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IN COLLIDER FOUR-JET EVENTS

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POSSIBLE SIGNATURE OF MULTIPLE PARTON INTERACTIONS IN COLLIDER FOUR-JET EVENTS*

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ABSTRACT

We discuss the role of multiple parton scattering in the production of four-jet events at the $S_{\bar{p}p}$ Collider. Taking into account the experimental conditions, we find that such a mechanism can contribute to the p_{out} distribution appreciably enough to be differentiated from the leading perturbative QCD.

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New improved experimental results on high p_T two- and multi-jet production in $\bar{p}p$ collisions at the CERN $S_{\bar{p}p}$ collider have recently been presented in the literature (1a,1b). These results confirm the QCD parton model picture based on elementary quark and gluon hard scattering subprocesses. Among them we would like to discuss in this note the four-jet events (1b), which are particularly interesting as a possible test of two competing production mechanisms. The leading QCD (LQCD) source of these events is represented by the perturbative $2 \rightarrow 4$ hard processes shown in Fig. 1a. The alternative source of four-jet events is represented by the double disconnected scattering (DDS) of two parton pairs in Fig. 1b, which has recently been discussed (2a,b,c). The latter mechanism, which is allowed by the composite hadron structure, is power suppressed (by the total jets transverse momentum p_T) with respect to the former one. Nevertheless, for increasing CM $\bar{p}p$ energy $\sqrt{s}$ and fixed p_T , it can give rise to four-jet events with a total rate which can become comparable to the perturbative one. This can be understood by simply observing that the total cross section for four-jet events from DDS can roughly be estimated as

$$\sigma_4^{\text{DDS}}(p_T^{\text{min}}) \approx \frac{\sigma_2^{\text{min}}(p_T^{\text{min}}) \cdot \sigma_2^{\text{min}}(p_T^{\text{min}})}{\sigma_{\text{TOT}}(s)}, \quad (1)$$

where σ_2 is the two-jet total cross section, p_T^{min} is the threshold in transverse momentum in order to define a bunch of particles as a jet, and σ_{TOT} is the total $\bar{p}p$ cross section. At collider energies and for p_T^{min} in the range of 10 GeV, the ratio $\sigma_2/\sigma_{\text{TOT}}$ is already of the order of some percent, which makes eq.(1) comparable in size to the order $O(\alpha_s^2)$ which characterizes the ratio σ_4/σ_2 for the perturbative QCD jets. Moreover, as $\sqrt{s}$ increases with fixed total p_T , the ratio $\sigma_4^{\text{LQCD}}(s)/\sigma_2(s)$ is expected not to vary too much, whereas $\sigma_4^{\text{DDS}}/\sigma_2$ should grow

appreciably, as a consequence of eq.(1).

The explicit expression for the DDS differential cross section has been worked out in Ref.(2). One can write in fact

$$\frac{d\sigma}{d^2p_{1T}d^2p_{2T}d^2y_1d^2y_2} = \frac{1}{2\pi R^2} \sum_{\mathbf{q}} \frac{G(x_1, x_2) G(x_3, x_4)}{d^2p_{1T}d^2y_1d^2y_2} \frac{d\hat{\sigma}}{d^2p_{1T}d^2y_1d^2y_2d^2y_4} \quad (2)$$

In eq.(2) $G(x_1, x_2)$ and $G(x_3, x_4)$ are the partons double fractional momentum distributions; p_{1T} and p_{2T} are the transverse momenta of the two outgoing jet pairs; y_1 are the jets rapidities, and R is a hadronic scale dimension, which can be taken of the order of 1 fm.

Estimates of integrated cross sections from eq. (2), confirming quantitatively the considerations made above, have been performed in Ref(2). The problem, however, is to define suitable signatures which could evidence, in a sample of four-jet events, the presence of those connected to DDS. Qualitatively, the most obvious signature for DDS is that the four jets should balance their transverse momenta pairwise, modulo small intrinsic p_T (this is why only p_{1T} and p_{2T} appear in eq.(2)), and moreover that the distribution in the azimuthal distance between the jet pairs should be flat. The point however is that in any case it is necessary to make a quantitative comparison with the four-jet events produced by LQCD in that same configuration of the transverse momenta. In addition, to be realistic, the various cuts, which are applied experimentally to obtain the sample of four jet events, should be properly taken into account.

Concerning the four-jet production by LQCD, an (almost) analytic estimate using the same cuts applied to the Collider events has recently been presented in Ref.(3). In particular in this paper the p_{out} distribution for four-jet events has been estimated in the configuration in which $\sqrt{s} = 540$ GeV, $|\eta| < 1.5$ (η is the jets pseudorapidity), $\Delta > 1$

(Δ is the jets separation in the lego plot) and $p_T^{\min} = 15$ GeV. The variable p_{out} is defined as the transverse momenta out of the plane identified by the jet of maximal transverse momentum and the beam:

$$p_{out} = \frac{1}{2} \sum_i |p_{i,out}| \quad (3)$$

The resulting distribution shows a peak centered around $p_{out} \simeq 25$ GeV, with an integrated cross-section of about 0.25 nb (which, given the present Collider luminosity, corresponds to an appreciable number of events).

We have computed the same p_{out} distribution of Ref.(3) for DDS jets as predicted from eq. (2), by integrating it over the same portion of phase space, allowed by the cuts reported above. Like in the previous calculation of Ref. 2), we have assumed a factorized form for the double parton distributions:

$$G(x_1, x_2) = G(x_1) G(x_2) (1 - x_1 - x_2) \theta(1 - x_1 - x_2) \quad (4)$$

with $G(x)$ the single parton densities, and the factor $(1 - x_1 - x_2)$ taking somehow into account the kinematical correlation among partons. Since the values of x involved in the calculation are much smaller than unity, such a form should be rather reasonable⁴⁾. Furthermore, we have used the scale $Q_i^2 = 2\hat{s}_i \hat{t}_i \hat{u}_i / (\hat{s}_i^2 + \hat{t}_i^2 + \hat{u}_i^2)$, where $\hat{s}_i, \hat{t}_i, \hat{u}_i$ are the invariant Mandelstam variables, for the two hard subprocesses of Fig. 1b both in α_s and in the distribution functions evolution, and have taken the explicit parametrizations of Ref.(5).

In Fig. 2 the resulting p_{out} distribution of DDS four-jet events is reported (solid line), and compared to the LQCD result of Ref.(3) (dashed line). As one can see, the DDS contribution to the p_{out} also shows a peak, much sharper than that of the LQCD, and centered around $p_{out} \simeq p_T^{\min}$. This fact reflects that the most likely configuration for the

DDS is that of four jets with same $p_T^{\min}$ equal to $p_T^{\min}$ and azimuthal angle of 90° between the two jet pairs (in order to maximize the p_{out}). It turns out that the integral of the solid curve is roughly equal to that of the dashed line, indicating a comparable number of events from DDS and from LQCD.

Total integrated four jet cross-sections have been estimated in Ref.(2b) at $\sqrt{s} = 540$ GeV, for $p_T^{\min} = 10$ GeV; the ratio $\sigma_h^{DDS}/\sigma_h^{LQCD}$ turns out to be of the order of 0.25. Increasing $p_T^{\min}$ one will therefore expect a much smaller ratio. In the present estimate a very important role is however played by the cuts on the final state. In fact these will not allow configurations with a small angular separation between any pair of jets. On the other hand, LQCD will be most important in this region of phase space. The present estimate is consistent with the estimate of Ref.(2c), where the final jets have also been required to be well separated.

Of course, these statements should be understood as a qualitative indication of the effect, rather than a sharp quantitative estimate, because as ever, there are overall uncertainties associated to the choice of the parton densities and to the value of the hadronic radius R in eq.(2). Moreover, also the LQCD estimate of Ref.(3) has been derived under various assumptions on the role played by the individual contributions to the elementary hard cross-section.

The sharpness of the DDS peak is obviously related to the power suppression with respect to the LQCD, as mentioned at the beginning. In this respect it may be interesting to look at the dependence of the effect on the threshold $p_T^{\min}$ to define a jet. This is represented in Fig.3 for $p_T^{\min} = 10, 15$ and 20 GeV. As expected, the DDS peak is extremely sensitive to the choice of the $p_T^{\min}$. Although a quantitative comparison with LQCD is not yet possible because $p_T^{\min} \neq 15$ GeV has not been considered in Ref.(3), one can nevertheless safely expect that the importance of the DDS four-jet events relative to the LQCD ones will grow for smaller values of $p_T^{\min}$, and will conversely quickly decrease for larger values of $p_T^{\min}$. It should be interesting to compare these results with the four-jet events which have recently been observed at the Collider.

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FIGURE CAPTIONS

- Fig. 1) a) Four jet production with LQCD
b) Four jet production with DDS
(see text)

Fig. 2) P_{out} distribution given by 4-jets final state from DDS (continuous curve) and from LQCD (dashed curve) with cut-offs on the final state phase space to match experimental resolution.
(see text).

Fig. 3) P_{out} distribution in the 4-jets DDS case as a function of p_T^{min} .

Fig. 1

Fig. 2

Fig. 3