Primary proton spectrum in the knee region observed by the Tibet hybrid experiment

The Tibet ASγ Collaboration

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Abstract

Proton spectrum in the knee region is obtained from the Tibet hybrid experiment consisting of the emulsion chambers and the Tibet II air shower array. The proton spectrum in the energy range $> 10^{15}$ eV shows the steepening of spectrum with power index -3.14$\pm$0.10 being 3.9σ deviation from that of direct observations below a few hundred TeV. Another estimate using a proton dominant chemical composition model also results in power index of -3.06$\pm$0.09 being 3.6σ deviation.

1. Introduction

The change of the spectral index of cosmic-ray energy spectrum between 10^{15} eV and 10^{16} eV is observed by many air shower experiments and called "knee", however, the reason remains still unknown. Possible explanations so far discussed by many authors are; (1) the change of chemical composition, which is related to the acceleration and propagation mechanisms of cosmic rays in our galaxy, (2) the existence of new (extragalactic) sources for high energy cosmic rays including some astrophysical particles, (3) the change of high energy hadronic interactions at very high energies and so on. The investigation of the chemical

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composition of cosmic rays has been made with various instruments on board satellites or balloons, however, the observed energy range is limited up to a few hundred TeV because of their extremely low fluxes, where protons are the main component and the change of spectral index has not been confirmed yet. One way to overcome the low flux is to carry out a ground based experiment with large area and stable observation for long period, however, there are difficulties of identifying the species of primary particles as well as the accurate determination of the incident energies due to the indirect method. It is possible, however, to improve the sensitivity of an air shower array to the primary composition as well as to the primary energy by measuring the air showers in coincidence with a detection of γ-families by large-area emulsion chamber at high mountain altitude. From the simulation study, following advantages in doing such an experiment are clarified. One is that the primary energy generating both of air showers and γ-families can be estimated with high accuracy due to small fluctuations in air shower size. Another is that the air shower events accompanied by γ-families are strongly favored to the protons among the primaries, so that we can get direct information about the protons around the knee region. Protons in the primaries are the key component to understand the origin of the knee.

2. Experiment

A hybrid experiment consisting of the emulsion chambers (ECs) with burst detectors (BDs) and the air shower array (AS array) of 298 scintillators with 15 m spacing (36,900 m^2) was carried out at Tibet Yangbajing (4,300 m a.s.l.) from 1996 through 1999. The total area of ECs was $80m^2$, having a $50cm \times 40cm$ area and 14 c.u. thickness (lead) in each unit, where X-ray films were inserted at 4, 6, 8, 10, 12 and 14 c.u. depths. The BDs with the same area were placed just below ECs. Each BD contains a plastic scintillator with the size of 160 cm $\times$ 50 cm $\times$ 2 cm, namely, 4 ECs were placed above one burst detector. Thus, 400 blocks of ECs and 100 BDs in total were used in this experiment. The X-ray films in ECs were exchanged by new ones every year to suppress the background. The AS array is triggered by BDs. For each γ-family event detected in ECs, its accompanied air shower can be found using information; (1) the location of the burst, (2) the time matching of the burst with the air shower and (3) the comparison of arrival direction of the gamma family with that of the air shower.

3. Analysis

The details of the method of analysis based on Monte Carlo simulations (Cosmos code[10]) with two different primary composition models and neural network analysis (ANN[11]) to identify the proton induced events have been already described at the last conference[4]. New method of EC analysis using image scanner is also described in a separate paper in this conference[5]. The statistics is increased by about factor 3 in this report compared with the last one by completing the EC analysis. The ANN target value distribution using 5 event characteristics * is shown in Fig.1 and Fig.2 for the assumptions of heavy dominant composition (HD) and proton dominant one (PD), respectively, using the data of whole energy range, where the training was made with t=0 for proton primary events and t=1 for others. The arrow with symbol T in the figure indicates the cut off value for the separation of proton-like and heavy-like events defined so as to cancel the contaminating numbers of events in both regions each other. The energy dependence of the value T was also examined using simulated data to reduce the error involved in the reduction of the contamination.

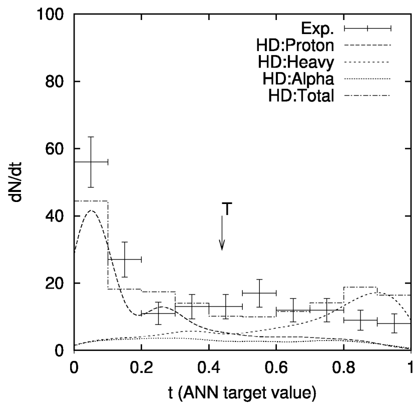

Fig. 1. ANN target value distribution (HD).T=0.439

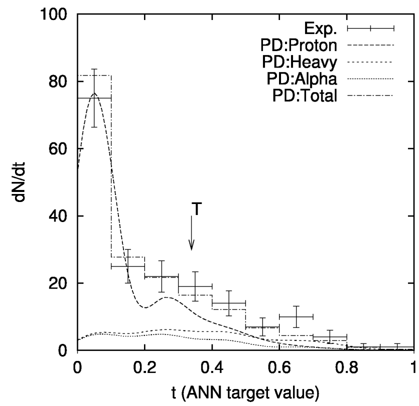

Fig. 2. ANN target value distribution (PD).T=0.339

4. Results

We present a result from 178 family events with accompanied air showers, among which 112 and 66 events are assigned as proton-like and heavy-like events, respectively, in case of the HD model, while 130 and 48 events in case of the PD model. The proton spectrum obtained in this analysis is shown in Fig.3, where plots labeled as HD are obtained from the analysis based on heavy dominant composition model, while those labeled as PD are based on proton dominant one. These two results agree well within statistical error showing there is no model dependences in our analysis.

5. Discussion and Conclusions

A fit for the low energy proton spectrum is made by T.K.Gaisser[8] using recent magnetic spectrometer measurements[1],[13] leading to a power index -2.74 in high energy region, which seems to accommodate direct observations up to a few hundred TeV, however, we have observed steepening of the proton spectrum in the knee region. The power index in $> 10^{15}$ eV region is estimated as -3.14±0.10 deviating by 3.9 σ from the extrapolation of the Gaisser's fit. Another estimate

*N_γ(multiplicity of a family), ΣE_γ(energy sum of a family), $< R_\gamma >$(mean lateral spread of a family), $< ER_\gamma >$(mean lateral spread of the family energy) and N_e(shower size)

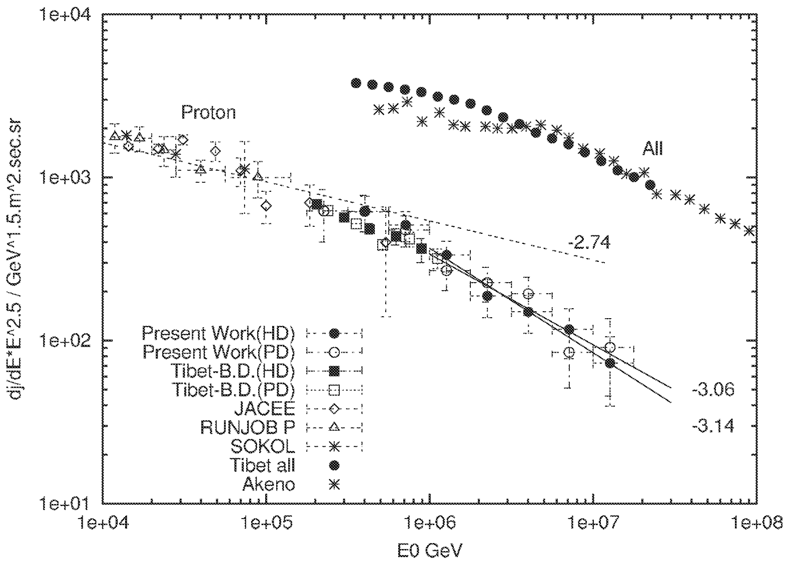

Fig. 3. Proton spectrum obtained by Tibet hybrid experiment. Other data points are JACEE,[7] RUNJOB[6], SOKOL[9], Tibet B.D[3], Tibet all[2] and Akeno[12]. Errors are statistical only.

based on the PD model also results in power index of -3.06±0.09 being 3.6σ deviation. If we estimate the break point of the proton spectrum at around 200 TeV from Fig.3 and assume other components also have the break point proportional to their atomic number, then the knee of the all-particle spectrum can be interpreted as the break point of the iron component.

References

[1] Alcaraz,J., et al. 2000, Physics Letters B, **490**, 27
[2] Amenomori,M., et al. 1996, APJ, **461**, 1, 408
[3] Amenomori,M., et al. 2000, Phys. Rev. D, **62**, 112002
[4] Amenomori,M., et al. 2001, Proc. of 27th ICRC, **1**, 18
[5] Amenomori,M., et al. 2003, Proc. of 28th ICRC, 008411-2
[6] Apanasenko,A.V., et al. 2001, Astroparticle Physics, **16**, 13
[7] Asakimori,K., et al. 1998, APJ, **502**, 278
[8] Gaisser,T.K., et al. 2001, Proc. of 23rd ICRC, **5**, 1643
[9] Ivanenko,I.P., et al. 1993, Proc. of 23rd ICRC, **2**, 17
[10] Kasahara,K., 2001, http://cosmos.n.kanagawa-u.ac.jp/~kasahara/ResearchHome/cosmosHome/index.html
[11] Lonnblad,L., et al. 1994, Comp.Phys.Com., **81**, 185
[12] Nagano,M., et al. 1984, J.Phys.G, **10**, 1295
[13] Sanuki,T., et al. 2000, APJ, **545**, 1135

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