

Talk given at the
"XVIII Rencontre de Moriond"
Les Arcs, France, March 1983

ISTITUTO NAZIONALE DI FISICA NUCLEARE
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PRODUCTION OF TRANSVERSE ENERGY IN HADRON COLLISIONS

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ABSTRACT

The production of large transverse hadronic energy is discussed as the effect of multigluon emission produced in the hard scattering of the hadron constituents.

Hadron production of high transverse energy-momenta (E_T - p_T) is normally believed to result from hard scattering among hadron constituents and to provide a direct test of the short-distance behaviour of strong interactions. A characteristic jet structure is then expected to dominate the final states.

Motivated by these ideas hadron collisions at very high energies have recently been investigated by various experiments⁽¹⁻⁵⁾ with large geometrical acceptance. The abundant production of events with large values of transverse energy, first reported by the NA5 group⁽¹⁾ at the CERN SPS, has been confirmed at Fermilab⁽²⁾ and ISR⁽³⁾ energies, and even more copiously observed⁽⁴⁻⁶⁾ at the CERN $p\bar{p}$ collider. However the measured cross sections, which change strongly with energy, are much larger than expected⁽⁶⁾ from QCD four jet production. In addition, up to reasonably large E_T , the event structure does not indicate, a sensible contribution from high p_T jets originated in a hard scattering of the constituents. Only very recently calorimeter-triggered experiments at the CERN ISR and $p\bar{p}$ collider⁽⁸⁻⁹⁾ have finally observed an important contribution from jet production at very large transverse energy.

The question arises therefore as to whether there exist two physically distinct mechanisms operating in a hadron-hadron collision at large E_T , appearing with a different configuration of the final states as well as with quite different cross sections. While there is little doubt that the jetty events, which are seen at higher E_T , reflect a hard scattering of the constituents and can henceforth be compared with the predictions of perturbative QCD, the origin of the softer component has not been definitively clarified and various interpretations have been given so far^(10,11,12).

In particular in a recent letter⁽¹²⁾ we have suggested that a mechanism similar to the one responsible for the transverse momentum properties⁽¹³⁾ of Drell-Yan pairs and weak bosons produced in hadron collisions is also operating here. The idea is quite simple. In any hard scattering process among the constituents a fraction of the initial parton subenergy is released in the form of soft QCD radiation, whose spectrum can be calculated to all orders in α_s . Furthermore the corresponding spectrum factorizes and, to leading order, is independent of the particular hard scattering process. Of course the very tail of the spectrum is modified by the detailed dynamics of a particular hard scattering process which takes over at appropriate large E_T , similarly to what happens in leptons pair production when $p_T \sim 0(M)$. In spite of the naïveté of the model used to illustrate these ideas - to simplify the calculation only quark-quark interactions were considered, with energy scaling cross sections - the results reproduce qualitatively those of more complete analysis⁽¹⁴⁾, which includes gg and qg interactions. In this talk I will present a brief account of this new analysis, which is based on our present knowledge of the techniques for summing leading and subleading logarithms of perturbative QCD.

We start with the basic formula for the soft E_T spectrum, where E_T is the total transverse energy of the QCD radiation emitted by the initial partons p_i and p_j in the hard reaction $p_i + p_j \rightarrow h$, with Born cross section σ_0^h .

$$\frac{d\sigma^{\text{soft}}}{dE_T} = \sum_{ij,h} \iint dx_1 dx_2 F_i(x_1) F_j(x_2) \frac{d\sigma^h}{dE_T}(x_1 x_2 S), \quad (1)$$

where S is the energy squared of the initial hadron system, $F_i(x)$ are the corresponding parton densities and for simplicity scaling violations are not indicated explicitly. Furthermore we have ($Q^2 \equiv x_1 x_2 S$):

$$\begin{aligned} \frac{dP}{dE_T} \equiv \frac{1}{h} \frac{d\sigma^h(Q)}{dE_T} &= \frac{1}{\pi} \int_0^\infty dx \cos \left[x E_T - \frac{2(c_i+c_j)}{\pi} \int_0^{Q/2} \frac{dq_T}{q_T} \ln \left(\frac{Q}{q_T} \right) \right. \\ &\left. \cdot \alpha(q_T) \sin(q_T x) \right] \cdot \exp \left\{ \frac{2(c_i+c_j)}{\pi} \int_0^{Q/2} \frac{dq_T}{q_T} \ln \left(\frac{Q}{q_T} \right) \alpha(q_T) \left[\cos(q_T x) - 1 \right] \right\}, \end{aligned} \quad (2)$$

with c_i and c_j the appropriate colour factors for quarks and gluons, $c_q = c_F = 4/3$ and $c_g = c_A = 3$. The expressions for the hard cross sections σ_o^h have been reported many times earlier⁽¹⁵⁾ and will not be reported here.

As well known, the dominant contributions to the various cross sections come from terms $\sim 1/t^2$, $1/u^2$ with t and u the usual Mandelstam variables for the parton subprocesses, reflecting the exchange of vector gluons. Furthermore the colour factors present in the different σ_o^h clearly favour gluon initiated subprocesses, as already emphasized in the literature⁽¹⁵⁾.

Let us consider the case where one does not single out a particular hard final state, as for the so called minimum bias events. Then one has to sum over h and integrate over the final parton momenta, as indicated in Eq. (1). The radiation from the final legs is automatically taken into account, because the process of dressing the final partons corresponds to a unit probability. This can be explicitly seen from the distribution (2) which is indeed normalized to one. Of course a measured value of E_T differs from the radiative - E_T of Eq. (1), by a amount $\langle E_T^{\text{fin}} \rangle$, which can be directly estimated from the partonic state and is of order of a few GeV. Then, for fixed i and j , integration over the final states gives

$$\sum_h \frac{d\sigma^{ij \rightarrow h}}{dE_T} = \frac{\pi a_s^2}{|t_{\text{min}}|} c_{ij} \frac{dP}{dE_T}, \quad (3)$$

where the factor c_{ij} are obtained from Ref. (15) and $|t_{\text{min}}| \approx p_{T\text{min}}^2$ is the minimum value of the transfer momentum in the subprocesses $p_i + p_j \rightarrow h$. Eq. (3) is a consequence of the factorization property of the soft spectrum, as indicated explicitly in Eq. (2). Therefore the quantity $(p_{T\text{min}})^{-2}$ fixes the scale of the soft component of $d\sigma/dE_T$. From our understanding of deep inelastic phenomena one would expect that a value $(p_{T\text{min}})^{-2} \sim 1 \text{ GeV}^{-2}$ gives the right order of magnitude, and indeed the analysis of the experimental data for $\sqrt{S} \sim 20+540 \text{ GeV}$, as shown below, confirms this naive expectation.

One finally obtains from Eqs. (1-2-3)

$$\frac{d\sigma^{\text{soft}}}{dE_T} = \sum_{ij} c_{ij} \iint dx_1 dx_2 F_i(x_1) F_j(x_2) \cdot \frac{\pi\alpha_s^2}{|t_{\min}|} \frac{dP}{dE_T}(x_1, x_2, S) \quad (4)$$

Let us comment on the validity of our expression (4). It is clear that this result cannot be trusted at very large E_T ($2E_T \lesssim \sqrt{S}$), where both the DLLA breaks down and genuine hard scattering effects are expected to take over. Indeed, evidence for jet structures at very large E_T has been recently shown⁽⁷⁻⁸⁻⁹⁾. Eq. (4) is therefore expected to hold in a range of medium-large values of E_T . For very large E_T the hard jet yield can be obtained in a standard way⁽¹⁵⁾ and will not be discussed here. Then a comparative role of the two components will indicate more precisely the transition region for each process. On the other hand Eq. (4) cannot be valid at too small values of E_T , because the contributions from the initial and final states cannot be simply factorized as in Eq. (4). We refer to Ref. (14) for a more detailed discussion on this point.

Then we show in Fig. (1) our results for πp collisions at 300 GeV, compared with the NA5 results⁽¹⁾. Only the soft component is shown. The normalization is absolute and, as stated above, depends on $(t_{\min})^{-1}$ which is fixed to the value 1 GeV^{-2} . In Fig. 2a) our predictions for $p\bar{p}$ collisions at c.m. energies of 540 GeV are compared with the UA1 data⁽⁴⁾. The theoretical curve is obtained with no restriction on the phase space of the emitted radiation. In order to study the rapidity (y) and the azimuthal (ϕ)-dependence we have restricted the full Δy or $\Delta\phi$ gluon ranges by a factor of two and three, and compared with data in Figs. (2b,c). From the inspection of the (1-2) figures follows that all dependences on the kinematical variables S , y , and ϕ are well reproduced. Furthermore in Fig. (2b) the region of transition between the soft and the hard components, and the latter has not been shown in the figure, is around $E_T=50 \text{ GeV}$, which is also consistent with the data.

So far the gluon contribution, which is dominant particularly at the collider energies, has been calculated with a scaling density $x g_p(x) \sim 3(1-x)^5$. The effect of scaling violations, as well as the use of a rather different form⁽¹⁶⁾ for the gluon density, namely $x g'_p(x, q^2) = A(1+Bx+Cx^2)(1-x)^{D+E} e^{-Fx}$, with $D \approx 6 + \ln \left[\frac{\ln q^2/\Lambda^2}{\ln q_0^2/\Lambda^2} \right]$, is indicated in Fig. 3, and amounts to a correction factor of order 2-3 to the scaling result.

Notice that our results do not depend on any assumption on the fragmentation into hadrons of quarks and gluons. This is not unconceivable since we look at totally inclusive distributions and therefore hadronization effects should be almost completely washed out.

Finally, because of the dominance of the gluons contribution, one should observe differences in the structure of the final states, as compared, for example, with what it is observed in purely quark initiated processes, like the production of Drell-Yan pairs or weak bosons. In particular the E_T behaviour of the hadron multiplicities or the transverse energy-momentum properties should reflect the effect of the different colour factors c_F and C_A associated to the QCD radiation emitted from the initial partons. A typical reaction to

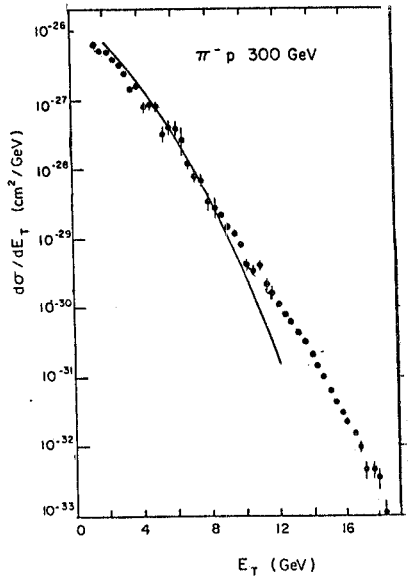


FIG. 1

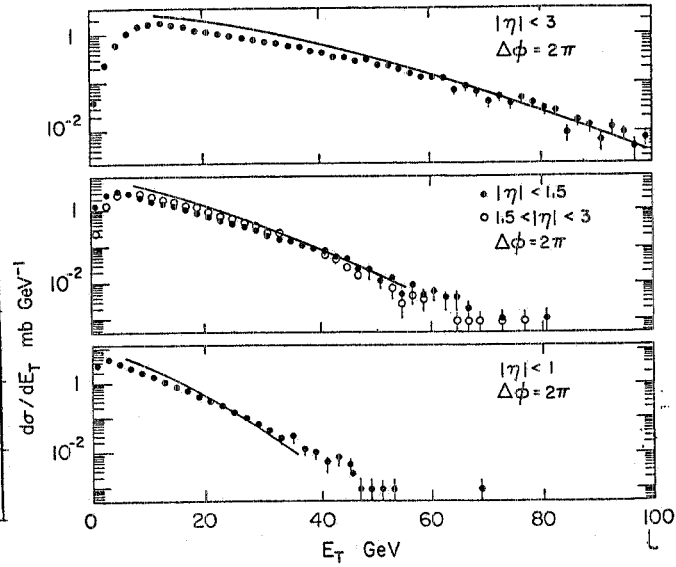


FIG. 2

study would be, for example, $\bar{p}p \rightarrow J_1 + J_2 + X$, where J_1 and J_2 are two hard jets observed in the final state. Then the properties of the associated hadrons in X should show appropriate similarities with those observed for the minimum bias events and at the same time reveal differences with the case of the production of electro-weak pairs.

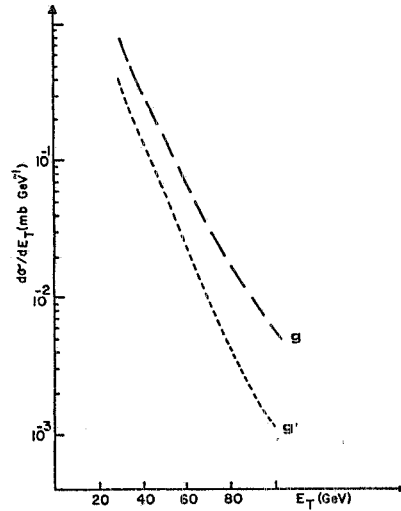


FIG. 3

In conclusion we have shown that most of the events which are produced at reasonably large E_T are the manifestation of gluon bremsstrahlung associated to hard parton scattering. They should not be considered just as an interesting background to back to back jet events, but they give as a complementary information on the QCD dynamics. More informations could be extracted from the data and, compared with the observed features in Drell-Yan processes, could reveal important differences leading to discriminate between quarks and gluons.

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