Health-check of supersymmetric E(6) models into the new decade

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Talk based on M.Frank, Y. Hiçyılmaz, S. Moretti and Ö. Özdal
"E_6 Motivated UMSSM Confronts Experimental Data" hep-ph/2004.01415

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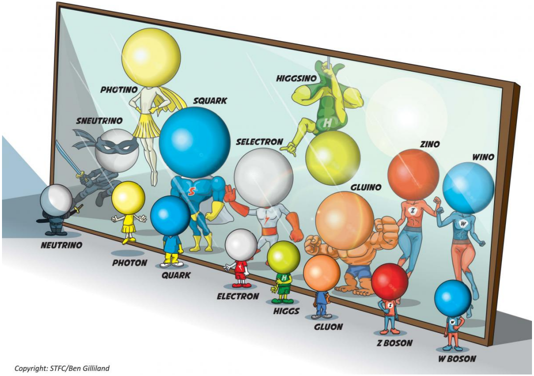
Outline

1. Introduction
    - Supersymmetry
    - Cons of MSSM
2. E_6 Motivated UMSSM
    - Model
    - Scanning Procedure and Experimental Constraints
3. Results
4. Conclusion

- Supersymmetry (SUSY) is one of the most studied NP theories at LHC, since it has remarkable advantages.,



- Supersymmetry (SUSY) is one of the most studied NP theories at LHC, since it has remarkable advantages.,
  - The Hierarchy Problem.
  - Natural light Higgs boson.
  - Unification of the gauge couplings.
  - WIMP candidate in order to solve the DM puzzle.

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    - WIMP candidate in order to solve the DM puzzle.
- Minimal Supersymmetric Standard Model (MSSM) is the simplest SUSY extension of the SM.

$$W_{MSSM} = \mu H_u H_d + Y_u \hat{Q} H_u \hat{U} + Y_d \hat{Q} H_d \hat{D} + Y_e \hat{L} H_d \hat{E}$$

Little Hierarchy Problem!!!

$$(m_h^{pole})^2 \approx m_Z^2 cos^2 2\beta + \Delta m_h^2$$

$$m_h^{pole} \approx 125\,GeV$$

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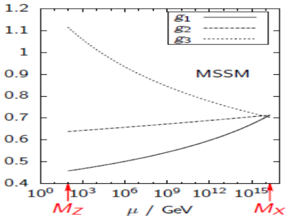

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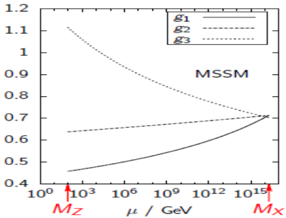
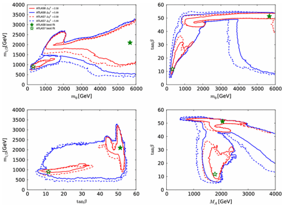


Excluded Parameter Space!!!



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- These models can dynamically generate the μ term at the EW scale.
- One of them is the scenario which can be realised by breaking the exceptional group E_6, so called E_6 motivated UMSSM.
  - The fundamental 27-dimensional representations.
  - Cancellation of gauge anomalies.
  - See-saw mechanisms for neutrino mass and mixing generation.

$$E_6 \to SO(10) \times U(1)_\psi \to SU(5) \times U(1)_\chi \times U(1)_\psi \to G_{\rm MSSM} \times U(1)'$$

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Superpotential:

$$W_{UMSSM} = Y_u \hat{Q} H_u \hat{U} + Y_d \hat{Q} H_d \hat{D} + Y_e \hat{L} H_d \hat{E} + \boxed{h_s S H_d H_u}$$

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U(1)' Charges:

Model	$\hat{Q}$	$\hat{U}^c$	$\hat{D}^c$	$\hat{L}$	$\hat{E}^c$	$\hat{H}_d$	$\hat{H}_u$	$\hat{S}$
$2\sqrt{6}\ U(1)_\psi$	1	1	1	1	1	-2	-2	4
$2\sqrt{10}\ U(1)_\chi$	-1	-1	3	3	-1	-2	2	0

$$Q^i = Q^i_\chi \cos\theta_{E_6} - Q^i_\psi \sin\theta_{E_6}$$

Higgs Potential:

$$V_{Higgs}^{UMSSM} = V_{Higgs}^{MSSM}|_{\mu = h_S S} + m_S^2|S|^2 + \frac{g'^2}{2}\left(Q_{H_u}|H_u|^2 + Q_{H_d}|H_d|^2 + Q_S|S|^2\right)$$

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Z-Z' Mass Mixing:

$$\mathbf{M_Z^2} = \begin{pmatrix} M_{ZZ}^2 & M_{ZZ'}^2 \\ M_{ZZ'}^2 & M_{Z'Z'}^2 \end{pmatrix} = \begin{pmatrix} 2g_1^2\sum_i t_{3i}^2\,|\langle\phi_i\rangle|^2 & 2g_1 g'\sum_i t_{3i}Q_i\,|\langle\phi_i\rangle|^2 \\ 2g_1 g'\sum_i t_{3i}Q_i\,|\langle\phi_i\rangle|^2 & 2g'^2\sum_i Q_i^2\,|\langle\phi_i\rangle|^2 \end{pmatrix}$$

$$\tan 2\alpha_{ZZ'} = \frac{2M_{ZZ'}^2}{M_{Z'Z'}^2 - M_{ZZ}^2}.$$

$$M_{Z,Z'}^2 = \frac{1}{2}\left[M_{ZZ}^2 + M_{Z'Z'}^2 \mp \sqrt{\left(M_{ZZ}^2 - M_{Z'Z'}^2\right)^2 + 4M_{ZZ'}^4}\right].$$

Kinetic Mixing:

$$\mathcal{L}_{\mathrm{kin}} \supset -\frac{\kappa}{2}\hat{B}^{\mu\nu}\hat{Z}'_{\mu\nu}$$

$$\begin{pmatrix} \hat{B}_\mu \\ \hat{Z}'_\mu \end{pmatrix} = \begin{pmatrix} 1 & -\frac{\kappa}{\sqrt{1-\kappa^2}} \\ 0 & \frac{1}{\sqrt{1-\kappa^2}} \end{pmatrix} \begin{pmatrix} B_\mu \\ Z'_\mu \end{pmatrix}$$

$$g_y = \frac{g_{YY}g_{EE} - g_{YE}g_{EY}}{\sqrt{g_{EE}^2 + g_{EY}^2}} = g_1,$$

$$g_{yp} = \frac{g_{YY}g_{EY} + g_{YE}g_{EE}}{\sqrt{g_{EE}^2 + g_{EY}^2}} = \frac{-\kappa g_1}{\sqrt{1-\kappa^2}},$$

$$g_p = \sqrt{g_{EE}^2 + g_{EY}^2} = \frac{g'}{\sqrt{1-\kappa^2}}$$

$$G = \begin{pmatrix} g_{YY} & g_{YE} \\ g_{EY} & g_{EE} \end{pmatrix}$$

Kinetic Mixing:

$$\mathcal{L}_{\rm int} = -\bar{\psi}_i\gamma^\mu\left[g_y Y_i B_\mu + (g_p Q_i + g_{yp} Y_i) Z'_\mu\right]\psi_i$$

$$Q_i^{eff} = Q_i - \kappa\frac{g_1}{g'} Y_i$$

Parameter Space

Parameter	Scanned range	Parameter	Scanned range
m_0	$[0., 3.]$ TeV	h_s	$[0., 0.7]$
$M_{1,4}/M_3$	$[-15., 15.]$	v_S	$[1., 15.]$ TeV
M_3	$[0., 3.]$ TeV	A_s	$[-5., 5.]$ TeV
M_2/M_3	$[-5., 5.]$	θ_{E_6}	$[-\pi/2, \pi/2]$
$\tan\beta$	$[1., 50.]$	κ	$[-0.5, 0.5]$
A_0	$[-5., -5.]$ TeV		

Constraints

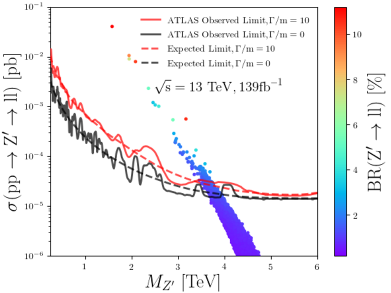
$$
\begin{aligned}
& m_h = 123 - 127 \text{ GeV(and SM} - \text{like couplings)}, \\
& m_{\tilde{g}} \geq 1.8 \text{ TeV}, \\
& 0.8 \times 10^{-9} \leq \mathrm{BR}(B_s \rightarrow \mu^+ \mu^-) \leq 6.2 \times 10^{-9} \ (2\sigma \text{ tolerance}), \\
& m_{\tilde{\chi}_1^0} \geq 103.5 \text{ GeV}, \\
& m_{\tilde{\tau}} \geq 105 \text{ GeV}, \\
& 2.99 \times 10^{-4} \leq \mathrm{BR}(B \rightarrow X_s \gamma) \leq 3.87 \times 10^{-4} \ (2\sigma \text{ tolerance}), \\
& 0.15 \leq \frac{\mathrm{BR}(B_u \rightarrow \tau \nu_\tau)_{\mathrm{UMSSM}}}{\mathrm{BR}(B_u \rightarrow \tau \nu_\tau)_{\mathrm{SM}}} \leq 2.41 \ (3\sigma \text{ tolerance}), \\
& 0.0913 \leq \Omega_{\mathrm{CDM}} h^2 \leq 0.1363 \ (5\sigma \text{ tolerance}).
\end{aligned}
\tag{1}
$$

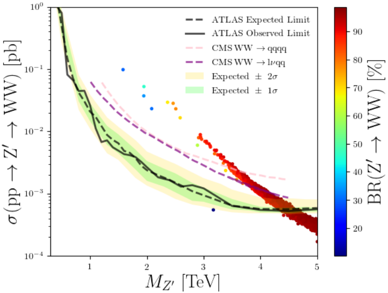
Colour Coding

- Grey: Radiative EWSB (REWSB) and neutralino LSP.
- Red: The subset of grey plus Higgs boson mass and coupling constraints, SUSY particle mass bounds and EWPT requirements.
- Green: The subset of red plus B-physics constraints.
- Blue: The subset of green plus WMAP constraints on the relic abundance of the neutralino LSP (within 5σ).
- Black: The subset of blue plus exclusion limits at the LHC from Z' direct searches via $pp \to Z' \to ll$ and $pp \to Z' \to WW$.

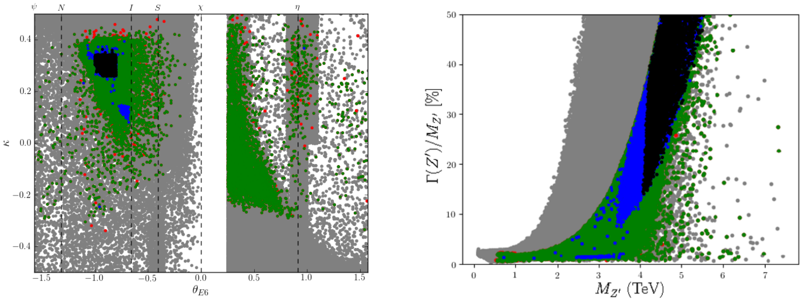
Z' Mass Limits

$\Gamma(Z' \to WW)$ is proportional to $M_{Z'}^5/M_W^4$ as well as $\sin^2\alpha_{ZZ'}$.

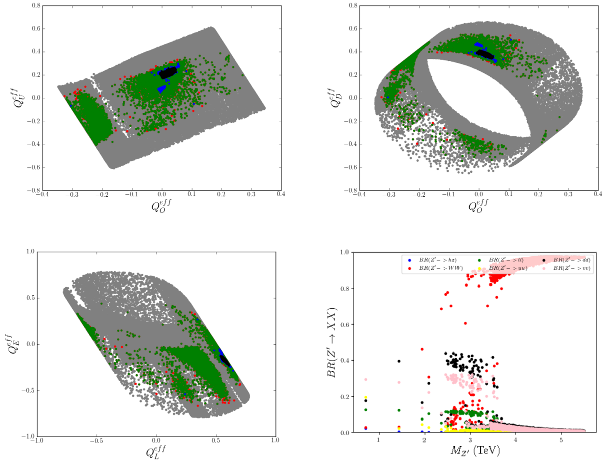




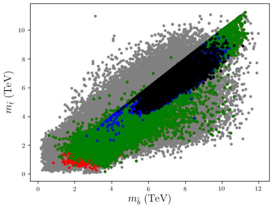
Parameter Space and Z' Decay Width

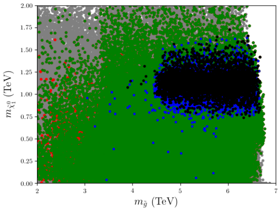


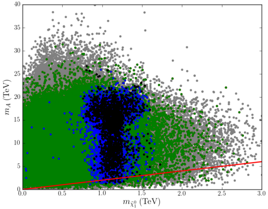
Effective U(1)' Charges and Z' Decays

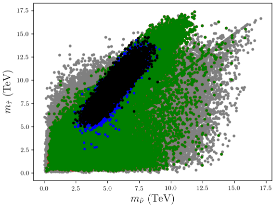


SUSY Mass Spectrum

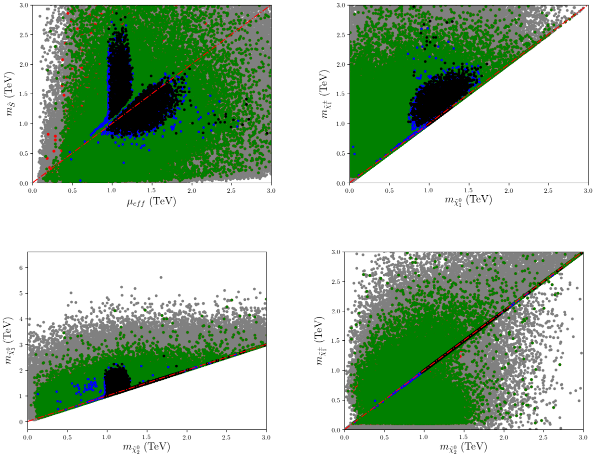




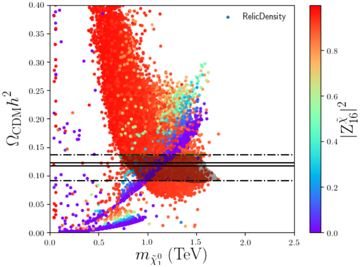


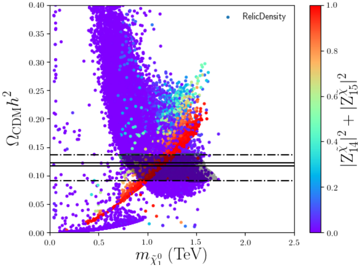


Neutralino Masses

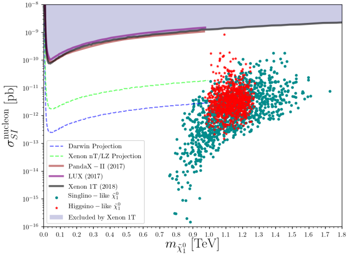


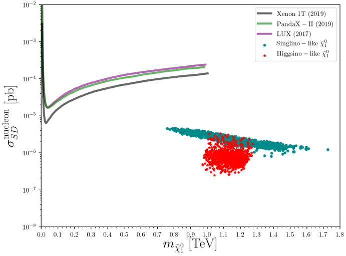
Dark Matter-Relic Density





Dark Matter-Direct Detection





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- We have studied on the gauge kinetic mixing between the Z and Z' states which in turn onsets a significant $Z'WW$ coupling. We have found that the $Z' \to WW$ decay channel overwhelm the $Z' \to ll$ one, thus producing a wide (yet, still perturbative) Z' state and so that it is the former and not the latter search channel that sets the limit on $M_{Z'}$, at 4 TeV,

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- The fundamental parameters, i.e., the gauge kinetic mixing coefficient and the E_6 mixing angle, are found to be $0.2 \lesssim \kappa \lesssim 0.4$ and $-1 \lesssim \theta_{E6} \lesssim -0.8$ radians.

- We have found two specific Dark Matter LSP compositions which are consistent with all current experimental bounds coming from relic density and direct detection experiments : a higgsino-like LSP neutralino with 0.9 TeV $\lesssim m_{\chi_1^0} \lesssim$ 1.2 TeV and a singlino-like LSP neutralino with 0.9 TeV $\lesssim m_{\chi_1^0} \lesssim$ 1.6 TeV.

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- Our soluitons which are compatible with experimental bounds include heavy sparticle spectrum for third generation sfermions ($m_{\tilde{t},\tilde{b}} \gtrsim$ 4 TeV and $m_{\tilde{\tau}} \gtrsim$ 5 TeV) as well as the gluino ($m_{\tilde{g}} \gtrsim$ 4 TeV).

Thank You for Your Attention!!!