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ON A POSSIBILITY OF MEASUREMENT OF QUARK CHARGES FROM DEEP INELASTIC BREMSSTRAHLUNG

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О возможности измерения зарядов кварков в процессе глубоконеупругого тормозного излучения

Обсуждается возможность определения зарядов кварков, образующих нуклоны, на основе исследования поведения структурной функции для разности глубоконеупругого тормозного излучения, сопровождающего рассеяние положительно и отрицательно заряженных лептонов на протонах и дейтонах. Рассмотрение произведено как для области энергий выше, так и ниже "цветного порога".

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On a Possibility of Measurement of Quark Charges from Deep Inelastic Bremsstrahlung

A possibility is discussed for determination of charges of constituent quarks on the basis of investigation of structure function behaviour for the bremsstrahlung cross section difference for positive and negative charged leptons on protons and deuterons. The consideration is made for energy regions both above and below the color threshold.

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

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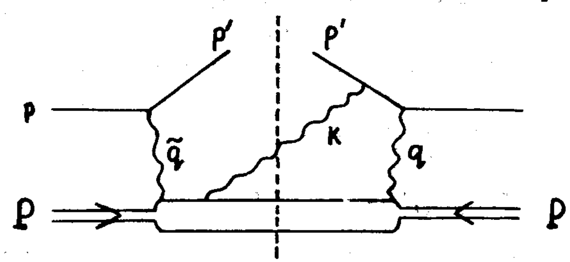
Brodsky, Gunion and Jaffe [1] noticed the possibility for a straightforward determination of charges of quark constituents of hadrons from the measurement of difference between the deep inelastic bremsstrahlung from positive (e^+, μ^+) and negative (e^-, μ^-)- charged leptons on nucleons. This difference is determined by the interference of Bethe-Heitler and Compton processes (Fig.1).



Compton Scattering

Bethe-Heitler scattering

Fig.1. The interference of the Bethe-Heitler and Compton processes

If the following conditions

$$Q^2, \tilde{Q}^2, 2Pq, 2P\tilde{q} \gg M^2, \quad (Q^2 \equiv -q^2, \tilde{Q}^2 \equiv -\tilde{q}^2) \qquad (1)$$

$$Q^2 - \tilde{Q}^2 = 2k\tilde{q} \gg M^2 \qquad (2)$$

are fulfilled, (M is the nucleon mass) then in a parton picture the leading contribution to the interference considered comes from the processes when all three photons scatter on the same parton. The corresponding structure function is proportional to the sum of cubes of charges weighted by probabilities $f_i(x)$ of finding the i-th parton with fraction x of the nucleon momentum in the infinite momentum reference frame /1/:

$$V(x) = \sum_i e_i^3 f_i(x) \ , \quad x \equiv \frac{Q^2}{2Pq} . \qquad (3)$$

An attempt to find the interference was undertaken in paper /2/.

In this note we discuss the possibility of discriminating between the models with fractional and integral charges of partons on the basis of measurement of the interference for protons and deuterons. This possibility is due to the fact that two-photon processes can distinguish these models in the energy region below the color threshold (threshold of production of hypothetical massive color states, the existence of which is assumed in models with "manifest" color), while one-photon processes cannot /3/. In the models with integral charges of quarks the electromagnetic current is a sum of the color singlet and color octet /4/:

$$J^{e.m.} = J^{(1^c)} + J^{(8^c)} \qquad (4)$$

If initial and final states are color singlets (usual hadrons), the contribution to one-photon processes arises only from a singlet part of eq. (4) whereas to two-photon processes the singlet part of product of two octet currents contributes also. We have for the structure function (3):

for the model with fractional-charged partons /1/ x)

$$V(x) = \sum_{\alpha=u,d,s} \left(\frac{1}{3} e_\alpha + \frac{2}{9} b_\alpha\right) f_\alpha(x) \ , e_u = \frac{2}{3} \ , e_d = e_s = -\frac{1}{3} \qquad (5)$$

for the model with integral-charged partons below the color threshold

$$V(x) = \sum_{\alpha=u,d,s} \left(\frac{5}{9} e_\alpha + \frac{2}{9} b_\alpha\right) f_\alpha(x) \qquad (6)$$

above color threshold

$$V(x) = \sum_{\alpha=u,d,s} e_\alpha f_\alpha(x) \qquad (7)$$

After integration over x one obtains the sum rules for the nucleus with Z protons and ($A-Z$) neutrons /1/:

$$\int_0^1 V(x)\,dx = \left.\begin{aligned} &\frac{5}{9} Z + \frac{2}{9}(A-Z) && \text{for (5)} \\ =\ &\frac{7}{9} Z + \frac{2}{9}(A-Z) && \text{for (6)} \\ =\ &Z && \text{for (7)} \end{aligned}\right\} \qquad (8)$$

Note that the leading contribution to the structure functions(3) is given by quarks which compose the initial hadron because the contributions of "sea" quarks and antiquarks cancel each other. Therefore, there are the charges of constituent quarks to be measured.

However, the determination of quark charges on the basis of sum rules is difficult for two reasons. First, in the energy presently available for electron beams (SLAC) the color degrees of freedom seem to be not excited. The difference between the predictions for r.h.s. of eq. (8) according to models with fractional and integral-charged quarks below threshold is not significant. Second, to saturate the sum rules (the left hand side of eq. (8)), it is necessary to make measurements in the domain of small x. However in this domain it is hard to satisfy the conditions (2) /5/.

For two models discussed it is more convenient to measure the difference in the behaviour of structure functions (5)-(7) themselves. So, in the energy region below threshold in both models the r.h.s. of eq. (8) for the neutron are equal while the functions (5),(6) depend on a variable x very differently. Therefore one may attempt to distinguish between the models by comparing the cross section difference for positive and negative lepton scattering on protons and deuterons in the correspon-

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x) The color model with fractional-charged quarks gives the same result because each color contributes with equal weight 1/3.

ding region of variable x . For these purposes one can use the parametrization of structure functions $f_i(x)$ known from experiments on deep inelastic scattering [6].

In Fig.2 the results of calculations for the energy of leptons E_{lab} = 13.5 GeV are presented by using two values for the cutoff parameter $Q^2 - \tilde{Q}^2 = 2k\tilde{q} = 1.5 M^2$ and $3M^2$ (The value of this parameter justifies the validity of the parton picture of deep inelastic bremsstrahlung to be discussed). Both the magnitude of effect of the cross section difference for the positive and negative-charged leptons(Fig.2a)versus the angle $\tilde{\theta}$ between the momenta of real and virtual photons $\vec{k}$ and $\tilde{\vec{q}} = \vec{p} - \vec{p}\,'$, respectively, and the ratio of these effects (Fig.2c) on deuteron and proton are presented. The effect magnitude depends strongly on the cutoff parameter while the ratio depends weakly. The main result is that in the model with integral-charged constituents the abovementioned ratio is less than unity (when $x \gtrsim 0.65$ the effect on a neutron is negative !). One should note that the total effect of the cross section difference for deep-inelastic bremsstrahlung is 0.15% and 0.02% of the basic process of deep inelastic scattering at the values of cutoff parameter of 1.5 M^2 and $3M^2$ respectively (at $y = 0.8$).

In accordance with the results of paper [1] , our calculations show that the maximal effect on a proton has a negative sign whereas in some kinematical region it may be positive. It is possible that for this reason in the experimental work [2] , the larger number of e^+-events was detected in a certain kinematical region.

This effect is rather greater at the energy E_{lab}= 150 GeV for which the corresponding results are presented in Fig.3. If we take the model with integral-charged quarks and suppose that the energy region is rather higher above threshold then, according to (7), we have the ratio of effects on deuteron and proton sufficiently less than unity at $\tilde{x} = \frac{\tilde{Q}^2}{2P\tilde{q}} = 0.7$.

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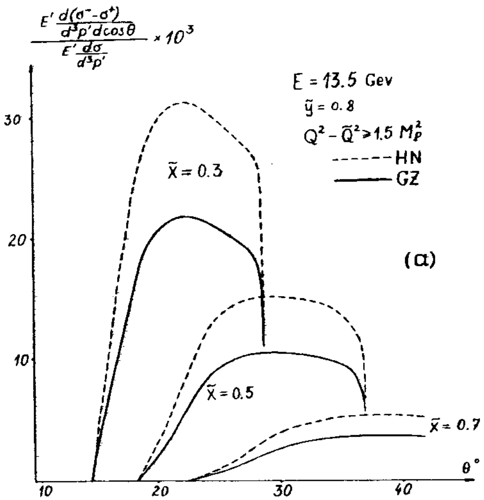
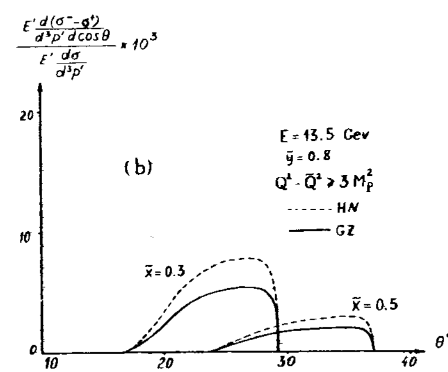
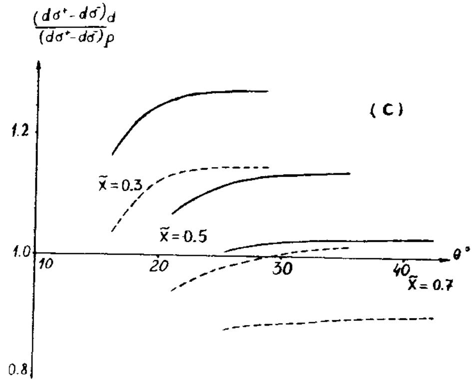


Fig.2. a) Effect of difference between deep-inelastic bremsstrahlung from negative and postivie-charged leptons on proton below the color threshold for Gell-Mann-Zweig (GZ) and Han-Nambu (HN) quark models, $Q^2 - \tilde{Q}^2 \geq 1.5\ M^2$.



b) The effect at $Q^2 - \tilde{Q}^2 \geq 3M^2$.



c) The ratio of effects on deuteron and proton below threshold.

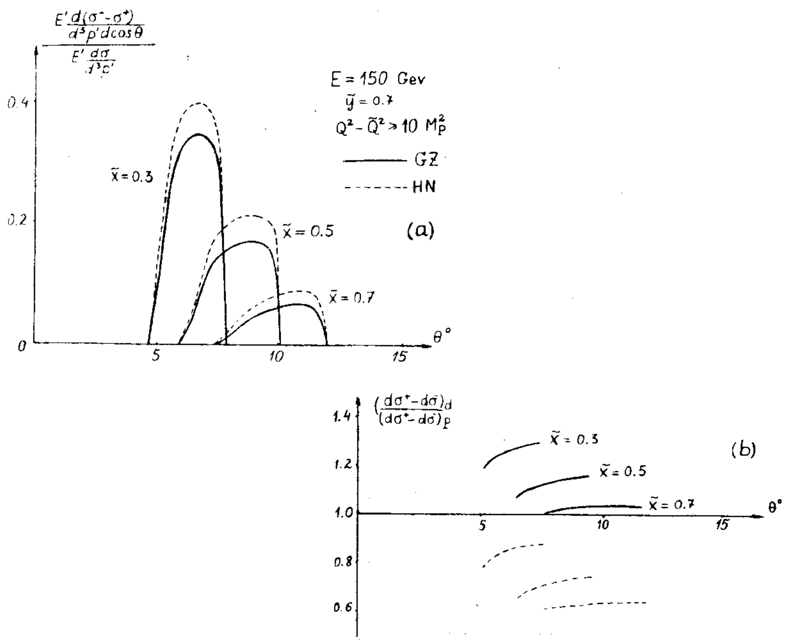


Fig.3. a–b) Those values as in Fig.2a,c above the color threshold.

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