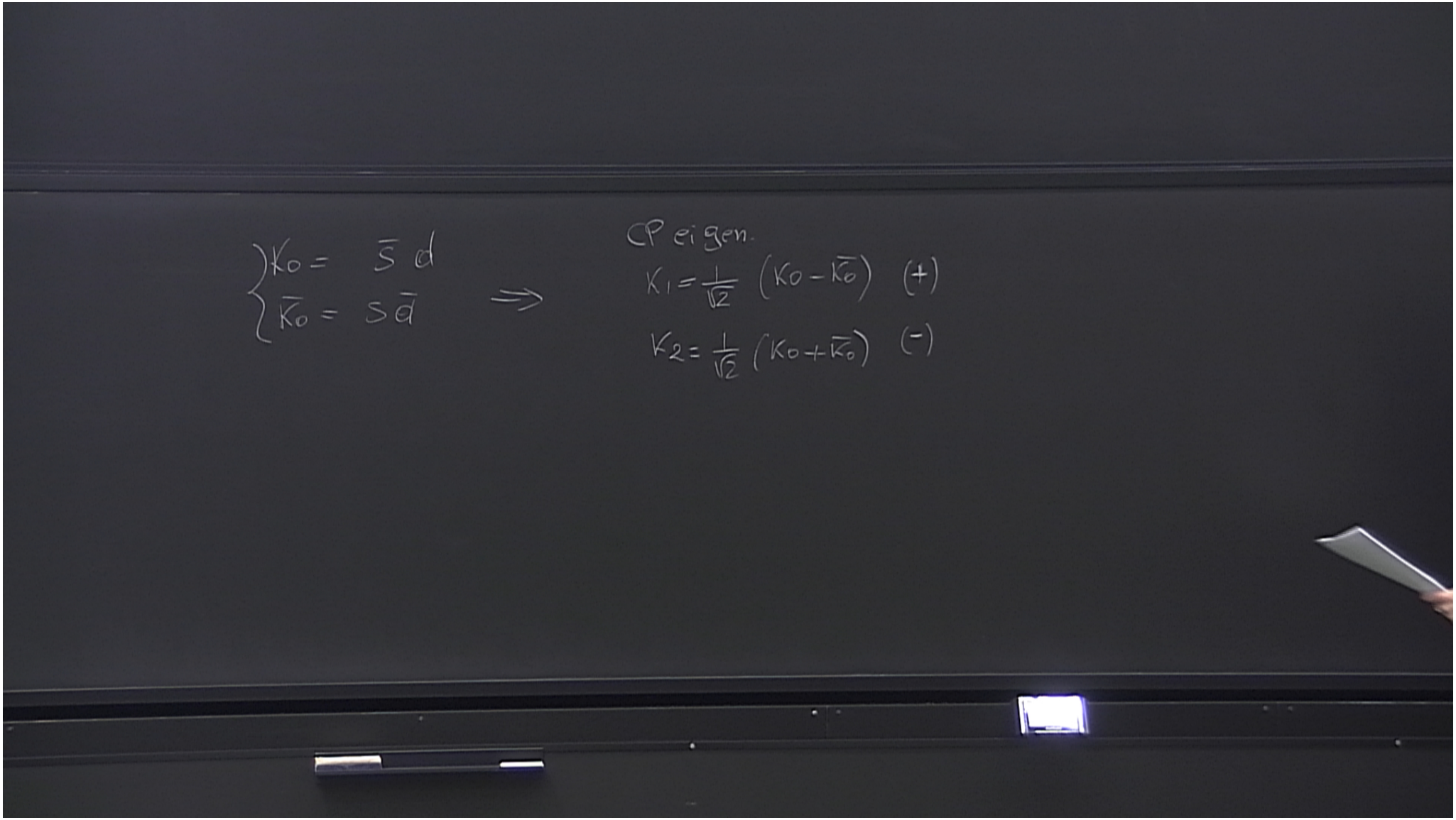
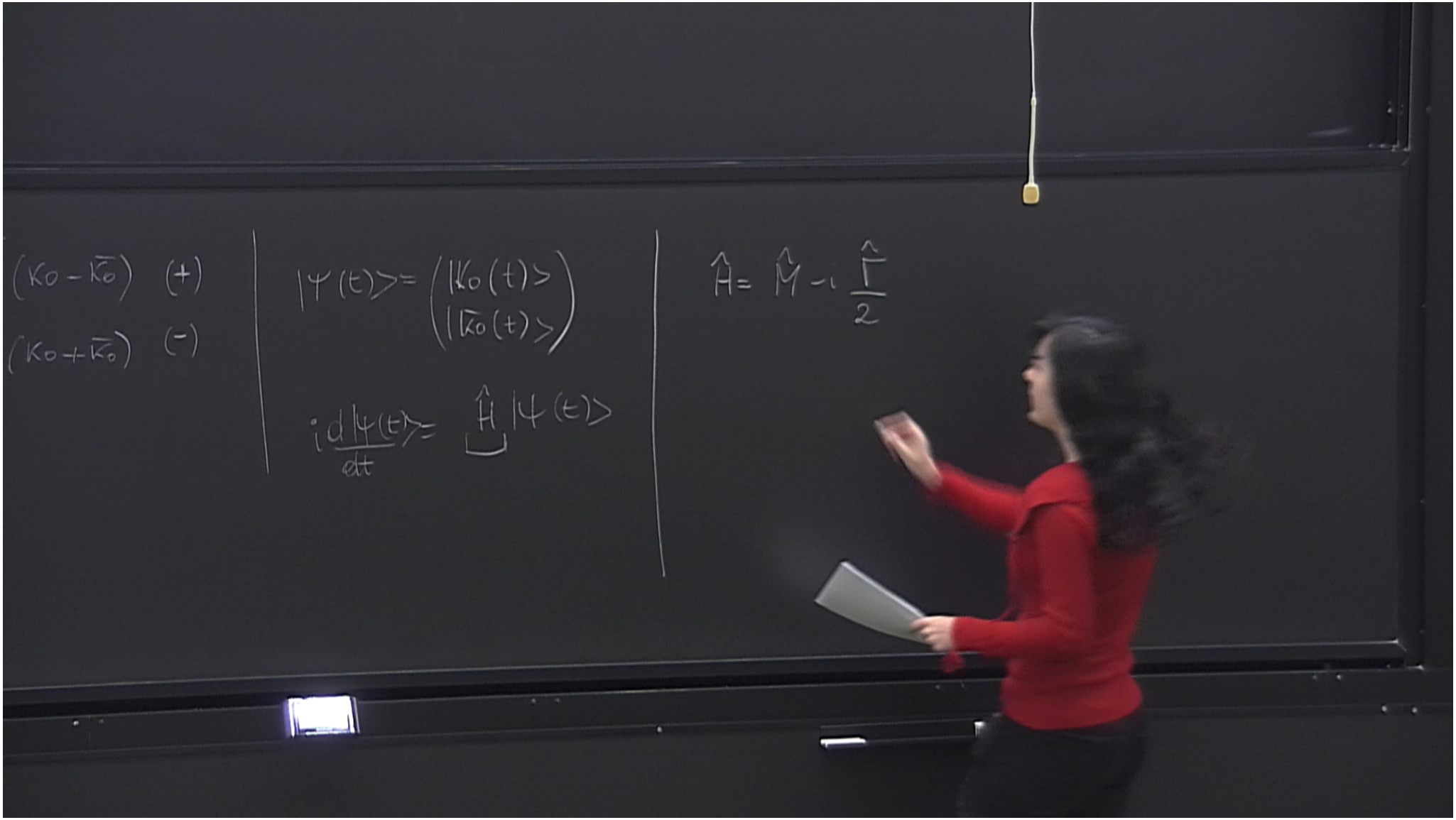
Title: Standard Model-13

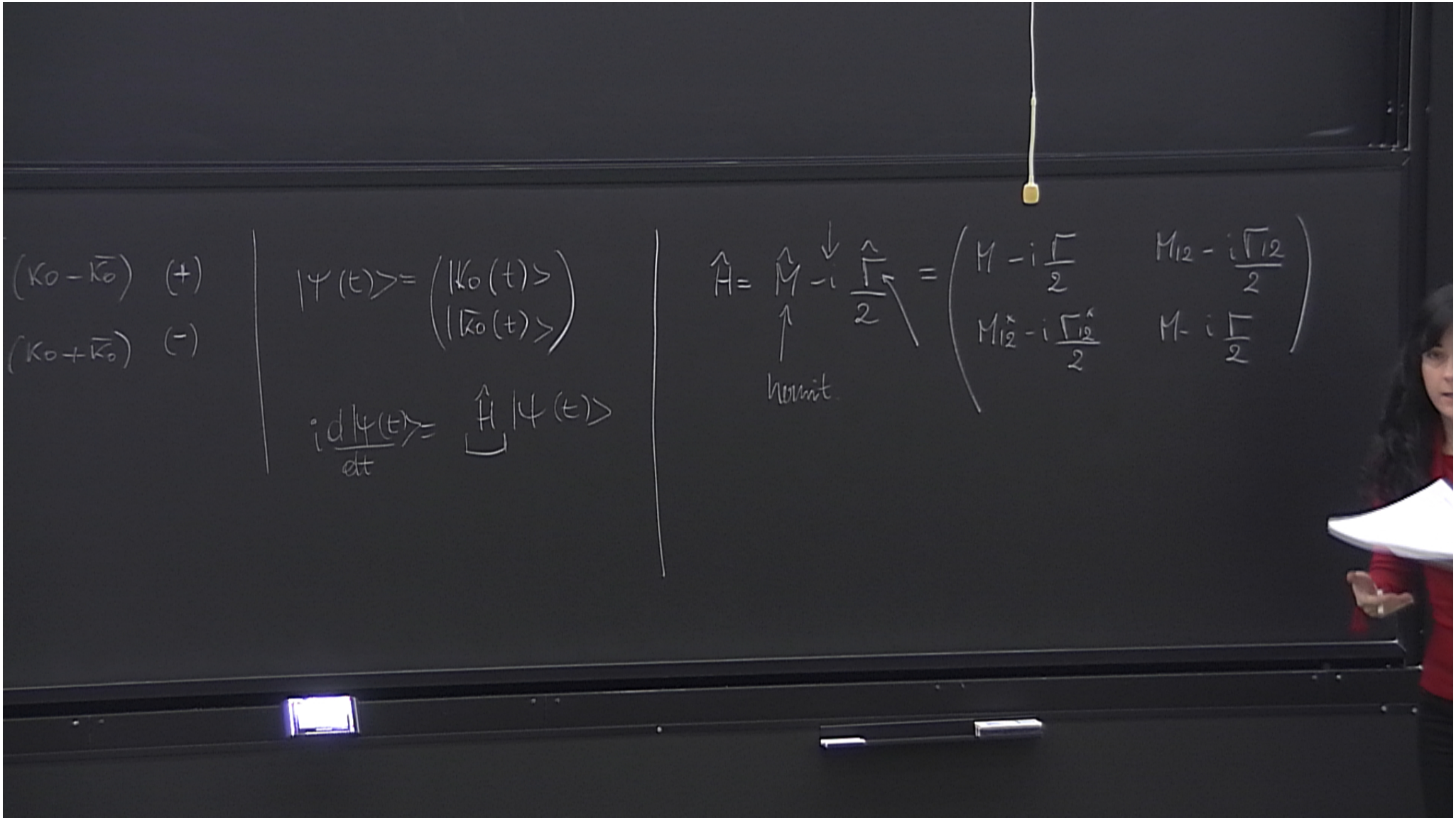
Date: Jan 21, 2015 09:00 AM

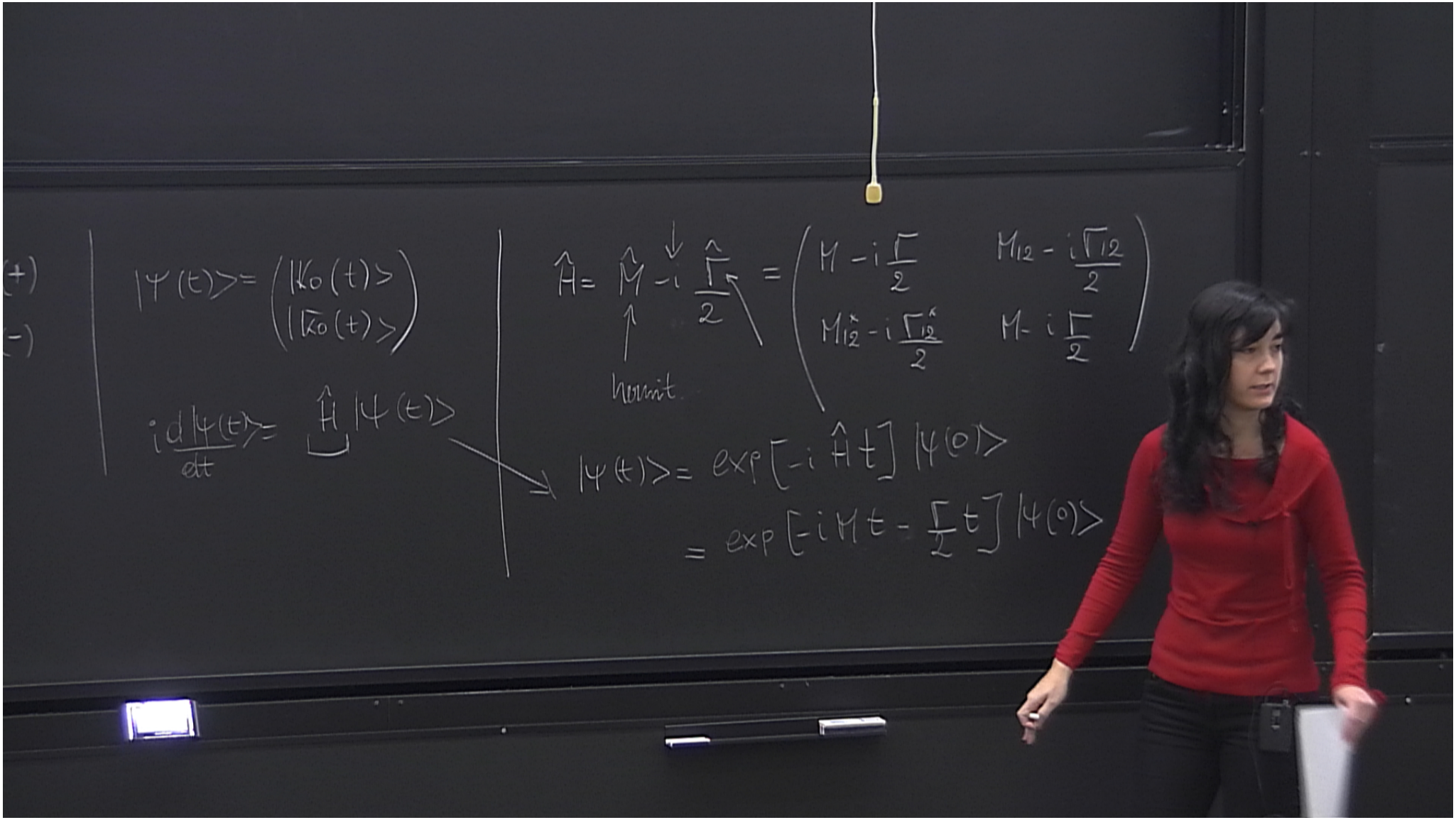
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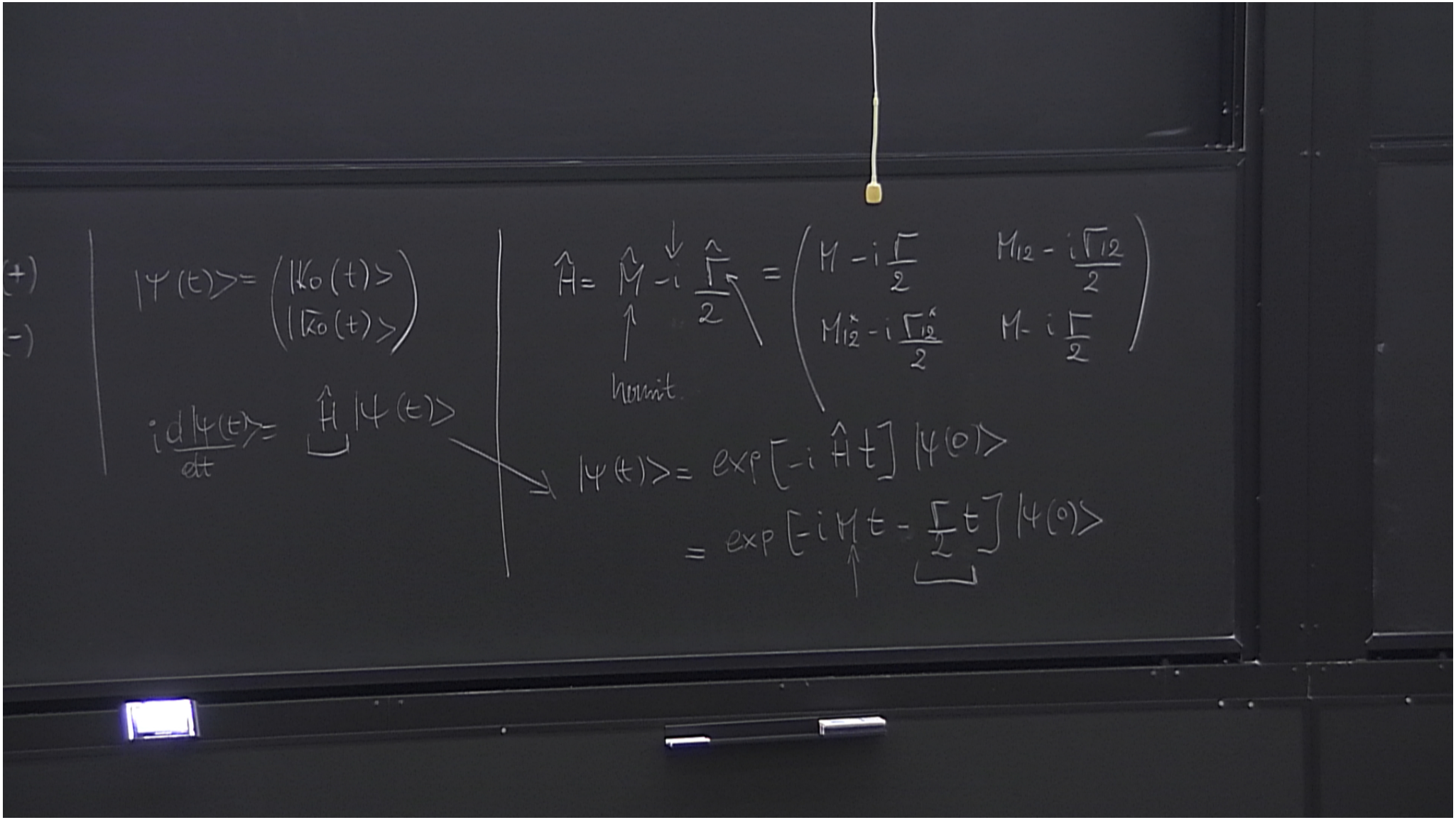
Abstract:

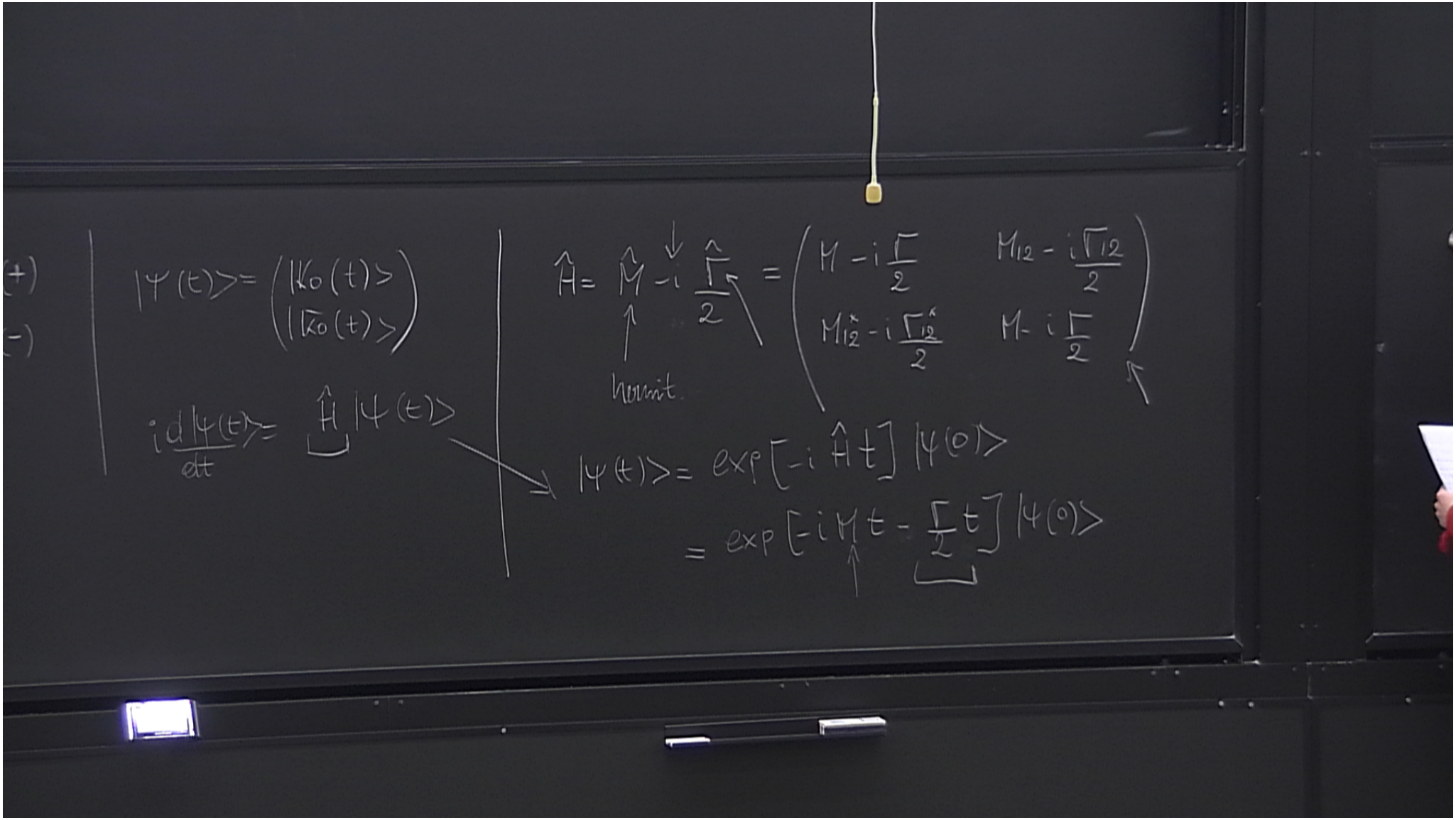

$\begin{cases} K_0 = \bar{s}\,d \\ \bar{K}_0 = s\,\bar{d} \end{cases} \Rightarrow$
CP eigen.
$K_1 = \frac{1}{\sqrt{2}}(K_0 - \bar{K}_0)$ (+)
$K_2 = \frac{1}{\sqrt{2}}(K_0 + \bar{K}_0)$ (-)

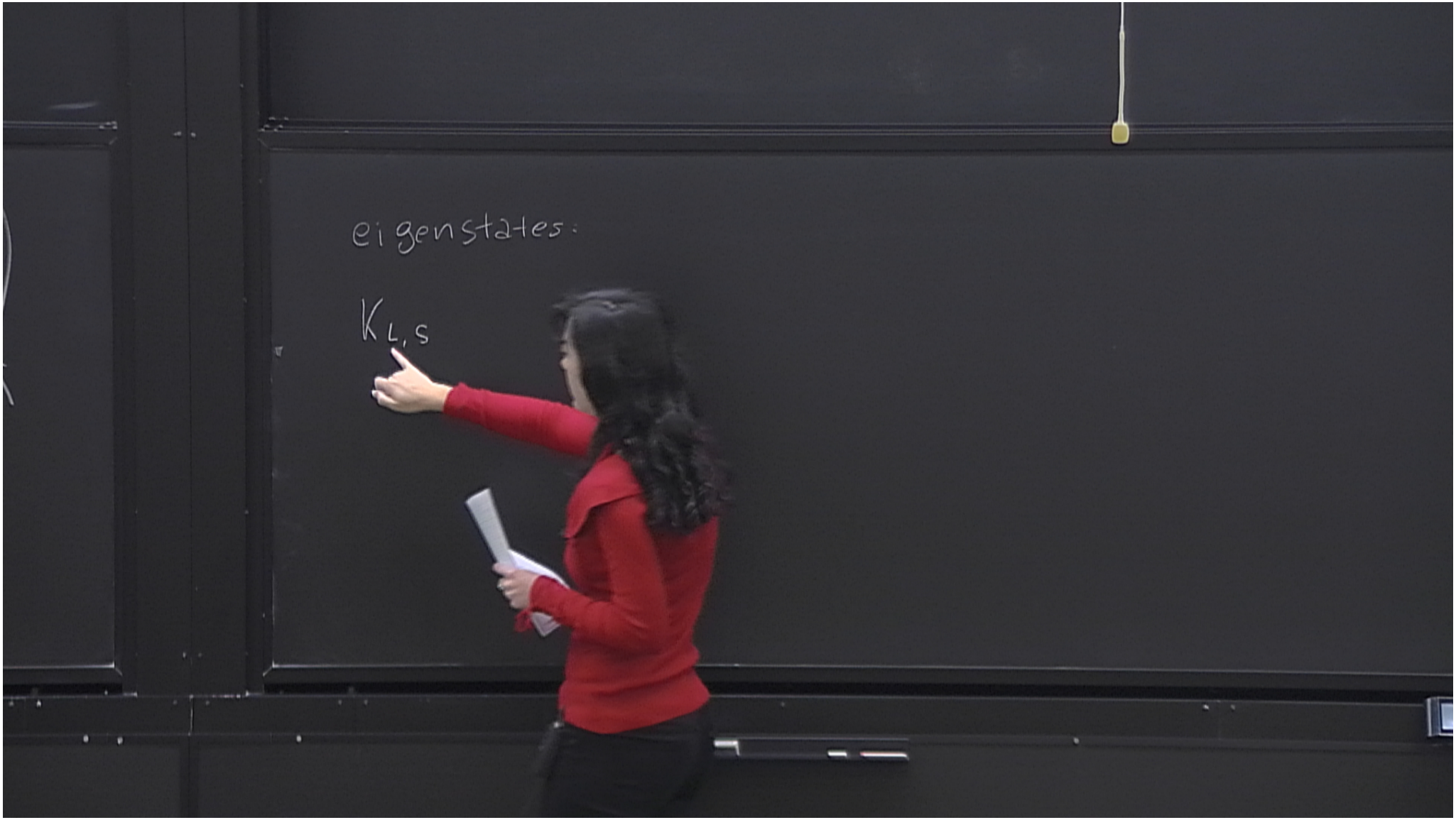

$(K_0 - \bar{K}_0)$ (+)
$(K_0 + \bar{K}_0)$ (−)
$|\psi(t)\rangle = \begin{pmatrix} |K_0(t)\rangle \\ |\bar{K}_0(t)\rangle \end{pmatrix}$
$i\frac{d|\psi(t)\rangle}{dt} = \hat{H}|\psi(t)\rangle$
$\hat{H} = \hat{M} - i\frac{\hat{\Gamma}}{2}$


$(K_0 - \bar{K}_0)$ (+)
$(K_0 + \bar{K}_0)$ (−)
$|\psi(t)\rangle = \begin{pmatrix} |K_0(t)\rangle \\ |\bar{K}_0(t)\rangle \end{pmatrix}$
$i\frac{d|\psi(t)\rangle}{dt} = \hat{H}|\psi(t)\rangle$
$\hat{H} = \hat{M} - i\frac{\hat{\Gamma}}{2} = \begin{pmatrix} M - i\frac{\Gamma}{2} & M_{12} - i\frac{\Gamma_{12}}{2} \\ M_{12}^* - i\frac{\Gamma_{12}^*}{2} & M - i\frac{\Gamma}{2} \end{pmatrix}$
hermit


$|\psi(t)\rangle = \begin{pmatrix} |K_0(t)\rangle \\ |\bar{K}_0(t)\rangle \end{pmatrix}$
$i\frac{d|\psi(t)\rangle}{dt} = \hat{H}|\psi(t)\rangle$
$\hat{H} = \hat{M} - i\frac{\hat{\Gamma}}{2} = \begin{pmatrix} M - i\frac{\Gamma}{2} & M_{12} - i\frac{\Gamma_{12}}{2} \\ M_{12}^* - i\frac{\Gamma_{12}^*}{2} & M - i\frac{\Gamma}{2} \end{pmatrix}$
hermit
$|\psi(t)\rangle = \exp[-i\hat{H}t]|\psi(0)\rangle$
$= \exp[-iMt - \frac{\Gamma}{2}t]|\psi(0)\rangle$

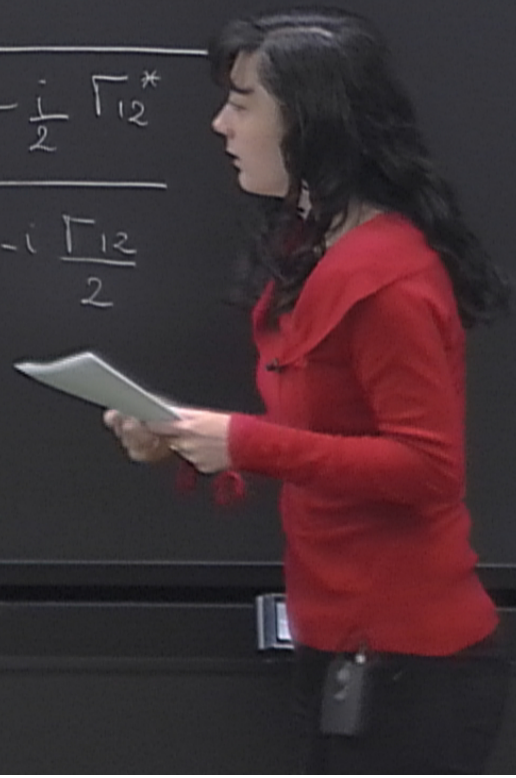

$|\psi(t)\rangle = \begin{pmatrix} |K_0(t)\rangle \\ |\bar{K}_0(t)\rangle \end{pmatrix}$
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hermit.
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(+)
(-)
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hermit.
$|\psi(t)\rangle = \exp[-i\hat{H}t]|\psi(0)\rangle$
$= \exp[-iMt - \frac{\Gamma}{2}t]|\psi(0)\rangle$


eigenstates:
$K_{L,S}$

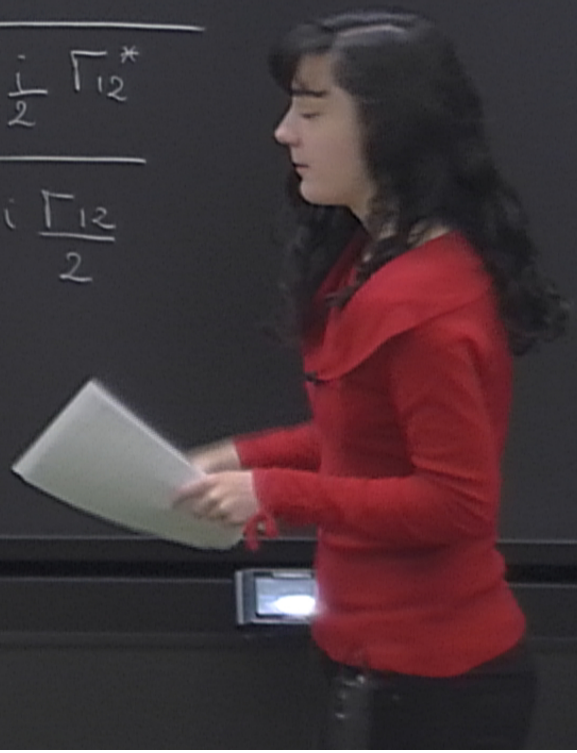
eigenstates:

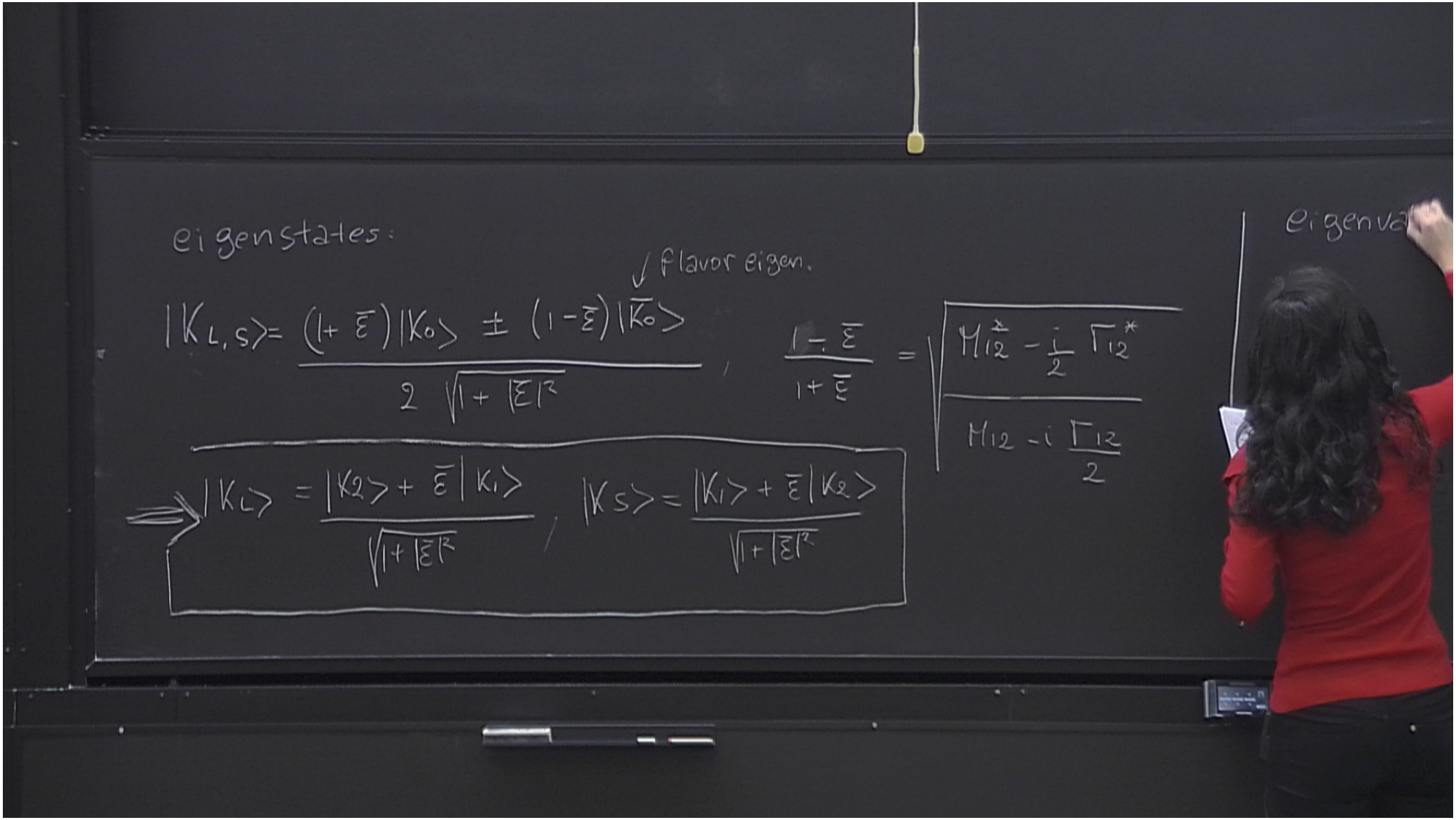
$$|K_{L,S}\rangle = \frac{(1+\bar{\varepsilon})|K_0\rangle \pm (1-\bar{\varepsilon})|\bar{K}_0\rangle}{2\sqrt{1+|\bar{\varepsilon}|^2}}, \qquad \frac{1-\bar{\varepsilon}}{1+\bar{\varepsilon}} = \sqrt{\frac{M_{12}^* - \frac{i}{2}\Gamma_{12}^*}{M_{12} - \frac{i}{2}\Gamma_{12}}}$$

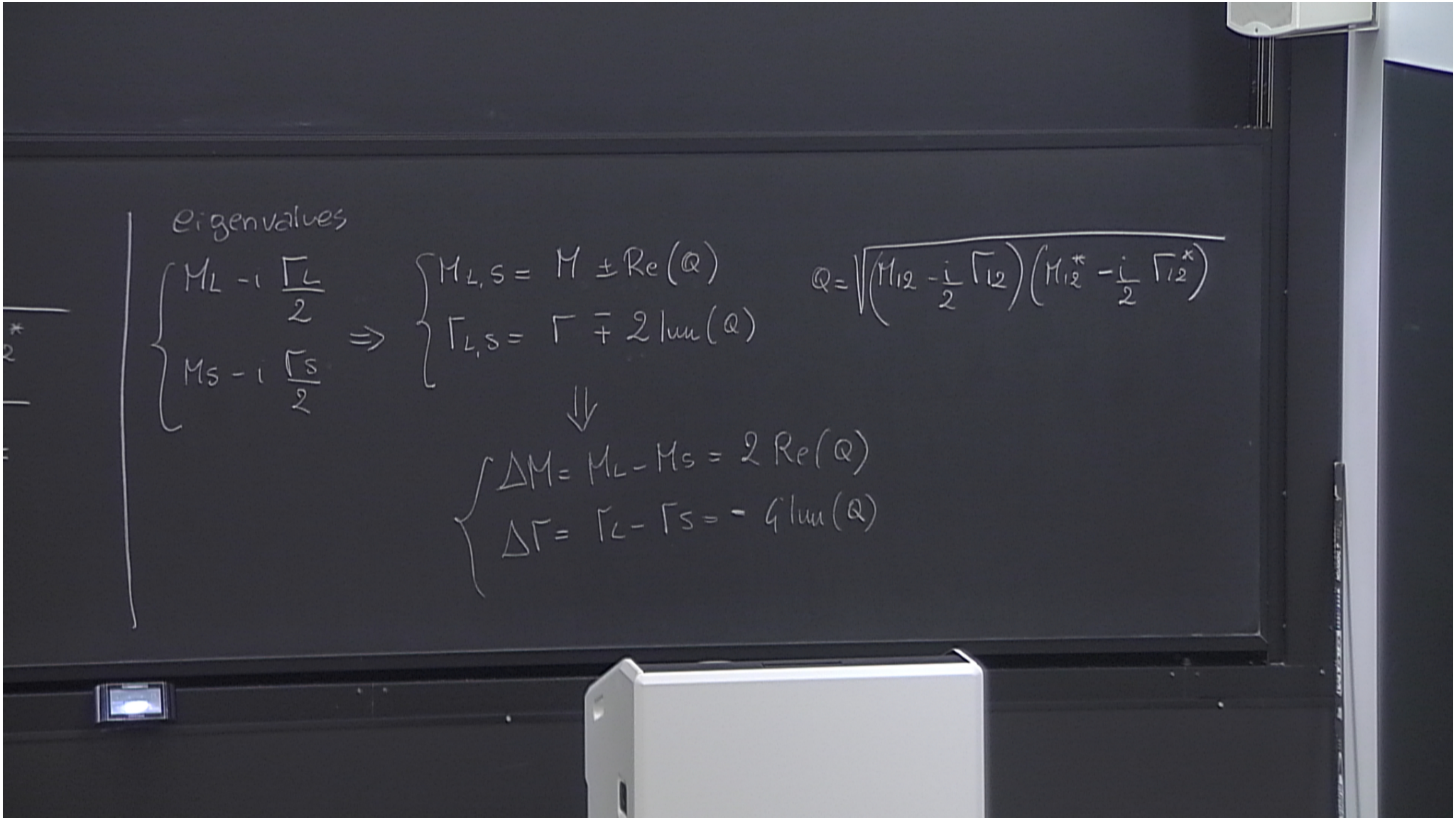


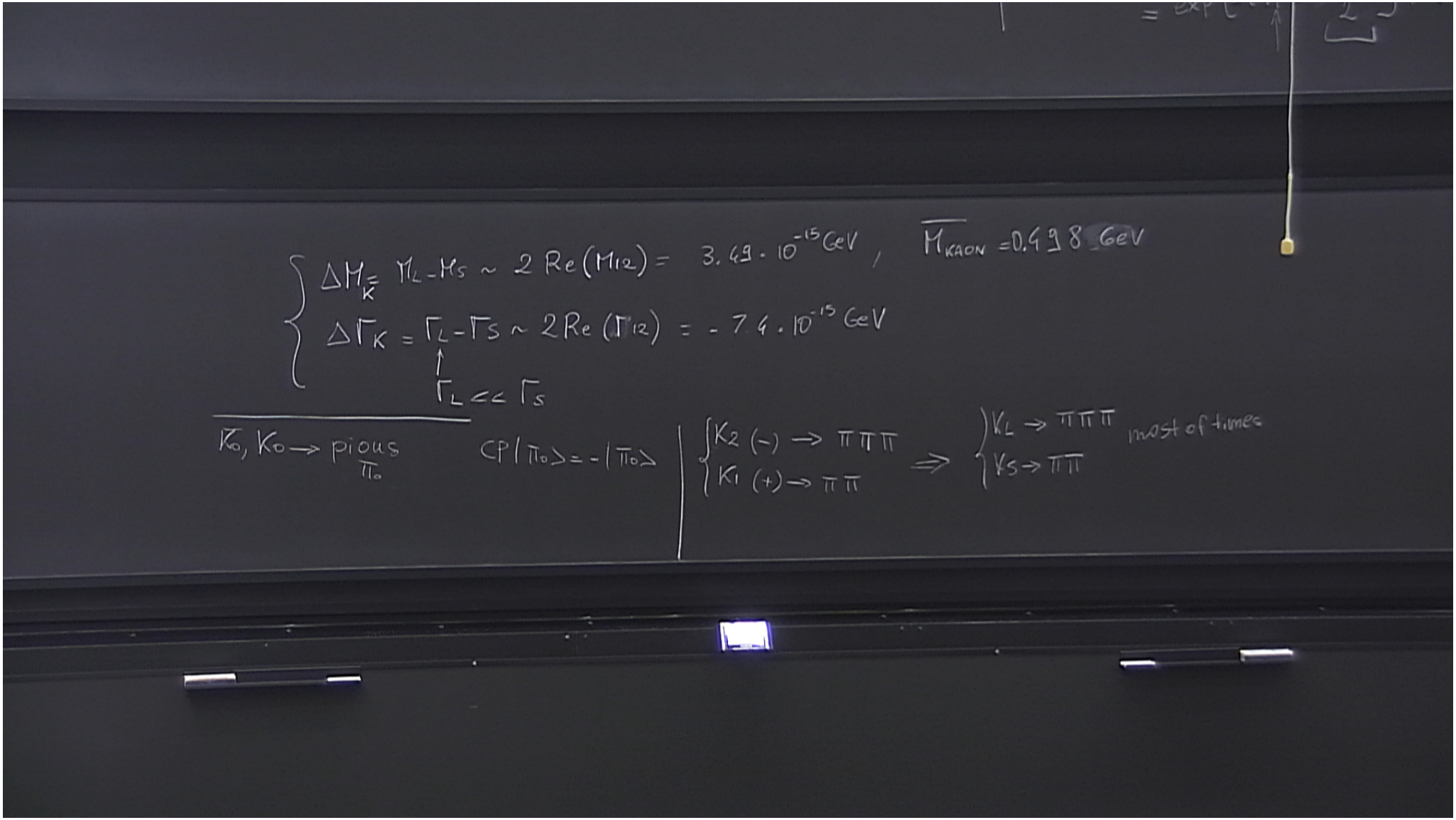
eigenstates:

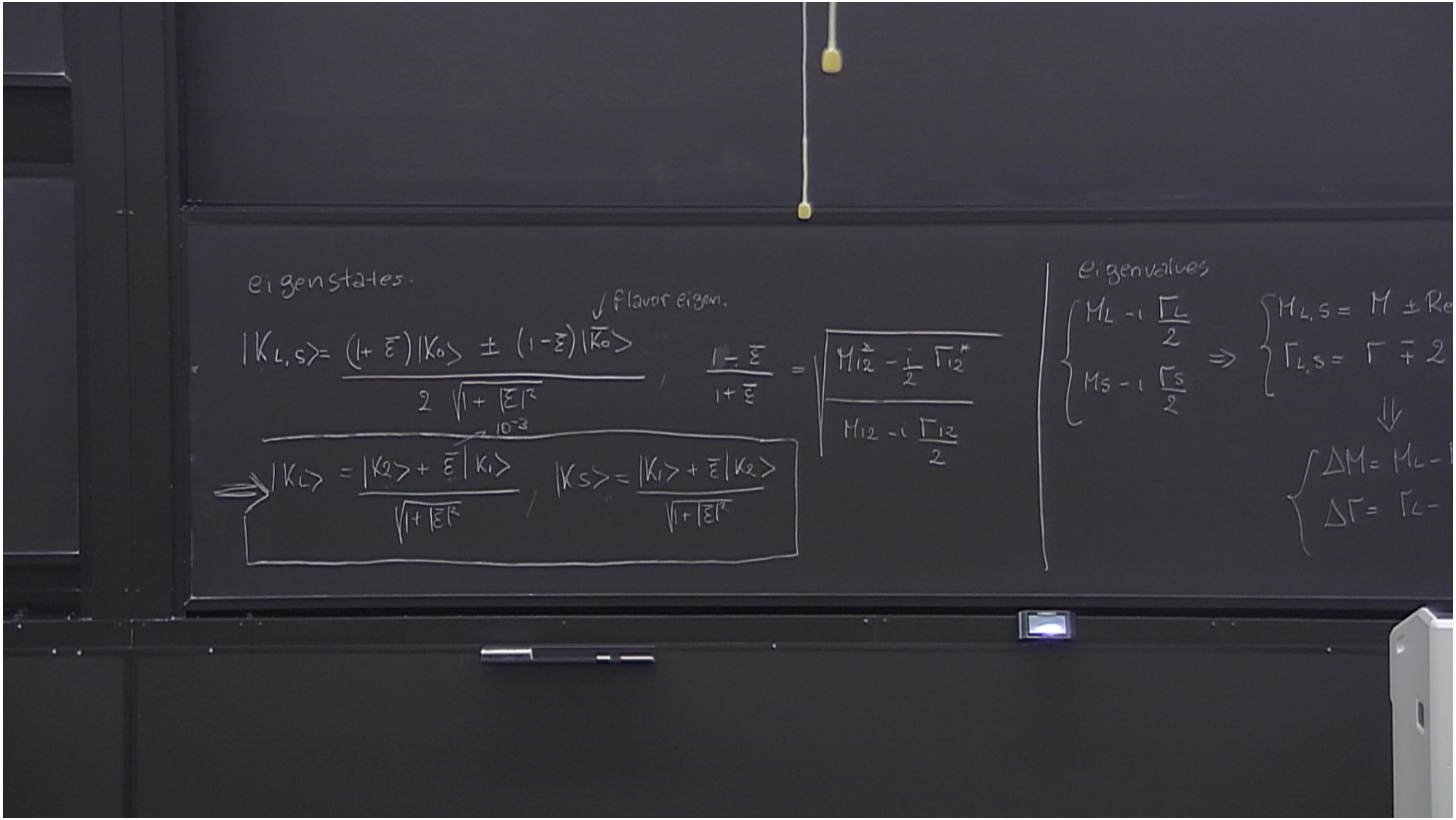
$$|K_{L,S}\rangle = \frac{(1+\bar{\varepsilon})|K_0\rangle \pm (1-\bar{\varepsilon})|\bar{K}_0\rangle}{2\sqrt{1+|\bar{\varepsilon}|^2}}, \qquad \frac{1-\bar{\varepsilon}}{1+\bar{\varepsilon}} = \sqrt{\frac{M_{12}^* - \frac{i}{2}\Gamma_{12}^*}{M_{12} - i\frac{\Gamma_{12}}{2}}}$$

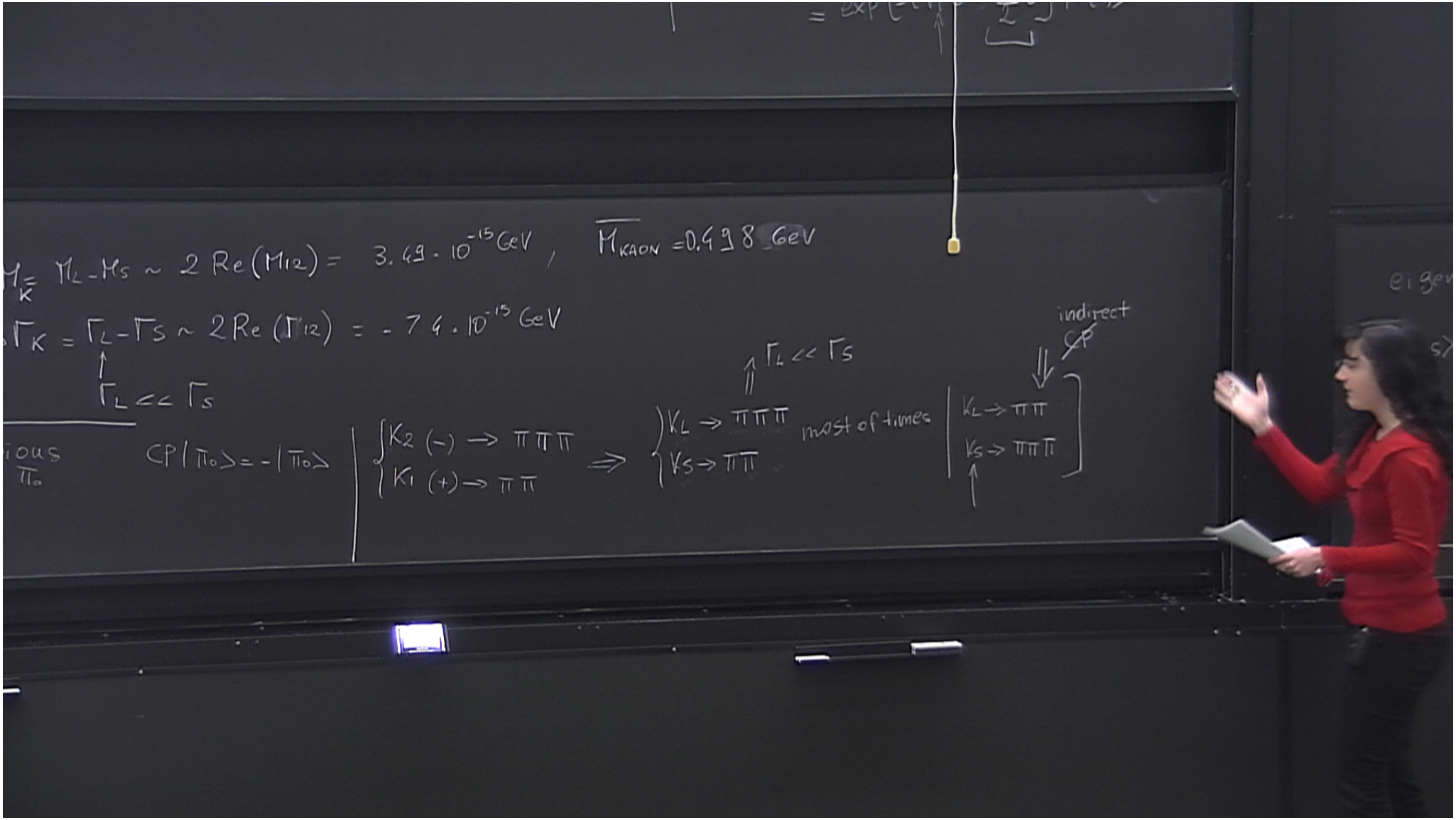



eigenstates:
flavor eigen.
$|K_{L,S}\rangle = \frac{(1+\bar{\varepsilon})|K_0\rangle \pm (1-\bar{\varepsilon})|\bar{K}_0\rangle}{2\sqrt{1+|\bar{\varepsilon}|^2}}$
$\frac{1-\bar{\varepsilon}}{1+\bar{\varepsilon}} = \sqrt{\frac{M_{12}^* - \frac{i}{2}\Gamma_{12}^*}{M_{12} - \frac{i}{2}\Gamma_{12}}}$
$\Rightarrow |K_L\rangle = \frac{|K_2\rangle + \bar{\varepsilon}|K_1\rangle}{\sqrt{1+|\bar{\varepsilon}|^2}}$, $|K_S\rangle = \frac{|K_1\rangle + \bar{\varepsilon}|K_2\rangle}{\sqrt{1+|\bar{\varepsilon}|^2}}$
eigenva

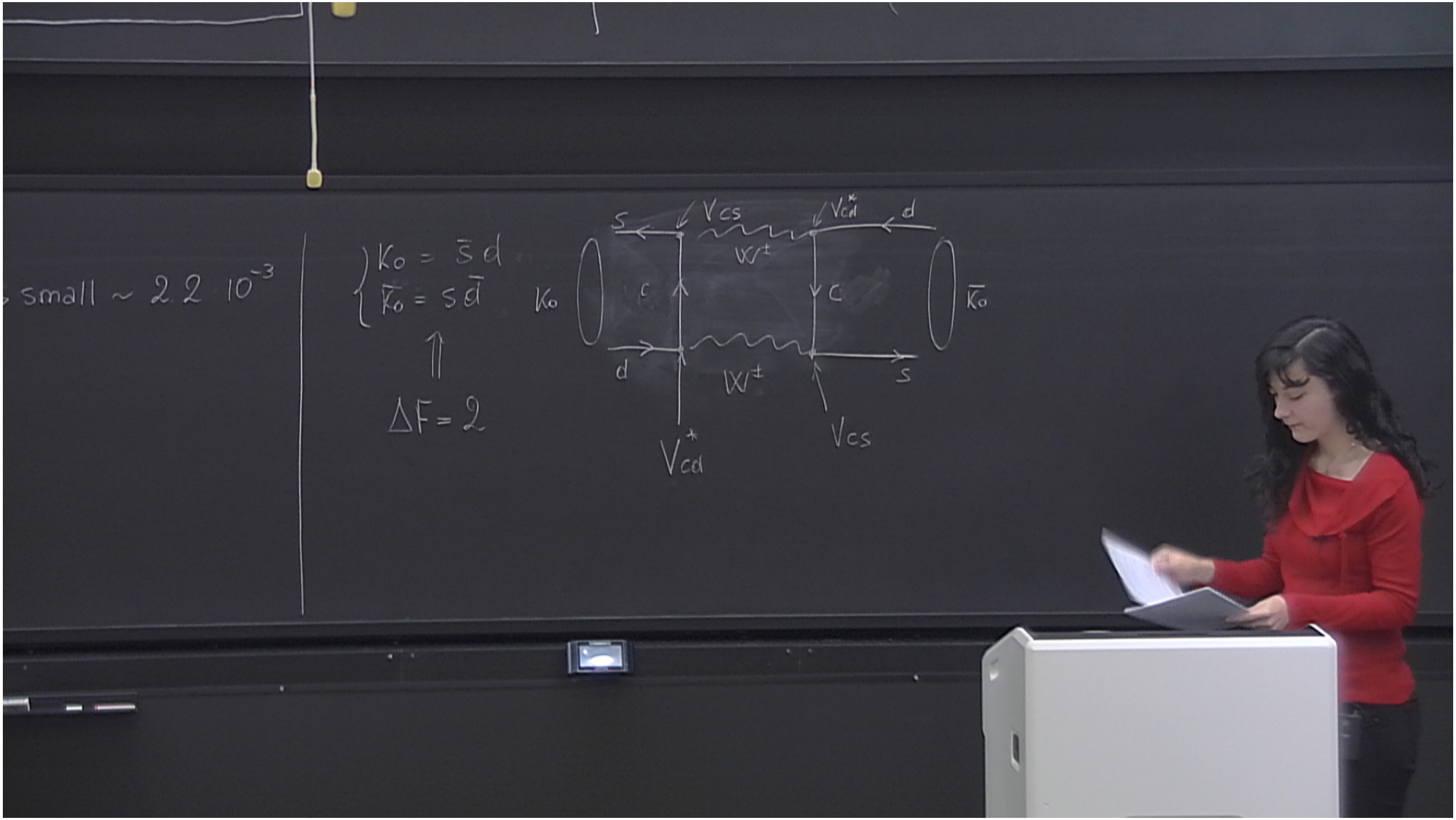

eigenvalues
$\begin{cases} M_L - i\frac{\Gamma_L}{2} \\ M_S - i\frac{\Gamma_S}{2} \end{cases} \Rightarrow \begin{cases} M_{L,S} = M \pm \mathrm{Re}(Q) \\ \Gamma_{L,S} = \Gamma \mp 2\,\mathrm{Im}(Q) \end{cases}$
$Q = \sqrt{\left(M_{12} - \frac{i}{2}\Gamma_{12}\right)\left(M_{12}^* - \frac{i}{2}\Gamma_{12}^*\right)}$
$\Downarrow$
$\begin{cases} \Delta M = M_L - M_S = 2\,\mathrm{Re}(Q) \\ \Delta\Gamma = \Gamma_L - \Gamma_S = -4\,\mathrm{Im}(Q) \end{cases}$

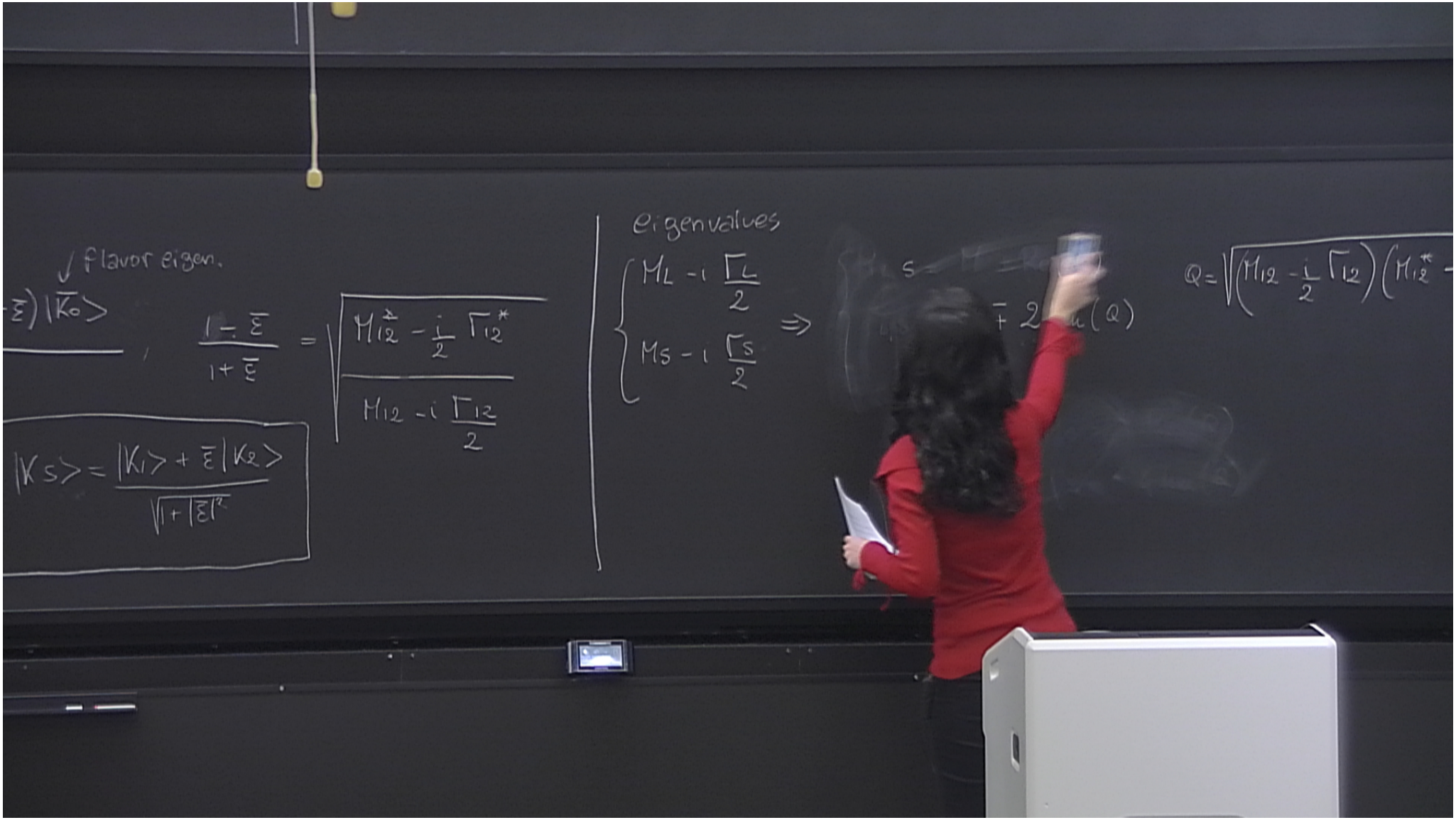

$\Delta M_K \equiv M_L - M_S \sim 2\,Re(M_{12}) = 3.49 \cdot 10^{-15}\,GeV$, $\overline{M}_{KAON} = 0.498\,GeV$
$\Delta\Gamma_K = \Gamma_L - \Gamma_S \sim 2\,Re(\Gamma_{12}) = -7.4 \cdot 10^{-15}\,GeV$
$\Gamma_L \ll \Gamma_S$
$\overline{K_0}, K_0 \rightarrow$ pions $\pi_0$
$CP|\pi_0\rangle = -|\pi_0\rangle$
$K_2(-) \rightarrow \pi\pi\pi$
$K_1(+) \rightarrow \pi\pi$
$\Rightarrow$
$K_L \rightarrow \pi\pi\pi$
$K_S \rightarrow \pi\pi$
most of times

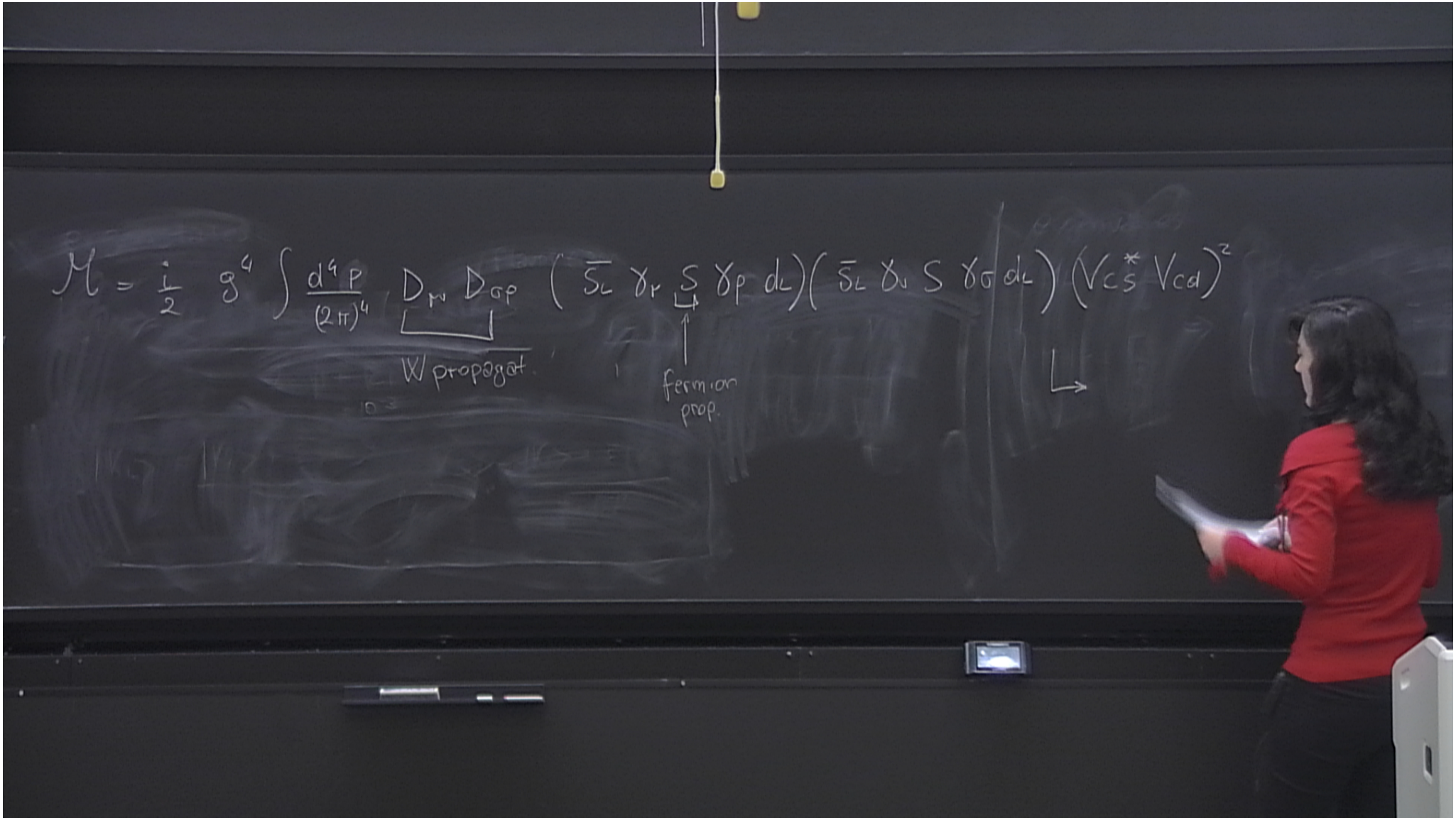

eigenstates.
flavor eigen.
$|K_{L,S}\rangle = \frac{(1+\bar{\varepsilon})|K_0\rangle \pm (1-\bar{\varepsilon})|\bar{K}_0\rangle}{2\sqrt{1+|\bar{\varepsilon}|^2}}$
$\frac{1-\bar{\varepsilon}}{1+\bar{\varepsilon}} = \sqrt{\frac{M_{12}^* - \frac{i}{2}\Gamma_{12}^*}{M_{12} - \frac{i}{2}\Gamma_{12}}}$
$\sim 10^{-3}$
$|K_L\rangle = \frac{|K_2\rangle + \bar{\varepsilon}|K_1\rangle}{\sqrt{1+|\bar{\varepsilon}|^2}}$, $|K_S\rangle = \frac{|K_1\rangle + \bar{\varepsilon}|K_2\rangle}{\sqrt{1+|\bar{\varepsilon}|^2}}$
eigenvalues
$\begin{cases} M_L - i\frac{\Gamma_L}{2} \\ M_S - i\frac{\Gamma_S}{2} \end{cases} \Rightarrow \begin{cases} M_{L,S} = M \pm \mathrm{Re} \\ \Gamma_{L,S} = \Gamma \mp 2 \end{cases}$
$\Downarrow$
$\begin{cases} \Delta M = M_L - \\ \Delta\Gamma = \Gamma_L - \end{cases}$

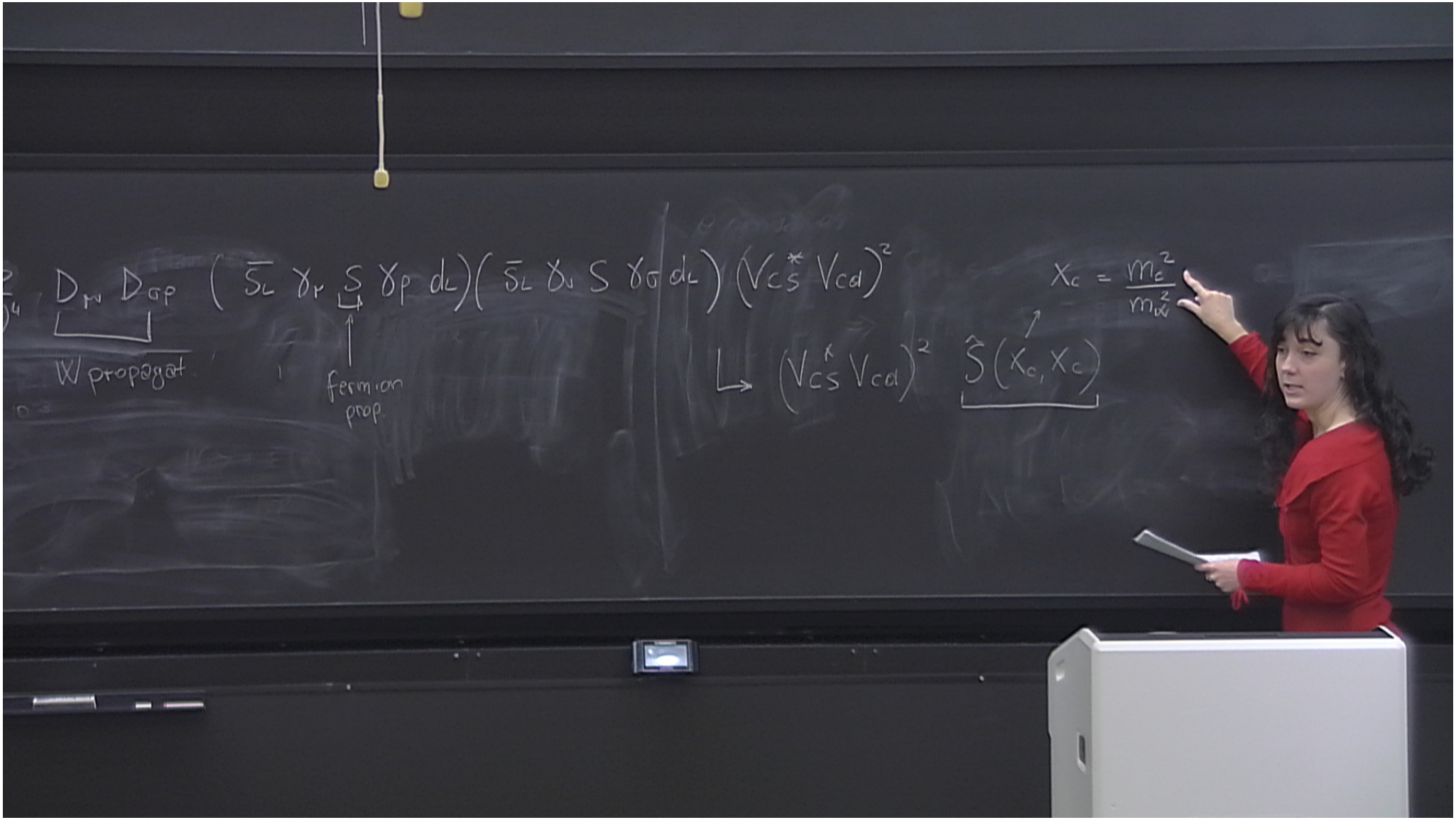

$M_{\bar{K}} \equiv M_L - M_S \sim 2\,Re(M_{12}) = 3.49 \cdot 10^{-15}\,GeV$, $\overline{M}_{KAON} = 0.498\,GeV$
$\Gamma_K = \Gamma_L - \Gamma_S \sim 2\,Re(\Gamma_{12}) = -7.4 \cdot 10^{-15}\,GeV$
$\Gamma_L \ll \Gamma_S$
$CP|\pi_0\rangle = -|\pi_0\rangle$
$K_2\,(-) \to \pi\pi\pi$
$K_1\,(+) \to \pi\pi$
$\Gamma_L \ll \Gamma_S$
$K_L \to \pi\pi\pi$
$K_S \to \pi\pi$
most of times
indirect CP
$K_L \to \pi\pi$
$K_S \to \pi\pi$

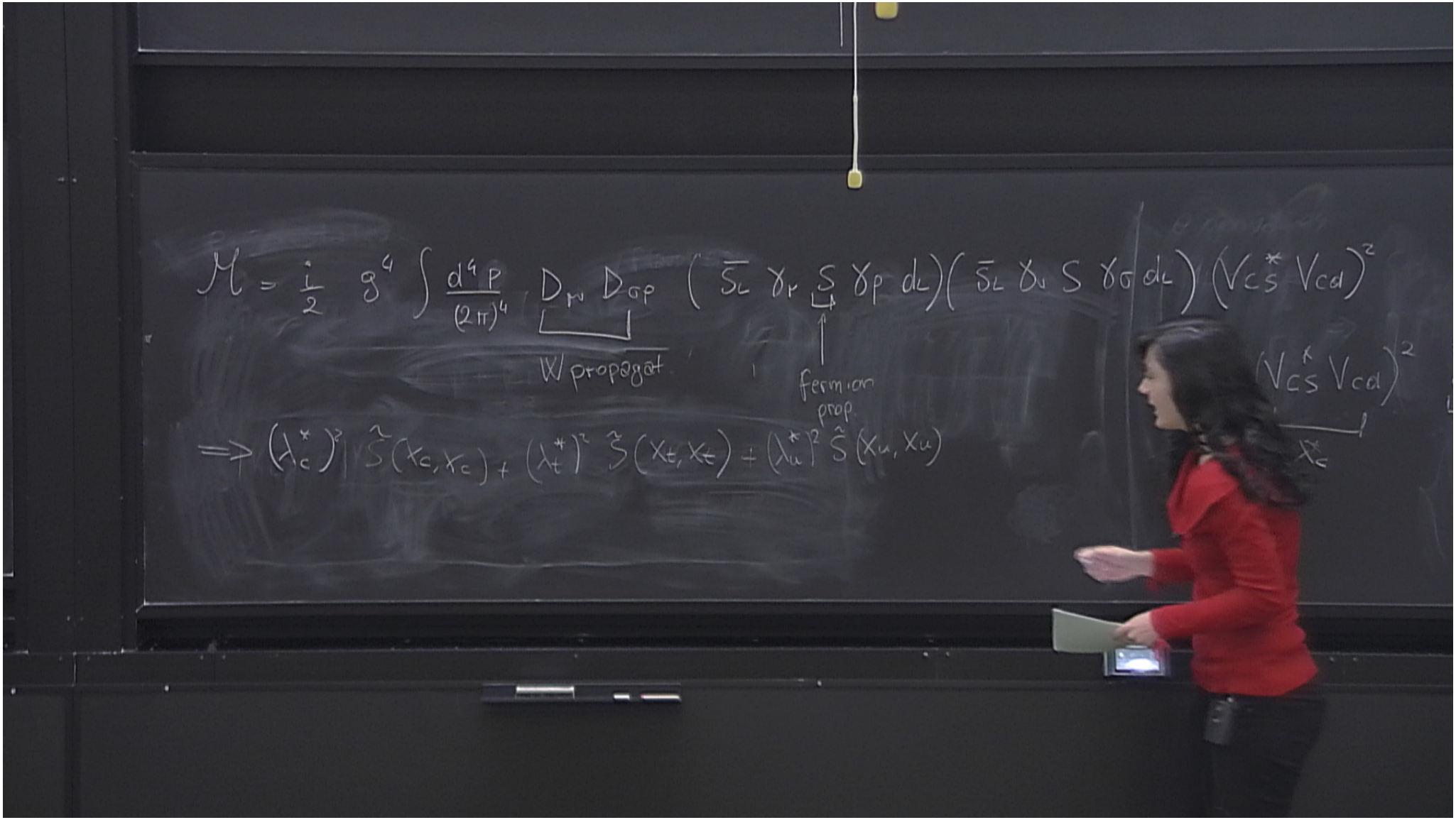

$\sqrt{1+|\varepsilon|^2}$
$\sqrt{1+|\varepsilon|^2}$
$\varepsilon_K \equiv \frac{A(K_L \to \pi\pi)}{A(K_S \to \pi\pi)}$ → small ~ 2.2 $10^{-3}$
$\propto$ Im (H12)

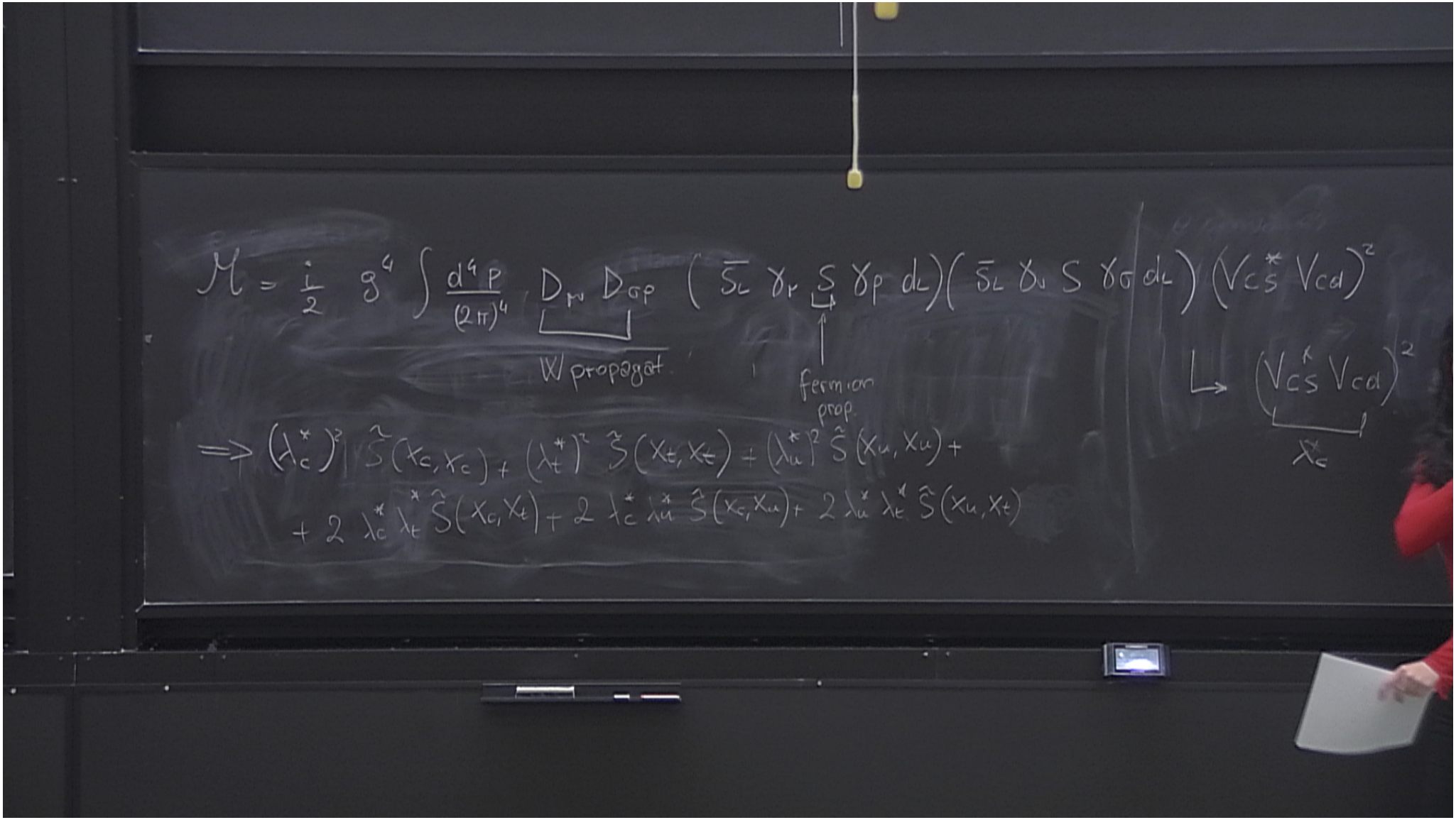

small ~ 2.2 10^-3
K0 = s̄ d
K̄0 = s d̄
⇑
ΔF = 2
K0
s
Vcs
V*cd
d
W±
c
c
K̄0
d
W±
s
V*cd
Vcs

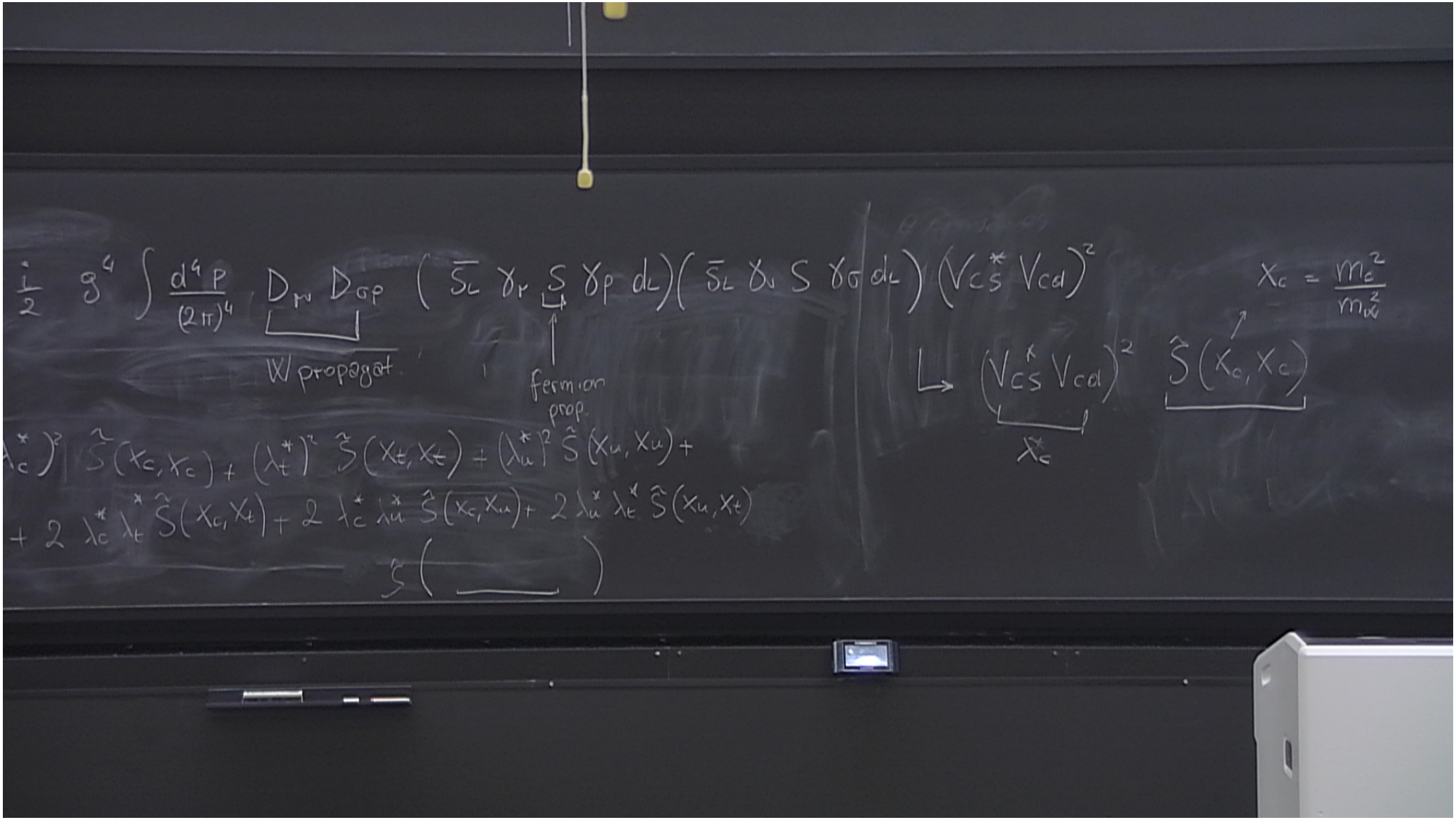

flavor eigen.
eigenvalues

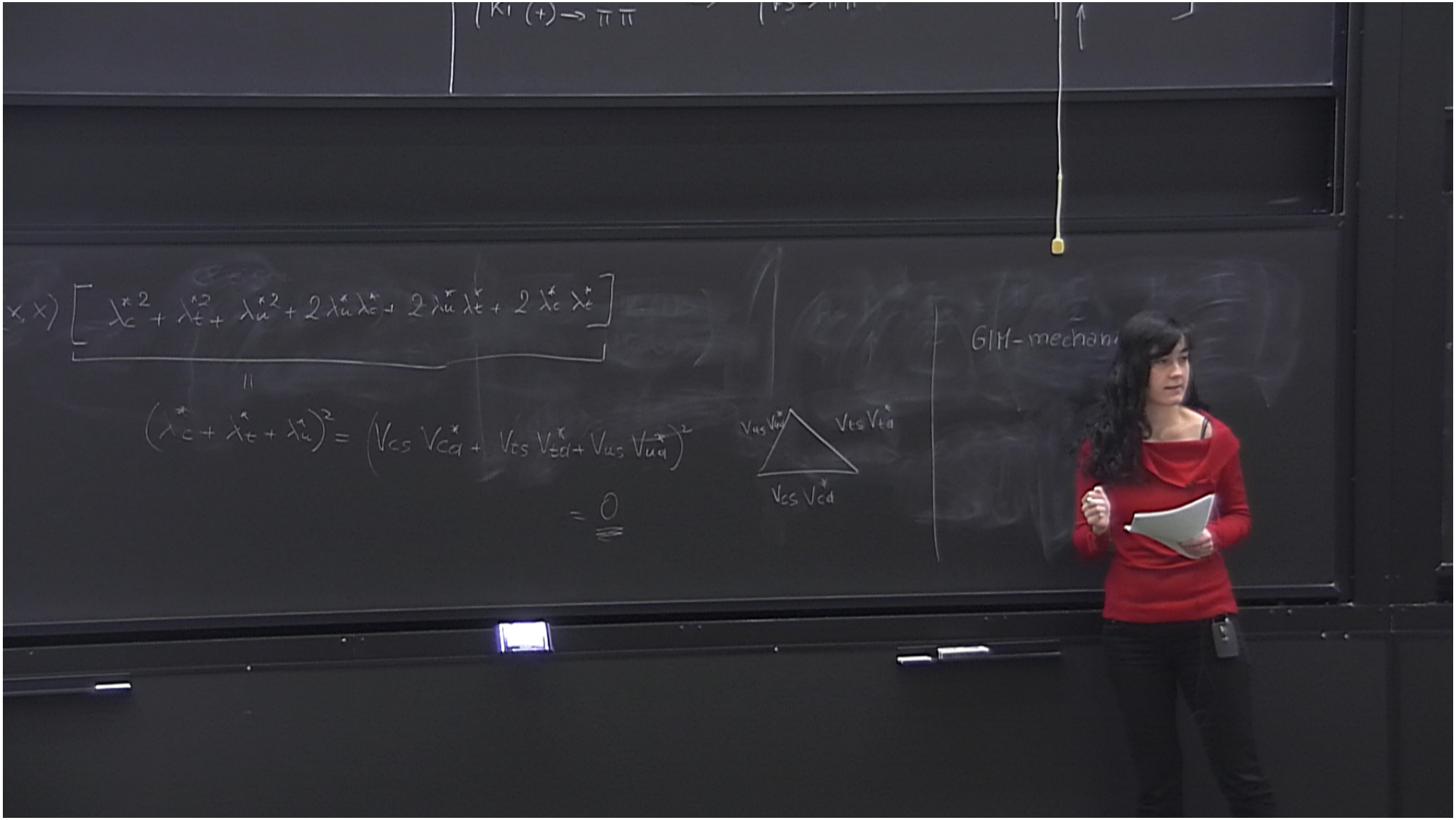

$\mathcal{M} = \frac{i}{2} g^4 \int \frac{d^4p}{(2\pi)^4} D_{\mu\nu} D_{\sigma\rho} (\bar{s}_L \gamma_\mu S \gamma_\rho d_L)(\bar{s}_L \gamma_\nu S \gamma_\sigma d_L)(V_{cs}^* V_{cd})^2$
W propagat.
fermion prop.

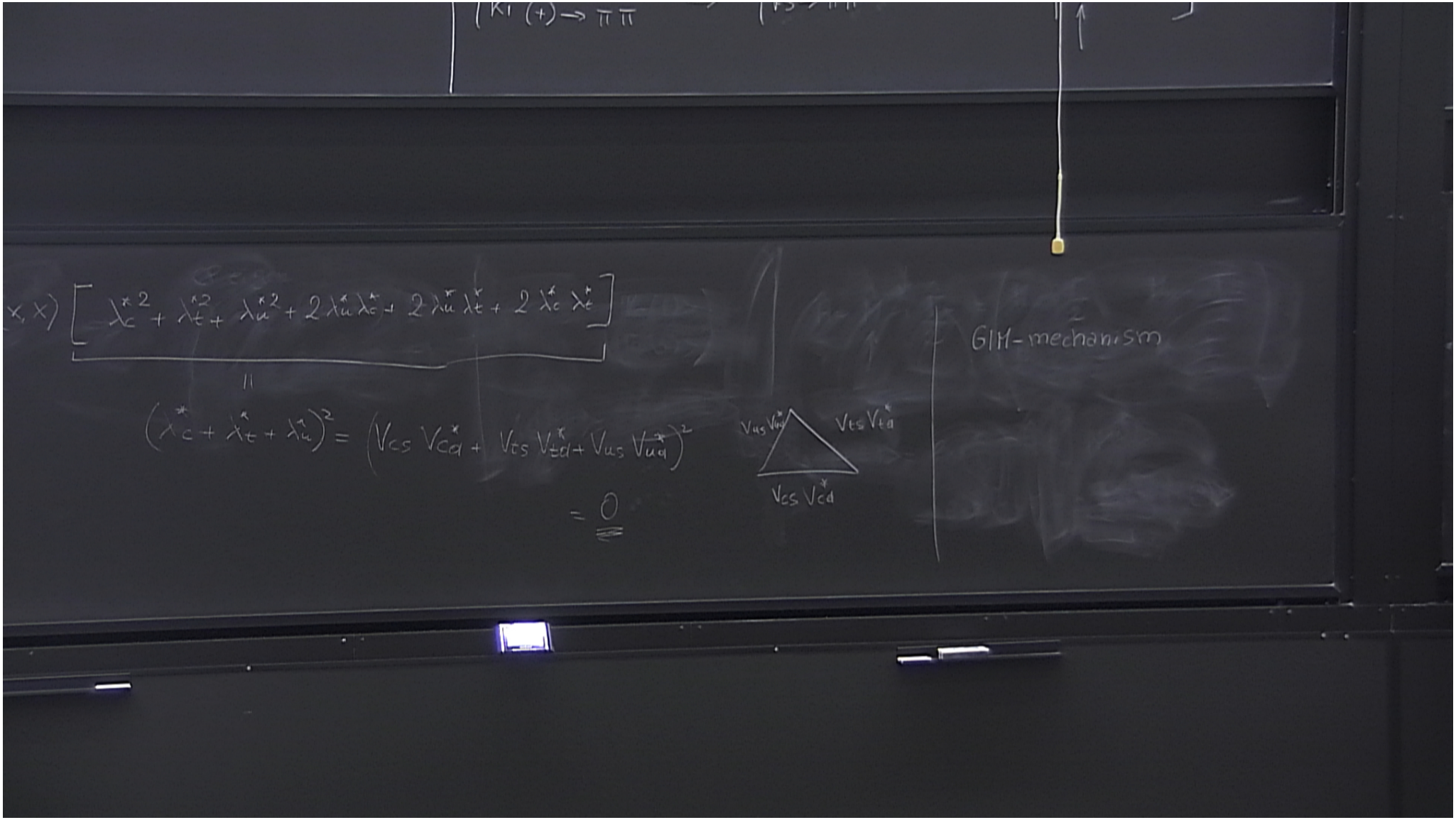

$D_{\mu\nu} D_{\alpha\beta} (\bar{s}_L \gamma_\nu s \gamma_\beta d_L)(\bar{s}_L \gamma_\mu s \gamma_\alpha d_L)(V_{cs}^* V_{cd})^2$
W propagat
fermion prop
$\hookrightarrow (V_{cs}^* V_{cd})^2 \hat{S}(x_c, x_c)$
$x_c = \frac{m_c^2}{m_W^2}$


W propagat
fermion prop


$\mathcal{M} = \frac{i}{2} g^4 \int \frac{d^4p}{(2\pi)^4} D_{\mu\nu} D_{\sigma\rho} (\bar{s}_L \gamma_\nu S \gamma_\rho d_L)(\bar{s}_L \gamma_\mu S \gamma_\sigma d_L)(V_{cs}^* V_{cd})^2$
W propagat
fermion prop.
$\hookrightarrow (V_{cs}^* V_{cd})^2$
$\lambda_c^*$
$\Rightarrow (\lambda_c^*)^2 \hat{S}(x_c, x_c) + (\lambda_t^*)^2 \hat{S}(x_t, x_t) + (\lambda_u^*)^2 \hat{S}(x_u, x_u) +$
$+ 2\lambda_c^* \lambda_t^* \hat{S}(x_c, x_t) + 2\lambda_c^* \lambda_u^* \hat{S}(x_c, x_u) + 2\lambda_u^* \lambda_t^* \hat{S}(x_u, x_t)$

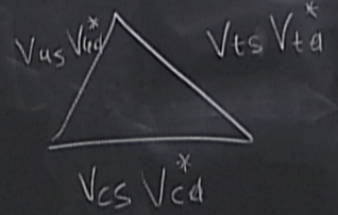

W propagat
fermion prop.
$x_c = \frac{m_c^2}{m_W^2}$
$\hat{S}(x_c, x_c)$
$\hat{S}(x_c, x_t)$
$\hat{S}(x_c, x_u)$
$\hat{S}(x_u, x_t)$


$K_1(+) \to \pi\pi$
GIM-mechan
$= 0$


$K_1(+) \to \pi\pi$
$\lambda_c^{*2} + \lambda_t^{*2} + \lambda_u^{*2} + 2\lambda_u^*\lambda_c^* + 2\lambda_u^*\lambda_t^* + 2\lambda_c^*\lambda_t^*$
$(\lambda_c^* + \lambda_t^* + \lambda_u^*)^2 = (V_{cs}V_{cd}^* + V_{ts}V_{td}^* + V_{us}V_{ud}^*)^2$
$= 0$
$V_{us}V_{ud}^*$
$V_{ts}V_{td}^*$
$V_{cs}V_{cd}^*$
GIM-mechanism

$\lambda_t^* + 2\lambda_c^*\lambda_t^*]$

$a + V_{ts}V_{td}^* + V_{us}V_{ud}^*)^2$



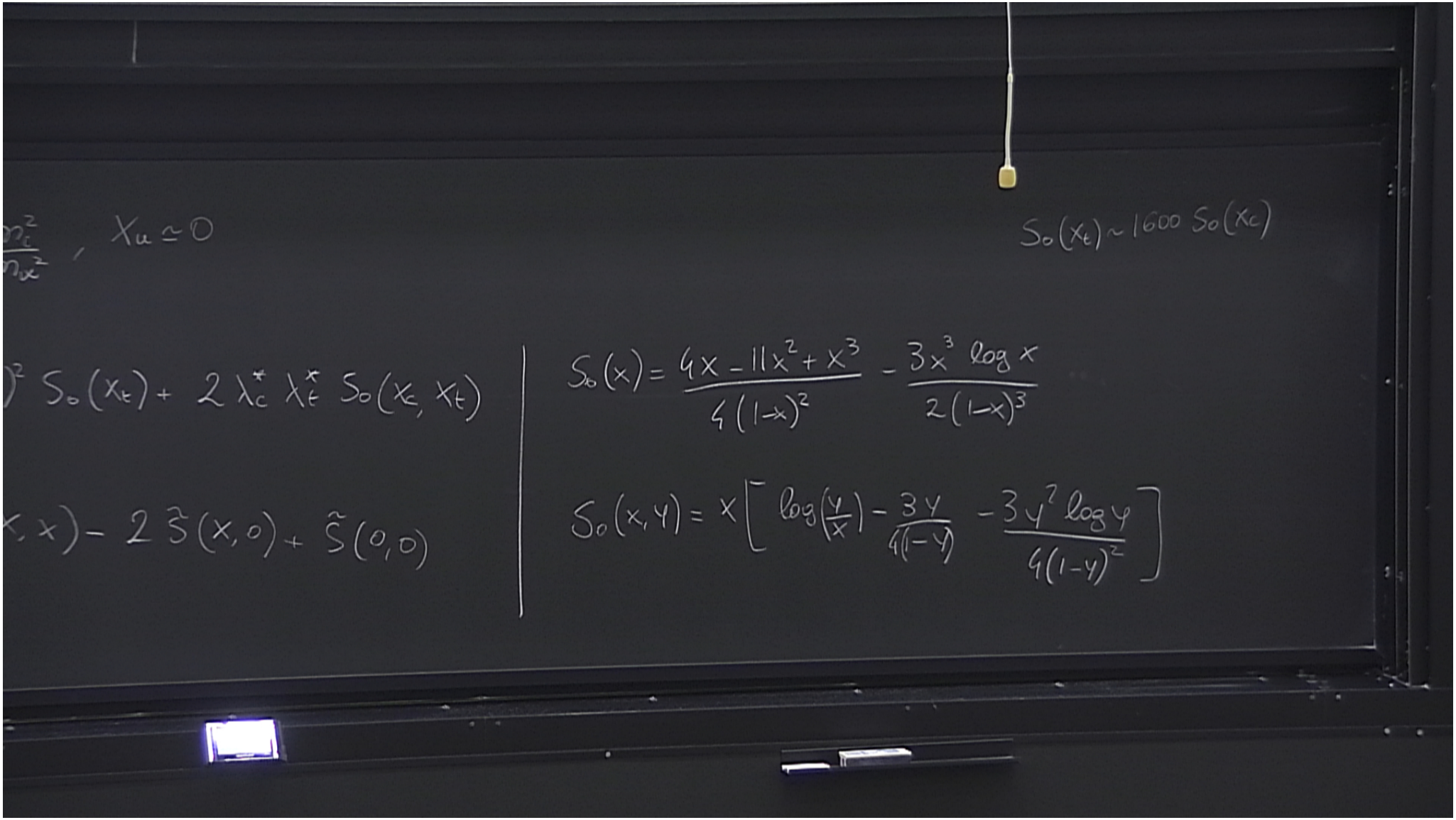

$= 0$

GIM-mechanism

$$\lambda_u^* = -\lambda_c^* - \lambda_t^* \qquad x = \frac{m_i^2}{m_W^2}, \quad x_u \simeq 0$$

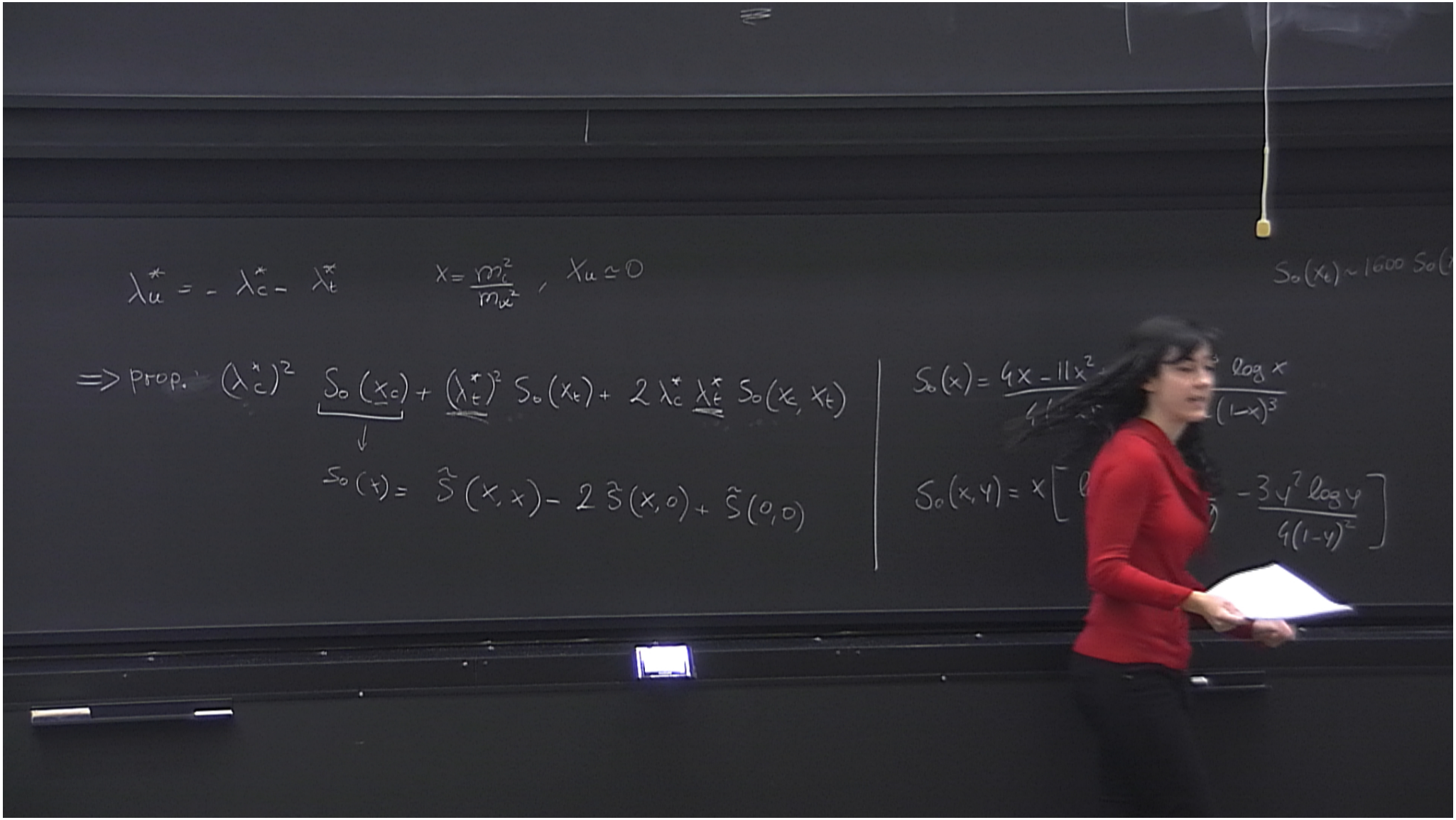
$$\Rightarrow \text{prop.} \; (\lambda_c^*)^2 \underbrace{S_0(x_c)} + (\lambda_t^*)^2 S_0(x_t) + 2\lambda_c^* \lambda_t^* S_0(x_c, x_t)$$

$$S_0(x) = \tilde{S}(x,x) - 2\tilde{S}(x,0) + \tilde{S}(0,0)$$


$\frac{m_c^2}{m_W^2}$, $x_u \simeq 0$
$S_0(x_t) \sim 1600\, S_0(x_c)$
$)^2 S_0(x_t) + 2\lambda_c^* \lambda_t^* S_0(x_c, x_t)$
$S_0(x) = \frac{4x - 11x^2 + x^3}{4(1-x)^2} - \frac{3x^3 \log x}{2(1-x)^3}$
$x, x) - 2\tilde{S}(x, 0) + \tilde{S}(0, 0)$
$S_0(x, y) = x\left[\log\left(\frac{y}{x}\right) - \frac{3y}{4(1-y)} - \frac{3y^2 \log y}{4(1-y)^2}\right]$


$\varepsilon_K \equiv \frac{A(K_L \to \pi\pi)}{A(K_S \to \pi\pi)}$ → small ~ 2.2 $10^{-3}$
$\propto \mathrm{Im}(H_{12})$
$V_{CKM} \sim 0.976$
$K_0 = \bar{s}d$
$\bar{K}_0 = s\bar{d}$
$\Delta F = 2$
$K_0$
$\bar{K}_0$
$V_{cs}$
$V_{cd}^*$
$V_{td}$
$V_{ts}$
s
d
c
t
W


$\varepsilon_K \equiv \frac{A(K_L \to \pi\pi)}{A(K_S \to \pi\pi)}$ → small ~ 2.2 $10^{-3}$
$\propto \mathrm{Im}(H_{12})$
$V_{CKM} = \begin{pmatrix} 0.976 & 0.22 & \\ -0.22 & 0.97 & \\ 8.6\,10^{-3}\exp[-i\,0.38] & -4\,10^{-2} & \end{pmatrix}$
$\exp(-i\cdot 1.2)$
$K_0 = \bar{s}d$
$\bar{K}_0 = s\bar{d}$
$\Updownarrow$
$\Delta F = 2$
$K_0$
$\bar{K}_0$
s
d
$V_{cs}$
$V_{cd}^*$
$V_{td}$
$V_{ts}^*$
c
c
d
s
$V_{cd}$
$V_{cs}$


$\lambda_u^* = -\lambda_c^* - \lambda_t^*$
$x = \frac{m_c^2}{m_W^2}$, $x_u \simeq 0$
$S_0(x_t) \sim 1600\, S_0($
$\Rightarrow$ prop. $(\lambda_c^*)^2\, S_0(x_c) + (\lambda_t^*)^2\, S_0(x_t) + 2\lambda_c^* \lambda_t^*\, S_0(x_c, x_t)$
$S_0(x) = \frac{4x - 11x^2}{}$ $\frac{\log x}{(1-x)^3}$
$S_0(x) = \tilde{S}(x,x) - 2\tilde{S}(x,0) + \tilde{S}(0,0)$
$S_0(x,y) = x\Big[$ $- \frac{3y^2 \log y}{4(1-y)^2}\Big]$