Testing of pfRICH Mirrors

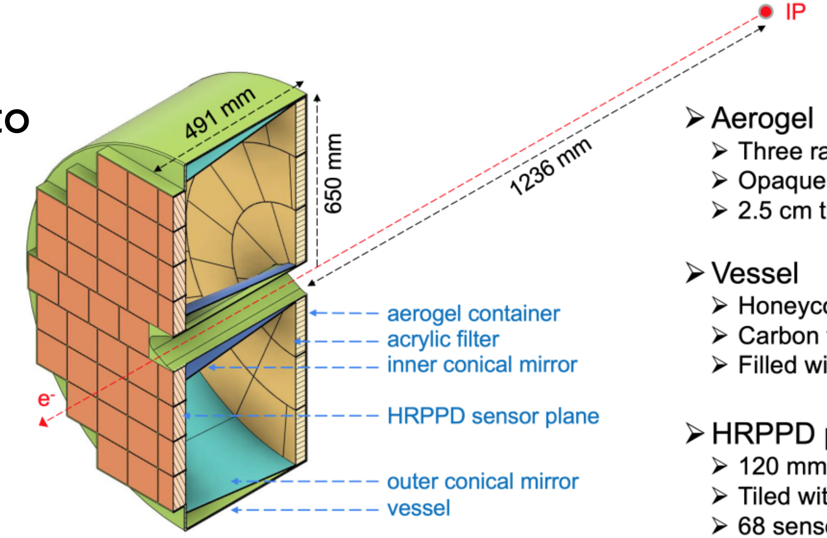
Jan Vanek, *et al.*
Brookhaven National Laboratory

EICUG Early Career Workshop 2025, Jefferson Laboratory

07/12/2025

PROXIMITY FOCUSING RICH FOR ePIC

- Proximity Focusing RICH is a vital sub-system of the future ePIC detector at EIC
  - Particle identification in electron going (negative) direction ($-3.5 < \eta < -1.5$, 2π in azimuth)
  - Pseudorapidity acceptance possible only thanks to **conical mirrors** to reflect Cherenkov light back onto sensor plane
- Primary physics motivation for pfRICH:
  - Identification of scattered electrons from deep inelastic scattering (DIS) events
  - Identification of charged hadrons for semi-inclusive DIS (SIDIS) analyses
- My involvement:
  - Physics performance simulations to validate minimum requirements for e/π^- separation and hadron PID
  - Participation on mirror development

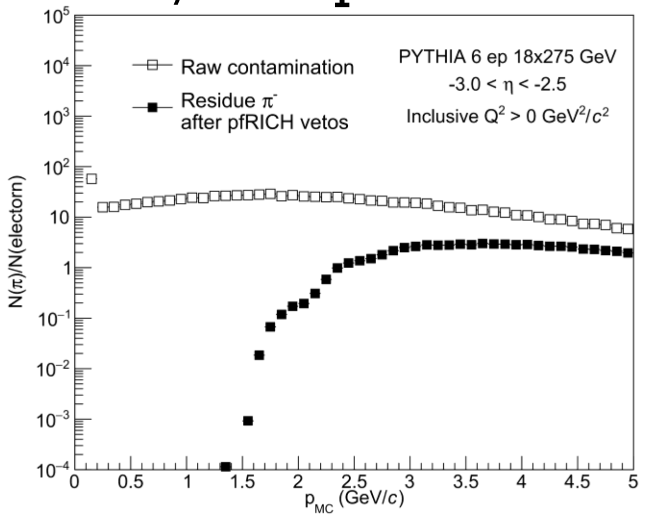


- Aerogel
  - Three radial bands
  - Opaque dividers
  - 2.5 cm thick, 42 tiles total
- Vessel
  - Honeycomb carbon fiber sandwich
  - Carbon fiber reinforced plastic (CFRP)
  - Filled with nitrogen
- HRPPD photosensors
  - 120 mm size
  - Tiled with a 3.0mm gap
  - 68 sensors total

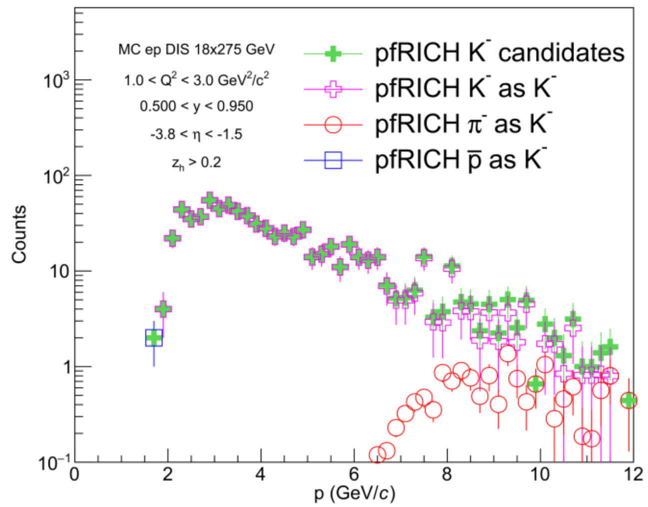
PHYSICS PERFORMANCE OF pfRICH

- (top) e/π^- separation inside pfRICH acceptance in PYTHIA 6 ep collisions at 18x275 GeV
  - Very good suppression below ca. 1.5 GeV/c
- (bottom) Kaon identification performance of pfRICH
  - Very good K^- purity up to about 6 GeV/c

e/π^- separation

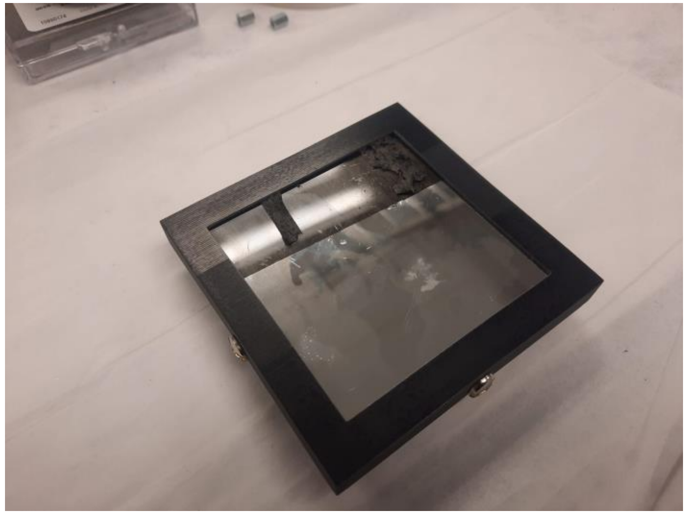


K (mis-)PID



MIRROR TESTING OVERVIEW

- Mirrors for pfRICH developed by BNL, Stony Brook University (SBU), and Purdue University
  - SBU + Purdue – mirror substrate production
  - SBU – mirror coating
  - BNL – mirror testing and reflectivity measurement
- Quick mirror design overview:
  - Lexan (polycarbonate) layer bonded to carbon fiber substrate using epoxy glue
  - Carbon fiber + Lexan substrates coated with combination of Cr and Al
  - Final mirrors are going to have a protective layer of SiO_2
- Testing of reflectivity of mirrors using “small test stand”
  - Test mirrors with size 7x7 cm
  - Measurement of absolute reflectivity:
    - Ratio of light intensity after it was reflected from mirror (now at 45 deg) and light intensity directly from the light source
    - Corrected for dark current of the photodiode



Monochromator automatic wavelength control

Monochromator power source

Photodiode readout

Dark box

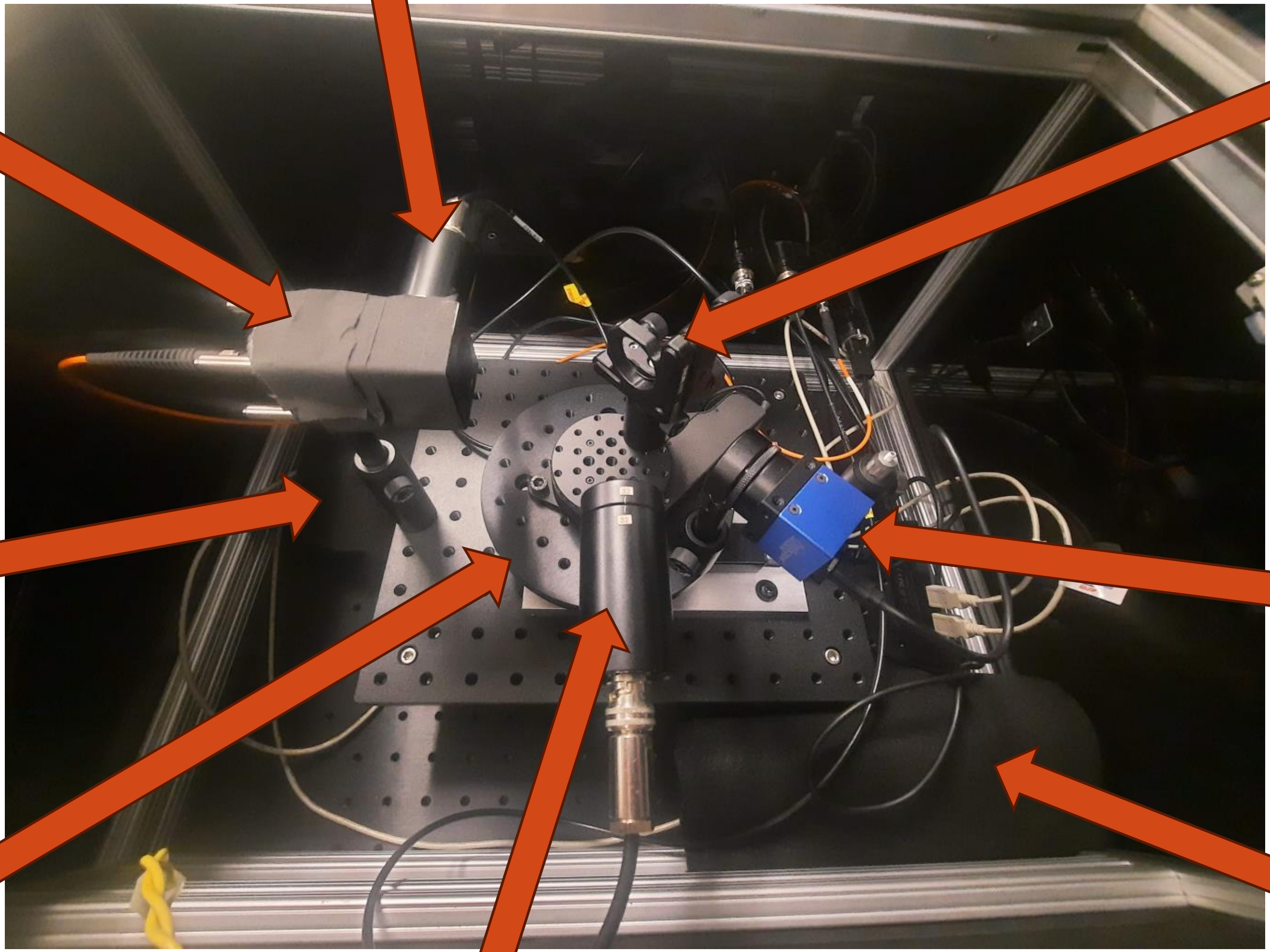
Computer

Monochromator

Reference photodiode

Light source with beam splitter

Mirror holder on top of the upper rotating stage



Top rotating stage control (under a cloth)

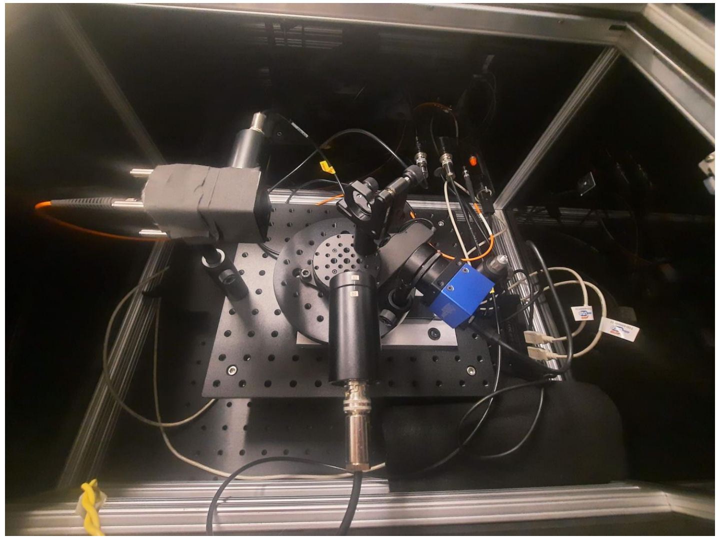
Camera

Bottom rotating stage

Bottom rotating stage control (under a cloth)

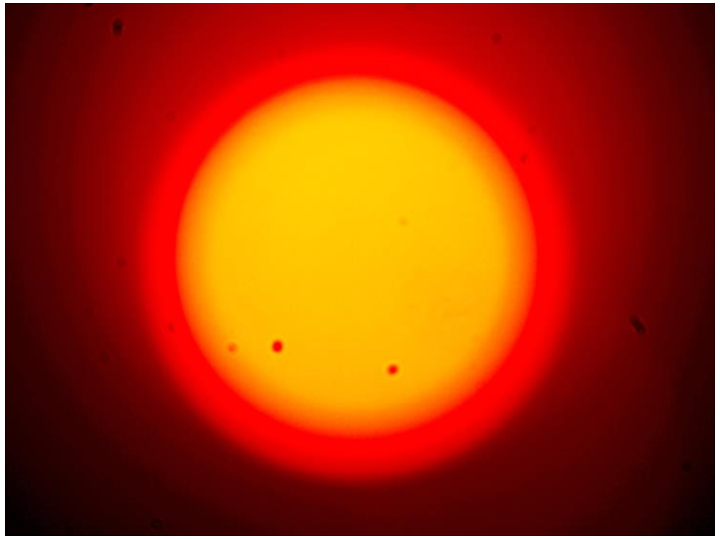
Measurement photodiode

REFLECTIVITY MEASUREMENT



- Reference measurements:
  - Dark current – accounts for dark current of photodiodes
  - Direct light – baseline measurement of light directly pointed on measurement photodiode

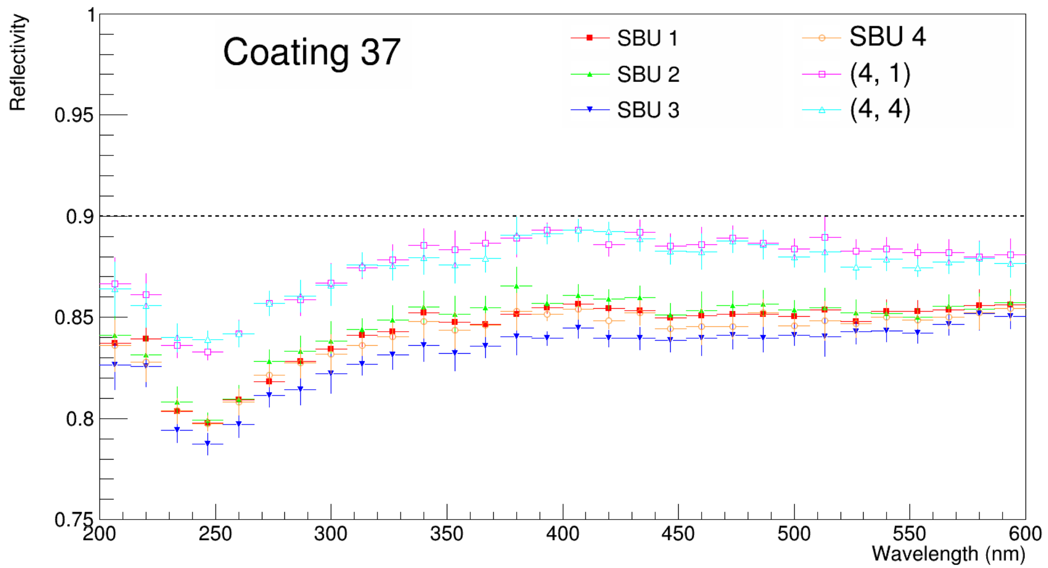
- Reflectivity measurement:
  - Insert tested mirror at 45 deg
  - Align beam spot using camera
  - Perform measurement with mirror



REFLECTIVITY MEASUREMENT

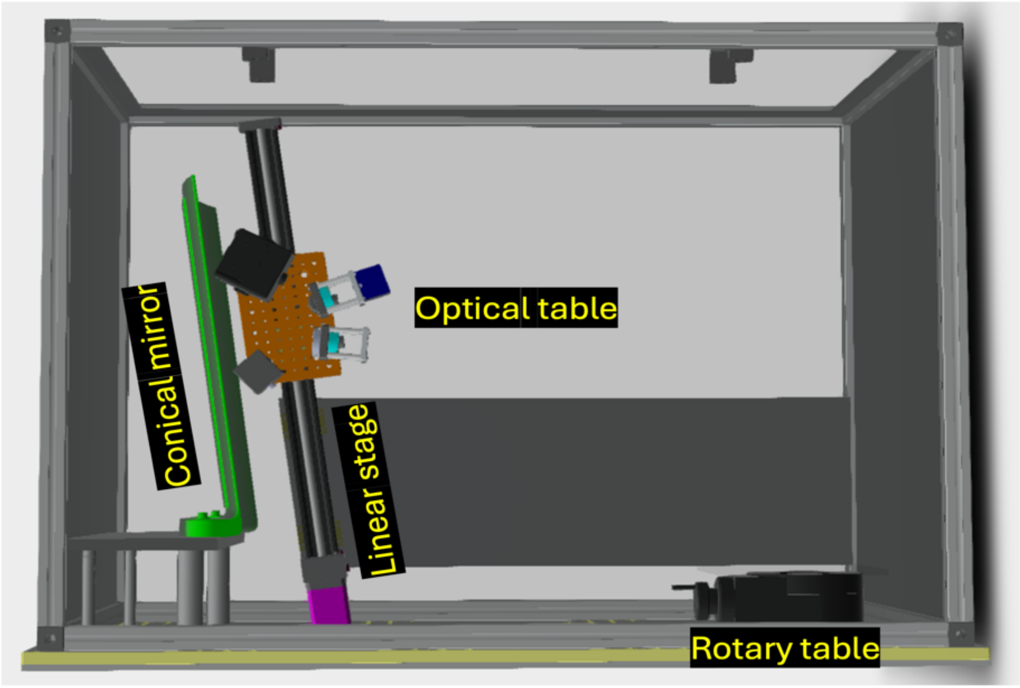
- Reflectivity measurement:
  - 30 wavelengths from 200 nm to 600 nm
  - Five measurements for each wavelength
    - Mean ± standard deviation
  - Reflectivity calculation:
    - Ratio of current measured by measurement photodiode at 45 deg (I_{45}) and current measured at direct light (I_{dir})
    - Correction factor for light intensity using reference photodiode
    - All currents corrected for dark current

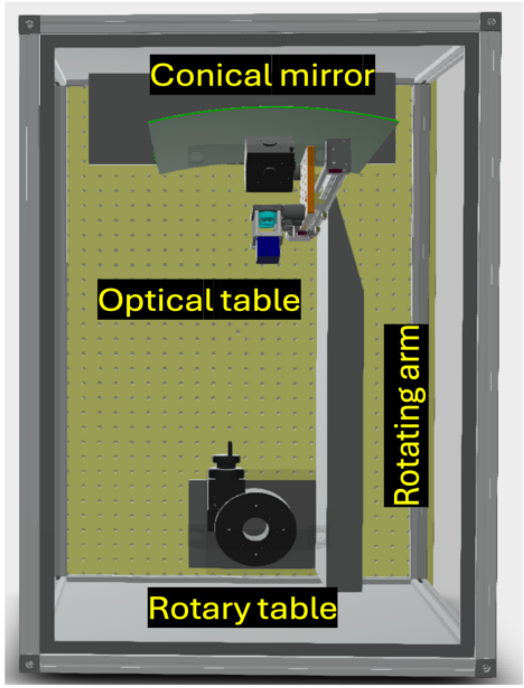
$$Reflectivity = \frac{I_{45}}{I_{dir}} \cdot \frac{I_{ref(dir)}}{I_{ref(45)}}$$

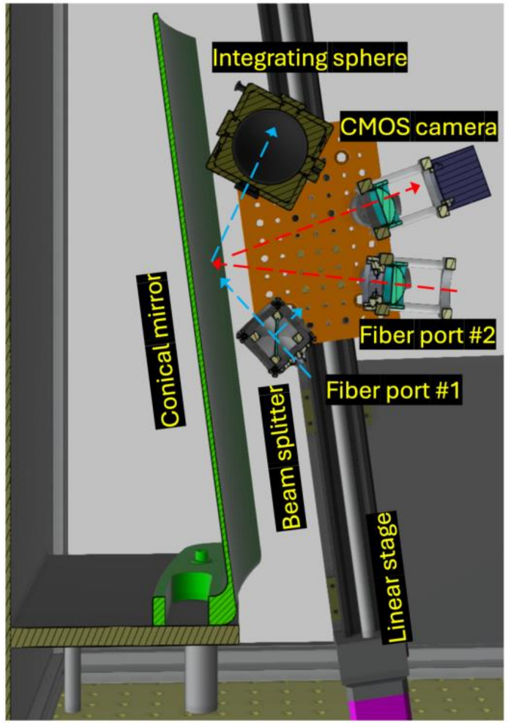


LARGE MIRROR TEST STAND

- New test setup for full scale mirrors for pfRICH
  - Currently being deployed at BNL
  - Will be used for **reflectivity measurement** and for evaluation of quality (waviness) of the mirror surface

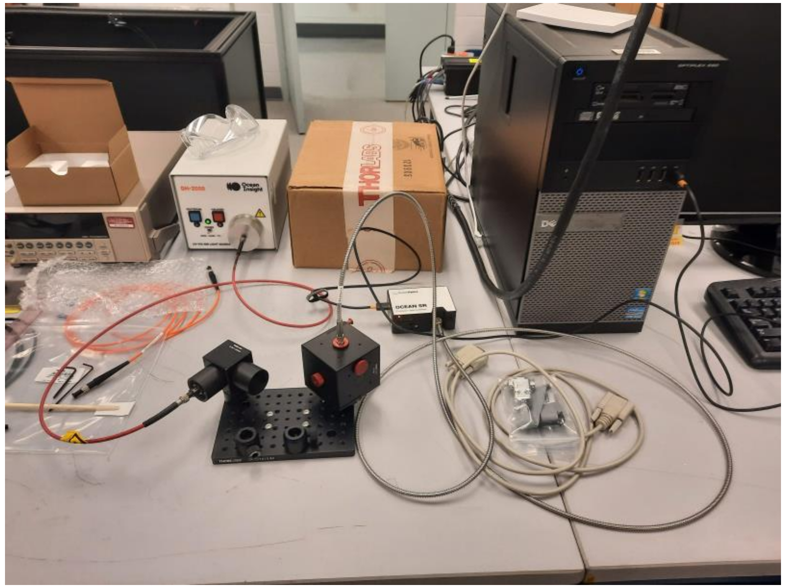


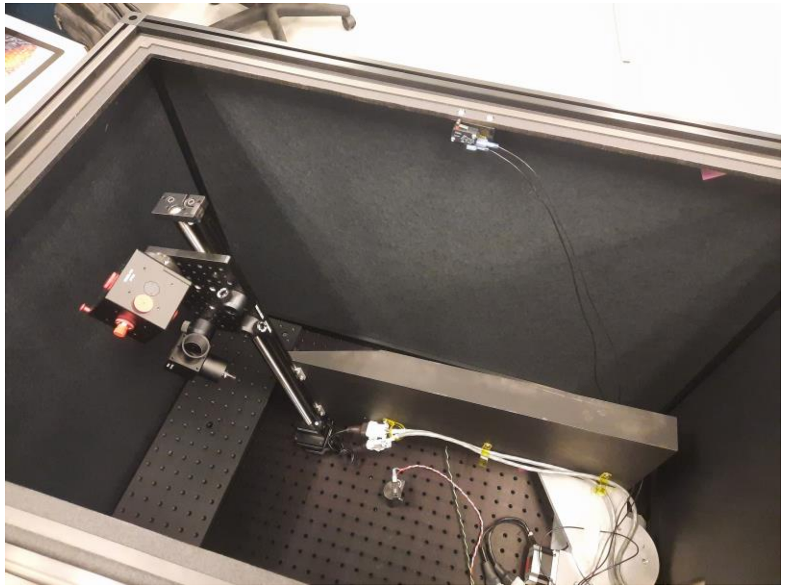




LARGE MIRROR TEST STAND

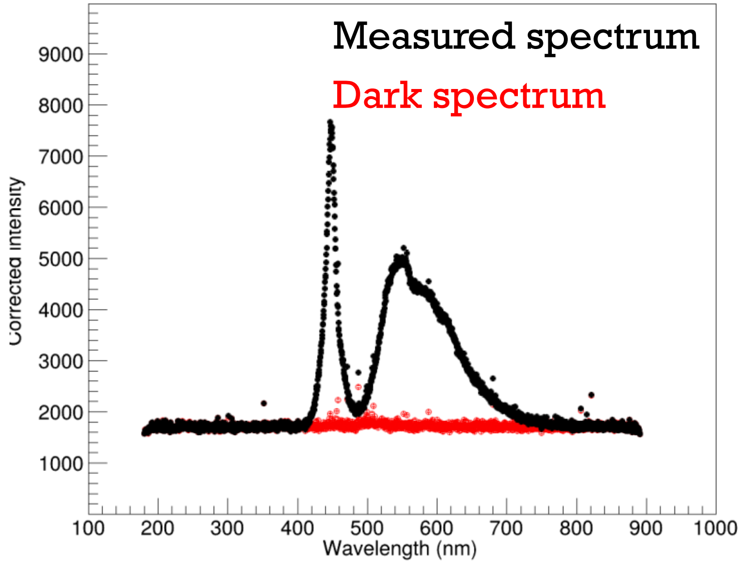
- My responsibility is development and commissioning of a test stand for reflectivity measurement of full-scale mirrors for pfRICH detector
  - **Software:** Movement of the stages (Velmex controllers), spectrometer readout (Ocean Optics)
  - **Hardware:** Assembly of components on the optical table and into the dark box

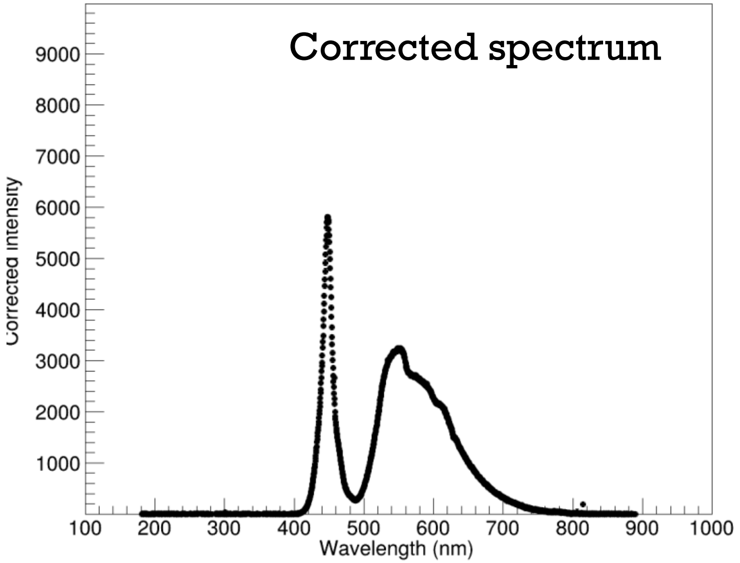




READOUT TESTING

- Readout is done using Ocean Optics spectrometer (Ocean SR)
  - Wavelength range about 180 nm to 900 nm
  - Installed and tested readout software for the spectrometer
- Key step in spectrum measurement is dark current correction:
  - (left) Spectrum of phone LED measured by spectrometer with the dark current baseline
  - (right) Corrected spectrum, after the dark current subtraction

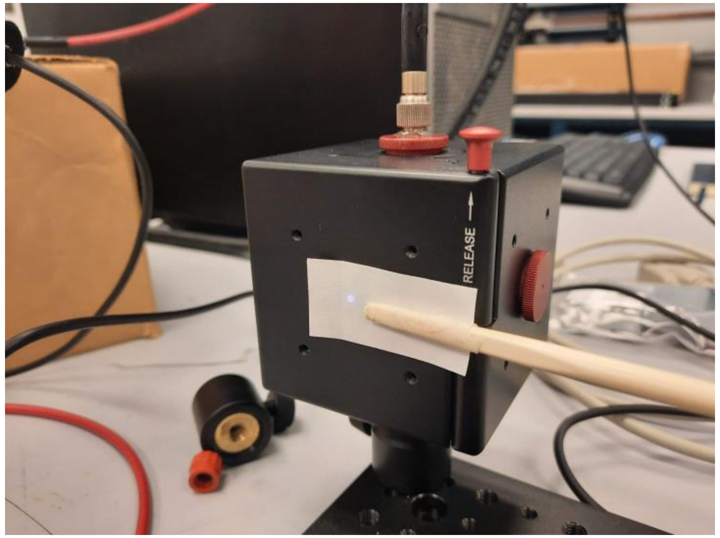




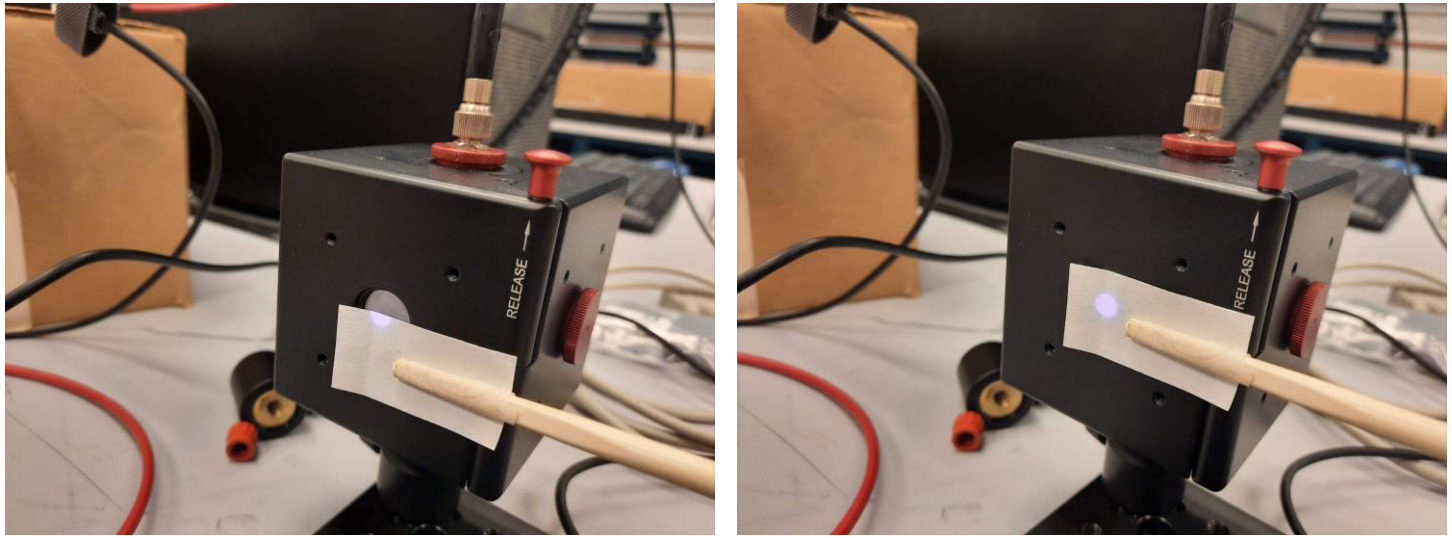
OPTICAL FIBERS – FROM LIGHT SOURCE

- Tests of different fibers from light source to collimator (200 μm, 600 μm)
  - Beam spot size for two different input fiber diameters
  - 200 μm spot small – seem to cause issues with readout (see next slide)
  - 600 μm – spot size larger, but seems to be reasonably small for input port on integrating sphere?
  - Will be tested with mirror inside of test stand

200 μm



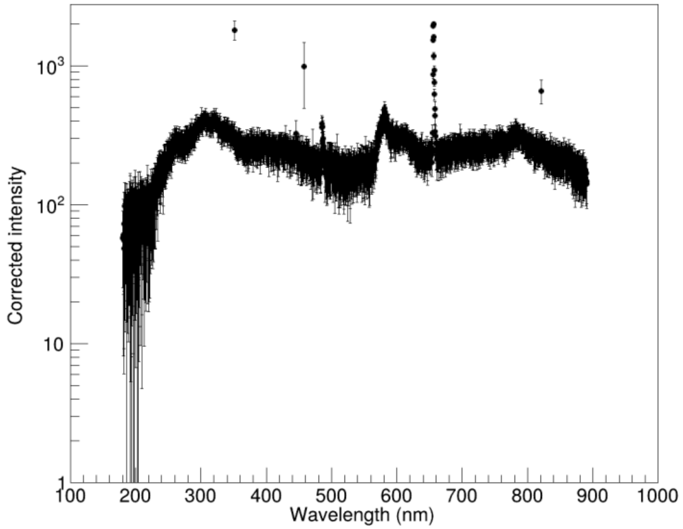
600 μm



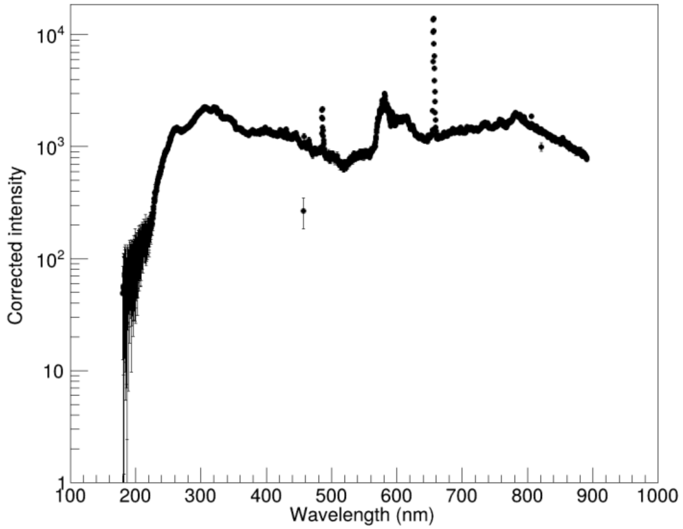
OPTICAL FIBERS – FROM LIGHT SOURCE

- Tests of different fiber combinations
  - From light source: 200 μm vs. 600 μm
  - From integrating sphere to spectrometer: multi-core fiber
  - Integrating time 1s, 10 measurements for each spectrum (mean, standard deviation)
  - After dark current correction
- Small fiber does not seem to provide enough light for the spectrometer

200 μm

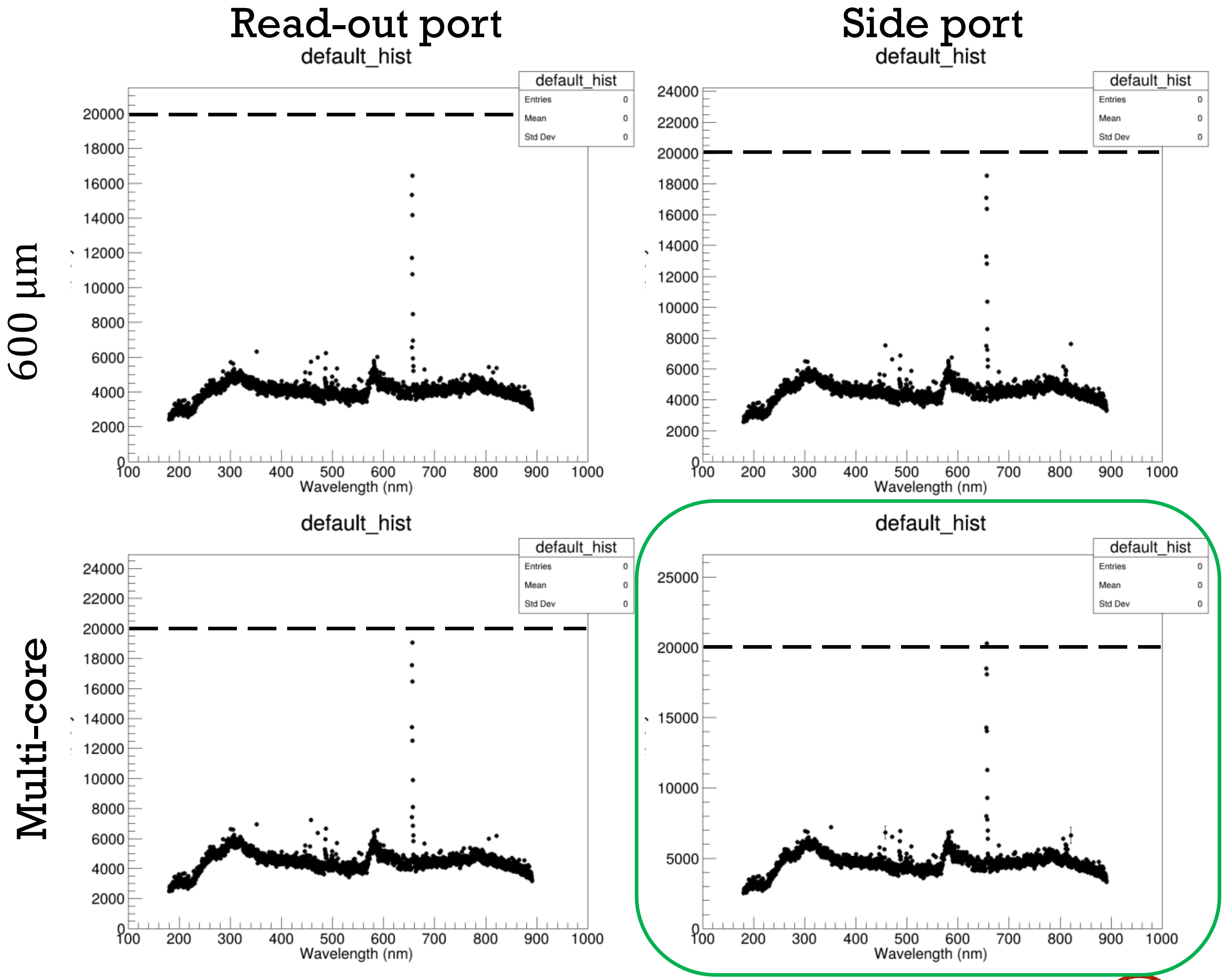


600 μm



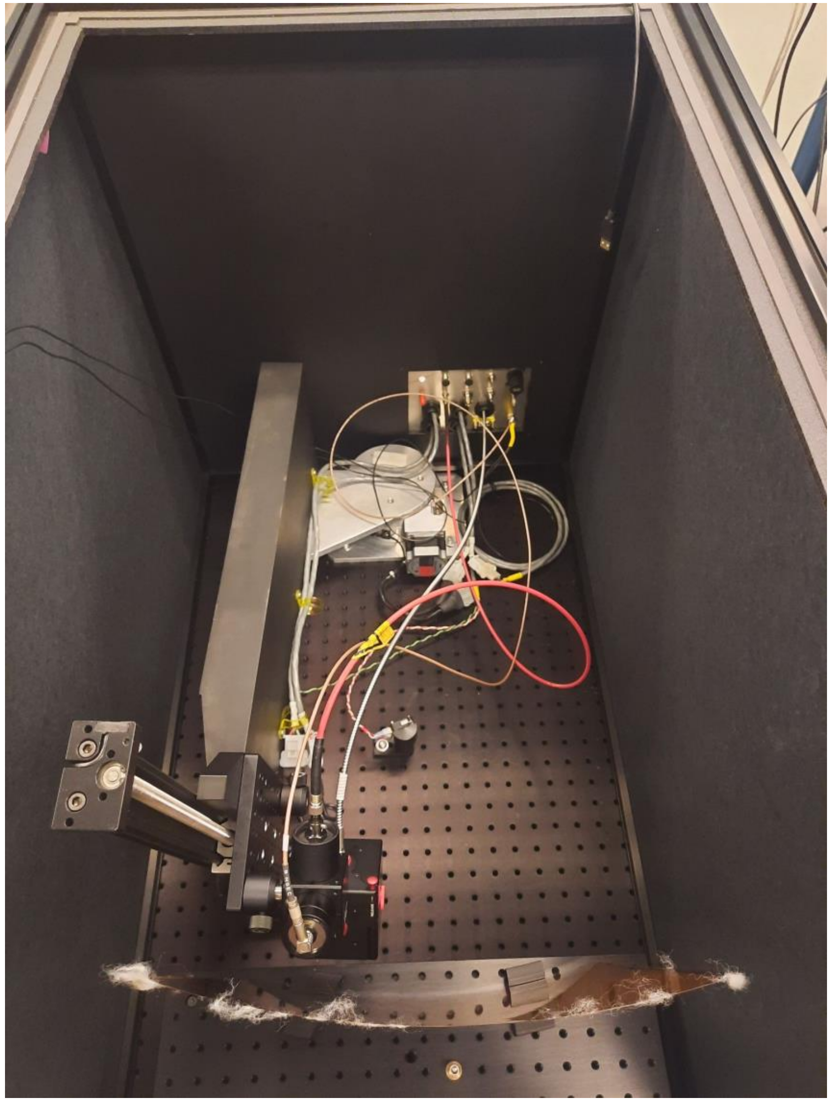
OPTICAL FIBERS – TO SPECTROMETER

- Tests of different fiber combinations
  - From light source: 600 μm
  - From integrating sphere to spectrometer: 600 μm vs. multi-core
    - Two different ports – read-out port vs. side port
  - Integrating time 1s
  - Uncorrected measured spectra (with dark current baseline)
- Multi-core fiber provides slightly more light than 600 μm
- Top port gives best light yield



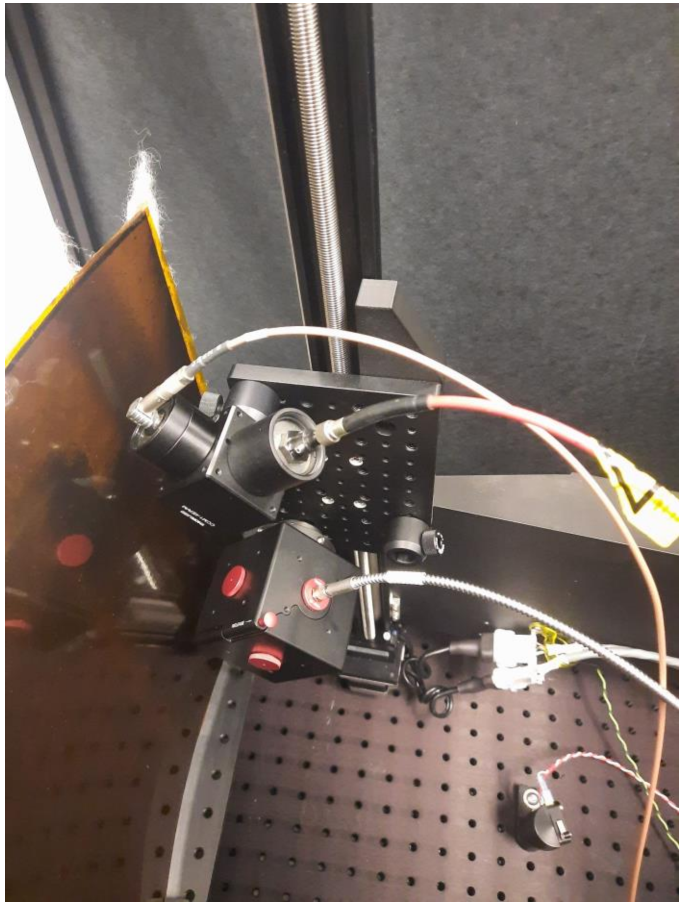
OPTICAL FIBERS – FITMENT

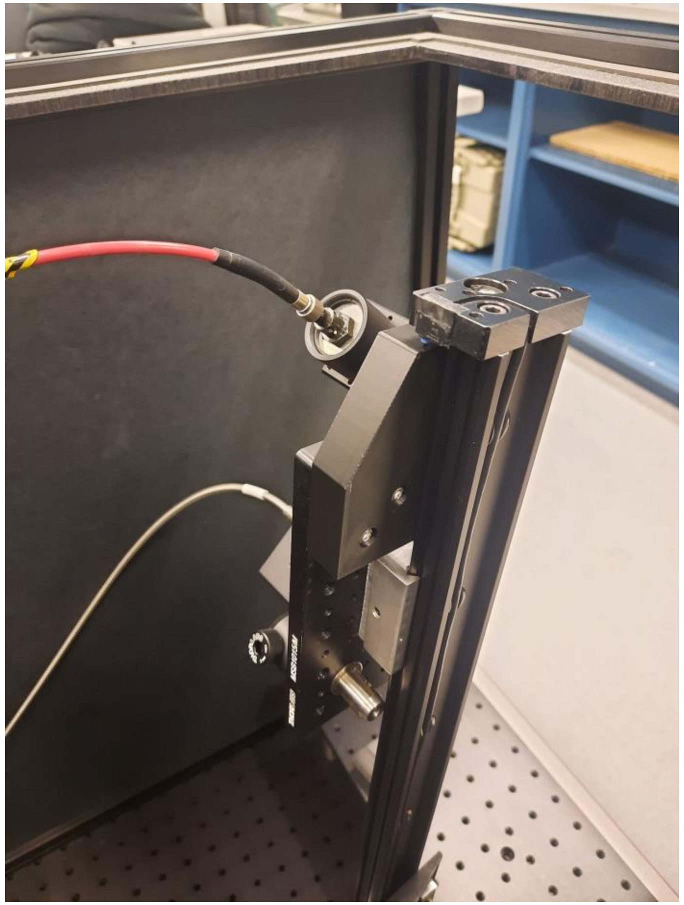
- Tested fiber and cable routing inside of the dark box
  - Full range of motion of stages tested
  - Selected integrating sphere output port (see photo)
    - Other ports can interfere with box walls
  - Custom 3D printed plug for multicore fiber



OPTICAL TABLE – FITMENT

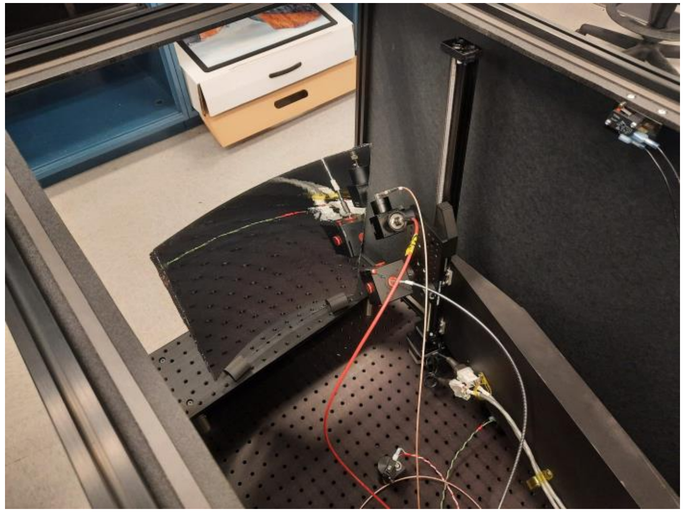
- Optical table with all components fitted to the dark box
  - Input collimator
  - Reference photodiode
  - Integrating sphere
  - All cables and fibers
- Test fitted with uncoated full-scale mirror (left)
- Had to limit linear stage range (right)
  - Top – custom 3D printed stop
  - Bottom – optical mount post

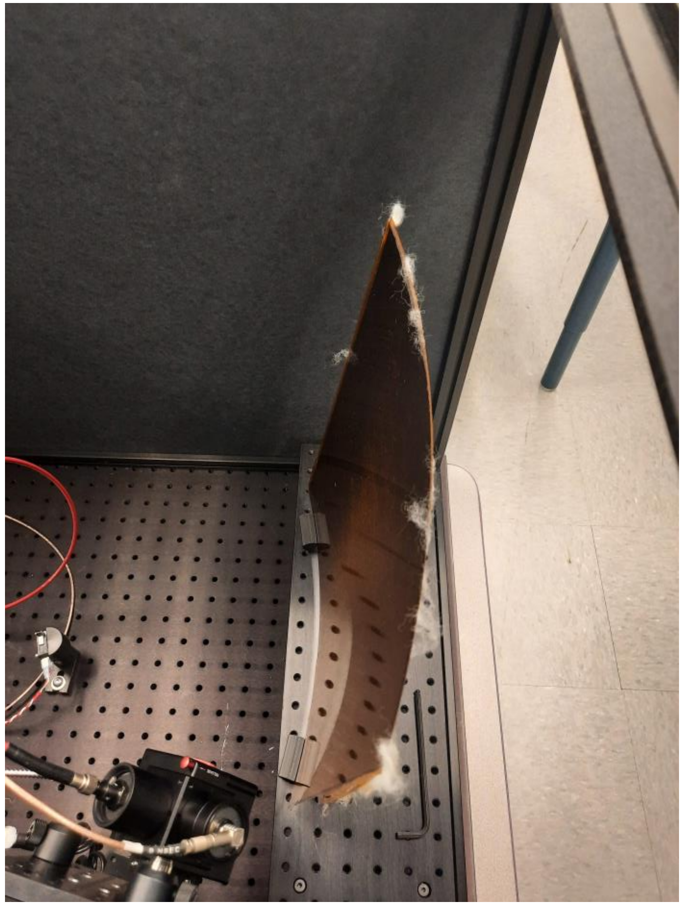


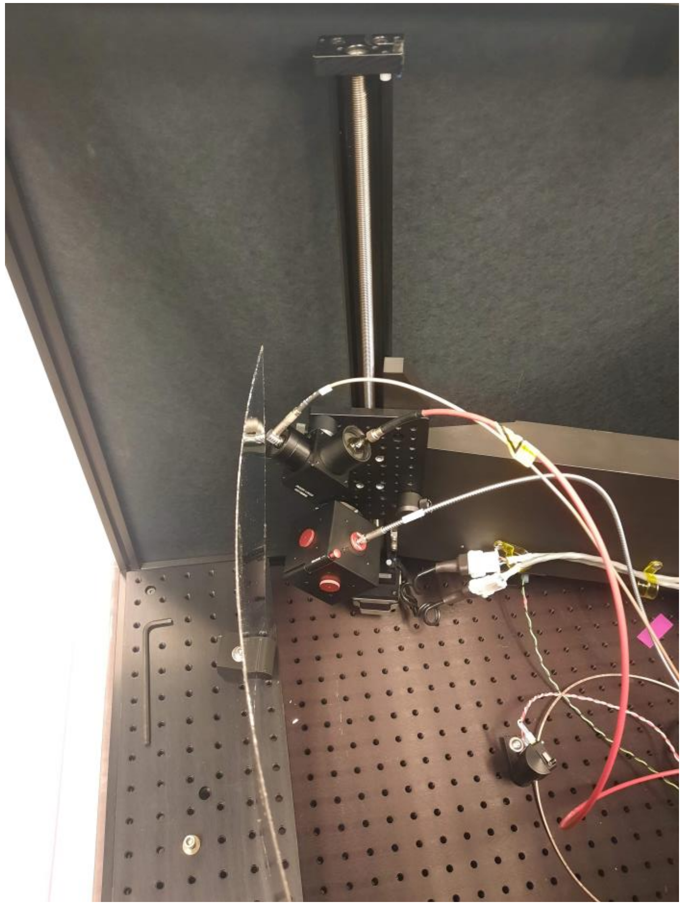


FULL SIZED MIRRORS

- Test with two full sized mirror samples
  - Uncoated mirror (middle)
    - Fits well at correct angle
  - Coated mirror (left and right)
    - Sits vertically – need correct angle
- Now designing new holders to ensure correct mirror tilt inside of dark box

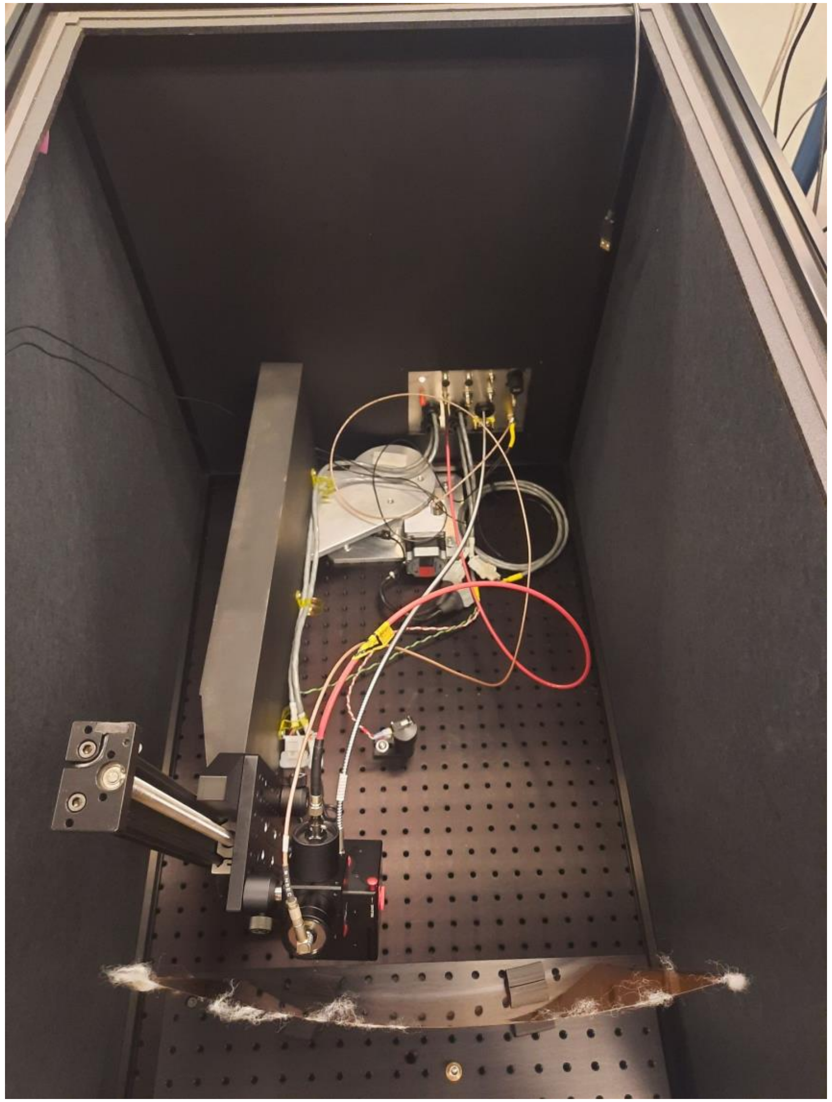






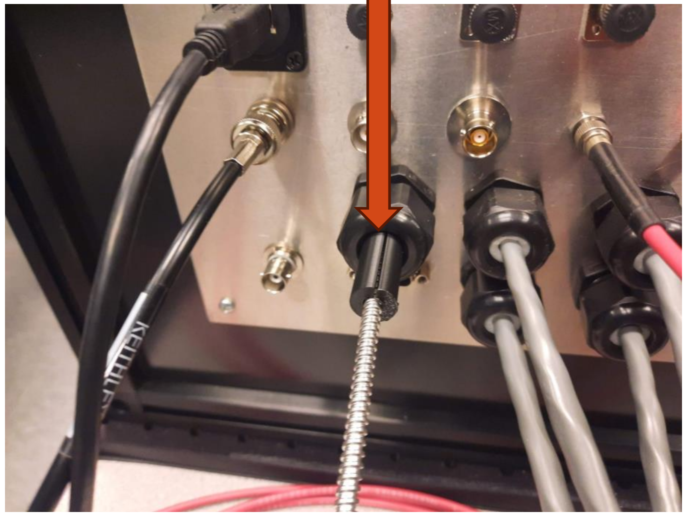
MOVEMENT OF STAGES

- Movement of stages is fully automated using Velmex stepping motor controller
  - Implemented framework that allows movement of both linear and rotating stages
  - Movement demo
- Tested that all cables and fibers work in full range of motion of the stages

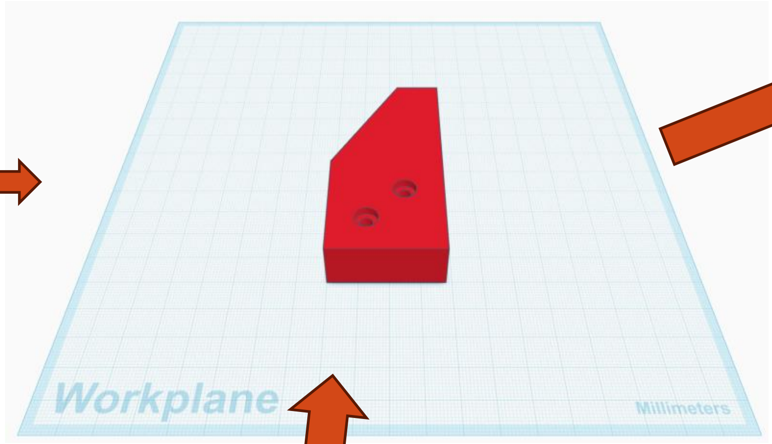


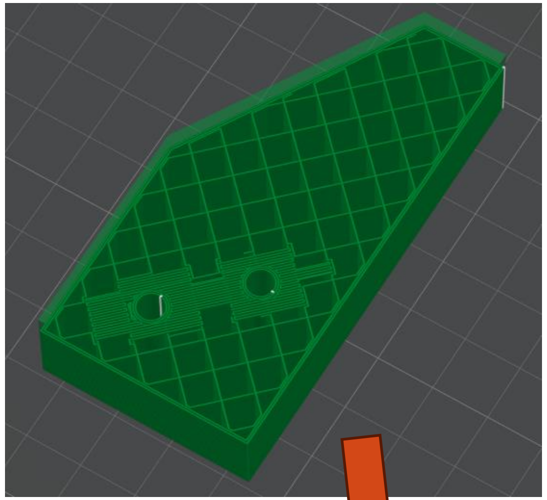
CUSTOM 3D PRINTED PARTS

- Full scale mirror holders
- Linear stage stops
- Plug for multicore fiber



3D model





Slicing for
3D printing

3D printing

Optimize design

SUMMARY AND OUTLOOK

- Large mirror test stand for full scale pfRICH mirrors close to deployment for first reflectivity measurements

- Outlook:
  - Optimization of mirror holder design
  - Optimization of output file format for reflectivity measurement
  - First reflectivity scans of full size pfRICH mirrors

THANK YOU FOR ATTENTION