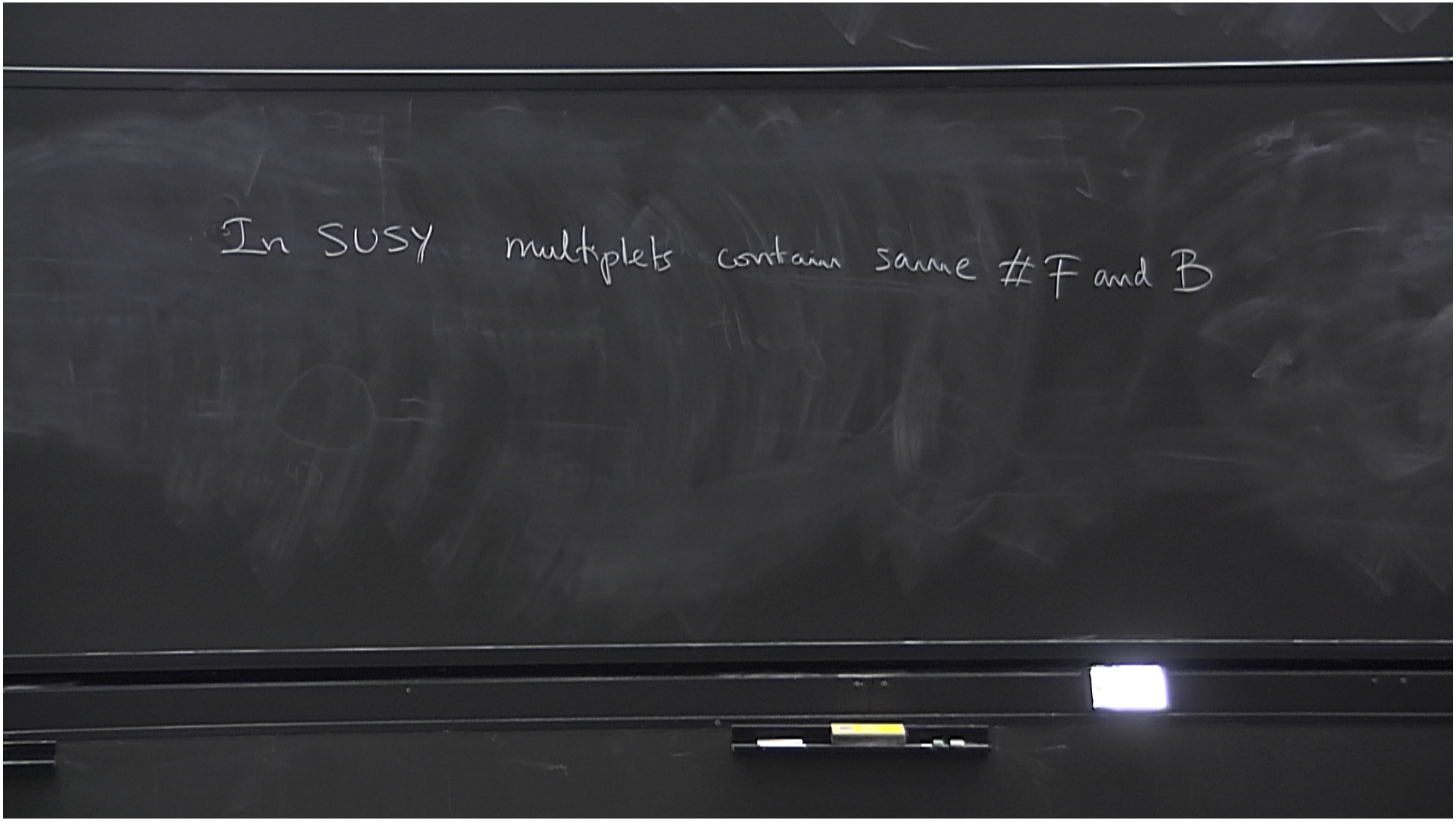
Title: Beyond the Standard Model (Review) - Lecture 7

Date: Feb 22, 2012 09:00 AM

URL: http://pirsa.org/12020078

Abstract:


In SUSY multiplets contain same # F and B

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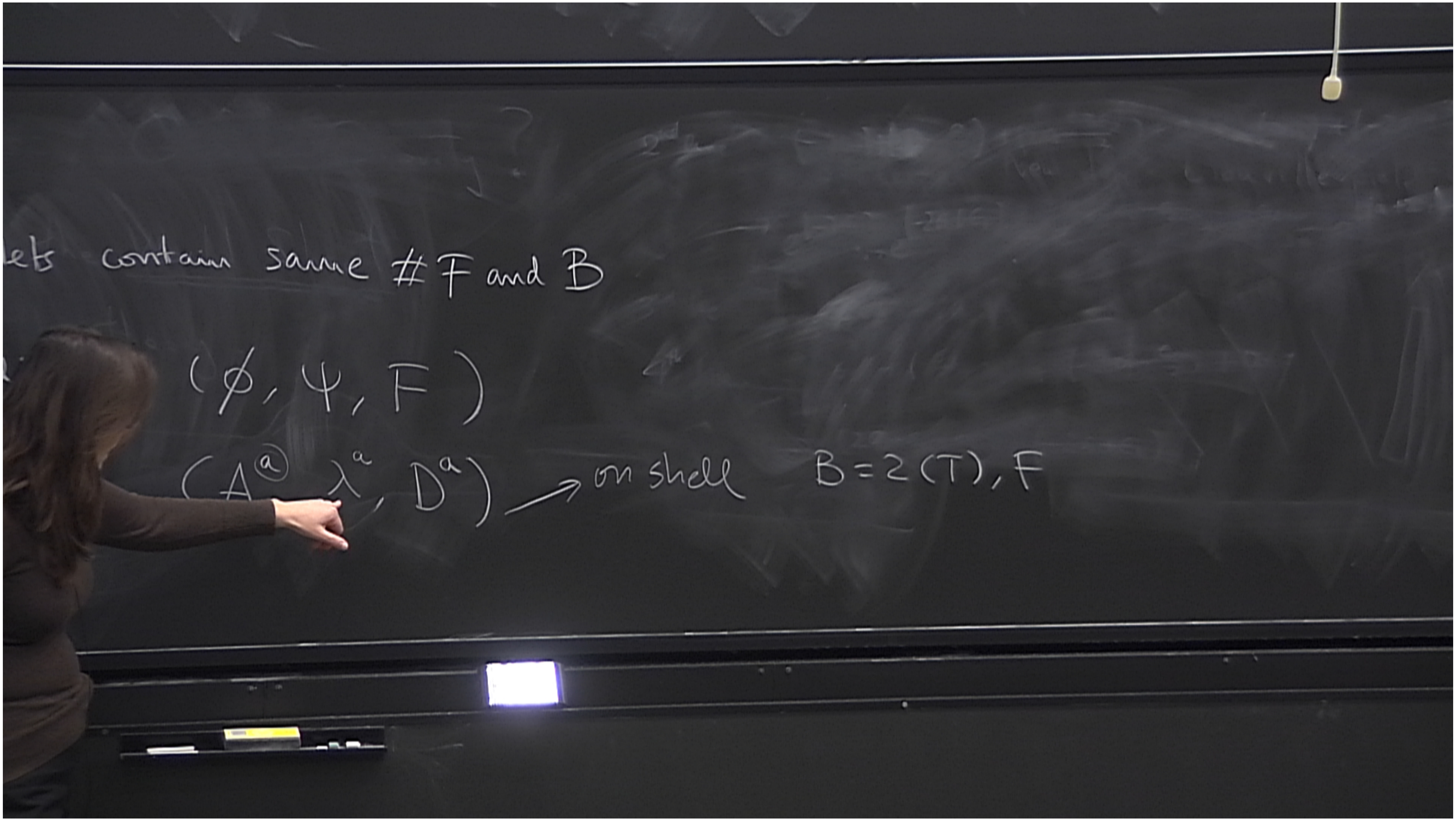
chiral supermultiplet (ϕ, ψ, F)

gauge (vector) " $(A_\mu^a, \lambda^a, D^a) \longrightarrow$ on shell

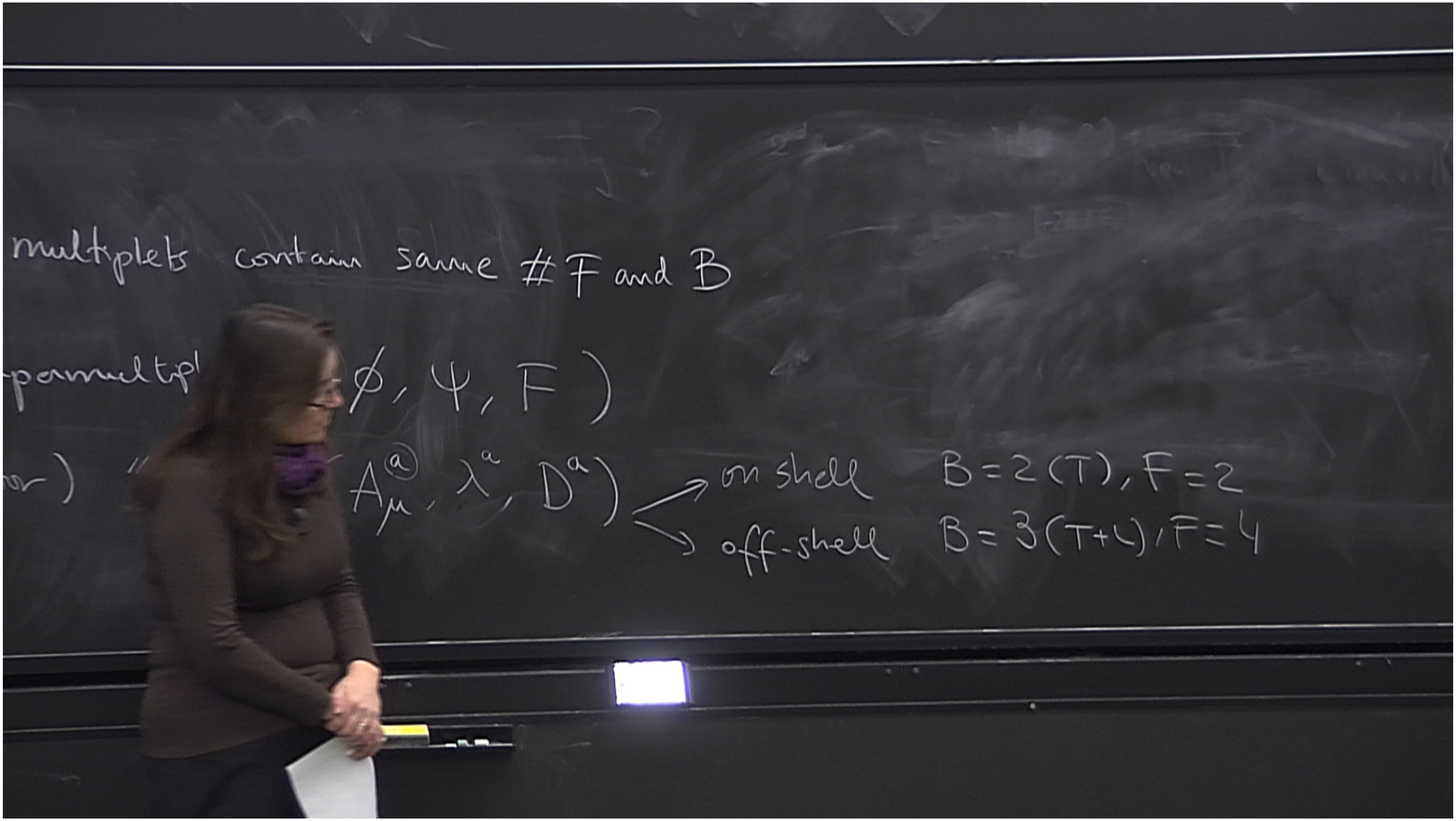

lets contain same # F and B
(ϕ, ψ, F)
(A^a, λ^a, D^a) → on shell B=2(T), F

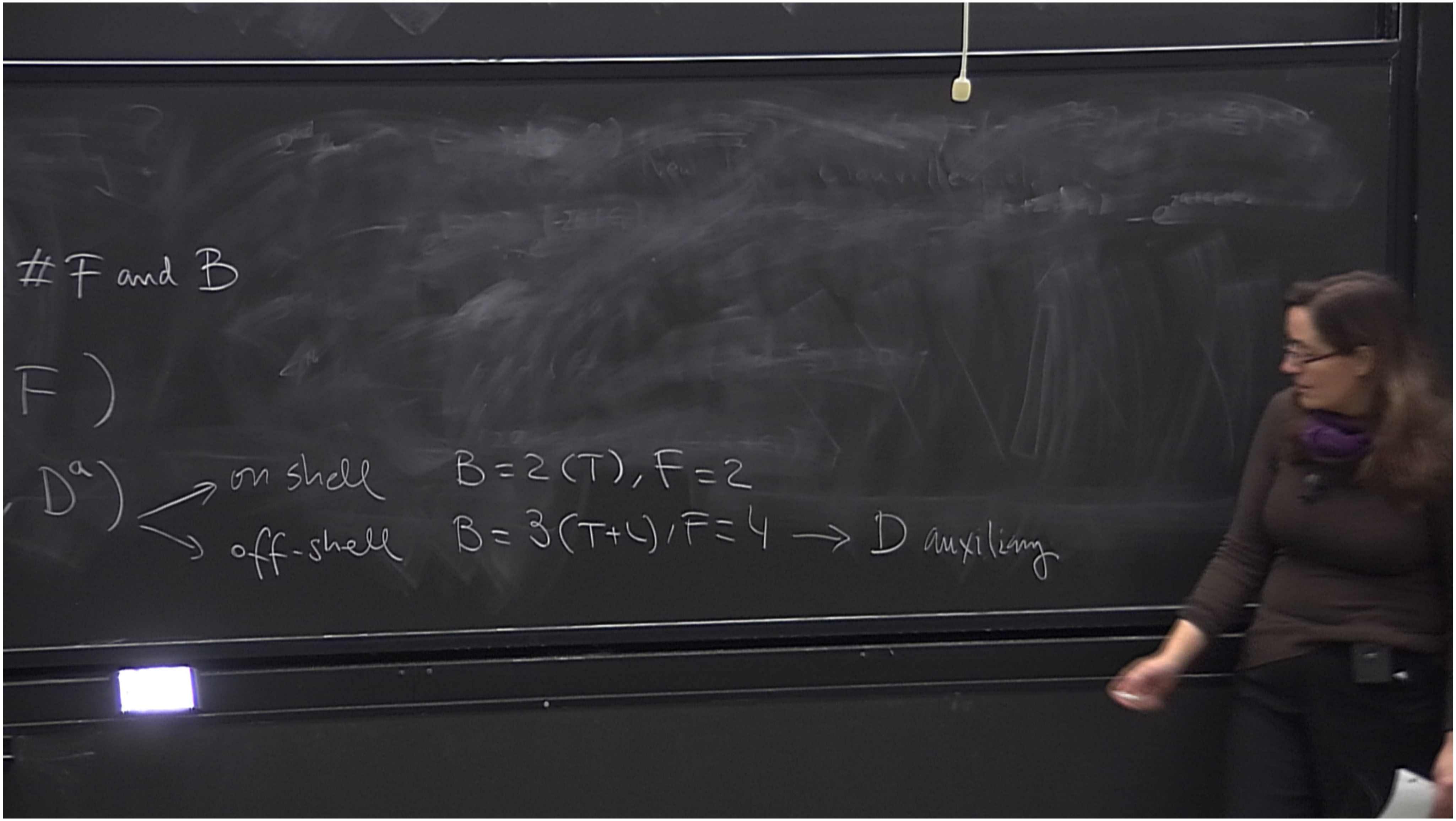
SY multiplets contain same # F and B

l supermultiplet (ϕ, ψ, F)

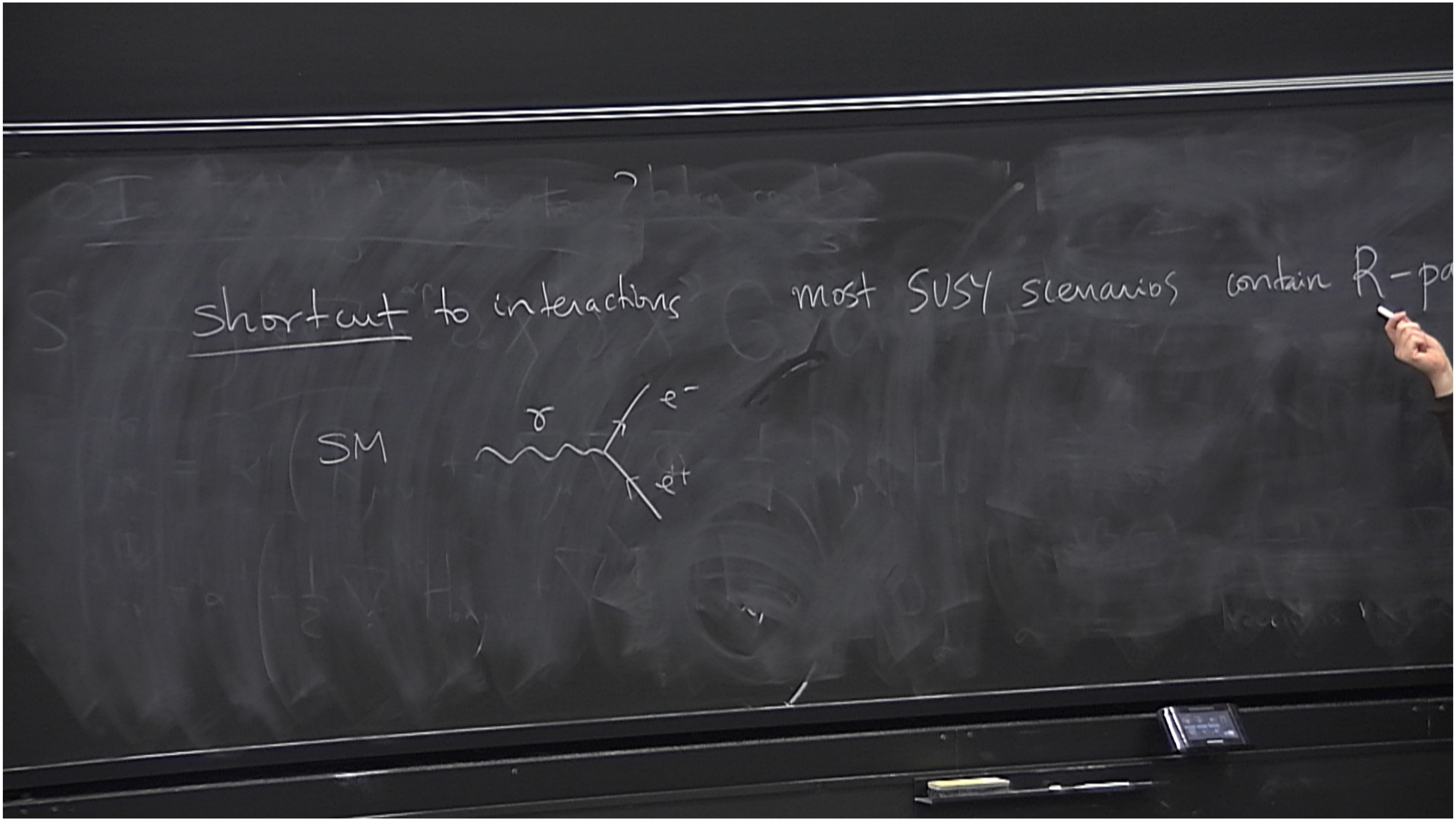
(vector) " $(A_\mu^a, \lambda^a, D^a)$ → on shell $B = 2\,(T), F = 2$

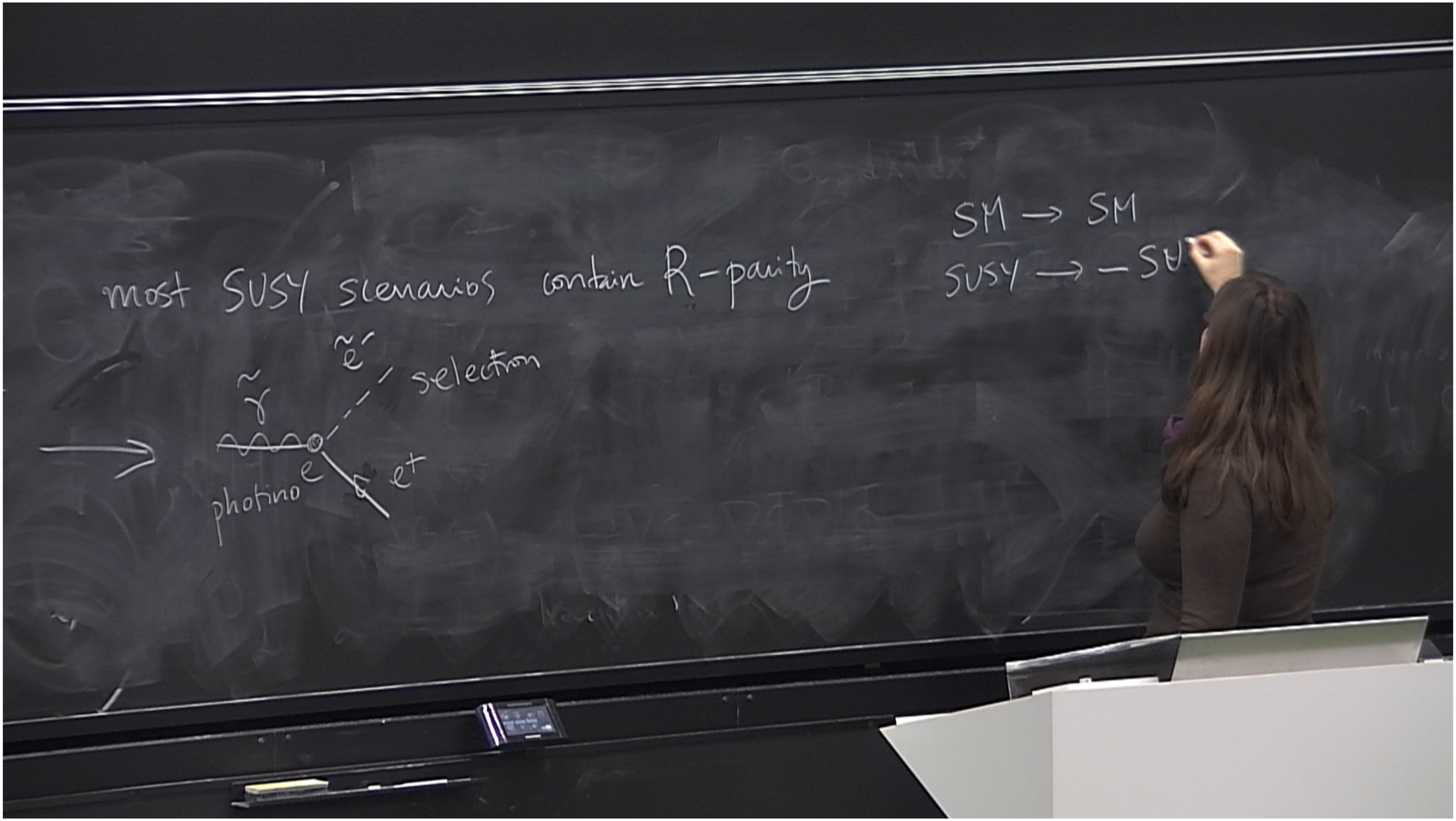
→ off-shell

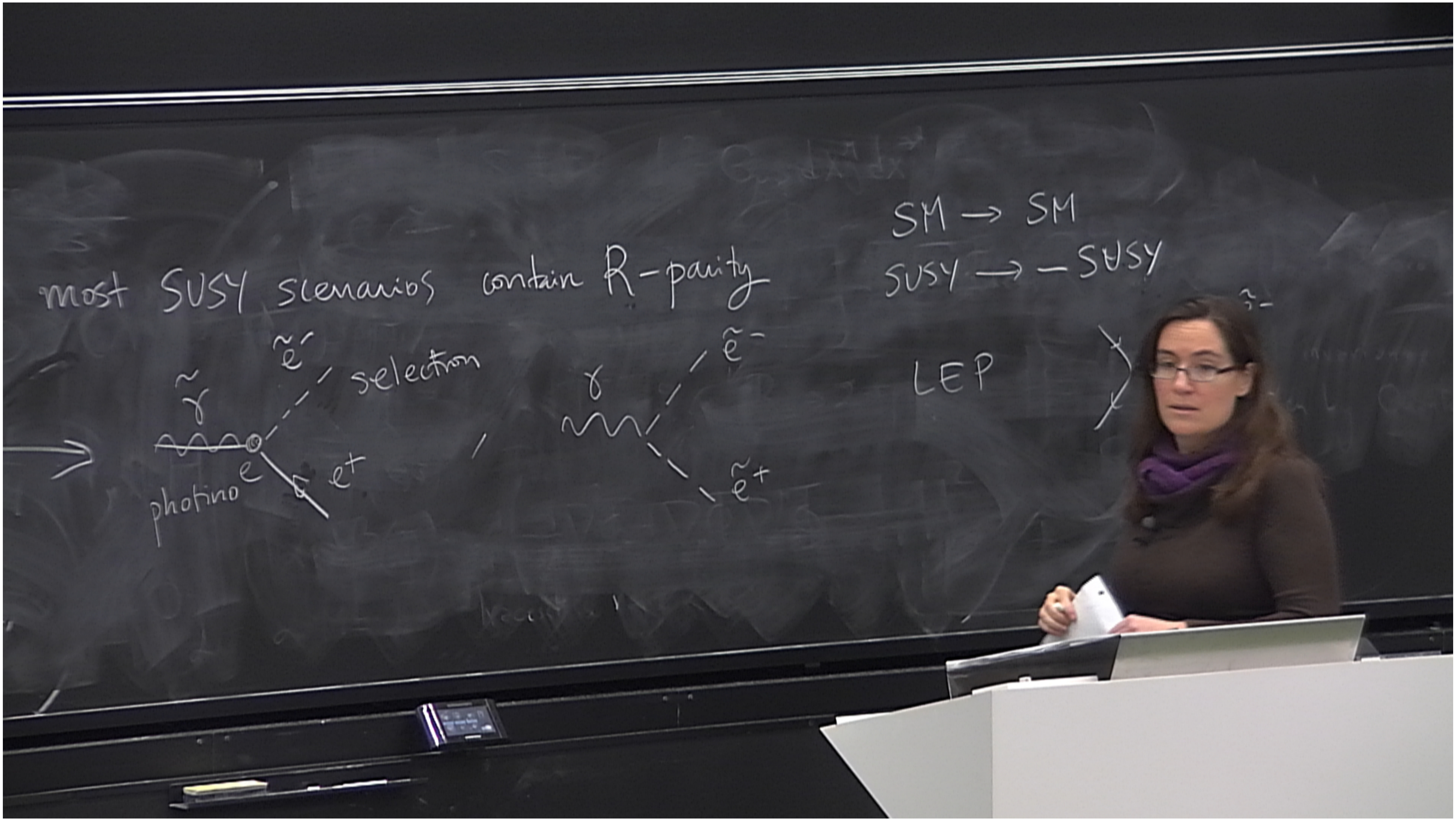

multiplets contain same # F and B
ϕ, ψ, F)
A_μ^a, λ^a, D^a)
on shell B = 2 (T), F = 2
off-shell B = 3 (T+L), F = 4

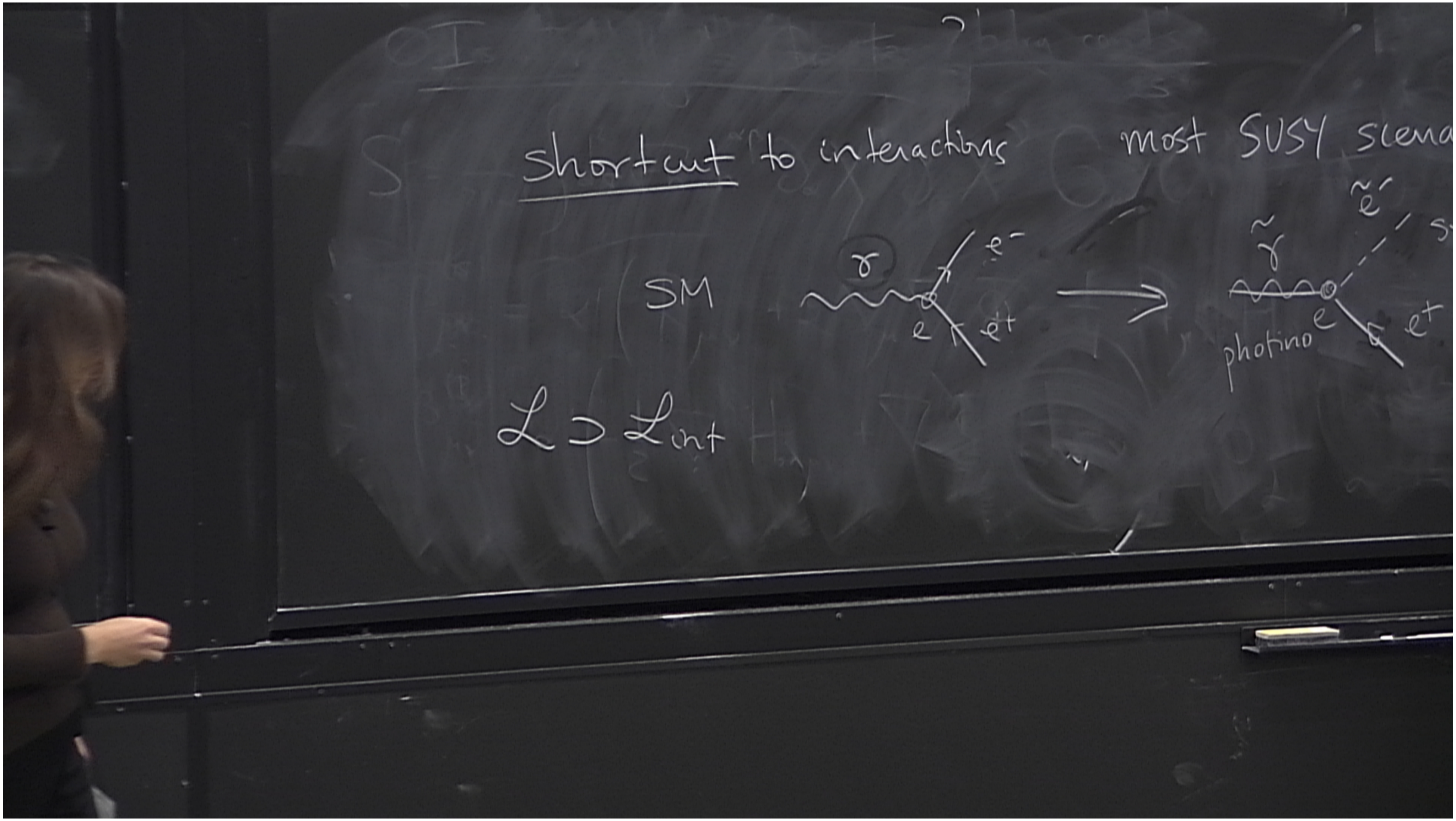

F and B
F)
D^a)
on shell B = 2 (T), F = 2
off-shell B = 3 (T+L), F = 4 → D auxiliary

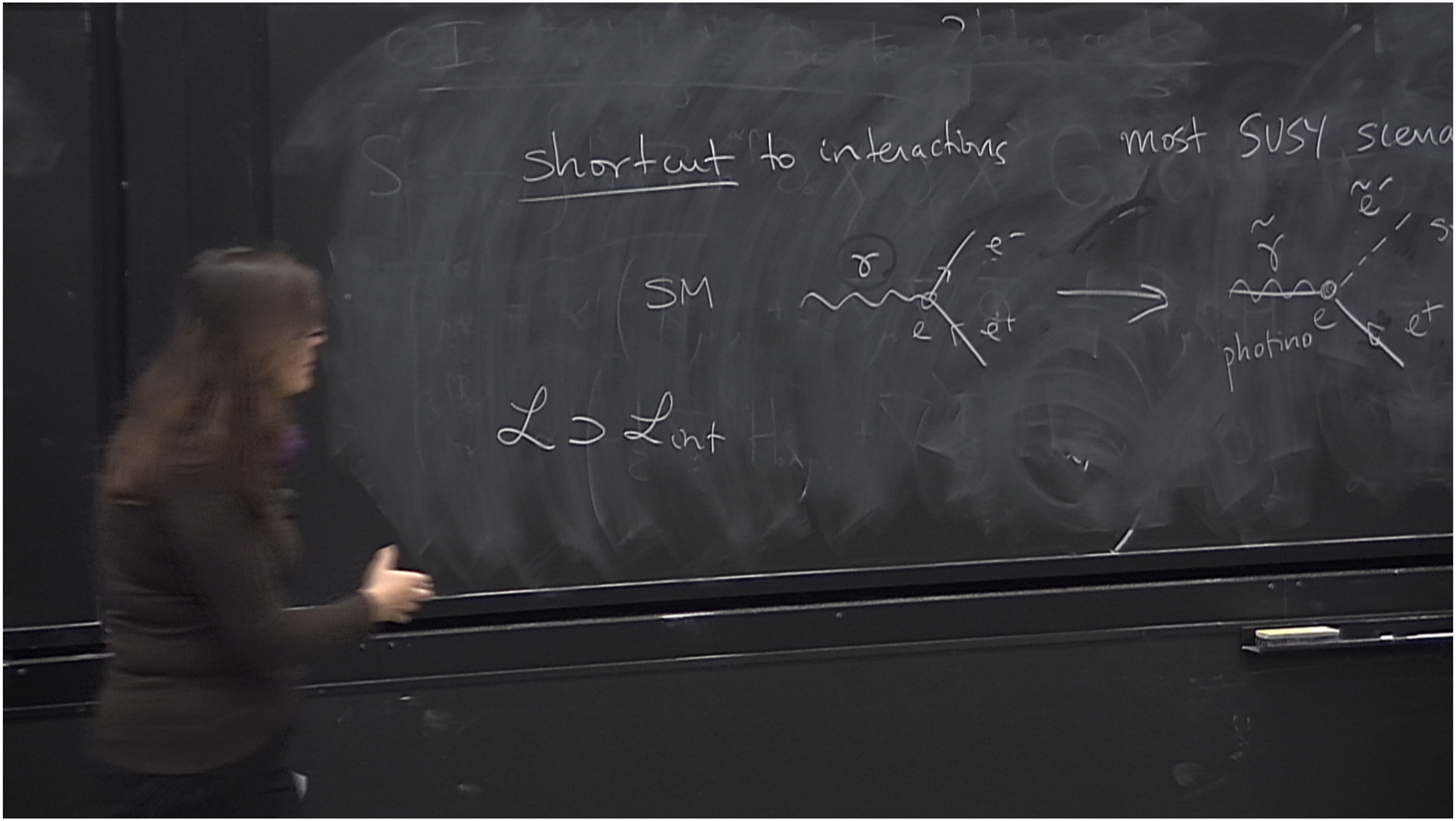
shortcut to interactions most SUSY scenarios contain R-parity

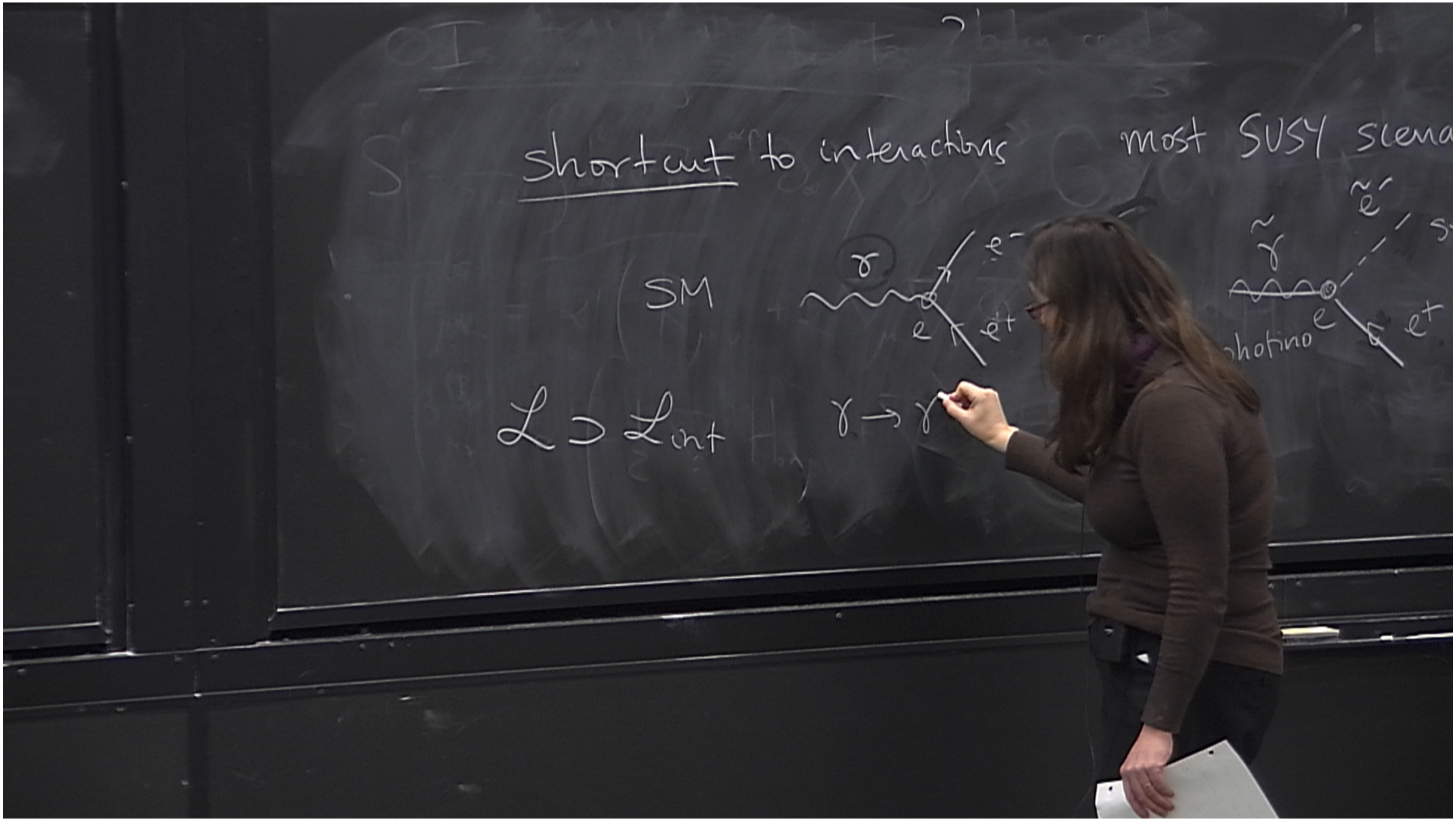

shortcut to interactions
most SUSY scenarios contain R-pa
SM
γ
e⁻
e⁺

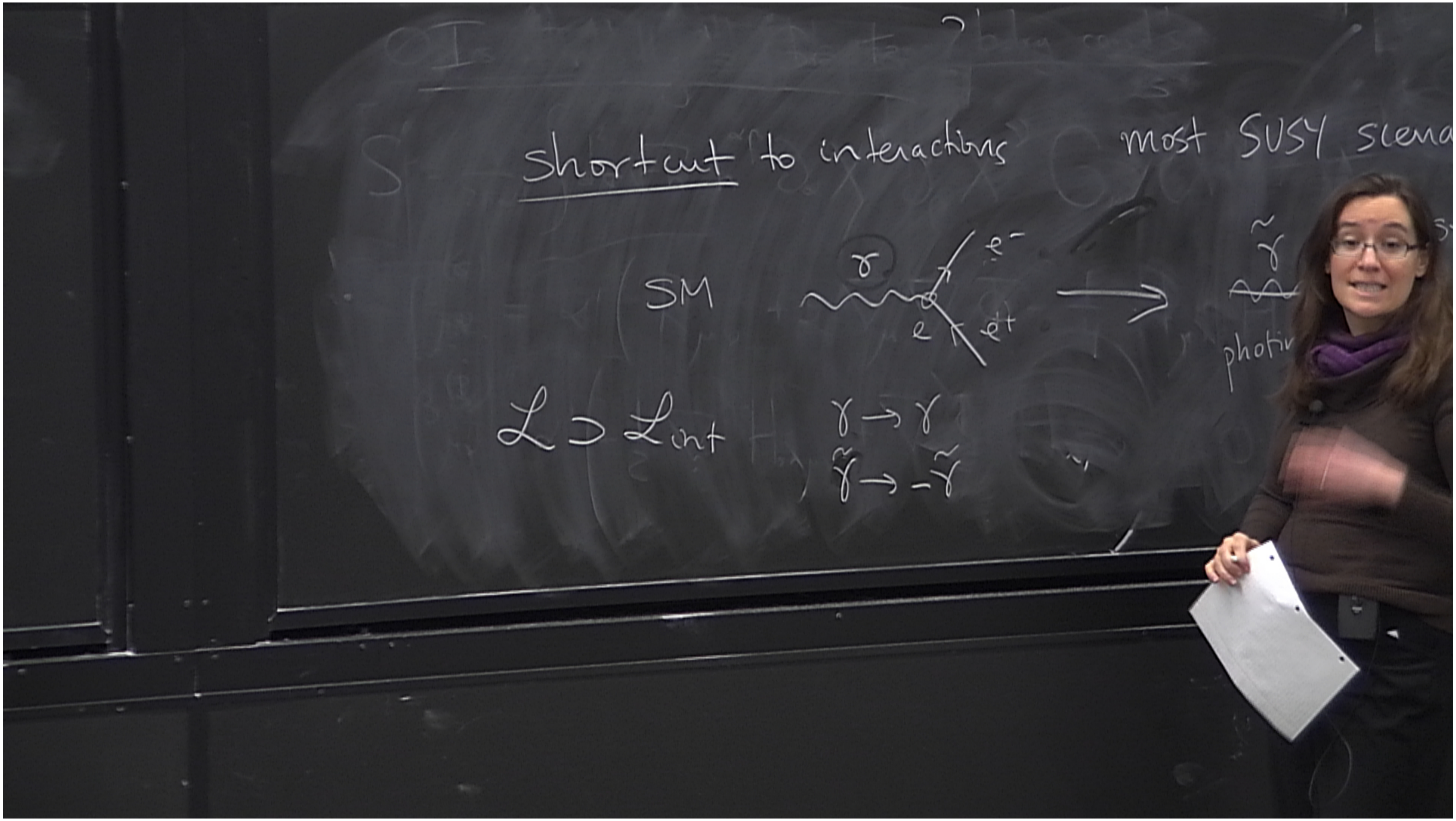

SM → SM
SUSY → − SU
most SUSY scenarios contain R-parity
selectron
photino
e
e+

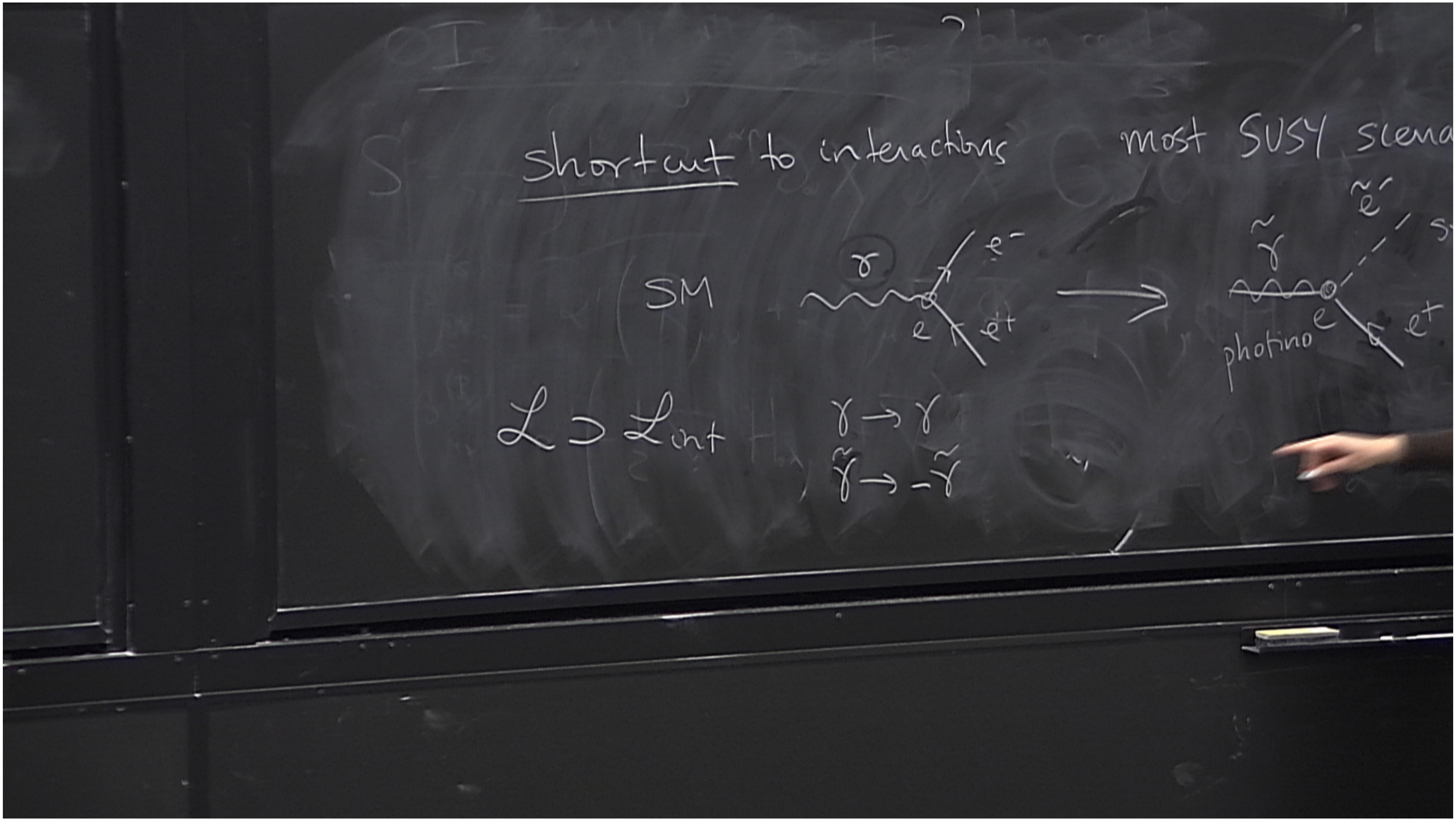

SM → SM
SUSY → − SUSY
most SUSY scenarios contain R-parity
selectron
photino
LEP

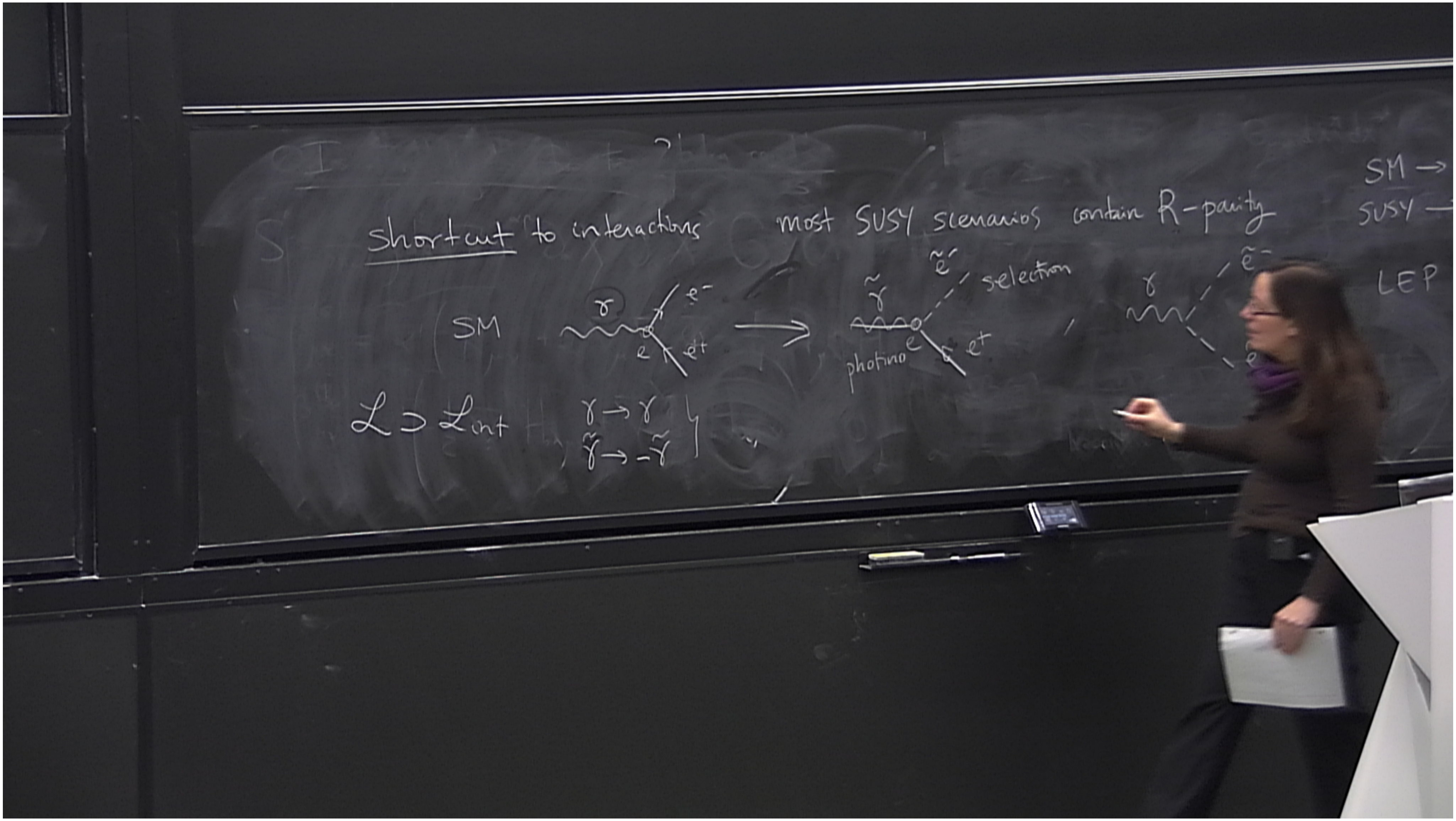

Shortcut to interactions
most SUSY
SM
γ
e⁻
e
e⁺
photino
L ⊃ L_int


shortcut to interactions
most SUSY
SM
γ
e⁻
e
e⁺
photino
$\mathcal{L} \supset \mathcal{L}_{int}$

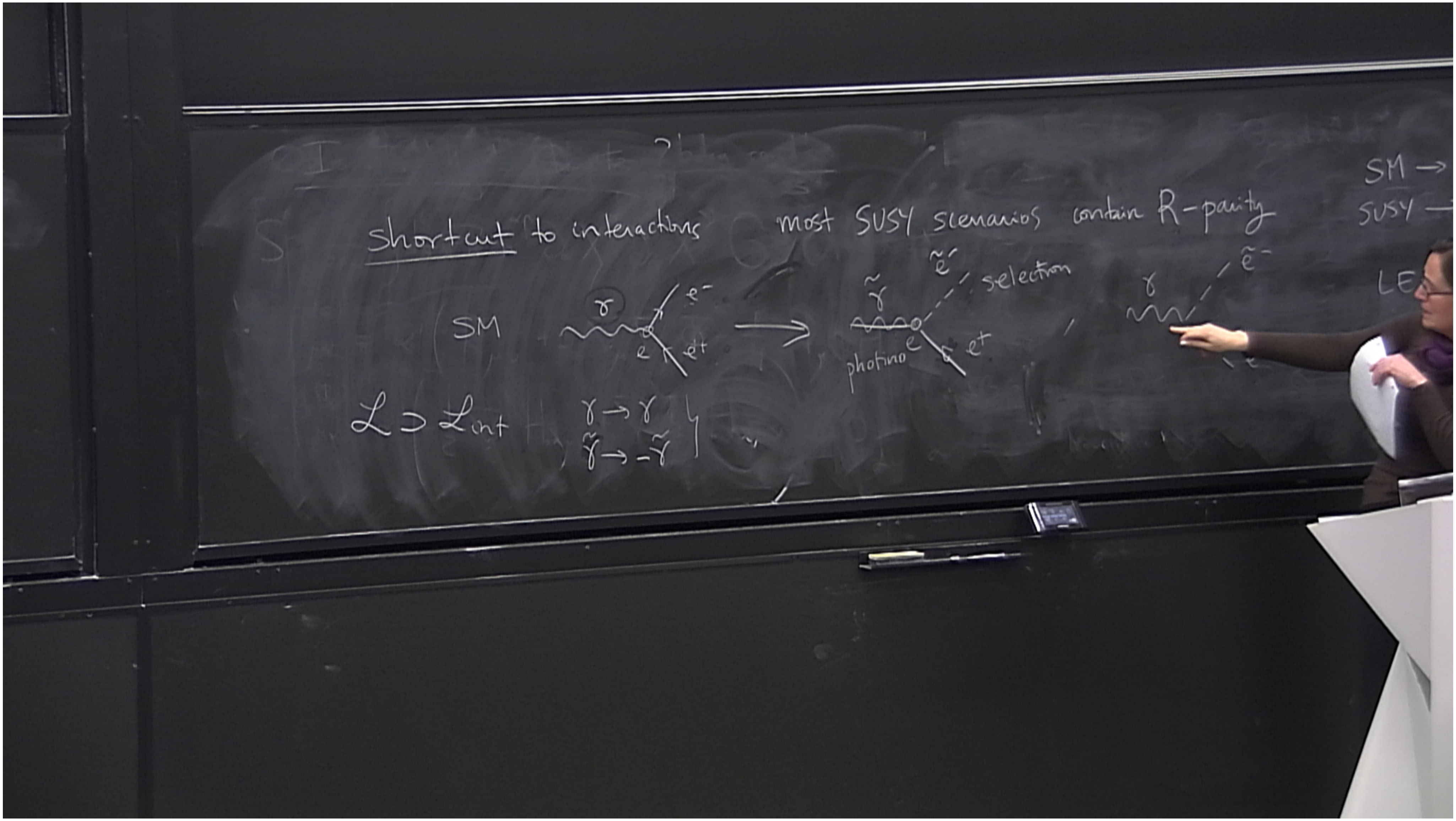

Shortcut to interactions
most SUSY
SM
γ
e⁻
e
e⁺
L ⊃ L_int
γ → γ

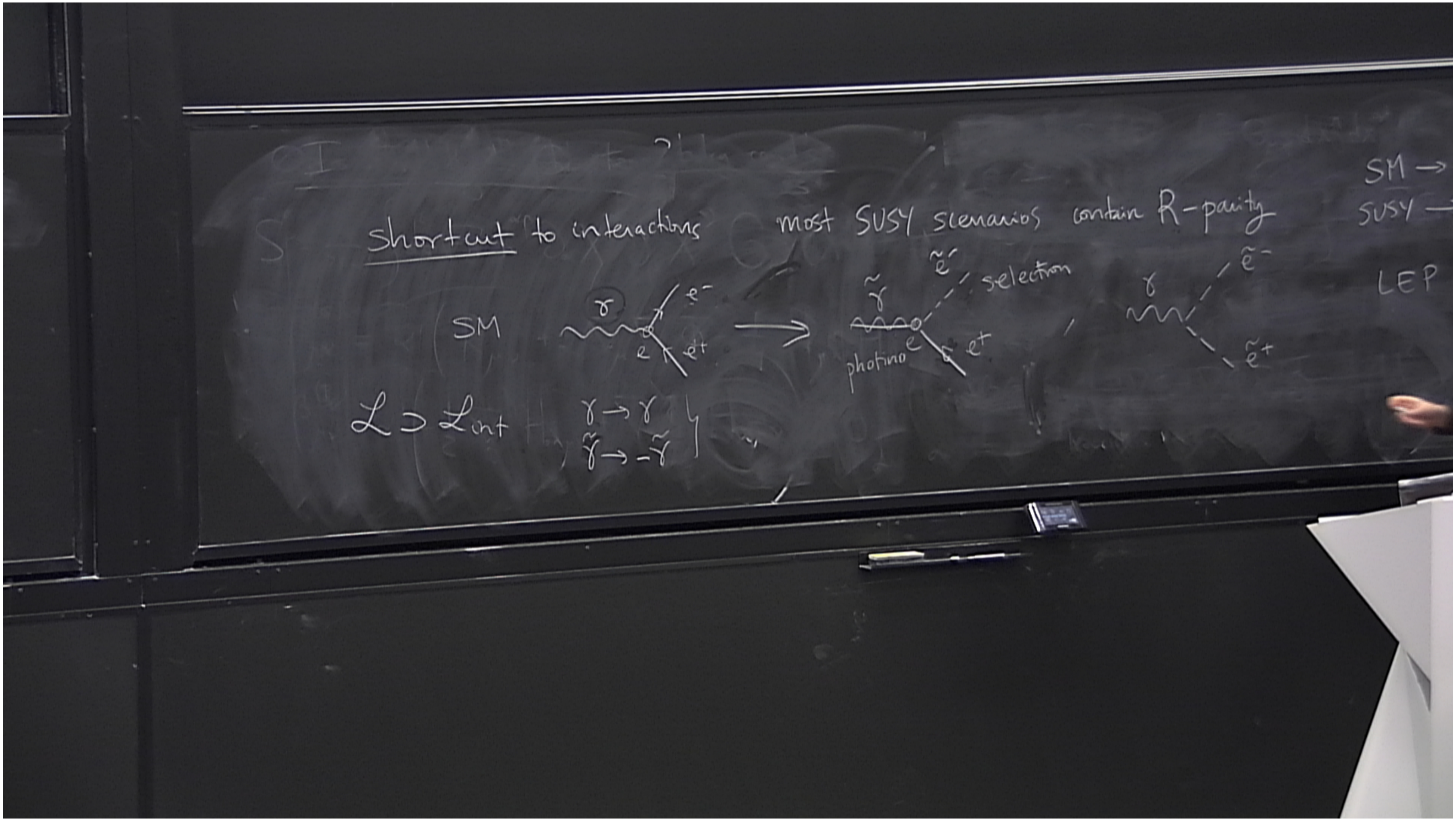

Shortcut to interactions
most SUSY scena
SM
γ
e^-
e^+
$\tilde{\gamma}$
photin
$\mathcal{L} \supset \mathcal{L}_{int}$
$\gamma \to \gamma$
$\tilde{\gamma} \to -\tilde{\gamma}$

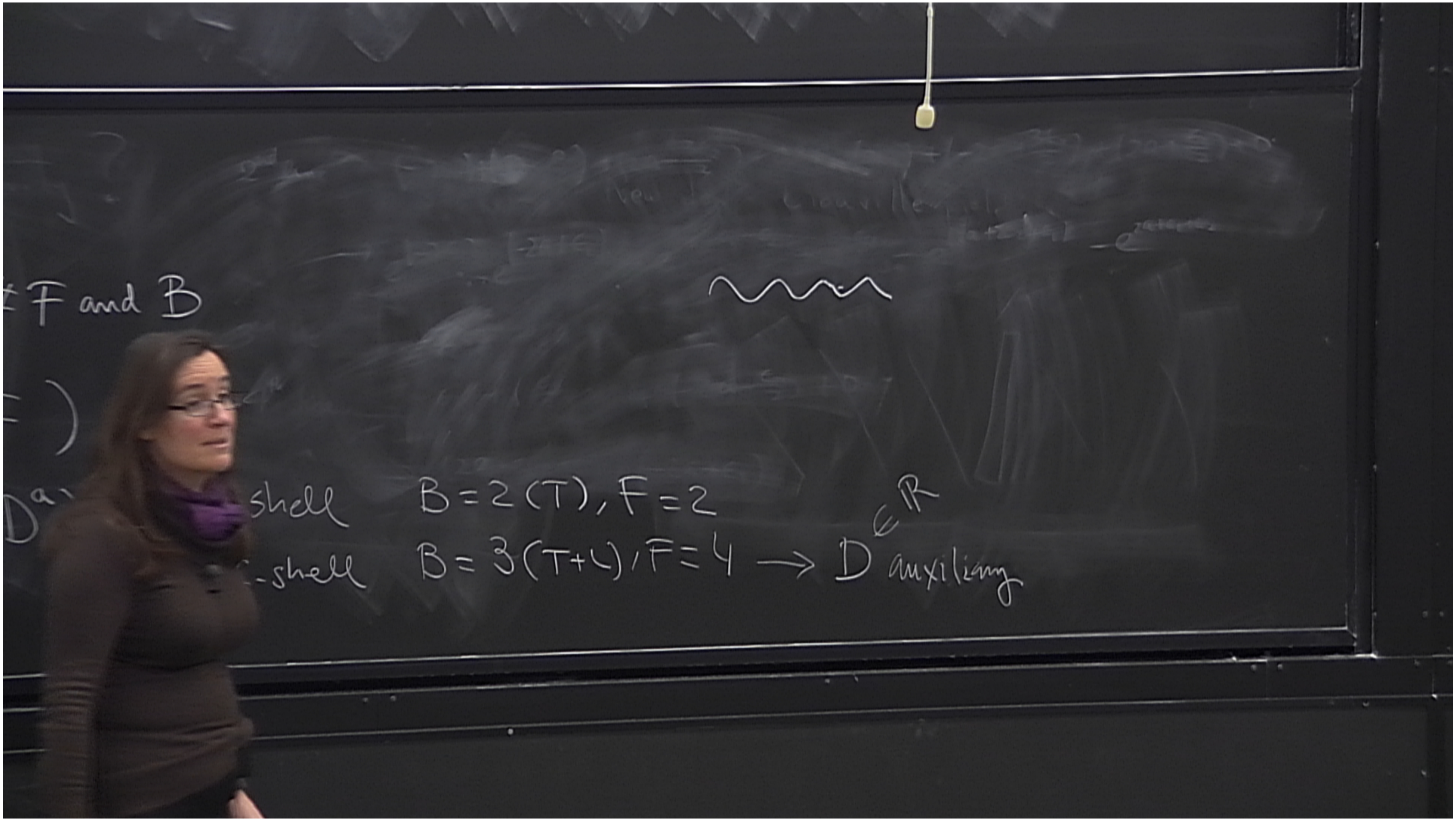

Shortcut to interactions
most SUSY scena
SM
γ
e^-
e
e^+
photino
$\tilde{\gamma}$
$\tilde{e}^-$
e^+
$\mathcal{L} \supset \mathcal{L}_{int}$
$\gamma \to \gamma$
$\tilde{\gamma} \to -\tilde{\gamma}$



Shortcut to interactions
most SUSY scenarios contain R-parity
SM →
SUSY →
SM
γ
e⁻
e
e⁺
photino
γ̃
ẽ⁻
selectron
e⁺
LEP
ℒ ⊃ ℒint
γ → γ
γ̃ → −γ̃


Shortcut to interactions
SM
γ
e^-
e^+
$\mathcal{L} \supset \mathcal{L}_{int}$
$\gamma \to \gamma$
$\tilde{\gamma} \to -\tilde{\gamma}$
most SUSY scenarios contain R-parity
$\tilde{\gamma}$
$\tilde{e}^-$
selectron
photino
$\tilde{e}^-$
SM →
SUSY →


Shortcut to interactions
SM
γ
e⁻
e
e⁺
L ⊃ L_int
γ → γ
γ̃ → −γ̃
most SUSY scenarios contain R-parity
γ̃
ẽ⁻
selectron
photino
e
ẽ
e⁺
γ
ẽ⁻
ẽ⁺
SM →
SUSY →
LEP


F and B
shell B=2(T), F=2
-shell B=3(T+L), F=4 → D auxiliary
∈ R

$\widetilde{W}^{\pm}$

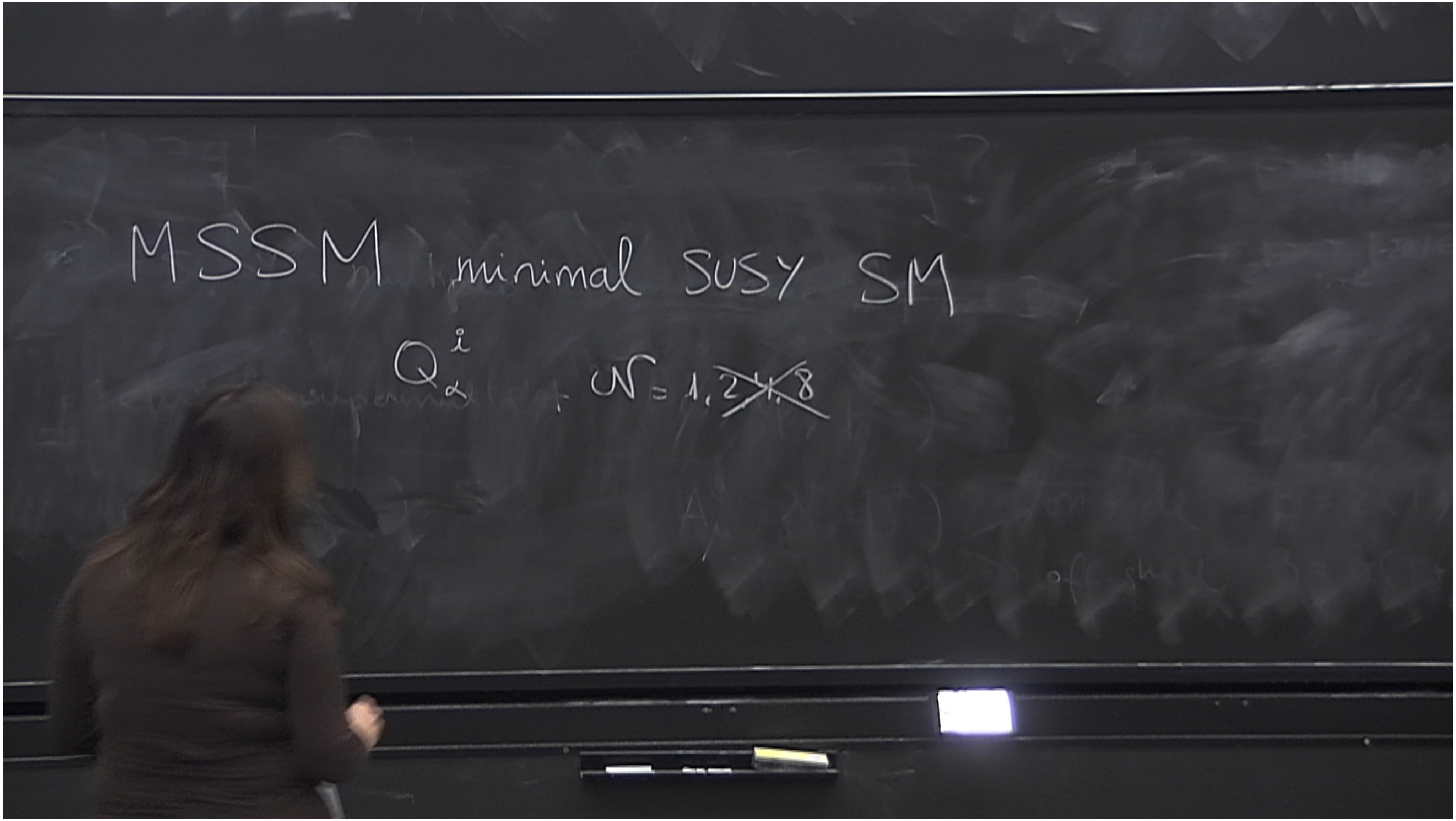
Wino

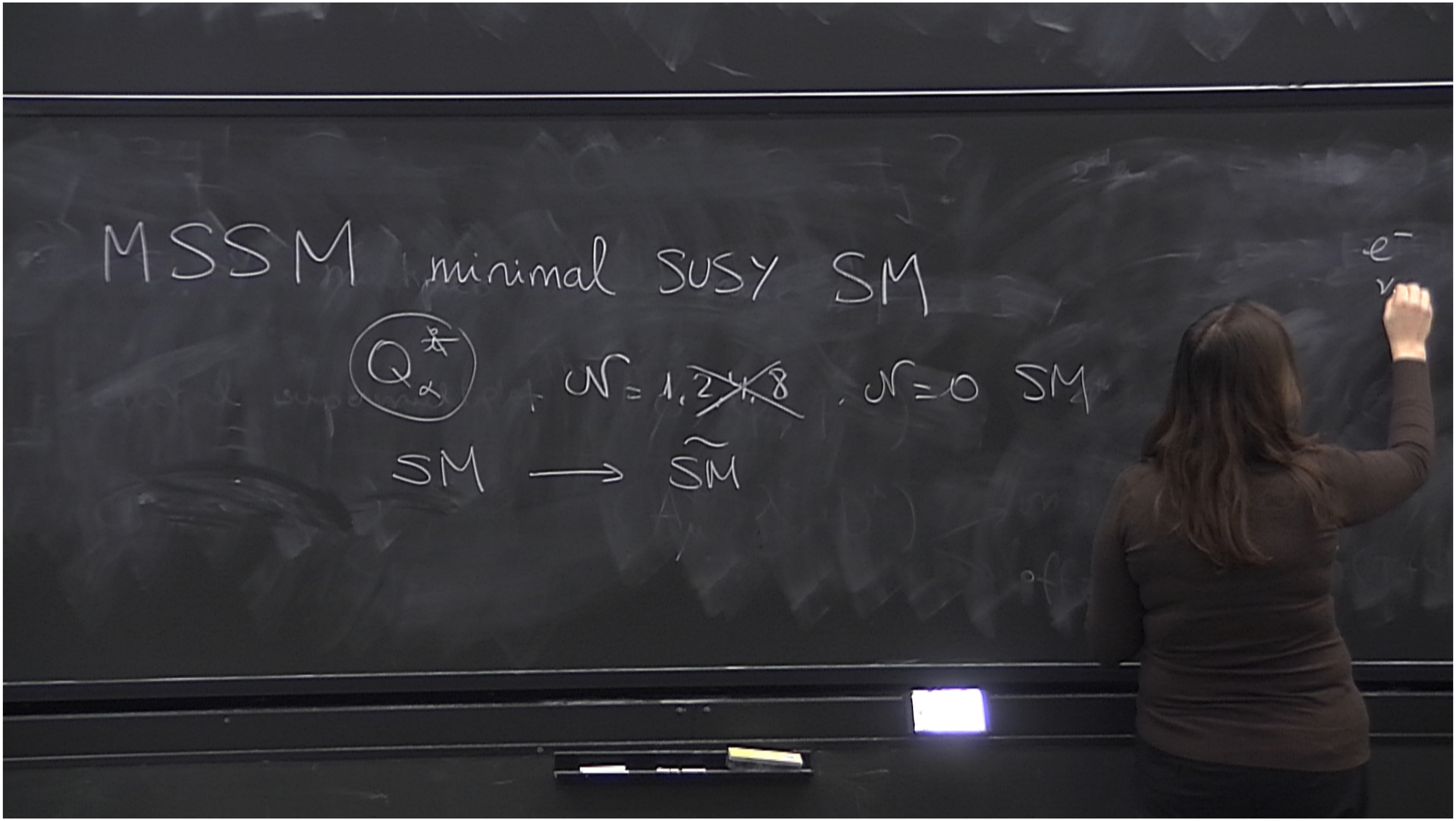
F and B

$F\,)$

$D^a)$ → on shell $B = 2\,(T),\ F = 2$

→ off-shell $B = 3\,(T+L),\ F = 4 \longrightarrow D \in \mathbb{R}$ auxiliary

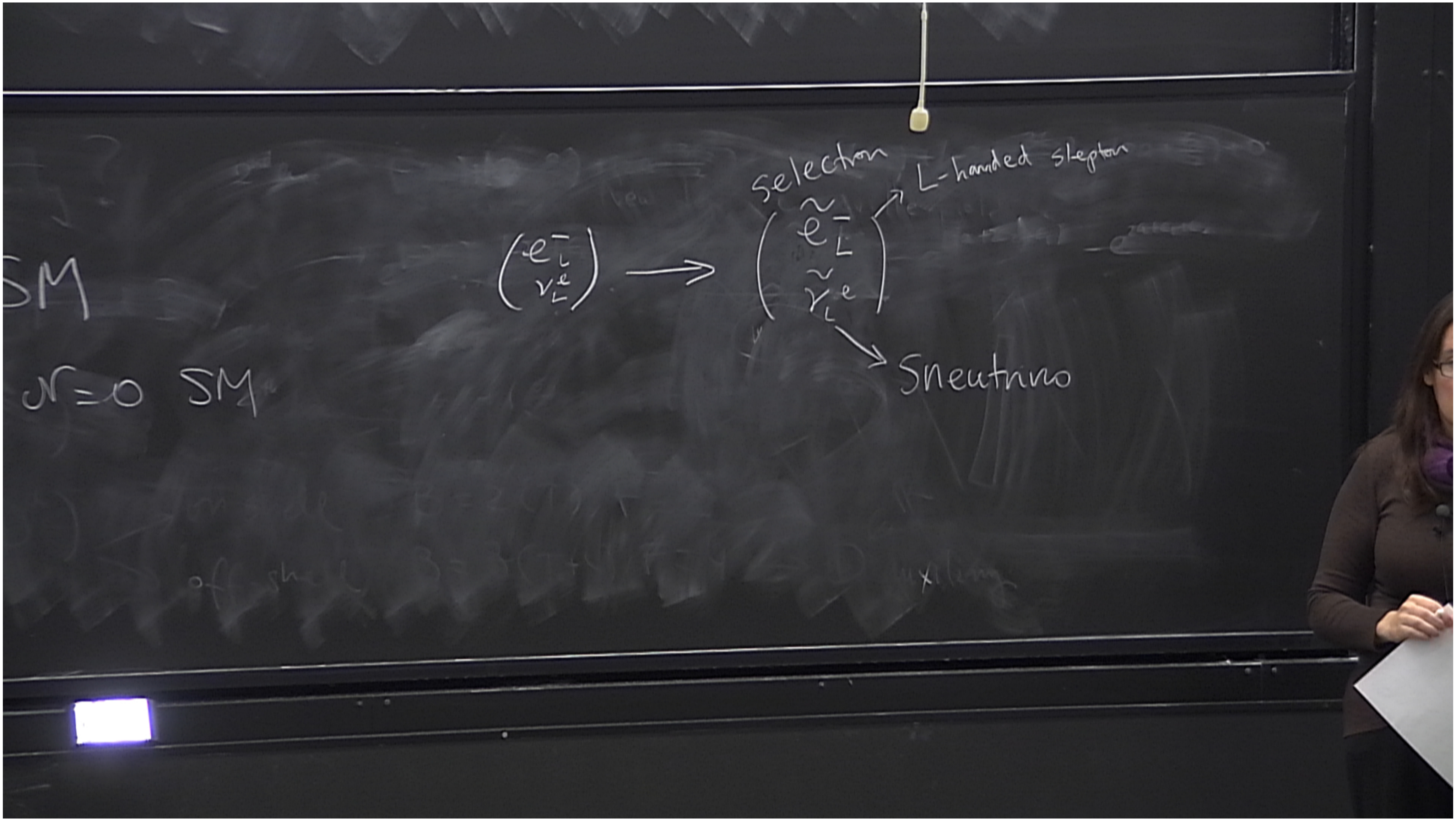

MSSM minimal SUSY SM
Q^i_α $\mathcal{N} = 1, 2, \cancel{4}, \cancel{8}$

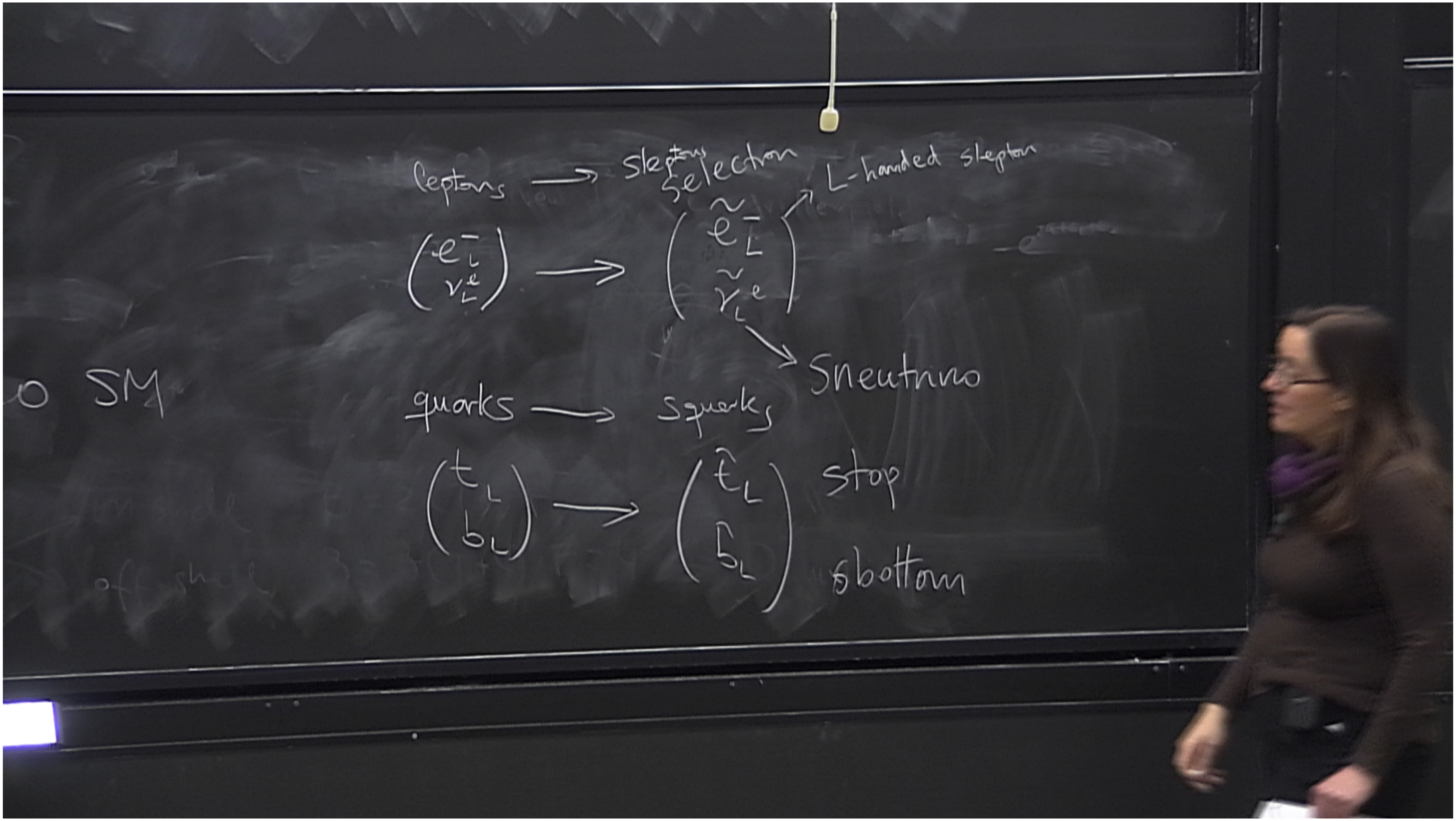

MSSM minimal SUSY SM
$Q_\alpha^{\dot{\alpha}}$
$\mathcal{N} = 1, 2, \cancel{4, 8}$
$\mathcal{N} = 0$ SM
SM ⟶ $\widetilde{SM}$
e^-

SM

$\mathcal{N}=0$ SM

$\begin{pmatrix} e^-_L \\ \nu^e_L \end{pmatrix} \longrightarrow \Big(\tilde{e}^-_L$ ↗ L-handed slepton


SM
N=0 SM
selectron
L-handed slepton
Sneutrino


leptons
sleptons
selectron
L-handed slepton
sneutrino
SM
quarks
squarks
stop
sbottom

o SM

leptons $\longrightarrow$ sleptons

selectron $\rightarrow$ L-handed slepton

$$\begin{pmatrix} e^-_L \\ \nu^e_L \end{pmatrix} \longrightarrow \begin{pmatrix} \tilde{e}^-_L \\ \tilde{\nu}^e_L \end{pmatrix}$$

$\rightarrow$ sneutrino

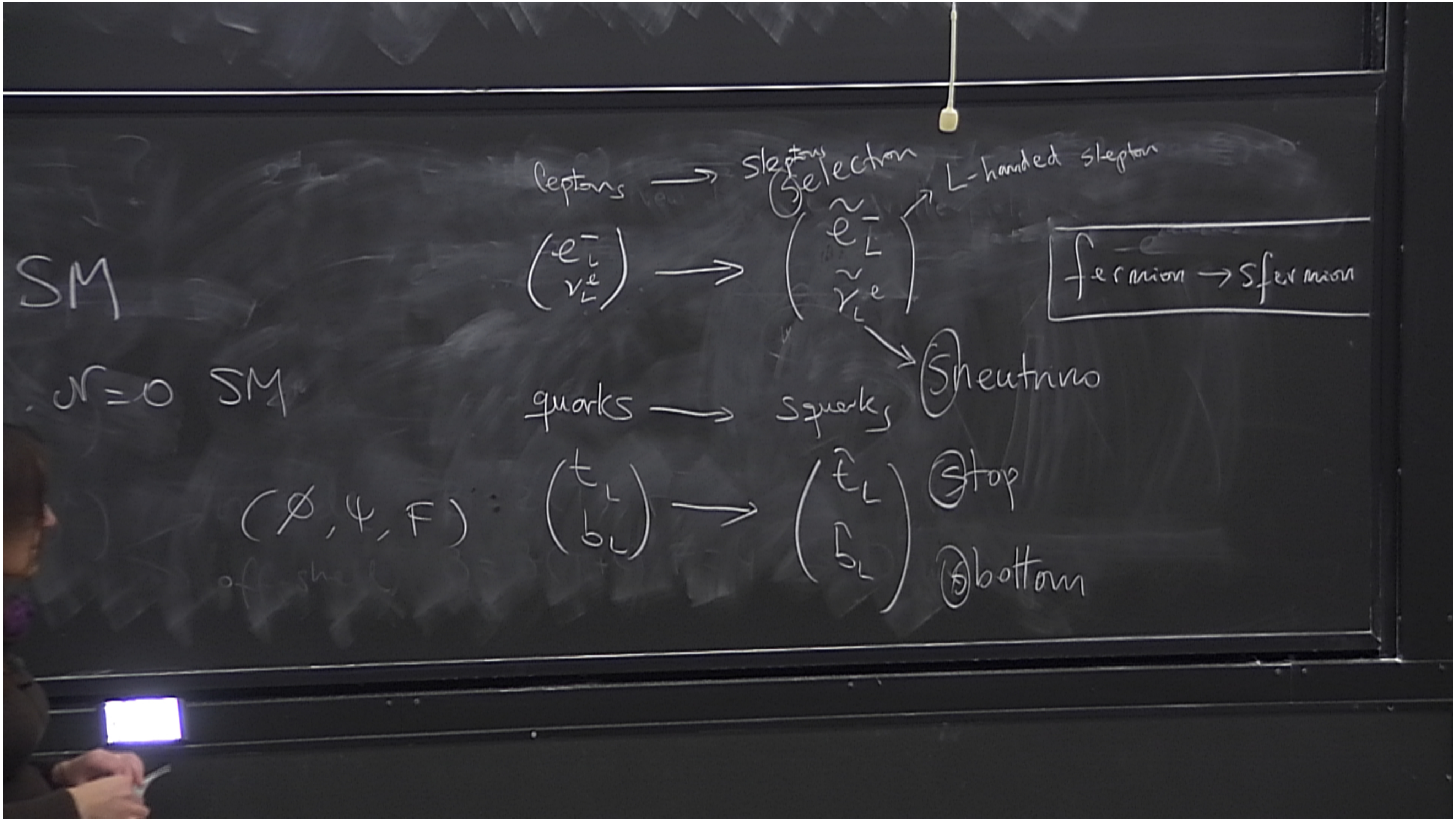
$$\boxed{\text{fermion} \rightarrow \text{sfermion}}$$

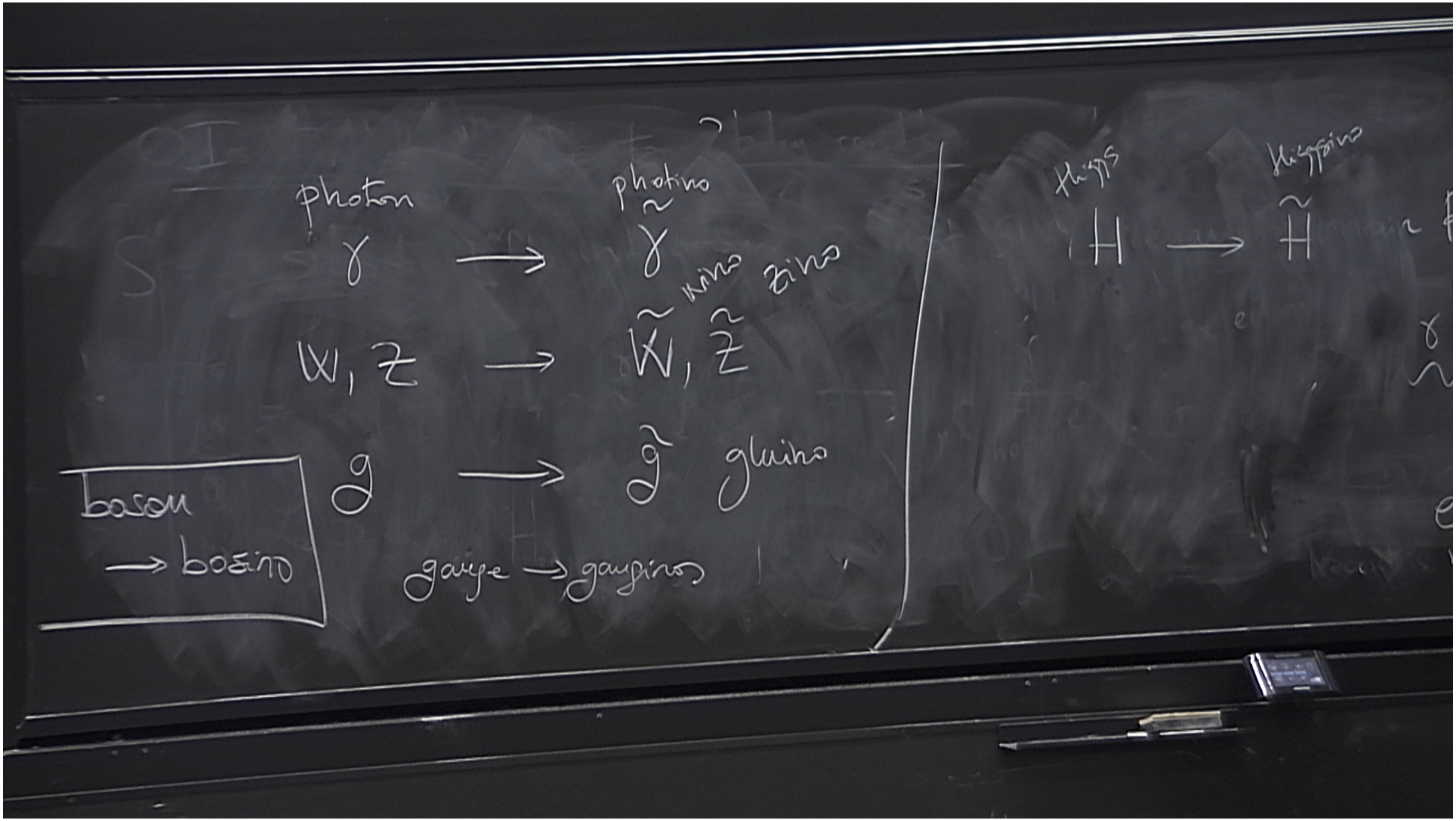
quarks $\longrightarrow$ squarks

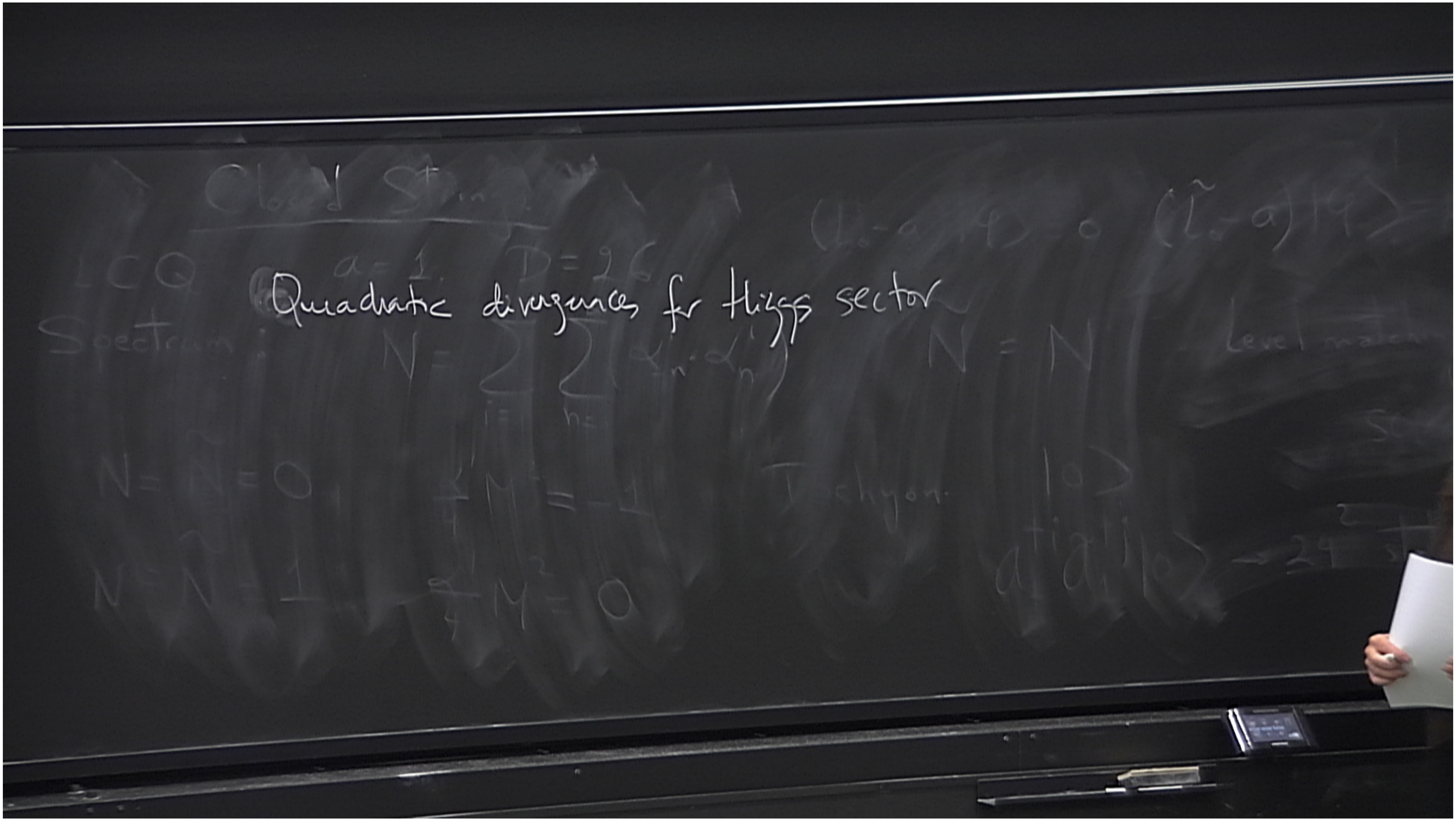
$$\begin{pmatrix} t_L \\ b_L \end{pmatrix} \longrightarrow \begin{pmatrix} \tilde{t}_L \\ \tilde{b}_L \end{pmatrix}$$

stop

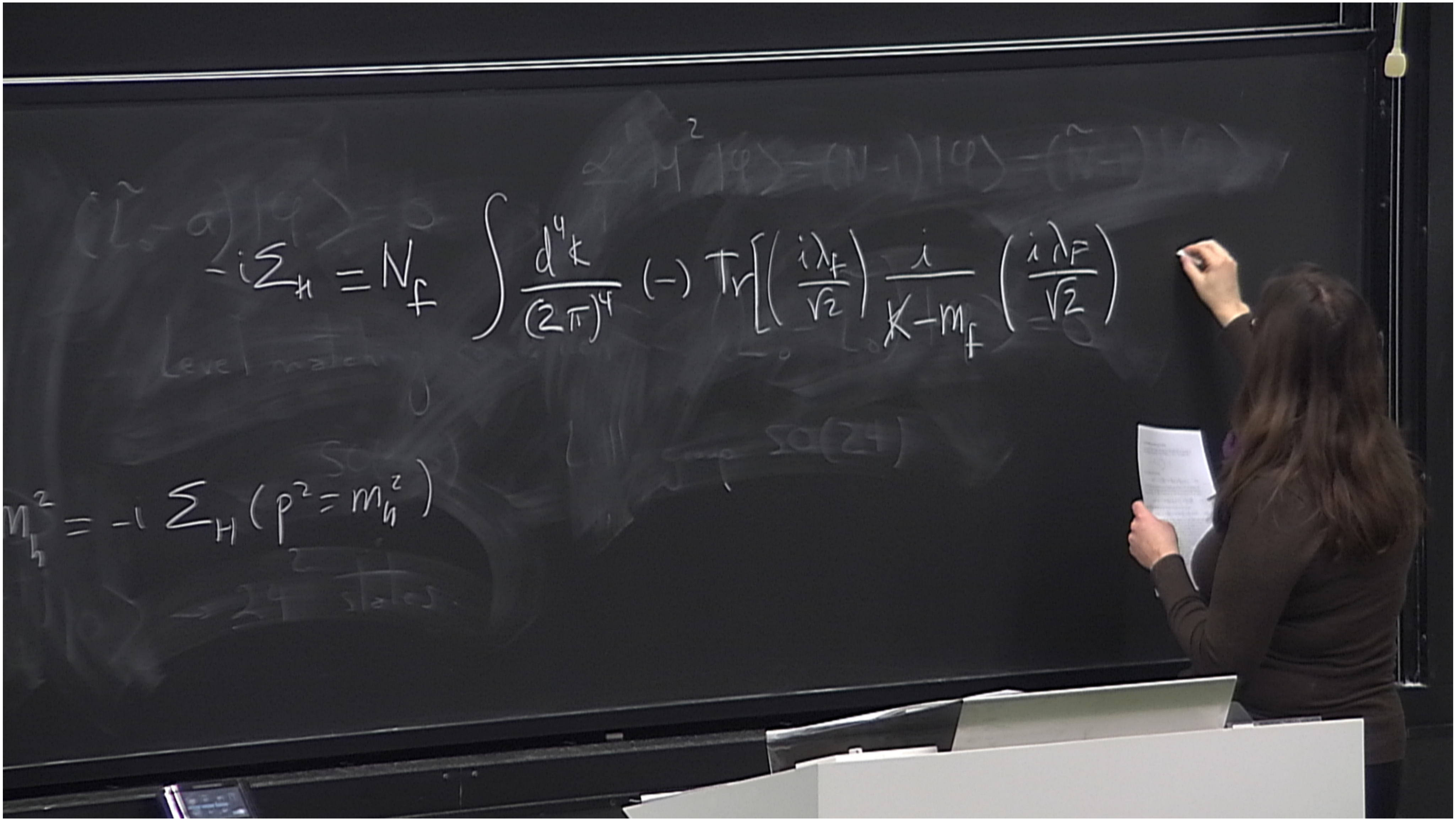
sbottom


SM
$\mathcal{N}=0$ SM
leptons → sleptons
selectron
L-handed slepton
$\begin{pmatrix} e^-_L \\ \nu^e_L \end{pmatrix} \longrightarrow \begin{pmatrix} \tilde{e}^-_L \\ \tilde{\nu}^e_L \end{pmatrix}$
sneutrino
fermion → sfermion
quarks → squarks
(ϕ, ψ, F)
$\begin{pmatrix} t_L \\ b_L \end{pmatrix} \longrightarrow \begin{pmatrix} \tilde{t}_L \\ \tilde{b}_L \end{pmatrix}$
stop
sbottom


photon
photino
γ → γ̃
W, Z → W̃, Z̃
wino
zino
g → g̃ gluino
boson
→ bosino
gauge → gauginos
Higgs
Higgsino
H → H̃

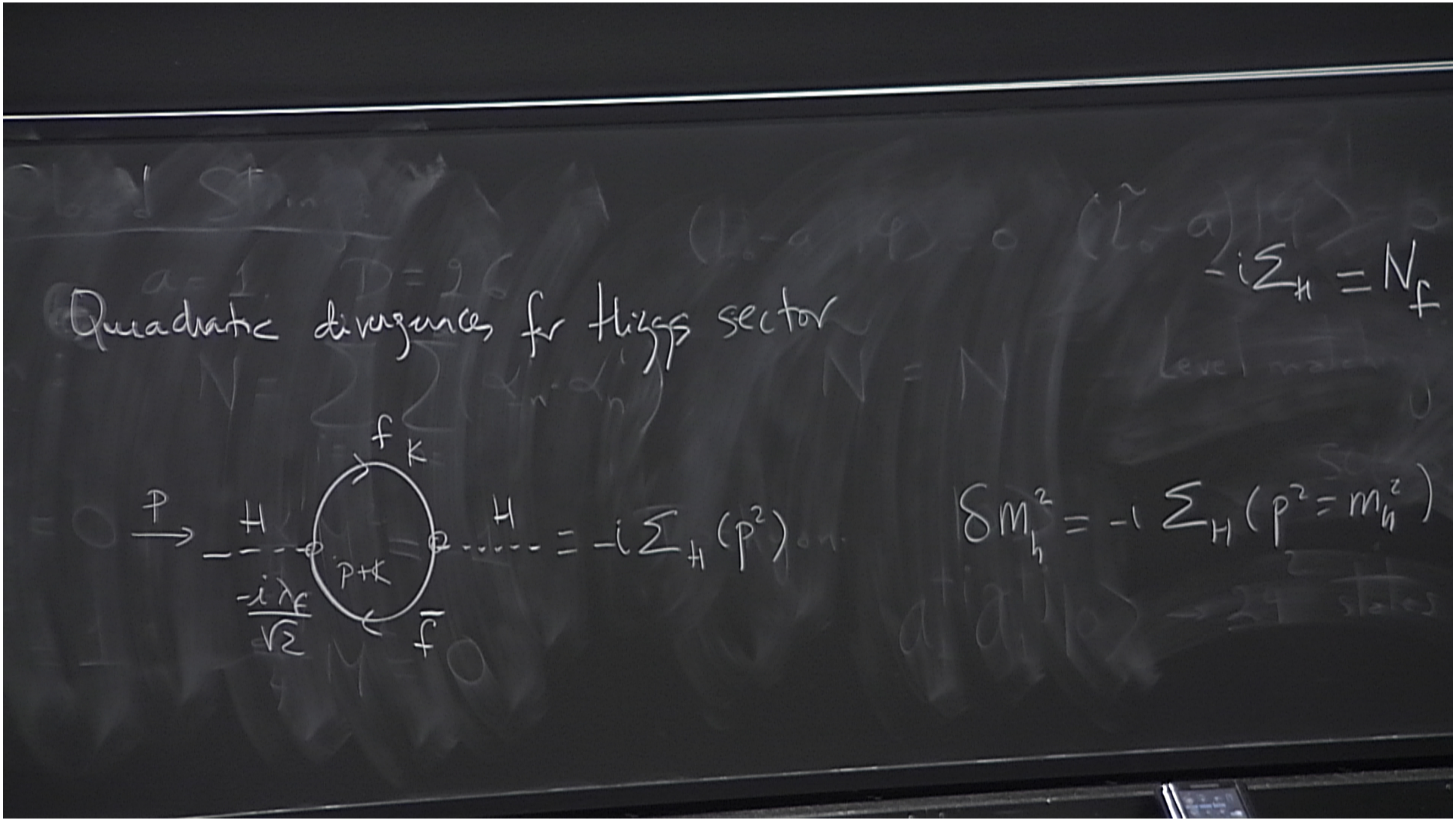

Quadratic divergences for Higgs sector

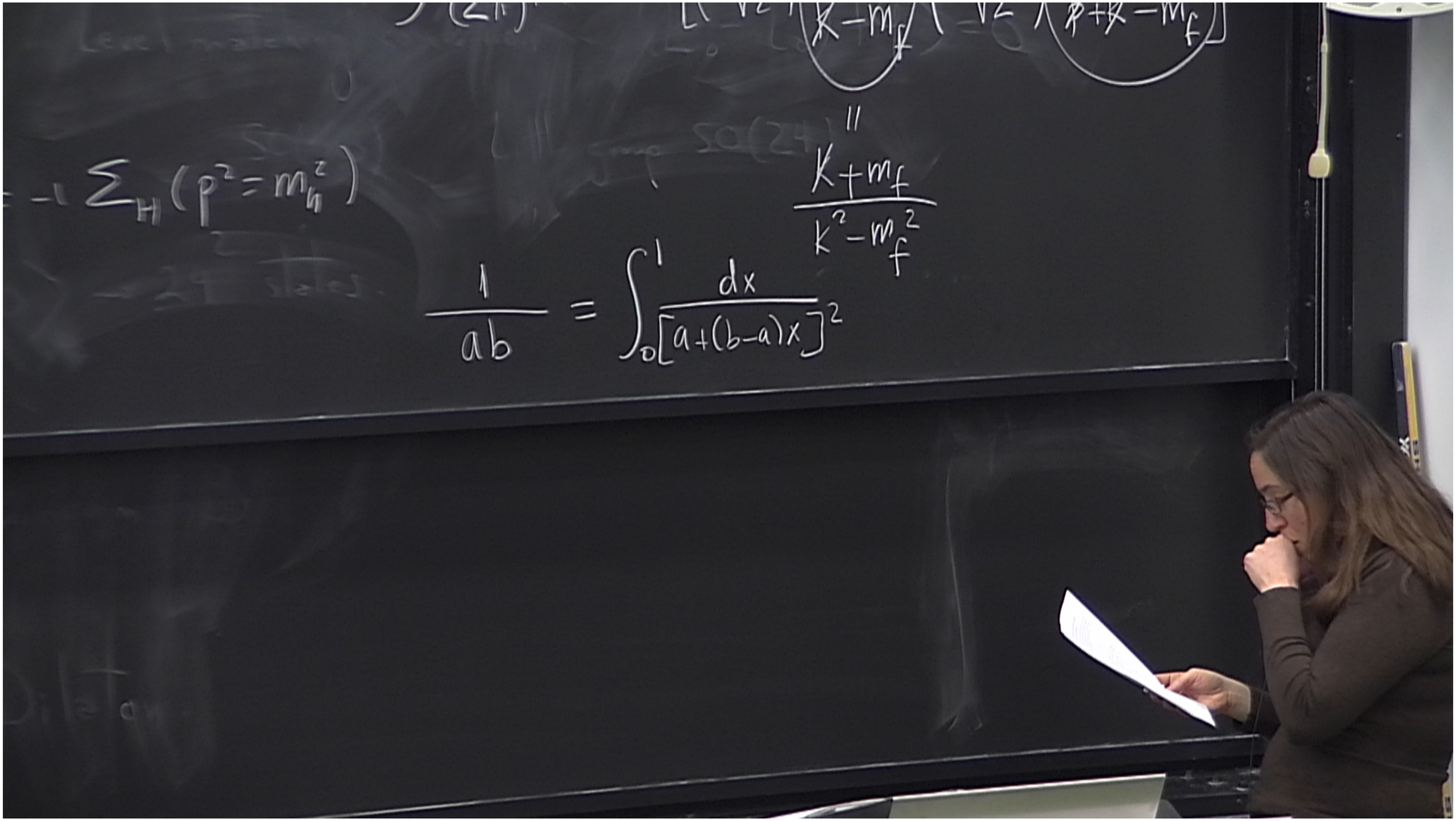
Quadratic divergences for Higgs sector
H
H

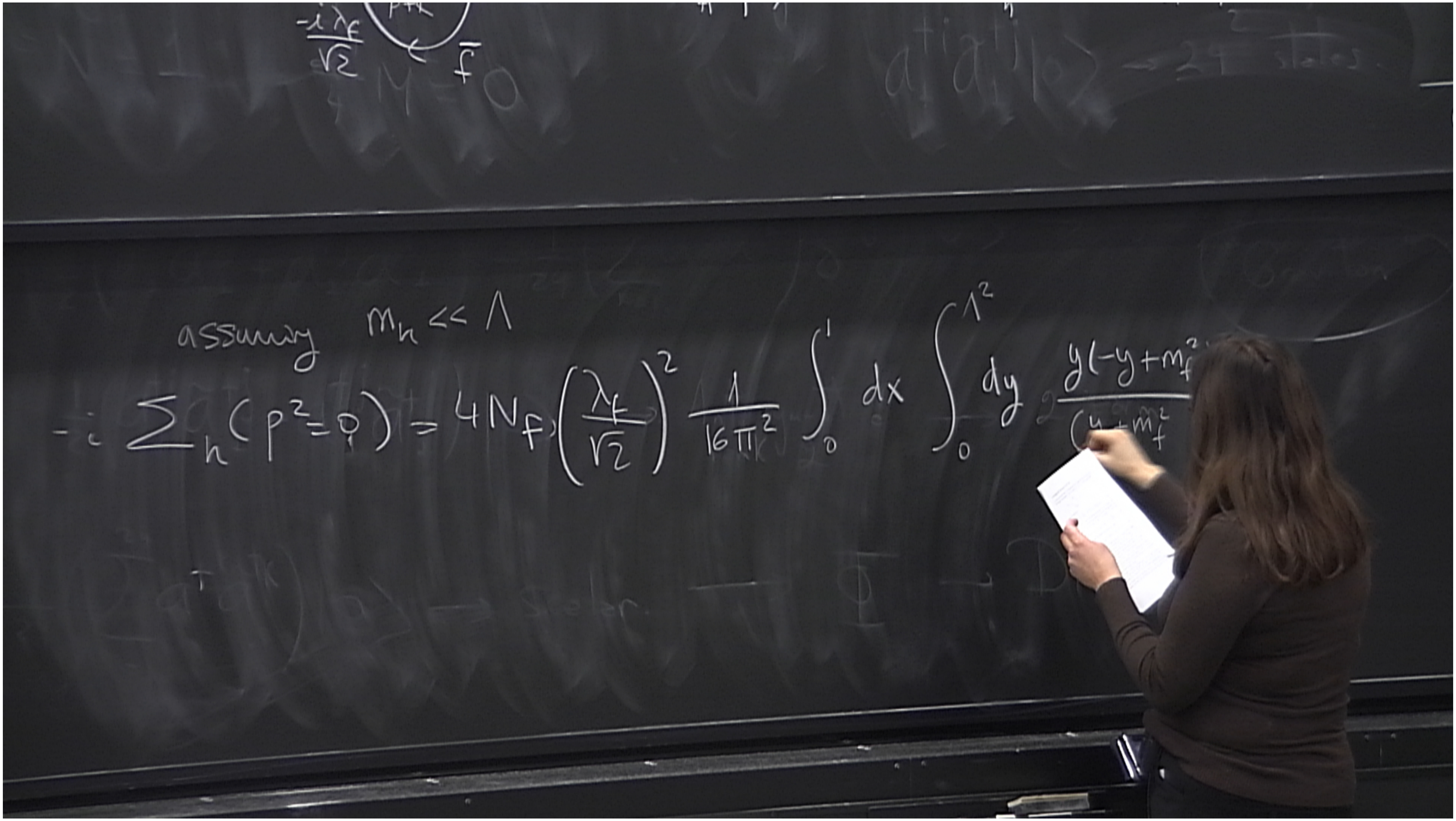

$-i\Sigma_H = N_f \int \frac{d^4k}{(2\pi)^4} (-)\, \mathrm{Tr}\Big[\left(\frac{i\lambda_f}{\sqrt{2}}\right) \frac{i}{\not{k} - m_f} \left(\frac{i\lambda_f}{\sqrt{2}}\right)$
$m_h^2 = -i\, \Sigma_H (p^2 = m_h^2)$

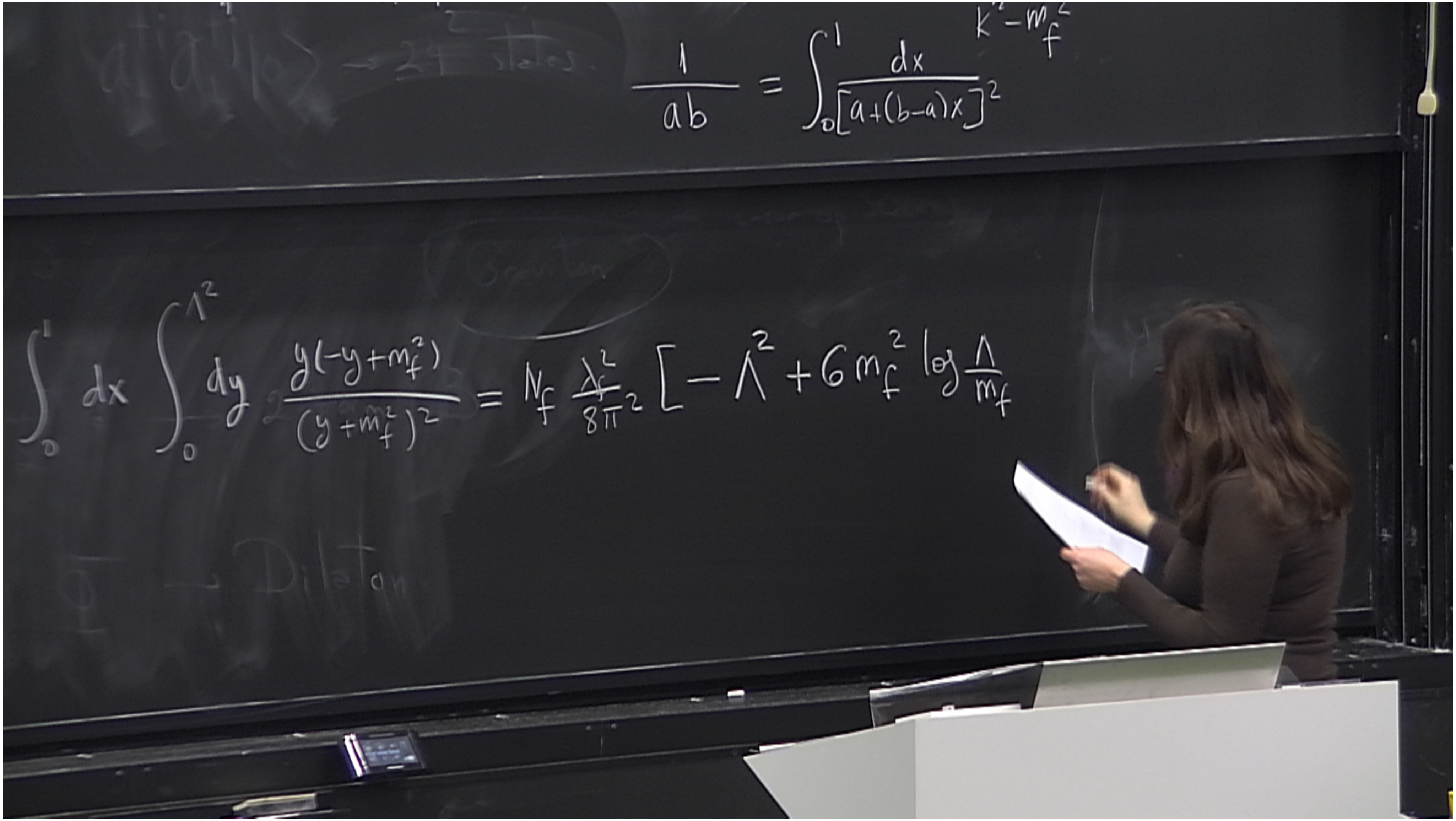
$$-i\Sigma_H = N_f \int \frac{d^4k}{(2\pi)^4} (-) \mathrm{Tr}\left[\left(\frac{i\lambda_f}{\sqrt{2}}\right)\frac{i}{\not{k}-m_f}\left(\frac{i\lambda_f}{\sqrt{2}}\right)\frac{i}{\not{p}+\not{k}-m_f}\right]$$

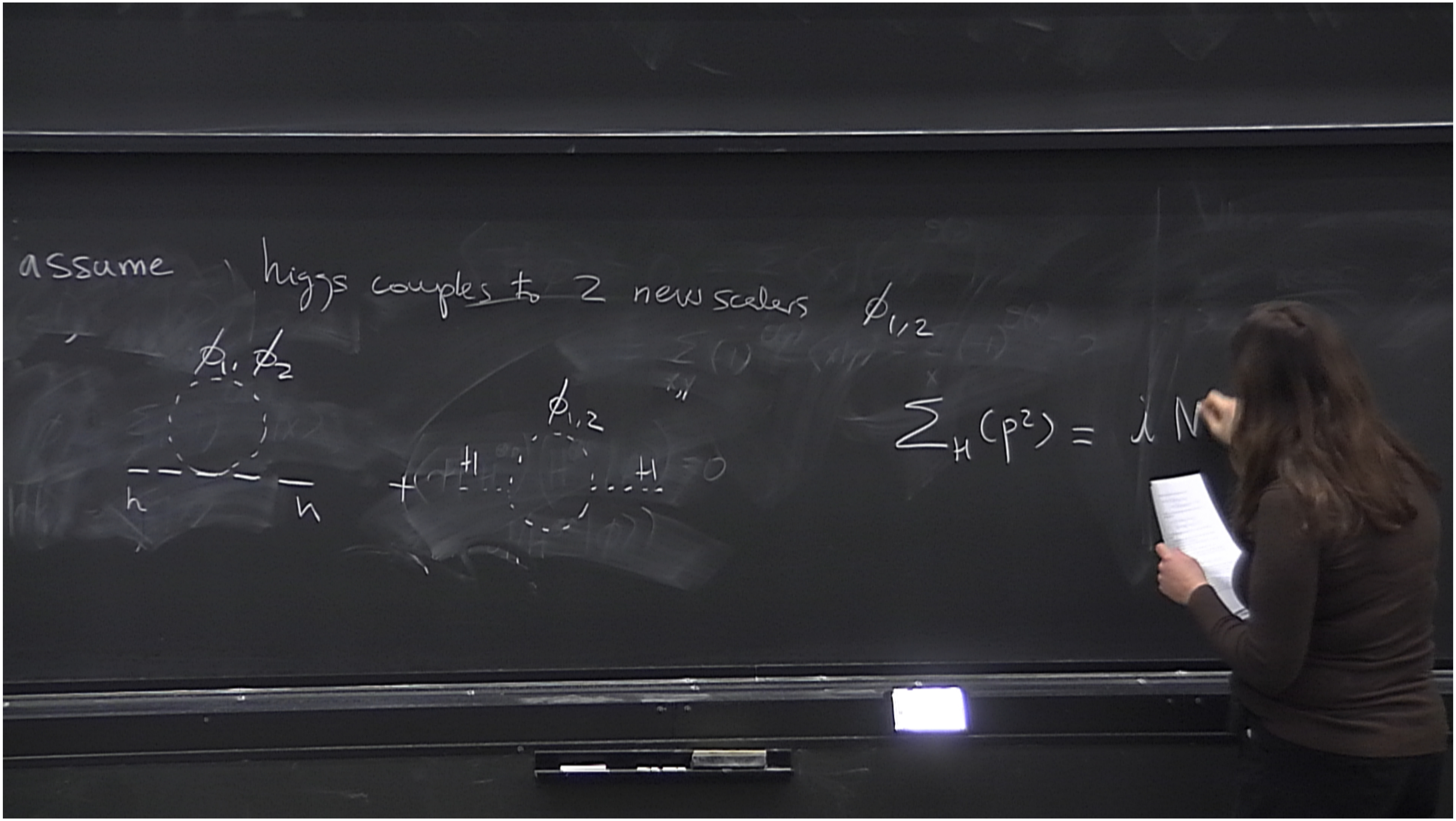
$$m_h^2 = -i\,\Sigma_H(p^2=m_h^2)$$

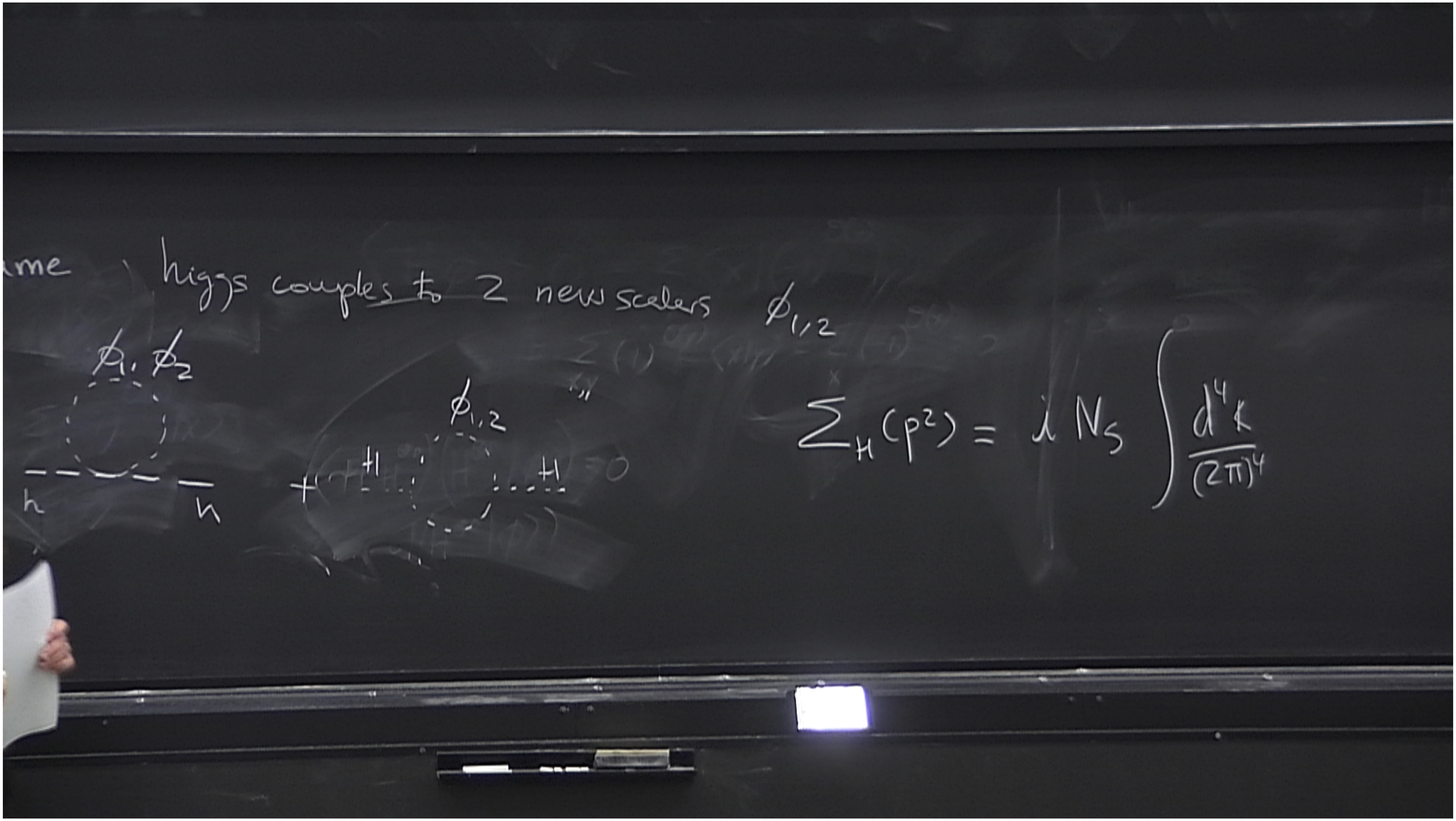

Quadratic divergences for Higgs sector
$-i\Sigma_H = N_f$
f
k
p
H
H
$= -i\Sigma_H(p^2)$
$p+k$
$\frac{-i\lambda_f}{\sqrt{2}}$
$\bar{f}$
$\delta m_h^2 = -i\Sigma_H(p^2 = m_h^2)$

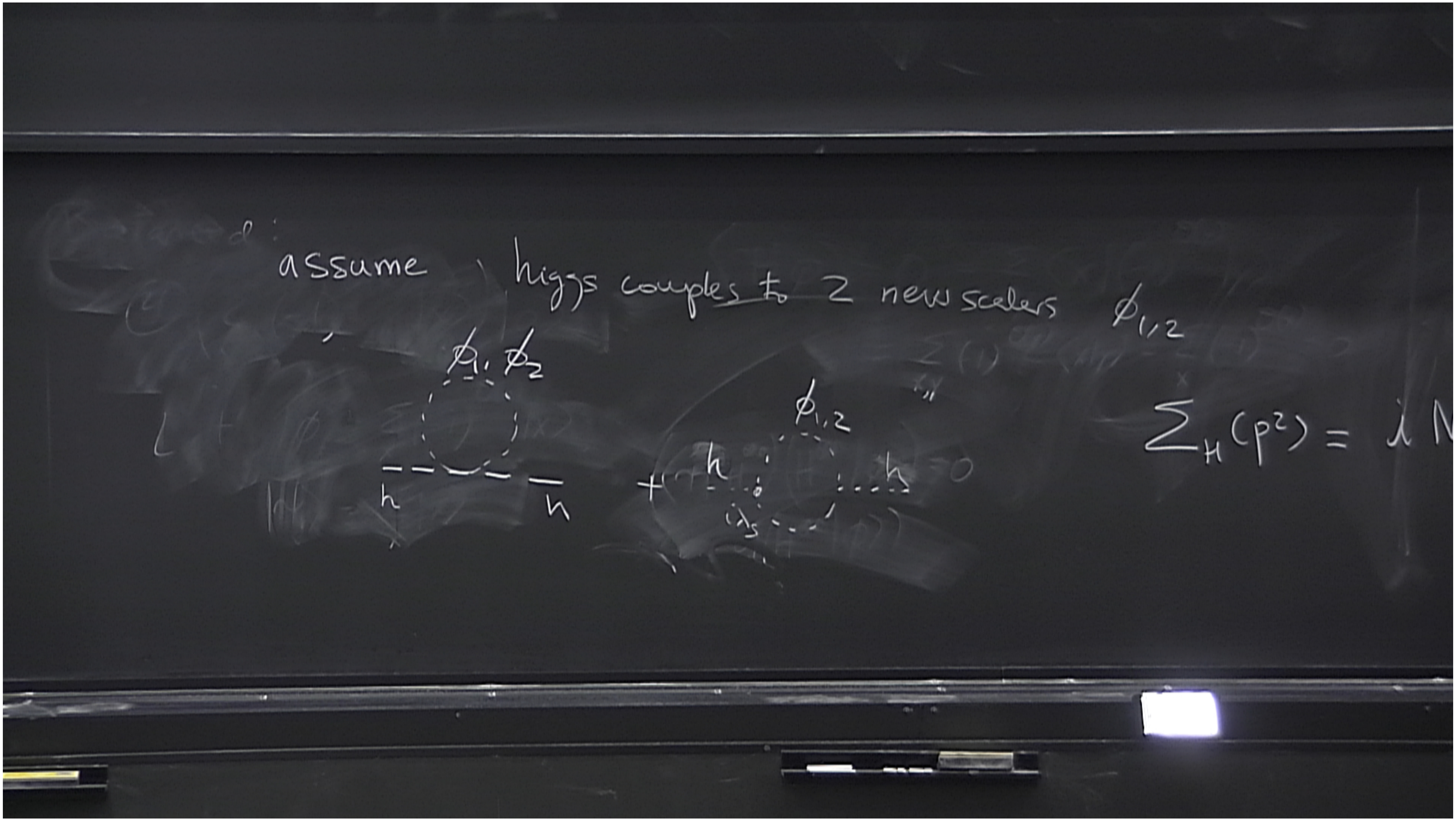

$-i\,\Sigma_H(p^2=m_h^2)$
$\frac{\not{k}+m_f}{k^2-m_f^2}$
$\frac{1}{ab}=\int_0^1\frac{dx}{[a+(b-a)x]^2}$


assuming $m_h << \Lambda$
$-i \Sigma_h (p^2=0) = 4N_f \left(\frac{\lambda_f}{\sqrt{2}}\right)^2 \frac{1}{16\pi^2} \int_0^1 dx \int_0^{\Lambda^2} dy$


$\frac{1}{ab} = \int_0^1 \frac{dx}{[a+(b-a)x]^2}$
$\int_0^1 dx \int_0^{\Lambda^2} dy \frac{y(-y+m_f^2)}{(y+m_f^2)^2} = N_f \frac{\lambda_f^2}{8\pi^2} [-\Lambda^2 + 6 m_f^2 \log \frac{\Lambda}{m_f}$


assume higgs couples to 2 new scalers $\phi_{1,2}$
ϕ_1, ϕ_2
h
h
$\phi_{1,2}$
H
H
$\Sigma_H(p^2) = i\,N$


me
higgs couples to 2 new scalers $\phi_{1,2}$
ϕ_1, ϕ_2
h
h
$\phi_{1,2}$
$\Sigma_H(p^2) = i N_S \int \frac{d^4k}{(2\pi)^4}$


assume higgs couples to 2 new scalers $\phi_{1,2}$
ϕ_1, ϕ_2
h
h
$\phi_{1,2}$
h
h
$\Sigma_H(p^2) = i$

$\phi_{1,2}$

$$\Sigma_H(p^2) = i N_S \int \frac{d^4k}{(2\pi)^4} (i\lambda_S) \left[\frac{1}{k^2-m_1^2} + \frac{i}{k^2-m_2^2} \right]$$

scalars $\phi_{1,2}$

$$\Sigma_H(p^2) = i N_S \int \frac{d^4k}{(2\pi)^4} (i\lambda_S) \left[\frac{i}{k^2-m_1^2} + \frac{i}{k^2-m_2^2} \right] +$$

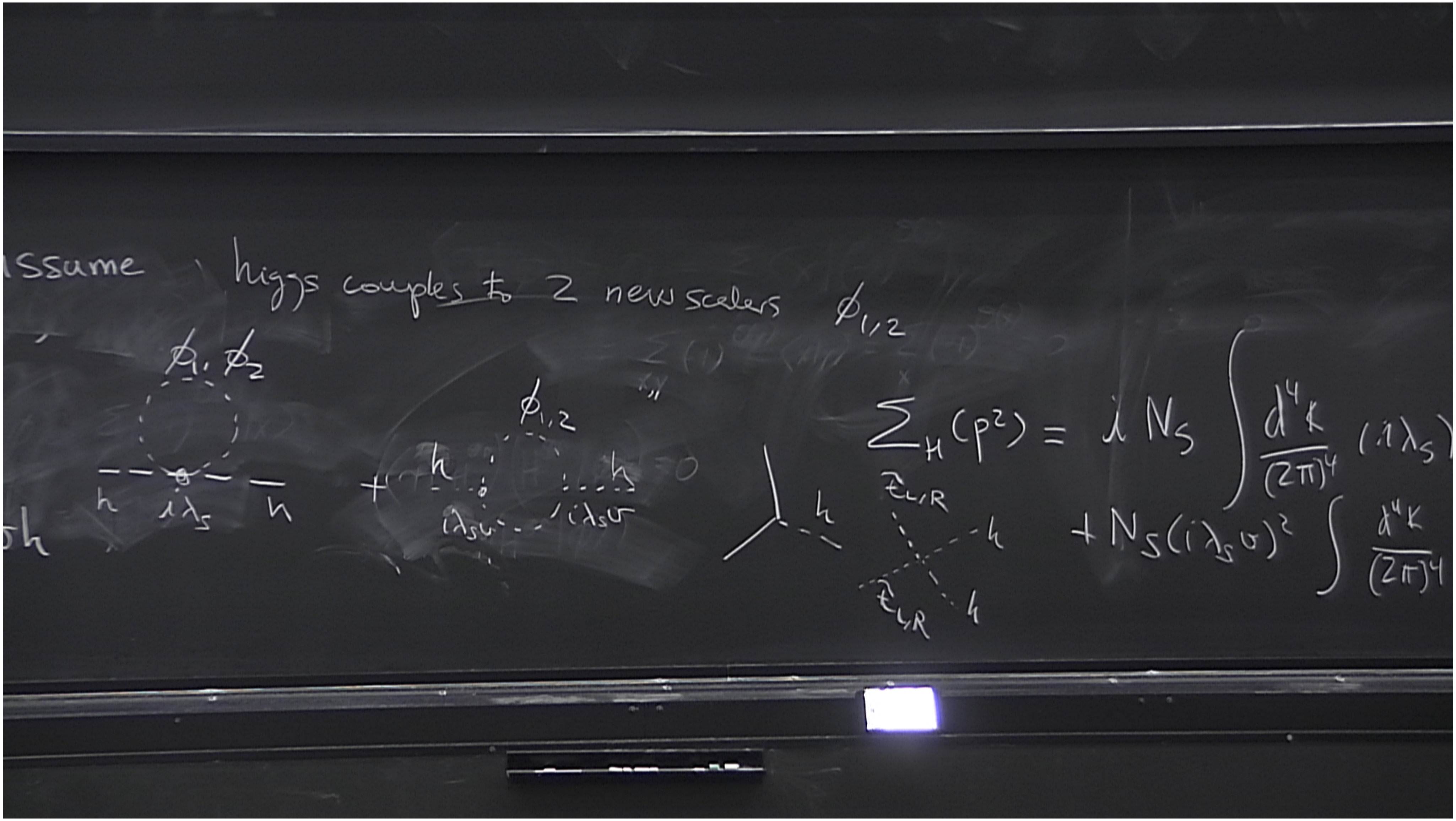
$$+ N_S (i\lambda_S v)^2 \int \frac{d^4k}{(2\pi)^4} \left[\frac{i}{k^2-m_1^2} \cdot \frac{i}{(k+p)^2-m_1^2} \right.$$

ers $\phi_{1,2}$

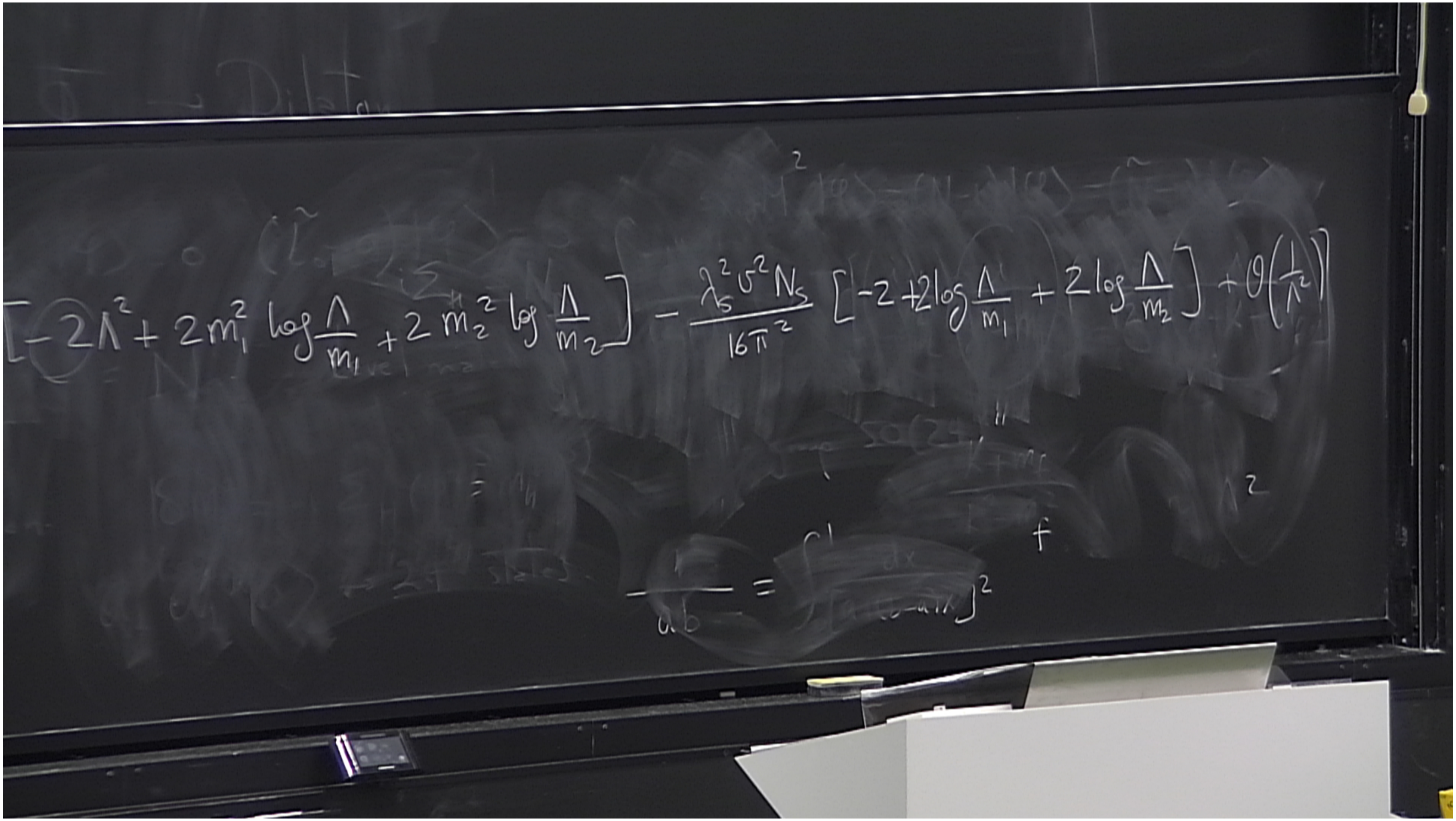
$$\sim \Lambda^2$$

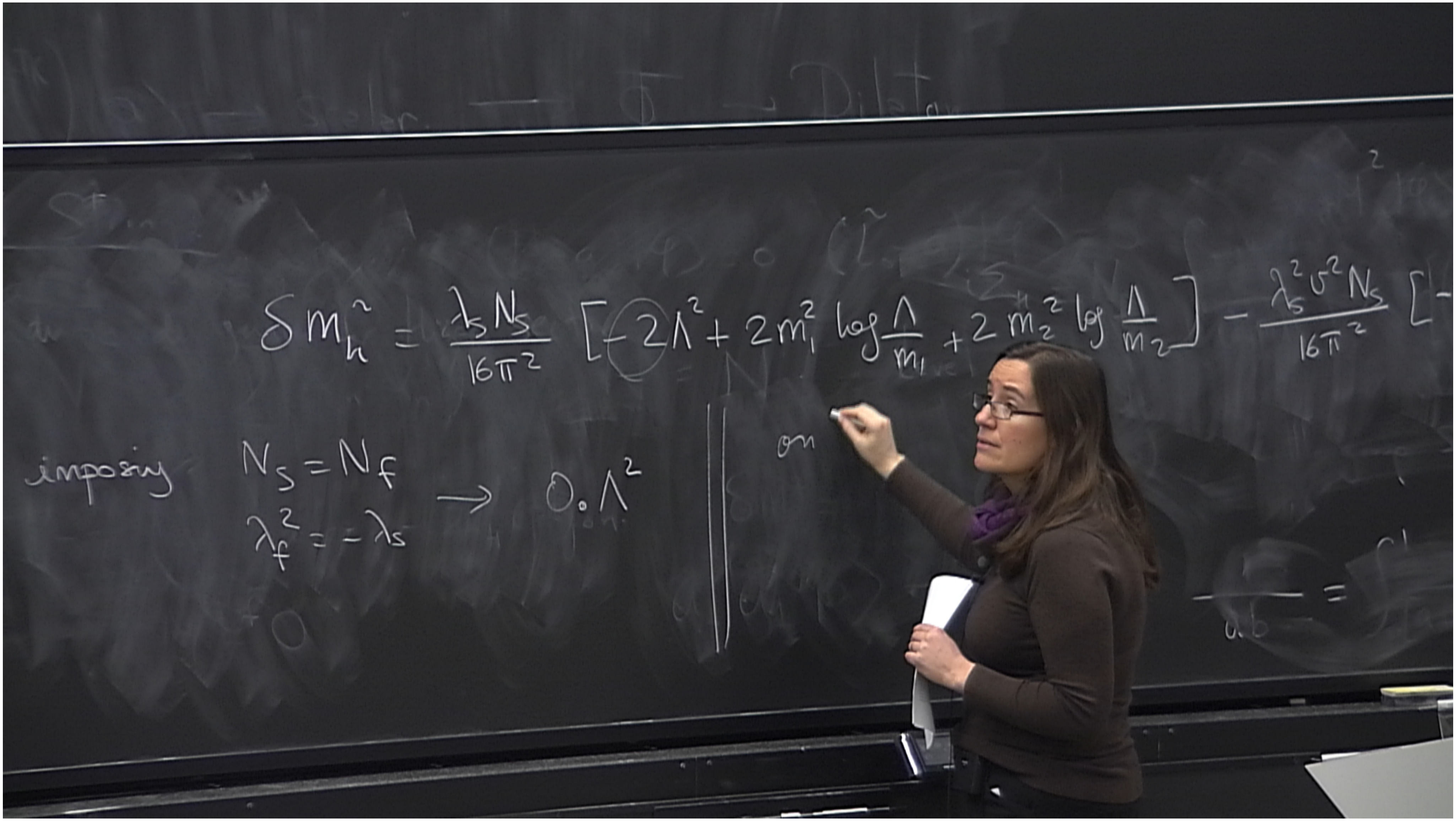
$$\Sigma_H(p^2) = i N_S \int \frac{d^4k}{(2\pi)^4} (i\lambda_S) \left[\frac{1}{k^2-m_1^2} + \frac{i}{k^2-m_2^2} \right] +$$

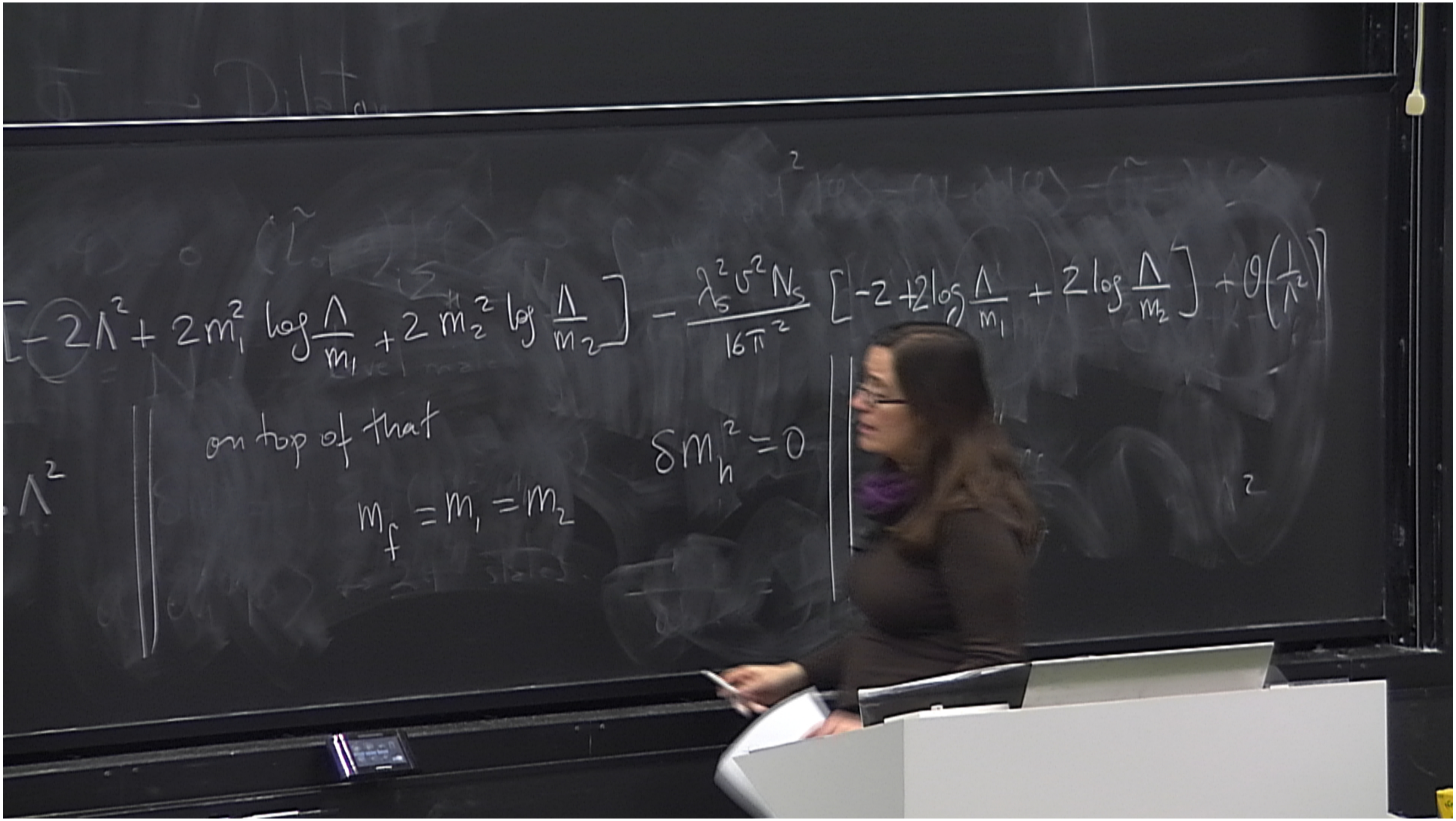
$$+ N_S (i\lambda_S v)^2 \int \frac{d^4k}{(2\pi)^4} \left[\frac{i}{k^2-m_1^2} \cdot \frac{i}{(k+p)^2-m_1^2} + (1 \to 2) \right]$$

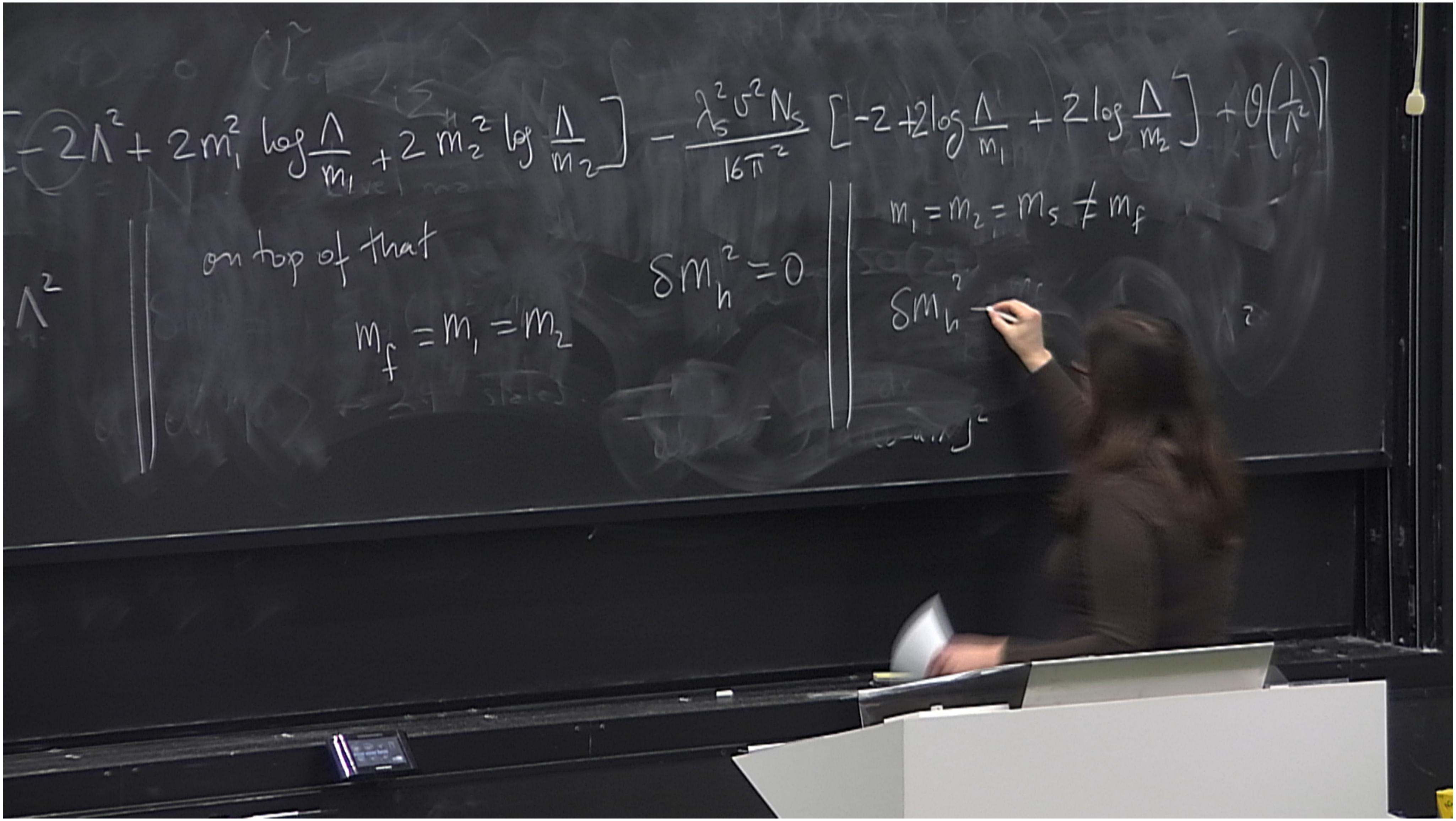

ssume
higgs couples to 2 new scalers $\phi_{1,2}$
ϕ_1, ϕ_2
h $i\lambda_S$ h
$\phi_{1,2}$
h h
$i\lambda_S v$ $i\lambda_S v$
$\tilde{t}_{L,R}$ h $\tilde{t}_{L,R}$ h
$\Sigma_H(p^2) = i N_S \int \frac{d^4k}{(2\pi)^4} (i\lambda_S)$
$+ N_S (i\lambda_S v)^2 \int \frac{d^4k}{(2\pi)^4}$

$$\delta m_h^2 = \frac{\lambda_S N_S}{16\pi^2}\left[-2\Lambda^2 + 2m_1^2 \log\frac{\Lambda}{m_1} + 2m_2^2 \log\frac{\Lambda}{m_2}\right] - \frac{\lambda_S^2 v^2 N_S}{16\pi^2}\left[-2 + \log \Lambda\right.$$


$[-2\Lambda^2 + 2m_1^2 \log\frac{\Lambda}{m_1} + 2m_2^2 \log\frac{\Lambda}{m_2}] - \frac{\lambda_s^2 v^2 N_s}{16\pi^2}[-2 + 2\log\frac{\Lambda}{m_1} + 2\log\frac{\Lambda}{m_2}] + \mathcal{O}(\frac{1}{\Lambda^2})]$


$\delta m_h^2 = \frac{\lambda_s N_s}{16\pi^2}\left[-2\Lambda^2 + 2m_1^2 \log\frac{\Lambda}{m_1} + 2m_2^2 \log\frac{\Lambda}{m_2}\right] - \frac{\lambda_s^2 v^2 N_s}{16\pi^2}\left[-\right.$
imposing $N_S = N_f$ $\longrightarrow$ $0\cdot\Lambda^2$
$\lambda_f^2 = -\lambda_s$
on


[−2Λ² + 2m₁² log Λ/m₁ + 2m₂² log Λ/m₂] − λ_s²v²N_s/16π² [−2 + 2 log Λ/m₁ + 2 log Λ/m₂] + O(1/Λ²)
on top of that
δm_h² = 0
m_f = m₁ = m₂


$-2\Lambda^2 + 2m_1^2 \log\frac{\Lambda}{m_1} + 2m_2^2 \log\frac{\Lambda}{m_2}\Big] - \frac{\lambda_s^2 v^2 N_s}{16\pi^2}\Big[-2 + 2\log\frac{\Lambda}{m_1} + 2\log\frac{\Lambda}{m_2}\Big] + \mathcal{O}\left(\frac{1}{\Lambda^2}\right)$
on top of that
$m_f = m_1 = m_2$
$\delta m_h^2 = 0$
$m_1 = m_2 = m_s \neq m_f$
δm_h^2

Λ^2

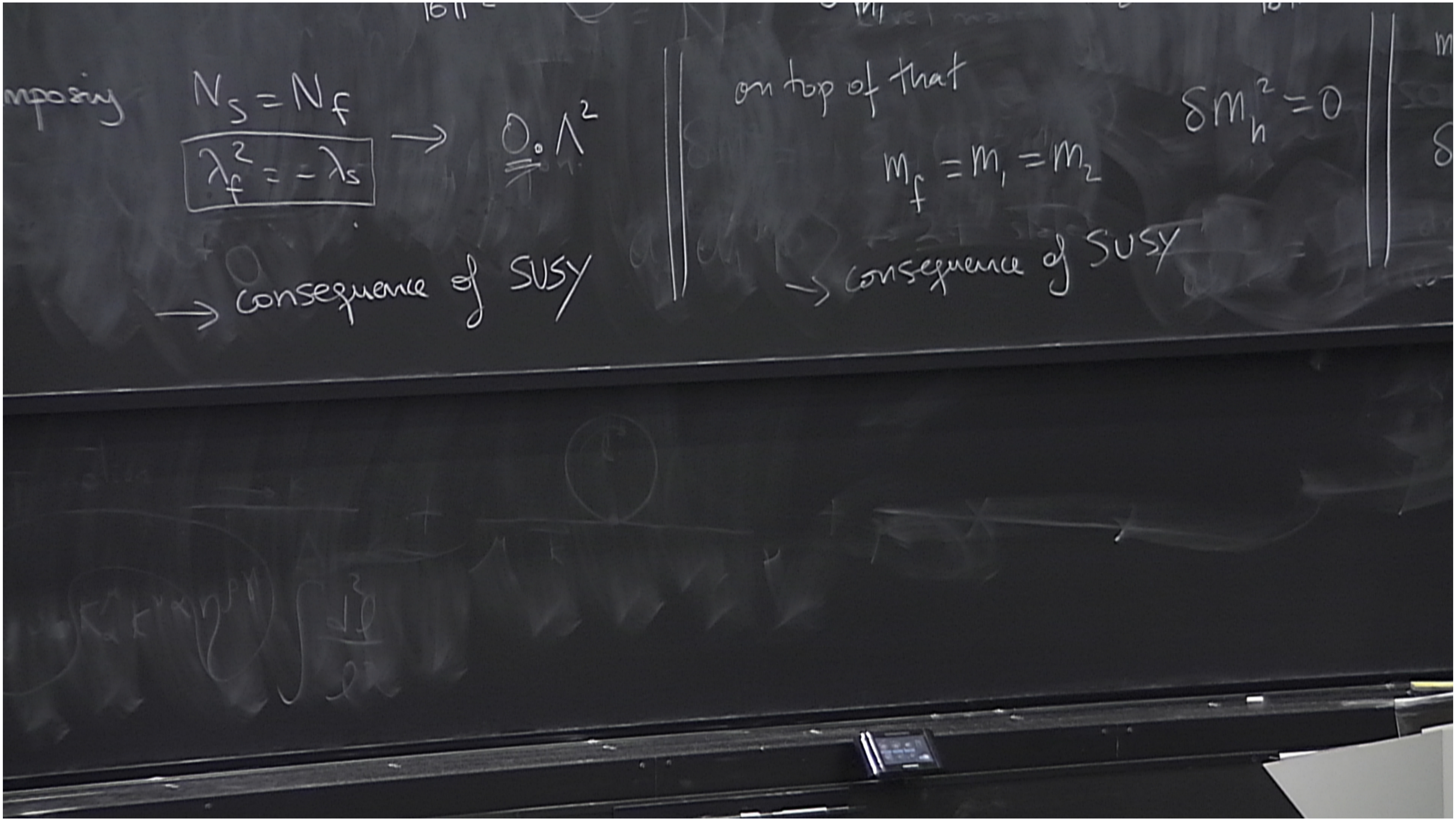
on top of that

$$m_f = m_1 = m_2$$

$$\delta m_h^2 = 0$$

$$m_1 = m_2 = m_S \neq m_f$$

$$\delta m_h^2 = \frac{\lambda_f^2 N_f}{4\pi^2}\left[(m_f^2 - m_S^2)\log\frac{\Lambda}{m_S} + 3 m_f^2 \log\left(\frac{m_S}{m_f}\right)\right]$$


mposing $N_S = N_f$
$\boxed{\lambda_f^2 = -\lambda_s}$ → $0 \cdot \Lambda^2$
→ consequence of SUSY
on top of that
$\delta m_h^2 = 0$
$m_f = m_1 = m_2$
→ consequence of SUSY

$$[Q, P_\mu] = 0$$

$$[Q, P^2] = 0$$

same supermultiplet B, F

fermion

Same supermultiplet B, F

$$Q|B\rangle = |F\rangle$$

$$\begin{cases} P^2 Q|B\rangle = Q P^2 |B\rangle = Q m_B^2 |B\rangle = m_B^2 \underbrace{Q|B\rangle} = m_B^2 |F\rangle \\ P^2 Q|B\rangle = P^2 |F\rangle = m_F^2 |F\rangle \end{cases}$$

fermion

same supermultiplet B, F

$$Q|B\rangle = |F\rangle$$

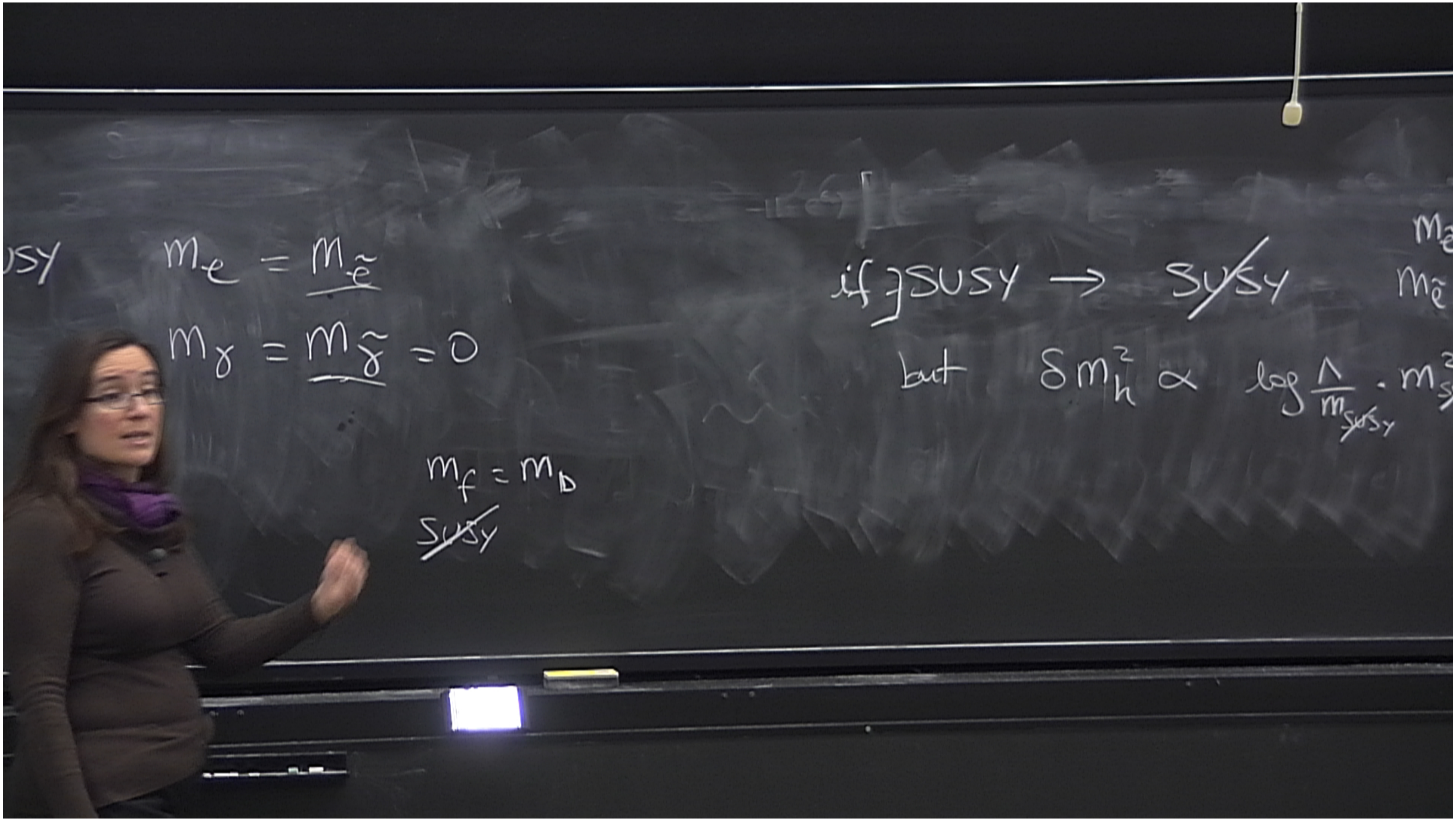
$$\begin{cases} P^2 Q|B\rangle = Q P^2 |B\rangle = Q m_B^2 |B\rangle = m_B^2 Q|B\rangle = \boxed{m_B^2 |F\rangle} \\ P^2 Q|B\rangle = P^2 |F\rangle = \boxed{m_F^2 |F\rangle} \end{cases}$$

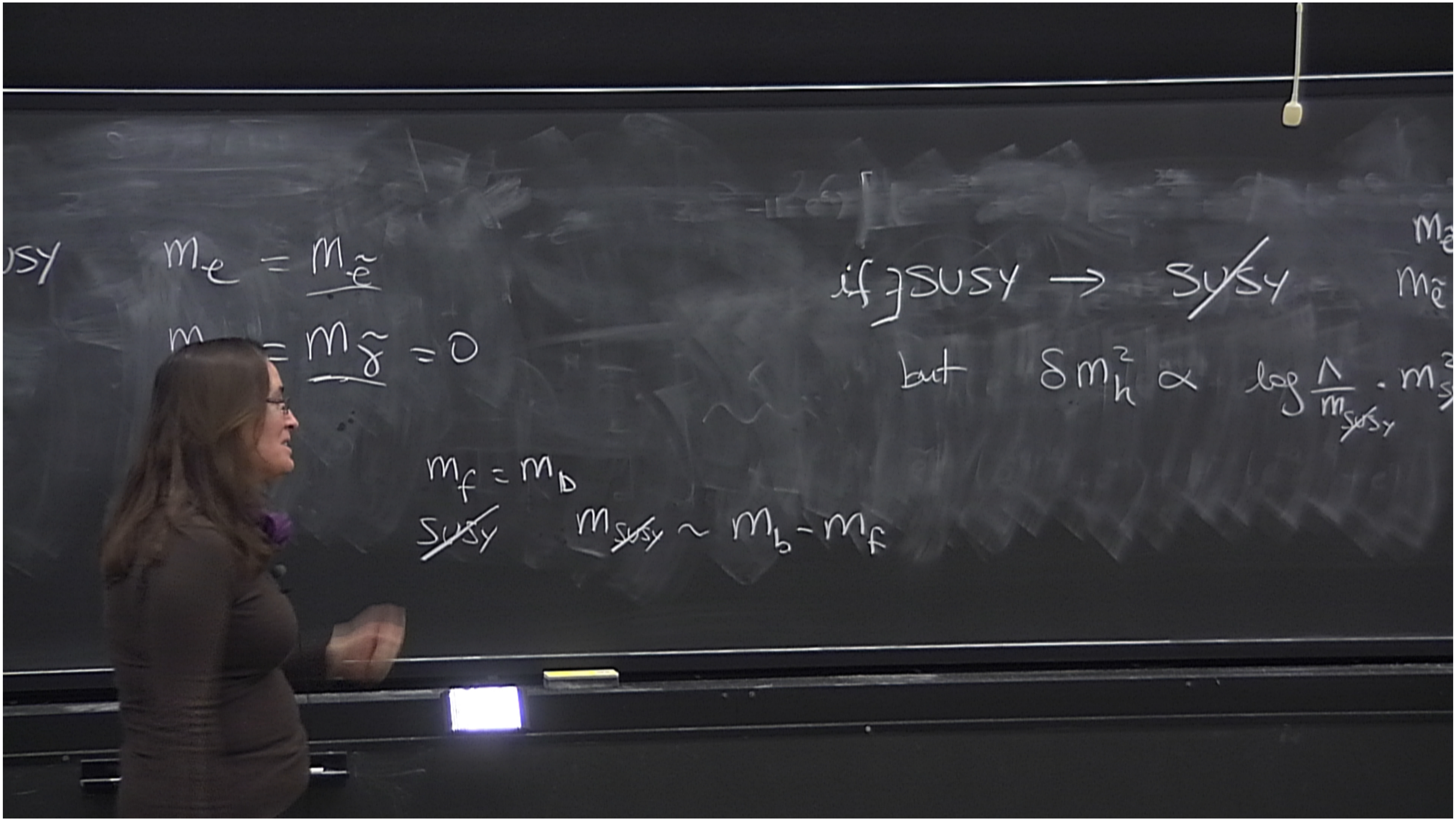
$$m_F = m_B$$

$\tilde{\gamma} = 0$

if $\exists$ SUSY $\rightarrow$ $\cancel{\text{SUSY}}$ $\quad m_{\tilde{e}} \gg m_e$

but $\delta m_h^2 \propto \log \dfrac{\Lambda}{m_{\cancel{SUSY}}} \cdot m_{\cancel{SUSY}}$


SUSY
$m_e = m_{\tilde{e}}$
$m_\gamma = m_{\tilde{\gamma}} = 0$
$m_f = m_b$
~~SUSY~~
if $\exists$ SUSY $\rightarrow$ ~~SUSY~~
but $\delta m_h^2 \propto \log \frac{\Lambda}{m_{\cancel{SUSY}}} \cdot m_s^2$
$m_{\tilde{e}}$



$m_e = m_{\tilde{e}}$
$= m_{\tilde{\gamma}} = 0$
if ∃ SUSY → $\cancel{\text{SUSY}}$
but $\delta m_h^2 \propto \log \frac{\Lambda}{m_{\cancel{SUSY}}} \cdot m$
$m_f = m_b$
$\cancel{\text{SUSY}}$ $m_{\cancel{SUSY}} \sim m_b - m_f$