The NMSSM and strings

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DESY

with S. Ramos-Sanchez'09

Plan

- Motivation
- Heterotic minilandscape overview
- Heterotic NMSSM
- Phenomenological constraints
- Conclusion

Motivation

- μ-problem

$$W = \lambda S H_1 H_2 \longrightarrow \mu = \lambda \langle S \rangle$$

- Higgs mass finetuning

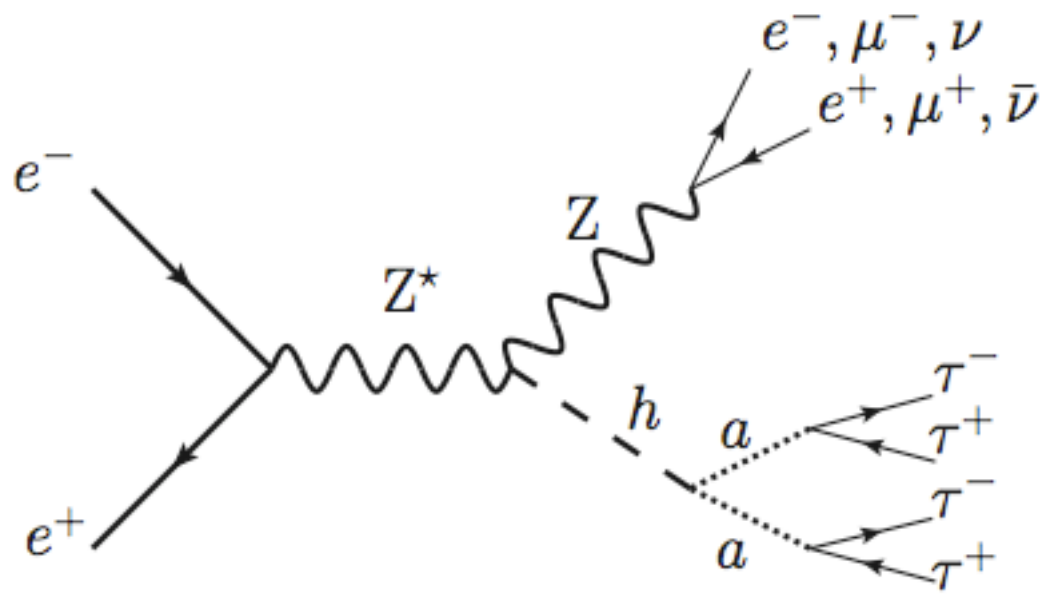
MSSM: $m_h > 114$ GeV ⇒ heavy superpartners

NMSSM: $m_h > 90$ GeV ⇒ no heavy sparticles

Dominant SM-like Higgs decay at LEP :

Dermisek, Gunion ’05

$h \rightarrow 2\,a \rightarrow 4\,\tau$ (4 jets)

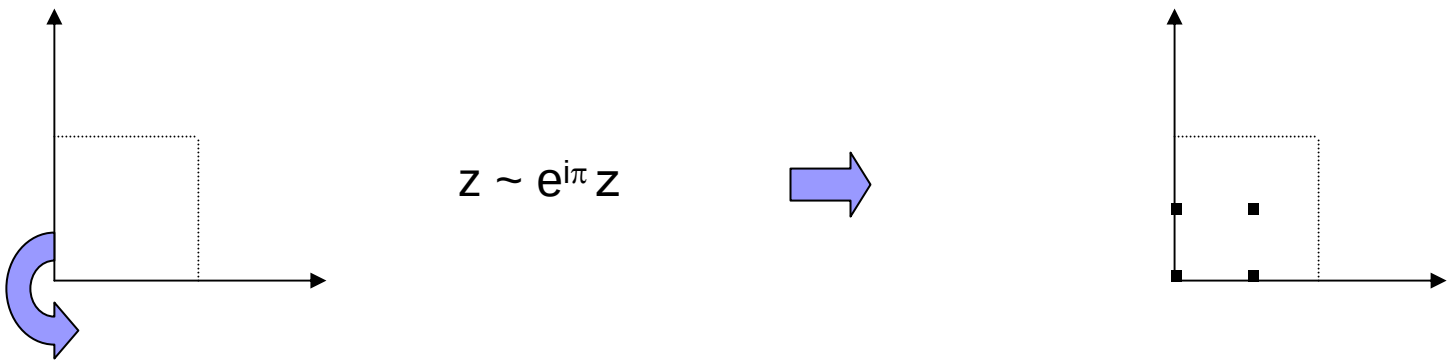


ALEPH `10 : $m_h < 100$ GeV possible (need a light pseudoscalar)

Heterotic minilandscape of MSSMs

Framework : E_8 X E_8 heterotic string

Compact space : orbifold



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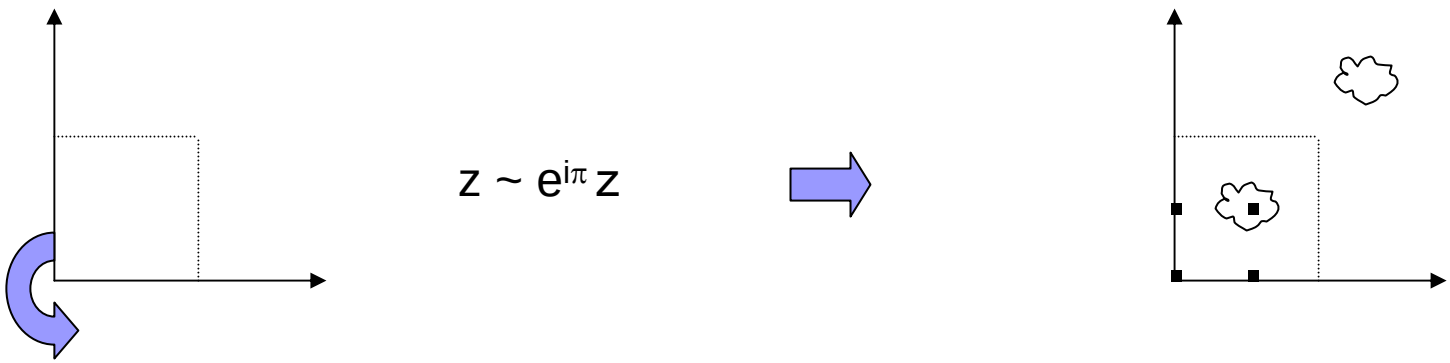
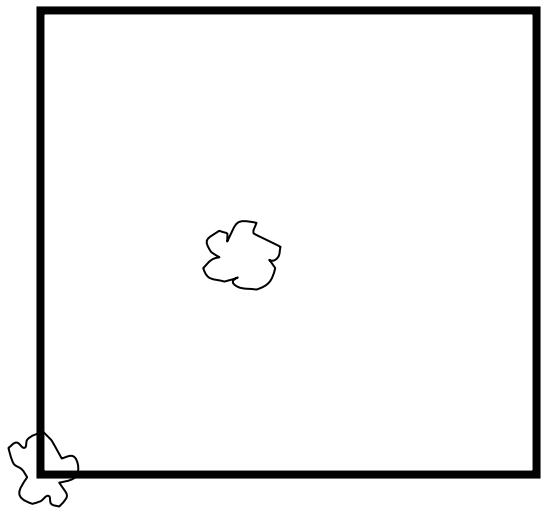


untwisted : *gauge*
twisted : *matter*

MSSM construction

Observation : fermions exhibit a GUT structure, gauge bosons don't



SO(10)

"a local GUT":

- SM generation = 16-plet of SO(10)
- SM symmetry = SU(3) X SU(2) X U(1)

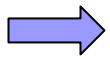
Result:

3-family MSSM (no exotics) from string theory

… but need further ingredients for healthy phenomenology

OL, Nilles, Raby, Ratz, Ramos-Sanchez, Vaudrevange, Wingerter '06-08

Systematic application of ``local GUTs''



heterotic minilandscape of MSSMs

O(100) models with

- exact MSSM spectrum
- gauge unification
- $Y_t \sim g$
- neutrino seesaw
- R-parity
- hidden sector

Heavy top

$W \sim g\, t_L\, t_R^c\, H$

top ~ *10D gaugino*

$W = g\, U_1\, U_2\, U_3$ with (scalar component of) $U_1 = A_1 + i\, A_2$, …

R-parity

Find non-anomalous $U(1)_{B-L}$ in E_8 X E_8

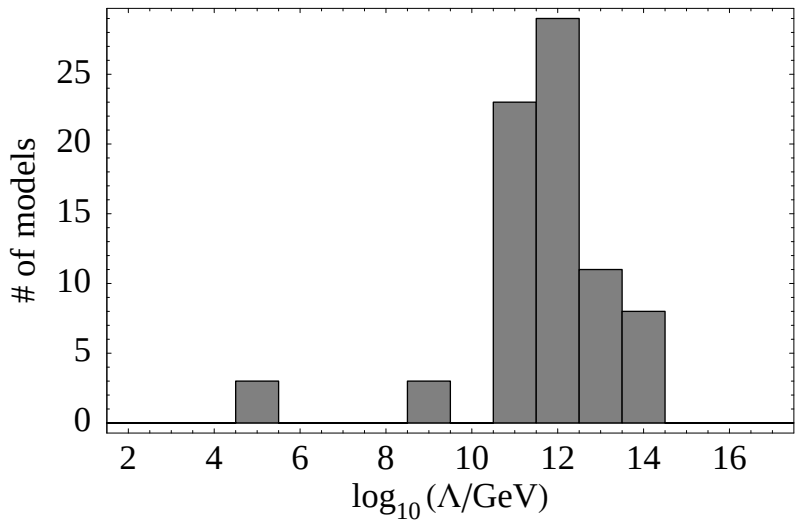
t_{B-L}= (1,1,0,0,0,-2/3,-2/3,-2/3) (1/2,1/2,0,1/2,1/2,0,0,0)

Identify SM singlets with even B-L charges $Q(s_i)$ = even

$\langle s_i \rangle$ break $U(1)_{B-L}$ to ``matter parity''

Hidden sector statistics : typically SU(5), SO(8),…

Gaugino condensation scale (in $\log_{10} \Lambda/\mathrm{GeV}$) :



EW scale = Λ^3 / M_{Pl}^2

Top-down motivation for TeV-scale superpartners

Heterotic NMSSM

NMSSM = MSSM + light singlet S that couples to the Higgses

$$W = \lambda\, S\, H_1\, H_2 + \xi\, S + M\, S^2 + \kappa\, S^3$$

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➡ Z_3 – NMSSM :

$$H_{1,2} \to e^{i\alpha} H_{1,2} \quad , \quad S \to e^{-2i\alpha} S$$

$$\alpha = 2\pi/3$$

$$W = \lambda\, S\, H_1\, H_2 \;+\; \kappa\, S^3$$

General feature :

S comes from the E_8 X E_8 sector 3

⇩

S is charged under some gauge symmetry

⇩

S , S^2 , S^3 , … – interactions forbidden

$$\kappa = \langle s_1\, s_2\, s_3 \ldots \rangle \;\ll\; 1$$

(in Planck units)

No similar constraint on λ ! $S\, H_1\, H_2$ *consistent with gauge symmetry*

Two types of heterotic NMSSMs :

(1) $\kappa << 1 \ , \ \lambda \sim 1 \longrightarrow$ Peccei-Quinn NMSSM

(2) $\kappa \ , \lambda << 1 \longrightarrow$ ``effective MSSM''

Peccei-Quinn limit

$W = \lambda \, S \, H_1 \, H_2 \Rightarrow H_{1,2} \longrightarrow e^{i\alpha} H_{1,2} \ , \ S \longrightarrow e^{-2i\alpha} S$

Spontaneous breaking of $U(1)_{PQ}$ produces a light boson A_{PQ}

$$A_{PQ} = \sin 2\beta \ (a \, \mathrm{Im} \, H_1 + b \, \mathrm{Im} \, H_2) + c \, \mathrm{Im} \, S$$

h A_{PQ} A_{PQ} - coupling >> Y_b ⇨ the SM Higgs decays to pairs of A_{PQ}

h → 2 A_{PQ} → 4 f

Can be relevant to the finetuning problem !

Effective MSSM limit

$\kappa , \lambda << 1$ ⇨ $< S > >>$ EW (required by the chargino mass limit)

$V(S) = m_S^2 S^2 + 2/3\ \kappa A_\kappa S^3 + \kappa^2 S^4$ at large S

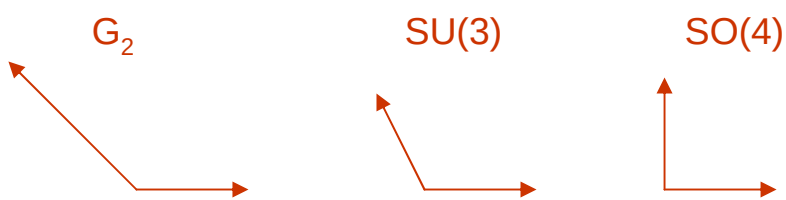
$<S> \sim EW / \kappa$ for $A_\kappa > 3\ m_S$

Very similar to the MSSM

Z_6-II Example

Lattice : G_2 X SU(3) X SO(4)

Twist : (1/6, 1/3, -1/2)



Scan the ``fertile patch'' of the heterotic minilandscape (2WL) :

no NMSSM

Problem : decoupling the exotics decouples the singlets

3 WL case : *NMSSMs are more common*

OL, Ramos-Sanchez '09

Example :

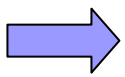
$V = (1/6, 1/3, -1/2, 0^5)\ (0^8)$
$W_2 = (1,1/2,0,1/2,1/2,-1/2,-1,0)(-1/4,3/4,1/4,1/4,3/4,-3/4,-3/4,3/4)$
$W_2' = (3/4,3/4,-1/4,-1/4,-1/4,3/4,1/4,1/4)(-1/4,-1/4,-1/4,-1/4,-1/4,1/4,1/4,3/4)$
$W_3 = (-5/6,-7/6,1/2,1/2,1/2,-1/2,-1/2,-1/2)(0,0,1/3,1/3,1/3,0,1,2/3)$

Local GUT : E_6 with a 27-plet

Gauge group after compactification : G_{SM} X SU(6) X $U(1)^7$

Matter : 3 SM generations + vector-like exotics

Many singlets develop VEVs



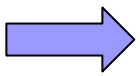
G.G. = G_{SM} X [SU(6) X U(1)]
Matter = 3 generations + Higgses + singlet

The μ– and S mass terms are zero to order s^6 in VEVs

$$W = \lambda S H_1 H_2 + \kappa S^3$$

$$\lambda \sim 1 \quad , \quad \kappa < O(s^5)$$

($\lambda = T_1 T_1 T_4$ coupling)



approximate Peccei-Quinn symmetry

Note : PQ is the (approximate) symmetry of the low energy theory only, results from string selection rules + our vacuum choice

Phenomenological constraints

How light can the pseudoscalar *A* be ?

$m_A^2 = -3 \kappa A_\kappa \langle S \rangle$ (+ corrections 1/ tan β)

- κ can be arbitrarily small (radiatively stable)
- PQ is anomalous , $m_A > 100$ keV (for S ~ EW)

Example: Z_6 model has $\kappa \sim s^6$ ⇨ $m_A \sim 100$ MeV

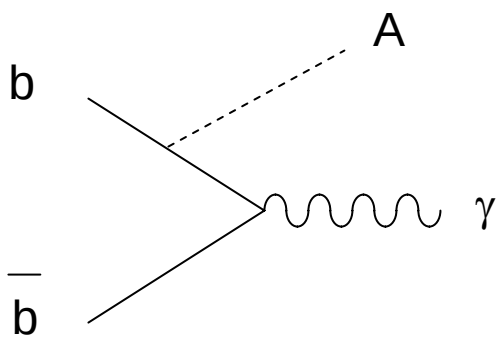
A-coupling to fermions :

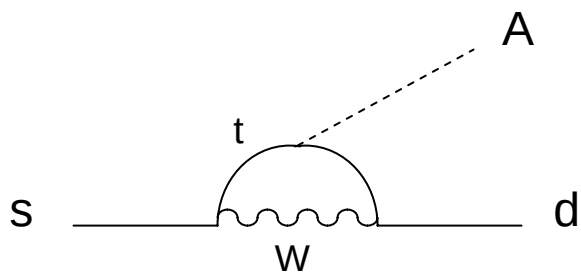
$$L = C_{Aff}\ Y_{SM}\ A\ (\ \bar{d}\,\gamma_5\,d\ +\ \cot^2\beta\ \bar{u}\,\gamma_5\,u\ +\ \dots\ )$$

In the NMSSM, $C_{Aff} = \cos\theta_A \tan\beta$ (θ_A = singlet-doublet mixing)

Rare decays :

Wilczek ' 78
Hall, Wise '81
Frere et al. '81
Hiller ' 04





$Y \longrightarrow \gamma + \text{inv.}$

$K \longrightarrow \pi + \text{inv.}$

For $m_A < 2\, m_\mu$:

$A \rightarrow \gamma\gamma\,,\ e^+ e^-$

$\tau c \sim 60$ km (m = 0.5 MeV , C_{Aff} = 1)

$\tau c \sim 2$ cm (m = 50 MeV , C_{Aff} = 1)

typically decays outside the detector

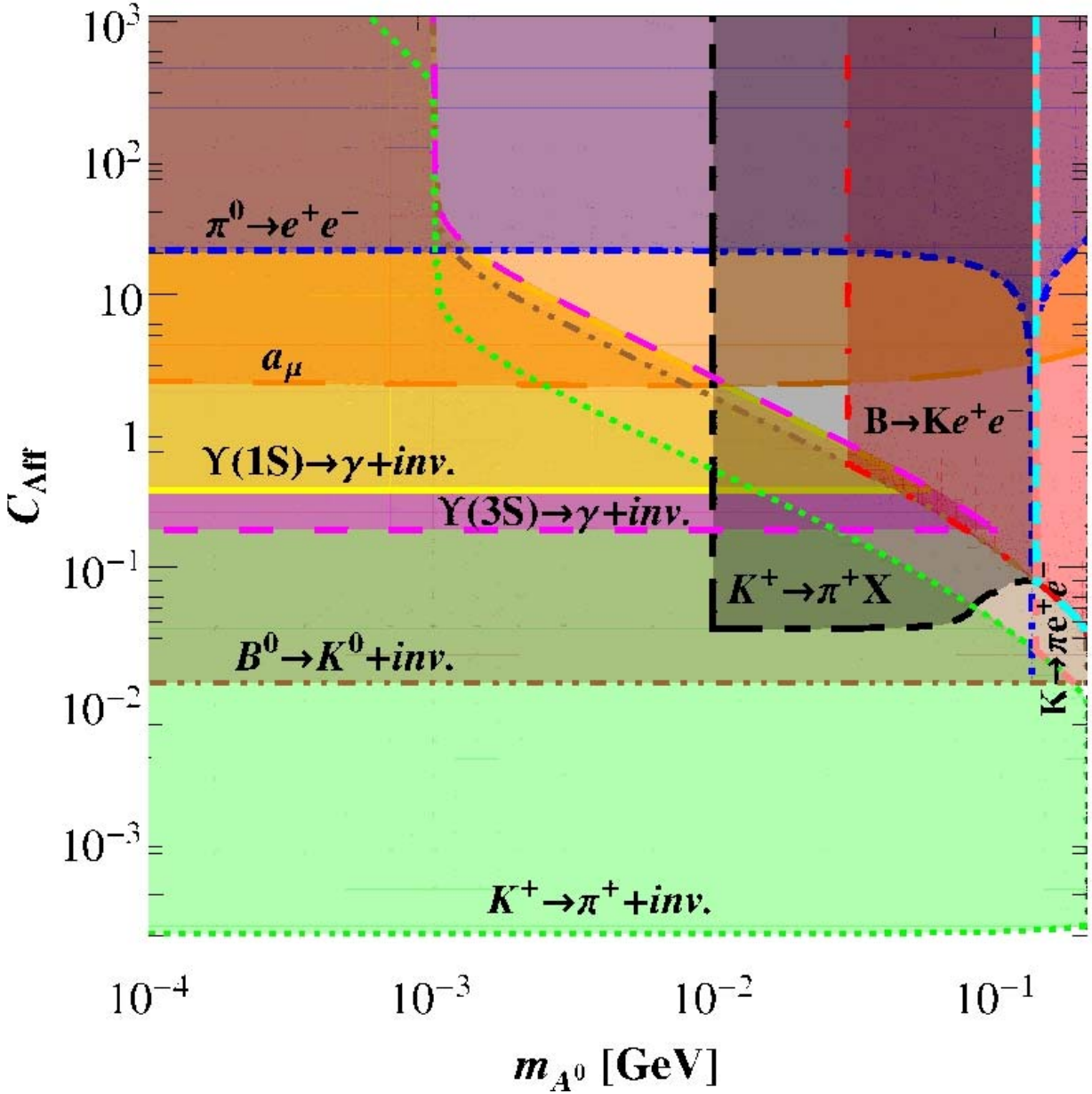
Otherwise, constraints from

$B \rightarrow K\ e^+ e^-$

$K \rightarrow \pi\ e^+ e^-$

$K \rightarrow \pi + X$

Andreas, OL, Ramos-Sanchez, Ringwald ‘10



Result :

$C_{Aff} < 10^{-4}$ (for $m_A < 2\, m_\mu$)

Applies to generic models with a light pseudoscalar

Cannot be achieved in the NMSSM (v/s ~ 10^{-4} and $m_A < 2\, m_\mu$)

$m_A > 2\, m_\mu$

LHC : $gg \rightarrow A \rightarrow \mu^+ \mu^-$

Conclusion

- stringy NMSSMs are rare (but possible)
- approximate Peccei-Quinn symmetry
- may be relevant to the finetuning problem
- $A \rightarrow \mu^+ \mu^-$