2019.09.19

The data

$\underline{SU(3)}$ $a = 1$ to 8 $\quad$ $\underline{SU(2)}$ $k = 1$ to 3 $\quad$ $\underline{U(1)}$

$$\mathcal{L}_{SM} = -\frac{1}{4} F^a_{\mu\nu} F^{a\mu\nu} - \frac{1}{4} W^k_{\mu\nu} W^{k\mu\nu} - \frac{1}{4} B_{\mu\nu} B^{\mu\nu}$$

$$+ \sum_{i=1}^{3} \left\{ Q_i^\dagger i D_\mu \sigma_-^\mu Q_i + u_{R_i}^\dagger i D_\mu \sigma_+^\mu u_{R_i} + d_{R_i}^\dagger i D_\mu \sigma_+^\mu d_{R_i} + L_i^\dagger i D_\mu \sigma_-^\mu L_i + \underline{l_{R_i}^\dagger i D_\mu \sigma_+^\mu l_{R_i}} \right\}$$

$$+ \nu_{R_i}^\dagger i D_\mu \sigma_+^\mu \nu_{R_i}$$

$$+ (D^\mu \phi)^\dagger (D_\mu \phi) - \frac{\lambda}{4} (\phi^\dagger \phi)^2 - \mu^2 \phi^\dagger \phi$$

$$+ \sum_{i,j=1}^{3} \left\{ y^u_{ij} \overset{-\frac{1}{6}}{Q_i^\dagger} \overset{+\frac{2}{3}}{u_{R_j}} \overset{-\frac{1}{2}}{\phi} + y^d_{ij} Q_i^\dagger d_{R_j} \phi^c + y^l_{ij} L_i^\dagger l_{R_j} \phi^c + h.c. \right.$$

after 1998

$$+ \frac{y^\nu_{ij}}{2\Lambda} (\phi^{c\dagger} L_i)^T (i\sigma^2)(\phi^{c\dagger} L_j) + h.c.$$

$$+ y^\nu_{ij} L_i^\dagger \nu_{R_j} \phi + h.c.$$

$$\phi^c = (-i\sigma^2)\phi^*$$

$\underline{SU(2)}$ $\quad \phi \to \phi' = U\phi$

$$\phi^* \to \phi^{*\prime} = U^* \phi^*$$

$$\phi^c \to \phi^{c\prime} = (-i\sigma^2) U^* \phi^* = U (-i\sigma^2) \phi^* = U \phi^c$$

$$D_\mu = \partial_\mu + i g_s T^a A^a_\mu + i g T^k W^k_\mu + i g' Y B_\mu$$

$$[D_\mu, D_\nu] = i g_s T^a F^a_{\mu\nu} + i g T^k W^k_{\mu\nu} + i g' Y B_{\mu\nu}$$

$$F^a_{\mu\nu} = \partial_\mu A^a_\nu - \partial_\nu A^a_\mu - g f^{abc} A^b_\mu A^c_\nu$$

$$W^k_{\mu\nu} = \partial_\mu W^k_\nu - \partial_\nu W^k_\mu - g \epsilon^{kom} W^o_\mu W^m_\nu$$

$$B_{\mu\nu} = \partial_\mu B_\nu - \partial_\nu B_\mu$$

$$\phi \to \phi' = U(x)\phi$$

$$D_\mu \to D'_\mu = U D_\mu U^{-1}$$

$$\frac{g_s^2}{4\pi} \sim \frac{1}{8.5}, \quad \frac{g^2}{4\pi} \sim \frac{1}{30}, \quad \frac{g'^2}{4\pi} \sim \frac{1}{98}$$

	SU(3)	SU(2)	U(1)$_Y$
$Q_i = \begin{pmatrix} u_{Li} \\ d_{Li} \end{pmatrix}$	3	2	$\frac{1}{6}$
u_{R_i}	3	1	$+2/3$
d_{R_i}	3	1	$-1/3$
$L_i = \begin{pmatrix} \nu_{Li} \\ l_{Li} \end{pmatrix}$	1	2	$-\frac{1}{2}$
l_{R_i}	1	1	-1
ν_{R_i}	1	1	0
ϕ	1	2	$-\frac{1}{2}$
ϕ^c	1	2	$+\frac{1}{2}$

Lorentz transformation

$$x^\mu \to x^{\mu\prime} = L^\mu{}_\nu x^\nu$$

$$A^\mu \to A^{\mu\prime} = L^\mu{}_\nu A^\nu$$

$$\Psi = \begin{pmatrix} \psi_L \\ \psi_R \end{pmatrix} \qquad \gamma^\mu = \begin{pmatrix} 0 & \sigma_+^\mu \\ \sigma_-^\mu & 0 \end{pmatrix}$$

$$\bar{\Psi} = \Psi^\dagger \gamma^0 = (\psi_R^\dagger, \psi_L^\dagger) \qquad \sigma_\pm^\mu = (1, \pm\vec{\sigma})$$

Lorentz Trans.

$$\psi_L \to \psi_L' = S_L \psi_L \qquad S_L = e^{\sum_{k=1}^{3} \frac{\sigma^k}{2}(-i\theta_k - \eta_k)}$$

$$\psi_R \to \psi_R' = S_R \psi_R \qquad S_R = e^{\sum_{k=1}^{3} \frac{\sigma^k}{2}(-i\theta_k + \eta_k)}$$

$$\boxed{S_L^\dagger S_R = S_R^\dagger S_L = 1}$$

$$\Rightarrow \psi_L^\dagger \psi_R + \psi_R^\dagger \psi_L$$

$$\psi_L^\dagger \sigma_-^\mu \psi_L, \ \psi_R^\dagger \sigma_+^\mu \psi_R$$

$$\boxed{\begin{matrix} S_L^\dagger \sigma_-^\mu S_L \\ S_R^\dagger \sigma_+^\mu S_R \end{matrix}}$$

$$\psi_L^c = (i\sigma^2)\psi_L^* \ \to \psi_L^{c\prime} = (i\sigma^2) S_L^* \psi_L^* = S_R (i\sigma^2) \psi_L^* = S_R \psi_L^c$$

$$\psi_R^c = (-i\sigma^2)\psi_R^* \ \to \psi_R^{c\prime} = S_L \psi_R^c$$

$$\psi_L^{c\dagger} \psi_L = ((i\sigma^2)\psi_L^*)^\dagger \psi_L = \psi_L^T (-i\sigma^2) \psi_L \ \text{: Majorana}$$

2019.09.19

$[J_i, J_j] = i\epsilon_{ijk} J_k \qquad [K_i, K_j] = -i\epsilon_{ijk} J_k$

$[J_i, K_j] = i\epsilon_{ijk} K_k$

$$\vec{A}^{\mu} \to \vec{A}^{\mu\prime} = L\,\vec{A}^{\mu}$$

$$\underline{L = e^{-i\sum_{\ell=1}^{3}(J_\ell \theta_\ell + K_\ell \eta_\ell)}}$$

$$J_2 = \begin{pmatrix} 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & i \\ 0 & 0 & 0 & 0 \\ 0 & \boxed{-i} & 0 & 0 \end{pmatrix}, \quad K_3 = \begin{pmatrix} 0 & 0 & 0 & i \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ i & 0 & 0 & 0 \end{pmatrix}$$

$$\psi_L \to \psi_L' = \Sigma_L \psi_L$$

$$L(\theta_2) = e^{-iJ_2\theta_2} = e^{-i\begin{pmatrix} 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & i \\ 0 & 0 & 0 & 0 \\ 0 & -i & 0 & 0 \end{pmatrix}\theta_2} = e^{\begin{pmatrix} 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & 0 \\ 0 & -1 & 0 & 0 \end{pmatrix}\theta_2} = \sum_{n=0}^{\infty}\left(\quad\right)^n \theta_2^n$$

$$= \begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & \cos\theta_2 & 0 & \sin\theta_2 \\ 0 & 0 & 1 & 0 \\ 0 & -\sin\theta_2 & 0 & \cos\theta_2 \end{pmatrix}.$$

$$\psi_L(p, J_z = -\tfrac{1}{2}) = \sqrt{m}\begin{pmatrix} 0 \\ 1 \end{pmatrix} \qquad p^\mu = (m, 0, 0, 0)$$

$$p^\mu \to p'^\mu = \underline{m(\cosh\eta, 0, 0, \sinh\eta)} = m\gamma(1, 0, 0, \beta)$$

$$L(\eta_3) = e^{-iK_3\eta_3} = e^{-i\begin{pmatrix} 0 & 0 & 0 & i \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ i & 0 & 0 & 0 \end{pmatrix}\eta_3} = e^{\begin{pmatrix} 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 \end{pmatrix}\eta_3}$$

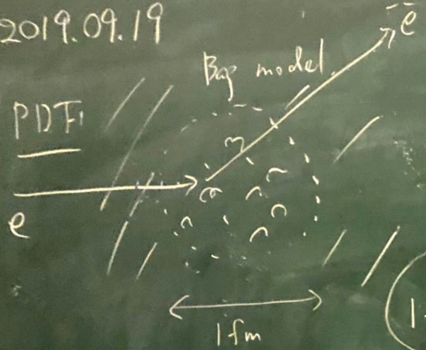
$$= \begin{pmatrix} \cosh\eta_3 & 0 & 0 & \sinh\eta_3 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ \sinh\eta_3 & 0 & 0 & \cosh\eta_3 \end{pmatrix} = \begin{pmatrix} \gamma & 0 & 0 & \gamma\beta \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ \gamma\beta & 0 & 0 & \gamma \end{pmatrix}$$

$$\psi_L(p, J_z = -\tfrac{1}{2}) = \sqrt{m}\, e^{\frac{\sigma^3}{2}(-\eta)}\begin{pmatrix} 0 \\ 1 \end{pmatrix} = \sqrt{m}\begin{pmatrix} e^{-\eta/2} & 0 \\ 0 & e^{+\eta/2} \end{pmatrix}\begin{pmatrix} 0 \\ 1 \end{pmatrix}$$

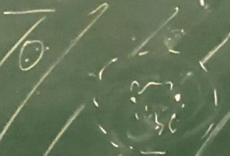
$$= \sqrt{m}\, e^{\eta/2}\begin{pmatrix} 0 \\ 1 \end{pmatrix} = \sqrt{m e^{\eta}}\begin{pmatrix} 0 \\ 1 \end{pmatrix} = \sqrt{m(\cosh\eta + \sinh\eta)}\begin{pmatrix} 0 \\ 1 \end{pmatrix} = \sqrt{E+p}\begin{pmatrix} 0 \\ 1 \end{pmatrix}$$

2019.09.19

PDF:



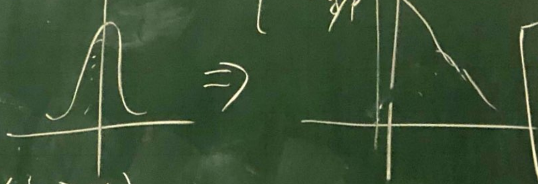
QED



super conductor

$$1\,\text{fm} \sim \frac{1}{200\,\text{MeV}}$$

$$\left\{\begin{array}{l} D_{u/p}(x) \sim (1-x)^3 \\ D_{d/p}(x) \sim (1-x)^4 \\ D_{g/p}(x) \sim (1-x)^5 \end{array}\right.$$



$d\tau dY$

$$d\sigma(pp \to X) = \sum_{a,b} \int D_{a/p}(x_a, Q)\, D_{b/p}(x_b, Q)\, \boxed{dx_a\, dx_b}\, d\hat{\sigma}(ab \to X)$$

$$\boxed{\begin{array}{l} dx_a\, dx_b = d\tau\, dY \\ \tau = x_a x_b \\ Y = \frac{1}{2}\ln\frac{x_a}{x_b} \end{array}}$$

$$s_{ab} = (p_a + p_b)^2 = 4 p_a \cdot p_b = 4 p_1 \cdot p_2 (x_a x_b) = s\, x_a x_b$$

$$Y = \frac{1}{2}\ln\frac{E_{ab} + p_{z\,ab}}{E_{ab} - p_{z\,ab}} = \frac{1}{2}\ln\frac{(x_a + x_b) + (x_a - x_b)}{(x_a + x_b) - (x_a - x_b)}$$

$$= \frac{1}{2}\ln\frac{x_a}{x_b}$$