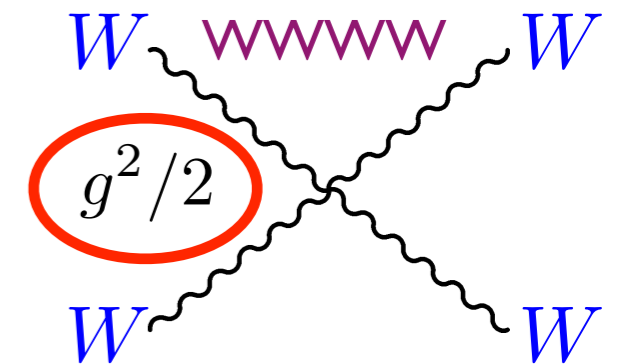
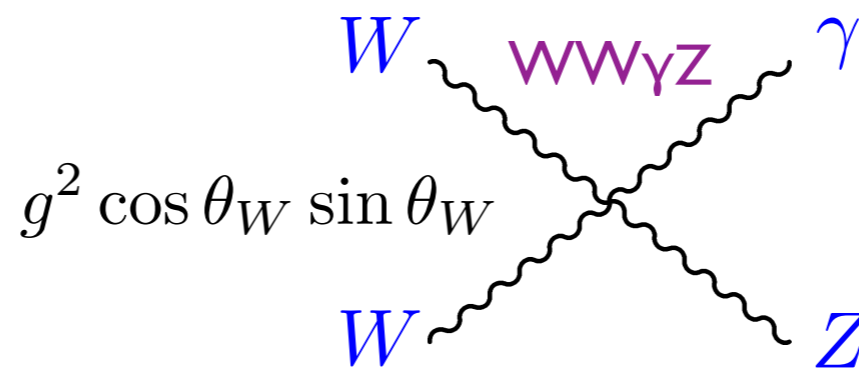
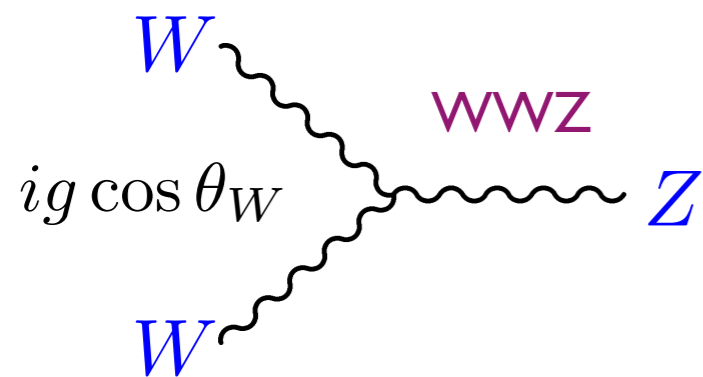
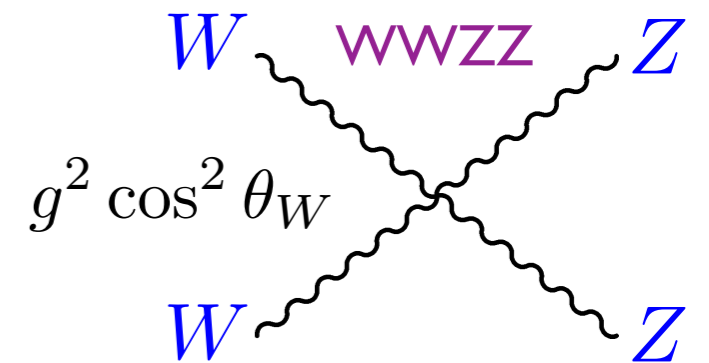
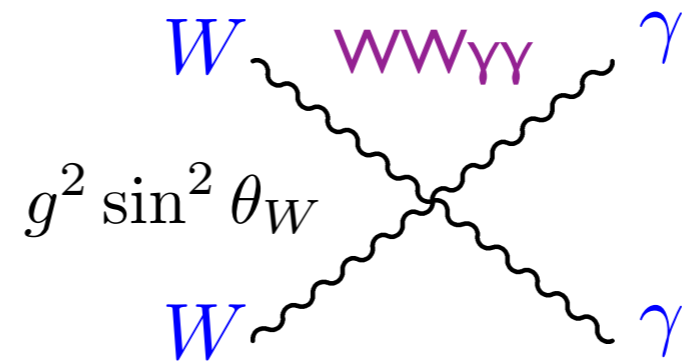
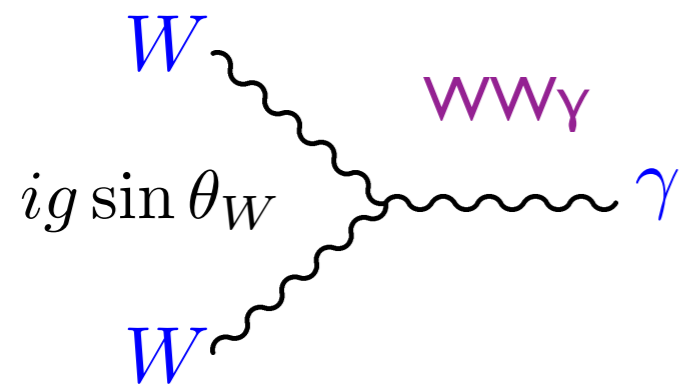


$$\begin{aligned}
\mathcal{L}_{\text{SM}} = & -\frac{1}{2} \partial_\nu g_\mu^a \partial_\nu g_\mu^a - g_s f^{abc} \partial_\mu g_\nu^a g_\mu^b g_\nu^c - \frac{1}{4} g_s^2 f^{abc} f^{ade} g_\mu^b g_\nu^c g_\mu^d g_\nu^e + \frac{1}{2} i g_s^2 (\bar{q}_j^\sigma \gamma^\mu q_j^\sigma) g_\mu^a + \bar{G}^a \partial^2 G^a + \\
& g_s f^{abc} \partial_\mu \bar{G}^a G^b g_\mu^c - \partial_\nu W_\mu^+ \partial_\nu W_\mu^- - M^2 W_\mu^+ W_\mu^- - \frac{1}{2} \partial_\nu Z_\mu^0 \partial_\nu Z_\mu^0 - \frac{1}{2c_W^2} M^2 Z_\mu^0 Z_\mu^0 - \frac{1}{2} \partial_\mu A_\nu \partial_\mu A_\nu - \\
& \frac{1}{2} \partial_\mu H \partial_\mu H - \frac{1}{2} m_h^2 H^2 - \partial_\mu \phi^+ \partial_\mu \phi^- - M^2 \phi^+ \phi^- - \frac{1}{2} \partial_\mu \phi^0 \partial_\mu \phi^0 - \frac{1}{2c^2} M \phi^0 \phi^0 - \beta_h \left[ \frac{2M^2}{g^2} + \frac{2M}{g} H + \frac{1}{2} (H^2 + \right. \\
& \left. \phi^0 \phi^0 + 2\phi^+ \phi^-) \right] + \frac{2M^4}{g^2} \alpha \quad \text{\textbf{The Standard Model Lagrangian}} \\
& W_\nu^+ W_\mu^- + Z_\mu^0 (W_\nu^+ \partial_\nu W_\mu^- - W_\nu^- \partial_\nu W_\mu^+) + Z_\mu^0 (W_\nu^+ \partial_\nu W_\mu^- - W_\nu^- \partial_\nu W_\mu^+) - \\
& \frac{1}{2} g^2 W_\mu^+ W_\mu^- W_\nu^+ W_\nu^- + \frac{1}{2} g^2 W_\mu^+ W_\nu^- W_\mu^+ W_\nu^- + g^2 c_W^2 (Z_\mu^0 W_\mu^+ Z_\nu^0 W_\nu^- - Z_\mu^0 Z_\nu^0 W_\mu^+ W_\nu^-) + g^2 s_W^2 (A_\mu W_\mu^+ A_\nu W_\nu^- - \\
& A_\mu A_\nu W_\mu^+ W_\nu^-) + g^2 s_W c_W [A_\mu Z_\nu^0 (W_\mu^+ W_\nu^- - W_\nu^+ W_\mu^-) - 2A_\mu Z_\mu^0 W_\nu^+ W_\nu^-] - g \alpha [H^3 + H \phi^0 \phi^0 + 2H \phi^+ \phi^-] - \\
& \frac{1}{8} g^2 \alpha_h [H^4 + (\phi^0)^4 + 4(\phi^+ \phi^-)^2 + 4(\phi^0)^2 \phi^+ \phi^- + 4H^2 \phi^+ \phi^- + 2(\phi^0)^2 H^2] - g M W_\mu^+ W_\mu^- H - \frac{1}{2} g \frac{M}{c_W^2} Z_\mu^0 Z_\mu^0 H - \\
& \frac{1}{2} i g [W_\mu^+ (\phi^0 \partial_\mu \phi^- - \phi^- \partial_\mu \phi^0) - W_\mu^- (\phi^0 \partial_\mu \phi^+ - \phi^+ \partial_\mu \phi^0)] + \frac{1}{2} g [W_\mu^+ (H \partial_\mu \phi^- - \phi^- \partial_\mu H) - W_\mu^- (H \partial_\mu \phi^+ - \\
& \phi^+ \partial_\mu H)] + \frac{1}{2} g \frac{1}{c_W} (Z_\mu^0 (H \partial_\mu \phi^0 - \phi^0 \partial_\mu H) - i g \frac{s_W^2}{c_W} M Z_\mu^0 (W_\mu^+ \phi^- - W_\mu^- \phi^+) + i g s_W M A_\mu (W_\mu^+ \phi^- - W_\mu^- \phi^+) - \\
& i g \frac{1-2c_W^2}{2c_W} Z_\mu^0 (\phi^+ \partial_\mu \phi^- - \phi^- \partial_\mu \phi^+) + i g s_W A_\mu (\phi^+ \partial_\mu \phi^- - \phi^- \partial_\mu \phi^+) - \frac{1}{4} g^2 W_\mu^+ W_\mu^- [H^2 + (\phi^0)^2 + 2\phi^+ \phi^-] - \\
& \frac{1}{4} g^2 \frac{1}{c_W^2} Z_\mu^0 Z_\mu^0 [H^2 + (\phi^0)^2 + 2(2s_W^2 - 1)^2 \phi^+ \phi^-] - \frac{1}{2} g^2 \frac{s_W^2}{c_W} Z_\mu^0 \phi^0 (W_\mu^+ \phi^- + W_\mu^- \phi^+) - \frac{1}{2} i g^2 \frac{s_W^2}{c_W} Z_\mu^0 H (W_\mu^+ \phi^- - \\
& W_\mu^- \phi^+) + \frac{1}{2} g^2 s_W A_\mu \phi^0 (W_\mu^+ \phi^- + W_\mu^- \phi^+) + \frac{1}{2} i g^2 s_W A_\mu H (W_\mu^+ \phi^- - W_\mu^- \phi^+) - g^2 \frac{s_W}{c_W} (2c_W^2 - 1) Z_\mu^0 A_\mu \phi^+ \phi^- - \\
& g^1 s_W^2 A_\mu A_\mu \phi^+ \phi^- - \bar{e}^\lambda (\gamma \partial + m_e^\lambda) e^\lambda - \bar{\nu}^\lambda \gamma \partial \nu^\lambda - \bar{u}_j^\lambda (\gamma \partial + m_u^\lambda) u_j^\lambda - \bar{d}_j^\lambda (\gamma \partial + m_d^\lambda) d_j^\lambda + i g s_W A_\mu [-(\bar{e}^\lambda \gamma^\mu e^\lambda) + \\
& \frac{2}{3} (\bar{u}_j^\lambda \gamma^\mu u_j^\lambda) - \frac{1}{3} (\bar{d}_j^\lambda \gamma^\mu d_j^\lambda)] + \frac{i g}{4c_W} Z_\mu^0 [(\bar{\nu}^\lambda \gamma^\mu (1 + \gamma^5) \nu^\lambda) + (\bar{e}^\lambda \gamma^\mu (4s_W^2 - 1 - \gamma^5) e^\lambda) + (\bar{u}_j^\lambda \gamma^\mu (\frac{4}{3}s_W^2 - 1 - \gamma^5) u_j^\lambda) + \\
& (\bar{d}_j^\lambda \gamma^\mu (1 - \frac{8}{3}s_W^2 - \gamma^5) d_j^\lambda)] + \frac{i g}{2\sqrt{2}} W_\mu^+ [(\bar{\nu}^\lambda \gamma^\mu (1 + \gamma^5) e^\lambda) + (\bar{u}_j^\lambda \gamma^\mu (1 + \gamma^5) C_{\lambda\kappa} d_j^\kappa)] + \frac{i g}{2\sqrt{2}} W_\mu^- [(\bar{e}^\lambda \gamma^\mu (1 + \gamma^5) \nu^\lambda) + \\
& (\bar{d}_j^\kappa C_{\lambda\kappa}^\dagger \gamma^\mu (1 + \gamma^5) u_j^\lambda)] + \frac{i g}{2\sqrt{2}} \frac{m_e^\lambda}{M} [-\phi^+ (\bar{\nu}^\lambda (1 - \gamma^5) e^\lambda) + \phi^- (\bar{e}^\lambda (1 + \gamma^5) \nu^\lambda)] - \frac{g}{2} \frac{m_e^\lambda}{M} [H (\bar{e}^\lambda e^\lambda) - i \phi^0 (\bar{e}^\lambda \gamma^5 e^\lambda)] + \\
& \frac{i g}{2M\sqrt{2}} \phi^+ [-m_d^\kappa (\bar{u}_j^\lambda C_{\lambda\kappa} (1 - \gamma^5) d_j^\kappa) + m_u^\lambda (\bar{u}_j^\lambda C_{\lambda\kappa} (1 + \gamma^5) d_j^\kappa)] + \frac{i g}{2M\sqrt{2}} \phi^- [m_d^\lambda (\bar{d}_j^\lambda C_{\lambda\kappa}^\dagger (1 + \gamma^5) u_j^\kappa) - \\
& m_u^\kappa (\bar{d}_j^\lambda C_{\lambda\kappa}^\dagger (1 - \gamma^5) u_j^\kappa)] - \frac{g}{2} \frac{m_u^\lambda}{M} H (\bar{u}_j^\lambda u_j^\lambda) - \frac{g}{2} \frac{m_d^\lambda}{M} H (\bar{d}_j^\lambda d_j^\lambda) + \frac{i g}{2} \frac{m_u^\lambda}{M} \phi^0 (\bar{u}_j^\lambda \gamma^5 u_j^\lambda) - \frac{i g}{2} \frac{m_d^\lambda}{M} \phi^0 (\bar{d}_j^\lambda \gamma^5 d_j^\lambda) + \bar{X}^+ (\partial^2 - \\
& M^2) X^+ + \bar{X}^- (\partial^2 - M^2) X^- + \bar{X}^0 (\partial^2 - \frac{M^2}{c_W^2}) X^0 + \bar{Y} \partial^2 Y + i g c_W W_\mu^+ (\partial_\mu \bar{X}^0 X^- - \partial_\mu \bar{X}^+ X^0) + i g s_W W_\mu^+ (\partial_\mu \bar{Y} X^- - \\
& \partial_\mu \bar{X}^+ Y) + i g c_W W_\mu^- (\partial_\mu \bar{X}^- X^0 - \partial_\mu \bar{X}^0 X^+) + i g s_W W_\mu^- (\partial_\mu \bar{X}^- Y - \partial_\mu \bar{Y} X^+) + i g c_W Z_\mu^0 (\partial_\mu \bar{X}^+ X^+ - \partial_\mu \bar{X}^- X^-) + \\
& i g s_W A_\mu (\partial_\mu \bar{X}^+ X^+ - \partial_\mu \bar{X}^- X^-) - \frac{1}{2} g M [\bar{X}^+ X^+ H + \bar{X}^- X^- H + \frac{1}{c_W^2} \bar{X}^0 X^0 H] + \frac{1-2c_W^2}{2c_W} i g M [\bar{X}^+ X^0 \phi^+ - \bar{X}^- X^0 \phi^-] + \\
& \frac{1}{2c_W} i g M [\bar{X}^0 X^- \phi^+ - \bar{X}^0 X^+ \phi^-] + i g M s_W [\bar{X}^0 X^- \phi^+ - \bar{X}^0 X^+ \phi^-] + \frac{1}{2} i g M [\bar{X}^+ X^+ \phi^0 - \bar{X}^- X^- \phi^0]
\end{aligned}$$

# The Gauge Sector



Triple and quartic gauge couplings  
are central predictions of the Electroweak theory

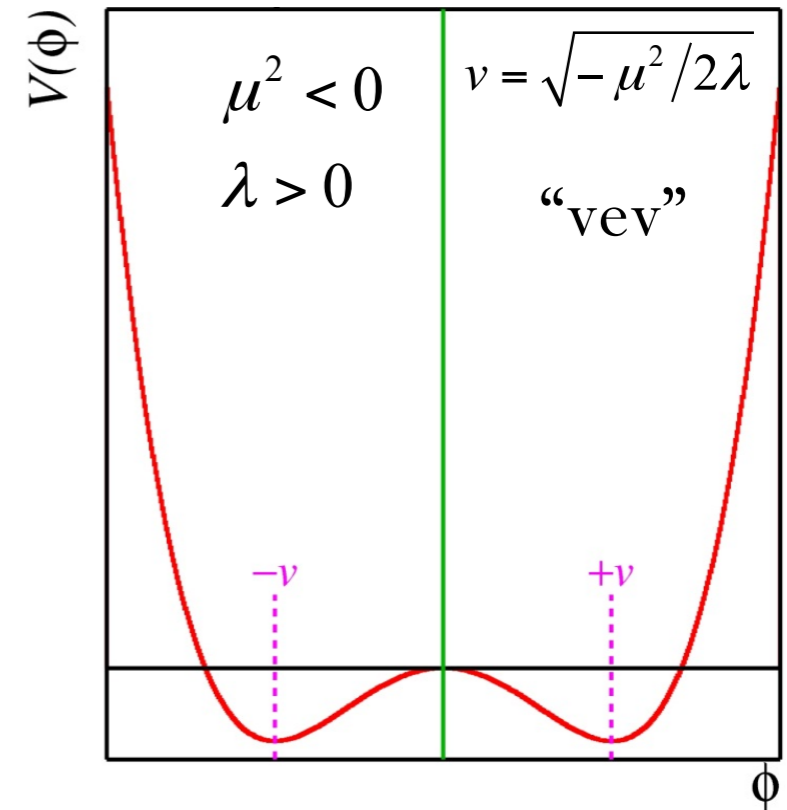
# The Higgs Sector

Higgs field v.e.v.  $v \equiv \langle 0|\phi|0\rangle = 246 \text{ GeV}$

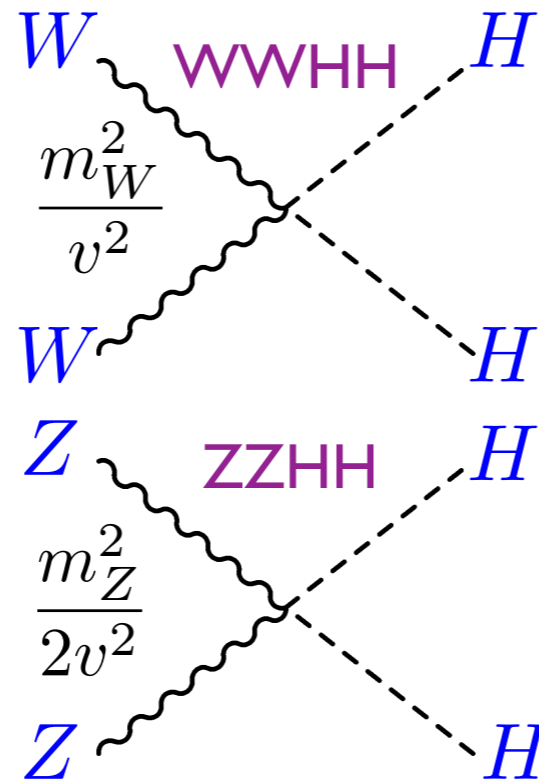
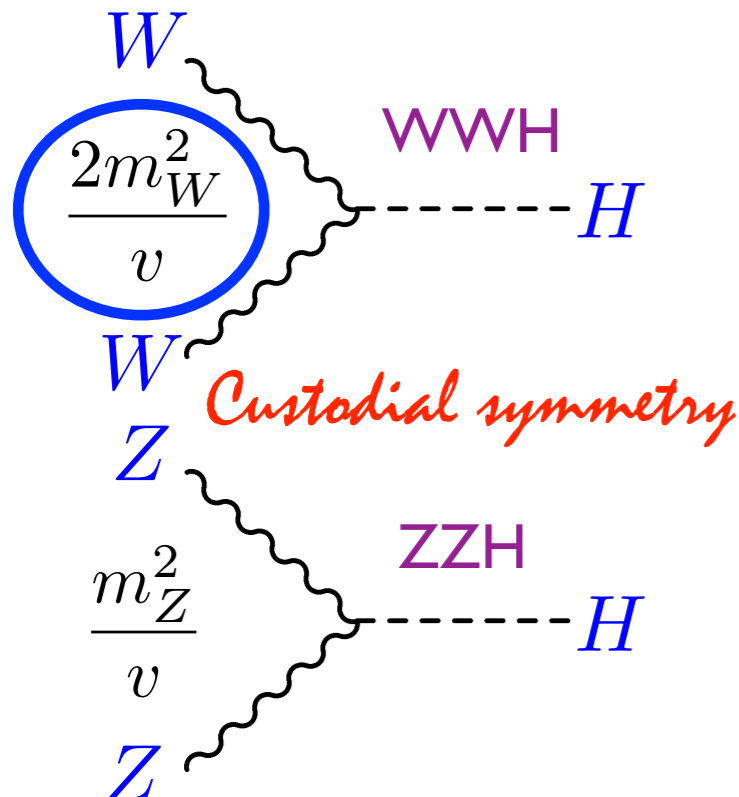
Higgs boson mass  $m_H = \sqrt{2\lambda}v$

Weak boson masses

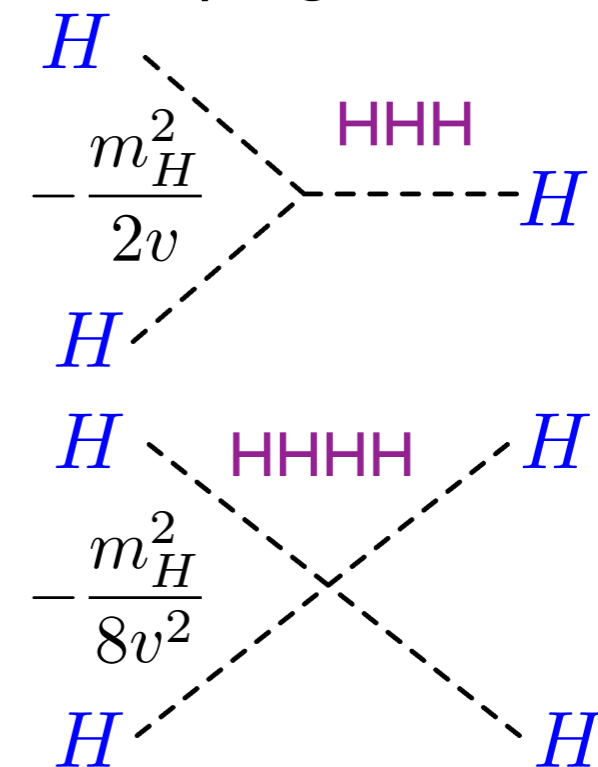
$$m_W \equiv \frac{gv}{2} \quad \text{and} \quad m_Z \equiv \frac{gv}{2 \cos \theta_W}$$



Couplings



Self couplings



# Fermion and Boson Masses

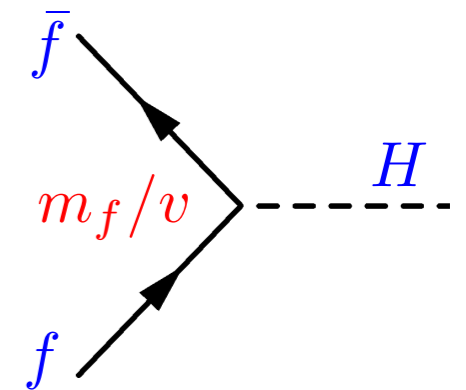
## Yukawa interaction terms between fermions and the Higgs field

- Lorentz scalar
- gauge invariant

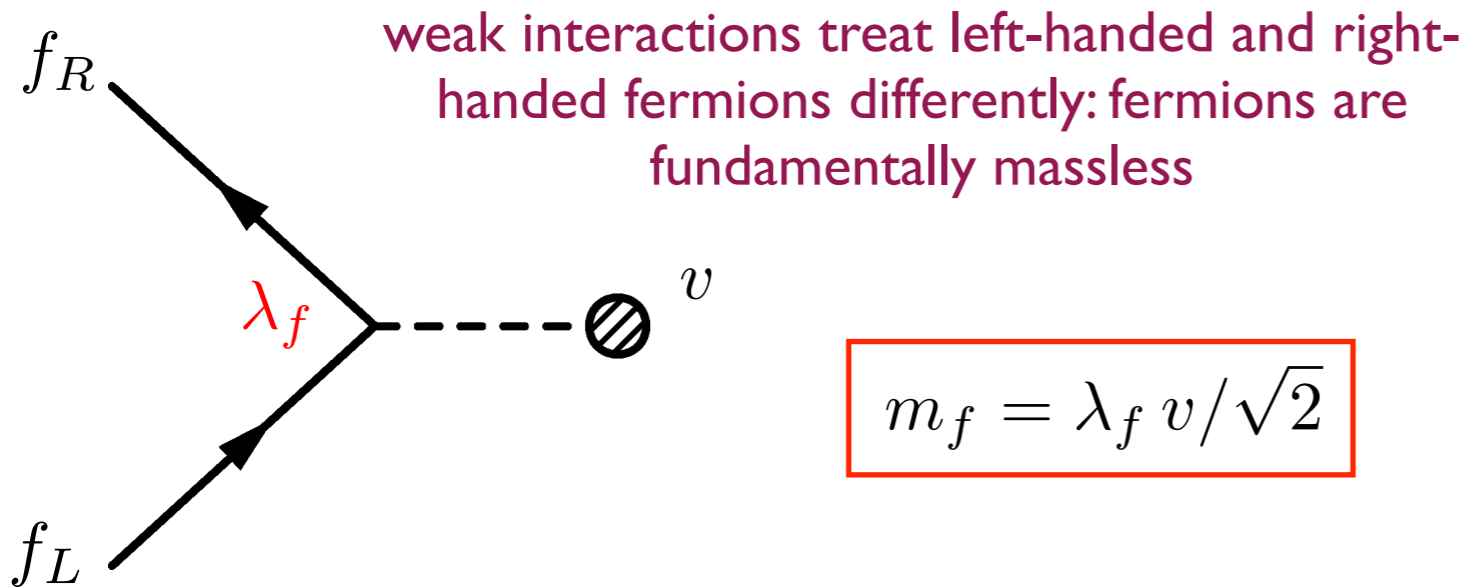
$$\lambda_f (\bar{F}_L \phi) f_R + \text{h.c.} \xrightarrow{\text{SSB}}$$

$$m_f \bar{f} f + m_f/v \bar{f} f h$$

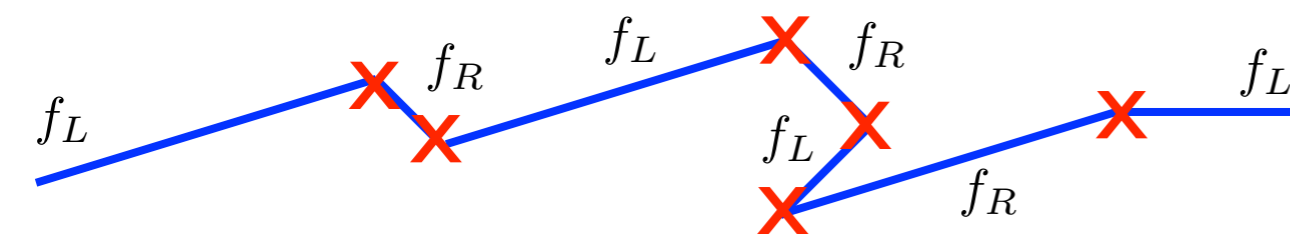
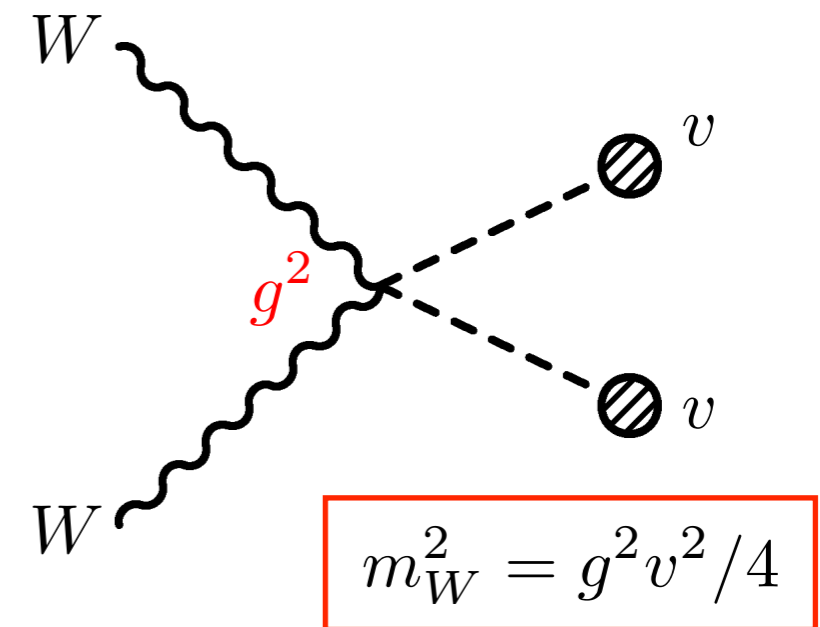
dim = 1 - 1 + 3/2 + 3/2 + 1 = 4



## Fermions acquire mass



## Bosons acquire mass



Higgs condensate connects left- and right- components

W and Z Bosons acquire a longitudinal polarisation through interaction with the Higgs condensate