Optimising Wavelength-Shifting Plates for Small-Area Photomultiplier Tubes in Water Cherenkov Detectors

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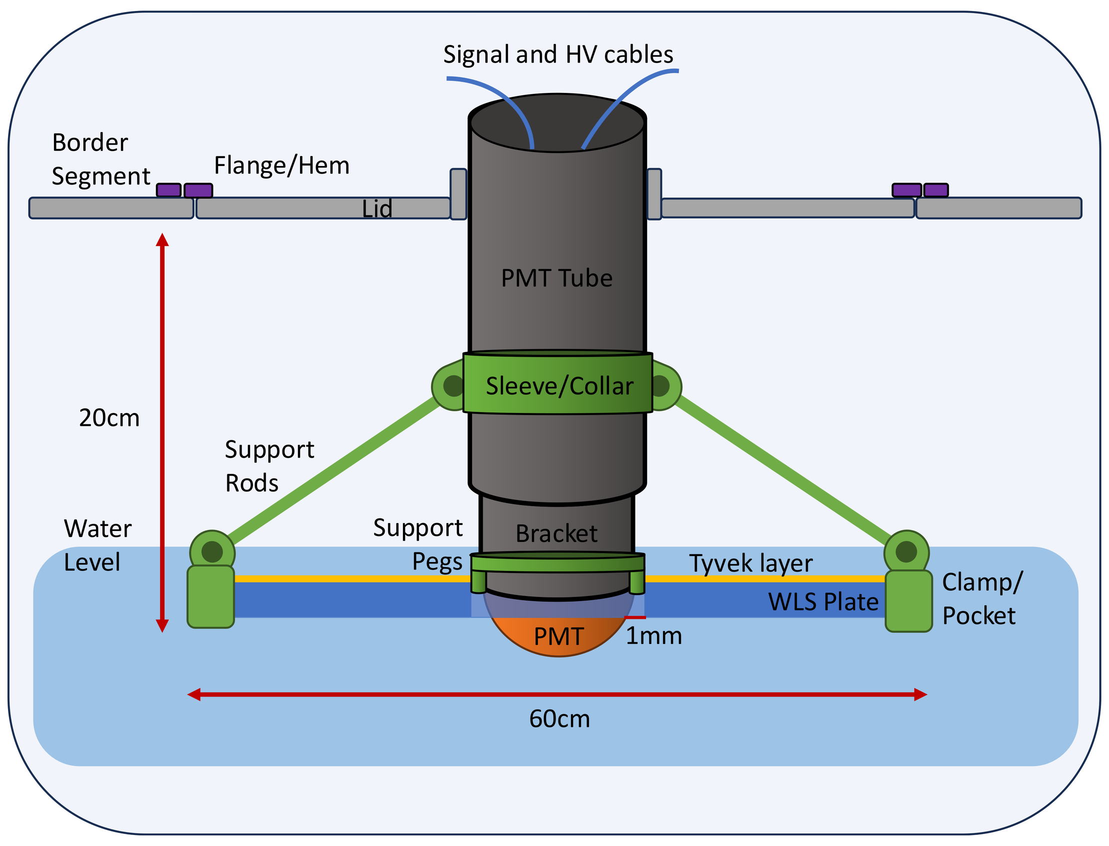
ABSTRACT

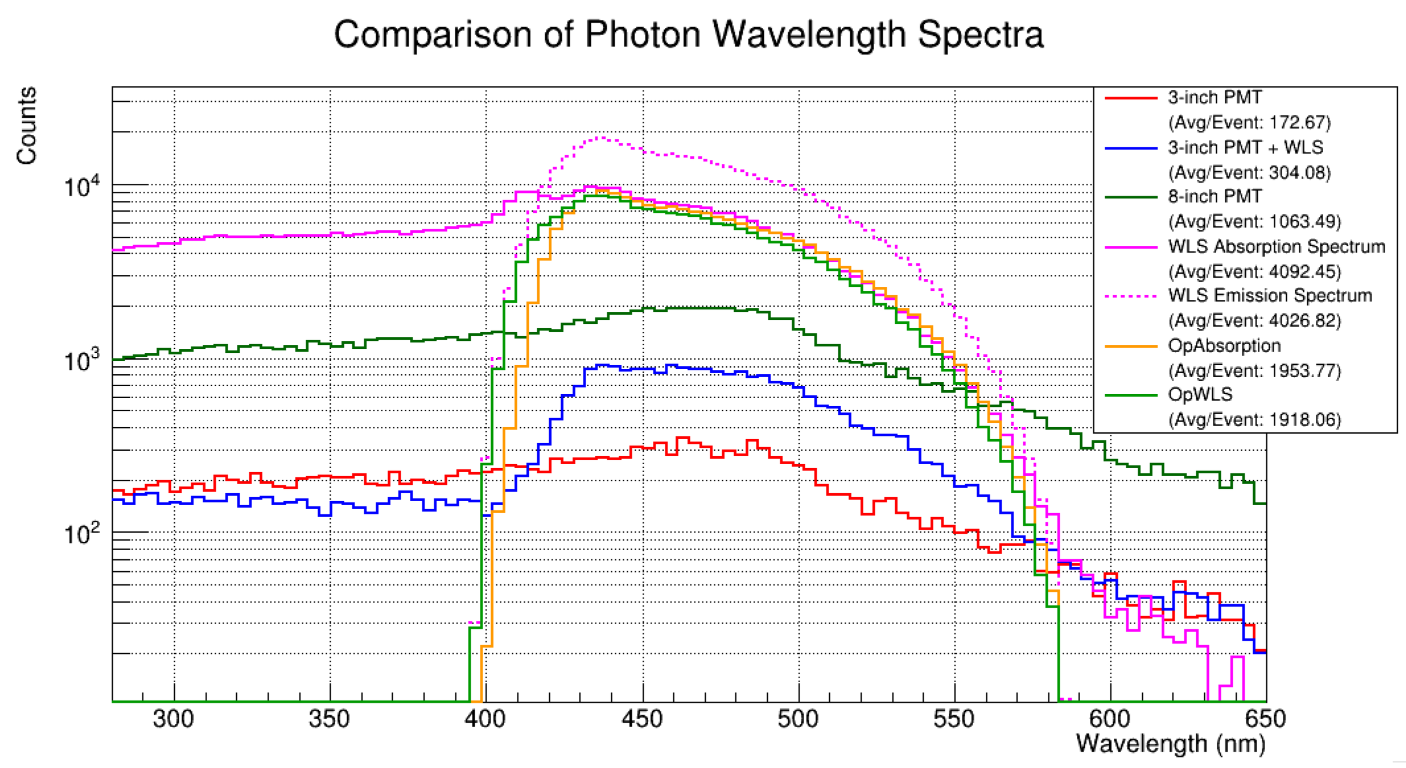
We present a preliminary investigation into the optimisation of wavelength-shifting (WLS) plates coupled to small-area photomultiplier tubes (PMTs) for use in water Cherenkov detectors. This study focuses on how variations in the WLS plate design and configuration influence detection efficiency. UsingGeant4 simulations, we systematically explore the effects of key geometric and material parameters of the WLS plates on light collection and guiding efficiency. Experimental measurements were conducted to validate the simulations, using Kuraray WLS plates coupled to a Hamamatsu 3-inch PMT in a custom water tank with a muon telescope for coincident trigger detection. We report how optimisation of these parameters can impact light yield, timing response, and overall detection efficiency. These findings provide insight into the feasibility of such a design for next-generation large-scale Cherenkov arrays.

DETECTOR CONCEPT



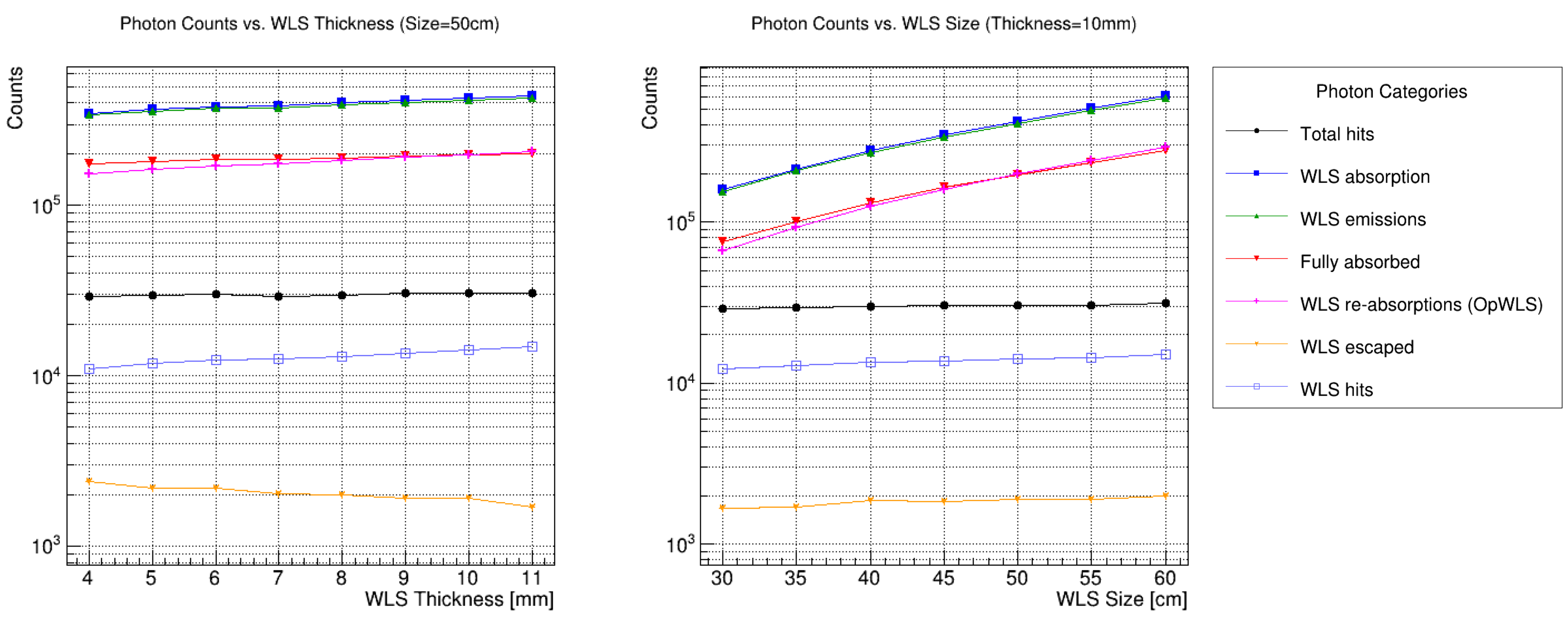
- Small-area, downward-facing photomultiplier tube (PMT).
- Partially embedded in a wavelength-shifting (WLS) plate.
- WLS plate absorbs Cherenkov photons and re-emits them at longer wavelengths.
- Re-emitted light matches PMT's peak quantum efficiency for improved detection.
- Reflective edges guide photons toward the PMT photocathode.

WAVELENGTH DISTRIBUTIONS



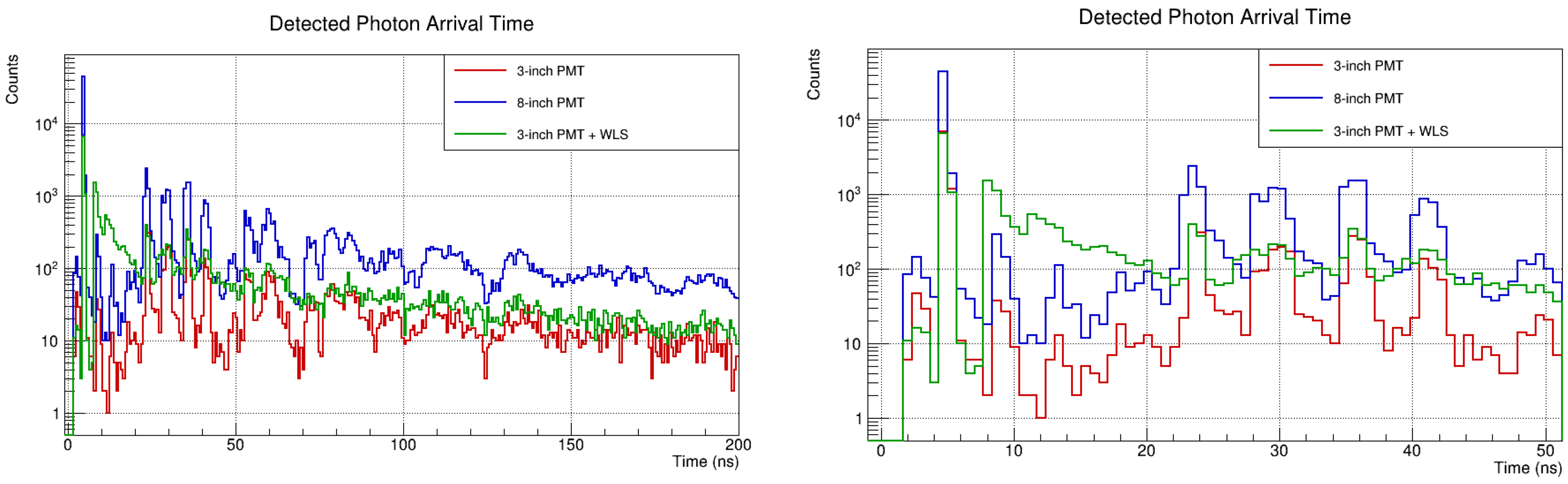
- Adding a 50 cm × 9 mm WLS plate to the 3-inch PMT increases photon hits by a factor of 1.76.
- Most re-emitted WLS photons are either re-absorbed for wavelength shifting or fully absorbed in the WLS plate or water.

WAVELENGTH SHIFTING PLATE OPTIMISATION



- WLS photons contribute 47 % of the total hits on the PMT.
- There is a linear relationship between plate size/thickness and the number of photon hits, demonstrating that larger and thicker plates capture more Cherenkov light.
- Thicker plates increase absorption, reducing photon escape, while larger plates tend to allow more re-emitted photons to reach the PMT.
- Plate area directly impacts cost, so an optimal "sweet spot" must be determined to balance performance and expense.
- Overall, the WLS plate design can be tuned to maximize photon collection efficiency without excessive material costs.

TIMING DISTRIBUTIONS



- Timing distributions for the 8-inch and 3-inch PMTs are broadly similar, differing mainly in gain
- All distributions exhibit a common pattern: an initial pedestal followed by a long, slow decay (<200 ns), likely from delayed Cherenkov photons reflecting within the tank.
- In the WLS case (<50 ns region), a secondary, long-tailed peak appears after the first pedestal, shorter than the baseline decay.
- This secondary feature is attributed to late-arriving photons re-emitted by the WLS plate, highlighting its effect on PMT timing response.

FUTURE WORK

- Follow-up experimental data will be collected using Leicester's custom-built water Cherenkov tank.
  - This will be compared with the results of the simulations to confirm the reliability of these findings.
  - The attenuation length of various WLS plate candidates will be compared.
- A small (0-1mm) gap between the WLS plate and PMT edge will be present, so future simulations will be run to determine any unforeseen effects.
- Model the PMT quantum efficiency in Geant4 simulations to more holistically assess detector performance.