Impact of Light Concentrators on Antineutrino Detection in WATCHMAN

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on behalf of the WATCHMAN Collaboration

AIT-WATCHMAN

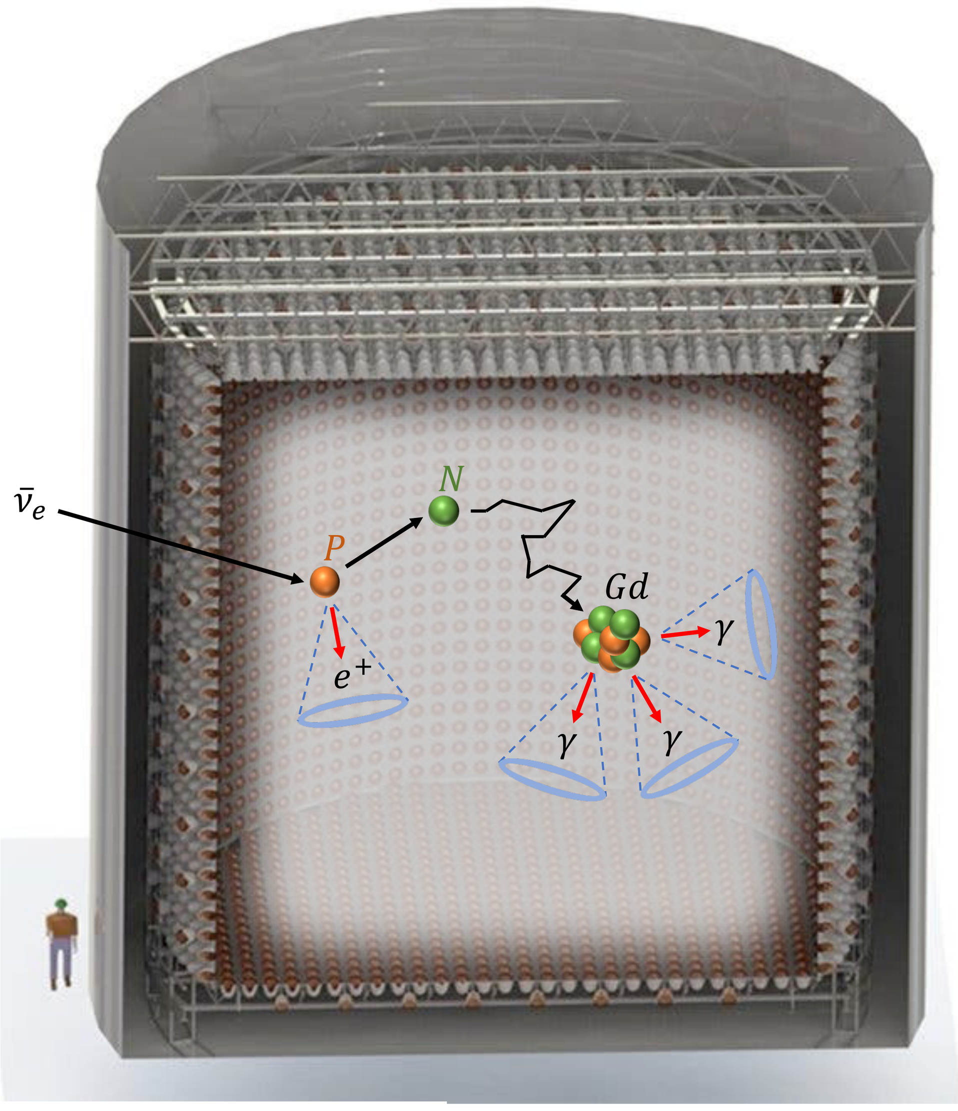
The WATer CHerenkov Monitor for AntiNeutrinos (WATCHMAN) is a proposed neutrino detector for the new Advanced Instrumentation Testbed (AIT) at Boulby Underground Laboratory, UK. It will demonstrate nuclear reactor monitoring at distances greater than several tens of kilometers as a less intrusive safeguards measure.

The 20 m x 20 m water Cherenkov detector will search for inverse beta interactions of antineutrinos.

$$\bar{\nu}_e + p \rightarrow e^+ + n$$

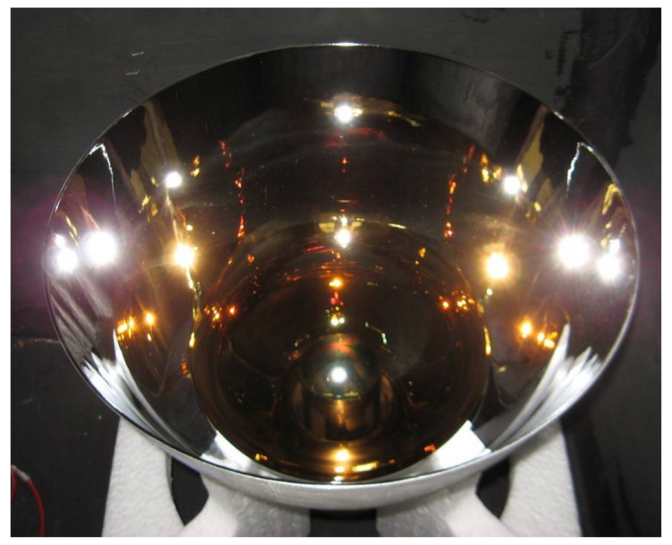
WATCHMAN could instrument gadolinium-doped water as the sensitive medium to monitor the Hartlepool Nuclear Power Station.

- 6 kt detector (~1 kt fiducial volume) with ~3300 inner PMTs and ~300 outer PMTs
- Located ~1 km underground
- 26 km standoff distance



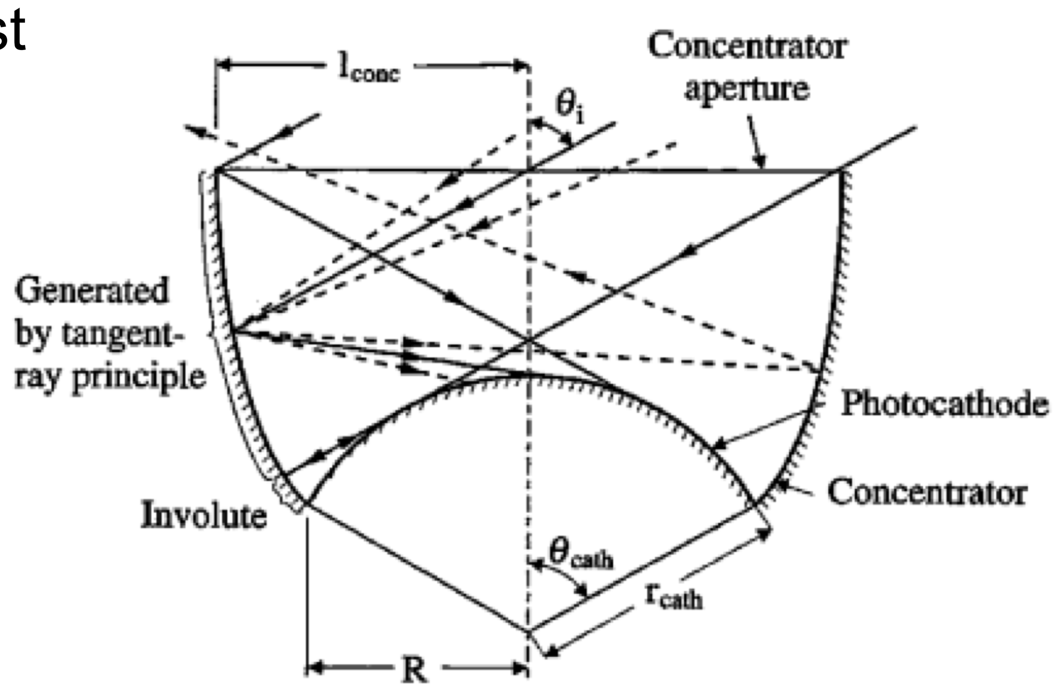
Can light detection be improved?

Light concentrators are devices which accept incident light up to a critical incident angle on an entrance aperture and reflect it into a narrowed exit aperture via a curved metallic surface [1].



- More light for better energy reconstruction
- Shield PMT radioactivity in some cases
- Decrease number of PMTs but maintain photocoverage for reduced cost

The curvature profile of the light concentrators was drawn using the **tangent-ray principle** of non-imaging optics [2],[3]. The profile can be optimized for any given detector geometry.



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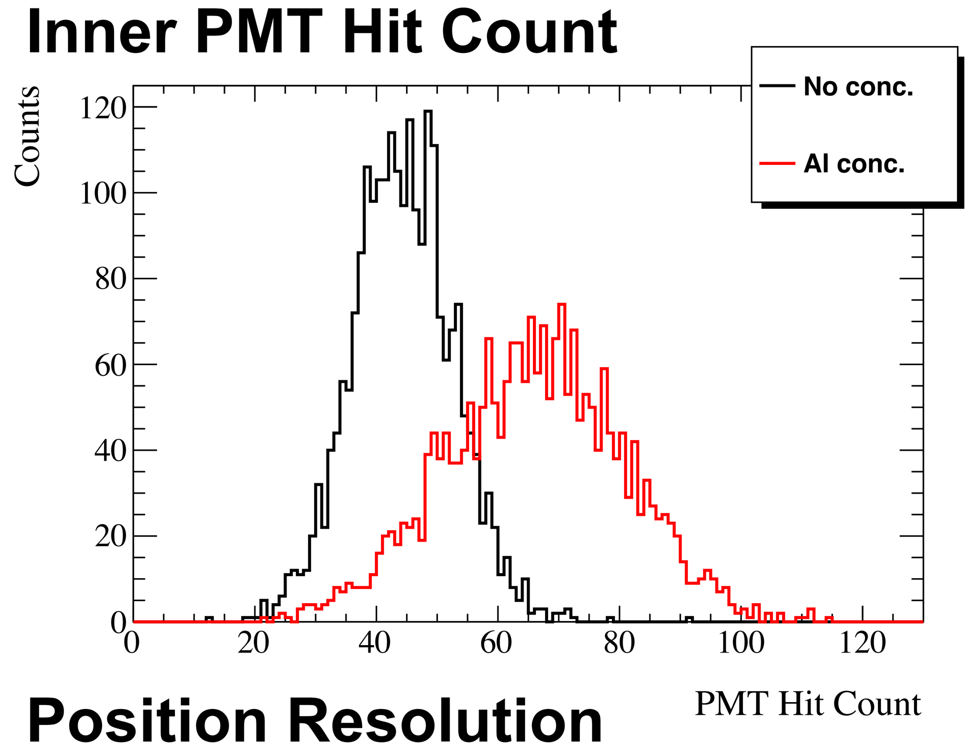
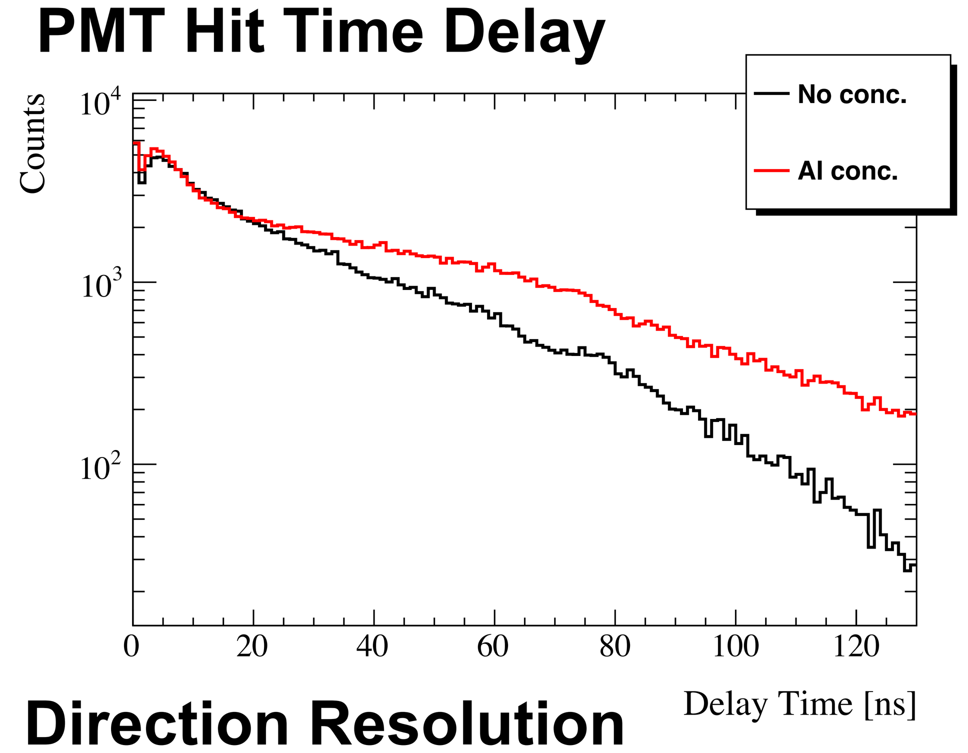
Simulation & Analysis

A concentrator optimized numerically for WATCHMAN using the tangent-ray method has outer radius 23 cm, inner radius 12.65 cm, depth 14 cm, and thickness 2mm; aluminum is the chosen surface material due to its high reflectivity in the Cherenkov light range. IBD events (0-10 MeV positrons) were simulated uniformly throughout the detector volume. Only events inside the fiducial volume were used in analysis.

Inner PMT Hit Count



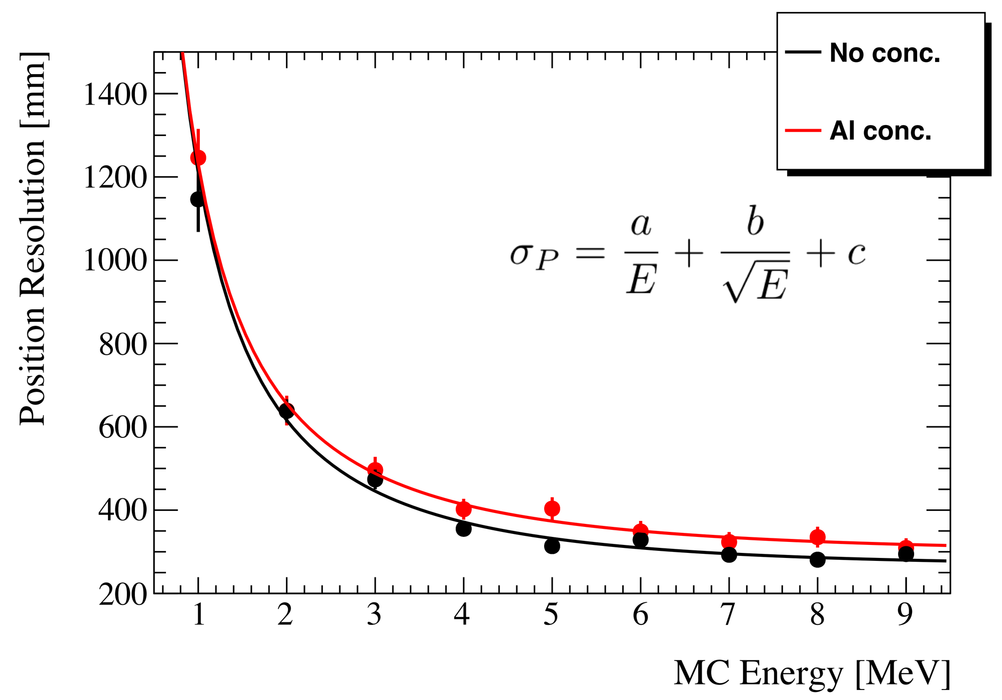
PMT Hit Time Delay



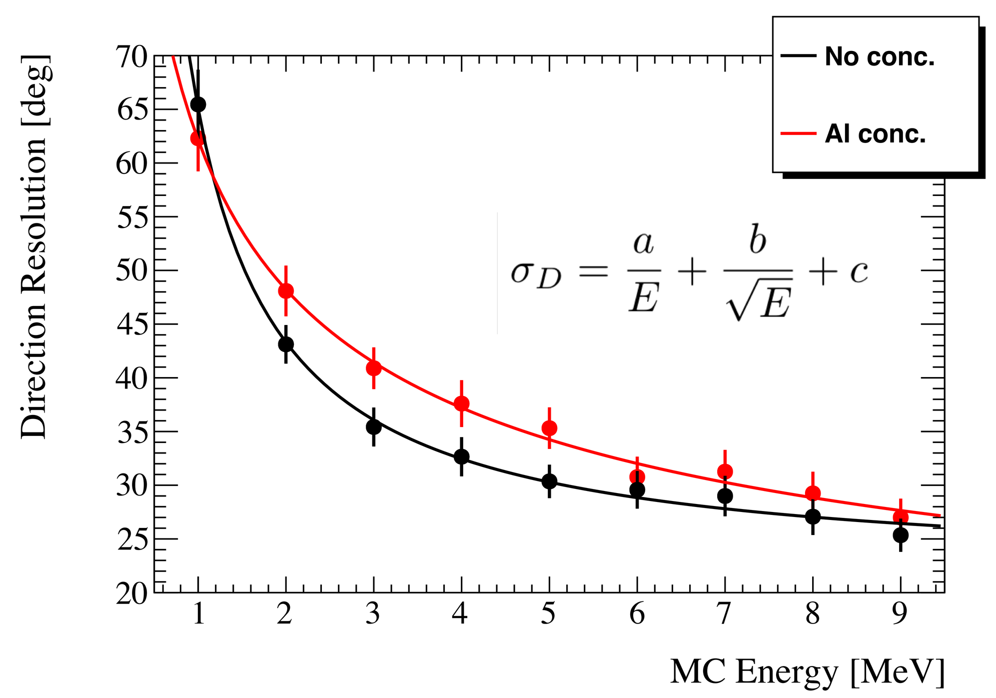
Simulation output of 5 MeV positrons shows that the PMT hit count is 39% higher when concentrators are added.

Also evident is a delay in PMT hit time on the order of 10 ns or longer due to extra reflections of the Cherenkov photons within the concentrators.

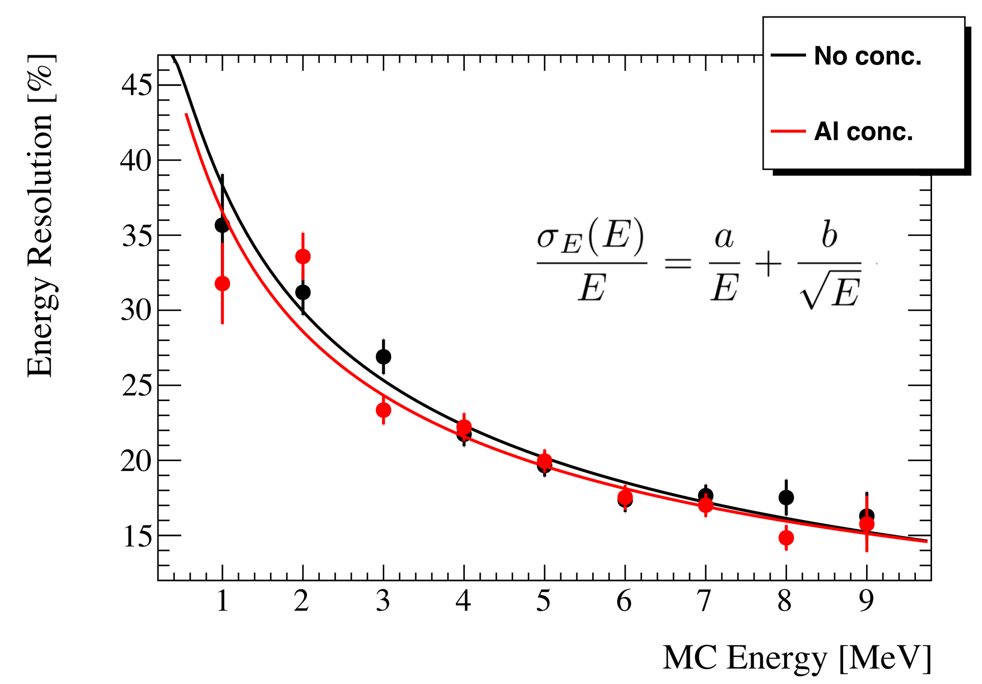
Position Resolution



Direction Resolution



Energy Resolution



The position, direction, and energy resolution of simulated 0-10 MeV positrons was fitted to the standard formulas. Due to the delayed effect concentrators have on PMT hit time, reconstruction deteriorates slightly. This results in slightly worse position and direction resolution when concentrators are used. However, the significant increase in collected light improves energy resolution.

Impact & Conclusions

Due to the large increase in PMT hits, the implementation of light concentrators would enable WATCHMAN to eliminate ~1400 PMTs from the inner detector while maintaining photocoverage. This is an important cost-saving measure. This very preliminary study shows that the addition of concentrators on average decreases position resolution by 11% and direction resolution by 9%. Concentrators increase the average energy resolution by 7%. One might argue that minor decreases in position and direction resolution are worth sacrificing for increased energy resolution and a significant decrease in cost. Detailed detector sensitivity studies of these trade-offs are still underway.

References:

[1] W. T. Welford and R. Winston, High Collection Nonimaging Optics (1989).
[2] G. Doucas et al., Light concentrators for SNO, NIMP RS A, 579 (1996).
[3] Long-Baseline Neutrino Experiment (LBNE), Conceptual Design Report (2018).

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