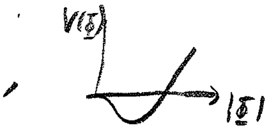
$\mathcal{L}_{SM}$ ist nun spezifiziert.

müssen nun etwas "Buchhaltung" betreiben:

SSB im Higgs-Sektor $\rightarrow$ Massenterme

Identifikation der Massen-Eigenzustände $\rightarrow$ Mischungsmatrizen

Erinnerung: (s.S.71) SSB, 

, $\Phi = \frac{1}{\sqrt{2}}\begin{pmatrix} 0+\phi_2+i\phi_1 \\ v+\phi_0-i\phi_3 \end{pmatrix} = \frac{1}{\sqrt{2}} e^{i\frac{\vec{\sigma}\vec{\phi}}{v}}\begin{pmatrix} 0 \\ v+\phi_0 \end{pmatrix}$

$\rightarrow \frac{1}{\sqrt{2}}\begin{pmatrix} 0 \\ v+H(x) \end{pmatrix}$ "unitäre Eichung"

(3)' $\Rightarrow$ $$\mathcal{L}_{Higgs} = m_W^2 W^{+\mu} W^-_\mu \left(1+\frac{H}{v}\right)^2 + \frac{1}{2} m_Z^2 Z^\mu Z_\mu \left(1+\frac{H}{v}\right)^2 + 0 \cdot Q^\mu Q_\mu$$
$$+ \frac{1}{2}(\partial_\mu H)(\partial^\mu H) - \left[\underline{-\frac{1}{4}\lambda v^4} + \frac{1}{2} m_H^2 H^2 + \lambda v H^3 + \frac{\lambda}{4} H^4\right]$$

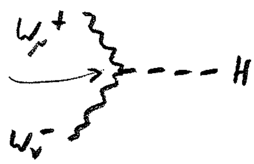
(Minimum des Higgs-Potentials. Konstante. irrelevant im SM; problematisch mit Gravitation! (("kosmologische Konstante", aber viel größer und mit anderem Vorzeichen als beobachtet))

wobei $W^\pm \equiv \frac{1}{\sqrt{2}}(A^1 \mp i A^2)$, $Z \equiv \sin(\theta_W) B + \cos(\theta_W) A^3$

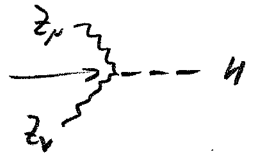
Photon $Q \equiv \cos(\theta_W) B - \sin(\theta_W) A^3$

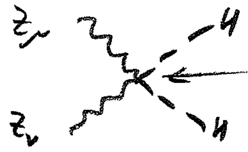
schwacher Mischungswinkel $\tan(\theta_W) = \frac{g_Y}{g_W} \Rightarrow \sin^2\theta_W = 1 - \frac{m_W^2}{m_Z^2}$

$m_W = \frac{g_W v}{2}$, $m_Z \equiv \frac{\sqrt{g_W^2+g_Y^2}\, v}{2} = \frac{m_W}{\cos(\theta_W)}$

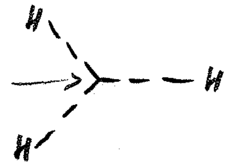
bzw. $2 g_{\mu\nu} \frac{m_W^2}{v}$ 

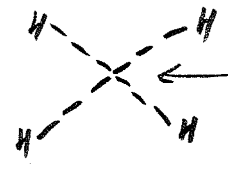
$2 g_{\mu\nu} \frac{m_W^2}{v^2}$

$2 g_{\mu\nu} \frac{m_Z^2}{v}$ 



$2 g_{\mu\nu} \frac{m_Z^2}{v^2}$

$3 \frac{m_H^2}{v}$ 



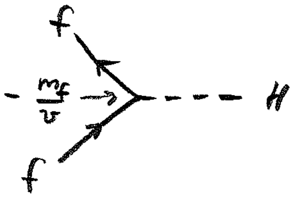
$3 \frac{m_H^2}{v^2}$

⑤' $\Rightarrow \mathcal{L}_{Yukawa} = -\sum\limits_{f} m_f \bar{\psi}_f \psi_f \left(1 + \frac{H}{v}\right)$

Fermionen ↗ f ↑ Masse-Eigenzustände der Fermionen

Erinnerung: benötigt werden 3×3 Mischungsmatrizen zur Diagonalisierung, vgl. S. 73/74

bzw.



Fermionen koppeln an Higgs mit Stärke $\frac{m_f}{v} = \frac{g_w m_f}{2 m_W}$

→ sehr schwache Kopplung, bis auf Top-Quarks + Higgs!

④$'_a$ $\Rightarrow \mathcal{L}_{Fer} \ni \mathcal{L}_{gel.\,Strom} = -\frac{g_w}{\sqrt{2}}\left[J_+^\mu W_\mu^- + \underbrace{(J_+^\mu)^\dagger}\, W_\mu^+\right]$

geladener Strom (vgl. S. 59)

$$= \sum_D \bar{D}_L \begin{pmatrix} 0 & \gamma^\mu \\ 0 & 0 \end{pmatrix} D_L \quad , \quad D_L \in \{ Q'_{iL}, L'_{iL} \} \quad , \quad i = 1..3 \text{ Gen.}$$

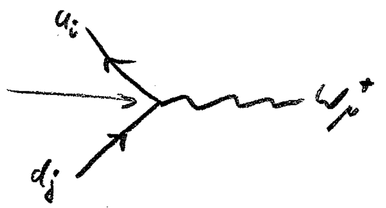
falls ν massiv, Dirac

$$= (\bar{u}\,\bar{c}\,\bar{t})\,\gamma^\mu \frac{1-\gamma^5}{2} \underbrace{V_{CKM}} \begin{pmatrix} d \\ s \\ b \end{pmatrix} + (\bar{\nu}_e\,\bar{\nu}_\mu\,\bar{\nu}_\tau)\,\gamma^\mu \frac{1-\gamma^5}{2} V_\ell \begin{pmatrix} e^- \\ \mu^- \\ \tau^- \end{pmatrix}$$

(V-A)-Form

$$V_{CKM} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ \vdots & \vdots & \vdots \\ \vdots & \vdots & \vdots \end{pmatrix} , \quad |V_{CKM}| \approx \begin{pmatrix} 1 & \lambda & \lambda^3 \\ \lambda & 1 & \lambda^2 \\ \lambda^3 & \lambda^2 & 1 \end{pmatrix} , \quad \lambda \approx \sin\theta_c \approx 0.22$$

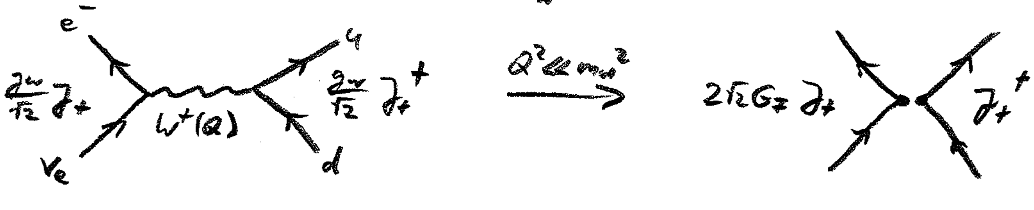
bzw. $\frac{g_w}{\sqrt{2}} \gamma_\mu \frac{1-\gamma^5}{2} V_{ij}^{CKM}$ →



<u>Bem.:</u> Im Limes $Q^2 \ll m_W^2$ erhält man das Fermi-Modell (vgl. S. 57):

$$\mathcal{L}^{eff.}_{gel.\,Strom} = -\boxed{2\sqrt{2}G_F}\, J_+^\mu (J_{+\mu})^\dagger$$

$$2\sqrt{2}G_F = \frac{g_w^2}{2m_W^2} = \frac{2}{v^2}$$



$$= \frac{g_w g_Y}{\sqrt{g_w^2+g_Y^2}} = g_Y \cos\theta_w = g_w \sin\theta_w$$

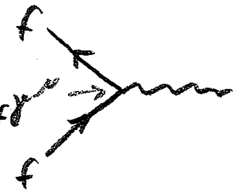
④$'_b$ $\Rightarrow \mathcal{L}_{Fer} \ni \mathcal{L}_{QED} = -e \underbrace{J_{em.}^{\mu}}\, Q_\mu$

Q_μ: Photon $= \cos\theta_w B_\mu - \sin\theta_w A_\mu^3$

el. mag. Strom $= \sum_{i=1}^{3} \left\{ \frac{2}{3} \bar{u}_i \gamma^\mu u_i - \frac{1}{3} \bar{d}_i \gamma^\mu d_i - \bar{e}_i \gamma^\mu e_i \right\}$

Generationen

hat dieselbe Form für schwache und Massen-EZ
((da die mischenden Fermionen die gleiche Ladung haben))

bzw. $-eq_f \gamma^\mu$  γ , $eq_f \equiv$ Ladung von f

④$'_c$ $\Rightarrow \mathcal{L}_{Fer} \ni \mathcal{L}_{neutr.Strom} = -\frac{g_w}{2\cos\theta_w} \underbrace{J_0^\mu}\, Z_\mu$

Z_μ: $\sin\theta_w B_\mu + \cos\theta_w A_\mu^3$

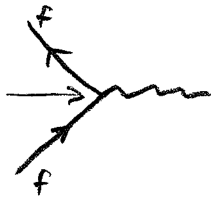
neutraler Strom (vgl. S. 60)

$$= \sum_D \bar{D}_L \begin{pmatrix} \gamma^\mu (c_V^u + c_A^u \gamma^5) & 0 \\ 0 & \gamma^\mu (c_V^d + c_A^d \gamma^5) \end{pmatrix} D_L$$

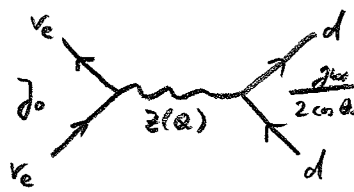
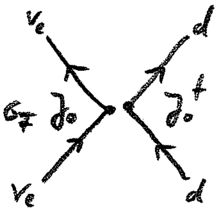
$$= \sum_{i=1}^{3} \left\{ \bar{u}_{iL} \gamma^\mu u_{iL} - \bar{d}_{iL} \gamma^\mu d_{iL} + \bar{\nu}_{iL} \gamma^\mu \nu_{iL} - \bar{e}_{iL} \gamma^\mu e_{iL} \right\}$$

$$-2 \sin^2\theta_w J_{em.}^\mu$$

hat wieder dieselbe Form für schwache und Massen-EZ

bzw. $-\frac{g_w}{2\cos\theta_w} \gamma^\mu (c_V^f + c_A^f \gamma^5)$  Z^μ

<u>Bem.:</u> wieder $Q^2 \ll m_Z^2 \Rightarrow \mathcal{L}^{eff}_{neutr.-Strom} = -2\sqrt{2} G_F J_0^\mu (J_{0\mu})^\dagger$

$\frac{g_w}{2\cos\theta_w} J_0$  $\frac{g_w}{2\cos\theta_w} J_0^\dagger$ $\xrightarrow{Q^2 \ll m_Z^2}$ $2\sqrt{2} G_F J_0$  $J_0^\dagger$

$$\left(\left(\frac{g_w^2}{4\cos^2\theta_w m_Z^2} = \frac{g_w^2}{4 m_W^2} = \sqrt{2} G_F \quad ; \quad \text{Faktor } 2 \;? \right)\right)$$