Amorphous Selenium Based VUV Photodetectors for use in Noble Element Detectors

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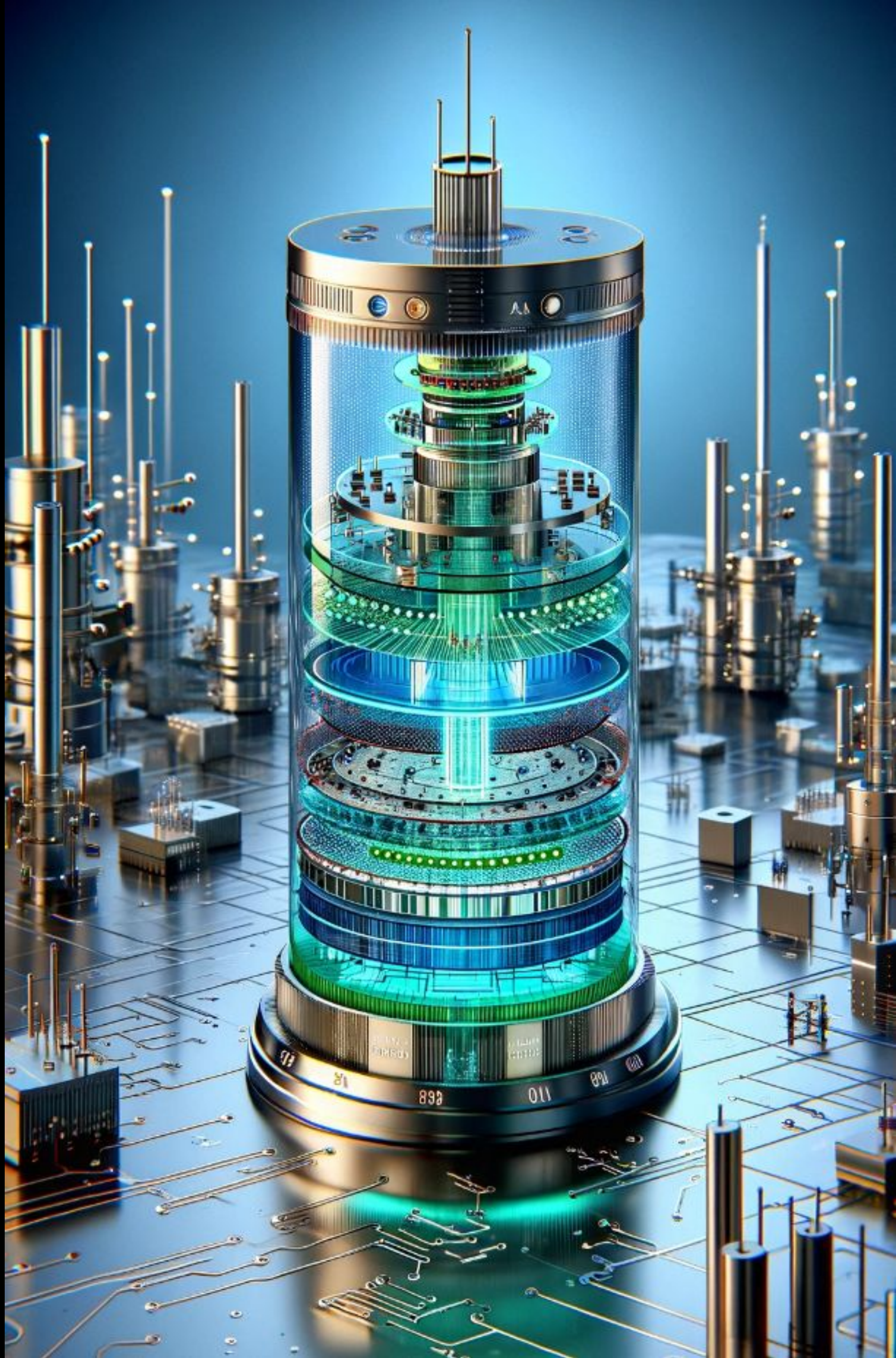
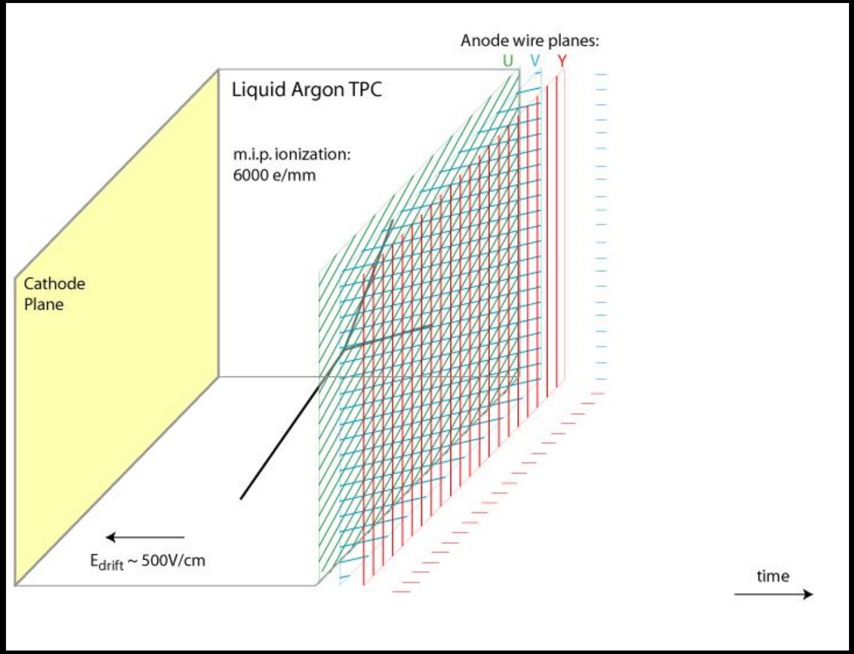
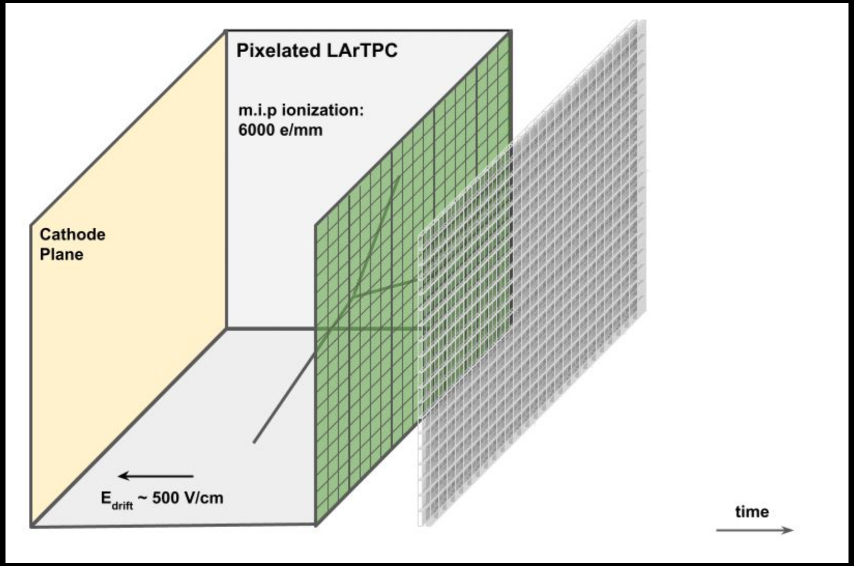


Pixelated Liquid Argon TPC

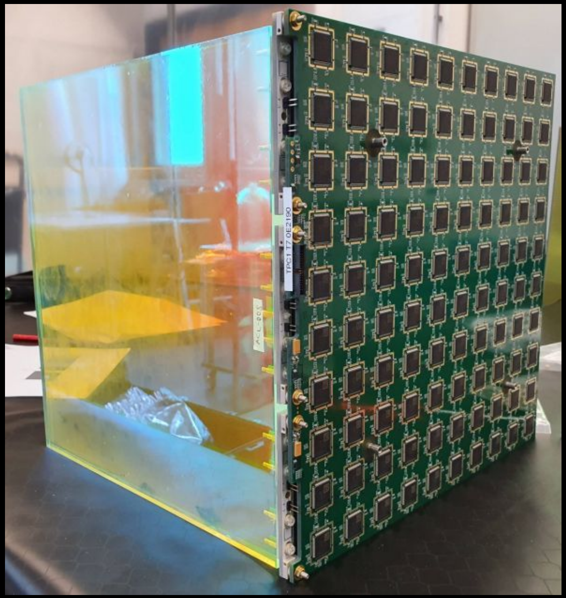
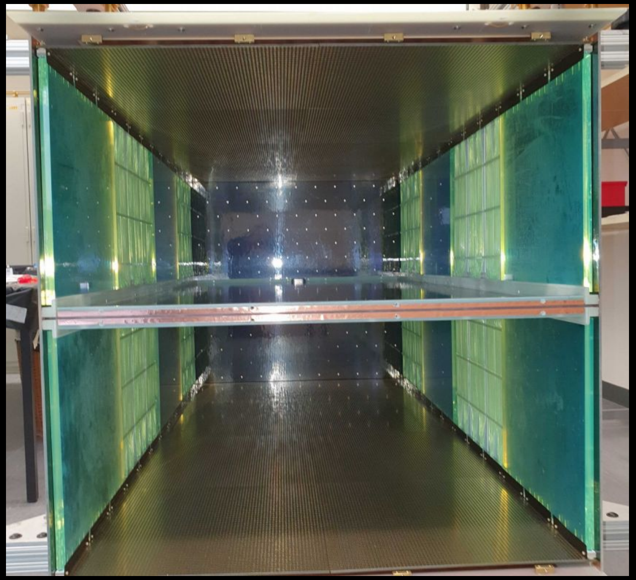
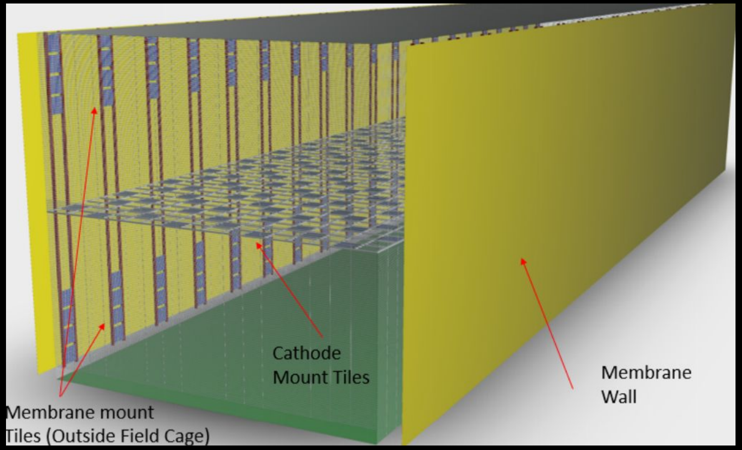
- **Liquid Argon Time Projection Chambers (LArTPC's) offer access to high quality, detailed information about neutrino interactions from MeV - GeV scales**
  - Conventional wire readout uses the 2D projection from multiple views to reconstruct the 3D interaction
    - *A very challenging endeavor!*
  - Dedicated pixel based readout preserves the native 3D information
    - ***Comes at the cost of many more channels***
      - LArPix ([1] and Q-Pix [2] have addressed this challenge by developing low power dedicated electronics for large scale LArTPC pixel readout
- **The advantages of a native 3D readout have been shown to increase both neutrino signal efficiency and background rejections**
  - Paper: JINST 15 P04009
- **The novel readout solution known as Q-Pix has also shown the enhancement to low energy neutrinos (e.g. supernova neutrinos) which are possible with a pixelated low-power, low-threshold sensor**
  - Paper: Phys. Rev. D 106, 032011 (2022)
- **More information about Q-Pix in Shion Kubota's talk in this session**

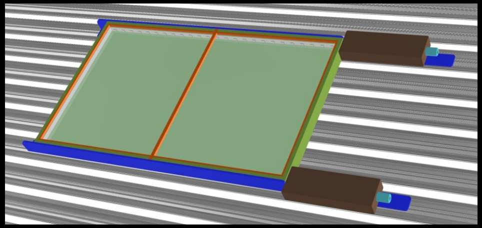
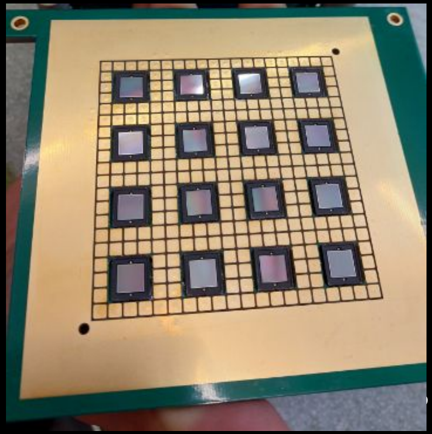




Photon Detection w/ Pixel Based Detector

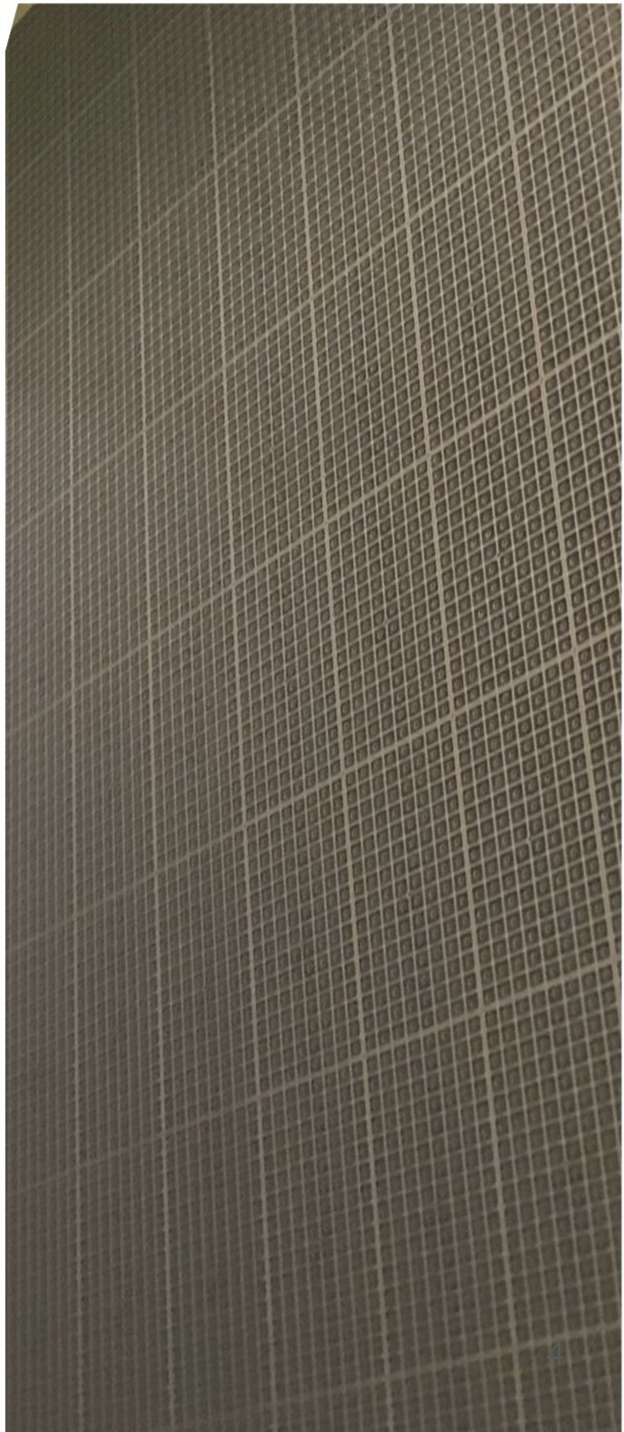
- **The pixel readout is opaque, and thus the conventional positioning of the light readout behind the charge collection plane is not possible**
- **A few different solutions have been explored to tackle this**
  - Dielectric waveguide which penetrates into the active volume and guides the light to SiPMs mounted on the pixel plane
    - Paper: Instruments 2018, 2(1), 3
  - Electrically floating photosensors and electronics mounted to the cathode and field cage
    - Paper: JINST 17 (2022) 01, C01067
  - Embedded SiPM's into the pixel plane
    - Paper: arXiv:2406.14121v1
  - Solutions give you 20-30% photon coverage with *O*(%) level efficiency

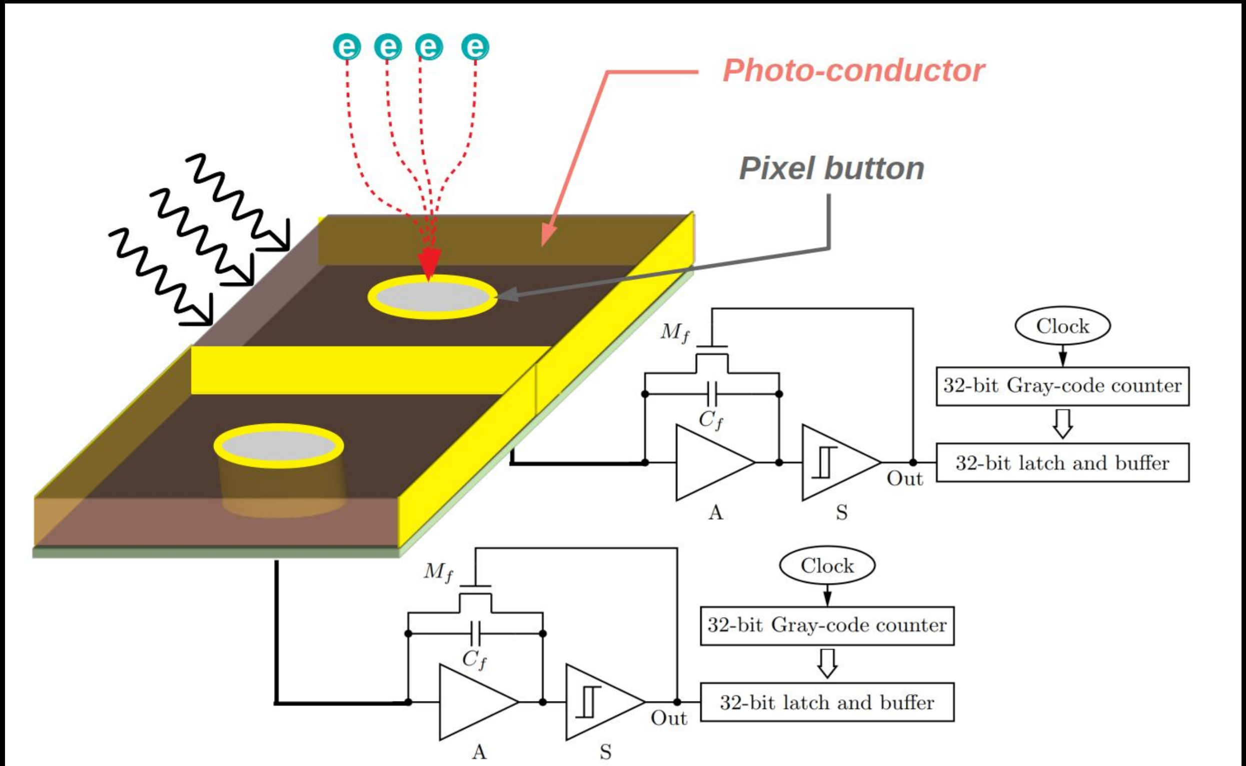



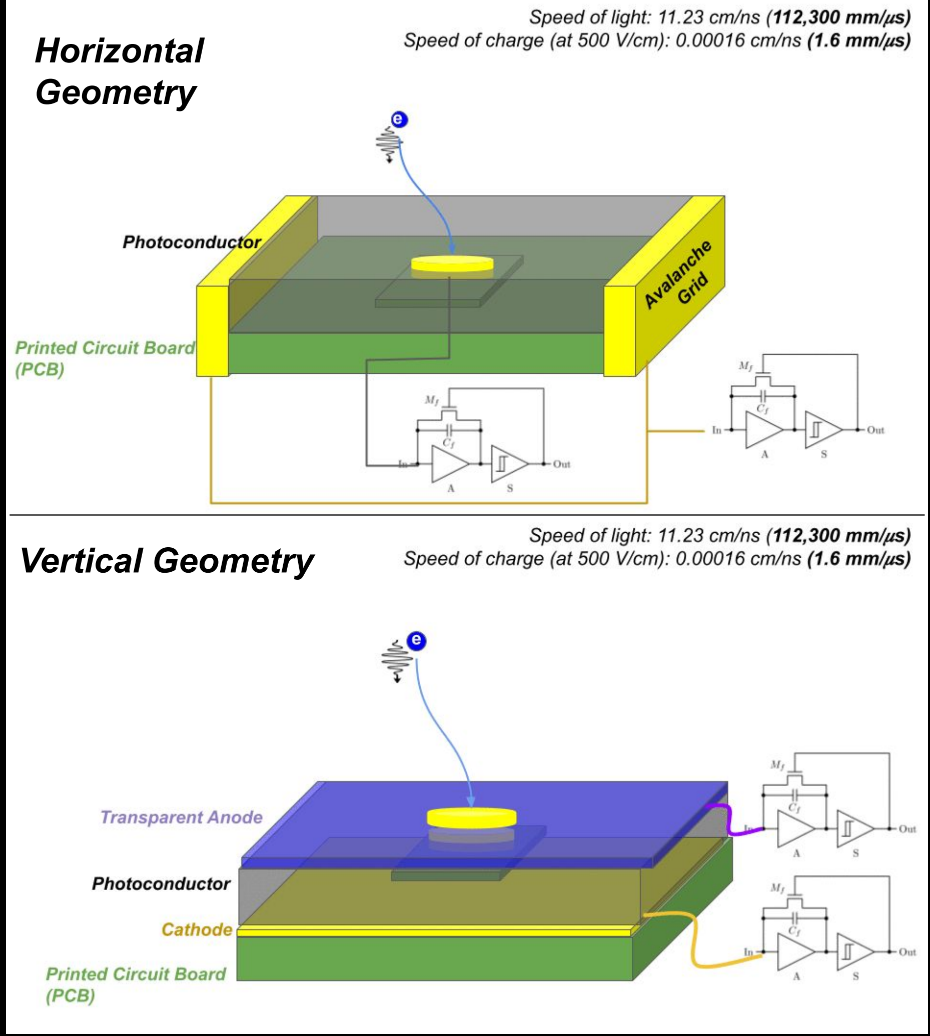
Pixels which also are photo-sensitive?

- What if the **whole pixel plane could collect light?**
- **A pixel plane sensitive to UV photons and ionization charge SIMULTANEOUSLY would be a major breakthrough**
  - Your effective instrumented area becomes enormous!
  - Even if the device has low efficiency you have a huge gain
  - **Q-Pix could be an “enabling technology” to realize this for LArTPC’s**



Concept of an integrated Q+L Sensor



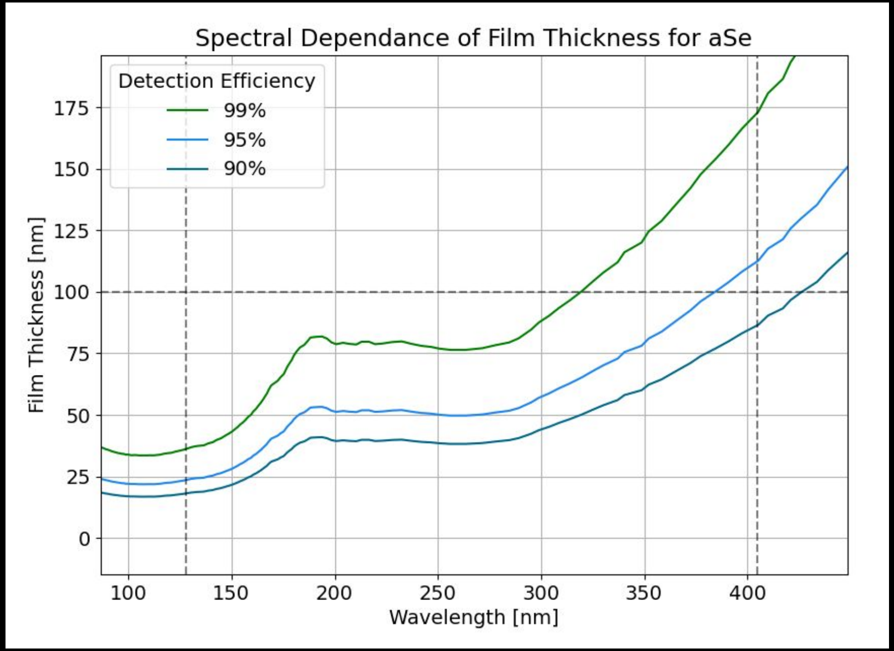


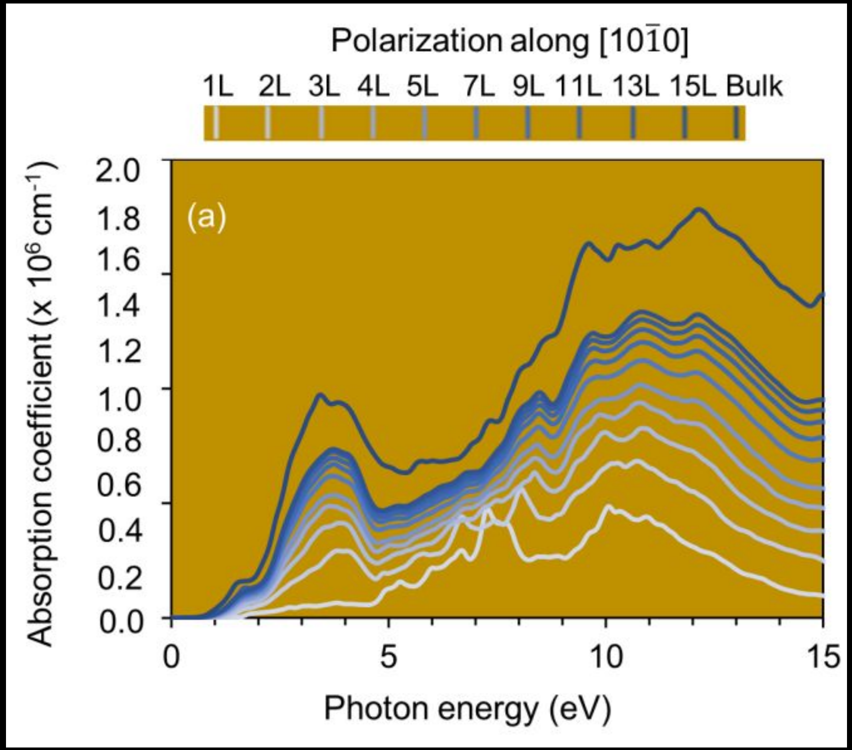
Can a photoconductive substrate applied to the pixel plane allow for the integration of charge (Q) and light (L) into one single sensor?

- **Lots of questions to be answered (photoconductor?, geometry?, electronics?, gain?, etc….)**

Searching for a novel photoconductor

- **There are a large number of potential photoconductors to be explored which could satisfy what we would like to do**
  - **Perovskites, Nanoplatelets, Organic Photodiodes, Selenium, etc….**
  - **Good opportunity to collaborate broadly with material science experts, national labs, and university groups**
- **We began with an investigation into amorphous selenium**
  - **Broadly used in medical imaging devices**
  - **Relatively cheap and has an easy manufacturing process (thermal evaporation)**
  - **Largely unexplored (but very promising) properties in VUV wavelengths**
    - Example of a DFT calculation done with condensed matter theorist to understand selenium properties (Langmuir 2022, 38, 28, 8485–8494)





The strategy for exploring amorphous selenium

- **Horizontal Device Proof of Concept**
  - Understand selenium properties to VUV light (Langmuir 2022, 38, 28, 8485–8494)
  - Develop a pulsed VUV light source for calibration (Review of Scientific Instruments 93, 053103)
  - Test its application on printed circuit board at cryogenic temperatures (arXiv:2207.11127 / JINST 18 (2023) 01, P01029)

This phase has been completed

- **Vertical Device Proof of Concept (subject of this talk)**
  - Develop a VUV transparent window novel vertical geometry
  - Demonstrate its functionality at various temperatures, fields, and light sources

NEW RESULTS!!!!

- **Low Photon Yield Demonstration**
  - Show viability of detector to have sensitivity to low VUV photon flux
  - Explore different geometries in detector construction
    - (windowless horizontal vs VUV transparent window vertical geometry)
  - Perform simulation studies to show the conferred benefit of a Q+L sensor for LArTPC's
  - Detailed simulations of amorphous selenium with various doping schemes

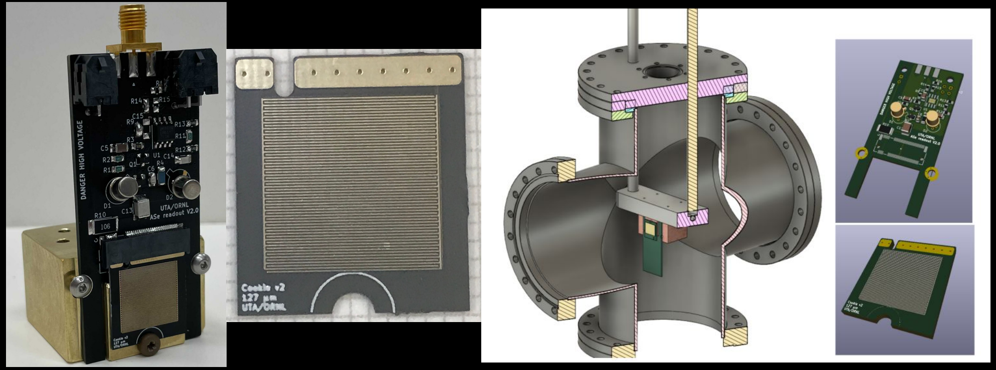
We'll show some preliminary NEW results from these efforts which are currently ongoing

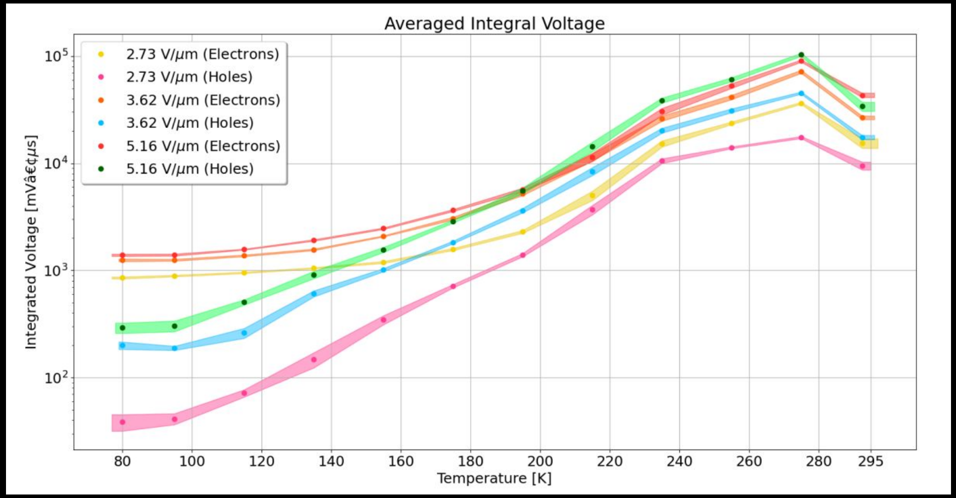
- **Build a scaled up demonstrator**
  - Operation of a small scale Q+L pixel based TPC
  - Construct large(r) scale pixel plane ($O(100cm^2)$) with aSe pixel based photon detector

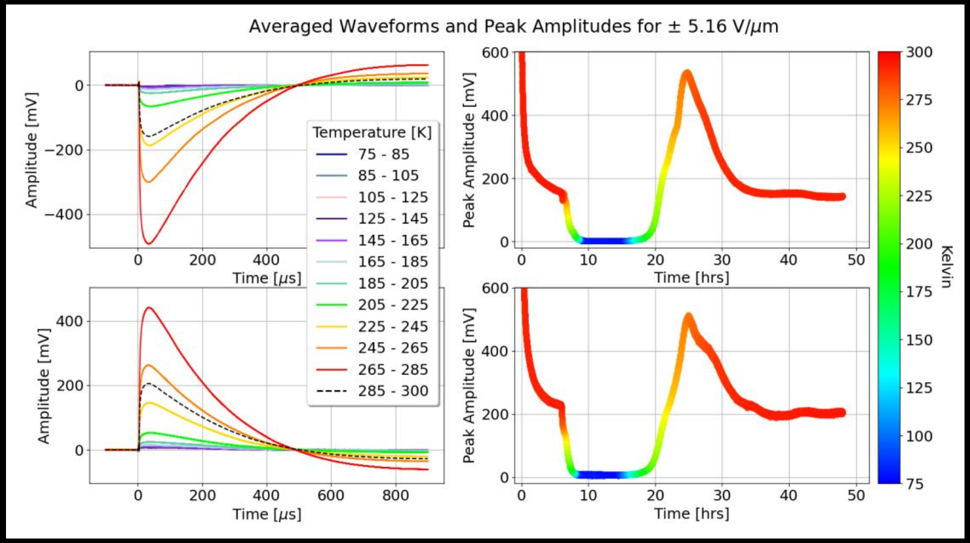
Proof of Concept

Four Key Findings

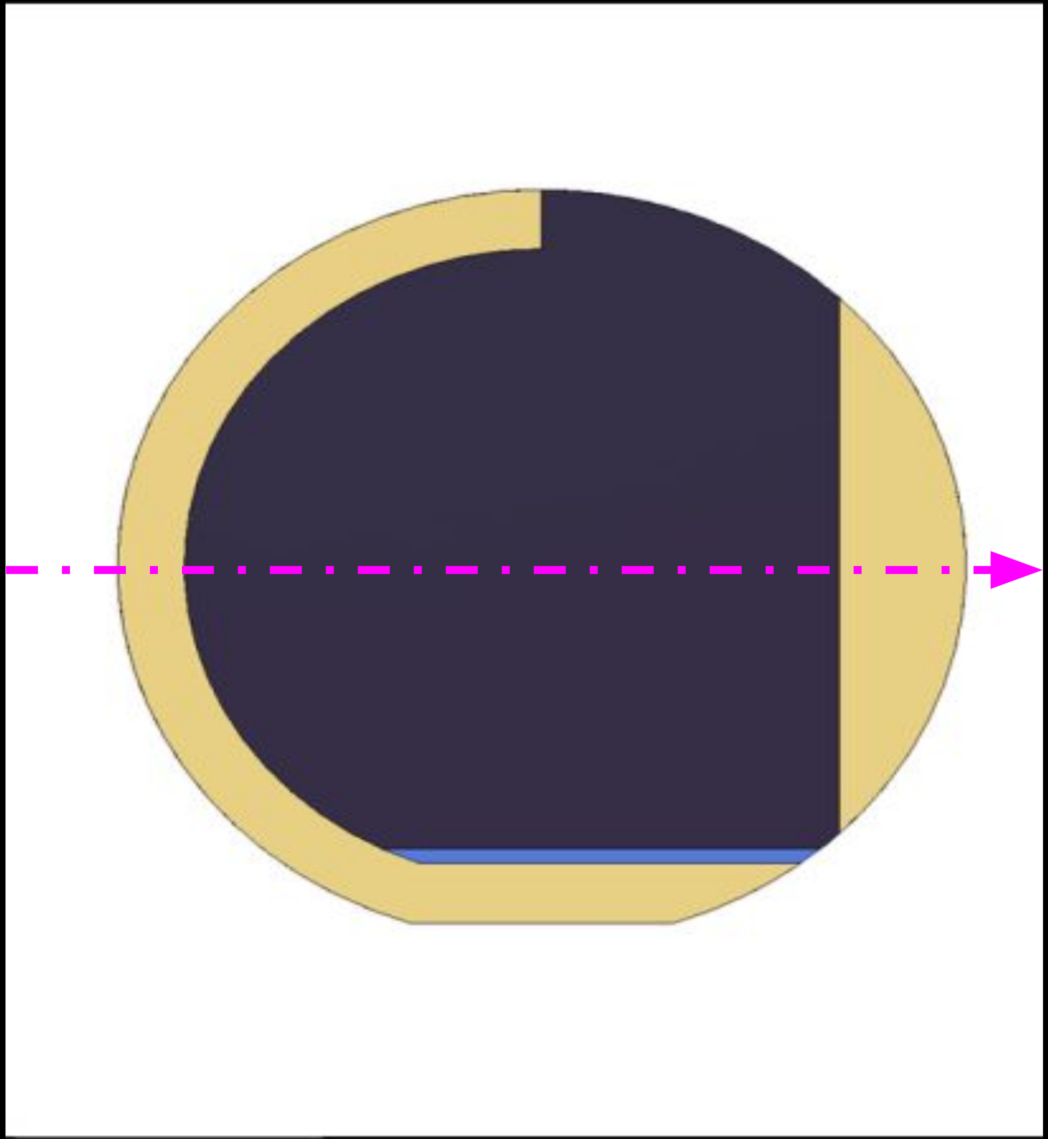
1. While the magnitude of the **peak amplitude is noticeably reduced at the lowest temperatures, it is definitively non-zero** and has a pulse shape consistent with a response due to signal from the flashlamp
2. The **magnitude of the peak amplitude scales approximately with the size of the applied field**
3. The peak amplitude at the lowest temperatures is consistently **higher when collecting electrons rather than holes**.
4. We observe a **reduction of the signal peak amplitude under repeated pulses** of light from the xenon lamp. This phenomenon is consistent with a phenomenon known as ghosting.



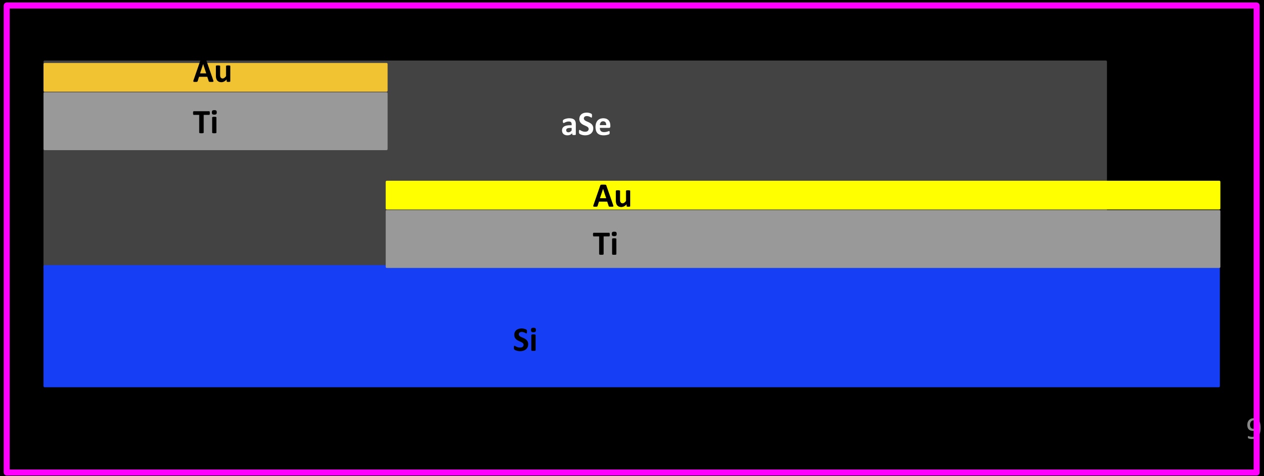




Vertical Structure

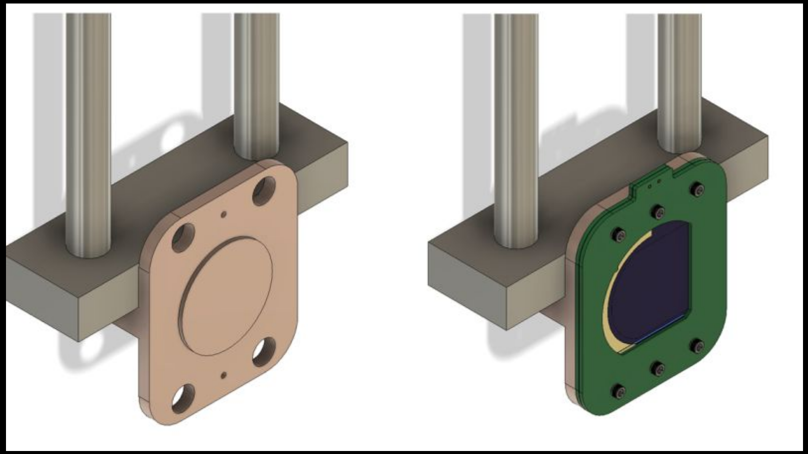


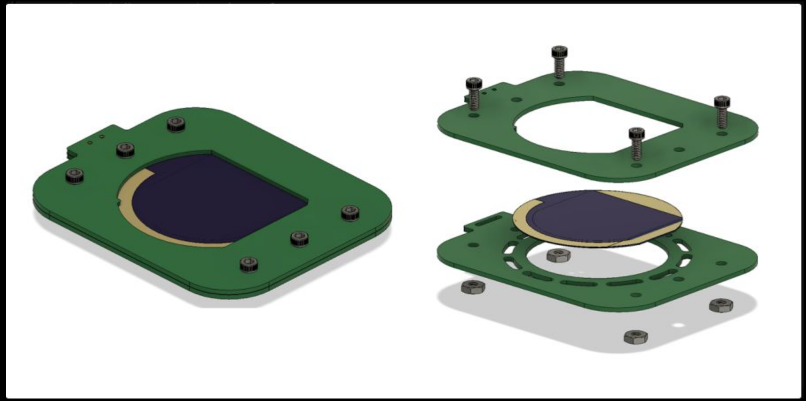
1. Starting with a Intrinsic Silica
2. E-Beam Evaporation Metal(Ti/Au or Cr)
3. Thermal Evaporation aSe (1 or 10 um)
4. E-Beam Evaporation Metal(Ti/Au or Cr)



Looking at this in cross-section

Vertical Structure





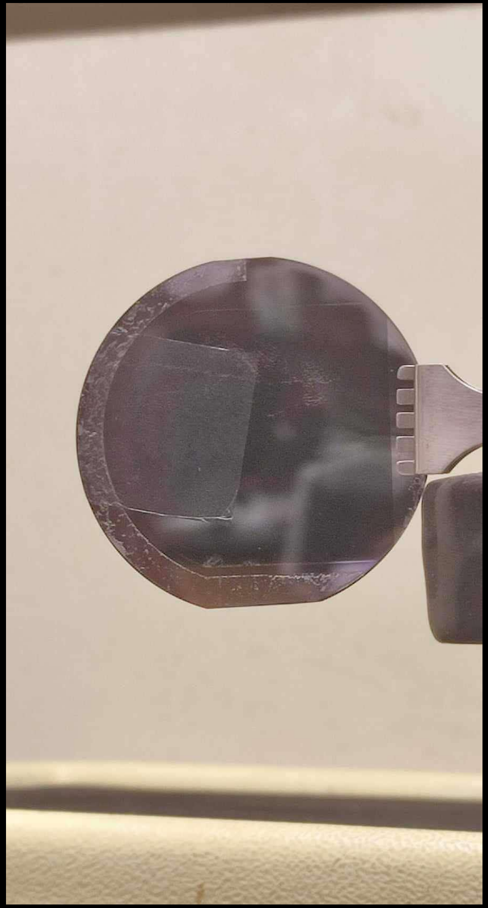
First Stage

After First Metal Deposition

Second Stage

After aSe deposition

Final Stage

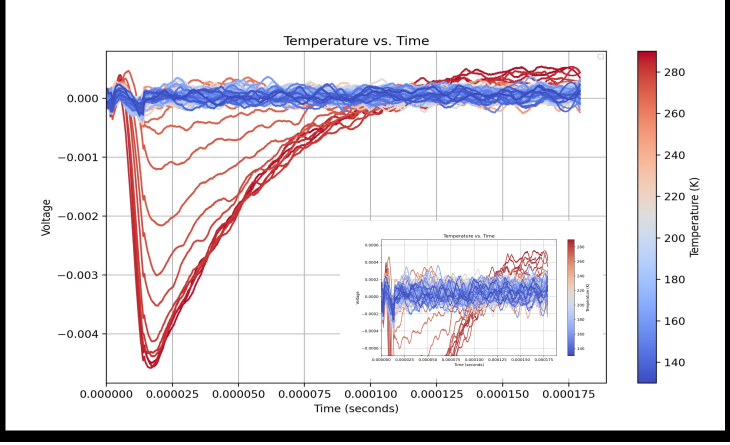


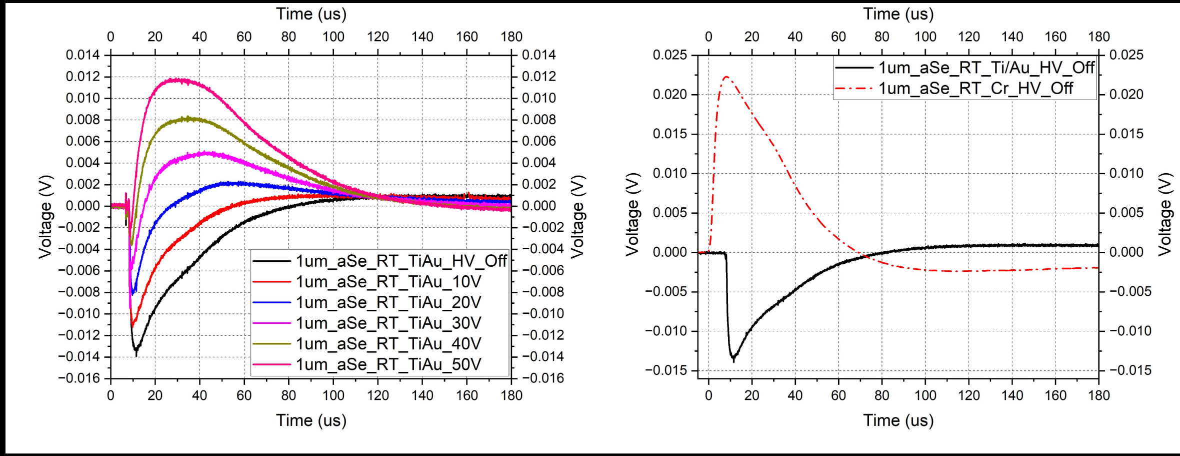
After Wet Graphene Transfer

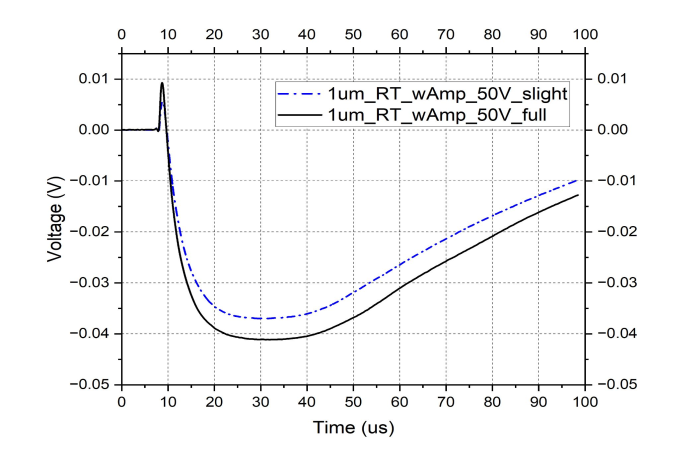
Vertical Devices

Four Key Findings

1. While the magnitude of the **peak amplitude is noticeably reduced at the lowest temperatures, it is definitively non-zero** and has a pulse shape consistent with a response due to signal from the flashlamp
2. The **magnitude of the peak amplitude scales approximately with the size of the applied voltage.**
3. Different metal contacts complement a different charge carrier signal.
4. We observe a **increase of the signal peak amplitude when the intensity of light** from the xenon lamp.



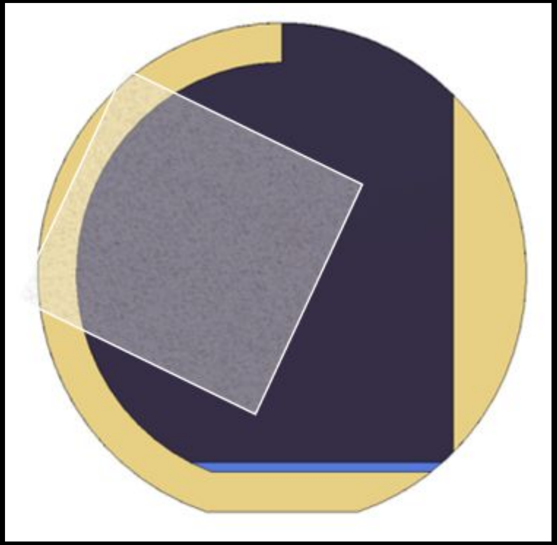




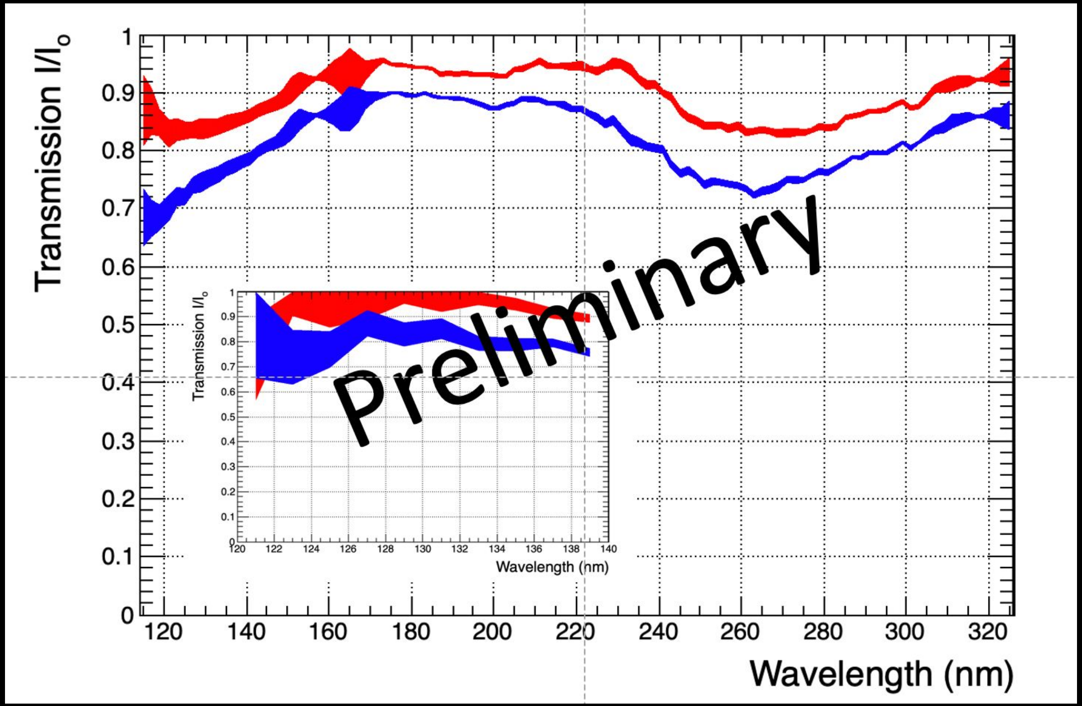
Reduced Light Intensity

Aperture fully open

Graphene as a transparent window

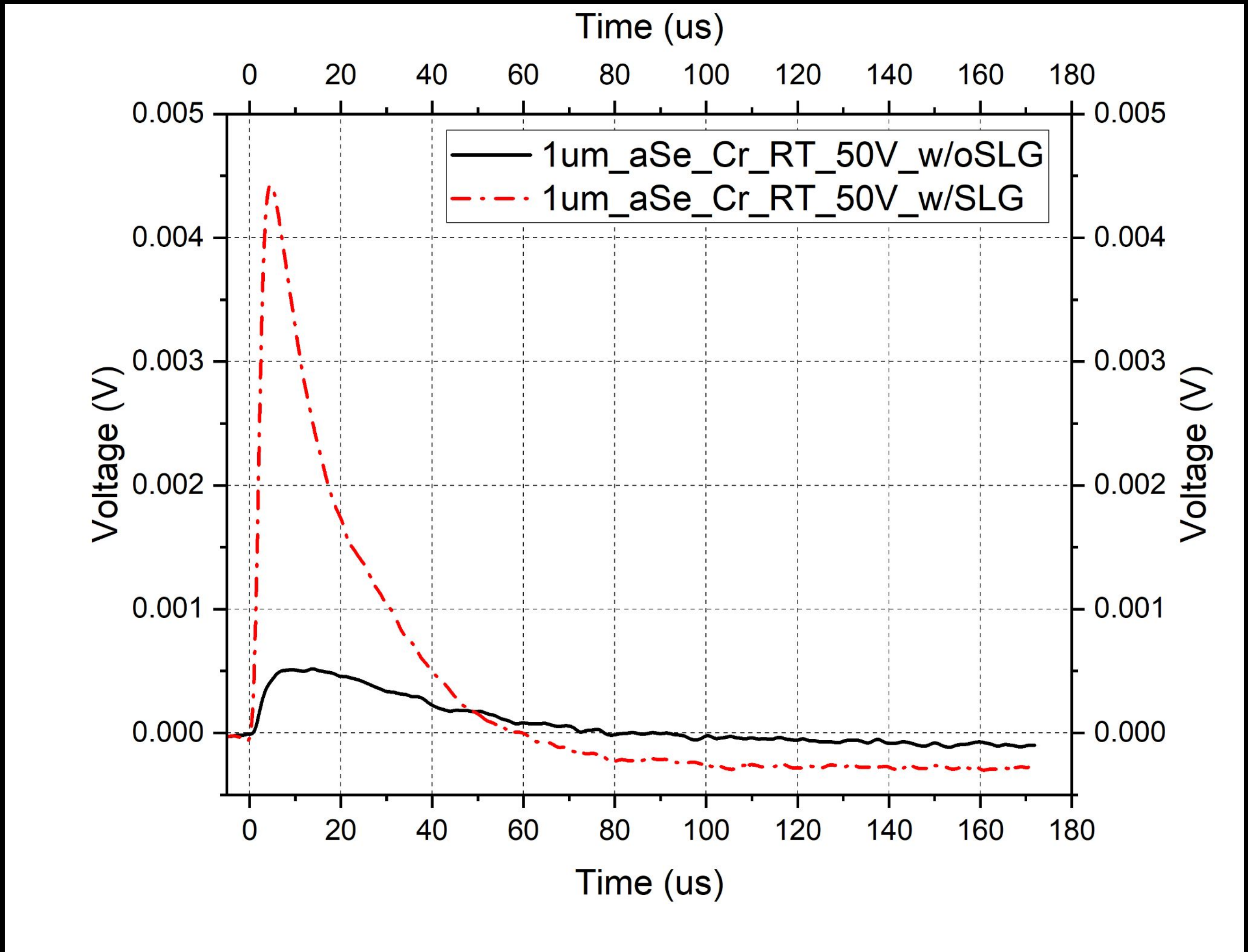


1. Multilayer and Single layer graphene transmission was tested of the range of 120 nm to 320 nm.
2. Graphene acts to increase the uniformity of the electric field across the aSe.
3. Graphene enhances the charge collection due to the geometry.



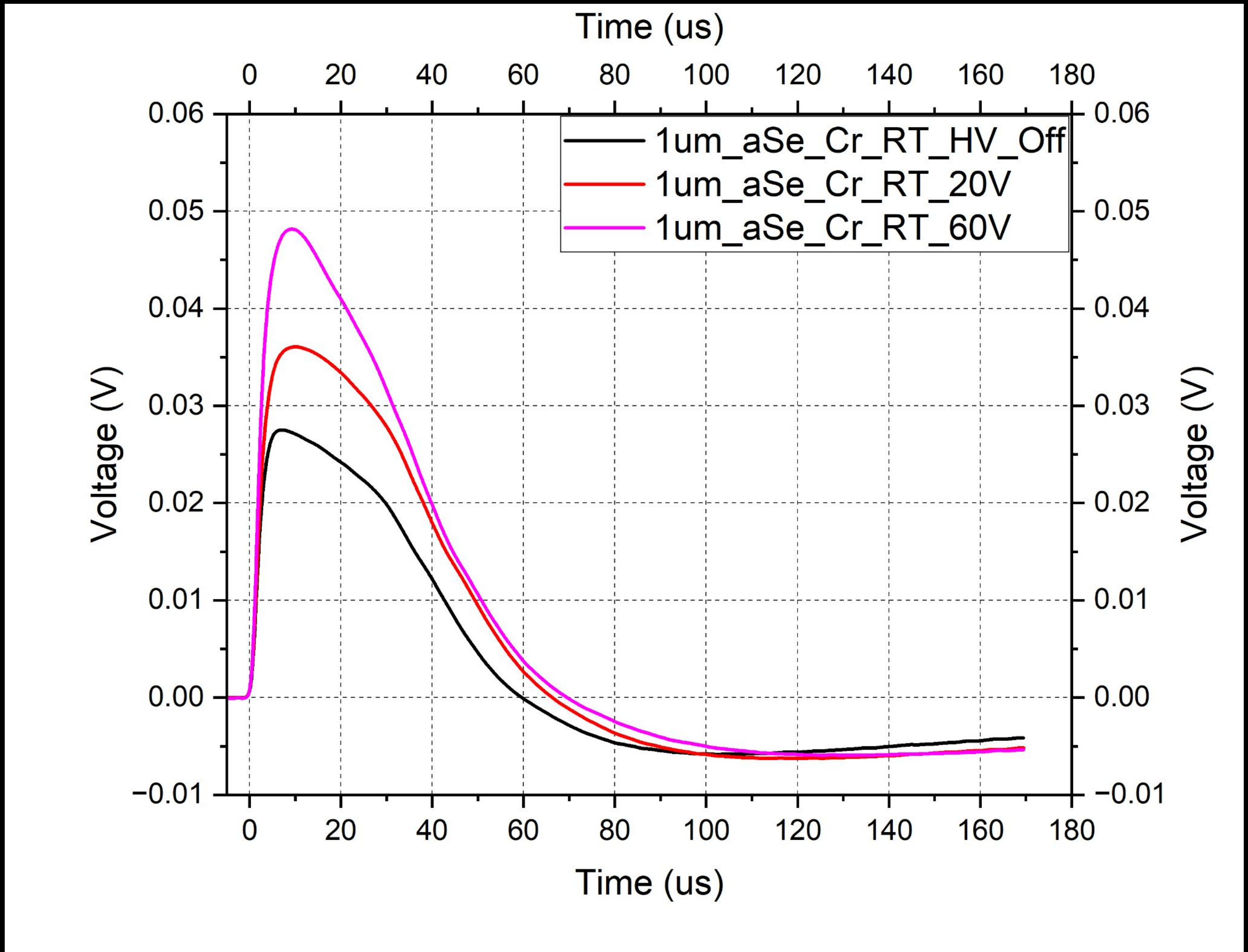
Results with MultiLayer Graphene

1. Direct comparison of the peak amplitude of the same device before and after graphene.



Results with MultiLayer Graphene

2. Magnitude of the peak amplitude scales proportionally to the amount of applied potential.



Next steps

1. Going forward vertical devices will be moved from intrinsic silica to fused silica due to its properties.
2. Different metal contacts will be investigated and their correlation to the signal produced from the amorphous selenium.
3. Move to the original device geometry that was proposed where the graphene will be covering the whole area of the amorphous selenium.

Summary

- I have given an overview of previous work done with the aSe as a photoconductor and the different device geometries.
- I have shown that the vertical geometry for aSe device is possible.
- I have also shown that graphene can function as a VUV transparent window and has shown promising results in room temperature schemes.
- Finally, I have given a clear view of what the upcoming stages of research are regarding the geometry and the understanding of its dynamics.






Special thanks to:

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ORNL: Michael Rooks

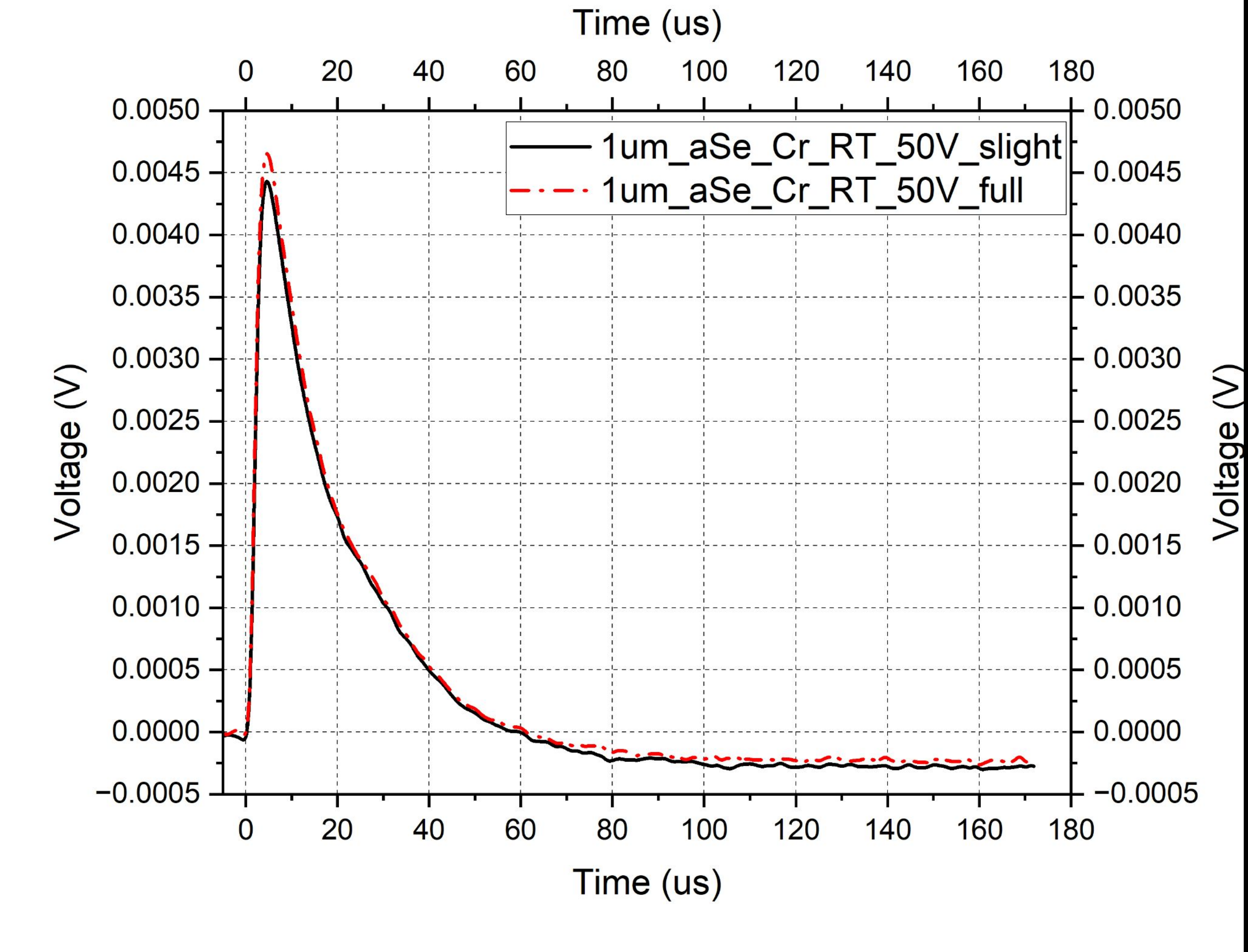
University of Manchester: Elena Gremlini

UCSC: Shiva Abbaszadeh and Katie Hellier

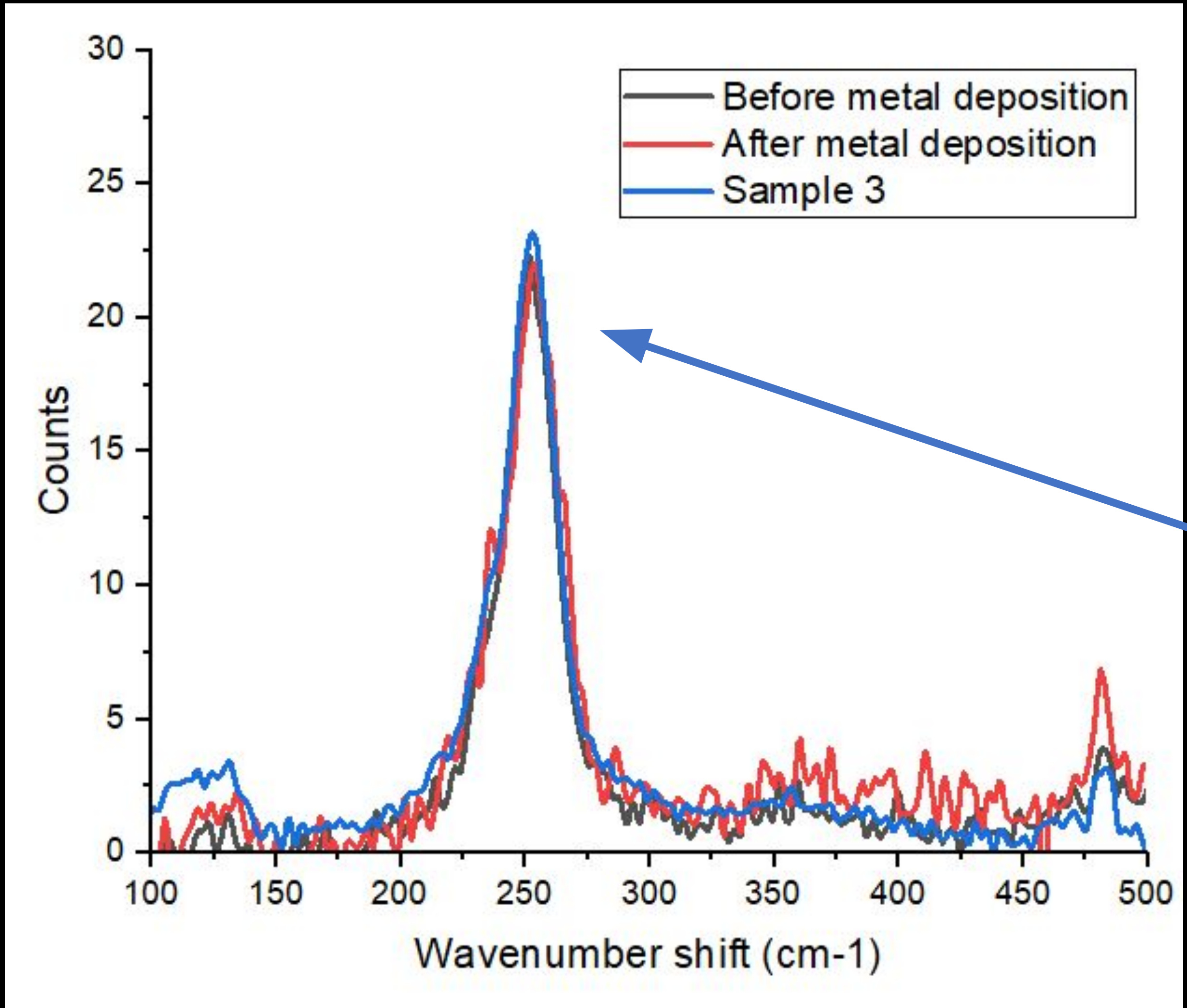
Backup Slides

Results with MultiLayer Graphene

3. Observed an increase on the signal peak, relating to the intensity of light incident to the sample.



Raman before and after depositing the second electrode



1. Raman Spectroscopy of before and after e-beam evaporation of second metal to ensure amorphous selenium.

The amorphous bands match before and after deposition.

Raman spectra after depositing graphene