LHC Phenomenology of SO(10) Models with Yukawa Unification

B. Charles Bryant[1]
Archana Anandakrishnan[1], Stuart Raby[1]

[1]The Ohio State University
Department of Physics

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SO(10) Models with Yukawa Unification

- Third family Yukawa unification in models, such as $\mathrm{SO}(10)$ or $\mathrm{SU}(4)_c \times \mathrm{SU}(2)_L \times \mathrm{SU}(2)_R$, can place significant constraints on the low energy SUSY spectrum
- The choice of boundary conditions determines these constraints and can lead to dramatically different low energy SUSY spectra
- Requiring Yukawa unification and good fits to top, bottom, and tau masses limits the number of viable boundary conditions
- We consider two types of $\mathrm{SO}(10)$ boundary conditions:
  (i) universal gaugino masses
  (ii) non-universal gaugino masses with *effective* "*mirage*" mediation

A. Anandakrishnan, S. Raby, and A. Wingerter - PhysRevD.87.055005
A. Anandakrishnan and S. Raby - PhysRevLett.111.211801

(i) universal gaugino masses

- universal squark and slepton masses, m_{16}
- universal cubic scalar parameter, A_0
- universal gaugino masses, $M_{1/2}$
- non-universal Higgs masses, $m^2_{H_{u(d)}} = m^2_{10}\left(1 - (+)\Delta^2_{m_H}\right)$
- Due to Yukawa unification of the third family at the GUT scale,

$$\tan\beta \approx 50$$

- Fitting the top, bottom, and tau masses restricts to the region of SUSY breaking parameter space with

$$A_0 \approx -2m_{16},\ m_{10} \approx \sqrt{2}m_{16},\ m_{16} > \text{few TeV},\ \mu, M_{1/2} \ll m_{16}$$

(ii) non-universal gaugino masses with *effective "mirage"* mediation

- The gaugino masses are given by

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

- α is the ratio of the anomaly mediation to gravity mediation contributions.
- universal scalar mass for the squarks and sleptons, m_{16}
- universal cubic scalar parameter, A_0
- non-universal Higgs mass parameters, m_{H_u} and m_{H_d}
- $\tan\beta \approx 50$

Model Parameters

Sector	Universal Gaugino Masses	#	Non-universal Gaugino Masses	#
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}, $M_{1/2}$, α, A_0, m_{H_u}, m_{H_d}	6
textures	λ	1	λ	1
SUSY (EW scale)	$\tan\beta$, μ	2	$\tan\beta$, μ	2
Total #		11		12

- A global χ^2 analysis was performed by varying the GUT scale model parameters to fit 11 low energy observables, M_W, M_Z, G_F, α_{em}^{-1}, $\alpha_s(M_Z)$, M_t, $m_b(m_b)$, M_τ, $\mathcal{B}(B \to X_s\gamma)$, $\mathcal{B}(B_s \to \mu^+\mu^-)$, and M_h
- m_{16}, $M_{1/2}$, α are fixed

Benchmark Points

	Ud	DMa	DMb	COa	COb	Md
$M_{1/2}$	300	450	600	450	485	-200
α	0	1.5	2.3	2.54	2.61	9
μ	879	660	1199	1027	1035	-355
m_{16}	20000	20000	29781	20000	20000	5000
χ^2/d.o.f	0.58	0.92	0.86	1.07	1.19	0.41
$M_{\widetilde{g}}$	1187	1130	1135	707	697	1107
$M_{\widetilde{t}_1}$	3728	3612	5832	3928	3951	1799
$M_{\widetilde{b}_1}$	4608	4770	7543	5453	5431	1592
$M_{\widetilde{\chi}_1^0}$	195	474	799	614	655	307
$M_{\widetilde{\chi}_2^0}$	382	557	836	629	683	360
$M_{\widetilde{\chi}_1^+}$	382	555	836	615	656	310
$M_{\widetilde{\chi}_2^+}$	888	691	1210	1037	1045	426
$\mathcal{B}(\widetilde{g} \to g\widetilde{\chi}_i^0)$	2%	11%	4%	44%	84%	1%
$\mathcal{B}(\widetilde{g} \to t\bar{t}\widetilde{\chi}_1^0)$	7%	2%	0%	0%	0%	8%
$\mathcal{B}(\widetilde{g} \to t\bar{t}\widetilde{\chi}_2^0)$	14%	4%	0%	0%	0%	8%
$\mathcal{B}(\widetilde{g} \to b\bar{b}\widetilde{\chi}_1^0)$	3%	4%	14%	51%	15%	14%
$\mathcal{B}(\widetilde{g} \to b\bar{b}\widetilde{\chi}_2^0)$	13%	9%	38%	2%	0%	12%
$\mathcal{B}(\widetilde{g} \to tb\widetilde{\chi}_1^\pm)$	60%	32%	42%	0%	0%	32%
$\mathcal{B}(\widetilde{g} \to tb\widetilde{\chi}_2^\pm)$	0%	20%	0%	0%	0%	16%

- Branching ratios calculated with `SDECAY`

A. Djouadi, Y. Mambrini, and M. Muhlleitner - j.cpc.2005.01.012

Analysis

- The ATLAS and CMS collaborations perform searches for the gluino and provide an allowed number of events from new physics
- For both boundary conditions, the scalars are sufficiently heavier than the gauginos
- No electroweakino contamination in gluino searches considered
- $\rightarrow$ Directly place bounds on the gluino masses in our models.

Analysis - CheckMATE

- The program CheckMATE was used to evaluate bounds on the gluino mass for each model.
- CheckMATE requires as input a file containing generated events and the production cross section of the sparticles of interest along with the total 1σ uncertainty on the cross section.
- Number of observed events in a given signal region $\rightarrow$ 95% CL upper limit on the allowed number of events by new physics, S_{Exp}^{95}
- In CheckMATE, the number of signal events S is determined for each signal region. The total 1σ uncertainty ΔS is estimated from user input.
- A model is considered excluded if ratio $r \geq 1$, where

$$r \equiv \frac{S - \Delta S}{S_{\text{Exp}}^{95}} .$$

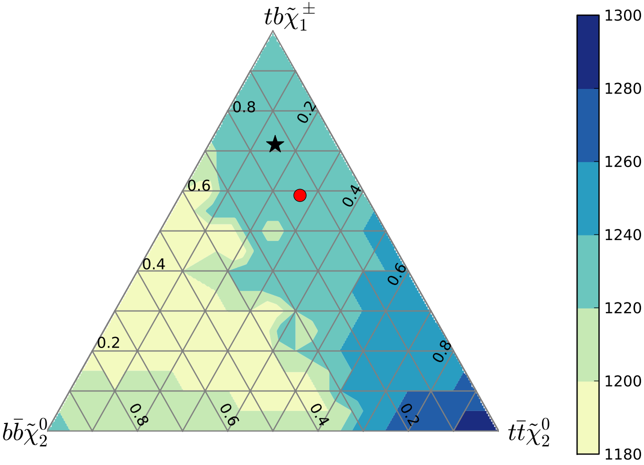
M. Drees, H. Dreiner, D. Schmeier, J. Tattersall, and J.S. Kim - hep-ph/1312.2591

Analysis - ATLAS Analysis & Results

- ATLAS analysis ATLAS-CONF-2013-061 is the most constraining analysis for our models with the exception of the points with compressed spectra
- The ATLAS-CONF-2013-061 analysis is a search for final states with large missing transverse momentum, at least four, six, or seven jets, at least three jets tagged as *b*-jets, and either zero or at least one lepton.
- Points Ud, Md, and DMa are ruled out
- Due to their compressed spectra, points DMb, COa, and COb are not ruled out
- $\rightarrow M_{\tilde{g}} \lesssim 1.2$ TeV ruled out unless spectrum is compressed

Tech. Rep. ATLAS-CONF-2013-061, CERN, Geneva, Jun, 2013.

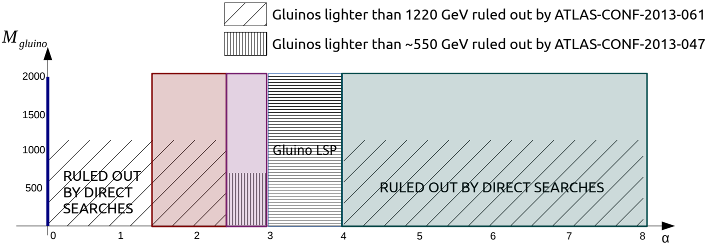
- 6 dominant branching ratios in our models: $b\bar{b}\widetilde{\chi}_1^0$, $t\bar{t}\widetilde{\chi}_1^0$, $tb\widetilde{\chi}_1^\pm$, $b\bar{b}\widetilde{\chi}_2^0$, $t\bar{t}\widetilde{\chi}_2^0$, and $tb\widetilde{\chi}_2^\pm$.
- Bounds for simplified models defined by 100% branching fractions to $b\bar{b}\widetilde{\chi}_1^0$, $t\bar{t}\widetilde{\chi}_1^0$, or $tb\widetilde{\chi}_1^\pm$ are approximately equal.
- Simplified models defined by 100% branching fractions to $t\bar{t}\widetilde{\chi}_2^0$ and $tb\widetilde{\chi}_2^\pm$ receive nearly the same limits.
- Our models are well approximated by models with branching fractions to combinations of $tb\widetilde{\chi}_1^\pm$, $b\bar{b}\widetilde{\chi}_2^0$, and $t\bar{t}\widetilde{\chi}_2^0$.
- We obtain exclusion limits for models defined by branching fractions to all combinations of these three decay modes and record the bounds on a triangle



- Lowest gluino masses allowed by ATLAS-CONF-2013-061. All masses are in GeV. The black star and red dot represent the universal and large α cases, respectively. ($M_{\tilde{\chi}_1^0} = 200$ GeV, $M_{\tilde{\chi}_2^0} = 300$ GeV)

A. Anandakrishnan and C. Hill - hep-ex/1403.4294

Summary



UNIVERSAL GAUGINO MASSES
α = 0

- Very heavy scalars: ≥ 10 TeV
- Bino LSP: Over-abundant dark matter
- Good fits require light gluino < 2 TeV

BENCHMARK MODELS
Ua, Ub, Uc, Ud, **Ue, Uf**

1.5 < α < 2. 5

- Well-tempered neutralino dark matter

BENCHMARK MODELS DMa, **DMb**

2.5 < α < 3. 0

- Compressed gaugino spectrum

BENCHMARK MODELS: **COa, COb**

α > 4. 0

- Non-universal gaugino masses
- Wino/Wino-Higgsino LSP: Under abundant dark matter
- Good fits with heavier gluino masses

BENCHMARK MODELS
Ma, Mb, Mc, Md, **Me, Mf**

- The lower bound on $M_{\tilde{g}}$ in Yukawa-unified $\mathrm{SO}(10)$ SUSY GUTs is generically $\sim$1.2 TeV at the 1σ level unless the spectrum is compressed