CERN-TH.4331/85

DECOLORIZATION AND NEUTRALIZATION OF JETS

I.M. Dremin

CERN - Geneva
and

P.N. Lebedev Physics Institute
Academy of Sciences of the U.S.S.R., Moscow

and

A.V. Leonidov

P.N. Lebedev Physics Institute
Academy of Sciences of the U.S.S.R., Moscow

A B S T R A C T

The space-time extension of neutralization of colour and electric charges of quarks in e^+e^- annihilation can be revealed by hard bremsstrahlung photons at large angles.

CERN-TH.4331/85

November 1985

1. - We are used to speak both in terms of quarks and hadrons. However, any transition from a quark to a hadron proceeds as a sudden change of both colour and electric charges. We should observe it in spectra of gluons and photons emitted by quarks.

Let us consider the process $e^+e^- \rightarrow$ a photon + neutral hadrons. If one knows nothing about quarks one would say that to first approximation the only bremsstrahlung photons are those emitted by colliding particles. With unconfined quarks one would admit that their bremsstrahlung should be added to that primary radiation. But what about confined quarks?

The creation of a quark-antiquark pair in e^+e^- annihilation is described classically as an instantaneous acceleration of two colour and electric charges at the e^+e^- collision point¹⁾⁻³⁾. Thus it is naturally accompanied by the photon and gluon bremsstrahlung. The properties of both photons and gluons depend on how the screening of quark charges (electric and colour ones, correspondingly) proceeds.

In the process of the conversion of e^+e^- pair into neutral particles, both charges are screened simultaneously (at least, it looks quite natural for the processes $e^+e^- \rightarrow \pi^0\gamma$ or $e^+e^- \rightarrow \gamma +$ two neutral jets, see Fig. 1). The damping of colour (and electric) charges is achieved by creation of new quark-antiquark pairs from the vacuum (the string breaking). It should be described by a universal distance R from the collision point ($R \rightarrow \infty$ for unconfined quarks).

Therefore their bremsstrahlung (both colour and electromagnetic one) should be allowed only within the finite length R . When the damping length R gets shorter the emission angles of corresponding field quanta increase^{*,2)-4)} because the low-frequency small-angle radiation is damped.

For gluon emission the difference between confined and unconfined quarks could be observed in three-jet events but as has been shown in Ref. 5), the effect is very small at energies higher than 10 GeV where three-jet events are distinguishable from two-jet events. That is why, to avoid the problem of a high-energy three-jet threshold, it was proposed⁶⁾ to look for a photon instead

*) In hadron-hadron collisions they could be large enough for ring-like structure to appear [see Refs. 4) and 6)].

of a gluon, i.e., for the above-mentioned events " $e^+e^- \rightarrow \gamma + \text{neutral hadrons}$ ", where the properties of the photon at sufficiently low e^+e^- energies can be different for confined and unconfined quarks.

The main conclusion we come at in this paper is that the precise measurements of the angular distribution of photons in such processes at rather low energies from 4 to 10 GeV would reveal the effective range of confinement R (or the length of neutralization and decolorization of quarks).

2. - In order to describe production of two electrically neutral jets and an extra photon, let us assume in accordance with Ref. 5) that the charge screening leads to the following effective propagator of a quark in e^+e^- centre-of-mass frame:

$$G(x-y) \sim \frac{\hat{x}-\hat{y}}{(x-y)^4} \cdot \exp[-|\vec{x}-\vec{y}|/R]. \quad (1)$$

The exponent is modelling the damping of charges (i.e., the "switch-on" function in terms of the Bogoliubov-Shirkov book).

Henceforth one gets in the momentum space (omitting the higher-order terms in R^{-1})

$$G(p) \sim \hat{p}/(p^2 + 2ip_0 R^{-1}) \quad (2)$$

(p_0 is the time component of the four-vector p_μ). One could notice the similarity of (2) to a propagator for the decaying particles.

Using the standard methods [see, e.g., Ref. 7)] one obtains the double-differential cross-sections of the process (divided by the total cross-section of a two-jet process without bremsstrahlung σ_0)^{*)}:

$$\frac{1}{\sigma_0} \frac{d^2\sigma}{dx_1 dx_2} = \frac{e_u^4 + e_d^4}{e_u^2 + e_d^2} \cdot \frac{\alpha}{2\pi} \frac{(1-x_1)(1-x_2)(x_1^2 + x_2^2)}{[(1-x_1)^2 + (QR)^{-2}][(1-x_2)^2 + (QR)^{-2}]} \quad (3)$$

*) Only the emission by quarks is taken into account (see below).

$$\frac{1}{6_0} \frac{d^2 \sigma}{du dT} = \frac{e_u^4 + e_d^4}{e_u^2 + e_d^2} \cdot \frac{16\alpha}{\pi} \frac{(1-T)^3}{(1-T)^2 + (QR)^2} \frac{u(1-u)[T^2(1-u)^2 + (1-u(2-T))]^2}{u^2(1-T)^2 + (1-u)^2(QR)^2} \quad (4)$$

where $e_u = 2/3$, $e_d = -1/3$ are the electric charges of u and d quarks, $x_{1,2,3} = 2E_{q,\bar{q},\gamma}/Q$, Q is the total energy in e^+e^- c.m.s., $E_{q,\bar{q},\gamma}$ are the energies of q, $\bar{q}$, γ , $T = \max\{x_1, x_2\}$ is the thrust, $u = (T/2)(1-\cos\theta)$ where θ is the angle between the thrust axis and the direction of the emitted γ . One may also write

$$x_3 = \frac{1-T}{1-u} \quad (5)$$

and the kinematical restrictions are

$$0.5 < u < \frac{1-\delta}{2-T-\delta}, \quad (6)$$

where $\delta = E_{2\min}/2Q$, $E_{2\min}$ is the minimal energy sufficient for the formation of a second jet.

In the limiting case $R \rightarrow \infty$, Eq. (3) restores the familiar form⁷⁾ with infra-red singularities for unconfined quarks.

3. - The difference between the above distributions and those in the limit $R \rightarrow \infty$ reveals itself only at sufficiently low energies for small enough R. In Figs. 2 and 3 we show the ratio of distributions at finite R to those at $R \rightarrow \infty$ for a fixed value of $T = 0.7(0.8)$ and for various R: $R = 1$; $\ln Q$; Q at $Q = 6; 8$ GeV. It strongly differs from unity for $R = 1$ or $\ln Q$. The events possess a very typical kinematic structure: the large emission angles (105° - 150°) and large photon energies (1.2-3.6 GeV).

It could help in eliminating the background from π^0 decays. Besides specific values of angles and energies, one should take into account the coplanarity condition in two- and three-particle processes.

Summarizing, the experimental study of hard photons emitted at large angles to the thrust axis in the process with two electrically neutral hadron jets in e^+e^- annihilation at centre-of-mass energies from 4 to 10 GeV could provide information about the size of the colour and electric quark charge screening region.

One of the authors (I.M.D.) is indebted to Professor M. Jacob for inviting him to CERN where the final part of the work was done.

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- Figure 1 -

- Figure 2 -

- Figure 3 -