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ON CONSEQUENCES OF THE SYMMETRY BREAKING IN THE t-QUARK ELECTROMAGNETIC VERTEX FOR t-PRODUCTION IN $\bar{p}p$ COLLISIONS

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Abstract

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In the framework of a dynamical breaking model of the electroweak symmetry a possibility to obtain a large t-quark mass due to chiral symmetry breaking in the electromagnetic vertex of the t-quark is considered. The self-consistent set of equations is considered for a value of anomalous magnetic moment. The essential part of the set is connected with the due appearance of a Goldstone pseudoscalar. Solution of the set provides values of anomalous moment κ, coupling constant of the pseudoscalar with the t-quark depending on the high-energy cut-off. The main consequences of a large $\kappa \simeq 1$ are discussed, especially for the t-quark production in Tevatron experiments. The mechanism results in additional contribution to t-production cross-section, which gives e.g. $\simeq 10\,pb$ for $M_t = 170\,GeV, \kappa = 1$, that do not contradict the existing data. The cross-section for process $\bar{p}p \to \bar{t}\,t\,\gamma$ and p_t distribution of γ are also calculated. The results could be considered as providing the best restrictions for the value κ of the anomalous magnetic moment of t. On the other hand the approach gives definite predictions for the t-quark quest, which could be compared with the existing and forthcoming data.

Аннотация

Арбузов Б.А. и Шичанин С.А. О следствиях нарушения симметрии в электромагнитной вершине t-кварка для рождения t в $\bar{p}p$-столкновениях: Препринт ИФВЭ 94-61. – Протвино, 1994. – 6 с., 2 рис., 2 табл., библиогр.: 7.

В рамках модели динамического нарушения электрослабой симметрии рассмотрена возможность получить большую массу t-кварка за счет нарушения киральной симметрии в электромагнитной вершине t-кварка. Рассмотрена самосогласованная система уравнений на значение аномального магнитного момента. Существенная часть системы связана с неизбежным появлением голдстоуновского псевдоскаляра. Решение системы дает значения аномального момента κ, константы взаимодействия псевдоскаляра с t-кварком в зависимости от обрезания при высоких энергиях. Обсуждаются главные следствия большого момента $\kappa \simeq 1$, особенно для экспериментов на Теватроне по рождению t-кварков. Механизм приводит к дополнительному вкладу в сечение рождения t и дает, например, $\simeq 10\,pb$ для $M_t = 170\,GeV$, $\kappa = 1$, что не противоречит существующим данным. Вычислены также сечение процесса $\bar{p}p \to \bar{t}t\gamma$ и распределение по p_t для γ. Результаты дают наилучшее ограничение на значение κ аномального магнитного момента t-кварка. С другой стороны, подход дает определенные предсказания для поисков t-кварка, которые можно сравнивать с существующими и будущими данными.

In the present paper we consider a possibility for the t-quark to have peculiar properties and corresponding experimental consequences. The t-quark differs from other quarks in its very large mass. It might be that the large t-mass is due to some additional interaction. This conjecture could be realized in the framework of a model of dynamical breaking of electroweak symmetry [1], [2]. The approach [1] does not assume the existence of elementary Higgs scalars as a starting point of the electroweak theory. As a substitute for the standard Higgs mechanism we study a set of dynamical equations for a three-W vertex and for mass operators of W and Z. The main point of the approach consists in the appearance of a new gauge-invariant vertex in the region of "small" momenta, corresponding to the effective Lagrangian $L_{eff} \sim \epsilon^{abc} W^a_{\mu\nu} W^b_{\nu\rho} W^c_{\rho\mu}$. The presence of the vertex in the region of small momenta is only provided by a form-factor decreasing sufficiently rapidly for large momentum variables. The region of action of the new interaction is bounded by some cut-off Λ. The model defines a self-consistent set of equations for the new vertex and for W, Z masses. The study of the set leads to the conclusion that the dynamical breaking of the symmetry is quite possible [1], and we obtain W and Z masses with the value of cut-off Λ of the TeV order of magnitude. There have to exist also scalars, however, they are not elementary, but they are bound states consisting of W-s and Z-s. The order of magnitude of their mass has to be $\simeq TeV$ as well.

The analogous considerations are applied to the problem of the t-mass origin [2]. Here we study a possibility to break the chiral symmetry, connected with the t-quark, via the appearance of an anomalous magnetic moment in the t electromagnetic vertex. Note, that a possible anomalous magnetic moment of the t-quark is discussed from different points of view in several papers, e.g. [3]. The additional term looks like

$$\Gamma_\mu(p,q) = i\,F(p^2,q^2,k^2)\,\frac{e\,\kappa}{2\,M}\,\sigma_{\mu\nu}\,k_\nu\,, \tag{1}$$

where $k = q - p$ is the photon momentum, p, $-q$ are, respectively, the momenta of t and $\bar{t}$. M is the t mass and $F(p^2, q^2, k^2)$ is a form-factor, which could be chosen, e.g., in form [1]

$$F(p^2, q^2, k^2) = \frac{\Lambda^6}{(\Lambda^2 - p^2)(\Lambda^2 - q^2)(\Lambda^2 - k^2)}, \tag{2}$$

where Λ is the cutoff mass parameter.

There are processes, which are sensitive to a value κ, in case κ is sufficiently large, e.g. transition $b \to s + \gamma$. In [4] the corresponding calculations are shown to give upper bounds for κ, which depend on t mass. Say, $\kappa \leq 6$ for $m = 150\,GeV$, $\kappa \leq 7$ for $M = 170\,GeV$. As we shall see further, the most sensitive test for κ provides the process of $\bar{t}\,t$ production. The value κ of the order of unity changes substantially predictions for cross-sections. So, the problem is, whether values $\kappa \simeq 1$ are natural. The approximation, which is used in [2], leads to values $\kappa \simeq 10$. However, we see, that this is too large. Now, let us take into account the well-known important effect.

We know from the very beginning of the chiral symmetry breaking science [5], that the appearance of Goldstone zero-mass pseudoscalar is inevitable in the case of a symmetry breaking. Here it means, that there exists $\bar{t}\,t$ bound state Φ, which interacts with t, $\bar{t}$ according to

$$L_{int} = g\,\bar{\psi}\,\gamma_5\,\psi\,\Phi\,, \tag{3}$$

where ψ is a spinor, describing t.

Equations for the t-quark magnetic vertex (1) and its mass are schematically presented in Fig.1.

Calculations give the following set of equations

$$\begin{aligned}
&e\cdot\kappa\cdot Z^2 = e\cdot\kappa\cdot\frac{g^2}{16\,\pi^2}\,;\\
&M\cdot Z^2 = M\cdot\frac{\alpha\,\kappa^2}{16\,\pi}\cdot y - M\cdot\frac{g^2}{16\,\pi^2}\cdot\Bigl(ln\,y - \frac{11}{6}\Bigr)\,;\\
&Z^2 = Z - \frac{\alpha\,\kappa^2}{32\,\pi}\cdot y - \frac{g^2}{32\,\pi^2}\cdot\Bigl(ln\,y - \frac{11}{6}\Bigr)\,;\\
&y = \frac{\Lambda^2}{M^2}\,.
\end{aligned} \tag{4}$$

Here Z is the t-quark renormalization constant, according to the following definition of its full propagator (the solid line in Fig.1)

$$G(p) = \frac{Z^{-1}}{i\,(M - \hat{p})}\,.$$

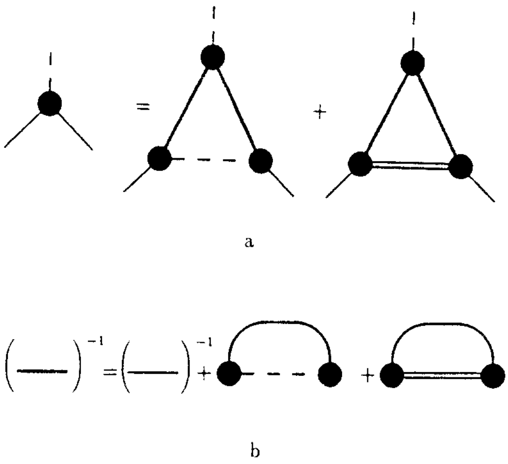

Fig. 1. Graphical equations for $\bar{t}t\gamma$ vertex (a) and for the t-quark mass operator (b). The solid line represents the t-quark, the dashed line – the photon and the double line represents $\bar{t}t$ bound pseudoscalar. Circles correspond to vertices (1) and (3).

Note, that the first term in vertex equation of Fig.1, containing photon exchange with vertices (1) turns to be zero. Set (4) has, of course, a trivial solution $M = 0$; $\kappa = 0$, which corresponds to the original symmetry being maintained. However, there is also nontrivial solution

$$\frac{g^2}{4\pi} = \frac{4\,\pi}{(ln\,y\,-\,\frac{1}{3})^2};$$
$$\kappa = \sqrt{\frac{16\pi\,(ln\,y\,-\,\frac{5}{6})}{\alpha\,y\cdot(ln(y)-\frac{1}{3})^2}}\,. \tag{5}$$

We see, that κ depends on a value of the cut-off. E.g. for $y = 700$, i.e. $\Lambda = 4.5\,TeV$, $\kappa = 1.03$, for $y = 220$, i.e. $\Lambda = 2.5\,TeV$, $\kappa = 2$. The values of Λ correspond to the t-quark mass $M = 170\,GeV$. Thus, the cut-off being of the order of magnitude $\simeq TeV$, κ is of the order of unity. In this sense values $\kappa \simeq 1$ are natural in our approach.

Now let us turn to $\bar{t}\,t$ production cross-section. We calculate it for proton-antiproton collisions at two c.m. energies: $1800\,GeV$ and $2000\,GeV$, using the current data on structure functions. For electromagnetic vertex we take just expression (1) and obtain results in the leading order, i.e. the additional term in a cross-section, which we deal with, is proportional to κ^2. The results for $\kappa = 1$ are presented in Table 1. We see, that e.g. for $M = 170\,GeV$ and

$E = 1800\,GeV$ we have $\Delta\sigma = 9.8\,pb$. For another value of κ numbers from Table 1 have to be multiplied by κ^2.

Table 1. Cross-section $\Delta\sigma\,pb$ of process $\bar{p}p \to \bar{t} + t + X$, $\kappa = 1$

M GeV	E=1800 GeV	E=2000 GeV
130	34.4	41.7
140	24.8	30.6
150	18.1	22.7
160	13.3	17.0
170	9.8	12.8
180	7.3	9.7
190	5.5	7.4

We see from the Table, that for $\kappa \simeq 1$ the additional term in $\bar{t}\,t$ cross-section is even larger than that, calculated in Standard Model (e.g., for $M = 170, E = 1800, \sigma_{SM} \simeq 5\,pb$). Experiments, looking for the t-quark at Tevatron imply stringent limitation on κ. Indeed, the recent CDF result [6] $\sigma = 13.9^{+6.1}_{-4.8}$ with $M = 174 \pm 10^{+13}_{-12}$ means that there is some place for an additional contribution to the cross-section. Using information from Table 1, and prescribing difference of the measured cross-section and the standard one to the magnetic term (1), we obtain estimate $|\kappa| = 1 \pm 0.5$. In fact it means, that $0 \le |\kappa| \le 2$. This limitation is much better, than that of [4]. Bearing in mind, that authors of [6] do not insist on decisive detection of t-production, we have to consider our result just as the upper bound on κ. However, a forthcoming improvement of t-production cross-section measurements will provide a possibility either to confirm the existence of magnetic term (1) or to reject this option.

We study also process $\bar{p}p \to \bar{t} + t + \gamma + X$. Its cross-section again for $\kappa = 1$ and Tevatron options is presented in Table 2. For another value of κ one multiplies the numbers by κ^4.

The cross-sections are not large, so there is no contradiction with the data. However, the process under discussion gives photons with very high p_t. The calculation shows, that for $M = 170\,GeV, E = 2000\,GeV$ the maximum of p_t distribution is located at $\simeq 30\,GeV$. The distribution is presented in Fig.2. As we can see, the distribution is stretched towards high values of p_t. E.g. 40% of events have $p_t \ge 100\,GeV$ and 23% have $p_t \ge 150\,GeV$.

Table 2. Cross-section $\Delta\sigma$ *pb* of process $\bar{p}\,p \to \bar{t} + t + \gamma + X$, $\kappa = 1$

M GeV	E=1800 GeV	E=2000 GeV
130	0.20	0.35
140	0.16	0.23
150	0.10	0.15
160	0.06	0.10
170	0.04	0.07
180	0.03	0.05
190	0.02	0.03

```
            Total =     10000 events

 P_t,GeV       0           260          520          780
+------+-------+------------+------------+------------+-------+
I    0 I    362I******************                            I
I   10 I    535I***************************                   I
I   20 I    718I************************************          I
I   30 I    697I***********************************           I
I   40 I    685I***********************************           I
I   50 I    665I**********************************            I
I   60 I    608I*******************************               I
I   70 I    603I*******************************               I
I   80 I    584I*****************************                 I
I   90 I    493I*************************                     I
I  100 I    473I************************                      I
I  110 I    434I**********************                        I
I  120 I    415I**********************                        I
I  130 I    343I******************                            I
I  140 I    288I***************                               I
I  150 I    326I*****************                             I
I  160 I    244I*************                                 I
I  170 I    211I***********                                   I
I  180 I    202I***********                                   I
I  190 I    157I*********                                     I
I  200 I    148I********                                      I
I  210 I    122I******                                        I
I  220 I     84I*****                                         I
I  230 I     94I*****                                         I
I  240 I     74I****                                          I
+------+-------+-------------------------------+--------------+
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Fig. 2. Photon p_t distribution for process $\bar{p}+p \to \bar{t}+t+\gamma+X$, $E = 2000 GeV$, $M = 170\,GeV$.

Results [6] present a hint for an extra contribution to $\bar{t}t$ production cross-section. In case this being confirmed, we have to look for some new mechanism, giving such a contribution. Here we have seen, that anomalous magnetic moment of t provides such mechanism. However, one could also propose another interaction of the t-quark, serving to explain data. Our results show, that a study of process $\bar{p}p \to \bar{t} + t + \gamma + X$ can discriminate between different possibilities. To look for such process one could use events tagged by b-particles from t-decays.

To conclude let us note, that we propose a self-consistent description of the t-quark properties. Of course, it is approximate and one could not guarantee $\kappa \simeq 1$ to be the reality. For the moment the best way to check the approach is a comparison with experiments on t production. There is also an important question, concerning the Goldstone pseudoscalar. Its existence is quite essential for all under discussion, and one have to ask: where is it? Indeed, it has to exist and to give observable effects. In this sense possible $60\,GeV$ 2γ cluster [7] is under suspicion. This possibility is discussed in [2]. Taking into account the arguments of the present paper, we conclude, that this variant do not contradict data on 2γ-s in Z decays. B.R. of $Z \to \gamma\gamma e^+e^-$ is estimated to be $\leq 10^{-7}$.

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