Purity Monitoring System for the SingleCube Detector at CSU

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SingleCube Detector

SingleCube is a small-scale liquid argon time-projection chamber (LArTPC) currently being operated at CSU in the Physics Department with the involvement of CSU faculty, undergraduates, graduate students, and others. SingleCube is used to test new LArTPC technologies and techniques.

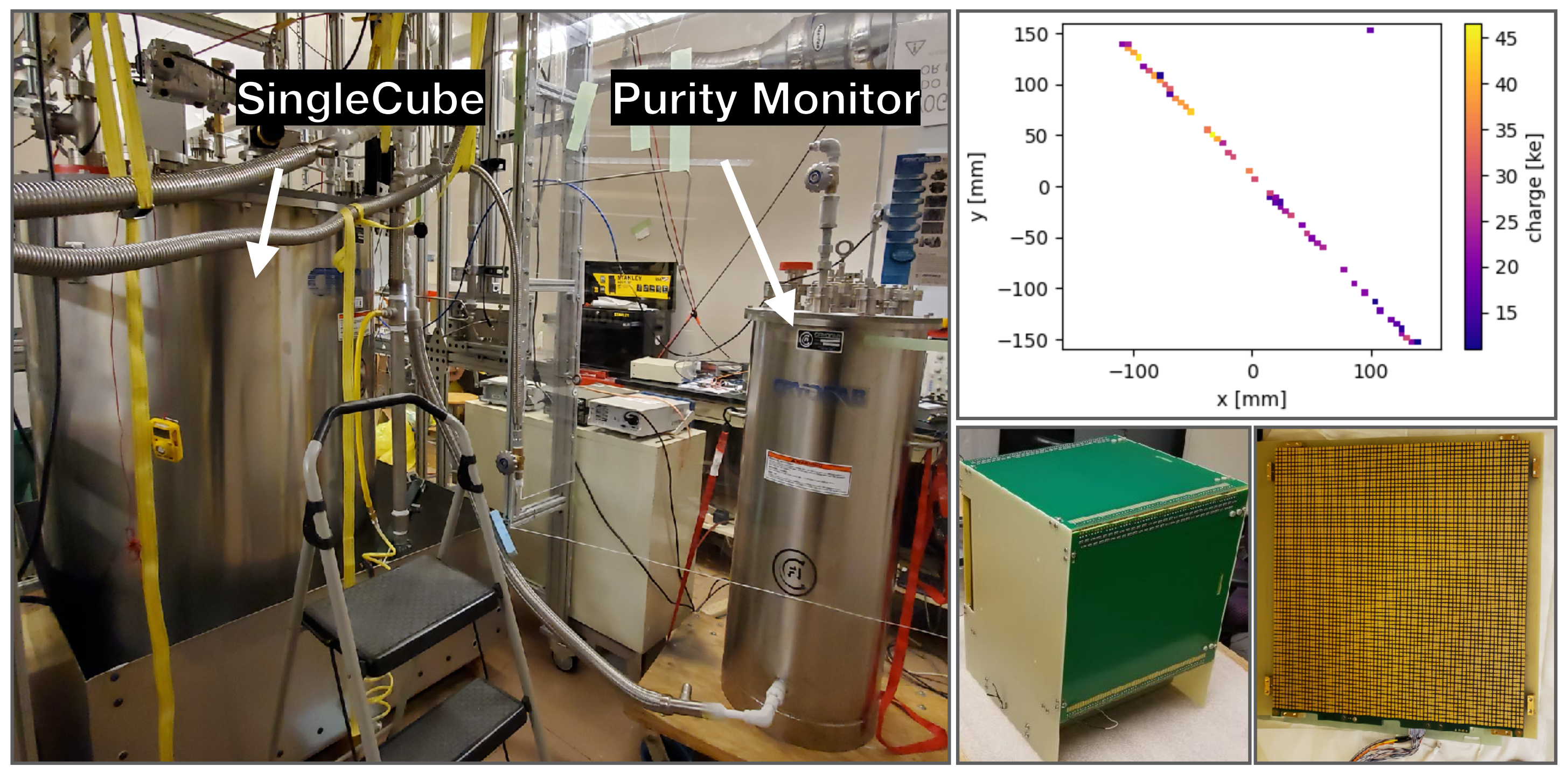


Fig. 1: The SingleCube cryostats (left), the SingleCube TPC and pixel plane (bottom right), and a charged particle track observed with SingleCube (top right)

Effects of Impurities

A **purity monitor** is a device often used to measure **electron lifetime** in a LArTPC [1,2].

Electron lifetime: average time before an electron is captured by an impurity.

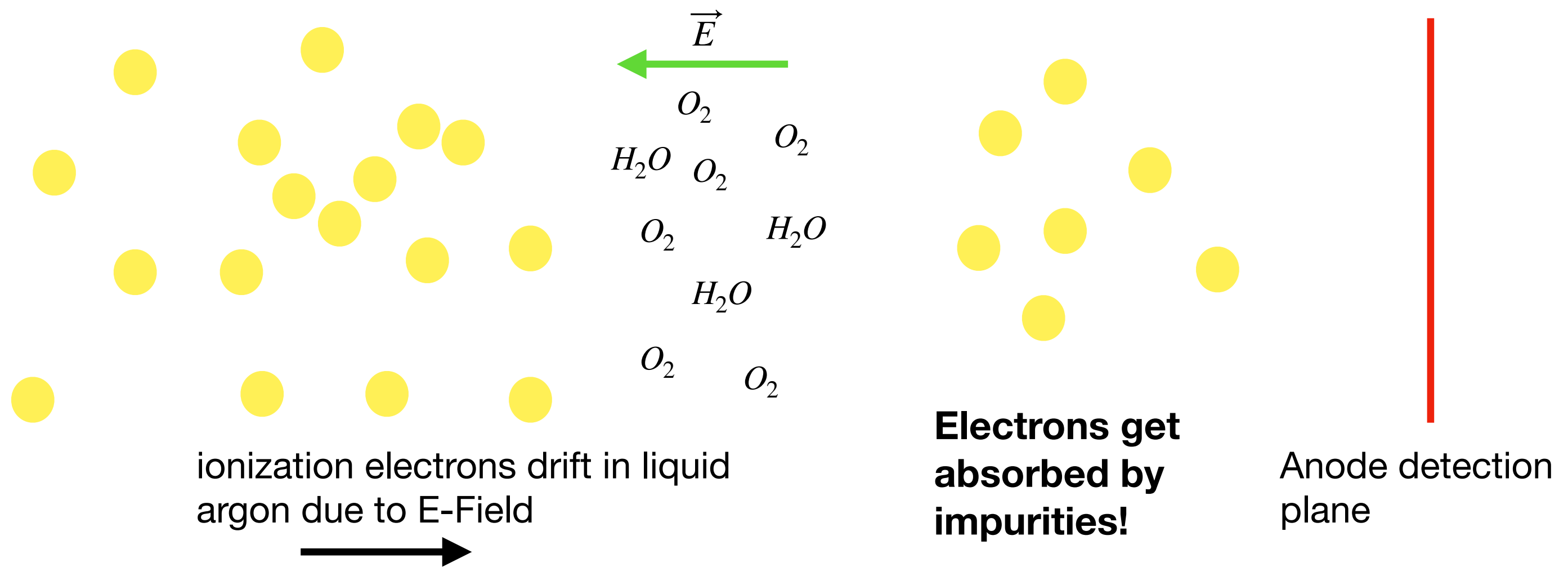


Fig. 2: Cartoon showing electron attachment to electronegative impurities in a LArTPC

Impurities can absorb ionization electrons and reduce scintillation light [3,4,5] and therefore have a very detrimental effect on detector operation.

Light Production and Photoelectric Effect

The number of photoelectrons produced on a photocathode depends partly on the material *work function*: the minimum energy needed to remove an electron.

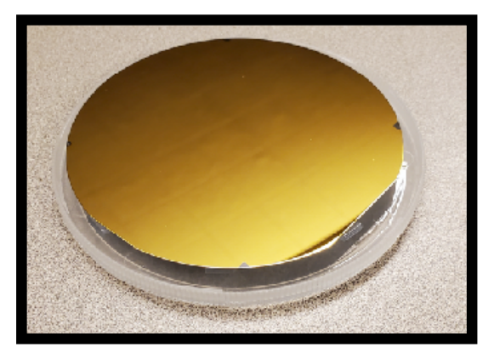


Fig. 3: A gold-coated silicon wafer to be used for the photocathode

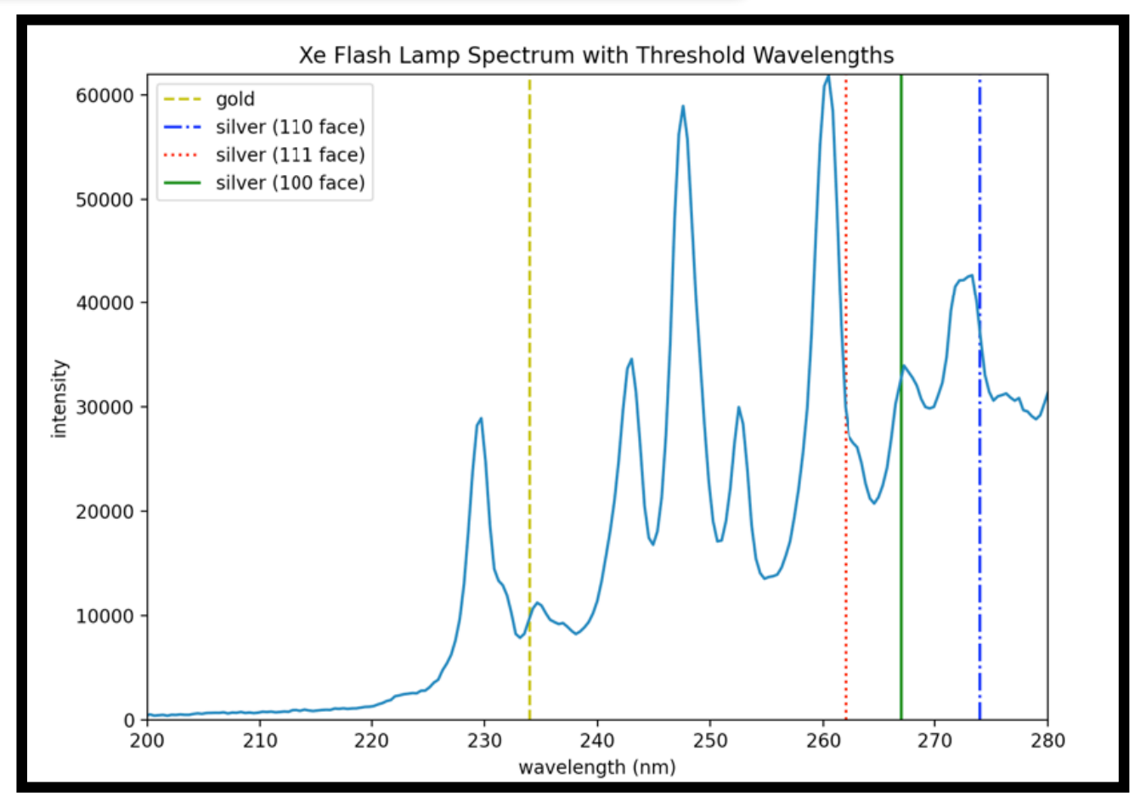


Fig. 4: Flash lamp spectrum with photoelectric threshold wavelengths overlaid for a few common materials

Purity monitor low signal size issues are common because of multiple effects:

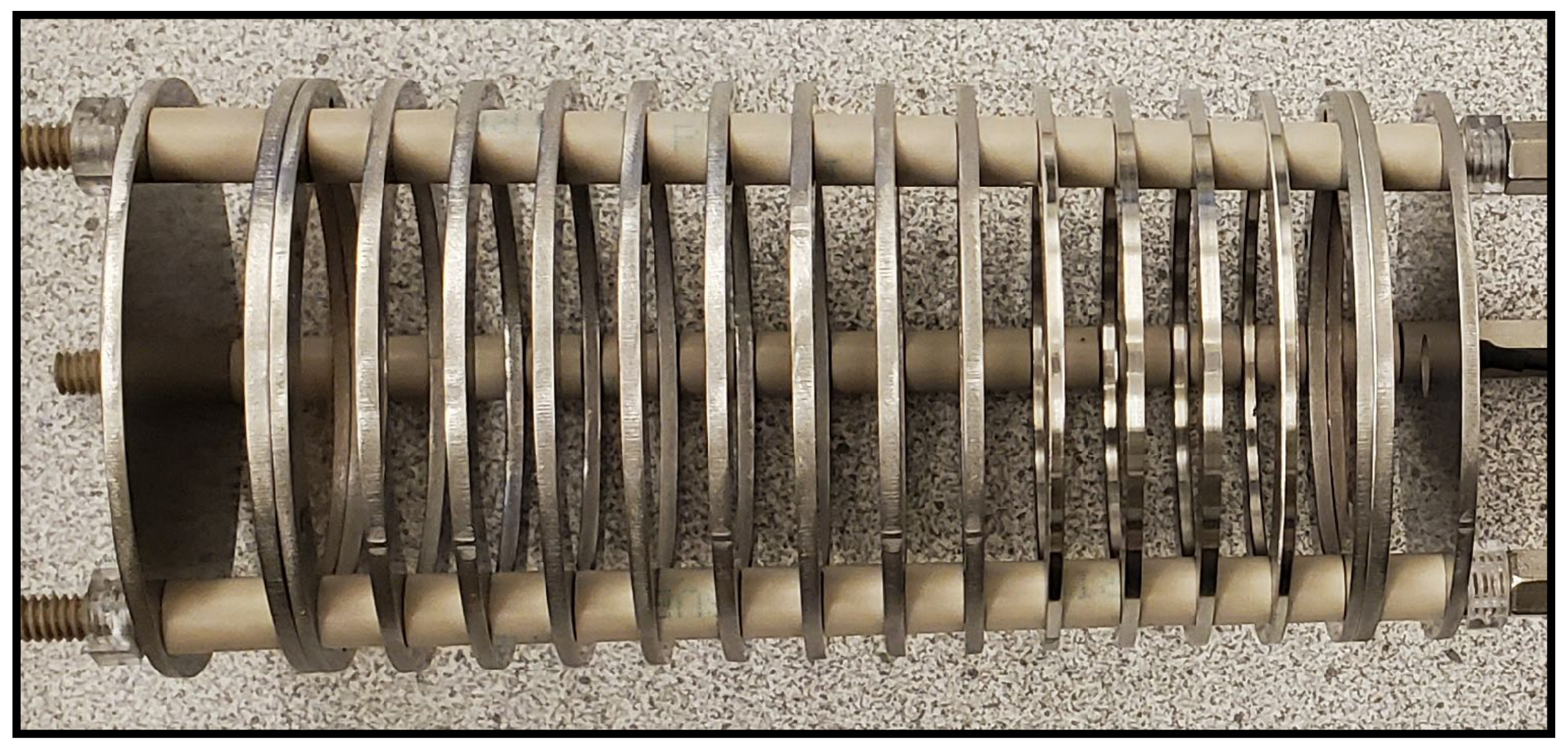
- Only photons with $\lambda \leq \lambda_{\text{threshold}}$ can eject electrons
- Materials like gold use a small portion of the lamp spectrum
- Low acceptance of 600 μm optical fiber
- Optical fiber light attenuation
- Quantum efficiency reduces the number of photoelectrons produced

Fig. 5: 60W Xenon flash lamp being used to produce photoelectrons. Produces a flash of light within 10 μs

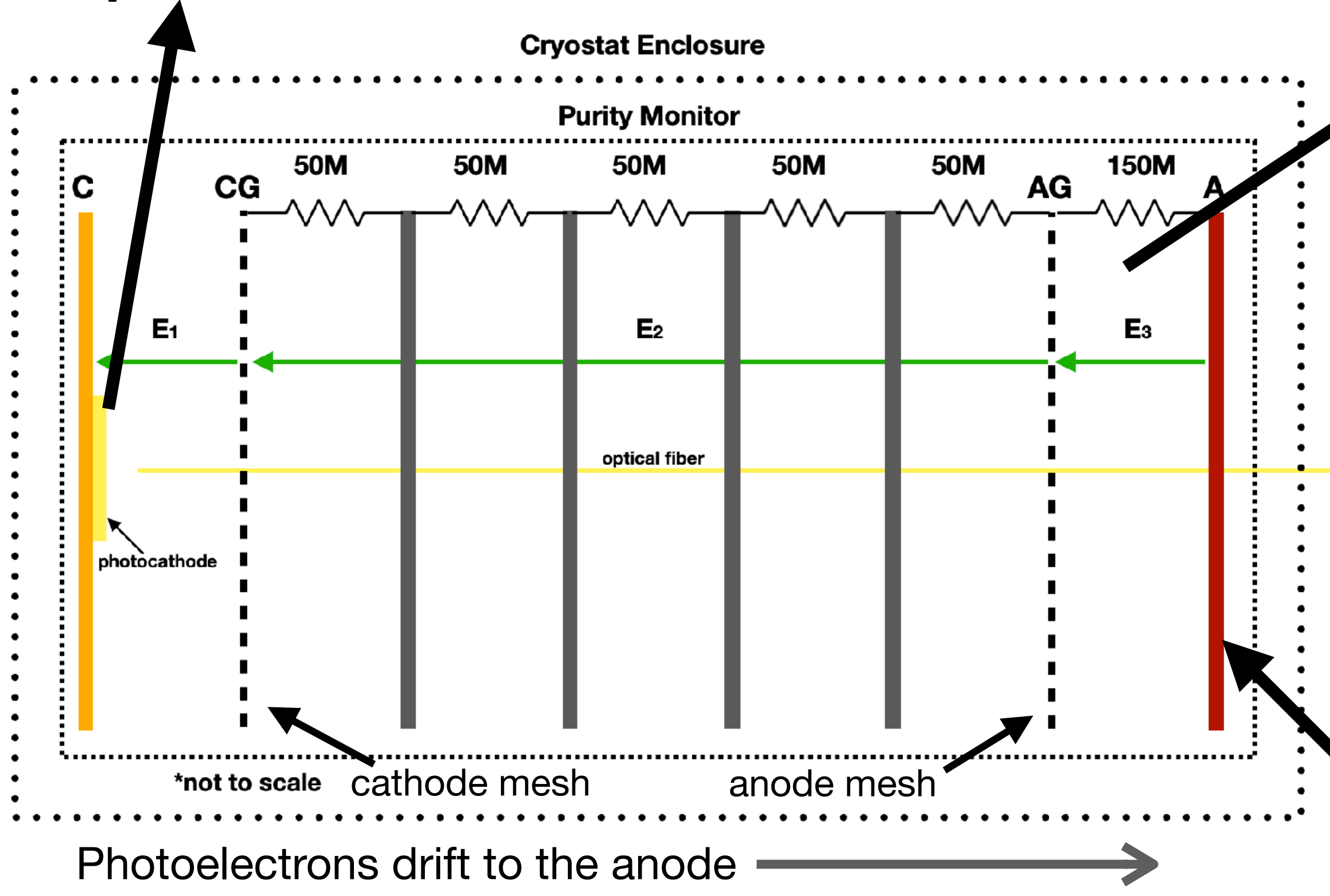
The Purity Monitor

A purity monitor gives an effective and reliable way to measure the level of impurities in a LArTPC like SingleCube.

Fig. 8: Purity monitor being developed at CSU



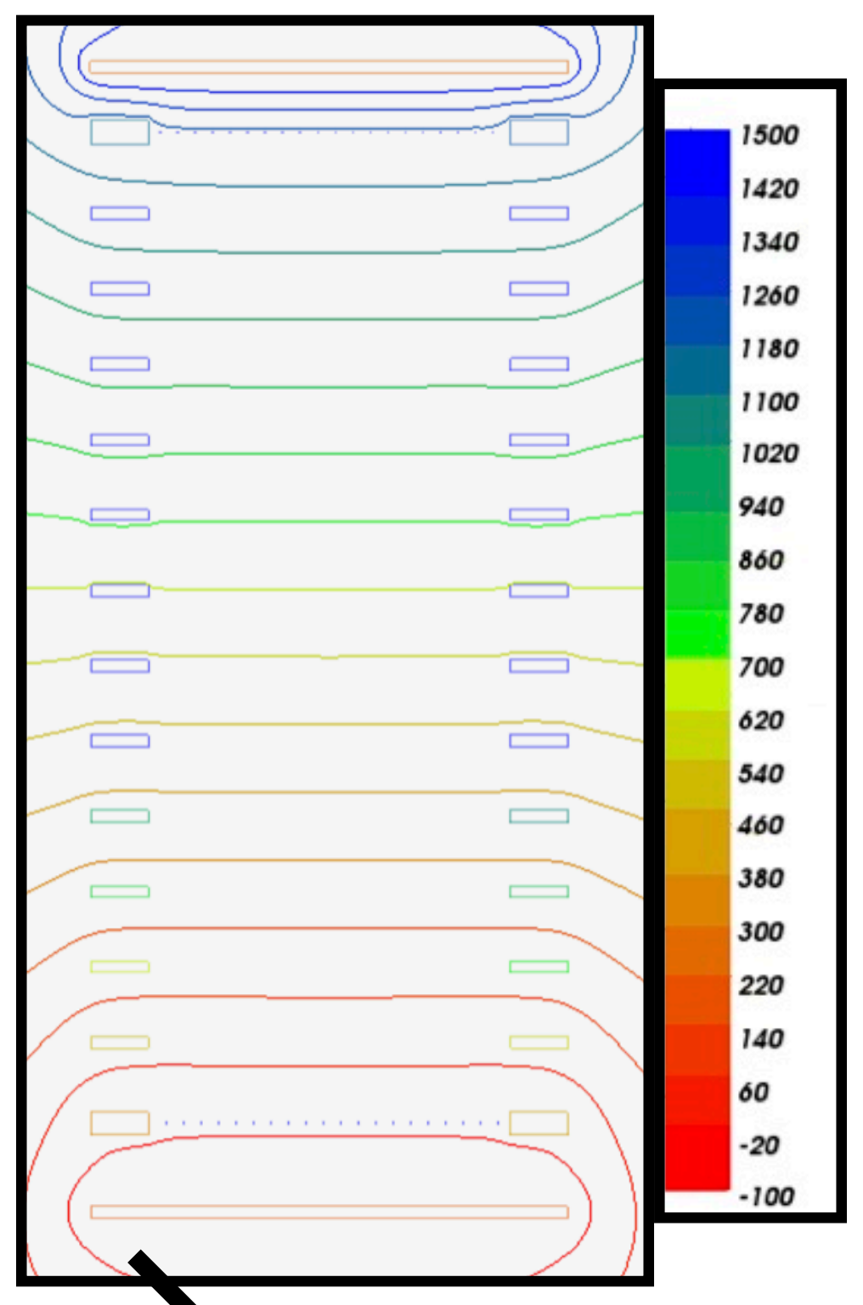
Electrons (Q_C) are generated at the photocathode via the **photoelectric effect.**



Photoelectrons drift to the anode

Fig. 11: Diagram of purity monitor showing some key components

Fig. 9: Equipotential E-Field simulation of purity monitor

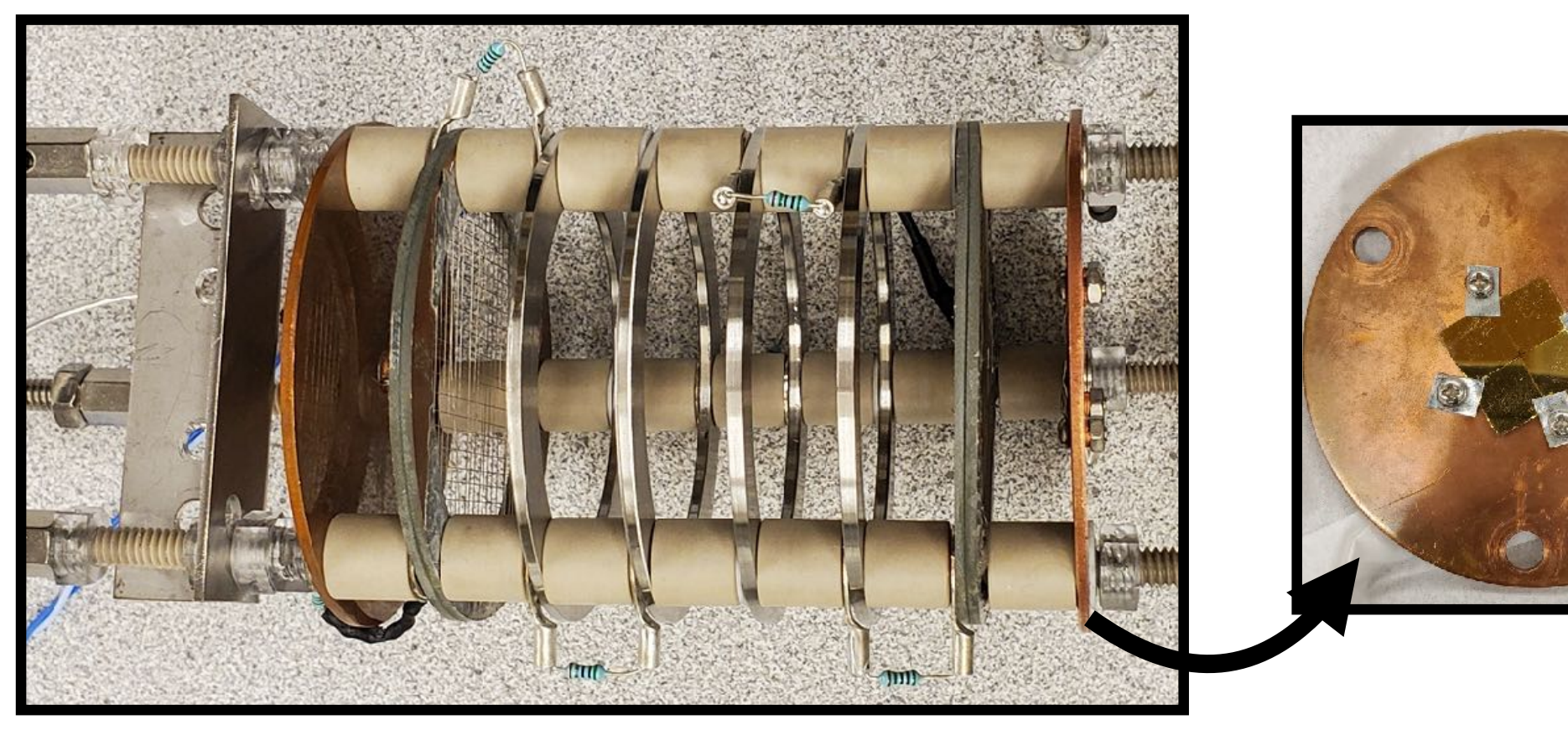


Voltage divider along purity monitor ensures a uniform drift field.

Lamp produces UV light to eject electrons from the photocathode

Electrons (Q_A) arrive at the anode after drifting through argon

Fig. 10: Purity monitor used in earlier tests, made at UT Arlington, alongside a picture of the cathode with gold photocathode



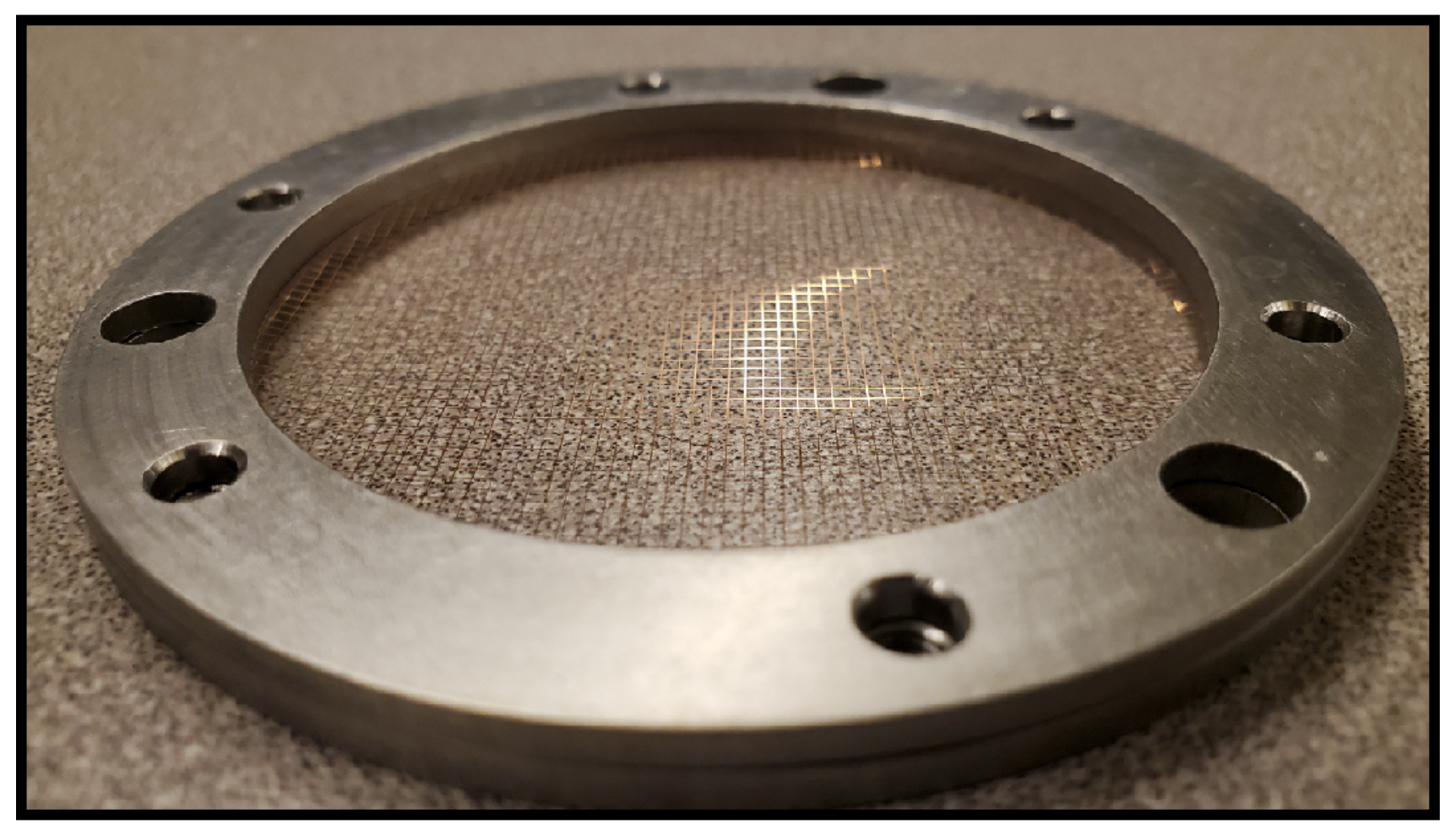


Fig. 12: Electroformed copper meshes contained in stainless steel frames used at CSU for the new purity monitor.
The wires are 63 μm thick with 953 μm spacing

- Wire meshes shield the anode and cathode from induced current caused by drifting charges.
- Wire diameter and spacing is chosen to ensure maximum shielding efficiency and maximum transparency of electrons [6].

Electronics System

- Measuring the drift time and the ratio of charge yields electron lifetime: $\tau = \dfrac{t_{\text{drift}}}{\ln(Q_C/Q_A)}$
- **Charge amplifiers** can integrate a current to produce an output voltage proportional to an input charge.
- The leakage current through the resistor is usually very small.
  - So the total charge is approximately: $Q_{\text{in}} \approx CV_{\text{peak}}$
- Therefore these circuits allow for an effective way to calculate Q_C and Q_A.

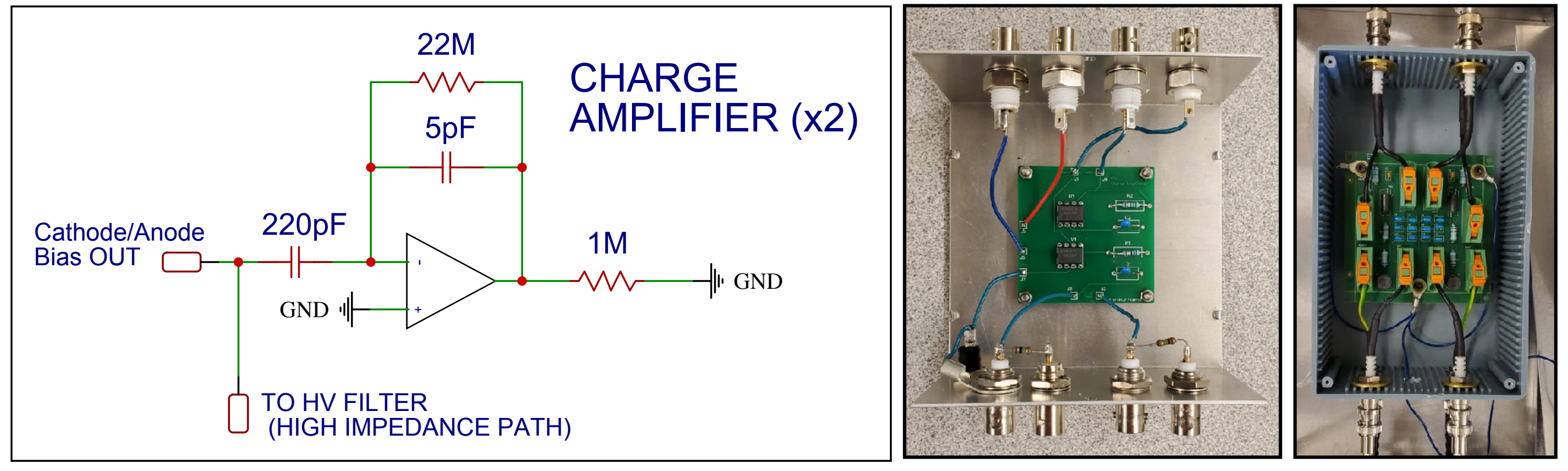


Fig. 13: Charge amplifier circuits designed for use in the purity monitor (left two images). The high voltage filters are shown on the right, built by CSU undergraduate Ross Mccaskey

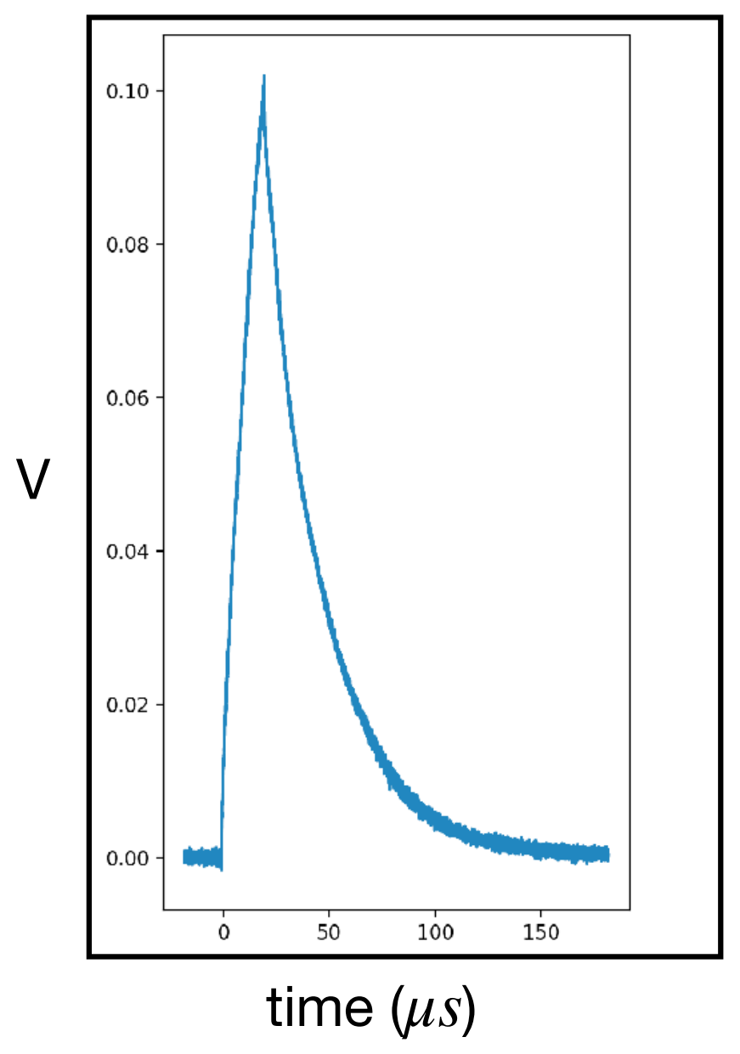


Fig. 14: Typical charge amplifier output

Vacuum tests have been successfully performed:

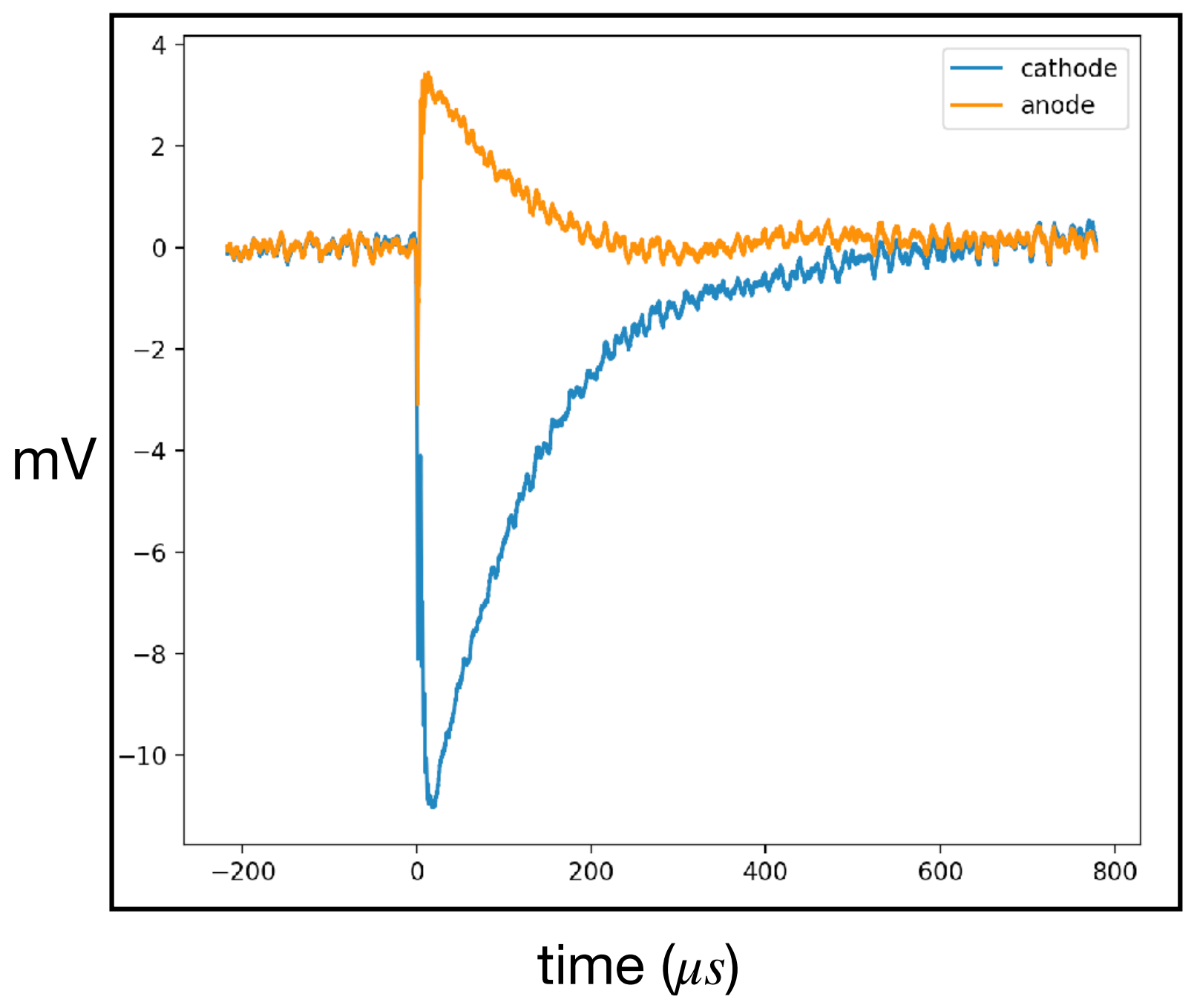


Fig. 15: Charge amplifier output from the original purity monitor in vacuum

Lenses are being tested to focus light into a 600 μm optical fiber to increase the light transmission to photocathode.

Spherical and chromatic aberrations are issues to manage since they effectively reduce light focused into fiber.

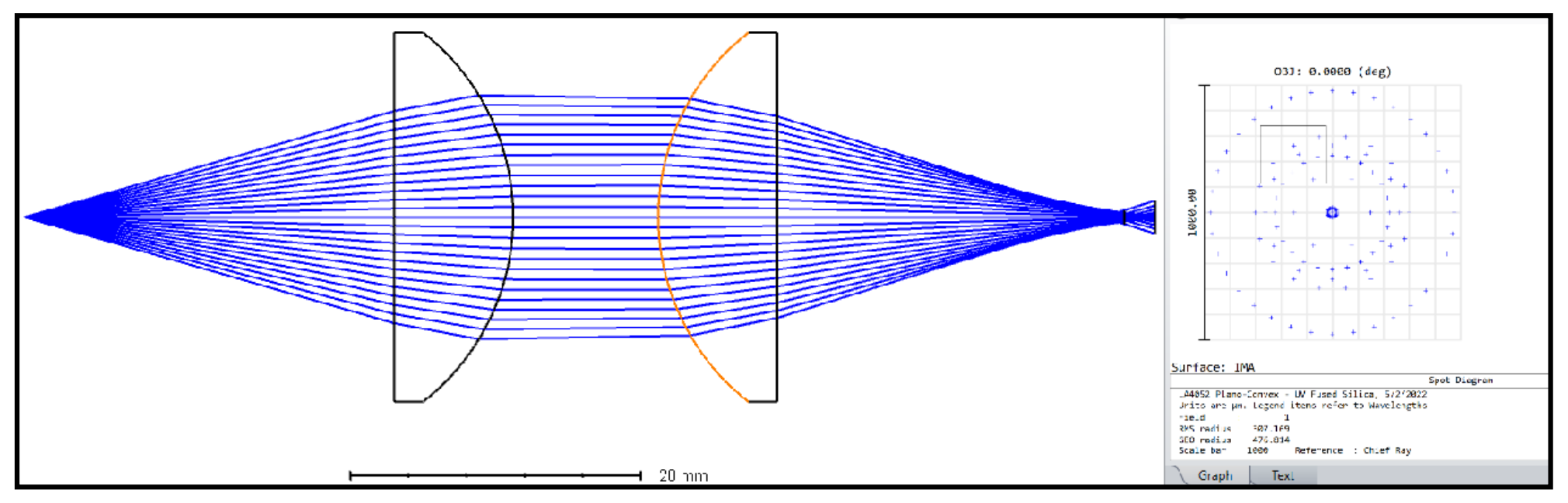


Fig. 6: Zemax simulation of two-UV-lens setup to focus light into optical fiber

Fig. 7: Lens tubes with lenses being used to test lens capabilities

References

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