Measurement of electron in-liquid amplification in pure argon

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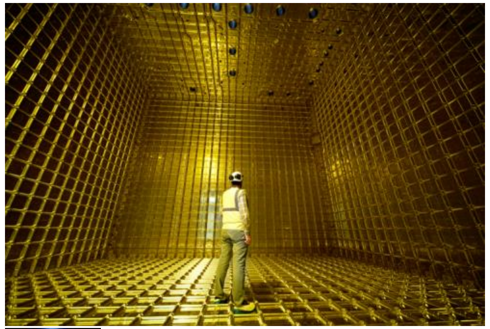
Motivation for the measurement

Beam Neutrino
Proton Decay
Supernova Neutrino
0νββ Decay
Solar Neutrino
WIMP Dark Matter
CEvNS

GeV
MeV
keV



μBooNE
SBND SHORT-BASELINE NEAR DETECTOR

nEXO

PANDA X
darkside

ArDM

LZ
Xe XENON Dark Matter Project

- Noble liquid TPC detectors are widely used for neutrino and dark matter physics, using:
  - Light
  - Charge
- Lots of efforts have been invested on improvement of:
  - Detector energy threshold
  - Signal-to-Noise ratio
- Possible solution:
  - **Electron in-liquid amplification**

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What is current design and limits?

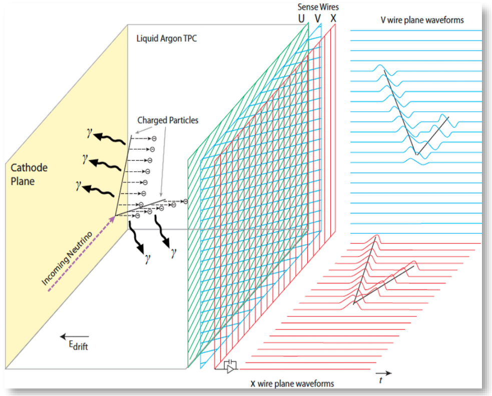
Nobel Liquid TPC

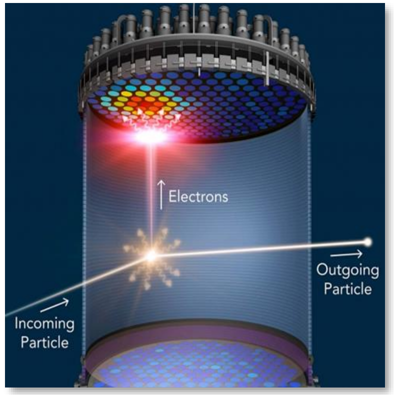
- *ph* → Detected by Photon Sensors
- e^- → Drift
  - Collected by Anode Plane → Pulse Amplification
  - Extracted to **Gas Phase**
    - Proportional Scintillation
    - Electron Avalanche

Is it possible to do:
Electron In-Liquid Amplification?

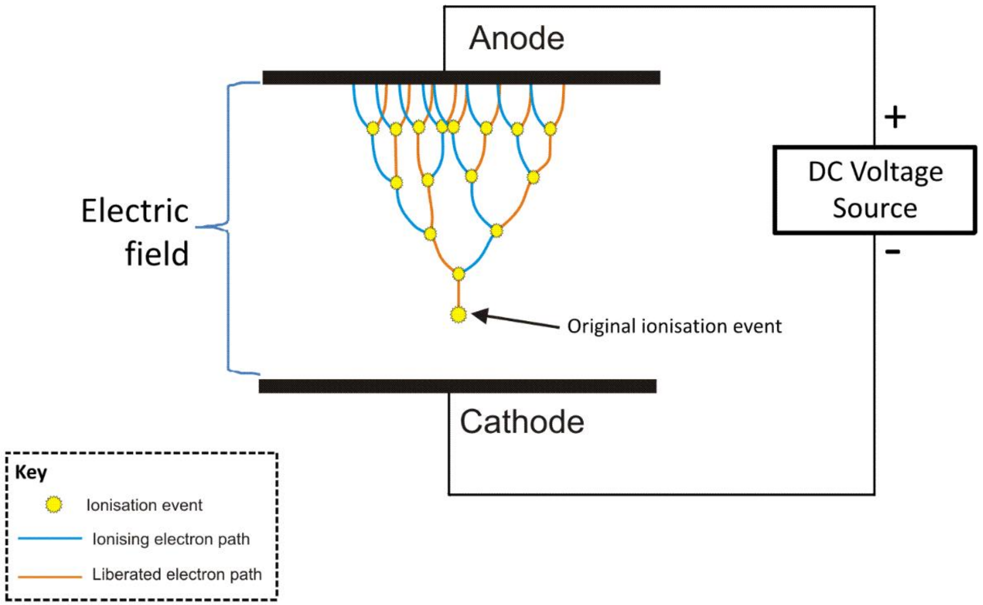
In-Liquid Amplification
Signal + Noise

Signal Amplification
Dual-Phase Operation





Can charge be amplification in liquid before collection?



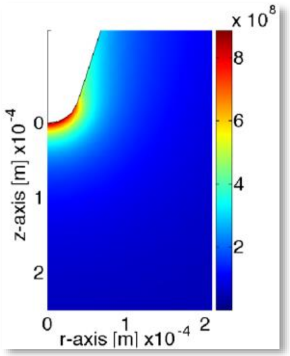
Will it occur in liquid noble element?

Let’s measure it!

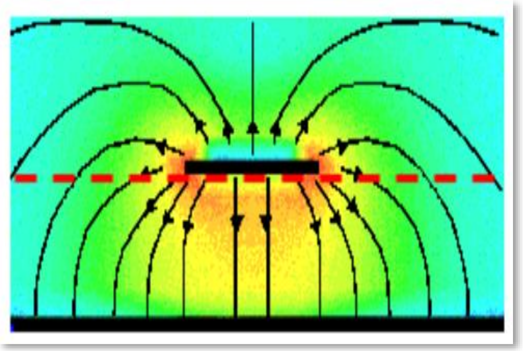
Past Research

- Proportional Scintillation
  - Optical readout tracking detector concept using secondary scintillation from liquid argon generated by a thick gas electron multiplier
  - First demonstration of a bubble-assisted Liquid Hole Multiplier operation in liquid argon
  - Initial evaluation of proportional scintillation in liquid Xenon for direct dark matter detection
  - Measurements of proportional scintillation andelectron multiplication in liquid xenon using thinwires
- Electron Avalanche
  - Electron multiplication in liquid argon on a tip array
  - Studies of electron avalanche behavior in liquid argon
  - Electron avalanches in liquid argon mixtures
  - LArCADe: Liquid Argon Charge Amplification Devices

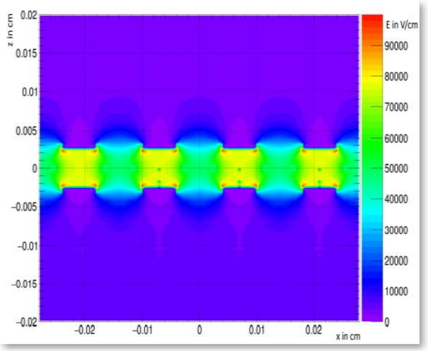
How to produce high electric field?



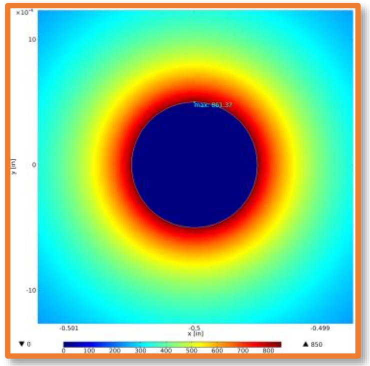
Needle Tip



Microstrip



(Thick) GEM

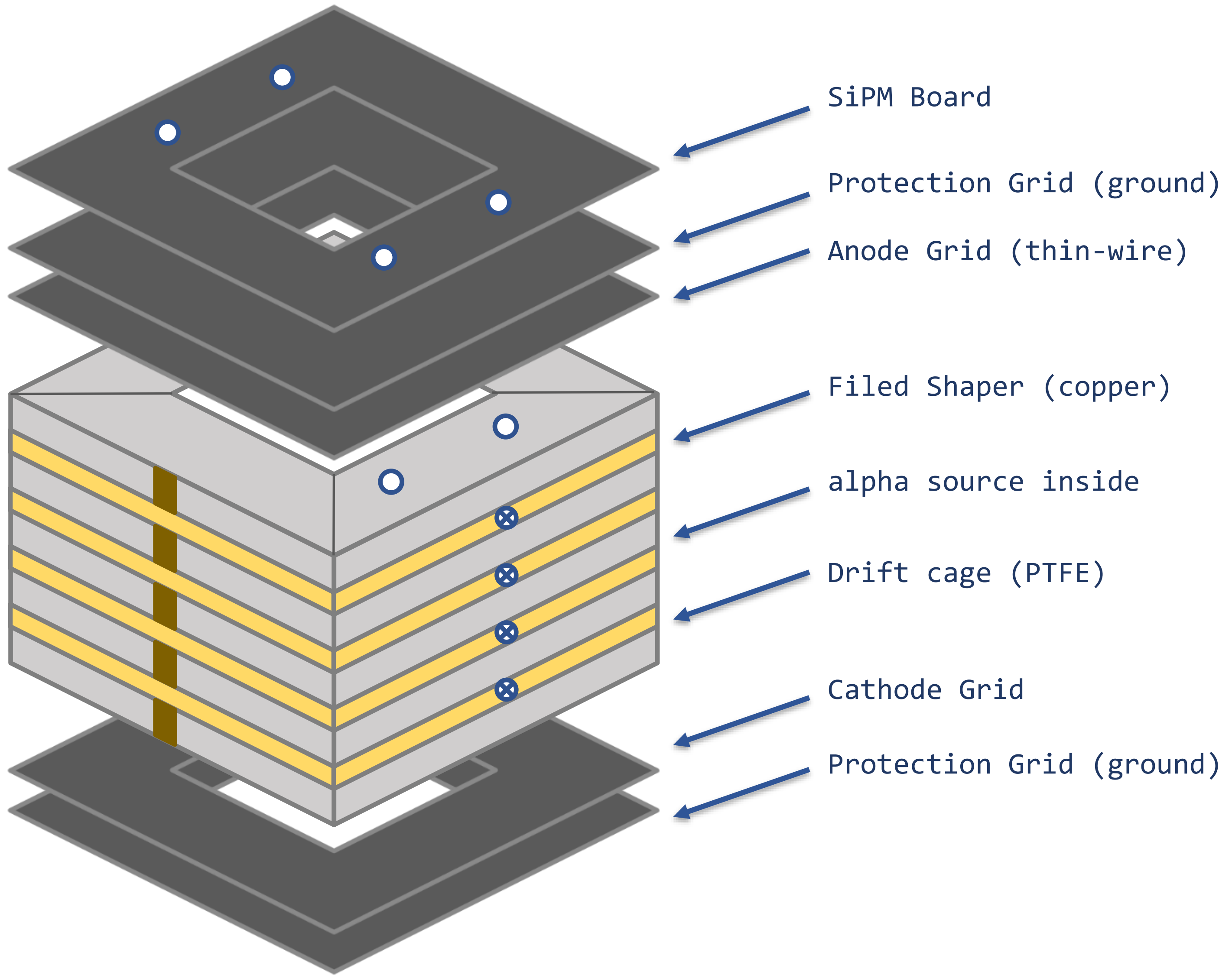


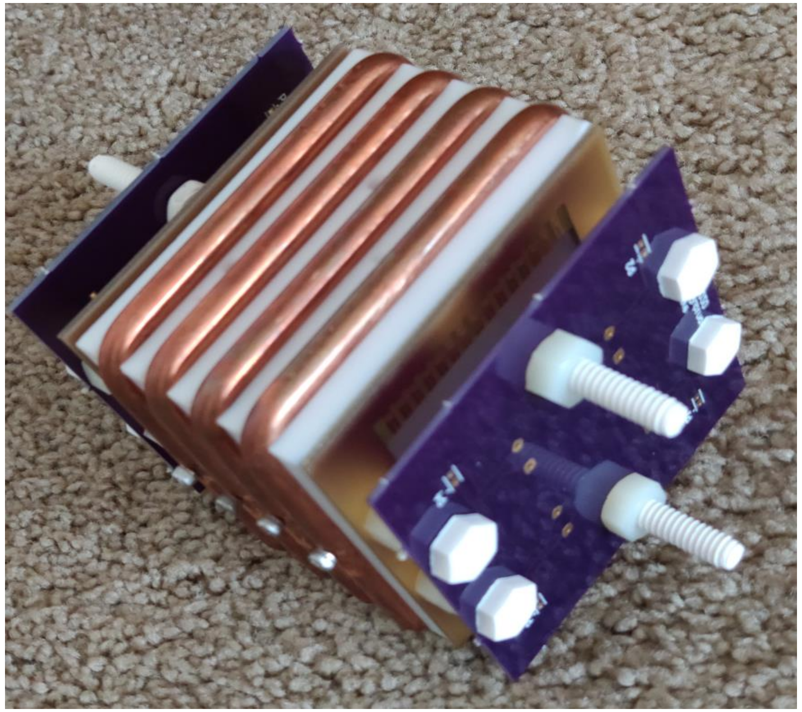
Thin Wire

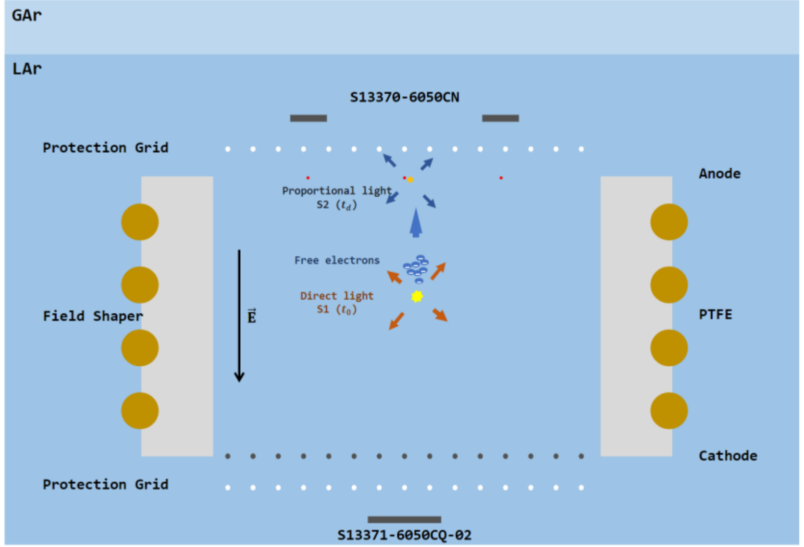
Advantages of using thin wire (~10μm) to produce high electric field

- Electric field produced by thin wire is easy to model and control
- The surface can be smooth without microscopic spurs or protrusions, which avoids local extremely high electric field
- There is no tip, which avoids corona discharge and reduces the heat input to avoid producing of bubble

Setup for the Measurement







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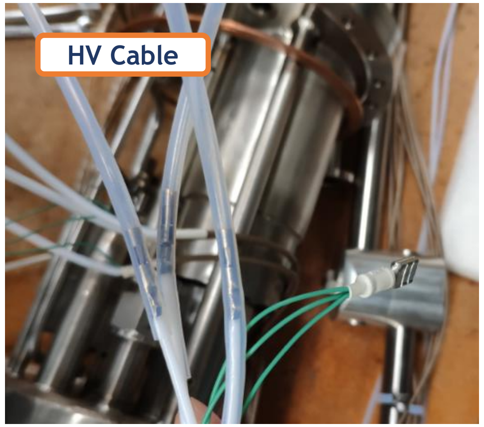
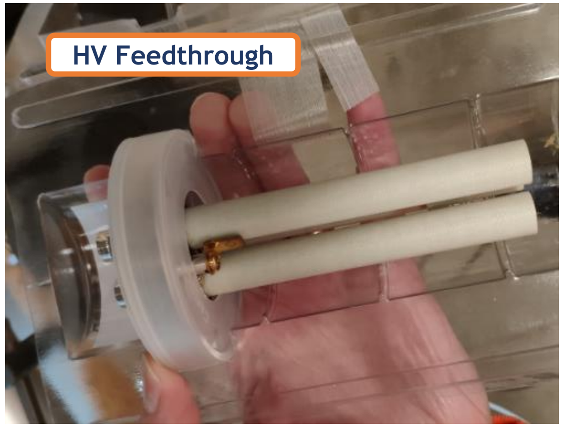
Electric field production

- Positive/Negative Droege supplies
- SHV-5 Feedthrough
- From +3.5kV to -2.5kV
  - Trips >3.5kV
  - Sparks >-2.5kV
- E-Field
  - Drift field: **0.4 – 1.2** kV/cm
  - Acceleration field: **1 – 2** MV/cm

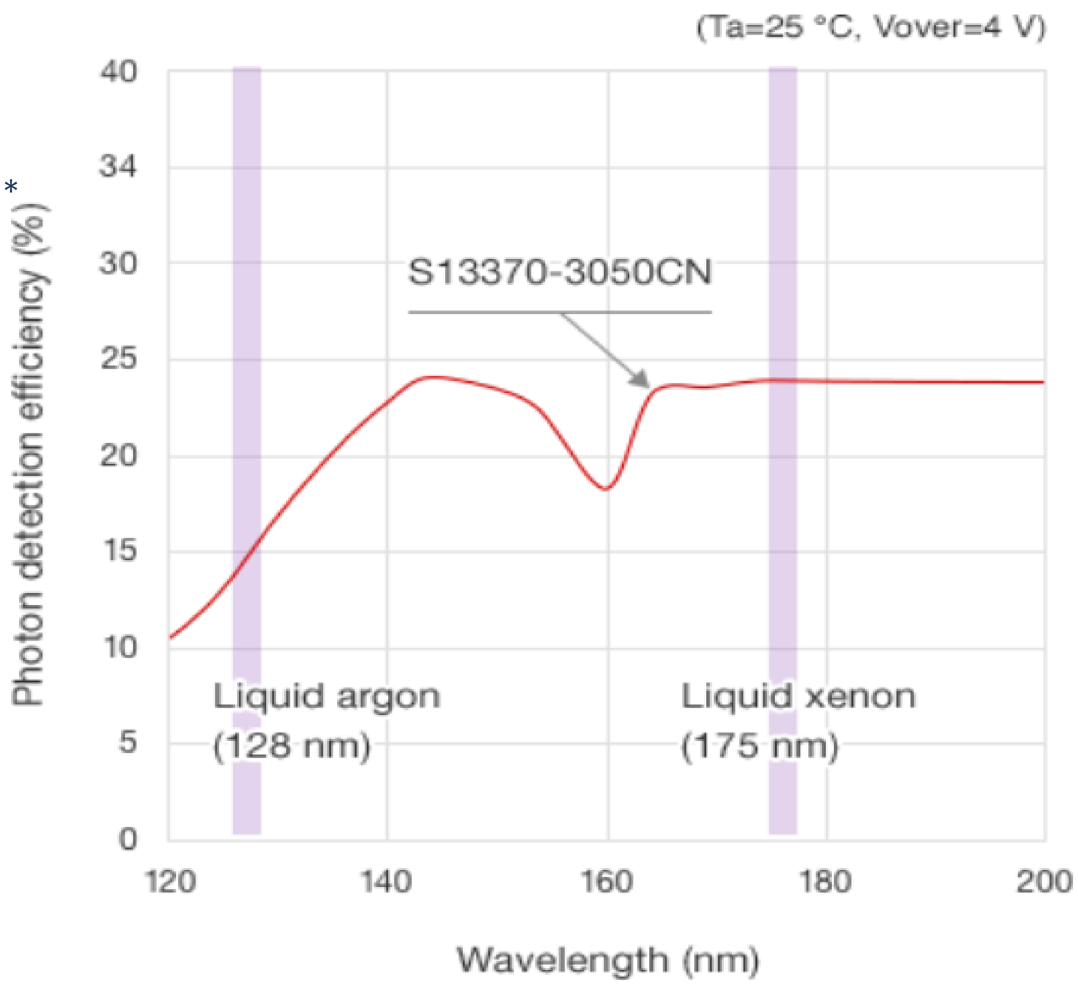




Anode kV	Cathode kV	Max Field* kV/cm	Drift Field kV/cm	Drift Velocity** cm/μs	Drift Time μs
2.0	0.0	1028.4	0.4	0.11	10.6
3.0	0.0	1542.6	0.6	0.14	8.6
3.5	0.5	1831.5	0.8	0.16	7.6
3.5	1.5	1895.2	1.0	0.18	6.9
3.5	2.5	1958.9	1.2	0.19	6.4

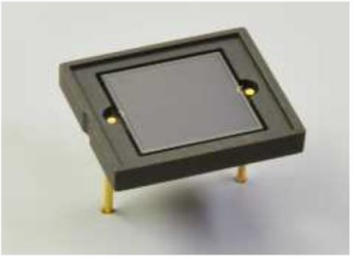
*Max field simulated by COMSOL Multiphysics
**Drift velocity calculated based on liquid argon property

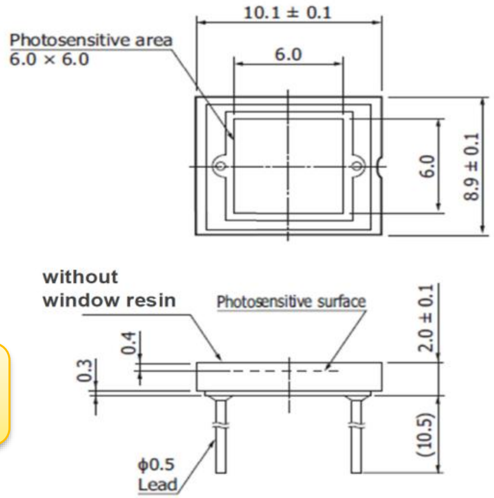
VUV photon detection



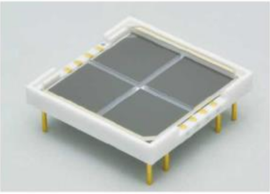
*Ref. Hamamatsu website

<S13370-6050CN / S13370-6075CN>

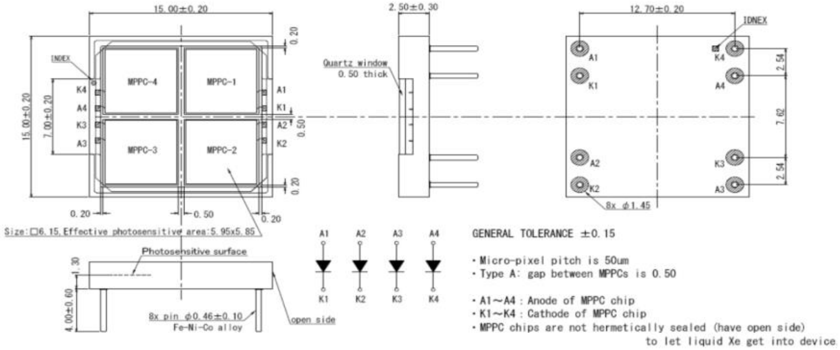




Sensitive for both
128nm and 178nm light



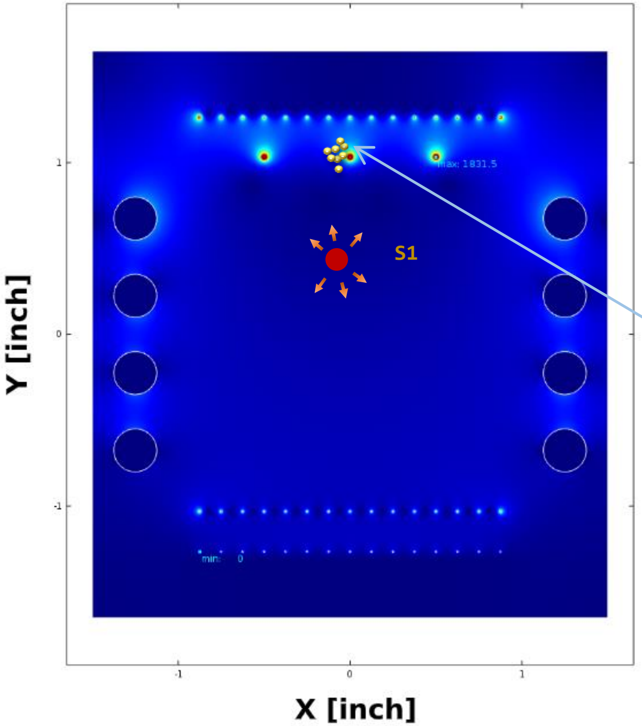
Sensitive for
only 178nm light

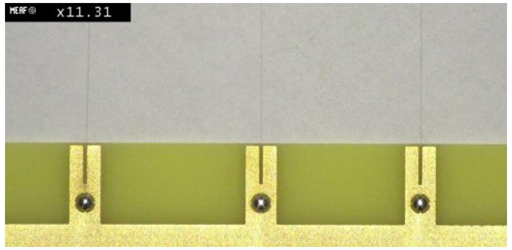


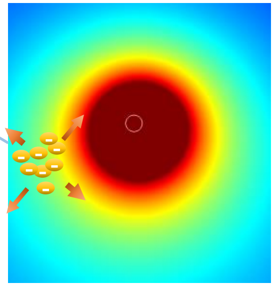
Principle for the measurement

^{241}Am α source

- Produce photons and electrons
- ~1-4% electrons escape from recombination under external electric field



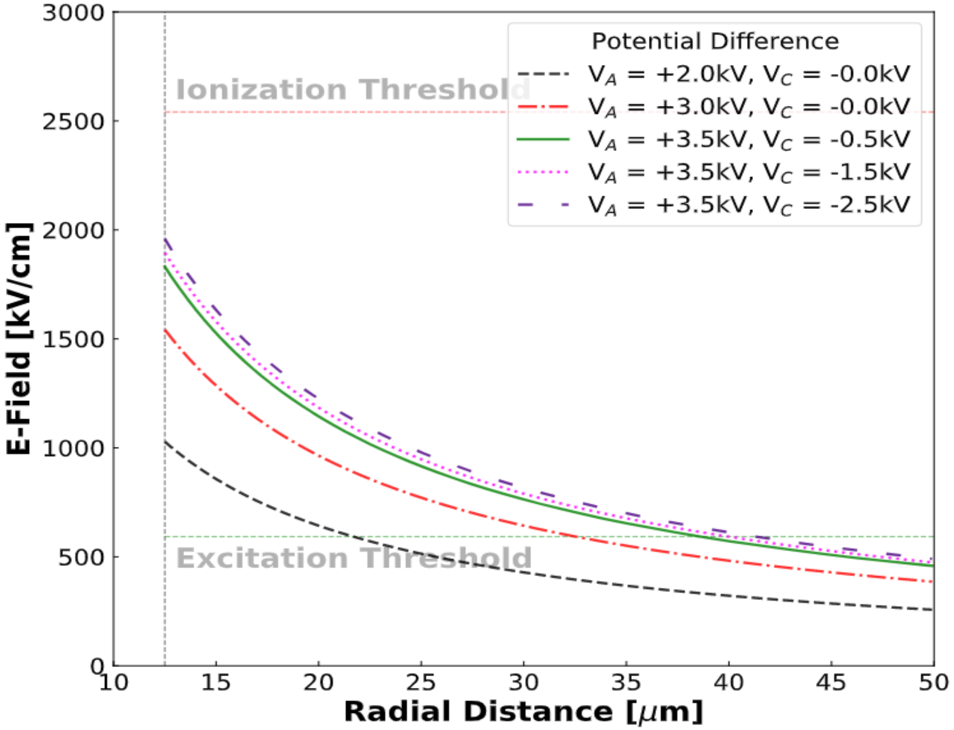




Charge amplified near the wire surface

High electric field

- GAr: homogeneous high field
- LAr: extremely high field near the surface of thin wires (12μm)



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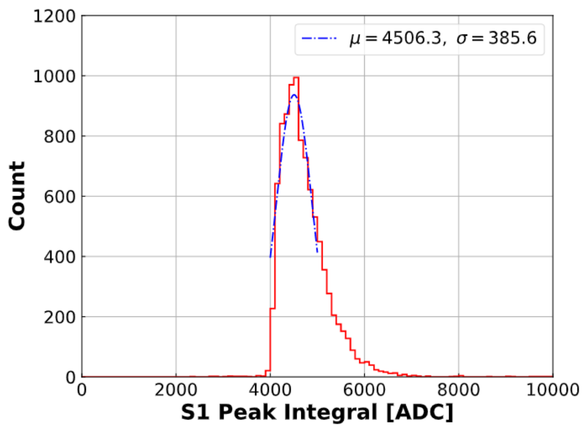
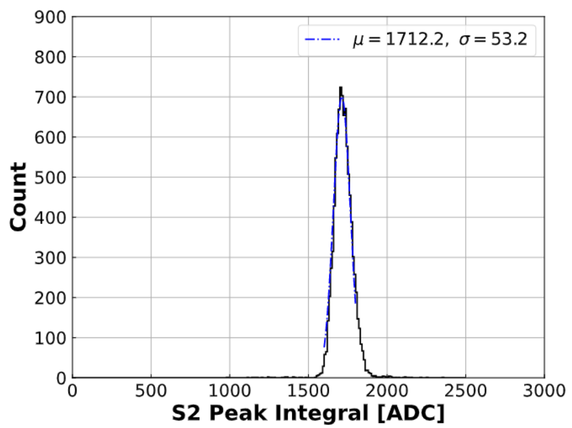
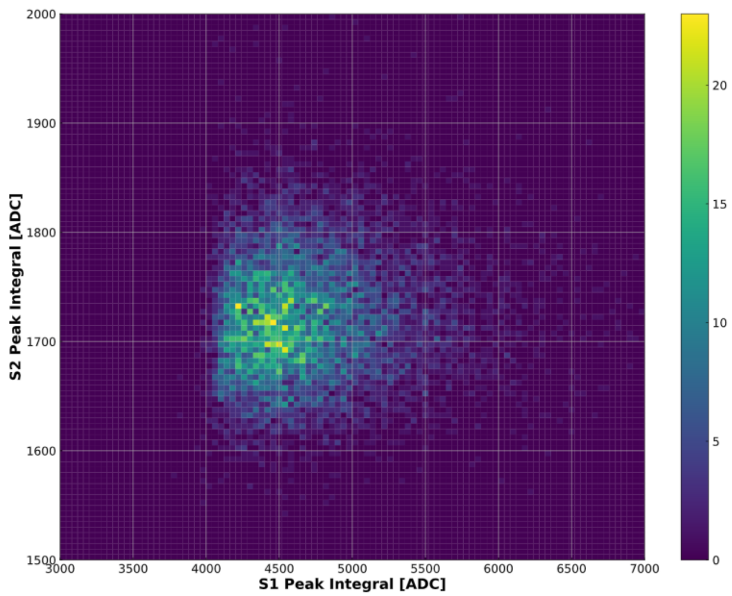
Initial measurement in liquid argon







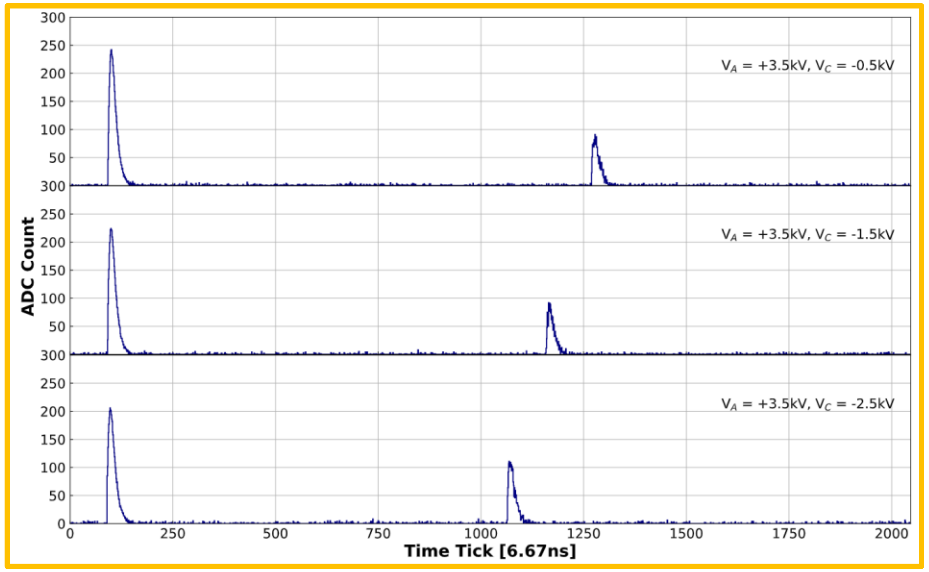
Threshold

Initial Measurement vs. Extrapolation (Gar* at 800bar)

- Proportional scintillation: **~1.8** vs **~0.6** MV/cm
- Electron avalanches: **>2.0** vs **~2.5** MV/cm

Gain

- Proportional scintillation: **~30** photons/electron



*Ref. threshold in gaseous argon

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Future measurement

- A second cryogenic operation in pure argon to address issues with:
  - Liqui argon purity
  - High voltage feedthrough
  - Humidity of VUV4 SiPM sensors
- A third cryogenic operation in xenon-doped argon
  - Xe-doping increases the light yield and shifts the scintillation light wavelength from 128nm to 175nm;
  - Xe-doping is useful for quenching possible self-sustained discharges in argon