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CORRELATION SIGNATURES OF STRONG INSTANTONS IN MULTIGLUON GAMMA-QUARK INTERACTIONS IN H1 EXPERIMENT AT HERA.

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Instanton-induced multigluon events in the processes of gamma-quark interactions at high energy are considered. Second correlation function for these processes is calculated in QCD and analyzed; the first quantum correction to the classical instanton configuration is taken into account. The features of the correlation function behaviour can be used as a signature of instanton in H1 experiment at HERA.

I Introduction

Multiparticle production processes induced by both weak instantons [1,2] and strong instantons [3,4] represent now large interest in high energy collisions.

As it is well-known, instantons (classical Euclidean field configurations [5]) represent quantum tunnelling transitions in Minkovski space-time. In Yang-Mills theories these phenomena are associated with the highly degenerated vacuum structure. In electro-weak theory instantons due to quantum anomaly [6] lead to the violation of baryon and lepton numbers conservation law [7]. Possibility of the baryon and lepton numbers nonconservation at high energy is connected with the problem of the baryon and antibaryon asymmetry in the observable part of the Universe [8]. At low energies (when energy of the process is less than barrier between different degenerated vacuum stages) cross section $\sigma^I_{tot} \approx 10^{-78}$ [5]. In high energy particle collisions (in multi TeV regime) the cross section can increase exponentially if it is associated with multi W, Z^0 and H-bosons production in the weak instanton field [1].

The needed energies are so high that it is very difficult to see such processes at the nowadays experiments.

From the other hand for strong instantons in QCD such phenomenon can exist at hundreds MeV [2] and be important in deep inelastic gamma-quark scattering for decreasing Bjorken variable X_{Bj} and high photon virtuality Q^2 [3]. Search of QCD-instantons has started already in high energy collisions at HERA (H1 experiment). The processes have some features: instanton contribution to structure function $F_2(X_{Bj}, Q^2)$ rises strongly with decreasing X_{Bj}; σ^I_{tot} strongly peaks with decreasing of X_{Bj}; hadronic band emission of semi-hard partons is isotropic in the instanton rest system; current quark jet and characteristic flavour, strangeness-K^0, charm and muon flow take place [4,9,10].

Moreover instanton-induced processes manifest new mechanism of multiparticle production and can contribute to intermittency exponent [11].

We study properties of the second correlation function as signature of instanton-induced multi-gluon state for classical instanton with the first quantum correction in QCD.

It should be noted, that for this effect the problem of taking into account the hadronization exists. Here it can be solved by the use of the local parton-hadron duality [12].

II Correlations of gluons induced by instanton

The following instanton solution is used [7]:

$$A_\mu^{a(cl)}(x) = \frac{2\eta^a_{\mu\nu}(x-z)_\nu}{g((x-z)^2+\rho^2)}, \qquad (1)$$

where $A^a_\mu(x)$ are gluon fields; $\eta^a_{\mu\nu}$ is a 't Hooft symbol [5]; ρ and z_ν are size and position of the instanton correspondingly; g is a constant of strong interaction; greek indexes μ,ν...=1,2,3,4 are the four-vector indexes, latin indexes a,b...=1,2,...,8 are SU(3)-group indexes; subscript "cl" denotes quasiclassical approximation.

It is convenient to use reduction formula [13] for the calculation of the amplitude of n gluon production in instanton field

$$T^{a_1a_2...a_n}_{\mu_1\mu_2...\mu_n}(k_1,k_2,...,k_n) = \int \prod_{j=1}^{n} dy_j e^{ik_jy_j}(k_j^2+m^2)\times$$

$$\times \int [DA] e^{-S[A]} A^{a_1}_{\mu_1}(x)...A^{a_n}_{\mu_n}(x) =$$

$$= \int \prod_{j=1}^{n} dy_j e^{ik_jy_j}(k_j^2+m^2) \int [DA] e^{-S[A]} (A^{a_1(cl)}_{\mu_1}(x) + A^{a_1(qu)}_{\mu_1}(x))...\times$$

$$\times (A^{a_n(cl)}_{\mu_n}(x) + A^{a_n(qu)}_{\mu_n}(x)) = \int \prod_{j=1}^{n} dy_j e^{ik_jy_j}(k_j^2+m^2)\times$$

$$\times \int [DA] e^{-S[A]} A^{a_1(cl)}_{\mu_1}(x)...A^{a_n(cl)}_{\mu_n}(x) + \int \prod_{j=1}^{n} dy_j e^{ik_jy_j}(k_j^2+m^2)\times$$

$$\times \int [DA] e^{-S[A]} A^{a_1(qu)}_{\mu_1}(x) A^{a_2(qu)}_{\mu_2}(x) A^{a_3(cl)}_{\mu_3}(x)...A^{a_n(cl)}_{\mu_n}(x) + ... \quad . \qquad (2)$$

In formula (2) we consider $A^a_\mu(x) = A^{a(cl)}_\mu(x) + A^{a(qu)}_\mu(x)$, where $A^{a(qu)}_\mu(x)$ is small fluctuations near classical field $A^{a(cl)}_\mu(x)$; subscript "qu" denotes quantum correction [14]. The first term in formula (2) corresponds to the main (quasiclassical) approximation and is given by the following expression [15]:

$$T^{(cl)a_1a_2...a_n}_{\mu_1\mu_2...\mu_n}(k_1,k_2,...,k_n) = (C_1)^n \prod_{j=1}^{n} \eta^{a_j}_{\mu_j\nu_j} k_j^{\nu_j}, \qquad (3)$$

where $k_1, k_2, ..., k_n$ are the 4-momenta of the produced gluons, $k_j = (\vec{k}_j, iE_j)$, $C_1 = 4\pi^2 i\rho^2/g$, m is effective gluon mass.

In the formula (3) we as usual do not write δ-function, which is connected with law of conservation of 4-momentum [1]. For the correct normalizing we must rewrite formula (3) in the following way:

$$T^{(cl)a_1a_2...a_n}_{\mu_1\mu_2...\mu_n}(k_1,k_2,...,k_n) = (C_1)^n \prod_{j=1}^{n} \eta^{a_j}_{\mu_j\nu_j} k_j^{\nu_j} \Theta(n_{max}-n), \qquad (3')$$

where $n_{max} = \sqrt{s}/m$.

Then the second term in (2) is the first quantum correction to the classical amplitude. It is calculated on the basis of gluon propogation function in instanton field [16] and is given by the next formula [2] (for two produced gluons):

$$T^{(qu)ab}_{\mu\nu}(k_1,k_2) = (C_2)^2 \eta^d_{\mu\alpha}\eta^d_{\nu\beta} k_1^\alpha k_2^\beta \varepsilon^{abc} \eta^c_{\kappa\lambda} \frac{k_1^\kappa k_2^\lambda}{(k_1,k_2)^2}, \qquad (4)$$

where $C_2 = 2\pi i\rho$; $(k_1,k_2) = (\vec{k}_1\vec{k}_2) - E_1E_2$.

We make the following natural assumption (in laboratory subsystem in *ep*-collision) [17]:

$$(k_i^L)^2 \gg (\vec{k}_i^T)^2 \gg m^2, \qquad k_i^T \equiv \mid \vec{k}_i^T \mid = k^T,$$
$$E_i \approx k^T chy_i, \qquad k_i^L \approx k^T shy_i. \qquad (5)$$

Let us write the expressions for the probabilities of the gluon production processes going through instanton mechanism in dependence on rapidity variables:

$$P_n(y_1,...,y_n) = \mid T_n^{(cl)}(y_1,...,y_n) + T_n^{(qu)}(y_1,...,y_n) \mid^2 \approx$$
$$\approx T_n^{(cl)}(y_1,...,y_n)\Big[T_n^{(cl)}(y_1,...,y_n)\Big]^* + T_n^{(qu)}(y_1,...,y_n)\Big[T_n^{(cl)}(y_1,...,y_n)\Big]^* +$$
$$+T_n^{(cl)}(y_1,...,y_n)\Big[T_n^{(qu)}(y_1,...,y_n)\Big]^* = A^n \prod_{j=1}^{n} ch2y_j \Theta(n_{max}-n)- \qquad (6)$$
$$-\alpha A^{n-2}\Big[\Pi(y_1,y_2)\, ch2y_3...ch2y_n + ... + \Pi(y_{n-1},y_n)\, ch2y_1...ch2y_{n-2}\Big]\times$$
$$\times\Theta(n_{max}-n);$$

where $A = 3(k^T)^2(C_1)^2$, $\alpha = 8(C_1)^2(C_2)^2(k^T)^2$, $\Pi(y_1,y_2) = sh(y_1-y_2)\times$ $\times th(y_1-y_2)$. In the formula (6) the first term corresponds to the classical approximation and the others are the first quantum correction contribution.

In order to calculate inclusive distribution $\rho_n(y_1,...,y_n)$ we must by standart method take into account all canals of the process. In our case we obtain:

$$\rho_n(y_1,...,y_n) = A^n ch2y_1...ch2y_n[\Theta(n_{max}-n) + R_0(n)]-$$
$$-\alpha A^{n-2}[\Pi(y_1,y_2)ch2y_3...ch2y_n + ... + \Pi(y_{n-1},y_n)ch2y_1...ch2y_{n-2}]\times$$
$$\times(\Theta(n_{max}-n) + R_0(n)) - \frac{\alpha}{2}A^n ch2y_1...ch2y_n \Pi(Y) R_2(n)-$$
$$-\alpha A^{n-1}[Q(Y,y_1)ch2y_2...ch2y_n + ... + Q(Y,y_n)ch2y_1...ch2y_{n-1}]R_1(n), \qquad (7)$$

where we denoted

$$\Pi(Y) = \int_{-Y}^{Y} \Pi(y_1,y_2)dy_1dy_2 =$$

$$= 4(sh(\frac{Y}{2}))^2 - \pi Y + 8\sum_{k=0}^{\infty} \frac{(-1)^k}{(2k+1)^2} exp(-\frac{Y}{2}[2k+1]) sh(\frac{Y}{2}[2k+1]);$$

$$Q(Y, y) = 2shY chy + arcth[sh(y - Y)] - arcth[sh(y + Y)];$$

$$R_i(n) = \sum_{m=1}^{\infty} \frac{[Ash2Y]^{m-i}}{(m-i)!} \Theta(n_{max} - n - m),$$

$$i = 0, 1, 2, \qquad (0 \le R_2(n) \le R_1(n) \le R_0(n) \le 1). \tag{8}$$

Two-particle correlation function in dependence on rapidities

$$C_2(y_1, y_2) = \rho_2(y_1, y_2) - \rho_1(y_1)\rho_1(y_2)$$

if $n_{max} \gg 1$ and $\Theta(n_{max} - 1) = \Theta(n_{max} - 2) = 1; R_i(1) \approx R_i(2) \approx 1; \quad i = 0, 1, 2,$ has the following form [18]:

$$C_2(y_1, y_2) = [-2A^2 + \frac{3}{2}\alpha A^2 \Pi(Y)] ch2y_1 ch2y_2 - 4\alpha A\pi ch(y_1 + y_2) th(y_1 - y_2) -$$

$$-2\alpha sh(y_1 - y_2) th(y_1 - y_2) + 2\alpha A shY [chy_1 ch2y_2 + chy_2 ch2y_1] +$$

$$+2\alpha A[arctg(\frac{chy_1}{shY}) ch2y_2 + arctg(\frac{chy_2}{shY}) ch2y_1]. \tag{9}$$

Corresponding curve lies in negative region of the plot $C_2(y_1, 0)$, has maximum at $y_1 = 0$ and minima at $y_1 = \pm 3,5$ (see fig.1).Central maximum corresponds to the quasiclassical part of (9); two minima are contribution of the first quantum correction. For the estimation the parameters are taken to have the next values: $\sqrt{s} = 50GeV$, $m = 100MeV$, $\rho = 1GeV^{-1}$, $Y \approx 4$, $k^T = 0,1GeV$.

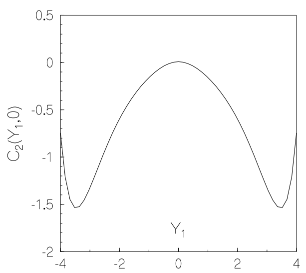

Fig.1. Correlation function vs. rapidity y_1 of one of the particle, when $y_2 = 0$.

III Conclusion

Thus, in addition to the known footprints of instanton induced events we have obtained two gluon correlation function which is negative and has specific structure at the rest system of one of the particle. It is very important, that the general problem of the infrared divergence of instantons is solved for the instanton-induced events in high-energy gamma-quark collision (in this case photon virtuality Q^2 plays the role of infrared cut-off for the instanton size ρ [19]). With the help of local parton-hadron duality the result can be used for hadrons and be interesting for HERA experiments [4].

In progress now are estimation of contributions of quantum corrections of higher orders and of adequate kinematical restrictions, separation of hadrons from semi-hard quarks and from accompanying gluons, Monte-Carlo analysis.

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