Study of geometric efficiency of photon detection in LArTPC using Monte Carlo simulation

Teixeira, V. [1], Muchak, L. [1], Steklain, A. [1], Adames, M. [1], Antoniassi, M. [1].
[1] UTFPR, Curitiba, Brazil

LIDINE 2024

Introduction

The detection of scintillation light in the LArTPC is an important part of the DUNE experiment, as it enables the determination of the neutrino energy and the initial interaction time. In this work, studies on the photon detection efficiency under different geometric conditions were conducted, using computer simulations with the GEANT4 software, considering the diffuse propagation of scintillation photons in liquid argon.

Methodology

In this work, two sets of simulations were conducted using the GEANT4 software: the first to evaluate the detection efficiency as a function of the distance between the emission point and the detector, and the second to assess the angular detection efficiency. In both cases, the experimental setup (Figure 1), as an approximation of the LArTPC structure, consisted of a cubic volume (chamber) filled with liquid argon and a silicon sensor on one of the walls as a detector of photons.

To evaluate the efficiency as a function of the distance between the source and the detector, five simulations were performed, varying the distance of an isotropic photon emission point perpendicularly from the center of the silicon sensor. For the evaluation of angular detection efficiency, six simulations were carried out, keeping the isotropic photon emission point fixed at a distance of 80 cm from the sensor and horizontally shifting the detector every 100 cm along the trajectory relative to the source, in six distinct positions.

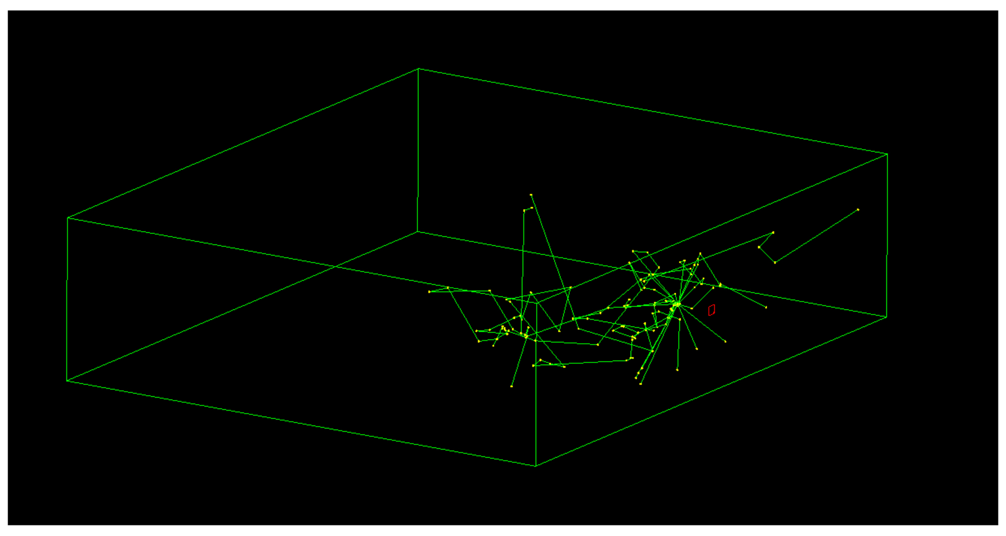


Figure 1: Setup of the simulated experiment in GEANT4.

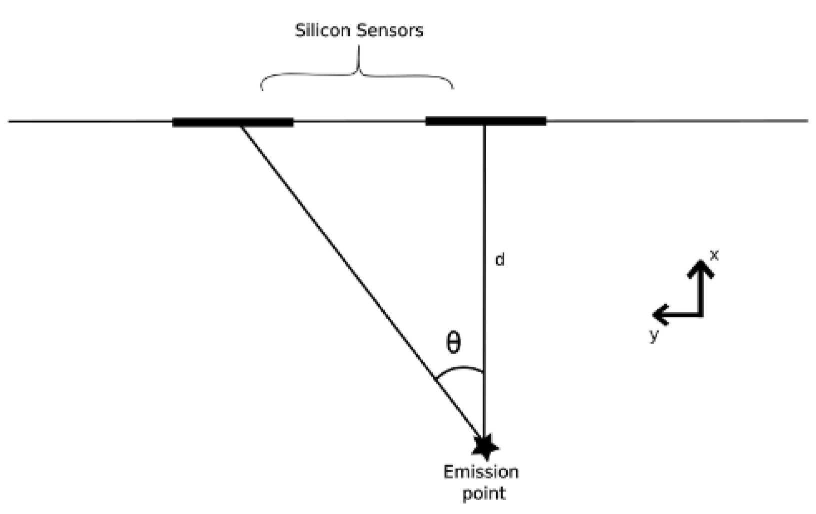


Figure 2: Schematic of the simulated experiment

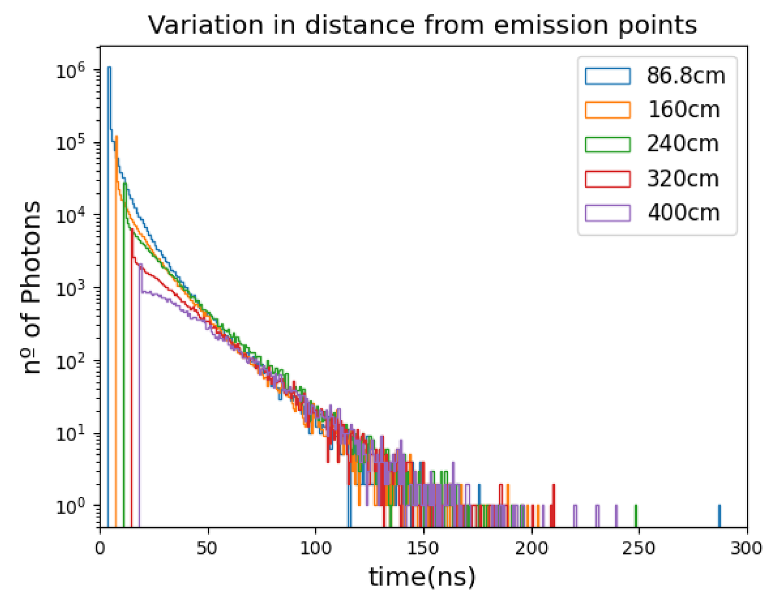
The simulation results allow for the determination of the temporal distribution, angular distribution, and photon detection efficiency for each examined geometric configuration. In addition to evaluating efficiency, the study also enabled the calculation of the correction factors for comparison with the following analytical model:

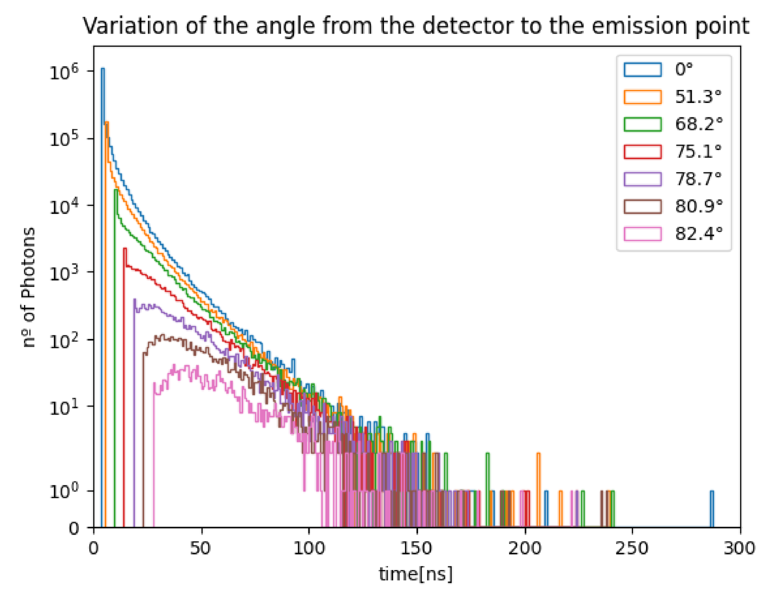
$$N_{an} = N_0 e^{-\mu d}\left(\frac{\omega_{det}}{4\pi}\right)cos\theta$$

where N_{an} is the number of photons detected, based on the initial number emitted N_0, reduced by an exponential attenuation factor, where μ is the attenuation coefficient and d is the distance traveled. The detection efficiency is represented by the fraction of the solid angle $\frac{\omega_{det}}{4\pi}$, and $cos\theta$ accounts for the angular alignment between the emission and detection directions.

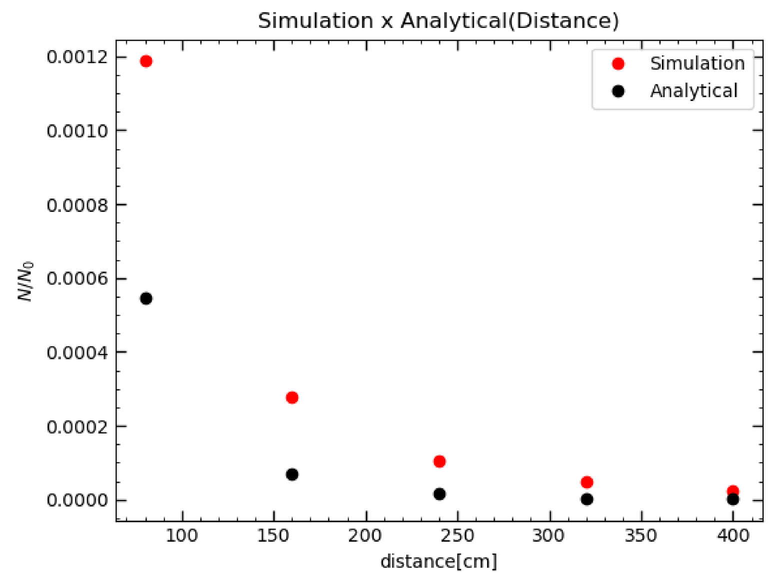
Results

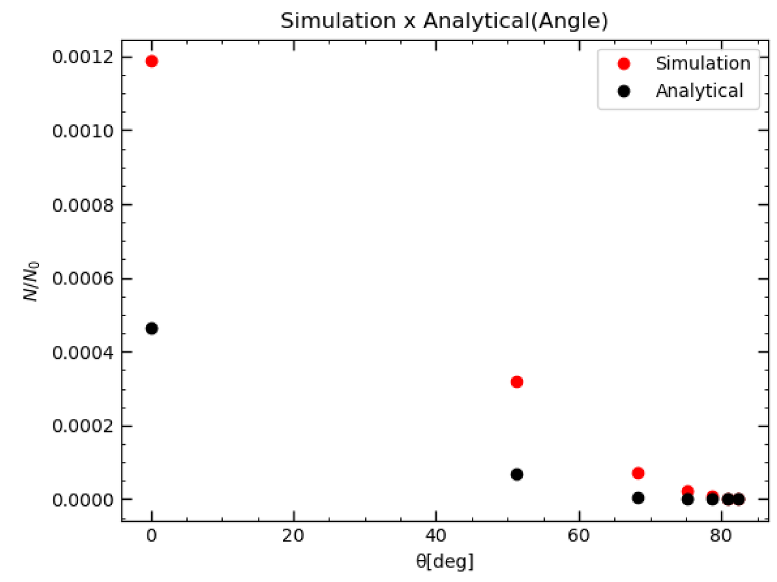
We present the results of the GEANT4 simulations accounting for variations in both distance and emission angles. The histograms show the temporal distribution of the detected photons as a function of distance and angle.



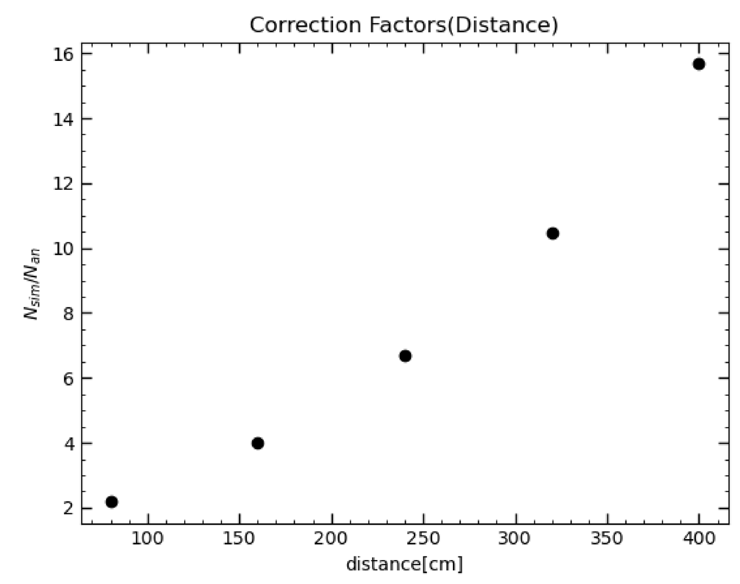


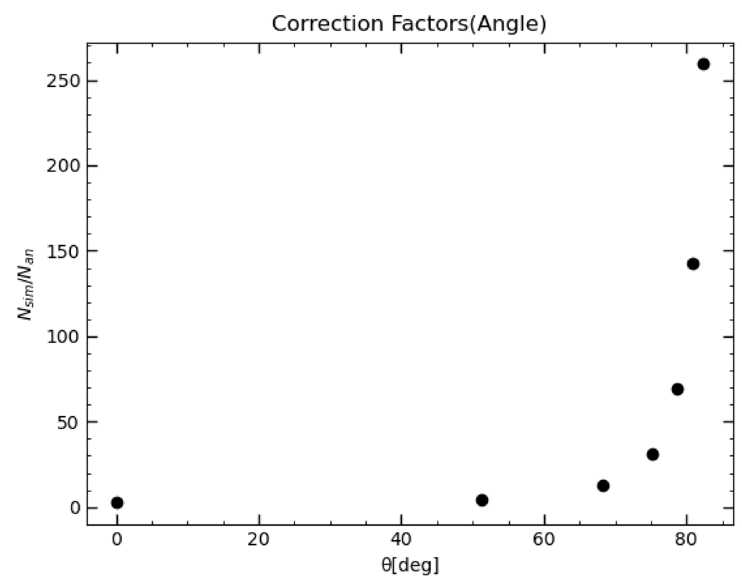
The following graphs demonstrate the relative detected number of photons, obtained by the simulations and the analytical method, both for the analysis as a function of distance and for the analysis as a function of detection angles.





Comparing the values obtained for the diffusive component using the simulation and the analytical method, we obtained the angular and distance correction factors, as shown in the graphs below.





Conclusions

- The simulations allowed the determination of the temporal distribution, photon detection efficiency and the calculation of correction factors for the analytical model.
- The simulation results demonstrate an increase in the relative diffusive component (Rayleigh scattering) with increasing source-detector distance.
- It is expected that this work will be useful for optimization and also for comparison with studies involving analytical models of diffuse propagation of photons in liquid argon.

KEY REFERENCES

[1] Souza, H. V. *ARAPUCA, light trapping device for the DUNE experiment.* **arXiv preprint arXiv:2112.02967.**, (2021).

[2] Garcia-Gamez, D., Green, P., Szelc, A. M. *Predicting transport effects of scintillation light signals in large-scale liquid argon detectors.* **The European Physical Journal C, 81(4)**,349 (2021).

[3] DUNE collaboration. *Deep Underground Neutrino Experiment (DUNE): Far detector technical design report. Volume III. DUNE far detector technical coordination."* **Journal of Instrumentation 15.8** , (2020).

ACKNOWLEDGEMENT AND PARTNERS

DUNE Deep Underground Neutrino Experiment
UTFPR Universidade Tecnológica Federal do Paraná
CNPq Conselho Nacional de Desenvolvimento Científico e Tecnológico
SETI PR.GOV.BR
ARAUCARIA

MORE INFORMATION

Marcelo Antoniassi
UTFPR - Federal University of Technology - Paraná
Curitiba / Brasil

antoniassi@utfpr.edu.br

www.dune-br.org