

Title: 12/13 PSI - Beyond the Standard Model Lecture 11

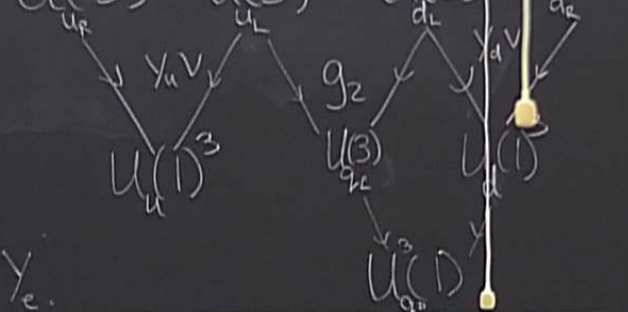
Date: Mar 05, 2013 09:00 AM

URL: <http://pirsa.org/13030034>

Abstract:

# Approximate Symmetries of SM

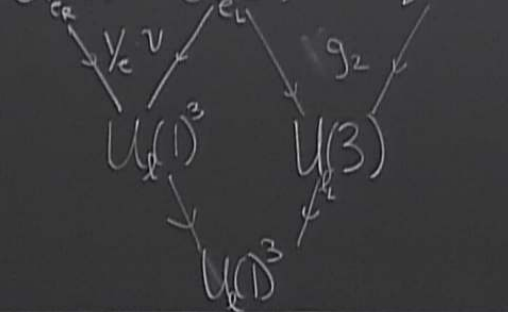
$$U(3) \times U(3) \times U(3) \times U(3)$$



$$Y_d + g_2^+ + Y_e$$

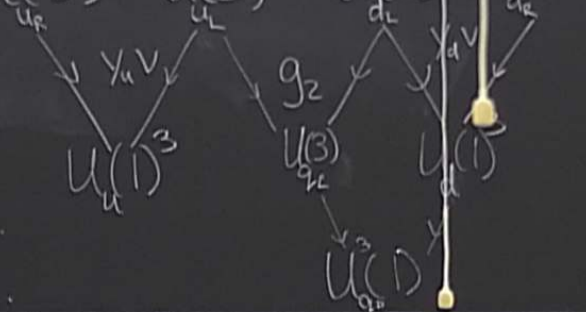
( $Y_{u,d,e}$  and  $g_2^+ \rightarrow 0$ )

$$U(3) \times U(3) \times U_2(3)$$



# Approximate Symmetries of SM

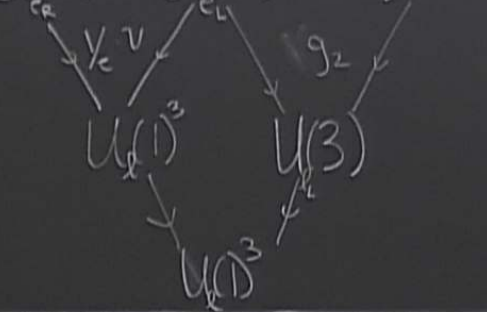
$$U(3) \times U(3) \times U(3) \times U(3)$$



$$Y_d + g_2^+ + Y_e$$

( $Y_{u,d,e}$  and  $g_2^+ \rightarrow 0$ )

$$U(3) \times U(3) \times U_2(3)$$

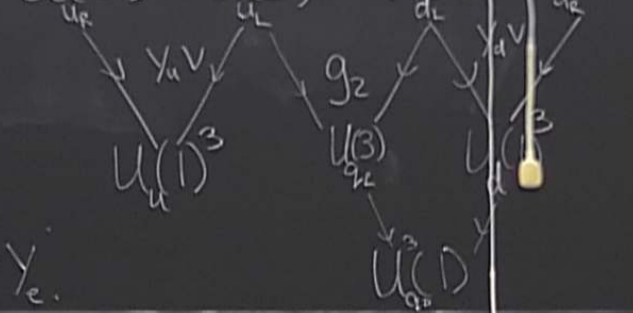


$$C_{SM} \ll \frac{g_2^2}{M_W^2}, \text{ look for } C_{BSM} \gg C_{SM} \sim \frac{g_2^2}{M_W^2}$$



Approximate symmetries of SM

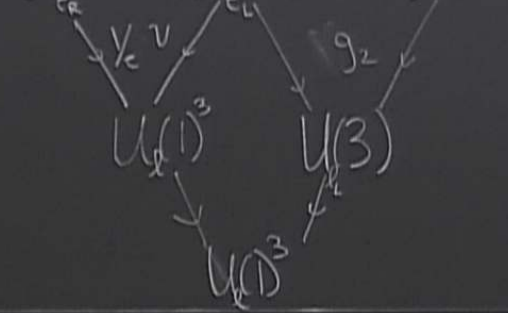
$$U(3) \times U(3) \times U(3) \times U(3)$$



$$Y_d + g_2 + Y_e$$

( $Y_{u,d,e}$  and  $g_2$ )

$$U(3) \times U(3) \times U_{\nu}(3)$$

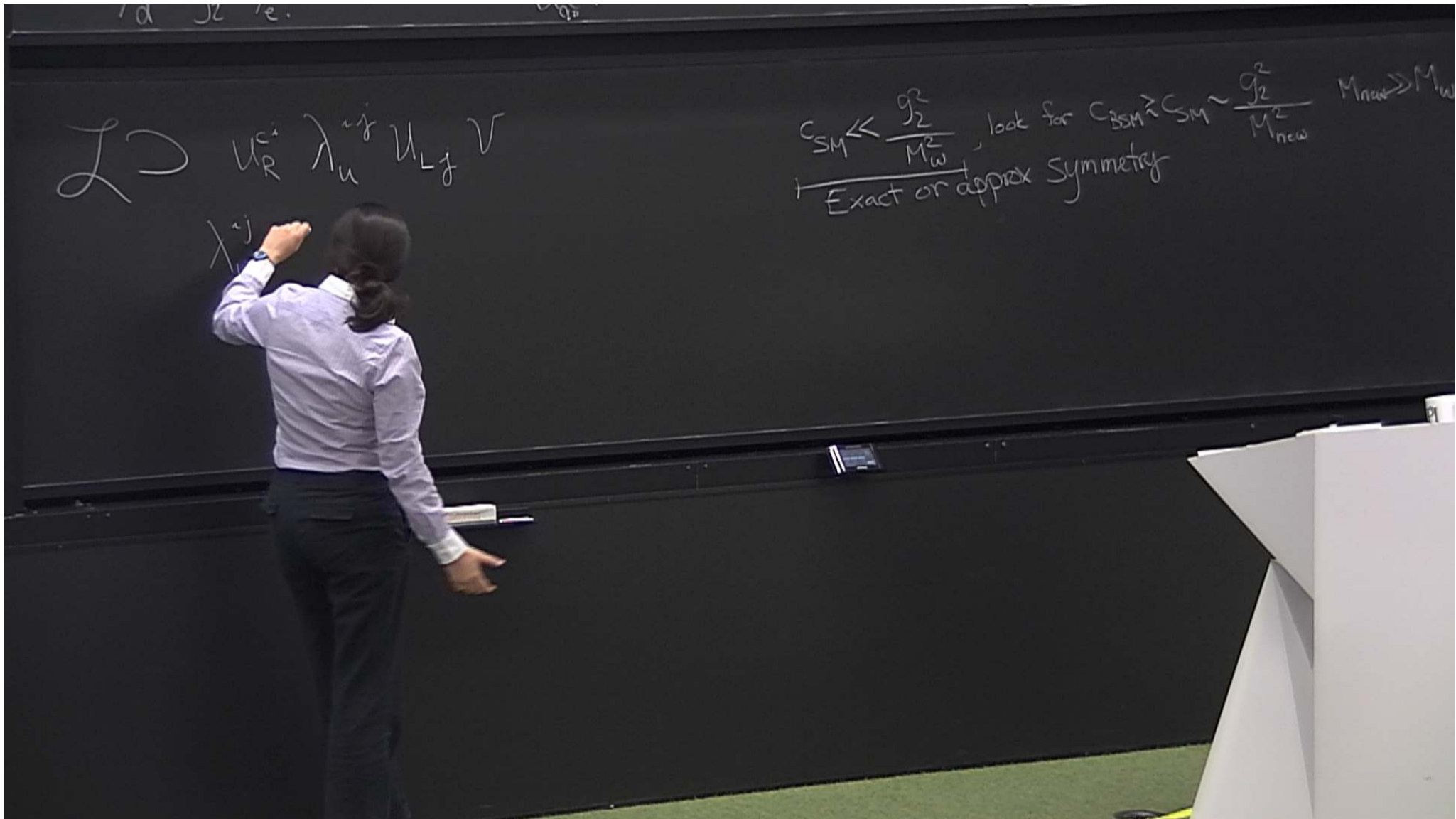


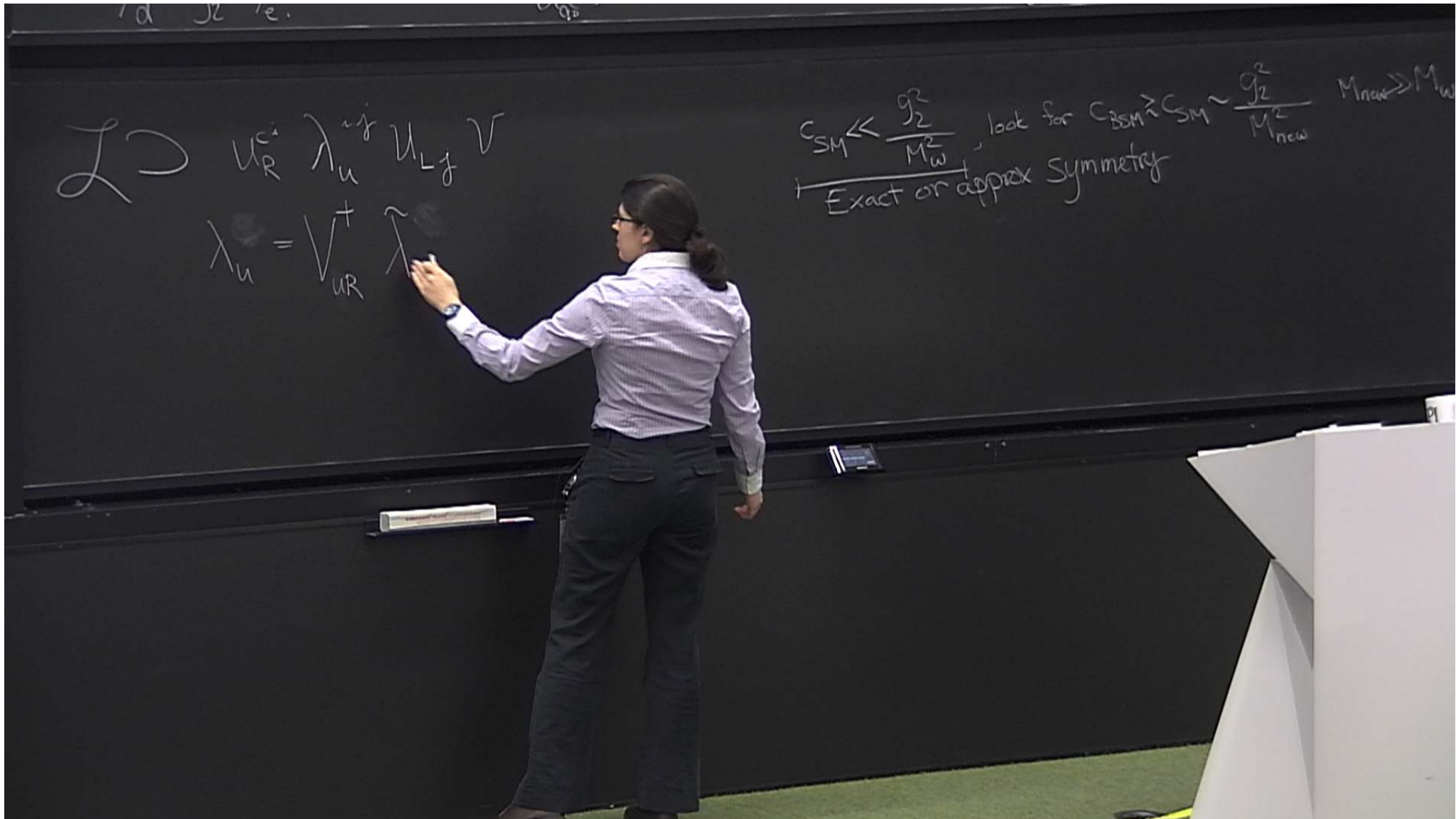
$$C_{SM} \leftarrow \frac{g_2^2}{M_W^2}, \text{ look for } C_{BSM} \rightarrow C_{SM} \sim \frac{g_2^2}{M_{new}^2} \quad M_{new} \rightarrow M_W$$



$C_{SM} \ll \frac{g_2^2}{M_W^2}$ , look for  $C_{BSM} \gtrsim C_{SM} \sim \frac{g_2^2}{M_{new}^2}$   $M_{new} \rightarrow M_W$   
Exact or approx symmetry



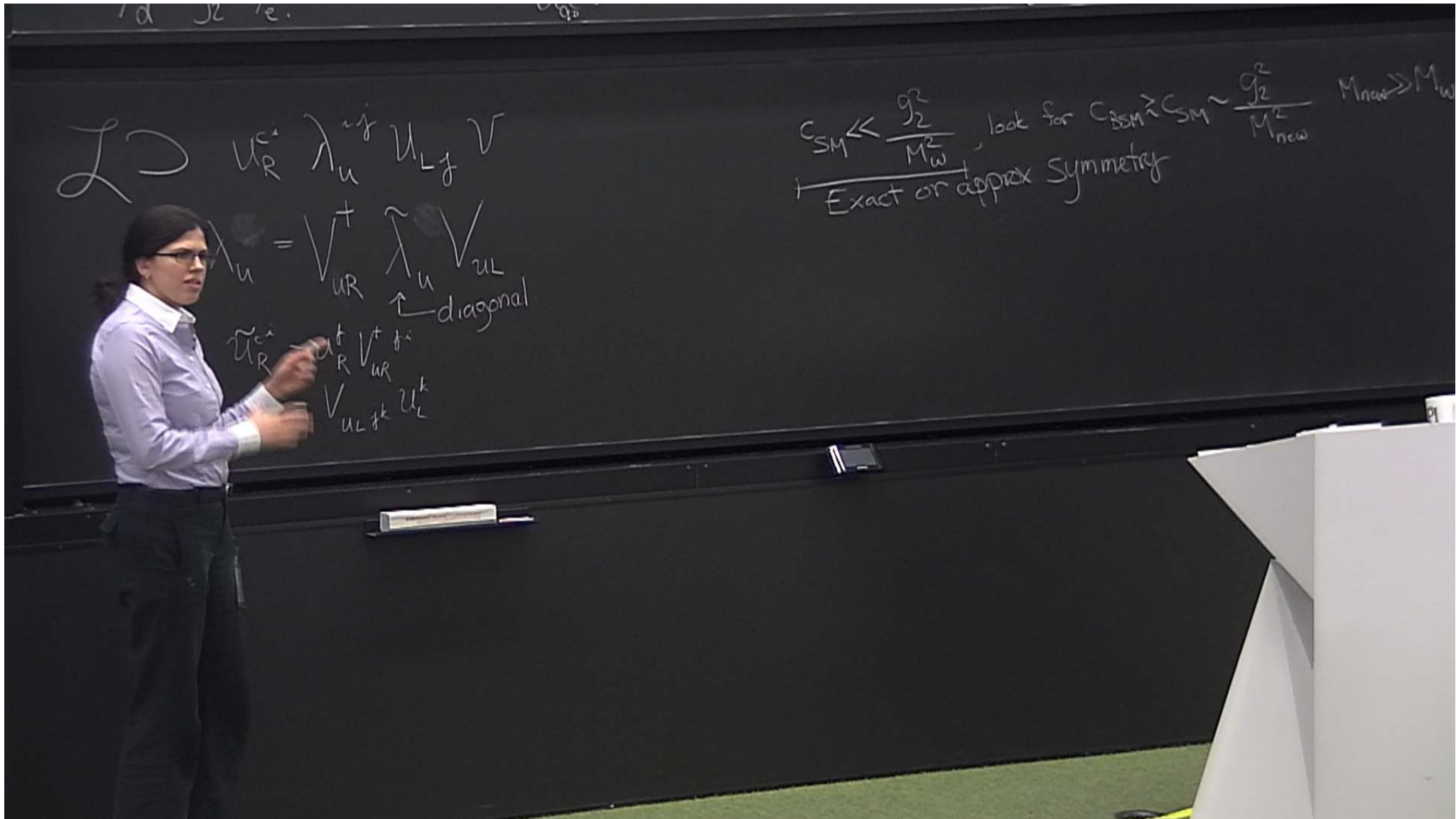




$$\mathcal{L} \supset U_R^c \lambda_{ij} U_{Lj} V$$
$$\lambda_{ij} = V_{UR}^\dagger \tilde{\lambda}_{ij}$$

$$c_{SM} \ll \frac{g_2^2}{M_W^2}, \text{ look for } c_{BSM} \rightarrow c_{SM} \sim \frac{g_2^2}{M_{new}^2} \quad M_{new} \rightarrow M_W$$

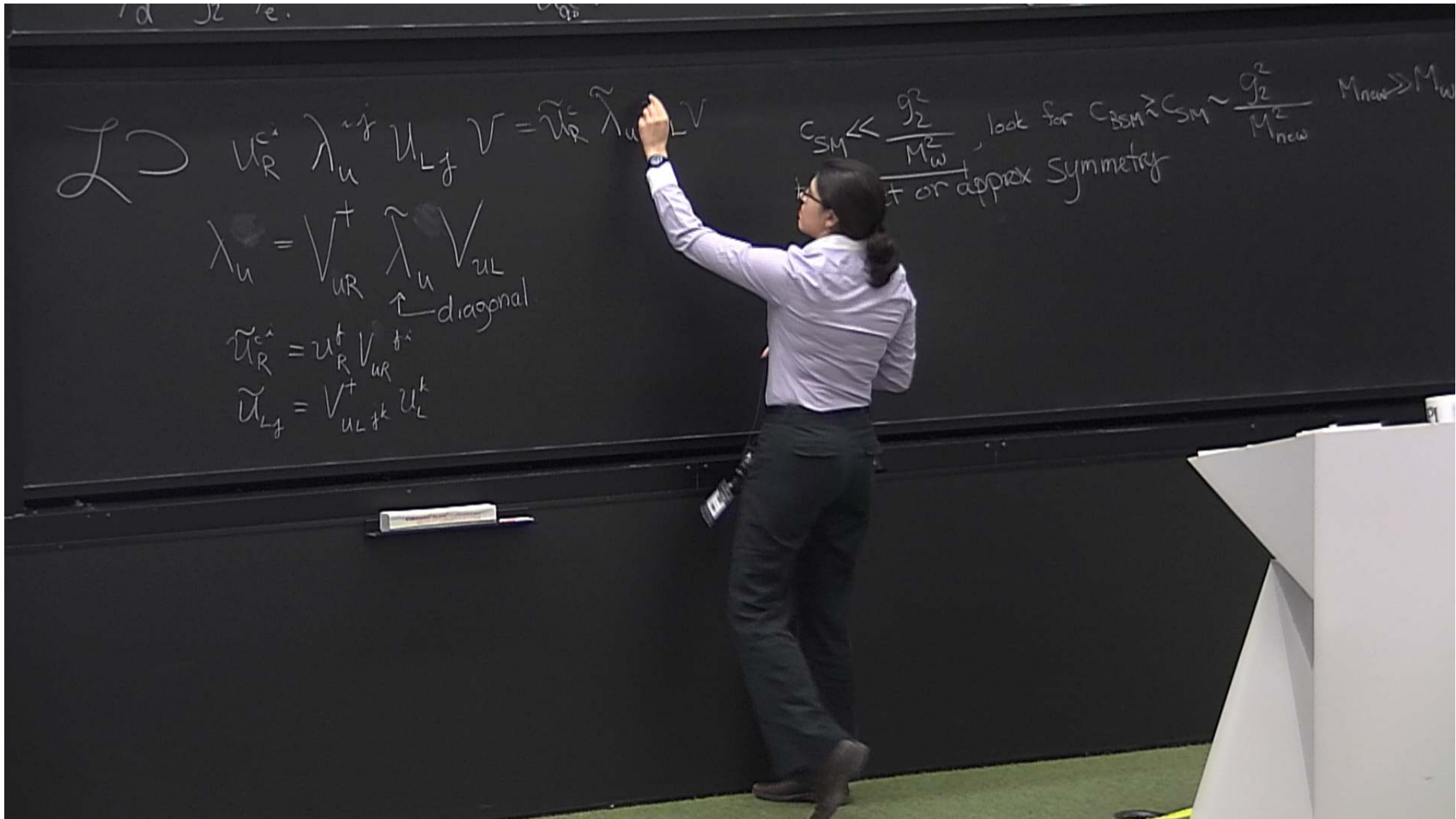
Exact or approx Symmetry



$$\begin{aligned}
 & \mathcal{L} \supset U_R^c \lambda_{ij} U_L^j V \\
 & = V_{UR}^\dagger \tilde{\lambda}_{ij} V_{UL} \\
 & \tilde{\lambda}_{ij} = \lambda_{ij} + \text{diagonal} \\
 & U_R^c = V_{UR}^\dagger U_L^k \\
 & V_{UL} \dagger U_L^k
 \end{aligned}$$

$$C_{SM} \ll \frac{g_2^2}{M_W^2}, \text{ look for } C_{BSM} \rightarrow C_{SM} \sim \frac{g_2^2}{M_{new}^2} \quad M_{new} \rightarrow M_W$$

Exact or approx Symmetry



$\mathcal{L} \supset U_R^c \lambda_u U_L + V = \tilde{U}_R^c \tilde{\lambda}_u \tilde{U}_L + V$   
 $\lambda_u = V_{UR}^\dagger \tilde{\lambda}_u V_{UL}$   
 $\tilde{U}_R^c = U_R^c V_{UR}^\dagger$   
 $\tilde{U}_L = V_{UL}^\dagger U_L$

Mass eigenbasis  
 Mass eigenstates  
 diagonal

$C_{SM} \ll \frac{g_2^2}{M_{new}^2}$ , look for  $C_{BSM} \rightarrow C_{SM} \sim \frac{g_2^2}{M_{new}^2}$   $M_{new} \rightarrow M_{W}$   
 Exact or approx Symmetry

$L$

$$U_R^c \lambda_u U_L^j \quad V = \tilde{V}_R^c \tilde{\lambda}_u \tilde{U}_L^j$$

$$\lambda_u = V_{UR}^\dagger \tilde{\lambda}_u V_{UL}$$

$$\tilde{U}_R^c = U_R^\dagger V_{UR}^\dagger$$

$$\tilde{U}_L^j = V_{UL}^\dagger U_L^k$$

Mass eigenstate basis

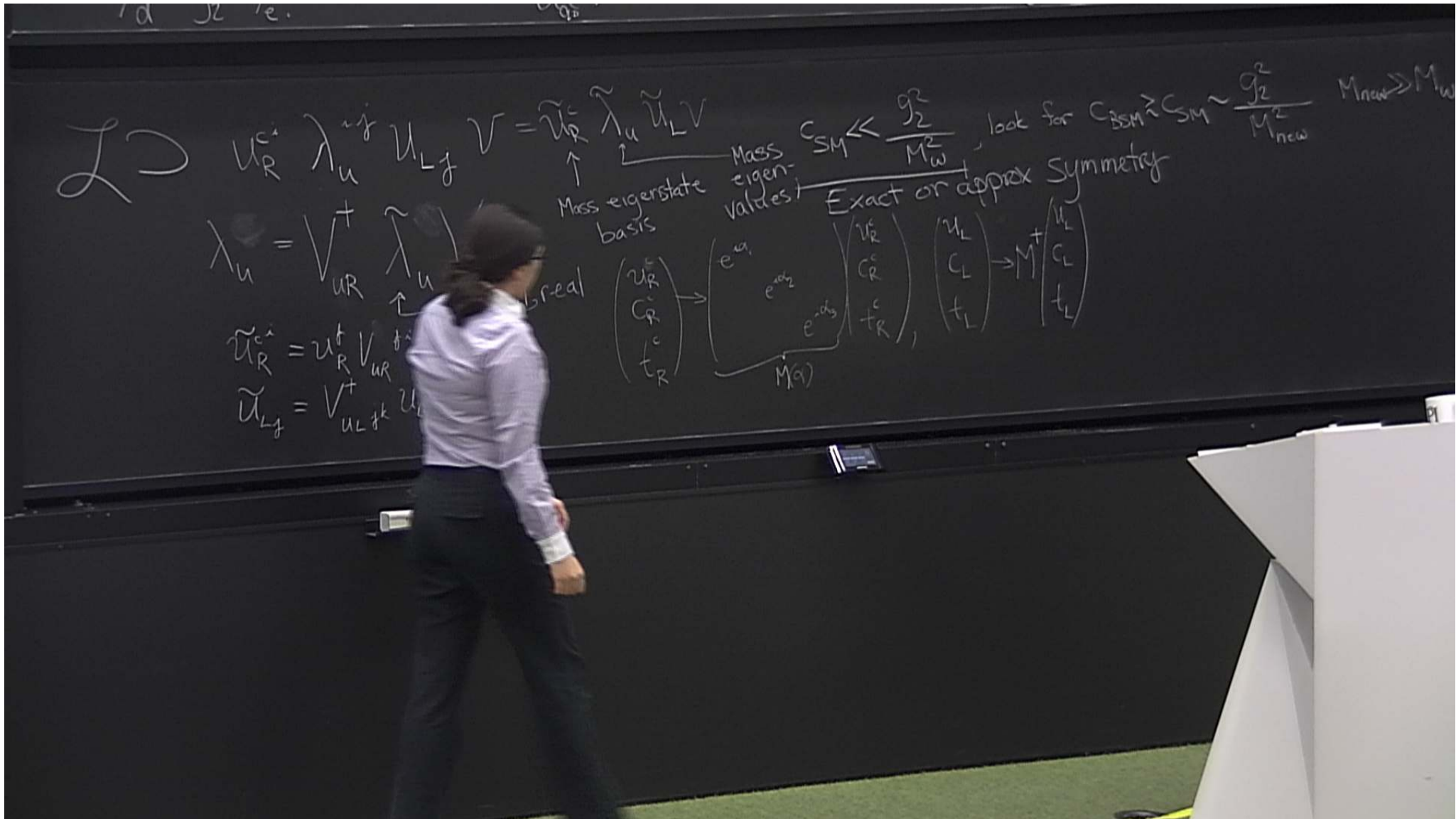
$$\begin{pmatrix} \tilde{u}_R^c \\ \tilde{c}_R \\ \tilde{t}_R \end{pmatrix} \rightarrow \begin{pmatrix} e^{i\alpha_1} \\ e^{i\alpha_2} \\ e^{i\alpha_3} \end{pmatrix} \begin{pmatrix} \tilde{V}_R^c \\ \tilde{C}_R \\ \tilde{T}_R \end{pmatrix}$$

Mass eigenvalues

$C_{SM} \ll \frac{g_2^2}{M_W^2}$ , look for  $C_{BSM} \rightarrow C_{SM} \sim \frac{g_2^2}{M_{new}^2}$   $M_{new} \rightarrow M_W$

Exact or approx Symmetry





$\mathcal{L} \supset \bar{u}_R^i \lambda_{ij} u_{Lj} + \bar{u}_R^c \tilde{\lambda}_u \tilde{u}_L V$   
 $V = \tilde{u}_R^c \tilde{\lambda}_u \tilde{u}_L V$   
 Mass eigenstate basis  
 $\lambda_u = V_{UR}^\dagger \tilde{\lambda}_u V_{UL}$   
 $\tilde{u}_R^c = U_R^\dagger V_{UR} \tilde{u}_R^c$   
 $\tilde{u}_{Lj} = V_{UL}^\dagger \tilde{u}_{Lj}$   
 $\begin{pmatrix} u_R^c \\ c_R^c \\ t_R^c \end{pmatrix} \rightarrow \begin{pmatrix} e^{i\alpha_1} \\ e^{i\alpha_2} \\ e^{i\alpha_3} \end{pmatrix} \begin{pmatrix} u_R^c \\ c_R^c \\ t_R^c \end{pmatrix}, \begin{pmatrix} u_L \\ c_L \\ t_L \end{pmatrix} \rightarrow M^\dagger \begin{pmatrix} u_L \\ c_L \\ t_L \end{pmatrix}$   
 $C_{SM} \ll \frac{g_2^2}{M_W^2}$ , look for  $C_{BSM} \rightarrow C_{SM} \sim \frac{g_2^2}{M_{new}^2}$   $M_{new} \rightarrow M_W$   
 Exact or approx Symmetry

9 re + 9 phases  $\longrightarrow$  3 physical reals



9 re + 9 phases  $\longrightarrow$  3 physical reals

$$U(3)_R \times U(3)_L \longrightarrow U(1)^3$$

9 gens      9 gens      3 gen.

9 re + 9 phases  $\longrightarrow$  3 physical reals

$$U(3)_{U_R} \times U(3)_{U_L} \longrightarrow U(1)^3$$

9 gens  $\quad$  9 gens  $\longrightarrow$  3 gen.

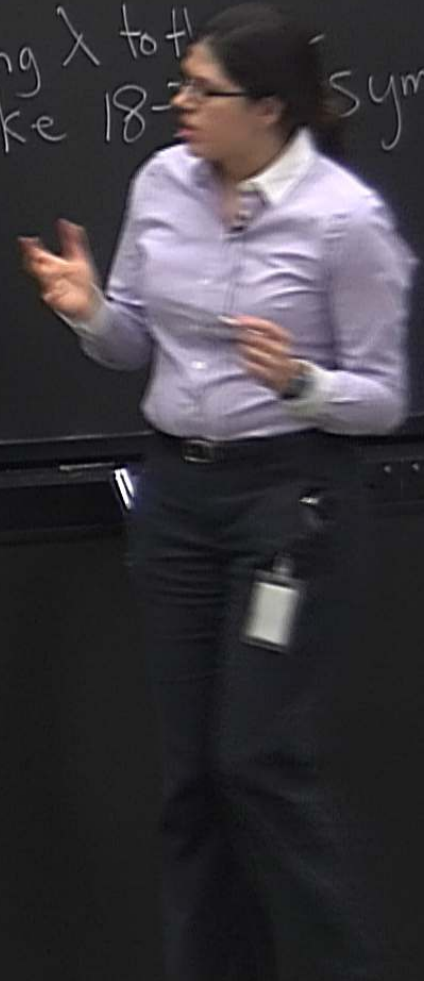
Adding  $\lambda$  to theory  
broke

9 re + 9 phases  $\xrightarrow{15 \text{ broken sym}}$  3 physical reals

$$U(3)_{U_R} \times U(3)_{U_L} \longrightarrow U(1)^3$$

9 gens      9 gens  $\longrightarrow$  3 gen.

Adding  $\lambda$  to H  
broke 18-7 symmetries



9 re + 9 phases  $\xrightarrow{15 \text{ broken sym}}$  3 physical reals

$$U(3)_{u_R} \times U(3)_{u_L} \longrightarrow U(1)^3$$

9 gens      9 gens  $\longrightarrow$  3 gen.

Adding  $\lambda$  to theory  
broke  $18-3=15$  symmetries

$$U = e^{iH}$$

9 re + 9 phases  $\xrightarrow{15 \text{ broken sym}}$  3 physical reals

$$U(3)_{u_R} \times U(3)_{u_L} \longrightarrow U(1)^3$$

9 gens  $\quad$  9 gens  $\longrightarrow$  3 gen.

$$iH = H \begin{pmatrix} r & r+i & r+i \\ & r & r+i \\ & & r \end{pmatrix}$$

Adding  $\lambda$  to theory  
broke  $18-3=15$  symmetries

9 re + 9 phases  $\xrightarrow{15 \text{ broken sym}}$  3 physical reals

$$\begin{matrix} 6\phi, 3r \\ U(3) \end{matrix} \times \begin{matrix} 6\phi, 3r \\ U(3) \end{matrix} \longrightarrow U(1)^3$$

9 gens  $\longrightarrow$  3 gen.

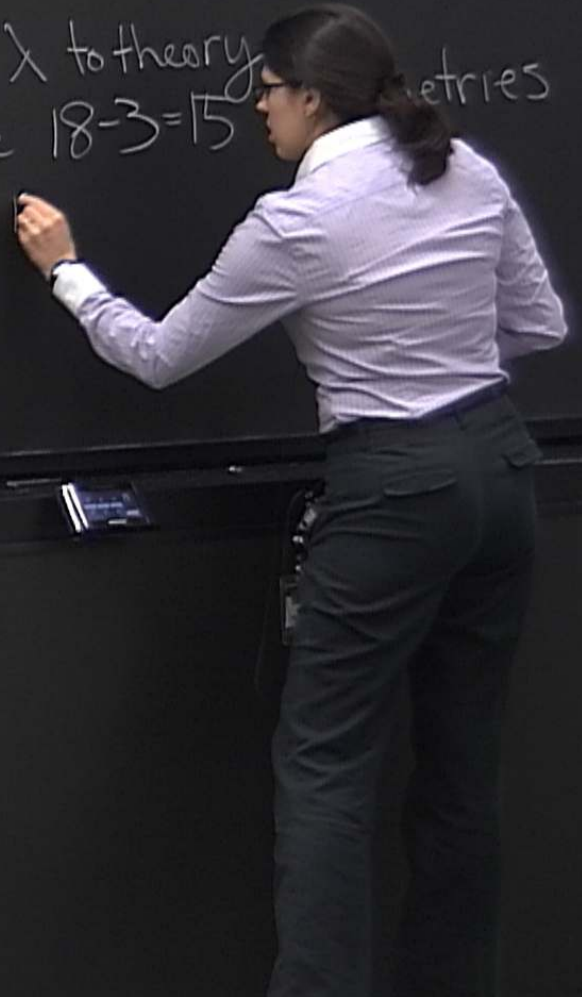
$$U = e^{iH} H \begin{pmatrix} r & r+i & r+i \\ & r & r+i \\ & & r \end{pmatrix} \rightarrow 6 \text{ re} + 3 \text{ im params.}$$

Removes 6 phases, 3 reals.

Adding  $x$  +  $y$  symmetries

$9 \text{ re} + 9 \text{ phases} \xrightarrow{15 \text{ broken sym}} 3 \text{ physical reals}$   
 $6\phi, 3r \quad 6\phi, 3re \quad \xrightarrow{\quad} \quad 3\phi, 3r$   
 $U(3) \times U(3) \xrightarrow{\quad} U(1)$   
 $U_R \quad U_L$   
 $9 \text{ gens} \quad 9 \text{ gens} \xrightarrow{\quad} 3 \text{ gen.}$   
 $U = e^{iH} H \begin{pmatrix} r & r+i & r+i \\ & r & r+i \\ & & r \end{pmatrix} \rightarrow 6 \text{ re} + 3 \text{ im params.}$   
 Removes 6 phases, 3 reals.

Adding  $\lambda$  to theory  
 broke  $18 - 3 = 15$  degrees of freedom



9 re + 9 phases  $\xrightarrow{15 \text{ broken sym}}$  3 physical reals

$$\begin{matrix} 6\phi, 3r \\ U(3) \\ U_R \end{matrix} \times \begin{matrix} 6\phi, 3r \\ U(3) \\ U_L \end{matrix} \longrightarrow \begin{matrix} 3\phi, 3 \\ U(1) \end{matrix}$$

9 gens      9 gens  $\longrightarrow$  3 gen.

$$U = e^{iH} H \begin{pmatrix} r & r+i & r+i \\ & r & r+i \\ & & r \end{pmatrix} \rightarrow 6 \text{ re} + 3 \text{ im params.}$$

Removes 6 phases, 3 reals.

Adding  $\lambda$  to theory  
broke  $18 - 3 = 15$  symmetries  
 $9 = 12 - 3$  rephasings  
6 real rotations

Interesting ops.  $(\bar{s}_L \sigma^\mu d_L)^2$

$(\bar{u}_R^c e_R^c)(\bar{e}_R^c \bar{e}_R^c)$   
↓  
 $U(1)$  charge  $1 \neq 0$   
 $\Rightarrow$  not in SM.

Interesting ops

$$(\bar{S}_L \sigma^\mu d_L)^2$$

$U(1)$  charge  $-2 \neq 0$   
 $\Rightarrow$  Not in SM... Yet!  
 $(Y_{1/2}, g_2)$  or  $(Y_{1/2}, g_2)$

$$(\bar{u}_R^c e_R^c)(\bar{e}_R^c \bar{e}_R^c)$$

$U(1)$  charge  $1 \neq 0$   
 $\Rightarrow$  not in SM.

$L \supset \bar{u}_R^c \lambda_u u_L + \bar{u}_L V = \bar{u}_R^c \lambda_u u_L V$   
 $\lambda_u = V_{UR}^\dagger \lambda_u V_{UL}$  (diagonal, real)  
 $\tilde{u}_R^c = u_R^\dagger V_{UR}^\dagger$   
 $\tilde{u}_L = V_{UL}^\dagger u_L^c$

Mass eigenstate basis  $\begin{pmatrix} u \\ c \\ t \end{pmatrix}$   
 Mass eigenvalues  $\begin{pmatrix} e^{i\phi_1} \\ e^{i\phi_2} \\ e^{i\phi_3} \end{pmatrix}$   
 CKM matrix  $\begin{pmatrix} V_{UR}^c \\ V_{UR}^c \\ V_{UR}^c \end{pmatrix}$   
 $C_{SM} \ll \frac{g_2^2}{M_W^2}$ , look for  $C_{BSM} \gtrsim C_{SM} \sim \frac{g_2^2}{M_{new}^2}$   
 Exact or approx Symmetry  $\begin{pmatrix} u_L \\ c_L \\ t_L \end{pmatrix} \rightarrow M^\dagger \begin{pmatrix} u_L \\ c_L \\ t_L \end{pmatrix}$   
 $M_{new} \rightarrow M_W$

9 re + 9 phases  $\xrightarrow{15 \text{ broken sym}}$  3 physical reals  
 $U(3)_{u_R} \times U(3)_{u_L} \rightarrow U(1)$   
 6  $\phi$ , 3 r  $\rightarrow$  3  $\phi$ , 3  
 9 gens  $\rightarrow$  3 gens  
 Adding  $\chi$  to theory  
 broke 18-3=15 symmetries  
 9=12-3 rephasings  
 6 real rotations  
 $U = e^{iH} H = \begin{pmatrix} r & r+i & r+i \\ r & r & r+i \\ r & r & r \end{pmatrix} \rightarrow 6 \text{ re} + 3 \text{ im para}$   
 Removes 6 phase

$(\psi_{R^c}^c) (\bar{\psi}_{R^c}^c)$   
 $\downarrow$   
U(1) charge  $1 \neq 0$   
 $\Rightarrow$  not in SM.

$\psi_u, \psi_d$

$U(3)_{\text{quarks}}^4$

$\rightarrow$

$U(1)_u^3 \times U(1)_d^3$   
 $\downarrow$  up mass eigenstates  
 $\downarrow$  down mass eigenstates

$(\bar{u}_R^c e_R^c)(\bar{e}_R^c e_R^c)$   
 $\downarrow$   
 $U(1)$  charge 1  $\neq 0$   
 $\Rightarrow$  not in SM.

$\gamma_u, \gamma_d$

$U(3)$   
quarks

$\rightarrow U(1)^3 \times U(1)^3$

$u$   
up mass eigenstates

$d$   
down mass eigenstates

$$g_2 W_\mu^+ \bar{u}_L^i \bar{\sigma}_\mu d_L^j \delta_{ij} + h.c.$$

$$g_2 W_\mu^+ \bar{\tilde{u}}_L V_u^+ \delta V_d \bar{\sigma}_\mu \tilde{d}_L$$

$$\tilde{u}_L = V_{uL}^+ u_L$$

$$\bar{u}_L = \bar{\tilde{u}}_L V^+$$

$$\tilde{d}_L = V_{dL}^+ d_L$$

$$d_L = V_{dL} d_L$$

U(1) charge  $\neq 0$   
 $\Rightarrow$  not in SM.

up mass  
 eigenstates

down  
 eigenstates

$$g_2 W_\mu^+ \bar{u}_L^\alpha \bar{\sigma}_\mu d_L^\beta \delta_{\alpha\beta} + h.c.$$

$$\tilde{u}_L = V_{u_L}^+ u_L$$

$$\bar{u}_L = \bar{u}_L V^+$$

$$g_2 W_\mu^+ \bar{u}_L V_{u_L}^+ \delta V_{d_L} \bar{\sigma}_\mu \tilde{d}_L$$

$(\mathbb{3}) \mathbb{3}, \bar{\mathbb{3}} \text{ of } U_d(\mathbb{3})$

$$\tilde{d}_L = V_{d_L}^+ d_L$$

$$d_L = V_{d_L} \tilde{d}_L$$



interesting ops

$$(\bar{5}_L \sigma^m d_L)^2$$

$U(1)$  charge  $-2 \neq 0$   
 $\Rightarrow$  Not in SM... Yet!  
 $(Y_u, g_2)$  or  $(Y_d, g_2)$

$$(\bar{u}_R^c e_R^c)(\bar{e}_R^c u_R^c)$$

$U(1)$  charge  $1 \neq 0$   
 $\Rightarrow$  not in SM.

$$Y_u, Y_d$$

$$U(3)_{\text{quarks}}$$

$$U(1)_u^3$$

up mass eigenstates

$$U(1)_d^3$$

down mass eigenstates

$$g_2 W_\mu^+ \bar{u}_L^i \sigma^m d_L^j \delta_{ij} + h.c.$$

$$g_2 W_\mu^+ \bar{u}_L V_{ud}^+ \delta V_d \sigma^m \tilde{d}_L$$

$U(3)_{3, \bar{3}} \text{ of } U_d(3)$

$$\tilde{u}_L = V_{uL}^+ u_L$$

$$\bar{u}_L = \bar{u}_L V^+$$

$$\tilde{d}_L = V_{dL}^+ d_L$$

$$d_L = V_{dL} d_L$$



$(\mathbf{3}, \bar{\mathbf{3}})$  of  $U_d(3)$

$V = V_u^\dagger S V_d$  unitary matrix 6 phases + 3 reals + 3 up masses, 3 down masses

$(\mathbf{3}, \bar{\mathbf{3}})$  of  $U_d(3)$

$$V = V_u^\dagger S V_d$$

unitary matrix

6 phases + 3 reals + 3 up masses, 3 down masses

$$\begin{matrix} e^{-i\alpha_1} & & & \\ & e^{-i\alpha_2} & & \\ & & e^{-i\alpha_3} & \\ & & & e^{-i\alpha_4} \end{matrix}$$



$\frac{1}{2} W_L \frac{1}{2} V_u \frac{1}{2} V_d \frac{1}{2} M \frac{1}{2} W_L$   
 $(\mathbf{3}, \mathbf{\bar{3}} \text{ of } U_d(3))$

$(V = V_u^\dagger \delta V_d \text{ unitary matrix } 6 \text{ phases} + 3 \text{ reals}) + 3 \text{ up masses, } 3 \text{ down masses.}$

1 unbroken  $U(1)$ :  $U(1)_B = \text{baryon \#}$  Equal rotation of every  $q$

5 broken  $U(1)'_s \rightarrow$  remove 5 phases, ( $V_{CKM} = 1 \text{ phase} \& 3 \text{ real nos}$ ) + 6 masses

$$V_{CKM} = \begin{pmatrix} & & \\ & & \\ & & \end{pmatrix}$$

$\begin{pmatrix} u \\ d \end{pmatrix}_L$   $\begin{pmatrix} u \\ d \end{pmatrix}_M$   $\begin{pmatrix} u \\ d \end{pmatrix}_R$   
 $\mathbb{1}(3), \mathbb{3}, \bar{3}$  of  $U_d(3)$

$(V = V_u^\dagger \delta V_d)$  unitary matrix (6 phases + 3 reals) + 3 up masses, 3 down masses.

1 unbroken  $U(1)$ :  $U(1)_B = \text{baryon \#}$  Equal rotation of every  $q$

5 broken  $U(1)'_s \rightarrow$  remove 5 phases, ( $V_{CKM} = 1$  phase & 3 real nos) + 6 masses  
 mixing angles  $\theta_{12}, \theta_{13}, \theta_{23}$

$$V_{CKM} = \begin{pmatrix} C_{12}C_{13} & S_{12}C_{13} & S_{13}e^{-i\delta} \\ \times & C_{12}C_{13} - S_{12}S_{13}e^{i\delta} & S_{12}C_{13} \\ \times & \times & C_{13}C_{13} \end{pmatrix} \approx \begin{pmatrix} 1 & \theta_{12} & \theta_{13}e^{-i\delta} \\ -\theta_{12} & 1 & \theta_{13} \\ -\theta_{13}e^{i\delta} & -\theta_{13} & 1 \end{pmatrix}$$

$(V = V_u^\dagger S V_d)$  unitary matrix 6 phases + 3 reals + 3 up masses, 3 down masses

1 unbroken  $U(1)$ :  $U(1)_B = \text{baryon \#}$ . Equal rotation of every  $q$

5 broken  $U(1)'_s \rightarrow$  remove 5 phases, ( $V_{CKM} = 1 \text{ phase} \& 3 \text{ real nos}$ ) + 6 masses

$$V_{CKM} = \begin{pmatrix} C_{12}C_{13} & S_{12}C_{13} & S_{13}e^{-i\delta} \\ \times & C_{12}C_{13} - S_{12}S_{13}e^{-i\delta} & S_{12}C_{13} \\ \times & \times & C_{13}C_{13} \end{pmatrix} \approx \begin{pmatrix} 1 & \theta_{12} & \theta_{13}e^{-i\delta} \\ -\theta_{12} & 1 & \theta_{23} \\ -\theta_{13}e^{i\delta} & -\theta_{23} & 1 \end{pmatrix}$$

$\theta_{12} \sim 0.2$   
 $\theta_{23} \sim 0.1$   
 $\theta_{13} \sim 0.01$

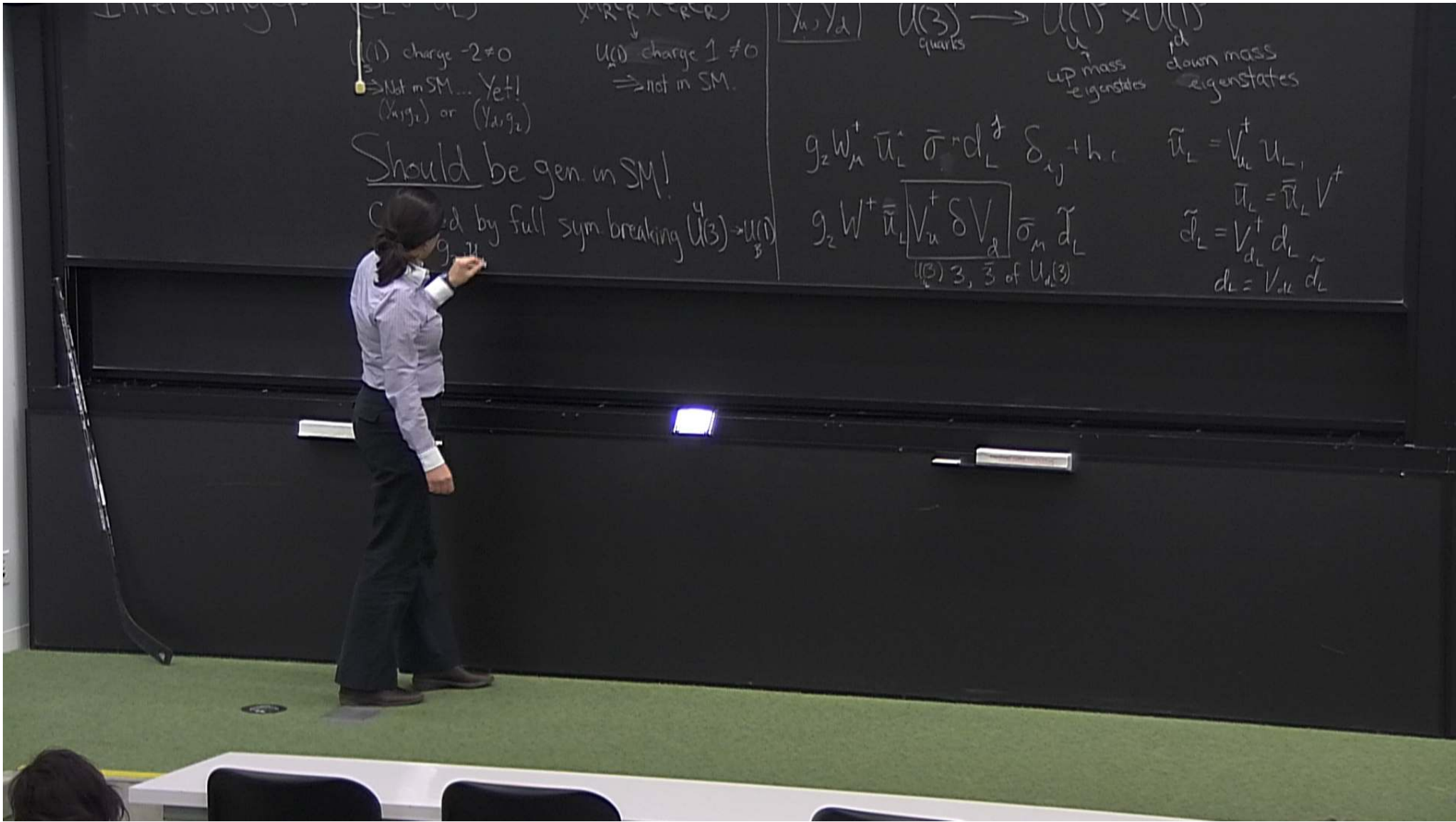
$(V = V_u^\dagger S V_d)$  unitary matrix 6 phases + 3 reals + 3 up masses, 3 down masses

1 unbroken  $U(1)$ :  $U(1)_B =$  baryon #. Equal rotation of every  $q$

5 broken  $U(1)'_s \rightarrow$  remove 5 phases, ( $V_{CKM} =$  1 phase & 3 real nos) + 6 masses

$$V_{CKM} = \begin{pmatrix} C_{12}C_{13} & S_{12}C_{13} & S_{13}e^{-i\delta} \\ \times & C_{12}C_{23} - S_{12}S_{23}e^{-i\delta} & S_{23}C_{12} \\ \times & \times & C_{23}C_{13} \end{pmatrix} \approx \begin{pmatrix} 1 & \theta_{12} & \theta_{13}e^{-i\delta} \\ -\theta_{12} & 1 & \theta_{23} \\ -\theta_{13}e^{i\delta} & -\theta_{23} & 1 \end{pmatrix}$$

$\theta_{12} \sim 0.2$   
 $\theta_{23} \sim 0.1$   
 $\theta_{13} \sim 0.01$



$K^0 \bar{K}^0$  mixing

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

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

$d_L$  creates LH d quarks.

$\bar{s}_L$  creates RH  $\bar{s}$  antiquarks

Ann. RH  $\bar{d}$  antiquarks

Ann. LH s quarks.

$$c \cdot (\bar{s}_L \bar{d}_L) \sim (\bar{s} \bar{d}) (s d)$$

$K^0 \bar{K}^0$  mixing

$K^0 \sim \frac{1}{\sqrt{2}}(u\bar{s} + d\bar{d})$

$d_L$  creates LH d quarks.

$\bar{s}_L$  creates RH  $\bar{s}$  antiqs

Ann. RH  $\bar{d}$  antiqs

Ann. LH s quarks.

$$c (\bar{s}_L \bar{d}_L)(d_L d_L) \sim (\bar{s} \bar{d})(s d)$$

$K^0 \bar{K}^0$  mixing

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

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

$d_L$  creates LH d quarks.

$\bar{s}_L$  creates RH  $\bar{s}$  antiqs

Ann. RH  $\bar{d}$  antiqs

Ann. LH s quarks.

$$c (\bar{s}_L \bar{d}_L)(d_L d_L) \sim (\bar{s}_L \bar{d}_L)(\bar{s}_L d_L)$$

$$\langle K^0 | (\bar{s}_L \bar{d}_L)^2 | K^0 \rangle \neq 0$$

$K^0 \bar{K}^0$  mixing

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

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

$$\langle K^0 | \bar{s}_L \sigma^n$$

$d_L$

creates LH d quarks.

$\bar{s}_L$

creates RH  $\bar{s}$  antiqs

Ann. RH  $\bar{d}$  antiqs

Ann. LH s quarks.

$$(\bar{s}_L \bar{\sigma}_L)(d_L d_L) \sim (\bar{s} \bar{\sigma}^n d_L)(\bar{s} \sigma_n d_L)$$

$$\langle K^0 | (\bar{s}_L \bar{\sigma}_L)(d_L d_L) | \bar{K}^0 \rangle = \langle K^0 | \bar{s}_L \bar{\sigma}^n d_L \left( \sum_X |X\rangle \langle X| \right) \bar{s}_L \sigma_n d_L | \bar{K}^0 \rangle$$

$K^0 \bar{K}^0$  mixing

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

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

$$\langle K^0 | \bar{s}_L \sigma^n$$

$d_L$  creates LH d quarks.

$\bar{s}_L$  creates RH  $\bar{s}$  antiqs

Ann. RH  $\bar{d}$  antiqs

Ann. LH s quarks.

$$c (\bar{s}_L \bar{d}_L)(d_L d_L) \sim (\bar{s}_L \sigma^n d_L)(\bar{s}_L \sigma_n d_L)$$

$$\langle K^0 | (\bar{s}_L \sigma^n d_L)^2 | \bar{K}^0 \rangle = c \langle K^0 | \bar{s}_L \sigma^n d_L \left( \sum_x |X\rangle \langle X| \right) \bar{s}_L \sigma_n d_L | \bar{K}^0 \rangle$$

$$\mathcal{L} \supset \frac{1}{\Lambda^2} (\bar{\psi}_L \sigma^{\mu\nu} d_L)^2$$

$$\frac{\Delta m_K}{m_K} = \frac{1}{m_K^2} \langle K^0 | H_{\text{int}} | K^0 \rangle = \frac{B}{\Lambda^2 m_K^2} f_K^2 m_K^2 = B \frac{f_K^2}{\Lambda^2}$$

measured  $10^{-14}$

$$\langle K^0 | (S_L^0 d_L) | K^0 \rangle = \langle K^0 | \bar{S}_L \bar{\sigma}^0 d_L (\sum_x |X\rangle \langle X|) \bar{S}_L \bar{\sigma}^0 d_L | K^0 \rangle \simeq \langle K^0 | \bar{S}_L \bar{\sigma}^0 d_L | 0 \rangle \langle 0 | \bar{S}_L \bar{\sigma}^0 d_L | K^0 \rangle = f_K^2 m_K^2$$

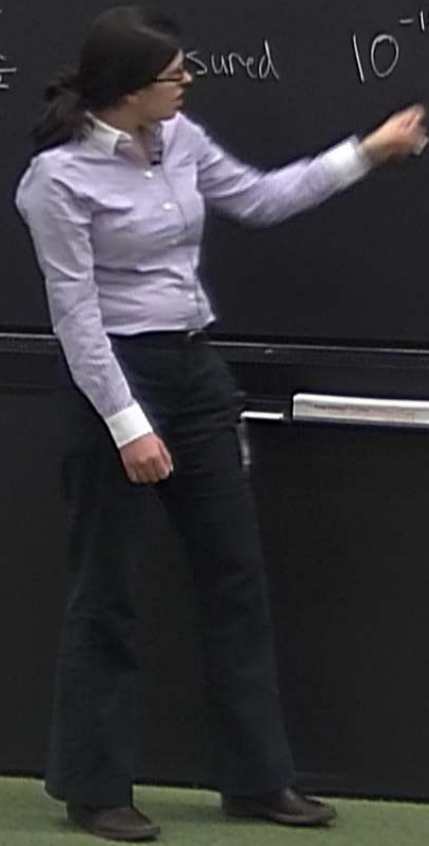
$$f_K^2 \simeq \frac{1}{\Lambda^2} (\bar{S}_L \bar{\sigma}^0 d_L)^2$$

$$\frac{\Delta m_K}{m_K} = \frac{1}{m_K^2} \langle K^0 | H_{\text{int}} | K^0 \rangle = \frac{B}{\Lambda^2 m_K^2} f_K^2 m_K^2 = B \frac{f_K^2}{\Lambda^2}$$

measured  $10^{-14}$

$$\Delta m \sim 10^{-12} \text{ MeV}$$

$$m \sim 500 \text{ MeV}$$



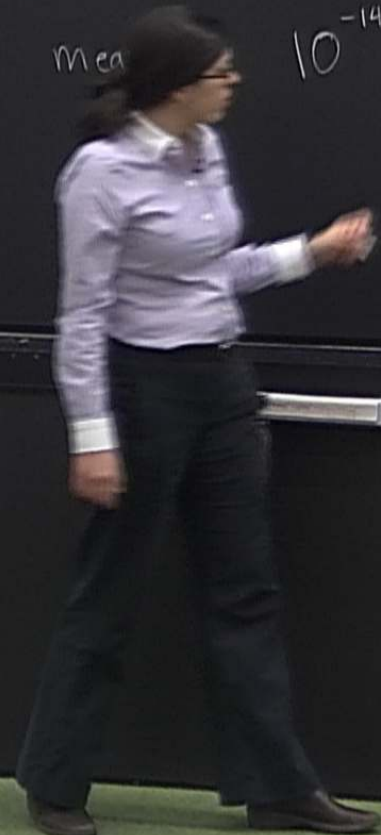
$$\langle K^0 | (S_L^0 d_L) | K^0 \rangle = \langle K^0 | \bar{S}_L \bar{\sigma}^0 d_L (\sum_x |X\rangle \langle X|) \bar{S}_L \bar{\sigma}^0 d_L | K^0 \rangle \approx \langle K^0 | \bar{S} \bar{\sigma}^0 d_L | 0 \rangle \langle 0 | \bar{S} \bar{\sigma}^0 d_L | K^0 \rangle = f_K^2 m_K^2$$

$$f_K^2 \approx \frac{1}{\Lambda^2} (\bar{S}_L \bar{\sigma}^0 d_L)^2$$

$$\frac{\Delta m_K}{m_K} = \frac{1}{m_K^2} \langle K^0 | H_{int} | K^0 \rangle = \frac{B}{\Lambda^2 m_K^2} f_K^2 m_K^2 = B \frac{f_K^2}{\Lambda^2}$$

mea  $10^{-14}$

$\Delta m \sim 10^{-12}$  MeV  
 $m \sim 500$  MeV



$$\langle K^0 | (\bar{s}_L \sigma^\mu d_L) | K^0 \rangle = \langle K^0 | \bar{s}_L \sigma^\mu d_L (\sum_X |X\rangle \langle X|) \bar{s}_L \sigma^\mu d_L | K^0 \rangle \simeq \langle K^0 | \bar{s}_L \sigma^\mu d_L | 0 \rangle \langle 0 | \bar{s}_L \sigma^\mu d_L | K^0 \rangle = f_K^2 m_K^2$$

$$\mathcal{L} \supset \frac{1}{\Lambda^2} (\bar{s}_L \sigma^\mu d_L)^2$$

$$\frac{\Delta m_K}{m_K} = \frac{1}{m_K^2} \langle K^0 | H_{\text{int}} | K^0 \rangle$$

$$f_K^2 m_K^2 = B \frac{f_K^2}{\Lambda^2}$$

measured  $10^{-14}$

$$\Delta m \sim 10^{-12} \text{ MeV}$$

$$m \sim 500 \text{ MeV}$$

$$\Lambda \sim 10^7 f_K \sim \underline{10^6 \text{ GeV}} \gg M_W^2$$

