Automatic searching for Fe-nucleus vertex points in balloon emulsion experiment RUNJOB

M. Furukawa[1], V.I. Galkin[5], M. Hareyama[1], Y. Hirakawa[2], M. Ichimura[2], N. Inoue[1], E. Kamioka[9], T. Kobayashi[1], V.V. Kopenkin[6], K.A. Kotelnikov[4], S. Kuramata[2], A.K. Managadze[6], H. Matsutani[3], N.P. Misnikova[4], R.A. Mukhamedshin[7], S. Nagasawa[1], R. Nakano[2], M. Namiki[8], H. Nanjo[2], S.N. Nazarov[5], S. Ohta[8],H. Ohtomo[2], D.S. Oshuev[6], N.G. Polukhina[4], P.A. Publichenko[6], I.V. Rakobolskaya[5],T.M. Roganova[6], G.P. Sazhina[6], H. Semba[11], T. Shibata[1], D. Shuto[2], H. Sugimoto[10], L.G. Sveshnikova[6], R. Tanaka[1], N. Yajima[8], T. Yamagami[8], I.V. Yashin[6], E.A. Zamchalova[6], G.T. Zatsepin[7], I.S. Zayarnaya[4]

(1) Faculty of Science and Technology, Aoyama Gakuin University, Tokyo, Japan
(2)Faculty of Science and Technology, Hirosaki University, Aomori, Japan
(3)School of Medicine, Hirosaki University, Aomori, Japan
(4)P.N.Lebedev Physical Institute of Russian Academy of Sciences, Moscow, Russia
(5)Physical Department, Moscow State University, Moscow, Russia
(6)D.V.Skobeltsyn Institute of Nuclear Physics, Moscow State University, Moscow, Russia
(7)Institute for Nuclear Researches of Russian Academy of Sciences, Moscow, Russia
(8)Institute of Space and Astronautical Science, Sagamihara, Japan
(9)Research and Development Department, National Center for Science Information System, Tokyo, Japan
(10)Shonan Institute of Technology, Shonan, Japan
(11)Department for Management, Urawa University, Urawa, Japan

Abstract

In 6 out of the 10 successful balloon flights in the RUNJOB experiment emulsion chambers comprised screen-type X-ray films (SXF). A new method has been developed, that allows selecting tracks produced by heavy nuclei with a wide microscope stage driven by stepping motors and optics interfaced to a PC.

In this paper we show the second step of the experimental procedure: tracing up nucleus tracks in emulsion layers, searching for and review of the interaction vertex points originated by heavy nuclei. The results and the analysis are presented in this work. It gives an opportunity to obtain in future heavy nucleus spectra with low threshold in a wide energy range using RUNJOB typical

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large exposures.

1. Introduction

In the frame of the RUNJOB experiment we have been performing cosmic ray observations by means of a balloon-borne chamber since 1995. In 4 out of 10 flights, we exposed emulsion chambers equipped with multilayered screen type X-ray films (SXF). A similar X-ray film type of was first used in the SANRIKU [1] experiment to detect cosmic ray nuclei heavier than oxygen. In RUNJOB the SXFs were used for heavy primaries with $Z > 17$ also.

A charged particle passing through an SXF records double dark spots on the X-ray film being seen by the naked eye. The duration of RUNJOB flights is much longer than the SANRIKU ones, which results in a much higher density of dark spots and the high-level background. The number of spots is as high as 200 thousand per layer. Reviewing experimental data demands the use of fully automated measurement systems. Automatic systems have been developed for scanning and tracking in Japan and in Russia. Presently, the processing of SXF data is performed independently in two laboratories. In this report we are going to discuss the results obtained by the Russian automatic system PAVIKOM [2].

2. Experimental Procedure

The chamber consists of five modules: primary block, target block, spacer block, calorimeter block and diffuser block. The chamber parameters are: total area is 0.2 m^2, total height is 23 cm (or 6.3 g/cm^2). The particle selection procedure applied in RUNJOB is trigged after detection of the energy flow released into electromagnetic component $\sum E_\gamma = E_0 K_\gamma$ in the calorimeter. However, due to the high energy threshold and small value of inelasticity K_γ in Fe collisions, the resultant energy threshold in E_0 equals to 20-30 TeV/particle for heavy nuclei. Another method used in this work is the tracing of all heavy primaries tracks from the top to bottom using screen-type X-ray films. Thus, there is no longer need in the electromagnetic calorimeter block, but just the primary and the target modules in which SXFs are included. This new method has the advantage of a detection threshold as low as 0.1 TeV.

The experimental procedure consists of four basic steps: scanning screen X-ray films, selection of spots in every SXF layer (image processing), reconstruction of the original trajectories of nuclei and searching for vertex points of iron interactions in the emulsion plate. Implementation of the first step is based on the use of the MICOS automated stage (a fully automatic measurement system). MICOS is a sensitive motorized stage that allows scanning wide-area nucleus emulsion plates with high accuracy. 10 RUNJOB SXF plates have been scanned by means of MICOS system; the stage is steered by special software.

The scanning has yielded 2,548 photos at each plate. Scanning a single plate takes about 2 hours; the size of an image is 10130 x 7620 μm^2 that corresponds to 1360 px by 1024 px.

An off-line analysis of the selected spots starts as a follow-up of SXF scanning, this is the second step. A special software (”SP”) has been designed to treat images: to detect spots, to calculate the centre-of-gravity and the darkness of the spots. These data are stored in a bank of spot coordinates. Over 300 thousand dark spots were detected per one SXF. We have finally obtained as many as 3 million spot coordinates in ten films (that are to be combined in separate tracks). Tracking is a complicated process based on a multilevel algorithm depending on a number of parameters.

Non-interacting reference tracks (called ”references”) are used to define the system of axes.

The next step in data processing is reconstruction of original trajectories from the spots in the chamber. Tracks are found with another special software (”SxfTrace”). Input data are the bank of spot coordinates over all the 10 layers, using the 3 million separate points. It is necessary to restore a picture of track passing through the chamber (these 3 million spots need to be restored in tracks lately). A smart algorithm allows collecting tracks as ordered trails of spots and outputs a data bank of tracks. Tracking takes up from 3 hours to 3 days, depending on various conditions on the PC Pentium-III/600/768Mb used. The number of found tracks passing through the entire block (13 layers) is about 13 thousand.

Found tracks are divided into three classes: stopped ones, interacted ones and passed through the chamber ones. The number of tracks decreases with the depth in the chamber. We have carried out simulation for all types of the obtained tracks and comparison with experimental data yields 50% efficiency for track detection. Unfortunately, tracks can be lost due to several reasons: high background, spots overlapping, accidental dust and scratches.

In order to find track losses while tracing up from layer to layer, we use reverse tracking (from bottom to top) and see that coefficient of losses in transition from layer to layer is $\sim 10\%$. Taking in account this coefficient for the number of simulated tracks, we get a good agreement with experimental results.

Once tracks have been detected in an SXF, correlated spots are traced up to nuclear emulsion plates to search for interaction points. In practice, trajectories reconstructed with accuracy better than 100 μm are found in emulsion with 100% efficiency. For these events, the prediction radius turns out to be 100 μm.

Tracking efficiently works for zenith angles within the region $0.3 < cos(\theta) < 0.8$. Tracks with small angles (actually vertical trajectories) are lost due to overlapping spots, tracks with big angles are difficult to trace up, because many candidate spots are located in prediction area. Thus, tracks with $cos(\theta) < 0.3$ are very likely to be false.

The final goal of the method is to predict the interaction points in nuclear emulsion and at the last step the predicted vertex points need to be studied with human visual analysis. We perform simulation for interaction-induced iron primaries in the chamber and see that searching for vertex point in semi-automated mode is possible only for interaction with energy more than 5-10 GeV/nucleon (that means 300-600 GeV per particle), since only such events are seen in emulsion as a narrow jet of secondaries. Our simulations show that only 1% of predicted candidates for interaction could be found by visual analysis.

3. Results

1) We completed the development of automatic measurement system of searching for Fe-nucleus vertex points of interactions in nuclear emulsion plates, based on Russian system PAVIKOV [2] in Lebedev Pysical Institute.

2) 50000 tracks of heavy nuclei in one block of RUNJOB chamber were selected and predictions of vertex poin locations in nuclear emulsion were calculated. For small part of these tracks we have performed the visual analysis of secondary particle jets originated after interaction in nuclear emulsion plates, and have shown that only 1% of jets can be selected visually as a narrow jet. This estimation coincides very well with calculated efficiency and correspondes to energy threshold of heavy nuclei selection ~10 GeV/nucleon.

3) The preliminary analysis shows that all selected events belong to a group of Fe and sub-Fe nuclei.

4) We have estimated experimentally the ratio of lost tracks 10% (while tracing down from layer to layer) and stopped tracks $\sim$ 2%. This estimation is in a good agreement with calculation.

Thus, we have carried out full cycle of data analysis and can see this method works and it is really efficient for heavy primaries. So, we can obtain more heavy primary events and extend the spectrum of heavy nuclei to low threshold in wide energy range using large exposure of RUNJOB experiment.

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