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Detection of cosmic ray by jet trigger method.

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Abstract.
Jet trigger is a method to detect high-energy cosmic-ray event by use of multiple meson production under the interaction point. This method has higher detection efficiency for heavy component of cosmic ray primary, compared with cascade trigger method. The scanning method and system by jet trigger was developed and investigated by use of target layer of passive type emulsion chamber in RUNJOB experiment. 56 events were detected in $40 \times 50cm^2$ and heavy primary of $Z > 10$ are 3 times as much as by cascade trigger method. Energy was determined by use of emitting angle of secondary charged particles and energy spectrum was obtained.

1 Introduction

The energy spectrum of cosmic ray gives us important informations about the origin, acceleration and propagation mechanism of cosmic ray. The ”knee” puzzle in the 10^{15} eV energy region has not been solved and the energy spectra for various elements in ”knee” energy region are quite important to settle various models of the origin, acceleration and propagation mechanism.

The phenomena based on the ionization loss and the curvature by magnetic field are not available to high-energy cosmic-ray detection near by knee region. There has been used cascade phenomena and transition radiation as high-energy cosmic-ray trigger. In the case of transition radiation method, it is not effective for proton (He) and difficult to determine the energy higher than several TeV/n.

Cascade trigger method so called ionization calorimeter has following shortcomings.

1. The mass absorber becomes heavier (several tons) and thicker for higher energy determination, and the statistics of detection becomes lower by both reasons of exposure aria and effective solid angle under the weight limit in the satellite or balloon experiment.

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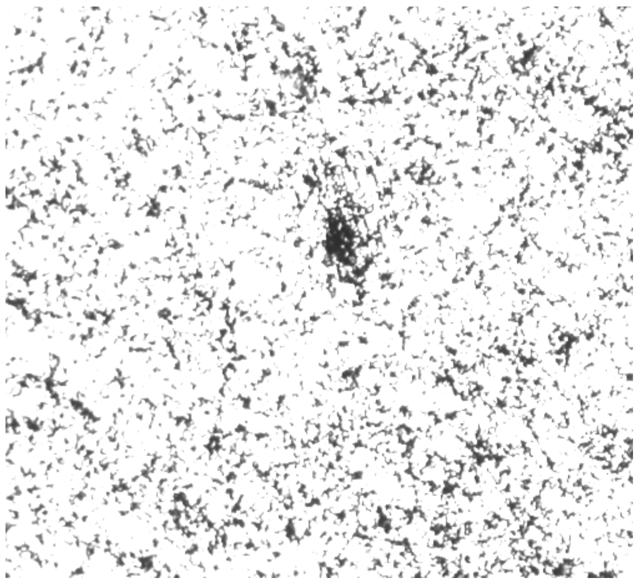

Fig. 1. Jet spot on X-ray film(width 0.5mm)

2. Large labor-consuming work is required for the tracing from cascade to primary cosmic ray.

3. Statistics of detection for the heavy component is limited, by the reason th at energy is distributed to multiplicity of secondary particles for heavy cosmic primaries.

The heavy component in high-energy region plays very important role to solve the ”knee” puzzle. Now it is quite important to develop a new method of high-energy detection, which has good statistics for heavy component of primary cosmic ray.

2 Jet trigger method

The jet trigger method was proposed in Calgary conference by Sanriku group(M.Ichimura et.al,1993). Event detection by jet trigger method is based on the multiple particle produc-

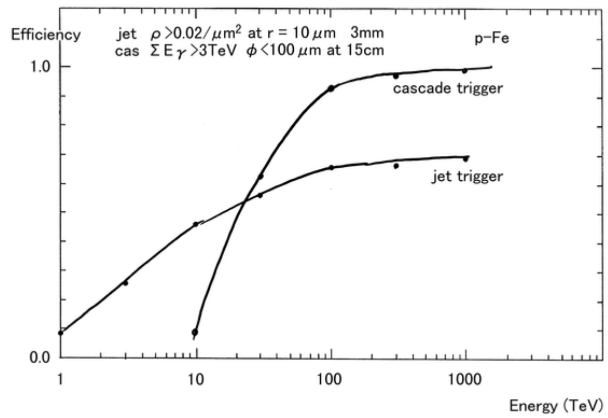

Fig. 2. Energy dedependence of efficiency for proton incident

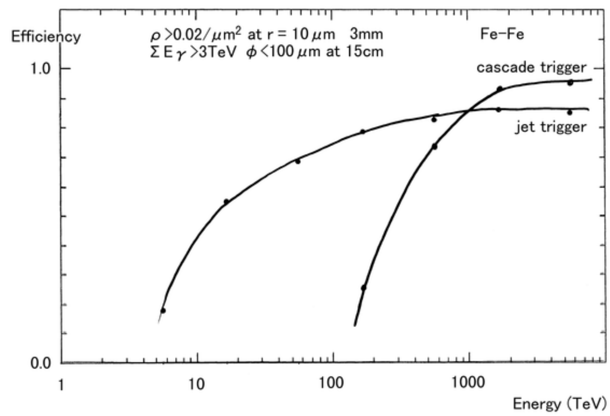

Fig. 3. Energy dedependence of efficiency for iron incident

tion. High dense charged track just after interaction makes a spot on the X-ray film, as is shown in Fig.1. The jet spot density depends on the multiplicity and emitting angle of secondary charged particles. The dependence on multiplicity gives a good advantage for the high multiplicity event by heavy incident particle, and the dependence on emitting angle gives a good advantage to high-energy trigger of detection.

The energy dependency of detection efficiency is shown in Fig.2 for proton- iron interaction, in Fig.3 for iron-iron interaction. Figure shows that the energy threshold of detection by jet trigger is much lower than by cascade trigger in the case of iron primary, which means that we can get the data in wide energy range by the single detector and we can discuss the inclination of energy spectra.

The jet spots are detected at just below the interaction point. This means that the mass absorber is not necessary and the detector can be thin and light weight, and give the following advantages.

1. Compared with the calorimeter by use of cascade method, it is possible to get a larger statistics by larger exposure area and larger effective solid angle with in the limit of weight.

2. It is possible to reduce labor-consuming work in the

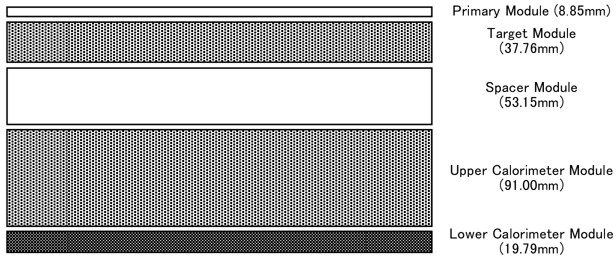

Fig. 4. Chamber structure

trace from cascade to primary cosmic ray.

The jet spot size is nearly about several tens μm which is one order smaller than cascade spot size and it is impossible to detect the jet spot by naked eye, as is used in the scan of cascade spots. There are many small size noise spots similar to jet spots from these noise spots, and the discrimination of jet spot is not so easy.

We developed a new system and method of jet spot scan, by use of large area stage (40cm$\times$50cm moving area) with CCD camera controlled by computer.

3 Experimental procedure

The emulsion chamber of RUNJOB IX experiment was used for investigation of jet trigger method. The chamber structure is shown in Fig.4, and only primary and target module was used in this research. Target module consists of 8 cycle sandwichs of stainlesssteel, nuclear emulsion and 2 sheet of X-ray films. The jet spot scan was performed according to following procedure.

1. Automatic spot scan on X-ray film by use of conputer controlled scanning system with CCD-camera and automatic stage.

2. Elimination of noise spot using various conditions by computer calculation.

3. Elimination of noise spot using nuclear emulsion on microscope.

3.1 Automatic spot scan

#200 X-ray film (40cm$\times$50cm size) is placed on x-y-z automatic stage, and image is taken into computer by CCD camera. The size of one image is 2.77mm$\times$2.60mm and the size of pixel is 5.41 μm$\times$ 5.41μm. The jet spot is characterized in high density of charged track, that is, high dark spot. Therefore, the brightness of an illuminant is set up in high brightness, in order to cut out a large number of thin noise spots. The focus of image changes in different location on stage. An auto focus system was developed using the minimum average value of light intensity in pixels in different z-axis point of camera. Host computer determines the best focus and processes the image and detects the candidate of the spot, and stage moves to next aria. After process of the image and output the spot data to file, next image is taken.

The image is processed according to the following procedure

1. Smoothing of light intensity in pixel by use of Savitxky-Golay convolution kernel.

2. Grouping of adjacent pixels of which light intensity is lower than a threshold value.

3. Calculation of aria S (number of pixels), mean light intensity H and total light intensity V of spot which is formed by above grouping.

This spot scan was performed on 8 X-ray films in all layers of target module and the candidates of jet spots are selected under some condition of above S, H and V value. The candidates of jet spots obtained by this scan contain a large number of noises as follows.

1.Scratch on film.

2.Floating dust on film.

3.Spot of stopping heavy particle in low energy.

The noises by scratch are on a long line and these noises are eliminated by the condition of plural points on the straight line. The noises of dust are eliminated by the check of correlation between the different data of same film, which is taken in different time. We have to take into account that the temperature is different in different time and the thermal expansion is not negligible for this correlation check. This expansion is not uniform and rather complex. The correction of the location was done by the statistic way of the correspondency of spot.

The number of candidate spots is reduced from several hundred thousand to about ten thousand by above 2 way eliminations . The final discrimination of jet spot from stopping heavy noises and the remaining noises after procedure above 2 way elimanations are performed on the nuclear emulsion by use of microscope. About several ten events of jet was pick out on one layer of target module.

3.2 Tracing

The jet detected on the nuclear emulsion is traced up to the incident primary particle through an interaction point. This trace up work is performed by use of automatic trace up system, which consists of microscope-equipped micro scanning stage, stage controller and computer. Computer calculates the prediction point on upper layer by use of reference track and the locations of jet on upper side and lower side of nuclear emulsion, and stage moves to the prediction point automatically.

3.3 Charge determination of primary

The primary chemical component is determined by use of delta ray counting or gap length of the primary track in the nuclear emulsion. The charge resolution is not good in this method and incident particles are classified in some groups (proton, He, Li–B, C–O, Ne–Si, Sub-Fe, Fe)

3.4 Energy determination

The energy of primary energy is determined by use of emitting angle of secondary charged particles of which method is developed by RUNJOB experiment. The estimated energy is checked by use of 2 different ways. One is the use of rapidity scaling(Feynman scaling)(R.P.Feynman,1969)), which depend on only emitting angle and give energy per nucleon. Another is the use of P_t constant, that is, the sum of P_t/θ which depends on angle and number of secondary particles.

4 Results

Scan was performed twice independently in 1999 and 2000. The selction condition of jet spot candidate was refined for the advantage to heavy incident primary in 2000. The number of detected incident particles is shown in Table 1, compared with the number of detected particles by cascade trigger method. The detected number of proton and He is nearly same with the number by cascade trigger.On the other hand,the detected number of heavy primary is much larger than the number by cascade trigger.

The zenith angle distribution is shown in Fig.7 for proton and in Fig.8 for heavier particle more than carbon. Only inclined events of proton or He primary are detected, as is shown in fIgure. It should be noted that a spot of proton or He is detected as a mixture of jet and cascade in the case of inclined event.

primary	1999	2000	and	total	cascade trigger
proton	8	12	4	16	14
He	8	9	2	15	16
Li∼B	0	3	0	3	3
C∼O	5	9	5	9	5
Ne∼Si	3	7	3	7	2
Sub-Fe	3	5	2	6	2
Fe	0	0	0	0	0
all	27	45	16	56	42

Table 1. Number of detected primary events

The ΣE_{ch} spectra are shown in Fig.5 for proton and He and for heavier particle more than carbon, compared with the spectrum by cascade trigger. These are raw spectrum without any corrections by detection efficiency, etc. This figure shows that jet trigger can detect higher energy event for proton and He compared with cascade trigger.The proton or He events detected by cascade trigger has short path length in the target module because of small solid angle, and the number of detected events is small by both reason of small cross section in target and small solid angle. On the other hand, the detection energy region of heavy particle is much lower than cascade trigger by the reason that jet trigger is not based on energy but on multiplicity of secondary particles.

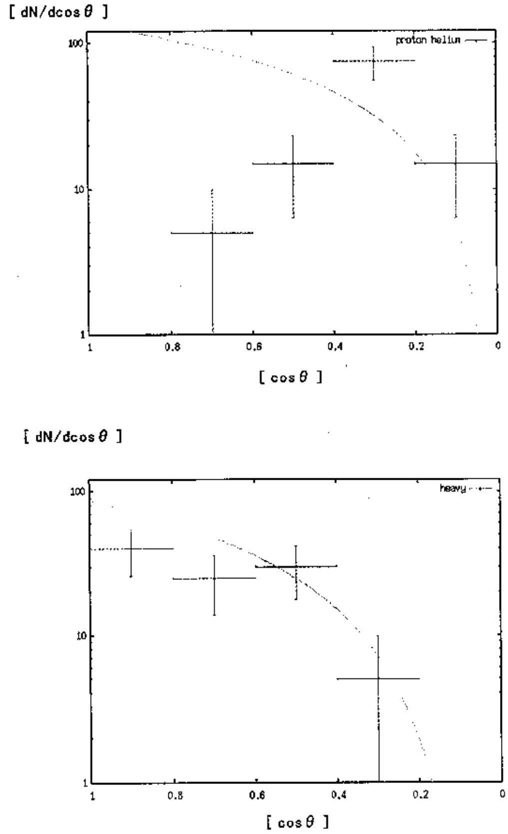

Fig. 5. Zenith angle distribution

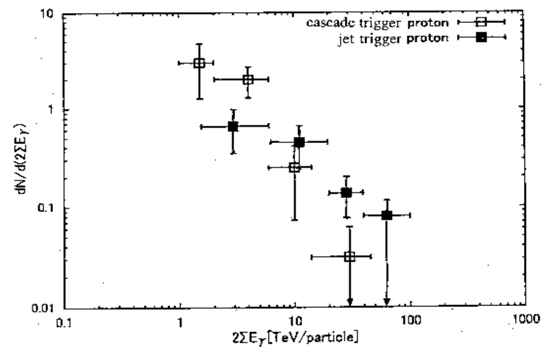

Fig. 6. Energy spectrum for proton primary

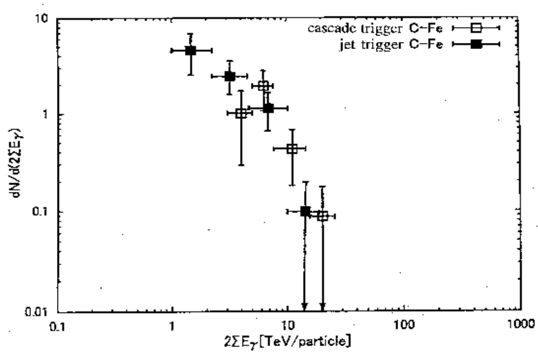

Fig. 7. Energy spectrum for heavy

5 Conclusion

The detection system of cosmic ray by jet trigger was developed, and the jet scan was performed by use of the #200 X-ray films in the chamber of RUNJOB experiment. The results obtained this research are summarized as follows.

1. The detection threshold energy for heavy primaries is much lower than by cascade trigger method, and this gives good statistics in long wide energy range by single experiment.

2. Light component (Proton and He) also can be detected in higher energy than by cascade trigger method.

3. The time spent for data process (tracing) is much shorter compared with cascade trigger method.

The validity of jet trigger method was established and this method will open new approach to the direct observation in the ”knee” energy region.

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