Introduction to SUPERSYMMETRY

2.- Minimal Supersymmetric Standard Model

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Minimal Supersymmetric Standard Model

- Must include all Standard Model particles and interactions
- Supersymmetric partners and SUSY version of SM interactions
- Supersymmetry must be softly broken

Chiral supermultiplets

LH SM fermion	$\leftrightarrow$	Scalar partner
$Q, u^c_R, d^c_R, L, e^c_R$		$\tilde{Q}, \tilde{u}^c_R, \tilde{d}^c_R, \tilde{L}, \tilde{e}^c_R$
2 Higgs	$\leftrightarrow$	fermionic part.
$H_1, \quad H_2$		$\tilde{H}_1, \quad \tilde{H}_2$

Vector supermultiplets

gauge bosons	$\leftrightarrow$	fermionic part.
B_μ, W^i_μ, G^a_μ		$\tilde{B}, \tilde{W}^i, \tilde{g}^a$

Gauge Interactions

Gauge self-interactions $-\frac{1}{4}F^a_{\mu\nu}F^{\mu\nu a} + i\bar{\lambda}^a\bar{\sigma}^\mu D_\mu\lambda^a$

with $D_\mu\lambda^a = \partial_\mu\lambda^a - gf^{abc}A^b_\mu\lambda^c$ for $SU(3)_C$, $SU(2)_L$ and $U(1)_Y$

Covariant derivatives $i\bar{\psi}\gamma^\mu D_\mu\psi + D_\mu\phi D^\mu\phi^*$

with $D_\mu = \delta_\mu + ig'YB_\mu + ig\frac{\tau^i}{2}W^i_\mu + ig_3\frac{\lambda^a}{2}G^a_\mu$ for ψ any of the MSSM left-handed fermions and ϕ any of the scalars

Gaugino interactions and D-terms $ig\sqrt{2}\left(\phi^*T^a\psi\lambda^a + \bar{\lambda}^a\bar{\psi}T^a\phi\right)$

$-\frac{1}{2}g^2(\sum_i \phi^*_i T^a\phi_i)$ for $SU(3)_C$, $SU(2)_L$ and $U(1)_Y$ and all the MSSM particles

MSSM Superpotential

Includes the Yukawa interactions of the SM

$$W = Y_d^{ij} Q_i H_1 d^c_{Rj} + Y_e^{ij} L_i H_1 e^c_{Rj} Y_u^{ij} Q_i H_2 u^c_{Rj} + \mu H_1 H_2$$

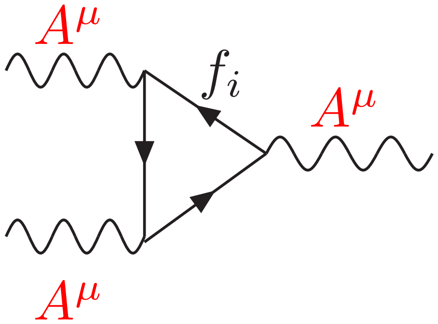
- Need of two Higgs doublets

$$Y_{Q_i} + Y_{d^c_R} = \frac{1}{6} + \frac{1}{3} = \frac{1}{2} \quad \Rightarrow \quad Y_{H_d} = -\frac{1}{2}$$
$$Y_{Q_i} + Y_{u^c_R} = \frac{1}{6} - \frac{2}{3} = -\frac{1}{2} \quad \Rightarrow \quad Y_{H_u} = \frac{1}{2}$$

in the SM $H_u = H$ and $H_d = H^*$. However, a Superpotential containing H^* would be non-supersymmetric.

A second doublet also required by anomaly cancellation.

Triangle diagram violates Ward identities and breaks gauge invariance.



$$\Longrightarrow \qquad \mathrm{Tr}[Y^3] = \mathrm{Tr}[T_3^2 Y] = 0$$

It cancels exactly for the SM fermions. But new charged fermion in Higgs supermultiplet. It must cancel with another fermion of opposite hipercharge.

- μ-term, Supersymmetric Higgs mass.

$$H_1^i = \begin{pmatrix} H_1^0 \\ H_1^- \end{pmatrix} \qquad H_2^i = \begin{pmatrix} H_2^+ \\ H_2^0 \end{pmatrix}$$

$$\mu H_1^i H_2^j \epsilon_{ij} = \mu (H_1^0 H_2^0 - H_1^- H_2^+)$$

R – Parity Other Gauge invariant terms can appear in W

$$W_{\Delta L=1} = \lambda^{ijk} L_i L_j e^c_{Rk} + \lambda'^{\,ijk} L_i Q_j d^c_{Rk} + \epsilon^i L_i H_2$$

$$W_{\Delta B=1} = \lambda''^{\,ijk}\, u^c_{Ri} d^c_{Rj} d^c_{Rk}$$

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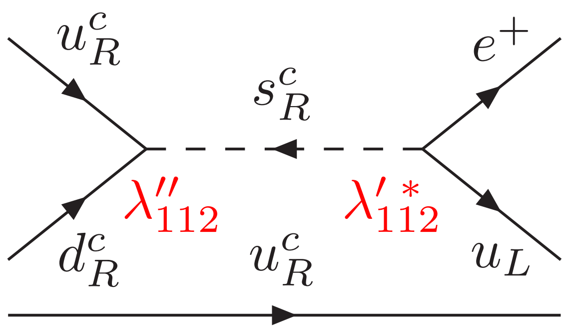
$$W_{\Delta B=1} = \lambda''^{\,ijk}\; u^c_{Ri} d^c_{Rj} d^c_{Rk}$$

violate baryon or lepton number by 1 unit. If both λ' and $\lambda'' \neq 0 \Rightarrow$ rapid proton decay!!



$$p^+ \to e^+ \pi^0 \Rightarrow \lambda'^{\,*}_{112} \cdot \lambda''_{112} \leq 2 \times 10^{-27}$$

New discrete symmetry, R-parity, forbids these terms

$R_P = (-1)^{3B+L+2S}$. SM particles and Higgs bosons $R_P = +1$, all superpartners $R_P = -1$

R_P conserved in the MSSM

- $W_{\Delta L=1}$ and $W_{\Delta B=1}$ absent in the MSSM.
- Lightest Supersymmetric Particle (LSP) stable (dark matter).
- Any sparticle decays into final state with odd number of LSP.
- In colliders, Supersymmetric particles only produced in pairs.

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It is also possible an R_P violating MSSM with $W_{\Delta L=1}$ or $W_{\Delta B=1}$ (not both) and stable proton.

- L or B is violated
- LSP is not stable anymore (not dark matter candidate).
- Single production of supersymmetric particles is possible.

Soft SUSY Breaking

- SUSY must be broken, $m_{\tilde{e}} \neq m_e, m_{\tilde{g}} \neq 0$.
- Solve hierarchy problem, broken by terms of possitive mass dimension Soft Supersymmetry Breaking, and $M_{susy} \leq \mathcal{O}(1$ TeV$)$.

  - Gaugino masses

$$L^{(1)}_{soft} = \frac{1}{2}\left(M_1\ \tilde{B}\tilde{B} + M_2\ \tilde{W}\tilde{W} + M_3\ \tilde{g}\tilde{g}\right) + h.c.$$

  - Scalar masses

$$L^{(2)}_{soft} = (m^2_{\tilde{Q}})_{ij}\tilde{Q}_i\tilde{Q}^*_j + (m^2_{\tilde{u}})_{ij}\tilde{u}^c_{Ri}\tilde{u}^{c*}_{Rj} + (m^2_{\tilde{d}})_{ij}\tilde{d}^c_{Ri}\tilde{d}^{c*}_{Rj} + (m^2_{\tilde{L}})_{ij}\tilde{L}_i\tilde{L}^*_j + (m^2_{\tilde{e}})_{ij}\tilde{e}^c_{Ri}\tilde{e}^{c*}_{Rj} + (m^2_{H_1})H_1H_1^*(m^2_{H_2})H_2H_2^*$$

  - Trilinear couplings and B–term

$$L^{(3)}_{soft} = (Y^A_d)^{ij}\tilde{Q}_iH_1\tilde{d}_{Rj} + (Y^A_e)^{ij}\tilde{L}_iH_1\tilde{e}^c_{Rj} + (Y^A_u)^{ij}\tilde{Q}_iH_2\tilde{u}^c_{Rj} + B\mu H_1H_2$$

$m^2_{\tilde{Q}}$, $m^2_{\tilde{u}}$, $m^2_{\tilde{d}}$, $m^2_{\tilde{L}}$ and $m^2_{\tilde{e}}$, hermitian 3×3 matrices in flavour space.
(Y^A_d), (Y^A_u) and (Y^A_u) complex 3×3 matrices

$$\Downarrow$$

Soft SUSY breaking in a completely general MSSM introduces more that 100 unknown parameters !!

Most of the possible flavour structures in soft terms severely constrained by experiment $\Rightarrow$ SUSY flavour and CP problems (??)

CMSSM (or mSugra)

Susy breaking mediated by gravity, minimal Kähler potential and gauge kinetic functions. At the Susy breaking scale:

$$m^2_{\tilde{Q}} = m^2_{\tilde{u}} = m^2_{\tilde{d}} = m^2_{\tilde{L}} = m^2_{\tilde{e}} = m^2_0\, \mathbf{1} \qquad m^2_{H_1} = m^2_{H_2} = m^2_0$$

$$(Y^A_d)_{ij} = A_0 (Y_d)_{ij} \qquad (Y^A_u)_{ij} = A_0 (Y_u)_{ij} \qquad (Y^A_e)_{ij} = A_0 (Y_e)_{ij}$$

CMSSM

- Minimal and simple realization of the MSSM.
- Similar sparticle masses in a general MSSM.
- Any generic MSSM must include at least the CMSSM physics.
- Main difference in FCNC and CP violation observables.
- Representative MSSM example for collider phenomenology.

Minimal number of new SUSY paramenters

m_0^2	$\rightarrow$	Universal scalar mass.	$M_{1/2}$	$\rightarrow$	Common gaugino mass.
A_0	$\rightarrow$	Universal trilinear.	B	$\rightarrow$	Soft Higgs mass.
μ	$\rightarrow$	Susy Higgs mass.	$\tan\beta$	$\rightarrow$	Ratio of Higgs vevs.

Soft breaking parameters defined at $\sim M_{GUT}$. Evolve them to M_W with Renormalization Group Equations (RGE).

- Gauge couplings and gaugino masses

$$\frac{d\alpha_a^{-1}}{dt} = -\frac{b_a}{2\pi} \qquad \frac{dM_a}{dt} = \frac{1}{8\pi^2} b_a g_a^2 M_a \qquad \frac{dM_a/g_a^2}{dt} = 0 \Rightarrow$$

$$\Rightarrow \frac{M_1}{\alpha_1} = \frac{M_2}{\alpha_2} = \frac{M_3}{\alpha_3} \qquad b_a = \left(\frac{33}{5}, 1, -3\right) \qquad t = \ln\left(\frac{Q}{Q_0}\right)$$

- Yukawa couplings (b–τ unification ...)

$$\frac{dy_t}{dt} = \frac{y_t}{16\pi^2}\left[6y_t^2 + y_b^2 - \tfrac{16}{3}g_3^2 - 3g_2^2 - \tfrac{13}{15}g_1^2\right]$$

$$\frac{dy_b}{dt} = \frac{y_b}{16\pi^2}\left[6y_b^2 + y_t^2 + y_\tau^2 - \tfrac{16}{3}g_3^2 - 3g_2^2 - \tfrac{7}{15}g_1^2\right]$$

$$\frac{dy_\tau}{dt} = \frac{y_\tau}{16\pi^2}\left[4y_\tau^2 + 3y_b^2 - 3g_2^2 - \tfrac{9}{5}g_1^2\right]$$

- Soft masses

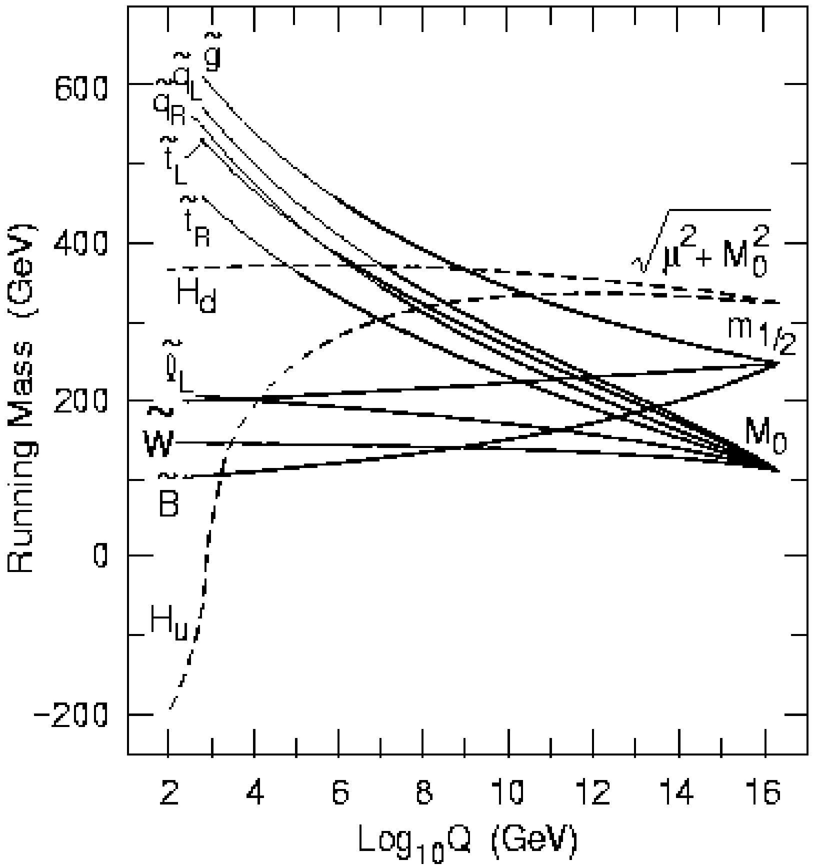
$$
\begin{aligned}
16\pi^2 \frac{d}{dt} m_{H_2}^2 &= 6y_t^2(m_{H_2}^2 + m_{Q_3}^2 + m_{U_3}^2) - 6g_2^2 M_2^2 - \frac{6}{5} g_1^2 M_1^2 \\
16\pi^2 \frac{d}{dt} m_{H_1}^2 &= -6g_2^2 M_2^2 - \frac{6}{5} g_1^2 M_1^2 \\
16\pi^2 \frac{d}{dt} m_{Q_3}^2 &= 2y_t^2(m_{H_2}^2 + m_{Q_3}^2 + m_{U_3}^2) - \frac{32}{3} g_3^2 M_3^2 - 6g_2^2 M_2^2 - \frac{2}{15} g_1^2 M_1^2 \\
16\pi^2 \frac{d}{dt} m_{U_3}^2 &= 4y_t^2(m_{H_2}^2 + m_{Q_3}^2 + m_{U_3}^2) - \frac{32}{3} g_3^2 M_3^2 - \frac{32}{15} g_1^2 M_1^2
\end{aligned}
$$

Full set of RGEs in literature. Fortran codes to obtain low energy param. in terms of high energy, ISASUSY, SOFTSUSY, SPHENO . . .

Mass of H_2 pushed down by top and absence of $SU(3)$ coupling

$$\Downarrow$$

Radiative Symmetry Breaking



Masses at M_W different but determined in terms of few GUT parameters.

Electroweak Symmetry Breaking

Now, Higgs potential at M_W, does it break EW symmetry?

$$V_{Higgs} = (m_{H_1}^2 + \mu^2)|H_1^0|^2 + (m_{H_2}^2 + \mu^2)|H_2^0|^2 + B\mu\, H_1^0 H_2^0 \; + \; (B\mu)^* H_1^{0*} H_2^{0*}$$
$$+ \quad \frac{g^2 + g'^2}{8}(|H_2^0|^2 - |H_1^0|^2)^2$$

Using gauge invariance rotate vevs to "neutral" components.

$H_1 = \begin{pmatrix} v_1 \\ 0 \end{pmatrix} \qquad H_2 = \begin{pmatrix} 0 \\ v_2 \end{pmatrix}$. Minimize potential, with $\tan\beta = v_2/v_1$

and $M_Z^2 = \frac{g^2 + g'^2}{2}(v_1^2 + v_2^2)$

$$\frac{dV_{Higgs}}{dH_1^0} = 0 \qquad B\mu = -\frac{1}{2}\left[(m_{H_1}^2 - m_{H_2}^2)\tan 2\beta + M_Z^2 \sin 2\beta\right]$$

$$\frac{dV_{Higgs}}{dH_2^0} = 0 \qquad \mu^2 = \frac{m_{H_2}^2 \sin^2\beta - m_{H_1}^2 \cos^2\beta}{\cos 2\beta} - \frac{1}{2}M_Z^2$$

Requirement of radiative symmetry breaking eliminates two parameters. CMSSM determined in terms of,

$$M_{1/2}, \quad m_0^2, \quad A_0, \quad \tan\beta$$

plus the sign (phase) of the μ parameter, not determined by the minimization conditions.

$$\Downarrow$$

Whole CMSSM spectrum determined in terms of 4 parameters

Once EW symmetry is broken, different particles can mix

Neutralinos	Charginos	Sfermions
$\tilde{B}, \tilde{W}^0, \tilde{H}_1^0, \tilde{H}_2^0$	$\tilde{W}^+, \tilde{H}^+$	$\tilde{f}_L, \tilde{f}_R$

(C)MSSM Spectrum

Whole CMSSM spectrum determined in terms of 4 parameters
$M_{1/2}, \quad m_0^2, \quad A_0, \quad \tan\beta$, after RGE to M_W

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- Gaugino masses

$$M_3 \simeq 2.8 M_{1/2}, \; M_2 \simeq 0.8 M_{1/2}, \; M_1 \simeq 0.4 M_{1/2}$$

- Sfermion get large gaugino (gluino) contribution $\tan\beta = 10$

$$m^2_{\tilde{Q}_{1(2)}} \simeq 6.5\, M^2_{1/2} + m_0^2 \qquad m^2_{\tilde{Q}_3} \simeq 5.3\, M^2_{1/2} + 0.75\, m_0^2 \qquad m^2_{\tilde{d}_{1(2)}} \simeq 6.1\, M^2_{1/2} + m_0^2$$

$$m^2_{\tilde{u}_{1(2)}} \simeq 6.15\, M^2_{1/2} + m_0^2 \qquad m^2_{\tilde{u}_3} \simeq 3.9\, M^2_{1/2} + 0.5\, m_0^2 \qquad m^2_{\tilde{d}_3} \simeq 5.8\, M^2_{1/2} + m_0^2$$

$$m^2_{\tilde{L}} \simeq 1.5\, M^2_{1/2} + m_0^2 \qquad m^2_{H_1} \simeq 0.21\, M^2_{1/2} + m_0^2 \qquad m^2_{\tilde{e}} \simeq 0.15\, M^2_{1/2} + m_0^2$$

$$m^2_{H_2} \simeq -2.7\, M^2_{1/2} - 0.12 m_0^2$$

SM	Superpartner	Q. Num.	SM	Superpartner	Q. Numb.
Q_L	squark doublet $\tilde{Q}_L$	$(3, 2, \frac{1}{6})$	L_L	slepton doublet $\tilde{L}_L$	$(1, 2, -\frac{1}{2})$
u_R	up squark singlet $\tilde{u}_R$	$(3, 1, \frac{2}{3})$	d_R	sdown singlet $\tilde{d}_R$	$(3, 1, -\frac{1}{3})$
e_R	selectron singlet $\tilde{e}_R$	$(1, 1, -1)$	ν_R	sneutrino right $\tilde{\nu}_R$	$(1, 1, 0)$
H_1	down higgsino $\tilde{H}_1$	$(1, 2, -\frac{1}{2})$	H_2	up higgsino $\tilde{H}_2$	$(1, 2, \frac{1}{2})$
g	gluino $\tilde{g}$	$(8, 1, 0)$	W	Wino $\tilde{W}$	$(1, 3, 0)$
B	bino $\tilde{B}$	$(1, 1, 0)$			

CMSSM Spectrum

MSSM Higgses

2 complex Higgs doublets $\rightarrow$ 8 real degrees of freedom

$$H_1 = \begin{pmatrix} H_1^0 \\ H_1^- \end{pmatrix} \qquad H_2 = \begin{pmatrix} H_2^+ \\ H_2^0 \end{pmatrix}$$

with $H_n^0 = \frac{1}{\sqrt{2}}(v_n + h_n + i a_n)$

we calculate Higgs masses from potential (Ex. 2 ($B\mu$ real, vev real)),

$$\begin{aligned} V_{Higgs} &= (\mu^2 + m_{H_1}^2)(|H_1^0|^2 + |H_1^-|^2) + (\mu^2 + m_{H_2}^2)(|H_2^0|^2 + |H_2^+|^2) \\ &+ (B\mu\, H_1^0 H_2^0 - B\mu\, H_1^- H_2^+ + c.c.) + \frac{g^2}{2}\left|H_1^{-*} H_2^0 + H_1^{0*} H_2^+\right|^2 \\ &+ \frac{g'^2 + g^2}{8}\left(|H_1^0|^2 + |H_1^-|^2 - |H_2^0|^2 - |H_2^+|^2\right)^2 \end{aligned}$$

Now, using the minimization conditions , $\partial V/\partial h_a = 0 \Longrightarrow$

$(\mu^2 + m_{H_1}^2) = -B\mu \ \tan\beta - \frac{1}{2} M_Z^2 \cos 2\beta$, $(\mu^2 + m_{H_2}^2) = -B\mu \ \cot\beta + \frac{1}{2} M_Z^2 \cos 2$,

we obtain for the pseudoscalar Higgs (basis $(a_1/\sqrt{2}, a_2/\sqrt{2})$)

$$M_I^2 \ = \begin{pmatrix} -B\mu \tan\beta & B\mu \\ B\mu & -B\mu \cot\beta \end{pmatrix}$$

Then, we obtain a massless would-be Goldstone

$G^0 = \frac{1}{\sqrt{2}}(\cos\beta a_1 - \sin\beta \ a_2)$ and a physical pseudoscalar,

$A = \dfrac{1}{\sqrt{2}}(\cos\beta \ a_1 + \sin\beta \ a_2)$ of mass $m_A^2 = -2B \ \mu/\sin 2\beta$

Then, the real neutral components (basis $(h_1/\sqrt{2}, h_2/\sqrt{2})$)

$$M_R^2 \ = \begin{pmatrix} -B\mu \tan\beta + M_Z^2 \cos^2\beta & B\mu - \frac{1}{2} M_Z^2 \sin 2\beta \\ B\mu - \frac{1}{2} M_Z^2 \sin 2\beta & -B\mu \cot\beta + M_Z^2 \sin^2\beta \end{pmatrix}$$

from here we get two eigenvalues, h^0, H^0 with a mixing $\sin\alpha$

$$m^2_{H,h} = \frac{1}{2}\left[m^2_A + M^2_Z \pm \sqrt{(m^2_A + M^2_Z)^2 - 4m^2_A M^2_Z \cos^2 2\beta}\right]$$

(tree level) $m_h \leq min(M_Z, m_A)|\cos 2\beta|$!!!!!

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(tree level) $m_h \leq min(M_Z, m_A)|\cos 2\beta|$!!!!!

Fortunately (?) this relation is corrected by large top–stop loops,

$$m^2_h \leq M^2_Z \cos^2 2\beta + \frac{m^2_t}{32\pi^2 M^2_W \sin^2\beta} \ln \frac{m_{\tilde{t}_1} m_{\tilde{t}_2}}{m^2_t}$$

$$m_h \lesssim 130 \text{ GeV}$$

similarly the charged Higgs

$$\begin{pmatrix} G^+ \\ H^+ \end{pmatrix} = \begin{pmatrix} \cos\beta & -\sin\beta \\ \sin\beta & \cos\beta \end{pmatrix} \begin{pmatrix} H_1^{-*} \\ H_2^+ \end{pmatrix}, \qquad m_{H^+} = m^2_A + M^2_W$$

Charginos

The Superpartners of $W^{\pm}$ and $H^{\pm}$ mix through a matrix,

$$M_{\chi^+} = \begin{pmatrix} M_2 & \sqrt{2} M_W \sin\beta \\ \sqrt{2} M_W \cos\beta & \mu \end{pmatrix} U^* \cdot M_{\chi^+} \cdot V^\dagger = \begin{pmatrix} m_{\chi_1^+} & 0 \\ 0 & m_{\chi_2^+} \end{pmatrix}$$

,

$$m_{\chi_{1,2}^+} = \frac{1}{2}\left[M_2^2 + \mu^2 + 2M_W^2 \mp \sqrt{(M_2^2 + \mu^2 + 2M_W^2)^2 - 4(\mu M_2 - M_W^2 \sin 2\beta)^2} \right]$$

In the limit $M_W << \mu, M_2$ and typically $M_2 < \mu$, the lightest chargino is gaugino-like while the heaviest one is higgsino-like

$$m_{\chi_1^+} \simeq M_2 - \frac{M_W^2 (M_2 + \mu \sin 2\beta)}{\mu^2 - M_2^2} \qquad m_{\chi_2^+} \simeq \mu + \frac{M_W^2 (\mu + \epsilon M_2 \sin 2\beta)}{} \mu^2 - M_2^2$$

Neutralinos

Neutral Higgsinos and neutral gauginos mix, in the basis
$\psi^0 = (\tilde{B}, \tilde{W}^0, \tilde{H}_1^0, \tilde{H}_2^0)$

$$M_{\tilde{N}} = \begin{pmatrix} M_1 & 0 & -M_Z c\beta s\theta_W & M_Z s\beta s\theta_W \\ 0 & M_2 & M_Z c\beta c\theta_W & M_Z s\beta c\theta_W \\ -M_Z c\beta s\theta_W & M_Z c\beta c\theta_W & 0 & -\mu \\ M_Z s\beta s\theta_W & -M_Z s\beta c\theta_W & -\mu & 0 \end{pmatrix}$$

this is diagonalized by a unitary matrix N

$$N^* \cdot M_{\tilde{N}} \cdot N^\dagger = \text{Diag.}(m_{\chi_1^0}, m_{\chi_2^0}, m_{\chi_3^0}, m_{\chi_4^0})$$

usually the lightest neutralino is the LSP and is approximately Bino,
$m_{\chi_1^0} \approx M_1 \simeq 0.4 M_{1/2}$, second is approx. Wino, $m_{\chi_2^0} \approx M_2 \simeq 0.8 M_{1/2}$
and the two heaviest neutralinos are Higgsino-like, $m_{\chi_{3,4}^0} \approx \mu$

Sfermion masses

$\tilde{f}_L$ and $\tilde{f}_R$ mix after EW breaking. 6×6 mixing matrix (in CMSSM small intergenerational mixing)

$$M^2_{\tilde{f}} = \begin{pmatrix} m^2_{\tilde{f}_{LL}} & m^2_{\tilde{f}_{LR}} \\ m^2_{\tilde{f}_{LR}} & m^2_{\tilde{f}_{RR}} \end{pmatrix} \qquad m^2_{\tilde{f}_{RR}} = m^2_{\tilde{f}_R} + m^2_f + M^2_Z \cos 2\beta s^2\theta_W Q_{em}$$

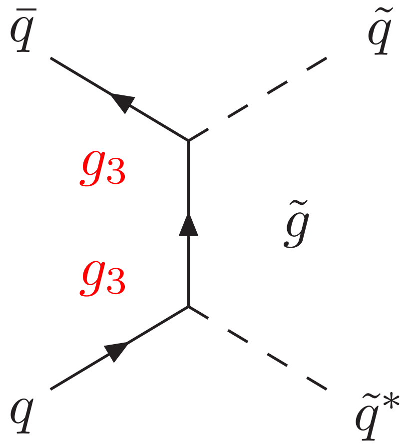
$$m^2_{\tilde{f}_{LL}} = m^2_{\tilde{f}_L} + m^2_f + M^2_Z \cos 2\beta (I_3 + s^2\theta_W Q_{em}) \qquad m^2_{\tilde{f}_{LR}} = m_f (A - \mu^{tg\beta}_{ctg\beta})$$

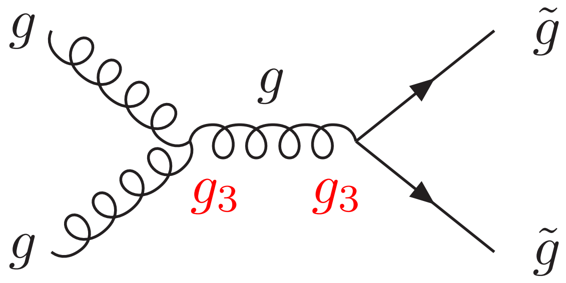
for $f =^{e,d}_{u}$. LR mixing is proportional to fermion masses, m_f. Only important for top (also bottom and tau in the large $\tan\beta$ regime)

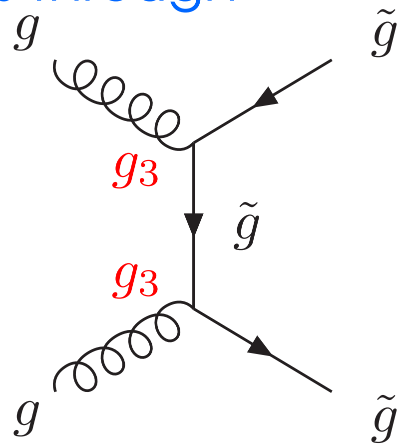
$$\begin{pmatrix} \tilde{t}_1 \\ \tilde{t}_2 \end{pmatrix} = \begin{pmatrix} \cos\theta_t & \sin\theta_t \\ -\sin\theta_t & \cos\theta_t \end{pmatrix} \begin{pmatrix} \tilde{t}_L \\ \tilde{t}_R \end{pmatrix}$$

Sparticle production

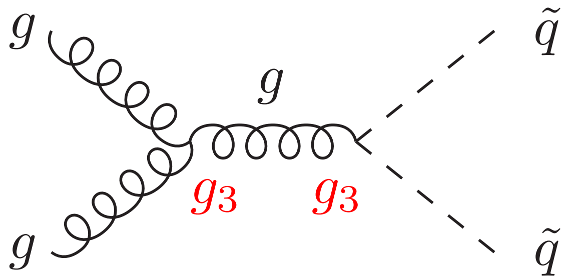
Gluino and Squark production (1st gen.) dominates through

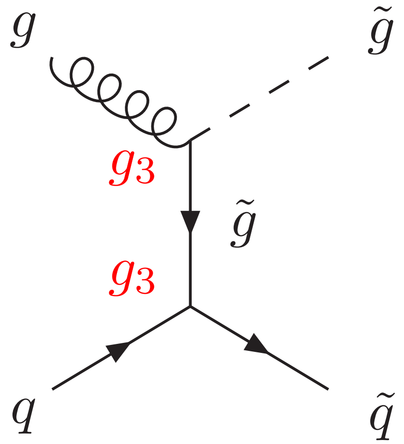






LHC strong constraints on gluino and 1st gen. squark masses, strongly produced.





Sparticle decays

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Charginos & Neutralinos: *i)* Lightest neutralino LSP, thus stable. *ii)* Other neutralinos and charginos decay through two- or three-body (with off-shell gauge boson) decays, all them with EW couplings.

$$\chi_i^0 \to Z\chi_j^0,\ W^-\chi_j^+,\ h\chi_j^0,\ l\tilde{l},\ \nu\tilde{\nu} \quad \chi_i^+ \to Z\chi_1^+,\ W^-\chi_j^0,\ h\chi_1^0,\ l\tilde{\nu},\ \nu\tilde{l}$$

$$\chi_i^0 \to f\bar{f}\chi_j^0,\ f\bar{f}'\chi_j^+ \qquad \chi_i^+ \to f\bar{f}\chi_1^+,\ f\bar{f}'\chi_j^0$$

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Sleptons: • Sleptons can not be the LSP (?) so two body decays to the LSP always allowed, and can also decay to other neutralinos and charginos if heavy enough

$$\tilde{l} \to l\chi_1^0, \qquad \tilde{\nu} \to \nu\chi_1^0$$

$$\tilde{l} \to l\chi_i^0,\ \ \nu\chi_i^- \quad \tilde{\nu} \to \nu\chi_i^0,\ \ l\chi_i^+$$

Squarks & gluinos

- If two body decays with strong coupling are allowed they always dominate

$$\tilde{q} \to q\tilde{g}, \qquad \tilde{g} \to q\tilde{q}$$

Otherwise squarks decay to quark chargino or neutralino through electroweak couplings

$$\tilde{q} \to q\chi_i^0, \quad q'\chi_i^-$$

and gluinos decay through an off-shell squark

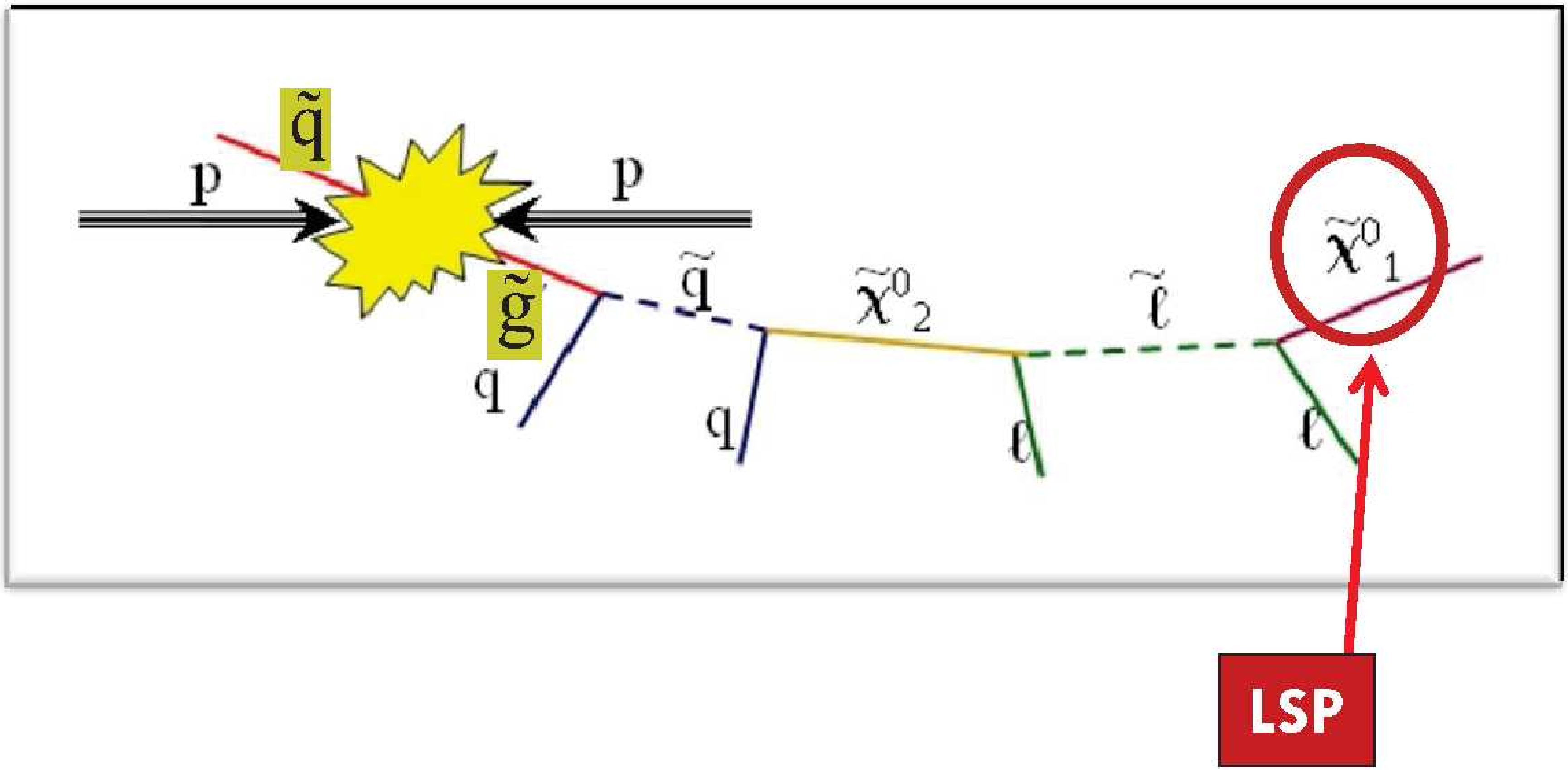
$$\tilde{g} \to qq\chi_i^0, \quad qq'\chi_i^-$$

Beyond CMSSM

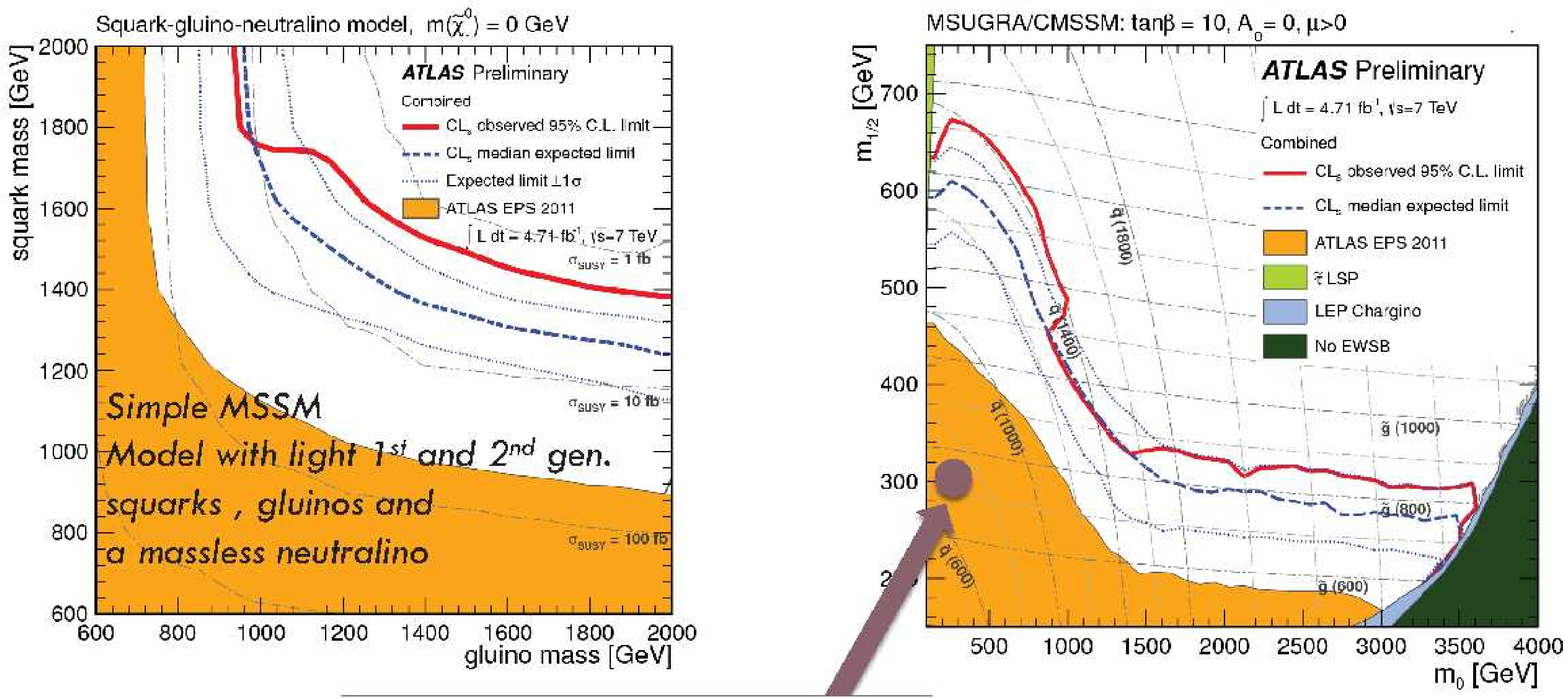
- Even in MSSM (no new supermultiplets) with conserved R-parity physics change with different soft breaking terms.
- Main features of the sparticle spectrum remain similar to CMSSM.
- Sfermion mixing produces sizable and interesting effects in FCNC and CP violation experiments.
- SUSY GUT models describe the physics at M_{GUT}, new processes like proton decay...
- R-parity violation allows single decay and production channels, new FCNC contributions
- NMSSM includes an additional gauge singlet supermultiplet to generate the μ term $\mathcal{O}(M_W)$, changes in the spectrum...

LHC CONSTRAINTS

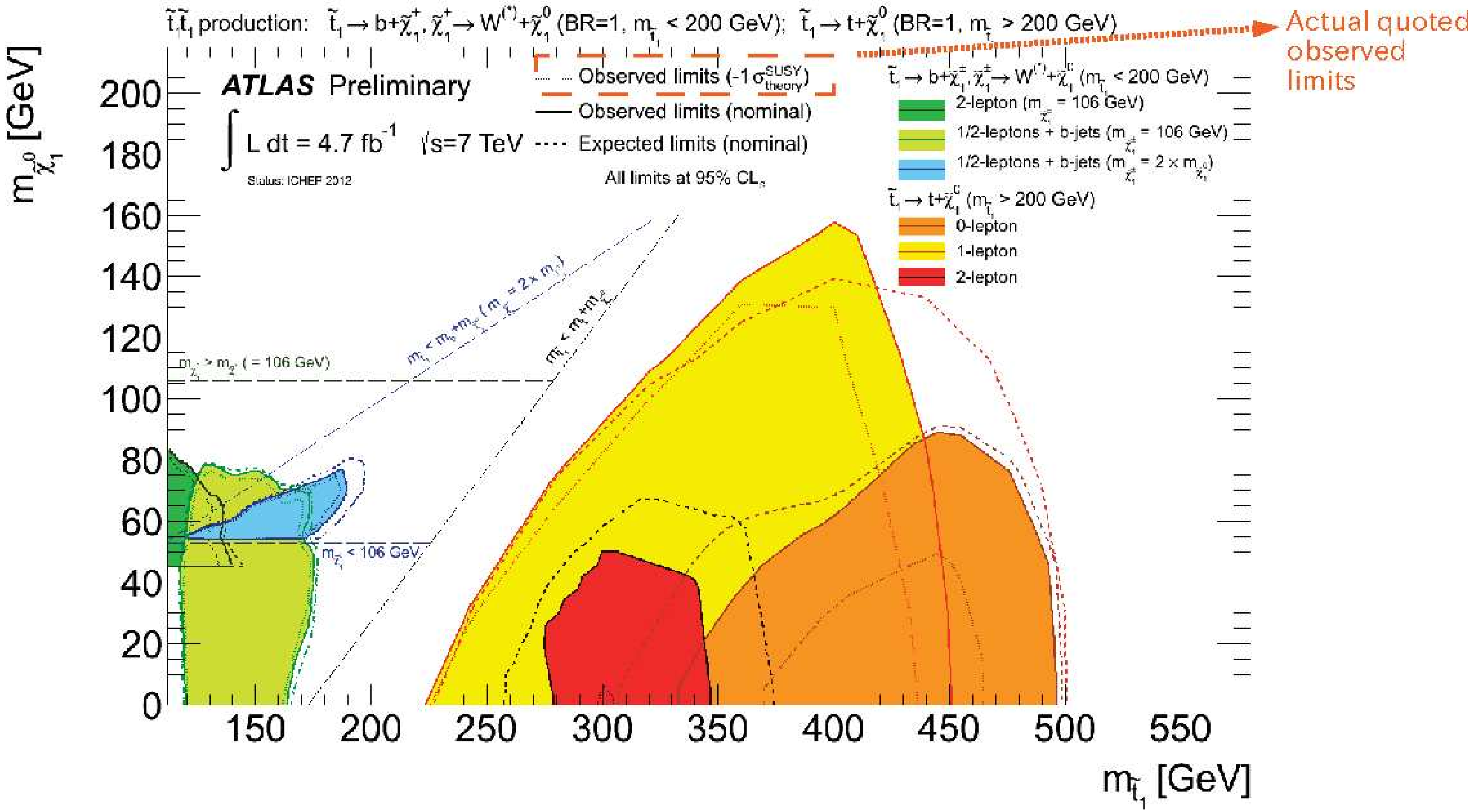
– Production of coloured particles with long decay chains. . .



– Search of jets + missing E_T:



– Stop ($\tilde{t}$) production:



$\Longrightarrow$ already ver stringent constraints for minimal models (CMSSM like), but not yet dead!!!