Parametrization of the photoelectron response of the Pierre Auger Observatory's SD Tank

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Abstract

In this work we show a parametrization of the response of the Pierre Auger Observatory's SD Tank to the arrival of individual particles. We consider a new setup for the SD Tank, introducing a soil layer under the module. With a package based on the Geant4 toolkit, we simulated the tank's photoelectron response to the interaction with the most common particles in an extensive air shower front, for energies in the MeV-TeV range. The resulting data was used to create a parametrization of the tank's response curves for particles with any energy and incidence angle within the simulated range. The parametrization was implemented in a software, called "response function", up to 10^8 times faster than the full simulation. We show this software is able to accurately mimic the Geant4 simulation results.

I. Introduction

The Pierre Auger Observatory's Surface Detector is responsible for the detection of cosmic ray-created particles arriving at the ground. It is made of an array of 1600 modules (called SD Tanks) spread over an area around 3000 Km^2 in Argentina. In this work we show a parametrization of the SD tank's response to the arrival of individual particles.

II. Simulation of interaction with the SD Tank

The simulation was created with a package based on the Geant4 toolkit, called "tank0Mod". It follows all the detection steps of the real module, giving as output the total number of photoelectrons detected. It also considers interactions with a 36 Km^2 soil layer under the module. We ran simulations for 10 types of particles with zenital angles between 0 and 60^o and energy in the MeV-TeV range. Each setup was simulated about 3000 times in order to create the photoelectron frequency distribution. In total we simulated over 1500 combinations of parameters.

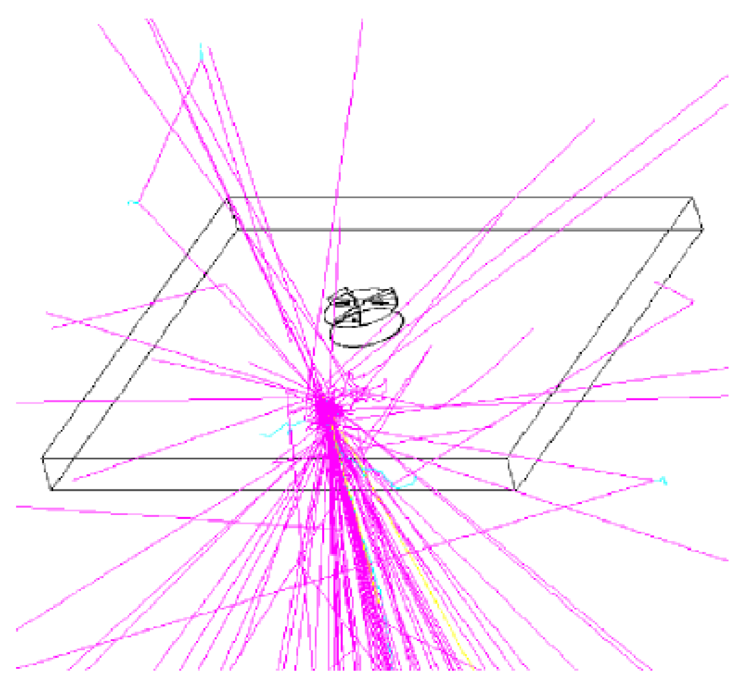

Fig. 1: The tank0Mod simulation, with the SD Tank at the center.

III. Parametrization

A good fit for the photoelectron frequency distribution was determined to be:

$$f(n) = \exp(\alpha + \beta n) + \gamma \exp\left(-(n-\mu)^2/2\sigma^2\right) \qquad (1)$$

and thus 5 parameters define the photoelectron distribution of each curve.

The goal of the parametrization was to write a software that used it to mimic the results obtained with tank0Mod, in a fraction of the full simulation time. The software, called "response function", was written in C. The parametrization data are kept in files accessed dynamically. For a given setup the response function interpolates linearly each parameter between the closest values present in the data. The Smirnov transform is then used on the interpolated function to choose the number n of photoelectrons returned. The response function also chooses whether the incoming particle interacts at all, based on the fraction of simulated events that generated detectable photoelectrons:

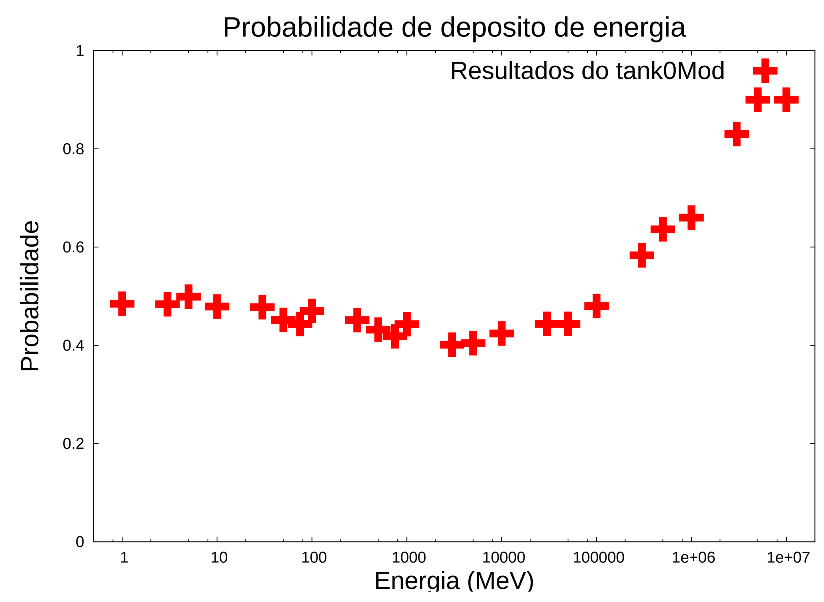

Fig. 2: Probability of interaction for the $\bar{n}$ particle with $\theta = 0^o$.

IV. Results

Bellow we compare the full simulation and the response function results for two cases: the antineutron with $E = 75$ MeVand $\theta = 75^o$ and the electron with $E = 3$ GeV and $\theta = 0^o$. First, we show the fitted photoelectron distribution for the two particles, using the tank0Mod simulation:

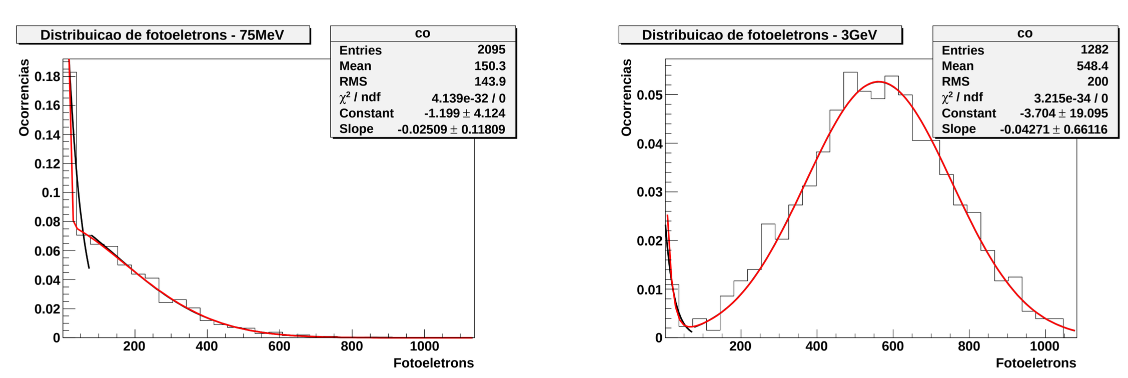

Fig. 3 and 4: Photoelectron distribution for the $\bar{n}$ and e^- particles, respectively.

Next we compare the simulated data, fitted distribution and the reconstructed distribution created by the response function[1]:

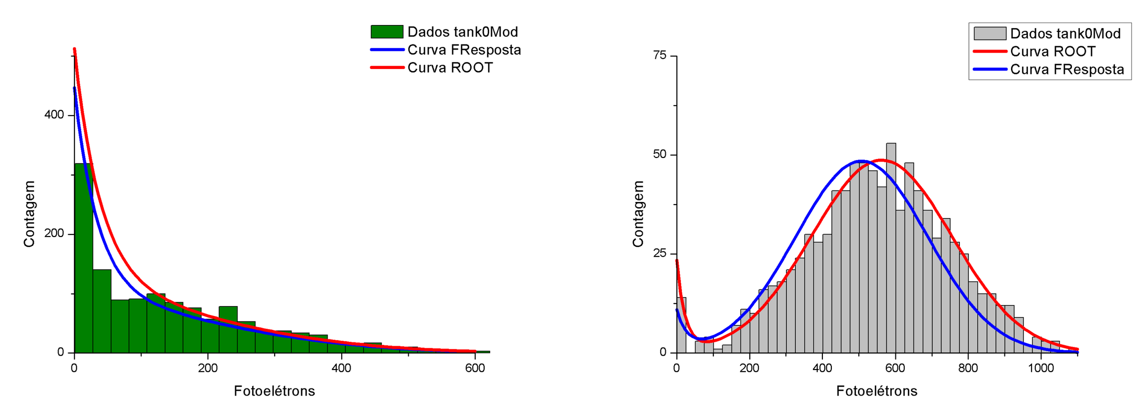

Fig. 5 and 6: Comparison of the tank0Mod data and the response function results.

Lastly, we show that the response function is able to sample numbers from the distribution it creates:

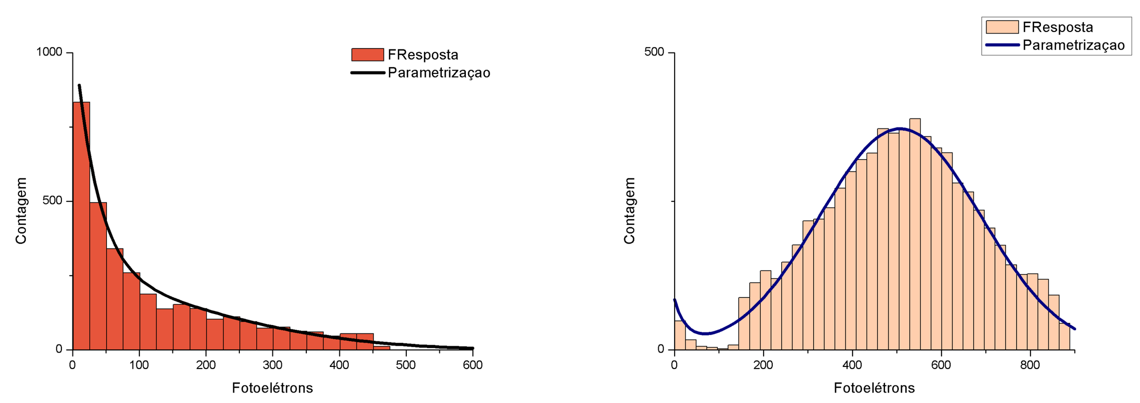

Fig 7 and 8: Comparison of the reconstructed distributions and response function results

Each of the above histograms were created with 10 000 runs of the response function. Each took ˜2 s to run on a Intel Core i3 processor, meaning a speed of 0.2 ms per run. Since a simulation of a typical TeV-scale particle with 100 events takes around 1 month, the response function can be up to 10^8 times faster than the full simulation.

V. Conclusions

The response function was able to accurately mimic the full simulation, and was much faster. It is independent of the internal workings of the Geant4 package used, and can be adapted for other simulations of the SD Tank.

Acknowledgements

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[1] Muller, M. A., *Estudo sobre as Interacoes de Hadrons nos Modulos de Superficie e Adjacencias, do Observatorio Pierre Auger*, PhD Thesis, IFGW-Unicamp (2007)

[2] aiser, T.; Hillas, A.M., *Proceedings of the International Cosmic Ray Conference* , 8:353 (1977)

[3] ossi, B.*High-Energy Particles.* New York: Prentice-Hall, 1952.

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[1]For these tests, the data for the two particles were removed from the response function