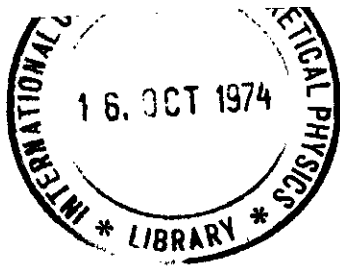


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# $e^+e^-$ ANNIHILATION INTO HADRONS

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A number of questions raised by the recent experimental results are examined:

1) The problem of the self-damping of  $\sigma_h = \sigma(e^+e^- \rightarrow \text{hadrons})$  through the strong vacuum polarization produced by itself<sup>1)</sup>. Dominance of the one-photon channel (i.e. one photon including vacuum polarization corrections) is assumed and accepted as valid at least until the corrections from vacuum polarization become as big as  $\sim 30\%$  or so. The imaginary part of vacuum polarization

$$\text{Im } \Pi(s) = \frac{\alpha}{3} R(s) = \frac{\alpha}{3} \frac{\sigma_h(s)}{\sigma_{\mu\mu}(s)}, \quad (1)$$

where  $\sigma_h$  is  $\sigma(e^+e^- \rightarrow \text{hadrons})$  and  $\sigma_{\mu\mu}$  is  $\sigma(e^+e^- \rightarrow \mu^+\mu^-)$  is supposed to behave as  $cs^\beta$  where  $\beta$  is  $< 1$  to ensure convergence of the usual once-subtracted dispersion relation for  $\Pi(s)$  (i.e. we assume that no new renormalization constants are necessary to calculate, for instance, the vacuum polarization corrections to  $g-2$ ). The ratio  $\sigma_h/\sigma_p$  where  $\sigma_p$  is the conventional point-like cross-section,

$$\sigma_p = \frac{4\pi\alpha^2}{3s}$$

shows a maximum whose value depends only on the exponent  $\beta$

$$\left( \frac{\sigma_h}{\sigma_p} \right)_{\text{max}} = - \frac{3}{8\alpha} \text{tg}(\pi\beta). \quad (2)$$

At the maximum

$$\left( \frac{\sigma_n}{\sigma_p} \right)_{\max} = \frac{1}{2} R(S_{\max}).$$

For instance, for  $\beta = 0.95$  the maximum in Eq.(2) is of 8.1 and is expected to occur at  $\sqrt{s} \cong 8 \div 9$  GeV; for  $\beta = 0.9$  it is of 16.7 at  $\sqrt{s} \cong 12 \div 14$  GeV; for  $\beta = 0.8$  it is of 37.3 and at  $\sqrt{s} \cong 22 \div 24$  GeV. The strong vacuum polarization will bring deviations from scaling in deep inelastic scattering (for instance, for  $\beta = 0.9$  one expects + 15% deviations in the ratio

$$\frac{F_2(\omega, Q^2)}{F_2(\omega, Q'^2)}$$

for  $Q'^2 = 5 \text{ GeV}^2$ ,  $Q^2 = 50 \text{ GeV}^2$ . (The deviations expected in asymptotic free theories are known to be  $\omega$ -dependent and of opposite sign<sup>2)</sup>.)

2) The superconvergence relation

$$\int ds \operatorname{Im} [\pi(s) - \pi_R(s)] = 0,$$

where asymptotically  $\operatorname{Im}\pi(s) \rightarrow \operatorname{Im}\pi_R(s)$  is considered and applied for  $\operatorname{Im}\pi_R(s) = \frac{\alpha}{3} cs^\beta$ . From calculation of the low-energy resonance contributions and an assumed constant behaviour of  $R(s)$  in the less known intermediate region after  $(1 \text{ GeV})^2$  and before the  $s^\beta$  rise one finds fits such as  $R(s) = 2(\sqrt{s})^{0.65}$ .

3) A phenomenological classification of sub-asymptotic contributions is given in terms of the singular behaviour for  $\omega \rightarrow 0$  of such terms. Three extreme models leading to linear rise of  $R(s)$ , constant addition to  $R$ ,<sup>3)</sup> and approach from below to constant  $R$ , are discussed and multiplicity bounds derived.

The massive quark model<sup>4)</sup> is examined in the frame of such classification. The sub-asymptotics of the parton model is calculated under plausible assumptions and shown to disagree with data unless the average transverse momentum  $\langle p_T \rangle$  in the parton disintegration is unreasonably high (at least  $\langle p_T \rangle \sim 0.8 \text{ GeV}$ ).

4) An argument is given showing directly through use of a sum rule related to the commutator

$$[[H, Q_i^{em}], j_i^{em}(0)]$$

that a strong long-range interaction among partons is needed to fit the data.

5) A brief review of existing models is given:

Calculations based on the work by Chanowitz, Ellis and Crewther  
(Terazawa, Etim, Greco, etc.)

Pati-Salam model with exotic current

Budini's theory of compound Yang-Mills fields

Renormalization group (Kogut's considerations)

Richter's idea (Greenberg-Yodh, Nanopoulos-Vlassopoulos)

Infinite parton model (Raitio, Hangoh, Cabibbo-Karl)

Statistical and thermodynamical models (Engels, Schilling, Satz)

Virtual baryons (Di Giacomo)

Cragie-Rothe: cascade model

Amati-Fubini: ideas of scaling

Model of Moffat et al.

Renard's and Bramon, Etim, Greco models

The calculation of Ferro-Fontan and Rubinstein

Spin-1 charged partons (Cleymans-Komen, Fritzsche-Minkowski).

#### REFERENCES

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- 2) D. Gross (to be published).
- 3) J. Polkinghorne (to appear in Phys. Letters).
- 4) R. Gatto and G. Preparata (CERN preprint, March 1972).