Title: Beyond Standard Model-3

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URL: http://pirsa.org/15020041

Abstract:

$$\mathcal{L} = \frac{1}{2}(\partial\phi)^2 - \frac{1}{2}m_0^2\phi^2 - \frac{\lambda_0}{4!}\phi^4$$

$$= \frac{1}{2}(\partial\tilde{\phi})^2 - \frac{1}{2}m^2\tilde{\phi}^2 - \frac{\lambda}{4!}\tilde{\phi}^4$$

$$+ \frac{1}{2}\delta Z(\partial\tilde{\phi})^2 - \frac{1}{2}\delta m^2\tilde{\phi}^2 - \frac{\delta\lambda}{4!}\tilde{\phi}^4$$

$$\Delta\Gamma^{(2)} \sim \Lambda^2 + m^2\ln\Lambda + p^2\ln\Lambda$$

$$\Delta\Gamma^{(4)} \sim \ln\Lambda$$

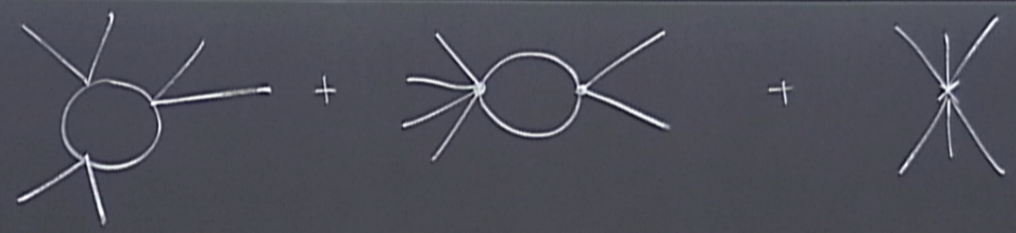
$$\mathcal{L} = \frac{1}{2}(\partial\phi)^2 - \frac{1}{2}m_0^2\phi^2 - \frac{\lambda_0}{4!}\phi^4 - \frac{\gamma_0}{M^2}\phi^6$$

$$= \frac{1}{2}(\partial\tilde{\phi})^2 - \frac{1}{2}m^2\tilde{\phi}^2 - \frac{\lambda}{4!}\tilde{\phi}^4 - \frac{\gamma}{M^2}\tilde{\phi}^6$$

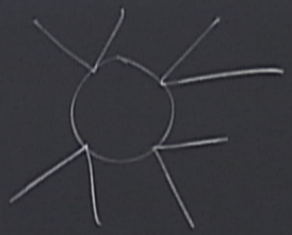
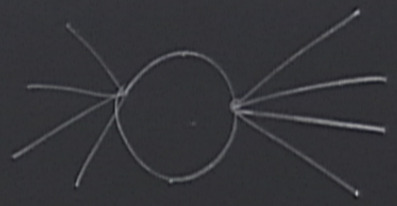
$$+ \frac{1}{2}\delta Z(\partial\tilde{\phi})^2 - \frac{1}{2}\delta m^2\tilde{\phi}^2 - \frac{\delta\lambda}{4!}\tilde{\phi}^4 - \frac{\delta\gamma}{M^2}\tilde{\phi}^6 .$$

$$\Delta\Gamma^{(2)} \sim \Lambda^2 + m^2\ln\Lambda + p^2\ln\Lambda$$

$$\Delta\Gamma^{(4)} \sim \ln\Lambda$$

$\Delta\Gamma^{(6)} \sim$  $+ \lambda^3 \int \frac{d^4 q_E}{(2\pi)^4} \left( \frac{1}{q_E^2 + m^2} \right)^3$ (finite) $+ \lambda \cdot \frac{\gamma}{M^2} \int \frac{d^4 q_E}{(2\pi)^4} \left( \frac{1}{q_E^2 + m^2} \right)^2$ $+ \frac{\delta\gamma}{M^2}$

$\frac{\lambda\gamma}{M^2} \ln \Lambda$

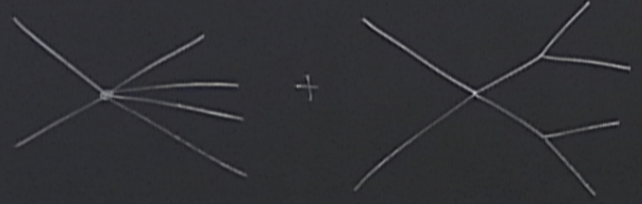
$\Delta\Gamma^{(8)} \sim$  + 

finite $\left(\frac{p}{M^2}\right)^2 \ln \Lambda$

With $\phi^6$, theory is no longer renormalizable!

$2 \to 4$ scattering

$\phi\phi \to \phi\phi\phi\phi$

$\mathcal{M} \sim$  $+$ 

$\Delta\sigma \sim \left(\frac{g}{M^2}\right)^2 p^2 \qquad \frac{\lambda^6}{p^2}$

$= g^2 \left(\frac{p}{M}\right)^4 \frac{1}{p^2}$

Lowest-dimensional ops. matter most at low energies ($p^2 \ll M^2$).

$\Rightarrow$ only need a finite number of ops.

$\Rightarrow$ need only a finite # of inputs.

# Symmetries

$$\mathcal{L} = \frac{1}{2}(\partial\phi)^2 - \frac{1}{2}m^2\phi^2 - \frac{\lambda}{4!}\phi^4 + (\text{c.t.})$$

$$\phi \to -\phi$$

$$\mathcal{L} \to \mathcal{L} - \frac{A}{3!}\phi^3$$

Would have asym if $\begin{cases} A \to -A \\ \phi \to -\phi \end{cases}$

$$\Delta\Gamma^{(4)} \sim \lambda^2 \cdot \ln\Lambda + (\text{even \# of } A \text{ factors})$$

$$\Delta\Gamma^{(3)} \sim \lambda A \ln\Lambda + \text{finite},$$

$$\propto A$$

$$\Delta\Gamma^{(2)} \sim A^2(\ln\Lambda + \text{finite})$$

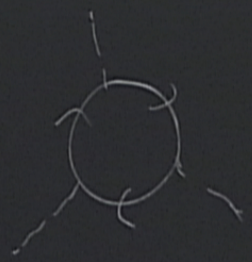
$$\mathcal{L} \to \mathcal{L} + \bar{\psi} i \gamma^\mu \partial_\mu \psi - y \phi \bar{\psi} \psi - M \bar{\psi} \psi$$

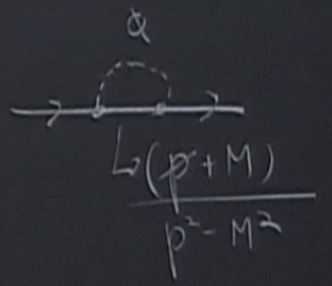
$$\begin{cases} \phi \to -\phi \\ \psi \to -i\gamma^5 \psi \\ \bar{\psi} \to \bar{\psi} i \gamma^5 \end{cases}$$

$$M \to -M$$

$$\Delta\Gamma^{(\bar{\psi}\psi)} \sim y^2 M \left( \ln \Lambda + \text{finite} \right)$$

$$\Delta\Gamma^{(\phi^3)} \sim y^3 \cdot M \ln \Lambda$$



$$\mathcal{L} = \frac{1}{2}(\partial\phi)^2 - \frac{1}{2}m^2\phi^2 - \frac{\lambda}{4!}\phi^4 + \bar{\Psi} i\gamma^\mu \partial_\mu \Psi - y\phi\bar{\Psi}\Psi \qquad \Psi\Psi \to \phi\phi:$$

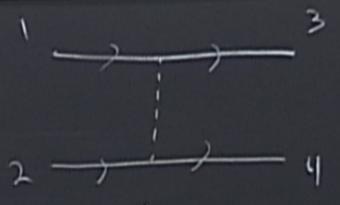
$$|p^2| << m^2$$

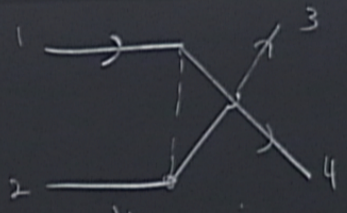
- Idea: find "effective theory with only $\Psi$ fields"

$$\mathcal{L}_{eff} = \bar{\Psi} i\gamma^\mu \partial_\mu \Psi$$

$\bar{\psi}\psi$

$\psi\psi \to \psi\psi$:




$$(\bar{u}_3 u_1)(\bar{u}_4 u_2)(-iy)^2 \frac{1}{t - m^2} \qquad (-iy)^2 \frac{1}{u - M^2} (\bar{u}_4 u_1)(\bar{u}_3 u_2)$$

$$\| \quad (p_1 - p_3)^2 \qquad \| \quad (p_1 - p_4)^2$$

$$\frac{-1}{m^2}\left(1 + \frac{t}{m^2} + \frac{t^2}{m^4} + \cdots\right)$$

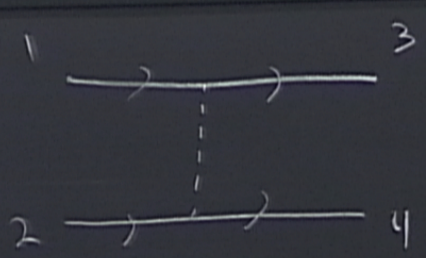
$$\mathcal{L} = \frac{1}{2}(\partial\phi)^2 - \frac{1}{2}m^2\phi^2 - \frac{\lambda}{4!}\phi^4 + \bar{\psi} i\gamma^\mu \partial_\mu \psi - y\phi\bar{\psi}\psi$$

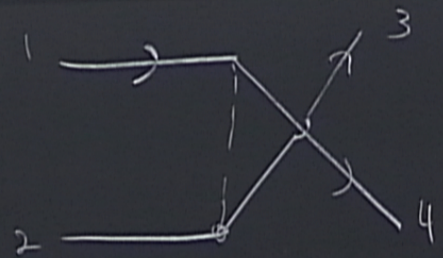
$|p^2| << m^2$

- Idea: find "effective theory with only $\psi$ fields"

$$\mathcal{L}_{eff} = \bar{\psi} i\gamma^\mu \partial_\mu \psi + \underbrace{\frac{y^2}{2m^2}(\bar{\psi}\psi)(\bar{\psi}\psi)}_{\text{leading interaction}} + \dots$$

$\psi\psi \to \psi\psi$:



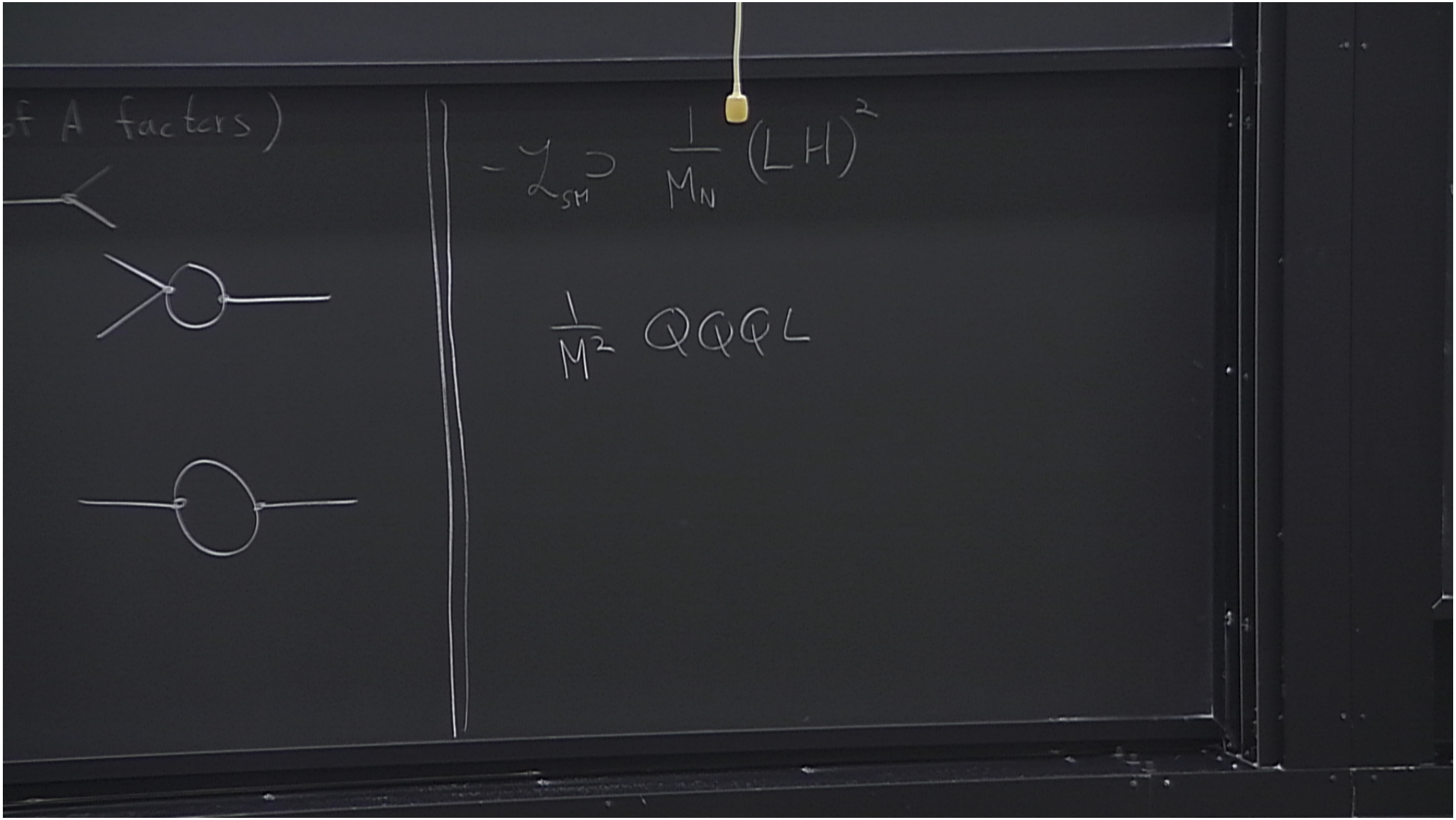

$$= (\bar{u}_3 u_1)(\bar{u}_4 u_2)(-iy)^2 \cdot \frac{i}{t - m^2}$$

$$t = (p_1 - p_3)^2$$

$$= (-iy)^2 \frac{i}{u - M^2} (\bar{u}_4 u_1)(\bar{u}_3 u_2)$$

$$u = (p_1 - p_4)^2$$

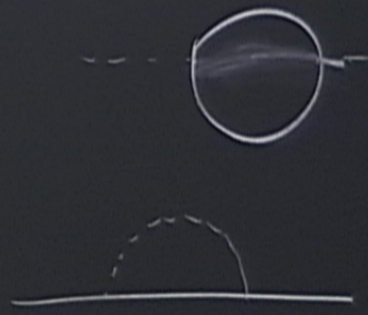
$$\frac{-1}{m^2}\left(1 + \frac{t}{m^2} + \frac{t^2}{m^4} + \cdots\right)$$


of A factors)
$-\mathcal{L}_{SM} \supset \frac{1}{M_N}(LH)^2$
$\frac{1}{M^2} QQQL$

$\mathcal{L} \to \mathcal{L} - M\bar{\psi}\psi$ $\qquad M \gg m$

$\Delta\Gamma^{(\phi^2)}(p) \sim (\text{divergent}) + \frac{y^2}{(4\pi)^2} M^2 \ln\left(\frac{p^2}{M^2}\right) + \ldots + c.t.$

$\Delta m^2$



$\Delta\Gamma^{(\bar{\psi}\psi)} \sim (\text{divergent}) + \frac{y^2}{(4\pi)^2} M \ln\left(\frac{p^2}{m^2}\right)$

$m^2 \gg M^2$