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Proton and Helium spectra observed by RUNJOB

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Abstract. We have been carrying out 10 of long duration balloon flights with emulsion chamber for observation of cosmic–ray primaries from 1995 through 1999. We report the energy spectra of proton and helium primaries basing on 45% of observed data which have been analyzed up to now.

Our results cover the energy range of 10 $\sim$ 300 TeV for proton, and 2 $\sim$ 50 TeV/n for helium. And one proton primary with the energy larger than 10^{15}eV is observed. Both of proton and helium spectra can connect to indirect measurement data smoothly.

1 Introduction

Japanese–Russo cosmic–ray physicists started a joint balloon program, called RUNJOB(RUssia–Nippon JOint Balloon program), in 1995 to clarify the chemical composition and the energy spectrum of cosmic–rays up to the knee region by direct observation.

10 balloon flights have been performed successfully from 1995 through 1999. Each flight has payload of two units of emulsion chamber with the unit size of 40cm $\times$ 50cm. They were launched from Kamchatka peninsula, and recovered near the Volga region after the exposure of $\sim$150 hours.

We have done the data analysis for 45% of all, 1995 and 1996 campaigns and a part of 1997 flight. The observed energy spectra of proton and helium components are reported here.

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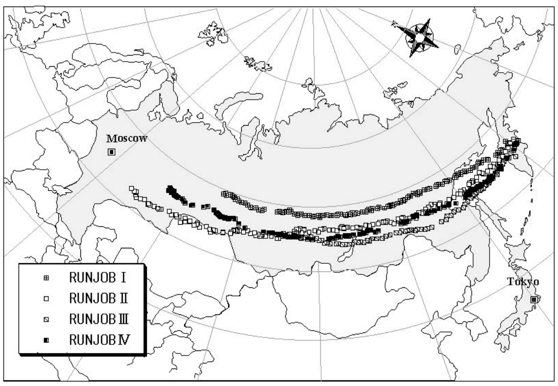

Fig. 1. Trajectories of four balloon flights performed in 1995 and 1996

2 Flight Situation

The trajectories and the altitude profiles of early four balloons are shown in Fig.1 and Fig.2, respectively. Other 6 flights have similar profiles. One finds on Fig.1 they are impressively stable for each flight between lat. 50°N and 60°N. In Fig.2, there are fluctuations of altitude due to the day–night effect, but the variation between the minimum and the maximunm altitudes is almost several times g/cm^2. It is not affective for proton and helium component, since their attenuation lengths in the atmosphere are more than 100 g/cm^2 and 50 g/cm^2, respectively. Mean altitude is about 30 km

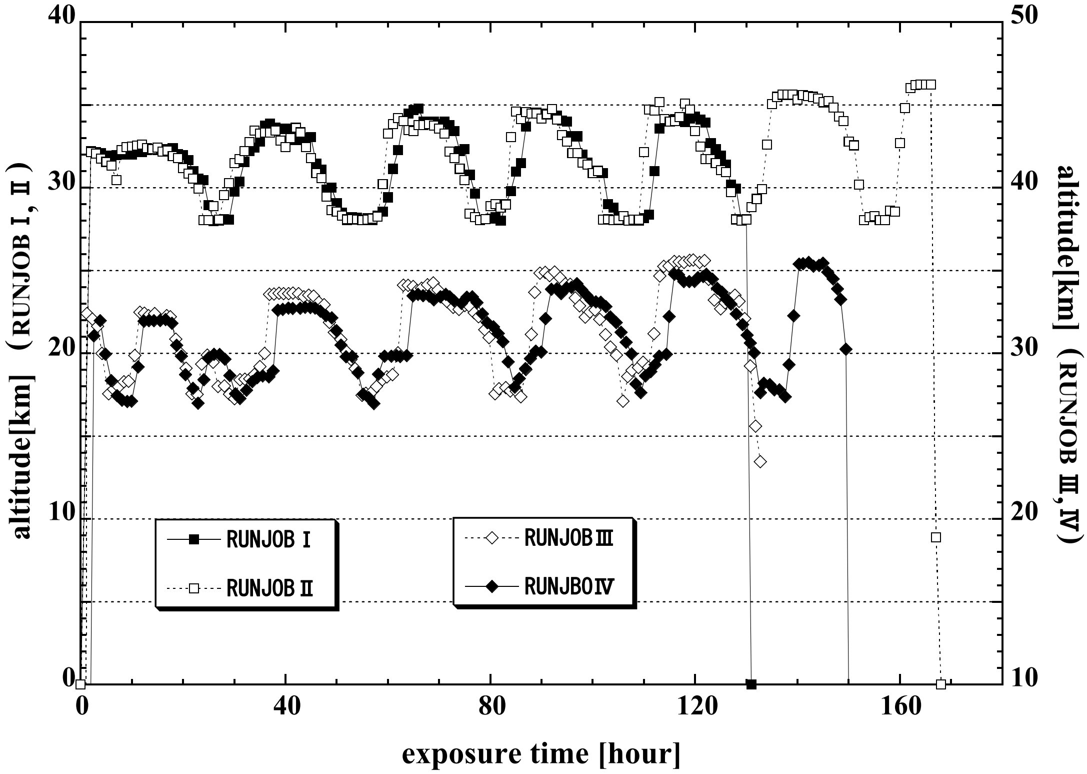

Fig. 2. altitude profiles of four balloons, RUNJOB I,II in 1995 and RUNJOB III,IV in 1996

which is corresponding to about 10 g/cm^2 of atmospheric depth.

3 Chamber Structure

We show the chamber structure which was used in 1995 and 1996 experiment in Fig.3. These are emulsion chambers with thin calorimeter and with large spacer. Detail of design is slightly changed year by year for improvement. The chamber consists of basically four parts, which provide following functions.

- **primary module** to identify the primary particle. It is composed of several photo-sensitive materials only.
- **target module** to produce the interaction. The acrylic plates or stainless steel plates are inserted as target material.
- **spacer module** to separate the secondary particles. This part is mainly composed by styrofoam. Large spacer enables us to measure the emission angle of secondary particles($\pi^{\pm}$'s, γ's). These data is used for energy estimation of primary particles.
- **calorimeter module** to induce and to observe the electromagnetic cascade showers. Multi–layered lead plates are inserted with photo–sensitive materials.

4 Data Analysis Procedure

First, we scan the dark spots of electromagnetic cascade shower on multi-layered #200-type X-ray films inserted in the calorimeter part by naked eye. After this scanning, detected dark spots are connected layer by layer, and we make a map of cascade shower. Next we find the corresponding tracks on emulsion plate under the microscope, and trace them up to the interaction point and upper primary track for each event.

In this stage, we can miss the track of proton primary due to enormous background tracks. In this case, we checked the tracks near by expected location very carefully, and investigated the feature of secondary tracks and cascade shower. We judged it is proton initiated event or not, basing on such information.

The primary charge is measured by CCD camera with image analysis of track recorded on emulsion plate.

We measured the spot darkness successively recorded on multi-sheets of X-ray film in the calorimeter part by photodensitometer, and also measured the emission angles of γ-rays which are recorded on the emulsion plate as multi core of cascade shower. The primary energy was estimated basing on these data. Details of analysis procedure are explained in Apanasenko et al. (2001).

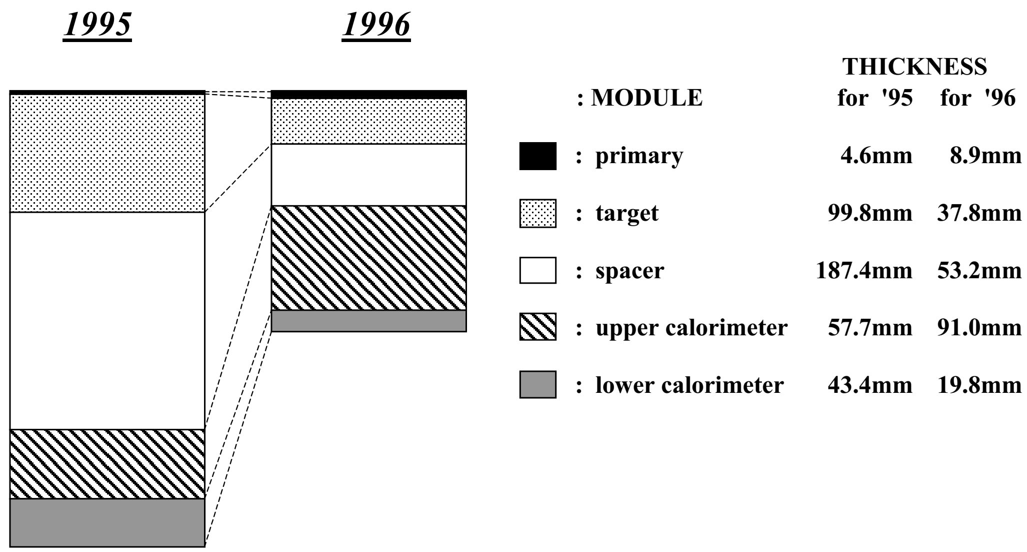

Fig. 3. Chamber structure in 1995 and 1996 experiments

5 Experimental Results

The proton and helium spectra obtained by RUNJOB experiment are shown in Fig.4, where the vertical axis is multiplied by $E_0^{2.5}$. We emphasis that these are not final result, because we analyzed only 45 % of all RUNJOB data up to now. The observed data obtained by other groups are shown in Fig.4 together(Grigorov et al.,1971; Asakimori et al., 1998; Zatsepin et al., 1994; Ryan et al., 1972; Ivanenko et al., 1993). All of these are results of direct observation with use of balloons or satellites. JACEE(Asakimori et al., 1998) and MUBBE(Zatsepin et al., 1994) groups have used the emulsion chambers as detector which is similar with ours. Other groups have used counter type detectors. In high energy region, we show the data of indirect measurement together(Amenomori et al., 2000).

For proton component, the absolute intensity is consistent for each groups in the energy region shown here. It must be remarkable that there is a PeV proton observed by RUNJOB experiment. This event is observed in 1995, and we found its shower energy, $\sum E_\gamma$, must be at least 500 TeV. It means the primary energy must be greater than 1 PeV = 10^{15}eV, even if the fluctuation of inelasticity is taking into account. This is the first event to confirm the existence of the particle which has the energy per nucleon greater than 10^{15} eV by direct observation. The highest point of RUNJOB in Fig.4 is includes only this event, and its absolute value is calculated with assumption that only one would be found for all of RUNJOB exposure, 10 flights. It seems that the proton intensity observed by direct observations is connected with indirect one smoothly.

For helium component, RUNJOB data is rather consistent with MUBEE data, and it seems to be parallel with proton spectrum. Also our data can connect with indirect data smoothly as same as proton component. On the other hand, the results of JACEE and SOKOL have discrepancy with our data. The reason of such difference between direct observations is not clear, but it must not be a simple statistic problem.

6 Summary

The energy spectra of proton and helium are reported basing on RUNJOB experiments. Proton spectrum covers the energy region of 10 $\sim$ 300 TeV, and one proton primary is observed with the energy larger than 10^{15}eV. For helium primary, the energy region of 2 $\sim$ 50 TeV/n is covered.

Our RUNJOB data is connected smoothly to indirect measurement in the high energy region for proton and helium, though there is discrepancy of helium intensity between several direct observations.

Ellison(1993) proposed a nonlinear shock acceleration process in SNR's. He predicts subtle differences in the power index between proton and helium, because ions with larger mass to charge ratio are accelerated more efficiently. The comparison of proton and helium spectra is interesting in connection with this suggestion.

Present our results are based on 45% of data obtained by RUNJOB experiments. After complete analysis, the energy spectra of proton and helium up to several $\times$ 100 TeV/particle will be established.

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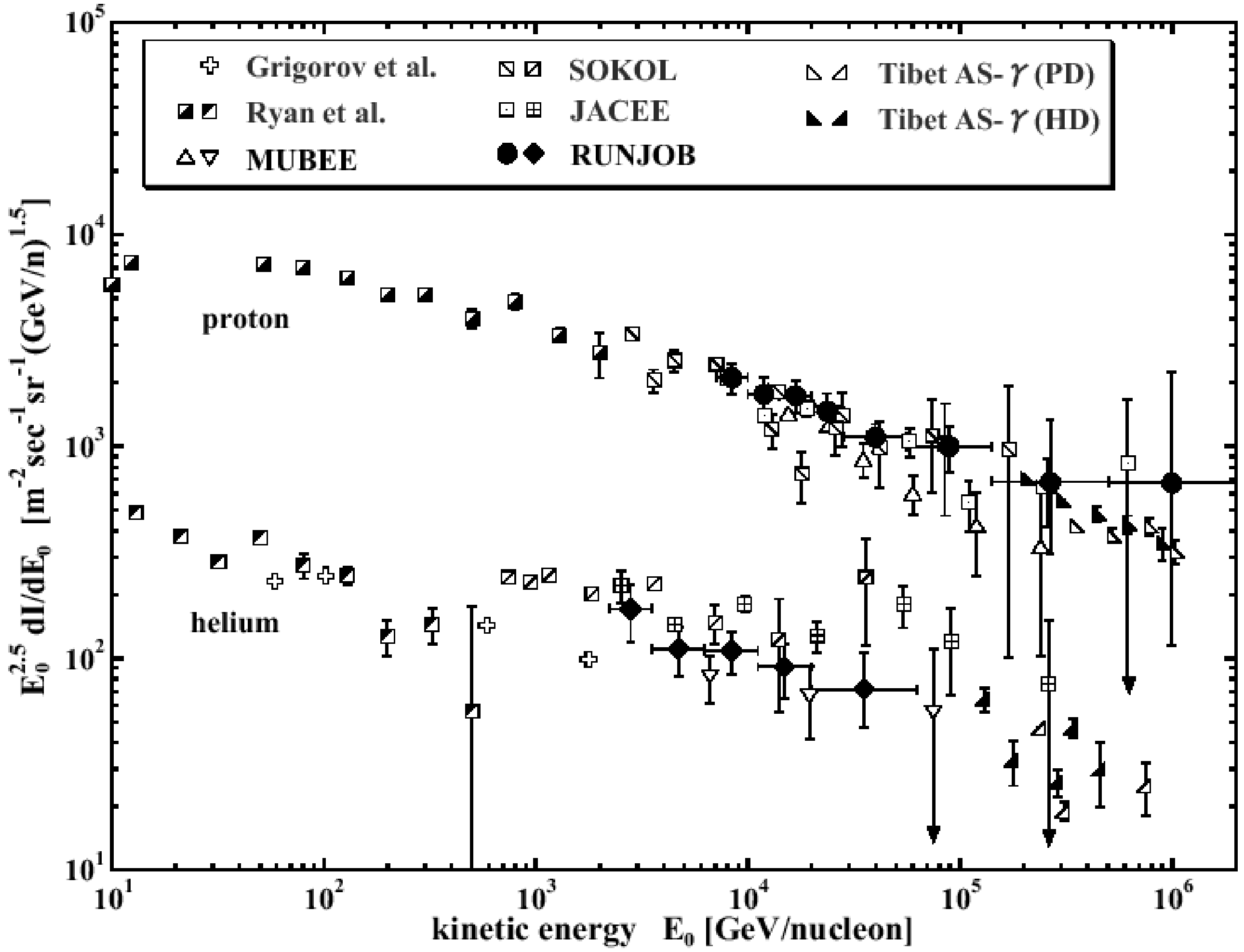

Fig. 4. Proton and helium spectra obtained by different groups. The vertical axis is multiplied by $E_0^{2.5}$ in order to emphasis the spectral feature

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