Heterotic Brane world:
the Geography of Extra Dimensions

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Outline

- MSSM and Grand Unification
- Heterotic string compactifications
- Gauge group geography in extra dimensions
- Local Grand Unification
- Benchmark scanario
- Hidden sector susy breakdown
- Mirage pattern of soft masses
- Four explicit schemes
- The Gaugino Code
- Outlook

Bottom-up input

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

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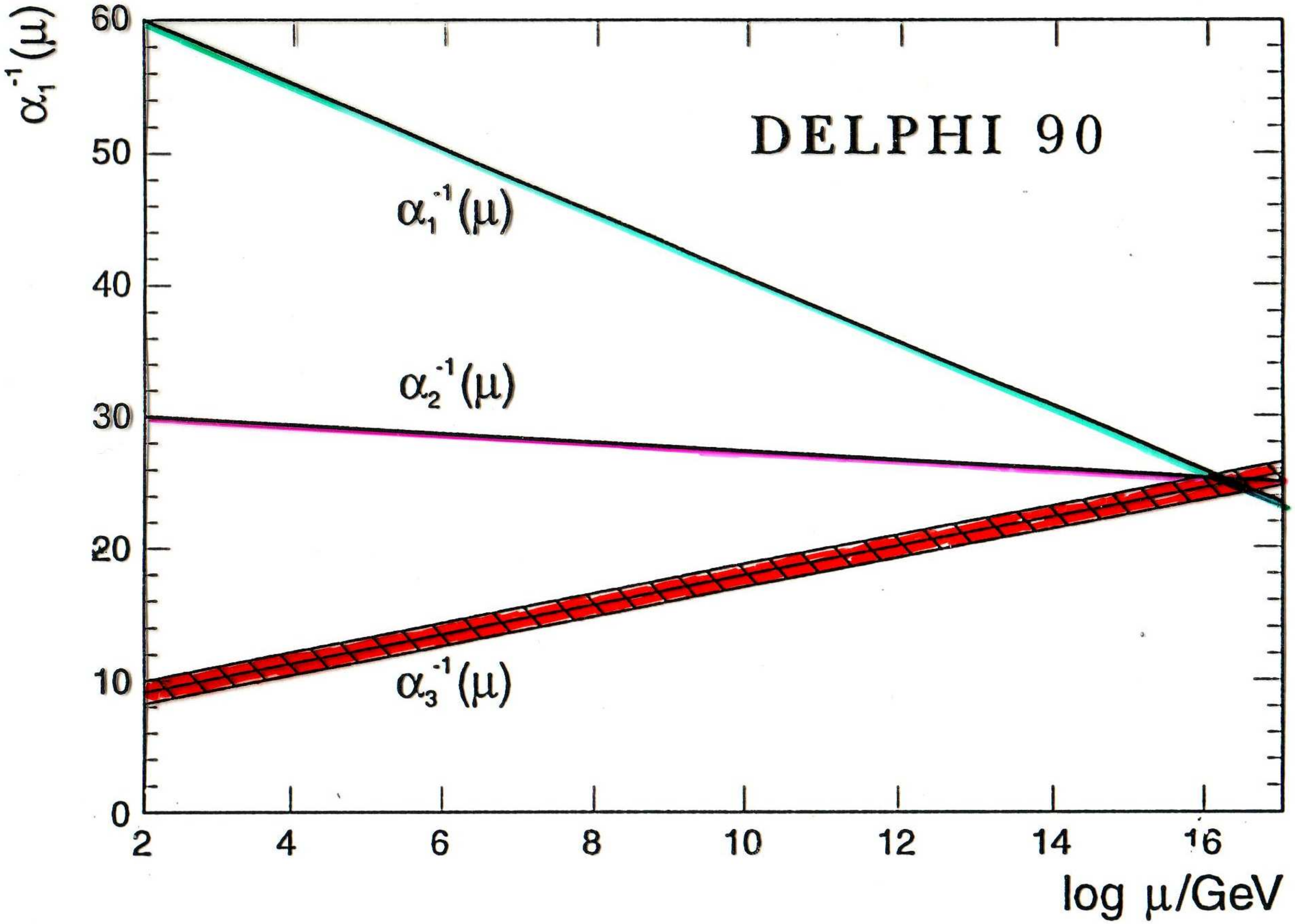
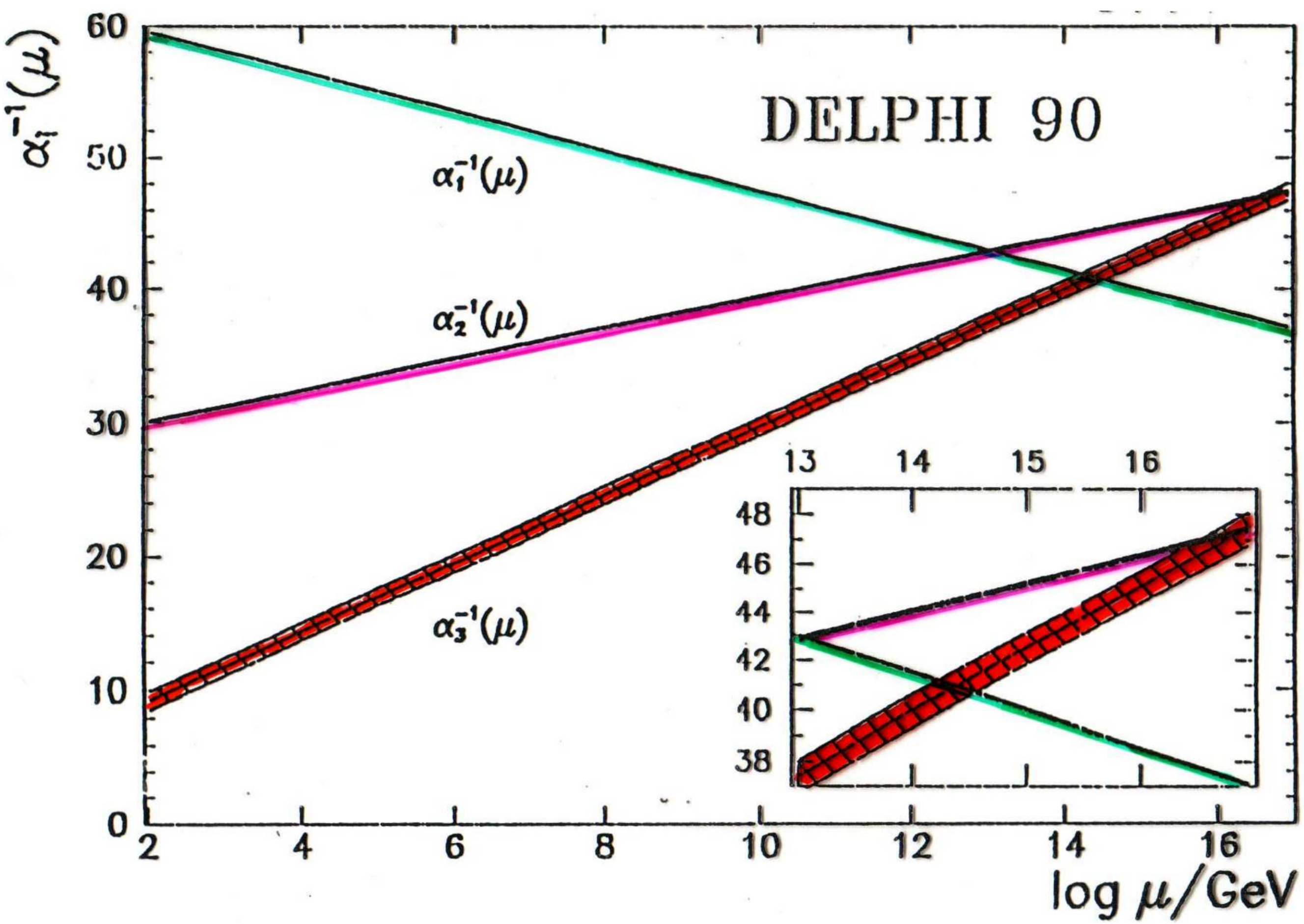
- Evolution of couplings constants of the standard model towards higher energies.

MSSM (supersymmetric)



Standard Model



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Can we avoid these problems in a more complete theory?

String theory candidates

In ten space-time dimensions.....

- Type I SO(32)
- Type II orientifolds
- Heterotic SO(32)
- Heterotic $E_8 \times E_8$
- Intersecting Branes $U(N)^M$

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....or in eleven

- Horava-Witten heterotic M-theory
- Type IIA on manifolds with G_2 holonomy

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What do we get from string theory?

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- extra spatial dimensions
- large unified gauge groups
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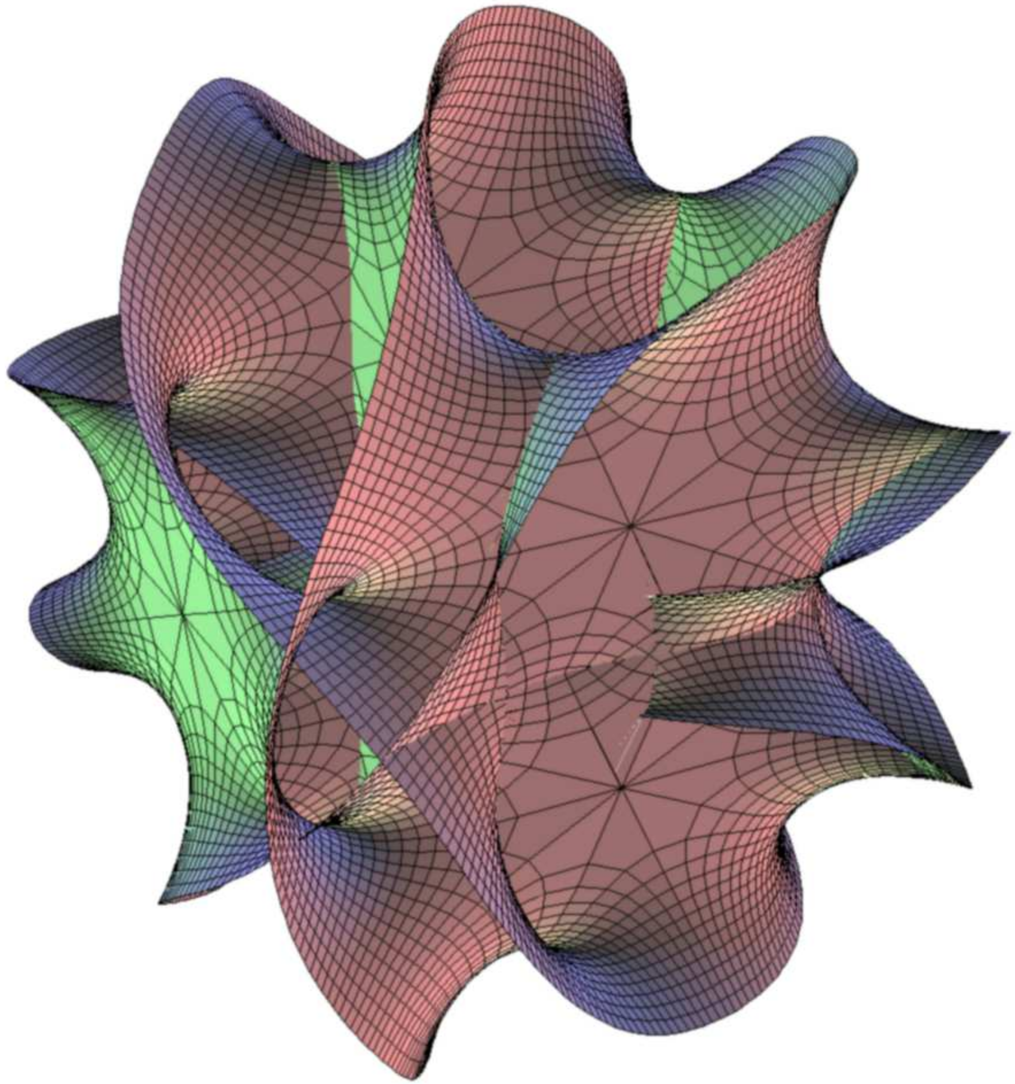
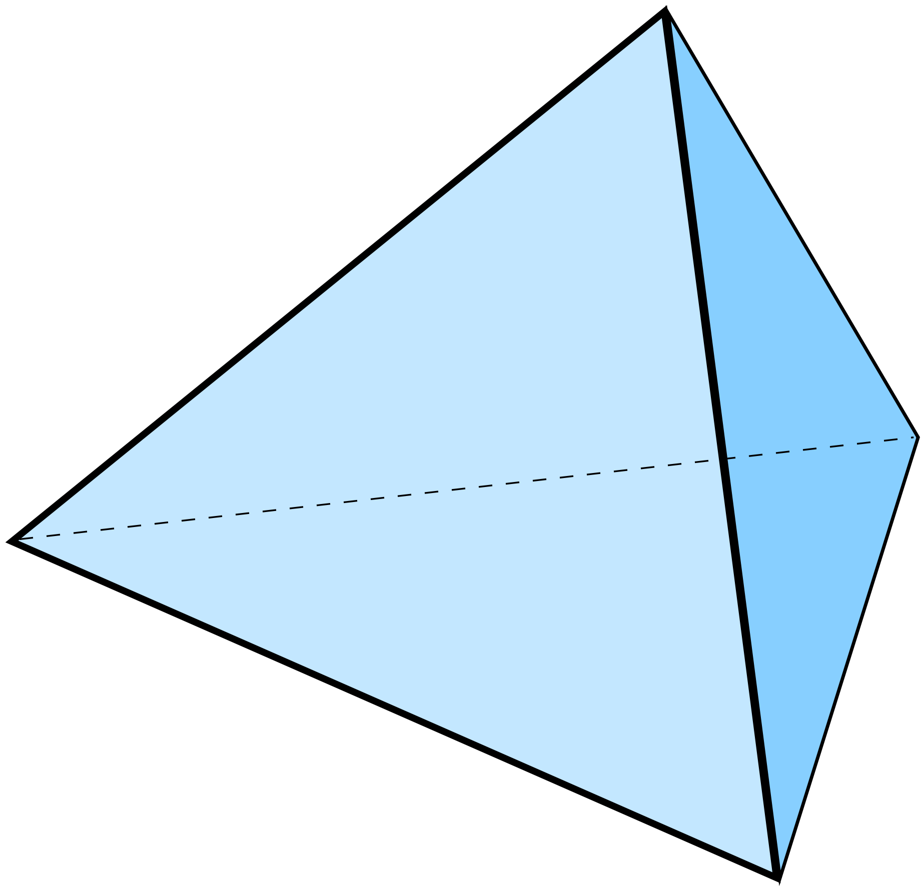
These are the building blocks for a unified theory of all the fundamental interactions.
But do they fit together, and if yes how?

We need to understand the mechanism of compactification of the extra spatial dimensions

Calabi Yau Manifold



Orbifold



Orbifolds

Orbifold compactifications combine the

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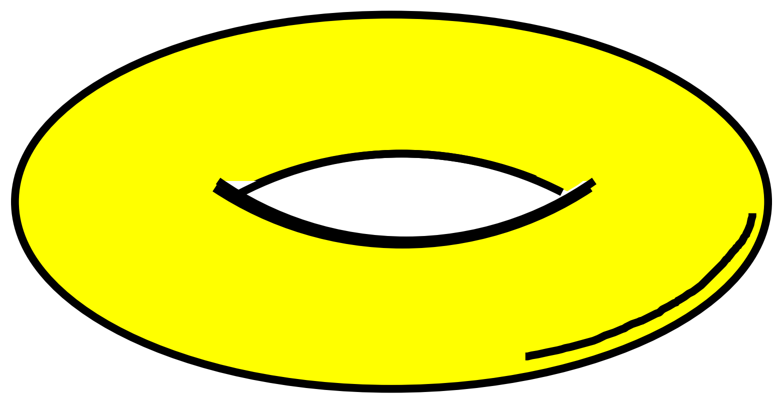
In case of the heterotic string fields can propagate

- in the Bulk ($d = 10$ untwisted sector)
- on 3-Branes ($d = 4$ twisted sector fixed points)
- on 5-Branes ($d = 6$ twisted sector fixed tori)

Torus T_2



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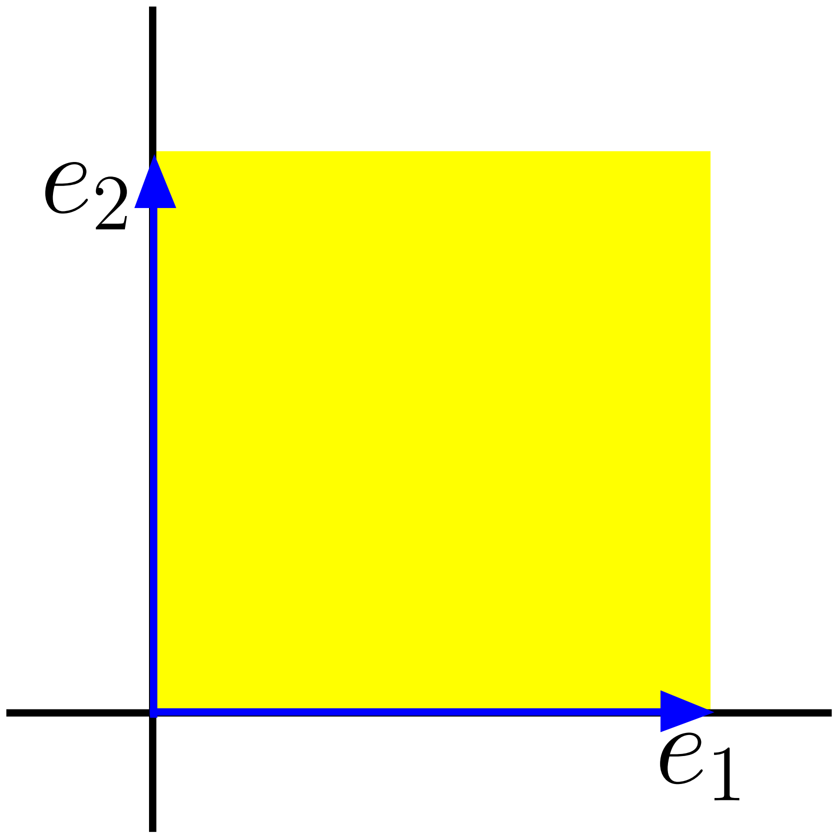
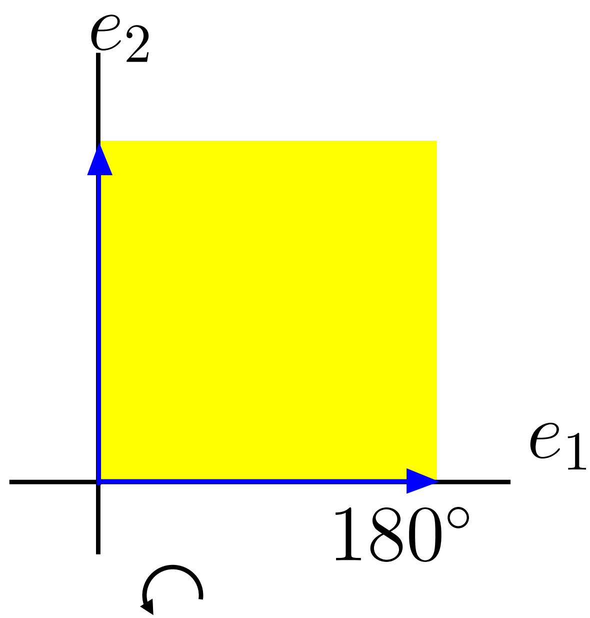


A Z_2 twist



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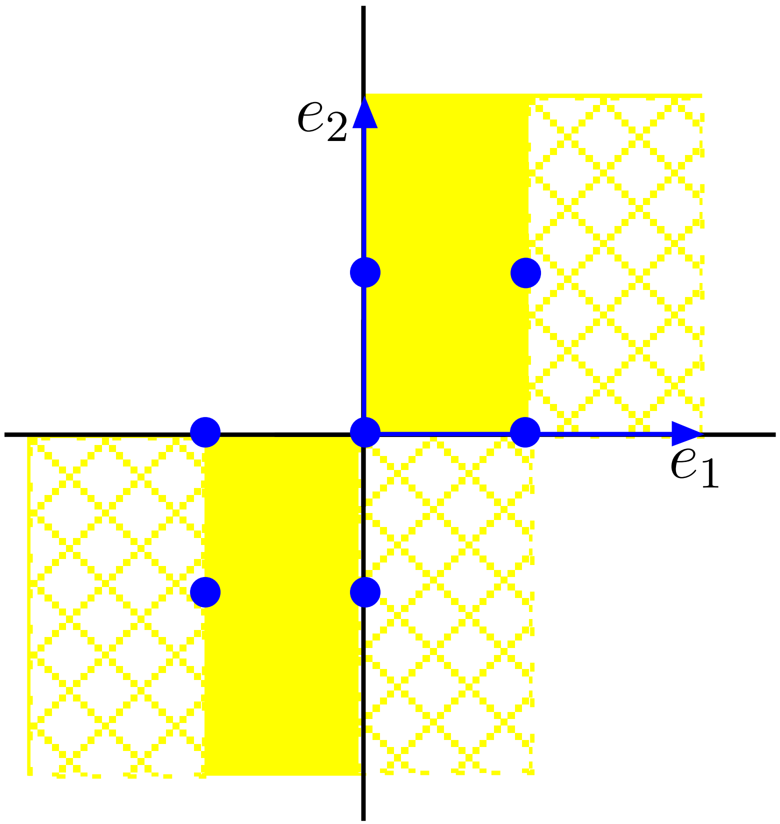
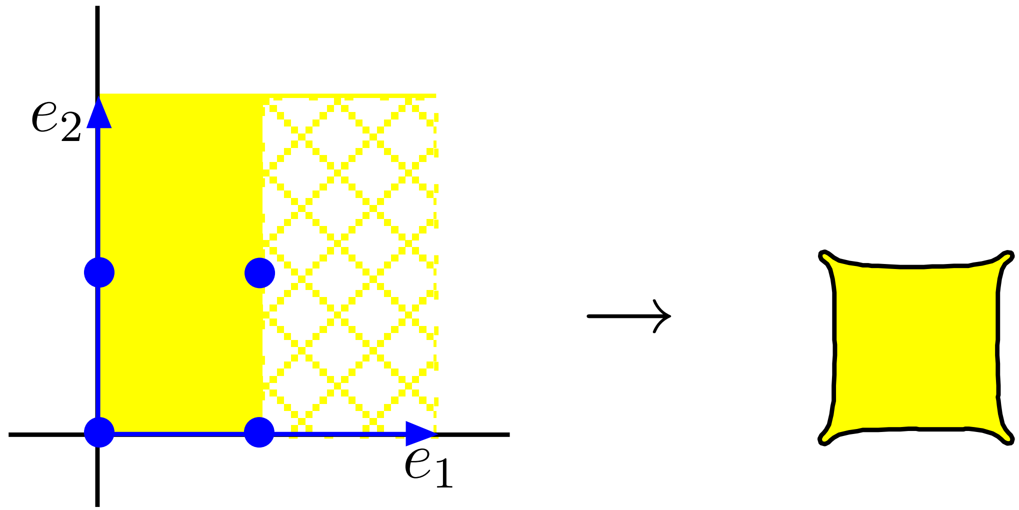
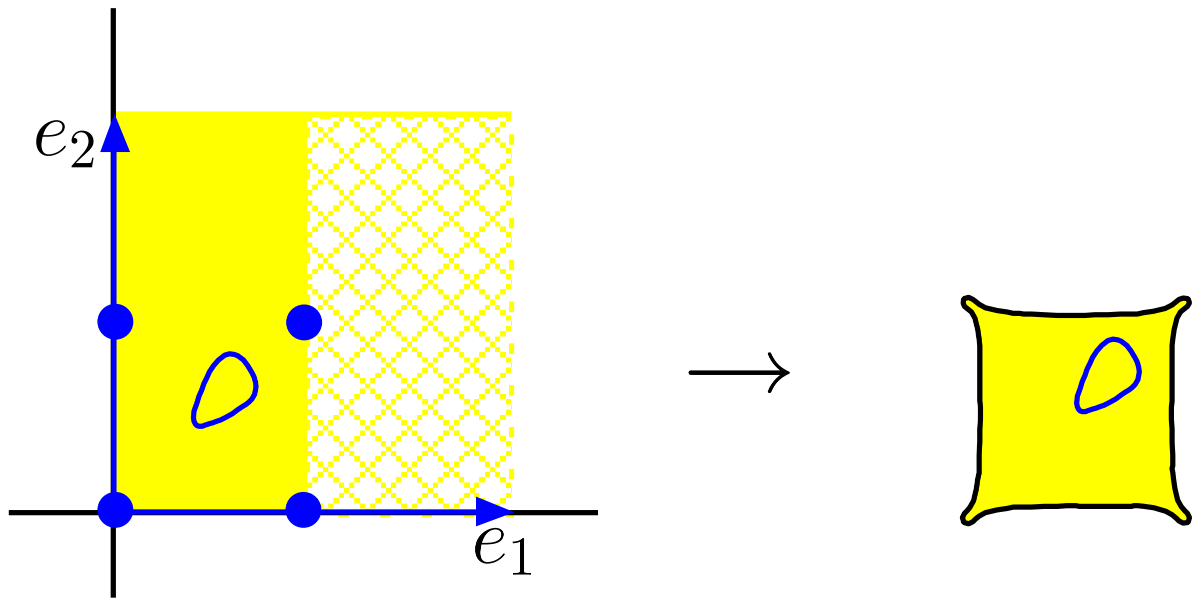


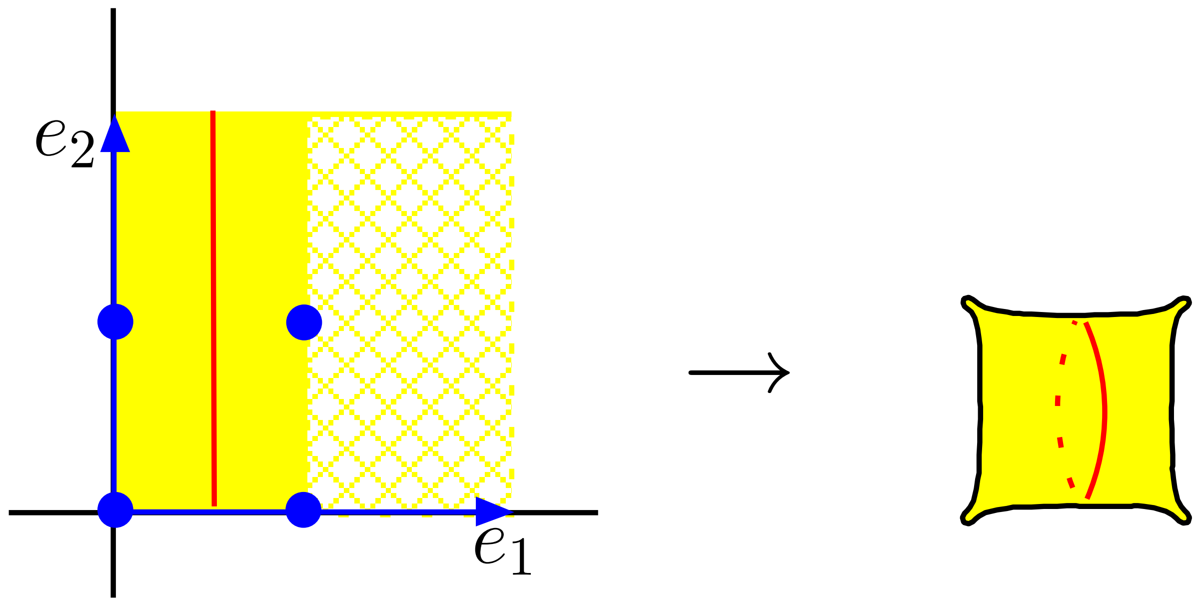
Ravioli



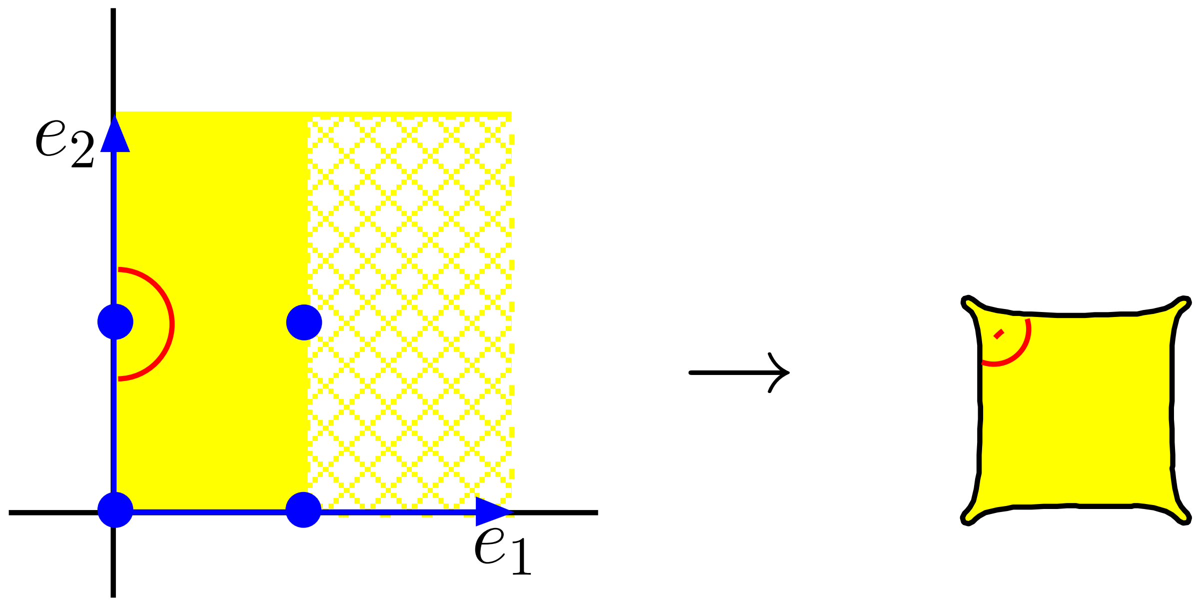
Bulk Modes



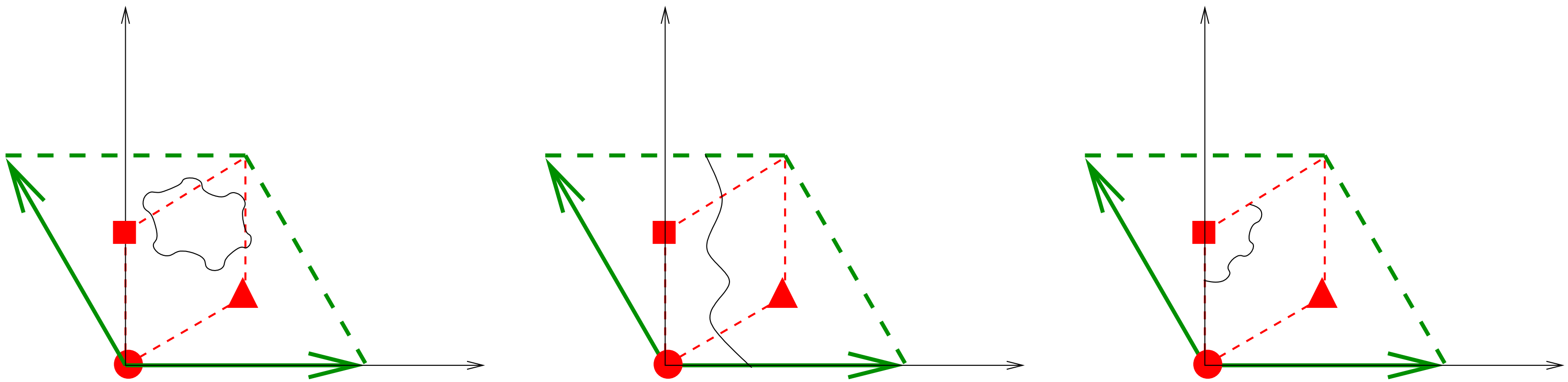
Winding Modes



Brane Modes



$\mathbb{Z}_3$ Example



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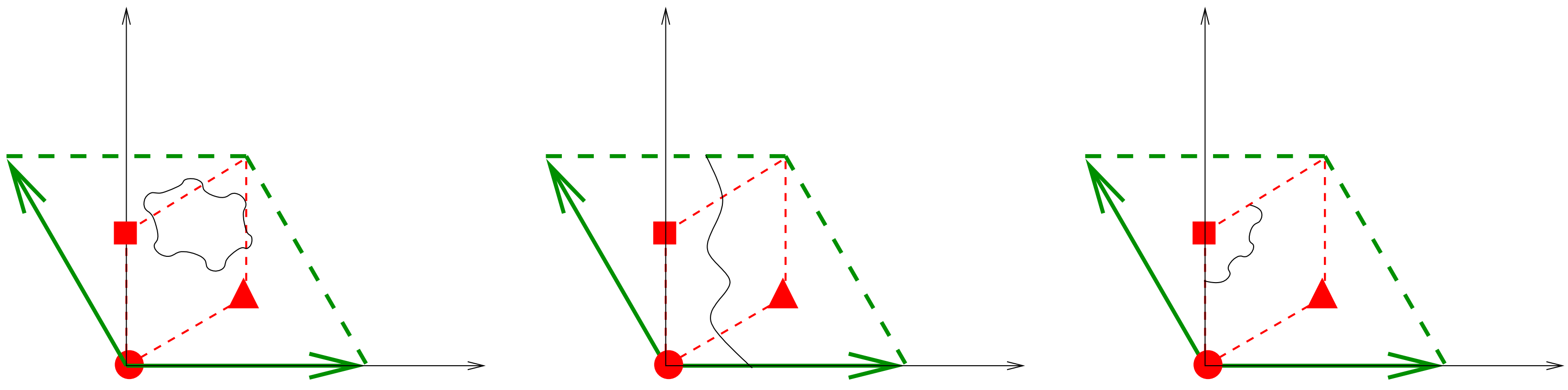

- Action of the space group on coordinates

$$X^i \rightarrow (\theta^k X)^i + n_\alpha e^i_\alpha, \quad k = 0, 1, 2, \quad i, \alpha = 1, \ldots, 6$$

- Embed twist in gauge degrees of freedom

$$X^I \rightarrow (\Theta^k X)^I \quad I = 1, \ldots, 16$$

Classification of $\mathbb{Z}_3$ Orbifold

Very few inequivalent models

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Case	Shift V	Gauge Group	Gen.
1	$\left(\frac{1}{3},\frac{1}{3},\frac{2}{3},0^5\right)\left(0^8\right)$	$\mathsf{E}_6\times\mathsf{SU}(3)\times\mathsf{E}_8'$	36
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3	$\left(\frac{1}{3},\frac{1}{3},0^6\right)\left(\frac{2}{3},0^7\right)$	$\mathsf{E}_7\times\mathsf{U}(1)\times\mathsf{SO}(14)'\times\mathsf{U}(1)'$	0
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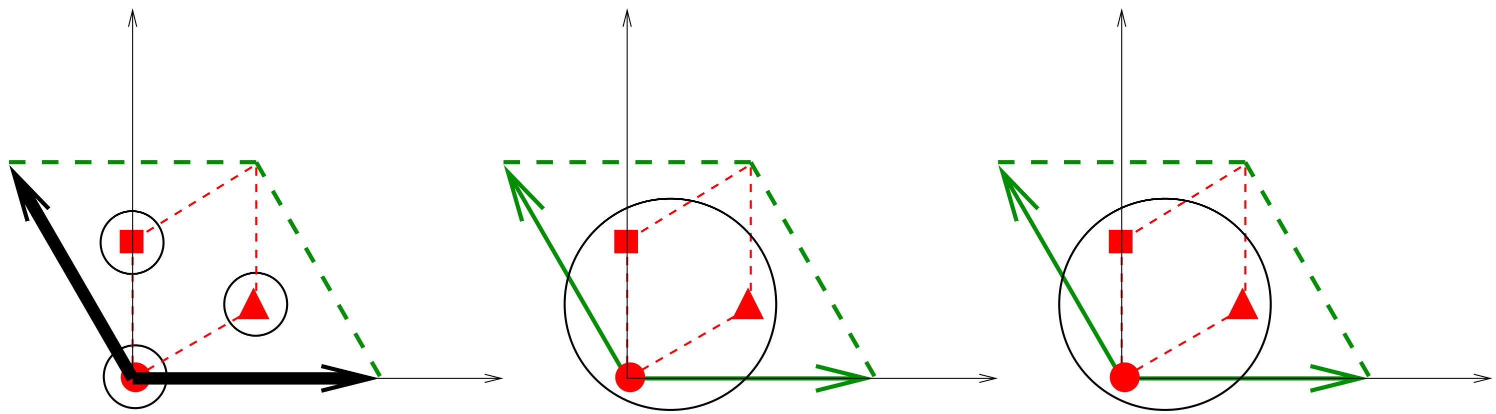
We need to lift this degeneracy ...

$\mathbb{Z}_3$ Orbifold with Wilson lines



Torus shifts embedded in gauge group as well

$$X^I \to X^I + V^I + n_\alpha A^I_\alpha$$

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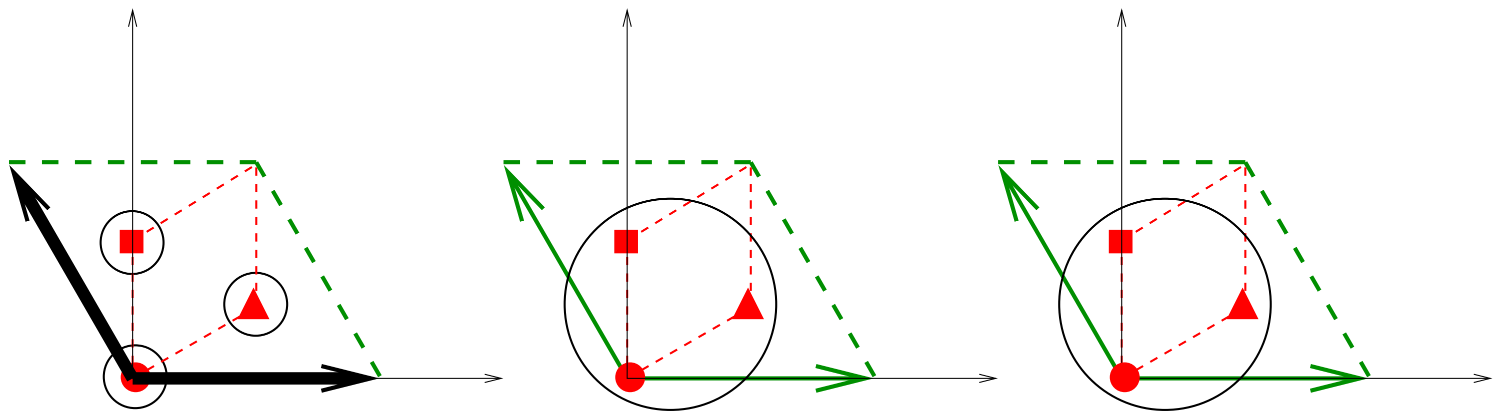

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- further gauge symmetry breakdown
- number of generations reduced

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Can we incorporate this into a string theory description?

Five golden rules

- Family as spinor of SO(10)
- Incomplete multiplets
- $N = 1$ superymmetry in $d = 4$
- Repetition of families from geometry
- Discrete symmetries of stringy origin (HPN, 2004)

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We need more general constructions to identify remnants of $SO(10)$ in string theory .....

Candidates

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Remnants of $SO(10)$ symmetry

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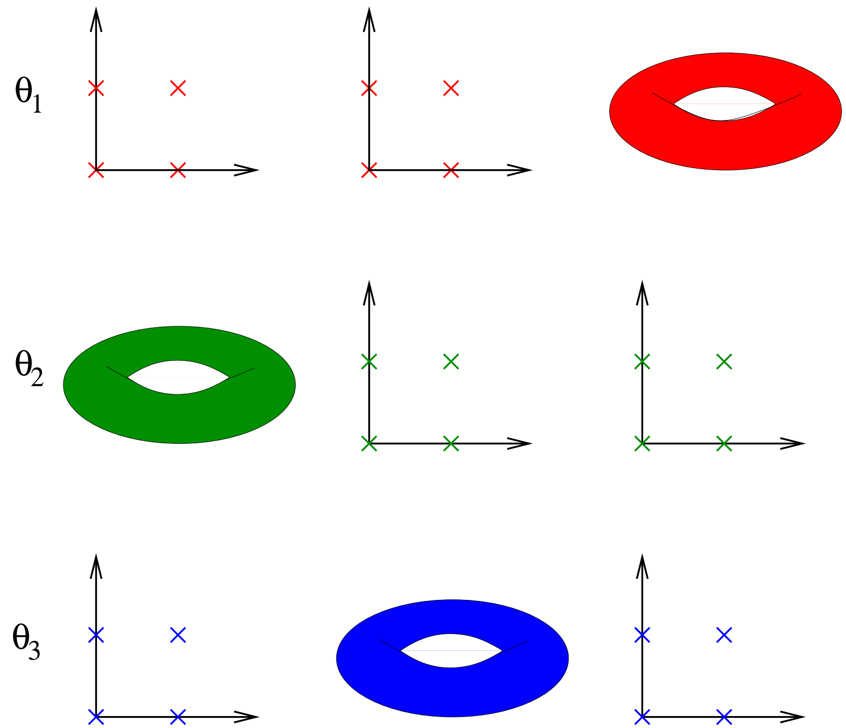
From this point of view, the Z_{2N} or $Z_N \times Z_M$ orbifolds do look more promising

$\mathbb{Z}_2 \times \mathbb{Z}_2$ Orbifold Example



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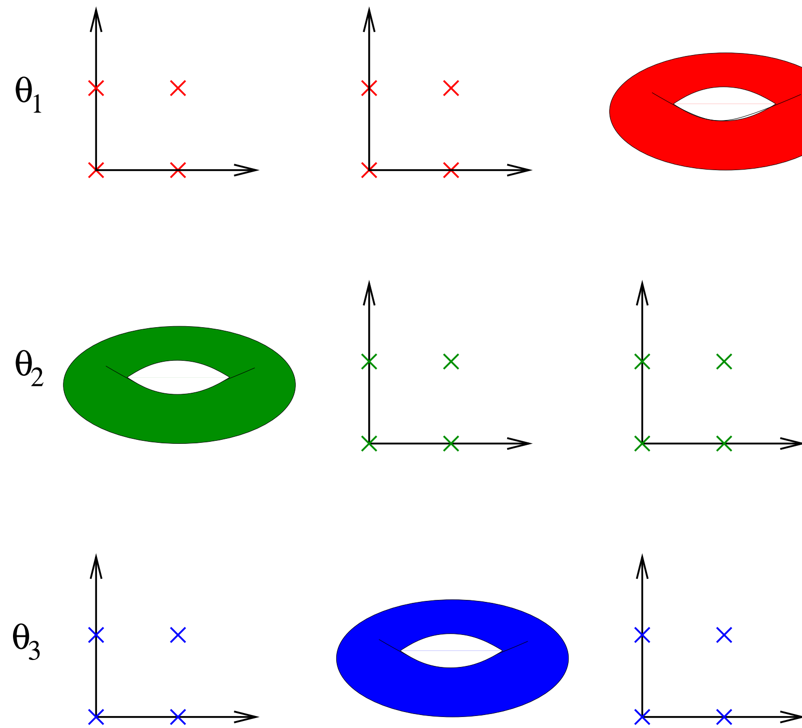
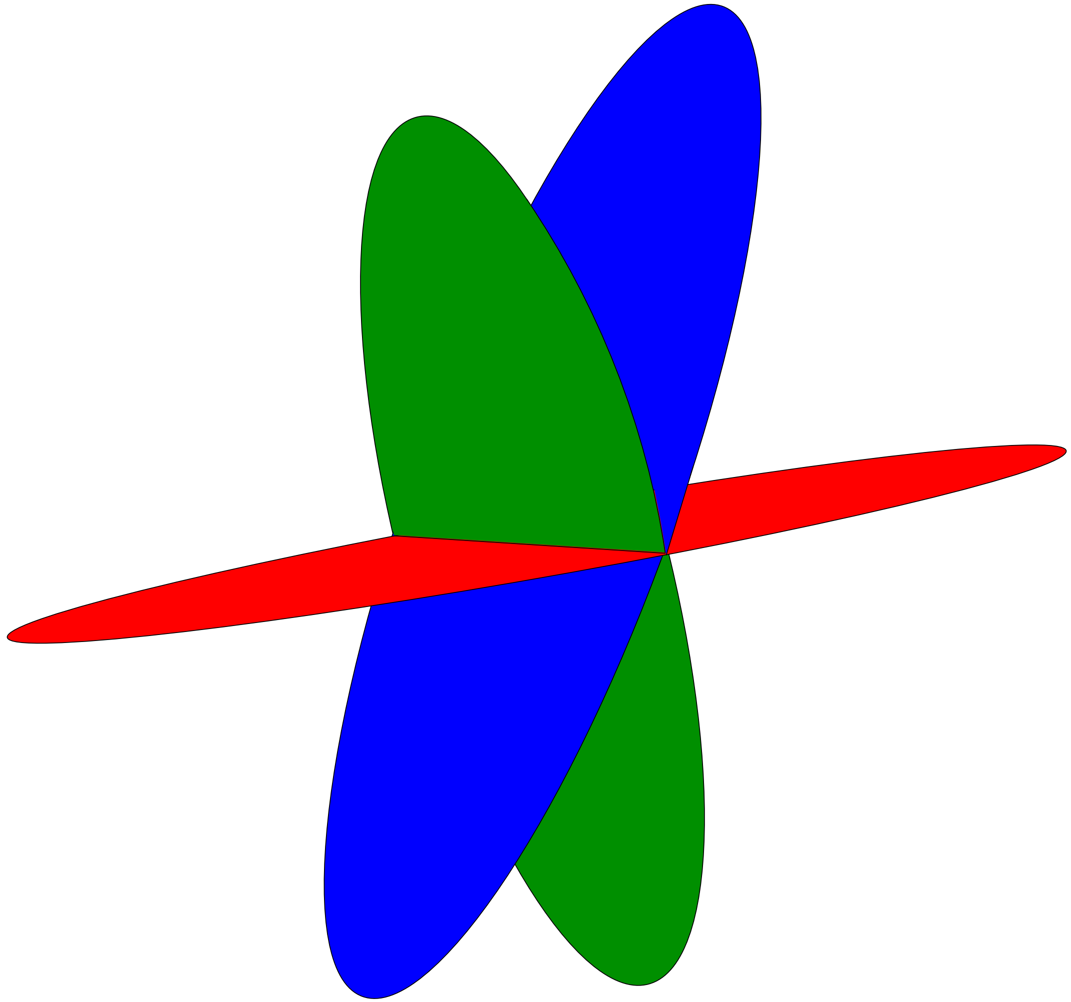


3 twisted sectors (with 16 fixed tori in each) lead to a geometrical picture of ....

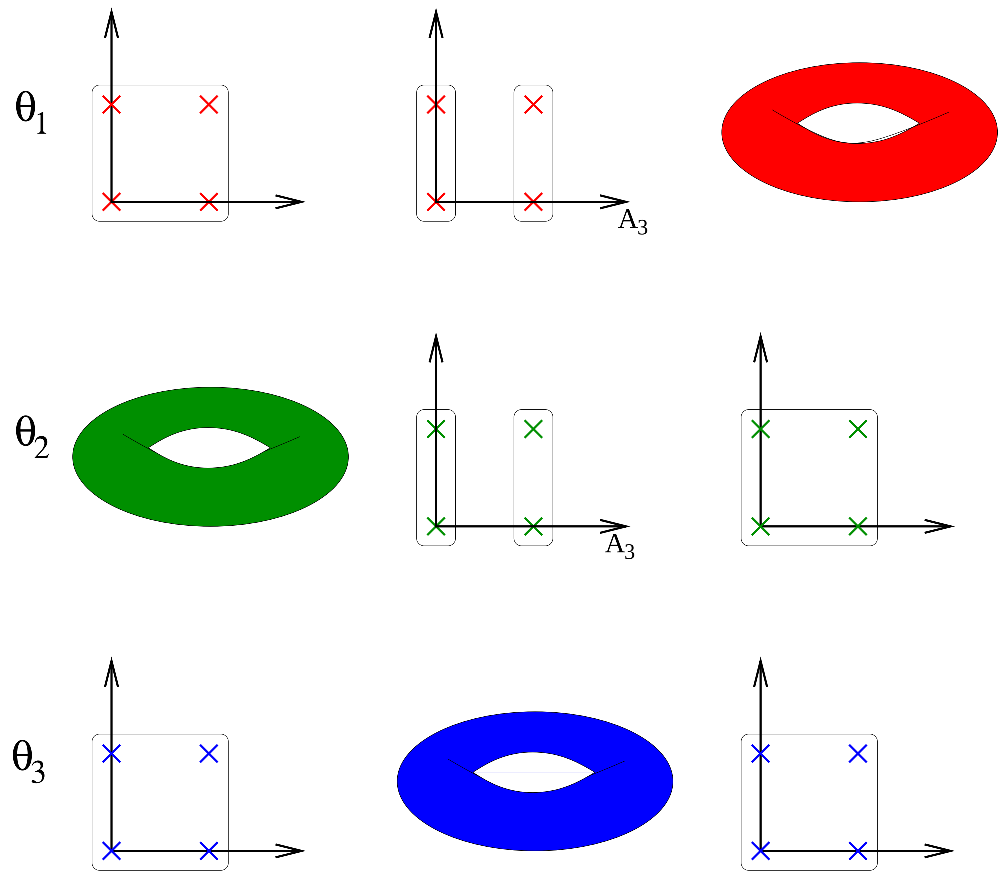
Intersecting Branes



$\mathbb{Z}_2 \times \mathbb{Z}_2$ classification

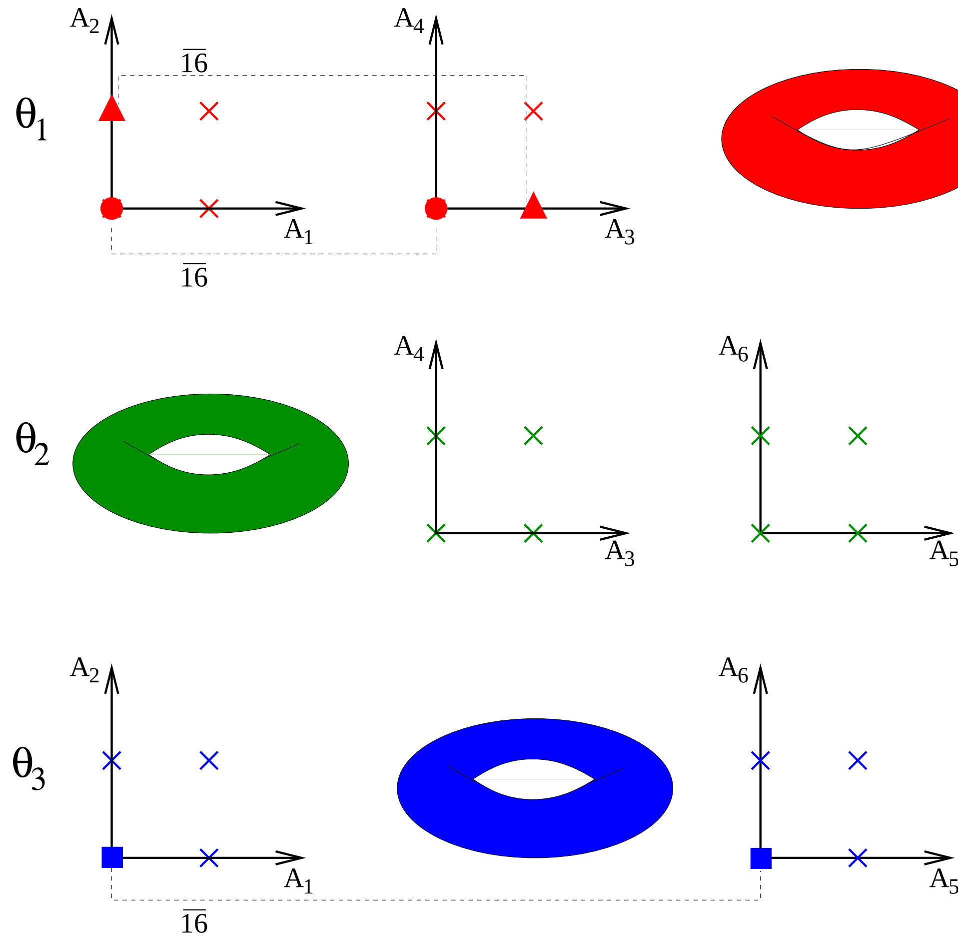
Case	Shifts	Gauge Group	Gen.
1	$\left(\frac{1}{2}, -\frac{1}{2}, 0^6\right)\ \left(0^8\right)$ $\left(0, \frac{1}{2}, -\frac{1}{2}, 0^5\right)\ \left(0^8\right)$	$E_6 \times U(1)^2 \times E_8'$	48
2	$\left(\frac{1}{2}, -\frac{1}{2}, 0^6\right)\ \left(0^8\right)$ $\left(0, \frac{1}{2}, -\frac{1}{2}, 0^4, 1\right)\ \left(1, 0^7\right)$	$E_6 \times U(1)^2 \times SO(16)'$	16
3	$\left({\frac{1}{2}}^2, 0^6\right)\ \left(0^8\right)$ $\left(\frac{5}{4}, {\frac{1}{4}}^7\right)\ \left(\frac{1}{2}, \frac{1}{2}, 0^6\right)$	$SU(8) \times U(1) \times E_7' \times SU(2)'$	16
4	$\left({\frac{1}{2}}^2, 0^5, 1\right)\ \left(1, 0^7\right)$ $\left(0, \frac{1}{2}, -\frac{1}{2}, 0^5\right)\ \left(-\frac{1}{2}, {\frac{1}{2}}^3, 1, 0^3\right)$	$E_6 \times U(1)^2 \times SO(8)'^2$	0
5	$\left(\frac{1}{2}, -\frac{1}{2}, -1, 0^5\right)\ \left(1, 0^7\right)$ $\left(\frac{5}{4}, {\frac{1}{4}}^7\right)\ \left(\frac{1}{2}, \frac{1}{2}, 0^6\right)$	$SU(8) \times U(1) \times SO(12)' \times SU(2)'^2$	0

$\mathbb{Z}_2 \times \mathbb{Z}_2$ with Wilson lines



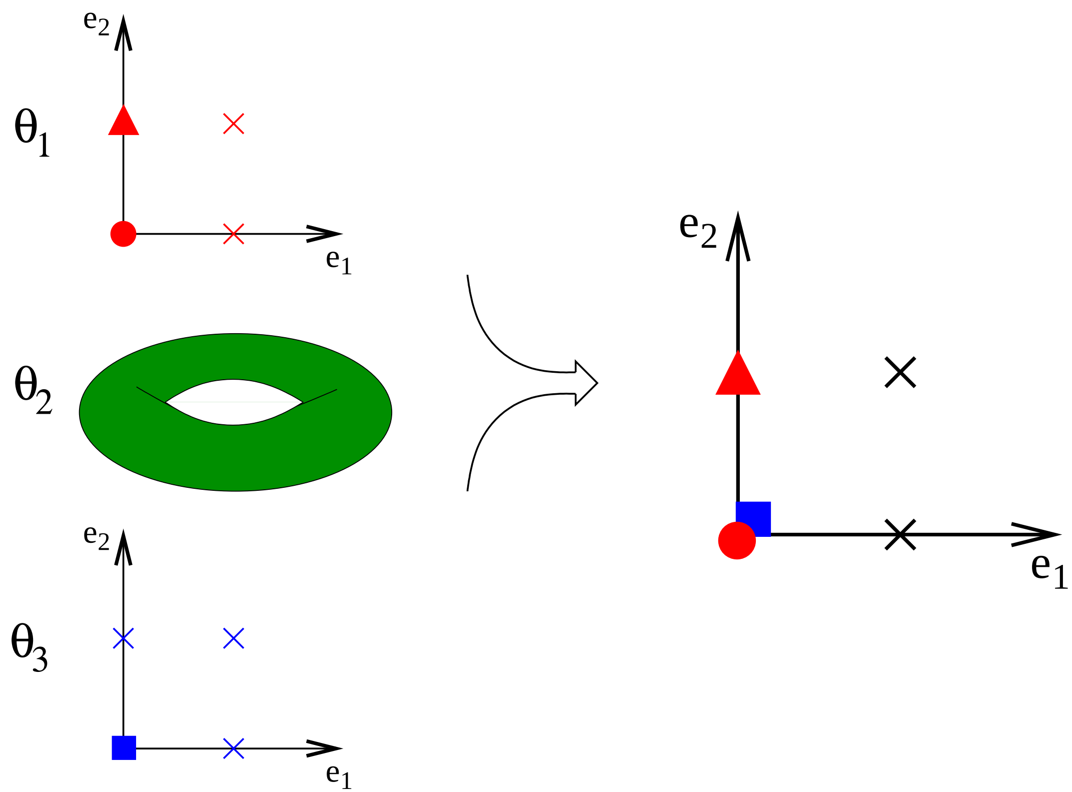
Again, Wilson lines can lift the degeneracy....

Three family $SO(10)$ toy model



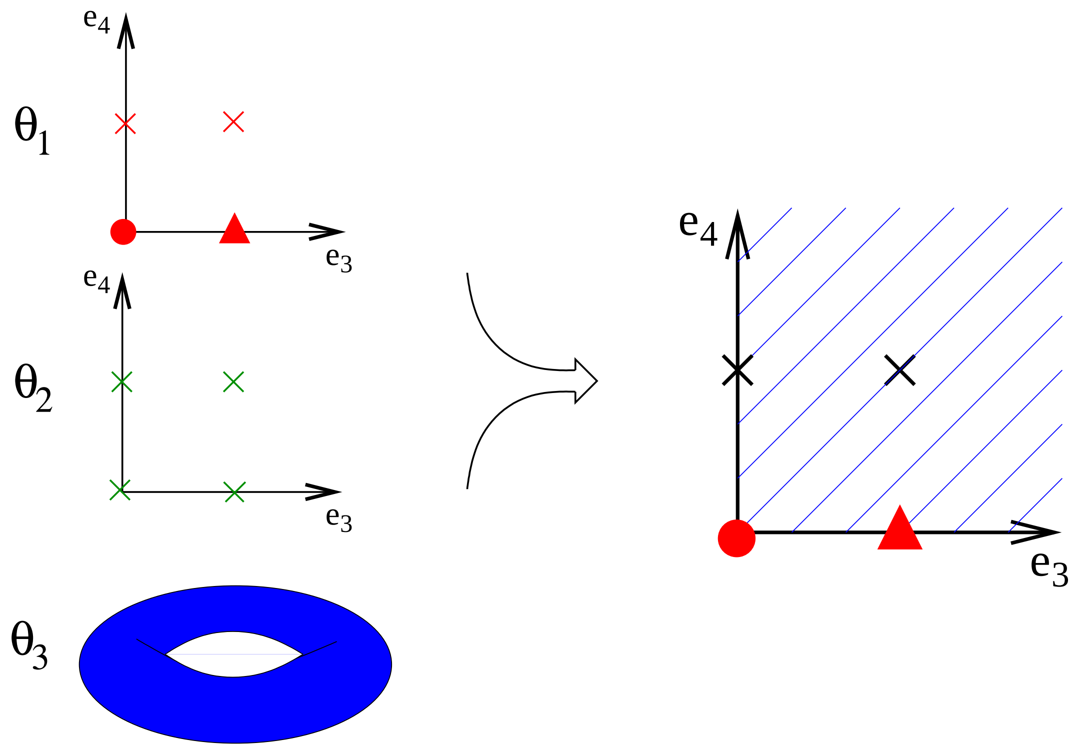
Localization of families at various fixed tori

Zoom on first torus ...



Interpretation as 6-dim. model with 3 families on branes

second torus ...



... 2 families on branes, one in (6d) bulk ...

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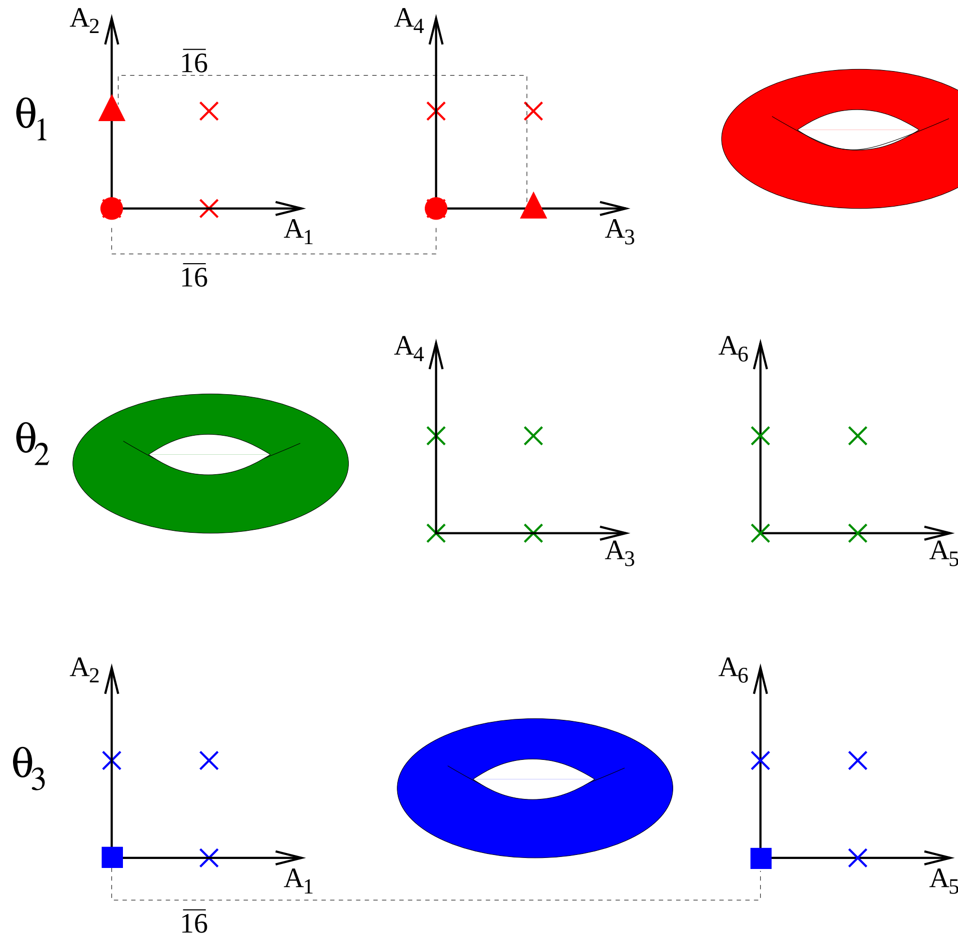

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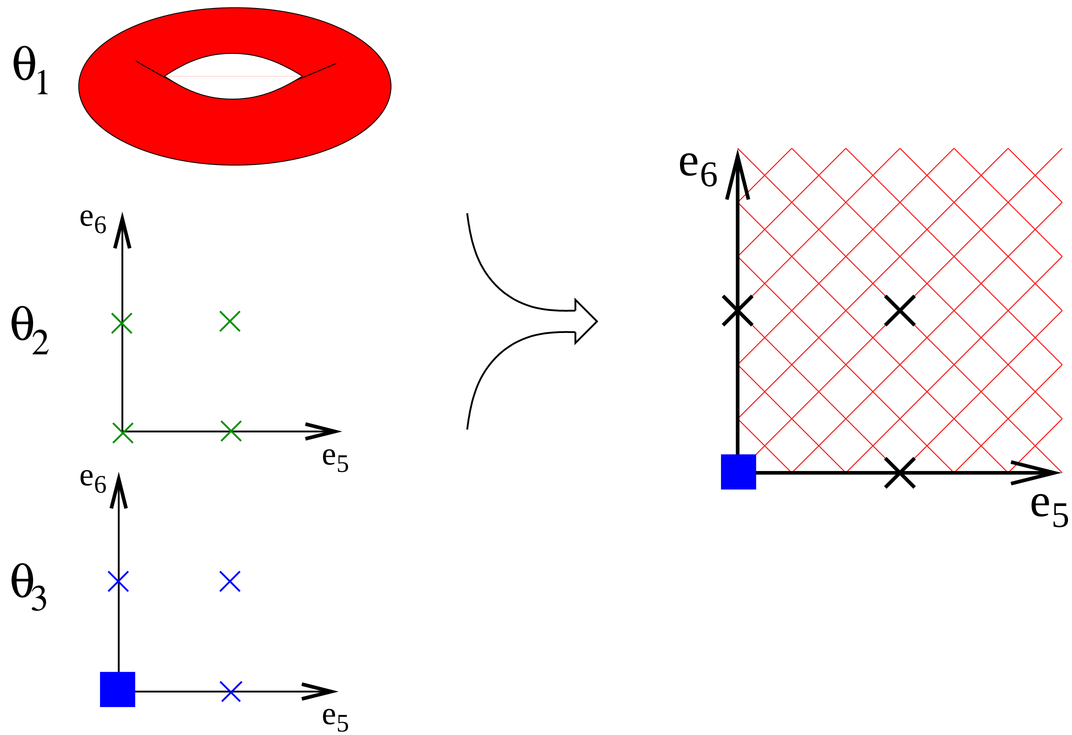

... 1 family on brane, two in (6d) bulk.

Geography

Many properties of the models depend on the geography of extra dimensions, such as

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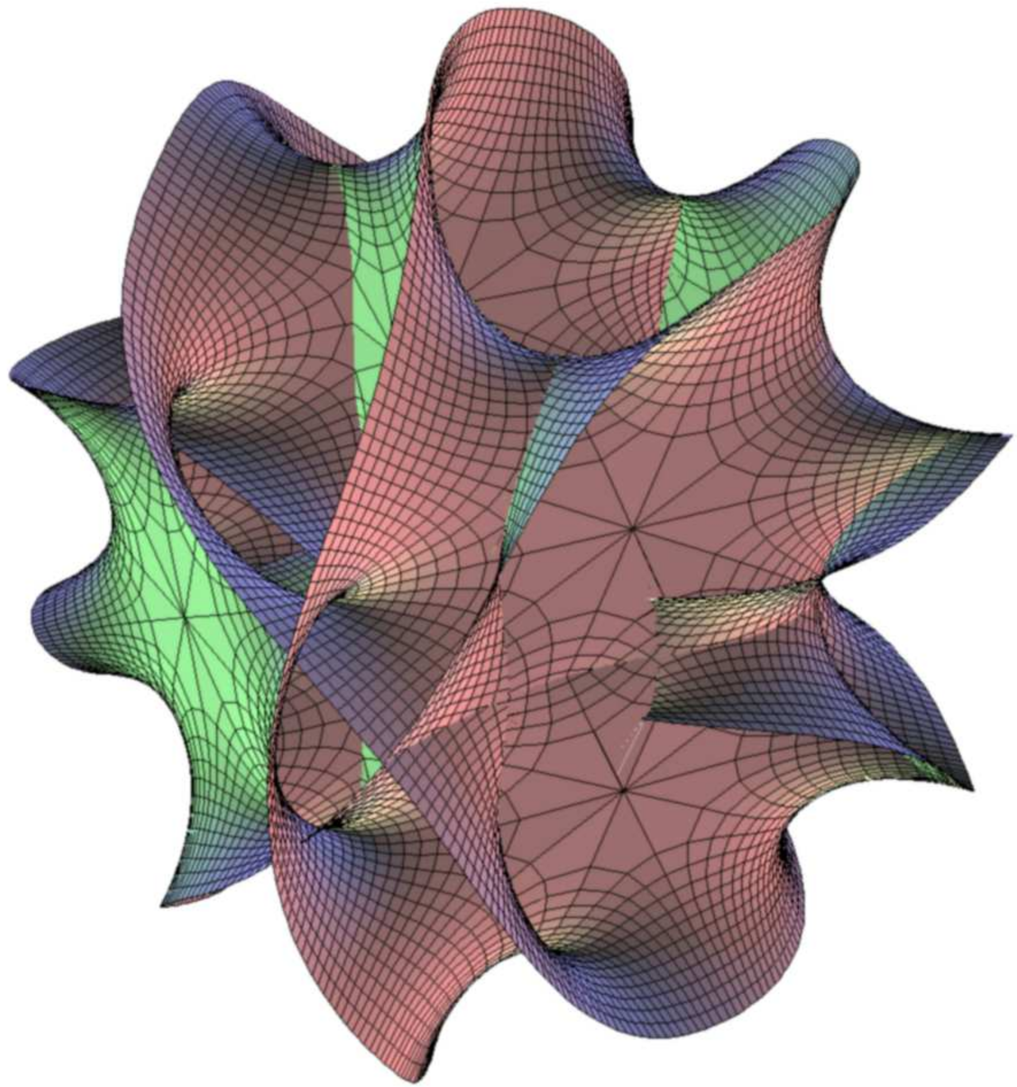
but there is also a “localization” of gauge fields

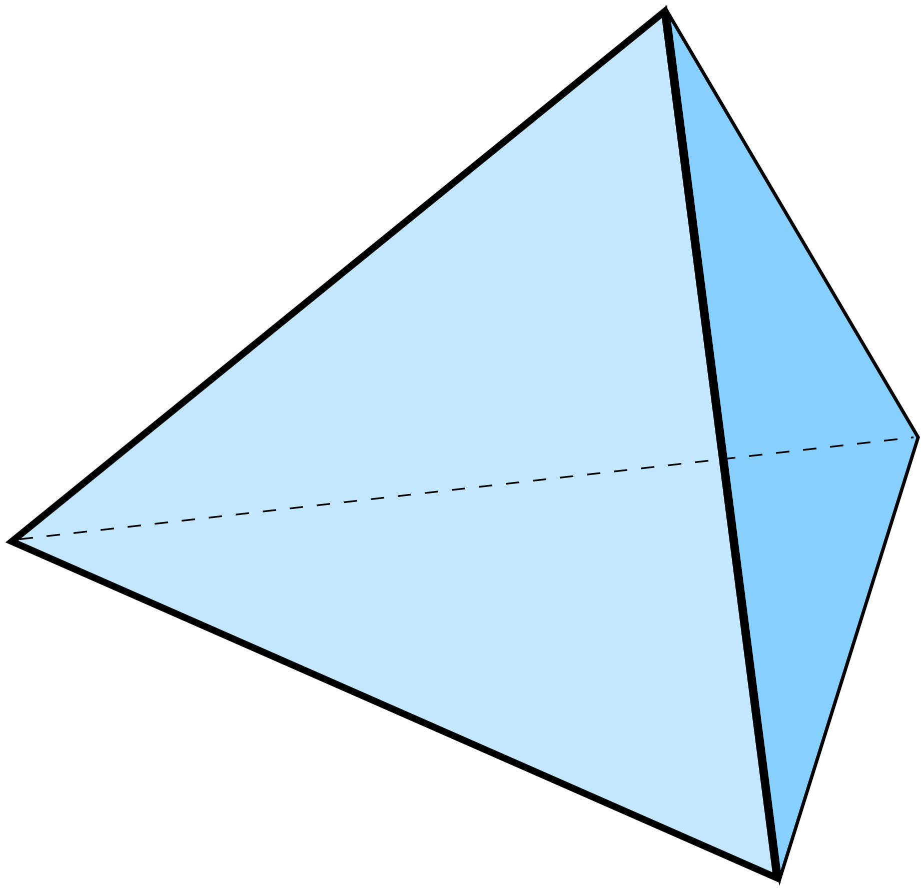
- $E_8 \times E_8$ in the bulk
- smaller gauge groups on various branes

Observed 4-dimensional gauge group is common subroup of the various localized gauge groups!

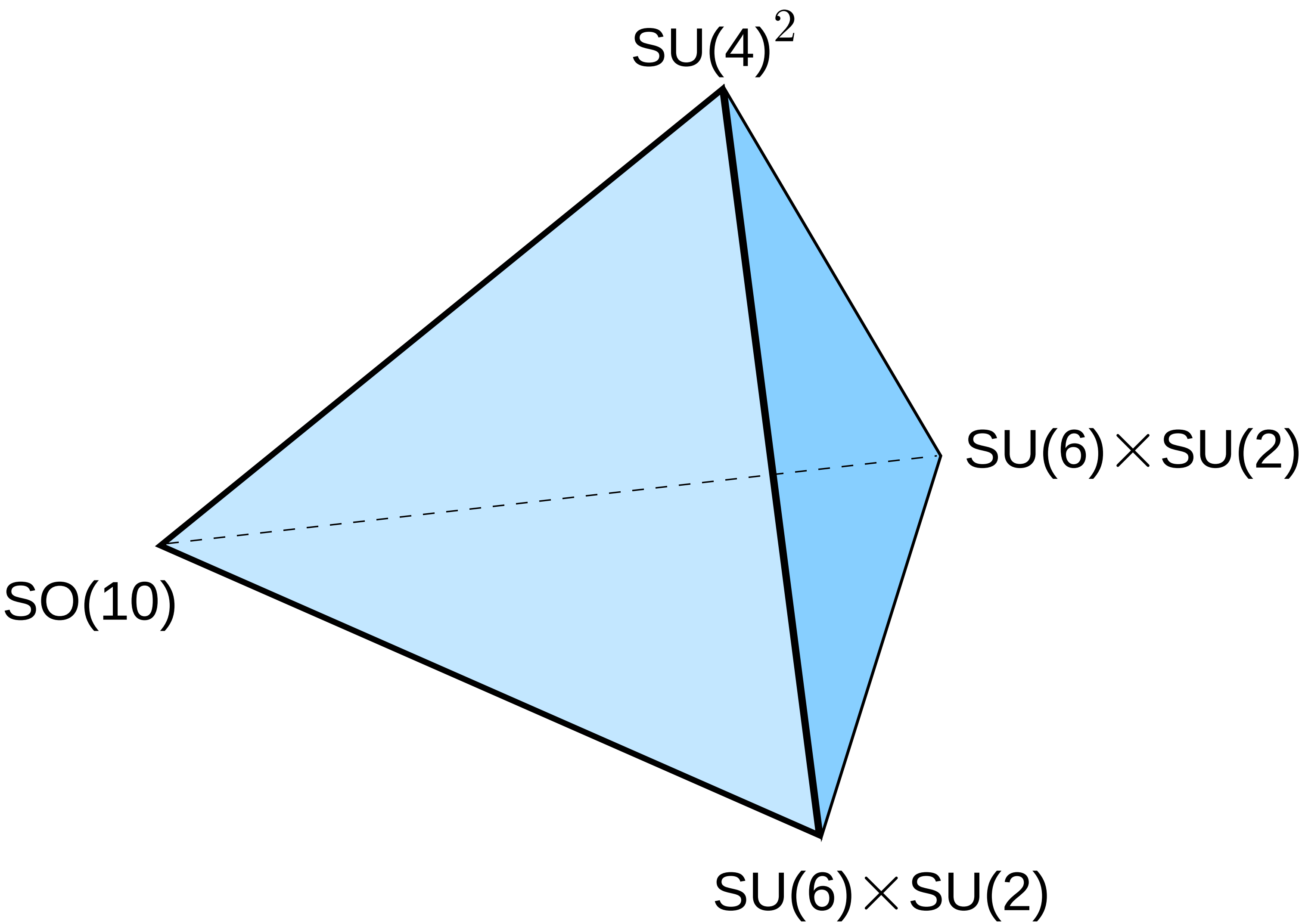
Calabi Yau Manifold



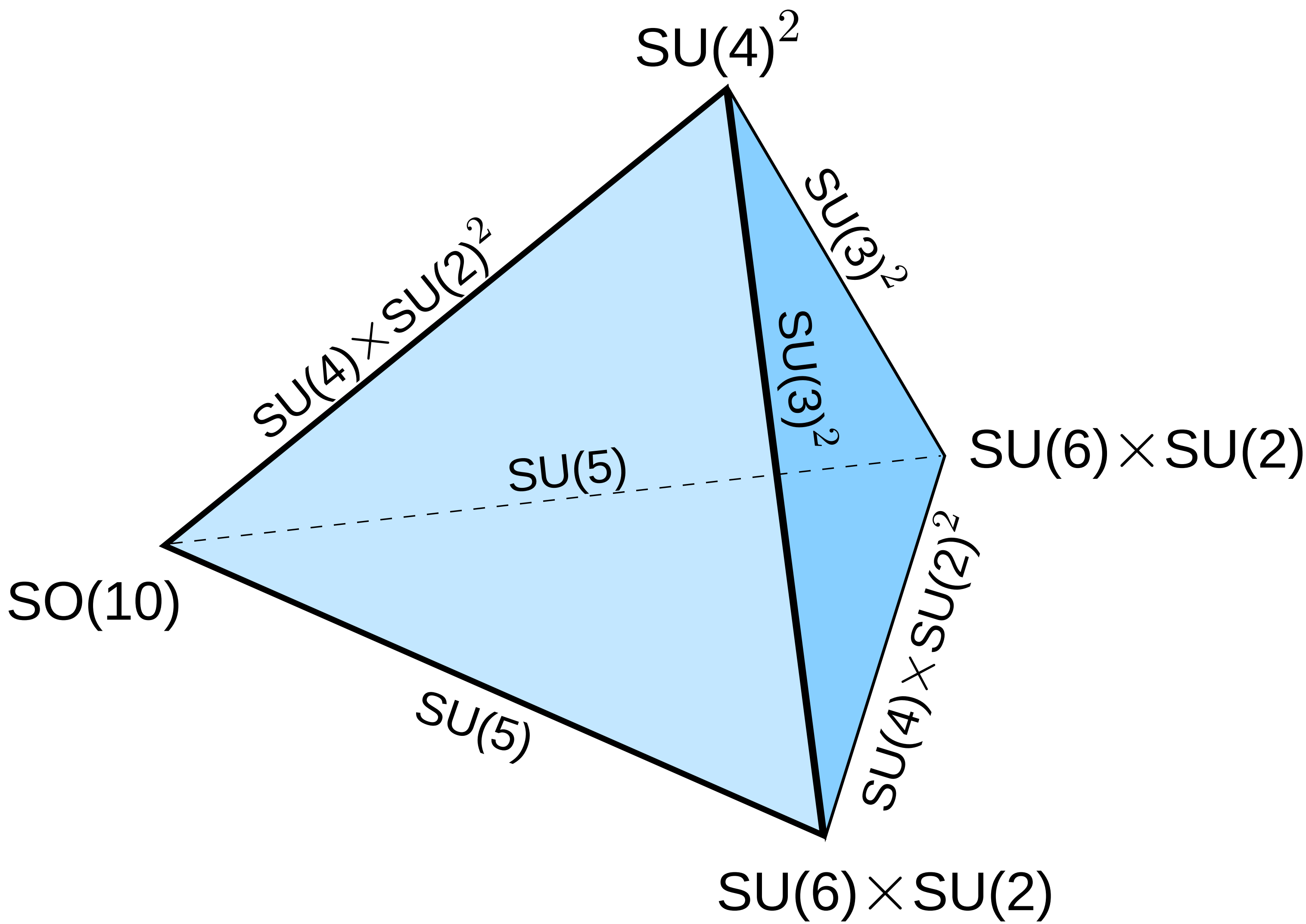
Orbifold



Localized gauge symmetries



Standard Model Gauge Group



Model building

We can easily find

- models with gauge group $SU(3) \times SU(2) \times U(1)$
- 3 families of quarks and leptons
- doublet-triplet splitting
- $N = 1$ supersymmetry (Förste, HPN, Vaudrevange, Wingerter, 2004)

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But explicit model building is tedious:

- removal of exotic states
- R parity
- “correct” hypercharge

Model building (II)

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Key properties of the models depend on geometry:

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- texture of Yukawa couplings
- number of families
- local gauge groups on branes
- electroweak symmetry breakdown

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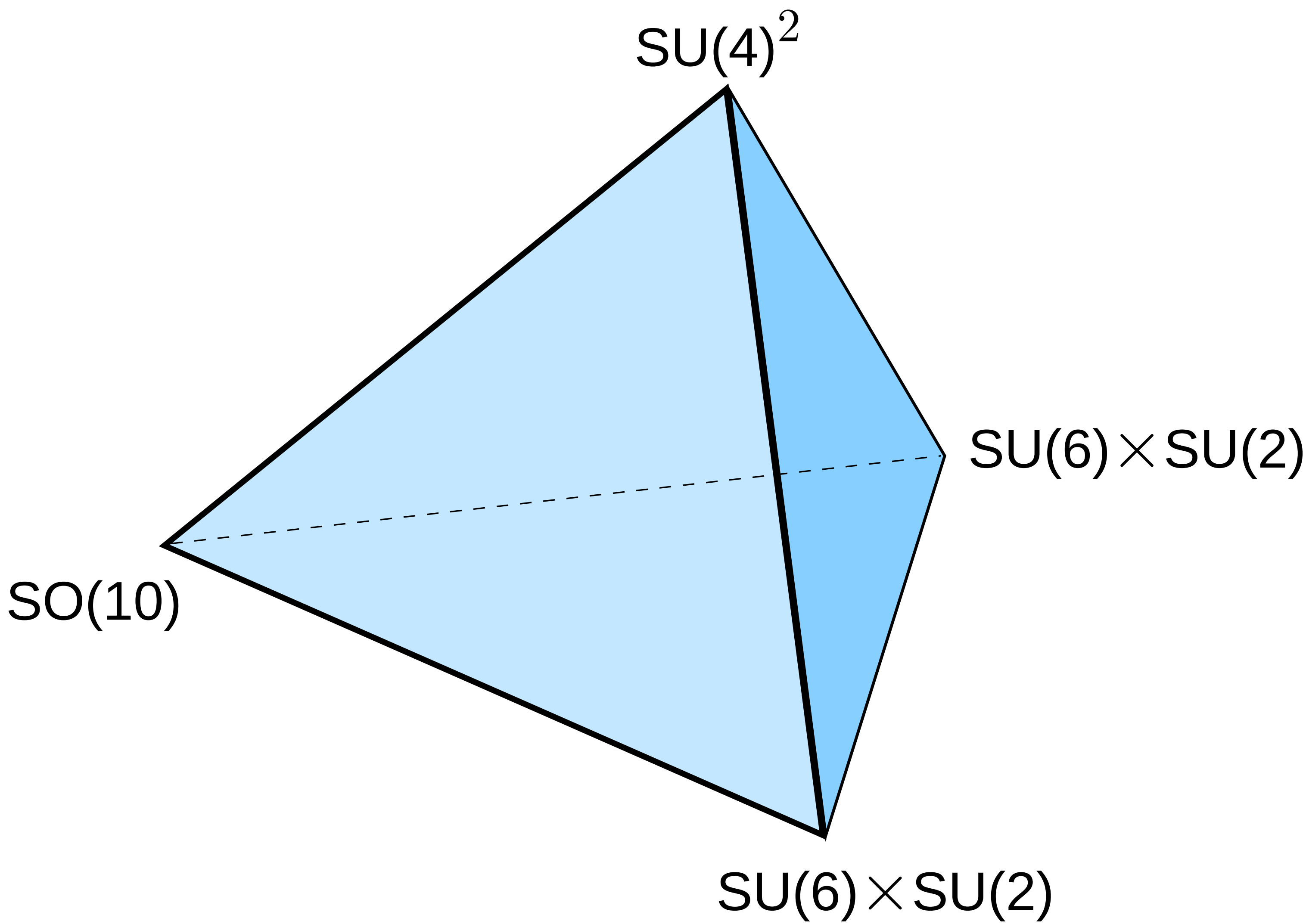
We need to exploit these geometric properties......

Localized gauge symmetries



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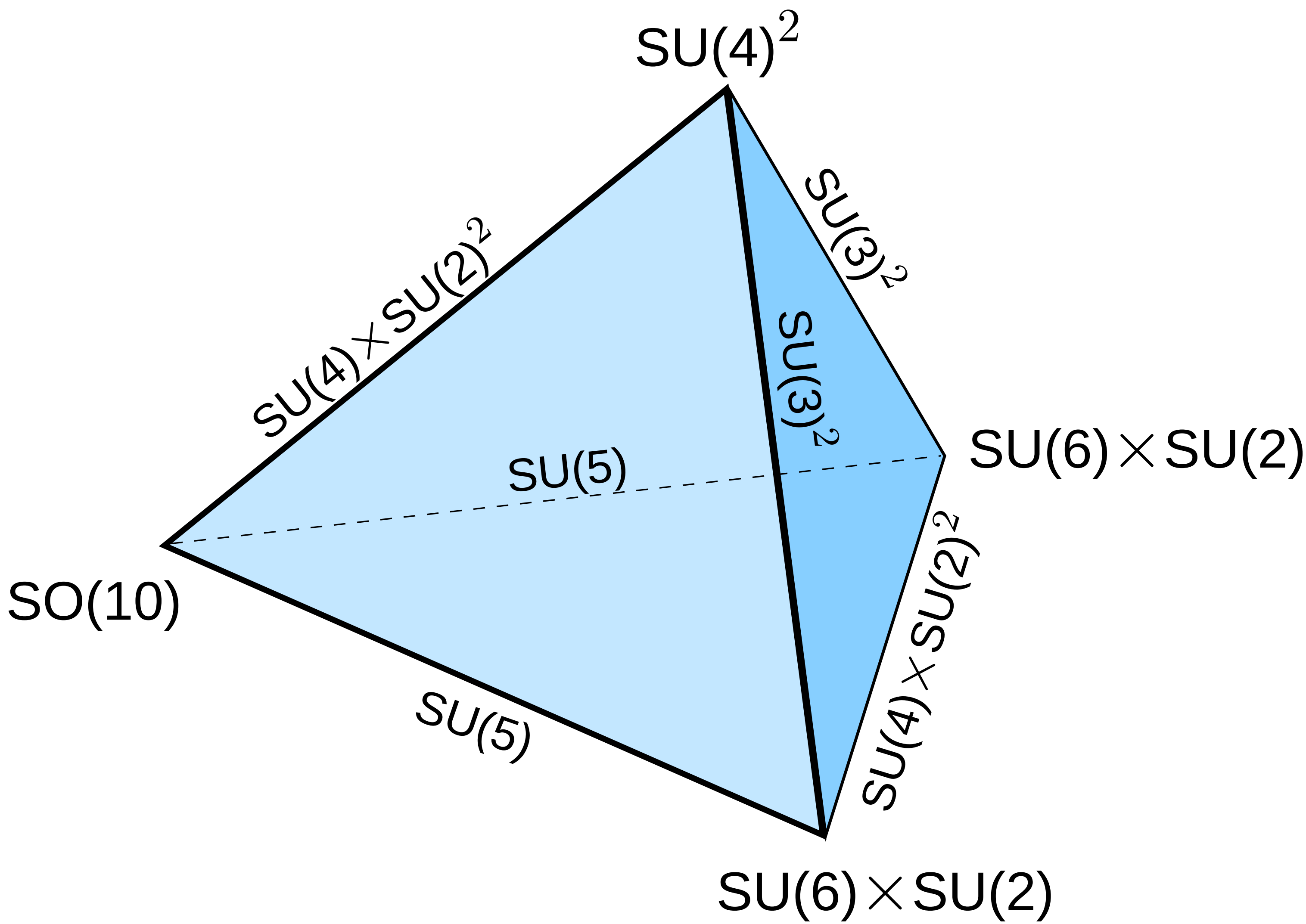

Local Grand Unification

In fact string theory gives us a variant of GUTs

- complete multiplets for fermion families
- split multiplets for gauge- and Higgs-bosons
- partial Yukawa unification

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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 GUTs, can be realized in the framework of the "heterotic braneworld".

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

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- $SO(10)$ is realized in the higher dimensional theory
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There could still be remnants of $SO(10)$ symmetry

- 16 of SO(10) at some branes
- correct hypercharge normalization
- R-parity
- family symmetries

that are very useful for realistic model building ...

Proton decay

- R-parity from SO(10) memory could avoid dangerous dimension-4 operators

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There are lots of opportunities,

but there is a strong model dependence

Unification

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- Yukawa couplings depend on location of Higgs and matter fields
- family symmetries arise if different fields live on the same brane
- Exponential suppression if fields at distant branes
- family symmetries might also arise if there is a symmetry between various fixed point locations
- GUT relations could be partially present, depending on the nature of the brane (e.g. SO(10) brane)

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Full classification seems to be too difficult (at the moment).
Work in progress:

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- $Z_2 \times Z_3$ standard model

(Buchmüller, Hamaguchi, Lebedev, Ratz, 2005)

The Higgs-mechanism in string theory...

...can be achieved via continuous Wilson lines. The aim is:

- electroweak symmetry breakdown
- breakdown of Trinification or Pati-Salam group to the Standard Model gauge group
- rank reduction

Continuous Wilson lines require specific embeddings of twist in the gauge group

(Ibanez, HPN, Quevedo, 1987)

- difficult to implement in the Z_3 case
- more promising for Z_2 twists

An example

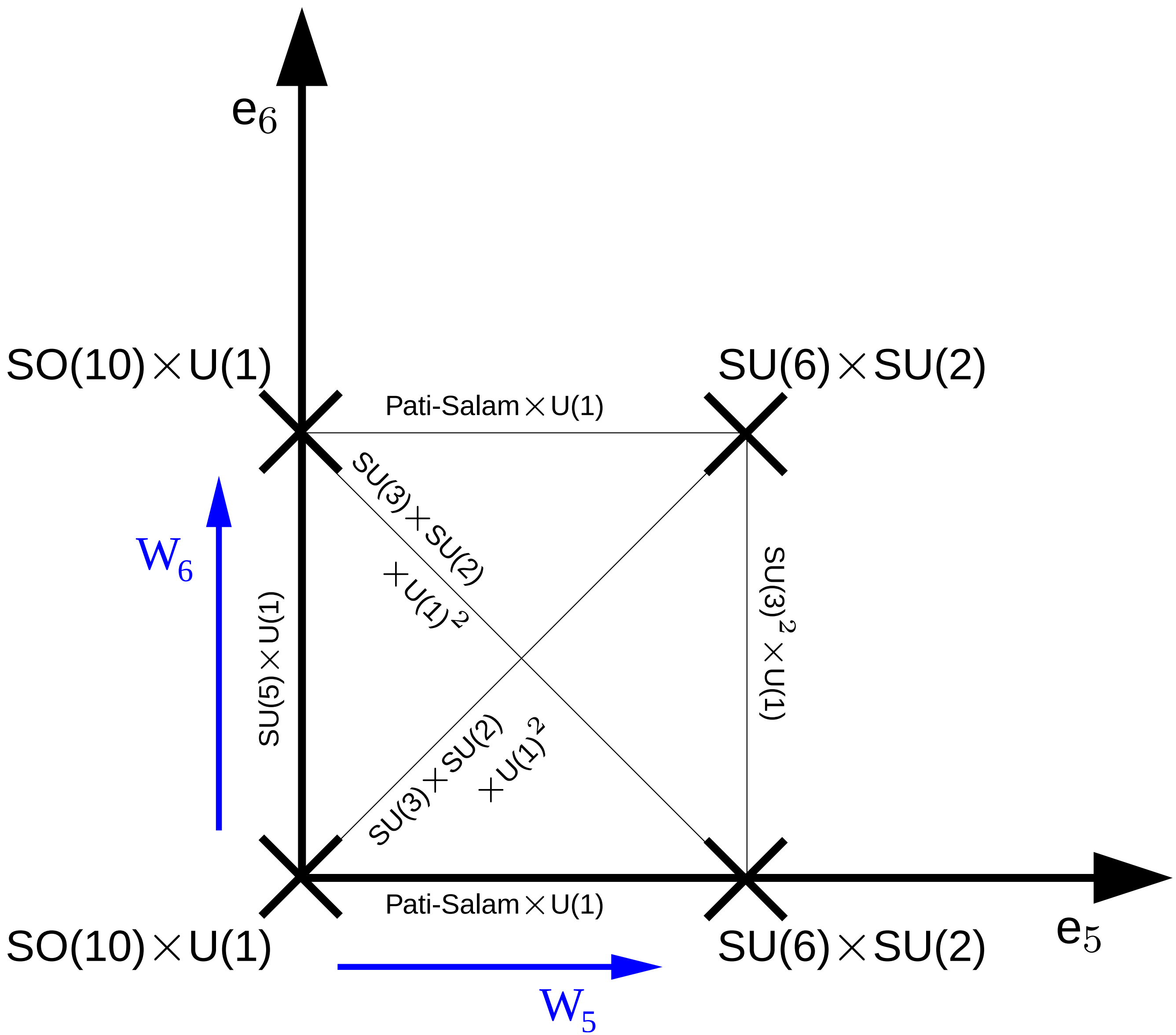
We consider a model that has E_6 gauge group in the bulk of a "6d orbifold". The breakdown pattern is

- $E_6 \to SO(10)$ via a Z_2 twist
- $SO(10) \to SU(4) \times SU(2) \times SU(2) \times U(1)$ via a discrete (quantized) Wilson line
- $SU(4) \times SU(2) \times SU(2) \to SU(3) \times SU(2) \times SU(2) \times U(1)$ via a continuous Wilson line (Förste, HPN, Wingerter, 2005)

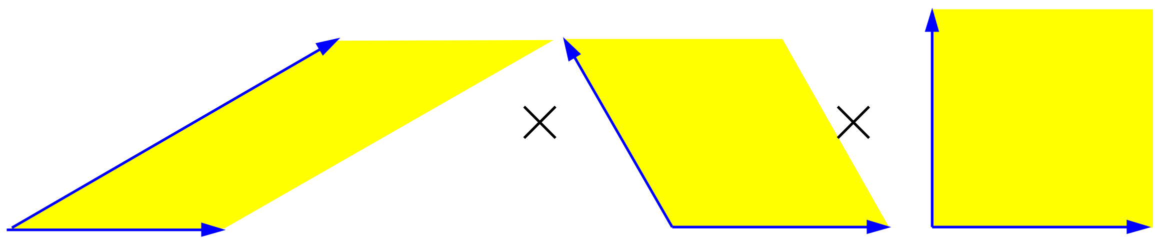
Such 6d models can be embedded in 10d string theory orbifolds. Models with consistent electroweak symmetry breakdown have been constructed.

(Förste, HPN, Wingerter, 2006)

Pati-Salam breakdown



Benchmark Scenario: Z_6 II orbifold



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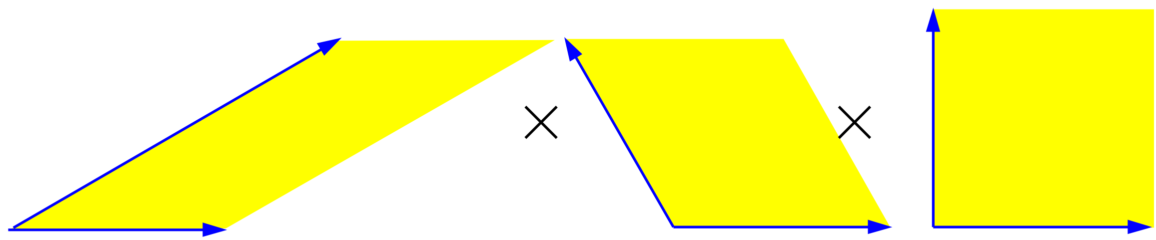

(Kobayashi, Raby, Zhang, 2004; Buchmüller, Hamaguchi, Lebedev, Ratz, 2004)

- provides fixed points and fixed tori
- allows for 61 different shifts out of which 2 lead to $SO(10)$ gauge group
- allows for localized 16-plets for 2 families
- $SO(10)$ broken via Wilson lines
- nontrivial hidden sector gauge group

Selection Strategy

criterion	$V^{\mathrm{SO}(10),1}$	$V^{\mathrm{SO}(10),2}$
models with 2 Wilson lines	$22,000$	$7,800$
SM gauge group $\subset$ SO(10)	3563	1163
3 net $(\mathbf{3},\mathbf{2})$	1170	492
non–anomalous $\mathrm{U}(1)_Y \subset \mathrm{SU}(5)$	528	234
3 generations $+$ vector-like	128	90

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

Decoupling of exotics

requires extensive technical work:

- analysis of Yukawa couplings $S^n E \bar{E}$
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Requirement of D-flatness

- vevs of S should not break supersymmetry
- anomalous U(1) and Fayet-Iliopoulos terms
- checking D-flatness with method of gauge invariant monomials

MSSM candidates

criterion	$V^{\mathrm{SO}(10),1}$	$V^{\mathrm{SO}(10),2}$
SM gauge group $\subset$ SO(10)	3563	1163
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3 generations $+$ vector-like	128	90
exotics decouple	106	85
D-flat solutions	105	85

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

The road to the MSSM

The benchmark scenario leads to

- 200 models with the exact spectrum of the MSSM (absence of chiral exotics)
- local grand unification (by construction)
- gauge- and (partial) Yukawa unification

(Raby, Wingerter, 2007)

- examples of neutrino see-saw mechanism

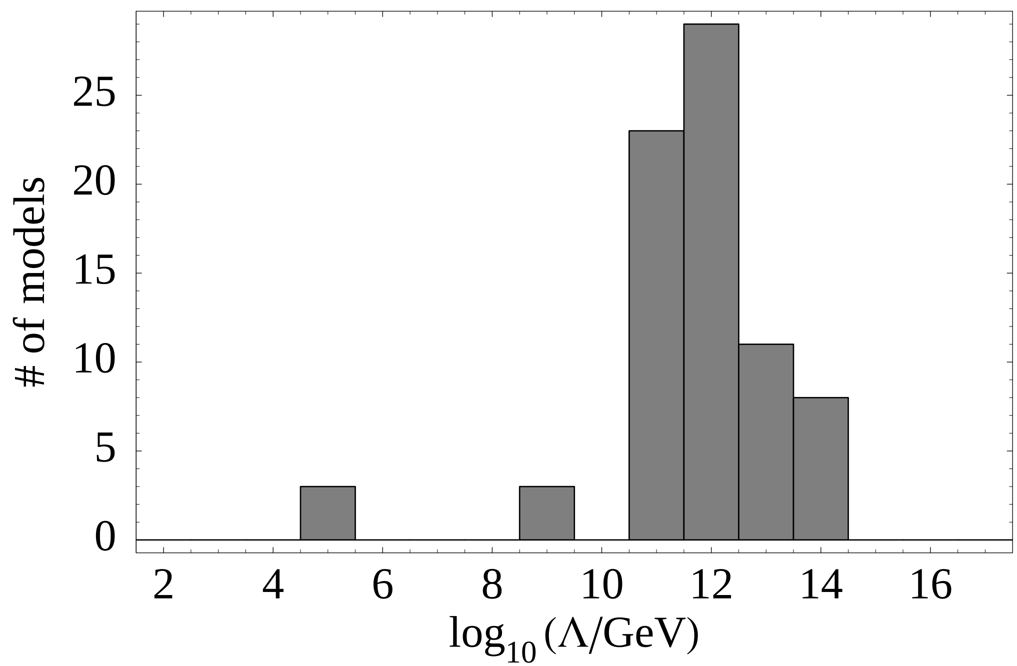
(Buchmüller, Hamguchi, Lebedev, Ramos-Sanchez, Ratz, 2007)

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

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

- hidden sector gaugino condensation

Hidden Sector Susy Breakdown



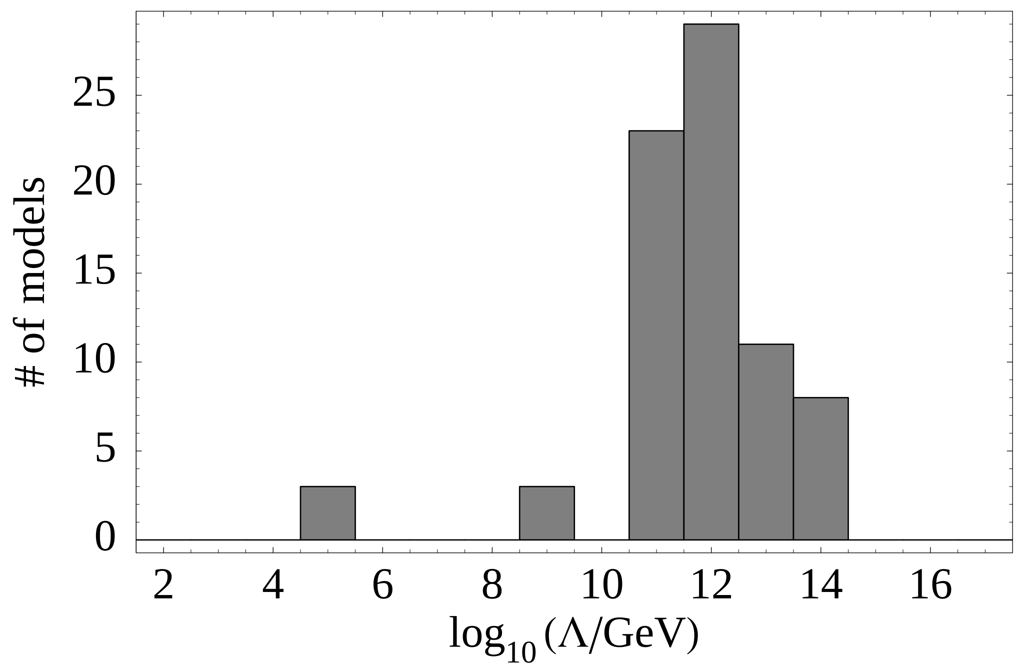
$m_{3/2} = \Lambda^3 / M^2_{\text{Planck}}$ (with $\Lambda = \mu \exp(-1/g^2_{\text{hidden}}(\mu))$)
from hidden sector gaugino condensation

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

Comparison to TypeII braneworld

- strategy based on geometrical intuition is successful
- properties of models can trace back the geometry of extra dimensions
- heterotic versus Type II braneworld
  - bulk gauge group
  - complete chiral multiplets
  - chiral exotics
  - R-parity (B-L and seesaw mechanism)
- localization of fields at various “corners” of Calabi-Yau manifold
- remnants of Grand Unification indicate that we live in a special place of the compactified extra dimensions!

Hidden Sector Susy Breakdown



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Basic Questions

- origin of the small scale?
- stabilization of moduli?
- adjustment of vacuum energy?

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Recent progress in

- moduli stabilization via fluxes in warped compactifications of Type IIB string theory

  (Dasgupta, Rajesh, Sethi, 1999; Giddings, Kachru, Polchinski, 2001)

- generalized flux compactifications of heterotic string theory

  (Becker, Becker, Dasgupta, Prokushkin, 2003; Gurrieri, Lukas, Micu, 2004)

Fluxes and gaugino condensation

Is there a general pattern of the soft mass terms?

We have (from "flux" and gaugino condensate)

$$W = \text{something} - \exp(-X)$$

where "something" is small and X is moderately large.

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where "something" is small and X is moderately large.

In fact in this simple scheme

$$X \sim \log(M_{\text{Planck}}/m_{3/2})$$

providing a "little" hierarchy.

(Choi, Falkowski, HPN, Olechowski, Pokorski, 2004)

Mixed Modulus Anomaly Mediation

The universal contribution from "Modulus Mediation" is therefore suppressed by the factor

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Numerically this factor is given by: $X \sim 4\pi^2.$

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Thus contributions from radiative corrections such as "Anomaly Mediation" become competitive, leading to a Mixed Modulus-Anomaly-Mediation scheme.

For reasons that will be explained later we call this scheme

MIRAGE MEDIATION

(Loaiza, Martin, HPN, Ratz, 2005)

The little hierarchy

$$m_X \sim \langle X \rangle m_{3/2} \sim \langle X \rangle^2 m_{\rm soft}$$

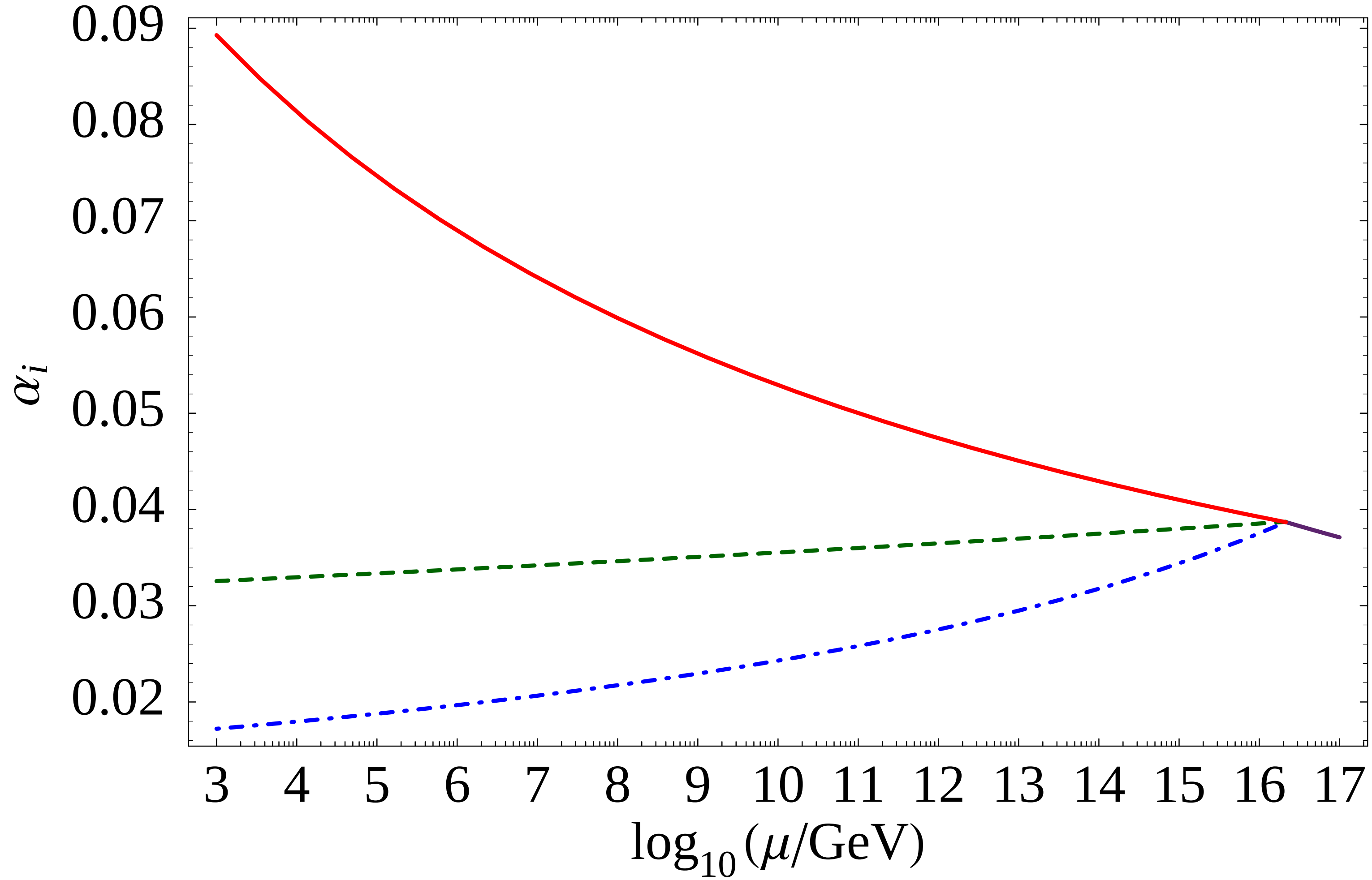
is a generic signal of such a scheme

- moduli and gravitino are heavy
- gaugino mass spectrum is compressed

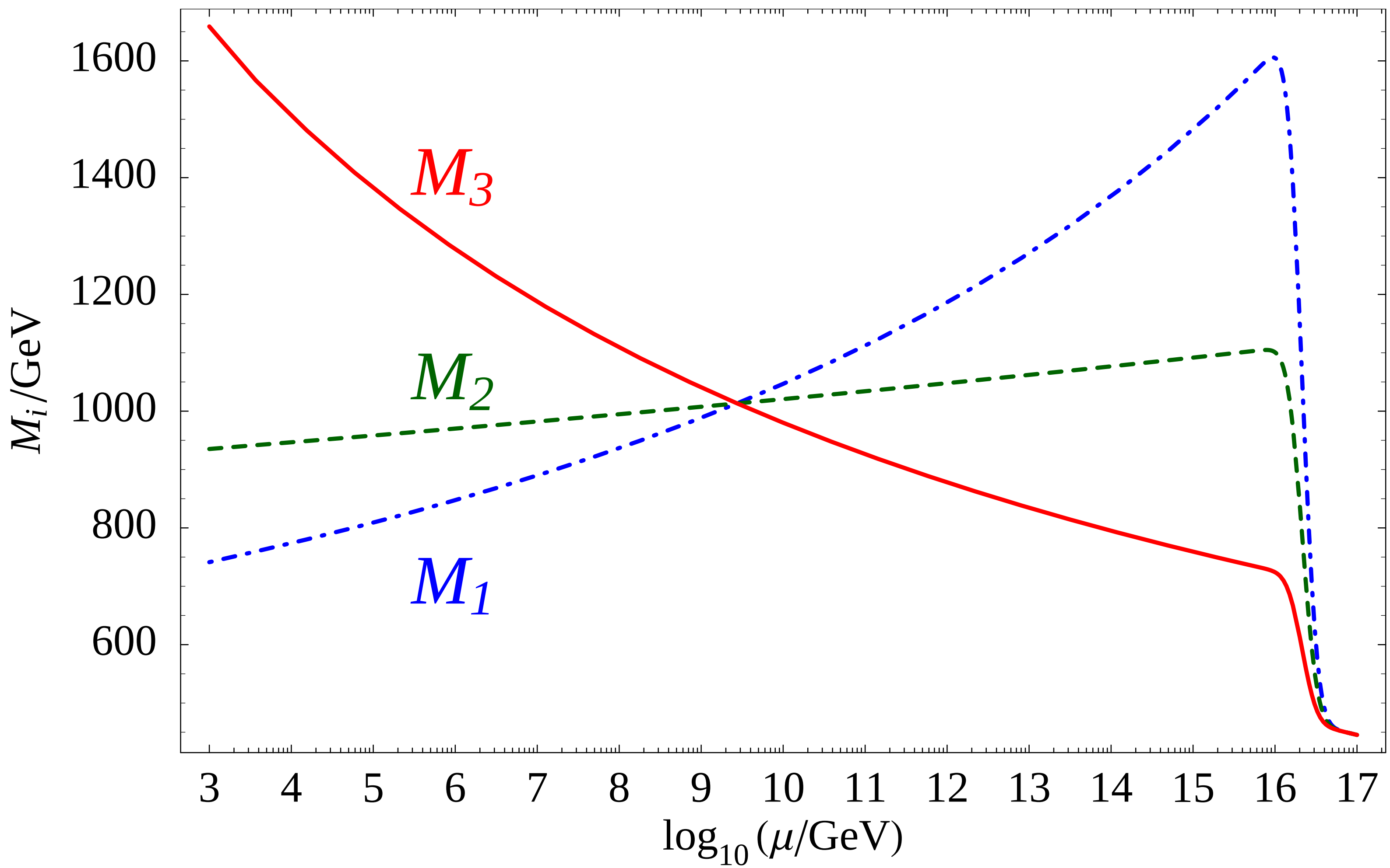
- mirage unification of gaugino masses

(Choi, Falkowski, HPN, Olechowski, 2005; Endo, Yamaguchi, Yoshioka, 2005; Choi, Jeong, Okumura, 2005)

Evolution of couplings



The Mirage Scale



Mirage Unification

Mirage Mediation provides a

- characteristic pattern of soft breaking terms.

To see this, let us consider the gaugino masses

$$M_{1/2} = M_{\rm modulus} + M_{\rm anomaly}$$

as a sum of two contributions of comparable size.

- $M_{\rm anomaly}$ is proportional to the β function, i.e. negative for the gluino, positive for the bino
- thus $M_{\rm anomaly}$ is non-universal below the GUT scale

The Mirage Scale (II)

The gaugino masses coincide

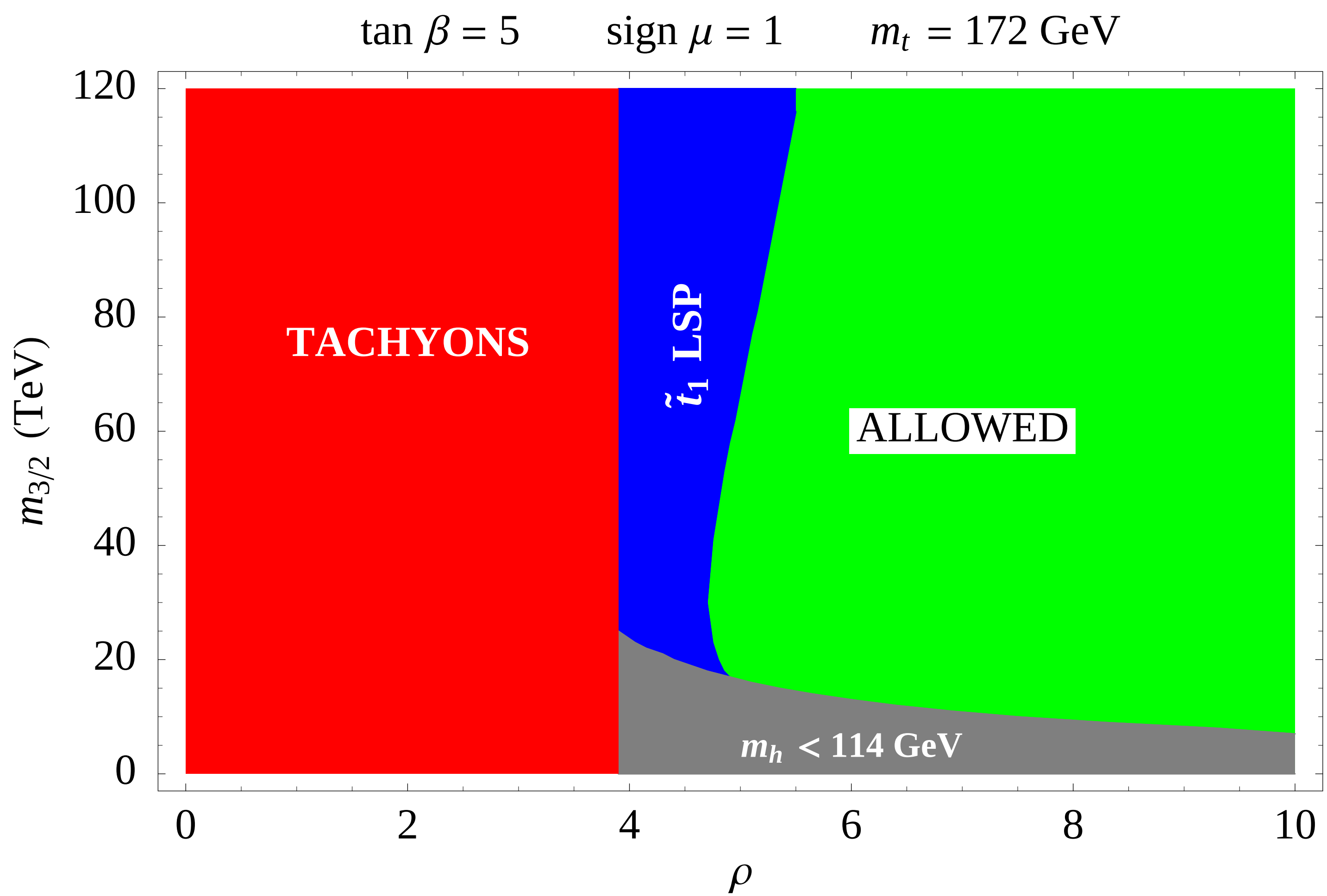
- above the GUT scale
- at the mirage scale $\mu_{\text{mirage}} = M_{\text{GUT}} \exp(-8\pi^2/\rho)$

where ρ denotes the “ratio” of the contribution of modulus vs. anomaly mediation. We write the gaugino masses as

$$M_a = M_s(\rho + b_a g_a^2) = \frac{m_{3/2}}{16\pi^2}(\rho + b_a g_a^2)$$

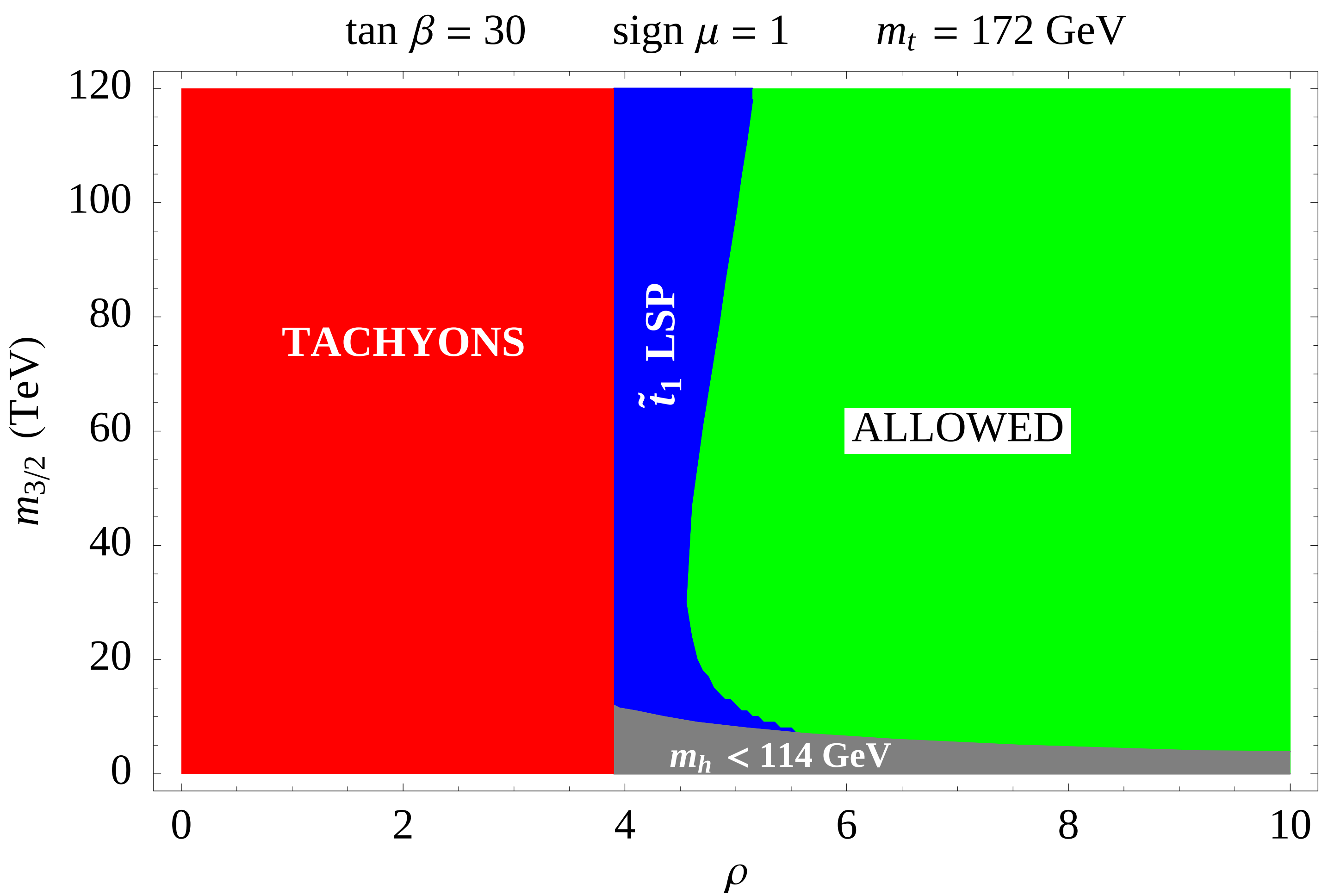
and $\rho \to 0$ corresponds to pure anomaly mediation.

Constraints on the mixing parameter



(Löwen, HPN, Ratz, 2006)

Constraints on ρ



(Löwen, HPN, Ratz, 2006)

The "MSSM hierarchy problem"

The scheme predicts a rather high mass scale

- heavy gravitino
- rather high mass for the LSP-Neutralino

One might worry about a fine-tuning to obtain

- the mass of the weak scale around 100 GeV from

$$\frac{m_Z^2}{2} = -\mu^2 + \frac{m_{H_d}^2 - m_{H_u}^2 \tan^2\beta}{\tan^2\beta - 1},$$

and there are large corrections to $m_{H_u}^2$......

(Choi, Jeong, Kobayashi, Okumura, 2005)

The "MSSM hierarchy problem"?

The influence of the various soft terms is given by

$$m_Z^2 \simeq -1.8\,\mu^2 + 5.9\,M_3^2 - 0.4\,M_2^2 - 1.2\,m_{H_u}^2 + 0.9\,m_{q_L^{(3)}}^2 + $$
$$+ 0.7\,m_{u_R^{(3)}}^2 - 0.6\,A_t\,M_3 + 0.4\,M_2\,M_3 + \dots\ ,$$

Mirage mediation improves the situation

- especially for small ρ
- because of a reduced gluino mass and a "compressed" spectrum of supersymmetric partners

(Choi, Jeong, Kobayashi, Okumura, 2005)

- explicit model building required

(Kitano, Nomura, 2005; Lebedev, HPN, Ratz, 2005; Pierce, Thaler, 2006; Dermisek, Kim, 2006; Ellis, Olive, Sandick, 2006; Martin, 2007)

Explicit schemes I

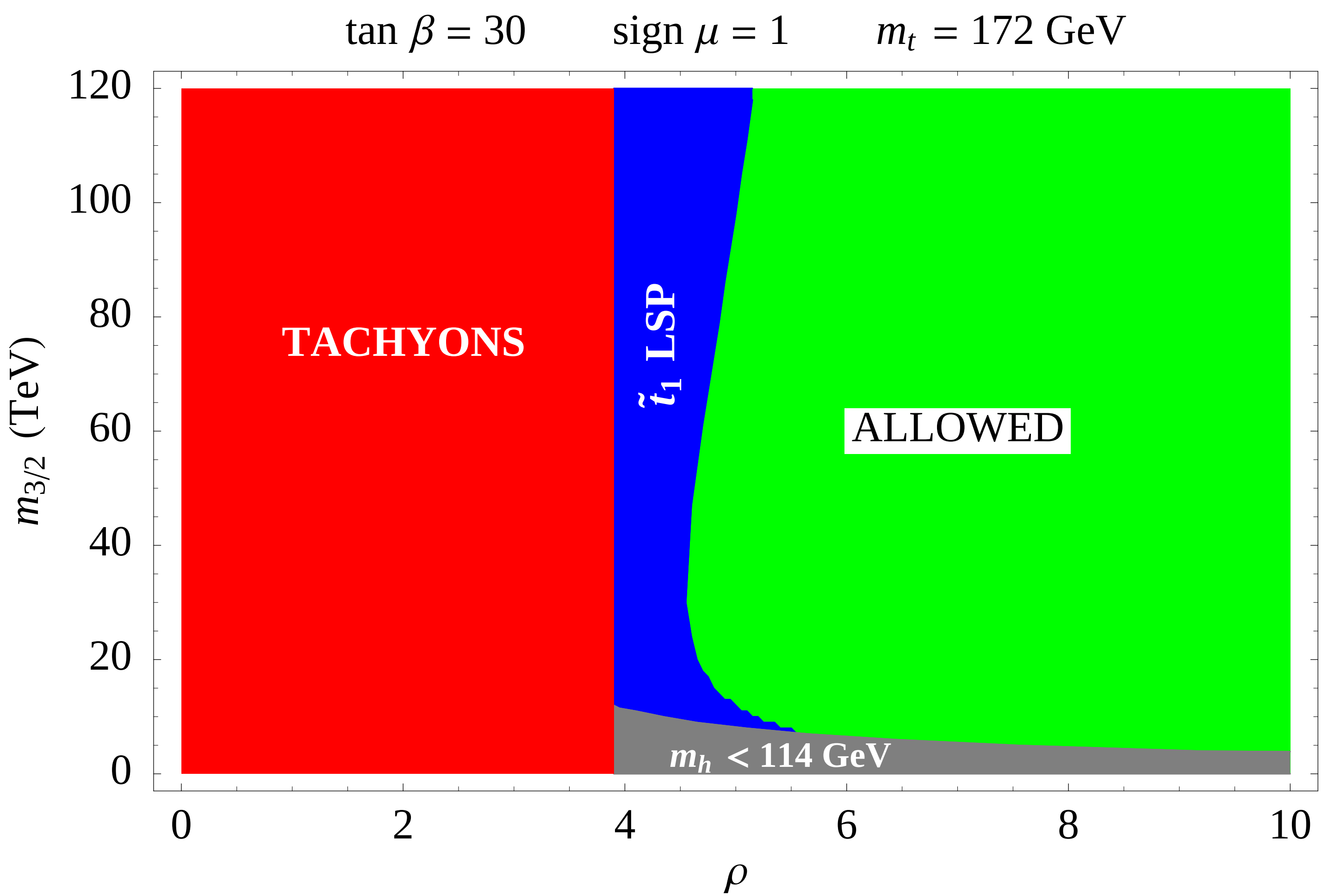
The different schemes depend on the mechanism of uplifting:

- uplifting with anti D3 branes

  (Kachru, Kallosh, Linde, Trivedi, 2003)

  - $\rho \sim 5$ in the original KKLT scenario leading to
  - a mirage scale of approximately 10^{11} GeV
- This scheme leads to pure mirage mediation:
  - gaugino masses and
  - scalar masses
- both meet at a common mirage scale

Constraints on ρ



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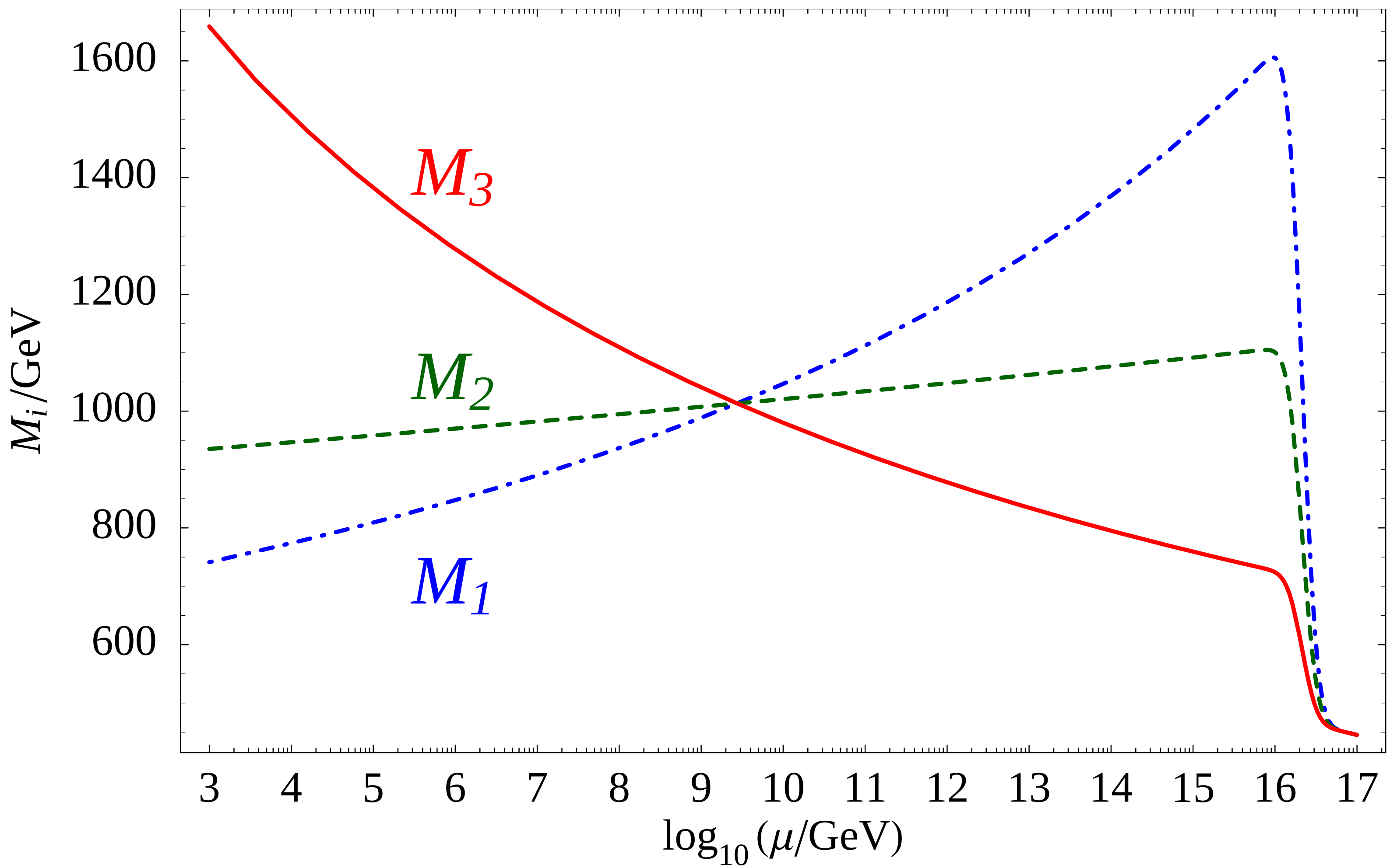

(Lebedev, HPN, Ratz, 2005)

Explicit schemes II

- uplifting via matter superpotentials

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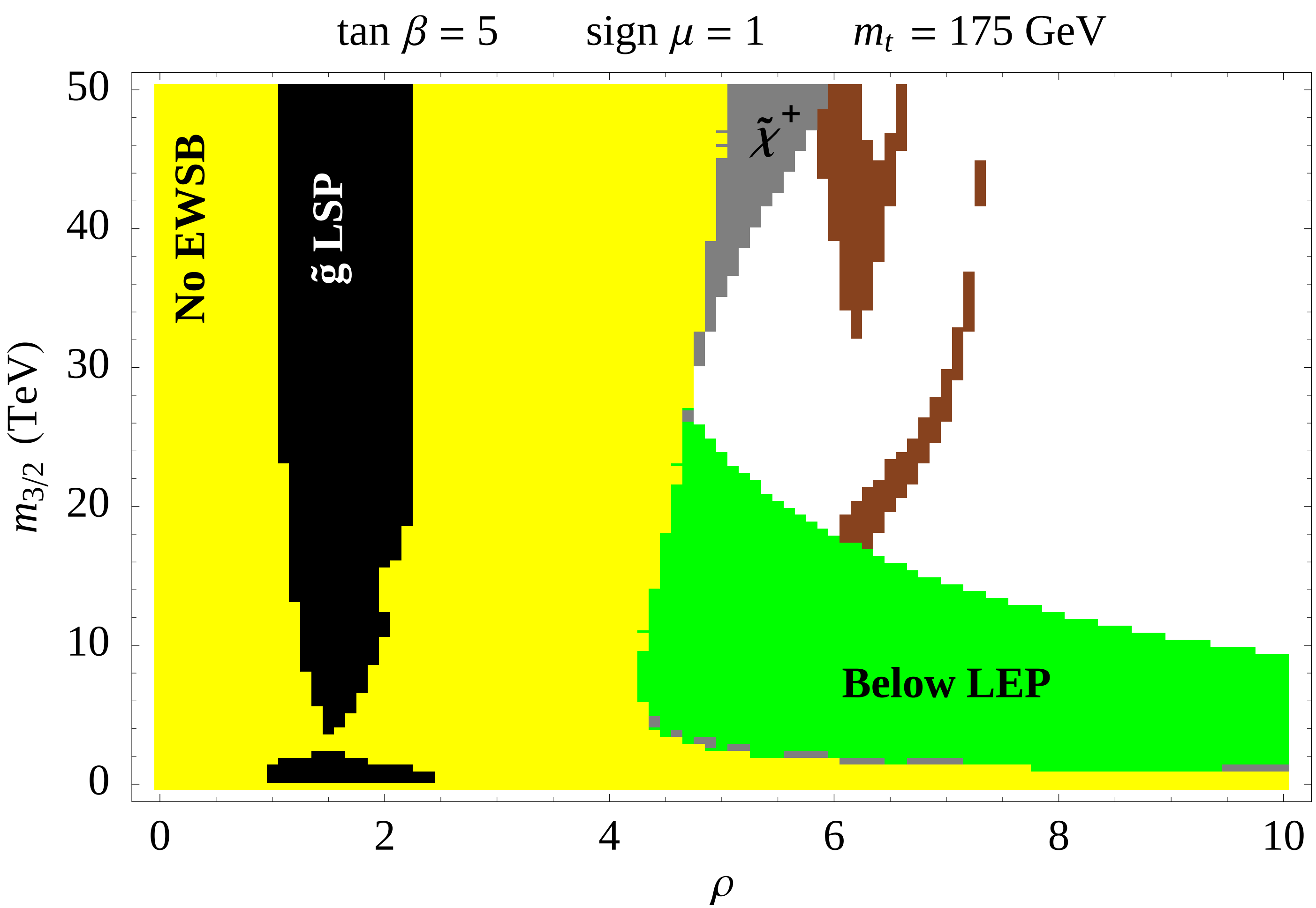
- gaugino masses still meet at a mirage scale

- soft scalar masses might be dominated by modulus mediation

- similar constraints on the mixing parameter

Constraints on the mixing parameter



(V. Löwen, 2007)

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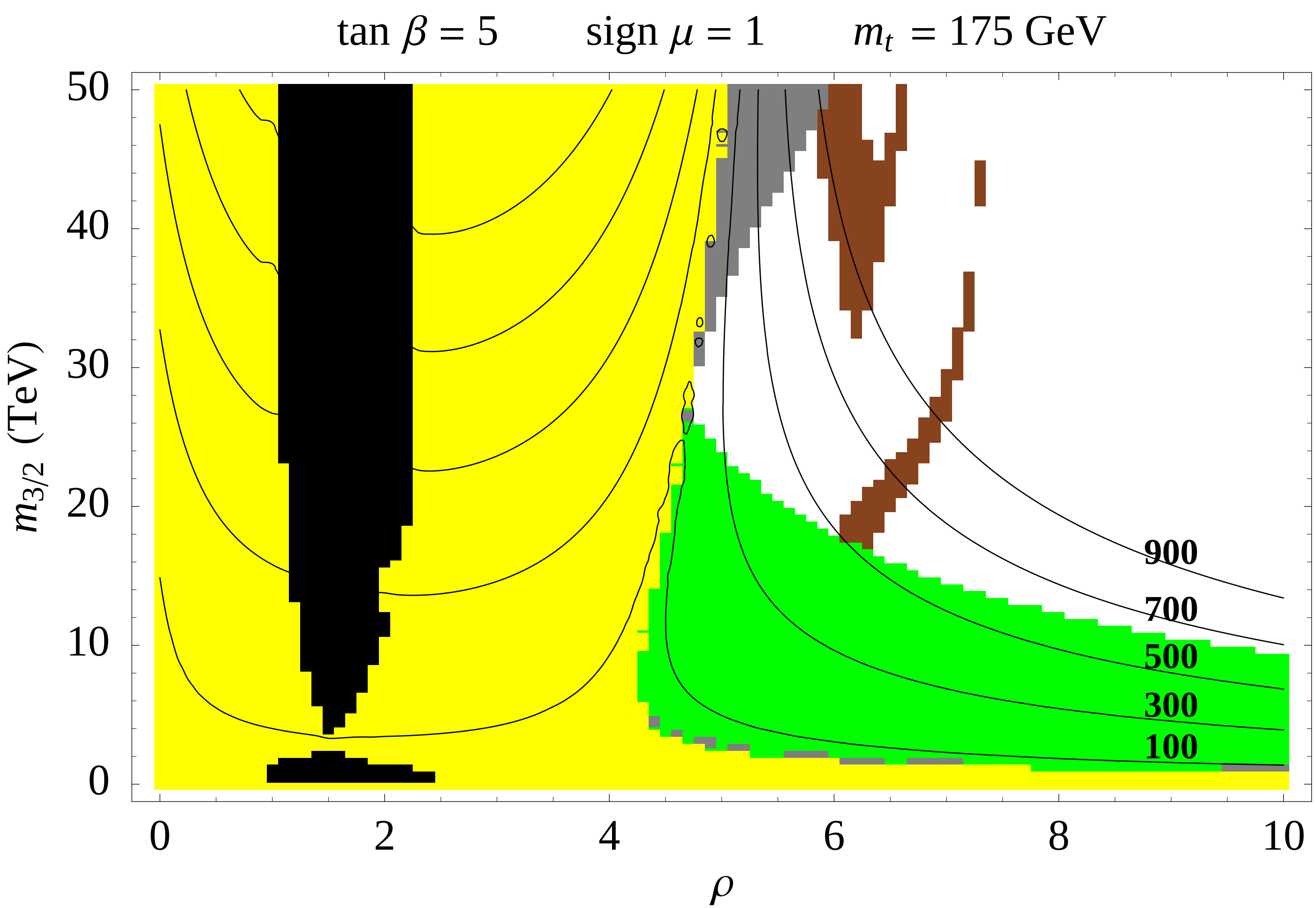

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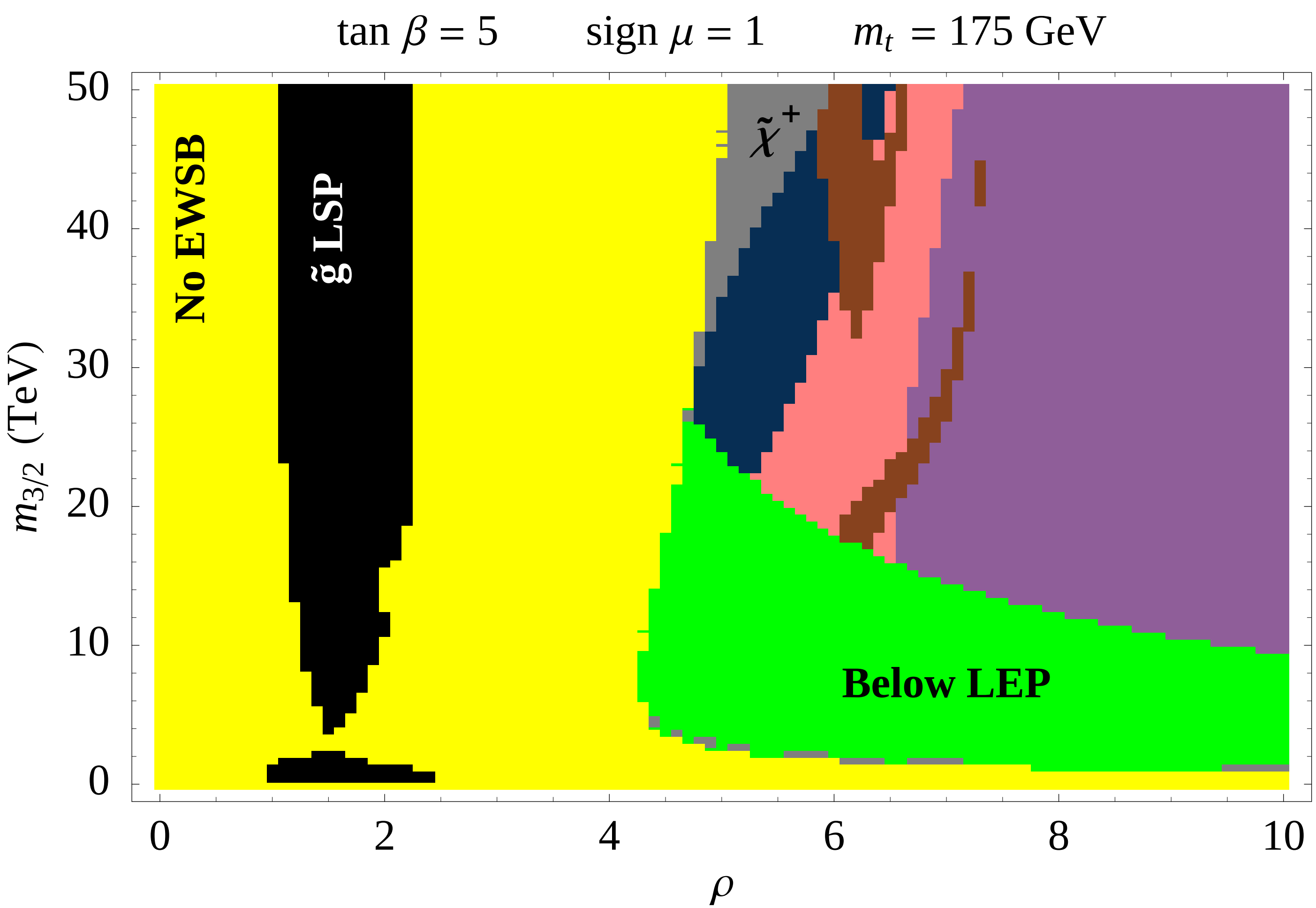

(V. Löwen, 2007)

Explicit schemes III

- This “relaxed” mirage mediation is rather common for schemes with F-term uplifting
  (Gomez-Reino, Scrucca; Dudas, Papineau, Pokorski; Abe, Higaki, Kobayashi, Omura; Lebedev, Löwen, Mambrini, HPN, Ratz ,2006)
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Main message

- predictions for gaugino masses are more robust than those for sfermion masses
- mirage (compressed) pattern for gaugino masses rather generic

Explicit schemes IV

In the heterotic case, we have

- hidden sector gaugino condensation
- potential run-away behaviour of the dilaton

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- hidden sector gaugino condensation
- potential run-away behaviour of the dilaton

Stabilization of dilaton via

- nontrivial corrections to Kähler potential

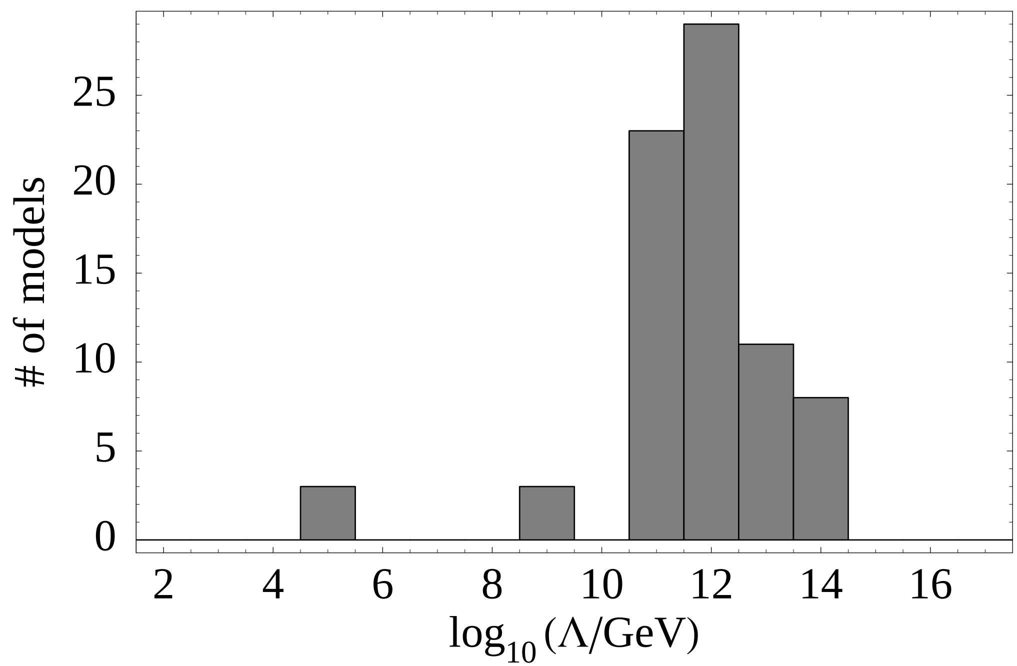
  (Barreiro, de Carlos, Copeland, 1998)

- “downlifting” via matter superpotentials

  (Löwen, HPN, 2008)

Again the uplifting sector becomes dominant at tree level

Hidden Sector Susy Breakdown



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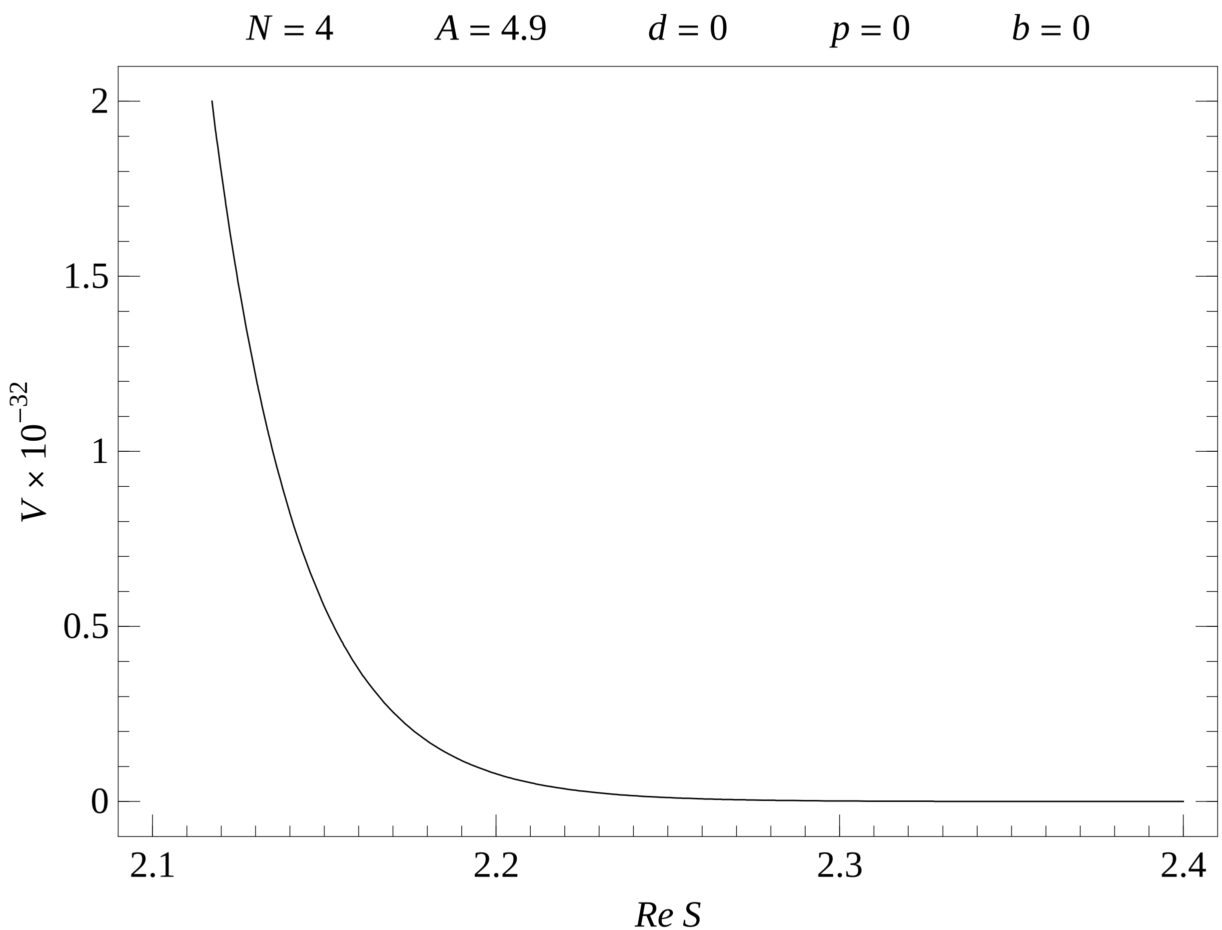
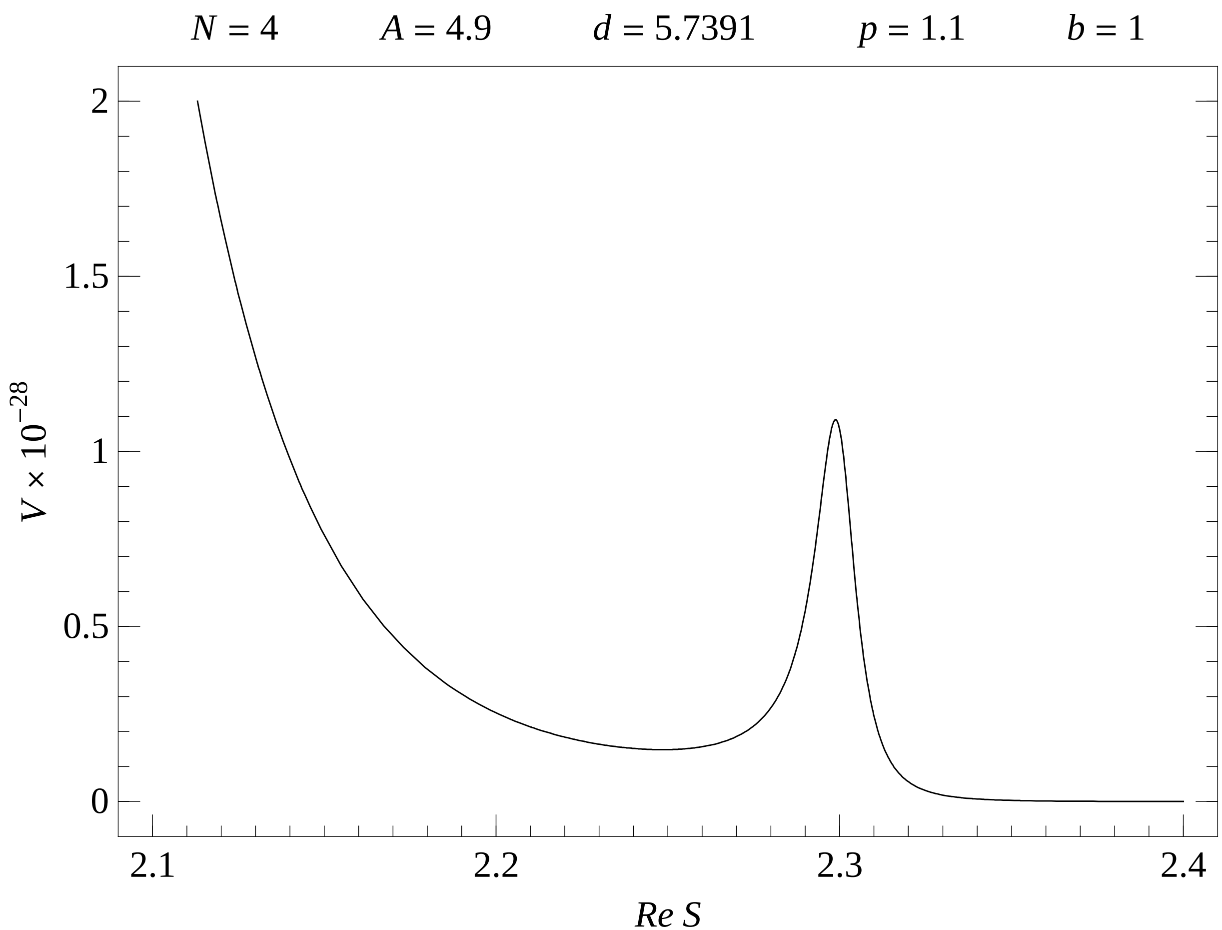
(Lebedev, HPN, Raby, Ramos-Sanchez, Ratz, Vaudrevange, Wingerter, 2006B)

Run-away potential

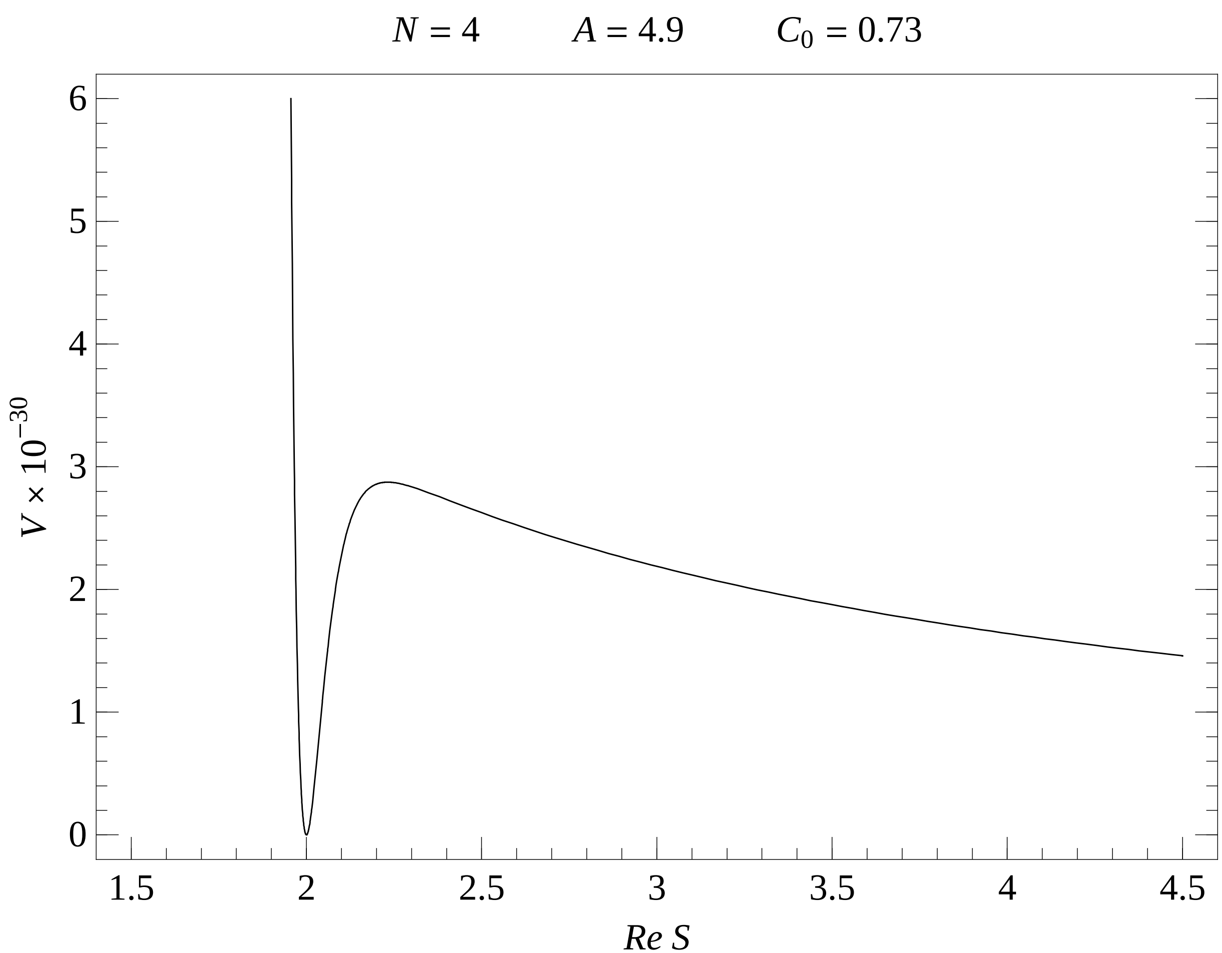


Corrections to Kähler potential



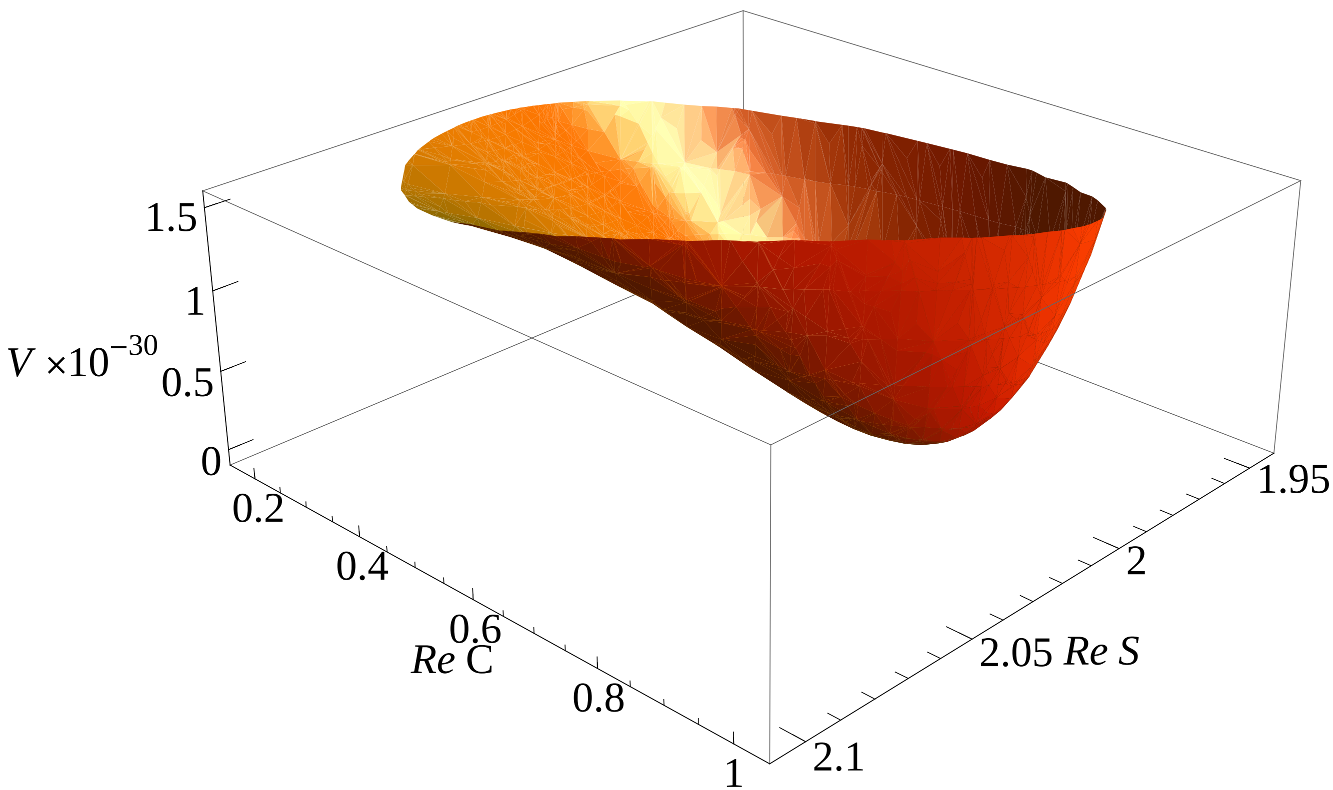
(Barreiro, de Carlos, Copeland, 1998)

Sequestered sector "uplifting"



(Lebedev, HPN, Ratz, 2006; Löwen, HPN, 2008)

Metastable "Minkowski" vacuum



(Löwen, HPN, 2008)

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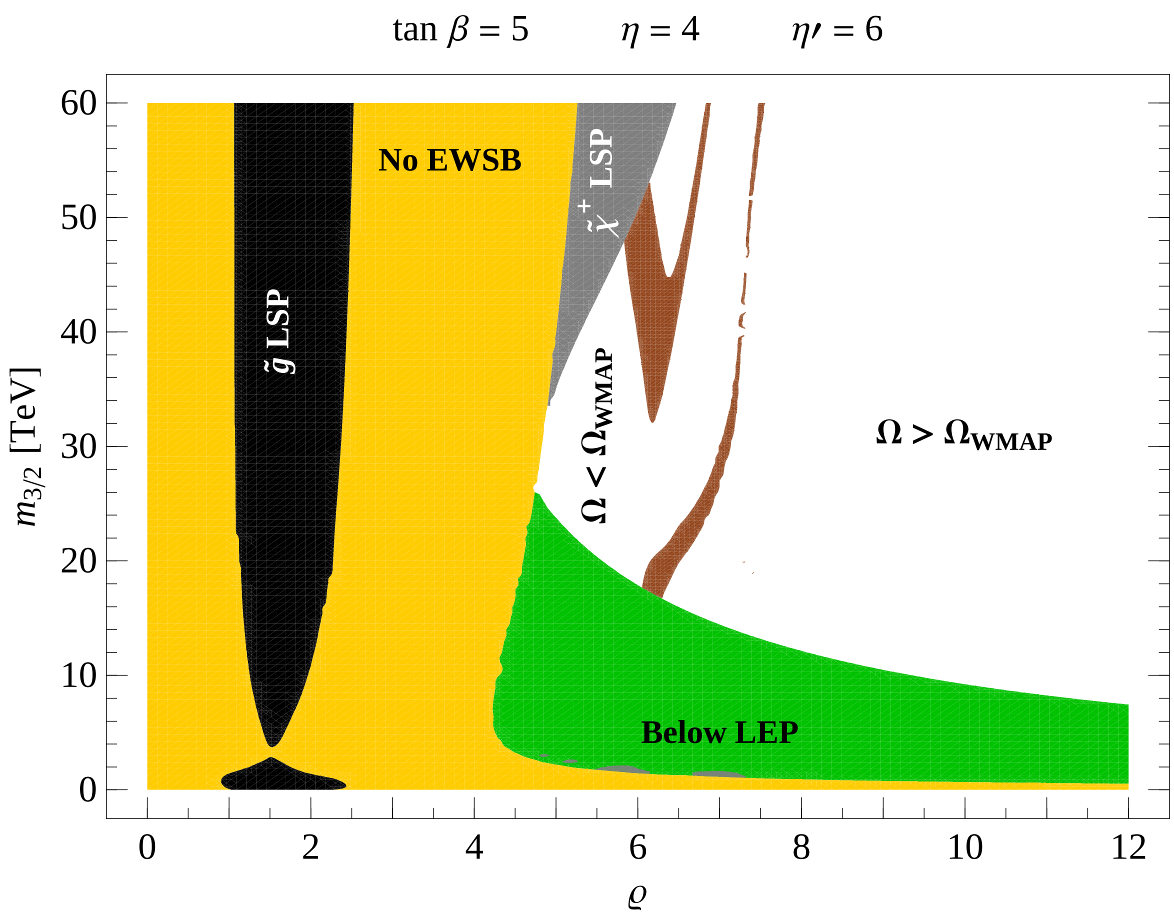

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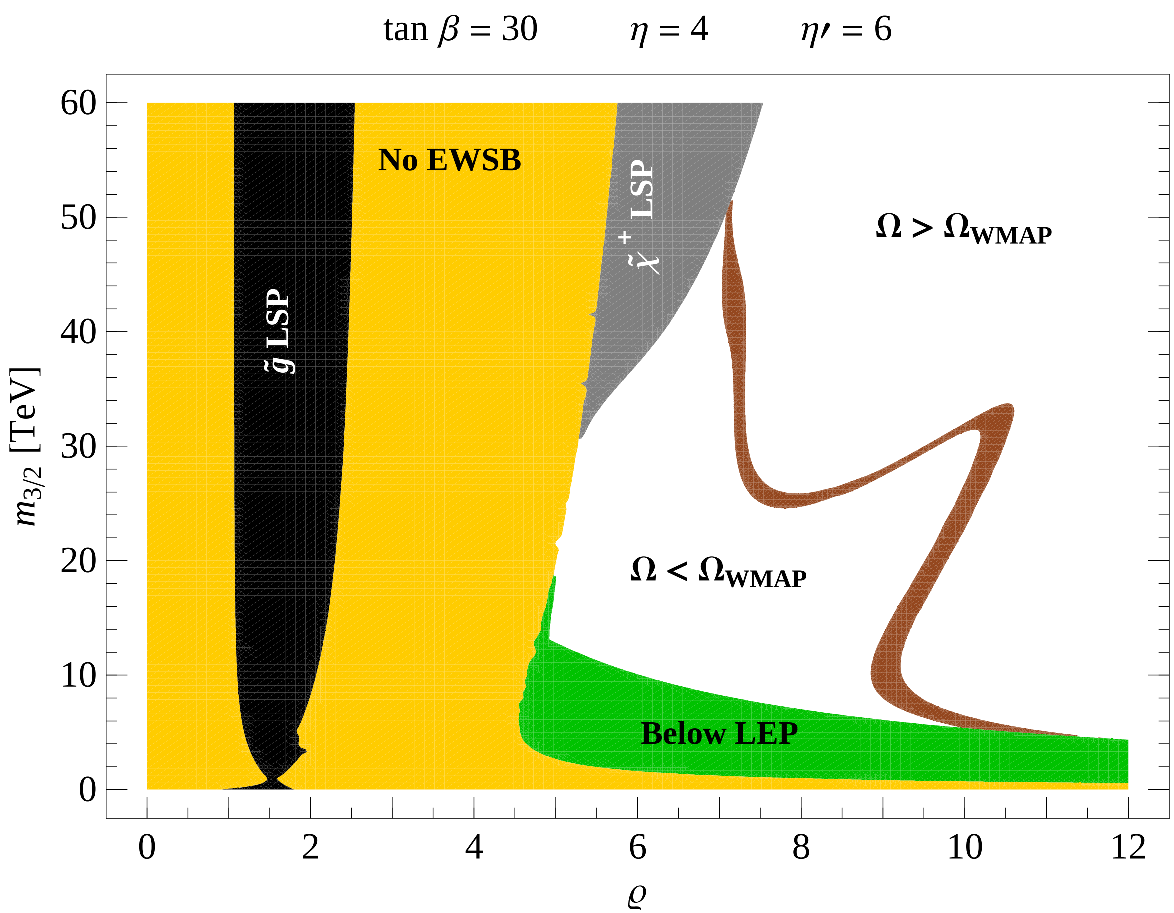

(Löwen, HPN, 2008)

Obstacles to D-term uplifting

In supergravity we have the relation

$$D \sim \frac{F}{W}$$

which implies that KKLT AdS minimum cannot be uplifted via D-terms.

(Choi, Falkowski, HPN, Olechowski, 2005)

Moreover in these schemes we have

$$F \sim m_{3/2} M_{\mathrm{Planck}} \quad \text{and} \quad D \sim m_{3/2}^2 .$$

So if $m_{3/2} \ll M_{\mathrm{Planck}}$ the D-terms are irrelevant.

(Choi, Jeong, 2006)

Some important messages

Please keep in mind:

- the uplifting mechanism plays an important role for the pattern of the soft susy breaking terms
- predictions for gaugino masses are more robust than those for sfermion masses
- dilaton/modulus mediation suppressed in many cases
- mirage pattern for gaugino masses rather generic

The string signatures

We might consider the following schemes:

- Type IIB string theory
- Type IIA string theory
- Heterotic string theory
- M-theory on manifolds with G_2 holonomy
- Heterotic M-theory

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Questions:

- are there distinct signatures for the various schemes?
- can they be identified with LHC data?

(Choi, HPN, 2007)

The Gaugino Code

How can we test these ideas at the LHC?

Look for pattern of gaugino masses

Let us assume the

- low energy particle content of the MSSM
- measured values of gauge coupling constants

$$g_1^2 : g_2^2 : g_3^2 \simeq \ 1 : 2 : 6$$

The evolution of gauge couplings would then lead to unification at a GUT-scale around 10^{16} GeV

Formulae for gaugino masses

$$\left(\frac{M_a}{g_a^2}\right)_{\rm TeV} = \tilde{M}_a^{(0)} + \tilde{M}_a^{(1)}|_{\rm anomaly} + \tilde{M}_a^{(1)}|_{\rm gauge} + \tilde{M}_a^{(1)}|_{\rm string}$$

$$\tilde{M}_a^{(0)} = \frac{1}{2} F^I \partial_I f_a^{(0)}$$

$$\tilde{M}_a^{(1)}|_{\rm anomaly} = \frac{1}{16\pi^2} b_a \frac{F^C}{C} - \frac{1}{8\pi^2} \sum_m C_a^m F^I \partial_I \ln(e^{-K_0/3} Z_m)$$

$$\tilde{M}_a^{(1)}|_{\rm string} = \frac{1}{8\pi^2} F^I \partial_I \Omega_a$$

The Gaugino Code

Observe that

- evolution of gaugino masses is tied to evolution of gauge couplings
- for MSSM M_a/g_a^2 does not run (at one loop)

This implies

- robust prediction for gaugino masses
- gaugino mass relations are the key to reveal the underlying scheme

3 CHARACTERISTIC MASS PATTERNS

(Choi, HPN, 2007)

mSUGRA Pattern

Universal gaugino mass at the GUT scale

- mSUGRA pattern:

$$M_1 : M_2 : M_3 \simeq \ 1 : 2 : 6 \simeq \ g_1^2 : g_2^2 : g_3^2$$

as realized in popular schemes such as gravity-, modulus- or dilaton-mediation

This leads to

- LSP χ_1^0 predominantly Bino
- $M_{\rm gluino}/m_{\chi_1^0} \simeq 6$

as a characteristic signature of these schemes.

Anomaly Pattern

Gaugino masses below the GUT scale determined by the β functions

- anomaly pattern:

$$M_1 : M_2 : M_3 \simeq \ 3.3 : 1 : 9$$

at the TeV scale as the signal of anomaly mediation.

For the gauginos, this implies

- LSP χ_1^0 predominantly Wino
- $M_{\text{gluino}}/m_{\chi_1^0} \simeq 9$

Pure anomaly mediation inconsistent, as sfermion masses are problematic in this scheme (tachyonic sleptons).

Mirage Pattern

Mixed boundary conditions at the GUT scale
characterized by the parameter ρ
(the ratio of modulus to anomaly mediation).

- $M_1 : M_2 : M_3 \simeq \ 1 : 1.3 : 2.5$ for $\rho \simeq 5$
- $M_1 : M_2 : M_3 \simeq \ 1 : 1 : 1$ for $\rho \simeq 2$

The mirage scheme leads to

- LSP χ_1^0 predominantly Bino
- $M_{\text{gluino}}/m_{\chi_1^0} < 6$
- a “compressed” gaugino mass pattern.

Uncertainties

String thresholds

$$\tilde{M}_a^{(1)}|_{\text{string}} = \frac{1}{8\pi^2} F^I \partial_I \Omega_a$$

Kähler corrections

$$\tilde{M}_a^{(1)}|_{\text{anomaly}} = \frac{1}{16\pi^2} b_a \frac{F^C}{C} - \frac{1}{8\pi^2} \sum_m C_a^m F^I \partial_I \ln(e^{-K_0/3} Z_m)$$

Intermediate thresholds

$$\tilde{M}_a^{(1)}|_{\text{gauge}} = \frac{1}{8\pi^2} \sum_\Phi C_a^\Phi \frac{F^{X_\Phi}}{M_\Phi}$$

Various string schemes

- Type IIB with matter on D7 branes:
  mirage mediation (Choi, Falkowski, HPN, Olechowski, 2005)
- Type IIB with matter on D3 branes:
  anomaly mediation? (Choi, Falkowski, HPN, Olechowski, 2005)
- Heterotic string with dilaton domination:
  mirage mediation (Löwen, HPN, 2008)
- Heterotic string with modulus domination:
  string thresholds might spoil anomaly pattern
  (Derendinger, Ibanez, HPN, 1986)
- M theory on "G_2 manifold":
  Kähler corrections might spoil mirage pattern
  (Acharya, Bobkov, Kane, Kumar, Shao, 2007)

Conclusion

String theory provides us with new ideas for particle physics model building, leading to concepts such as

- Local Grand Unification
- Mirage Mediation

Geography of extra dimensions plays a crucial role:

- localization of fields on branes,
- presence of sequestered sectors

LHC might help us to verify some of these ideas!