Study of air shower particles behavior near the core region

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Abstract: ARGO-YBJ experiment has two kinds of signals in the shower working mode which allow coverage the energy region from TeV to PeV region. One is the digital strip pattern, another is so-called ‘big pad’ mode, which is the analog signal counting the pulse height on half of a RPC, proportional to the number of hitting particles. In this paper on the basis of Monte Carlo simulation method, several parameters by using the Big Pad recorded signal close to the shower core is discussed, which is sensitive to the cosmic ray composition. and preliminary comparison between data and MC is shown

Keywords: Big Pad, near core region, ARGO-YBJ

1 Introduction

The all particle energy spectrum of cosmic rays shows a distinctive feature around PeV, known as ‘knee’ region. The study of the cosmic ray spectrum steepening and its chemical composition in this region have been an important topic to understand the acceleration mechanism and possibly to discriminate between different production models for high energy cosmic rays. However, due to rather low flux, the direct measurements at the ‘knee’ region, such as RUNJOB[1] and JACEE [2], have been limited by their poor statistics. At the same time many ground-based air shower experiments have been carried out on this topic through indirect observations.

Although there are a lot of reports on the primary spectrum and the primary composition, up to now the existing experimental data show a rather large disagreement. For example the proton spectrum measured by the Tibet AS-γ [3] experiment shows a ‘knee’ like structure around 200 TeV, while the KASCADE [4] experiment gives the spectrum changed at higher energy around 2 PeV. Thus new experimental approaches are needed to find a way out from this unclear experimental scenario. ARGO-YBJ appears a good candidate: high observation level ($606\ \mathrm{g/cm^2}$) and its nearly full coverage(93%) of the equipped area, are two unique merits. The former makes the detection level very close to the shower maximum position at this energy region, so that the shower fluctuation and model dependence can be minimized. The latter allows sampling in detail the shower pattern in a large area around the core region, giving,therefore, a premium for the elemental composition studies. In this paper we discuss the ability of the ARGO-YBJ experiment to explore the different primaries by measuring the big pad signals around core region.

2 Detector set-up

The ARGO-YBJ experiment[5] is located in Tibet(P.R. China) at the Yangbajing Cosmic Ray Observatory (30.11°N, 90.53°E) at an altitude of 4300 m a.s.l., corresponding to a vertical atmospheric depth of 606 $g\ cm^{-2}$. ARGO-YBJ detector is composed of 153 modular units (called clusters), and can be divided into 2 parts: the central carpet and the guard ring. The central full coverage carpet consists of 130 clusters which cover an area of $78 \times 74\ \mathrm{m}^2$ and the guard ring contains additional 23 clusters extending area to $110 \times 100\ \mathrm{m}^2$. Each cluster contains 12 Resistive Plate Chamber (RPCs). For strip pattern working mode every RPC is divided in to 10 pads of $56 \times 62\ \mathrm{cm}^2$, which is further divided into 8 strips offering the digital signal and allowing the digital strip pattern. In order to extend the dynamic range, a charge readout layer has been implemented by installing each RPC chamber with two Big Pads, $140 \times 122.5\ cm^2$ each (the so-called Big Pad). Each RPC chamber is summed-up by the analog read-out and and gives rise to the so-called big pad signals (2 pads/chamber).

The ARGO-YBJ has been taking data with its full layout since November 2007 with the average trigger rate about 3.5 kHz. And the analog readout of Big Pad has started to work from the end of the year 2009. Since July 2010, the analog range has moved to the 20 V setting. For each Big Pad readout signal, taking into account the electronics calibration and the possible effect from the inconsistency among Big Pads, the analog ADC readout can be converted

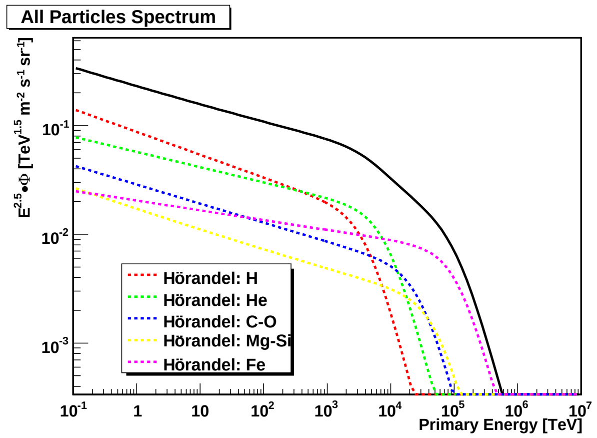

Figure 1: The simulated energy spectrum for 5 elements.

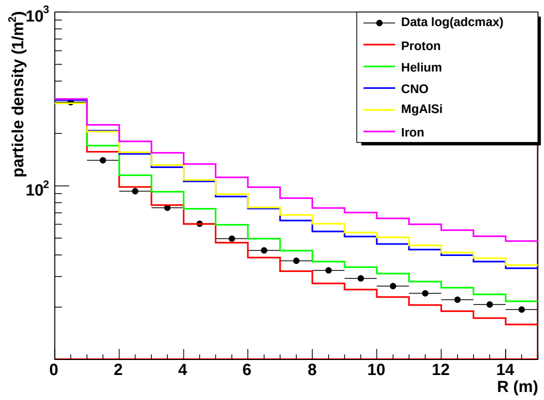

Figure 3: The lateral distribution from experiment data and the simulation samples.

to the number of particles. The details can be found in the this conference [6, 7].

3 Monte Carlo Simulation

Two steps are adopted in the simulation procedure. Firstly the air shower cascading in the atmosphere is simulated using the CORSIKA package [8], QGSJET2 and GHEISHA models are used to generate simulation samples with primary energy range from 10 TeV to 10 PeV with zenith angle up to 15°. The simulation of the detector response is based on a GEANT3-based simulation program, named ARGOG, reproducing the detector geometry and materials. In particular, the Big Pad is considered as a sensitive volume, generating a hit for each crossing charged particle. The saturation is set to 10^4 particles$/m^2$.

In this study, a model[9] is adopted to consider the composition of incident cosmic rays. In this model, the primary chemical composition is divided into 5 groups: Proton(abbreviated as H and with mass number=1), Helium(He, 4), light nuclei(C-O,7), median nuclei(Mg-Si,13) and iron nuclei(Fe,56). Following this model, the component fractions in the simulated energy range from 10TeV to 10PeV are: H 37.0%, He 29.7%, C-O 13.4%, Mg-Si 7.7% and Fe 12.2%, shown in Fig.1.

4 data analysis and results

All experimental data and simulation samples are treated in the same analysis procedure. After the standard medea++ reconstruction and the following data selection, the left data and samples are used in the later analysis.

In order to select high energy event, to get enough information around the shower core and to reduce the error caused by the shower reconstruction, only internal, quasi-vertical events are used. These events are selected by using the following cut criteria:

- The reconstructed zenith angle is less than 15°;
- Number of fired pad $N_{hit} > 5000$ and number of fired Big Pads with (ADC > 10) $N_{BP} > 10$.
- In this analysis, the central carpet is artificially divided into two parts: the internal detector (the 6×9 clusters in the center) and the external detector (the outer 76 clusters around). The average particle density measured by the inner and outer region are marked as ρ_{in}, ρ_{out} respectively. By requiring ρ_{in}/ρ_{out} >1.2, just internal events are used for the later analysis.
- In this work in order to firstly understand the data and to study the sensitive parameters, just the logarithmic value of maximum Big Pad signal between 2.5 to 3 of data from Dec. 2010 to Mar. 2011 is used.

Figure 2 gives an example of the lateral distribution of the selected events. The shower core in the upper left panel in the figure 2 is reconstructed by the digital output, and in the upper right panel the location of maximum analog readout Big Pad detector during this event is treated as shower core position; in the down left panel, the shower core is reconstructed by combining the measurement with analog readout and digital outputs; in the down right panel on the base of the combination of analog readout and digital readout, a global fitting is adopted during the shower core determination which means direction fitting and core determination are simultaneous. From this example, one can see with the Big Pad signal shower core reconstruction can be improved apparently, and with the combination of Big Pad and strip signal, further improvement can be achieved. In here, to simply the analysis process, the position of the maximum analog signal is used as the shower core location.

4.1 lateral distribution in the near core region (r<15 m)

figure 3 gives the lateral distribution from the data and simulations. Comparing with iron showers, with the same en-

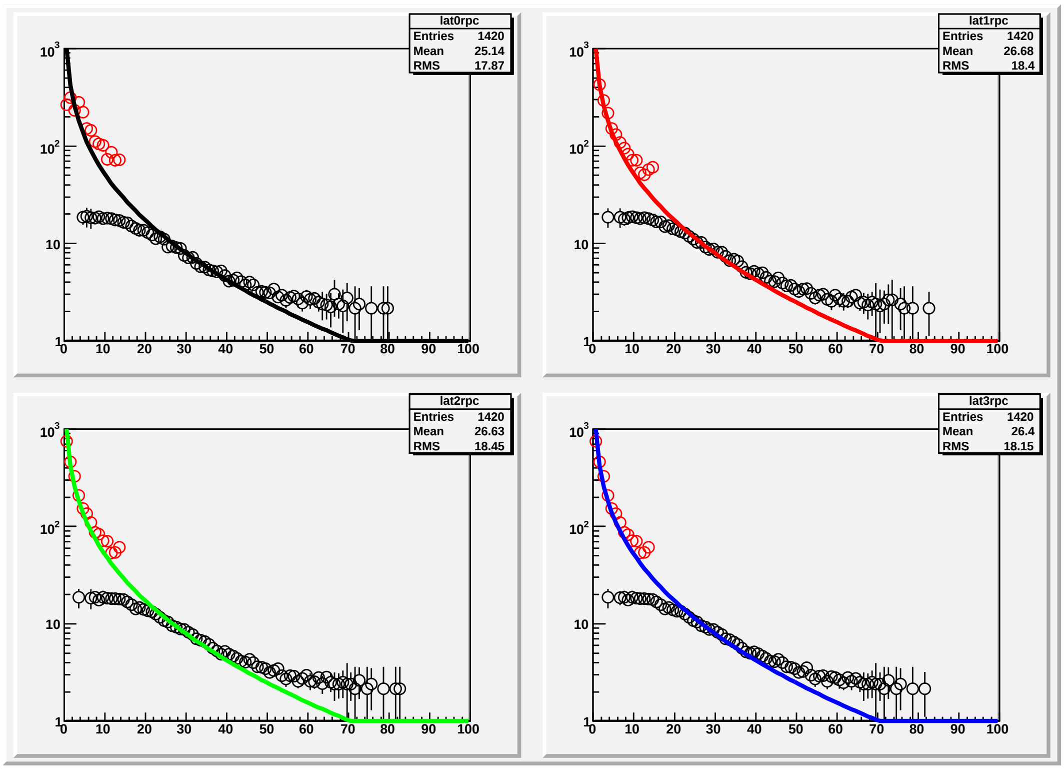

Figure 2: The lateral distribution of a experimental event: X axis is the distance to the shower core in the unit of meter, Y axis is the particle density in the unit of ($1/m^2$). The red point is for Big Pad analog readout signal, the black point stands for digital result, the flating tendency shown in black dot is due to the effect of strip staturation. . The 4 panels are relative to 4 different shower core location see details in the text.

ergy the proton induced showers develop deeper in the atmosphere, one can expect that the proton induced shower shows up a steeper and narrower lateral distribution. Here a parameter is calculated to study different primaries on the basis of this aspect: density ratio, $\Lambda = \rho_i/\rho_j$, where ρ_i and ρ_j are measured average particle densities at two radial distances. Figure 4 shows the density ratio at i=0-5 m and j= 5-10 m. One can clearly see, as expected, the proton showers have the highest density gradient among them so a mean value turns smaller as the primaries turn heavier. Moreover the lighter the primary is the larger the fluctuation is.

4.2 Asymmetry of near core region behavior

For hadron primaries there may exist some local clustering phenomena for the received signal. ARGO-YBJ carpet detector offers a chance to explore this point, considering the ARGO-YBJ carpet detector full-coverage characteristics. Here by using the same event samples, the received number of particles between 0–10 meter are calculated in 8 equal-azimuth region (with $45°$ spacing) according to their location relative to the shower core. By searching the maximum and minimum value among them, i.e. $N_{\max}$, $N_{\min}$, a parameter ξ is defined as ξ=$(N_{\max} - N_{\min})/(N_{\max} + N_{\min})$ to study the asymmetry of the recorded particles. Generally speaking for iron initiated showers parameter ξ tends to be smaller. while larger ξ is mostly generated by proton.

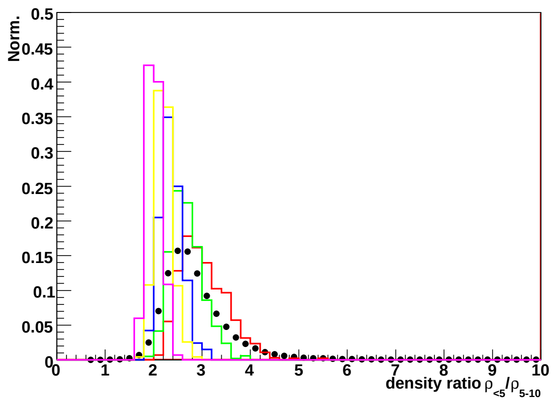

Figure 4: The distribution of the density ratio, Λ from data and simulations. The marker and color has same meaning as above figure.

5 Conclusion

On the basis of Monte Carlo simulation study, the shower lateral density ratio around core and the asymmetry of the recorded signal by Big Pad have been proved to be sensitive parameters to infer the characteristics of the primary particles in our interested region. Particularly, the asymme-

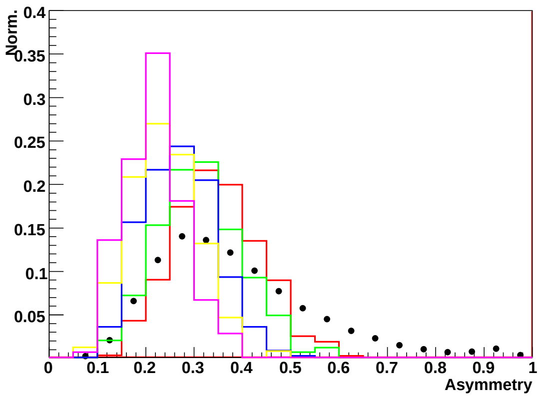

Figure 5: The Distribution of the asymmetry, ξ between data and simulation.

try around shower core is a 'unique' feature of ARGO-YBJ carpet.

Preliminary comparison between data and MC shows a pretty consistent result. The application of these parameters to the more energy regions is under study. To further discriminate proton from helium background by using the correlation between parameters and the modification to the classification algorithm (for example, to use artificial neural network) will be the next step for our work.

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