Monte Carlo study of the water Cherenkov muon veto for the COSINUS experiment

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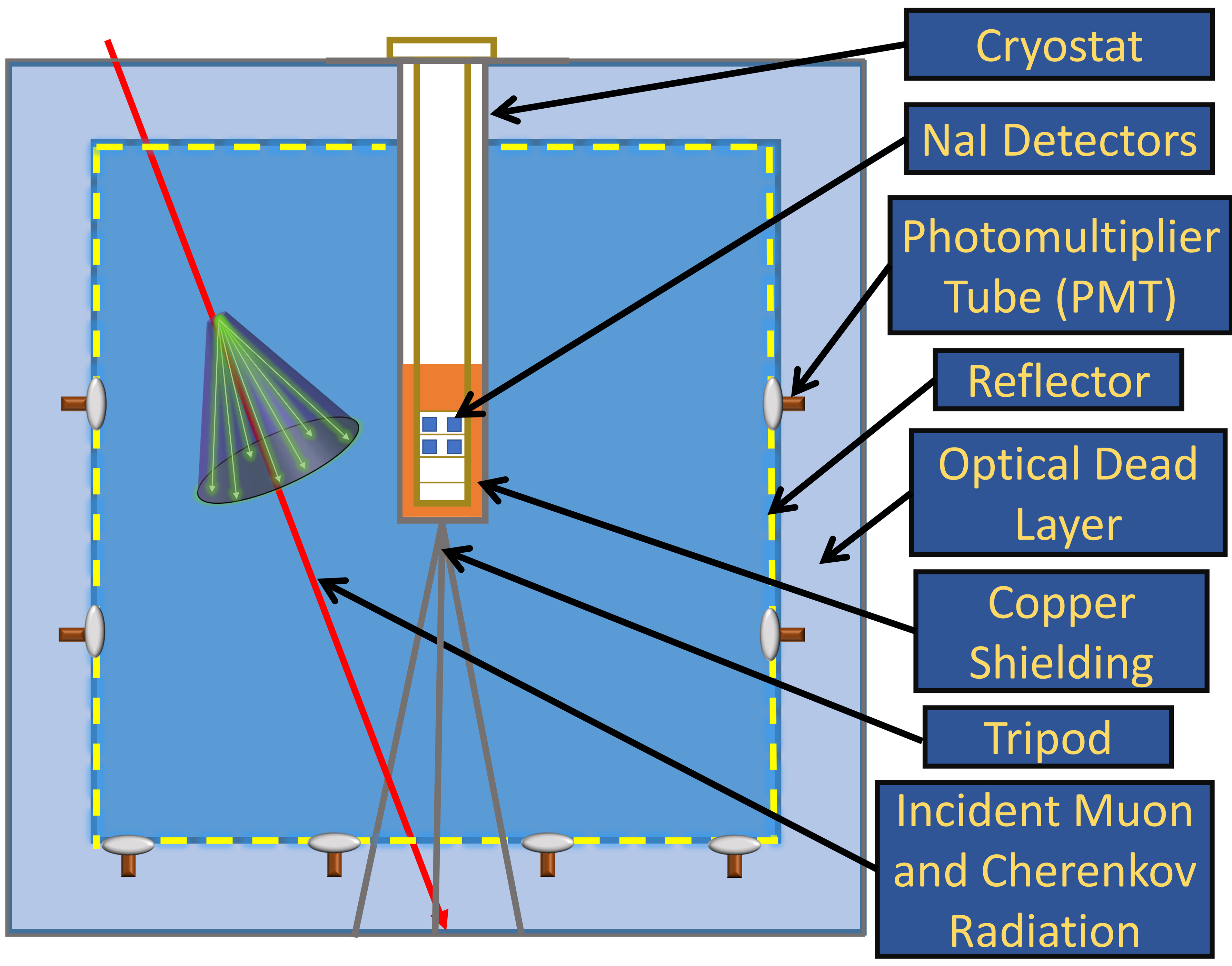
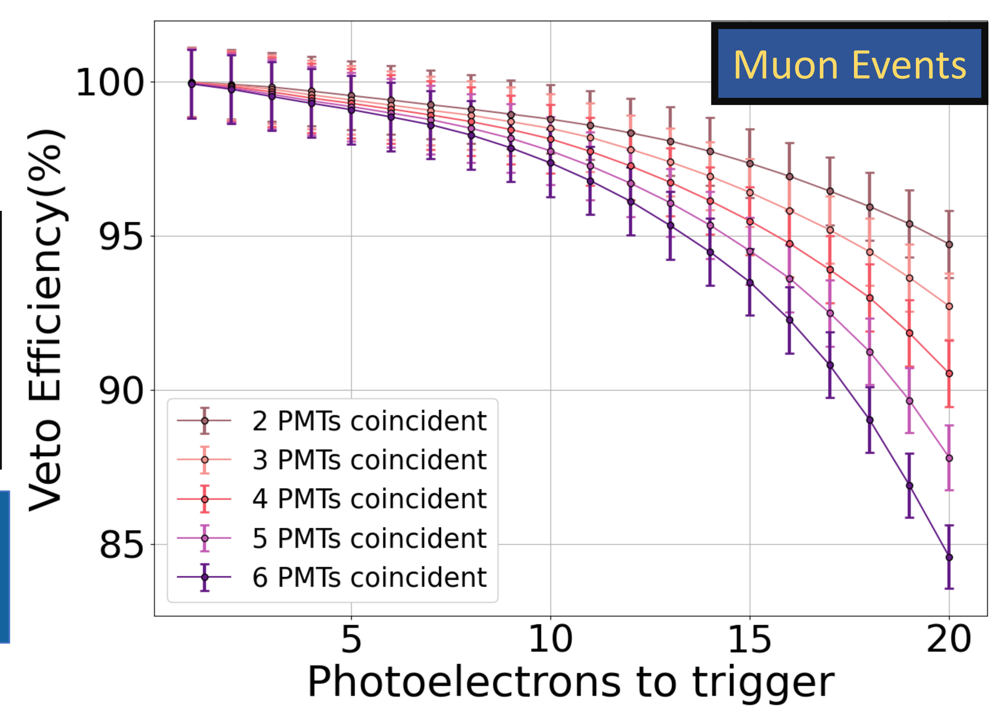
COSINUS Experiment

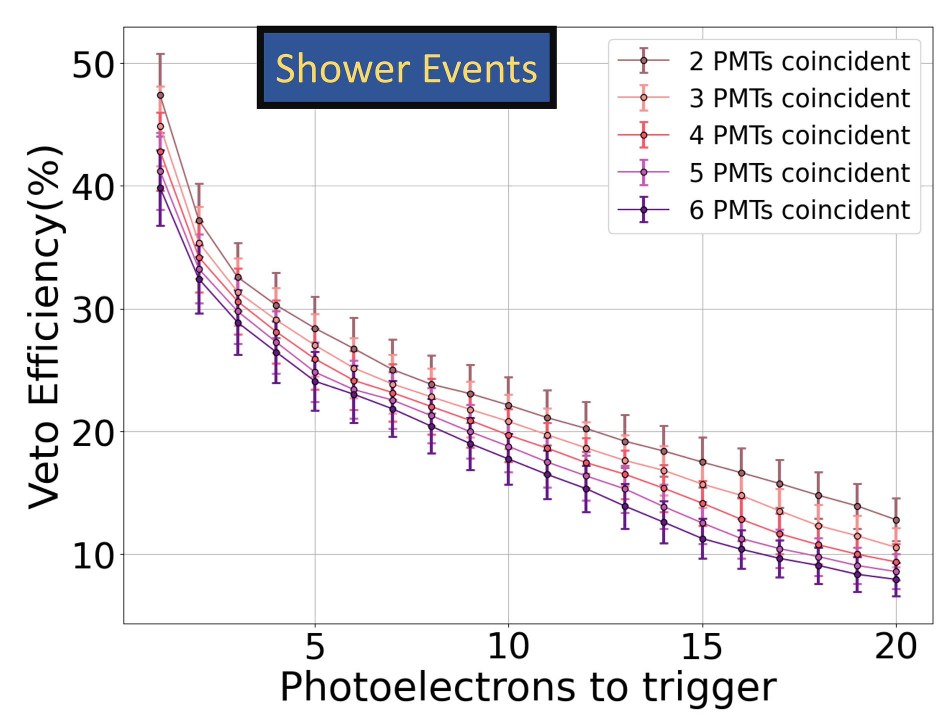
- The COSINUS (Cryogenic Observatory for SIgnatures seen in Next-generation Underground Searches) [1] experiment will perform a model-independent test of the DAMA/LIBRA dark matter claim.
- Uses Sodium Iodide (NaI) crystals as scintillating calorimeters (operated at mK temperature) allowing for both phonon and light channel readout. Giving event-by-event particle discrimination.
- COSINUS is under construction in Hall B at the INFN Gran Sasso National Laboratory. Data taking begins in 2024.



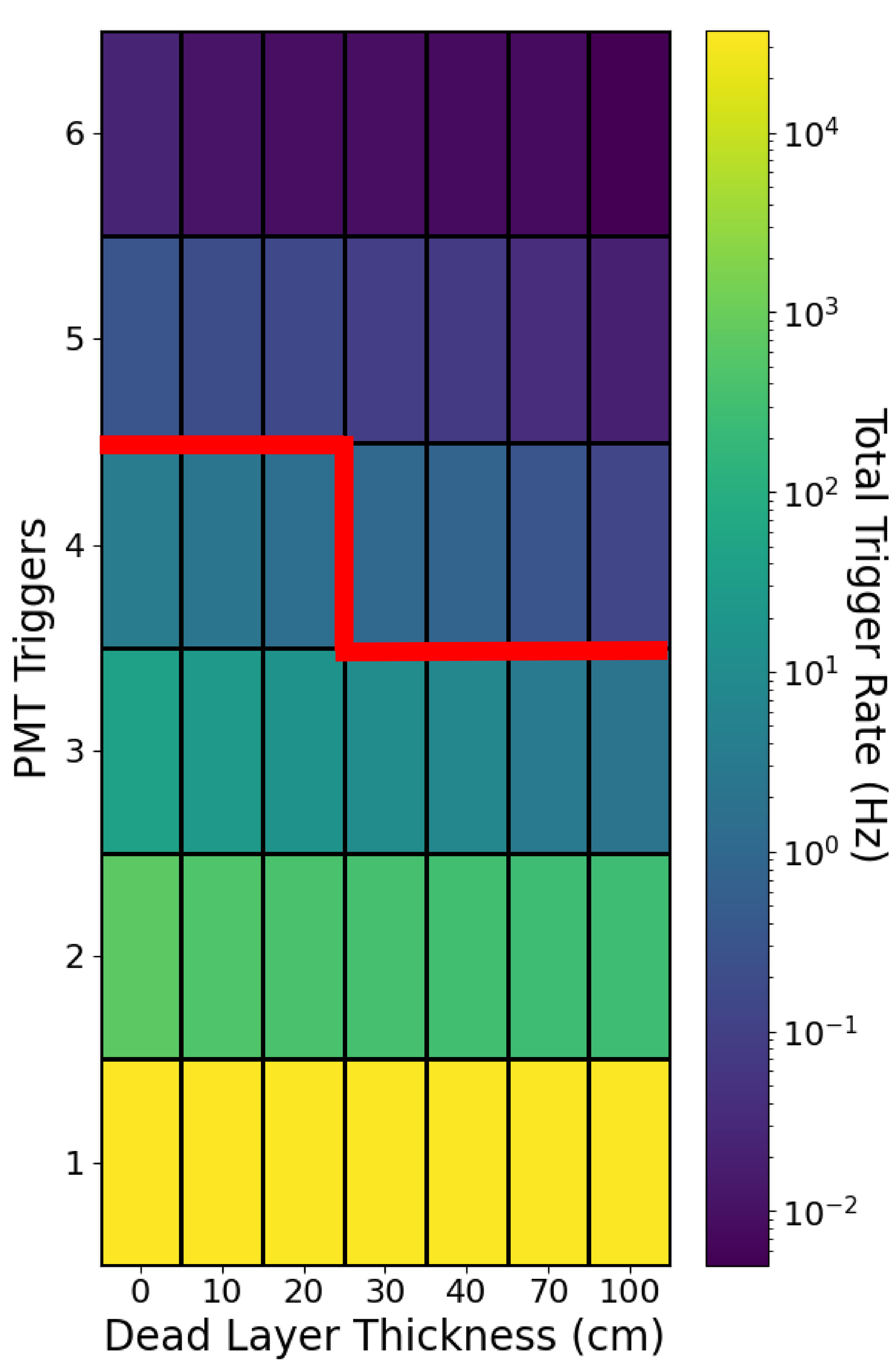
Water Cherenkov Muon Veto

- Neutrons from cosmogenic radiation is the largest background for the NaI crystals: 3.5 +/- 0.7 cts kg^{-1} yr^{-1}
- Can be mitigated by an active water Cherenkov muon veto [2]
- Efficiency of tagging direct **muon** events and **showers** of secondary particles was simulated through ImpCRESST [3] and MUSUN [4].
- Many experimental configurations were tested: no. of PMTs, PMT placement, reflector strength,





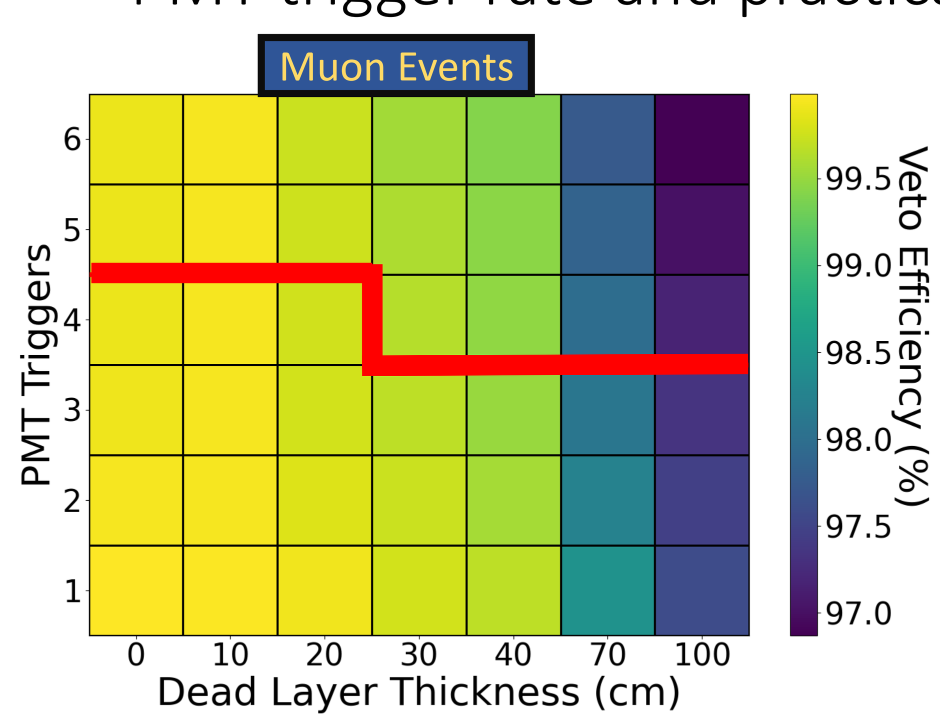
Background triggering of the PMTs

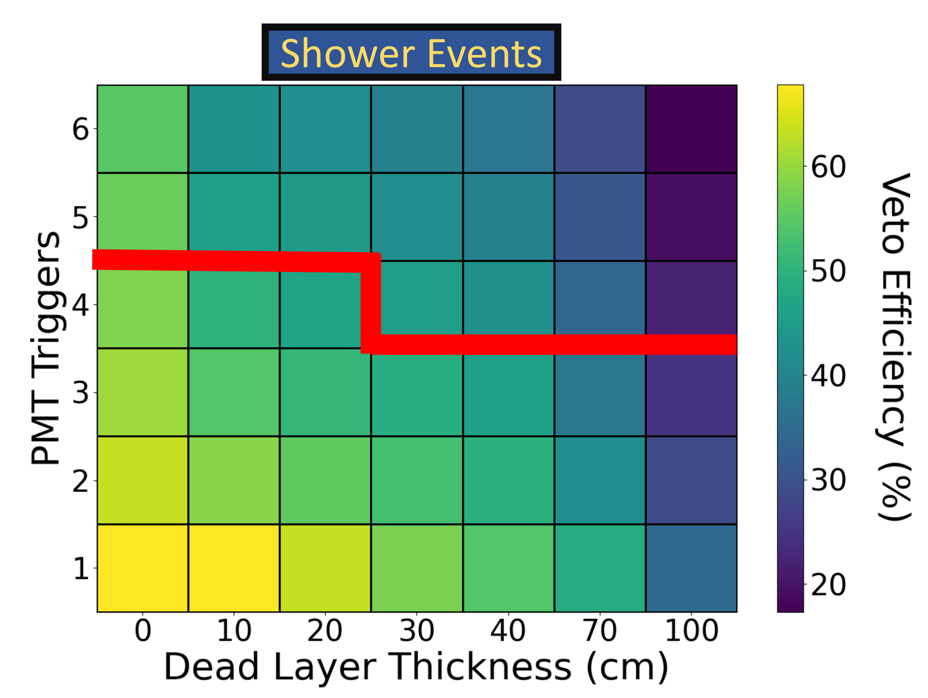


- Spurious triggers in a PMT can be induced by dark counts or the ambient gamma background.
- For a <1% chance of spurious coincidence with a cryogenic event, a < 1 Hz PMT rate is required
- The total PMT rate can be reduced by:
  - An optical dead layer (region not instrumented by the PMTs) through the inclusion of a reflective foil
  - Requiring a higher-fold PMT coincidence.
- Experimental setups that give a trigger rate <1 Hz are shown above the red line

Veto efficiency

- A larger volume of the dead layer results in a decrease of veto efficiency
- Goal is to maximize veto efficiency while maintaining a low PMT trigger rate and practical considerations





Final Configuration

- 28 PMTs 8-inch diameter R5912-30 Hamamatsu, 18 along bottom, 10 along the wall
- Optical dead layer of 30-40 cm to account for length of PMT and reduce the PMT trigger rate
- Gives 97.0 +/- 2.2 % veto efficiency (99% muons and 45% shower event efficiency.)
- Cosmogenic neutron background now: 0.11 +/- 0.08 cts kg^{-1} yr^{-1}
- For phase-I exposure of 1000 kg days this is less then one event.

References

1. Angloher, G., et al. "Deep-underground dark matter search with a COSINUS detector prototype." *arXiv preprint arXiv:2307.11139* (2023).
2. Stukel, Matthew, et al. "Background suppression in the COSINUS experiment: Active muon veto and radiopure materials selection." *SciPost Physics Proceedings* 12 (2023): 032.
3. Abdelhameed, A. H., et al. "Geant4-based electromagnetic background model for the CRESST dark matter experiment." *The European Physical Journal C* 79 (2019): 1-18.
4. Kudryavtsev, V. A. "Muon simulation codes MUSIC and MUSUN for underground physics." *Computer Physics Communications* 180.3 (2009): 339-346.