Light Collection Measurements and Simulations of Wavelength Shifting Plates for Water-Cherenkov Detectors

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Introduction

Berkeley UNIVERSITY OF CALIFORNIA Nuclear Engineering

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Research Focus Area: Radiation Detection
Planned Graduation: December 2022

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Steven Dazeley
Marc Bergevin

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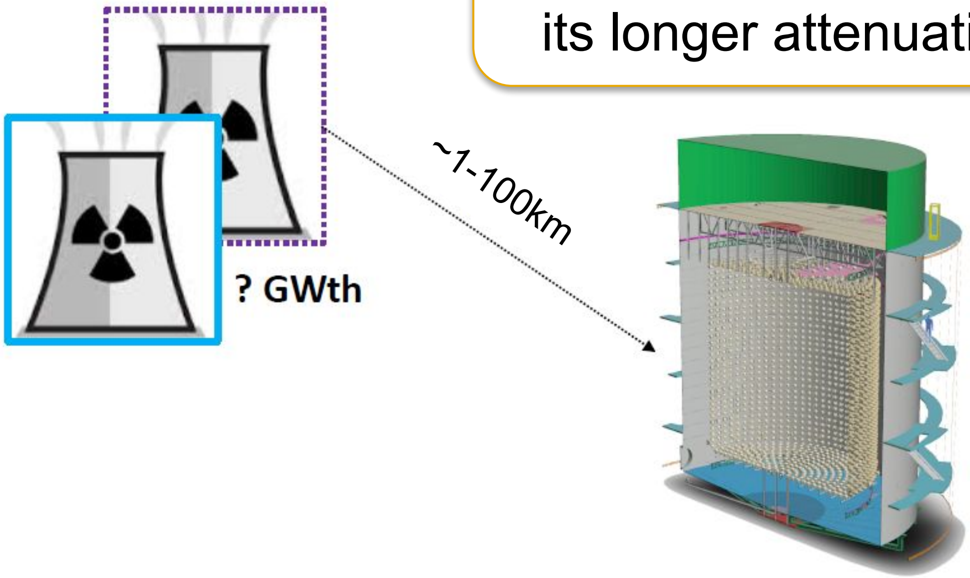
Mission Relevance

Antineutrinos in support of international safeguards?

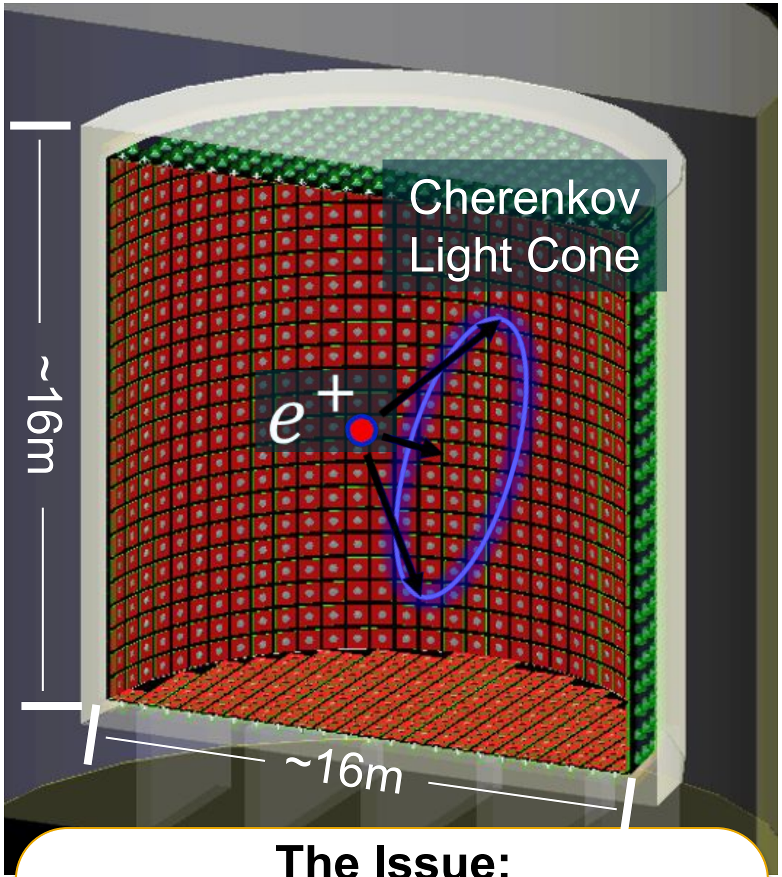
Large-scale water-based detectors may be able to detect, exclude, or verify the presence or operation of a nuclear reactor within a 1-100km radius

Large (ton to kiloton scale) detectors with diameters of tens of meters need to use water-based media due to its longer attenuation length compared to scintillator



Exclusion of unknown reactors over such a large area is not currently possible through any other detector technology and can help detect and deter the illicit generation of special nuclear materials

Background:
Antineutrino Detection



The Issue:
The Cherenkov process produces little light; we need to maximize light collection for performance!

An antineutrino interacts in the detector via **Inverse Beta Decay**, producing a positron and a neutron

The positron immediately produces **prompt Cherenkov light** as it travels through the medium

The neutron is absorbed at a later time on gadolinium and produces gamma rays, resulting in **delayed Cherenkov light**

Cherenkov light is collected by **photomultiplier tubes (PMTs)**, which convert it into an electric signal, which can then be used to reconstruct the antineutrino interaction

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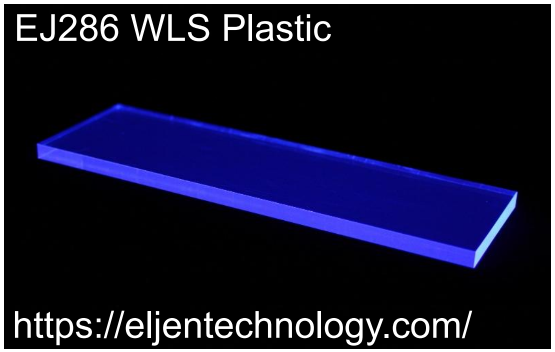
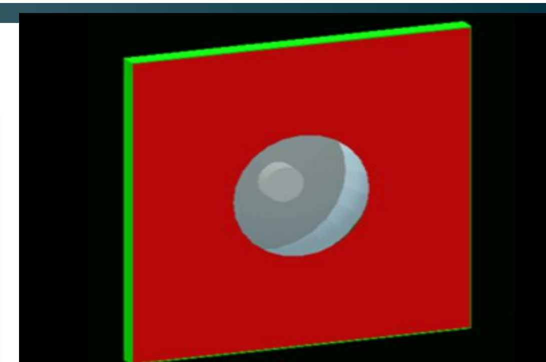
Research Goals



Guiding Question:
Can WLS plates improve the performance of large water-based Cherenkov detectors by increasing light collection and energy resolution?

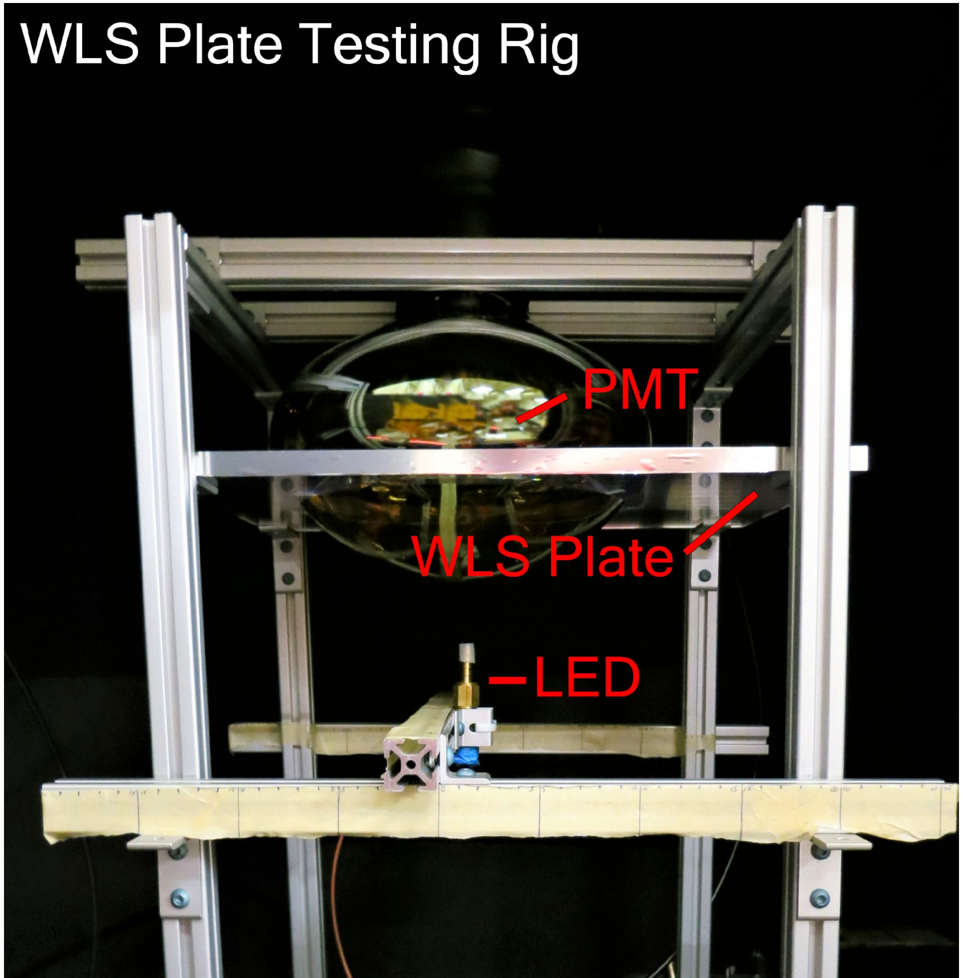

A simulation of a WLS Plate, with a reflector, coupled to a PMT.

WLS plates collect additional light that would have missed a PMT and redirect it towards the PMT for detection

Cherenkov light is mostly created in the UV spectrum, and the plates shift Cherenkov light to visible blue light, where PMT quantum efficiency is higher

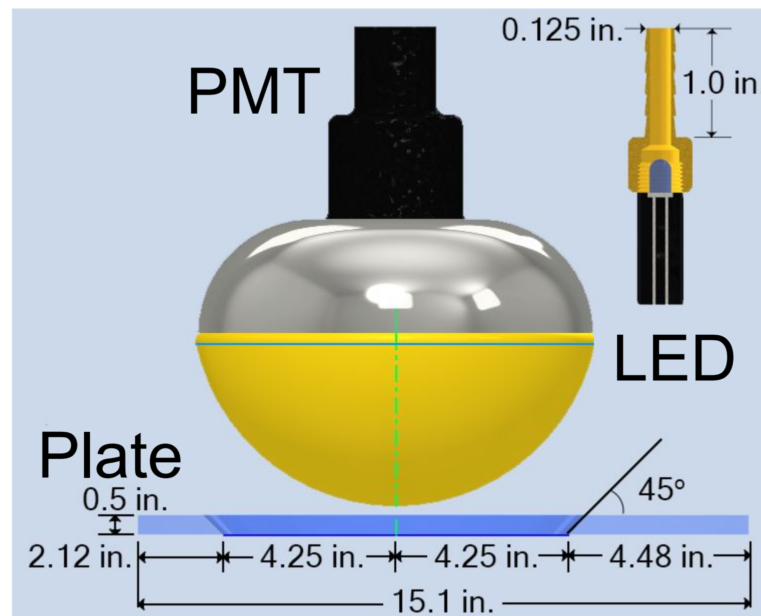
But WLS plates degrade position reconstruction resolution, creating a trade-off that will be studied in future works

Experimental Tests

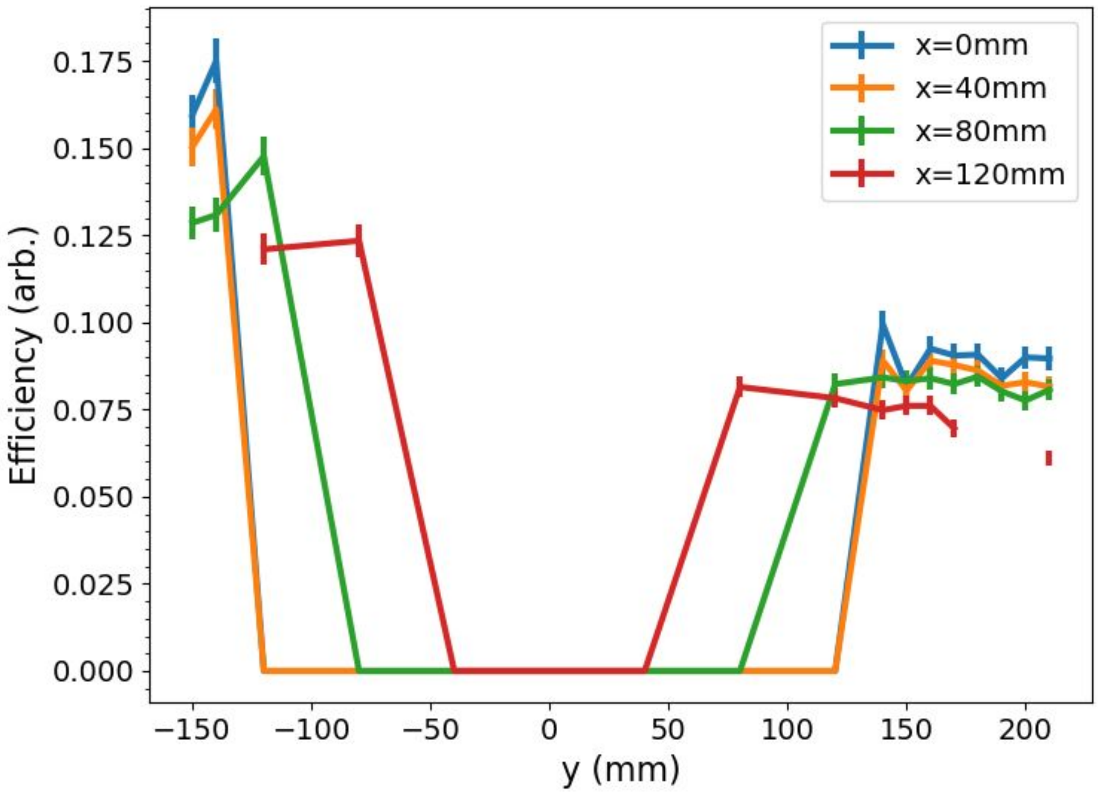


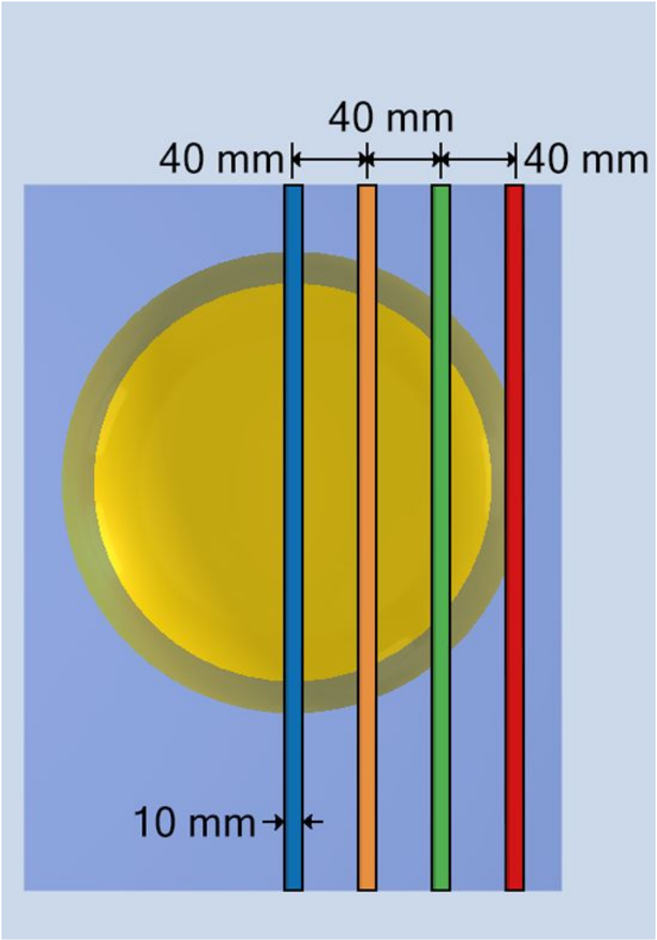
PMT: 10 in. Hamamatsu R7081 PMT
WLS Plate: EJ286 WLS Plate with Reflector
LED: Moveable Collimated LED

Need to experimentally test the light collection of a WLS plate to see how much additional light can be captured



Experimental Results





Findings:

Largely constant collection efficiency across the plate surface, except at plate-PMT interface

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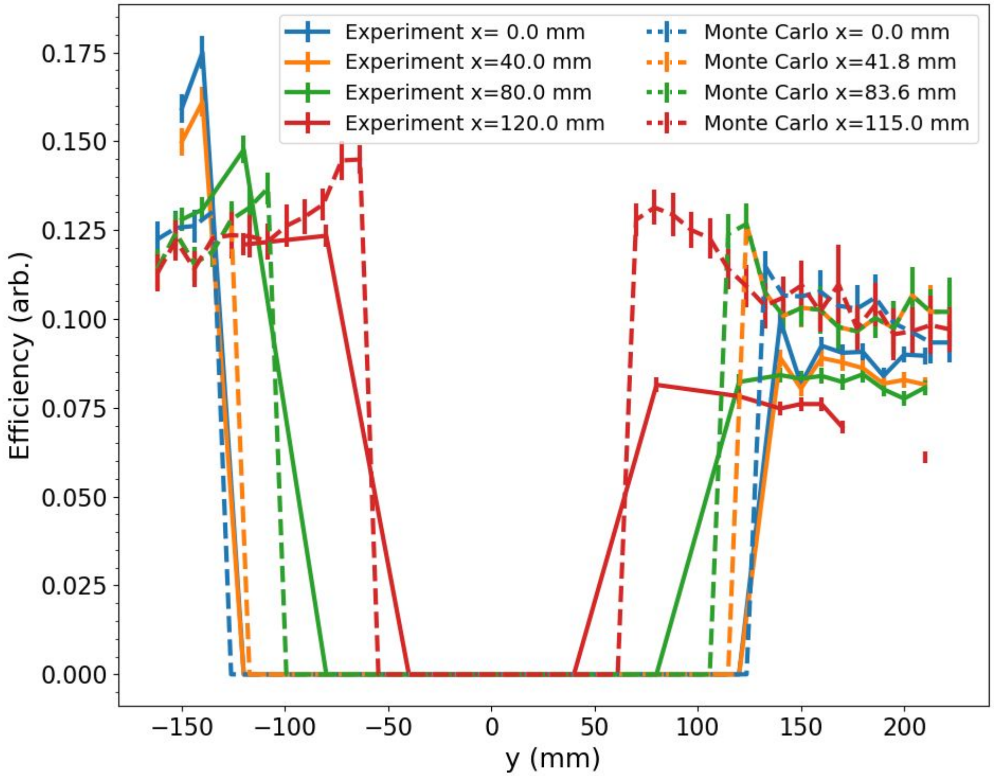
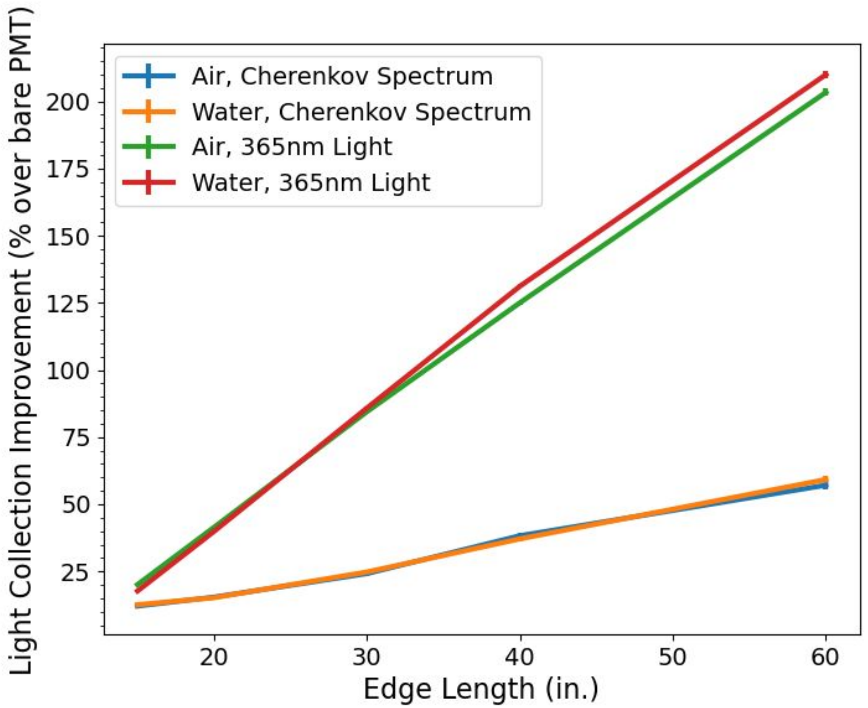
Simulation Results



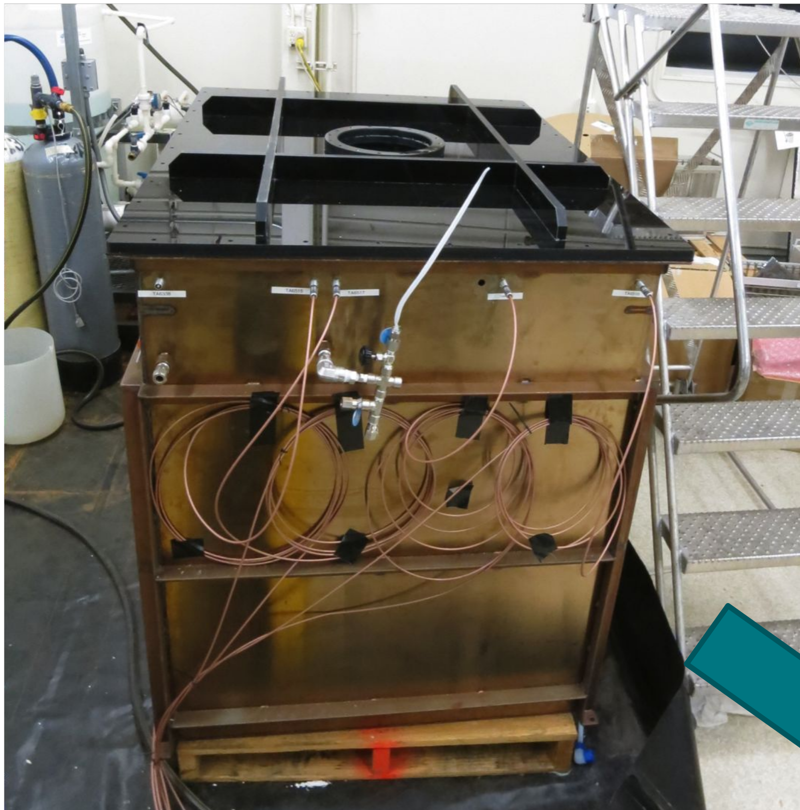
Next, simulations were validated with the experimental results and used to test plate sizes that were not available in the lab

Reflector	Light Increase	
	Experimental	Simulated
Yes	$7.4 \pm 0.7\%$	$7.1 \pm 0.2\%$
No	$-0.08 \pm 0.7\%$	$-1.2 \pm 0.2\%$
Yes & using Optical Grease	$16.2 \pm 0.7\%$	$16.2 \pm 0.2\%$

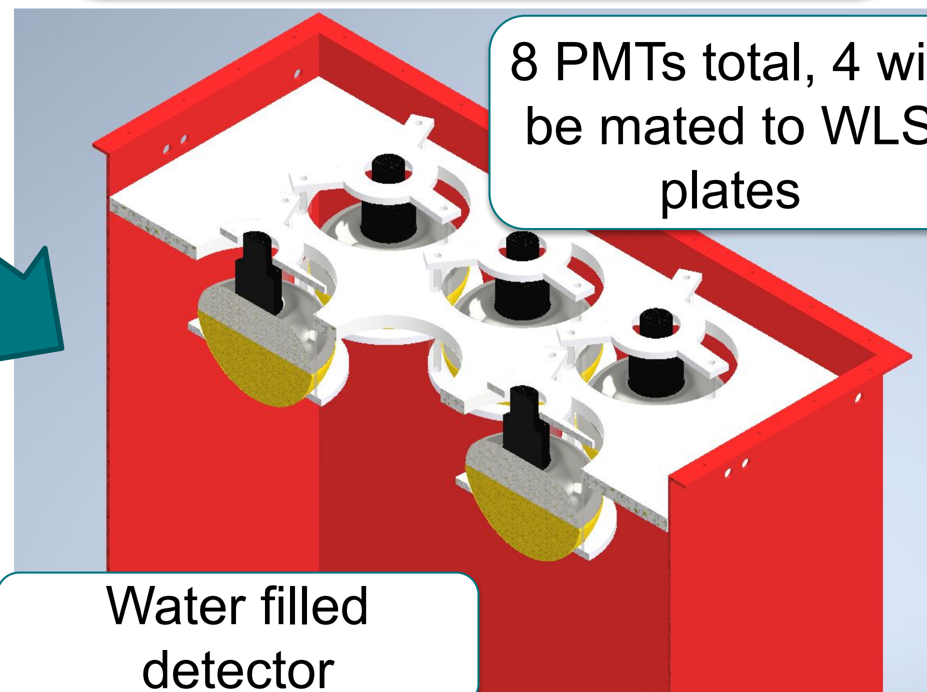


- Results consistent between experiment and simulations
- Larger plates allow for linear light collection improvement, but results with Cherenkov light will be different (somewhat lower) than experiments with an LED

Future Work



Preparations for in-water testing of WLS plates and PMTs in a one-ton detector are ongoing; test will use both an LED and Cherenkov light from cosmogenic muons to better represent real detector performance



8 PMTs total, 4 will be mated to WLS plates

Water filled detector

Results will validate full-detector simulations to predict plate behavior in a large-scale detector

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The NSSC Experience

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Lawrence Livermore National Laboratory

Favorite Opportunities:

- Research at LLNL
- Deputy Director at NPWG
- Keepin Summer Program at LANL
- Policy boot camp at GWU

Los Alamos NATIONAL LABORATORY

GW Boot Camp on Nuclear Security Policy

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