Features of warped geometry in presence of Gauss-Bonnet coupling [1] [2] [3]

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SUSY 2013

ICTP,Trieste,Italy

Date : 29/08/2013

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

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

[3] **Sayantan 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-Klien (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

►**Determining the modified warp factor, the brane tensions and addressing the gauge hierarchy issue.**

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► **Comparing our results with that obtained through the usual RS analysis.**

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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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► **5D MODEL ACTION**

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

where

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

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

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

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

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

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► **BACKGROUND METRIC**

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

► 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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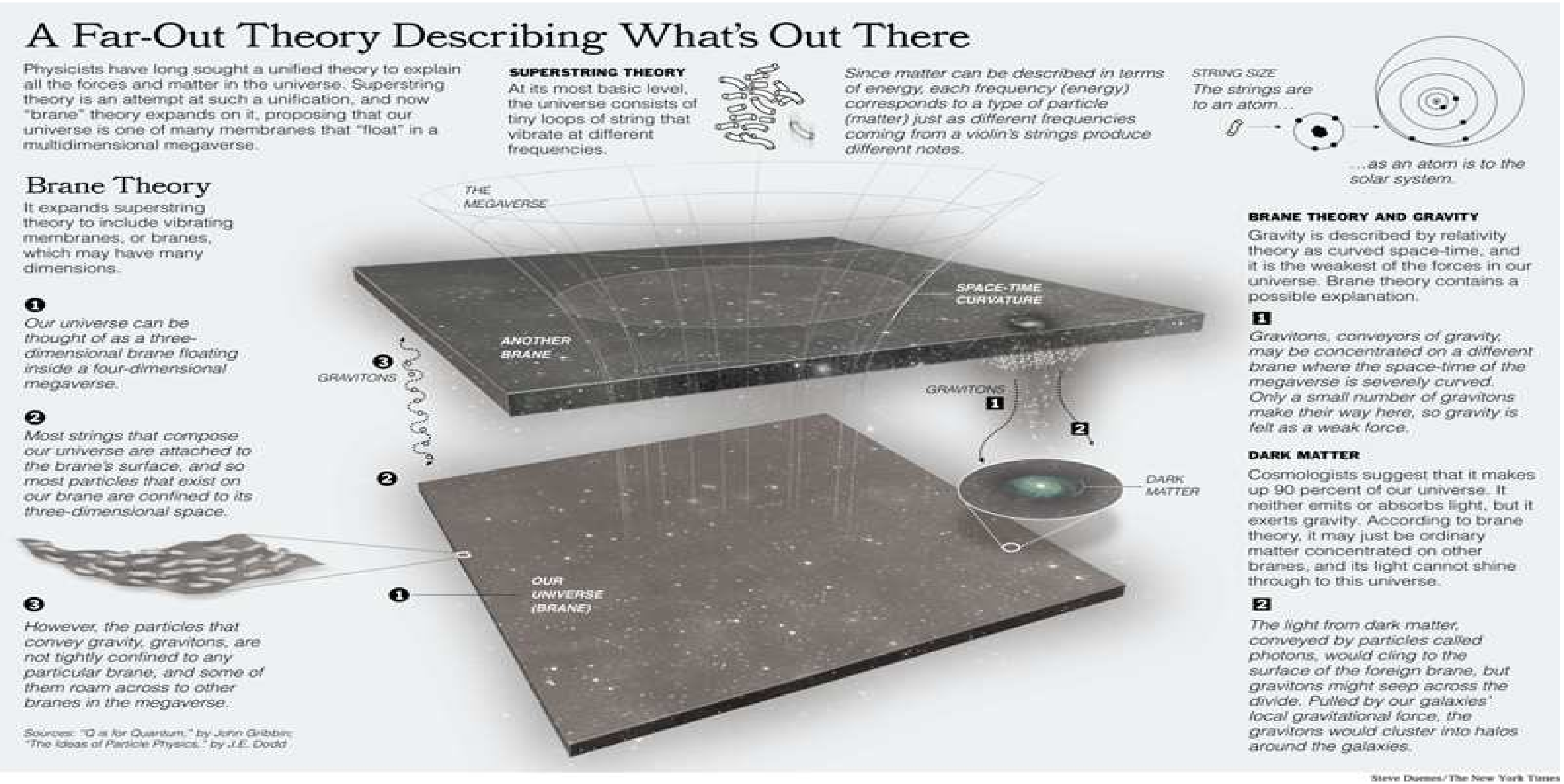
THE BACKGROUND WARPED GEOMETRY MODEL

► **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 (Klevanov- 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



WARP FACTOR AND BRANE TENSION

▶ **EINSTEIN GAUSS BONNET EQN**

$$\sqrt{-g_{(5)}}\left[G^{(5)}_{AB}+\frac{\alpha_{(5)}}{M^2_{(5)}}\left(1-A_1 e^{\theta_1\phi}\right)H^{(5)}_{AB}\right]=$$

$$-\frac{e^{\theta_2\phi}}{M^3_{(5)}}\left[\Lambda_{(5)}\sqrt{-g_{(5)}}g^{(5)}_{AB}+\sum_{i=1}^{2}T_{(i)}\sqrt{-g^{(i)}_{(5)}}g^{(i)}_{\alpha\beta}\delta^{\alpha}_{A}\delta^{\beta}_{B}\delta(y-y_{(i)})\right]$$

▶ **GRAVIDILATON EQN**

$$\frac{\theta_2}{M^2_{(5)}}\sum_{i=1}^{2}T_{(i)}\sqrt{-g^{(i)}_{(5)}}e^{\theta_2\phi}\delta(y-y_{(i)})=$$

$$\sqrt{-g_{(5)}}\left\{\alpha_{(5)}A_1\theta_1\left[R^{ABCD(5)}R^{(5)}_{ABCD}-4R^{AB(5)}R^{(5)}_{AB}+R^2_{(5)}\right]\right.$$

$$\left.+2\frac{\Lambda_{(5)}}{M^2_{(5)}}\theta_2 e^{\theta_2\phi}+\frac{\Box_{(5)}\phi}{M_{(5)}}\right\}$$

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where $G^{(5)}_{AB}=\left[R^{(5)}_{AB}-\frac{1}{2}g^{(5)}_{AB}R_{(5)}\right]$

$$H^{(5)}_{AB}=2R^{(5)}_{ACDE}R^{CDE(5)}_{B}-4R^{(5)}_{ACBD}R^{CD(5)}-4R^{(5)}_{AC}R^{C(5)}_{B}+2R^{(5)}R^{(5)}_{AB}$$

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

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

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

WARP FACTOR AND BRANE TENSION

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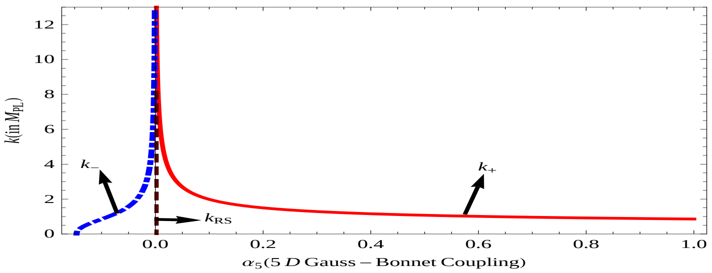
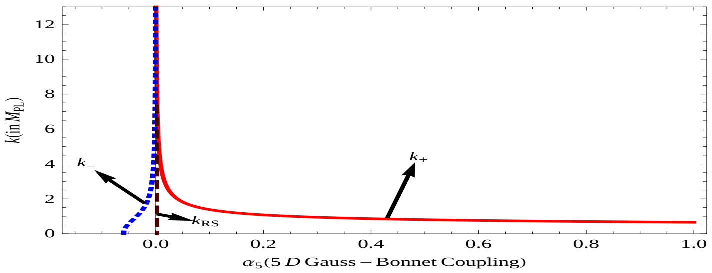
★**RANDALL-SUNDRUM (RS) LIMIT**:-

$$(\alpha_{(\mathbf{5})}, \mathbf{A_1}, \theta_{\mathbf{1}}, \theta_{\mathbf{2}}) \to \mathbf{0} \Rightarrow \begin{cases} \mathbf{k_-} \to \mathbf{k_{RS}} = \sqrt{-\dfrac{\mathbf{\Lambda_{(5)}}}{\mathbf{24M_{(5)}^3}}} & \textbf{with } \Lambda_{(5)} < 0 \\ \mathbf{k_+} \to \infty \end{cases}$$

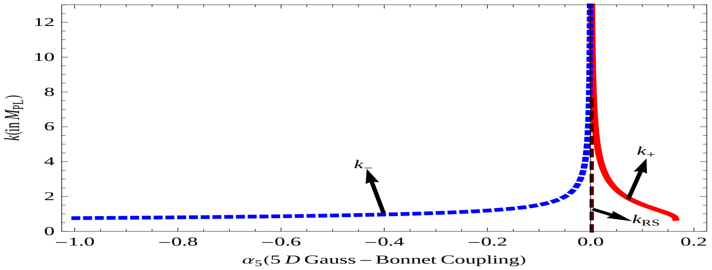
WARP FACTOR AND BRANE TENSION



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



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



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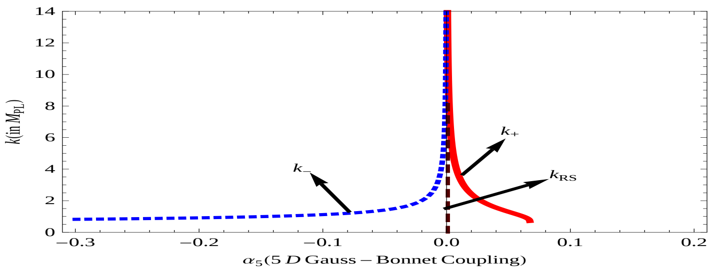

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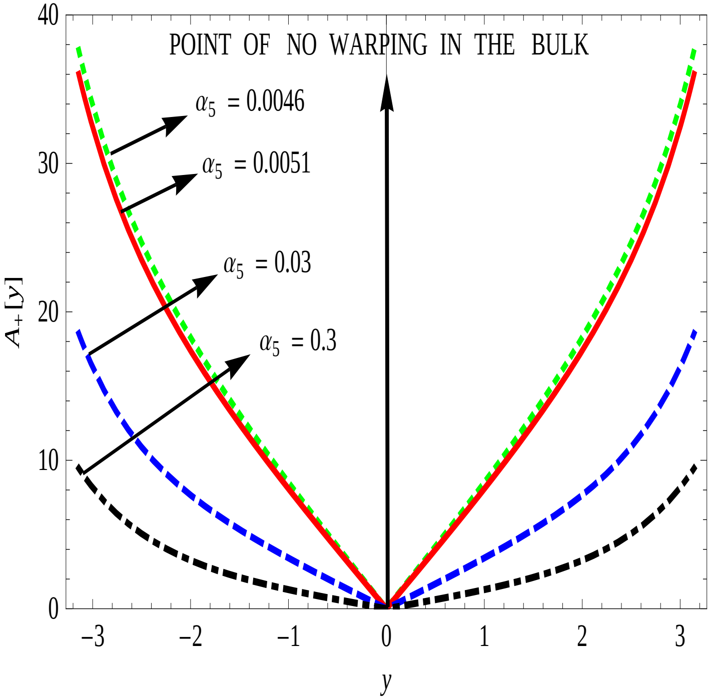
WARP FACTOR AND BRANE TENSION



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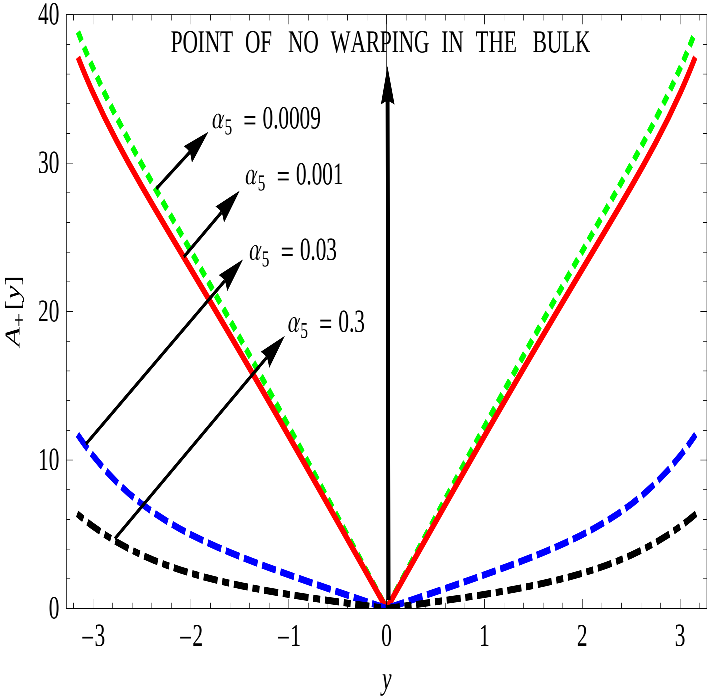

(f) $\Lambda_{(5)} > 0$ and $A_1 < 0$

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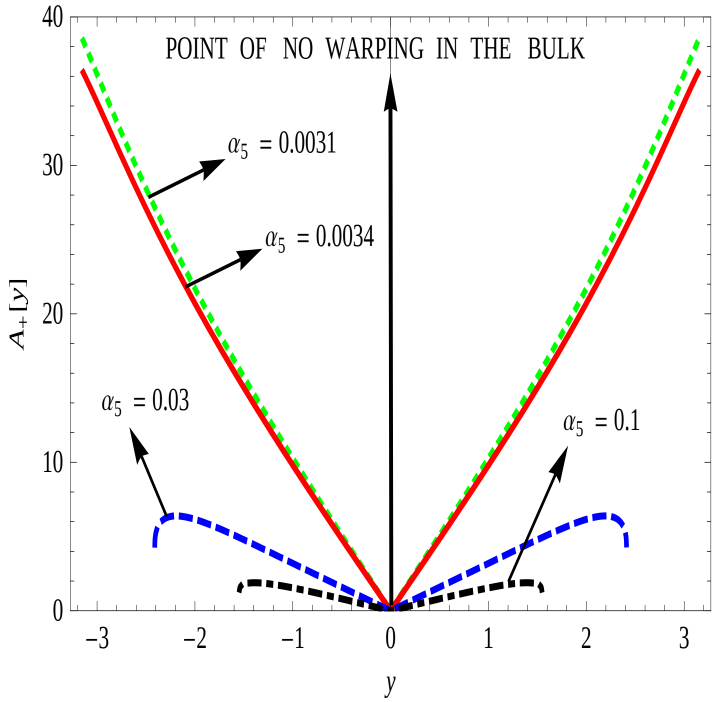

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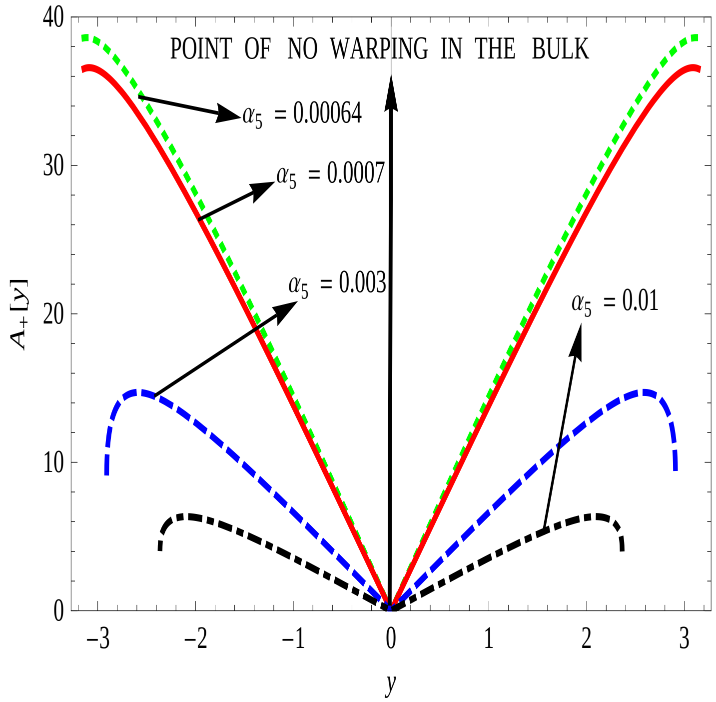

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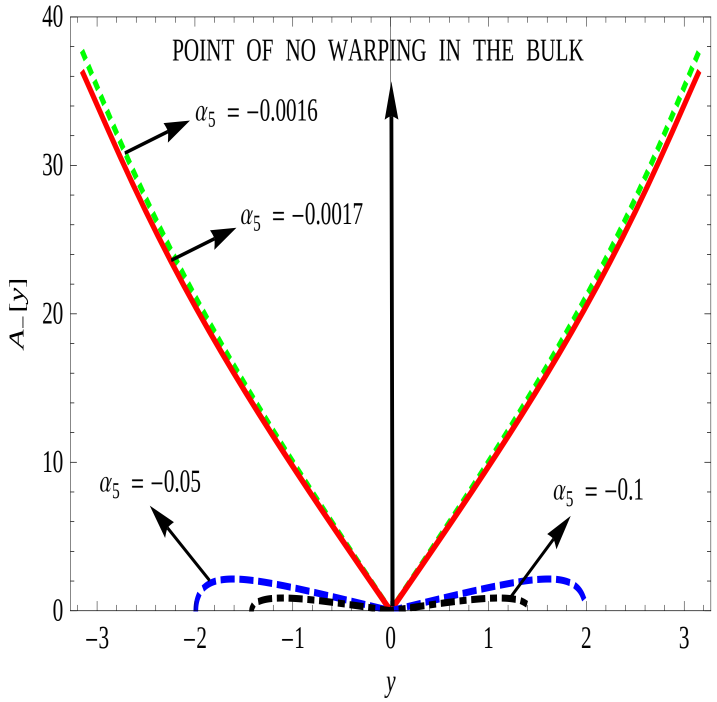

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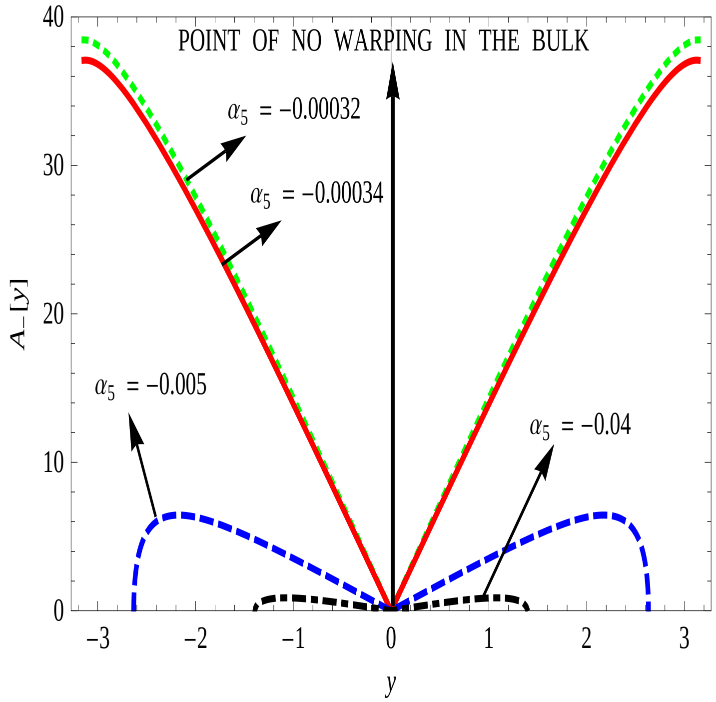

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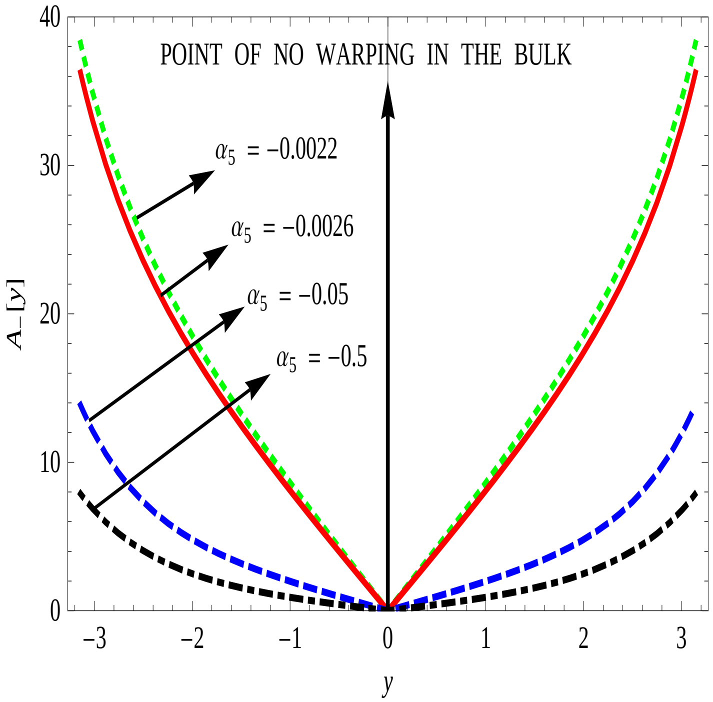
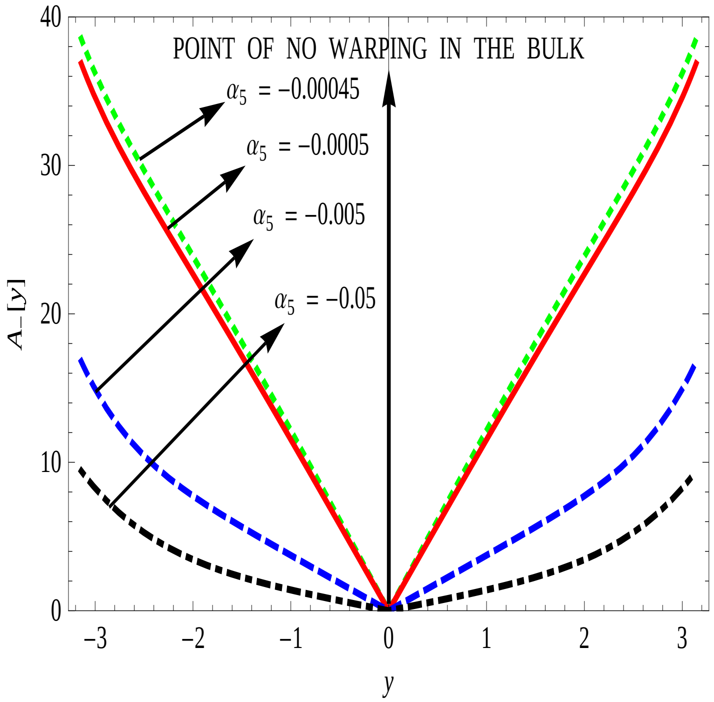


(k) $\Lambda_{(5)} < 0$ and $A_1 > 0$



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WARP FACTOR AND BRANE TENSION

► BRANE TENSION

$$T^{\pm}_{\mathbf{vis}} = -T^{\mp}_{\mathbf{hid}} =$$

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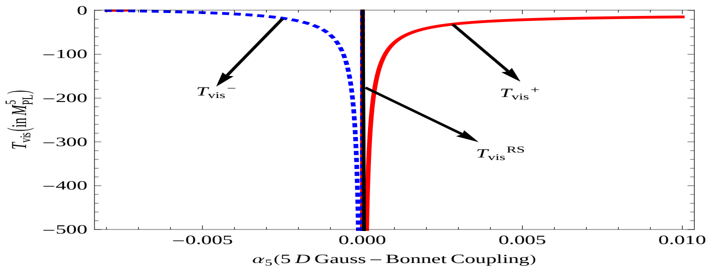
WARP FACTOR AND BRANE TENSION



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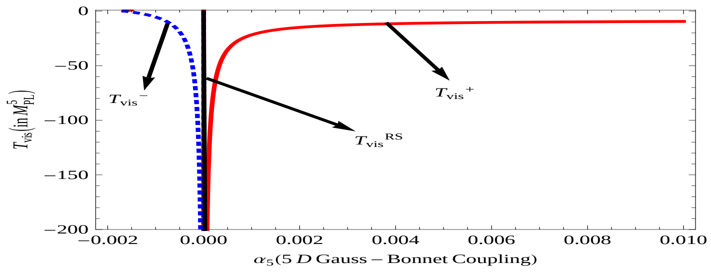

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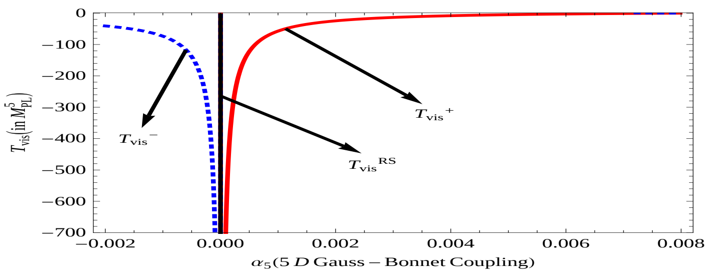

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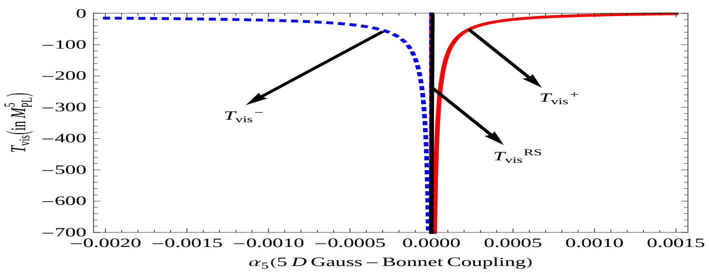

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ANALYSIS OF BULK KK SPECTRUM

► **GRAVITON MASS SPECTRUM:**

ANALYSIS OF BULK KK SPECTRUM

▶GRAVITON MASS SPECTRUM:

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

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

where

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

•4D effective action:$\mathbf{S}_G \supset \int d^4x \sum_{n=0}^{\infty} \mathbf{h}^{\alpha\beta\ (n)}(x)\mathbf{h}^{(n)}_{\alpha\beta}(x) \left(m^{\mathbf{G}}_n\right)^2_\pm$

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

ANALYSIS OF BULK KK SPECTRUM

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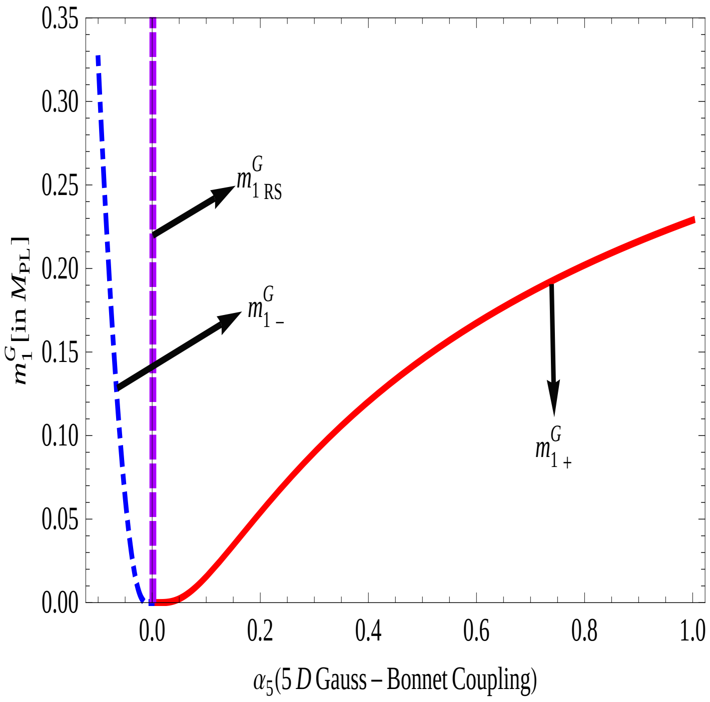

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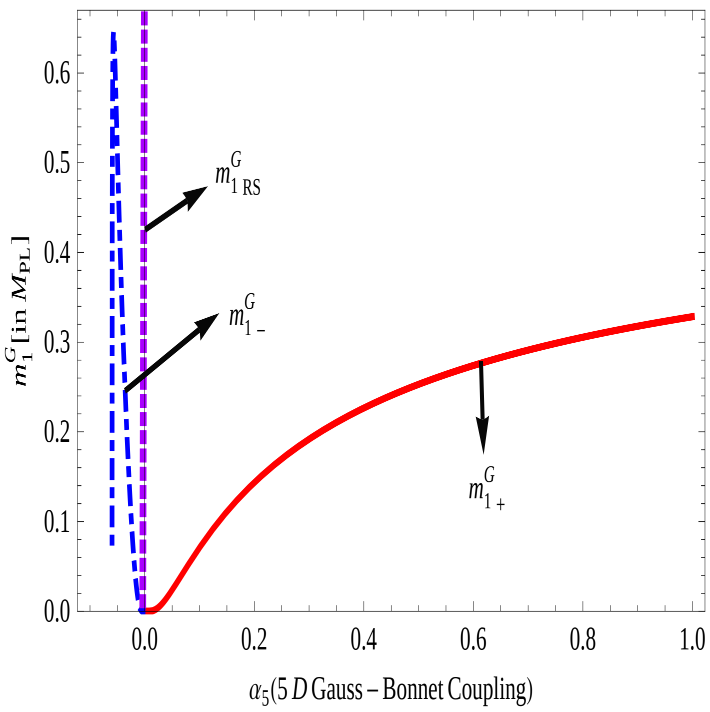

(r) $\Lambda_{(5)} > 0$ and $A_1 < 0$

ANALYSIS OF BULK KK SPECTRUM

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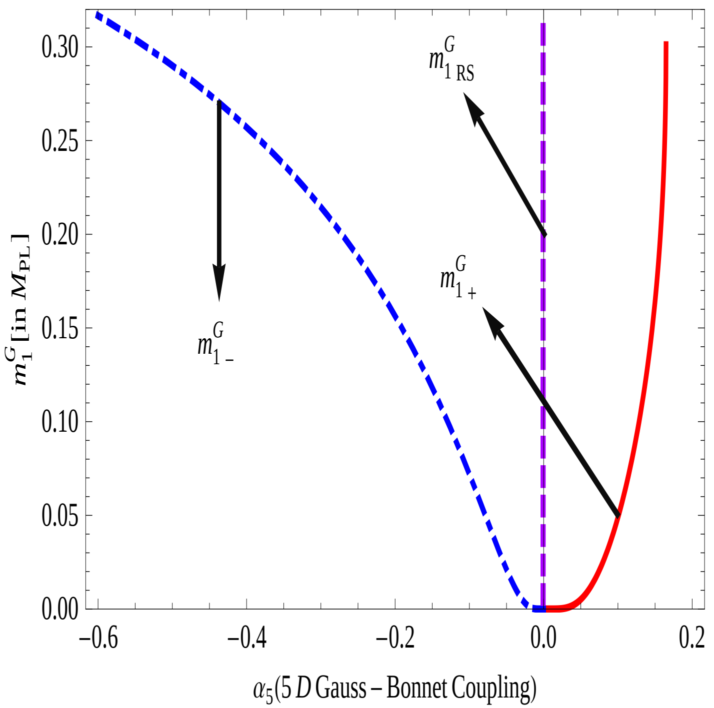
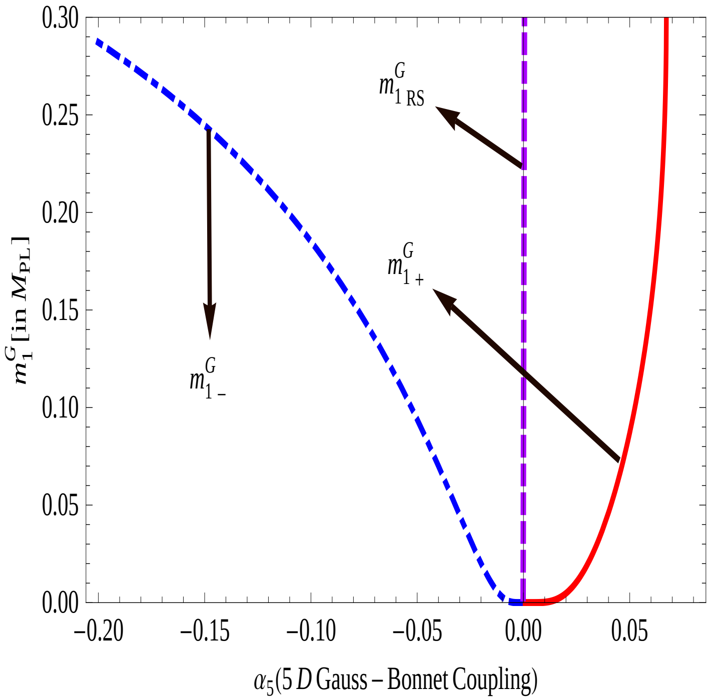


(s) $\Lambda_{(5)} < 0$ and $A_1 > 0$



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ANALYSIS OF BULK KK SPECTRUM

► **SCALAR MASS SPECTRUM:**

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▶SCALAR MASS SPECTRUM:

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

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

where

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• **4D effective action:**

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

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

where

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

•**4D effective action:**

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

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

ANALYSIS OF BULK KK SPECTRUM

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

ANALYSIS OF BULK KK SPECTRUM

▶$\mathcal{U}(1)$ 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:** $\mathcal{A}_\mu(x,y) = \sum_{n=0}^{\infty}\mathcal{A}_\mu^{(n)}(x)\,\frac{\chi^{(n)}_{\pm;\mathcal{A}}(y)}{\sqrt{r_c}}$

where

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

•**4D effective action:**

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

ANALYSIS OF BULK KK SPECTRUM

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

ANALYSIS OF BULK KK SPECTRUM

►**MASSIVE FERMION MASS SPECTRUM:**

ANALYSIS OF BULK KK SPECTRUM

►MASSIVE FERMION MASS SPECTRUM:

• $S_f = \int d^5x \, [Det(\mathcal{V})] \; \Big\{ i\bar{\Psi}_{\mathbf{L},\mathbf{R}}(x,y)\gamma^\alpha \mathcal{V}^M_\alpha \overleftrightarrow{\mathbf{D}}_\mu \Psi_{\mathbf{L},\mathbf{R}}(x,y)\delta^\mu_M$

$- sgn(y) m_f \bar{\Psi}_{\mathbf{L},\mathbf{R}}(x,y)\Psi_{\mathbf{R},\mathbf{L}}(x,y) + \; h.c. \Big\}$

where

• $\overleftrightarrow{\mathbf{D}}_\mu := \Big(\overleftrightarrow{\partial}_\mu + \frac{g^{NP}}{16} \Big(\mathcal{V}_N^{[\hat{A}} \partial_{[\mu} \mathcal{V}_{P]}^{\hat{B}]}$
$+ \frac{1}{2} g^{TS} \mathcal{V}_N^{[\hat{A}} \mathcal{V}_T^{\hat{B}]} \partial_{[S} \mathcal{V}_{P]}^{\hat{C}} \mathcal{V}_\mu^{\hat{D}} \eta_{\hat{C}\hat{D}} \Big) [\Gamma_{\hat{A}}, \Gamma_{\hat{B}}] + i g_f \mathcal{A}_\mu \Big)$

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

• $\{\Gamma^{\hat{A}}, \Gamma^{\hat{B}}\} = 2\eta^{\hat{A}\hat{B}}$**,** $\eta^{\hat{A}\hat{B}} = diag\,(-1, +1, +1, +1, +1)$

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

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

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

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

ANALYSIS OF BULK KK SPECTRUM

▶**MASSIVE FERMION MASS SPECTRUM:**

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

where

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

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

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

BULK GRAVITON & BRANE SM FIELD INTERACTION

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

BULK GRAVITON & BRANE SM FIELD INTERACTION

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

- **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 counter part in RS model and the GB coupling make the detectability of the signature of KK mode graviton through $H \to \tau\bar{\tau}$ 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:

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

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

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

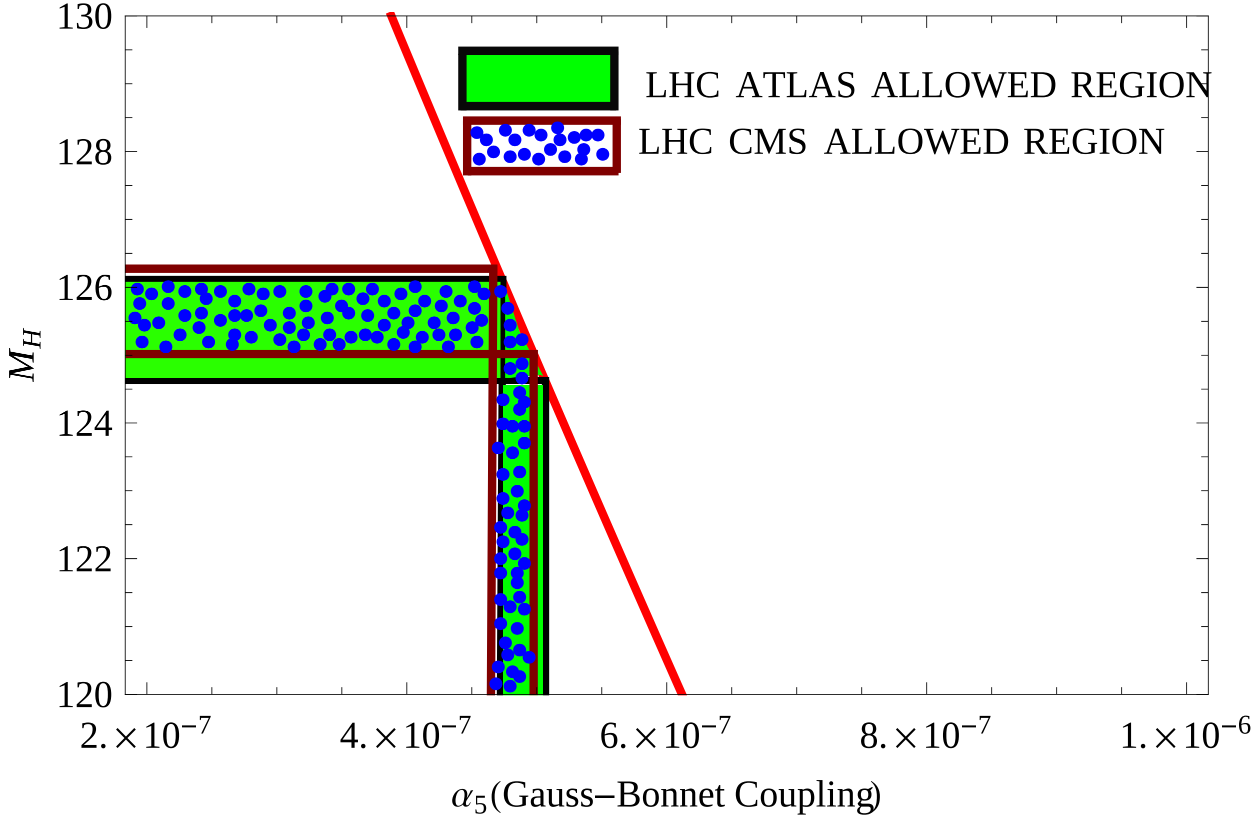
- Zeroth mode scalar mass:

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

COLLIDER CONSTRAINTS ON THE GB COUPLING

▶**<u>HIGGS MASS CONSTRAINT</u>**:

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



COLLIDER CONSTRAINTS ON THE GB COUPLING

▶μ **PARAMETER CONSTRAINT FROM** $H \to (\gamma\gamma, \tau\bar{\tau})$ **CHANNELS**:

$$\bullet \mu = \frac{\mathbf{\Sigma(pp \to H_0)}}{\mathbf{\Sigma(pp \to H_{SM})}} \times \frac{\mathbf{BR(H_0 \to l_1 l_2)}}{\mathbf{BR(H_{SM} \to l_1 l_2)}}$$

$$= \begin{cases} \mathbf{1.6 \pm 0.3} & \text{for ATLAS } l_1 = l_2 = \gamma \\ \mathbf{0.77 \pm 0.27} & \text{for CMS } l_1 = l_2 = \gamma \\ \mathbf{0.8 \pm 0.7} & \text{for ATLAS } l_1 = \tau, l_2 = \bar{\tau} \\ \mathbf{1.10 \pm 0.4} & \text{for CMS } l_1 = \tau, l_2 = \bar{\tau} \end{cases}$$

with

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

COLLIDER CONSTRAINTS ON THE GB COUPLING

- **Total decay width:**

$$\boxed{\Gamma_{\textbf{total}} \approx \Gamma(\mathbf{H}_0 \to W^+W^-) + \Gamma_{\textbf{fer}}}$$

where

- $\Gamma(\mathbf{H}_0 \to W^+W^-) = \frac{m_s^4}{48 m_W^2} F_{\mathcal{W}}^2 F_{\mathcal{G}}^2 T\left(m_W^2, m_s^2\right)$

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

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

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

- **Diphoton decay width:**

$$\boxed{\Gamma(\mathbf{H}_0 \to \gamma\gamma) = \frac{m_s^3}{3456 \pi^5 m_W^4} F_{\mathcal{A}}^2 F_{\mathcal{W}}^2 \left[2 + \frac{12 m_W^2}{m_s^2} + \frac{12 m_W^2}{m_s^2}\left(2 - \frac{4 m_W^2}{m_s^2}\right)\left\{sin^{-1} \frac{1}{\sqrt{\frac{4 m_W^2}{m_s^2}}}\right\}^2\right]^2}$$

COLLIDER CONSTRAINTS ON THE GB COUPLING

• **Dilepton decay width:**

$$\Gamma(\mathbf{H}_0 \to gg) = \frac{m_{f_4}^2 N_g}{256\pi^5 m_s} F_{\mathcal{Q}_4}^2 F_{\mathcal{G}_g}^4 \left[1 + \left(1 - 4\frac{m_{f_4}^2}{m_s^2} \right) \left\{ sin^{-1} \frac{1}{2\sqrt{\frac{m_{f_4}^2}{m_s^2}}} \right\}^2 \right]^2$$

• **Differential production cross section of the scalar:**

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

we define gluon momentum fraction as:

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

• $g_p(x_p, M_s^2)$ **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

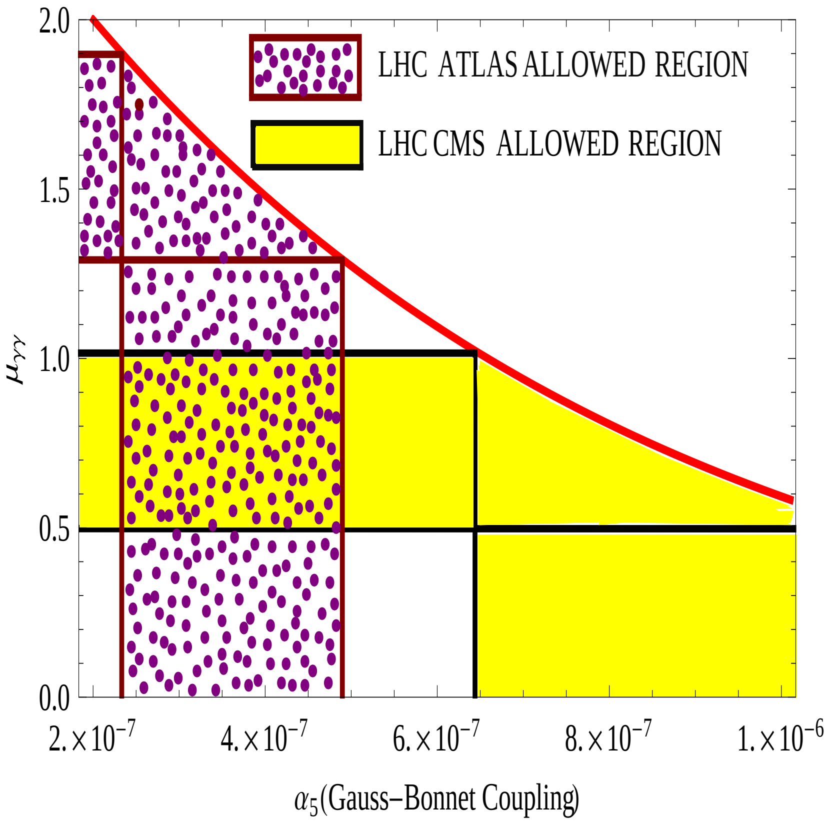
•VERTEX FACTORS IN 4D EFFECTIVE THEORY:

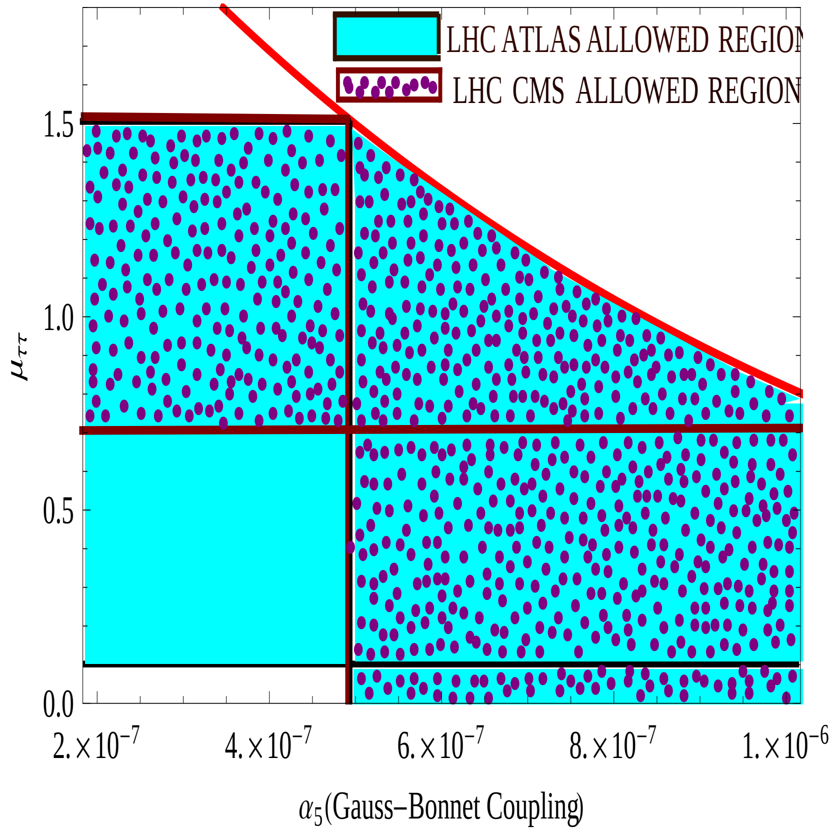
$$\begin{aligned}
F_{\mathcal{Q}} &= y_\eta \mathcal{Q}^{000} = \frac{2N_f^2 N_s}{m_f r_c} \sinh\left(m_f r_c \pi\right), \\
F_{\mathcal{G}} &= \frac{g_f \mathcal{G}^{000}}{\sqrt{r_c}} = \frac{g_f N_f^2}{\sqrt{2\pi r_c}} \frac{\sinh\left(k_\alpha - 2m_f\right)\pi r_c}{(k_\alpha - 2m_f) r_c}, \\
F_{\mathcal{W}} &= h_w \mathcal{W}^{000} = h_w N_s, F_{\mathcal{A}} = \frac{g_e}{r_c^{\frac{3}{2}}} \mathcal{A}^{000} = \frac{g_e}{\sqrt{2\pi r_c^3}}
\end{aligned}$$

with the following overlapping integrals:

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

COLLIDER CONSTRAINTS ON THE GB COUPLING





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

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

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.

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THANKS FOR YOUR TIME.........