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TEST OF THE MECHANISM OF DIRECT PHOTON PRODUCTION IN πp COLLISIONS

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We propose a method of estimating the contributions of Compton and annihilation processes to the direct photon production at large p_T in πp collisions. It is based on general assumptions about composition of hadrons of quarks and gluons. An illustration of the proposed method is made by a detailed calculation using scale invariant and scale breaking structure functions.

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It has been noticed that quark–gluon Compton scattering and quark–antiquark annihilation with a gluon production (Fig. 1) can give rise to real photons at high p_T accompanied by away side jets [1]. (For other sources of direct photons see Ref. [2].) The mechanism is essentially the same as for the production of lepton pairs coming from the high mass virtual photons. The production of real direct photons in pp collisions has been calculated in Ref. [3]. The experimental evidence of the existence of real direct photons in pp collisions has been found [4] despite the large background of indirect photons from the decay of hadrons. We show here that by studying direct photon production at large or even moderate p_T in π^-p and π^+p collisions one can estimate the contributions of the Compton graph from Fig. 1a and annihilation graph from Fig. 1b for π^-p collisions. This can be done by measuring the ratio

$$R = \frac{\sigma(\pi^- p \to \gamma X)}{\sigma(\pi^+ p \to \gamma X)} = \frac{\sigma^-}{\sigma^+} \approx \frac{\sigma_C+\sigma_A^-}{\sigma_C+\sigma_A^+} \approx 1+\frac{\sigma_A^-}{\sigma_C}. \tag{1}$$

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Here $\sigma_C = d\sigma_C/dp_T^\gamma dy^\gamma$ is the contribution of the Compton graph, which is common for π^-p and π^+p collisions. Further, $\sigma_A^\mp = d\sigma_A^\mp/dp_T^\gamma dy^\gamma$ is the contribution of the annihilation graph. It is composed of two parts: (*i*) the valence–valence annihilation, σ_v^- and σ_v^+ which is different for π^-p and π^+p collisions, (*ii*) the valence–sea and sea–sea annihilation σ_s which contributes equally to both π^-p and π^+p.

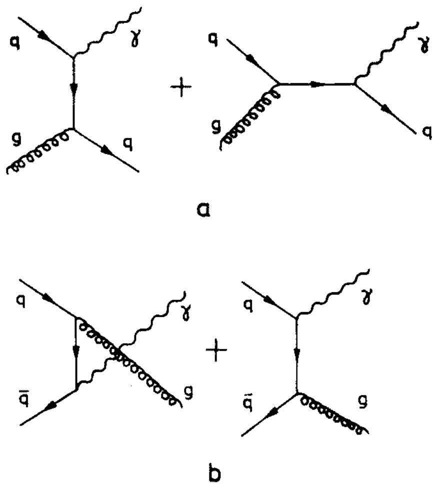

Fig. 1. Two types of elementary processes contributing to the real direct photon production in hadron–hadron collisions: a) Compton-like scattering with gluons in the initial state, b) quark pair annihilation into a photon and a gluon

The contribution to the direct photon production of the quark–quark scattering with one of the final quarks emitting a photon (qq → qqγ) was calculated in Ref. [5] and was found to be small.

In writing the relation (1) it is essential to notice that the Compton contribution σ_C dominates σ_A^+, except at p_T close to $p_{T\max}$. This follows from the standard assumption that about a half of pion momentum is taken by gluons. In the region where σ_A^+ can not be completely neglected with respect to σ_C, we expand

$$R \approx \frac{1+\sigma_A^-/\sigma_C}{1+\sigma_A^+/\sigma_C} \approx 1+\frac{\sigma_A^- - \sigma_A^+}{\sigma_C} \approx 1+\frac{\sigma_A^-}{\sigma_C} \tag{2}$$

because, due to the quark content of π^- and π^+

$$\sigma_A^- = \sigma_v^- + \sigma_s \gg \sigma_A^+ = \sigma_v^+ + \sigma_s. \tag{3}$$

We thus expect that relation (1) holds approximately over a large range of p_T. Moreover we can estimate separately σ_A^- and σ_C because

$$\sigma_C \approx \sigma^+ \tag{4}$$

so that

$$\sigma_A^- \approx \sigma^- - \sigma^+. \tag{5}$$

This is the main result of this paper. Indeed, the knowledge of contributions of the Compton and annihilation graphs gives us interesting information about direct photon production in πp collisions.

To illustrate these relations we calculated $d\sigma/dp_T^\gamma dy^\gamma$ using the graphs of Fig. 1 for the subprocesses and the proton and pion structure functions, derived from counting rules, taken from Ref. [6]

$$\frac{d\sigma}{dp_T^\gamma dy^\gamma} = p_T^\gamma \int dy \frac{c}{s\hat{s}} \left[-\left(\frac{\hat{u}}{\hat{s}} + \frac{\hat{s}}{\hat{u}}\right) g_\pi(x_2) \sum_q q_p(x_1) - \left(\frac{\hat{t}}{\hat{s}} + \frac{\hat{s}}{\hat{t}}\right) g_p(x_1) \sum_q q_\pi(x_2) + \tfrac{4}{3}\left(\frac{\hat{u}}{\hat{t}} + \frac{\hat{t}}{\hat{u}}\right) \sum_q \left(q_p(x_1)\bar{q}_\pi(x_2) + \bar{q}_p(x_1) q_\pi(x_2)\right) \right]. \tag{6}$$

Here p_T^γ and y^γ are the transverse momentum and the rapidity of the emitted photon and y is the rapidity of the away side jet. Furthermore

$$c = \frac{2\pi}{3}\alpha\alpha_s, \quad \alpha_s = \tfrac{12}{25}\pi/\ln\left(\frac{\hat{s}}{\lambda^2} + \lambda_1\right), \quad x_1 = \frac{p_T^\gamma}{\sqrt{s}}(e^y + e^{y^\gamma}),$$

$$x_2 = \frac{p_T^\gamma}{\sqrt{s}}(e^{-y} + e^{-y^\gamma}), \quad \hat{s} = x_1 x_2 s, \quad \hat{t} = -p_T^{\gamma 2}(1 + e^{y^\gamma - y}),$$

$$\hat{u} = -\hat{s} - \hat{t}, \quad \lambda^2 = 0.5\ \mathrm{GeV}^2, \quad \lambda_1 = 1. \tag{7}$$

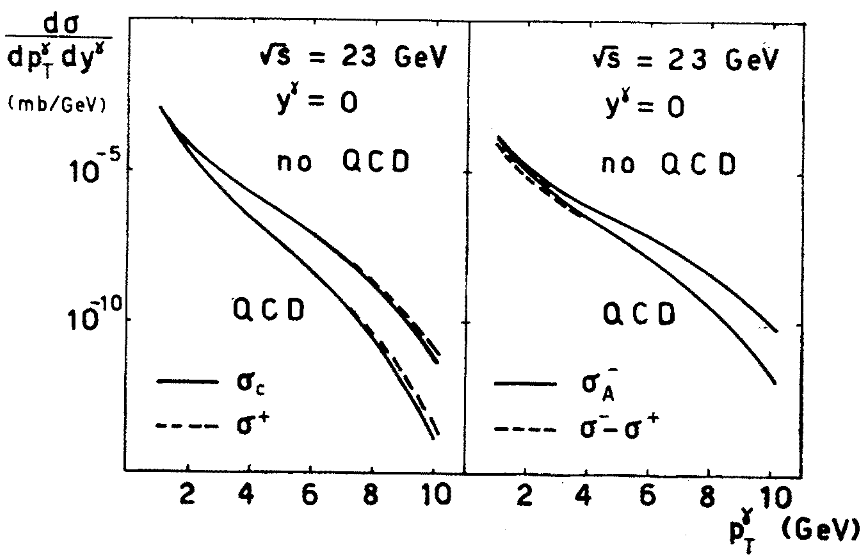

Fig. 2. Comparison between predicted and calculated values of σ_C and σ_A^- from the model described in the text: a) σ_C (continuous line) and σ^+ (broken line), b) σ_A^- (continuous line) and $\sigma^- - \sigma^+$ (broken line). Upper curves correspond to the calculation with the scale invariant structure functions and lower curves correspond to the calculation with the scale breaking structure functions according to QCD

The scale variable Q^2 was taken here to be equal to $\hat{s}$, the total energy squared of the elementary process.

The first two terms of the integrand in Eq. (6) represent the Compton scattering and the last term the annihilation. The difference between π^-p and π^+p collisions is contained in the structure functions $q_\pi(x_2)$.

The comparison of σ_C and σ^+ at $\sqrt{s} = 23$ GeV and $y^\gamma = 0$ is made in Fig. 2a for scale invariant and scale breaking structure functions. The agreement with Eq. (4) is good, except at large values of p_T. Introducing the scale breaking strongly decreases the cross section (cf. Ref. [3]) but σ_C and σ^+ remain close to each other.

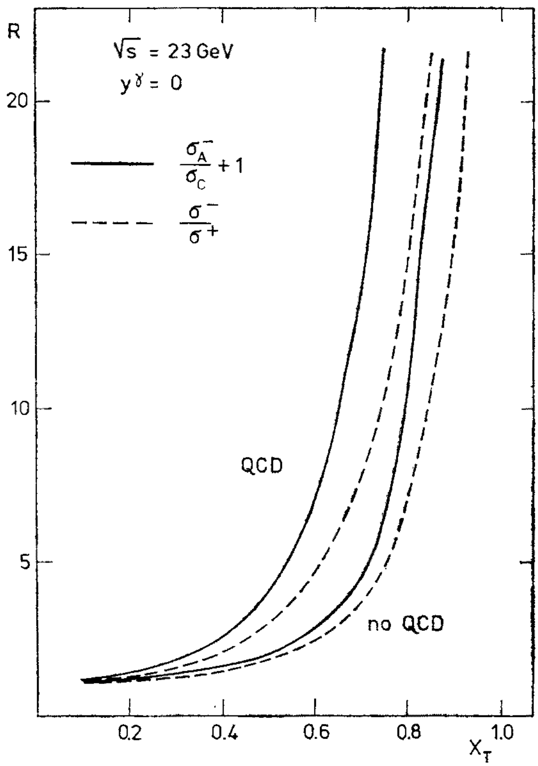

Fig. 3. Comparison between the ratio of direct photons produced in π^-p and π^+p collisions (broken line) and $1+\sigma_A^-/\sigma_C$ (continuous line). Upper pair of curves corresponds to the calculation with the scale breaking structure functions according to QCD and lower pair of curves corresponds to the calculation with the scale invariant structure functions

Similarly, in Fig. 2b we plot σ_A^- and compare it with $\sigma^- - \sigma^+$. The agreement with Eq. (5) is very good except at very small p_T. We have also made similar checks for $\sqrt{s} = 63$ and 800 GeV and various values of y^γ. We conclude that relations (4) and (5) are well satisfied over a large range of p_T^γ, $\sqrt{s}$ and y^γ.

In Fig. 3 we plot the ratio of direct photons produced in π^-p and π^+p collisions and $1+\sigma_A^-/\sigma_C$ as suggested by Eq. (1). For the scaling structure functions the agreement with

Eq. (1) is reasonably good and the curves do not depend on energy. The discrepancy for the scale violating structure functions can be explained by the fact that in standard parametrizations the glue distribution fastly decreases with scaling variable Q^2, and gluons do not carry about a half of hadron momentum anymore, even at moderate values of Q^2. We have also made calculation for $\sqrt{s} = 63$ and 800 GeV and we found similar tendencies.

Moreover let us add that for the annihilation graph (Fig. 1b) the valence–valence annihilation σ_v^- dominates for all values of p_T for π^-p collisions, whereas in π^+p the valence–sea and sea–sea annihilations σ_s dominate at small p_T and σ_v^+ at large p_T. This means that one can use $\sigma_A^- \approx \sigma_v^-$ to determine the valence quark distribution in the pion.

Finally we remark that the πp collisions may be a better reaction to look for real direct photons than the pp collisions because of the larger cross section.

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REFERENCES

[1] R. Rückl, S. J. Brodsky, J. F. Gunion, *Phys. Rev.* **D18**, 2469 (1978); F. Halzen, D. F. Scott, *Phys. Rev.* **D18**, 3378 (1978); F. Halzen, Proc. 19th Int. Conf. High Energy Physics, Tokyo 1978, p. 214; D. Jones, R. Rückl, *Phys. Rev.* **D20**, 232 (1979).

[2] C. O. Escobar, *Nucl. Phys.* **B98**, 173 (1975); E. L. Feinberg, *Nuovo Cimento* **34A**, 391 (1976); G. R. Farrar, S. C. Frautschi, *Phys. Rev. Lett.* **36**, 1017 (1976); H. Fritzsch, P. Minkowski, *Phys. Lett.* **69B**, 316 (1977).

[3] A. P. Contogouris, S. Papadopoulos, M. Hongoh, *Phys. Rev.* **D19**, 2607 (1979).

[4] P. Darriulat et al., *Nucl. Phys.* **B110**, 365 (1976); E. Amaldi et al., *Phys. Lett.* **84B**, 360 (1979); M. Diakonou et al., *Phys. Lett.* **87B**, 292 (1979) and talk by C. W. Fabjan at the EPS Geneva Conference 1979.

[5] P. Aurenche, J. Lindfors, preprint TH.2768-CERN.

[6] J. F. Owens, E. Reya, *Phys. Rev.* **D17**, 3003 (1978).