Study of atmospheric Showers Simulations, for Low Energies using Trasgos

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Abstract. In this work we present a new proposal to study the primary radiation mass composition at low energies for atmospheric extended showers (EAS), using detectors called Trasgos (TRack and time reconStructinG bOx). There consist on a stack of timing Resistive Plate Chambers (tRPC) with the advantages of high time and space resolution, as well as tracking capabilities. These characteristics allow us to analyze the arrival of the secondary particles and the fine structure of the EAS front. Our simulations consider the lateral distribution of particles near to the core of the EAS, where the electromagnetic to muonic ratio depends more strongly of the effective cross section, i.e. the mass of the primary particle.

1. Introduction

Victor Hess discovered the Cosmic Rays in 1912. He installed three electroscopes in a balloon in order to measure the rate of ionization in the atmosphere. Hess found that such rate increased to about three times with respect to the measured at sea level [1]. These results suggested that the radiation was coming from outside of the Earth. Later studies showed that there is a dependence between the energy of the primary cosmic rays and its possible sources: the Sun, at lower energies, X-ray binaries, pulsars, supernova remnants in the Galaxy and other astronomical objects at higher energies.

The Fermi Gamma-ray Space Telescope [2] measured the diffuse gamma radiation from 1 to 100 GeV approximately. For energies from 1 TeV to 10 TeV, ground based gamma ray telescopes have observed emission from supernova remnants, as expected. However the relation between these observations and the fluxes of high energy protons and nuclei, measured at Earth is not completely clear.

Direct measurements are made at high altitude with the aid of balloons, see Fig.1, and other experiments like PAMELA [4] and CREAM [5, 6], measured the spectrum of protons and helium. PAMELA reported that the spectra becomes harder above a rigidity of 200 GeV. CREAM observed such behavior only for heavier primary cosmic rays [6].

Indirect measurements on the primary cosmic ray energy spectrum for energies above $\sim 10^6$ GeV are made by large experimental arrays located on the ground. This type of experiments allow the study of the secondary particles produced along the extensive air showers. In these cases, the information about primary cosmic ray composition is limited and the relation between
the observed signal at the ground and the primary energy depends on the mass of the primary nucleus. It is important to note the relation between the measured signal and the estimated primary energy depends on the hadronic interaction models used.

There are different particle detection techniques. Scintillating material based detectors are suitable to detect mostly electrons, positrons and muons. Some other experiments, as the surface array detectors of the Pierre Auger Observatory [7] and IceTop [8] use tanks filled with water or ice to detect the Cherenkov radiation produced by charged particles inside the tanks. This method is sensitive to electrons, positrons and muons in the shower.

Experiments like HEGRA [9] and TUNKA [10] used unshielded photo-multipliers looking up at the sky to detect the atmospheric Cherenkov light generated by the extensive air shower. In these cases, the chemical composition of the primary cosmic rays is studied through the lateral distribution of the Cherenkov light at the ground. The atmospheric fluorescence technique used in Pierre Auger Observatory [7] traces the isotropically emitted nitrogen fluorescence lines excited by the passage of charged particles through the atmosphere. Thus, this method is a calorimetric measurement of the energy of each event. By tracing each shower profile, a depth of maximum is assigned to each event. This parameter is sensitive to the primary cosmic ray composition.

There are two possible scenarios two explain the flux suppression at the highest end of the energy spectrum. In one scenario, the energy spectrum around $10^{19.5}$ eV is dominated by heavy nuclei. Here, the upper limit of the particle acceleration is very close to the one from the Greisen-Zatsepin-Kuzmin (GZK) suppression. A second scenario suggest a mixed or heavy composition at the source, such that the flux suppression comes from the photo-desintegration of heavy nuclei and other GZK energy losses. Independently of the acceleration mechanism, the arrival directions of protons at sufficiently high energy are expected to be correlated with their source directions [11].

Some of the most important points of this new proposal is that Trasgos have a good space, angular and time resolution. Thus, Trasgos will allow us to study in detail the shower front
structure near the core of primary cosmic ray interaction. We will be able to perform an event by event analysis, of the electromagnetic and muonic components of the shower. We expect to improve the estimation of the primary mass composition.

2. Trasgos (TRAck reconStructig bOxes)
The primary cosmic ray composition give us information about the origin of the cosmic rays. Depending of the cosmic rays composition, it will be possible to know which astrophysics scenario is more viable.

For these reasons, some of the most important dedicated cosmic ray experiments have plans to improve or upgrade their original detector configuration in order to improve their measurements of the mass composition. One example is the Trasgos detectors [12]. A first Trasgo detector station is now operative at the University of Santiago de Compostela [13].

Hybrid arrays complemented with a relatively small tRPC detectors will improve the determination of the muon - electromagnetic ($\mu$/EM) ratio event by event, and may allow us to improve the measurement mass of the primary cosmic radiation, that may help us to unveil the origin of this energetic particles.

The main objective of the Trasgo detectors is to perform a detail study of the shower front, i.e. to determine the shape of the shower components with enough precision to estimate the composition of the primary particle of the shower. These detectors are based on tRPC Fig. 2, which have the advantage of covering large areas in an affordable way. Some of the most important characteristics of Trasgos are:

- High temporal resolution, $\sim 100$ ps, which allow us a good measurement of the temporal profile of the EAS.
- High granularity, to study with good accuracy the arriving particles of the shower, individually.
- Tracking, which allow us to estimate the arriving direction of single charged particles of the EAS front and particle identification by software.

![Figure 2: Left: A first prototype of Trasgo, already installed at Santiago Compostela University. Right: Particle identification capability of a Trasgo.](image)

3. Work Proposal
With Trasgos, we will collect valuable data to study the characteristics of the EAS with a core located very close to the detector, where we expect a high density of particles. For this reason, we propose a systematic study of the main variables of the showers and the correlation between them. This study can be done for different kind of primary particles: gammas, protons, carbon
and iron nuclei at different energies and zenith angles. We will also consider in our simulations different hadronic interaction models.

To achieve our goal, we propose a global networking, called CORSAIR (Cosmic Ray SimulAtIon Research Network). To generate the simulate events we will use CORSIKA[14]. CORSIKA is specially design to simulate extensive air showers. The program allow us to fix the energy, arriving angle and primary particle of the event. The interval of energy for this study will be from $10^2$ GeV to $10^5$ GeV with zenith angles between $0^\circ$ and $60^\circ$. Each data set will have around 10 000 simulated events, at this moment the network includes: Puebla (Mexico), Tunja (Colombia) and Santiago de Compostela (Spain).

![Laboratorio Nacional de Supercómputo del Sureste de México (LNS)](image)

Figure 3: Laboratorio Nacional de Supercómputo del Sureste de México (LNS) facilities located at Puebla University.

### 4. Work in Progress and Future Work

Up to now, all the necessary software to simulate the EAS is installed at the high performing computing Laboratory(LNS, Laboratorio Nacional de Supercómputo del Sureste de México), Fig.3. The simulated events have the following characteristics:

- Proton as primary particle.
- Primary Energies: 10 GeV, 13.3 GeV, 17.8 GeV, up to 100 GeV in logarithmic scale.
- Zenith angles: $0^\circ$-$12.8^\circ$, $12.8^\circ$-$22.3^\circ$, $22.3^\circ$-$30.0^\circ$.

Between $10^5$ and $10^4$ events for each set will be simulated as a function of the energy. These libraries will help us to understand the behavior of the showers to establish some correlation between their observables to find significant trends both in energy and radial distribution. This analysis will allow us to propose a new parameters or signature to estimate the mass of the primary cosmic ray.

We will also make a comparison between the data collected by Trasgos detectors and the Monte Carlo generated by the proposed network. A Trasgo network around the globe is also planned, (see Fig.4).
Figure 4: We show the different places where it is planned to install a Trasgo.

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