Using Chroma Ray-Tracing Software to Determine the Trigger Conditions for nEXO's Outer Detector

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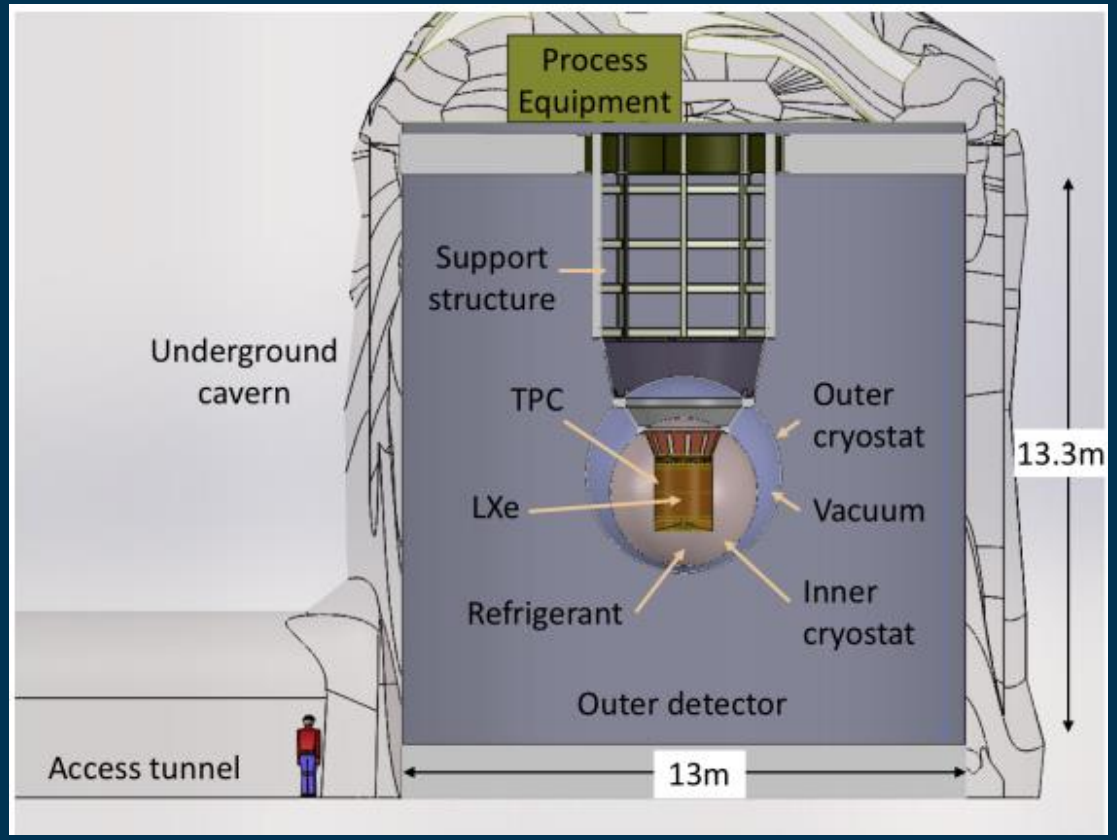
Canada

nEXO

What is nEXO?

- The goal of nEXO is to find neutrino-less double beta decay. This would demonstrate the neutrino as a Majorana particle, which is physics beyond the standard model
- It involves 5 tonnes of liquid xenon enriched to 90% ^{136}Xe inside a Time Projection Chamber (TPC) to be installed ~2km underground at SNOLAB
- The Cryostat containing the TPC is suspended within a cylindrical water tank

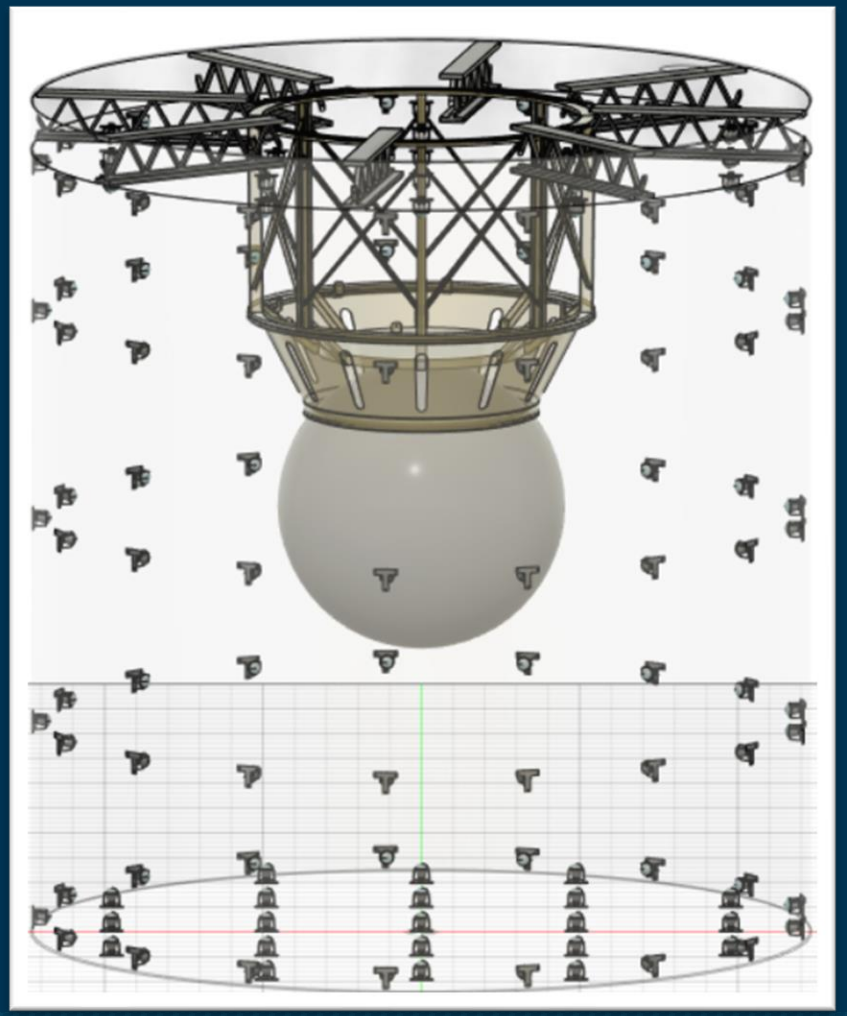


nEXO pre-conceptual design report[1]

1 S. Al Kharusi, A. Alamre, J.B. Albert et al., "nEXO Pre-Conceptual Design Report", arXiv:1805.11142v2, Aug. 2018.

the Outer Detector

- The Outer Detector (OD) is the water tank equipped with Photomultiplier Tubes (PMTs) to observe Cherenkov radiation from muons.
- Fast neutrons induced by cosmic muons that reach the TPC can be captured on ^{136}Xe
- This could create ^{137}Xe, whose decay can mimic the 0νββ signal
- A layer of cover gas is used in the OD

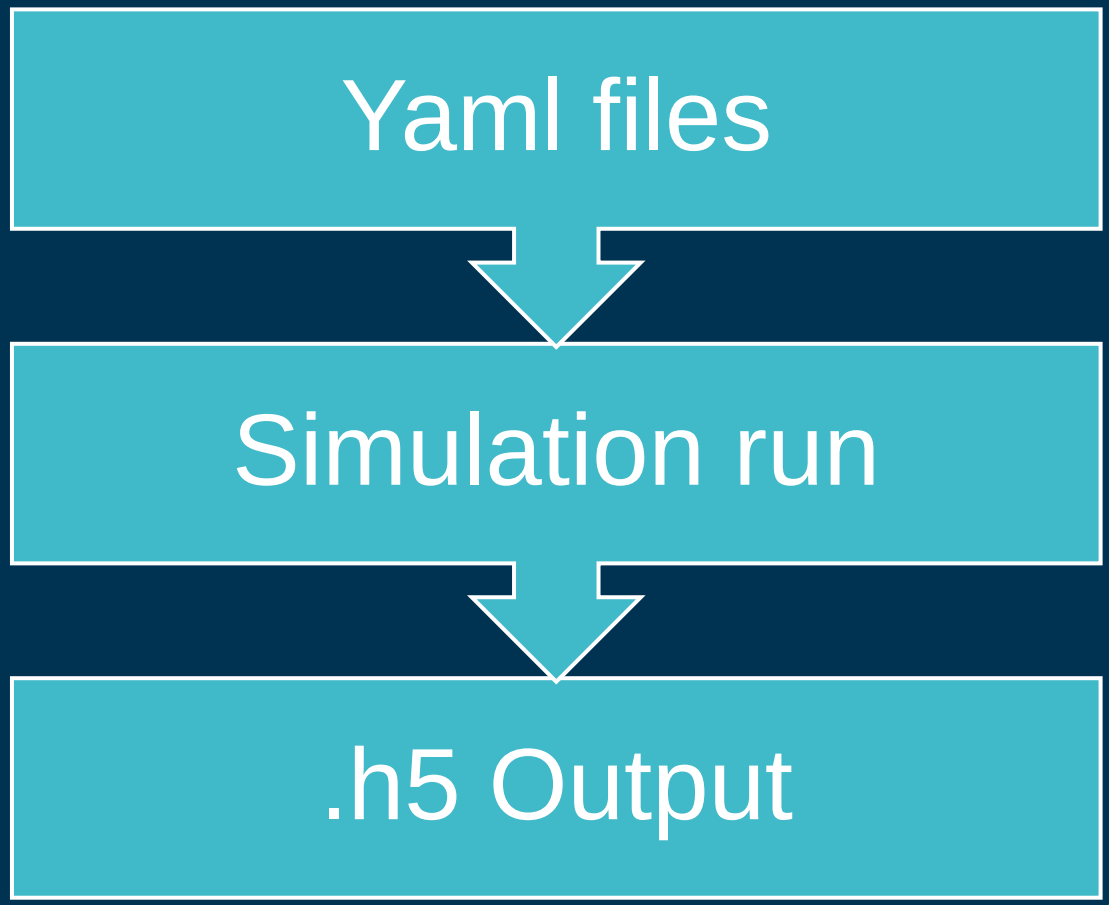


What is Chroma

- Chroma is a highly parallelized GPU based ray tracing tool
- We chose to use Chroma because this parallelization made the simulations ~100 times faster when compared to similar Geant 4 simulations
- Physics processes are dealt with externally
- Muon path and Cherenkov photon generation code separate from chroma
  - Cherenkov angle
  - Muon paths
  - Photons per unit track length of muons
  - Photon spectrum

How Simulating With Chroma Works

- Simulation yaml includes:
  - Geometry used
  - Number of muons/photons
  - Type of generator
  - Materials in geometry
- Optical properties yaml includes:
  - Index of refraction
  - Scattering length
  - Detection
  - Absorption



Trigger Conditions Considered

Analysis begins with 3 conditions:

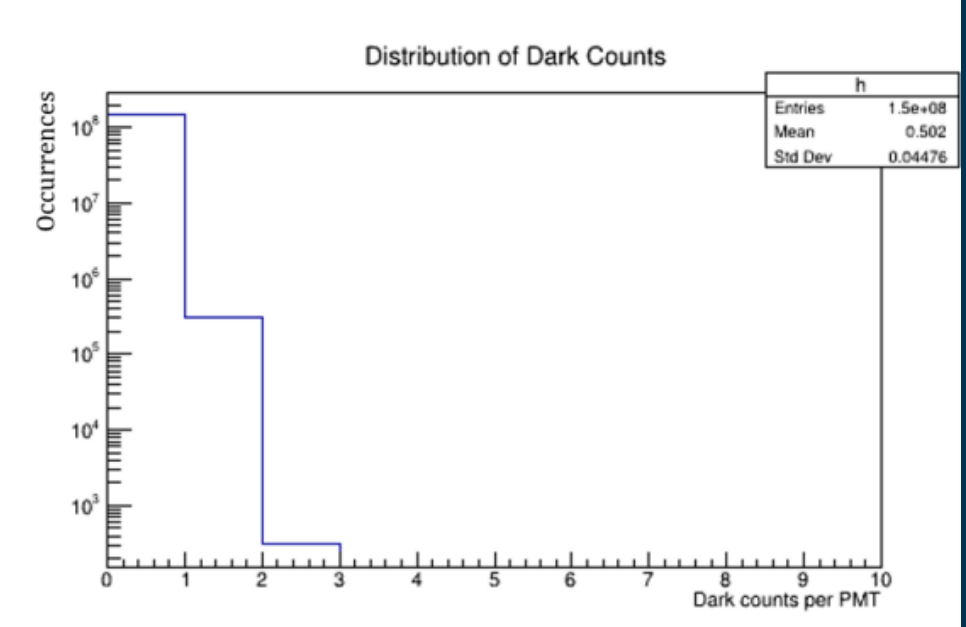
Counts per PMT	Photons a PMT needs to be considered hit
Time window	Time limit for PMT hits to be considered coincident
Number of PMTs	Separate PMTs needed to register as hits for the muon to be considered tagged

Factors that Determine These Trigger Conditions

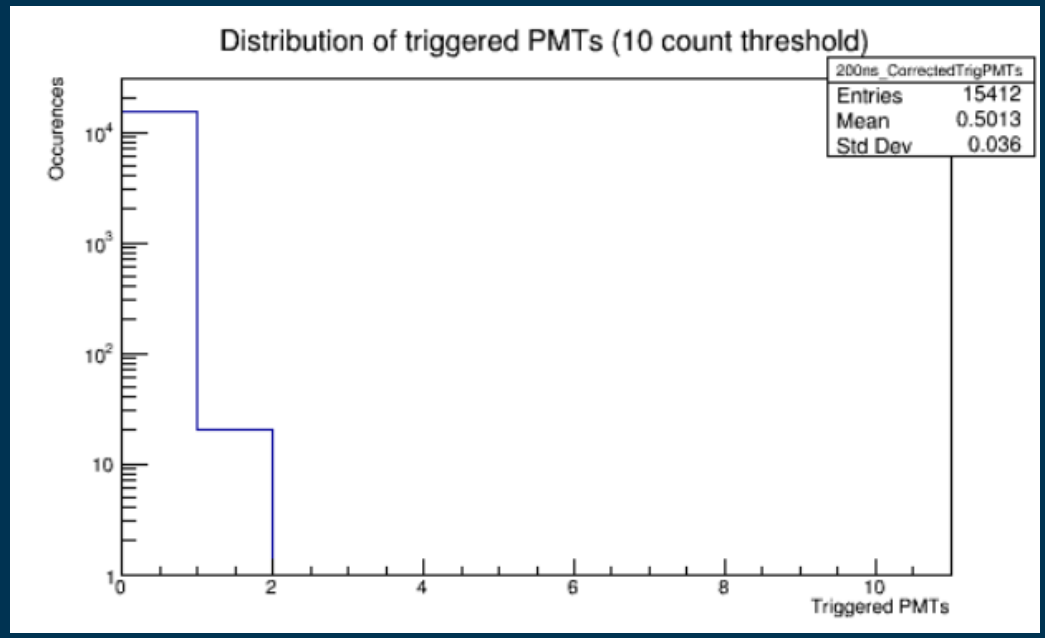
Background counts

- PMT dark rate
- Gamma radiation in surrounding rock

Preliminary values were previously calculated by Remington Hill[1]



Poisson distribution of expected dark rate counts per PMT for 150 PMT arrangement (200 ns time window)

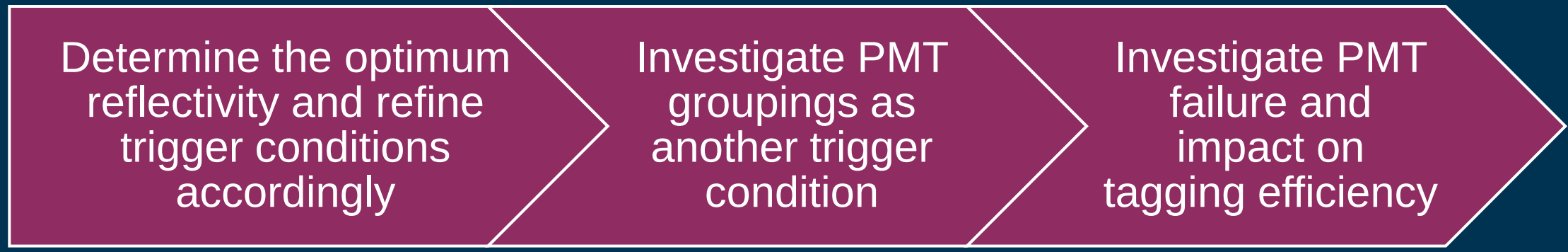


Distribution of triggered PMTs from mono-energetic 2.614 MeV gammas with a 10 count threshold

[1] R.Hill, U. Wichoski, C. Licciardi, “nEXO OD Muon Veto Efficiency”, nEXO Internal Document. March 2020

How Chroma will Help Inform Conditions

We aim to use Chroma to:



The investigation into these is ongoing

Properties Tested

- Testing was done on:
  - Quantum Efficiency of PMTs
    - QE angular dependence in Chroma
  - Reflectivity
  - Absorption
  - Index of refraction
- Component interfaces were tested
- Testing was done through small scale simulations
- Various geometries created specifically for tests

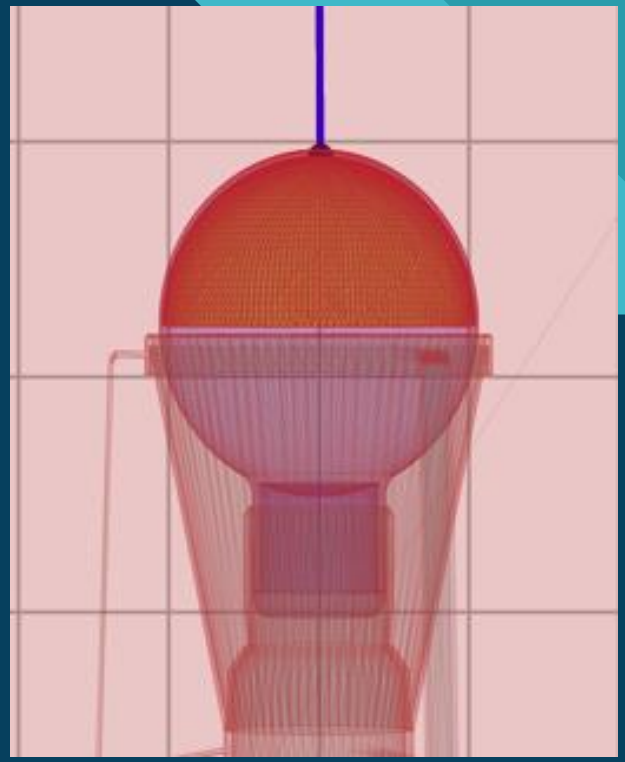
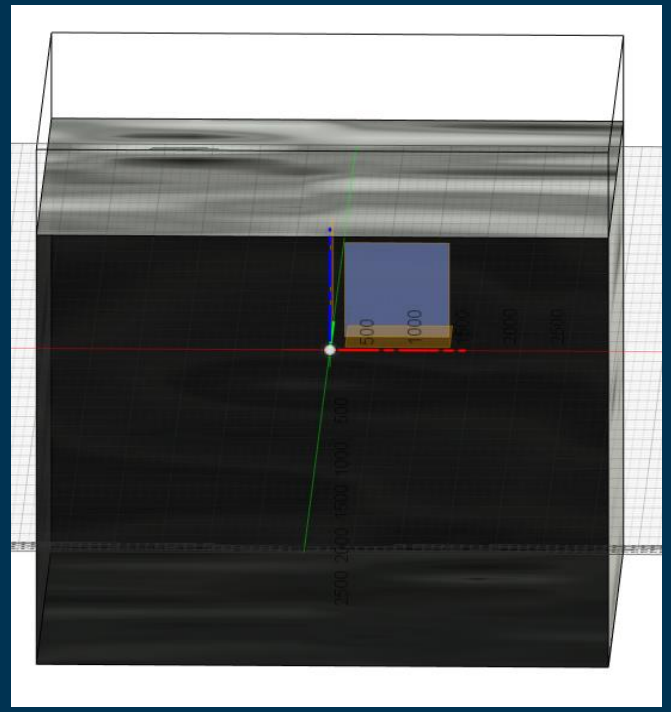


Figure of photons hitting the center of fully absorbing PMT

Testing Geometries

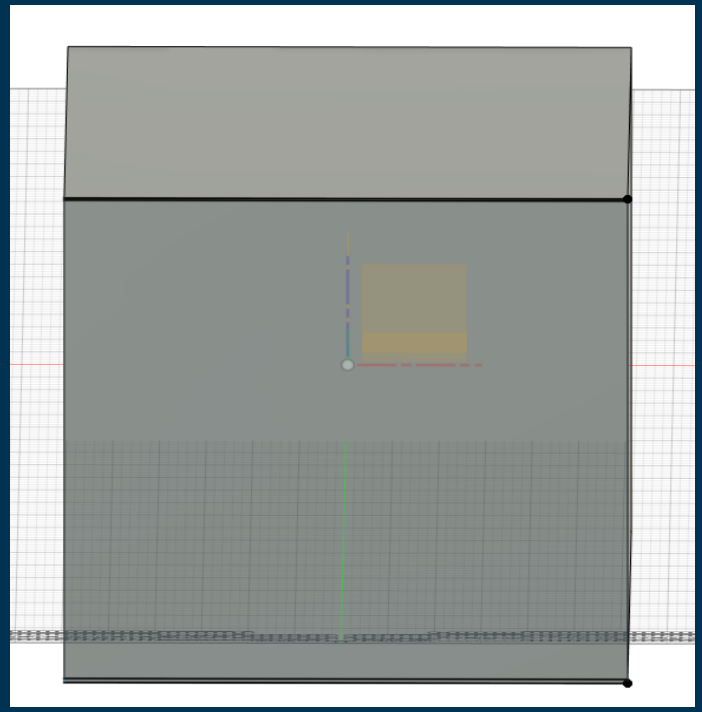
Separated Cube

- Used for tests involving the interfacing of two material



Border Box

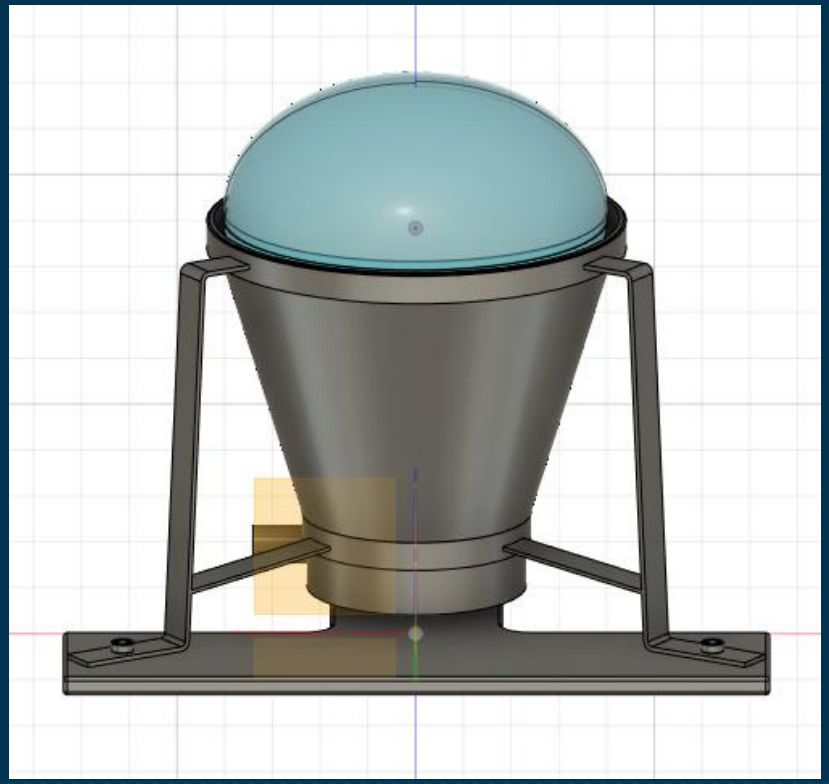
- Hollow box used to surround the separated cube geometry and act as an exterior similar to the water tank



Testing Geometries

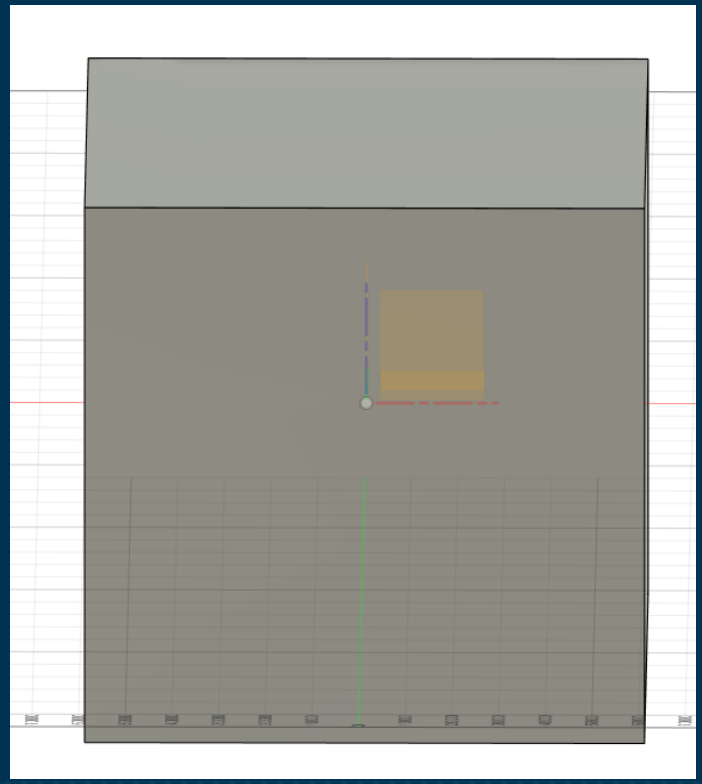
Photo-Multiplier Tube

- Used for tests involving the detection of PMTs



Detector

- Hollow box used to envelop all tests to ensure all photons interact and are therefore plotted



Reflectivity Check

- Separated cube used with the border box for testing reflectivity
- Number reflected = number detected
- For 100 000 photons 39 520 were reflected. Very close to expected 40%

```
StainlessSteel: #will vary for tests
  SpecularReflectivity: 0.4
  Absorption: 0.6
  #DiffuseReflectivity: 0.05
```

Optical properties used in test

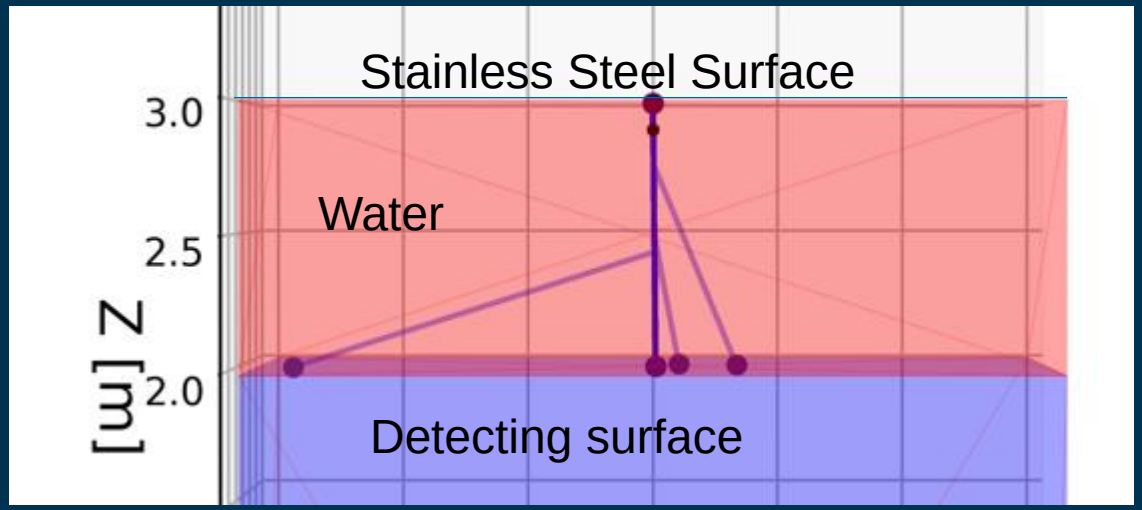
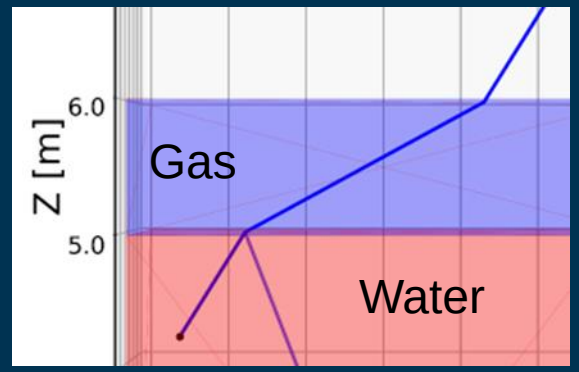


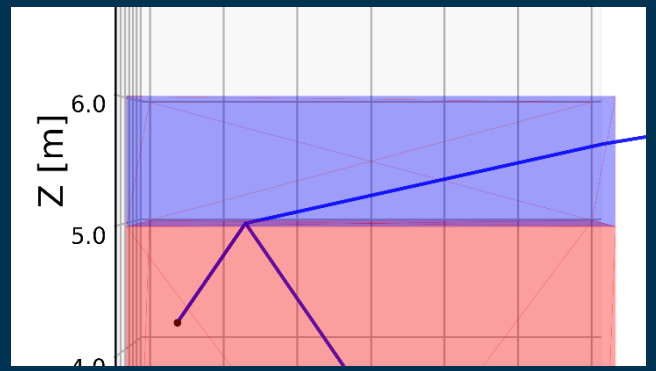
Diagram of the reflectivity test run

Total Internal Reflection

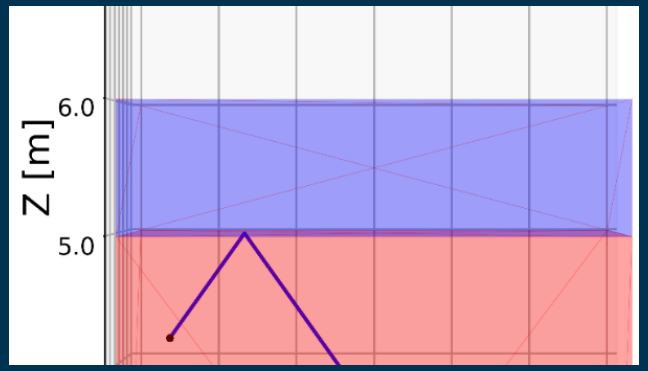
- In this test, the split box was used with the top (blue) considered to be nitrogen gas and the bottom (red) considered to be water.
- A set of photons of uniform wavelength shot from the water into gas at varying angles.
- Using the Index of refraction from our files (water = 1.339, gas = 1.0003) we expected to see total internal reflection at 48.3˚



45 degrees for angle of incidence



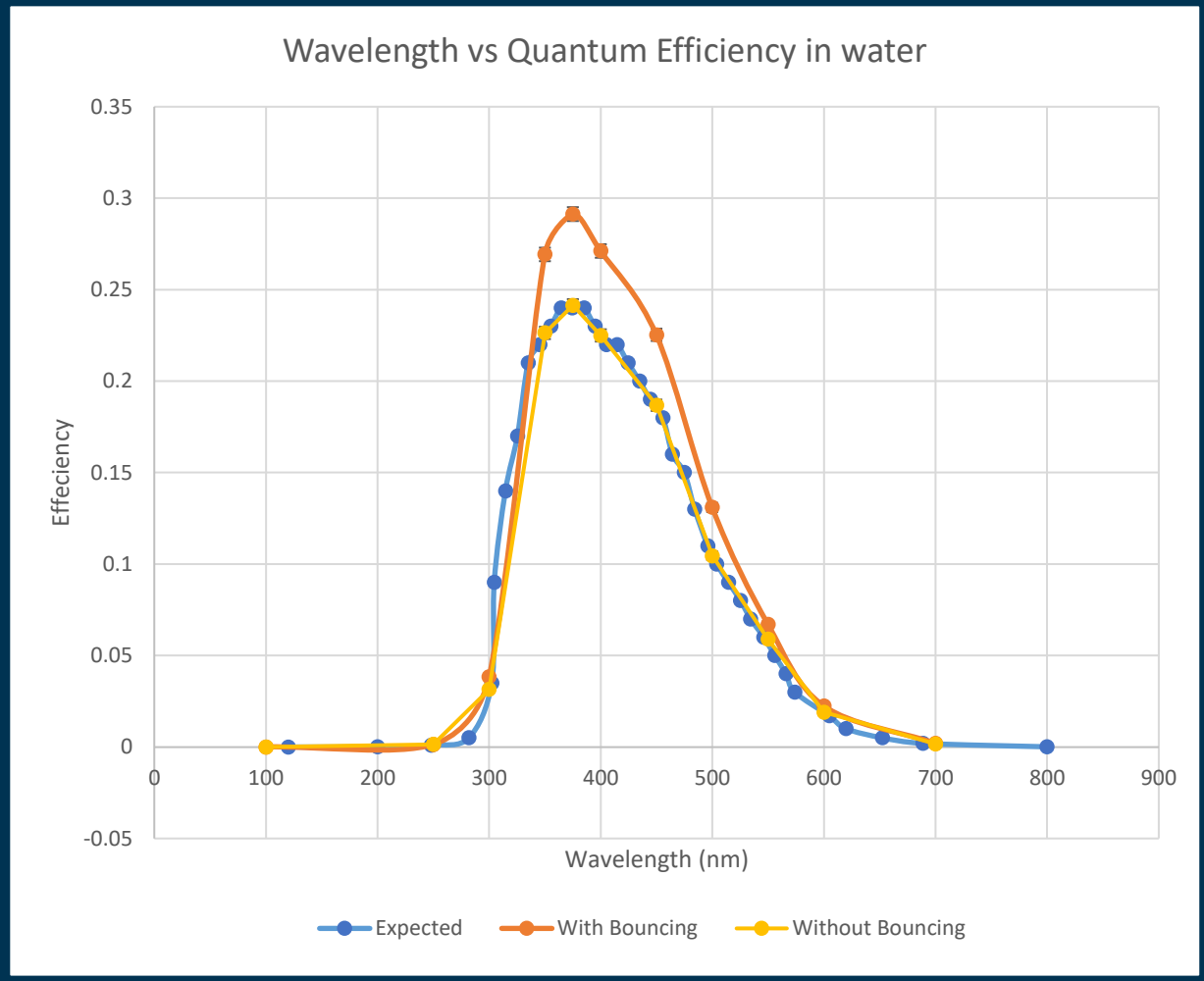
47.7 degrees for angle of incidence

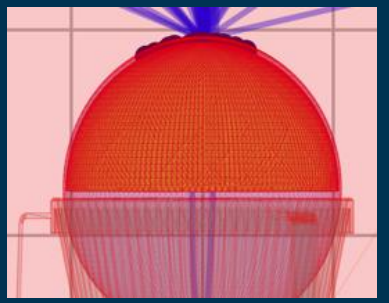


48.8 degrees for angle of incidence

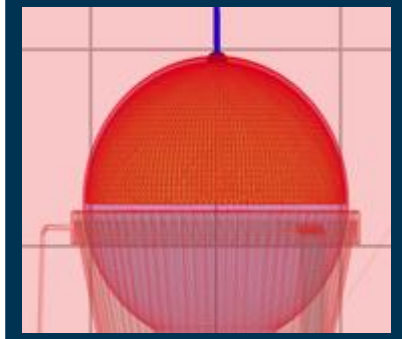
Quantum Efficiency 1

- 20 000 Photons shot to hit the direct center of photocathode
- Issue noticed where the photons would reflect inside glass
- This affected quantum efficiency
- Fixed by absorbing the photons that were not detected





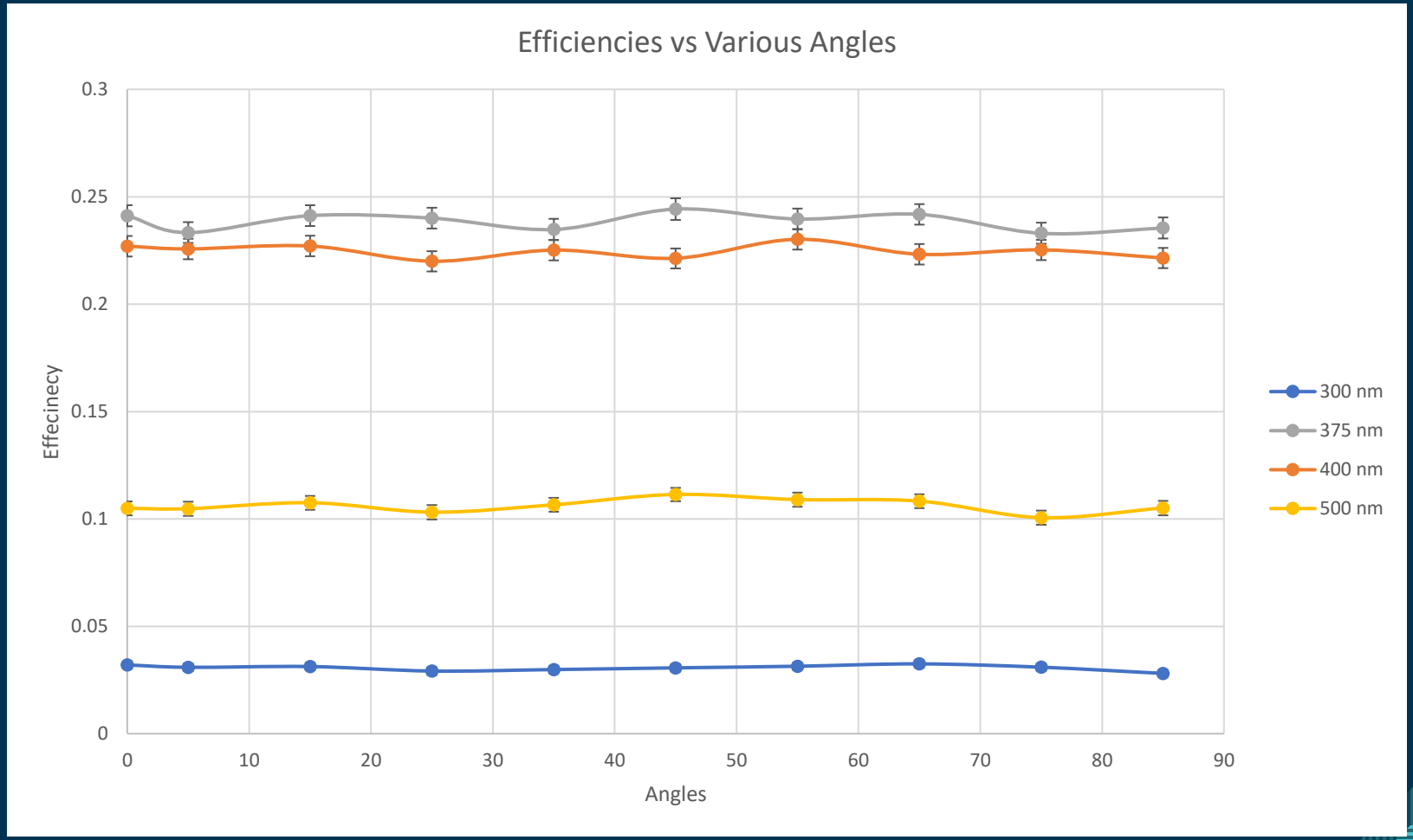
Example of the photons bouncing inside glass



Example of the photons after fixing bounce

Quantum Efficiency 2

- 20000 Photons shot at various angles to see how this affected quantum efficiency
- Expected non-angular QE
  - 0.035 for 300 nm
  - 0.24 for 375 nm
  - 0.22 for 400 nm
  - 0.1 for 500 nm
- The angle did not seem to have a noticeable effect.
- We expected to see some variation so further investigation will follow



Conclusion

- Despite having tested many properties, there are a few more to test before finishing:
  - Investigating angular PMT response
  - Murky water
  - Absorption and scattering length
  - Absorbing interfaces shared by two bodies
- Once these have finished, the Chroma results will then be used to help finalize PMT placement, reflectivity, and trigger conditions

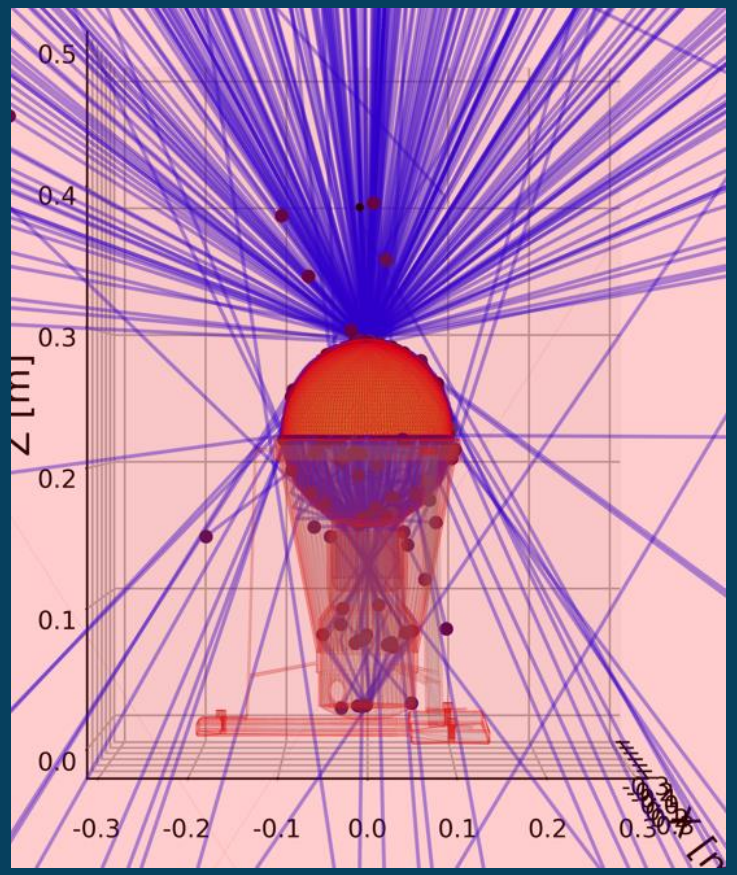
Aknowledgements

I would like to thank everybody who helped me and guided me through the year especially

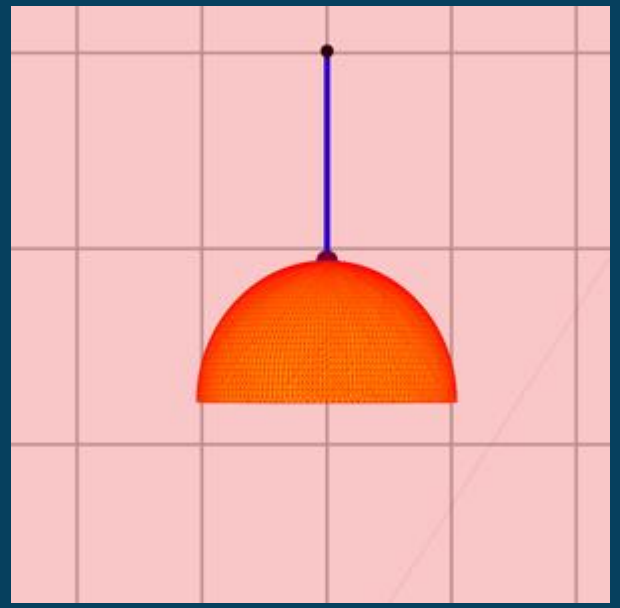
- Regan Ross
- Soud Al Kharusi
- Dr. Erica Caden
- Dr. Caio Licciardi

I would also like to thank Megan McArthur and W. C. Chen for helping to set up Star server to make all the optical properties tests much quicker and easier

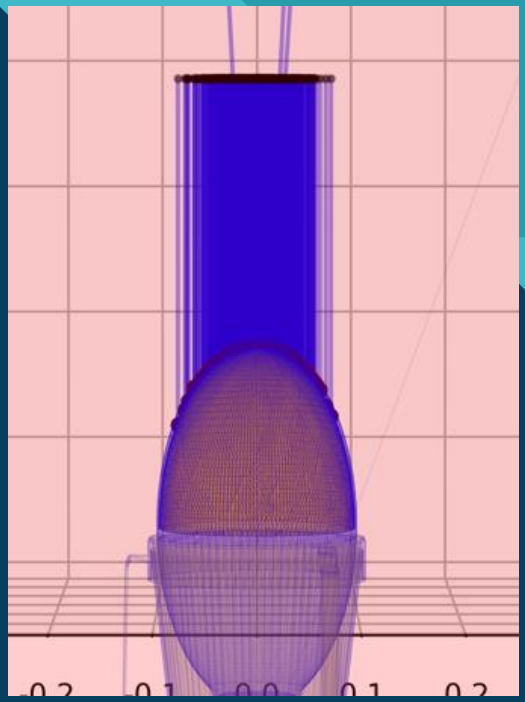
Backup slides/Photos



Fun super bouncing plot



Photocathode only plot



Angular/ Hollow beam testing

Content

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- How Chroma works

Trigger Conditions

- What conditions we consider
- Factors that affect these conditions
- How Chroma will help inform conditions

Optical Properties

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- Testing Geometries

Optical Testing Results

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- Total Internal Reflection
- Quantum Efficiency

Conclusion

- Conclusion
- Aknowledgements