Aerogel Test Stand QA & QC Procedures
ePIC Detector RICH Sub-Systems

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Abstract

This document reviews the important aerogel quantities that need to be assessed as part of the pfRICH aerogel production QA/QC. The procedures and the experimental setups used to assess these quantities will be discussed. Note, this document is preliminary and still a work in progress.

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1 Aerogel Tile Properties

Aerogels are widely used in Cherenkov detectors due to their unique optical properties and lightweight nature. To ensure optimal performance in these detectors, aerogels must exhibit several key properties:

- **Refractive Index**: This parameter is crucial as it determines the Cherenkov threshold, the minimum velocity a particle must have to emit Cherenkov radiation.
- **Transparency**: High transparency is essential to minimize the absorption and scattering of Cherenkov light. This ensures that the light can travel through the aerogel with minimal loss, maintaining its intensity and clarity.
- **Density**: Aerogels are characterized by their very low density, typically between the the order of $\sim 10^{-2} - 10^{-1}\ g/cm^3$. This property minimizes the material's interaction with particles other than Cherenkov radiation, preserving the detector's accuracy.
- **Homogeneity**: Uniform refractive index and density across the aerogel are important for consistent Cherenkov light production and propagation. Variations can lead to inaccuracies in particle detection.
- **Hydrophobicity**: Hydrophobic aerogels are preferred because they resist absorbing moisture from the air. Moisture can degrade the aerogel's optical properties and mechanical integrity.
- **Thickness**: The thickness of the aerogel layer needs to be optimized to produce a sufficient number of Cherenkov photons while allowing enough path length for particle detection. This typically ranges from a few millimeters to a few centimeters.

In summary, aerogels designed for Cherenkov detectors need to balance multiple properties, including a low and controlled refractive index, high transparency, low density, homogeneity, mechanical stability, hydrophobicity, and appropriate thickness. These characteristics ensure that the aerogel can effectively produce and transmit Cherenkov light, enabling accurate and reliable particle detection in high-energy physics experiments.

2 Process and Procedures

2.1 Refractive Index

The refractive index n can be measured using the so-called prism method. The prism method is a straightforward and precise technique for determining the refractive index of transparent materials, including aerogel tiles. It involves measuring the angle of deviation of light passing through a prism-shaped aerogel tile. Figure 4 shows the experimental setup used for measuring the refractive index. The aerogel tile is placed on a turntable and light from a laser source is incident on the tile. The tile is rotated until the deflection angle θ_{out} reaches a minimum. When at the minimum deflection angle, the refractive index is given by:

$$n = \sin\left(\frac{\beta + \theta_{out}}{2}\right) / \sin\left(\frac{\beta}{2}\right), \tag{1}$$

where β is the angle making up the corner of the aerogel tile ($\approx 90^o$). The deflection angle is determined by measuring the laser spot displacement x a distance L from the aerogel. The refractive index is measured using each of the four aerogel corners and then averaged together for a final nominal value.

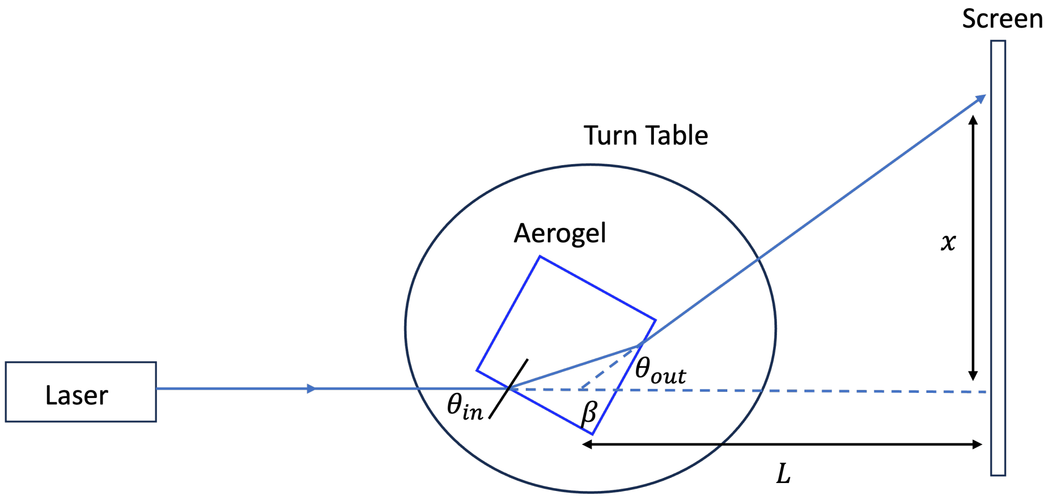

Figure 1: Block diagram of refractive index measurement via the prism method.

The prism method can only be used if the aerogel tiles have optical quality edges. However, it is anticipated that the final pfRICH production tiles will be water-jet cut from a bulk aerogel piece , resulting in non-optical quality edges and rendering the prism method non-applicable. Another method, which exploits the correlation between refractive index and density is being investigated as a was to determine the bulk refractive index.

2.2 Transparency

The aerogel's transmittance is measured across the ultraviolet (UV) and visible (Vis) spectrum. The transparency is quantified by the percentage of light transmitted through the aerogel at various wavelengths. A fiber optic cable is coupled to each of the narrow wavelength LEDs and serves as the input light source. Light from the LEDs is incident on the face of the aerogel tile and the transmitted light then passes into an integrating sphere. The integrating sphere collects the light into a fiber optic that is connected to a UV/Vis spectrometer where the light intensity is measured as a function of wavelength, I_{aero}. The aerogel is placed on a stage which can move horizontally and vertically relative to the incident LED light, allowing for transmittance measurements across the surface of the aerogel. Both the aerogel, its transnational stage, and integrating sphere are contained within a dark box. The LED transmittance measurement setup is shown in Fig. 2. The measurement is repeated for each LED without the aerogel present to obtain a reference intensity, I_{ref}. Finally, a background intensity is measured by running the spectrometer with the LED sources powered off, I_{bkgd}. The transmittance for each LED is given by:

$$T_{\lambda_i} = \frac{I_{aero} - I_{bkgd}}{I_{ref} - I_{bkgd}}. \tag{2}$$

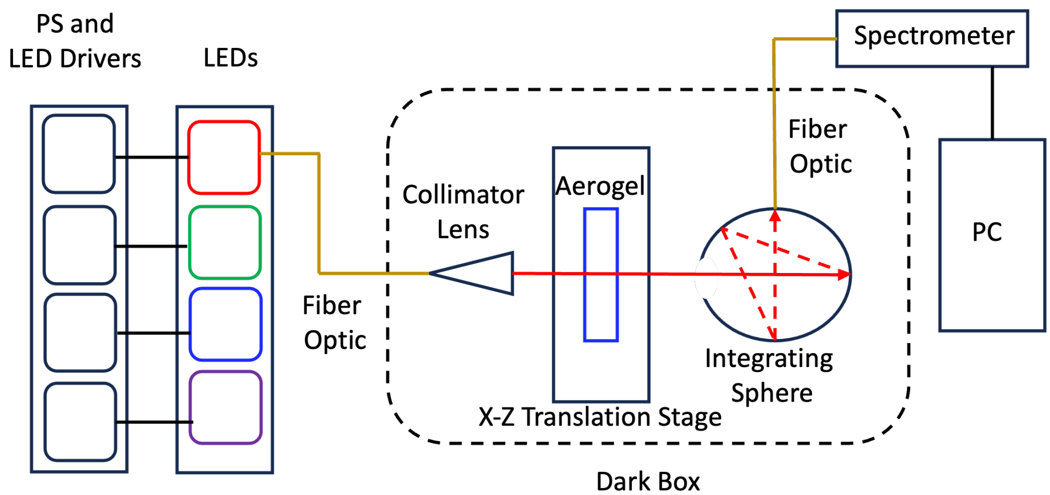

Figure 2: Block diagram of LED transmittance measurement station.

Once the transmittance is measured from several discrete LEDs, they can be plotted vs. their respective wavelengths to obtain a wavelength dependent transmittance information. This data can be parameterized with the fit function:

$$T(\lambda) = Ae^{-\frac{Bt}{\lambda^8}} e^{-\frac{Ct}{\lambda^4}}, \tag{3}$$

where A, B, and C are the fit parameters, t is the thickness of the aerogel tile, and λ is the wavelength of the impinging light. The parameter A is known as the scattering surface coefficient, and C is the clarity factor.
The fit parameters in Eq. 3 can be used to extract properties like the transmission (Λ_{trans}), absorption (Λ_{abs}), and scattering (Λ_{scat}) lengths through the Hunt formula:

$$T(\lambda) = e^{-\frac{t}{\Lambda_{trans}}} = e^{-t\left(\frac{1}{\Lambda_{abs}} + \frac{1}{\Lambda_{scat}}\right)}. \tag{4}$$

From Eqs. 3 and 4:

$$\Lambda_{trans} = -\frac{t}{ln(A)}, \quad \Lambda_{scat} = \frac{\lambda^4}{C}, \quad \Lambda_{abs} = \frac{t\lambda^8}{Bt - \lambda^8 ln(A)} \tag{5}$$

Using the fit parameters, one can plot as a function of the wavelength the extracted transmission, absorption, and scattering lengths. One can also extract the various lengths and transmittance at a fixed wavelength for quick QA comparisons across different tiles.

2.3 Density

The density of the aerogel can be determined from measuring its volume using a ruler, caliper, or touch probe. While its mass can be determined from a high precision scale.

2.4 Homogeneity

The homogeneity of the aerogel can be assessed through its transmittance and refractive index uniformity. How the transmittance varies across the aerogel surface can be assess using the LED transmittance setup described in Sec. 2.2. This allows us to study how the transmittance at each wavelength varies over the aerogel surface. Measuring the refractive index gradient over the aerogel surface allows for an assessment of the refractive index uniformity. The setup for this measurement is currently under investigation.

2.5 Hydrophobicity

The aerogel tiles are hydrophobic and should be resistant water and moisture. However, we will store aerogel tile in a humidity controlled dry box.

3 Experimental Setup

3.1 Refractive Index: Prism Method

The setup used to measure the refractive index via the prism method is detailed in Sec. 2.1 and shown in Fig. 4. A $403nm$ laser, with a beam spot of about $3mm$ was placed $26cm$ from the aerogel tile, which was placed on a turntable. The deflected light was measured on a screen placed about $2m$ from the aerogel. The aerogel was rotated to find the minimum deflection relative to the beam spot position when no aerogel sample is present. Figure 4 shows the laser passing through a corner of the aerogel sample during a refractive index measurement. These measurements can also be done using an available $639nm$ laser.

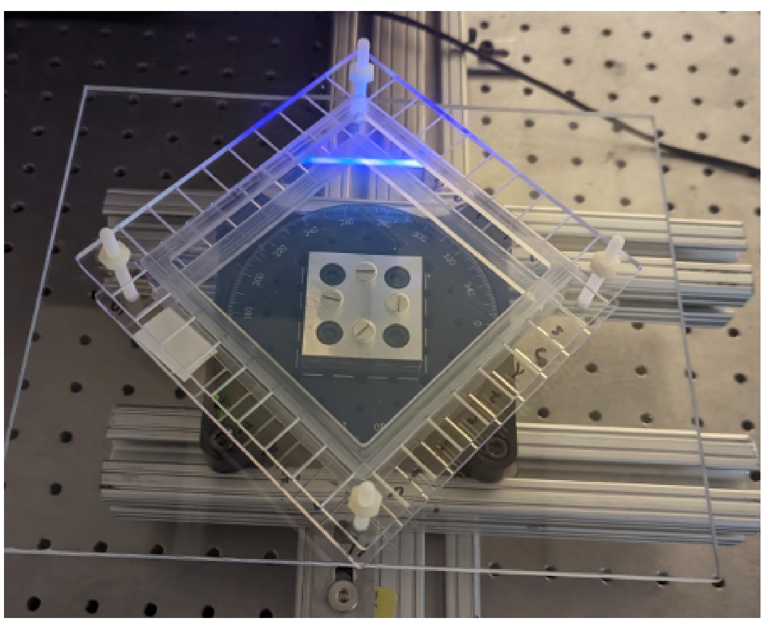

Figure 3: $403nm$ laser passing through the corner of an aerogel tile during a refractive index measurement via the prism method.

Equipment Below is a detailed list of the equipment used in the refractive index prism method measurements:

- Thorlabs Laser PL255: Compact laser module with USB connector, 403nm, 4.5mW
- Thorlabs Laser PL252: Compact laser module with USB connector, 639nm, 4.5mW
- Rotation Stage (RP03): 4in Manual Rotation Platform

3.2 LED Transmittance Setup

The transmittance was measured using a four LED system constructed at Temple University. The measurement procedure is described in Sec. 2.2 and a block diagram of the setup is shown in Fig. 2. The setup consists of four LEDs of different wavelengths(340nm, 430nm, 530nm, and 625nm) providing four discrete transmittance measurements. Each LED has its own power supply and LED driver unit. The LED light is transported through a 600μm diameter fiber optic cable, with one end coupled to the LED and the other to a collimating lens. The collimated light is incident on an aerogel sample that is place about 3cm from the lens, and has a beam spot of about 3mm. The transmitted light has a beam spot diameter of about 10mm when enters it enters the integrating sphere positioned about 12cm from the aerogel. The integrating sphere inner walls are highly reflective PTFE material and has an opening port diameter of about 2.5cm. The light entering the integrating sphere reflects off the inner walls until it enters a 200μm diameter fiber optic that couples the integrating sphere to a UV/Vis spectrometer. The spectrometer is connected to a PC via usb cable for analysis. The aerogel tile sits on a platform that is mounted to a vertical Al extrusion that is able to slide along the extrusion. The vertical Al extrusion is mounted to a slide stage that is installed on a horizontal Al extrusion, which allows aerogel to move perpendicular to the beam direction. This setup allows measurements to be carried out over the area of the aerogel for uniformity studies. The collimator lens, aerogel and its translation stages, and integrating sphere are contained inside of a dark box to minimize ambient light and other possible external light sources that could impact the measurement.

Equipment Below is a detailed list of the equipment used in the LED transmittance measurements:

- Thorlabs 625nm LED: 625nm, 13.2mW (Min) Fiber-Coupled LED, 1000mA, SMA
- Thorlabs 530nm LED: M530F3 - 530nm, 6.8mW (Min) Fiber-Coupled LED, 1000mA, SMA
- Thorlabs 430nm LED: M430F1 - 430nm, 5.3mW (Min) Fiber-Coupled LED, 500mA, SMA
- Thorlabs 340nm LED: M340F4 - 340nm, 0.45mW (Min) Fiber-Coupled LED, 600mA, SMA
- Thorlabs UPLED USB-Controlled LED Driver: 1.2A Max, 8V Max

- Thorlabs DS12 12 VDC: $4A$ Regulated Power Supply with M8 Connector, $100 - 240$ VAC
- Thorlabs $600\mu m$ diameter Fiber Optic (M114L01): $600\mu m$, 0.22 NA, SMA-SMA Solarization-Resistant MM Fiber Patch Cable
- Thorlabs $200\mu m$ diameter Fiber Optic (M151L01): $200\mu m$ diameter, 0.22 NA, SMA-SMA Fiber Patch Cable, High OH
- Ocean Optics collimating lens: 74-UV UV/VIS Collimating Lens, $200 - 2500$ nm
- Thorlabs Integrating sphere: $1in$ port diameter, 2 $5mm$ SM1-threaded ports, manufactured from highly reflective ($> 95\%$ at $250nm - 2500nm$, $> 99\%$ at $350nm - 1500nm$) PTFE-bulk material.
- CCD Spectrometer (CS200): $200nm - 1000nm$ wavelength range, FWHM $= 2nm$ @ $633nm$.

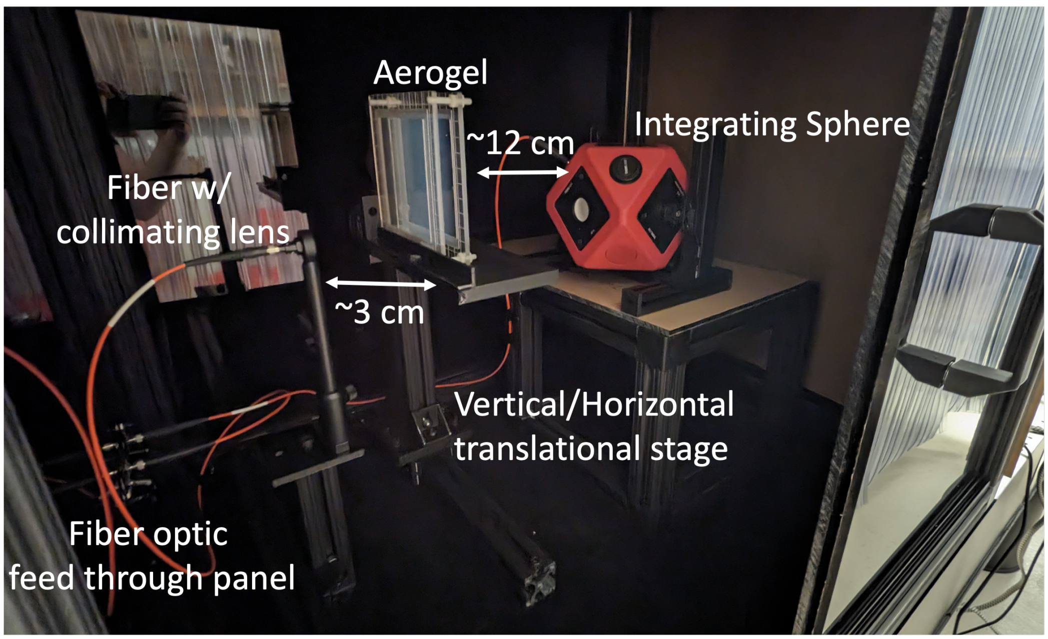

Figure 4: Inside view of the LED transmittance measurement station dark box.

4 Record Keeping

The common database that will be used for ePIC will meet the needs of cataloging aerogel QA/QC results. The database software has yet to be selected, however, its requirements have been documented and will meet the aerogel QA/QC needs which require:

- **Tile Tracking**: It is important to always know the location of the aerogel tiles. Each tile will have a database entry that includes its current location. If a tile is in transit, the entry will include shipping details such as the destination, origin, and tracking number. Once the tile is received, the database entry will be updated accordingly.

- **Measurement Results**: All measurements for each aerogel tile will be documented in the database. This includes: Transmittance and its fit vs. wavelength, extracted transmission and scattering lengths vs. wavelength, and transmittance uniformity. These measurements will be represented in plot formats and a text file with the plotted values will also be available.

  Additionally, each tile will have an associated table containing measurements of density, transmittance fit parameters, and refractive index. The table will also list transmittance, transmission length, and scattering length at a specified wavelength.

References