Enhanced electroluminescence in LXe on thin strips

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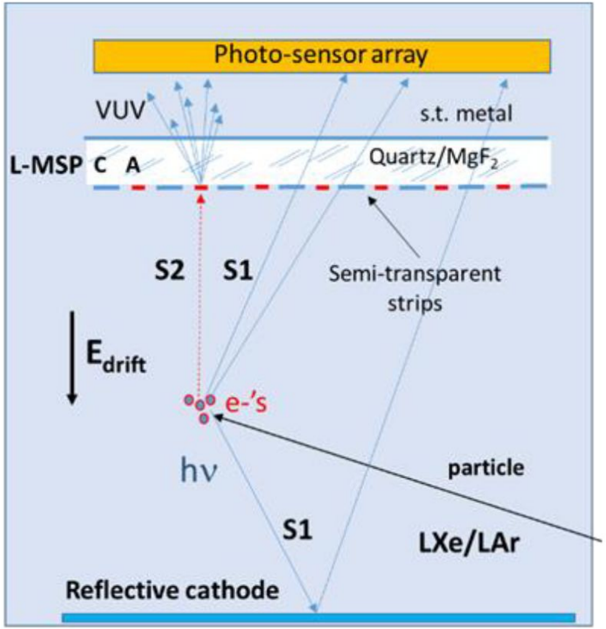
Single-phase detectors with EL amplification

- Advantages
    - No liquid-gas interface
        - Reduced instabilities (interface ripples)
        - No delayed e^- emission or e^- transfer inefficiency through interface
        - No gate-interface-anode alignment problems
        - Potential improvement for S2-only events (e.g. lower background)
- Drawbacks
    - Electric fields ~few 100 kV/cm required for electroluminescence (EL)
    - So far, lower light yield than dual-phase detectors

Breskin 2023



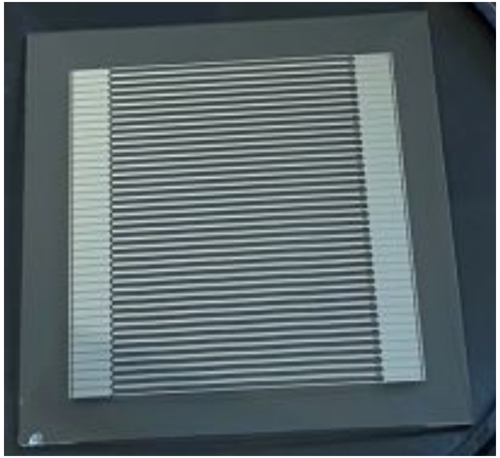
Single phase concept based on microstrips

EL amplification in noble liquids

- Thin wires
    - Simple
    - Challenges in upscaling
        - Wire tensioning
        - Difficult to deploy long wires
        - Wire staggering under high fields
- Microstrips
    - Mechanically more robust
    - Modular
    - Instabilities due to insulating substrate?
    - VUV transparency still to be worked out

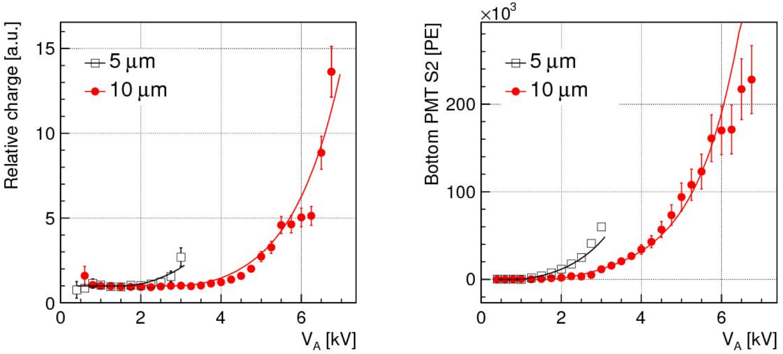
Tönnies et al

Martinez-Lema et al

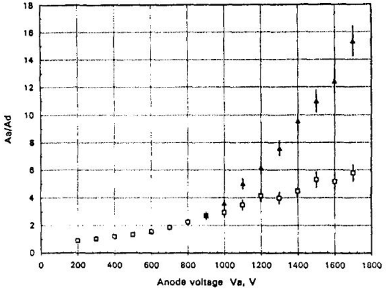


EL amplification in LXe

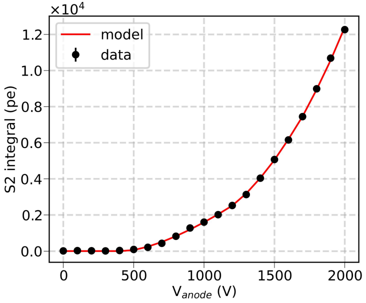
- Thresholds
  - Charge multiplication ~ 725 kV/cm Aprile et al
  - Electroluminiscence ~ 412 kV/cm Aprile et al
  - Microstrips measurements in agreement Martinez-Lema et al
- Thin wires (5-25 μm)
  - ~ 290 photons/ie, ~x14 charge gain @ 6.75 kV Aprile et al
  - 17 photons/ie @ 3.6 kV & single electron sensitivity Qi et al
  - 29 photons/ie @ 4.4 kV Tönnies et al
- Microstrips
  - ~x10 e^- multiplication @ 1.7 kV Policarpo et al
  - ~33 photons/ie @ 2 kV Martinez-Lema et al



Aprile et al



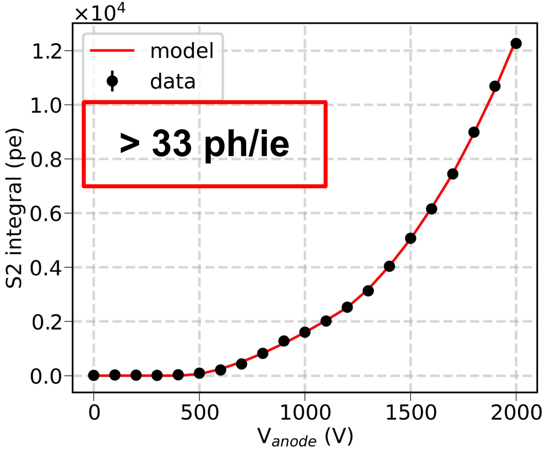
Policarpo et al



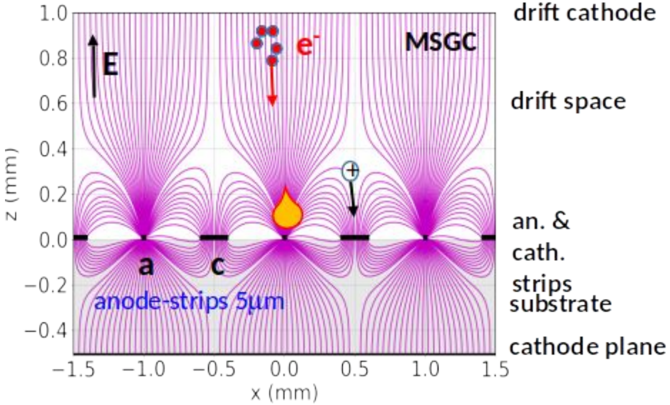
Martinez-Lema et al

LIDINE-2023: EL amplification on MSGC

- MSGC: wide (400 μm) cathode interleaved with narrow (8 μm) anode strips with 1 mm pitch on glass
- ≥ 33 photons/electron at strips ΔV = 2 kV, ~x3 e^- multiplication



MSGC

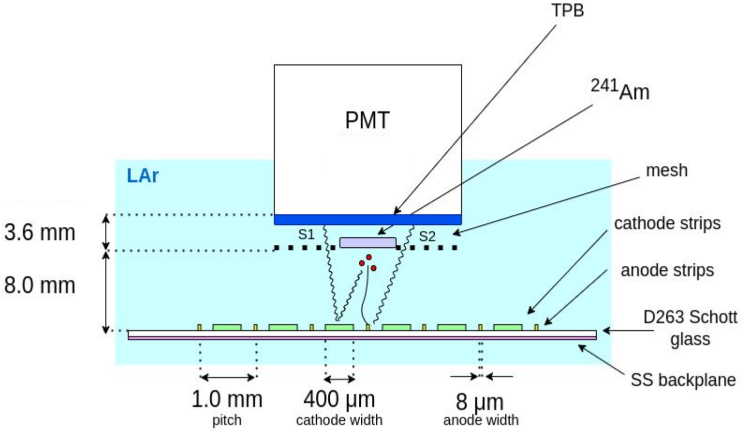


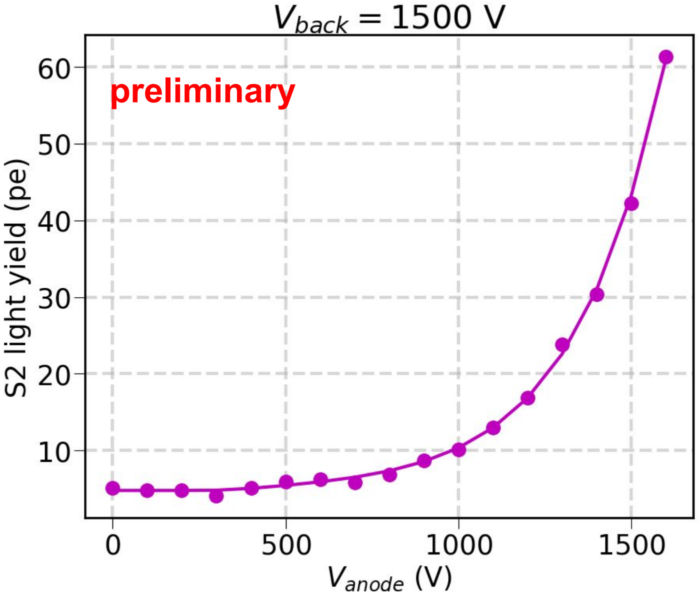
Martinez-Lema et al

Microstrips in LAr (preliminary)

Not presented
in LIDINE 2023!

- Same geometry as in LXe
- Lower light yield than LXe (~1 ph/ie)
- EL threshold ~350-600 kV/cm
- CM threshold ~430-650 kV/cm

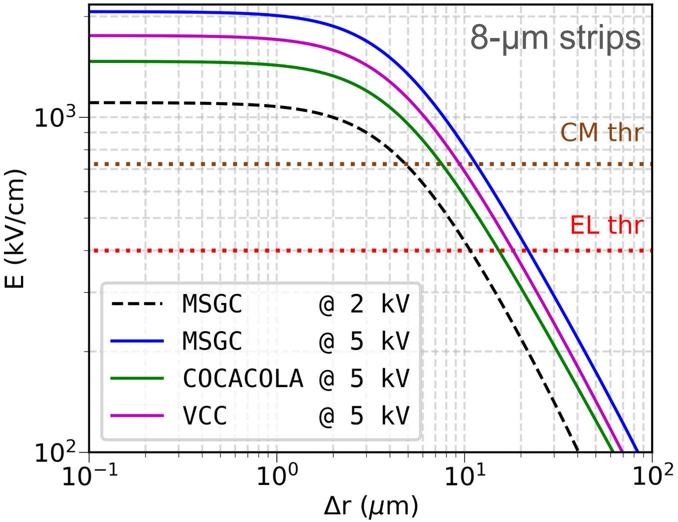


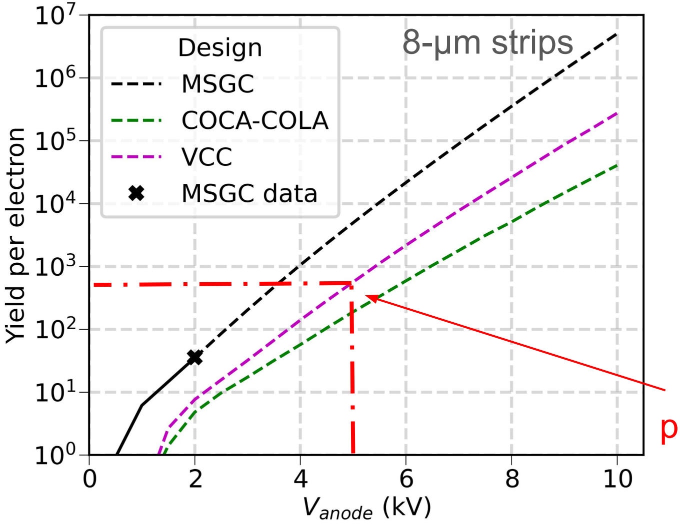


paper in preparation

Prospects of different MSP geometries

- MSGC operation is limited by discharges between anode and cathode strips
    - Other geometries can enhance light yield
    - COMSOL-based extrapolations predict much higher light yields for ΔV = 5 kV (unreachable with MSGC)



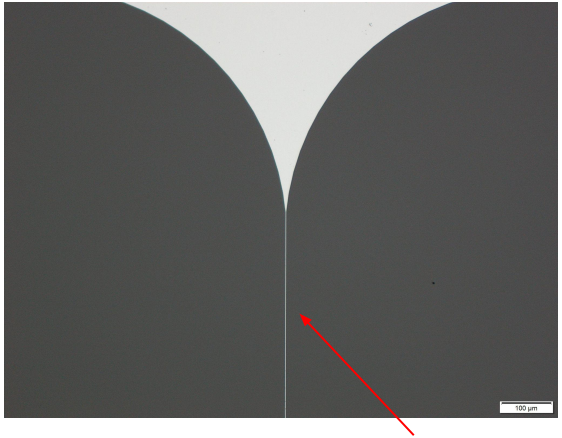


~550 photons/e-

Martinez-Lema et al

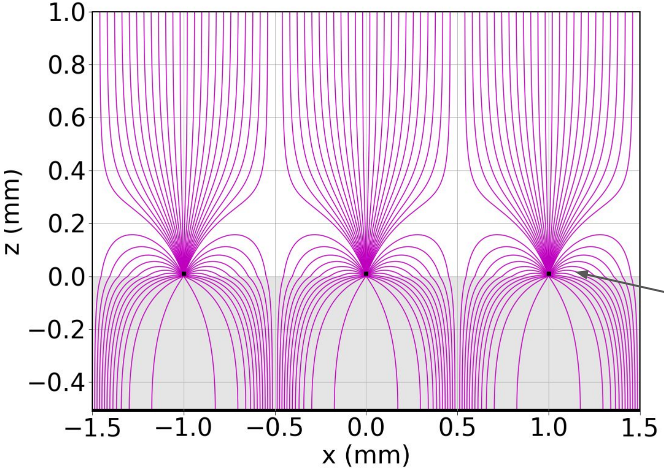
Virtual Cathode Chamber (VCC) design

- Thin anode strips on top face
- Thin conductive layer on the bottom face
- Higher applicable potentials
- First proposed by [Capeans et al]()



anode strip

VCC field configuraiton

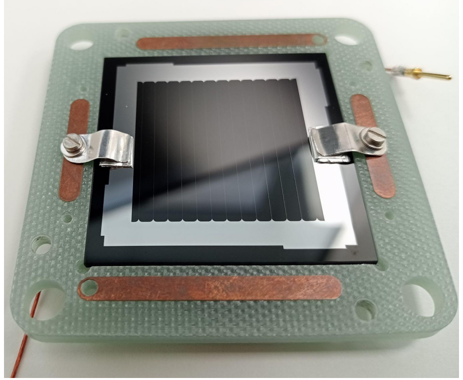


drift electrode

anode strips

virtual cathode

Our setup



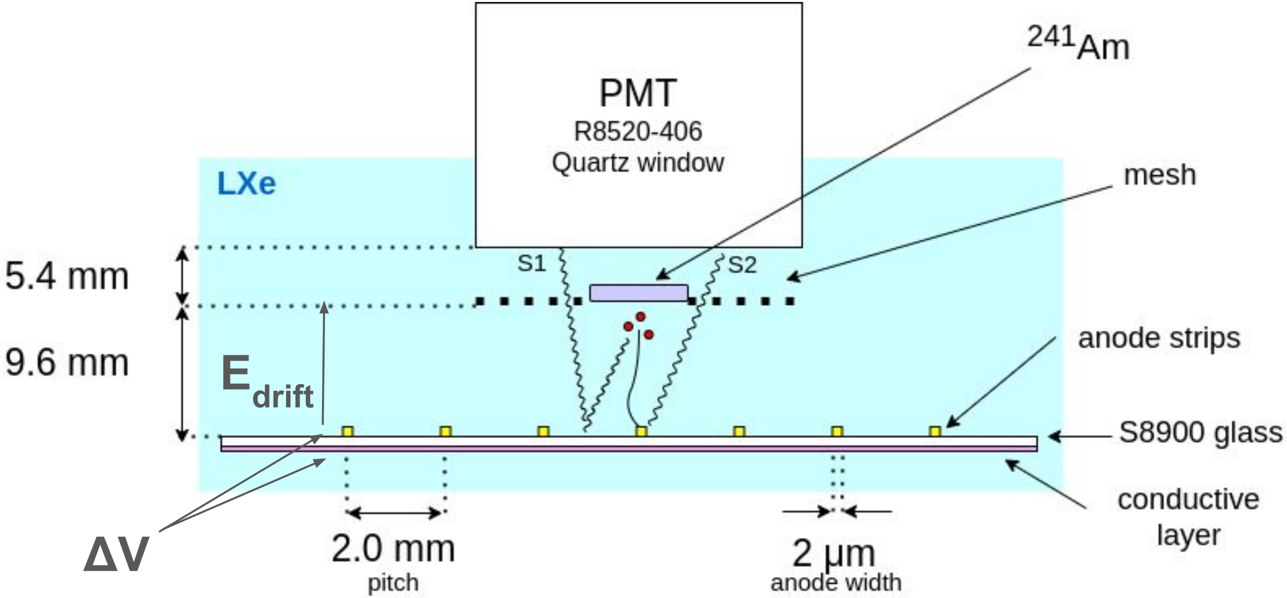
Our plate

2-µm-wide anode strips, 130 nm thick

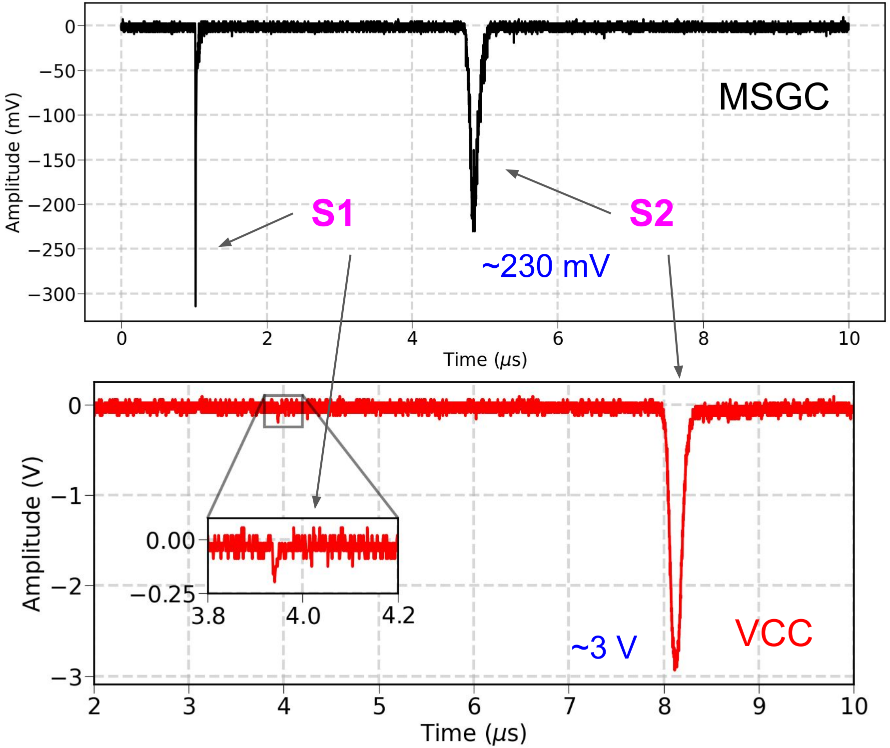
1.5-mm-thick substrate

S8900 semiconductive glass*

*previously used in MSGC



Typical PMT waveforms



V_{source} = -2.0 kV
$V_{cathode}$ = ground
V_{back} = -2.0 kV
V_{anode} = +1.6 kV
ΔV = 1.6 kV

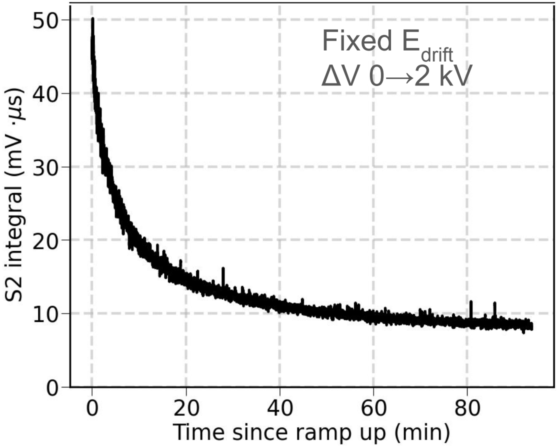
V_{source} = - 2.0 kV
V_{back} = - 1.75 kV
V_{anode} = +3.25 kV
ΔV = 5.0 kV

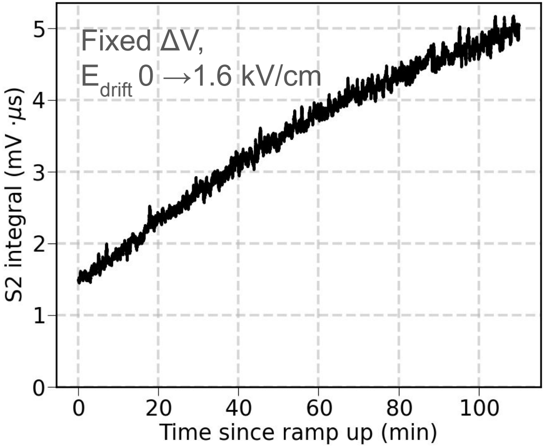
$\Delta V = V_{anode} - V_{back}$

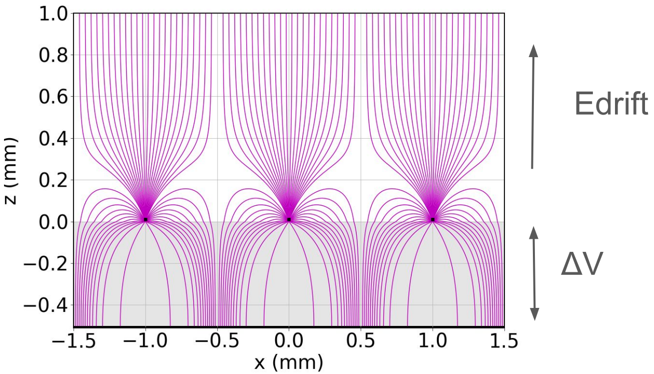
Substrate charge up/polarization

under review!

- Strong reduction of S2 yield over time
- Stable photoyield only after several hours
- Possible interpretations:
    - Polarization of the substrate
    - Charging up of the surface unlikely: very low source rate & very low charge multiplication



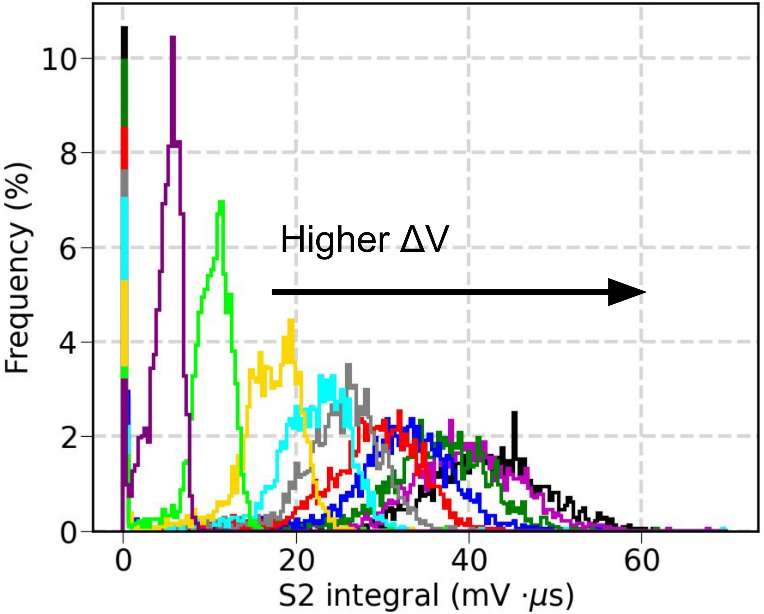




Light yield vs voltage

- PMT waveform integrated on a fixed time window
- Converted to PE based on an in-situ PMT calibration
- S2 integral increases with ΔV
- **EL threshold @ ΔV ~ 200 V**

V_{source} = -2.0 kV
V_{anode} = +3.0 kV



Light yield vs voltage

- Measurements taken with a fixed few min delay between data points to reduce time-dependence
- Light yield @ ΔV = 5 kV, close to saturation: **~30 photons/e$^-$**

Experimental parameters

$\Omega/4\pi$ ~ 7.9 %

T ~ 81%

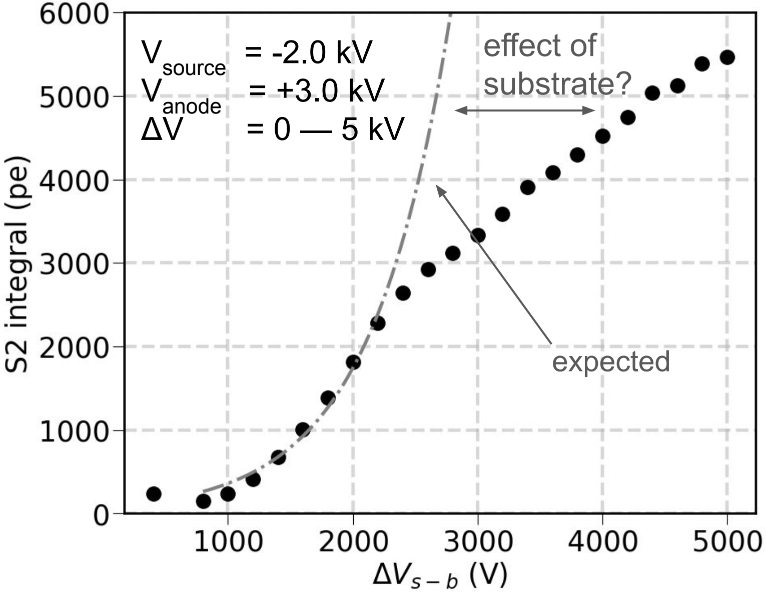
QE ~ 28%

N_{ie} ~ 10500

$$LY = \frac{S2}{\frac{\Omega}{4\pi} \cdot T \cdot QE_{PMT} \cdot N_{ie}}$$

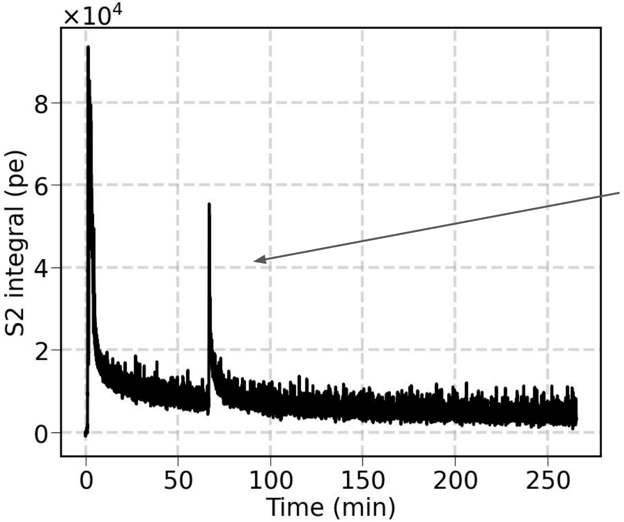
mesh transparency

from alpha particles



Maximum light yield

- Observe S2 as a function of time for **ΔV = 5 kV**
- Maximum initial S2 ~ $9.3 \cdot 10^4$ photons → **~500 photons/electron**
- Different substrate might results in a stable high light yield

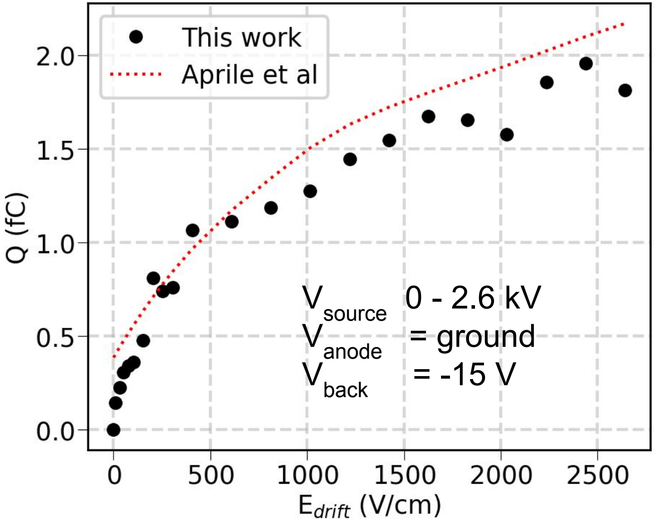


Discharge

G. Martínez Lema – Enhanced electroluminescence in LXe - LIDINE, 28/08/2024

Charge

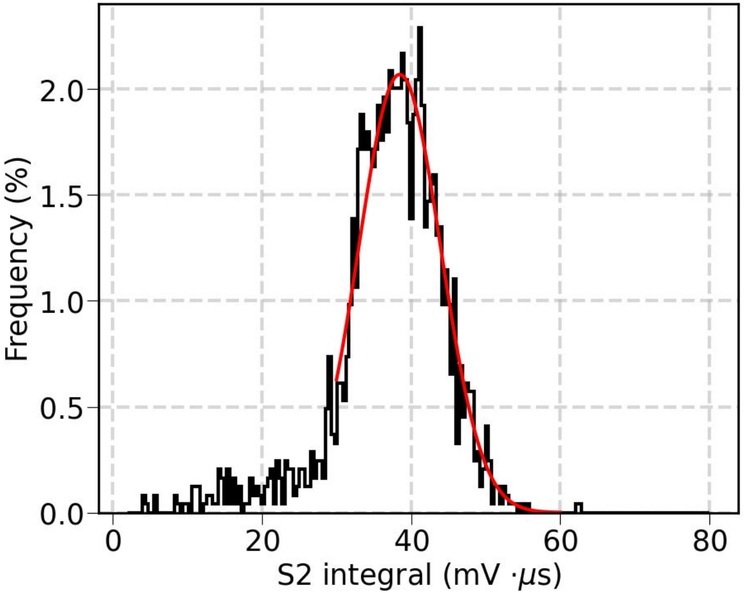
- Parallel plate configuration (no field across plate)
- Charge sensitive preamp on strips
- In agreement with Aprile et al
- Other charge measurements in progress



V_{source} 0 - 2.6 kV
V_{anode} = ground
V_{back} = -15 V

Preliminary energy resolution

- Gaussian fit to the S2 integral spectra
- σ/μ ~ 14 % @ ΔV = 5 kV
- Affected by time variations of S2 yield
- Potential to improve with different substrate



Summary

- Single-phase detectors →solutions to problems faced by dual-phase TPCs
- Microstrip plates →EL & CM in liquid with some charge and high light yields
- Former light yield measurement in LXe potentially improved using a VCC design
    - up to **~500 photons/electron** before substrate chargeup/polarization
    - **~30 photons/electron** in more stable conditions (VCC) vs 33 photons/electron (MSGC)
    - Performance severely compromised by the choice of substrate
    - Charge multiplication yields still under study
- Other substrates must be studied to improve stability
    - Quartz or MgF_2 needed for high UV transparency
    - Lower resistivity ion glass vs electronic glass?
    - Could surface resistivity be lowered by surface treatment (e.g. ion implantation)? Experts needed!

Paper in preparation!

Acknowledgements

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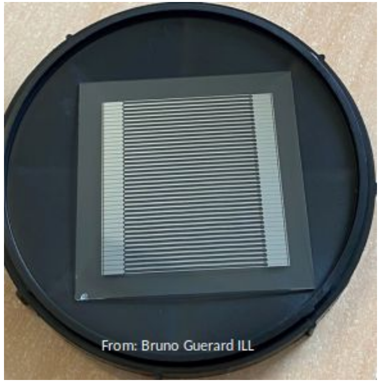
- GML thanks Dr. Lior Arazi of the Unit of Nuclear Engineering at Ben Gurion University & VC thanks the Physics Faculty of Weizmann Institute, for their support.

Thank you for your attention

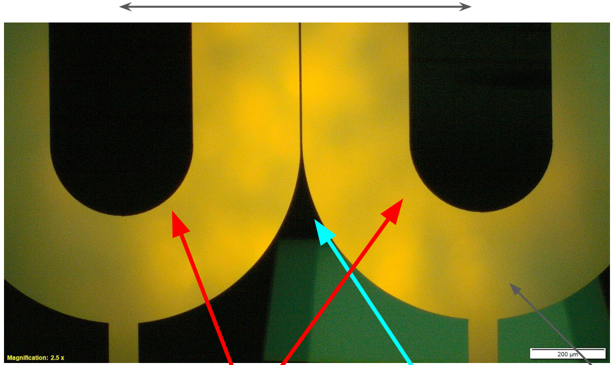
Backup

Microstrips

- First proposed by A. Oed in 1988 for the MicroStrip Gas Chamber (MSGC)
- Thin strips deposited on a substrate (ideally VUV-transparent)
- Original design: cathode and anode strips interleaved


From: Bruno Guerard ILL

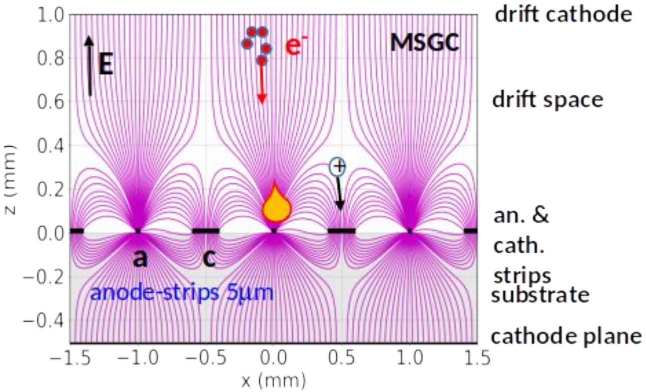
1 mm



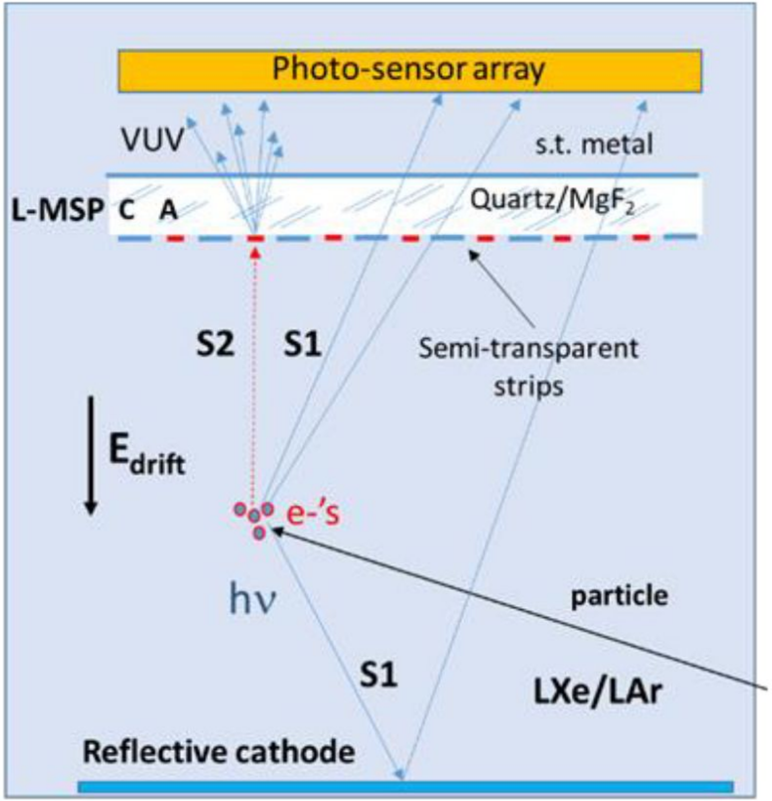
cathode strips

anode strip

light seen through the substrate



Single phase concept with Microstrips



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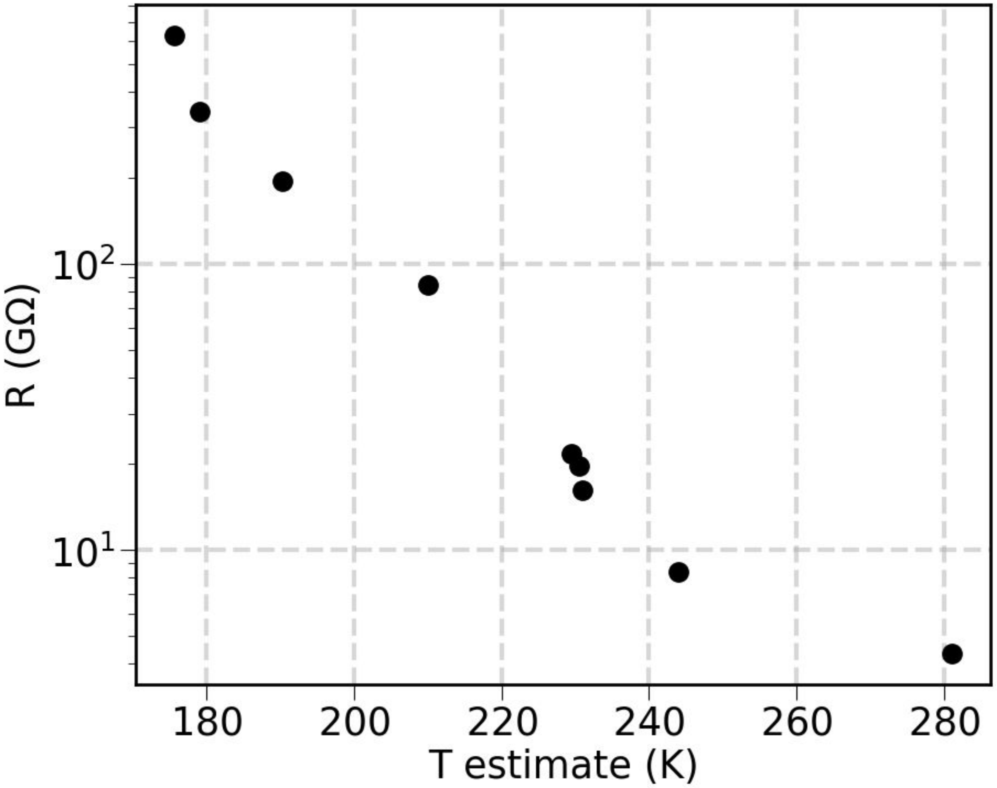
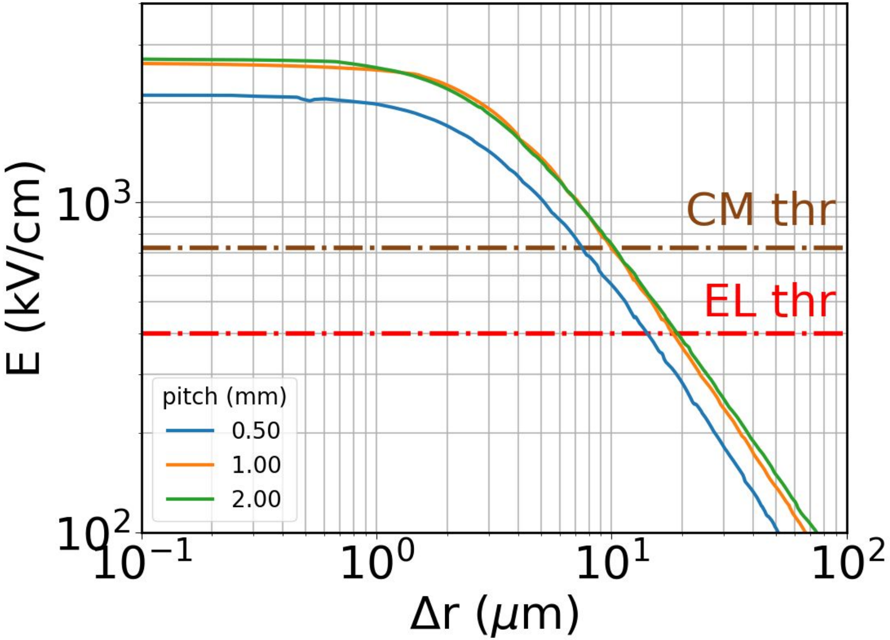
Substrate resistivity vs T

Temperature measured during detector cooldown

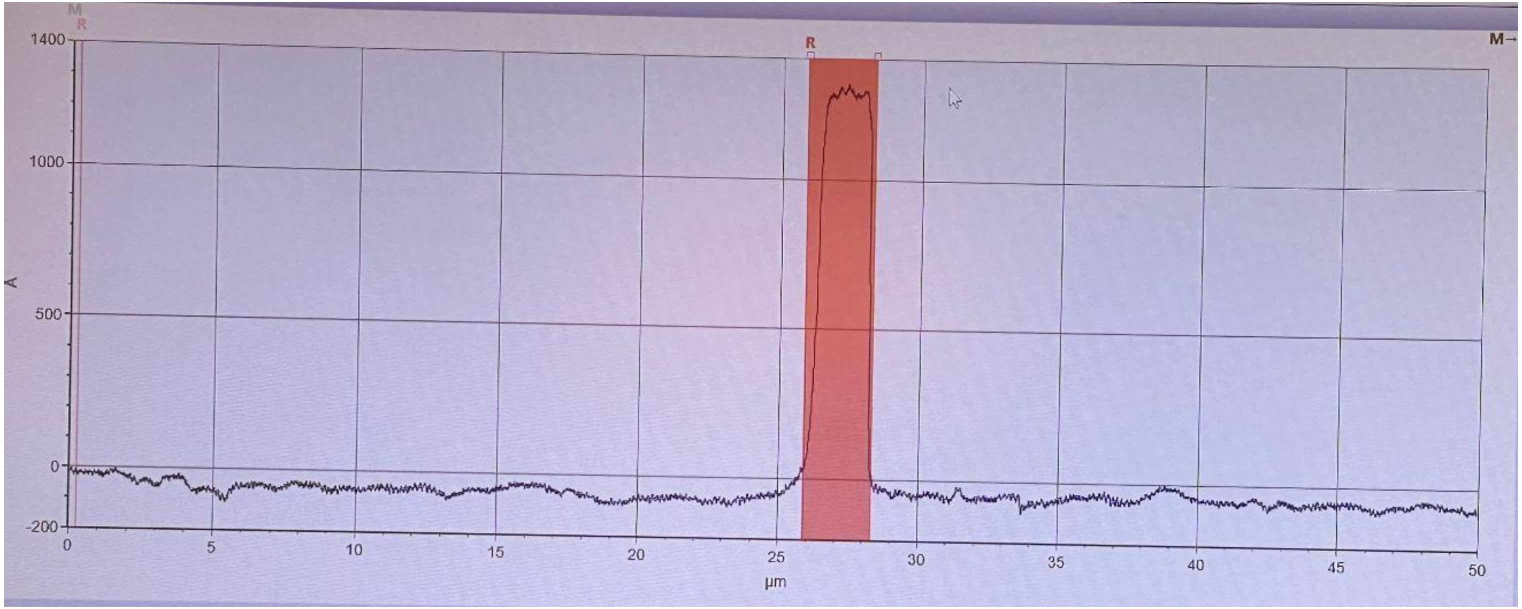


Geometry optimization

- Current geometry
  - 2 mm pitch
  - 2 µm strip width
  - 1.5 mm substrate thickness
  - Semiconductive glass
- Possible optimizations
  - 1 mm pitch →same field, less insulating area
  - Different substrate



Strip profile



EL & CM model

Aprile et al

$$\begin{cases} \dfrac{dN_e}{dx} = N_e(x) \cdot \theta_0 \cdot e^{-\frac{\theta_1}{E(x)-\theta_2}} \\ \dfrac{dN_\gamma}{dx} = N_e(x) \cdot \theta_3 \cdot (E(x) - \theta_4) \end{cases}$$

θ_{0-4} model parameters

E(x) from COMSOL