The discrete beauty of local GUTs

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Outline

- Evidence for grand unification and
- the usefulness of global $U(1)$ symmetries

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require a consistent UV-completion of the theory!

- string theory supplies
  - the concept of local grand unification
  - discrete symmetries
- moduli stabilization and Susy breakdown
  - fluxes, gaugino condensation and uplifting
  - gravity and mirage mediation

GUT evidence

Experimental findings suggest the existence of two new scales of physics beyond the standard model

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$M_{\mathrm{GUT}} \sim 10^{16}\mathrm{GeV}$ and $M_{\mathrm{SUSY}} \sim 10^{3}\mathrm{GeV}$:

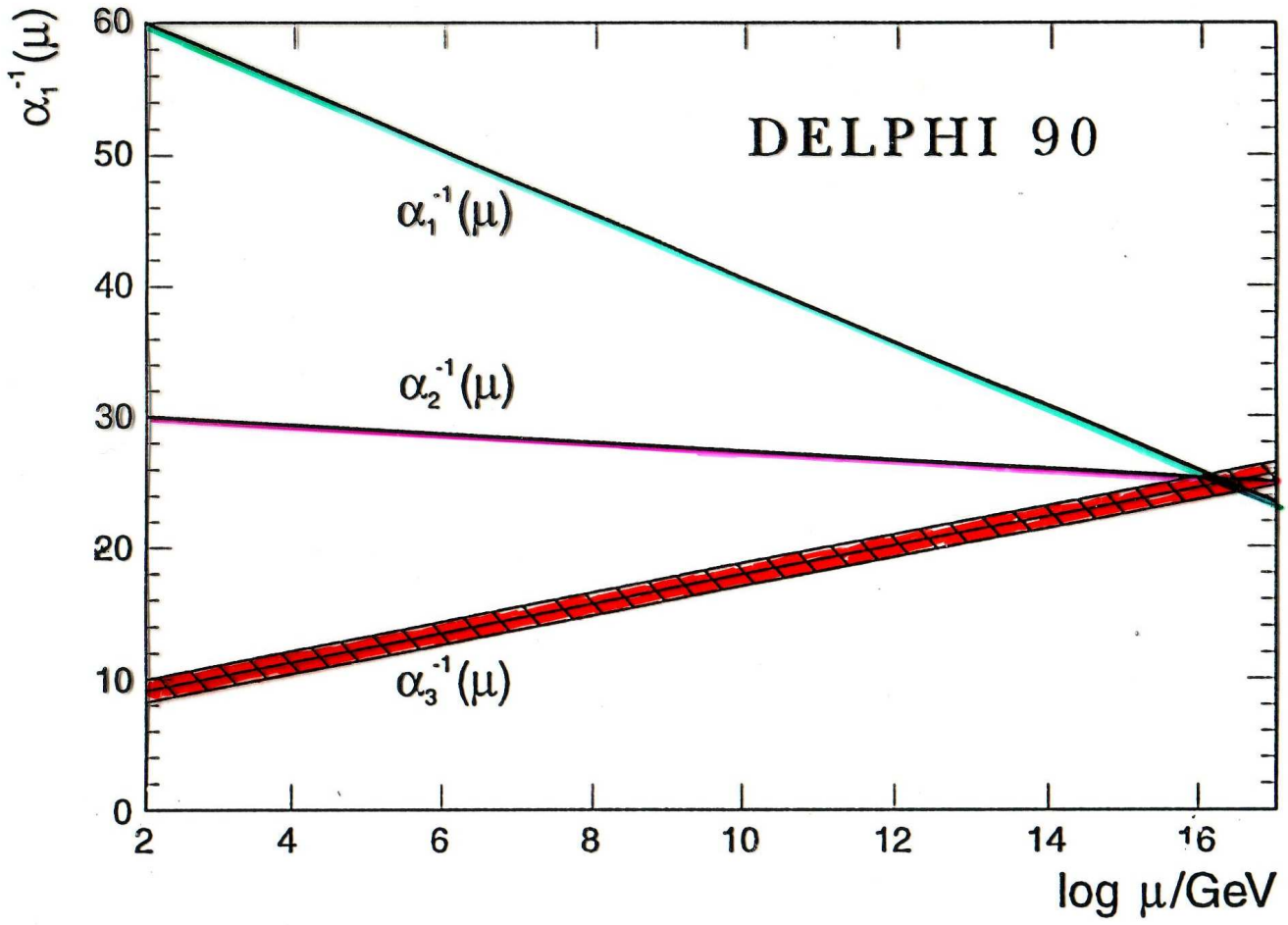
- Neutrino-oscillations and “See-Saw Mechanism”

  $m_\nu \sim M_W^2/M_{\mathrm{GUT}}$

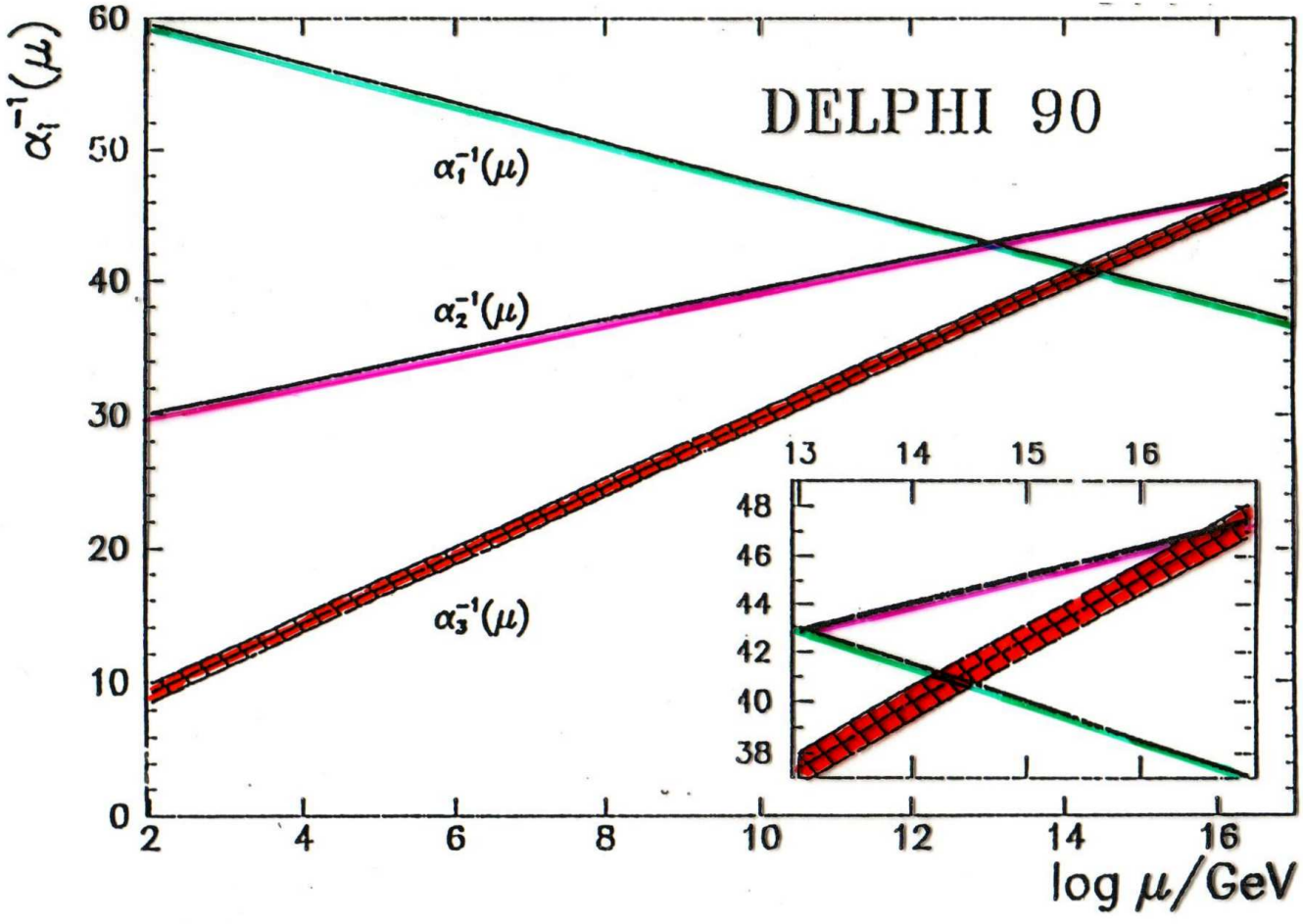
  $m_\nu \sim 10^{-3}\mathrm{eV}$ for $M_W \sim 100\mathrm{GeV}$,

- Evolution of couplings constants of the standard model towards higher energies.

MSusySM = MSSM



Standard Model



The fate of global symmetries

Global $U(1)$ symmetries are very useful for

- absence of FCNC (solve flavour problem)
- Yukawa textures à la Frogatt-Nielsen
- solutions to the μ problem
- axions and the strong CP-problem
- R-symmetry and proton stability

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But they might be destroyed by gravitational effects:

- we need a UV-completion of the theory
- with a consistent incorporation of gravity

String theory as a UV-completion

What do we get from string theory?

- supersymmetry
- extra spatial dimensions
- (large unified) gauge groups
- consistent theory of gravity
- many discrete symmetries
- but no global continuous symmetries

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String theory could serve as the UV-completion with a consistent incorporation of gravity,
but we need to make contact with the real world (MSSM).

Local Grand Unification

In fact string theory gives us a variant of GUTs

- complete multiplets for fermion families
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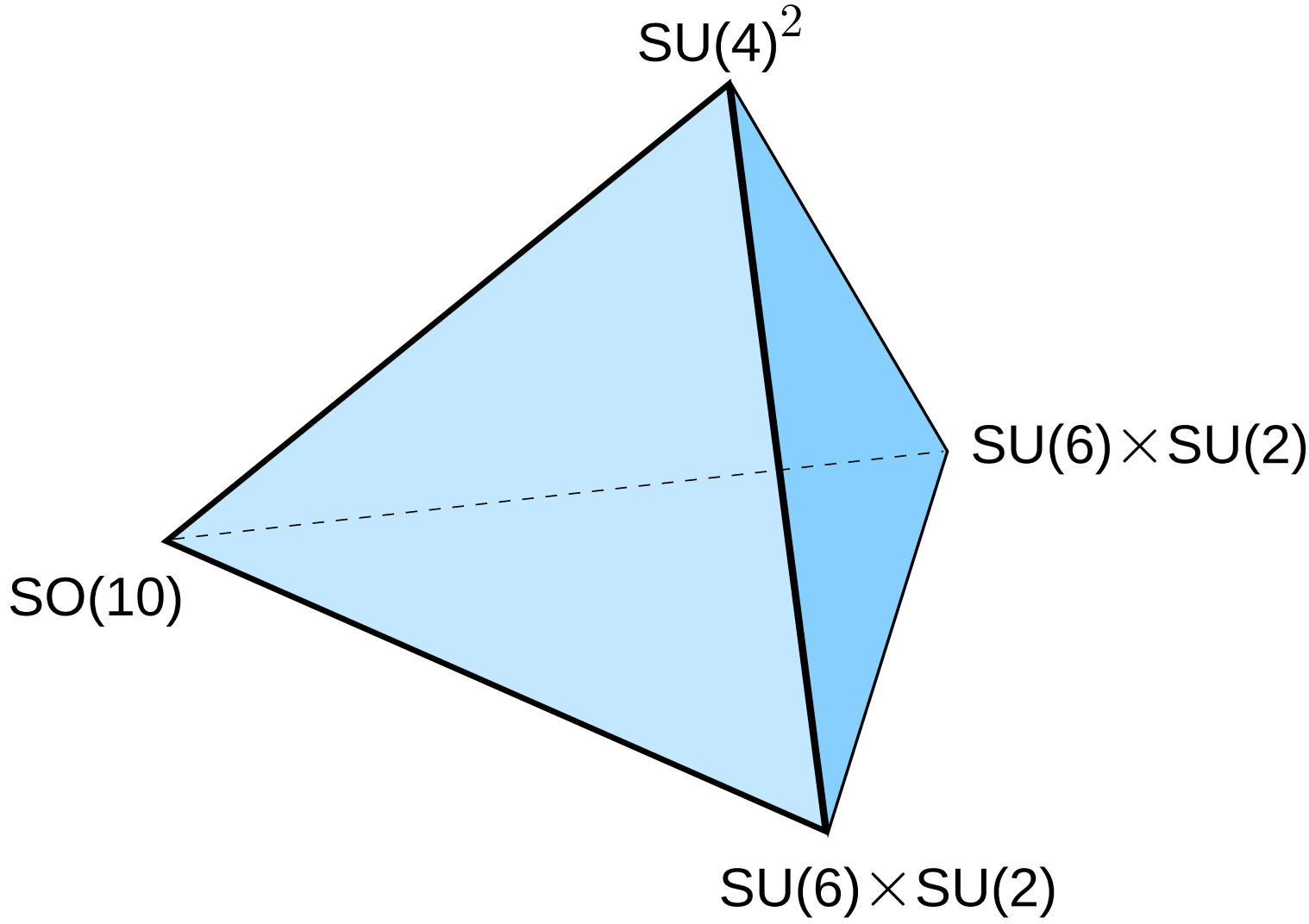
Key properties of the theory depend on the geography of the fields in extra dimensions.

This geometrical set-up called local grand unification, can be realized in the framework of the "heterotic braneworld".

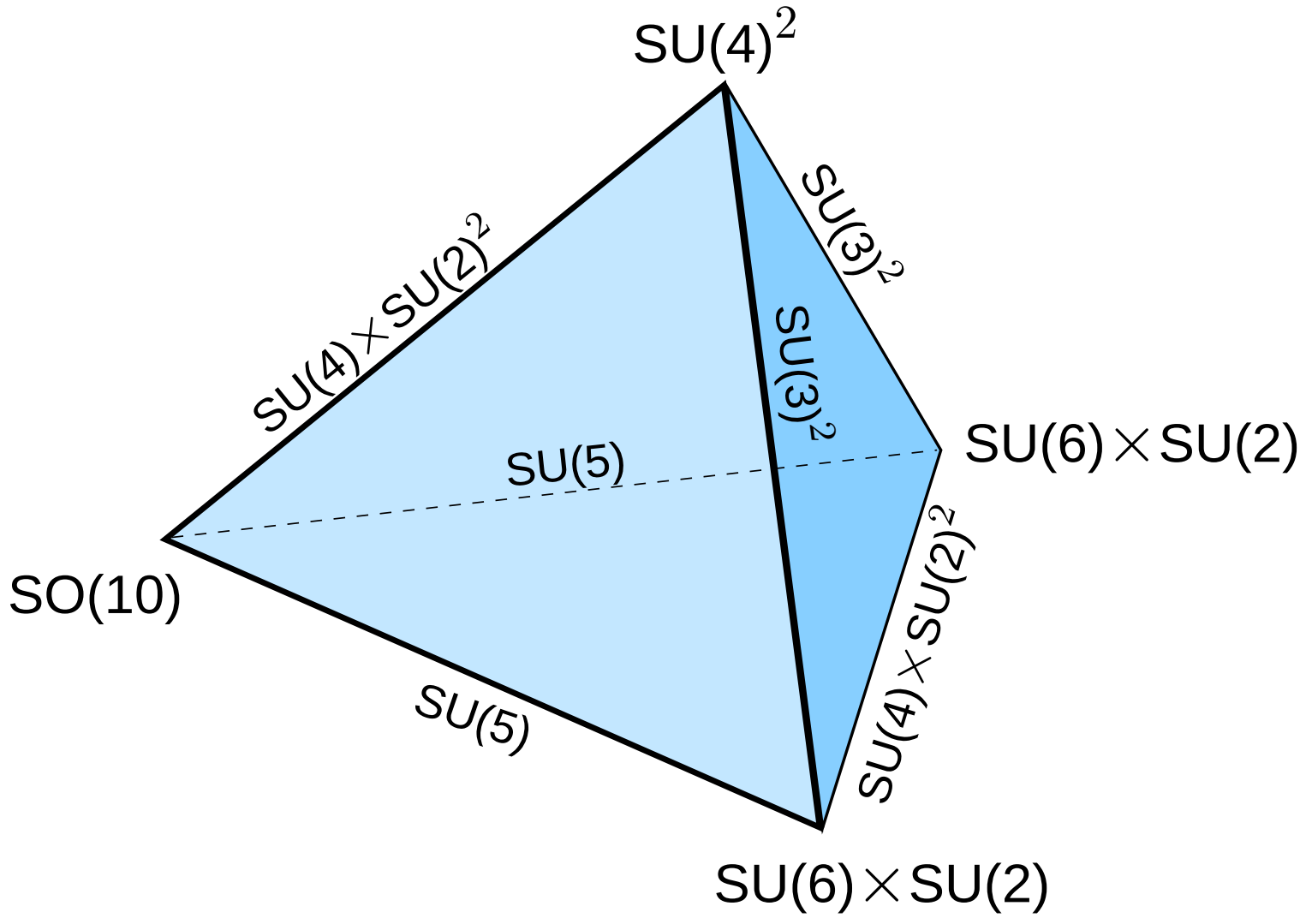
(Förste, HPN, Vaudrevange, Wingerter, 2004; Buchmüller, Hamaguchi, Lebedev, Ratz, 2004)

Localized gauge symmetries



(Förste, HPN, Vaudrevange, Wingerter, 2004)

Standard Model Gauge Group



The Heterotic Braneworld

- many models with the exact spectrum of the MSSM (absence of chiral exotics)

  (Lebedev, HPN, Raby, Ramos-Sanchez, Ratz, Vaudrevange, Wingerter, 2007-2009)

- local grand unification (by construction)
- gauge- and (partial) Yukawa unification

  (Raby, Wingerter, 2007)

- examples of neutrino see-saw mechanism

  (Buchmüller, Hamguchi, Lebedev, Ramos-Sanchez, Ratz, 2007)

- models with R-parity + solution to the μ-problem

  (Lebedev, HPN, Raby, Ramos-Sanchez, Ratz, Vaudrevange, Wingerter, 2007)

- gaugino condensation and mirage mediation

  (Löwen, HPN, 2008)

Symmetries

String theory gives us

- gauge symmetries
- discrete global symmetries from geometry and stringy selection rules (Kobayashi, HPN, Plöger, Raby, Ratz, 2006)
- accidental global $U(1)$ symmetries in the low energy effective action

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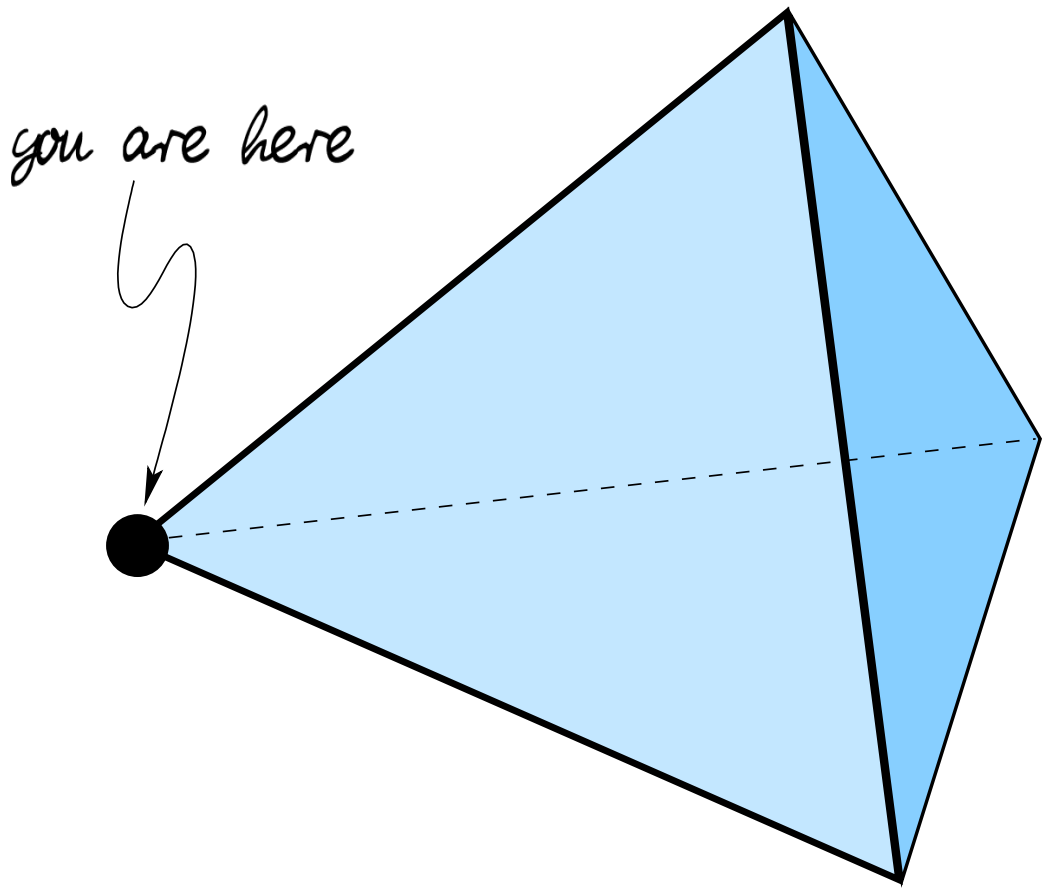
Location matters



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We might live close to a fixed point with enhanced symmetries that explain small parameters in the low energy effective theory.

These symmetries can be trusted as we are working within a consistent theory of gravity.

Applications of global symmetries

Applications of discrete and accidental global symmetries:

- (nonabelian) family symmetries (and FCNC)

  (Ko, Kobayashi, Park, Raby, 2007)

- Yukawa textures (via Frogatt-Nielsen mechanism)
- a solution to the μ-problem

  (Lebedev, HPN, Raby, Ramos-Sanchez, Ratz, Vaudrevange, Wingerter, 2007)

- creation of hierarchies

  (Kappl, HPN, Ramos-Sanchez, Ratz, Schmidt-Hoberg, Vaudrevange, 2008)

- proton stability via “Proton Hexality”

  (Dreiner, Luhn, Thormeier, 2005; Förste, HPN, Ramos-Sanchez, Vaudrevange, 2010)

- approximate global $U(1)$ for a QCD accion

  (Choi, Kim, Kim, 2006; Choi, HPN, Ramos-Sanchez, Vaudrevange, 2008)

A Benchmark Model

At the orbifold point the gauge group is

$$SU(3) \times SU(2) \times U(1)^9 \times SU(4) \times SU(2)$$

- one $U(1)$ is anomalous
- there are singlets and vectorlike exotics
- decoupling of exotics and breakdown of gauge group has been verified
- remaining gauge group

$$SU(3) \times SU(2) \times U(1)_Y \times SU(4)_{\text{hidden}}$$

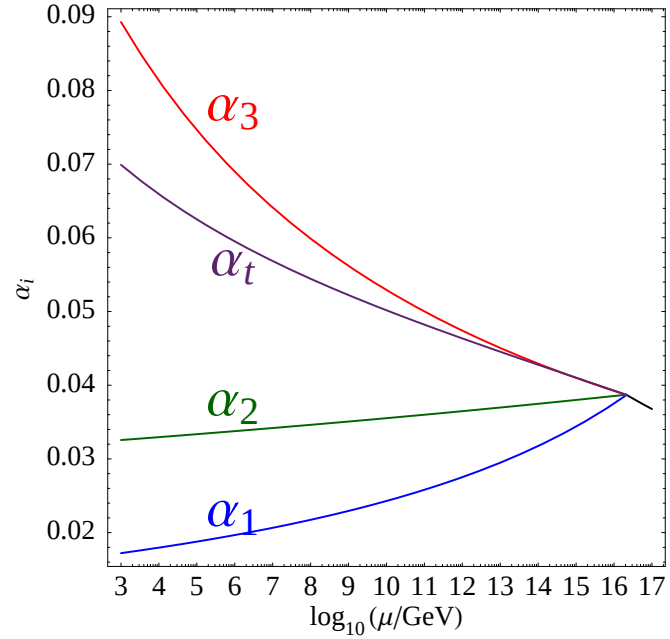
- for discussion of neutrinos and R-parity we keep also the $U(1)_{B-L}$ charges

Spectrum

#	irrep	label		#	irrep	label
3	$(\mathbf{3},\mathbf{2};\mathbf{1},\mathbf{1})_{(1/6,1/3)}$	q_i		3	$(\overline{\mathbf{3}},\mathbf{1};\mathbf{1},\mathbf{1})_{(-2/3,-1/3)}$	$\bar{u}_i$
3	$(\mathbf{1},\mathbf{1};\mathbf{1},\mathbf{1})_{(1,1)}$	$\bar{e}_i$		8	$(\mathbf{1},\mathbf{2};\mathbf{1},\mathbf{1})_{(0,*)}$	m_i
$3+1$	$(\overline{\mathbf{3}},\mathbf{1};\mathbf{1},\mathbf{1})_{(1/3,-1/3)}$	$\bar{d}_i$		1	$(\mathbf{3},\mathbf{1};\mathbf{1},\mathbf{1})_{(-1/3,1/3)}$	d_i
$3+1$	$(\mathbf{1},\mathbf{2};\mathbf{1},\mathbf{1})_{(-1/2,-1)}$	ℓ_i		1	$(\mathbf{1},\mathbf{2};\mathbf{1},\mathbf{1})_{(1/2,1)}$	$\bar{\ell}_i$
1	$(\mathbf{1},\mathbf{2};\mathbf{1},\mathbf{1})_{(-1/2,0)}$	h_d		1	$(\mathbf{1},\mathbf{2};\mathbf{1},\mathbf{1})_{(1/2,0)}$	h_u
6	$(\overline{\mathbf{3}},\mathbf{1};\mathbf{1},\mathbf{1})_{(1/3,2/3)}$	$\bar{\delta}_i$		6	$(\mathbf{3},\mathbf{1};\mathbf{1},\mathbf{1})_{(-1/3,-2/3)}$	δ_i
14	$(\mathbf{1},\mathbf{1};\mathbf{1},\mathbf{1})_{(1/2,*)}$	s_i^+		14	$(\mathbf{1},\mathbf{1};\mathbf{1},\mathbf{1})_{(-1/2,*)}$	s_i^-
16	$(\mathbf{1},\mathbf{1};\mathbf{1},\mathbf{1})_{(0,1)}$	$\bar{n}_i$		13	$(\mathbf{1},\mathbf{1};\mathbf{1},\mathbf{1})_{(0,-1)}$	n_i
5	$(\mathbf{1},\mathbf{1};\mathbf{1},\mathbf{2})_{(0,1)}$	$\bar{\eta}_i$		5	$(\mathbf{1},\mathbf{1};\mathbf{1},\mathbf{2})_{(0,-1)}$	η_i
10	$(\mathbf{1},\mathbf{1};\mathbf{1},\mathbf{2})_{(0,0)}$	h_i		2	$(\mathbf{1},\mathbf{2};\mathbf{1},\mathbf{2})_{(0,0)}$	y_i
6	$(\mathbf{1},\mathbf{1};\mathbf{4},\mathbf{1})_{(0,*)}$	f_i		6	$(\mathbf{1},\mathbf{1};\overline{\mathbf{4}},\mathbf{1})_{(0,*)}$	$\bar{f}_i$
2	$(\mathbf{1},\mathbf{1};\mathbf{4},\mathbf{1})_{(-1/2,-1)}$	f_i^-		2	$(\mathbf{1},\mathbf{1};\overline{\mathbf{4}},\mathbf{1})_{(1/2,1)}$	$\bar{f}_i^+$
4	$(\mathbf{1},\mathbf{1};\mathbf{1},\mathbf{1})_{(0,\pm 2)}$	χ_i		32	$(\mathbf{1},\mathbf{1};\mathbf{1},\mathbf{1})_{(0,0)}$	s_i^0
2	$(\overline{\mathbf{3}},\mathbf{1};\mathbf{1},\mathbf{1})_{(-1/6,2/3)}$	$\bar{v}_i$		2	$(\mathbf{3},\mathbf{1};\mathbf{1},\mathbf{1})_{(1/6,-2/3)}$	v_i

Unification

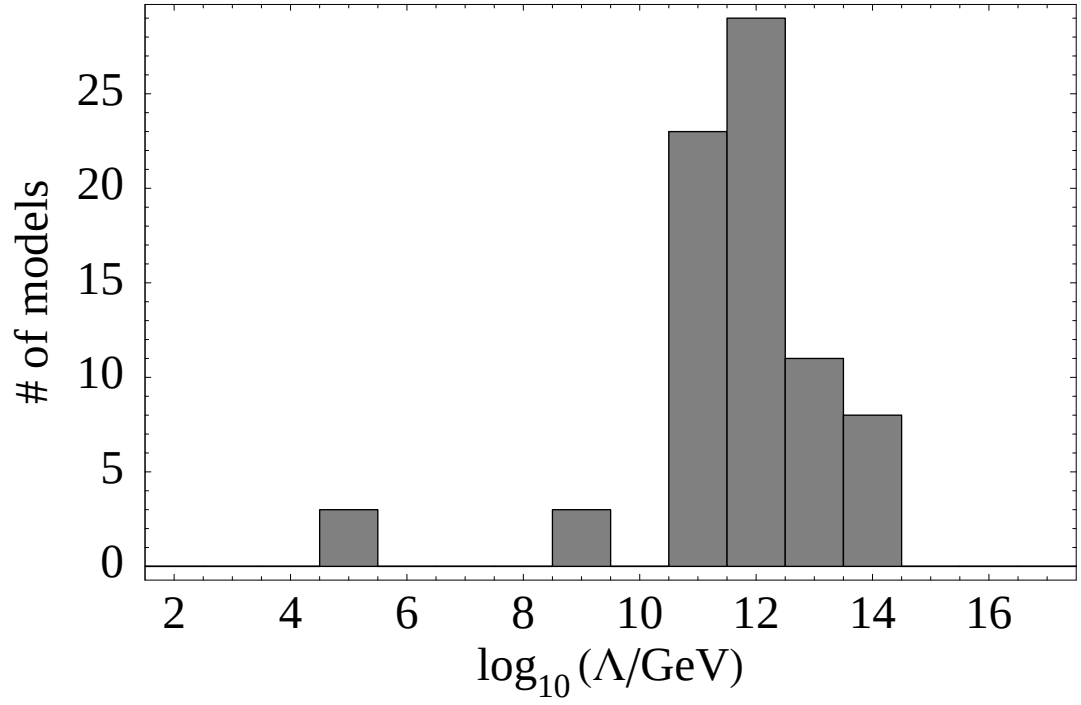
- Higgs doublets are in untwisted (U3) sector
- heavy top quark
- $\mu-$term protected by a discrete symmetry



- threshold corrections ("on third torus") allow unification at correct scale around 10^{16} GeV
- natural incorporation of gauge-Yukawa unification

(Hosteins, Kappl, Ratz, Schmidt-Hoberg, 2009)

Hidden Sector Gaugino Condensation



Gravitino mass $m_{3/2} = \Lambda^3/M^2_{\rm Planck}$ and $\Lambda \sim \exp(-S)$

(Lebedev, HPN, Raby, Ramos-Sanchez, Ratz, Vaudrevange, Wingerter, 2006)

Dilaton (Modulus) Domination

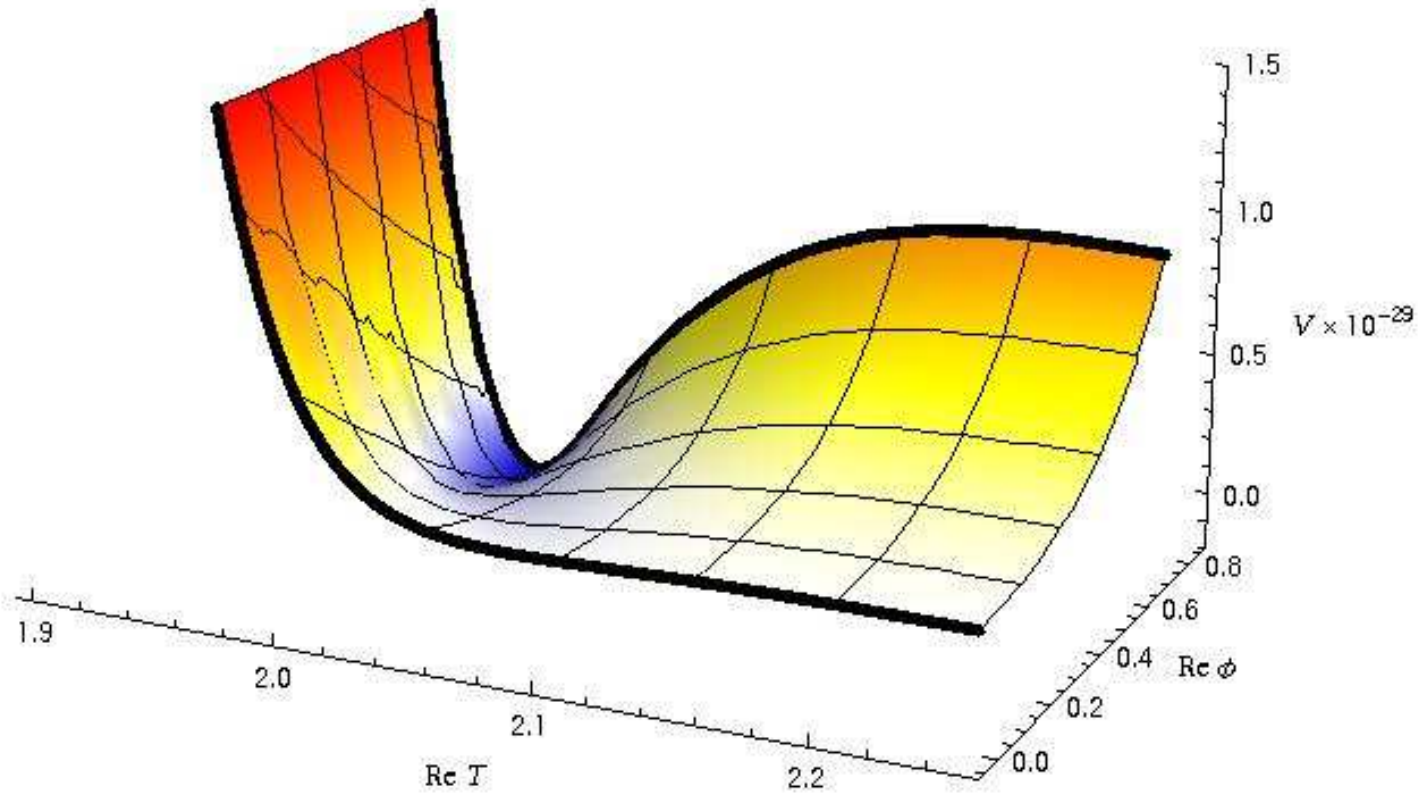
This leads to a variant the "gravity mediation" scenario,

- but we still have to adjust the vacuum energy.

Here we need a "downlifting" mechanism:

- "downlifting" mechanism can fix S as well (no need for nonperturbative corrections to the Kähler potential)

Downlift



(Löwen, HPN, 2008)

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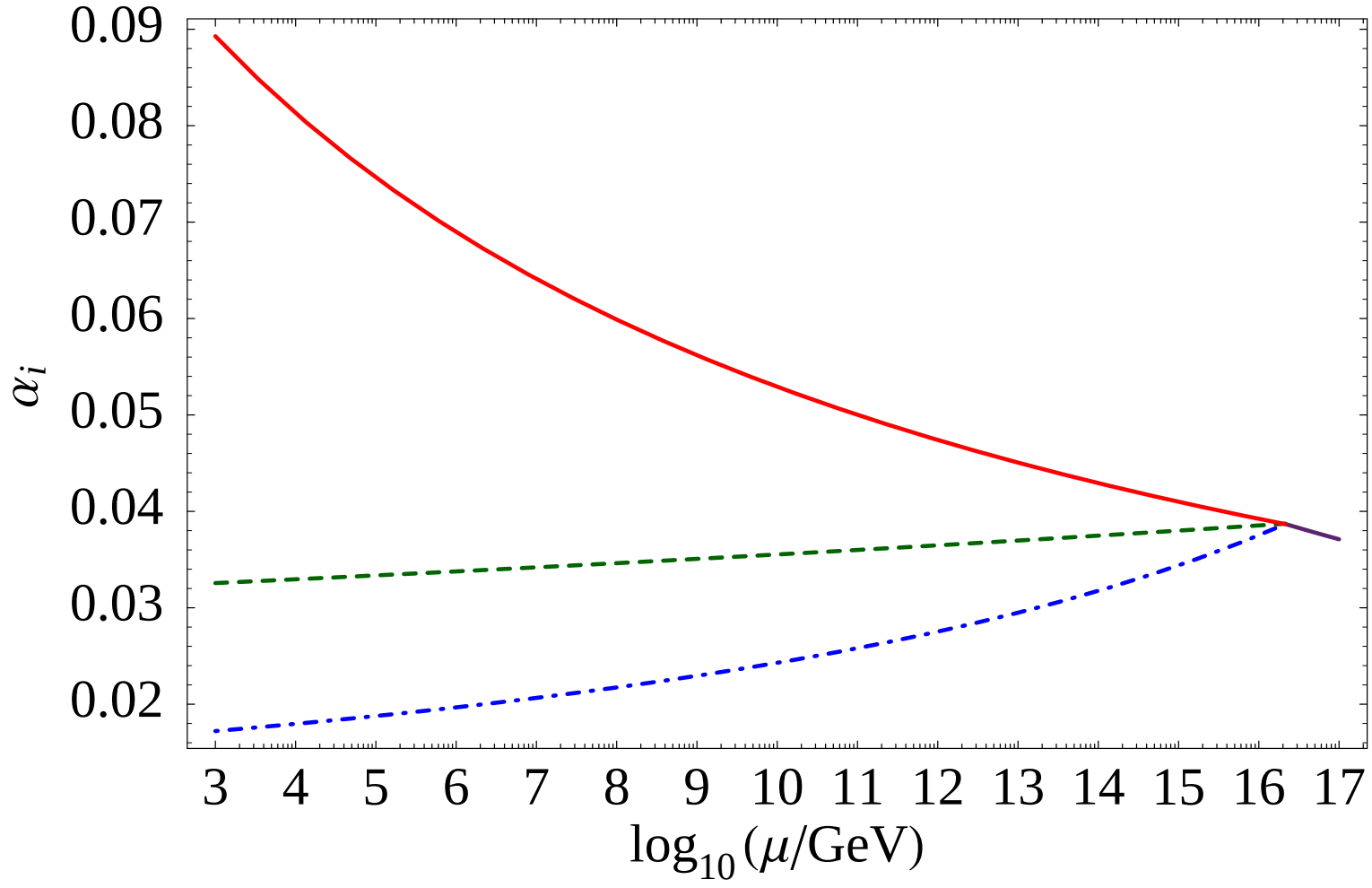
- gives a suppression factor $\log(m_{3/2}/M_{\rm Planck})$

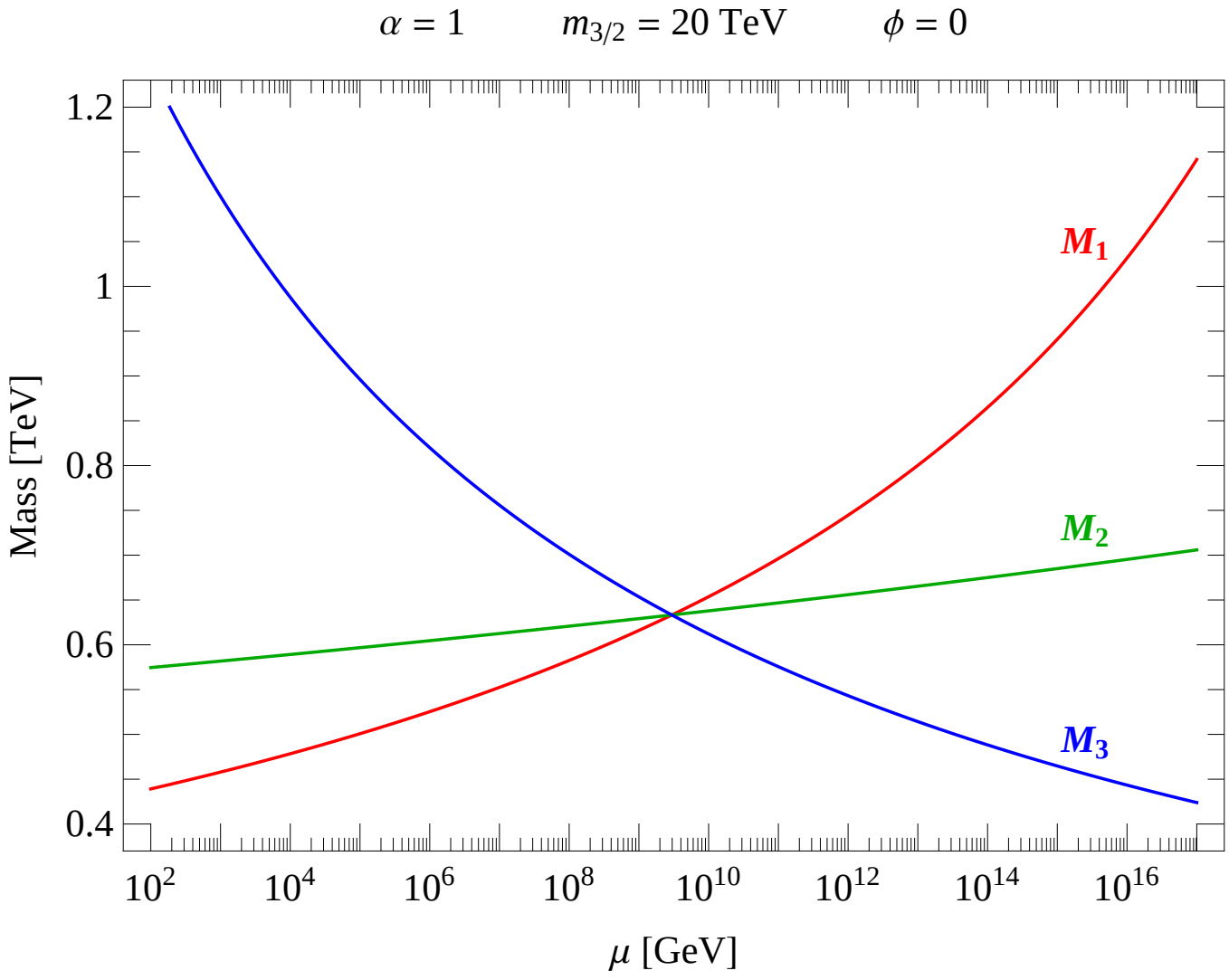
  (Choi, Falkowski, HPN, Olechowski, 2005)

- mirage mediation: mixed modulus-anomaly mediation for the gaugino masses

Evolution of couplings



Mirage Scale



Can we test this at the LHC?

At the LHC we scatter

- protons on protons, i.e.
- quarks on quarks and/or
- gluons on gluons

Thus LHC will be a machine to produce strongly interacting particles. If TeV-scale SUSY is the physics beyond the standard model we might expect LHC to become a

GLUINO FACTORY

with cascade decays down to the LSP neutralino.

The Gaugino Code

Mixed boundary conditions at the GUT scale characterized by the parameter α:
the ratio of modulus to anomaly mediation.

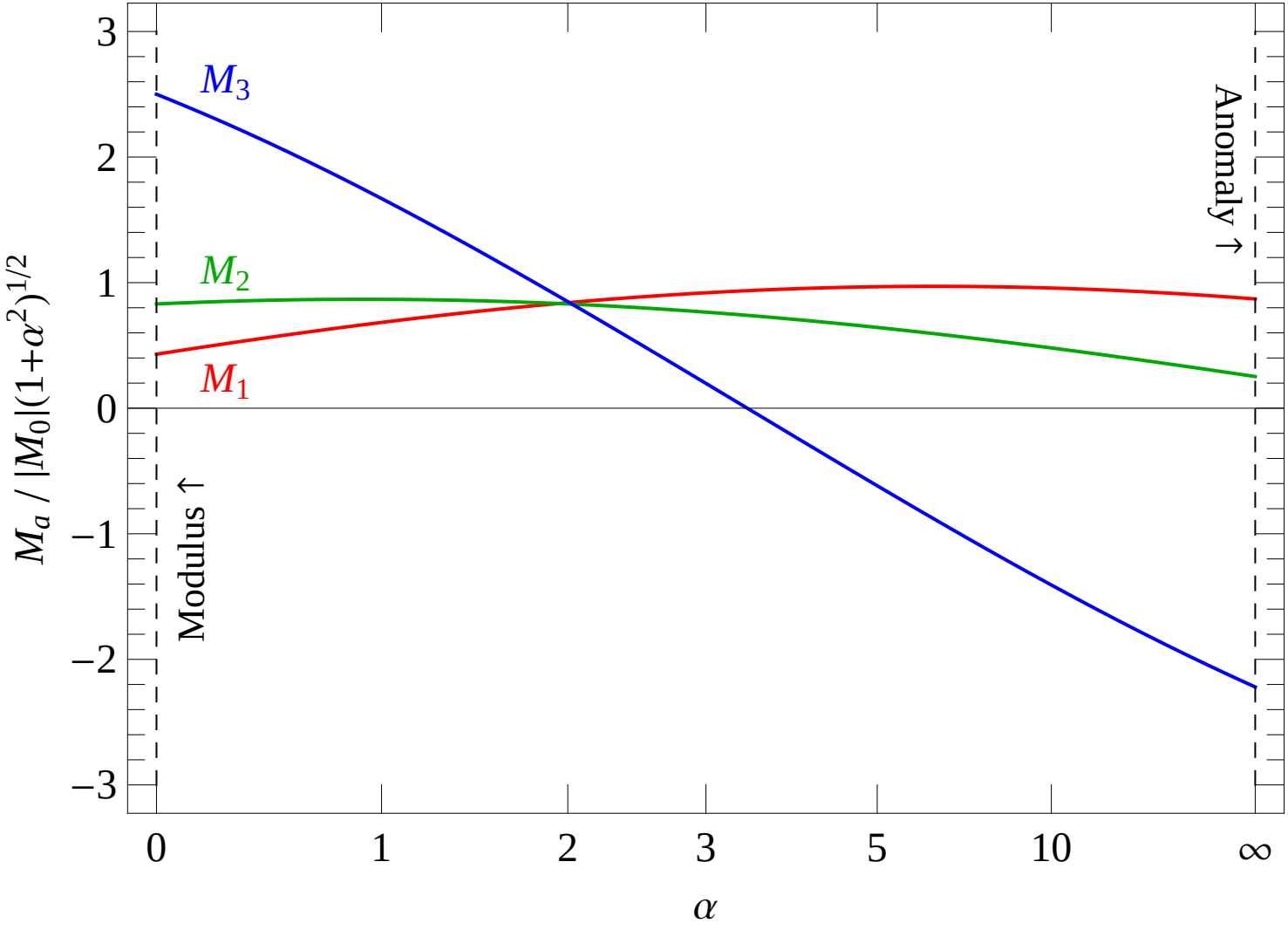
- $M_1 : M_2 : M_3 \simeq 1 : 2 : 6$ for $\alpha \simeq 0$
- $M_1 : M_2 : M_3 \simeq 1 : 1.3 : 2.5$ for $\alpha \simeq 1$
- $M_1 : M_2 : M_3 \simeq 1 : 1 : 1$ for $\alpha \simeq 2$
- $M_1 : M_2 : M_3 \simeq 3.3 : 1 : 9$ for $\alpha \simeq \infty$

The mirage scheme leads to

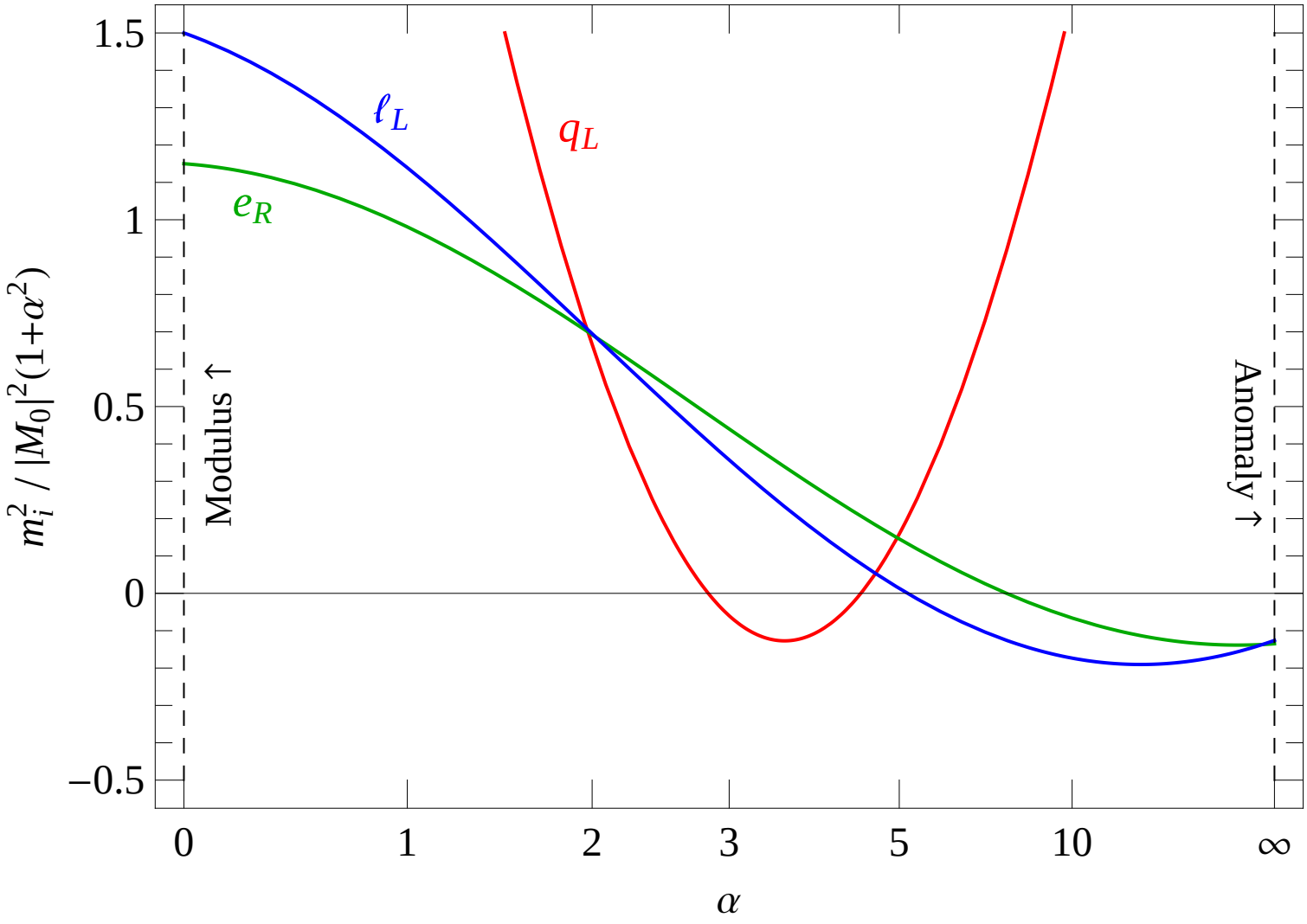
- LSP χ_1^0 predominantly Bino
- a “compact” gaugino mass pattern.

(Choi, HPN, 2007; Löwen, HPN, 2009)

Gaugino Masses



Scalar Masses



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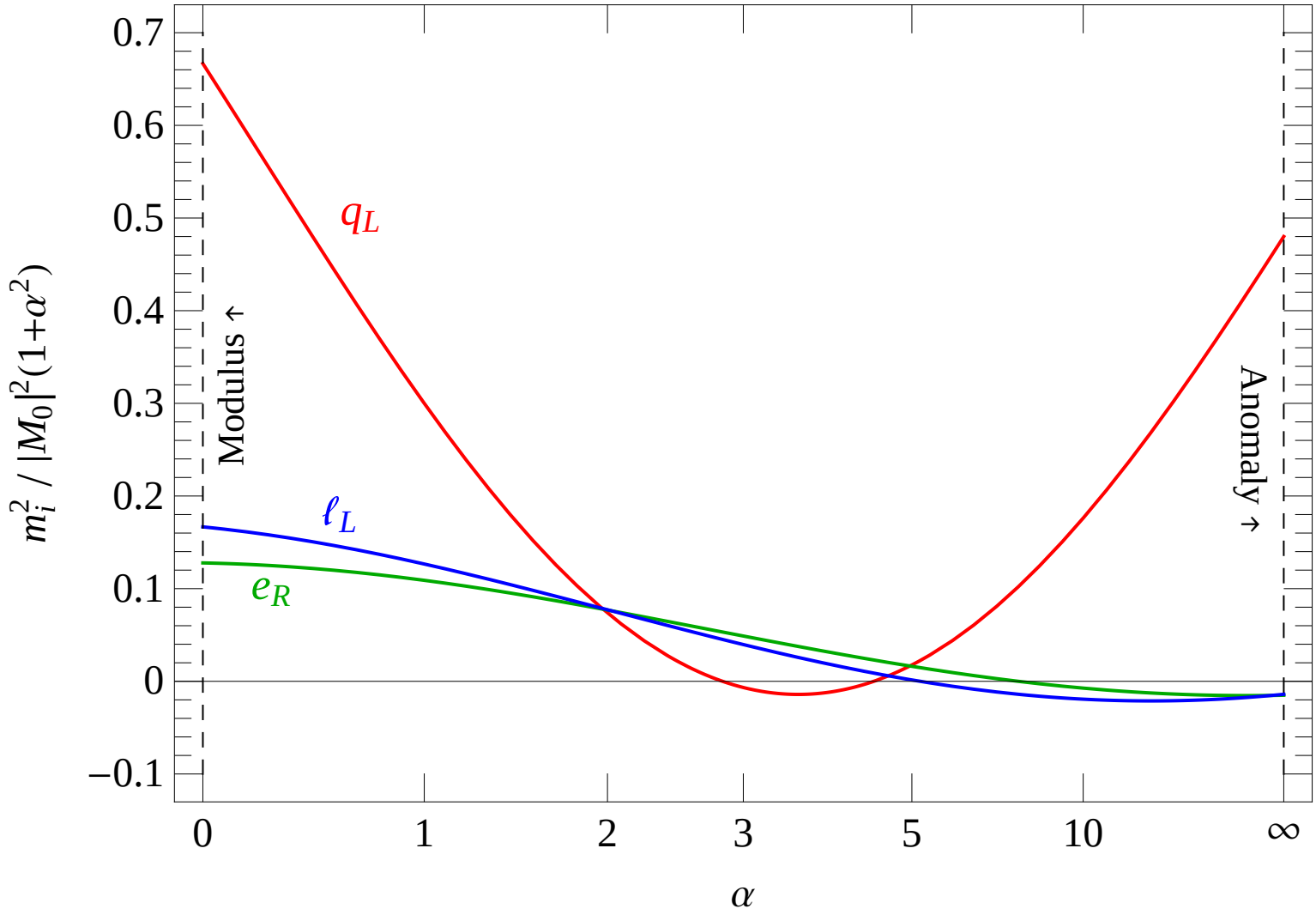
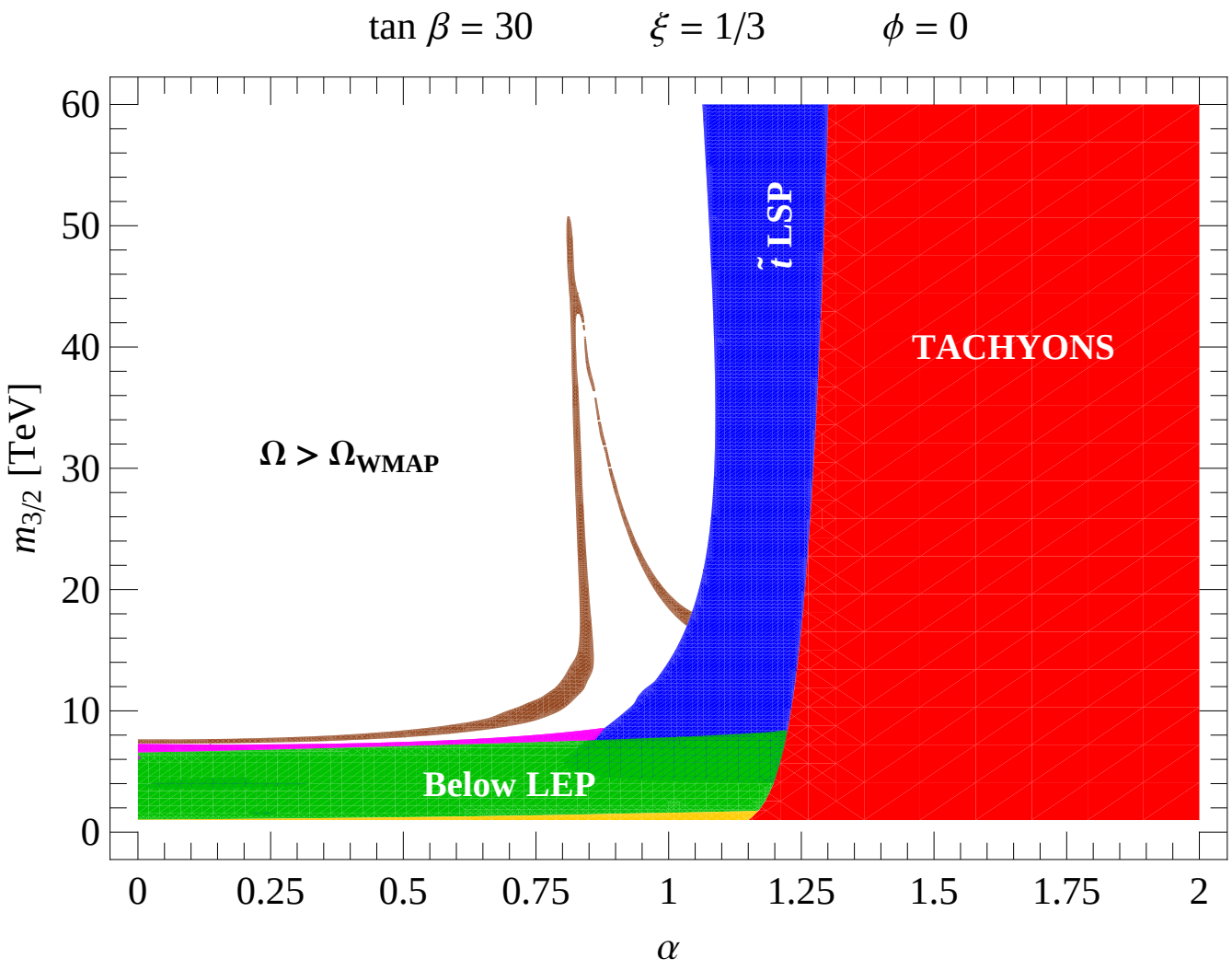
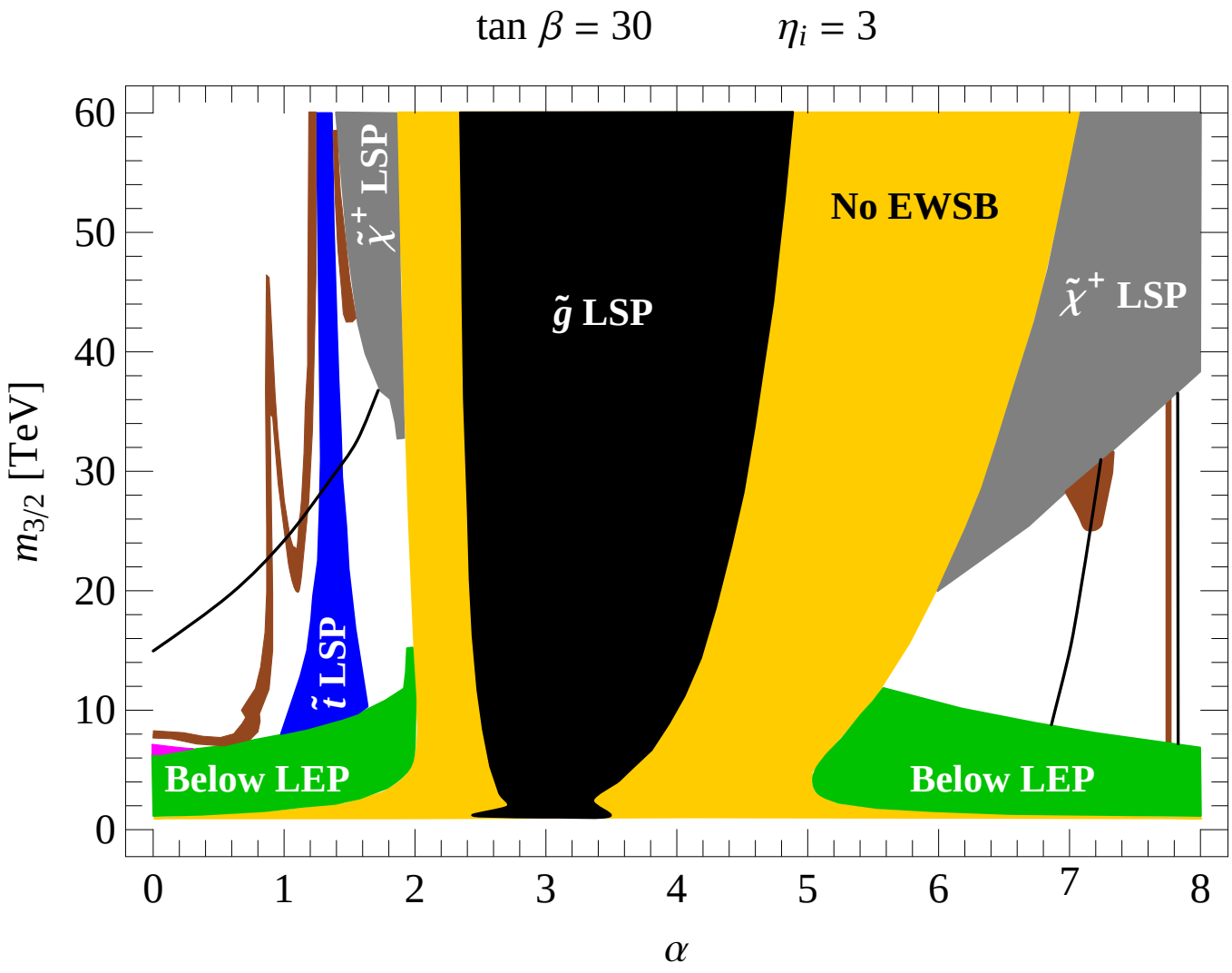


Constraints on α



Constraints on α (modified mirage)



Conclusion

String theory might provide us with a consistent UV-completion of the MSSM including

- Local Grand Unification
- Accidental symmetries (of discrete origin)

Geography of extra dimensions plays a crucial role:

- gauge-Yukawa unification and a naturally heavy top
- gravity-mirage mediation without a “flavour problem”

We seem to live at a special place in the extra dimensions!

The LHC might clarify the case for (local) grand unification.

Where do we live?