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Prompt photon production in the bremsstrahlung at NICA energies

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Abstract

The differential cross-section of prompt photon production in the subprocess of bremsstrahlung $qq \to qq\gamma$ of proton-proton collisions at energies $\sqrt{s}$=10 GeV has been determined without and taking into account of longitudinal polarization of colliding particles. The dependence of differential cross section of bremsstrahlung process on the energy of the colliding particles $\sqrt{s}$, the transverse momentum p_T, the cosine of the scattering angle *Cos(ϑ)*, the rapidity *y* of photon and x_T has been investigated. The ratio of the differential cross section of bremsstrahlung to the sum of the differential cross sections of Compton scattering of a quark-gluon, annihilation of a quark-antiquark pair, and bremsstrahlung is 0.03%.

Keywords: proton-proton collisions, prompt photon, bremsstrahlung
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1. Introduction

Prompt photons are produced in proton-proton collisions provide data on the development of the quark-gluon phase, the distribution of partons in nucleons, and the testing of perturbative QCD (pQCD).

Prompt photons only interact electromagnetically, their mean free path typically exceeds the transverse dimension of the region of hot matter produced by any

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nuclear collision by a significant amount.

In the energies of the European LHC or the American "Tevatron", as a result of colliding nucleons, in addition to prompt photons, numerous elementary particles are born, including mesons, thermal photons and others.

Prompt photons are produced by the hard scattering of partons in protons, as well as by Compton scattering of quark-gluon, annihilation of quark-antiquark pair and bremsstrahlung of quarks [1-3]. At LHC energies, pQCD in leading order (LO) and next-to-leading order (NLO), which predominate, is used to characterize these processes.

Our theoretical calculations were done with protons colliding at energies of $\sqrt{s}$=10 Gev, which doesn't take into account the production of extra elementary particles. Since protons colliding at energies $\sqrt{s}$=10 Gev, greatly restrict the possibility of producing extra elementary particles [4,5].

The purpose of the article is to investigate role of the bremsstrahlung to production of prompt photons in energies$\sqrt{s}$=10 Gev. In order to achieve this, the dependence of differential cross-sections of the bremsstrahlung process has been calculated without and taking into account of polarization of colliding particles.

Investigation of differential cross-section on the energy $\sqrt{s}$ of colliding protons, transverse momentum p_T, cosine of the scattering angle, and rapidity of photon has carried out.

2. Differential cross-section of $qq \to qq\gamma$ process

Collision of protons has been considered in parton model. Calculations were made in LO approximation. The prompt photon production in the bremsstrahlung process has been considered with 16 Feynman diagrams, constructed by FeynArts. Matrix elements of all diagrams have written and the following invariants of Mandelstam of process has been determined:

$$s = (p_1 + p_2)^2 = (k_1 + p_3 + p_4)^2, \qquad t = (p_1 - k_1)^2 = (p_4 + p_3 - p_2)^2,$$

$$u = (p_2 - k_1)^2 = (p_4 + p_3 - p_1)^2, \qquad q_1 = (p_1 - p_3)^2 = (k_1 + p_4 - p_2)^2,$$

$$q_2 = (p_2 - p_4)^2 = (k_1 + p_3 - p_1)^2, \qquad s_1 = (p_4 + p_3)^2 = (p_1 + p_2 - k_1)^2,$$

$$t_1 = (p_1 - p_4)^2 = (k_1 + p_1 - p_2)^2, \qquad u_1 = (p_2 - p_2)^2 = (k_1 + p_4 - p_1)^2,$$

$$q_3 = (p_3 + k_1)^2 = (p_1 + p_2 - p_1)^2, \qquad q_4 = (p_4 + k_1)^2 = (p_1 + p_2 - p_3)^2.$$

The square of matrix element of process *M* at quark mass $m_q = 0$ has been calculate in FeynCalc. Differential cross-section of process has been calculated as in [6]:

$$\frac{d\sigma}{dt} = \frac{s_1}{16\pi^2 s^4} |\bar{M}|^2$$

The longitudinal polarization of colliding protons was taken into account as in [7]:

$$U(p_1)\bar{U}(p_1) = \frac{1}{2}(1-\lambda_1\gamma_5)(\hat{p}_1+m_1),$$

$$U(p_2)\bar{U}(p_2) = \frac{1}{2}(1-\lambda_2\gamma_5)(\hat{p}_2+m_2).$$

Distribution functions of *u*-, *d* quarks and *g* gluon on *x* are taken from [8-10]:

$$G_{q/h} = A_0 x^{A_1}(1-x)^{A_2} e^{A_3 x}(1+e^{A_4}x)^{A_5},$$

$$G_{\gamma/h} = \frac{\alpha_E}{2\pi}\left(A_u e_u^2 \tilde{P}_{\gamma q} \circ u^0(x) + A_d e_d^2 \tilde{P}_{\gamma q} \circ d^0(x)\right),$$

where,

$$(P_{ab} \circ G_b)(x,\mu_F) = \int_0^1 dz \int_0^1 dy \delta(zy-x) P_{ab}(z) G_b(y,\mu_F),$$

$$\tilde{P}_{\gamma q}^{(0)}(z) = (1+(1-z)^2)/z,$$

$$A_i = ln\left(Q_0^2/Q_i^2\right)\ Q_0 = 1{,}295\ GeV, Q_u = 6\ MeV, Q_d = 10\ MeV$$

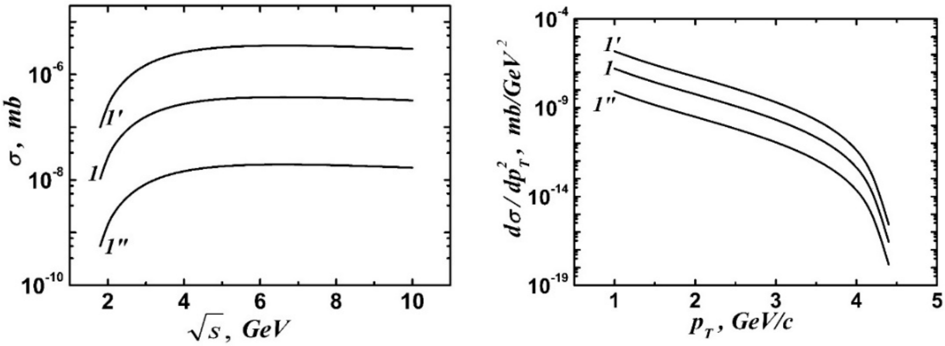
correspondingly. Values of parameters of distribution function is taken from [8].

3. Numerical calculations and discussion

The dependencies of the differential cross-sections calculated without and taking into account of polarization initial particles at the product of the helicity of the colliding particles $\lambda_1\lambda_2$=0.81 on transverse momentum are shown in Fig.1(a,b).

As sen from Fig.1(a) showed that the differential cross-section of the bremsstrahlung process increase with increasing the energy of colliding particles. At high energies of colliding particles in proton have high speed consequently, a sharp decreasing in speed due to braking will be significant. Also, it is well known that the bremsstrahlung that results is inversely proportional to the square of acceleration of particle. In the bremsstrahlung process, it is evident that high-energy particle collisions produce photons with a substantial transverse momentum. This corresponded to the saturation part of the curve of dependence of differential cross-section on the energy of the colliding particles.

As can be seen from Fig.1(b), the differential cross-section decreases with increasing values of the transverse momentum p_T and it has maximum values at low values of the transverse momentum. The interaction of particles with different polarization of spin of quark is different. The production of photons with a small transverse momentum is more likely.



a) b)

Fig. 1(a,b). The dependencies of the differential cross-section calculated without (curve 1) and taking into account of longitudinal polarization of colliding particles at $\lambda_1\lambda_2$=0.81; -0.81, correspondingly curve 1′,1′′ on the energy of colliding particles (a), transverse momentum p_T (b).

In the Fig.2 is shown the dependence of the ratio of differential cross-sections calculated without and taking into account longitudinal polarization on transverse momentum p_T.

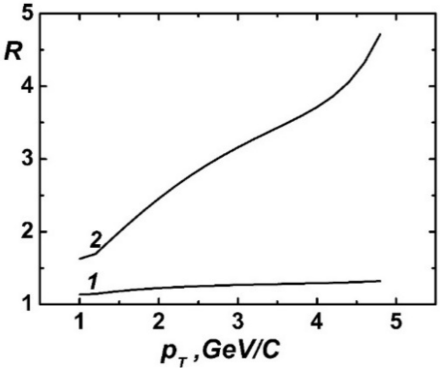
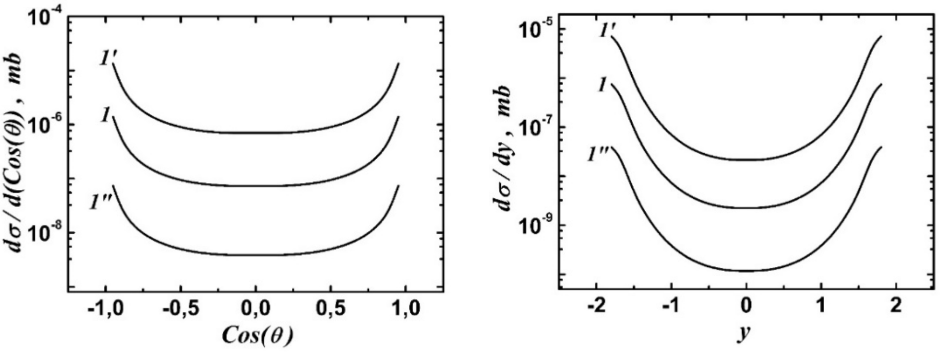


Fig. 2. The dependence of the ratio of differential cross-sections calculated without and taking into account longitudinal polarization on transverse momentum p_T, curve 1 calculated at $\lambda_1\lambda_2$=0.25, curve 2 - at $\lambda_1\lambda_2$=0.81

The ratio of differential cross-sections calculated without and taking into account longitudinal polarization increase with increasing transverse momentum p_T. At large p_T values the dependence of differential cross-section on transverse momentum calculated without polarization more strongly is chaged than the dependence of differential cross-section on transverse momentum calculated with polarization. Additionally, it should be highlighted that, as can be shown from Fig.2, the polarization order of colliding particles has effect on the differential cross-section of the bremsstrahlung process.

In the Fig.3(a,b) are shown the dependencies of the differential cross-section calculated without and taking into account polarization on cosine of scattering angle and rapidity of photon.



a) **b)**

Fig. 3(a,b). The dependencies of the differential cross-section calculated without (curve 1) and taking into account polarization at $\lambda_1\lambda_2$=0.81; -0.81, correspondingly curve 1',1'' on the cosine of scattering angle (Fig.3(a)) and rapidity of photon *y* (Fig.3(b)).

The dependence of the differential cross section on the cosine scattering angle of photon has a maximum at the exit angle 16 and 164 degrees. The photon is most likely scattered in the direction of the collision axis (Fig.3(a)).

In the large interval changing of rapidity of photon *y* value of the differential cross-section is constant. From Fig.3(b) it is clear that the value of the differential cross-section reaches its maximum near the points *y*=-1.95 and *y*=1.95 and begins to decrease with a change in the value of y. For small values of *y*, the differential cross section decreases.

In the Fig. 4 are shown the dependencies of the differential cross-sections calculated without and taking into account polarization of colliding protons on x_T.

Fig. 5 shows the dependence of differential cross-section of prompt photon production in proton-proton collisions at Compton scattering of quark-gluon, the annihilation of quark-antiquark pair and bremsstrahlung on transverse momentum p_T calculated with taking into account parton distribution function CT14QED.

As can be shown in Fig.5, the dependence of differential cross-section of Compton scattering is higher than differential cross-sections other processes. The contribution of Compton scattering to the total differential cross-section is significant (>51%). Annihilation of quark-antiquark pair and bremsstrahlung processes, correspondingly, contribute 48% and 0.03% of the total differential cross-sections production of prompt photons.

In the Fig.6 is presented the ratio of differential cross-section of annihilation and bremsstrahlung processes calculated without and taking into account longitudinal polarization.

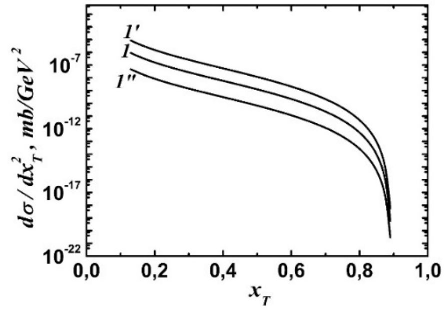


Fig. 4. The dependencies of the differential cross-sections calculated without (curve 1) and taking into account polarization of colliding protons at $\lambda_1\lambda_2$=0.81; -0.81, correspondingly curve 1',1'' on x_T.

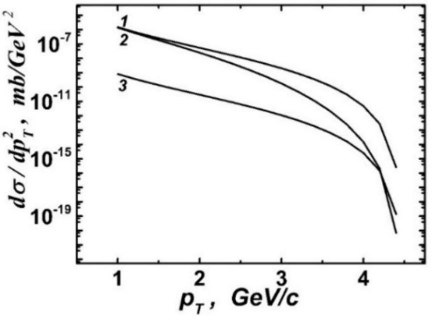
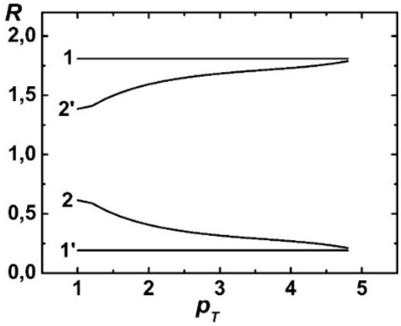


Fig. 5. The dependence of differential cross-section of prompt photon production in proton-proton collisions at Compton scattering (curve 1), the annihilation of quark-antiquark pair (curve 2) and bremsstrahlung (curve 3) on transverse momentum p_T

Fig. 6. The ratio (R) of differential cross-section of annihilation (curves 1, 1') and bremsstrahlung (curves 2, 2') processes calculated without and taking into account longitudinal polarization at $\lambda_1\lambda_2$ =-0.81 curves 1, 2 and $\lambda_1\lambda_2$ =0.81 curves 1', 2'



As seen from Fig.6 the differential cross-section of the annihilation process calculated at the negative value of polarization order (curve 1) is bigger than the differential cross-section of the process calculated at the positive value of polarization order (curve 1'), The dependence of the ratio of differential cross-sections of the annihilation process calculated with and without polarization at $\lambda_1\lambda_2$ =-0.81 and 0.81 is constant and equal to 1.81 and 0.19, correspondingly. It shows that the relation between differential cross-sections calculated with and without polarization may expressed by: $\sigma_{annhl,pol}$=(1- $\lambda_1\lambda_2$) σ_{annhl}. As seen effect of polarization to annihilation and bremsstrahlung process is different.

4. Conclusions

The differential cross-section of the bremsstrahlung process increases with increasing energy of colliding protons. This is because partons have a high speed at high energies of colliding protons and therefore a sharp decrease in speed due to braking will be significant.

The differential cross-section of the process decreases with increasing the transverse momentum of photons.

The differential cross-section has a maximum value at angles of 16^0 and 164^0 (at *y*=±1.95, correspondingly), which indicates that the produced photons are scattered at a small angle to the collision axis.

Distribution function of prompt photons produced in bremsstrahlung on transverse momentum more obliquely to the side of the larger transverse momentum p_T.

The contribution of bremsstrahlung to the total differential cross-section of the process of production of the prompt photon is 0.03% of the total differential cross-section.

Polarization of the colliding particle little affects the bremsstrahlung process and strong affects the annihilation of quark-antiquark pair process.

Investigation of energy spectrum of photons produced in the Compton scattering of quark-gluon, annihilation of quark-antiquark pair and bremsstrahlung processes showed that temperature of photons is 200, 10 MeV, correspondingly.

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