Enhancing Neutrino Detection: Investigating Scintillation and Cherenkov Light in Liquid Argon

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Neutrinos

Neutrinos are fundamental subatomic particles that are in the lepton family in the Standard Model of particle physics. Due to their incredibly small size and minimal interaction, neutrinos are difficult to detect without large detectors. Neutrino detectors have been established worldwide because of their role in different fields including particle physics, astrophysics, and cosmology. Traditional neutrino detectors analyze either Cherenkov photons or scintillation photons or are Time Projection Chambers which collect ionized charges in an applied electric field.

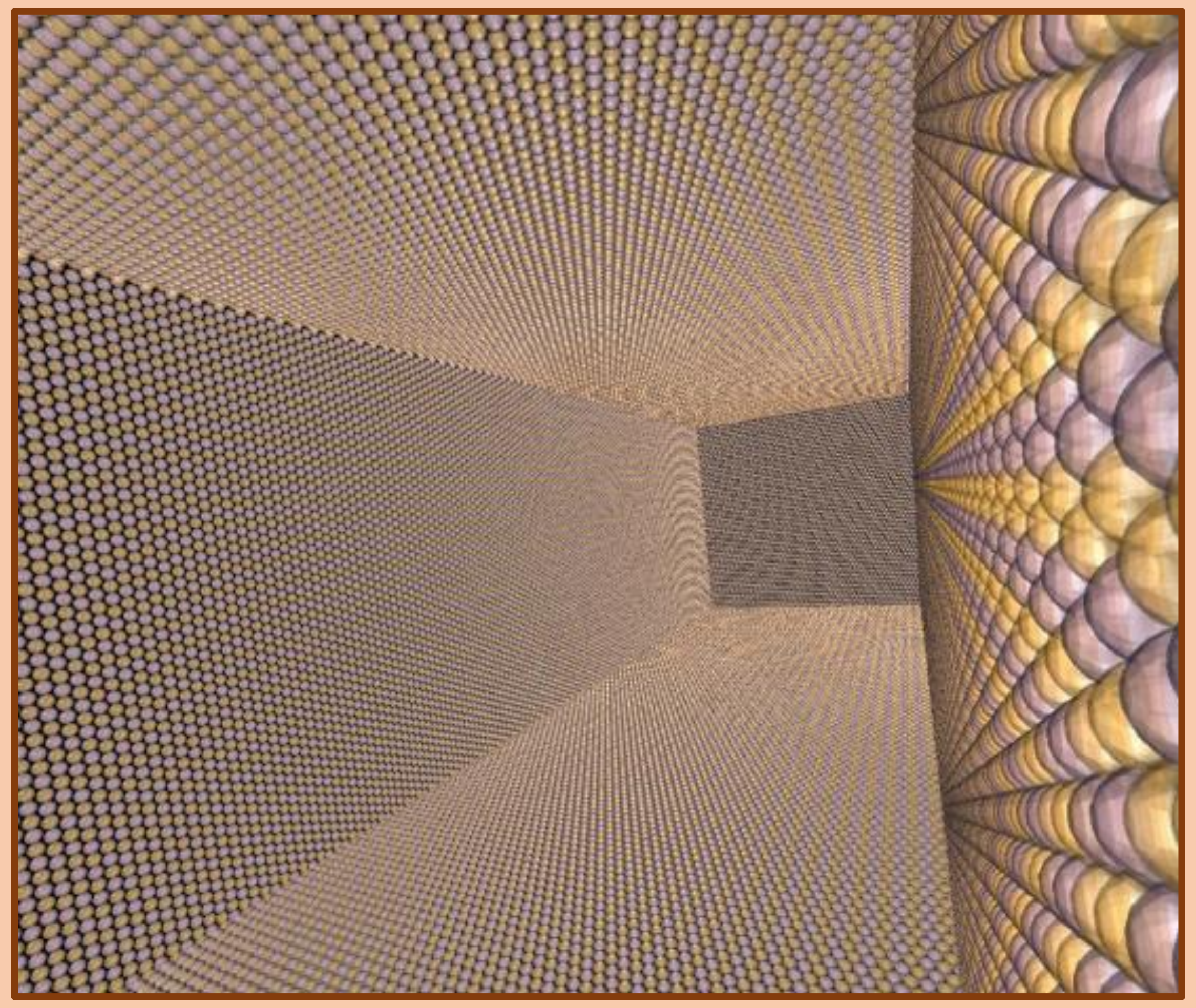
Archers Detector Concept

This research is developing Archers, a simple detector concept to detect both the directional Cherenkov photons and the abundant scintillation photons produced during neutrino interactions. The primary objective of Archers is to attain:

- A high Cherenkov photon yield
- A high scintillation photon yield
- A high purity of Cherenkov photons

By combining detection capabilities for both Cherenkov and scintillation photons, the Archers detector concept offers an approach that has the potential to provide researchers with a more comprehensive dataset for studying neutrino properties.

The Archers Detector

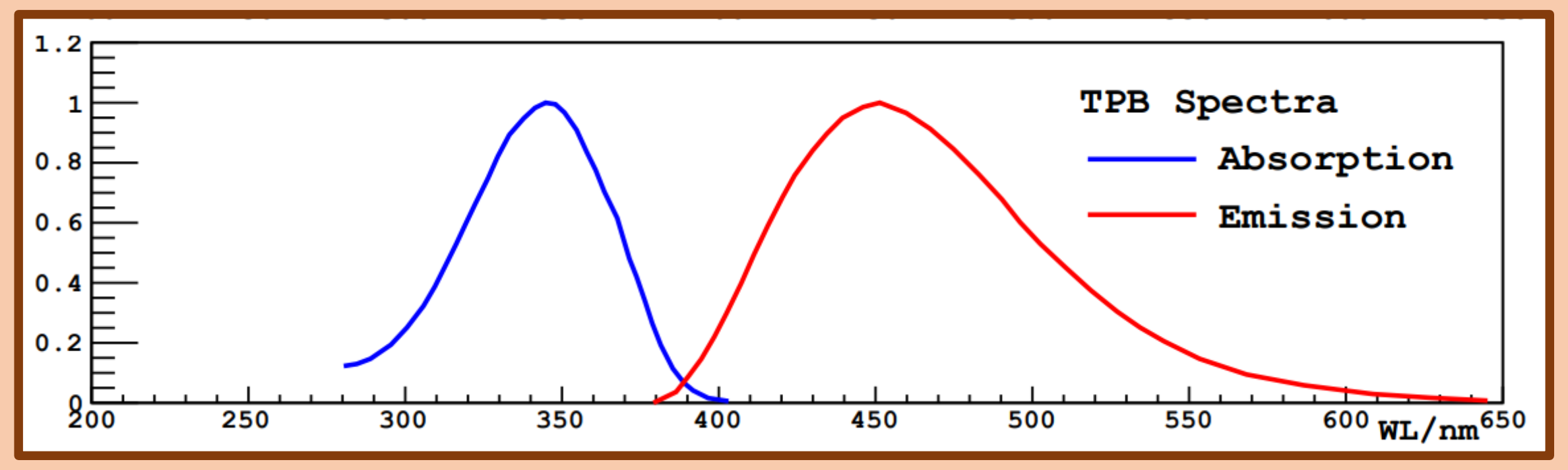


Visualization of the inside of the detector. TPB-coated PMTs are purple. We simulate a ~20-kt liquid argon neutrino detector with about 60,000 10-in photomultiplier tubes (PMTs).

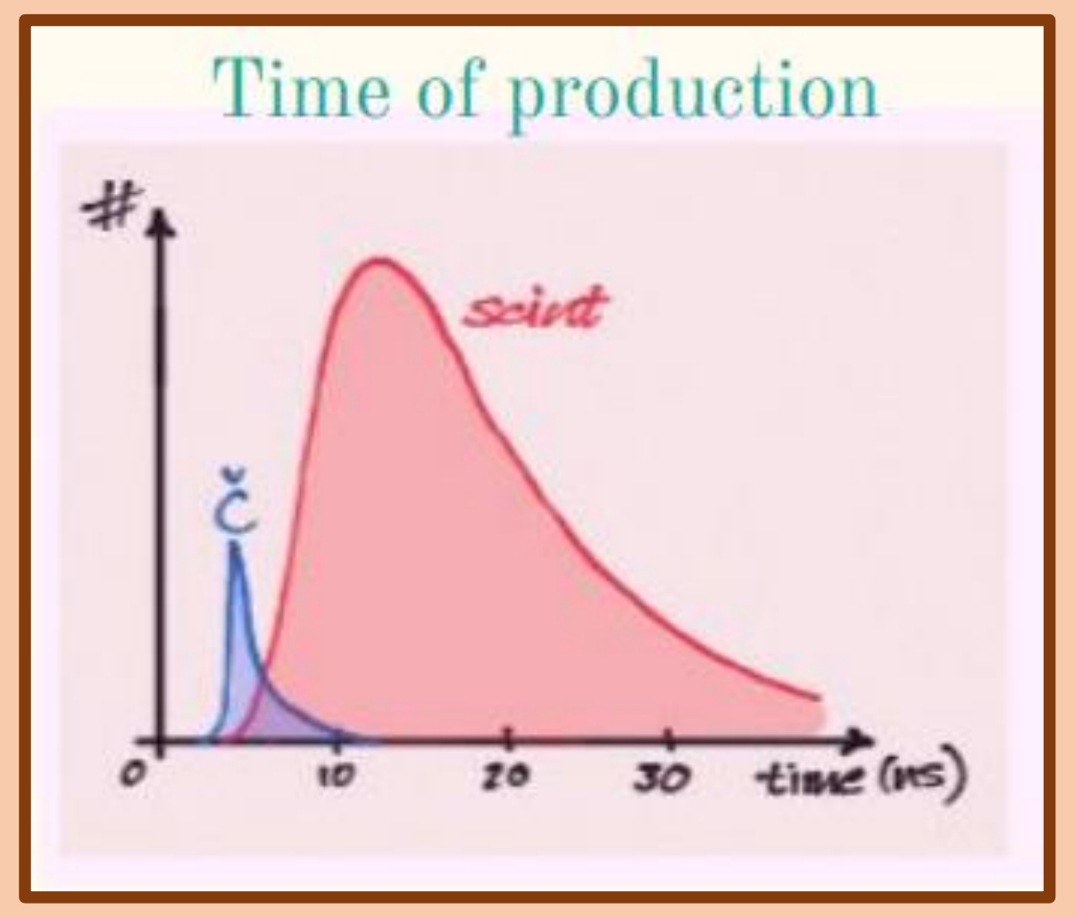
Photon Discrimination in Archers

The distinction between the Cherenkov and scintillation photons is achievable in argon because the scintillation emitted narrowly around 128 nm while the Cherenkov distribution is broad (proportional to 1/lambda^2).

In the ~20-kt of liquid argon are around 60,000 PMTs where half of them are coated in 1,1,4,4-tetraphenyl-1,3-butadiene (TPB). TPB is a wavelength shifter that shifts the wavelength of the scintillation photons into a wavelength range detectable by the PMTs (left figure). Despite the shifter being used for scintillation photons, the TPB coated PMTs are still able to detect Cherenkov photons.

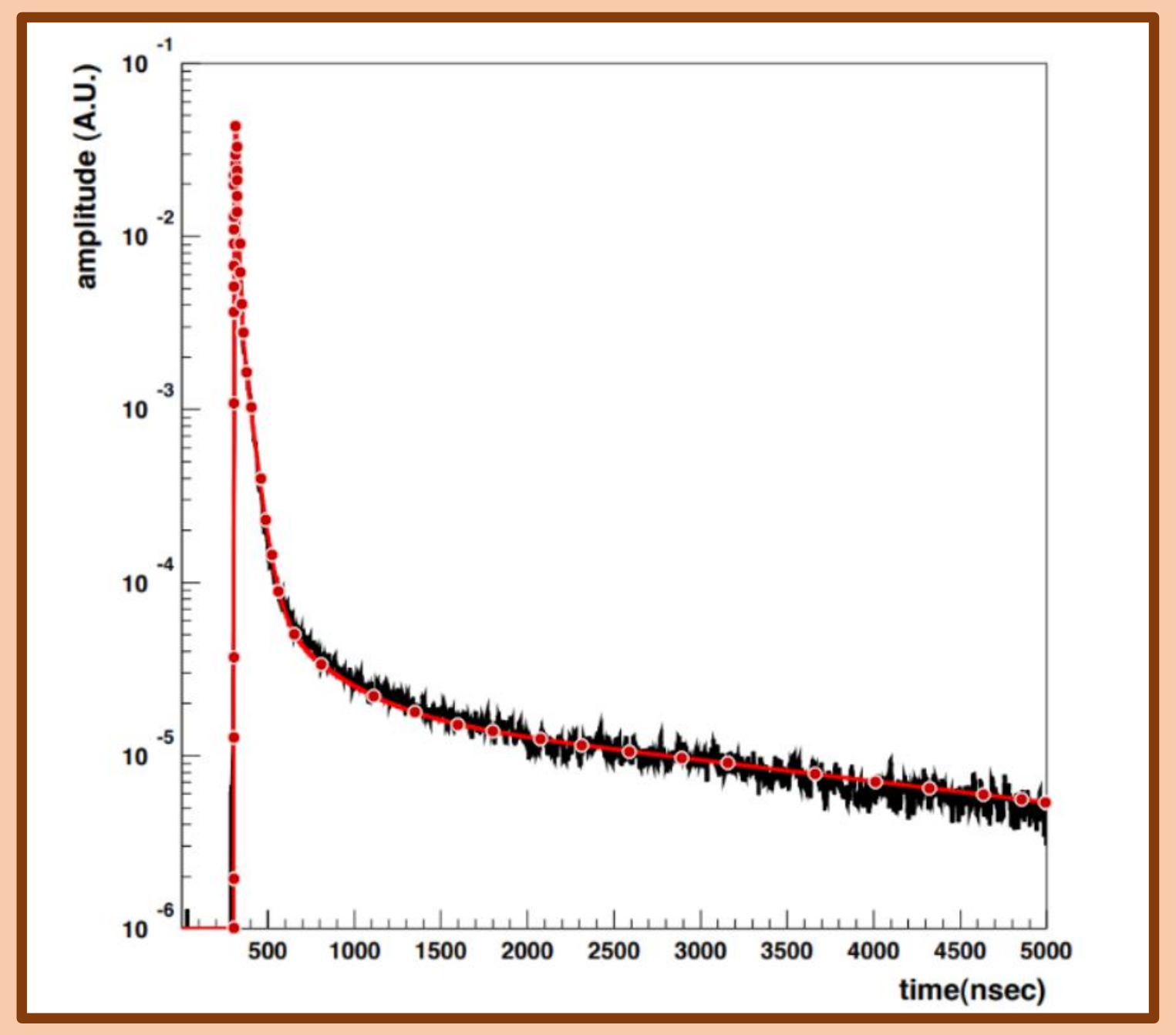


Xu, J. (2012). *Study of Argon from Underground Sources for Dark Matter Detection* [Ph.D., Princeton, NJ : Princeton University]. http://arks.princeton.edu/ark:/88435/dsp015712m665h



We can further separate the two types of photons using their detection times - Cherenkov is produced promptly while scintillation takes time to be emitted (middle figure) and additional time to have their wavelengths shifted (right figure).

The time response of the TPB was added to get a more realistic detector description. An improvement to the purity was made by incorporating an array of data points obtained from a graph of the amplitude (A.U.) versus time (ns). The figure below shows the decay time of TPB that we incorporated into the code.



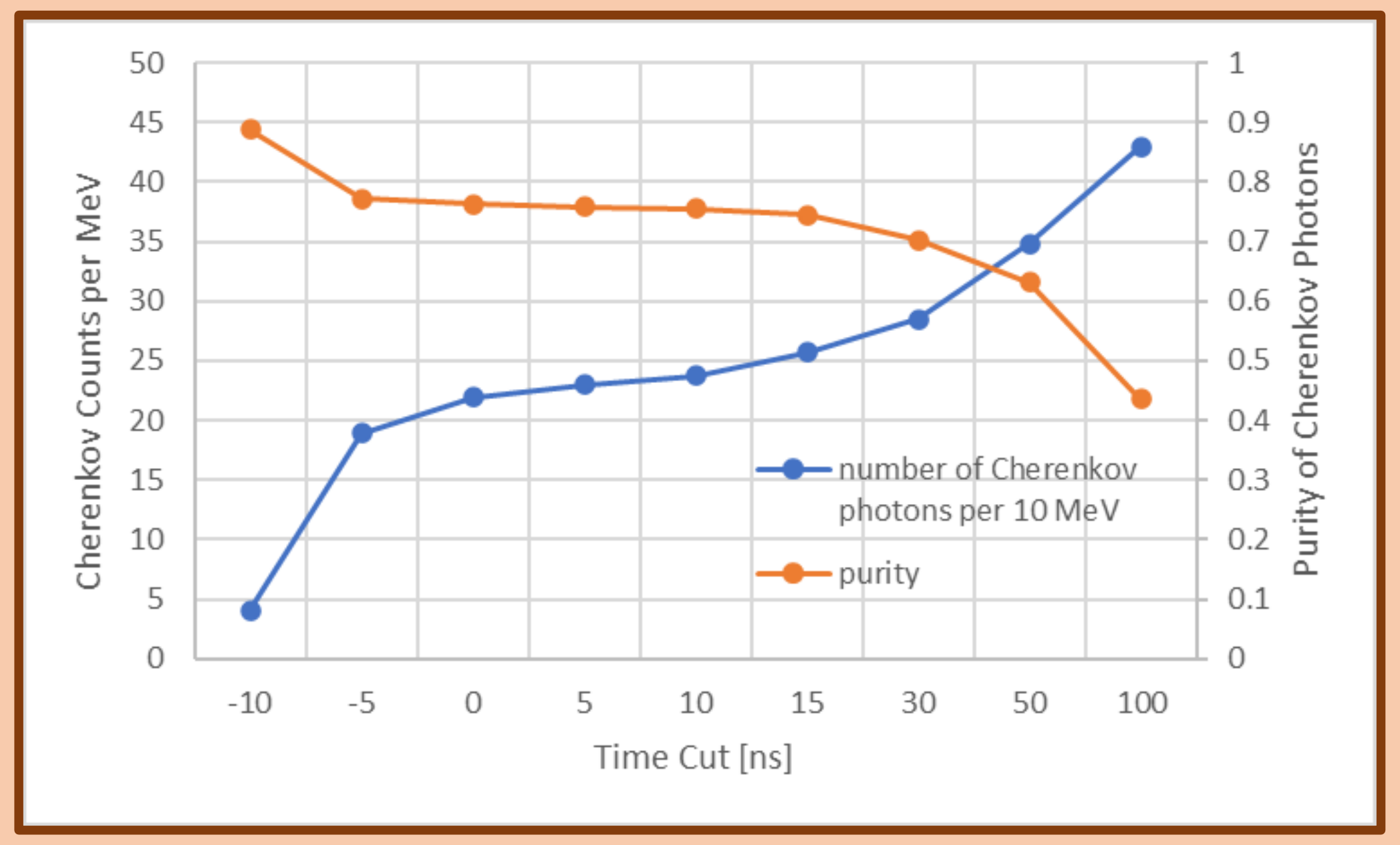
Segreto, E. (2014). Evidence of delayed light emission of TetraPhenyl Butadiene excited by liquid Argon scintillation light. *Arxiv*. https://arxiv.org/pdf/1411.4524v1.pdf

Simulation Method

Our neutrino detector is simulated using graphics processing units (GPUs) to combat problems that come with simulating a large number of photons within a large detector volume. The simulations are run with Chroma and pyrat.

Results: Cherenkov Counts and Purity

The main objective of this research is to understand and explore the capabilities of a liquid argon detector optimized to detect photons. The performance of the detector is evaluated by analyzing the amount of detected Cherenkov and scintillation photons, and the purity of each (with focus on the less abundant Cherenkov photons).



The graph above shows the number of Cherenkov photons detected from a 10-MeV electron at the detector center and the purity of the Cherenkov photons, for a given photon time cut. The time is the time-of-flight corrected photon detection time. Times can be negative because the finite time resolution of the PMTs introduces smearing in the detected times. The results show that the Cherenkov purity ranges from 0.7 to 0.8, in the first few tens of ns. The corresponding number of detected Cherenkov photons is about 20-30 p.e./MeV, which is very good compared to modern Cherenkov detectors (~7 p.e./MeV).

Discussion and Future Aims

The simulation results of the Archers detector provide promising outcomes with the purity range of the Cherenkov photons being in the range of 0.7 to 0.8. This purity highlights the detectors effectiveness in detecting Cherenkov photons compared to other Cherenkov detectors. Our preliminary findings are showing high yields of Cherenkov and scintillation photons, along with a notable level of purity. These findings demonstrate the future potential of efficient photon detection.

Moving forward with this research, the new goal would be to explore alternative wavelength shifters as a means of optimizing the efficiency of scintillation photon detection while maintaining the effective detection of Cherenkov photons.

In recent developments, blinders between the PMTs have been added into the code to reduce impurity from photons reemitted by the TPB. The blinders are not represented in the data presented.

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