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Brane-Higgs fields
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)
[3-brane] where gravity scale is reduced down to TeV!
=> no more gauge hierarchy problem (with SM scale)

Randall, Sundrum

I) Interval model

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

II) $S^1/Z_2$ Orbifold model
**B – The methodologies**

**5D approach:**

- **Higher-dimensional model definition**
  - All symmetries
  - Field content
  - Geometrical set-up
  - Action minimisation ↔ Current condition
  - Natural BC & Essential BC
  - Equations of motion
  - Mass spectrum, Profiles

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).

\[
\delta_{F} S_{\text{bulk}} = \int d^{4}x \left( \int_{-\pi R}^{0} + \int_{0}^{\pi R} \right) dy \left\{ \delta F \frac{\partial L_{\text{kin}}}{\partial F} + \delta \left( \partial_{M} F \right) \frac{\partial L_{\text{kin}}}{\partial \partial_{M} F} \right\}
\]
\[
= \int d^{4}x \left( \int_{-\pi R}^{0} + \int_{0}^{\pi R} \right) dy \left\{ \delta F \frac{\partial L_{\text{kin}}}{\partial F} + \partial_{M} \left[ \delta F \frac{\partial L_{\text{kin}}}{\partial \partial_{M} F} \right] - \delta F \partial_{M} \frac{\partial L_{\text{kin}}}{\partial \partial_{M} F} \right\}
\]

\[
Q_{L} \left( x^{\mu}, y \right) = \frac{1}{\sqrt{2\pi R}} \sum_{n=0}^{+\infty} q_{L}^{n}(y) \psi_{L}^{n} \left( x^{\mu} \right)
\]

Barcelo, Mitra, GM
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

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

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

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

\[ j^4 \bigg|_{\pi_R} = 0 \]

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

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

...like in GR context: AdS/CFT duality, Gibbons-Hawking and scalar terms
III) Result overview

From mathematically rigorous analyses...

1) (--) : $f^n_L(y) = B^n_L \sin(m_n y)$, (++) : $f^n_R(y) = B^n_R \cos(m_n y)$; $\sin(m_n \pi R) = 0$,
2) (++) : $f^n_L(y) = B^n_R \cos(m_n y)$, (--) : $f^n_R(y) = -B^n_R \sin(m_n y)$; $\sin(m_n \pi R) = 0$,
3) (--) : $f^n_L(y) = B^n_L \sin(m_n y)$, (+-) : $f^n_R(y) = B^n_L \cos(m_n y)$; $\cos(m_n \pi R) = 0$,
4) (+-) : $f^n_L(y) = B^n_R \cos(m_n y)$, (--) : $f^n_R(y) = -B^n_R \sin(m_n y)$; $\cos(m_n \pi R) = 0$.

Yukawa coupling

\[
\begin{align*}
\{ (+\times) & : q^n_L(y) = A^n_q \cos(M_n y), (-\times) : q^n_R(y) = -A^n_q \sin(M_n y), \\
(-\times) & : d^n_L(y) = A^n_d \sin(M_n y), (+\times) : d^n_R(y) = A^n_d \cos(M_n y),
\end{align*}
\]

\[
\tan(M_n \pi R) = \left| \frac{X}{2} \right|, \quad A^n_q = e^{i(\alpha^n_0 + \alpha y)}, \quad A^n_d = e^{i\alpha^n_0},
\]

\[
\tan(M_n \pi R) = -\left| \frac{X}{2} \right|, \quad A^n_q = e^{i(\alpha^n_0 + \alpha y \pm \pi)}, \quad A^n_d = e^{i\alpha^n_0},
\]

<table>
<thead>
<tr>
<th>No boundary characteristic</th>
<th>Vanishing current condition [EBC]</th>
<th>Bilinear brane terms [NBC]</th>
</tr>
</thead>
<tbody>
<tr>
<td>4D Approach</td>
<td>(Impossible)</td>
<td>BC (±)</td>
</tr>
<tr>
<td>5D Approach</td>
<td>(Impossible)</td>
<td>(Impossible)</td>
</tr>
</tbody>
</table>
D – Wave function jumps

I) Interval models
No fermion profile discontinuities.

II) Orbifold models
Fermion profile jumps arise!
- Mathematically consistent,

\[ S_{\text{bulk}} = \int d^4x \left( \int_{\pi R}^{0} dy \mathcal{L}_{\text{kin}} + \int_{0}^{\pi R} dy \mathcal{L}_{\text{kin}} \right) \]

\[ f(0) = f(0^+) \]

- 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,

\[ S_{Y} = \int d^4x \mathcal{L}_{Y}(x^\mu, \pi R) \]
\[ \mathcal{L}_{Y} = -Y_{5} HQ_{L}D_{R} \]

- 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):

\[ Y' \]

\[ - Y_5 \ H Q_R^\dagger \ D_L \]

\[ \Rightarrow \] 

\[ \text{KK effects in } g_{h\gamma\gamma} : < \text{few 10's } \% \ [Y] \ // 5\% \ (14\text{TeV} \ 300\text{fb}^{-1} \text{HL-LHC}), \ 2\% \ (1000 \text{GeV/}fb^{-1} \text{ILC}) \]

in SM \[ y_{htt} \text{ and } y_{hbb} : < \text{few 10's } \% \ [Y] \ // 7\% \ (\text{at } LHC, LC) \]

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

\[ \text{[hep-ph]} \]

\[ \Rightarrow \text{No significant FC quark Yukawa interactions from misalign.} \]

\[ \Rightarrow \text{No strong KK mass constraints from} \]


Azatov et al.

\[ \Rightarrow \text{And no significant FC quark/lepton Yukawa couplings} \]

\[ \Rightarrow \text{No detectable exotic decays } \ t \rightarrow ch \ \text{or } \ h \rightarrow \mu\tau \] (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)...