SUSY Forever

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Predictions

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- Experiments within the next five to ten years will tell us whether supersymmetry at the weak scale is a myth or reality. (Nilles, 1984)

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The statement was motivated in view of LEP. Today we wait for LHC results. Where are we now?

- No sign for physics beyond the Standard Model
- No (SM) Higgs boson seen either
- Do we have to worry?

A well-motivated pattern

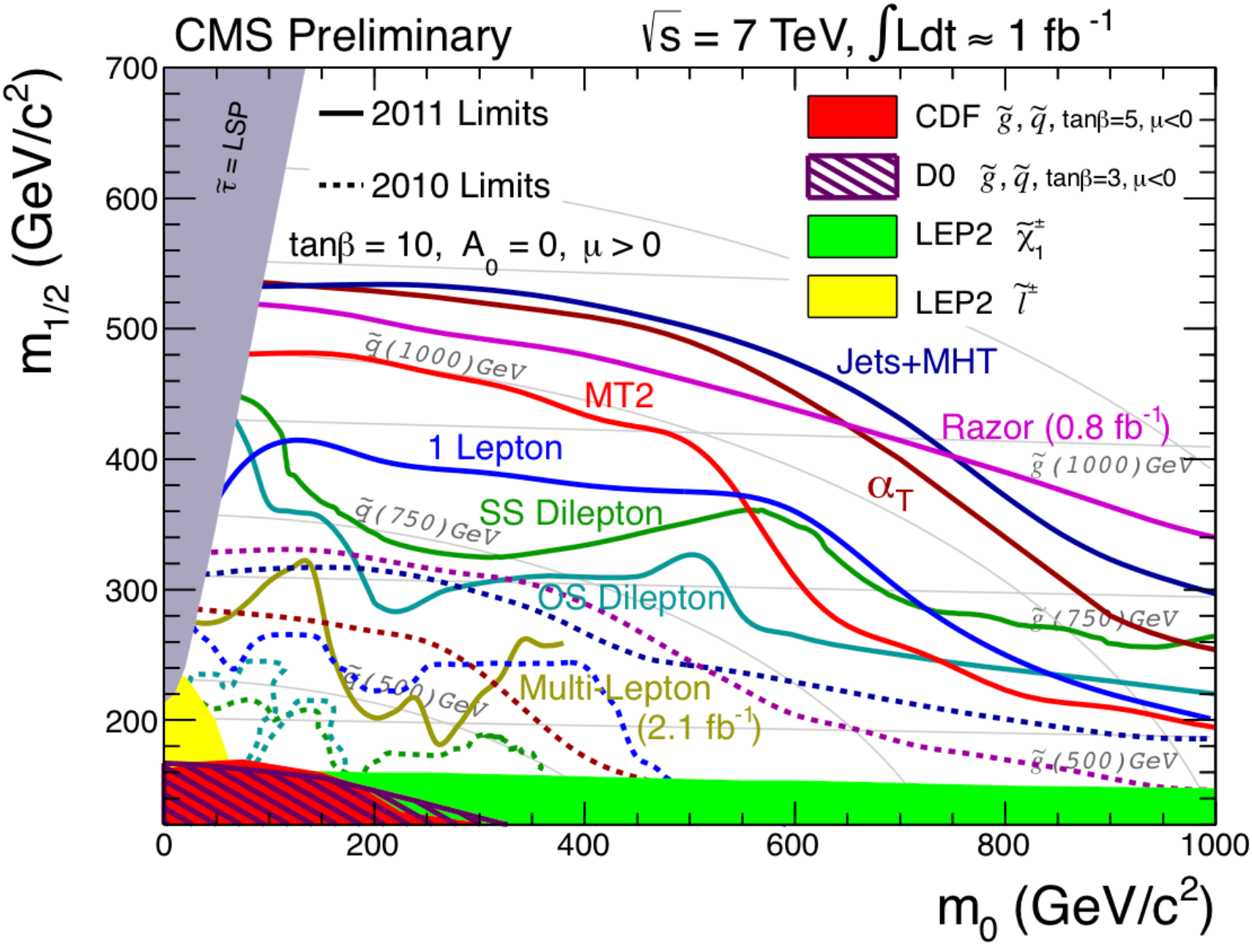
A specific pattern for the soft masses with a large gravitino mass in multi-TeV range (e.g. $O(50)$TeV)

- normal squarks and sleptons in multi-TeV range
- top squarks $(\tilde{t}_L, \tilde{b}_L)$ and $\tilde{t}_R$ in TeV-range (suppressed by $\log(M_{\rm Planck}/m_{3/2}) \sim 4\pi^2$)
- A-parameters in TeV range
- gaugino masses in TeV range
- mirage pattern for gaugino masses (compressed spectrum)

A well motivated pattern emerging from the heterotic string.

(Krippendorf, Nilles, Ratz, Winkler, 2012)

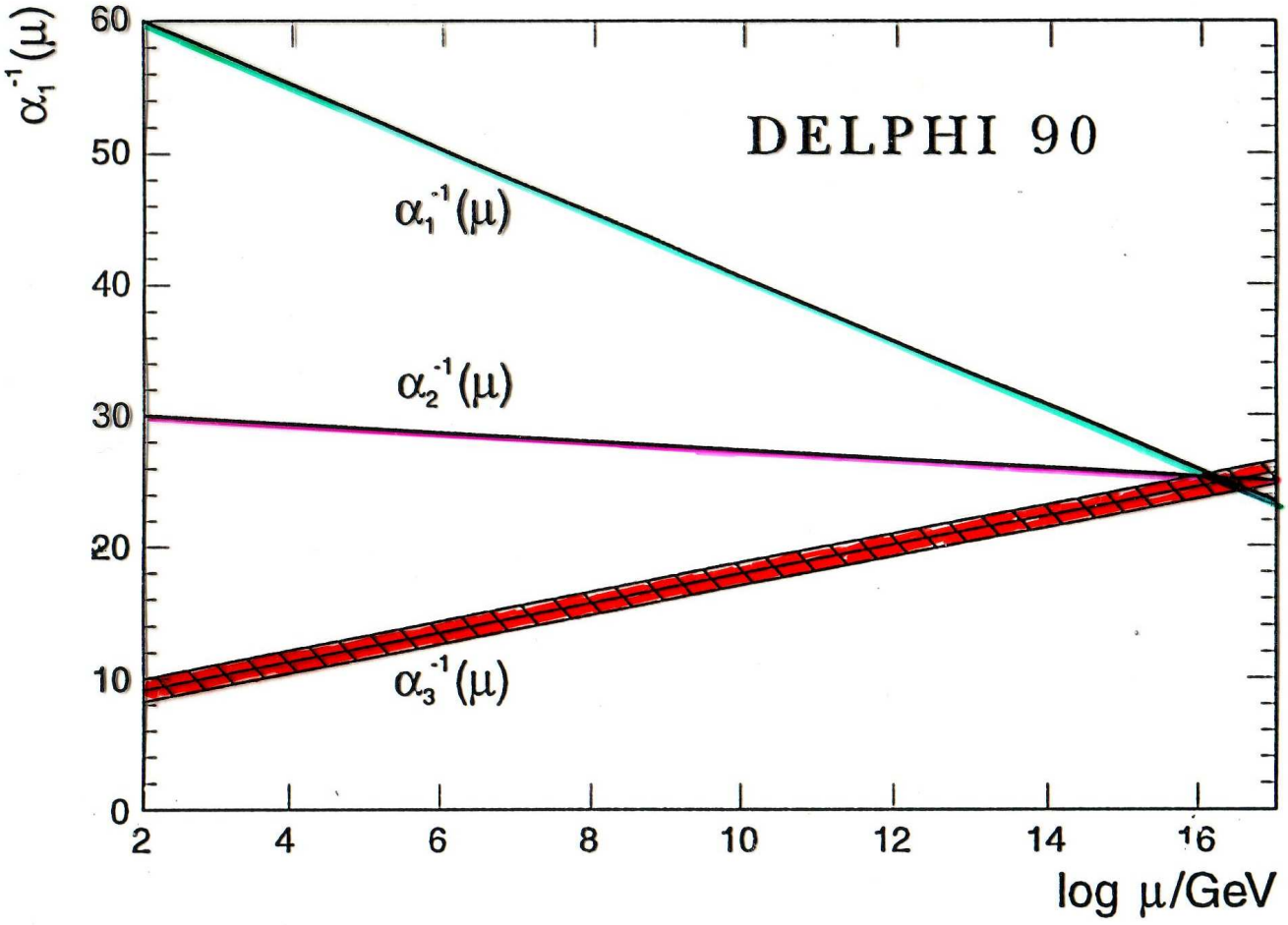
SUSY Search


CMS Preliminary
√s = 7 TeV, ∫Ldt ≈ 1 fb -1
2011 Limits
2010 Limits
tanβ = 10, A0 = 0, μ > 0
τ̃ = LSP
CDF g̃, q̃, tanβ=5, μ<0
D0 g̃, q̃, tanβ=3, μ<0
LEP2 χ̃1±
LEP2 l̃±
Jets+MHT
MT2
Razor (0.8 fb-1)
1 Lepton
αT
SS Dilepton
OS Dilepton
Multi-Lepton (2.1 fb-1)
q̃(1000)GeV
q̃(750)GeV
q̃(500)GeV
g̃(1000)GeV
g̃(750)GeV
g̃(500)GeV
m1/2 (GeV/c2)
m0 (GeV/c2)
700
600
500
400
300
200
0
200
400
600
800
1000

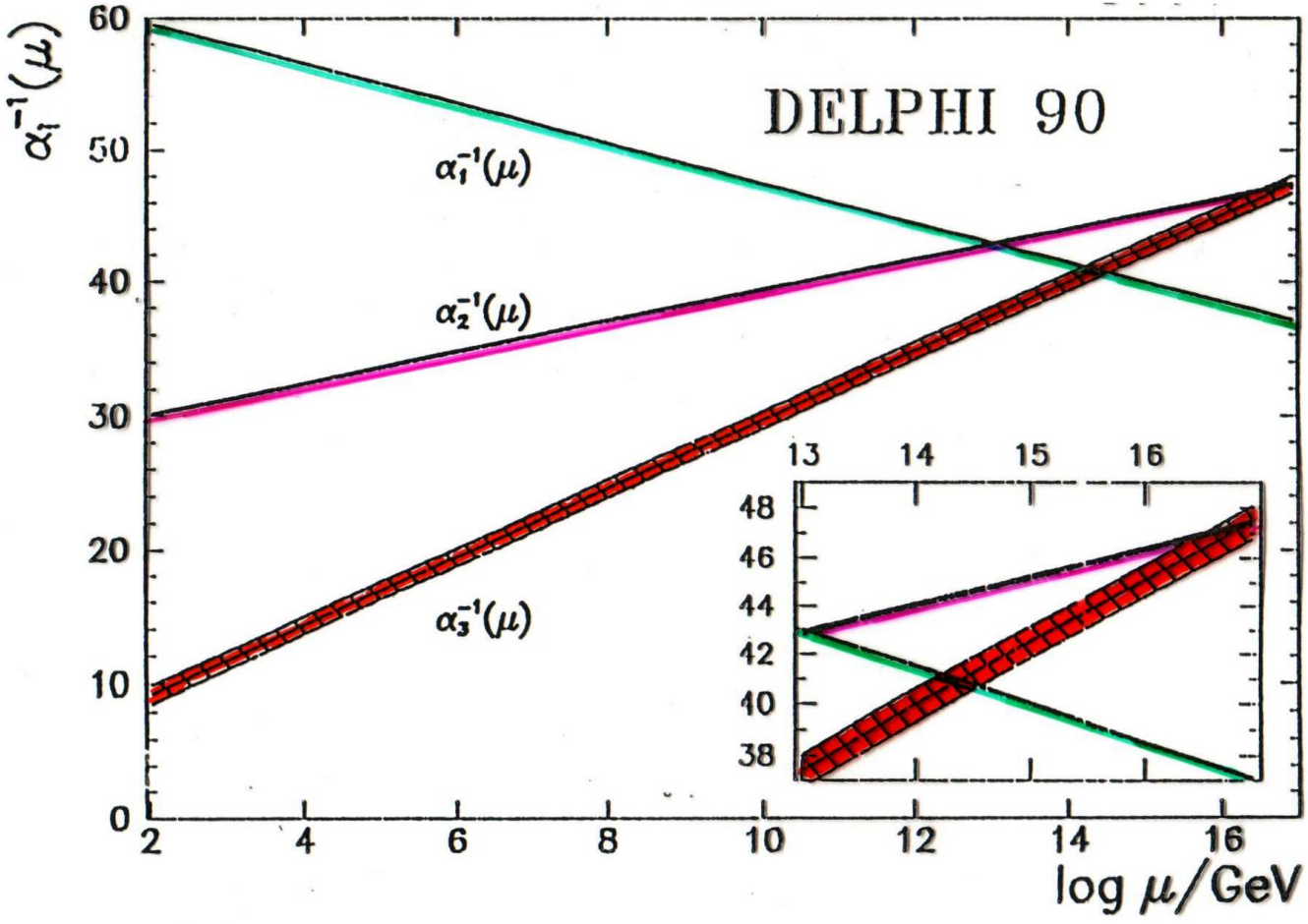
SUSY Predictions

- gauge coupling unification (mainly from gauginos)

MSSM (supersymmetric)



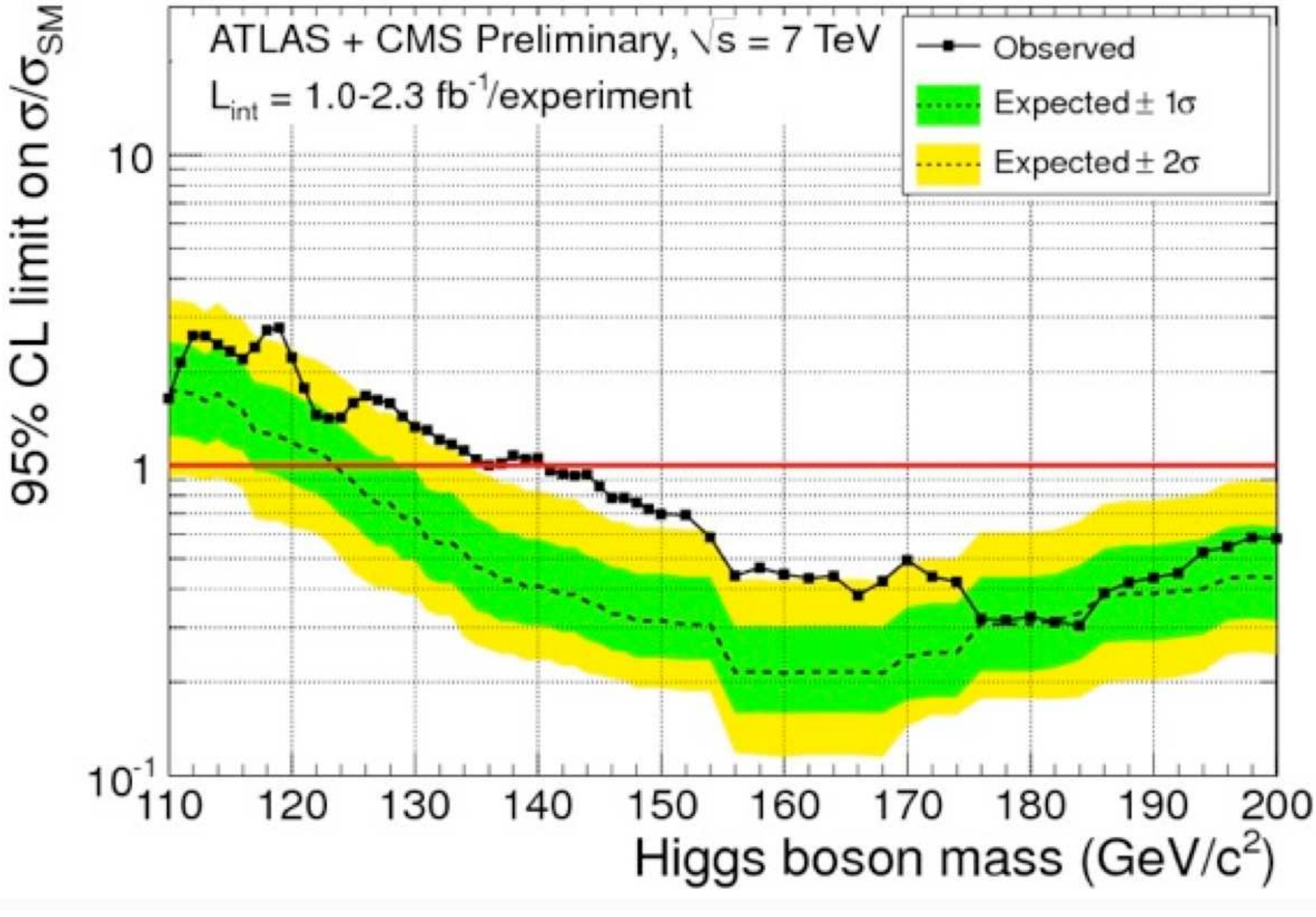
Standard Model



SUSY Predictions

- gauge coupling unification (mainly from gauginos)
- 2 Higgs (super) multiplets
- heavy top quark
- upper bound on the lightest Higgs boson
  (a unique prediction compared to other scenarii for physics beyond the Standard Model)

Higgs-Window



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What are the mass scales?

- lightest Higgs mass less than 130 GeV (e.g. 118 GeV)
- superpartners TeV or multi-TeV?
- light LSP?
- old “No Lose” theorem: 20+20 TeV at the SSC

The “Top Story”

- tau and bottom found in the 70’s: prediction of top quark
- toponium ($t\bar{t}$) at 27 GeV
- PETRA/PEP with CM-energy up to 40 GeV
- discovery of Higgs form $t\bar{t}$ to Higgs + Gamma?

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The Top Quark is a special particle!

- early 80's: SUSY models with radiative EW-symmetry breakdown required heavy top-quark
- even 50 GeV was considered ridiculous
- a natural reason for 175 GeV: "Gauge-Top-Unification"
- today heavy top needed for $m_H > 114$ GeV

Some questions

What are “natural” values for SUSY?

- gaugino mass pattern
- gaugino versus fermion masses
- which parameters are more “robust”

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Can we rule out SUSY?

- find a heavy Higgs (this opportunity has been missed already)
- find something else as physics BeyondSM
- does SUSY die or has it to fade away?

Messages

Some theoretical guidelines:

- wait till we know the mass of Higgs boson
- gaugino mass predictions are more robust
- "sequestering" allows a large hierarchy between gaugino and sfermion masses
- "sequestering" limited by $\log(m_{3/2}/M_{\rm Planck})$

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Potentially relevant questions:

- what is the pattern of gaugino masses?
- are super-heavy sfermions possible?
- are some of the soft mass terms suppressed?

Reading the Gaugino Code

First step to 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

Gravity (Modulus) Mediation

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- and dilaton-mediation

This leads to

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

as a characteristic signature of these schemes.

Anomaly Mediation

Gaugino masses below the GUT scale are 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
- $G = M_{\rm gluino}/m_{\chi_1^0} \simeq 9$

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

Top-down arguments

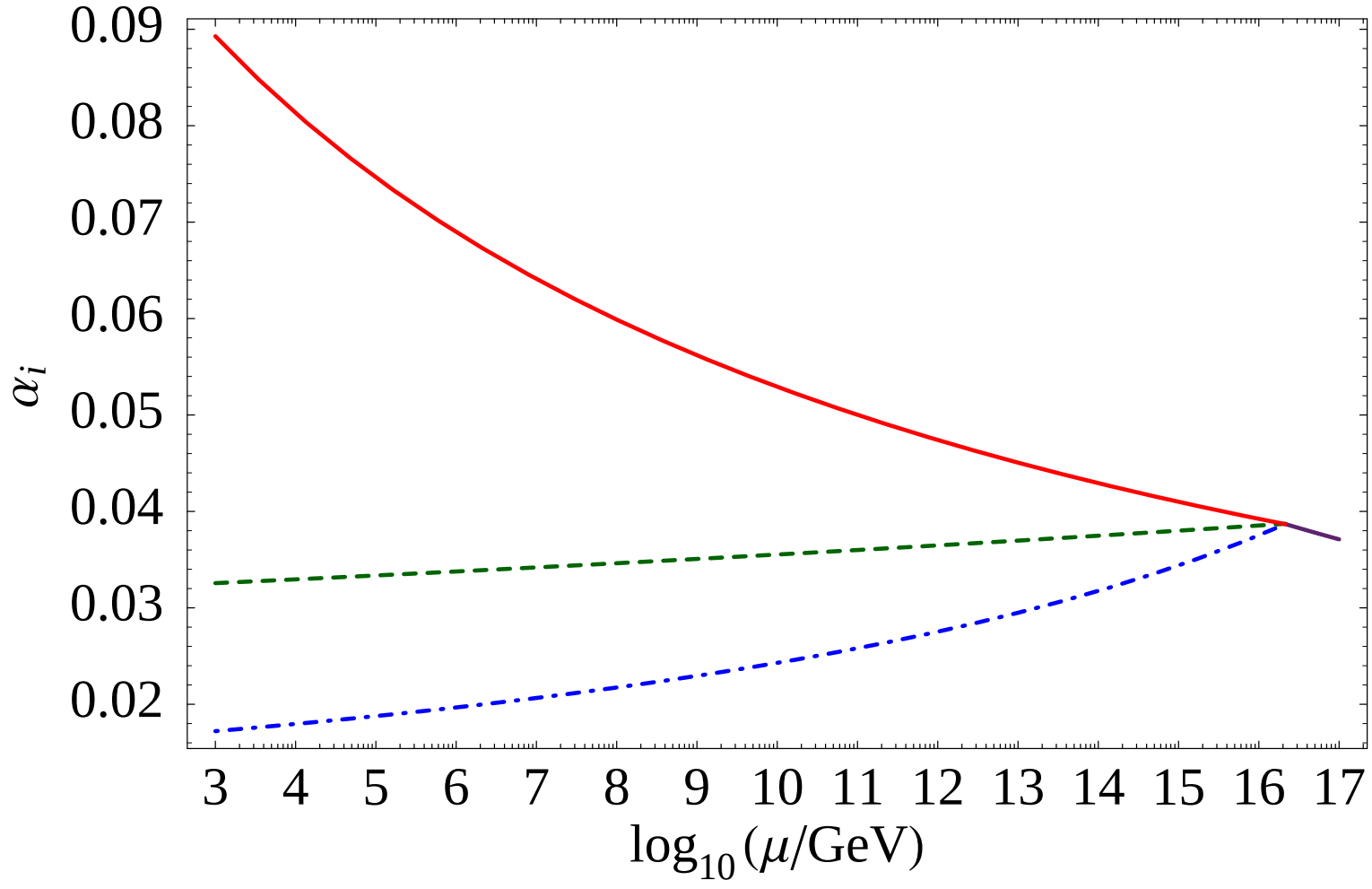
In string theory we have (from flux and gaugino condensate)

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

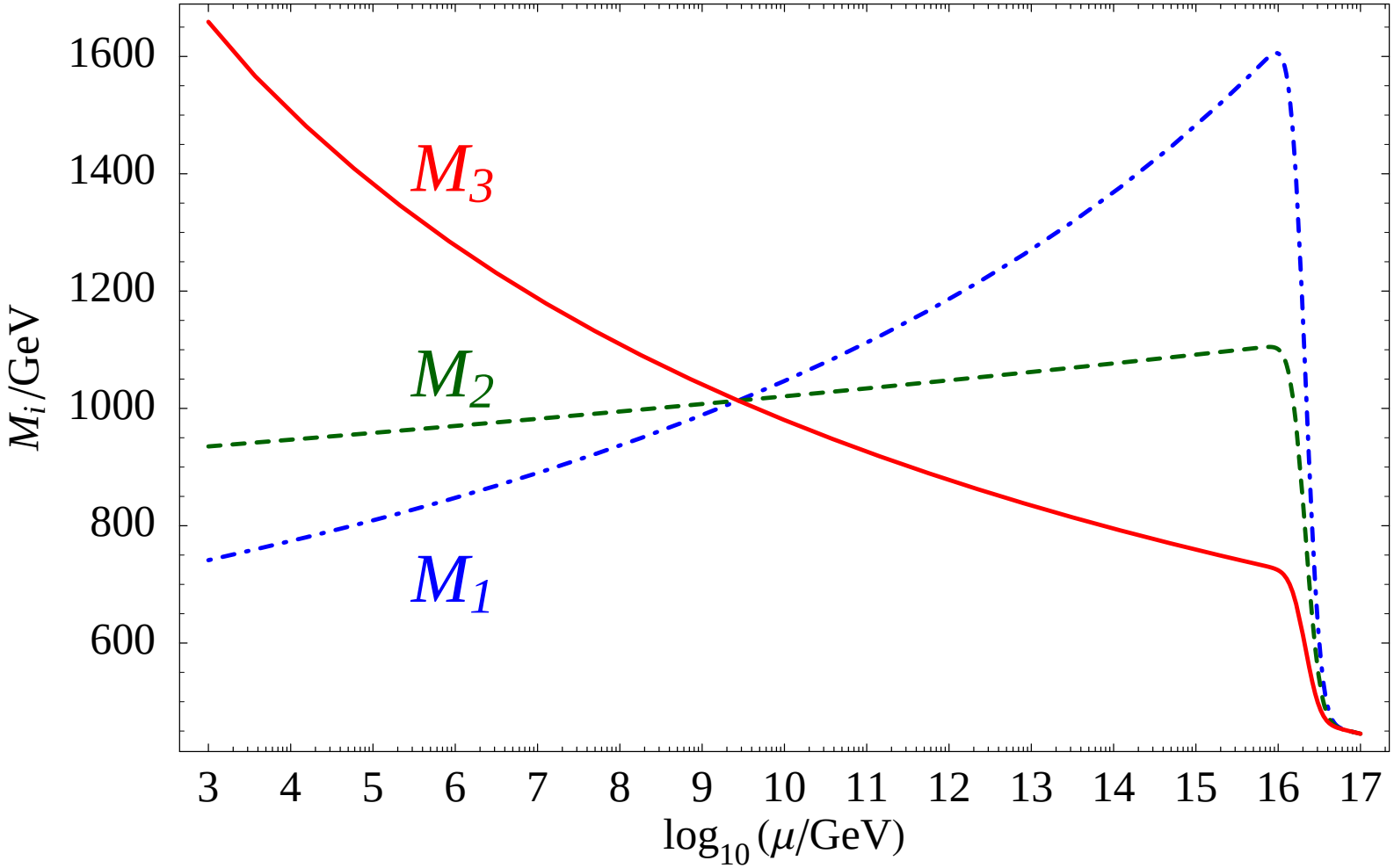
- modulus mediation suppressed
  $X \sim \log(M_{\text{Planck}}/m_{3/2}) \sim 4\pi^2$
- radiative corrections become relevant (proportional to the β function, i.e. negative for the gluino, positive for the bino)
- Mixed mediation scheme: Mirage Mediation (MMAM)
- Mirage pattern for gaugino masses:
  $m_{1/2} \sim m_{3/2}/4\pi^2$

(Choi, Falkowski, Nilles, Olechowski, 2005)

Evolution of couplings

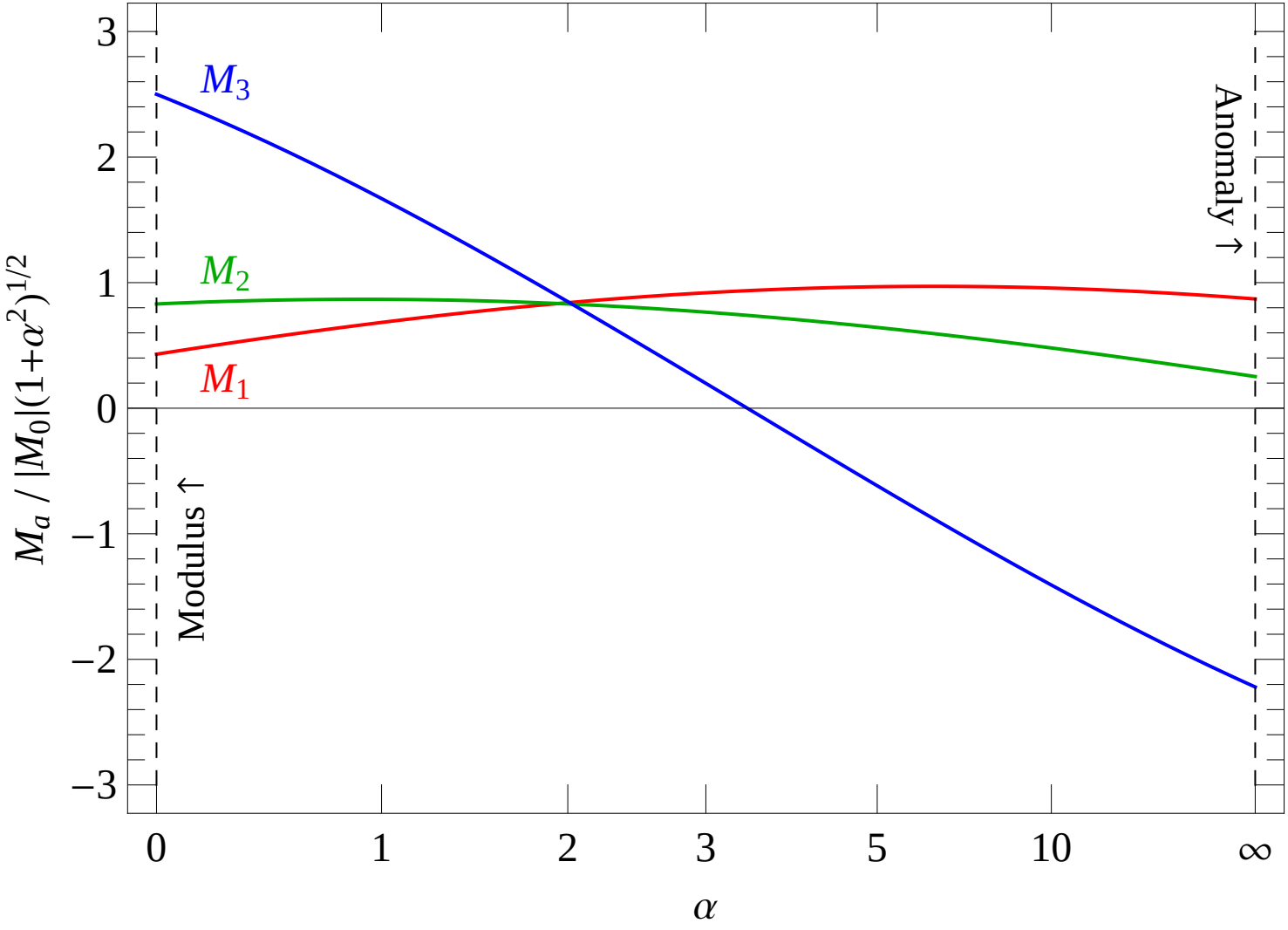


The Mirage Scale



(Lebedev, HPN, Ratz, 2005)

Gaugino Masses



Mirage Pattern

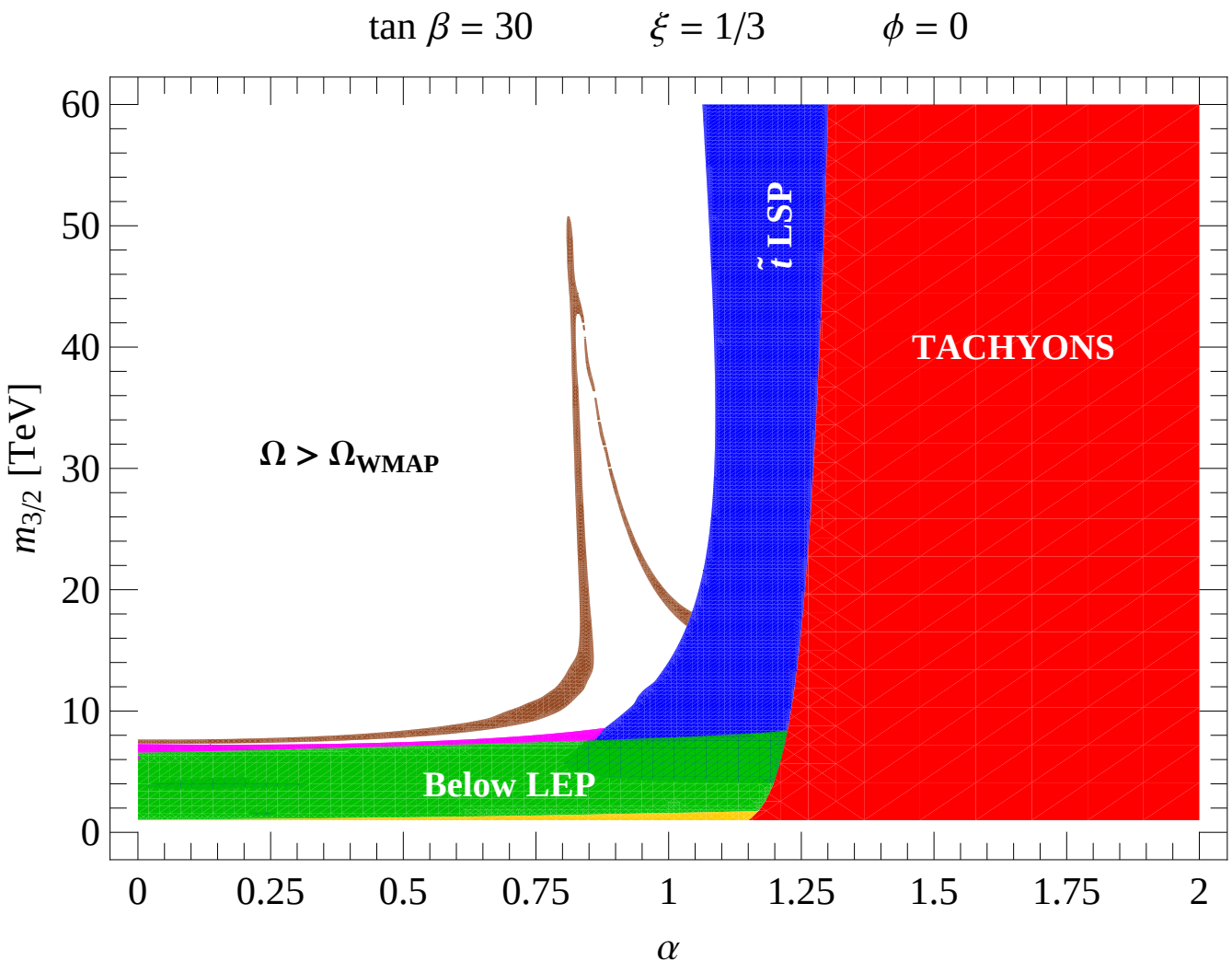
Mixed boundary conditions at the GUT scale
characterized by the parameter α:
the ratio of modulus to anomaly mediation.

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

The mirage scheme leads to

- LSP χ_1^0 predominantly Bino
- $G = M_{\text{gluino}}/m_{\chi_1^0} < 6$
- a “compact” (compressed) gaugino mass pattern
  (a challenge for LHC searches).

Constraints on α



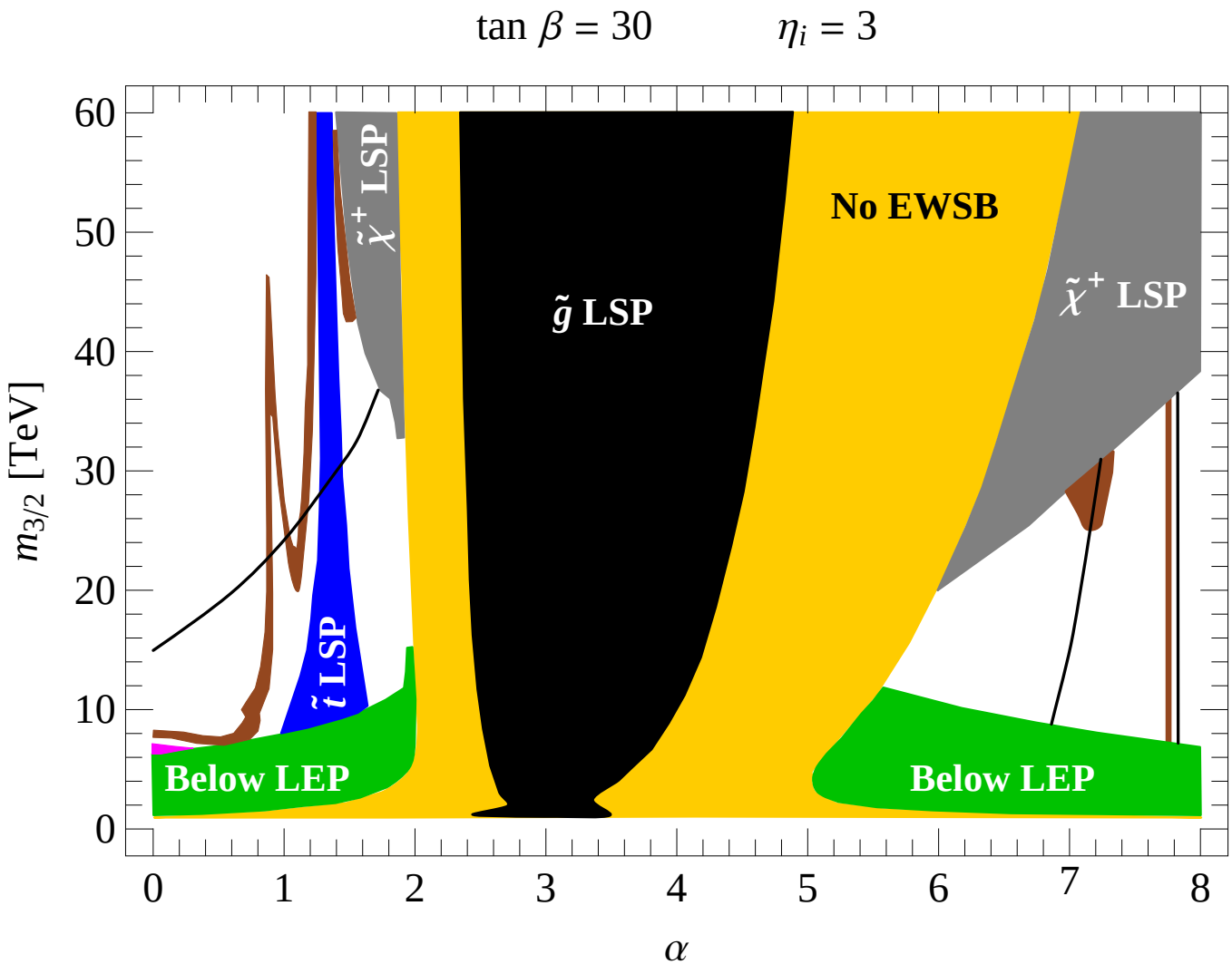
Top-Down argument II

- scalar masses are less protected

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

  - large contributions to sfermion masses
  - removes potential tachyons
  - Heavy squarks and sleptons: e.g. $m_0 \sim 50$TeV

Constraints on α



Lessons from heterotic string theory

- scalar masses are less protected
  - heavy squarks and sleptons: $m_0 \sim O(50)$TeV
- But, the top quark plays a special role
  - a large value of the top-quark Yukawa coupling requires a special location of top and Higgs in extra dimensions of string theory

    (Lebedev, Nilles, Raby, Ramos-Sanchez, Ratz, Vaudrevange, Wingerter, 2007)
  - this is a result of gauge-Yukawa-unification

    $g_{\rm top} \sim g_{\rm gauge} \sim g_{\rm string}$

    that explains the large values of the top-quark mass
  - stops remain in TeV range

    (Krippendorf, Nilles, Ratz, Winkler, 2012)

The Pattern

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Can this be confirmed (or ruled out) by the LHC?

The overall scale

There is no (reliable) prediction for the gravitino mass

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- “no lose” criterion (SSC with 20+20 TeV)
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Betting in the early 80’s

- I bet that supersymmetry will be discovered before SSC gets into operation
- I bet that supersymmetry will have been forgotten before SSC gets into operation

Continued prediction

There is still some optimism in 2011:

- Experiments within the next five to ten years will tell us whether supersymmetry at the weak scale is a myth or reality.

We have to wait and see.

Bavarian Philosopher

(K. Valentin, 1882-1948)

- Früher haben wir langsam gewartet, heute warten wir immer schneller.

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