Evaporative R&D for Detector Construction

Preet Mann

July 12, 2025

Stony Brook University
Center for Frontiers in Nuclear Science

Introduction:

- An overview of electron beam deposition techniques and experiments conducted at Stony Brook University for PID / Tracking Detectors.

- An emphasis on **pfRICH** (proximity focusing ring imaging cherenkov detector) development, ***PID*** *sub detector in* ***ePIC***. SBU aims to develop and coat high reflectivity mirrors to increase the overall acceptance of the detector.

- As well as a novel R&D effort to redefine multi-wire drift chambers (**MWDC**) technology using coated carbon fiber wires. The application of these efforts would be **applicable to future tracking detectors** - potential EIC 2nd detector, FCC-ee, etc.

Overview

❖ **pfRICH** : Proximity Focusing Ring Imaging Cherenkov detector; PID [e/π, π/K/p identification]

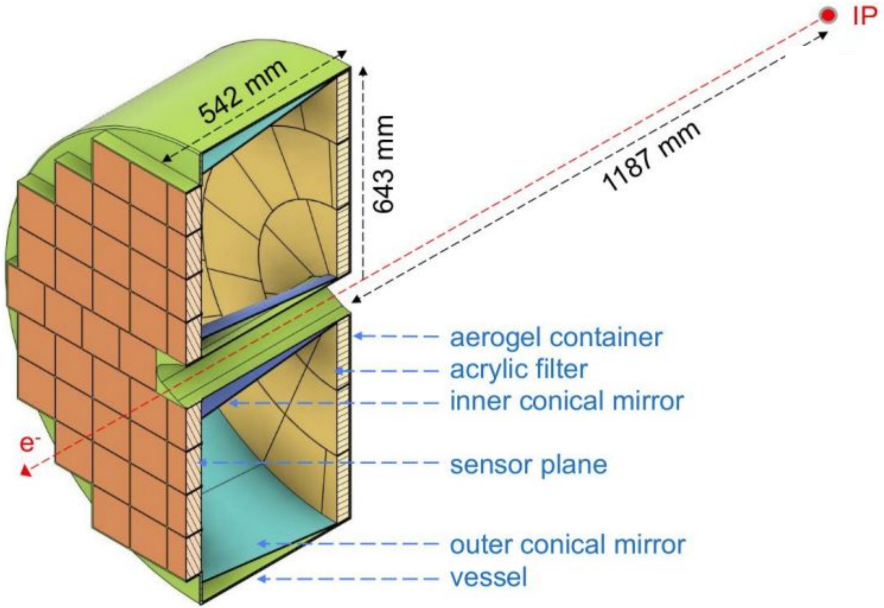
➢ Covers the backward (electron going) region between -3.5 $< \eta \leq -1.5$ with 2π azimuthal coverage

➢ Cherenkov photons are formed by interaction with aerogel radiator $\langle n \rangle \sim 1.045$

➢ **Conical mirrors** line the inner and outer diameter to direct photons towards the HRPPD sensor plane, these mirrors use a smooth lexan plastic adhered to a molded carbon fiber which provides rigidity/backing to increase the overall acceptance

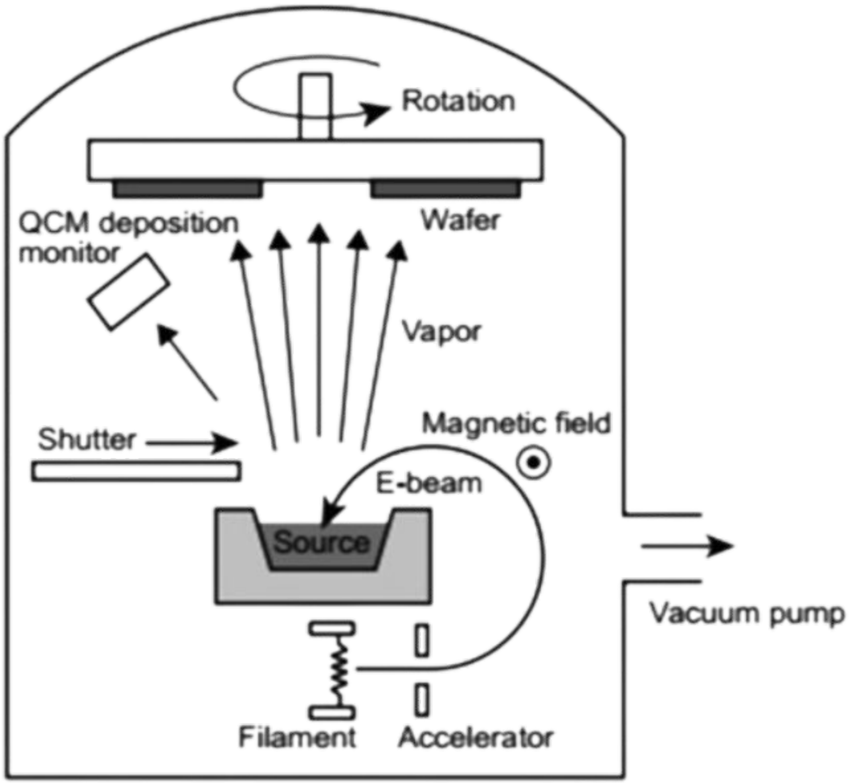
➢ Mirrors cover **300 - 600 nm wavelength** region with **90% reflectivity** at 45°

➢ 49 Evaporative coatings since 2023



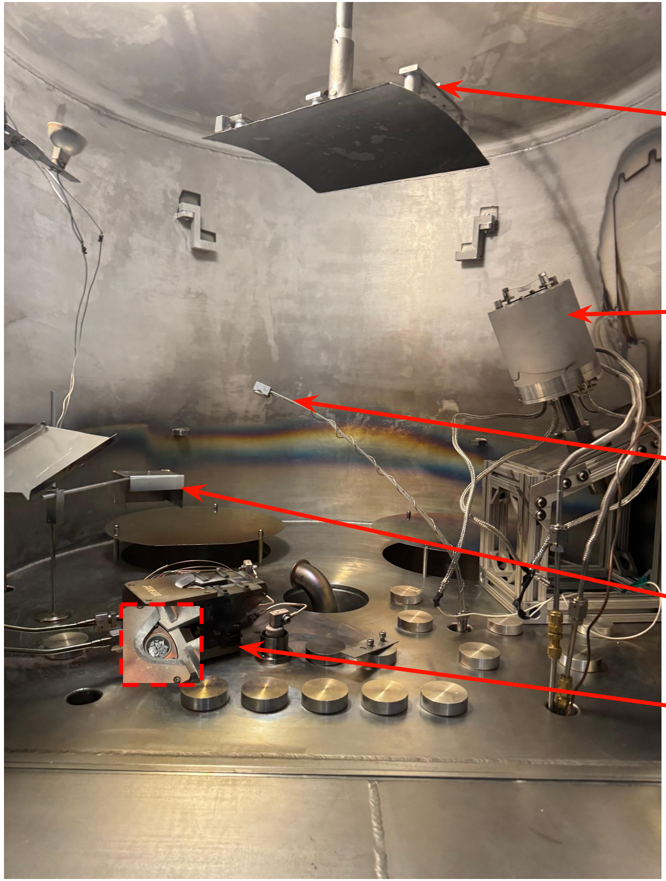
Evaporation Processes

- Film deposition occurs via **two main processes**
  - **PVD** is a process in which source material is vaporized and condenses into a film
    - E-Beam, Sputtering, Ion Plating…
  - **CVD** is a process in which decomposition or reactions create a film.
    - Plasma reactions or liquid solvents
- **pfRICH Coatings occur via e-beam**, source material vaporizes and isotropically condenses upon a substrate



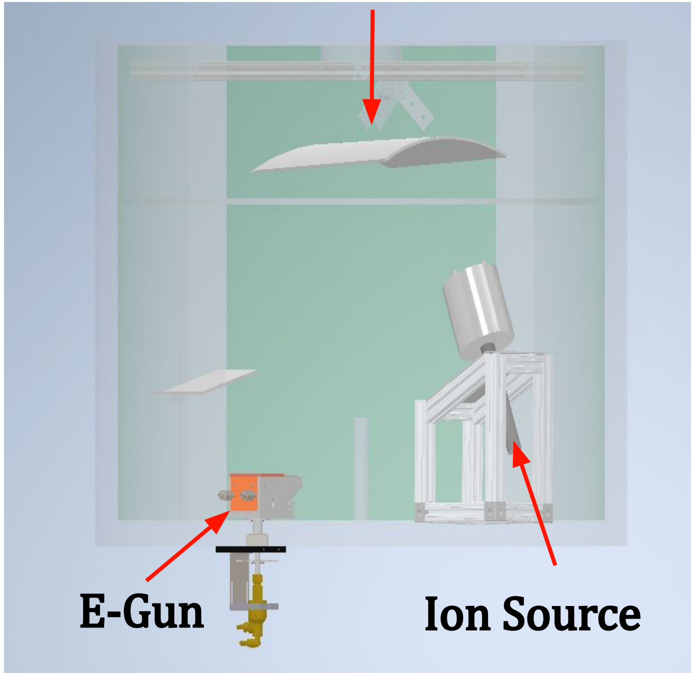
What We Need?

Evaporator Exterior with
10^{-6} torr vacuum capabilities

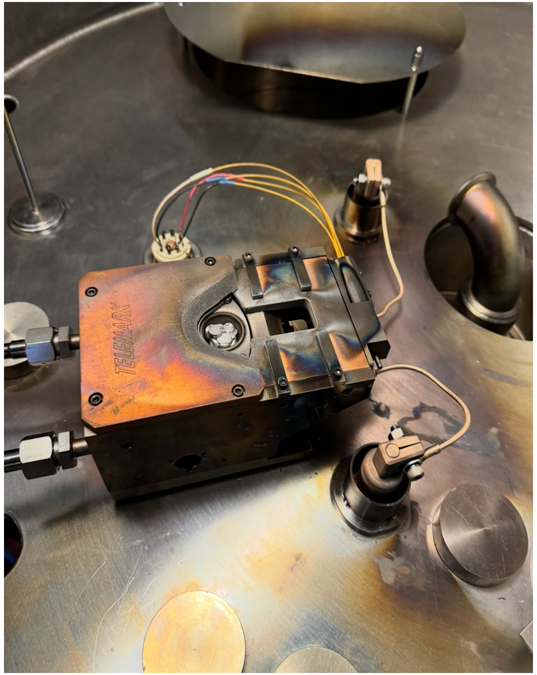


Currently Chamber Design

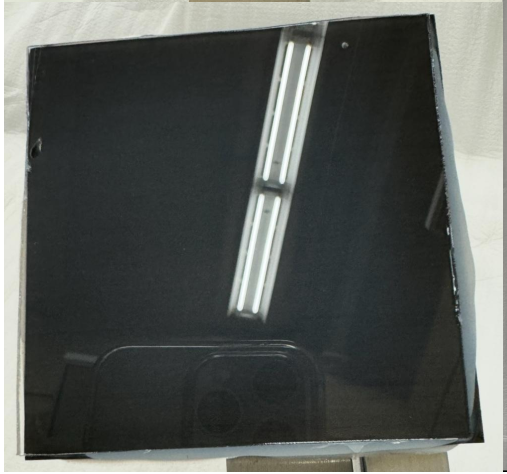
Mirror substrate

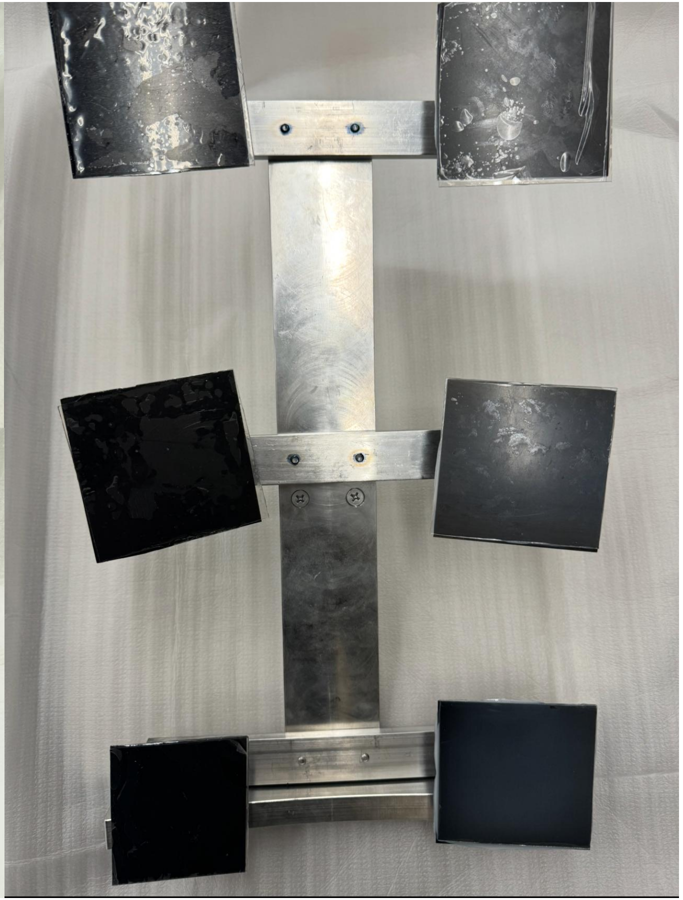


June 2025



Substrate:



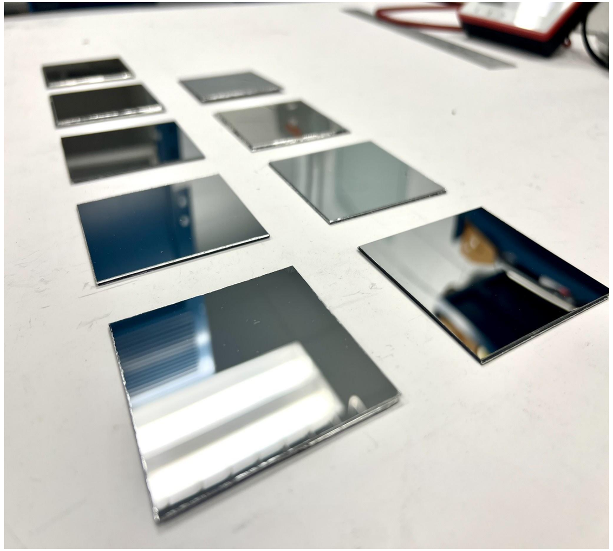


- Flat substrates are co-bonded both by SBU for in house testing and by Purdue University, who ultimately manufacture the curved base material for pfRICH.

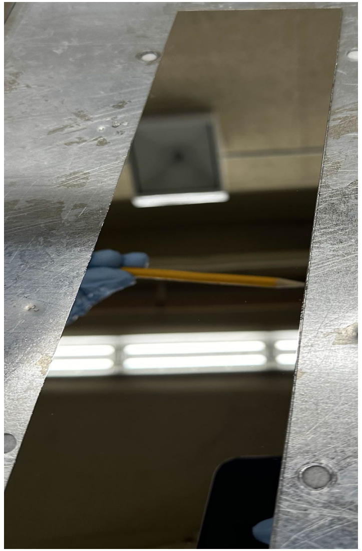
- Carbon fiber is painted with epoxy and then a lexan is applied over it, this lexan has a protective film to prevent contamination

- A thin layer of Chromium is deposited onto lexan, this serves as a primer and allows for adhesion of the reflective aluminum coating.

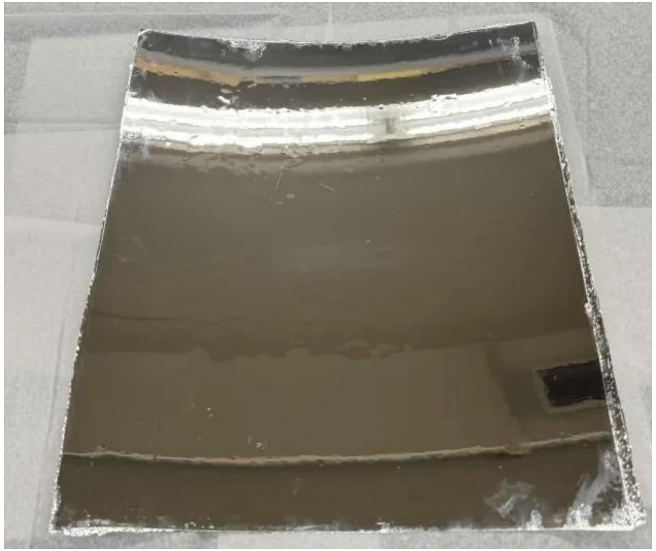
pfRICH Results:



SBU Produced Test Substrate

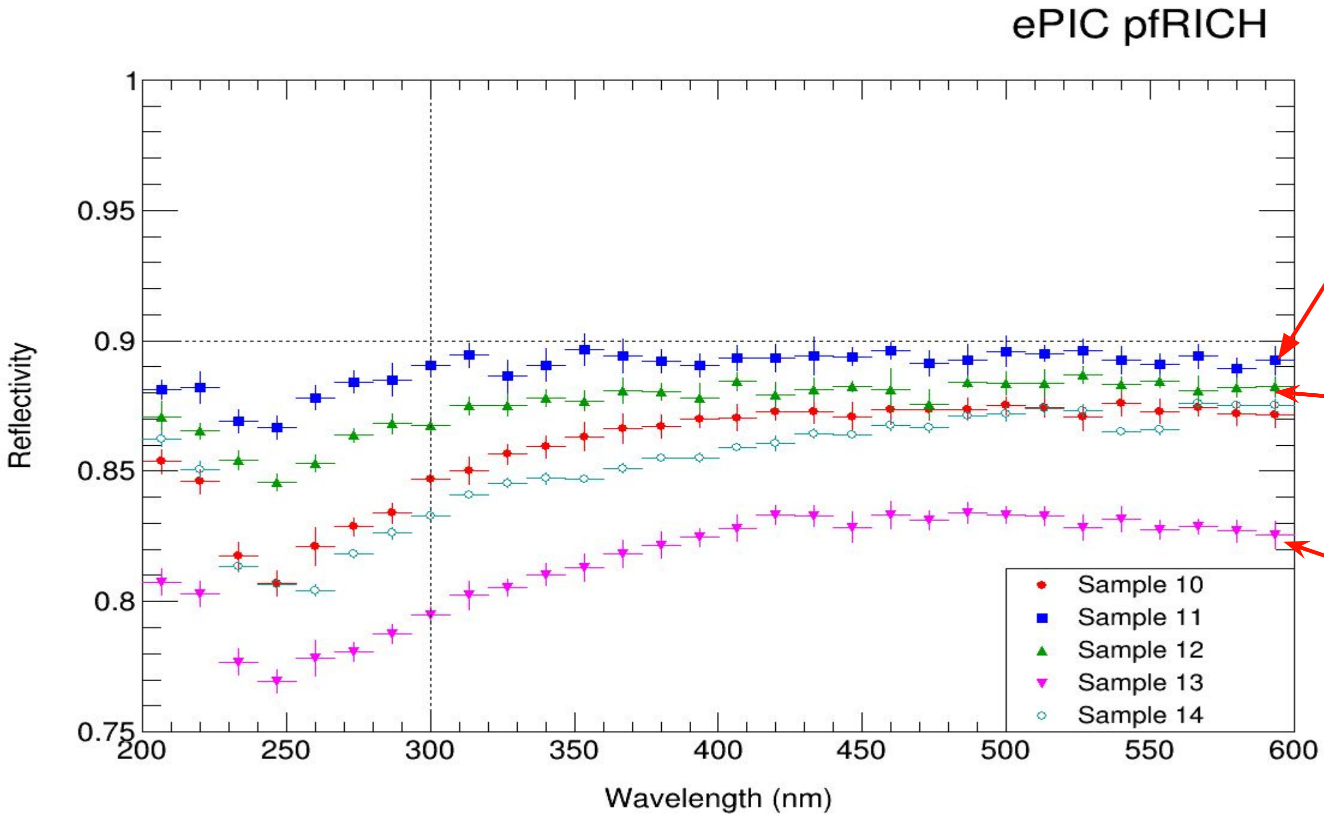


Large Mirror Test



pfRICH Full Scale Mirror Test Piece

Reflectivity Variation {2024}



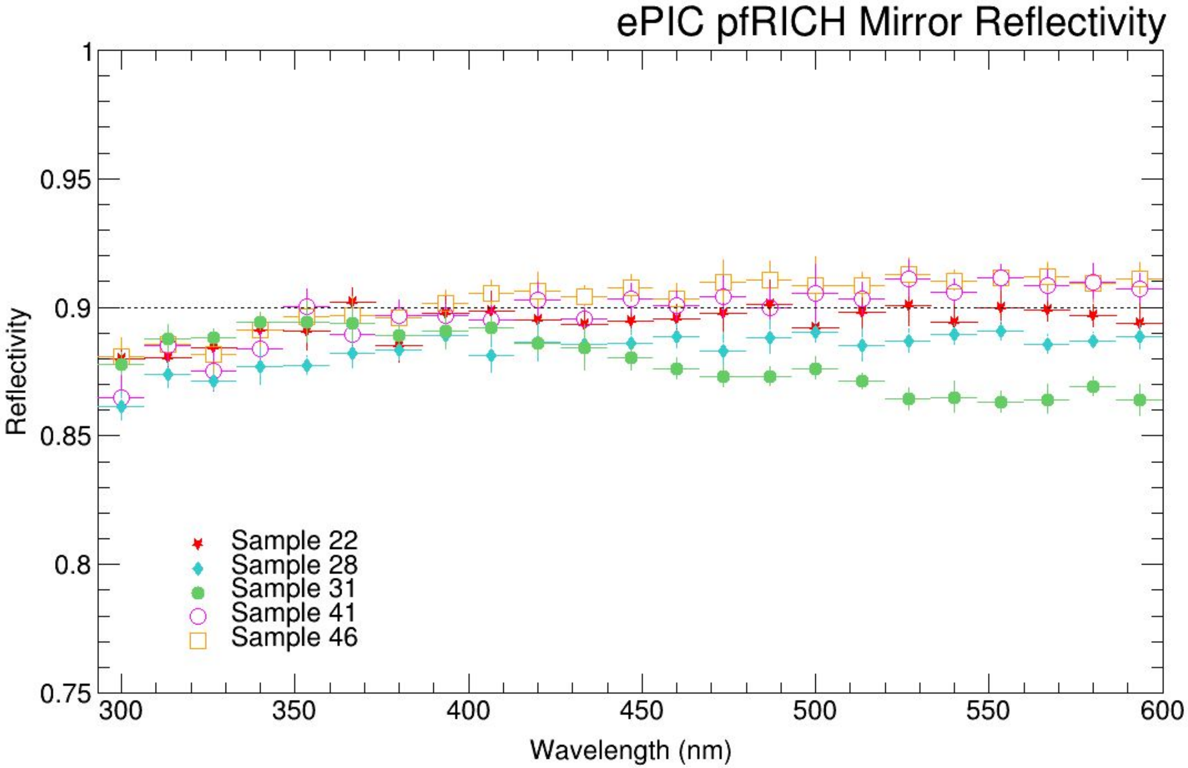
Coating 11:
12.36 KAng Al
5.08 KAng Cr
60 RPM

Coating 12:
12.27 KAng Al
5.17 KAng Cr
30 RPM

Coating 13:
3.51 KAng Al
2.06 KAng Cr
30 RPM

Peak sample reflectivity across coatings

Reflectivity Results {2025}

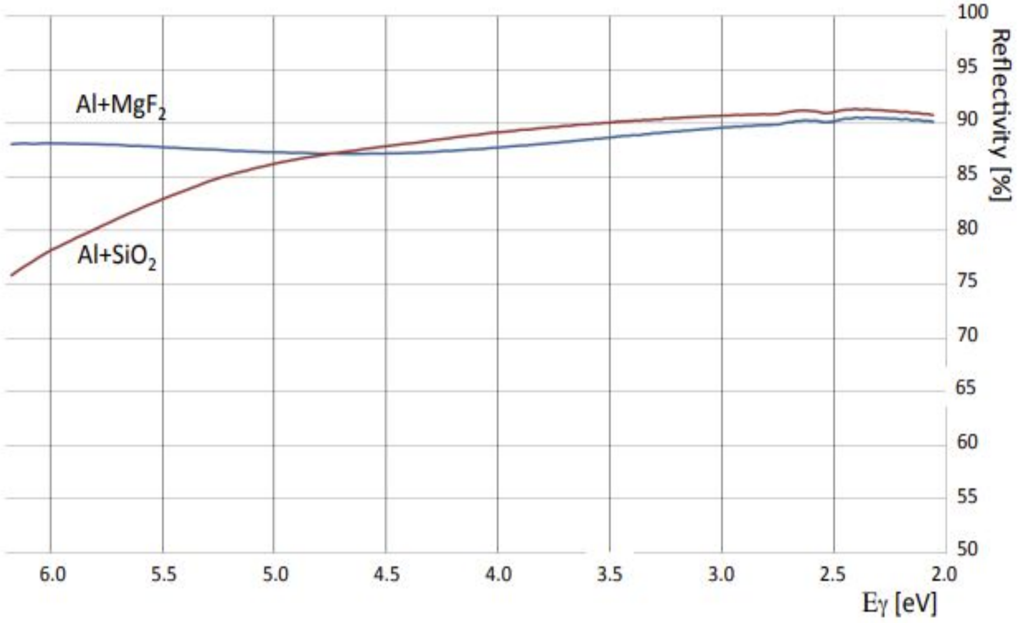


Recent advancements in coating recipes have resulted in achieving our goal, **with over 90% reflectivity results in certain regions for small samples** . Samples within a given coating have $\pm 1\%$ non uniformity.

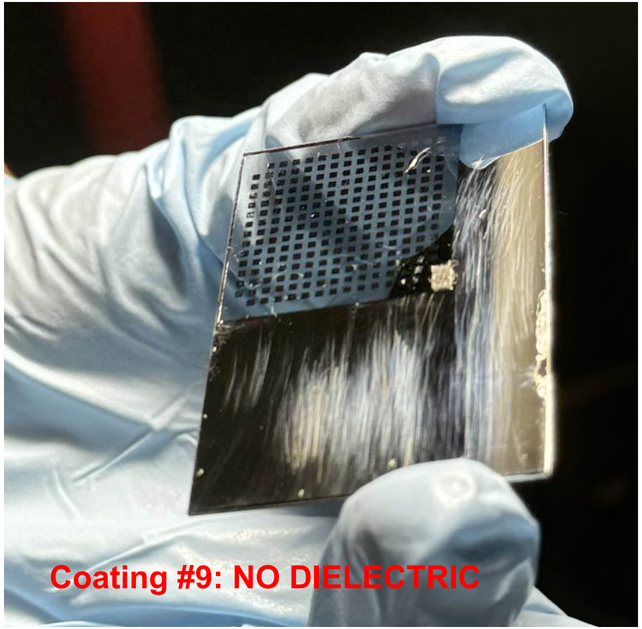
Current efforts aim to translate these results on large curved mirrors

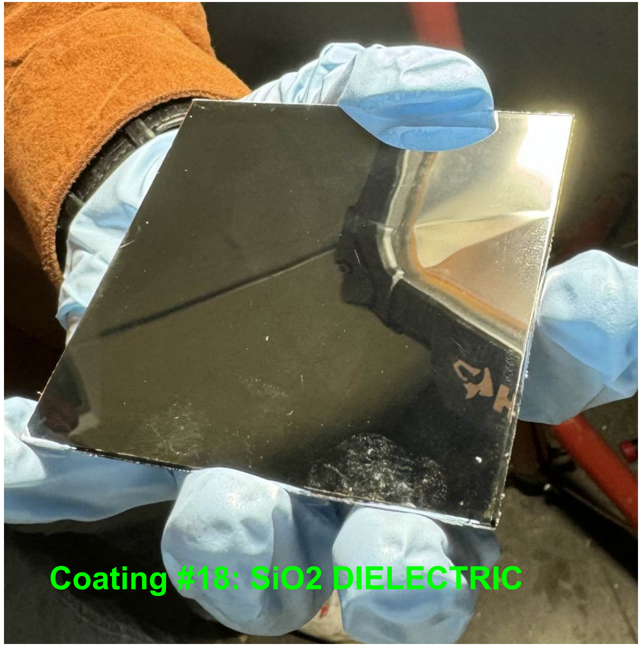
Dielectric Protective Coatings

❖ Mirrors oxidize overtime and are prone to contaminants that can damage the film. Protective coatings allow for long term use of the same mirrors with little to no cost in reflectance. Specific dielectrics have unique constraints for adhesion, with pfRICH mirrors employing SiO2.



SiO2 coating as a protective layer



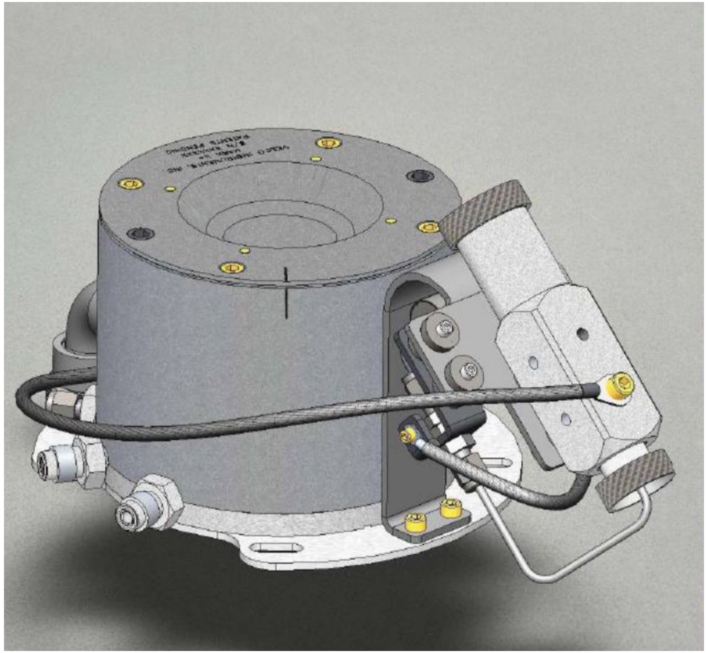


SiO2 is an extremely successful protective layer for pfRICH Mirrors!

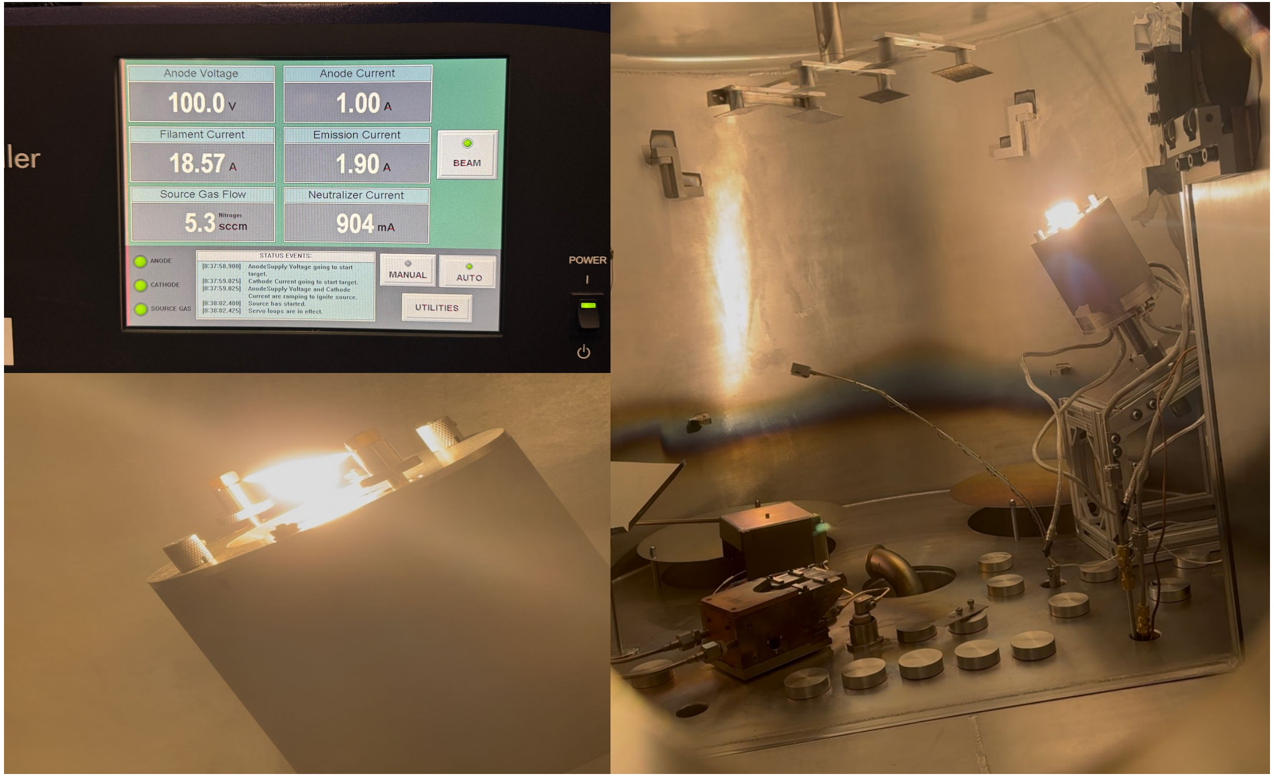
Both images are cleaned with Isopropyl + Kimwipe

Ion Source

- **IAE** (ion assisted evaporation) - Inert gasses enter the ion source, a voltage is applied and ions bombard the substrate while deposition occurs.
  - low energy ions vaporize any contamination (dust, water vapor…)
  - Higher energy applications offer greater surface mobility and adhesion of vapor clusters/particles
  - Increased arrival energy results in improved grain structure and uniform deposition
- Application of this technique with argon has been a large step forward in pfRICH mirror production.



Ion Source In Operation



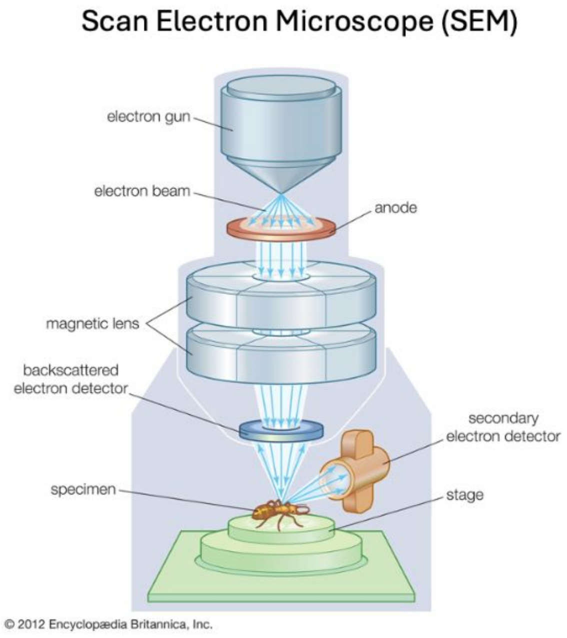
Ion Source has proven to be stable at low voltage settings for over 15+ mins of continuous operation.

Scanning Electron Microscope Imaging

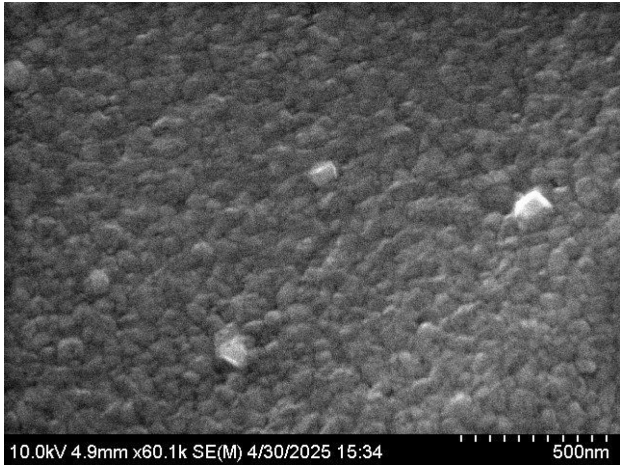
- ❖ Characterization of our mirrors goes beyond relative reflectivity measurements, we aim to analyze the structure and uniformity of the film itself and its impact on our reflectivity results.

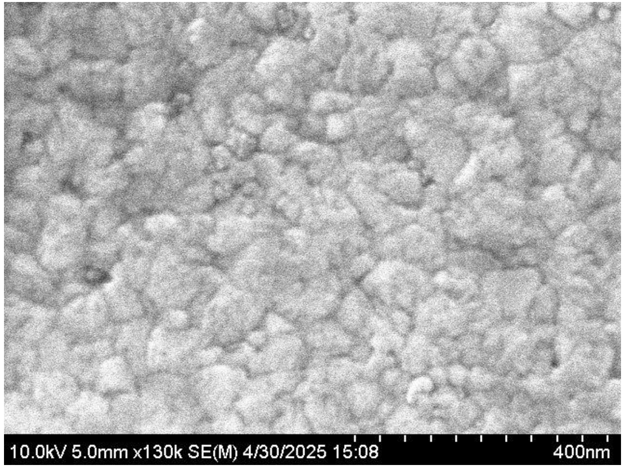
- ❖ Surface roughness and has the following direct relationship with reflectivity. Estimated roughness values from SEM scans can give an indication to the quality of reflectance

$$R(\lambda, \theta, \sigma) = R_0(\lambda, \theta) \cdot \exp\left[-\left(4\pi\sigma \cdot \frac{\cos\theta}{\lambda}\right)^2\right]$$



Coatings under the SEM





- ❖ Better quality mirrors are more difficult to image via SEM, generally we an see the unique structures and texture of the deposition.

- ❖ Shown above is a post evaporation analysis of the granularity and structures formed by the Al droplets.
  ~ 40-100 nm

Where do we stand?

- pfRICH Mirror coatings have come a long way in a short period of time, conclusively having shown 7cm x 7cm substrates **can achieve an average 90% reflectivity between 300 nm - 600 nm**

- A wide variety of tools and techniques are applied, including rotation of the substrate, protective coatings, and Ion bombardment; iterating and refining these processes is a **pivotal next step in determining the upper limit of mirror quality.** Application of these processes are relevant for nearly all RICH detector mirrors.

- Currently coatings transition into full scale curved mirrors, in conjunction with BNL personnel and test stands we can assess impacts to uniformity and reflectance from the curvature.
  - Earlier efforts with smaller curved samples have found little impact to uniformity or reflectance, but it remains to be seen how this translates on large scales.

Overview

- **MWDC R&D** : Aims to develop extremely low budget coated ~20 micron carbon fiber wires for multi wire drift chambers. This novel approach to MWDC is relevant to future tracking detectors (EIC 2nd detector, FCC, etc.)
  - *(Supported by LDRD 25-043)*

- Gaseous Detectors (e.g. Multi Wire Drift Chamber, older Time Projection Chambers, Straw Tubes) signal the passage of charged particles by gathering the electrons produced by interactions the medium. These detectors are widely used for precise tracking due to their large active volume and spatial resolution.

- Beyond tracking, there has been use of MWDCs for PID via truncated Bethe Bloch <dE/dx>


PHENIX Drift Chamber Prototype (Located at SBU)

Physical Constraints + Relevancy

- **Typical MWDC:**
  - ~20-50 μm diameter sense wires (biased to 1-2kV) for detection ~90-150 μm field wires to allow for a uniform electric field
  - Gold plated Tungsten Wires, **large costs for 10k - 100k+ wires**
  - Conductivity in the range of 5.4×10^7 S/m to 6.30×10^7 S/m (siemens/meter) - low thermal impact, low resistive losses
  - Generally **0.1 N - 0.5 N tension to prevent wire sagging** , varies…

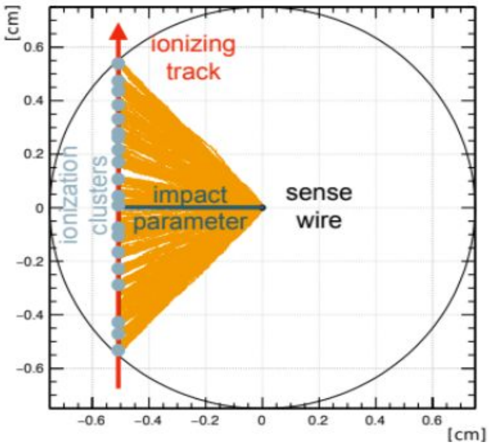
$$T_c \geq \frac{C^2 V_0^2}{4\pi\epsilon w^2} L^2$$

T_c wire tension
w cell width
L wire length

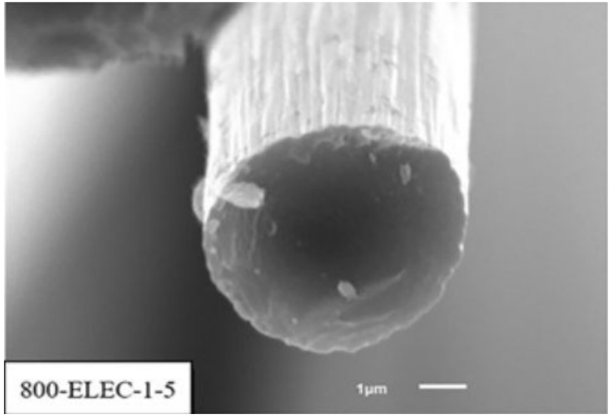
C capacitance per unit length
V_0 voltage anode-cathode

- Carbon fiber wires show “jagged” or “hairy” structures on a microscopic scale, deviations up to 10-100 nm on well made fibers are commonplace. Structural imperfections can result in arc discharges and inability to handle high voltage, (**bare c.f. wires have been shown to deform at 1000V**) uniform metallic coatings alleviate this issue and result in strong and conductive wires.

- Initial results of coating silver upon C.F. have been promising.



Geant simulation of dynamics within a chamber cell.
Ref: George Iakovidis (BNL)



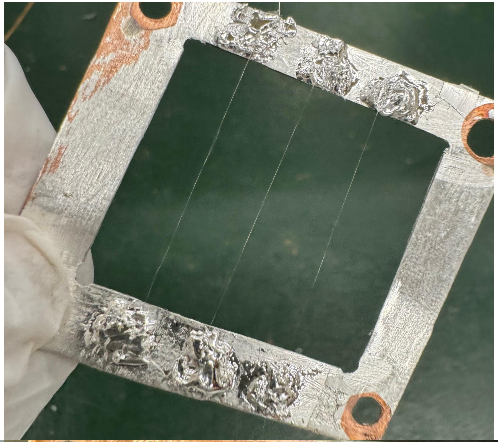
Microstructures of raw C.F. Fiber under SEM Scan. (Yang et al. SEM Microstructure)

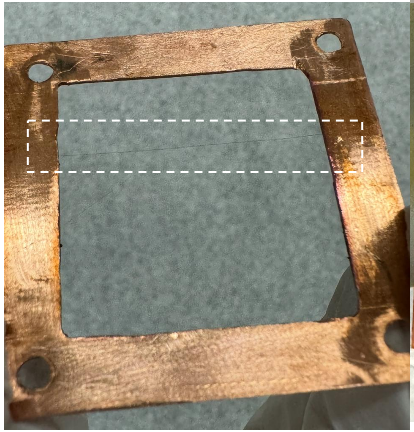
Substrate Prep and First Coating

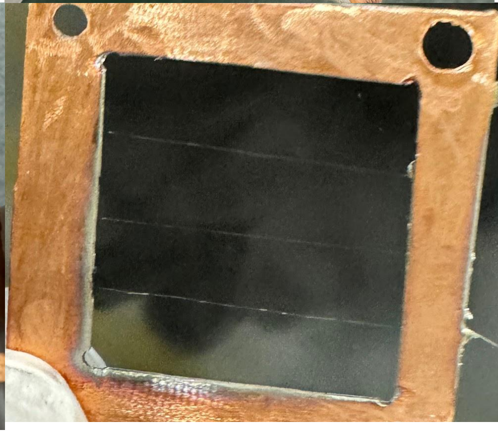
- For preliminary testing, carbon fiber strands were soldered onto thin copper frames to provide a mounting structure.

- These wires are individual fibers cut and isolated by hand, future works will use high quality, pre separated fibers.

- The visual contrast between an uncoated and coated wire is apparent, some material unsurprisingly adhered to the sides of the wire despite no rotation mechanism.

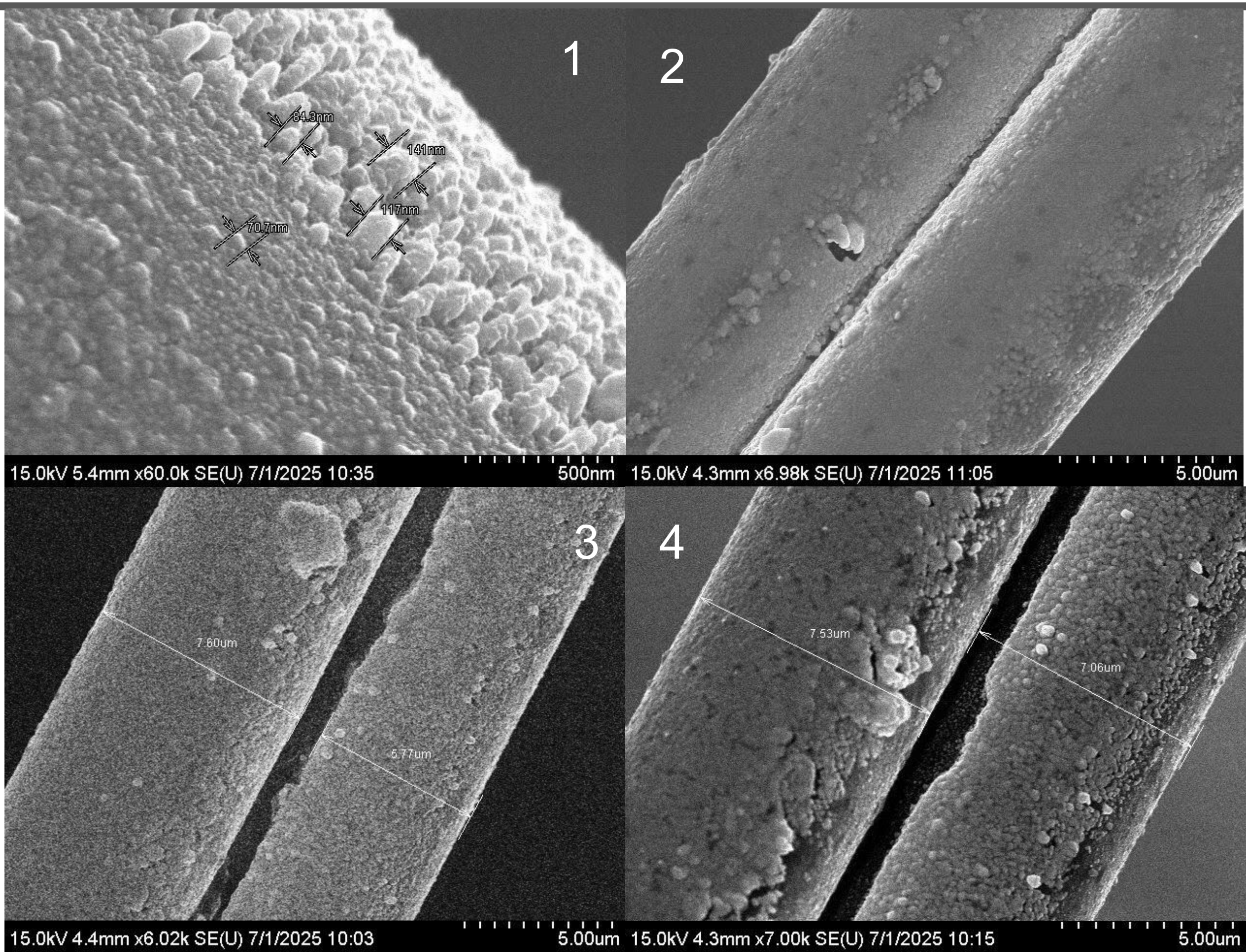






SEM Results

- The images depict 4 different hand separated carbon fiber wires coated with silver for the first time.
  - Image 1-2 depict 2 wires at a height immediately above the electron-gun
  - Image 3-4 depict 2 wires at different resolution, placed a meter away from the electron gun
- The following images are prior to any substrate rotation or bombardment. Silver theoretically required no priming layer, our test adequately proved silvers adhesion capabilities.



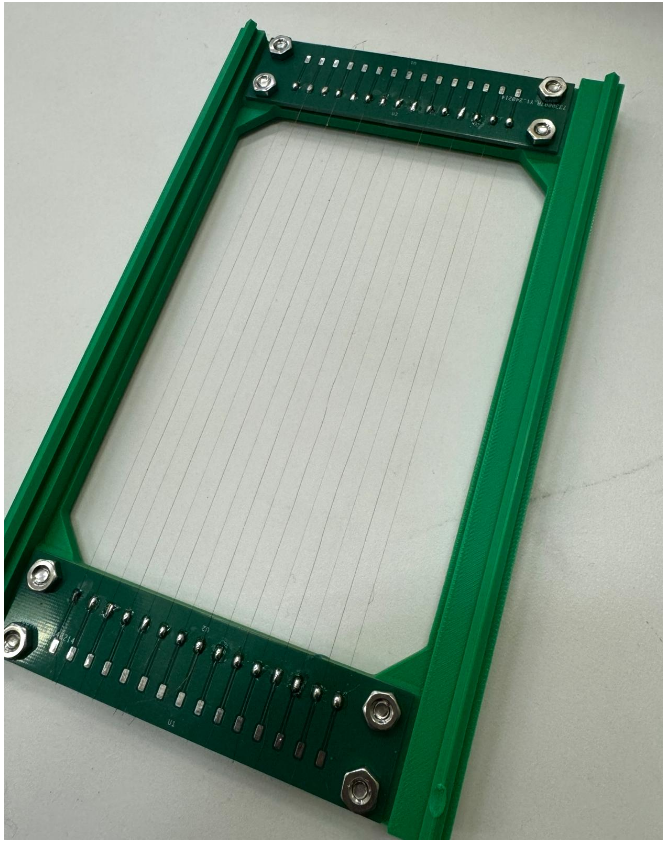
Upcoming Efforts

❖ The addition of the following will provide uniform, fully coated, and testable wires:

➢ Rotation of the wires along ϕ-axis
➢ Cleaning and substrate preparation with Ion Source
➢ Pre-tensioning of wires in a premade cell

❖ We aim to introduce **cryogenic pumping** into our system, with **capabilities of 10^-9 torr**, this will greatly improve stability during coating and reduce residual gas contamination as well as a new 3D for printing of mounts

❖ We remain confident this can be upscaled and provide a unique approach to how MWDC's are constructed, greatly improving the cost and approach in future detectors.



QnA

Thank you for your attention

Backup Slides:

Progression / Outlook:

❖ Currently we are in our third phase of R&D, having purchased a cryogenic pump to improve film adhesion and a 3D printer to have quick fixture turn arounds. We now transition into the crucial phase of testing coated wire capabilities.

Period	Objective	Description
1	Design	Fixture / Geometry Design + Initial Purchases
2	Initial Coating	Adhesion tests of Silver
3	System Additions	Cryogenic Pump + UHV Vacuum Motor + 3D Printer
4	Wire Testing	Examining physical properties of coated wires
5	Cell Construction	Coating a testable cell module
6	Mock MWDC Construction	Testing of a mock 1-cell MWDC