

Features of warped geometry in presence of Gauss-Bonnet coupling ^{1 2 3}

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¹Sayantan Choudhury, Soumitra SenGupta & Soumya Sadhukhan,
arXiv:1308.1477[hep-ph]

²Sayantan Choudhury, Soumitra SenGupta, arXiv:1306.0492[hep-th]

³Sayantan Choudhury, Soumitra SenGupta, arXiv:1301.0918[hep-th],
JHEP 02 (2013) 136

Outline of My Talk

★ Highlights....

★ Einstein Gauss-Bonnet warped geometry model in presence of string loop corrections and dilaton couplings

★ Warp factor and brane tension

★ Analysis of bulk Kaluza-Klein (KK) spectrum.....

★ Bulk Graviton & brane SM field interaction in presence of Gauss-Bonnet coupling.....

★ Collider constraints on the Gauss-Bonnet coupling from Higgs phenomenology....

★ Bottom lines....

HIGHLIGHTS

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- ▶ **Comparing our results with that obtained through the usual RS analysis.**
- ▶ **Stringent collider constraints on GB coupling from different phenomenological probes obtained from 125 GeV Higgs.**

THE BACKGROUND WARPED GEOMETRY MODEL

▶ 5D MODEL ACTION

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$$S_{(5)} = S_{EH} + S_{GB} + S_{loop} + S_{Bulk} + S_{Brane}$$

where

$$S_{EH} = \frac{M_{(5)}^3}{2} \int d^5x \sqrt{-g_{(5)}} R_{(5)}$$

$$S_{GB} = \frac{\alpha_{(5)} M_{(5)}}{2} \int d^5x \sqrt{-g_{(5)}} \left[R^{ABCD(5)} R_{ABCD}^{(5)} - 4R^{AB(5)} R_{AB}^{(5)} + R_{(5)}^2 \right]$$

$$S_{loop} = -\frac{\alpha_{(5)} A_1 M_{(5)}}{2} \int d^5x \sqrt{-g_{(5)}} e^{\theta_1 \phi} \left[R^{ABCD(5)} R_{ABCD}^{(5)} - 4R^{AB(5)} R_{AB}^{(5)} + R_{(5)}^2 \right]$$

$$S_{Bulk} = \int d^5x \sqrt{-g_{(5)}} \left[\mathcal{L}_{Bulk}^{field} - 2\Lambda_{(5)} e^{\theta_2 \phi} \right]$$

$$S_{Brane} = \int d^5x \sum_{i=1}^2 \sqrt{-g_{(5)}^{(i)}} \left[\mathcal{L}_{(i)}^{field} - T_{(i)} e^{\theta_2 \phi} \right] \delta(y - y_{(i)})$$

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► BACKGROUND METRIC

$$ds_{(5)}^2 = g_{AB} dx^A dx^B = e^{-2A(y)} \eta_{\alpha\beta} dx^\alpha dx^\beta + r_c^2 dy^2$$

► S^1/Z_2 orbifold points are $y_i = [0, \pi]$ and PBC in $-\pi \leq y \leq \pi$.

THE BACKGROUND WARPED GEOMETRY MODEL

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THE BACKGROUND WARPED GEOMETRY MODEL

- ▶ **From a theoretical standpoint, like RS the proposed warped geometry model has its underlying motivation in the backdrop of string theory where the throat geometry (Klebanov- Strassler) solution exhibits warping character.**
- ▶ **The higher curvature perturbative corrections to usual RS model originate naturally in string theory where power expansion in terms of inverse string tension yields the higher order corrections to pure Einstein's gravity.**

THE BACKGROUND WARPED GEOMETRY MODEL

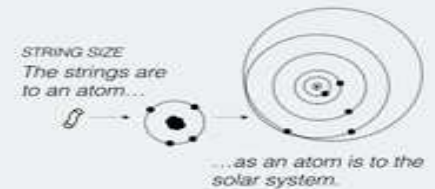
A Far-Out Theory Describing What's Out There

Physicists have long sought a unified theory to explain all the forces and matter in the universe. Superstring theory is an attempt at such a unification, and now "brane" theory expands on it, proposing that our universe is one of many membranes that "float" in a multidimensional megaverse.

SUPERSTRING THEORY
At its most basic level, the universe consists of tiny loops of string that vibrate at different frequencies.



Since matter can be described in terms of energy, each frequency (energy) corresponds to a type of particle (matter) just as different frequencies coming from a violin's strings produce different notes.



Brane Theory

It expands superstring theory to include vibrating membranes, or branes, which may have many dimensions.

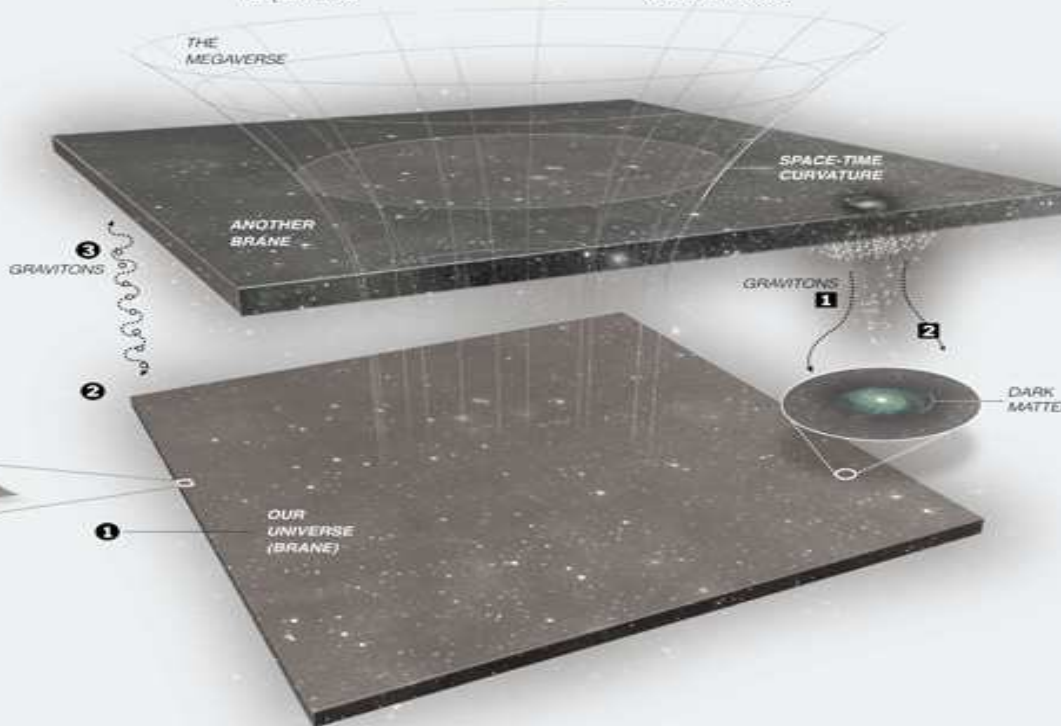
1
Our universe can be thought of as a three-dimensional brane floating inside a four-dimensional megaverse.

2
Most strings that compose our universe are attached to the brane's surface, and so most particles that exist on our brane are confined to its three-dimensional space.



3
However, the particles that convey gravity, gravitons, are not tightly confined to any particular brane, and some of them roam across to other branes in the megaverse.

Sources: "Q as for Quantum," by John Gribbin; "The Ideas of Particle Physics," by J.E. Dodd



BRANE THEORY AND GRAVITY

Gravity is described by relativity theory as curved space-time, and it is the weakest of the forces in our universe. Brane theory contains a possible explanation.

1
Gravitons, conveyors of gravity, may be concentrated on a different brane where the space-time of the megaverse is severely curved. Only a small number of gravitons make their way here, so gravity is felt as a weak force.

DARK MATTER

Cosmologists suggest that it makes up 90 percent of our universe. It neither emits or absorbs light, but it exerts gravity. According to brane theory, it may just be ordinary matter concentrated on other branes, and its light cannot shine through to this universe.

2
The light from dark matter, conveyed by particles called photons, would cling to the surface of the foreign brane, but gravitons might seep across the divide. Pulled by our galaxies' local gravitational force, the gravitons would cluster into halos around the galaxies.

Steve Domes/The New York Times

WARP FACTOR AND BRANE TENSION

▶ EINSTEIN GAUSS BONNET EQN

$$\sqrt{-g^{(5)}} \left[G_{AB}^{(5)} + \frac{\alpha^{(5)}}{M_{(5)}^2} (1 - A_1 e^{\theta_1 \phi}) H_{AB}^{(5)} \right] =$$
$$-\frac{e^{\theta_2 \phi}}{M_{(5)}^3} \left[\Lambda^{(5)} \sqrt{-g^{(5)}} g_{AB}^{(5)} + \sum_{i=1}^2 T_{(i)} \sqrt{-g_{(5)}^{(i)}} g_{\alpha\beta}^{(i)} \delta_A^\alpha \delta_B^\beta \delta(y - y_{(i)}) \right]$$

▶ GRAVIDILATON EQN

$$\frac{\theta_2}{M_{(5)}^2} \sum_{i=1}^2 T_{(i)} \sqrt{-g_{(5)}^{(i)}} e^{\theta_2 \phi} \delta(y - y_{(i)}) =$$
$$\sqrt{-g^{(5)}} \left\{ \alpha^{(5)} A_1 \theta_1 \left[R^{ABCD(5)} R_{ABCD}^{(5)} - 4R^{AB(5)} R_{AB}^{(5)} + R_{(5)}^2 \right] \right.$$
$$\left. + 2 \frac{\Lambda^{(5)}}{M_{(5)}^2} \theta_2 e^{\theta_2 \phi} + \frac{\square^{(5)} \phi}{M_{(5)}} \right\}$$

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where $G_{AB}^{(5)} = \left[R_{AB}^{(5)} - \frac{1}{2} g_{AB}^{(5)} R_{(5)} \right]$

$$H_{AB}^{(5)} = 2R_{ACDE}^{(5)} R_B^{CDE(5)} - 4R_{ACBD}^{(5)} R^{CD(5)} - 4R_{AC}^{(5)} R_B^C{}^{(5)} + 2R_{(5)} R_{AB}^{(5)}$$

$$- \frac{1}{2} g_{AB}^{(5)} \left(R^{ABCD(5)} R_{ABCD}^{(5)} - 4R^{AB(5)} R_{AB}^{(5)} + R_{(5)}^2 \right)$$

WARP FACTOR AND BRANE TENSION

▶ DILATON FIELD

$$\phi(y) = \sum_{p=1}^2 \left(\frac{|y|}{\theta_p^{\frac{5}{2}}} + \frac{1}{\theta_p} \right)$$

▶ WARP FACTOR

$$A(y) := A_{\pm}(y) = k_{\pm} r_c |y|$$

where

$$k_{\pm} = \sqrt{\frac{3M_{(5)}^2}{16\alpha_{(5)}(1-A_1 e^{\theta_1 \phi})} \left\{ 1 \pm \sqrt{1 + \frac{4\alpha_{(5)}(1-A_1 e^{\theta_1 \phi})\Lambda_{(5)} e^{\theta_2 \phi}}{9M_{(5)}^5}} \right\}}$$

WARP FACTOR AND BRANE TENSION

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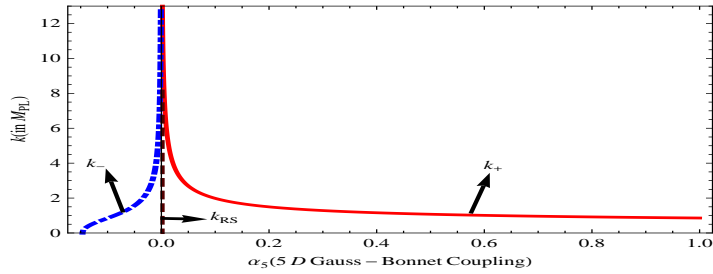
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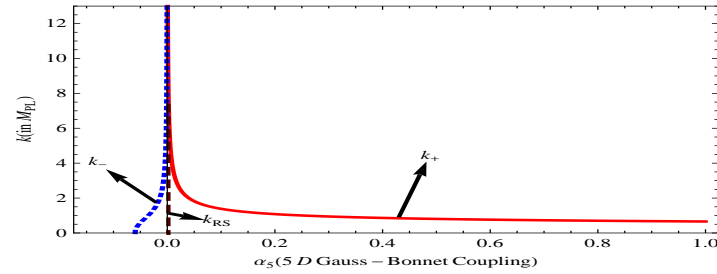
★ RANDALL-SUNDRUM (RS) LIMIT:-

$$(\alpha_{(5)}, \mathbf{A}_1, \theta_1, \theta_2) \rightarrow \mathbf{0} \Rightarrow \begin{cases} \mathbf{k}_- \rightarrow \mathbf{k}_{\text{RS}} = \sqrt{-\frac{\Lambda_{(5)}}{24M_{(5)}^3}} & \text{with } \Lambda_{(5)} < 0 \\ \mathbf{k}_+ \rightarrow \infty \end{cases}$$

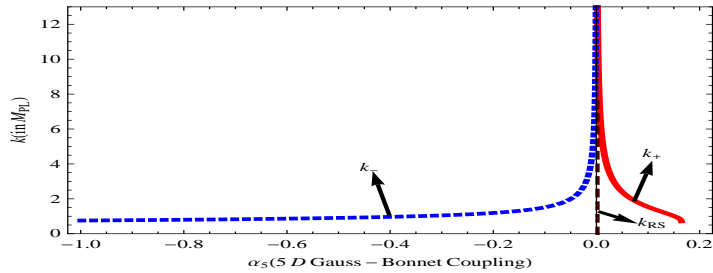
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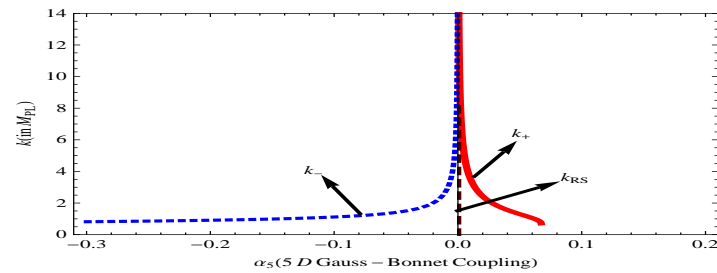
(a) $\Lambda_{(5)} > 0$ and $A_1 > 0$



(b) $\Lambda_{(5)} > 0$ and $A_1 < 0$

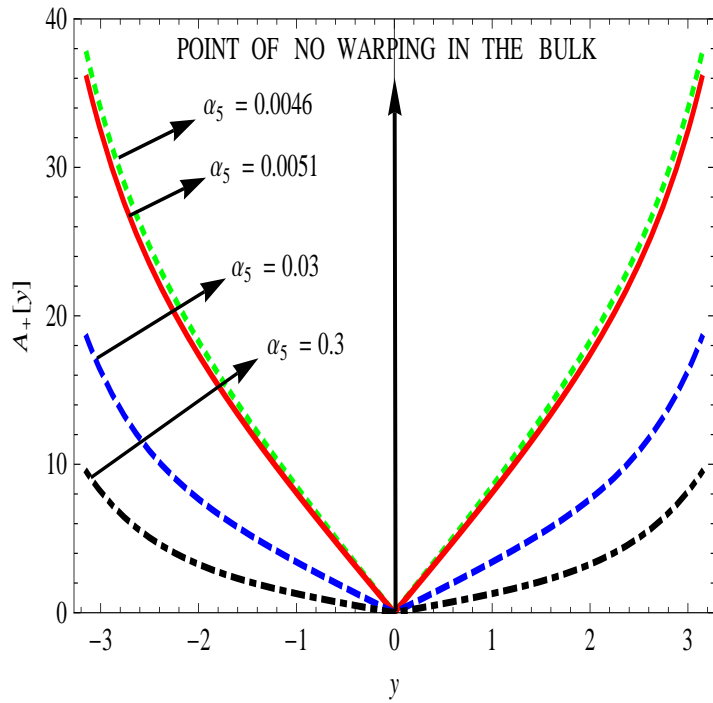


(c) $\Lambda_{(5)} < 0$ and $A_1 > 0$

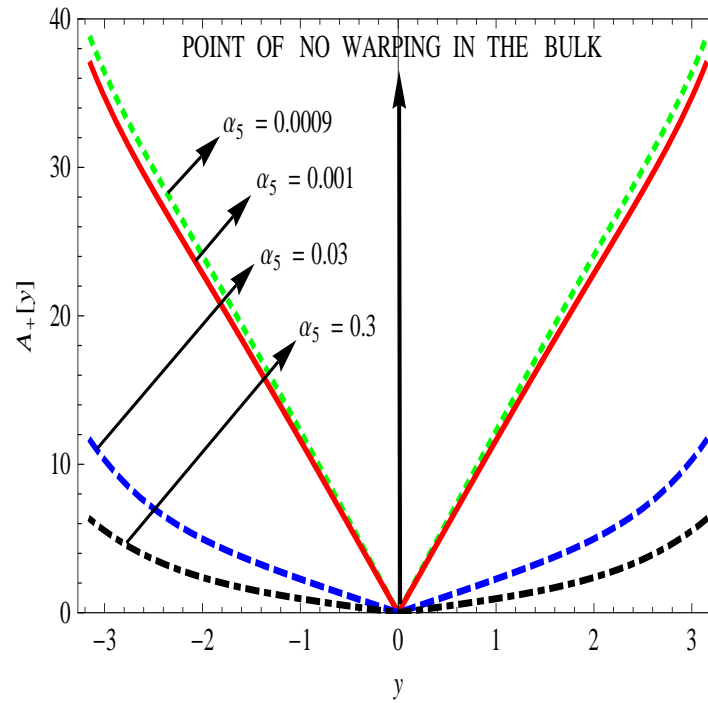


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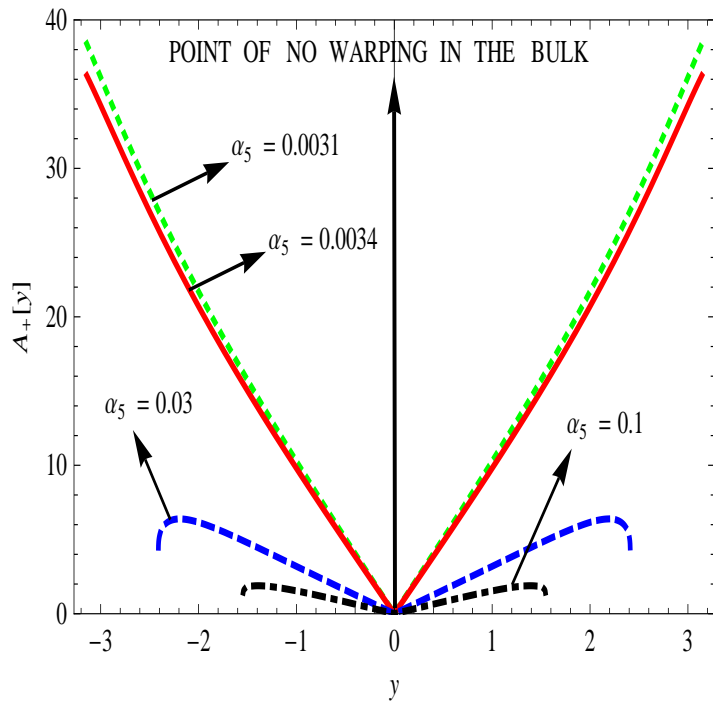


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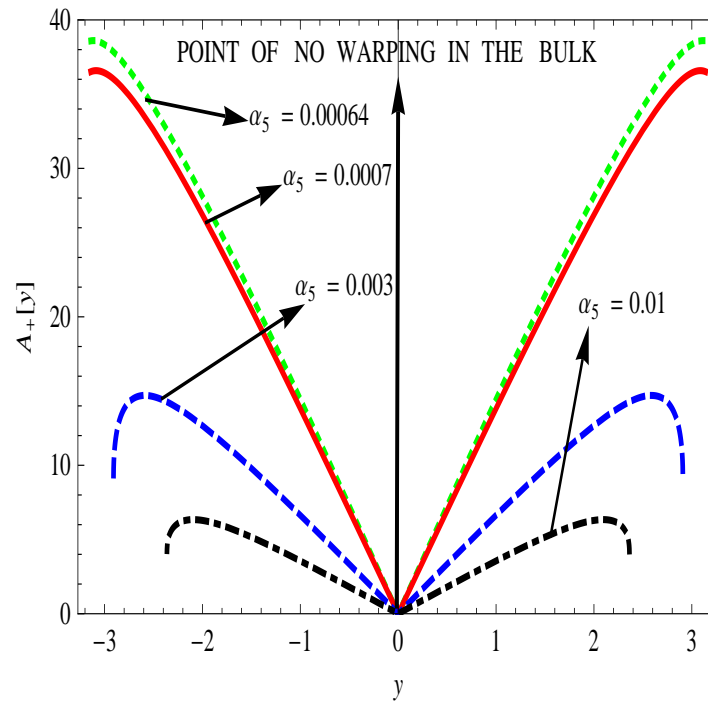


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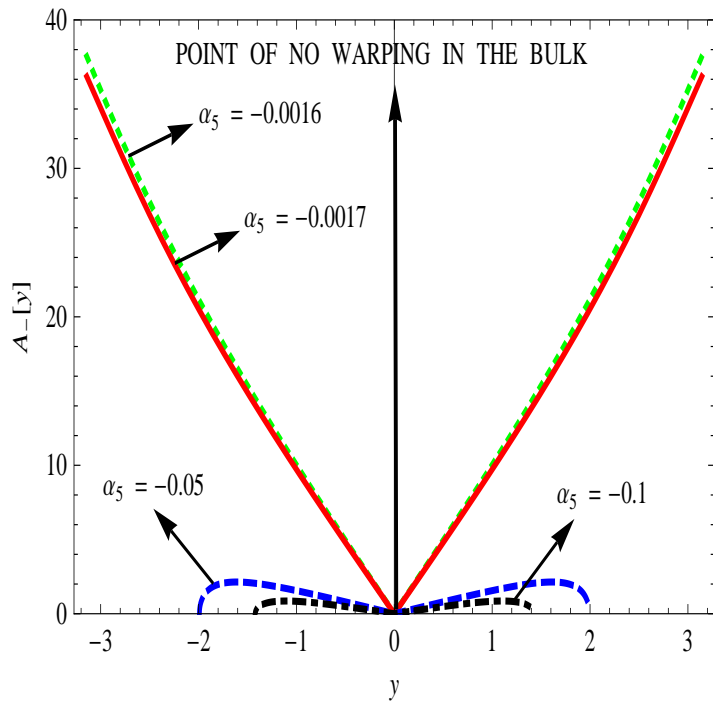


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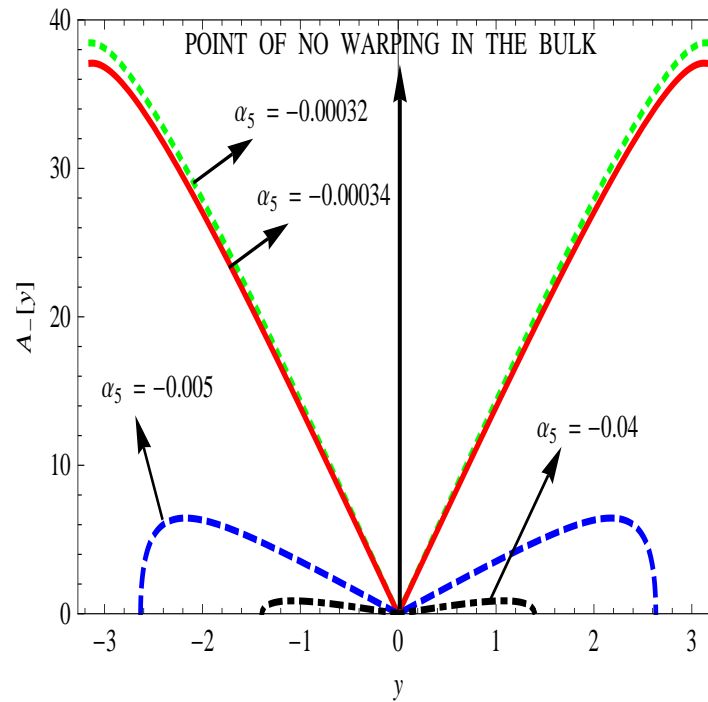


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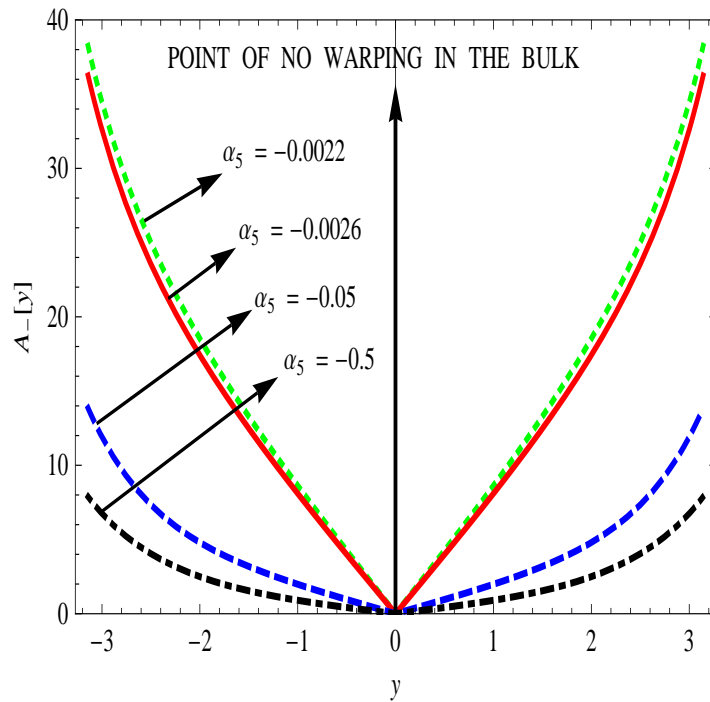


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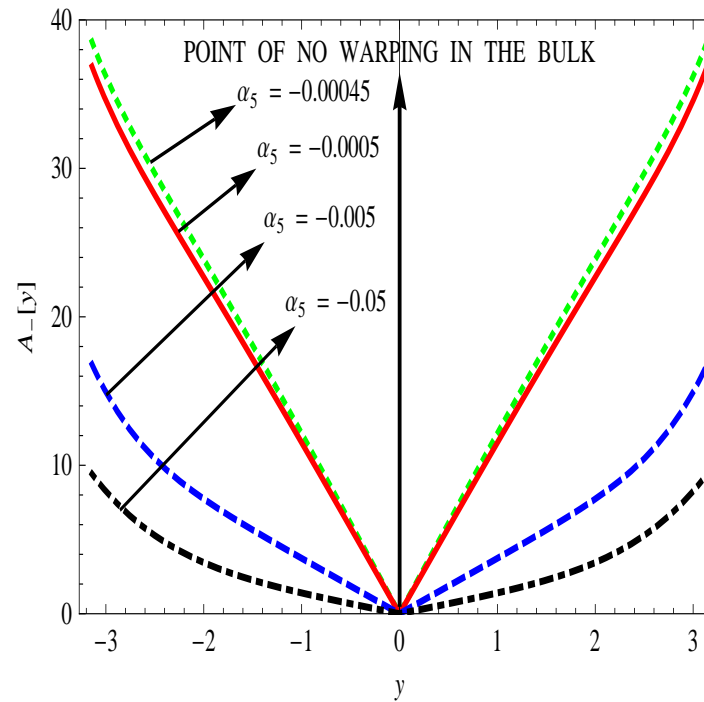


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WARP FACTOR AND BRANE TENSION



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WARP FACTOR AND BRANE TENSION

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$$T_{\text{vis}}^{\pm} = -T_{\text{hid}}^{\mp} = \pm \left\{ 6k_{\pm} M_{(5)}^3 e^{-\theta_2 \phi} \left[4 - \frac{4\alpha_{(5)} (1 - A_1 e^{\theta_1 \phi})}{3M_{(5)}^2} k_{\pm}^2 r_c^2 \right] \right\}$$

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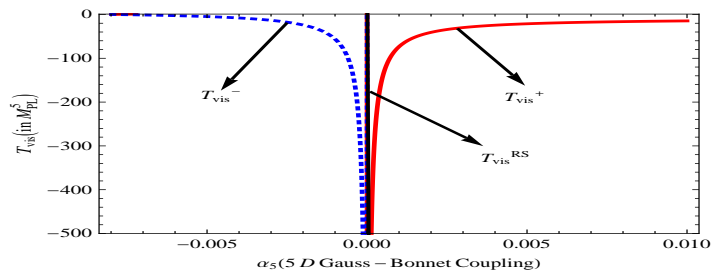
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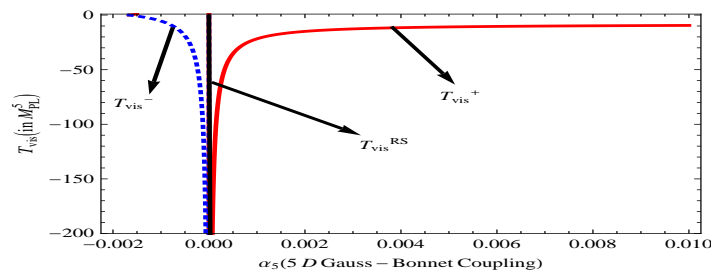
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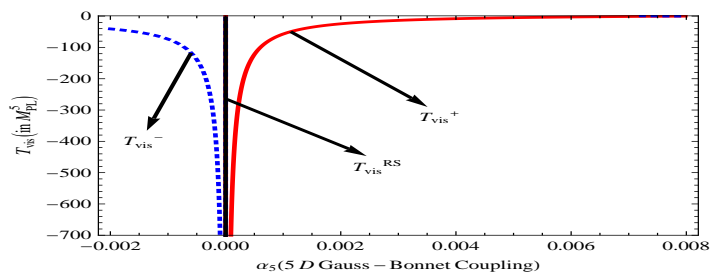
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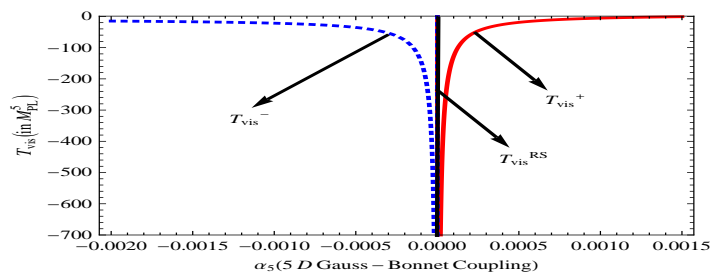
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- Spin-2 transeverse and traceless graviton d.o.f. are generated via tensor perturbation in the warped metric.

- KK reduction ansatz:
$$\mathbf{h}_{\alpha\beta}(x, y) = \sum_{n=0}^{\infty} \mathbf{h}_{\alpha\beta}^{(n)}(x) \frac{\chi_{\pm; \mathbf{G}}^{(n)}(y)}{\sqrt{r_c}}$$

where

$$\chi_{\pm; \mathbf{G}}^{(n)}(y) = \begin{cases} \frac{\sqrt{\mathbf{k}_{\pm} r_c} e^{2\mathbf{k}_{\pm} r_c |y|} \mathcal{J}_2\left(\frac{(m_n^{\mathbf{G}})_{\pm}}{\mathbf{k}_{\pm}} e^{\mathbf{k}_{\pm} r_c |y|}\right)}{e^{\mathbf{k}_{\pm} r_c \pi} \mathcal{J}_2\left(\frac{(m_n^{\mathbf{G}})_{\pm}}{\mathbf{k}_{\pm}} e^{\mathbf{k}_{\pm} r_c \pi}\right)} & \text{for } n > 0 \\ \sqrt{\mathbf{k}_{\pm} r_c} & \text{for } n = 0. \end{cases}$$

- 4D effective action: $S_G \supset \int d^4x \sum_{n=0}^{\infty} \mathbf{h}^{\alpha\beta (n)}(x) \mathbf{h}_{\alpha\beta}^{(n)}(x) (m_n^{\mathbf{G}})_{\pm}^2$

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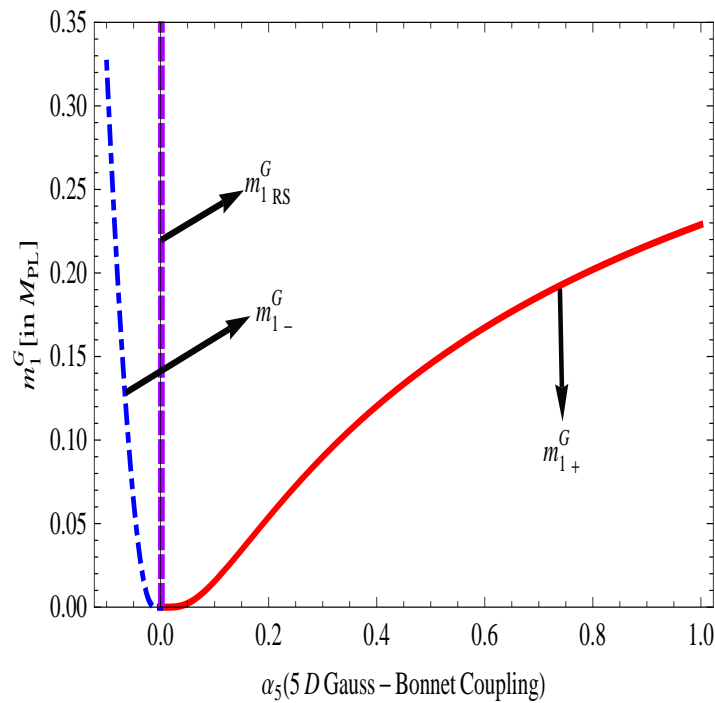
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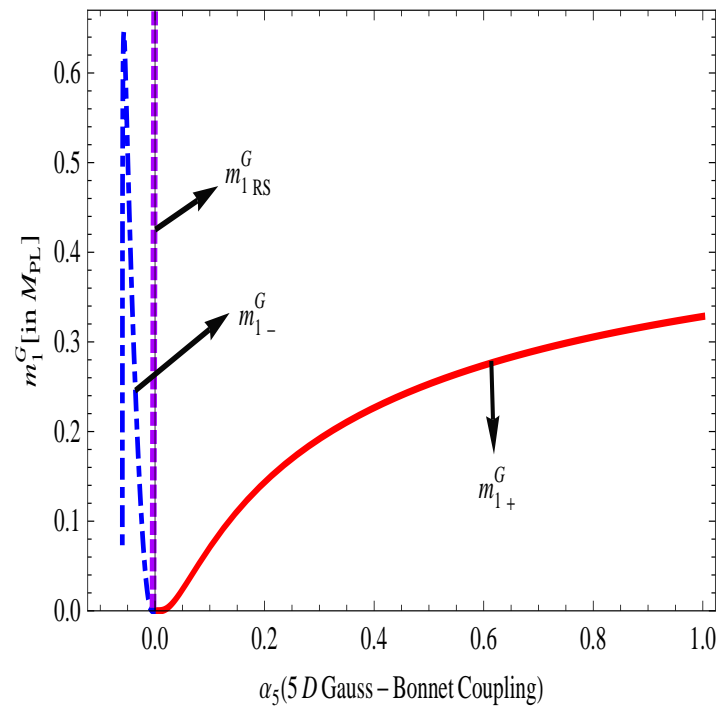
• KK graviton mass spectra:
$$(m_n^{\mathbf{G}})_{\pm} \approx \left(n + \frac{1}{2} \mp \frac{1}{4}\right) \pi k_{\pm} e^{-k_{\pm} r_c \pi}$$

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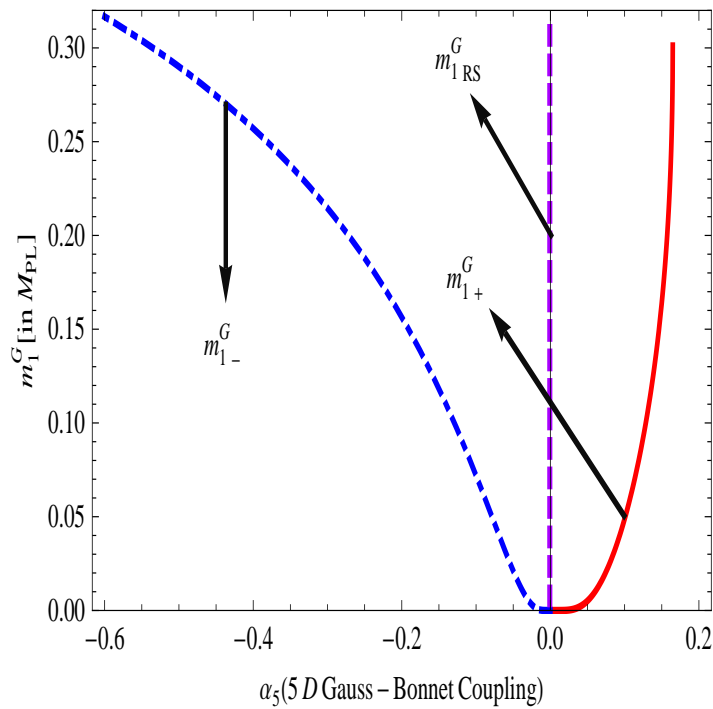
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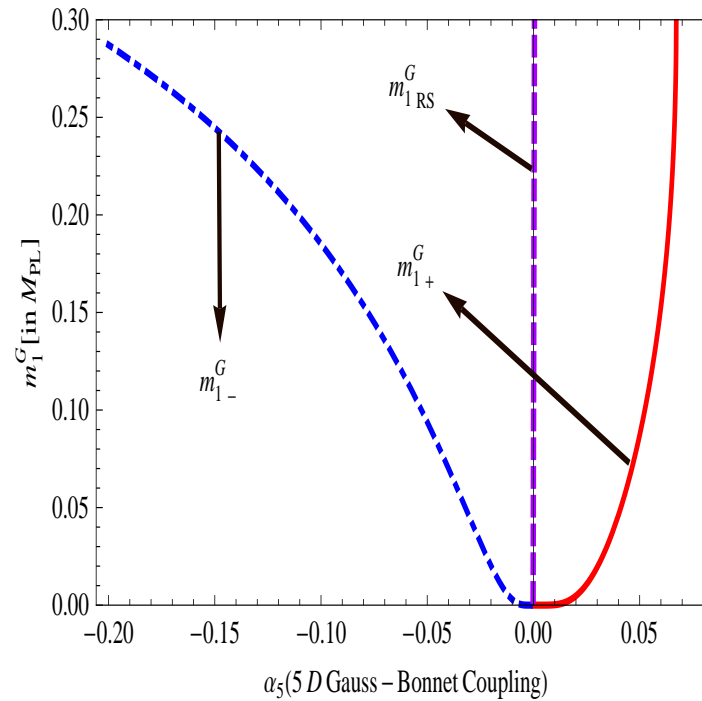
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- $S_{\Phi} = \frac{1}{2} \int d^5x \sqrt{-g^{(5)}} \left[g^{AB} \vec{\partial}_A \Phi(x, y) \vec{\partial}_B \Phi(x, y) - m_{\Phi}^2 \Phi^2(x, y) \right]$

- **KK reduction ansatz:** $\Phi(x, y) = \sum_{n=0}^{\infty} \Phi^{(n)}(x) \frac{\chi_{\pm; \Phi}^{(n)}(y)}{\sqrt{r_c}}$

where

$$\chi_{\pm; \Phi}^{(n)}(y) = \begin{cases} \frac{\frac{(m_n^{\Phi})_{\pm}^2}{k_{\pm}^2} e^{k_{\pm} r_c \pi} \sqrt{k_{\pm} r_c} e^{2k_{\pm} r_c |y|}}{\sqrt{\frac{(m_n^{\Phi})_{\pm}^2}{k_{\pm}^2} e^{2k_{\pm} r_c \pi} + 4 - (\nu_{\pm}^{\Phi})^2}} \mathcal{J}_{\nu_{\pm}^{\Phi}}\left(\frac{(m_n^{\Phi})_{\pm}}{k_{\pm}} e^{k_{\pm} r_c |y|}\right) & \text{for } n > 0 \\ \sqrt{\frac{k_{\pm} r_c}{1 - e^{-2k_{\pm} r_c \pi}}} \mathcal{J}_{\nu_{\pm}^{\Phi}}\left(\frac{(m_n^{\Phi})_{\pm}}{k_{\pm}} e^{k_{\pm} r_c \pi}\right) & \text{for } n = 0. \end{cases}$$

- **4D effective action:**

$$S_{\Phi} = \int d^4x \sum_{n=0}^{\infty} \left[\eta^{\mu\nu} \vec{\partial}_{\mu} \Phi^{(n)}(x) \vec{\partial}_{\nu} \Phi^{(n)}(x) - (m_n^{\Phi})_{\pm}^2 (\Phi^{(n)}(x))^2 \right]$$

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$$\chi_{\pm; \Phi}^{(n)}(y) = \begin{cases} \frac{\frac{(m_n^{\Phi})_{\pm}^2}{k_{\pm}^2} e^{k_{\pm} r_c \pi} \sqrt{k_{\pm} r_c} e^{2k_{\pm} r_c |y|}}{\sqrt{\frac{(m_n^{\Phi})_{\pm}^2}{k_{\pm}^2} e^{2k_{\pm} r_c \pi} + 4 - (\nu_{\pm}^{\Phi})^2}} \mathcal{J}_{\nu_{\pm}^{\Phi}}\left(\frac{(m_n^{\Phi})_{\pm}}{k_{\pm}} e^{k_{\pm} r_c |y|}\right) & \text{for } n > 0 \\ \sqrt{\frac{k_{\pm} r_c}{1 - e^{-2k_{\pm} r_c \pi}}} \mathcal{J}_{\nu_{\pm}^{\Phi}}\left(\frac{(m_n^{\Phi})_{\pm}}{k_{\pm}} e^{k_{\pm} r_c \pi}\right) & \text{for } n = 0. \end{cases}$$

• 4D effective action:

$$S_{\Phi} = \int d^4x \sum_{n=0}^{\infty} \left[\eta^{\mu\nu} \vec{\partial}_{\mu} \Phi^{(n)}(x) \vec{\partial}_{\nu} \Phi^{(n)}(x) - (m_n^{\Phi})_{\pm}^2 (\Phi^{(n)}(x))^2 \right]$$

- **KK scalar mass spectra:** $(m_n^{\Phi})_{\pm} \approx \left(n + \frac{1}{2} \nu_{\pm}^{\Phi} - \frac{3}{4} \right) \pi k_{\pm} e^{-k_{\pm} r_c \pi}$

ANALYSIS OF BULK KK SPECTRUM

► $\mathcal{U}(1)$ GAUGE FIELD MASS SPECTRUM:

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► $\mathcal{U}(1)$ GAUGE FIELD MASS SPECTRUM:

- $S_{\mathcal{A}} = -\frac{1}{4} \int d^5x \sqrt{-g_{(5)}} \mathcal{F}_{MN}(x, y) \mathcal{F}^{MN}(x, y)$, $\mathcal{F}_{MN} := \overrightarrow{\partial}_{[M} \mathcal{A}_{N]}(x, y)$
- **KK reduction ansatz:** $\mathcal{A}_{\mu}(x, y) = \sum_{n=0}^{\infty} \mathcal{A}_{\mu}^{(n)}(x) \frac{\chi_{\pm; \mathcal{A}}^{(n)}(y)}{\sqrt{r_c}}$

where

$$\chi_{\pm; \mathcal{A}}^{(n)}(y) = \begin{cases} \frac{e^{\mathbf{k}_{\pm} r_c |y|} \sqrt{\mathbf{k}_{\pm} r_c} \mathcal{J}_1\left(\frac{(m_n^{\mathcal{A}})_{\pm}}{\mathbf{k}_{\pm}} e^{\mathbf{k}_{\pm} r_c |y|}\right)}{e^{\mathbf{k}_{\pm} r_c \pi} \mathcal{J}_1\left(\frac{(m_n^{\mathcal{A}})_{\pm}}{\mathbf{k}_{\pm}} e^{\mathbf{k}_{\pm} r_c \pi}\right)} & \text{for } n > 0 \\ \frac{1}{\sqrt{2\pi}} & \text{for } n = 0. \end{cases}$$

• **4D effective action:**

$$S_{\mathcal{A}} = - \int d^4x \sum_{n=0}^{\infty} \eta^{\nu\lambda} \left[\frac{1}{4} \eta^{\mu\kappa} \mathcal{F}_{\kappa\lambda}^{(n)}(x) \mathcal{F}_{\mu\nu}^{(n)}(x) + \frac{1}{2} (m_n^{\mathcal{A}})_{\pm}^2 \mathcal{A}_{\nu}^{(n)}(x) \mathcal{A}_{\lambda}^{(n)}(x) \right]$$

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where

$$\chi_{\pm; \mathcal{A}}^{(n)}(y) = \begin{cases} \frac{e^{k_{\pm} r_c |y|} \sqrt{k_{\pm} r_c} \mathcal{J}_1\left(\frac{(m_n^{\mathcal{A}})_{\pm}}{k_{\pm}} e^{k_{\pm} r_c |y|}\right)}{e^{k_{\pm} r_c \pi}} & \text{for } n > 0 \\ \frac{1}{\sqrt{2\pi}} & \text{for } n = 0. \end{cases}$$

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- **KK mass spectra:** $(m_n^{\mathcal{A}})_{\pm} \approx \left(n \mp \frac{1}{4}\right) \pi k_{\pm} e^{-k_{\pm} r_c \pi}$

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► MASSIVE FERMION MASS SPECTRUM:

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► MASSIVE FERMION MASS SPECTRUM:

$$\bullet S_f = \int d^5x [Det(\mathcal{V})] \left\{ i\bar{\Psi}_{\mathbf{L},\mathbf{R}}(x,y)\gamma^\alpha \mathcal{V}_\alpha^M \overleftrightarrow{\mathbf{D}}_\mu \Psi_{\mathbf{L},\mathbf{R}}(x,y)\delta_M^\mu - \text{sgn}(y)m_f \bar{\Psi}_{\mathbf{L},\mathbf{R}}(x,y)\Psi_{\mathbf{R},\mathbf{L}}(x,y) + h.c. \right\}$$

where

$$\bullet \overleftrightarrow{\mathbf{D}}_\mu := \left(\overleftrightarrow{\partial}_\mu + \frac{g^{NP}}{16} \left(\mathcal{V}_N^{[\hat{A}} \partial_{[\mu} \mathcal{V}_P^{\hat{B}]} + \frac{1}{2} g^{TS} \mathcal{V}_N^{[\hat{A}} \mathcal{V}_T^{\hat{B}]} \partial_{[S} \mathcal{V}_P^{\hat{C}]} \mathcal{V}_\mu^{\hat{D}]} \eta^{\hat{C}\hat{D}} \right) [\Gamma_{\hat{A}}, \Gamma_{\hat{B}}] + ig_f \mathcal{A}_\mu \right)$$

$$\bullet \Gamma^{\hat{A}} = (\gamma^\mu, \gamma_5 := \frac{i}{4!} \epsilon_{\mu\nu\alpha\beta} \gamma^\mu \gamma^\nu \gamma^\alpha \gamma^\beta = i\gamma_4)$$

$$\bullet \{\Gamma^{\hat{A}}, \Gamma^{\hat{B}}\} = 2\eta^{\hat{A}\hat{B}}, \quad \eta^{\hat{A}\hat{B}} = \text{diag}(-1, +1, +1, +1, +1)$$

$$\bullet \mathcal{V}_4^{\hat{A}} = 1, \quad \mathcal{V}_\mu^{\hat{A}} = e^{A_\pm(y)} \delta_\mu^{\hat{A}}, \quad Det(\mathcal{V}) = e^{-4A_\pm(y)}$$

$$\bullet g_{MN} := \left(\mathcal{V}_M^{\hat{A}} \otimes \mathcal{V}_N^{\hat{B}} \right) \eta_{\hat{A}\hat{B}}$$

$$\bullet \Psi_{\mathbf{L},\mathbf{R}}(x,y) \equiv \mathcal{P}_{\mathbf{L},\mathbf{R}} \Psi(x,y), \quad \mathcal{P}_{\mathbf{L},\mathbf{R}} = \frac{1}{2} (1 \mp \gamma_5)$$

$$\bullet \mathcal{P}_{\mathbf{R}} + \mathcal{P}_{\mathbf{L}} = 1, \quad \mathcal{P}_{\mathbf{R}}\mathcal{P}_{\mathbf{L}} = \mathcal{P}_{\mathbf{L}}\mathcal{P}_{\mathbf{R}} = 0$$

ANALYSIS OF BULK KK SPECTRUM

► MASSIVE FERMION MASS SPECTRUM:

• **KK reduction ansatz:** $\Psi_{\mathbf{L},\mathbf{R}}(x, y) = \sum_{n=0}^{\infty} \Psi_{\mathbf{L},\mathbf{R}}^{(n)}(x) \frac{e^{2A_{\pm}(y)}}{\sqrt{r_c}} \hat{f}_{\mathbf{L},\mathbf{R}}^{(n)}(y)$

where

$$\hat{f}_{\mathbf{L},\mathbf{R}}^{(n)}(y) = \begin{cases} \frac{\frac{(m_n^{\mathbf{L},\mathbf{R}})_{\pm} e^{k_{\pm} r_c |y|}}{k_{\pm}} \mathcal{J}_{\mp\left(\frac{1}{2} + \frac{m_f}{k_{\pm}}\right)}\left(\frac{(m_n^{\mathbf{L},\mathbf{R}})_{\pm} e^{k_{\pm} r_c |y|}}{k_{\pm}}\right)}{e^{k_{\pm} r_c \pi} \sqrt{(m_n^{\mathbf{L},\mathbf{R}})_{\pm} r_c} \mathcal{J}_{\mp\left(\frac{1}{2} + \frac{m_f}{k_{\pm}}\right)}\left(\frac{(m_n^{\mathbf{L},\mathbf{R}})_{\pm} e^{k_{\pm} r_c \pi}}{k_{\pm}}\right)} & \text{for } n > 0 \\ \sqrt{\frac{2 \left[e^{\left(1 \pm 2 \frac{m_f}{k_{\pm}}\right) k_{\pm} r_c \pi} - 1 \right]}{\left(1 \pm 2 \frac{m_f}{k_{\pm}}\right) k_{\pm} r_c}} e^{\pm \frac{m_f}{k_{\pm}} k_{\pm} r_c |y|} & \text{for } n = 0. \end{cases}$$

• $S_f = \int d^4x \sum_{n=0}^{\infty} \sum_{p=0}^{\infty} \bar{\Psi}_{\mathbf{L},\mathbf{R}}^{(n)}(x) \left[i \left(\delta^{np} \overleftrightarrow{\partial}_{\alpha} + \frac{ig_f}{\sqrt{r_c}} \sum_{m=0}^{\infty} \mathcal{I}_{\mathbf{L},\mathbf{R}}^{(nmp)} \mathcal{A}_{\alpha}^{(m)}(x) \right) \gamma^{\alpha} - m_n^{\mathbf{L},\mathbf{R}} \delta^{np} \right] \Psi_{\mathbf{L},\mathbf{R}}^{(p)}(x)$

• **KK mass spectra:** $(m_n^{\mathbf{L},\mathbf{R}})_{\pm} \approx \left(n + \frac{1}{2} \left[\frac{m_f}{k_{\pm}} \pm \frac{1}{2} \right] - \frac{1}{4} \right) \pi k_{\pm} e^{-k_{\pm} r_c \pi}$

BULK GRAVITON & BRANE SM FIELD INTERACTION

- $$\begin{aligned}\mathcal{S}_{\text{SM-G}} &= -\frac{\mathcal{K}_{(5)}}{2} \int d^5x \sqrt{-g_{(5)}} \mathbf{T}_{\text{SM}}^{\alpha\beta}(x) \mathbf{h}_{\alpha\beta}(x, y) \delta(y - \pi) \\ &= -\frac{\sqrt{k_{\pm} r_c} \mathcal{K}_{(5)}}{2} \int d^4x \mathbf{T}_{\text{SM}}^{\alpha\beta}(x) \left[\mathbf{h}_{\alpha\beta}^{(0)}(x) + e^{k_{\pm} r_c \pi} \sum_{n=1}^{\infty} \mathbf{h}_{\alpha\beta}^{(n)}(x) \right]\end{aligned}$$

BULK GRAVITON & BRANE SM FIELD INTERACTION

- $\mathcal{S}_{\text{SM-G}} = -\frac{\mathcal{K}_{(5)}}{2} \int d^5x \sqrt{-g_{(5)}} \mathbf{T}_{\text{SM}}^{\alpha\beta}(x) \mathbf{h}_{\alpha\beta}(x, y) \delta(y - \pi)$
 $= -\frac{\sqrt{k_{\pm} r_c} \mathcal{K}_{(5)}}{2} \int d^4x \mathbf{T}_{\text{SM}}^{\alpha\beta}(x) \left[\mathbf{h}_{\alpha\beta}^{(0)}(x) + e^{k_{\pm} r_c \pi} \sum_{n=1}^{\infty} \mathbf{h}_{\alpha\beta}^{(n)}(x) \right]$
- **The graviton KK mode couplings decrease due to GB interaction leading to the decrease in their detection signature in collider experiments unless one modifies the value of r_c to resolve the gauge hierarchy problem.**
- **The graviton KK mode masses decrease from their counterpart in RS model and the GB coupling make the detectability of the signature of KK mode graviton through $H \rightarrow \tau\bar{\tau}$ more pronounced.**
- **The detectability of graviton KK mode can also be achieved by studying gravidilatonic interaction via the model parameters A_1, θ_1 and θ_2 obtained from string loop correction.**

COLLIDER CONSTRAINTS ON THE GB COUPLING

- **We consider** $(A_1, \theta_1, \theta_2) = 0$ **in the proposed model.**
- **Modified Warp factor:**

$$A(y) = k_\alpha r_c |y| = \sqrt{\frac{3M_5^2}{16\alpha_5} \left[1 - \left(1 + \frac{4\alpha_5 \Lambda_5}{9M_5^5} \right)^{\frac{1}{2}} \right]} r_c |y|.$$

- **SSB is occurring in the bulk and after KK reduction the zeroth mode scalar is compared with SM Higgs in the brane.**

$$S_{\text{SSB}} \supset \int d^5x \sqrt{-g_{(5)}} \left\{ \frac{1}{2} [g^{AB} \partial_A \mathbf{H}(x, y) \partial_B \mathbf{H}(x, y) + m_h^2 \mathbf{H}^2(x, y)] + m_f \Psi \bar{\Psi} + y_\eta \mathbf{H} \Psi \bar{\Psi} + h_w \mathbf{H} W^+ W^- \right\}$$

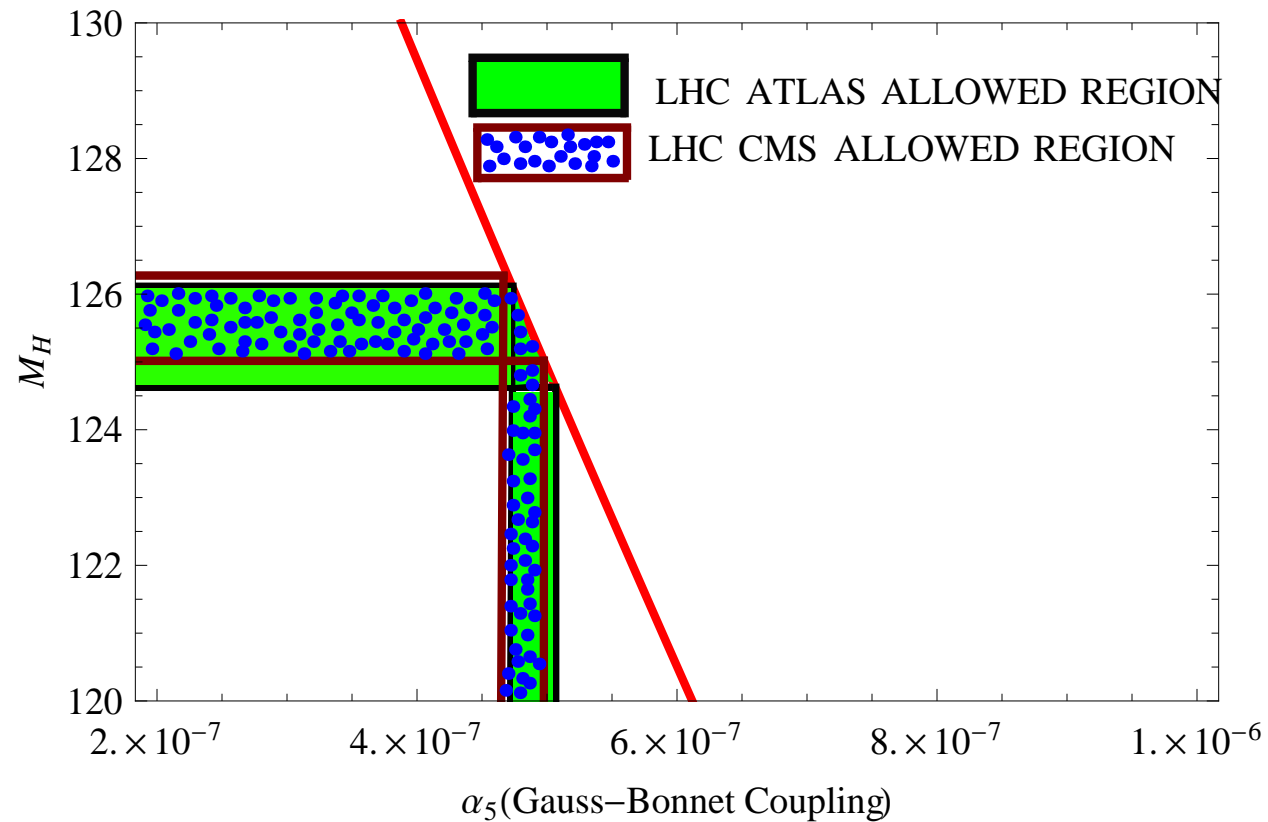
- **Zeroth mode scalar mass:**

$$m_s \approx M_H \approx \left(\frac{1}{2} \sqrt{4 + \frac{m_h^2}{k_\alpha^2}} - \frac{3}{4} \right) \pi k_\alpha e^{-k_\alpha r_c \pi}$$

COLLIDER CONSTRAINTS ON THE GB COUPLING

► HIGGS MASS CONSTRAINT:

$$M_H^{CMS} = (125.7 \pm 0.3)_{-0.3}^{+0.3} \text{ GeV}, M_H^{ATLAS} = (125.5 \pm 0.2)_{-0.6}^{+0.5} \text{ GeV}$$



COLLIDER CONSTRAINTS ON THE GB COUPLING

► μ PARAMETER CONSTRAINT FROM $H \rightarrow (\gamma\gamma, \tau\bar{\tau})$ CHANNELS:

$$\bullet \mu = \frac{\Sigma(\text{pp} \rightarrow \text{H}_0)}{\Sigma(\text{pp} \rightarrow \text{H}_{\text{SM}})} \times \frac{\text{BR}(\text{H}_0 \rightarrow l_1 l_2)}{\text{BR}(\text{H}_{\text{SM}} \rightarrow l_1 l_2)}$$
$$= \begin{cases} 1.6 \pm 0.3 & \text{for ATLAS } l_1 = l_2 = \gamma \\ 0.77 \pm 0.27 & \text{for CMS } l_1 = l_2 = \gamma \\ 0.8 \pm 0.7 & \text{for ATLAS } l_1 = \tau, l_2 = \bar{\tau} \\ 1.10 \pm 0.4 & \text{for CMS } l_1 = \tau, l_2 = \bar{\tau} \end{cases}$$

with

$$\bullet \text{BR}(\text{X} \rightarrow l_1 l_2) = \frac{\Gamma(\text{X} \rightarrow l_1 l_2)}{\Gamma(\text{X} \rightarrow \text{all decay channels})}$$

COLLIDER CONSTRAINTS ON THE GB COUPLING

- Total decay width:**

$$\Gamma_{\text{total}} \approx \Gamma(\mathbf{H}_0 \rightarrow W^+W^-) + \Gamma_{\text{fer}}$$

where

- $\Gamma(\mathbf{H}_0 \rightarrow W^+W^-) = \frac{m_s^4}{48m_W^2} F_W^2 F_G^2 T(m_W^2, m_s^2)$

with $T(m_W^2, m_s^2) = \int d(k^2) \frac{[\lambda^{\frac{3}{2}}(m_W^2, k^2, m_s^2) + \lambda^{\frac{1}{2}}(m_W^2, k^2, m_s^2) \frac{12k^2 m_W^2}{m_s^4}]}{(k^2 - m_W^2)^2 + \Gamma_W^2 m_W^2}$

and $\lambda(m_W^2, k^2, m_s^2) = \left(1 - \frac{m_W^2}{m_s^2} - \frac{k^2}{m_s^2}\right)^2 - \frac{4m_W^2 k^2}{m_s^4}$.

- $\Gamma_{\text{fer}} \approx \sum_{i=1}^4 \Gamma(\mathbf{H}_0 \rightarrow f_i \bar{f}_i) = \frac{N_c m_s}{8\pi} \sum_{i=1}^4 F_{Q_i}^2 \left(1 - \frac{4m_{f_i}^2}{m_s^2}\right)^{\frac{3}{2}}$

- Diphoton decay width:**

$$\Gamma(\mathbf{H}_0 \rightarrow \gamma\gamma) = \frac{m_s^3}{3456\pi^5 m_W^4} F_A^2 F_W^2 \left[2 + \frac{12m_W^2}{m_s^2} + \frac{12m_W^2}{m_s^2} \left(2 - \frac{4m_W^2}{m_s^2}\right) \left\{ \sin^{-1} \frac{1}{\sqrt{\frac{4m_W^2}{m_s^2}}} \right\}^2 \right]^2$$

COLLIDER CONSTRAINTS ON THE GB COUPLING

- Dilepton decay width:

$$\Gamma(\mathbf{H}_0 \rightarrow gg) = \frac{m_{f_4}^2 N_g}{256\pi^5 m_s} F_{Q_4}^2 F_{G_g}^4 \left[1 + \left(1 - 4 \frac{m_{f_4}^2}{m_s^2} \right) \left\{ \sin^{-1} \frac{1}{2\sqrt{\frac{m_{f_4}^2}{m_s^2}}} \right\}^2 \right]^2$$

- Differential production cross section of the scalar:

$$\frac{d\sigma}{dy}(p\bar{p} \rightarrow \mathbf{H}_0 + X) = \frac{\pi^2 \Gamma[\mathbf{H}_0 \rightarrow \mathbf{gg}]}{8m_s^3} g_p(x_p, m_s^2) g_{\bar{p}}(x_{\bar{p}}, m_s^2)$$

we define gluon momentum fraction as:

$$x_p = \frac{m_s e^y}{\sqrt{s}}, \quad x_{\bar{p}} = \frac{m_s e^{-y}}{\sqrt{s}}$$

- $g_p(x_p, M_s^2)$ is the gluon distribution function in proton at the gluon momentum fraction x_p .

- $\sqrt{s} \Rightarrow$ BEAM ENERGY

COLLIDER CONSTRAINTS ON THE GB COUPLING

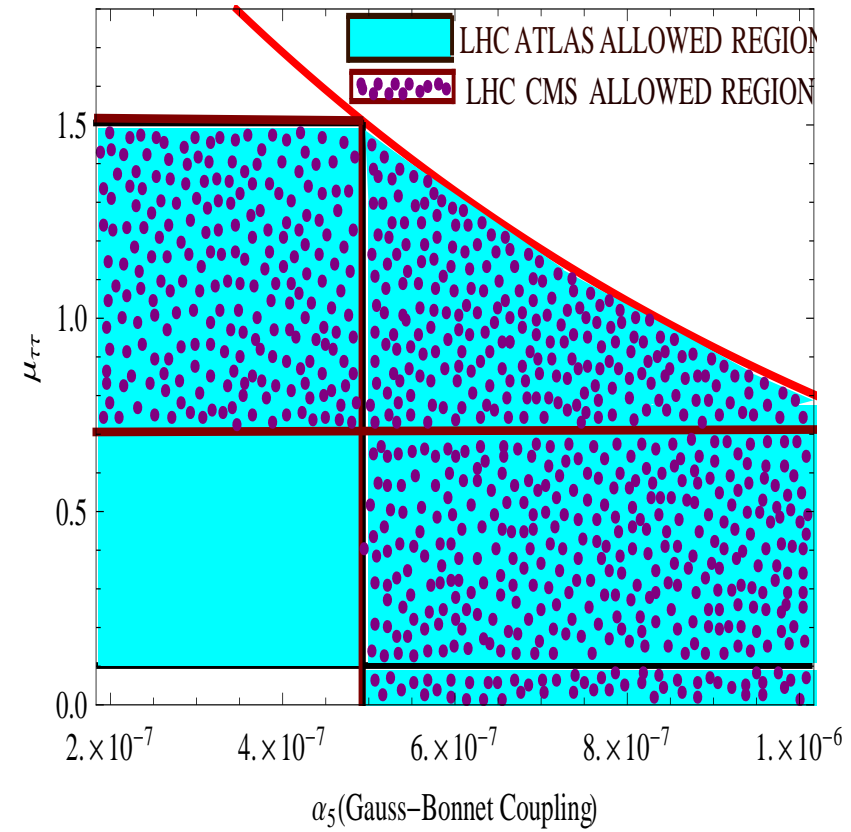
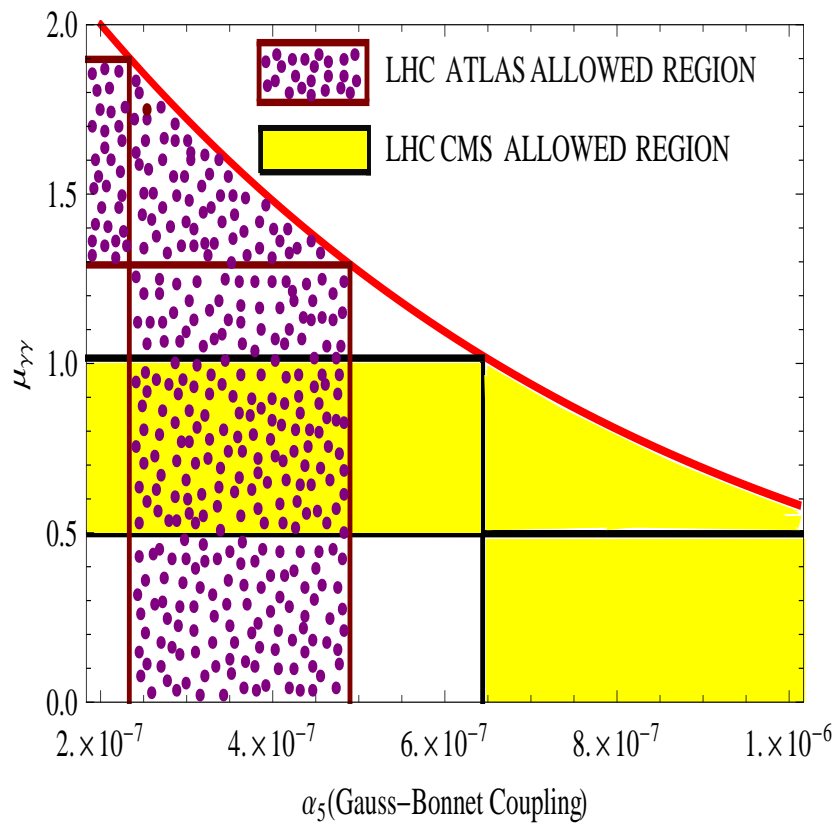
• VERTEX FACTORS IN 4D EFFECTIVE THEORY:

$$F_Q = y_\eta Q^{000} = \frac{2N_f^2 N_s}{m_f r_c} \sinh(m_f r_c \pi),$$
$$F_G = \frac{g_f \mathcal{G}^{000}}{\sqrt{r_c}} = \frac{g_f N_f^2}{\sqrt{2\pi r_c}} \frac{\sinh(k_\alpha - 2m_f)\pi r_c}{(k_\alpha - 2m_f)r_c},$$
$$F_W = h_w \mathcal{W}^{000} = h_w N_s, F_A = \frac{g_e}{r_c^{\frac{3}{2}}} \mathcal{A}^{000} = \frac{g_e}{\sqrt{2\pi r_c^3}}$$

with the following overlapping integrals:

$$Q^{000} := \int_{-\pi}^{+\pi} dy e^{4A(y)} \chi_{\mathbf{H}}^{(0)}(y) \hat{f}_{\mathbf{L}}^{(0)*}(y) \hat{f}_{\mathbf{L}}^{(0)}(y),$$
$$\mathcal{G}^{000} := \int_{-\pi}^{+\pi} dy e^{A(y)} \hat{f}_{\mathbf{L}}^{(0)*}(y) \chi_{\mathcal{A}/\mathcal{A}_a}^{(0)}(y) \hat{f}_{\mathbf{L}}^{(0)}(y),$$
$$\mathcal{W}^{000} := \int_{-\pi}^{+\pi} dy \chi_{\mathbf{H}}^{(0)}(y) \chi_{\mathcal{A}_a}^{(0)}(y) \chi_{\mathcal{A}_a}^{(0)}(y),$$
$$\mathcal{A}^{000} := \int_{-\pi}^{+\pi} dy \chi_{\mathcal{A}}^{(0)}(y) \chi_{\mathcal{A}_a}^{(0)}(y) \chi_{\mathcal{A}_a}^{(0)}(y).$$

COLLIDER CONSTRAINTS ON THE GB COUPLING



• **Combined constraint from $(M_H + \mu_{\gamma\gamma} + \mu_{\tau\tau}) \Rightarrow$**

$$4.8 \times 10^{-7} < \alpha_{(5)} < 5.1 \times 10^{-7}$$

BOTTOM LINES

- **Need to address all phenomenological aspects which can explore various hidden features of string phenomenology in presence of GB coupling.**
- **Detection of graviton KK mode in future collider experiments are more pronounced in presence of GB coupling via stringy gravidilatonic interaction.**

BOTTOM LINES

- **Need to address all phenomenological aspects which can explore various hidden features of string phenomenology in presence of GB coupling.**
- **Detection of graviton KK mode in future collider experiments are more pronounced in presence of GB coupling via stringy gravidilatonic interaction.**
- **Stringent bound on the GB coupling obtained from the collider constraints in pure EHGB warped geometry model are in good agreement with solar system constraint.**
- **Need to address various cosmological aspects of inflation and other alternative proposals, CMB physics including different types and features of primordial non-Gaussianity.**

BOTTOM LINES

- For all the cases the estimated GB coupling is below the upper bound of GB coupling ($\alpha_5 < 1/4$) as obtained from the viscosity entropy ratio in presence of GB coupling.
- By studying the phenomenological/cosmological features in presence of GB coupling various features of string theory can be explored from its low energy effective counterpart.

BOTTOM LINES

- For all the cases the estimated GB coupling is below the upper bound of GB coupling ($\alpha_5 < 1/4$) as obtained from the viscosity entropy ratio in presence of GB coupling.
- By studying the phenomenological/cosmological features in presence of GB coupling various features of string theory can be explored from its low energy effective counterpart.
- Supergravity, as the low energy limit of heterotic string theory also yields the GB term as the leading order correction and therefore became an active area of interest as a modified theory of gravity from which we can also study the various hidden aspects of beyond SM physics.
- By studying the phenomenological consequences of radion with vev in the range 1-1.5 TeV we can also explain the consistency with the first graviton excitation mass > 3 TeV.

REFERENCES

- **L. Randall and R. Sundrum, Phys. Rev. Lett. 83 (1999) 3370 [hep-ph/9905221].**
- **L. Randall and R. Sundrum, Phys. Rev. Lett. 83 (1999) 4690 [hep-th/9906064].**
- **P. Dey, B. Mukhopadhyaya and S. SenGupta, Phys. Rev. D 81 (2010) 036011 [arXiv:0911.3761].**
- **B. Mukhopadhyaya, S. Sen, S. Sen and S. SenGupta, Phys. Rev. D 70 (2004) 066009 [hep-th/0403098].**
- **B. Mukhopadhyaya, S. Sen and S. SenGupta, Phys. Rev. Lett. 89 (2002) 121101 [hep-th/0204242].**
- **U. Maitra, B. Mukhopadhyaya and S. SenGupta, arXiv:1307.3018 [hep-ph].**

THANKS FOR YOUR TIME.....