Y-Unified GUTS: MSSM at large tanβ

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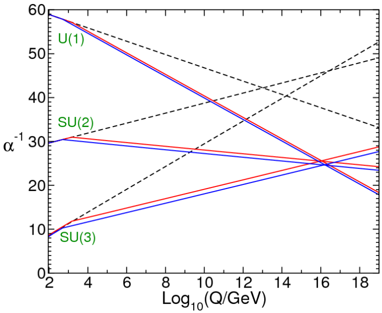
Based on arXiv:1212.0542 (Phys. Rev. D 87, 055005 (2013))
& arXiv:1303.5125
& arXiv:1307.7723 (Accepted in PRD)
& work in progress
with Stuart Raby, B. Charles Bryant, Linda Carpenter (OSU),
Kuver Sinha (Syracuse), Akın Wingerter(LPSC)

Theory Seminar, Los Alamos National Lab

Outline

- Introduction to SO(10) SUSY GUTS
- Constraints from Yukawa Unification
- The Analysis
- Spectrum and Phenomenology
- Effective "Mirage" Mediation.
- Summary

Supersymmetric GUTS



Dimopoulos, Raby, Wilczek (1981)
(Fig. from Martin's Primer)

- Argument in favor of SUSY, independent of the solution to hierarchy problem.
- Requires some superpartners of around the TeV scale.
- Unification of couplings at $\sim 10^{16}$ GeV.

SO(10) GUTS and Yukawa Unification

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

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

- 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.

$$\lambda_t = \lambda_b = \lambda_\tau = \lambda_{\nu_\tau} = \lambda$$

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

Yunification and Boundary Conditions

- One can use Yukawa Unification to constrain the GUT scale boundary conditions.

Yukawa Unification & Soft SUSY breaking

- 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

- Badziak, Olechowski & Pokorski

  JHEP 2011:147

- Gogoladze, & Shafi,Un

  JHEP 2012:028; PLB 704, 201

- Ajaib, Gogoladze, Shafi, & Un

  JHEP 2013:139

- **AA** & Raby

  arXiv:1303.5125

Recent papers on Yukawa unification (created using wordle)

A quick refresher

GUT scale parameters of a 'minimal' SO(10) SUSY GUT

- m_{16} - Universal scalar mass
- m_{10} - Universal Higgs mass
- $M_{1/2}$ - Universal gaugino mass
- A_0 - Trilinear coupling
- $\tan\beta$ - Ratio of the Higgs vev.
- g - Unified gauge coupling
- λ - Unified Yukawa coupling at the GUT scale

Higgs vev

- Ratio of the Higgs vev is defined as

$$\tan\beta = \frac{v_u}{v_d} = \frac{\langle H_u \rangle}{\langle H_d \rangle}$$

- Fermion masses are generated by coupling to the Higgs boson

$$\mathcal{L} \supset \lambda_t v_u \bar{t} t + \lambda_b v_d \bar{b} b + \lambda_\tau v_d \bar{\tau} \tau$$

The value of $\tan\beta$ is restricted by the requirement of Yukawa unification.

$$\underline{\tan\beta \simeq 50}$$

Yunification and Boundary Conditions

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Yukawa Unification & Soft SUSY breaking

- tan$\beta \simeq 50$

Bottom quark mass

- In the large $\tan\beta$ regime, there are large corrections to the bottom quark mass.

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

Hall et. al; Carena et. al; Blazek et. al

- In order to fit data, $\delta m_b/m_b \simeq -(few)\%$

$$\mu M_{\tilde{g}} > 0; \Rightarrow \mu A_t < 0$$

Trilinear Coupling $A_0 < 0$

Electroweak Symmetry Breaking

- The RGEs for the up and down-type Higgs mass squared can be written as:

$$\frac{dm_{Hd}^2}{dt} = \frac{2}{16\pi^2}\left(-\frac{3}{5}g_1^2M_1^2 - 3g_2^2M_2^2 - \frac{3}{10}g_1^2S + 3\lambda_b^2X_b + \lambda_\tau^2X_\tau\right)$$

$$\frac{dm_{Hu}^2}{dt} = \frac{2}{16\pi^2}\left(-\frac{3}{5}g_1^2M_1^2 - 3g_2^2M_2^2 + \frac{3}{10}g_1^2S + 3\lambda_t^2X_t + \lambda_{\nu_\tau}^2X_{\nu_\tau}\right)$$

- RGE evolution in standard MSSM scenarios

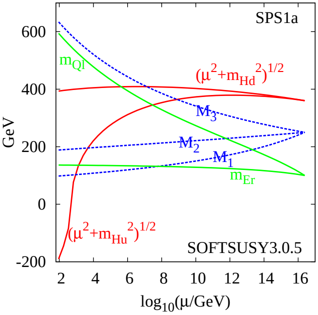

Fig from SOFTSUSY

Electroweak Symmetry Breaking

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$$\frac{dm_{Hu}^2}{dt} = \frac{2}{16\pi^2}\left(-\frac{3}{5}g_1^2M_1^2 - 3g_2^2M_2^2 + \frac{3}{10}g_1^2S + 3\lambda_t^2X_t + \lambda_{\nu_\tau}^2X_{\nu_\tau}\right)$$

- In Yunified models, since, $\lambda_t = \lambda_b = \lambda_\tau = \lambda_\nu = \lambda$, in order for REWSB, one needs

$$m_{Hu}^2 < m_{Hd}^2$$

Non-universal Higgs masses!

Yunification and Boundary Conditions

- One can use Yukawa Unification to constrain the GUT scale boundary conditions.

Yukawa Unification & Soft SUSY breaking

- tanβ
- Corrections to bottom mass
- Non-universal Higgs mass

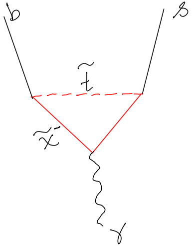
$B_s \to X_s\gamma$

Exp $\mathcal{BR}(B_s \to X_s\gamma)_{Exp} = (3.43 \pm 0.30) \times 10^{-4}$

SM NNLO $\mathcal{BR}(B_s \to X_s\gamma)_{SM} = (3.15 \pm 0.23) \times 10^{-4}$

In MSSM,

$$C_7^{\tilde{\chi}^+} \propto \frac{\mu A_t}{\tilde{m}^2} \tan\beta \times sign(C_7^{SM})$$



Data constrains

$$C_7^{eff} = C_7^{SM} + C_7^{SUSY} \simeq \pm C_7^{SM}$$

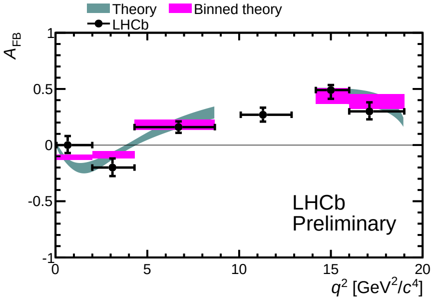
- $C_7^{SUSY} \simeq -2C_7^{SM}$, implying light scalars.
- $C_7^{SUSY} \simeq 0$, implying heavy scalars scalars.

Which possibility does data accommodate?

$B \to K^* \mu^+ \mu^-$

Forward-Backward Asymmetry in $B \to K^* \mu^+ \mu^-$!

- If $C_7^{eff} = +C_7^{SM}$, then A_{FB} crosses zero at some momentum.
- If $C_7^{eff} = -C_7^{SM}$, then there is no zero-crossing in the A_{FB}.



2012 Result from LHCb

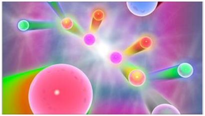
Heavy Scalars

Breaking News!

Popular physics theory running out of hiding places

By Pallab Ghosh
Science correspondent, BBC News

Researchers at the Large Hadron Collider have detected one of the rarest particle decays seen in nature.



Supersymmetry predicts heavy versions of all the particles we know about - "super particles"

The finding deals a significant blow to the theory of physics known as supersymmetry.

Many researchers had hoped the LHC would have confirmed this by now.

Supersymmetry, or Susy, has gained popularity as a way to explain some of the inconsistencies in the traditional theory of subatomic physics known as the Standard Model.

The new observation, reported at the **Hadron Collider Physics conference in Kyoto** and outlined in **an as-yet unpublished paper**, is not consistent with many of the most likely models of Susy.

Prof Chris Parkes, who is the spokesperson for the UK participation in the LHCb experiment, told BBC News: "Supersymmetry may not be dead but these latest results have certainly put it into hospital."

Supersymmetry theorises the existence of more massive versions of particles that have already been detected.

If found, they might help explain the phenomenon known as dark matter. Galaxies appear to rotate faster at their edges than the matter we see

Related Stories

- LHC puts supersymmetry in doubt
- Higgs results 'get even stronger'
- Higgs-like particle 'discovered'

“

$B_s \to \mu^+\mu^-$

2012 LHCb $\mathcal{BR}(B_s \to \mu^+\mu^-)_{Exp} = (3.2 \pm 1.5) \times 10^{-9}$

SM $\mathcal{BR}(B_s \to \mu^+\mu^-)_{SM} = (3.37 \pm 0.31) \times 10^{-9}$

- MSSM contributions are enhanced in the large $\tan\beta$ limit.

$$\mathcal{BR}(B_s \to \mu^+\mu^-) \propto \frac{(\tan\beta)^6}{M_A^4}$$

- In MSSM models with large $\tan\beta$, $M_A \geq 1500 \ GeV$

Standard Model like Higgs

Yunification and Boundary Conditions

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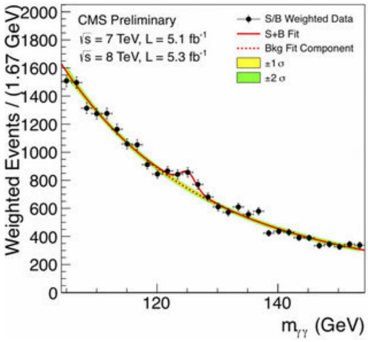
Yukawa Unification & Soft SUSY breaking

- tanβ
- Corrections to bottom mass
- Non-universal Higgs mass
- Flavor Physics NEW!

Discovery of the millenia



CMS ; ATLAS

$M_h = 125.3 \pm 1\ GeV$

Light Higgs Mass

Boundary conditions consistent with minimal Yukawa unification:

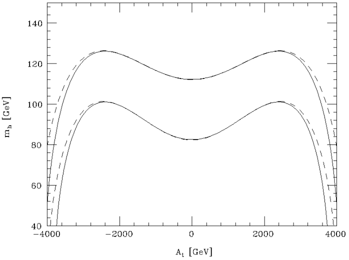
$$m_{16} > \text{few TeV}; \qquad m_{10} \sim \sqrt{2} m_{16};$$

$$A_0 \sim -2m_{16}; \qquad \mu, M_{1/2} << m_{16};$$

$$\tan\beta \sim 50$$

Bagger, Feng, et al

Maximal mixing region - easy to get ~ 125 GeV Higgs.



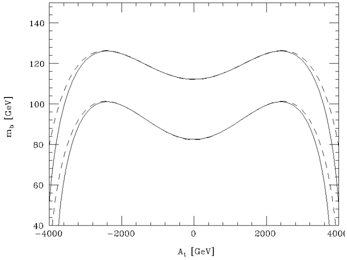
Carena, Quiros, Wagner

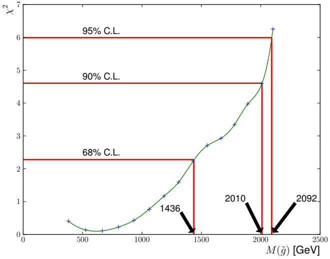
Higgs and Bottom quark

To fit bottom quark mass:

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

Fitting the Higgs mass:





$m_{16} = 20$ TeV

Yunification and Boundary Conditions

- One can use Yukawa Unification to constrain the GUT scale boundary conditions.

Yukawa Unification & Soft SUSY breaking

- tanβ
- Corrections to bottom mass
- Non-universal Higgs mass
- Flavor Physics NEW!
- Higgs Mass NEW!

Neutrino sector

Observables in the neutrino sector:

$$\begin{aligned}
\sin^2\theta_{12} &= 0.27 - 0.34 \\
\sin^2\theta_{23} &= 0.34 - 0.67 \\
\sin^2\theta_{13} &= 0.016 - 0.030 \\
\Delta m^2_{21} &= (7.00 - 8.09)\times 10^{-5}\ \mathrm{eV}^2 \\
\Delta m^2_{31} &= (2.27 - 2.69)\times 10^{-3}\ \mathrm{eV}^2
\end{aligned}$$

(3σ range) from Nu-fit Collaboration

$$\begin{aligned}
\theta_{13}^{exp} &= 9^\circ(7.29 - 9.96) \\
\theta_{13}^{DR-model} &\lesssim 6^\circ
\end{aligned}$$

DayaBay; Reno

Flavor violating corrections to the Kähler potential.

Chen, Fallbacher et al

Yunification and Boundary Conditions

- One can use Yukawa Unification to constrain the GUT scale boundary conditions.

Yukawa Unification & Soft SUSY breaking

- tanβ
- Corrections to bottom mass
- Non-universal Higgs mass
- Flavour Physics
- Higgs Mass
- Neutrino masses and mixing angles

Dermisek-Raby Model

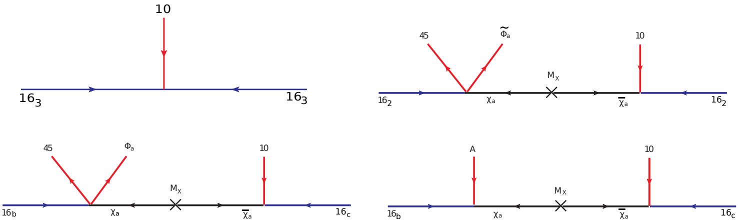
Recent analysis by **AA**, S.Raby, and A. Wingerter 1212.0542

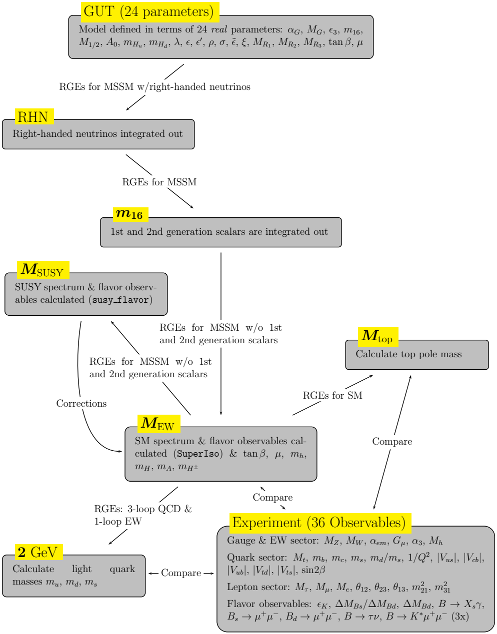
Sector	Third Family Analysis	#	Full three family Analysis	#
gauge	$\alpha_G,\ M_G,\ \epsilon_3$	3	$\alpha_G,\ M_G,\ \epsilon_3$	3
SUSY (GUT scale)	$m_{16},\ M_{1/2},\ A_0,\ m_{H_u},\ m_{H_d}$	5	$m_{16},\ M_{1/2},\ A_0,\ m_{H_u},\ m_{H_d}$	5
textures	λ	1	$\epsilon,\ \epsilon',\ \lambda,\ \rho,\ \sigma,\ \tilde{\epsilon},\ \xi$	11
neutrino		0	$M_{R_1},\ M_{R_2},\ M_{R_3}$	3
SUSY (EW scale)	$\tan\beta,\ \mu$	2	$\tan\beta,\ \mu$	2
Total #		11		24

(Compared to 32 parameters in the CMSSM)

$$W_{ch.fermions} = \lambda\ 16_3\ 10\ 16_3 + 16_a\ 10\ \chi_a + \bar{\chi}_a\ (M_\chi\ \chi_a + \ 45\ \frac{\phi_a}{\hat{M}}\ 16_3\ +\ 45\ \frac{\tilde{\phi}_a}{\hat{M}}\ 16_a + A\ 16_a)$$

Effective operators to generate the first two family and off-diagonal Yukawa couplings.





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
$\boldsymbol{m_{16}}$
1st and 2nd generation scalars are integrated out
$\boldsymbol{M}_{\text{SUSY}}$
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
$\boldsymbol{M}_{\text{top}}$
Calculate top pole mass
Corrections
RGEs for SM
$\boldsymbol{M}_{\text{EW}}$
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

SUSY Spectrum

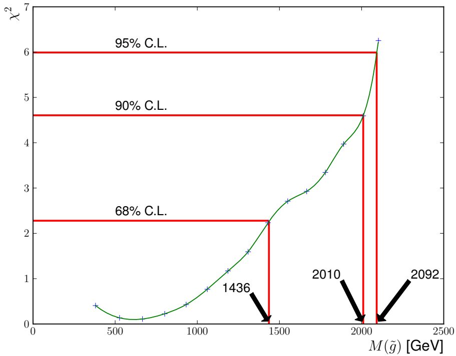
Benchmark Points

m_{16}	10 TeV	15 TeV	20 TeV	25 TeV	30 TeV
A_0	-20.2 TeV	-30.6 TeV	-41.1 TeV	-51.3 TeV	-61.6 TeV
μ	791	513	1163	1348	1647
$M_{1/2}$	201	201	168	158	162
χ^2	49.65	31.02	26.58	27.93	29.48
M_A	2333	3662	1651	2029	2036
$m_{\tilde{t}_1}$	1681	2529	3975	4892	5914
$m_{\tilde{b}_1}$	2046	2972	5194	6353	7660
$m_{\tilde{\tau}_1}$	3851	5576	7994	9769	11620
$m_{\tilde{\chi}_1^0}$	133	134	137	149	167
$m_{\tilde{\chi}_1^+}$	260	263	279	309	351
$M_{\tilde{g}}$	853	850	851	910	1004

SUSY spectrum is predominantly determined by fitting:

- Third family masses
- light Higgs mass
- $\mathcal{BR}(B_s \to X_s\gamma)$ and $\mathcal{BR}(B_s \to \mu^+ \mu^-)$

SUSY Spectrum



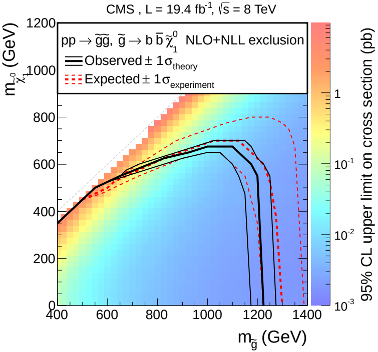
$m_{16} = 20$ TeV

SUSY spectrum is predominantly determined by fitting:

- Third family masses
- light Higgs mass
- $\mathcal{BR}(B_s \to X_s\gamma)$ and $\mathcal{BR}(B_s \to \mu^+\,\mu^-)$

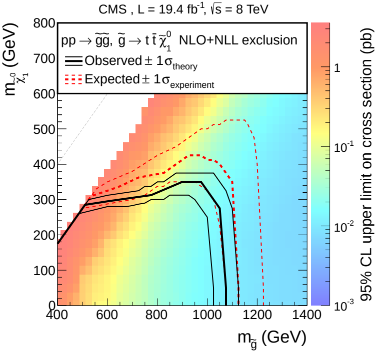
TOPOLOGIES

T1bbbb



$$\mathcal{BR}(\tilde{g} \to b\bar{b}\tilde{\chi}^0_1) = 100\%$$

T1tttt



$$\mathcal{BR}(\tilde{g} \to t\bar{t}\tilde{\chi}^0_1) = 100\%$$

Results from CMS wiki

Not so simplified model

AA, Bryant, Raby, and Wingerter: arXiv:1307.7723, arXiv:1308.2232

Benchmark point with $m_{16} = 20\ TeV$, $M_{\tilde{g}} = 1.06\ TeV$

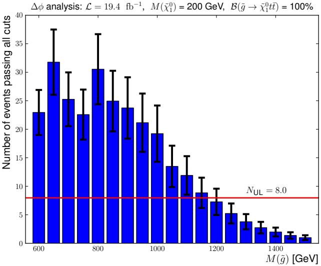
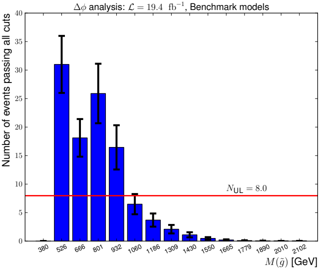
$$\begin{aligned}
\mathcal{BR}(\tilde{g} \to b\bar{t}\tilde{\chi}_1^+) &= 27\% \\
\mathcal{BR}(\tilde{g} \to t\bar{b}\tilde{\chi}_1^-) &= 27\% \\
\mathcal{BR}(\tilde{g} \to t\bar{t}\tilde{\chi}_2^0) &= 22\% \\
\mathcal{BR}(\tilde{g} \to g\tilde{\chi}_1^0) &= 15\%
\end{aligned}$$

Compare with data from LHC

Analysis	Luminosity	Signal Region	Reference
SS di-lepton	10.5	$N_{\rm jet} \geq 4,\ N_{\rm b-jet} \geq 2,$ $E_T^{\rm miss} > 120,\ H_T > 200$	CMS-SUS-12-017
α_T analysis (for Simplified models) (for the benchmark models)	11.7	$N_{\rm jet} \geq 4,\ N_{\rm b-jet} = 3,\ H_T > 875$ $N_{\rm jet} \geq 4,\ N_{\rm b-jet} = 2,\ 775 < H_T < 875$	CMS-SUS-12-028
$\Delta\phi$ analysis	19.4	$N_{\rm b-jet} \geq 3,\ E_T^{\rm miss} > 350,\ H_T > 1000$	CMS-SUS-12-024

Yunified vs Simplified

From Hadronic $\Delta\hat{\phi}$ analysis:

T1tttt	Benchmark Model
	
$M_{\tilde{g}} \geq 1100 GeV$	$M_{\tilde{g}} \geq 1000 GeV$

MATON $\rightarrow$ SDECAY $\rightarrow$ PYTHIA $\rightarrow$ DELPHES

Rare Processes

	Current Limit	10 TeV	20 TeV	30 TeV
e EDM $\times 10^{28}$	< 10.5 e cm	-0.224	-0.0173	-0.0084
μ EDM $\times 10^{28}$	$(-0.1 \pm 0.9) \times 10^{9}$ e cm	34.6	3.04	1.20
τ EDM $\times 10^{28}$	$-0.220 - 0.45 \times 10^{12}$ e cm	-2.09	-0.185	-0.0732
BR$(\mu \to e\gamma) \times 10^{12}$	< 2.4	5.09	0.211	0.0447
BR$(\tau \to e\gamma) \times 10^{12}$	$< 3.3 \times 10^{4}$	58.8	2.40	0.502
BR$(\tau \to \mu\gamma) \times 10^{8}$	< 4.4	1.75	0.0837	0.0182
sin δ		-0.60	-0.27	-0.53

- $\mathcal{BR}(\mu \to e\ \gamma) \sim 10^{-12} - 10^{-13}$ for values of $m_{16} = 15 - 25$ TeV. Latest result from MEG $\mathcal{BR}(\mu \to e\gamma) < 0.57 \times 10^{-12}$.
- Neutrinos obey a normal hierarchy.

PROBLEMS:

- Bino LSP - over-abundant dark matter. (Axions Baer, Haider, et al.)
- $(g-2)_\mu$ too small, due to heavy scalars (sleptons).

PART II

arXiv:1303.5125 **AA** and Stuart Raby

- We investigate a new set of boundary conditions at the GUT scale, consistent with Yukawa unification.
- Non-universal gaugino masses with mirage pattern.

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

Choi, Nilles

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

- We choose $\mu < 0$, $M_{1/2} < 0$ such that $M_3 > 0$ and $M_{1,2} < 0$

Simultaneously satisfy (i) corrections to bottom quark mass (ii) $BR(B_s \to X_s \gamma)$ and (iii) anomalous magnetic moment of muon*.

Badziak, Olechowski, Pokorski

* Now, ruled out after the Higgs result.

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

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

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

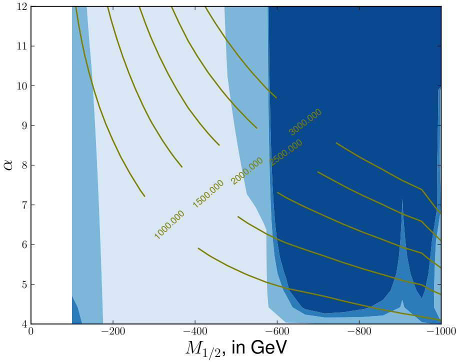
Sector	Third Family Analysis
gauge	α_G, M_G, ϵ_3
SUSY (GUT scale)	m_{16}, $M_{1/2}$, α, A_0, m_{10}, D
textures	λ
SUSY (EW scale)	$\tan\beta$, μ
Total #	12

SUSY Spectrum

NUHM	"Just-so"	D-term
m_{16}	5.00 TeV	5.00 TeV
A_0	8.07 TeV	5.59 TeV
μ	-615 GeV	-1.29 TeV
$M_{1/2}$	-105 GeV	-100 GeV
α	11.59	11.99
M_A	1558	1236
$m_{\tilde{t}_1}$	1975	2920
$m_{\tilde{b}_1}$	2049	2158
$m_{\tilde{\tau}_1}$	2473	3601
$m_{\tilde{\chi}_1^0}$	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

- Very different spectrum from the minimal Yukawa unification scenario.
- Heavier gluino, degenerate charginos and neutralinos.

SUSY Spectrum



- Very different spectrum from the minimal Yukawa unification scenario.
- Heavier gluino, degenerate charginos and neutralinos.

Degenerate Chargino-Neutralino

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

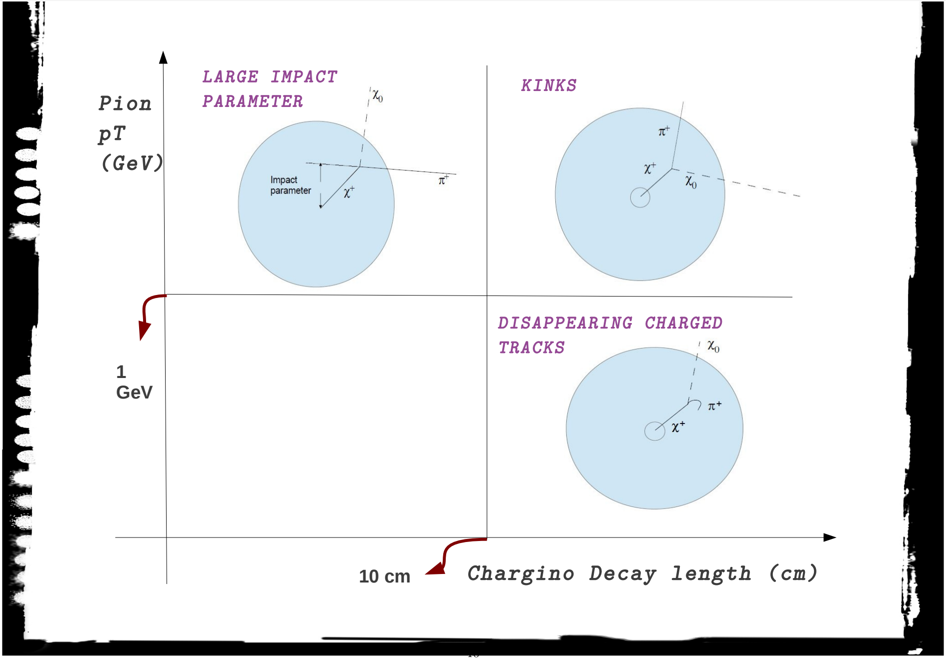
Signatures:

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

- Disappearing charged tracks, kinks, large impact parameter.
- Associated photon and Z production

Work in progress with Linda Carpenter & Stuart Raby
Linda's talk at SUSY

Topologies



Pion pT (GeV)
LARGE IMPACT PARAMETER
Impact parameter
KINKS
DISAPPEARING CHARGED TRACKS
1 GeV
10 cm
Chargino Decay length (cm)

Branching Ratios for the "Just-so" Higgs splitting scenario

$$\begin{aligned}\mathcal{BR}(\tilde{g} \rightarrow b\bar{t}\tilde{\chi}_1^+) &= 14\% \\ \mathcal{BR}(\tilde{g} \rightarrow t\bar{b}\tilde{\chi}_1^-) &= 14\% \\ \mathcal{BR}(\tilde{g} \rightarrow t\bar{t}\tilde{\chi}_2^0) &= 8\% \\ \mathcal{BR}(\tilde{g} \rightarrow g\tilde{\chi}^0) &= 63\%\end{aligned}$$

Branching Ratios for the D-term splitting scenario

$$\begin{aligned}\mathcal{BR}(\tilde{g} \rightarrow b\bar{t}\tilde{\chi}_1^+) &= 38\% \\ \mathcal{BR}(\tilde{g} \rightarrow t\bar{b}\tilde{\chi}_1^-) &= 38\% \\ \mathcal{BR}(\tilde{g} \rightarrow t\bar{t}\tilde{\chi}_1^0) &= 14\% \\ \mathcal{BR}(\tilde{g} \rightarrow b\bar{b}\tilde{\chi}_1^0) &= 4\%\end{aligned}$$

Work in progress with Charles Bryant & Stuart Raby

Summary

Yunified SUSY GUTS -

- $\tan\beta \approx 50$, CP odd Higgs mass, $m_A \gg M_Z$. Light Higgs is predicted to be Standard Model-like.

In the minimal Yukawa-unified scenario:

- I, II family of scalars are of the order $m_{16} > 10\,TeV$, third family scalars are naturally much lighter.
- Upper bound on the gluino mass, in order to fit the Higgs mass.
- Cannot be described by a simple 'simplified model'.

In the effective mirage mediation scenario:

- Very different 'lighter' spectrum.
- Degenerate charginos and neutralinos. Wino-like LSP.
- Interesting signatures at the LHC.
- Well tempered neutralinos can be accomodated.

Thank you!

EXTRA SLIDES

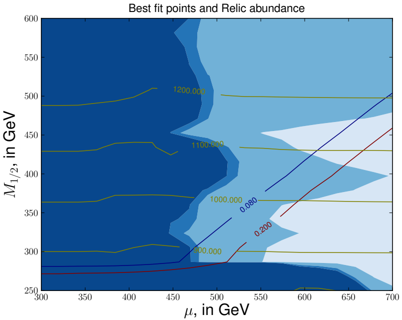
Benchmark Point

GUT scale parameters	m_{16}	20	$M_{1/2}$	0.25	A_0	-41
EW parameters	μ	.8	$\tan\beta$	50		
Spectrum	$m_{\tilde{t}_1}$	3.695	$m_{\tilde{b}_1}$	4.579	$m_{\tilde{\tau}_1}$	7.834
	$m_{\tilde{\chi}_1^0}$	0.172	$m_{\tilde{\chi}_1^+}$	0.342	$M_{\tilde{g}}$	1.061
	$m_{\tilde{u},\tilde{d},\tilde{e}}$	20	$m_{\tilde{c},\tilde{s},\tilde{\mu}}$	20	M_A	2.2
Gluino Branching Fractions	$g\widetilde{\chi}_4^0$	38%	$g\widetilde{\chi}_3^0$	35%	$tb\widetilde{\chi}_1^\pm$	14%
	$g\widetilde{\chi}_2^0$	8%	$t\bar{t}\widetilde{\chi}_1^0$	1.2%	$b\bar{b}\widetilde{\chi}_1^0$	0.006%

Dark Matter

- Universal Yunified models - bino LSP
- Effective Mirage scenario - wino LSP

Well Tempered neutralinos in Yukawa unified models:



Work in progress with Kuver Sinha