Proceedings of ICRC 2001: 141 © Copernicus Gesellschaft 2001

ICRC 2001

The energy spectrum around the knee region observed at Mt. Chacaltaya

Honda,K.[1], **N. Ohmori**[2], **K. Shinozaki**[3], **N. Inoue**[3], **M. Tamada**[4], **N. Kawasumi**[1], **K. Hashimoto**[1], **I. Tsushima**[1], **A Ohsawa**[5], **H. Aoki**[6], **K. Yokoi**[7], **T. Matano**[8], **N. Martinic**[9], **R. Ticona**[9], **and C. Aguirre**[9]

[1]Faculty of Engineering,Yamanashi University,Kofu,400–8511,Japan
[2]Faculty of Science, Kochi University ,780–8520, Japan
[3]Faculty of Science, Saitama University, 388–8570, Japan
[4]Faculty of Science and Technology, Kinki University, 577–8520, Japan
[5]Institute for Cosmic Ray Research,University Tokyo,277–8582, Japan
[6]Faculty of Science, Souka University, 192–8577, Japan
[7]College of science and Engineering,J apan
[8]Shibakubo-cho 3–28–10,Tanashi, 188–0014, Japan
[9]Institute de Investigaciones Fisicas Universidad Mayor de San Andres, Bolivia

Abstract. Observation of EAS with the combination of emulsion chamber and EAS array is undergone at Mt.Chacaltaya. We report on the size spectrum of EAS observed in about 5 years and discuss the energy spectrum and composition in this spectrum range. The corresponding energy range is between 10^{14}eV and 10^{16}eV and includes the knee region. To discuss these characteristics ,detailed EAS simulations were fulfilled with the condition of arrangement of the array ,trigger and detector response. Specially,by the method of the different trigger efficiency between initiated low and high mass composition,the result of proton spectrum obtained at near 10^{14}eV is also reported.

1 Introduction

Explaining the knee region of the energy spectrum of the cosmic ray (CR) would shed light on CR origin and acceleration mechanism. But the possibility that the change of hadronic interaction at this energy range exists will puts some limits this speculation. For ground based array,the experimental observables which are measured in order to exact information about the energy spectrum are charged components of showers with density , muon , hadron detectors or $\check{C}$ erenkov detectors. Many experiments using the combined array of these detectors have been fulfilled to get the information of primary energy spectrum. However, the method to estimate the energy spectrum mainly depends on the assumed mass composition and simulated EAS developments through the atmosphere. Two fold assumption is hard to resolve clearly. Among these methods, it is simple method to estimate EAS size from the observation of low energy charged particles. Moreover, by choosing the observation altitude to be most effective to the development of EAS for the corresponding energy range of CR,one of the unsolved problem can be reduced. In our case,Chacaltaya altitude is fit to observe the maximum development of shower in the energy region $\sim 10^{15}$ eV and fluctuation of shower development is minimized. However, with only one station, we can not conclude the CR mass composition and spectrum in knee region. It is clear to combine results observed at different altitude which fits to observe some range of primary energy each other. Also, it is necessary observed values are comparable to each other directory. To this aim ,in this report we show the size spectrum observed at Mt. Chacaltaya altitude as an example.

Correspondence to: K. Honda
(khonda@ms.yamanashi.ac.jp)

2 Experiment and Analysis

The combined experiment of a air shower array and an emulsion chamber at Mt. Chacaltaya (Bolivia, 5200m a.s.l., 540 g/cm^2 of atmospheric depth) was started from 1979. The array consists 45 scintillation detectors for measuring of charged particles (9 detectors of $1m^2$, 36 detectors of $0.25m^2$) and 13 fast-timing detectors(FT)for measuring the direction (5 detectors of $1m^2$, 8 detectors of $0.25m^2$) from 1991 as shown Fig.1. The array cover an area of radius 50m, a lot of detectors are concentrated to near the emulsion cham-

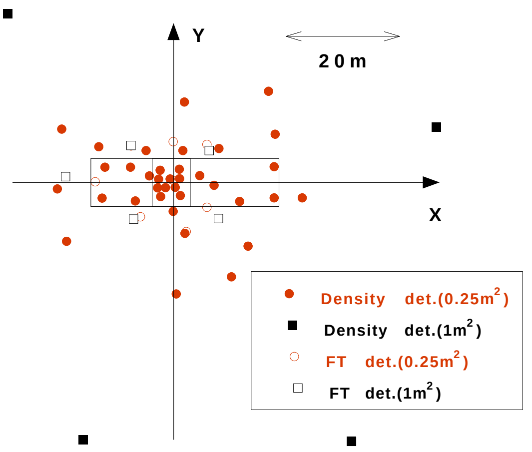

Fig. 1. The arrangement of our air shower array.

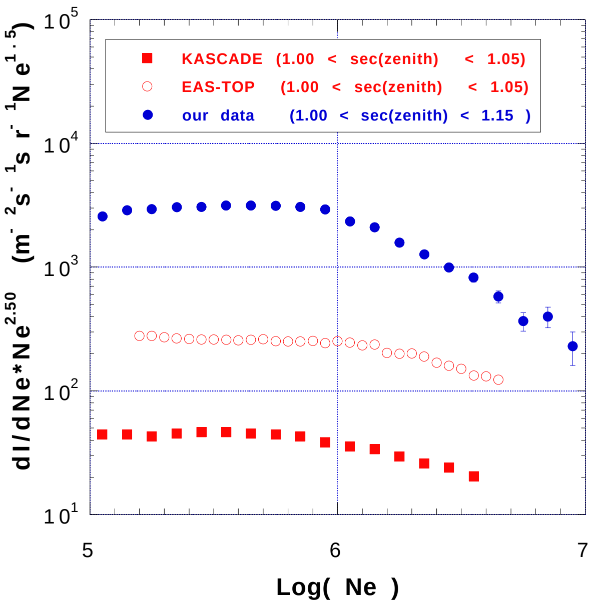

Fig. 2. Observed shower size spectrum is shown with closed circle. The shower size spectra of EAS-TOP(810 g/cm^2 and KASCADE(sea level) are shown in figure.

ber room. All detectors are using with 5cm thickness of plastic scintillator except 5 FT detectors with 10cm thickness. The recording system of the air shower is triggered above $\sim 10^4$ size [Kawasumi (1996)].

3 Results and Discussion

3.1 Size Spectrum

As explained in the experimental setups,using 45 scintillation counters and 13 FT detectors, incident angle and electron size of EAS were determined. The experiment for this analysis was carried out from 1992 to 1995. Total number of showers recorded is $\sim 3.3 \times 10^7$ in the effective observation time $\sim 7 \times 10^7$ seconds. The method to estimate the incident angle for each shower is ,using the all combination of 3 FT detectors to determine an incident angle , the most probable incident angle is obtained with the method of cluster analysis on these available combination of data. Compared with the EAS simulated FT data,the estimation errors of angle are lower than 3 degrees above the size range 10^4 . In the small shower size region, this method shows superiority to the usual least square method. For several scintillation counters show the fluctuation of the response (less than 20 %) in the observation period, corrections were applied with the statistical method for these detectors. Our array is not effective to observing lager size region. However, to arrange detectors compactly near the center of array and to limit analyzed showers whose shower axis hit within 6m radius from the center, showers to determine the size spectrum become more accurate in the smaller size region $\sim 10^5$. Observed shower size spectrum is shown in Fig. 2 with other size spectra observed at lower altitudes [Aglieta (1999)] ,[Castellina (2001)] .

3.2 Energy Spectrum

The primary energy spectrum can be extracted from the measured electron size spectrum with informations of the mass composition and the relation between electron size and primary energy. In fact,the evaluated electron size spectrum is the convolution of the energy spectrum and a function describing the probability of a given primary to produce a shower with a certain size. With using EAS simulation,this relation between the electron size and the primary energy can be given. However, above probability function between size and energy depends not only on the EAS simulation code that describes EAS development in the atmosphere, but also on the response function characteristic to EAS array including detector response and the procedure to estimate the electron size from observed shower data.

The mass composition to investigate this knee region is not yet fixed even to use as the initial condition. So,avoiding the additive assumption,we have not used the assumption on mass composition. Moreover, primary mass is assumed to be proton only or to be iron only to the energy spectrum estimated for two extreme cases,. Followings are procedures to get the probability function we used. Simulation code is CORSIKA code with QGS Jet model. For each primary mass,about 10^5 events was simulated with energy above 2×10^4 GeV for proton primary and 5×10^4 GeV for iron primary. Simulated shower components were sampled to the real Chacaltaya EAS array and simulated the detector response for each detector (plastic scintillator with 0.25 m^2 area and 5 cm thickness) Those simulated EAS data were re-analyzed to get the size with the same procedure on the

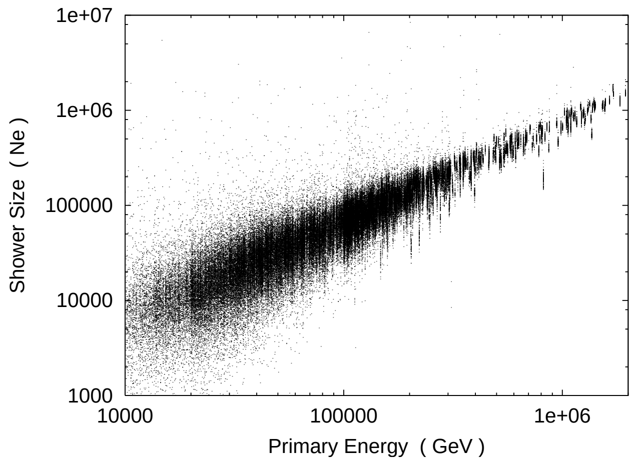

Fig. 3. Relation between Simulated primary energy and estimated shower size for proton . Trigger bias is included in this figure.

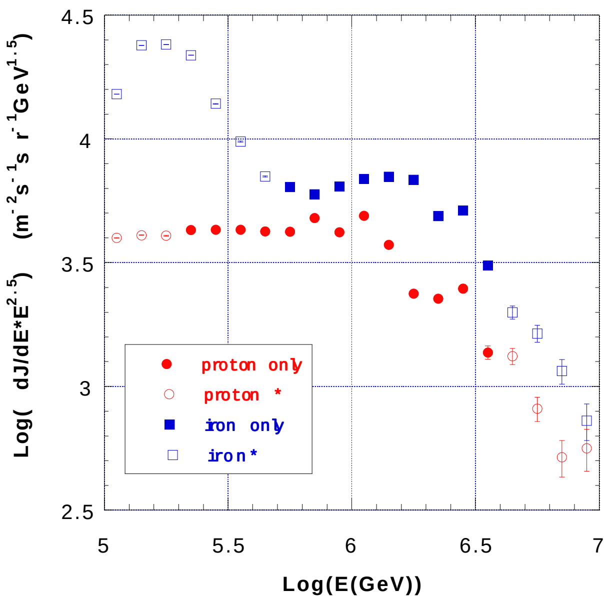

Fig. 4. Converted energy spectrum for proton and iron primary assumptions. circle is proton and square is iron primary. proton* and iron* in the figure mean the effect from the trigger bias for lower energy region, using the extrapolation for the high energy region.

same condition as explained section 3.1. .

For proton primary case,an example of the simulated size and energy relation is figured in Fig.3. The distribution profile of primary energy which results in a fixed size has a peak at the median, however the width of distribution is wide enough for a small size shower to contribute to the higher tail of energy spectrum. In the lower energy region is diffused by the trigger condition on the observability.

We tabulated probability function between size and energy,and converted observed electron size spectrum to an energy spectrum for each mass assumptions (proton only and iron only).

The converted energy spectrum is shown in Fig.4. In the energy range above Log(E(GeV))=6.6 for proton primary and iron primary shown with open circles and squares in this figure, the probability function to transform from size to energy was used with the extrapolated relation from the lower size and corresponding energy region shown with closed circles and squares. Because simulated number of showers is not enough to cover this energy range,but the energy distribution for fixed size has more sharp shape like a delta function. And as mentioned before, we used the tabulated probability distribution function, energy spectra for each composition show a little fluctuation on energy as seen. However, for iron component,the gross feature bumped in the energy range from 5.0 to 5.7 is the effect of the trigger condition,because in simulated shower initiated from iron primary shows the most effective trigger biases below the 5.7 region. and cannot be observed with such frequency. The effect of the trigger condition (at 90 % level) extends to the energy range below 5.3 for proton primary and 5.7 for iron primary. These effects are shown as different markings (open circles and squares) in the figure.

4 Conclusion

Our energy spectrum is re-display with overlapping other experimental results in Fig. 5 [Aglieta (1999)],[Amenomori (2000)], [Castellina (2001)] .

Below 5.7 in log energy scale,our energy spectrum only shows the case of lighter elements like proton dominated . In the energy region from 5.7 to 6.1, frequency difference between pure proton and iron is much small and has only 0.2 decade in this scale that corresponds to the difference ($\leq$ 50 %) in differential energy scale. Because in this energy region showers reach near the shower maximum at Mt. Chacaltaya altitude (540 g/cm^2) ,and the difference of shower development between these two primary masses is minimized. Above 6.1 in log energy scale, the frequency difference between proton primary and iron primary increase with energy and the imaginary turning point (knee) spreads from near 6.1 to 6.5 depending on the assumed mass composition. Comparing with other observed results, our data have relatively higher frequency than other experimental values. Especially in the energy region between 5.7 to 6.1 our data have relatively good reliance , but the difference is clear on the frequency. On this point,we can not exclude the possibility that produced some systematic difference with other experiments at this time.

.

Acknowledgements. I would like to thank staffs of Instituto de Investigaciones Physicas to keep the Loboratry at Mt. Chacaltaya.

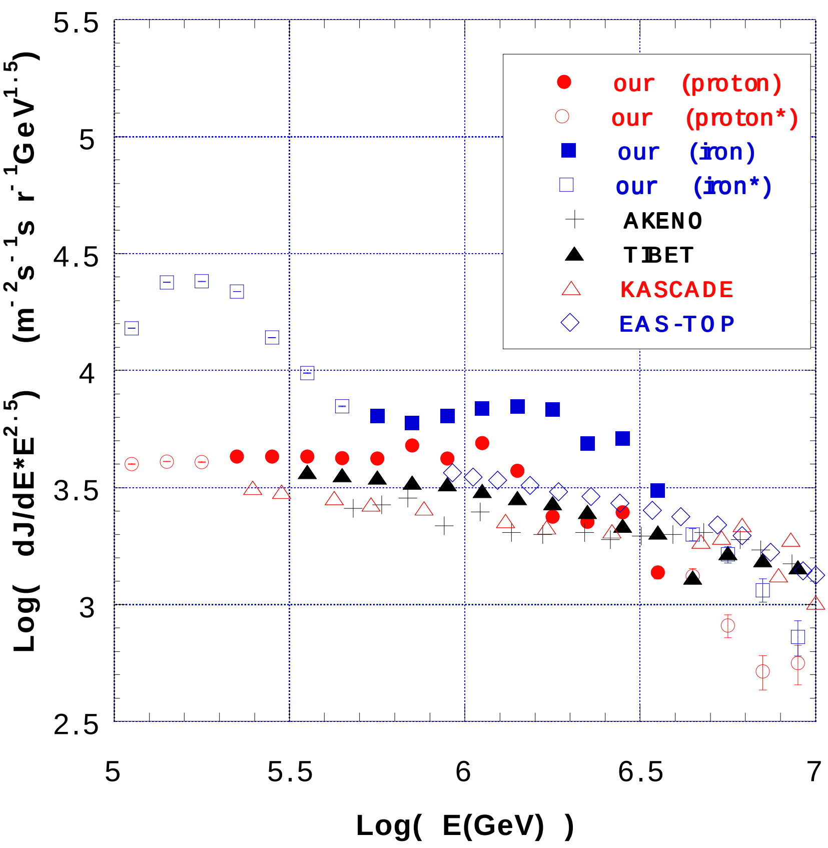

Fig. 5. Comparison between our energy spectra and other experiments .

References

N.Kawasumi et. al., Phys. Rev. D, 53, 3534–3546, 1996.
S.Petrera, IL Nuovo Cimento, 19, 737–754, 1996.
M.Aglietta et.al., Astroparticle Phys., 10, 1–9, 1999.
M.Amenomori et.al., Phys. Rev. D, 62, 112002-1–13, 2000.
A.Casrellina, Nuclear Physics B(Proc. Suppl.), 97, 35–47, 2001.