

Title: PSI 2018/2019 - Beyond Standard Model - Lecture 11

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Collection: PSI 2018/2019 - Beyond Standard Model (Boyle)

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EFT/RG:

$$Z = \int_{p < \Lambda} \mathcal{D}\phi e^{-S_\Lambda[\phi]}$$

$$L_\Lambda[\varphi] = \frac{1}{2}(\partial_\mu \varphi)^2 + \sum_i \Lambda^{d-d_i} g_i(\Lambda) \bigcirc_i(\varphi, \partial\varphi)$$

↑
mass dimension d_i
 n_i copies of φ

$$\varphi(x) = \int_{p < \Lambda} \frac{d^d p}{(2\pi)^d} e^{ipx} \tilde{\varphi}(p)$$

$$= \underbrace{\int_{p < \Lambda'} \frac{d^d p}{(2\pi)^d} e^{ipx} \tilde{\varphi}(p)}_{\phi(x)} + \underbrace{\int_{\Lambda' < p < \Lambda} \frac{d^d p}{(2\pi)^d} e^{ipx} \tilde{\varphi}(p)}_{\chi(x)}$$

$$\mathcal{D}\varphi = \mathcal{D}\phi \mathcal{D}\chi$$

$$Z = \int_{p < \Lambda} \mathcal{D}\phi e^{-S_\Lambda[\phi]}$$

$$L_\Lambda[\phi] = \frac{1}{2}(\partial_\mu \phi)^2 + \sum_i \Lambda^{d-d_i} g_i(\Lambda) \bigcirc_i(\phi)$$

↑
mass dimension n_i copies

$$= \int_{p < \Lambda'} \mathcal{D}\phi \int_{\Lambda' < p < \Lambda} \mathcal{D}\chi e^{-S_\Lambda[\phi+\chi]} \leftarrow S_\Lambda[\phi+\chi] = S_\Lambda[\phi] + \hat{S}_\Lambda[\phi, \chi]$$

$$= \int \mathcal{D}\phi e^{-S_\Lambda[\phi]} \underbrace{\int \mathcal{D}\chi e^{-\hat{S}_\Lambda[\phi, \chi]}}_{e^{-\delta S_\Lambda[\phi]}}$$

$$S_{\Lambda'}[\phi] = S_\Lambda[\phi] + \delta S_\Lambda[\phi]$$

$$L_\Lambda[\phi] = \frac{1}{2}(\partial_\mu \phi)^2 + \sum_i \Lambda^{d-d_i} g_i(\Lambda) \mathcal{O}_i(\phi, \partial\phi)$$

$$S_\Lambda[\phi + \chi] = S_\Lambda[\phi] + \hat{S}_\Lambda[\phi, \chi]$$

↑
mass dimension d_i
 n_i copies of ϕ

$S_\Lambda[\phi, \chi]$

$$S_{\Lambda'}[\phi] = S_\Lambda[\phi] + \delta S_\Lambda[\phi] = \frac{Z}{2}(\partial_\mu \phi)^2 + \sum_i \Lambda'^{d-d_i} Z^{n_i/2} g_i(\Lambda') \mathcal{O}_i(\phi, \partial\phi)$$

$$\phi(x) = \int_{p < \Lambda} \frac{d^d p}{(2\pi)^d} e^{ipx} \tilde{\phi}(p)$$

$$= \underbrace{\int_{p < \Lambda'} \frac{d^d p}{(2\pi)^d} e^{ipx} \tilde{\phi}(p)}_{\phi(x)} + \underbrace{\int_{\Lambda' < p < \Lambda} \frac{d^d p}{(2\pi)^d} e^{ipx} \tilde{\phi}(p)}_{\chi(x)}$$

$$\frac{1}{2}(\partial_\mu \phi)^2 + \sum_i \Lambda^{d-d_i} g_i(\Lambda) \Theta_i(\phi, \partial\phi)$$

$$S_\Lambda[\phi] + \hat{S}_\Lambda[\phi, \chi]$$

↑
mass dimension d_i ,
 n_i copies of ϕ

$$\phi(x) = \int_{p < \Lambda} \frac{d^d p}{(2\pi)^d} e^{ipx} \tilde{\phi}(p)$$

$$= \underbrace{\int_{p < \Lambda'} \frac{d^d p}{(2\pi)^d} e^{ipx} \tilde{\phi}(p)}_{\phi(x)} + \underbrace{\int_{\Lambda' < p < \Lambda} \frac{d^d p}{(2\pi)^d} e^{ipx} \tilde{\phi}(p)}_{\chi(x)}$$

$$\begin{aligned} S_{\Lambda'}[\phi] &= S_\Lambda[\phi] + \delta S_\Lambda[\phi] = \frac{Z}{2}(\partial_\mu \phi)^2 + \sum_i \Lambda'^{d-d_i} Z^{n_i/2} g_i(\Lambda') \Theta_i(\phi, \partial\phi) \\ &= \frac{1}{2}(\partial_\mu \phi)^2 + \sum_i \Lambda'^{d-d_i} g_i(\Lambda') \Theta_i(\phi, \partial\phi) \end{aligned}$$

$$\phi = Z^{1/2} \phi$$

$$\Lambda \frac{d}{d\Lambda} Z = \left(\Lambda \frac{\partial}{\partial \Lambda} \bigg|_{g_i} + \Lambda \frac{\partial g_i}{\partial \Lambda} \frac{\partial}{\partial g_i} \right) Z = 0$$

$$\Lambda \frac{\partial g_i}{\partial \Lambda} = \underbrace{(d_i - d) g_i}_{\text{classical}} + \underbrace{\beta_{\text{quantum}}(g_i)}_{\text{quantum}}$$

$$d(\ln g_i) = (d_i - d) d(\ln \Lambda) \rightarrow \left(\frac{g_{ij}}{g_i} \right) = \left(\frac{\Lambda}{\Lambda_{uv}} \right)^{d_i - d}$$

$$\frac{1}{2} \left(\frac{1}{\Lambda^2} \right) \left(\frac{1}{\Lambda^2} \right) \left(\frac{1}{\Lambda^2} \right)$$

$$= \left(\frac{\Lambda}{\Lambda_{uv}} \right)^{d-d}$$

$$\Lambda^{d-d_i} g_i(\Lambda) = \Lambda_{uv}^{d-d_i} \left[g_i(\Lambda_{uv}) + \delta g_i^{\text{quant}} \right]$$

$$\Lambda^2 g_i(h^\dagger h) = \Lambda_{uv}^2 \left[g_i(\Lambda_{uv}) + \delta g_i^{\text{quant}} \right]$$

$$B(g) = - \left[\frac{11}{3} C_2(G) - \frac{1}{3} n_s T(R_s) \right]$$
$$SU(N) = N$$

$$\text{Tr}[T^a T^b] = T(R_S) \delta^{ab}$$

$$\beta(g) = - \left[\frac{11}{3} C_2(G) - \frac{1}{3} n_s T(R_s) - \frac{4}{3} n_f T(R_f) \right] \frac{g^3}{16\pi^2}$$

$SU(N) = N$ $T(R) = \frac{1}{2}$

$$\text{Tr}[T^a T^b] = T(R) \delta^{ab}$$

$$\beta(g_3) = - \left[\frac{11}{3} \times 3 - \frac{4}{3} \left(\frac{1}{2} \right) 2 \times 3 \right] \frac{g^3}{16\pi^2}$$

$$\begin{pmatrix} \frac{1}{2} & \\ & \frac{1}{2} \end{pmatrix} \begin{pmatrix} 1 \\ 1 \end{pmatrix}$$

$$\beta(g_1) = - \left[\frac{11}{3} \times 0 - \frac{1}{3} \times 2 \left(\frac{1}{2} \right)^2 - \frac{2}{3} \left[6 \left(\frac{1}{6} \right)^2 + 3 \left(\frac{2}{3} \right)^2 + 3 \left(\frac{-1}{3} \right)^2 + 2 \left(\frac{-1}{2} \right)^2 + (-1)^2 \right] \right] \frac{g^3}{16\pi^2}$$

$b_3 = -7$ b_1

$$- \frac{1}{6} - 2 \left\{ \frac{1}{6} + \frac{4}{3} + \frac{1}{3} + \frac{1}{2} + 1 \right\}$$

$$\frac{g^3}{16\pi^2}$$

$$\text{Tr}[T^a T^b] = T(R_S) \delta^{ab}$$

$$\begin{pmatrix} \frac{1}{2} & \\ & \frac{1}{2} \end{pmatrix} \begin{pmatrix} 1 \\ -1 \end{pmatrix}$$

$$\sqrt{\frac{3}{5}} \begin{pmatrix} -\frac{1}{2} & & \\ & -\frac{1}{2} & \\ & & \frac{1}{3} \end{pmatrix} \begin{pmatrix} l_L \\ \\ d_R^c \end{pmatrix}$$

$$D_m = \partial_m + ig_1 Y B_m$$

$$\text{Tr}[T^a T^b] = \frac{1}{2}$$

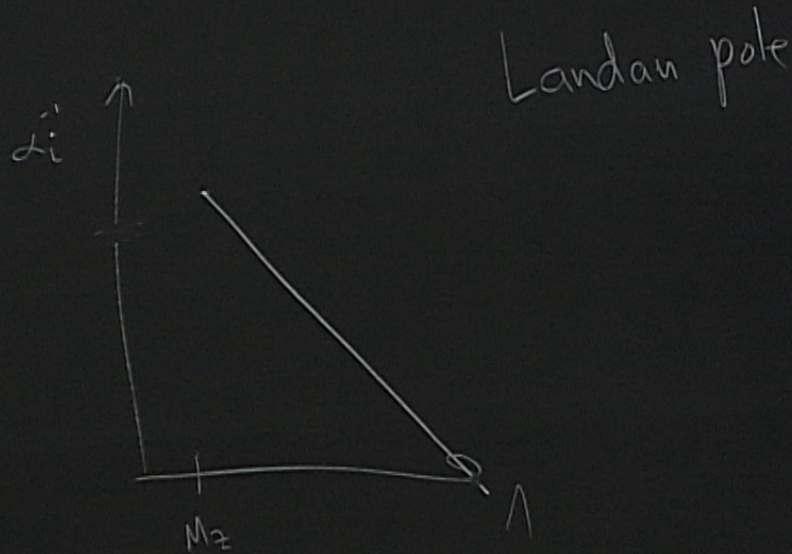
$$D_m = \partial_m + i g_5 \frac{T^a}{\sqrt{3}} X_m^a$$

$$\left(\frac{1}{4} \times 2 + \frac{1}{9} \times 3 \right) = \frac{5}{6} \left(\frac{3}{5} \right)$$

$$\left[\left(\frac{2}{3} \right)^2 + 3 \left(\frac{-1}{3} \right)^2 + 2 \left(\frac{-1}{2} \right)^2 + (-1)^2 \right] 3 = \frac{41}{6} \frac{g_1^3}{16\pi^2}$$

$$\alpha_i = \frac{g_i^2}{4\pi}$$

$$\alpha_i^{-1}(\Lambda) = \alpha_i^{-1}(M_Z) - \frac{b_i}{2\pi} \ln\left(\frac{\Lambda}{M_Z}\right)$$



$$\beta_h = \frac{1}{16\pi^2} \left[\frac{9}{2} h^3 - 8g_3^2 h - \frac{9}{4} g_2^2 h - \frac{17}{2} g_1^2 h \right]$$

$$\beta_\lambda = \frac{1}{16\pi^2} \left[24\lambda^2 + 12\lambda h^2 - 6h^4 \right]$$

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$SO(10)$
 $\downarrow$
Pati-Salam

$$-m^2(h+h) + \frac{\lambda(h)}{4}(h+h)^4$$

