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Approximation of lateral distribution of atmospheric Cherenkov light at different observation levels. Comparison with previous results

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Using one large detector and partially modified CORSIKA code version are obtained the lateral distributions of Cherenkov light flux densities at several observation levels for different particle primaries precisely at 536 g/cm^2 Chacaltaya, 700 g/cm^2 Moussala and 875 g/cm^2 Kartalska field observation levels for hadronic primaries and gamma quanta in the energy range 100GeV-1PeV. On the basis of the solution of over-determined inverse problem the approximation of these distributions is obtained aiming to use the same function for all primaries, using the same model function for several observation levels, but with different model parameters. The approximations are compared with polynomial approximation obtained with different method and with different χ^2. Both approximations are used for detector efficiency estimation for the different experiments in preparation.

1. Introduction

In the field of high and ultra high-energy astroparticle physics one can find several interesting problems to investigate. In one hand it is important to estimate with big precision the energy spectrum of the primary cosmic ray and at the same time to estimate their mass composition. This is important in attempt to build a model about their origin and acceleration mechanisms. Above 10^{14} eV the only possibility for cosmic ray measurement is ground based i.e. the detection of the secondary cosmic ray thus one or several of EAS components. At the same time it is important to cover the gap between the ground based and the space-born gamma ray astronomy. Currently gamma ray energies between 20 and 250 GeV are not accessible to space-borne detectors and ground-based air Cherenkov detectors. The scientific potential of the ground based gamma ray astronomy is enormous and covers astrophysics and fundamental physics. In one hand it is possible to study objects such as supernova remnants, active galactic nuclei and pulsars. On the other hand the observations especially in the range of low energies will help to understand well the various acceleration mechanisms assumed to be at the origin of very high-energy gamma quanta. One of the most convenient techniques in cosmic ray investigation is the atmospheric Cherenkov technique [1]. Several in preparation experiments such as TACTIC [2] or MAGIC [3] used the image technique i.e. the reconstruction of the Cherenkov image of the shower. The registration of the atmospheric Cherenkov light in EAS can be applied for both of the mentioned above problems. On the other hand it is possible to measure the Cherenkov light flux densities using several detectors. The reconstruction of lateral distribution of atmospheric Cherenkov light is on the basis of previously proposed method for mass composition and energy estimation of primary particle [4]. Moreover this method permits to reject gamma induced showers from hadronic induced events.

2. Discussion

The basis of the method is connected with as flat as possible and as less as possible statistical fluctuation lateral distribution of Cherenkov light densities the aim to obtain the best fit and small uncertainties of model parameters. With this in mind a slowly modified, actually the code output CORSIKA [5] code with GHEISHA [6] and QGSJET [7] hadronic interaction models is used. One large detector is used for the simulation in attempt to reduce the statistical fluctuations.

The simulated events are primary protons in wide energy range. Using the REGN code [8] is obtained the approximation of the different obtained lateral distributions with the same model function. In Figure.1 are presented the lateral distributions with the corresponding approximation for primary proton induced events at 536 g/cm^2 observation level, in Figure.2 and Figure.3 for 700 g/cm^2 and 875g/cm^2 observation level respectively.

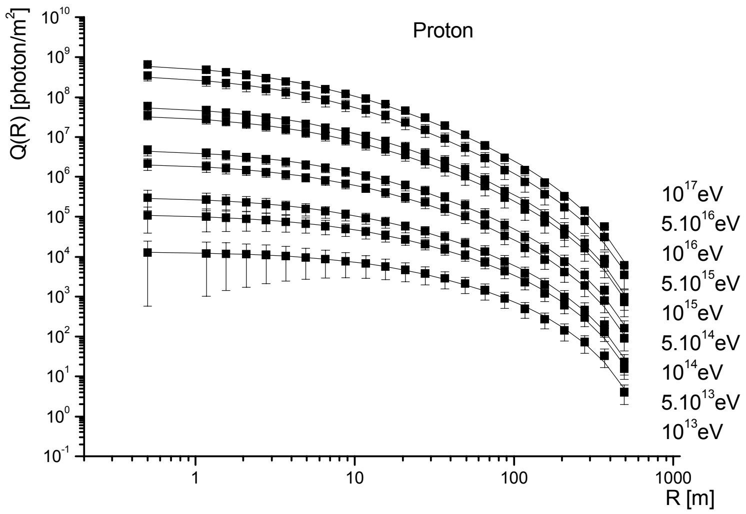

Figure 1. Lateral distribution of Cherenkov light initiated by primary proton in the energy range 10^{13} –10^{17} eV simulated with the Corsika (scatter line) code and the obtained approximation (solid line) at 536 g/cm^2 observation level

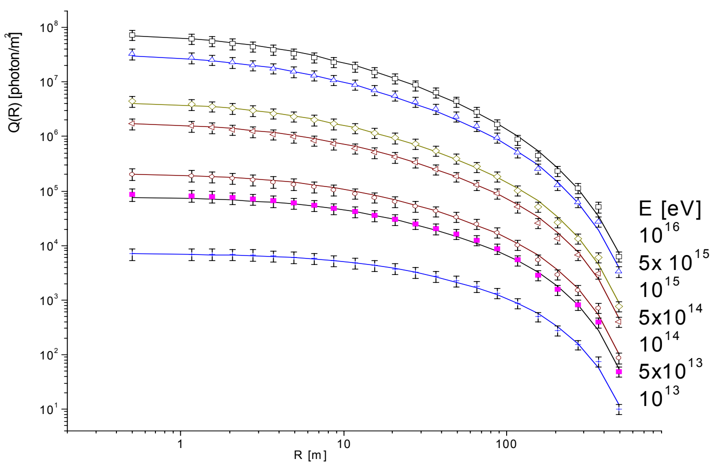

Figure 2. Lateral distribution of Cherenkov light initiated by primary proton in the energy range 10^{13} –10^{16} eV simulated with the Corsika (scatter line) code and the obtained approximation (solid line) at 700 g/cm^2 observation level

The different observation levels simulations and approximations are carried out for solving different problems.

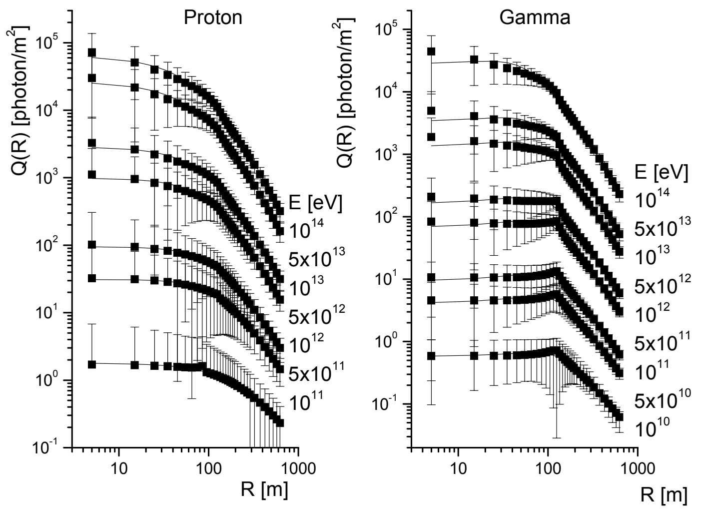

Figure 3. Lateral distribution of Cherenkov light initiated by primary proton and gamma quanta in the energy range 10^{11} –10^{14} eV simulated with the Corsika (scatter line) code and the obtained approximation (solid line) at 875 g/cm^2

At 536g/cm^2 observation level the actual approximation can be applied using the proposed methodology [4] for mass composition and energy spectrum estimation around the “knee” [4]. At the same time with the HECRE [9] experimental proposal are studied the possibilities for ground based gamma ray astronomy [10]. It is very important to obtain with big precision the end of the distribution. This permits in one hand to decrease the χ^2 of the approximation and thus to obtain better results for separation of the different primaries. On the other hand estimate better the energy of the primary particle, which reflects on model parameters and thus permits to reduce the parameter values uncertainties, therefore on separation between the different primaries. At 700 g/cm^2 the obtained approximation is used for fast Monte Carlo simulation of the detector response of Ice Lake experiment [11]. It is compared with the actual polynomial approximation, which was for the first time used for Plana experiment proposal detector response simulation [12]. The obtained result shows that the proposed model gives additional actually better as χ^2 approximation, which permits to estimate with big precision the expected thresholds of the experiment and counting rates. Moreover this study gives as additional result that the polynomial approximation gives some problems in a continuous energy spectrum because the bad approximation of the parameters as a function of the energy. Contrarily the proposed model approximation [4] presented in Figure. 2 because the strong non linearity of the model and taking into account the monotonic behavior of the model parameters as a function of the energy approximation gives more precise simulation of the detector response. In this analysis the data on Cherenkov light flux densities is used to simulate the amplitude spectrum and to estimate the energy of the air shower thus the primary particle energy. At 875 g/cm^2 observation the model calculations are carried out for the future Kartalska field experiment with design similar to the HOTOVO telescope [13]. Taking into account the less number of detectors actually applied for the previously proposed model [4] the realistic topic for research is the ground based gamma ray astronomy. This is the reason to simulate the gamma quanta induced showers presented in Figure. 3. Even in the case of gamma quanta initiated particles the proposed approximation is not with the same quality as for the hadronic primaries one can reject the nuclei induced showers from electromagnetic showers. One possible improvement is to propose a different model function for the different primaries, which reflects on the facility of data analysis. Summarizing the proposed approximations and the methodology with non linear inverse problem solutions gives excellent possibility for energy estimation of the primary cosmic ray with precision around 10-15% at different observation levels and to reject the hadronic induced showers from gamma quanta induced showers. Moreover using one universal model function gives additional advantages for reconstruction strategy and data analysis.

3. Conclusions

Using simulated with Corsika code data the lateral distribution of atmospheric Cherenkov light flux densities are approximated with help of one model function in wide energy range and at different observation levels. This permits in one hand to build an appropriate model and method for energy reconstruction and mass composition estimation of primary cosmic ray at different observation levels in wide energy range, experiment proposals etc… On the other hand one can use the obtained results for ground based gamma ray astronomy. At the same time using the same model function for the different observation levels and particles permits to build the same strategy for event reconstruction and to adjust the model using the behavior of model parameters as a function of the observation level and the energy of the primary particle.

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