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Heavy primary spectra observed by RUNJOB

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Abstract. RUssian Nippon JOint Balloon (RUNJOB) has been observing the primary spectra of cosmic ray nuclei since 1995. Data from 6 out of 10 succesful flights will be used to report the spectra of heavy primaries up to iron nucleus with the energy range more than 10^{14} eV/particle.

The details of analysis like charge and energy determinations will be also given.

1 Introduction

The fraction of heavy components in primary cosmic rays are essential to undesrstand the origin of the 'knee'. The accerelation mechanism working at the expanding shock front of super nova remnants (SNR) has the acceleration limit proportional to ZE_{max}. So the fraction of heavy components will be larger if the origin of the knee is due to this acceleration limit.

Keeping the above in mind, we carried out RUNJOB experiment to observe all components of primary cosmic rays. We extend the primary spectra up to around 10^4 GeV/nucleon for CNO, NeMgSi and Fe groups.

The analysis methods, charge determination, energy detemination and detection efficiencies are presented as well as the experimental results.

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2 Analysis Methods

2.1 charge determination

First of all, we have to identify the primary particle in the emulsion plate above the interaction point. To reduce the scanning area, we are using more than ten relativistic heavy primaries as the reference for the computer-aided large stage. We achived the typical location accuracy of around 90 μm. But this accuracy is not enough to identify protons because of massive background protons. Then we add two or more reference heavy tracks near the interaction point to improve the accuracy up to 50 μm. Then we identify the primary, checking the zenith and azimuthal angles.

After we identify the primary track, the charge of the primary particle is detrmined by the photometric method in the nuclear emulsion. The calibration of this method is done using Sanriku experiments [Ichimura et al. (1993)] which employed screen type x-ray films and the results of the calibration are shown in Figure 1. And charge resolution is showon in Figure 2.

2.2 energy determination

Apparently our chambers are not thick enough to detrmine high energies by the photometric method. We can only observe the shpwer maimum for the events with large zenith angle. This situation is shown in Figure 7.

We develop the new energy determination method using angular distribution of secondary particles. The angular distribution has been used for long time in cosmic ray emul-

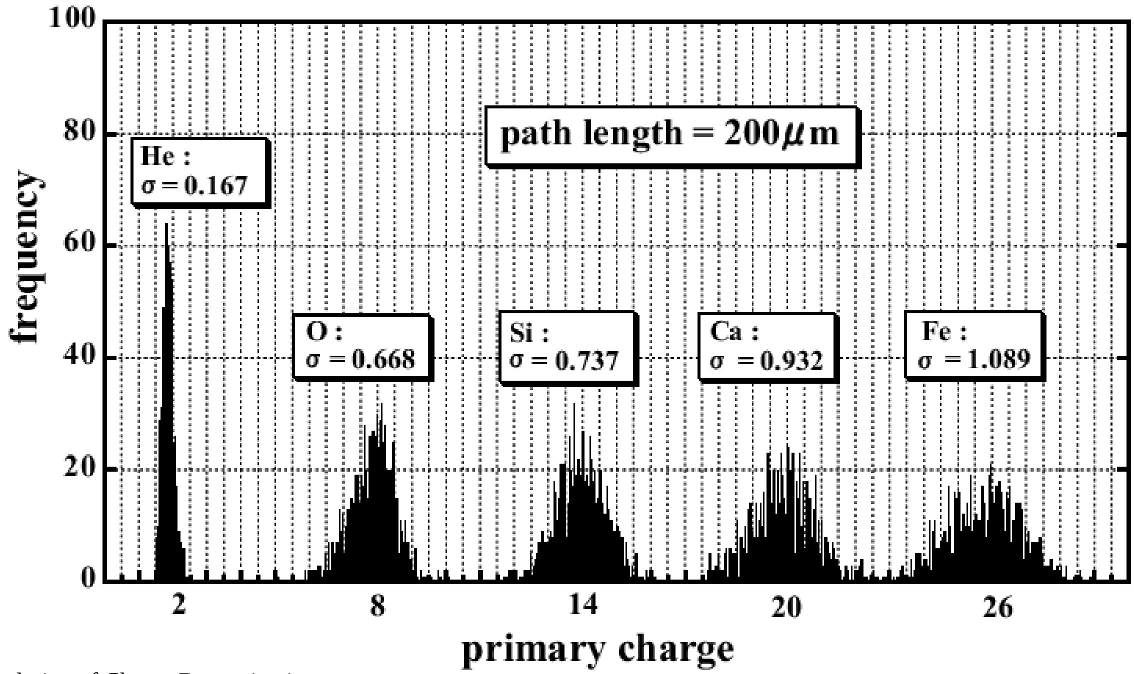

Fig. 2. Resolution of Charge Determination

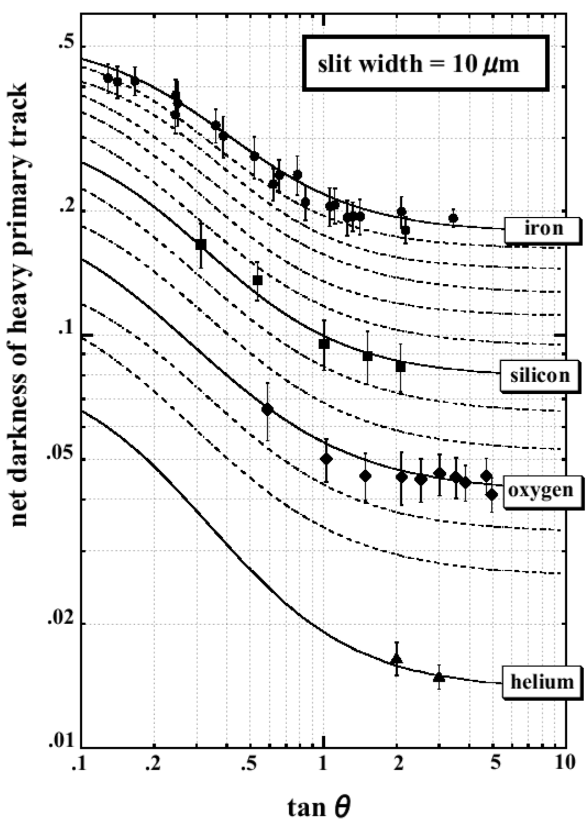

Fig. 1. Calibration for the charge determination

sion experiments but we make use of the fact that the average transverse momentum depends on the emmison angle. Here we are using the gamma rays from π^0 mesons. The phenominological equation is used to fit the Lorentz factor. The comparison of this method with the conventional photometric method is shown in Figure 3.

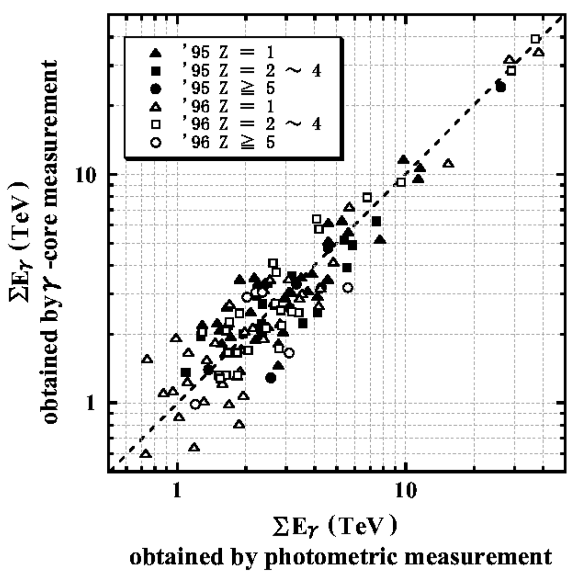

Fig. 3. Compariosn of energy determination methods

$$\langle p_t = p_0[1 - e^{-u}] \quad (1)$$

$$whereu \equiv \frac{\theta \sum E_\gamma}{nq_0}, \quad (2)$$

$$p_0 = 200\text{MeV/c} \quad (3)$$

$$q_0 = 80\text{MeV/c} \quad (4)$$

p_0 and q_0 are determined from Chacaltaya experiment and FRITIOF Monte Carlo simulation, which is satisfactory for our case.

By the parameters

$$Y \equiv \log_{10}(\sum E_{\gamma,estimated}/\sum E_{gamma,true}) \quad (5)$$

$$\sigma = \sqrt{\langle Y^2 \rangle - \langle Y \rangle^2} \quad (6)$$

energy resolutions σ are 0.158 for Chacaltaya Experiment, 0.163 for FRITIOF proton and 0.136 for FRITIOF iron.

2.3 detection efficiency

Full simulation to find the detection efficiencies are carried out. The essential gredients of the simulation is sumarized in Table 1

interaction cross section	
for nucleus	hard-sphere model
	soft-sphere model
for proton	soft-sphere model with energy dependence
interaction model	FRITIOF
cascade shower	Shibata's data bank

Table 1. Simulation for the detection efficiencies

Reference for simulations

hard-sphere model	Hargen, F.A. et al. (1977)
soft-sphere model	Karol, P.J. et al. (1975)
FRITIOF	Hong, P. (1992)
Shibata's data bank	Fujinaga, T. et al. (1989)

The details are explained in [Apanasenkp, A. et al. (2001)]. Here we present the result in Fig. 4.

95 chamber is less efficient bacause X-ray films used has higher threshold and 95 chamber has larger spacing factor.

3 Heavy Primary Spectra

Although the statistics is not large, we present our results along with other observations for three groups, CNO, Ne-Mg-Si and iron group. Iron group of our experiment contains nuclei of the charge rannge Z= 26 $\sim$ 28, but for JACEE and SOKOL Z = 17 $\sim$ 25 are also contained.

Our flux of CNO and Ne-Mg-Si groups are less than those of JACEE and SOKOL specially in the energy region more than 10 TeV/nucleon, but iron group is almost consistent even though there is uncertainties mentioned above.

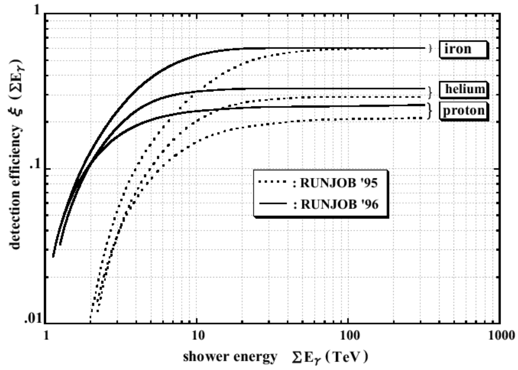

Fig. 4. detection efficiencies

Our results indicate that the slopes of the spectra become gradually harder as it gets heavier. For CNO, the spectral index is $\sim$ 2.65 and for iron group, $\sim$ 2.55.

The secondary to primary ratio of cosmic ray nuclei is important to understand the propagation. We show here the ratio sub-Fe (Z=17$\sim$ 25) / Fe with the results of Sanriku experiments [Kamioka et al. (1997)] in Fig. 6. RUNJOB results lie on the simple extraporation of Sanriku experiment.

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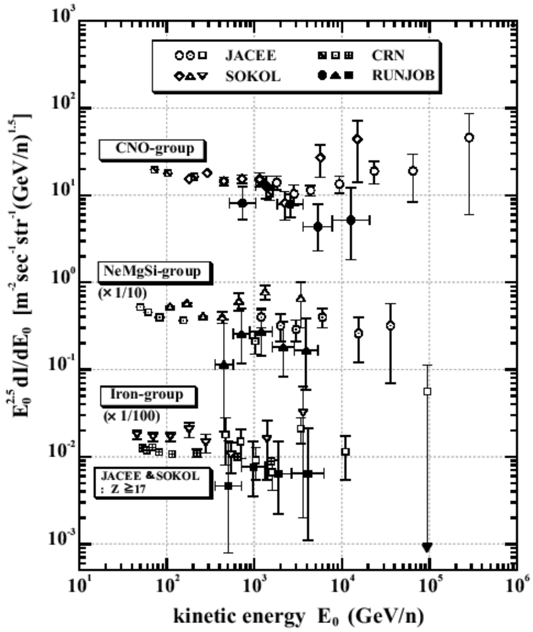

Fig. 5. Primary spectra of heavy components

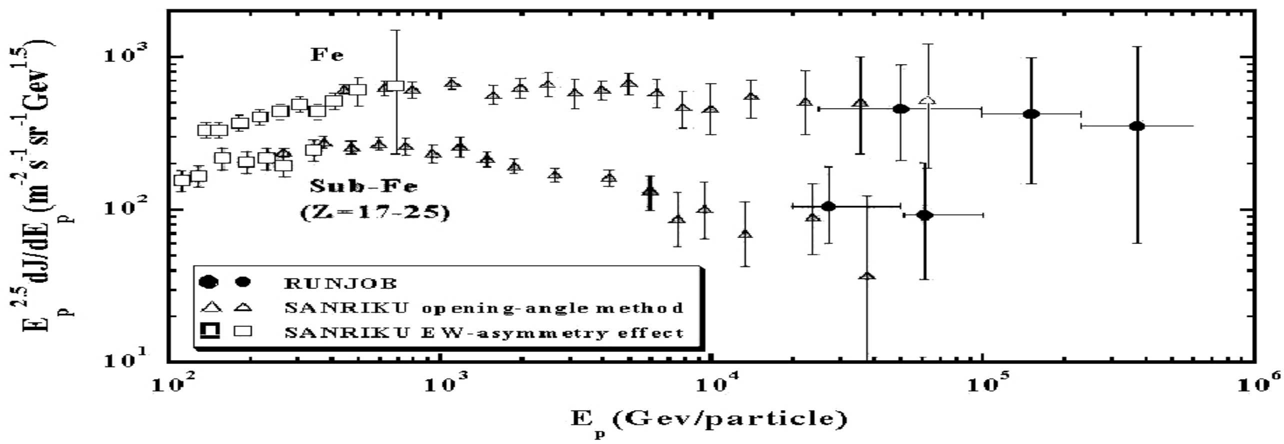

Fig. 6. sub-Fe / Fe ratio

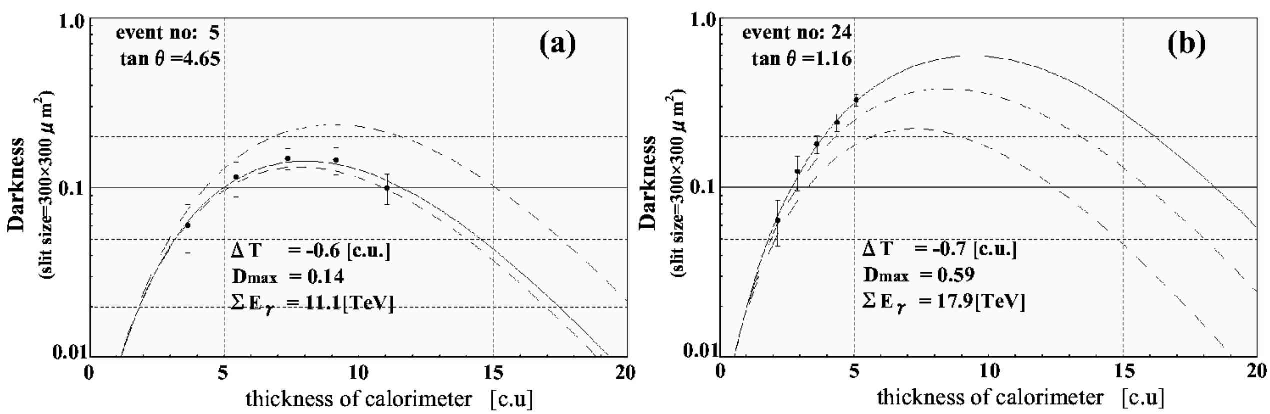

Fig. 7. Transition curves