Письма в ЖЭТФ, том 60, вып.2, стр.75 - 79 ©1994 г. 25 июля

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

B.A.Arbuzov, S.A.Shichanin

Institute for High Energy Physics
142284 Protvino, Moscow Region, Russia

Submitted 2 June 1994

In the framework of a model of a dynamical breaking of the electroweak symmetry the possibility is considered to obtain a large t-quark mass due to chiral symmetry breaking in the electromagnetic vertex of the t-quark. The selfconsistent set of equations is considered for a value of an 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 to 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 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 existing and forthcoming data.

In the present work we consider a possibility of the t-quark to have a peculiar properties and corresponding experimental consequences. The t-quark differs from other quarks by 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 the 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 only is 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 selfconsistent 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 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 also $\simeq$ TeV.

The analogous considerations are applied to the problem of the t-mass origin [2]. Here we study a possibility of the breaking of the chiral symmetry, connected with the t-quark, via 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, 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 the 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 the 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 $m = 150\,\mathrm{GeV}$, $\kappa \leq 7$ for $M = 170\,\mathrm{GeV}$. As we shall see further, the most sensitive test for κ provides the process of $\bar{t}t$ production. Value κ of order of unity changes predictions for cross-sections substantially. 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 spinor, describing t.

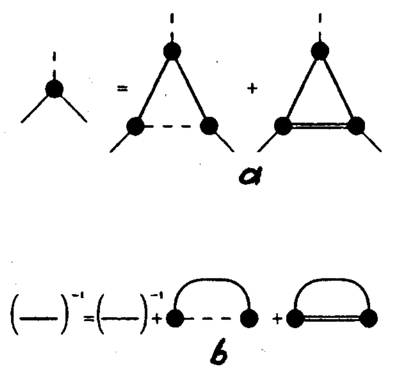

Fig.1. Graphical equations for $\bar{t}t\gamma$ vertex (a) and for the t-quark mass operator (b). Full line represents the t-quark, dash line - the photon and double line represents $\bar{t}t$ bound pseudoscalar. Circles correspond to vertices (1) and (3)

Equations for the t-quark magnetic vertex (1) and its mass are schematically presented at Fig.1. Calculations give the following set of equations

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

$$y = \frac{\Lambda^2}{M^2}.$$

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

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

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 trivial solution $M = 0$; $\kappa = 0$, which corresponds to the original symmetry be maintained. However, there is also nontrivial solution

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

We see, that κ depends on a value of the cut-off. E.g. for $y = 700$, i.e. $\Lambda = 4.5\,\mathrm{TeV}$, $\kappa = 1.03$, for $y = 220$, i.e. $\Lambda = 2.5\,\mathrm{TeV}$, $\kappa = 2$. Values of Λ correspond to the t-quark mass $M = 170\,\mathrm{GeV}$. Thus, the cut-off being of order of magnitude $\simeq$TeV, κ is of 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. That is 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 $M = 170\,\mathrm{GeV}$ and $E = 1800\,\mathrm{GeV}$ 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 more than that, calculated in Standard Model. E.g. for $M = 170, E = 1800, \sigma_{SM} \simeq 5\,\mathrm{pb}$. Experiments, looking for the t-quark at Tevatron imply stringent limitation on κ. Indeed, the last 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 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 at Table 2. For another value of κ one multiplies the numbers by κ^4.

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

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

```
               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
+-------+-----------------------------------------------------+
```

Fig.2. Photon p_t distribution for process $\bar{p}+p \to \bar{t}+t+\gamma+X$, $E = 2000\,\mathrm{GeV}$, $M = 170\,\mathrm{GeV}$

Results [6] present a hint for an extra contribution to $\bar{t}t$ production cross-section. In the case this be confirmed, we have to look for some new mechanism, giving such contribution. Here we have seen, that anomalous magnetic moment of

t provides such mechanism. However, one could propose also another additional 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 selfconsistent description of the t-quark properties. Of course it is approximate and one could not guarantee that $\kappa \simeq 1$ is 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 arguments of the present note, we conclude, that this variant do not contradict to data on 2γ-s in Z decays. B.R. of $Z \to \gamma\gamma e^+ e^-$ is estimated to be $\leq 10^{-7}$.

This work is supported by RFFR under project 94-02-03545.

---

1. B.A.Arbuzov, Phys. Lett. **B288**, 179 (1992).
2. B.A.Arbuzov, Preprint IHEP 93-22, Protvino, 1993.
3. D.Atwood, A.Aeppli, and A.Soni, Phys. Rev. Lett. **69**, 2754 (1992); G.Kane, G.A.Ladinski, and C.P.Yuan, Phys. Rev. **D45**, 124 (1992).
4. J.L.Hewett and T.G.Rizzo, Phys. Rev. **D49**, 319 (1994).
5. Y.Nambu and G.Iona-Lasinio, Phys. Rev. **122**, 345 (1961).
6. CDF Collab., FERMILAB-PUB-94/097-E, Batavia, 1994.
7. L3 Collab., O.Adriani et al., Phys. Lett. **B295**, 337 (1992).