Inert Neutralino Dark Matter in the E_6SSM

Jonathan Hall, Southampton University

Friday 27^{th} August 2010

Contents

- Motivations for the E_6SSM
- The E_6SSM
- The E_6SSM Neutralinos and Charginos
- The Inert Neutralino LSP
- Dark Matter Predictions
- Conclusions

Motivations for the E_6SSM

S. F. King, S. Moretti and R. Nevzorov [arXiv:hep-ph/0510419]

- The E_6SSM is a string theory inspired model where the GUT group E_6 is broken below a large energy scale
- The model has automatic anomaly cancellation
- A type-I see-saw mechanism explains light neutrino masses

- Being a supersymmetric model, softly broken at the TeV scale, this model does not suffer from the hierarchy problem
- It also does not suffer from the μ problem of the MSSM
- In the E_6SSM, like in other singlet extended models, the μ term is generated radiatively when a SM-singlet acquires a VEV, naturally related to the soft breaking scale

The E_6SSM

S. F. King, S. Moretti and R. Nevzorov [arXiv:hep-ph/0510419]

- E_6 is broken below a large energy scale

$$\begin{aligned} E_6 &\to SO(10) \times U(1)_\psi \to SU(5) \times U(1)_\psi \times U(1)_\chi \\ &\to SU(3) \times SU(2) \times U(1)_Y \times U(1)_N \end{aligned}$$

- Anomaly cancellation is ensured by having complete 27 representations of E_6 (three generations i)

$$\begin{aligned} 27_i \to & (10, 1)_i + (\bar{5}, 2)_i \\ & + (\bar{5}, -3)_i + (5, -2)_i \\ & + (1, 5)_i + (1, 0)_i \end{aligned}$$

$$\mathcal{W} = \lambda_{ijk} S_i H_{dj} H_{uk} + \kappa_{ijk} S_i D_j \bar{D}_k + \cdots$$

$$\mu = \lambda_{333} \langle S_3 \rangle = \lambda s / \sqrt{2}$$

The E_6SSM continued

S. F. King, S. Moretti and R. Nevzorov [arXiv:hep-ph/0510419]

- A generalised version of matter parity is imposed, but which allows exotics to decay
- There are two options under which exotics are interpreted as either di-quarks or lepto-quarks

- However, an approximate symmetry Z_2^H is also imposed in order to prevent FCNCs
- Under Z_2^H only S_3, H_{d3} and H_{h3} are even
- The first and second generations of Higgs doublets and "Higgs singlets" then have suppressed couplings to ordinary matter
- This then explains why the first and second generations are inert

The E_6SSM Neutralinos and Charginos

S. F. King, S. Moretti and R. Nevzorov [arXiv:hep-ph/0510419]

- In the USSM neutralino interaction basis $\tilde{\chi}^0_{\rm int} =$

$$\left(\tilde{B} \quad \tilde{W}^3 \quad \tilde{H}^0_{d3} \quad \tilde{H}^0_{u3} \;\middle|\; \tilde{S}_3 \quad \tilde{B}' \right)^{\rm T}$$

the USSM neutralino mass matrix $M^{\rm n}_{\rm USSM} =$

$$\left(\begin{array}{cccc|cc} M_1 & 0 & -m_Z s_W c_\beta & m_Z s_W s_\beta & 0 & 0 \\ 0 & M_2 & m_Z c_W c_\beta & -m_Z c_W s_\beta & 0 & 0 \\ -m_Z s_W c_\beta & m_Z c_W c_\beta & 0 & -\mu & -\mu_s s_\beta & g_1' v c_\beta Q_d^N \\ m_Z s_W s_\beta & -m_Z c_W s_\beta & -\mu & 0 & -\mu_s c_\beta & g_1' v s_\beta Q_u^N \\ \hline 0 & 0 & -\mu_s s_\beta & -\mu_s c_\beta & 0 & g_1' s Q_s^N \\ 0 & 0 & g_1' v c_\beta Q_d^N & g_1' v s_\beta Q_u^N & g_1' s Q_s^N & M_1' \end{array} \right)$$

where

- $\mu_s = \lambda v/\sqrt{2}$,
- $\langle H_{d3} \rangle = v\cos(\beta)/\sqrt{2}$, and
- $\langle H_{u3} \rangle = v\sin(\beta)/\sqrt{2}$

The E_6SSM Neutralinos and Charginos continued

J. P. Hall and S. F. King [arXiv:0905.2696 [hep-ph]]

- In the full E_6SSM neutralino interaction basis $\tilde{\chi}^0_{\text{int}} =$

$$\left(\tilde{B} \quad \tilde{W}^3 \quad \tilde{H}^0_{d3} \quad \tilde{H}^0_{u3} \;\middle|\; \tilde{S} \quad \tilde{B}' \;\middle|\; \tilde{H}^0_{d2} \quad \tilde{H}^0_{u2} \quad \tilde{S}_2 \;\middle|\; \tilde{H}^0_{d1} \quad \tilde{H}^0_{u1} \quad \tilde{S}_1 \right)^{\text{T}}$$

the E_6SSM neutralino mass matrix $M^{\text{n}} =$

$$\begin{pmatrix} M^{\text{n}}_{\text{USSM}} & B_2 & B_1 \\ B_2^{\text{T}} & A_{22} & A_{21} \\ B_1^{\text{T}} & A_{21}^{\text{T}} & A_{11} \end{pmatrix}$$

where

$$A_{\alpha\beta} = -\frac{1}{\sqrt{2}} \begin{pmatrix} 0 & \lambda_{\alpha\beta} s & f^u_{\beta\alpha} v \sin(\beta) \\ \lambda_{\beta\alpha} s & 0 & f^d_{\beta\alpha} v \cos(\beta) \\ f^u_{\alpha\beta} v \sin(\beta) & f^d_{\alpha\beta} v \cos(\beta) & 0 \end{pmatrix}$$

where $\lambda_{\alpha\beta} = \lambda_{3\alpha\beta}$, $f^d_{\beta\alpha} = \lambda_{\alpha 3\beta}$, and $f^u_{\beta\alpha} = \lambda_{\alpha\beta 3}$

The E_6SSM Neutralinos and Charginos continued

J. P. Hall and S. F. King [arXiv:0905.2696 [hep-ph]]

- In the E_6SSM chargino interaction basis $\tilde{\chi}^{\pm}_{\text{int}} =$

$$\left(\tilde{W}^+ \quad \tilde{H}^+_{u3} \quad \tilde{H}^+_{u2} \quad \tilde{H}^+_{u1} \;\middle|\; \tilde{W}^- \quad \tilde{H}^-_{d3} \quad \tilde{H}^-_{d2} \quad \tilde{H}^-_{d1} \right)^{\mathrm{T}}$$

the E_6SSM chargino mass matrix $M^{\mathrm{c}} =$

$$\begin{pmatrix} & C^{\mathrm{T}} \\ C & \end{pmatrix}$$

where

$$C = \begin{pmatrix} M_2 & \sqrt{2} m_W \sin(\beta) & 0 & 0 \\ \sqrt{2} m_W \cos(\beta) & \mu & \frac{1}{\sqrt{2}} x^d_2 s & \frac{1}{\sqrt{2}} x^d_1 s \\ 0 & \frac{1}{\sqrt{2}} x^u_2 s & \frac{1}{\sqrt{2}} \lambda_{22} s & \frac{1}{\sqrt{2}} \lambda_{21} s \\ 0 & \frac{1}{\sqrt{2}} x^u_1 s & \frac{1}{\sqrt{2}} \lambda_{12} s & \frac{1}{\sqrt{2}} \lambda_{11} s \end{pmatrix}$$

J. P. Hall and S. F. King [arXiv:0905.2696 [hep-ph]]

- As an example, demonstrating the relevant physics for determining the amount of dark matter, let us briefly consider the following parametrisation:

$$\lambda' = \lambda_{22} = \lambda_{11} \qquad f = f_{22}^d = f_{22}^u = f_{11}^d = f_{11}^u$$

varying λ', f and $\tan(\beta)$

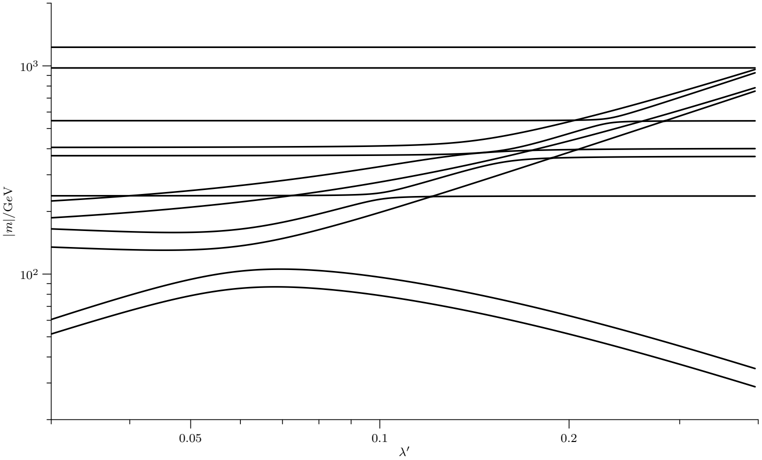
- The A matrices become

$$A_{22} = A_{11} = -\frac{1}{\sqrt{2}}\begin{pmatrix} 0 & \lambda' s & f v \sin(\beta) \\ \lambda' s & 0 & f v \cos(\beta) \\ f v \sin(\beta) & f v \cos(\beta) & 0 \end{pmatrix}$$
$$A_{21} = \epsilon A_{22}$$

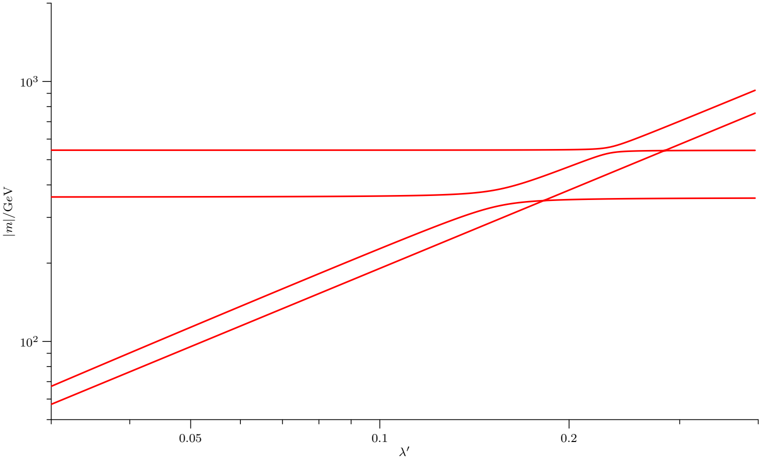
- The inert scalars and exotics are assumed heavy

J. P. Hall and S. F. King [arXiv:0905.2696 [hep-ph]]

- $s = 3000$ GeV, $\tan(\beta) = 1.5$, $f = 1$, $\epsilon = 0.1$



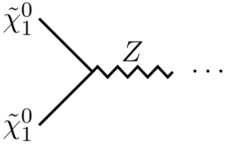
- $s = 3000$ GeV, $\tan(\beta) = 1.5$, $f = 1$, $\epsilon = 0.1$

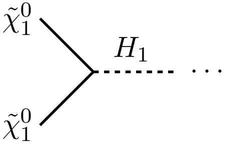


The Inert Neutralino LSP LSP composition

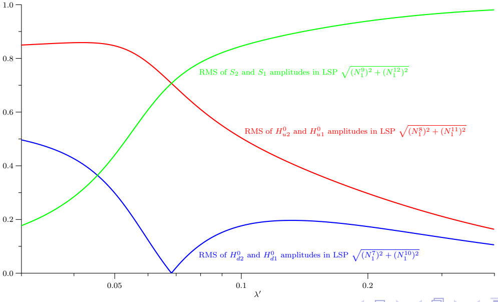
J. P. Hall and S. F. King [arXiv:0905.2696 [hep-ph]]

- The most important annihilation channels are





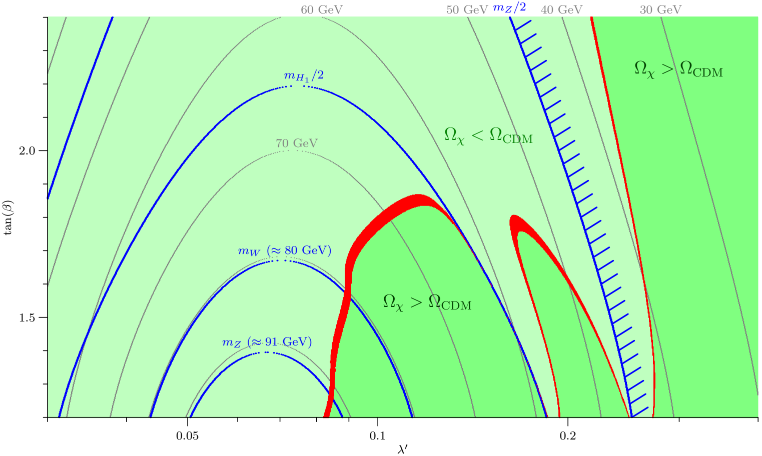
- $s = 3000$ GeV, $\tan(\beta) = 1.5$, $f = 1$, $\epsilon = 0.1$



Dark Matter Predictions `MicrOMEGAs` analysis

J. P. Hall and S. F. King [arXiv:0905.2696 [hep-ph]]

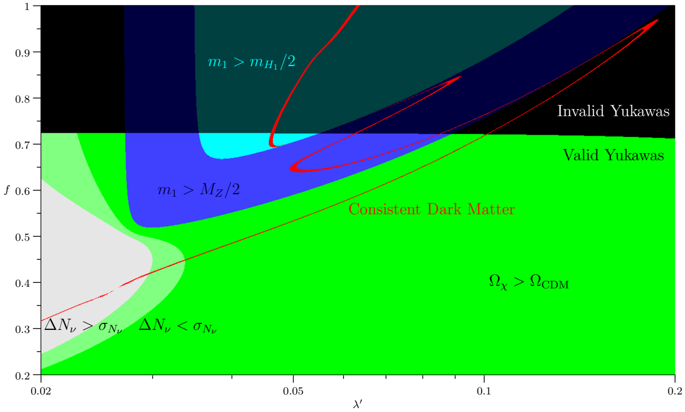
- $s = 3000$ GeV, $f = 1$, $\epsilon = 0.1$



Dark Matter Predictions Additional considerations

J. P. Hall and S. F. King (in preparation)

- $s = 2400$ GeV, $\tan(\beta) = 1.7$ $\qquad N_\nu = 2.9840 \pm 0.0082$



- This parametrisation is consistent with the E_6SSM flavour theory proposed in *R. Howl and S. F. King* [arXiv:0908.2067 [hep-ph]]

J. P. Hall, S. F. King, R. Nevzorov, S. Pakvasa and M. Sher (in preparation)

- If the two lightest inert neutralinos are lighter than half of the Higgs mass they typically dominate its width
- This greatly reduces the chances of discovering the Higgs by its decay into photons
- As an example if $\mathrm{Br}(H_1 \to \tilde{\chi}_2^0\tilde{\chi}_2^0, \tilde{\chi}_2^0\tilde{\chi}_1^0, \tilde{\chi}_1^0\tilde{\chi}_1^0) \sim 95\%$, $\mathrm{Br}(H_1 \to \gamma\gamma)$ is decreased by a factor of about 20
- It is possible that $H_1 \to \tilde{\chi}_2^0\tilde{\chi}_2^0 \to \mu\mu\bar{\mu}\bar{\mu}\tilde{\chi}_1^0\tilde{\chi}_1^0$ could be detected, but the requisite mass splitting between $\tilde{\chi}_2^0$ and $\tilde{\chi}_1^0$ is not a typical feature

Conclusions

- The E_6SSM is motivated for several reasons
- The observed dark matter relic density can be accounted for in this model
- The only hard limit on the USSM (MSSM) parameter space from dark matter considerations is that $\tan(\beta)$ should be less than about 2
- In fact the lightest USSM-like supersymmetric particle could even be charged

- We are currently looking at dark matter in a GUT constrained version of the full model, expanding on the version of the constrained E_6SSM studied in *P. Athron, S. F. King, D. J. Miller, S. Moretti and R. Nevzorov* [arXiv:0904.2169 [hep-ph]]