A holographic fourth generation: signals at the LHC

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Beyond the 3SM generation at the LHC era
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Subject of the talk

I) Motivations

II) A 5D model with a fourth generation

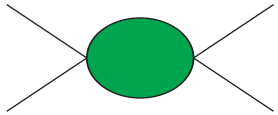
III) Electroweak symmetry breaking from the fourth generation condensation

IV) Electroweak precision tests

V) Phenomenology: production and detection of the fourth generation

VI) Conclusions

Motivations

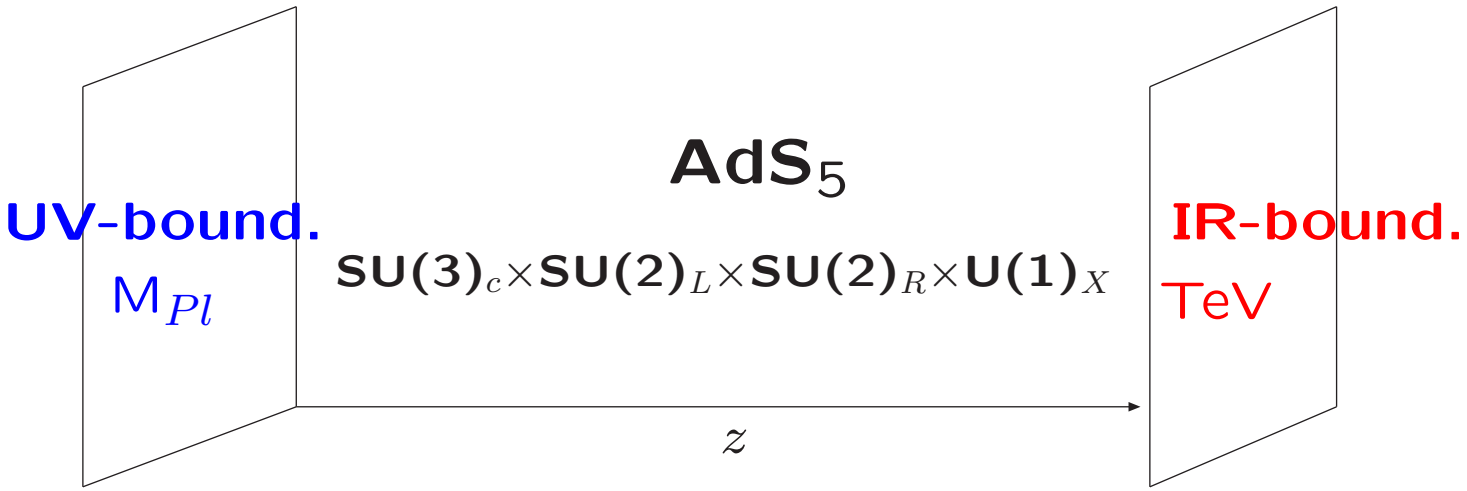


- EWSB by top quark condensation (Bardeen, Hill, Lindner '90)
- prediction: top quark too heavy: $\Lambda \sim O(1)$TeV $\Rightarrow m_t \sim 700$GeV
- for larger new physics scale: $\Lambda \sim 10^{15}$TeV $\Rightarrow m_t \sim 200$GeV

- condensation of a heavy fourth generation: $m_U \sim 700$GeV, but:
- what is the fundamental theory leading to 4ferm. interaction?
- how to obtain SM fermion masses?

- A fourth generation in 5D
- KK-gauge vectors mediate the 4ferm. interaction
- bulk 4-fermion operators M_{PL} supressed
- solve the fermionic spectrum naturally

5D Model



- RS: solve the hierarchy problem localizing the Higgs in IR
- Bulk gauge symmetry: custodial isospin symmetry
- Four generations of 5D fermions ($m_f^{5D} = c_f k$)
- 1'st and 2'nd generations localized in UV: $c_{1,2} > 1/2$
- 3'rd generation partially localized in IR: $-1/2 \leq c_3 \leq 1/2$
- 4'th generation localized in IR: $c_4 \leq 1/2$

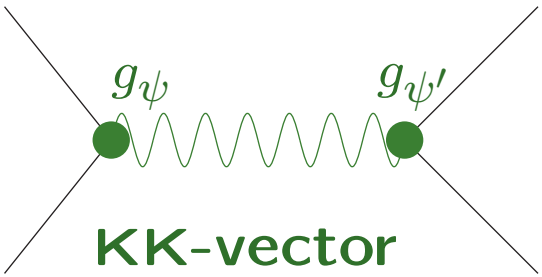
4-fermion interactions

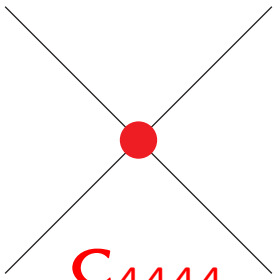
KK decomposition $\Phi(\mathbf{x},\mathbf{z}) = \sum_{\mathbf{n}} \mathbf{f_n}(\mathbf{z})\Phi^{(\mathbf{n})}(\mathbf{x})$

5D gauge interaction: $\mathbf{g_5} \int dz\ \sqrt{g}\ \bar{\psi}(x,z)\gamma^\mu A_\mu(x,z)\psi(x,z)$

5D 4-fermion interaction: $\frac{\mathbf{C_{ijkl}}}{M_{Pl}^3} \int dz\ \sqrt{g}\ \bar{\psi}_L^i(x,z)\psi_R^j(x,z)\bar{\psi}_R^l(x,z)\psi_L^k(x,z)$

- strong interaction for fermion 0-modes localized in IR





Low energy effective theory: EWSB

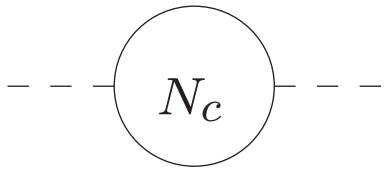
- Integrating out the heavy resonances, at scale $M_{KK} \sim 3$TeV

$$\mathcal{L} = i\bar{U}_L \not{D} U_L + i\bar{U}_R \not{D} U_R + \frac{g_U^2}{M_{KK}^2}(\bar{U}_L U_R\, \bar{U}_R U_L)$$

- introduce an "auxiliary" Higgs field H

$$\mathcal{L} = i\bar{U}_L \not{D} U_L + i\bar{U}_R \not{D} U_R + g_U\, \bar{Q}_L H U_R - M_{KK}^2 H^\dagger H + h.c.$$

- at scale $\mu < M_{KK}$ dynamical H: $\mathcal{L}(\mu) = Z_H |D_\mu H|^2 - {m_H}^2 |H|^2 + \ldots$

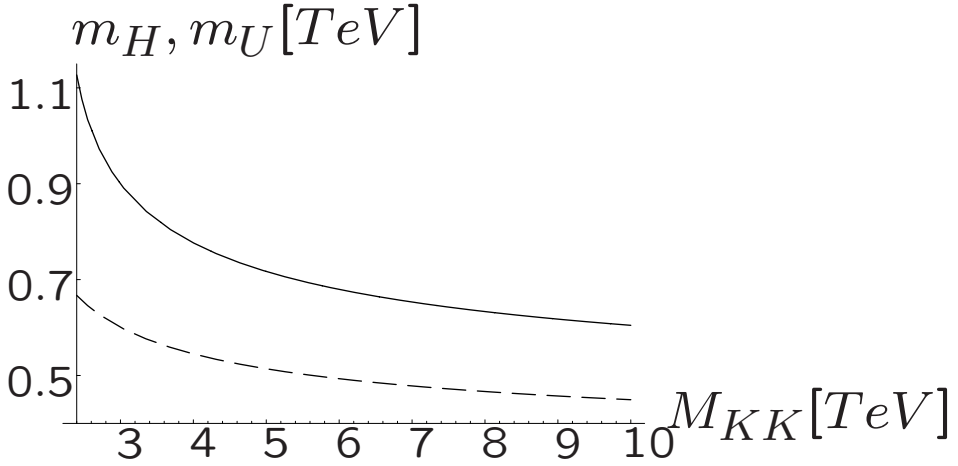


$$\Rightarrow\ -M_{KK}^2 \left(1 - \frac{g_U^2 N_c}{8\pi^2}\right) |H|^2 + \frac{g_U^2 N_c}{16\pi^2} \ln\left(\frac{M_{KK}^2}{\mu^2}\right)\ |D_\mu H|^2$$

EWSB: critical coupling: ${g_U}^2 > \frac{8\pi^2}{N_c} \Rightarrow m_H^2 < 0$

Mass Predictions

RGEs for Yukawa g_U and Higgs selfcoupling λ

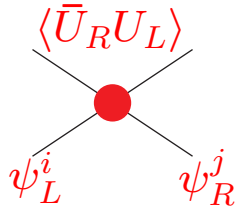


for $M_{KK} \sim 3\text{TeV} \Rightarrow m_U \simeq 650\text{GeV}$ (dashed line)

$m_H \simeq 900\text{GeV}$ (continuous line)

Masses of SM Fermions

4th generation 0-mode condensate: $\langle \bar{U}_R U_L \rangle \sim m_U^3$



$\Rightarrow$ 5D 4-fermion interactions generate mass terms

- light fermions (1st and 2nd generations): $c_L^i, -c_R^j > 1/2$

$$m_{ij} \sim C_{ij44} \frac{m_U^3}{TeV^2} \left(\frac{TeV}{M_{Pl}}\right)^{c_L^i - c_R^j - 1}$$

- heavy fermions (3rd generation): $c_L^3, -c_R^3 < 1/2$

$$m_{33} \sim C_{3344} \frac{m_U^3}{TeV^2} \frac{\sqrt{(1-2c_L^3)(1+2c_R^3)}}{4-c_L^3+c_R^3-c_L^4+c_R^4}$$

Electroweak precision tests

- Tree-level S parameter, as in any natural AdS-model (without 4th generation):

$$S \simeq 12\pi \frac{v^2}{M_{KK}^2} \simeq 0.25 \quad \text{for } M_{KK} \sim 3 \text{ TeV}.$$

- 1-Loop contributions to S from heavy Higgs and 4th gen.:

$$S_H \simeq \frac{1}{6\pi} \log \frac{m_H}{m_H^{ref}} \sim 0.1$$

$$S_{4gen} \simeq \frac{N_c}{6\pi}(1 - \frac{2}{3} \log \frac{m_U}{m_D}) \sim 0.1 \quad \text{model dependent}$$

- 1-Loop contributions to T:

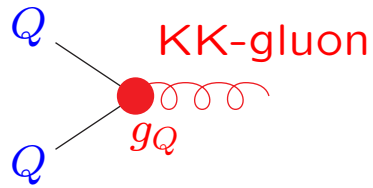
  heavy Higgs: T<0, but

  having U more localized in TeV than D: T>0.

Phenomenology

Production of quarks of 4th generation

Test the large couplings g_Q inducing the condensation



We have studied different leptonic signals:

$2l^{\pm}$, 3 leptons, 4 leptons.

- Significant excess due to 4th generation with:
luminosity $L \sim 0.5 fb^{-1}$ for $m_D \sim 300 - 600$ GeV.

- It is almost impossible to see the KK-resonance at the LHC.

Conclusions

- We have built a 5D model of EWSB with a 4th generation.

- The model breaks the EW symmetry by the condensation of the 4th generation.

- SM fermion masses from 5D 4f operators $\Rightarrow$ right Yukawas.

- Heavy 4th generation $m_U \sim 650$ GeV and Higgs $m_H \sim 900$ GeV.

- EWPT: large S-parameter $\Rightarrow$ need to supress S.

- Crucial test: strong coupling between KK-gluon and 4th gen. $\Rightarrow$ not possible due to large KK-gluon width and uncertainties.

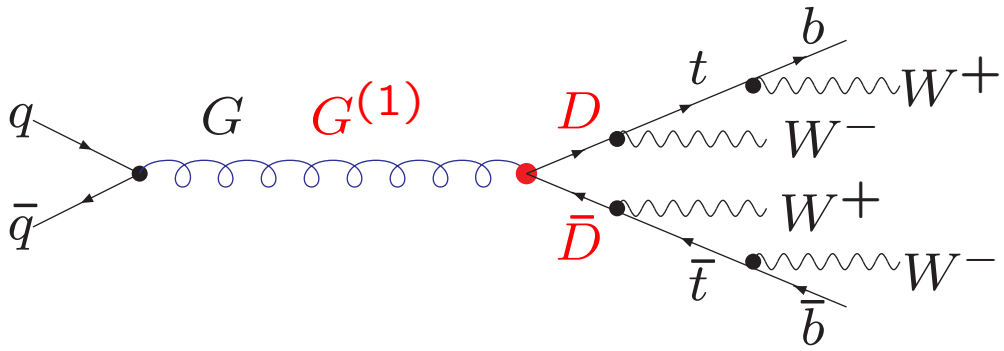
- Future: test large couplings with KK-weak bosons.

Phenomenology

- QCD production of quarks of 4th generation

crucial test: large couplings between $G^{(1)}$ and U, D

KK gluons preferentially decay to fourth generation.



- Problem: $G^{(1)}$ width is too large

$$\Gamma_1 = \frac{M_1}{48\pi} \sum_\psi g_{1\psi}^2 \sim M_1$$

$\Rightarrow$ not possible to see $G^{(1)}$ over backgd., just production excess

Signal: two same-sign lepton

- To supress large $t\bar{t}$ backgd.: signal $2l^{\pm} + 2j$
- Backgds.: $t\bar{t}$, $t\bar{t} + W's$, $W^{\pm}W^{\pm} + jets$, $W^{\pm}Z + jets$
- Cuts: $p_t(j_{1,2}) > 100$GeV, $p_t(l_{1,2}) > 50$GeV

cross sect.	$\sigma_{QCD} + \sigma_{KK}$[fb]	σ_{QCD}[fb]
signal: $m_D = 300$GeV	87.0	83.4
signal: $m_D = 450$GeV	54.2	48.8
signal: $m_D = 600$GeV	17.8	15.5
background	6.2	6.2

- Required luminosity for significant excess (5σ)

m_D[GeV]	300	450	600
L_{min}[pb^{-1}]	20	53	487

Disentangle the KK-gluon?

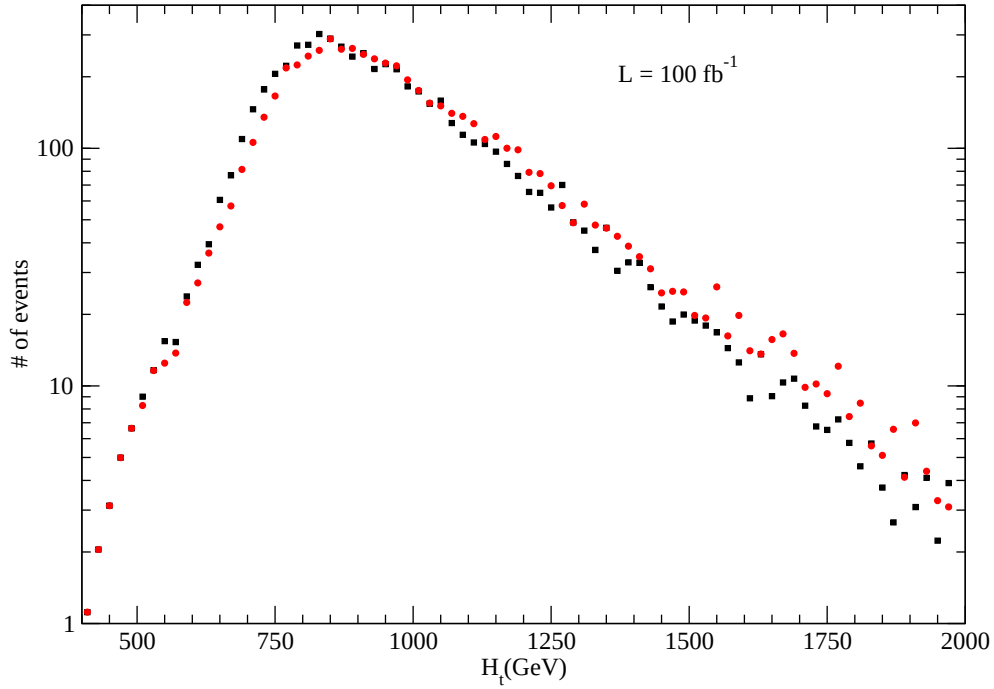
- D production is very sensitive to m_D

Lower m_D in pure QCD mimics KK-gluon effect

$m_D = 450$ + KK-gluon

$m_D = 435$ no KK-gluon

$\sigma_{5D} = \sigma_{4D}$



Signals with 3 and 4 leptons

- Clear excess over SM backgd.

Design cuts: $p_t(j_{1,2})$, $m_{inv}(l^+l^-)$

final state| scenario	$m_D = 300$	$m_D = 450$	$m_D = 600$	backgd.
3 leptons	71.6 fb	38.6 fb	11.2 fb	0.6 fb
4 leptons	0.94 fb	1.19 fb	0.57 fb	-

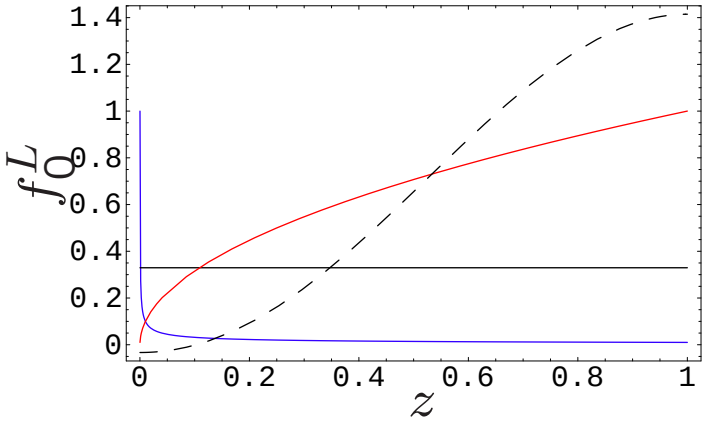
- Test: if there is a 4th gen. $\Rightarrow$ these signals must be seen.

- Even harder to disentangle the KK-gluon.

Fermion localization

$\mathcal{L} = i\bar{\Psi} e_A^M \Gamma^A D_M \Psi - m_\Psi \bar{\Psi}\Psi$

$m_\psi = ck$ determines the 0-mode fermion localization



UV $c > 1/2$, ex: $c = 1$, IR $c < -1/2$, ex: $c = 0$

ex: $c = 1/2$ (black continuous), 1st-KK gluon (black dashed)