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INTERNATIONAL CONFERENCE ON COSMIC RAYS AND THE EARTH STORM Part III

III-7-14. Application of Diagram Method to the Calculation of Characteristics for Nucleon-Nucleon Interaction at the Energy of 300 Bev and Their Comparison with Experimental Data*

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1. Recently nucleon-nucleon interactions at $E_L \sim 300$ GeV[1,2,3] were investigated with new improved experimental techniques in the Lebedev Physical Institute of the Academy of Science of the USSR. Many data testify to the fact that an essential part of these nuclear interactions consists of one-meson ("peripheral") interactions, which can be described by Feynman's diagrams, given in Fig. 1.

Theoretical treatment of such interactions by the diagram method was already given in refs.[4),5)]. Paper[4)] deals only with "one-jet" diagram (Fig. 1a) which can explain only a part of recorded interactions ($\sim 30\%$[4)]). In ref.[5)] a "two-jet" diagram was investigated (Fig. 1b) and it was shown that this diagram describes the main bulk of experimental data.

As it was shown in papers[5) 9)] the interaction cross-section described by the diagram of Fig. 1b may have the form:

$$\sigma_{pp}=\frac{2}{(2\pi)^3 P_0^2\cdot E_0^2}\times\int dz\cdot dy\cdot\sqrt{z^2-m^2\mu^2}\cdot\sqrt{y^2-m^2\mu^2}\times\left[\frac{1}{\kappa^2+\mu^2}-\frac{1}{\delta^2+\mu^2}\right]\times\left[\frac{10}{9}\cdot\sigma_{3/2}(z)\cdot\sigma_{3/2}(y)+\frac{16}{9}\sigma_{3/2}(z)\cdot\sigma_{1/2}(y)+\frac{1}{9}\sigma_{1/2}(z)\cdot\sigma_{1/2}(y)\right] \quad (1)$$

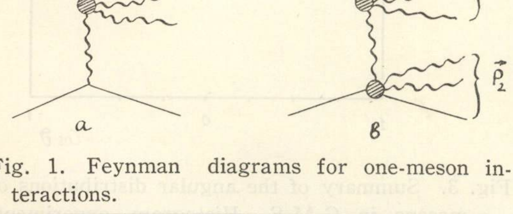

Fig. 1. Feynman diagrams for one-meson interactions.

where

$$y=\frac{1}{2}(\mathfrak{M}_1{}^2-m^2-\mu^2)=m\omega_L{}^{(1)}\ ;$$

$$z=\frac{1}{2}(\mathfrak{M}_2{}^2-m^2-\mu^2)=m\omega_L{}^{(2)}$$

$$\kappa^2=(P_0-P_1)^2-(E_0-E_1)^2\ ;$$

E_0, P_0, m — energy, 3-momentum and mass of primary particle in C.M.S. $E_1, P_1(E_2, P_2)$—total energy and 3-momentum of jet 1. (and 2); $\mathfrak{M}_1=\sqrt{E_1^2-P_1^2}$, $\mathfrak{M}_2=\sqrt{E_2^2-P_2^2}$—"mass" of these jets. $\sigma_{3/2}(y)$ and $\sigma_{1/2}(y)$—cross-section of π-N interaction for Lab-energy ω_L and isospins 3/2 and 1/2, respectively.

Here the designations of ref.[9)] are used. In ref.[5)] it was shown that for the description of nucleon-nucleon interactions at 200 GeV the data on π-N interactions at accelerators' energies were necessary. These data, both experimental[6),7)] and theoretical, were obtained only recently and in previous paper[5)] they were not used. Therefore some important characteristics of N-N interactions as, for example, angular distribution of secondary π-mesons in C.M.S. were not computed. In present paper we attempt to describe the process in more detail taking into account recent experimental data on π-N interactions at accelerator energies.

In paper[5)] it was shown that at high energies it is impossible to extend integration over the whole region of variables $\mathfrak{M}_1$, $\mathfrak{M}_2$, κ^2 that is allowed by conservation laws, and it becomes necessary to introduce a cut-off for κ^2 by putting $\kappa^2 \leq \delta^2$.

In our case the value of δ was specified by the requirement that the calculated cross-section should be of the order of observed one (according to refs.[1-3)] $\sigma_{NN} \sim 30$ mb).

Total NN-cross-sections were calculated

* This paper was not read due to the absence of authors.

Table I.

	Total N-N cross-section σ_{tot} mb.	Percentage of cases with $n_s<4$ (%)	$\sigma(n_s>4)$ mb.
2	2.8	—	—
3	8.5	39.5	3.4
4	17	48.1	8.2
5	27	53.2	14

according to Eq. (1) for various values of δ. The results are given in Table I.

In further calculations it was admitted that $\delta=5\mu$. The effective region of values of $\omega_L=z/m$, y/m (*i.e.* the region mainly contributing to integral (1)) was: $\omega_L=5\sim 20$ GeV. The experimental data on π-N interactions at $5\sim 7$ GeV and above are of the utmost importance. $\sigma_{\pi N}(z)$ for various z's were taken from π-N experimental data at π-meson L. S. energies $\omega_L\leq 2$ BeV, and at $\omega_L>2$ GeV $\sigma_{\pi N}(z)$ was admitted to be constant: $\sigma_{\pi N}=\text{const.}\approx 30$ mb.

2. Multiplicity distribution of charged particles was calculated by using experimental data on average multiplicities of π-N interactions at given values of $\omega_L^{(1)}=y/m$ and $\omega_L^{(2)}=z/m$ (*i.e.* of $\mathfrak{M}_1$, and $\mathfrak{M}_2$) and integrating them according to Eq. (1). Elastic π-N interactions which, at $\omega_L\geq 2$ BeV, are of the diffraction type, were also taken into consideration: according to ref.[10] it was assumed that the diffraction π-N cross-section is one-third of the total one.

For $\omega_L>7$ GeV experimental data are absent and it was necessary to make a reasonable extrapolation of average multiplicities known for $\omega_L\leq 7$ GeV. Previously (see refs.[7),11)]), the average multiplicity for inelastic interactions at $\omega_L\sim 7$ GeV was estimated according to statistical theory as well as to a model of excited "$\pi\pi$-fire ball". They turned out to agree with each other and with experimental data in the region $\omega_L\leq 7$ GeV. Therefore, for $\omega_L>7$ GeV we used "$\pi\pi$-fire ball" model multiplicities. The result is that 46% of cases are few particle stars ($n_s<4$). These cases were not investigated experimentally. Thus, for the comparison with experiment we confine ourselves only to cases $n_s\geq 4$. Corresponding cross-sections are given in Table I, and n_s-distribution for $n_s\geq 4$, as well as experimental results—on Fig. 2.

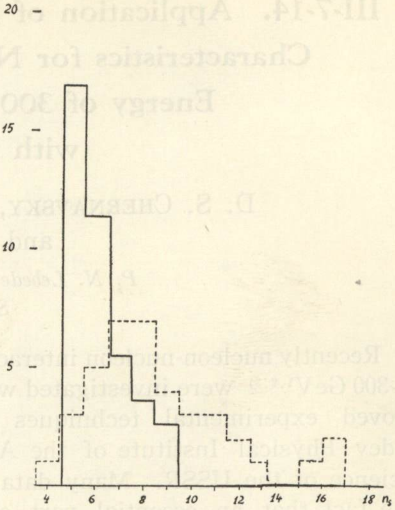

Fig. 2. n_s-distribution ($n_s>4$). Solid line—theory, broken line—experiment.

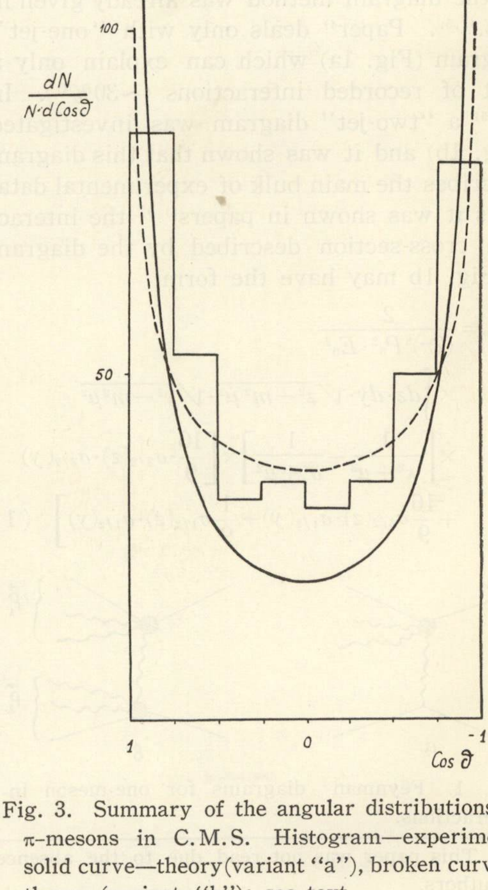

Fig. 3. Summary of the angular distributions of π-mesons in C.M.S. Histogram—experiment, solid curve—theory (variant "a"), broken curve—theory (variant "b"); see text.

They differ from each other essentially for $n_s>4$: This is due probably to the discrimination in the shower selections. On the other hand, this difference may well have a physical meaning. This discrepancy is at present under investigation.

3. Angular distribution of secondary particles in the C.M.S. was also calculated as in ref.[9] for $n_s>4$. Two suppositions concerning angular distribution in π-N collision (used for a vertex in N-N collision) at $\omega_L>7$ GeV were made: a) it is the same as for $\omega_L=7$ GeV, b) angular distribution is described by "$\pi\pi$-fire ball" model. In Fig. 3, resulting angular distributions in N-N collision are given, together with experimental histogram. It can be seen that the version (b) describes experimental data better than (a). This convinces that for real π-N interactions at 7 GeV $<\omega_L<20$ GeV the "$\pi\pi$-fire ball" model should yield a good agreement with experiment with respect to angular distribution. Experimental check of this conclusion would be rather important.

It should be noted that, although the angular distribution proved to be symmetric as a whole, it is asymmetric in some individual cases. In order to estimate the contribution of symmetric cases, the distribution over the values of $\bar{\gamma}$ ($\bar{\gamma}$ is γ factor of $\pi\pi$-system relative to C.M.S.) can be used. The $\bar{\gamma}$-distribution is given in Fig. 4, as well as the experimental histogram. It is clear that it shows the predominance of small $\bar{\gamma}$.

4. Inelasticity coefficient (K_c) distribution is computed in C.M.S. One can easily show that at high energies K in laboratory or in mirror system is close to K_c.

For the calculation of K_c, were used experimental data on angular and energy distribution of recoil nucleons in π-N interactions up to $\omega_L=7$ GeV. Note that at large ω_L, K_c coincides practically with inelasticity coefficient of a nucleon in π-N interaction in the system where primary π-meson is at rest, *i.e.*, with the value of "target mass" M_t (see ref.[4]).

At $\omega_L>7$ GeV we took the same values of K_c as obtained exprimetally at $\omega_L=7$ GeV.

In case of a diffraction interaction in any vertex, K_c was determined by the formula $K_c\approx\mathfrak{M}^2/4\bar{\gamma}_c^2$, which can be easily obtained kinematically.

The calculated distribution of K_c is given in Fig. 5. Three regions different in their character can be distinguished; a) $K_c<0.1$: here contribute mainly the cases in which there is diffraction interaction in one of vertices. b) $0.1<K_c<0.4$: to this region contribute the cases where one isobar ($\mathfrak{M}=1.3$) is produced in one of the vertices, and also that part of cases (at $\omega_L\geq7$ BeV), in which $M_t<0.3$. c) $0.4<K_c<0.8$: where the rest of cases contribute.

Experimentally obtained distribution (the histogram on Fig. 5) reveals more cases for

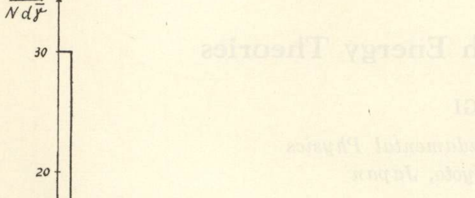

Fig. 4. $\bar{\gamma}$-distribution. Histogram—experiment, Solid curve—theory.

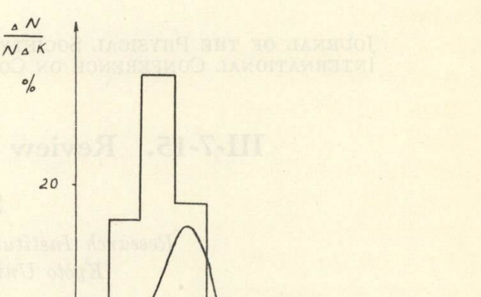

Fig. 5. K_c-distribution. Histogram—experiment, solid curve—theory.

$0.1<K_c<0.3$, than was computed. The difference may be due to diagram of Fig. 1a, which is not taken into account.

Actually, according to ref.[4] the N-N interaction cross-section due to processes of Fig. 1a-type can give about 30% of the total one, and their inelasticity coefficients are within the interval $K_c<0.3$.

5. From the above comparison it is seen that one-meson approximation with both the diagram of the Fig. 1a and that of Fig. 1b can explain main characteristic properties of N-N interaction at $E_L=300$ GeV. The cases with relatively large values of inelasticity coefficient ($0.4<K_c<0.8$) find an explanation, as well as existence of symmetric and asymmetric showers. Thus, it is possible that multimeson processes (so-called head-on collisions) do not contribute very essentially to the N-N interaction at high energies.

It should be stressed that the present consideration cannot be of high accuracy, but it is an estimating character. Partly this is due to the absence of experimental data on π-N interactions for $\omega_L=10\sim20$ GeV.

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III-7-15. Review of High Energy Theories

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The high energy theory is related to the theories in various fields and covers the vast domain of phenomena. It is not possible, therefore, to make an over-all review of high energy theory. Here we shall confine ourselves to the theory of elementary interaction, namely to the multiple particle creation in nucleon-nucleon or in pion-nucleon collision.

The experiments on jets, on which many excellent works have been reported at this conference, seem to indicate that there exist various types of collision. The so-called "double maxima stars" may be considered as one of them. They have been analyzed by the use of, for instance, "fire-ball" model. Although someone may be reluctant to recognize this phenomenon as revealing a special kind of collision, this phenomenon should not be treated as a simple fluctuation.