

Brane-Higgs fields

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Outline

A – The scenarii

B – The methodologies

C – Beyond Higgs regularisation

D – Wave function jumps

E – UV origin of chirality

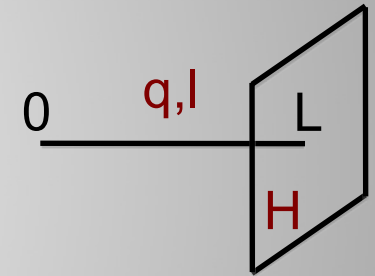
F – Phenomenological impacts

A – The scenarii

Framework : Higgs boson at a point along warped extra dimension(s)
 hep-ph/9905221 [3-brane] where gravity scale is reduced down to TeV !
 Randall, Sundrum => no more gauge hierarchy problem (with SM scale)

I) Interval model

- Fermions in the bulk (for FCNC, flavours,...),
- Toy model with flat compact space.

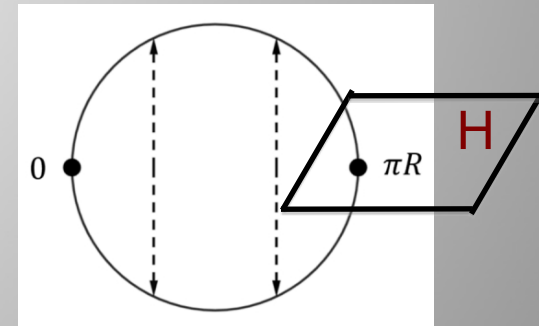


II) S^1/Z_2 Orbifold model

$$\mathcal{L} [\Phi(x^\mu, -y)] = \mathcal{L} [\Phi(x^\mu, y)]$$

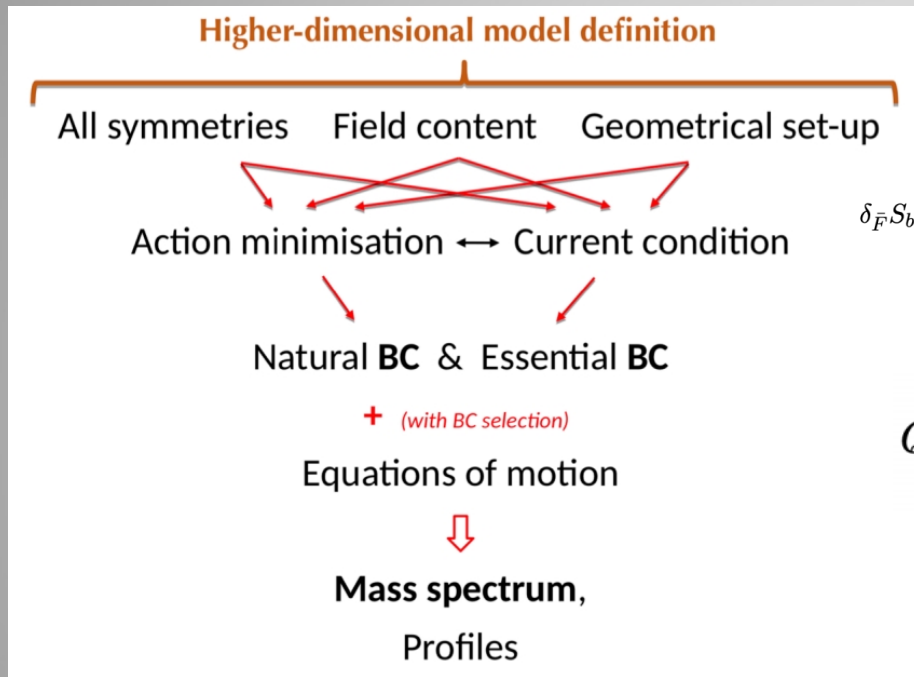
$$\Phi(x^\mu, -y) = \mathcal{T}\Phi(x^\mu, y)$$

$$\mathcal{L}_{kin} = \frac{i}{2} (\bar{Q}\Gamma^M \overleftrightarrow{\partial}_M Q + \bar{D}\Gamma^M \overleftrightarrow{\partial}_M D)$$



B – The methodologies

5D approach:



$$\begin{aligned} \delta_{\bar{F}} S_{bulk} &= \int d^4x \left(\int_{-\pi R^+}^{0^-} + \int_0^{\pi R} \right) dy \left\{ \delta_{\bar{F}} \frac{\partial \mathcal{L}_{kin}}{\partial \bar{F}} + \delta \left(\partial_M \bar{F} \right) \frac{\partial \mathcal{L}_{kin}}{\partial \partial_M \bar{F}} \right\} \\ &= \int d^4x \left(\int_{-\pi R^+}^{0^-} + \int_0^{\pi R} \right) dy \left\{ \delta_{\bar{F}} \frac{\partial \mathcal{L}_{kin}}{\partial \bar{F}} + \partial_M \left[\delta_{\bar{F}} \frac{\partial \mathcal{L}_{kin}}{\partial \partial_M \bar{F}} \right] - \delta_{\bar{F}} \partial_M \frac{\partial \mathcal{L}_{kin}}{\partial \partial_M \bar{F}} \right\} \end{aligned}$$

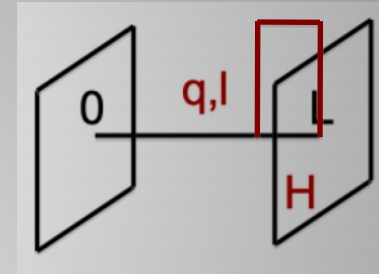
$$Q_L(x^\mu, y) = \frac{1}{\sqrt{2\pi R}} \sum_{n=0}^{+\infty} q_L^n(y) \psi_L^n(x^\mu)$$

Barcelo, Mitra, GM
arXiv:1408.1852 [hep-ph]

4D approach for KK tower masses *with Yukawa couplings*:

- 1) use **free 5D** method results (KK masses & profiles),
- 2) **bi-diagonalise** effective **4D field** mass matrix (**mixings**).

C – Beyond Higgs regularisation



I) No Brane-Higgs regularisation (width to 0)

- Two regularisation processes **non** physically **equivalent**.
- No theoretical **motivation**, no guarantee to remain in **same model**.
- Mathematical **inconsistencies** like mixing functions and distributions.

=> *irrelevant debate on ggF calculation non-commutativity*

*Carena ; Neubert ; Toharia ; Goertz...
initial paper: arXiv:1303.5702 [hep-ph]*

II) EBC or BBT

- Essential Boundary Conditions (**EBC**, not Natural BC) are **necessary**:
vanishing probability fermion currents [in both dual models].

$$\partial_M j^M = 0, \text{ with, } j^M = \sum_{F=Q,D} j_F^M$$

$$j_Q^M = -\alpha \bar{Q} \Gamma^M Q, \quad j_D^M = -\alpha' \bar{D} \Gamma^M D$$

$$j^4 \Big|_{\pi_R} = 0$$

- Their rôle can be played by new Bilinear Brane Terms (**BBT**).

$$S_B = \int d^4x \left(\sigma_0^Q \bar{Q}Q \Big|_0 + \sigma_{\pi_R}^Q \bar{Q}Q \Big|_{\pi_R} + \sigma_0^D \bar{D}D \Big|_0 + \sigma_{\pi_R}^D \bar{D}D \Big|_{\pi_R} \right)$$

*...like in GR context : AdS/CFT duality,
Gibbons-Hawking and scalar terms*

III) Result overview

From mathematically rigorous analyses...

Free case

- 1) $(--)$: $f_L^n(y) = B_L^n \sin(m_n y)$, $(++)$: $f_R^n(y) = B_L^n \cos(m_n y)$; $\sin(m_n \pi R) = 0$,
- 2) $(++)$: $f_L^n(y) = B_R^n \cos(m_n y)$, $(--)$: $f_R^n(y) = -B_R^n \sin(m_n y)$; $\sin(m_n \pi R) = 0$,
- 3) $(-+)$: $f_L^n(y) = B_L^n \sin(m_n y)$, $(+-)$: $f_R^n(y) = B_L^n \cos(m_n y)$; $\cos(m_n \pi R) = 0$,
- 4) $(+-)$: $f_L^n(y) = B_R^n \cos(m_n y)$, $(-+)$: $f_R^n(y) = -B_R^n \sin(m_n y)$; $\cos(m_n \pi R) = 0$.

Yukawa coupling

$$\begin{cases} (+\times): q_L^n(y) = A_q^n \cos(M_n y), & (-\times): q_R^n(y) = -A_q^n \sin(M_n y), \\ (-\times): d_L^n(y) = A_d^n \sin(M_n y), & (+\times): d_R^n(y) = A_d^n \cos(M_n y), \end{cases}$$

$$\tan(M_n \pi R) = \left| \frac{X}{2} \right|, \quad A_q^n = e^{i(\alpha_0^n + \alpha_Y)}, \quad A_d^n = e^{i\alpha_0^n},$$

$$\tan(M_n \pi R) = - \left| \frac{X}{2} \right|, \quad A_q^n = e^{i(\alpha_0^n + \alpha_Y \pm \pi)}, \quad A_d^n = e^{i\alpha_0^n},$$

	No boundary characteristic	Vanishing current condition [EBC]	Bilinear brane terms [NBC]
4D Approach	<i>(Impossible)</i>	BC (\pm)	BC (\pm)
5D Approach	<i>(Impossible)</i>	<i>(Impossible)</i>	BC (\times)

D – Wave function jumps

I) Interval models

No fermion profile discontinuities.

II) Orbifold models

Fermion profile jumps arise !

- **Mathematically consistent,**

$$S_{bulk} = \int d^4x \left(\int_{-\pi R^+}^{0^-} dy \mathcal{L}_{kin} + \int_0^{\pi R} dy \mathcal{L}_{kin} \right) \quad f(0) = f(0^+)$$

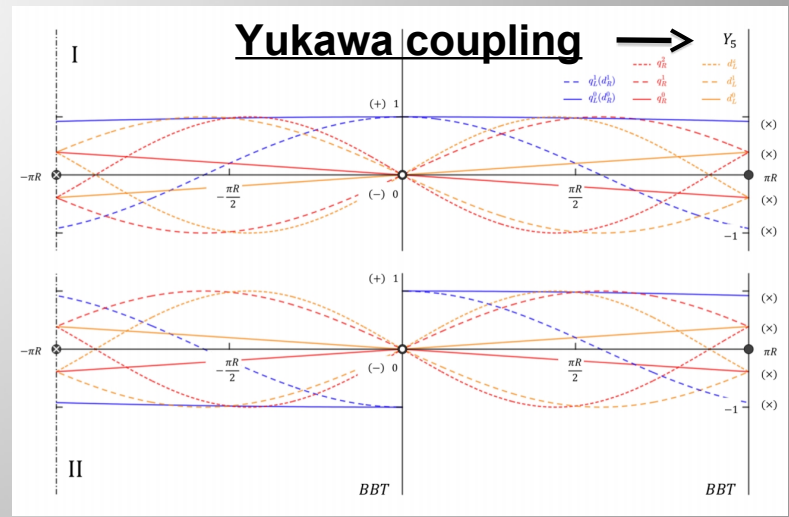
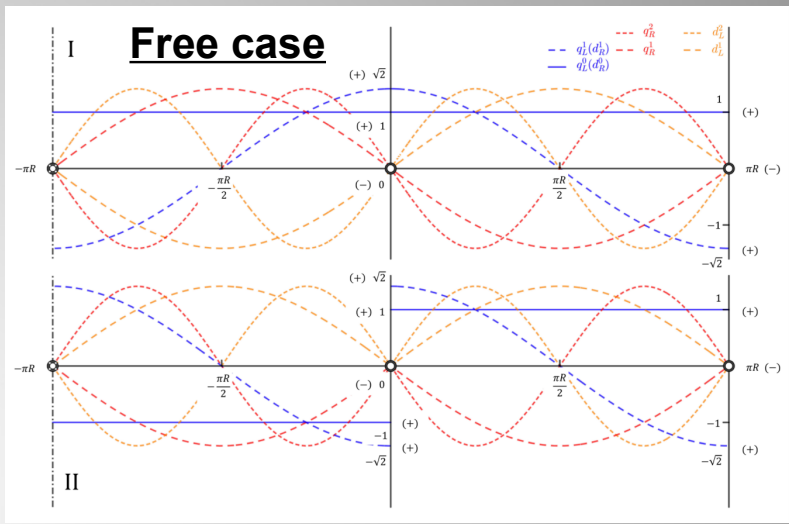
- disappear for some **free solution parities** but unavoidable with brane-Yukawa couplings,

- physical impact neither on KK mass spectrum nor on 4D effective Yukawa couplings,

$$S_Y = \int d^4x \mathcal{L}_Y(x^\mu, \pi R)$$

$$\mathcal{L}_Y = -Y_5 H Q_L^\dagger D_R$$

- models even with physical jumps probably exist...



E – UV origin of chirality

The choice of EBC type (or equivalently of BBT) – via inclusive parity SYM. – generates the chiral nature of the low-energy model **and** the SM field chiralities.

F – Phenomenological impacts

No ‘wrong-chirality’ Yukawa coupling dependence (4D/5D method):

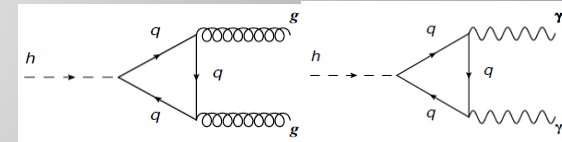
$$- Y'_5 H Q_R^\dagger D_L$$

=> **KK effects** in $g_{h\gamma\gamma}$: < few 10's % [Y] // 5% (14TeV 3000fb⁻¹ HL-LHC), 2% (1000 GeV/fb⁻¹ ILC)

in SM y_{htt} and y_{hbb} : < few 10's % [Y] // 7% (“ “ “ ”), 1% (500 “ “ ”)

...to be estimated in RS (e.g. Neubert et al.) // (1312.4974, Peskin)

[hep-ph]

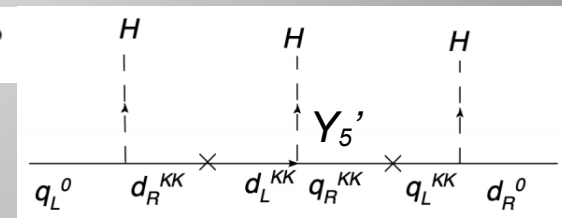


=> No significant FC quark Yukawa interactions from misalign.

=> no strong KK mass **constraints** from $\bar{K} - K, \bar{B} - B$

arXiv:0906.1990 [hep-ph]

Azatov et al.



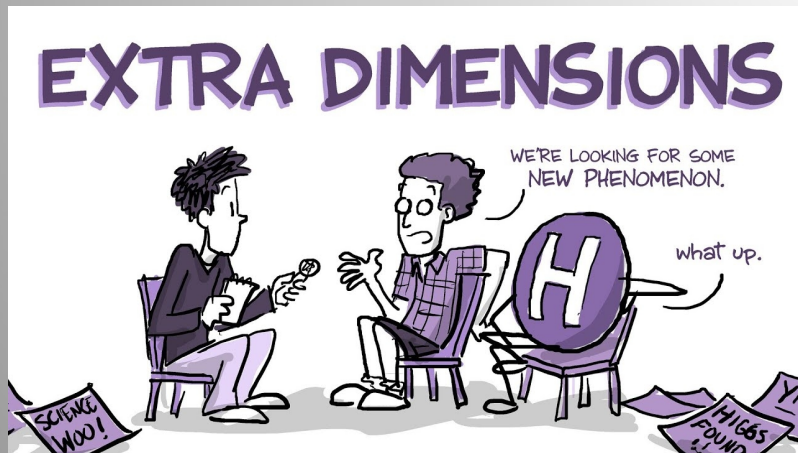
=> And no significant FC quark/lepton Yukawa couplings

=> no **detectable** exotic decays $t \rightarrow ch$ or $h \rightarrow \mu\tau$. (at LHC, LC) ?

Conclusions

Rigorous treatments of brane-Higgs scenarii:

- ☀ **No brane-Higgs regularisation**
- ☀ **EBC** or **BBT** : outside or inside the action
- ☀ **Profile discontinuities** via improper integrals
- ☀ Path towards **UV origin of chirality**



Only soften potential New Physics FC effects in the Higgs sector at LHC (LC)...