Vanishing SUSY soft masses under $E_7/SO(10)$ coset models

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Outline

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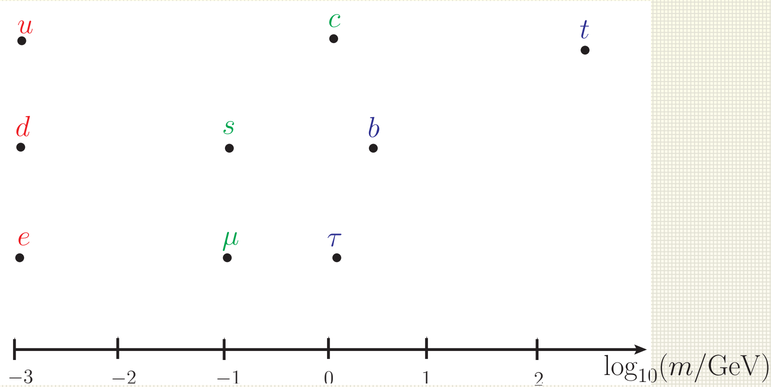
Hierarchy of Yukawa couplings?



Ad-hoc $\Rightarrow$ dynamical origin of mass?

Field content of standard model?

Gauged adjoint and chiral fundamental

- Gauge some group $H \subset G$ in real representation
- Where does chiral field in fundamental of H come from?

Hint from pions

- Take $SU(2)/U(1)$ toy model
- Broken X and $Y \Rightarrow Z = X + iY$, $Z^* = X - iY$
- $SU(2) \sim S^3 \Longrightarrow S^3/U(1) \sim \mathbb{CP}^1$
- Gauge $U(1)$, toy pions in fundamental complex representation
- Need fermionic analogue

Other problems ...

Problems of the Standard Model

- Higgs hierarchy problem
- Dark matter
- Gauge unification

⋮

Problems of supersymmetry

- μ problem $\Rightarrow m_H \to 0$?
- Flavor/CP problem $\Rightarrow m_{0(3)} \gg m_{0(1,2)}$?

⋮

Natural way to accomplish this? Follow hint ...

Outline

1. Introduction
   - Motivations
   - Coset Spaces
2. $E_7/SO(10)$ GUT Model
   - Preliminaries
   - Model Aspects
   - Low Energy Results
3. Experimental constraints
   - LHC 7 TeV
   - Dark Matter Detection
4. Summary

Strategy

Coset spaces

- $M_P,\ M_{GUT}\ , M_\Lambda \gg M_{SUSY}$
- Higgs bosons = Pseudo-Nambu-Goldstone (NG) bosons at M_Λ

Pseudo-Nambu-Goldstone fermions

- 1st and 2nd generation Standard Model fermions = SUSY partners of NG bosons
- Leave 3rd generation as matter fields $\sim M_{SUSY}$

$\Rightarrow$ Need SUSY nonlinear σ model!

How to construct one?

Formulation of SUSY nonlinear σ model

Nonlinear σ model

Under global symmetry breaking $G \rightarrow H$,

$$\mathcal{L}_{NGB}^{NL} = -\left(\partial^{\mu}\pi_i\right) g^{ij}\left(\pi/f_\pi\right)\left(\partial_\mu \pi_j\right)$$

$$\mathcal{L}_{NGF}^{NL} = \frac{c_{ijkl}}{f_\pi^2}\left(\bar{\psi}_i\gamma^\mu\psi_j\right)\left(\bar{\psi}_k\gamma_\mu\psi_l\right)$$

The Kähler potential

Supersymmetric generalization of nonlinear σ model:

$$\mathcal{L}_{SUSY}^{NL} = K\left(\Phi, \Phi^\dagger\right)\Big|_{\theta\theta\bar{\theta}\bar{\theta}}$$

Broken d.o.f.'s parameterize Kähler manifold

Technical points

Invariance of K

- Kähler transformation:

$$K(\Phi, \Phi^\dagger) \to K(\Phi, \Phi^\dagger) + F(\Phi) + F^\dagger(\Phi^\dagger)$$

- Under supergravity, W can break G-invariance on Kähler manifold

Solution criteria

- G/H must be non-compact [Bagger and Witten, Phys. Lett. B **118**, 103 (1982)]
- H must have no $U(1)$ factors [Kugo and Yanagida, Prog. Theor. Phys. **124**, 555 (2010)]

Technical points (cont'd)

- General form of Kähler potential:

$$K = v^2 F(\det[\Psi^\dagger_\alpha \Psi^\alpha])$$

- v is scale of G breaking, $F(x)$ freedom from broken $U(1)$'s
- G nonlinearly realized by Ψ^α
- For a simple example manifold, see:

SKM, Nojiri, Sudano, Yanagida, JHEP **01**, 131 (2011)

Supergravity and SUSY breaking

- Couple to supergravity:

$$\Delta\mathcal{L} = \frac{3}{4}\int d^2\theta d^2\bar{\theta}\mathcal{E}\left(\bar{\mathcal{D}}\bar{\mathcal{D}} - 8R\right)\exp\left(\frac{1}{3}K(\Psi,\Psi^\dagger)\right)$$

- Introduce hidden SUSY breaking sector:

$$K = K(\Psi,\Psi^\dagger) + Z^\dagger Z + ...$$

- NG bosons remain massless, but QNGB d.o.f.'s from broken $U(1)$'s inside Ψ get mass $\Rightarrow$ "novino" superfields

Outline

Choosing $G = E_7$

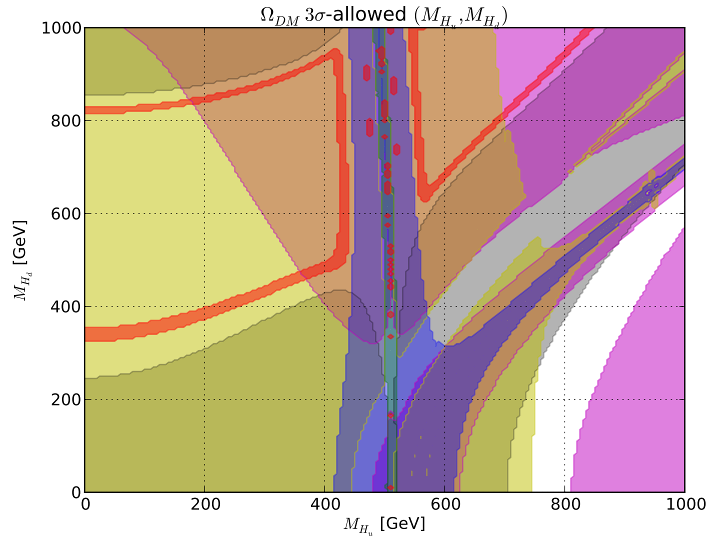
Formal motivations for E_7

- Appears in $N = 8$ supergravity
- Nonlinear realization gives the "simplest field theory" [Arkani-Hamed, Cachazo, Kaplan arXiv:0808.1446]

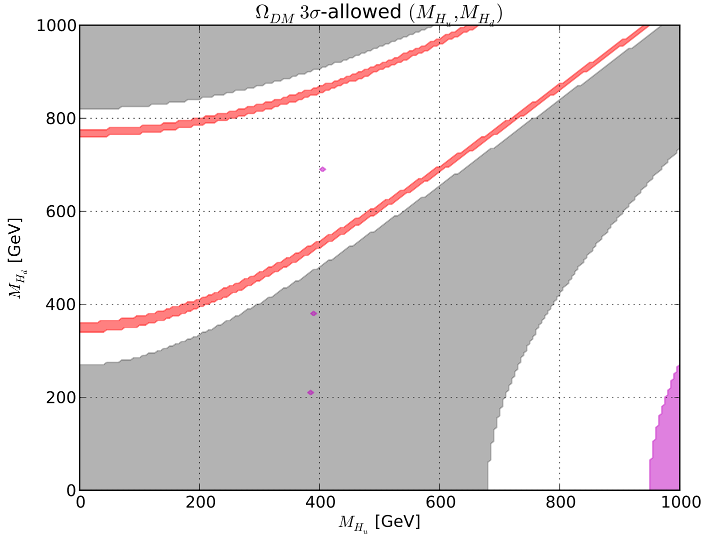
GUT representations

- $SU(5) \supset (5 + 5^*)_H \bigoplus 10 \bigoplus 5^*$
- $SO(10) \supset 10_H \bigoplus 16 \rightarrow (5 + 5^*)_H \bigoplus 10 \bigoplus 5^* \bigoplus 1$
- E_7 gives right flavor cosets:
  - $E_7/[SU(5) \times U(1)^3] \rightarrow (10 \bigoplus 5^*) \times 3 + 5_H$
  - $E_7/[SO(10) \times U(1)^2] \rightarrow (10 \bigoplus 5^*) \times 2 + (5 + 5^*)_H$
- E_6 too small, E_8 gives mirror families

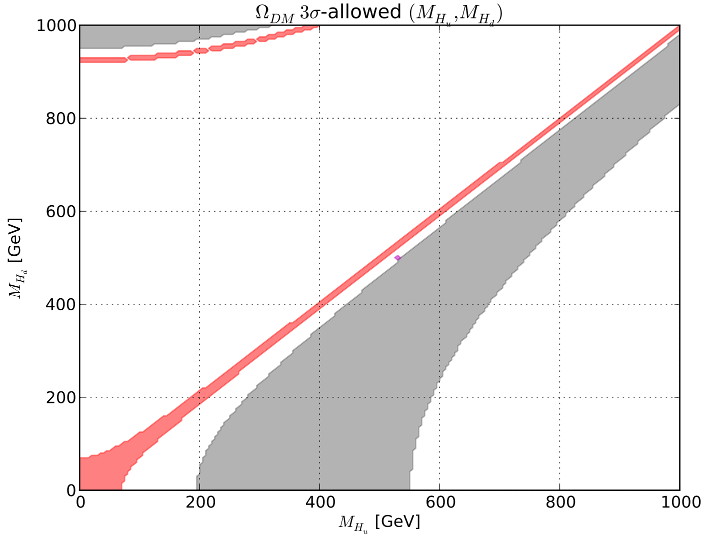
Light 5^*, Light 10 (3rd generation)



Heavy 5^*, Heavy 10



Heavy 5^*, Heavy 10 ($M_{input} = M_P$)



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$SU(5)$ of $E_7/SO(10)$

- Global symmetry must be gauged anyway $\Rightarrow$ gauge $SU(5) \subset SO(10)$
- *Explicitly* break $U(1)^2$ for coupling to supegravity, gives two novinos N_1, $N_2 \sim M_P$
- Superpotential:

$$W = W_Y + W_S + W_\Sigma + W_H + W_{SSB}$$

where

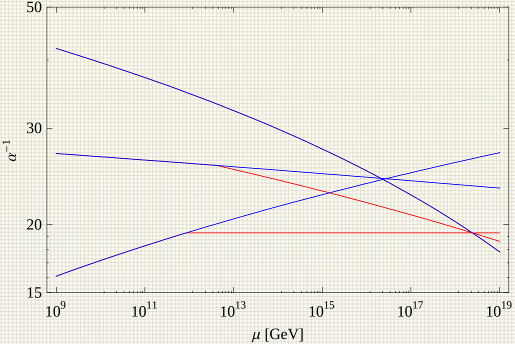
$$\begin{aligned}
W_Y &= Y_u \cdot 10 \cdot 10 \cdot 5_H + Y_d \cdot 10 \cdot 5^* \cdot 5^*_H \\
W_S &= M_\nu \cdot 1 \cdot 1 + M_N \cdot N \cdot N \\
W_\Sigma &= M_\Sigma \mathrm{Tr}\,\Sigma^2 + \lambda \mathrm{Tr}\,\Sigma^3 \\
W_H &= \not\lambda_1 \cdot 5_H \cdot \Sigma \cdot 5^*_H + \not\mu \cdot 5_H \cdot 5_H \\
W_T &= \lambda_T \cdot 5_H \cdot 75 \cdot 50 + \mathrm{c.c.}
\end{aligned}$$

Making $M_{GUT} \approx M_P$

$$\Sigma \sim 24 \supset (8,1) \oplus (1,3) \oplus (1,1) \oplus (3,2) \oplus (3^*,2)$$

- Since gauging anyway, gauge un-Higgsed part of 24
- R-charge of $\mathrm{Tr}\,\Sigma^3 \neq 2 \Longrightarrow \lambda \ll 1$ natural $\Longrightarrow$ $m_{3,8} \ll M_{GUT}$

Choose: $\sim 10^{12}$ GeV



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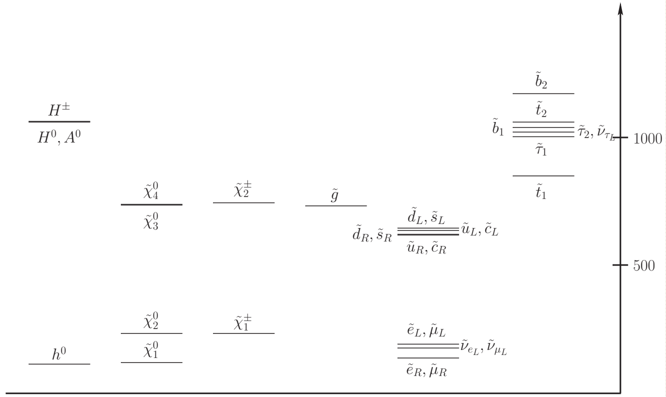
Spectrum of model point



$\tan\beta = 10$, $m_{1/2} = 300$ GeV, $m_{0(3)} = 1000$ GeV

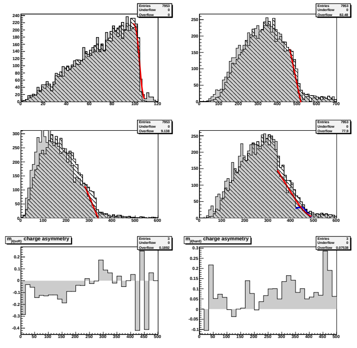
Reconstruction of model point

- 7 fb^1 @ 14 TeV in the LHC
- For this point:

$$\%n_b \geq 1 \quad = \quad 0(+5)\%$$
$$\%n_\tau \geq 1 \quad = \quad 2(+7)\%$$
$$\%n_l \geq 2 \quad = \quad 14\%$$

- Typical mSUGRA point:

$$\%n_b \geq 1 \quad = \quad 30(+5)\%$$
$$\%n_\tau \geq 1 \quad = \quad 17(+7)\%$$
$$\%n_l \geq 2 \quad = \quad 4\%$$



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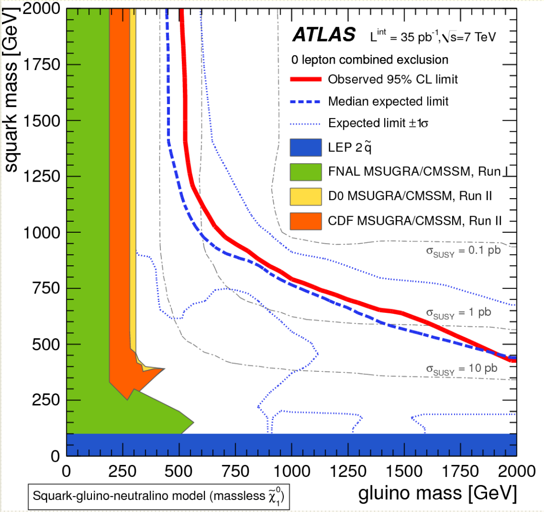
Newest model-independent constraints



Simulation events

Comparing with ATLAS for 35pb^{-1}

- 0-lepton search limited by systematics
- Tension will increase lsightly with $\mathfrak{L}$
- Can raise M_3 independently of $M_{1,2}$ for Ω_{DM}

Region	SM	Δ_{JES}	Model
A	118	+32/-23	5
B	10	+4.0/-1.9	5
C	88	+26/-18	4
D	2.5	+1.0/-0.4	0.44

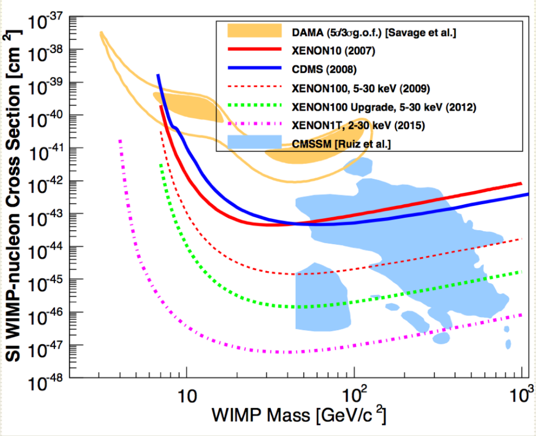
Similar $\sim 1\sigma$ tension v. systematics in jets+1-lepton search

Outline

Dark matter phenomenology

Detection

- $\sigma_{\chi N} \simeq 10^{-46} \longrightarrow$ excludable by XENON1T
- χ_1^0 mostly bino, $< \sigma v >_{\chi\chi}$ is p-wave suppressed



Summary

Created consistent $E_7/SO(10)$ GUT with distinctive collider signatures

ATLAS constraints must be followed carefully; if exclude the model, must work out explicitly how to lift M_3