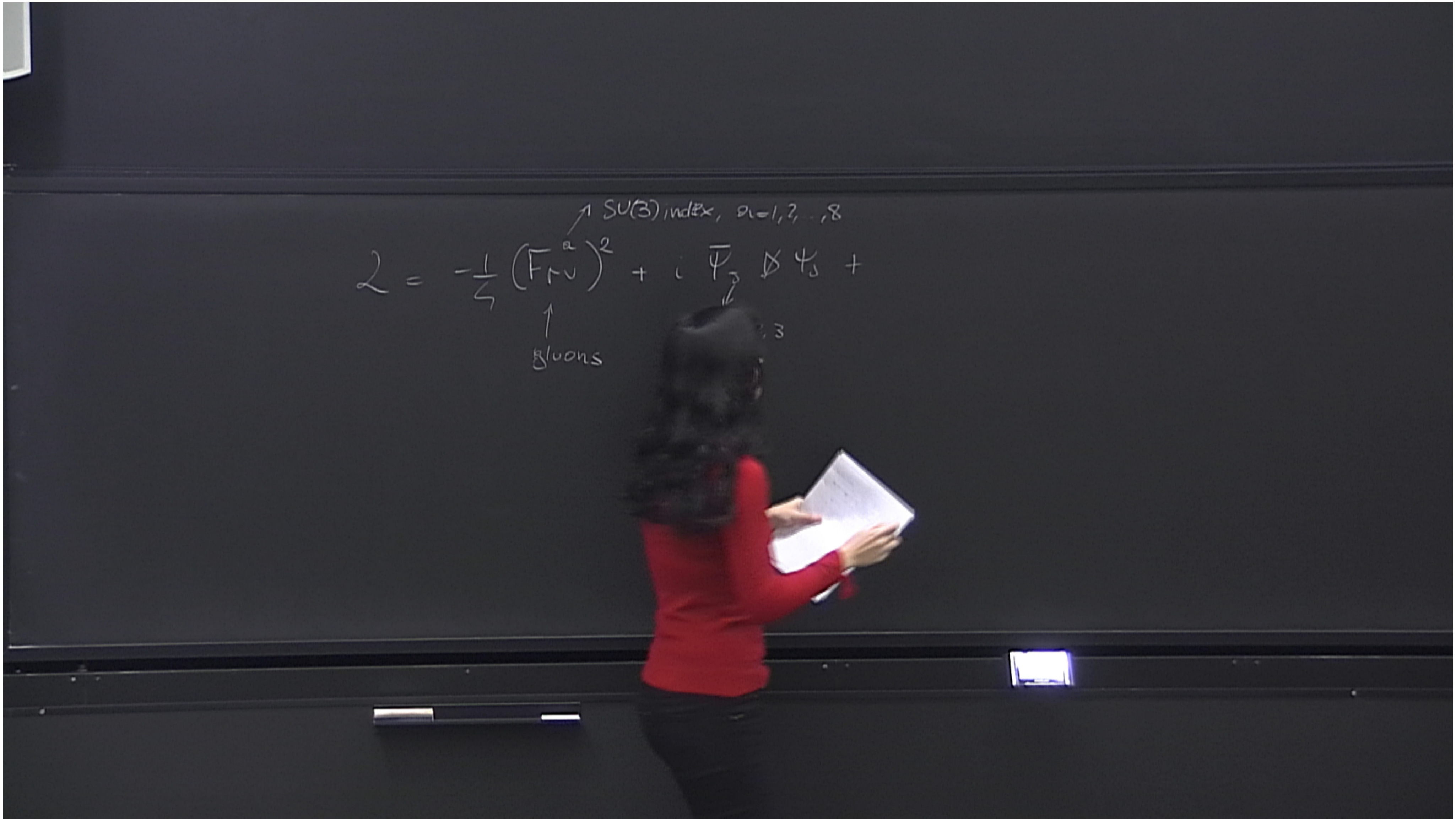
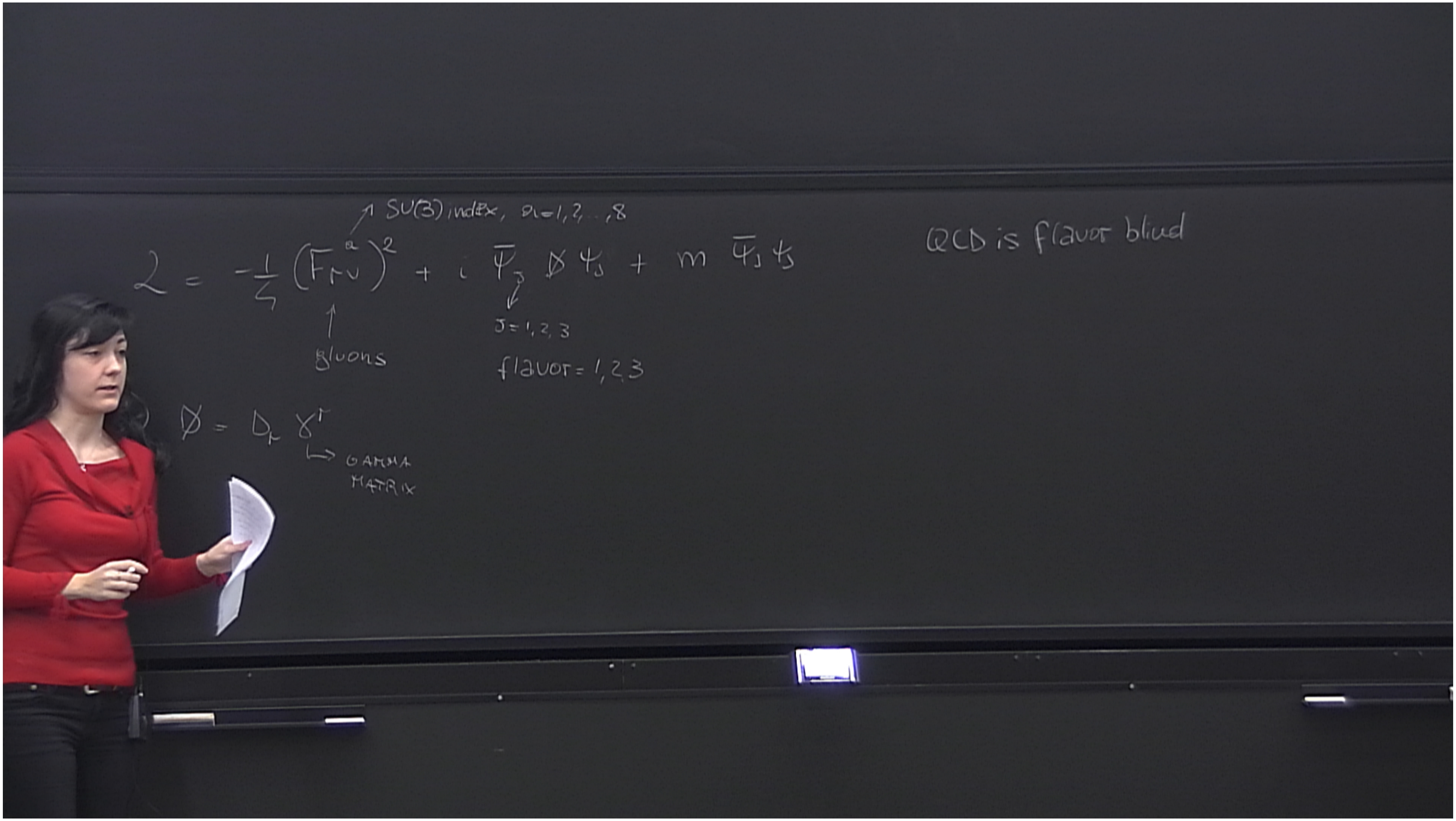
Title: Standard Model-12

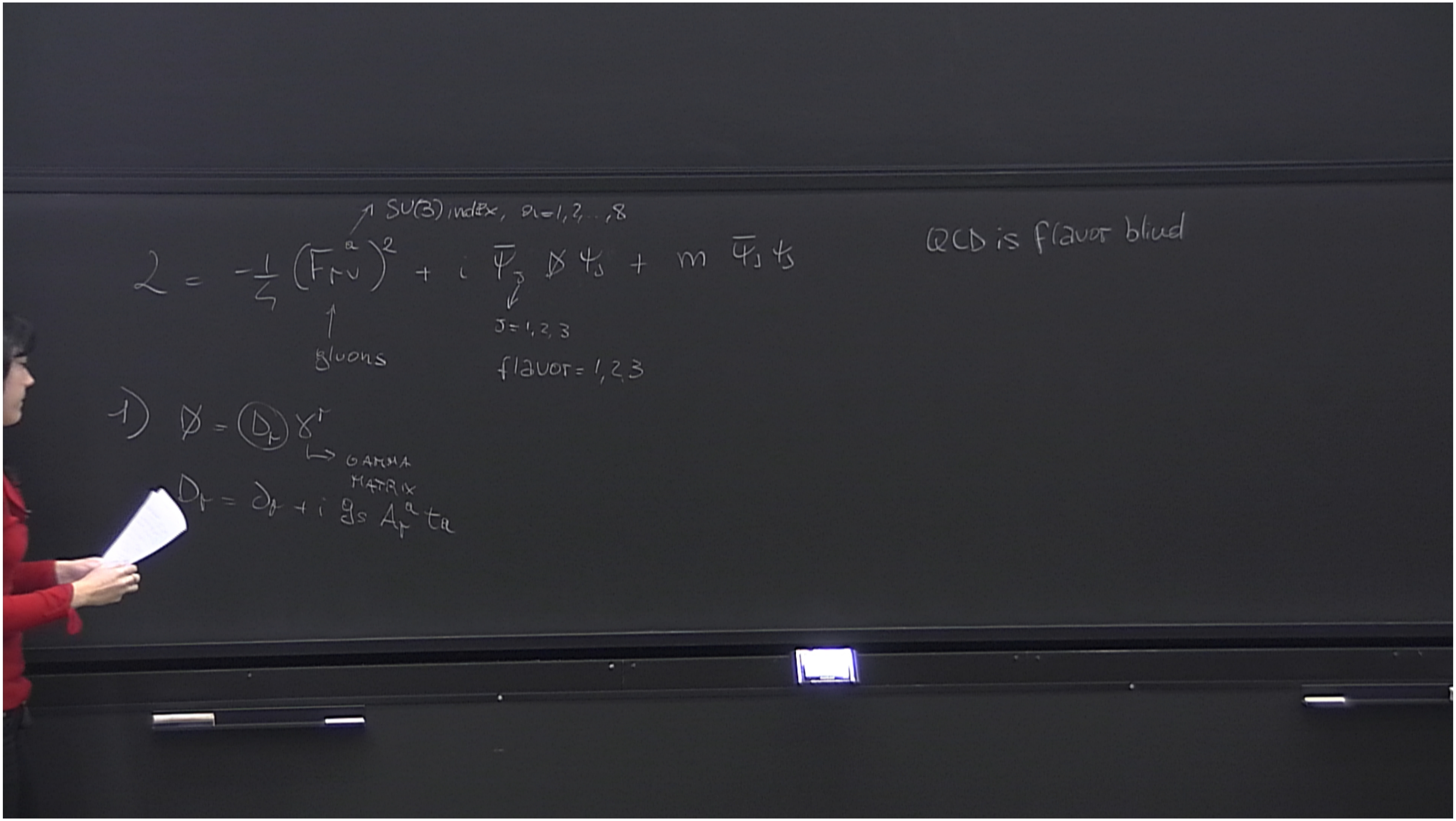
Date: Jan 20, 2015 09:00 AM

URL: http://pirsa.org/15010015

Abstract:


SU(3) index, a=1,2,..,8
$\mathcal{L} = -\frac{1}{4}(F_{\mu\nu}^{a})^2 + i\,\bar{\Psi}_j \not{D} \Psi_j +$
gluons


SU(3) index, $a=1,2,\ldots,8$
$\mathcal{L} = -\frac{1}{4}(F_{\mu\nu}^{a})^2 + i\,\bar{\psi}_j \not{D} \psi_j + m\,\bar{\psi}_j \psi_j$
gluons
$j = 1,2,3$
flavor = 1, 2, 3
$\not{D} = D_\mu \gamma^\mu$
GAMMA MATRIX
QCD is flavor blind


SU(3) index, a=1,2,...,8
$\mathcal{L} = -\frac{1}{4}(F_{\mu\nu}^{a})^2 + i\,\bar{\Psi}_j \not{D}\, \Psi_j + m\,\bar{\Psi}_j \Psi_j$
QCD is flavor blind
gluons
j=1,2,3
flavor=1,2,3
1) $\not{D} = D_\mu \gamma^\mu$
GAMMA MATRIX
$D_\mu = \partial_\mu + i g_s A_\mu^a t_a$

SU(3) index, $a=1,2,\dots,8$

QCD is flavor blind

$$\mathcal{L} = -\frac{1}{4}\left(F_{\mu\nu}^{a}\right)^2 + i\,\bar{\Psi}_j \not{D}\, \Psi_j + m\,\bar{\Psi}_j \Psi_j$$

gluons

$j = 1,2,3$

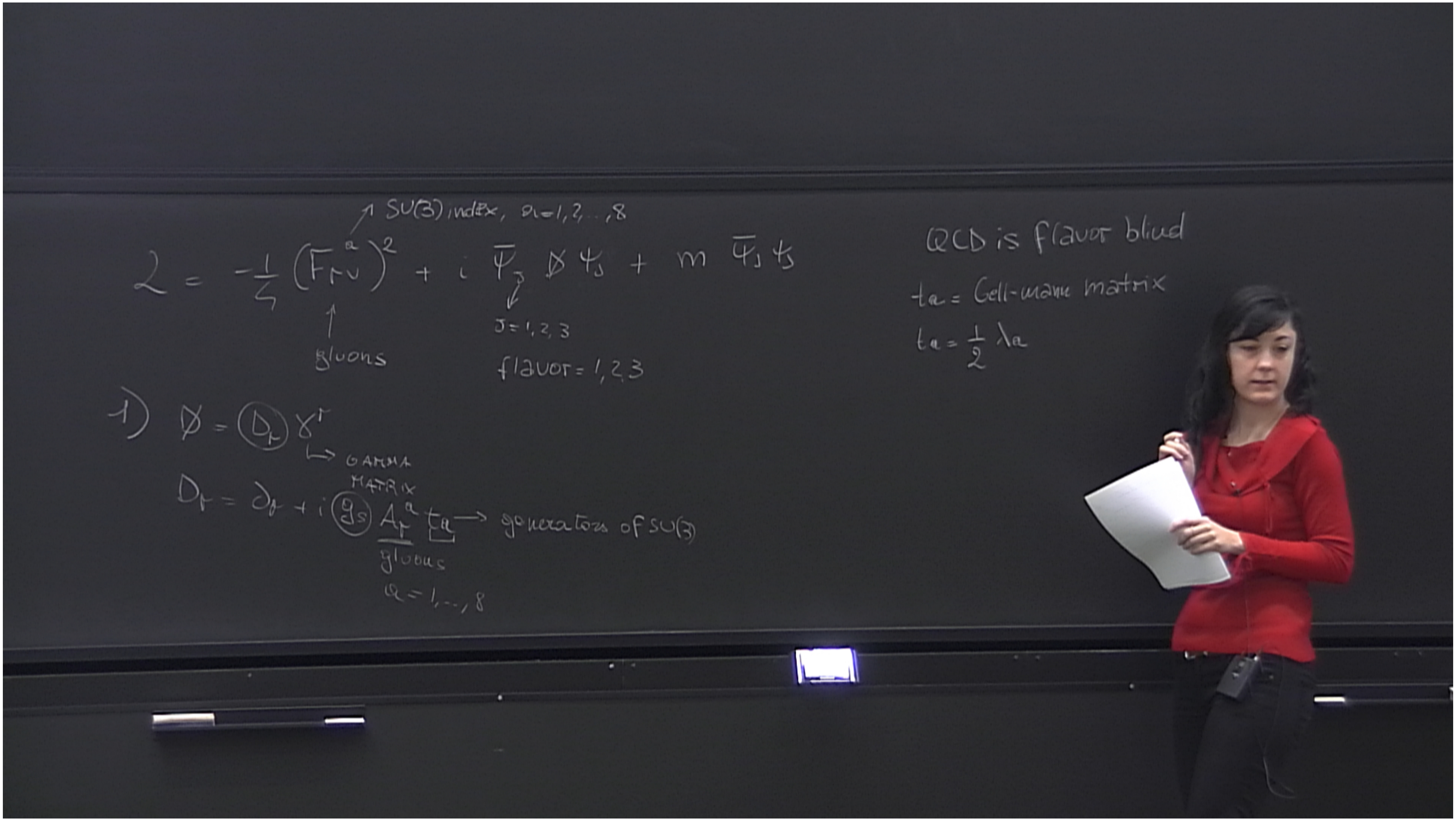
flavor $= 1,2,3$

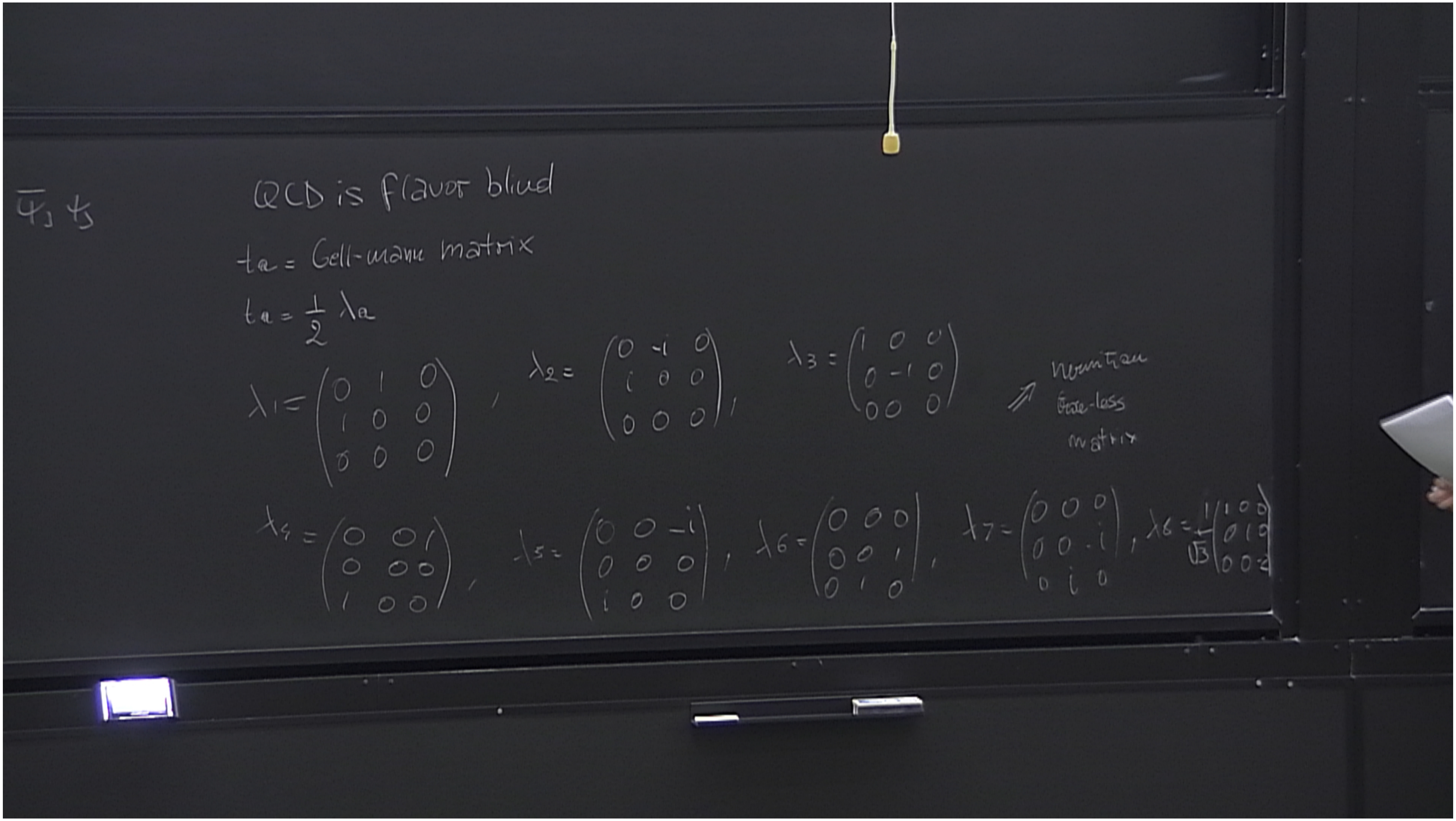
1) $\not{D} = D_\mu \gamma^\mu$

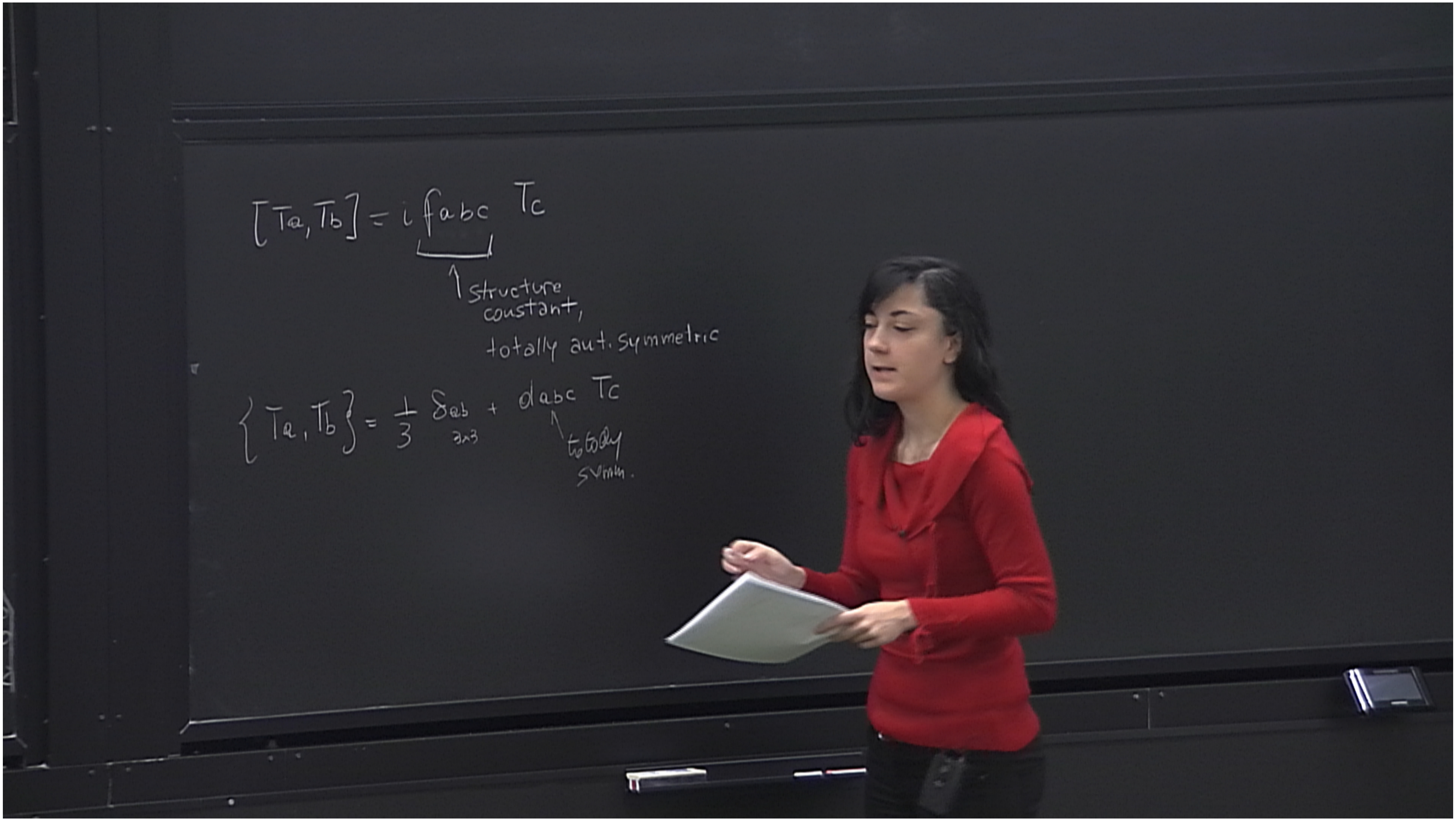
GAMMA MATRIX

$$D_\mu = \partial_\mu + i\, g_s\, \underbrace{A_\mu^a}_{\text{gluons}}\, t_a$$

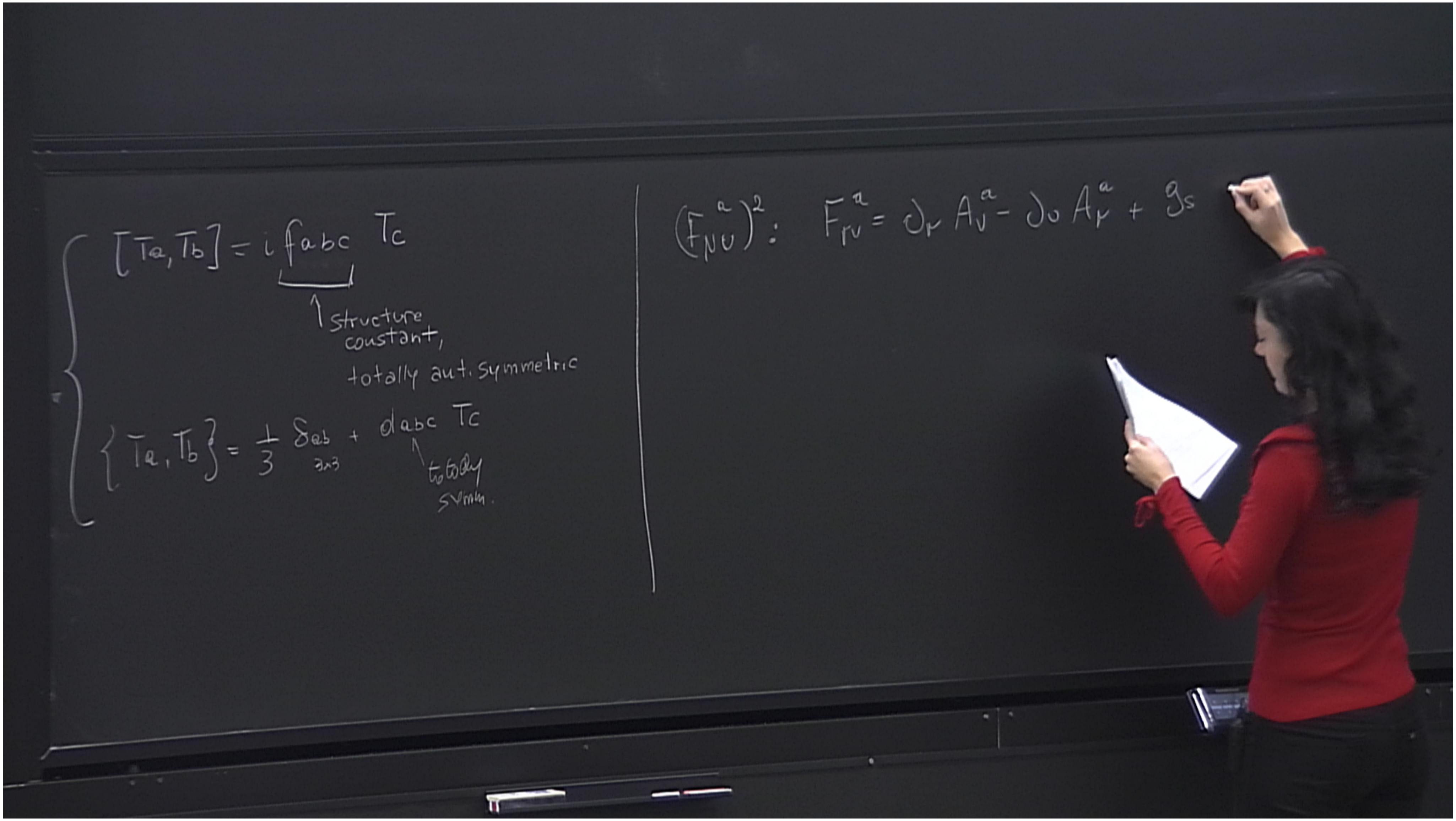
$a = 1,\dots,8$

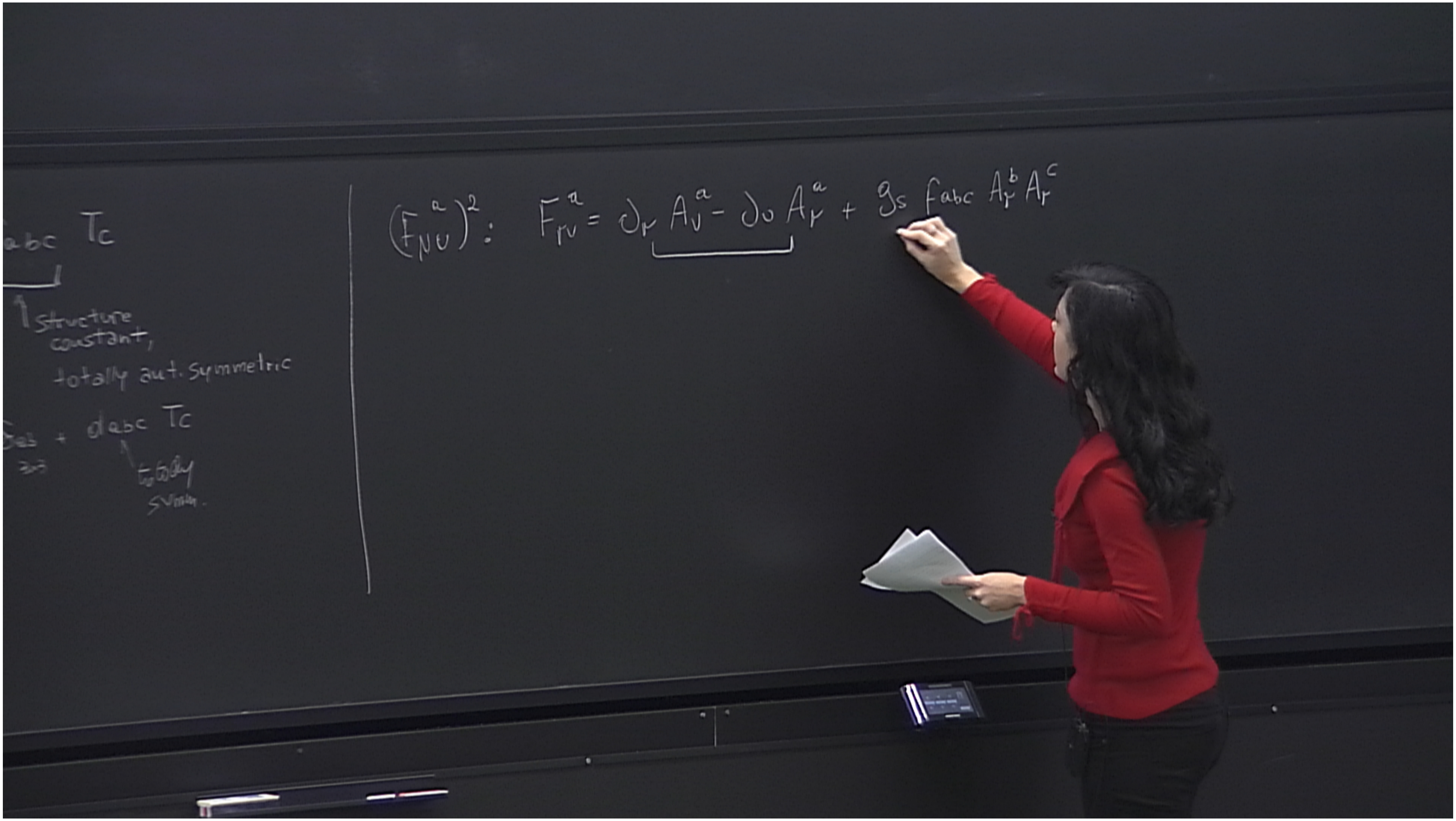

SU(3) index, a=1,2,..,8
$\mathcal{L} = -\frac{1}{4}(F_{\mu\nu}^a)^2 + i\,\bar{\Psi}_j \not{D} \Psi_j + m\,\bar{\Psi}_j \Psi_j$
gluons
j = 1,2,3
flavor = 1,2,3
QCD is flavor blind
t_a = Gell-mann matrix
$t_a = \frac{1}{2}\lambda_a$
1) $\not{D} = D_\mu \gamma^\mu$
GAMMA MATRIX
$D_\mu = \partial_\mu + i\, g_s A_\mu^a t_a$
generators of SU(3)
gluons
a = 1,..,8

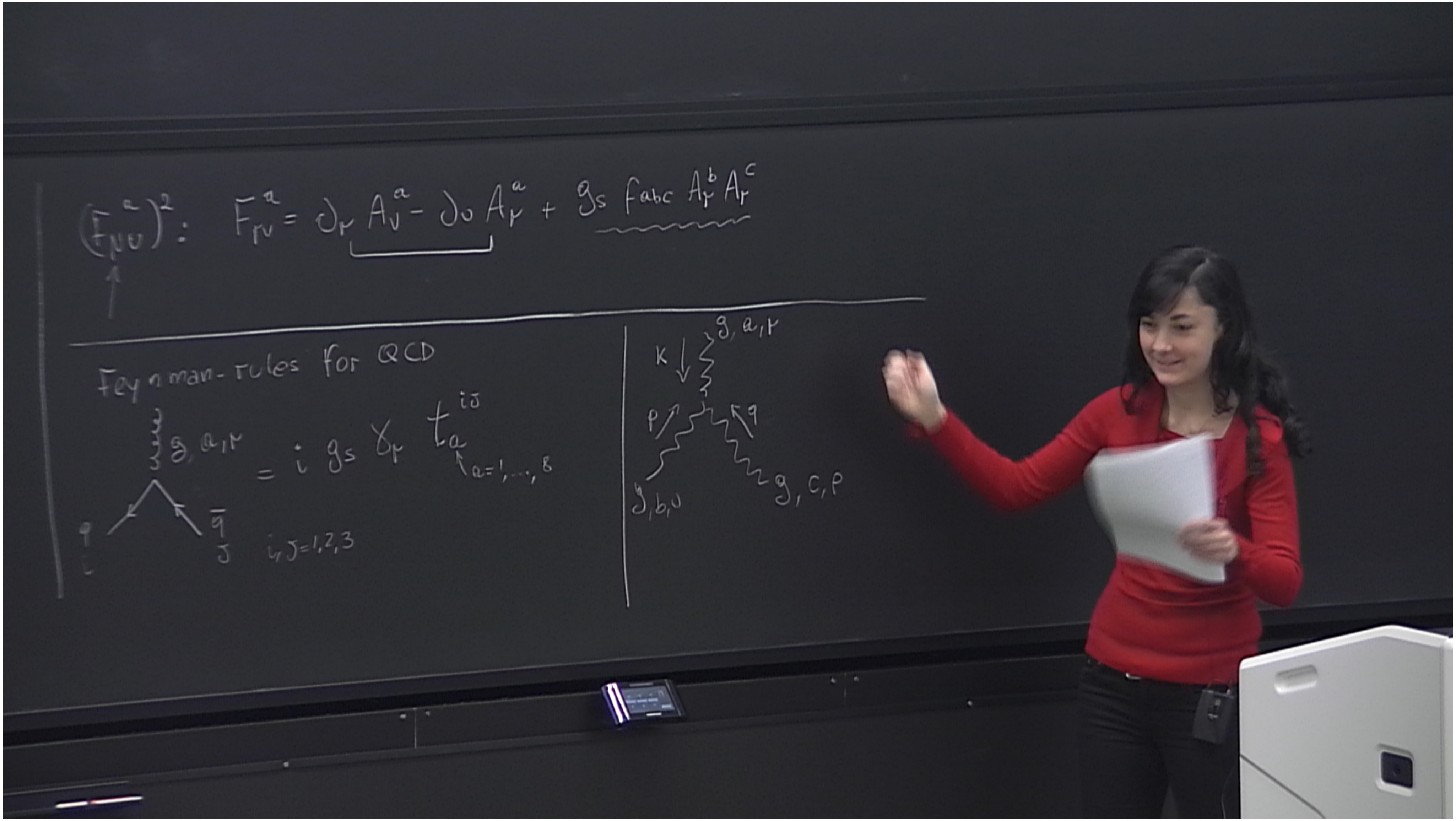

QCD is flavor blind
t_a = Gell-mann matrix
$t_a = \frac{1}{2}\lambda_a$
$\lambda_1 = \begin{pmatrix} 0 & 1 & 0 \\ 1 & 0 & 0 \\ 0 & 0 & 0 \end{pmatrix}$, $\lambda_2 = \begin{pmatrix} 0 & -i & 0 \\ i & 0 & 0 \\ 0 & 0 & 0 \end{pmatrix}$, $\lambda_3 = \begin{pmatrix} 1 & 0 & 0 \\ 0 & -1 & 0 \\ 0 & 0 & 0 \end{pmatrix}$
hermitian
trace-less
matrix
$\lambda_4 = \begin{pmatrix} 0 & 0 & 1 \\ 0 & 0 & 0 \\ 1 & 0 & 0 \end{pmatrix}$, $\lambda_5 = \begin{pmatrix} 0 & 0 & -i \\ 0 & 0 & 0 \\ i & 0 & 0 \end{pmatrix}$, $\lambda_6 = \begin{pmatrix} 0 & 0 & 0 \\ 0 & 0 & 1 \\ 0 & 1 & 0 \end{pmatrix}$, $\lambda_7 = \begin{pmatrix} 0 & 0 & 0 \\ 0 & 0 & -i \\ 0 & i & 0 \end{pmatrix}$, $\lambda_8 = \frac{1}{\sqrt{3}}\begin{pmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & -2 \end{pmatrix}$

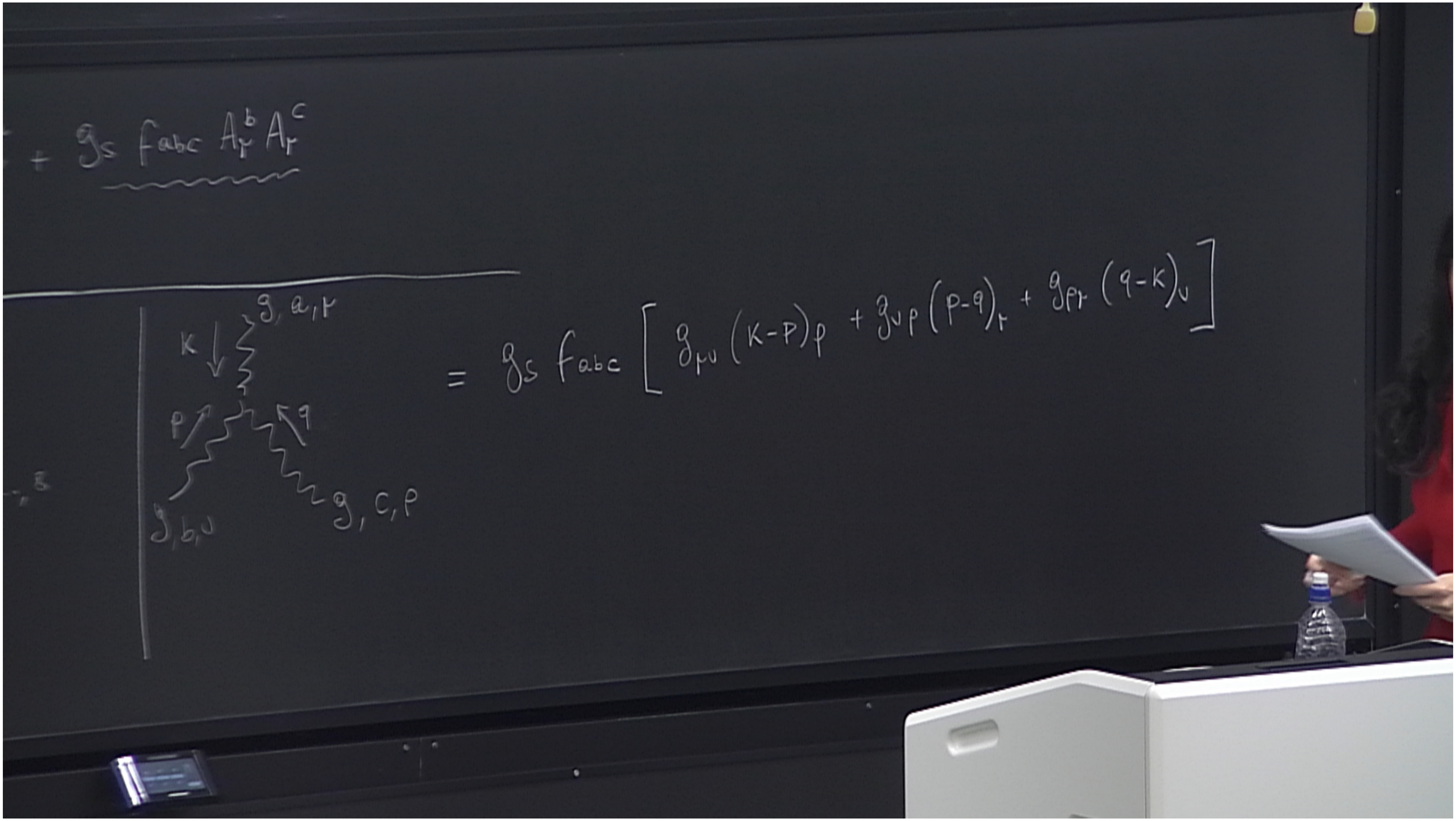

[Ta, Tb] = i fabc Tc
structure constant,
totally aut. symmetric
{Ta, Tb} = 1/3 δab + dabc Tc
3x3
symm.

$$
\begin{cases}
[T_a, T_b] = i \underbrace{f_{abc}}_{\substack{\text{structure constant,} \\ \text{totally ant. symmetric}}} T_c \\
\{T_a, T_b\} = \frac{1}{3} \underset{3\times 3}{\delta_{ab}} + \underbrace{d_{abc}}_{\substack{\text{totally} \\ \text{symm.}}} T_c
\end{cases}
$$

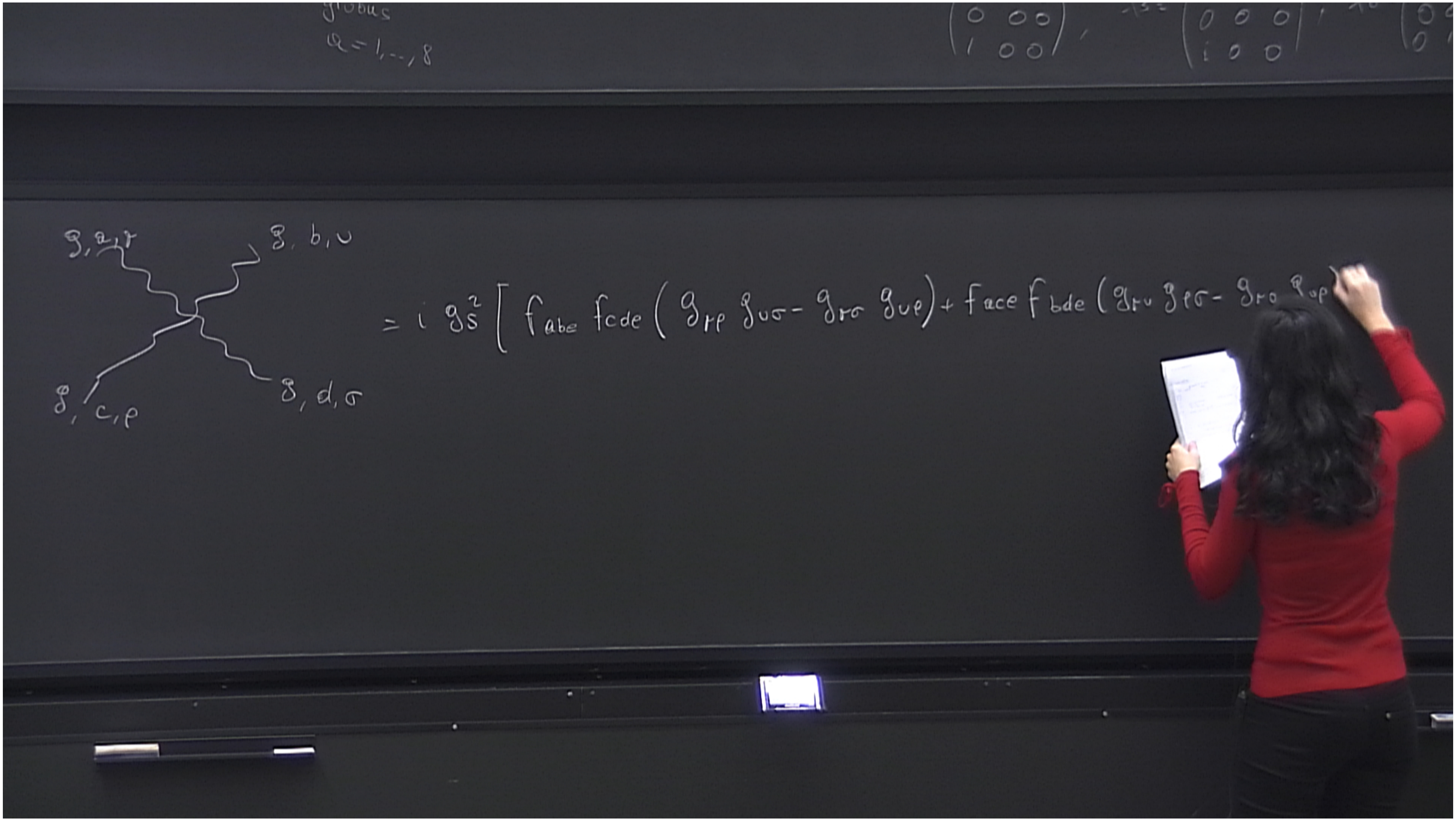

$[T_a, T_b] = i f_{abc} T_c$
structure constant,
totally ant. symmetric
$\{T_a, T_b\} = \frac{1}{3} \delta_{ab} + d_{abc} T_c$
3x3
totally symm.
$(F^a_{\mu\nu})^2 : F^a_{\mu\nu} = \partial_\mu A^a_\nu - \partial_\nu A^a_\mu + g_s$

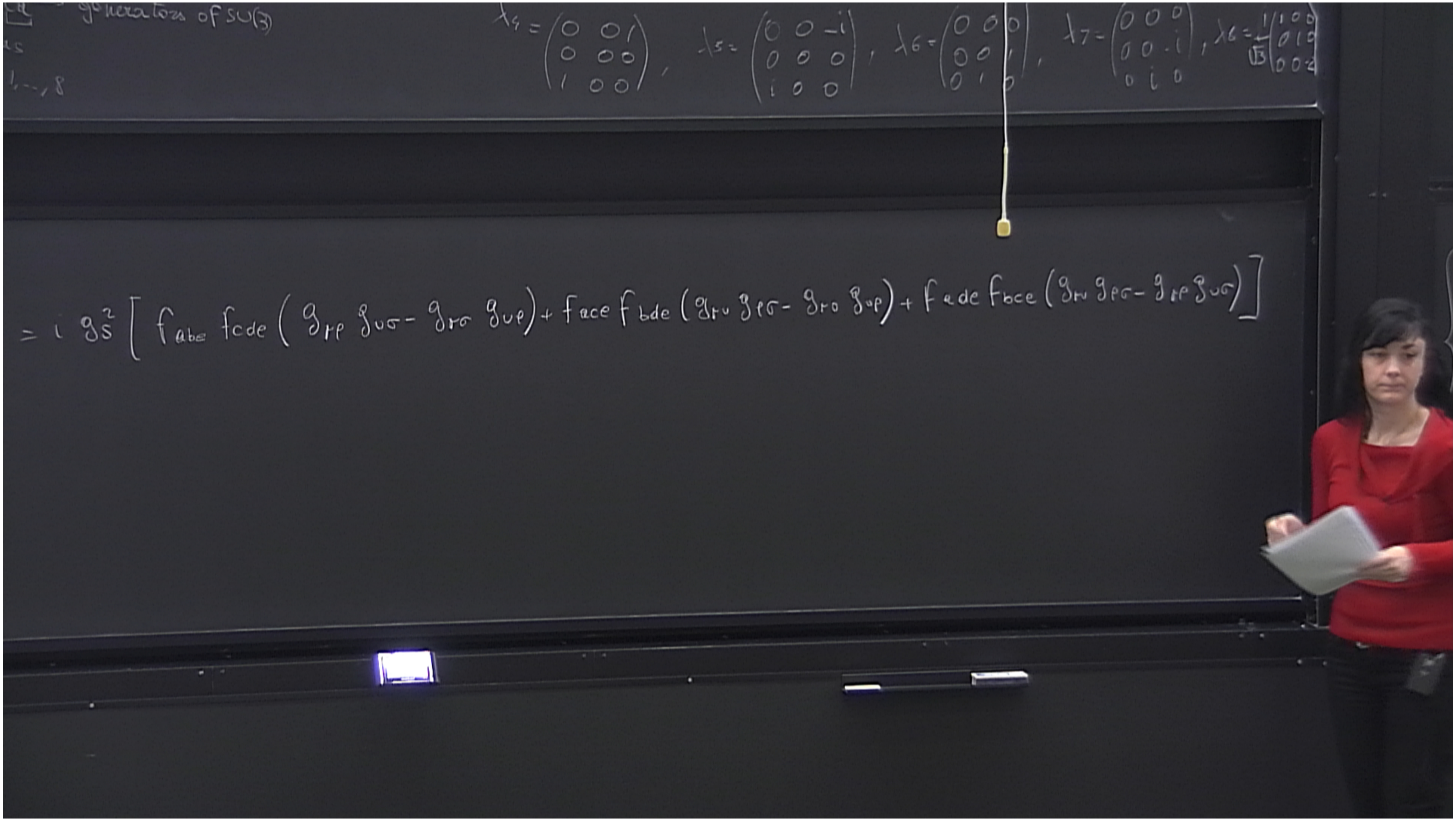

structure
constant,
totally ant. symmetric
dabc Tc
totally
symm.

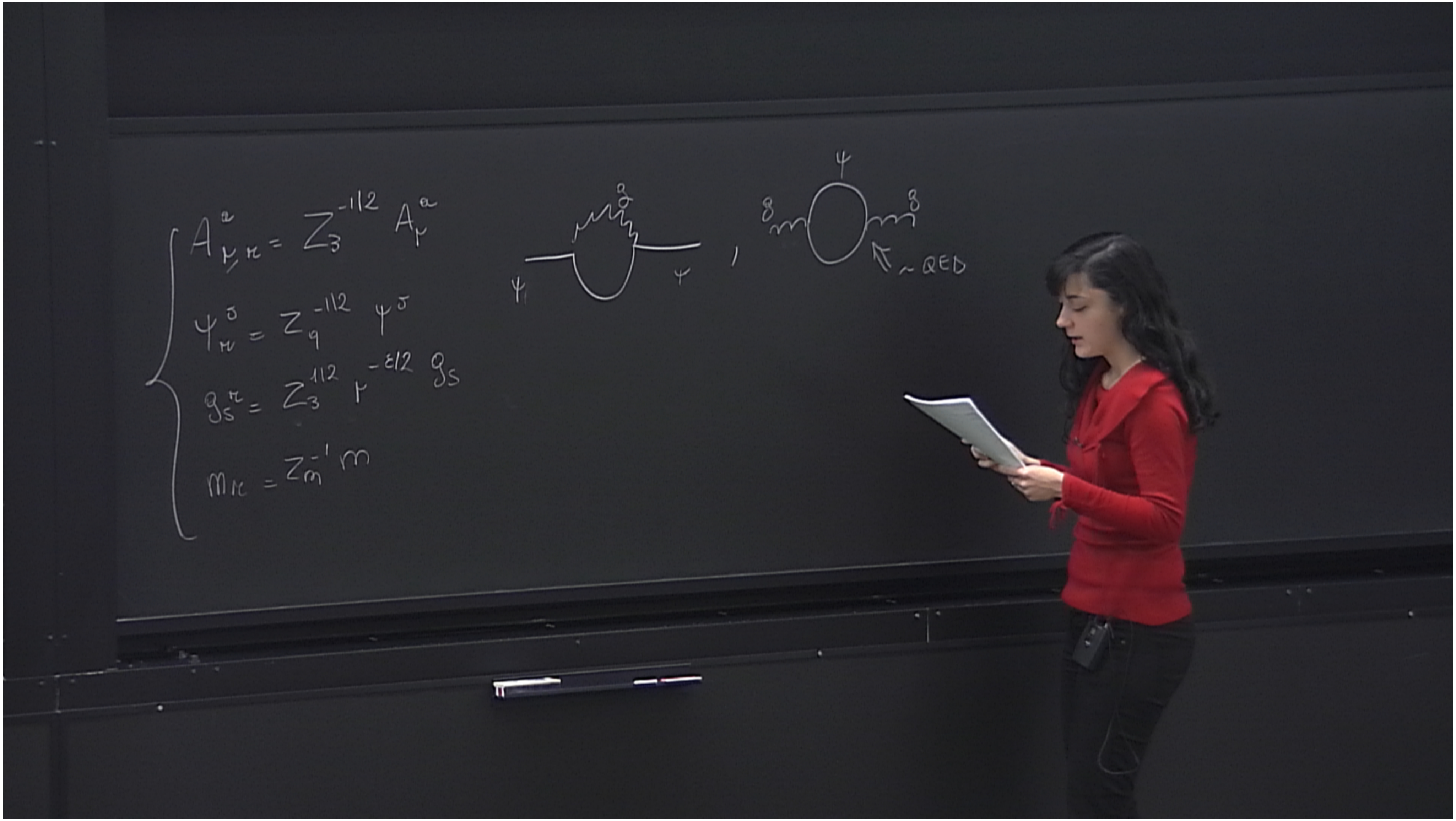

$(F_{\mu\nu}^a)^2$: $F_{\mu\nu}^a = \partial_\mu A_\nu^a - \partial_\nu A_\mu^a + g_s f_{abc} A_\mu^b A_\mu^c$
Feynman-rules for QCD
g, a, μ
$= i g_s \gamma_\mu t_a^{ij}$
a = 1, …, 8
q
i
$\bar{q}$
j
i, j = 1, 2, 3
g, a, μ
k
p
q
g, b, ν
g, c, ρ

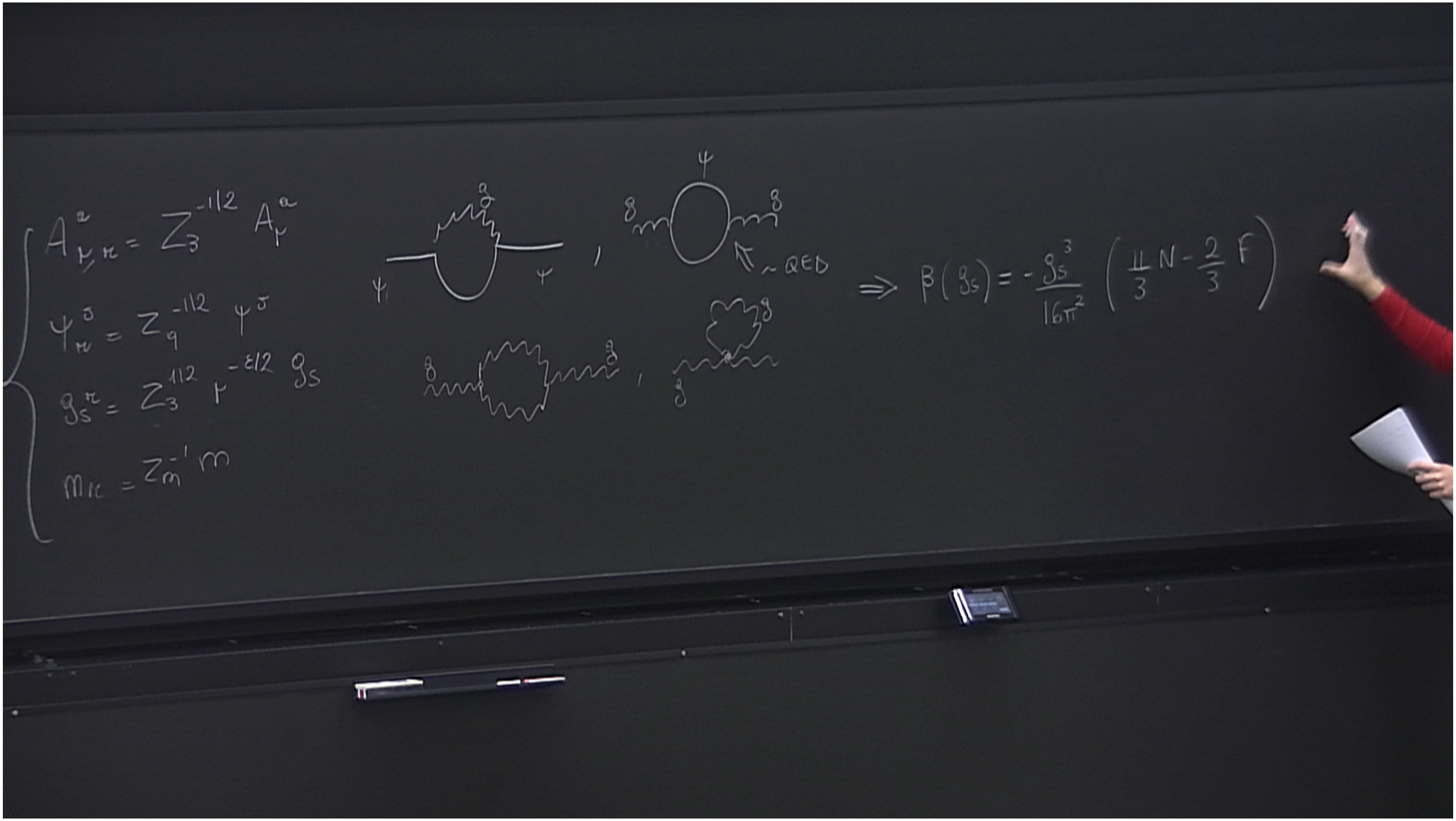


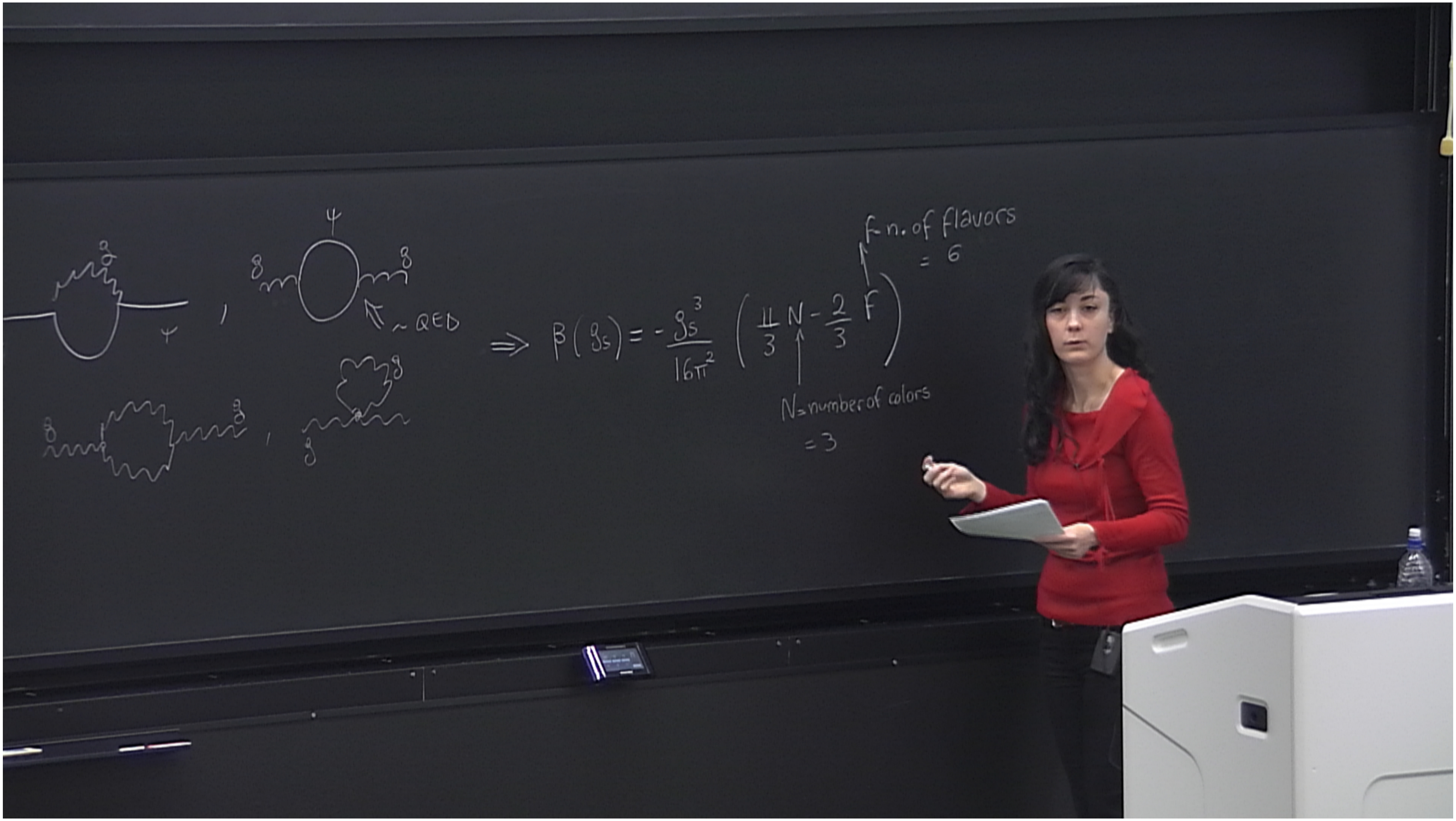
$+ g_s f_{abc} A^b_\nu A^c_\rho$
g, a, μ
k
p
q
g, b, ν
g, c, ρ
$= g_s f_{abc} \left[g_{\mu\nu} (k-p)_\rho + g_{\nu\rho} (p-q)_\mu + g_{\rho\mu} (q-k)_\nu \right]$

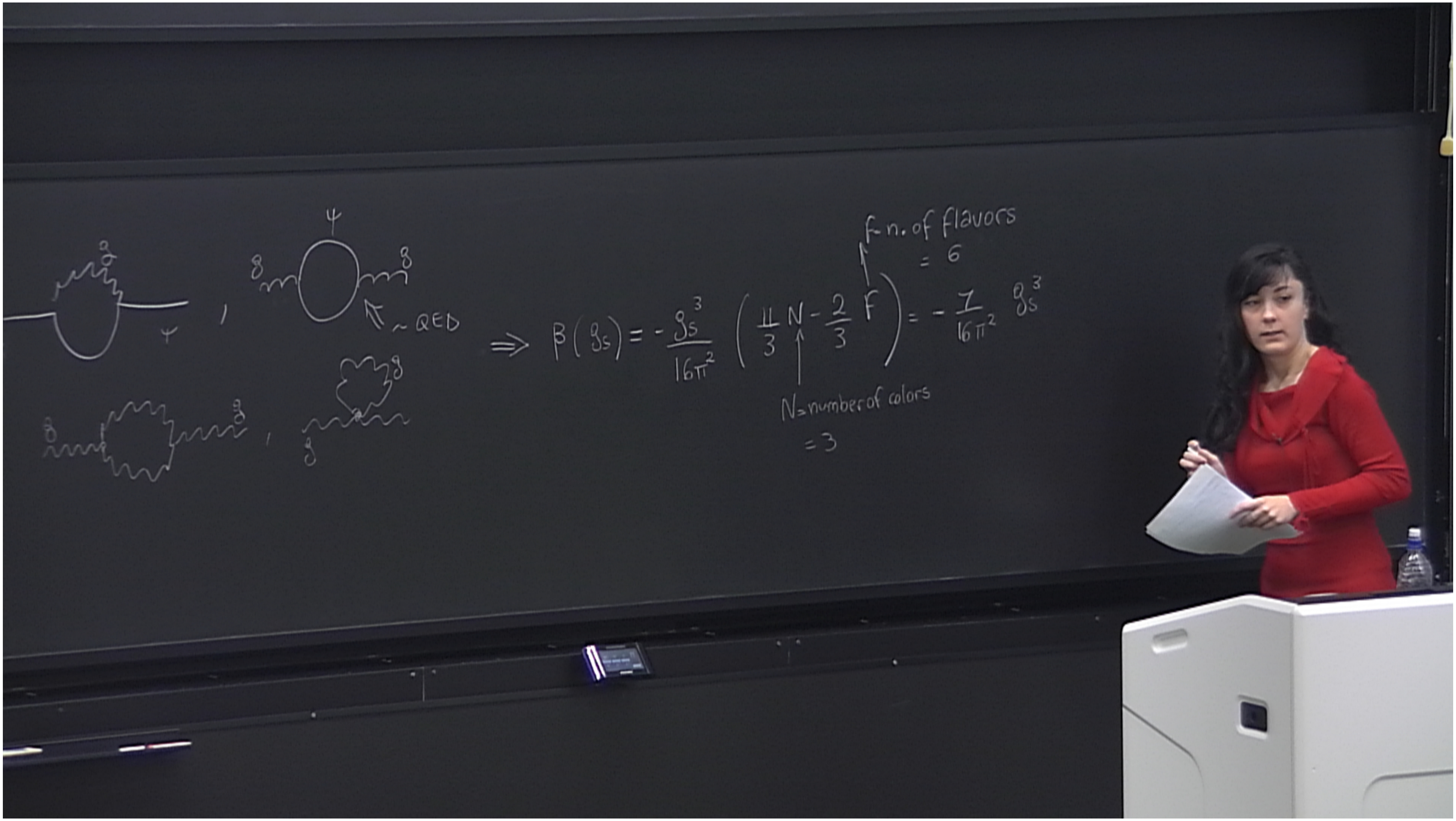

$a = 1, \dots, 8$
g, a, γ
g, b, ν
g, c, ρ
g, d, σ
$= i\, g_s^2 \Big[f_{abe} f_{cde} \big(g_{\gamma\rho}\, g_{\nu\sigma} - g_{\gamma\sigma}\, g_{\nu\rho} \big) + f_{ace} f_{bde} \big(g_{\gamma\nu}\, g_{\rho\sigma} - g_{\gamma\sigma}\, g_{\nu\rho} \big)$

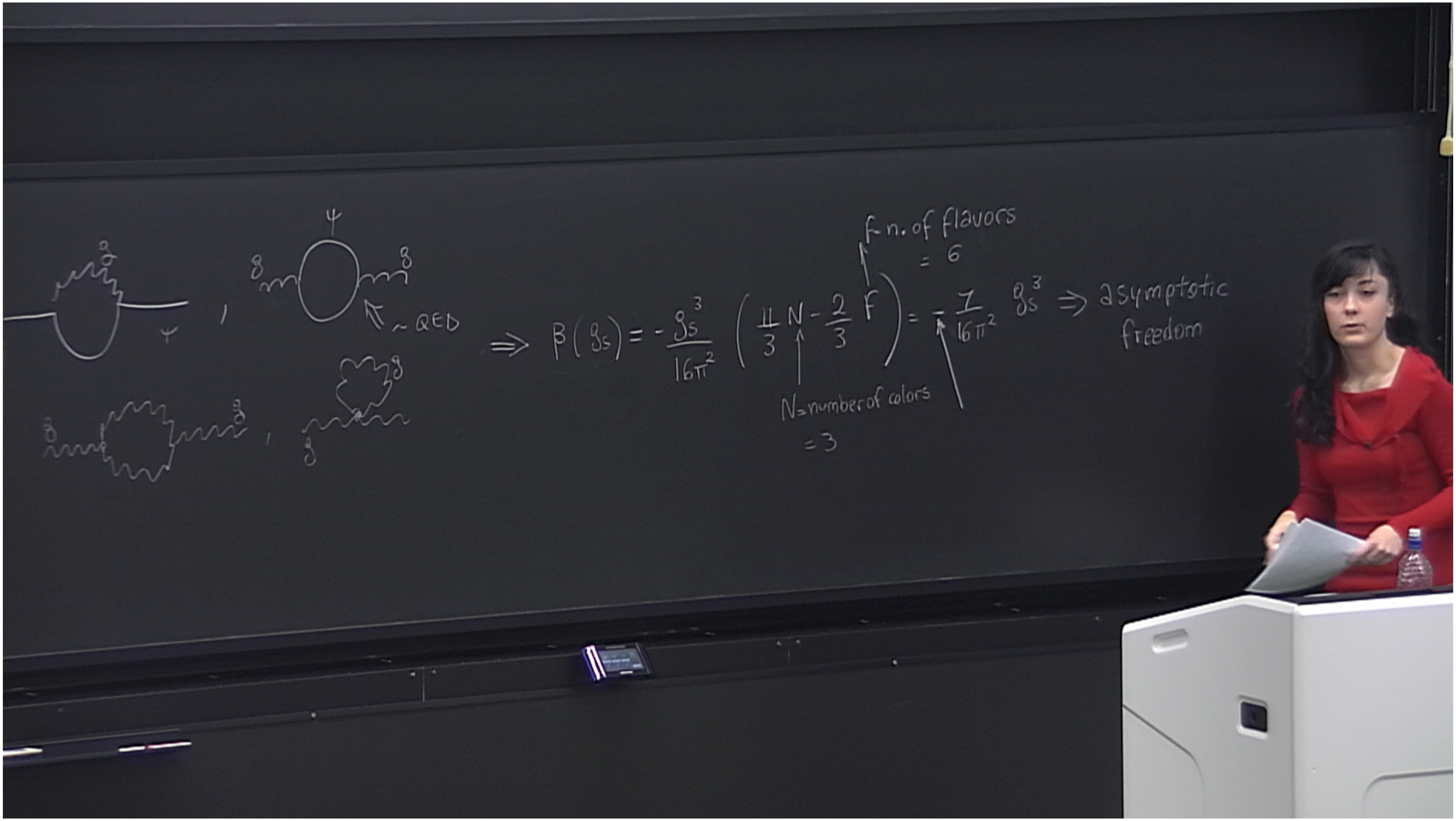

generators of SU(3)
$\lambda_4 = \begin{pmatrix} 0 & 0 & 1 \\ 0 & 0 & 0 \\ 1 & 0 & 0 \end{pmatrix}, \lambda_5 = \begin{pmatrix} 0 & 0 & -i \\ 0 & 0 & 0 \\ i & 0 & 0 \end{pmatrix}, \lambda_6 = \begin{pmatrix} 0 & 0 & 0 \\ 0 & 0 & 1 \\ 0 & 1 & 0 \end{pmatrix}, \lambda_7 = \begin{pmatrix} 0 & 0 & 0 \\ 0 & 0 & -i \\ 0 & i & 0 \end{pmatrix}, \lambda_8 = \frac{1}{\sqrt{3}}\begin{pmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & -2 \end{pmatrix}$
1, ..., 8
$= i g_s^2 \left[f_{abe} f_{cde} \left(g_{\mu\rho} g_{\nu\sigma} - g_{\mu\sigma} g_{\nu\rho} \right) + f_{ace} f_{bde} \left(g_{\mu\nu} g_{\rho\sigma} - g_{\mu\sigma} g_{\nu\rho} \right) + f_{ade} f_{bce} \left(g_{\mu\nu} g_{\rho\sigma} - g_{\mu\rho} g_{\nu\sigma} \right) \right]$


$A^a_{\mu,r} = Z_3^{-1/2} A^a_\mu$
$\psi^\sigma_r = Z_q^{-1/2} \psi^\sigma$
$g_s^r = Z_3^{1/2} \mu^{-\varepsilon/2} g_s$
$m_r = Z_m^{-1} m$
ψ
g
$\sim$ QED

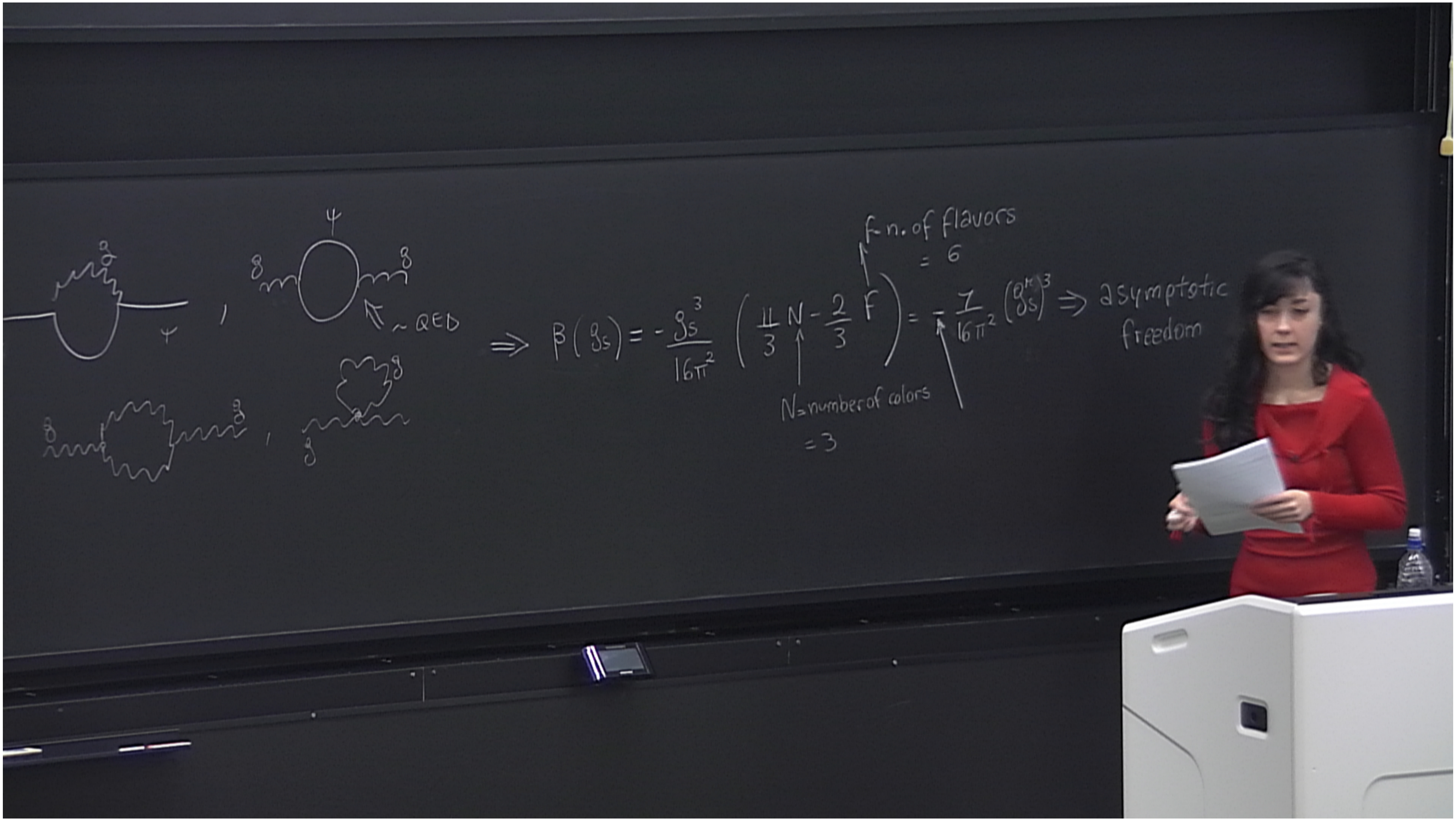

$A^a_{\mu,r} = Z_3^{-1/2} A^a_\mu$
$\psi^j_r = Z_q^{-1/2} \psi^j$
$g_s^r = Z_3^{1/2} \mu^{-\varepsilon/2} g_s$
$m_r = Z_m^{-1} m$
ψ
g
~ QED
$\Rightarrow \beta(g_s) = -\frac{g_s^3}{16\pi^2}\left(\frac{11}{3}N - \frac{2}{3}F\right)$

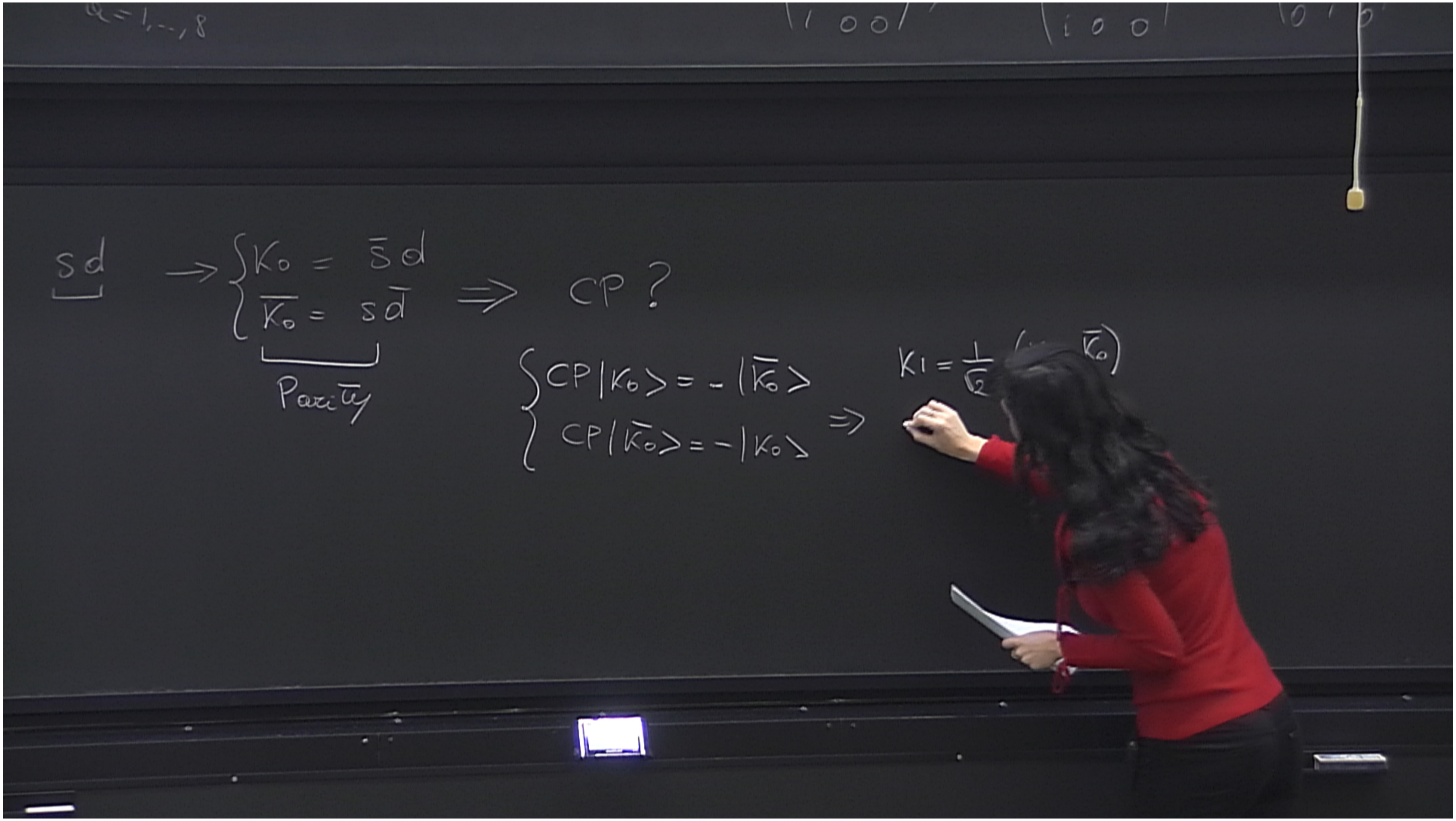

$\Rightarrow \beta(g_s) = -\frac{g_s^3}{16\pi^2}\left(\frac{11}{3}N - \frac{2}{3}f\right)$
f = n. of flavors
= 6
N = number of colors
= 3
~ QED


~ QED
f- n. of flavors
= 6
β(g_s) = - g_s^3 / 16π^2 (11/3 N - 2/3 f) = - 7 / 16π^2 g_s^3
N=number of colors
=3

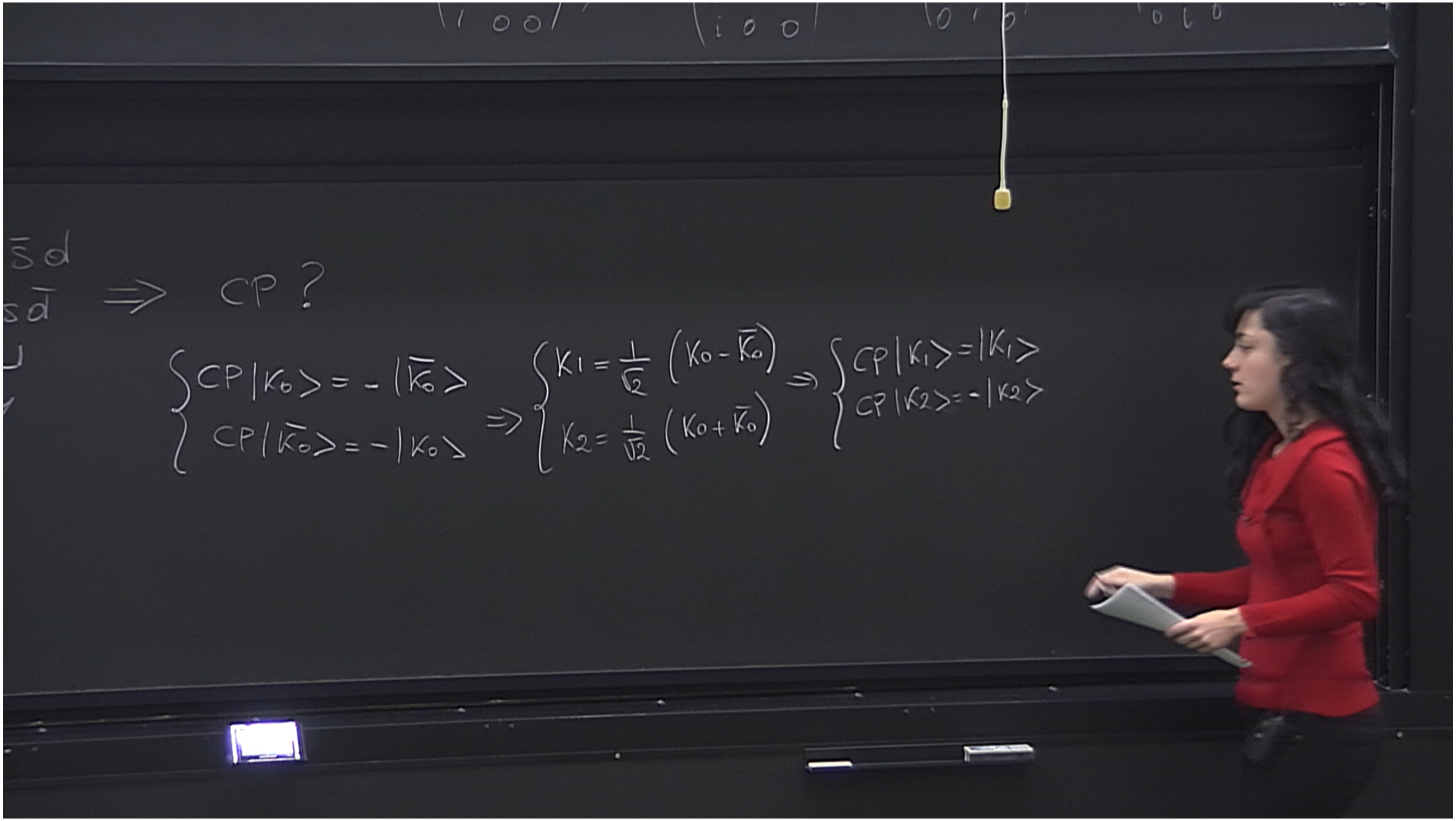


ψ
g
~ QED
f = n. of flavors
= 6
⇒ β(g_s) = − g_s^3 / 16π^2 (11/3 N − 2/3 f) = − 7 / 16π^2 g_s^3 ⇒ asymptotic freedom
N = number of colors
= 3


f = n. of flavors
= 6
~ QED
N = number of colors
= 3
asymptotic
freedom



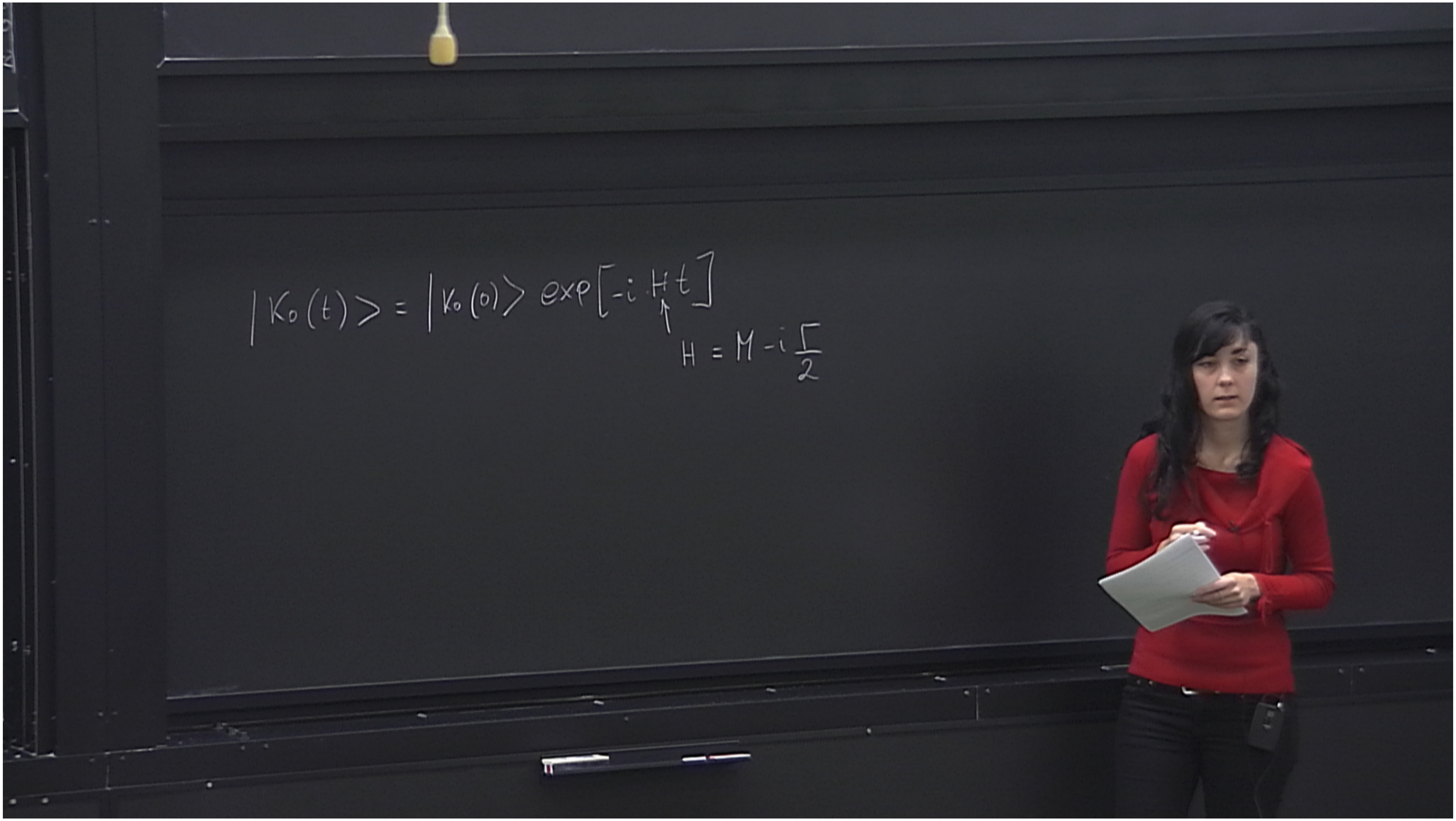
sd
$K_0 = \bar{s}d$
$\bar{K}_0 = s\bar{d}$
Parity
CP ?
$CP|K_0\rangle = -|\bar{K}_0\rangle$
$CP|\bar{K}_0\rangle = -|K_0\rangle$

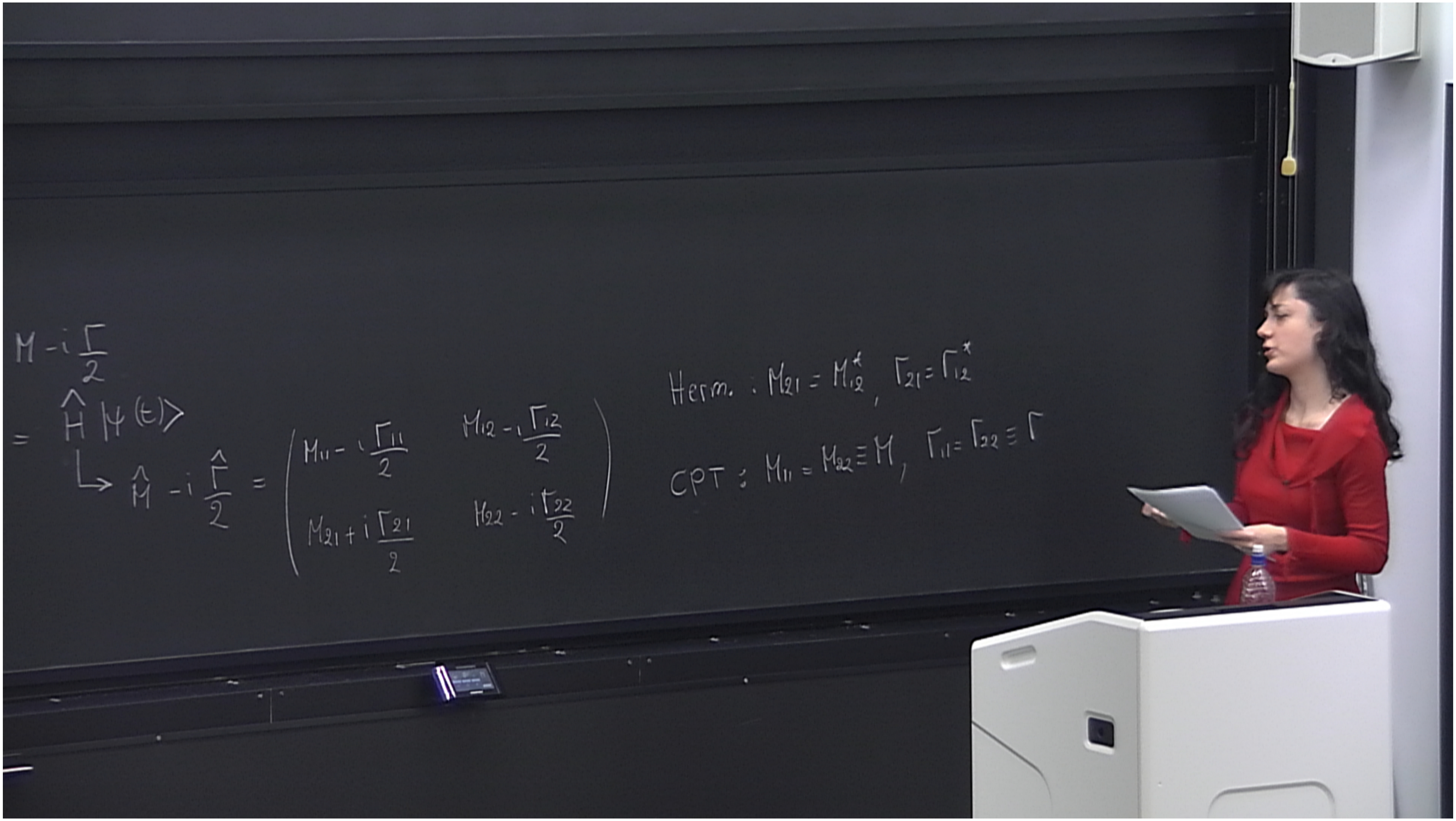

$\bar{s}d$
$s\bar{d} \Rightarrow CP?$
$CP|K_0\rangle = -|\bar{K}_0\rangle$
$CP|\bar{K}_0\rangle = -|K_0\rangle$
$\Rightarrow$
$K_1 = \frac{1}{\sqrt{2}}(K_0 - \bar{K}_0)$
$K_2 = \frac{1}{\sqrt{2}}(K_0 + \bar{K}_0)$
$\Rightarrow$
$CP|K_1\rangle = |K_1\rangle$
$CP|K_2\rangle = -|K_2\rangle$

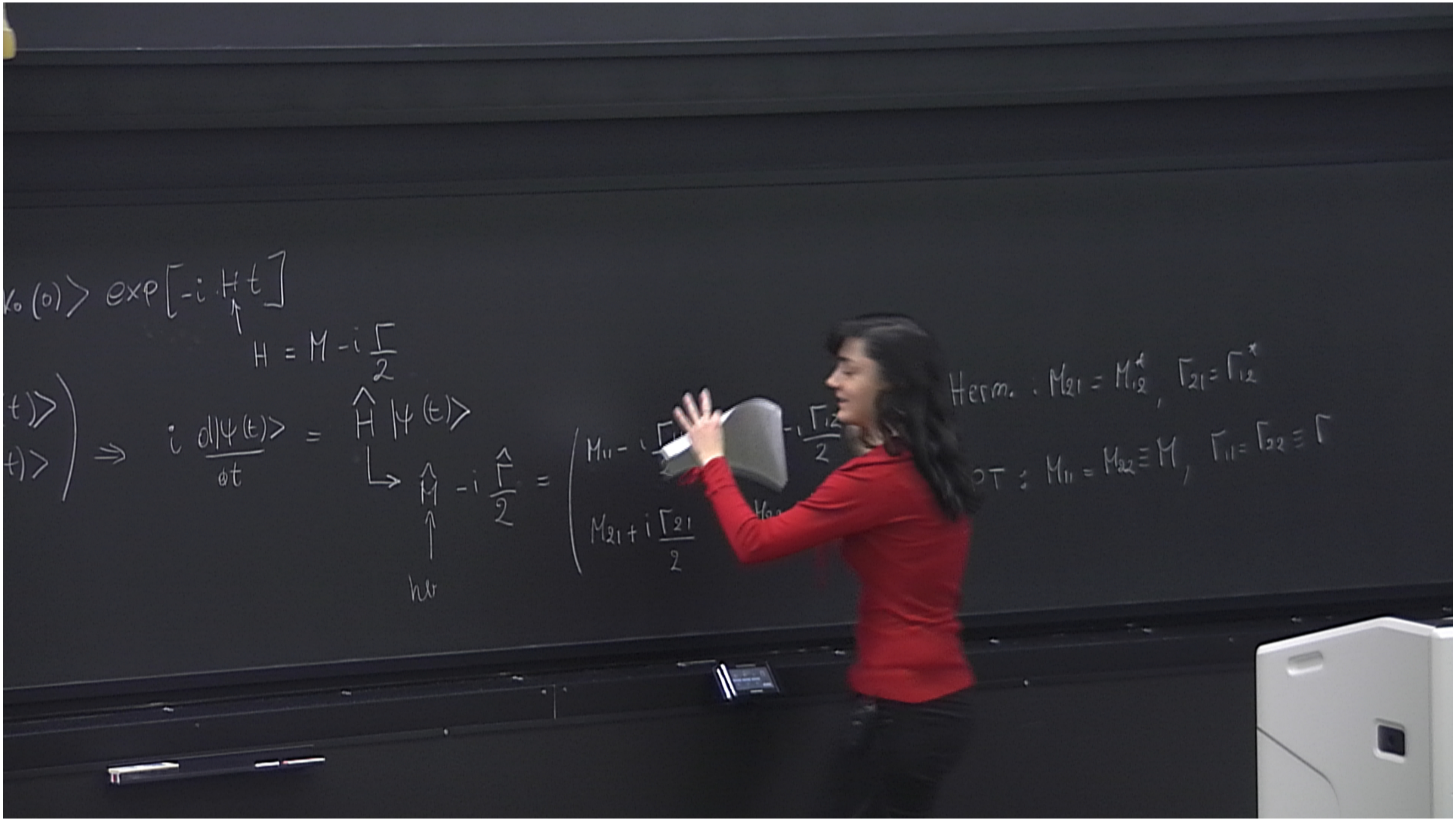
$\bar{s}d$

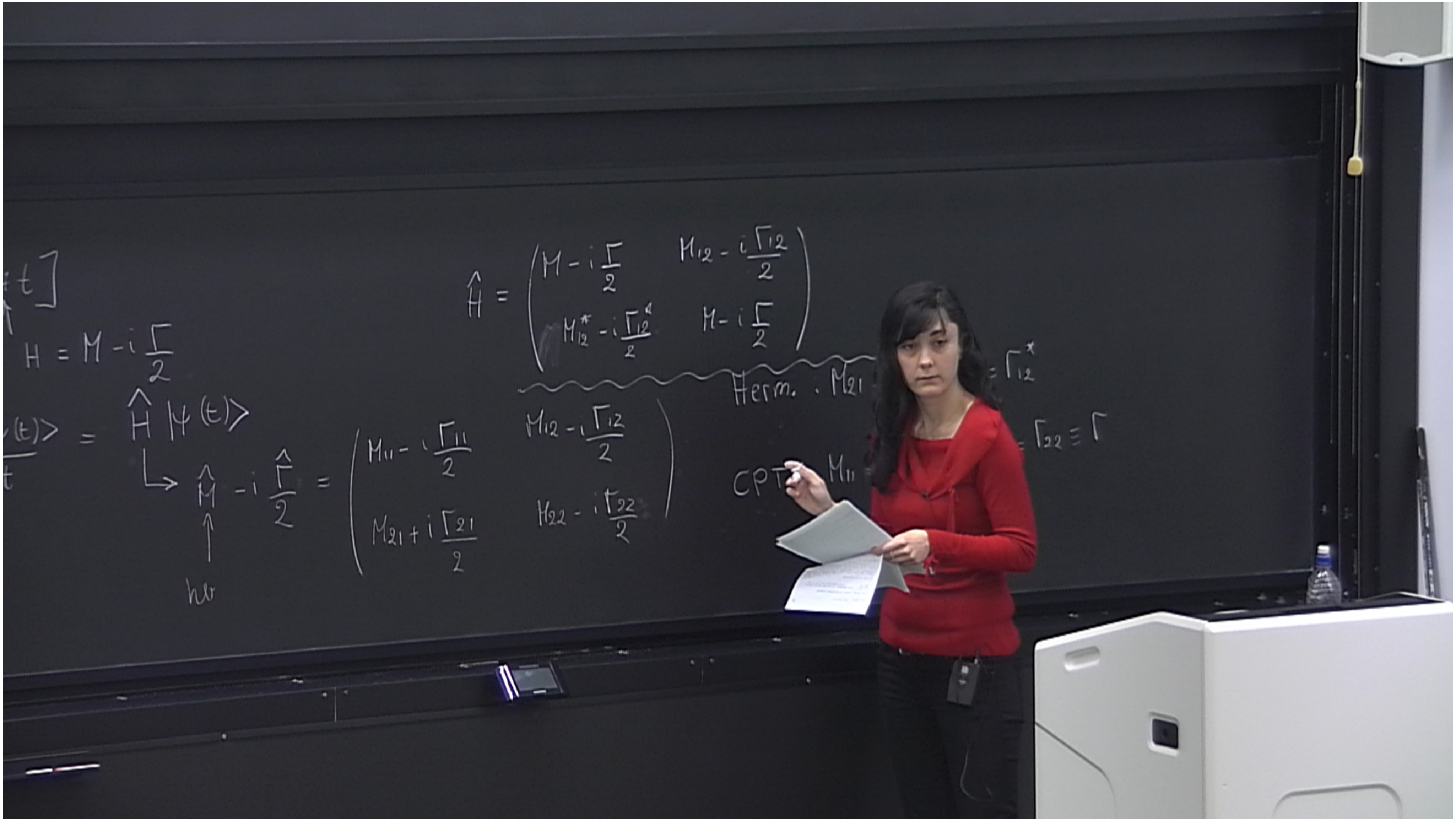
$s\bar{d} \Rightarrow CP\,?$

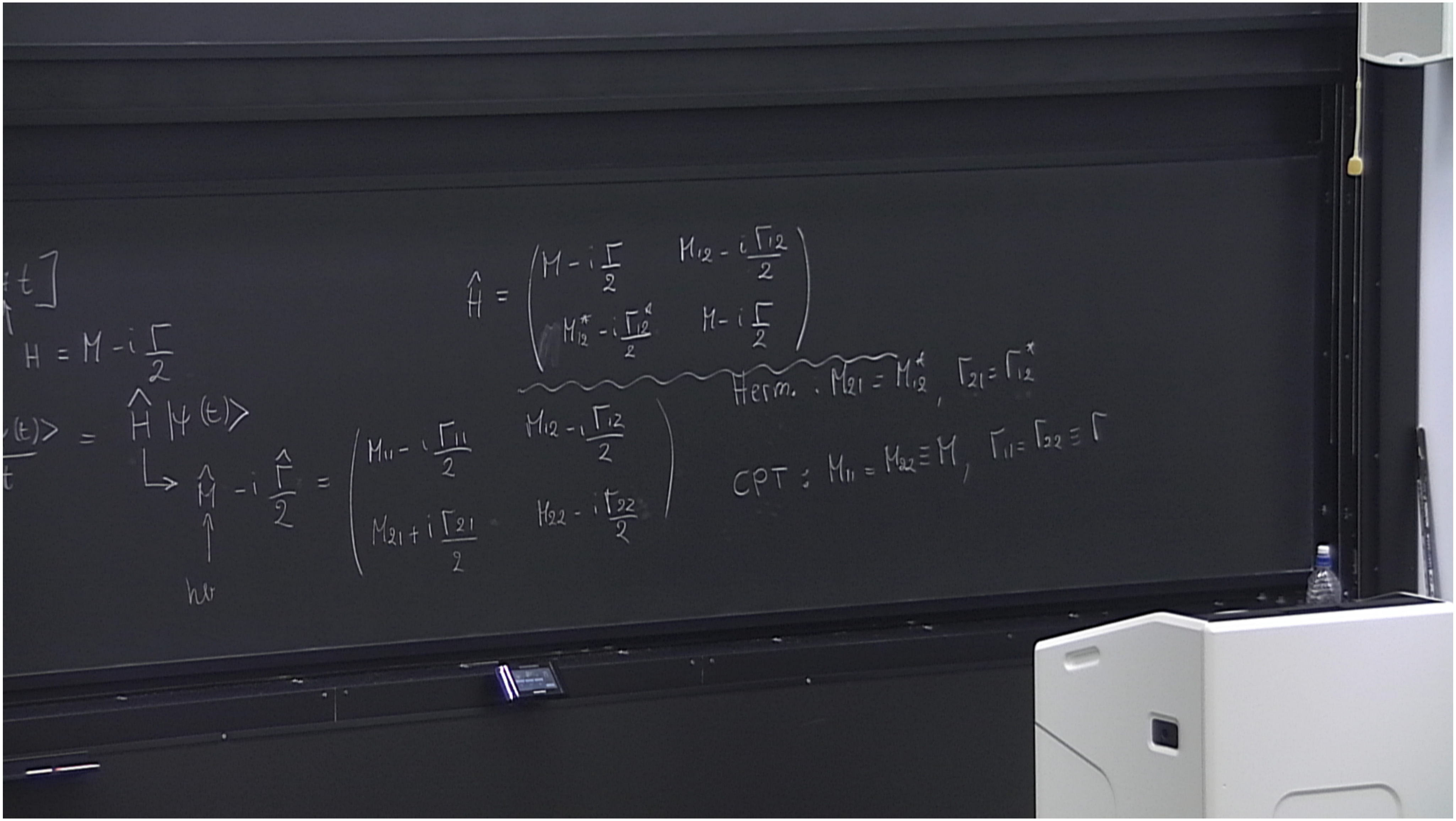
$$\begin{cases} CP|K_0\rangle = -|\bar{K}_0\rangle \\ CP|\bar{K}_0\rangle = -|K_0\rangle \end{cases} \Rightarrow \begin{cases} K_1 = \frac{1}{\sqrt{2}}\left(K_0 - \bar{K}_0\right) \\ K_2 = \frac{1}{\sqrt{2}}\left(K_0 + \bar{K}_0\right) \end{cases} \Rightarrow \begin{cases} CP|K_1\rangle = |K_1\rangle \\ CP|K_2\rangle = -|K_2\rangle \end{cases} \Rightarrow \text{physical?}$$


$|K_0(t)\rangle = |K_0(0)\rangle \exp[-i H t]$
$H = M - i\frac{\Gamma}{2}$


$M - i\frac{\Gamma}{2}$
$= \hat{H}|\psi(t)\rangle$
$\hookrightarrow \hat{M} - i\frac{\hat{\Gamma}}{2} = \begin{pmatrix} M_{11} - i\frac{\Gamma_{11}}{2} & M_{12} - i\frac{\Gamma_{12}}{2} \\ M_{21} + i\frac{\Gamma_{21}}{2} & M_{22} - i\frac{\Gamma_{22}}{2} \end{pmatrix}$
Herm. : $M_{21} = M_{12}^*$, $\Gamma_{21} = \Gamma_{12}^*$
CPT : $M_{11} = M_{22} \equiv M$, $\Gamma_{11} = \Gamma_{22} \equiv \Gamma$


exp[-i H t]
H = M - i Γ/2
Herm. : M21 = M12*, Γ21 = Γ12*
M11 = M22 ≡ M, Γ11 = Γ22 ≡ Γ


H = M - i Γ/2
Herm.
CPT



$\hat{H} = \begin{pmatrix} M - i\frac{\Gamma}{2} & M_{12} - i\frac{\Gamma_{12}}{2} \\ M_{12}^* - i\frac{\Gamma_{12}^*}{2} & M - i\frac{\Gamma}{2} \end{pmatrix}$
$H = M - i\frac{\Gamma}{2}$
$\hat{H}|\psi(t)\rangle$
$\hat{M} - i\frac{\hat{\Gamma}}{2} = \begin{pmatrix} M_{11} - i\frac{\Gamma_{11}}{2} & M_{12} - i\frac{\Gamma_{12}}{2} \\ M_{21} + i\frac{\Gamma_{21}}{2} & M_{22} - i\frac{\Gamma_{22}}{2} \end{pmatrix}$
Herm. : $M_{21} = M_{12}^*$, $\Gamma_{21} = \Gamma_{12}^*$
CPT : $M_{11} = M_{22} \equiv M$, $\Gamma_{11} = \Gamma_{22} \equiv \Gamma$