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HIGH E_T JETS AND DOUBLE SCATTERING

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The recently found excess of high E_T jets over current QCD predictions is attributed to gluon radiation at double scattering process inside a nucleon. The order of magnitude estimate of the cross section fits experimental findings rather well. The specific features of the process are discussed. Various similar hadronic effects related to the short radiation length are described.

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It has been recently found [1] that the experimental cross section for high E_T jets is significantly higher than current QCD predictions. It is appealing to ascribe this excess to "new" physics, in particular, to new contact terms in the Lagrangian at the scale of lengths $10^{-16}-10^{-17}$cm corresponding to transverse jet energies $E_T \geq 200$ GeV. As the authors of [1] claim, however, such an appeal "is not defensible" until other traditional mechanisms are fully taken into account.

We propose the gluon radiation at double scattering process as the candidate for such a mechanism. It has not yet been taken into account in current QCD fits. The short radiation length of an impinging quark suffering two subsequent collisions inside a hadron target is in charge of high E_T gluon radiation. Here, we provide the order of magnitude estimates only. The more detailed treatment will be published elsewhere.

First, let us give some qualitative arguments in favor of it. In the target rest system, the proton with energy $E_L \sim 1.8 \cdot 10^6$ GeV hits the antiproton at rest ($E_{c.m.} \sim 1.8$ TeV), and one of its quarks scatters twice on antiquarks located at the distance $l \sim 1$ Fm. The first scattering can trigger the emission of a virtual gluon which moves, in this system, at the angle of the order of $10^{-3}-10^{-4}$ to the primary direction of the quark. For the real particles it would mean the c.m.s. angle close to $\pi/2$, i.e. small c.m.s. pseudorapidity. Thus, it "separates" from the quark to the transverse distance $(10^{-3}-10^{-4})l \sim 10^{-16}-10^{-17}$cm when the quark suffers another scattering. To resolve such a structure, it should be large transverse momentum ($q_T > 200$ GeV) scattering. Only then the gluon can be created as a hadron jet. Such a scattering is a rare process, and, consequently, the probability of gluon radiation at high E_T is strongly suppressed. It can nevertheless become larger than traditional QCD probabilities which do not take into account the double scattering radiation.

Electrodynamics analogies are helpful to elucidate the main features, and they were previously used by the author [2-4]. However, the upper bounds for probabilities were only obtained because no averaging procedure of the scattering process was invoked. At high E_T, they strongly overestimate the real probabilities as shown below. In what follows, for the order of magnitude estimates we shall adopt the soft processes approximation taking into account the large transverse momenta in the averaging procedure only. This is justified until transverse energy becomes high enough to impose the energy conservation limits.

As well known in electrodynamics [5], the total amplitude for soft radiation induced by multiple scattering factorizes into the elastic scattering amplitude and the radiation amplitude. Recently, it was considered in detail in papers [6-10] with possible extension to QCD. We adopt here this analogy (see [2-4, 6-8]). The radiation cross section can be written as

$$\frac{\omega}{\sigma}\frac{d^3\sigma}{d^3k} = \frac{\alpha_c C_F}{\pi^2\omega^2}\langle|\sum_{i=1}^{N}\mathbf{J}_i|^2 + 2\mathrm{Re}\sum_{i=1}^{N}\sum_{j=i+1}^{N}\mathbf{J}_i\mathbf{J}_j(e^{ik(x_i-x_j)}-1)\rangle \tag{1}$$

for N scattering centers located at points x_i. The emission current is

$$\mathbf{J}_i = \frac{\mathbf{u}_i}{u_i^2} - \frac{\mathbf{u}_{i-1}}{u_{i-1}^2}, \tag{2}$$

$$\mathbf{u}_i = \frac{\mathbf{k}_T}{\omega} - \frac{\mathbf{p}_{iT}}{E}, \tag{3}$$

where $\mathbf{k}, \omega$ denote the momentum and energy of the emitted quanta, E is the primary energy, $\mathbf{p}_{iT}$ is the total transverse transfer to i-th scattering, α_c is strong coupling constant and $C_F = 4/3$. The average in (1) is done over the transverse transfers and longitudinal coordinates. This formula is valid in electrodynamics but does not account for the rescattering of emitted gluons and the radiation by exchanged gluons in QCD (see [7,8]). It is used here for qualitative estimates only.

For the double scattering ($N = 2$), one term is only left in the second part of eq.(1). It vanishes at $x_i = x_j$, i.e. it describes the radiation emitted in between the two scattering centers. The first part of (1) corresponds to coherent emission on a target as a single radiating center and is given by the current QCD fits. We are interested in the situation when the incoherence due to the interference overwhelms it. The correction term to the cross section due to incoherent double scattering is given [3] by

$$\frac{\omega}{\sigma}\frac{d^3\sigma}{d^3k} = \langle\frac{4\alpha_c C_F}{\pi^2\omega^2\theta^2}\sin^2\frac{\omega l\theta^2}{4}\rangle, \tag{4}$$

where all the variables are expressed in the laboratory system. The experimentally measured cross section [1] can be obtained from (4) as

$$\frac{d^2\sigma}{dE_T d\eta} = \langle\frac{8\alpha_c C_F\sigma}{\pi E_T}\sin^2\frac{E_T l\theta}{4}\rangle, \tag{5}$$

where $\eta = -\ln \mathrm{tg}\theta/2$ is the pseudorapidity.

For $E_T \sim 200\,\mathrm{GeV}$, $l \sim 1\,\mathrm{Fm}$, $\theta < 10^{-3}$, the argument of sin is small. The averaging over the pseudorapidity interval at a given E_T done in [1] leads then to

$$\frac{1}{\Delta\eta}\int\frac{d^2\sigma}{dE_T d\eta}d\eta \approx \langle\frac{\alpha_c C_F\sigma E_T l^2\theta_{max}^2}{4\pi\Delta\eta}\rangle, \tag{6}$$

where θ_{max} is the l.s. angle corresponding to $\eta = 0.1$ in the c.m.s. It is approximately given by $\theta_{max} \approx (2m/E_L)^{1/2} = (4m^2/s)^{1/2}$, where m is a nucleon mass. The average over longitudinal distances in (6) has been done for a fixed distance l between the scatterers i.e. with $\Delta(x_2 - x_1 - l)$. The averaging prescription of the transverse transfers asks for special discussion. If one describes the scattering centers by the screened (at some distance $1/\mu$) Coulomb potential [6,8] then it means that the average in (6) is defined as

$$\langle\langle\ldots\rangle\rangle = \int \prod_{i=1}^{2} \frac{\mu^2 d^2 q_{iT}}{\pi(q_{iT}^2 + \mu^2)^2}(\ldots). \tag{7}$$

The integration should start from completely different values of q_T for the two centers as discussed above. For soft scattering, it should begin at $q_T = 0$ while for hard scattering the low limit is equal to E_T. The averages provide, correspondingly, the factors 1 and μ^2/E_T^2. The final estimate of the cross section reads

$$\frac{1}{\Delta\eta}\int \frac{d^2\sigma}{dE_T d\eta} d\eta \approx \frac{\alpha_c C_F \sigma m^2 (\mu l)^2}{\pi \Delta\eta s E_T}. \tag{8}$$

It is reasonable to consider $l \sim 2/\mu, \sigma = \sigma_{el} \approx 10^{-26}\,\mathrm{cm}^2, \alpha_c C_F \sim 0.1$. At $E_T =$ $200\,\mathrm{GeV}$, $(s)^{1/2} = 1.8 \cdot 10^3\,\mathrm{GeV}$ one gets from (8)

$$\frac{1}{\Delta\eta}\int \frac{d^2\sigma}{dE_T d\eta} d\eta \approx 3 \cdot 10^{-3}\,\mathrm{nb/GeV} \tag{9}$$

to compare with the experimental value [1] $(5.11\pm0.17) \cdot 10^{-3}\,\mathrm{nb/GeV}$. According to Fig.1 in [1], the current QCD predictions underestimate the experimental values at $E_T \sim 200\,\mathrm{GeV}$ by about 10-15% only. Thus eq. (8) overestimates the double scattering radiation. However, this estimate should only be trusted by an order of magnitude because of undefiniteness in the choice of μl and of the averaging procedure but it shows that the double scattering process can contribute a noticeable share to the cross section at E_T=200 GeV.

The energy dependence implied by eq. (8) predicts that the similar effect at energy $s^{1/2}$=540 GeV could be observed for lower transverse energies $E_T \approx 130\,\mathrm{GeV}$. However, the cross section decrease at larger E_T predicted by (8) is too slow to fit the experimental data [1]. There are some reasons for this failure. First, at larger E_T and larger θ the argument of sin in (5) becomes comparable to 1, and it provides additional damping of the cross section omitted above. Second, the very first scattering can happen also at larger transfers. The corresponding average can then give rise to a stronger damping factor decreasing with E_T. Third, the most important factor can come out of the decrease of the parton distribution functions which are not considered here. The more rigorous treatment is in order to get quantitative results. Nevertheless, the qualitative estimates are very encouraging. Earlier estimates [2-4] did not take into account the damping factor μ^2/E_T^2 due to hard scattering and gave the upper limits strongly exceeding realistic values.

At the end, we mention other effects in hadroproduction which could be related to the gluon radiation from the limited distance. Those are the peculiar structure of spike centers distribution observed by NA22 collaboration in pp collisions at E_L=250-360 GeV [11,12] and the suppression of the accompanying radiation in heavy-quark jets as compared to light-quark ones in SLD experiments [13] at Z^0 peak. The first effect was theoretically considered in [2-4]. It appears at smaller E_T and smaller energies because s and E_T dependence in eq. (8) still favors it to be of comparable size with current QCD estimates of radiation at a single scattering. The second one is related to the short lifetime of heavy quarks and is analogous to earlier proposals [14] to use the specific features of the radiation from a finite length for measuring the lifetime of the top quark.

Further tests of these effects should be done. For spikes, it must be E_T distributions of spike particles, measured separately for spikes within and outside the bumps over the background found in [11,12]. There could be slight excess of higher E_T particles in the first group of events. For the accompanying radiation of heavy quark jets, one should observe the ring-like structure of it, i.e. the accompanying hadrons are emitted at comparatively large angles to the direction of flight of heavy quark.

Altogether, if confirmed, the three effects can provide us the insight to the nature of QCD radiation at finite length either due to the double scattering of light quarks or due to the decay of heavy quarks. In its turn, it would show in more details the internal structure of hadrons.

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