Collider signatures of E_6SSM

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Outline

- Introduction
- Exceptional SUSY model
- Higgs sector
- Z' and exotica phenomenology
- Conclusions

Based on:

S. F. King, S. Moretti and R. Nevzorov, arXiv:hep-ph/0701064;

S. F. King, S. Moretti and R. Nevzorov, Phys. Rev. D 73 (2006) 035009;

S. F. King, S. Moretti and R. Nevzorov, Phys. Lett. B 634 (2006) 278.

Introduction

- SUSY leads to a partial unification of the SM gauge interactions with gravity within SUGRA models.
- But MSSM being incorporated in supergravity suffers from the μ problem. Indeed

$$W_{SUGRA} = W_0(h_m) + \mu(h_m)(\hat{H}_d \hat{H}_u) + ...,$$

where $\mu(h_m) \sim M_{Pl}$ or $\mu(h_m) = 0$.

- The correct pattern of EW symmetry breaking requires

$$\mu(h_m) \sim 100 - 1000 \,\text{GeV} .$$

- In the superstring inspired E_6 models gauge symmetry forbids any bilinear terms in W allowing interaction

$$W_{E_6} = \lambda S(H_d H_u) + \dots .$$

- By means of the Hosotani mechanism E_6 may be broken to

$$E_6 \to SU(3)_C \times SU(2)_W \times U(1)_Y \times U(1)_\psi \times U(1)_\chi \,,$$

where $E_6 \to SO(10) \times U(1)_\psi, \quad SO(10) \to SU(5) \times U(1)_\chi.$

- The obtained rank–6 model can be reduced further to rank–5 model that contains only one extra $U(1)'$ factor

$$U(1)' = U(1)_\chi \cos\theta + U(1)_\psi \sin\theta \,.$$

- At the EW scale field S acquires VEV breaking $U(1)'$ and providing natural solution of the μ–problem

$$\mu_{eff} = \lambda < S > \ .$$

Exceptional SUSY model

- For a special value of

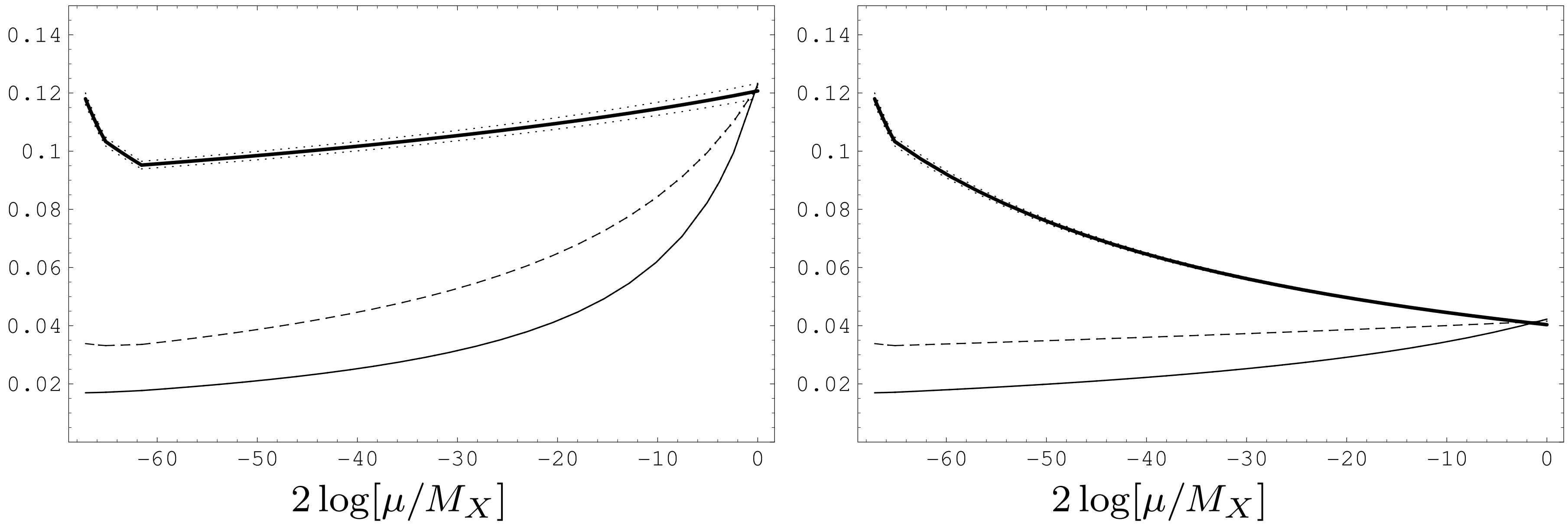
$$\theta = \arctan\sqrt{15}$$

  that corresponds to $U(1)_N$ symmetry, right handed neutrino remains sterile after the breakdown of E_6.

- Only in this exceptional SUSY model (E_6SSM) right handed neutrino can be superheavy that allows
  - to shed light on the origin of lepton mass hierarchy ,
  - to avoid stringent constraint on $M_{Z'}$ following from nucleosynthesis and cosmological observations ,
  - to generate lepton asymmetry which gets converted into baryon asymmetry through the EW phase transition.

- Anomalies in the E$_6$SSM are cancelled if the particle contents form complete 27 representations of E_6.
- To ensure the gauge coupling unification $SU(2)$ doublet and anti doublet from extra 27 and $\overline{27}$ (H' and $\overline{H}'$) should be introduced.

Two–loop RG flow of $\alpha_i(\mu)$ in the E$_6$SSM and MSSM



- Together with survivors the particle contents of the E$_6$SSM become

$$3\left[(Q_i,\, u^c_i,\, d^c_i,\, L_i,\, e^c_i)\right]+3(D_i,\, \overline{D}_i)+$$
$$+3(H_{2i})+3(H_{1i})+3(S_i)+3(N^c_i)+H'+\overline{H}'\,,$$

where D_i and $\overline{D}_i$ are exotic quarks, H_{1i} and H_{2i} are either Higgs or non–Higgs fields.

- To prevent rapid proton decay the invariance under some discrete symmetry should be imposed.
- To suppress baryon number violating and flavour changing processes one can postulate Z_2^H symmetry under which all superfields except $H_d\equiv H_{1,3}$, $H_u\equiv H_{2,3}$ and $S\equiv S_3$ are odd.

- The Z_2^H symmetry reduces the structure of Yukawa interactions to:

$$W_{\mathrm{E_6SSM}} \simeq \lambda_i S(H_{1i}H_{2i}) + \kappa_i S(D_i\overline{D}_i) + f_{\alpha\beta}S_\alpha(H_d H_{2\beta}) + \tilde{f}_{\alpha\beta}S_\alpha(H_{1\beta}H_u) + W_{MSSM}(\mu=0)\,,$$

  where $\alpha, \beta = 1, 2$ and $i = 1, 2, 3$.
- But Z_2^H symmetry can only be approximate since it ensures that the lightest exotic quark is stable.
- There are two different ways to impose an appropriate Z_2 symmetry leading to the baryon and lepton number conservation which imply
  - exotic quarks are diquarks, i.e. $B_{D,\overline{D}} = \mp 2/3$;
  - exotic quarks are leptoquarks, i.e. $B_{D,\overline{D}} = \pm 1/3,\ L_{D,\overline{D}} = \pm 1$.

- The terms which allow D and $\overline{D}$ to decay are given by

$$W_1 = g^Q_{ijk} D_i (Q_j Q_k) + g^q_{ijk} \overline{D}_i d^c_j u^c_k \, .$$

  if exotic quarks are diquarks and

$$W_2 = g^E_{ijk} e^c_i D_j u^c_k + g^D_{ijk} (Q_i L_j) \overline{D}_k \, ,$$

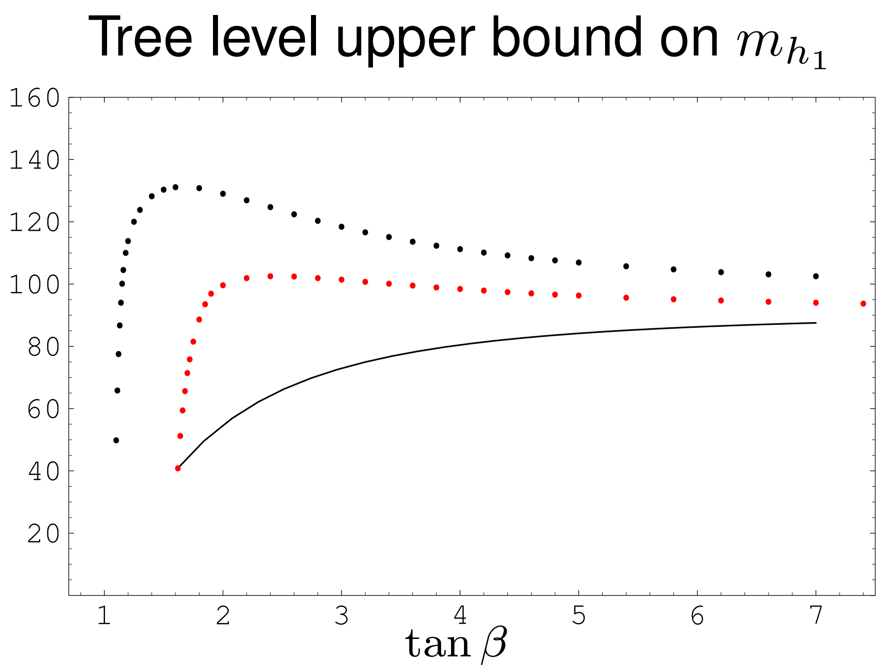
  if exotic quarks are leptoquarks.
- To provide the correct breakdown of EW symmetry and to suppress FCNC processes we assume that
  - only S, H_d and H_u are allowed to have Yukawa couplings of the order of unity ;
  - the Yukawa couplings of other exotic particles to quarks and leptons are suppressed. In particular the Yukawa couplings of non–Higgs fields to the quarks and leptons of the first two generations are less than 10^{-4} and 10^{-3} respectively .

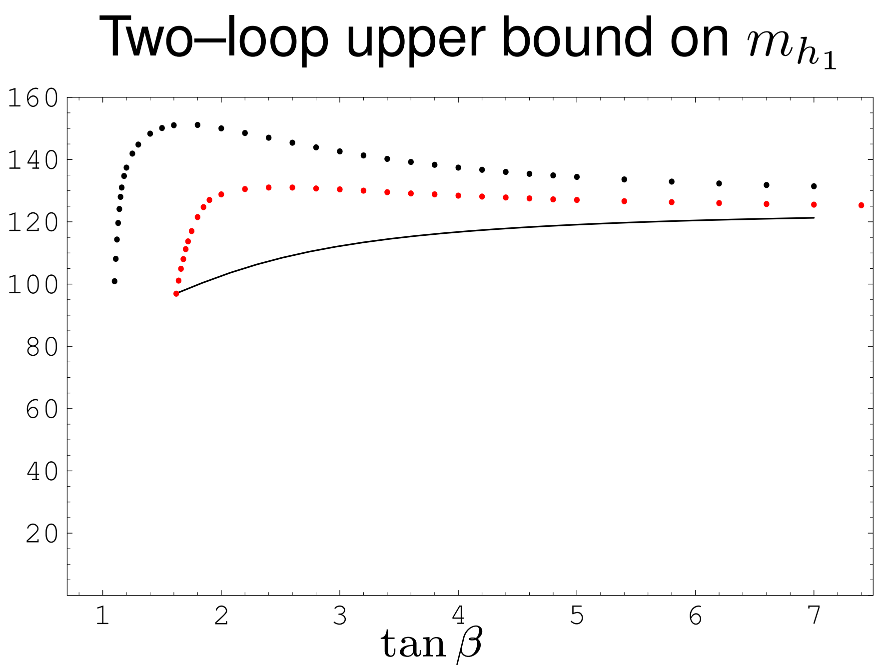
Higgs sector

- The E_6SSM Higgs sector involves H_d, H_u and S.
- After the gauge symmetry breaking four goldstone modes are absorbed by W, Z and Z'.
- At the tree level CP is preserved in the Higgs sector of the E_6SSM so that the Higgs spectrum contains
  - one pseudoscalar m_A^2 ,
  - two charged states $m_{H^\pm}^2 = m_A^2 + O(M_Z^2)$,
  - three scalars $m_{h_3}^2 = m_A^2 + O(M_Z^2),\ m_{h_2}^2 = M_{Z'}^2 + O(M_Z^2)$.
- The mass of the lightest Higgs particle in the E_6SSM is limited from above

$$m_{h_1}^2 \lesssim M_Z^2 \cos^2 2\beta + \frac{\lambda^2}{2} v^2 \sin^2 2\beta + \\ + g_1'^2 v^2 (\tilde{Q}_1 \cos^2\beta + \tilde{Q}_2 \sin^2\beta)^2 + \Delta_t + \Delta_D\,.$$

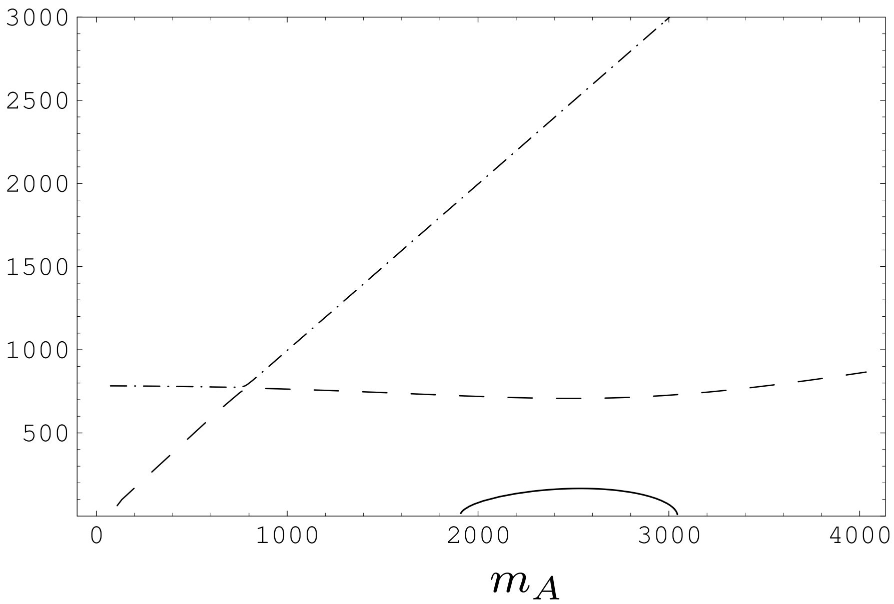
- The upper limit on the lightest Higgs mass in the E_6SSM is considerably larger than in the MSSM and NMSSM.
- Even at the tree level m_{h_1} can be heavier $120\,\mathrm{GeV}$.
- In the two–loop approximation the upper bound on m_{h_1} does not exceed $150-155\,\mathrm{GeV}$.

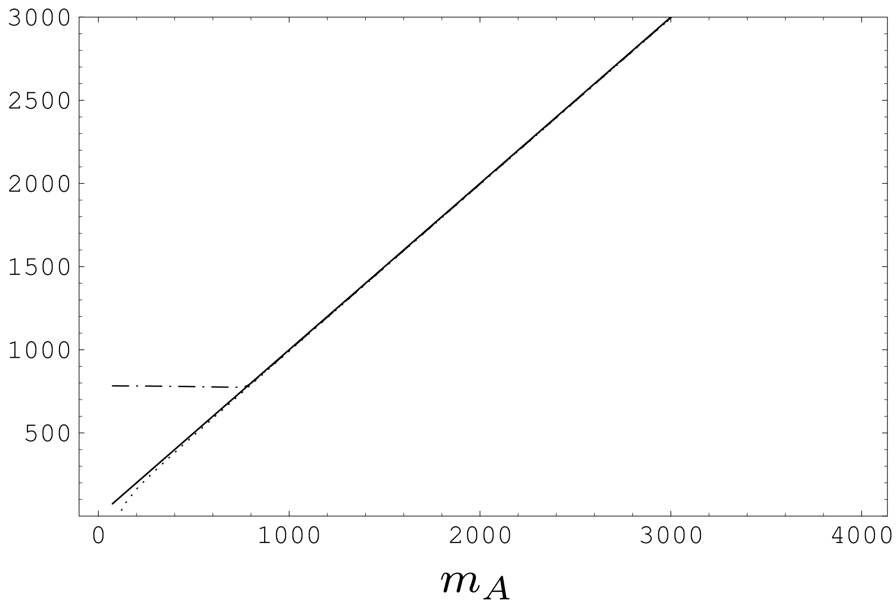




- When $m_{h_1} > 130 - 135\,\text{GeV}$ the requirement of vacuum stability maintains mass hierarchy in the Higgs spectrum so that charged, CP–odd and CP–even states lie beyond the TeV range.
- In this case only the lightest Higgs scalar can be discovered at the LHC and ILC.

One–loop Higgs boson spectrum





Z' and exotica phenomenology

- Higgs bosons, Z' and exotic particles may be produced at future colliders.
- At the LHC the Z' boson can be discovered if it has a mass below $4 - 4.5$ TeV.

A.Leike, Phys.Rept. 317 (1999) 143; J.Kang, P.Langacker, Phys.Rev.D 71 (2005) 035014.

- Its diagnostic via asymmetries should be possible up to $M_{Z'} \simeq 2 - 2.5$ TeV.

M.Dittmar, A.Nicollerat, A-S.Djouadi, Phys.Lett.B 583 (2004) 111.

- At the LHC the production cross section of $D\overline{D}$ can be comparable with $\sigma(pp \to t\bar{t} + X)$.

- The hierarchical structure of the Yukawa interactions in the E$_6$SSM implies that exotic quarks decay either via

$$\overline{D} \to t + \tilde{b}\,, \qquad \overline{D} \to b + \tilde{t}$$

if exotic quarks $\overline{D}_i$ are diquarks or via

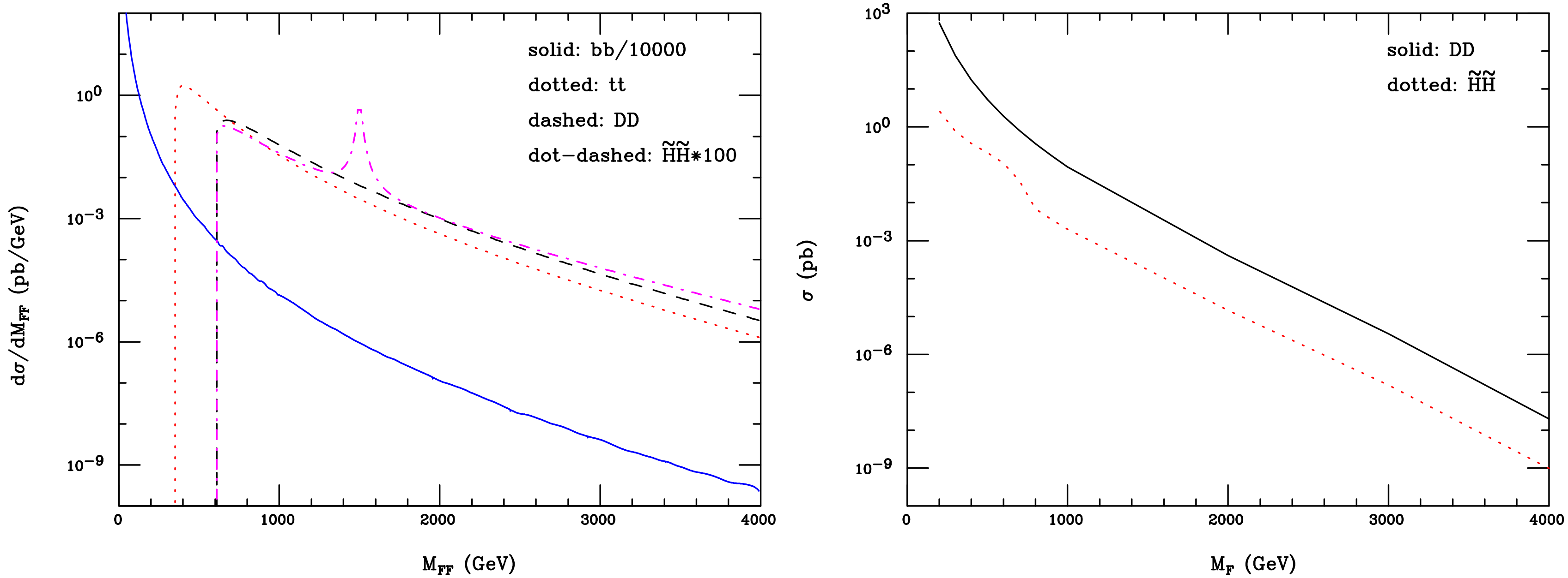
$$D \to t + \tilde{\tau}\,, \qquad D \to \tau + \tilde{t}\,,$$
$$D \to b + \tilde{\nu}_\tau\,, \qquad D \to \nu_\tau + \tilde{b}\,,$$

if exotic quarks D_i are leptoquarks.

- Assuming that $\tilde{f} \to f + \chi^0$ the exotic quark will produce either t– and b–quarks or t–quark and τ–lepton in the final state with rather high probability.

- Since $\sigma(pp \to D\overline{D} + X)$ may be comparable with $\sigma(pp \to t\bar{t} + X)$ the presence of light exotic quark will result in enhancement of the cross sections of
  - $pp \to Q\overline{Q}Q'\overline{Q}' + X$ if exotic quarks are diquarks;
  - $pp \to Q\overline{Q}l\bar{l} + X$ if new quark states are leptoquarks.

Cross sections for pair production of exotic particles at the LHC



Conclusions

- We have presented a self–consistent supersymmetric model with additional $U(1)_N$ factor which naturally arises after the breakdown of E_6 symmetry.
- The SM like Higgs boson mass in the E_6SSM does not exceed $150 - 155\,\text{GeV}$.
- When $m_{h_1} > 135\,\text{GeV}$ the masses of the charged, CP–odd and heaviest CP–even Higgs states are almost degenerate and very large

$$m_{H^{\pm}} \simeq m_A \simeq m_H \gtrsim 1\,\text{TeV}\,.$$

- The possible manifestations of the considered model at the LHC are enhanced production of l^+l^-, $t\bar{t}$ or $b\bar{b}$ pairs coming from either Z' boson or exotic particle decays.