$Q = T_3 + Y$

MSSM

	$SU(3)_c$	$SU(2)_L$	$U(1)_Y$
$(\tilde{u}_L, \tilde{d}_L)_i\ (u_L, d_L)_i$	$\square$	$\square$	$1/6$
$\bar{u}_i = \tilde{u}^*_{Ri}\ \ u^\dagger_{Ri}$	$\bar{\square}$	1	$-2/3$
$\bar{d}_i$ $\tilde{d}^*_{Ri}\ \ d^\dagger_{Ri}$	$\bar{\square}$	1	$1/3$
$(\tilde{\nu}_L, \tilde{e}_L)_i\ (\nu_L, e_L)_i$	1	$\square$	$-1/2$
$= e^*_R\ \ e^\dagger_{Ri}$	1	1	1
$(H_u^+, H_u^0)\ (\tilde{H}_u^+, \tilde{H}_u^0)$	1	$\square$	$1/2$
$G\ \ \tilde{G}$	Ad	1	0
$W^0, W^\pm, \tilde{W}^0, \tilde{W}^\pm$	1	Ad	0
$B, \tilde{B}$	1	1	0
$(H_d^0, H_d^-)\ (\tilde{H}_d^0, \tilde{H}_d^-)$	1	$\square$	$-1/2$

$u_i = (u, c, t)$

$d_i = (d, s, b)$

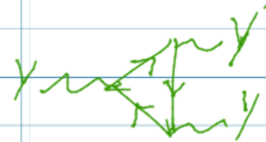
$e_i = (e, \mu, \tau)$

$\nu_i = (\nu_e, \nu_\mu, \nu_\tau)$

$Q_i = (\tilde{u}_L, \tilde{d}_L)_i, (u_L, d_L)_i$

$L_i = (\tilde{\nu}_L, \tilde{e}_L)_i\ (\nu_L, e_L)$

Anomaly Cancelation



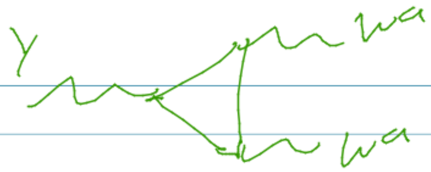
$$= 3(2Y_Q^3 + Y_{u_R}^3 + Y_{d_R}^3) + 2Y_L^3 + Y_{e_R}^3$$

$$= 3\left(2\left(\tfrac{1}{6}\right)^3 - \left(\tfrac{2}{3}\right)^3 + \left(\tfrac{1}{3}\right)^3\right) + 2\left(-\tfrac{1}{2}\right)^3 + 1^3$$

$$= \frac{1}{36} - \frac{8}{9} + \frac{1}{9} - \frac{2}{8} + 1$$

$$= \frac{1 - 32 + 4}{36} + \frac{6}{8}$$

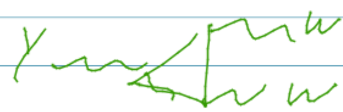
$$= \frac{-27}{36} + \frac{3}{4} = 0$$



$$3Y_Q \tfrac{1}{2}\delta^{ab} + Y_L \tfrac{1}{2}\delta^{ab} = \left(3\tfrac{1}{6} - \tfrac{1}{2}\right)\tfrac{1}{2}\delta^{ab} = 0$$

H_u H_d

$$\propto \left(\tfrac{1}{2}\right)^3 + \left(-\tfrac{1}{2}\right)^3 = 0$$



$$\propto \left(\tfrac{1}{2} + -\tfrac{1}{2}\right)\tfrac{1}{2}\delta^{ab} = 0$$

Witten: Even # $SU(2)$ $\square$'s

otherwise $\int e^{-S} \to -\int e^{-S} = 0$

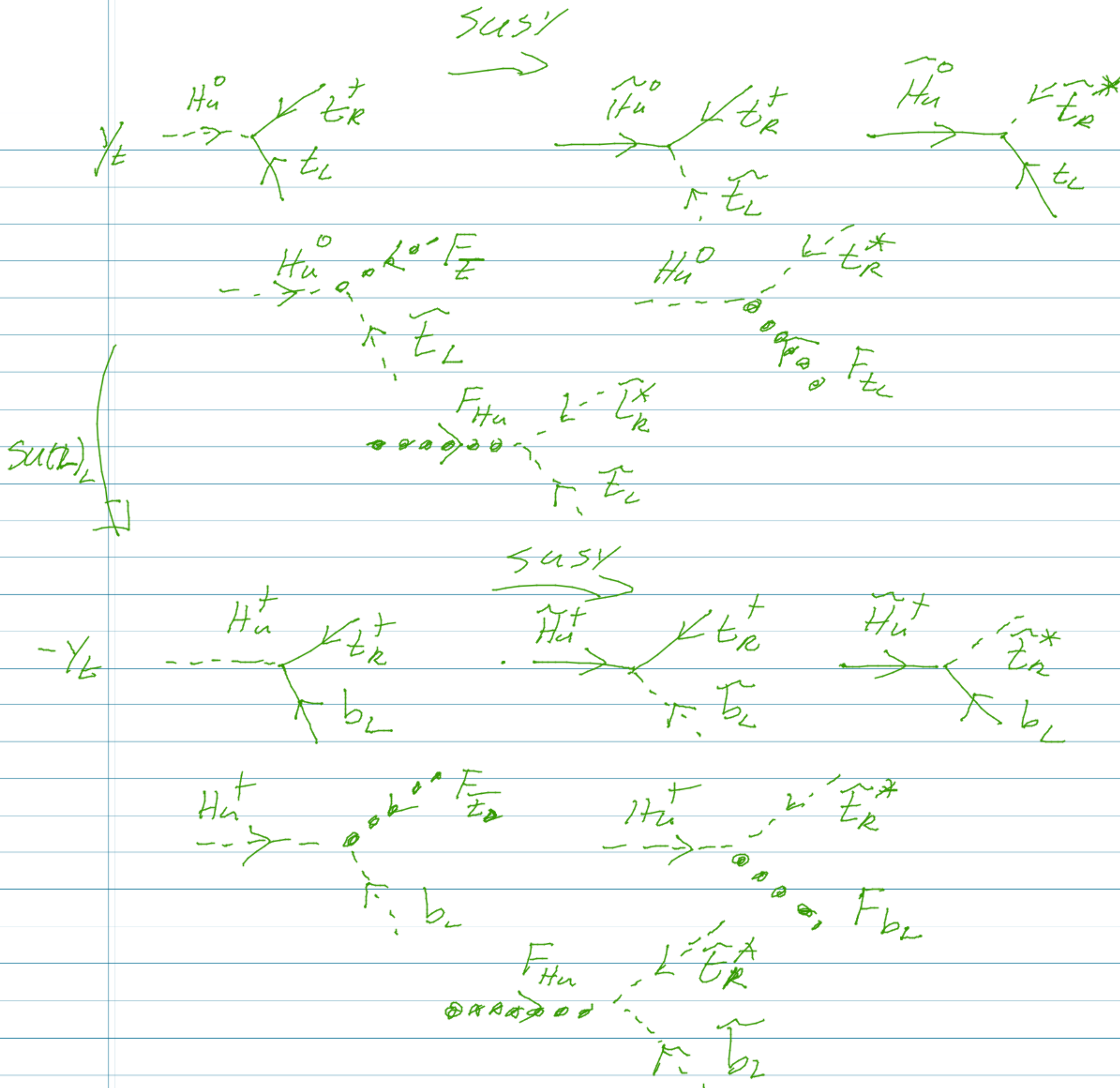
$$W = \bar{u}_i^a Y_{u\,i}{}^{j} Q_{ja\alpha} H_{u\beta}\epsilon^{\alpha\beta} - \bar{d} Y_d Q H_d - \bar{e} Y_e L H_d + \mu H_u H_d$$

holomorphy H_u and H_d

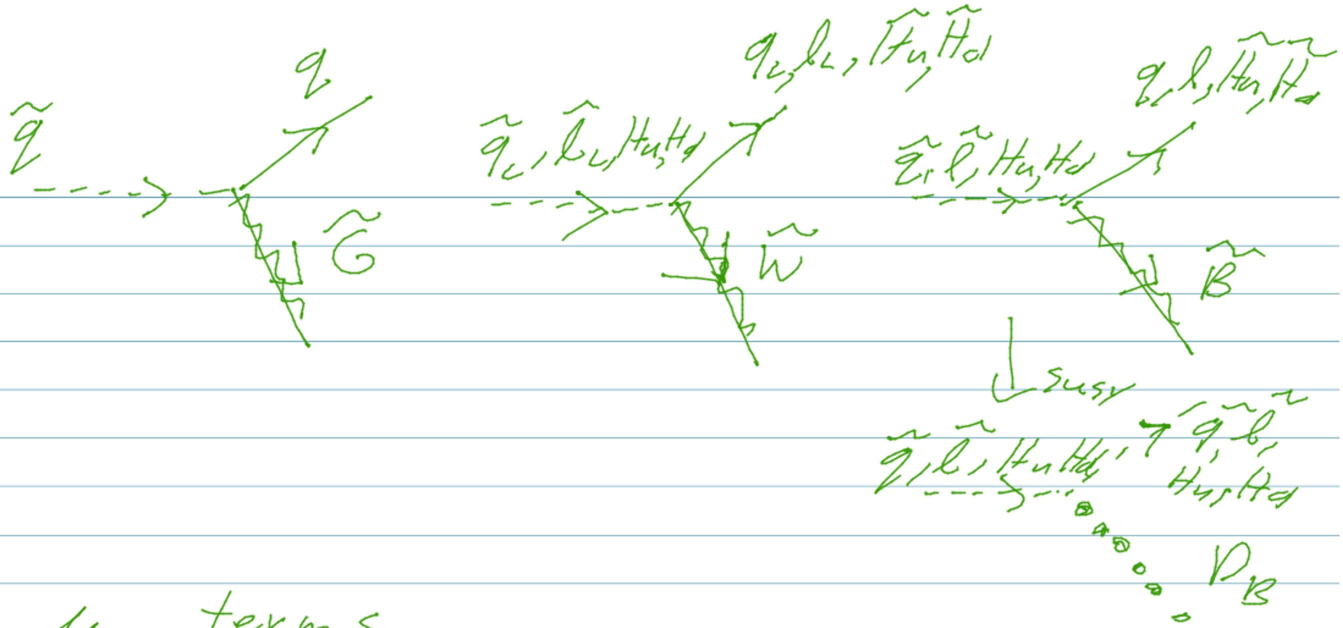
$m_t \gg m_c, m_u$ $m_b \gg m_s, m_d$ $m_\tau \gg m_\mu, m_e$

$$Y_u \propto \begin{pmatrix} 0 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & y_t \end{pmatrix} \quad Y_d = \begin{pmatrix} 0 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & y_b \end{pmatrix} \quad Y_e = \begin{pmatrix} 0 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & y_\tau \end{pmatrix}$$

$$W = y_t\left(\bar{t} t_L H_u^0 - \bar{t} b_L H_u^+\right) - y_b\left(\bar{b} t_L H_d^- - \bar{b} b_L H_d^0\right)$$
$$- y_\tau\left(\bar{\tau} \nu_{\tau L} H_d^- - \bar{\tau}\tau_L H_d^0\right) + \mu\left(H_u^+ H_d^- - H_u^0 H_d^0\right)$$



SUSY
y_t
H_u^0
t_R^+
t_L
$\tilde{H}_u^0$
$\tilde{t}_L$
$\tilde{t}_R^*$
$F_{\bar{t}}$
F_{t_L}
F_{H_u}
$SU(2)_L$
SUSY
$-y_t$
H_u^+
b_L
$\tilde{H}_u^+$
$\tilde{b}_L$
F_{t_R}
F_{b_L}



μ terms

$$\mathcal{L}_{\mu\,\text{mass}} = -\mu\left(\tilde H_u^+ \tilde H_d^- - \tilde H_u^0 \tilde H_d^0\right) + \text{h.c.}$$
$$- |\mu|^2 \left(|H_u^0|^2 + |H_u^+|^2 + |H_d^0|^2 + |H_d^-|^2\right)$$

stable minimum at origin

to understand EW SB
need soft-breaking terms

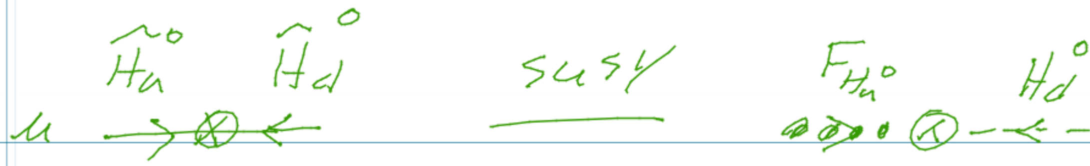
why is $|\mu|^2 \sim \mathcal{O}(m_{soft}^2)$

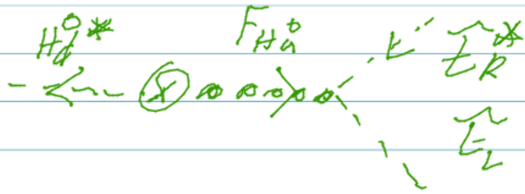
"μ-problem"

class of solutions: $\mu = 0$ at tree-level

then generated by soft SUSY breaking

for now just a parameter

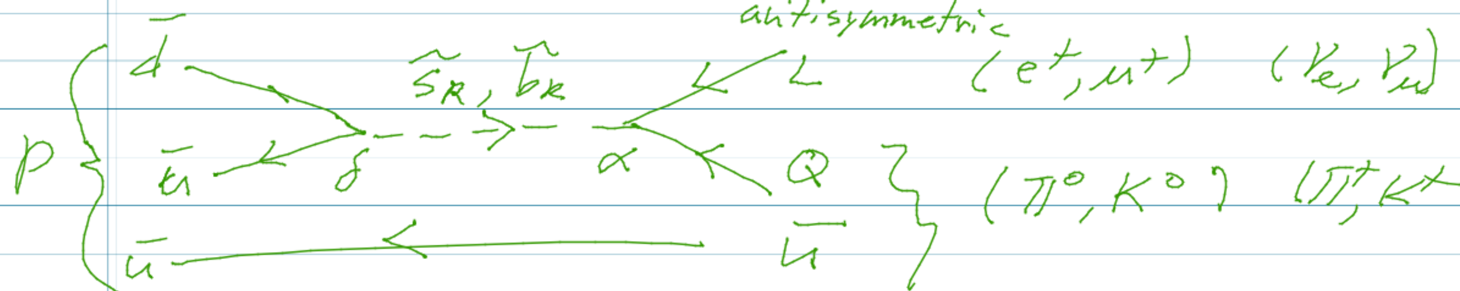




$\sim \mu^* Y_t$

$$\mathcal{L}^{\mu}_{\text{trilinear}} = \mu^* \Big(\tilde{\bar{u}}\, Y_u\, \tilde{u}\, H_d^{0*} + \tilde{\bar{d}}\, Y_d\, \tilde{d}\, H_u^{0*} + \tilde{\bar{e}}\, Y_e\, \tilde{e}\, H_u^{0*} + \tilde{\bar{u}}\, Y_u\, \tilde{d}\, H_d^{-} + \tilde{\bar{d}}\, Y_d\, \tilde{u}\, H_u^{+*} + \tilde{\bar{e}}\, Y_e\, \tilde{\nu}\, H_u^{+*} \Big) + \text{h.c.}$$

$$W_{\text{diaster}} = \alpha^{ijk} Q_i L_j \bar{d}_k + \beta^{ijk} L_i L_j \bar{e}_k + \gamma^i L_i H_u + \underset{\substack{\uparrow \\ \text{antisymmetric}}}{\delta^{ijk}} \bar{u}_i \bar{d}_j \bar{d}_k$$



Lepton and Baryon # violation

$$\Gamma \sim \left|\frac{\alpha\delta}{m_{\tilde q}^2}\right|^2 \frac{m_p^5}{8\pi}$$

$$\tau_p = \frac{1}{\Gamma} \approx \frac{8\pi}{|\alpha\delta|^2}\frac{1}{m_p}\left(\frac{m_{\tilde q}}{m_p}\right)^4$$

$$\sim \frac{25}{|\alpha\delta|^2}\frac{1}{1\,\mathrm{GeV}}\frac{1\,\mathrm{sec}}{10^{24}\,\mathrm{GeV}^{-1}}\left(\frac{m_{\tilde q}}{1\,\mathrm{TeV}}\frac{1\,\mathrm{TeV}}{1\,\mathrm{GeV}}\right)^4$$

$$= \frac{25}{|\alpha\delta|^2}\frac{10^{12}}{10^{24}}\left(\frac{m_{\tilde q}}{1\,\mathrm{TeV}}\right)^4 \mathrm{sec}$$

$$= 2.5\times 10^{-11}\,\mathrm{sec}\,\frac{1}{|\alpha\delta|^2}\left(\frac{m_{\tilde q}}{1\,\mathrm{TeV}}\right)^4$$

$$\tau_{\mathrm{exp}} > 10^{32}\ \mathrm{years} \sim 3\times 10^{39}\,\mathrm{sec}$$

$$\frac{1}{|\alpha\delta|^2} > 10^{50}$$

$$|\alpha\delta| < 10^{-25}$$

Invent a new symmetry

R Parity

(observed particles) $\to$ (observed particle)

(superpartners) $\to -$(superpartner)

forbids $W_{disaster}$

$$R = (-1)^{3(B-L)+2S \to F}$$

R parity is a Z_2 not $U(1)_R$

$U(1)_R$ forbids soft gaugino masses

1) at colliders superpartners are produced in pairs

2) lightest superpartner (LSP) is stable (dark matter candidate)

3) each sparticle (heavier than LSP) must decay to an odd number of LSP's

Soft Breaking

$$\mathcal{L}^{MSSM}_{soft} = -\frac{1}{2}\left(M_3 \tilde{G}\tilde{G} + M_2 \tilde{W}\tilde{W} + M_1 \tilde{B}\tilde{B}\right) + h.c.$$
$$- \left(\tilde{\bar{u}} A_u \tilde{Q} H_u - \tilde{\bar{d}} A_d \tilde{Q} H_d - \tilde{\bar{e}} A_e \tilde{L} H_d \right) + h.c.$$
$$- \tilde{Q}^* m_Q^2 \tilde{Q} - \tilde{L}^* m_L^2 \tilde{L} - \tilde{\bar{u}} m_{\bar{u}}^2 \tilde{\bar{u}}^*$$
$$- \tilde{\bar{d}} m_{\bar{d}}^2 \tilde{\bar{d}}^* - \tilde{\bar{e}} m_{\bar{e}}^2 \tilde{\bar{e}}^* - m_{H_u}^2 H_u^* H_u$$
$$- m_{H_d}^2 H_d^* H_d - \left(b H_u H_d + h.c. \right)$$

$M_i,\ A_p \sim m_{soft}$

$m_p^2,\ b \sim m_{soft}^2$

105 new parameters