

Title: PSI 2019/2020 - Standard Model and Beyond part 2 - Lecture 2

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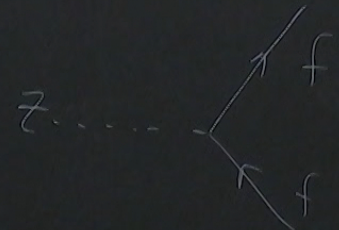
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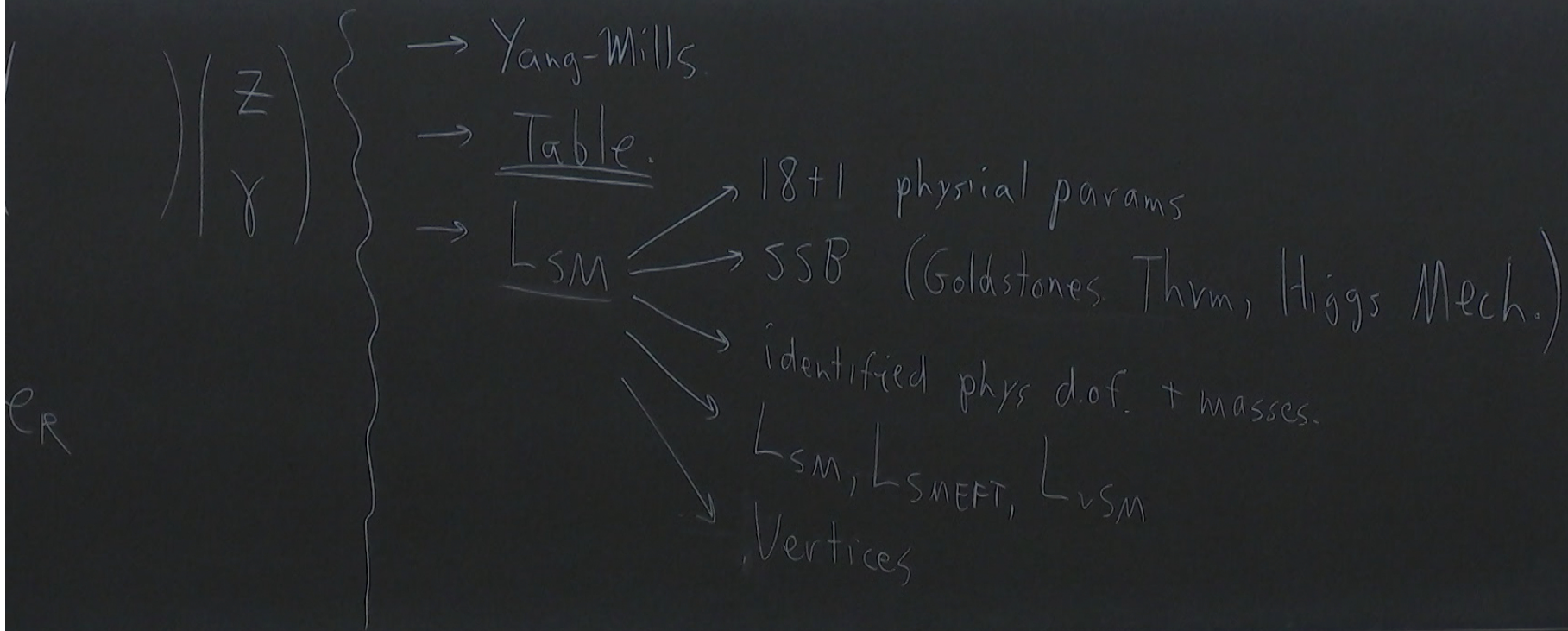
Lecture 14

SM + B

$$\begin{pmatrix} W^3 \\ B \end{pmatrix} = \begin{pmatrix} & \\ & \end{pmatrix} \begin{pmatrix} Z \\ \gamma \end{pmatrix} \left\{ \begin{array}{l} \text{---} \\ \text{---} \end{array} \right.$$



$$\bar{e}_R (\not{\partial} + i(1)g_B B_m) e_R$$



Anomalies:

$$\varphi \rightarrow \varphi'$$

$$S[\varphi] \rightarrow S[\varphi'] = S[\varphi]$$

$$\int \mathcal{D}[\varphi] e^{iS[\varphi]/\hbar}$$

Global

Gauge

Global $\phi \rightarrow e^{i\alpha} \phi(x)$ B, L

Gauge $\phi(x) \rightarrow e^{i\alpha(x)} \phi(x)$ inconsistency!

$$Z = \int \mathcal{D}A \mathcal{D}\psi_R \mathcal{D}\bar{\psi}_R e^{i \int d^4x \left[-\frac{1}{4} F_{\mu\nu}^a F_{\mu\nu}^a + \bar{\psi}_R \not{D} \psi_R \right]}$$

$$\psi_R \rightarrow e^{i\alpha} \psi_R \quad \mathcal{D}\psi_R \mathcal{D}\bar{\psi}_R \rightarrow \mathcal{D}\psi_R \mathcal{D}\bar{\psi}_R e^{i \int d^4x \frac{\alpha g^2}{32\pi^2} F_{\mu\nu}^a \tilde{F}_{\mu\nu}^a}$$

$$L \rightarrow L + \Delta L \quad \Delta L = \frac{\alpha g^2}{32\pi^2} F_{\mu\nu}^a \tilde{F}_{\mu\nu}^a$$

Vertices

$$+ \bar{\psi}_R \not{\partial} \psi_R]$$

$$i \int d^4x \frac{\alpha g^2}{32\pi^2} F_{\mu\nu}^a \tilde{F}_a^{\mu\nu} \quad \tilde{F}_a^{\mu\nu} = \epsilon^{\mu\nu\alpha\beta} F_{\alpha\beta}^a$$

$$\frac{\alpha g^2}{32\pi^2} F_{\mu\nu}^a \tilde{F}_a^{\mu\nu}$$

$$L_{SM} = (\text{bosonic}) + (\text{fermion kinetic})$$

$$- [\bar{q}_L \gamma_\mu h d_R + \bar{q}_L \gamma_\mu \hat{h} u_R + \bar{l}_L \gamma_\mu h e_R + \text{h.c.}]$$

$$+ \frac{\Theta_3 g_3^2}{32\pi^2} G_{\mu\nu}^a \tilde{G}^{\mu\nu}_a + \frac{\Theta_2 g_2^2}{32\pi^2} W_{\mu\nu}^a \tilde{W}^{\mu\nu}_a + \frac{\Theta_1 g_1^2}{32\pi^2} B_{\mu\nu} \tilde{B}^{\mu\nu}$$

$$\gamma_d = V_d^\dagger y_d U_d$$

$$\gamma_u = V_u^\dagger y_u U_u$$

$$\gamma_e = V_e^\dagger y_e U_e$$

onic) + (fermion kinetic)

$$[Y_d h d_R + \bar{q}_L Y_u \hat{h} u_R + \bar{l}_L Y_e h e_R + \text{h.c.}]$$

$$\frac{1}{2} G_{\mu\nu}^a \tilde{G}^{\mu\nu}_a + \frac{O_2 g^2}{32\pi^2} W_{\mu\nu}^a \tilde{W}^{\mu\nu}_a + \frac{O_1 g_i^2}{32\pi^2} B_{\mu\nu} \tilde{B}^{\mu\nu}$$

$$[V_{CKM} y_d h d_R + \bar{q}_L y_u \hat{h} u_R + \bar{l}_L y_e h e_R + \text{h.c.}]$$

$$Y_d = V_d^\dagger y_d U_d$$

$$Y_u = V_u^\dagger y_u U_u$$

$$Y_e = V_e^\dagger y_e U_e$$

$$\alpha_j = \beta_j = \alpha$$

$$\begin{aligned} q_L^j &\rightarrow e^{i\alpha_j} q_L^j \\ u_R^j &\rightarrow e^{i\alpha_j} u_R^j \\ d_R^j &\rightarrow e^{i\beta_j} d_R^j \end{aligned}$$

$$\begin{aligned}
 \Delta L = & \left(\underbrace{-6}_{q_L} + \underbrace{3}_{u_R} + \underbrace{3}_{d_R} \right) \frac{\alpha g_3^2}{32\pi^2} G_{\mu\nu}^a \tilde{G}_a^{\mu\nu} + \left(-3 \times 3 \right) \frac{\alpha g_2^2}{32\pi^2} W_{\mu\nu}^a \tilde{W}_a^{\mu\nu} + \left(-\left(\frac{1}{6}\right)^2_{3 \times 3 \times 2} + \left(\frac{2}{3}\right)^2_{3 \times 3} + \left(\frac{1}{3}\right)^2_{3 \times 3} \right) \frac{\alpha g_1^2}{32\pi^2} B_{\mu\nu} \tilde{B}^{\mu\nu} \\
 = & \frac{g_\alpha}{32\pi^2} \left[-g_2^2 W \tilde{W} + g_1^2 \left(\frac{1}{2} \right) B \tilde{B} \right]
 \end{aligned}$$

$$\begin{aligned}
 \Delta L = & \left(\underbrace{-6}_{q_L} + \underbrace{3}_{u_R} + \underbrace{3}_{d_R} \right) \frac{\alpha g_3^2}{32\pi^2} G_{\mu\nu}^a \tilde{G}_a^{\mu\nu} + \left(-3 \times 3 \right) \frac{\alpha g_2^2}{32\pi^2} W_{\mu\nu}^a \tilde{W}_a^{\mu\nu} + \left(-\left(\frac{1}{6}\right)^2 3 \times 3 \times 2 + \left(\frac{2}{3}\right)^2 3 \times 3 + \left(\frac{1}{3}\right)^2 3 \times 3 \right) \frac{\alpha g_1^2}{32\pi^2} B_{\mu\nu} \tilde{B}^{\mu\nu} \\
 & \qquad \qquad \qquad \uparrow \\
 = & \frac{g_\alpha}{32\pi^2} \left[-g_2^2 W \tilde{W} + g_1^2 \left(\frac{1}{2} \right) B \tilde{B} \right] \quad B \text{ is anom}
 \end{aligned}$$

$$\begin{aligned}
 G_a^{\mu\nu} &+ (-3 \times 3) \frac{\alpha g_2^2}{32\pi^2} W_{\mu\nu}^a \widetilde{W}_a^{\mu\nu} + \left(-\left(\frac{1}{6}\right)^2 3 \times 3 \times 2 + \left(\frac{2}{3}\right)^2 3 \times 3 + \left(\frac{1}{3}\right)^2 3 \times 3 \right) \frac{\alpha g_1^2}{32\pi^2} B_{\mu\nu} \widetilde{B}^{\mu\nu} \\
 &= \frac{g_2^2}{32\pi^2} \left[-g_2^2 W \widetilde{W} + g_1^2 \left(\frac{1}{2} \right) B \widetilde{B} \right] \quad B \text{ is anomalous}
 \end{aligned}$$

$$\begin{aligned}
 l_L^j &\rightarrow e^j l_L^j \\
 e_R^j &\rightarrow e^j e_R^j
 \end{aligned}$$

$1/3$	0
$1/3$	0
$1/3$	0
0	1
0	1
0	1

L is also anomalous

but no more freedom to soak up parameters

can eliminate Θ_2 , but not Θ_3, Θ_1

$B-L$ not anomalous ($\Delta L = 0$)