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Nuclear Physics B (Proc. Suppl.) 175–176 (2008) 443–446
NUCLEAR PHYSICS B PROCEEDINGS SUPPLEMENTS
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Simulation study of air shower particles near the core region

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The ARGO-YBJ experiment has two kinds of signals in the shower working mode which allows coverage of 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 an RPC, proportional to the number of hitting particles. In this paper by using the Monte Carlo simulation method the ARGO-YBJ sensitivity to the cosmic ray composition is discussed, by using the ‘big pad’ signal for measuring the number of particles detected close to the shower core.

1. Introduction

The study of the cosmic ray spectrum steepenning and its chemical composition between 10^{14} eV and 10^{16} eV, so-called ‘knee’, have been an important topic to understand the acceleration mechanism and possibly discriminate between diferent production models for high energy cosmic rays. However due to the rather low flux, 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 have been many 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 experiment shows a knee like structure around 200 TeV, while the KASCADE [3] experiment gives the spectrum change at a 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 to do that and is presently under construction at the Yangbajing High Altitude Cosmic Rays Laboratory (Tibet, China, 4300 m a.s.l.). High observation level (606 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 to sample 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

ARGO-YBJ detector is composed of 154 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 covering an area of 78×74 m^2 and the guard ring contains 24 other clusters extending the area to 110×100 m^2. Each cluster contains 12 Resistive Plate Chamber (RPCs). For strip pattern working mode every RPC is divided into 10 pads of 56×62 cm^2, which are further divided into 8 strips offering the digital signal and allowing a digital strip pattern to be built. For the big pad working mode five contiguous pads, in every RPC chamber, are electronically summed-up as far as the analog read-out is concerned, and give rise to the so-called big pad signals (2 pads/chamber). The layout of the detector is shown in figure 1.

0920-5632/$ – see front matter
doi:10.1016/j.nuclphysbps.2007.11.048

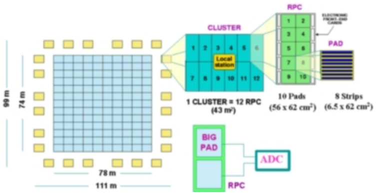

Figure 1. ARGO detector set-up

3. Monte Carlo simulation

For the present study the simulation consists of 2 steps, air shower generation and detector response. The CORSIKA code [5] and QGSJET + GHEISHA models are used to generate shower samples with primary energy ranging from 10^{14} eV to 10^{16} eV and zenith angle between 0°–45°. Four primaries are used as possible primaries, hydrogen (protons), helium, magnesium and iron. The second step is the detector response. At this moment a toy model is implemented. The CORSIKA output is projected onto a symmetric grid array, each cell of the grid having the same size as a big pad, the area of total grid array just matches the ARGO-YBJ detector. According to measurement, if the number of particles recorded is less than 10^4 particles/m^2 the pad signal is assumed to be linear (not saturated). On the base of this point the expected number of particles including the Poisson fluctuations for each detector is calculated. To increase the statistics each shower is projected 10 times onto the array with random core within the central carpet. A total of more than 50,000 showers have been generated. Figure 2 is a simulated 1 PeV vertical proton shower, the density profile can be clearly distinguished, and appears to be an evident premium of ARGO-YBJ detector configuation and technique.

3.1. Core resolution

With the ARGO-YBJ full coverage character, the reconstructed core is searched for using the center of gravity method. By setting a limited space around the detector with the maximum signal, the shower core position is found. The resolution of the shower core is around 1.4 meter at an energy of 1 PeV, and the distribution is shown in Figure 3.

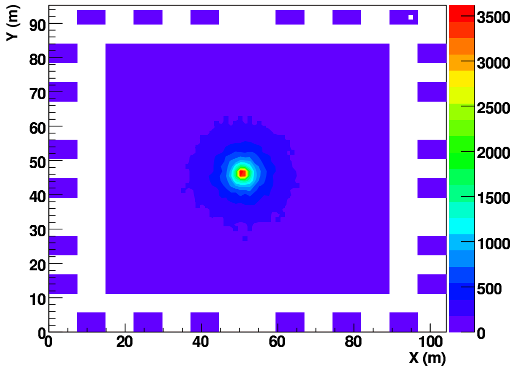

Figure 2. A Monte Carlo event induced by a vertical 1 PeV proton.

The shower core position is reconstructed using the method of the center of gravity, which takes great advantage of the full coverage that features ARGO-YBJ. The core postion is found (using a fitting process) in a fiducial area surrounding the pad where the maximum signal is registered. Figure 3 shows the distribution of the distance between the generated and reconstructed core for a 1 PeV shower, from which a resolution of 1.4 m can be quoted.

3.2. Shower lateral distribution

Comparing with iron showers for the same energy, proton induced showers develop deeper in the atmosphere, and one can expect that the proton induced shower shows a steeper and more narrower lateral distribution. Two parameters are calculated to study different primaries on the base of this aspect. (1) density ratio, $\Lambda = \rho_i/\rho_j$, where ρ_i and ρ_j are measured average particle densities at two radial distances. (2) the mean lateral spread radius, $\langle R\rangle = \Sigma(N_k\ r_k)/\Sigma N_k$, where N_k and r_k are respectively, the number of detected particles and the radial distance to the shower

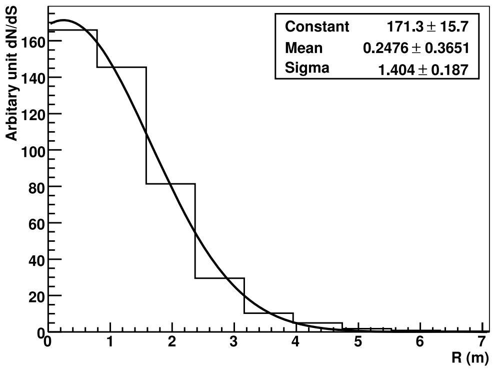

Figure 3. The resolution of core position

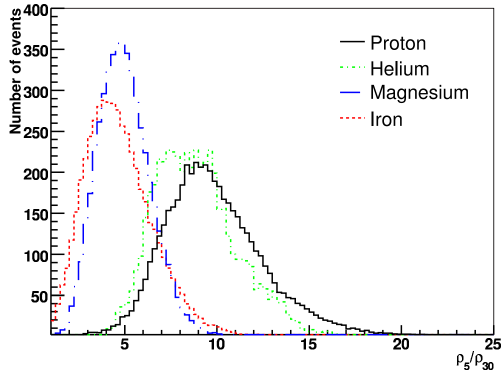

Figure 4. Density ratio for vertical 100 TeV H, He, Mg and Fe.

core for the k^{th} detector respectively. Figure 4 shows the density ratio $\Lambda = \rho_i/\rho_j$ at i=5 m and j= 30 m for the above 4 primaries with energy of 100 TeV in the vertical direction. As expected, proton showers have the highest density gradient among them, and as the mean value of Λ turns smaller, the primaries turn heavier. In this figure another point is also obvious: the lighter the primary, the larger the fluctuation. In table 1, the detailed density ratio and its RMS values at 4 different distances are listed. It can be noticed that on increasing the distance the difference between the primaries turns larger. The scatter plot between density ratio and mean lateral spread radius for these 4 primaries is shown in figure 5. It is seen that the showers with larger $\langle R\rangle$ and smaller Λ are from heavier primaries.

Table 1
Density ratio value and its RMS

Λ	Fe	Mg	He	H
ρ_5/ρ_{20}	2.4±0.7	3.0±0.7	4.6 ±1.1	5.1±1.2
ρ_5/ρ_{30}	3.7±1.2	5.0±1.4	8.0 ±2.4	10.0±3.1
ρ_5/ρ_{40}	5.5±1.8	7.7±2.4	11.4±4.3	17.1±6.0
ρ_5/ρ_{50}	7.9±2.8	11.4±3.8	14.5±6.3	27.2±10.7

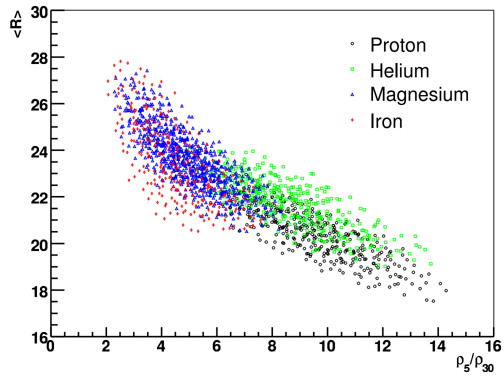

Figure 5. The correlation between the density ratio and the mean spread radius.

3.3. Asymmetry of the density ratio

For heavy primaries there exist some local clustering phenomena for the received signal. ARGO-YBJ carpet detector offers a chance to explore this point. Using the same event samples, the density ratio between 1–5 meter and 15–20 meter are calculated in 8 equal-azimuth region (with 45° spacing) according to their location relative to the

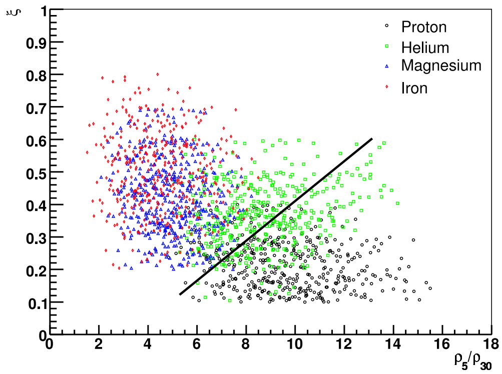

Figure 6. The scatter plot between the asymmetry of density ratio and the density ratio for 4 primaries with energy of 100 TeV.

shower core. By searching for the maximum and minimum value among them, i.e. $\Lambda_{\max}$, $\Lambda_{\min}$, a parameter ξ is defined as $(\Lambda_{\max}-\Lambda_{\min})/(\Lambda_{\max}+\Lambda_{\min})$ to study the asymmetry of the density ratio. Generally for iron initiated showers the parameter Λ tends to be smaller and parameter ξ tends to be larger, while larger Λ and smaller ξ is mostly generated by protons. The scatter plot between Λ and ξ for the 4 different primaries is shown in figure 6. By setting a cut in this 2 dimensional plane (see solid line), light primaries (protons and helimum nuclei) can be selected from heavy nuclei respectively at the 85% and 50% level, with a residual contamination from Mg and Fe at the 2% level.

4. Discussion

On the basis of Monte Carlo simulation study, the shower lateral density ratio around core (i.e., density gradient) and its asymmetry and the mean lateral distance have been proved to be powerful tools to infer the characteristics of the primary particles in our interested region (100 TeV–10 PeV). Particularly the asymmetry of density ratio around shower core is a 'unique' feature of ARGO-YBJ carpet. The simulation shows ARGO-YBJ detector has good ability to 'pick up' light component with good efficiency. Our next work will focus on discriminating proton from helium background by using the correlation between parameters and the modification to the classification algorithm (for example, to use artificial neural network).

This work is supported in China by NSFC(10120130794), the Chinese Ministry of Science and Technology, the Chinese Academy of Sciences, the Key Laboratory of Particle Astrophysics, CAS, and in Italy by the Istituto Nazionale di Fisica Nucleare (INFN).

REFERENCES

1. http://runjob.boon.ru.
2. http://marge.phy.washington.edu/jacee/.
3. KASCADE Collaboration, Astroparticle Physics 16(2002)245.
4. C. Pino, ARGO-YBJ internal note, `ARGO-YBJ/2003-005`.
5. D. Heck, et al., Report FZKA 6019, Institut fur Kernphysik, Forschungszentrum Karlsruhe, 1998.
6. M. Kobal, Astropart. Phys. **15** (2001) 259.
7. T. Antoni, et al., `astro-ph/0505413`.