Soft-Wall Stabilization

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Introduction: Warped extra dimensions

We will concentrate on 5D geometries with a metric

$$ds^2 = e^{-2A(y)}\eta_{\mu\nu}dx^\mu dx^\nu + dy^2 = e^{-2A(z)}\left(\eta_{\mu\nu}dx^\mu dx^\nu + dz^2\right)$$

The RS model [1]

$$\text{AdS: } e^{-2A(y)} = e^{-2ky} = \frac{1}{(kz)^2}$$

- RS1: Two branes. Requires stabilization of brane separation.
  GW mechanism [2]: introduction of a bulk scalar field.
- RS2: Single brane (UV).

[1] Randall, Sundrum (1999)
[2] Goldberger, Wise (2009)

Soft-Wall models

- Warped models with a single brane (y=0).
  - Metric is AdS near the brane.
- IR brane is replaced by a naked singularity at finite y (y_s).
  - y_s needs to be dynamically fixed by a GW-like mechanism.
  - Can correspond to finite or infinite z_s.
- Give rise to interesting phenomenology:
  - Modelization of Regge behaviour of excited mesons (AdS/QCD). [1]
    $$(\ m_n^2 \sim n \ )$$
  - Alternative to RS1 for EWSB models. [2]
  - 5D description of unparticles with a mass gap. [3]

[1] Karch, Katz, Son, Stephanov (2006) ; Gürsoy, Kiritsis (2007)
[2] Falkowski, Perez-Victoria (2008) ; Batell, Gherghetta, Sword (2008)
[3] Cacciapaglia, Marandella, Terning (2008) ; Falkowski, Perez-Victoria (2008)

The Scalar-Gravity system

- The metric is generated by the background of a bulk scalar field $\phi(y)$ with boundary conditions at the brane $\phi(y=0)=\phi_0$.
  - Provides a mechanism to stabilize the length of the extra dimension.
- In order to find the backreaction we need to solve the Einstein EOM

The "superpotential" method [4] (mathematical *trick*)

$$V(\phi) \equiv 3\left(\partial_\phi W(\phi)\right)^2 - 12 W(\phi)^2$$

$$\phi'(y) = \partial_\phi W(\phi[y]) \qquad A'(y) = W(\phi[y])$$

[4] DeWolfe, Freedman, Gubser, Karch (2000)

A classification of soft-wall models

- Depending on the asymptotic behaviour of the superpotential $W(\phi)$ near the singularity, we get different behaviours

$W(\phi)$	$\leq \phi^2$	$> \phi^2$ $< e^\phi$	e^ϕ	$e^\phi \phi^\beta$ $0 < \beta \leq \frac{1}{2}$	$> e^\phi \phi^{\frac{1}{2}}$ $< e^{2\phi}$	$\geq e^{2\phi}$
y_s	∞	finite				
z_s	∞				finite	
mass spectrum*	continuous	continuous w/ mass gap		discrete		
				$m_n \sim n^{2\beta}$	$m_n \sim n$	
consistent solution**	yes					no

* Fluctuations of any bulk field.

** Boundary EOMs satisfied at y_s and singularity of the "good kind" [5]

[5] Gubser (2000)

A soft-wall model with natural stabilization

- Let us consider a simple soft-wall model with the listed properties

$$W(\phi) = k\left(1 + e^{\nu\phi}\right) \quad 0 \leq \nu \leq 2$$

$$A(y) = ky - \frac{1}{\nu^2}\log\left(1 - \frac{y}{y_s}\right) \quad , \quad \phi(y) = -\frac{1}{\nu}\log\left[\nu^2 k(y_s - y)\right]$$

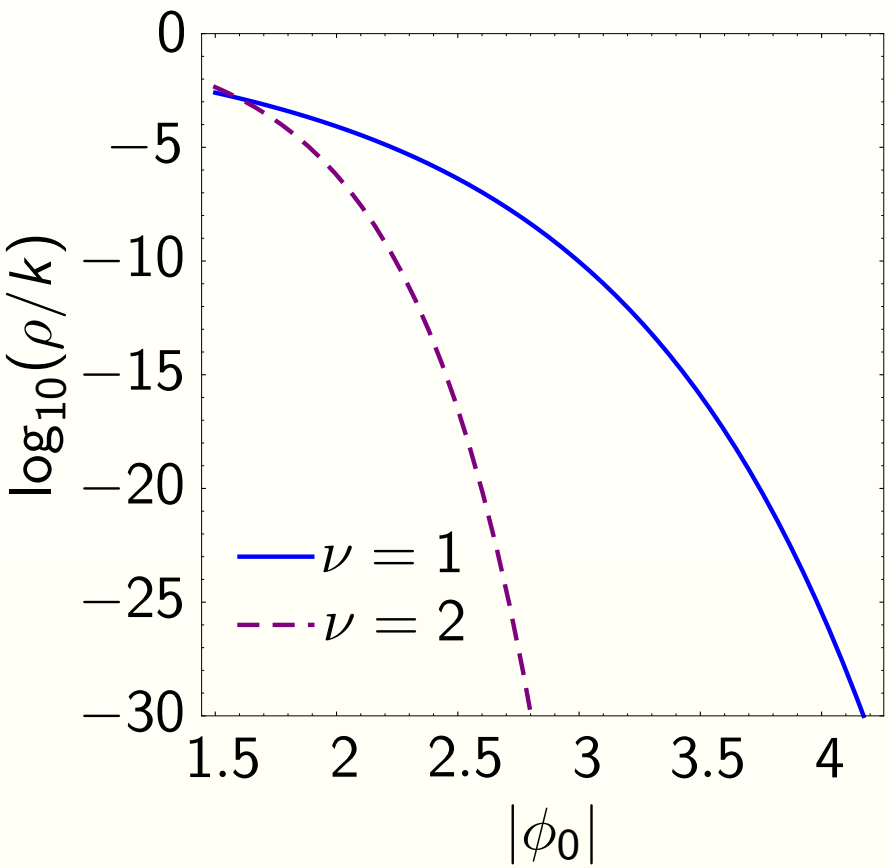
- The singularity is located at $ky_s = \frac{1}{\nu^2}e^{-\nu\phi_0}$
- The relevant mass scale is $\rho = k(ky_s)^{-1/\nu^2}e^{-ky_s}$

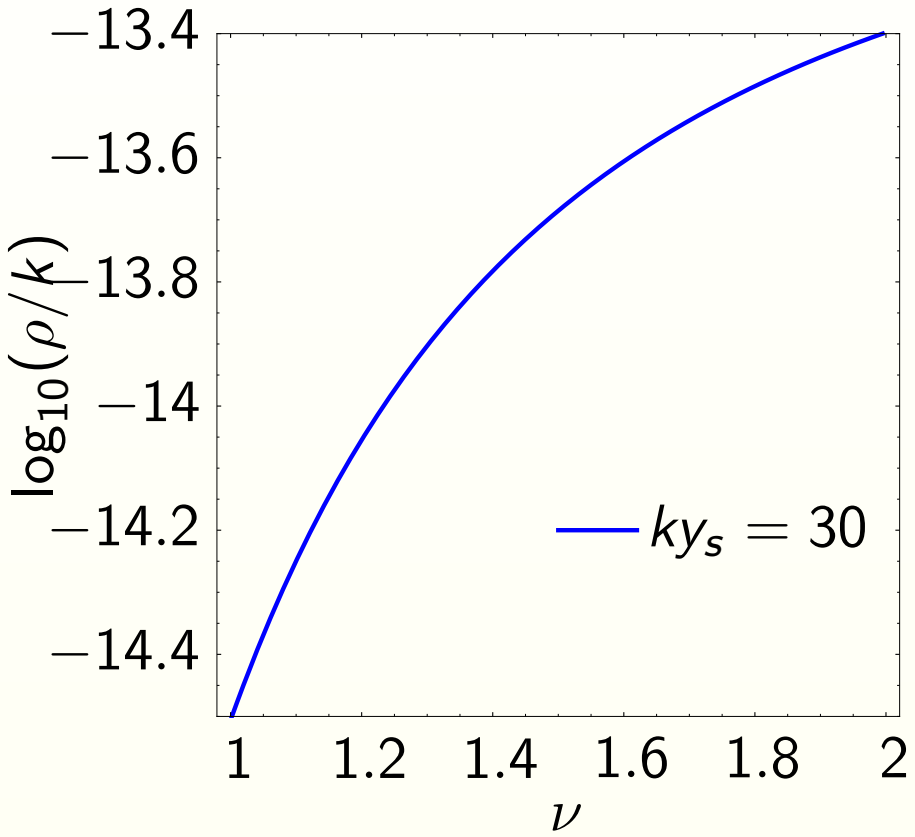
$$\log\frac{k}{\rho} \sim \frac{e^{\nu(-\phi_0)}}{\nu^2} + \cdots$$

Double exponential: A huge hierarchy can be generated with very little fine-tuning.

The hierarchy generation

$$ky_s = \frac{1}{\nu^2} e^{-\nu\phi_0} \qquad \frac{\rho}{k} = (ky_s)^{-1/\nu^2} e^{-ky_s}$$

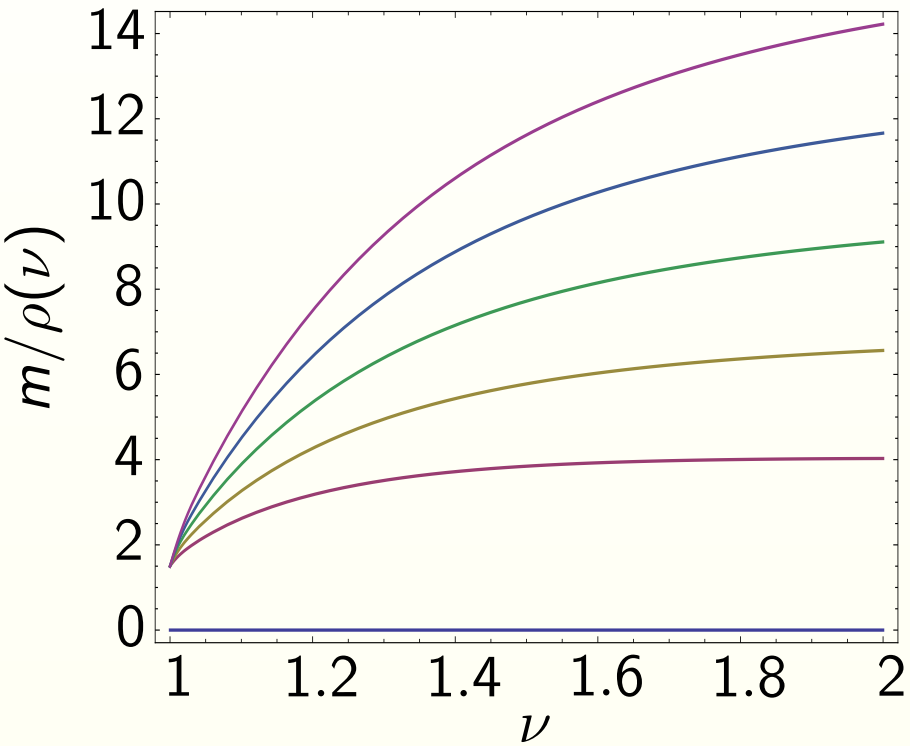




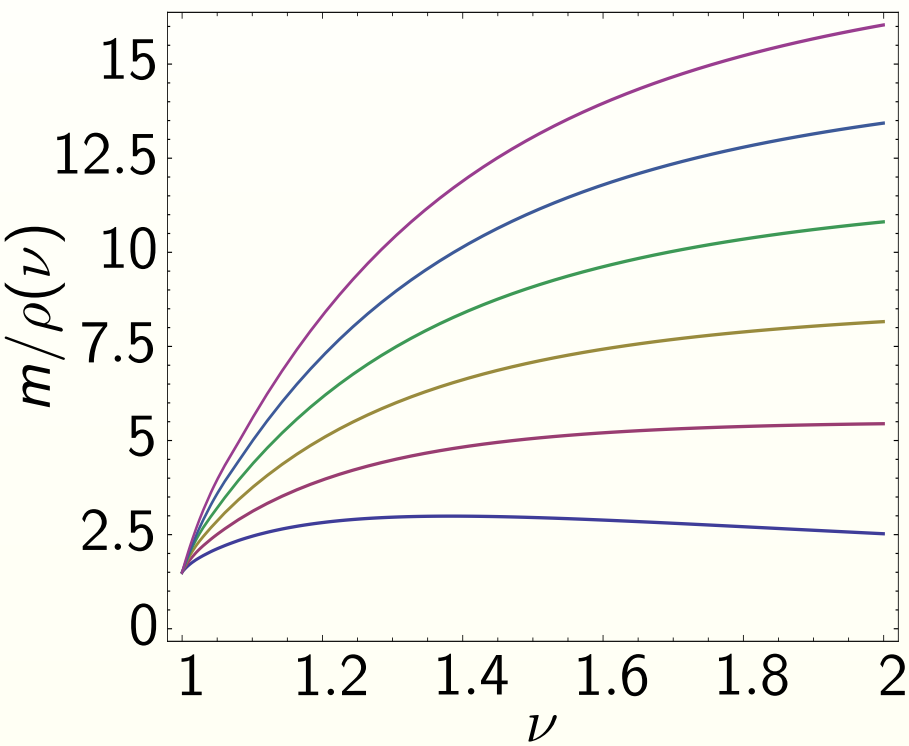
Mass spectrum

- The mass spectrum of any field propagating in the bulk behaves as
  - $0 < \nu < 1 \Rightarrow$ continuous w/o mass gap
  - $\nu = 1 \Rightarrow$ continuous w/ mass gap
  - $\nu > 1 \Rightarrow$ discrete ($m_n \sim n$)

graviton



bulk scalar - radion



Future work

- $\nu > 1$: KK modes can be produced at LHC by their interaction with matter. Specific signatures different from RS1.
- In order to solve the gauge hierarchy problem the Higgs boson should propagate in the bulk (KK modes are localized near the singularity).
- For $\nu = 1$, the continuum spectra with a mass gap can interact with SM fields in the brane. Could describe unparticle phenomenology within a concrete model.
- When $m_n^2 \sim n$, a phenomenological descripton of AdS/QCD would be possible, and the QCD scale can be naturally stabilized.