Title: 13/14 PSI - Standard Model Review - Lecture 13

Date: Jan 22, 2014 09:00 AM

URL: http://pirsa.org/14010024

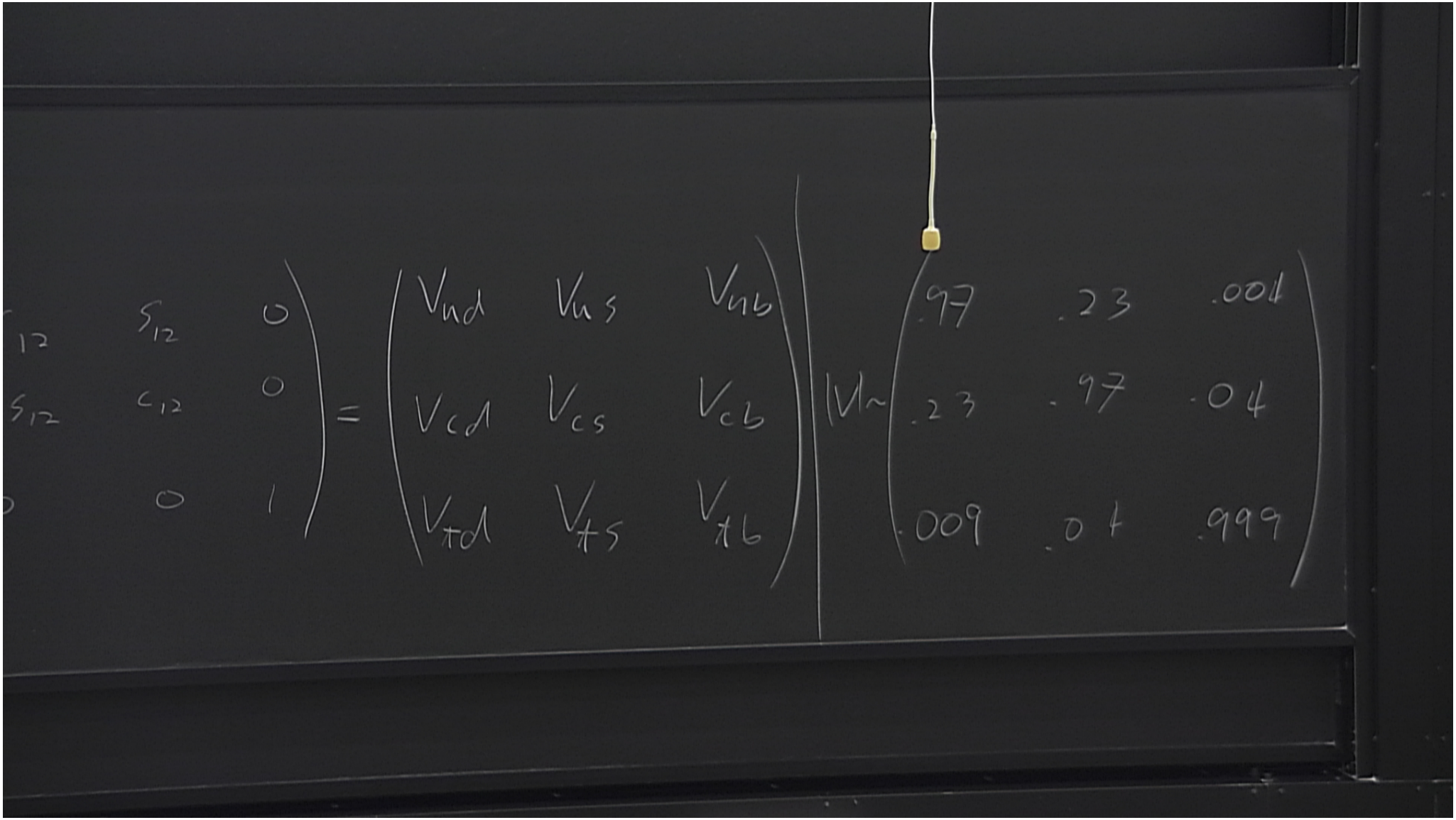
Abstract:

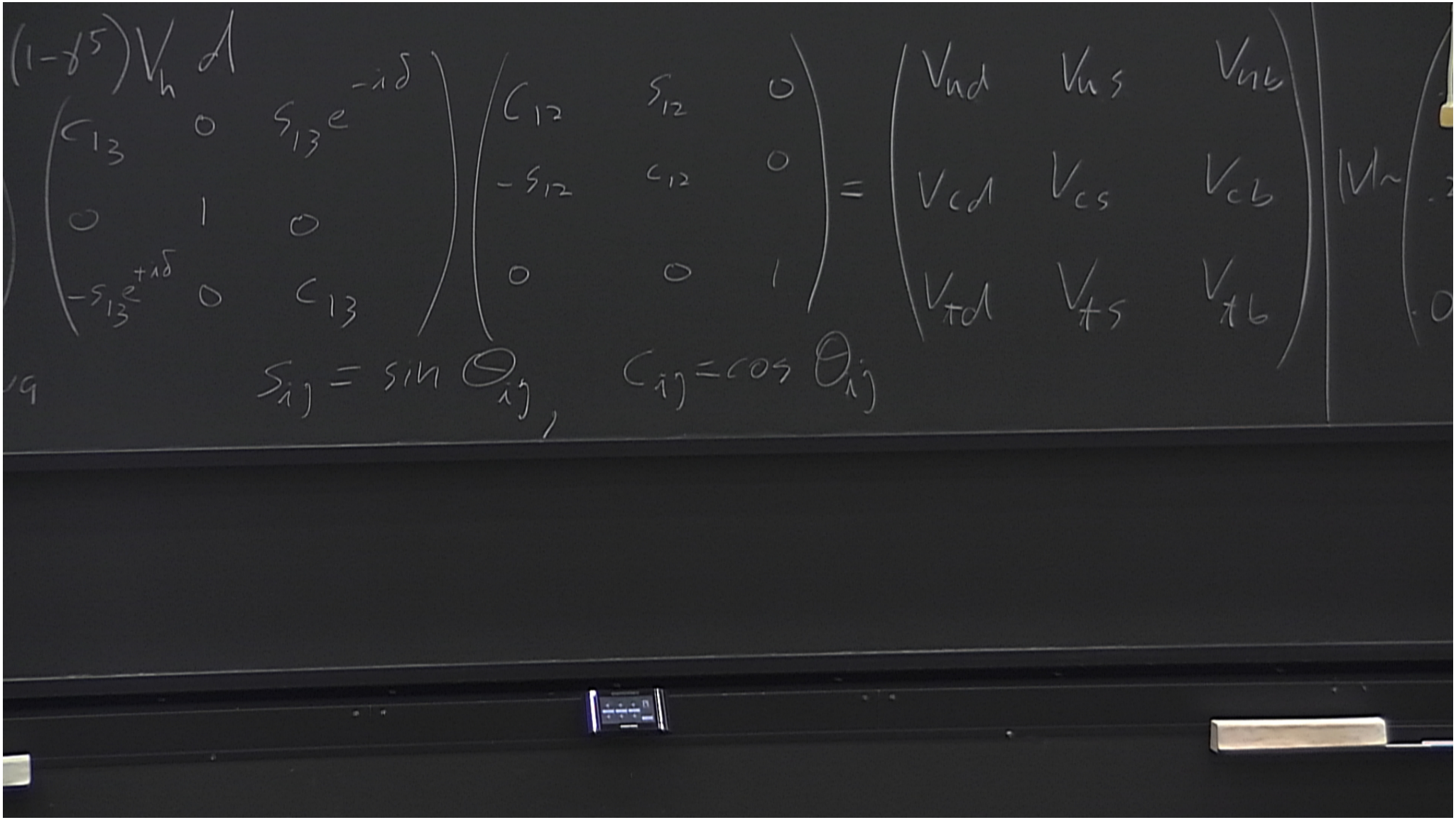
(13) - Unitarity Triangle
- Higgs

$$J_W^{\mu +} = \bar{\nu}\gamma^\mu(1-\gamma^5)V_l e + \bar{u}\gamma^\mu(1-\gamma^5)V_h d$$

$$V_h \equiv V_{CKM} = \begin{pmatrix} 1 & 0 & 0 \\ 0 & c_{23} & -s_{23} \\ 0 & -s_{23} & c_{23} \end{pmatrix} \begin{pmatrix} c_{13} & 0 & s_{13}e^{-i\delta} \\ 0 & 1 & 0 \\ -s_{13}e^{+i\delta} & 0 & c_{13} \end{pmatrix} \begin{pmatrix} c_{12} & s_{12} & 0 \\ -s_{12} & c_{12} & 0 \\ 0 & 0 & 1 \end{pmatrix}$$

Cabibbo - Kobayashi - Maskawa


$\begin{pmatrix} c_{12} & s_{12} & 0 \\ -s_{12} & c_{12} & 0 \\ 0 & 0 & 1 \end{pmatrix} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix}$
$|V| \sim \begin{pmatrix} .97 & .23 & .001 \\ .23 & .97 & .04 \\ .009 & .04 & .999 \end{pmatrix}$

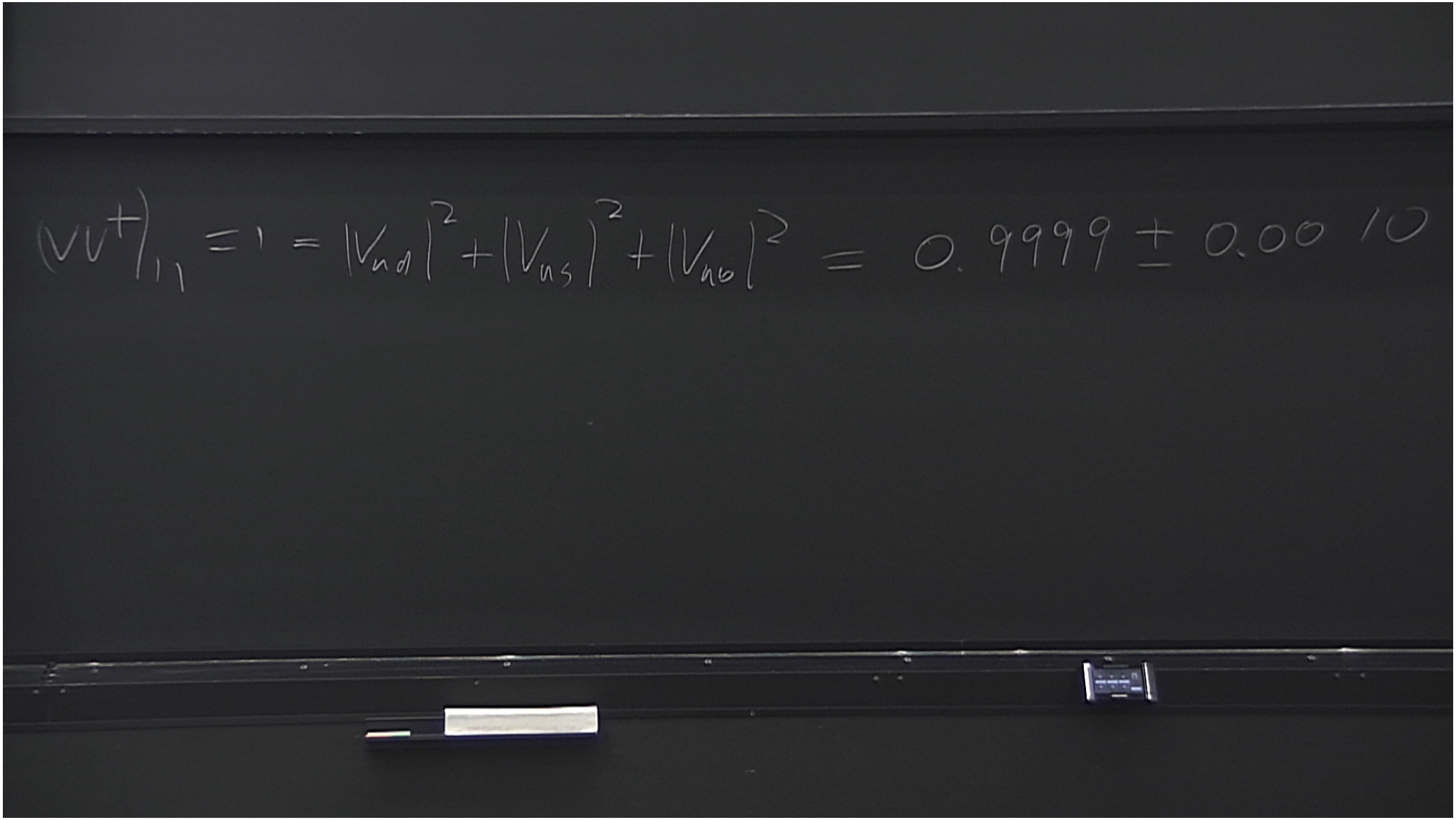

$(1-\gamma^5)$ V_h d
$\begin{pmatrix} c_{13} & 0 & s_{13}e^{-i\delta} \\ 0 & 1 & 0 \\ -s_{13}e^{+i\delta} & 0 & c_{13} \end{pmatrix}$
$\begin{pmatrix} c_{12} & s_{12} & 0 \\ -s_{12} & c_{12} & 0 \\ 0 & 0 & 1 \end{pmatrix}$
$= \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix}$
$s_{ij} = \sin\theta_{ij}$, $c_{ij} = \cos\theta_{ij}$

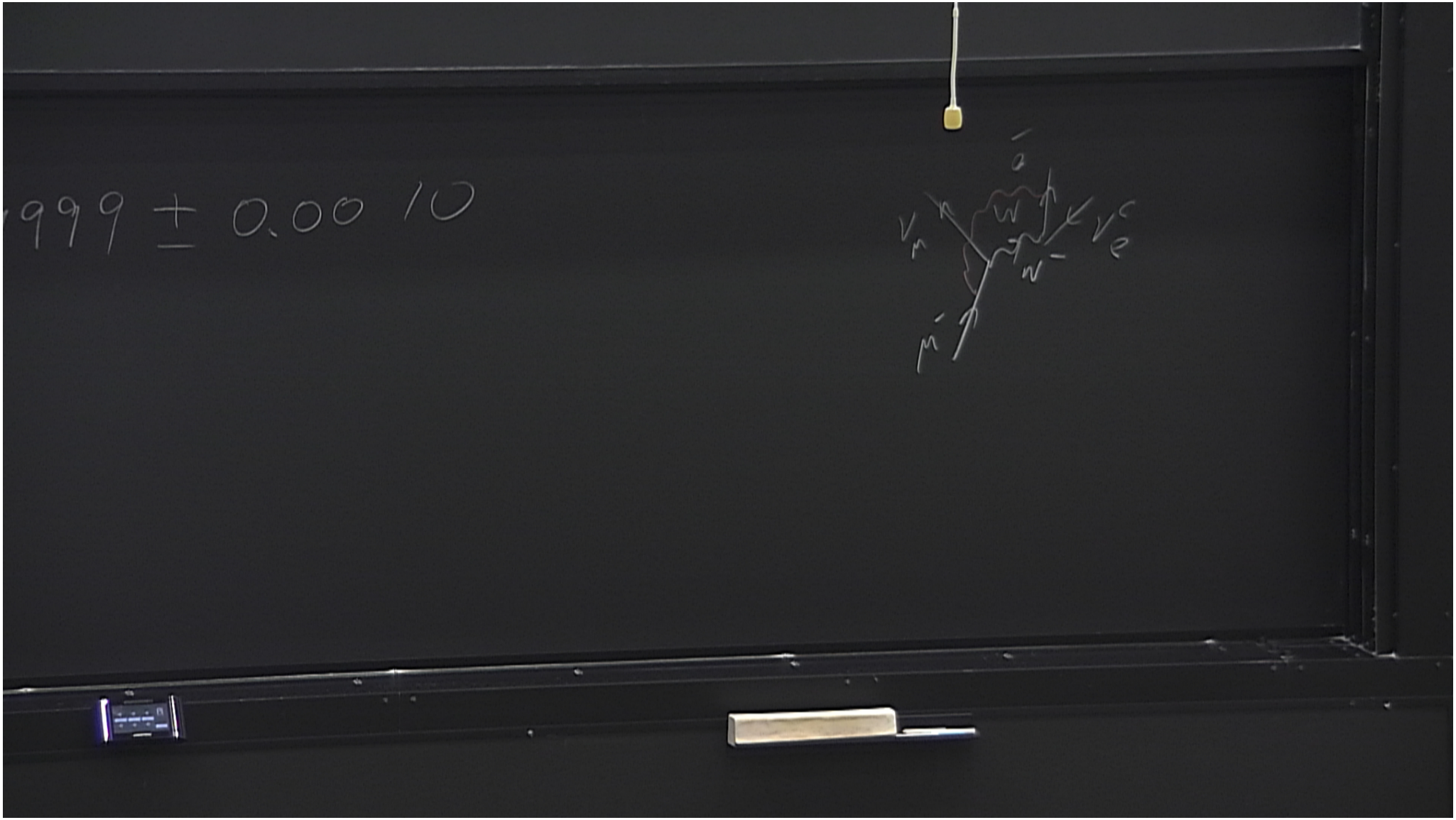
$$V \sim \begin{pmatrix} 1-\frac{\lambda^2}{2} & \lambda & A\lambda^3(\rho - i\eta) \\ -\lambda & 1-\frac{\lambda^2}{2} & A\lambda^2 \\ A\lambda^3(1-\rho-i\eta) & -A\lambda^2 & 1 \end{pmatrix} + O(\lambda^4)$$

$\lambda \sim .23 \sim \sin\theta_C \sim s_{12}$

$A = 0.81$ From $b \to c$

ρ, η are OF $O(1)$


$(VV^\dagger)_{11} = 1 = |V_{ud}|^2 + |V_{us}|^2 + |V_{ub}|^2 = 0.9999 \pm 0.0010$

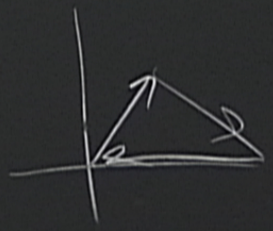

999 ± 0.00 10
W
ν_μ
ν_e
μ^-
e^-

$$(VV^\dagger)_{11} = 1 = |V_{ud}|^2 + |V_{us}|^2 + |V_{ub}|^2 = 0.9999 \pm$$

$$(V^\dagger V)_{31} = 0 = V_{ub}^* V_{ud} + V_{cb}^* V_{cd} + V_{tb}^* V_{td}$$

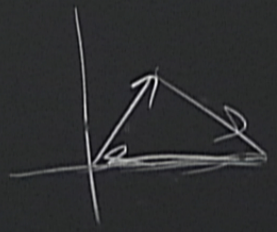
$$(VV^\dagger)_{11} = 1 = |V_{ud}|^2 + |V_{us}|^2 + |V_{ub}|^2 = 0.9999 \pm$$

$$(V^\dagger V)_{31} = 0 = V_{ub}^* V_{ud} + V_{cb}^* V_{cd} + V_{tb}^* V_{td}$$

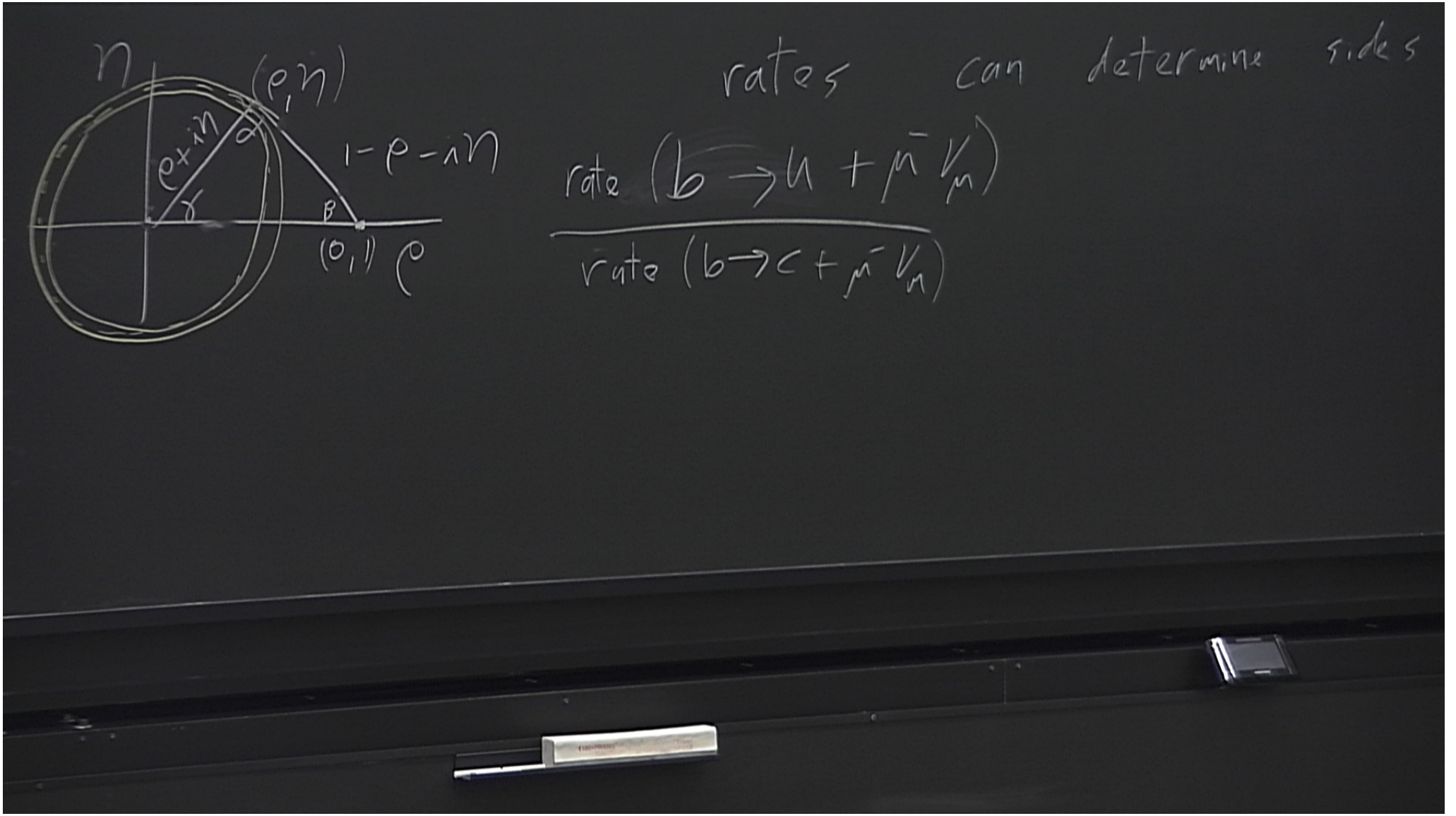


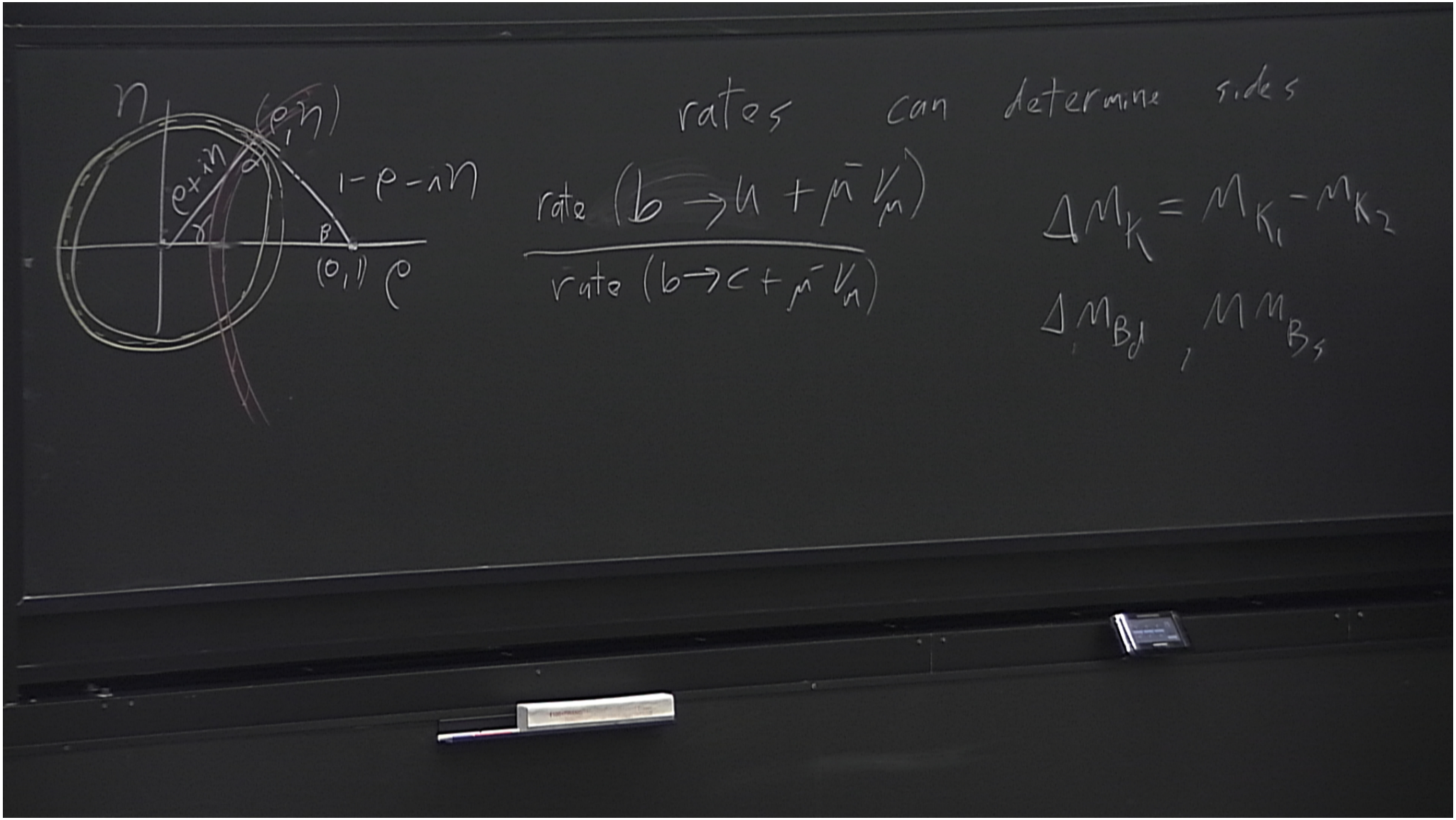
$$(V^\dagger V)_{11} = 1 = |V_{ud}|^2 + |V_{us}|^2 + |V_{ub}|^2 = 0.9999 \pm 0.00 1$$

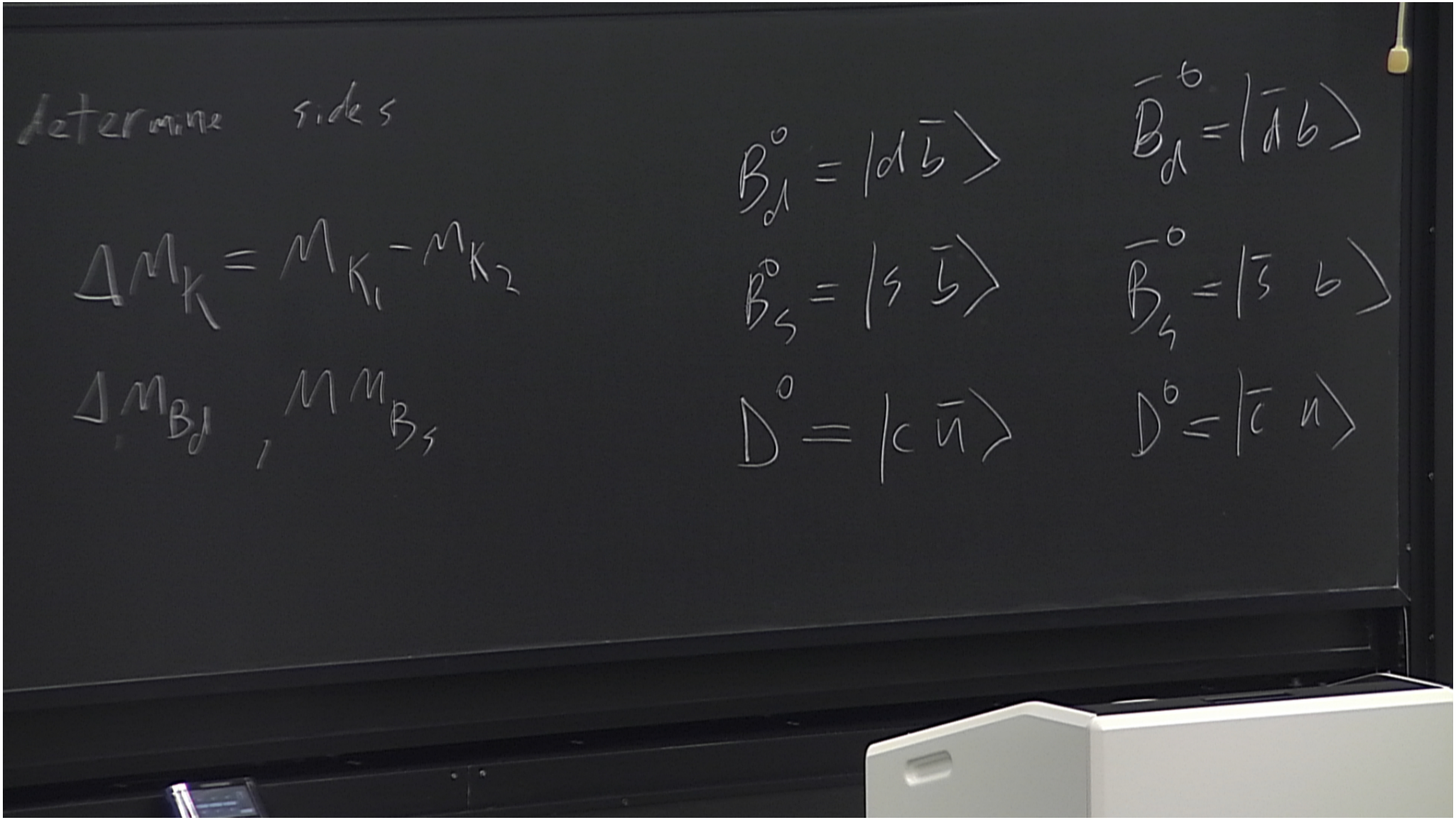
$$(V^\dagger V)_{31} = 0 = V_{ub}^* V_{ud} + V_{cb}^* V_{cd} + V_{tb}^* V_{tb}$$ unit

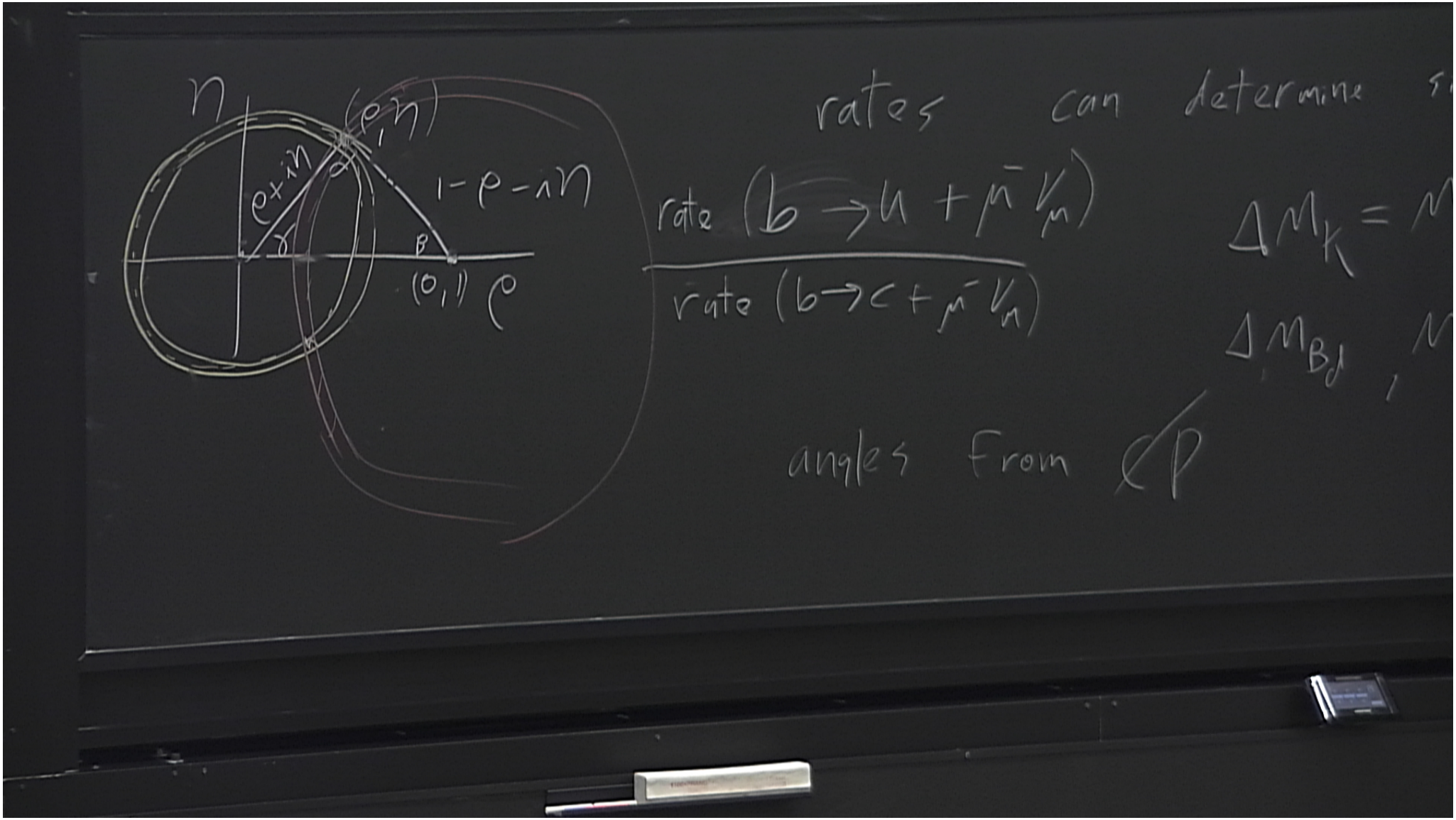


$|V_{cb}^* V_{cd}|$ is well-known

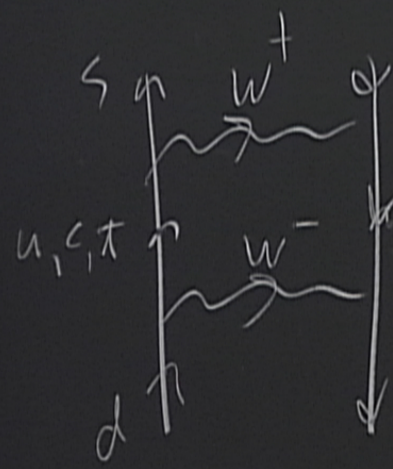

n
(ρ,η)
ρ+λη
α
γ
β
1-ρ-λη
(0,1)
(ρ
rates can determine sides
rate (b → u + μ⁻ ν_μ)
rate (b → c + μ⁻ ν_μ)


rates can determine sides
η
(ρ,η)
$1-\rho-\eta$
$\rho+i\eta$
α
β
$(0,1)$
ρ
$\frac{\text{rate}(b\to u+\mu^-\bar{\nu}_\mu)}{\text{rate}(b\to c+\mu^-\bar{\nu}_\mu)}$
$\Delta m_K = m_{K_1} - m_{K_2}$
Δm_{B_d}, Δm_{B_s}


determine sides
$\Delta M_K = M_{K_1} - M_{K_2}$
ΔM_{B_d}, $M M_{B_s}$
$B_d^0 = |d\bar{b}\rangle$
$\bar{B}_d^0 = |\bar{d}b\rangle$
$B_s^0 = |s\bar{s}\rangle$
$\bar{B}_s^0 = |\bar{s}b\rangle$
$D^0 = |c\bar{u}\rangle$
$\bar{D}^0 = |\bar{c}u\rangle$


(ρ,η)
ρ+iη
α
β
1-ρ-iη
(0,1)
ρ
rates can determine
rate (b → u + μ⁻ ν̄μ)
rate (b → c + μ⁻ ν̄μ)
ΔMK =
ΔMBd ,
angles from

$K_{S,L} = \frac{K_1 \mp K_2}{\sqrt{2}}$ for CP conserved



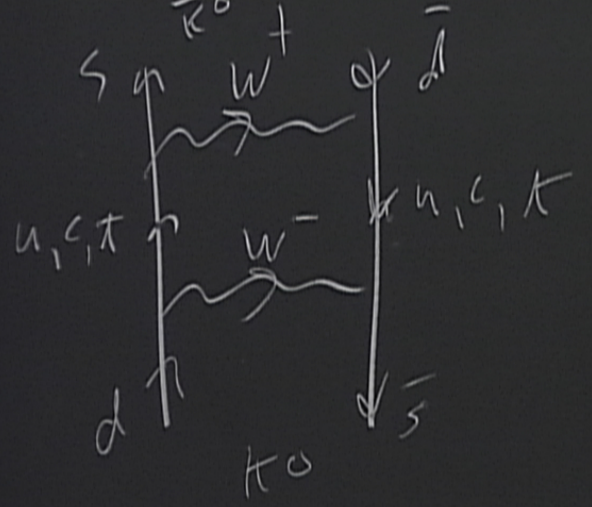
$K_L \to \pi^+\pi^-, \pi^0\pi^0$

CP = -1 CP = +1

amplitude $\sim 10^{-3}$

$K_S \to 2\pi$ amplitude

$K_{S,L} = \frac{K^0 \mp \bar{K}^0}{\sqrt{2}}$ for CP conserved

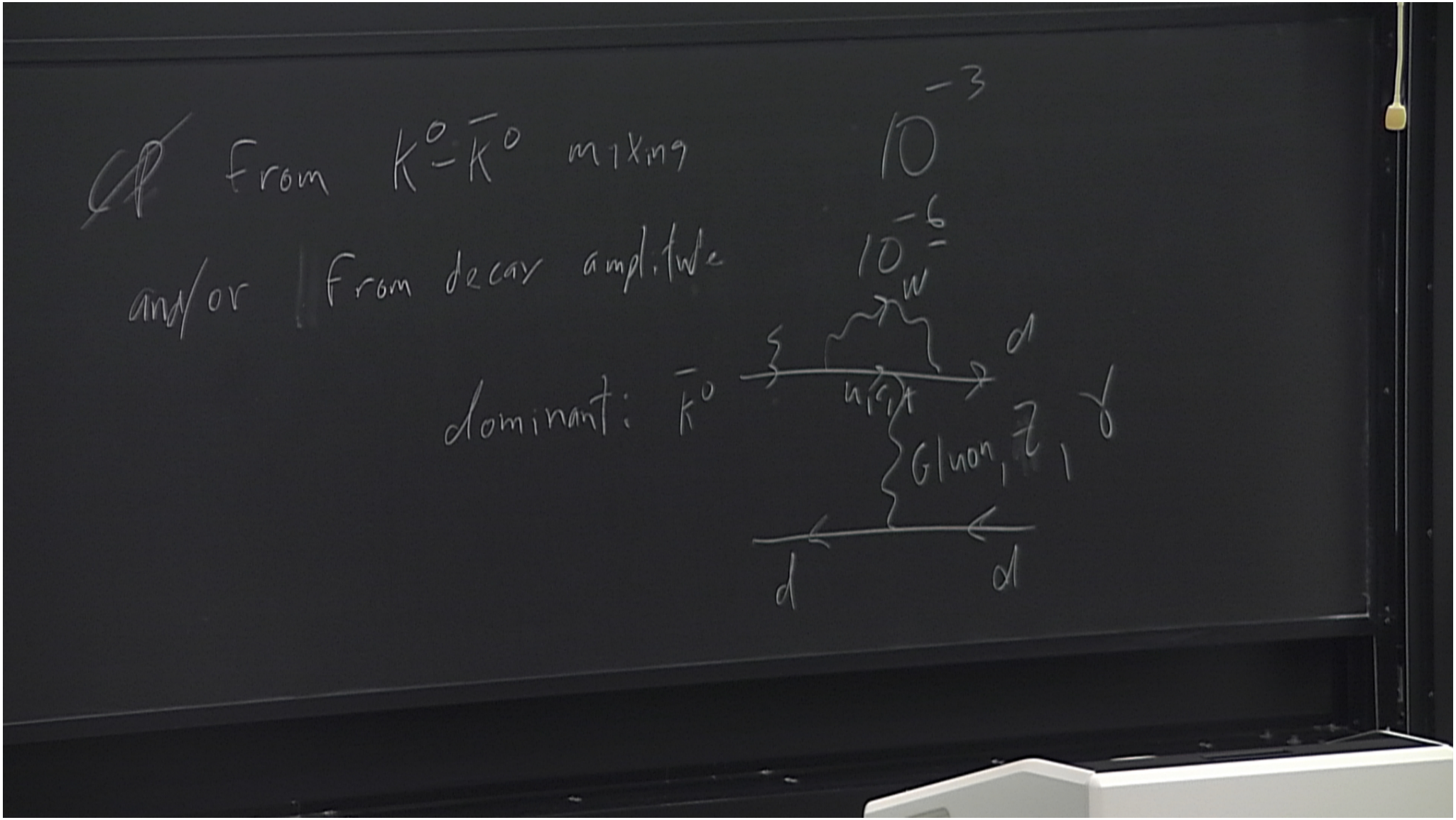


$K_L \to \pi^+\pi^-, \pi^0\pi^0$

CP = −1 CP = +1

amplitude $\sim 10^{-3}$

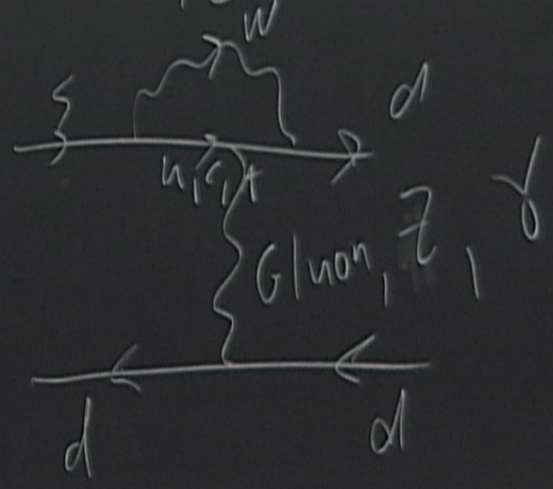
$K_S \to 2\pi$ amplitude


CP From $K^0-\bar{K}^0$ mixing 10^{-3}
and/or From decay amplitude 10^{-6}
dominant: $\bar{K}^0$
W
s
d
u,c,t
Gluon, Z, γ
d
d

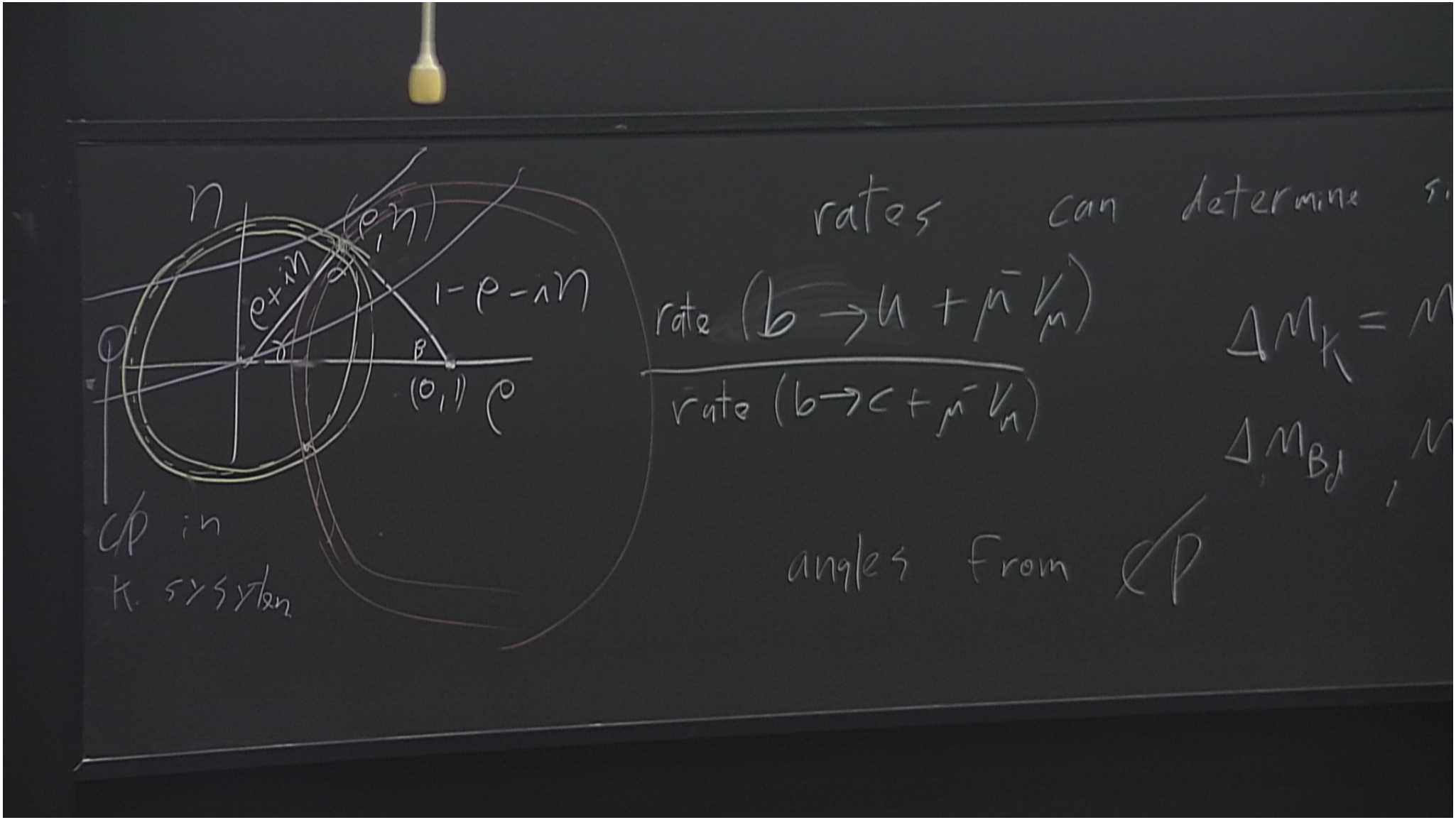
CP From $K^0 - \bar{K}^0$ mixing 10^{-3}

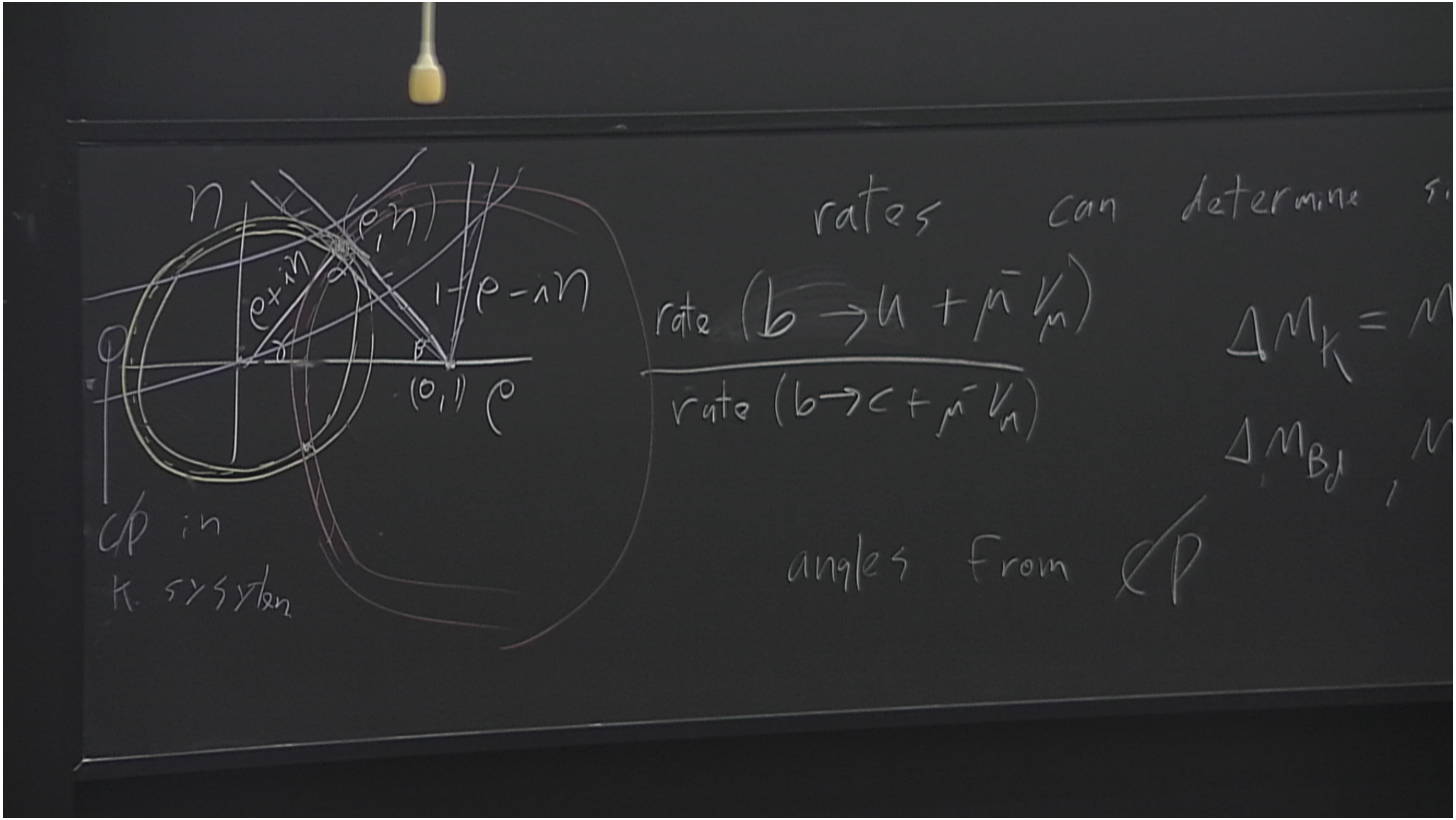
and/or | From decay amplitude 10^{-6}

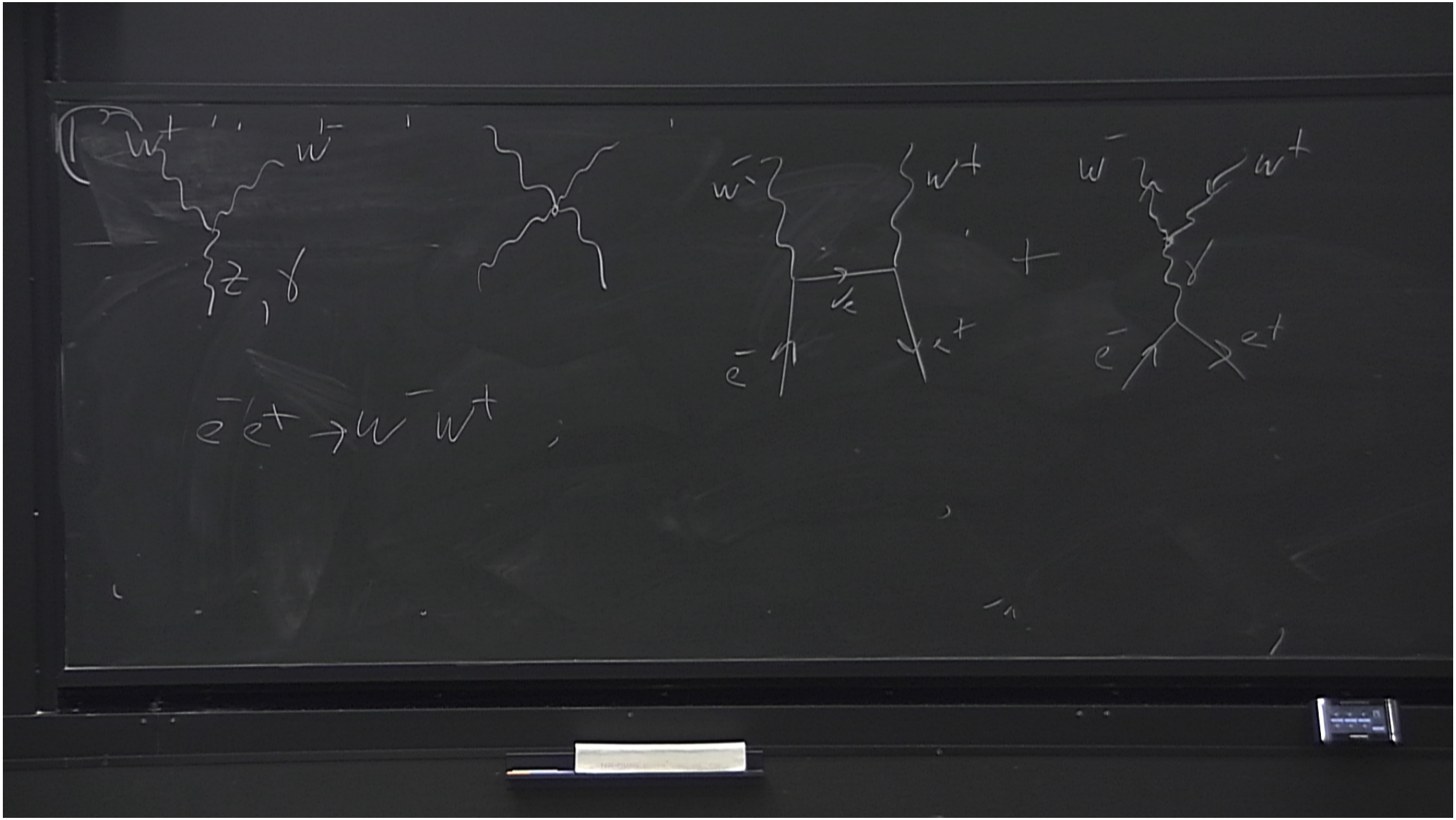
dominant: $\bar{K}^0$

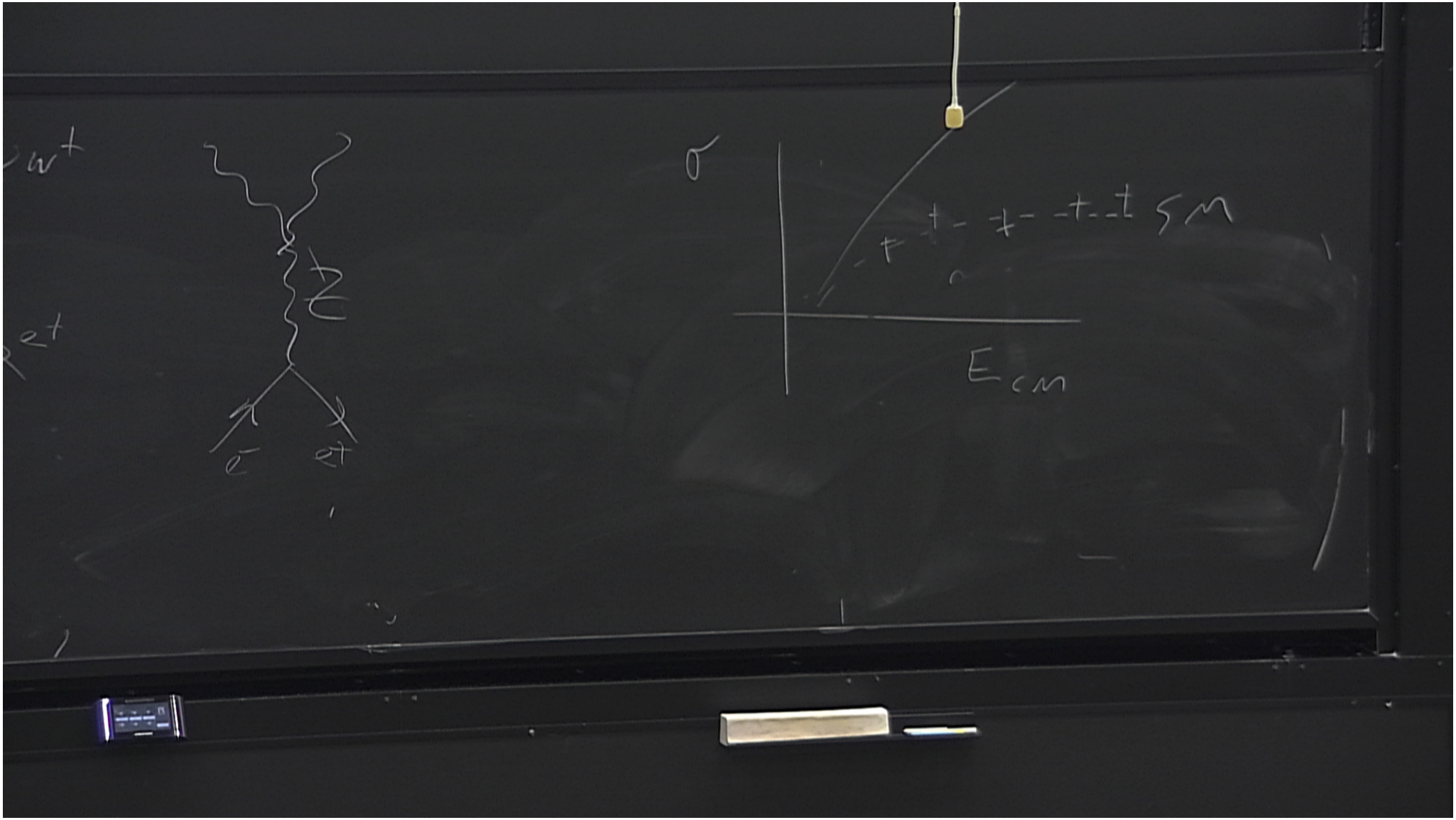


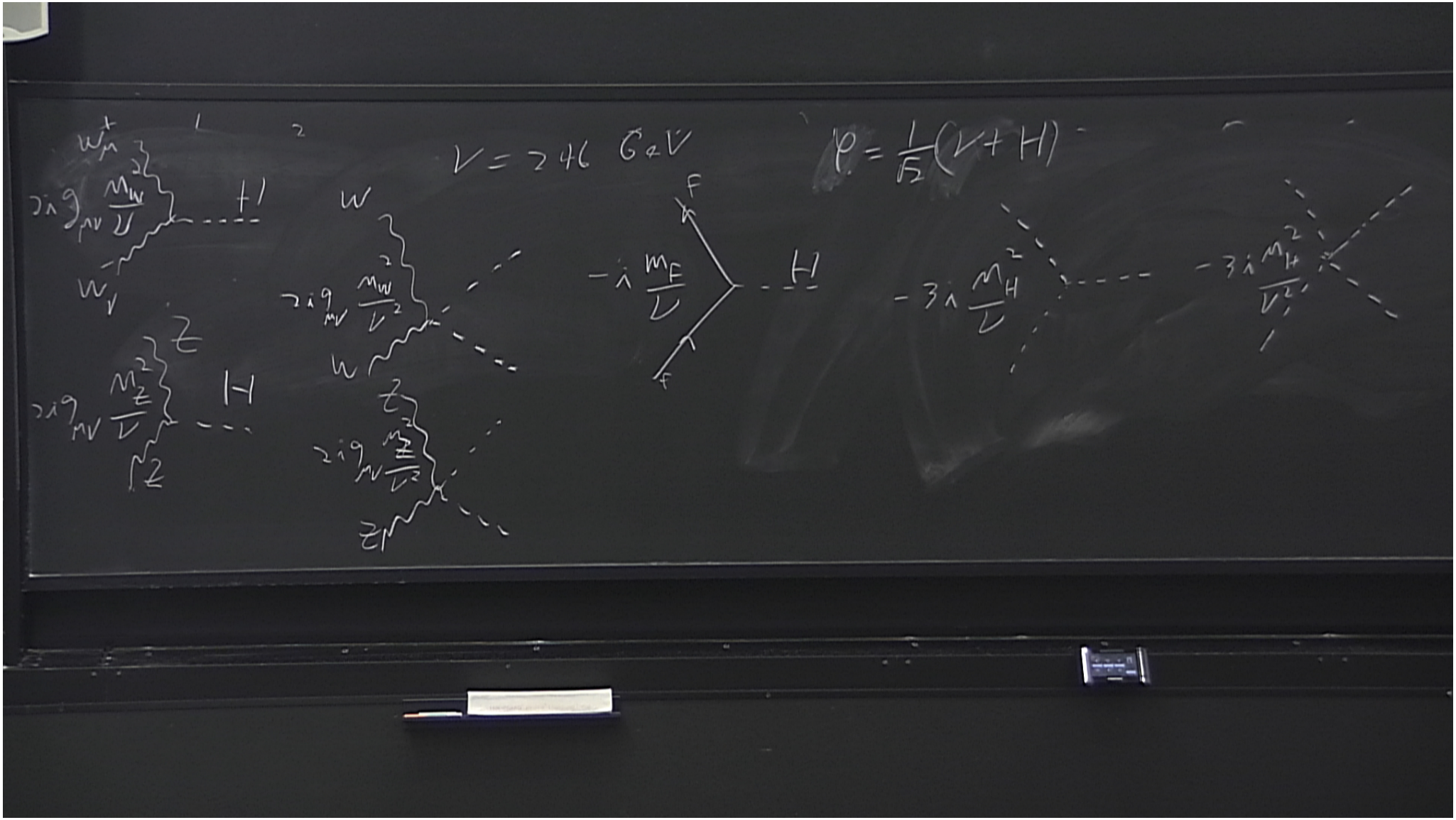
penguin diagram

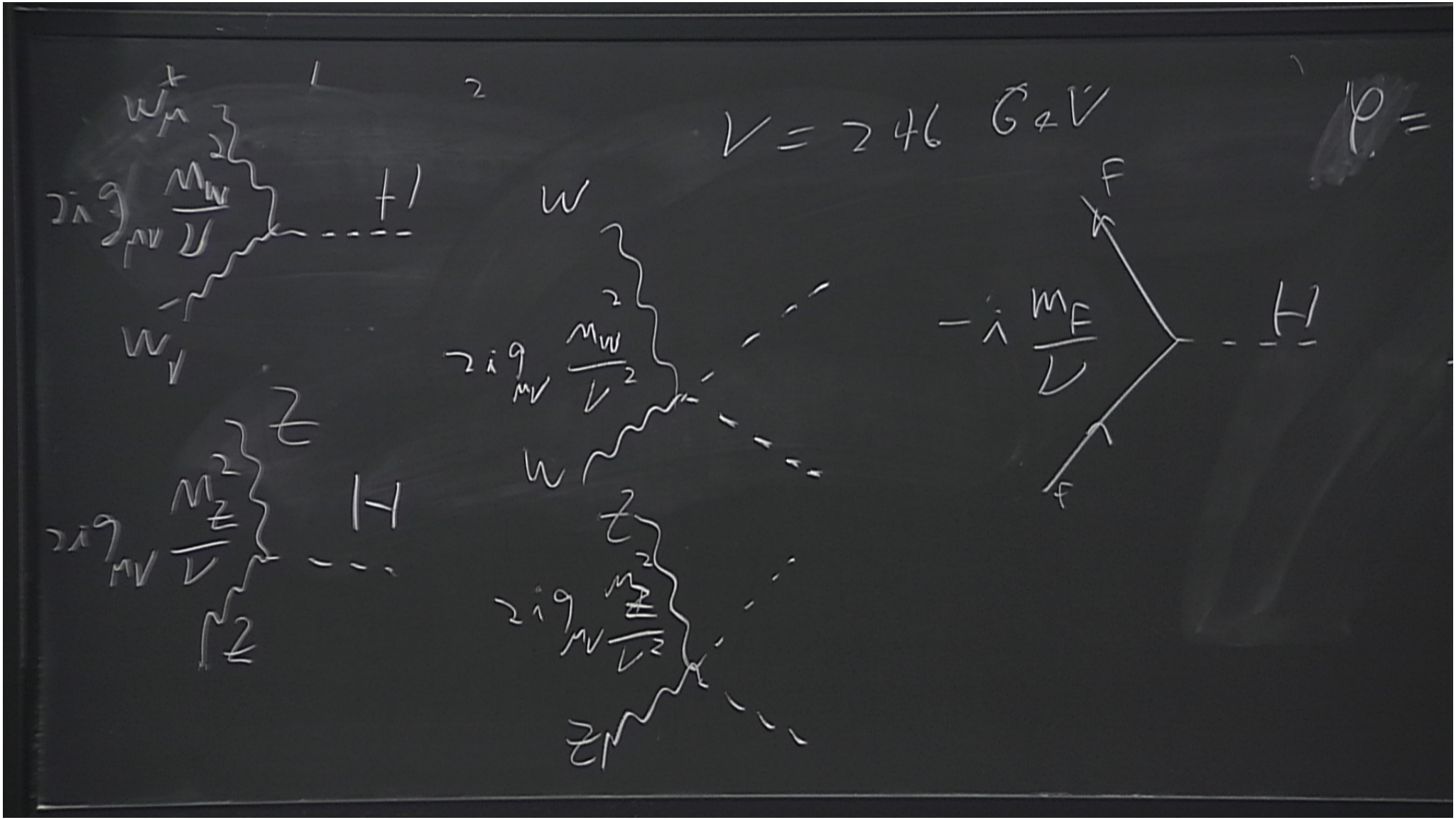

ρ+iη
(ρ,η)
1-ρ-iη
α
β
(0,1)
(0,0)
CP in
K. system
rate (b → u + μ⁻ ν̄μ)
rate (b → c + μ⁻ ν̄μ)
rates can determine
ΔMK =
ΔMBd
angles from CP

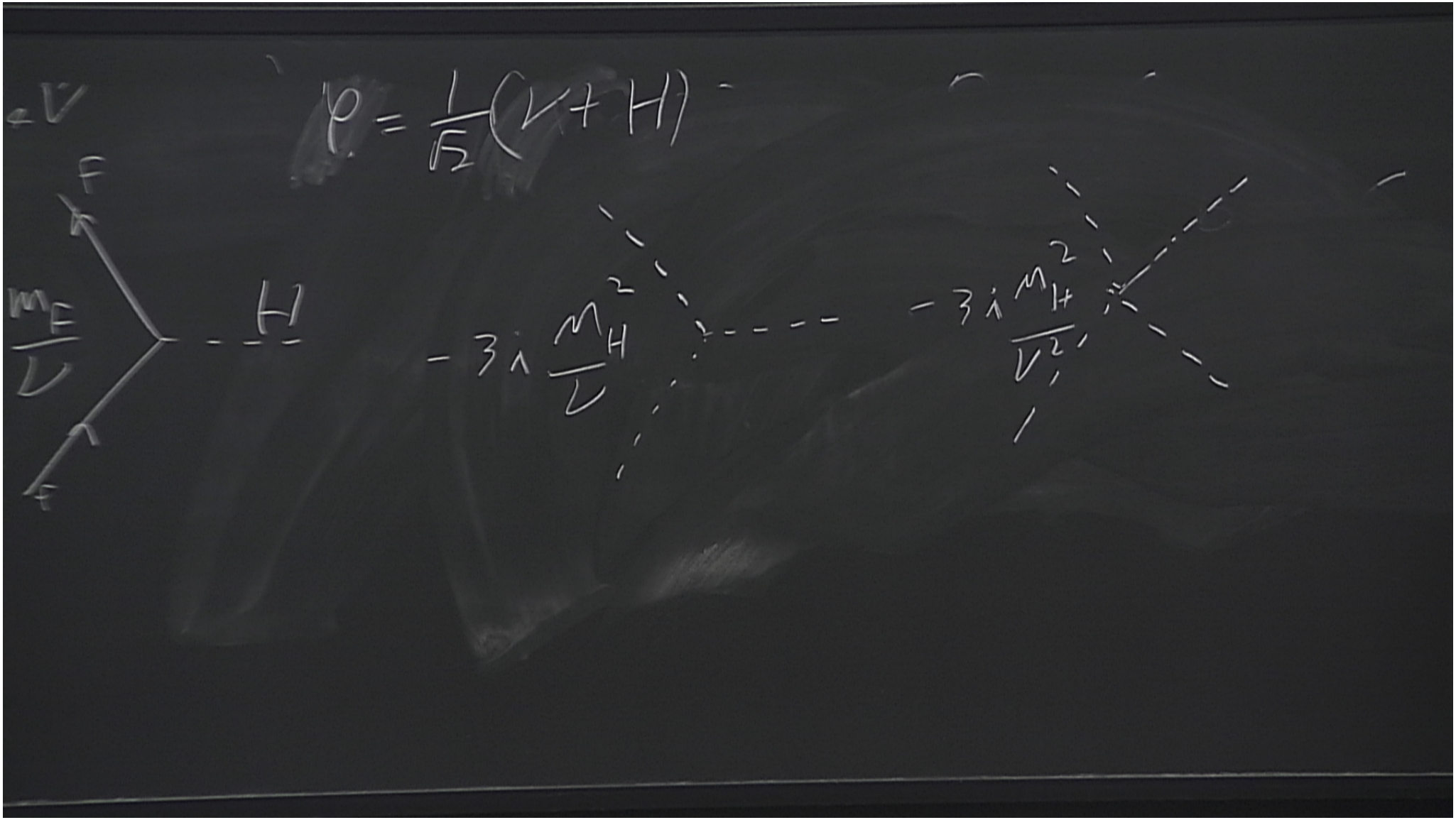

rates can determine
rate (b → u + μ⁻ ν̄μ)
rate (b → c + μ⁻ ν̄μ)
ΔM_K = M
ΔM_Bd , M
angles from CP
CP in
K. system
(0,1)
(ρ,η)
1-ρ-iη
ρ+iη

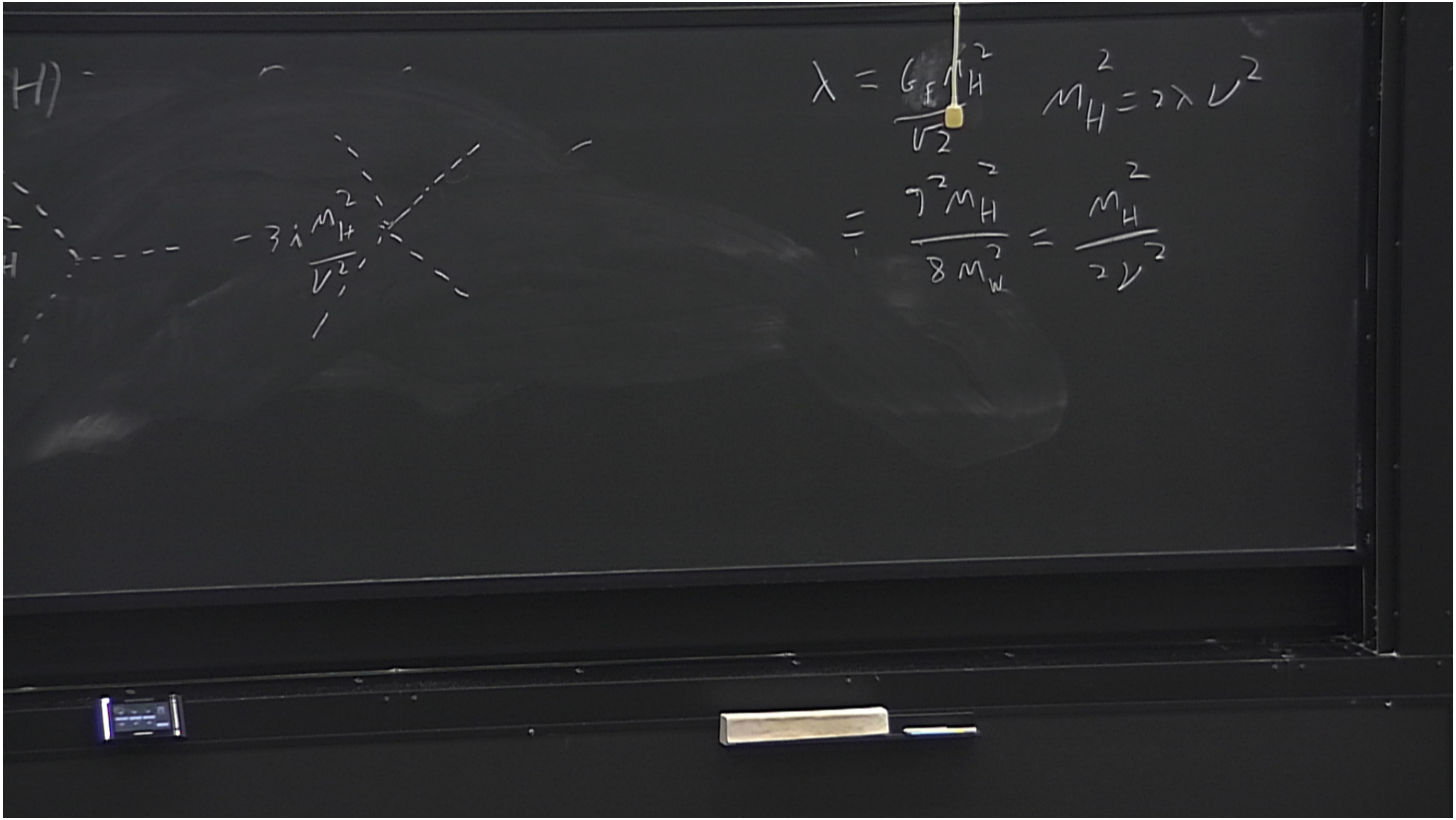

W+
W-
Z, γ
W-
W+
e-
e+
+
W-
W+
γ
e-
e+
e⁻e⁺ → W⁻W⁺

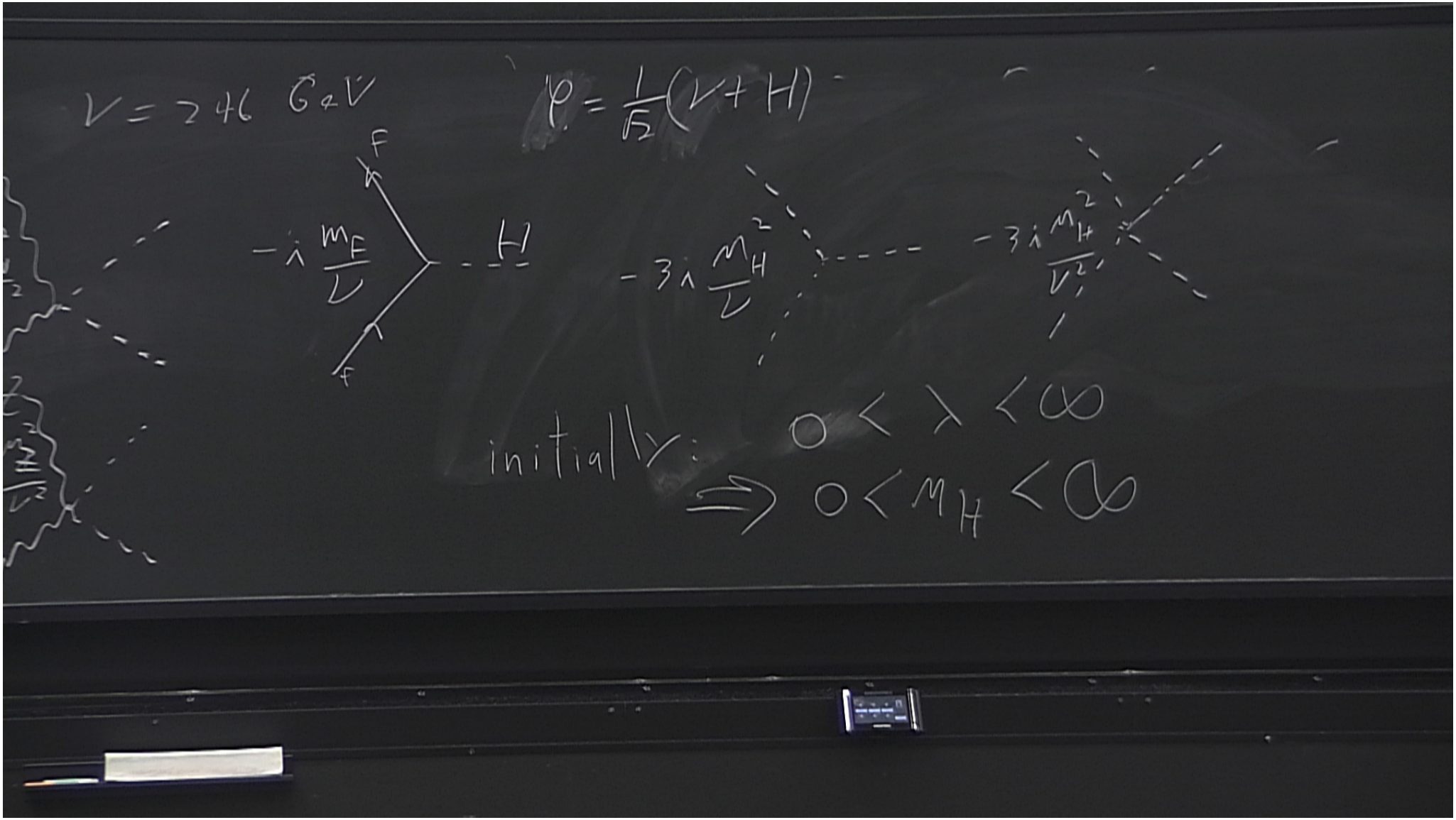

σ
E_{cm}


$v = 246\ GeV$
$\rho = \frac{1}{\sqrt{2}}(v + H)$
$2ig_{\mu\nu}\frac{m_W}{v}$
$2ig_{\mu\nu}\frac{m_W}{v^2}$
$-i\frac{m_F}{v}$
$-3i\frac{m_H}{v}$
$-3i\frac{m_H^2}{v^2}$
$2ig_{\mu\nu}\frac{m_Z^2}{v}$
$2ig_{\mu\nu}\frac{m_Z^2}{v^2}$


W_μ^+
1
2
$V = 246$ GeV
$\rho =$
$2ig_{\mu\nu}\frac{M_W}{V}$
H
W
$2ig_{\mu\nu}\frac{M_W}{V^2}$
W
F
$-i\frac{M_F}{V}$
H
F
Z
$2ig_{\mu\nu}\frac{M_Z^2}{V}$
H
Z
$2ig_{\mu\nu}\frac{M_Z^2}{V^2}$
Z
Z

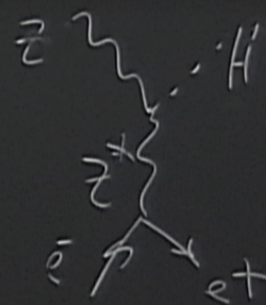

$\rho = \frac{1}{\sqrt{2}}(v + H)$
f
f
H
$\frac{m_f}{v}$
$-3i\frac{m_H^2}{v}$
$-3i\frac{m_H^2}{v^2}$


H)
$-3i\frac{M_H^2}{v^2}$
$\lambda = \frac{G_F M_H^2}{\sqrt{2}}$
$M_H^2 = 2\lambda v^2$
$= \frac{g^2 M_H^2}{8 M_W^2} = \frac{M_H^2}{2v^2}$


$V = 246$ GeV
$\rho = \frac{1}{\sqrt{2}}(v + H)$
F
F
H
$-i\lambda \frac{m_F}{v}$
$-3i\lambda \frac{m_H^2}{v}$
$-3i\frac{m_H^2}{v^2}$
initially: $0 < \lambda < \infty$
$\Rightarrow 0 < m_H < \infty$

Theory bounds: Triviality, vacuum stability

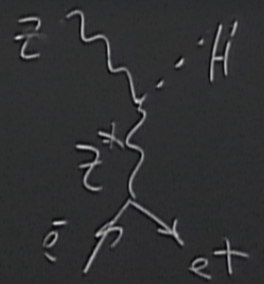
LEP 2 $e^+e^- \to Z^* \to Z + H$



$\Rightarrow 0 < M_H <$

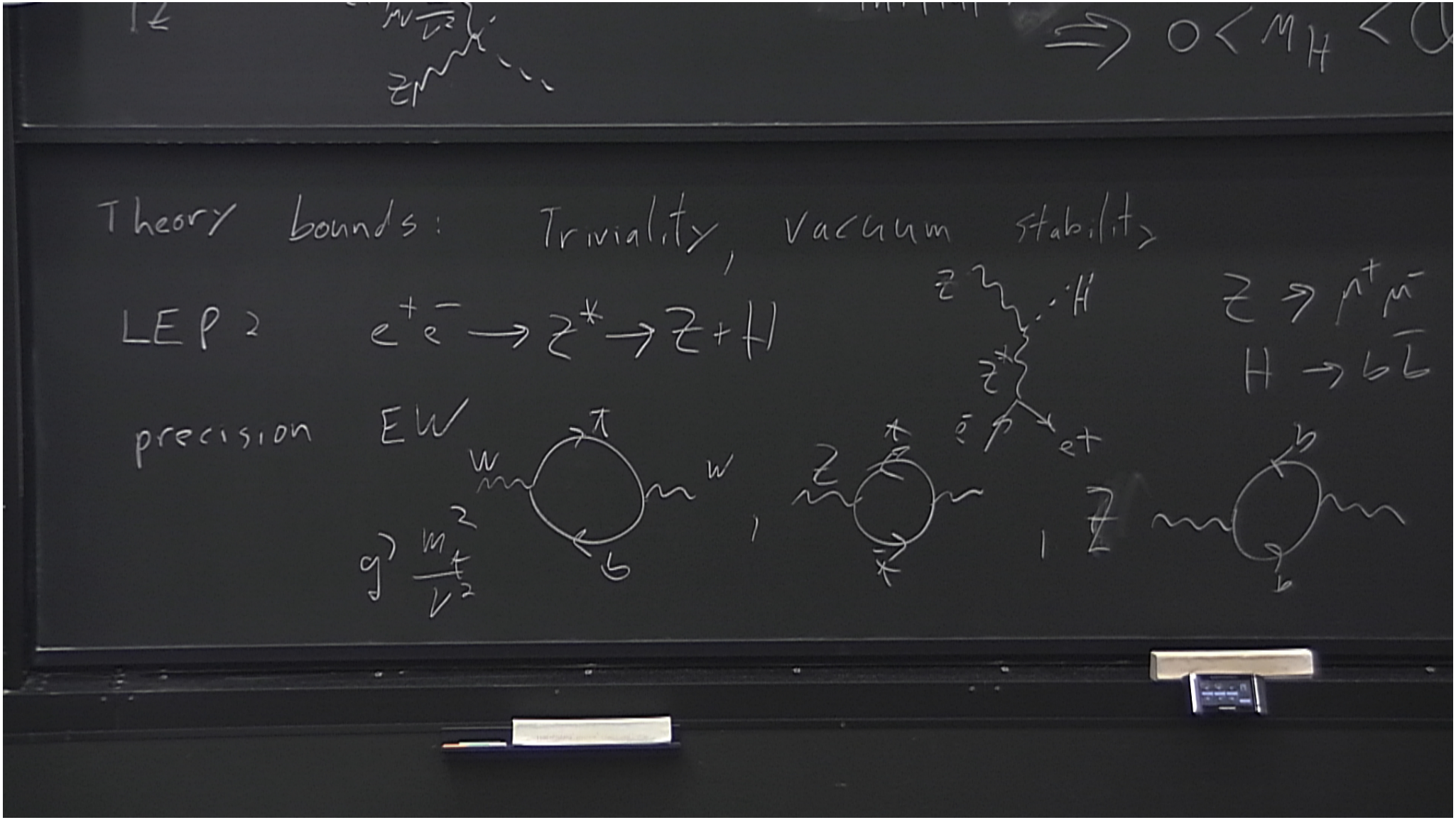
Theory bounds: Triviality, vacuum stability

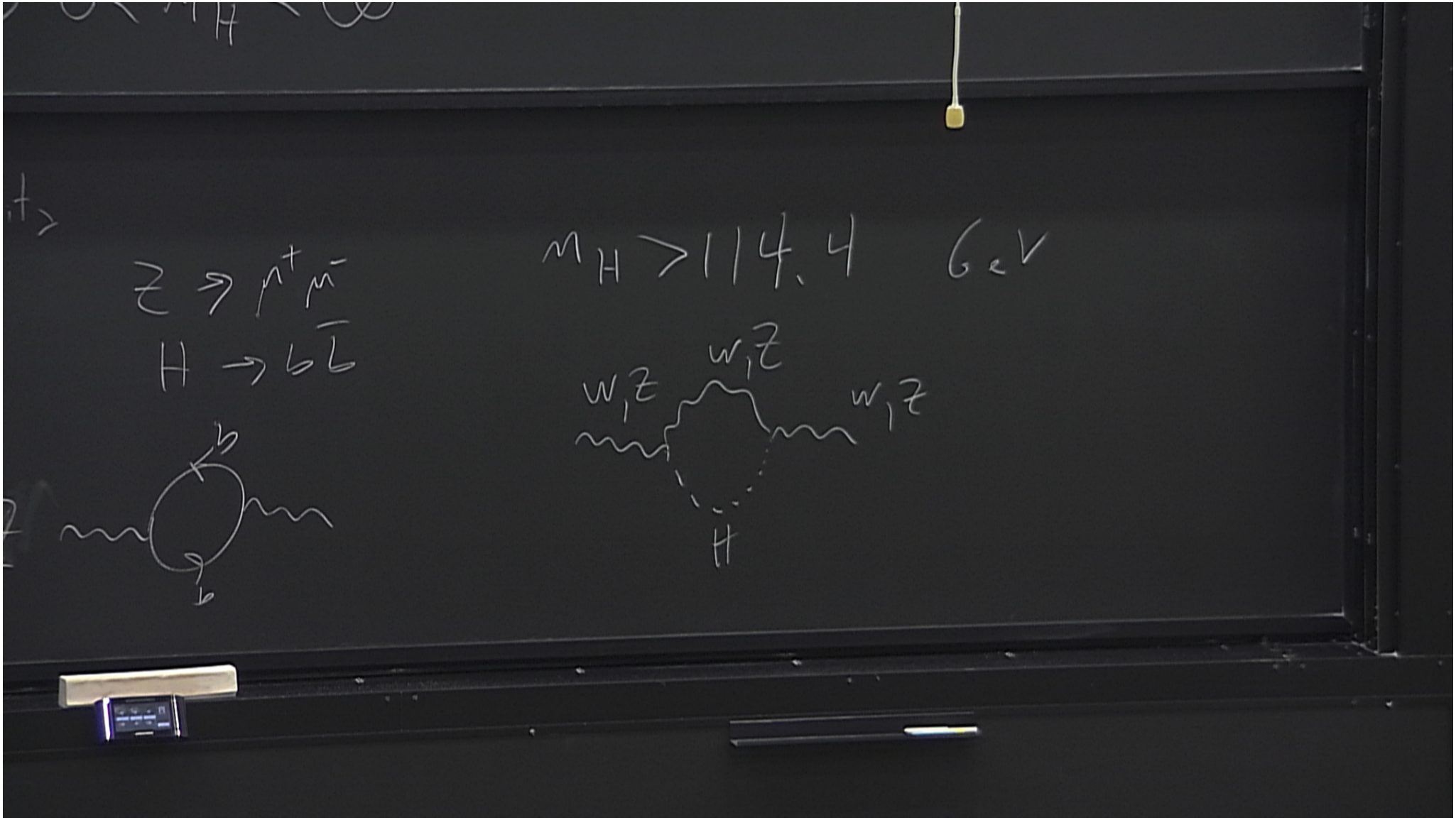
LEP 2 $e^+e^- \to Z^* \to Z + H$

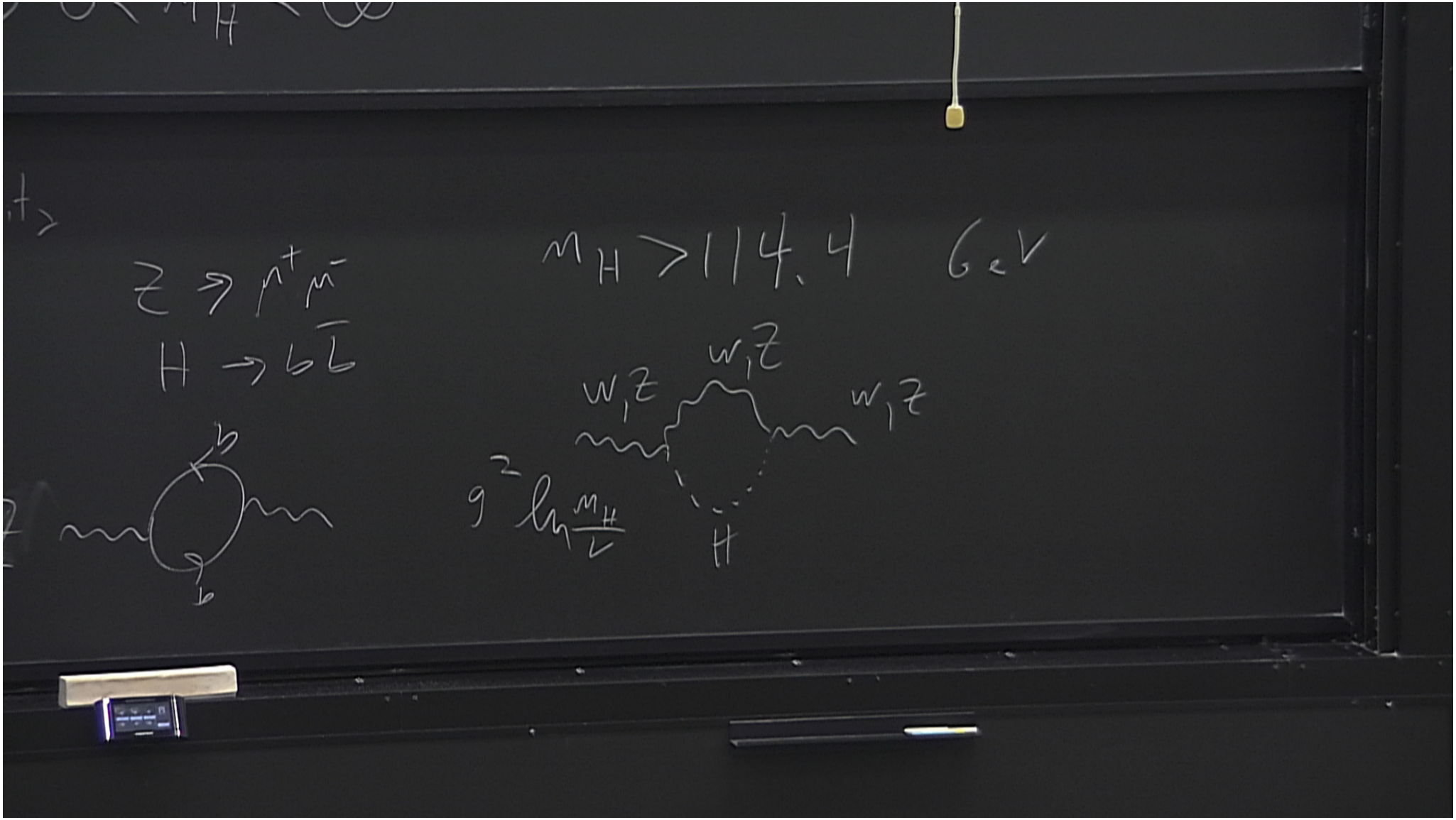


$Z \to \mu^+\mu^-$

$H \to b\bar{b}$


$\Rightarrow 0 < M_H <$
Theory bounds: Triviality, vacuum stability
LEP2 $e^+e^- \to Z^* \to Z + H$
precision EW
$g \frac{m_t^2}{M_W^2}$
W
W
t
b
Z
H
e
e+
$Z \to \mu^+\mu^-$
$H \to b\bar{b}$


$Z \to \mu^+ \mu^-$
$H \to b\bar{b}$
$m_H > 114.4$ GeV
W, Z
W, Z
W, Z
H
b
b

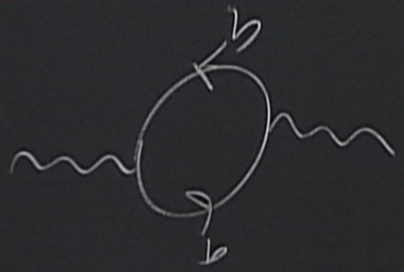

$m_H > 114.4$ GeV
$Z \to \mu^+ \mu^-$
$H \to b\bar{b}$
W, Z
W, Z
W, Z
$g^2 \ln \frac{m_H}{L}$
H
b
b

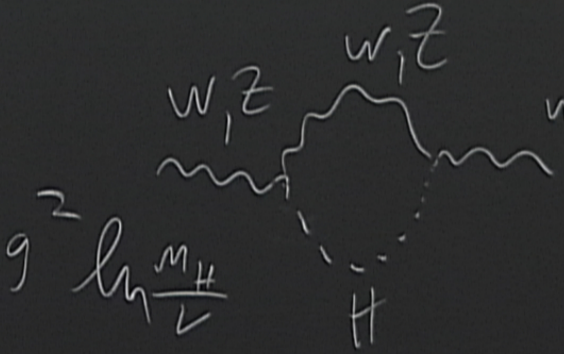
$Z \to \mu^+ \mu^-$

$H \to b\bar{b}$

$M_H > 114.4$ GeV

$M_H < 150$ GeV

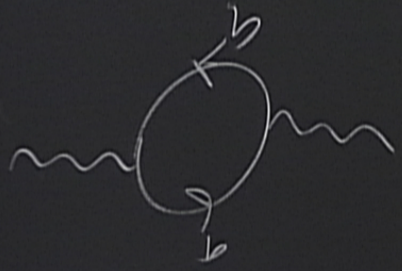




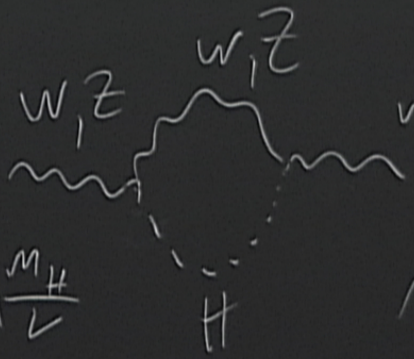
$g^2 \ln \frac{M_H}{L}$

$Z \to \mu^+ \mu^-$

$H \to b\bar{b}$



$m_H > 114.4$ GeV

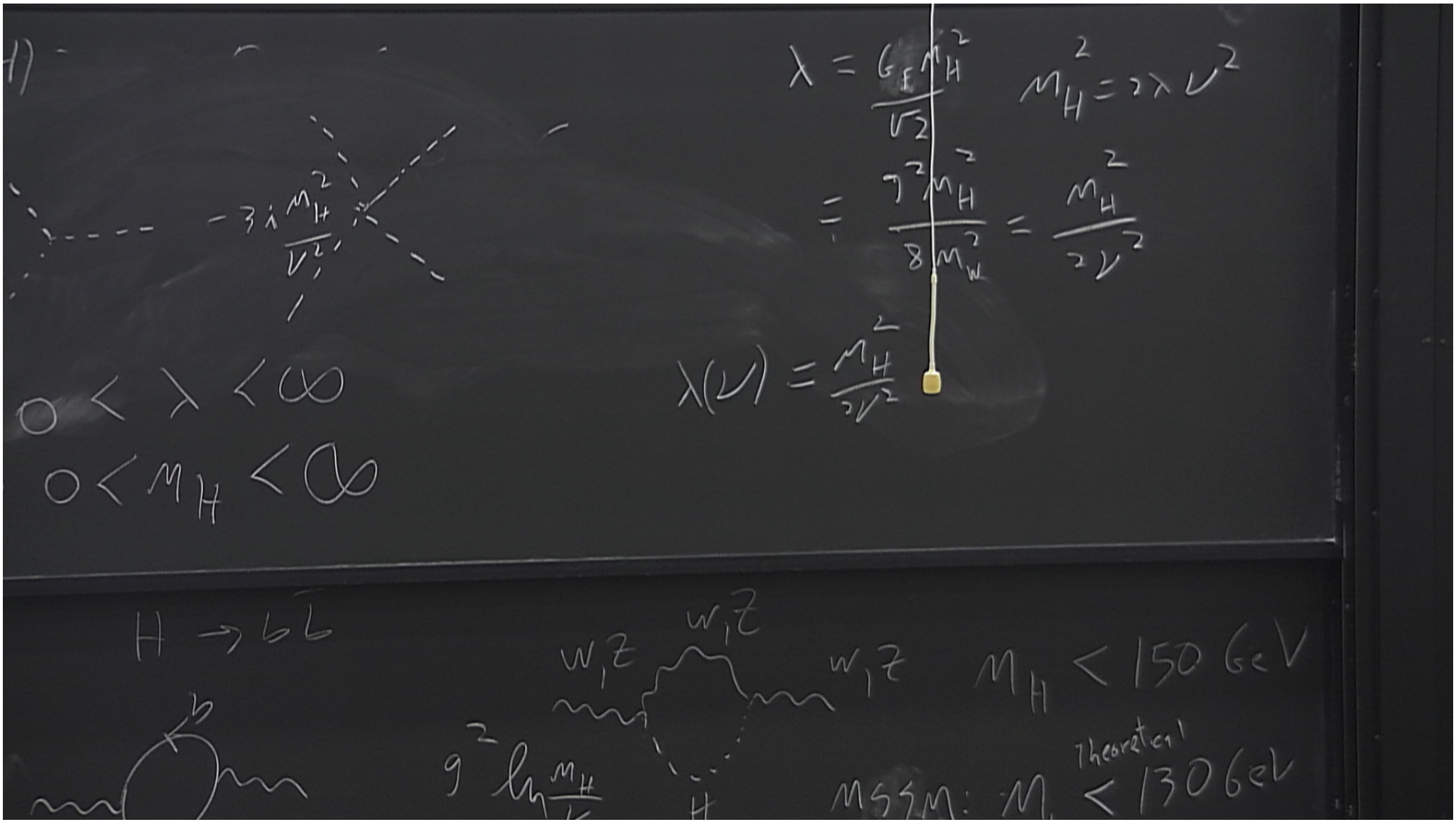


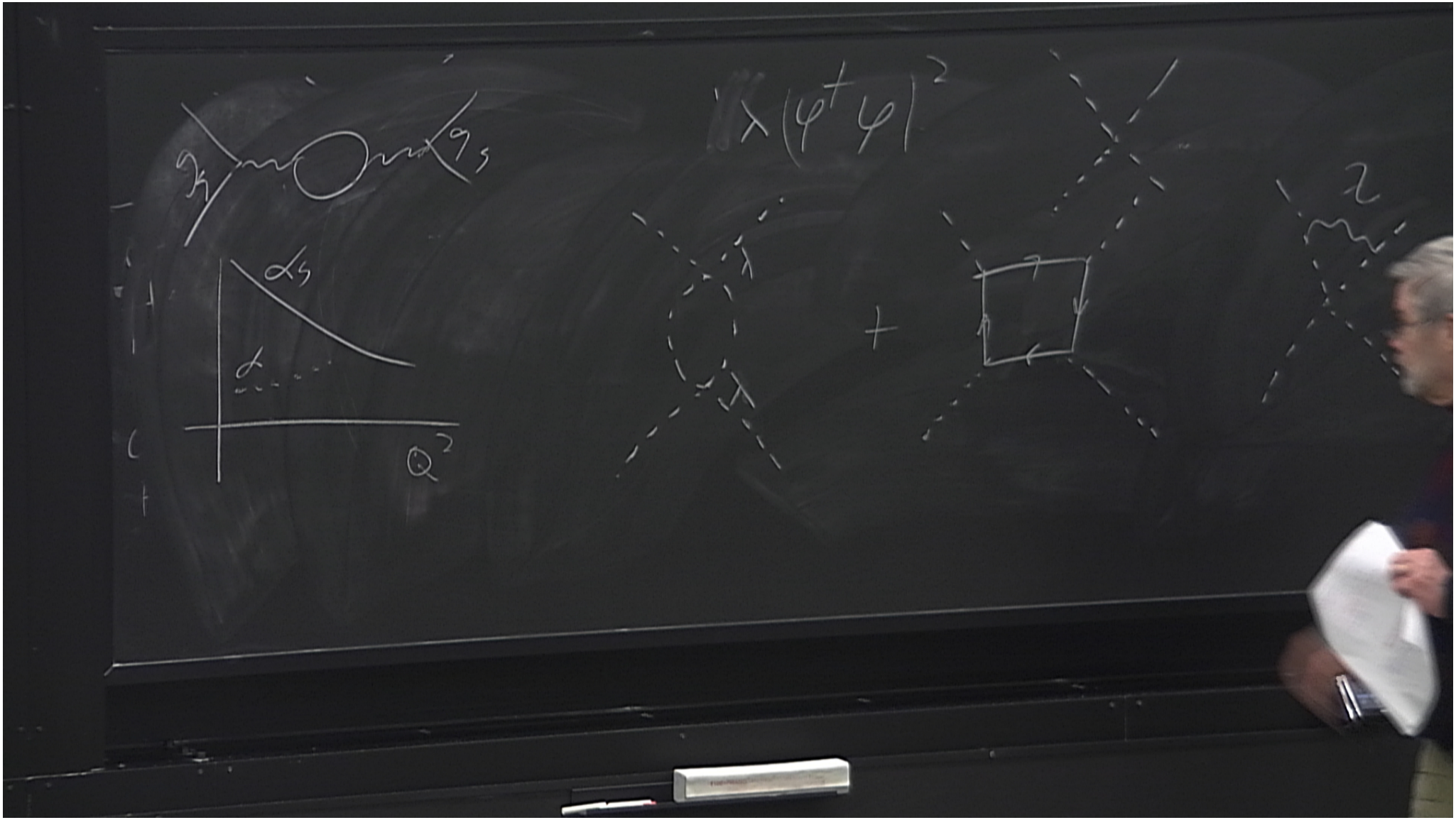
$g^2 \ln \frac{m_H}{L}$

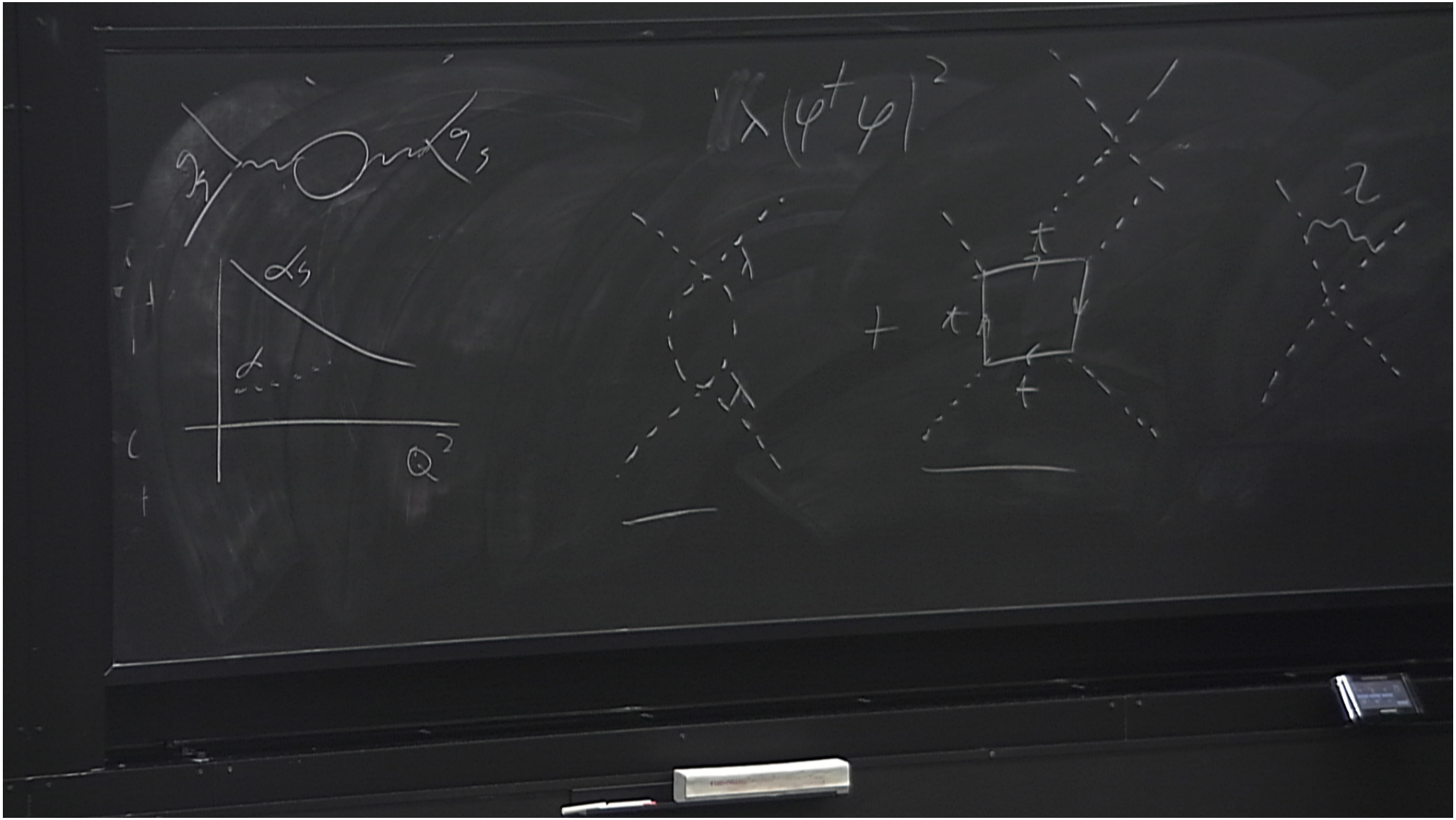
$m_H < 150$ GeV

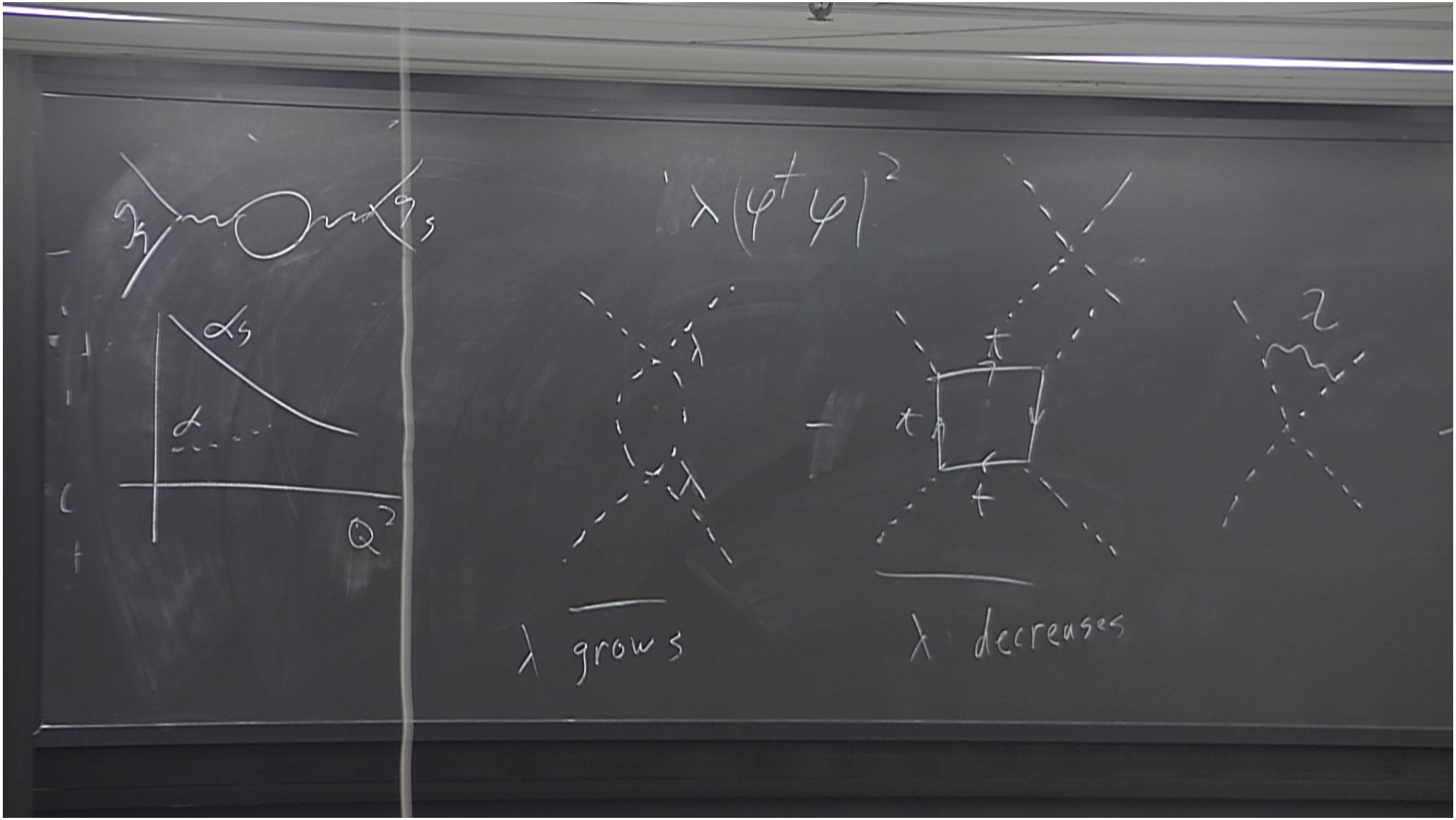
MSSM: $m_h < 130$ GeV (Theoretical)

$m_h \to 150$

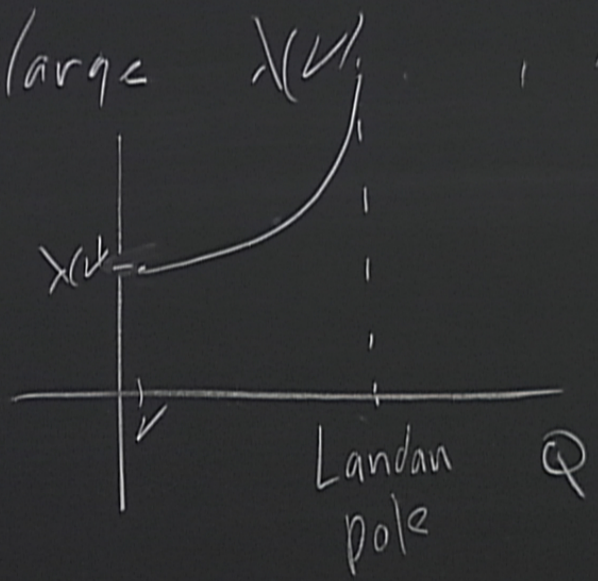

$-3i\frac{m_H^2}{v^2}$
$\lambda = \frac{G_F m_H^2}{\sqrt{2}}$
$m_H^2 = 2\lambda v^2$
$= \frac{g^2 m_H^2}{8 m_W^2} = \frac{m_H^2}{2v^2}$
$\lambda(v) = \frac{m_H^2}{2v^2}$
$0 < \lambda < \infty$
$0 < m_H < \infty$
$H \to b\bar{b}$
W, Z
W, Z
W, Z
$m_H < 150$ GeV
$g^2 \ln \frac{m_H}{v}$
MSSM: $m_h < 130$ GeV
theoretical


α_s
Q^2
$\lambda(\phi^\dagger\phi)^2$
+
+


α_s
Q^2
$\lambda(\phi^\dagger\phi)^2$
Z

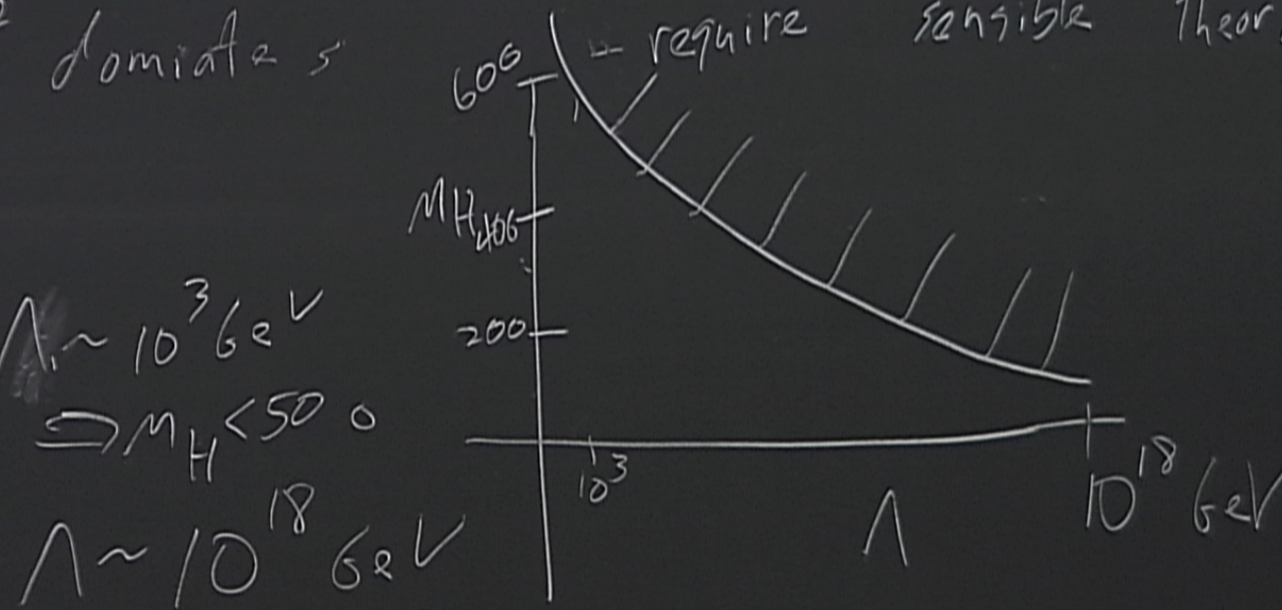

$\lambda(\varphi^\dagger\varphi)^2$
α_s
Q^2
λ grows
λ decreases

For large $\chi(L)$, λ^2 dominates - require sensible



λ^2 dominates

require sensible Theory up to

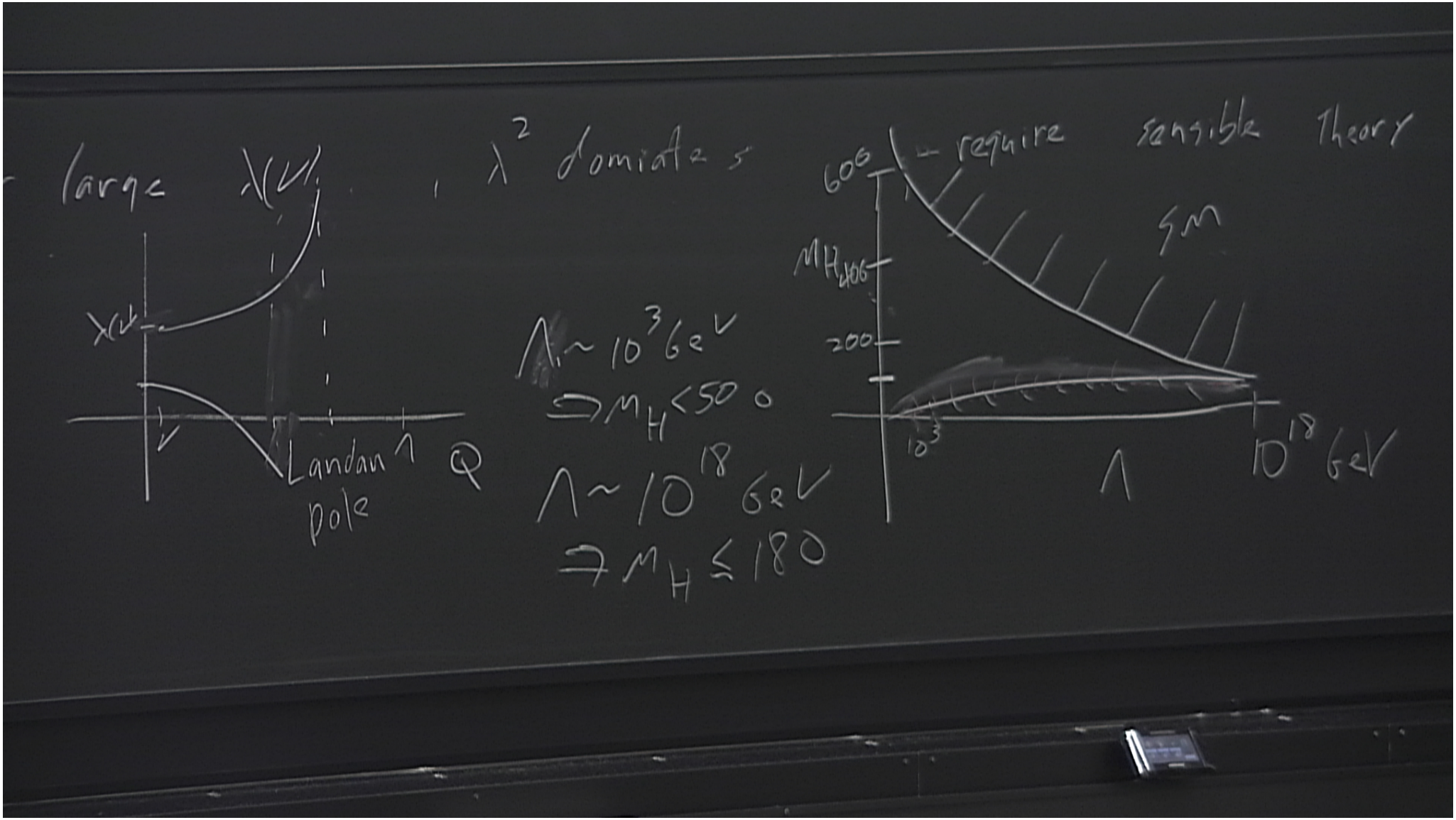


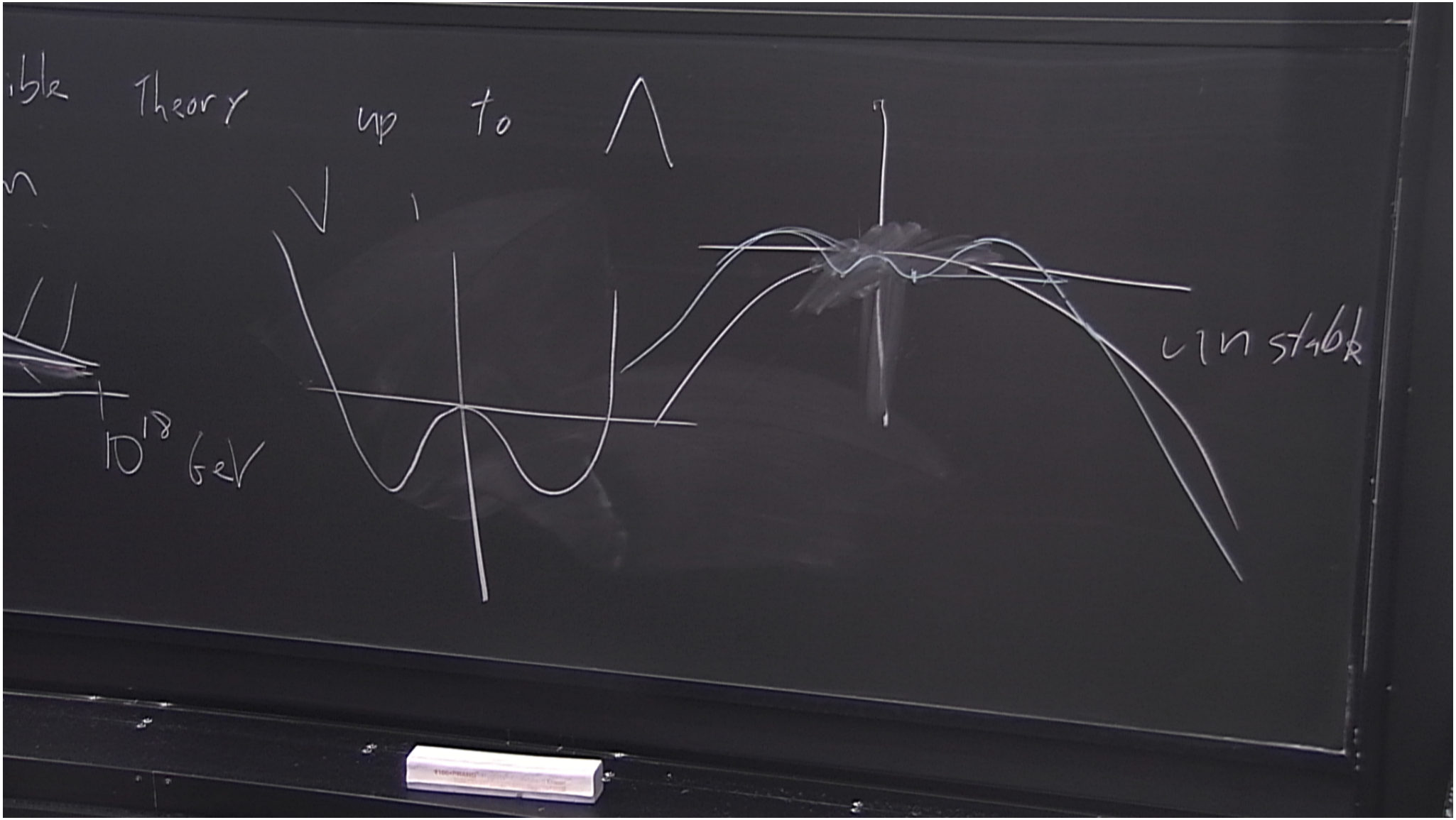
$\Lambda \sim 10^3$ GeV

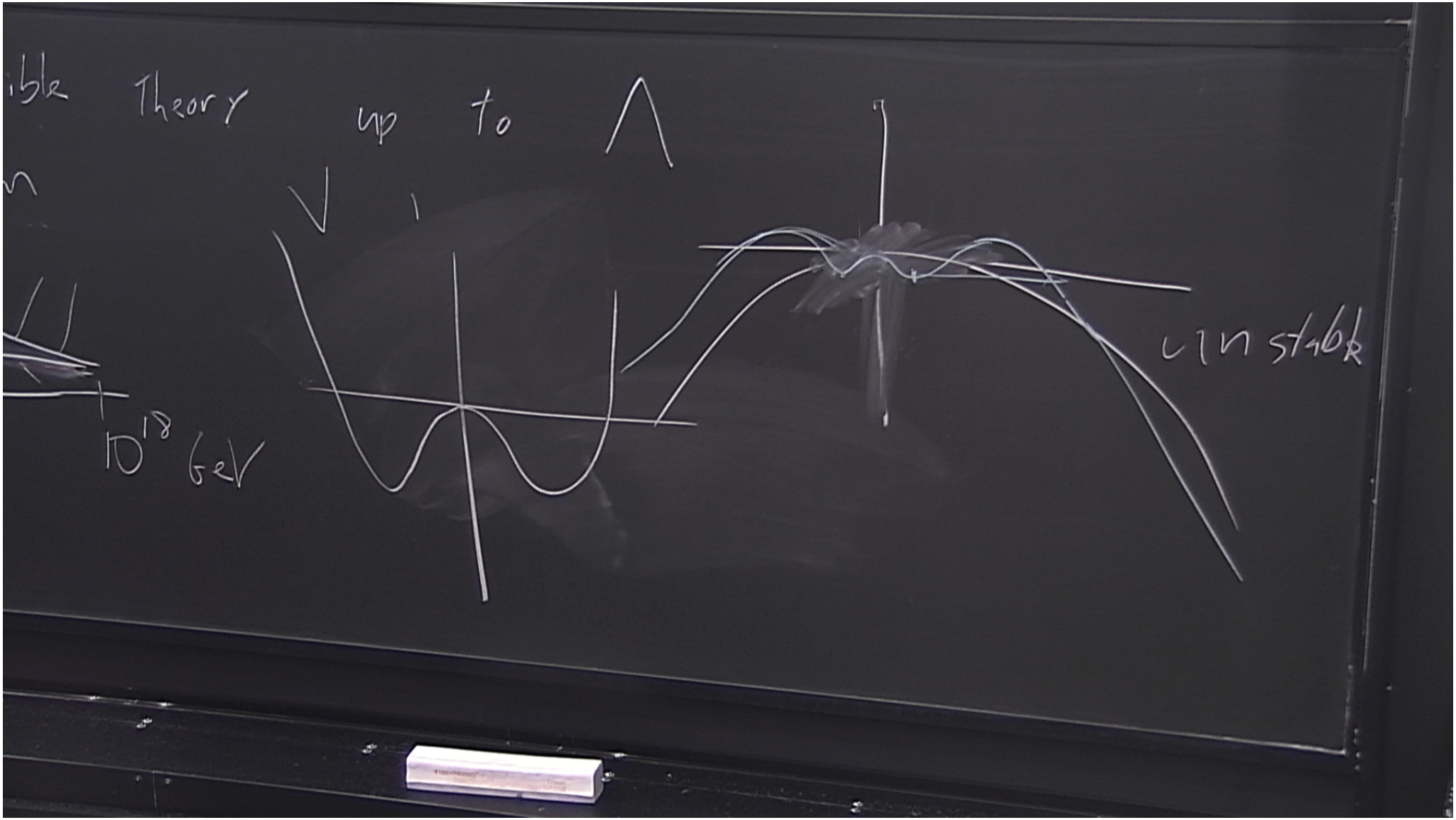
$\Rightarrow M_H < 500$

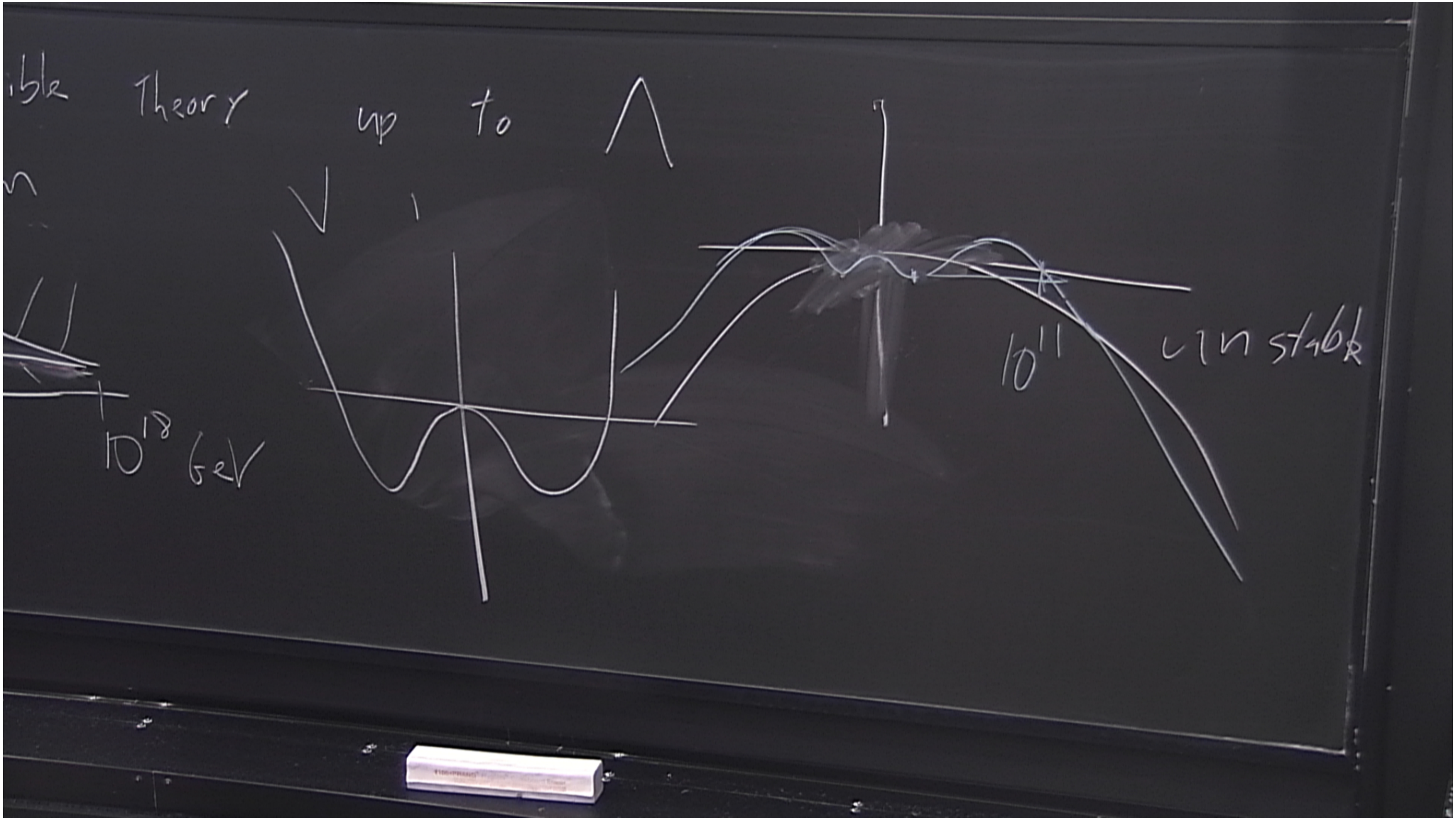
$\Lambda \sim 10^{18}$ GeV

$\Rightarrow M_H \lesssim 180$


large
$\lambda(v)$
$\lambda(v)$
v
Landau pole
Q
λ^2 dominates
$\Lambda \sim 10^3$ GeV
$\Rightarrow M_H < 500$
$\Lambda \sim 10^{18}$ GeV
$\Rightarrow M_H \lesssim 180$
600
M_H
200
10^3
Λ
10^{18} GeV
require
sensible Theory
SM


ible Theory up to Λ
10^18 GeV
unstable


ible Theory up to Λ
10^{18} GeV
unstable


ible Theory up to Λ
10^{18} GeV
10^{11}
unstable