Thin A-Se films for Novel Scintillation Light Detectors

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Huge thanks to:
Michael Febbraro, ORNL
Shiva Abbaszadeh, UCSD
Jonathan Asaadi, Austin McDonald, Michael Rooks, UTA

Pixel TPCs

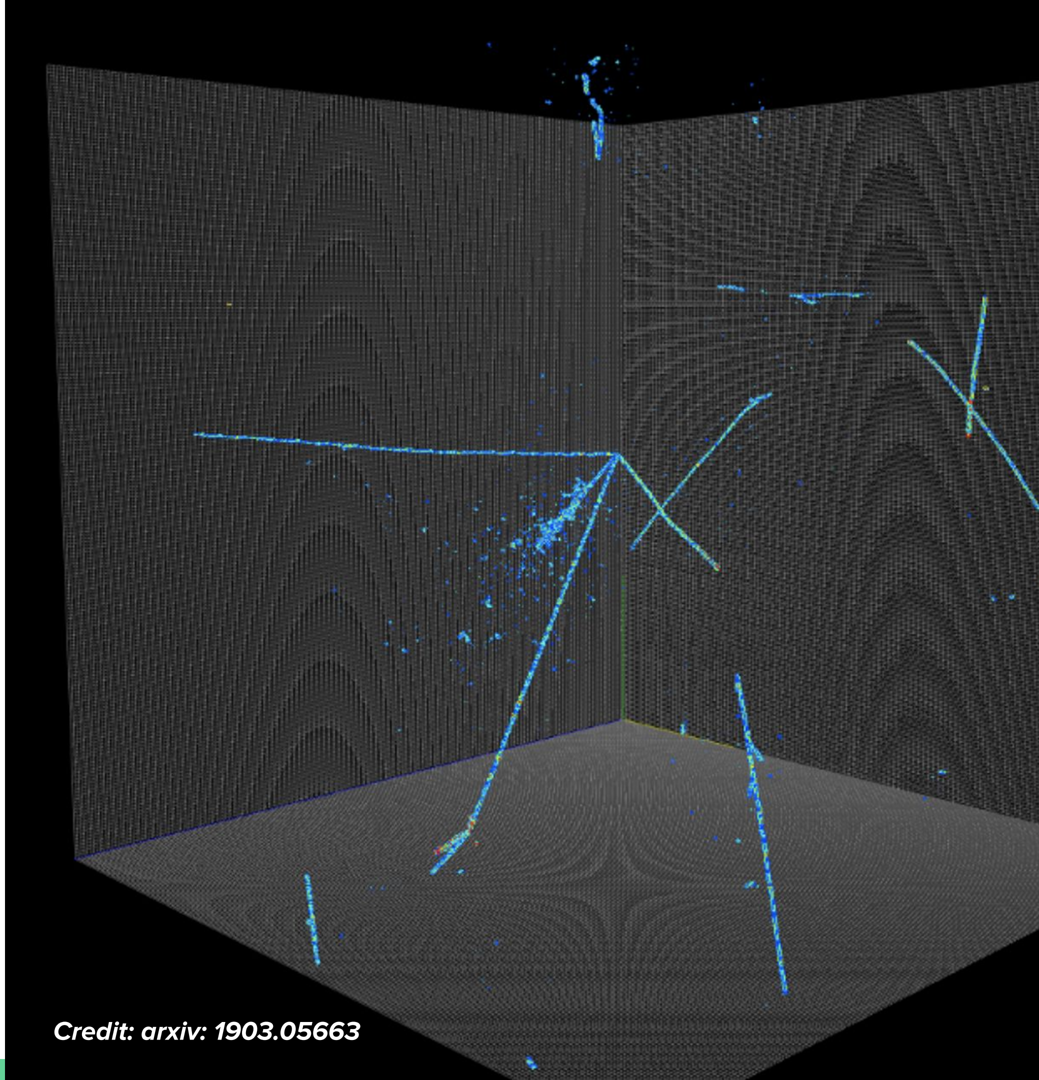
Pixel TPCs are at the forefront of noble element detector R&D even for kiloton scale neutrino detectors (see Q-Pix talks by Austin McDonald and Gang Liu, LArPix by Booke Russell)

They offer a number of competitive advantages wrt traditional wire readouts

The **readout space coincides w/ the physical projected space**:

➜ native 3D reconstruction w/ same spatial resolution

➜ abated ambiguities (mm vs m projections)



Credit: arxiv: 1903.05663

Light collection system: where to?

In traditional wire readouts, a rather coarse light collection system is mounted behind the wires of the anode plane:

➔ VUV light can reach the light collection system

Ar scintillation light λ = 128 nm

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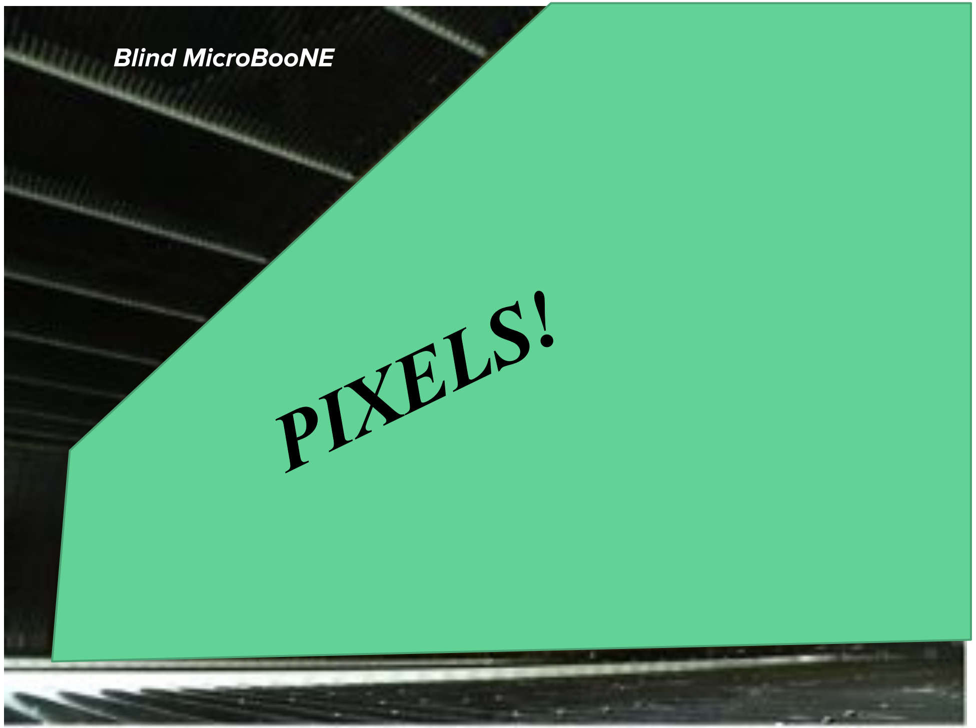

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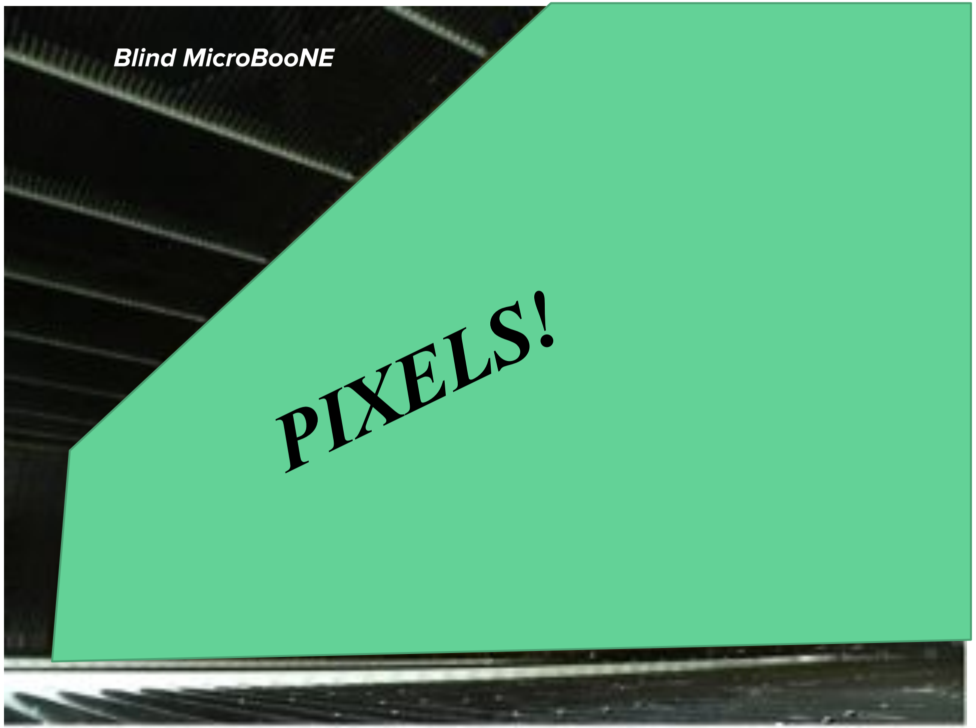
➜ VUV light can reach the light collection system

Pixels are embedded in PCB: **opaque boards** to the VUV light!
Different placements of traditional light detectors needs demonstrated and would likely result in a coarse light sampling



Ar scintillation light λ = 128 nm

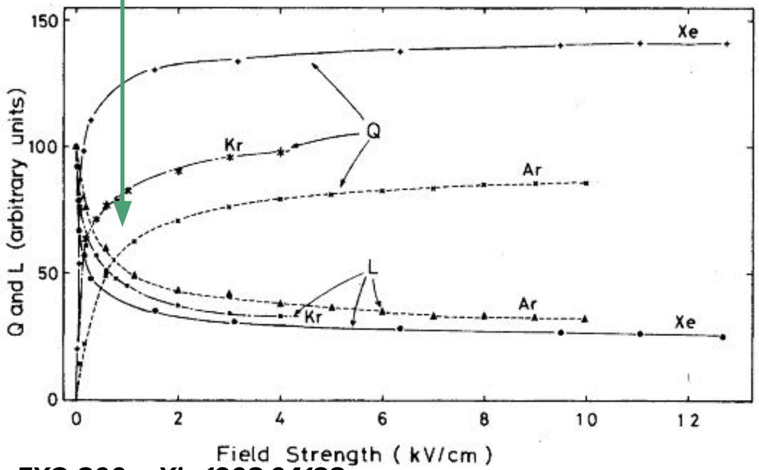
Charge & Light in Nobles?

At E = 500 V/cm (typical LArTPC field)
½ of half of energy released by charged particles in LAr goes in scintillation light

➡ Light holds ½ of the information
Boost detection capabilities especially at low E with light and charge combination.

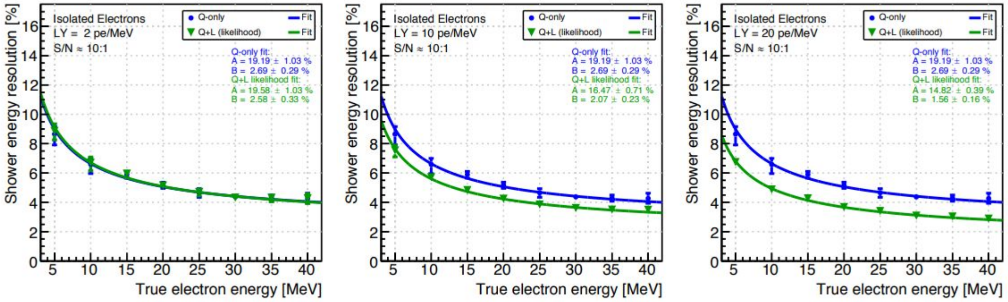
DUNE LIVES HERE!

Phys. Rev. B, vol. 20, no. 8, p. 3486, 1979



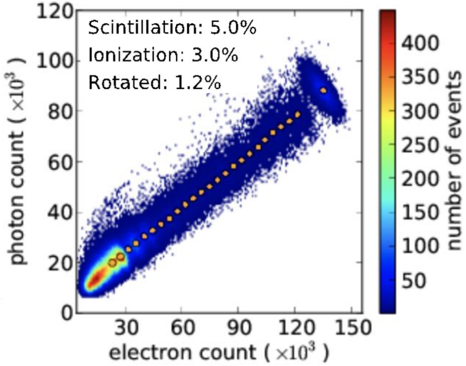
LArIAT arXiv:1909.07920

S/N ~ 10



LY = 2 pe/MeV *LY = 10 pe/MeV* *LY = 20 pe/MeV*

EXO-200 arXiv:1908.04128



Renew interest in the community highlighted by Szydagis et all. ***arxiv.2102.10209***

Turning flaws into strengths

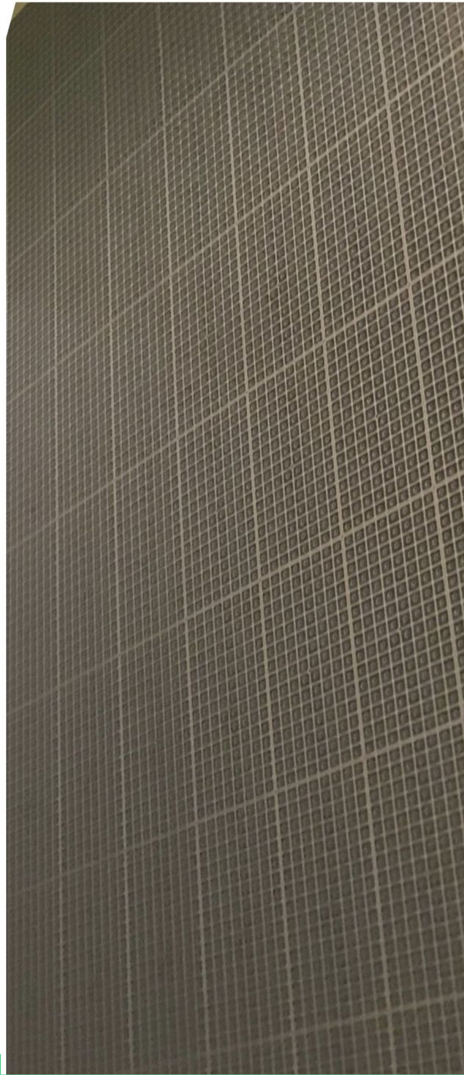
A pixel plane sensitive to UV photons and ionization charge SIMULTANEOUSLY would be a major breakthrough

Multiple modality pixels: a pixel capable to detect both UV light and femtocoulomb charge

➜ The effective instrumented area becomes **enormous**: 100% anode surface
➜ Light-Charge w/ same readout: extremely granular light collection
➜ Light-Charge matching is **straightforward**
➜ Even in case of low QE efficiency*, huge gain from photocathode coverage

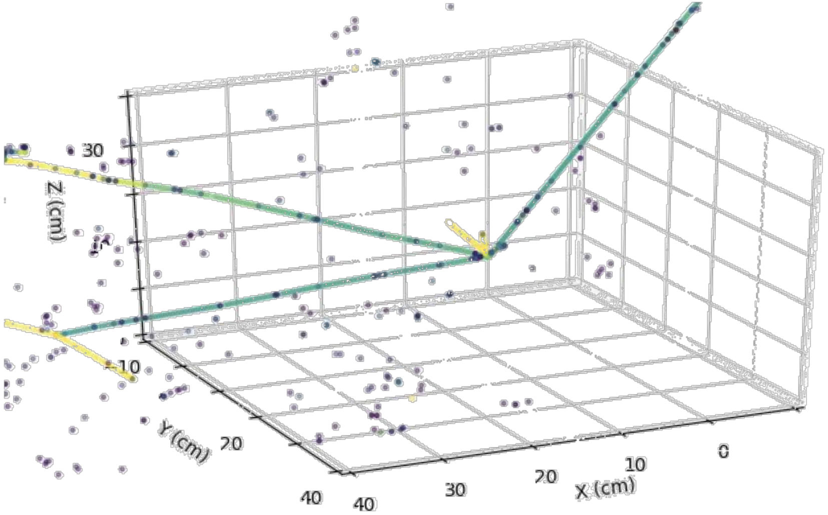
****Note: The idea under development has the potential for good UV photon efficiency***

Wide surface high granularity light detector: interesting stand alone applicability!



High granularity detectors: light imaging?

Charge simulation on neutrino interaction



High granularity detectors: light imaging?

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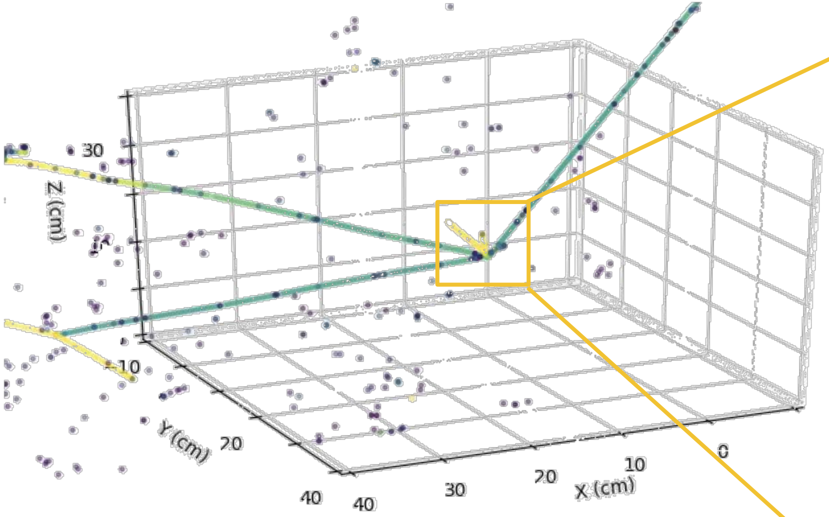
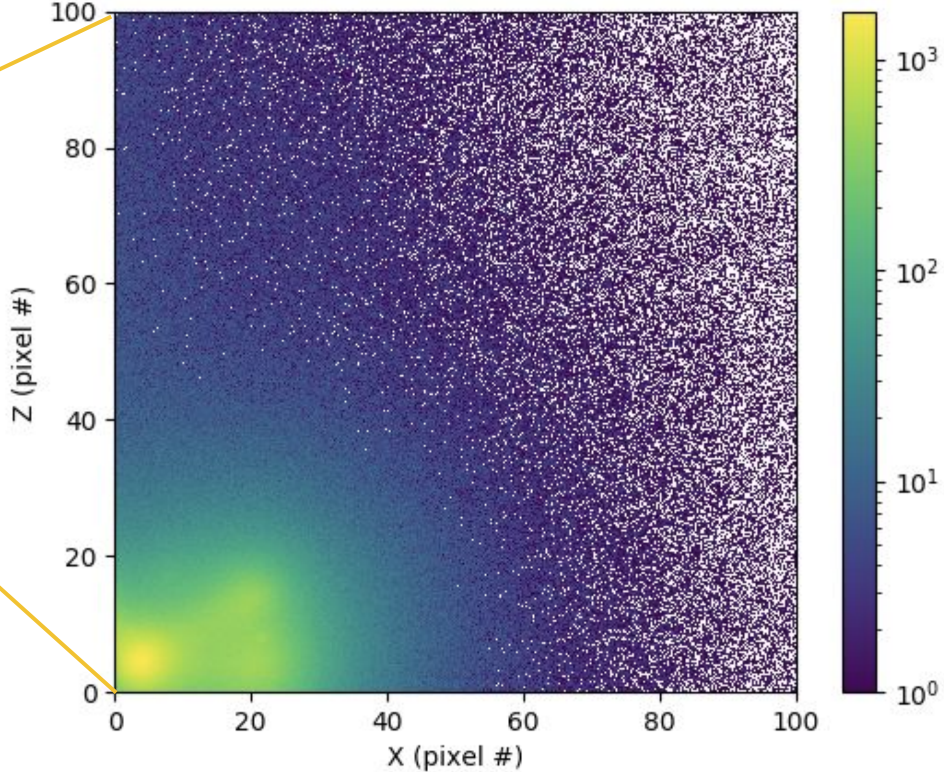


Light simplified simulation for same event



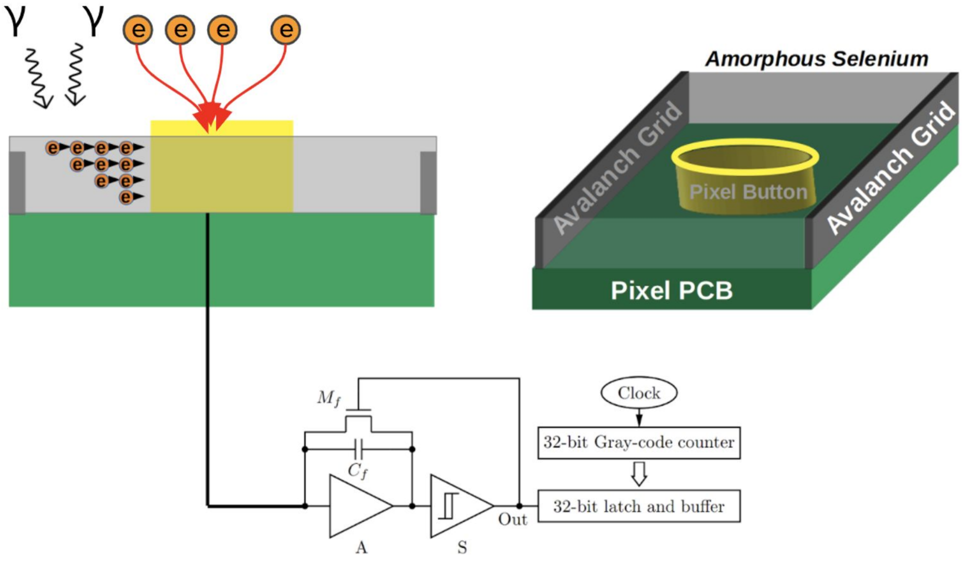
Interesting developments in ML techniques to extract to deconvolve light degradation effects.

Amorphous Selenium Coatings

Multiple modality pixel: develop pixel coatings with photo-conducting material.

First material:
Amorphous Selenium
➜ Commonly used in
X-Ray digital radiography devices
➜ Never used in cold: LAr ~ 87k!
(Big “make it or break it” challenge)

When VUV γ strikes the A-Se,
the γ is absorbed and a e-h pair is created
with an extremely high probability
if the A-Se layer is thick enough.



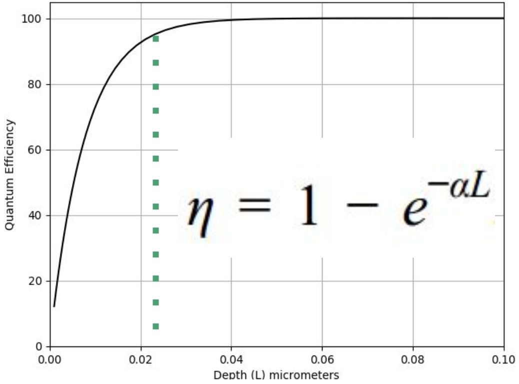
Q-Pix Readout

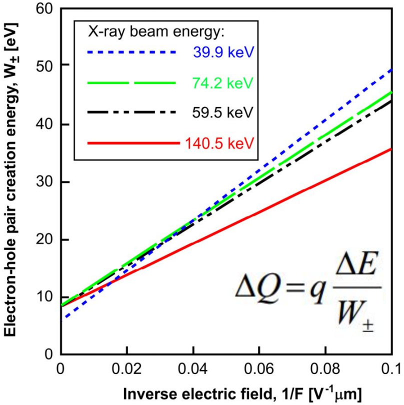
What’s special about A-Se? Photons

The literature on amorphous selenium reports an attenuation coefficient α ~130 μm^{-1} for photons at 128 nm, resulting in a
<u>QE than 99% for thin coatings (> 1 μm)</u>

1 γ ↔ resulting on avg in ~ 1.3 e-h pairs: single photon sensitivity not excluded.

At the theoretical break down voltage (90 V/μm) the gain factor is ~ 1.5 10^3
Electron yield for 2+ γ is compatible w/ Q-Pix readout [1800-6000 e]





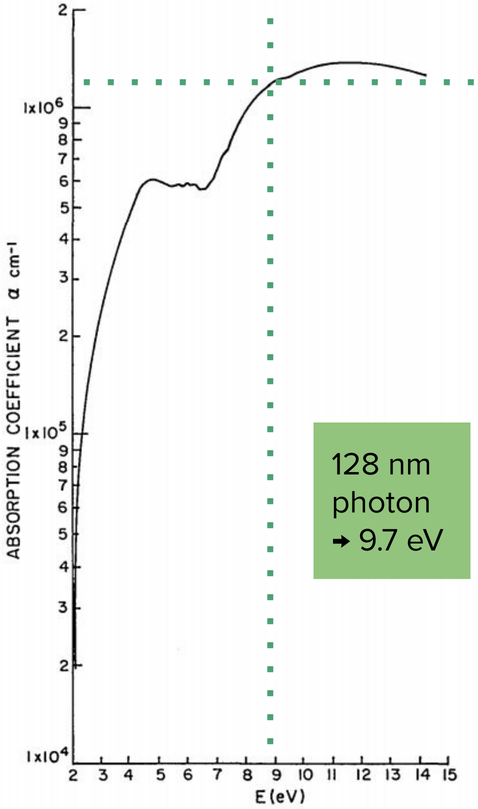


FIG. 6. The spectral dependence of the absorption coefficient, α, of amorphous selenium.

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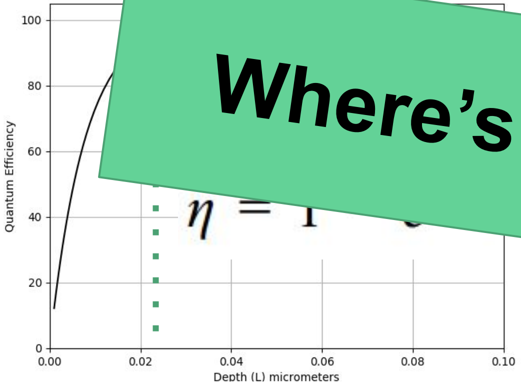
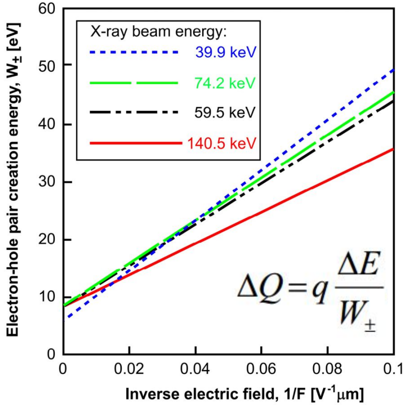
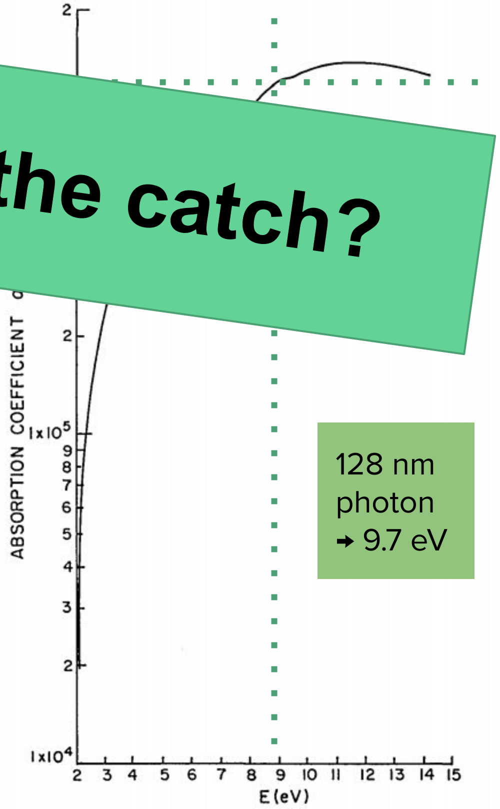


Where’s the catch?





128 nm photon → 9.7 eV

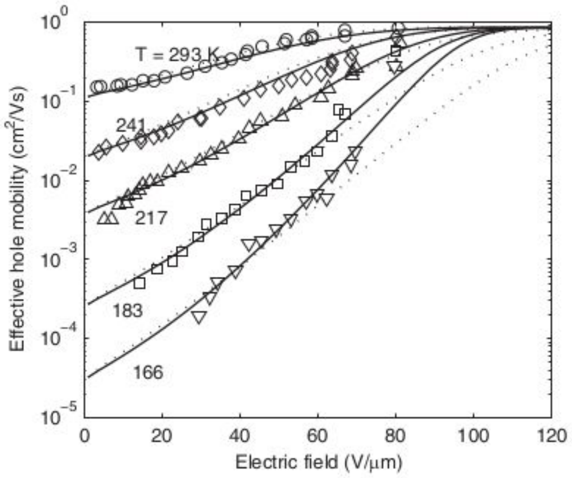
FIG. 6. The spectral dependence of the absorption coefficient, α, of amorphous selenium.

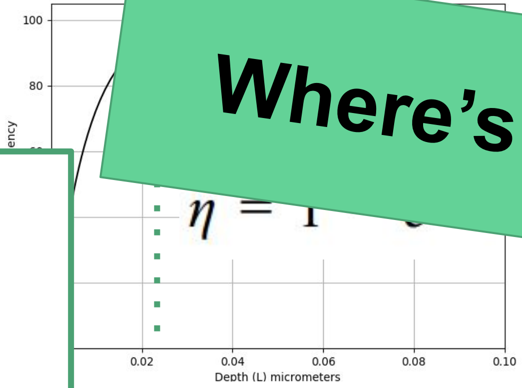
What’s special about A-Se? Photons

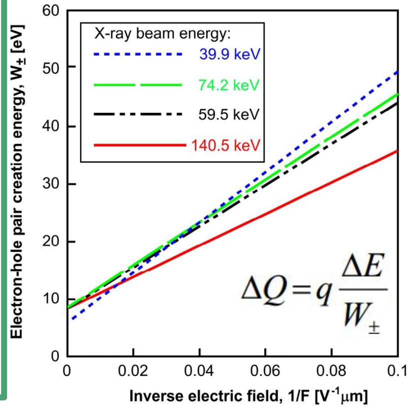
The literature on amorphous selenium reports an attenuation coefficient α $\sim$130 µm^{-1} for photons at 128 nm,

Where’s the catch?

Mobility of carriers might drop at low T







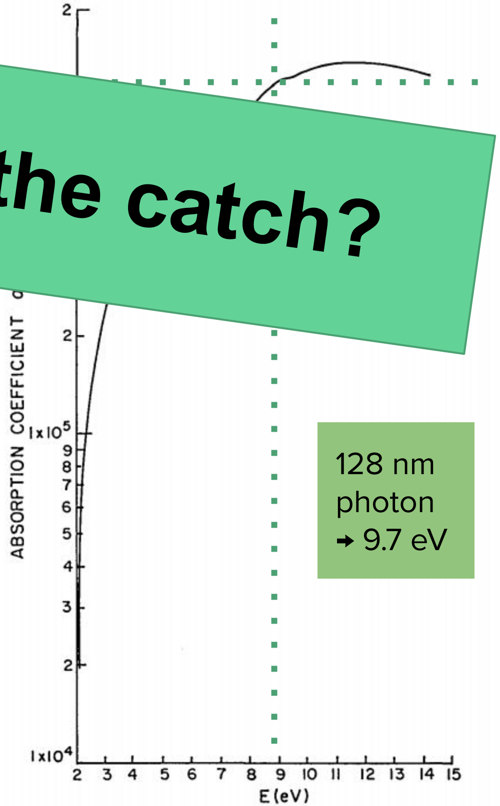


FIG. 6. The spectral dependence of the absorption coefficient, α, of amorphous selenium.

128 nm photon ➔ 9.7 eV

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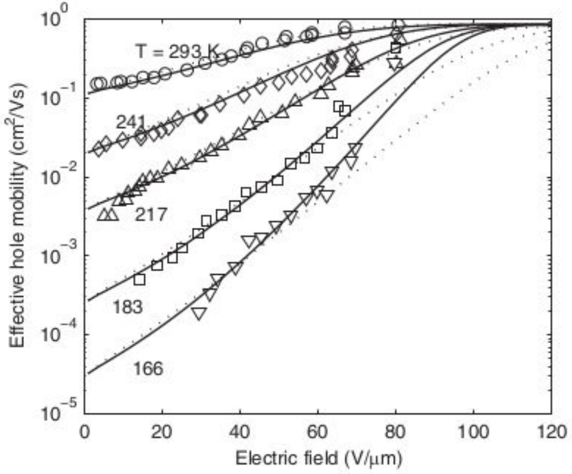
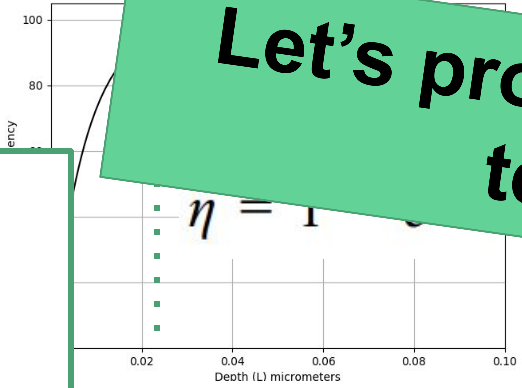
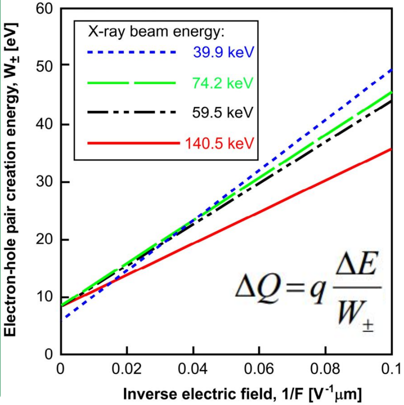




Let’s prototype and test!



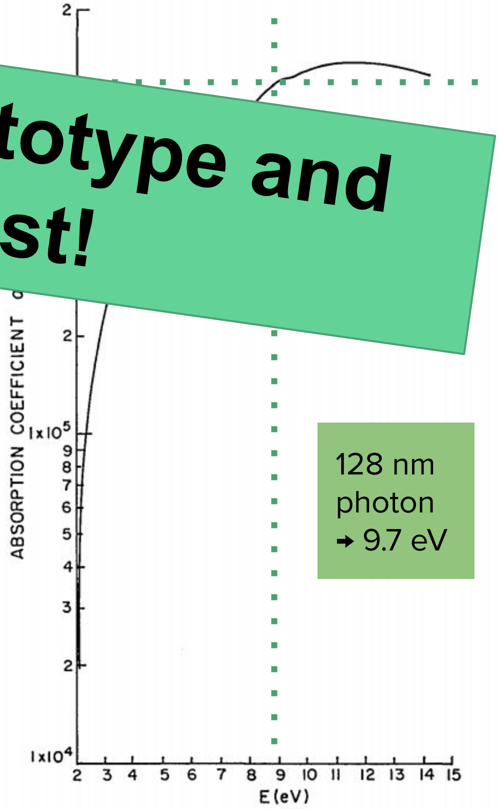
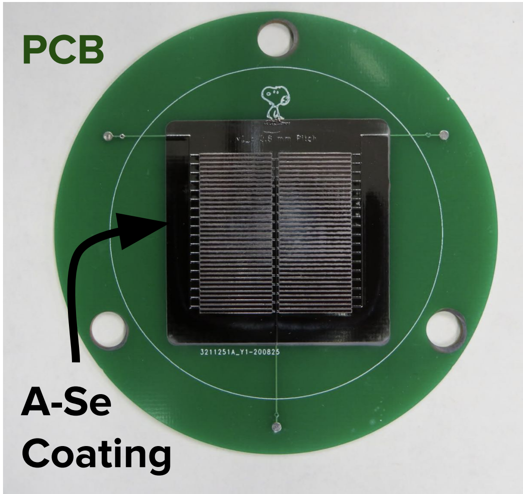


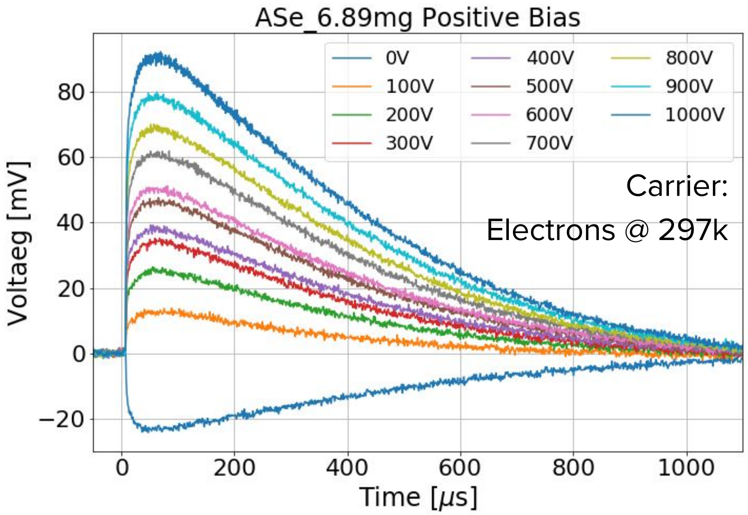
FIG. 6. The spectral dependence of the absorption coefficient, α, of amorphous selenium.

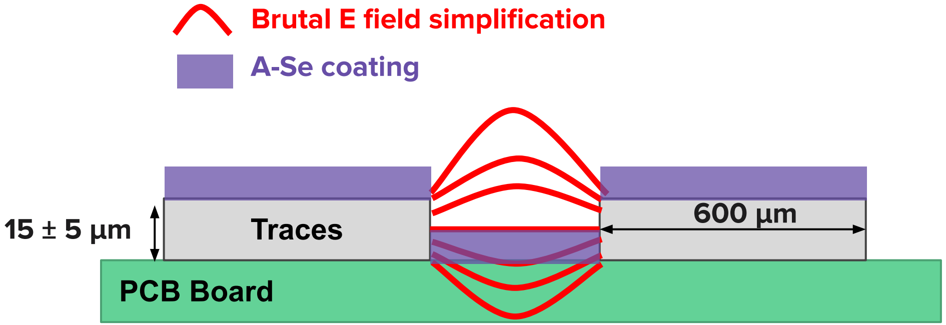
128 nm photon → 9.7 eV

First prototype & tests

A-Se deposited through thermal evaporation on commercial printed circuit board. First prototype: 200 μm spacing.
UTA test: vacuum 20mtorr, different voltage points, source Xe light. **We saw signal!** Max E ~ 5V/μm: far from avalanche regime.



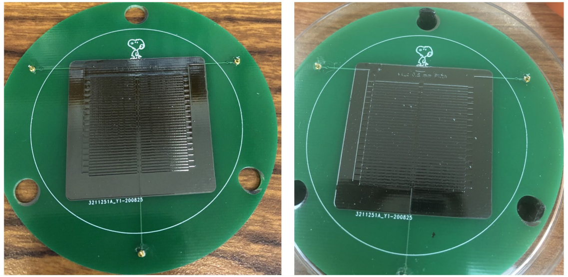




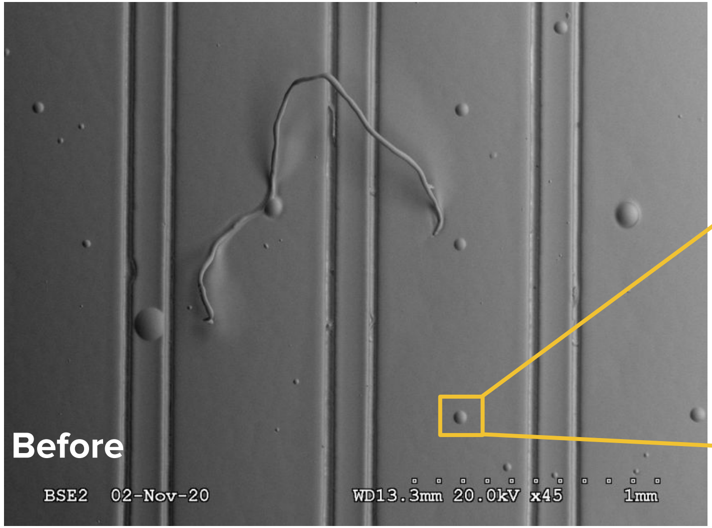
~~Make it or~~ break it: cryo!

Before

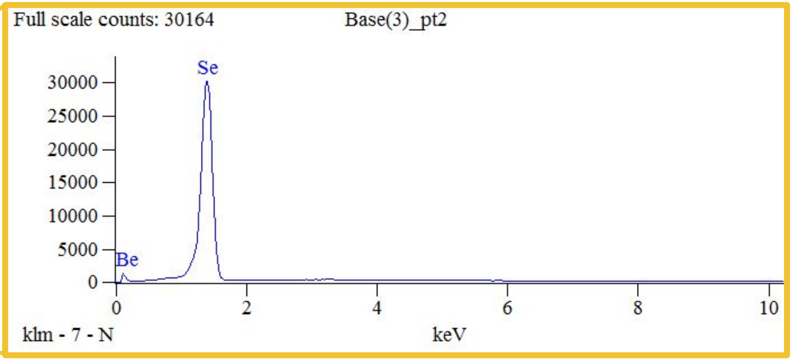
After



Fast or turbulent cryo cycle can damage the film.
After slow (40 min) manual immersion, no damage visible by eye… so we SEM scanned it.



Energy Dispersive Analysis of X-Rays (EDAX): material composition



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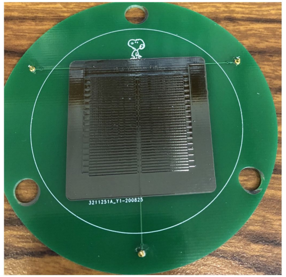
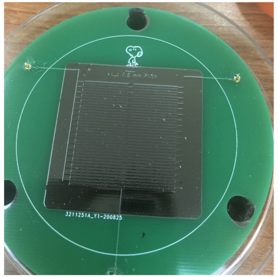


After



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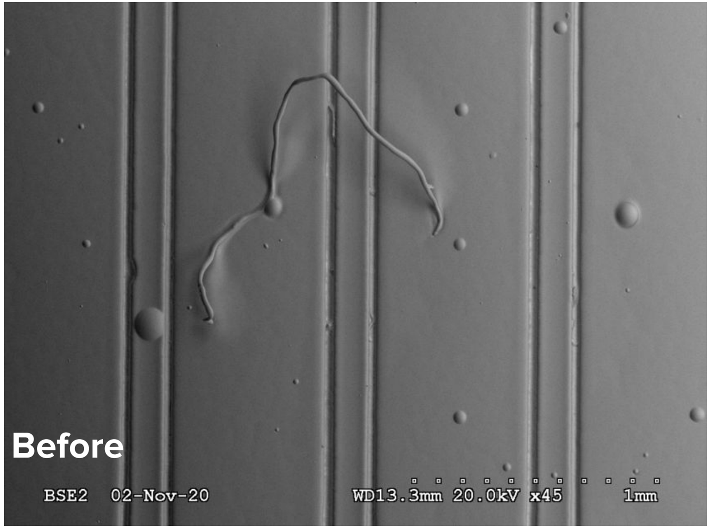

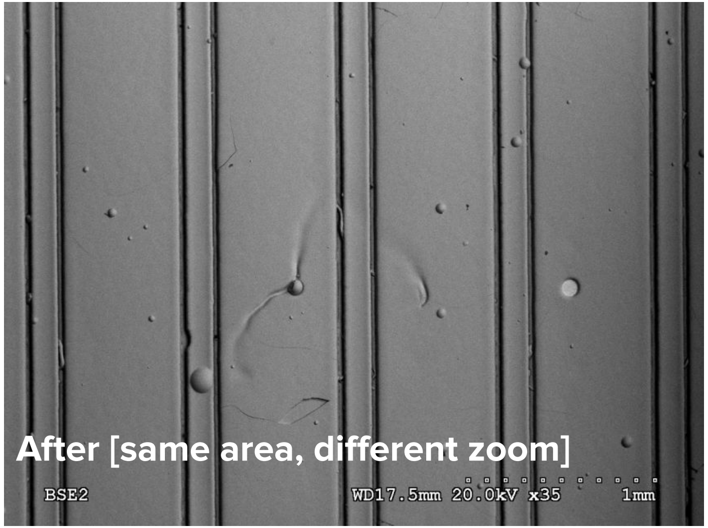

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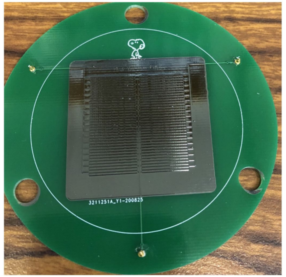

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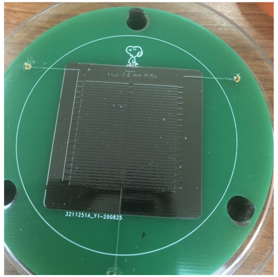

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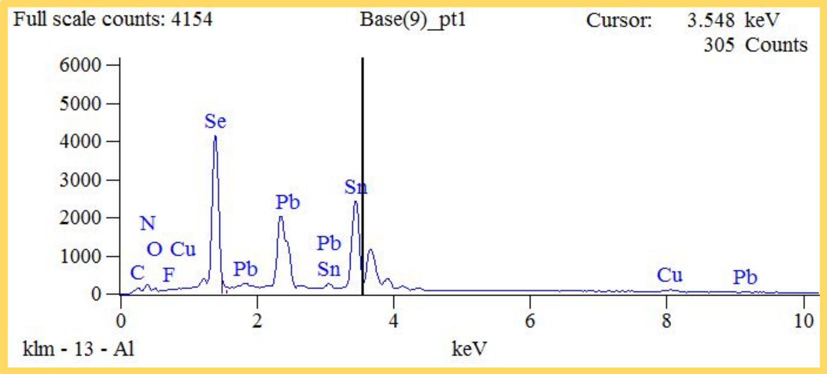

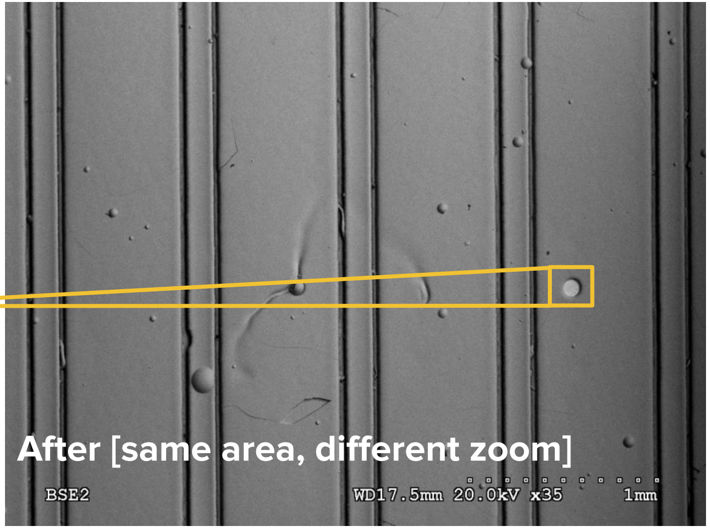

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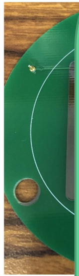
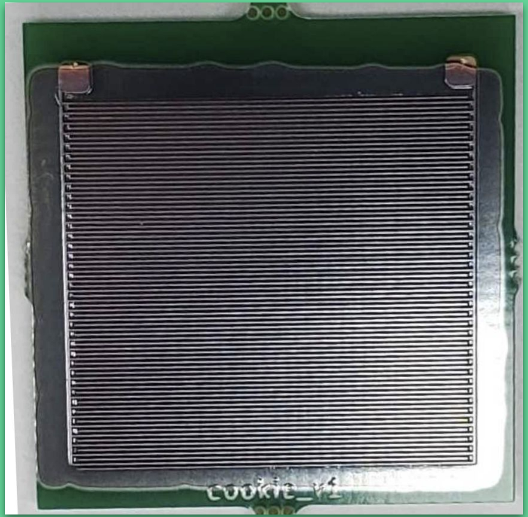


Focus for the second round of tests:
Cryo Temperatures for noble liquids (~87k)

Improved prototype: 127 µm spacing
Reduced spacing the easiest way to increase E field in this simple design.



2 inch x 2 inch

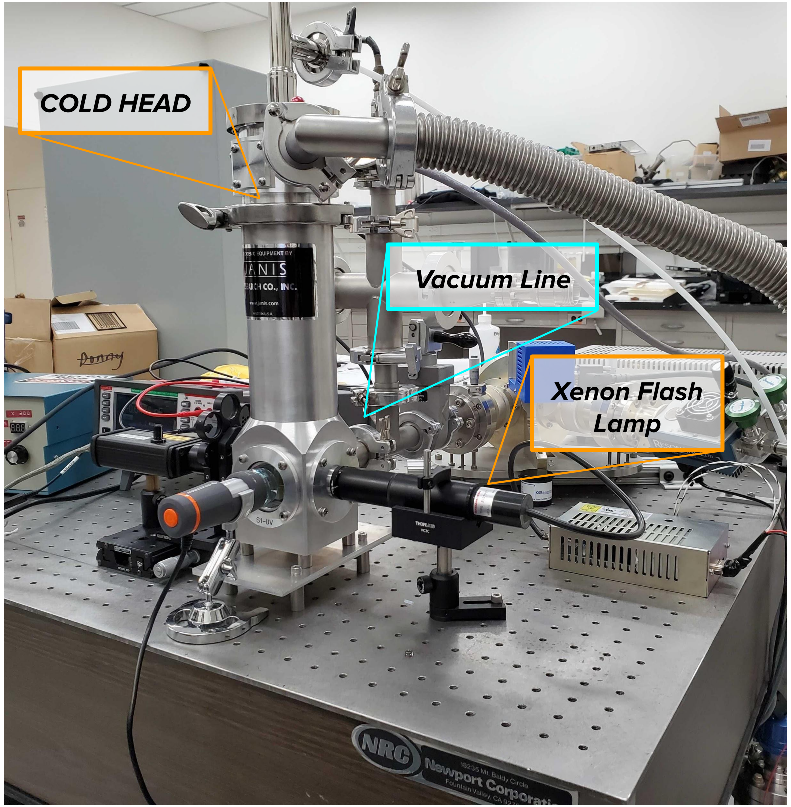
ible

ards.

Fu

klm -

ORNL Setup

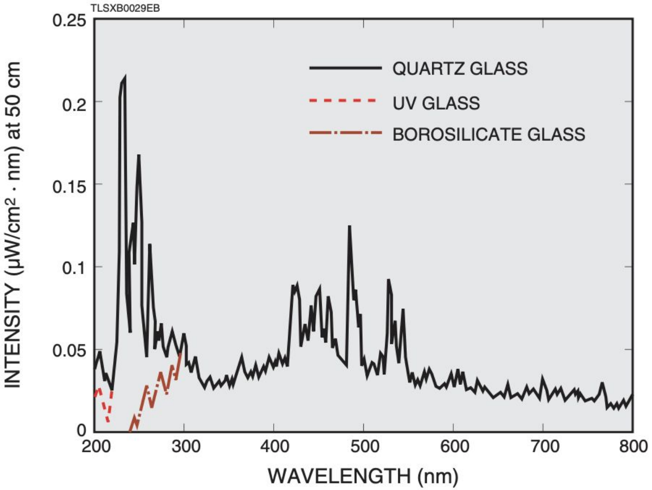


Vacuum: ~1.5 10^{-5} torr

Cold head: Janis ST-100, can be driven @ 50mK res

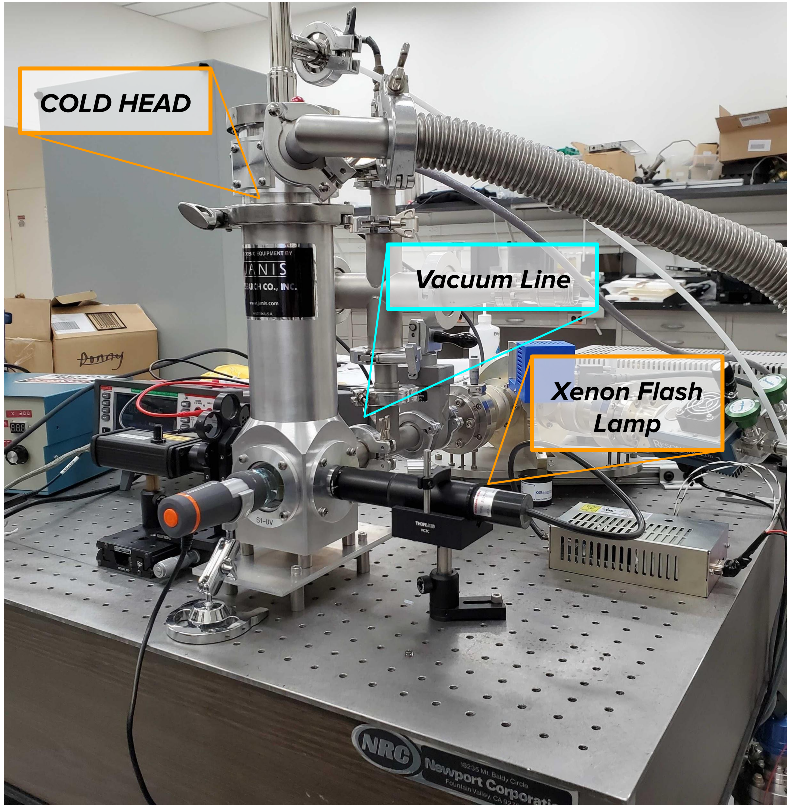
Temperature: Range Explored [78k - 297k]

Source: Hamamatsu Xe flash lamp: wide spectral range not ideal, but sufficient for temperature tests.



From hamamatsu

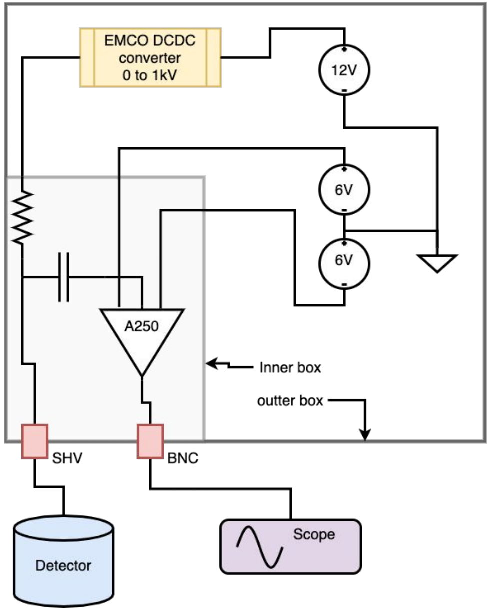
ORNL Setup



Simple capacitive **ReadOut**.

DC/DC converter driven up to 500 V.

Low noise charge sensitive preamp.



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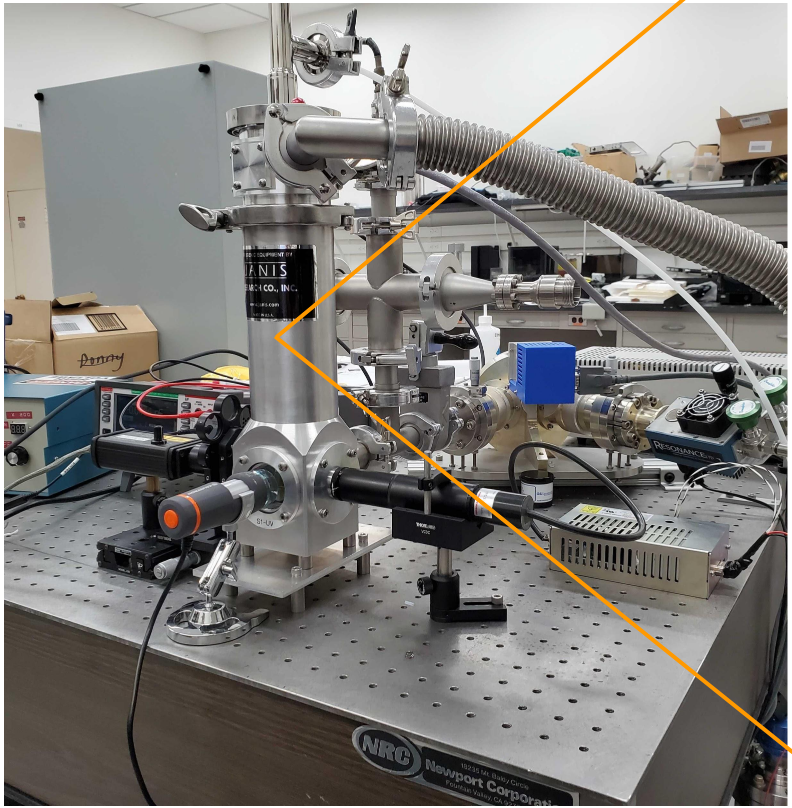
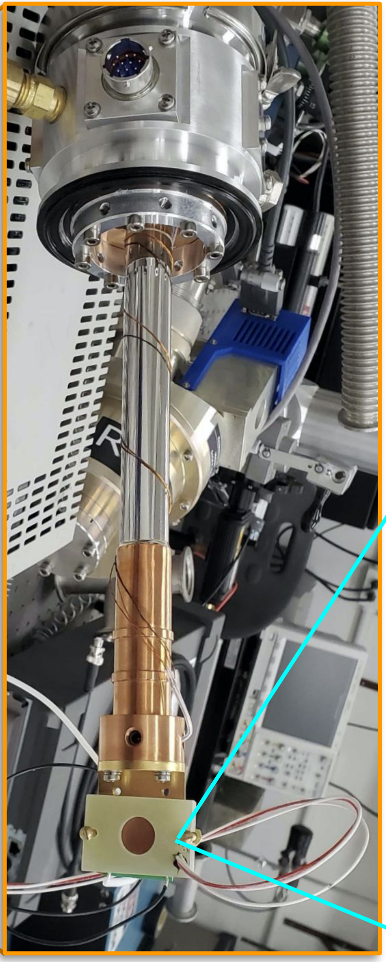
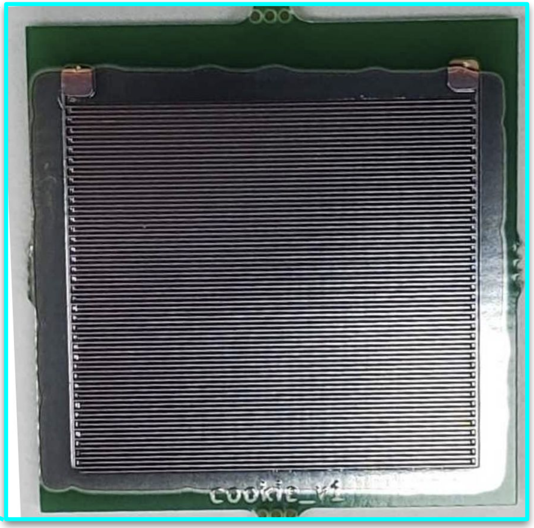
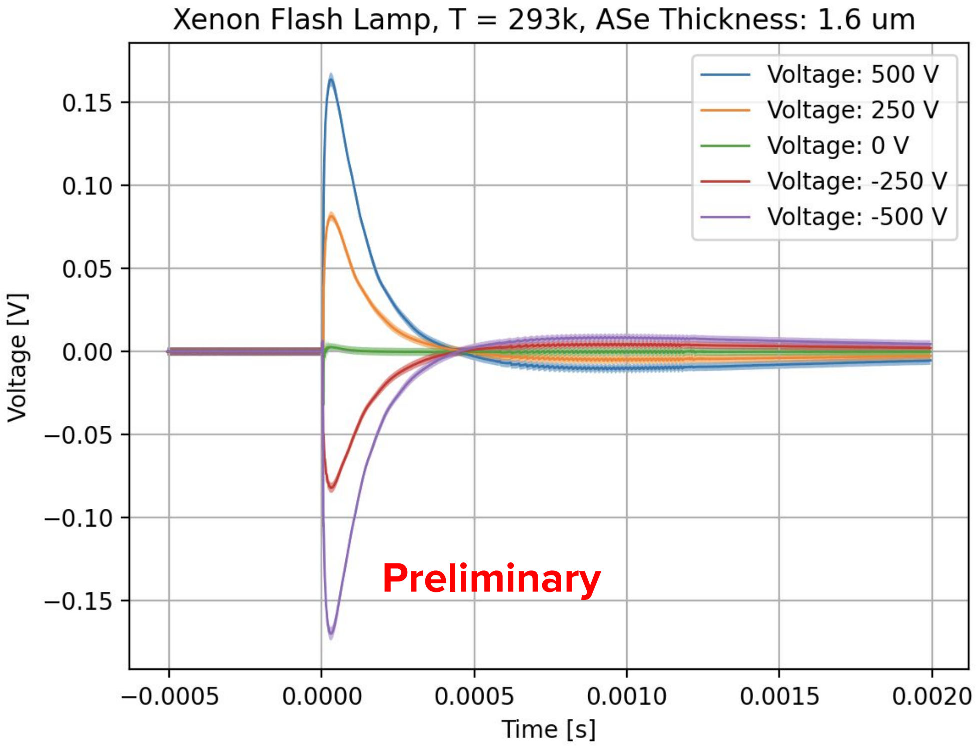




Insert cookie coated board HERE!

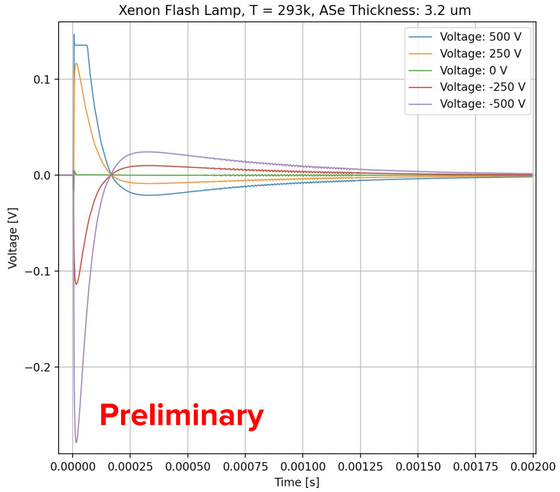


Does it work at room temp?



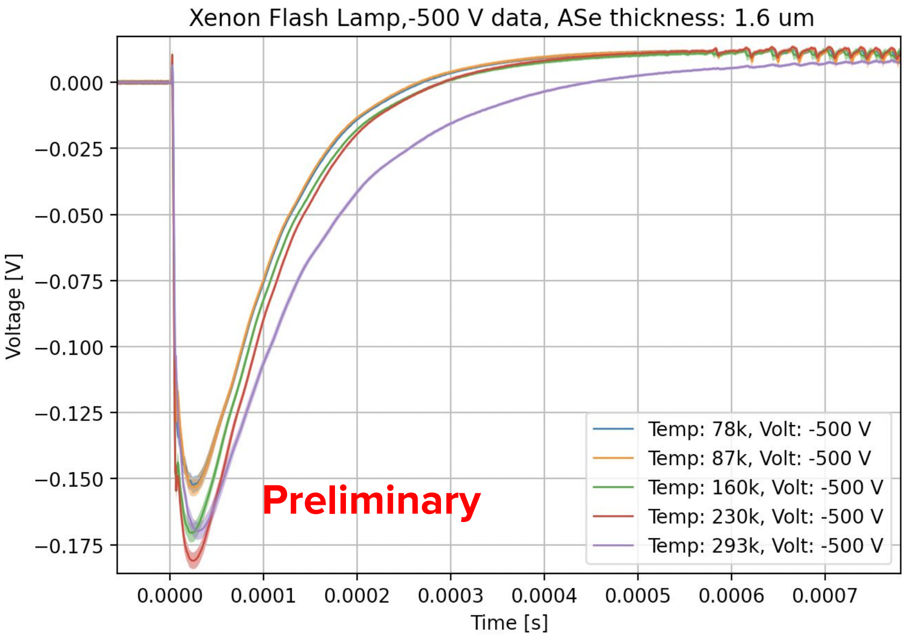
Still far from avalanche regime ($E \sim 8$ V/µm), but… we see light with second prototype (as in in first prototype!)

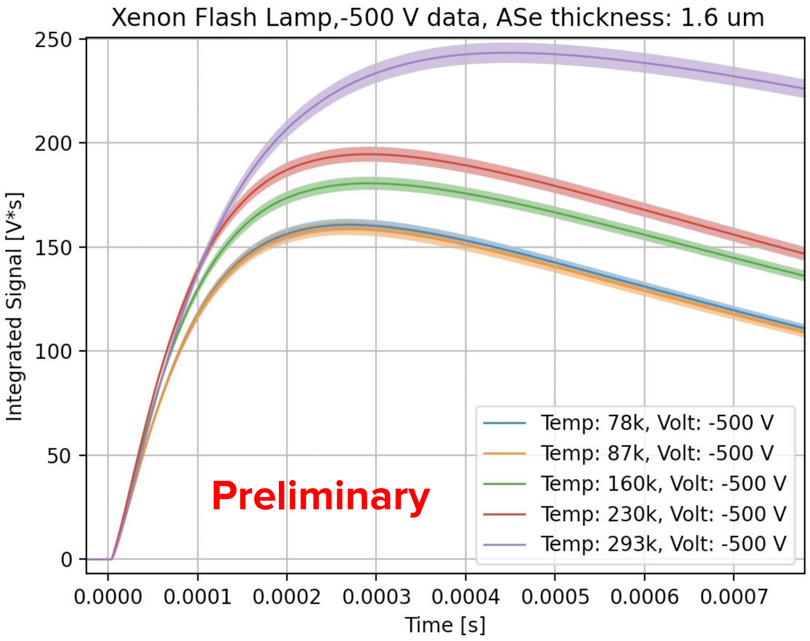
We tried different coatings (3.2 µm) also successful.



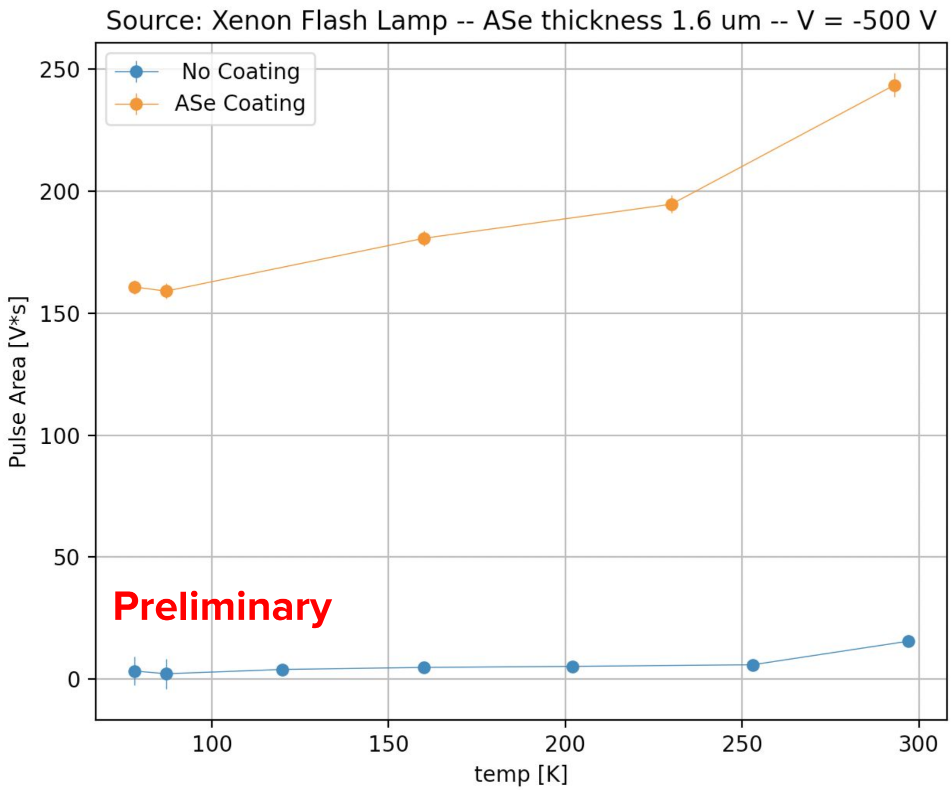
Does it work in cold!?!

YES!! Very encouraging!! **First UV-rich photon detection in cold (down to 78k) with A-Se**!





Does the signal come from the ASe?



Same bias applied to a “bare” board (No ASe), and to a board coated with a 1.6 µm thick film.

The integrated signal increases as a function of temperature (as expected) for the coated board.
No signal for the bare board.

Going forward: next "break it" questions

Our measurement proves that the response at cryo and room temp are not vastly dissimilar: **first observation at temperatures needed for noble liquids TPCs.**

- Can we see 128-178 nm light with this simple device?
  (Innovative Ar light source under development)

- Can we reach the A-Se avalanche regime, needed for single PE sensitivity?
  (Even smaller pitches, different substrates, dopants!)

- Does the A-Se kill the noble element purity?
  An issue for charge…

Effort funded through FNAL LDRD

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Our measurement proves that the response at cryo and room temp are not vastly dissimilar: **first observation at temperatures needed for noble liquids TPCs**

Widening our network of experts to weed out quickly bad ideas: working on sisters setups at
UTA, ORNL & FNAL
and
in close contact with condensed matter theorists, radiology and medical application experts…
the best is yet to come, stay tuned!

→ Does the A-Se kill the noble element purity?
An issue for charge…

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Thank you!!!

Does the signal come from the ASe?

Voltage scan.
The sign of the bias applied determines the types of carriers:
Negative voltage ↔ Holes
Positive voltage ↔ Electrons

Difference in signal strength when reversing bias is consistent with charge of carrier type in the ASe, and observation on first prototype.