A COMPARISON BETWEEN COMPTON SCATTERING ON INTEGER AND FRACTIONALLY CHARGED QUARKS

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The predictions of the integer charged quark model with strictly conserved color quantum numbers for deep inelastic Compton scattering are compared with those of the fractionally charged quark model for the different γ energies. The gluon distribution structure function is derived in the framework of the integer charged quark model.

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1. *Introduction*

The fractionally charged quark model [1] is generally widely accepted. However, the experimental situation is far from being clarified. By their design the integer charged quark models [2—5] are usually equivalent to the fractionally charged quark models in the color singlet sector. One may expect the dramatic differences to appear above the threshold for the excitation of the nonsinglet color states but this threshold may be at a very high energy.

Bjorken and Paschos [6] and later Chanowitz [7] have shown that the second order electromagnetic transitions (e.g. Compton scattering of the photon on quarks, two photon interactions in $e^+ e^-$) can discriminate between the fractional and the integer quark models, even below the color threshold.

In Fig. 1 we present the graph corresponding to the QED Compton scattering. In this process we measure the color average value of the 4-th power of the quark charge: $\langle Q^4 \rangle$. However, Lipkin [8] has raised objection that, due to the color oscillations between two vertices in this process, that may be not the case. Lipkin's objection is not relevant in our opinion if proper (high-q^2) kinematical region is chosen in which the nonperturbative contribution can be factorized. Then, due to the high-q^2 value, the strong inter-

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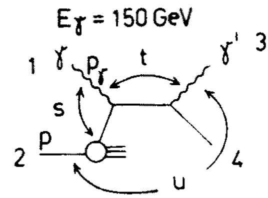
1) $x \cdot s >> m_n^2$
2) $-t >> m_n^2$
3) $m_x^2 >> m_n^2$
4) $-x \cdot u >> m_n^2$
5) $p_\perp^2 << E_\gamma^2 \frac{u^2}{s^2}$



$s = (q_1 + q_2)^2$
$t = (q_1 - q_3)^2$
$u = (q_2 - q_3)^2$

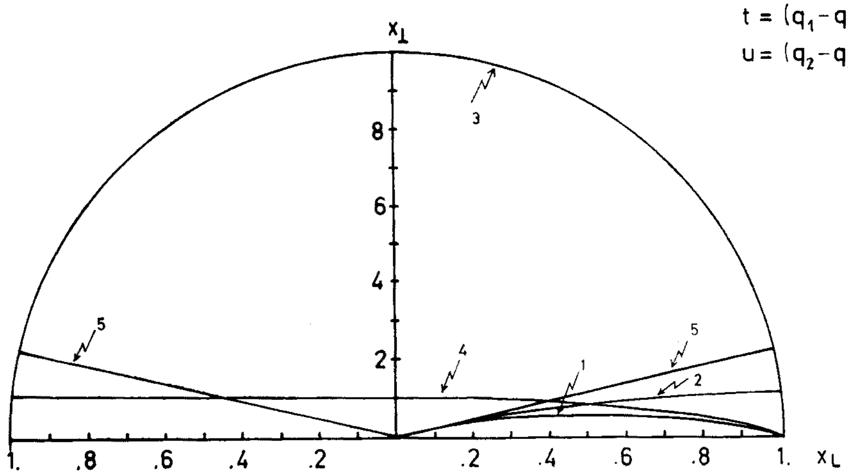


Fig. 1. Peyrou plot with the kinematic boundaries calculated for 150 GeV γp Compton scattering (see accompanying graph)

action coupling constant α_s should be small and the emission and absorption of the gluons between two vertices can be neglected.

The aim of the present work is to compare the fractionally and integer charged quark hypotheses in the framework of the models in which color is a strictly conserved quantum number. The process we shall study is the Compton scattering on quarks.

2. *The models*

Assuming the fractionally charged quark hypothesis the double differential cross--section for Compton scattering can be written as [6]:

$$\frac{d^2\sigma}{d\Omega dE} = \frac{\alpha^2}{4m_n E_0^2 \sin^2 \frac{\theta}{2}} \left(\frac{E}{E_0} + \frac{E_0}{E}\right) \sum_a \bar{Q}_a[q_a(x) + \bar{q}_a(x)]. \tag{1}$$

Here E_0 and E are the energy of the incident and scattered photon respectively; $\bar{Q} = \frac{1}{3}\,(\sum_i Q_i^4)_a$, where i, a and Q refer to the quark color, flavor and charge, m_n is the nucleon mass, θ is the γ scattering angle in the laboratory system, $q_a(x)$ and $\bar{q}_a(x)$ are the valence and the sea quark distributions in the target nucleon.

Several models have been proposed with integer charges for the quarks. We shall consider the one proposed by Vereshkov et al. [5], a $U(1)\times SU_L(2)\times SU(3)$ theory in which the color quantum number is strictly conserved. The main feature of such a model is that the photon couples to the gluons that are no longer all electrically neutral. The double differential cross-section for the Compton scattering [9] in this case is:

$$\frac{d^2\sigma}{d\Omega dE} = \frac{\alpha^2}{4m_n E_0^2 \sin^2\frac{\theta}{2}}\left[\left(\frac{E}{E_0}+\frac{E_0}{E}\right)\sum_a \bar{Q}_a(q_a(x)+\bar{q}_a(x))\right.$$

$$\left.+\left[6-\tfrac{8}{3}\left(\frac{E}{E_0}+\frac{E_0}{E}\right)+\tfrac{4}{3}\left(\frac{E^2}{E_0^2}+\frac{E_0^2}{E^2}\right)\right](G(x)+\bar{G}(x))\right], \tag{2}$$

where $G(x)$ and $\bar{G}(x)$ are the gluon and antigluon structure functions.

The kinematics of the process is illustrated in Fig. 1. The model can be applied in the region defined [9] by the inequalities:

$$xs \gg m_n^2; \quad -t(=-q^2) \gg m_n^2; \quad m_X^2 \gg m_n^2;$$

$$-xu \gg m_n^2; \quad p_\perp^2 \gg E_\gamma^2\frac{u^2}{s^2}. \tag{3}$$

Fig. 1 represents also the Peyrou plot with kinematic boundaries derived from the above conditions for 150 GeV Compton scattering.

To compute the cross sections of the QED Compton scattering for the integer charges of the quarks and gluons one needs their structure functions consistent with the model. The use of the structure functions of quarks and gluons determined from the deep inelastic electron and muon scattering under the assumption of the fractional charges is not justified here.

In the high-q^2 limit one may use the measured values of $F_1(x, q^2)$ and $F_2(x, q^2)$[1] structure functions of the proton and the ratio R of the longitudinal and transverse photon absorption cross sections:

$$R \equiv \frac{\sigma_L}{\sigma_T} \underset{-q^2\to\infty}{=} \frac{F_2 - xF_1}{xF_1} = \frac{[G(x)+\bar{G}(x)]}{18\sum_a Q_a^2[q_a(x)+\bar{q}_a(x)]}. \tag{4}$$

In this high-q^2 limit the following relation holds:

$$F_1(x) = \sum_a (Q_a^{IC})^2\,[q_a^{IC}(x)+\bar{q}_a^{IC}(x)] = \sum_a (Q_a^{FC})^2\,[q_a^{FC}(x)+\bar{q}_a^{FC}(x)] \tag{5}$$

where IC stands for integer charges and FC for fractional charges assumptions.

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[1] In the present work the F_1 and F_2 functions were determined from the quark distributions parametrized by the CDHS collaboration [10].

There is still no unique solution for $[u^{IC}+\bar{u}^{IC}]$ and $[d^{IC}+\bar{d}^{IC}]$ functions. We assume that the shape of the quark distributions is model independent and therefore the change in the normalization is proportional to the ratio $(Q_a^{FC})^2/(Q_a^{IC})^2$:

$$[u^{IC}+\bar{u}^{IC}] = \tfrac{2}{3}\,[u^{FC}+\bar{u}^{FC}]$$

$$[d^{IC}+\bar{d}^{IC}] = \tfrac{1}{3}\,[d^{FC}+\bar{d}^{FC}]. \tag{6}$$

We have also assumed that

$$\bar{u}^{FC} = \tfrac{1}{2}\,\overline{\text{sea}}^{FC}, \qquad \bar{d}^{FC} = \tfrac{1}{2}\,\overline{\text{sea}}^{FC}. \tag{7}$$

The results are not very sensitive to these assumptions since the quark contribution to the cross section in the IC model is only $\sim 10\%$.

We have made the calculations under the assumption of the integer charged quarks in the limit $-q^2 \to \infty$. In this limit the ratio R may be taken either from experiment or derived from energy momentum conservation.

Recent experiments [12] indicate smaller values of $R(-0.13 \div 0.10)$ than those measured at SLAC at lower energies $(0.17 \div 0.21)$.

From the requirement of the energy momentum conservation

$$\int x[u(x)+\bar{u}(x)+d(x)+\bar{d}(x)+G(x)+\bar{G}(x)]dx = 1 \tag{8}$$

we calculate the R value equal to 0.23.

This result is larger than recent measurements [12] but no conclusion may follow from this fact because of the large experimental errors.

3. *The results and conclusions*

We have made our calculations for different energies of the incoming photon: 21, 40, 100 and 150 GeV.

All the calculations in the IC model [5] have been made with $R = 0.23$, and CDHS [10] parametrization of the quark structure functions has been used in relation (5). The Buras-Gaemers parametrization [17] was also tried and does not change the results. Figure 2 shows the gluon and antigluon structure function (solid line) in the IC quark model. For comparison the gluon distribution function according to the CDHS [10] parametrization (dashed line) is also shown.

The gluon structure function determined in the IC model is flatter than the one corresponding to the FC hypothesis. This fact supports our statement that the use of the structure functions derived under the assumption of the fractional charges of the quarks is not justified in the model with integer charges.

Table I contains the values of the cross-sections for the different energies, integrated over $p_\perp$ of the photon > 1 GeV/c.

The characteristic features are:

(*i*) the cross-section values for the IC model are two orders of magnitude higher than those for FC model

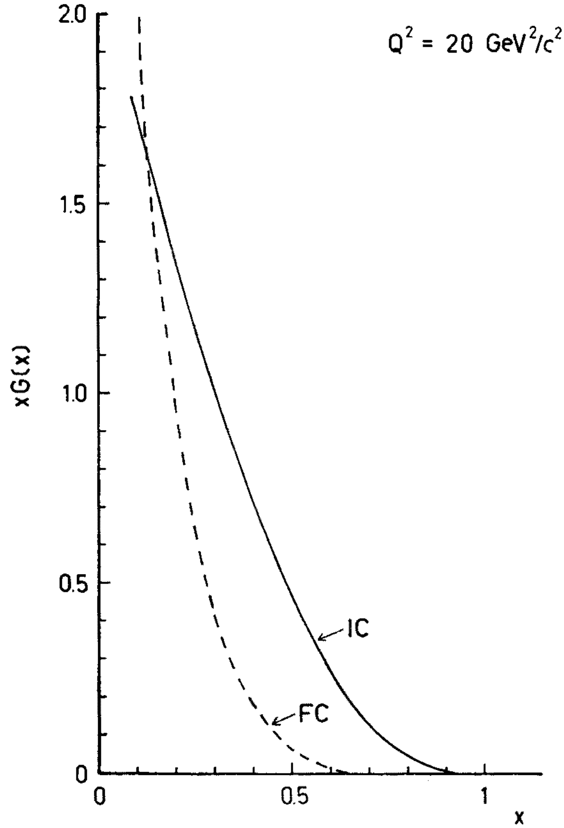

Fig. 2. The gluon structure functions in ---- FC: fractionally charged quark model [10], ——— IC: integer charged quark model derived for the high $-q^2$ $(-q^2 \to \infty)$ from the Vereshkov model (see text)[5]

TABLE I

Cross-sections of the QED Compton scattering for IC and FC models

Energy of the γ [GeV]	Cross-section [nb] FC model	Cross-section [nb] IC model
21	6.06	142.3
40	7.36	222.0
100	8.80	336.6
150	8.66	384.4

and (*ii*) the cross-section rises rapidly with energy for the IC assumption, while a constant behaviour is observed for the FC model.

The results are presented in Fig. 3 (a, b) in the form of the $\frac{d\sigma}{dp_\perp}$ cross-sections for IC and FC assumptions respectively. The difference observed in the shape of these distributions is mainly due to the gluon contribution.

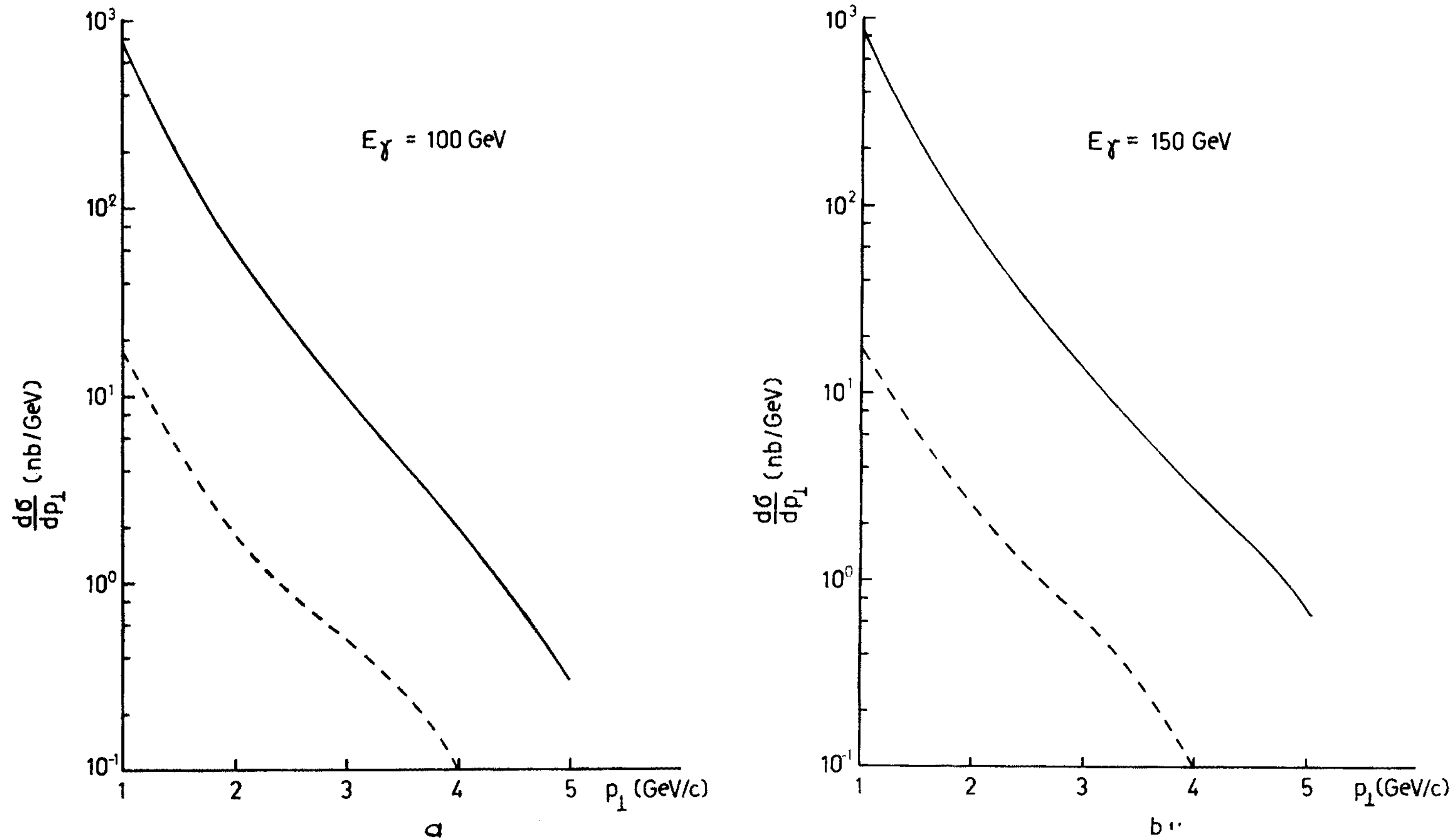

Fig. 3. $\frac{d\sigma}{dp_t}$ cross-sections for γp Compton scattering at $E_\gamma = 100$ GeV (a) and $E_\gamma = 150$ GeV (b) - - - - FC model, ——— IC model

There are very few data existing on the deep inelastic Compton scattering of real photons. The only experiment that has studied this process was carried out by Caldwell et al. [13] in the low energy photon bremsstrahlung beam at SLAC originating from 21 GeV/c e^- beam. Their data could favor the integer charged quark model but their experimental errors are so large that one cannot draw any definite conclusion. Moreover the contribution of the non point-like part of the photon to the studied process is very large (perhaps even dominant) at this energy and for the observed $p_\perp$ values. However, their data have been analysed by several authors [9, 14], who claim consistency with the IC hypothesis. These analyses have been performed using the same structure functions as in the FC quark model and are not internally consistent.

There was an attempt made by the 20—70 GeV/c photon collaboration at CERN [15] to extract the deep inelastic Compton process. We present the predictions of the

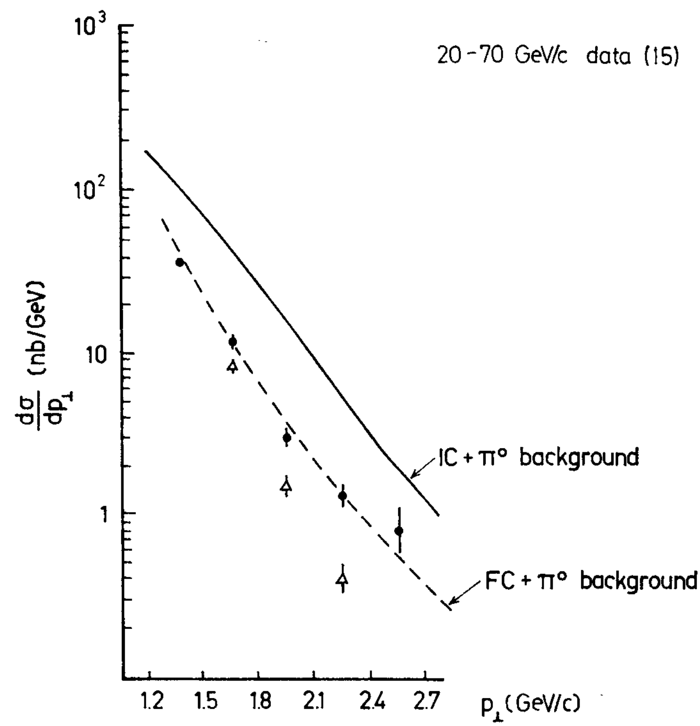

Fig. 4. Lower (△) and upper (○) limits for photons in the 20–70 GeV CERN experiment [15]. The curves show Monte-Carlo predictions based on the π^0's and η's plus the contribution of the QED Compton scattering for the - - - - FC model, ——— IC model

integer charged quark model together with their data in Fig. 4. Both the data and the results of the calculations contain the 120 mrad angular acceptance cutoff.

The presented data, however inaccurate, favor the fractionally charged quarks. As for the conclusion there is no clear experimental evidence for the integer charge hypothesis of the quarks coming from experiments studying Compton process. The proposed model by Vereshkov et al. [5] will be tested by the high energy photon experiment which has started at the CERN SPS accelerator [16].

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Note added in proof. Preliminary NA–14 results rule out an integer charge model; P. Petroff, preprint LAL 82/14, April 1982.

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