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SENILE SCALING IN ELECTRON-POSITRON
ANNIHILATION

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A B S T R A C T

An important difference is pointed out between the approach to scaling behaviour in deep inelastic scattering and annihilation. In the framework of the massive quark model a quantitative analysis of the breaking terms is carried out for the total and the one-particle inclusive cross-sections. Good agreement with available data is found.

The recent CEA ¹⁾ and preliminary SPEAR ²⁾ data have confirmed the abundant multihadron production observed at lower Frascati energies ³⁾, showing an increase of the ratio R of annihilation into hadrons to $\mu^+\mu^-$ annihilation up to $\sqrt{q^2} \sim 5 \text{ GeV}$ ⁴⁾. It has been already emphasized ²⁾ that the CEA-SPEAR data constitute serious difficulties to naïve parton or canonical light-cone approaches. On the other hand, the present data can be well interpreted on the basis of a more realistic description, as we shall show in this note ⁵⁾.

Let us first make a trivial but relevant observation about the location of asymptopia in deep inelastic annihilation. In deep inelastic scattering, where

$$\omega = \frac{2\nu}{Q^2} \geq 1, \quad Q^2 = -q^2 \quad (1)$$

large Q^2 clearly implies large ν . However, in deep inelastic annihilation, defining

$$x = \frac{2\nu}{q^2} \leq 1 \quad (2)$$

ν can be quite small for x around $x_{\min} = (2m_\pi/\sqrt{q^2})$, even for large q^2 . Therefore asymptotism in ν (even precocious, i.e., $2\nu \gtrsim 2 + 3 \text{ GeV}^2$) does not yet imply asymptotism in q^2 over the whole x range.

We are now going to make use of this observation in the framework of the massive quark model ^{6),7)}, where it can be turned into a quantitative statement.

We write for the one-pion inclusive cross-section (via one photon)

$$E \frac{d^3\sigma}{d^3p} = \frac{\alpha^2}{(q^2)^2} [2\bar{W}_1(q^2, \nu) + \bar{W}_2(q^2, \nu) \left(\frac{\nu^2}{m_\pi^2 q^2} - 1 \right) \sin^2\theta] \quad (3)$$

Already this equation shows that a practically isotropic distribution is to be expected when x is small even at fairly large q^2 , in spite of the spin $\frac{1}{2}$ nature of the hadronic constituents. The $(1+\cos^2\theta)$ distribution holds only for x large ⁷⁾.

When integrated over angle, Eq. (3) gives

$$\frac{d\sigma}{dx} = \frac{2\pi\alpha^2}{q^2} \bar{W}(x, q^2) \left(x^2 - \frac{4m_\pi^2}{q^2} \right)^{\frac{1}{2}} \quad (4)$$

where $\bar{W}(x, q^2)$ for fixed x and $q^2 \rightarrow \infty$ tends to $\frac{4}{3} \bar{F}_1(x)$. We also recall ⁸⁾ that for $x \rightarrow 0$ one has $\bar{F}_1(x) \propto x^{-2}$, whereas for $x \rightarrow 1$ $\bar{F}_1(x) \propto (1-x)^2$. The behaviour x^{-2} for small x gives the asymptotic plateau in the rapidity variable. Non-asymptotic contributions can be related, because of the short-range order picture implicit in the massive quark model, to the corresponding non-asymptotic terms in the reaction

$$p + p \rightarrow \pi^- + \text{any thing} \quad (5)$$

Indeed leading particle effects are absent in the reaction (5) so that it can be directly compared to the annihilation of the virtual quark-antiquark pair. We thus parametrize ⁸⁾ $\bar{W}(x, q^2)$ in Eq. (4) for small x as

$$\bar{W}(x, q^2) \sim \frac{1}{x^2} \left(1 - \frac{\lambda}{q^2 x} \right) \quad (6)$$

The actual value of λ can be inferred from the experimental data ⁹⁾, and we find $\lambda \simeq 1.4 \text{ GeV}^2$. In Fig. 1 we plot versus x the ratio between $q^2(d\sigma/dx)$ for the two values of $\sqrt{q^2} = 4.8 \text{ GeV}$ and of $\sqrt{q^2} = 3.8 \text{ GeV}$ as obtained from Eq. (6) and compare it with the preliminary data ²⁾.

In order to determine the behaviour of the total cross-section, we can isolate two mechanisms: the "diffractive" mechanism and the meson Regge exchange. The latter contributes to R a term

$$\sim \frac{3 \text{ GeV}}{\sqrt{q^2}} \quad (7)$$

as previously estimated ⁷⁾. It will dominate in the low energy region (i.e., $\sqrt{q^2} \lesssim 2 + 3 \text{ GeV}$). The "diffractive" mechanism contributes to R a term

$$R_\infty \left(1 - \frac{\mu}{q^2} \log q^2 \right) \quad (8)$$

where the first non-leading contribution has been included ¹⁰⁾.

To estimate μ we assume that, as indicated by experiment, a large fraction of the total energy is carried away by pions. We can thus approximate the energy conservation sum rule as

$$\sigma \simeq \frac{1}{2} \sum_i \int_{\frac{2m_\pi}{\sqrt{q^2}}}^1 \frac{d\sigma}{dx} \pi_i x dx \quad (9)$$

Inserting Eq. (4) and using Eq. (6) for small x together with the threshold behaviour $\sim(1-x)^2$ for $x \sim 1$, one finally gets (q^2 in units GeV^2)

$$R \simeq R_{\infty} \left(1 - \frac{2.8}{q^2} \log \frac{q^2}{4m_{\pi}^2} \right) + \frac{3}{(q^2)^{1/2}} \quad (10)$$

In Fig. 2 we separately show the two contributions to R in Eq. (10) with the tentative choice $R_{\infty}=6$, which fits the data ¹¹⁾. Notice that below $\sqrt{q^2}=3.5$ GeV the "diffractive" contribution has been smoothly extrapolated to zero. As we have previously emphasized ⁷⁾, the problem of such a large R_{∞} is left open in the model, where R_{∞} is not a priori connected to the charges of the constituents.

We finally note that the assignment of all missing energy ²⁾ to neutral pions would conflict with our description. A possibility would be that when the energy increases the energy fraction carried away by kaons and etas increases (up to say $\sim \frac{1}{2}$ of the energy going to pions). This is suggested by the form of the structure functions (the energy distribution being more sensitive to the structure functions at larger x values). Also the energetic particles are supposed to obey the $(1+\cos^2\theta)$ law rather than being isotropic.

In conclusion, we want to mention that a still growing R ratio showing no sign of levelling off for $\sqrt{q^2} > 6$ GeV, and/or a steeper behaviour than x^{-1} for $q^2(d\sigma/dx)$ at small x , would both be in conflict with the interpretation advanced here.

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R E F E R E N C E S

- 1) H. Newman et al., Phys.Rev.Letters 32, 483 (1974).
- 2) B. Richter, talk given at the Chicago APS Meeting (February, 1974).
- 3) See, e.g., A. Zichichi, invited review paper, "Outlook on Particle Production using Leptons only", IVth International Symposium on Multiparticle Hadrodynamics, Pavia, August 1973, to be published in "La Rivista del Nuovo Cimento".
- 4) In the next future SPEAR and DORIS will push this limit to $\sqrt{q^2} \sim 9 \text{ GeV}$.
- 5) For an alternative interesting proposal, see :
D. Amati and S. Fubini, CERN preprint TH.1823 (1974).
- 6) G. Preparata, Phys.Rev. D7, 2973 (1973).
- 7) R. Gatto and G. Preparata, Nuclear Phys. B67, 362 (1973).
- 8) A. Bassetto and M. Toller, Nuovo Cimento Letters 2, 409 (1971);
L. Caneschi, Nuclear Phys. B68, 77 (1974).
- 9) See, for example, the review talk by :
J.C. VanderVelde, in High Energy Collisions (1973) - Stony Brook;
C. Quigg Ed., American Institute of Physics (1974).
- 10) For the rôle of such a term in inclusive reactions, see Ref. 8), Note that the crossing argument which eliminates the contribution of this term to the total hadron-hadron cross-section does not apply here.
- 11) We thank Professor Zichichi for kindly making available to us the BCF data before publication.

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FIGURE CAPTIONS

- Figure 1 : The ratio of $q^2(d\sigma/dx)(q^2, x)$ for the two values of $q_1^2 = 14.44 \text{ GeV}^2$ and $q_2^2 = 23.04 \text{ GeV}^2$ computed from the curves of Ref. 2), compared with the theoretical prediction (continuous line).
- Figure 2 : A collection of presently available data compared with Eq. (10). The -.-.- line represents an extrapolation of the "diffractive" contribution to zero q^2 done by hand.

Fig. 1

Fig. 2