Double-layered Water Cherenkov Detector for the Southern Wide-field Gamma-ray Observatory (SWGO)

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Water Cherenkov Detector

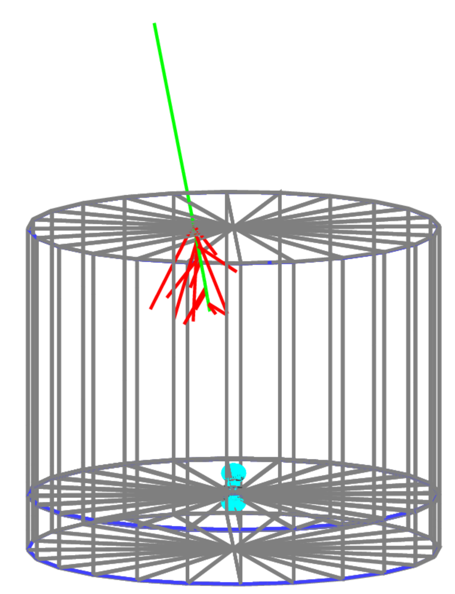

Figure 1: Cylindrical Double Layered WCD (DLWCD) design comprising an upper chamber ($\pi \times 1.91^2 \times 2.5\ m^3$) with white walls and black bases (top and bottom) and an entirely white lower chamber ($\pi \times 1.91^2 \times 0.5\ m^3$). The upper chamber comprises an 8" PMT facing upwards, and the lower chamber comprises an 8" PMT facing downwards. A μ^+ (green) penetrates the DLWCD and produces photons (red). The number of photons has been limited here for illustration purposes. (Download pdf to view embedded simulation.)

Unit Design

The double-layered WCD (DLWCD) is a candidate design for SWGO:

- Upper Chamber. A light-tight chamber with combination of reflective and non-reflective surfaces, and a single upward-facing light sensor. Provides timing information and an estimate of total local particle energy per unit area.
- Lower Chamber. A light-tight chamber with a highly reflective lining and a single light sensor facing downwards. Enables $\mu^\pm$ tagging.

Particle Detection Efficiency

The simulations use GEANT4 [1] within a simulation framework adapted from the HAWC collaboration [2].

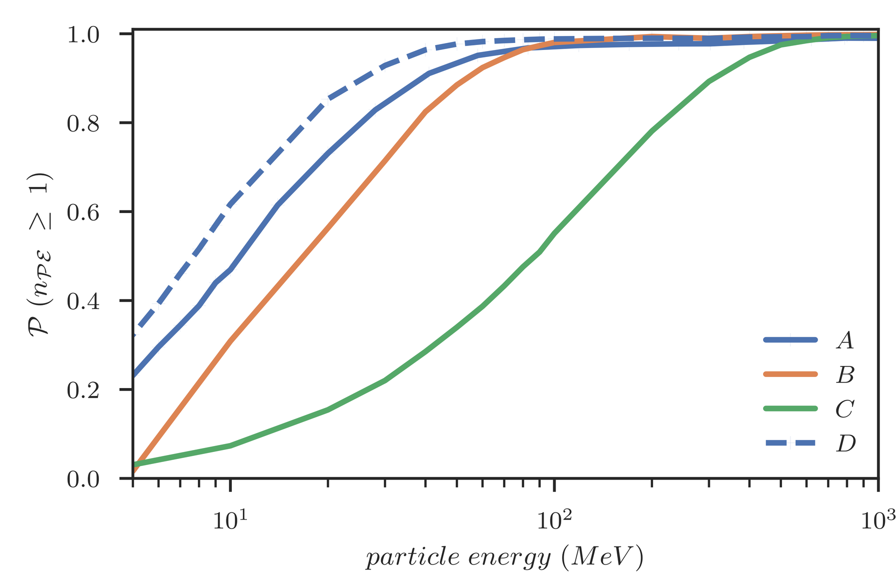

Figure 2: Injection of vertical γ-rays across the top surface of different WCD designs.[A] white cylindrical DLWCD unit ($\pi \times 1.91^2 \times 2.5\ m^3$) with a black top and an 8" PMT, a [B] HAWC - like design ($\pi \times 3.65^2 \times 4\ m^3$) with black walls, a central 10" PMT and 3x8" PMTs', a [C] LHAASO - like black unit ($5 \times 5 \times 4.5\ m^3$) with an open top and an 8" PMT and a [D] white cylindrical DLWCD unit ($\pi \times 1.71^2 \times 3\ m^3$) with a black top and an 8" PMT.

Array

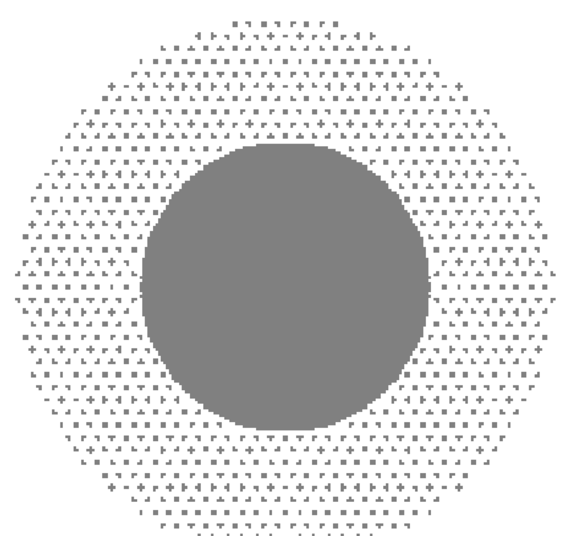

Figure 3: Simulated array layout of cylindrical DLWCDs with a dense inner array (> 80%) and sparser outer array (∼ 8%). The simulation here (download pdf) shows a 500 GeV γ−ray shower at a Zenith angle of 20° impinging upon the array.

Angular Resolution

Fit of Landau distribution to arrival times as a function of distance to shower core and charge to obtain mean and width parameters followed by a 3-parameter likelihood fit (MINUIT [3]).

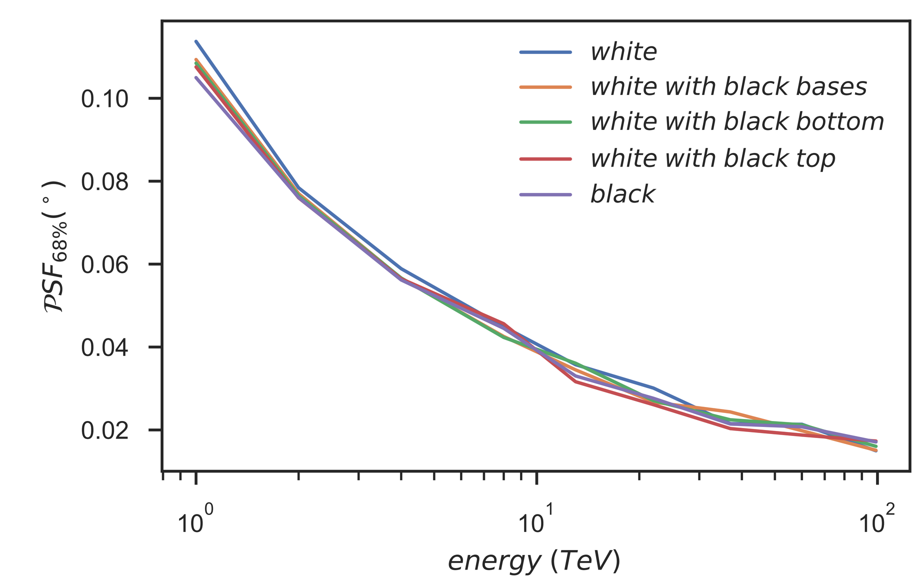

Figure 4: 68% containment for 1 - 100 TeV vertical γ-ray's for an array of double-layered WCD's (upper - $\pi \times 1.91^2 \times 2.5\ m^3$) with ∼ 80% fill factor varying the material properties. Showers thrown at the center of the array.

Gamma - Hadron Separation

Template-based maximum log-likelihood method comprising charge in the two chambers implemented to discriminate between γ-ray and hadron induced air showers. An exclusion region is defined to account for the high transverse momentum of $\mu^\pm$ and punch-through of γ & $e^\pm$ close to the shower core.

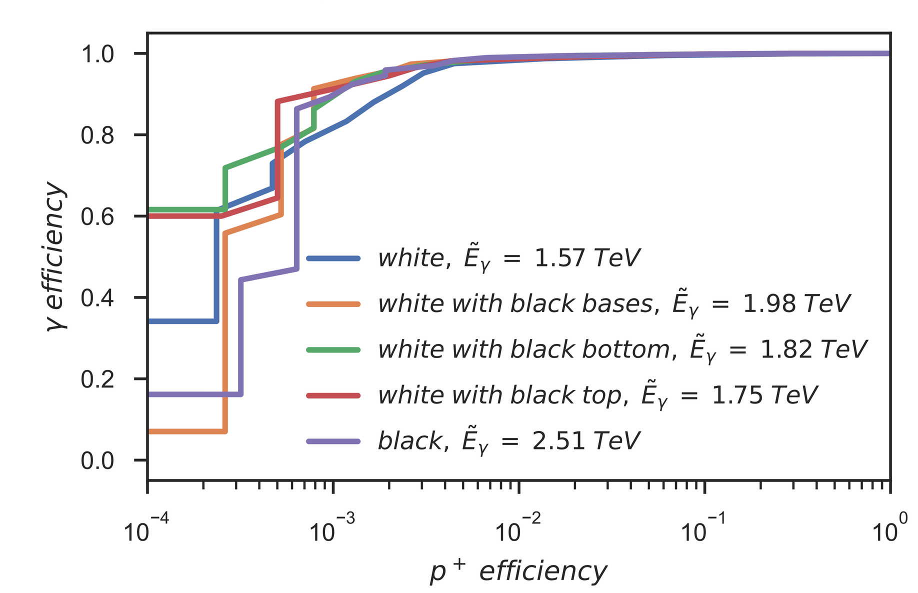

Figure 5: Gamma - Hadron separation efficiency for an array of double-layered WCD's (upper - $\pi \times 1.91^2 \times 2.5\ m^3$) with ∼ 80% fill factor varying material reflectivity, an exclusion region of 40 m and $547 \leq nhits < 1280$.

Summary

- The Southern Wide-field Gamma-ray Observatory (SWGO) will use the well-established and cost-effective technique of detecting Cherenkov light produced in water-filled detection units for TeV gamma-ray astronomy.
- The double-layered WCD leverages material and aspect-ratio to enhance sensitivity, achieve excellent angular resolution and gamma hadron separation.

References

[1] S. Agostinelli et al., *Nucl. Instrum. Methods Phys. Res.* **A 506** 205-303 (2003).

[2] A. U. Abeysekara et al. (HAWC Collaboration), *Astrophys. J.* **843**, 39 (2017).

[3] F. James, MINUIT Function Minimization and Error Analysis: Reference Manual Version, 94.1, CERN-D-506 (2017)

Additional Information

Double-layered WCD for SWGO proceeding

Contact Information

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