Isolated-Photon Production in Polarized Hadronic Collisions

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After a short discussion on the definition of isolated-photon cross sections in perturbative QCD, I present phenomenological predictions relevant for polarized hadron-hadron collisions in the RHIC energy range. The possibility of measuring Δg is investigated.

1. PHOTON ISOLATION IN pQCD

The production of photons in hadronic collisions is quite interesting under two different aspects. Since the photon couples directly only to quarks, photon signals can be used to study the hard dynamics in a cleaner way with respect to processes where only hadrons are involved; the obvious drawback is that prompt-photon cross sections are much smaller than - say - jet cross sections. Secondly, photon data constitute an unique tool for pinning down the gluon density at intermediate and large x, since the number of partonic processes involved is smaller with respect to other processes which are equally or more sensitive to the gluon density. Unfortunately, the real situation is much worse than that described above. The main reason is that in a complicated environment, like that arising in high-energy hadronic collisions, there are lots of photons around, mainly coming from the decay $\pi^0 \to \gamma\gamma$. This is a huge background, since the two photons are often detected as a single one. However, the signature of photons coming from hadron decays is rather different from that of prompt photons, the mother hadron being usually surrounded by other hadrons. Therefore, photons originating from decays have the same direction of a relatively large number of hadrons. It follows that an efficient way of selecting prompt-photon events is that of requiring the photon to be *isolated* from hadron tracks in the detector. There is also a further complication: photons can originate from fluctuations of hadrons with the same quantum numbers. Perturbative QCD is not able to deal with hadrons, and the fluctuation of a hadron into a photon is effectively described by the (non-perturbative) fragmentation of a parton into a photon. The cross section for the process $H_1 H_2 \to \gamma + X$ is therefore written as follows

$$\sigma_\gamma^{(H_1 H_2)} = f_i^{(H_1)} \otimes f_j^{(H_2)} \otimes \hat{\sigma}_{ij;\gamma} + f_i^{(H_1)} \otimes f_j^{(H_2)} \otimes \hat{\sigma}_{ij;k} \otimes D_\gamma^{(k)}. \qquad (1)$$

The first term in the RHS of this equation describes the production of photons in the hard process $ij \to \gamma + X$ (direct mechanism), while in the second term (fragmentation mechanism) the hard process is $ij \to k{+}X$, with the parton k eventually fragmenting into a photon, in a way parametrized by the fragmentation function (FF) $D_\gamma^{(k)}$, which is not calculable in perturbation theory but is universal. Of course, the fragmentation mechanism does not give any clean information on the parton dynamics. However, the photon produced in this way will be close to the hadron remnants; therefore, the isolation condition will reduce the contribution of the fragmentation mechanism to the physical cross section.

The key question is: how much? In fact, in perturbative QCD the direct and fragmentation parts are very closely related, since there are divergences that cancel only when these two contributions are summed together. From the phenomenological point of view this is annoying, since it is difficult to estimate the impact of the very poorly known FFs on prompt-photon analyses. However, there exists at least one isolation prescription [1] which is such that the contribution of the fragmentation part to the physical observables is exactly zero, and still the cross section is finite at all orders in perturbation theory. The isolation condition is as follows: drawing a cone of half-angle R_0 around the photon axis (in the $\eta-\phi$ plane), and denoting by $E_{T,had}(R)$ the total amount of transverse hadronic energy inside a cone of half-angle R, the photon is isolated if the following inequality is satisfied:

$$E_{T,had}(R) \leq \epsilon_\gamma p_{T\gamma} \mathcal{Y}(R), \qquad (2)$$

for all $R \leq R_0$. Here, $p_{T\gamma}$ is the transverse momentum of the photon. The function $\mathcal{Y}$ can be rather freely chosen, provided that it vanishes fast enough for $R \to 0$. A sensible choice is the following:

$$\mathcal{Y}(R) = \left(\frac{1-\cos R}{1-\cos R_0}\right)^n, \quad n=1, \quad \epsilon_\gamma = 1. \qquad (3)$$

Notice that the ordinary cone isolation can be recovered from eqs. (2) and (3) by setting $n=0$ and $\epsilon_\gamma = \epsilon_c$. I also stress that the same prescription can be applied, with trivial modifications, to any other type of hard collisions. It has been shown that this definition of isolated photon leads to an infrared-safe cross section in perturbative QCD. More details can be found in ref. [1].

2. ISOLATED PHOTONS AT RHIC

The arguments of the previous section apply to both polarized and unpolarized collisions. In the following, I will present phenomenological predictions relevant for isolated-photon production in polarized hadronic collisions, in the RHIC energy range ($\sqrt{S} = 200 \div 500$ GeV). The results are accurate to NLO in QCD. Studies of unpolarized hadronic collisions, for higher center-of-mass energies, have been presented elsewhere [2]. The computer code used here is a modification of that of ref. [2]. I start from considering the perturbative stability of isolated-photon cross sections. This is an important issue to study, since it is well known that the isolation cuts result in an imperfect cancellation of soft singularities, which might lead to unreliable perturbative results. As customary when a NNLO calculation is lacking, the perturbative stability is studied looking at the variation of the cross section induced by the variation of the factorization and renormalization scales with respect to a default scale μ_0. A sample result is given in fig. 1, where the p_T spectrum of the photon is presented. From the figure, we can see that the size of the radiative corrections is moderate, and the scale dependence is milder at NLO than at LO. Only the renormalization scale has been varied; the dependence of the cross section upon the factorization scale is small at LO, and is basically zero at NLO. Other observables have been studied as well, and they display the same pattern of scale dependence as the p_T spectrum presented in fig. 1. Results for unpolarized scattering (of relevance since the measurable quantities are asymmetries rather than absolute cross sections) have also been obtained, and they are consistent with their polarized counterpart. In summary, it seems that the perturbation series in the case of isolated photons defined as in eq. (2) is under control, and NLO results can be used to perform a sensible phenomenological study.

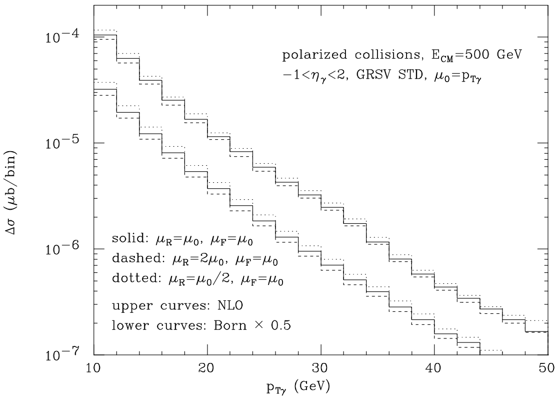

Figure 1. Scale dependence of the p_T spectrum.

The main goal of collecting isolated-photon data at RHIC will that of measuring the gluon density Δg in the polarized proton. This quantity is to a large extent unknown at present, and the various available parametrizations are very different from each other. The isolated-photon cross section is much smaller than, for example, the single-inclusive jet cross section (using GRSV STD densities [3], default scales and $\sqrt{S} = 500$ GeV, the former is 2.9 10^{-4} μb in the range $p_{T\gamma} > 10$ GeV, $-1 < \eta_\gamma < 2$, while the latter is 3.4 10^{-1} μb in the range $p_{Tj} > 10$ GeV, $-1 < \eta_j < 1$). Therefore, although in principle a measurement of Δg performed with photon events is cleaner and simpler (the cross section at LO depends linearly upon Δg, while in the jet case the dependence is quadratic), it remains to see whether in practice the sensitivity to Δg will be large enough to allow a discrimination between the various parametrizations. This issue is studied in fig. 2, where the $p_{T\gamma}$ dependence of the longitudinal asymmetry is presented. The asymmetry has been calculated for three different sets of polarized parton densities: GRSV STD, GRSV MAXg [3], and GS-C [4]. The latter two sets represent quite an extreme choice: all the other available densities return an asymmetry whose value is larger than that obtained with GS-C and smaller than that obtained with GRSV MAXg. For the three asymmetries, the MRST set [5] has been adopted to compute the unpolarized cross section. Fig. 2 also displays the minimum observable value of the asymmetry:

$$(\mathcal{A}_{p_T})_{min} = \frac{1}{P^2}\frac{1}{\sqrt{2\sigma\mathcal{L}\epsilon}}, \tag{4}$$

where $\mathcal{L}$ is the integrated luminosity, P is the polarization of the beam, and the factor $\epsilon \leq 1$ accounts for experimental efficiencies; σ is the unpolarized cross section integrated over a small range in transverse momentum (p_T bin). The quantity defined in eq. (4) is plotted (dot-dashed line) in fig. 2, for $\epsilon = 1$, $P = 1$, $\mathcal{L} = 100$ pb^{-1} and a p_T-bin size of 2 GeV. Taking into account that RHIC expects to collect a luminosity much higher than 100 pb^{-1}, that a value of $P = 0.7$ is realistic, and hoping for detector performances such that $\epsilon \simeq 1$, we see from the figure that the asymmetry is measurable at the lowest $p_{T\gamma}$ values, regardless of the polarized density set adopted. The measurement is increasingly difficult for larger $p_{T\gamma}$, probably becoming impossible for transverse momenta of the order of $40 \div 50$ GeV. At $\sqrt{S} = 200$ GeV asymmetries are larger, but $(\mathcal{A}_{p_T})_{min}$ is also larger, and the conclusions are unchanged.

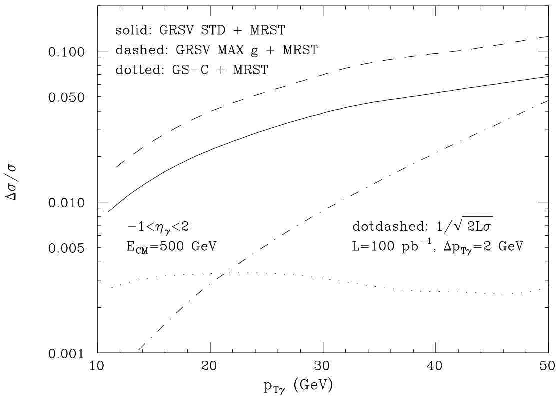

Figure 2. Asymmetry versus $p_{T\gamma}$. The minimum observable asymmetry is also shown.

In summary, I presented NLO results for photon production in polarized hadronic collisions, the photon being isolated in a way such that the cross section does not depend upon the fragmentation part. A more complete discussion will be given elsewhere [6]. Phenomenological predictions have been given for the RHIC energy range. It has been shown that the perturbative series is under control, and that isolated photon production at RHIC will be a viable tool in the study of the polarized parton densities.

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