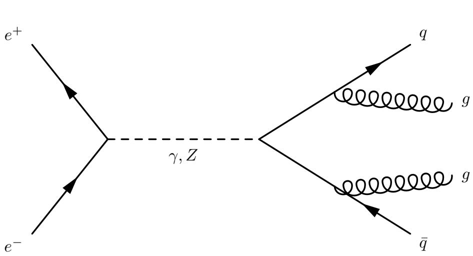
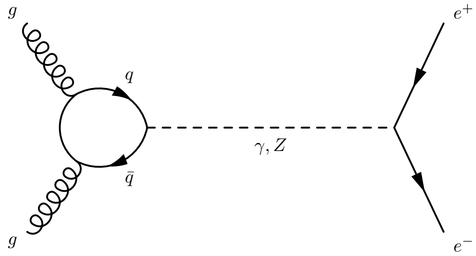
1 SM and beyond: Allowed, forbidden and discovery process

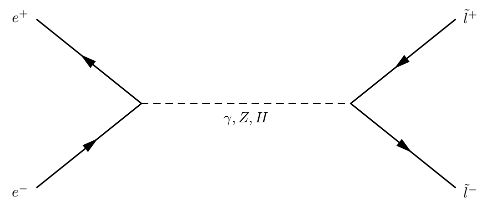
1. 1. - Electromagnetic
         - 1, 2, 3, 4, 6, 8, 11, 12, 13, 14, 15, 16, 20
       - Weak
         - 5, 7, 10, 13, 18, 19
   2. Particle decay, lifetime and branching
   3. Conservation laws, suppression, etc.
   4. process 3,4,8,10,11, 14 and 18 more important



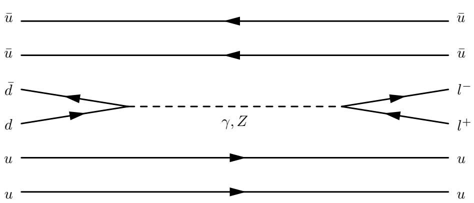
(1) $e^+e^- \to q\bar{q}gg$



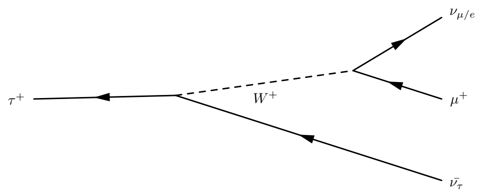
(2) $gg \to e^+e^-$



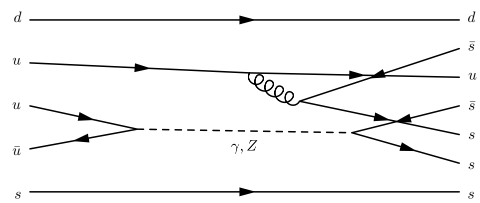
(3) $e^+e^- \to \tilde{l}^+\tilde{l}^-$



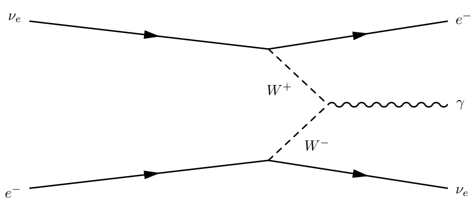
(4) $p\bar{p} \to l^+l^-x$



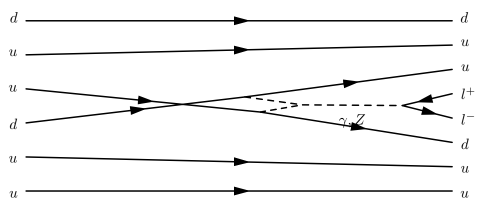
(5) $\tau^+ \to \mu^+\bar{\nu}_\tau\nu_{e/\mu}$



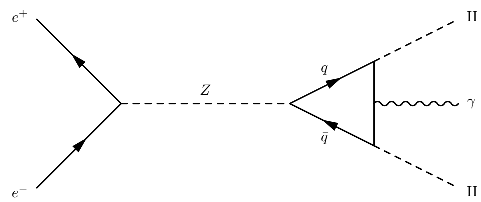
(6) $k^-p \to \omega^-k^+k^0$



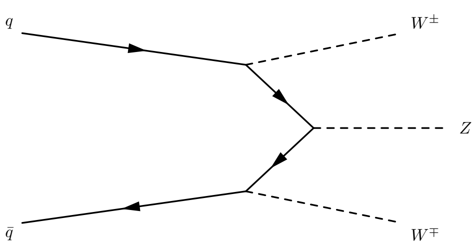
(7) $e^-\nu_e \to \nu_e\gamma e^-$



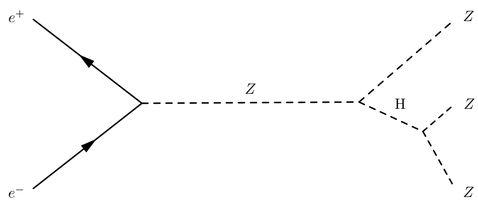
(8) $pp \to ppl^+l^-$



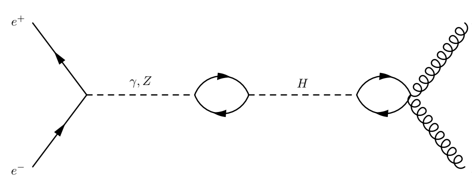
(9) $e^-e^+ \to \gamma HH$



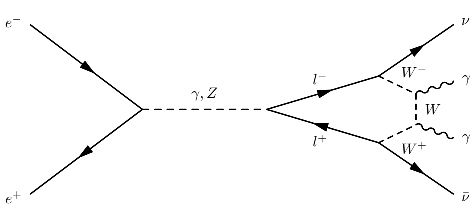
(10) $qq \to W^\pm W^\mp Z$



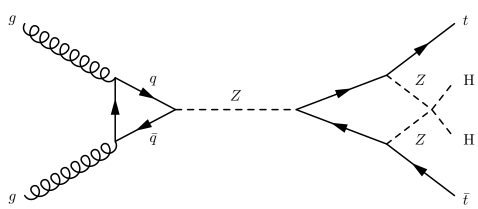
(11) $e^-e^+ \to ZZ$



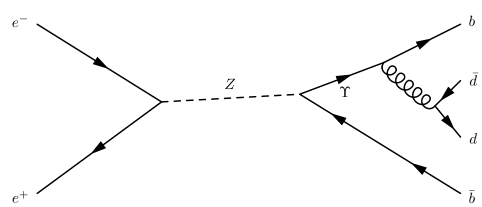
(12) $e^-e^+ \to H \to gg$



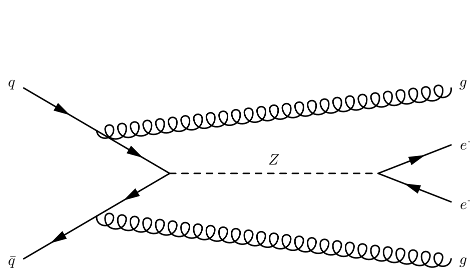
(13) $e^+e^- \to \nu\bar{\nu}\gamma\gamma$



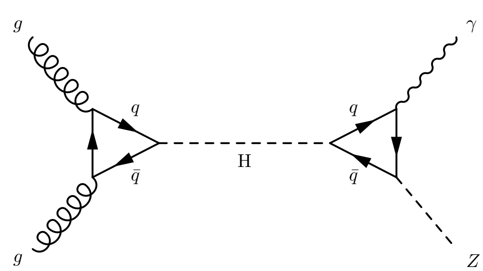
(14) $gg \to t\bar{t}HH$



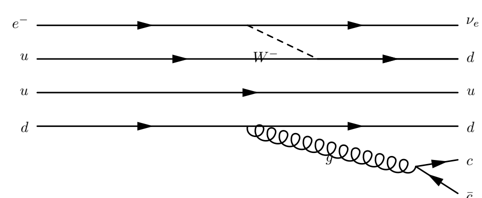
(15) $e^+e^- \to \Upsilon(3s) \to B^0\bar{B}^0$



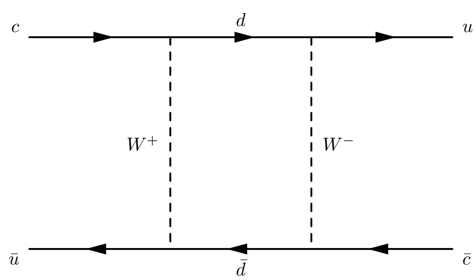
(16) $q\bar{q} \to gge^-e^+$



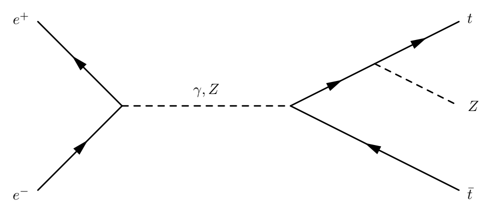
(17) $gg \to Z\gamma$



(18) $gg \to t\bar{t}HH$



(1) $D^0 \longleftrightarrow \bar{D}^0$



(2) $e^+e^- \to t\bar{t}Z$

2 Top quark and W boson

2.1 CKM and W-boson

The CKM-matrix is a unitary matrix where each element holds information about the strength of the flavour changing weak deacys which happens between quarks. These changes are mediated with the $W^{\pm}$ boson. When four quarks were discovered it was created two sets of equation describing the decay from down and strange into top and charm. Seeing that with CP-violation could not be explained with these four quarks, they added another generation to create the CKM-matrix:

$$\begin{bmatrix} d' \\ s' \\ b' \end{bmatrix} = \begin{bmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{bmatrix} \begin{bmatrix} d \\ s \\ b \end{bmatrix} \tag{1}$$

The W boson is a mediater of the weak force, it has either $+1$ or -1 charge so it can react with charged particles. In regards to the CKM-matrix it is the mediator for decaying quarks between up and down types as well as changing flavours. V_{ud} can be experimentally shown from the ration between netron decay and μ decay.
V_{us} is shown in the $K^+ \to \pi^0 e^+ \nu_e$ decay process.
V_{cs} is experimentally shown in hadronic decays of $W^{\pm}$ and $D \to \bar{K} e^+ \nu_e$ process.

2.2 Top quark production

In an $e^- e_+$ anihilation there will be produced a γ or Z which in turn can decay into a $q\bar{q}$. This pair can be a $t\bar{t}$ but is not favorable due to its high mass.

As for the pp-collison there are alot that can happen. It can produce $e^- e^+$ which was discussd above. Gluons, g, can be produced which in turn decay into $t\bar{t}$-pair, and g going into $b\bar{b}$ in which one of the b's interacts with a W to become a singel t.

When a $p\bar{p}$ annihilation occurs there are high probability of high energy g to be produced which have enough energy to decay into $t\bar{t}$, and $b\bar{b}$ to W and bt for a single top.

2.3 Top quark decay

The top quark is very heavy compared to the other elementary particles in the standard model. Due to this mass it only as a lifetime of $5 \times 10^{-25}\,s$, and therefore do not have time to create hadrons, and is the only quark we can observe alone in some sense. Because of that it deacys into a W and a bottom, strange or down quark, which is also the only observed decay mode of the t quark.

The large mass sets the t apart from the other quarks, it decays too fast to hadronize,

2.4 Branching ratios of top decays

$$W_i = \frac{\Gamma_i/\Gamma}{\tau} \approx G_F(\Delta m)^5$$

$G_F \approx 1.17 \times 10^{-5}\, GeV^{-2}$
The branching ratio will be about the size of the mass difference in the process.

$m_t \approx 173\, GeV$, $m_b \approx 4\, GeV$, $m_c \approx 1\, GeV$, $m_s \approx 95\, MeV$, $m_\tau \approx 1776\, MeV \approx 2\, GeV$

$t \to b + c\bar{s}$

$$\Delta m = m_t - m_b - m_c - m_s \approx 168\, GeV$$

$t \to b + \tau^+\nu_\tau$ aproximate the neutrino to be massless.

$$\Delta m = m_t - m_b - m_{\tau^+} \approx 167\, GeV$$

3 Gauge theories