Initial Design Concepts for pfRICH Laser Monitoring System

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System Design Constraints

Goal of System:

- Use a light source with adequate timing resolution to monitor timing performance of HRPPDs
- Use same light source to monitor mirror reflectivity/PC QE over life of experiment

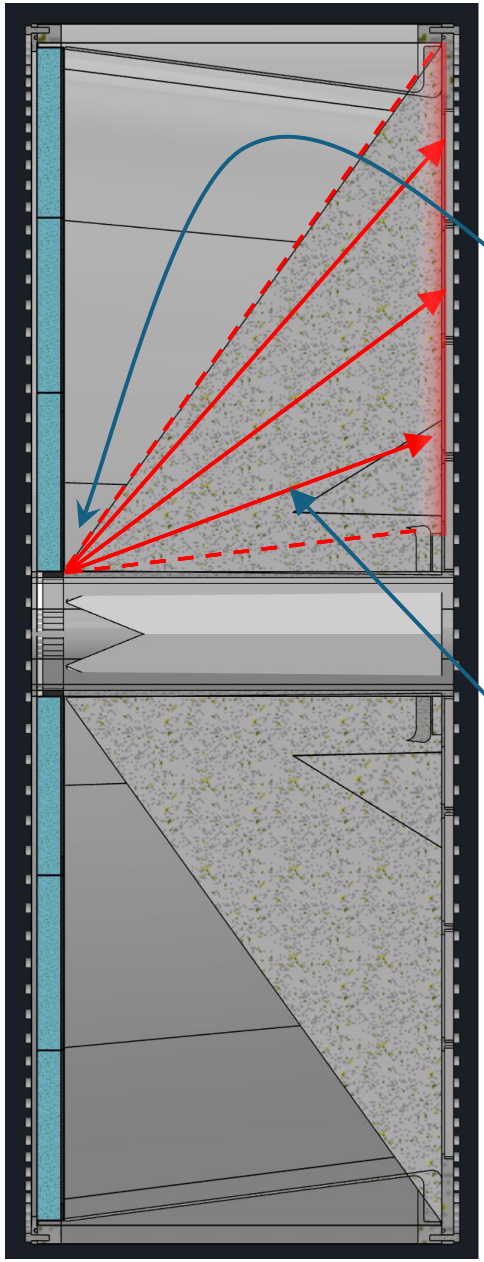
Constraints:

- Every HRPPD pixel must get single photon hits (after N number of pulses, accumulate ~5K single photon events per pixel)
- Prefer good uniformity such that 5K events are uniform across det. acceptance (maybe not critical)
- Must distinguish photon point of origin (ie, which fiber)
    1. HRPPD illumination: how to distinguish overlapping light profiles from multiple fibers?
    2. Mirror illumination: how to distinguish between reflected and direct photons from same fiber?

Design Strategy:

- HRPPD illumination: timing difference (ie, “fiber delay lines”) take care of ambiguity from light profile overlap from multiple fibers
- Mirror Illumination:
    a. “HRPPD fibers” will mostly (ie, >95% of the time [goal]) only illuminate the HRPPD with occasional reflections from mirrors
    b. “Mirror fibers” ” will mostly (ie, >95% of the time [goal]) only illuminate the mirror with occasional hits from direct photons (multiple reflections can be identified by timing)
    c. For rays traveling close to parallel to mirror surface, the pathlength difference between a direct ray and a reflected ray become too small to distinguish using timing info. This will result in some efficiency loss in correctly identifying reflected from direct photons. This efficiency loss may be minimized by using a light baffle to help reduce the number of such parallel rays.
    d. Overall, this shouldn’t be a big problem
        i. For timing, if the pathlength is too small to detect, then the problem isn’t noticeable
        ii. For QE, since the mean amplitude for the reflected and direct rays is not affected much (ie, small counts in pulse height distr.) by parallel rays, this should have a small impact on the QE/reflectivity measurement

Method of Light Delivery



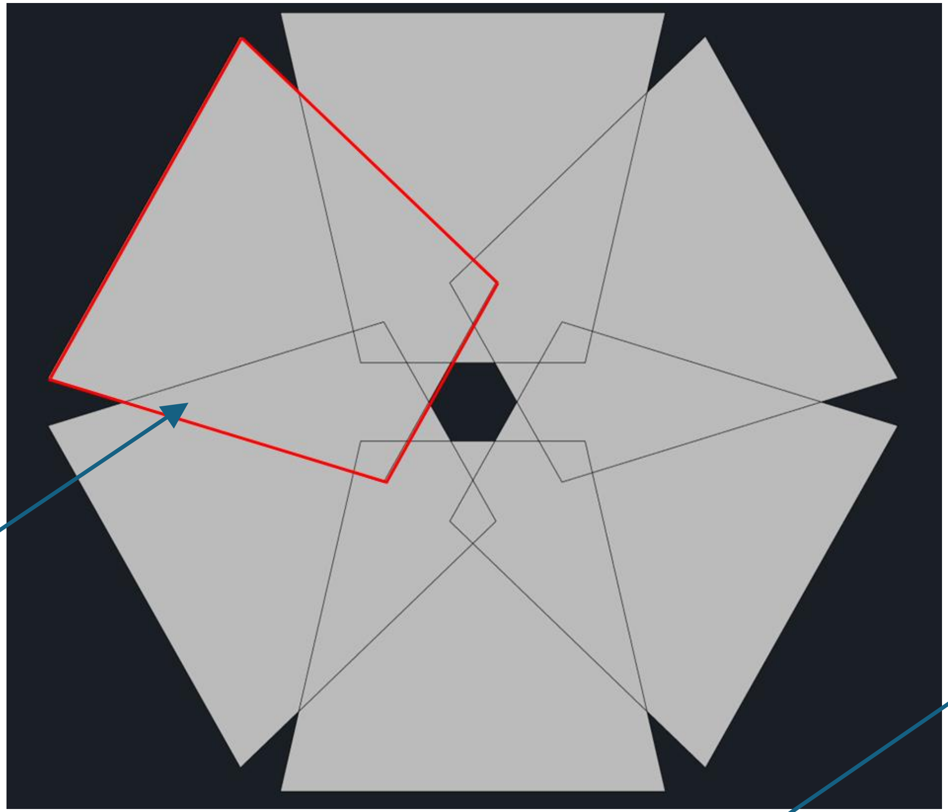
Array of 6 fibers may be used for direct illumination of HRPPDs + array 6 fibers may be used to reflect light off of the mirrors

Here 1 of 6 fibers directly illuminates a HRPPD from gap between inner mirror and aerogel

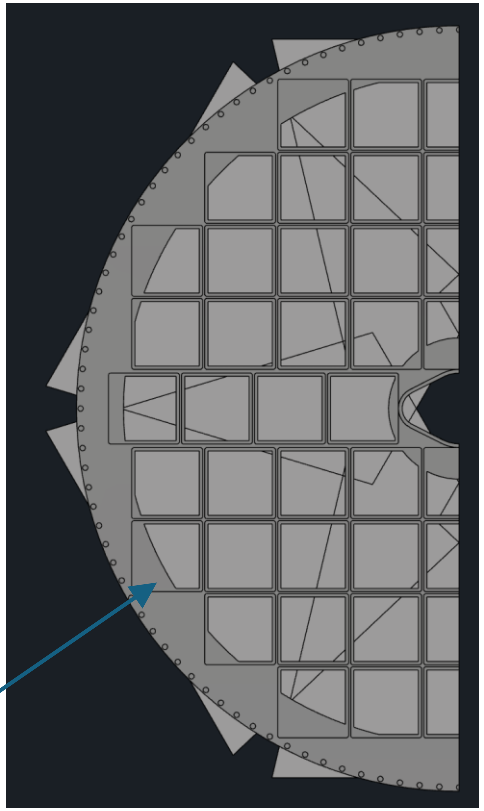
*Tilt angle of fiber is critical to minimize reflections from mirror; can also use baffle to better shape light profile

The light path from a given fiber to a HRPPD pixel defines the photon flight length

Light profiles from 6 fibers for direct illumination



HRPPD coverage

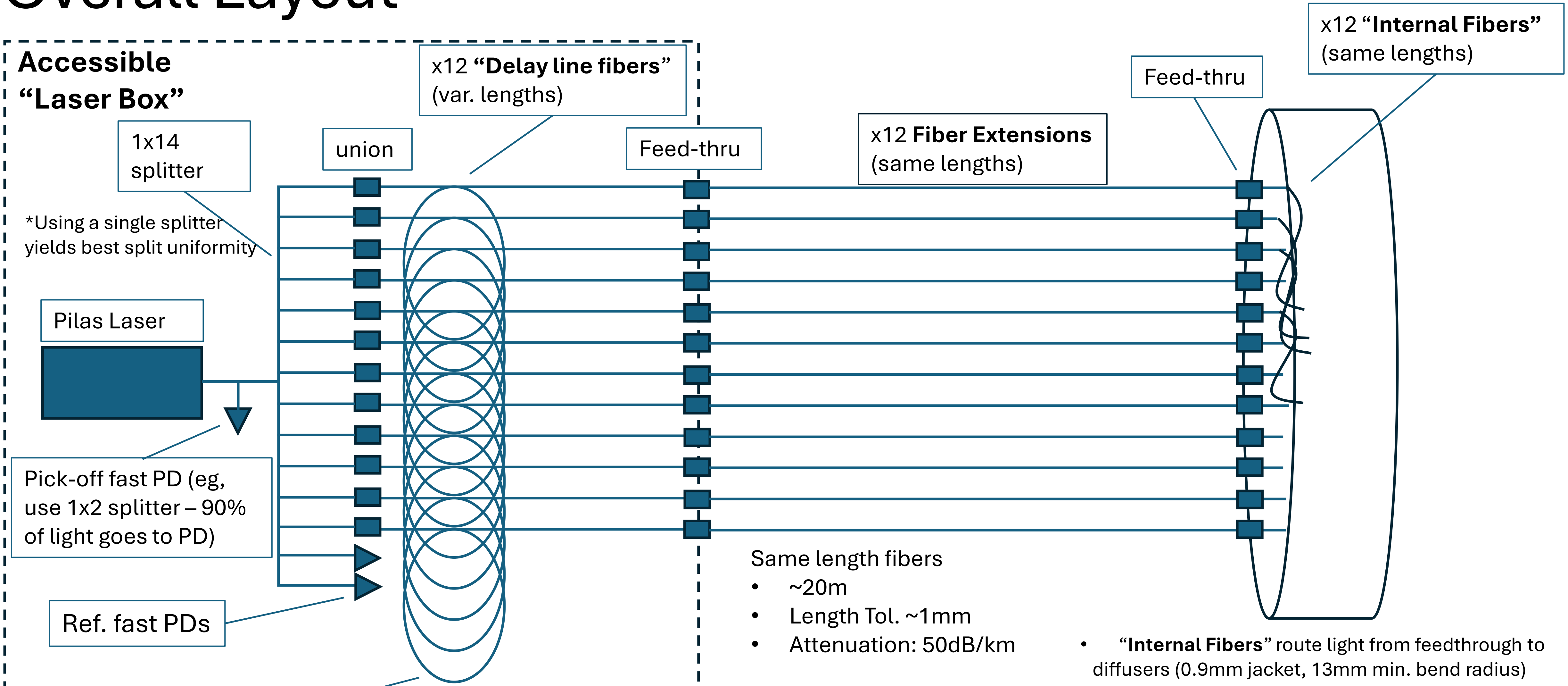


Light profile from a single fiber on the HRPPD sense plane

*Overlapping profiles can be separated in time using different length fibers

6 fibers for direct HRPPD illumination + 6 fibers for the mirror illumination should suffice to illuminate all HRPPD pixels

Overall Layout



- 100ps → 2cm
- Length diff. ~20cm (~1ns)
- Length Tol. ~1mm

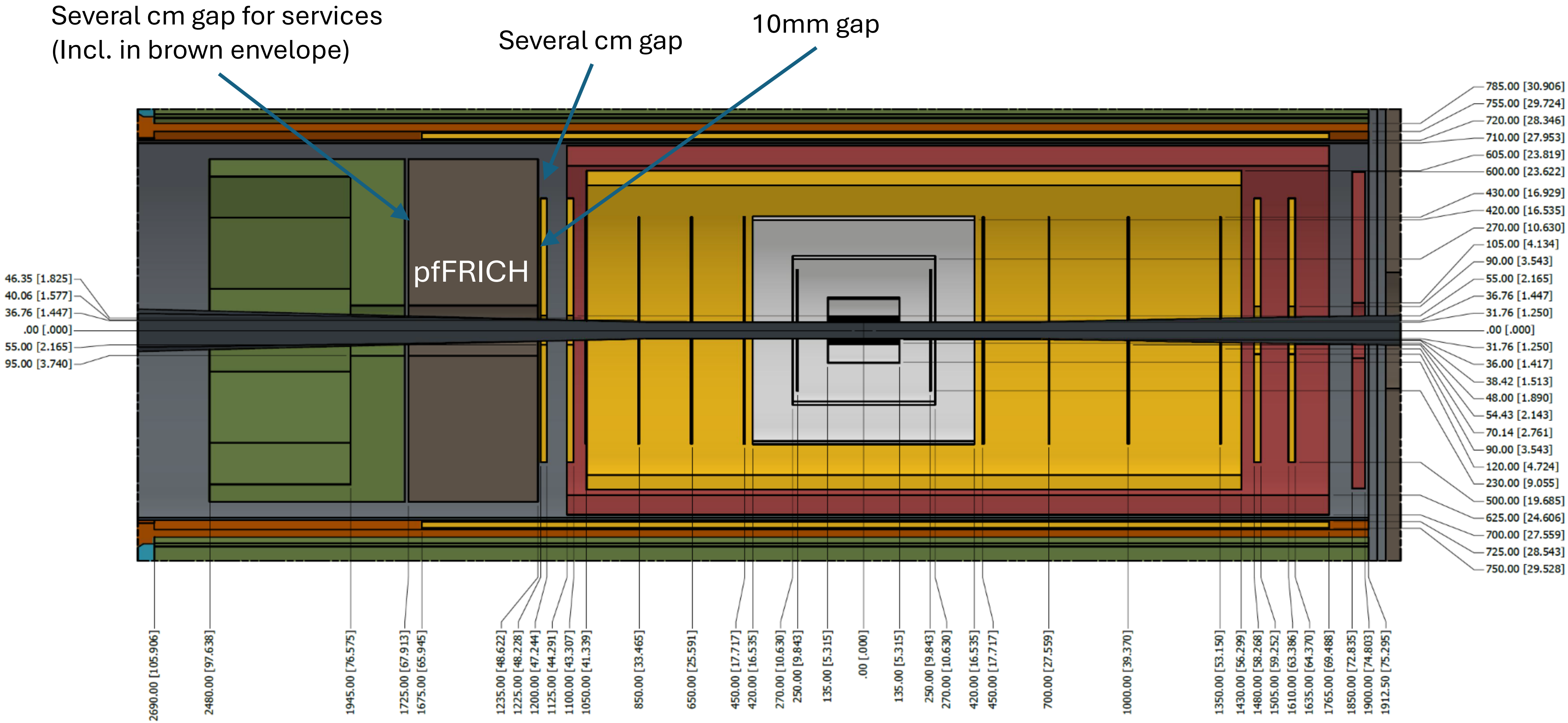
*All Fiber: Thorlabs S405-XP (3mm jacket)

*Connector type: FC/PC or FC/APC

- “**Internal Fibers**” route light from feedthrough to diffusers (0.9mm jacket, 13mm min. bend radius)
- Rim of inner mirror or rim of outer mirror are possibilities as feedthrough locations
- Gap between outer mirror and aerogel and gap between inner mirror and aerogel are options for routing inner fibers
- Use custom sized diffuser discs in custom fixture to hold diffuser on fiber tip (minimally affect detector acceptance)

pfRICH Envelope

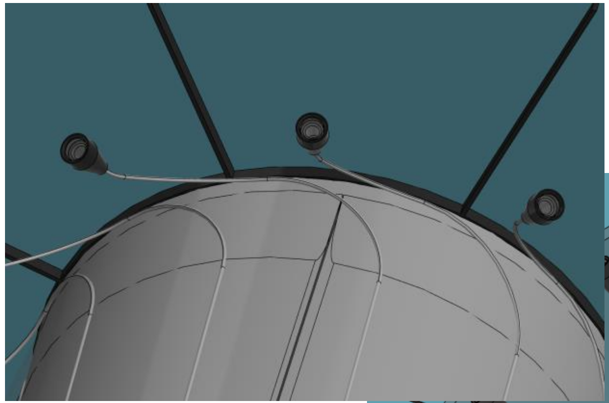
Some options for introducing fibers into pfRICH vessel, but all are tight

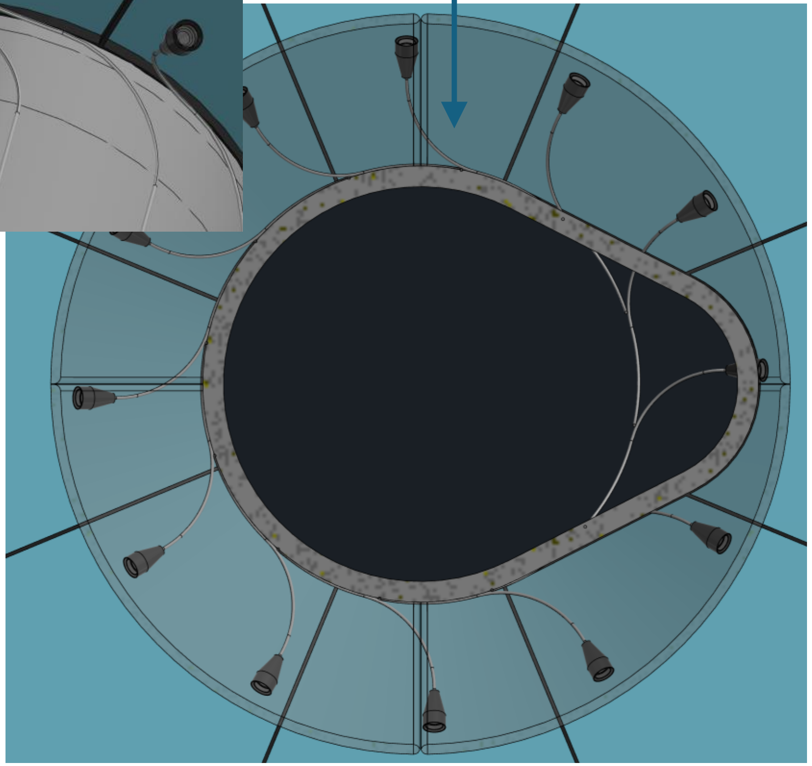


Options for routing internal fibers

Arrange fibers into a circular array of “source points” (6 “direct fibers” + 6 “mirror fibers” in odd/even pattern) facing the HRPPD sense plane

- ➢ Here use 30mm fiber bend radius; utilize compound bending angles

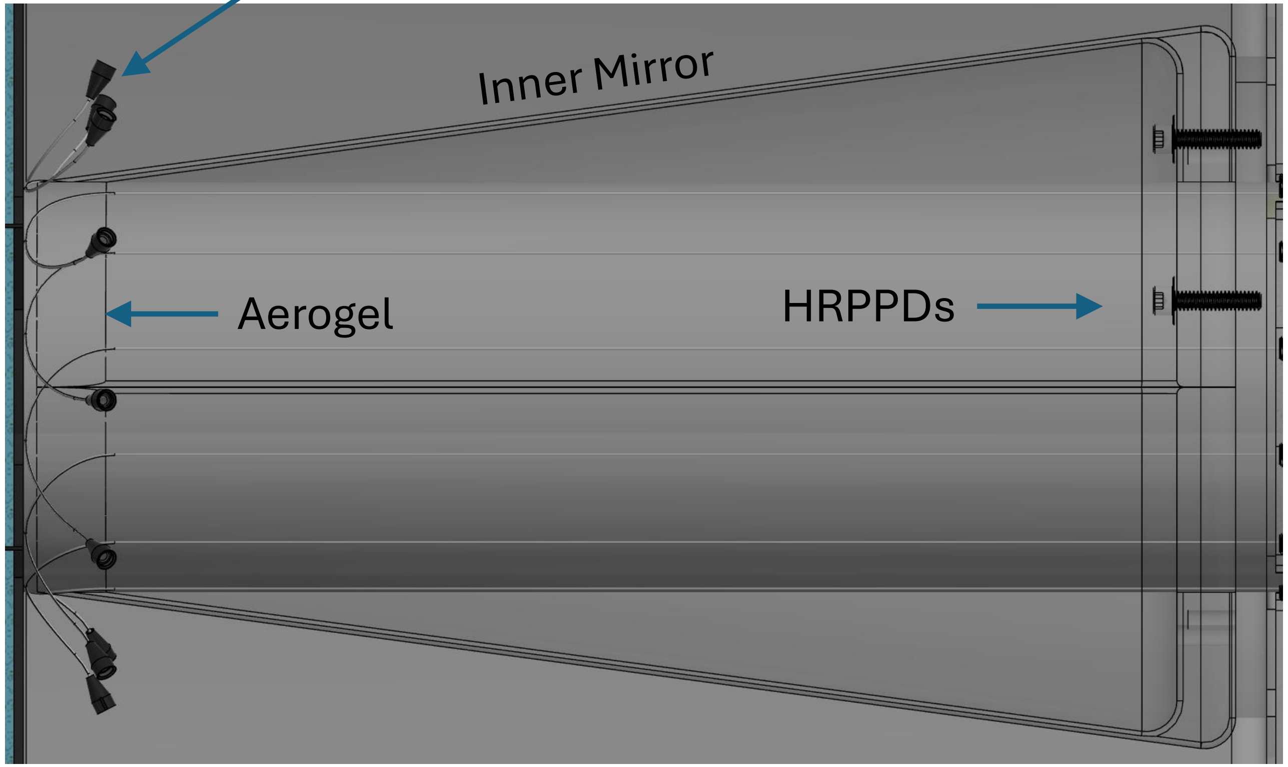




Fibers emanate from inner mirror on aerogel side (may require making notches in mirror for clearance)

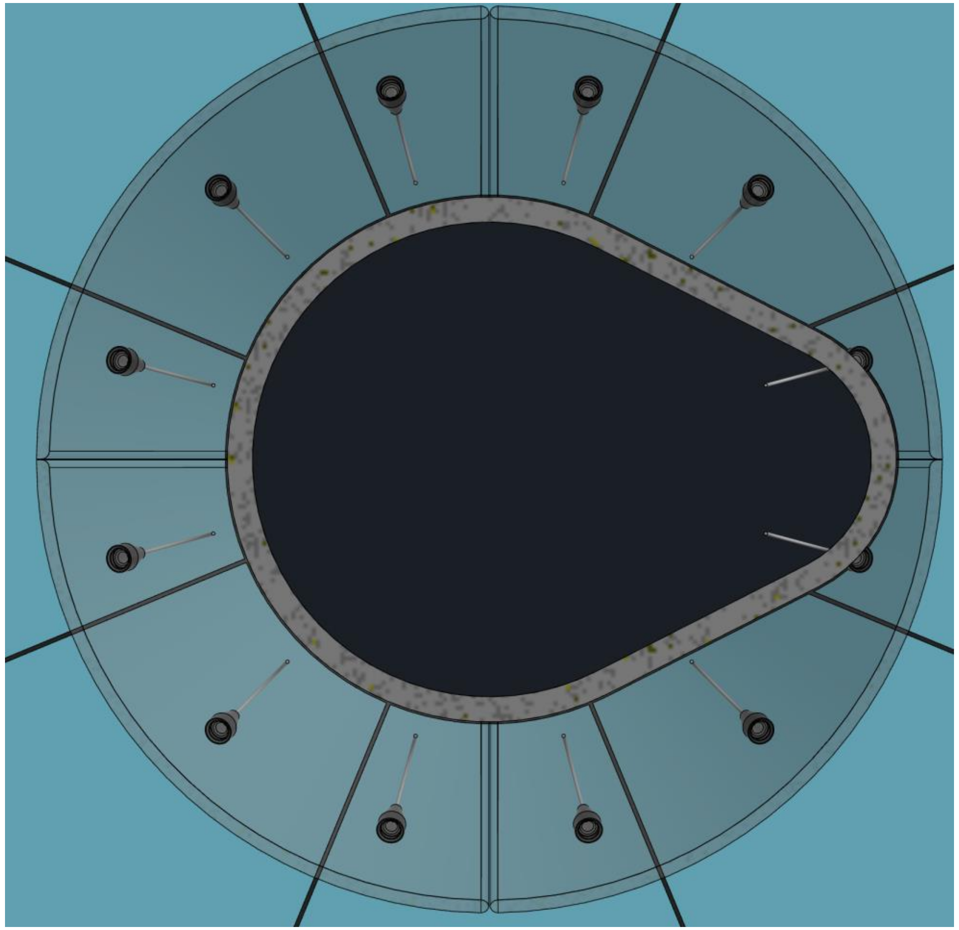
Rigid jacket for holding fiber at fixed angle

Fixture for diffuser on fiber tip (custom 3D printed piece)



Another option for routing internal fibers

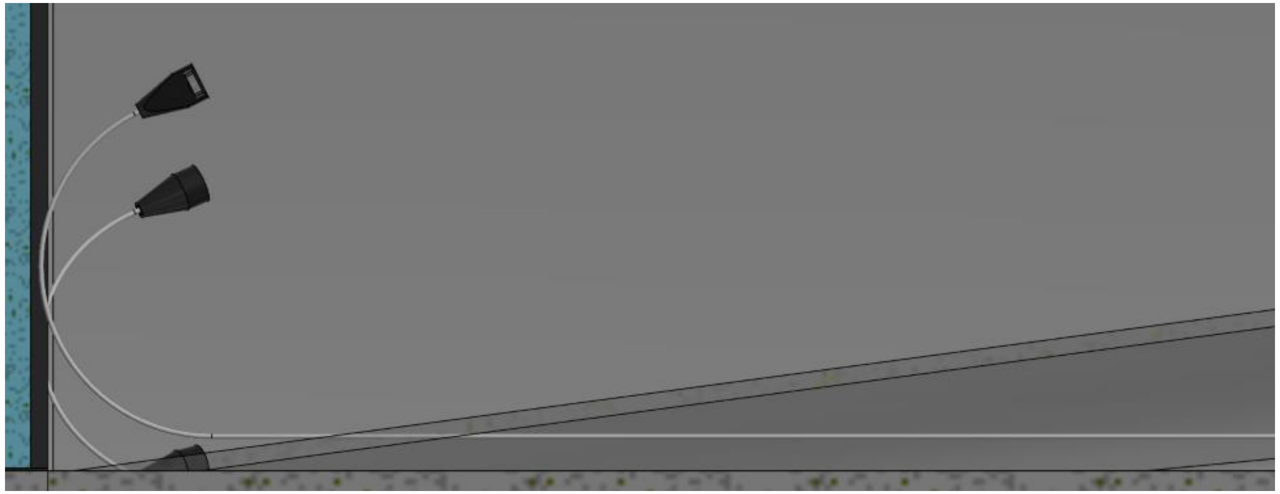
➢ 10mm fiber bend radius; no compound angles used (simple design)
(requires using Thorlabs S405-XP fiber)



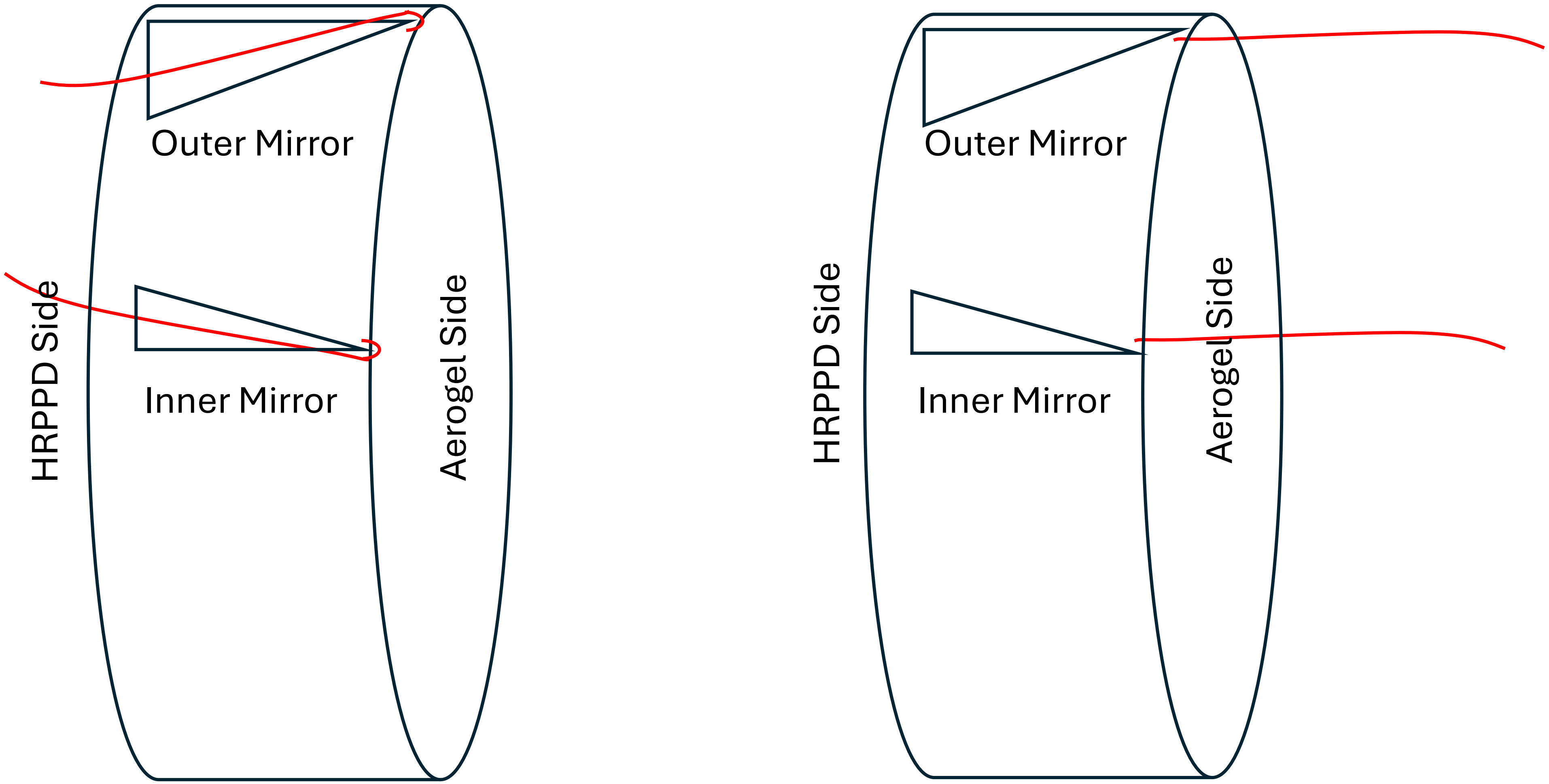
Fibers emanate from inner mirror rim on aerogel side

- may require making notches in mirror for clearance
- If compound angle bends are used, may be able to avoid notching mirror, or at least place notches in convenient location at rim

➢ Other options must also be checked, including introducing fibers from rim of outer mirror



Possible paths for internal fibers



We are working on a design for each of these options...

Fiber Optics

Possible splitters

- 1x2 up to1x16 possible (custom)
- Have quote for 1x16 (S405-XP fiber, 405nm) $~3600, 6 wks
- If using two lasers, we simply replace 1x14 with two 1x7
- The fewer the splitters used, the better the split ratio uniformity

405 nm Single Mode Fused Fiber Optic Couplers / Taps (thorlabs.com)

Possible feedthrough

- Small size
- Cheap ~$60 apiece
- Can be made to have reasonable gas seal
- Can pot an array of them in a G10 flange, which can then be glued into the honeycomb structure of the vessel

Thorlabs - ADAFCPM3 FC/PC to FC/PC or FC/APC to FC/APC Mating Sleeve, Narrow Precision Key (2.0 mm), D-Hole

Laser

NKT Photonics Pilas PIL040-FC

- Fiber coupled
- 405nm (3.06eV photons)

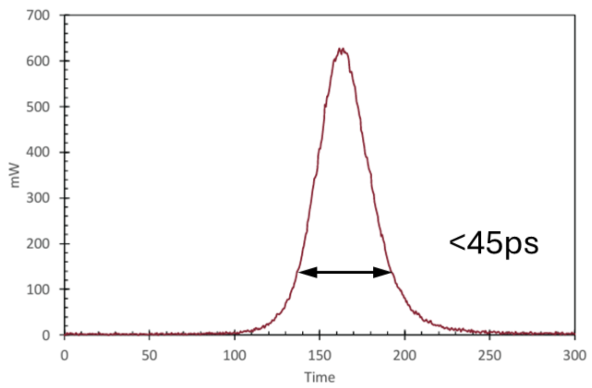
SPECIFICATIONS

Optical

Pulse repetition rate [MHz] [1]	Pulse-on-demand (0 to 40)
Frequency resolution [Hz]	1 @ 50 Hz
Beam quality, TEM_{00}	$M^2 < 1.2$
Polarization extinction ratio [dB]	> 20 (unpolarized fiber)
Timing jitter, rms [ps]	< 3

1) Pulse-on-demand with external trigger. Internal trigger >25 Hz.

Pulse profile



Model	Output	Wavelength	Spectral width	Pulse width	Peak power	Avg. power [1]	Max. repetition rate
PIL037-FS	Free space	375 ± 10 nm	< 5 nm	< 70 ps	> 150 mW	> 0.5 mW	40 MHz
PIL037-FC	FC/APC	375 ± 10 nm	< 5 nm	< 70 ps	> 60 mW	> 0.2 mW	40 MHz
PIL040-FS	Free space	405 ± 15 nm	< 5 nm	< 45 ps	> 350 mW	> 0.8 mW	40 MHz
PIL040-FC	FC/APC	405 ± 15 nm	< 5 nm	< 45 ps	> 160 mW	> 0.25 mW	40 MHz

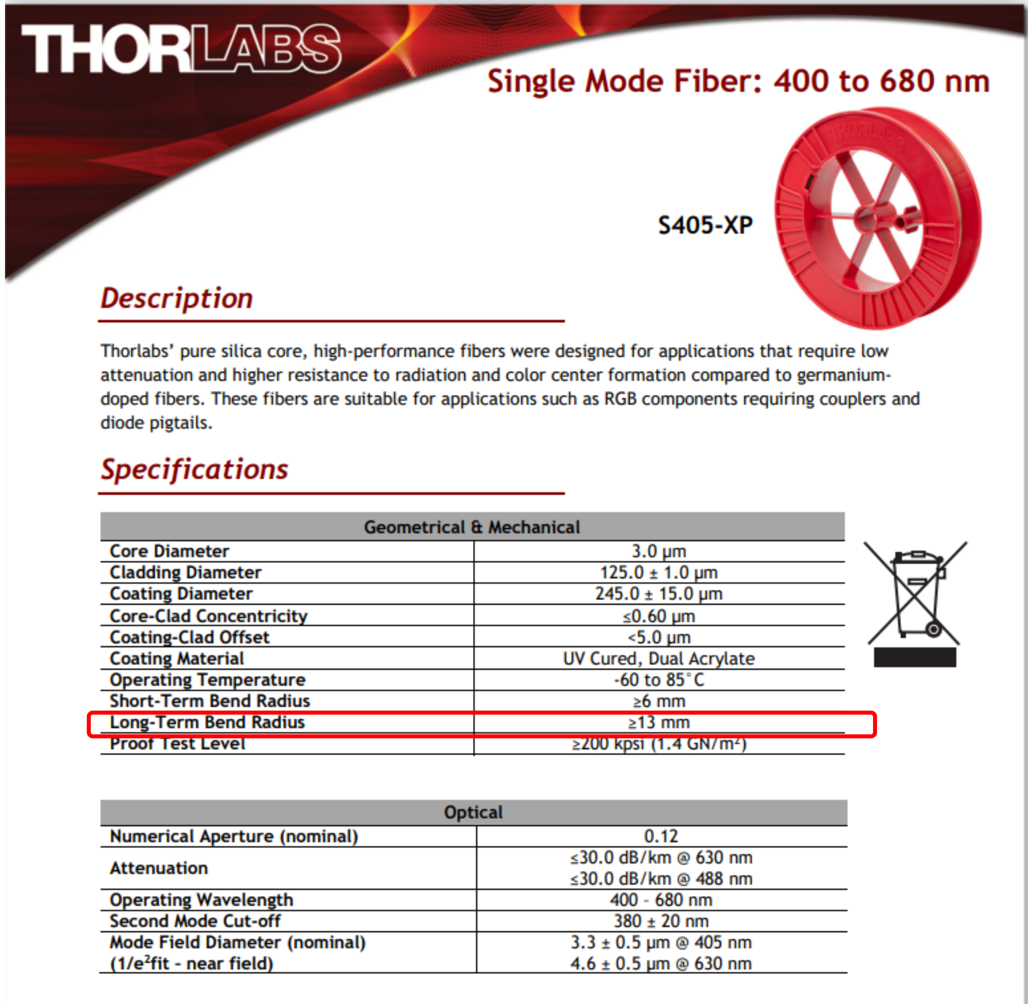
Light Delivery Specs

Laser Specs: NKT PILAS 040FC	Pilas Laser Source	Units	Notes
Pulse Energy	7.2	pJ/pulse	*After 1m Fiber, incl. coupling eff.
Pulse Width	45	ps	1/e
Beam Spot diam. (1/e2)	small, but divergent	mm	Diode exit aperture
Max Rep Rate	4.00E+07	Hz	Max
N_photons (405nm --> 3.06eV)	1.5E+07	Nph/pulse	
Avg Power	2.88E+02	uW	at Max rep rate
Peak Power	160.00	mW	
Coupling Light into Ext. Fiber			
Fiber Atten. @ 405nm	0.05	dB/m	Thorlabs S-405-XP, low bend radius
Total fiber length	20	m	Extension fibers from laser to pfRICH vessel
Tot. Fiber Atten.	1	dB	
Fiber Trans. Efficiency over full length	80	%	
Fiber splitter Eff + Coupling Eff. (Excess Loss)	75	%	Conservative (optical return and insertion losses)
Typical Diffuser Trans.	90	%	(Incl. losses due to abs. + refl.)
Gas Trans.	98	%	Over pathlength from fiber to HRPPD window
Tot. Eff.	53	%	
Initial pickoff for Mon. PD	1/10		
Fiber Splitter N-output branches	14		
Max Photons Delivered per Fiber Branch	5.6E+04	Nph/pulse	(Incl. pickoff for PD Mon. and Fiber Splitter)

- To achieve single photon response from the HRPPDs, each fiber must only deliver tens of photons per pulse, thus the laser intensity will have to be attenuated considerably ($x10^4$)

Fiber Specs

- Single mode fiber preserves timing characteristics of laser pulse (ie, no modal dispersion)
- This SM fiber model was chosen mainly for its small min. bending radius (for routing purposes)



THORLABS

Single Mode Fiber: 400 to 680 nm

S405-XP

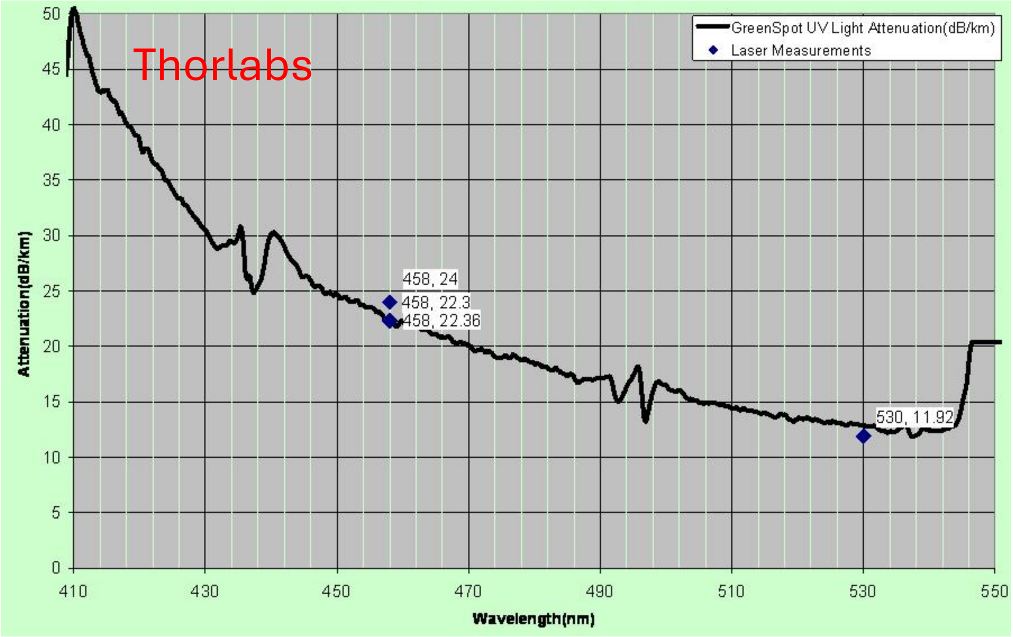
Description

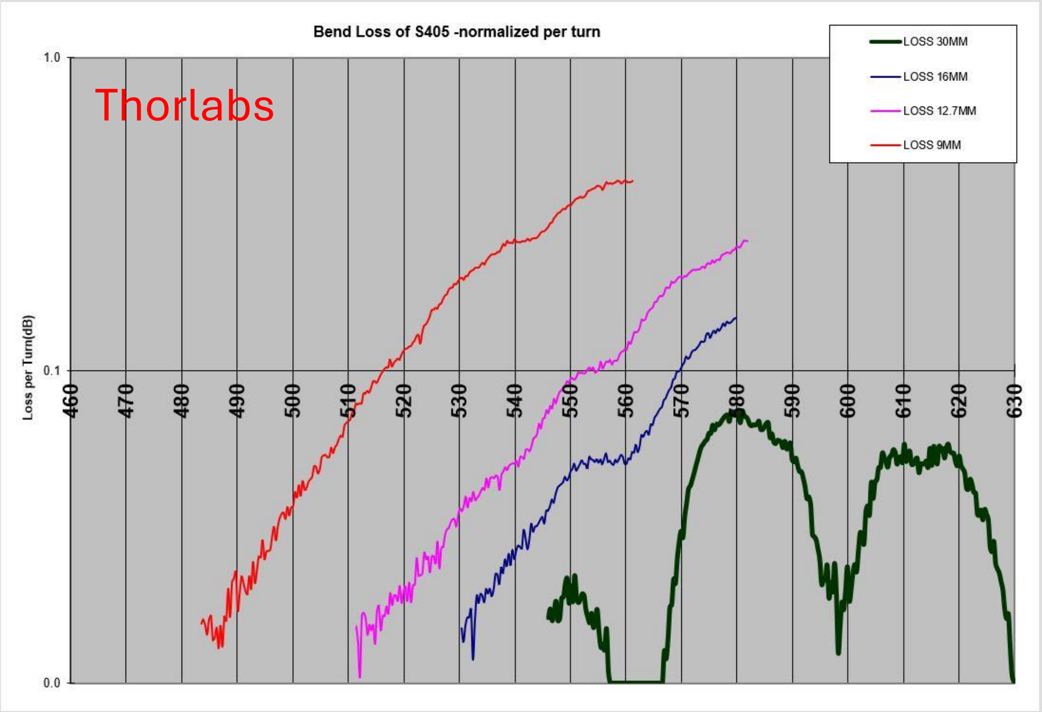
Thorlabs' pure silica core, high-performance fibers were designed for applications that require low attenuation and higher resistance to radiation and color center formation compared to germanium-doped fibers. These fibers are suitable for applications such as RGB components requiring couplers and diode pigtails.

Specifications

Geometrical & Mechanical	
Core Diameter	3.0 µm
Cladding Diameter	125.0 ± 1.0 µm
Coating Diameter	245.0 ± 15.0 µm
Core-Clad Concentricity	≤0.60 µm
Coating-Clad Offset	<5.0 µm
Coating Material	UV Cured, Dual Acrylate
Operating Temperature	-60 to 85° C
Short-Term Bend Radius	≥6 mm
Long-Term Bend Radius	≥13 mm
Proof Test Level	≥200 kpsi (1.4 GN/m²)

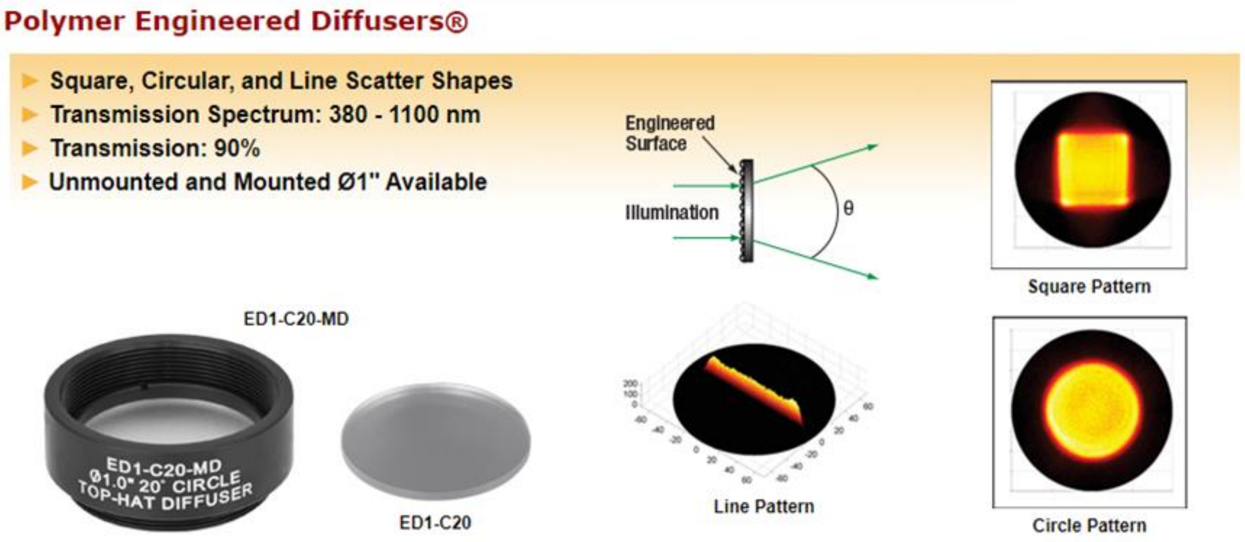
Optical	
Numerical Aperture (nominal)	0.12
Attenuation	≤30.0 dB/km @ 630 nm ≤30.0 dB/km @ 488 nm
Operating Wavelength	400 - 680 nm
Second Mode Cut-off	380 ± 20 nm
Mode Field Diameter (nominal) (1/e²fit - near field)	3.3 ± 0.5 µm @ 405 nm 4.6 ± 0.5 µm @ 630 nm





Diffuser

- We have identified a diffuser with sufficient specs for this application (incident beam size, square light profile, div. angle, trans. eff.)
- However, the off the shelf part is too large, therefore we have requested a custom size: **5mm x 5mm square**, which Thorlabs can offer
- This will be integrated into the fixture that mounts to the fiber tip (design of this fixture to be finalized)

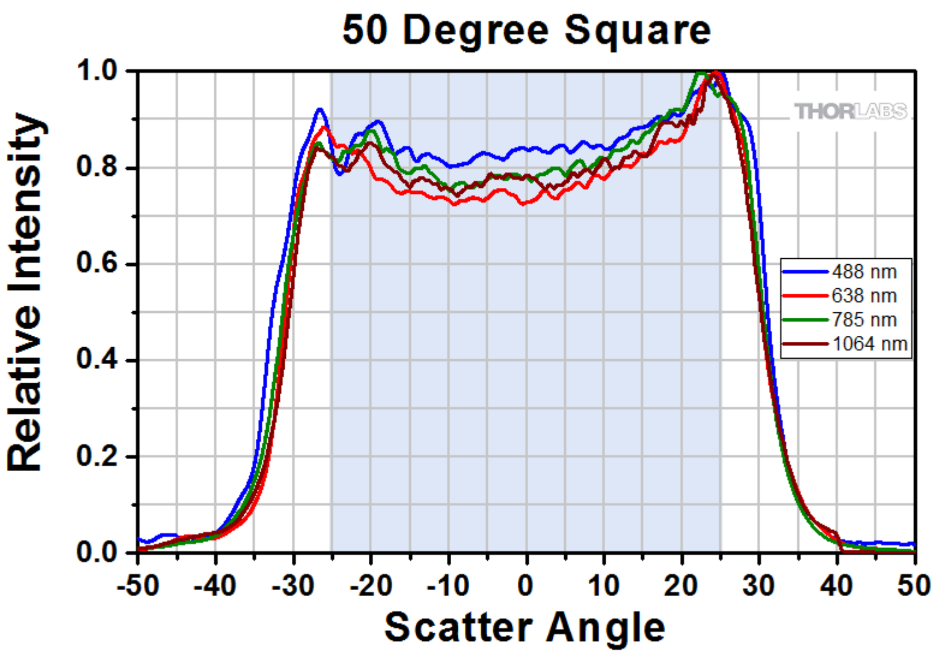


Common Specifications	
Material	Injection Molded ZEONOR
Design Wavelength[a]	400 - 700 nm (Achromatic)
Transmission Spectrum[a]	380 - 1100 nm
Diffuser Diameter	Ø25.4 mm (Ø1")
Diffuser Thickness	1.5 mm (0.06")
Incident Beam Size	≥0.5 mm
Index of Refraction	1.53

a. The ZEONOR substrate has a broad transmission spectrum, but the Polymer Engineered Diffusers® are only guarenteed to meet the divergence angle specifications within the design wavelength range (see *Graphs* tab).

Item #	Pattern	Divergence[a]			Transmission Efficiency
		Flat Intensity Region[b]	50% of Max Intensity[c]	10% of Max Intensity[d]	
ED1-C20(-MD)	Circle	20°	27°	36°	90%
ED1-C50(-MD)	Circle	50°	60°	70°	90%
ED1-S20(-MD)	Square	20°	27°	36°	90%
ED1-S50(-MD)	Square	50°	60°	70°	90%
ED1-L4100(-MD)	Line	100°	105°	115°	90%

a. Angles are defined for collimated 633 nm incident light. Other wavelengths or degrees of collimation may cause nominal variance, see *Graphs* tab.
b. The divergence angle of the Polymer Engineered Diffuser is defined by the flattest region of the relative intensity (see *Graphs* tab).
c. Angle by which relative intensity has dropped to 50%
d. Angle by which relative intensity has dropped to 10%



Ray Tracing Sims

Use Trace Pro™ to simulate light profiles on sense plane for both reflected and direct rays to optimize fiber positioning/orientation

First attempt to recreate flat top light profile from fiber + diffuser