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Unusual Properties of the Central Production of Glueballs and Instantons

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Abstract

It is shown that instantons provide a natural mechanism to explain an unusual azimuthal angular dependence of the production of the even-parity glueball candidates in central pp collision. A different azimuthal angular dependence for instanton-induced production of the odd-parity glueballs is predicted.

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Recently, very interesting experimental data on central production of glueball candidates have been published by WA91 and WA102 Collaborations [1], [2]. These data have shown an unusual strong dependence of the cross section for production of glueball candidates on

$$dP_t = |p'_{1t} - p'_{2t}|, \tag{1}$$

where p'_{it}, $i = 1, 2$, are the transverse momentum of the final protons. The experimental data are specified by a significant enhancement at small values of dP_t of the production of $f_0(1500), f_J(1710), f_2(1900)$, which are the candidates for even-parity glueball states [3], in comparison with the known $q\bar{q}$ mesons. This experimental observation opened the door for investigation of the properties of glueballs in diffractive processes [4]. A possible dynamical explanation of this feature, based on the broken scale invariance has been suggested in ref.[5]. However the final result of ref.[5] shows only a weak dependence of the cross section for glueball production at the relative azimuthal angle Φ between transverse momenta of the final protons. It turns out that this weak dependence is related just with the kinematics of the double-diffractive production of mesons and is not connected with some specific properties of glueballs.

In this letter, we suggest a new mechanism for central glueball production, based on the instanton structure of the QCD vacuum.

The instantons describe the tunneling between different gauge-rotated classical vacua in QCD and reflect the nonabelity of theory of strong interactions. The instanton–induced quark-quark t'Hooft [6] interaction plays a very important role in chiral symmetry breaking and in the appearance of the masses of constituent quarks and hadrons (see reviews [7], [8]).

It is very important that besides famous quark-quark interaction, the existence of the instantons in QCD vacuum should lead to specific quark-qluon [9] and gluon-gluon interactions.

Just the instanton-induced gluon-gluon interaction can give an important contribution to the central production of glueballs in the pp collision due to the diagram shown in Fig.1. It should be mentioned that the possibility of a large instanton contribution to the glueball production comes from the non-perturbative origin of the instanton field which gives the factor $1/\alpha_s$ into the production cross section for each gluon that is connected with the instanton.

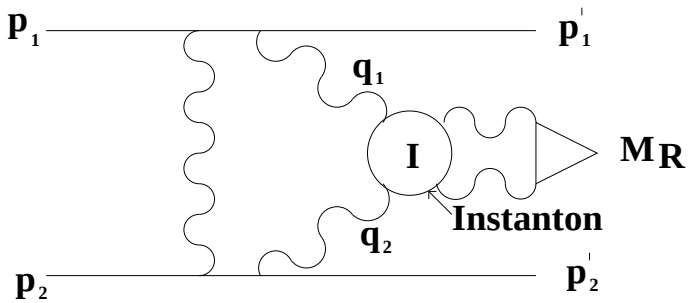

Figure 1: *The contribution to the central glueball production induced by instantons.*

Let us estimate the Φ dependence of the instanton-induced glueball double-diffractive production. The wave function of gluons incoming onto the instanton (see Fig.1) is given by the Fourier transform of the instanton field

$$A^a_\mu(q) = \frac{16\pi^2}{g_s}\frac{\bar{\eta}_{a\mu\nu}q_\nu}{q^4}(1 - \frac{1}{2}K_2(\rho|q|)\rho^2q^2) \equiv \bar{\eta}_{a\mu\nu}q_\nu f(q^2), \tag{2}$$

where the t'Hooft's symbol $\bar{\eta}_{a\mu\nu}$ in the Minkowsky space is

$$\bar{\eta}_{aij} = \epsilon_{aij}, \ \bar{\eta}_{a0i} = i\delta_{ai}, \tag{3}$$

and $\bar{\eta}_{a\mu\nu}$ is antisymmetric under the interchange of μ and ν.

At high energies the matrix element of the reaction presented in Fig.1 is given by the formula

$$M \approx \bar{\eta}_{a\mu\nu}\bar{\eta}_{a\mu'\nu'}q_{1\nu}q_{2\nu'}\tilde{p}_{1\mu}\tilde{p}_{2\mu'}F({q_1}^2,{q_2}^2), \tag{4}$$

where $q_i = p_i - p_i'$, $\tilde{p}_i = p_i + p_i'$, and $F({q_1}^2,{q_2}^2)$ is a form factor which contributes negligibly to the Φ dependence and therefore we will neglect it.

To obtain formula (4), the leading-gluon model for the pomeron has been used (see a discussion in [5]). In this model the meson production (Fig.1) is determined by the fusion of the two leading gluons from different pomerons whereas the remained gluons from the pomerons provide only colourlessness.

The contraction of the t'Hooft's symbols Eq.(4) is

$$\bar{\eta}_{a\mu\nu}\bar{\eta}_{a\mu'\nu'} = M^{even}_{\nu\mu\nu'\mu'} + M^{odd}_{\nu\mu\nu'\mu'} \tag{5}$$

where

$$M^{even}_{\nu\mu\nu'\mu'} = g_{\nu\nu'}g_{\mu\mu'} - g_{\nu\mu'}g_{\nu'\mu}, \tag{6}$$

and

$$M^{odd}_{\nu\mu\nu'\mu'} = \epsilon_{\nu\nu'\mu\mu'}. \tag{7}$$

It is easy to check that two terms in (5) contribute to the production of mesons with opposite parities. This follows from the fact that one can rewrite the even part of the amplitude (5), (6) through the even-parity product of the field strengths of incoming gluons $G^a_{\mu\nu}G^a_{\mu'\nu'}$, whereas the odd-parity part (7) can be represented by the formula $G^a_{\mu\nu}\widetilde{G}^a_{\mu'\nu'}$, where $\widetilde{G}^a_{\mu'\nu'} = \epsilon_{\mu'\nu'\rho\tau}G^a_{\rho\tau}/2$. Therefore in the production of the even- (odd-) parity glueballs only the first (second) term in (5) can contribute.

In the center of mass system of initial protons the momenta of initial and final particles are

$$\begin{aligned} p_1 &\approx (P,0,P), \quad p_2 \approx (P,0,-P) \\ {p_1}' &\approx (x_1P,\vec{p}_{1t},x_1P), \quad {p_2}' \approx (x_2P,\vec{p}_{2t},-x_2P) \end{aligned} \tag{8}$$

By using this formula and (6), (7) one can obtain the following Φ dependence of the even- and odd-parity glueball production cross-section induced by instantons:

$$\sigma_{even} \sim |M|^2 \sim (\vec{p}_{1t}.\vec{p}_{2t})^2 \sim cos^2\Phi, \tag{9}$$

$$\sigma_{odd} \sim |M|^2 \sim |\vec{p}_{1t} \times \vec{p}_{2t}|^2 \sim sin^2\Phi, \tag{10}$$

To predict the total Φ dependence of the glueball production, one should take into account the kinematic restrictions for the meson production [5]. For the symmetric kinematics $x_1 = x_2 = x_P - 1$, $t_1 \approx t_2$, by using the pomeron flux factor

$$f_P(x_P) \propto x_P^{1-2\alpha(t)}, \tag{11}$$

where $\alpha(t) = 1 + \epsilon + \alpha' t$ is the pomeron trajectory with $\epsilon = 0.085$ and $\alpha' = 0.25GeV^2$, one can obtain from the double-diffractive cross section formula [2]

$$\frac{d\sigma}{d\Phi} \approx f_P^2(x_P)\frac{d\hat{\sigma}}{d\Phi} \tag{12}$$

[2] The kinematic relation $x_P = (M_R^2 + 2|t|(1 - cos\Phi))^{1/2}/\sqrt{s}$ [5], where M_R is the mass of the glueball was used to obtain (13), (14).

the following Φ dependence of even- and odd-parity glueball production

$$\frac{d\sigma^{even}}{d\Phi} \sim \left(\frac{s}{M_R^2 + 2|t|(1-cos\Phi)}\right)^{1+2\epsilon+2\alpha' t} cos^2\Phi \tag{13}$$

and

$$\frac{d\sigma^{odd}}{d\Phi} \sim \left(\frac{s}{M_R^2 + 2|t|(1-cos\Phi)}\right)^{1+2\epsilon+2\alpha' t} sin^2\Phi. \tag{14}$$

The distribution (13) for the lightest scalar glueball candidate $f_0(1500)$ production for $t = -0.5GeV^2$ in WA91 and WA102 experiments is shown in Fig.2. This distribution significantly differs from the distribution predicted within model [5]. The difference is connected with a much more larger enhancement of the even-parity glueball production at small values of Φ and its suppression at $\Phi \approx \pi/2$. This dependence is in qualitative agreement with experimental data [1], [2].

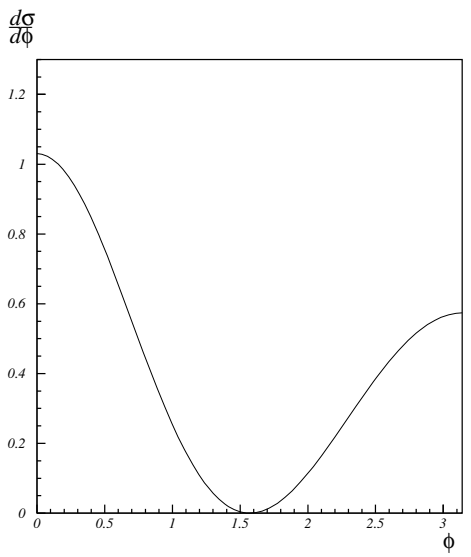

Figure 2: Φ-*dependence of the instanton contribution to* $f_0(1500)$ *even-parity meson central production at* $t = -0.5GeV^2$.

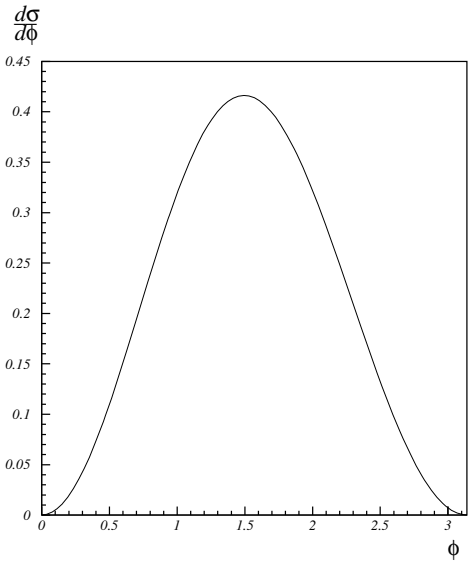

Figure 3: Φ- *dependence of the instanton contribution to the central production of odd-parity glueball with mass* $M_R = 2250MeV$ *at* $t = -0.5GeV^2$.

For the production of the odd-parity glueballs there should be an opposite situation. Indeed, their cross section should be small at small values of Φ and significantly larger at $\Phi \approx \pi/2$. The corresponding distribution for the production of the odd-parity lightest glueball candidate 0^{-+} with the mass $M_R(0^{-+}) \approx 1.5M_R(0^{++}) \approx 2250MeV$ [3] is presented in Fig.3.

Recently the experimental data on the production of pseudoscalar neutral mesons π^0, η, η' in the central pp collision have been published [10]. It was discovered that the production mechanism for η and η' differs from the mechanism of the π^0 production. Indeed, it was found that the cross section for the η and η' production are greatest when the azimuthal angle Φ between p_t of two final protons is $\pi/2$. From our point of view, due to the large value of matrix elements [11]

$$< 0|\frac{3\alpha_s}{4\pi} G^a_{\mu\nu}\tilde{G}^a_{\mu\nu}|\eta >= \sqrt{\frac{3}{2}} f_\pi m_\eta^2,$$

$$< 0|\frac{3\alpha_s}{4\pi}G^a_{\mu\nu}\tilde{G}^a_{\mu\nu}|\eta' >= \sqrt{3}f_\pi m^2_{\eta'} \qquad (15)$$

the diagram in Fig.1 can significantly contribute also to η and η' production, which leads to the enhancement of production at $\Phi \approx \pi/2$.

In summary, the new mechanism for central production of glueballs is suggested. It is based on the instanton picture of the QCD vacuum and provide a natural explanation of the unusual kinematical dependence of cross sections of production of glueball candidates. This observation gives a nice opportunity to investigate the properties of the complicated QCD vacuum in the double-diffractive production of mesons.

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References

[1] D.Barberis et al., WA91 Collaboration, *Phys. Lett.* **B388** (1996) 853.

[2] D.Barberis et al., WA102 Collaboration, *Phys. Lett.* **B397** (1997) 339;
A.Kirk et al., WA102 Collaboration, hep-ph/9810221.

[3] G.Bali et al. (UKQCD), *Phys. Lett.* **B309** (1993) 378;
D.Weingarten, hep-lat/9608070;
J.Sexton et al., *Phys. Rev. Lett.* **75** (1995) 4563.

[4] F.E.Close and A.Kirk, *Phys. Lett.* **B397** (1997) 333.

[5] J.Ellis and D.Kharzeev, CERN-TH/98-349, RIKEN-BNL preprint, hep-ph/9811222.

[6] 't Hooft *Phys. Rev.* **D14** (1976) 3432.

[7] T.Schäfer and E.V.Shuryak, *Rev. Mod. Phys.* **70** (1998) 1323.

[8] D.I.Diakonov, hep-ph/9602375.

[9] N.I.Kochelev, *Phys. Lett.* **B426** (1998) 149.

[10] D.Barberis et al., WA102 Collaboration, *Phys. Lett.* **B427** (1998) 398.

[11] V.A.Novikov, M.A.Shifman, A.I.Vainshtein, A.I.Zakharov, *Nucl. Phys.* **B165** (1980) 55;
M.A. Shifman, *Phys. Rep.* **209** (1991) 341.