11.6. Fermion-Massen

① Explizite Fermion-Massen in der Dirac-Gleichung zerstören SU(2)-Invarianz! (außer wenn $m_e = m_\nu$)

② Masseterm verbindet links- und rechtshändige Fermionen:

$$\boxed{\begin{aligned} i\gamma^\mu \partial_\mu e_L &= m e_R \\ \text{und} \quad i\gamma^\mu \partial_\mu e_R &= m e_L \end{aligned}}$$

oder:

$$m \bar{e}_R e_R = \tfrac{1}{4} m \, \bar{e}\, \overline{(1+\gamma^5)}(1+\gamma^5) e = \tfrac{1}{4} m \, \bar{e}\, (\bar{1} + \bar{\gamma}^5)(1+\gamma^5) e$$

$$\bar{\gamma}^5 = -\gamma^5: \quad \gamma^0 \gamma^{5+} \gamma^0 = -\gamma^0\gamma^0\gamma^5 = -\gamma^5 \quad (\gamma^{5+} = \gamma^5)$$

$$= \tfrac{1}{4} m \, \bar{e}\, \underbrace{(1-\gamma^5)(1+\gamma^5)}_{0} e = 0$$

③ Benutze Higgsfeld um die Struktur durch Wechselwirkung zu erzeugen:

$$(*) \quad i\gamma^\mu \partial_\mu \begin{pmatrix} \nu_e \\ e \end{pmatrix}_L = \tilde{g}_e \begin{pmatrix} \phi^+ \\ \phi^0 \end{pmatrix} e_R$$

$\tilde{g}_e$ ↑ „Yukawa-Kopplung"

④ (*) ist eichinvariant!

⑤ Benötigt eine Yukawa-Kopplung pro massives Fermion.

⑥ im Lagrange-Formalismus:

$$\mathcal{L}_{Lepton} = \bar{R}\, i\gamma^\mu (\partial_\mu - i g' B_\mu) R \; +$$

$$\bar{L}\, i\gamma^\mu \left(\partial_\mu + i\frac{g}{2}\vec{\tau}\cdot\vec{W}_\mu - i\frac{g'}{2} B_\mu\right) L$$

und $\mathcal{L}_{Yukawa} = - \tilde{g}_e \left[\bar{R}(\phi^\dagger L) + (\bar{L}\phi) R\right]$

⑦ Kopplung von Fermionen an Higgs ist proportional zu deren Masse!

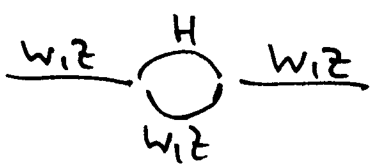
$$\Gamma(H \to f\bar{f}) = \frac{G_F}{\sqrt{2}} M_H \frac{m_q^2}{4\pi} \cdot N_c$$

$N_c = 1$ für Leptonen
$N_c = 3$ " Quarks

⑧ Bisher kein direktes Hinweis auf Higgs-Boson:

Grenze $m_H > 114.4$ GeV (95% C.L.)

⑨ Indirekte Hinweise durch virtuelle Effekte:

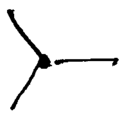


$m_H \lesssim 200$ GeV 95% C.L.

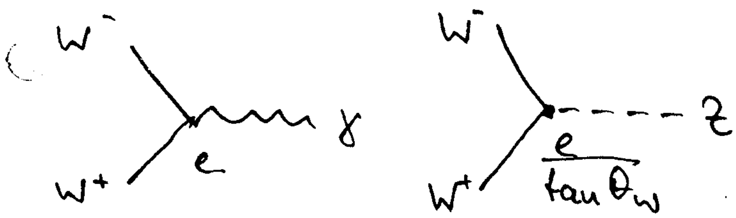
11.7. Gauge Boson Self-Interactions

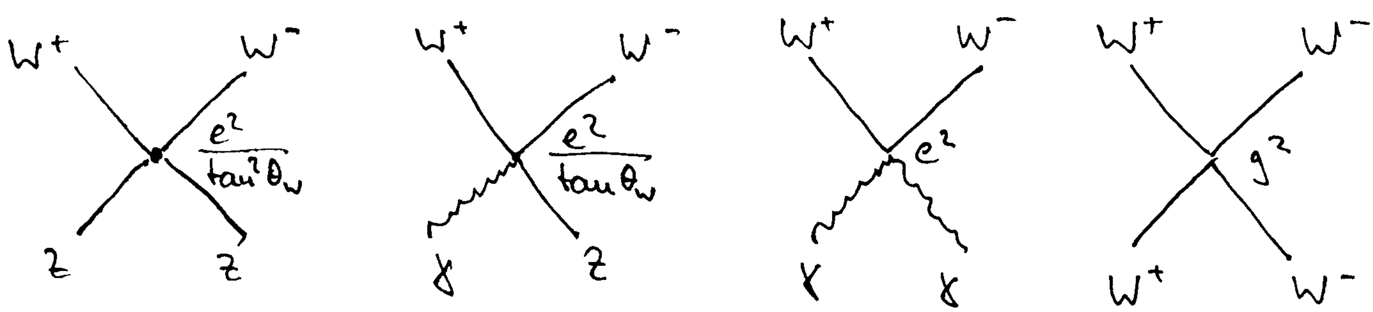
Field Strength Tensor $\vec{F}_{\mu\nu} = \partial_\mu \vec{W}_\nu - \partial_\nu \vec{W}_\mu - g\,\vec{W}_\mu \times \vec{W}_\nu$

Lagrangian: $\mathcal{L} = \frac{1}{4} \vec{F}_{\mu\nu} \vec{F}^{\mu\nu}$

$\mathcal{L}$ contains terms
- "$\partial W \partial W$" —— kinetic Energy
- "$g(\partial W)WW$"  triple gauge couplings
- "$g^2 WWWW$"  quartic gauge couplings

In the SM, there are:





all other combinations are forbidden.

15.5 The Standard Model: The Final Lagrangian

To summarize the standard (Weinberg–Salam) model, we gather together all the ingredients of the Lagrangian. The complete Lagrangian is:

$$
\begin{aligned}
\mathcal{L} = & -\tfrac{1}{4}\mathbf{W}_{\mu\nu}\cdot\mathbf{W}^{\mu\nu} - \tfrac{1}{4}B_{\mu\nu}B^{\mu\nu} && \left\{\begin{array}{l}\text{W}^{\pm}, \text{Z}, \gamma \text{ kinetic} \\ \text{energies and} \\ \text{self-interactions}\end{array}\right. \\
& + \bar{L}\gamma^{\mu}\left(i\partial_{\mu} - g\frac{1}{2}\boldsymbol{\tau}\cdot\mathbf{W}_{\mu} - g'\frac{Y}{2}B_{\mu}\right)L \\
& + \bar{R}\gamma^{\mu}\left(i\partial_{\mu} - g'\frac{Y}{2}B_{\mu}\right)R && \left\{\begin{array}{l}\text{lepton and quark} \\ \text{kinetic energies} \\ \text{and their} \\ \text{interactions with} \\ \text{W}^{\pm}, \text{Z}, \gamma\end{array}\right. \qquad (15.40) \\
& + \left|\left(i\partial_{\mu} - g\frac{1}{2}\boldsymbol{\tau}\cdot\mathbf{W}_{\mu} - g'\frac{Y}{2}B_{\mu}\right)\phi\right|^{2} - V(\phi) && \left\{\begin{array}{l}\text{W}^{\pm}, \text{Z}, \gamma, \text{ and Higgs} \\ \text{masses and} \\ \text{couplings}\end{array}\right. \\
& -(G_1\bar{L}\phi R + G_2\bar{L}\phi_c R + \text{hermitian conjugate}). && \left\{\begin{array}{l}\text{lepton and quark} \\ \text{masses and} \\ \text{coupling to Higgs}\end{array}\right.
\end{aligned}
$$