

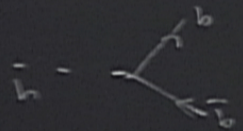
Title: 12/13 PSI - Standard Model Review Lecture 12

Date: Jan 22, 2013 09:00 AM

URL: <http://pirsa.org/13010039>

Abstract:

$$\Gamma(h \rightarrow b\bar{b})$$



$$-i \frac{m_b}{v}$$

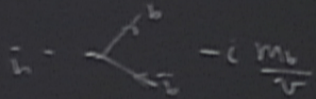
$$m_b(m_h)$$

$$\rightarrow m_b\left(\frac{m_r}{2}\right)$$

$$\Gamma(h \rightarrow b\bar{b}) = \frac{3}{8\pi} \frac{m_b^2}{v^2} m_h$$

$b\bar{b}$ bound state called γ

$$\Gamma(h \rightarrow b\bar{b})$$



$$\Gamma(h \rightarrow b\bar{b}) = \frac{3}{8\pi} \frac{m_b^2}{v^2} m_h$$

$$m_b(m_h) \rightarrow m_b\left(\frac{m_h}{2}\right)$$

$b\bar{b}$ bound state called Υ

$$m_b^{(0)} =$$

$$\Gamma(h \rightarrow b\bar{b})$$

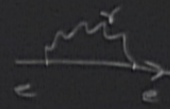
$b\bar{b}$ bound state called Υ



$$-i \frac{m_b}{v}$$

$$m_b(m_b)$$

$$\rightarrow m_b\left(\frac{m_{\Upsilon}}{2}\right)$$



$$\Gamma(h \rightarrow b\bar{b}) = \frac{3}{8\pi} \frac{m_b^2}{v^2} m_h$$

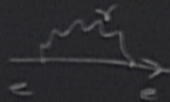
$$m_b^{(0)} = Z_m m_b(\mu)$$

$$Z_m = Z_m^{\text{electron}} \left(e^2 \rightarrow g^2 \frac{4}{3} \right)$$

$$Z_m = 1 - \frac{g^2}{16\pi^2 \epsilon}$$

$b\bar{b}$ calico γ
 bound state

$$\rightarrow m_b \left(\frac{m_{\gamma}}{2} \right)$$



$$m_b^{(e)} = Z_m m$$

$$Z_m \Rightarrow \left(e^2 \rightarrow \frac{2}{3} \frac{4}{3} \right)$$

$$\begin{cases} 0 = \mu \frac{d}{d\mu} m_b^{(e)} \\ = \left(\mu \frac{d}{d\mu} Z_m \right) m_b + Z_m \mu \frac{d}{d\mu} m_b \\ \mu \frac{d}{d\mu} m_b = - \frac{1}{Z_m} \left(\mu \frac{d}{d\mu} Z_m \right) \end{cases}$$

b₁ calico V

$$\rightarrow m_b(\frac{m_r}{2})$$

$$m_b^{(e)} = Z_m m_b(u)$$

$$Z_m \Rightarrow Z_m^{\text{electron}}(e^2 \rightarrow \frac{2}{3})$$

$$Z_m = 1 - \frac{g^2}{16\pi^2 \epsilon}$$

$$\beta(g) = \mu \frac{dg}{d\mu} = -\frac{6g^3}{2\pi^2} + \dots$$

$$0 = \mu \frac{d}{d\mu} m_b^{(e)}$$

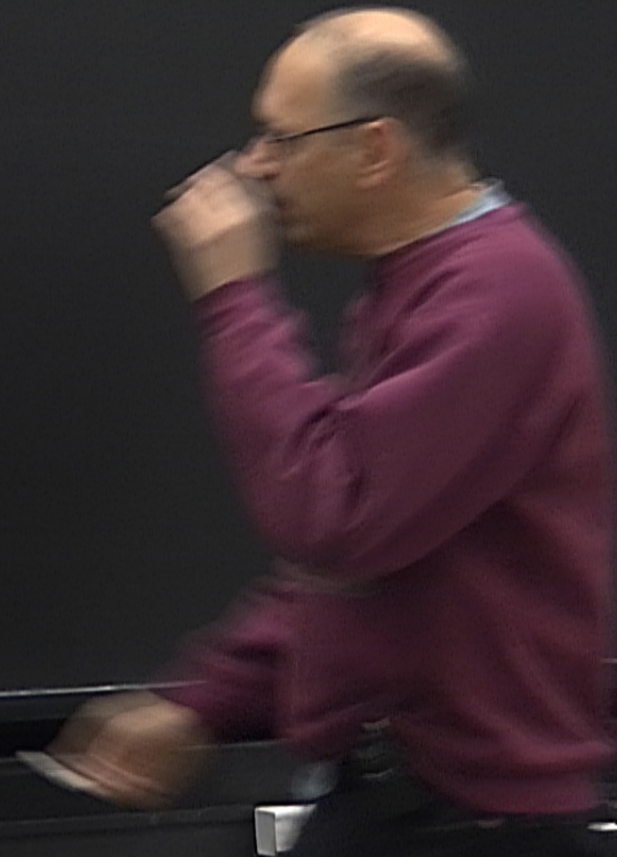
$$= \left(\mu \frac{d}{d\mu} Z_m \right) m_b + Z_m \mu \frac{d}{d\mu} m_b$$

$$\mu \frac{d}{d\mu} m_b = -\frac{1}{Z_m} \left(\mu \frac{d}{d\mu} Z_m \right) m_b$$

$$\frac{1}{Z_m} \mu \frac{d}{d\mu} Z_m = \frac{6g^2}{16\pi^2}$$

$$\mu \frac{d}{d\mu} m_b = \gamma_m(g) m_b$$

$$\gamma_m(g) = -\frac{8g^2}{16\pi^2}$$



$$\mu \frac{d}{d\mu} m_b = \gamma_m(g) m_b$$

$$\gamma_m(g) = -\frac{8g^2}{16\pi^2}$$

$$\left[m_b(10^{15} \text{ GeV}) \simeq m_\tau \right]$$

$$\mu \frac{d}{d\mu} m_b = \gamma_m(g) m_b$$

$$\gamma_m(g) = -\frac{8g^2}{16\pi^2}$$

$$m_b(\mu_2) = \exp \left[\int_{g(\mu_1)}^{g(\mu_2)} \frac{\gamma_m(g)}{\beta(g)} dg \right]$$

$$\left[m_b(10^{15} \text{ GeV}) \simeq m_\tau \right]$$

$$\mu \frac{d}{d\mu} m_b = \gamma_m(g) m_b$$

$$\left[m_b(10^{15} \text{ GeV}) \simeq m_\tau \right]$$

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$$m_b(\mu_2) = \exp \left[\int_{g(\mu_1)}^{g(\mu_2)} \frac{\gamma_m(g)}{\beta(g)} dg \right] m_b(\mu_1)$$

$$\mu \frac{d}{d\mu} m_b = \gamma_m(g) m_b$$

$$\gamma_m(g) = -\frac{8g^2}{16\pi^2}$$

$$m_b(\mu_2) = \exp \left[\int_{g(\mu_1)}^{g(\mu_2)} \frac{\gamma_m(g)}{\beta(g)} dg \right] m_b(\mu_1)$$

$$\left[m_b(10^{15} \text{ GeV}) \simeq m_\tau \right]$$

$$m_b(\mu_L) = \left[\frac{\alpha_s(\mu_L)}{\alpha_s(\mu_1)} \right]^{\left(\frac{4}{11} \right)} m_b(\mu_1)$$

$$\mu \frac{d}{d\mu} m_b = \gamma_m(g) m_b$$

$$\gamma_m(g) = -\frac{8g^2}{16\pi^2}$$

$$m_b(\mu_2) = \exp \left[\int_{g(\mu_1)}^{g(\mu_2)} \frac{\gamma_m(g)}{\beta(g)} dg \right] m_b(\mu_1)$$

$$\left[m_b(10^{15} \text{ GeV}) \simeq m_\tau \right]$$

$$m_b(\mu_L) = \left[\frac{\alpha_s(\mu_L)}{\alpha_s(\mu_1)} \right]^{\left(\frac{4}{11 - \frac{2}{3}N_f} \right)} m_b(\mu_1)$$

$$\mu \frac{d}{d\mu} m_b = \gamma_m(g) m_b$$

$$\gamma_m(g) = -\frac{8g^2}{16\pi^2}$$

$$m_b(\mu_2) = \exp \left[\int_{g(\mu_1)}^{g(\mu_2)} \frac{\gamma_m(g)}{\beta(g)} dg \right] m_b(\mu_1)$$

$$\left[m_b(10^{15} \text{ GeV}) \simeq m_\tau \right]$$

$$m_b(\mu_2) = \left[\frac{\alpha_s(\mu_2)}{\alpha_s(\mu_1)} \right]^{\left(\frac{4}{11 - \frac{2}{3}N_f} \right)} m_b(\mu_1)$$

$$m_b \left[m_b(10^5 \text{ GeV}) \simeq m_\tau \right]$$

$$m_b(\mu_b) = \left[\frac{\alpha_s(\mu_b)}{\alpha_s(\mu_1)} \right]^{\left(\frac{4}{11 - \frac{2}{3} N_f} \right)} m_b(\mu_1)$$

$$1 + a_1 \alpha_s(\mu_1) \ln\left(\frac{\mu_2^2}{\mu_1^2}\right) + a_2 \left(\alpha_s(\mu_1) \ln\left(\frac{\mu_2^2}{\mu_1^2}\right) \right)^2 + \dots$$

$$\left[\int_{g(\mu_1)}^{g(\mu_2)} \frac{\gamma_m(g)}{\beta(g)} dg \right] m_b(\mu_1)$$

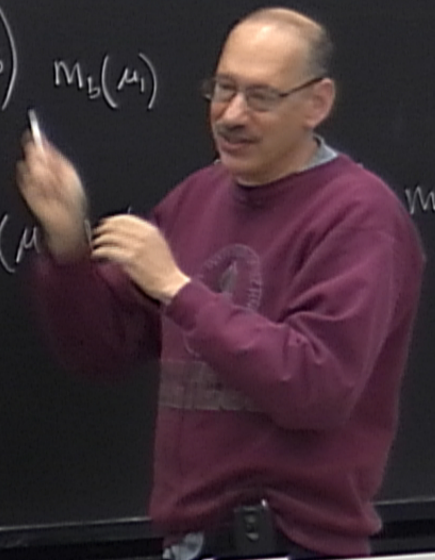
$$\left[m_b(10^5 \text{ GeV}) \simeq m_\tau \right]$$

$$m_b(\mu_0) = \left[\frac{\alpha_s(\mu_0)}{\alpha_s(\mu_1)} \right]^{\left(\frac{4}{11 - \frac{2}{3} N_f} \right)} m_b(\mu_1)$$

$$m_b(\mu_0) = \left[1 + a_1 \alpha_s(\mu_1) \ln\left(\frac{\mu_0^2}{\mu_1^2}\right) + a_2 \left(\alpha_s(\mu_1) \ln\left(\frac{\mu_0^2}{\mu_1^2}\right) \right)^2 + \dots \right] m_b(\mu_1)$$

$$\left. \frac{\gamma_m(g)}{\beta(g)} dg \right] m_b(\mu_1)$$

$$\begin{aligned}
 &= \gamma_m(g) m_b \quad \left[m_b(10^{15} \text{ GeV}) \simeq m_\tau \right] \\
 &\frac{8g^2}{16\pi^2} \\
 &\exp \left[\int_{g(\mu_1)}^{g(\mu_2)} \frac{\gamma_m(g)}{\beta(g)} dg \right] m_b(\mu_1) \\
 &m_b(\mu_2) = \left[\frac{\alpha_s(\mu_2)}{\alpha_s(\mu_1)} \right]^{\left(\frac{4}{11 - \frac{2}{3} N_f} \right)} m_b(\mu_1) \\
 &m_b(\mu_1) = \left[1 + a_1 \alpha_s(\mu_1) \ln \left(\frac{\mu_2^2}{\mu_1^2} \right) + a_2 \alpha_s^2(\mu_1) \ln^2 \left(\frac{\mu_2^2}{\mu_1^2} \right) \right] m_b(\mu_1)
 \end{aligned}$$



π^0 $\pi^+ \pi^-$
 $K^0, \bar{K}^0$
 η

$$m_\pi \sim 140 \text{ MeV}$$

$$\pi^- \sim \bar{u}d$$

$$m_K \sim 495 \text{ MeV}$$

$$K^0 \sim \bar{s}d$$

$$m_\eta \sim 540 \text{ MeV}$$

$\pi^0, \pi^+ \pi^-$

$K^+, K^-, K^0, \bar{K}^0$

η

$m_\pi \sim 140 \text{ MeV}$

$m_K \sim 495 \text{ MeV}$

$m_\eta \sim 540 \text{ MeV}$

$\pi^- \sim \bar{u}d$

$K^0 \sim \bar{s}d$

$$\mathcal{L}_{\text{QCD}} = \bar{q} i \not{D} q + \bar{q} m_q q$$

$$q = \begin{pmatrix} u \\ d \\ s \end{pmatrix}, \quad m_q = \begin{pmatrix} m_u & 0 & 0 \\ 0 & m_d & 0 \\ 0 & 0 & m_s \end{pmatrix}$$

$$\mathcal{L}_{\text{CD}} = \bar{q} i \not{D} q - \bar{q} m_q q$$

$$q = \begin{pmatrix} u \\ d \\ s \end{pmatrix}, \quad m_q = \begin{pmatrix} m_u & 0 & 0 \\ 0 & m_d & 0 \\ 0 & 0 & m_s \end{pmatrix}$$

$$q_L \rightarrow D_L(\lambda) q_L$$

$$q_R \rightarrow D_R(\lambda) q_R$$

$$q_L = \frac{1}{2}(1 - \gamma_5) q$$

$$q_R = \frac{1}{2}(1 + \gamma_5) q$$

$$\mathcal{L}_{\text{ch}} = \bar{q}_L \not{D} q_L + \bar{q}_R \not{D} q_R$$

$$q_L \rightarrow q'_L = L q_L$$

3x3 special unitary matrix
 $SU(3)_L$

$$q_R \rightarrow q'_R = R q_R$$

In limit $m_q \rightarrow 0$
 $SU(3)_L \times SU(3)_R$

$$\mathcal{L}_{\text{QCD}} = \frac{1}{2} \bar{q}_L \not{D} q_L + \frac{1}{2} \bar{q}_R \not{D} q_R$$

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$$\mathcal{L}_{\text{QCD}} = \bar{q}_L \not{D} q_L + \bar{q}_R \not{D} q_R$$

$$q_L \rightarrow q'_L = L q_L$$

3x3 special
unitary matrix
 $SU(3)_L$

$$q_L \rightarrow e^{i\alpha} q_L$$

$$q_R \rightarrow e^{-i\alpha} q_R$$

$$q_R \rightarrow q'_R = R q_R$$

In limit $m_q \rightarrow 0$
 $SU(3)_L \times SU(3)_R$

$$\bar{q}_L \not{D} q_L + \bar{q}_R \not{D} q_R$$

$$b_R = \frac{1}{2}(1 + \gamma_5)$$

$$q_L' = L q_L$$

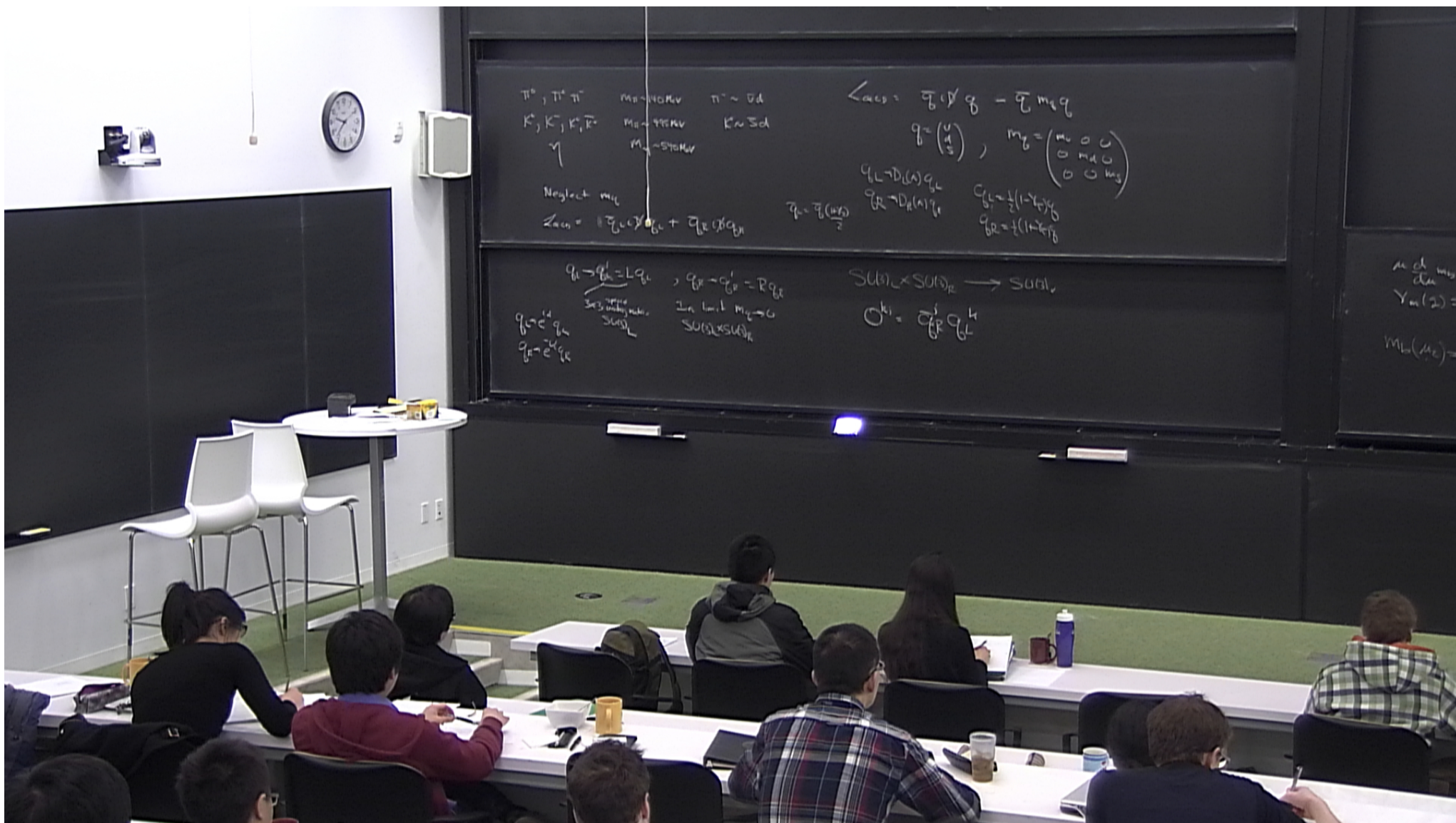
$$q_R \rightarrow q_R' = R q_R$$

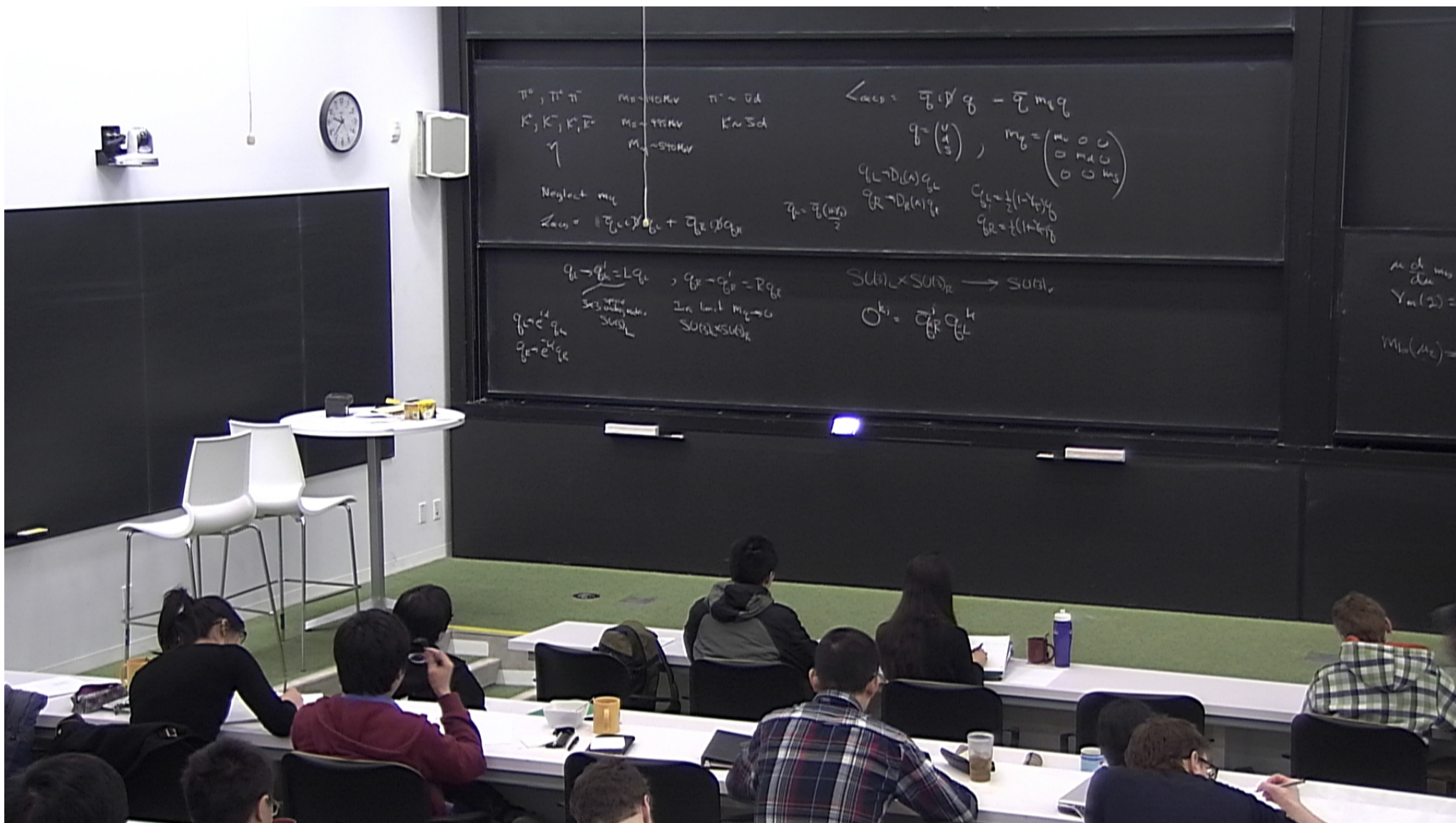
special
unitary matrix
 $SU(3)_L$

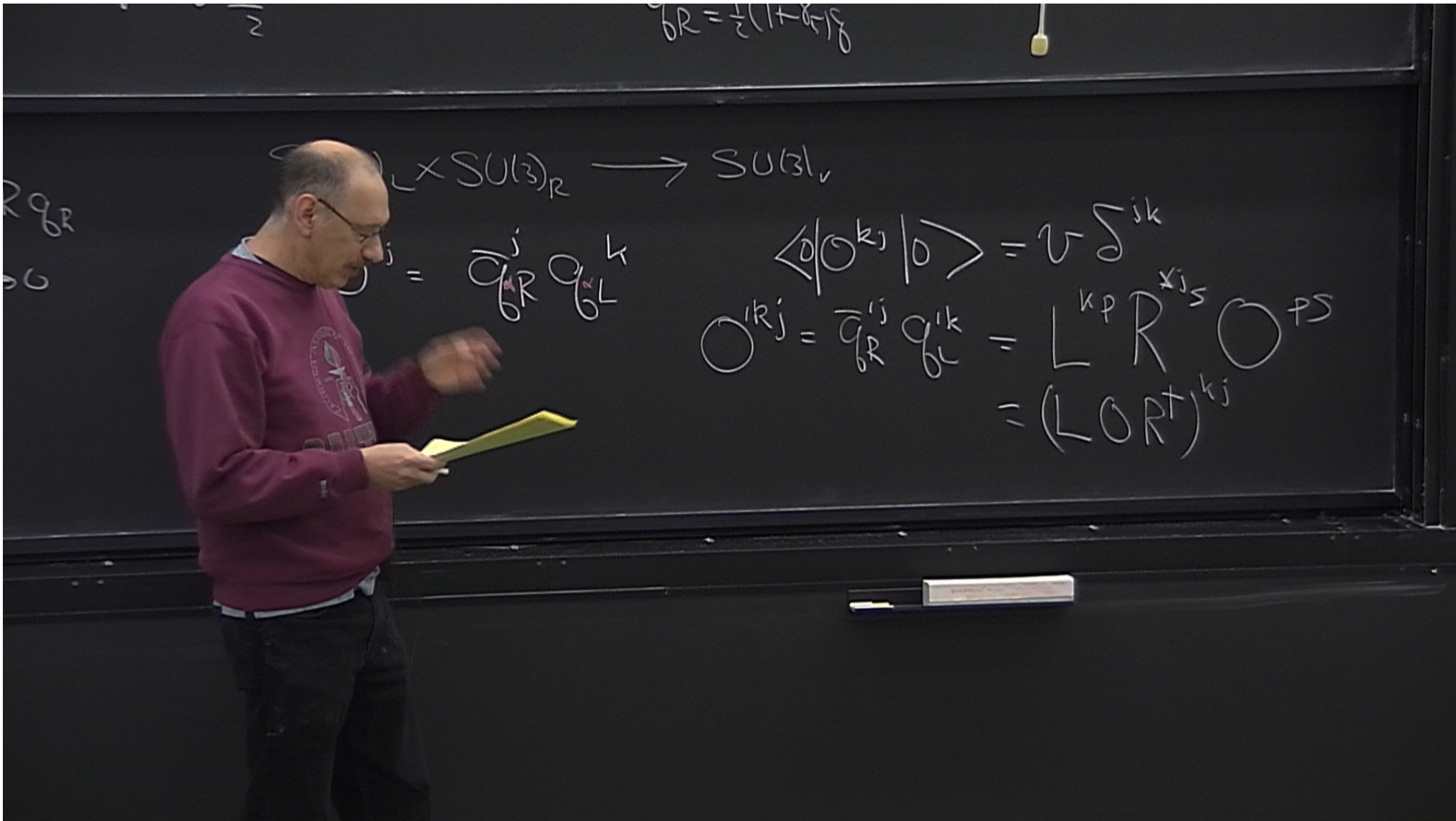
In limit $m_c \rightarrow 0$

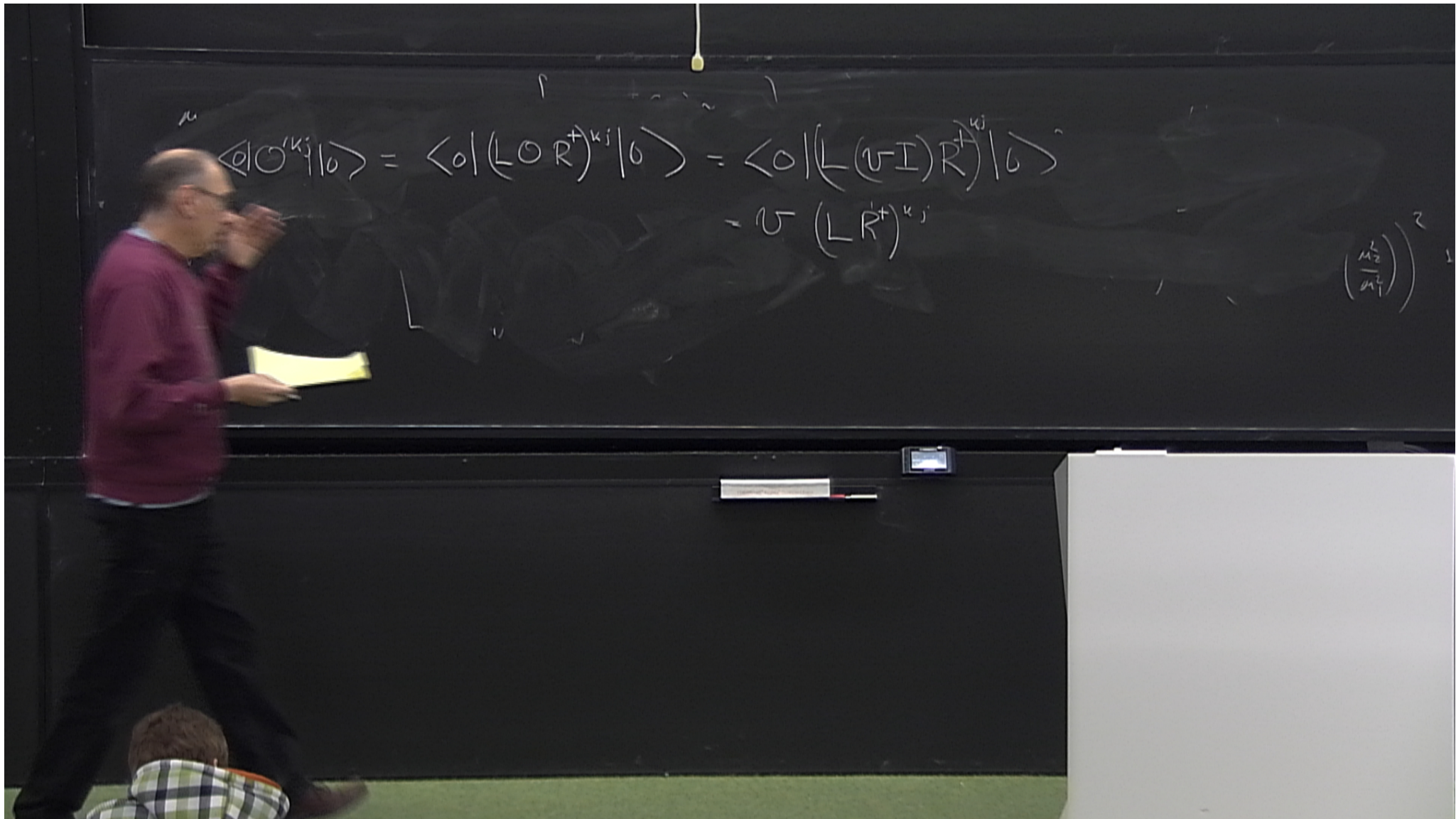
$$SU(3)_L \times SU(3)_R$$

$$SU(3)_L \times SU(3)_R \longrightarrow SU(3)_V$$









$$\langle 0 | O^{kj} | 0 \rangle = \langle 0 | (L O R^+)^{kj} | 0 \rangle = \langle 0 | (L (U I) R^+)^{kj} | 0 \rangle \\ = U (L R^+)^{kj}$$

$$\left(\frac{M_2}{M_1} \right)^2$$

$$\langle 0 | O^{kj} | 0 \rangle = \langle 0 | (L O R^\dagger)^{kj} | 0 \rangle = \langle 0 | (L (U I) R^\dagger)^{kj} | 0 \rangle$$

$$= U (L R^\dagger)^{kj}$$

$$\langle 0 | O^{kj} | 0 \rangle = U \delta^{kj}$$

$$\left(\frac{M_2}{M_1} \right)^2$$

$$\langle 0 | O^{kj} | 0 \rangle = \langle 0 | (L O R^\dagger)^{kj} | 0 \rangle = \langle 0 | (L (U I) R^\dagger)^{kj} | 0 \rangle$$

$$\langle 0 | O^{kj} | 0 \rangle = U \delta^{kj} \quad SU(3)_L \times SU(3)_R \rightarrow SU(3)_V \quad U (L R^\dagger)^{kj}$$

$$\left(\frac{M_2}{M_1} \right)^2$$

$$\begin{aligned}
 \langle 0 | O^{ij} | 0 \rangle &= \langle 0 | (L O R^\dagger)^{ij} | 0 \rangle = \langle 0 | (L (U I) R^\dagger)^{ij} | 0 \rangle \\
 \langle 0 | O^{ij} | 0 \rangle &= U \delta^{ij} \quad \quad \quad SU(3)_L \times SU(3)_R \rightarrow SU(3)_V \quad \quad \quad U (L R^\dagger)^{ij} \\
 O^{ij} &\rightarrow U \sum_k (x) \\
 &\rightarrow \Sigma' = L \Sigma R^\dagger
 \end{aligned}$$

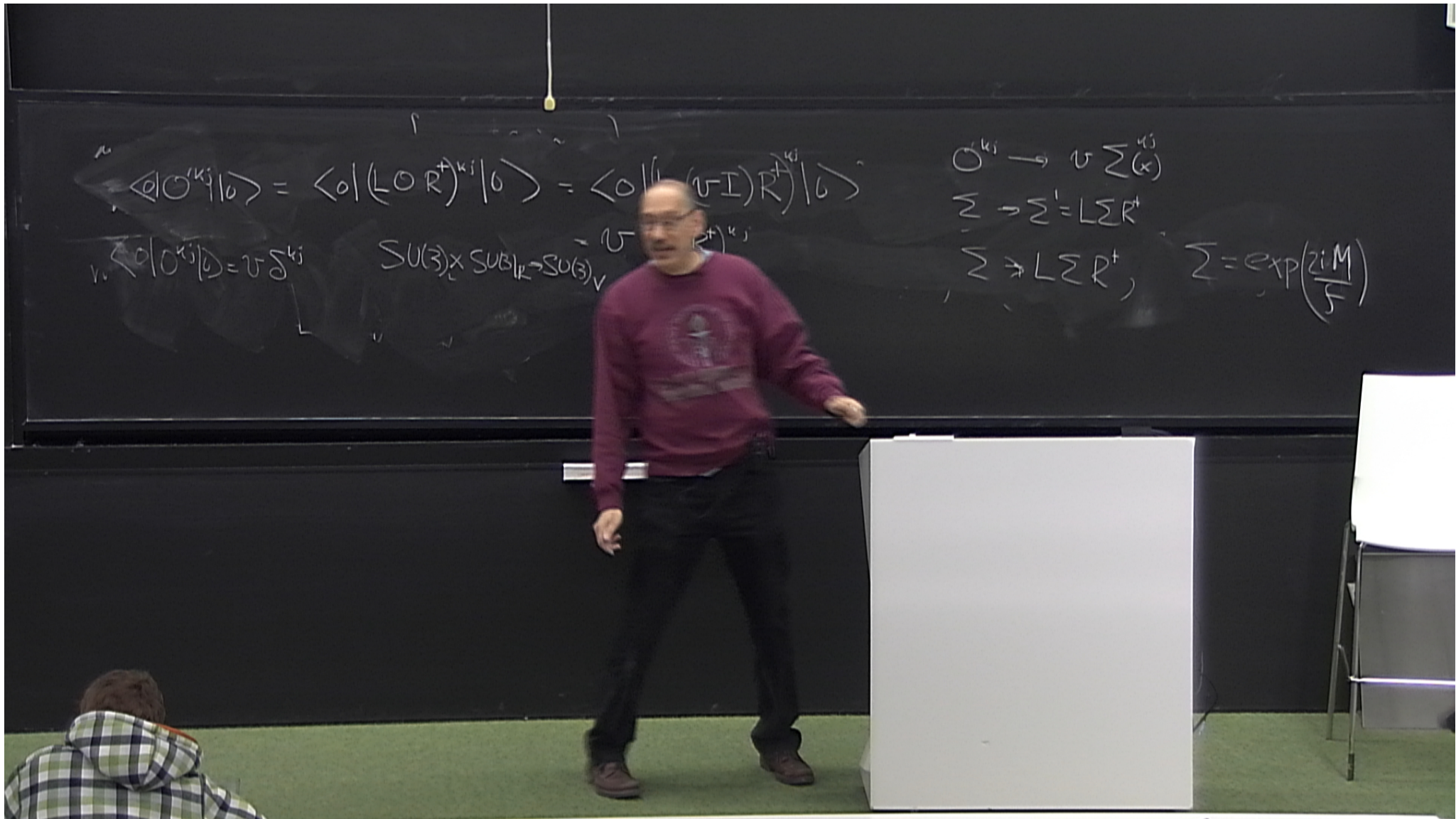
$$\langle 0 | 0 \rangle = \langle 0 | (L R^\dagger)^{k_j} | 0 \rangle = \langle 0 | (L (U I) R^\dagger)^{k_j} | 0 \rangle$$

$$U = U \delta^{k_j} \quad SU(3)_L \times SU(3)_R \rightarrow SU(3)_V \quad U (L R^\dagger)^{k_j}$$

$$O^{k_j} \rightarrow U \Sigma^{k_j}$$

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

$$\Sigma \rightarrow L \Sigma R^\dagger, \quad \Sigma = \exp\left(\frac{2iM}{f}\right)$$



$$\langle 0 | O^{ij} | 0 \rangle = \langle 0 | (L O R^\dagger)^{ij} | 0 \rangle = \langle 0 | (U I) R^\dagger | 0 \rangle$$

$$\langle 0 | O^{ij} | 0 \rangle = U \delta^{ij}$$

$$SU(3)_L \times SU(3)_R \rightarrow SU(3)_V$$

$$O^{ij} \rightarrow U \Sigma^{ij}$$

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

$$\Sigma \rightarrow L \Sigma R^\dagger, \quad \Sigma = \exp\left(\frac{2iM}{f}\right)$$

$$v \langle 0 | \phi^{ij} | 0 \rangle = v \delta^{ij}$$

$$SU(3)_L \times SU(3)_R \rightarrow SU(3)_V$$

$$= U (L R^\dagger)^{ij}$$

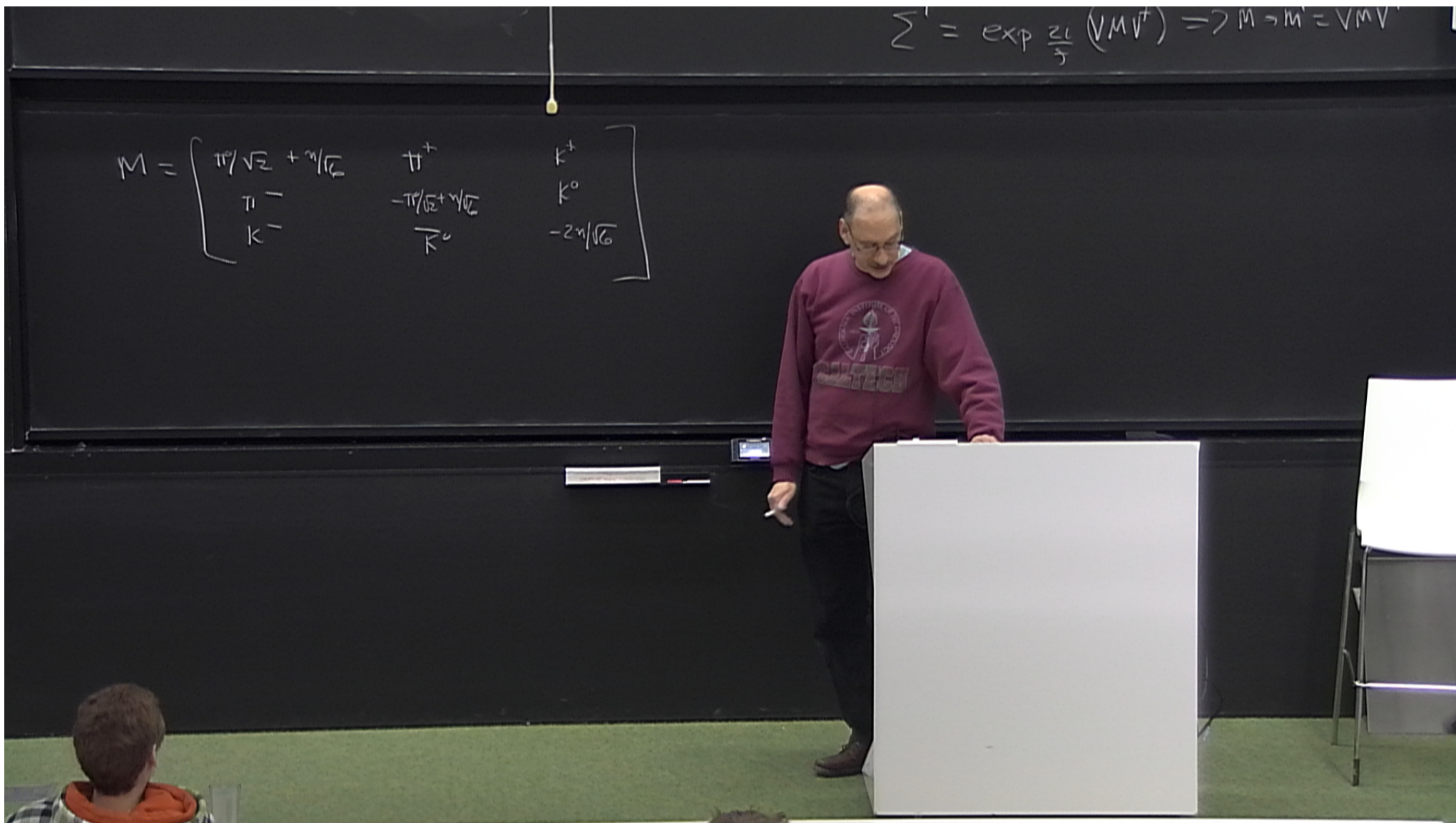
$$L=R=V$$

$$\Sigma \rightarrow \Sigma' = V \Sigma V^\dagger$$

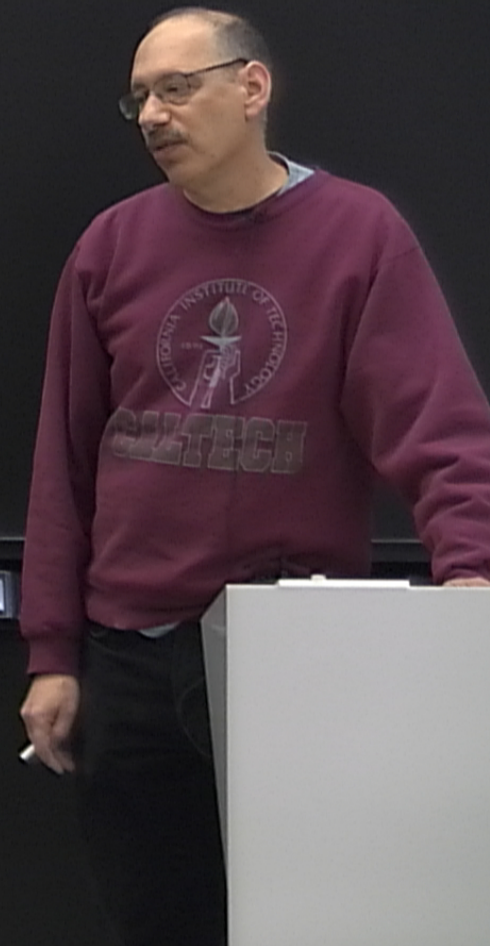
$$\Sigma' = \exp \frac{2i}{f} (VMV^\dagger) \Rightarrow M \rightarrow M' = VMV^\dagger$$

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

$$\Sigma \rightarrow L \Sigma R^\dagger, \quad \Sigma = \exp \left(\frac{2iM}{f} \right)$$



$$M = \begin{bmatrix} \pi^0/\sqrt{2} + \eta/\sqrt{6} & \pi^+ & K^+ \\ \pi^- & -\pi^0/\sqrt{2} + \eta/\sqrt{6} & K^0 \\ K^- & \bar{K}^0 & -2\eta/\sqrt{6} \end{bmatrix}$$



$$\left[\begin{array}{c} k^+ \\ k^0 \\ -2n/\sqrt{6} \end{array} \right]$$

$$\text{Tr } \Sigma^+ \Sigma$$

$$\begin{aligned} \rightarrow \text{Tr } \Sigma'^+ \Sigma' &= \text{Tr } (L \Sigma R)^+ L \Sigma R \\ &= \text{Tr } R^+ \Sigma^+ \cancel{L^+} \overset{4}{L} \Sigma R \\ &= \text{Tr } \Sigma^+ \Sigma = 3 \end{aligned}$$

$$\begin{bmatrix} k^+ \\ k^0 \\ -2n/\sqrt{6} \end{bmatrix}$$

$$\text{Tr } \Sigma^+ \Sigma$$

$$\begin{aligned} \rightarrow \text{Tr } \Sigma'^+ \Sigma' &= \text{Tr } (L \Sigma R)^+ L \Sigma R \\ &= \text{Tr } R^+ \Sigma^+ \cancel{L^+ L} \Sigma R \\ &= \text{Tr } \Sigma^+ \Sigma = 3 \end{aligned}$$

$$M = \begin{bmatrix} \pi^0/\sqrt{2} + \eta/\sqrt{6} & \pi^+ & K^+ \\ \pi^- & -\pi^0/\sqrt{2} + \eta/\sqrt{6} & K^0 \\ K^- & \bar{K}^0 & -2\eta/\sqrt{6} \end{bmatrix}$$

$$\mathcal{L} = \frac{f^2}{2} \text{Tr} \partial_\mu \Sigma^+ \partial^\mu \Sigma + \dots$$

$$\text{Tr} \Sigma^+ \Sigma \rightarrow \text{Tr} \Sigma^{1+} \Sigma^1 =$$

$$M = \begin{bmatrix} \pi^0/\sqrt{2} + \eta/\sqrt{6} & \pi^+ & K^+ \\ \pi^- & -\pi^0/\sqrt{2} + \eta/\sqrt{6} & K^0 \\ K^- & \bar{K}^0 & -2\eta/\sqrt{6} \end{bmatrix}$$

$$\text{Tr} \Sigma^+ \Sigma \rightarrow \text{Tr} \Sigma^{I+} \Sigma^I =$$

$$\mathcal{L} = \frac{f^2}{2} \text{Tr} \partial_\mu \Sigma^+ \partial^\mu \Sigma + \dots \leftarrow \text{more derivs}$$