pfRICH full size mirror test stand at BNL

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Executive summary

We propose to build a new pfRICH mirror surface scanning setup in Rm 1-213 in Physics 510D.

The setup will be fully automated, and will allow one to perform surface scans of the absolute reflectivity of pfRICH conical mirror sector prototypes *with a size up to 40 cm in one dimension*, as a function of wavelength between ~300 nm and ~700 nm. We will also make an attempt to develop a 2D surface mapping procedure and estimate the non-specular (diffuse) fraction of the reflected light.

The setup will be built mostly from readily available components, including a recently purchased Ocean Optics SR-6UVV240-25 spectrometer with a deuterium / halogen light source, and should be brought into operation on a time scale of two months.

The developed testing procedure, software, and most of the essential equipment will be later used in a reflectivity / 2D surface mapping scanner of the fully assembled pfRICH detector.

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Apparatus [in a configuration with an outer pfRICH conical mirror]

A CAD model of the setup is shown in Figure 1. It will consist of a custom 23” x 25” x 35” dark box mounted on a 24” x 36” Thorlabs optical breadboard, a Velmex B48 rotary table and an X-Slide

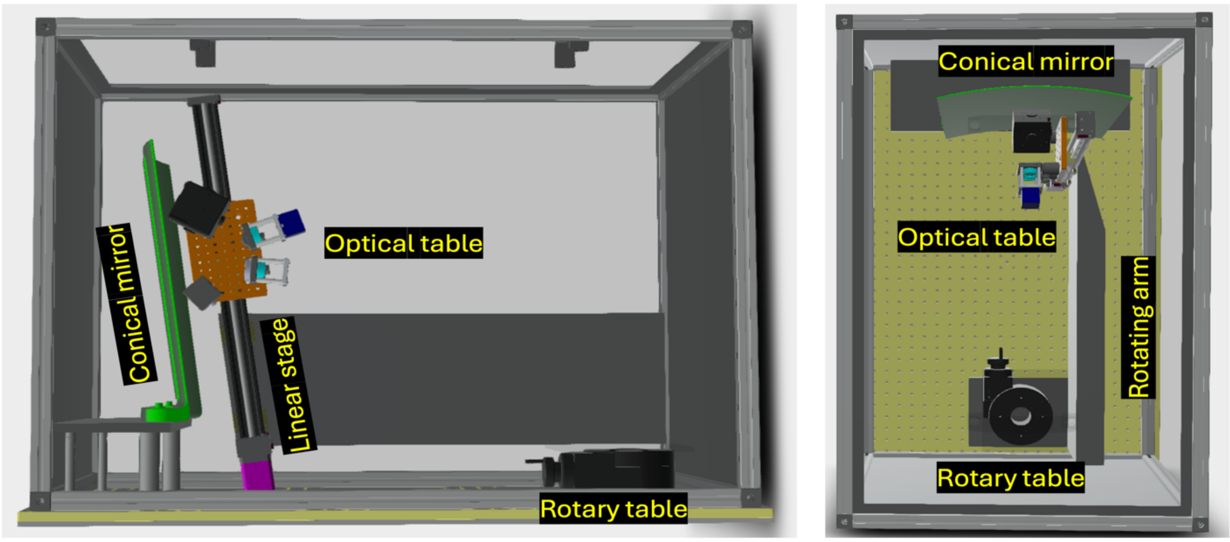

Figure 1 CAD model of the mirror test stand, with side walls and a lid taken out. Left: side view. Right: top view. See text for more details

linear stage with an 18” travel, and an optical head with two independent sets of equipment:

- Ocean Optics 74-UV collimator, fiber coupled to an Ocean Optics light source and a 50 mm diameter Thorlabs integrating sphere, also fiber coupled to an Ocean Optics spectrometer as a receiver
- A point-to-point focusing configuration of 1” diameter Thorlabs lenses, projecting light from a single mode fiber tip coupled to an appropriate laser source (like a PiLas laser) onto an AmScope CMOS camera sensor

An outer full size pfRICH conical mirror sector prototype will be permanently mounted at an appropriate height on the base breadboard, in such a way that the cone symmetry axis is the same as the rotary table axis. Motion control will allow the optical head to travel within the required range of +/- 15^0 azimuthally and about +/- 200 mm along the conical surface, preserving nominally the same relative position of the optical head with respect to the point of reflection across the whole mirror surface, with a reflection in a vertical plane at about 50-55^0 to the normal for a reflectivity scan and about 10-12^0 to normal for surface mapping. The rotating arm will be supported by a Teflon padded foot (not shown in the model).

The setup will have a newly installed Linux Debian 12 PC attached to it, for automated data collection (steering of the rotary and linear stages, the spectrometer, the CMOS camera, as well as the picoammeter readout of a reference photodiode), and data analysis.

A zoomed in view of the optical table is shown in Figure 2.

Surface reflectivity scans

This functionality (see Figure 2, blue arrows) will be used for full surface area reflectivity scans as a function of wavelength. Light with a continuous wavelength spectrum (provided by an Ocean Optics DH2000 light source) will be delivered to the optical head through a UV-graded fiber with a relatively small (200 μm) diameter core to minimize the reflected light spot size as seen by the integrating sphere, without losing too much of the initial photon flux. It will then get collimated, and passed through a 1 mm thick sapphire plate installed at 45^0, acting as a ~85:15 beam splitter over the entire wavelength range of interest. The reflected beam photon flux will be continuously monitored by a reference Hamamatsu photodiode (S1226-8BQ) with an 8 mm x 8 mm nominal active area (not shown in the picture; existing package needs to be miniaturized in order to fit). The photodiode current will be measured by a Keithley 6487 picoammeter. The through going light will be focused in a point-to-parallel configuration by the Ocean Optics 74-UV collimating lens onto the conical mirror surface, reflected back into an ~11 mm diameter port on the Thorlabs 2P3/M integrating sphere, and coupled to the Ocean Optics SR-6UVV240-25 spectrometer via a large (> 600 μm) diameter UV-graded fiber, to maximize the luminosity. The spectrometer will produce a reflected light wavelength spectrum for a given 2D point on the mirror surface. This spectrum, normalized to a reference photodiode current, will be compared against a similar spectrum of light reflected by a 1" Thorlabs PF10-03-F01 reference mirror mounted next to the pfRICH conical one (not shown on the picture). Absolute reflectivity of the reference mirror will be calibrated once, using our existing small size setup in Rm 2-201. A comparison between the two spectra provides a wavelength dependency of the conical mirror absolute reflectivity in a given point on its surface. Once we manage to integrate the provided Ocean Optics Linux software into our data taking scripts, the procedure can be fully automated.

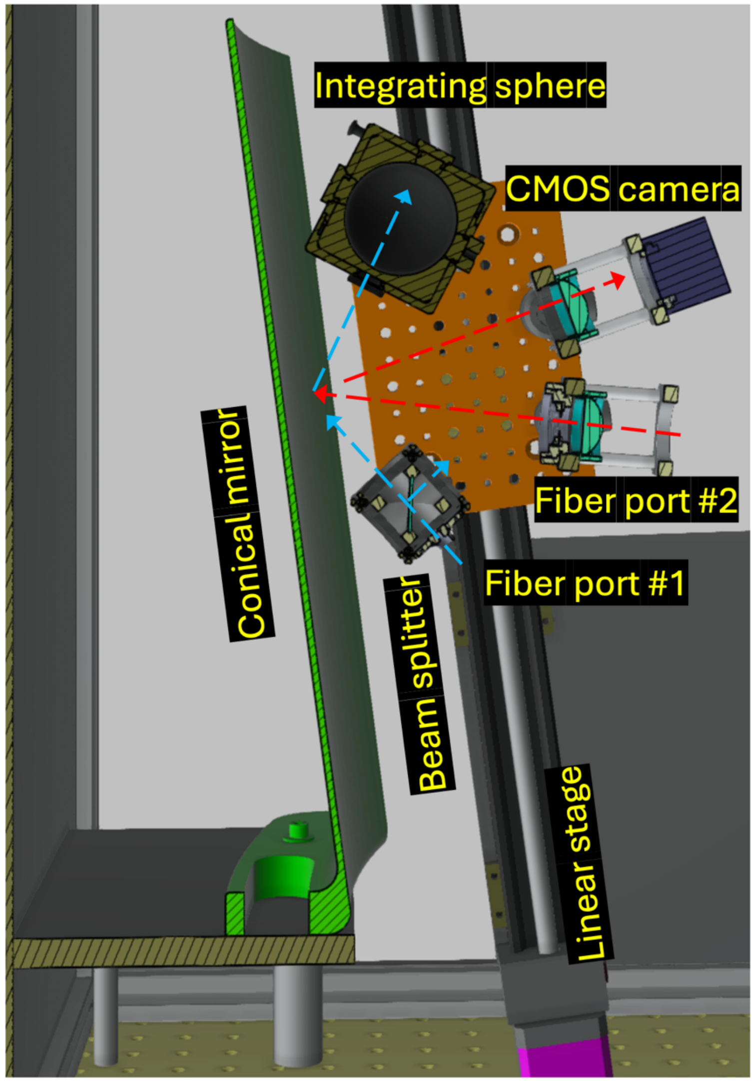

Figure 2 A zoomed in vertical cross-cut view of the optical table installed next to the conical mirror surface. See text for more details.

Configuration with an inner pfRICH conical mirror

The pfRICH inner mirrors will be a special case, not only because they are of a convex shape, but also because they will require a +/-45 degree azimuthal rotation, which one clearly cannot implement in a compact dark box without dismounting the long rotation arm used to scan the outer mirrors.

Dismounting the rotating arm after initially tuning all of the components seems to be suboptimal.

It is presently anticipated that in order to scan the inner mirrors, the rotating arm will be fixed at a 0^0 (or some other appropriate angle), and will provide only a linear motion of the optical table. The inner mirror sector will be mounted on its own rotary stage in front of the optical table, to provide an azimuthal degree of freedom in case automation is really a must. The easiest option would probably be to use a second readily available Velmex B48 rotary stage, see Figure 3.

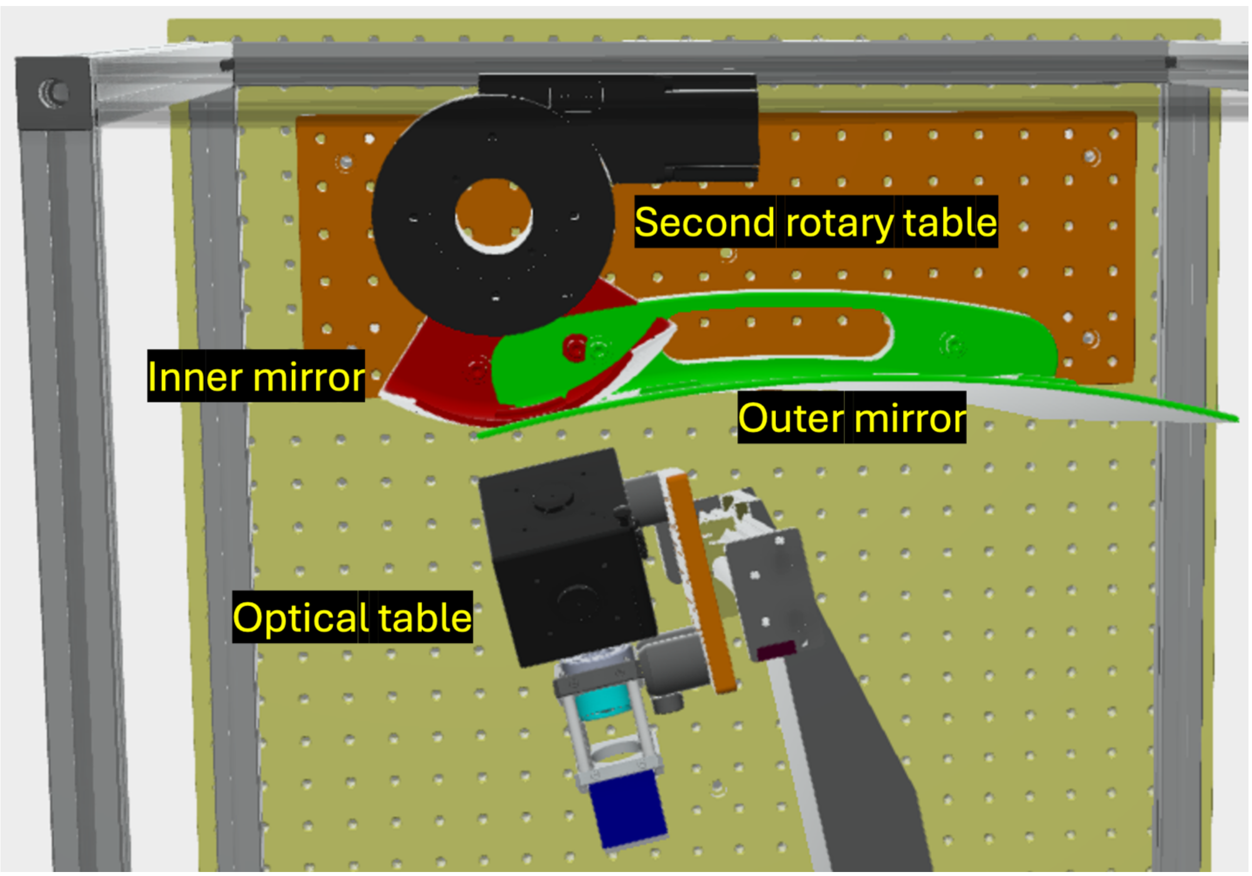

Figure 3 A possible implementation of azimuthal rotation scheme in a configuration with the inner conical mirror. The rotating arm is installed at 12^0. The outer mirror is shown for illustrative purposes only.

With a bit of repositioning of the components in the setup, the second stage may fit (see the picture) and provide azimuthal movement in the range of roughly +/-40 degrees.

Yet another option would be to use a Thorlabs PRM1Z8/M rotary stage (same as the ones installed on a small mirror test stand in 2-201; needs to be purchased) with a max vertical load limit of 1.4 kg, if it can operate a ~0.5 kg inner mirror on a small, cantilevered support arm. This stage will certainly fit, and will provide the whole +/-45 degree rotation range. An existing Thorlabs CR1/M-Z7 stage has a small formfactor; the manual says it has a 25 lbs. vertical load capacity (confirmed experimentally to manage a 4 kg weight), and it will certainly fit in the available space, potentially even without a need to dismount the 1" Thorlabs reference mirror.

As a last resort one can either implement a custom geared slewing bearing based rotation system, or a second arm with its own optical table.

Mirror 2D surface mapping

A second functionality for this setup (Figure 2, red arrows) will be an attempt to perform a 2D surface scan to determine its deviation from a nominal conical shape. Monochromatic light from a source which can be coupled into a single mode fiber with a field view of ~3 μm (like a PiLas laser) will be focused by a pair of Thorlabs LA1805-ML lenses with a focal length of 30 mm in a point-to-parallel-to-point configuration from the fiber tip to an AmScope MD-310BS CMOS camera bare sensor (5.12 mm x 3.84 mm size, 2.5 μm pixels), without an intermediate focus at the point of reflection on the mirror surface. The spot size on the conical mirror surface will rather be controlled using a diaphragm, installed right next to the first lens, see Figure 2. The hope is that the movement of the reflected light spot across the sensor active area when illuminating different points on the mirror surface will be sufficient to derive a 2D surface *normal* map of the mirror *for the purposes of Inverse Ray Tracing (IRT) reconstruction,* which may or may not be equivalent to measuring the 2D surface *shape* per se by using an appropriate mechanical profilometer.

Broadening of the reflected point-like source image (as compared to a possible broadening observed with a stock Thorlabs mirror) may also indicate a degree of a non-specular reflection which cannot be captured by a total reflected flux measurement in the configuration with an integrating sphere.

Deliverables and timelines

The fully functional test stand as described in the previous section and shown in Figure 1, will be built and ready for full size conical mirror scans in the course of November 2024.

Relevant stage specifications

Both the Velmex B48 (rotary) and X-Slide XN10 (linear) stages should meet our requirements; see the table below. In particular, a rotary stage at a lever arm ~600mm will provide a positioning accuracy of ~300 µm (and a reproducibility ~3 µm).

	Accuracy	Reproducibility	Max cantilevered load	Max dynamic thrust
B48	100 arc-sec	1 arc-sec	500 lbs.-in	
XN10	~75 µm	~2.5 µm		10 lbs.

Rotating arm rigidity analysis

FEA performed on the rotating arm, under realistic assumptions about the optical table components weight, as shown in Figure 4, indicate that an overall deflection will not exceed ~250 microns, even if there is not support foot installed below the X-Slide linear stage assembly.

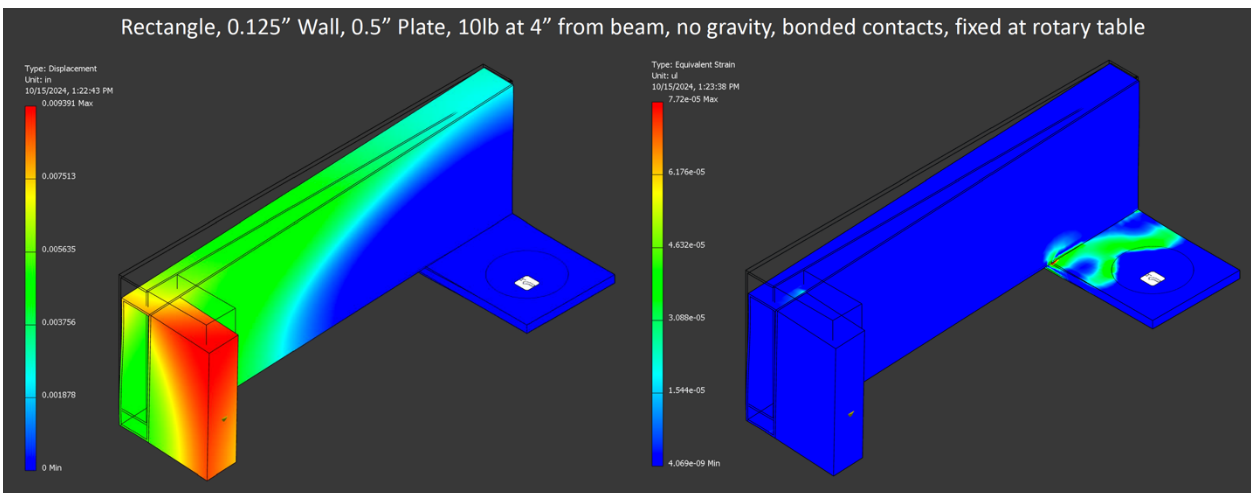

Figure 4 Left: expected deflection of the rotating arm is expected to be less than 10 mil. Right: strain will be mostly localized at the ½” thick interface plate between the rotary table and the rotating arm.