Study on the fitting functions of air shower profiles

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Abstract

Research Description: The Cherenkov Telescope Array (CTA) is the next generation ground-based observatory for gamma-ray astronomy at very-high energies. With more than 100 telescopes located in the northern and southern hemispheres, CTA will be the world's largest and most sensitive high-energy gamma-ray observatory. One of the scientific motivations is to develop an analysis chain to allow CTA to be also a cosmic-ray (CR) experiment in the TeV energy range.

The longitudinal development of air showers generated by gamma-rays and CR will be reconstructed by CTA using a fit of a trial function. By this fit, it is possible to get an important parameter like the X_{max} of the shower, which is commonly used for the mass composition of CR.

In this project, we propose the study of two kinds of trial function, Gaisser-Hillas and Gaussian in age, to be tested on a set of simulated showers generated by CONEX. The goal is to investigate which function describes better the different kind of shower profiles and the fitting stability under the cutting of the shower profiles.

1 Introduction

Cosmic-rays (CR) are mostly protons (90%) followed by a smaller fraction of Helium nuclei (9%) and heavier nuclei (1%). They are continuously hitting the earth's atmosphere. When CR or gamma-ray interact with the components of the atmosphere, a cascade of secondary particles is generated. The number of particles at first increase, reach a maximum and then attenuate (see figure 1a taken from [1]). The atmospheric depth of this maximum, called shower maximum or X_{max}, is the most common way of inferring the primary composition of CR. Xmax depends on primary mass for an specific energy (see figure 1b). The motivation of this project is to study which function fits better to each kind of air shower in the TeV energy range. The idea of this project is based on [2].
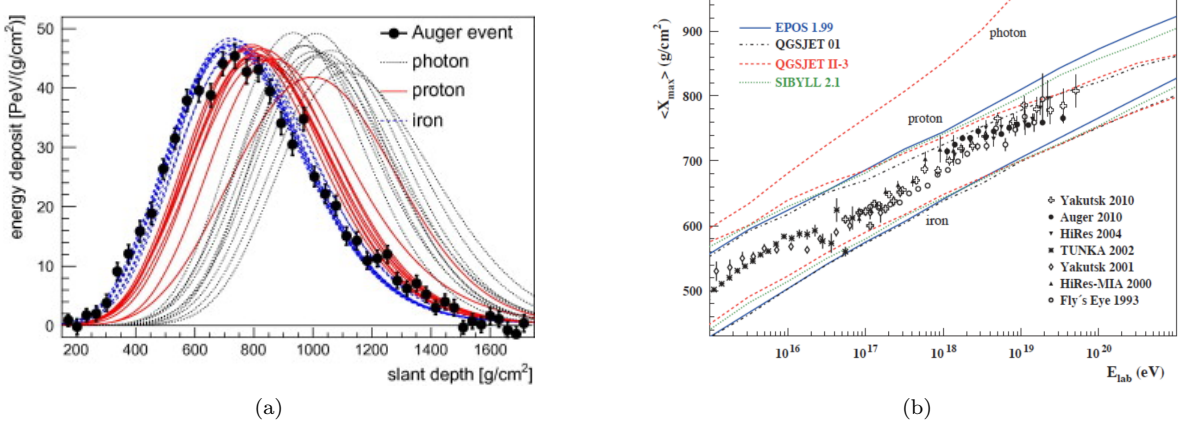

Figure 1: (a) Example of a longitudinal air shower development as measured with fluorescence telescopes, compared to simulated air showers for three different primary particle types. (b) Average of Xmax vs energy, as measured by different experiments. simulations of air showers are also shown. Image taken from https://www.ung.si/~sstanic/teaching/APP/P_Ghia_CosmicRayDetection_I.pdf

2 Trials functions to fit longitudinal profile

Gaisser-Hillas (GH) function and Gaussian in age (GIA) have been traditionally used to fit he longitudinal profile. The GH function defines the number of particles N at the atmospheric depth X measure in g/cm^2 as:

$$N(X)_{GH} = N_{max} \left(\frac{X - X_0}{X_{max} - X_0} \right)^{\frac{X_{max} - X_0}{\lambda}} e^{-\frac{X - X_{max}}{\lambda}},$$ (1)

where Nmax and Xmax are physically meaningful, being the maximum number of particles in the shower, and the longitudinal depth which the shower reaches the maximum number of particles respectively. X_0 and λ has no direct physical meaning. In contrast the GIA function is defines as:

$$N(s)_{GIA} = N_{max} \ e^{-\frac{1}{2} \left(\frac{s-1}{\sigma} \right)^2},$$ (2)

where the shower age s is defined as:

$$s = \frac{3X}{X + 2X_{max}}.$$ (3)

At shower maximum $s = 1$. For more details see [3].

3 Simulations

The simulations used in this project will be done using CONEX [4]. The set of primary particles and energy is defined as follows:

- Primary particle: It will be considered three different kind of primary particles: gamma, proton and iron.

- Primary energy: the showers will be 10 TeV, 50 TeV, 100 TeV and 300 TeV.

For each primary particle and primary energy a set of 1000 shower will be simulated using the QGSJETII-04 [reference] as hadronic interaction model (see table 1).

particle	Energy [TeV]	Number of showers
γ	10	1000
p	10	1000
Fe	10	1000
γ	50	1000
p	50	1000
...	...	...

Table 1: Number of simulated showers.

As result of the simulations, the number of particles along the atmosphere is obtained. The output is written in the form of ROOT files using the ROOT data analysis framework https://root.cern/.

4 Goal of the project

Study the stability of the fitting by cutting the shower profile.

5 Test of the functions

The fitting procedure starts by fitting a quadratic polynomial function in order to get the first guess of Nmax and Xmax parameters. The first procedure is done just by fitting the two functions and comparing Xmax obtained by each one.

The second procedure involves to cut the profiles as follows: a range of $\Delta X = 300 \text{g/cm}^2$ is selected randomly, so that Xmax remains inside the field of view. The fitting is done in these cut-profiles obtaining a different Xmax for each function. The difference between the Xmax obtained before and after the cut is called ΔX_{max}^{cut}.

5.1 Results to be obtained:

5.1.1 1st results:

- Plot of the $\langle \mathrm{X_{max}^{GH}} - \mathrm{X_{max}^{GIA}} \rangle$ as a function of the energy for the three different primary particles.

- Plot the Xmax distribution obtained by fitting of GH and GIA function for the three particles and an specific energy.

- Make a table with the average values of the functions parameters obtained after the fitting for each particle and energy.

5.1.2 2nd procedure:

The following graphs could be done for each primary particle:

- Plot the ΔX_{max}^{cut} distribution for all energy range for GH and GIA functions.

- Plot the average and the RMS of the ΔX_{max}^{cut} distribution as function of the energy.

- Which fitting describes better the longitudinal profile for each kind of shower?

6 Week tasks

- Test the code to make histograms TH1D, TGraph, TTree and do the assignment described in the ROOT tutorial.

- Test the code to fit a quadratic polynomial function around the maximum.

- Write a code defining the GH and GIA functions and fit the profiles.

- Obtain the first results.

- Obtain the second results.

7 Timeline

Week	Topic/Assignment	status
18 - 22 Ap	ROOT tutorial	done
25 - 29 Ap	Check results	...
2 - 6 May	Write code GH & GIA / fit	...
9 - 13 May	Get First results	...
16 - 20 May	Get Second results	...
23 - 27 May	present the results	...

Table 2: timeline.

References

[1] Karl-Heinz Kampert and Michael Unger. Measurements of the cosmic ray composition with air shower experiments. *Astroparticle Physics*, 35(10):660–678, 2012.

[2] Raul Ribeiro Prado and Vitor de Souza. A study on the fitting functions of energy deposit profile of cosmic rays showers. In *33rd International Cosmic Ray Conference*, page 0640, 2013.

[3] J. A. J. Matthews, R. Mesler, B. R. Becker, M. S. Gold, and J. D. Hague. A Parametrization of Cosmic Ray Shower Profiles Based on Shower Width. *J. Phys. G*, 37:025202, 2010.

[4] Till Bergmann, R. Engel, D. Heck, N. N. Kalmykov, Sergey Ostapchenko, T. Pierog, T. Thouw, and K. Werner. One-dimensional Hybrid Approach to Extensive Air Shower Simulation. *Astropart. Phys.*, 26:420–432, 2007.