Simulations of a sectioned Water Cherenkov Detector for upgrading the LAGO experiment in Sierra Negra.

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Abstract: LAGO project is an international collaboration of water Cherenkov detectors at high altitude sites. In México, the LAGO experiment is located in Sierra Negra, at 4600 m altitude. In this paper we present the results of the simulated detector response under differents initial conditions for a new design, dividing the tank in four equal sections to improve the efficiency. The simulations were carried out using GEANT4.

Keywords: cosmic rays, water Cherenkov detector, GEANT4.

1 Introduction

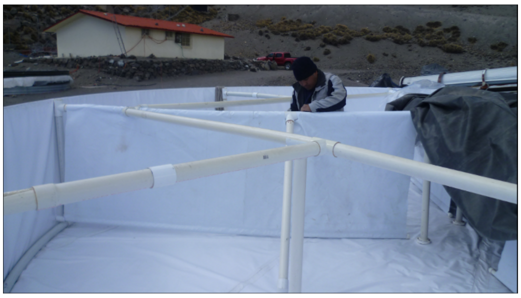
Cosmic rays are charged particles that bombard constantly the Earth's atmosphere from outer space from all directions. When they interact with the atmosphere, may produce showers of secondary particles, called extensive air shower (EAS). Depending on the nature of the primary particle, there are two different kinds of showers, a hadronic shower if the primary is a hadron or an electromagnetic shower if the primary was a lepton (like a photon or an electron). In both cases, different particle processes happen trough the development of the shower. The secondary particles generated, travel at relativistic speed, and radiate blue light due the Cherenkov effect in a dielectric media, as the air and also the water. The maximum production of secondary particles is given at 6000 m.a.s.l. At lower altitude, the energy is not enough to continue producing particles, and just the muonic component is capable to keep travelling.

In ground, and taking in account the altitude of the maximum production of particles, different kind of detectors are used to research this kind of physical phenomena. Some of them take advantage of the Cherenkov effect to indirectly detect cosmic rays and other kinds of particles. The water Cherenkov detector (WCD) have one or an array of photomultiplier tubes (PMT) to count the number of photons produced by particles passing through the water. In fact, cosmic rays never stop coming, so we should detect a rate signal in the PMT's, proportional to the number of secondaries.

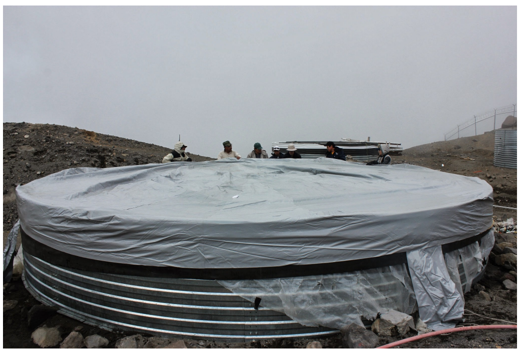
LAGO stands for Large Aperture Gamma Ray Burst Observatory. In this paper, we present two different scenarios to be simulated. In the first one, we simulated muons that impinge vertically on a quarter tank, with a geometry like LAGO, in order to display an expected response of the detector. This tank contained a line of 10 PMTs inside. The second scene, corresponds to a block of particles generated in Corsika that simulated one second of rate, with conditions like the LAGO altitude and location. The secondaries obtained were introduced to a simulated tank, that contained 4 lines of 10 PMTs each one. The tank was sectioned in four slices, separated with Tyvek walls, in order to obtain more signal, originated by the photons bounce on the walls. We also simulated the tank without walls. The tank with PMTs in different positions determines their right place to count more photons. We compare the simulated results with and without walls.

2 LAGO Experiment

The LAGO collaboration is an international network of high mountain experiments, that uses WCD with the single particle technique for the detection of gamma ray burst (GRB). Project sites are Chacaltaya-Bolivia, Marcapomacocha-Perú, Pico Espejo-Venezuela, Bucaramanga-Colombia and Sierra Negra-México.



(a) Installation of Tyvek walls inside a tank.



(b) LAGO experiment landscape, with one of the three tanks in front.

Fig. 1: LAGO site. Sierra Negra, México.

2.1 LAGO setup

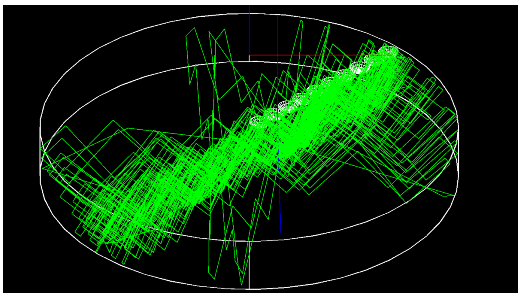
LAGO in México, located at 4600 m altitude, is capable to detect showers produced by gamma photons with energies ranging from 1 GeV to 1 TeV. The single particle technique consists in measuring a significant excess of events above the background rate on all the detectors in a short period of time (∼0.01s onwards) due a GRB. These events must be compared in coincidence with satellites [1].

Currently LAGO in Sierra Negra, is designed with a triangle array of three cylindrical tanks of 7.3 m in diameter and a height of 1 m. The body and bottom of each tank are covered with a high diffusive and reflective Banner bag, that is filled with high quality purified water, up 1.1 m of level. One last update made in the setup, is to have sectioned tanks in four slices of the same size, each one with a 20.32 cm ET-Enterprises PMT, model 9354KBL, installed up towards the bottom. The tank is covered with a reflective and diffuser material Tivek in every internal surface and externally protected with a black, light tight bag, see figure 1 [2]. In the middle of the array, there will be another cylindrical tank with the same diameter but 5.0 m in height, in order to discriminate cosmic rays from GRBs.

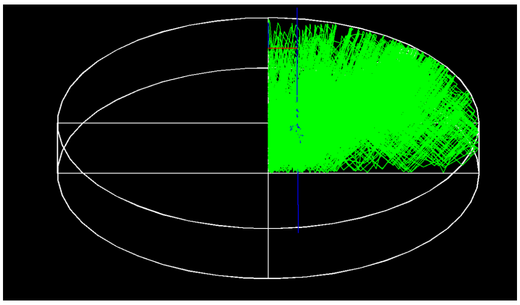
3 Simulations

3.1 GEANT4

Simulations are required in particles physics because the nature of the processes that results in generation of particles with motions is dominated by likelihood. GEANT4 is a very powerful software tool, developed by CERN, that predicts the behaviour of a given particle detector. Provides a set of tools to describe the geometry and the material properties of an detector setup. All relevant physics processes are included. [3]



(a) LAGO tank without walls simulated in GEANT4. Muon vertically incident with energy of 1 GeV.



(b) LAGO tank with walls simulated in GEANT4. Muon vertically incident with energy of 1 GeV.

Fig. 2: Ilustrative simulation of the tank for incident muon.

3.2 Geometry and muons simulation

For this application, the WCD consists of an aluminium cylindrical tank, inside of it, the walls, top, bottom and the inner cylinder cavity were declared with Tyvek properties, filled with water. The PMTs were declared as hemispherical domes at the top of the tank, with an ideal sensitive photocathode that detects, absorbs and counts every photon hit.

In order to assure a correct Cherenkov emission and also to know if the walls setup is the best choice, we simulate a LAGO tank with a line of 10 PMTs with and without walls. We injected a group of 10 000 muons, all with energy of 4 GeV, separated temporarily by 10 seconds, distributed randomly over a square of 3.6 x 3.6 m^2 covering the slice where the PMTs are located. It is useful to simulate incident muons, for calibration of the WCD [4].

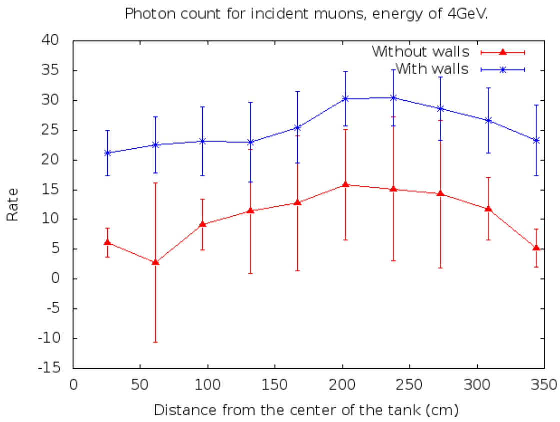


Fig. 3: Average of photons detected by the PMTs, produced by vertical incident muons.

3.2.1 Results of muon simulations

The results of this preliminary test are shown in figure 3. As we can see, when muons are injected to the tank, the average of photons detected by the PMTs is greater when the the tank has walls. The maximum photons were collected at 2 m from distance respect of the tank's center.

3.3 Simulation with showers

In this simulation stage, we use Corsika which utilizes Monte Carlo method to simulate EAS's taking in account the altitude, the place, the atmospheric model, the Earth's electromagnetic field, among other parameters.

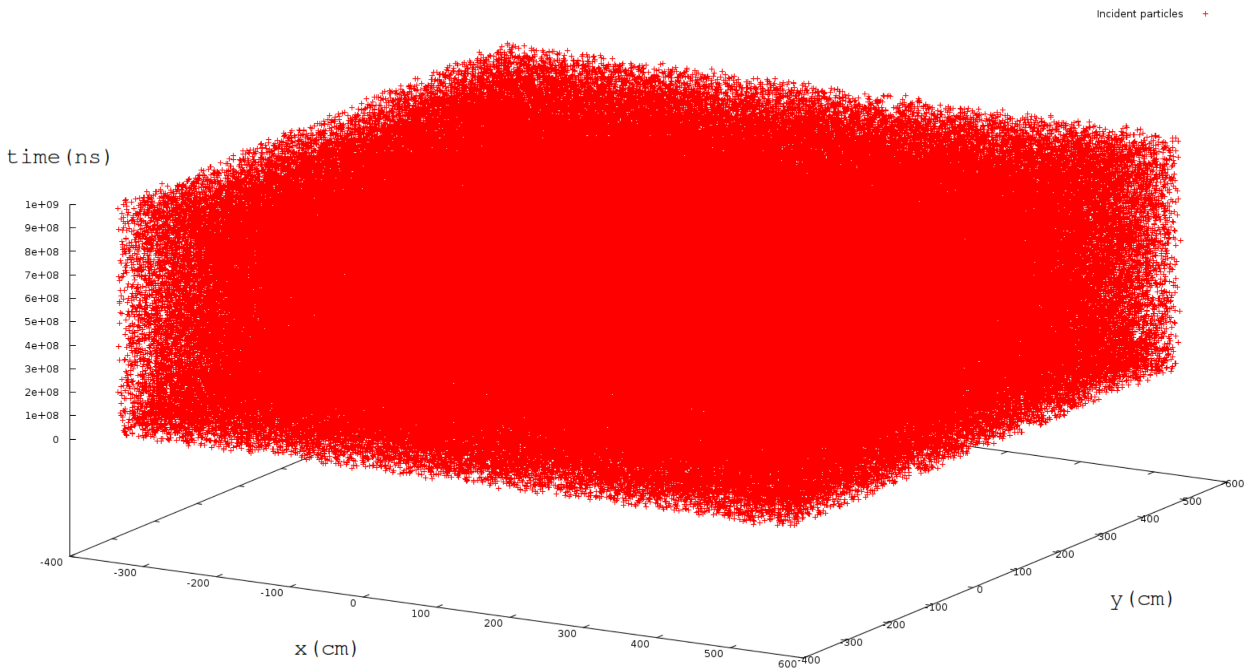
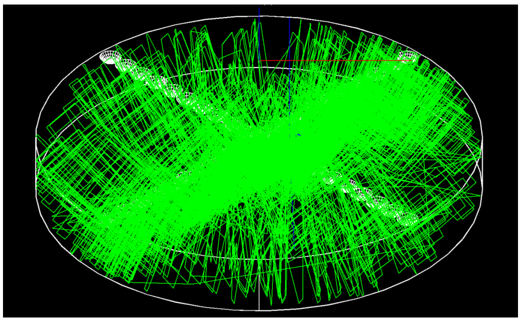
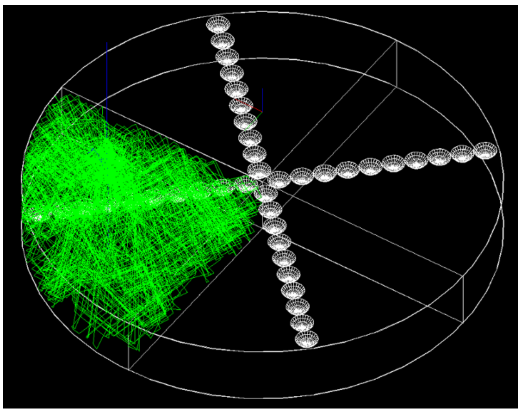


Fig. 4: Block of input of particles.



(a) LAGO tank without walls simulated in GEANT4. Muon vertically incident with energy of 1 GeV.



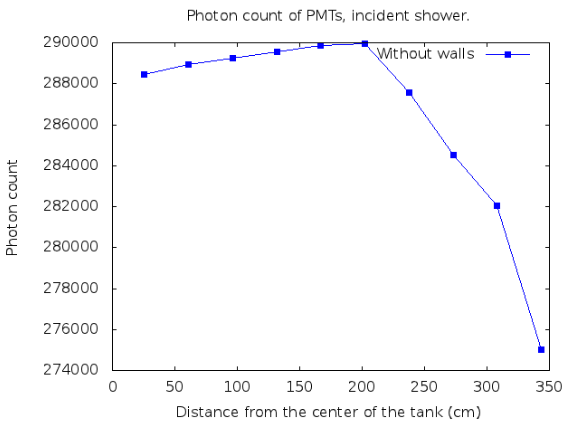
(b) LAGO tank with walls simulated in GEANT4. Muon vertically incident with energy of 1 GeV.

Fig. 5: Ilustrative simulation of the tank for incident block of particles.

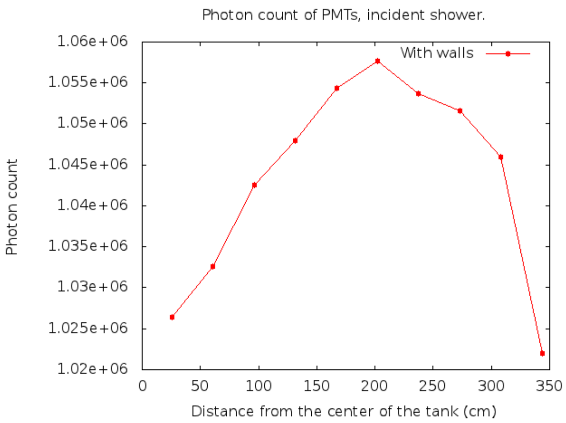
To obtain one second of particle rate, we simulate about 8000 showers with proton particle as primary, incident angle ranging from 0 to 15 degrees, an energy from 10 GeV to 300 GeV and a slope of energy spectrum of -2.7. Every particle generated from the shower was randomly distributed in an area of 9.2 x 9.2 m^2 that covers the tank. It was also temporarily distributed, in order to obtain approximately 4000 particles/m^2s [5]. The particle block is shown in the figure 4.

The simulated tank presents a line of 10 PMTs in every sector, and the simulations were performed with and without walls. The incident particles are exactly the same in both cases. For the without walls case, the photons generated for the passing particle have the likelihood of hit one of the 40 PMTs available, while in the walls case just have the 10 PMTs of the slice. Therefore, the ratio in the counting is 4:1 with respect the walls case. The resulting counts of photons takes into account this count ratio.

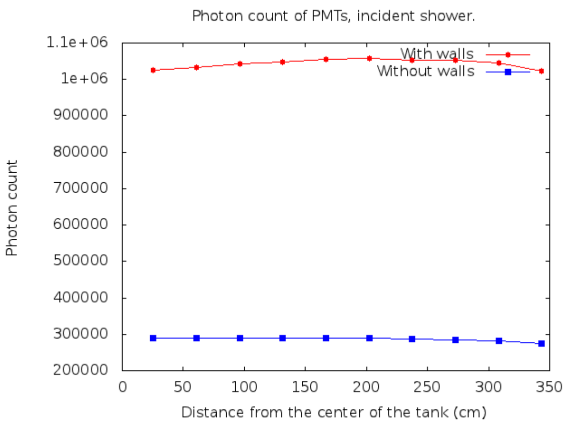
3.3.1 Results of simulations with showers



(a) Resulting photon count from the simulated tank without walls.



(b) Resulting photon count from the simulated tank with walls.



(c) Comparative of photon count between the tank simulation with and without tanks.

Fig. 6: Photon count from the simulation with an incident block of one second of particles.

The results are shown in figure 6. When the block of one second of particles were injected, it is seen that the count at the end of the tank decline in the without walls case, and the maximum of counts is located at 2 m of distance from the center of the tank, as we can see in figure 6 a). In the figure 6 b), the with walls case, the count decline both in the center as in the end of the tank. The maximum count of photons is also at 2 m of distance from the center. The rate is incremented by mean 27.26 % respect to the tank without walls.

4 Conclusions

According to the results, it is a good alternative installing walls in the LAGO tanks. The likelihood that more photons will reach the photomultiplier is raised by 27.26% in the photon rate, in comparision with the original design without walls. It is also confirmed that the maximum value of arrival of photons is when the PMT is at 202.23 cm $\pm$ 20.3 cm to the center. Preliminary tests have been carried out at the site and the simulated results are ready to be comparated with real data.

Acknowledgement: The INAOE, for financial support.

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