Yukawa Unification Predictions for the LHC

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Snowmass on the Pacific - KITP

Highlights

- t-b-τ Yukawa unification is very well motivated in the context of SUSY (SO(10)) GUTS.
- Yukawa unification is achieved in models with an "effective" mirage mediation boundary conditions for the gaugino masses.
- Distinct boundary conditions & very precise predictions

Large $\tan\beta$

- No simplified decay topology for the gluinos. Bounds are weaker than in the case of simplified models.

Why is the gluino mass important in these models?
What are the collider constraints on gluinos in these models?

SO(10) GUTS and Yukawa Unification

$$SO(10) \rightarrow SU(3)_C \times SU(2)_L \times U(1)_Y \times U(1)_{(B-L)}$$

$$16 \rightarrow \underset{Q}{(3,2)_{1/3,1/3}} + \underset{\bar{u}}{(\bar{3},1)_{-4/3,-1/3}} + \underset{\bar{e}}{(1,1)_{-2,1}} + \underset{\bar{d}}{(\bar{3},1)_{2/3,-1/3}} + \underset{L}{(1,2)_{-1,-1}} + \underset{\bar{\nu}}{(1,1)_{0,1}}$$

- SO(10) GUTS are very economical - **16** dimensional representation.
- Only renormalizable Yukawa coupling is of the form,

$$W \supset \lambda\ 16\ 10\ 16$$

  allowing for unified Yukawa couplings at the GUT scale.
- Third family Yukawa Unification is consistent with current data:

$$\lambda_t = \lambda_b = \lambda_\tau = \lambda_\nu = \lambda$$

- Effective higher dimensional operators could generate the first two family *hierarchical* Yukawa couplings.

Minimal Y-unified GUTS

AA, Raby & Wingerter: arXiv:1212.0542 (Phys. Rev. D 87, 055005 (2013))

Sector	Third Family Analysis	#	Full three family Analysis	#
gauge	α_G, M_G, ϵ_3	3	α_G, M_G, ϵ_3	3
SUSY (GUT scale)	m_{16}, $M_{1/2}$, A_0, m_{H_u}, m_{H_d}	5	m_{16}, $M_{1/2}$, A_0, m_{H_u}, m_{H_d}	5
textures	λ	1	ϵ, ϵ', λ, ρ, σ, $\tilde{\epsilon}$, ξ	11
neutrino		0	M_{R_1}, M_{R_2}, M_{R_3}	3
SUSY (EW scale)	$\tan\beta$, μ	2	$\tan\beta$, μ	2
Total #		11		24

$$A_0 \sim -2m_{16}; \qquad m_{10} \sim \sqrt{2}m_{16};$$

$$m_{16} > \text{few TeV}; \qquad \mu, M_{1/2} << m_{16};$$

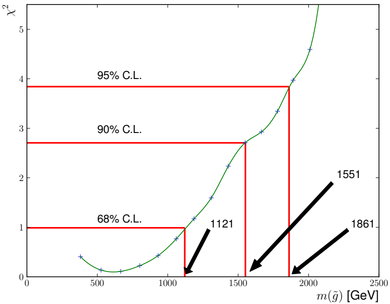
$$\tan\beta \sim 50$$

Blazek, Dermisek & Raby: PRL 88, 11804; PRD 65, 115004
Baer & Ferrandis: PRL 87, 211803
Auto, Baer, Balazs, Belayaev, Ferrandis,& Tata: JHEP 0306:023
Tobe & Wells: NPB 663,123
Dermisek, Raby, Roszkowski, & Ruiz de Austri: JHEP 0304:037; JHEP 0509:029
Baer, Kraml, Sekmen, & Summy: JHEP 0803:056; JHEP 0810:079

Minimal Y-unified GUTS

General features

- Heavy Scalars (first, second families $>$ 10 TeV)
- Gluinos $\lesssim$ 2 TeV
- Bino LSP



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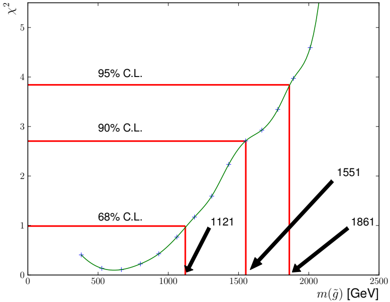
$$\delta m_b / m_b \simeq \frac{g_3^2}{12\pi^2} \frac{\mu M_{\tilde{g}} \tan\beta}{m_{\tilde{b}}^2} + \frac{\lambda_t^2}{32\pi^2} \frac{\mu A_t \tan\beta}{m_{\tilde{t}}^2}$$

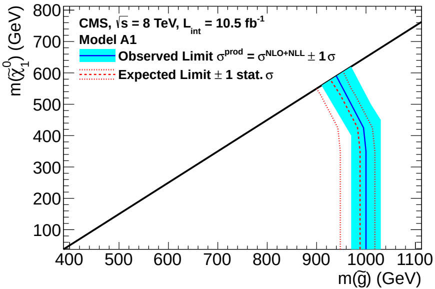


Gluino decay Rates

Branching Ratios for $M_{\tilde{g}} = 800\text{GeV}$:

$$\begin{aligned}\mathcal{BR}(\tilde{g} \to b\bar{t}\tilde{\chi}_1^+) &= 26\% \\ \mathcal{BR}(\tilde{g} \to t\bar{b}\tilde{\chi}_1^-) &= 26\% \\ \mathcal{BR}(\tilde{g} \to t\bar{t}\tilde{\chi}_2^0) &= 22\% \\ \mathcal{BR}(\tilde{g} \to g\tilde{\chi}^0) &= 18\%\end{aligned}$$

CMS Results from 10.5 fb^{-1} of data for $\tilde{g} \to t\bar{t}\chi^0$ 100% of the time:



Work in progress with Brandon Bryant, Stuart Raby, and Akın Wingerter

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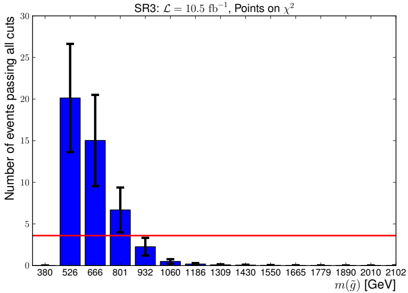
Same sign dileptons + b-jets + MET search from CMS



MET > 120 GeV; HT > 200 GeV

Effective "Mirage" Mediation

arXiv:1303.5125 AA and Stuart Raby

- Non-universal gaugino masses with mirage pattern.

$$M_i = \left(1 + \frac{g_G^2 b_i \alpha}{16\pi^2} \log\left(\frac{M_{Pl}}{m_{16}}\right)\right) M_{1/2}$$

where $M_{1/2}$ and α are free parameters and $b_i = (33/5, 1, -3)$

- For large α, $|M_2| < |M_1|$.

NUHM	"Just-so"	D-term
$m_{\tilde{\chi}_1^0}$	231.98	219.11
$m_{\tilde{\chi}_1^+}$	232.05	219.11
$\Delta M \equiv M_{\tilde{\chi}^+} - M_{\tilde{\chi}^0}$	519 MeV	434 MeV
$M_{\tilde{g}}$	882	874

Signatures

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$$\chi^{\pm} \to \chi^{0}\pi^{\pm}$$

- Gluino decays - No same sign dileptons from chargino decays.
- Associated photon and Z production

Work in progress with Brandon Bryant, Linda Carpenter and Stuart Raby

Summary

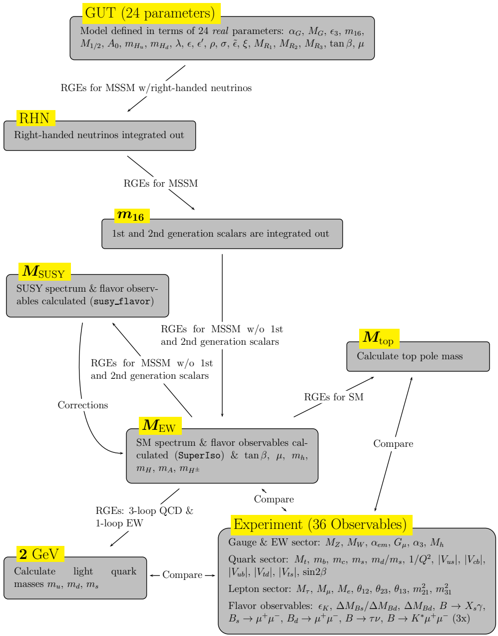
- Yukawa unified SUSY is well-motivated.
- The gluino mass is constrained in these models.

  From fitting to bottom quark mass and the Higgs mass.
- The lower bound on the gluino in these models is about 20% weaker than simplified models.

  Gluino decay topology is non-simplified.

THANK YOU!

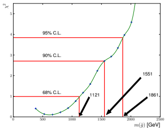
BACK-UP


GUT (24 parameters)
Model defined in terms of 24 *real* parameters: α_G, M_G, ϵ_3, m_{16}, $M_{1/2}$, A_0, m_{H_u}, m_{H_d}, λ, ϵ, ϵ', ρ, σ, $\tilde{\epsilon}$, ξ, M_{R_1}, M_{R_2}, M_{R_3}, $\tan\beta$, μ
RGEs for MSSM w/right-handed neutrinos
RHN
Right-handed neutrinos integrated out
RGEs for MSSM
m_{16}
1st and 2nd generation scalars are integrated out
M_{SUSY}
SUSY spectrum & flavor observables calculated (susy_flavor)
RGEs for MSSM w/o 1st and 2nd generation scalars
RGEs for MSSM w/o 1st and 2nd generation scalars
M_{top}
Calculate top pole mass
Corrections
RGEs for SM
M_{EW}
SM spectrum & flavor observables calculated (SuperIso) & $\tan\beta$, μ, m_h, m_H, m_A, $m_{H^\pm}$
Compare
Compare
RGEs: 3-loop QCD & 1-loop EW
Experiment (36 Observables)
Gauge & EW sector: M_Z, M_W, α_{em}, G_μ, α_3, M_h
Quark sector: M_t, m_b, m_c, m_s, m_d/m_s, $1/Q^2$, $|V_{us}|$, $|V_{cb}|$, $|V_{ub}|$, $|V_{td}|$, $|V_{ts}|$, $\sin 2\beta$
Lepton sector: M_τ, M_μ, M_e, θ_{12}, θ_{23}, θ_{13}, m^2_{21}, m^2_{31}
Flavor observables: ϵ_K, $\Delta M_{Bs}/\Delta M_{Bd}$, ΔM_{Bd}, $B \to X_s\gamma$, $B_s \to \mu^+\mu^-$, $B_d \to \mu^+\mu^-$, $B \to \tau\nu$, $B \to K^*\mu^+\mu^-$ (3x)
2 GeV
Calculate light quark masses m_u, m_d, m_s
Compare

SS Dilepton Analysis

	SR0	SR1	SR2	SR3	SR4	SR5	SR6	SR7	SR8
No. of jets	≥ 2	≥ 2	≥ 2	≥ 4	≥ 4	≥ 4	≥ 4	≥ 3	≥ 4
No. of btags	≥ 2	≥ 2	≥ 2	≥ 2	≥ 2	≥ 2	≥ 2	≥ 3	≥ 2
Lepton charges	$++/--$	$++/--$	$++$	$++/--$	$++/--$	$++/--$	$++/--$	$++/--$	$++/--$
E_T^{miss}	>0 GeV	>30 GeV	>30 GeV	>120 GeV	>50 GeV	>50 GeV	>120 GeV	>50 GeV	>0 GeV
H_T	>80 GeV	>80 GeV	>80 GeV	>200 GeV	>200 GeV	>320 GeV	>320 GeV	>200 GeV	>320 GeV
Fake BG	25 ± 13	19 ± 10	9.6 ± 5.0	0.99 ± 0.69	4.5 ± 2.9	2.9 ± 1.7	0.7 ± 0.5	0.71 ± 0.47	4.4 ± 2.6
Charge-flip BG	3.4 ± 0.7	2.7 ± 0.5	1.4 ± 0.3	0.04 ± 0.01	0.21 ± 0.05	0.14 ± 0.03	0.04 ± 0.01	0.03 ± 0.01	0.21 ± 0.05
Rare SM BG	11.8 ± 5.9	10.5 ± 5.3	6.7 ± 3.4	1.2 ± 0.7	3.4 ± 1.8	2.7 ± 1.5	1.0 ± 0.6	0.44 ± 0.39	3.5 ± 1.9
Total BG	40 ± 14	32 ± 11	17.7 ± 6.1	2.2 ± 1.0	8.1 ± 3.4	5.7 ± 2.4	1.7 ± 0.7	1.2 ± 0.6	8.1 ± 3.3
Event yield	43	38	14	1	10	7	1	1	9
N_{UL} (13% unc.)	27.2	26.0	9.9	3.6	10.8	8.6	3.6	3.7	9.6
N_{UL} (20% unc.)	28.2	27.2	10.2	3.6	11.2	8.9	3.7	3.8	9.9
N_{UL} (30% unc.)	30.4	29.6	10.7	3.8	12.0	9.6	3.9	4.0	10.5

Gluino Lowerbound



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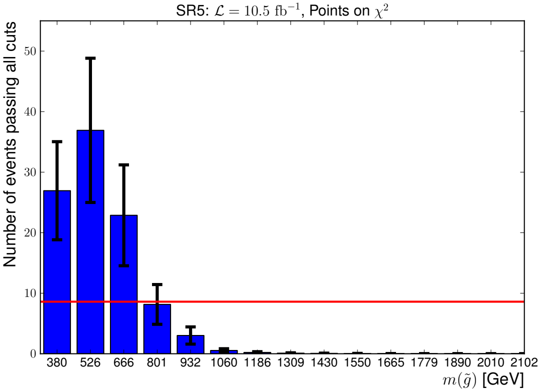

MET > 50 GeV; HT > 320 GeV

Scalar Masses

- Two different cases for non-universal Higgs masses [NUHM] with "just so" Higgs splitting

$$m^2_{H_{u(d)}} = m^2_{10} - (+)2D$$

or,

- D-term Higgs splitting, in addition, squark and slepton masses are given by

$$m^2_a = m^2_{16} + Q_a D, \;\; \{Q_a = +1, \{Q, \bar{u}, \bar{e}\}; -3, \{L, \bar{d}\}\}$$

with the U(1) D-term, D, and SU(5) invariant charges, Q_a.

Sector	Third Family Analysis
gauge	α_G, M_G, ϵ_3
SUSY (GUT scale)	m_{16}, $M_{1/2}$, α, A_0, m_{10}, D
textures	λ
SUSY (EW scale)	$\tan\beta$, μ
Total #	12