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A.V. Efremov, S.V. Ivanov,* V.A. Nesterenko*

COLOUR-SYMMETRY-BREAKING EFFECTS IN HARD PROCESSES

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* The Rostov State University.

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The colour as a quantum number was suggested [1] more than fifteen years ago to resolve the difficulties in quark statistics. Simultaneously, the possibility of the colour symmetry breaking and realization of integer-charge models was considered. The question of colour symmetry breaking remains still open though the great increase of experimental facilities could shed light on this problem.

The investigation (2-6) of gauge unified models with integer-charged quarks shows that the wide-spread opinion that the QCD is the only candidate for the strong interaction theory is too hasty. The delusion is called by the clear contradiction of the naive integer-charge parton model with the large-momentum-transfer experiments and also by the groundless application of perturbation theory to the two-photon decays of π^0- and η-mesons (see refs. [6,7]).

There are two reasons which suppress the manifestation of true charge of quarks and gluons. The first one is connected with the gauge formulation of the theory on the basis of $U(1) \otimes SU(3)_C \otimes SU(2)_L$ group and with spontaneous breaking of the symmetry *. In the colour symmetric case the interaction is caused by exchange of one massless colourless (colour singlet) photon field S_μ and massless colour octet gluon fields G^a_μ . The spontaneous breaking mixes however the singlet and the eight component of the octet (in model [1]). So, the combination

$$A_\mu = S_\mu \cos\chi + G^8_\mu \sin\chi$$

stays massless and plays the role of the photon, and the orthogonal combination

$$B_\mu = -S_\mu \sin\chi + G^8_\mu \cos\chi$$

acquires a nonzero current mass m_B. The mixing angle χ is determined (see, e.g., ref. [3]) by the ratio of the gauge interaction constants of groups $U(1)$ and $SU(3)$ and by the dispersion of quark charges Q_C

$$\mathrm{tg}^2\chi = 2D\, g_1^2/g_3^2 , \quad D = \sum_C Q_C^2 - \frac{1}{3}\left(\sum_C Q_C\right)^2 .$$

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* In what follows we disregard the weak-interaction effects and consider only the unified theory of electrostrong interactions based on the $U(1) \otimes SU(3)_C$ group.

The quark-lepton interaction in this theory is not due to the exchange by photons only but also by massive B-gluon.

Consistency of such a theory with QED effects (the cross section of $e^+e^- \to \mu^+\mu^-$ and the muon anomalous magnetic moment) results in the following constraint on the mixing angle and the B-gluon current mass /3/

$$\mathrm{tg}\,\chi < 10^{-2}, \quad m_B = 0.1 \div 0.4 \ \ \mathrm{GeV}/c^2, \ (\leq \Lambda_{QCD}).$$

Due to the small value of m_B the colour symmetry is restored in lepton-hadron processes (e.g., $e^+e^- \to$ hadrons or $eh \to eX$) when the "mass" of the virtual photon $q^2 \gg m_B^2$. This is because of the cancellation of the octet parts of the photon propagator and of B-gluon. As a result, one can observe in these conditions only the singlet part (averaged over colours) of the quark and gluon charges.

The second reason of colour averaging is the colourlessness of the observed hadron states. (We shall neglect a small, $\approx \alpha$, admixture of the octet state due to the electromagnetic corrections in the theory). Just as in the standard QCD we can only guess why all observed hadrons are colour singlets. Either the colour states have a great mass, which is above the experimental possibility, or they are totally forbidden as true asymptotical states and can exist only as virtual states during the "confinement time" $\sim R_{con}/c$. One should stress that the statement about the colourlessness of physical hadron states just as the statement about colour confinement cannot be proved (or disproved) in a perturbative approach. These have to be accepted cum grano salis and somehow inserted into the perturbative approach.

This hypothesis being accepted leads immediately to the conclusion that any one-photon process feels only averaged over colour charges of quarks and gluons, because the transition from one to another singlet state is possible only through a singlet current operator. That is why the process $pp \to \gamma X$ measured at CERN /8,9/ cannot be considered as a test for the colour symmetry breaking. Such one-photon processes can test at best the presence of scalar (higgs?) charged particles which can exist in Nature without any breaking of the colour symmetry. True charges of quarks and gluons can be felt only by two- (or many-) photon processes.

There is an opinion /10/, however, that the multi-photon processes also feel only the averaged charge up to the threshold of real-colour-states production. So, up to this energy we cannot observe the breaking of colour symmetry. The argumentation is based on the ansatz that in the course of propagation of a quark in a gluon field of hadrons there is a rapid oscillation ($T_{osc} \sim 1/M_{color}$) of its colour due to the production and absorption of soft gluons. So, the two vertices of the quark-photon interaction (e.g., in the process $\gamma\gamma \to 2$ jets) are not correlated in colour and only the colour singlet part of the electromagnetic current will contribute to each vertex. As a matter of fact, this would mean a nonapplicability of the parton picture to the hard many-photon processes up to a momentum transfer $\sim M_{color}$.

One can prove, however, that it is not the case when the colour singlet channel in the two-photon system is considered i.e., when all the other real hadrons which take part in the process are colourless. This can be done by summing all soft gluons just as in the standard QCD using the method of works/11,12/. In this case besides the singlet-singlet currents, the octet-octet-currents combination contributes also and there is a noticeable difference between the standard QCD and "electrostrong" interaction theory (ES) with broken colour symmetry. The main source of this difference is the factor $\frac{1}{3}(\Sigma Q^2_{cf})^2$ in the ES-theory instead of $3Q^4_f$ in the standard QCD for each flavour f in quark diagrams and also an additional contribution of gluon diagrams with the charge factor $\frac{1}{8}(\sum_{c\le c'}(Q_c-Q_{c'})^2)^2$.

Let us discuss now the experimental data on the two-photon rigid processes $\gamma p \to \gamma X$ /13/ , $\gamma\gamma \to 2$ jets /14,15,16/.

The first results on the hard two-photon process were obtained at SLAC, where the photoproduction of high k_T photons in the process $\gamma p \to \gamma X$ was measured/15/. The maximal k_T was 1.7 GeV/c. It appears that the experimental cross section is about one order of magnitude higher than the standard QCD prediction (Fig.1). These data were analyzed also in the framework of the ES-theory/4/ and a much better agreement with experiment was indicated. (The shift of the ES-curve shown in Fig.1 compared with the work/4/ is due to the singlet state projection). However, the momentum $k_T \le 1.7$ GeV/c is not large enough as to make a definite statement about colour symmetry breaking.

A very interesting information was obtained at DESY by three experimental groups PLUTO, TASSO, and JADE/14,15,16/ on the process $e^+e^- \to e^+e^- + 2$ jets with high p_T hadronic jets. Three methods were used:

a) Detection of both final leptons at a squared momentum transfer $q^2 > 0.1$ (GeV/c)^2.

b) Detection of one final lepton with the minimal momentum transfer $q^2_{min} > 0.03$ (GeV/c)^2. The second lepton was not registered, so for it $q^2 \simeq 0$. (The "single tag scheme").

c) Detection of no leptons (The "no-tag scheme").

The PLUTO group analyzed all two-jet events in the total hadron energy region of $W_{vis} = 3\div9$ GeV and the transverse jet

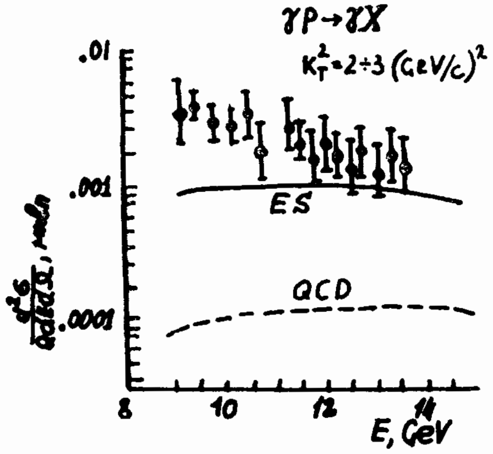

Fig.1

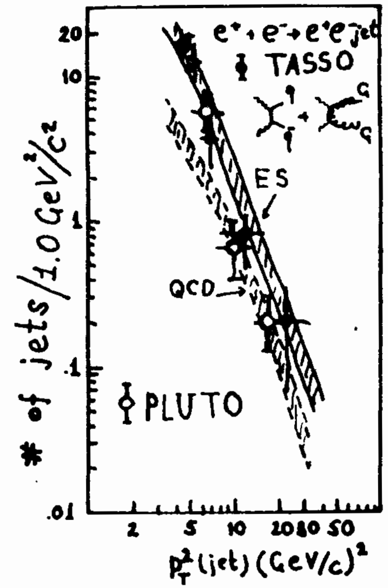

Fig.2

momentum $0.5\div15$ (GeV/c)^2. The TASSO collaboration used the no-tag scheme. The experimental results of these two collaborations are given in Fig.2. The results of calculation in the standard QCD and in the ES-theory/5/ which includes quarks, and gluon diagrams in the ES-theory are also given. (The theoretical errors are due to uncertainty in the fragmentation function of parton into charge hadrons. One can see that the agreement of the ES-theory with experiment is much better again. The deflection of QCD from experiment can be hardly explained by the high twist correction.

It is necessary, however, to have in mind two reservations. First, the difference between both theories is possible only when both lepton momenta transfer $q^2 \ll m^2_B$, which is according to work/3/ of an order of 100÷400 MeV (order of Λ_{QCD}). Due to summation of measurements in the no-tag and single-tag scheme with $q^2 \simeq (0.18$ GeV$)^2$ calculations in the ES-theory (made for real photons) give a bit higher value than the experiment. Second, there is no guarantee that three-jet events with one jet along the collision axis also contributed. The true value of the photon scattering energy is also unknown.

Concerning the JADE-collaboration data one can say that they used "single-tag" scheme with $q^2_{min} \simeq (0.4$ GeV/c$)^2$ and for this reason are less sensitive to charges of quarks.
Another independent test of colour symmetry would be mea-

surements of the process $pp \to \gamma\gamma X$ with two high-k_T photons balancing each other, which was discussed at the CERN workshop[8]. The estimation of the cross section of the process in the ES-theory gives

$$\frac{d\sigma(pp\to\gamma\gamma X)}{d\sigma(pp\to\mu^+\mu^- X)} \simeq \frac{2S}{K_T^2} \ln \frac{K_T^2}{(K_T^2)_{min}} .$$

So, it is available for measurement in the region $k_T > 3$ GeV/c, where the production of direct γ's becomes higher than the background due to high p_T $\pi^0 \to \gamma\gamma$ -decay.

One may conclude that the experimental data provide some indications on colour symmetry breaking, so more refined experimental tests are necessary. In our opinion, the solution of this problem is not less important than the discovery of the W-boson, for instance.

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Ефремов А.В., Иванов С.В., Нестеренко В.А. E2-82-433
Эффекты нарушения цветовой симметрии в жестких процессах

Рассмотрена возможность спонтанного нарушения цветовой симметрии $U(1) \otimes SU(3)_C$ и целого заряда кварков. Показано, что однофотонные жесткие процессы чувствуют лишь усредненные по цвету заряды кварков и глюонов. Истинные заряды могут проявляться только в жестких процессах с двумя /или более/ реальными фотонами. Имеющиеся пока экспериментальные данные $\gamma p \to \gamma X$, $\gamma\gamma \to$ jet + jet лучше согласуются с целыми зарядами.

Работа выполнена в Лаборатории теоретической физики ОИЯИ.

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Efremov A.V., Ivanov S.V., Nesterenko V.A. E2-82-433
Colour-Symmetry-Breaking Effects in Hard Processes

A possibility of colour symmetry $U(1) \otimes SU(3)_C$ spontaneous breaking and integer-charged quarks is considered. It is argued that one-photon processes are sensitive only to the colour-averaged charges of quarks and gluons. The true charges can be observed in rigid processes involving at least two real photons. The available now experimental data on processes $\gamma p \to \gamma X$, $\gamma\gamma \to$ jet + jet are in better agreement with the integer-charges than with the standard QCD.

The investigation has been performed at the Laboratory of Theoretical Physics, JINR.

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