Title: Beyond Standard Model-9

Date: Feb 27, 2015 09:00 AM

URL: http://pirsa.org/15020049

Abstract:

$$\boxed{\text{LSP}: \ \chi^0_1, \ \tilde{\nu}, \ \tilde{G} \qquad e^{-m/T}}$$

$$-\mathcal{L}_{soft} \supset m^2_{Q_{ij}} \tilde{Q}_i^\dagger Q_j$$

$$m^2_{23} \tilde{Q}_2^\dagger \tilde{Q}_3$$

$$\begin{pmatrix} \tilde{c}_L \\ \tilde{s}_L \end{pmatrix} \qquad \begin{pmatrix} \tilde{t}_L \\ \tilde{b}_L \end{pmatrix}$$

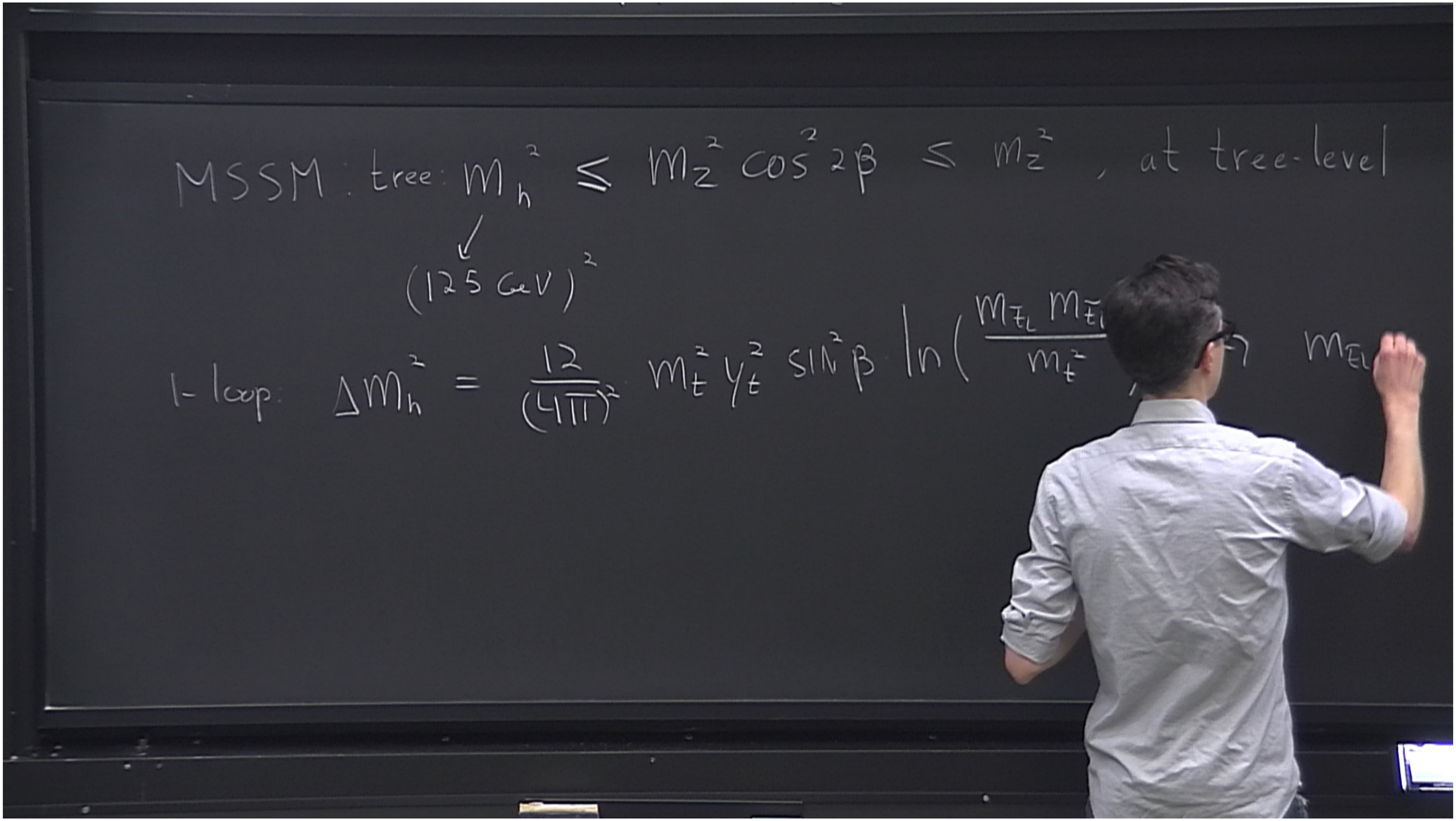
"Anarchic" soft terms $\Rightarrow m_{soft} \gtrsim 100$ TeV

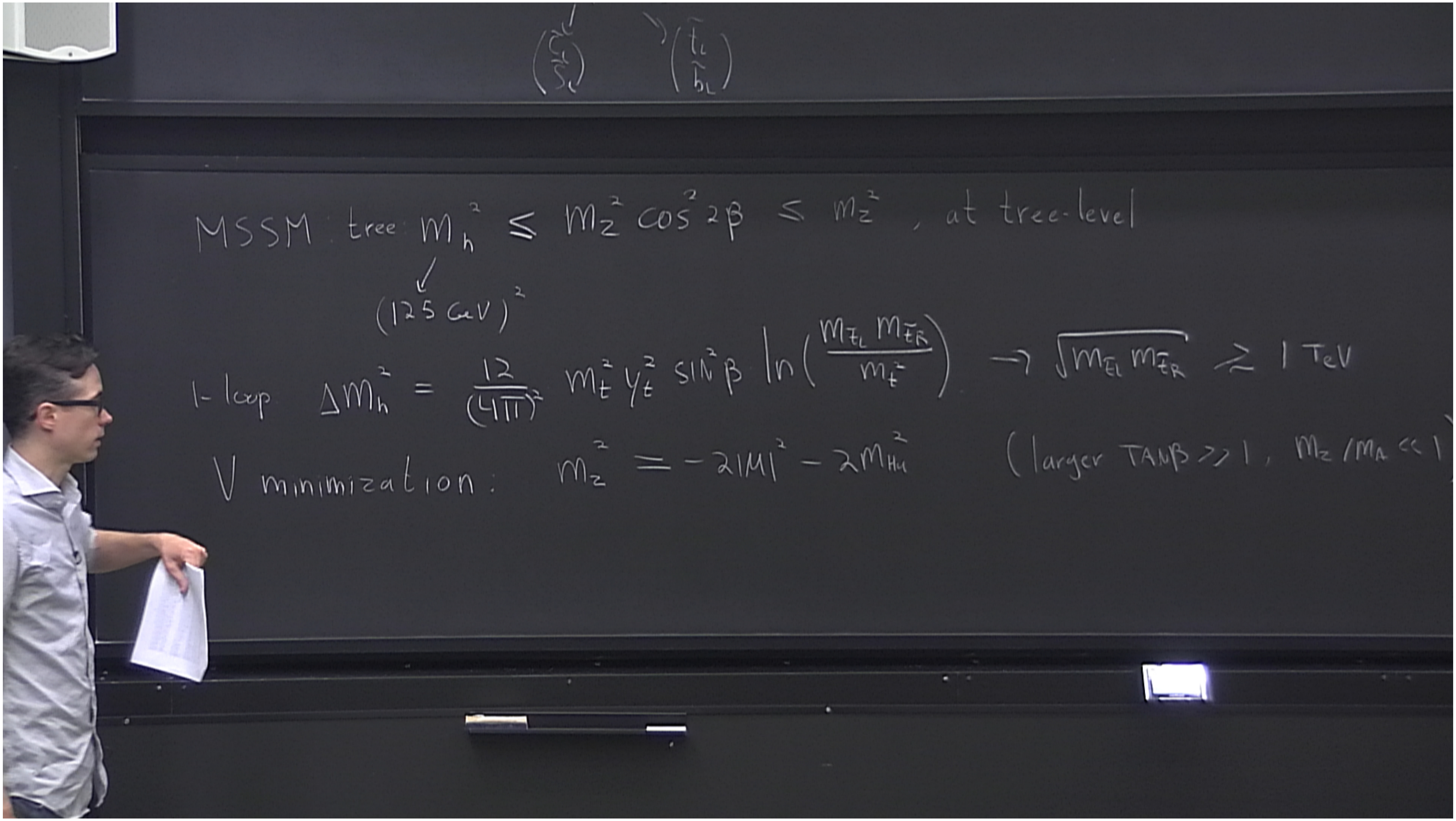
$\sim 10^5$ GeV

$$\Delta m^2 \sim \frac{y^2}{(4\pi)^2} m_{soft}^2$$

"Diagonal" soft terms automatic in gauge + anomaly mediation, not gravity med.

$\begin{pmatrix} \tilde{t}_L \\ \tilde{b}_L \end{pmatrix}$


MSSM: tree: $m_h^2 \leq m_Z^2 \cos^2 2\beta \leq m_Z^2$, at tree-level
$(125\ \mathrm{GeV})^2$
1-loop: $\Delta m_h^2 = \frac{12}{(4\pi)^2} m_t^2 y_t^2 \sin^2\beta \ln\left(\frac{m_{\tilde{t}_L} m_{\tilde{t}}}{m_t^2}\right.$
$m_{\tilde{t}_L}$



$\begin{pmatrix}\tilde{c}_L\\ \tilde{s}_L\end{pmatrix}$ $\begin{pmatrix}\tilde{t}_L\\ \tilde{b}_L\end{pmatrix}$
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V minimization: $m_Z^2 = -2|\mu|^2 - 2m_{H_u}^2$
(larger $\tan\beta \gg 1$, $m_Z/m_A \ll 1$

$$M_{23}\, Q_2\, Q_3$$

$$\begin{pmatrix} \tilde{c}_L \\ \tilde{s}_L \end{pmatrix} \qquad \begin{pmatrix} \tilde{t}_L \\ \tilde{b}_L \end{pmatrix}$$

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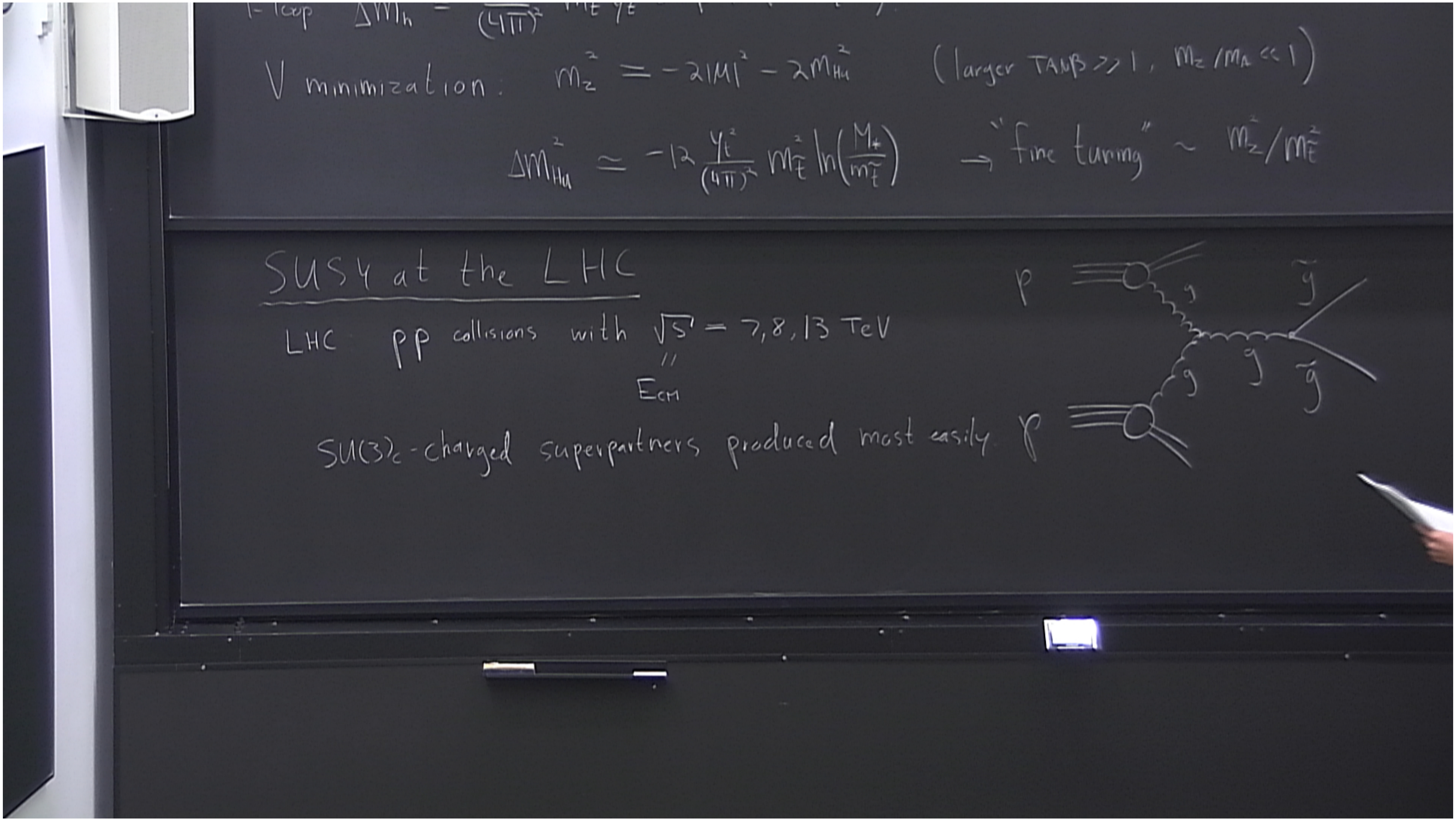
V minimization : $m_Z^2 = -2|\mu|^2 - 2m_{H_u}^2$ (larger $\tan\beta \gg 1$, $m_Z/m_A \ll 1$)

$$\Delta m_{H_u}^2 \simeq -12 \frac{y_t^2}{(4\pi)^2} m_{\tilde{t}}^2 \ln\left(\frac{M_*}{m_{\tilde{t}}}\right) \rightarrow \text{"fine tuning"} \sim m_Z^2/m_{\tilde{t}}^2$$



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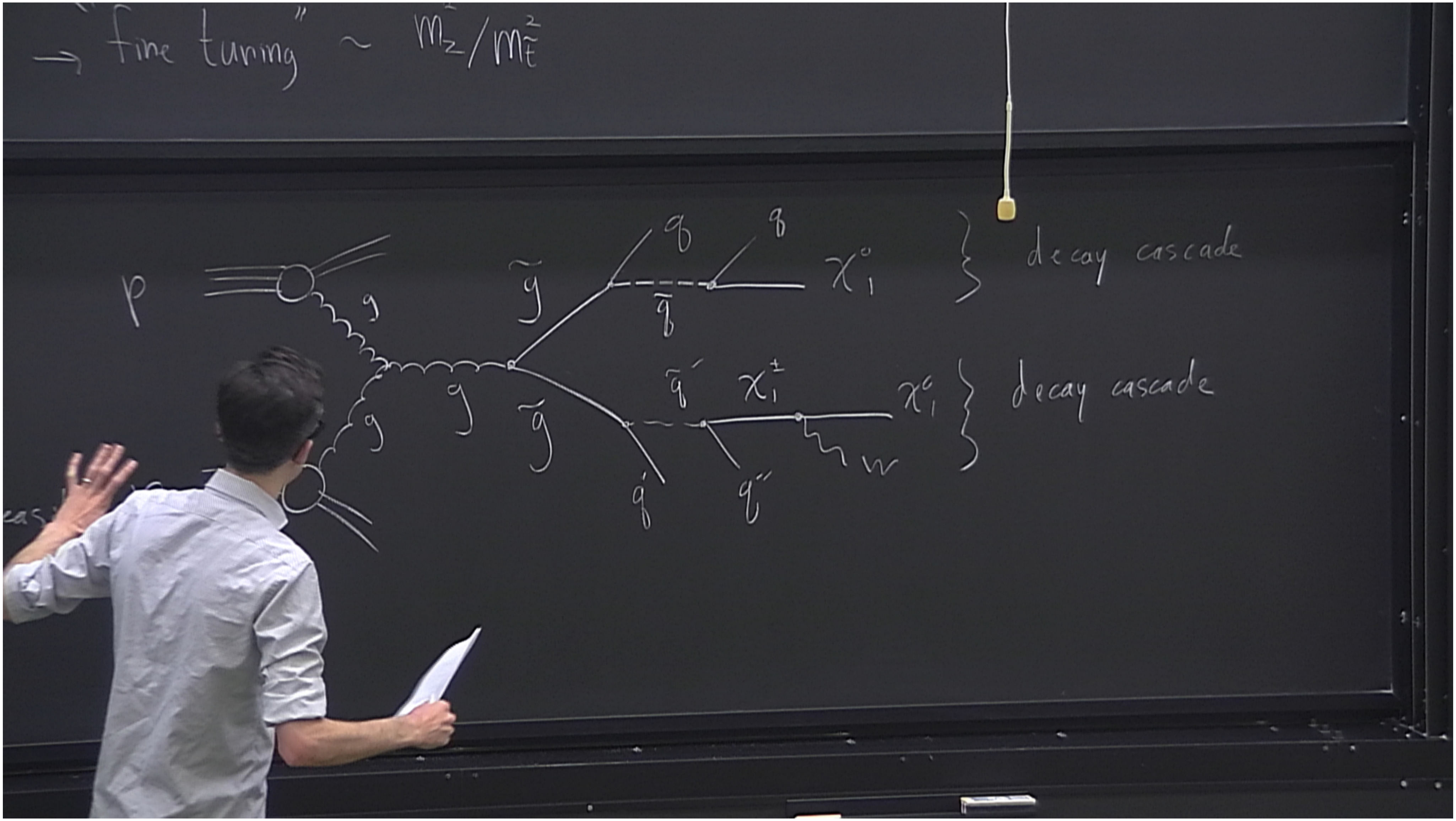
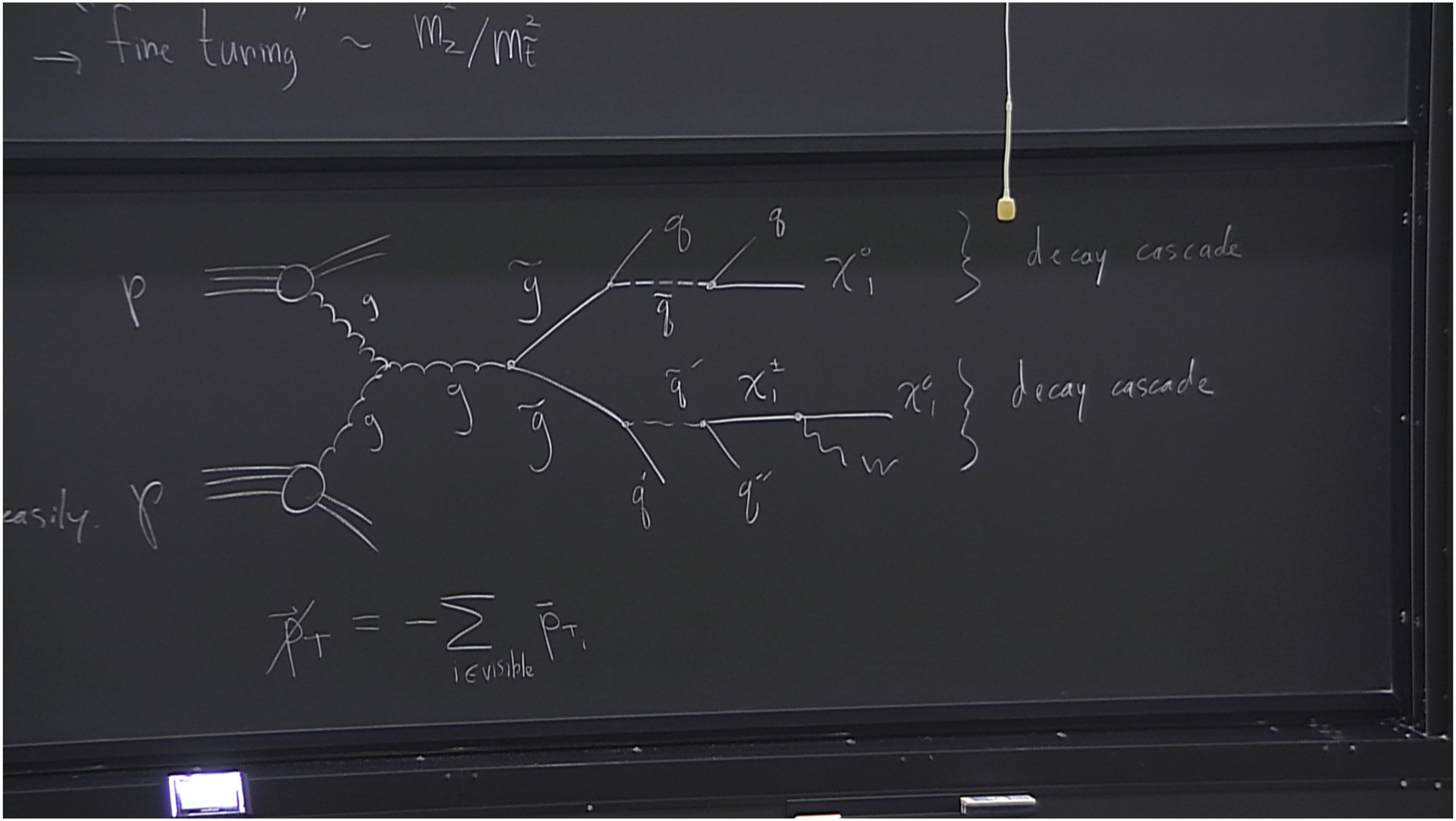
SUSY at the LHC
LHC pp collisions with $\sqrt{s} = 7, 8, 13$ TeV
E_{cm}
$SU(3)_c$-charged superpartners produced most easily
p
g
g
g
$\tilde{g}$
$\tilde{g}$
p


→ "fine tuning" ~ $m_Z^2/m_{\tilde{t}}^2$
p
g
$\tilde{g}$
q
$\bar{q}$
χ_1^0
decay cascade
$\tilde{q}'$
$\chi_1^\pm$
χ_1^0
decay cascade
W
q'
q''



→ "fine tuning" ~ $m_Z^2/m_{\tilde{t}}^2$
p
p
easily.
g
g
g
$\tilde{g}$
$\tilde{g}$
q
q
$\bar{q}$
$\tilde{q}'$
$\chi_1^\pm$
χ_1^0
χ_1^0
q'
q''
W
decay cascade
decay cascade
$\vec{\not{p}}_T = -\sum_{i \in \text{visible}} \bar{p}_{T_i}$

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SUSY at the LHC

LHC: pp collisions with $\sqrt{s} = 7, 8, 13$ TeV
$\qquad\qquad\qquad\qquad\qquad\qquad\quad \| \; E_{CM}$

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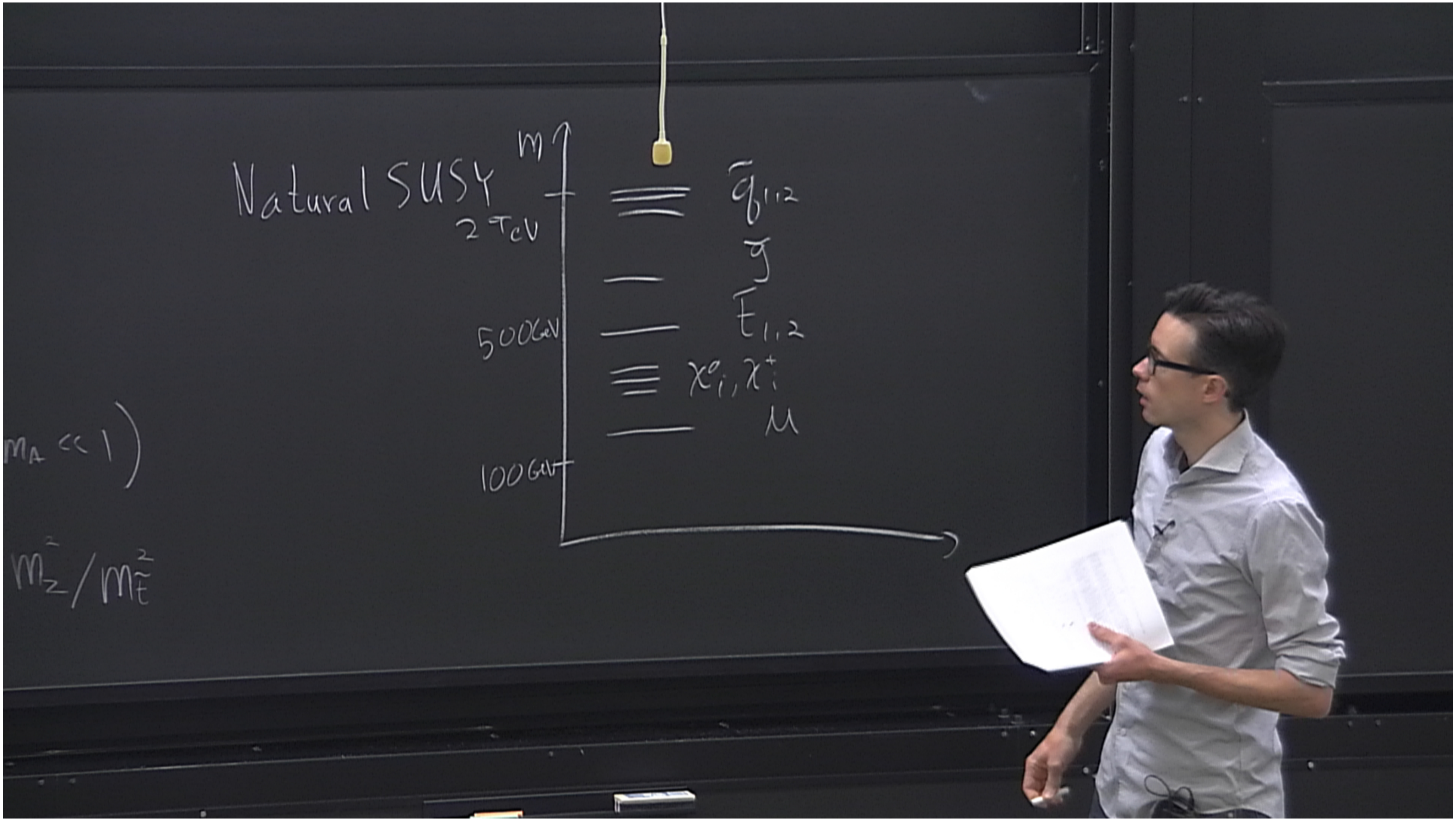
p

p

$\vec{\not{p}}_T =$



Natural SUSY
m
2 TeV
500GeV
100GeV
$\tilde{q}_{1,2}$
$\tilde{g}$
$\tilde{t}_{1,2}$
χ^0_i, χ^+_i
μ
$m_A << 1)$
$m_Z^2/m_{\tilde{t}}^2$

MSSM: tree: $m_h^2 \leq m_Z^2 \cos^2 2\beta \leq m_Z^2$, at tree-level

$m_h^2 \to (125\ \mathrm{GeV})^2$

Na

1-loop: $\Delta m_h^2 = \frac{12}{(4\pi)^2} m_t^2 y_t^2 \sin^2\beta \ln\left(\frac{m_{\tilde{t}_L} m_{\tilde{t}_R}}{m_t^2}\right) \to \sqrt{m_{\tilde{t}_L} m_{\tilde{t}_R}} \gtrsim 1\ \mathrm{TeV}$

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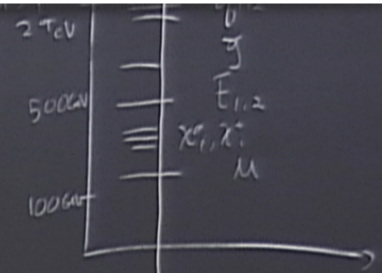


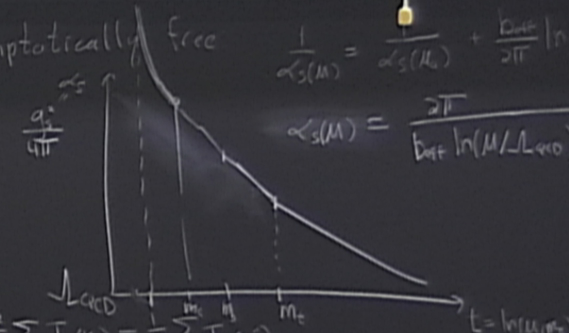
Strong Coupling + Compositeness

QCD $\mathcal{L}_{QCD} = -\frac{1}{4} G^a_{\mu\nu} G^{a\mu\nu} + \sum_I \bar{q}_I (i\gamma^\mu D_\mu - m_I) q_I$

$\boxed{m_u = 2.5\ \text{MeV},\ m_d = 5.3\ \text{MeV},\ m_s = 110\ \text{MeV}}$, $m_c = 1.2\ \text{GeV}$, $m_t = 174\ \text{GeV}$, $m_b = 4.5\ \text{GeV}$

$\frac{dg}{dt} = \beta(t) = \frac{-b}{(4\pi)^2} g^3$, $b = \frac{11}{3} C_2(A) - \frac{2}{3} \sum_r T_2(r) - \frac{1}{3} \sum_{r'} T_2(r')$

asymptotically free



$\frac{1}{\alpha_s(\mu)} = \frac{1}{\alpha_s(\mu_0)} + \frac{b_{eff}}{2\pi} \ln\left(\frac{\mu}{\mu_0}\right)$

$\alpha_s(\mu) = \frac{2\pi}{b_{eff} \ln(\mu/\Lambda_{QCD})}$

$(125\ \mathrm{GeV})^2$

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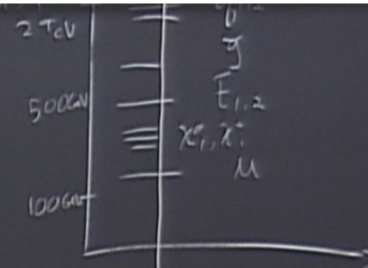

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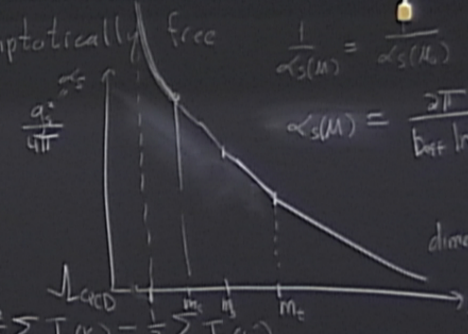


$\frac{1}{\alpha_s(M)} = \frac{1}{\alpha_s(M_0)} + \frac{b_{eff}}{2\pi} \ln\left(\frac{M}{M_0}\right)$

$\alpha_s(M) = \frac{2\pi}{b_{eff} \ln(M/\Lambda_{QCD})}$

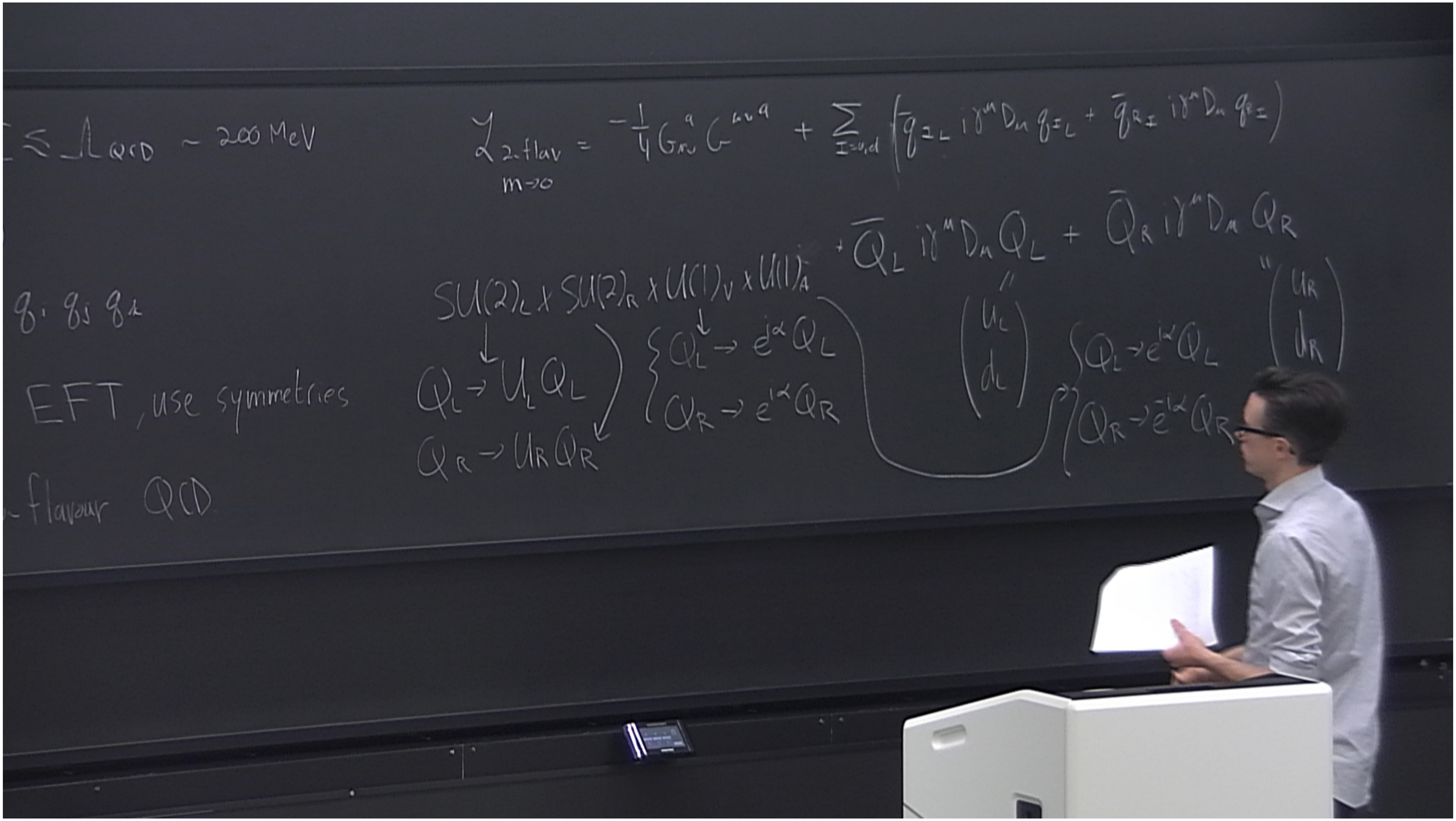
dimensional transmutation

Low-energy: $E \lesssim \Lambda_{QCD} \sim 200\ \text{MeV}$

meson $\sim \bar{q} q$

baryon $\sim \epsilon_{ijk}\, q_i\, q_j\, q_k$

Idea: low-energy EFT, use symmetries



≲ Λ_QCD ~ 200 MeV
L_2-flav, m→0 = −1/4 G^a_μν G^μν a + Σ_I=u,d (q̄_IL iγ^μ D_μ q_IL + q̄_RI iγ^μ D_μ q_RI)
q_i q_j q_k
EFT, use symmetries
flavour QCD
SU(2)_L × SU(2)_R × U(1)_V × U(1)_A
Q_L → U_L Q_L
Q_R → U_R Q_R
Q_L → e^iα Q_L
Q_R → e^iα Q_R
= Q̄_L iγ^μ D_μ Q_L + Q̄_R iγ^μ D_μ Q_R
u_L
d_L
u_R
d_R
Q_L → e^iα Q_L
Q_R → e^−iα Q_R

$$\mathcal{L}_{\substack{2\text{-flav}\\ m\to 0}} = -\frac{1}{4} G^a_{\mu\nu} G^{\mu\nu a} + \sum_{I=u,d} \left(\bar{q}_{I_L}\, i\gamma^\mu D_\mu q_{I_L} + \bar{q}_{R_I}\, i\gamma^\mu D_\mu q_{R_I} \right)$$

$$= \bar{Q}_L\, i\gamma^\mu D_\mu Q_L + \bar{Q}_R\, i\gamma^\mu D_\mu Q_R$$

$$Q_L = \begin{pmatrix} u_L \\ d_L \end{pmatrix} \qquad Q_R = \begin{pmatrix} u_R \\ d_R \end{pmatrix}$$

$$SU(2)_L \times SU(2)_R \times U(1)_V \times \cancel{U(1)_A}$$

$$\begin{cases} Q_L \to U_L Q_L \\ Q_R \to U_R Q_R \end{cases} \qquad \begin{cases} Q_L \to e^{i\alpha} Q_L \\ Q_R \to e^{i\alpha} Q_R \end{cases} \qquad \begin{cases} Q_L \to e^{i\alpha} Q_L \\ Q_R \to e^{-i\alpha} Q_R \end{cases}$$

Idea: low-energy EFT, use symmetries $Q_L \to U_L Q_L$ ($Q_R \to$

$Q_R \to U_R Q_R$

Start with two-flavour QCD.

$$\langle \bar{q}_{RJ} \, q_{LI} \rangle = \delta_{IJ} \Lambda^3_{QCD}$$