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JET-JET PRODUCTION IN THE MULTI-TeV ENERGY RANGE

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ABSTRACT

Using the parton model with leading-log QCD corrections, we extrapolate the cross-section for $p\bar{p}$ two-jet production into the multi-TeV energy region. We evaluate its dependence on the transverse momentum, the jet-jet invariant mass, and on the rapidities, and we expose the cross-section sensitivity on the structure function parametrizations. Signatures for quark compositeness are given.

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The recent observation of hadron-jets at the CERN $p\bar{p}$ collider, ^{1,2)} and in particular the relatively large number of 2-jet events provides strong evidence in favour of perturbative QCD³⁾. This new field is at present extensively studied⁴⁾, the details on the constituent dynamics are carefully evaluated and there is no significant disagreement with the theoretical predictions⁵⁾.

The successes of the CERN $p\bar{p}$ project, the near completion of the Fermilab Tevatron, and the theoretically motivated demand for even higher energies⁶⁾ has in the recent past led to an increased interest in the physics in the multi-TeV energy region⁷⁾. It therefore is desirable to extrapolate the jet-jet cross sections to such large energies and to compare the kinematical distributions at $\sqrt{s} = 540$ GeV, 2 TeV and 20 TeV.

If quarks are composed of even more elementary constituents⁸⁾ one may expect that their interaction is described by an effective four-fermion interaction which in a first attempt is assumed to be flavour diagonal and of the product form of two left-handed color and isospin singlet currents.

The above three points have motivated us to carry out a systematic analysis of jet-jet production in $p\bar{p}$ collisions and we here present the most important results. In the following we describe our assumptions and calculation procedures, and subsequently we present our results.

The cross section for $p\bar{p}$ 2-jet production in the framework of perturbative QCD reads ⁹⁾

$$d\sigma/dq_t^2 dy_1 dy_2 = \sum_{x_1, x_2} \left[\frac{d\hat{\sigma}}{d\hat{t}}(\hat{t}) \cdot u(x_1) \bar{u}(x_2) + \frac{d\hat{\sigma}}{d\hat{u}}(\hat{u}) \cdot \bar{u}(x_1) u(x_2) \right] \quad (1)$$

The $u(x_i)$ are the (scale dependent) quark/gluon momentum distributions in the proton/antiproton. The transverse momentum of each of the two final state jets is denoted by q_t . The effects due to the primordial transverse momentum are ignored. Summation over the corresponding quark/gluon contributions is assumed. The momentum fractions are given by

$$x_1 = \frac{x_t}{2} [e^{y_1} + e^{y_2}] , \quad x_2 = \frac{x_t}{2} [e^{-y_1} + e^{-y_2}] \quad (2)$$

with $x_t \equiv 2q_t/\sqrt{s}$. The squared $p\bar{p}$ energy is $s \equiv (2E)^2$, and the y_i are the rapidities of the two jets. The Mandelstam variables on the constituent level read

$$\begin{aligned} \hat{s} &= x_1 x_2 s , & \hat{t} &= \frac{s}{2} [-x_1 x_2 + \sqrt{x_1 x_2 (x_1 x_2 - x_t^2)}] \\ \hat{u} &= \frac{s}{2} [-x_1 x_2 - \sqrt{x_1 x_2 (x_1 x_2 - x_t^2)}] \end{aligned} \quad (3)$$

The integrated 2-jet cross section is easiest obtained by integrating first over the rapidities and subsequently over the transverse momentum. The integration boundaries are

$$\begin{aligned} y_1^- \leq y_1 \leq y_1^+ & , \quad y_1^\pm \equiv \pm \ln \left[\left(\frac{\sqrt{s}}{q_t} \right) - \exp(\mp y_2) \right] \\ y_2^- \leq y_2 \leq y_2^+ & , \quad y_2^\pm \equiv \ln \left[(E \pm p_L) / q_t \right] \\ p_t \leq q_t \leq \frac{\sqrt{s}}{2} & , \quad p_L \equiv \sqrt{E^2 - q_t^2} \end{aligned} \quad (4)$$

Note that q_t is the transverse momentum of each jet, (with all primordial transverse momenta being ignored), whereas we will denote by p_t the lower cutoff on transverse momenta.

There are eight quark/gluon subprocesses

$$\begin{array}{ll} 1: q_1 q_2 \rightarrow q_1 q_2 & 5: q \bar{q} \rightarrow g g \\ 2: q_1 q_1 \rightarrow q_1 q_1 & 6: g g \rightarrow q \bar{q} \\ 3: q_1 \bar{q}_1 \rightarrow q_2 \bar{q}_2 & 7: q g \rightarrow q g \\ 4: q_1 \bar{q}_1 \rightarrow q_1 \bar{q}_1 & 8: g g \rightarrow g g \end{array} \quad (5)$$

The parton cross sections are evaluated in lowest order of the strong coupling constant ¹⁰⁾. All higher order (leading-log) contributions are included in the renormalization group summation of perturbative QCD, resulting in the scale dependence of the momentum distributions. The next-to-leading corrections are ignored and thus all subsequent results do not include any K-factor.

If, in the framework of the usual $SU_3 \times SU_2 \times U_1$ gauge theory, the quarks are composite at the energy scale ζ , the strong forces binding their constituents induce flavour-diagonal and helicity-conserving contact interactions; these, as we will notice, can lead to sizeable effects. Following Ref. 11) we analyse the simplified case of a product of two left-handed color- and isospin-singlet currents

$$\mathcal{L}_{qq} = A \left(\frac{g^2}{\zeta^2} \right) \frac{1}{2} (\bar{q}_L \gamma^\mu q_L) (\bar{q}_L \gamma_\mu q_L) \quad (6)$$

which allows for a first estimate of the kinematical effects. The strong coupling constant is g , and $q_L \equiv (1 - \gamma_5) u_q$. For the parton cross sections including these contributions we refer to Ref. 12).

The numerical analysis has been carried out using the BGOR¹³⁾, GROR¹⁴⁾, BETAL¹⁵⁾, GHR¹⁶⁾ and the CDHS¹⁷⁾ parametrizations for the scale dependent momentum distributions with the scale defined by: $Q^2 = 2 \hat{s} \hat{t} \hat{u} / (\hat{s}^2 + \hat{t}^2 + \hat{u}^2)$. The resulting variations as well as the cross section spread due to changes in the scale parameter Λ will be discussed when presenting our results.

The energy dependence of the integrated $p\bar{p}$ 2-jet cross section is shown in Fig. 1a by the solid curves. The $\sqrt{s}$ energy scale extends over four orders of magnitudes. The shaded areas show the theoretical uncertainties which will be discussed below. The cross sections were evaluated for several values of the lower transverse momentum cutoff $p_t = (15, 50, 150, 400, 800, 1000, 2000)$ GeV; we typically get

$$\sigma_{jj}(\sqrt{s}=2\text{TeV}) = (3.10^{-28}, 10^{-30}, 10^{-33}, 5.10^{-36}, 2.10^{-43}, 0., 0.) \text{ cm}^2 \quad (6)$$

$$\sigma_{jj}(\sqrt{s}=20\text{TeV}) = (4.10^{-27}, 8.10^{-29}, 10^{-30}, 10^{-32}, 2.10^{-34}, 6.10^{-35}, 6.10^{-37}) \text{ cm}^2 \quad (7)$$

The familiar cross section rise with growing energy is mostly due to the strong rise of the QCD corrected gluon momentum distribution at low- x values. The cross section is built up by the contributions of the subprocesses 1-8 in Eq. (5). The dashed curves carrying the numbers of the subprocesses indicate their importance. The processes 7 + 8 dominate at large $\sqrt{s}$ -values and the closest competitor, the subprocess 1, lies more than an order of magnitude below.

The shaded areas indicate the cross section spread if different parametrizations for the scale dependent momentum distributions are used. At large energies almost all parametrizations lead to predictions which do not differ by more than a factor 2. The BETAL parametrization overestimates the gluon contribution and its strongly rising crosssection for $\sqrt{s} > 10^4$ GeV is likely due to an incomplete Mellin inversion. The sea-parton dominated contribution of subprocess 1 varies within a factor 2 for different parametrizations. The BGOR parametrization always lies at the lower end of the cross section spread. The solid curves were calculated for $\Lambda = 0.5$ GeV. We have varied the scale parameter within $0.2 \text{ GeV} \leq \Lambda \leq 0.5 \text{ GeV}$ and found at large $\sqrt{s}$ values a cross section reduction whereas for $\sqrt{s} \lesssim 2 \text{ TeV}$ the cross sections are enhanced as compared to the solid curves. Thus, the lower boundary of the shaded areas follows from the BGOR parametrization with $\Lambda = 0.2/0.5 \text{ GeV}$, whereas the upper boundary is given by the highest predictions of the earlier indicated set of parametrizations.

In order to display the p_t cutoff dependence, we show in Fig. 1b the cross section falloff at $\sqrt{s} = 2,20$ TeV. The shaded areas again indicate the theoretical uncertainties with the same criteria as explained above. The dotted curve illustrates the influence of the contact terms as an early signature of quark compositeness if the typical scale is $\zeta = 1$ TeV. We so far were concerned with the fully integrated cross section. For a comparison we have also indicated the size of the differential cross sections at $\sqrt{s} = 2,20$ TeV. We have in particular evaluated: $d\sigma/dq_t$ (curves 1), $d\sigma/dy dq_t$ (curves 2) and $d\sigma/dy_1 dy_2 dq_t$ (curves 3) with all rapidities vanishing, and we show in Fig. 1b their variation with increasing transverse momentum. Comparing the integrated and q_t -non-integrated cross sections one notices a considerable difference in rate which is partially a reflection of the flattening out of the q_t dependence as the transverse momentum grows.

In Fig. 2 we focus on the single-jet cross section in the central region and show the falloff with increasing transverse momentum at $\sqrt{s} = 540$ GeV and 2,20 TeV. The rapid falloff at the upper end of the spectrum is due to phase space limitations with $x_1, x_2 \rightarrow 1$. The shaded areas again indicate the cross section spread for different parametrizations of the scale dependent momentum distributions and variations of the scale parameter: $0.2 \text{ GeV} \leq \Lambda \leq 0.5 \text{ GeV}$. At the upper end of the phase space boundary the variations are small. The subprocesses 7,8 involving gluons in the initial state are suppressed, as one can see from the dashed curves representing the sum 7+8, and therefore the uncertainties due to the gluon distributions are unimportant. The variation of the Λ parameter is without much influence since it enters via $\ln(Q^2/\Lambda^2)$ into α_s and the momentum distributions, and Q^2 is large.

The dotted curves in Fig. 2 show the influence of the contact terms due to composite quarks whereby the changes for different values of the bound state scale ζ are indicated. Assuming $\zeta = 1$ TeV, we infer from the $\sqrt{s} = 2(20)$ TeV curves that differences in rate as a signature of quark compositeness may be expected above $q_t \gtrsim 300$ (500) GeV. If ζ is bigger, the required transverse momentum values are even larger. Thus, any measurable quantity involving transverse momenta below the above values is less suitable for the detection of compositeness.

For $q_t = 100$ GeV typical cross section values at the analyzed $p\bar{p}$ energies are

$$\left. \frac{d\sigma}{dy dq_t} \right|_{y=0} \sim (10^{-31}, 5 \cdot 10^{-34}, 3 \cdot 10^{-36}) \text{ cm}^2/\text{GeV}. \quad (8)$$

An increase of the $p\bar{p}$ energy thus rises the rates by orders of magnitude. At $\sqrt{s} = 540$ GeV qq scattering is most influential whereas at $\sqrt{s} = 2, 20$ TeV the cross section is completely dominated by qg and gg scattering. For a fixed rate of say $d\sigma/dy dq_t [y=0] \sim 10^{-35} \text{ cm}^2/\text{GeV}$ the transverse momentum values corresponding to the investigated energies are : $q_t = (90, 180, 550)$ GeV. We conclude, increasing the present $p\bar{p}$ energy by a factor 40 leads to typical transverse momenta which are a factor 5 bigger.

We have determined the jet-jet invariant mass (M) distribution $d\sigma/dM(p_t)$ and give in Fig. 3 our results. Out of the, at first confusing, variety of curves one separates three groups which differ by their $p\bar{p}$ energy $\sqrt{s} = 540$ GeV, 2 TeV as indicated near the M-axis. In each group there are two solid curves which were worked out assuming the indicated lower transverse momentum cutoff p_t . At $\sqrt{s} = 540$ GeV (2, 20 TeV) we choose $p_t = 15, 50$ GeV (50, 150 GeV). The shaded areas indicate the theoretical uncertainties.

These cross sections were obtained by integrating over the full rapidity range. If instead the rapidities are constrained to the central region, the cross sections decrease by (several) orders of magnitude. The dotted curves in each of the three groups of lines have been calculated under the constraint $|y_i| \leq 1$. As the $p\bar{p}$ energy increases the suppression becomes stronger since the eliminated rapidity regions are more and more significant. Since the unconstrained jet-jet invariant mass distribution is to a large extent built up by the transverse momenta close to the lower cutoff p_t , the possibility to see effects of quark compositeness is very much reduced. Due to the relation

$$M^2 = q_t^2 \left[2 + e^{(y_1 - y_2)} + e^{-(y_1 - y_2)} \right] \quad (9)$$

a cut in the rapidity variable, at fixed M^2 , pushes the transverse momenta q_t to larger values and therefore reduces the rates. The positive aspect is however that a significant signal for quark compositeness may be expected. In Fig. 3 we have indicated the cross section expectations for different values of the compositeness scale ζ ; the indicated numbers are in GeV-units. At $\sqrt{s} = 540$ GeV (2 TeV, 20 TeV) one may give the lower limits in the region $\zeta \geq 400$ GeV (1 TeV, 2 TeV) provided sufficient data around $M \sim 300$ GeV (800 GeV, 2 TeV) are available. If one tries to push ζ to larger values the needed event rates become rather low. Still assuming $|y_i| \leq 1$ we have in Fig. 3 also indicated the influence of the subprocesses 7 + 8. At $\sqrt{s} = 20$ TeV the M-distribution is almost completely dominated by qg and gg scattering whereas at $\sqrt{s} = 2$ TeV, and even more at 540 GeV, qq scattering becomes very influential at the upper end of the mass spectrum.

The theoretical uncertainties due to the different parametrization of the QCD scale dependence are indicated by the shaded areas. We have used the same criteria as for Fig. 1a. Since at the upper phase space boundaries the influence of the gluon initiated subprocesses is reduced, the errors, resulting to a large extent from the gluon distributions, become smaller. Note however that the gluon contributions can vary by orders of magnitude for different parametrizations when considered separately.

In Fig. 4a we display the rapidity dependence of the differential cross section: $d\sigma/(dy_1 dy_2 dq_t)$ at the $p\bar{p}$ energies $\sqrt{s}=540$ GeV, 2 TeV, 20 TeV. Thus we again distinguish three groups of lines with the corresponding energy indicated near the rapidity axis. The transverse momentum is fixed at $q_t=50$ GeV, whereas the rapidities of jet 1 and jet 2 are a priori free variables (apart from momentum conservation). Instead of presenting the full two-dimensional cross section dependence we vary the rapidity of jet 1 (y_1) and limit ourselves to the lines $y_2=+y_1$ (curve a in Fig. 4a), $y_2=-y_1$ (curves b), $y_2=0$ (curves c) in the y_1, y_2 -plane. The shaded areas reflect the theoretical uncertainties and the dashed lines indicate the gain in rate if q_t -integration is performed with the lower transverse momentum cutoff $p_t=50$ GeV. Since most contribution to the q_t -integral comes from the region close to the lower cutoff p_t , the q_t -integrated cross section shows almost the same features as the distribution differential in q_t .

At the $p\bar{p}$ energies $\sqrt{s}=540$ GeV, 2 TeV, 20 TeV the rapidity distributions extend to $|y_i| \lesssim 1.8, 3.2, 5.5$, roughly. If q_t is lowered (increased) these values obviously get bigger (smaller). The cross section behaves differently under the above defined correlation constraints. We analyze in particular the solid curves at $\sqrt{s}=2$ TeV. The curve c ($y_2=0$) extends farthest into the rapidity region. The jet 2 thus leaves the interaction region at 90° with no longitudinal momentum and jet 1 uses up all the available energy. The curves a,c remain rather flat in the central region whereas curve b drops off rather rapidly. As the rapidities get larger both jets preferentially emerge in the same longitudinal direction as compared to their ejection with opposite longitudinal momenta. The reason for these characteristics lies in Eq. 2) and the x -dependence of the momentum distributions. We briefly analyze x_1, x_2 as a function y_1 . We vary y_1 from its negative to its positive limits and fix y_2 by the above correlation constraints. In case a) ($y_2=+y_1$) x_1 grows from very small values to reach 1 at $y_1=2.8$. x_2 analogously drops from 1 to very small values. In case b) ($y_2=-y_1$) x_1 is at negative rapidity values close to 1, it subsequently drops to a small value at $y_1=0$, and subsequently it grows again to 1 at $y_1=3$. The curve is $y_1 \leftrightarrow -y_1$ symmetric x_2 follows the same

curve in the opposite direction. In case c) ($y_2 = 0$) x_1 grows from quite small values and reaches 1 at $y_1 = 3.6$. x_2 analogously drops from 1 to quite small values. At $y_1 = 0$ the $x_1 (= x_2)$ values for the cases a), b), c) all agree. These x_1, x_2 characteristics are the essential clue for an understanding of the different behaviours of the curves a,b,c in Fig. 4a. In particular one understands the rapid falloff of curves b where x_1, x_2 reach small values only in the central region, for larger rapidity values x_1, x_2 get large and consequently the predominant influence of the gluon initiated processes is strongly reduced. In the cases a) or c) one of the two x-values gets (very) small, and since the gluon distribution is in the low-x region very large, the qg scattering process is favoured.

This behaviour is confirmed by our calculations. In Fig. 4b we show the percentage of each constituent process contributing to the cross section in Fig. 4a. We vary the rapidity y_1 on the horizontal axis and notice for instance that curve b is at large rapidities dominated to 80% by qq and $q\bar{q}$ scattering. Similarly curves a,c are dominated by qg scattering, as expected. Note the rapid falloff of the contribution 8: $gg \rightarrow gg$ with increasing rapidity.

We thus have found a so far unrecognized kinematical region which is dominated by quark-quark scattering. This insight applies in the same way to the analogous curves at different energies. It in particular applies to $\sqrt{s} = 540$ GeV where experimental analyses in this region will soon become possible.

When going through the presented analysis we have verified that the higher-twist corrections¹⁸⁾ are unimportant, they are at most on the percentage level. Since the transverse momenta become large we do not think that the next-to-leading QCD corrections are substantial.

From the preceding analysis of the jet-jet physics in the TeV energy range we emphasize: the cross section rates substantially increase, the effects due to quark compositeness are substantial, and further we found a kinematical region where qq/ $q\bar{q}$ scattering significantly dominates over qg/gg scattering. Whether nature behaves in the extrapolated manner is, in our mind, worth the effort to find out.

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REFERENCES

- 1) UA2 Collaboration, CERN: M. Banner et al., Phys. Lett. 118B (1982) 203;
P. Bagnaia et al., Z. Phys. C20 (1983) 117, P. Bagnaia et al.,
"Measurement of Very Large Transverse Momentum Jet Production at the CERN
 $p\bar{p}$ Collider", CERN-EP/84-12.
- 2) UA1 Collaboration, CERN: G. Arnison et al., Phys. Lett. 123B (1983) 115,
132B (1983) 214 and 132B (1983) 223.
- 3) For reviews see: H.D. Politzer, Phys. Rep. 14C (1974) 129;
W. Marciano and H. Pagels, Phys. Rep. 36C (1978) 137; E. Reya 69C (1981) 195;
A. Petermann, Phys. Rep. 53C (1979) 157.
- 4) For reviews see:
M. Jacob, "Physics at Collider Energy", CERN-Report, July 1983.
- 5) For a list of recent theoretical papers see refs. 1).
- 6) J. Ellis, ".... and for our next spectroscopy?", CERN preprint TH.3747(1983)
- 7) M. Jacob, "Collider Physics - Present and Future", Ref. TH.3693-CERN, 1983
- 8) See e.g. : H. Fritzsch and G. Mandelbaum, Phys. Lett. 102B (1981) 319;
R. Barbieri, R.N. Mohapatra and A. Masiero, Phys. Lett. 105B (1981) 369;
for an extended list of reference see the review by L. Lyons, Progr. in
Particle and Nuclear Physics, 10 (1983) 227.
- 9) For the kinematics see e.g.: K. Kajantie, J. Lindfors and R. Raitio,
Nucl. Phys. B144 (1971) 422.
- 10) B.L. Combridge, J. Kripfganz and J. Ranft, Phys. Lett. 70B (1977) 234;
J.F. Owens, E. Reya and M. Glück, Phys. Rev. D18 (1978) 1501;
R. Cutler and D. Sivers, Phys. Rev. D17 (1978) 196.
- 11) E.J. Eichten, K.D. Lane and M.E. Peskin, Phys. Rev. Lett. 50 (1983) 811.
- 12) M. Abolins, B. Blumenfeld, E. Eichten, H. Kagan, K. Lane, J. Leveille, D. Pellett,
M. Peskin and J. Wiss, Proceedings of the DPF Summer Study on Elementary
Particle Physics and Future Facilities, Snowmass, Colorado 1982, p. 274.
- 13) J.F. Owens and E. Reya, Phys. Rev. D17 (1978) 3003, A. Buras and K. Gaemers,
Nucl. Phys. B132 (1978) 269, (called BGOR parametrization).
- 14) M. Glück and E. Reya, Nucl. Phys. B130 (1971) 76; J.F. Owens and E. Reya,
Phys. Rev. D17 (1978) 3003, (called GROR parametrization).
- 15) R. Baier, J. Engels and B. Petersson, Zeitschr.f.Physik C2 (1979) 265,
(called BETAL parametrization).
- 16) M. Glück, E. Hoffmann and E. Reya, Zeitschr.f.Physik C13 (1982) 119,
(called GHR parametrization).
- 17) CDHS Collaboration, CERN: I. Abramowicz et al., Zeitschr.f.Physik C13
(1982) 199; F. Eisele, private communication, (called CDHS parametrization).
- 18) E.L. Berger, Zeitschr.f.Physik, C4 (1980) 289; and private communication.

Figure Captions

Fig. 1a: Energy dependence of the integrated cross section with the lower transverse momentum cutoff: $p_t=15,50,150$ GeV. The shaded areas indicate the cross section spread and the dashed curves show the influence of the subprocesses in Eq.5).

Fig. 1b: Cross section dependence on the lower transverse momentum cutoff p_t at $\sqrt{s}=2,20$ TeV. The size of the corresponding distributions differential in q_t and y_1 at vanishing rapidities is indicated.

Fig. 2 : Transverse momentum dependence of the $p\bar{p}$ 2-jet cross section at $\sqrt{s}=540$ GeV and 20 TeV. The shaded areas reflect the theoretical uncertainties and the dashed lines show the influence of the subprocesses 7 + 8 in Eq.5). The dotted curves indicate the influence of the contact terms if composite quarks are assumed.

Fig. 3 : Jet-jet invariant mass dependence of the $p\bar{p}$ 2-jet cross section at $\sqrt{s}=540$ GeV, 2 TeV and 20 TeV with the lower transverse momentum cutoff p_t indicated near the solid curves; the shaded areas reflect the theoretical uncertainties. The dotted curves show the influence of a rapidity cutoff $|y| \leq 1$ as well as the deviations due to the contact terms if composite quarks are assumed. The dashed lines illustrate the influence of the constituent processes 7 + 8 in Eq.5) under the same conditions. For each $\sqrt{s}$ energy there is a separate M-scale; for the 2 TeV -curves it is lowered.

Fig. 4a: The rapidity correlations: $y_2=+y_1$ (curve a), $y_2=-y_1$ (curve b) $y_2=0$ (curve c) at $\sqrt{s}=540$ GeV, 2 TeV and 20 TeV with the transverse momentum $q_t=50$ GeV. The shaded areas indicate the theoretical uncertainties and the dashed lines show the q_t -integrated cross section with the lower transverse momentum cutoff : $p_t=50$ GeV.

Fig. 4b: Percentage of the constituent processes 1-8 in Eq. 5) contributing to the rapidity correlations a-c at $\sqrt{s}=2$ TeV shown in Fig. 4a.

$$p\bar{p} \rightarrow \text{jet} + \text{jet} + X$$

(Integrated cross section)

FIG. 1

$p\bar{p} \rightarrow \text{jet} + X$

[q_T -Dependence]

FIG. 2

$p\bar{p} \rightarrow \text{jet} + \text{jet} + X$

[Mass distribution]

FIG. 3

FIG. 4