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Minimal SO(10) Splits Supersymmetry.

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MINIMAL *SO*(10) SPLITS SUPERSYMMETRY*

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July 3, 2008

***Work in progress in collaboration with Borut Bajc and Miha Nemevšek.**

OUTLINE

- **THE MODEL: MAIN FEATURES**
- **LOW SCALE SUSY AND *V* MASS**
- **SPLIT SUSY AND *V* MASS**
  (EXPERIMENTAL SIGNATURES)
- **CONCLUSIONS**

MINIMAL SUSY $SO(10)$ — MSGUT*

REPRESENTATIONS: $16_{F\,i}, (i = 1, 2, 3)$ 210_H 126_H $\overline{126}_H$ 10_H

SUPERPOTENTIAL: $W_Y = 16_F(Y_{10}10_H + Y_{\overline{126}}\overline{126}_H)16_F$

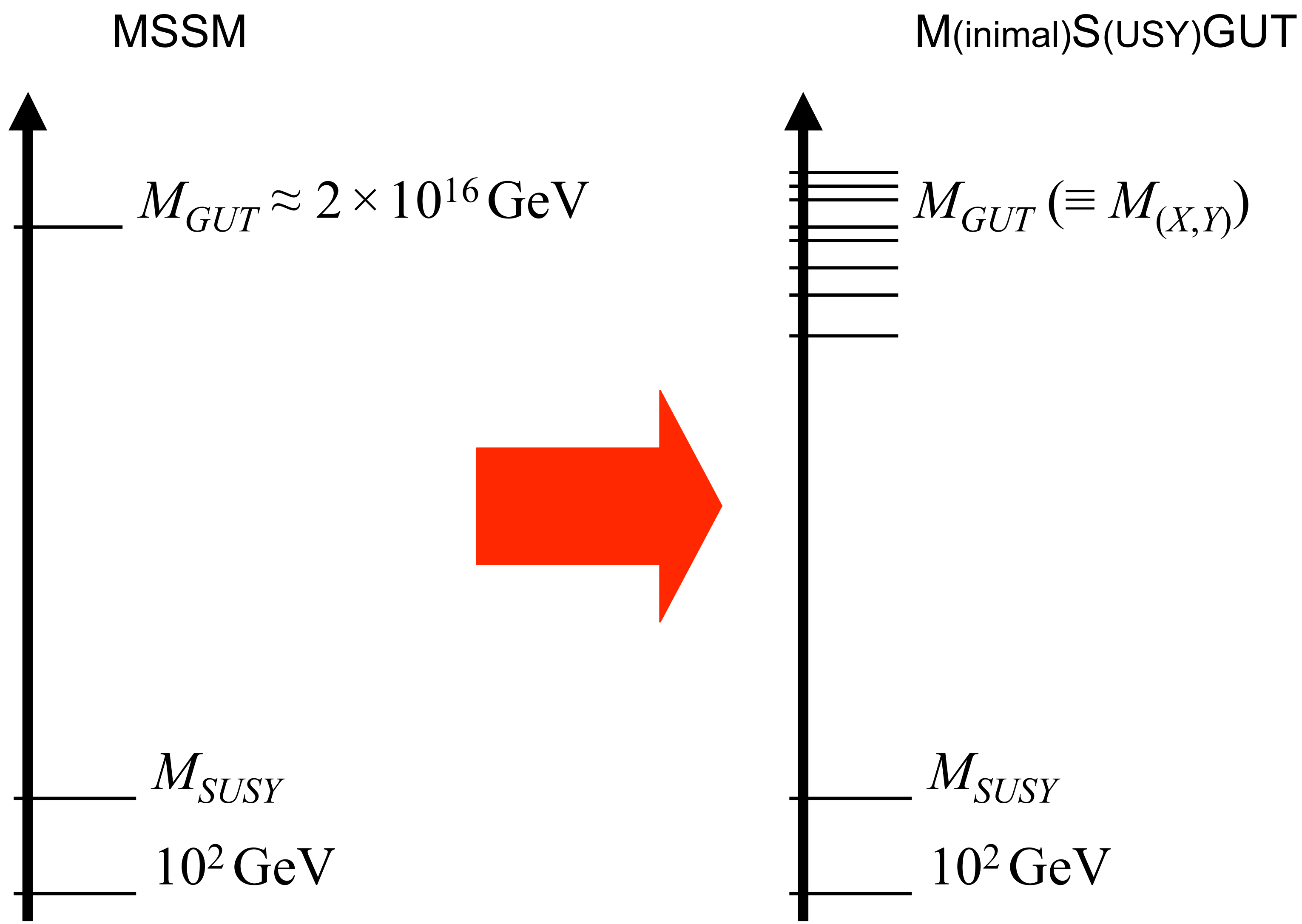
(fermion masses)

$$W_H = \frac{m}{4!}210_H^2 + \frac{\lambda}{4!}210_H^3 + \frac{M}{5!}126_H\overline{126}_H + \frac{\eta}{5!}126_H 210_H\overline{126}_H + m_H^2 10_H{}^2 + \frac{1}{4!}210_H 10_H(\alpha 126_H + \overline{\alpha}\overline{126}_H)$$

(unification)

*T. E. Clark, T. K. Kuo and N. Nakagawa, Phys. Lett. B 115 (1982) 26; K. S. Babu and R. N. Mohapatra, Phys. Rev. Lett. 70 (1993) 2845; C. S. Aulakh, B. Bajc, A. Melfo, G. Senjanovic and F. Vissani, Phys. Lett. B 588 (2004) 196; …

UNIFICATION IN MINIMAL $SO(10)$*

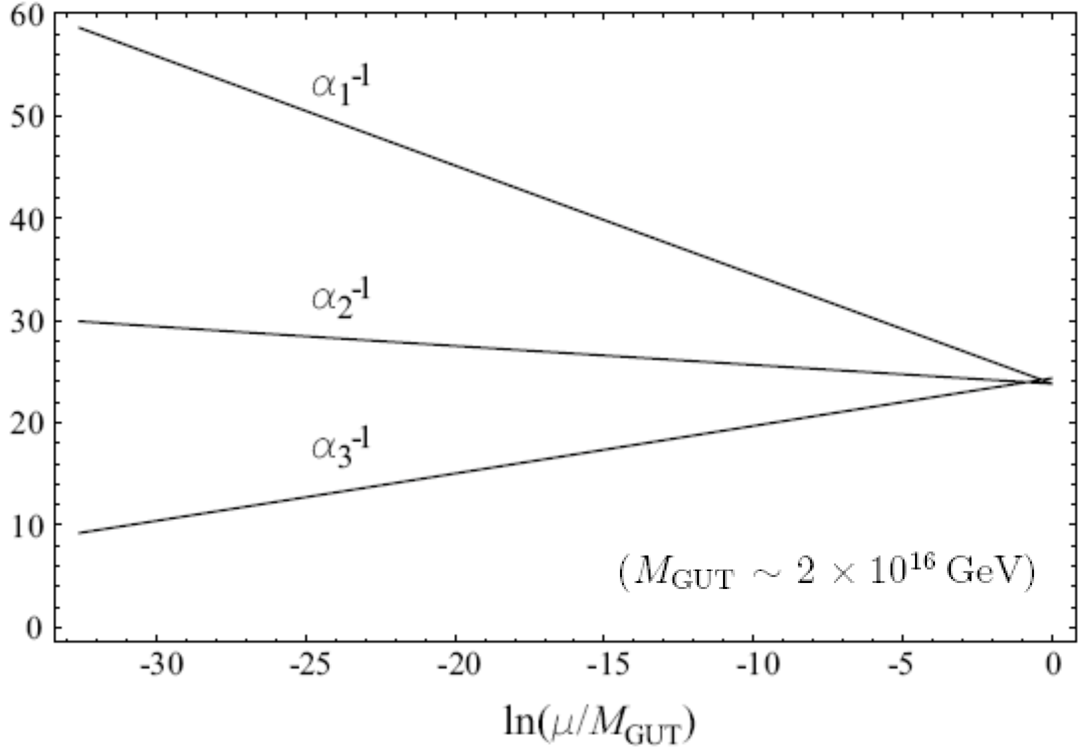


MSSM: GAUGE COUPLING UNIFICATION

$\alpha_1(M_Z) = 0.016949 \pm 0.000005$

$\alpha_2(M_Z) = 0.033816 \pm 0.000027$

$\alpha_3(M_Z) = 0.1176 \pm 0.0020$



MSGUT: GAUGE COUPLING UNIFICATION*

?

*B. Bajc et al, hep-ph/0402122; C. S. Aulakh and S. K. Garg, hep-ph/0512224; S. Bertolini, T. Schwetz and M. Malinsky, hep-ph/0605006; …

MINIMAL SUSY $SO(10)$

CONDITIONS*:

$$M = m\frac{\eta}{\lambda}\frac{3 - 14x + 15x^2 - 8x^3}{(x-1)^2} \quad \ldots$$

RELEVANT PARAMETERS*:

$$m, \quad \alpha, \quad \overline{\alpha}, \quad |\lambda|, \quad |\eta|, \quad \phi = \arg(\lambda) = -\arg(\eta), \quad x = \mathrm{Re}(x) + i\mathrm{Im}(x), \quad g_{GUT}, \quad M_{SUSY}$$

$\phi \to 0$

RGEs: gauge coupling constants

$\tan\beta$

RGEs: Yukawa couplings

*C. S. Aulakh, B. Bajc, A. Melfo, G. Senjanovic and F. Vissani, Phys. Lett. B 588 (2004) 196.

FERMION MASSES IN MINIMAL *SO*(10)*

$$M_u = \frac{N_u}{N_d} \tan\beta [M_d + \xi(M_d - M_e)]$$

$$M_n = \frac{v}{m}\frac{\sin^2\beta}{\cos\beta}\alpha\sqrt{\frac{|\lambda|}{|\eta|}}\frac{N_u^2}{N_d}\left[m_I\, f_I + m_{II}\, f_{II}\right]$$

$$m_I = M_e(M_d - M_e)^{-1}M_e - 6\xi M_e + 9\xi^2(M_d - M_e)$$

$$m_{II} = M_d - M_e$$

OUR CONVENTION: $\hat{M}_j = U_j^T M_j U_j,\ j = u, d, e, n$

*B. Bajc, A. Melfo, G. Senjanovic and F. Vissani, hep-ph/0511352.

TYPE II CONTRIBUTION TO ν MASS

$$F_{II} = \frac{v}{m}\frac{\sin^2\beta}{\cos\beta}\alpha\sqrt{\frac{|\lambda|}{|\eta|}}\frac{N_u^2}{N_d}|f_{II}|$$

$$F_{II} \sim 0.2 \times 10^{-9}$$

b–τ UNIFICATION

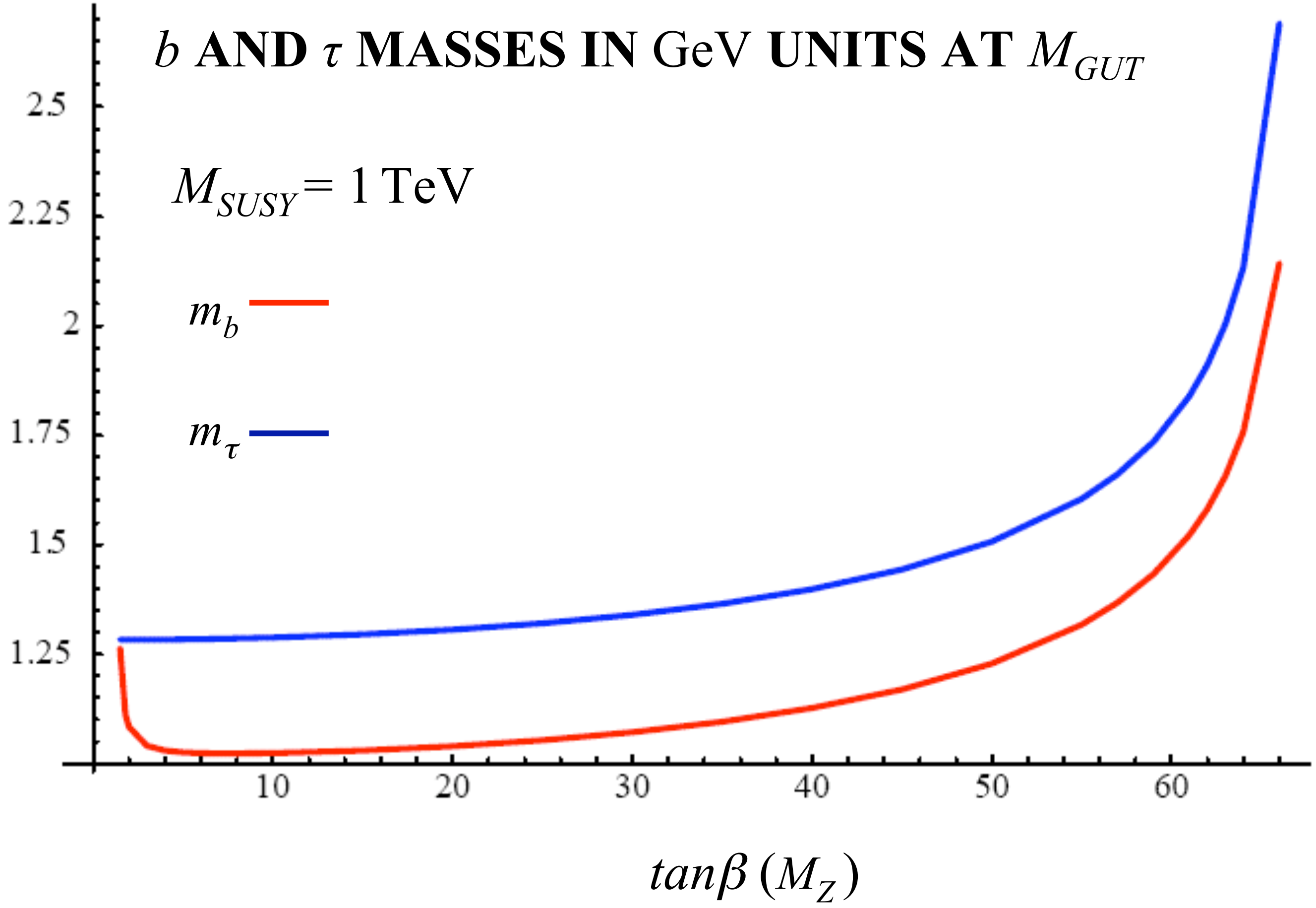
$$m^{-1} < \frac{f(x)}{|\lambda|}\frac{\sqrt{\pi}}{5 \times 10^{15}\,\mathrm{GeV}\sqrt{A_S}}$$

⇒ UPPER BOUND ON ν MASS FROM PROTON STABILITY!

$$M_{(X,Y)} = m\frac{g_{GUT}}{|\lambda|}\sqrt{4\left|\frac{1-x-2x^2}{x-1}\right|^2 + 2\left|\frac{2x(2x^2+x-1)}{(x-1)^2}\right|^2} = m g_{GUT}\frac{f(x)}{|\lambda|}$$

PROTON DECAY ($d = 6$)

b–τ UNIFICATION



m_b-$m_\tau \approx 0.25 \times 10^9$ eV

$F_{II} \sim 0.2 \times 10^{-9}$

$(m_\nu)_{33} \approx 0.05$ eV

THE M_Z DATA ARE FROM hep-ph/0607208 by I. D, P. P. Pérez and G. Rodrigo.

PROTON DECAY ($d = 6$)

THEORY:

$$\Gamma^{p\to\pi^0 e^+} = \frac{m_p}{16\pi f_\pi^2} A_L^2 \, |\alpha|^2 (1+D+F)^2$$
$$\left[A_{SR}^2 \left|k_1^2 V^{11} + k_2^2 (V_q)^{*11} (V_q V)^{11}\right|^2 + A_{SL}^2 k_1^4 \left|V^{11} + (V_q)^{*11} (V_q V)^{11}\right|^2\right]$$

EXPERIMENT:

$$\tau(p \to \pi^0 e^+) > 1.6 \times 10^{33}\,\text{years}$$

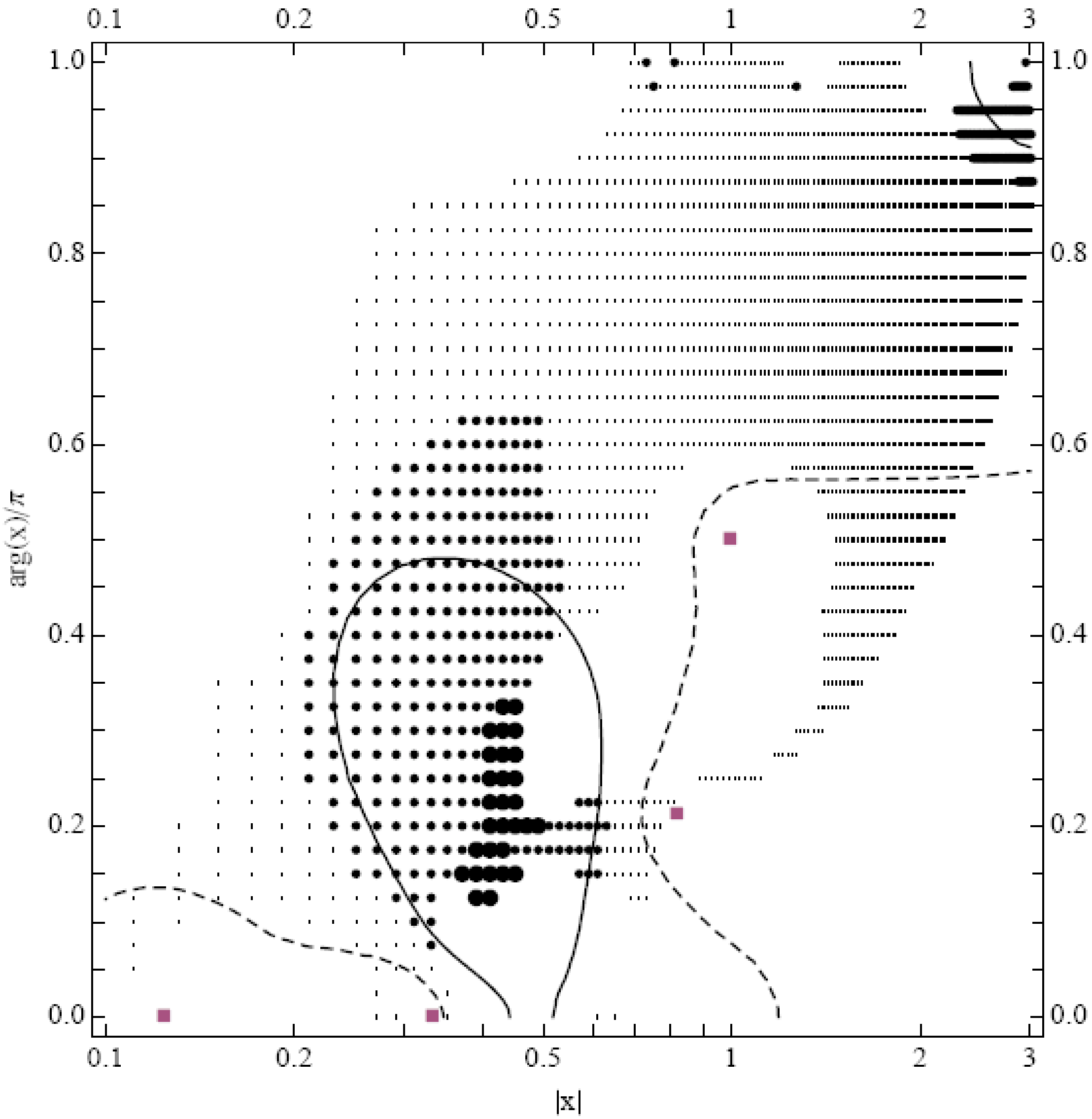
$$M_{(X,Y)} = m \frac{g_{GUT}}{|\lambda|} \sqrt{4 \left| \frac{1 - x - 2x^2}{x-1} \right|^2 + 2 \left| \frac{2x(2x^2 + x - 1)}{(x-1)^2} \right|^2} = m g_{GUT} \frac{f(x)}{|\lambda|}$$

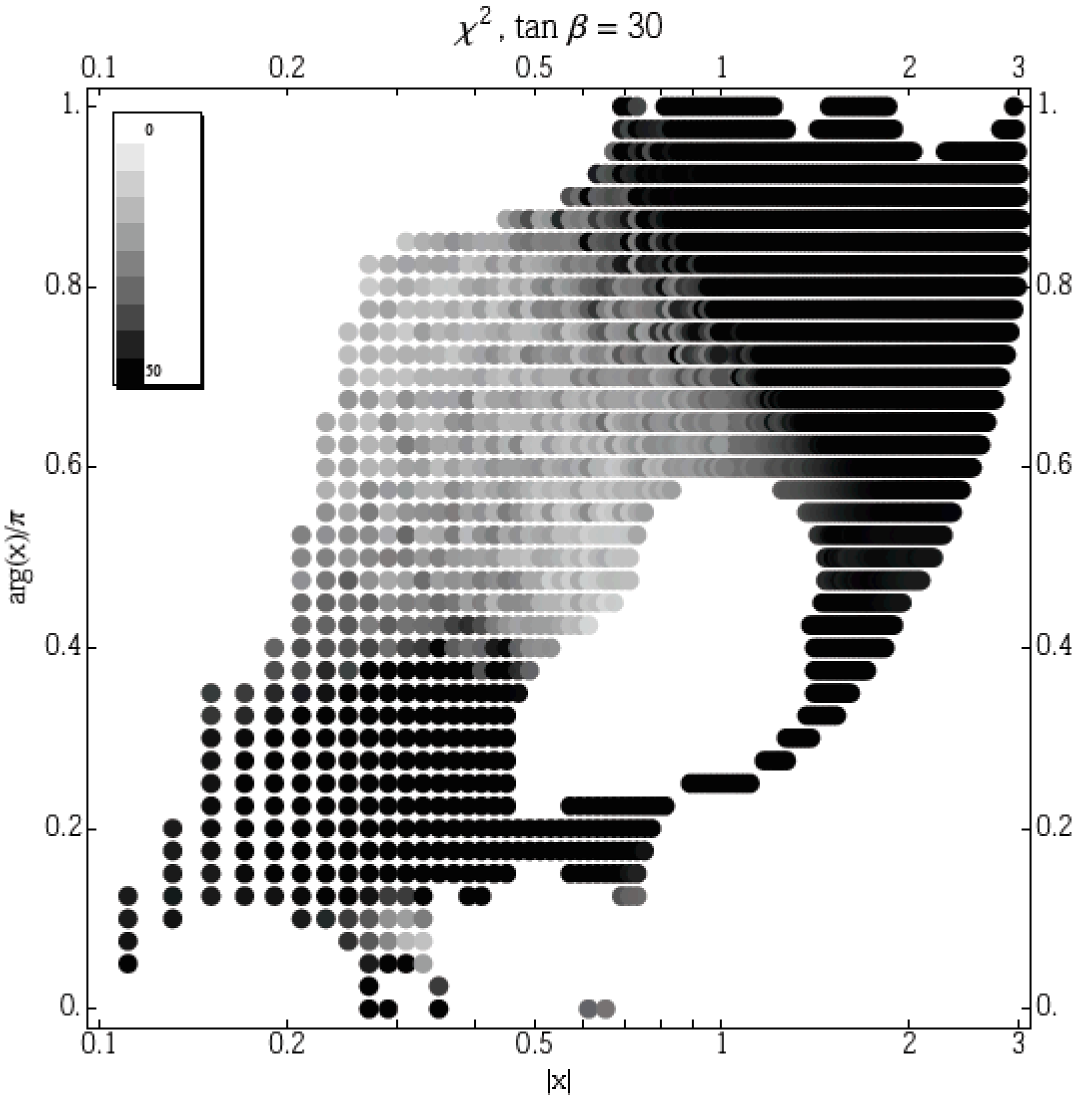
$$V = U_d^\dagger U_e \qquad V_q = U_u^\dagger U_d \qquad k_{1\,(2)}^2 = \frac{2\pi\alpha_{GUT}}{M^2_{(X,Y)\,((X',Y'))}}$$

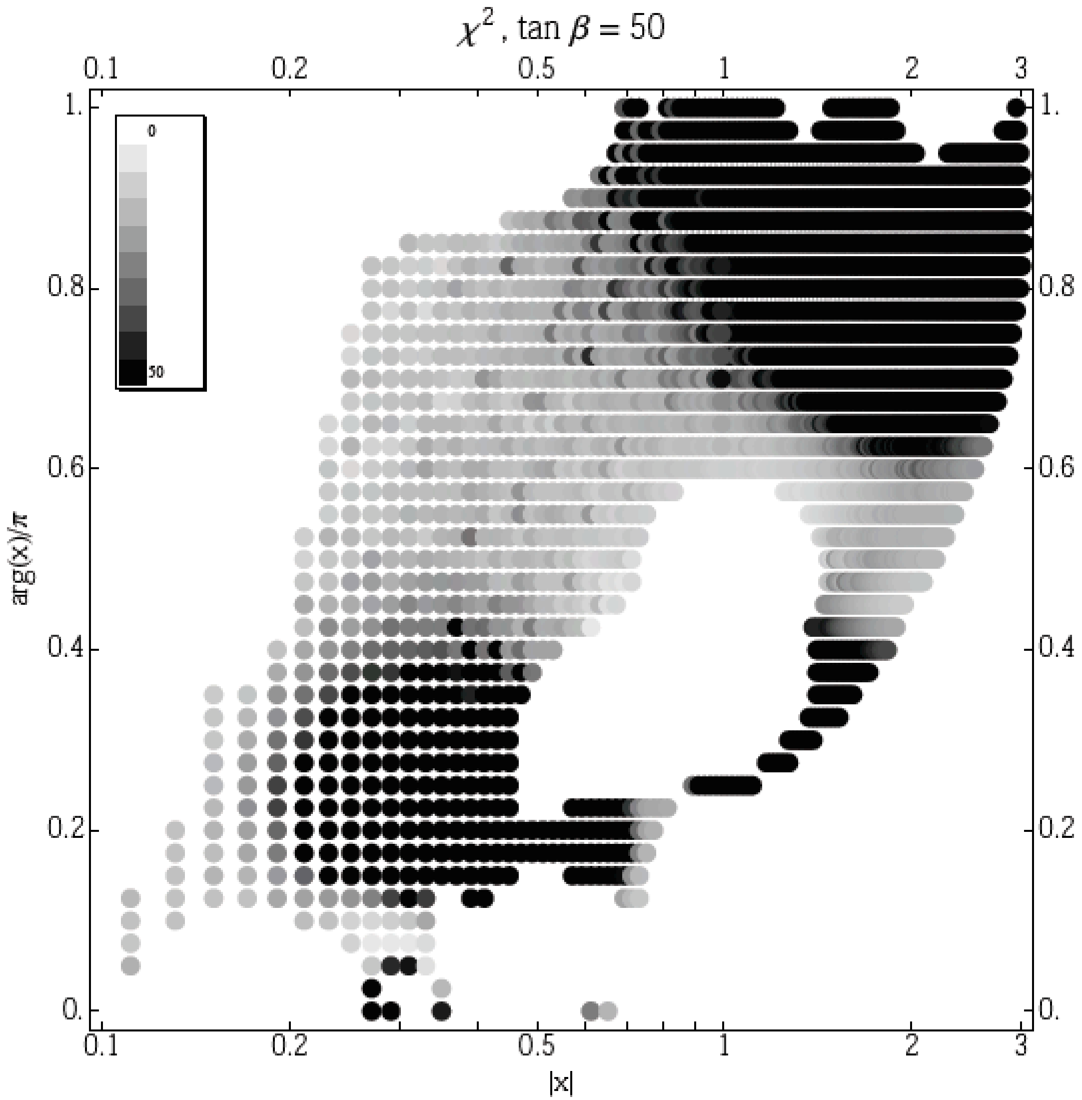
$$M_{(X,Y)} \approx M_{(X',Y')} \qquad A_{S\,L} \approx A_{S\,R} = A_S$$

LOW SCALE SUSY AND ν MASS

$$\eta = \lambda = \alpha = \overline{\alpha} = 1 \qquad \tan\beta = 50$$




χ^2, tan $\beta = 30$
0
50
arg(x)/π
|x|



χ^2, tan $\beta = 50$
0
50
0.1
0.2
0.5
1
2
3
1.
0.8
0.6
0.4
0.2
0.
arg(x)/π
|x|

SPLIT SUSY* AND ν MASS

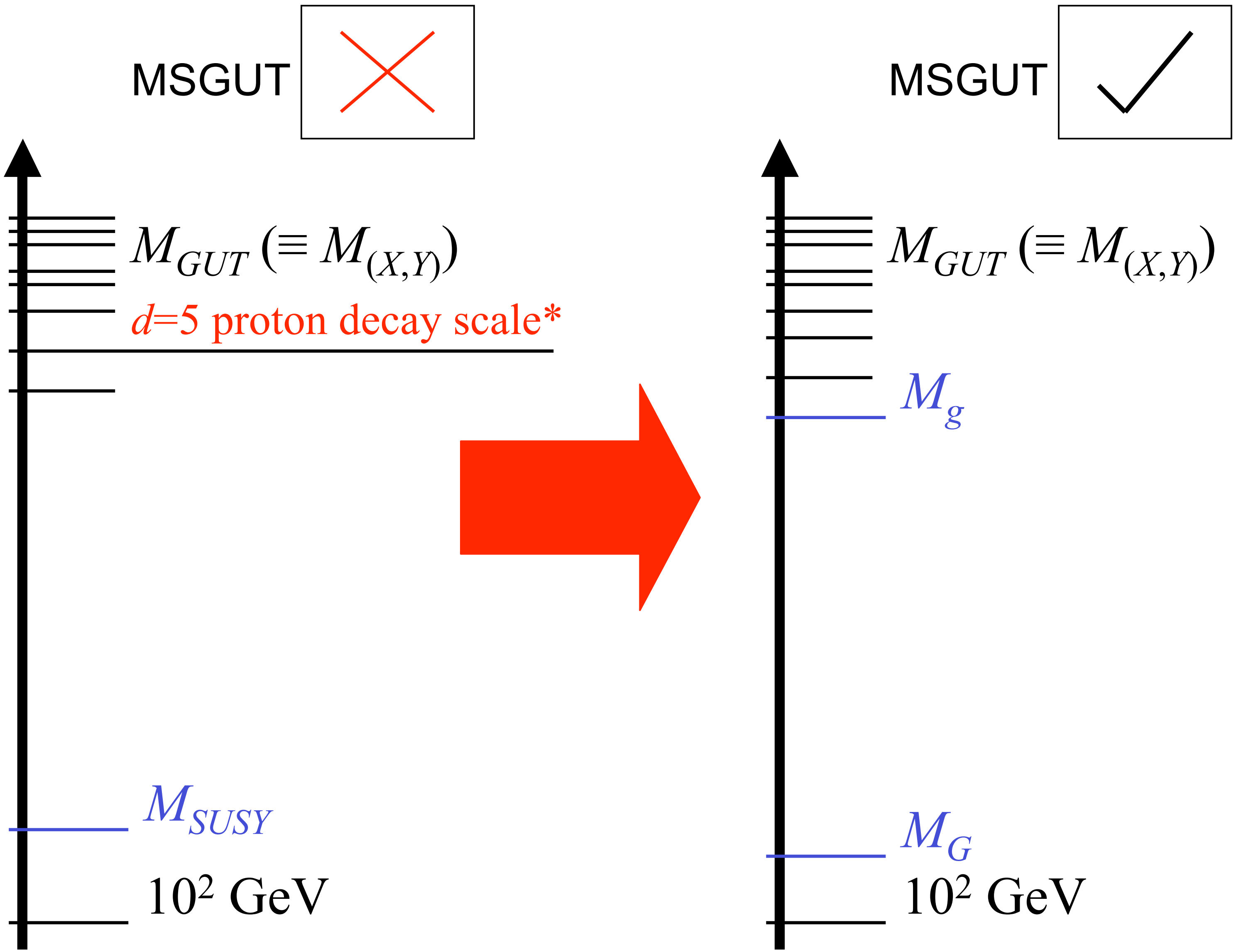
RELEVANT STEPS:

i) We maximize F_{II} in order to have a viable neutrino scale. This fixes x, m (M_{GUT}), α, $\overline{\alpha}$, λ and η.

ii) We check whether unification takes place by solving three equations for the running of gauge couplings for three unknowns — g_{GUT}, M_g and M_G.

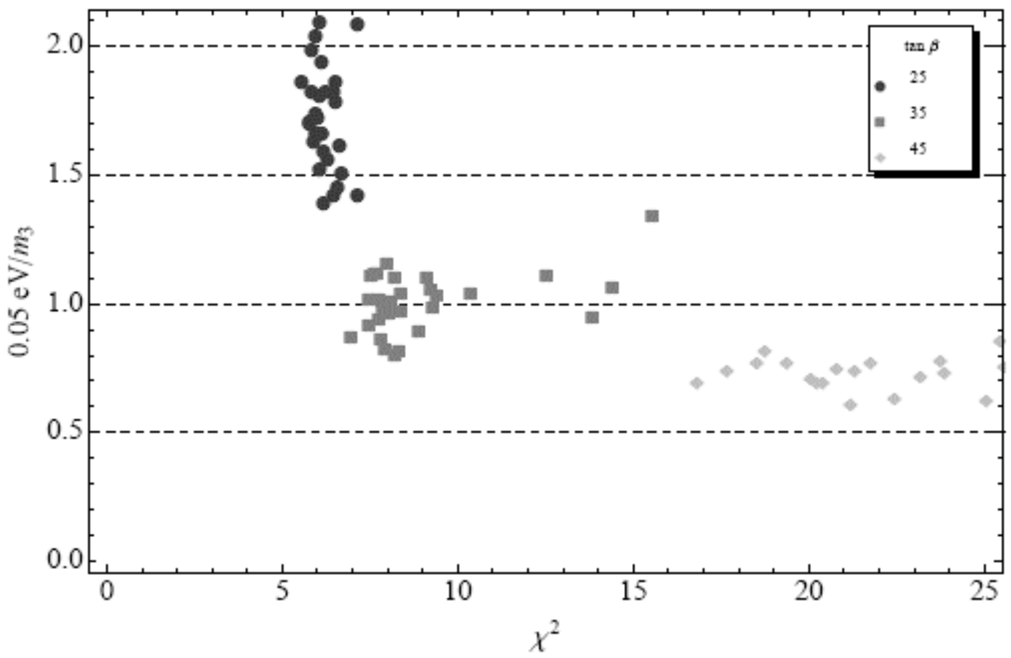
iii) We run masses of quarks and charged leptons and the CKM parameters to M_{GUT} for a given *tanβ* and perform numerical fit that also includes fitting of neutrino masses as well as solar and atmospheric angles.

*N. Arkani-Hamed and S. Dimopoulos, hep-ph/0405159; G. F. Giudice and A. Romanino, hep-ph/0406088.



*T. Fukuyama et al, hep-ph/0406068; B. Dutta et al, 0712.1206 [hep-ph].

PRELIMINARY RESULTS: ν MASS VS. χ^2



PRELIMINARY RESULTS: $|U_{e3}|$ VS. χ^2

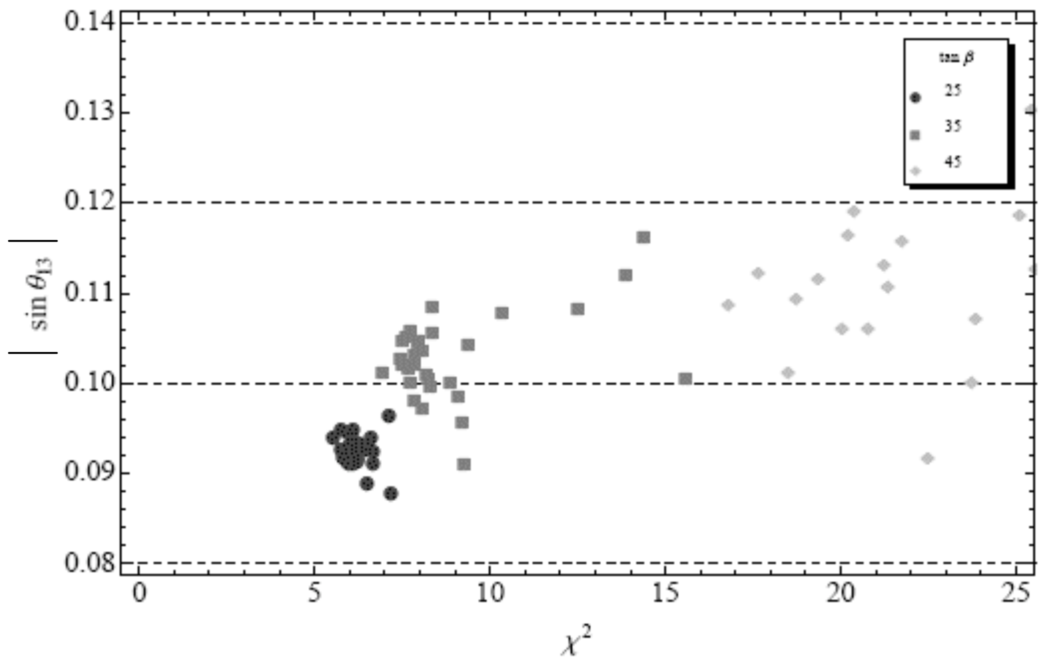


Table 1: Input and output parameters of the numerical fit for $\tan\beta = 35$ with $\chi^2 = 8.09319$, $m_3 = 0.045\,\mathrm{eV}$, $m_2 = 0.0088\,\mathrm{eV}$ and $m_1 = 0.0015\,\mathrm{eV}$. Unification takes place for $|x| = 0.109648$, $arg(x)/\pi = 0.5$, $\alpha = 2.25464$, $\overline{\alpha} = 11.$, $\eta = 10.7529$, $\lambda = 0.03$, $\ln M_{GUT}/M_g = 3.82438$, $\ln M_{GUT}/M_G = 24.3486$, $g_{GUT} = 1.22$ and $M_{GUT} = 5.4 \times 10^{15}\,\mathrm{GeV}$.

observable	FIT	RGE	pull
m_e(MeV)	0.42491	0.42491	
m_μ(GeV)	0.08970	0.08970	
m_τ(GeV)	1.541	1.541	
m_u(MeV)	0.55	0.55	0.019847
m_c(GeV)	0.217	0.215	0.0739264
m_t(GeV)	73.15	67.78	0.79109
m_d(MeV)	0.26	1.2	−2.25182
m_s(MeV)	26.4	22.0	0.58308
m_b(GeV)	0.901	0.914	−0.136006
s_{12}^{CKM}	0.239956	0.227229	0.800175
s_{23}^{CKM}	0.0478599	0.0474469	0.217581
s_{13}^{CKM}	0.004492	0.004487	0.0120442
δ^{CKM}	1.15172	0.994788	0.788766
s_{12}^{PMNS}	0.446992	0.55	−0.706773
s_{23}^{PMNS}	0.572297	0.69	−0.461712
s_{13}^{PMNS}	0.103476		
m_2/m_3	0.178027	0.18	−0.0986272

Table 2: Input and output parameters of the numerical fit for $\tan\beta = 35$ with $\chi^2 = 7.5$, $m_3 = 0.049\,\mathrm{eV}$, $m_2 = 0.0089\,\mathrm{eV}$ and $m_1 = 0.0015\,\mathrm{eV}$. Unification takes place for $|x| = 0.1$, $arg(x)/\pi = 0.46$, $\alpha = 2.15012$, $\overline{\alpha} = 11.$, $\eta = 10.9998$, $\lambda = 0.03$, $\ln M_{GUT}/M_g = 2.12491$, $\ln M_{GUT}/M_G = 24.8055$, $g_{GUT} = 1.22$ and $M_{GUT} = 5.4 \times 10^{15}$ GeV.

observable	data at M_Z	FIT	RGE	pull
m_e(MeV)	0.4866613	0.4433781	0.4433781	
m_μ(GeV)	0.10273	0.09359	0.09359	
m_τ(GeV)	1.746	1.601	1.601	
m_u(MeV)	1.6	0.57	0.56	0.015
m_c(GeV)	0.628	0.223	0.221	0.081
m_t(GeV)	171.5	74.7	69.7	0.723
m_d(MeV)	3.5	0.26	1.3	−2.28
m_s(MeV)	62	27.2	22.6	0.576
m_b(GeV)	2.89	0.927	0.932	−0.047
s_{12}^{CKM}	0.2272	0.2355	0.2272	0.519
s_{23}^{CKM}	0.0422	0.0481	0.0479	0.116
s_{13}^{CKM}	0.00399	0.00453	0.00453	−0.006
δ^{CKM}	0.995	1.097	0.995	0.515
s_{12}^{PMNS}	0.55	0.46	0.55	−0.576
s_{23}^{PMNS}	0.69	0.56	0.69	−0.723
s_{13}^{PMNS}		0.103		
m_2/m_3		0.18	0.18	0.0

PROTON DECAY SIGNATURES*

$$\tau(p \to \pi^0 e^+)$$

$$\tau(p \to K^+ \bar{\nu})/\tau(p \to \pi^0 e^+) = 119 \pm 5$$

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-
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ALL RELEVANT PHASES ARE DETERMINED FROM THE FIT.
ALL RELEVANT MASSES ARE FOUND FROM UNIFICATION.

*P. Filevies Perez, hep-ph/0403286.

CONCLUSIONS

•Preliminary results indicate that the minimal *SO*(10) with low scale SUSY fails to accommodate relevant neutrino mass scale.

•Split SUSY case not only generates viable *ν* scale but allows for consistent description of all known masses and mixing parameters in a particular region of parameter space.

•The model yields interesting signatures for the next generation of proton decay experiments and observable U_{e3}.