Brane-Higgs fields

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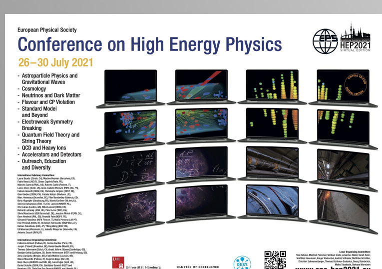


- 27/07/2021 -

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

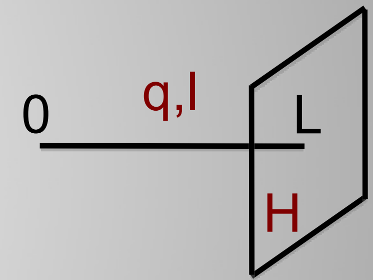
Framework : Higgs boson at a point along warped extra dimension(s)

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.

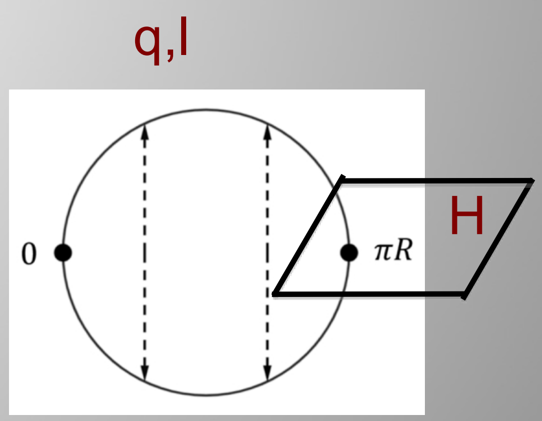


II) S^1/Z_2 Orbifold model

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

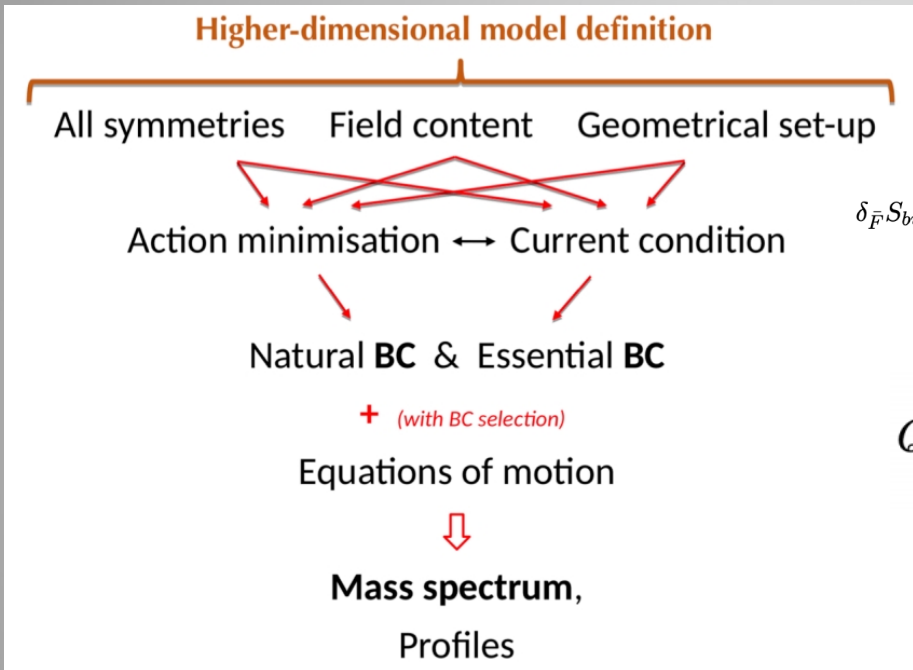
$$\Phi(x^\mu,-y) = \mathcal{T}\,\Phi(x^\mu,y)$$

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



B – The methodologies

5D approach:



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

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

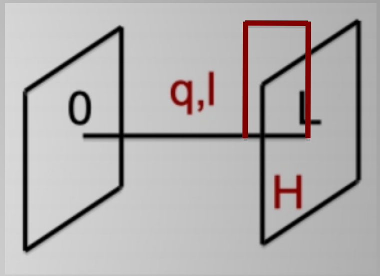
Barcelo, Mitra, GM
arXiv:1408.1852 [hep-ph]

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].

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

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

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

- 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

$$1)\quad (--):\ f_L^n(y) = B_L^n\ \sin(m_n\, y)\,,\ (++):\ f_R^n(y) = B_L^n\ \cos(m_n\, y)\,;\ \sin(m_n\, \pi R) = 0\,,$$

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

$$3)\quad (-+):\ f_L^n(y) = B_L^n\ \sin(m_n\, y)\,,\ (+-):\ f_R^n(y) = B_L^n\ \cos(m_n\, y)\,;\ \cos(m_n\, \pi R) = 0\,,$$

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

Yukawa coupling

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

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

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

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

D – Wave function jumps

I) Interval models

No fermion profile discontinuities.

II) Orbifold models

Fermion profile jumps arise !

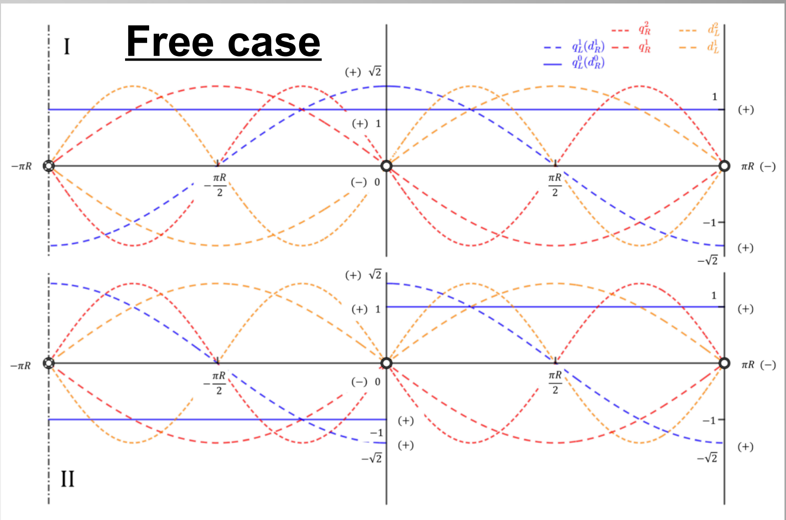
- ***Mathematically*** *consistent,*

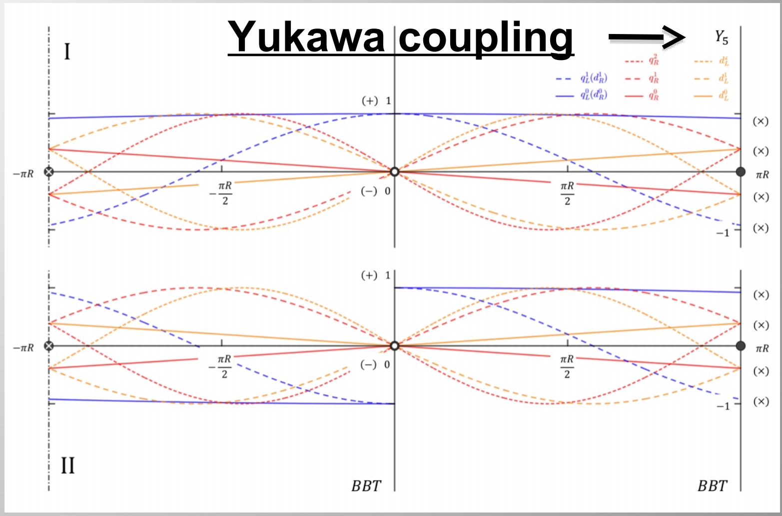
$$S_{bulk} = \int d^4x \left(\int_{-\pi R^+}^{0^-} dy \; \mathcal{L}_{kin} + \int_0^{\pi R} dy \; \mathcal{L}_{kin} \right) \qquad f(0) = f(0^+)$$

- *disappear for some* ***free*** *solution parities but unavoidable with brane-Yukawa* ***couplings****,*
- *physical impact neither on KK* ***mass spetrum*** *nor on 4D effective* ***Yukawa couplings****,*

$$S_Y = \int d^4x \, \mathcal{L}_Y(x^\mu, \pi R) \qquad \mathcal{L}_Y = -Y_5 \; H Q_L^\dagger D_R$$

- *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.*

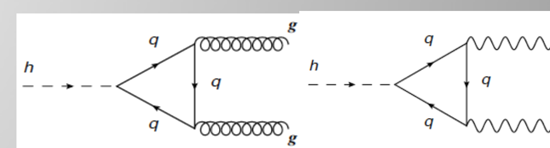
F – Phenomenological impacts

No ‘wrong-chirality’ Yukawa coupling dependence (4D/5D method): $-\,Y_5'\;HQ_R^\dagger D_L$

=> *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]

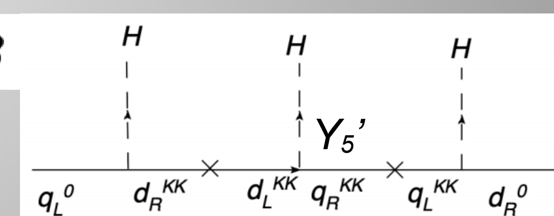


=> *No significant FC quark Yukawa interactions from misalign.*

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

arXiv:0906.1990 [hep-ph]

Azatov et al.



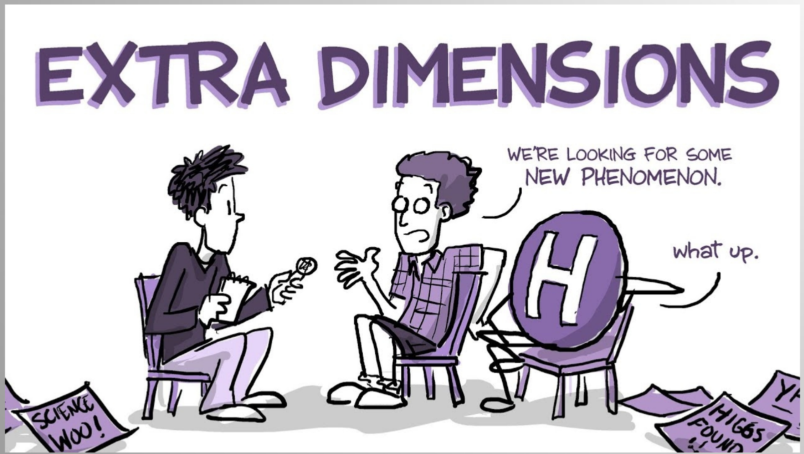
=> *And no significant FC quark/lepton Yukawa couplings*

*=> no **detectable** exotic decays* $t \to ch$ *or* $h \to \mu\tau$ *(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)...