COSINUS

On an active muon veto system for the COSINUS experiment

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COSINUS

Cryogenic Observatory for SIgnals seen in Next Generation Underground Searches

COSINUS

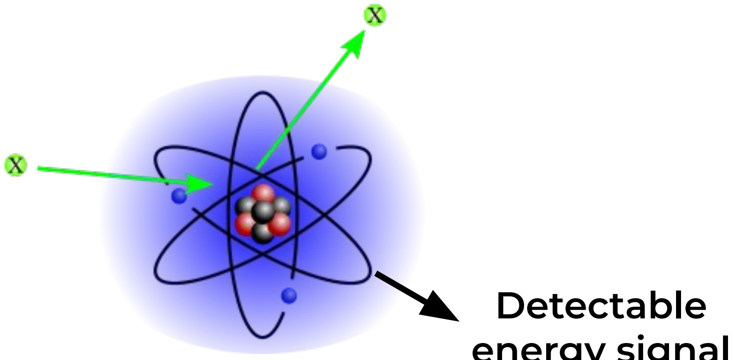
Direct dark matter detection

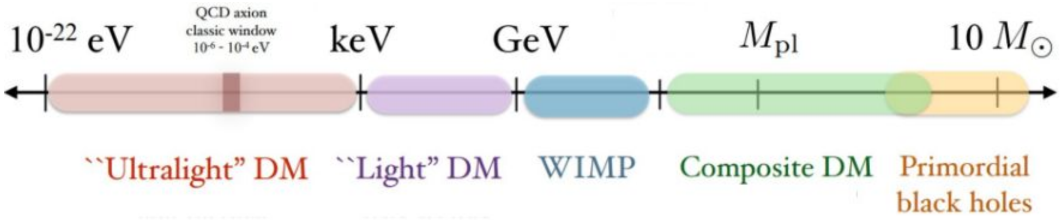
Dark matter

- ❖ No charge
- ❖ No self-interaction
- ❖ Cold
- ❖ Stable

WIMP

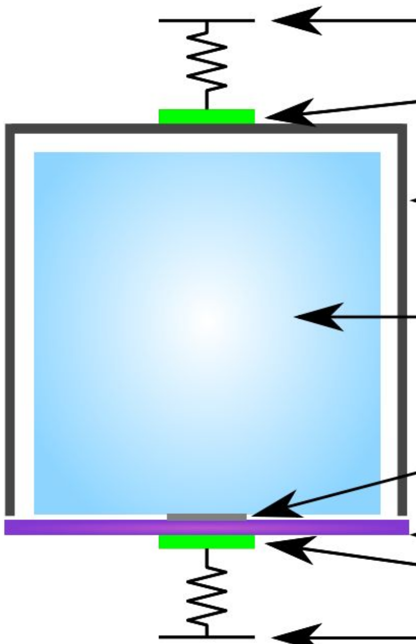
- ❖ All above and...
- ❖ O(GeV) mass



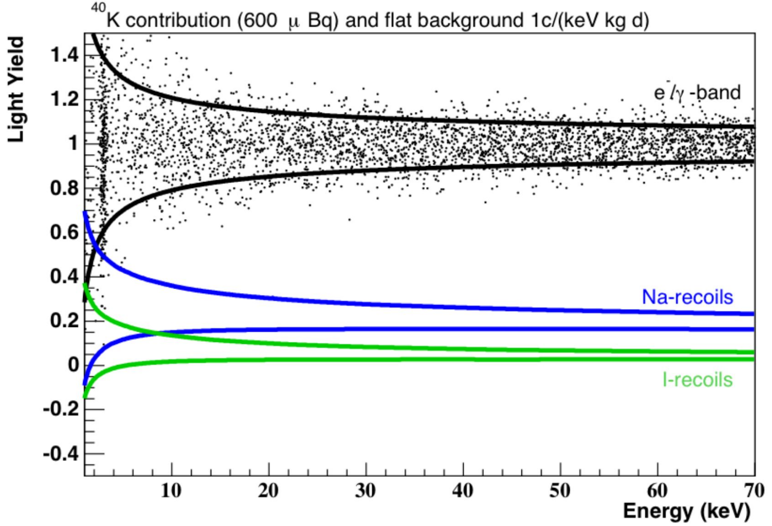


T. Lin (2019)

Cryogenic detectors



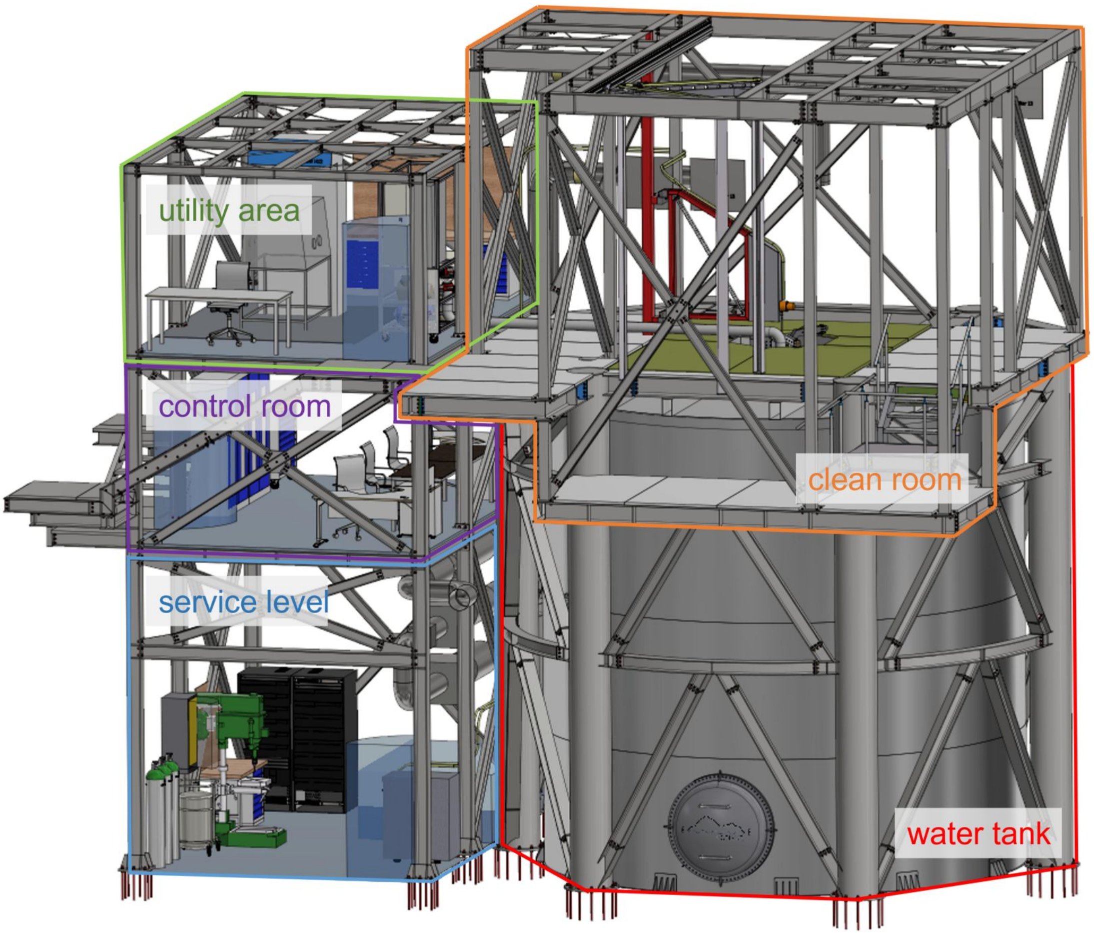
Particle discrimination (NaI)

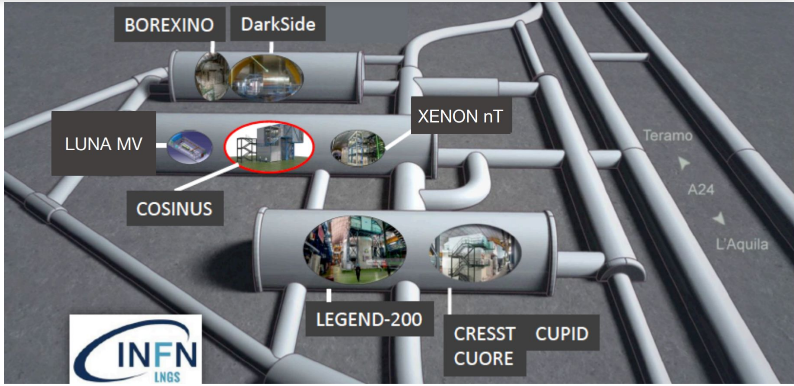


$$Light\ yield = \frac{Energy\ in\ Light}{Total\ Energy}$$

doi: 10.1140/epjc/s10052-022-10184-5

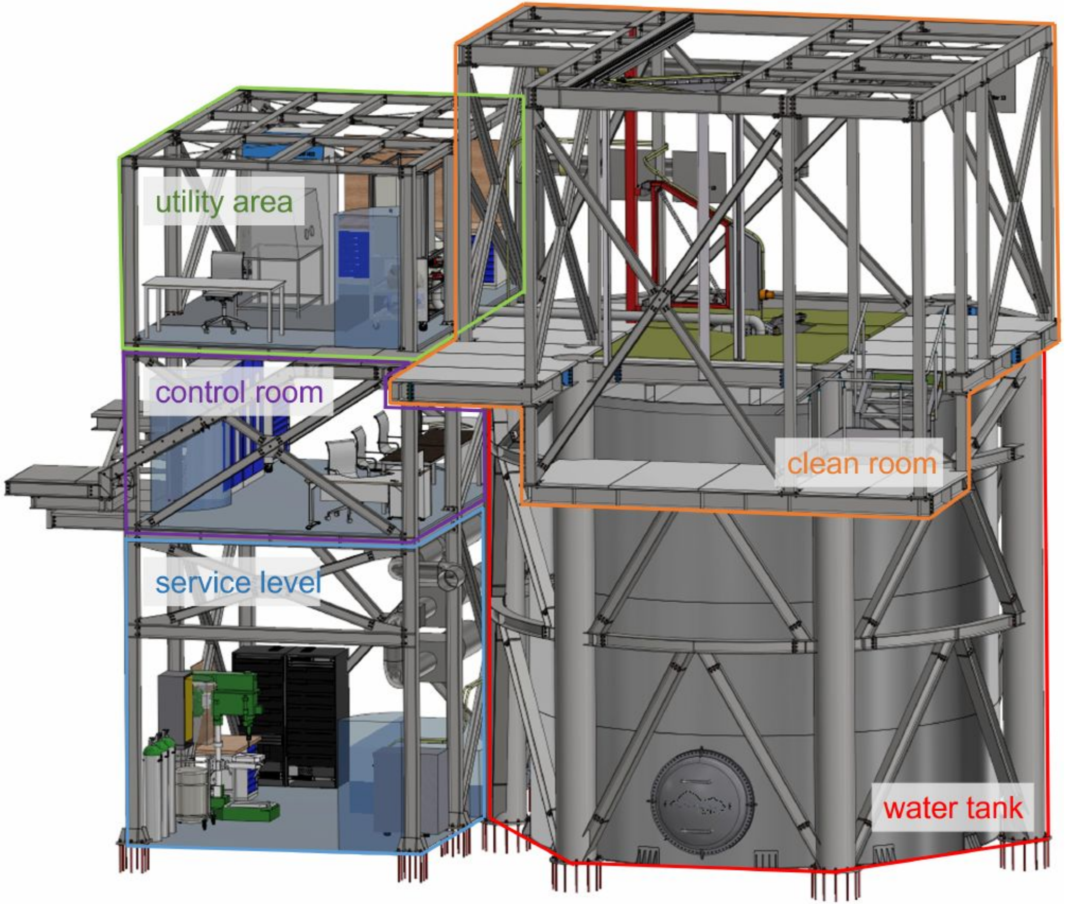
The COSINUS experiment site





- Clear division in multiple working areas
- Instrumented water tank for muon veto, surrounding cryostat.
- Cleanroom facility above cryostat/water tank for easy access and sample manipulation

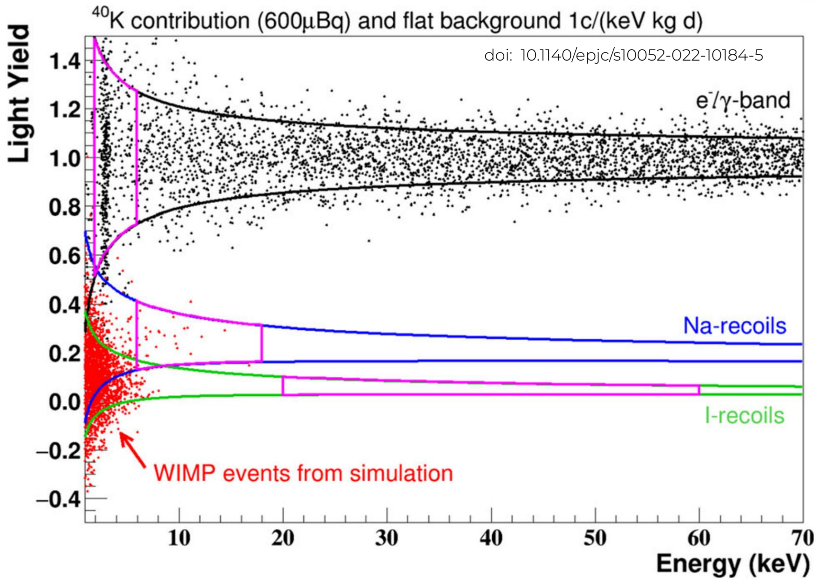
The COSINUS experiment site



The COSINUS experiment site

The COSINUS experiment site

Danger!

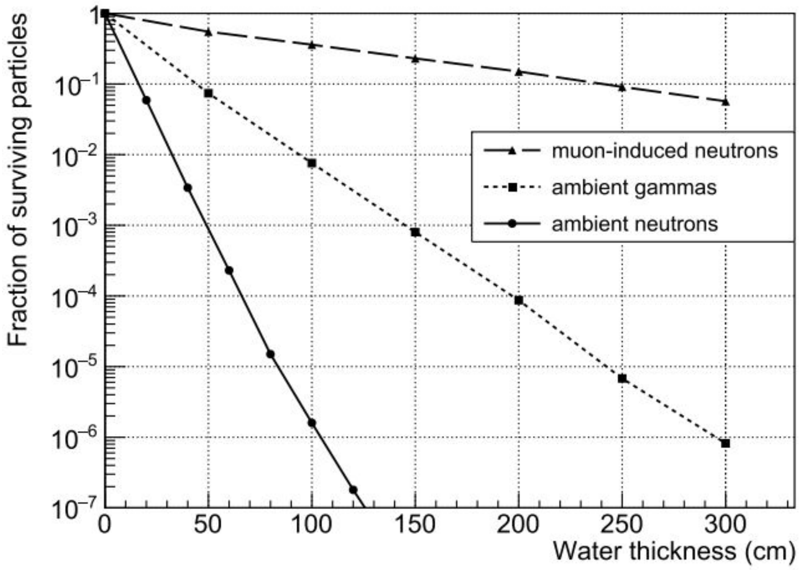


Neutrons!

The COSINUS experiment site

- Water tank as **passive** shielding

- Ambient and radiogenic neutron simulated at 1 neutron per kg . year for NaI detector



The COSINUS muon veto system

Publications on muon veto system

- **Passive shielding**: "*Simulation-based design study for the passive shielding of the COSINUS dark matter experiment*", 2022, doi: 10.1140/epjc/s10052-022-10184-5

- **Active shielding**: "*Water Cherenkov muon veto for the COSINUS experiment: design and simulation optimization*", on peer-review process.

The COSINUS muon veto system

Publications on muon veto system

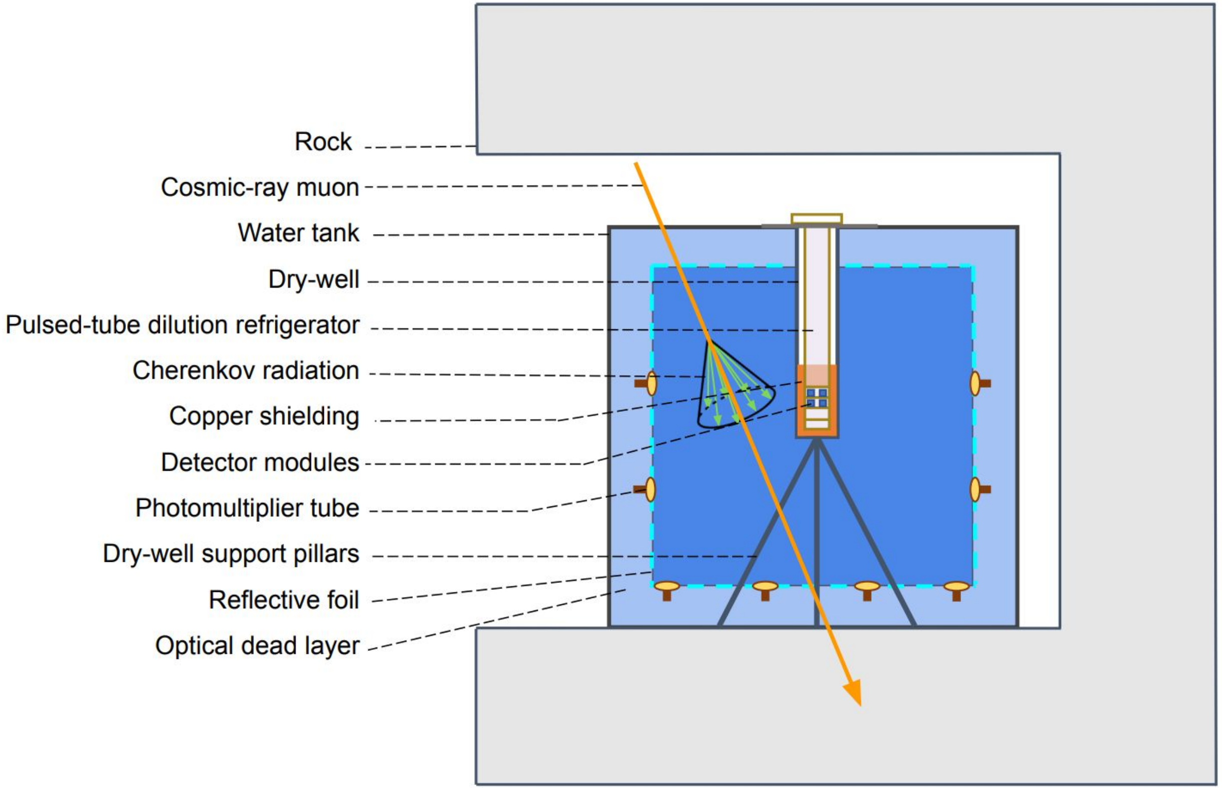
- **Passive shielding**: "*Simulation-based design study for the passive shielding of the COSINUS dark matter experiment*", 2022, doi: 10.1140/epjc/s10052-022-10184-5

→ *"...muon-induced spallation and subsequent hadronic showers result in a further emission of neutrons. A muon veto to tag such events is therefore crucial."*

- **Active shielding**: "*Water Cherenkov muon veto for the COSINUS experiment: design and simulation optimization*", on peer-review process.

→ *"The active veto will reduce the cosmogenic neutron background rate to 0.11 ± 0.02 cts ·kg^{-1} · year^{-1}"*

The COSINUS muon veto system



- Cherenkov light can come from cosmogenic muons (95%) or showers of those muons (5%).
- MUSUN code used for generating muons, ImpCRESST used for physics simulation
- 7x7 cylindrical water tank with 28 PMTs. Internal surface covered with reflective foil

Goals and challenges

- Effectively detect (and veto) muons that generate neutrons

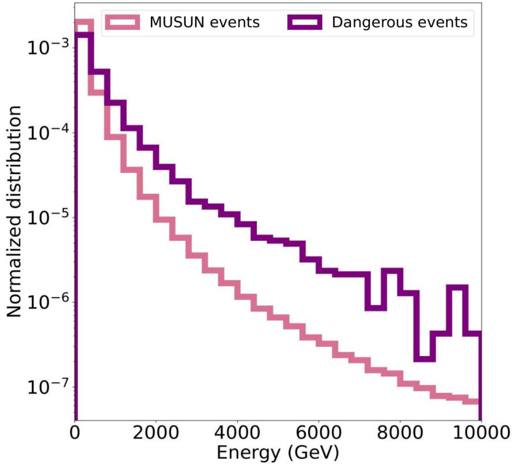
Hamamatsu R5912-30

- Consider the ambient gamma background(~10^5 ɣs per second though water tank)

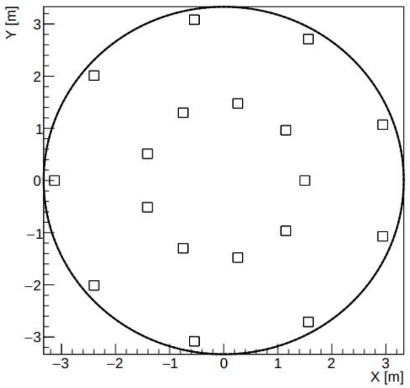
- Take dark counts (~1200/6000 Hz) into account

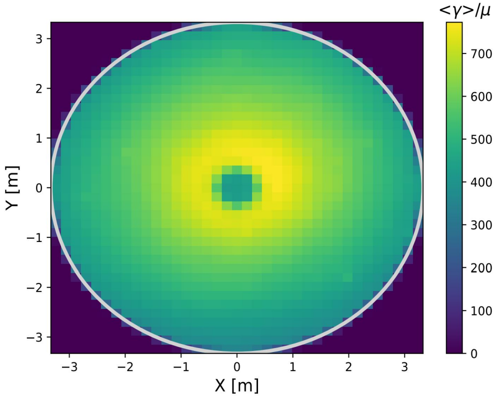
Muon veto simulation

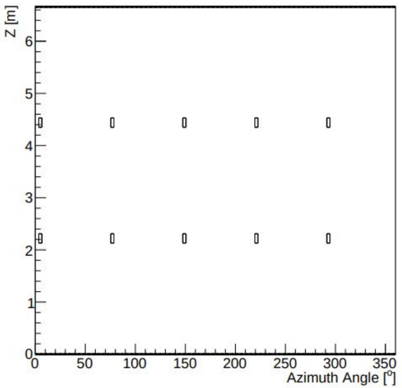
- 30x10^6 muons simulated (~13 years) ➔ 11682 (**~0.04%**) tagged as dangerous (i.e. muon-induced neutrons enter the detector volume)
- Higher energy events tend to be more dangerous (negligible angular resolution)

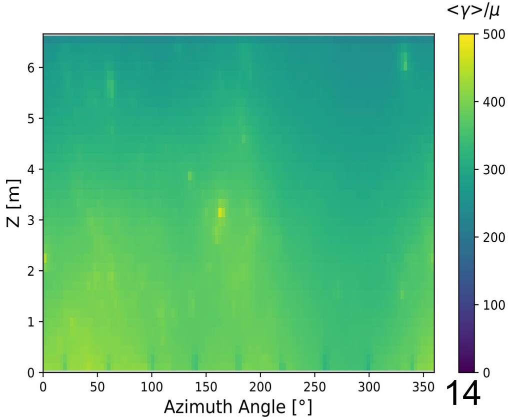


- Illumination map can be reconstructed:







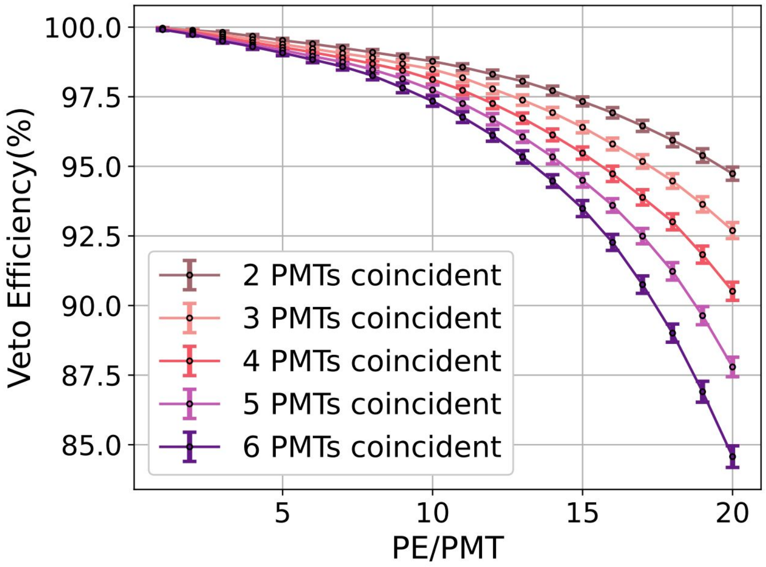


Muon veto efficiency

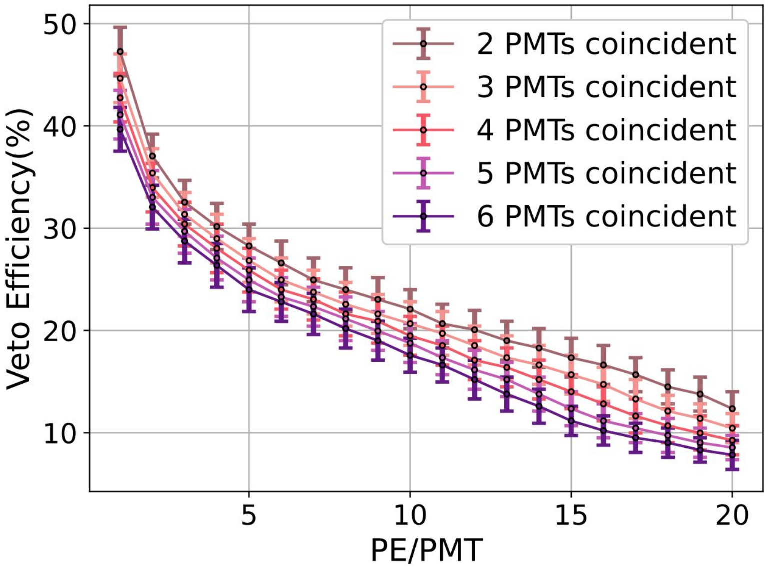
- Efficiency can be **optimized** varying two parameters: **threshold** and **coincidence**

- Ideally, threshold will be set at 1 PE, what about coincidence?

Muon events



Shower events



Ambient gamma background

- Gamma photons sub-products can also generate Cherenkov radiation

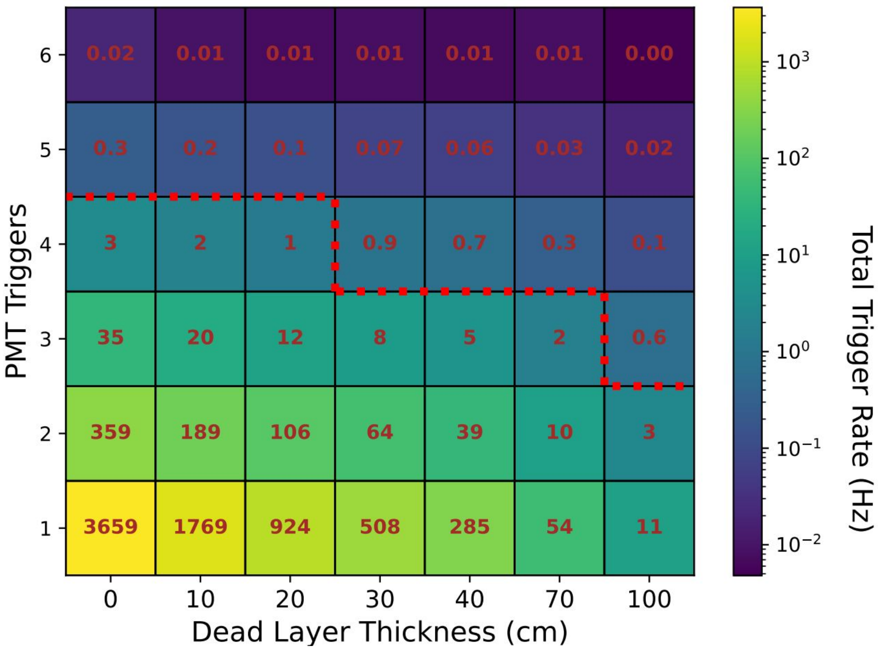
- Utilizing an optical dead layer may drastically reduce this background

- The probability **p** of having a spurious background event in coincidence with a signal event in our detector during a period ΔT is given by

$$p(\Delta T) = 1 - e^{-R_B \Delta T}$$

where R_B is the rate of the background event.

For a ΔT = 10ms and p < 0.01, RB should be < 1Hz.



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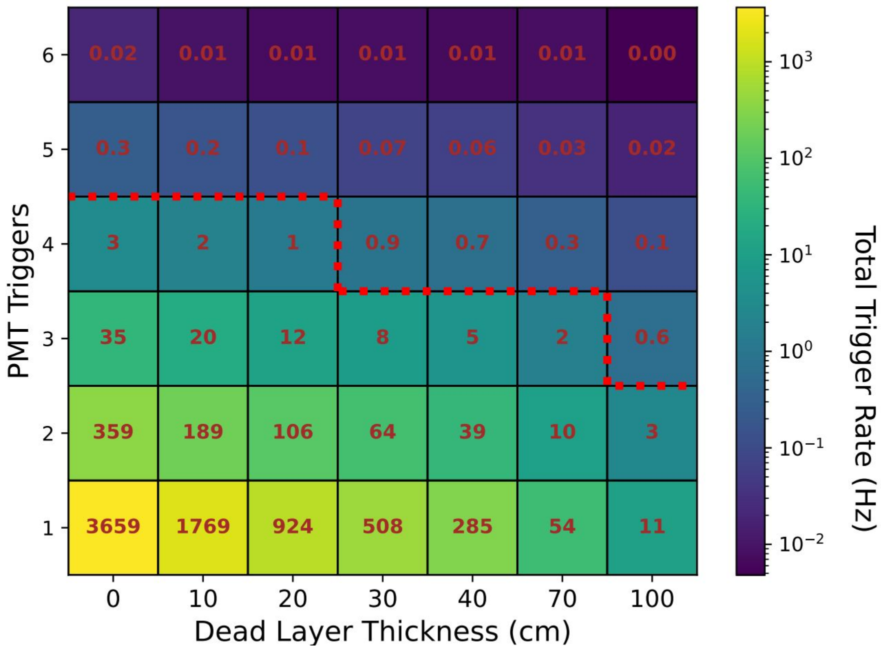
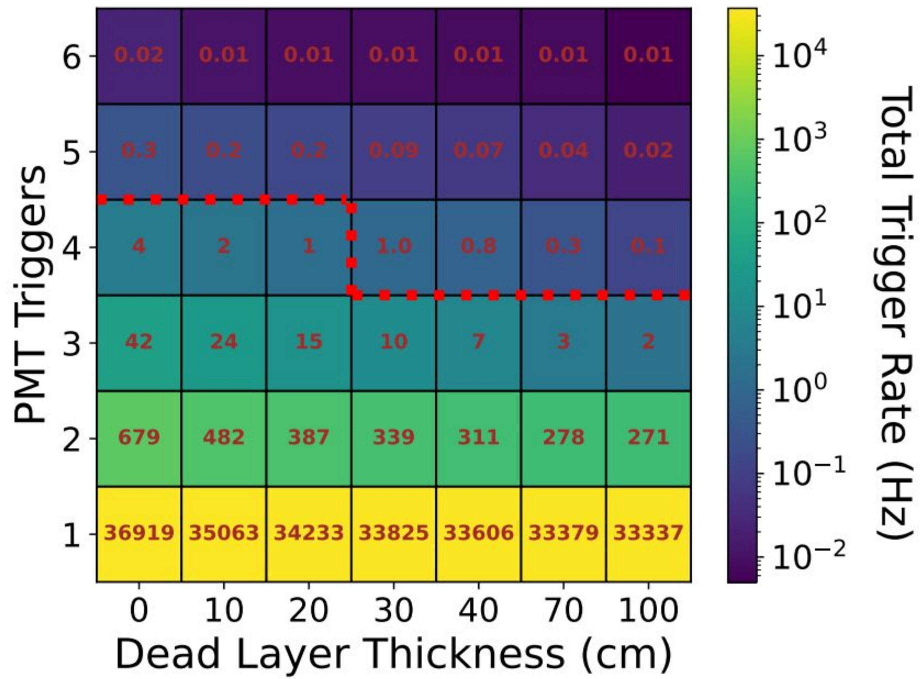


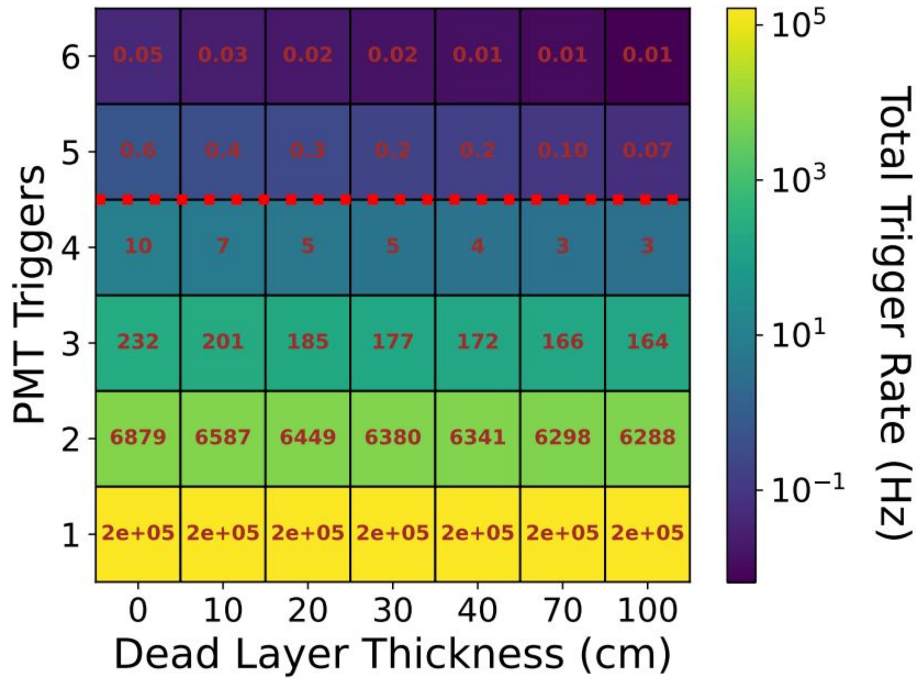
Dead layer not recommended!

Dark current

- Dark current can be taken into account by adding it as a Poisson-like contribution over gamma background



1200Hz



6000Hz

Conclusions

- Effectively detect (and veto) muons that generate neutrons

Hamamatsu R5912-30

→ 5-fold PMT coincidence yield a efficiency veto of **99.63(16)%** for muons and **44.4+-5.6 %** for showers (while the first composes 95% of dangerous events!)

- Consider the ambient gamma background(~10^5 γs per second though water tank)

→ **5-fold PMT coincidence reduces rate <1Hz**

- Take dark counts (~1200/6000 Hz) into account

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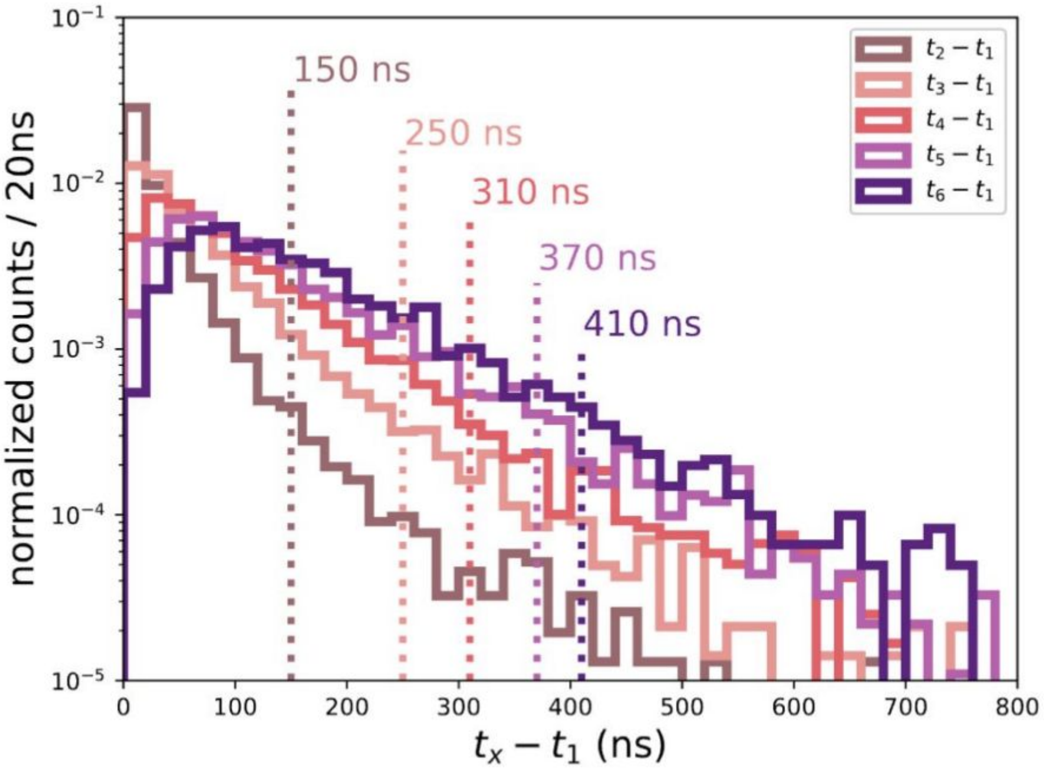
Muon-induced neutron background of **0.11±0.02 $\text{cts} \cdot \text{kg}^{-1} \cdot \text{year}^{-1}$**



- For a 6-fold PMT coincidence 95% of events will be tagged with a coincidence window of > 410 ns