MULTIPLICITY DISTRIBUTIONS AND CORRELATIONS AT HIGH ENERGIES

WITH DIFFRACTION AND PIONIZATION

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A B S T R A C T

Moments of multiplicity distributions and two-particle correlations at high energies are compared with predictions of the two-component model. Experimental two-particle correlations at $\sqrt{s} = 31$ GeV are in agreement with the predicted dominance of the long range correlations. Multiplicity moments given by the model show a strong energy dependence not seen in the experimental data.

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1. - One of the most basic results from the CERN ISR is the existence of a plateau in the rapidity distribution of pions. This fact is most naturally explained by the short range correlation hypothesis. However, the short range correlation hypothesis does not include the possibility of diffraction which leads asymptotically to constant channel cross-sections ¹⁾. More generally, the existence of a strong peak in the x distribution of protons ²⁾ near $|x| = 1$ is in contradiction with this hypothesis. The simple explanation for the plateau can be, nevertheless, maintained assuming the existence of two distinct reaction mechanisms : a) a pionization component that is of the short range correlation type and, b) a diffractive component giving the fast protons and not contributing to the central region in the rapidity distribution (at least asymptotically).

Simple versions of the two-component idea have been recently discussed by several authors ^{3),4)}. The main support for this approach comes from the following observation : it has been found experimentally that in the pp collisions the energy dependence of the ratio $D/\langle n \rangle$ ($D^2 = \langle n^2 \rangle - \langle n \rangle^2 = f_2 - \langle n \rangle$) obeys a parametrization

$$\frac{D}{\langle n \rangle} = a + \frac{b}{\langle n \rangle}$$

[or, equivalently, $f_2 = a^2 \langle n \rangle^2 + (2ab - 1) \langle n \rangle + b^2$] with $a = -b = 0.585$ ^{*)}, ⁵⁾. This behaviour can be easily understood in the framework of the two-component model. In this case, we can indeed write

$$f_2 = \alpha_D f_2^D + \alpha_\pi f_2^\pi + \frac{\alpha_D}{\alpha_\pi} (\langle n_D \rangle - \langle n \rangle)^2 \quad (1)$$

*) The 100, 200 and 300 GeV/c NAL points are also consistent with this parametrization. The points in the energy range 50-300 GeV/c are also consistent with the constant ratio $D/\langle n \rangle = 0.5$.

Subscripts D and π refer to diffraction and pionization components, α_D and α_π are their relative contributions to the total inelastic cross-section. Assuming that diffraction has an essentially energy independent multiplicity distribution and that f_2^π grows at most like $\ln s$ (as follows from the short range correlation hypothesis) we can identify the coefficients of the leading terms in the formulae for $f_2 = (\alpha_D/\alpha_\pi) = a^2$. In this way, one obtains a reasonable value of about 8 mb for diffraction in pp collisions which is consistent with other estimates. In particular the recent analysis of the energy dependence of the topological cross-sections leads to a similar result ⁴⁾.

In this note, we extend the study of the two-component model in two complementary directions. First, we consider higher moments of multiplicity distributions in the energy interval 50-300 GeV/c. We find a strong energy dependence in the model which is not seen in the data in that energy interval. Then we study the two-particle correlation function $C_2(y_1, y_2)$ at the ISR energy $\sqrt{s} = 31$ GeV. In our model, the strong positive correlations observed in the data are to a large extent due to the existence of a sizeable diffractive component which does not contribute appreciably in the central rapidity region at ISR energies. They are therefore long range in character. Interpreting them as short range correlations only would be difficult since one would have to consider for that purpose a cluster of six charged particles on the average. This is already more than half the mean multiplicity and hardly acceptable in terms of a simple pionization picture.

2. - A possible way of studying multiplicity distributions is to look at the multiplicity moments. A recent analysis by Slattery ⁶⁾ shows that the quantities $(\langle n^q \rangle)/(\langle n \rangle^q)$ for $q \leq 10$ are within errors energy independent in the energy range 50-300 GeV/c. A similar analysis with similar results can be done for the central moments $\mu_q = \langle (n - \langle n \rangle)^q \rangle$. The quantities $C_q = \mu_q / \langle n \rangle^q$ are shown in Fig. 1 as functions of the average charged multiplicity ^{*}).

It is easy to calculate the asymptotic values of the quantities C_q in the two-component model. The calculation gives $C_q = \alpha_\pi (\alpha_D / \alpha_\pi)^q + (-1)^q \alpha_D$ and this prediction disagrees in most cases with the observed almost constant values of the C_q 's in the energy range between 50-300 GeV/c (Fig. 2) ⁷⁾ (in particular the asymptotic predictions for odd moments are negative). This discrepancy leads us to study the energy dependence of the ratios C_q in the two-component model. We choose $\alpha_D = 0.255$ in agreement with the observed behaviour of the ratio $D/\langle n \rangle$ ⁵⁾. The high energy values of topological cross-sections set a lower limit on the average multiplicity of the diffractive component $\langle n \rangle_D \gtrsim 4$ (for $\alpha_D = 0.255$) ⁴⁾. The value of f_2^π necessary to fit the second moment $\mu_2 = f_2 + \langle n \rangle$ is strongly correlated with the chosen value for $\langle n \rangle_D$. We have found a good fit with $\langle n \rangle_D = 4.35$ and $f_2^\pi = \langle n \rangle_\pi - 4$. The value of f_2^π corresponds to a Poisson distribution for negative particles. This distribution for the pionization component together with the quoted values for $\langle n \rangle_D$ has then been used to calculate higher moments. The calculation is not sensitive to further details of the diffractive component as long as $\langle n \rangle_D$ is clearly smaller than $\langle n \rangle_\pi$. This requirement limits our calculations to energies $\gtrsim 50$ GeV/c. The results are shown in Fig. 1. We observe a clear energy dependence in the model calculations in disagreement with the data ^{**)}. It may be possible that this energy dependence can be weakened locally (in particular for higher moments) by introducing a cut-off due to energy conservation

^{*}) The C_q 's provide a more sensitive test for theoretical models than the ratio $(\langle n^q \rangle)/(\langle n \rangle^q)$ due to smaller experimental errors.

^{**)} It is possible to increase simultaneously f_2^π and $\langle n \rangle_D$ or to decrease α_D and $\langle n \rangle_D$ without affecting the quality of the fit to C_2 . This, however, does not improve the agreement for higher moments.

in the tail of the multiplicity distribution. However, in general an energy dependence cannot be avoided as the asymptotic predictions are far from the present values. The asymptotic predictions cannot be changed without invoking long range correlations for the pionization component or introducing energy dependence in the diffractive component which means spoiling the simple properties of either one.

3. - We have also studied the two-particle correlation function.

$$C_2(y_1, y_2) = \frac{1}{\sigma_{in}} \frac{d^2\sigma}{dy_1 dy_2} - \frac{1}{\sigma_{in}^2} \frac{d\sigma}{dy_1} \frac{d\sigma}{dy_2}$$

at ISR energies in the framework of the two-component model. Having two mechanisms we can write

$$C_2(y_1, y_2) = \alpha_D C_2^D(y_1, y_2) + \alpha_\pi C_2^\pi(y_1, y_2) + \frac{\alpha_D}{\alpha_\pi} \left(\frac{1}{\sigma_{in}} \frac{d\sigma}{dy_1} - \frac{1}{\sigma_D} \frac{d\sigma_D}{dy_1} \right) \left(\frac{1}{\sigma_{in}} \frac{d\sigma}{dy_2} - \frac{1}{\sigma_D} \frac{d\sigma_D}{dy_2} \right) \quad (2)$$

The last term of formula (2) gives long range correlations due to the mixture of two mechanisms. At energies such that the diffractive component can be neglected in the central rapidity region this term has the simple form

$$\frac{\alpha_D}{\alpha_\pi} \frac{1}{\sigma_{in}^2} \frac{d\sigma}{dy_1} \frac{d\sigma}{dy_2}$$

for both y_1 and y_2 in the central region.

The other contribution to this region comes from the short range correlations of the pionization component $C_2^\pi(y_1, y_2)$. A straightforward separation⁸⁾ of the two components is possible only at energies where the central region is broader than the correlation length of C_2^π . To study this problem at ISR energies, we have chosen a definite model for the diffractive component. In this model we have only single dissociation with an

isotropic decay of the dissociated system. The mass spectrum of this system is chosen to give the same multiplicity distribution as used for the diffractive component in the calculation of moments. The results of our analysis can be compared with the preliminary ISR data at $\sqrt{s} = 31 \text{ GeV}$ ⁹⁾. The comparison is shown in Fig. 3 for the ratio ^{*)}

$$R(\eta_1, \eta_2) = C_2(\eta_1, \eta_2) / \frac{1}{\sigma_{in}^2} \frac{d\sigma}{d\eta_1} \frac{d\sigma}{d\eta_2}$$

The data are compatible with the existence of the long range correlations given by the model which moreover provide a major part of the measured correlation function. The difference between the theoretical curve in Fig. 3 and the data should then be given by the short range correlations of the term C_2^π . As a simple model for short range correlations we consider an independent emission of clusters of particles. We denote the average density of clusters in rapidity by $\rho(Y)$, the average multiplicity of clusters by $\langle n \rangle$ and the one and two particle distributions from the decay of a cluster at rapidity Y by $D^{(1)}(Y-y)$ and $D^{(2)}(Y-y_1, Y-y_2)$, respectively ($\int D^{(1)}(Y-y) dy = \langle n \rangle$, $\int D^{(2)}(Y-y_1, Y-y_2) dy_1 dy_2 = \langle n(n-1) \rangle$). Then the single particle distribution is given by the formula (in all the following formulae we give only the contribution of pionization to the corresponding quantities) :

$$\frac{1}{\sigma_{in}} \frac{d\sigma}{dy} = \alpha_\pi \int \rho(Y) D^{(1)}(Y-y) dY$$

and the two-particle correlation function has the following form :

$$C_2(y_1, y_2) = \alpha_\pi \int \rho(Y) D^{(2)}(Y-y_1, Y-y_2) dY.$$

In the plateau region $[\rho(Y) = \text{const}]$ we get :

$$R(y_1, y_2) = \frac{1}{\langle n \rangle \frac{1}{\sigma_{in}} \frac{d\sigma}{dy}} \int D^{(2)}(Y-y_1, Y-y_2) dY \quad (3)$$

$[(1/\sigma_{in})(d\sigma/dy)]$ is the plateau value of the single particle distribution].

*) The experimental data are presented as a function of $\eta = -\log \tan \theta/2$. We have used the same variable in our calculation. The single particle distribution $(1/\sigma_{in})(d\sigma/d\eta)$ used for theoretical curve is taken from the same experiment.

To avoid extra assumptions about the form of $D^{(2)}(Y-y_1, Y-y_2)$ we integrate formula (3) over y_2 and get :

$$\int R(y_1, y_2) dy_2 = \frac{\langle n(n-1) \rangle}{\langle n \rangle} \frac{1}{\frac{1}{\sigma_{in}} \frac{d\sigma}{dy}} \quad (4)$$

Assuming two charged particles per cluster (this leads to the Poisson distribution for negative particles used in the moment calculation) and taking $(1/\sigma_{in})(d\sigma/dy) = 2.3$ ^{*)}, ⁹⁾ we obtain the value 0.43 for the integral (4). The value of $\int R(y_1=0, y_2) dy_2$ obtained from Fig. 3 is about 0.8. With our assumptions about the pionization component we obtain therefore only 50% of the needed short range correlations. It is, however, difficult to say how serious this discrepancy is as it is only 20% of the total experimentally observed correlations. It would be extremely interesting to have more accurate data. At the same time correlations among charged and neutral particles and between two π^- 's would help to probe the present approach much better. In the discussed model, the size of the long range correlations (expressed in terms of the ratio R) for particles with given charges is expected to be close to that found for all charged particles. In particular we expect that the over-all correlation function for two π^- 's will be broader than for all charged particles.

We notice also that in trying to explain all the observed positive correlations by short range correlations due to clustering we get for the ratio $\langle n(n-1) \rangle / \langle n \rangle$ of formula (4), a value of about 5 (to be compared with the mean value of charged particles at present energy of about 10).

Finally, we mention that the long range correlations given by the last term of formula (2) cross zero at the same value of y_2 independently of the value of y_1 which seems to be consistent with the data.

*) This number is taken from the $d\sigma/d\eta$ distribution. The value of $d\sigma/dy$ is about 15% higher. On the other hand, other ISR experiments and the coefficient of the $\log s$ term in the fit to the energy dependence of mean multiplicity indicate that even the value 2.3 may be somewhat too high.

We conclude that the two-component model is able to explain the main observed features of the two-particle correlations $[C_2(y_1, y_2) \text{ and } f_2]$. When the correlations are better known this may look as a first approximation only. In particular, the analysis of higher multiplicity moments seems to suggest the necessity of further corrections to the simple model.

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REFERENCES

- 1) K.G. Wilson - Cornell University Preprint CLNS-131 (1970).
- 2) M.G. Albrow et al. - Contribution to the XVI International Conference on High Energy Physics, Batavia (1972).
- 3) K. Fiałkowski - Phys.Letters 41B, 379 (1972) ;
L. Van Hove - CERN Preprint TH. 1581 (1972).
- 4) C. Quigg and J.D. Jackson - NAL Preprint NAL-THY-93 (1972) ;
H. Harari and E. Rabinovici - Weizmann Institute Preprint (1972) ;
K. Fiałkowski and H.I. Miettinen - Rutherford Preprint RPP/T/37 (1972).
- 5) A. Wroblewski - Warsaw University Preprint IFD 72/2 (1972).
- 6) P. Slattery - University of Rochester Preprint UR-409 (1972).
- 7) E.L. Berger et al. - Argonne Report (1972) ;
Soviet-French Collaboration - Contribution to the XVI International Conference on High Energy Physics, Batavia (1972) ;
J. Chapman et al. - Phys.Rev.Letters 29, 1686 (1972) ;
G. Charlton et al. - Phys.Rev.Letters 29, 515 (1972), and Contribution to the XVI International Conference on High Energy Physics, Batavia (1972) ;
F.T. Dao et al. - Phys.Rev.Letters 29, 1627 (1972).
- 8) W.R. Frazer et al. - University of California (San Diego) Preprint UCSD-10P10-113 (1972).
- 9) Pisa-Stony Brook-ISR Collaboration - Contribution to the XVI International Conference on High Energy Physics, Batavia (1972).
Data are shown in :
M. Jacob - Plenary Session Report to the same Conference, CERN Preprint TH. 1570 (1972).

FIGURE CAPTIONS

Figure 1 The ratios $C_q = \mu_q / \langle n \rangle^q$ for charged particles as functions of $\langle n \rangle$ for $q = 2 \dots 7$. The multiplicity distributions are taken from Ref. 7). The curves give the predictions of the two-component model with 25.5 % diffraction. The mean multiplicity of diffraction is 4.35 and the charged multiplicity distribution of pionization corresponds to a Poisson distribution for negative particles.

Figure 2 Mean values of the ratios $C_q = \mu_q / \langle n \rangle^q$ from experiments in the energy range 50-300 GeV/c⁷⁾. The asymptotic predictions of the two-component model are given by the solid line for even values of q and by the dotted line for odd values of q . The predictions correspond to 25.5 % diffraction.

Figure 3 The two-particle correlation function $C_2(\eta_1, \eta_2)$ for all charged particles at $\sqrt{s} = 31$ GeV. The experimental data⁹⁾ are shown by open circles. The solid line gives the predicted contribution of long range correlations [the last term of formula (2)] calculated from the experimental single particle spectrum⁹⁾ and a model for the diffractive component described in the text. The difference (dots) between the data points and the solid line should be given by short range correlations of the pionization component.

FIG.1

FIG. 2

FIG. 3