DIRECT $\gamma$-QUANTA IN HADRON-HADRON COLLISIONS.

POLARIZATION PHENOMENA

M. P. Rekalo

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Polarization phenomena occurring in $\gamma$-quantum formation during hadron-hadron collisions are analyzed in general form. Special attention is given to calculation of the Stokes photon parameters as functions of the target vector polarization. In addition, P-odd polarization phenomena are considered for processes $a_1 + a_2 \rightarrow \gamma + X$, where $a_1$ and $a_2$ are the colliding hadrons and $X$ indicates unrecorded particles.

1. The study of formation of direct high energy $\gamma$-quanta in hadron-hadron collisions [1, 2] $a_1 + a_2 \rightarrow \gamma + X$, where $a_1$ and $a_2$ are the colliding hadrons and $X$ is an undetected set of particles, is of interest in that it may verify various predictions of quantum chromodynamics [3, 4]. Of special importance are experiments on the polarization properties of the $\gamma$-quanta formed [5]. Information on $\gamma$-quantum polarization can be obtained from the process of muon pair formation $a_1 + a_2 \rightarrow \mu^+ + \mu^- + X$ (with small values of invariant mass $\mu^+ \mu^-$). The muon angular distribution is sensitive to the linear polarization of the $\gamma$-quantum; in order to measure $\gamma$-quantum circular polarization it is necessary to measure the longitudinal polarization of one of the muons. Such experiments can be performed at present [6].

In the present study we will consider in general form the dependence of the polarization states of direct $\gamma$-quanta produced by the reaction $a_1 + a_2 \rightarrow \gamma + X$ on the polarization of one of the colliding hadrons, $a_1$, for example. The importance of performing experiments with a polarized hadron target to verify quantum chromodynamics has been discussed more than once [7, 8]. Here we will not concretize the $\gamma$-quantum formation mechanism, but limit ourselves to the most general properties of any possible mechanism, such as conservation of hadron electromagnetic field.

2. We write the differential section of the process $a_1 + a_2 \rightarrow \gamma + X$, corresponding to registration of only the generated $\gamma$-quantum, in the form:

$$
\frac{d^2 \sigma}{d^2 \gamma} = \frac{\epsilon^2}{4 V p_1 p_2 - m_1^2 m_2^2} \frac{d^2 \gamma_1}{2w(2\pi)^2} e_\mu^2 \epsilon_{\mu \mu}^2 ,
$$

$$
W_{+} = (2\pi)^4 \sum_n \int J_\mu J_{\mu}^* (p_1 + p_2 - \kappa - p_3) dP_{+}^{(n)},
$$

$$
dP_{+}^{(n)} = \frac{d^2 t_1}{2\epsilon_1 (2\pi)^3}, \cdots, \frac{d^2 t_n}{2\epsilon_n (2\pi)^3},
$$

where $\epsilon_\mu$ is the $\gamma$-quantum polarization 4-vector; $k$, $p_1$, $p_2$ are the 4-momenta of the photon and colliding hadrons (where $m_1$ and $m_2$ are their masses); $J_\mu$ is the electromagnetic current of the transition $a_1 + a_2 \rightarrow \gamma + X$; $\epsilon_{\mu \mu}$ is the energy (momentum) of the $i$-th hadron in the

We will consider further the case of a vector polarization \( s \) for hadron \( \alpha_1 \) \((s^2 = -1, s \cdot p_1 = 0)\). Then the following general structure can be written for the tensor \( W^{(\text{em})}_{\mu
u} \):

\[
W^{(\text{em})}_{\mu
u} = W_{\mu
u} + W_{\mu
u}(s),
\]

\[
W_{\mu
u}(s) = \frac{1}{s^2} (S \cdot p_2) \left[ \delta_{\mu\nu} - \frac{1}{2} p_\mu p_\nu \right]
\]

\[
= \frac{1}{s^2} \left[ (p_1 + p_2) \cdot \varepsilon + k \cdot (p_1 + p_2) \right] (\kappa \cdot p_1 + \kappa \cdot p_2).
\]

Thus, the polarization states of the photon formed in a hadron–hadron collision with one vector-polarized hadron in the initial state are characterized by eight structural functions, with six of these defining the dependence on the vector polarization of the initial hadron \( \alpha_1 \). In the general case the structural functions depend on three invariant quantities: \( s = (p_1 + p_2)^2 \), \( t = (k - p_1)^2 \), \( u = (k - p_2)^2 \).

Analysis of the structure of tensor \( W_{\mu\nu} \) leads to the following general conclusions, valid for any \( \gamma \)-quantum formation mechanism.

1. If hadron \( \alpha_1 \) is polarized perpendicularly to the plane of the reaction, then unpolarized or linearly polarized \( \gamma \)-quanta can be formed.

2. Formation of circularly polarized \( \gamma \)-quanta is possible only if the polarization vector of the initial hadron lies in the reaction plane.

3. Transverse target polarization can manifest itself only in the presence of strong interaction effects between hadrons in the initial and final states.

This last conclusion is related to the fact that the corresponding correlations \((s \cdot k \times p_1\) if unpolarized \( \gamma \)-quanta are formed, or \(s \cdot e \times k \cdot p_1\) if \( \gamma \)-quanta with linear polarization are formed) are \( T \)-odd. Therefore the direct \( \gamma \)-quantum formation mechanisms usually considered in quantum chromodynamics in quark–antiquark \((q + \bar{q} \rightarrow G + \gamma, q\) is a quark, \( G\), a gluon) or quark–gluon \((G + q + q + \gamma)\) interactions will not lead to these correlations (in the Born approximation normally used). The same is true for the \( \pi q \)-collision mechanism, \( \pi + q \rightarrow q + \gamma \).

The polarization states of the \( \gamma \)-quantum can be conveniently characterized by the Stokes parameters \( \xi_1 \) [9]:

\[
e_{\alpha} e_{\beta}^* = \delta_{\alpha\beta} + \frac{1}{2} \left( e_{\alpha}^{(1)} e_{\beta}^{(1)} + e_{\alpha}^{(2)} e_{\beta}^{(2)} \right) + \frac{\xi_1}{2} \left( e_{\alpha}^{(1)} e_{\beta}^{(3)} + e_{\alpha}^{(3)} e_{\beta}^{(1)} \right) -
\]

\[-\frac{i}{2} \xi_2 \left( e_{\alpha}^{(1)} e_{\beta}^{(2)} - e_{\alpha}^{(2)} e_{\beta}^{(1)} \right) + \frac{\xi_3}{2} \left( e_{\alpha}^{(1)} e_{\beta}^{(3)} - e_{\alpha}^{(3)} e_{\beta}^{(1)} \right),
\]

where \( e^{(1)} \) and \( e^{(2)} \) are independent mutually orthogonal 4-vectors, \( e^{(1,2)} \times k = 0 \).

We will assume that the 3-vector \( e^{(1)} \) is located in the plane of the reaction \( \alpha_1 + \alpha_2 + \gamma + X \), while the 3-vector \( e^{(2)} \) is orthogonal to this plane. Then for the parameters \( \xi_1 \) we obtain the following expressions in terms of the invariant structural functions:

\[
\lambda \xi_1 = P \cdot e^{(1)} E \cdot e^{(1)} (s \cdot \kappa S_3 + s \cdot p_3 S_1),
\]

\[
X = \kappa \cdot p_1 (s \cdot \kappa S_3 + s \cdot p_3 S_3),
\]

\[
X = \left| P \cdot e^{(1)} \right|^2 (W_3 + s \cdot E S_2),
\]

\[
X = W + P \cdot W + E \cdot s (S_3 - P \cdot S_3).
\]

From this it is evident, in particular, that the linear polarization of the \( \gamma \)-quantum formed is characterized by the Stokes parameter \( \xi_3 \).

3. Using the same method, polarization phenomena can also be described for \( P \)-odd effects in direct quantum formation processes. These effects may arise due to the process \( \pi + q \rightarrow \)