Sensitivity of the Tibet hybrid experiment (Tibet-III + MD) for primary proton spectrum between 30 TeV and a few hundreds of TeV's

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Abstract

In the Tibet ASγ experiment, continuous observations of cosmic rays and gamma rays above a few TeV have been carried out using the Tibet-III air shower detector array and the water Cherenkov muon detector array (MD) to study TeV gamma-ray astronomy, cosmic ray anisotropy, and the chemical composition of cosmic rays and their energy spectrum around the "knee" region. In this study, we have developed a method to measure proton spectra from 30 TeV to 400 TeV using the difference in the number of muons depending on the shower primary nuclide. The systematic errors due to the primary composition models and interaction models of the proton spectrum obtained by using this method were evaluated by a Monte Carlo simulation. It was found that the proton events could be selected with 90% purity and the systematic errors between these models were summarized as less than ±36% in total.

Introduction

The composition and the spectrum of the cosmic nucleus around the "knee" energy region are important to study the acceleration limit of cosmic rays and their origin. Proton occupies most of the cosmic rays up to the tens of the TeV region, but due to the acceleration limit, the intensity gradually decreases and the spectral shape changes significantly. The energy range of tens to hundreds of TeV is an intermediate energy between the direct observation using balloons, satellites, space stations, etc., and the indirect observations on the ground, and is one of the regions where further observations are expected. We have developed a new method to measure the proton spectra with tens to hundreds of TeV energies using the data obtained in the Tibet ASγ experiment.

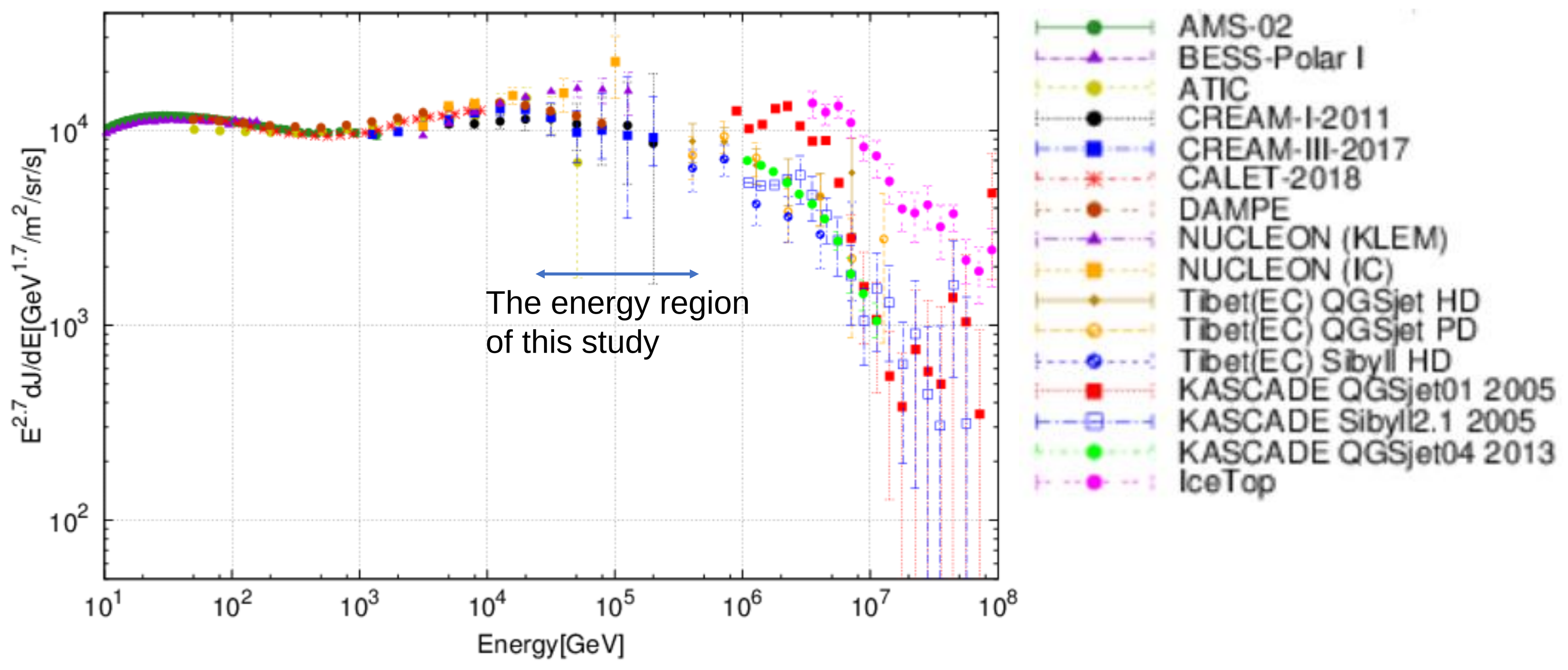

Figure 1: Energy spectrum of protons

Tibet ASγ experiment

We are observing extensive air showers using the Tibet-III air shower array and a water Cherenkov detector array (MD) located at Yangbajing, 4300 m above sea level (Figure 2). The Tibet-III consists of 597 detectors, covering an area of about 65000 m^2. The MD is a detector consisting of four pools, 64 cells in total, and is located 2.4 m below Tibet-III.

Method

The number of muons in the air shower depends on the mass number of the primary particles. Proton events were separated from other heavy nucleus using the number of muons measured by MD. The behavior of particles in the air shower and the detectors were calculated by Monte Carlo simulation, and the performance of this proton measurement method was evaluated. For air shower generation, Sibyll 2.3c, QGSjet-II-04, and FLUKA were used as interaction models, and Shibata-model (heavy Dominant) and Gaisser-fit-model (helium dominant) were used as cosmic ray composition models.

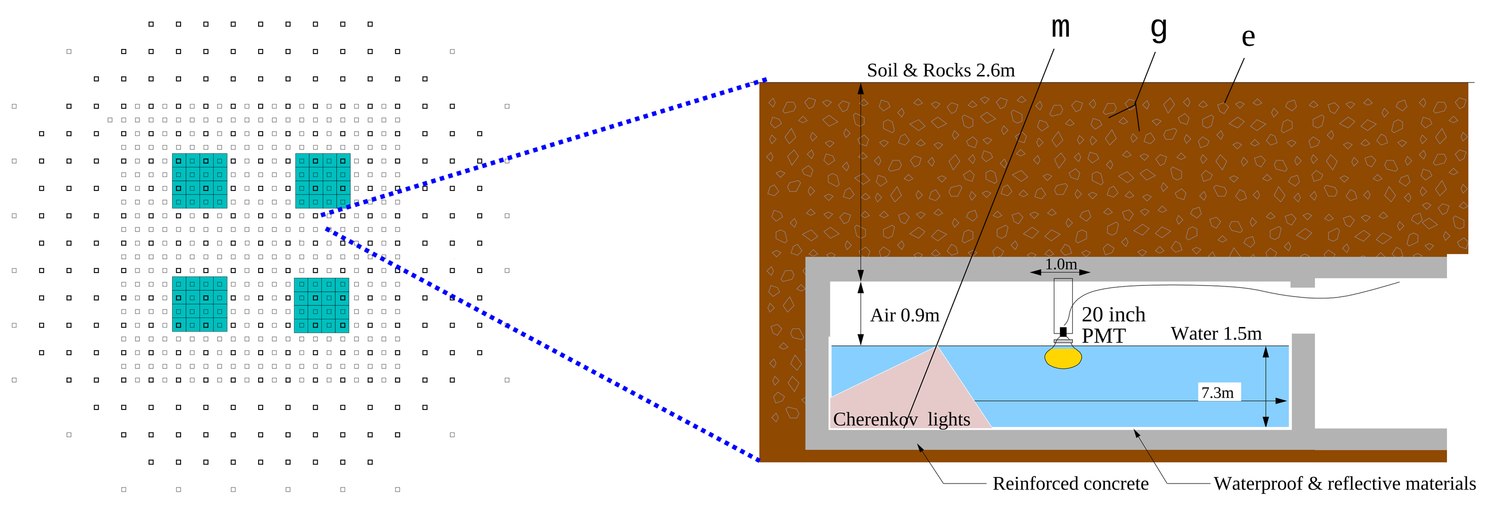

Figure 2: Schematic view of Tibet air shower detector.
Tibet-III air shower array (left) and MD (right)

Results

Figure 3 is a scatter plot of the number of charged particles (Σρ) and the number of muons. The red plot shows protons, and the gray shows other nuclei. The solid line represents the cut value that separates protons from others. Using this cut value, it is possible to select an event in which the proportion of protons is 90%, as shown in figure 4. The cut value depends on Σρ, and protons were extracted with a detection efficiency of approximately 17% at an energy of 36 TeV and with 8% at 400 TeV. The energy resolution of these selected proton-like events was +53% on the upper side and -32% on the lower side at 36 TeV, +27% on the upper side and -21% on the lower side at 420 TeV. These calculations were performed for each cosmic ray composition model and interaction model. Finally, the detection efficiency obtained by these analysis was used to recalculate the spectrum from the detected shower events.

To evaluate the systematic error for the proton spectrum due to the difference between each model used in the analysis, the air shower event generated using both the Shibata composition model and Sibyll were converted to proton spectrum using the parameters obtained in each model. Figure 5 shows the proton spectra calculated for each model, and the systematic error due to the composition model and the interaction model in this method was found to be approximately ± 36% in total.

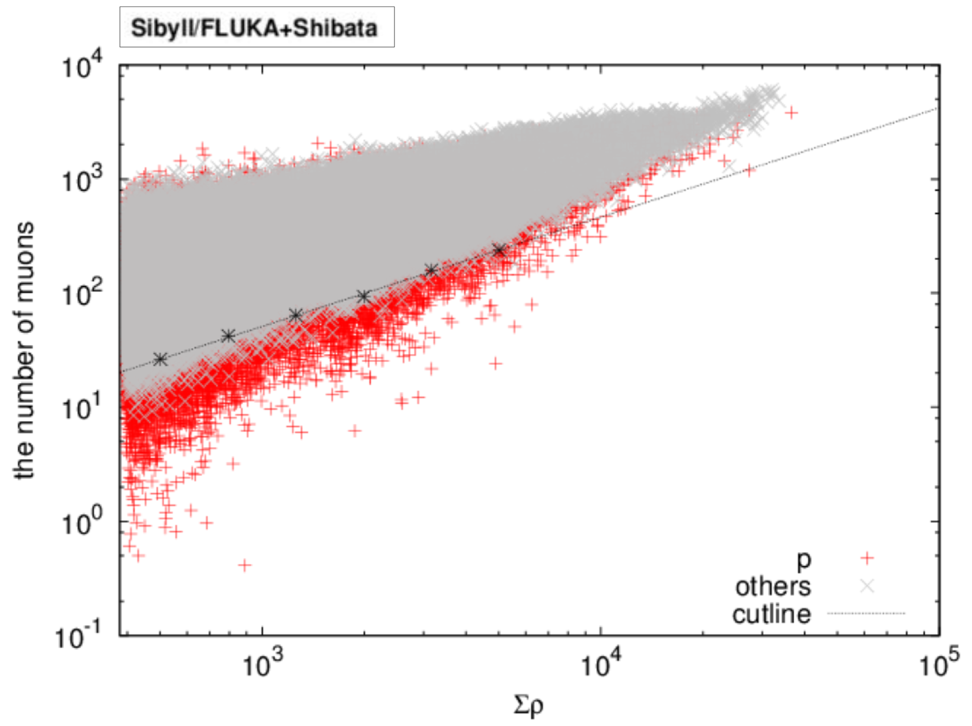

Figure 3: Scatter plot of Σρ and # of muons

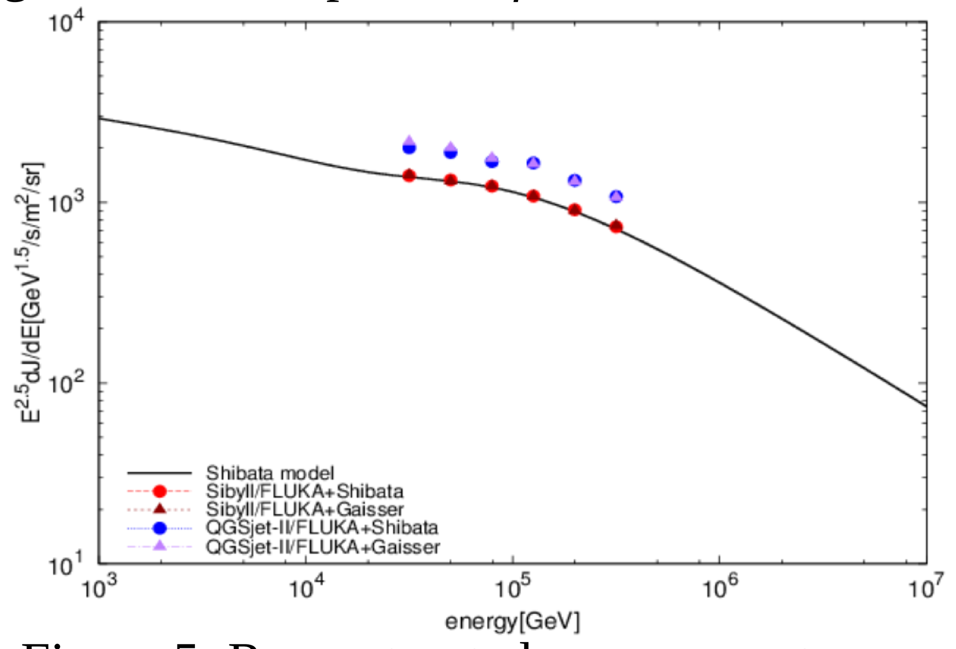

Figure 5: Reconstructed energy spectrum of protons (MC)

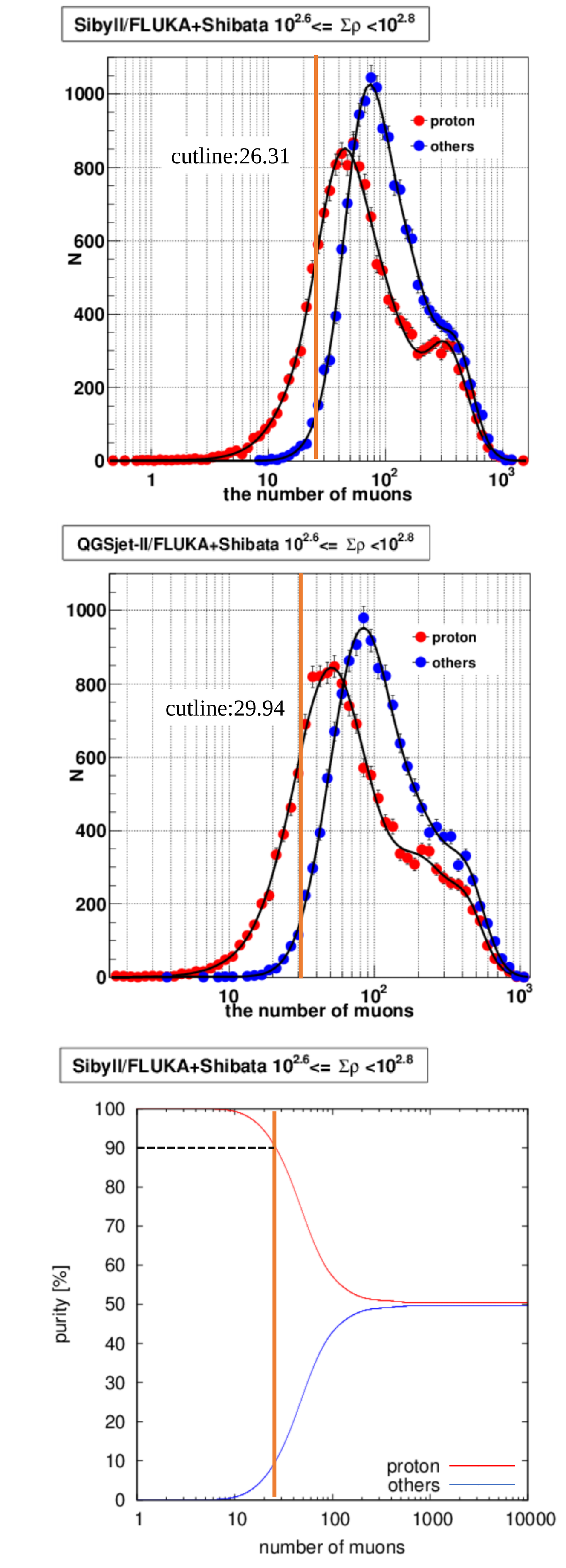

Figure 4: Muon histogram and purity