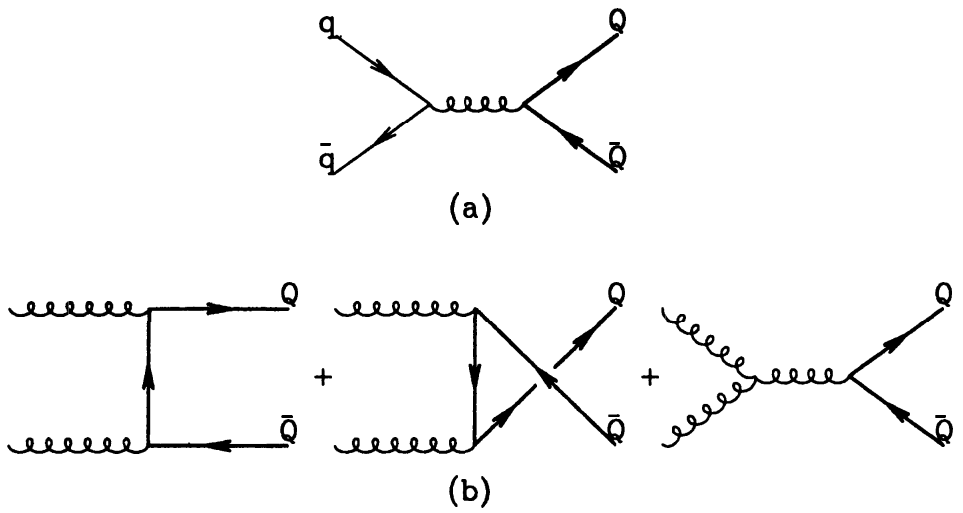

Fig. 10.8. Lowest-order Feynman diagrams for heavy quark production.

tion of the charged Higgs boson mass, for various choices of the unknown angle β.

The decay modes of the H^+ determine the signature for its detection: it should decay predominantly to $c\bar{s}$ and $\bar{\tau}\nu_\tau$, with a predominance of the former at small $\tan\beta$. If the vacuum expectation values of the two Higgs fields are taken to be equal ($\tan\beta = 1$), the branching fraction into $c\bar{s}$ is 64% and into $\bar{\tau}\nu_\tau$ is 31%.

10.3 Heavy quark production

10.3.1 Leading order

We now turn to the mechanisms by which hadrons containing heavy quarks are produced in hadronic reactions. The leading-order processes for the production of a heavy quark Q of mass m in hadron-hadron collisions are

$$\begin{aligned} &(a) \quad q(p_1) + \bar{q}(p_2) \to Q(p_3) + \overline{Q}(p_4) \\ &(b) \quad g(p_1) + g(p_2) \to Q(p_3) + \overline{Q}(p_4) \ , \end{aligned} \tag{10.47}$$

where the four-momenta of the partons are given in brackets. The Feynman diagrams which contribute to the matrix elements in $O(g^2)$ are shown in Fig. 10.8[3]. The corresponding invariant matrix elements squared [13,14] which result from the diagrams in Fig. 10.8 are given in Table 10.2. The matrix elements squared have been averaged (summed) over initial (final) colours and spins, as indicated by $\overline{\sum}$. We have introduced the following

[3] We remind the reader that $g^2 = 4\pi\alpha_S$.

Process	$\overline{\sum}\lvert\mathcal{M}\rvert^2/g^4$
$q\,\bar{q} \to Q\,\bar{Q}$	$\frac{4}{9}\left(\tau_1^2+\tau_2^2+\frac{\rho}{2}\right)$
$g\,g \to Q\,\bar{Q}$	$\left(\frac{1}{6\tau_1\tau_2}-\frac{3}{8}\right)\left(\tau_1^2+\tau_2^2+\rho-\frac{\rho^2}{4\tau_1\tau_2}\right)$

Table 10.2. Lowest-order processes for heavy quark production. $\overline{\sum}|\mathcal{M}|^2$ is the invariant matrix element squared. The colour and spin indices are averaged (summed) over initial (final) states.

notation for the ratios of scalar products:

$$\tau_1 = \frac{2p_1.p_3}{\hat{s}}, \quad \tau_2 = \frac{2p_2.p_3}{\hat{s}}, \quad \rho = \frac{4m^2}{\hat{s}}, \quad \hat{s} = (p_1+p_2)^2. \tag{10.48}$$

In leading order, the short-distance cross section is obtained from the invariant matrix element in the usual way:

$$d\hat{\sigma}_{ij} = \frac{1}{2\hat{s}}\,\frac{d^3p_3}{(2\pi)^3 2E_3}\,\frac{d^3p_4}{(2\pi)^3 2E_4}(2\pi)^4\delta^4(p_1+p_2-p_3-p_4)\,\overline{\sum}\,|\mathcal{M}_{ij}|^2\,. \tag{10.49}$$

The first factor is the flux factor for massless incoming particles. The other terms come from the phase space for $2 \to 2$ scattering.

Consider first the hadronic differential cross section. In terms of the rapidity y, (Eq. (7.16)) and transverse momentum, p_T, the relativistically invariant phase space volume element of the final-state heavy quarks is

$$\frac{d^3p}{E} = dy\,d^2p_T\,. \tag{10.50}$$

Using Eqs. (7.1) and (10.49) the result for the invariant cross section may be written as

$$\frac{d\sigma}{dy_3 dy_4 d^2p_T} = \frac{1}{16\pi^2\hat{s}^2}\sum_{ij} x_1 f_i(x_1,\mu^2)\,x_2 f_j(x_2,\mu^2)\overline{\sum}\,|\mathcal{M}_{ij}|^2\,. \tag{10.51}$$

The energy-momentum delta function in Eq. (10.49) fixes the values of x_1 and x_2 if we know the transverse momenta and rapidity of the outgoing heavy quarks. In the centre-of-mass system of the incoming hadrons we may write the components of the parton four-momenta as

$$\begin{aligned} p_1 &= \tfrac{1}{2}\sqrt{s}(x_1,0,0,x_1) \\ p_2 &= \tfrac{1}{2}\sqrt{s}(x_2,0,0,-x_2) \\ p_3 &= (m_T\cosh y_3, p_T, 0, m_T\sinh y_3) \end{aligned}$$