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ϱ-MESON PRODUCTION AND CHARGED-NEUTRAL CORRELATION IN HIGH ENERGY PROTON-PROTON INTERACTIONS

By L. J. Reinders

University College London*

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A simple model for multi-particle production is presented with exact conservation of isospin, assuming that the pions in the final state come from the decay of isospin-one clusters, which consist either of single pions or ρ-mesons. The model is shown to reproduce the experimental charged-neutral correlation.

Many authors [1–5] have studied the effect of isospin conservation in multi-particle production. In particular it has been shown [2, 3] that the broadening of the charged particle distribution i. e. the Wróblewski relation for the dispersion of the charged particles $D_c \simeq 0.576 \langle n_c \rangle$ is an automatic consequence of isospin conservation. In reference [4], moreover, it has been proven that independent pion emission as a mechanism for multi-particle production fails to reproduce both the Wróblewski relation and the charged-neutral correlation which has been observed to become positive at high energies. Cluster production has been shown to be able to reproduce a positive correlation [6]; the agreement with the data however is still very poor.

In this letter we will present a simple model for high energy proton-proton collisions with exact conservation of isospin for the production of isospin-one "clusters" which can be either single pions or ϱ-mesons, and gives good agreement with the data for the charged-neutral correlation. Taking the decay modes for the ϱ-mesons as usual

$$\varrho^+ \to \pi^+\pi^0, \quad \varrho^- \to \pi^-\pi^0, \quad \varrho^0 \to \pi^+\pi^- \tag{1}$$

the generating functions for the pions inside the cluster can be written:

$$g_c(x, x_0) = (1-\alpha)x + \alpha x x_0 \tag{2}$$

for a charged cluster and

$$g_0(x, x_0) = (1-\alpha)x_0 + \alpha x^2 \tag{3}$$

* Address: Department of Physics and Astronomy, University College London, Gower Street, London WCIE 6BT, England.

for a neutral one, where α is the probability for a cluster to be a ϱ-meson. If $P(N, N_0)$ is the probability for the production of N clusters, among which N_0 are neutral, the generating function for the cluster reads:

$$G(x, x_0) = \sum_{N,N_0} x^{N-N_0}((1-\alpha)+\alpha x_0)^{N-N_0}((1-\alpha)x_0+\alpha x^2)^{N_0}P_c(N, N_0). \tag{4}$$

For the distribution $P_c(N, N_0)$ we take the pion distribution of Ref. [3, 4], generalized for arbitrary $I = 1$ objects [6], which assures exact conservation of isospin. We will restrict the discussion to final states where the total isospin of the pions is zero, in which case

$$P_c(N, N_0) = \frac{(N+1)!}{N_0!}\left[\frac{(N_0-1)!!}{(N+1)!!}\right]^2 P_c(N) \qquad N, N_0 \text{ even}, \tag{5}$$

with $P_c(N)$ the distribution for the total number of clusters.

From equation (4) we can calculate the charged-charged and neutral-charged correlation functions

$$f_{c0} = \alpha\langle N_c\rangle+\alpha F_{2c}+2\alpha(1-\alpha)F_{20}+2\alpha^2F_{c0}+(1-\alpha)F_{c0}, \tag{6}$$

$$f_{2c} = 2\alpha\langle N_0\rangle+F_{2c}+4\alpha F_{c0}+4\alpha^2F_{20}, \tag{7}$$

where F_{c0}, F_{20} and F_{2c} are the neutral-charged, neutral-neutral and charged-charged correlation functions for the clusters; $\langle N_c\rangle$ and $\langle N_0\rangle$ are the average numbers of charged and neutral clusters. Explicit formulae for these quantities can be obtained from reference [4]. The average number of pions is related to the average number of clusters by

$$\langle n\rangle = (1+\alpha)\langle N\rangle, \tag{8}$$

and similarly

$$\langle n_0\rangle = \alpha\langle N_c\rangle+(1-\alpha)\langle N_0\rangle. \tag{9}$$

At high energies terms of order $\langle N\rangle$ can be neglected, and we get for (6) and (7)

$$f_{c0} \simeq \tfrac{2}{15}(-\alpha^2+6\alpha+1)\langle N^2\rangle-\tfrac{2}{9}(\alpha+1)^2\langle N\rangle^2, \tag{10}$$

$$f_{2c} \simeq \tfrac{4}{15}(3\alpha^2+2\alpha+2)\langle N^2\rangle-\tfrac{4}{9}(\alpha+1)^2\langle N\rangle^2. \tag{11}$$

Using the Wróblewski relation in (11) we can express $\langle N^2\rangle$ in terms of $\langle N\rangle^2$. The resulting expression implies that the production of clusters cannot be uncorrelated, as we get that $F_2 = \langle N(N-1)\rangle-\langle N\rangle^2$ is proportional to $\langle N\rangle^2$ instead of $\langle N\rangle$ what would be the case for a Poisson distribution. Substituting the result for $\langle N^2\rangle$ in (10), we find that f_{c0} becomes positive for $\alpha \geqslant 0.11$, reaching its maximum value for $\alpha = 1$.

A more detailed comparison with experiment is possible if we consider the average number of neutral pions as a function of charged particles, which can be calculated from the generating function (4) as

$$P(n_c)\langle n_0(n_c)\rangle = \frac{1}{n_c!}\frac{\partial^{n_c}}{\partial x^{n_c}}\frac{\partial}{\partial x_0}G(x, x_0)|_{x=0,\, x_0=1}, \tag{12}$$

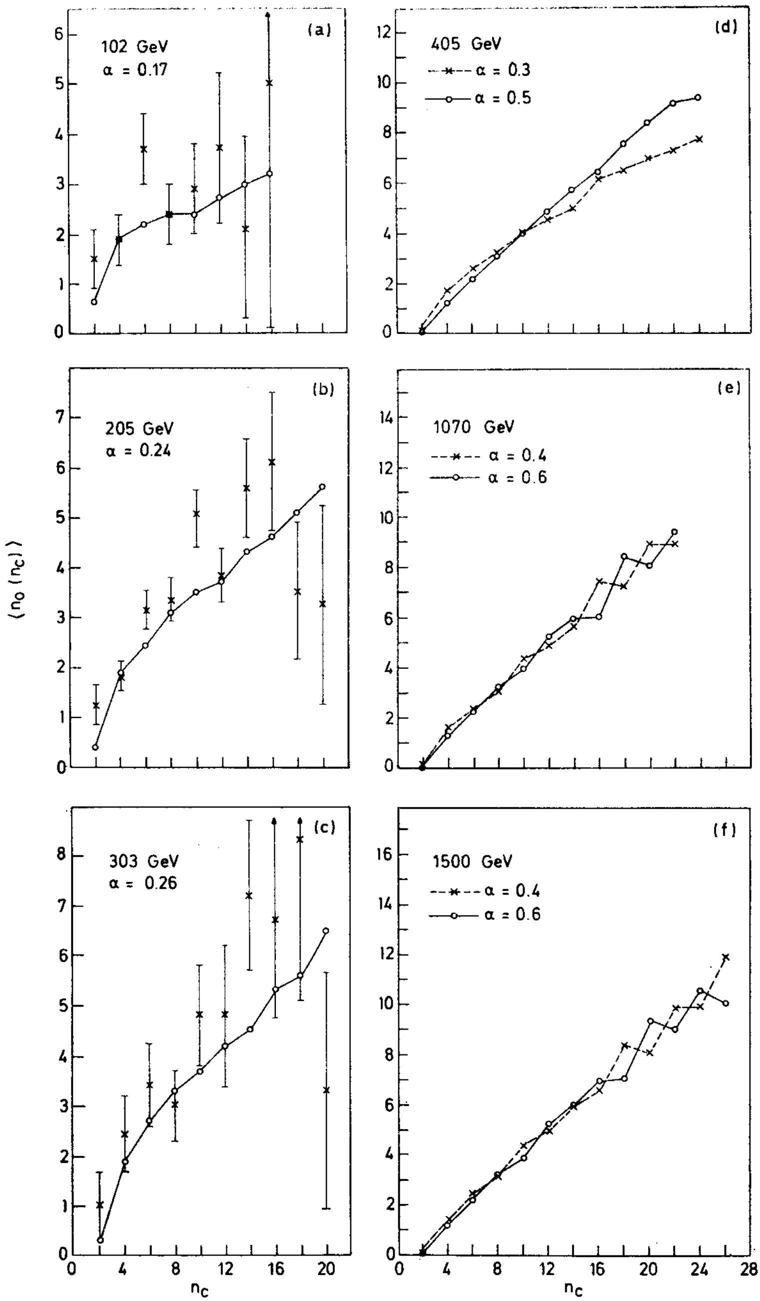

Fig. 1.a-c — predictions for $\langle n_0(n_c)\rangle$ compared with data at 102, 205 and 303 GeV. d-f — Predictions for $\langle n_0(n_c)\rangle$ at 405, 1070 and 1500 GeV

where $P(n_c)$ is the multiplicity distribution for the charged pions. We find in terms of the cluster distribution $P(N, N_0)$

$$\langle n_0(n_c)\rangle = \alpha n_c + \frac{1}{P(n_c)} \sum_{m=0}^{\frac{1}{2}n_c} \sum_{N_0=m}^{\infty} \binom{N_0}{m} \alpha^m (1-\alpha)^{N_0-m} [(1-\alpha)N_0 - 2m\alpha] \times P_c(n_c - 2m + N_0, N_0), \tag{13}$$

and for $P(n_c)$

$$P(n_c) = \sum_{m=0}^{\frac{1}{2}n_c} \sum_{N_0=m}^{\infty} \binom{N_0}{m} (1-\alpha)^{N_0-m} \alpha^m P_c(n_c - 2m + N_0, N_0). \tag{14}$$

Experimentally $P(n_c)$ is unequal zero up to $n_c^{\max}$, where $n_c^{\max}$ depends on the energy. Inserting equation (5) in (14) we find immediately that $P_c(N) = 0$ for $N > n_c^{\max}$ and we are left with $\frac{1}{2}n_c^{\max}$ equations with $\frac{1}{2}n_c^{\max}$ unknowns (n_c and N are both even), which can be solved for $P_c(N)$. Inserting the resulting $P_c(N)$ in (13), $\langle n_0(n_c)\rangle$ can be calculated as a function of α, and compared with the data. We have followed this procedure for 102, 205 and 303 GeV for the energy of the incoming proton, for which energies the topological cross-sections as well as $\langle n_0(n_c)\rangle$ have been measured [7–12].

Figures 1a-c show the calculated $\langle n_0(n_c)\rangle$ which is in good agreement with the data and a clear improvement on the results of reference [6]. The parameter α rises slowly with energy from 0.17 at 102 GeV till 0.26 at 303 GeV. At 405 GeV [7] and at ISR energies [13] data exist on topological cross-sections, but not yet for $\langle n_0(n_c)\rangle$. We have used our method to predict $\langle n_0(n_c)\rangle$. At each energy there exists a satisfactory solution of (14) for a broad range of α values, although this gets increasingly difficult at the highest energies, where the production of pions via higher resonances may become important. Figures 1d-f show the corresponding predictions for $\langle n_0(n_c)\rangle$ for the energies 405, 1070 and 1500 GeV.

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