

DORY

An Optical Module in the nEXO Outer Detector Monitoring & Calibration System

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— Naming the Talk

**Design, Development, and Characterization of
an Optical Module for Monitoring and Calibration of
the nEXO Water Cherenkov Muon Veto**

Naming the Talk

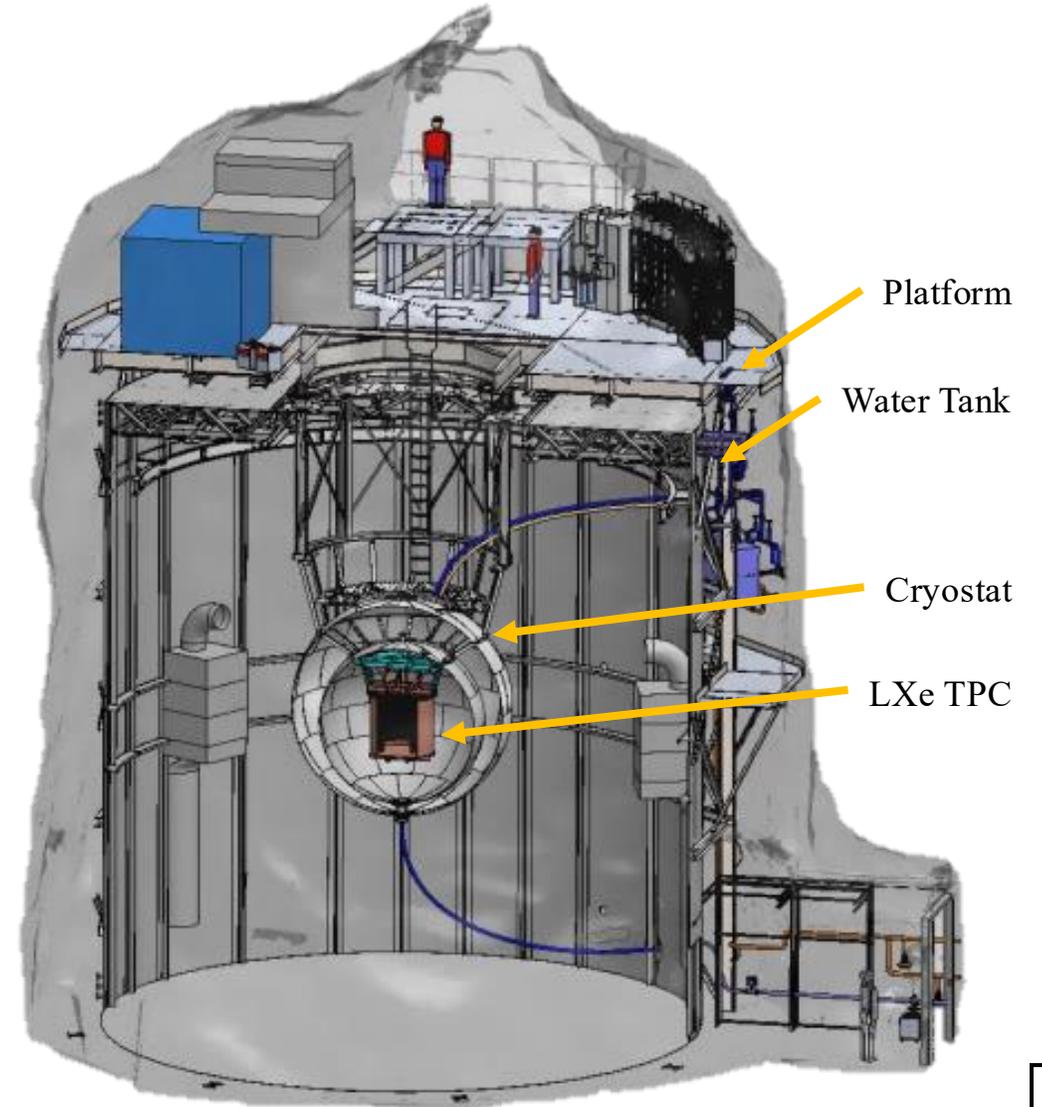
Design, Development, and Characterization of an Optical Module for Monitoring and Calibration of the nEXO Water Cherenkov Muon Veto

1. What Is a Water Cherenkov Muon Veto?
2. Why Is Monitoring and Calibration Necessary?
3. How Is It Monitored and Calibrated?



The nEXO Experiment

- nEXO is a proposed neutrinoless double beta ($0\nu\beta\beta$) decay search using the isotope ^{136}Xe .
- Liquid xenon (LXe) is housed in a cylindrical copper Time Projection Chamber (TPC).
- The TPC is enclosed in a spherical, vacuum-insulated cryostat filled with HFE-7200 cryogenic fluid.
- The central detector is surrounded by the Outer Detector (OD), a water Cherenkov muon veto system.



nEXO Outer Detector

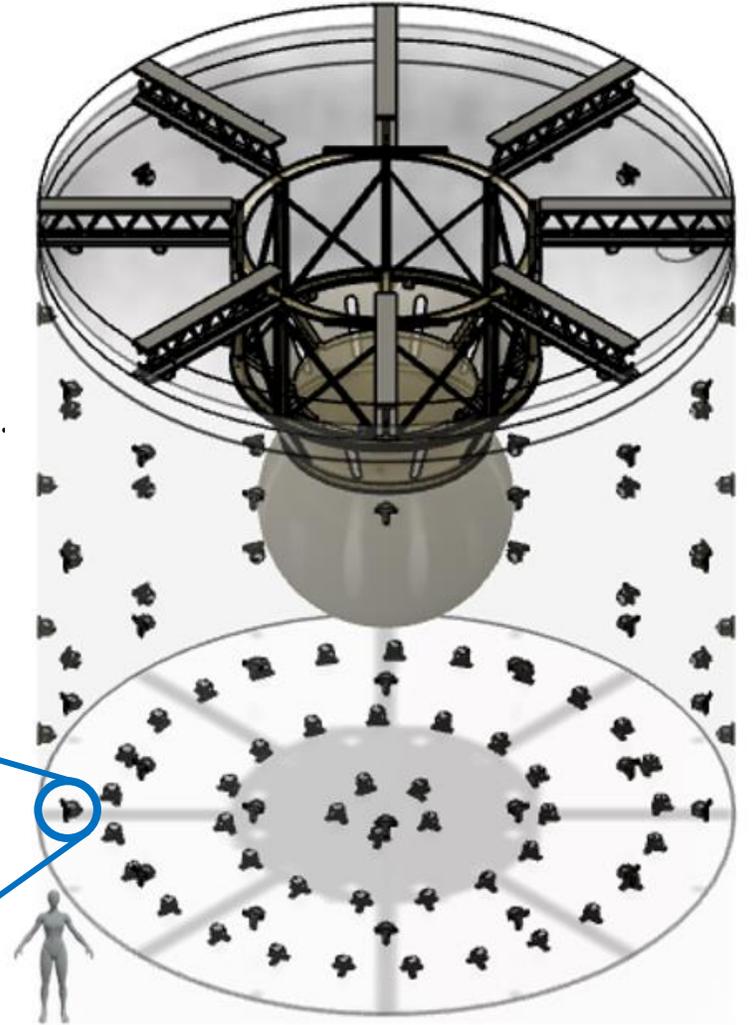
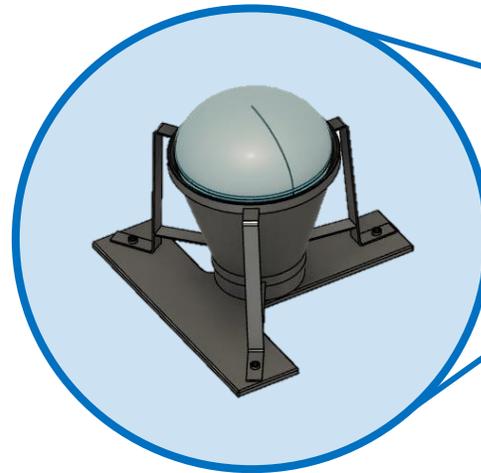
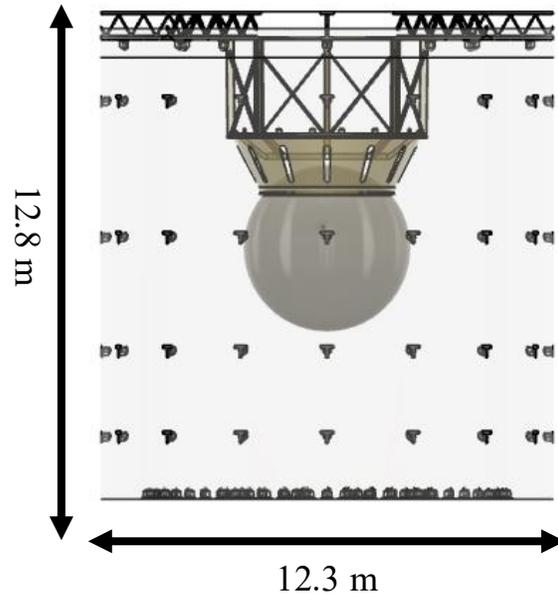
Surrounding the inner detector is a:

- Water tank with a 12.3 meters diameter and 12.8 meters height
- Contains 1.5 kilotonnes of ultra-pure water
- Equipped with 125 Hamamatsu R5912 photomultiplier tubes (PMTs)

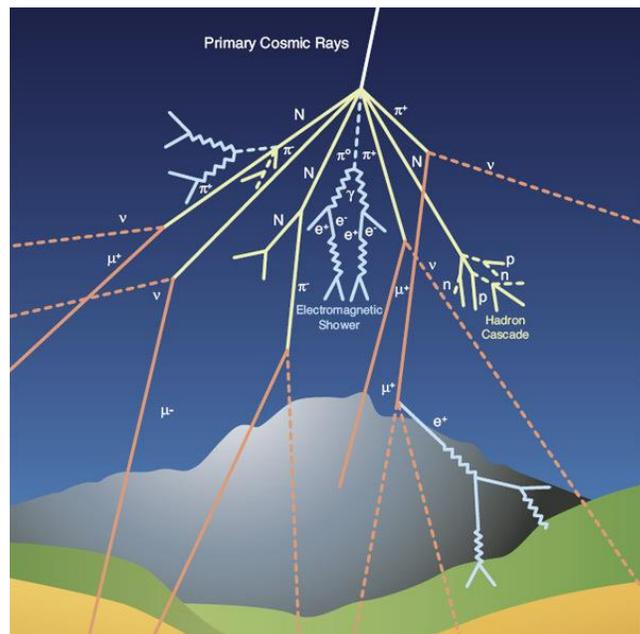
The water shield and PMT system together form the nEXO OD.

OD provides:

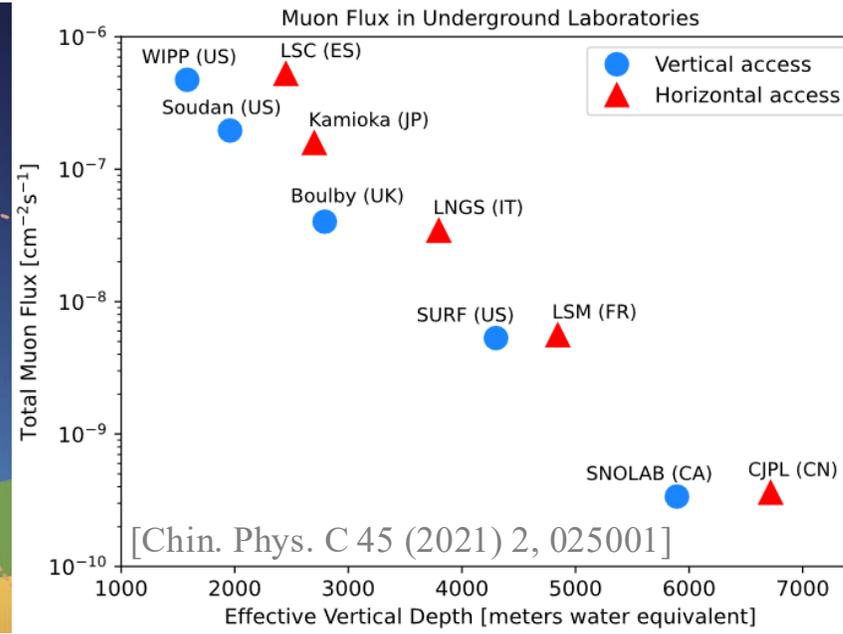
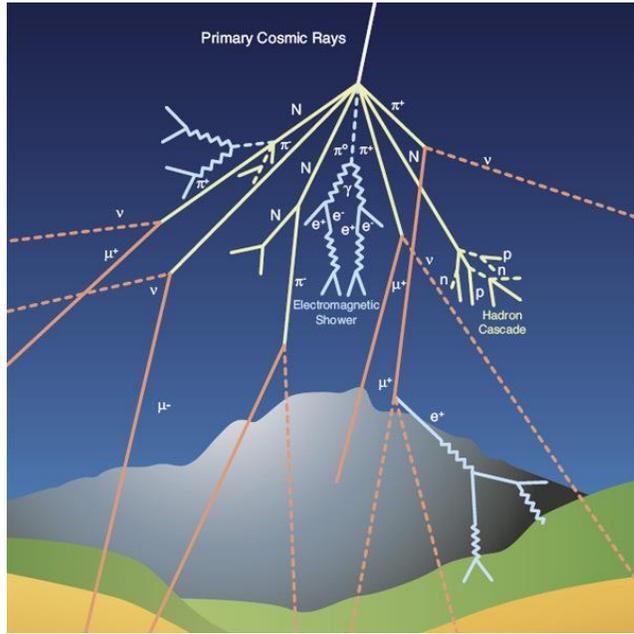
- Passive shielding – reduces external gamma and neutron radiation entering the TPC.
- Active muon tagging – detects muons through their Cherenkov light in water.



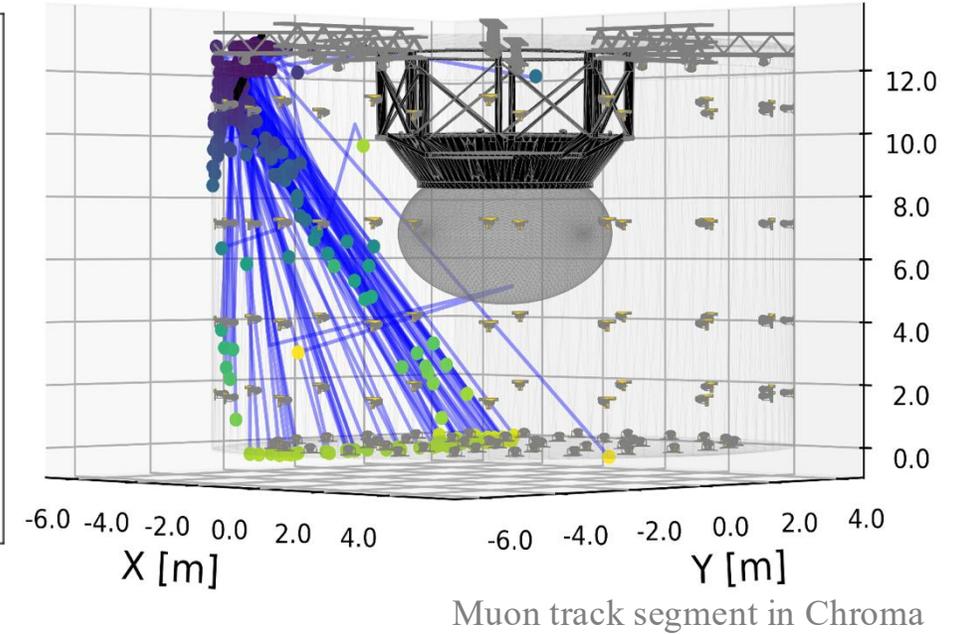
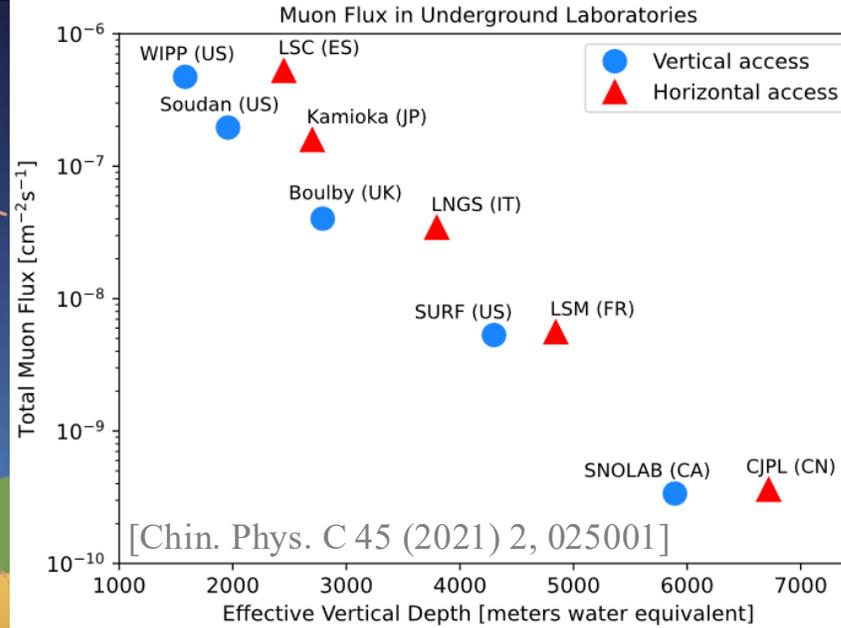
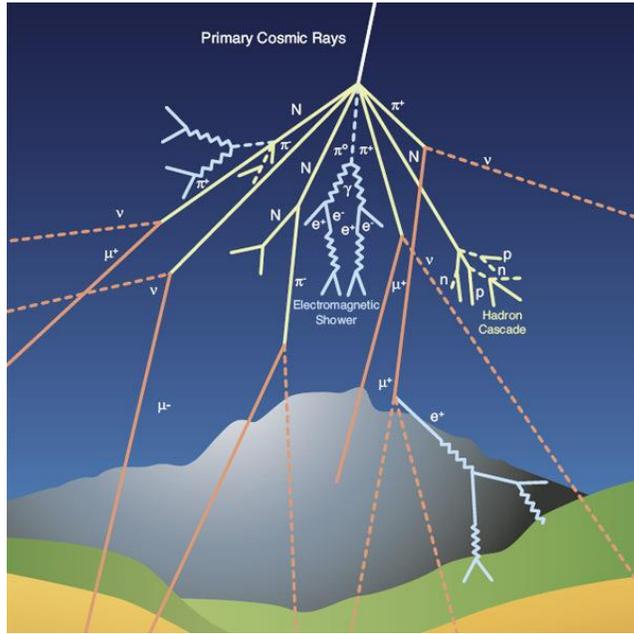
Water Cherenkov Muon Veto



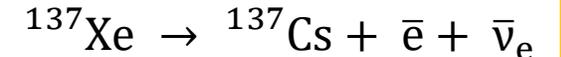
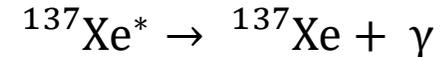
Water Cherenkov Muon Veto



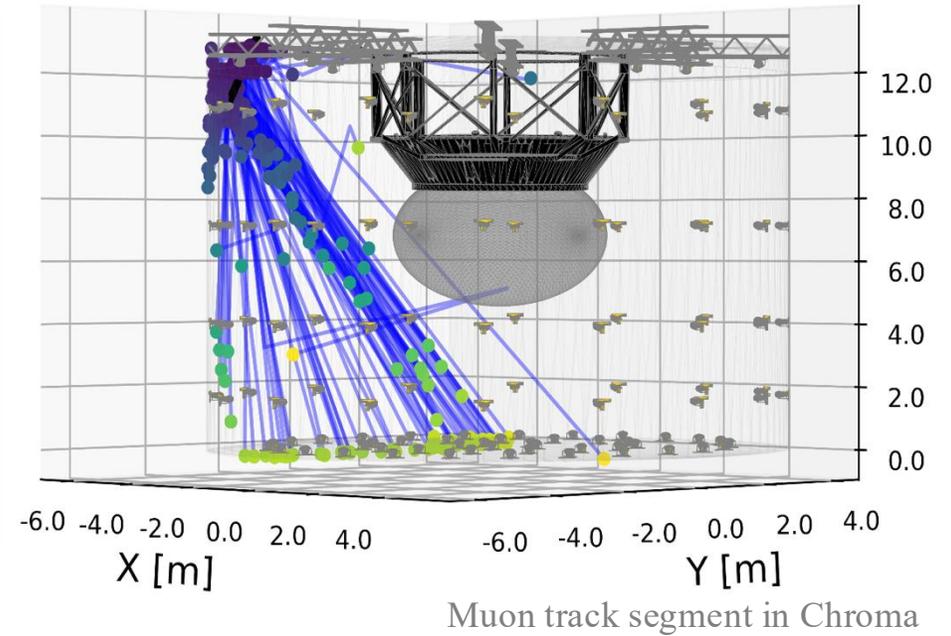
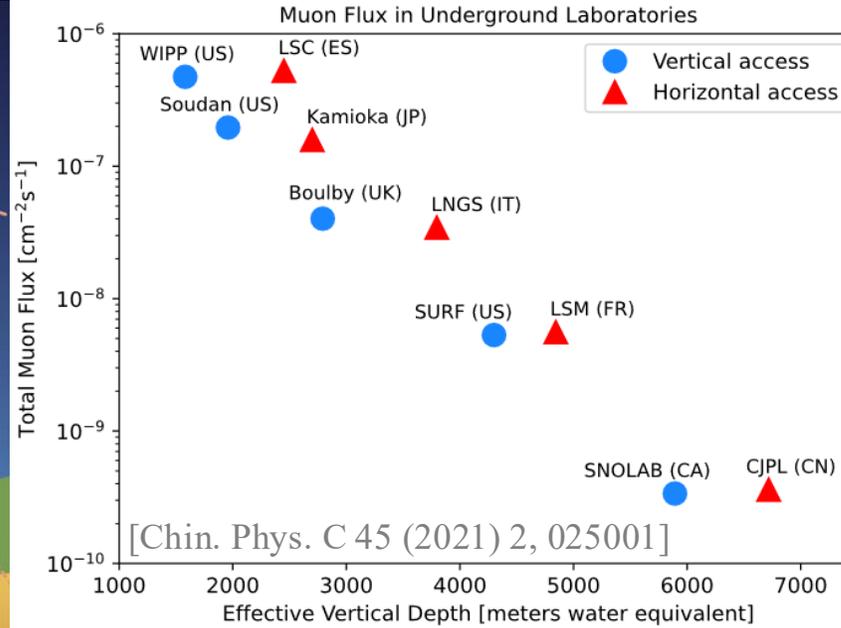
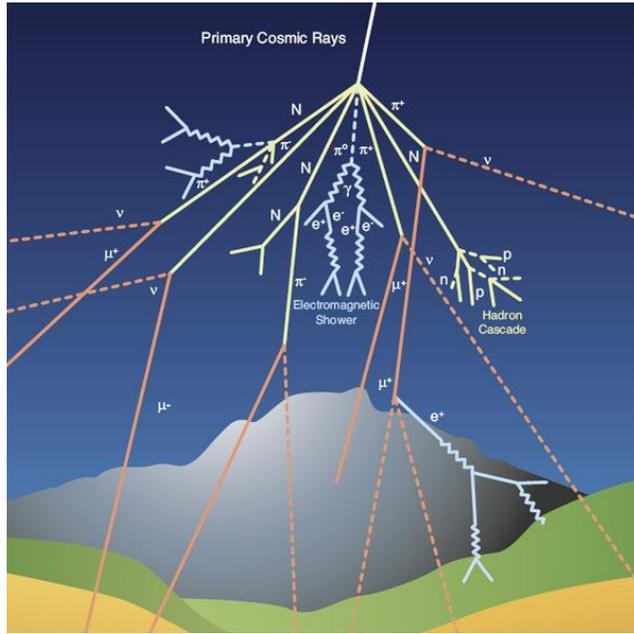
Water Cherenkov Muon Veto



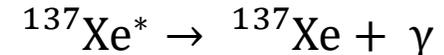
A muon passing through the water tank produces hundreds of neutrons



Water Cherenkov Muon Veto



A muon passing through the water tank produces hundreds of neutrons



Tag muons via their Cherenkov emission in the water tank

Select ~ 10 milliseconds of TPC data

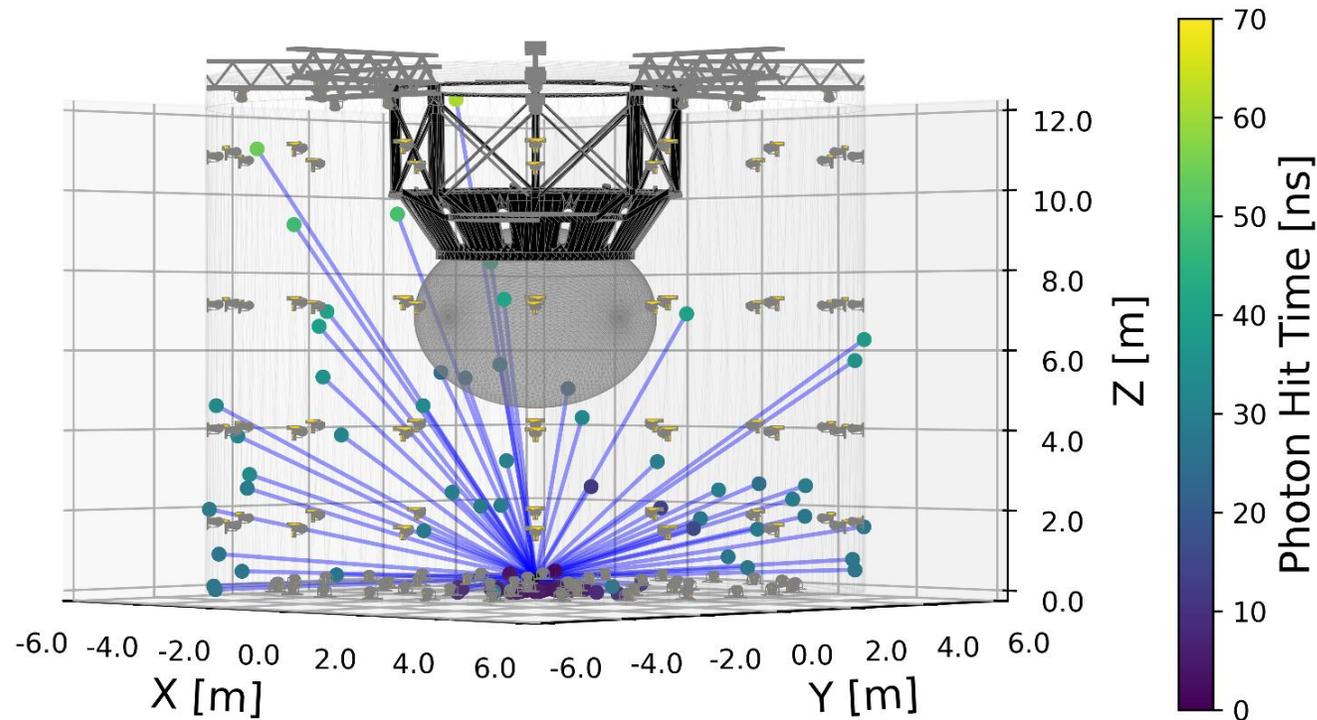
Search for gamma signatures from ${}^{136}\text{Xe}(n, \gamma){}^{137}\text{Xe}$

If gamma signatures are detected, veto the TPC readout for an additional number of half-lives of ${}^{137}\text{Xe}$

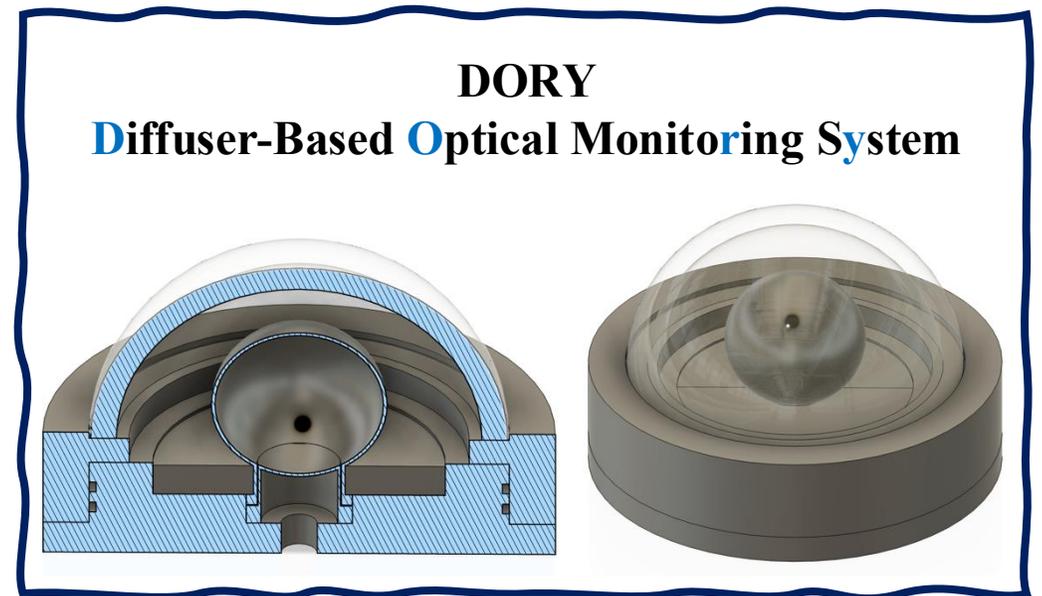
Outer Detector Monitoring & Calibration System

A monitoring and calibration system is being developed for OD;

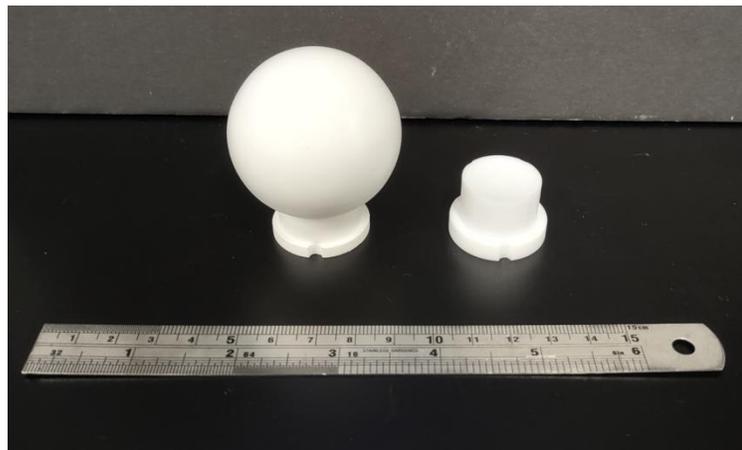
- Purpose: To calibrate the timing properties of the PMT readout system, monitor the optical properties and quality of the water, and track the performance of OD throughout the lifetime of the experiment.
- System concept: Laser-based fiber-optic setup delivering light to optical modules (DORY) inside the water tank.



Simulation of a 390 nm point light source emitting isotropically across the OD



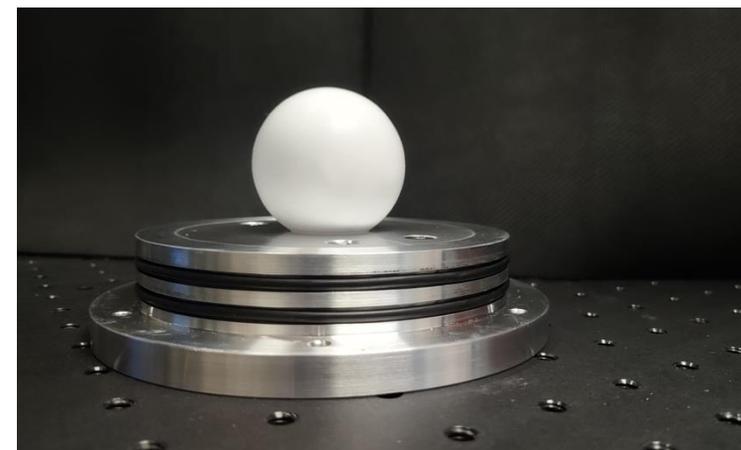
DORY: An Optical Module for Outer Detector Monitoring & Calibration



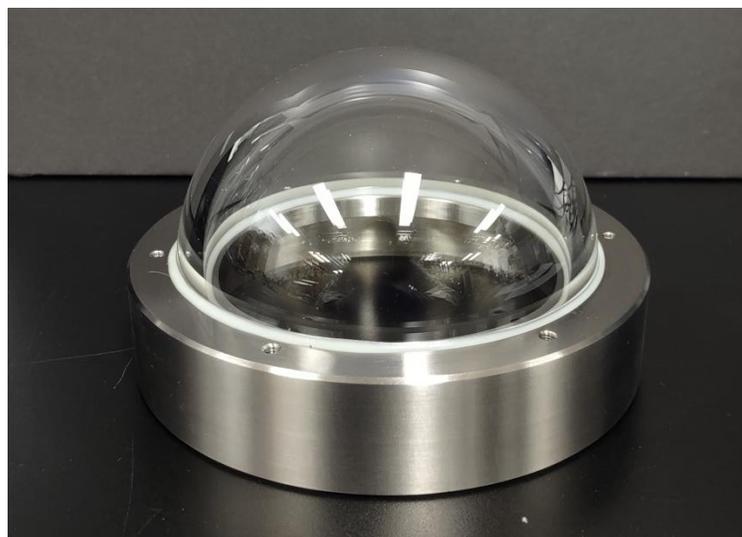
Optical Teflon (PTFE) plug and sphere



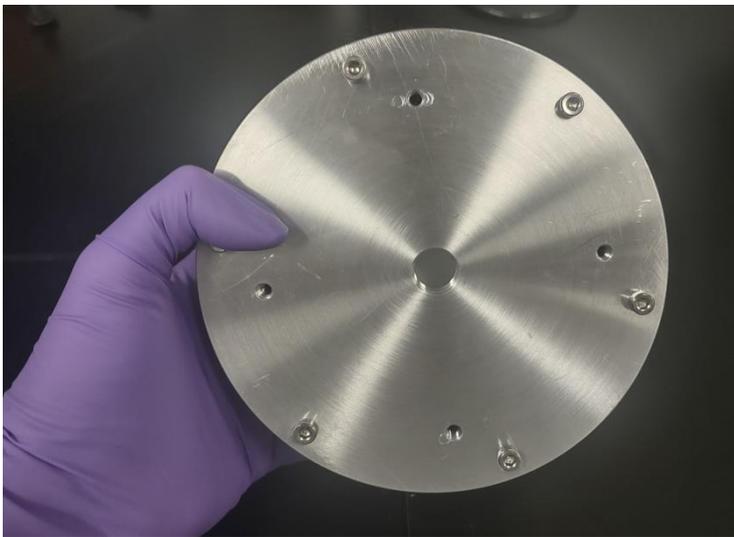
Assembly of the PTFE diffuser



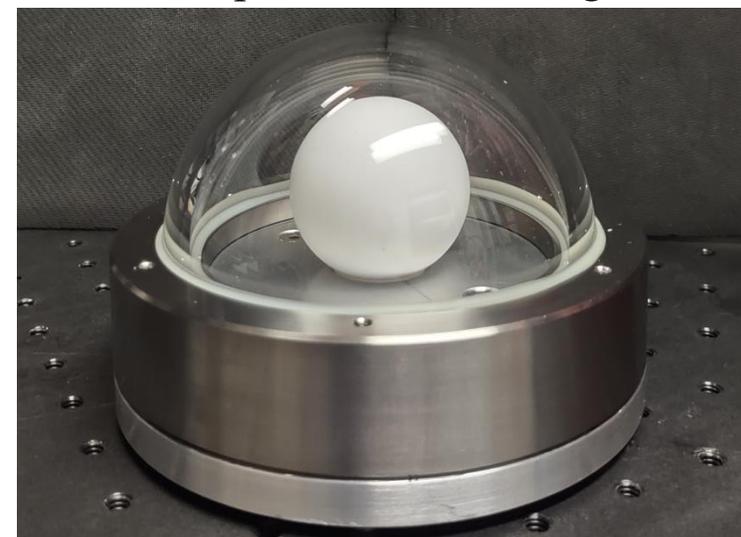
Diffuser assembly with aluminum components and O-rings



Pressure housing made of borosilicate (H-K9L) glass and titanium flange

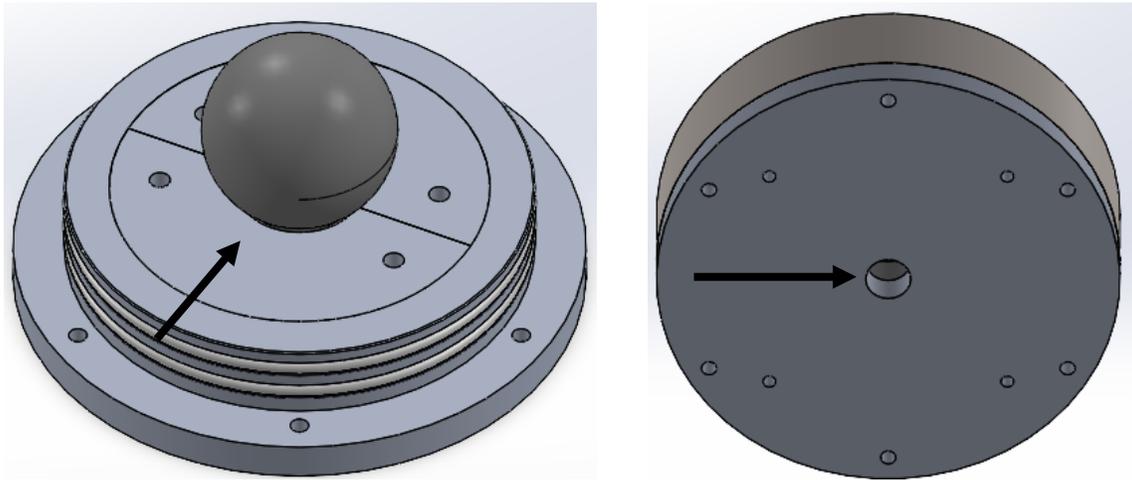


Back of the DORY

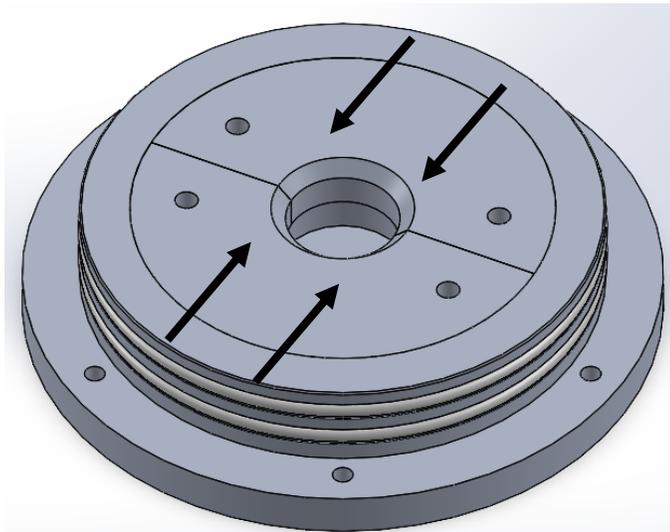


First DORY prototype

DORY Upgrades

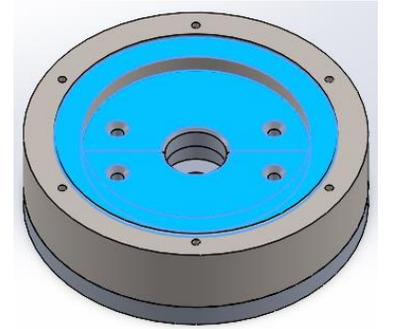


Addition of a self-monitoring photosensor and modification of the back opening to accommodate required feedthroughs

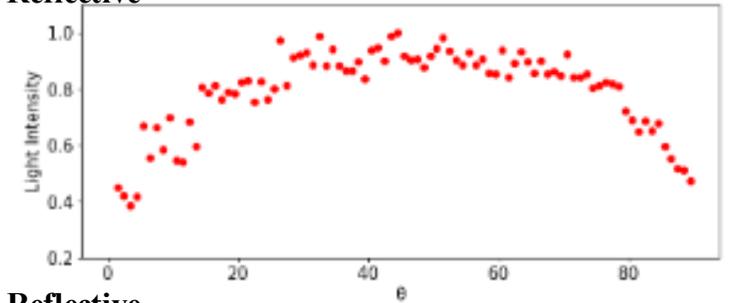


Improving assembly and disassembly

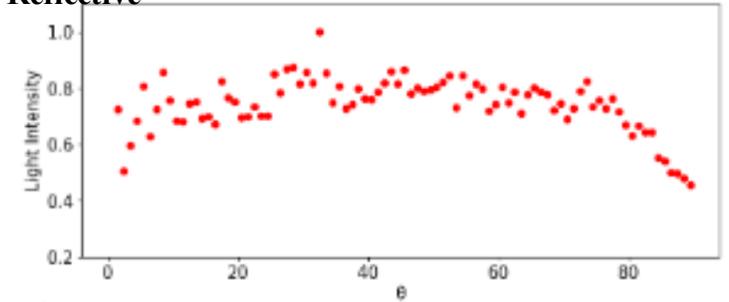
Improving isotropic emission profile



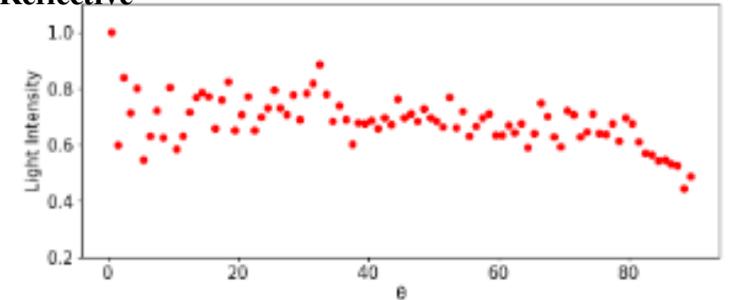
80% Reflective



50% Reflective



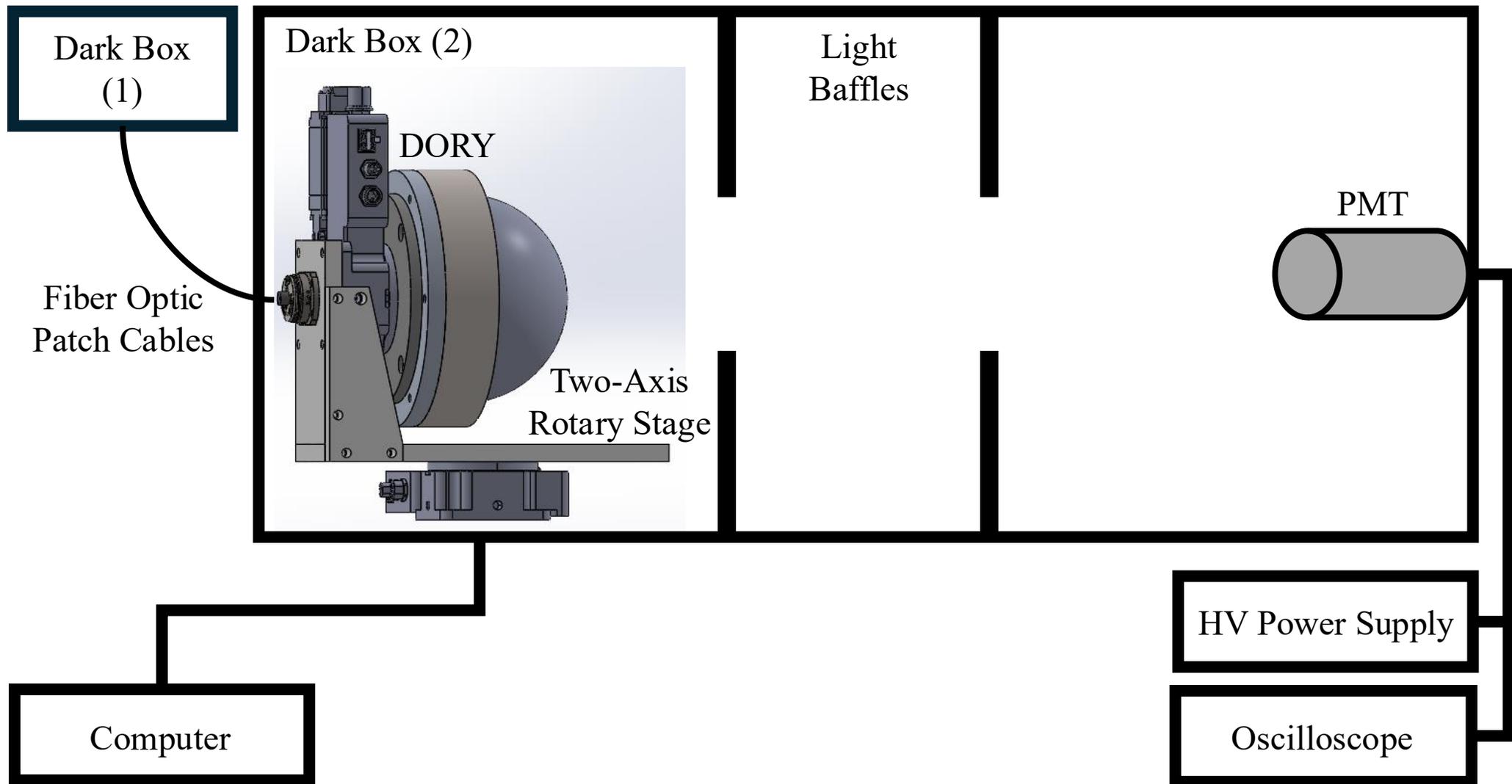
0% Reflective



Light intensity per solid angle as function of zenith angle

Cite: Irina Nitu

DORY Test Setup



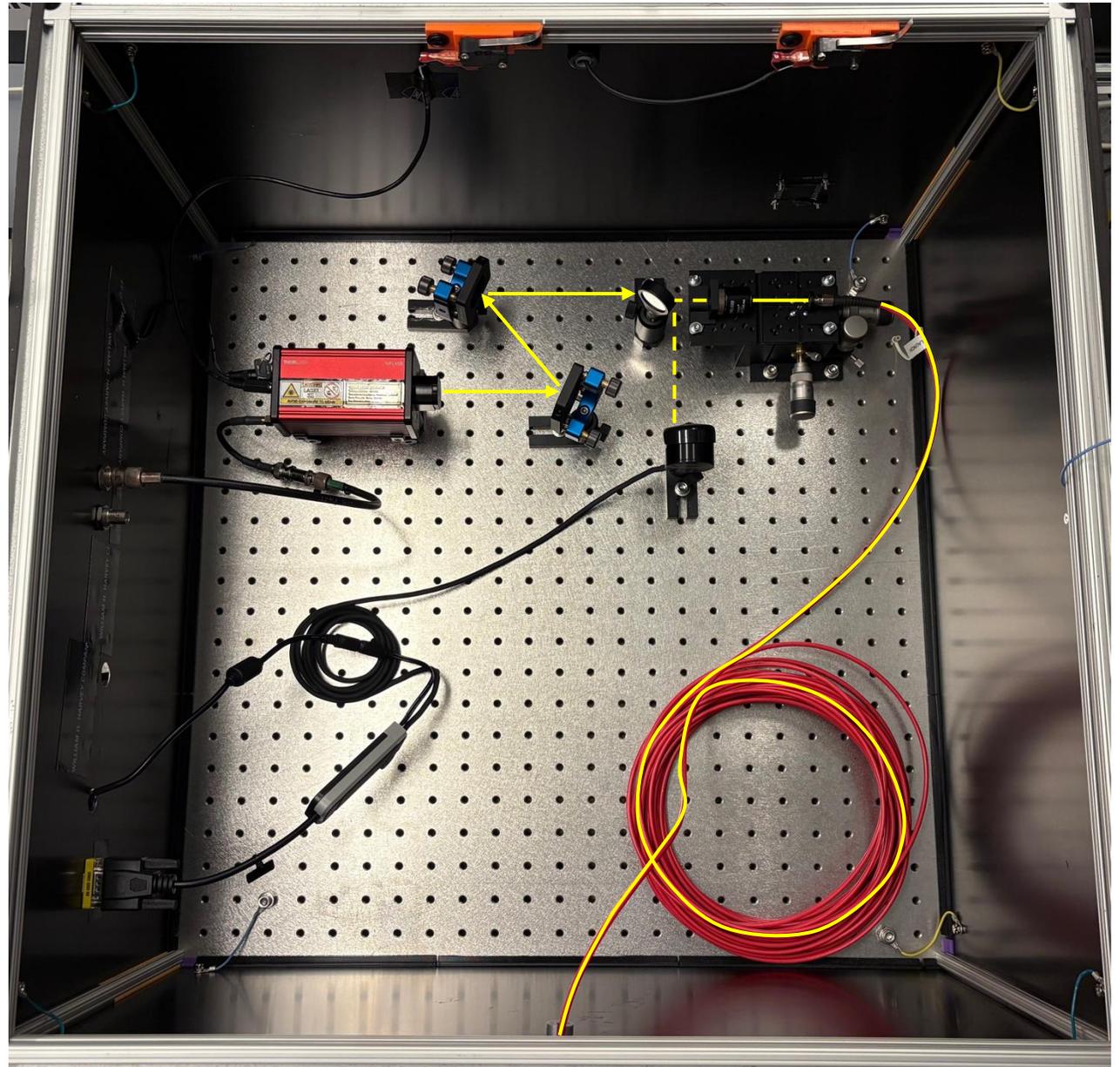
Laser Control Dark Box

Components

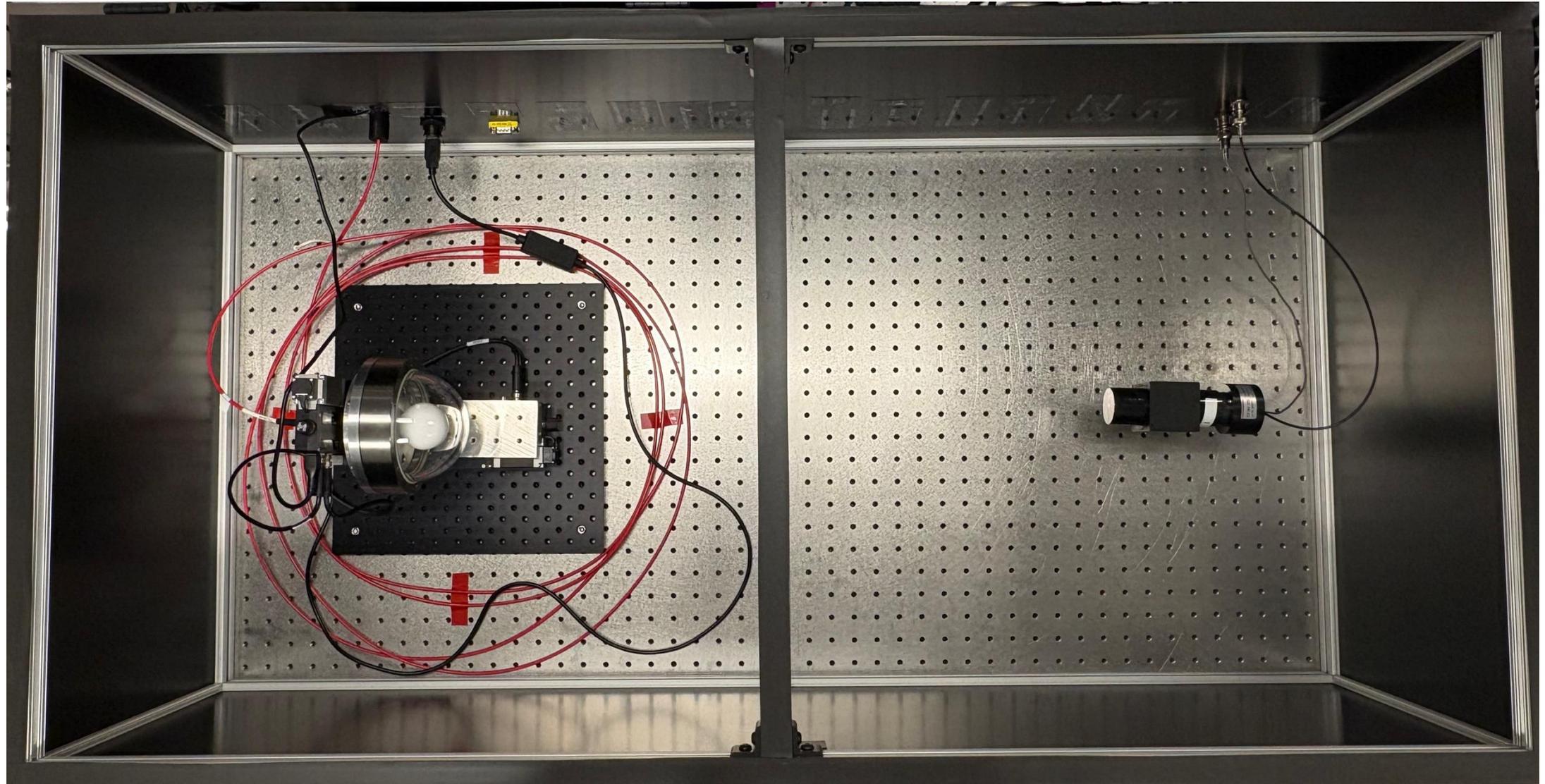
- Laser: Thorlabs NPL45B, 450 nm
- Fiber Launcher: Thorlabs MBT613D
- Fiber: Thorlabs UM22-600
- Power Meter: Gentec-EO PH100-Si-HA-IDR-D0
- Optics: 2 mirrors, 1 beam splitter (50:50)
- Laser Triggering: Function generator
 - Square wave
 - 2 MHz
 - 5 Vpp
 - 0 V offset
 - 50% duty cycle

Laser output power: 0.5 mW

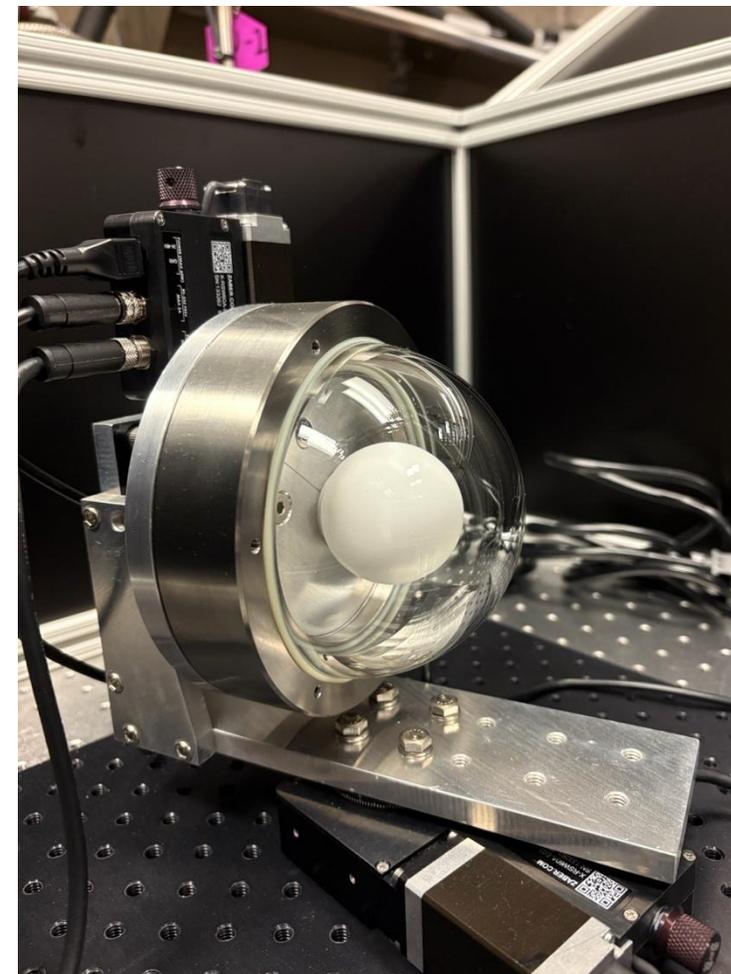
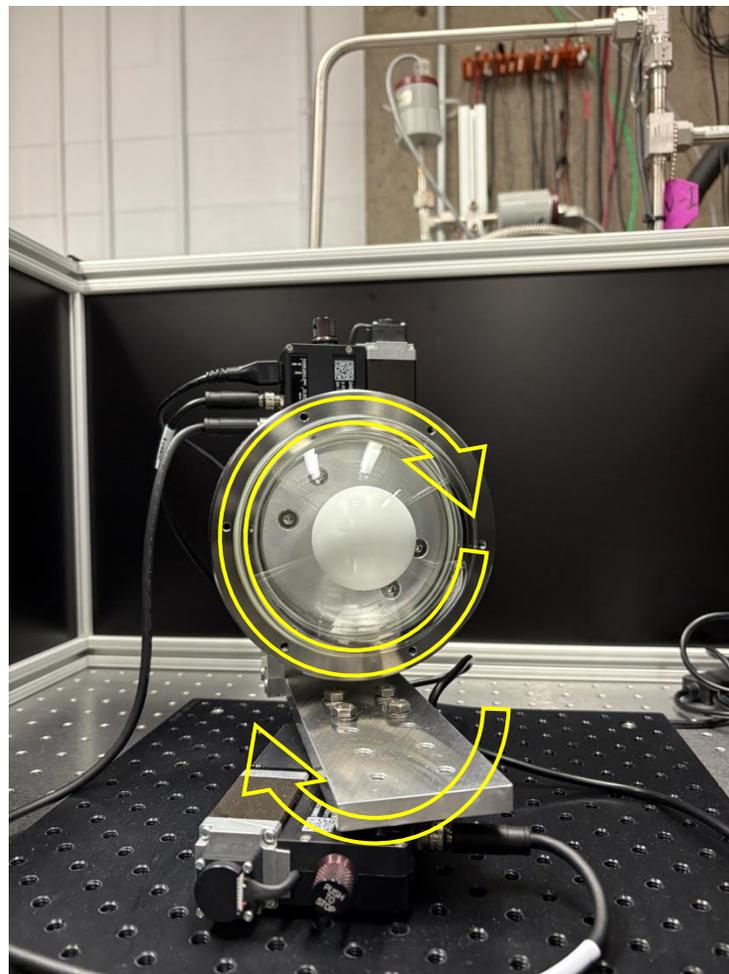
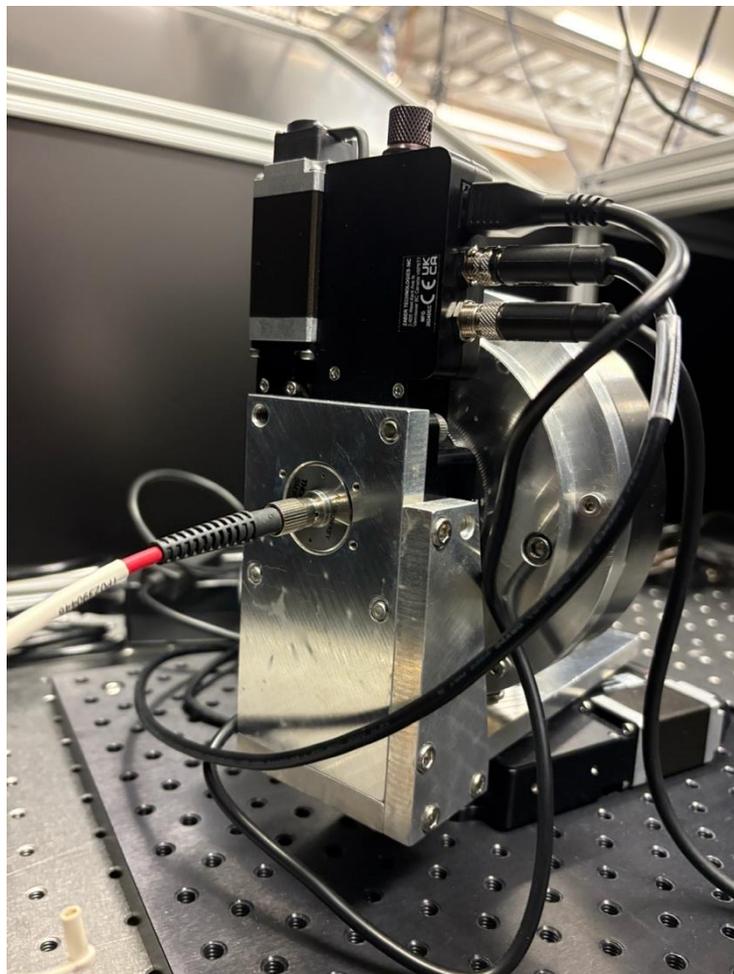
Fiber output power: 0.3 mW



Main Dark Box

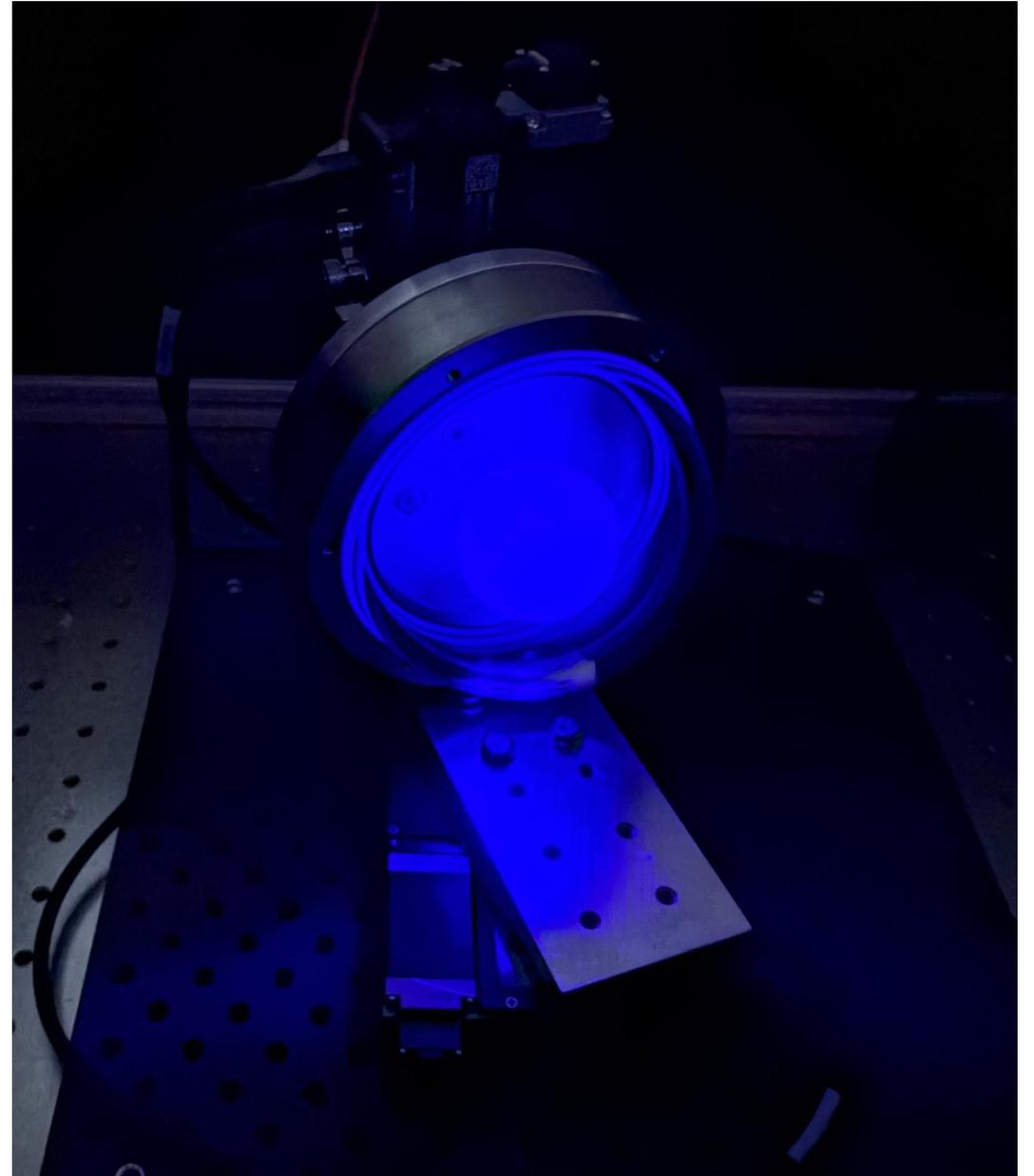


Main Dark Box

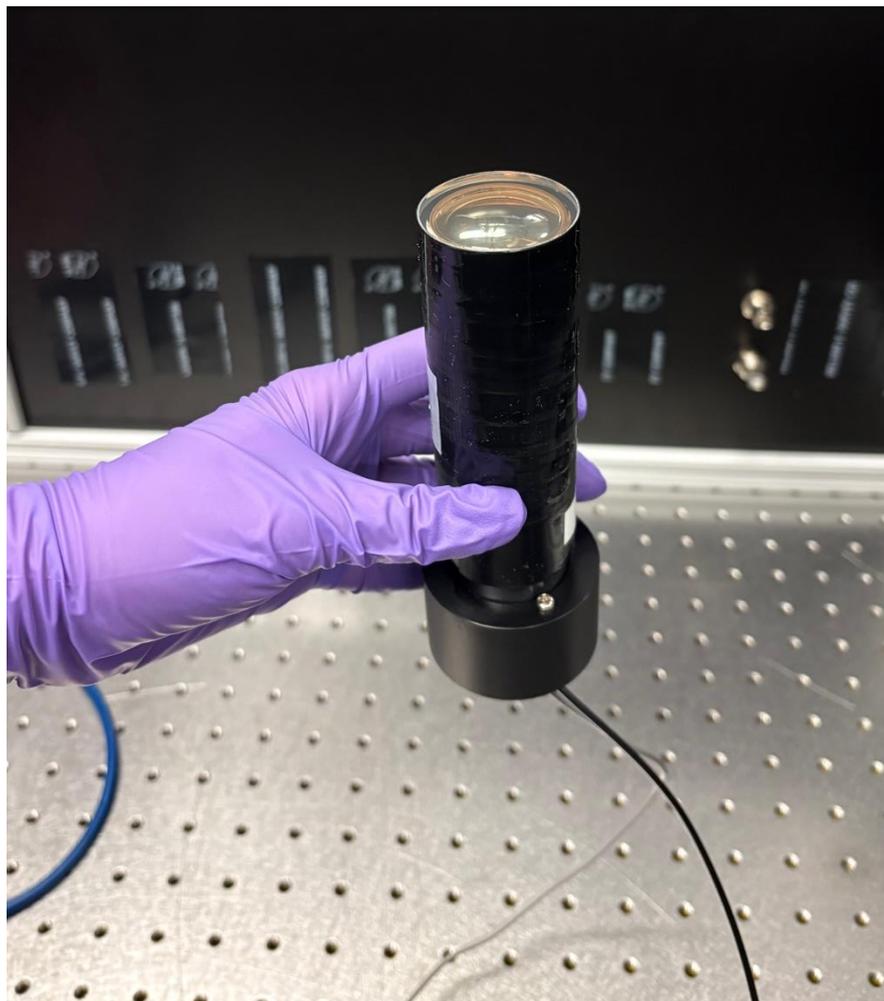


Motorized two-axis rotary stage with DORY mounted

DORY at Work

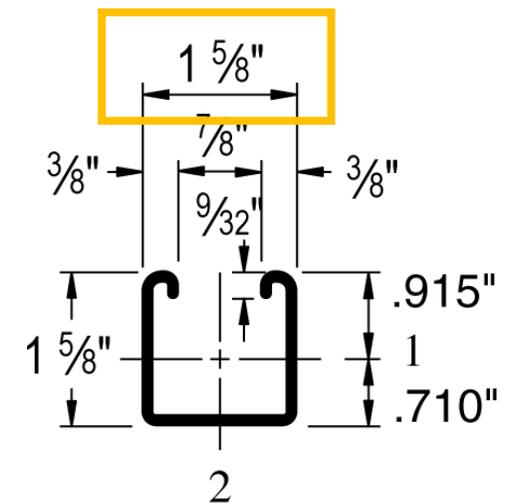
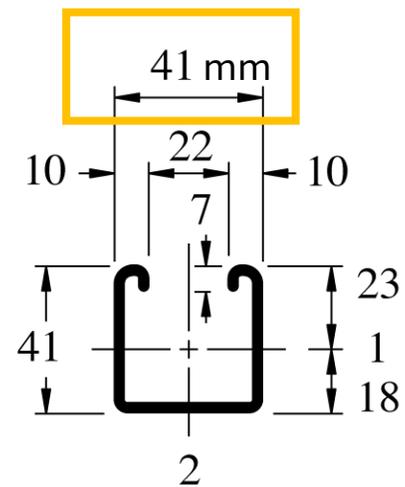
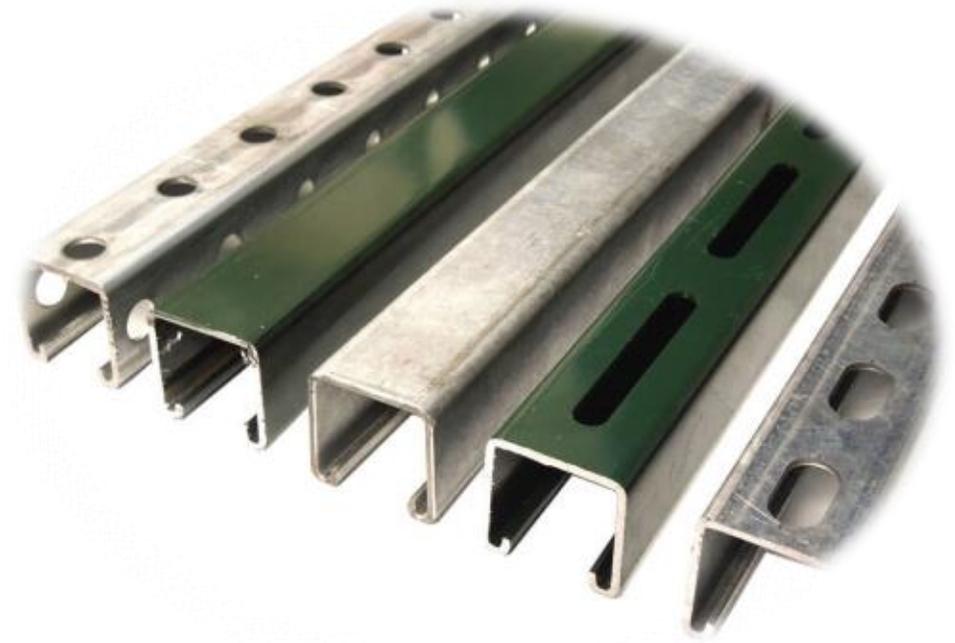
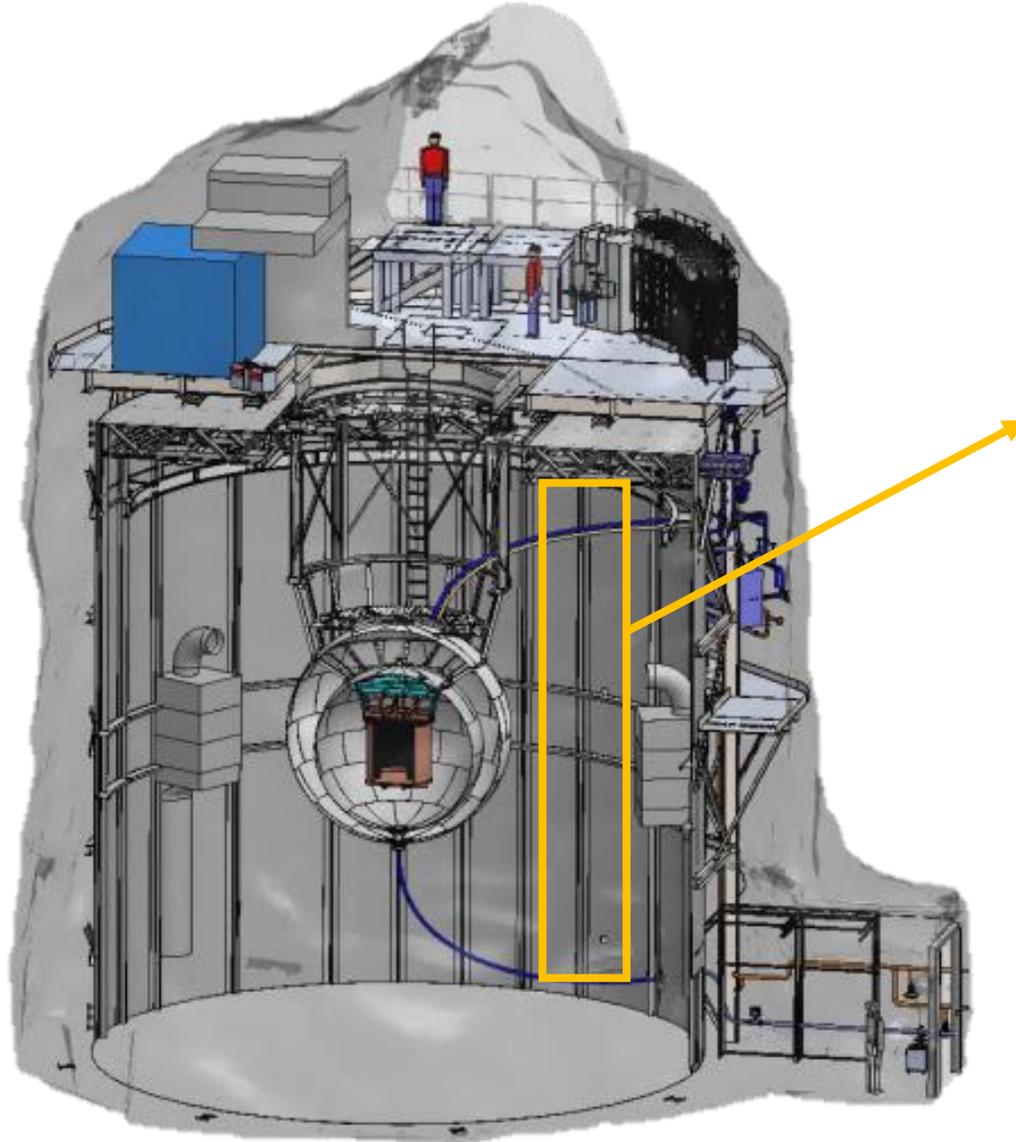


Main Dark Box

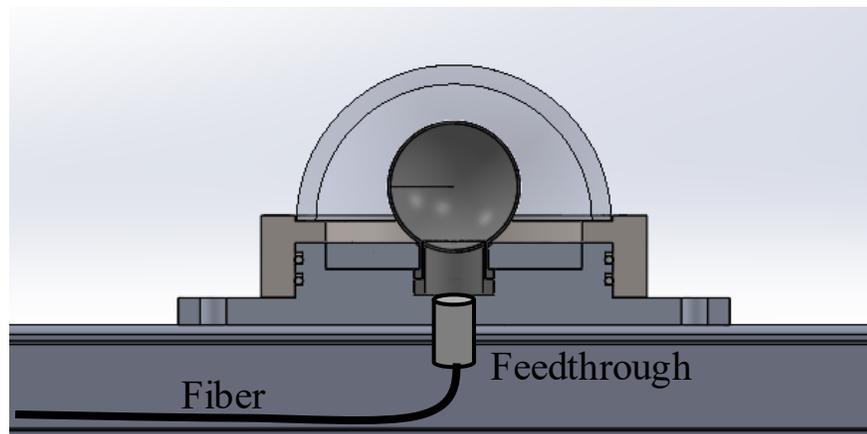
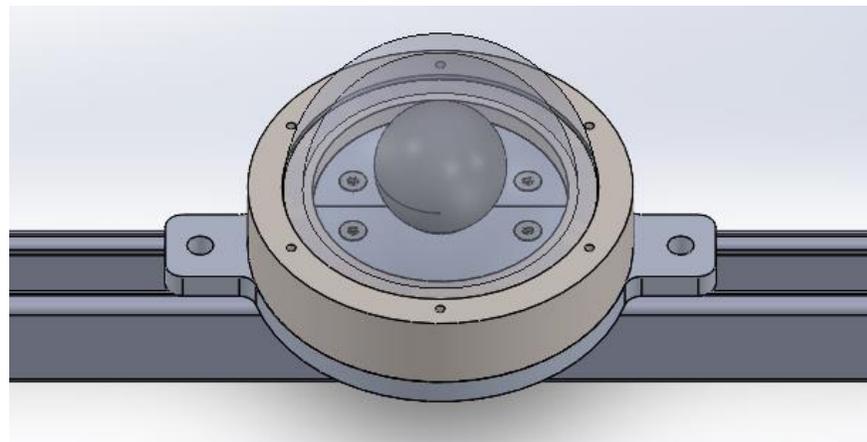
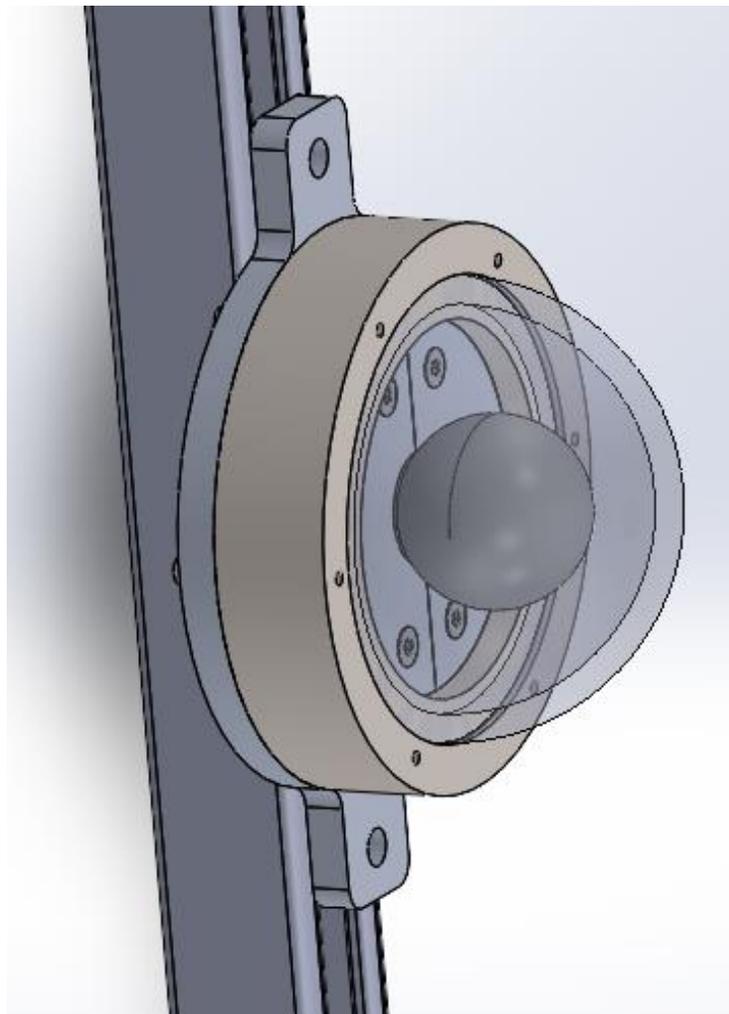
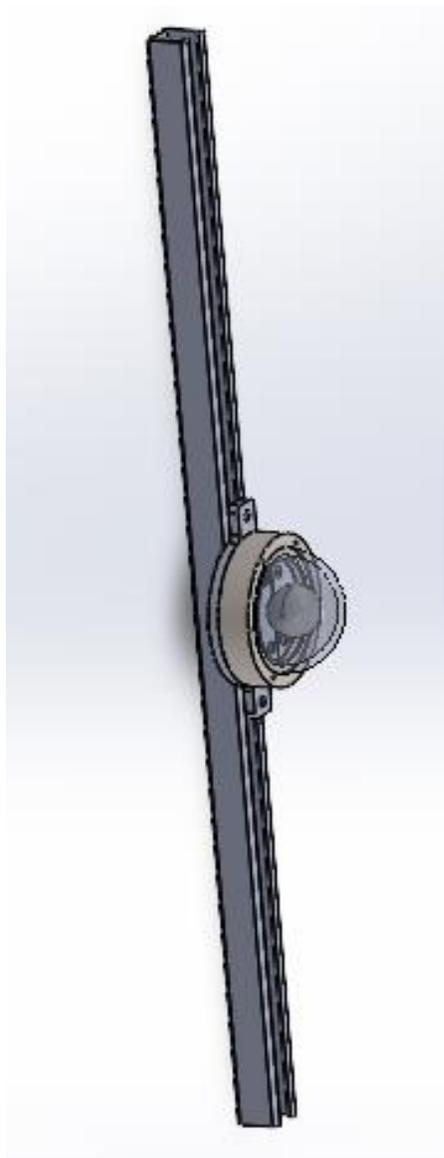


PMT for recording the DORY emission profile and its HV power supply

Installation of DORY in the OD Water Tank



Installation of DORY in the OD Water Tank

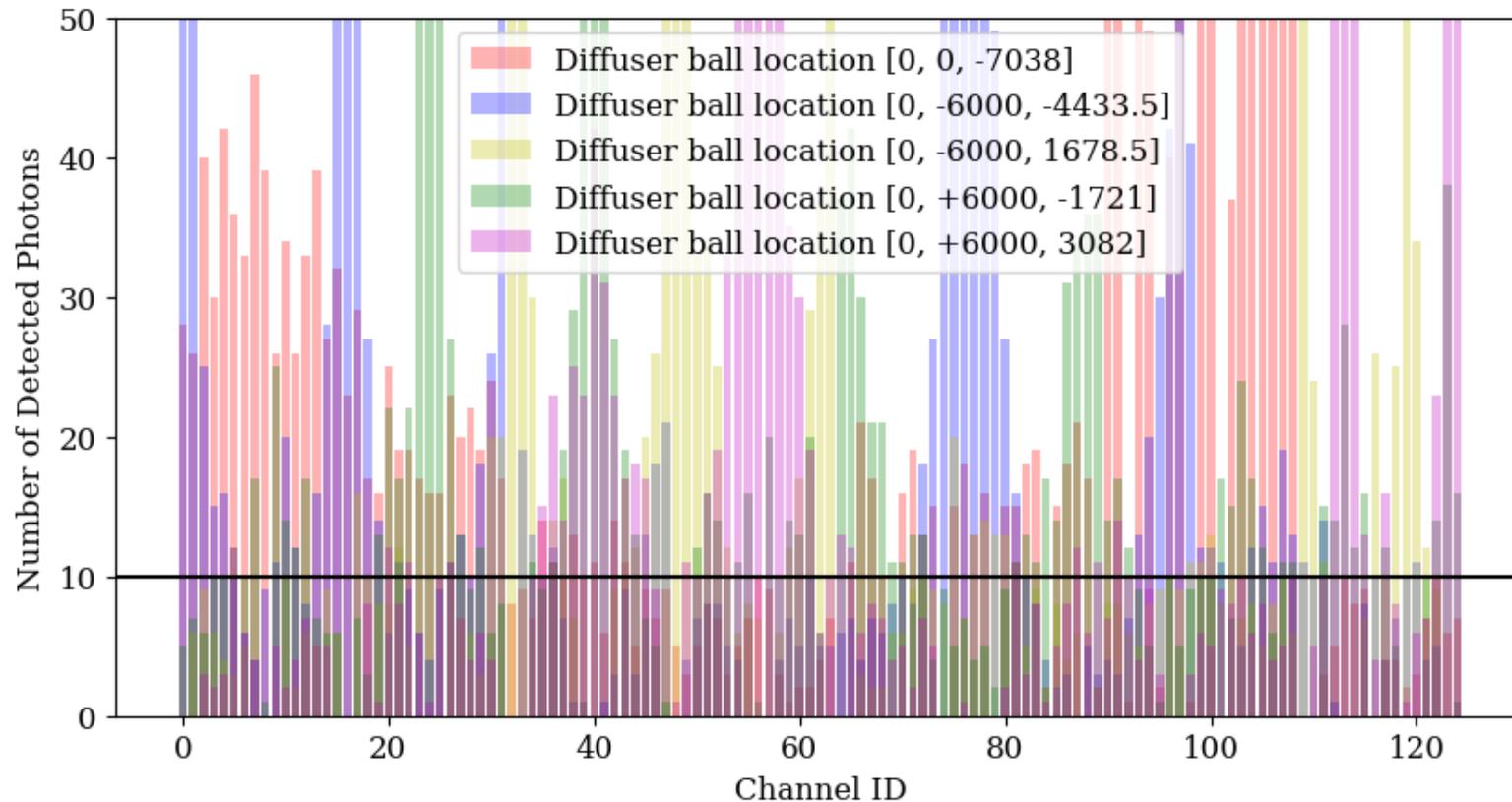


Not drawn to scale.

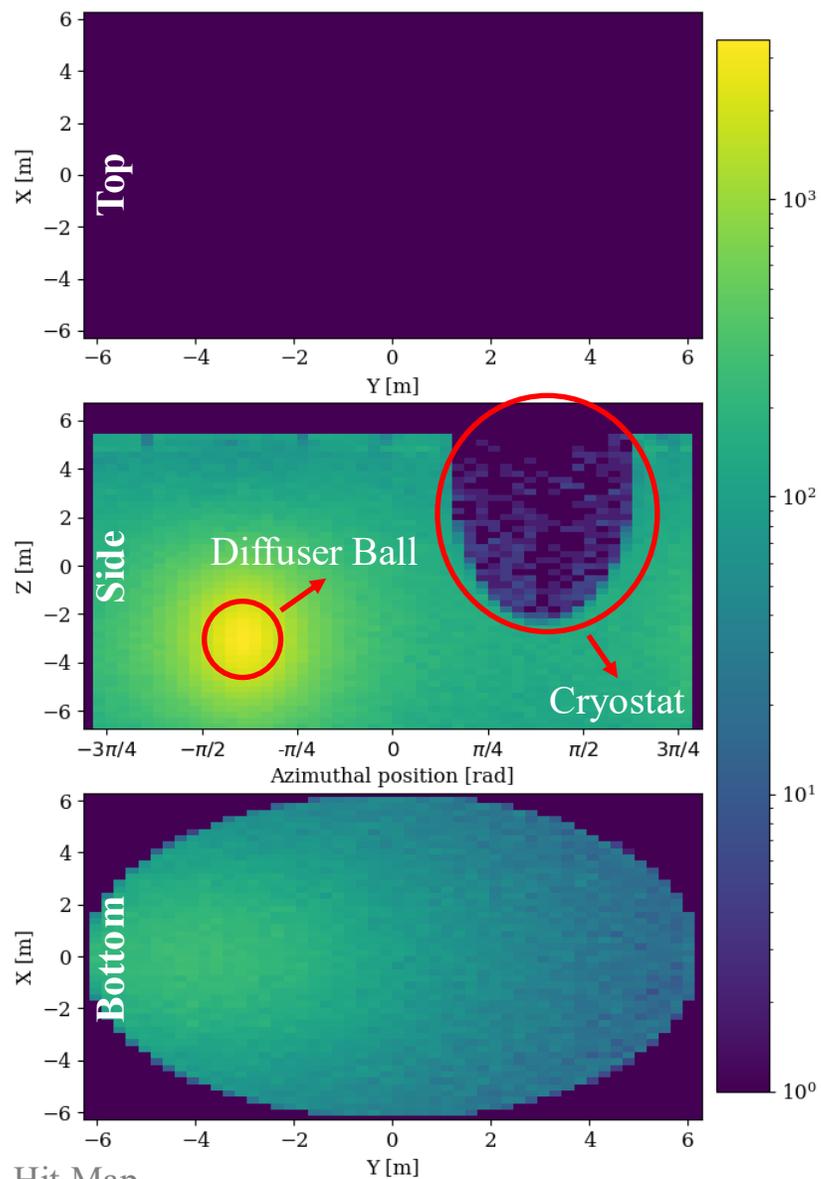
Simulation: Concept Validation & Optimization

An effective monitoring and calibration system:

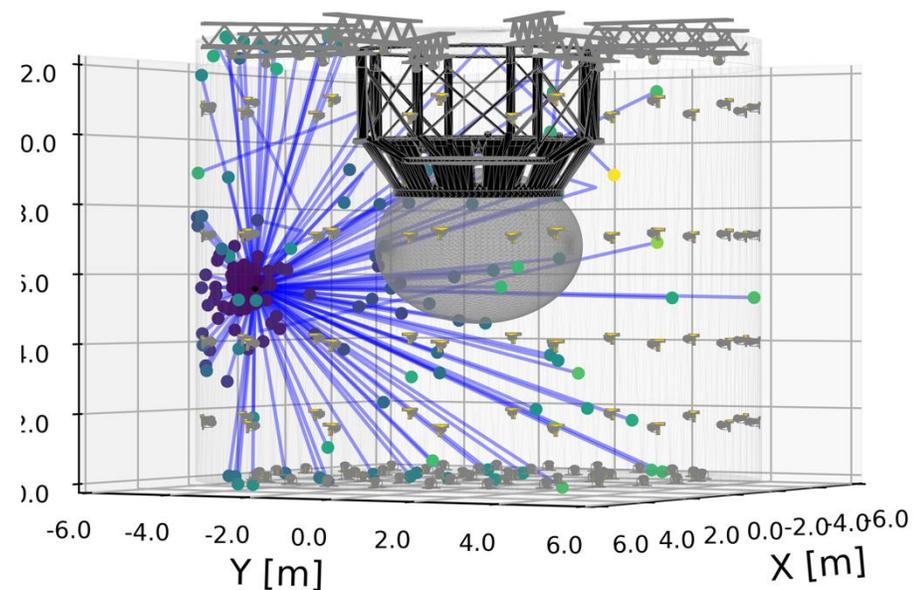
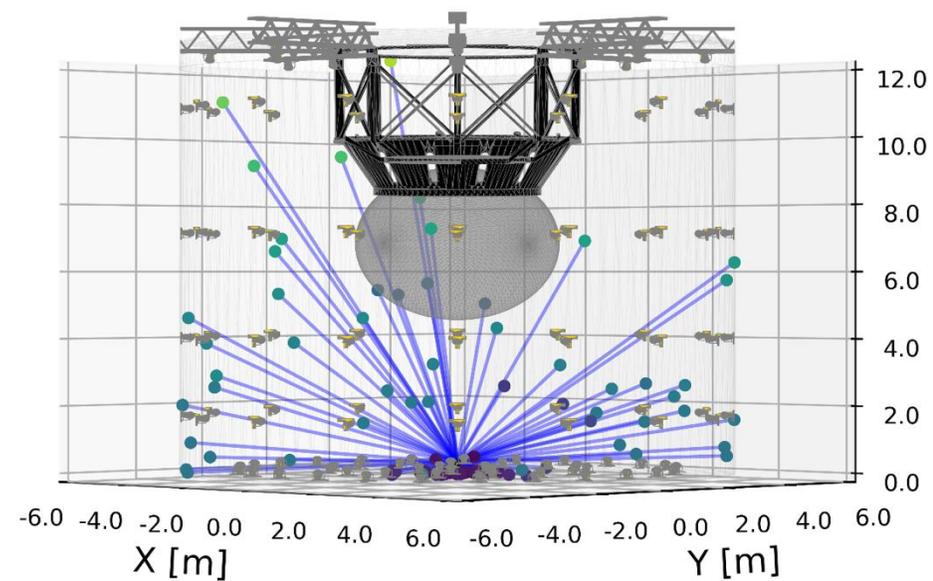
- All PMTs receive at least 10 photons and no more than 10^7 photons per second.
- Each PMT is illuminated by **at least** one Dory such that it receives between 10 and 10^7 photons per second. (For some PMTs, multiple Dory units can provide this illumination.)



Simulation: Concept Validation & Optimization

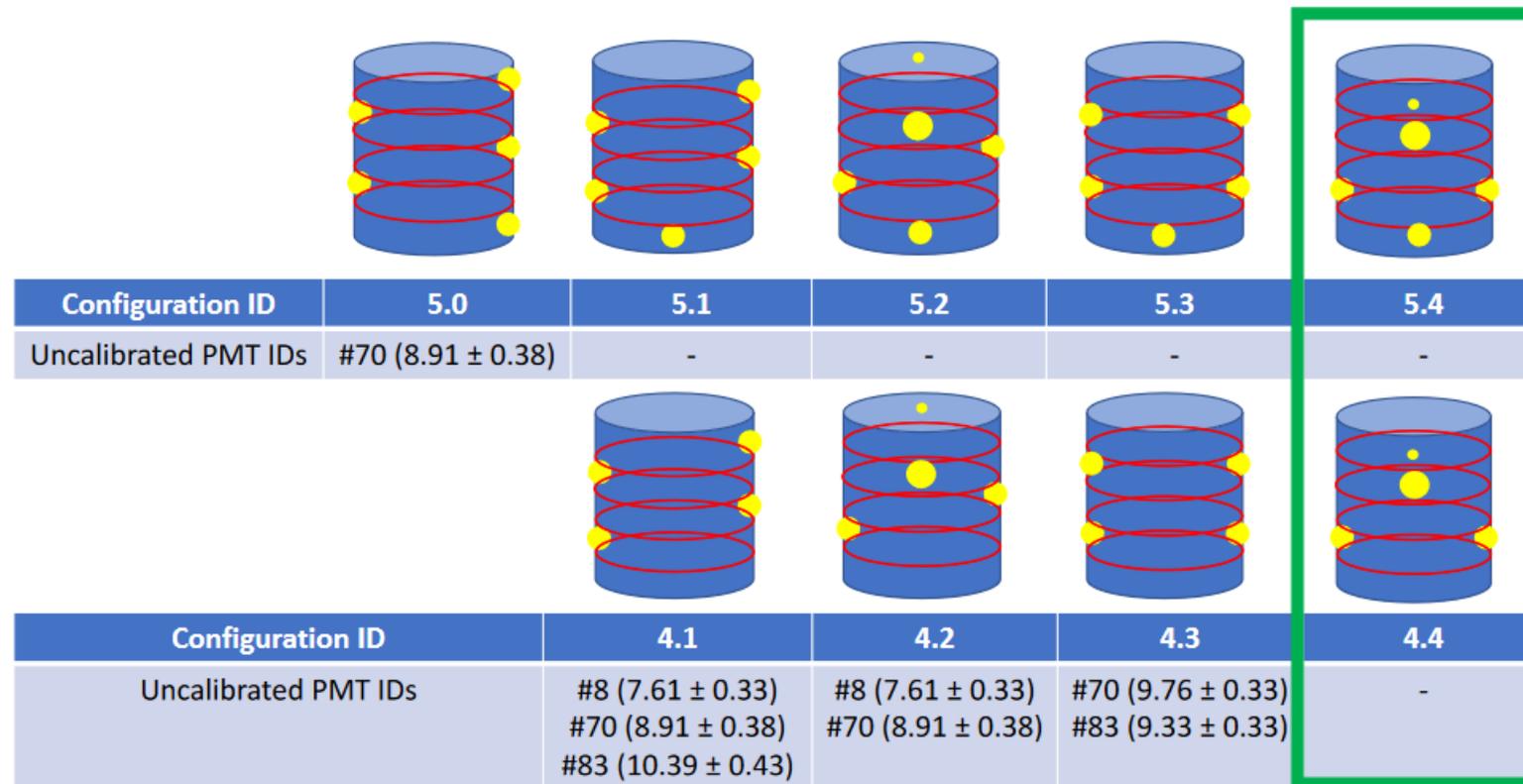


Hit Map



Simulation: Concept Validation & Optimization

- A single DORY cannot illuminate all PMTs due to shadowing by the cryostat.
- Using two or three DORY units requires high initial light intensity, causing saturation of nearby PMTs.
- Four DORY units can illuminate all PMTs in a specific configuration.
- We chose **five DORY units** as the optimal setup to ensure full coverage and provide redundancy in case one unit fails.
- As long as the five DORY units are distributed **uniformly** around the tank, the system operates effectively.



Cite: Irina Nitu

Talk in a Nutshell

DORY Development

First prototype built
Upgrades Planned

Test Setup

Characterizing full angular emission
Test setup prepared and ready for data collection.

Installation

DORY Units mounted on floor or walls using Unistruts

Simulation Work

Concept validated with Chroma
Optimized system parameters

Even if nEXO doesn't happen...

Check out our recent publication in the latest issue of Physics in Canada (PiC) — [2025, Volume 81, pages 47–52.](#)

DORY

