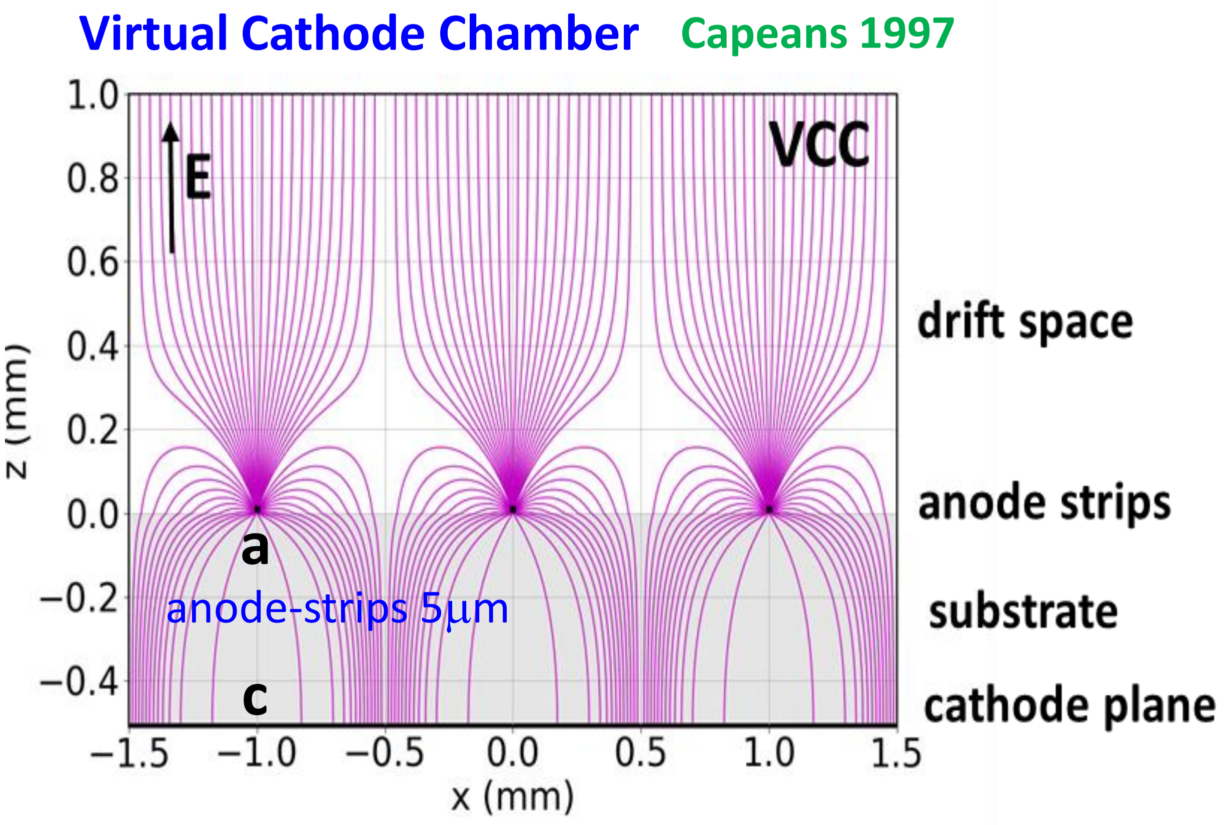
produced by wet-etching.



MSPs: MSGC & VCC



Weakness: **sparks a-c** ➔ limit HV

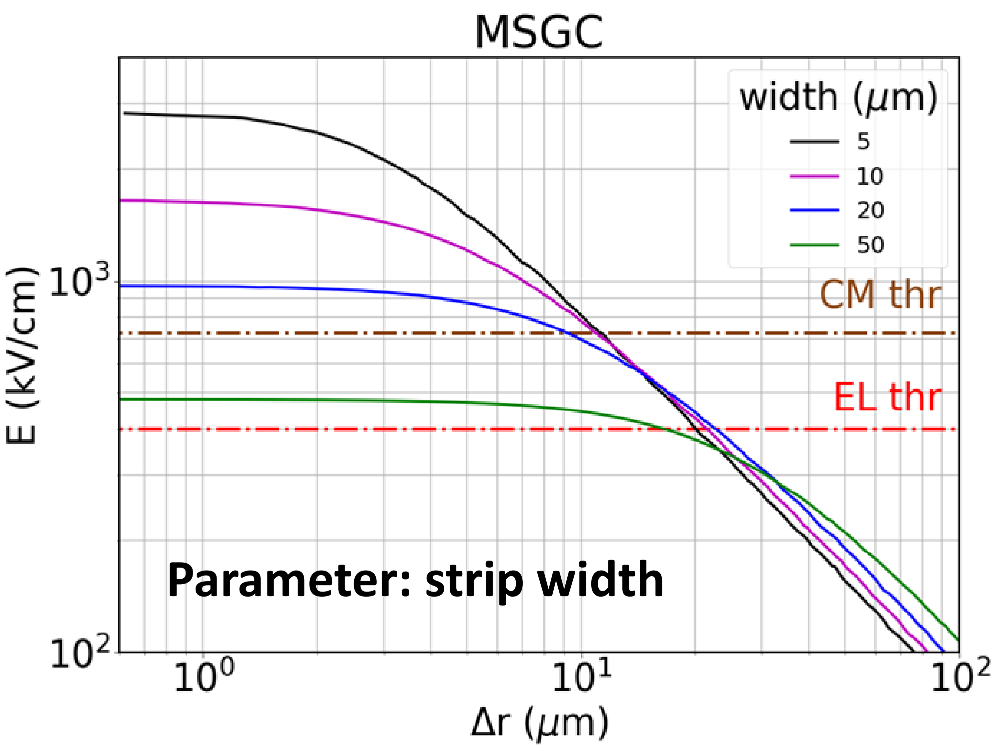


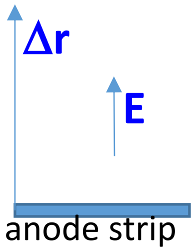
Benefit: **spark-less**.

The substrate separates strips from cathode plane

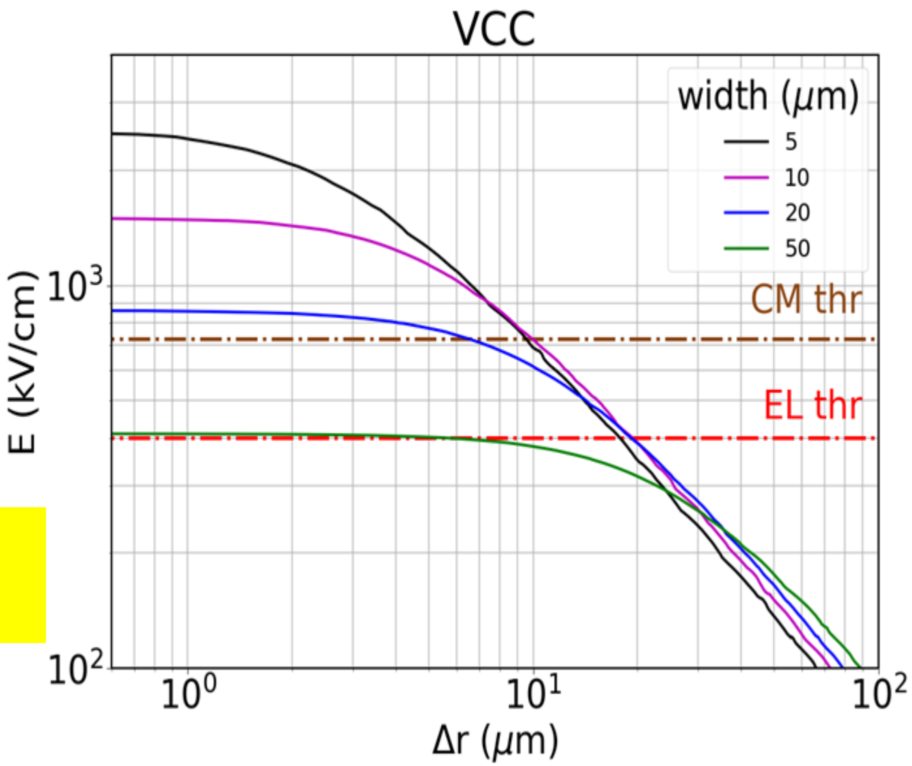
Field-line simulations: substrate 0.5mm; anode-strips 5μm; cathode-strips 200μm; drift-gap=1.9mm; strip pitch=1mm. Potentials: V_a=5KV; V_c=0; backplane: V_b=0; drift: V_d=-300V.

Simulated E vs distance from anode strip: MSGC vs VCC





CM: exponential growth with field

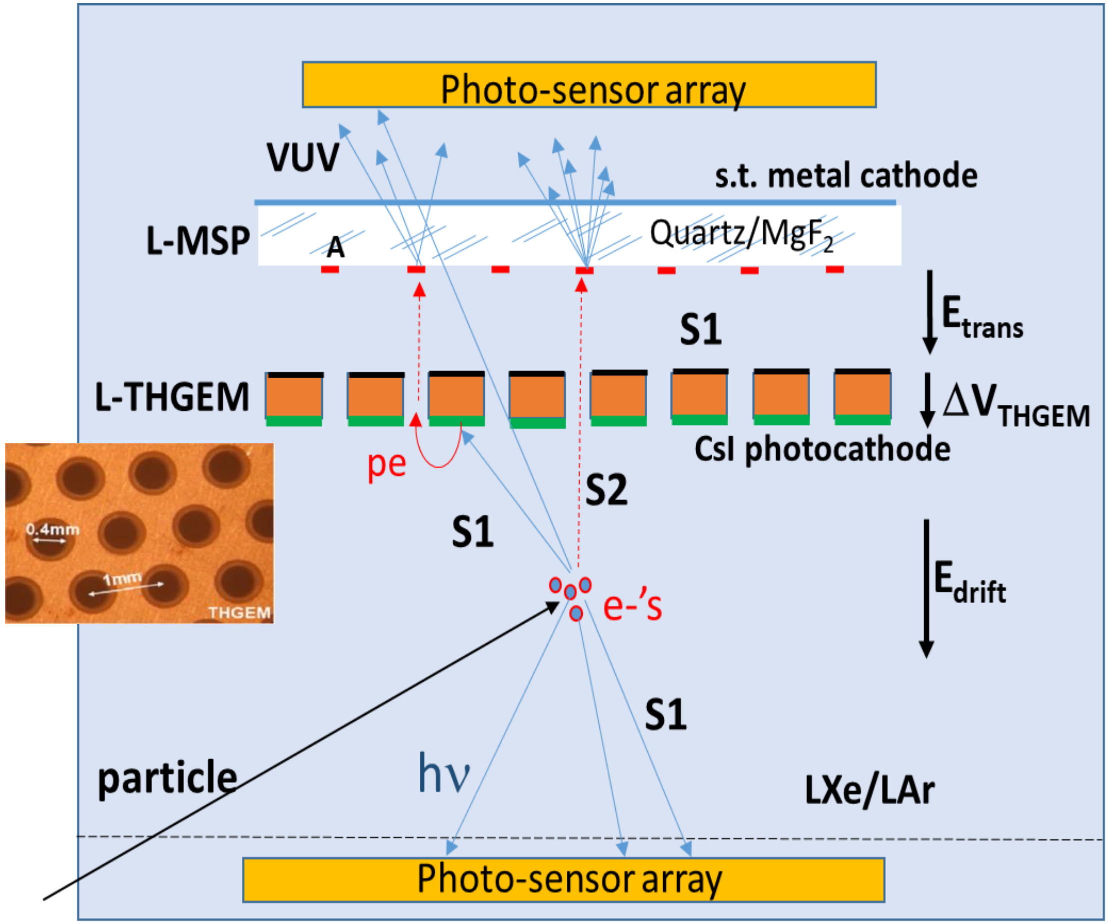


E vs distance from strip: substrate 0.5mm; anode-strips **5-50µm**; cathode-strips 200µm; drift-gap=1.9mm; strip pitch=1mm. Potentials: **V_a=5KV**; V_c=0; backplane: V_b=0; drift: V_d=-300V.

MSGC & VCC: ~same results but **5kV not applicable in MSGC (sparks)** ➔**V_a (VCC) > V_a (MSGC) !!!**
➔ EL threshold **~ 20µm from strip surface.** CM threshold **~10µm from surface.** (thresholds: **Aprile 2014**)

Single-phase S1 & S2 - proposed concepts

Single-phase I: cascaded THGEM + MSP ➔ S1 & S2

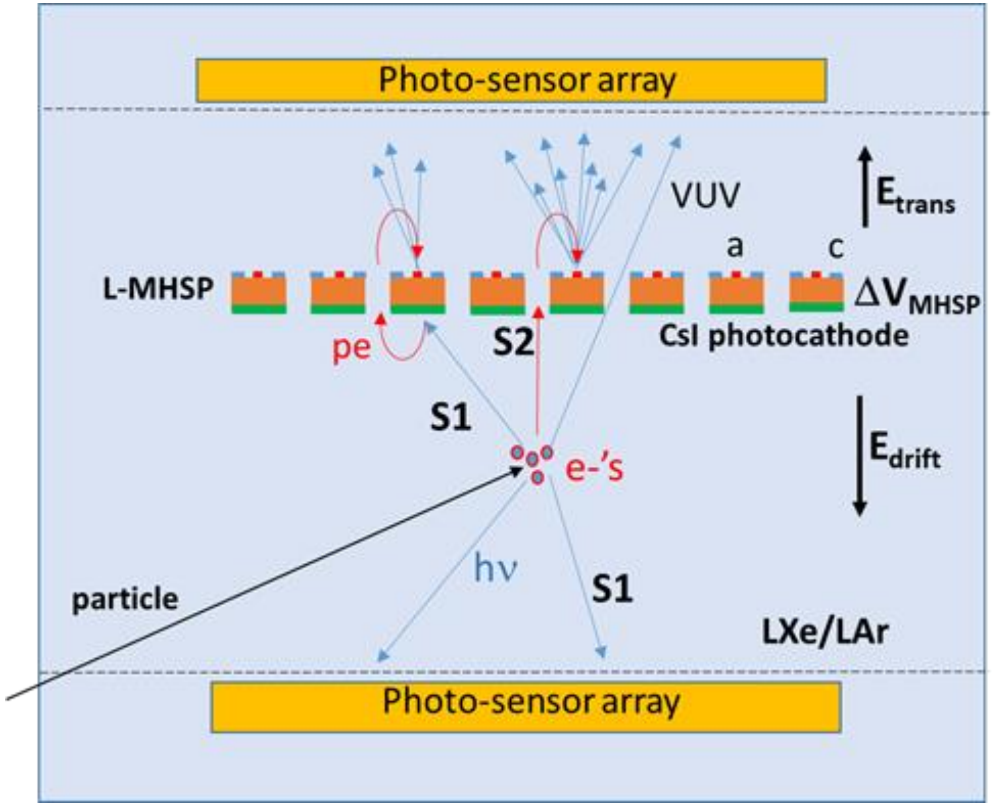


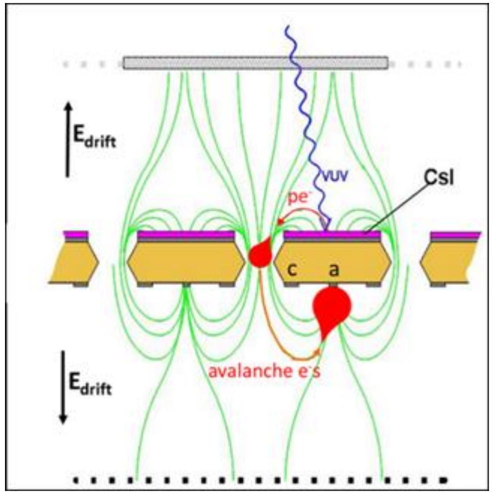
- Single-phase two-stage TPC with **CsI-coated L-THEM + L-MSP (here L-VCC)** strip multiplier;
- The L-VCC has semi-transparent Cr or Ni electrodes on VUV-transparent substrate.
- **S2 e- & S1 UV-pe** (CsI) are collected by L-THGEM holes and efficiently transferred to the L-VCC anode strips. **(MARTINEZ LEMA talk LIDINE22)**
- VUV photons from EL+small-avalanche near strips, are detected through the substrate.
- A fraction of S1 photons – are detected by bottom photo-sensors or reflected by a mirror-cathode (not shown) to the CsI.

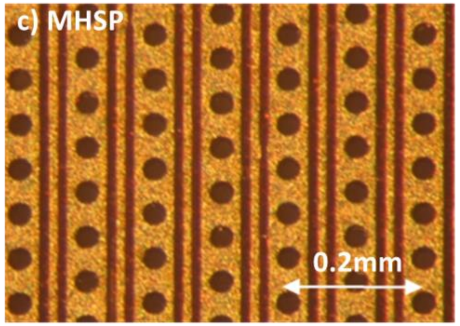
CsI QE on perforated electrodes: about 25%

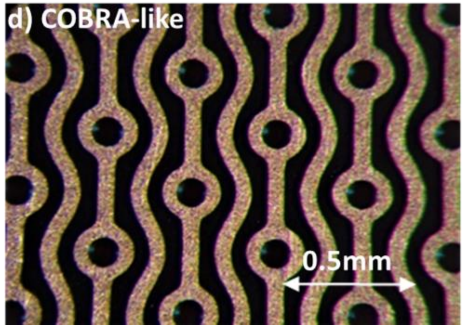
ERDAL 2021 https://jinst.sissa.it/jinst/theses/2021_JINST_TH_002.jsp

Single-phase II: Micro Hole & Strip Plate (MHSP) ➔ S1 & S2







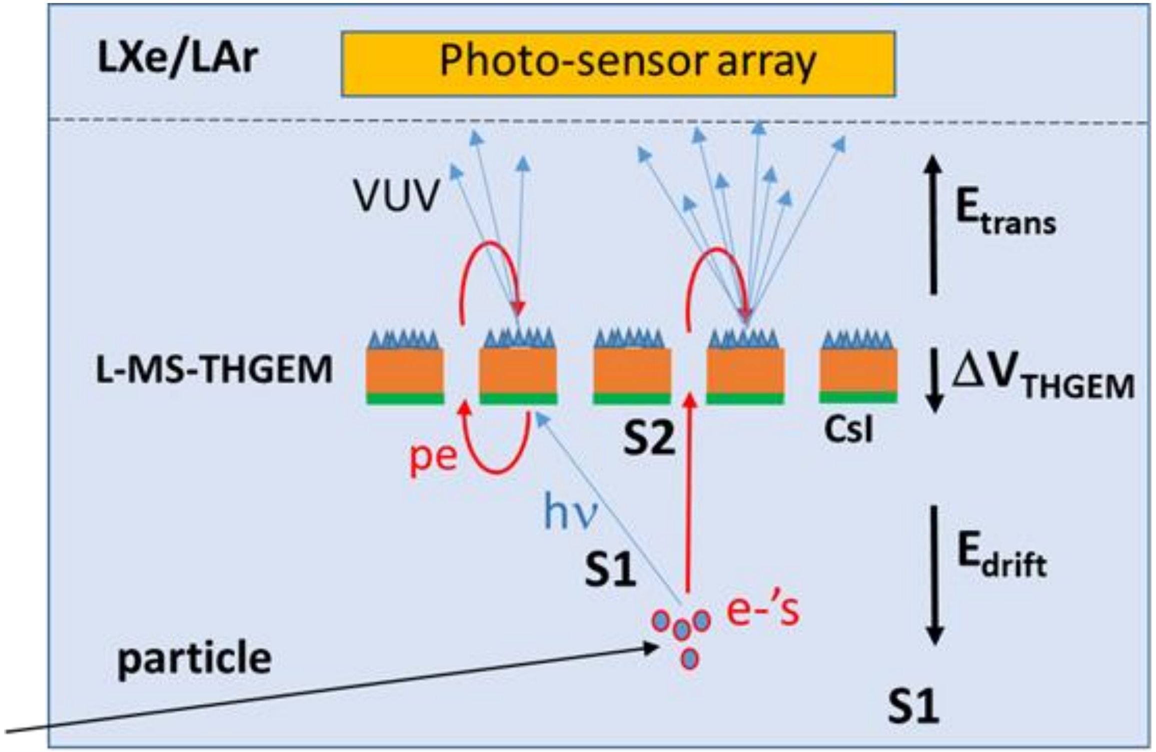


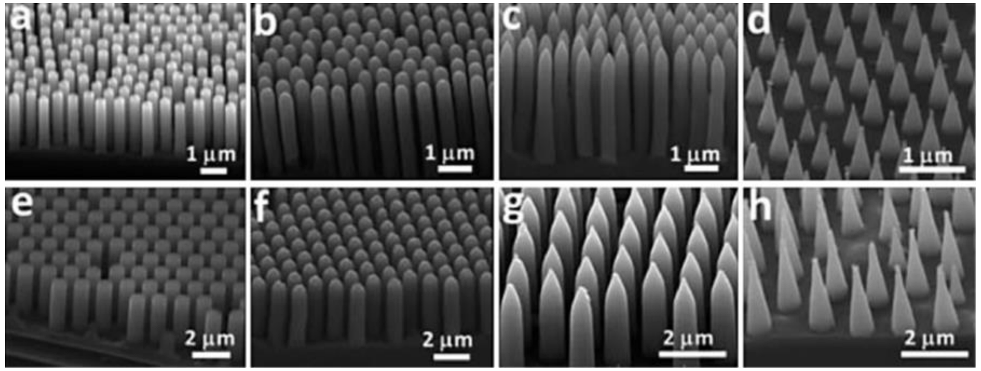
MHSP: Veloso, Rev Sci. Instr. 71, 2371 (2000)
https://doi.org/10.1063/1.1150623

Current technologies➔ few-μm strips

- 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 (or reflected by a mirror cathode).

Single-phase III: Micro-structured electrode➔ S1 & S2



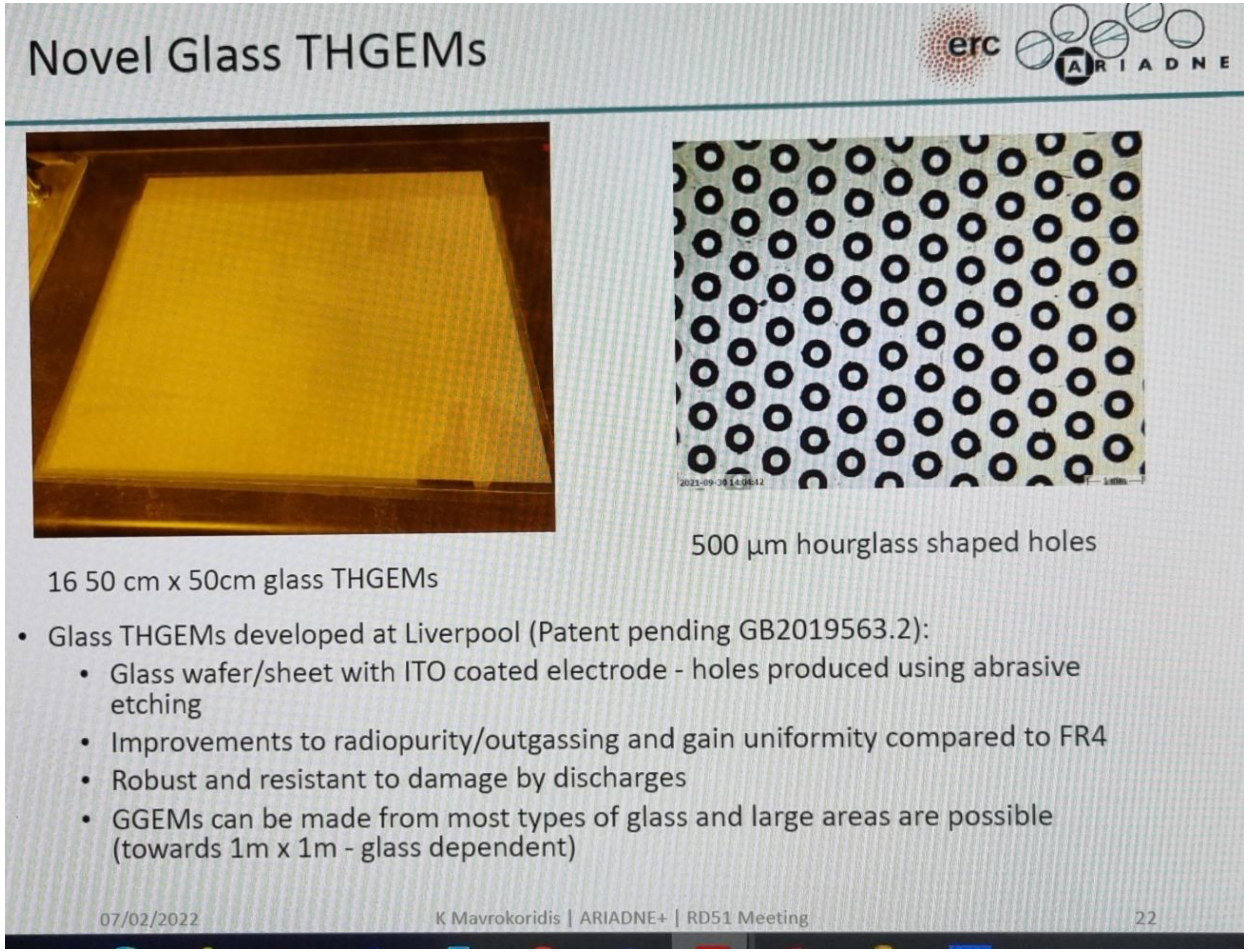


Hao Lin https://doi.org/10.1039/C3TA11889D

- A single-phase TPC with a Liquid microstructure-coated 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

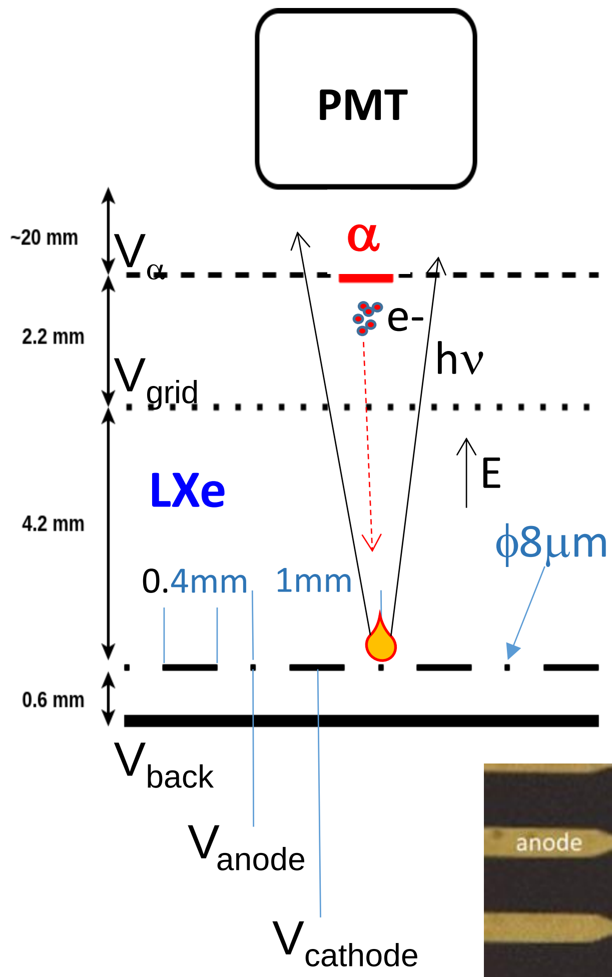
- So far, borofloat 33 glass and fused silica glass electrodes (the latter of *higher radio purity*) produced by abrasive formation of sub-mm holes.
- Electrode surfaces coated by resistive ITO film;
- Can be patterned, by laser techniques – e.g. to form **COBRA-like patterns**.
- Thin strips and metallic 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

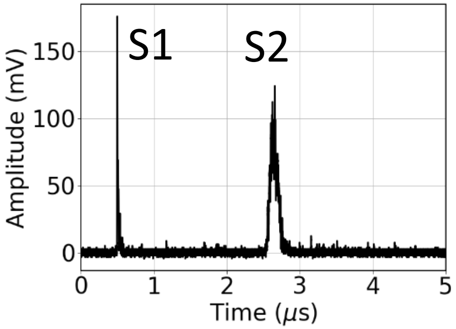
Very Preliminary results

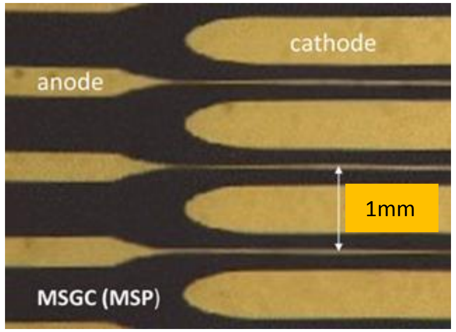
Microstrip Plate - Preliminary results

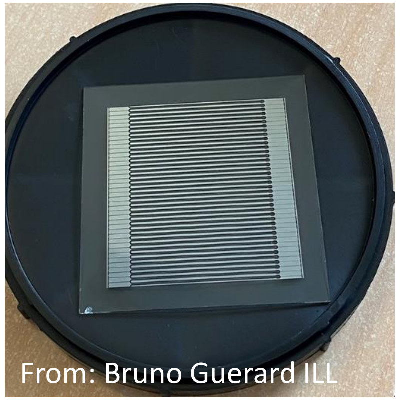
Setup



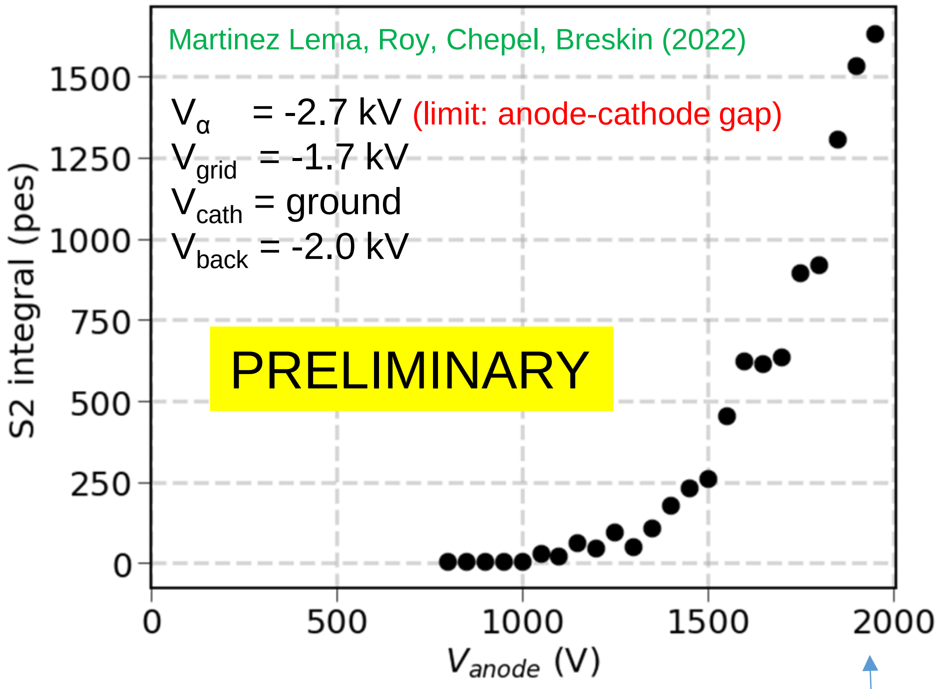
Single event







Average of S2 spectrum vs V_{anode}

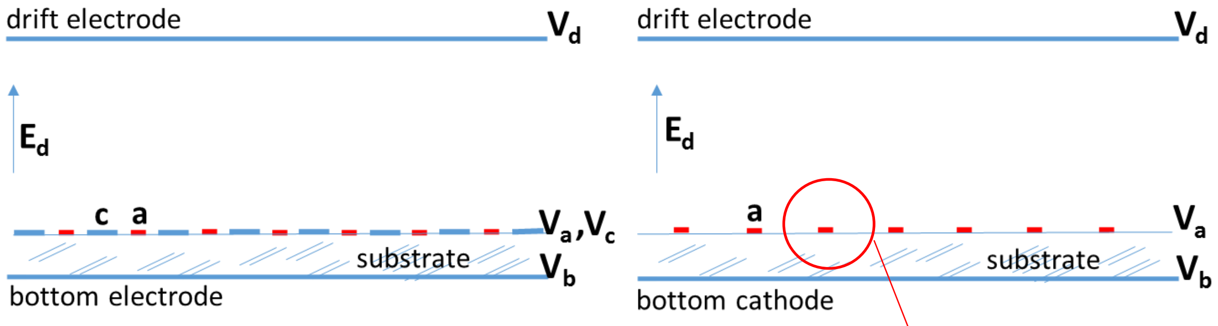


$\Omega \sim 6$ %
T ~ 90%
QE ~ 40%
Q_{total} (α) ~ 1 fC
Y ~ 10 photons/e⁻

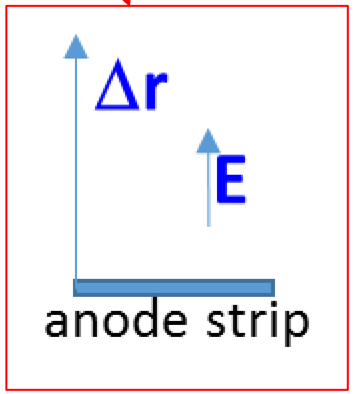
Charge gain ~ 4
MSGC spark limit)

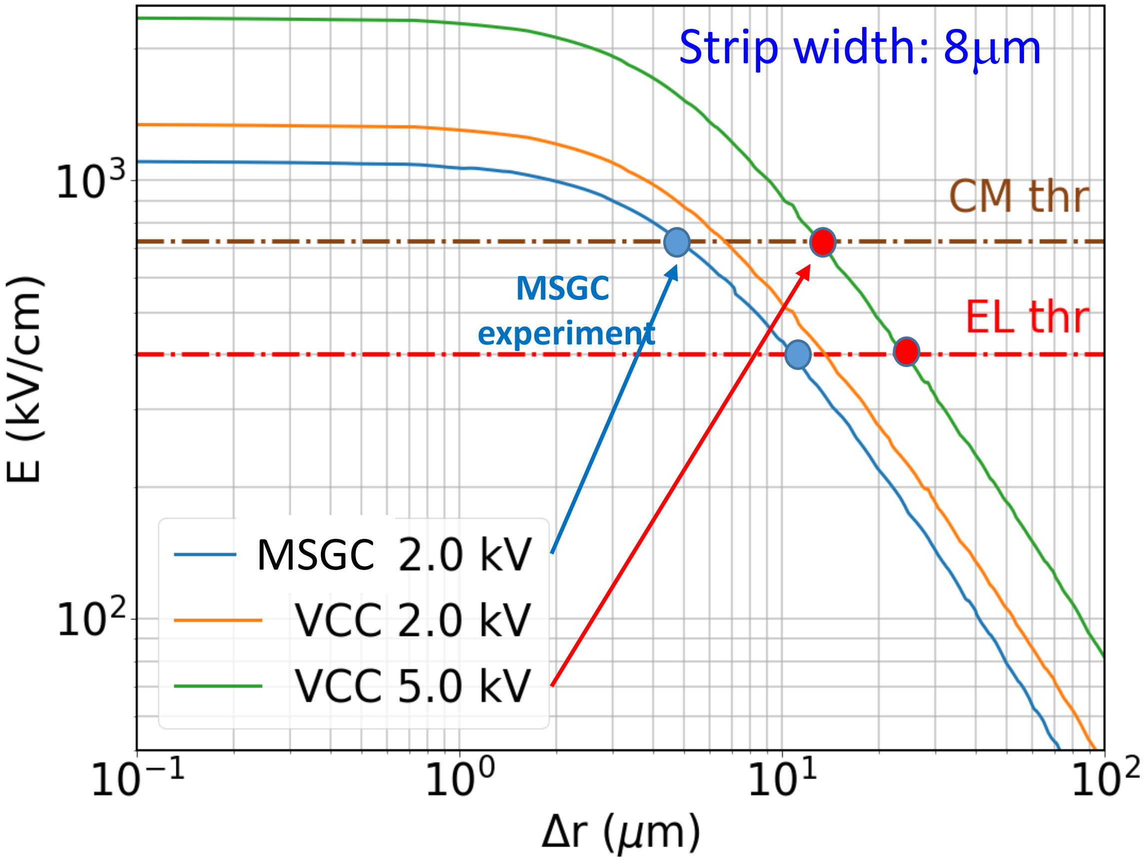
Reminder:
MSP LXe: CM~10
Policarpo et al. NIMA 1995

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**

Summary & Status:

- New single-phase concepts combining micro-patterned strips, microstructures, hole-multipliers and VUV-photocathodes.
- Sensitive to e- & photons ➔ S1 & S2
- High photoyields/e- expected ➔ "easier" for photo-sensors (reduced dark-current issues)
- No "mechanical & electrostatic problems expected (e.g. as of wires)
- **Proof-of-principle**
  ➔ MSGC **preliminary** photoyield ~ **10 photons/e** @ charge gain=4 (a-c HV limits)

- *Many open questions…*
- *Simulations & exp. R&D on MSPs configurations (LAr, LXe)*
- *Planned R&D on micro- & nanostructures*
- *Planned R&D on stability of VUV-photocathodes in noble liquids*
- *Sensor modules design (multiplier/photo-sensors)*

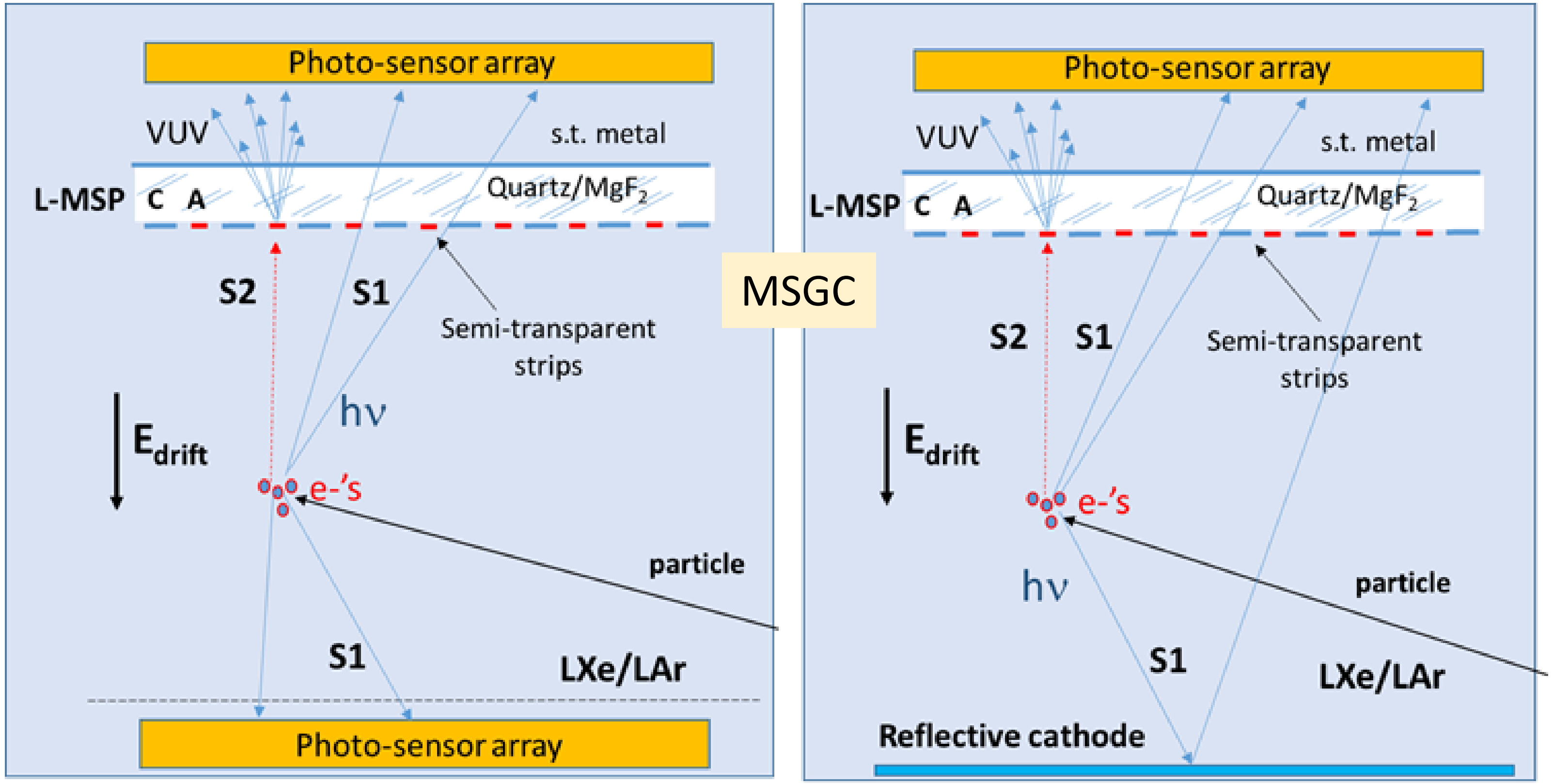
- **Open for collaborations**

Thank you

Backup slides

Single-phase with Micro Strip Plates (MSP)

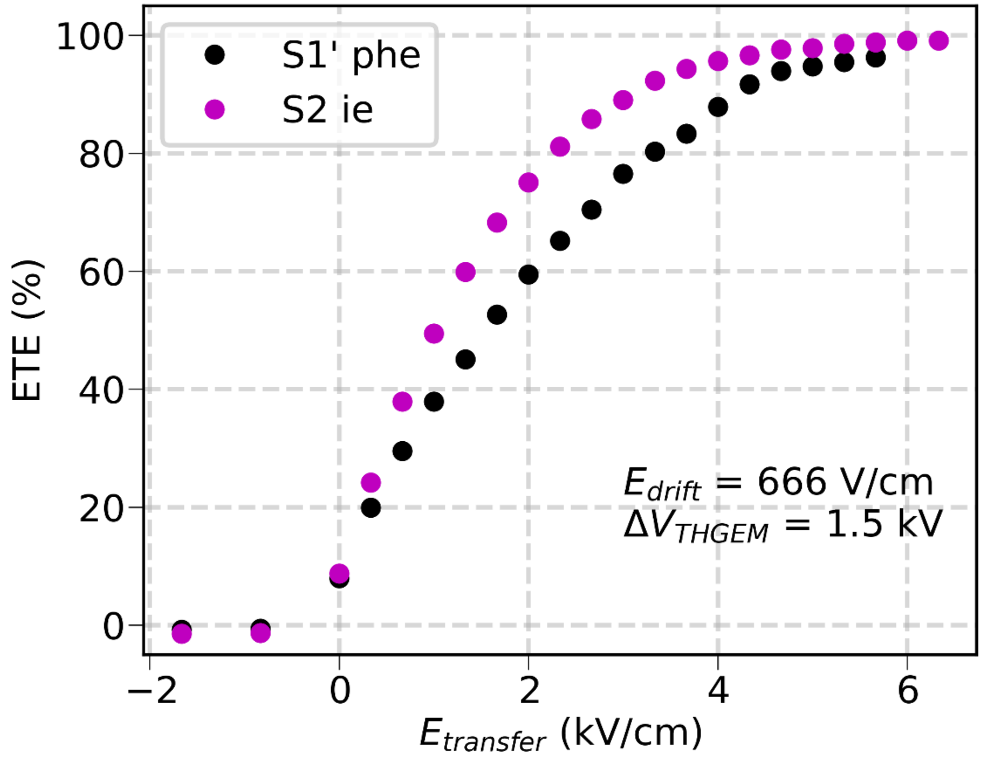
S2: **EL+avalanche** on strips. S2 Photons detected through VUV-transparent substrate
S1: photons detected (no amplification) by top and bottom photo-sensors (bottom can be replaced by mirror)

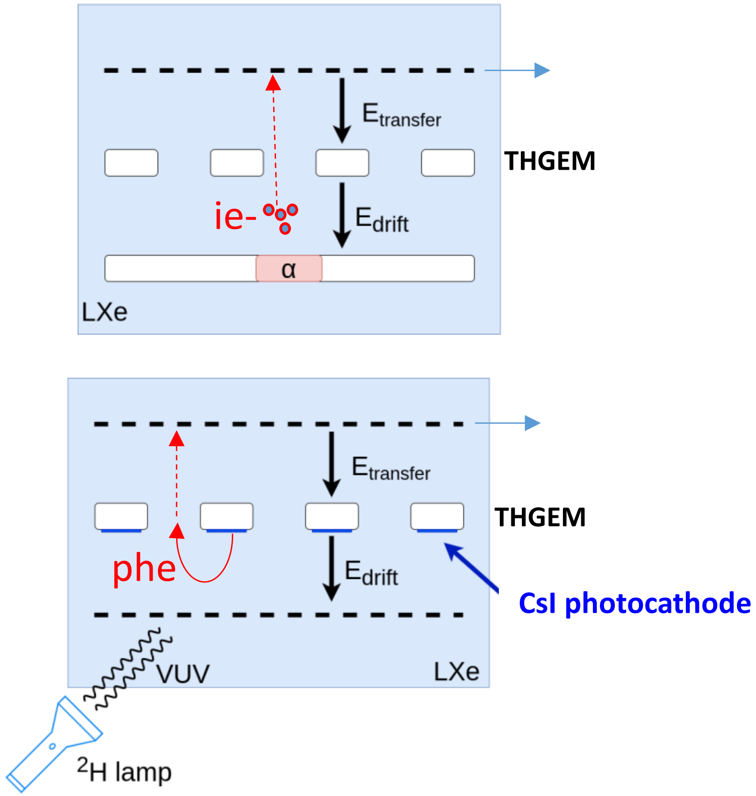


- MSP formed on VUV-transparent substrate, with thin Ni or Cr electrodes.
- **MSP**: MSGC, VCC, others
- Charges deposited in liquid, undergo EL & small CM at high field, near **anode strips**.
- The effective light-emission region function of MSP type, & potentials applied to electrodes.

Policarpo, x10 electron multiplication in LXe with MSGC NIMA 1995
https://doi.org/10.1016/0168-9002(95)00457-2

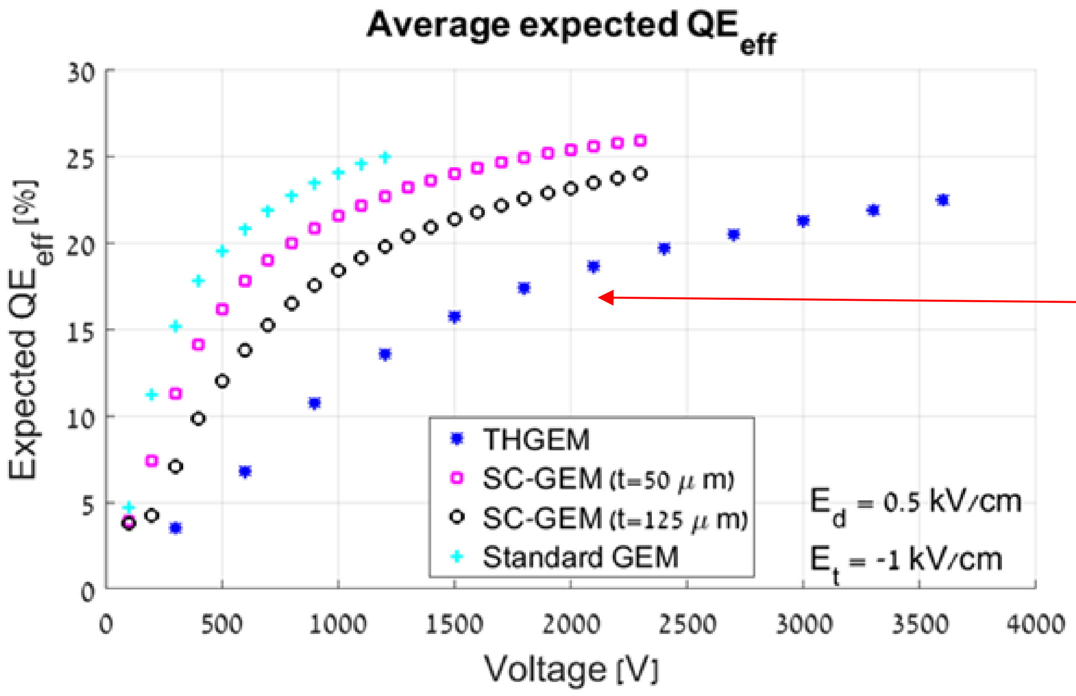
e- & pe- transfer through THGEM holes in LXe

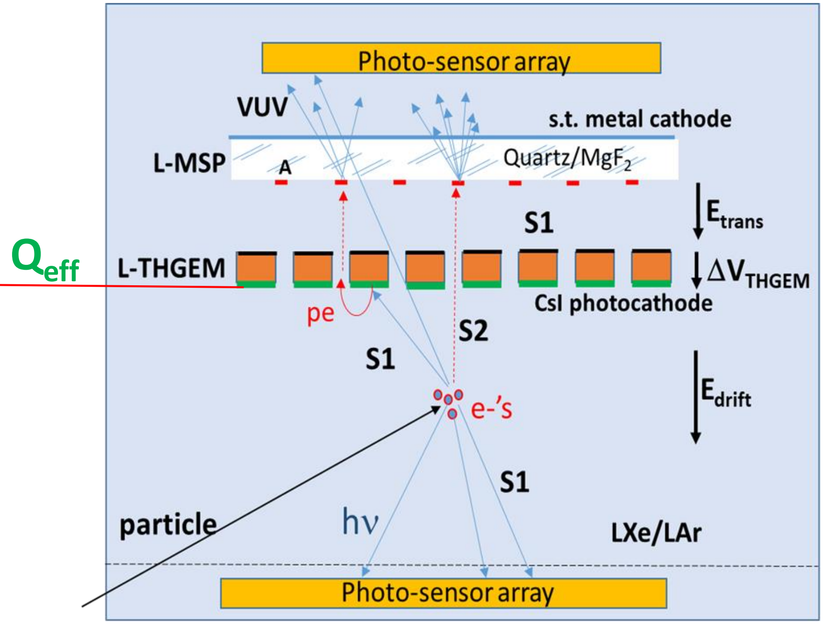




Talk by Gonzalo Martinez Lema; LIDINE2022

Effective quantum efficiency Q_{eff} of CsI in LXe





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.