Title: Beyond Standard Model-7

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Abstract:

$$W_{MSSM} = \mu H_u \cdot H_d + y_u Q \cdot H_u U^c - y_d Q \cdot H_d D^c - y_e L \cdot H_d E^c$$

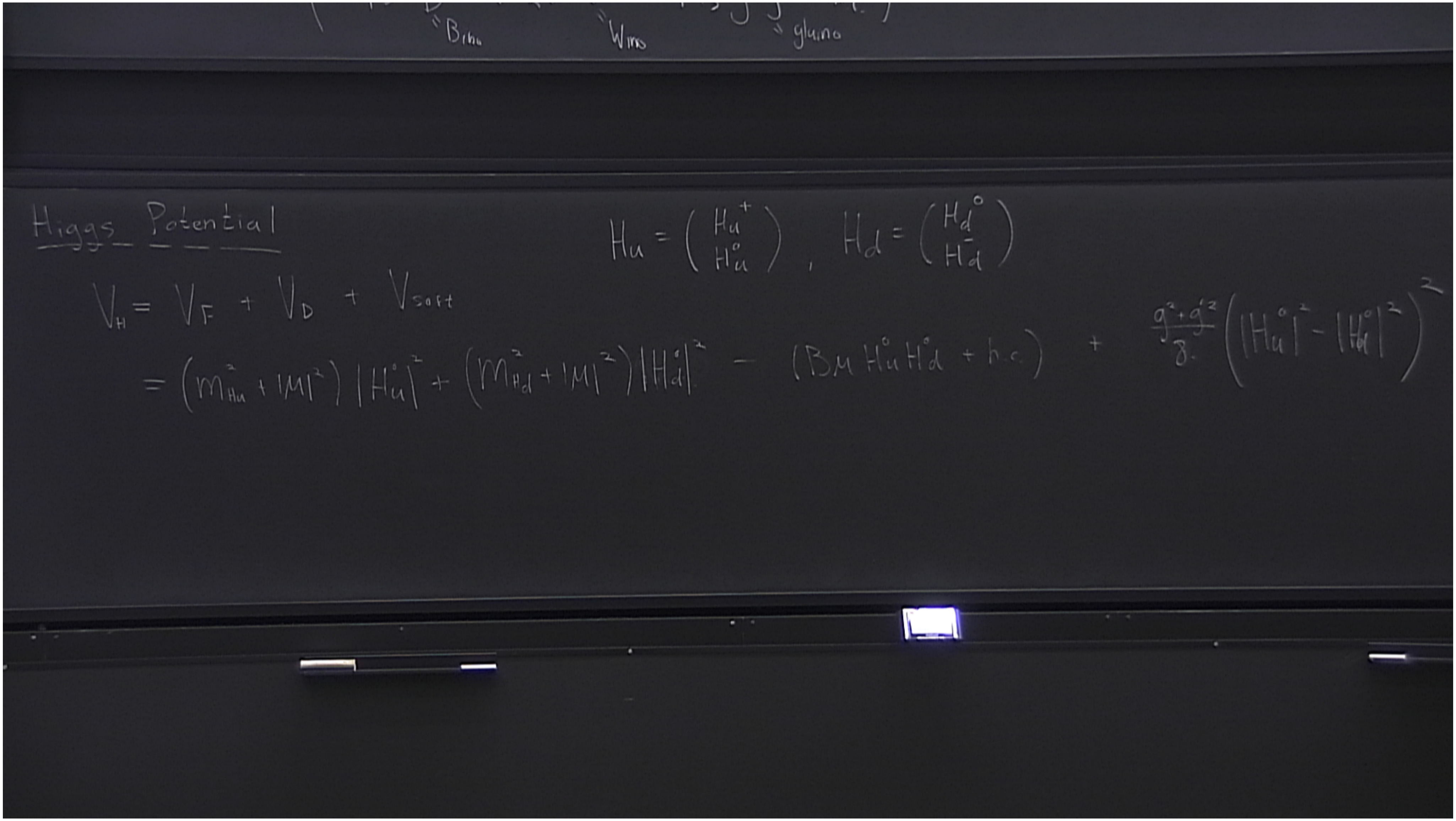
$$-\mathcal{L}_{soft} = m_{H_u}^2 |H_u|^2 + m_{H_d}^2 |H_d|^2 - (B\mu \, H_u \cdot H_d + h.c.)$$

$$+ m_Q^2 |\tilde{Q}|^2 + \ldots$$

$$+ (y_u A_u \tilde{Q} \cdot H_u \tilde{U}^c + \ldots + h.c.)$$

$$+ \frac{1}{2} \left( M_1 \tilde{B}^0 \tilde{B}^0 + M_2 \tilde{W}^a \tilde{W}^a + M_3 \tilde{g}^r \tilde{g}^r + h.c. \right)$$

($\tilde{B}^0$: Bino, $\tilde{W}^a$: Wino, $\tilde{g}^r$: gluino)


Bino
Wino
gluino
Higgs Potential
$H_u = \begin{pmatrix} H_u^+ \\ H_u^0 \end{pmatrix}, \quad H_d = \begin{pmatrix} H_d^0 \\ H_d^- \end{pmatrix}$
$V_H = V_F + V_D + V_{soft}$
$= (m_{H_u}^2 + |\mu|^2)|H_u^0|^2 + (m_{H_d}^2 + |\mu|^2)|H_d^0|^2 - (B\mu H_u^0 H_d^0 + h.c.) + \frac{g^2+g'^2}{8}(|H_u^0|^2 - |H_d^0|^2)^2$

## Higgs Potential

$$H_u = \begin{pmatrix} H_u^+ \\ H_u^0 \end{pmatrix}, \quad H_d = \begin{pmatrix} H_d^0 \\ H_d^- \end{pmatrix}$$

$$V_H = V_F + V_D + V_{soft}$$

$$= \left(m_{H_u}^2 + |\mu|^2\right)|H_u^0|^2 + \left(m_{H_d}^2 + |\mu|^2\right)|H_d^0|^2 - \left(B\mu H_u^0 H_d^0 + h.c.\right)$$

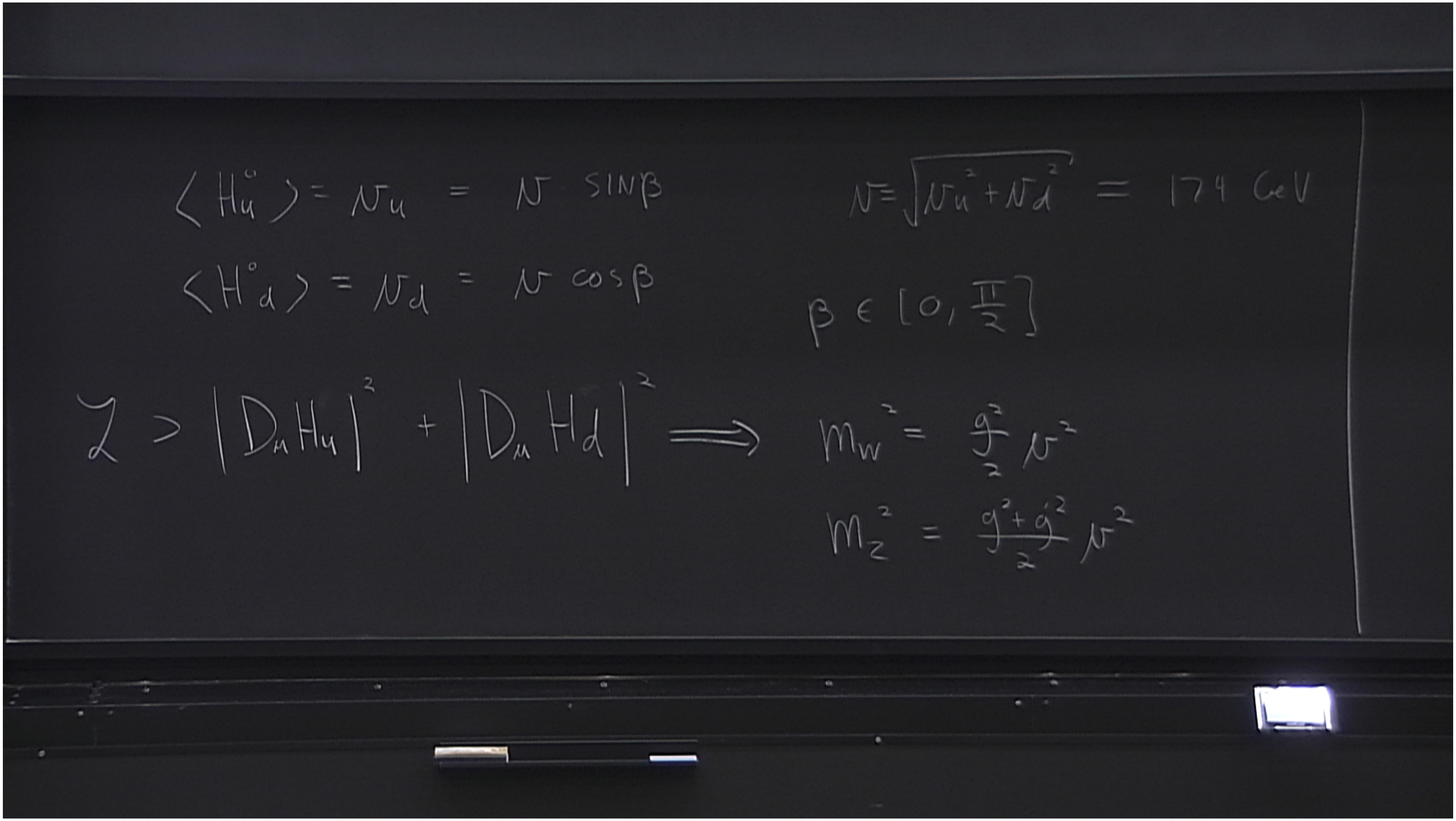
↳ assume $H_u^0, H_d^0$ are real, positive at the min.

$$= \begin{pmatrix} H_u^+ \\ H_u^0 \end{pmatrix}, \quad H_d = \begin{pmatrix} H_d^0 \\ H_d^- \end{pmatrix}$$

$$|H_d^0|^2 - (B\mu H_u^0 H_d^0 + h.c.) + \frac{g^2+g'^2}{8}\left(|H_u^0|^2 - |H_d^0|^2\right)^2$$

D-flat for $|H_u^0| = |H_d^0|$

t the min.



$\langle H_u^0 \rangle = v_u = v \sin\beta$
$v = \sqrt{v_u^2 + v_d^2} = 174$ GeV
$\langle H_d^0 \rangle = v_d = v \cos\beta$
$\beta \in [0, \frac{\pi}{2}]$
$\mathcal{L} \supset |D_\mu H_u|^2 + |D_\mu H_d|^2 \Longrightarrow$
$m_W^2 = \frac{g^2}{2} v^2$
$m_Z^2 = \frac{g^2 + g'^2}{2} v^2$

eV

$H_u^0, H_d^0, H_u^+, H_d^-$

$H_u^0, H_d^0$: one combination ↳ $Z^0$ long.

$H_u^+, H_d^-$: two parts ↳ $W^\pm$ long.

$8 - 3 = 5$ physical "Higgs states"

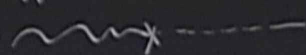
$$\langle H_u^0 \rangle = v_u = v \sin\beta \qquad v \equiv \sqrt{v_u^2 + v_d^2} = 174\ \text{GeV}$$

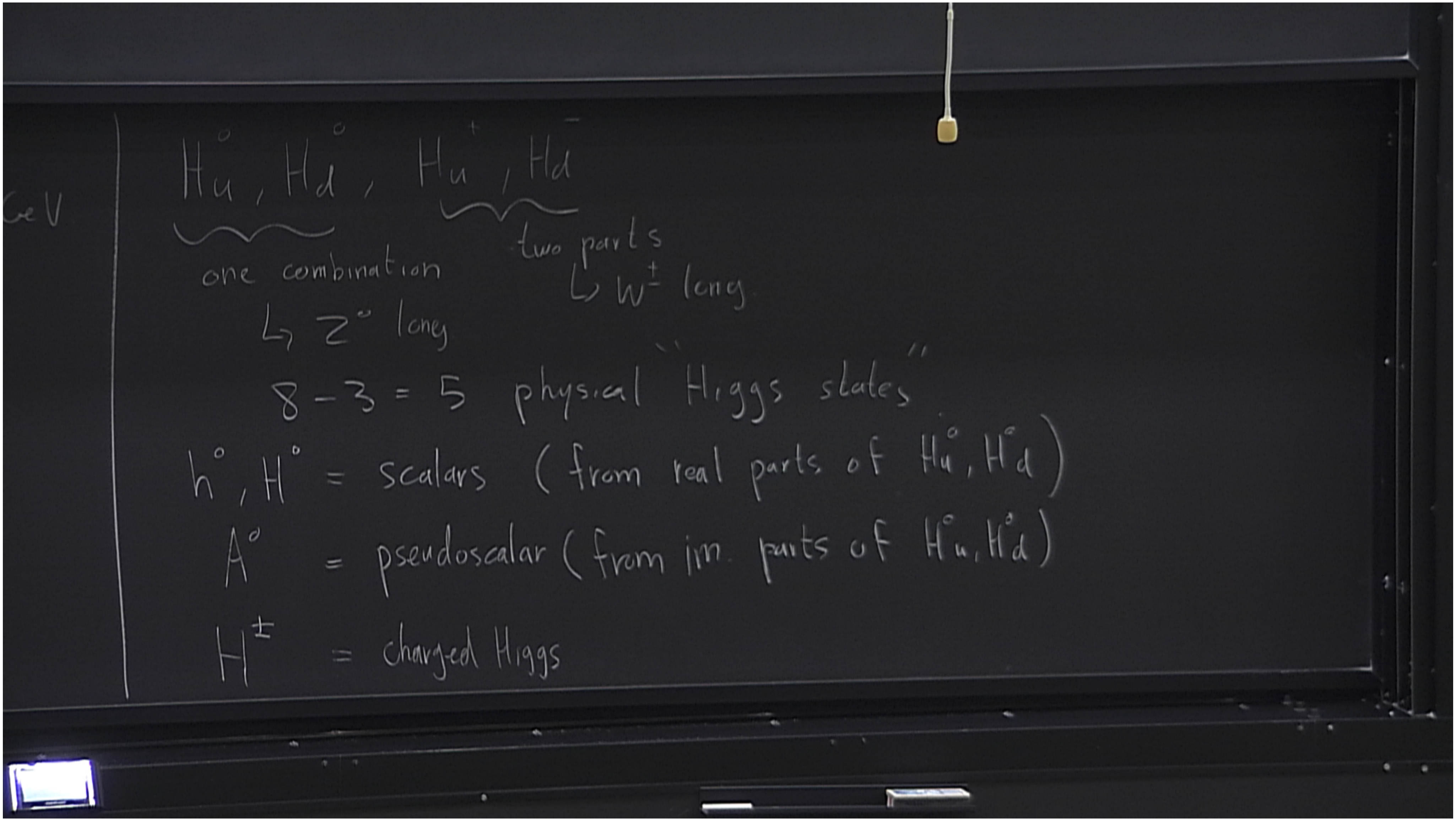
$$\langle H_d^0 \rangle = v_d = v \cos\beta \qquad \beta \in [0, \tfrac{\pi}{2}]$$

$$\mathcal{L} \supset |D_\mu H_u|^2 + |D_\mu H_d|^2 \Longrightarrow m_W^2 = \frac{g^2}{2} v^2$$

$$m_Z^2 = \frac{g^2 + g'^2}{2} v^2$$

$$\frac{g v_u}{2} W_\mu^+ \partial_\mu H_u^- \qquad W^\mu$$




$H_u^0, H_d^0, H_u^+, H_d^-$
one combination
↳ $Z^0$ long
two parts
↳ $W^\pm$ long
8 − 3 = 5 physical "Higgs states"
$h^0, H^0$ = scalars (from real parts of $H_u^0, H_d^0$)
$A^0$ = pseudoscalar (from im. parts of $H_u^0, H_d^0$)
$H^\pm$ = charged Higgs

sFermion: $\tilde{f}_L, \tilde{f}_R$ $\quad \left(\sim \tilde{f}^{c*}\right)$

$$\longrightarrow \begin{pmatrix} m_Q^2 + m_u^2 + D_L & m_u(A_u - \mu\cot\beta) \\ m_u(A_u - \mu\cot\beta) & m_{u^c}^2 + m_u^2 + D_R \end{pmatrix}$$

Ignore LR for first two gens. $\qquad D_{L,R} \sim m_Z^2$

$\tilde{u}_L, \tilde{u}_R, \tilde{d}_L, \tilde{d}_R, \tilde{s}_L, \tilde{s}_R, \tilde{c}_L, \tilde{c}_R$.

Keep mixing for third gen: $\tilde{t}_1, \tilde{t}_2, \tilde{b}_1, \tilde{b}_2, \tilde{\tau}_1, \tilde{\tau}_2$

$$m_i \leq m_{i+1}$$

$M_i < M_{i+1}$

gauginos + higgsinos  gluino: $\tilde{g}$, $M_{\tilde{g}} = M_3$

e.g. $\sqrt{2}\, g\, H_u^{\dagger}\, \tilde{H}_u\, t^a\, \tilde{W}^a \to \sqrt{2}\, g\, v_u\, \tilde{H}_u\, t^a\, \tilde{W}^a \Rightarrow$ gaugino-higgsino mixing ~

$\Rightarrow \tilde{H}_u^0, \tilde{H}_d^0, \tilde{W}^3, \tilde{B}^0$ mix to make four neutralinos, $\chi_i^0$, $|m_i$

$\Rightarrow \tilde{H}_u^+, \tilde{H}_d^-, \tilde{W}^{\pm}$ mix to make two Dirac charginos. $\chi_i^{\pm}$, $|m$

$= M_3$

$\tilde{W}^a \Rightarrow$ gaugino-higgsino mixing $\sim m_W \sin\beta$

four neutralinos, $\chi^0_i$, $|m_i| \leq |m_{i+1}|$, Majorana, $i = 1, 2, 3, 4$

two Dirac charginos: $\chi^\pm_i$, $|m_i| \leq |m_{i+1}|$, $i = 1, 2$

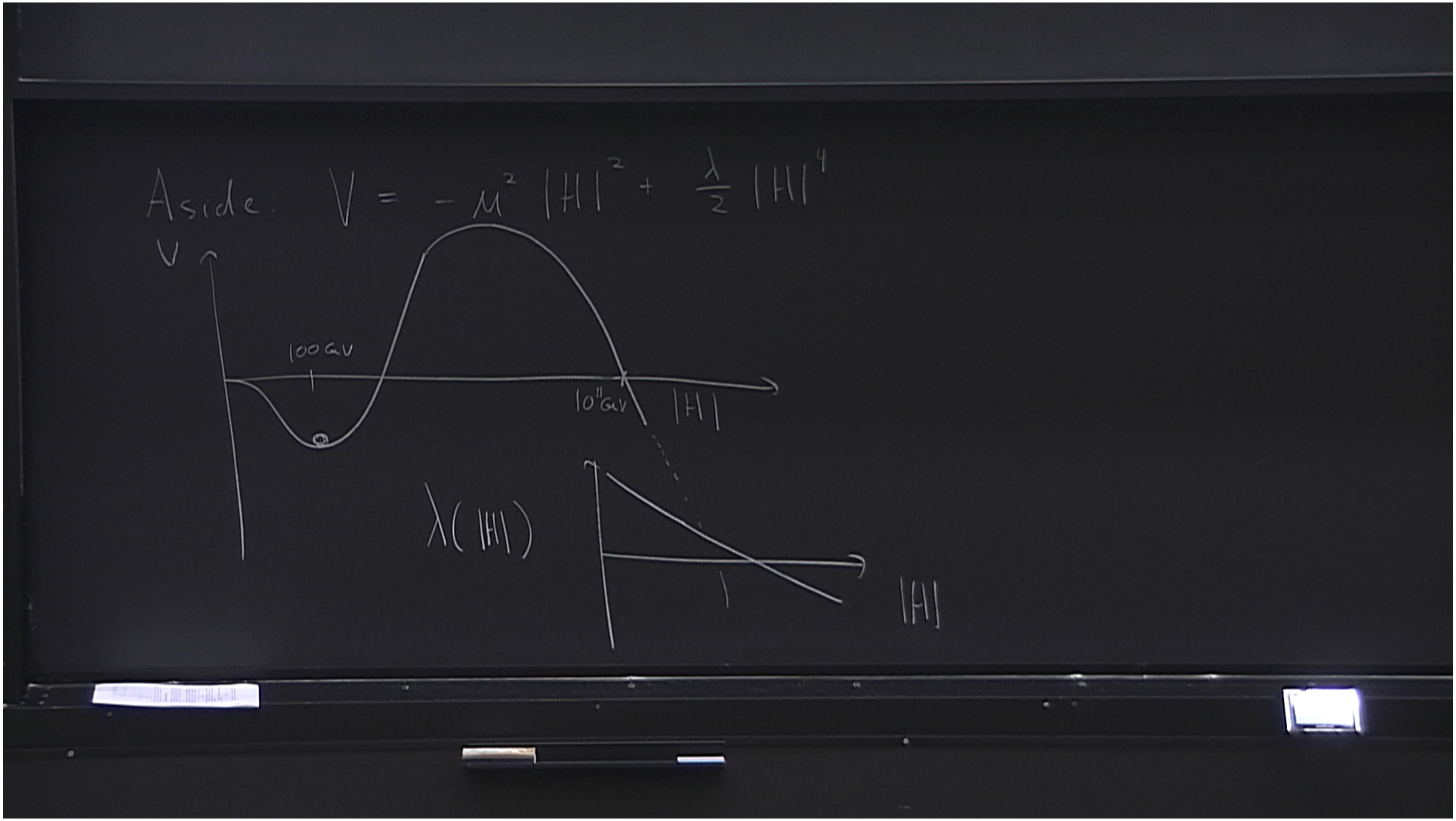
gauginos + higgsinos    gluino: $\tilde{g}$, $M_{\tilde{g}} = M_3$

e.g. $\sqrt{2}\, g\, H_u^\dagger \tilde{H}_u t^a \tilde{W}^a \rightarrow \sqrt{2}\, g\, v_u\, \tilde{H}_u t^a \tilde{W}^a \Rightarrow$ gaugino-higgsino mixing

$\Rightarrow \tilde{H}_u^0, \tilde{H}_d^0, \tilde{W}^3, \tilde{B}^0$ mix to make four neutralinos, $\chi_i^0$, …

$\Rightarrow \tilde{H}_u^+, \tilde{H}_d^-, \tilde{W}^\pm$ mix to make two Dirac charginos. $\chi_i^\pm$, …

$s = \frac{3}{2}$ gravitino $\tilde{G}$



Aside: $V = -\mu^2 |H|^2 + \frac{\lambda}{2} |H|^4$
V
100 GeV
$10^{11}$ GeV
|H|
λ(|H|)
|H|

# Models for SUSY Breaking

$$4\langle 0|H|0\rangle = \langle 0|\left(Q_1\bar{Q}_1 + \bar{Q}_1 Q_1 + Q_2\bar{Q}_2 + \bar{Q}_2 Q_1\right)|0\rangle$$

$$= \|\bar{Q}_1|0\rangle\|^2 + \|Q_1|0\rangle\|^2 + (1\leftrightarrow 2) \geq 0$$

Preserved SUSY: $Q_\alpha|0\rangle = 0 = \langle 0|\bar{Q}^{\dot\alpha}$

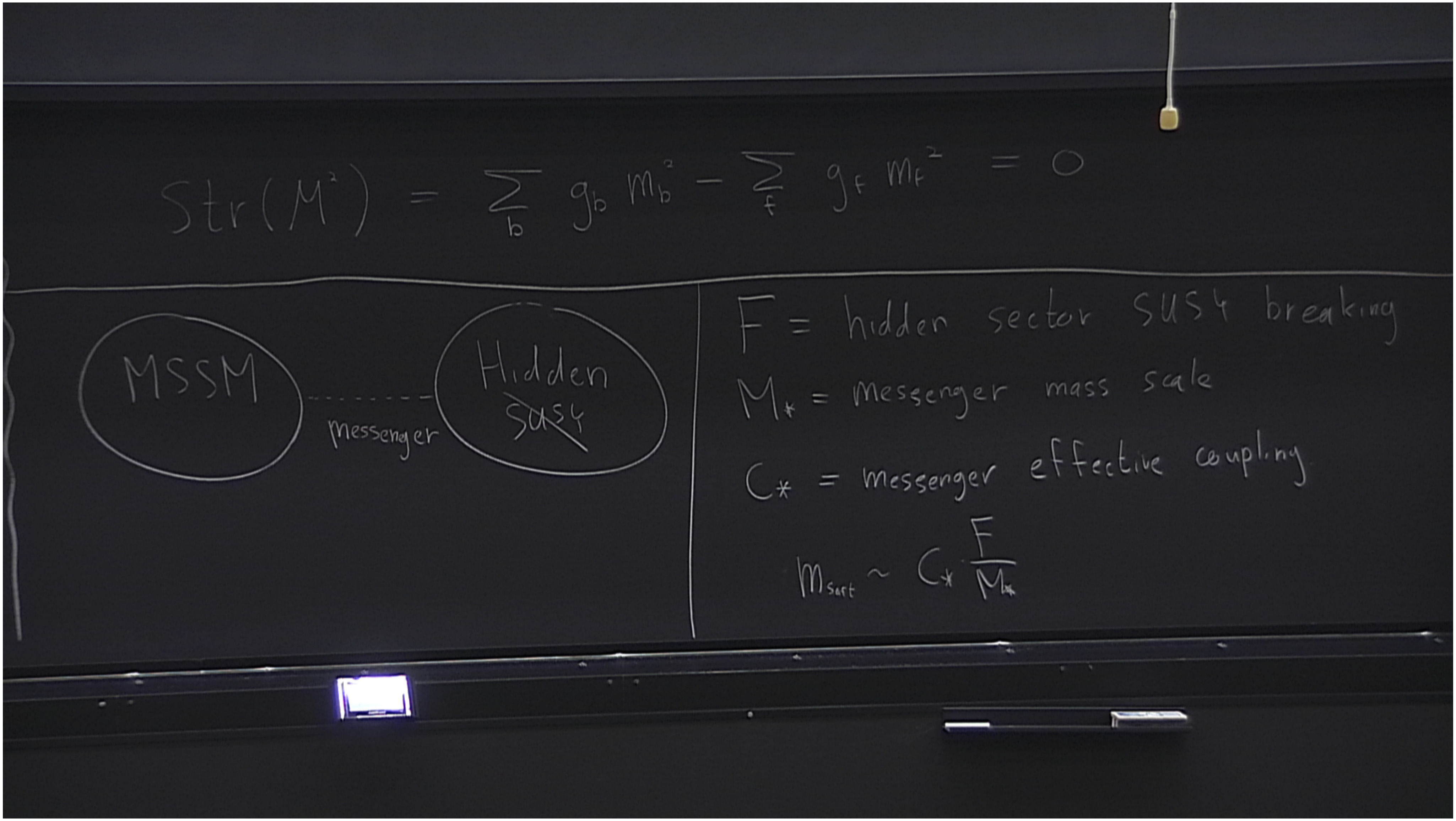
Spontaneously broken: $Q_\alpha|0\rangle \neq 0$, for some $\alpha$ $\rightarrow$ $\langle H\rangle > 0 \sim \langle V_F + V_D\rangle$

$F_i$ or $D^a$ non-zero for SUSY breaking
(spontaneous)

$+ \ \bar{Q} = Q_1 \big) |0\rangle$

$(1 \Leftrightarrow 2) \geq 0$

$\langle H \rangle > 0 \sim \langle V_F + V_D \rangle = \left\langle \sum_i |F_i|^2 + \frac{1}{2} (D^a)^2 \right\rangle$



$Str(M^2) = \sum_b g_b m_b^2 - \sum_f g_f m_f^2 = 0$
MSSM
messenger
Hidden
~~susy~~ SUSY
F = hidden sector SUSY breaking
$M_*$ = messenger mass scale
$C_*$ = messenger effective coupling
$m_{soft} \sim C_* \frac{F}{M_*}$