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e^+e^- Annihilation into Hadrons.

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In view of the increasing interest in colliding-beam experiments to be soon completed at Frascati, we present some predictions on e^+e^- annihilation into hadrons, based on a statistical model for the inelastic ep scattering together with the parton picture of the e.m. interactions of hadrons.

The inelastic ep scattering is usually described (1) in terms of the double differential cross-section $d^2\sigma/dq^2 d\nu$, where q^2 and ν are the photon mass squared and energy in the laboratory system. The quantity $d\sigma/dq^2$, obtained by integrating over ν, is more directly connected to the statistical model (2) previously proposed in connection to the large-angle pp and ep elastic scattering. In fact, in ref. (2) the following expression was derived for the elastic ep scattering at large momentum transfers:

$$\left.\frac{d\sigma}{dq^2}\right|_{\text{elastic}} = \left.\frac{d\sigma}{dq^2}\right|_{M} P_{NB}(q^2)\,, \tag{1}$$

where $d\sigma/dq^2|_M$ is the Mott cross-section and $P_{NB}(q^2) \sim \exp[-\sqrt{-q^2}/T]$ has the meaning of the probability that the proton does not break up when the momentum transferred to it takes the value $-q^2$. It follows immediately that the inelastic ep differential cross-section is given by

$$\left.\frac{d\sigma}{dq^2}\right|_{\text{inelastic}} = \left.\frac{d\sigma}{dq^2}\right|_{M} (1 - P_{NB}(q^2))_{q^2\to-\infty} \simeq \left.\frac{d\sigma}{dq^2}\right|_{M}. \tag{2}$$

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(1) S. D. Drell and J. D. Walecka: *Ann. of Phys.*, **28**, 18 (1964).
(2) M. Greco: *Phys. Lett.*, **27** B, 234, 578 (1968).

This result seems to be consistent with the experimental data (3). By comparing eq. (2) with the same quantity as derived in the parton model (4)

$$\frac{d\sigma}{dq^2}\bigg|_{\text{inelastic}} = \frac{d\sigma}{dq^2}\bigg|_{M} \sum_N P_N \left(\sum_i^N Q_i^2\right), \tag{3}$$

where P_N is the probability of finding a configuration of N partons in the proton and $\sum_i^N Q_i^2$ is the sum of the squares of the charges of the partons in units of e, we obtain

$$\sum_N P_N\left(\sum_i^N Q_i^2\right) = 1\,. \tag{4}$$

This constraint is certainly satisfied in the cases of one spin 0 or $\frac{1}{2}$ parton of unit charge and three quarks of usual charges. The three-quark model in a background of quark-antiquark pairs does not satisfy eq. (4) if the mean square charge of the cloud is taken to be statistical. More exotic cases could be possible, but we are interested to find out what implications can be deduced in the e^+e^- annihilation channel from relation (4). In this case the parton model suggests the following form for the asymptotic cross-section (4,5):

$$\sigma(q^2 = 4E^2) = \frac{4\pi\alpha^2}{3q^2}\left(\sum_N P_N^{\frac{1}{2}}\left(\sum_i^N Q_i^2\right) + \frac{1}{4}\sum_N P_N^0\left(\sum_i^N Q_i^2\right)\right), \tag{5}$$

where $P_N^{\frac{1}{2}}$ and P_N^0 are respectively the distribution of the spin-$\frac{1}{2}$ and spin-0 partons. By taking into account eq. (4) we have the following cases:

$$\sigma(q^2 = 4E^2) = \frac{4\pi\alpha^2}{3q^2} \qquad \text{spin-}\tfrac{1}{2}\text{ parton}, \tag{6a}$$

$$\sigma(q^2 = 4E^2) = \frac{\pi\alpha^2}{3q^2} \qquad \text{spin-0 parton}, \tag{6b}$$

$$\sigma(q^2 = 4E^2) = \frac{8}{9}\frac{\pi\alpha^2}{q^2} \qquad \text{three-quark model}. \tag{6c}$$

The last equation, which gives $\sum_N P_N\left(\sum_i^N Q_i^2\right) = \frac{2}{3}$ is due to the fact that we have to sum over all possible three-quark intermediate states while in (4) the sum is extended

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(3) F. J. GILMAN: invited talk presented at the *1969 Intern. Symp. on Electron and Photon Interactions at High Energies* (Liverpool, 1969).

(4) J. D. BJORKEN and E. A. PASCHOS: *Phys. Rev.*, **185**, 1975 (1969); S. D. DRELL, D. J. LEVY and TUNG-MOW YAN: *Phys. Rev. Lett.*, **22**, 744 (1969); *Phys. Rev.*, **187**, 2159 (1969); see also the references quoted in (3).

(5) N. CABIBBO, G. PARISI and M. TESTA: Istituto di Fisica, Roma, Internal Report n. 266 (1970), to be published.

only on the proton configuration. The upper limit for the total hadronic cross-section follows therefore to be

$$\bar{\sigma}(q^2) = \frac{4}{3}\frac{\pi\alpha^2}{q^2}\,, \tag{7}$$

which is the well-known pointlike fermion pair production value.

We can now proceed further by assuming a statistical principle of maximality in the timelike region. Namely the e^+e^- annihilation into hadrons goes via a creation of a parton-antiparton pair, which then strongly interacts in order to produce the final state. In the strong-interaction region we require that the entropy, defined as (3)

$$S = k \log W \tag{8}$$

in terms of the probability W of the occurence of the state, will attain its maximal value. So we are led to formulate the hypothesis that a spin-$\frac{1}{2}$ particle (or three quarks with the proton quantum numbers as in the spacelike region) only contributes to the annihilation cross-section. We suggest therefore the equation (7) for the asymptotic e^+e^- hadron total cross-section. This corresponds to assume that eq. (4) holds also in the timelike region, which is equivalent to require that the same intermediate states occur in both the scattering and annihilation regions. A consequence of eq. (7) would be a kind of symmetry principle between e.m. and strong interactions in the sense that at sufficiently high energies lepton pairs and hadrons are produced with exactly the same rate.

In the above picture a possible candidate for such spin-$\frac{1}{2}$ parton would be the proton. In this case we will not expect the appearance of « jets » in hadron production unless perhaps at very high energies; more probably the $p\bar{p}$ pair produced will annihilate very rapidly into the final state. We will not predict therefore any particular asymmetry in the angular distribution of produced particles, or any peculiar selection rule.

Finally, in order to extend this scheme to the analysis of the different channels in the e^+e^- annihilation, it is necessary to use a definite model for the final-state $p\bar{p}$ interaction, for example a statistical one (6). This last point will be discussed elsewhere.

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(6) See for instance: J. D. BJORKEN and S. J. BRODSKY: SLAC-PUB-662.