

Title: PSI 2015/2016 More/Beyond Standard Model - Lecture 12

Date: Mar 08, 2016 09:00 AM

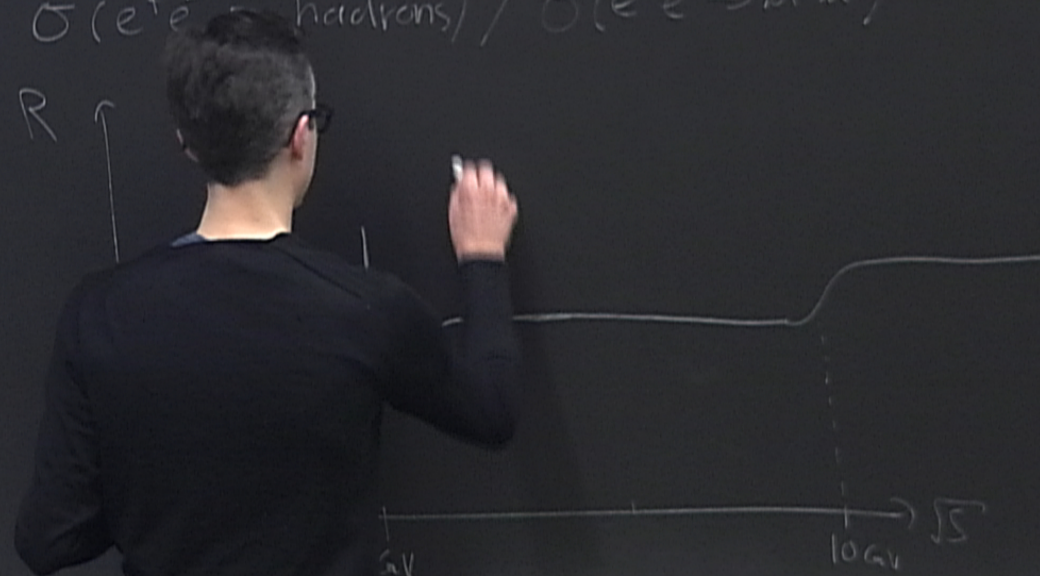
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Abstract:

Beyond χ -PT.

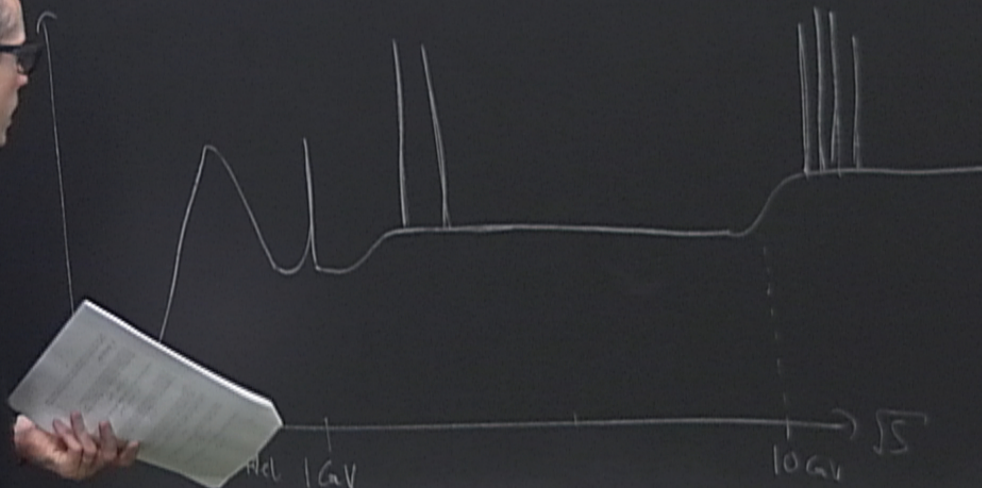
$$R = \sigma(e^+e^- \rightarrow \text{hadrons}) / \sigma(e^+e^- \rightarrow \mu^+\mu^-)$$

R



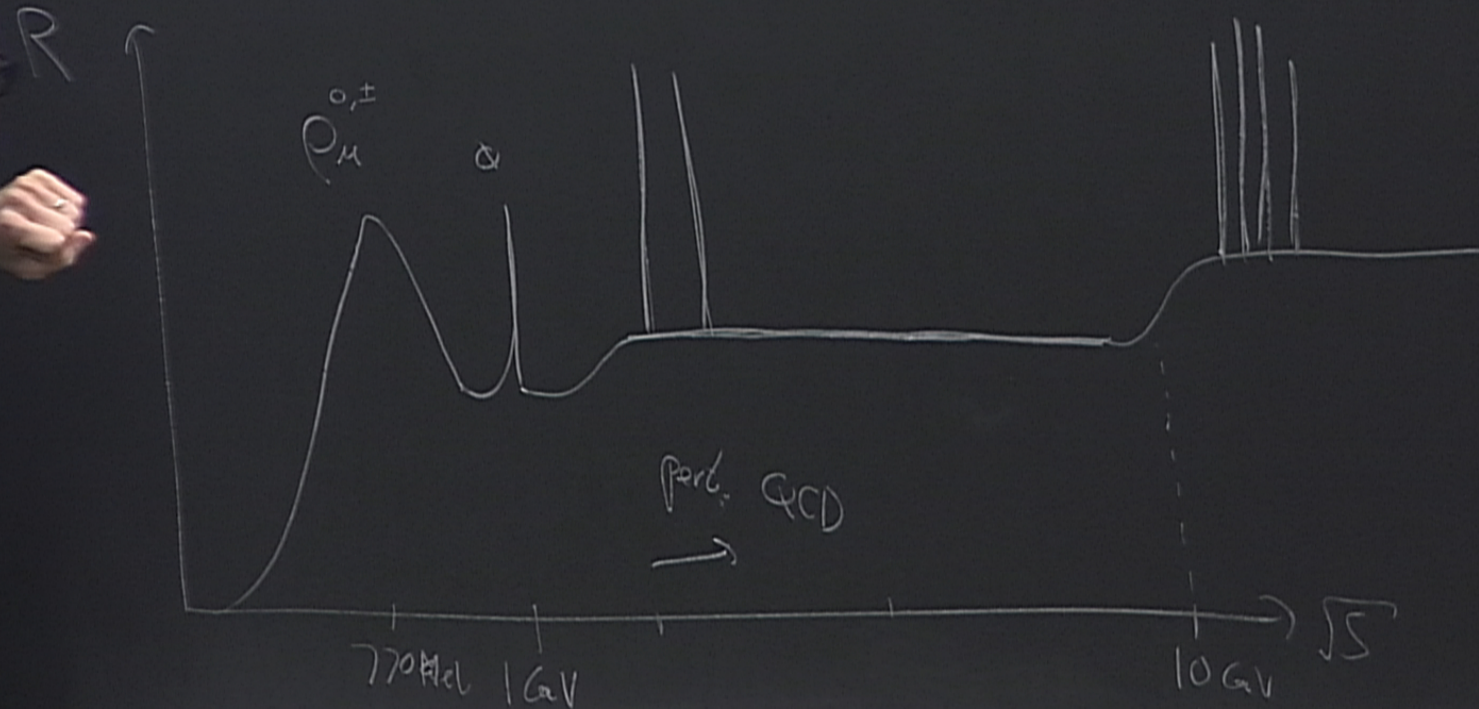
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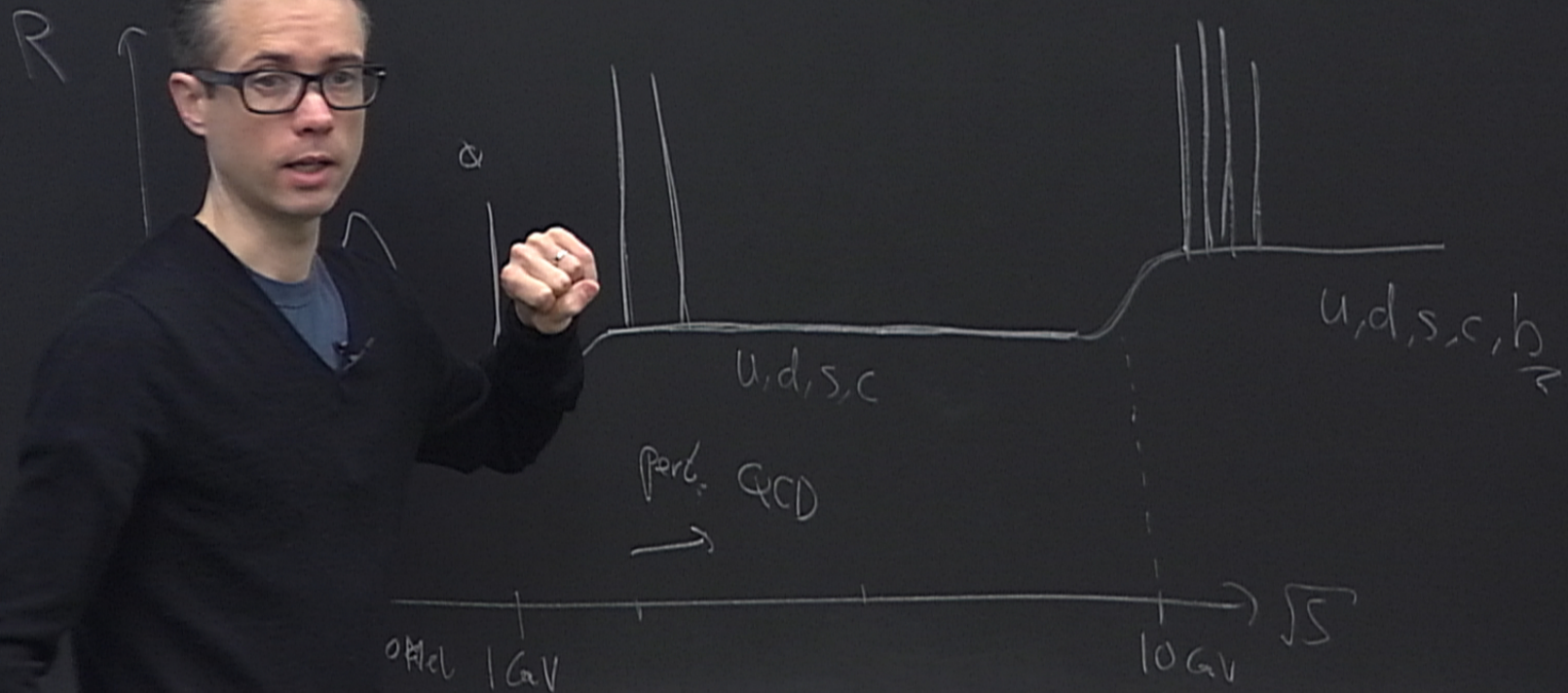
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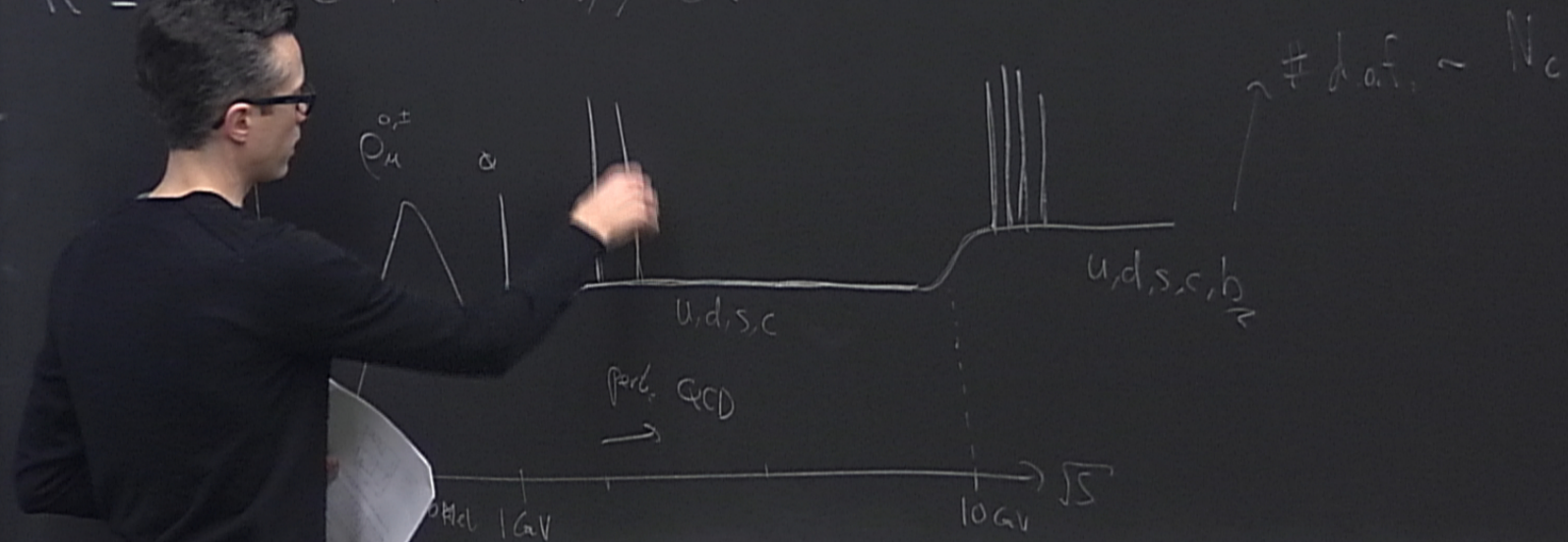
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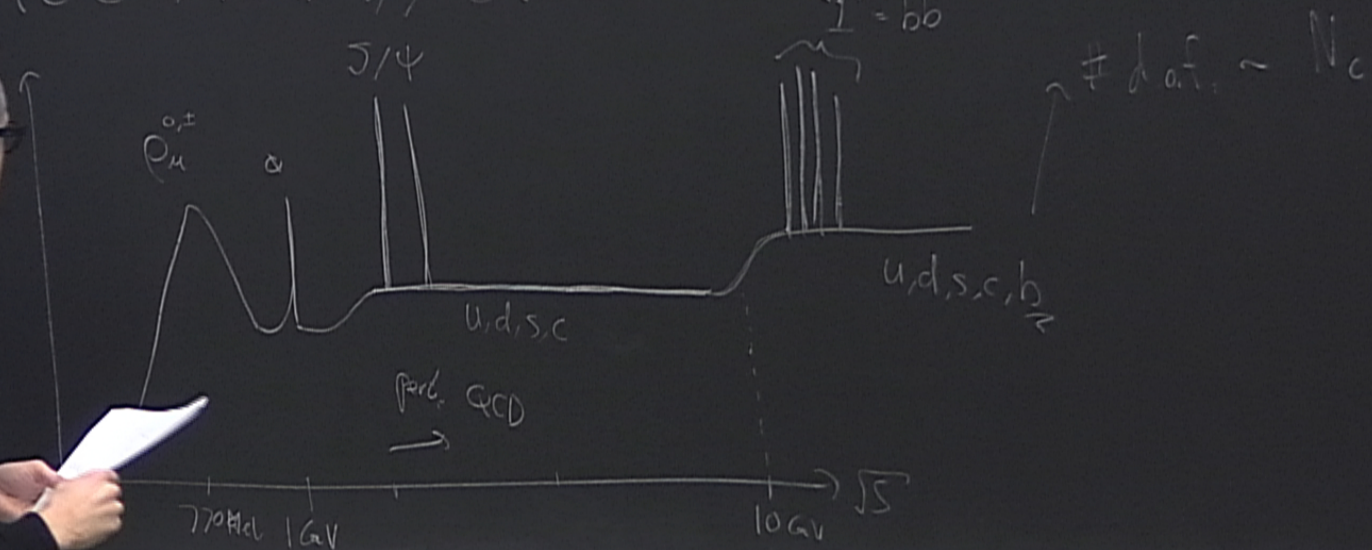
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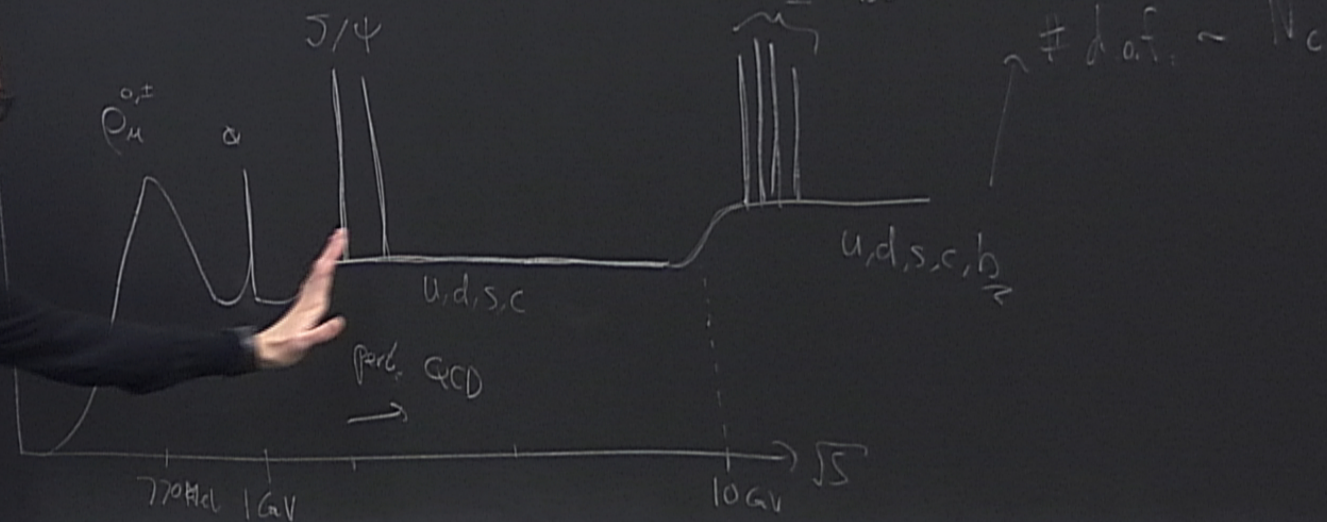
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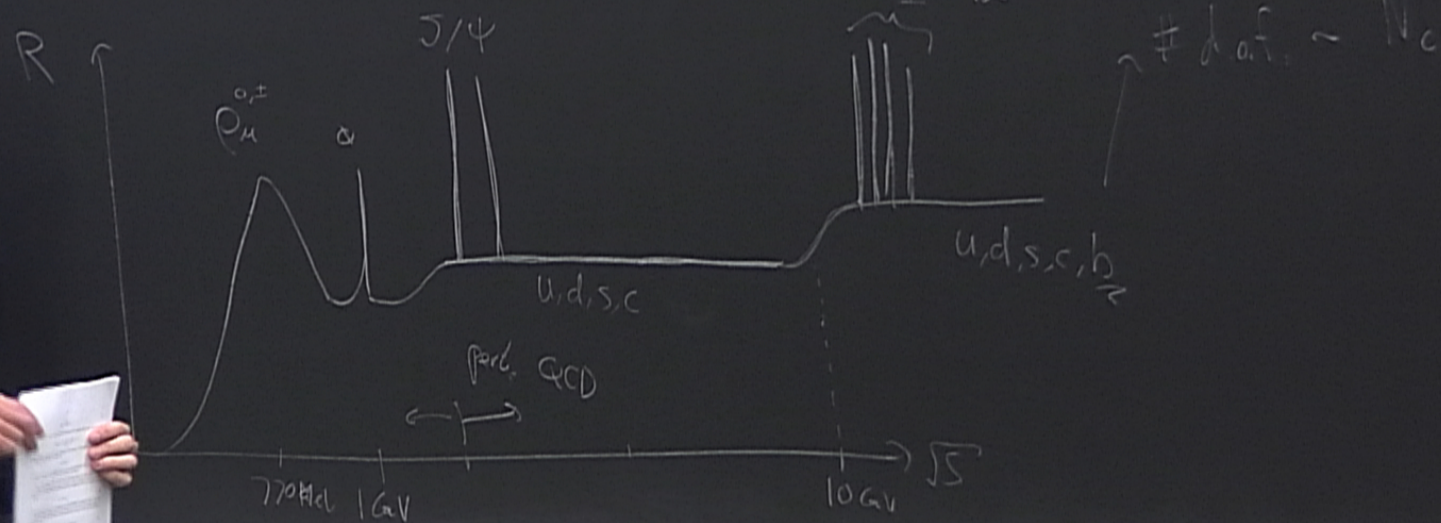
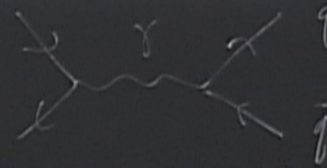
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Beyond χ -PT.

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$$\mathcal{L}_p^4 = \frac{A \cdot f^2}{\Lambda_X^2} \text{tr}(\partial_\mu \partial_\nu \Sigma^\dagger \partial^\mu \partial^\nu \Sigma)$$

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$$\sim \frac{p^4}{f^2 \Lambda_\chi^2}$$

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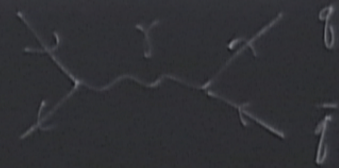
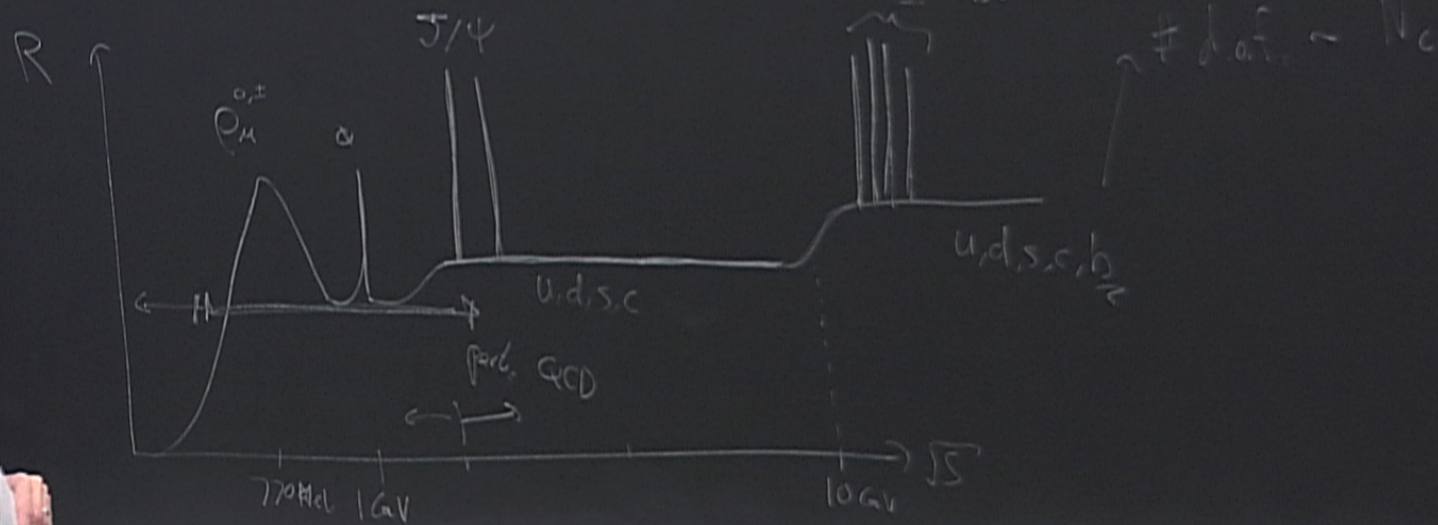


$$\frac{p^4}{\Lambda_X^2}$$

$$\frac{p^2}{\Lambda_X^2}$$

Beyond χ -PT.

$$R = \sigma(e^+e^- \rightarrow \text{hadrons}) / \sigma(e^+e^- \rightarrow \mu^+\mu^-)$$



$$Z_p =$$

$$\mathcal{L}_p = \frac{A \cdot f^2}{\Lambda_X^2} \text{tr} \left(\underbrace{\partial_\mu \partial_\nu \Sigma^\dagger}_{\text{}} \underbrace{\partial^\mu \partial^\nu \Sigma}_{\text{}} \right)$$



$$\frac{p^4}{f^2 \Lambda_X^2}$$

$$\Lambda_X \sim m_\rho$$

$$\frac{p^2}{f^2}$$

$$\Gamma \sim \frac{g^2}{4\pi} \frac{(\#)}{\text{}} \cdot m$$

of final states

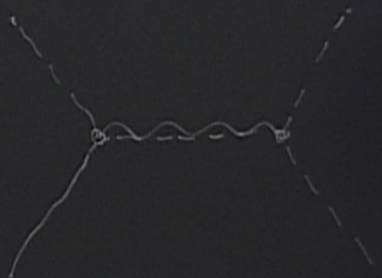
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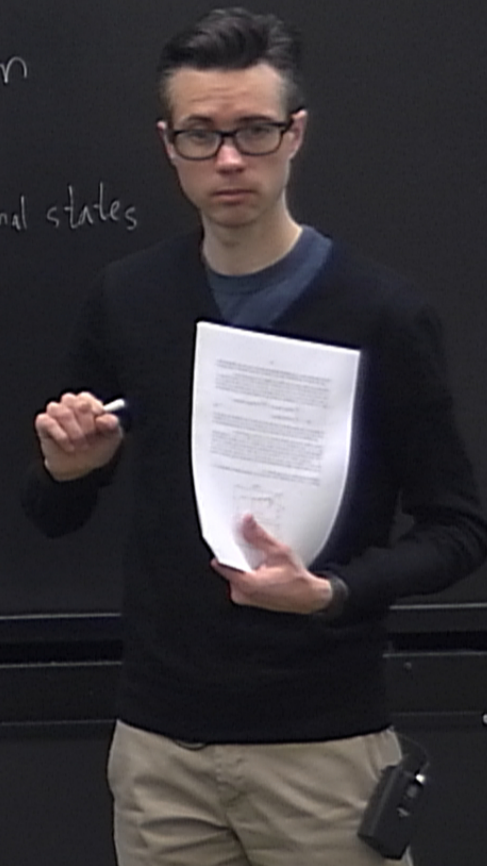
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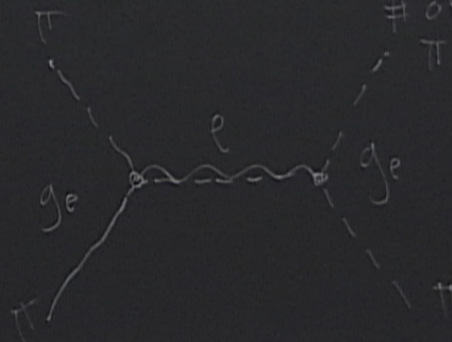
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of final states



Technicolor

$$\mathcal{L} = \bar{Q}_L \gamma^\mu D_\mu Q + \bar{Q}_R i \gamma^\mu D_\mu Q_R - \frac{1}{4} G_{\mu\nu}^a G^{\mu\nu a}$$

Technicolor

$$\mathcal{L} = \bar{Q}_L \gamma^\mu D_\mu Q_L + \bar{Q}_R i \gamma^\mu D_\mu Q_R - \frac{1}{4} G_{\mu\nu}^a G^{\mu\nu a}$$

$SU(2)_L \times U(1)_Y$ gauging

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$SU(3)_c \times SU(2)_L \times U(1)_Y$ gauging

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$\overline{SU(3)}_C \times SU(2)_L \times U(1)_Y$ gauging

$$D_\mu Q_L = \partial_\mu + i g_3 \underbrace{G_\mu^a}_{SU(3)} \underbrace{T^a}_{\text{color}} + i g_2 \underbrace{W_\mu^d}_{SU(2)} \underbrace{T^d}_{\text{weak}} + i g' Y B_\mu$$

Technicolor

$$\mathcal{L} = \bar{Q}_L \gamma^\mu D_\mu Q_L + \bar{Q}_R i \gamma^\mu D_\mu Q_R - \frac{1}{4} G_{\mu\nu}^a G^{\mu\nu a}$$

$SU(3)_C \times SU(2)_L \times U(1)_Y$ gauging

$$D_\mu Q_L = \partial_\mu + ig_3 \underbrace{G_\mu^a t^a}_{SU(3)} + ig_2 \underbrace{W_\mu^d t^d}_{SU(2)} + ig' \underbrace{Y}_{\frac{1}{6}} B_\mu$$

$$D_\mu Q_R = \partial_\mu + ig_3 G_\mu^a t^a + 0 + ig' \underbrace{Y}_{\left(t_R^3 + \frac{1}{6}\right)} B_\mu$$

Technicolor

$$\mathcal{L} = \bar{Q}_L \gamma^\mu D_\mu Q_L + \bar{Q}_R i \gamma^\mu D_\mu Q_R - \frac{1}{4} G_{\mu\nu}^a G^{\mu\nu a}$$

$\mathcal{L} \times \overline{\mathcal{L}} \times SU(2)_L \times U(1)_Y$ gauging

$$D_\mu Q_L = \partial_\mu + ig_3 \underbrace{G_\mu^a t^a}_{SU(3)} + ig_2 \underbrace{W_\mu^d t_L^d}_{SU(2)} + ig' \underbrace{Y}_{\frac{1}{6}} B_\mu$$

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Gauge: $SU(3)_c \times SU(2)_L \times U(1)_Y$

Global: $SU(2)_L \times SU(2)_R \times U(1)_V$

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Global: $SU(2)_L \times SU(2)_R \times U(1)_V$

$$Y = t_R^3 + \frac{1}{6} \stackrel{B/2}{=}$$

$$Q_{em} = t_L^3 + Y = \left(t_L^3 + t_R^3 + \frac{1}{6} \right)$$

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$$Y = t_R^3 + \frac{1}{6} \quad B/2$$

$$Q_{LR} \rightarrow e^{i\alpha(t_R^3 + \frac{1}{6}\mathbb{1})} Q_{LR}$$

$$Q_{em} = t_L^3 + Y = \left(t_L^3 + t_R^3 + \frac{1}{6} \right)$$

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$$Y = t_R^3 + \frac{1}{6} \quad B/2$$

$$Q_{L,R} \rightarrow e^{i\alpha(t_R^3 + \frac{1}{6})} Q_{L,R}$$

$$Q_{em} = t_L^3 + Y = \left(t_L^3 + t_R^3 + \frac{1}{6} \right), \quad Q_{L,R} \rightarrow e^{i\alpha(t_L^3 + t_R^3 + \frac{1}{6})} Q_{L,R}$$

$$\langle \bar{Q}_R Q_L \rangle = \int_{\text{QCD}} 1$$

$$\int_{\text{QCD}} L(\dots) R^\dagger$$

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$$\overbrace{L(\dots)R^\dagger}$$

$$\underbrace{SU(2)_L \times SU(2)_R}_{\mathfrak{f}} \rightarrow SU(2)_V \rightarrow \text{EWSB}$$

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$$\underbrace{SU(2)_L \times SU(2)_R}_{\mathfrak{f}} \rightarrow SU(2)_V \rightarrow \text{EWSB, breaks } SU(2)_V, U(1)_V$$

$$\underbrace{SU(2)_V \times U(1)_V}_{U(1)_{\text{em}}}$$

$$\mathcal{L} = \frac{f^2}{4} \text{tr} (D_\mu \Sigma^\dagger D^\mu \Sigma)$$

$$D_\mu \Sigma = \partial_\mu \Sigma + ig t_L^a W_\mu^a \Sigma - ig' B_\mu \Sigma t_R^3$$

$R \sim L / - \sim L_{QCD}$

$\sim$

$(\dots) R^\dagger$

$SU(2)_L \times SU(2)_R \rightarrow SU(2)_V \rightarrow \text{EWSB, breaks } SU(2)_L, U(1)_Y$

$SU(2)_V \times U(1)_V$
 $\sim$
 $U(1)_{em}$

$\Sigma \rightarrow L \Sigma R^\dagger$

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$$D_\mu \Sigma = \partial_\mu \Sigma + ig t_L^a W_\mu^a \Sigma - ig' B_\mu \Sigma t_R$$

$$\mathcal{L} = \frac{f}{2} g W_\mu^+ \partial^\mu \pi^- + \frac{f}{2} g W_\mu^- \partial^\mu \pi^+ + \frac{f}{2} (g W_\mu^3 + g' B_\mu) \pi^0$$

$$+ \frac{f^2}{4} \left[g^2 W_\mu^+ W^{\mu -} + (g W_\mu^3 - g' B_\mu)^2 \right]$$

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$$m_W = \frac{g}{2} f, \quad m_Z = \frac{\sqrt{g^2 + g'^2}}{2} f, \quad m_\gamma = 0$$

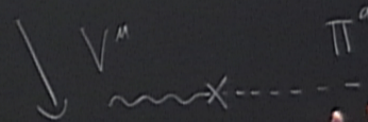
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$$\frac{f^2}{4} \text{tr} (D_\mu \Sigma^\dagger D^\mu \Sigma)$$

$$\Sigma = \partial_\mu \Sigma + ig t_L^a W_\mu^a \Sigma - ig' B_\mu \Sigma t_R^3$$

$$\frac{f^2}{2} g W_\mu^+ \partial^\mu \pi^- + \frac{f^2}{2} g W_\mu^- \partial^\mu \pi^+ + \frac{f^2}{2} (g W_\mu^3 + g' B_\mu) \pi^0$$

$$+ \frac{f^2}{4} \left[g^2 W_\mu^+ W^{\mu-} + (g W_\mu^3 - g' B_\mu)^2 \right] + \dots$$

$$\downarrow \begin{array}{c} V^\mu \quad \pi^a \\ \sim \times \cdots \end{array}$$

$\Downarrow \pi^\pm, \pi^0$ are eaten by $W^\pm, Z^0$.

$$m_W = \frac{g}{2} f, \quad m_Z = \frac{\sqrt{g^2 + g'^2}}{2} f, \quad m_\gamma = 0$$

$$m_w = \frac{g}{2} f$$

Technicolor

$$G_{TC} = SU(N_{TC})$$

Techniquarks: $Q_L = \begin{pmatrix} U_L \\ D_L \end{pmatrix} = (N_{TC}, 1, 2, 0)$

$$Q_R = \begin{pmatrix} U_R \\ D_R \end{pmatrix} = (N_{TC}, 1, 1, \pm \frac{1}{2})$$

Technicolor

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new techniquarks

 t_R^3 $\equiv$ t_R^3

$$m_W = \frac{g}{2} f$$

$$\langle Q_L \rangle$$

$$m_W = \frac{g}{2} f, \quad m_Z = \frac{\sqrt{g^2 + g'^2}}{2} f, \quad m_\gamma = 0$$

$$\langle \bar{Q}_{Rj} Q_{Li} \rangle = \int_{T_c}^3 \delta_{ij}$$

$\hookrightarrow 200 \text{ GeV}$

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$$SU(2)_L \times SU(2)_R \times U(1)_V \rightarrow SU(2)_V \times U(1)_V$$

$\downarrow$

$$SU(2)_L \times U(1)_Y \longrightarrow U(1)_{em}$$

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3 broken gauge generators

3 NGBs

$$\langle Q_R, Q_L \rangle = \int_{T_c}^2 \delta_{IS}$$

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$$SU(2)_L \times SU(2)_R \times U(1)_V \rightarrow SU(2)_V \times U(1)_V$$

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3 broken gauge generators
3 NGBs

$$\Sigma(x) = \exp\left[2i\pi^a t^a / f_{TC}\right]$$

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3 broken gauge generators
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$$\Sigma(x) = \exp\left[2i\pi^a t^a / f_{TC}\right]$$

$\nearrow$ TC scale

$$m_W = \frac{g}{2} f, \quad m_Z = \frac{\sqrt{g^2 + g'^2}}{2} f, \quad m_\gamma = 0$$

$$\langle Q_R, Q_L \rangle = \int_{T_c}^3 \delta_{\mathbb{R}^5}$$

$\hookrightarrow 200 \text{ GeV}$

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3 broken gauge generators

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$$\Sigma(x) = \exp\left[2i\pi^a t^a / f_{TC}\right]$$

$$f_{TC} = N$$

$\nearrow$ TC scale

$$m_Z = \frac{g}{2} f, \quad m_Z = \frac{\sqrt{g^2 + g'^2}}{2} f, \quad m_Y = 0$$

$$\langle Q_R, Q_L \rangle = \int_{T_C}^3 \delta_{IS}$$

$\hookrightarrow 200 \text{ GeV}$

$$SU(2)_L \times SU(2)_R \times U(1)_V \rightarrow SU(2)_V \times U(1)_V$$

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3 broken gauge generators

3 NGBs

$$\Sigma(x) = \exp \left[2i \pi^a t^a / f_{TC} \right]$$

$$f_{TC} = N = 174 \text{ GeV}$$

$\nearrow$ TC scale

$$m_1 = \frac{g}{2} f, \quad m_2 = \frac{\sqrt{g^2 + g'^2}}{2} f, \quad m_r = 0$$

$$\langle Q_{Rj} Q_{Li} \rangle = \int_{T_c}^3 \delta_{ij}$$

3 broken gauge generators

3 NGBs

$$\Sigma(x) = \exp\left[2i\pi^a t^a / f_{TC}\right]$$

$$F_{TC} = N = 174 \text{ GeV}$$

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2. Massless technipions for $N_f > 1$.
3. Technibaryon number conserved...
4. No Higgs boson.

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Composite Higgs:

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Composite Higgs: - usually get $m_h \sim f_{\pi}$.

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- Higgs properties modified by $(\frac{\Lambda}{f_{TC}})$.

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- } can be fixed

↳ Want scalar bound state with $(1, 2, \frac{1}{2})$.

Composite Higgs.

- usually get $m_h \sim f_{TC}$.
- Higgs properties modified by $(\frac{N_c}{f_{TC}}) \lesssim 0.3$.