Aspects of string phenomenology in the LHC era

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- 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 $M_P \rightarrow$ TeV

- physical motivations $\Rightarrow$ favored energy regions:

  - High:
    \[
    \begin{align*}
    M_P^* & \simeq 10^{18} \text{ GeV} \\
    M_{\text{GUT}} & \simeq 10^{16} \text{ GeV}
    \end{align*}
    \]
    Heterotic scale

  - Intermediate: around $10^{11}$ GeV ($M_s^2/M_P \sim$ TeV)
    SUSY breaking, strong CP axion, see-saw scale

  - Low: TeV (hierarchy problem)
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 % - %₀ fine-tuning ‘little’ hierarchy problem
Excellent LHC performance

Number of events = Cross section $\times$ Luminosity

LHC 2011 RUN (3.5 TeV/beam)

- ATLAS 5.626 fb$^{-1}$
- CMS 6.136 fb$^{-1}$
- LHCb 1.217 fb$^{-1}$
- ALICE 4.877 pb$^{-1}$

LHC 2012 RUN (4 TeV/beam)

- ATLAS 23.255 fb$^{-1}$
- CMS 23.255 fb$^{-1}$
- LHCb 2.189 fb$^{-1}$
- ALICE 9.531 pb$^{-1}$

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(generated 2012-12-07 08:25 including fill 3378)
New boson discovery at LHC: is it the scalar remnant of the Brout-Englert-Higgs mechanism for breaking the EW symmetry?

\[ m_H = 125.5 \pm 0.2 \text{ (stat.)} \pm 0.5 \text{ (syst.)} \gtrsim 6 \sigma \]

\[ m_H = 125.8 \pm 0.4 \pm 0.4 \text{ GeV} \]

6.8 \sigma significance
Possible Higgs boson events
I. Antoniadis (CERN)

**ATLAS SUSY Searches** - 95% CL Lower Limits (Status: ICHEP 2012)

![Diagram of SUSY searches and mass limits for various particle interactions and decay modes, with mass scales on the x-axis and limits on the y-axis.](image)

- **Inclusive searches**
  - MSUGRA/CMSSM: 0 lep + j's + E_{T,miss}
  - GMSB: 2 lep OSSF + E_{T,miss}
  - GGM: \gamma + E_{T,miss}

- **3rd gen. squarks, gluinos mediated**
  - g \to b\bar{b} \chi_1 (virtual b): 0 lep + 1/2 b+j's + E_{T,miss}
  - g \to b\bar{b} \chi_1 (real b): 0 lep + b+j's + E_{T,miss}
  - g \to t\bar{t} \chi_1 (virtual t): 1 lep + 1/2 t+j's + E_{T,miss}
  - g \to t\bar{t} \chi_1 (virtual t): 2 lep (SS) + j’s + E_{T,miss}

- **3rd gen. squarks, direct production**
  - bb \to b\bar{b} \chi_1: 0 lep + 2-jets + E_{T,miss}
  - \tilde{t} \tilde{b} \chi_1: 1/2 lep + b-jet + E_{T,miss}
  - \tilde{t} \tilde{t} \chi_1: 1 lep + j’s + E_{T,miss}
  - \tilde{t} \tilde{t} \chi_1 (GMSB): \tilde{Z} \tilde{\tau}_L \chi_1:

- **EW, Higgs decays**
  - Higgs \to WW, ZZ, \gamma\gamma
  - Higgs mass limits for various Higgs boson masses.

- **Long-lived particles**
  - Stable \tilde{R}-hadrons: Full detector
  - Stable \tilde{R}-hadrons: Pixel detector only

- **RPV**
  - Bilinear RPV: 1 lep + j’s + E_{T,miss}
  - BCI RPV: 4 lep + E_{T,miss}

- **Hypermultiplet gluinos**
  - 4 jets, m_{\tilde{g}} = m_{\tilde{M}_1}

- **Spin dependent WIMP interaction**
  - Monojets + E_{T,miss}

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*Only a selection of the available mass limits on new states or phenomena shown.*
Remarks on the value $\sim 125$ GeV

- consistent with expectation from precision tests of the SM
- favors perturbative physics quartic coupling $\lambda = \frac{m_H^2}{v^2} \approx 1/8$
- window to new physics

If confirmed:

- compatible with supersymmetry but appears fine-tuned in its minimal version $^{[11]}$
- early to draw a general conclusion before LHC13/14 e.g. an extra singlet or split families can alleviate the fine tuning $^{[12]}$
- very important to measure its properties and couplings $^{[16]}$
- any deviation of its couplings to top, bottom and EW gauge bosons implies new light states involved in the EWSB altering the fine-tuning
\[ \Delta \alpha_{\text{had}}^{(5)} = 0.02761 \pm 0.00036 \]
Upper bound on the lightest scalar mass:

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

\[ m_h \sim 126 \text{ GeV} \Rightarrow m_{\tilde{t}} \sim 3 \text{ TeV} \text{ or } A_t \sim 3m_{\tilde{t}} \sim 1.5 \text{ TeV} \]

\[ \Rightarrow \% \text{ to a few } \% \text{ fine-tuning} \]

minimum of the potential: \[ m_Z^2 = 2 \frac{m_1^1 - m_2^2 \tan^2 \beta}{\tan^2 \beta - 1} \sim -2m_2^2 + \cdots \]

RG evolution: \[ m_2^2 = m_2^2(M_{\text{GUT}}) - \frac{3\lambda_t^2}{4\pi^2} m_t^2 \ln \frac{M_{\text{GUT}}}{m_{\tilde{t}}} + \cdots \]

\[ \sim m_2^2(M_{\text{GUT}}) - \mathcal{O}(1)m_{\tilde{t}}^2 + \cdots \]
MSSM with dim-5 and 6 operators

parametrize new physics above MSSM by higher-dim effective operators

relevant super potential operators of dimension-5:

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

\( \eta_1 \): generated for instance by a singlet

\[ W = \lambda \sigma H_1 H_2 + M \sigma^2 \quad \rightarrow \quad W_{\text{eff}} = \frac{\lambda^2}{M} (H_1 H_2)^2 \]

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

\( \eta_1 \): corresponding soft breaking term

spurion \( S \equiv m_S \theta^2 \)
Physical consequences of MSSM$_5$: Scalar potential

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

- $\eta_1,2 \Rightarrow$ quartic terms along the D-flat direction $|h_1| = |h_2|

- potential stability $\Rightarrow \eta_2 \geq 4|\eta_1|

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

only $\eta_2$ 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: $\propto \eta_1^2$

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

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

Bernal-Blum-Nir-Losada ’09
MSSM Higgs 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

(\text{without SUSY}) \Rightarrow

\text{large tan} \beta \text{ expansion: } \delta_6 m_h^2 = f v^2 + \cdots

\text{constant receiving contributions from several operators}

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

m_S = 1 \text{ TeV}, M = 10 \text{ TeV}, f_0 \sim 1 - 2.5 \text{ for each operator}

\Rightarrow m_h \simeq 103 - 119 \text{ GeV}

\Rightarrow \text{MSSM with dim-5 and dim-6 operators:}

possible resolution of the MSSM fine-tuning problem \[^9\]
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?

Instability of the SM Higgs potential $\Rightarrow$ metastability of the EW vacuum
If the weak scale is tuned $\Rightarrow$ split supersymmetry is a possibility

Arkani Hamed-Dimopoulos '04, Giudice-Romanino '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
  \[ m_S \sim \text{few - thousands TeV} \]
  - gauginos: a loop factor lighter than scalars ($\sim m_{3/2}$)
- natural string framework: intersecting (or magnetized) branes
  \[ \text{IA-Dimopoulos '04} \]
  - D-brane stacks are supersymmetric with massless gauginos
  - intersections have chiral fermions with broken SUSY & massive scalars
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 $\Rightarrow$ $0.5 \lesssim g_{U(1)_R} \lesssim 1$
- present LHC limits: $m_{Z''} \gtrsim 3 - 4$ TeV (for $Z'' \simeq B - L$ or $U(1)_R$)
- interesting LHC phenomenology and cosmology [22]
Standard Model on D-branes: SM$^{++}$

3-Baryonic

2-Left

1-Right

1-Leptonic

Sp(1) $\equiv$ SU(2)

$U(1)^3 \Rightarrow$ hypercharge + B, L $^{[32]}$
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 neutrino number close to 4

$\rightarrow$ use the 3 $\nu_R$’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)
Scalar potential:

\[ V(H, H'') = \mu^2 |H|^2 + \mu''^2 |H''|^2 + \lambda_1 |H|^4 + \lambda_2 |H''|^4 + \lambda_3 |H|^2 |H''|^2 \]

5 parameters \(\Rightarrow\) \(v, m_h, v'', m_{h''} + \) a scalar mixing angle \(\alpha\)

\(\Rightarrow\) 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 \(500\) GeV \(\lesssim m_{h''} \lesssim 5\) TeV
$M_{Z''} = 4.5$ TeV; $M_s = 10^{14}, 10^{16}, 10^{19}$ GeV
Alternative answer: Low UV cutoff $\Lambda \sim \text{TeV}$

- low scale gravity $\Rightarrow$ extra dimensions: large flat or warped
- low string scale $\Rightarrow$ low scale gravity, ultra weak string coupling

$M_s \sim 1 \text{ TeV} \Rightarrow$ volume $R_{\perp}^n = 10^{32} l_s^n$ \text{[34]} ($R_\perp \sim .1 - 10^{-13} \text{ mm for } n = 2 - 6$)

- 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 $\times \Lambda^2$ \text{[28]}

But unification has to be probably dropped

New Dark Matter candidates e.g. in the extra dims
2 types of compact extra dimensions:

- parallel ($d_\parallel$): $\lesssim 10^{-16}$ cm (TeV)
- transverse ($\perp$): $\lesssim 0.1$ mm (meV) [??]
Origin of EW symmetry breaking?

possible answer: radiative breaking

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

\[ \mu^2 = 0 \text{ at tree but becomes } < 0 \text{ at one loop} \]

non-susy vacuum

simplest case: one scalar doublet from the same brane

\[ \Rightarrow \text{tree-level } V \text{ same as susy: } \lambda = \frac{1}{8}(g_2^2 + g'^2) \]

D-terms

\[ \mu^2 = -g^2 \varepsilon^2 M_s^2 \leftarrow \text{effective UV cutoff} \]

\[ \varepsilon^2(R) = \frac{R^3}{2\pi^2} \int_0^\infty \frac{\theta_2^4}{16l^4\eta^{12}} \left( il + \frac{1}{2} \right) \sum_n n^2 e^{-2\pi n^2 R^2 l} \]
\( R \to 0 : \quad \varepsilon(R) \approx 0.14 \quad \text{large transverse dim} \quad R_{\perp} = l_s^2/R \to \infty \)

\( R \to \infty : \quad \varepsilon(R)M_s \sim \varepsilon_\infty/R \quad \varepsilon_\infty \approx 0.008 \quad \text{UV cutoff: } M_s \to 1/R \)

Higgs scalar = component of a higher dimensional gauge field

\( \Rightarrow \varepsilon_\infty \) calculable in the effective field theory
Quartic coupling \Rightarrow mass prediction:

- tree level: \( M_H = M_Z \)
- low-energy SM radiative corrections (from top quark): \( M_H \sim 120 \text{ GeV} \)
  
  Casas-Espinosa-Quiros-Riotto, Carena-Espinosa-Quiros-Wagner '95

Increasing \( \lambda \rightarrow g^2/4 \sim 1/8 \) \( \Rightarrow \) \( M_H \sim \nu/2 = 125 \text{ GeV} \)

Also \( M_s \) or \( 1/R \sim a \text{ few or several TeV} \)
Accelerator signatures: 4 different scales

- Gravitational radiation in the bulk \(\Rightarrow\) missing energy
  
  present LHC bounds: \(M_* \gtrsim 2.5 - 4 \text{ TeV}\)

- Massive string vibrations \(\Rightarrow\) e.g. resonances in dijet distribution
  
  \[M^2_j = M^2_0 + M^2_s j\]
  
  maximal spin: \(j + 1\)

  higher spin excitations of quarks and gluons with strong interactions
  
  present LHC limits: \(M_s \gtrsim 4.5 \text{ TeV}\)

- Large TeV dimensions \(\Rightarrow\) KK resonances of SM gauge bosons
  
  \[M^2_k = M^2_0 + k^2/R^2\]

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

- extra \(U(1)\)'s and anomaly induced terms
  
  masses suppressed by a loop factor from \(M_s\) \([32]\)
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)

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

or massless in the absence of such anomalies [21]
- $B$ and $L$ become massive due to anomalies
  - Green-Schwarz terms
- the global symmetries remain in perturbation
  - Baryon number $\Rightarrow$ proton stability
  - Lepton number $\Rightarrow$ protect small neutrino masses
- no Lepton number $\Rightarrow$ extra $Z'$
- $B, L \Rightarrow$ extra $Z'$s
  - with possible leptophobic couplings leading to CDF-type $Wjj$ events

$Z' \sim B$ lighter than 4d anomaly free $Z'' \sim B - L$
More general framework: large number of species

\[ N \text{ particle species} \Rightarrow \text{lower quantum gravity scale: } M_*^2 = \frac{M_p^2}{N} \]

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

derivation from: black hole evaporation or quantum information storage

\[ M_* \sim 1 \text{ TeV} \Rightarrow N \sim 10^{32} \text{ particle species!} \]

2 ways to realize it lowering the string scale

1. Large extra dimensions \quad \text{SM on D-branes [26]}

\[ N = R^n \, l_s^n : \text{number of KK modes up to energies of order } M_* \sim M_s \]

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

\[ N = \frac{1}{g_s^2} \text{ with } g_s \sim 10^{-16} \quad \text{SM on NS5-branes} \]

I.A.-Pioline '99, I.A.-Dimopoulos-Giveon '01
More general framework: large number of species

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

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: \( L \gtrsim R_s \Rightarrow L \gtrsim \sqrt{N}/M_p = 1/M_* \)

\[ M_* \simeq 1 \text{ TeV} \Rightarrow N \sim 10^{32} \text{ particle species}! \]
What is LST? 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: $(M_6 \otimes R_+) \times SU(2) \equiv S^3$

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

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

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

compactify to $d = 4 (M_6 \rightarrow M_4) \Rightarrow g_{YM} \sim 2d$ volume

$\rightarrow$ model independent part: linear dilaton
“cut” the space of the extra dimension $\Rightarrow$ gravity on the brane

Toy 5d bulk model

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

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

Tuning conditions: $T_{\text{vis}} = -T_{\text{hid}} \leftrightarrow \Lambda < 0$ [40]
Constant dilaton and AdS metric: Randal Sundrum model

spacetime = slice of AdS$_5$ : \[ ds^2 = e^{-2k|y|} \eta_{\mu\nu} dx^\mu dx^\nu + dy^2 \]

\[ k^2 \sim \Lambda/M_5^3 \]

- 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

\[ m_n = c_n k e^{-2kr_c} \sim \text{TeV} \quad c_n \approx (n + 1/4) \text{ for large } n \]

\[ \Rightarrow \text{ spin-2 TeV resonances in di-lepton or di-jet channels} \]
Linear dilaton background IA-Arvanitaki-Dimopoulos-Giveon '11

Dilaton \( \Phi = -\alpha |y| \) and flat metric \( \Rightarrow \)

\[ g_s^2 = e^{-\alpha |y|} ; \quad ds^2 = e^{2\alpha |y|} (\eta_{\mu\nu} dx^\mu dx^\nu + dy^2) \quad \leftarrow \text{Einstein frame} \]

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

\[ \begin{array}{ccc}
\text{SM-brane} & M_W & \text{bulk} \\
\text{SM-brane} & M_W & \text{bulk} \\
y = 0 & -|\Lambda| & y = r_c \\
\end{array} \]

- 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 \( \alpha \sim 1 \text{ TeV} \quad r_c^{-1} \sim 30 \text{ GeV} \)

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

  \[ \Rightarrow \] extra suppression by a factor \( (\alpha r_c) \sim 30 \)

- width: \( 1/(\alpha r_c)^2 \) suppression \( \sim 1 \text{ GeV} \)

  \[ \Rightarrow \] 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

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

add dilaton boundary potentials ⇒

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

- Confirmation of the EWSB scalar 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?
- LHC enters a new era with possible new discoveries