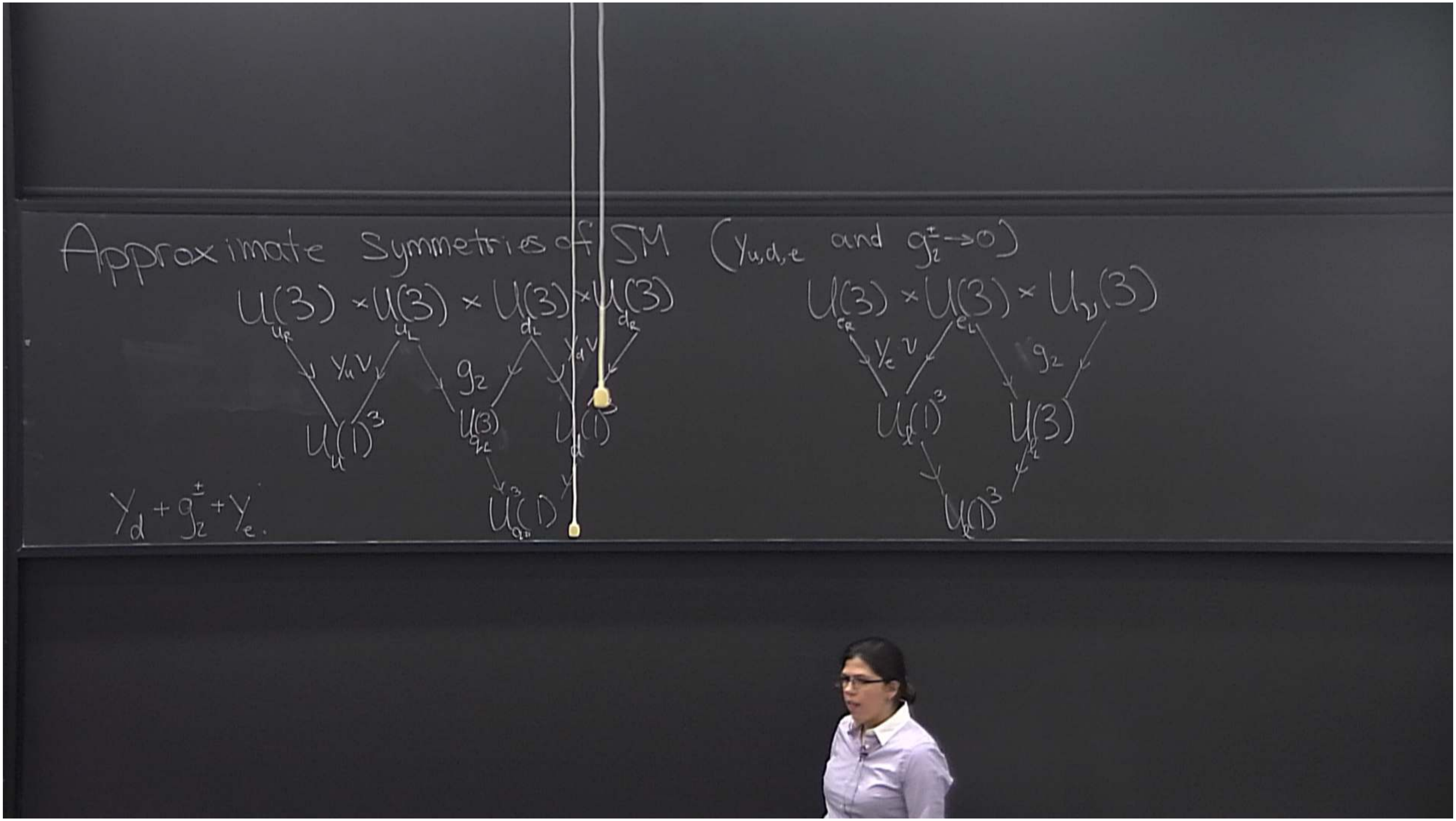
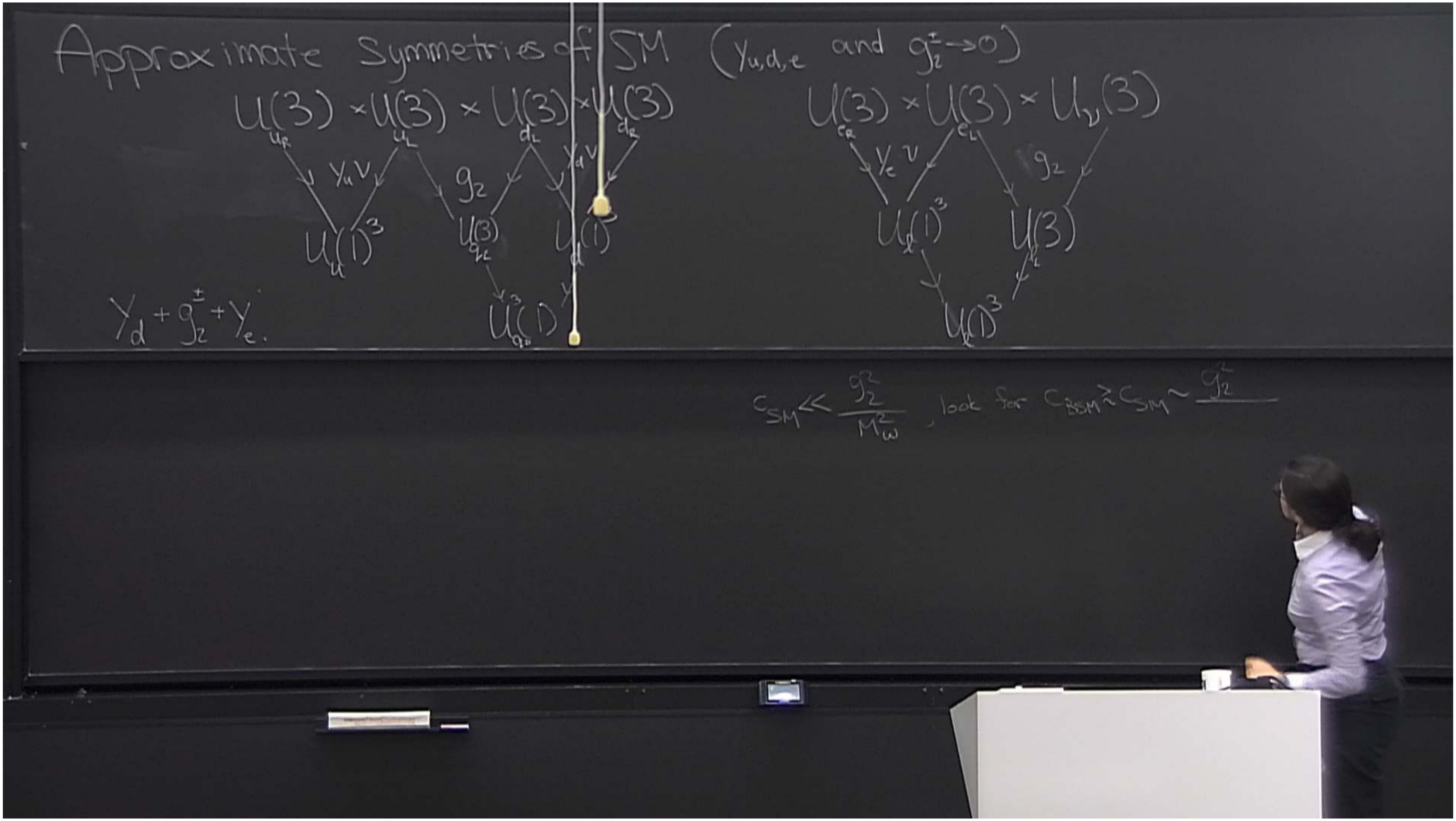
Title: 12/13 PSI - Beyond the Standard Model Lecture 11

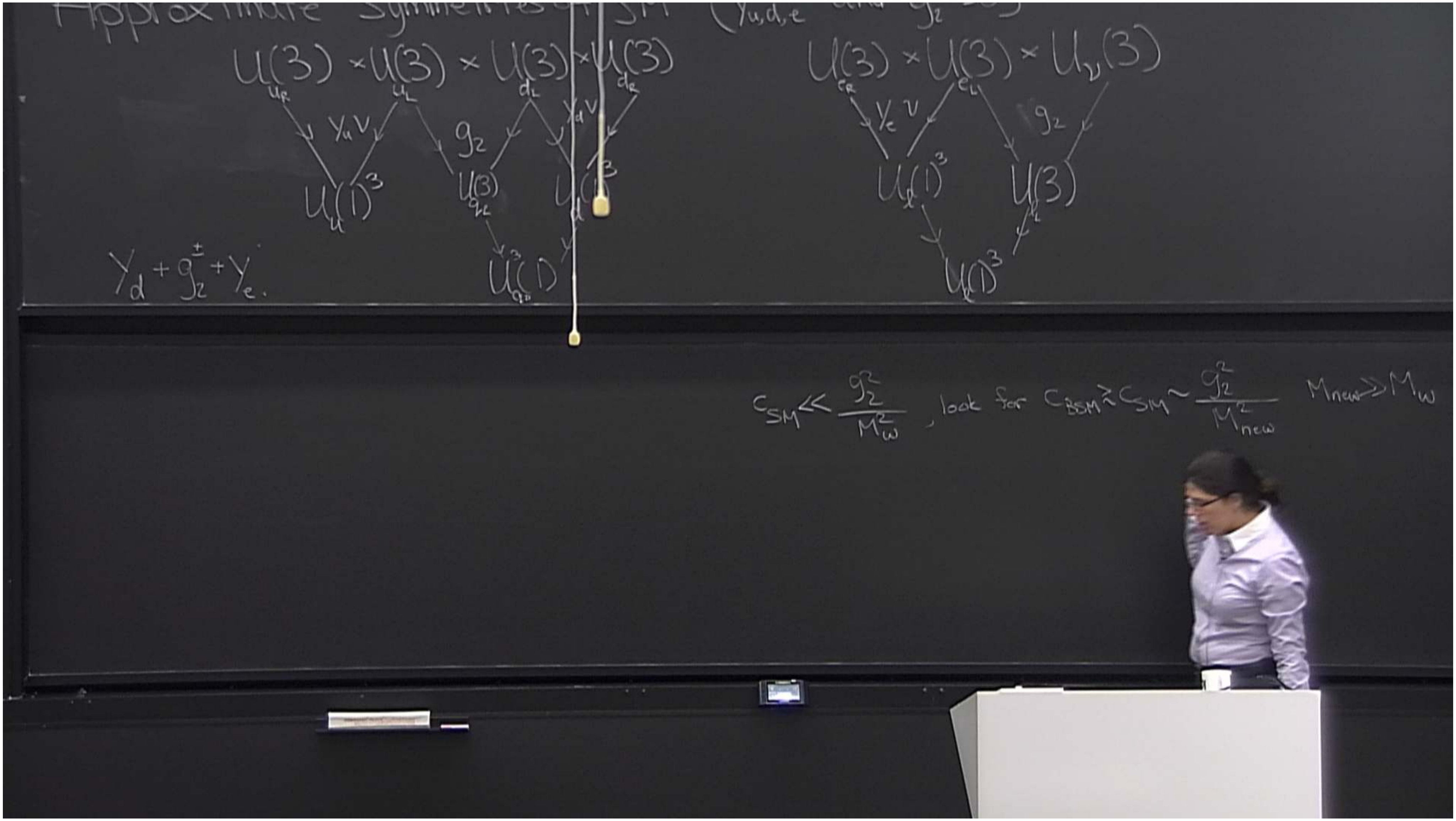
Date: Mar 05, 2013 09:00 AM

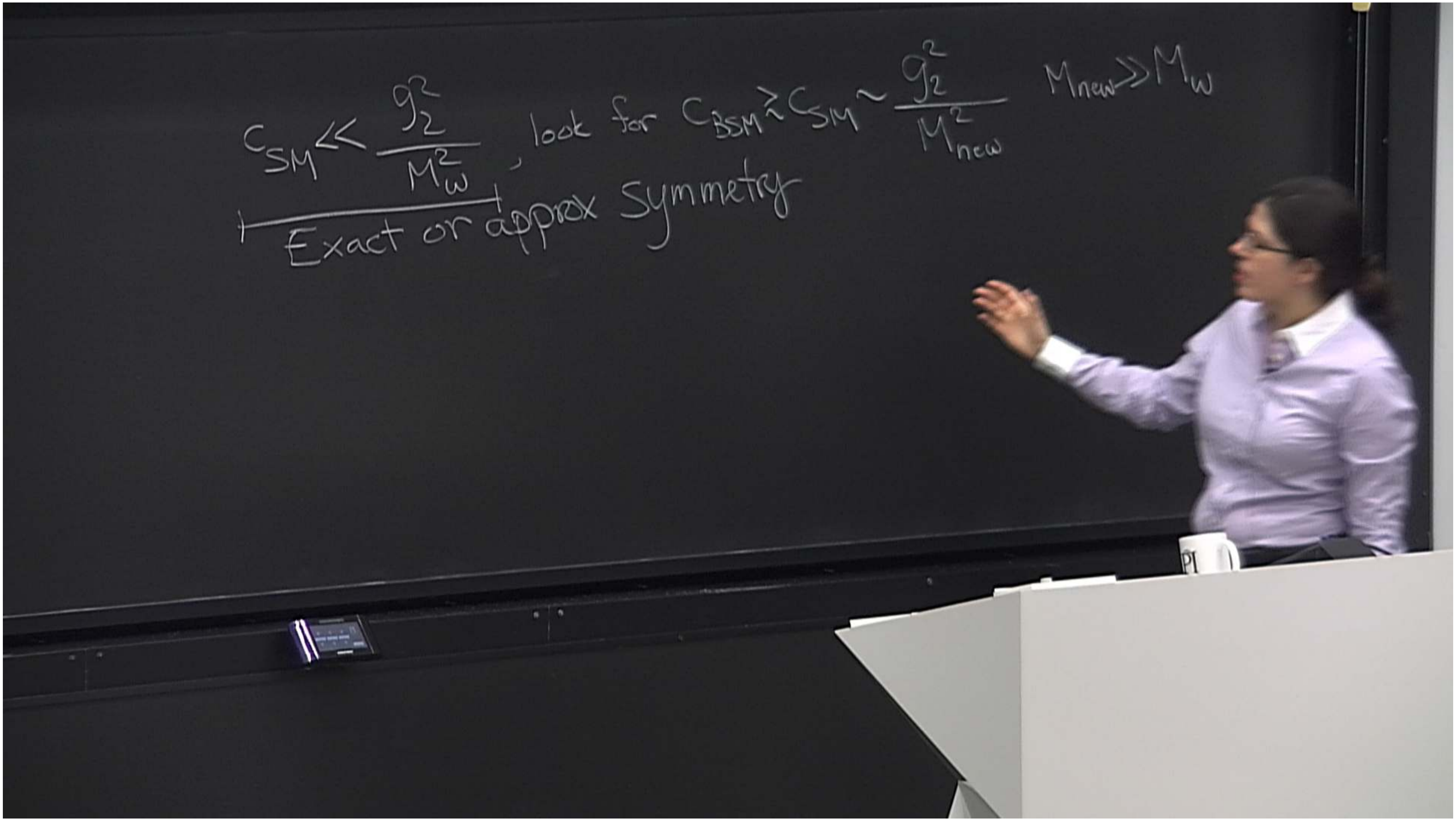
URL: http://pirsa.org/13030034

Abstract:

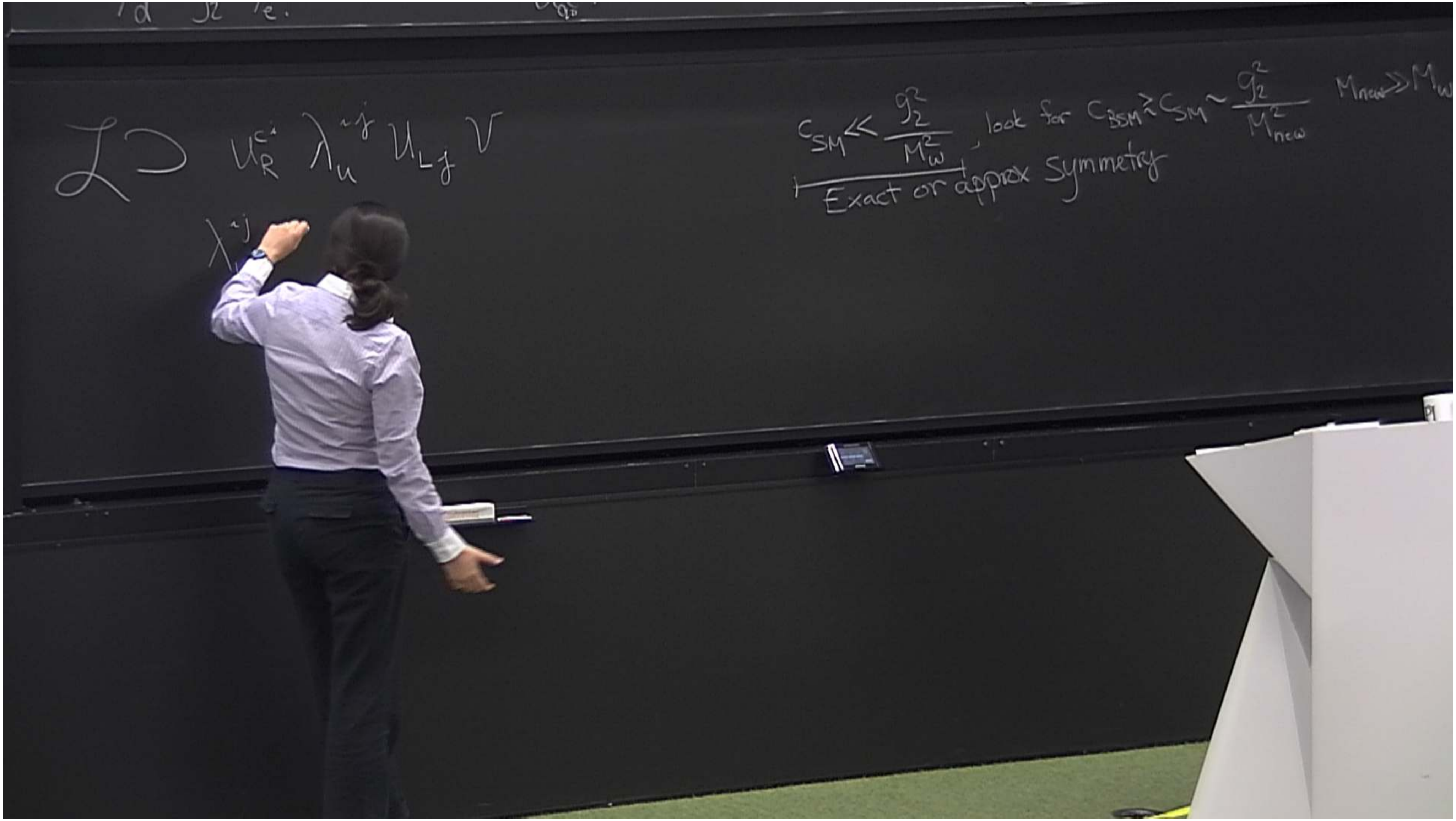

Approximate Symmetries of SM (y_{u,d,e} and g_2^± → 0)
U(3) × U(3) × U(3) × U(3)
U(3) × U(3) × U_ν(3)
y_u v
g_2
y_d v
y_e v
g_2
U_u(1)^3
U(3)
U_d(1)
U_ℓ(1)^3
U(3)
U(1)^3
U_ℓ(1)^3
Y_d + g_2^± + Y_e.

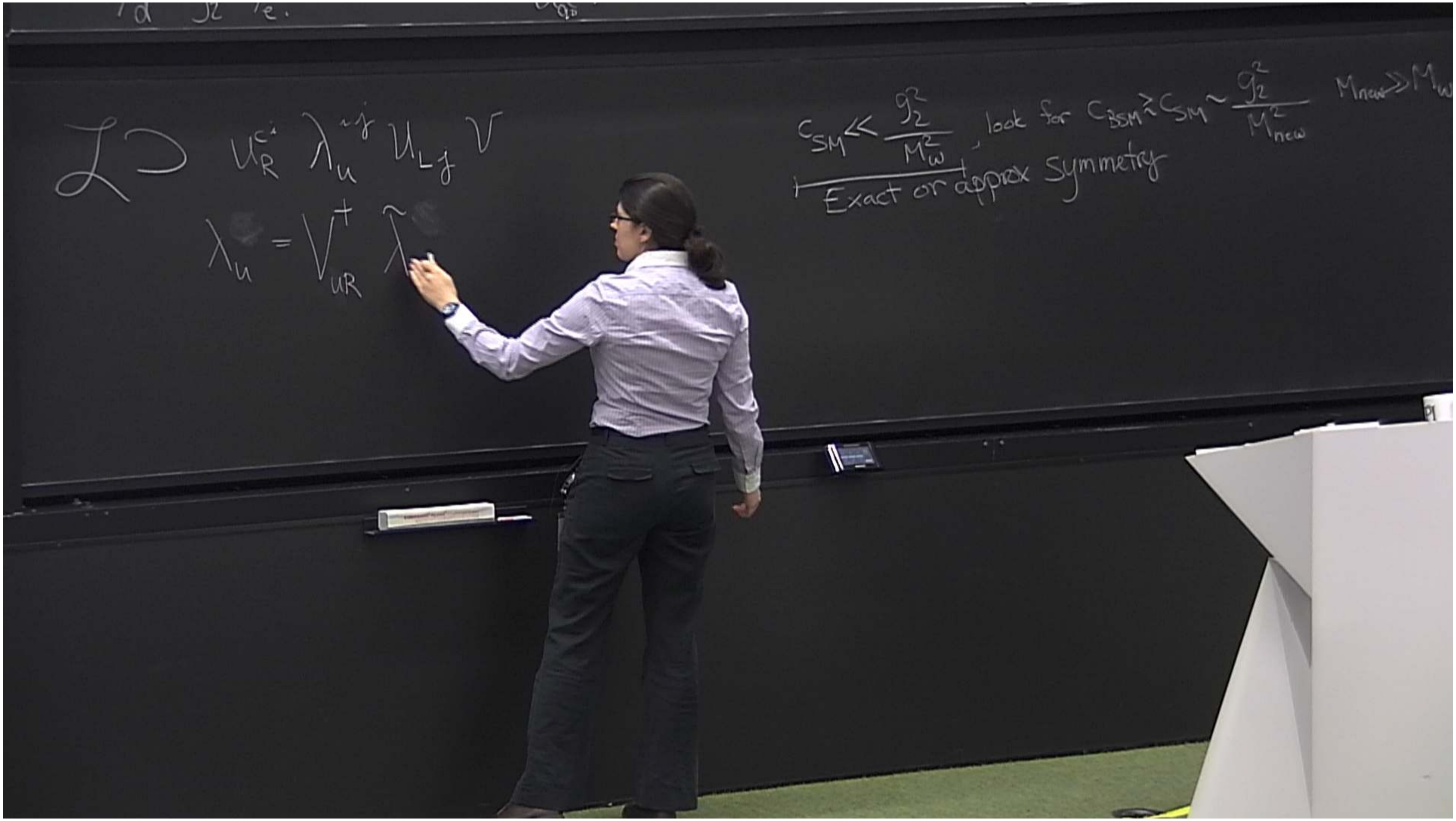

Approximate Symmetries of SM (Yu,d,e and g2± → 0)
U(3) × U(3) × U(3) × U(3)
U(3) × U(3) × U(3)
Yd + g2± + Ye.
look for

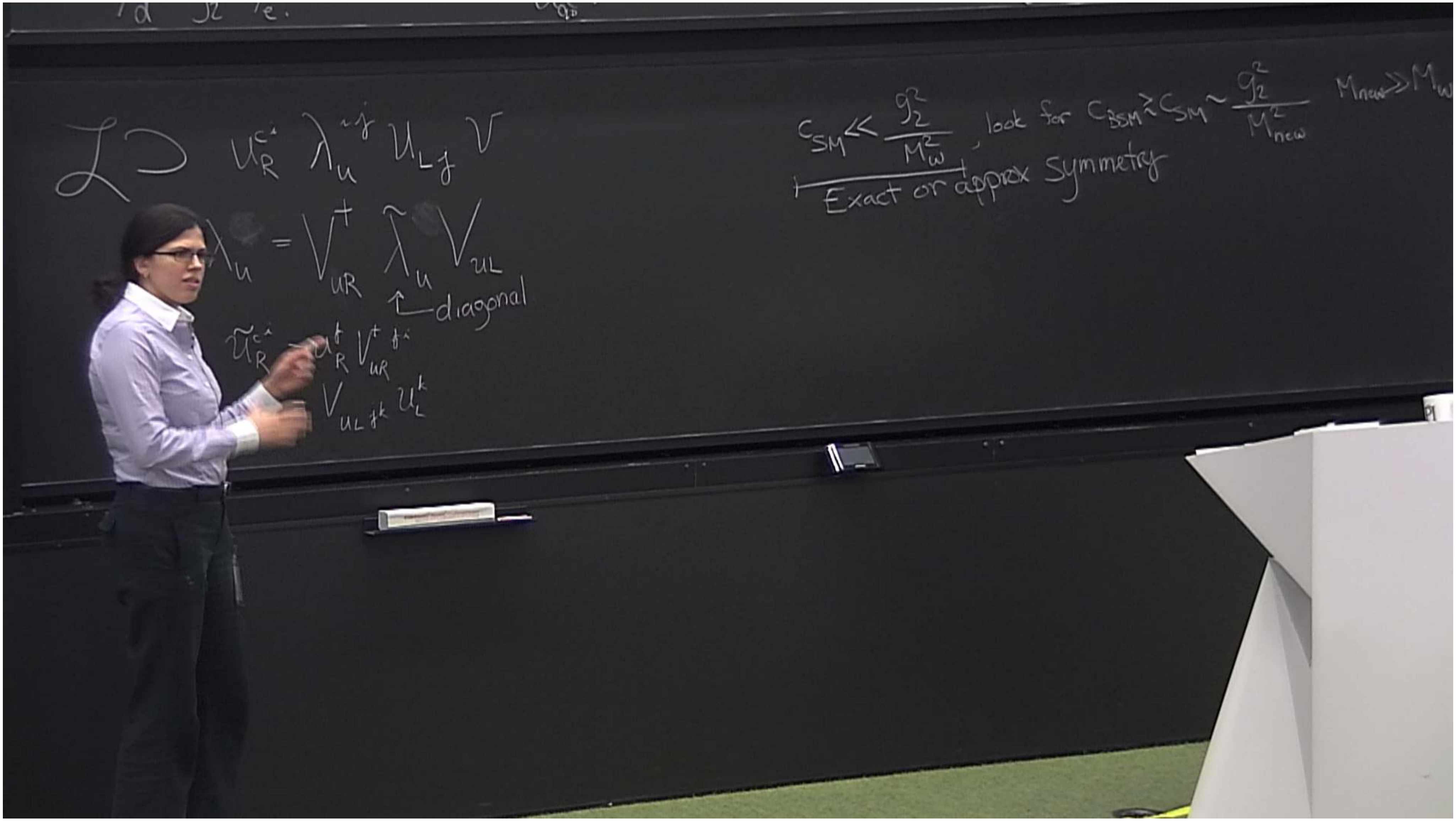

U(3) × U(3) × U(3) × U(3)
U(3) × U(3) × U(3)
g2
U(3)
U(1)3
Yd + g2± + Ye.
CSM << g2^2 / MW^2 , look for CBSM ≳ CSM ~ g2^2 / Mnew^2   Mnew >> MW

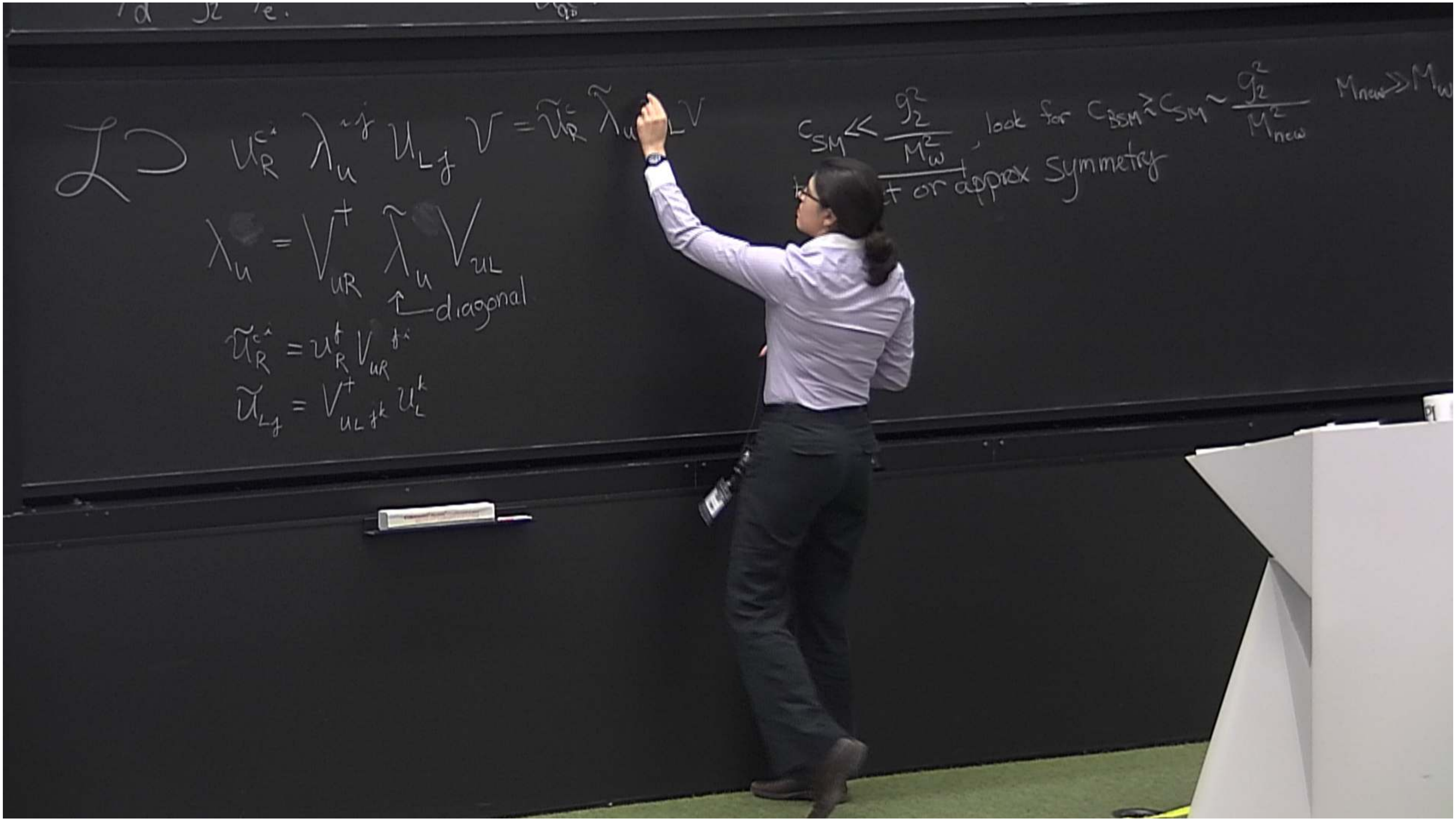


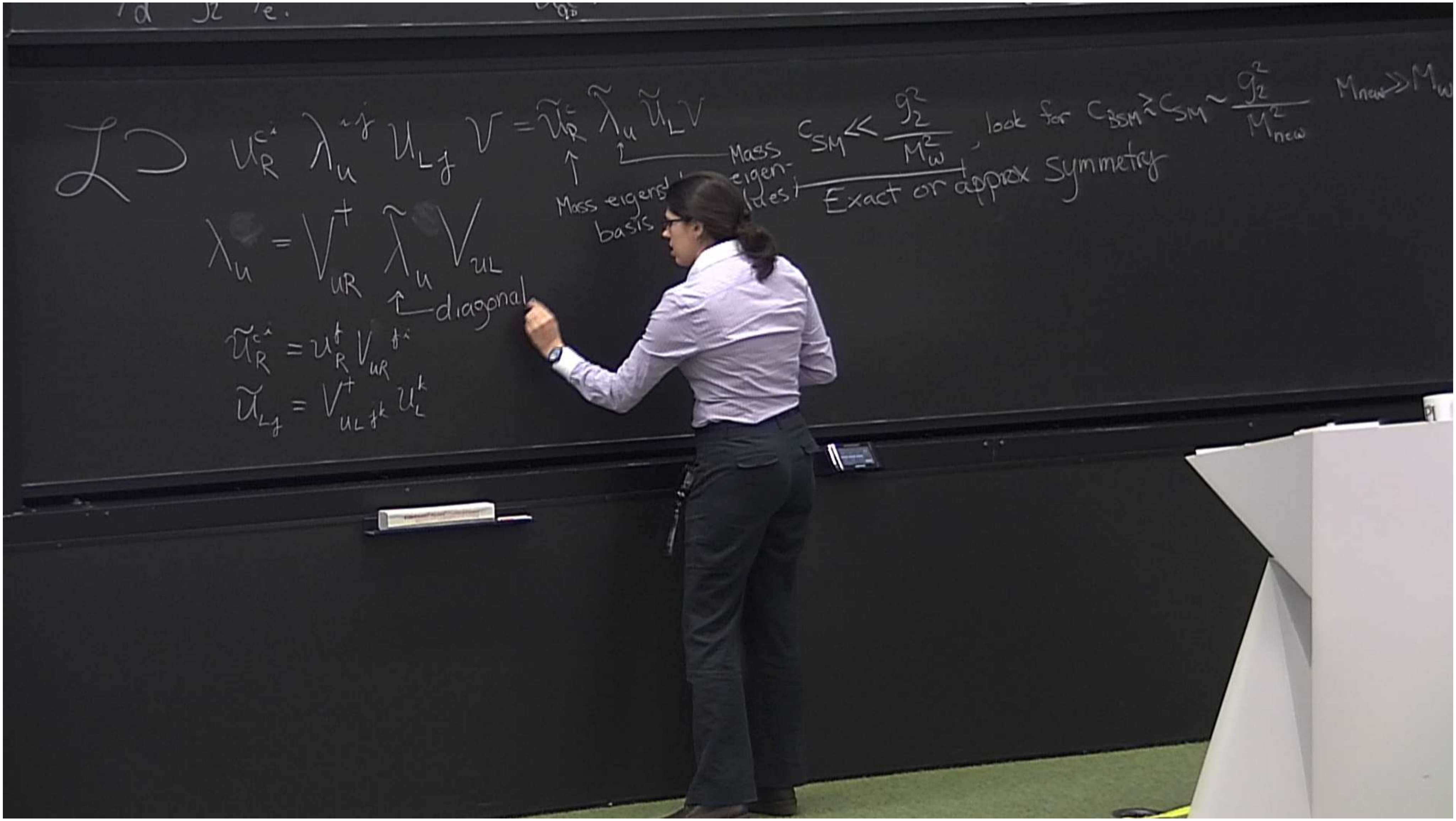
$c_{SM} \ll \frac{g_2^2}{M_W^2}$, look for $c_{BSM} \gtrsim c_{SM} \sim \frac{g_2^2}{M_{new}^2}$ $M_{new} \gg M_W$
Exact or approx symmetry

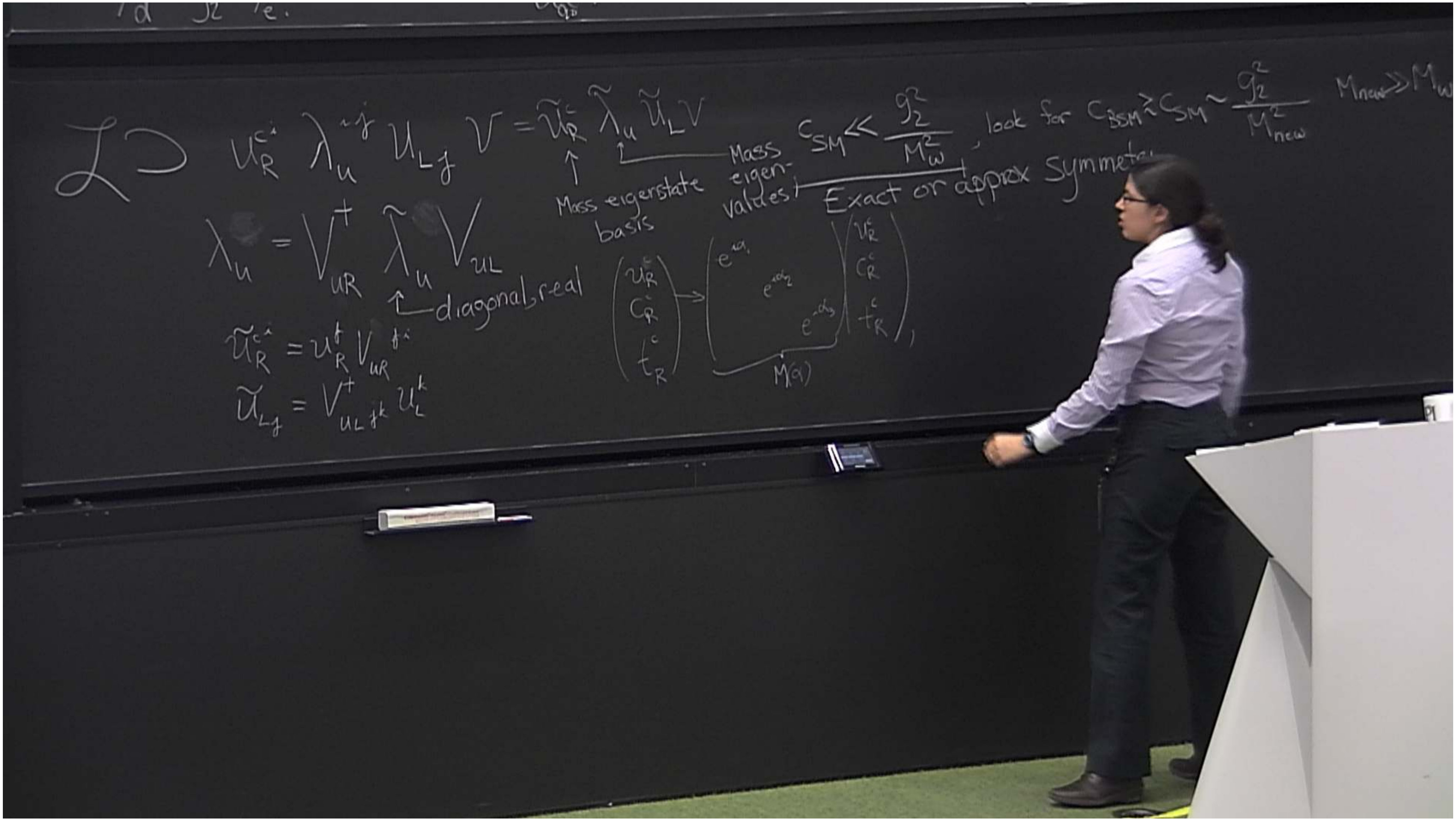

$\mathcal{L} \supset u_R^{c\,i} \lambda_u^{ij} u_{Lj} v$
$c_{SM} \ll \frac{g_2^2}{M_W^2}$, look for $c_{BSM} \gtrsim c_{SM} \sim \frac{g_2^2}{M_{new}^2}$ $M_{new} \gg M_W$
Exact or approx symmetry

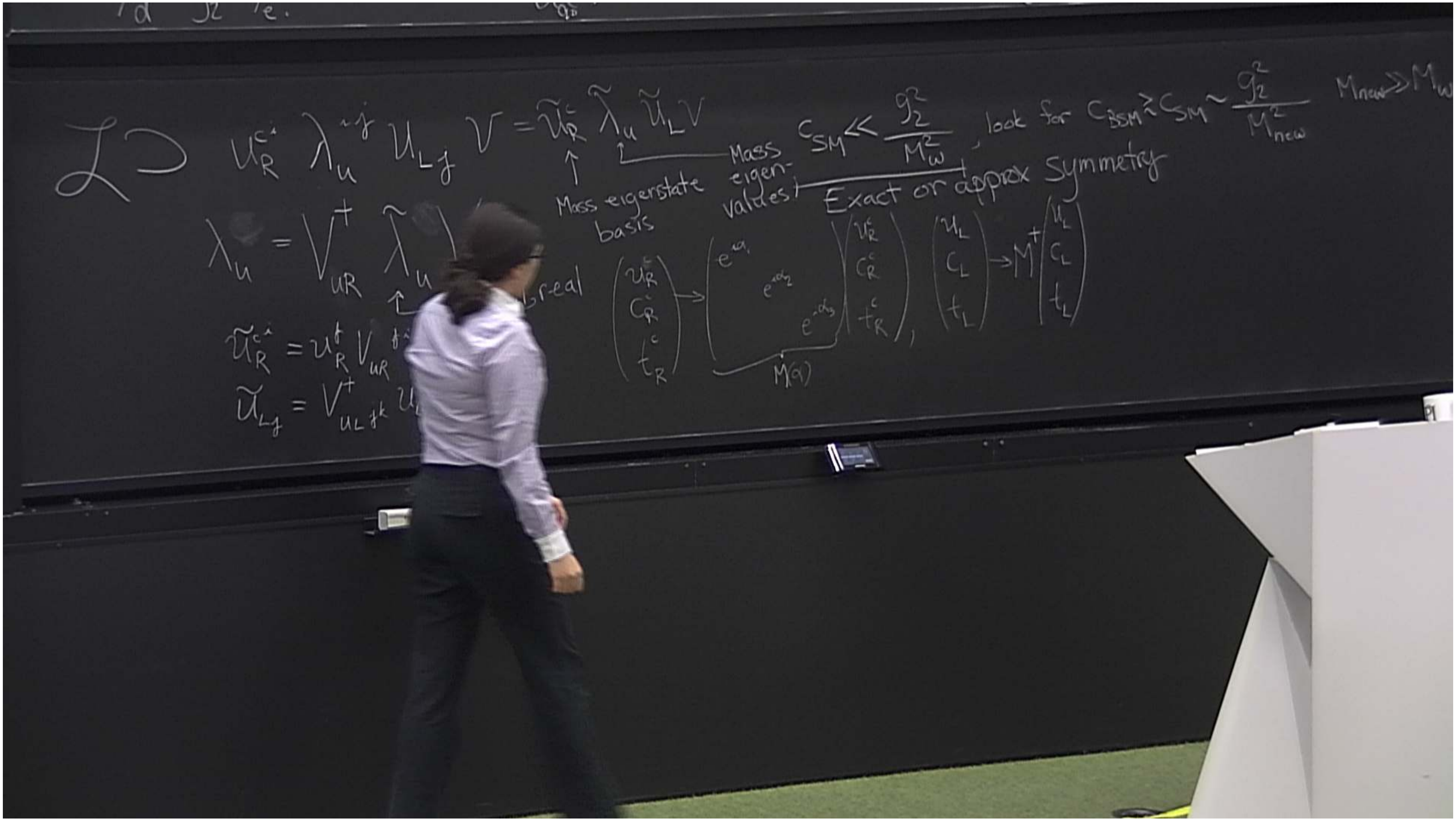

$\mathcal{L} \supset u_R^{c\,i} \lambda_u^{ij} u_{Lj} V$
$\lambda_u = V_{uR}^{\dagger} \tilde{\lambda}$
$c_{SM} \ll \frac{g_2^2}{M_W^2}$, look for $c_{BSM} \gtrsim c_{SM} \sim \frac{g_2^2}{M_{new}^2}$
$M_{new} \gg M_W$
Exact or approx symmetry

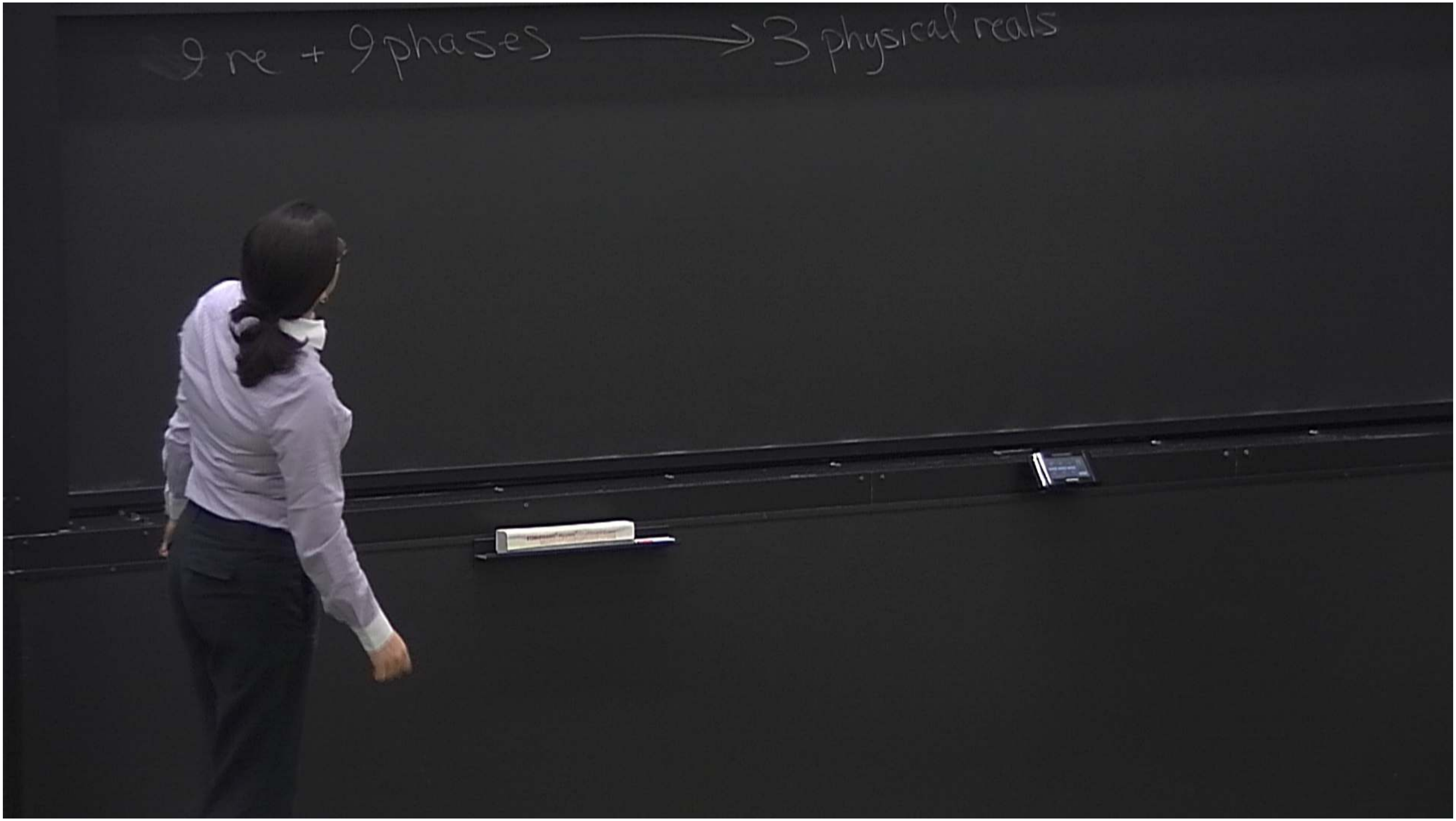

diagonal
look for
Exact or approx symmetry

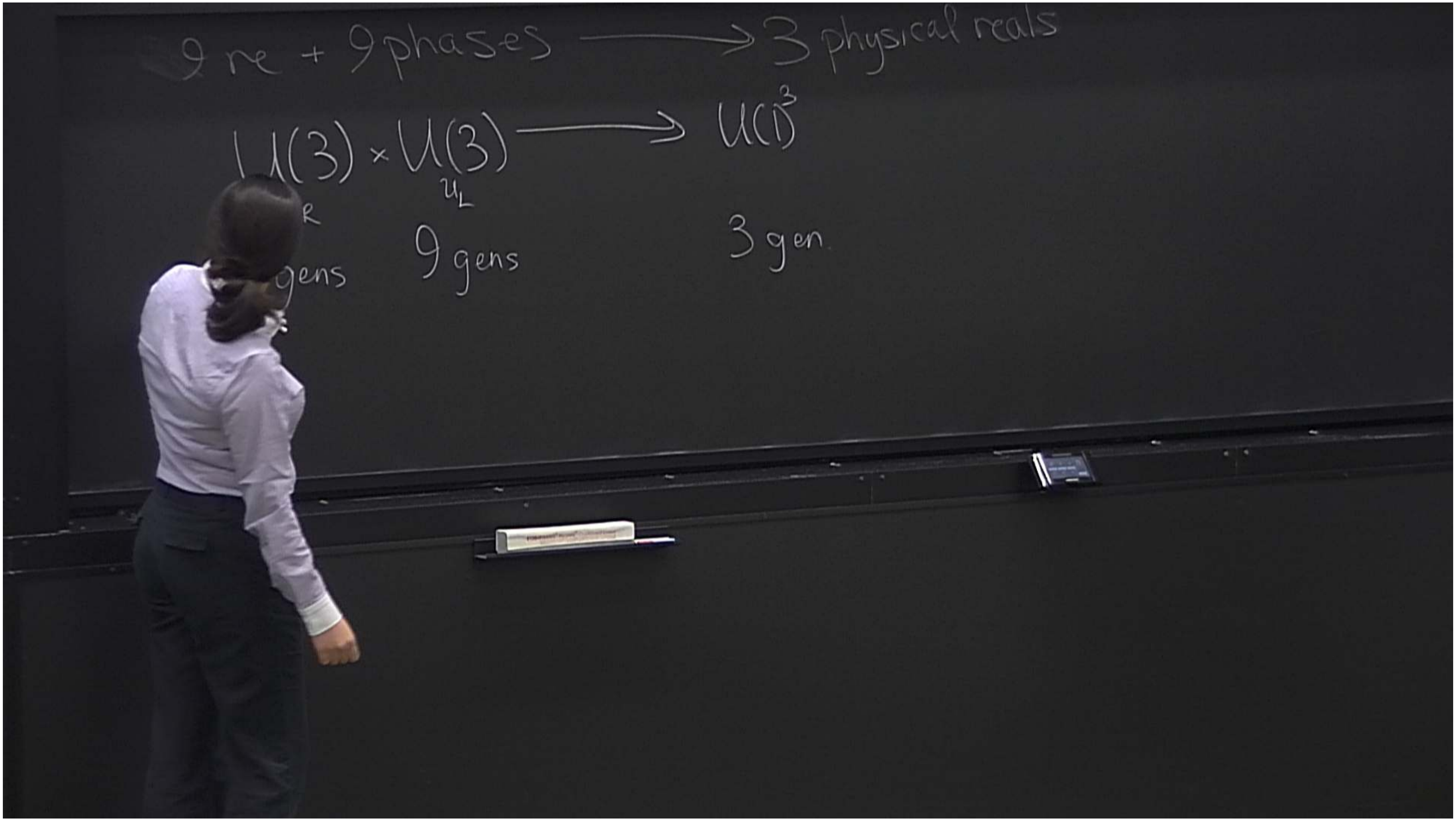

look for
or approx symmetry
diagonal

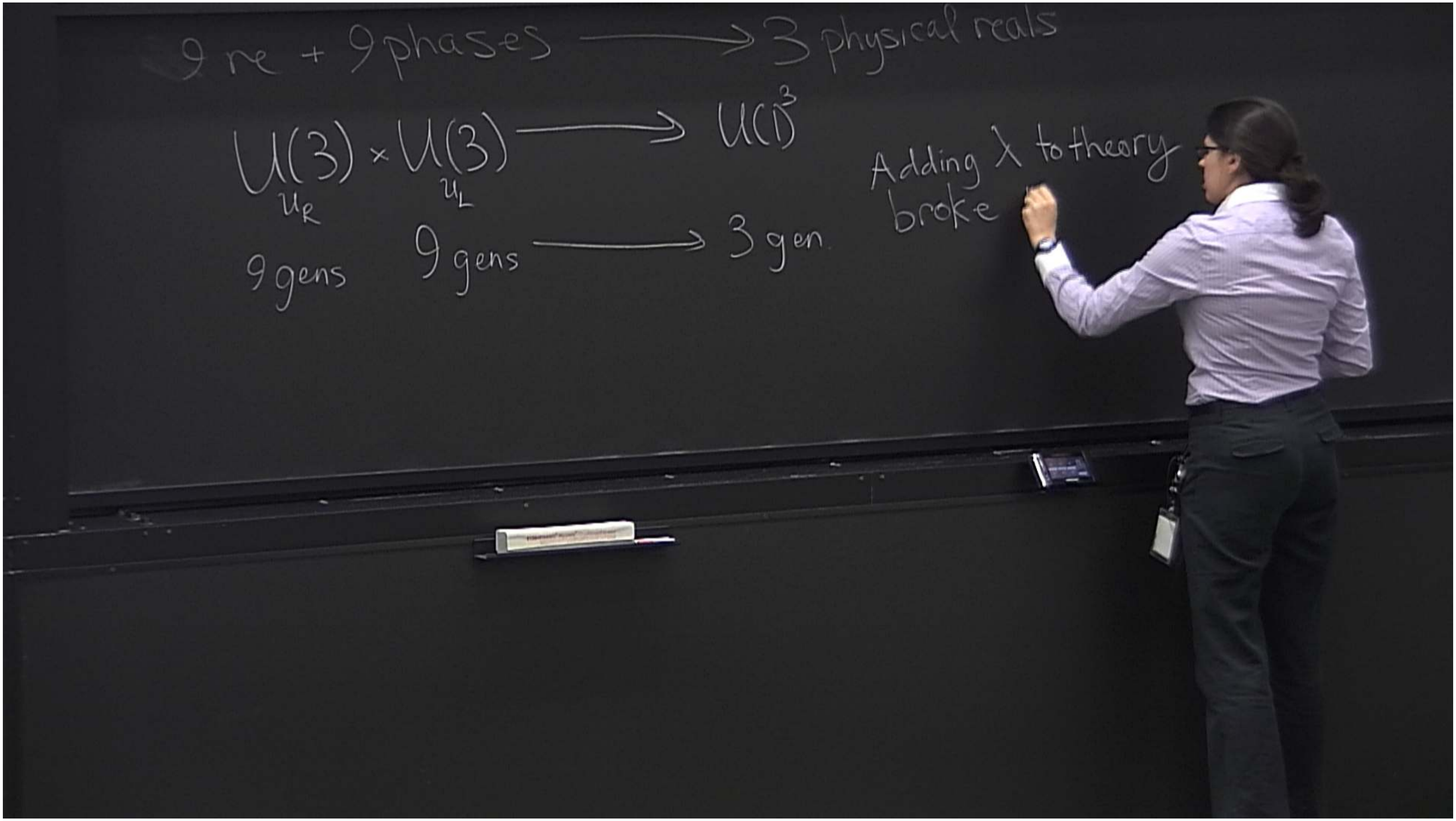

Mass
eigen-
Exact or approx symmetry
look for
diagonal
basis

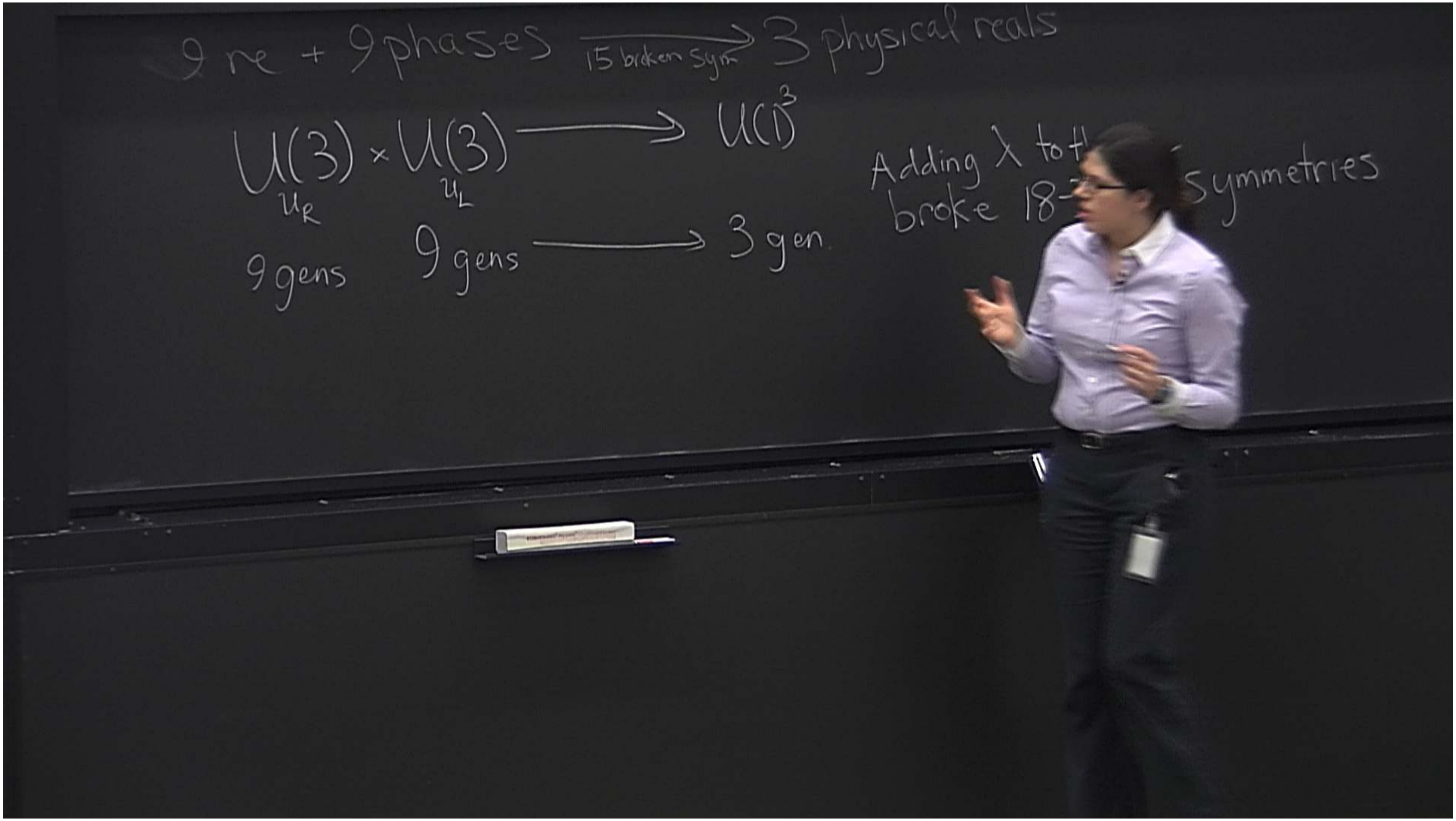

Mass eigenstate basis
Mass eigen-values
diagonal, real
Exact or approx symmetry
look for
M(α)

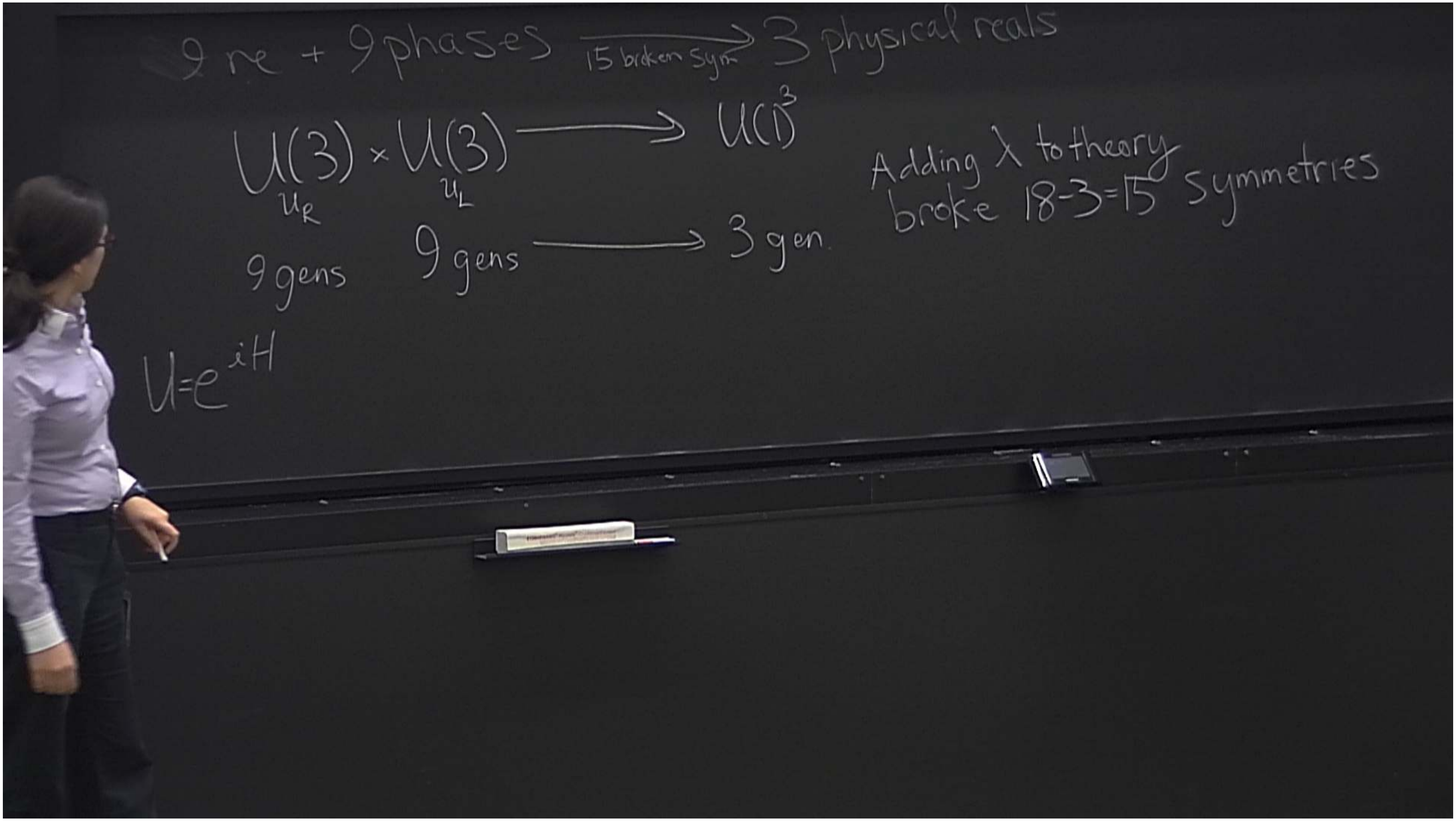

Mass eigenstate basis
Mass eigenvalues
look for
Exact or approx symmetry
real

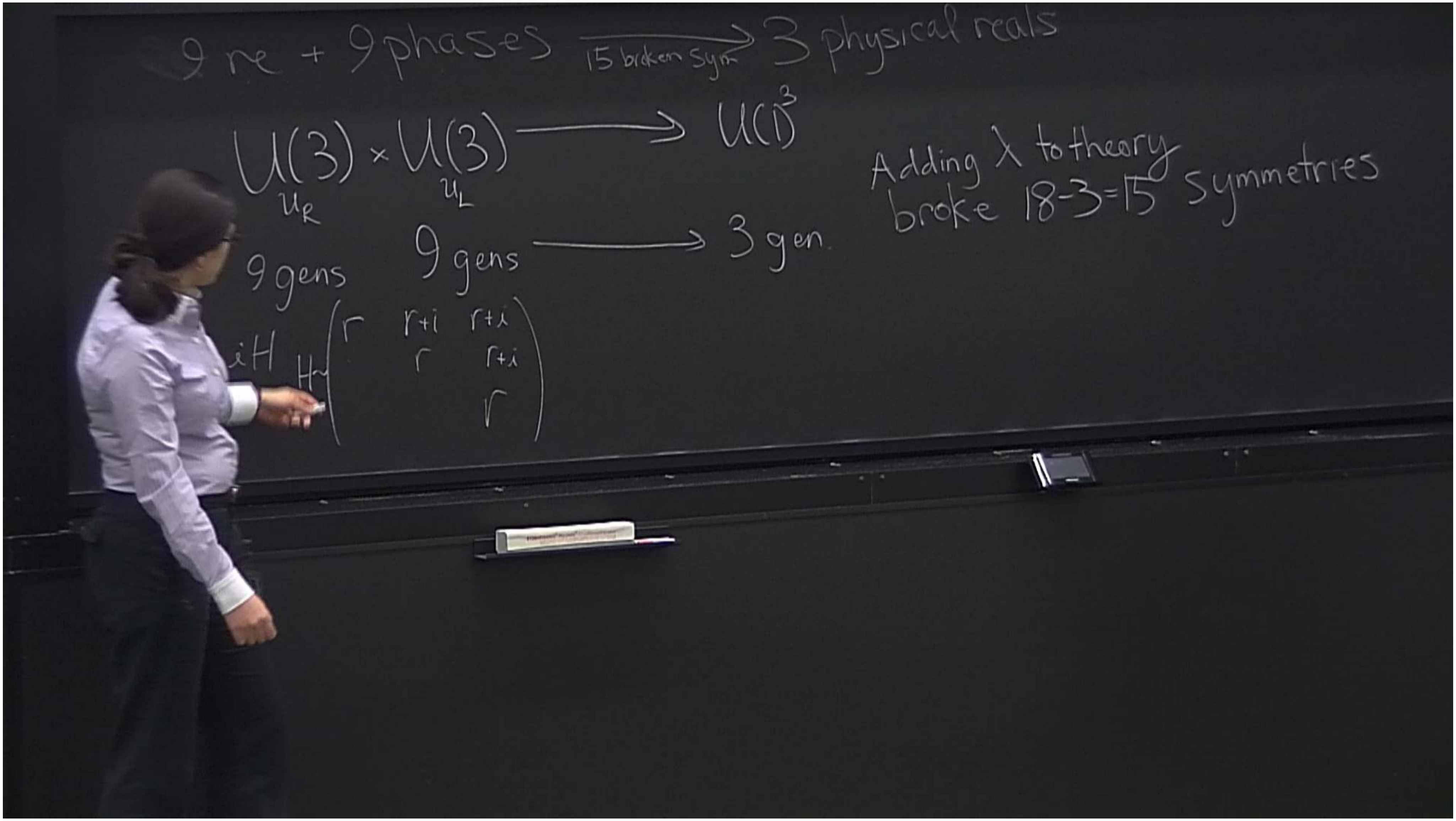

9 re + 9 phases → 3 physical reals

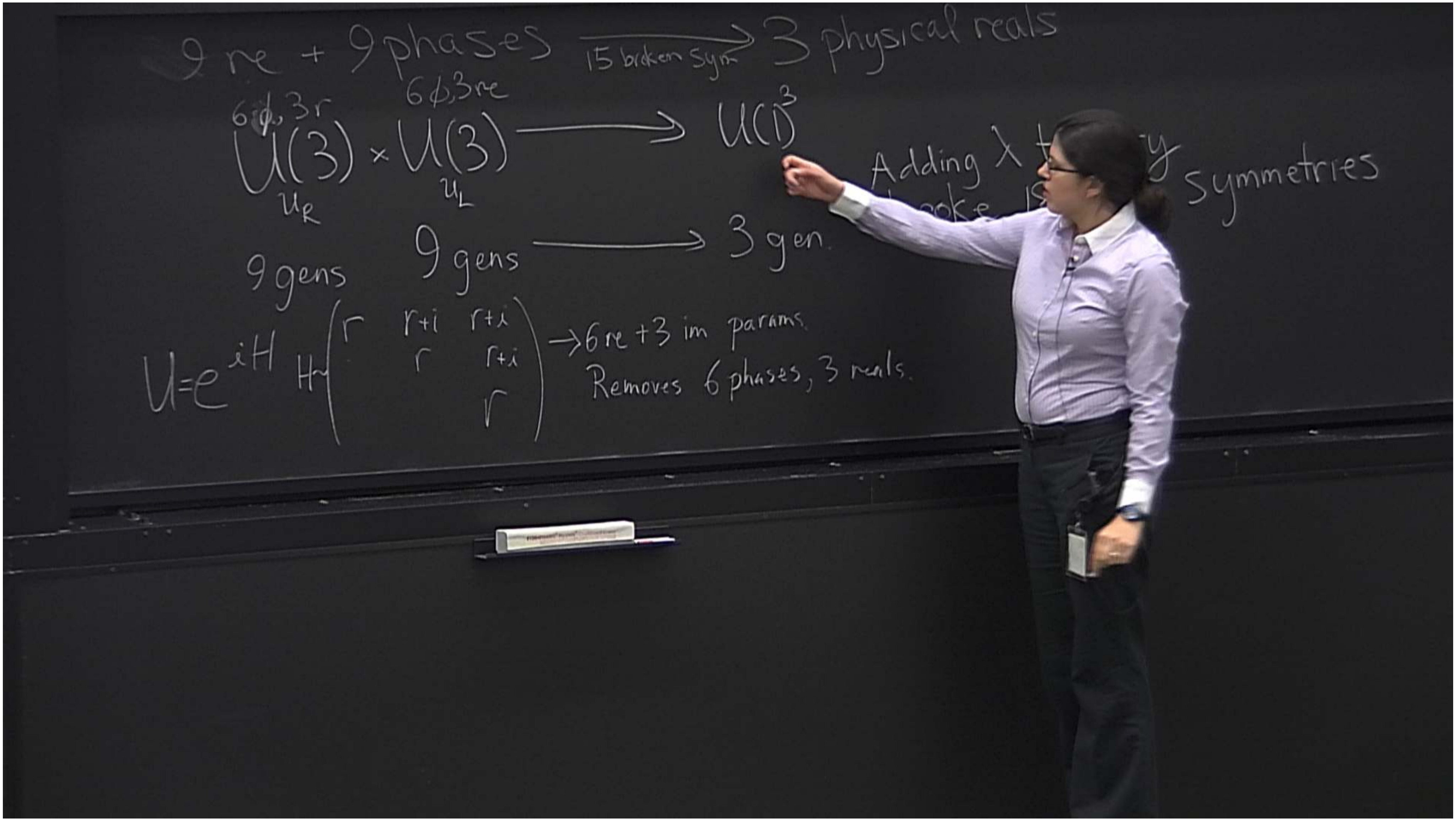

9 re + 9 phases → 3 physical reals
U(3) × U(3) → U(1)^3
u_L
gens
9 gens
3 gen.

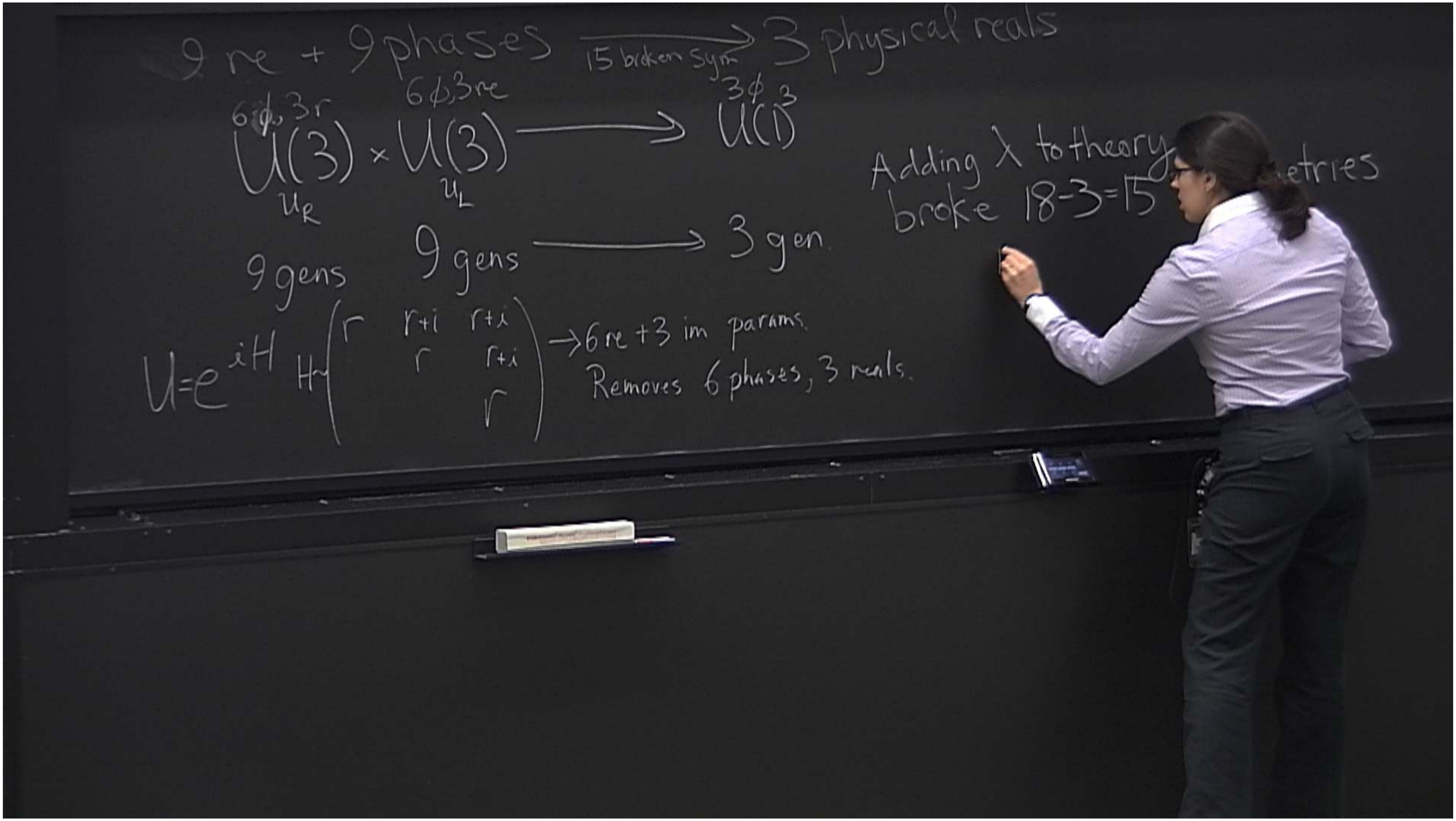

9 re + 9 phases → 3 physical reals
U(3) × U(3) → U(1)³
u_R u_L
9 gens 9 gens → 3 gen.
Adding λ to theory
broke


9 re + 9 phases
15 broken sym
3 physical reals
U(3) × U(3)
u_R
u_L
U(1)^3
9 gens
9 gens
3 gen.
Adding λ to
broke 18
symmetries

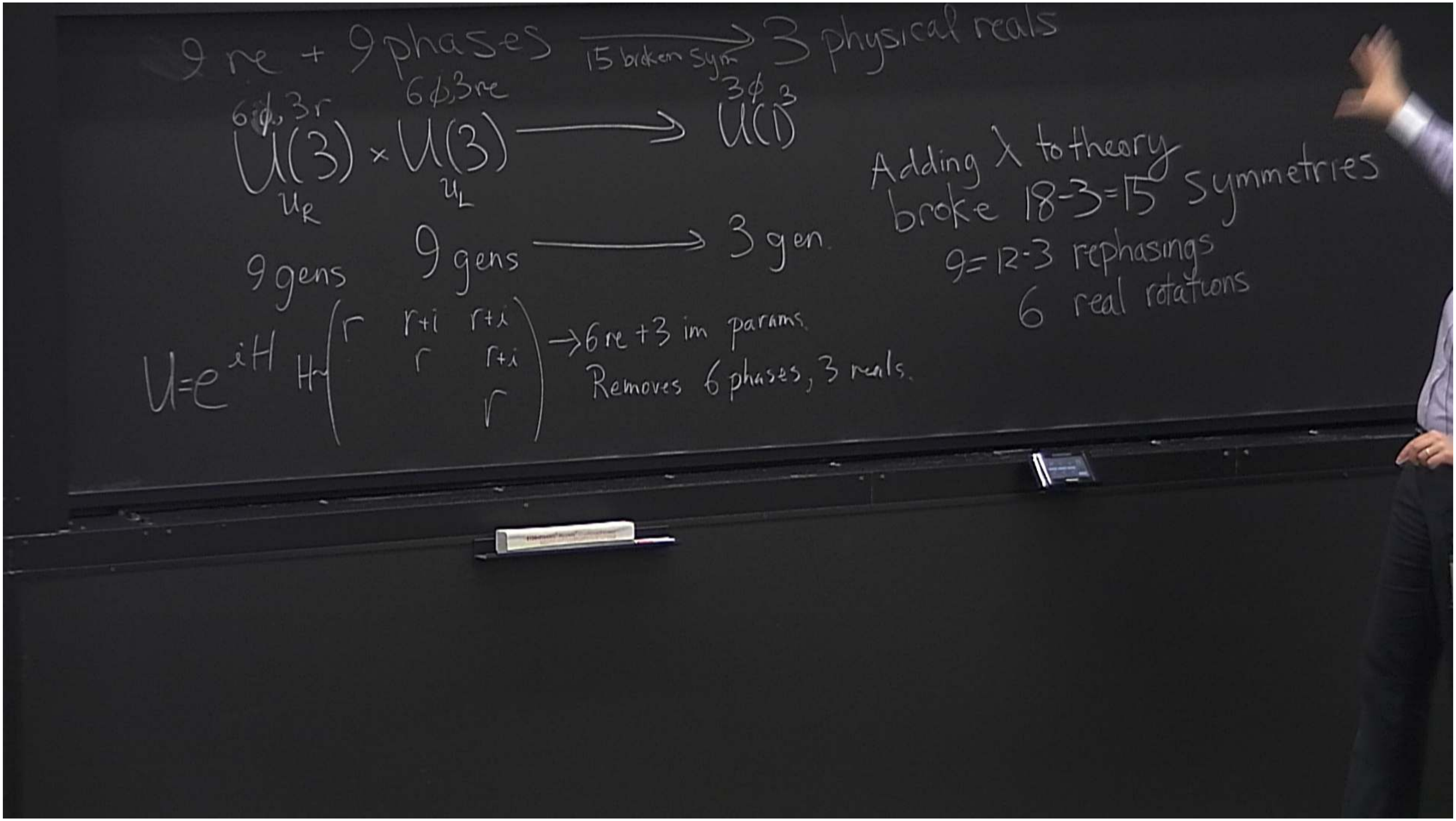

9 re + 9 phases
15 broken sym
3 physical reals
U(3) × U(3) → U(1)3
uR uL
9 gens 9 gens → 3 gen.
Adding λ to theory
broke 18-3=15 symmetries
U=eiH


9 re + 9 phases
15 broken sym
3 physical reals
U(3) × U(3)
U(1)3
uR
uL
Adding λ to theory
broke 18-3=15 symmetries
9 gens
9 gens
3 gen.
iH
H~
r r+i r+i
r r+i
r


9 re + 9 phases
15 broken sym
3 physical reals
6φ, 3r
6φ, 3re
U(3) × U(3)
U(1)³
u_R
u_L
Adding λ
symmetries
9 gens
9 gens
3 gen.
U=e^iH
H~
r r+i r+i
r r+i
r
→6 re +3 im params.
Removes 6 phases, 3 reals.



9 re + 9 phases
15 broken sym
3 physical reals
6ϕ, 3r
6ϕ, 3re
3ϕ
U(3) × U(3) → U(1)^3
u_R
u_L
9 gens
9 gens → 3 gen.
Adding λ to theory
etries
broke 18-3=15
U=e^iH
H~
r r+i r+i
r r+i
r
→6 re + 3 im params.
Removes 6 phases, 3 reals.


9 re + 9 phases
15 broken sym
3 physical reals
6φ, 3r
6φ, 3re
3φ
U(3) × U(3) → U(1)^3
u_R
u_L
9 gens
9 gens → 3 gen.
Adding λ to theory
broke 18-3=15 symmetries
9=12-3 rephasings
6 real rotations
U=e^iH
H~
r r+i r+i
r r+i
r
→6 re +3 im params.
Removes 6 phases, 3 reals.

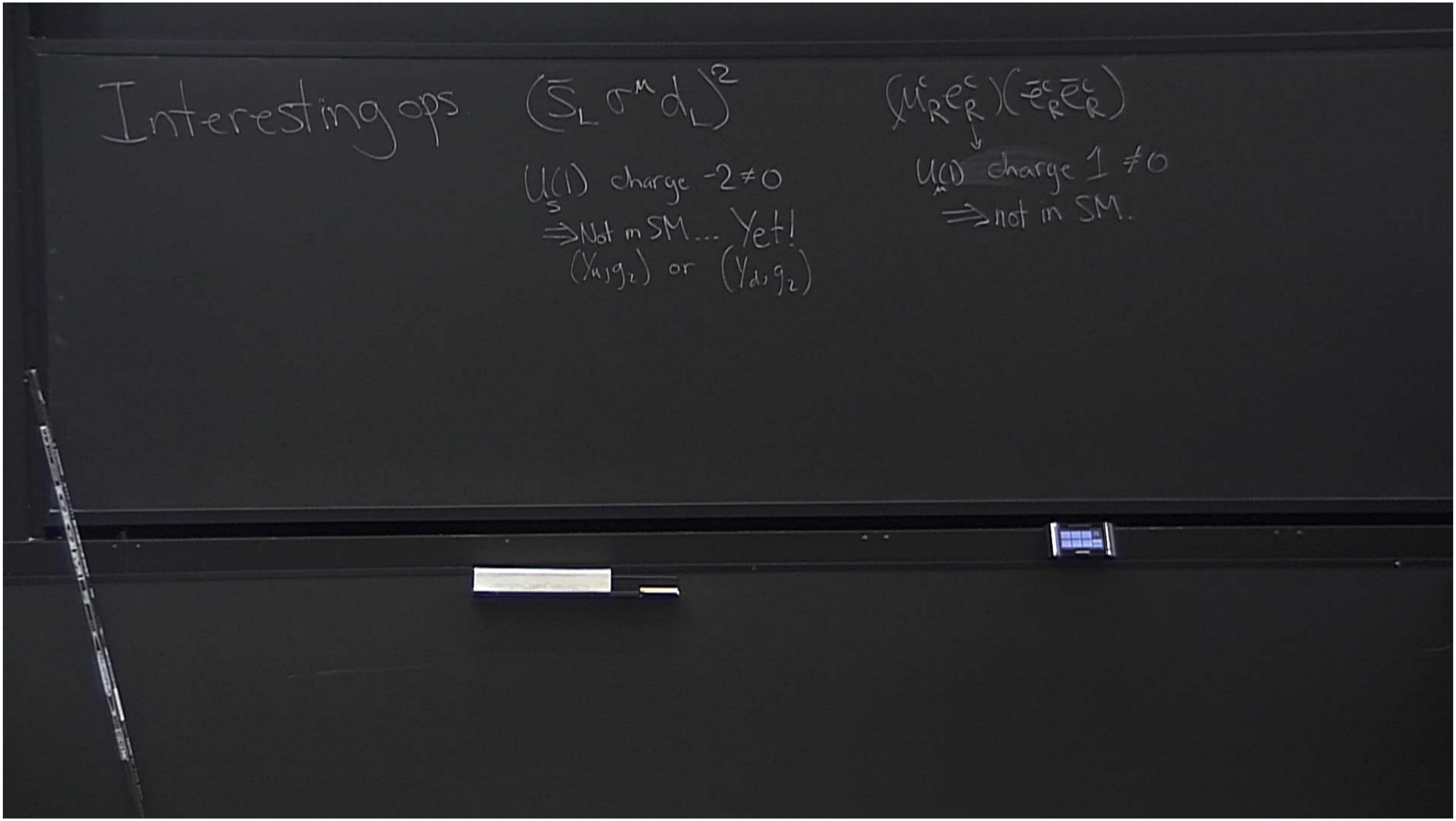
Interesting ops $(\bar{s}_L \sigma^\mu d_L)^2$

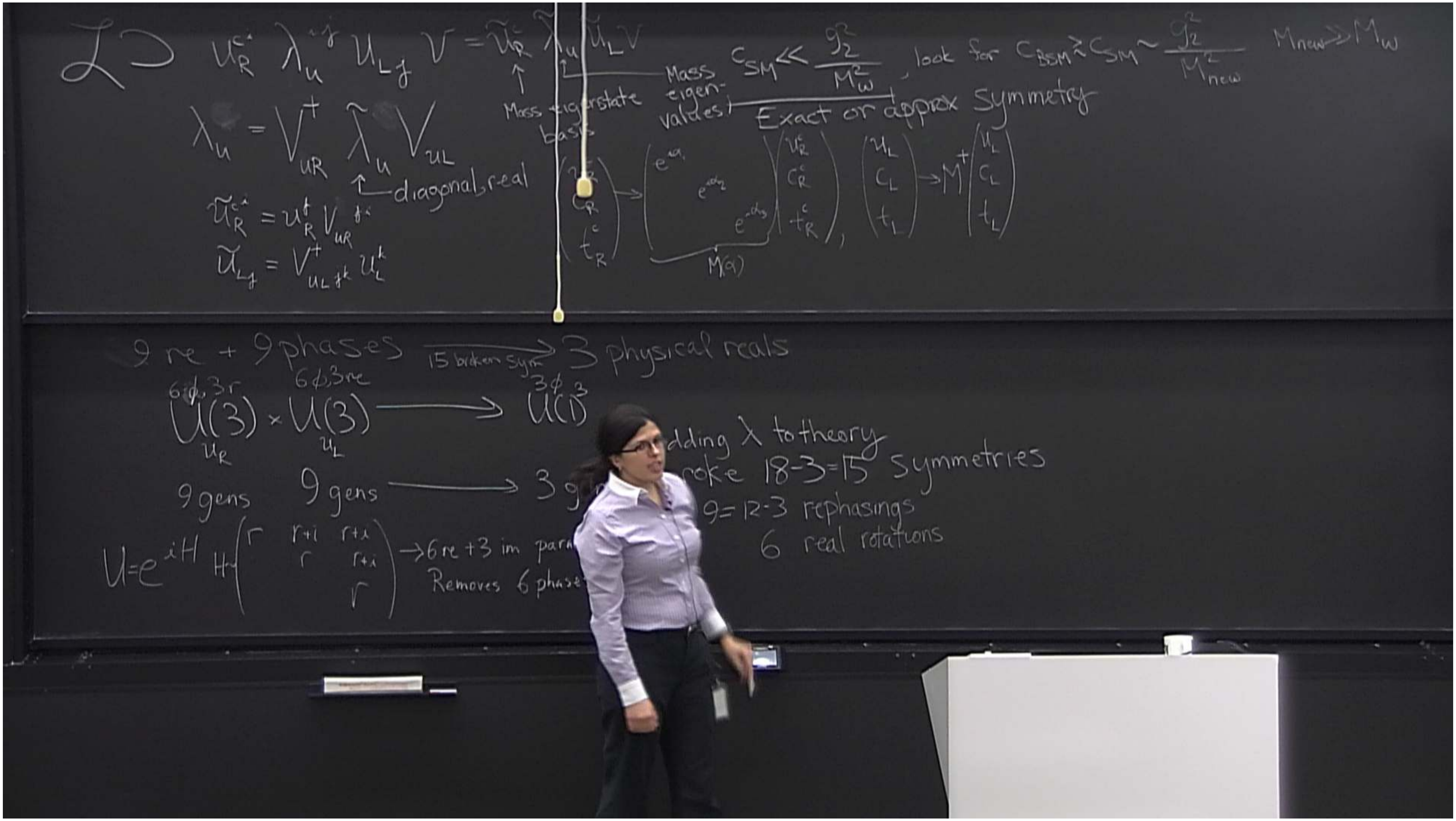
$(\mu^c_R e^c_R)(\bar{e}^c_R \bar{e}^c_R)$

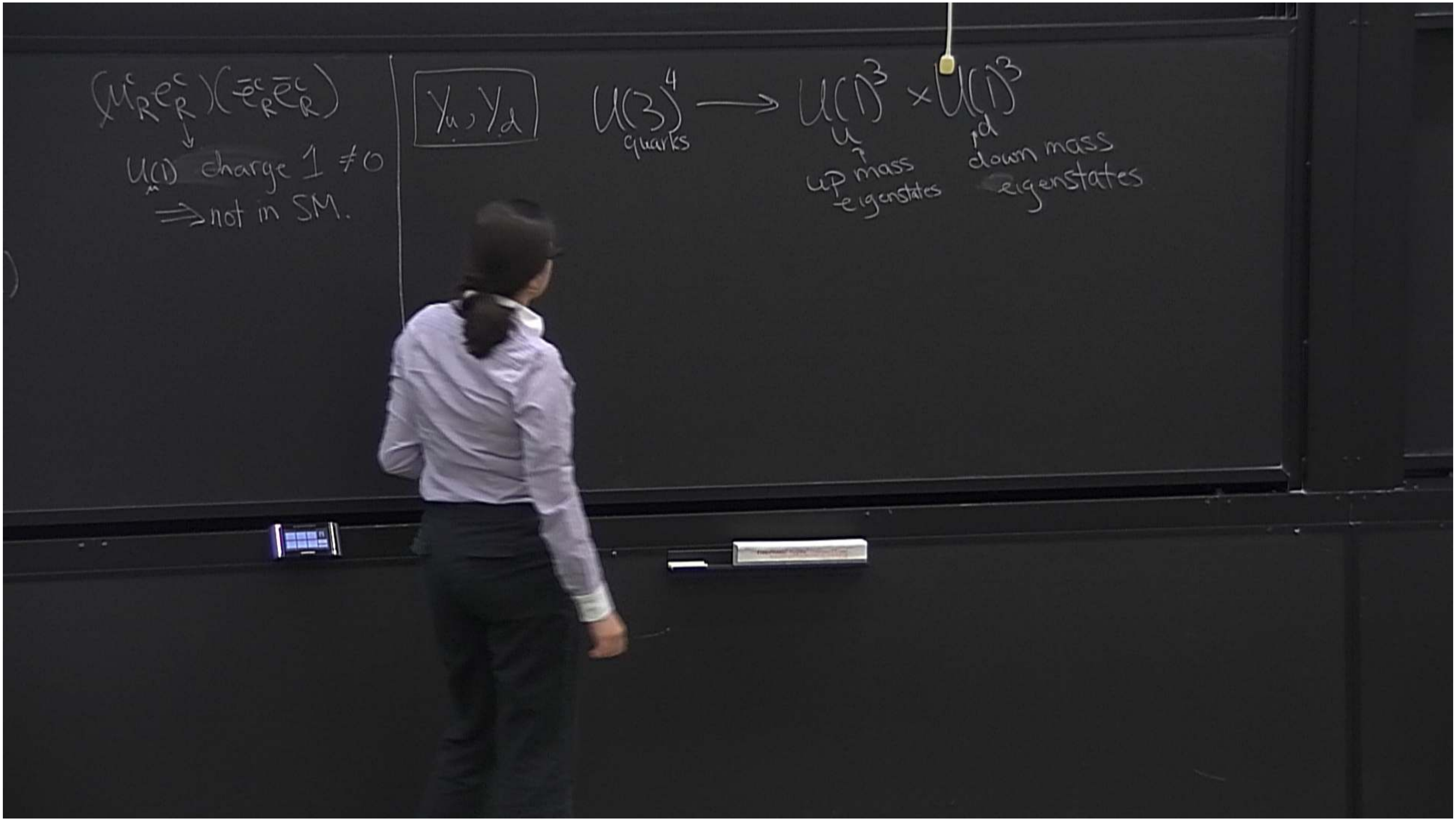
$\downarrow$

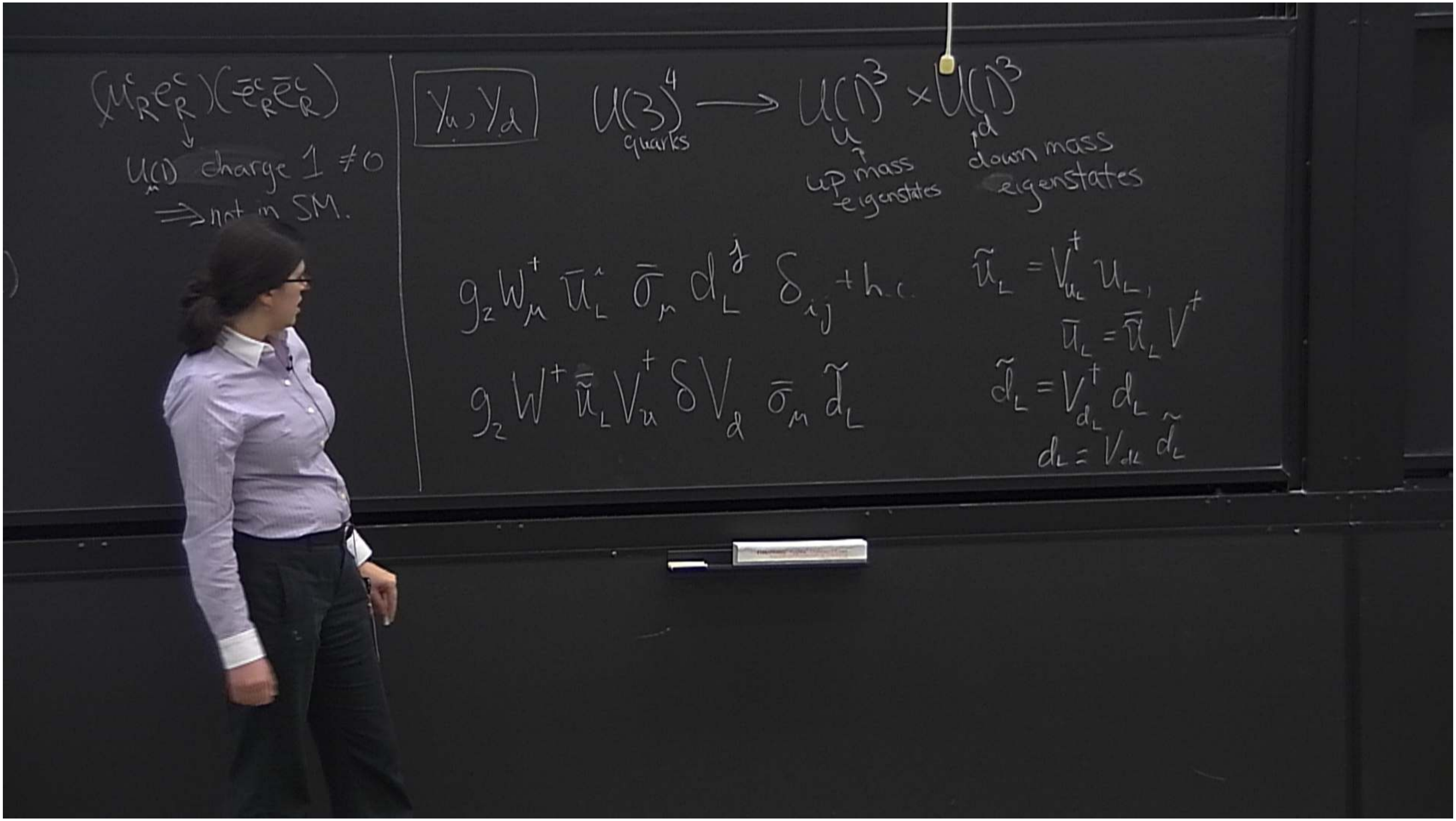
$U(1)_\mu$ charge $1 \neq 0$

$\Rightarrow$ not in SM.

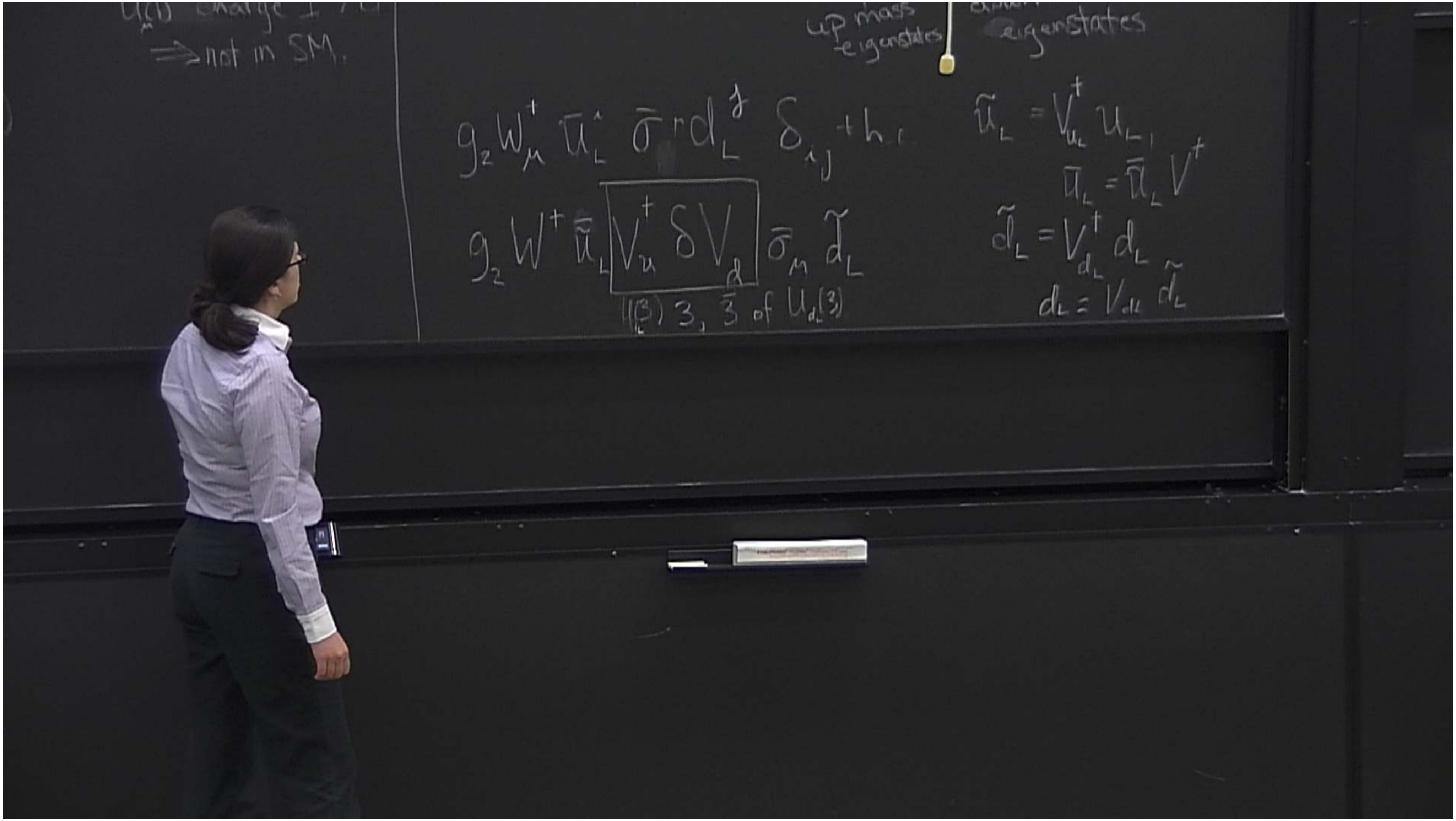

Interesting ops. $(\bar{s}_L \sigma^\mu d_L)^2$
$U_s(1)$ charge $-2 \neq 0$
⇒ Not in SM... Yet!
(Y_u, g_2) or (Y_d, g_2)
$(\mu^c_R e^c_R)(\bar{e}^c_R \bar{e}^c_R)$
$U_\mu(1)$ charge $1 \neq 0$
⇒ not in SM.

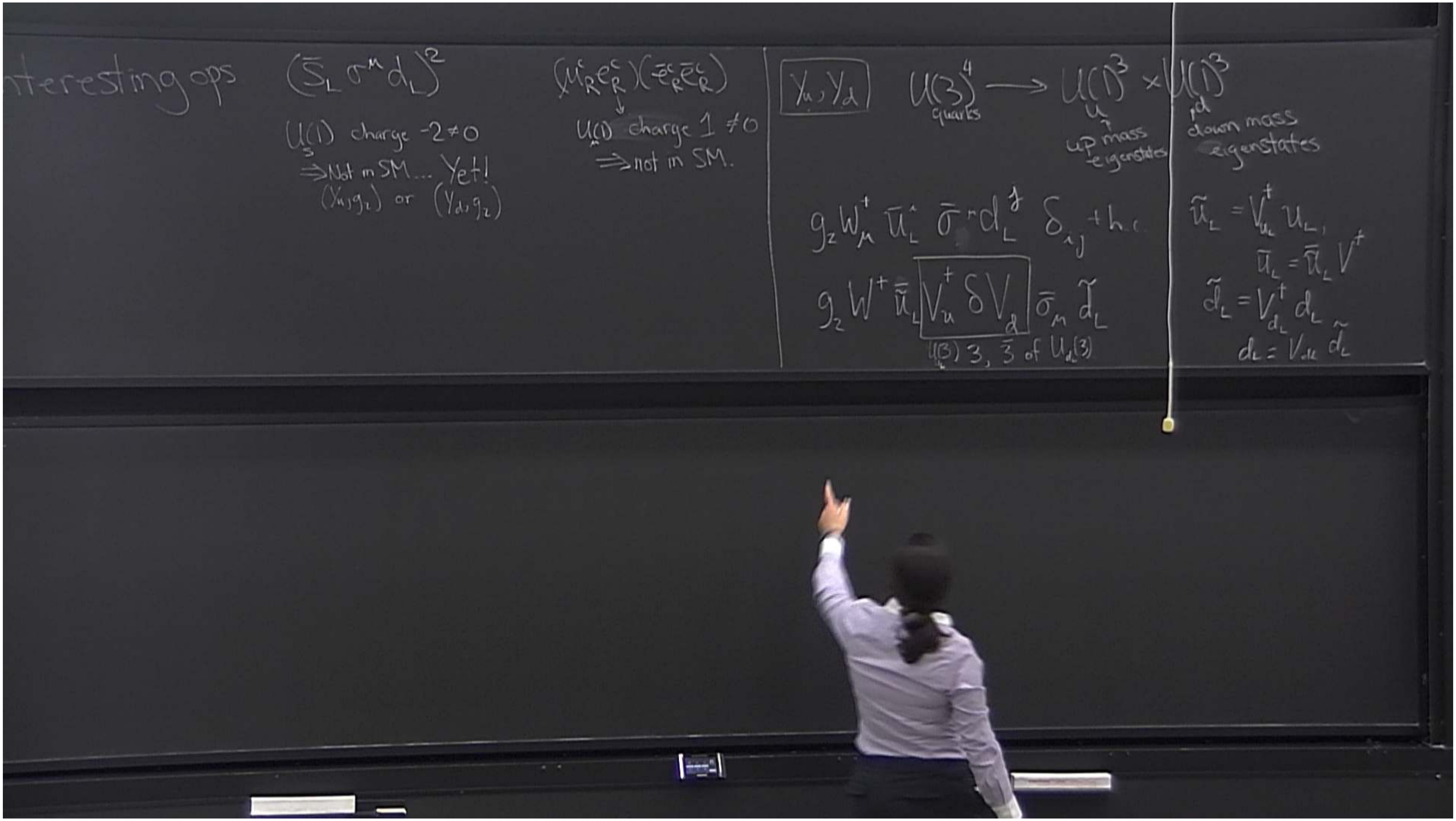

Mass eigenstate basis
Mass eigen-values
diagonal, real
Exact or approx symmetry
look for
9 re + 9 phases
15 broken sym
3 physical reals
9 gens
9 gens
adding λ to theory
broke 18-3=15 symmetries
9=12-3 rephasings
6 real rotations
Removes 6 phases

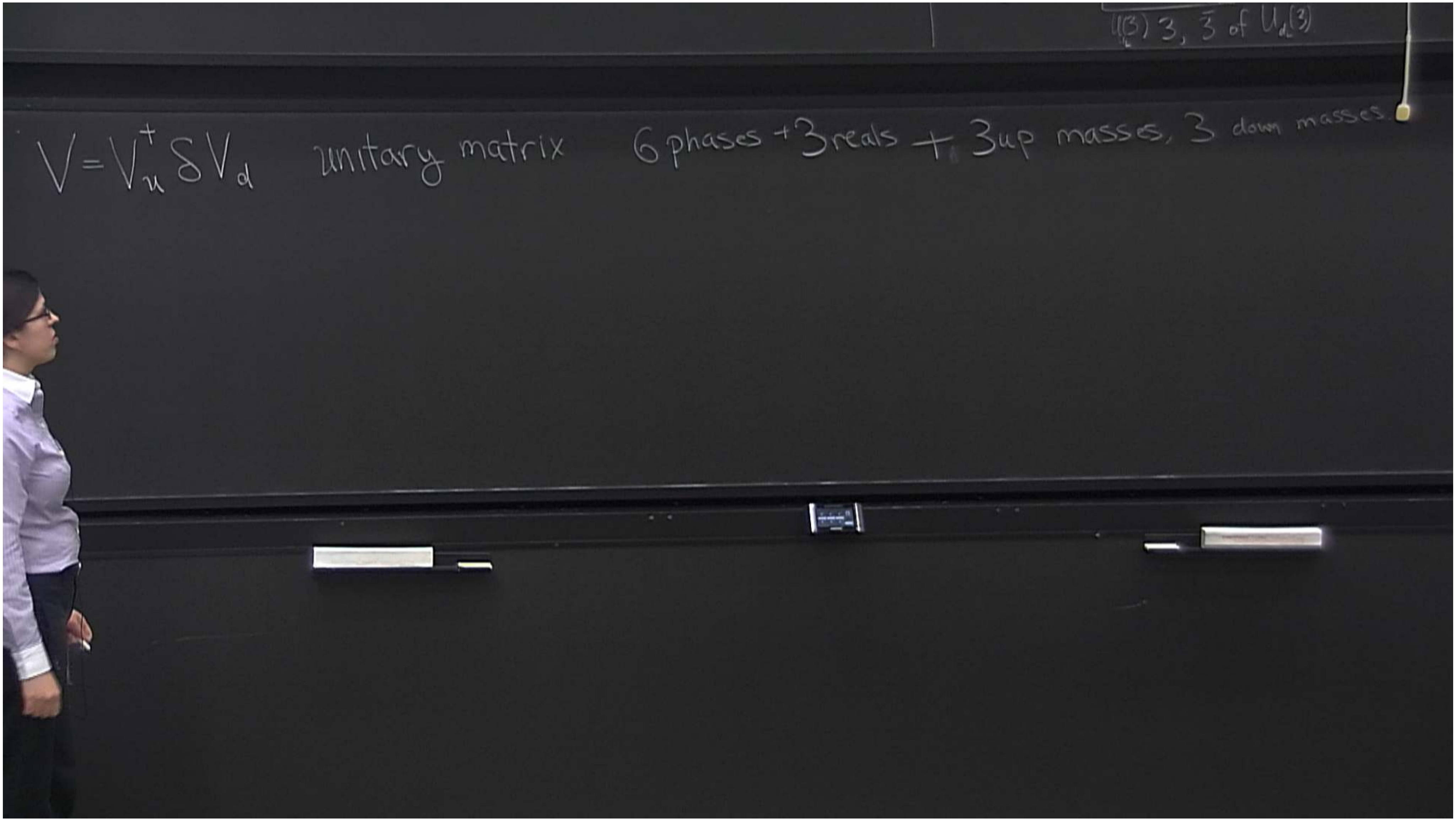

(μ^c_R e^c_R)(ē^c_R ē^c_R)
U(1) charge 1 ≠ 0
⇒ not in SM.
Y_u , Y_d
U(3)^4 → U(1)^3 × U(1)^3
quarks
u
d
up mass eigenstates
down mass eigenstates

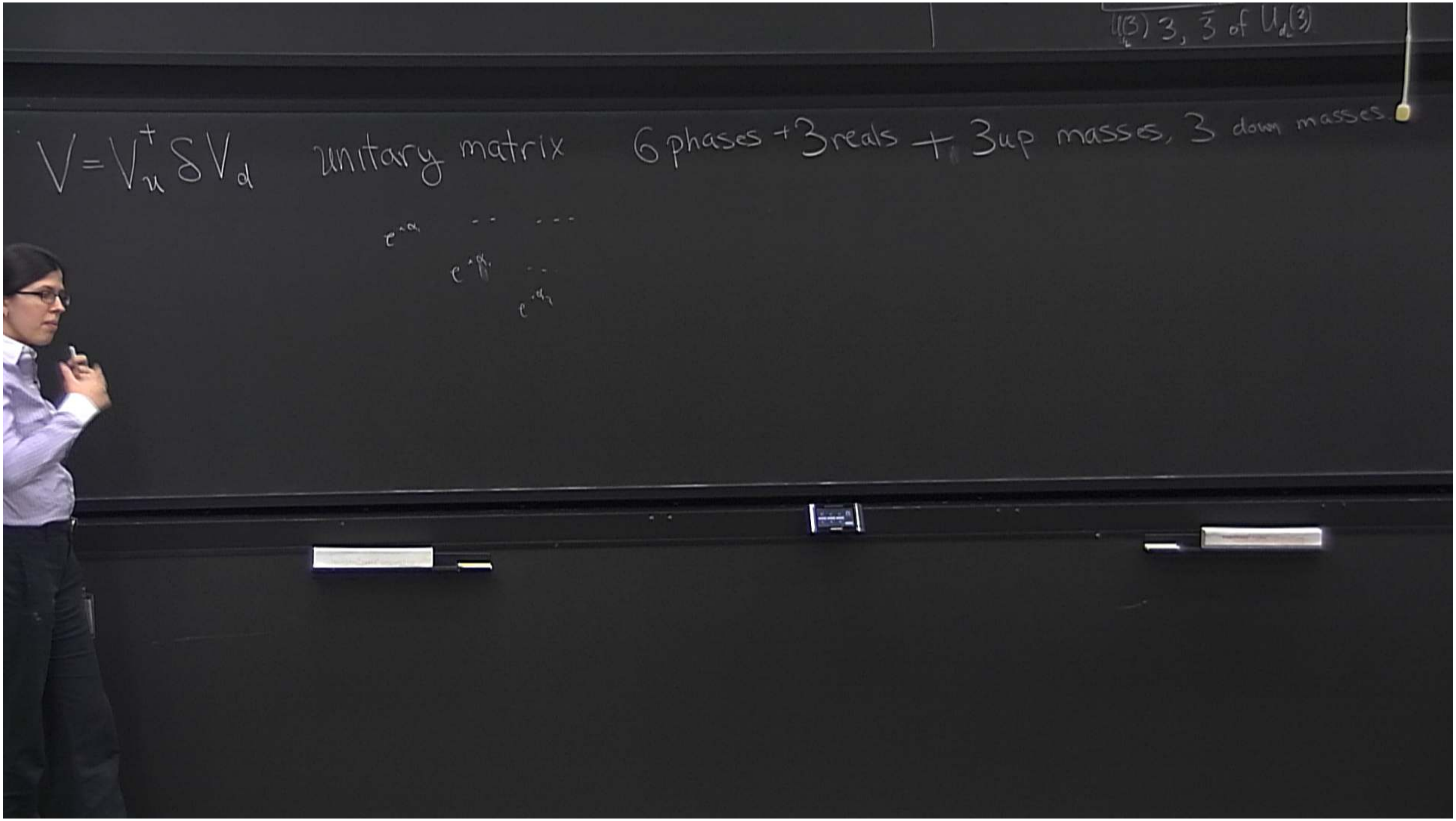


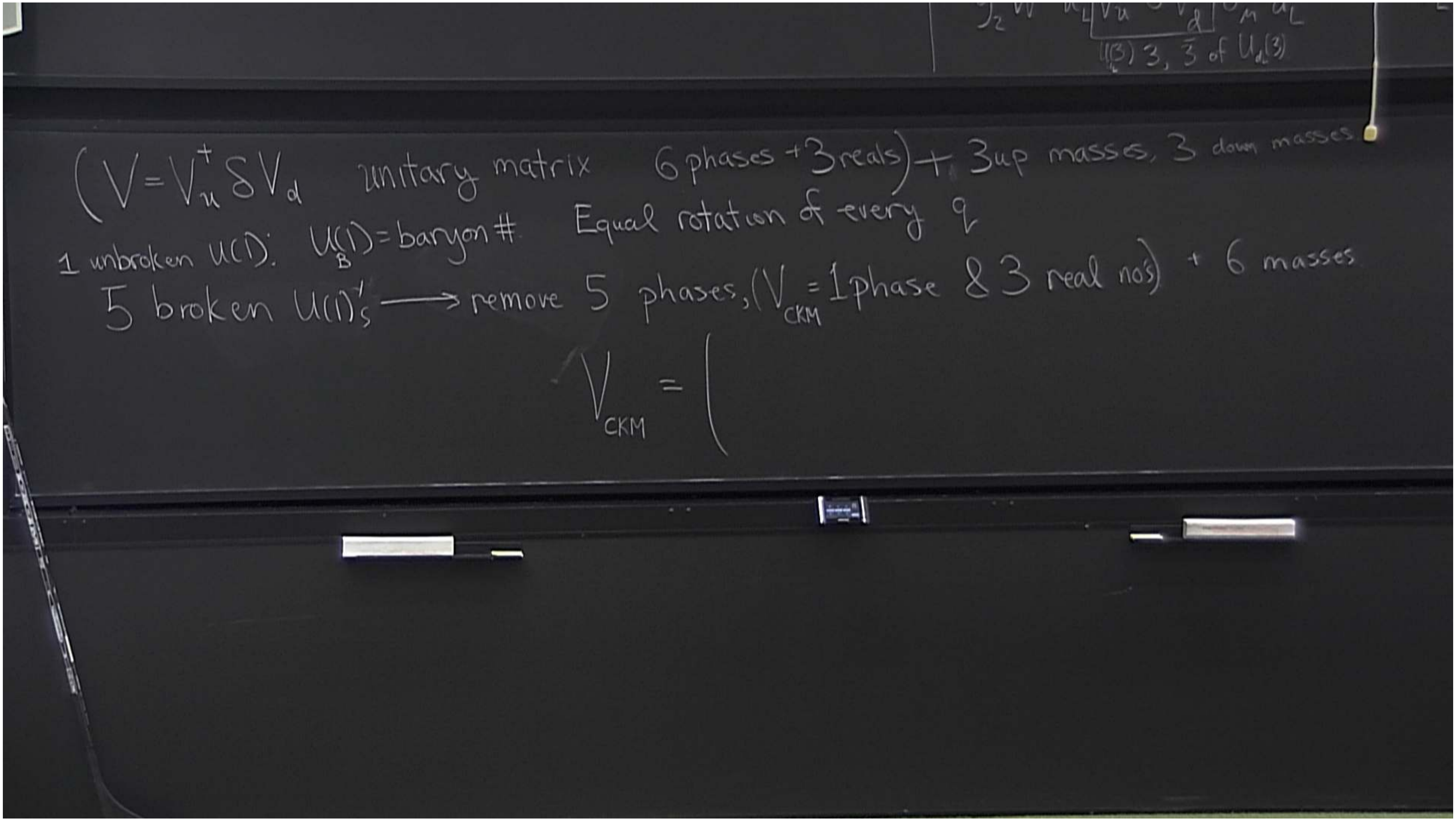
U(1) charge 1 ≠ 0
⇒ not in SM.
Y_u, Y_d
U(3)^4 → U(1)^3 × U(1)^3
quarks
up mass eigenstates
down mass eigenstates
g_2 W_μ^+ ū_L^i σ̄_μ d_L^j δ_ij + h.c.
g_2 W^+ ū_L V_u^† δ V_d σ̄_μ d̃_L


⇒ not in SM.
up mass eigenstates
eigenstates
$g_2 W_\mu^+ \bar{u}_L^i \bar{\sigma}^\mu d_L^j \delta_{ij}$ + h.c.
$g_2 W^+ \bar{\tilde{u}}_L V_u^\dagger \delta V_d \bar{\sigma}_\mu \tilde{d}_L$
$\tilde{u}_L = V_{u_L}^\dagger u_L$,
$\bar{u}_L = \bar{\tilde{u}}_L V^\dagger$
$\tilde{d}_L = V_{d_L}^\dagger d_L$
$d_L = V_{dL} \tilde{d}_L$
3, $\bar{3}$ of $U_{d_L}(3)$


interesting ops
$(\bar{s}_L \sigma^\mu d_L)^2$
$U(1)_s$ charge $-2 \neq 0$
⇒ Not in SM... Yet!
(Y_u, g_2) or (Y_d, g_2)
$(u^c_R e^c_R)(\bar{e}^c_R \bar{e}^c_R)$
$U(1)_\mu$ charge $1 \neq 0$
⇒ not in SM.
Y_u, Y_d
$U(3)^4_{\text{quarks}} \longrightarrow U(1)^3_u \times U(1)^3_d$
up mass eigenstates
down mass eigenstates
$g_2 W^+_\mu \bar{u}^i_L \bar{\sigma}^\mu d^j_L \delta_{ij} + h.c.$
$g_2 W^+ \bar{\tilde{u}}_L V^\dagger_u \delta V_d \bar{\sigma}_\mu \tilde{d}_L$
$U_u(3)$ 3, $\bar{3}$ of $U_d(3)$
$\tilde{u}_L = V^\dagger_{u_L} u_L$,
$\bar{\tilde{u}}_L = \bar{u}_L V^\dagger$
$\tilde{d}_L = V^\dagger_{d_L} d_L$
$d_L = V_{d_L} \tilde{d}_L$


U(3) 3, 3̄ of U_d(3)
V = V_u^† δ V_d unitary matrix 6 phases + 3 reals + 3 up masses, 3 down masses


3, 3̄ of U_d(3)
V = V_u^† δ V_d unitary matrix
6 phases + 3 reals + 3 up masses, 3 down masses.


U_L(3) 3, 3̄ of U_d(3)
(V = V_u^† δ V_d unitary matrix 6 phases + 3 reals) + 3 up masses, 3 down masses.
1 unbroken U(1): U_B(1) = baryon # Equal rotation of every q
5 broken U(1)'s ⟶ remove 5 phases, (V_CKM = 1 phase & 3 real no's) + 6 masses
V_CKM = (

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

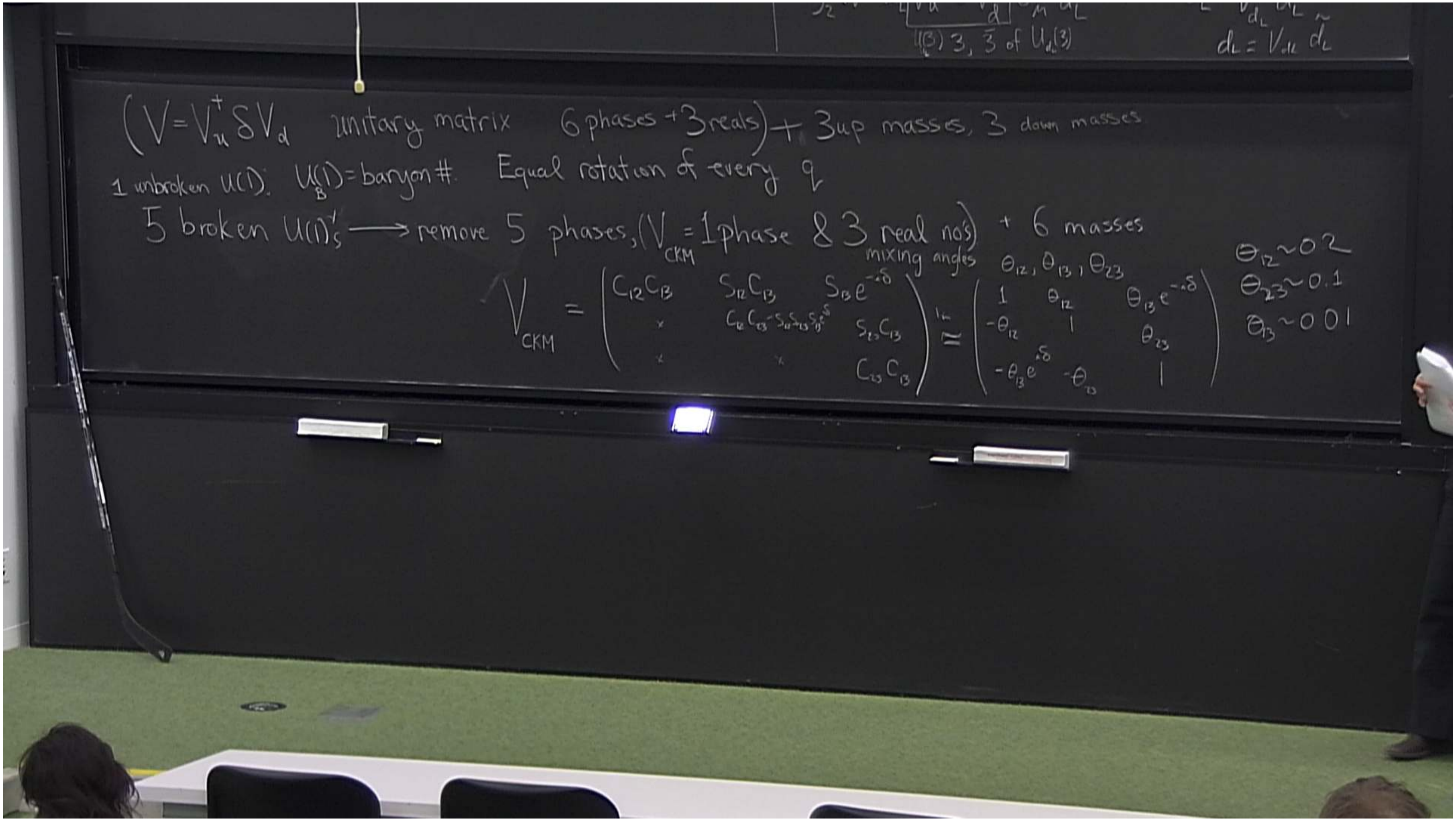
$\left(V = V_u^\dagger \delta V_d\right.$ unitary matrix 6 phases + 3 reals$\left.\right)$ + 3 up masses, 3 down masses.

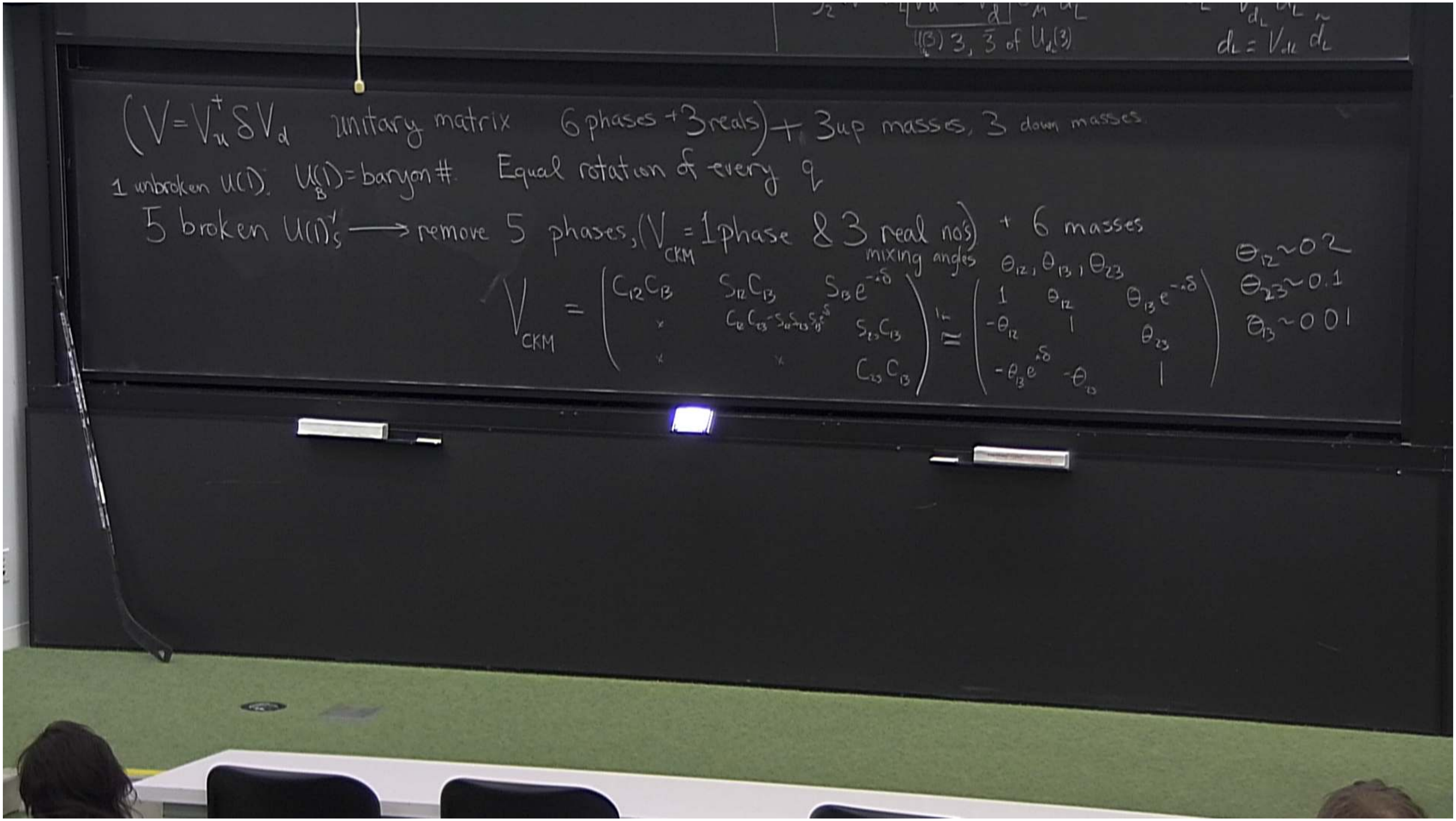
1 unbroken U(1): $U_B(1)$ = baryon #. Equal rotation of every q

5 broken $U(1)$'s $\longrightarrow$ remove 5 phases, (V_{CKM} = 1 phase & 3 real no's) + 6 masses

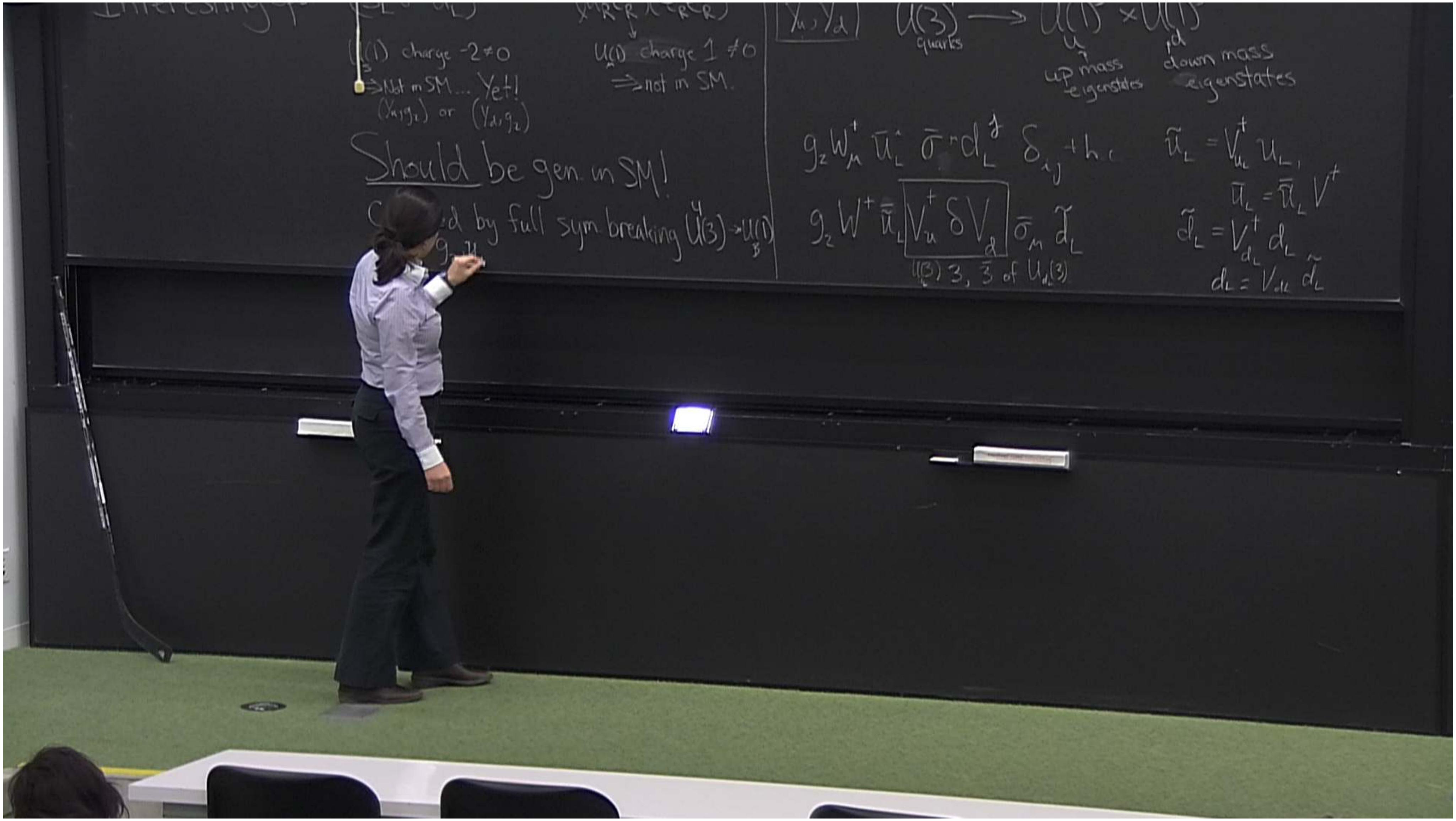
mixing angles $\theta_{12}, \theta_{13}, \theta_{23}$

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

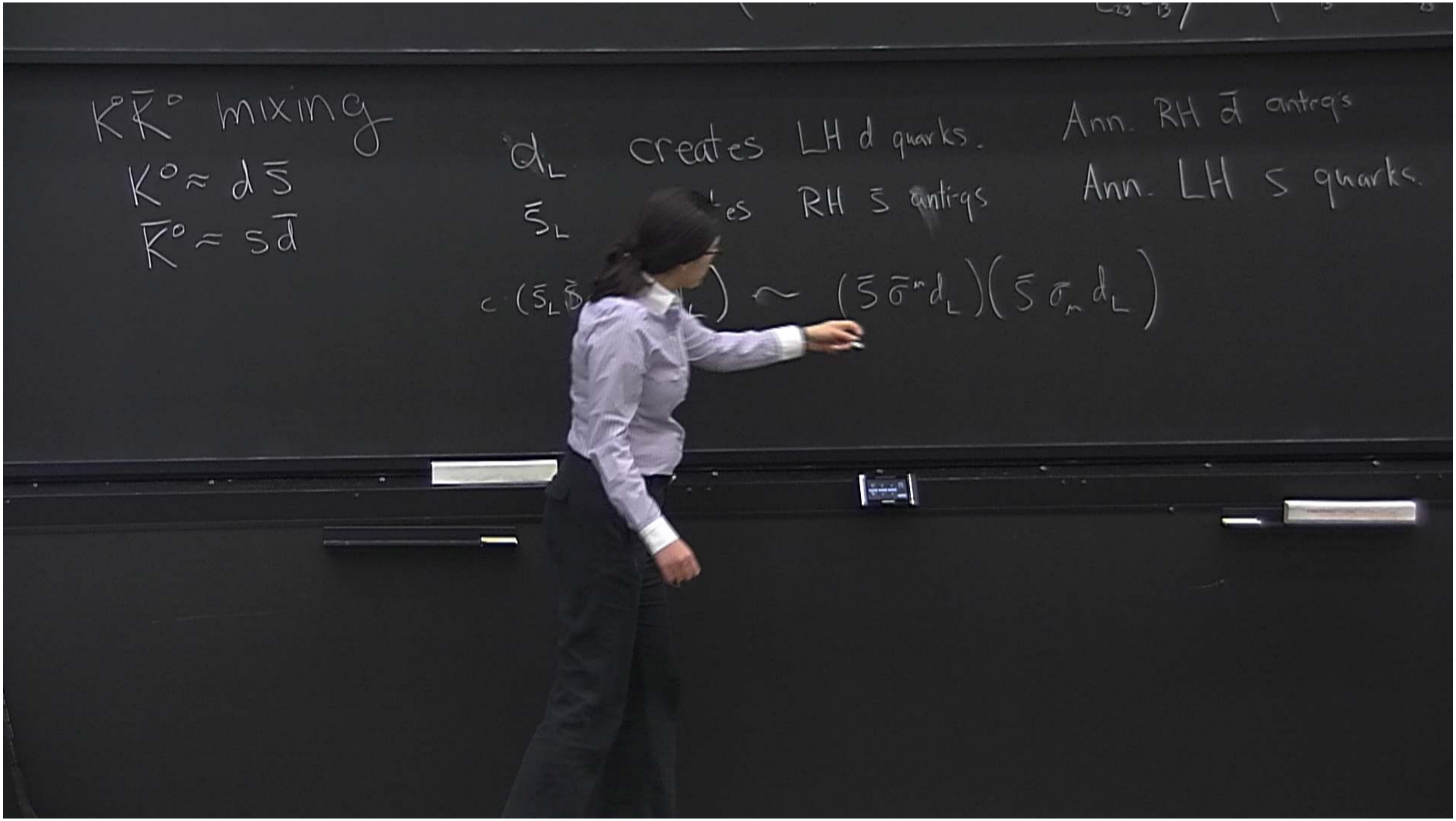

(V = V_u^† δ V_d unitary matrix 6 phases + 3 reals) + 3 up masses, 3 down masses
1 unbroken U(1): U_B(1) = baryon #. Equal rotation of every q
5 broken U(1)'s ⟶ remove 5 phases, (V_CKM = 1 phase & 3 real no's) + 6 masses
mixing angles θ_12, θ_13, θ_23
θ_12 ~ 0.2
θ_23 ~ 0.1
θ_13 ~ 0.01

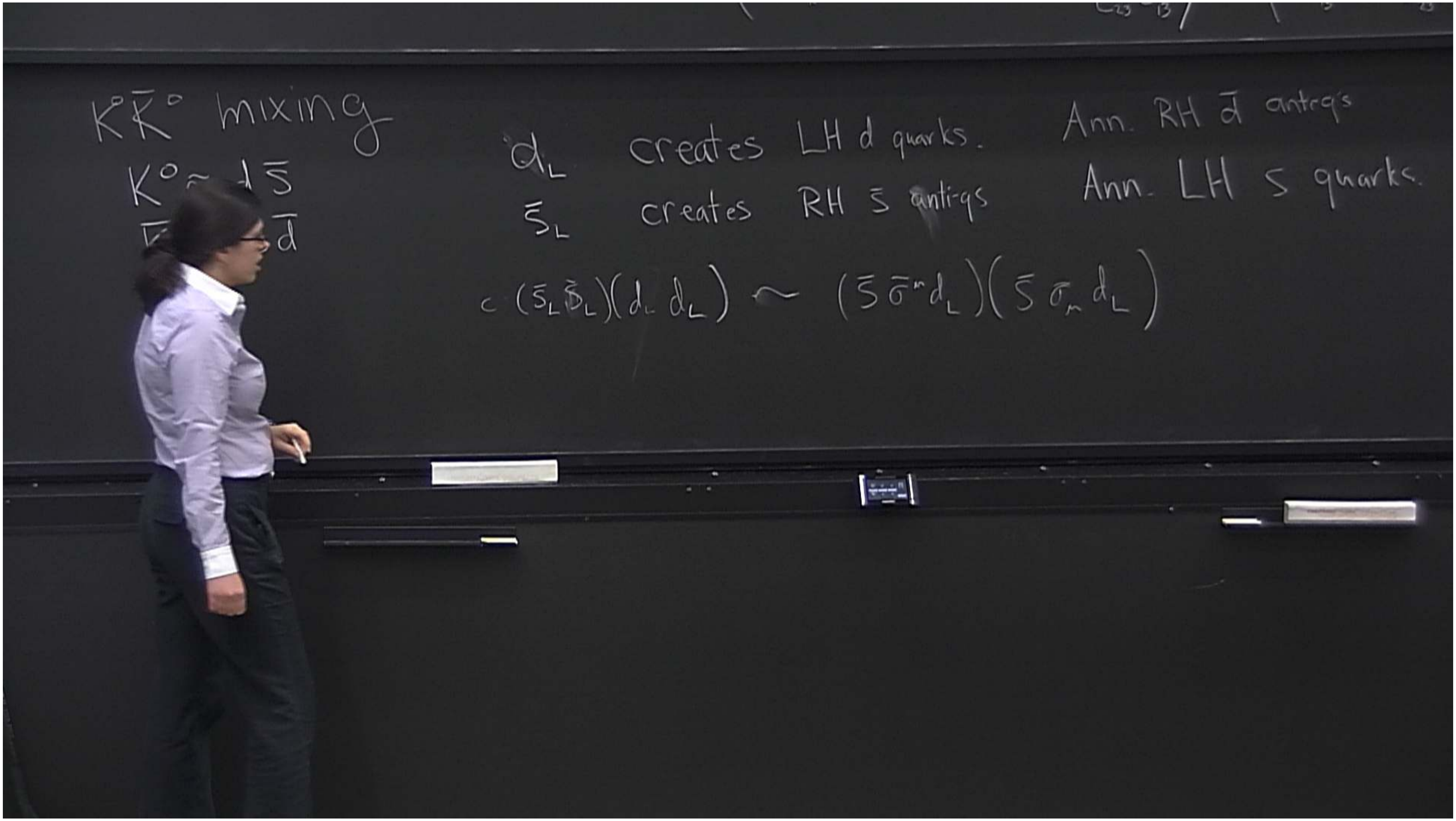


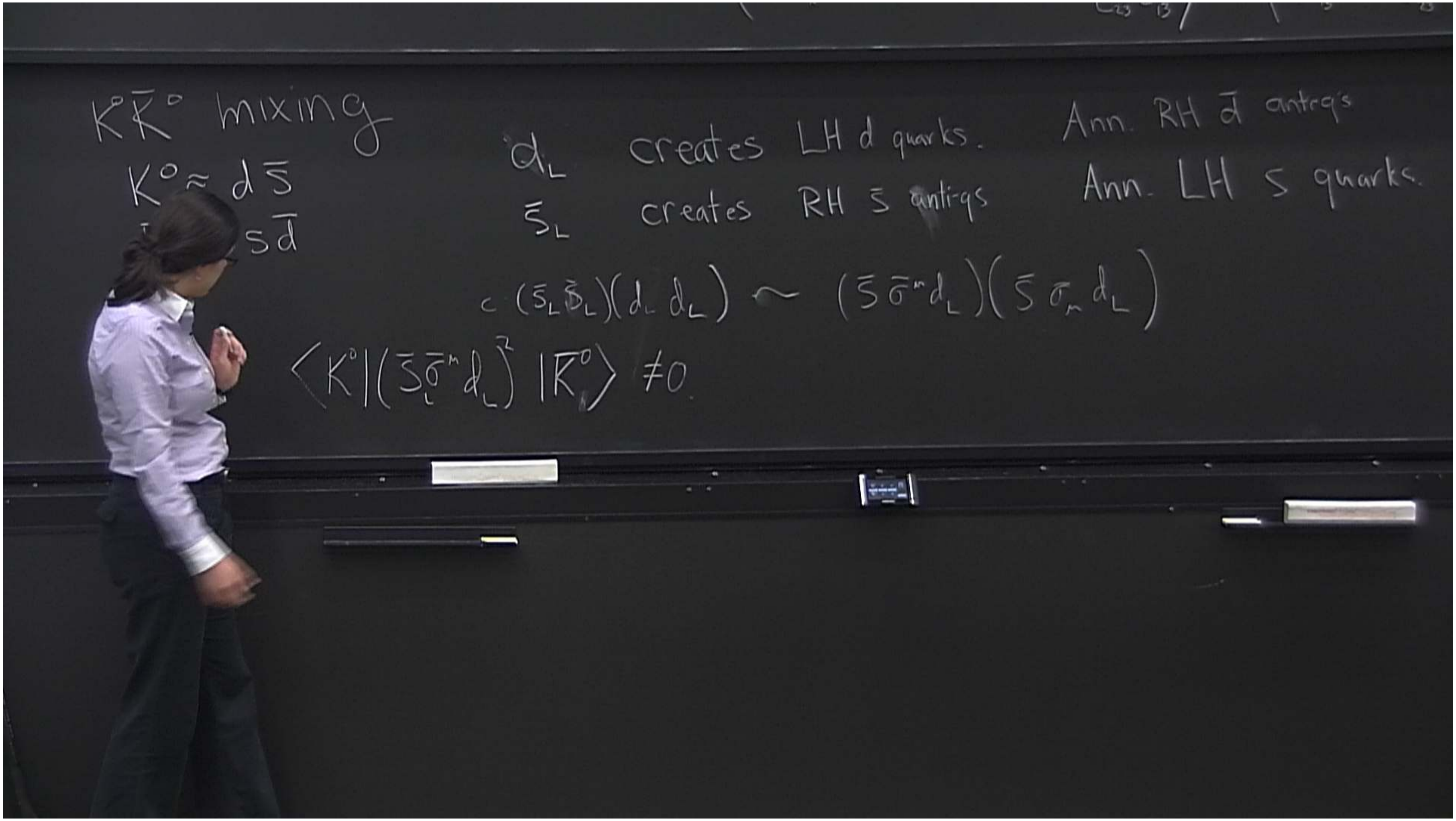
$(V = V_u^\dagger \delta V_d$ unitary matrix 6 phases + 3 reals) + 3 up masses, 3 down masses
1 unbroken U(1): $U_B(1)$ = baryon #. Equal rotation of every q
5 broken U(1)'s ⟶ remove 5 phases, (V_{CKM} = 1 phase & 3 real no's) + 6 masses
mixing angles $\theta_{12}, \theta_{13}, \theta_{23}$
$\theta_{12} \sim 0.2$
$\theta_{23} \sim 0.1$
$\theta_{13} \sim 0.01$

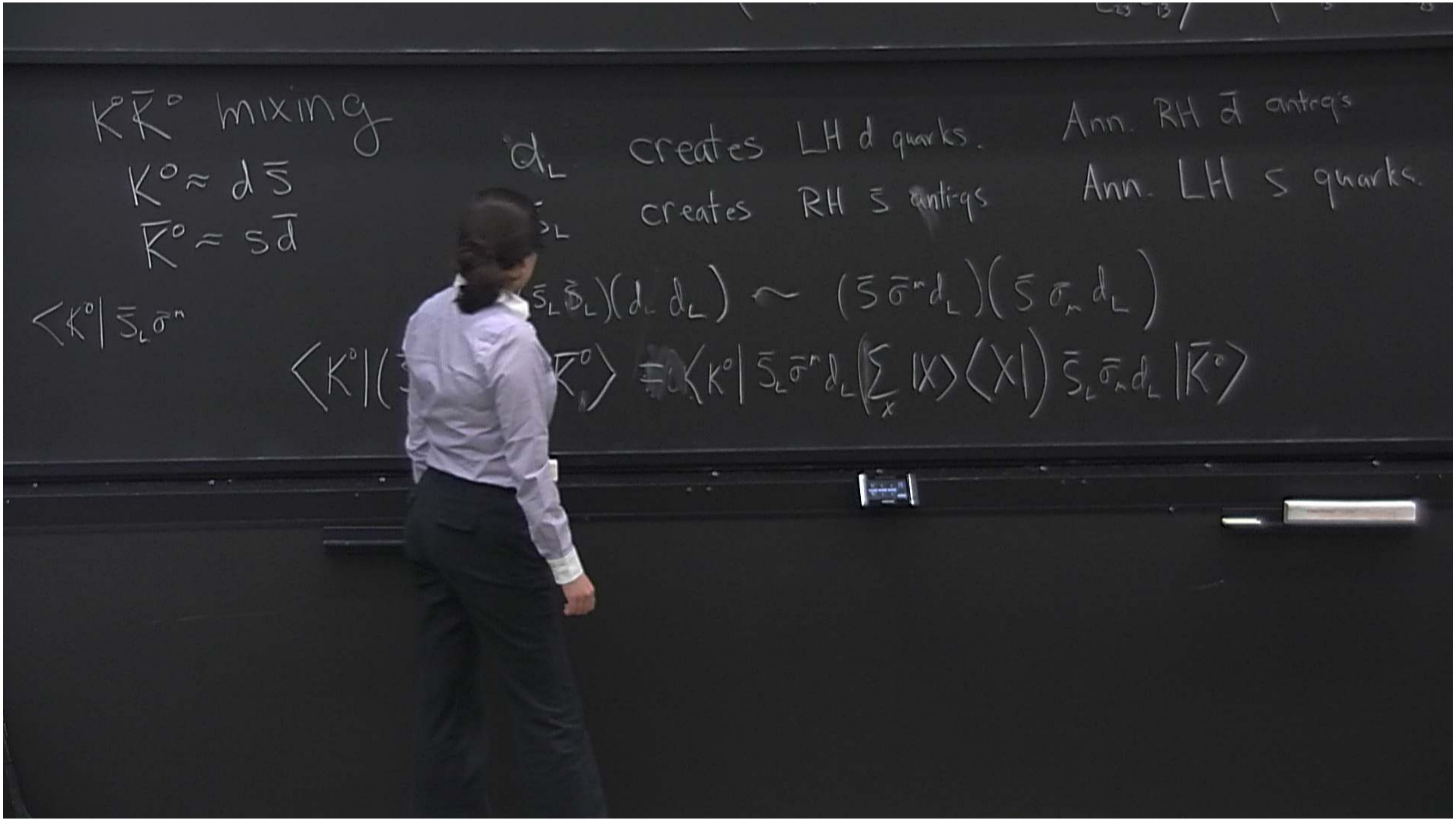


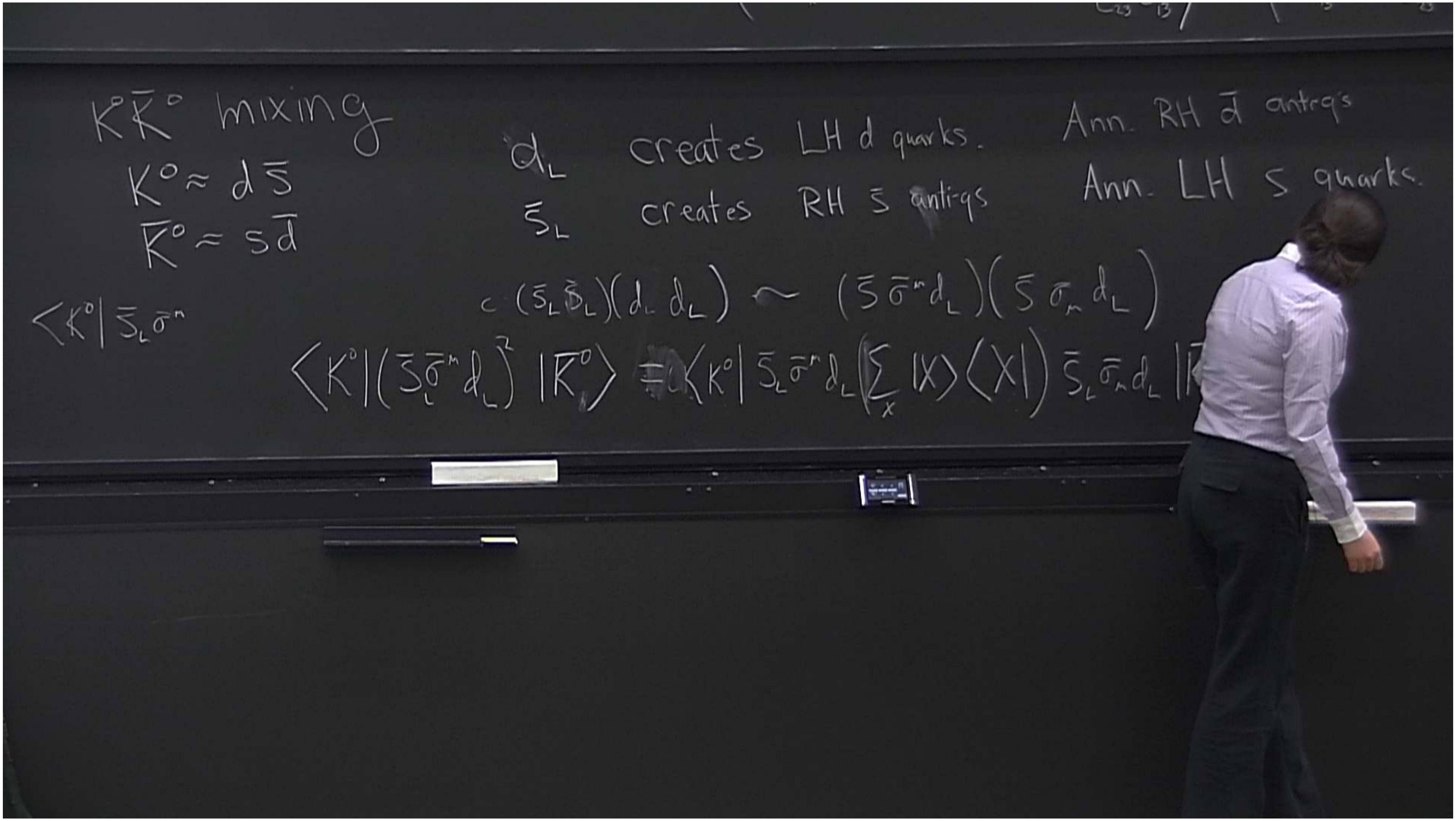
U(1) charge -2 ≠ 0
⇒ Not in SM... Yet!
U(1) charge 1 ≠ 0
⇒ not in SM.
Should be gen. in SM!
by full sym. breaking
quarks
up mass eigenstates
down mass eigenstates
U(3) 3, 3̄ of U_d(3)


K⁰K̄⁰ mixing
K⁰ ≈ d s̄
K̄⁰ ≈ s d̄
d_L creates LH d quarks.
Ann. RH d̄ antiq's
s̄_L es RH s̄ anti-qs
Ann. LH s quarks.
~ (s̄ σ̄^μ d_L)(s̄ σ_μ d_L)


K⁰K̄⁰ mixing
d_L creates LH d quarks. Ann. RH d̄ anti-q's
s̄_L creates RH s̄ anti-qs Ann. LH s quarks.


K°K̄° mixing
K° ≈ d s̄
s d̄
d_L creates LH d quarks.
Ann. RH d̄ antiq's
s̄_L creates RH s̄ anti-qs
Ann. LH s quarks.
c (s̄_L s̄_L)(d_L d_L) ~ (s̄ σ̄^μ d_L)(s̄ σ_μ d_L)
⟨K°|(s̄_L σ̄^μ d_L)² |K̄°⟩ ≠ 0.


K°K̄° mixing
K° ≈ d s̄
K̄° ≈ s d̄
d_L creates LH d quarks. Ann. RH d̄ anti-q's
s̄_L creates RH s̄ anti-qs Ann. LH s quarks.

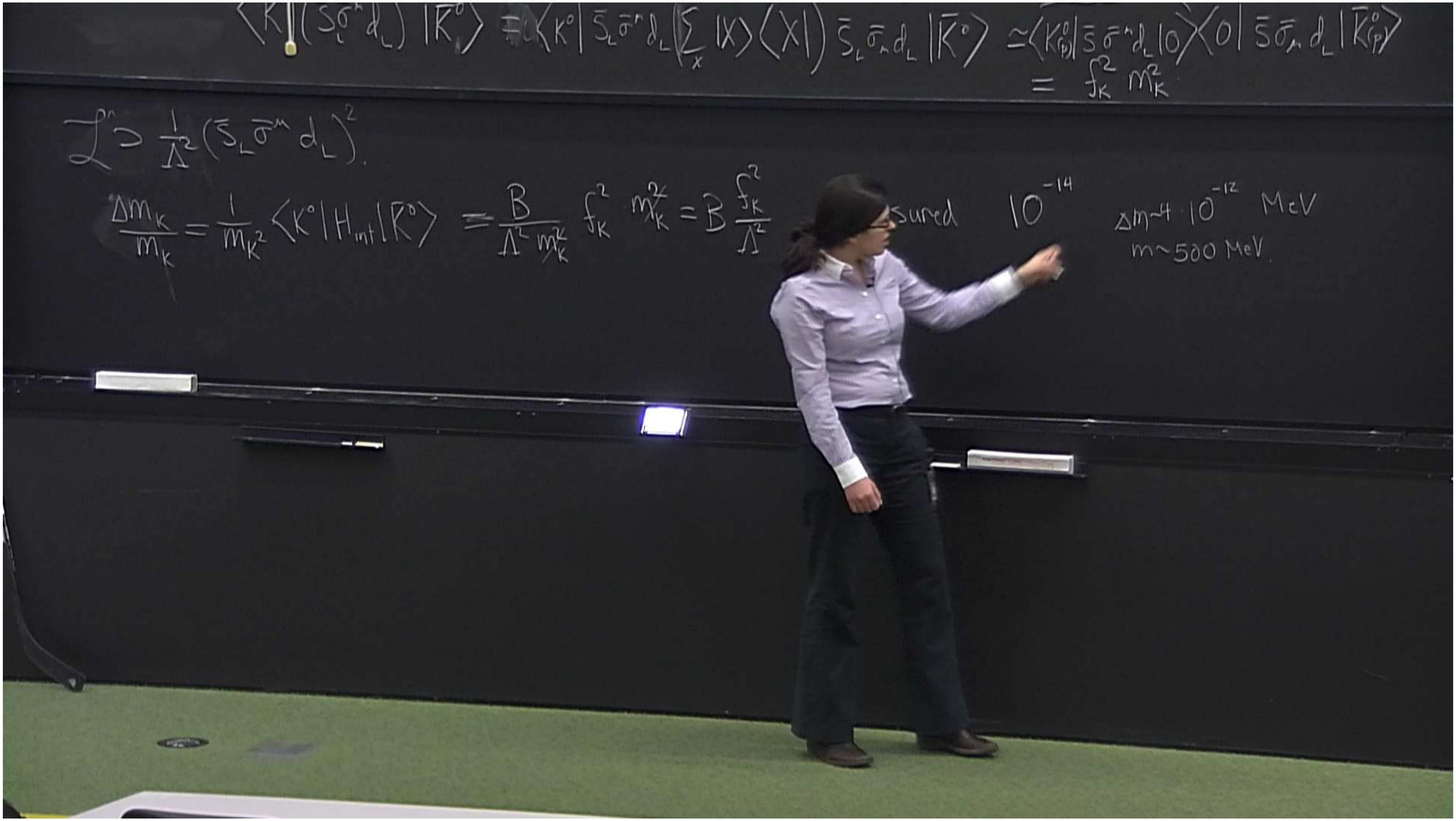

$K^0\bar{K}^0$ mixing
$K^0 \approx d\bar{s}$
$\bar{K}^0 \approx s\bar{d}$
d_L creates LH d quarks. Ann. RH $\bar{d}$ antiq's
$\bar{s}_L$ creates RH $\bar{s}$ anti-qs Ann. LH s quarks.
$c\,(\bar{s}_L \bar{s}_L)(d_L d_L) \sim (\bar{s}\bar{\sigma}^\mu d_L)(\bar{s}\bar{\sigma}_\mu d_L)$
$\langle K^0 | \bar{s}_L \bar{\sigma}^\mu$
$\langle K^0 | (\bar{s}_L \bar{\sigma}^\mu d_L)^2 | \bar{K}^0 \rangle = \langle K^0 | \bar{s}_L \bar{\sigma}^\mu d_L \left(\sum_X |X\rangle\langle X|\right) \bar{s}_L \bar{\sigma}_\mu d_L |\bar{K}$

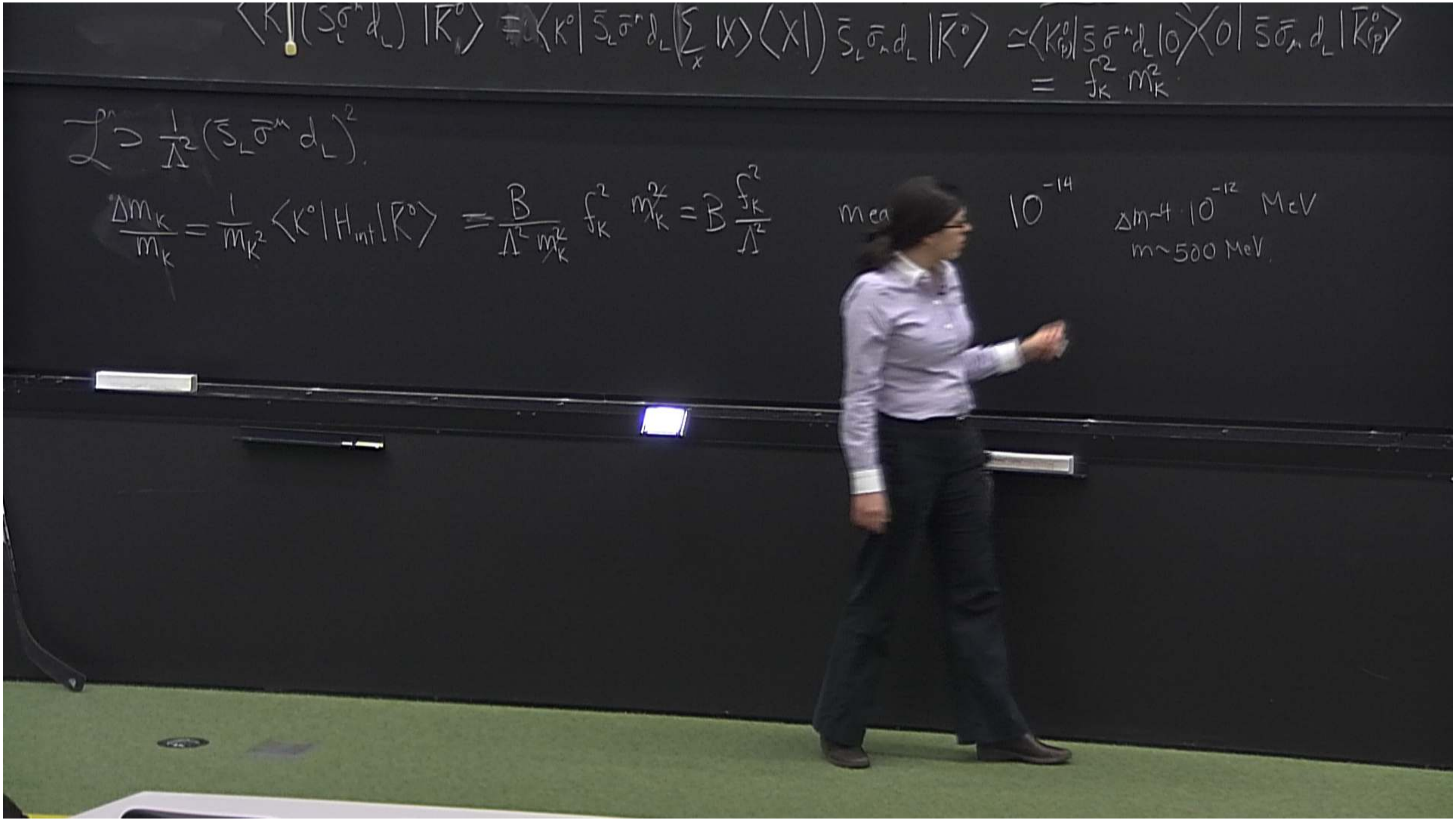
$= f_K^2 m$

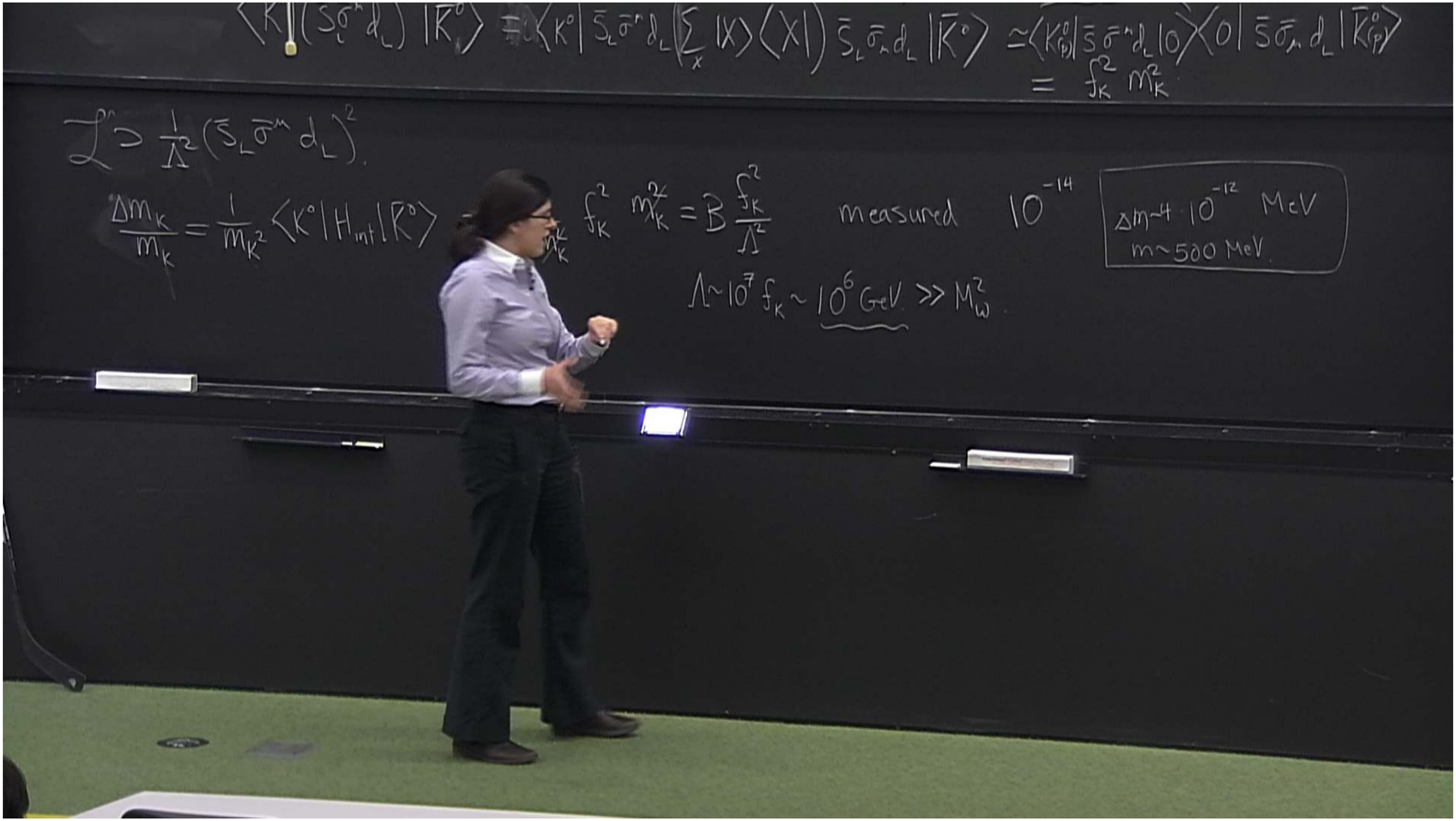
$$\mathcal{L} \supset \frac{1}{\Lambda^2}(\bar{s}_L \bar{\sigma}^\mu d_L)^2$$

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

measured 10^{-14}


sured
10^-14
Δm~4 · 10^-12 MeV
m~500 MeV


$\mathcal{L} \supset \frac{1}{\Lambda^2}(\bar{s}_L \bar{\sigma}^\mu d_L)^2$
$\frac{\Delta m_K}{m_K} = \frac{1}{m_K^2}\langle K^0 | H_{int} | \bar{K}^0 \rangle = \frac{B}{\Lambda^2 m_K^2} f_K^2 m_K^2 = B \frac{f_K^2}{\Lambda^2}$
$= f_K^2 m_K^2$
10^{-14}
$\Delta m \sim 4 \cdot 10^{-12}$ MeV
$m \sim 500$ MeV


measured 10^{-14}
$\Delta m \sim 4 \cdot 10^{-12}$ MeV
$m \sim 500$ MeV
$\Lambda \sim 10^{7} f_K \sim 10^{6}$ GeV $\gg M_W^2$