Minimal Susy SO(10), DM and LHC

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- SLRM: R_p, m_ν and DM
- SO(10) MSGUT and NMSGUT
- Realistic fits of MSSM hard couplings(21 parameters)
- Characteristic Susy Spectra.
- Exotic Phenomenology: B decay, LSP features, Precision signals, LHC signals......

BSM Hint Complex

- Unification of couplings in SM $\sim 10^{14}$ GeV $\Rightarrow \not{B} - \not{L}$
- Neutrino oscillations + SM Gauge invariance

$$\Rightarrow m_\nu \neq 0 : \Lambda_{B-L} \sim M_W^2/m_\nu > 10^{13} - 10^{16} GeV$$

  OR unnaturally light and weakly coupled ν_Rs

- Scalar Higgs $\Rightarrow$ Instability mixes M_W and Λ_{NP} : GHP
- Susy allows stabilization AND yields exact g_i confluence at $M_X^0 \sim 10^{16.25}$ GeV
- Neutrino mass $\Leftrightarrow$ *Susy* $\Leftrightarrow$ Baryon decay/Unification : OUROBOUROS

Dark Matter

- Astronomy : Dark, Collisionless Matter $\Omega h^2 \sim 0.1$ necessary : WIMP(χ) long standing favourite.
- Relic $\Rightarrow \rho_{CDM} \sim 0.3 GeV/cc$
- Neutral, colourless to evade limits :
- $\tau_\chi >> 10^{18}$ sec for relic :
- $\Rightarrow \sigma_{ann} \sim 10^{-33} cm^2$ About right for a 100 GeV WIMP
- Neutralino in MSSM $\equiv$ SSM $\oplus R_p$ fits the bill

MSSM, R PARITY and B-L

- SM : Gauge Invariance, Renormalizability $\Rightarrow$
  $B, L(perturbative) \Rightarrow B - L$ (Exact, Unique Global U(1)).

- MSSM: Sfermions & Shiggs $\Rightarrow$
  $\mathcal{L}_{\Delta_{B,L}\neq 0} = [W_{\not R_p}]_F = [\mu' LH + \lambda LLe^c + \lambda' LQd^c + \lambda'' u^c d^c d^c]_F \Rightarrow$
  catastrophic B, L violation $\Rightarrow \tau_p^{d=4} \sim (\frac{gM_S}{\lambda_{\not R} M_X})^4 \tau_p^{d=6} \Rightarrow$
  $\lambda\lambda' < 10^{-26}$

- $R_p : Z_2$: *Susy Particles odd* : forbids B,L violating terms
  Mohapatra : (1986) : $R_p = (-1)^{3(B-L)+2S} = (-)^{2S} M_p \Rightarrow$
  $M_p \subset U(1)_{B-L} \subset G_{LR} \subset G_{PS} \subset SO(10)$

- Even B-L vevs(M_ν Compatible) $\Rightarrow$ R$\surd\surd \Rightarrow : \Rightarrow$
  LSP Stable : good as Dark Matter
  MSLRMs : CSA,Benakli,Senjanovic, Melfo ....(1995-8)

SusyLR models, Seesaw and R_p : What and Why ?

- Left-Right models : $SU(2)_L \times SU(2)_R \times U(1)_{B-L} \times SU(3)_c \oplus \Delta(3,1,2) + \Delta^c(1,3,-2) + \Phi(2,2,0)$
- Parity/C $\equiv$ LR symmetry,
  Fermions:$Q = T_{3L} + T_{3R} + (B-L)/2$
  $L_L(2,1,-1) \oplus L^c_L(1,2,1) \oplus Q_L(2,1,1/3) \oplus Q^c_L(1,2,-1/3)$
- Gauged B-L in LR $\Rightarrow M_p \subset$ gauge symmetry Neither ad-hoc nor unprotected
- Renormalizable seesaw : Even B-L neutrino mass Higgs vevs $\Rightarrow$ SLRM $\rightarrow MSSM \oplus R_p \oplus m_\nu^{Weinberg}$
- $\Lambda_{B-L} \sim M_{\nu^c_L} >> M_W$ naturally explains $m_\nu <<< M_W$
- Type I : $m_\nu \sim (m^\nu_D)^T {M_{\nu^c_L}}^{-1} m^\nu_D$; also
  $M_{\nu^c_L} \sim f < \Delta^c(1,3,-2) >$

- Type II : $m_\nu \sim< \Delta_L(3,1,+2) >\sim M_W^2 < \Delta^c(1,3,-2) > /M_\Delta^2$ via EW breaking induced tadpole.

- Susy seesaw preserves R_p during $G_{LR} \to G_{123}$

- $M_{\nu_L^c} >> M_{W,S} \Rightarrow< \tilde{\nu}^c >= 0$ $\not{R}_p$ IFF $< \tilde{\nu}_L >\neq 0$

- $m_\nu \to 0 \Rightarrow B-L$, exact in effective theory $\Rightarrow$If $< \tilde{\nu}_L \neq 0 >$ pseudo-doublet-Majorons $J = Im\tilde{\nu} \oplus R = Re(\tilde{\nu}); M_{J,R} \sim \sqrt{m_\nu M_S}$ (from Weinberg operator induced soft term) $\Rightarrow$ NOT ALLOWED BY Z WIDTH

- So Soft terms in Susy LR Seesaw models MUST preserve *exact* $R_p \Rightarrow$ Stable LSP

VIRTUES OF SO(10) UNIFICATION

- $\{Q_L, L_L, u^c_L, d^c_L, l^c_L) \oplus \nu^{\mathbf{c}}_{\mathbf{L}}\} \equiv 16$: Tight and complete
- Simple Tri-band FM Higgs Channel Spectrum

$$\begin{aligned} 16 \otimes 16 &= 10 \oplus 120 \oplus 126 \Rightarrow (10 + 120 + \overline{126}_H) \\ \overline{126} &= (15,2,2) + \Delta_R(10,1,3) + \Delta_L(\overline{10},3,1) + (6,1,1) \end{aligned}$$

- $M_p \subset U(1)_{B-L} \subset G_{LR} \subset G_{PS} \subset SO(10) \quad \bigoplus < \Delta_{L,R} > \Rightarrow R_p$, Stable LSP
- NATURAL HOME TO BOTH SEESAWS :
  $\vec{\Delta}_R(1,3,-2), \vec{\Delta}_L(3,1,2) \subset \overline{126}$ PRESERVE R_p :
  $M_{B-L} \sim < \vec{\Delta}_R >_{SM=0} \Rightarrow M_{\nu^c} \Rightarrow M^I_\nu$
  $\frac{v_W^2}{M_{B-L}} \sim < \vec{\Delta}_L >_{Y=2,T_{3L}=-1} \Rightarrow\Rightarrow M^{II}_\nu$

TWO SCHOOLS OF SO(10)

Renormalizable SO(10)	NON-REN GUTS
Renormalizable couplings	Non Renorm. couplings
No ad-hoc symmetries	Ad-hoc symmetries necessary
Large(126,210,..) few (AS)	Small (10,16,45,54) irreps (AF)
# Parameter minimal	Unlimited # parameters
No Higgs duplication	Duplicates Higgs
$M_p \subset SO(10)$	R_p broken
Only B-L even vevs	"string motivated" Z_2
Higgs-Matter distinct	Higgs-Matter mix
a) $210 \oplus 126 \oplus \overline{126}$	$16_H^n \oplus 10 \oplus 45^m$ plethora
b)$54 \oplus 45 \oplus 126 \oplus \overline{126}$	

SO(10) BASICS

- Rank **5** , Fundamental tensor 10 , Adjoint : $\mathbf{45} = 10 \cdot 9/2$ (generators)
- Maximal Subgroups :

(a) $SU(5) \times U(1)$ (b) PS: $SU(4) \times SU(2)_L \times SU(2)_R$.

- $45_A = (15,1,1)_{C,B-L,J} \oplus (1,3,1)_{W_L} \oplus (1,1,3)_{W_R} \oplus (6,2,2)_{X,X_{flip}}$
- Vector Fundamental **10** :
  $H_i = H_a(6,1,1) + H_{\tilde{\alpha}}(1,2,2) = 5_1 + \bar{5}_1$
- **Spinor Fundamental** : SO(10) Clifford algebra :
  $2^5 = 16_+ \oplus \overline{16}_- \quad ; \quad (4,2,1) \oplus (\bar{4},1,2)$
- **Antisymmetric Tensors :**
  $A_{ij}(\mathbf{45}), O_{ijk}(\mathbf{120}), \Phi_{ijkl}(\mathbf{210}), \Sigma^{(\pm)}_{ijklm}(\mathbf{126})$

FITS IN SO(10)

- Gauge Unification : : $g_i(M_Z) \Rightarrow g(M_X), M_X, \Delta_3(M_X)$
- Fermion Data for GUT To Explain :
  Measured(17) : $m_{q,l}, \theta_i^{CKM}, \delta^{CKM}, \Delta m_\nu^2, \theta_{12,23}^{PMNS}$
  Bounded: $\theta_{13}^{PMNS} < .1$
- **Awaited (4) :** $M_\nu, \delta^{PMNS}, \alpha_{1,2}^{PMNS}$
- Yukawa couplings : $h = h^T, f = f^T, g = -g^T$
  $W = \mathbf{16}_A \times \mathbf{16}_B \cdot (h_{AB}\mathbf{10} + f_{AB}\overline{\mathbf{126}} + g_{AB}\mathbf{120})$
- Seesaw masses :

$$\begin{aligned} M_\nu^I &= v r_4 \hat{n} \\ M_\nu^{II} &= 2 v r_3 \hat{f} \\ \hat{n} &= (\hat{h} - 3\hat{f})\hat{f}^{-1}(\hat{h} - 3\hat{f}) \end{aligned}$$

GENERIC FITTING FRENZY

- Babu and Mohapatra (1992): $\mathbf{10} \oplus \overline{\mathbf{126}} \Leftrightarrow \quad m_{q,l} \Rightarrow$ Predictive in the Neutrino Sector ? : failure (1992,93,94..) success : Matsuda, Koide , Fukuyama, Nishiura (2002): Type I, large θ^{PMNS}, GENERIC fit.

- Bajc, Senjanovic, Vissani (2003) Large PMNS mixing angle $b - \tau$ unification connection.Goh Mohapatra Ng : Type II : 3 generations : Good GENERIC Fits .

$$M_\nu^{II} \sim f < \Delta_L > \sim (M_d - M_l) \sim m_\tau \begin{pmatrix} & \epsilon^2 & \epsilon^2 \\ \epsilon^2 & & \frac{(m_b - m_\tau)}{m_\tau} \end{pmatrix} \Rightarrow$$

MSSM : $m_b \simeq m_\tau(M_X)(all\ simple\ GUTs) \quad \Rightarrow \theta_{23}^{PMNS} \simeq 1$

- HOWEVER, GENERIC FITS NO GUIDE to ACTUAL GUTS GUT SPECIFIC formulae needed : 16×16 clebsches CSA,Girdhar(2004,5), NULL EIGENVECTORS OF $\mathcal{H}$ CSA, Bajc, Melfo, Senjanovic,Vissani ; CSA, Girdhar(2005)

MSGUT

- **AM Higgs** : $< \mathbf{210}(\Phi_{ijkl}),\ \ \overline{\mathbf{126}}(\overline{\mathbf{\Sigma}}_{ijklm})\ \ ,\mathbf{126} > \Rightarrow$
  $Susy\ SO(10) \longrightarrow MSSM$ (CSA, Mohapatra, CKN (1983))

- **Superpotential**

$$
\begin{aligned}
W &= m\ 210^2 + \lambda\ 210^3 + M\ 126 \cdot \overline{126} + \eta\ 210 \cdot 126 \cdot \overline{126} \\
&+ 10 \cdot 210(\gamma\ 126 + \bar{\gamma}\ \overline{126}) \\
&+ M_H\ 10^2 + h_{AB}\ 16_A \cdot 16_B + f'_{AB}\ 16_A 16_B
\end{aligned}
$$

  Superpotential Parameters : (**25**) **Minimal !** ABMSV(2003)

- **GUT scale VEVS** : $SO(10) \rightarrow MSSM$

$$
\begin{aligned}
\langle(15,1,1)\rangle_{210} &: a \qquad \langle(15,1,3)\rangle_{210} : \omega \\
\langle(1,1,1)\rangle_{210} &: p \qquad \langle(10,1,3)\rangle_{126,\overline{126}} : \sigma, \bar{\sigma}
\end{aligned}
$$

- D Terms, preserve SUSY : $|\sigma| = |\overline{\sigma}|$

- F Terms : SSB completely analyzable 4 eqns $\Rightarrow$ **Cubic in**

$x = -\lambda\omega/m : \xi = \frac{\lambda M}{\eta m}$. (ABMSV 2003)

$8x^3 - 15x^2 + 14x - 3 = -\xi(1-x)^2$

- Chiral GUT scale spectra and Threshold effects : 52 MSSM multiplet sets,
  26 MSSM types : 18 unmixed , 8 mixed : 504 Fields CSA, Girdhar(2003,2004) ; Fukuyama, Ilakovac, Kikuchi, Mejanac, Okada (2004), BMSV (2004)

- Type I ,Type II GENERIC fits : freedom to choose M_ν scale, Relative strength of Type I / Type II *assumed*. NOT JUSTIFIED IN MSGUT where magnitude and relative strength fully specified : is it viable ?? NO!**Demo** CSA(2005) **Proof**: CSA,Garg (2005-November), **Checked** Bertolini, Schwetz,Malinski(2006-April)

NMSGUT : FM-Higgs Completion

- $\mathbf{10} \oplus \overline{\mathbf{126}}$ FM Higgs irreps $\Rightarrow$ Type I , Type II Seesaw failure : $\oplus$**120**-plet : THIRD FM CHANNEL $\Rightarrow$VIABLE m_ν???
- NEW SCENARIO : $h \oplus g >> f \quad \Rightarrow (m_{q,l}, \theta_q^i, \delta_c)$.
- $f << h, g \Rightarrow$ Type I boosted ($\hat{n} \sim \hat{f}^{-1}$)

$$W_{120} = M_O\ 120 \cdot 120 + k\ 10 \cdot 120 \cdot 210 + \rho\ 120 \cdot 120 \cdot 210$$
$$+\zeta\ 120 \cdot 126 \cdot 210 + \bar{\zeta}\ 120 \cdot \overline{126} \cdot 210 + g_{[AB]} 16_A \cdot 16_B \cdot 120$$

- Parameter Counting : Complex Case

$M_O, k, \rho, \zeta, \bar{\zeta}, g_{AB} : (1+1+1+2+3) \times 2 - 1 = 15 \oplus 24 \ \ (old) = 39$

(Still Minimal but marginally)

THRESHOLD CORRECTIONS AND NMSGUT

- $10 \oplus 120$ only for Charged fermion fit $\Rightarrow$ (a) $m_{d,s}^{MSSM}(M_Z) \sim m_{d,s}^{MSSM}(M_Z)/5$ (b) Tree Level: $m_s - m_\mu = m_b - m_\tau$ (c) $m_{d,s}^{MSSM}(M_Z) \sim 1.2\, m_{d,s}^{MSSM}(M_Z)$ well known tension in b-τ-t unification.
- $\tan\beta \sim m_t/m_b \sim 40-60$ generic in SO(10) GUTs. Single **10** $t-b-\tau$ unification allows $\tan\beta \sim 50-60 \sim m_t/m_b$ only.
- LARGE SUSY THRESHOLD CORRECTIONS to $m_{T_3=-.5}^{quark}$ AT LARGE $\tan\beta$ (α_s(gluino) and ($A_t y_t^2$ loops for 3d gen)) Also 10-15% gluino corrections for m_{top}. Carena,Olechowski,Pokorski and Wagner(1994); Hall Ratzzi and Sarid(1994)

$$\frac{y_i^{GUT}(M_S)\cos\beta}{y_i^{SM}(M_S)} = \frac{1}{1 + \epsilon_i(m_{\tilde{f}}, M_i, \mu, A_t)\ \tan\beta}$$

- Dominant corrections for quarks:

$$\epsilon_i^G = -\frac{2\alpha_S}{3\pi}\frac{\mu}{M_3}H_2(u_{\tilde{Q}_i}, u_{\tilde{d}_i}) \qquad \epsilon^y = -\frac{y_t^2}{16\pi^2}\frac{A_t^0}{\mu}H_2(v_{\tilde{Q}_3}, v_{\tilde{u}_3})$$

- $H_2 < 0 \Rightarrow$ lowering $y_{d,s}^{SGUT} \Rightarrow$ $\mu, -A_t >> M_{\tilde{f}}$ with cancellation for y_b. Fitting gives third gen sfermions heavier than first two. Distinct region of Susy parameter space, class of spectra, LHC signatures

- In NMSGUT : THRESHOLD CORRECTIONS AT M_X to Yukawas also important :

$$Y_u = (1 + \Delta_{\bar{u}} + \Delta_u + \Delta_H)Y_u^0$$
$$Y_d = (1 + \Delta_{\bar{d}} + \Delta_d + \Delta_{\bar{H})}Y_d^0$$

$\Delta_{f,\bar{f},H}$ wavefunction shifts due to loops with 1 or 2 Heavy fields. Here 120-plet and large $Y_{120} \Rightarrow \Delta_f \sim 30\%, \Delta_H \sim 1 - 10$ easily possible. $b - \tau = s - \mu$ now relaxed.

$d = 5$ NUCLEON DECAY

- FAMILIAR $\bar{t}[\bar{3},1,-\frac{2}{3}] \oplus t[3,1,\frac{2}{3}] \oplus$ NOVEL $P[3,3,\pm\frac{2}{3}], K[3,1,\pm\frac{8}{3}]$ Multiplet types contribute to baryon violation in SO(10) BABU,PATI,WILCZEK(2000);CSA,GIRDHAR,GARG(2004,2006)

$$W_{eff}^{\Delta B\neq 0} = -\hat{L}_{ABCD}(\frac{1}{2}\epsilon\hat{Q}_A\hat{Q}_B\hat{Q}_C\hat{L}_D) - \hat{R}_{ABCD}(\epsilon\bar{\hat{e}}_A\bar{\hat{u}}_B\bar{\hat{u}}_C\bar{\hat{d}}_D)$$

$$\begin{aligned}\hat{L}_{ABCD} &= \mathcal{S}_1{}^1\tilde{h}_{AB}\tilde{h}_{CD} + \mathcal{S}_1{}^2\tilde{h}_{AB}\tilde{f}_{CD} + \mathcal{S}_2{}^1\tilde{f}_{AB}\tilde{h}_{CD} + \mathcal{S}_2{}^2\tilde{f}_{AB}\tilde{f}_{CD} \\ &- \mathcal{S}_1{}^6\tilde{h}_{AB}\tilde{g}_{CD} - \mathcal{S}_2{}^6\tilde{f}_{AB}\tilde{g}_{CD} + \sqrt{2}(\mathcal{P}^{-1})_2{}^1\tilde{g}_{AC}\tilde{f}_{BD} \\ &- (\mathcal{P}^{-1})_2{}^2\tilde{g}_{AC}\tilde{g}_{BD}\end{aligned}$$

SEARCH/FILTRATION

- Selected only fits with
  $-.0015 < \Delta\alpha_S(M_S) < -.004$
  $\Delta(LogM_X) \geq 0$
  $15 > \Delta\alpha_G^{-1} > -22$
  $Mx(LLLLX, RRRRMX) < 10^{-21} GeV^{-1}$
- Threshold corrections $\sim$ Log(Ratios of Soft masses) $\Rightarrow$ Scale M_S not fixed. But stable LSP a main virtue ! : DM cosmology $\Rightarrow$ 10 – 150 GeV ! Impose : Bino LSP in ranges $(I :> 101 GeV; II : 5 - 50 GeV; III : 50 - 100 GeV)$
- Experimental constraints : Charged sfermion and Chargino masses $> 110 GeV$.

NUMERICAL SEARCH FOR COMPLETE GUT PARAMETERS

$m_f(M_Z), \theta_f(M_Z)$ AT $Q = M_Z$

$\Downarrow$

$\Rightarrow$ MSSM (+threshold corrections) $\Rightarrow$ y_f^{MSSM} at fixed $v, \tan\beta$

$\Downarrow$

2 loop MSSM FLOW to $10^{16.3} GeV$

$\Downarrow$

$y_f(M_X^0)$, fit to NMSGUT downhill simplex Search, Antusch errors

$\Downarrow$

Initially Fit all but $y_{b,d,s}$ accurately

2 loop MSSM soft + hard $\Downarrow$ $M_X \to M_Z$ RG Flow

with achieved yukawas& random soft$\Downarrow$ Sugra$(m_0, m_{1/2}, A_0, m_H^2, m_{\bar{H}}^2)$

Large $\tan\beta$ Corrections at $M_S = M_Z \Rightarrow (m, \theta^{SM}) \Rightarrow$ Optimal soft susy parameters. ITERATE

Parameter	$Value$	Field $[SU(3),SU(2),Y]$	$Masses$ $(Units\ of 10^{16} Gev)$
χ_X	0.0464	$A[1,1,4]$	645.6423
χ_Z	0.0148	$B[6,2,5/3]$	0.3633
$h_{11}/10^{-6}$	0.0212	$C[8,2,1]$	35.720, 325.280, 339.020
$h_{22}/10^{-4}$	0.0344	$D[3,2,7/3]$	35.032, 349.701, 362.742
h_{33}	0.0026	$E[3,2,1/3]$	0.583, 26.331, 26.331
$f_{11}/10^{-6}$	$0.0781 - 0.1368i$		28.661, 393.609, 441.491
$f_{12}/10^{-6}$	$-1.9955 - 0.0830i$	$F[1,1,2]$	6.1501, 6.1501
$f_{13}/10^{-5}$	$0.0580 + 0.0517i$		25.3113, 325.2783
$f_{22}/10^{-5}$	$6.6036 - 4.9627i$	$G[1,1,0]$	0.091, 0.716, 0.718
$f_{23}/10^{-4}$	$2.0080 + 2.3459i$		0.718, 30.691, 30.921
$f_{33}/10^{-3}$	$-1.0051 + 0.4427i$	$h[1,2,1]$	1.437, 20.709, 34.271
$g_{12}/10^{-4}$	$0.0605 + 0.1232i$		541.461, 563.216
$g_{13}/10^{-5}$	$-0.0460 + 1.8407i$	$I[3,1,10/3]$	1.2553
$g_{23}/10^{-4}$	$6.3251 + 5.7460i$	$J[3,1,4/3]$	1.387, 14.308, 14.308
$\lambda/10^{-2}$	$-0.8601 - 1.4974i$		44.047, 383.452
η	$-10.3248 + 2.5325i$	$K[3,1,8/3]$	50.906, 468.835
ρ	$0.7042 - 2.2528i$	$L[6,1,2/3]$	24.182, 752.081
k	$0.0151 - 0.0805i$	$M[6,1,8/3]$	761.5548
ζ	$1.6200 + 0.5400i$	$N[6,1,4/3]$	757.7856
$\bar{\zeta}$	$1.0084 + 0.4594i$	$O[1,3,2]$	1454.7414
$m/10^{16}GeV$	0.0380	$P[3,3,2/3]$	14.500, 1130.983
$m_o/10^{16}GeV$	$-21.05e^{-iArg(\lambda)}$	$Q[8,3,0]$	1.0407
γ	3.7081	$R[8,1,0]$	0.404, 1.546
$\bar{\gamma}$	-2.8691	$S[1,3,0]$	1.7528
x	$0.9397 + 0.6629i$	$t[3,1,2/3]$	1.150, 19.66, 47.99, 78.65

I-1-a : Column 1 contains values of the NMSGUT-SUGRY-NUHM parameters at M_X derived from an accurate fit to all 18 fermion data and compatible with RG constraints.

Parameter	$Value$	Field $[SU(3),SU(2),Y]$	$Masses$ $(Units\ of 10^{16} Gev)$
Δ_X	1.1625		252.51, 337.254, 7050.35
Δ_G	4.8629	$U[3,3,4/3]$	1.4803
$\Delta\alpha_3(M_Z)$	−0.0128	$V[1,2,3]$	1.0459
$\{M^{\nu^c}/10^{11}GeV\}$	0.01, 14.65, 613.85	$W[6,3,2/3]$	877.2002
$\{M^{\nu}_{II}/10^{-12}eV\}$	0.4997, 927.38, 38856.88	$X[3,2,5/3]$	0.353, 28.201, 28.201
$M_\nu(meV)$	2.17, 7.63, 42.34	$Y[6,2,1/3]$	0.4446
$\{\mathrm{Evals[f]}\}/10^{-7}$	0.15, 282.68, 11844.25	$Z[8,1,2]$	1.5383
Soft parameters	$\mathrm{m}_{\frac{1}{2}} = -88.707485$	$\mathrm{m}_0 = 4198.698405$	$\mathrm{A}_0 = -1.18317080 \times 10^5$
at M_X	$\mu = 9.42058182 \times 10^4$	$\mathrm{B} = -5.93989944 \times 10^9$	$\tan\beta = 50.0000$
	$\mathrm{M}^2_{\bar{\mathrm{H}}} = -7.17820644 \times 10^9$	$\mathrm{M}^2_{\mathrm{H}} = -6.77889204 \times 10^9$	$\mathrm{R}_{\frac{b\tau}{s\mu}} = 2.6935$
$Max(\lvert L_{ABCD}\rvert, \lvert R_{ABCD}\rvert)$	$6.11492157 \times 10^{-23}\ \mathrm{GeV}^{-1}$		

I-1-a : Unificaton parameters and mass spectrum of superheavy and superlight fields are also given. The values of $\mu(M_X), B(M_X)$ are determined by RG evolution from M_Z to M_X of the values determined by the EWRSB conditions.

Parameter	Value	Parameter	Value
M_1	124.9405	$M_{\tilde{\bar{u}}_1}$	5392.7409
M_2	328.3854	$M_{\tilde{\bar{u}}_2}$	5392.0072
M_3	569.9247	$M_{\tilde{\bar{u}}_3}$	17882.2800
$M_{\tilde{\bar{l}}_1}$	1101.7265	$A^{0(l)}_{11}$	−75168.6925
$M_{\tilde{\bar{l}}_2}$	165.2234	$A^{0(l)}_{22}$	−75083.1231
$M_{\tilde{\bar{l}}_3}$	11100.2290	$A^{0(l)}_{33}$	−47868.8258
$M_{\tilde{L}_1}$	6400.1281	$A^{0(u)}_{11}$	−86227.1077
$M_{\tilde{L}_2}$	6353.8668	$A^{0(u)}_{22}$	−86226.5267
$M_{\tilde{L}_3}$	10210.7805	$A^{0(u)}_{33}$	−43721.2056
$M_{\tilde{\bar{d}}_1}$	2917.3151	$A^{0(d)}_{11}$	−75501.8910
$M_{\tilde{\bar{d}}_2}$	2916.5721	$A^{0(d)}_{22}$	−75501.2453
$M_{\tilde{\bar{d}}_3}$	26552.1018	$A^{0(d)}_{33}$	−32031.4611
$M_{\tilde{Q}_1}$	4928.6003	$\tan\beta$	50.0000
$M_{\tilde{Q}_2}$	4927.9841	$\mu(M_Z)$	76666.7570
$M_{\tilde{Q}_3}$	22679.2999	$B(M_Z)$	9.66716576×10^8
$M^2_{\bar{H}}$	-6.03005600×10^9	M^2_H	-6.32493925×10^9

I-1-d: Values (GeV) in of the soft Susy parameters at M_Z (evolved from the soft SUGRY-NUHM parameters at M_X). The values of soft Susy parameters at M_Z determine the Susy threshold corrections to the fermion yukawas. The matching of run down fermion yukawas in the MSSM to the SM parameters determines soft SUGRY parameters at M_X. Note the heavier third sgeneration. The values of $\mu(M_Z)$ and the corresponding soft susy parameter $B(M_Z) = m_A^2 \sin 2\beta/2$ are determined by imposing electroweak symmetry breaking conditions. m_A is the mass of the CP odd scalar in the in the Doublet Higgs. The sign of μ is assumed positive.

Field	$Mass(GeV)$
$M_{\tilde{G}}$	569.9247
$M_{\chi^{\pm}}$	$328.38, 76666.85$
M_{χ^0}	$124.94, 328.38, 76666.81, 76666.82$
$M_{\tilde{\nu}}$	$6399.784, 6353.520, 10210.565$
$M_{\tilde{e}}$	$1102.65, 6400.31, 160.56, 6354.33, 10105.12, 11196.70$
$M_{\tilde{u}}$	$4928.29, 5392.61, 4927.63, 5391.92, 17876.33, 22684.87$
$M_{\tilde{d}}$	$2917.43, 4928.98, 2916.66, 4928.38, 22663.07, 26566.04$
M_A	219898.0779
$M_{H^{\pm}}$	219898.0926
M_{H^0}	219898.0583
M_{h^0}	111.4513

I-1-e: Spectra of supersymmetric partners calculated ignoring generation mixing effects. Inclusion of such effects changes the spectra only marginally. Due to the large values of μ, B, A_0. The LSP and light chargino are essentially pure Bino and Wino($\tilde{W}_{\pm}$). The light gauginos and light Higgs h^0, are accompanied by a light smuon and sometimes selectron. The rest of the sfermions have multi-TeV masses. The mini-split supersymmetry spectrum and large μ, A_0 parameters help avoid problems with FCNC and CCB/UFB instability[?]. The sfermion masses are ordered by generation not magnitude. This is useful in understanding the spectrum calculated including generation mixing effects. The mass of the Higgs particles are calculated by incorporating one loop contributions to the Ew symmetry breaking as well as to the effective potential[?, ?].

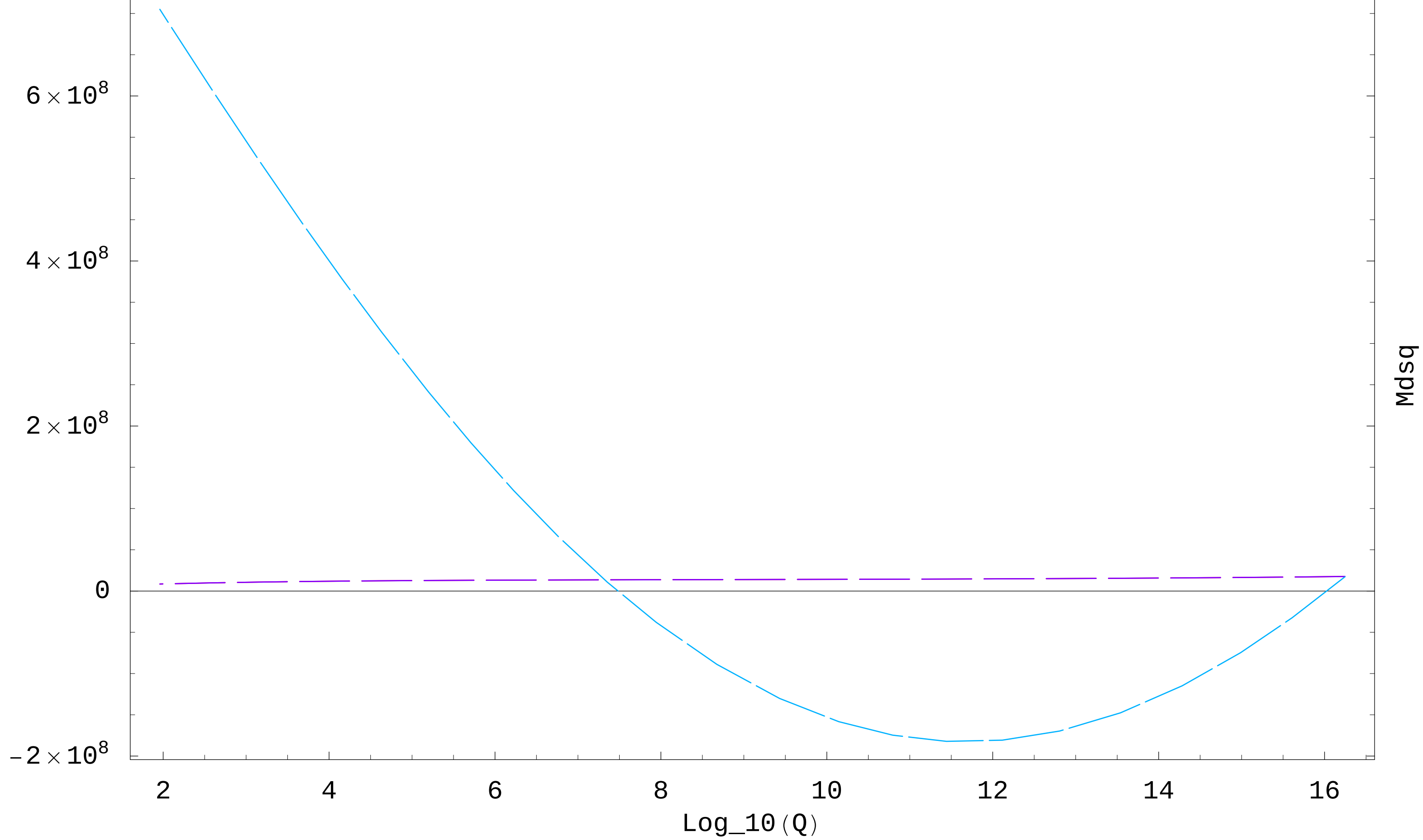


Figure 1: $\beta^{(1)}_{\mathbf{m}^2_Q} = (\mathbf{m}^2_Q + 2m^2_H)\mathbf{Y}^\dagger_u \mathbf{Y}_u + (\mathbf{m}^2_Q + 2m^2_{\bar{H}})\mathbf{Y}^\dagger_d \mathbf{Y}_d + ...$. Two loop RG evolution of $M^2_{\tilde{\bar{d}}}$ from M^0_X to M_Z for Case I-1. Red: $M^2_{\tilde{\bar{d}}}$, Blue: $M^2_{\tilde{\bar{s}}}$, Green: $M^2_{\tilde{\bar{t}}}$. Note the strong growth in the the third sgeneration mass at low energies. The same behaviour is exhibited by all sfermions.

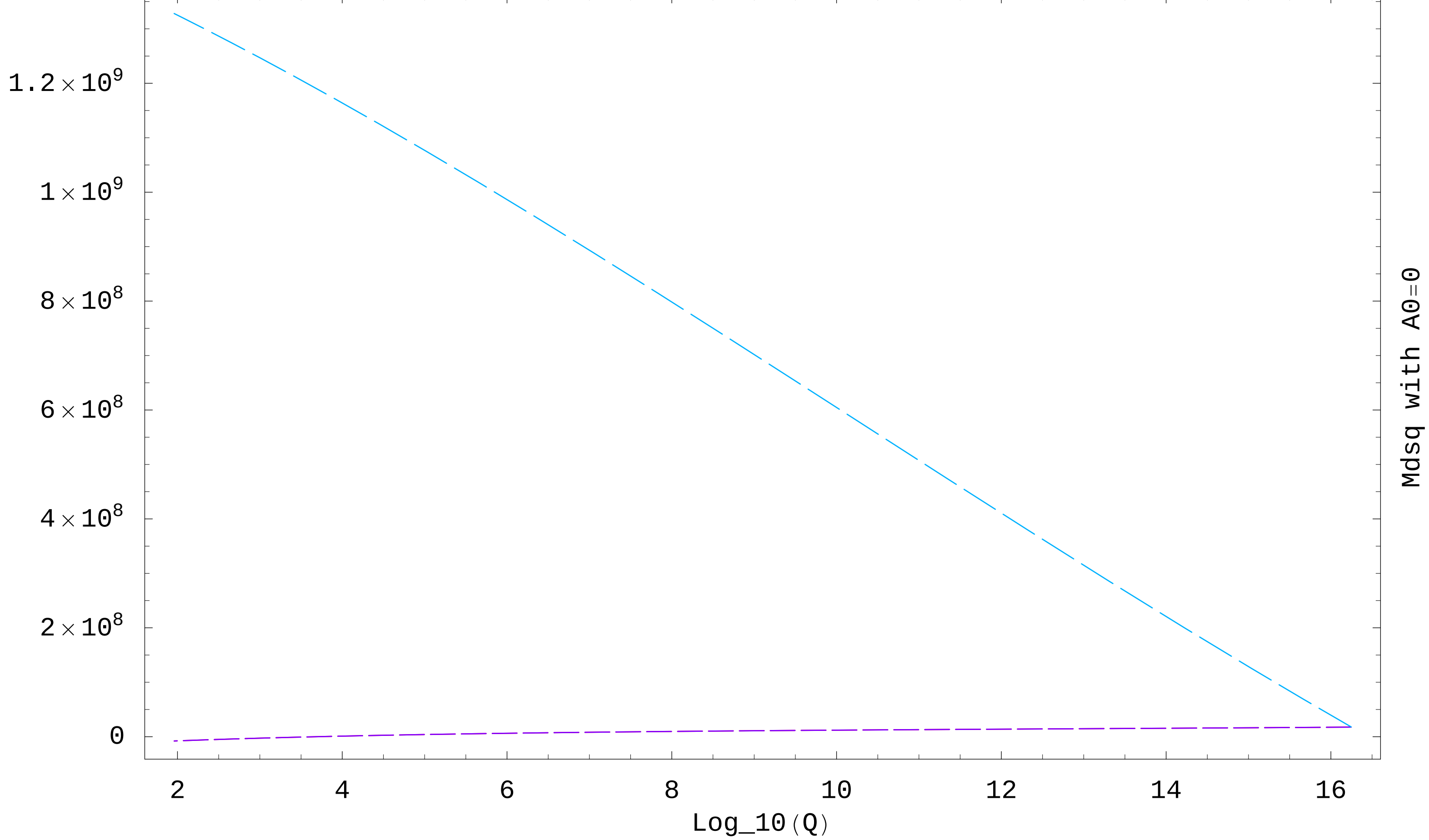


Figure 2: Little effect of A_0 : Hypothetical Two loop RG evolution of $M^2_{\tilde{d}}$ from M^0_X to M_Z with $A_0(M_X) = 0$ for Case I-1. Red: $M^2_{\tilde{\bar{d}}}$, Blue: $M^2_{\tilde{\bar{s}}}$, Green: $M^2_{\tilde{\bar{t}}}$. Note the strong growth in the the third sgeneration mass at low energies. The same behaviour is exhibited by all sfermions.

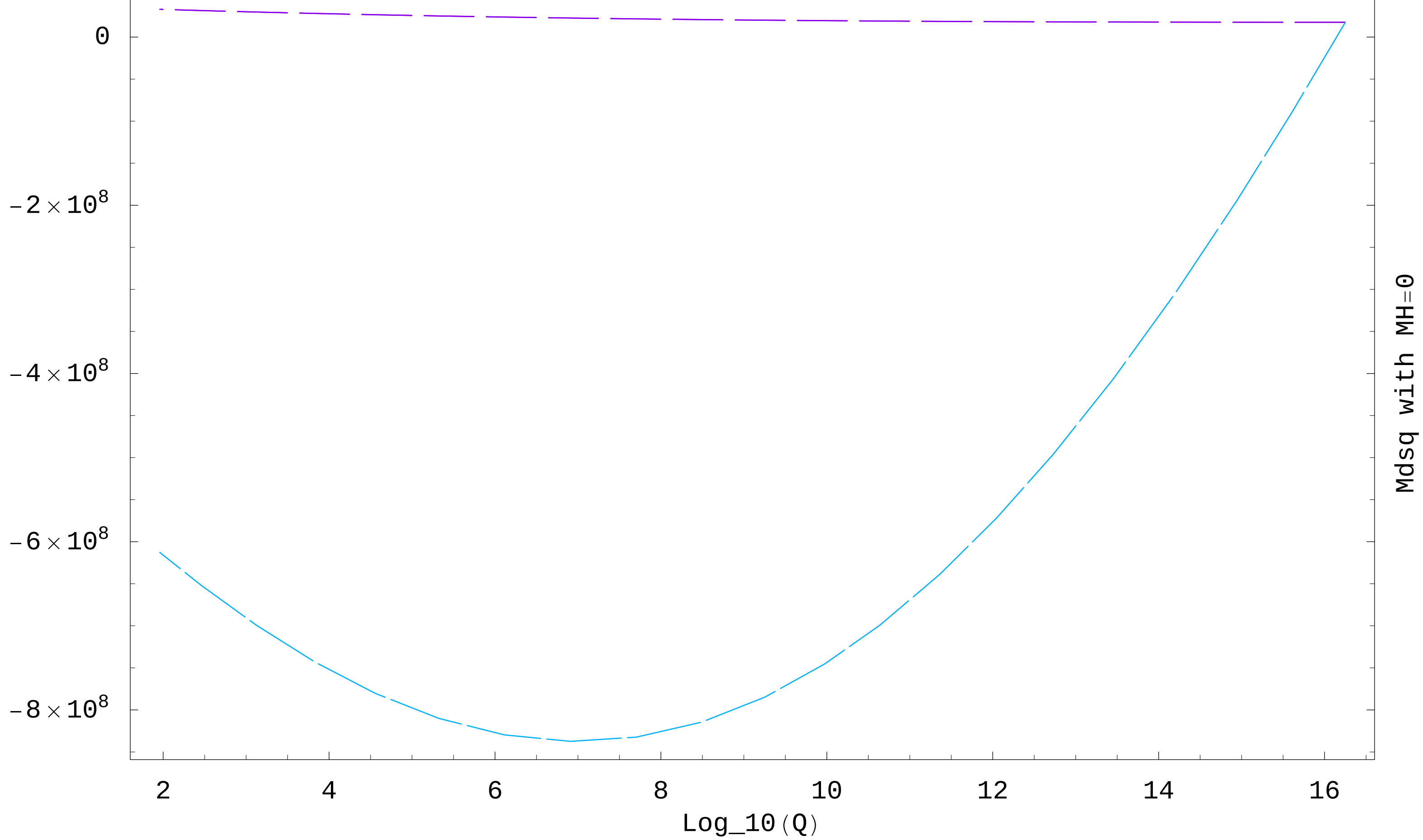


Figure 3: Effect of large $M^2_{H,\bar{H}}$: Hypothetical Two loop RG evolution of $M^2_{\tilde{d}}$ from M^0_X to M_Z with $M^2_H(M_X) = M^2_{\bar{H}}(M_X) = 0$ for Case I-1. Red: $M^2_{\tilde{\bar{d}}}$, Blue: $M^2_{\tilde{\bar{s}}}$, Green: $M^2_{\tilde{\bar{t}}}$. Note the strong *decrease* in the the third sgeneration mass at low energies while the first two generations are unaffected. Putting $A_0 = 0$ has essentially no effect except that the increase becomes linear. The same behaviour is exhibited by all sfermions.

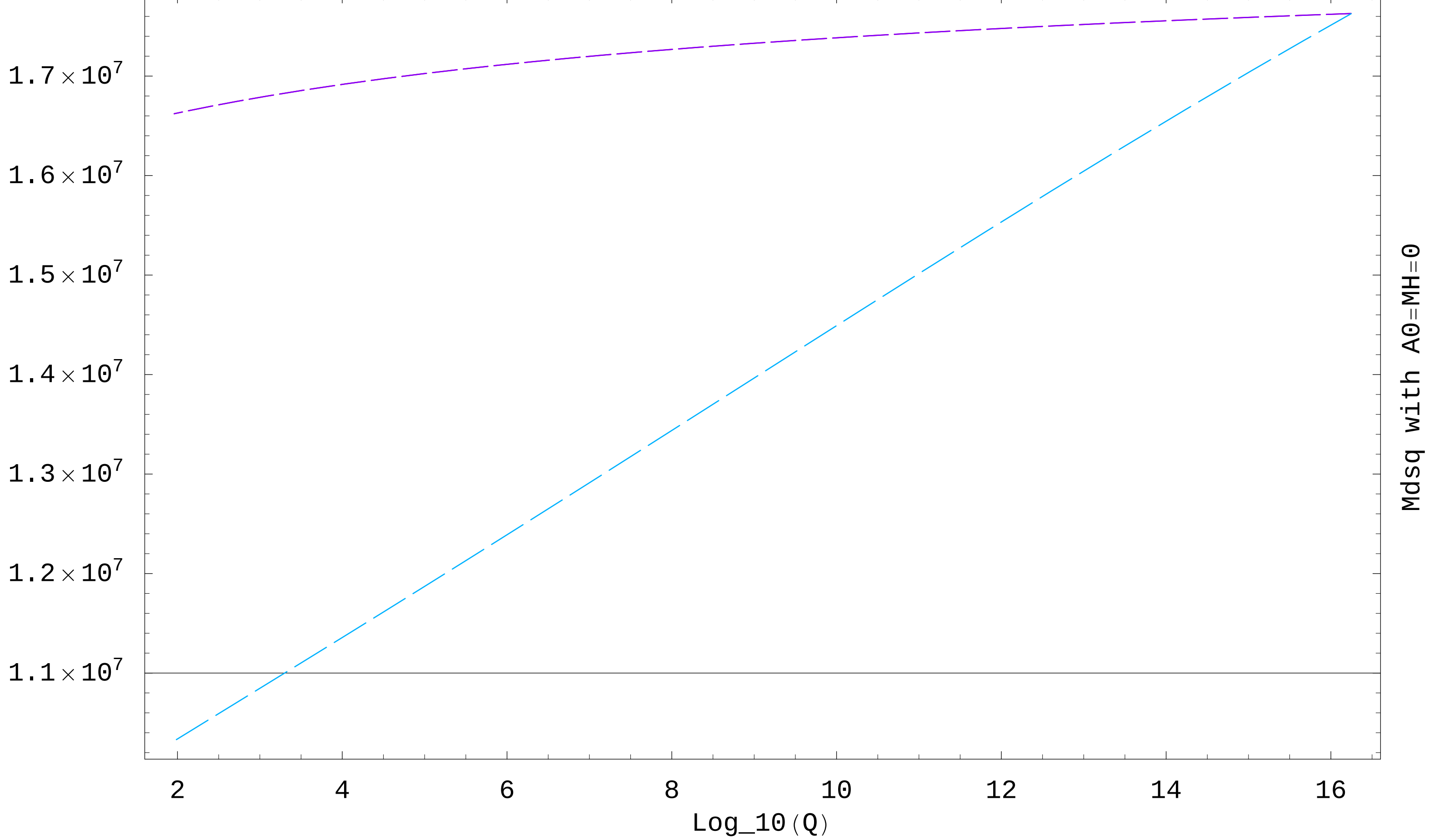


Figure 4: Little effect of A_0 : Hypothetical Two loop RG evolution of $M^2_{\tilde{d}}$ from M^0_X to M_Z with $M^2_H(M_X) = M^2_{\bar{H}}(M_X) = 0 = A_0(M_X)$ for Case I-1. Note the strong *decrease* in the the third sgeneration mass at low energies while the first two generations are unaffected. The removal of the curvilinear decrease in favour of a linear one is the only effect of putting $A_0 = 0$ in addition. The same behaviour is exhibited by all sfermions.

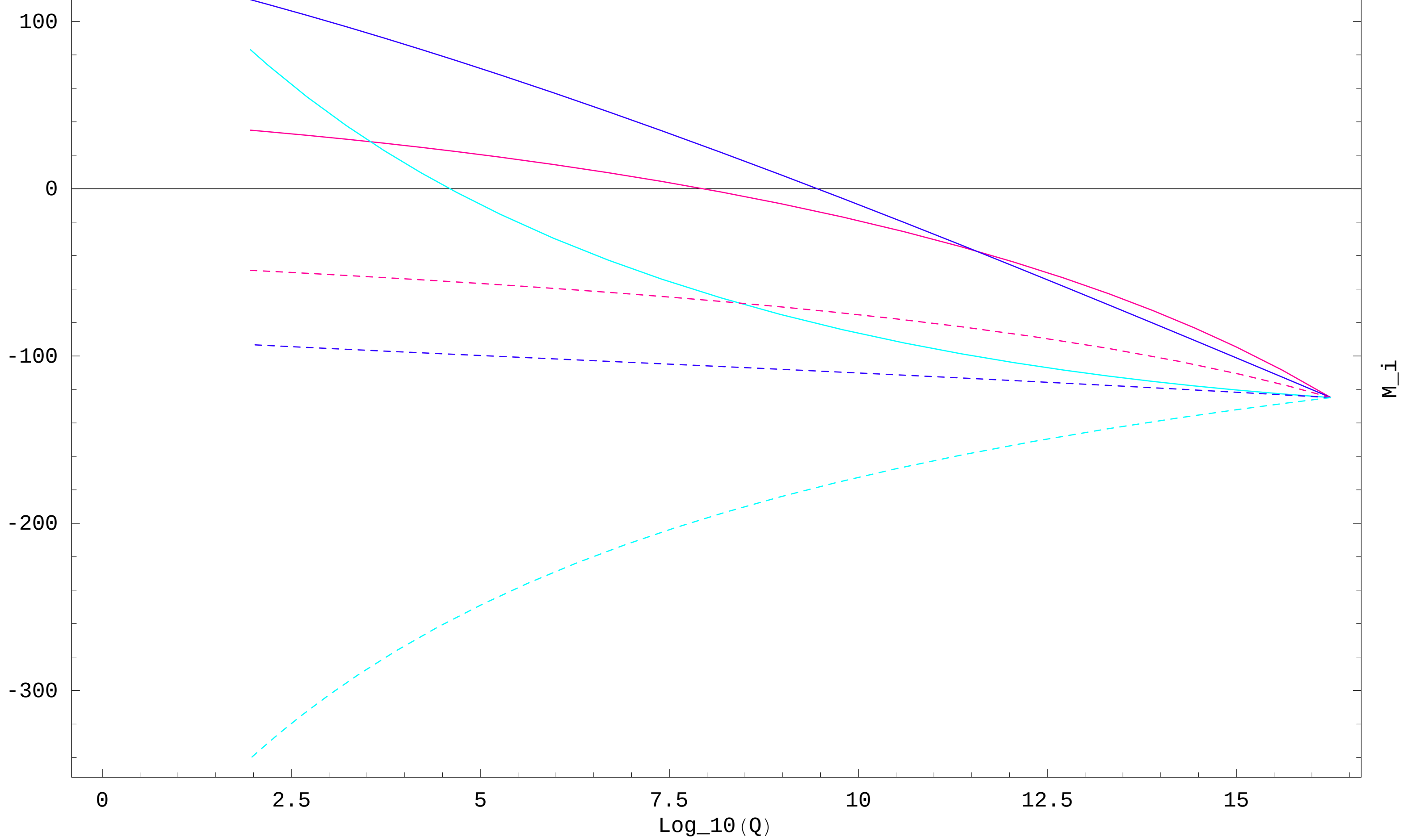


Figure 5: $\frac{d}{dt}M_a = \frac{2g_a^2}{16\pi^2}B_a^{(1)}M_a + \frac{2g_a^2}{(16\pi^2)^2}\{\sum_{b=1}^3 B_{ab}^{(2)} g_b^2(M_a + M_b) + \sum_{x=u,d,e} C_a^x(\mathrm{Tr}[Y_x^\dagger A_x] - M_a \mathrm{Tr}[Y_x^\dagger Y_x])\}$. Hypothetical 2-loop RG evolution of gaugino masses with $A_0 \neq 0$ (full lines) and with $A_0 = 0$ (dashed lines) for Case II-1. Red:M_1, Blue M_2, Green M_3. Notice how the Gluino mass can even fall below the Wino mass when $A_0 \neq 0$.

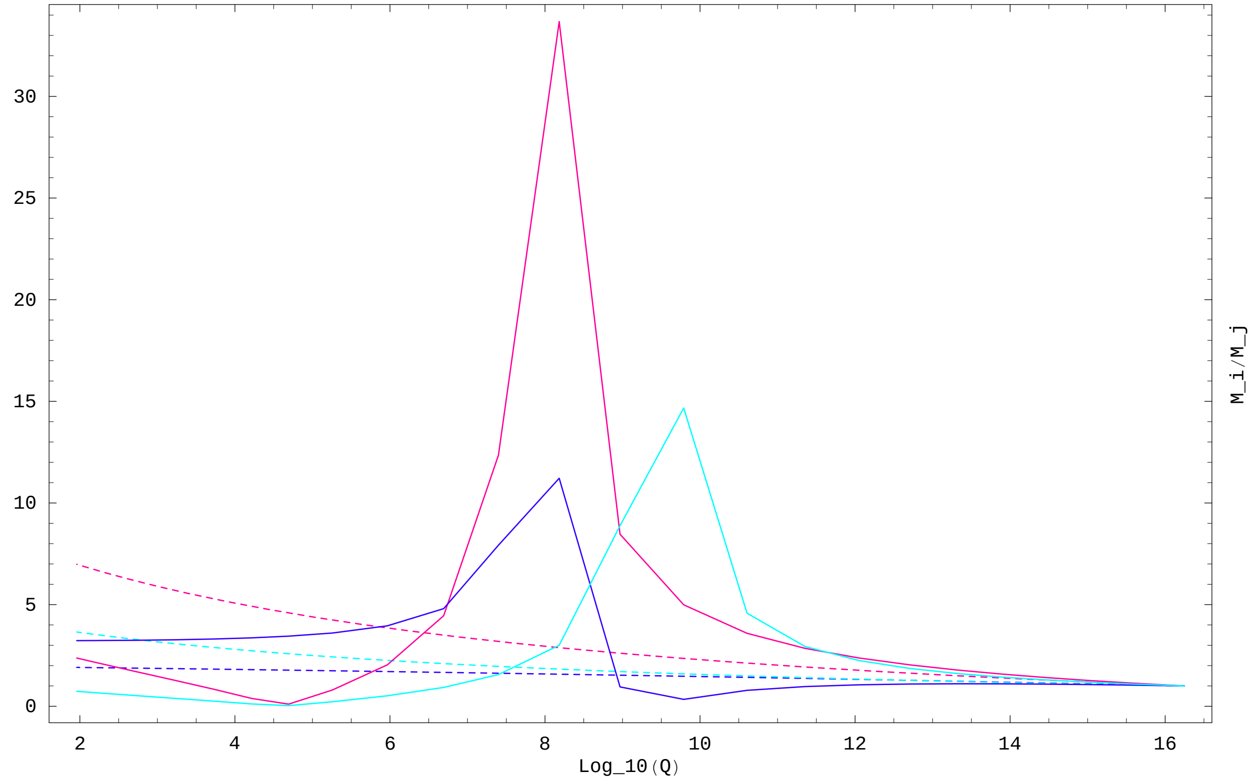
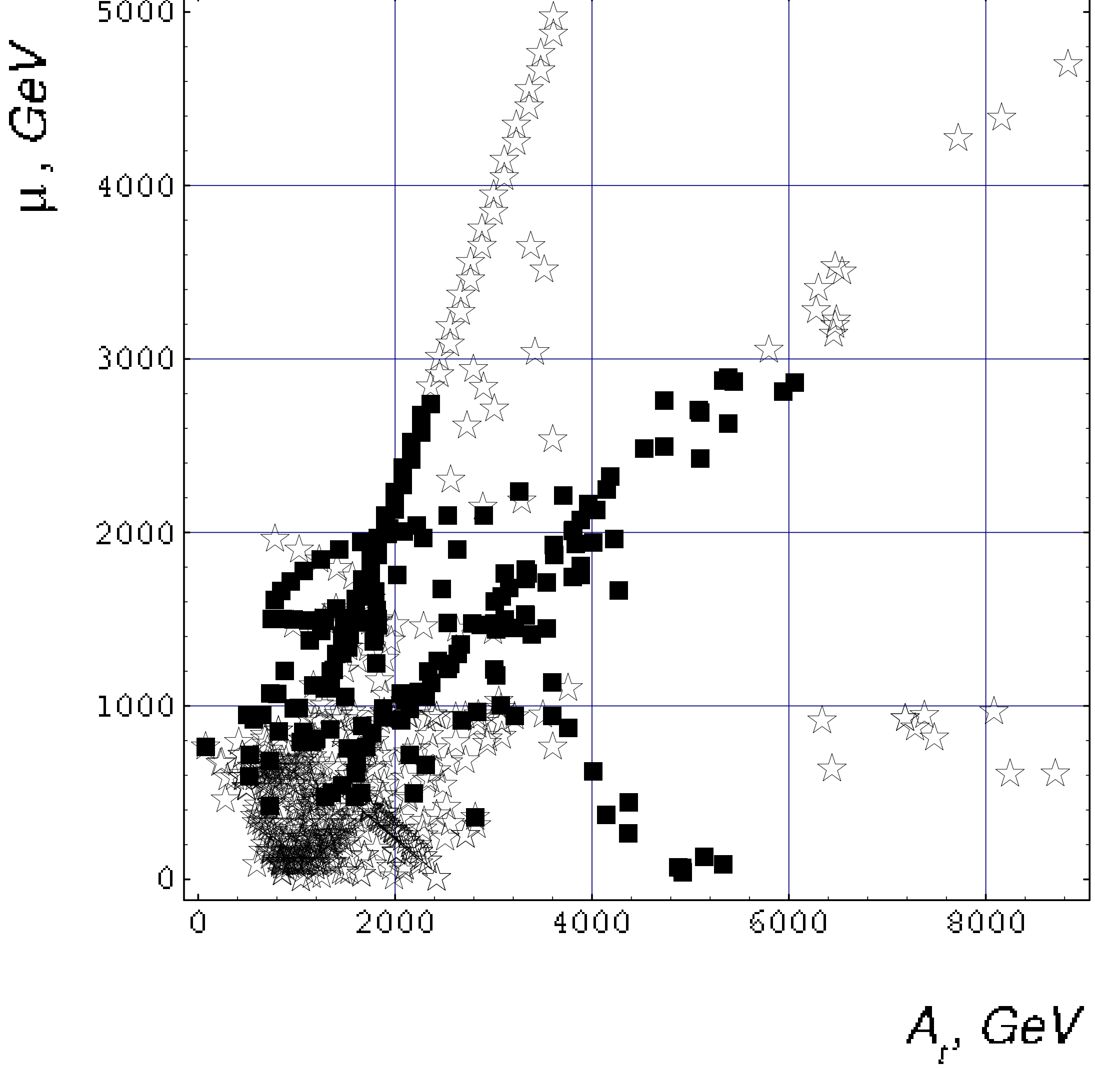


Figure 6: Hypothetical Two loop RG evolution of ratios of gaugino mass ratos with $A_0 \neq 0$ (full lines) and with $A_0 = 0$ (dashed lines) for Case II-1. Red : M_3/M_1, Blue: M_2/M_1 , Green M_3/M_2. In the case $A_0 = 0$, the gaugino masses follow the standard evolution to the $1:2:7$ ratio at low energies



“*Tunneling probability for unphysically large values of A_t and μ The points marked with stars correspond to MSSM “standard/realistic vacua” that are long lived on the scale of the age of the universe. From Kusenko, Langacker and Segre, Phys. Rev. D* **54** *(1996) 5824.*

Particle $\Rightarrow$	LSP	$Winos$	$Gluino$	$Higgs$	$Sfermions$
Case $\Downarrow$	$(\tilde{B})$	$(\tilde{W}^{\pm,0})$	$\tilde{g}$	h^0	$\tilde{\bar{f}}, \tilde{F}$
$I-1$	0.125	0.328	0.570	0.111	$1.1(\tilde{\bar{e}}), 0.16(\tilde{\bar{\mu}})$
$I-2$	0.105	0.354	0.269	0.113	$1.89(\tilde{\bar{e}}), 0.3(\tilde{\bar{\mu}}), 0.82(\tilde{\bar{d}}), 0.83(\tilde{\bar{s}})$
$I-3$	0.147	0.406	0.599	0.115	$1.63(\tilde{\bar{e}}), 0.39(\tilde{\bar{\mu}})$
$I-4$	0.104	0.302	0.351	0.128	$0.12(\tilde{\bar{e}}), 0.89(\tilde{\bar{\mu}}), 1.7(\tilde{\bar{d}}), 1.7(\tilde{\bar{s}})$
$II-1$	0.035	0.113	0.83	0.130	$1.05(\tilde{\bar{e}}), 1.14(\tilde{\bar{\mu}}), 0.32(\tilde{\bar{d}}), 0.32(\tilde{\bar{s}}), 2.49(\tilde{\bar{u}}), 2.49(\tilde{\bar{c}}), 2.49(\tilde{Q}_{1,2})$
$II-3$	.044	.144	0.09	.124	$2.15(\tilde{\bar{e}}), 2.07(\tilde{\bar{\mu}}), 0.46(\tilde{\bar{d}}), 0.46(\tilde{\bar{s}}), 0.20(\tilde{\bar{u}}), 0.20(\tilde{\bar{c}}), 2.45(\tilde{Q}_{1,2})$
$II-4$	0.035	0.110	0.082	0.127	$1.67(\tilde{\bar{e}}), 1.68(\tilde{\bar{\mu}}), 0.364(\tilde{\bar{d}}), 0.36(\tilde{\bar{s}}), 1.36(\tilde{\bar{u}}), 1.36(\tilde{\bar{c}}), 2.11(\tilde{Q}_{1,2})$
$III-1$	0.100	0.271	0.429	0.117	$0.105(\tilde{\bar{e}}), 0.91(\tilde{\bar{\mu}}), 2.29(\tilde{\bar{d}}), 2.29(\tilde{\bar{s}})$
$III-2$	0.99	0.342	0.232	0.113	$1.87(\tilde{\bar{e}}), 0.34(\tilde{\bar{\mu}}), 0.72(\tilde{\bar{d}}), 0.71(\tilde{\bar{s}})$
$III-3$	0.98	0.273	0.387	0.118	$1.06(\tilde{\bar{e}}), 0.14(\tilde{\bar{\mu}}), 2.15(\tilde{\bar{d}}), 2.15(\tilde{\bar{s}})$
$III-4$	0.94	0.284	0.269	0.128	$.09(\tilde{\bar{e}}), 0.11(\tilde{\bar{\mu}}), 1.17(\tilde{\bar{d}}), 1.17(\tilde{\bar{s}})$

Table 1: Table of nominally discoverable particles. Mass values (in TeV) below 2.5 TeV, rounded off to two decimal places, calculated at tree level(except the Higgs which include one loop corrections) using two loop RGE equations *including* generation mixing. The principal component of the mass eigenstate is indicated in brackets after the mass value. The eigenstates are quite pure.

Case	$\tau_p(M^+\nu)$	$\Gamma(p\to\pi^+\nu)$	$BR(p\to\pi^+\nu_{e,\mu,\tau})$	$\Gamma(p\to K^+\nu)$	$BR(p\to K^+\nu_{e,\mu,\tau})$
$I-1$	2.4×10^{36}	6.2×10^{-38}	$\{3.605\times10^{-7},0.082,0.918\}$	3.5×10^{-37}	$\{2.808\times10^{-5},0.119,0.881\}$
$I-2$	1.8×10^{34}	7.9×10^{-36}	$\{4.805\times10^{-5},0.076,0.924\}$	4.8×10^{-35}	$\{1.124\times10^{-4},0.114,0.886\}$
$I-3$	5.7×10^{36}	2.4×10^{-38}	$\{3.226\times10^{-7},0.100,0.900\}$	1.5×10^{-37}	$\{2.341\times10^{-5},0.139,0.861\}$
$I-4$	5.7×10^{34}	1.7×10^{-36}	$\{7.362\times10^{-5},0.052,0.947\}$	1.6×10^{-35}	$\{9.080\times10^{-5},0.046,0.953\}$
$II-1$	1.5×10^{36}	9.7×10^{-38}	$\{1.788\times10^{-6},0.114,0.886\}$	5.9×10^{-37}	$\{3.608\times10^{-5},0.170,0.829\}$
$II-3$	1.7×10^{36}	7.4×10^{-38}	$\{1.903\times10^{-6},0.153,0.847\}$	5.1×10^{-37}	$\{2.649\times10^{-5},0.205,0.795\}$
$II-4$	6.2×10^{33}	1.6×10^{-35}	$\{5.787\times10^{-5},0.071,0.929\}$	1.5×10^{-34}	$\{7.957\times10^{-5},0.069,0.931\}$
$III-1$	2.3×10^{36}	6.5×10^{-38}	$\{5.661\times10^{-7},0.088,0.912\}$	3.7×10^{-37}	$\{2.536\times10^{-5},0.128,0.872\}$
$III-2$	5.0×10^{34}	3.3×10^{-36}	$\{3.325\times10^{-5},0.050,0.950\}$	1.7×10^{-35}	$\{9.214\times10^{-5},0.093,0.907\}$
$III-3$	2.2×10^{36}	6.2×10^{-38}	$\{5.908\times10^{-7},0.103,0.897\}$	4.0×10^{-37}	$\{1.989\times10^{-5},0.141,0.859\}$
$III-4$	6.2×10^{33}	1.6×10^{-35}	$\{5.787\times10^{-5},0.071,0.929\}$	1.5×10^{-34}	$\{7.957\times10^{-5},0.069,0.931\}$

Table of $d=5$ operator mediated proton lifetimes τ_p (yrs), decay rates $\Gamma(yr^{-1})$ and Branching ratios in the dominant Meson $^+ + \nu$ channels.

Case	$B.R(b \to s\gamma)$	Δa_μ	$\Delta\rho$
$I-1$	3.294×10^{-4}	5.796×10^{-9}	5.985×10^{-6}
$I-2$	3.293×10^{-4}	5.471×10^{-9}	2.397×10^{-5}
$I-3$	3.294×10^{-4}	2.300×10^{-9}	2.825×10^{-6}
$I-4$	3.293×10^{-4}	7.238×10^{-9}	6.064×10^{-7}
$II-1$	3.290×10^{-4}	1.360×10^{-10}	2.503×10^{-6}
$II-3$	3.287×10^{-4}	1.035×10^{-10}	3.385×10^{-6}
$II-4$	3.278×10^{-4}	1.043×10^{-10}	3.612×10^{-6}
$III-1$	3.293×10^{-4}	8.058×10^{-9}	3.718×10^{-6}
$III-2$	3.293×10^{-4}	6.824×10^{-9}	2.105×10^{-5}
$III-3$	3.295×10^{-4}	8.689×10^{-9}	3.743×10^{-6}
$III-4$	3.294×10^{-4}	7.452×10^{-9}	5.989×10^{-7}

Table Low energy constraints from the limits on the branching ratio for $b \to s\gamma, \Delta a_\mu$ and $\Delta\rho$. The $b \to s\gamma$ branching ratio values are in the centre of the region $(3-4\times 10^{-4}) \pm 15\%$ determined by measurements at CLEO,BaBar and Belle. The current difference between experiment and theory for the muon magnetic moment anomaly is $\Delta a_\mu = 255(63)(49) \times 10^{-11}$.

Conclusions

- SO(10) NMSGUT with Threshold corrections at M_S, M_X and NUHM yields accurate fits to ALL MSSM data, $\tau_p > 10^{34} yr$, precision observables acceptable $\Rightarrow$ complete realistic, predictive, falsifiable phenomenology.
- Characteristic soft spectra : Super heavy Heavy Third sgeneration, 2-4 light sfermions(1-2 sgen), Light gauginos $\Rightarrow$ NMSGUT falsifiable at LHC.
- LSP can be light and is always near pure Bino $\oplus 100 - 300$ GeV light sfermions $\Rightarrow$ effective CDM cosmology.
- Novel MSSM viable Soft parameter region, $\mu, -A_0, M_H^2, M_{\tilde{f}_3}^2 >>> M_{gaugino,lightsquarks}, M_{\tilde{f}_{1,2}} < 300 GeV$.
- $M_X \sim> 10^{18} GeV$, SO(10) gauge divergence below $M_{Planck} \Rightarrow$ hints of gravity gauge unification.