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M. Greco: BACK-TO-BACK JETS AS A TEST OF THE THREE GLUON COUPLING

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ABSTRACT

The study of the relative transverse momentum distributions of back-to-back jets produced at the Sp$\bar{p}$S collider is suggested to provide a clean test of gluon-gluon dynamics.

Hadron production with large transverse energy (E_T) has been investigated by recent experiments[1-5] in a wide range of c.m. energies (20 GeV $\lesssim \sqrt{s} \lesssim$ 540 GeV). The increasing dominance of jet production at sufficiently large E_T has been clearly observed in ISR experiments[6-7] and, more dramatically, at the CERN Sp$\bar{p}$S collider[5-8]. The dynamics of parton-parton hard scattering clearly emerges at this highest energy and indeed the experiments confirm[9] the simple one gluon exchange mechanism predicted by perturbation QCD to lowest order in the strong coupling constant α_s.

An additional firm prediction of QCD is that in the hard scattering process between the hadron constituents (quarks and gluons) a fraction of the initial parton subenergy is released in form of soft radiation. This idea has been extensively studied in Drell-Yan processes and in the production of vector bosons in hadron hadron collisions, in particular for the case of the transverse momentum distributions[10,11]. Here the effect is quite subtle, since all order terms on α_s need to be taken into account. Fortunately resummation techniques can be reliably applied. Then the resulting theoretical predictions have been successfully tested[12] in a very wide range of energies. Similar ideas have also been applied[13-15] to purely hadronic processes, by considering the soft radiation associated to hard parton subprocesses.

A further important test of these ideas, and in particular of the different radiation properties of quarks and gluons, is provided by the study of the QCD radiation accompanying two back-to-back jets produced at the $p\bar{p}$ collider energies[14]. In fact the gluon-gluon scattering gives there the dominant contribution to jet production, in contrast to the case of weak boson production where only the quarks play an essential role. Therefore one encouters a unique testing ground for QCD predictions concerning the process of bremsstrahlung initiated by gluons.

In the present work we discuss the relative k_T distribution of two back-to-back jets at the collider energies, in order to get a direct evidence for the three gluon coupling, one of the most striking QCD predictions. The basic idea is that the Sudakov form factor, which regulates the two gluon jets k_T-distribution, depends upon C_A ($C_A = 3$), in contrast to the case of electroweak pairs produced in the annihilation of q and $\bar{q}$, which is related to C_F ($C_F = 4/3$). Of course this observation only reflects the well known fact that gluons radiate more than quarks.

Based on the factorization property of soft emissions in gauge theories[17] and on the resummation techniques of the perturbation series in the improved double leading logarithmic approximation[18] we write for the soft transverse momentum distribution in the subprocess

$p_i(x_1) + p_j(x_2) \rightarrow p_\ell + p_m + X$

$$\frac{1}{\sigma_o} \left. \frac{d\sigma(x_1, x_2)}{dk_T^2} \right|_{ij \rightarrow lm} \simeq$$

$$\simeq \frac{1}{2}\int b\, db\, J_o(bk_T)\exp\left[S_{ij}(b, q_{Tmax})\right]\left[F_i(x_1, \frac{1}{b^2})F_j(x_2, \frac{1}{b^2})\right] \tag{1}$$

where k_T is the relative transverse momentum of the partons p_ℓ and p_m - the two final jets - i.e. $k_T = p_{\ell T} + p_{mT}$, and σ_o is the Born cross section of the hard subprocess, integrated over the phase space of the emerging jets. Furthermore the parton densities $F_{i,j}$ are taken at the scale $\sim 1/b^2$), and the Sudakov form factors are given by

$$S_{ij}(b, q_{Tmax}) = \frac{1}{\pi}\int_0^{q_{Tmax}} \frac{dq}{q}(L_i + L_j)\,\alpha(q)\left[J_o(bq) - 1\right] \tag{2}$$

with $L_i = c_i\left[\ln(\frac{s}{q^2}) - a_i\right]$, $c_i = C_{F,A}$, $a_i = 3/2$, $(\frac{11}{6} - \frac{N_f}{9})$ for quarks and gluon respectively/19/. We have taken $N_f = 3$, which leads to $a_a = a_g = 3/2$. Finally $q_{Tmax} = \frac{\sqrt{s}}{2}(1 - M^2_{lm}/s)$, where $s = Sx_1x_2$ is the initial parton energy squared and M^2_{lm} is the invariant mass squared of the final parton system.

Experimentally, a jet is usually defined as a sizeable fraction of the total energy deposited within a certain cone, aligned along the axis of the parent parton. This definition automatically leads to include inside the cone the radiation emitted from the final parton. This observation explains the appearence in eq. (1) of the Sudakov form factors corresponding to the initial partons only.

Then for the reaction of interest $p\bar{p} \to J_1J_2 + X$, with $M^2_{J_1J_2}$ fixed, one has to appropriately sum eq. (1) over the initial and final parton states and integrate over x_1 and x_2. As stated above, because of the dominance of gluon-gluon interactions at collider energies, the resulting distribution mainly tests terms depending on $c_i + c_j = 2C_A$ in eq. (2), in contrast to the case of electroweak pair production, where only the term corresponding to $c_i + c_j = 2C_F$ is essentially playing a role. The theoretical prediction given above does not include finite terms of order α_s, coming from hard gluon bremsstrahlung and virtual one loop correc tions, which have not been all computed so far. From the previous experience[11] in the case of the k_T distributions of weak boson at collider energy, our result should be sufficiently accurate up to $k_T \sim 20$GeV, where hard effects could start to be sizeable.

In order to proceed further, we have still to specify the parton densities. While the quark distributions are rather well established, we will use two different forms for the less well known gluon density, which drastically differ at large Q^2, in order to check the uncertainties of the theoretical prediction. The first parametrization used (called I) has been proposed by Glück et al.[20], and is often adopted in the literature. The second one (called II) has been given by the CDHS group[21] and leads to a much more sizeable glue at large Q^2.

Our predictions are shown in Fig. 1 for a di-jet mass $M_{JJ} = 60$ GeV. A variation of M_{JJ} in the range 40-80 GeV does not change appreciably the result. On the other hand the dependence on the gluon distribution function is also tolerable, as clearly seen from the figure. In order to show the size of the effect of gluon-gluon dynamics, we also compare in Fig. 1 the previous prediction with the hypotethical case where gluons, described by the usual distribution I, radiate like quarks, namely all $c_i = C_F$ in eqs. (1-2), including the Born cross sections. Clearly the effect is sizeable.

In conclusion we have shown that the observation of the relative k_T distribution of back-to-back jets at the $p\bar{p}$ collider can provide a sensible test of gluon-gluon dunamics.

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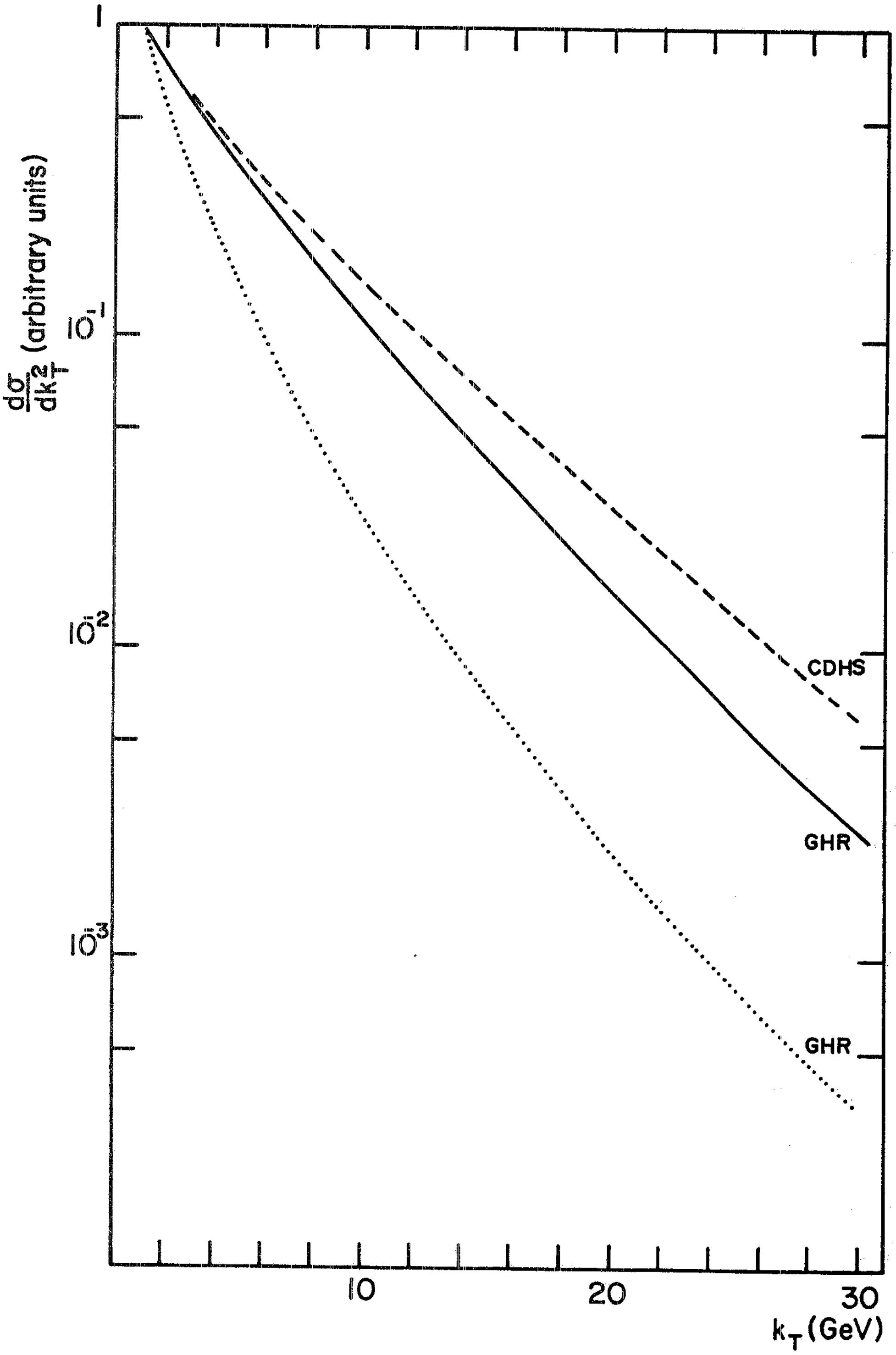

FIG. 1 - $d\sigma/dk_T^2$ versus k_T: (i) full line: gluon distribution function according to parametrization I; (ii) dashed line: gluon distribution function according to parametrization II; (iii) dotted line: gluon distribution function I, with $C_A = C_F$ in eqs. (1-2), see text.

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