

# Flavor Trivial warped models @ hadron colliders

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in coloboration w/ O. Gedalia, S.J. Lee, G. Perez & E. Pontón*

# Motivations

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**RS** solves the hierarchy problem! *Randall & Sundrum '99*

w/ « anarchic » 5D  $Y$ 's RS addresses the SM+NP flavor puzzles

*Arkani-Hamed & Schmaltz '00*

*Grossman & Neubert '00*

*Agashe & Perez '03*

however...

...

- EWPTs' tension: better w/ custodial sym. yet  $m_{KK} > 4 \text{ TeV}$
- little hierarchy problem:  $m_H \approx 5 \text{ TeV}$  (ok if  $Higgs=PGB$ )
- flavor issues:  $\epsilon_K$  needs  $m_{KK} > 8.5 \text{ TeV} / Y$  *Gedalia et al. '08*
- little CP problem: n-EDM requires  $m_{KK} > 3.6 \text{ TeV} \times Y$

$\epsilon_K$ +EDM yields a severe bound:  $m_{KK} > 9.6 \text{ TeV}$  ! <sup>NEW</sup>

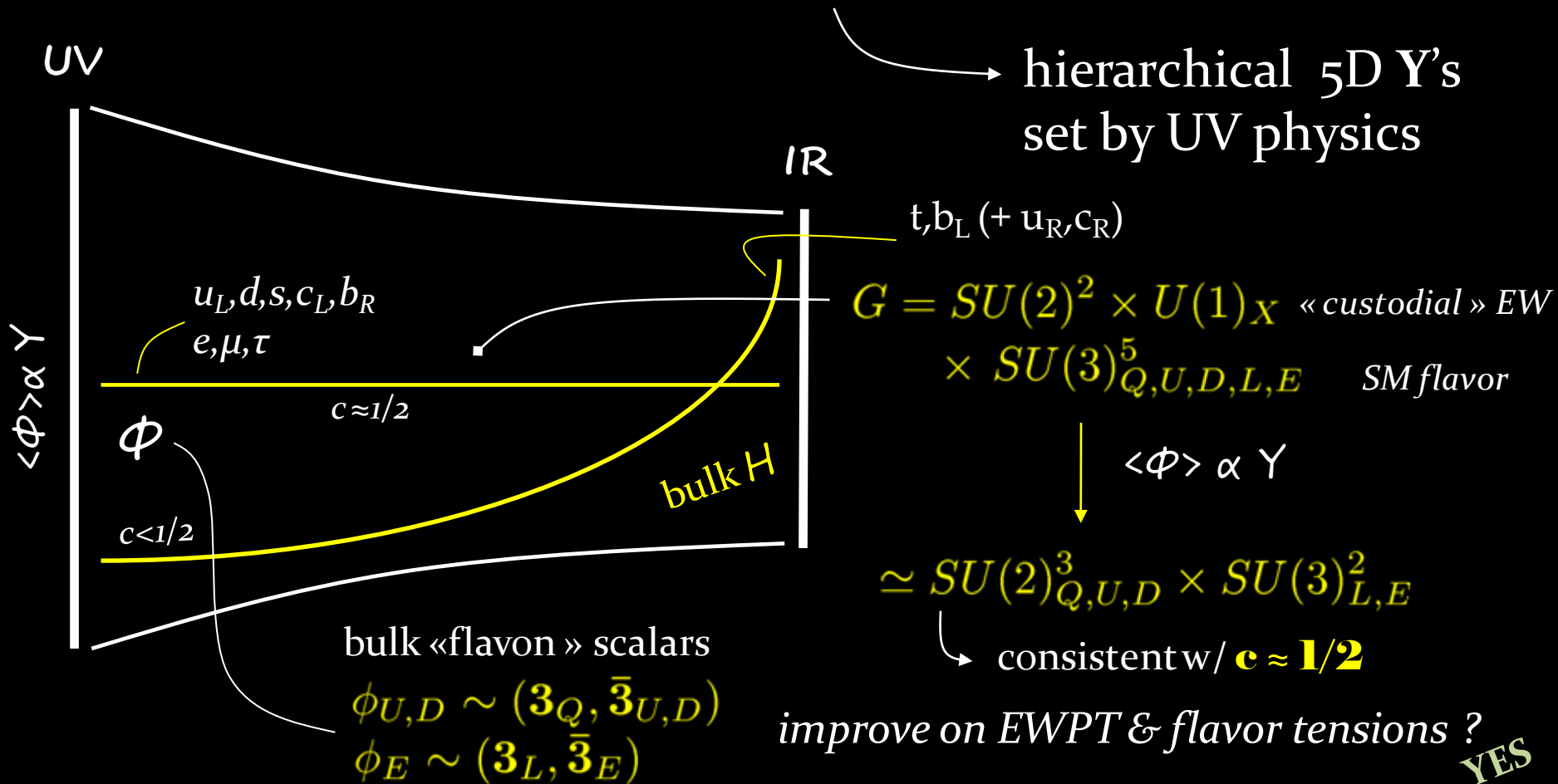
*it doesn't seem any better than SUSY...*

# Flavor Trivial RS

a bulk version of  
Rattazzi & Zaffaroni '00

Flavor puzzles are not tight to the TeV scale:  $\frac{(\bar{d}_i d_j)^2}{\Lambda_F^2} \quad \Lambda_F > 10^4 \text{ TeV}$

...so let's give up on split fermions + RS-GIM ideas



# EWPT | Global fit results

$c \lesssim \frac{1}{2}$  all fermions are « composite » | highly non-oblique corr'

- 1) match RS to the **20** EFT ops' measured @LEP<sub>1+2</sub>  
(including all large Yukawa enhanced 1-loop corr' to  $S, T, Zbb$ )
- 2) do  $\chi^2$  analysis of FTRS w.r.t.  **$m_{KK}, c_{Q3}, c_t, c_b, c_{Qi}, c_{ui}, c_{di}, c_L, c_e$**
- 3) we find a « sweet-spot » where:

• FTRS fits better than SM:  $\frac{\chi^2}{\text{d.o.f.}} \Big|_{\text{SM}} \simeq 0.95 \lesssim \frac{\chi^2}{\text{d.o.f.}} \Big|_{\text{FTRS}} \simeq 0.97$

•  **$m_{KK} > 2.1$  (1.7) TeV** @ $2\sigma$  for 1 (6) d.o.f.

anarchic RS:

**$m_{KK} > 4.6$  TeV** @ $2\sigma$

NEW

• very composite  $u_R$  is favored  **$c_u \approx -0.5$**   $\rightarrow$  axial KK-gluon

*lead to exciting pheno' at hadron colliders !*

# Improved Naturalness?

Higgs  $\neq$  PGB but...

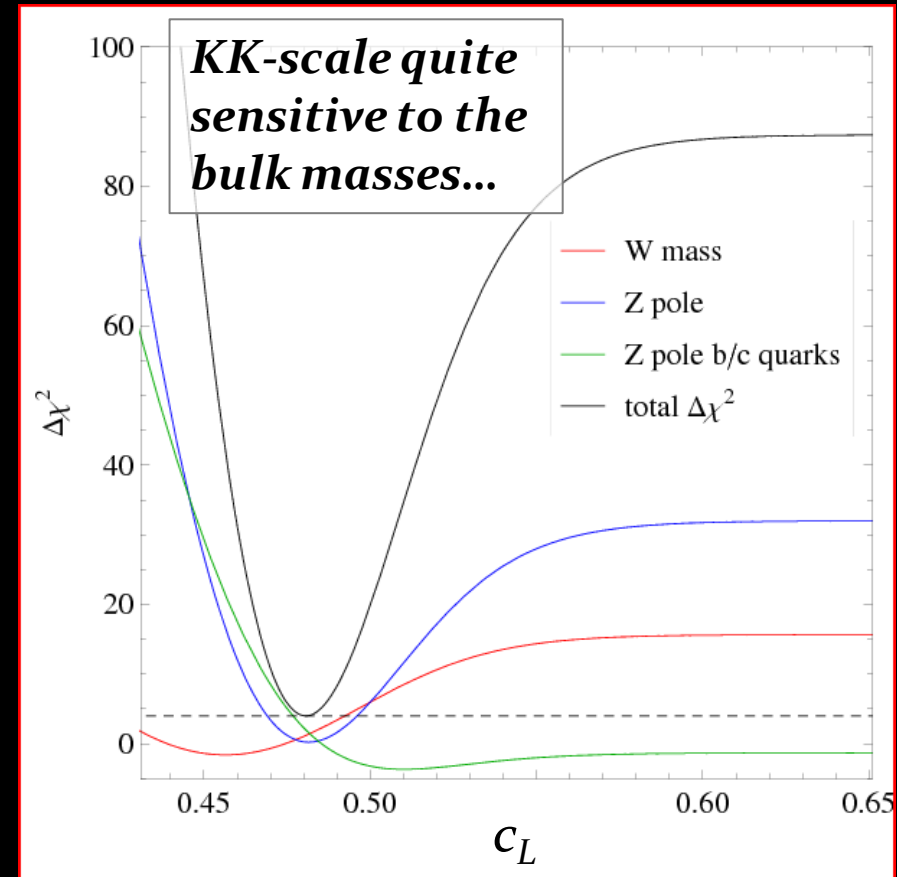
let's assume  $m_H$  is cut at  $m_{KK}$

$$FT \approx \frac{v^2}{m_{KK}^2} \approx \begin{matrix} \mathbf{2\%} & \text{anarchic} \\ \mathbf{10\%} & \text{flavor trivial} \end{matrix}$$

yet, lower  $m_{KK}$  has a price:

$$\frac{\Delta m_{KK}}{m_{KK}} \frac{c}{\Delta c} \approx \begin{matrix} \mathbf{20\%} & (c_t) & \text{anarchic} \\ \mathbf{5\%} & (c_L) & \text{flavor trivial} \end{matrix}$$

$$(\Delta c = g^2/16\pi^2 \sim \mathbf{0.03})$$



FTRS seems as natural as anarchic RS

...but with a much lower KK-scale!

# FCNCs & EDMs

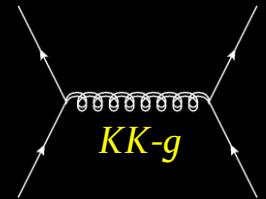
RS flavor spurions =  $\mathbf{Y}_{UD}, \mathbf{F}_{QUD}(\mathbf{c})$  |  $\mathbf{M}_{UD} = \mathbf{F}_Q \mathbf{Y}_{UD} \mathbf{F}_{UD}$

bulk flavor sym.  $\rightarrow \mathbf{c}_{QUD} = \mathbf{1}_{QUD} + \mathbf{Y}_{UD}^2 + \mathbf{Y}_{UD}^4 + \dots$

(if  $\mathbf{Y}_b \ll \mathbf{1}, [\mathbf{M}_U, \mathbf{Y}_U] = \mathbf{0}$ )

5D (G)MFV expansion Perez & Randall '07  
Kagan, Perez & Volanski '08

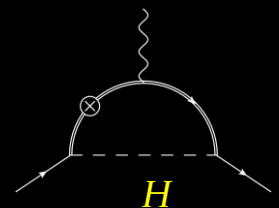
- $\epsilon_K$ ? **fine!** ( $\approx U(2)$ -sym + hierarchical 5D Y's)



- $B_{s,d}$ ? **also fine!**  $LLLL \approx \frac{g_{s*}^2}{6m_{KK}^2} (V_{tb} V_{td,s}^*)^2 (f_{Q^3}^2 - f_{Q^{1,2}}^2)$

with a slight increase of the KK scale:  $m_{KK} > 2.4 \text{ TeV}$

- EDM?  $d_n \approx \frac{em_s}{8\pi^2 m_{KK}^2} Y_t^2 V_{ts}^2 \approx 0.1 \left( \frac{1.7 \text{ TeV}}{m_{KK}} \right)^2 \times d_n^{\text{exp}}$



# Like-sign dimuon anomaly

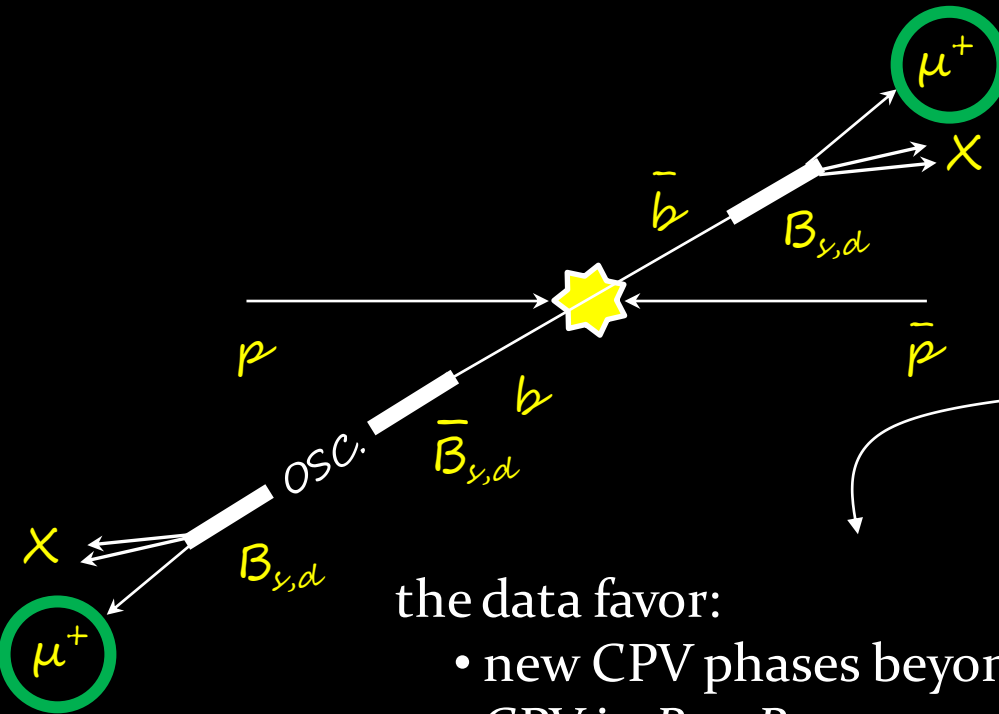
$$A_{SL}^b \equiv \frac{N^{++} - N^{--}}{+} \neq 0$$

CPV

DØ@2010:

$$A_{SL} \times 10^3 = -9.6 \pm 2.9$$

$$\approx \text{SM} - 3.2\sigma$$



the data favor:

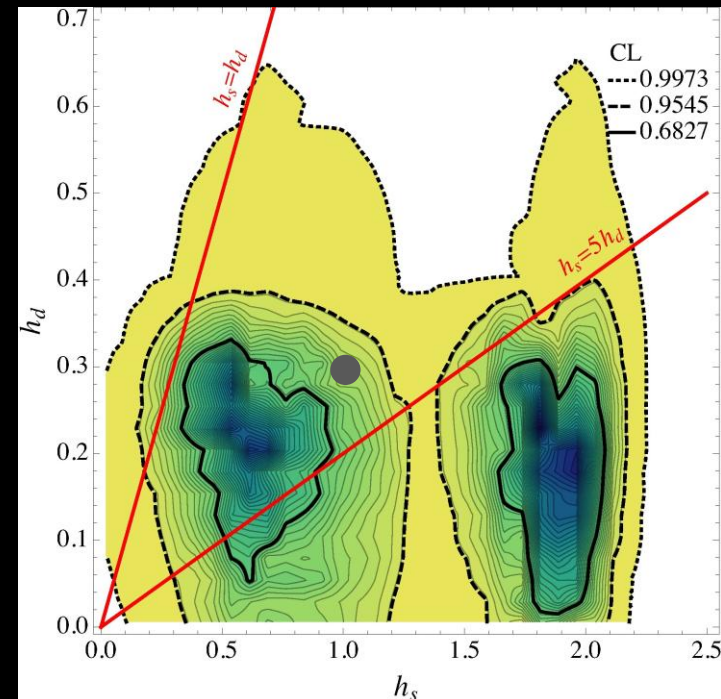
- new CPV phases beyond KM
- CPV in  $B_s > B_d$  *Ligeti et al. '10*

so we need:

- a new phase
- **LRLR** dominates over **LLLL** for  $B_s$  only

both are achievable by increasing  $Y_b$

...but  $m_{KK} > 2.6 \text{ TeV}$



# FB asymmetry in tt production

CDF@2011  $A_{\text{FB}}(m_{t\bar{t}} > 450 \text{ GeV}) = 0.48 \pm 0.11 = \text{SM} + 3.4\sigma$

...while X-sec is within  $1\sigma$

New Physics needs to interfere w/SM

- from data itself *Grinstein et al '11*  $\longrightarrow$
- from an EFT analysis *CD et al '11*

$$\frac{1}{\Lambda_{\text{NP}}^2} \bar{u} \gamma^\mu \gamma_5 T^a u \bar{t} \gamma_\mu \gamma_5 T^a t / \text{SM} \gtrsim 10\%$$

RS candidate = s-channel KK-gluon

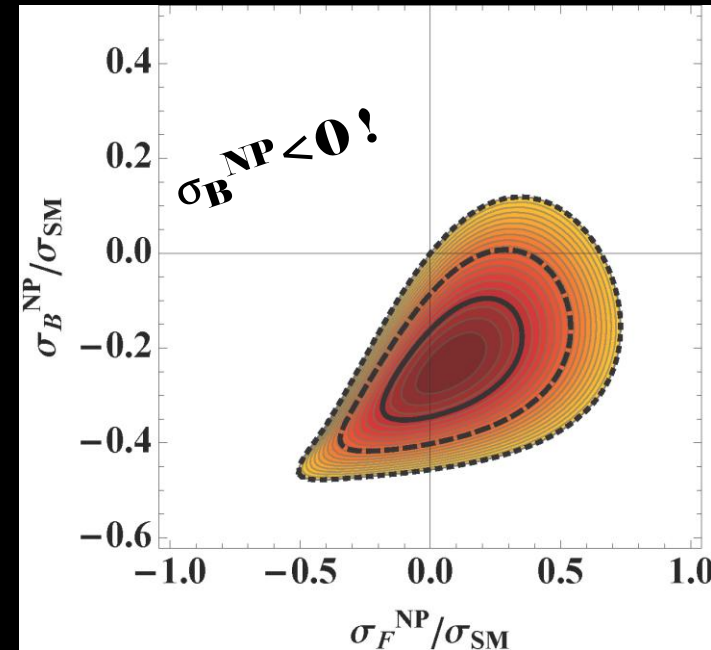
- anarchic RS?

no axial cpl' to  $u\bar{u}$   $\longrightarrow$  no  $A_{\text{FB}}$  *Agashe & Perez '04*  
*Bauer et al. '10*

- Flavor Triviality? 2 TeV KK-scale + composite  $u_R \longrightarrow \bar{u}_R \gamma^\mu T^a u_R \bar{t}_L \gamma_\mu T^a t_L$

SM+FTRS:  $A_{\text{FB}}(>450 \text{ GeV}) = 0.2 (2.6\sigma)$  while  $A_{\text{FB}}(\text{inclusive}) = 0.12 (<1\sigma)$

*CD et al '11*





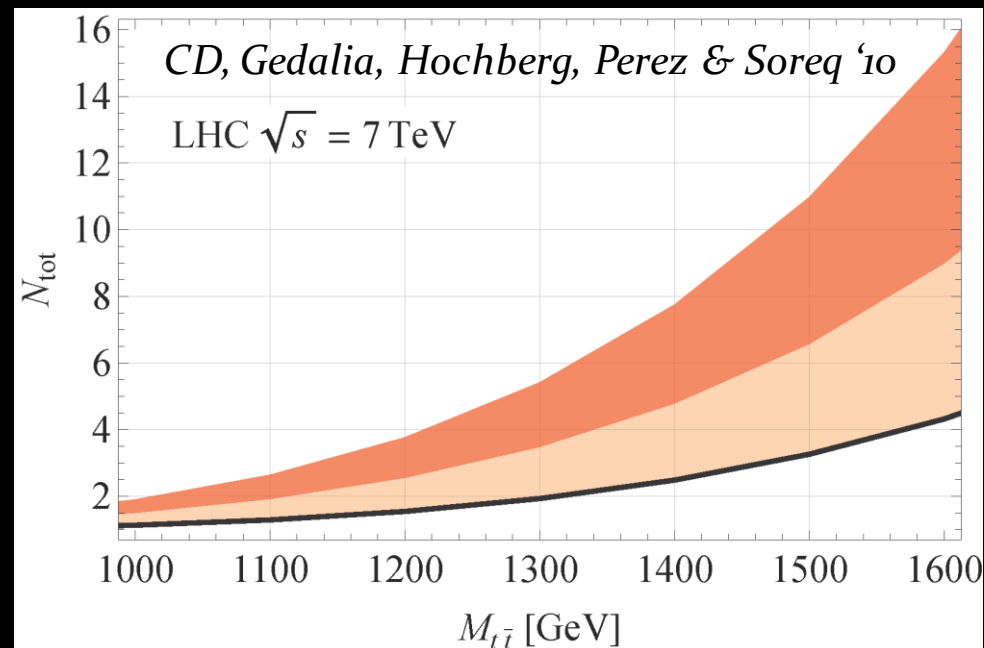
# LHC prospects

- low KK-scale yields  $\mathcal{O}(pb)$  KK-gluon production X-sec  
→  $\sim 10^3$  events w/  $5fb^{-1}$  of data
- production of flavor gauge bosons

*Csaki, Kagan, Lee, Perez & Weiler 'to appear*

- If axigluon-like KK-gluon drives top AFB, expect an enhancement in the  $t\bar{t}$  X-sec tail

$$N = \frac{d\sigma^{\text{SM}+\text{NP}}/dM_{t\bar{t}}}{d\sigma^{\text{SM}}/dM_{t\bar{t}}}$$



# Conclusions

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- anarchic RS has little hierarchy problem + severe CP & flavor problems
- Flavor Trivial RS (w/ SM flavor addressed by UV physics) yields:
  - $m_{KK} \sim 2 \text{ TeV}$  consistent with EWPT, FCNCs and EDMs constraints
  - BSM CPV in Bs ( $> B_d$ ) is achievable at large  $\tan \beta$
  - sizable high mass top  $A_{FB}$  ( $\sim 2\sigma$  from CDF, but not worse than other models)
- Interesting feature, so far *unique* to FTRS:  
hierarchy problem « *implies* » a large top  $A_{FB}$