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A Study of the Three-Jet Production Background

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19

ABSTRACT

A background for three-jet production is studied with an invariant mass of any two jets equal to the mass of $W^{\pm}$ or Z^0. The results include pure QCD and the interference of the QCD and EW interactions at the tree level and gives the cross section of an order of 10^5 pb at 1 TeV. Helicity amplitudes squared for all relevant subprocesses of the interference terms at the parton level are given.

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1. Introduction

Jet productions [1] in hadron colliders at CERN and FERMI-LAB have provided a successful test of the pertubative QCD [2], and have already been detailed comparisons of the theory with experiments [3]. The detailed study of one-jet and two-jets, up to the order of α_s^3, were discussed in [4]. Pure QCD for three-jet production were also written [7], and were tested at CDF. In this paper, we study the background for three-jet production in pp and $p\bar{p}$ collisions, and include the QCD-EW interference parts. We are particularly interested in the case, in which an invariant mass of any two jets is equal to the mass of Z^0 or $W^{\pm}$. The completed results of helicity amplitudes [5] squared of the QCD and EW [6] interference terms will be given in section (2). Result and conclusion will be put into section (3).

2. Results for spin-dependent matrix elements

At the parton level, the production of three jets at large p_T can proceed via the amplitudes of $H_9 - H_{17}$ in figure 2, which involve $q\bar{q}$, qq, qq' and $q\bar{q}'$ scattering with radiation of a gluon, together with all other amplitudes for $2 \to 3$ parton scattering from the subprocesses $gg \to gq\bar{q}$ or (ggg), $q\bar{q} \to ggg$, $qg \to qgg$ or $(qq\bar{q})$ and $\bar{q}g \to \bar{q}q\bar{q}$ or $(\bar{q}gg)$. All these subprocesses give rise to the dominant QCD background. Helicity amplitude techniques are used to obtain the spin-dependent matrix elements. Results can be separated into the parity conserving and violating terms.

For the subprocess of $q(p_1)+\bar{q}'(p_2) \to q(p_4)+\bar{q}'(p_3)+g(p_5)$, we only consider the diagrams $W_1 - W_4$ which interfere with $H_9 - H_{13}$ in figure 1, where q and q' denote the different quark flavors. The parity conserving piece of the amplitude squared, average over initial colors, and summed over final colors and spins is given

by

$$|M(-++-)|^2 = \frac{2^9\pi^3\alpha_s^2\alpha V_{qq'}}{3^3 sin^2\theta_W}\frac{(s_{13}^2+s_{24}^2)}{t_2}\Bigg\{\frac{1}{(s_{12}-M_W^2)}\Bigg[\frac{8}{s_{14}t_3}\left(\frac{g_3}{t_4}+\frac{f_2}{t_3}\right) - \frac{1}{s_{23}t_1}\left(\frac{g_2}{t_4}+\frac{g_1}{t_3}\right) + \frac{8}{s_{23}t_4}\left(\frac{f_3}{t_4}+\frac{g_3}{t_3}\right) - \frac{9}{s_{14}s_{23}}\left(\frac{g_3}{t_4}+\frac{f_2}{t_3}\right)\Bigg] - \frac{(s_{34}-M_W^2)}{(s_{34}-M_W^2)^2+\Gamma_W^2M_W^2)t_1}\left(\frac{g_1}{s_{14}t_3}+\frac{8f_1}{s_{23}t_1}-\frac{g_2}{s_{23}t_4} + \frac{9g_1}{s_{14}s_{23}}\right)\Bigg\} \quad (1)$$

where $s_{ij} = 2p_ip_j$, $t_i = 2p_ip_5$; $f_1 = -2t_1s_{34}$, $f_2 = -2s_{14}t_3$, $f_3 = -2t_4s_{13}$; $g_1 = -t_1s_{34} - t_3s_{14} - t_4s_{13}$; $g_2 = 2t_1s_{34} + g_1$ and $g_3 = g_2 - 2s_{13}t_4$. M_W and Γ_W are the mass and width of the W particle respectively. The parity violating part is given by

$$|M(-++-)|^2 = \frac{2^{11}\pi^3\alpha_s^2\alpha M_W\Gamma_W V_{qq'}^2 x_\epsilon(s_{13}^2-s_{24}^2)}{27t_1t_2t_3t_4 sin^2\theta_W}\Bigg[\frac{1}{(s_{34}-M_W^2)^2+M_W^2\Gamma_W^2} \times\left(\frac{t_4}{s_{14}}+\frac{t_3}{s_{23}}-\frac{9t_3t_4}{s_{14}s_{23}}\right)\Bigg] \quad (2)$$

where $V_{qq'}$ is a Cabbibo-Kobayashi-Maskawa matrix element, and the parity violating invariant is given by $x_\epsilon = \epsilon_{\mu\nu\alpha\beta}p_1^\mu p_2^\nu p_3^\alpha p_4^\beta$. α_s is the strong coupling constant and only four flavors of quarks are taken into account. $\alpha = \frac{1}{137}$ is the fine structure constant. θ_W is the weak angle.

For the interference between diagrams $Z_5 - Z_8$ and $H_9 - H_{13}$ in figure 1, the parity conserving terms are given by

$$|M(-++-)|^2 = \frac{2^8\pi^3\alpha_s^2\alpha L_qL_q'}{3^2 sin^2\theta_W(1-sin^2\theta_W)}\frac{(s_{13}^2+s_{24}^2)}{t_1t_2t_3t_4} \times\left(\frac{1}{(s_{23}-M_Z^2)s_{14}}+\frac{1}{(s_{14}-M_Z^2)s_{23}}\right)\left(g_3t_1+g_1t_4\right). \quad (3)$$

$$|M(----)|^2 = \frac{2^8\pi^3\alpha_s^2\alpha R_qL_q'}{3^2 sin^2\theta_W(1-sin^2\theta_w)}\frac{(s_{12}^2+s_{34}^2)}{t_1t_2t_3t_4}$$

$$\times\left(\frac{1}{(s_{23}-M_Z^2)s_{14}}+\frac{1}{(s_{14}-M_Z^2)s_{23}}\right)\left(g_3t_1+g_1t_4\right). \quad (4)$$

where L_q and R_q are the left and right coupling constants of quark flavors respectively, and $L_u = 1 - \frac{4}{3}sin^2\theta_W$, $L_d = (-1+\frac{2}{3}sin^2\theta_W)$ and $R_q = -2e_qsin^2\theta_W$. e_q is the quark charges. M_Z and Γ_Z are the mass and width of the Z^0 particle respectively. The hermitian conjugate of eqn.(3) and eqn.(4) gives $|M(+--+)|^2$ and $|M(++++)|^2$ respectively. For the parity violating term, there is an extra minus sign for its hermitian conjugate. The amplitude square is then given by,

$$|M|^2 = \frac{1}{4}(|M(-)|^2 + |M(+)|^2),$$

where $|M(-)|^2 = |M(-++-)|^2 + |M(----)|^2$, and $|M(+)|^2 = |M(+--+)|^2 + |M(++++)|^2$.

For the subprocess of $q(p_1) + \bar{q}(p_2) \to q(p_4) + \bar{q}(p_3) + g(p_5)$, the relevant diagrams are $Z_1 - Z_8$ and $H_9 - H_{18}$ in fig 2. The parity conserving parts of amplitude are given by

$$|M(-++-)|^2 = \frac{2^8\pi^3\alpha_s^2\alpha L_q^2}{27sin^2\theta_W(1-sin^2\theta_w)}\frac{(s_{13}^2+s_{24}^2)}{t_2} \times\Bigg[\frac{1}{(s_{12}-M_Z^2)}\Bigg[-\frac{8}{s_{14}t_3}\left(\frac{g_3}{t_4}+\frac{f_2}{t_3}\right)+\frac{1}{s_{23}t_1} \times\left(\frac{g_2}{t_4}+\frac{g_1}{t_3}\right)-\frac{8}{s_{23}t_4}\left(\frac{f_3}{t_4}+\frac{g_3}{t_3}\right)+\frac{9}{s_{14}s_{23}}\left(\frac{g_3}{t_4}+\frac{f_2}{t_3}\right) - \frac{3}{t_1s_{34}}\left(\frac{g_2}{t_4}+\frac{g_1}{t_3}\right)\Bigg]+\frac{1}{(s_{14}-M_z^2)t_3}\left(\frac{3g_1}{s_{23}t_1}-\frac{3g_3}{s_{23}t_4} - \frac{g_3}{s_{12}t_4}+\frac{8f_2}{s_{12}t_3}-\frac{g_1}{t_1s_{34}}+\frac{9g_1}{s_{12}s_{34}}\right) + \frac{(s_{34}-M_Z^2)}{t_1((s_{34}-M_Z^2)^2+M_Z^2\Gamma_Z^2)}\Bigg[\frac{g_2}{s_{14}t_3}-\frac{8f_1}{t_1s_{23}}+\frac{g_2}{t_4s_{23}} - \frac{9g_1}{s_{14}s_{23}}-\frac{3}{s_{12}}\left(\frac{g_2}{t_4}+\frac{g_1}{t_3}\right)\Bigg] + \frac{1}{(s_{23}-M_Z^2)}\Bigg[\frac{3}{s_{14}t_3}\left(\frac{g_1}{t_1}+\frac{g_3}{t_4}\right)$$

$$+\frac{1}{t_1}\left(\frac{8g_2}{s_{12}t_4}+\frac{g_1}{s_{12}t_3}+\frac{8f_1}{t_1s_{34}}-\frac{9f_1}{s_{12}s_{34}}\right)$$
$$+\frac{1}{t_4}\left(\frac{8f_3}{s_{12}s_{45}}-\frac{g_3}{s_{12}t_3}+\frac{8g_2}{t_1s_{34}}-\frac{9g_2}{s_{12}s_{34}}\right)\Bigg]. \tag{5}$$

$$|M(-+-+)|^2 = -\frac{2^8\pi^3\alpha_s^2\alpha L_qR_q}{9sin^2\theta_W(1-sin^2\theta_W)}\frac{(s_{23}^2+s_{14}^2)}{t_1t_2t_3t_4s_{12}s_{34}}$$
$$\times\left(\frac{s_{12}}{(s_{12}-M_Z^2)}+\frac{(s_{34}-M_Z^2)s_{34}}{((s_{34}-M_Z^2)^2+M_Z^2\Gamma_Z^2)}\right)$$
$$\times\left(g_2t_3+g_1t_4\right) \tag{6}$$

$$|M(----)|^2 = \frac{2^8\pi^3\alpha_s^2\alpha L_qR_q}{9sin^2\theta_W(1-sin^2\theta_W)}\frac{(s_{12}^2+s_{34}^2)}{t_2t_1t_3t_4}$$
$$\times\left(\frac{1}{(s_{14}-M_Z^2)s_{23}}+\frac{1}{(s_{23}-M_Z^2)s_{14}}\right)\left(g_1t_4+g_3t_1\right). \tag{7}$$

The corresponding parity violating terms are given by

$$|M(-++-)|^2 = \frac{2^{10}\pi^3\alpha_s^2\alpha M_Z\Gamma_Z x_\epsilon(s_{13}^2-s_{24}^2)}{27t_2sin^2\theta_W(1-sin^2\theta_W)}\left\{\frac{1}{(s_{34}-M_Z^2)^2+M_Z^2\Gamma_Z^2}\right.$$
$$\left.\times\frac{1}{t_1}\left[\frac{1}{s_{14}t_3}+\frac{1}{s_{23}t_4}-\frac{9}{s_{14}s_{23}}-\frac{3}{s_{12}}\left(\frac{1}{t_3}+\frac{1}{t_4}\right)\right]\right\} \tag{8}$$

$$|M(-+-+)|^2 = \frac{2^{10}\pi^3\alpha_s^2\alpha M_Z\Gamma_Z L_qR_qx_\epsilon(s_{23}^2-s_{14}^2)}{9t_1t_2t_3t_4sin^2\theta_W(1-sin^2\theta_W)s_{12}}\frac{1}{((s_{34}-M_Z^2)^2+M_Z^2\Gamma_Z^2)}$$
$$\times\left(t_3+t_4\right) \tag{9}$$

The value of $|M|^2$ for the subprocess of $q\bar{q}\to q\bar{q}g$ can be calculated in a similar way for $q\bar{q}'\to q\bar{q}'g$

The interference term for the subprocess $q(p_1)+\bar{q}(p_2)\to q'(p_4)+\bar{q}'(p_3)+g(p_5)$, comes from diagrams Z_1-Z_4 and H_9-H_{13} in fig 3. The parity conserving terms

of amplitude squared are given by

$$|M(-++-)|^2 = \frac{-2^8\pi^3\alpha_s^2\alpha L_qL_q'}{9sin^2\theta_W(1-sin^2\theta_W)}\frac{(s_{13}^2+s_{24}^2)}{t_1t_2t_3t_4s_{12}s_{34}}\left(t_3g_2+t_4g_1\right)$$
$$\times\left(\frac{s_{12}}{(s_{12}-M_Z^2)}+\frac{(s_{34}-M_Z^2)s_{34}}{((s_{34}-M_Z^2)^2+M_Z^2\Gamma_Z^2)}\right) \tag{10}$$

$$|M(-+-+)|^2 = \frac{-2^8\pi^3\alpha_s^2\alpha L_qR_q'}{9sin^2\theta_W(1-sin^2\theta_W)}\frac{(s_{23}^2+s_{14}^2)}{t_1t_2t_3t_4s_{12}s_{34}}\left(t_3g_2+t_4g_1\right)$$
$$\times\left(\frac{s_{12}}{(s_{12}-M_Z^2)}+\frac{(s_{34}-M_Z^2)s_{34}}{((s_{34}-M_Z^2)^2+M_Z^2\Gamma_Z^2)}\right) \tag{11}$$

$|M(+--+)|^2$ and $|M(+-+-)|^2$ are the hermitain conjugate of eqn.(10) and (11) respectively. The parity violating terms are similar, except that there is an extra minus sign. For the interference between the diagrams W_5-W_8 and H_9-H_{13} in figure 3, the parity conserving piece is given by

$$|M(-++-)|^2 = -\frac{2^8\pi^3\alpha_s^2\alpha V_{qq'}}{9sin^2\theta_W}\frac{(s_{13}^2+s_{24}^2)}{t_2}$$
$$\times\left\{\frac{1}{(s_{14}-M_W^2)t_3}\left[\frac{g_3}{s_{12}t_4}-\frac{8f_3}{s_{12}t_3}+\frac{g_1}{t_1s_{34}}-\frac{9g_1}{s_{12}s_{34}}\right]\right.$$
$$-\frac{1}{(s_{23}-M_W^2)}\left[\frac{1}{t_1}\left(\frac{8g_2}{s_{12}t_4}-\frac{g_1}{s_{12}t_3}+\frac{8f_1}{t_1s_{34}}-\frac{9f_1}{s_{12}s_{34}}\right)\right.$$
$$\left.\left.-\frac{1}{t_4}\left(\frac{8f_3}{s_{12}t_4}-\frac{g_3}{s_{12}t_3}+\frac{8g_2}{t_1s_{34}}-\frac{9g_2}{s_{12}s_{34}}\right)\right]\right\} \tag{12}$$

Its parity violating part is given by

$$|M(-++-)|^2 = \frac{2^{10}\pi^3\alpha_s^2\alpha M_Z\Gamma_Z x_\epsilon L_qL_q'(s_{24}^2-s_{13}^2)}{9t_1t_2t_3t_4s_{12}sin^2\theta_W(1-sin^2\theta_W^2)}$$
$$\times\frac{(t_3+t_4)}{(s_{34}-M_Z^2)^2+M_Z^2\Gamma_Z^2} \tag{13}$$

$$|M(-+-+)|^2 = \frac{2^{10}\pi^3\alpha_s^2\alpha M_Z\Gamma_Z x_\epsilon L_qR_q'(s_{23}^2-s_{14}^2)}{9t_1t_2t_3t_4s_{12}sin^2\theta_W(1-sin^2\theta_W^2)}$$

$$\times \frac{(t_3+t_4)}{(s_{34}-M_Z^2)^2+M_Z^2\Gamma_Z^2}. \tag{14}$$

For the subprocess of $q(p_1)+q'(p_2)\to q(p_4)+q'(p_3)g(p_5)$, the interference is between diagrams W_1-W_4 and H_9-H_{13} in figure 4, with the parity conserving terms given by

$$\begin{aligned}|M(----)|^2 =& \frac{2^9\pi^3\alpha_s^2\alpha V_{qq'}}{27sin^2\theta_W}\frac{(s_{12}^2+s_{34}^2)}{t_3}\\ &\times\left\{\frac{-1}{(s_{24}-M_W^2)t_1}\left[\frac{a_2}{s_{14}t_2}-\frac{8b_1}{s_{23}t_1}-\frac{a_1}{t_4s_{23}}+\frac{9a_2}{s_{14}s_{23}}\right]\right.\\ &+\frac{1}{(s_{13}-M_W^2)}\left[\frac{1}{t_4}\left(\frac{a_1}{s_{23}t_1}-\frac{8a_3}{s_{14}t_2}+\frac{8b_2}{t_4s_{23}}-\frac{9a_3}{s_{14}s_{23}}\right)\right.\\ &\left.\left.-\frac{1}{t_2}\left(\frac{a_2}{s_{23}t_1}+\frac{8a_3}{s_{23}t_4}-\frac{8b_3}{t_2s_{14}}-\frac{9b_3}{s_{23}s_{14}}\right)\right]\right\}. \end{aligned}\tag{15}$$

where $a_1 = s_{12}t_4+t_1s_{24}-s_{14}t_2$; $a_2 = t_4s_{12}-s_{14}t_2-t_1s_{24}$; $a_3 = s_{12}t_4+s_{14}t_2-t_1s_{24}$; and $b_1 = 2s_{24}t_1$; $b_2 = 2t_4s_{12}$; $b_3 = 2s_{14}t_2$

For the interference between diagrams Z_5-Z_8 and H_9-H_{13}, the parity conserving terms are given by

$$\begin{aligned}|M(----)|^2 =& \frac{2^8\pi^3\alpha_s^2\alpha L_qL_q'}{9sin^2\theta_W(1-sin^2\theta_W)}\frac{(s_{12}^2+s_{34}^2)}{t_1t_2t_3t_4}\\ &\times\left(\frac{1}{(s_{23}-M_Z^2)s_{14}}+\frac{1}{(s_{14}-M_Z^2)s_{23}}\right)\left(a_3t_1-a_2t_4\right)\end{aligned}\tag{16}$$

$$\begin{aligned}|M(-++-)|^2 =& \frac{2^8\pi^3\alpha_s^2\alpha L_qR_q'}{9sin^2\theta_W(1-sin^2\theta_W)}\frac{(s_{24}^2+s_{23}^2)}{t_1t_2t_3t_4}\\ &\times\left(\frac{1}{(s_{23}-M_Z^2)s_{14}}+\frac{1}{(s_{14}-M_Z^2)s_{23}}\right)\left(a_3t_1-a_2t_4\right).\end{aligned}\tag{17}$$

where $|M(++++)|^2$ and $|M(+--+)|^2$ are the hermitian conjugates of eqns (16) and (17) respectively. The results of eqn.(15), (16), (17) and the hermitian conjugates of eqn.(16) and (17) give the amplitude squared $|M|^2$. It is easy to obtain the results of the subprocess of $\bar{q}(p_1)+\bar{q}'(p_2)\to\bar{q}(p_4)+\bar{q}'(p_3)+g(p_5)$, which should be equal to $|M|^2$.

For the subprocess of $q(p_1)+q(p_2)\to q(p_4)+q(p_3)+g(p_5)$, if particle 3 and 4 are interchanged, an extra minus sign should be put in the amplitude due to the antisymmetry of two identical fermions. Finally for the interference between diagrams Z_1-Z_8 and H_9-H_{18} in figure 5, the parity conserving piece of the amplitude squared is given by

$$\begin{aligned}|M(----)|^2 =& \frac{2^8\pi^3\alpha_s^2\alpha L_q^2}{27sin^2\theta_W(1-sin^2\theta_W^2)}\frac{(s_{12}^2+s_{34}^2)}{t_3}\\ &\times\left\{\frac{1}{(s_{24}-M_Z^2)t_1}\left[\frac{a_2}{s_{14}t_2}-\frac{8b_1}{s_{23}t_1}-\frac{a_1}{t_4s_{23}}+\frac{9a_2}{s_{14}s_{23}}\right]\right.\\ &-\frac{1}{(s_{13}-M_Z^2)}\left[\frac{1}{t_4}\left(\frac{a_1}{s_{23}t_1}-\frac{8a_3}{s_{14}t_2}+\frac{8b_2}{t_4s_{23}}-\frac{9a_3}{s_{14}s_{23}}\right)\right.\\ &\left.+\frac{1}{t_2}\left(\frac{a_2}{s_{23}t_1}+\frac{8a_3}{s_{23}t_4}-\frac{8b_3}{t_2s_{14}}-\frac{9b_3}{s_{23}s_{14}}\right)\right]\\ &\left.-3\left(\frac{1}{s_{13}(s_{24}-M_Z^2)}+\frac{1}{s_{24}(s_{13}-M_Z^2)}\right)\left(\frac{g_1}{t_1t_4}+\frac{g_2}{t_1t_2}\right)\right\}\\ &+\left[1\leftrightarrow 2\right].\end{aligned}\tag{18}$$

$$\begin{aligned}|M(-+-+)|^2 =& \frac{2^8\pi^3\alpha_s^2\alpha L_qR_q}{9sin^2\theta_W(1-sin^2\theta_W)}\frac{(s_{14}^2+s_{13}^2)}{t_1t_2t_3t_4}\\ &\times\left(\frac{1}{(s_{13}-M_Z^2)s_{24}}+\frac{1}{(s_{24}-M_Z^2)s_{13}}\right)\left(a_1t_2-a_2t_4\right)\end{aligned}\tag{19}$$

$$\begin{aligned}|M(-++-)|^2 =& \frac{2^8\pi^3\alpha_s^2\alpha L_qR_q}{9sin^2\theta_W(1-sin^2\theta_W)}\frac{(s_{24}^2+s_{23}^2)}{t_1t_2t_3t_4}\\ &\times\left(\frac{1}{(s_{14}-M_Z^2)s_{23}}+\frac{1}{(s_{23}-M_Z^2)s_{14}}\right)\left(a_3t_1+a_2t_4\right).\end{aligned}\tag{20}$$

$|M(++++)|^2$, $|M(+-+-)|^2$ and $|M(+--+)|^2$ are the hermitian conjugates of eqn.(18), (19) and (20) respectively. The corresponding amplitude squared for the subprocess of $\bar{q}(p_1)+\bar{q}(p_2)\to\bar{q}(p_3)+\bar{q}(p_4)+g(p_5)$ are related to the eqns.(18), (19), (20) and their hermitian conjuates. Thus it is easy to obtain the values of $|M|^2$.

We define an observable cross section by:

$$\sigma = \int d\sigma$$

where $d\sigma$ is the differential cross section for finding three-jet production. Then

$$\int d\sigma = \sum_{ij} \frac{1}{1+\delta_{ij}} \int dx_a dx_b f_i^a(x_a, Q^2) f_j^b(x_b, Q^2) \frac{d\sigma_{ij}}{d\phi d\Psi} d\phi d\Psi.$$

For hadron-hadron collisions, we choose $d\Psi = dx_a dx_b dy_3 dy_g ds_{34}$, where x_a and x_b are the parton momentum fractions, and y_3 and y_g are the center of mass rapidities of the hadronic jet with momentum p_3 and the gluon respectively, and $d\phi = d\phi_3$. s_{34} is the invariant mass of any two jets. ϕ_3 is the relative angle between two jets. It is for the reason that there is only one ϕ dependence in the calculation. $f_i^a(x_a, Q^2)$ and $f_j^b(x_b, Q^2)$ are the parton distribution functions [9]. The computer program "Vegas" [8] is used to calculate this integral.

3. Results

Results for pp and $\bar{p}p$ are shown in fig. (6-7), and only include (u,d,s,c) flavor contributions to our calculations. We choose the width of s_{34} so that $(M_W - \Gamma_W)^2 \leq s_{34} \leq (M_W + \Gamma_W)^2$ and also $(M_Z - \Gamma_Z)^2 \leq s_{34} \leq (M_W + \Gamma_Z)^2$. We also symmetrize the hadronic jets since it is almost impossible to identify the flavors of a hadronic jet. For the cross section we impose a set of refection-symmetric cuts $|y_i| \leq 4$, $|p_{iT}| \geq 5$ GeV, $\theta_{ij} \geq 15^o$, where i,j denote three different jets $i \neq j$, to ensure that the hadronic jets are well-resolved and to exclude regions of phase space where the tree level calculations presented here become unrelaible.

We find that the background for the three-jet production with the invariant mass of two jets is equal to M_Z^2 or M_W^2 is an order of 10^5 pb at 1 TeV.

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FIGURE CAPTIONS

1. FIG.1 Soild lines denote quarks, wavy lines electroweak boson and curly line gluons. The QCD amplitudes $H_9 - H_{13}$ can interfere with the amplitudes of $W_1 - W_4$ via W exhange and of $Z_5 - Z_9$ via Z^0 exchange for the subprocess of $q\bar{q}' \to q\bar{q}'g$.

2. FIG.2 Soild lines denote quarks, wavy lines electroweak boson and curly line gluons. The QCD amplitudes $H_9 - H_{18}$ can interfere with the amplitudes $Z_5 - Z_9$ the subprocess of $q\bar{q} \to q\bar{q}g$.

3. FIG.3 Soild lines denote quarks, wavy lines electroweak boson and curly line gluons. The QCD amplitudes $H_9 - H_{13}$ can interfere with the amplitudes of $W_5 - W_8$ via W exhange and of $Z_1 - Z_4$ via Z^0 exchange for the subprocess of $q\bar{q} \to q'\bar{q}'g$.

4. FIG.4 Soild lines denote quarks, wavy lines electroweak boson and curly line gluons. The QCD amplitudes $H_9 - H_{18}$ can interfere with the amplitudes of $Z_1 - Z_8$ for the subprocess of $qq \to qqg$.

5. FIG.5 Soild lines denote quarks, wavy lines electroweak boson and curly line gluons. The QCD amplitudes $H_9 - H_{13}$ can interfere with the amplitudes of $W_1 - W_4$ via W exhange and of $Z_5 - Z_9$ via Z^0 exchange for the subprocess of $qq' \to qq'g$.

6. FIG.6 The background for three-jet production in pp collision: the data points (circle) are for the $s_{34} = M_W^2$ and (square) are for the $s_{34} = M_Z^2$.

7. FIG.7 The background for three-jet production in $p\bar{p}$ collision: the data points (circle) are for the $s_{34} = M_W^2$ and (square) are for the $s_{34} = M_Z^2$.

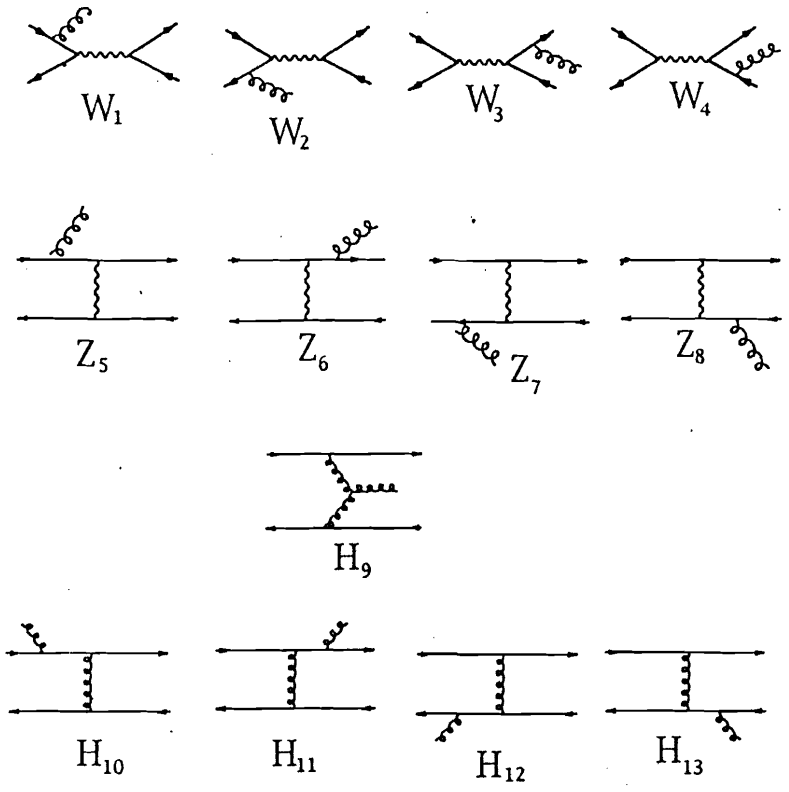

W1
W2
W3
W4
Z5
Z6
Z7
Z8
H9
H10
H11
H12
H13

FIG 1.

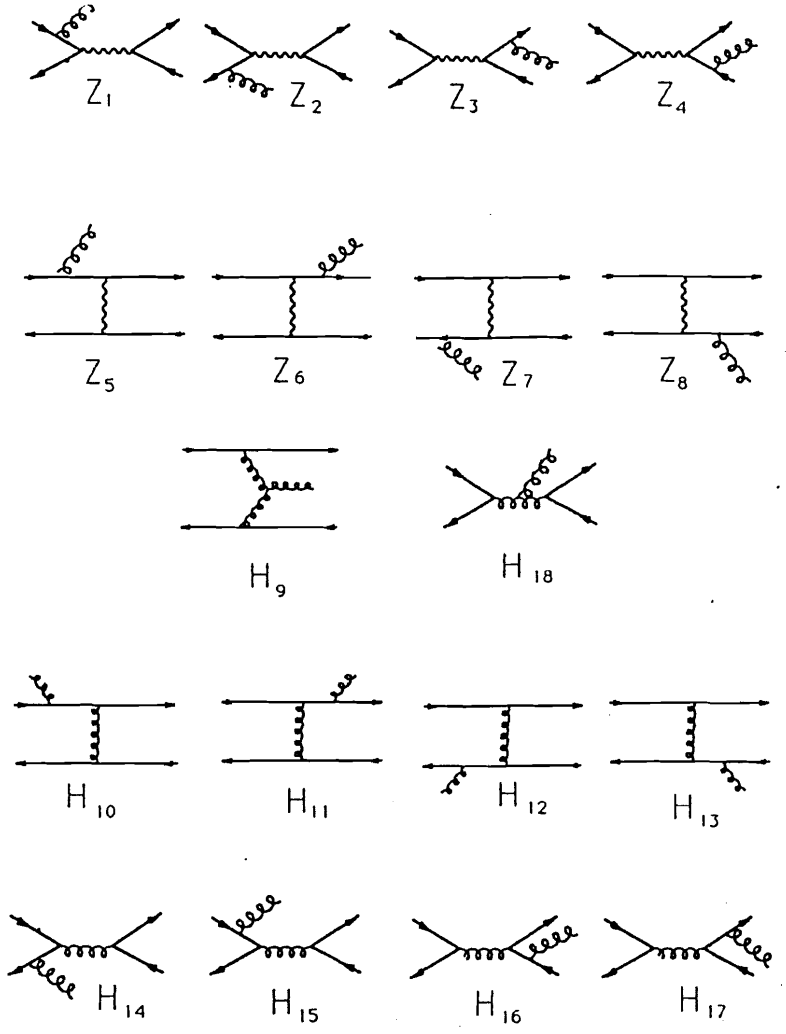

Z1
Z2
Z3
Z4
Z5
Z6
Z7
Z8
H9
H18
H10
H11
H12
H13
H14
H15
H16
H17

FIG 2

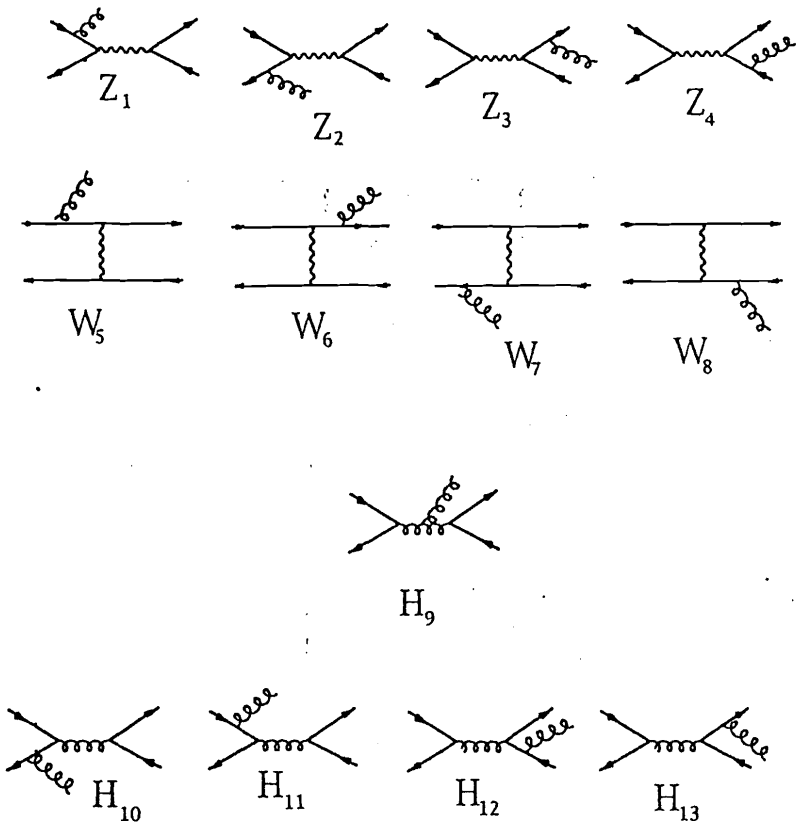

Z_1
Z_2
Z_3
Z_4
W_5
W_6
W_7
W_8
H_9
H_{10}
H_{11}
H_{12}
H_{13}

FIG 3

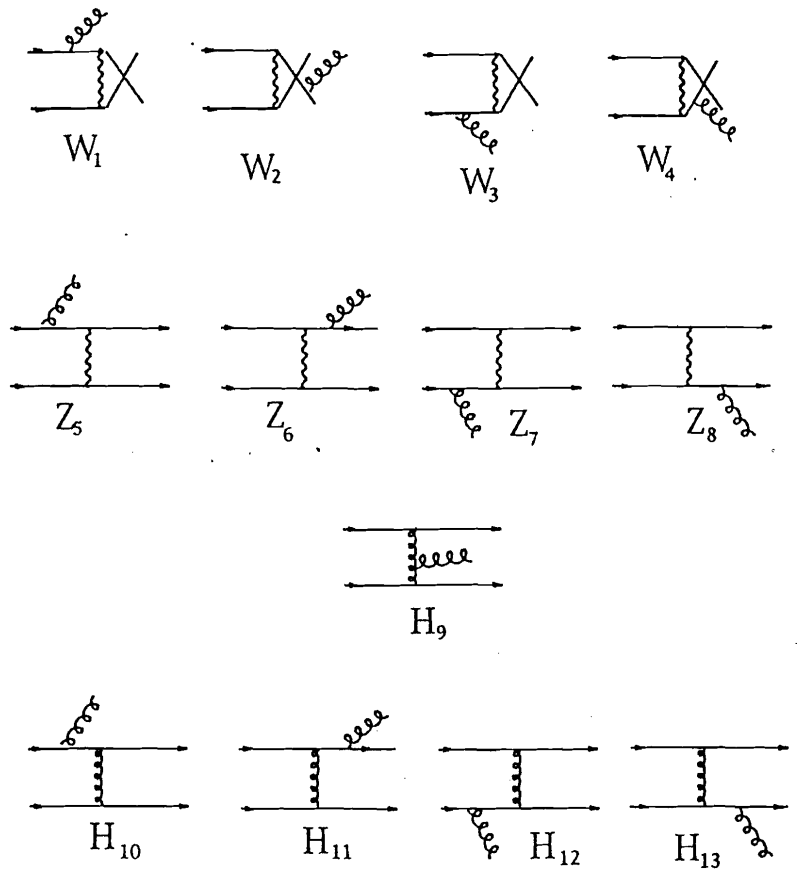
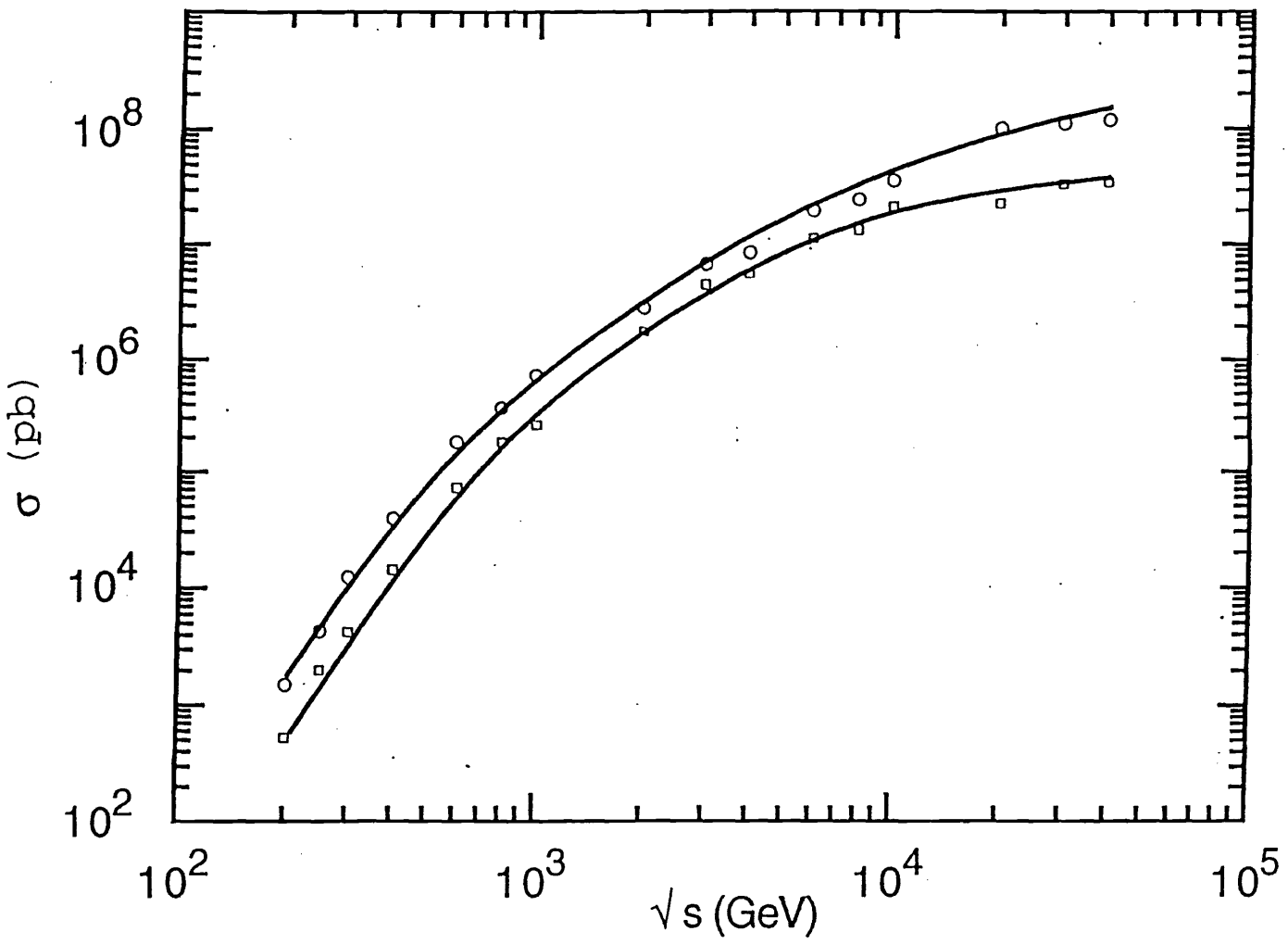

W_1
W_2
W_3
W_4
Z_5
Z_6
Z_7
Z_8
H_9
H_{10}
H_{11}
H_{12}
H_{13}

FIG 4

Fig. 7



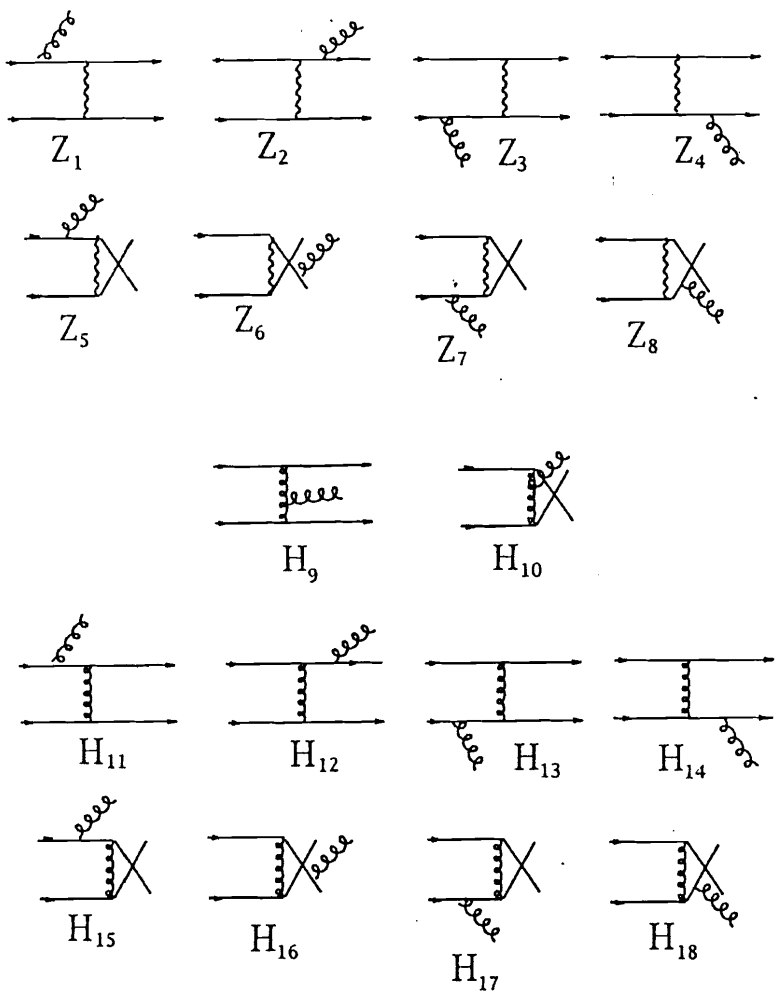
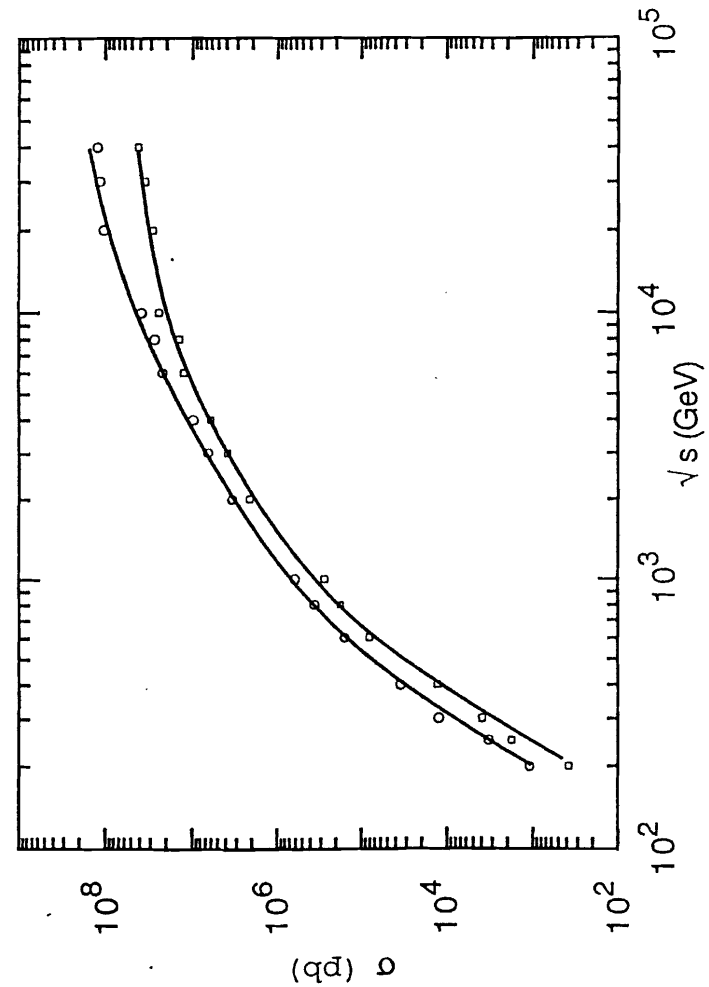

Z1
Z2
Z3
Z4
Z5
Z6
Z7
Z8
H9
H10
H11
H12
H13
H14
H15
H16
H17
H18

Fig. 6


σ (pb)
10^8
10^6
10^4
10^2
√s (GeV)
10^2
10^3
10^4
10^5