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Diffractive production of high p_t photons at a future linear collider

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Abstract

We examine the prospects for studying the diffractive production of high p_t photons in the process $\gamma\gamma \to \gamma X$ at a future linear collider operating in both ee and $\gamma\gamma$ modes. The high luminosity associated with a linear collider make it the ideal place to measure this process.

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1 Introduction

In the pursuit to understand diffraction in strong interactions it is sensible to focus on those rapidity gap processes that we are in principle able to compute reliably, i.e. using QCD perturbation theory. Of all such processes, diffractive high p_t photon production stands out as the one most accessible to perturbation theory. The process can already be studied at HERA via $\gamma p \to \gamma X$ where the final state photon is well separated in rapidity from the debris of the proton, X [1, 2, 3, 4]. Note that it is not necessary to measure the system X and that this enhances the reach in rapidity significantly. We shall show that the equivalent process can be studied at proposed future high energy e^+e^- and $\gamma\gamma$ colliders with much higher event rates. Note that the process $\gamma\gamma \to \gamma\gamma$ is in principle also possible. However, the rates for this process are probably too low even for a future linear collider and we do not consider it further. We also remark that the current LEP collider is not able to measure either of these processes due to insufficient luminosity. For a much more detailed account of most of the results presented here, we refer to [5].

Theoretical interest in the process $\gamma\gamma \to \gamma X$ dates back to the work of [6] where calculations were performed in fixed order perturbation theory and to lowest order in α_s. Recent work has extended this calculation to sum all leading logarithms in energy, for real incoming photons [2] and for real and virtual incoming photons [3, 5]. The cross-section for relevant hard subprocess, $\gamma q \to \gamma q$, can be written

$$\frac{d\sigma_{\gamma q}}{dp_t^2} \approx \frac{1}{16\pi \hat{s}^2} |A_{++}|^2 \tag{1}$$

and we have ignored a small contribution that flips the helicity of the incoming photon. The photon-quark CM energy is given by $\hat{s}$. To leading logarithmic accuracy [2, 3]

$$A_{++} = i\alpha\alpha_s^2 \sum_q e_q^2 \frac{\pi}{6} \frac{\hat{s}}{p_t^2} \int_{-\infty}^{\infty} \frac{d\nu}{1+\nu^2} \frac{\nu^2}{(\nu^2+1/4)^2} \frac{\tanh \pi\nu}{\pi\nu} F(\nu)\, \mathrm{e}^{z_0 \chi(\nu)} \tag{2}$$

where

$$z_0 \equiv \frac{3\alpha_s}{\pi} \log \frac{\hat{s}}{p_t^2}, \tag{3}$$

$\chi(\nu) = 2(\Psi(1) - \mathrm{Re}\Psi(1/2 + i\nu))$ is the BFKL eigenfunction [7], $F(\nu) = 2(11 + 12\nu^2)$ for on-shell photons and there is a sum over the quark charges squared, e_q^2. The full photon-photon cross-section is obtained after multiplying by the photon parton density functions:

$$\frac{d\sigma_{\gamma\gamma}}{dx dp_t^2} = \left[\frac{81}{16} g(x,\mu) + \Sigma(x,\mu)\right] \frac{d\sigma_{\gamma q}}{dp_t^2} \tag{4}$$

and we take the factorization scale $\mu = p_t$. Throughout we take $\alpha_s = 0.2$, as indicated by HERA and Tevatron data [8].

The larger z_0, the larger the rapidity gap between the outgoing photon and the system X. Since

$$z_0 \approx \frac{3\alpha_s}{\pi} \Delta\eta.$$

For $z_0 \gtrsim 0.5$ one begins to access the most interesting Regge region [9].

$\int dt\ \mathcal{L}_{ee} = 50$ fb^{-1}		
θ_γ mrad	σ pb	Events
$\sqrt{s_{ee}} = 500$ GeV		
100	0.14	6.9k
200	0.027	1.4k
300	0.0066	0.3k
$\sqrt{s_{ee}} = 1$ TeV		
100	0.41	21k
200	0.088	4.4k
300	0.021	1.0k

Table 1: The integrated cross-section and number of events for $ee \to ee\gamma X$ at a future linear collider.

2 Results: e^+e^- mode

Since it is not possible to measure this process at LEP, we turn our attention immediately to a future linear collider operating in e^+e^- mode and at $\sqrt{s} = 500$ GeV and $\sqrt{s} = 1$ TeV. We impose three different cuts on the minimum angle (θ_γ) of the emitted photon and make a cut to ensure that its energy is above 5 GeV. Our results are insensitive to this photon energy cut since we also impose a cut on the subprocess centre-of-mass energy: $\hat{s} > 10^3$ GeV^2. This cut is not easy to implement experimentally, but is essentially related to the size of the final state rapidity gap. Making this cut ensures that z_0 is large, i.e. the photon and the system X are well separated. We also make an anti-tag cut on the outoing electron and positron, i.e. we insist that they be emitted at angles less than 100 mrad. When quoting event rates, we assume a total integrated luminosity of 50 fb^{-1}. In all cases, we show the cross-section integrated over the p_t of the emitted photon subject to the constraint 1 GeV $< p_t <$ 10 GeV and over the invariant mass of the system X subject to $M_X <$ 10 GeV. The photon flux of [10] and the photon parton density functions of [11] were used. Our results are summarized in Table 1.

The range of z_0 values accessible to a future linear collider are restricted by the requirement that the photon appear in the detector. However, one does gain by going to higher beam energies since the dissociated system X does not need to be seen. In this sense optimal configurations involve a relatively soft photon colliding with a hard photon. For the scenarios presented in the table, we find $0.4 < z_0 < 1.8$ which is well into the region of interest. Due to the softness of the bremsstrahlung photon spectrum one gains appreciably in rate by progressing to higher beam energies. Note the very strong dependence upon the minimum angle of the detected photon.

3 Results: $\gamma\gamma$ mode

Next we turn to the photon collider. For the flux of photons we use typical parameters [12]: $x = 4.8$, $P_c = -1$ (i.e. negative helicity laser photons) and $2\lambda = 1$ (i.e. 100% longitudinally polarized electron

$\int dt\ \mathcal{L}_{ee} = 50$ fb^{-1}		
θ_γ mrad	σ pb	Events
$\sqrt{s_{ee}} = 500$ GeV		
100	1.32	66k
200	0.20	10k
300	0.045	2.3k
$\sqrt{s_{ee}} = 1$ TeV		
100	1.40	70k
200	0.22	11k
300	0.048	2.4k

Table 2: The integrated cross-section and number of events for $ee \to ee\gamma X$ at a future photon collider.

and positron beams). The choice $2\lambda P_c = -1$ leads to a hard photon spectrum:

$$\int_{0.65}^{z_{max}} dz \frac{d\mathcal{L}_{\gamma\gamma}}{dz} = 30\% \tag{5}$$

where $z_{max} = x/(x+1)$, $z = W_{\gamma\gamma}/\sqrt{s}$ ($\sqrt{s}/2$ is the electron beam energy) and the integral down to $z = 0$ is defined to give unity. We use the photon flux of [13] and normalize it to obtain the e^+e^- cross-section using the "rule of thumb" $\mathcal{L}_{\gamma\gamma}(z > 0.65) \approx 0.15\ \mathcal{L}_{ee}$ [12]. In particular the e^+e^- rate is determined using

$$\sigma_{ee} = \frac{0.15}{0.30} \int_0^{z_{max}^2} d\tau \int_{\tau/z_{max}}^{z_{max}} dy\ f(y,\tau)\ \sigma_{\gamma\gamma} \tag{6}$$

where

$$\frac{d\mathcal{L}_{\gamma\gamma}}{d\tau} = \int_{\tau/z_{max}}^{z_{max}} dy\ f(y,\tau) \tag{7}$$

and $\tau = z^2$. We are able to use a single photon luminosity function since the $\gamma\gamma$ cross-section is independent of the photon helicity (for transverse photons).

Table 2 shows our results for the photon collider, assuming the same cuts as in the previous section.

The z_0 range for the photon collider is similar to that for the e^+e^- collider, i.e. for the events in Table 2 $0.4 < z_0 < 1.8$. For the photon collider, the photon spectrum is not soft. This means that ultimately the rate depletes as the beam energy increases. This can be seen in the table where the 500 GeV and 1 TeV rates are similar. Going to higher beam energies leads to a slow reduction in rate (however the typical z_0 range does still move to higher values). For example, at a 5 TeV collider the cross-section is 1.4 pb and the z_0 range is $0.5 \sim 2$ ($\theta_\gamma = 0.1$). The drop in rate as one increases the detected photon angle is even more dramatic than in the e^+e^- mode and is a consequence of the harder photon spectrum.

One can imagine further improving the capabilities of the photon collider by arranging to use one soft photon spectrum and one harder spectrum. The harder photon dissociates into a very forward system whilst the softer photon is easier to scatter into the detector. One way to do this would be to operate the photon collider with $2P_c\lambda = +1$ to produce the softer spectrum and $2P_c\lambda = -1$ for the harder spectrum. Even better would be to operate in the $e\gamma$ mode where a soft bremsstrahlung photon is made to collide with a hard Compton photon.

4 Summary

A linear e^+e^- collider operating at 500 GeV and beyond is the ideal place to study the diffractive production of high p_t photons via $\gamma\gamma \to \gamma X$. It will have the capacity to provide very important information in abundance on the short distance domain of large rapidity gap physics. Operating in the photon collider mode offers the opportunity to further enhance the rate. In all cases, the rate grows rapidly with decreasing angle of the detected photon.

This short note has focussed on the production of high p_t photons. Also of tremendous interest is the production of high p_t vector particles in general, e.g. ρ, ω, ϕ and J/Ψ. These processes would also occur in abundance at a future linear collider.

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