

LECTURE 3.

END OF SUSY

EXTRA DIMENSIONS

SUSY BREAKING

EFFECTIVE DESCRIPTION OF ~~SUSY~~

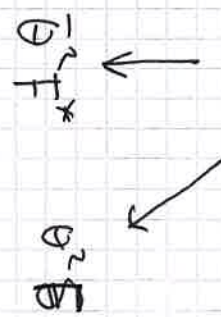
$S \leftarrow$ field in hidden sector



$$\langle S \rangle = \dots + \theta^2 \langle F \rangle$$

Want a catalog of leading non-renormalizable terms
connecting S to ϕ

$$\frac{1}{M^2} \int \phi^\dagger \phi S^\dagger S d^4\theta \longrightarrow m_\varphi^2 = |V|^2 \frac{F^2}{M^2} \text{ Scalar mass}$$



$$b \frac{1}{M^2} \int \phi^2 S^\dagger S d^4\theta + h.c. \longrightarrow b \varphi^2 \frac{F^2}{M^2} \text{ B-fermion}$$

$$\frac{1}{M} \int \phi^3 S d^2\theta \longrightarrow a \varphi^3 \frac{F}{M} \text{ A-fermion}$$

$$\frac{1}{M} \int W_\alpha W^\alpha S d^2\theta \longrightarrow \frac{F}{M} \lambda_\alpha \lambda^\alpha \text{ gaugino mass}$$

$$m_{\text{soft}} = \frac{F}{M}$$

- $A \sim m_{\text{soft}}$
- $B \sim m_{\text{soft}}^2$
- $m_\varphi^2 \sim m_{\text{soft}}^2$
- $m_\lambda \sim m_{\text{soft}}$
- $m_{\text{soft}} \sim$ few hundred GeV
- TeV

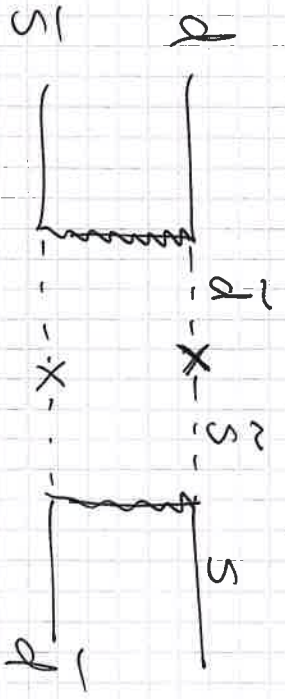
$$\mathcal{L} = \mathcal{L}_{\text{SUSY}} + \mathcal{L}_{\text{soft}}$$

$$\begin{aligned} \mathcal{L}_{\text{soft}} = & -\frac{1}{2} (M_3 \bar{g}g + M_2 \tilde{W} \cdot \tilde{W} + M_1 \bar{B}B) \\ & + (A_u \bar{Q} H_u \tilde{U} + A_d (\quad) + A_e (\quad)) \\ & + \bar{Q}^2 + \sqrt{m_a^2} \bar{Q} + \frac{\tilde{U}}{U} + \frac{\tilde{D}}{D} + \dots \\ & + m_{H_u}^2 |H_u|^2 + m_{H_d}^2 |H_d|^2 + B_\mu H_u H_d + \text{h.c.} \end{aligned}$$

105 new param's.

Very strong flavor constraints on flavor structure of soft breaking terms!

E.g. Squarks can contribute to $K-\bar{K}$ mixing



$$\frac{\Delta m_{ds}^2}{m_{SUSY}^2} \lesssim 4 \cdot 10^{-3} \left(\frac{m_{SUSY}}{500 \text{ GeV}} \right)$$

Assume : organizing principle: soft breaking universality

At some scale all soft breaking terms are

flavor universal

EWSB in SUSY

Only source for Higgs quadratic in MSSM

$$V_D = \frac{1}{2} g^2 |H_u^+ H_d|^2 + \frac{1}{8} (g^2 + g'^2) (|H_u|^2 - |H_d|^2)^2$$

In SM $\sim \sqrt{\lambda} v$

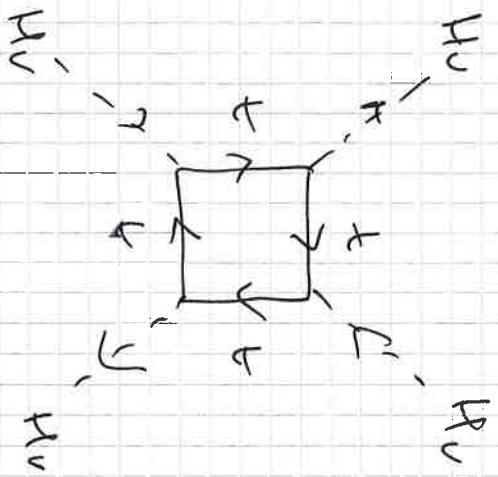
$$V_H = V_D + (\mu^2 + m_H^2) |H_u|^2 + (\mu^2 + m_{H_d}^2) |H_d|^2 - B_\mu H_u H_d$$

t.h.c.

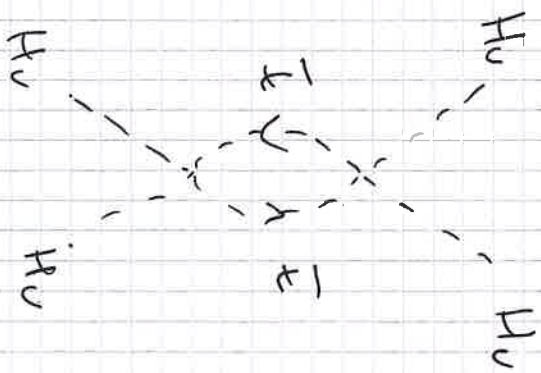
$H_u, H_d \rightarrow 8$ comp's $- 3$ eaten

$\rightarrow 5$
 \swarrow h, H \leftarrow neutral
 \searrow CP-odd charged Higgs

Ways out:



include radiative corrections!



$$\lambda = \lambda_{\text{soft}} + \frac{6 |g_t|^4}{16\pi^2} \log \left(\frac{m_{\tilde{t}_1} m_{\tilde{t}_2}}{m_{\tilde{t}}^2} \right)$$

to make this large \rightarrow need to split stop & top a lot.

to get 125 GeV $m_{\tilde{t}} \sim$ multi TeV!

$m_{\tilde{t}}$ kills feeds into quadratic term!

$$H_0 = \begin{pmatrix} H_0^+ \\ H_0^0 \\ H_0^- \end{pmatrix} \begin{matrix} \swarrow \\ \leftarrow \\ \searrow \end{matrix} \text{NEV'S.}$$

$$H_d = \begin{pmatrix} H_d^0 \\ H_d^- \end{pmatrix}$$

$$\langle H_u \rangle = \begin{pmatrix} 0 \\ v_u \end{pmatrix}$$

$$\langle H_d \rangle = \begin{pmatrix} v_d \\ 0 \end{pmatrix}$$

$$\frac{v_u}{v_d} = \tan \beta$$

minimize the full Higgs pot!

$$\frac{M_2^2}{2} = -\mu^2 + \frac{m_{Hd}^2 - m_{H_0^0}^2 \tan^2 \beta}{\tan^2 \beta - 1}$$

$$\sin 2\beta = \frac{2B_\mu}{2\mu^2 + m_{H_u}^2 + m_{H_d}^2}$$

$$m_H^2 = \frac{1}{2} \left[M_2^2 + m_A^2 \pm \sqrt{(M_2^2 + m_A^2)^2 - 4m_A^2 M_2^2 \cos^2 2\beta} \right]$$

$$m_A^2 = \frac{B_\mu}{\sin \beta \cos \beta}$$

$$m_{H^0} \leq M_2 |\cos 2\beta|$$

$$\Delta_{mH_0}^2 = -\frac{3y_e^2}{4H^2}$$

$$m_{\tilde{e}}^2$$

$$\log\left(\frac{\Delta}{m_{\tilde{e}}^2}\right)$$

Little hierarchy of SSB!

EXTRA DIMENSIONS

IDEA:
more S-T dimensions than we observe
additional dimensions should be compact!

1.) Kaluza-Klein tower

Assume $\lambda \ll R$, compact \rightarrow radius R

Free scalar

ϕ massless

$$S = \int d^5x \frac{1}{2} \partial_\mu \phi \partial^\mu \phi \quad x_5 = y$$

Write in terms of Fourier modes

$$\phi(x,y) = \frac{1}{\sqrt{2\pi R}} \sum_n \phi^{(n)}(x) e^{i \frac{n}{R} y}$$

$$(\phi^{(n)})^\dagger = \phi^{(-n)} \quad (\text{to keep it real})$$