Aspects of string phenomenology in the LHC era

I. Antoniadis

- High string scale, SUSY and 125 GeV Higgs
- Low scale strings and extra dimensions
- Extra $U(1)$'s
- Tiny string coupling and linear dilaton background

Connect string theory to the real world:

What is the value of the string scale M_s ?

- arbitrary parameter : Planck mass $M_P \longrightarrow$ TeV

- physical motivations $\Rightarrow$ favored energy regions:

- High : $\begin{cases} M_P^* \simeq 10^{18}\ \text{GeV} & \text{Heterotic scale} \\ M_{\rm GUT} \simeq 10^{16}\ \text{GeV} & \text{Unification scale} \end{cases}$

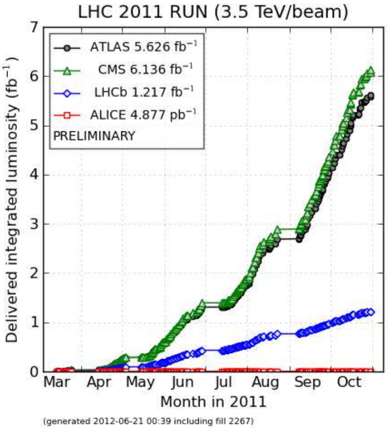
- Intermediate : around 10^{11} GeV ($M_s^2/M_P \sim$ TeV)

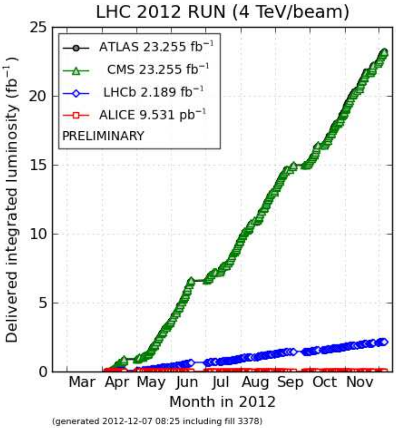
  SUSY breaking, strong CP axion, see-saw scale

- Low : TeV (hierarchy problem)

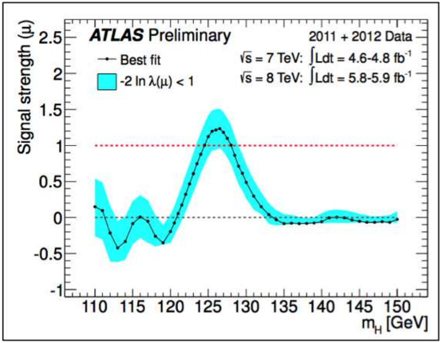
Excellent LHC performance

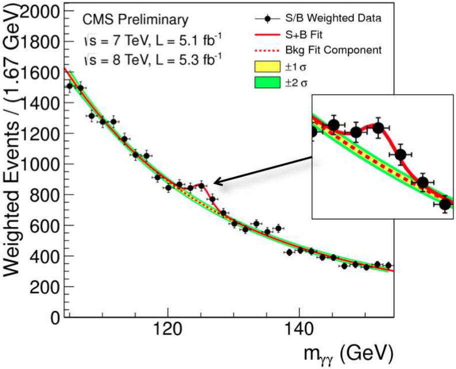
Number of events = Cross section × Luminosity





Higgs boson discovery





$m_H = 125.5 \pm 0.2\,(\mathrm{stat.}) \pm 0.5\,(\mathrm{syst.})$ $m_H = 125.7 \pm 0.3 \pm 0.3\ \mathrm{GeV}$

Beyond the Standard Model of Particle Physics: driven by the mass hierarchy problem

Standard picture: low energy supersymmetry

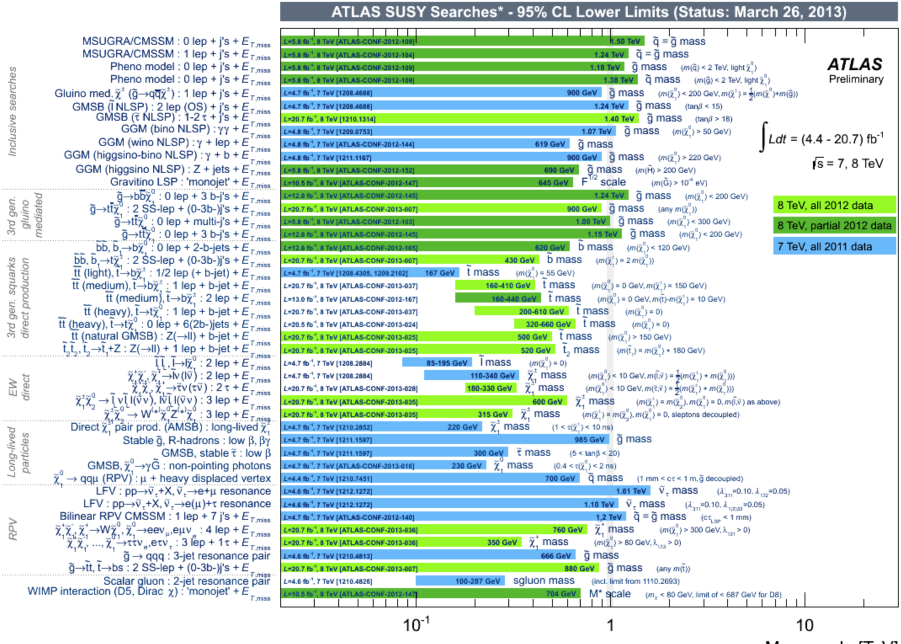
Natural framework: Heterotic string (or high-scale M/F) theory

Advantages:

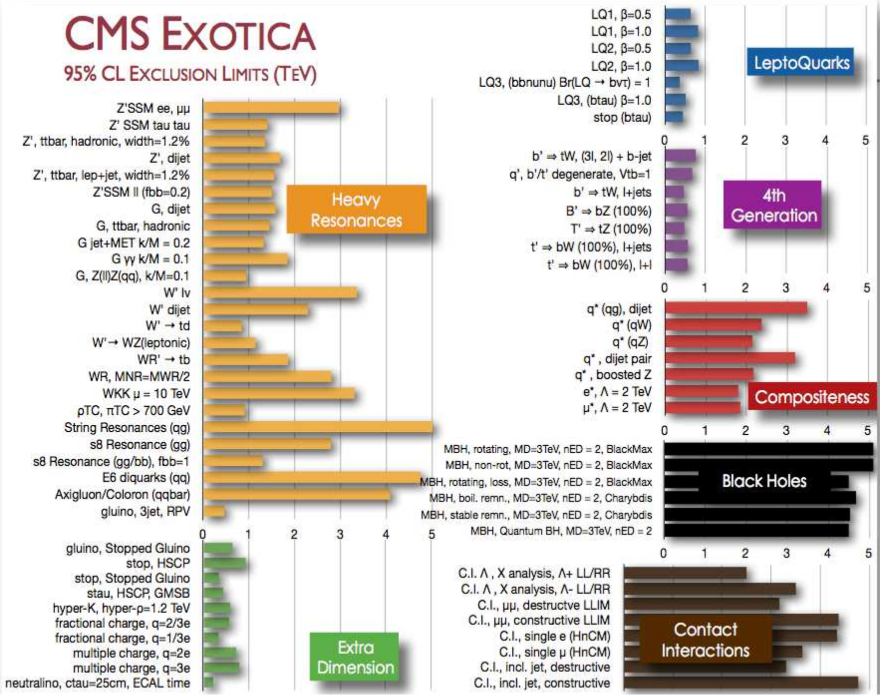
- natural elementary scalars
- gauge coupling unification
- LSP: natural dark matter candidate
- radiative EWSB

Problems:

- too many parameters: soft breaking terms
- MSSM : already a % - ‰ fine-tuning 'little' hierarchy problem



*Only a selection of the available mass limits on new states or phenomena shown.
All limits quoted are observed minus 1σ theoretical signal cross section uncertainty.


CMS EXOTICA
95% CL EXCLUSION LIMITS (TEV)
Z'SSM ee, μμ
Z' SSM tau tau
Z', ttbar, hadronic, width=1.2%
Z', dijet
Z', ttbar, lep+jet, width=1.2%
Z'SSM ll (fbb=0.2)
G, dijet
G, ttbar, hadronic
G jet+MET k/M = 0.2
G γγ k/M = 0.1
G, Z(ll)Z(qq), k/M=0.1
W' lν
W' dijet
W' → td
W'→ WZ(leptonic)
WR' → tb
WR, MNR=MWR/2
WKK μ = 10 TeV
ρTC, πTC > 700 GeV
String Resonances (qg)
s8 Resonance (gg)
s8 Resonance (gg/bb), fbb=1
E6 diquarks (qq)
Axigluon/Coloron (qqbar)
gluino, 3jet, RPV
Heavy Resonances
gluino, Stopped Gluino
stop, HSCP
stop, Stopped Gluino
stau, HSCP, GMSB
hyper-K, hyper-ρ=1.2 TeV
fractional charge, q=2/3e
fractional charge, q=1/3e
multiple charge, q=2e
multiple charge, q=3e
neutralino, ctau=25cm, ECAL time
Extra Dimension
LQ1, β=0.5
LQ1, β=1.0
LQ2, β=0.5
LQ2, β=1.0
LQ3, (bbnunu) Br(LQ → bντ) = 1
LQ3, (btau) β=1.0
stop (btau)
LeptoQuarks
b' ⇒ tW, (3l, 2l) + b-jet
q', b'/t' degenerate, Vtb=1
b' ⇒ tW, l+jets
B' ⇒ bZ (100%)
T' ⇒ tZ (100%)
t' ⇒ bW (100%), l+jets
t' ⇒ bW (100%), l+l
4th Generation
q* (qg), dijet
q* (qW)
q* (qZ)
q* , dijet pair
q* , boosted Z
e*, Λ = 2 TeV
μ*, Λ = 2 TeV
Compositeness
MBH, rotating, MD=3TeV, nED = 2, BlackMax
MBH, non-rot, MD=3TeV, nED = 2, BlackMax
MBH, rotating, loss, MD=3TeV, nED = 2, BlackMax
MBH, boil. remn., MD=3TeV, nED = 2, Charybdis
MBH, stable remn., MD=3TeV, nED = 2, Charybdis
MBH, Quantum BH, MD=3TeV, nED = 2
Black Holes
C.I. Λ , X analysis, Λ+ LL/RR
C.I. Λ , X analysis, Λ- LL/RR
C.I., μμ, destructve LLIM
C.I., μμ, constructive LLIM
C.I., single e (HnCM)
C.I., single μ (HnCM)
C.I., incl. jet, destructive
C.I., incl. jet, constructive
Contact Interactions

Remarks on the value of the Higgs mass ~ 125 GeV

- consistent with expectation from precision tests of the SM
- favors perturbative physics quartic coupling $\lambda = m_H^2/v^2 \simeq 1/8$

Window to new physics

- compatible with supersymmetry

  but appears fine-tuned in its minimal version [10]

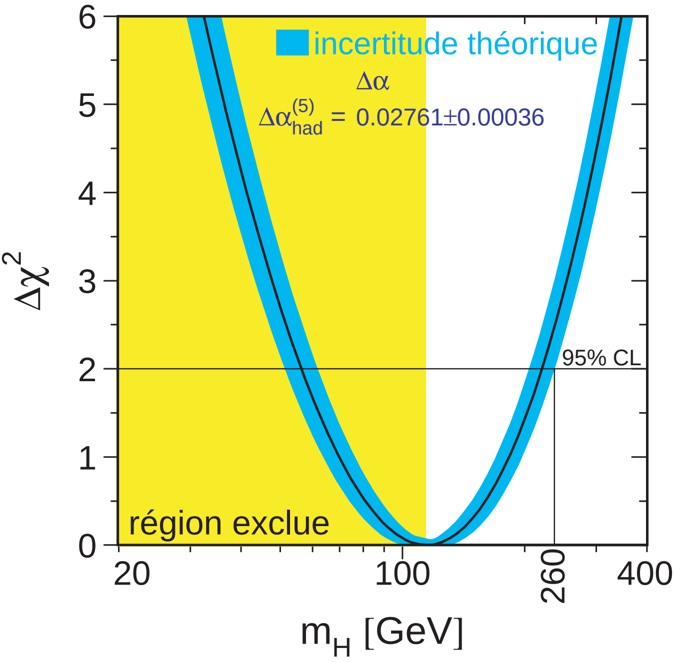
  early to draw a general conclusion before LHC13/14

  e.g. an extra singlet or split families can alleviate the fine tuning [11]

- very important to measure its properties and couplings [15]

  any deviation of its couplings to top, bottom and EW gauge bosons

  implies new light states involved in the EWSB altering the fine-tuning


incertitude théorique
Δα
Δα(5)had = 0.02761±0.00036
95% CL
région exclue
Δχ2
mH [GeV]
0
1
2
3
4
5
6
20
100
260
400

Fine-tuning in MSSM

Upper bound on the lightest scalar mass:

$$m_h^2 \lesssim m_Z^2 \cos^2 2\beta + \frac{3}{(4\pi)^2}\frac{m_t^4}{v^2}\left[\ln\frac{m_{\tilde{t}}^2}{m_t^2} + \frac{A_t^2}{m_{\tilde{t}}^2}\left(1 - \frac{A_t^2}{12 m_{\tilde{t}}^2}\right)\right] \lesssim (130\, GeV)^2$$

$m_h \simeq 126$ GeV $\Rightarrow m_{\tilde{t}} \simeq 3$ TeV or $A_t \simeq 3 m_{\tilde{t}} \simeq 1.5$ TeV

$\Rightarrow$ % to a few ‰ fine-tuning

minimum of the potential: $m_Z^2 = 2\dfrac{m_1^1 - m_2^2 \tan_\beta^2}{\tan^2\beta - 1} \sim -2m_2^2 + \cdots$

RG evolution: $m_2^2 = \; m_2^2(M_{\rm GUT}) - \dfrac{3\lambda_t^2}{4\pi^2} m_{\tilde{t}}^2 \ln\dfrac{M_{\rm GUT}}{m_{\tilde{t}}} + \cdots$ [26]

$$\sim m_2^2(M_{\rm GUT}) - \mathcal{O}(1) m_{\tilde{t}}^2 + \cdots$$ [8]

MSSM with dim-5 and 6 operators

I.A.-Dudas-Ghilencea-Tziveloglou '08, '09, '10

parametrize new physics above MSSM by higher-dim effective operators

relevant super potential operators of dimension-5:

$$\mathcal{L}^{(5)} = \frac{1}{M} \int d^2\theta \, (\eta_1 + \eta_2 S) \, (H_1 H_2)^2$$

η_1 : generated for instance by a singlet

$$W = \lambda \sigma H_1 H_2 + M\sigma^2 \quad \rightarrow \quad W_{\rm eff} = \frac{\lambda^2}{M} \, (H_1 H_2)^2$$

Strumia '99 ; Brignole-Casas-Espinosa-Navarro '03
Dine-Seiberg-Thomas '07

η_1 : corresponding soft breaking term   spurion $S \equiv m_S \, \theta^2$

Physical consequences of MSSM$_5$: Scalar potential

$$\mathcal{V} = m_1^2|h_1|^2 + m_2^2|h_2|^2 + B\mu(h_1 h_2 + \mathrm{h.c.}) + \frac{g_2^2 + g_Y^2}{8}\left(|h_1|^2 - |h_2|^2\right)^2$$
$$+ \left(|h_1|^2 + |h_2|^2\right)\left(\eta_1 h_1 h_2 + \mathrm{h.c.}\right) + \frac{1}{2}\left[\eta_2 (h_1 h_2)^2 + \mathrm{h.c.}\right] + \mathcal{O}\left(\eta_i^2\right)$$

- $\eta_{1,2} \Rightarrow$ quartic terms along the D-flat direction $|h_1| = |h_2|$
- potential stability $\Rightarrow \eta_2 \geq 4|\eta_1|$

requiring η-corrections to be smaller than MSSM mass matrix elements $\Rightarrow$

only η_2 can change the tree-level bound $m_h \leq m_Z$ but marginally

Relevance of dim-6 operators

Relaxing the condition on potential positivity: guaranteed by dim-6 ops

only one dim-6 along the D-flat direction induced by dim-5: $\propto \eta_1^2$

$$W = \eta_1 (H_1 H_2)^2 \longrightarrow V = \left| \frac{\partial W}{\partial H_i} \right|^2 \sim \eta_1^2 \, |H_1 H_2|^2 \left(|H_1|^2 + |H_2|^2 \right)$$

- tree-level mass can increase significantly
- bigger parameter space for LSP being dark matter

Bernal-Blum-Nir-Losada '09

MSSM Higss with dim-6 operators

dim-6 operators can have an independent scale from dim-5

Classification of all dim-6 contributing to the scalar potential

(without $SU\!\!\!/SY$) $\Rightarrow$

large $\tan\beta$ expansion: $\delta_6 m_h^2 = f v^2 + \cdots$

constant receiving contributions from several operators

$f \sim f_0 \times \left(\mu^2/M^2,\ m_S^2/M^2,\ \mu m_S/M^2,\ v^2/M^2\right)$

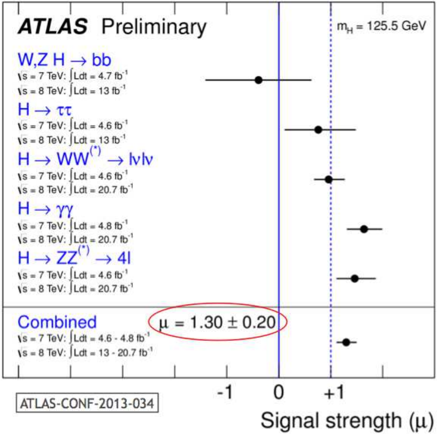
$m_S = 1$ TeV, $M = 10$ TeV, $f_0 \sim 1 - 2.5$ for each operator

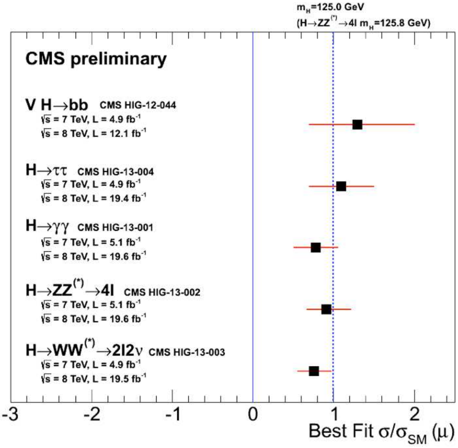
$\Rightarrow m_h \simeq 103 - 119$ GeV

$\Rightarrow$ MSSM with dim-5 and dim-6 operators:

possible resolution of the MSSM fine-tuning problem [8]

Couplings of the new boson vs SM



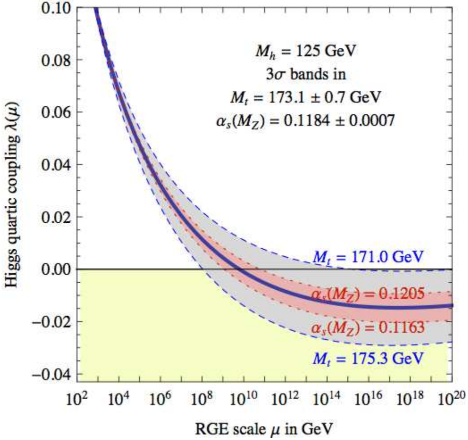


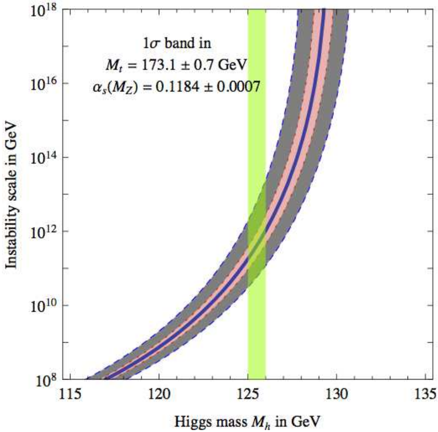
exclusion : spin 2 and pseudoscalar at 95% CL

Agreement with Standard Model expectation at $\sim 2\,\sigma$

Can the SM be valid at high energies?

Degrassi-Di Vita-Elias Miró-Espinosa-Giudice-Isidori-Strumia '12





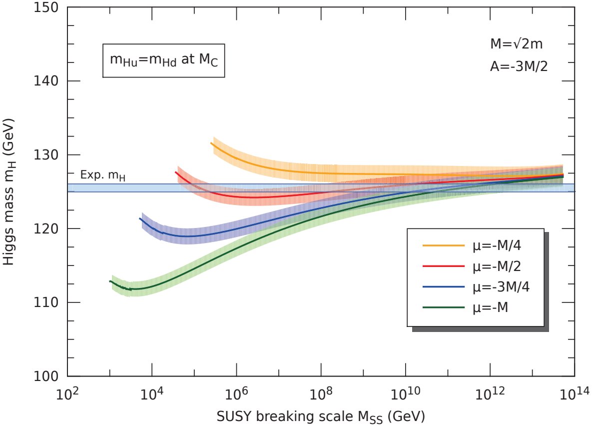
Instability of the SM Higgs potential $\Rightarrow$ metastability of the EW vacuum

SUSY : $\lambda = 0 \Rightarrow \tan\beta = 1$

$H_{SM} = \sin\beta\, H_u - \cos\beta\, H_d^*$ $\qquad$ $\lambda = \frac{1}{8}(g_2^2 + g'^2)\cos^2 2\beta$

$\lambda = 0$ at a scale $\geq 10^{10}$ GeV $\Rightarrow m_H = 126 \pm 3$ GeV

Ibanez-Valenzuela '13



e.g. for universal $\sqrt{2}m = M = M_{SS},\ A = -3/2M$

If the weak scale is tuned $\Rightarrow$ split supersymmetry is a possibility

Arkani Hamed-Dimopoulos '04, Giudice-Romaninio '04

- natural splitting: gauginos, higgsinos carry R-symmetry, scalars do not
- main good properties of SUSY are maintained

  gauge coupling unification and dark matter candidate
- also no dangerous FCNC, CP violation, ...
- experimentally allowed Higgs mass $\Rightarrow$ 'moderate' split

  $m_S \sim$ few - thousands TeV

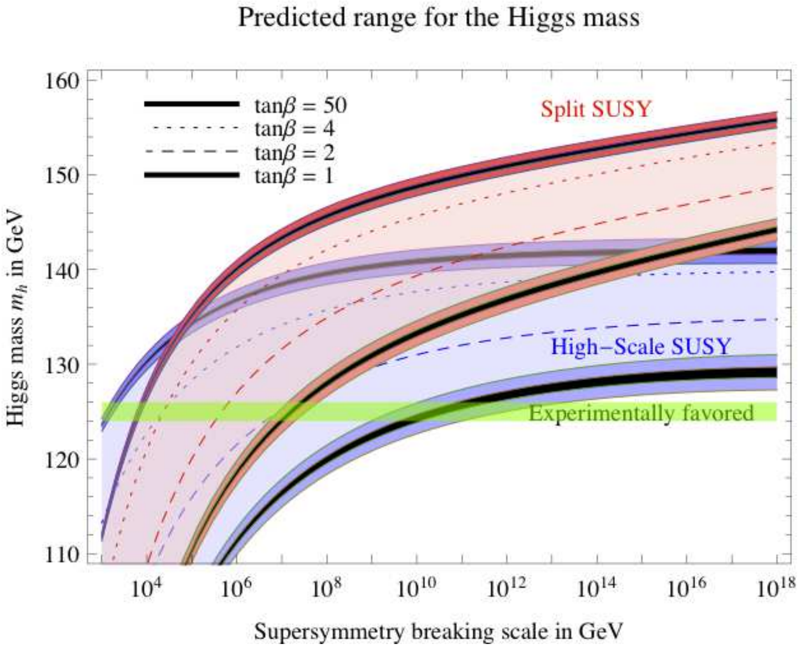
  gauginos: a loop factor lighter than scalars ($\sim m_{3/2}$)
- natural string framework: intersecting (or magnetized) branes

  IA-Dimopoulos '04

  D-brane stacks are supersymmetric with massless gauginos

  intersections have chiral fermions with broken SUSY & massive scalars

Giudice-Strumia '11



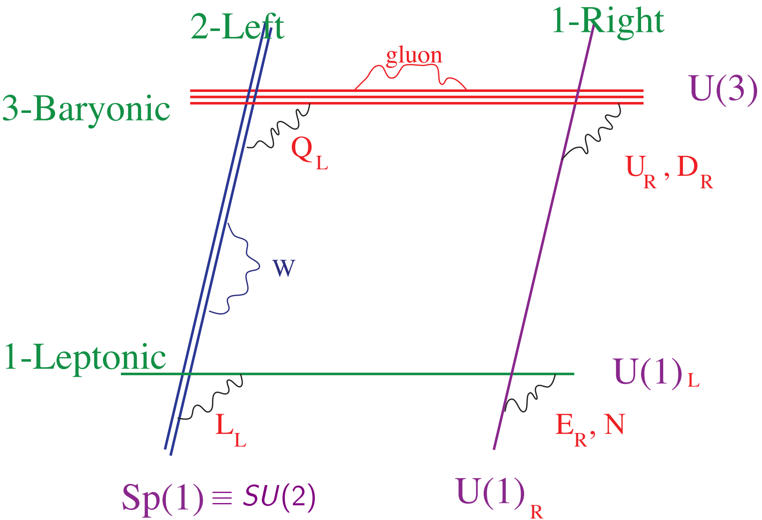
An extra $U(1)$ can also cure the instability problem

Anchordoqui-IA-Goldberg-Huang-Lüst-Taylor-Vlcek '12

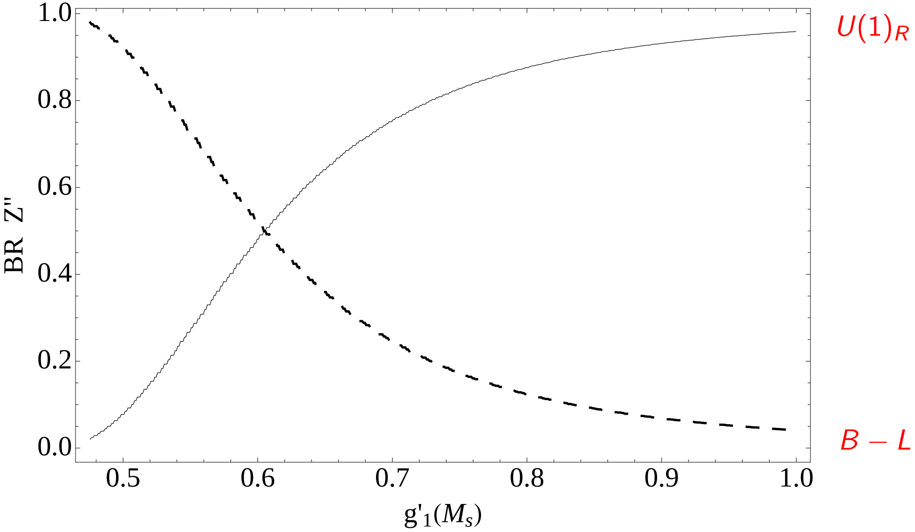
- B anomalous and superheavy
- $B - L$ massless at the string scale (no associated 6d anomaly)

  but broken at TeV by a scalar VEV with the quantum numbers of N_R
- L-violation from higher-dim operators suppressed by the string scale
- $U(3)$ unification, Y combination $\Rightarrow$ 2 parameters: 1 coupling + $m_{Z''}$
- perturbativity $\Rightarrow 0.5 \lesssim g_{U(1)_R} \lesssim 1$
- interesting LHC phenomenology and cosmology [23]

Standard Model on D-branes : SM^{++}



$U(1)^3 \Rightarrow$ hypercharge + B, L [31]


U(1)_R
B − L
BR Z''
g'1(Ms)
1.0
0.8
0.6
0.4
0.2
0.0
0.5
0.6
0.7
0.8
0.9
1.0

- Rotation of $U(1)$'s from the string to low energy basis Z, Z', Z'': completely fixed in terms of the couplings
  - Decoupling of anomalous $Z' \simeq B$
  - Z'' linear combination of $B - L$ and $U(1)_R$
- Recent cosmological observations indicate extra relativistic component dark radiation parametrized by an effective ν-number close to 4 *
  $\rightarrow$ use the 3 ν_R's interacting with SM fermions via Z''
  data: their decoupling during the quark-hadron transition
  $\Rightarrow 3.5 \lesssim M_{Z''} \lesssim 7$ TeV (within LHC14 discovery potential)

* before Planck results

Stability analysis in (non-susy) SM^{++} AAGHLTV '12

Scalar potential:

$$V\left(H,H''\right)=\mu^2\left|H\right|^2+\mu'^2\left|H''\right|^2+\lambda_1\left|H\right|^4+\lambda_2\left|H''\right|^4+\lambda_3\left|H\right|^2\left|H''\right|^2$$

5 parameters $\Rightarrow v, m_h, v'', m_{h''}$ + a scalar mixing angle α

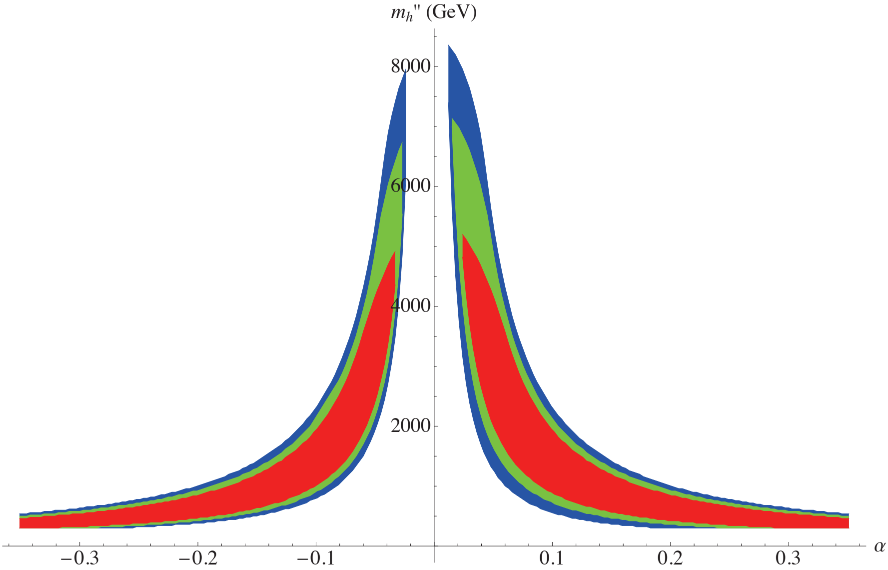
$\Rightarrow$ 3 free parameters : $m_{h''}, \alpha, v'' \leftrightarrow M_{Z''}$

Stability conditions: $\lambda_1 > 0, \quad \lambda_2 > 0, \quad \lambda_1\lambda_2 > \frac{1}{4}\lambda_3^2$

RGE analysis up to M_s $\Rightarrow$ stability is possible in SM^{++}

for $0.02 \lesssim |\alpha| \lesssim 0.35$ and $500\ \mathrm{GeV} \lesssim m_{h''} \lesssim 5\ \mathrm{TeV}$

$M_{Z''} = 4.5$ TeV; $M_s = 10^{14}$, 10^{16}, 10^{19} GeV



Alternative answer: Low UV cutoff $\Lambda \sim$ TeV

- low scale gravity $\Rightarrow$ extra dimensions: large flat or warped

- low string scale $\Rightarrow$ low scale gravity, ultra weak string coupling

$M_s \sim 1$ TeV $\Rightarrow$ volume $R_\perp^n = 10^{32}\, l_s^n$ [33] ($R_\perp \sim .1 - 10^{-13}$ mm for $n = 2-6$)

- spectacular model independent predictions

- radical change of high energy physics at the TeV scale

Moreover no little hierarchy problem:

radiative electroweak symmetry breaking with no logs

$\Lambda \sim$ a few TeV and $m_H^2 =$ a loop factor $\times\, \Lambda^2$ [10]

But unification has to be probably dropped

New Dark Matter candidates e.g. in the extra dims

Origin of EW symmetry breaking?

possible answer: radiative breaking — I.A.-Benakli-Quiros '00

$V = \mu^2 H^\dagger H + \lambda (H^\dagger H)^2$

$\mu^2 = 0$ at tree but becomes < 0 at one loop — non-susy vacuum

simplest case: one scalar doublet from the same brane

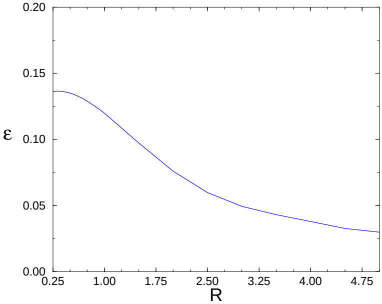
$\Rightarrow$ tree-level V same as susy: $\lambda = \frac{1}{8}(g_2^2 + g'^2)$ — D-terms

$\mu^2 = -g^2 \varepsilon^2 M_s^2 \leftarrow$ effective UV cutoff

UV $\qquad$ $e^{-\pi l}$

$$\varepsilon^2(R) = \frac{R^3}{2\pi^2}\int_0^\infty dl\, l^{3/2}\, \frac{\theta_2^4}{16\, l^4 \eta^{12}}\left(il + \frac{1}{2}\right) \sum_n n^2 e^{-2\pi n^2 R^2 l}$$

IR $\qquad$ 1



$R \to 0\;:\;\; \varepsilon(R) \simeq 0.14$ large transverse dim $R_\perp = l_s^2/R \to \infty$

$R \to \infty :\;\; \varepsilon(R) M_s \sim \varepsilon_\infty / R$ $\quad \varepsilon_\infty \simeq 0.008$ UV cutoff: $M_s \to 1/R$

Higgs scalar $=$ component of a higher dimensional gauge field

$\Rightarrow \varepsilon_\infty$ calculable in the effective field theory

$$\lambda = g^2/4 \sim 1/8 \quad \Rightarrow \quad M_H \simeq v/2 = 125 \text{ GeV}$$

M_s or $1/R \sim$ a few or several TeV

Accelerator signatures: 4 different scales

- Gravitational radiation in the bulk $\Rightarrow$ missing energy

  present LHC bounds: $M_* \gtrsim 3 - 5$ TeV

- Massive string vibrations $\Rightarrow$ e.g. resonances in dijet distribution

$$M_j^2 = M_0^2 + M_s^2\, j \quad ; \quad \text{maximal spin} : j + 1$$

  higher spin excitations of quarks and gluons with strong interactions

  present LHC limits: $M_s \gtrsim 5$ TeV

- Large TeV dimensions $\Rightarrow$ KK resonances of SM gauge bosons I.A. '90

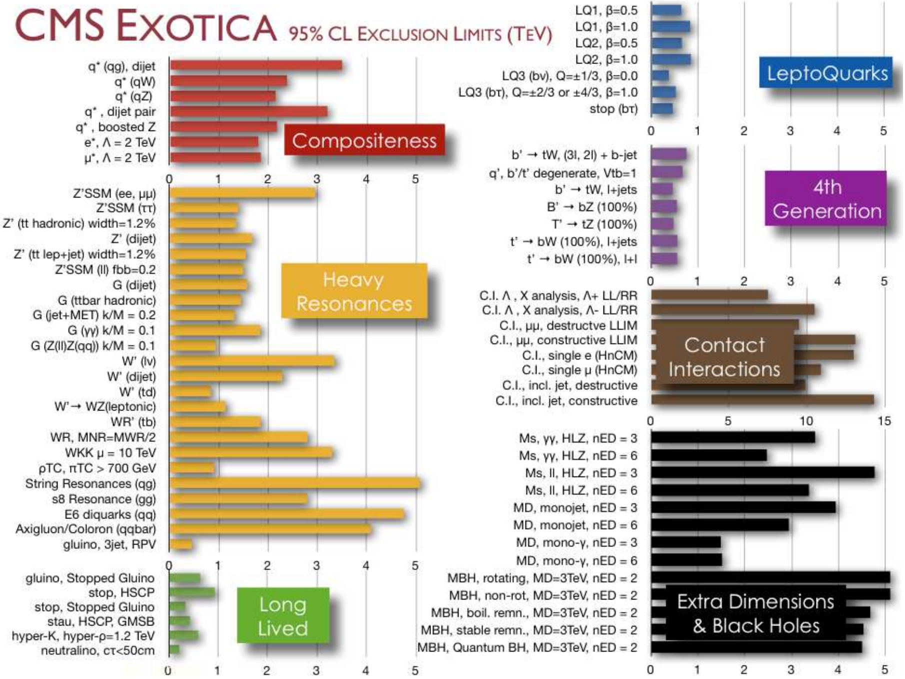
$$M_k^2 = M_0^2 + k^2/R^2 \;\; ; \;\; k = \pm 1, \pm 2, \ldots$$

  experimental limits: $R^{-1} \gtrsim 0.5 - 4$ TeV (UED - localized fermions)

- extra $U(1)$'s and anomaly induced terms

  masses suppressed by a loop factor from M_s [31]

CMS EXOTICA 95% CL EXCLUSION LIMITS (TEV)



Extra $U(1)$'s and anomaly induced terms

masses suppressed by a loop factor

usually associated to known global symmetries of the SM

(anomalous or not) such as (combinations of)

Baryon and Lepton number, or PQ symmetry

Two kinds of massive $U(1)$'s: I.A.-Kiritsis-Rizos '02

- 4d anomalous $U(1)$'s: $M_A \simeq g_A M_s$

- 4d non-anomalous $U(1)$'s: (but masses related to 6d anomalies)

$M_{NA} \simeq g_A M_s V_2 \leftarrow$ (6d$\rightarrow$4d) internal space $\Rightarrow M_{NA} \geq M_A$

or massless in the absence of such anomalies [21]

TeV string scale

- B and L become massive due to anomalies

  Green-Schwarz terms

- the global symmetries remain in perturbation

  - Baryon number $\Rrightarrow$ proton stability

  - Lepton number $\Rrightarrow$ protect small neutrino masses

  no Lepton number $\Rrightarrow \frac{1}{M_s} LLHH \rightarrow$ Majorana mass: $\frac{\langle H \rangle^2}{M_s} LL$

  $\sim$ GeV

- $B, L \Rrightarrow$ extra Z's

  with possible leptophobic couplings leading to CDF-type Wjj events

  $Z' \simeq B$ lighter than 4d anomaly free $Z'' \simeq B - L$ [42]

More general framework: large number of species

N particle species $\Rightarrow$ lower quantum gravity scale : $M_*^2 = M_p^2/N$

Dvali '07, Dvali, Redi, Brustein, Veneziano, Gomez, Lüst '07-'10

derivation from: black hole evaporation or quantum information storage

$M_* \simeq 1$ TeV $\Rightarrow N \sim 10^{32}$ particle species !

2 ways to realize it lowering the string scale

1. Large extra dimensions SM on D-branes [26]

   $N = R_\perp^n \, l_s^n$: number of KK modes up to energies of order $M_* \simeq M_s$

2. Effective number of string modes contributing to the BH bound

   $N = \dfrac{1}{g_s^2}$ with $g_s \simeq 10^{-16}$ SM on NS5-branes

I.A.-Pioline '99, I.A.-Dimopoulos-Giveon '01

More general framework: large number of species

N particle species $\Rightarrow$ lower quantum gravity scale : $\quad M_*^2 = M_p^2/N$

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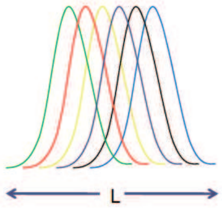
derivation from: black hole evaporation or quantum information storage

Pixel of size L containing N species storing information:



localization energy $E \gtrsim N/L \rightarrow$

Schwarzschild radius $R_s = N/(LM_p^2)$

no collapse to a black hole : $L \gtrsim R_s \Rightarrow L \gtrsim \sqrt{N}/M_p = 1/M_*$

$M_* \simeq 1$ TeV $\Rightarrow N \sim 10^{32}$ particle species !

Decouple gravity from NS5-branes

Analogy from D3-branes : decouple gravity $\Rightarrow$ $M_s \to \infty$, g_s fixed

$\to$ (conformal) Field Theory (CFT)

simplest case: 4d $\mathcal{N} = 4$ super Yang Mills $SU(N)$

parameters: number of branes N, gauge coupling g_{YM}

NS-5 branes: M_s finite, $g_s \to 0$ $\to$ (little) String Theory without gravity

simplest case: 6d LST (chiral IIA or non-chiral IIB)

massless sector: 6d $SU(N)$ of tensors (IIA) or vectors (IIB)

at a non-trivial fixed point

parameters: number of branes N, string scale M_s

How to study LST ? Using gauge/gravity duality

Gravity background : near horizon geometry (holography) Maldacena '98

Analogy from D3-branes : $AdS_5 \times S^5$

parameters: AdS radius $r_{AdS} M_s$, $g_s \leftrightarrow N, g_{YM}$

supergravity validity: $r_{AdS} M_s >> 1$, $g_s << 1 \Rightarrow$ large N, $g_{YM}^2 N$

$\rightarrow$ model independent part : AdS_5

NS-5 branes : $(\mathcal{M}_6 \underset{\uparrow}{\otimes} R_+) \times SU(2) \equiv S^3$

linear dilaton background in 7d flat string-frame metric $\Phi = -\alpha|y|$

Aharony-Berkooz-Kutasov-Seiberg '98

parameters: M_s, α (or S^3 radius) $\leftrightarrow N$

sugra validity: small $\alpha \Rightarrow$ large N

compactify to $d = 4\,(\mathcal{M}_6 \rightarrow \mathcal{M}_4) \Rightarrow g_{YM} \sim$ 2d volume

$\rightarrow$ model independent part : linear dilaton

Put gravity back **but weakly coupled**

"cut" the space of the extra dimension $\Rightarrow$ gravity on the brane

Toy 5d bulk model

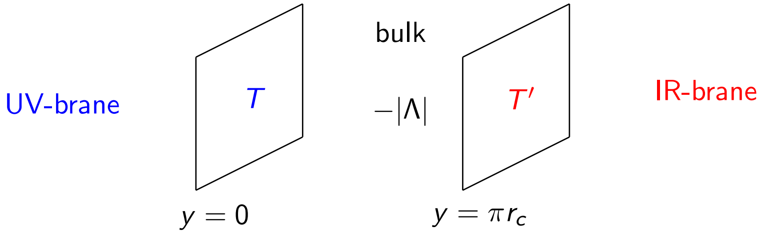
$$S_{bulk} = \int d^4x \int_0^{r_c} dy \sqrt{-g}\, e^{-\Phi} \left(M_5^3 R + M_5^3 (\nabla\Phi)^2 - \Lambda\right)$$

$$S_{vis(hid)} = \int d^4x \sqrt{-g} \left(e^{-\Phi}\right) \left(L_{SM(hid)} - T_{vis(hid)}\right)$$

Tuning conditions: $T_{vis} = -T_{hid} \leftrightarrow \Lambda < 0$ [39]

Constant dilaton and AdS metric : Randal Sundrum model

spacetime = slice of AdS$_5$: $ds^2 = e^{-2k|y|}\eta_{\mu\nu}dx^\mu dx^\nu + dy^2$ $\quad k^2 \sim \Lambda/M_5^3$



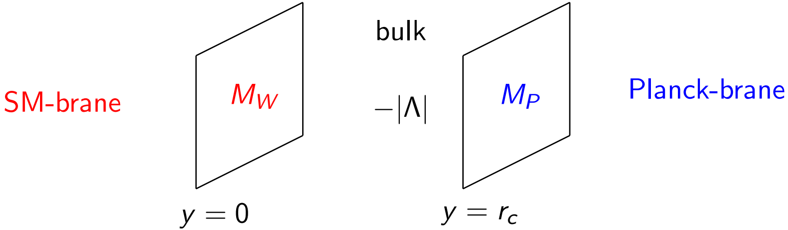
- exponential hierarchy: $M_W = M_P e^{-2kr_c}$ $\quad M_P^2 \sim M_5^3/k$ $\quad M_5 \sim M_{GUT}$
- 4d gravity localized on the UV-brane, but KK gravitons on the IR

$m_n = c_n\, k\, e^{-2kr_c} \sim$ TeV $\quad c_n \simeq (n + 1/4)$ for large n

$\Rightarrow$ spin-2 TeV resonances in di-lepton or di-jet channels dilaton $\Phi = -\alpha|y|$ and flat metric $\Rightarrow$

$$g_s^2 = e^{-\alpha|y|} \;;\; ds^2 = e^{\frac{2}{3}\alpha|y|}\left(\eta_{\mu\nu}dx^\mu dx^\nu + dy^2\right) \leftarrow \text{Einstein frame}$$

$z \sim e^{\alpha y/3} \Rightarrow$ polynomial warp factor + log varying dilaton



- exponential hierarchy: $g_s^2 = e^{-\alpha|y|}$ $\quad M_P^2 \sim \frac{M_5^3}{\alpha} e^{\alpha r_c}$ $\quad \alpha \equiv k_{RS}$
- 4d graviton flat, KK gravitons localized near SM

LST KK graviton phenomenology

- KK spectrum : $m_n^2 = \left(\frac{n\pi}{r_c}\right)^2 + \frac{\alpha^2}{4}$; $n = 1, 2, \ldots$

  $\Rightarrow$ mass gap + dense KK modes $\alpha \sim 1$ TeV $r_c^{-1} \sim 30$ GeV

- couplings : $\frac{1}{\Lambda_n} \sim \frac{1}{(\alpha r_c) M_5}$

  $\Rightarrow$ extra suppression by a factor $(\alpha r_c) \simeq 30$

- width : $1/(\alpha r_c)^2$ suppression ~ 1 GeV

  $\Rightarrow$ narrow resonant peaks in di-lepton or di-jet channels

- extrapolates between RS and flat extra dims $(n = 1)$

  $\Rightarrow$ distinct experimental signals

Radion stabilization

Cox-Gherghetta '12

Similar to RS using the dilaton as the Goldeberger-Wise scalar

add dilaton boundary potentials $\Rightarrow$

radion stabilization with the desired hierarchy

Radion phenomenology different from RS:

- mass spectrum: similar to the graviton KK modes

  with possible lower parametrically mass gap
- new radion couplings to SM fields besides to the trace of $T_{\mu\nu}$
- larger coupling to the radion 0-mode relative to KK excitations
- Higgs-radion mixing $\Rightarrow$

  branching fraction to $\gamma\gamma$ can be significantly enhanced

Conclusions

- Higgs discovery at the LHC:

  important milestone of the LHC research program

- Precise measurement of its couplings is of primary importance

- Hint on the origin of mass hierarchy and of BSM physics

  - natural or unnatural SUSY?
  - low string scale in some realization?
  - something new and unexpected?

  all options are still open

- LHC enters a new era with possible new discoveries