Processing of very high energy proton events with using new method of searching for primary cosmic rays in Emulsion Chamber (on RUNJOB experiment data)

I.S.Zayarnaya
P.N. Lebedev Physical Institute of the RAS, Leninsky pr. 53, Moscow, Russia
E-mail: zayar@sci.lebedev.ru

Abstract. The primary proton tracks are identified in about half of events referred to proton ones in the Russian-Japanese balloon-born emulsion chamber RUNJOB experiment. Re-processing of experimental data obtained in long-term exposure of RUNJOB-3B, 6A, 11A, 11B emulsion chambers (EC) with new method for searching of the primary cosmic particles leads to confirm that as well as earlier single charged primary tracks are not found in about half of events referred to the proton ones with energy \( E_0 > 20 \) TeV and zenith angle \( \tan(\theta) \leq 5 \). In this paper the new method for searching and tracing of the primary cosmic particles in EC’s and characteristics of studied events (energy, angle, pass length of the primary particles until their interaction in EC) are presented.

1. Introduction
RUNJOB (RUssian-Nippon JOint Balloon) balloon experiment was performed from 1995 to 1999 year. The goal of the experiment was the investigation of primary cosmic rays in the energy range \( 10^{12}-10^{15} \) eV by using of emulsion chambers exposed in the stratosphere for a long time.

On results of data processing the primary proton tracks were identified in about half of events referred to proton ones in the Russian-Japanese balloon-born emulsion chamber RUNJOB experiment. Re-processing of experimental data obtained in long-term exposure of RUNJOB-3B, 6A, 11A, 11B emulsion chambers (EC) with new method for searching of the primary cosmic particles leads to confirm that as well as earlier single charged primary tracks are not found in about half of events referred to the proton ones with energy \( E_0 > 20 \) TeV and zenith angle \( \tan(\theta) \leq 5 \). In this paper the new method for searching and tracing of the primary cosmic particles in EC’s and characteristics of studied events (energy, angle, pass length of the primary particles until their interaction in EC) are presented.
2. New method for the searching and tracing of primary cosmic particles registered in Emulsion Chamber

To get the coordinates of the primary particles interacted in Emulsion Chamber the triangulation method was used in RUNJOB experiment. It involves the determination of a trajectory of the primary particle using the coordinate measurements of background multiply charged nuclei near this primary one. The location accuracy of this method is in the mean about 35 microns [1]. The new method of searching and tracing of the primary particles is based on two assumptions:

1) The trajectories of analyzed nucleons and nuclei of cosmic rays in EC are straight lines
2) The thickness of the emulsion layer and base of nuclear emulsion plate (NEP), the distance between NEPs within a small local area ($\sim 1 \text{ cm}^2$) taken to be constant.

In the new method, as in earlier used one the coordinates of background charged particles ($Z > 0$) near the analyzed event are measured but the system of coordinates is connected with the track of one from these background particles and two adjacent emulsion plates are taken for the measurements in order to the assumption 2 was best possible way feasible. One axis of the coordinate system is located along the projection of background nucleus trajectory on emulsion layer. Figure 1 shows an exemplary diagram of positions of the particles in the plane of nuclear emulsion plates.

To determine the coordinates and the track projection lengths of the primary particle track on the emulsion layer and on the base of nuclear emulsion plate being above the interaction point the following relations obtained in [5] are used:

Fig.1. Diagram of positions of the particles in the plane of nuclear emulsion plates
\[
\begin{align*}
X_{pr, j+1} &= X_{jet, j} + \frac{\Delta X_n \cdot P_{jet, j} \cdot \sin(\beta_j)}{P_{n, j} \cdot \sin(\alpha_j)} \\
Y_{pr, j+1} &= Y_{jet, j} + \frac{\Delta Y_n \cdot (P_{b, j} - P_{jet, j} \cdot \cos(\beta_j))}{(P_{b, j} - P_{n, j} \cdot \cos(\alpha_j))}
\end{align*}
\] (1)

\[
\begin{align*}
L_{pr, j+1} &= \frac{L_{n, j+1} \cdot L_{jet, j}}{L_{n, j}} \\
P_{pr, j+1} &= \frac{P_{n, j+1} \cdot P_{jet, j}}{P_{n, j}}
\end{align*}
\] (2)

Here \((X_{ij}, Y_{ij})\), \(L_{ij}\), \(P_{ij}\) – the coordinates and track projection lengths of the measuring particles on the emulsion layer and on base of NEP, respectively; \(\alpha_j\) – the azimuth angle of background nucleus; \(\beta_j\) – the azimuth angle of the secondary particles jet; index \(i\) indicates the type of particles (primary particle (pr), the secondary particles jet (jet), the background nuclei (b, n)); \(j\) - number of nuclear emulsion plate; \(\Delta X_n, \Delta Y_n\) – the difference between the measured values of the coordinates of the background nucleus on the nuclear emulsion plates. Figure 2 shows the deviation distribution of measured coordinates of nuclei from the predicted ones.

Fig. 2. The deviation (\(|\Delta X|, |\Delta Y|\)) distribution of measured coordinates of nuclei from the predicted ones.
The location accuracy ($\sigma$) of the new method for primary cosmic nuclei ($Z \geq 2$) is about 22 microns.

The new method was tested on the nucleus-nucleus interactions registered in the RUNJOB-3B, 6A, 11A, 11B emulsion chambers. Identification of nuclei ($Z > 2$) is completely coincided.

3. The result of re-searching of primary particles for events referred to proton ones

Repeated search of primary proton track with use of new method was carried out for events registered in the RUNJOB-3B, 6A, 11A, 11B emulsion chambers with shower energy threshold $\Sigma E_\gamma \geq 5$ TeV and with the zenith angle $\tan(\theta) \leq 5$.

After looking for proton tracks in all events (33) from four emulsion chambers obtained results are following:

a) all initially observed protons in RUNJOB experiment also were found with use of the new method; 
b) there is about half of events in which proton tracks are not found in each EC. 
c) the jets of secondary particles from two nucleon-nucleus interactions are located closely to the borders of the emulsion plates where there is a distortion in the emulsion layer. For these events, one can be sure that there are no candidates of the primary particles with the charge $Z \geq 2$ on these layers.

Thus, about half of proton tracks are not found by use of two different methods. In Table 1 the characteristics of these events are shown.

Table 1. The characteristics high energy proton events referred to the proton ones.

| No event | Primary particle | $\tan(\theta)$ | $\Sigma E_\gamma$ | Pass length of particle in EC in units of mean free pass length for proton | Pass length of particle in EC in cascade units |
|----------|------------------|----------------|-------------------|---------------------------------------------------------------------|---------------------------------------------|
| 3B 025   | p                | 0.64           | 15.97             | 0.044                                                               |                                             |
| 3B 082   | p                | 3.24           | 6.58              | 0.168                                                               |                                             |
| 3B 095   | -                | 4.83           | 85.48             | 0.482                                                               | 11.64                                      |
| 3B 116   | -                | 2.29           | 7.39              | 0.247                                                               | 5.91                                       |
| 3B 189   | -                | 4.64           | 8.71              | 0.351                                                               | 8.87                                       |
| 3B 211   | -                | 4.74           | 10.8              | 0.662                                                               | 15.99                                      |
| 3B 226   | p                | 1.41           | 15.09             | 0.168                                                               |                                             |
| 3B 240   | p                | 0.85           | 5.54              | 0.127                                                               |                                             |
| 3B 311   | p                | 0.28           | 7.43              | 0.032                                                               |                                             |
| 3B 318   | ?                | 0.4            | 9.76              | 0.017                                                               | 0.135                                      |
| 6A 046   | -                | 2.66           | 7.88              | 0.43                                                                | 9.9                                        |
| 6A 051   | -                | 1.07           | 48.42             | 0.101                                                               | 0.8                                        |
| 6A 150(base) | p | 1.23           | 6.03              | 0.092                                                               |                                             |
| 6A 204   | p                | 2.29           | 42.45             | 0.039                                                               |                                             |
| 6A 267   | -                | 3.36           | 63.56             | 0.241                                                               | 6.48                                       |
| 6A 465   | p                | 3.98           | 15.46             | 0.056                                                               |                                             |
| 6A 519   | ?                | 4.78           | 9.22              | 0.135                                                               | 3.6                                        |
| 11A 17   | p                | 1.94           | 5.83              | 0.069                                                               |                                             |
| 11A 25   | p                | 1.14           | 14.44             | 0.035                                                               |                                             |
| 11A 67   | -                | 1.79           | 28.48             | 0.125                                                               | 3.1                                        |
| 11A-91 | p  | 0.65 | 5.37 | 0.187 |
|--------|----|------|------|-------|
| 11A 299 | -  | 1.11 | 6.63 | 0.33  |
| 11A 427 | -  | 4.74 | 5.71 | 0.545 |
| 11A 525 | p  | 3.51 | 5.97 | 0.299 |
| 11A 593 | p  | 3.97 | 6.48 | 0.585 |
| 11A 619 | -  | 2.14 | 10.48| 0.449 |
| 11A 1133 | - | 0.14 | 6.1  | 0.239 |
| 11B 090 | p  | 1.24 | 27.05| 0.128 |
| 11B 560 | -  | 3.88 | 16.06| 0.165 |
| 11B 596 | -  | 4.54 | 18.84| 0.509 |
| 11B 600 | -  | 4.85 | 5.91 | 0.482 |
| 11B 614 | p  | 2.99 | 5.26 | 0.494 |
| 11B 892 | p  | 2.96 | 16.33| 0.397 |

In the column of the table with a primary particle a minus means unfound proton track, the question sign means presence of distortion in the emulsion layer.

Comparing the characteristics of the events it is seen that the average value of shower energy $\langle \Sigma E_\gamma \rangle$ and the average value of pass length of particles in every emulsion chamber for events with found and unfound proton track in the mean for all EC are differed by about 1.5 and 2 times respectively. The most of events with unfound primary proton tracks have zenith angle more than 60°, but the relative number of found proton tracks with zenith angles $\geq 60^\circ$ is not small and consists half of all events with the observed proton track. However, the author's opinion is that this difference can be regarded as just an indication. The statistics of events with selected thresholds on the energy and zenith angle (in the mean just 8 events per one emulsion chamber) does not permit the definite conclusion about this difference. The processing of additional events is needed to obtain statistically significant data.

4. Conclusions

By using of two different methods for the searching and tracing of the primary cosmic particle in events registered in RUNJOB-3B, 6A, 11A, 11B the emulsion chambers exposed in 1996, 1997, 1999 with the shower energy threshold $\Sigma E_\gamma \geq 5$ TeV and zenith angle $\tan \theta \leq 5$ (about $\frac{1}{4}$ the total statistics of RUNJOB experimental data with these thresholds) we got similar results: the single charged particle track is not found in about half of the events referred to the proton ones.

Since we cannot explain such a big number events with missed proton tracks by mentioned methodological reasons and there is no other indication on the presence of TeV neutrons in the primary cosmic rays, some other processes which could produce neutral particles at high altitudes in the atmosphere should be proposed.

References

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