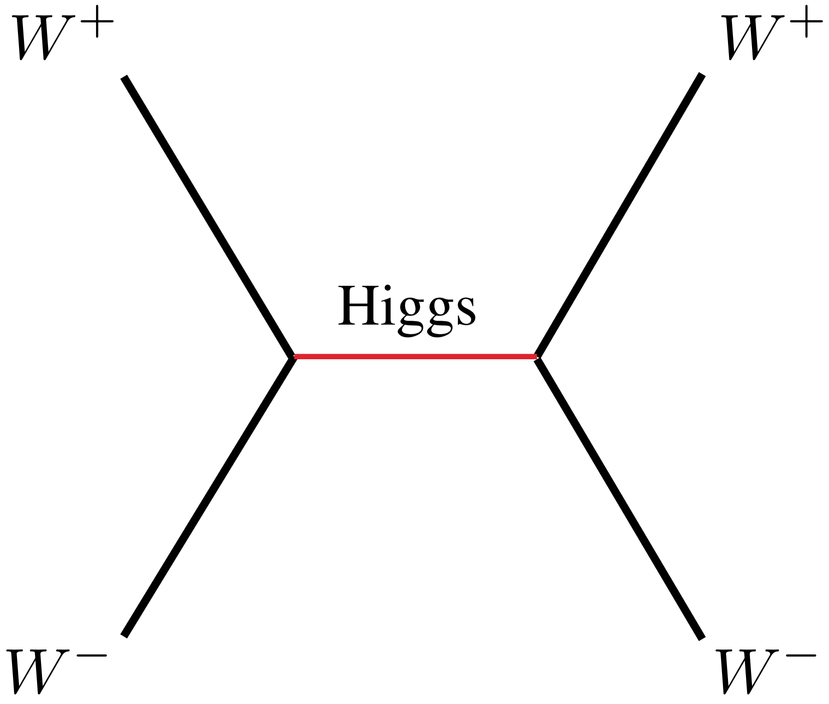
The Higgs Completes the Standard Model



$$\lim_{E\to\infty} \mathcal{A} \propto \text{const.}$$

With the inclusion of the Higgs particle, the theory remains predictive.

Theory requires a Higgs mass < 1 TeV

II

Constructing the Supersymmetric Standard Model

Supersymmetry

Bosons ⟷ Fermions

Chiral

Symmetry

Spin 0 ⟷ Spin 1/2

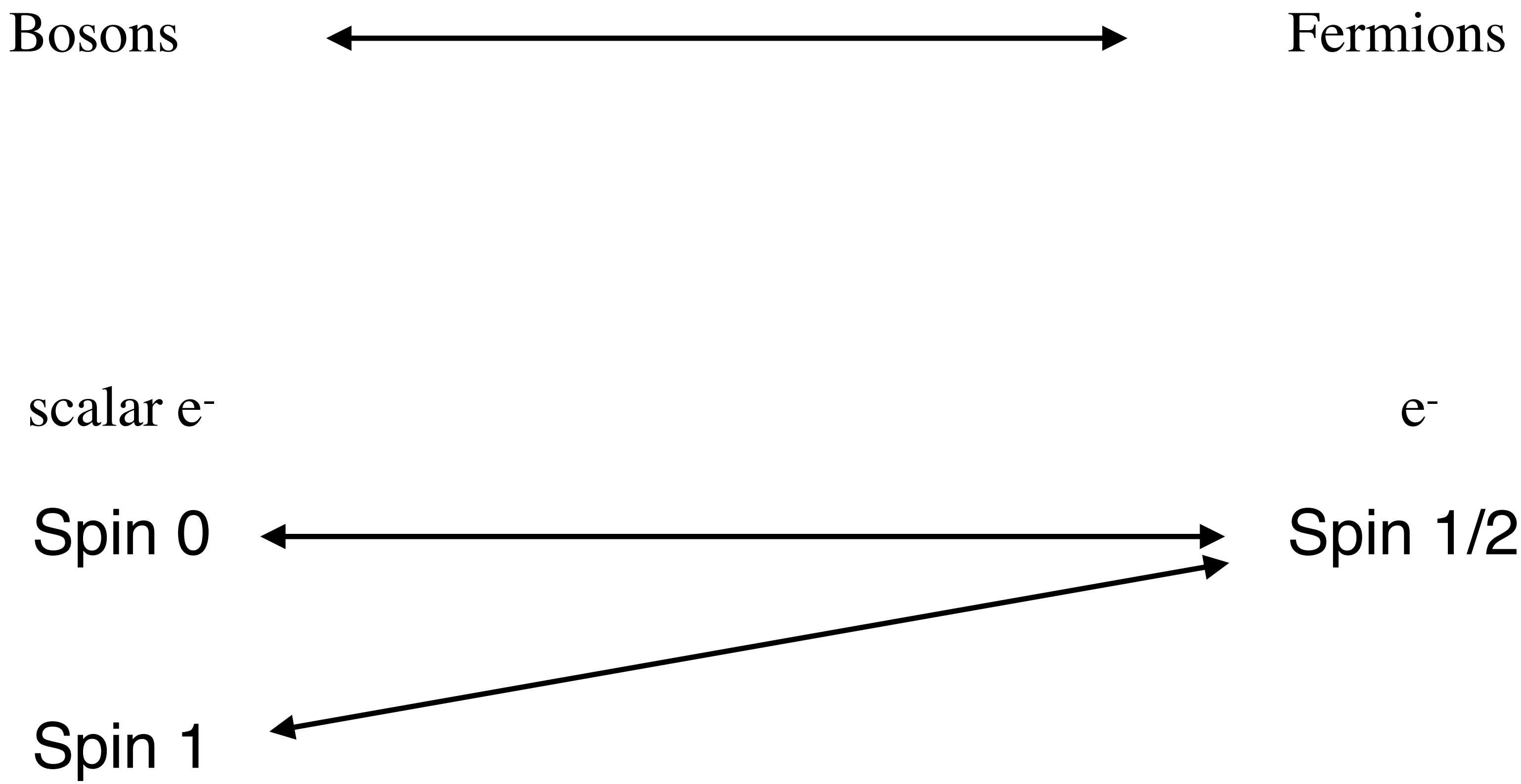
Supersymmetry

Bosons ⟷ Fermions

scalar e^- | e^-

Spin 0 ⟷ Spin 1/2

Supersymmetry



Supersymmetry

Bosons ⟷ Fermions

scalar e^- | e^-

Spin 0 ⟷ Spin 1/2

photon partner

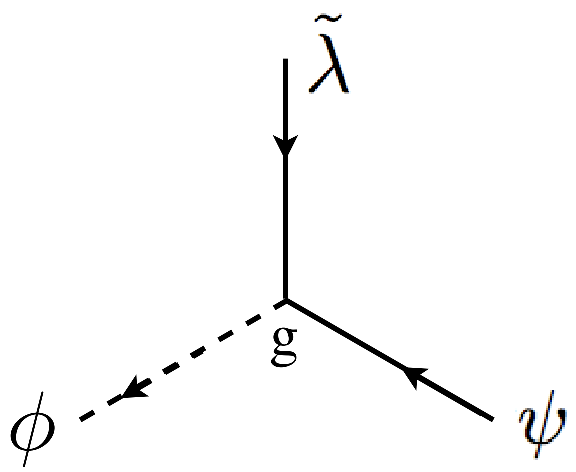
Spin 1

photon

Gauge fields in Supersymmetry

$\tilde{\lambda}$ 1 left-handed fermion and 1 right-handed anti-fermion

A^{μ} Two polarizations - right circular and left circular



When ϕ is charged

Preamble: Supersymmetric QED

Fermions all written as left-handed. So we need one electron and one anti-electron

e, e^c

$W = m_e\, e\, e^c$

$$\mathcal{L}_{susy} = \sqrt{2} g_{em} (\tilde{e}^* e \lambda + \text{h.c.}) - \sqrt{2} g_{em} (\tilde{e}^{c*} e^c \lambda + \text{h.c.}) - \frac{1}{2} g_{em}^2 (|\tilde{e}^c|^2 - |\tilde{e}|^2)^2$$

Preamble: Supersymmetric QED

Fermions all written as left-handed. So we need one electron and one anti-electron

e, e^c

$W = m_e\, e\, e^c$

$$\mathcal{L}_{susy} = \sqrt{2} g_{em}(\tilde{e}^* e \lambda + \text{h.c.}) - \sqrt{2} g_{em}(\tilde{e}^{c*} e^c \lambda + \text{h.c.}) - \frac{1}{2} g_{em}^2 (|\tilde{e}^c|^2 - |\tilde{e}|^2)^2$$

Replace with $\frac{1}{2}\sum_a g_a^2 (\phi^* T^a \phi)^2$

for general group

SU(2) - T=Pauli/2

SU(3) - T= Gell-mann/2

Supersymmetrize the SM

$$W = H\ QD^c + H\ QU^c$$

Need two Higgses.

Supersymmetrize the SM

$$W = H\ QD^c + \cancel{H\ QU^c}$$

Need two Higgses.

Supersymmetrize the SM

$$W = H\ QD^c + H^c QU^c$$

Need two Higgses.

Supersymmetrize the SM

$$W = H_1 Q D^c + H_2 Q U^c$$

Need two Higgses.

Supersymmetrize the SM

$$W = H_1 Q D^c + H_2 Q U^c$$

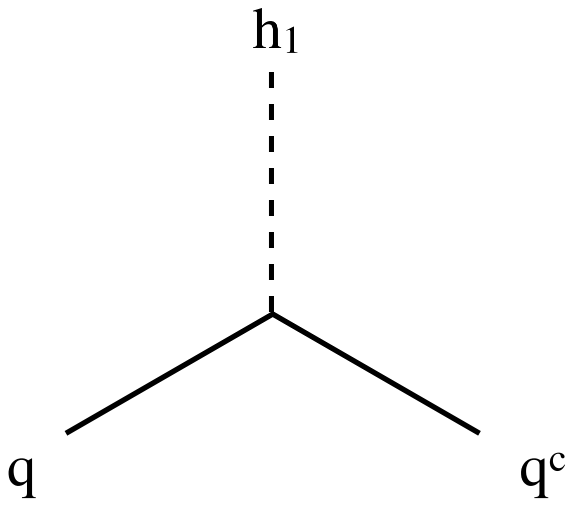
Need two Higgses.

$$H_1 = H_d = H \quad H_2 = H_u = \bar{H} = H^c$$

$$\tan\beta = \langle H_2 \rangle / \langle H_1 \rangle$$

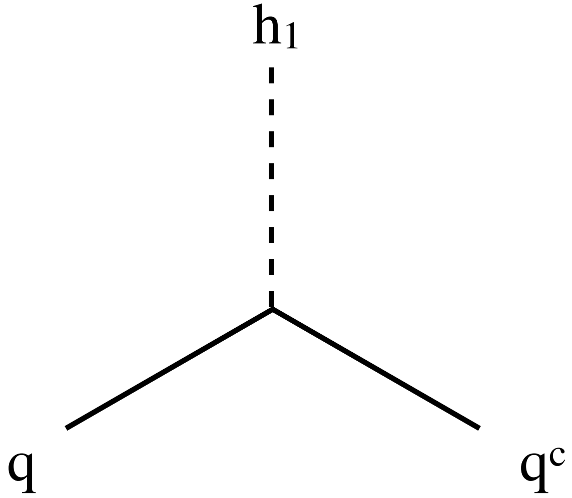
SSM - the superpotential

$$W = H_1 Q D^c + H_2 Q U^c + H_1 L E^c + \mu H_1 H_2$$



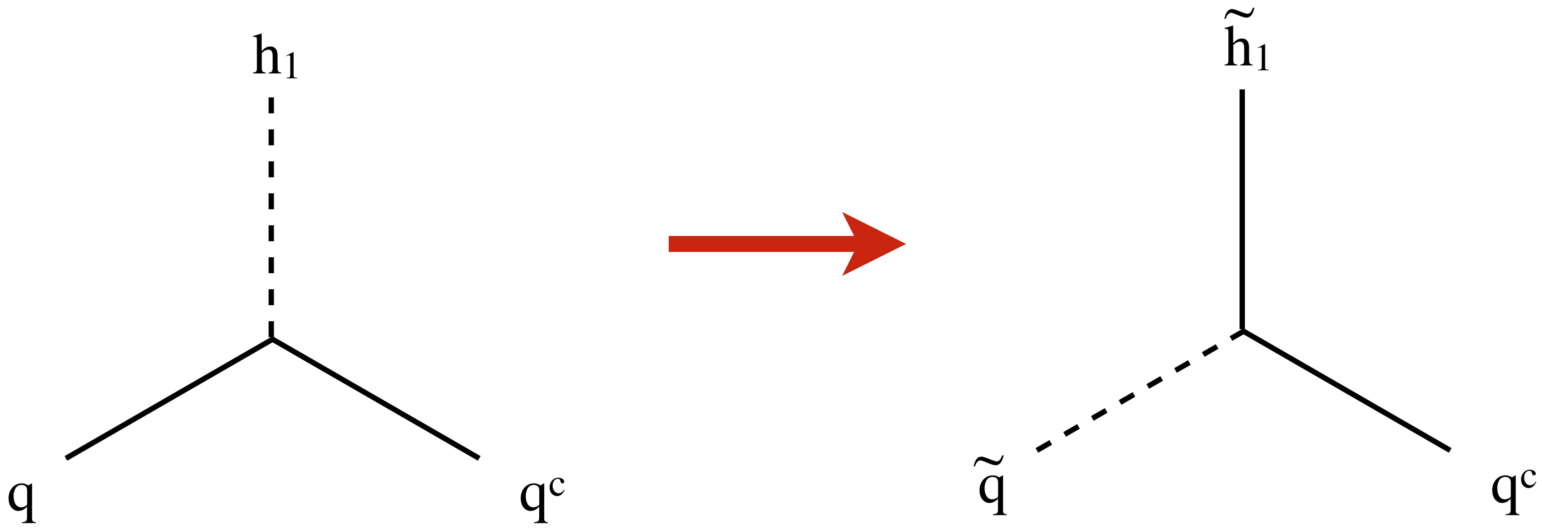
SSM - the superpotential

$$W = H_1 Q D^c + H_2 Q U^c + H_1 L E^c + \mu H_1 H_2$$



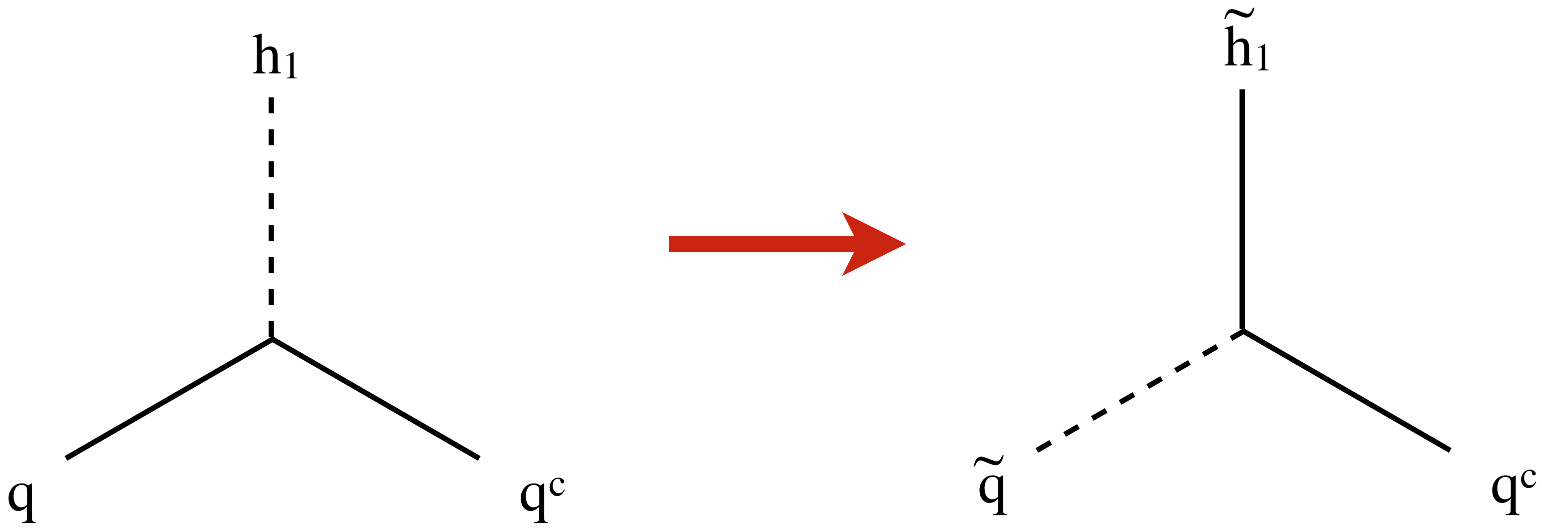
SSM - the superpotential

$$W = H_1 Q D^c + H_2 Q U^c + H_1 L E^c + \mu H_1 H_2$$



SSM - the superpotential

$$W = H_1 Q D^c + H_2 Q U^c + H_1 L E^c + \mu H_1 H_2$$



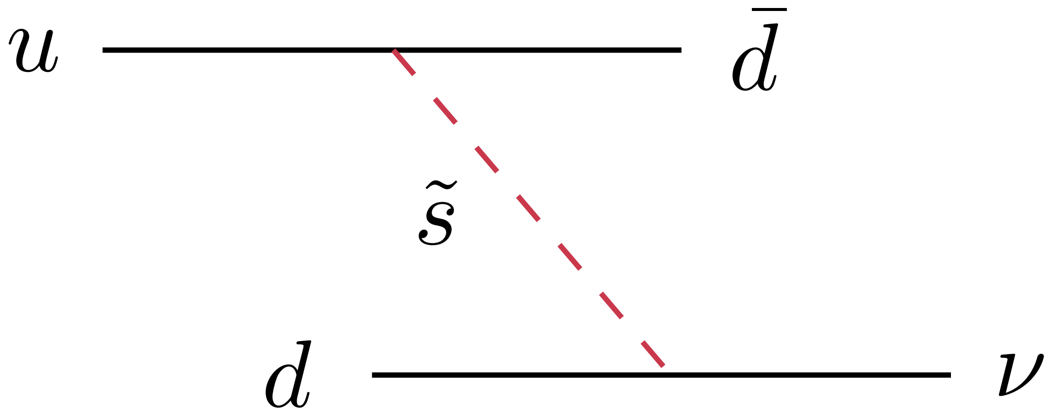
There are always two superpartners attached to each vertex.
Is there a ‘parity’ symmetry?

A Supersymmetric Standard Model

$$W = H_1 Q D^c + H_2 Q U^c + H_1 L E^c + \mu H_1 H_2$$
$$+ L Q D^c + U^c D^c D^c + L L E^c + \mu_L L H_2$$

A Supersymmetric Standard Model

$$W = H_1 Q D^c + H_2 Q U^c + H_1 L E^c + \mu H_1 H_2$$
$$+ L Q D^c + U^c D^c D^c + L L E^c + \mu_L L H_2$$



$p \rightarrow \pi^+ \nu$ ~ 1 hour

A Supersymmetric Standard Model

$$W = H_1 Q D^c + H_2 Q U^c + H_1 L E^c + \mu H_1 H_2$$
$$+ L Q D^c + U^c D^c D^c + L L E^c + \mu_L L H_2$$

Introduce a parity symmetry

$$Q \to -Q$$
$$H \to +H$$

Equivalent to:

$$\phi_{SM} \to +\phi_{SM}$$
$$\tilde{\phi}_{SP} \to -\tilde{\phi}_{SP}$$

A Supersymmetric Standard Model

$$W = H_1 Q D^c + H_2 Q U^c + H_1 L E^c + \mu H_1 H_2$$

$$\cancel{+ L Q D^c + U^c D^c D^c + L L E^c + \mu_L L H_2}$$

Introduce a parity symmetry

$$Q \rightarrow -Q$$

$$H \rightarrow +H$$

Equivalent to:

$$\phi_{SM} \longrightarrow +\phi_{SM}$$

$$\tilde{\phi}_{SP} \longrightarrow -\tilde{\phi}_{SP}$$

A Supersymmetric Standard Model

$$W = H_1 Q D^c + H_2 Q U^c + H_1 L E^c + \mu H_1 H_2$$

$$+ L Q D^c + U^c D^c D^c + L L E^c + \mu_L L H_2$$

Introduce a parity symmetry

$$Q \rightarrow -Q \qquad H \rightarrow +H$$

Equivalent to:

$$\phi_{SM} \longrightarrow +\phi_{SM} \qquad \tilde{\phi}_{SP} \longrightarrow -\tilde{\phi}_{SP}$$

R Parity

Consequences of R Parity

- Electroweak precision easily satisfied
- Must pair produce superpartners
- Missing E_T
- Dark Matter

The Minimal Supersymmetric SM

Names		spin 0	spin 1/2	$SU(3)_C, SU(2)_L, U(1)_Y$
squarks, quarks	Q	$(\widetilde{u}_L \ \ \widetilde{d}_L)$	$(u_L \ \ d_L)$	$(\mathbf{3}, \mathbf{2}, \frac{1}{6})$
(×3 families)	$\overline{u}$	$\widetilde{u}^*_R$	$u^\dagger_R$	$(\overline{\mathbf{3}}, \mathbf{1}, -\frac{2}{3})$
	$\overline{d}$	$\widetilde{d}^*_R$	$d^\dagger_R$	$(\overline{\mathbf{3}}, \mathbf{1}, \frac{1}{3})$
sleptons, leptons	L	$(\widetilde{\nu} \ \ \widetilde{e}_L)$	$(\nu \ \ e_L)$	$(\mathbf{1}, \mathbf{2}, -\frac{1}{2})$
(×3 families)	$\overline{e}$	$\widetilde{e}^*_R$	$e^\dagger_R$	$(\mathbf{1}, \mathbf{1}, 1)$
Higgs, higgsinos	H_u	$(H_u^+ \ \ H_u^0)$	$(\widetilde{H}_u^+ \ \ \widetilde{H}_u^0)$	$(\mathbf{1}, \mathbf{2}, +\frac{1}{2})$
	H_d	$(H_d^0 \ \ H_d^-)$	$(\widetilde{H}_d^0 \ \ \widetilde{H}_d^-)$	$(\mathbf{1}, \mathbf{2}, -\frac{1}{2})$

Names	spin 1/2	spin 1	$SU(3)_C, SU(2)_L, U(1)_Y$
gluino, gluon	$\widetilde{g}$	g	$(\mathbf{8}, \mathbf{1}, 0)$
winos, W bosons	$\widetilde{W}^\pm \ \ \widetilde{W}^0$	$W^\pm \ \ W^0$	$(\mathbf{1}, \mathbf{3}, 0)$
bino, B boson	$\widetilde{B}^0$	B^0	$(\mathbf{1}, \mathbf{1}, 0)$

A Supersymmetric Standard Model

Two remaining problems:

A Supersymmetric Standard Model

Two remaining problems:

The names are silly.

A Supersymmetric Standard Model

Two remaining problems:

~~The names are silly.~~

A Supersymmetric Standard Model

Two remaining problems:

~~The names are silly.~~

There are no superpartners with the same masses as standard model particles (I mean in nature).

A Supersymmetric Standard Model

Two remaining problems:

~~The names are silly.~~

There are no superpartners with the same masses as standard model particles (I mean in nature).

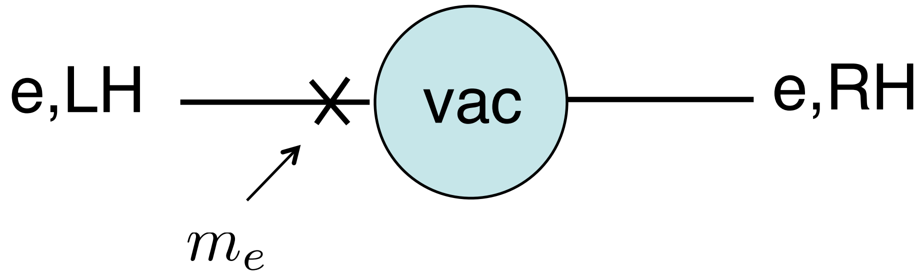
The higgs does not get a vev.

Give Mass to Superpartners

Remember the electron:

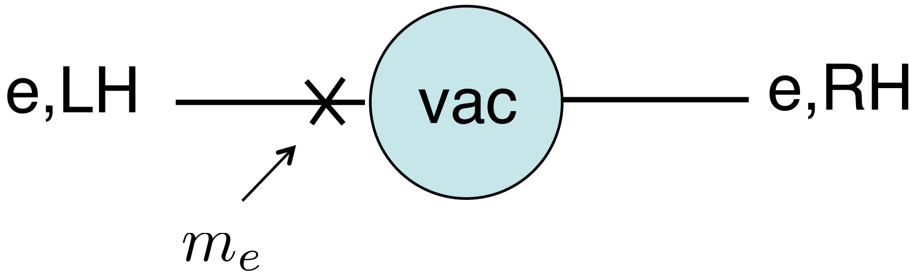
Give Mass to Superpartners

Remember the electron:



Give Mass to Superpartners

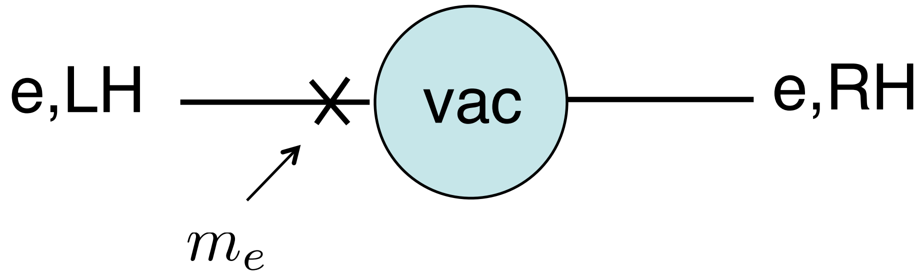
Remember the electron:



$$\delta m_e \sim \epsilon \, m_e \ln \Lambda \qquad \text{(dimensional analysis)}$$

Give Mass to Superpartners

Remember the electron:

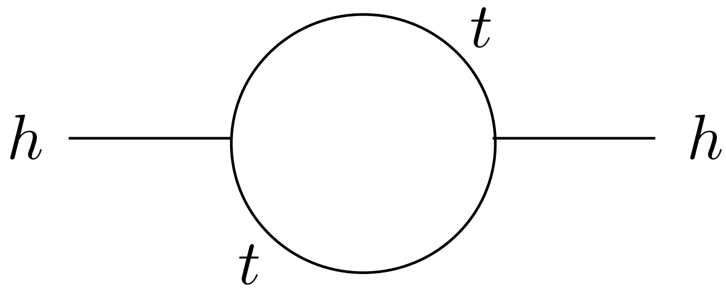


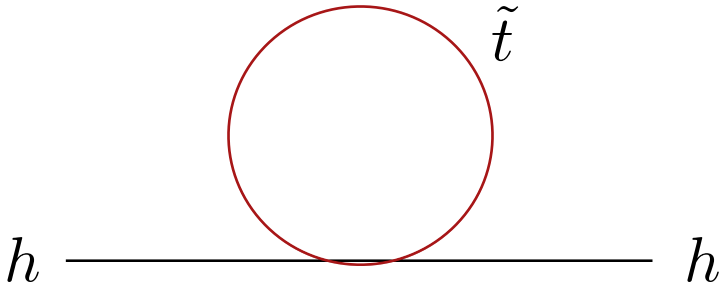
$$\delta m_e \sim \epsilon\, m_e \ln \Lambda \qquad \text{(dimensional analysis)}$$

Similarly, contributions to the Higgs mass will be proportional to the mass of superpartners (the ‘mass’ of supersymmetry breaking).

Supersymmetry could be an approximate symmetry and still stabilize the Higgs mass scale (solve the hierarchy problem).

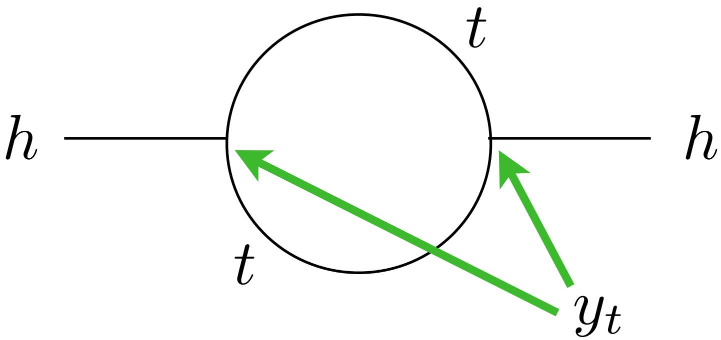
Top - Stop cancelation

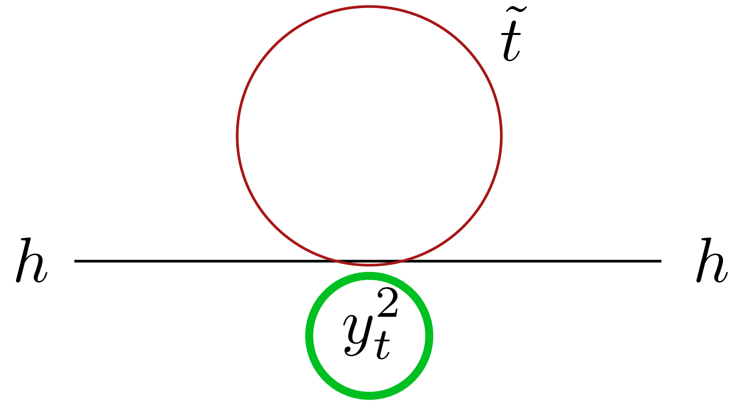




Exact supersymmetry - cancelation exact (up to w.f. ren.)

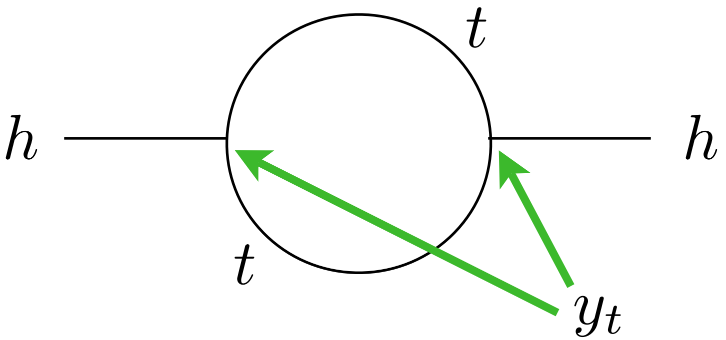
Top - Stop cancelation

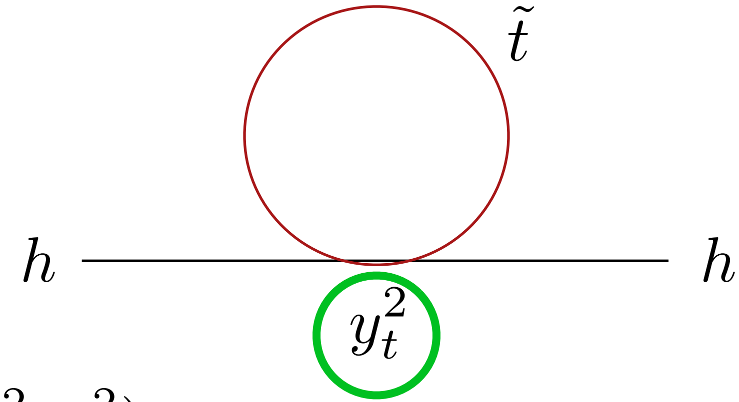




Exact supersymmetry - cancelation exact (up to w.f. ren.)

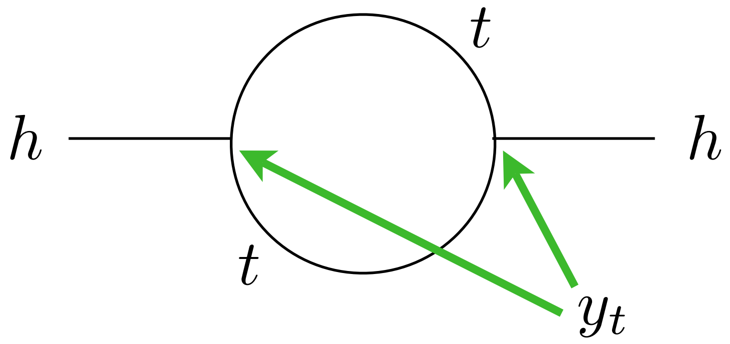
Top - Stop cancelation

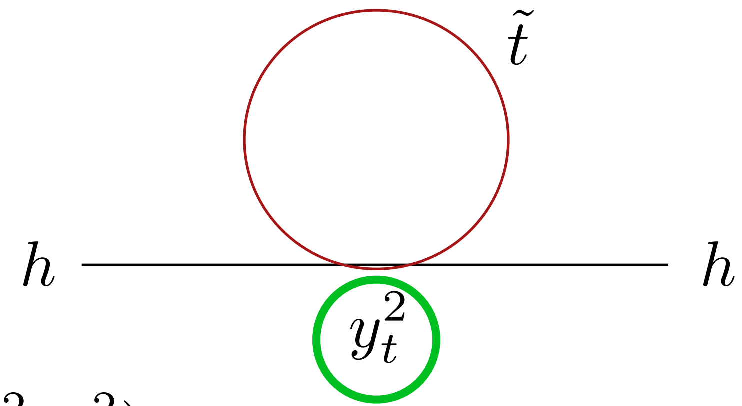




Broken SUSY $\qquad \delta m_h^2 = f(m_t^2, m_{\tilde{t}}^2, y_t^2)$

Top - Stop cancelation

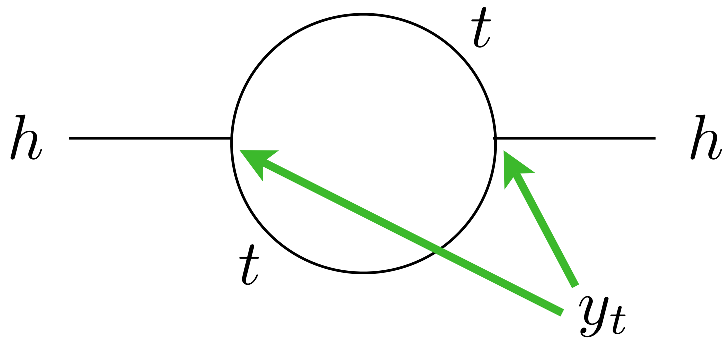


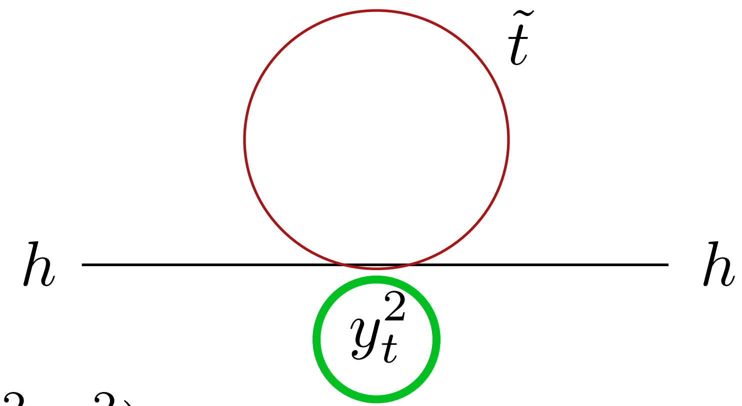


Broken SUSY $\delta m_h^2 = f(m_t^2, m_{\tilde{t}}^2, y_t^2)$

$$m_{\tilde{t}}^2 \neq m_t^2 \quad \rightarrow \quad \delta m_h^2 \propto (m_{\tilde{t}}^2 - m_t^2) \ln \Lambda$$ Soft breaking

Top - Stop cancelation



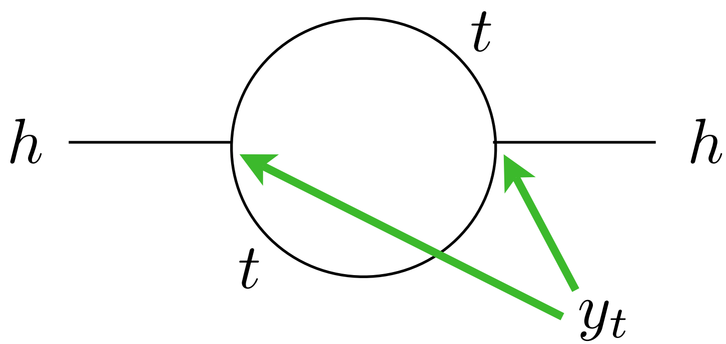


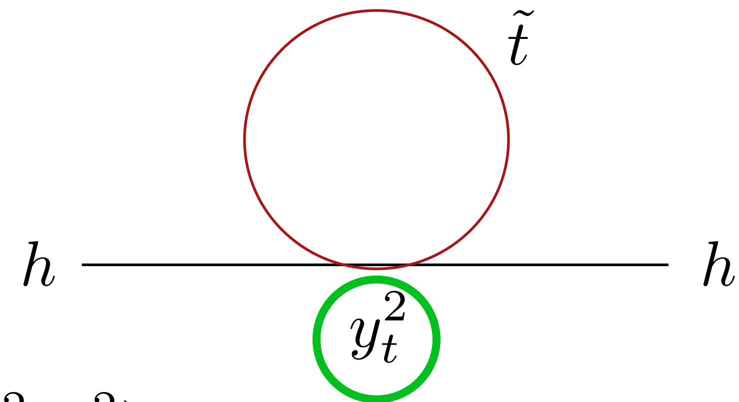
Broken SUSY $\qquad \delta m_h^2 = f(m_t^2, m_{\tilde{t}}^2, y_t^2)$

$$m_{\tilde{t}}^2 \neq m_t^2 \quad \rightarrow \quad \delta m_h^2 \propto (m_{\tilde{t}}^2 - m_t^2) \ln \Lambda \qquad \text{Soft breaking}$$

$$y_{\tilde{t}}^2 \neq y_t^2 \quad \rightarrow \quad \delta m_h^2 \propto (y_{\tilde{t}}^2 - y_t^2) \Lambda^2 \qquad \text{Hard breaking}$$

Top - Stop cancelation





Broken SUSY $\quad \delta m_h^2 = f(m_t^2, m_{\tilde{t}}^2, y_t^2)$

$$m_{\tilde{t}}^2 \neq m_t^2 \quad \rightarrow \quad \delta m_h^2 \propto (m_{\tilde{t}}^2 - m_t^2) \ln \Lambda$$ Soft breaking

$$y_{\tilde{t}}^2 \neq y_t^2 \quad \rightarrow \quad \delta m_h^2 \propto (y_{\tilde{t}}^2 - y_t^2) \Lambda^2$$ Hard breaking

remove the scalar top (“stop”) Hard breaking

Electroweak Symmetry Breaking

Reminder - in the Standard Model:

$$V \sim -\frac{1}{2}m^2h^2 + \frac{1}{4}\lambda h^4 \qquad \frac{\partial V}{\partial h} = 0 \rightarrow \langle h \rangle \equiv v = \sqrt{m^2/\lambda}$$

Electroweak Symmetry Breaking

Reminder - in the Standard Model:

$$V \sim -\frac{1}{2}m^2h^2 + \frac{1}{4}\lambda h^4 \qquad \frac{\partial V}{\partial h} = 0 \rightarrow \langle h \rangle \equiv v = \sqrt{m^2/\lambda}$$

MSSM:

$$\lambda = \frac{g_Z^2}{2}\left[\frac{1}{2}|H_1|^2 - \frac{1}{2}|H_2|^2\right]^2$$

The quartic in the MSSM comes for free, and the squared mass gets a negative contribution from the stop.

$$\delta m_{H_u}^2 \sim -\frac{3}{4\pi^2}y_t^2 m_{\tilde{t}}^2 \log \Lambda/m_{\tilde{t}}$$

Status

- Superpartners at $\sim$ 100 GeV?
- Electroweak symmetry breaking works
- No problems with electroweak precision
- Contains a viable dark matter WIMP (after saving the proton)

Number of Parameters

Masses for everybody.

- Scalar partners of LH fermions
- Scalar partners of RH fermions
- L-R masses after the Higgs gets a vev (A terms)
- Higgs mass parameters

Number of Parameters

Masses for everybody.

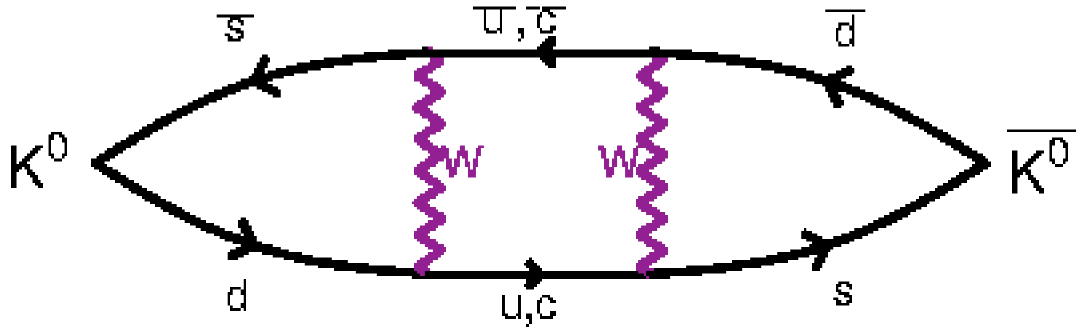
- Scalar partners of LH fermions
- Scalar partners of RH fermions
- L-R masses after the Higgs gets a vev (A terms)
- Higgs mass parameters

108 New Parameters (minus 1)

Parameters: Soft masses

$$
\begin{aligned}
\mathcal{L}_{\rm soft}^{\rm MSSM} \;=\;& -\frac{1}{2}\left(M_3\widetilde{g}\widetilde{g} + M_2\widetilde{W}\widetilde{W} + M_1\widetilde{B}\widetilde{B} + {\rm c.c.}\right) \\
& - \left(\widetilde{\overline{u}}\,\mathbf{a_u}\,\widetilde{Q}H_u - \widetilde{\overline{d}}\,\mathbf{a_d}\,\widetilde{Q}H_d - \widetilde{\overline{e}}\,\mathbf{a_e}\,\widetilde{L}H_d + {\rm c.c.}\right) \\
& -\widetilde{Q}^\dagger\,\mathbf{m^2_Q}\,\widetilde{Q} - \widetilde{L}^\dagger\,\mathbf{m^2_L}\,\widetilde{L} - \widetilde{\overline{u}}\,\mathbf{m^2_{\overline{u}}}\,\widetilde{\overline{u}}^\dagger - \widetilde{\overline{d}}\,\mathbf{m^2_{\overline{d}}}\,\widetilde{\overline{d}}^\dagger - \widetilde{\overline{e}}\,\mathbf{m^2_{\overline{e}}}\,\widetilde{\overline{e}}^\dagger \\
& - m^2_{H_u}H_u^*H_u - m^2_{H_d}H_d^*H_d - (bH_uH_d + {\rm c.c.})\,.
\end{aligned}
$$

Flavor Constraint



$\sim m_c^2$

Small in the standard model because the CKM matrix is unitary

$$V_{ud}^* V_{us} + V_{cd}^* V_{cs} + V_{td}^* V_{ts} = 0$$

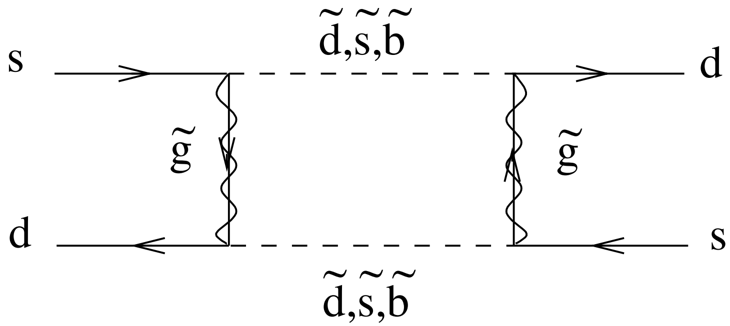
Soft masses - “Flavor Space”

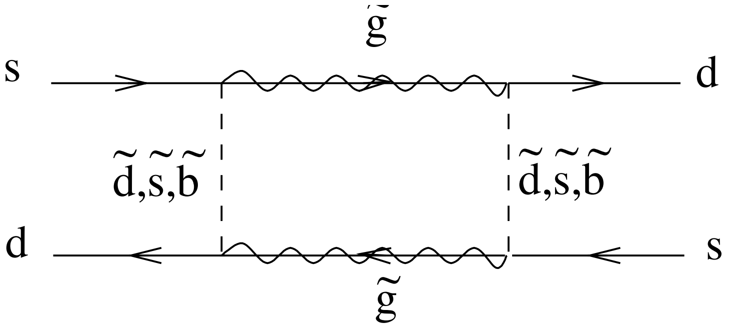
$$\begin{pmatrix} \tilde{d} & \tilde{s} & \tilde{b} \end{pmatrix}^* \cdot \begin{pmatrix} \tilde{m}^2_{dd} & \tilde{m}^2_{ds} & \tilde{m}^2_{db} \\ \tilde{m}^2_{sd} & \tilde{m}^2_{ss} & \tilde{m}^2_{sb} \\ \tilde{m}^2_{bd} & \tilde{m}^2_{bs} & \tilde{m}^2_{bb} \end{pmatrix} \cdot \begin{pmatrix} \tilde{d} \\ \tilde{s} \\ \tilde{b} \end{pmatrix}$$

Soft masses - "Flavor Space"

$$\begin{pmatrix} \tilde{d} & \tilde{s} & \tilde{b} \end{pmatrix}^* \cdot \begin{pmatrix} \tilde{m}^2_{dd} & \tilde{m}^2_{ds} & \tilde{m}^2_{db} \\ \tilde{m}^2_{sd} & \tilde{m}^2_{ss} & \tilde{m}^2_{sb} \\ \tilde{m}^2_{bd} & \tilde{m}^2_{bs} & \tilde{m}^2_{bb} \end{pmatrix} \cdot \begin{pmatrix} \tilde{d} \\ \tilde{s} \\ \tilde{b} \end{pmatrix}$$

$$\frac{m^2_{\tilde{d}\tilde{s}}}{m^2_{\tilde{s}\tilde{s}}} < few \times 10^{-4} \quad \text{for} \quad m^2_{\tilde{q}} = 500\ \text{GeV}$$



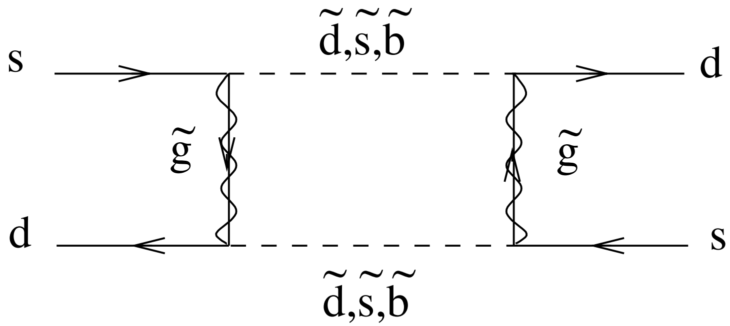


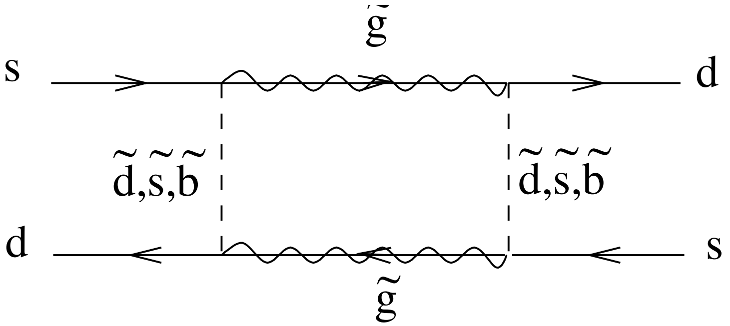
Soft masses - "Flavor Space"

Important because standard model process is also a loop

The problem goes away if the scalar masses are degenerate.

$$\frac{m^2_{\tilde{d}\tilde{s}}}{m^2_{\tilde{s}\tilde{s}}} < few \times 10^{-4} \quad \text{for} \quad m^2_{\tilde{q}} = 500 \text{ GeV}$$





Parameters: Soft masses

$$\mathcal{L}_{\rm soft}^{\rm MSSM} = -\frac{1}{2}\left(M_3\widetilde{g}\widetilde{g} + M_2\widetilde{W}\widetilde{W} + M_1\widetilde{B}\widetilde{B} + {\rm c.c.}\right)$$
$$-\left(\widetilde{\overline{u}}\,\mathbf{a_u}\,\widetilde{Q}H_u - \widetilde{\overline{d}}\,\mathbf{a_d}\,\widetilde{Q}H_d - \widetilde{\overline{e}}\,\mathbf{a_e}\,\widetilde{L}H_d + {\rm c.c.}\right)$$
$$-\widetilde{Q}^\dagger\,\mathbf{m_Q^2}\,\widetilde{Q} - \widetilde{L}^\dagger\,\mathbf{m_L^2}\,\widetilde{L} - \widetilde{\overline{u}}\,\mathbf{m_{\overline{u}}^2}\,\widetilde{\overline{u}}^\dagger - \widetilde{\overline{d}}\,\mathbf{m_{\overline{d}}^2}\,\widetilde{\overline{d}}^\dagger - \widetilde{\overline{e}}\,\mathbf{m_{\overline{e}}^2}\,\widetilde{\overline{e}}^\dagger$$
$$-m_{H_u}^2 H_u^* H_u - m_{H_d}^2 H_d^* H_d - (bH_uH_d + {\rm c.c.})\,.$$

Parameters: Soft masses

$$
\begin{aligned}
\mathcal{L}_{\text{soft}}^{\text{MSSM}} = & -\frac{1}{2}\left(M_3\widetilde{g}\widetilde{g} + M_2\widetilde{W}\widetilde{W} + M_1\widetilde{B}\widetilde{B} + \text{c.c.}\right) \\
& -\left(\widetilde{\overline{u}}\,\mathbf{a_u}\,\widetilde{Q}H_u - \widetilde{\overline{d}}\,\mathbf{a_d}\,\widetilde{Q}H_d - \widetilde{\overline{e}}\,\mathbf{a_e}\,\widetilde{L}H_d + \text{c.c.}\right) \\
& -\widetilde{Q}^\dagger\,\mathbf{m^2_Q}\,\widetilde{Q} - \widetilde{L}^\dagger\,\mathbf{m^2_L}\,\widetilde{L} - \widetilde{\overline{u}}\,\mathbf{m^2_{\overline{u}}}\,\widetilde{\overline{u}}^\dagger - \widetilde{\overline{d}}\,\mathbf{m^2_{\overline{d}}}\,\widetilde{\overline{d}}^\dagger - \widetilde{\overline{e}}\,\mathbf{m^2_{\overline{e}}}\,\widetilde{\overline{e}}^\dagger \\
& - m^2_{H_u}H_u^*H_u - m^2_{H_d}H_d^*H_d - (bH_uH_d + \text{c.c.}) .
\end{aligned}
$$

single parameters times the identity matrix

Parameters: Soft masses

proportional to Yukawa couplings

$$\mathcal{L}_{\rm soft}^{\rm MSSM} = -\frac{1}{2}\left(M_3\widetilde{g}\widetilde{g} + M_2\widetilde{W}\widetilde{W} + M_1\widetilde{B}\widetilde{B} + {\rm c.c.}\right)$$
$$-\left(\widetilde{\overline{u}}\,\mathbf{a_u}\,\widetilde{Q}H_u - \widetilde{\overline{d}}\,\mathbf{a_d}\,\widetilde{Q}H_d - \widetilde{\overline{e}}\,\mathbf{a_e}\,\widetilde{L}H_d + {\rm c.c.}\right)$$
$$-\widetilde{Q}^\dagger\,\mathbf{m_Q^2}\,\widetilde{Q} - \widetilde{L}^\dagger\,\mathbf{m_L^2}\,\widetilde{L} - \widetilde{\overline{u}}\,\mathbf{m_{\overline{u}}^2}\,\widetilde{\overline{u}}^\dagger - \widetilde{\overline{d}}\,\mathbf{m_{\overline{d}}^2}\,\widetilde{\overline{d}}^\dagger - \widetilde{\overline{e}}\,\mathbf{m_{\overline{e}}^2}\,\widetilde{\overline{e}}^\dagger$$
$$-m_{H_u}^2 H_u^* H_u - m_{H_d}^2 H_d^* H_d - (bH_uH_d + {\rm c.c.})\,.$$

single parameters times the identity matrix

$$\mathbf{a_u = y_u}\ \mathrm{A_u}$$

Simplified Parameter Space

gaugino masses: $M_{1,2,3}$

squarks and sleptons: $m_{q,u,d,l,e}$

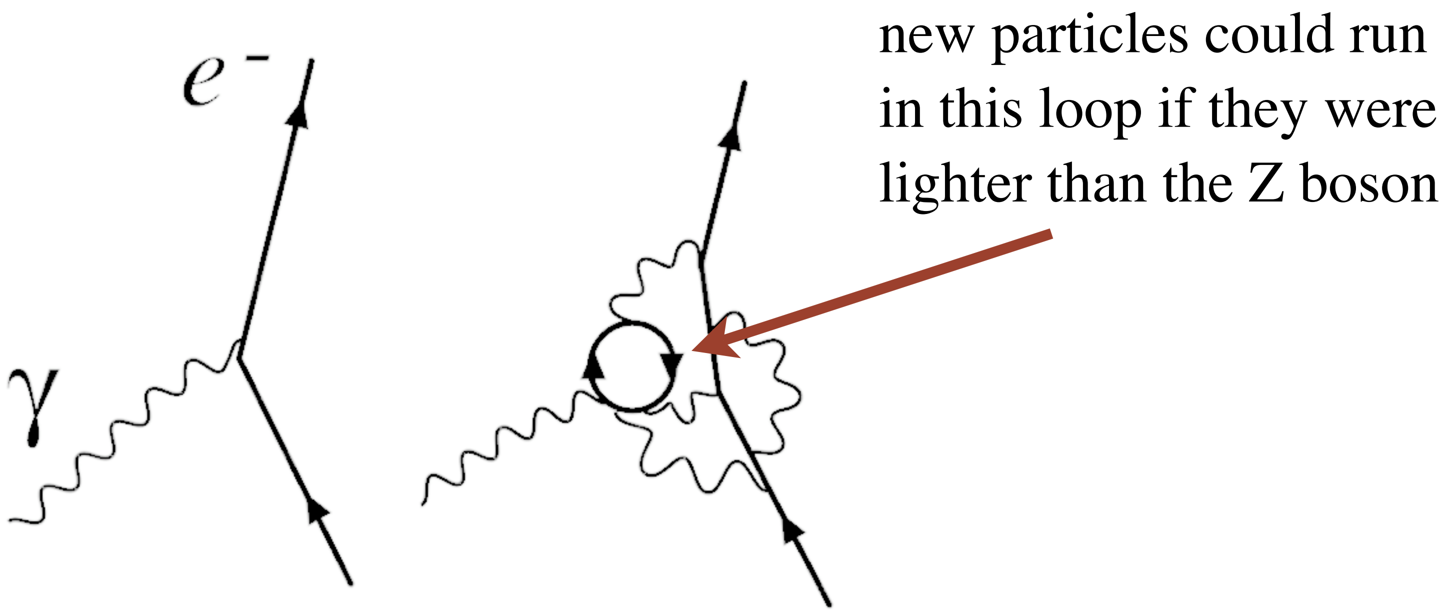
scalar^3 : $A_{u,d,l}$

higgs masses: $m_{1,2}$, b

All real: 14 parameters (mu is exchanged for the Z-mass)

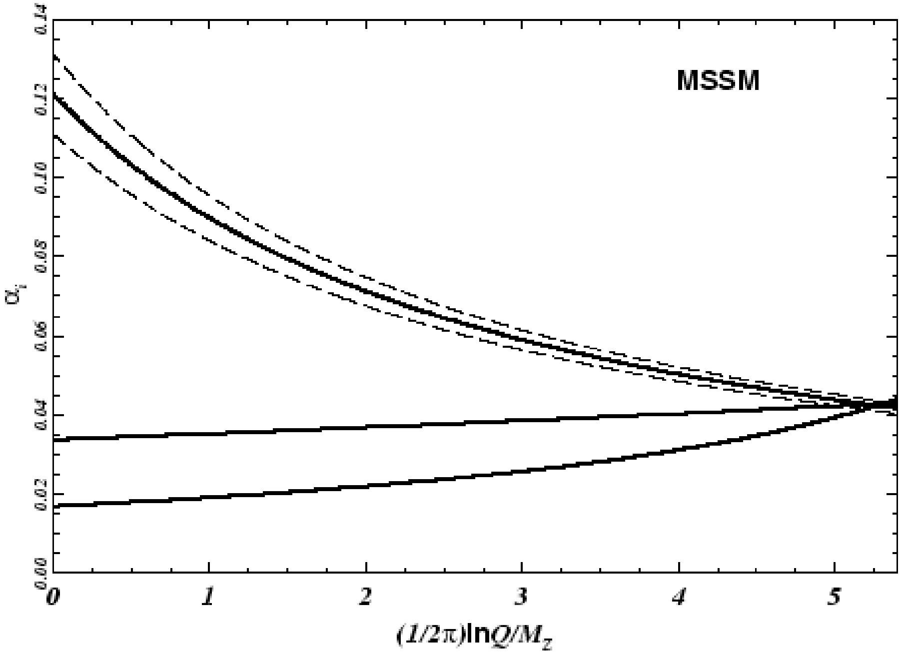
b can be exchanged for $\tan\beta$

Renormalization of couplings

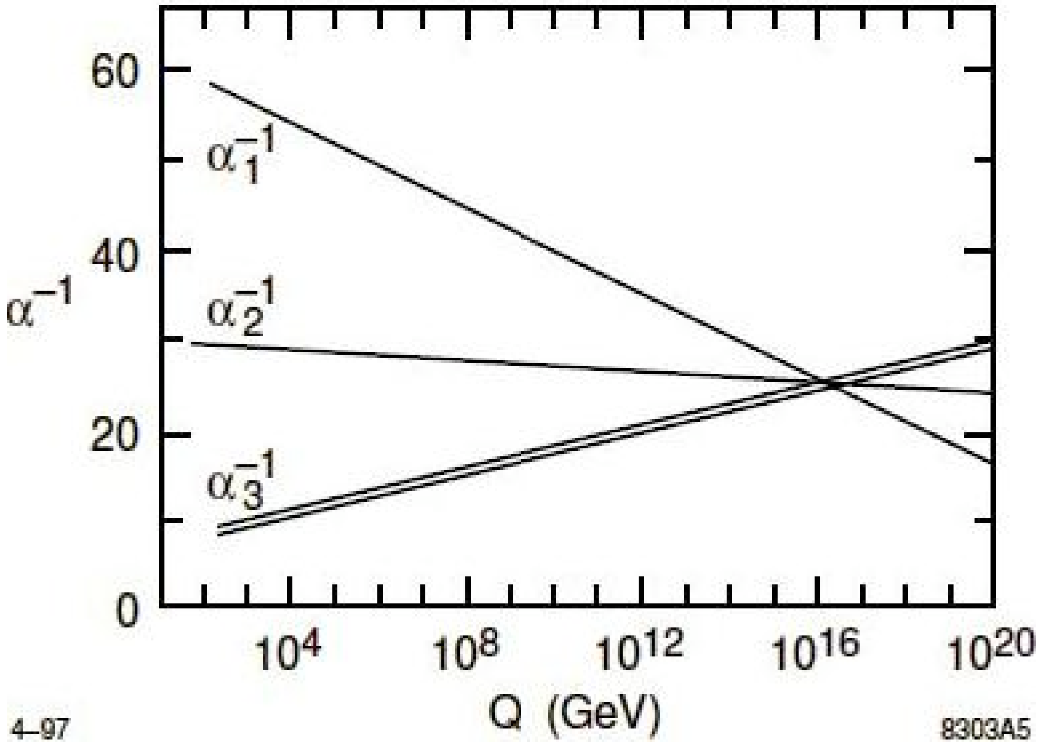


$$\alpha(1\,\mathrm{eV}) \simeq \frac{1}{137} \qquad \alpha(M_Z) \simeq \frac{1}{128}$$

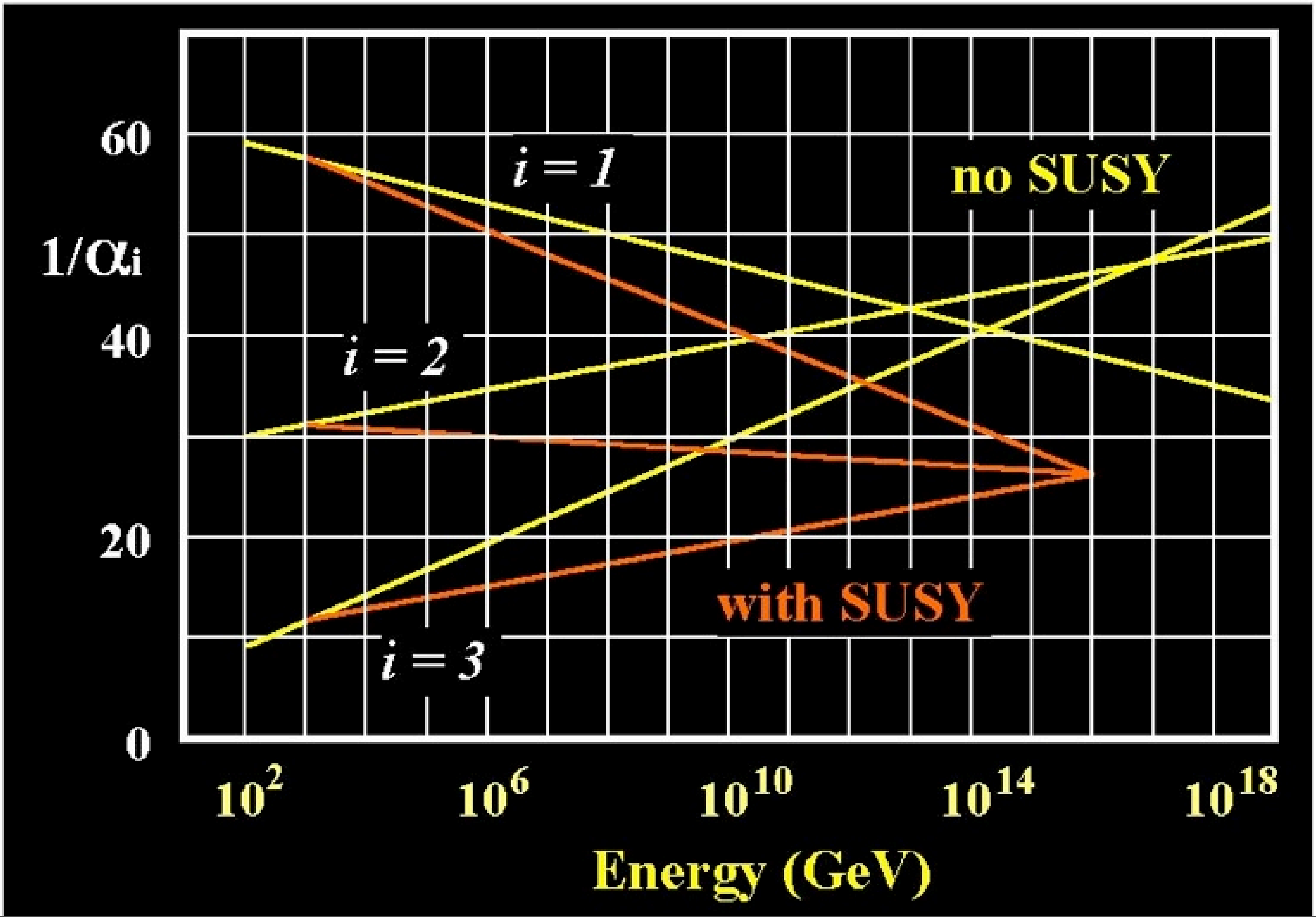
Evolution of gauge couplings



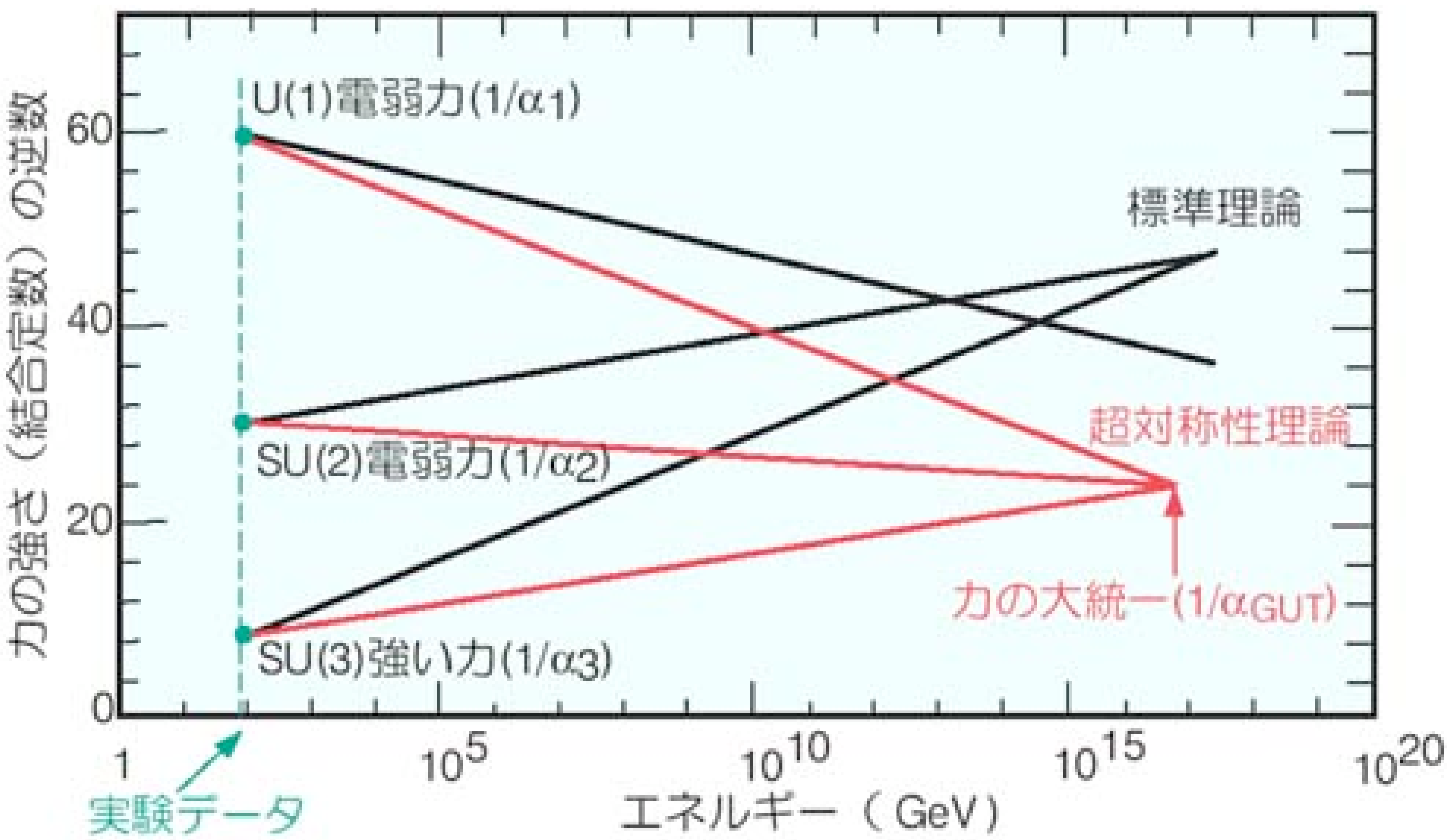
Evolution of gauge couplings



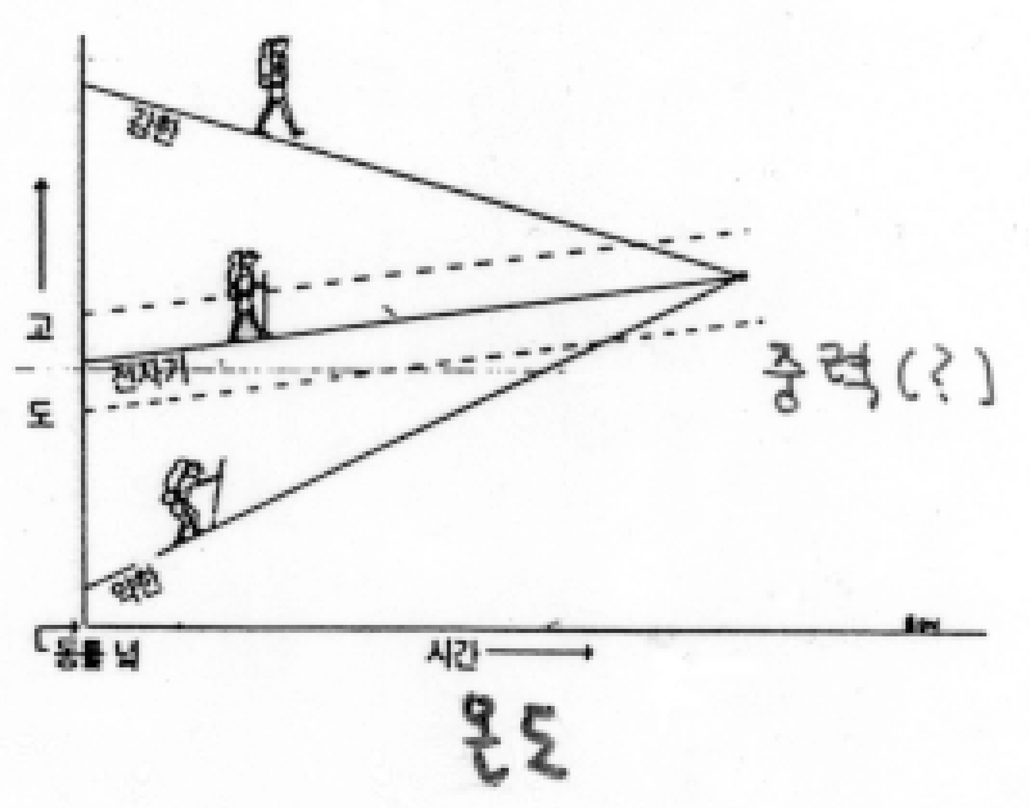
Evolution of gauge couplings



Evolution of gauge couplings



Evolution of gauge couplings



Simplifying even more

Pick a universal mass for all scalar partners, and another for all gauginos.

mSUGRA

$$m_0, M_{1/2}, A, \tan\beta, \ \mathrm{sgn}(\mu)$$

Build models of dynamical SUSY breaking

- Gauge Mediation: 3.5
- Anomaly Mediation: 2.5-5.5
- Gaugino Mediation: 1.5-4.5
- ...

Simplified parameter spaces

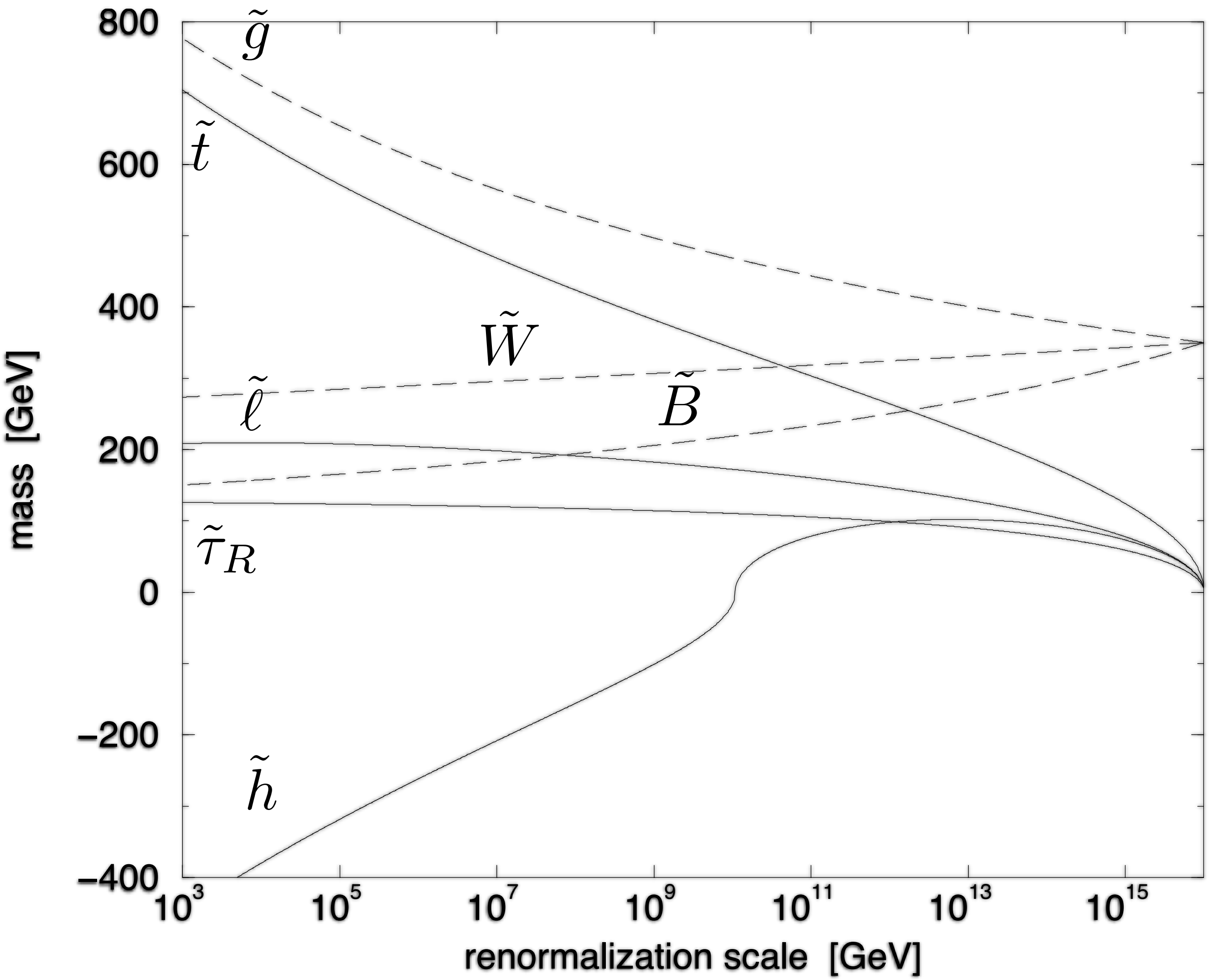
Partial Justification

If there is a Grand Unified theory at high energies, the gauginos will also be unified in a group, and in the case of SO(10), the squarks and sleptons are also unified.

These would be the conditions at the GUT scale.

Does not justify the degeneracy of flavors or assigning the same mass to the Higgses.

Typical Spectrum



The Higgs Mass

$$\text{MSSM} \quad \rightarrow \; m_{higgs} < 130 \text{ GeV}$$

??????????

With 100 new parameters!

The Higgs Mass

Reminder - in the Standard Model:

$$V \sim -\frac{1}{2}m^2h^2 + \frac{1}{4}\lambda h^4$$

$$\frac{\partial V}{\partial h} = 0 \to \langle h \rangle \equiv v = \sqrt{m^2/\lambda}$$

$$m^2_{phys} \sim \lambda v^2$$

We know the relationship, not the mass

The Supersymmetric Higgs Mass

The quartic coupling is dimensionless - thus supersymmetric to a good degree

$$\lambda = \frac{g_Z^2}{2}\left[\frac{1}{2}|H_1|^2 - \frac{1}{2}|H_2|^2\right]^2$$

Predicted quartic!

$$m_h = M_Z|\cos 2\beta| \qquad \text{with} \qquad \tan\beta = \langle H_2\rangle / \langle H_1\rangle$$

What now?

Corrections to the Higgs mass

$$\lambda v^2 = m^2_{phys} = 2\mu^2 + m^2_{soft}$$

$$\delta(m_h^2)_{phys} \propto y_t^2 m_t^2 \ln(m_{\tilde{t}}/m_t)$$ grows as a log

$$\delta(m_h^2)_{soft} \propto y_t^2 m_{\tilde{t}}^2 \ln(\Lambda/m_{\tilde{t}})$$ grows as a power

Typically need stop masses near 1 TeV

Higgs Potential

$$\lambda|h|^4 \rightarrow \frac{g^2}{8}\left[|H_1|^2 - |H_2|^2\right]^2$$

$$m_h = M_Z|\cos 2\beta|$$

SUSY-breaking loop required - same size as tree.

$$(m_h^2)_{tree} + \delta m_h^2 > (114\,\mathrm{GeV})^2$$

(Big Susy-breaking in top sector)

Direct Search Bounds

Charginos ~ 100 GeV

Staus ~ 80 GeV

→

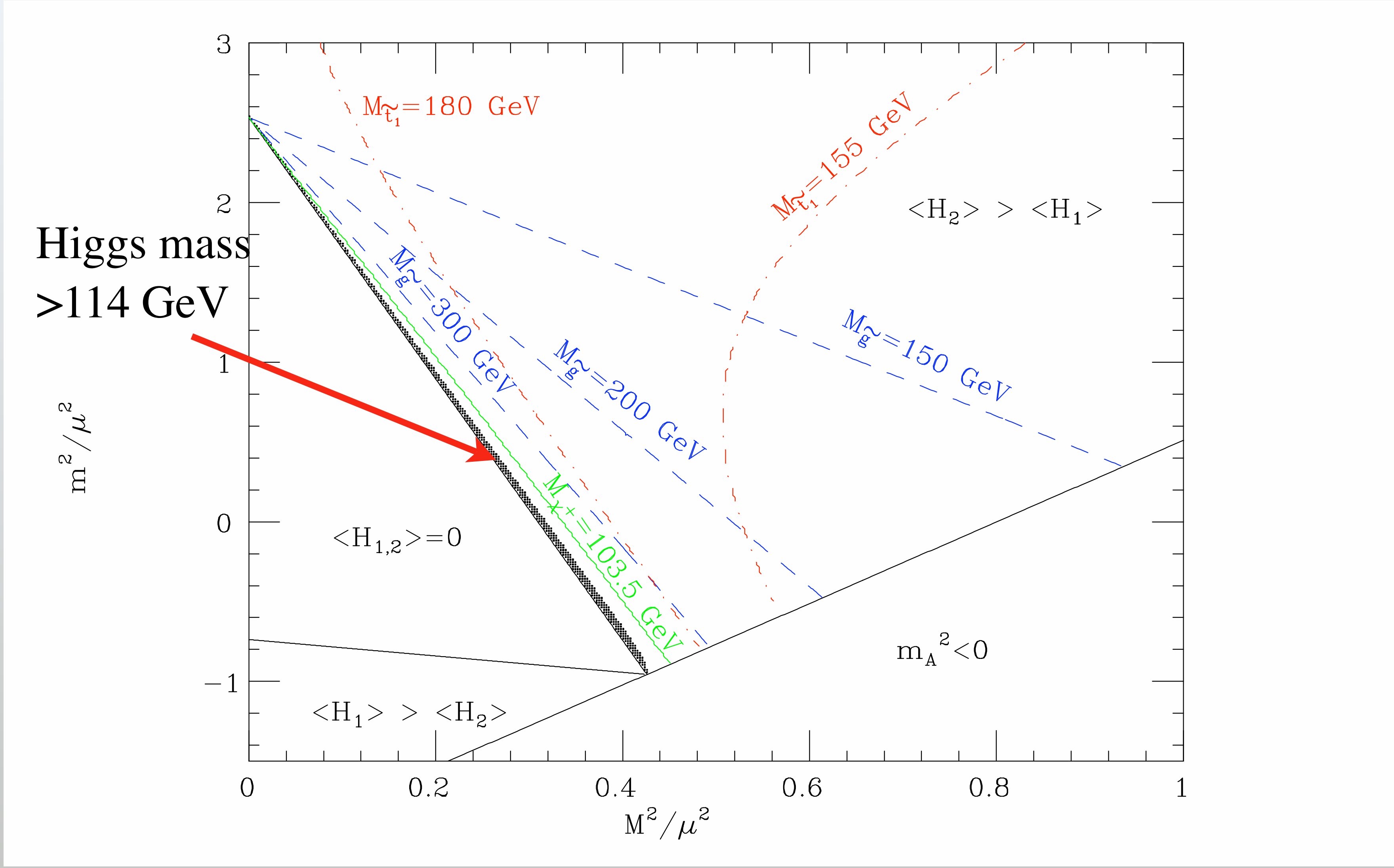
Stops ~ 350 - 400 GeV

Higgs soft mass ~ 300 GeV

$$\mu^2 - (300\ \mathrm{GeV})^2 = m^2_{higgs}/2 \sim (75\ \mathrm{GeV})^2$$

~ 6% tuning

State of mSUGRA



Giudice, Rattazzi ‘06