Nuclear Science and Security Consortium
Virtual Scholar Showcase 2020

Measurements of Attenuation and Scattering in Water-Based Liquid Scintillator

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NUCLEAR SCIENCE and SECURITY CONSORTIUM

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Introduction

Current work: Research in support of neutrino detection technologies

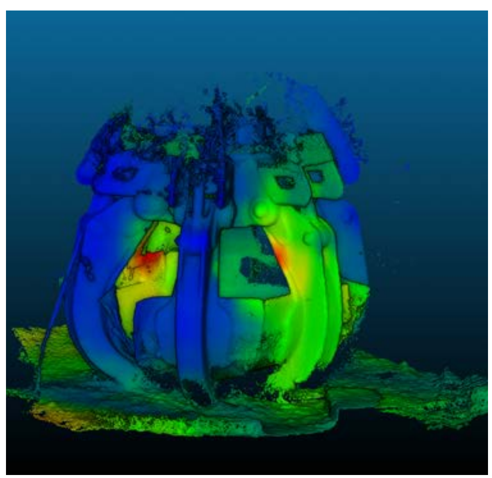
Focus: Radiation detection and nuclear instrumentation

Crosscutting area: Modeling and Simulations

Academic Advisor
Professor Kai Vetter
Dept. of Nuclear Engineering

Lab Mentor
Dr. Adam Bernstein
Rare Event Detection Group

Lab Mentor
Professor Kai Vetter
Applied Nuclear Physics Group



Past work: 3D coded aperture imaging for safeguards.
Right: Reconstruction of demolition claw at Chernobyl

WbLS is an innovative liquid-scintillator solution for large-volume detectors

- Majority (97-99.5%) water
- Micelles contain nonpolar liquid scintillator
- Photon yield from 100-10k/MeV
- Claimed high transparency
- Potentially very low cost

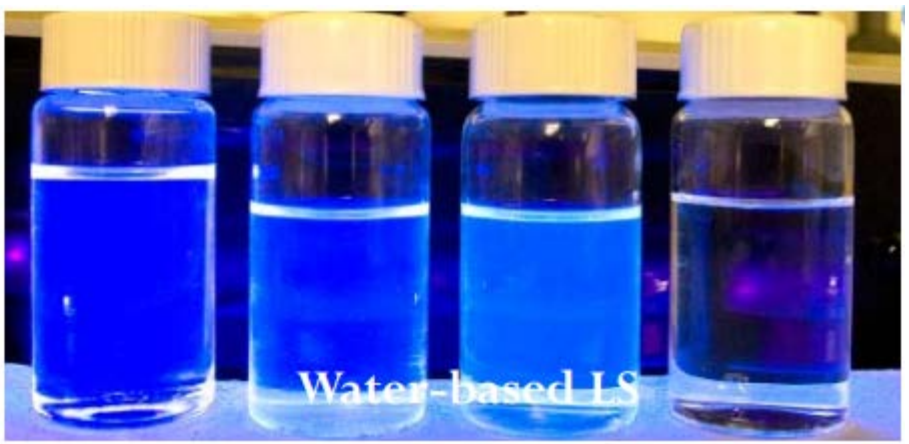


Image credit: Minfeng Yeh, Brookhaven National Lab

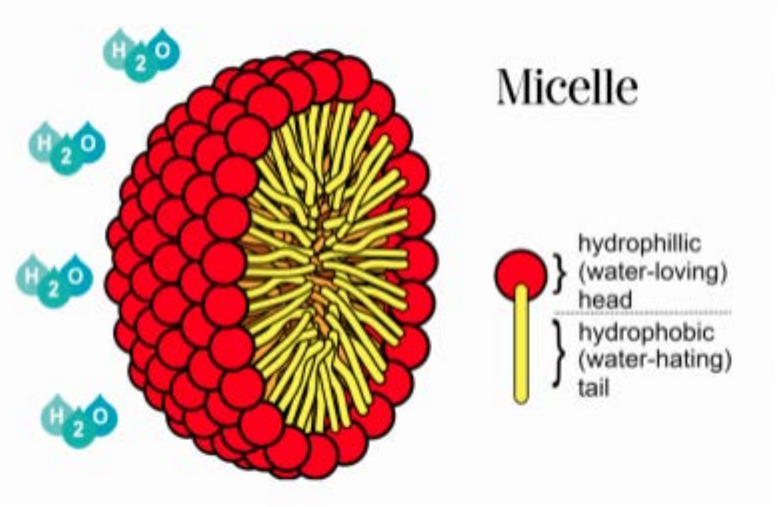
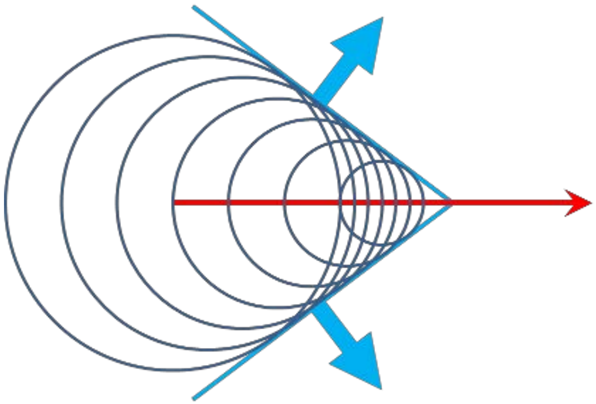


Image credit: UC Davis, Svoboda group

What problem does it solve?

- **LS: High light yield, short attenuation length**
  - High energy resolution, but directional information from Cherenkov lost
- **Water: low light yield, long attenuation length**
  - Good directional information (long attenuation length), but no light yield below Cherenkov threshold (.8MeV)
- **WbLS: Best of both worlds?**
  - Can explore physics below water's Cherenkov threshold while maintaining directional information—potentially revolutionary for rare event searches



Preservation of Cherenkov rings in a ~kT scale detector requires an attenuation length on the order of 20m

WbLS may meet this threshold and allow significant physics exploration below the Cherenkov threshold

Remaining questions: Suitability for large detector volumes

- **Existing samples of various WbLS formulations have been tested using small-scale (10mm cuvette) UV/VIS spectroscopy systems**
  - Small sample testing has upper limit of ~4.5m attenuation length
  - Some formulations have shown promising behavior (good attenuation characteristics beyond 400nm)
  - Scattering behavior has **not** been characterized

Image credit: Shimadzu. Model UV-1800

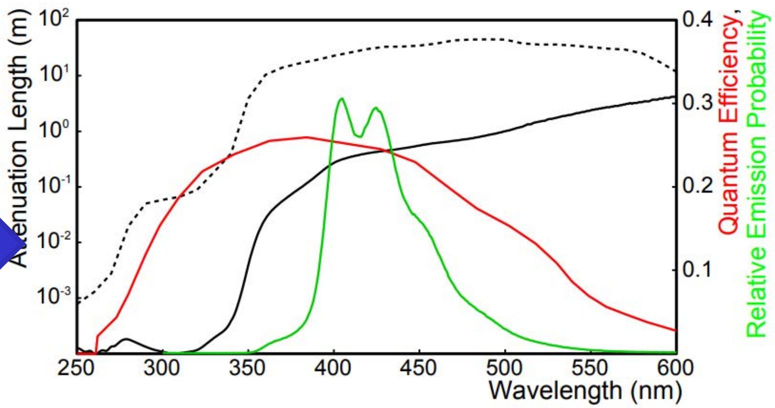
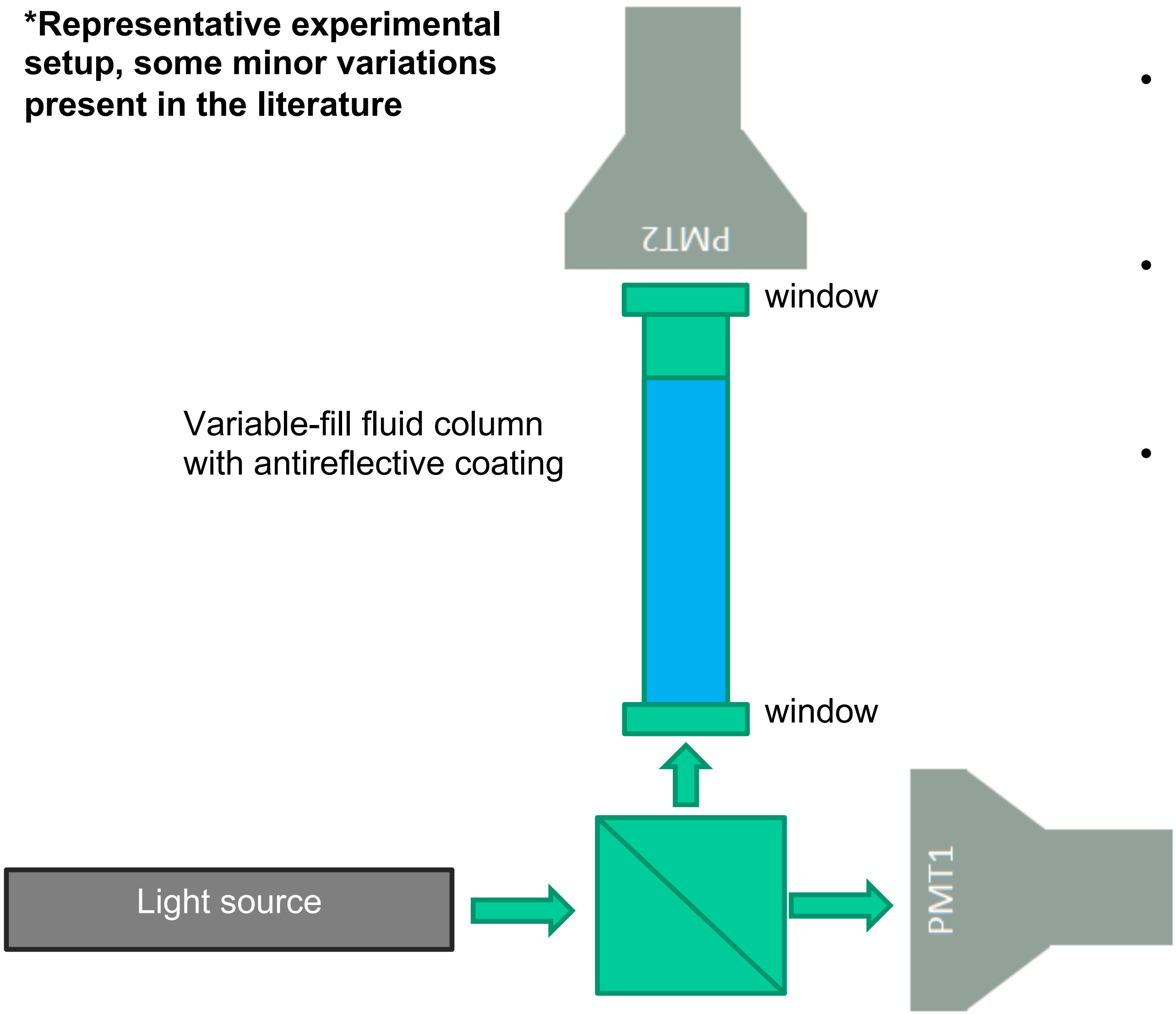


Image credit: Bignell, L et al. Characterization and Modeling of a Water-based Liquid Scintillator. BNL 111618-2015-JA

Small-sample testing is useful for ***relative*** characterization of various mixtures, not suitable for attenuation length

Past attempts at long-attenuation length measurements have had mixed results

***Representative experimental setup, some minor variations present in the literature**



- Basic design borrowed from a mid-70s paper on water attenuation length
- Uses a variable height water column and a tunable light source
- Ratio of PMT1/PMT2 gives attenuation

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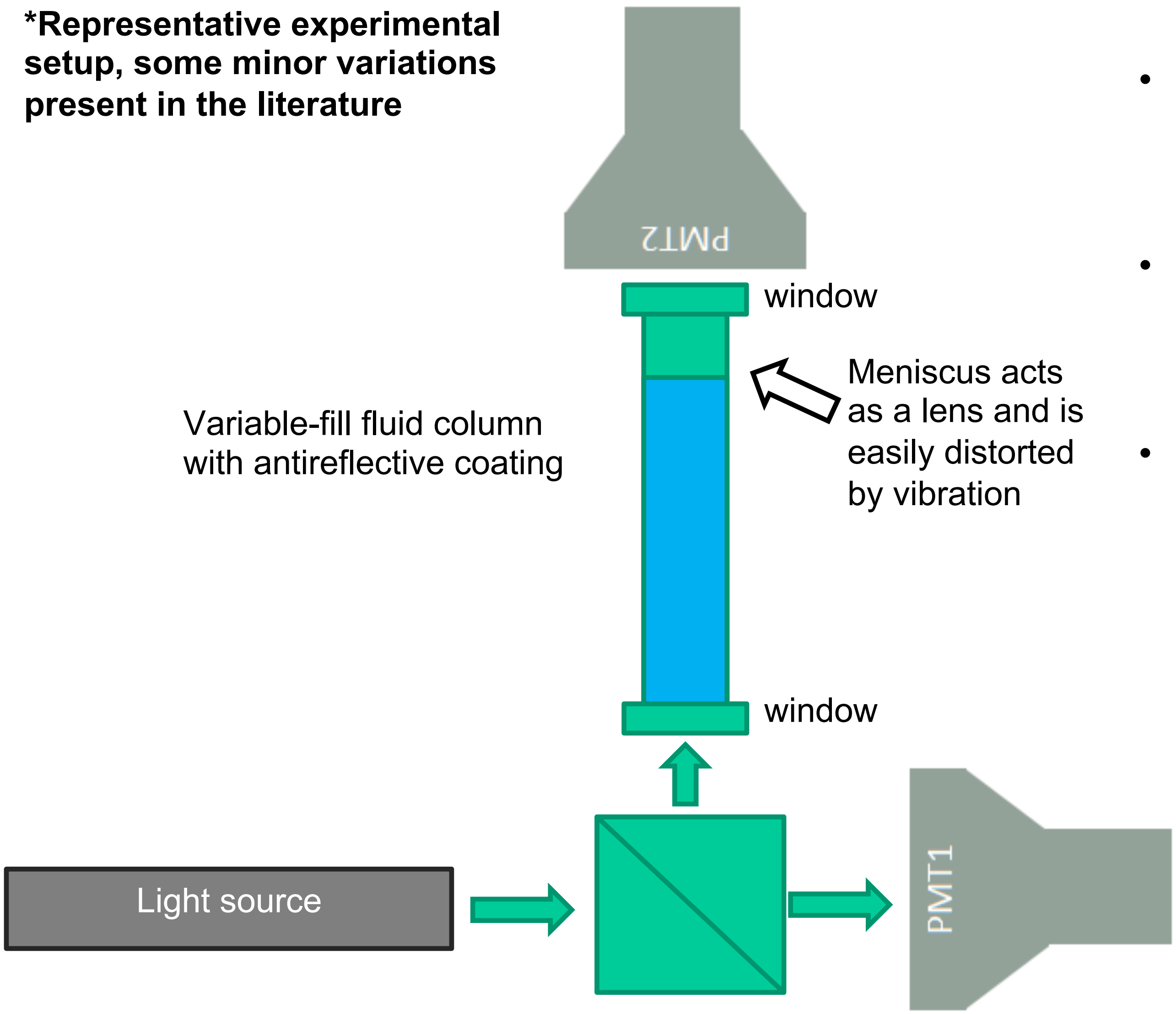

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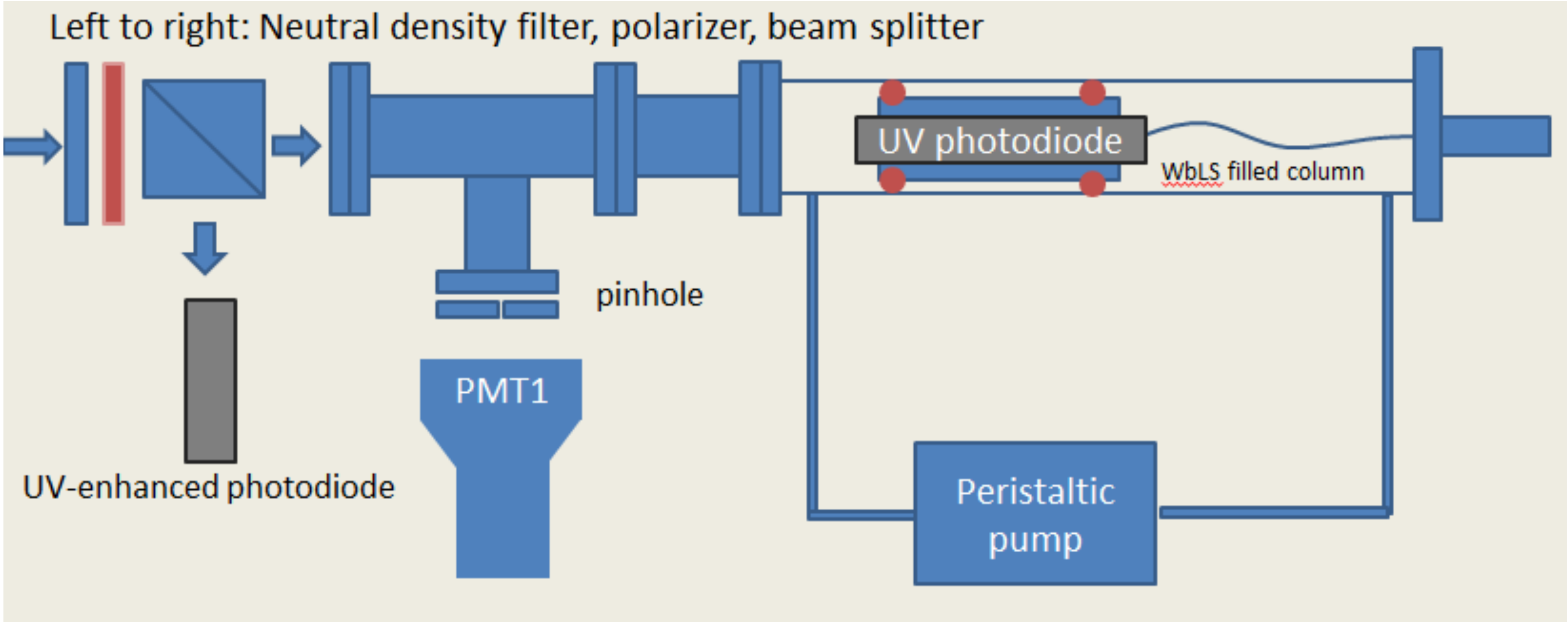
Experimental design

- **Use horizontal, liquid-filled structure with moveable sensor/reflector assemblies to measure absorption at varying path lengths**
  - Standard ConFlat DN275 304L SS fittings + 1/4in Swagelok 316SS hardware
  - Design for 3-8m OAL
  - Adjust path length using a movable sensor driven by hydraulic pressure
- **Provide three or more side-ports to measure scattering**
  - Several are used to check measurement consistency
- **Maximize use of COTS components**
  - Eliminate fabrication when possible
  - Use all metal sealing surfaces, minimize fluoropolymer use
- **System should be flexible, reconfigurable and provide for quick drain, fill and disassembly**

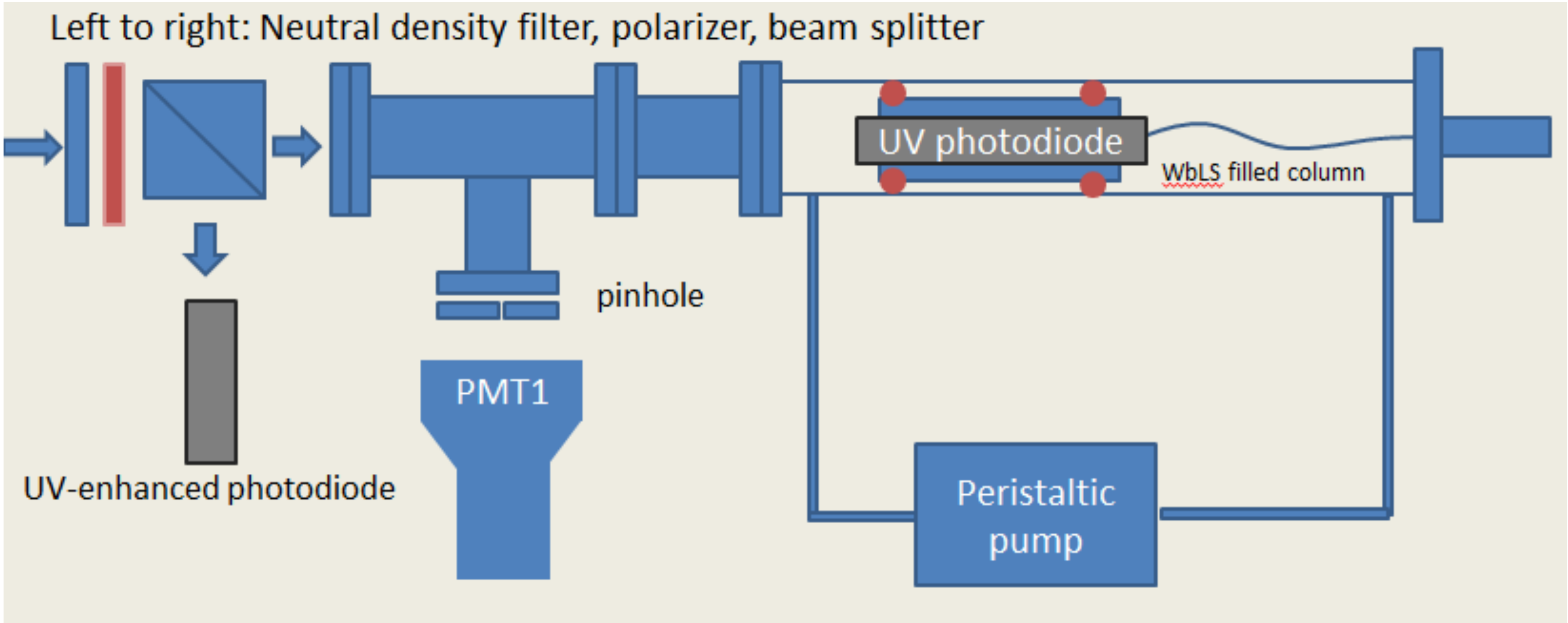
This design does not have the same issues with an unstable air-water interface



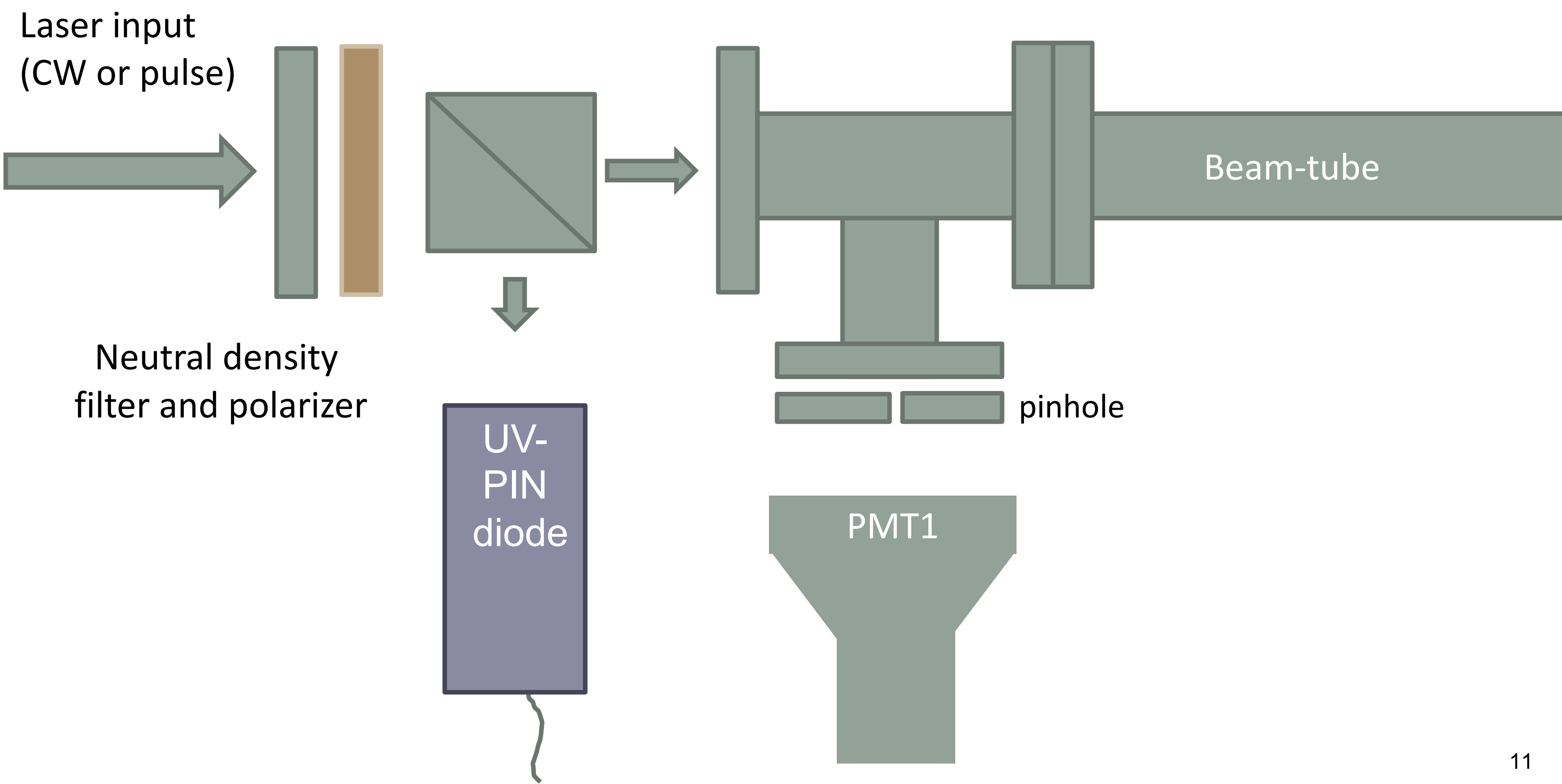
Basic system diagram, scattering ports omitted

Basic design features

- Sealed column with no air-water interface
- Alignment issues minimized by collecting optics
- UV-enhanced photodiodes used for attenuation measurement
- Fill liquid used as working fluid for path-length adjustment system

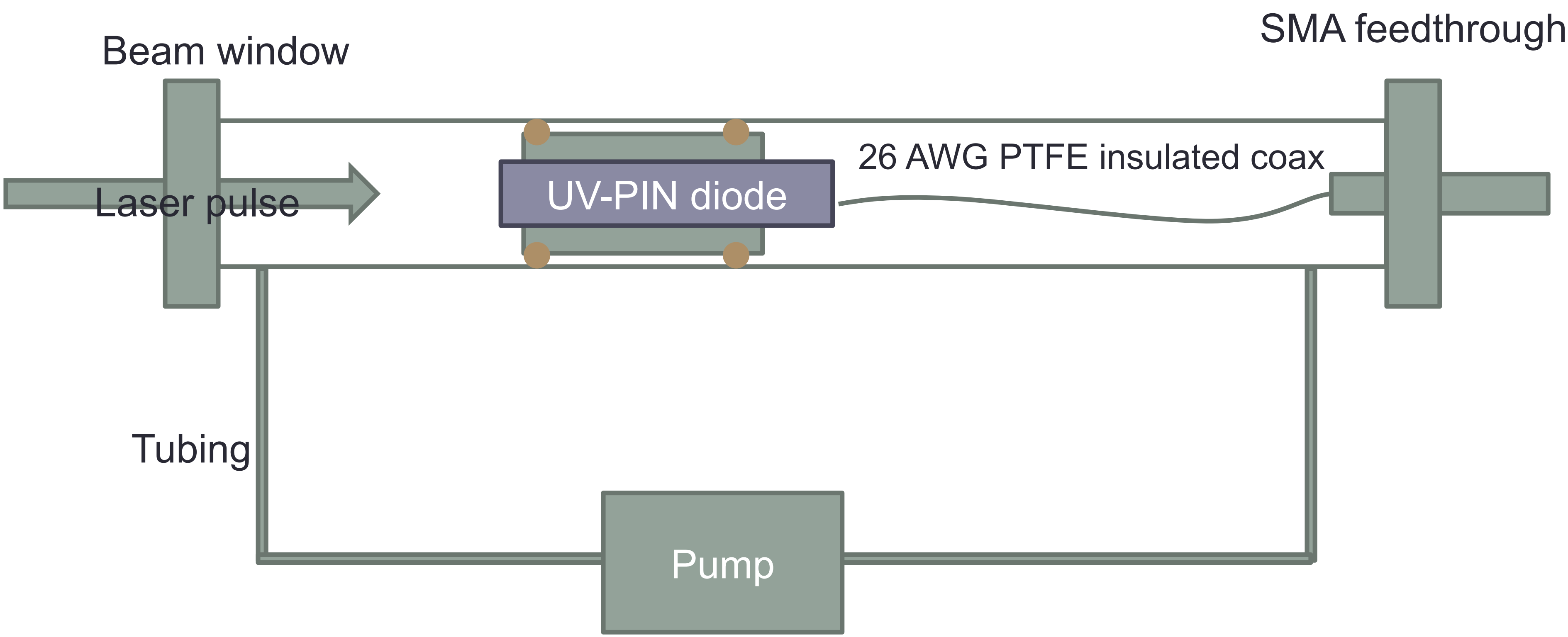


Front-end beam path diagram



Beam tube design (submerged sensor)

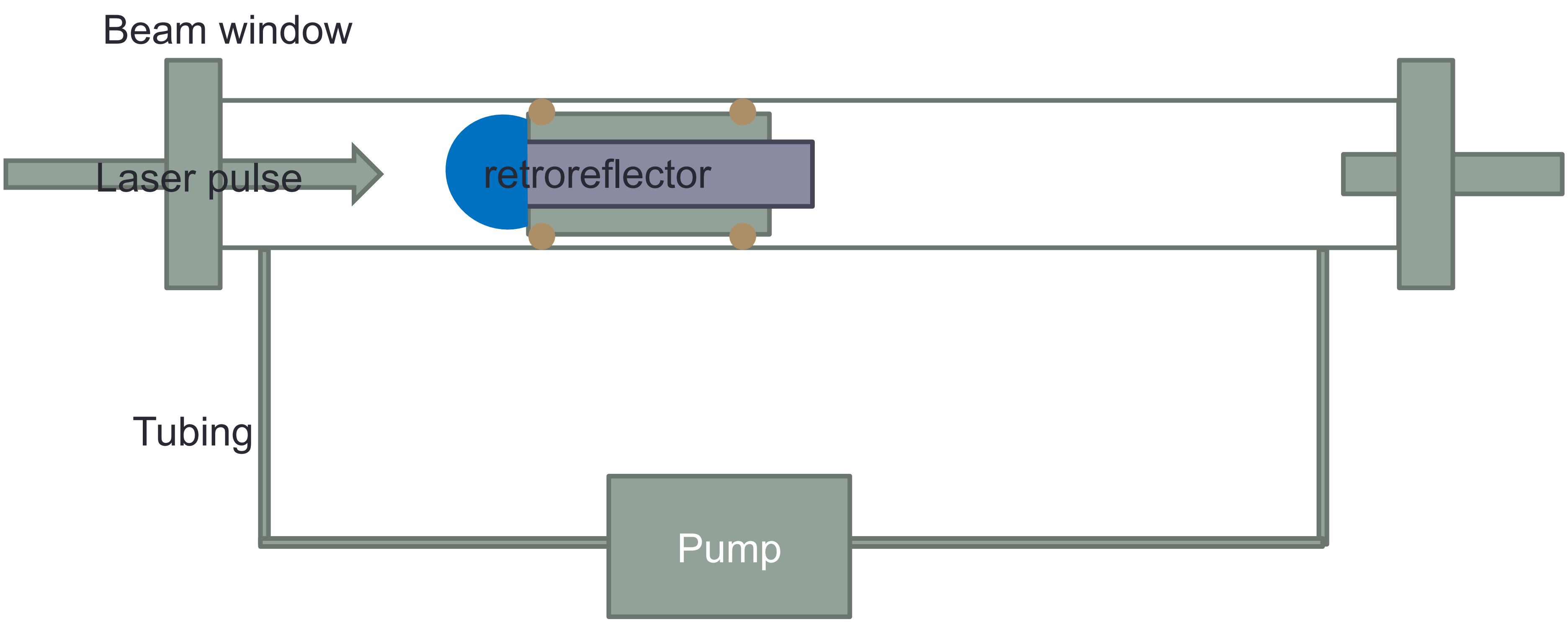
- UV-PIN diode beam power monitor uses standard SM05 optical mounts to allow for inclusion of baffles and/or new lenses if needed



McMaster-Carr peristaltic pump (50cm/min with ¼” ID norprene)

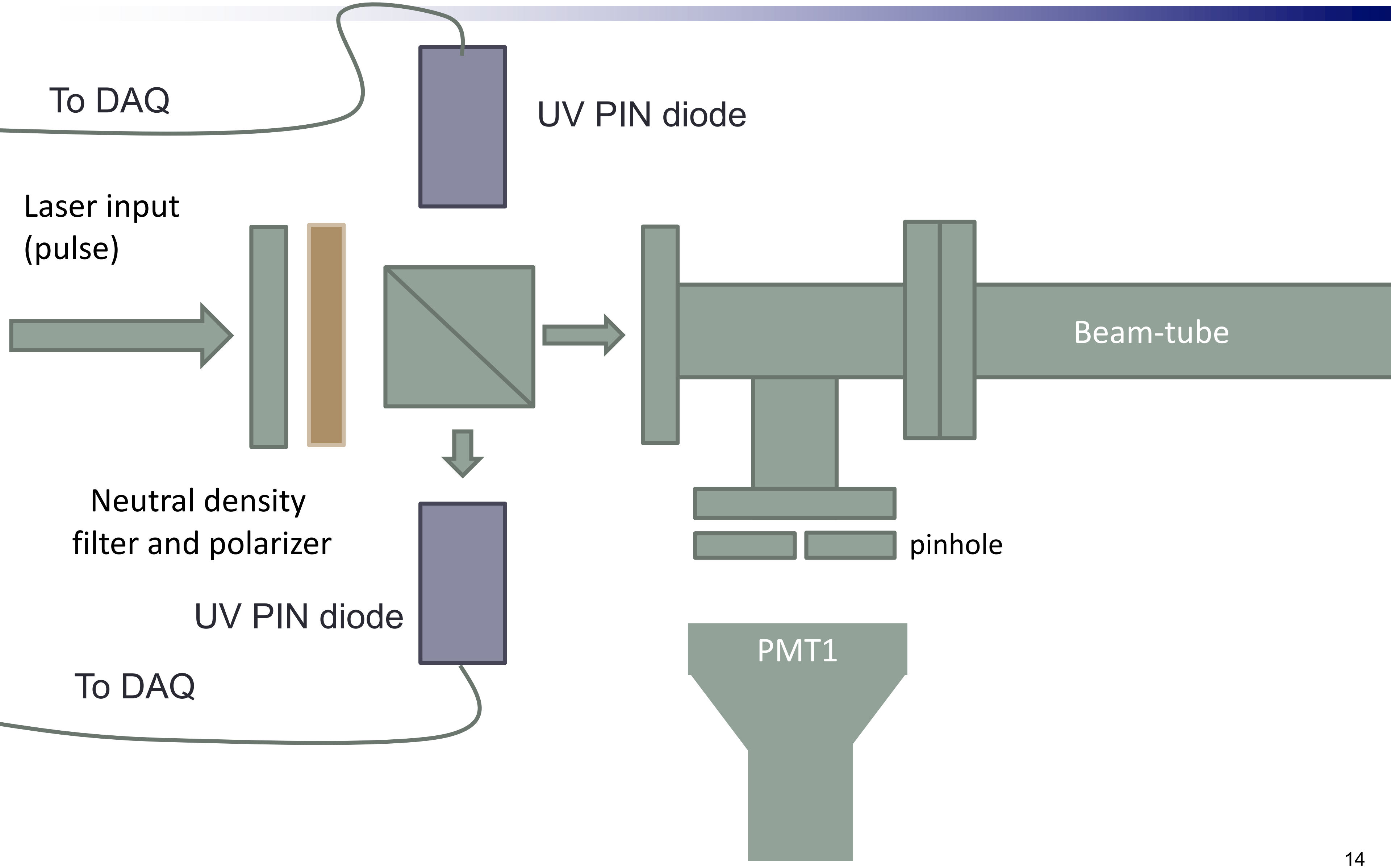
Beam tube design (retroreflector)

- SM1-threaded retroreflector can be screwed into the SM05 mount with an adapter, and system operated in pulse or CW mode

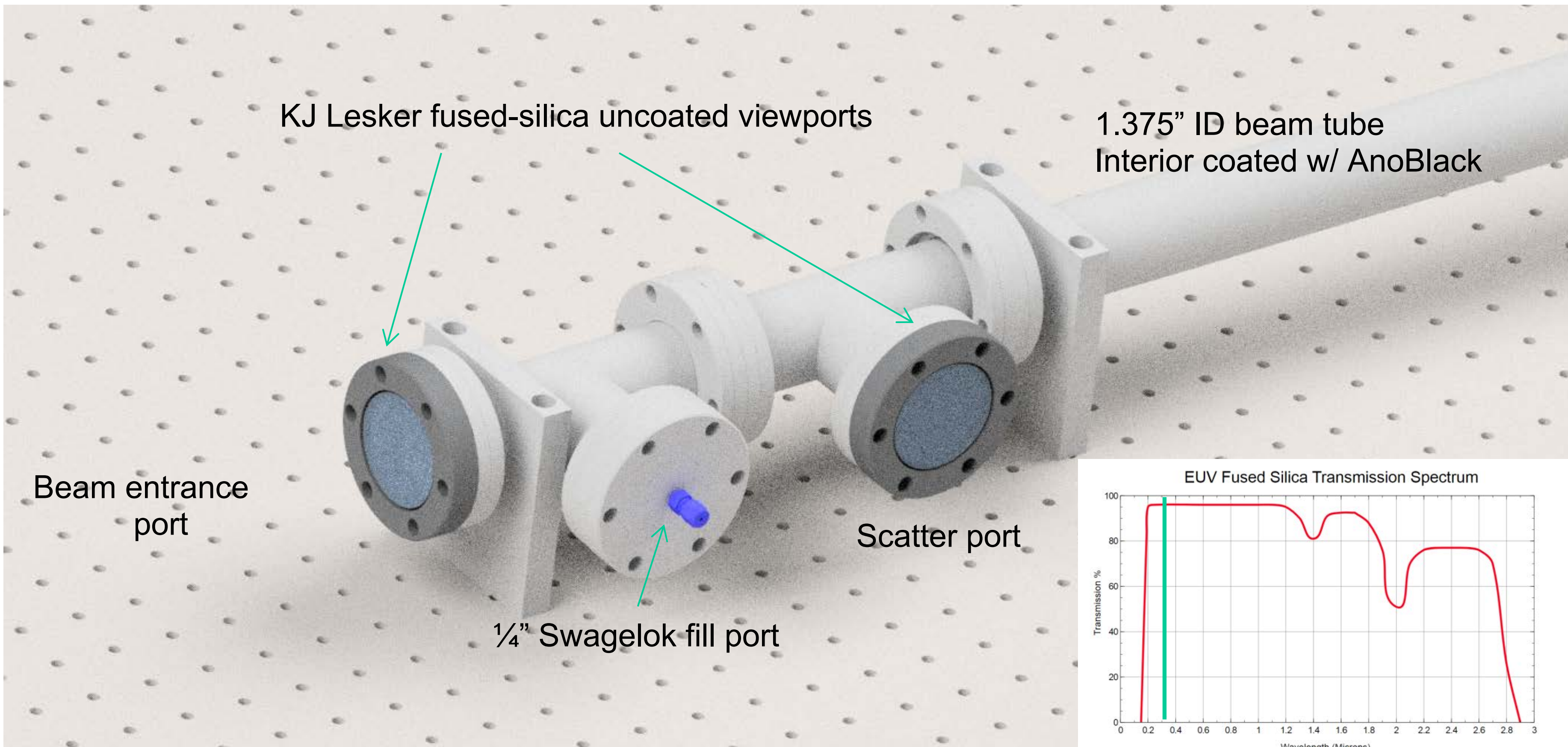


McMaster-Carr peristaltic pump (50cm/min with ¼” ID norprene)

Beam path (with retroreflector)

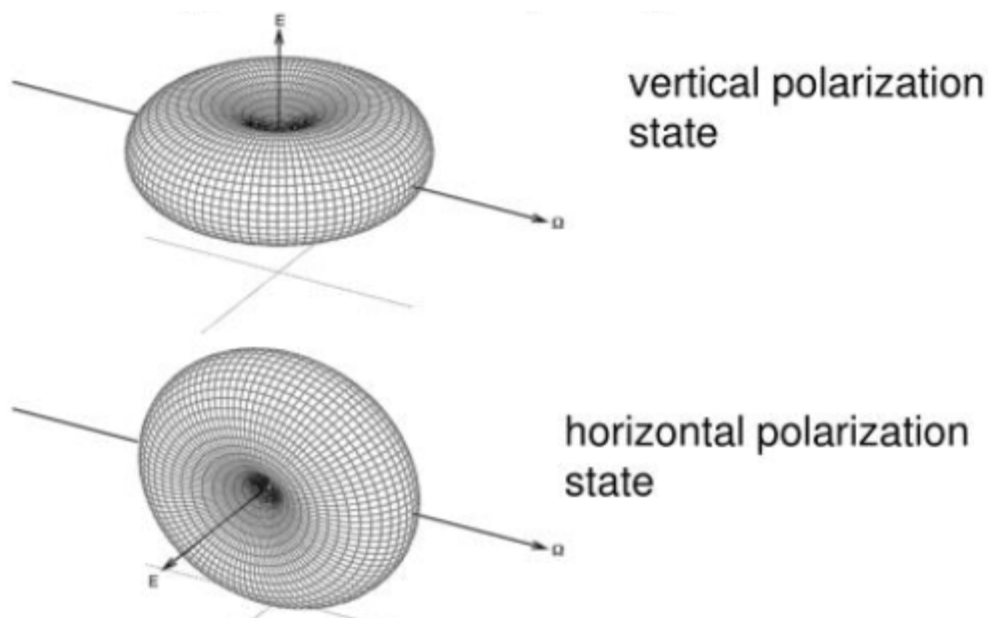


Beam entrance port:
100% COTS, 2.75” CF hardware



Review: Scattering in fluids

- Anticipated scattering modes: Rayleigh (water), Mie (micelles)
- Micelle size and size distribution unknown
- Water component: Rayleigh scattering
- Micelle/LS component: Mie scattering + some small % Rayleigh



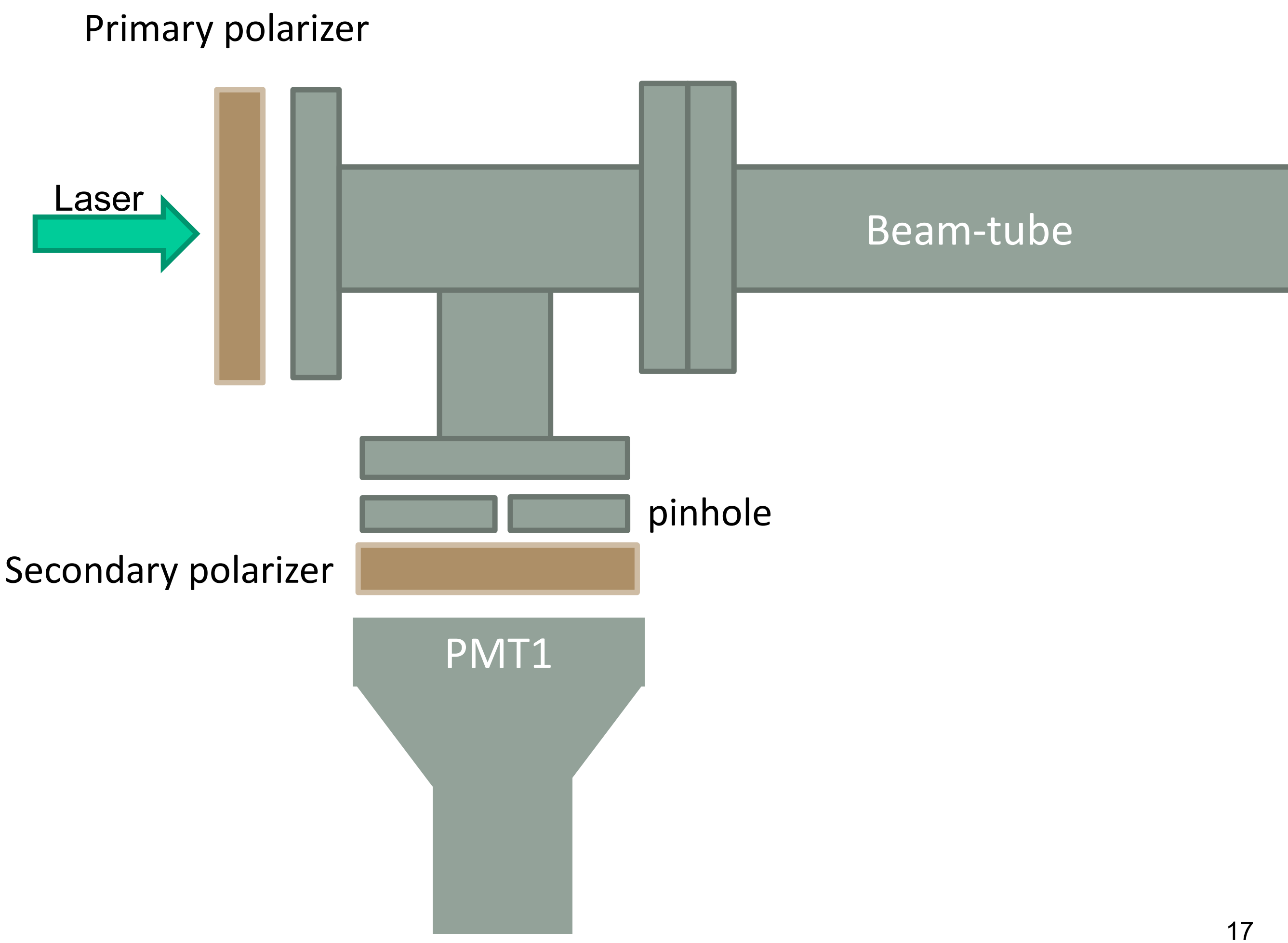
Rayleigh scattering– Straightforward polarization-dependent phase function

Mie scattering– Much more complicated phase function depending on micelle size/index

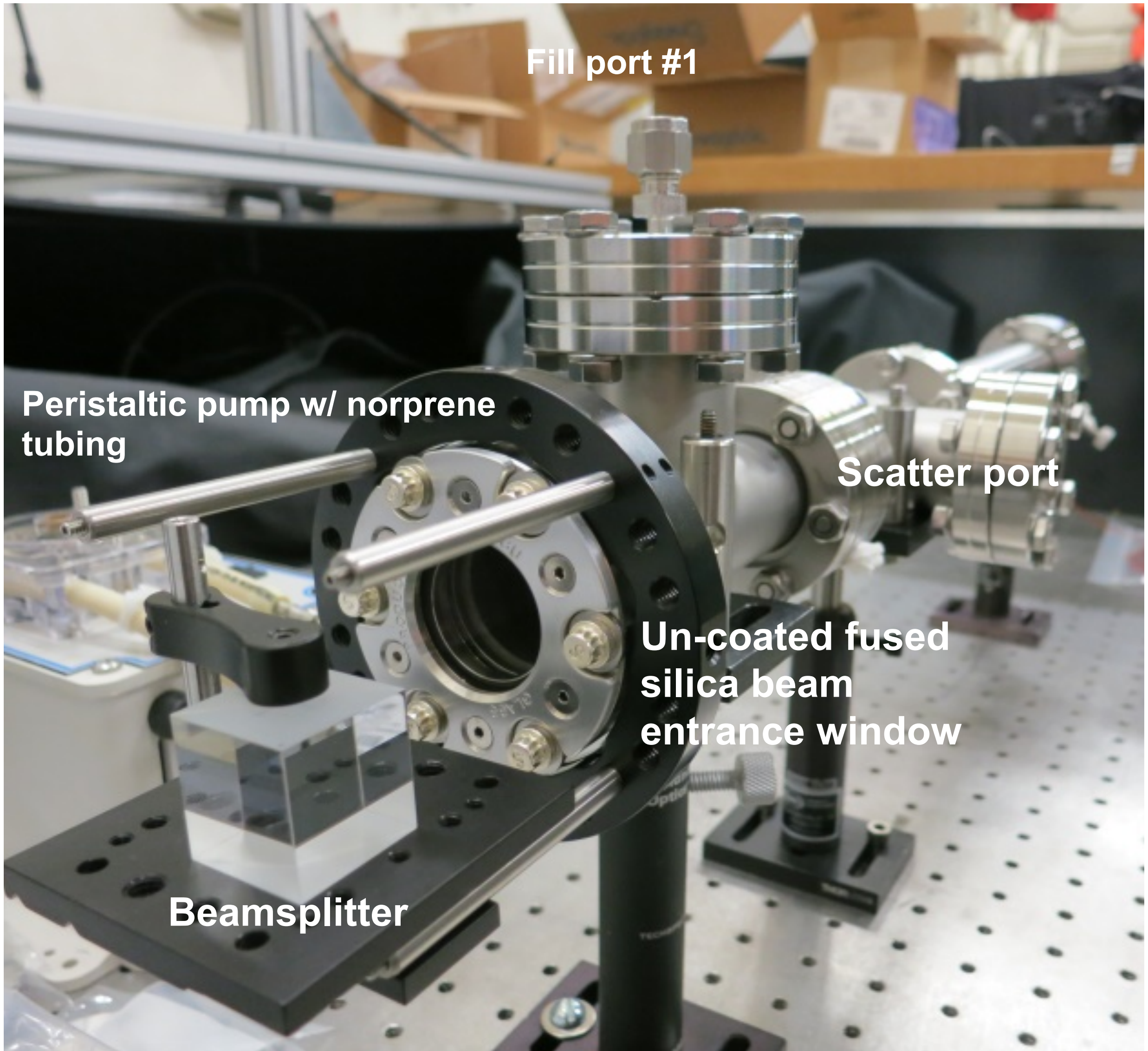
Bohren, Craig F., and Donald R. Huffman. Absorption and scattering of light by small particles. John Wiley & Sons, 2008.

Separation of scattering components by polarization

Rotation of primary vs secondary polarizers allows separation of Rayleigh scattering component



Current status of the system



Since this photo was taken, the hydraulic system has been plumbed and the two 96” beam tubes affixed to the optical table.

The system awaits ESH check-off and fill/drain testing.

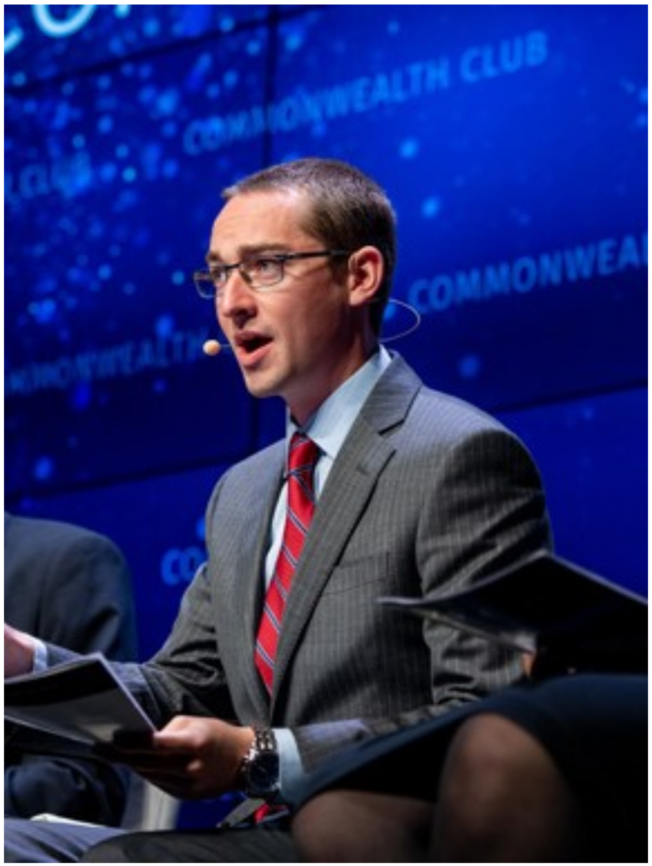
Fill and DAQ design are nearly complete

- **Isolation/fill:**
  - Valve block design allows for isolation and fill without a pressure source
  - NO air contact whatsoever in fill design→ minimizes contamination hazards

- **DAQ:**
  - UV-PIN diode biased to 20V, no amplifer necessary with 10mW light source.
    - Can be read with scope w/single shot data recording feature
    - May use LabJack DAQ and LabView software to automate readout
  - Scattering ports (PMT-equipped) can be read using an existing DAQ (working w/Austin Mullen)

NSSC Experience

Public Policy and Nuclear Threats (PPNT) 2018: Established links with CISAC and CSIS, began working with Sig Hecker on US-China and US-Russia forums (YPNF5 at Stanford, YPNF6 in Moscow)



Panel appearance at the Commonwealth Club as part of the Fort Ross Dialogue on US-Russia relations, October 2019.

Meeting in Beijing with Stanford center affiliates to discuss verification technologies, November 2019.

CSIS Tech primer written with the Berkeley Nuclear Policy Working Group (NPWG) on a novel radiation detection technique

Acknowledgements

2019 NSSC Fall Workshop at LLNL

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