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INTERNATIONAL CONFERENCE ON COSMIC RAYS AND THE EARTH STORM Part III

III-6-10. Interactions of Nucleons with Heavy Nuclei of Photographic Emulsions at Energies Higher than 10^{12} ev

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Double maximum angular distributions in nucleon-nucleon and nucleon-nucleus collisions

In recent papers concerning double maximum angular distribution[1,2] of secondaries, produced in high energy collisions, it has been pointed out that this type of distribution appears in collisions of primary nucleons with energies $>10^{12}$ ev characterized by small evaporation, small multiplicity and high anisotropy. ($N_h \leq 5$, $n_s \leq 20$, $\sigma > 0.6$). We can consider that in this group of jets the abundance of collisions of the incident nucleon with only one nucleon of the target is rather high. We have described the observed angular distributions by means of the two-centre model. But already on the Moscow Conference (1959) examples had been presented[3,4] in which the double maximum distributions were observed for collisions with heavy nuclei. In the present report, a more systematic investigation of the occurrence of double maximum distribution in collisions of nucleons with heavy nuclei of photographic emulsions will be described.

Experimental material

We will describe 14 jets produced by singly charged or neutral primaries with energies higher than 10^{12} eV and characterized by high evaporation and very high multiplicity ($N_h > 8$, $n_s > 40$). This selection gives a very well defined type of collisions which may be interpreted as central collisions with heavy nuclei of photographic emulsion. The characteristics of these jets are given in Fig. 1.

Deviation of the angular distribution from the normal one

In Fig. 1 the angular distributions of individual jets are presented. The differential distributions (dN/dX *vs* $X=(x-\langle x\rangle)/\sigma$ where $x-\langle x\rangle=\log \gamma_c \tan\theta$) are normalized to the same anisotropy $\sigma=1$ and divided into intervals corresponding to equal areas of the Gaussian curve. In Fig. 1 the sequence of the jets listed corresponds to increasing anisotropy parameter σ. We see that on this sample, as well as in N-N collisions the double maximum shape of angular distribution becomes more pronounced with increasing σ-values.

In Fig. 2 the composite differential angular distribution for all 14 jets is given. The deviation of this distribution from the normal one is on the level of ~ 3 standard deviations.

For characterizing of individual events we had introduced[1] the parameter D, which is the measure of the deviation from the normal shape, towards the double maximum one. (For normal distribution $D=0$, for double maximum distribution $0<D\leq 1$). In Fig. 3 the D-values of our 14 jets are plotted *vs* the anisotropy parameter σ. Here we see again the very pronounced effect of two maxima (high D-values) for high anisotropy (high σ-values). From 14 jets, 11 show $D>0$ and only three $D<0$. 5 jets with the highest anisotropy show individual deviations from the Gaussian shape on the level of ~ 2 standard deviations. In 6 events both cones of the jets are so well separated that it is possible to investigate the shape of the angular distribution in each cone separately. In Table I we have summarized the multiplicities and anisotropy parameters for separate cones. n_1, σ_1 for the narrow and n_2, σ_2 for the diffuse cone.

Problem of symmetry and anisotropy of angular distribution in collisions with heavy nuclei

It seems from the data of Table I that there is an asymmetry of angular distribution for narrow and diffuse cones. In average the multiplicity in the narrow cone is smal-

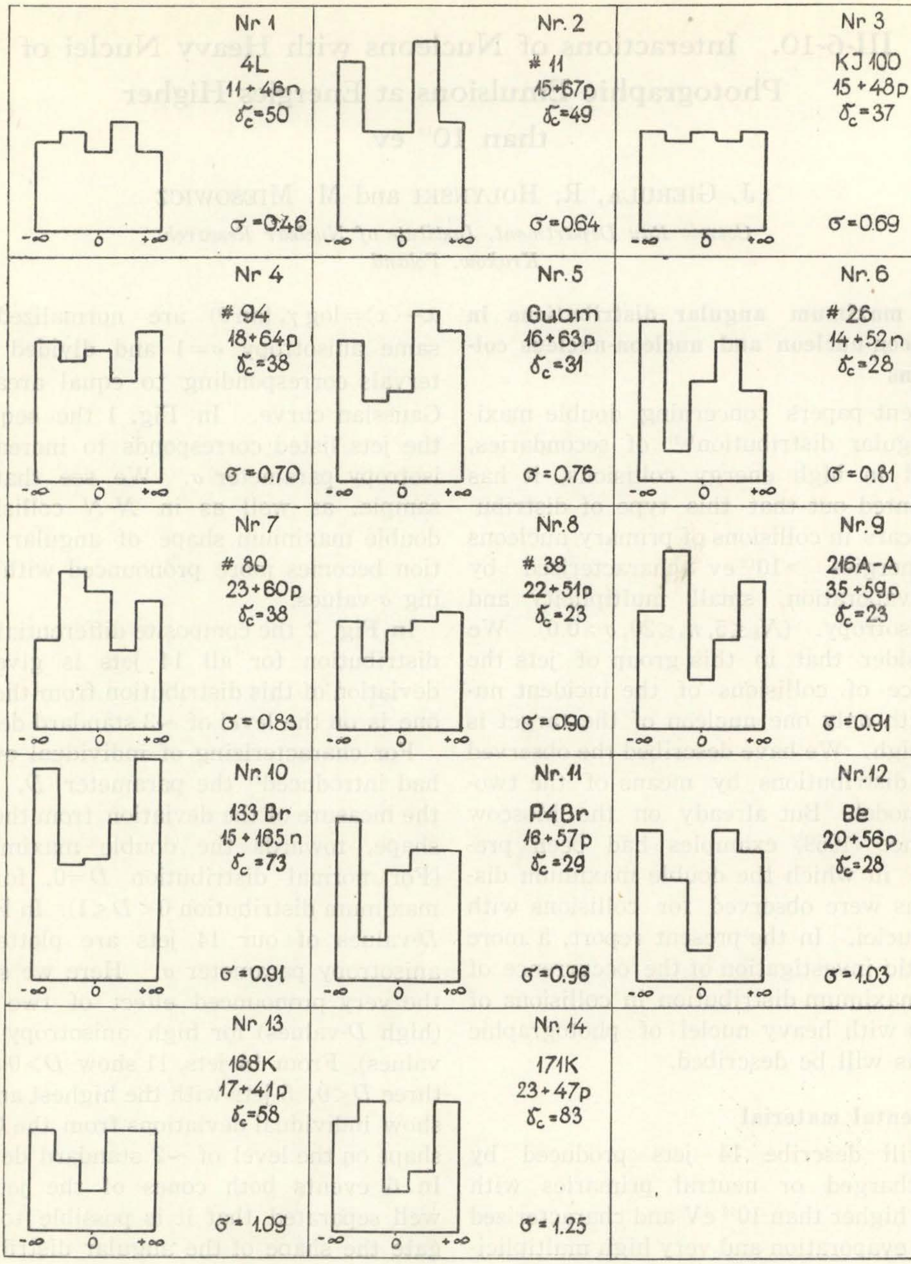

Fig. 1. Histograms of individual jets. Angular distribution in the $\frac{x-<x>}{\sigma}$ coordinate divided into intervals corresponding to equal areas of the normal curve. List of jets: Nr 1: Private communication from Radium Institute USSR Academy of Science-Leningrad. Nr 2 and 7: Barkow, Chamany, Haskin, Jain, Lohrmann, Teucher, Schein: Phys. Rev. **122** (1961) 617. Nr. 3: Unpublished. Nr 4, 5, 6 and 8: Gierula, Haskin, Lohrmann: Phys. Rev. **122** (1961) 626. Nr 9: Sanko, Takibayev, Shakhova, Balats: JETP **37** (1959) 3. Nr 10: Private communication from H. H. Wills Laboratory, Bristol. Nr 11: Perkins, Progress in Elem. Particles and Cosmic Ray Phys. **5** (1960) 257. Nr 12: Hanni, Lang, Teucher, Winzeler: Nuovo Cimento **4** (1956) 1473. Nr 13 and 14: Bartke, Czachowska, Holynski, Rybicki: Acta Phys. Polon. **20** (1961) 331.

ler than in the diffuse one ($n_1 < n_2$). We see that the angular distributions in narrow cones are roughly isotropic ($\sigma_{isotr}=0.39$) as in N-N collisions. On the other hand for diffuse cones we observe higher σ-values ($\sigma_1 < \sigma_2$). In Fig. 4, we have the composite histogram of angular distributions for 6 jets from the Table I. We see here also the asymmetry mentioned. The minimum of the distribution does not coincide with the value corresponding to γ_c calculated by means of Castagnoli formula. In our opinion the observed asymmetry is the consequence of the secondary interactions in the target nucleus. Perkins[5] had analyzed the event P4 Br (16+57p) and came to the conclusion that the tracks of this jet with angles $\theta > 0.1$ are of the secondary origin. We think that this effect has a general character for jets with high evaporation and very high multiplicity. In the diffuse cones of these jets there are particles of secondary origin. One can interpret the observed phenomena on the basis of assumption of emission of particles from two centres, taking into account secondary interactions. In this picture both centres emit mesons isotropically, but the slow one emits mesons inside the nucleus and they

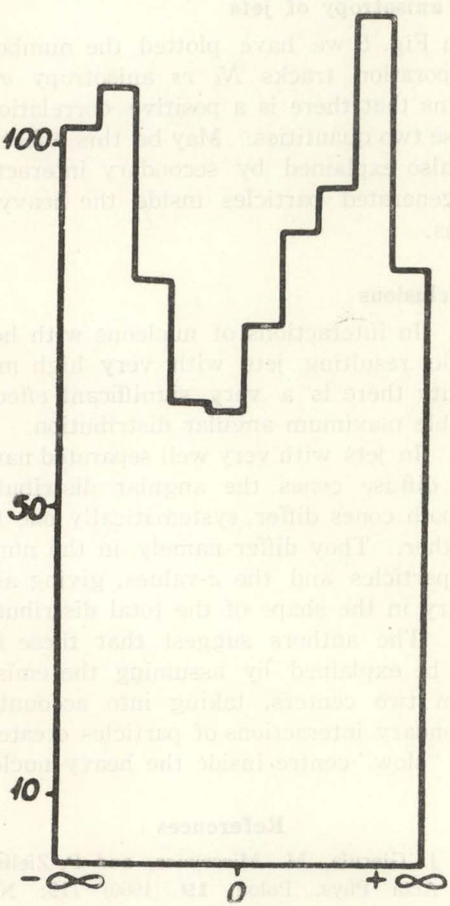

Fig. 2. Histogram of the composite differential angular distributions of 14 jets given in Fig. 1.

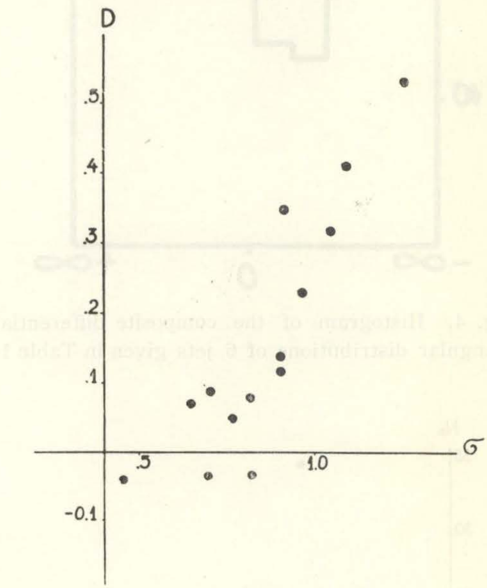

Fig. 3. Correlation between the parameter D and the anisotropy σ.

Table I.

		γ_c	σ	n_1	n_2	σ_1	σ_2
26s (Chicago)	14+52n	28	0.81	16	36	0.29	0.52
216 (Alma Ata)	35+59p	23	0.91	33	26	0.29	0.52
P4 (Bristol)	16+57p	29	0.96	18	39	0.24	0.54
Be (Bern)	20+56p	28	1.03	24	30	0.32	0.56
168K (Krakow)	17+41p	58	1.09	17	24	0.35	0.58
171K (Krakow)	23+47p	83	1.25	24	23	0.40	0.62
mean				22	28	0.34	0.53

interact in it. This increases the spread of angles of the diffuse cones. In the paper Bartke *et al.*[4] it had been stated that the average σ-value for nucleon-nucleus collisions are higher than for N-N collisions in the same interval of γ_c. It is now possible that this difference is caused only by secondary interactions and the measured σ-value does not represent the real anisotropy of the main collision.

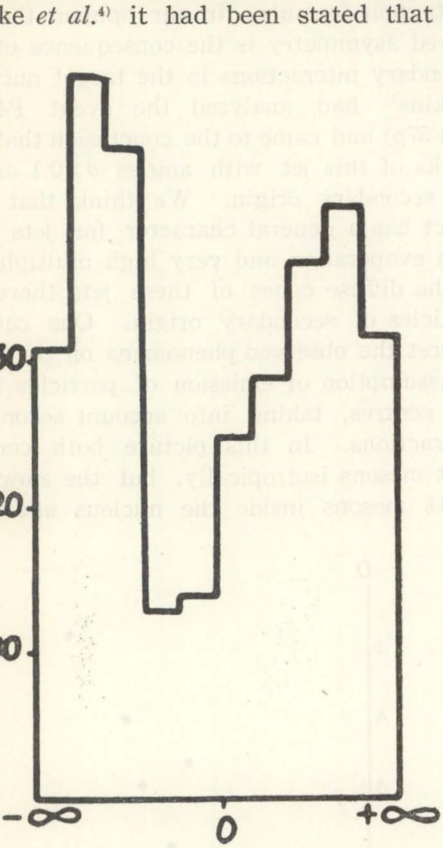

Fig. 4. Histogram of the composite differential angular distributions of 6 jets given in Table 1.

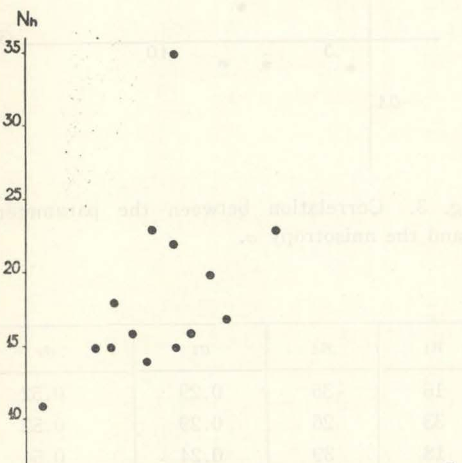

Fig. 5. Correlation between the number of evaporation tracks N_h and anisotropy σ.

Correlation between the evaporation and the anisotropy of jets

In Fig. 5 we have plotted the number of evaporation tracks N_h *vs* anisotropy σ. It seems that there is a positive correlation of these two quantities. May be this effect can be also explained by secondary interactions of generated particles inside the heavy nucleus.

Conclusions

1. In interactions of nucleons with heavy nuclei resulting jets with very high multiplicity there is a very significant effect of double maximum angular distribution.

2. In jets with very well separated narrow and diffuse cones the angular distributions in both cones differ systematically one from another. They differ namely in the number of particles and the σ-values, giving asymmetry in the shape of the total distribution.

3. The authors suggest that these facts can be explained by assuming the emission from two centers, taking into account the secondary interactions of particles created in the "slow"-centre inside the heavy nuclei.

References

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Discussion

Kaneko, S: I would like to know how much error do you have in estimating σ value on the average.

Miesowicz, M.: The errors for individual σ_1 and σ_2 is of the order of 10~15%. But the difference taken for all 6 jets is more significant.

Zhdanov, G. B.: Have you taken into account of the possible influence of the velocity spread of secondary particles on the shape of two maxima of angular distribution?

Miesowicz, M.: No.

Powell, C. F.: I'm not quite sure what extent your picture is compatible with that of Prof. McCusker's group, in which the penetration through the center of silver nuclei only gives the very low value of N_h. In your interpretation of these events with high N_h, you assume that they are due to the penetration of the center of silver nuclei.

Miesowicz: These are the phenomena of collision of nucleon with heavy nuclei. Prof. McCusker described the phenomena of central collision of π meson with nuclei, and, in his picture, the fireball decay inside the nucleus or outside the nucleus depends on the γ value of this fireball. In our picture, I believe, the fast fireball ($\gamma \sim 500$) goes out and the slow fireball ($\gamma \sim 5$) may decay inside the nucleus.

Koshiba, M.: If we take Prof. Miesowicz's model, there's no reason why we can not expect the same effect when π meson goes through silver. Because in this case we can expect only the slow fireball.

Miesowicz: I agree with you.

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INTERNATIONAL CONFERENCE ON COSMIC RAYS AND THE EARTH STORM Part III

III-6-11. High Energy Nuclear Interaction with Isotropic Distribution of Generated Particles

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While scanning 1 liter of photoemulsions of the NIKFI-R type exposed during ~150 hours at an altitude of ~10 km, an interesting event of the type $2+3+40p$ (Fig. 1) was found.

Angular distribution of the secondary particles were measured twice and from 4 to 8 cross sections of shower by the corresponding planes perpendicular to emulsion surface were used. This provided a reliable recording of all the produced particles and exclusion of electron-positron pair and random tracks.

Fig. 2 displays the angular distribution of particles obtained (circles) the continuation of the primary particle track taken as the shower axis direction.

The same figure shows the calculated curves for an isotropic distribution of particles in a certain coordinate system. In one case (the dotted curve) an assumption was used on equal velocities of the particles β_i ($\beta_i=\beta_c$, where β_c—velocity of the given coordinate system) and in another case—an assump-

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