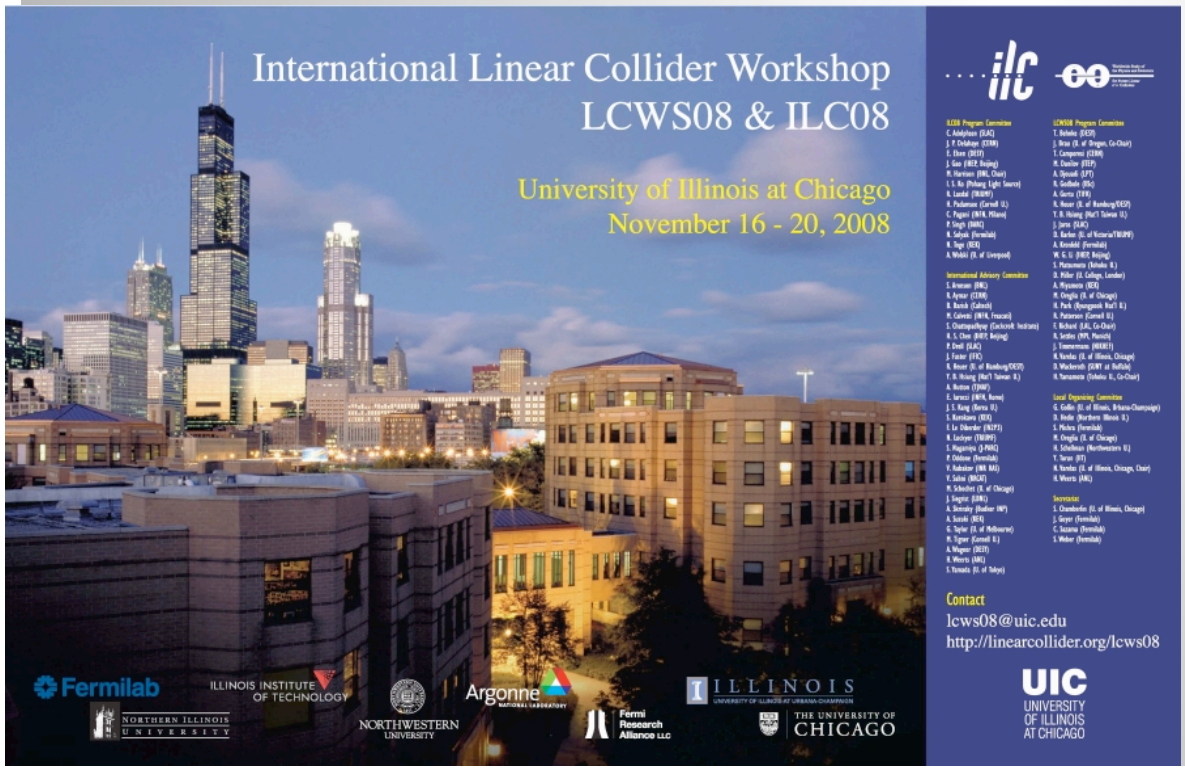
Warped extra-dimension paradigm: precision EW data & tests at ILC

G. Moreau

Laboratoire de Physique Théorique, Orsay, France



partly from…

C. Bouchart,
G.M. ***NPB 2008***

A. Djouadi, G.M.,
F. Richard ***NPB 2007***

PLAN

I) Introduction

II) Comparison of EW fits in RS/SM

III) The case of heavy flavors

IV) Testing warped ED models at ILC

V) Conclusion

I) Introduction

Problems/Solutions in the Higgs boson sector

a) Quantum instability of the Higgs mass: $\delta m_h^2 \propto \Lambda_{NP}^2$

~> Supersymmetry (MSSM): $\delta m_h^2 \approx \tilde{m}^2 \approx (10^2\,GeV)^2$ as no quadratic dvg.

~> Extra Dimensions (ADD,RS): δm_h^2 protected by $\Lambda_{NP} < M_{grav} \approx TeV$

(Higgsless): models without Higgs boson !

~> Composite Higgs (MHCM): δm_h^2 protected by $\Lambda_{NP} = \Lambda_{IR} \approx TeV$

[& possibly till Λ_{NP} via a global symmetry]

b) Quantum instability of the Higgs quartic coupling λ

~> Supersymmetry (MSSM): SUSY => $\lambda = g^2$ protects λ

~> Extra Dimensions (gauge-Higgs unif.): GAUGE SYM. => $\lambda = g^2$ protects λ

(Higgsless): no high-energy Higgs potential

c) EW Symmetry Breaking dynamics

~> Supersymmetry (mSUGRA): EWSB triggered by negative Higgs mass induced radiatively (via top quark loop)

~> Composite Higgs (MHCM): EWSB triggered by negative Higgs mass induced radiatively (via top quark loop)

~> Extra Dimensions (Higgsless): SB by field Boundary Conditions & KK masses for fermions/bosons

So the main approaches towards the Higgs questions are SUSY or ED like

+ renew of interest for ED-type scenarios:

EXP. – no discovery of superpartners @ LEPII (nor Tevatron Run II)

TH. – AdS/CFT correspondance (98') => calculability of EW observables (03') in Composite Higgs scenarios (84')

+ other attractive features of the Extra-Dimension scenarios:

– WIMP candidates for the dark matter of universe (UED,RS)
  stable due to a KK-parity

– Unification of gauge couplings (ADD) at high-energies (RS)

– Fermion mass and flavor models (ADD,RS) ≠ ***in SUSY***

– ED = necessary ingredient for high-energy string theories

The EW constraints in the warped ED models:

Bulk gauge bosons/fermions mix with their KK excitations
=> tree-level contributions to EW observables
so the challenges are to…

[1] respect the constraints from EW precision data

~> Bulk custodial symmetry

$$\begin{array}{ccc} O(4) & & SU(2)_L \times SU(2)_R \\ \Downarrow & \approx & \Downarrow \\ O(3) & & SU(2)_V \times P_{LR} \end{array}$$

~> Brane-localized kinetic terms for fermions/gauge fields

[2] interprete anomalies in the SM fit of EW data (main one: A^b_{FB})

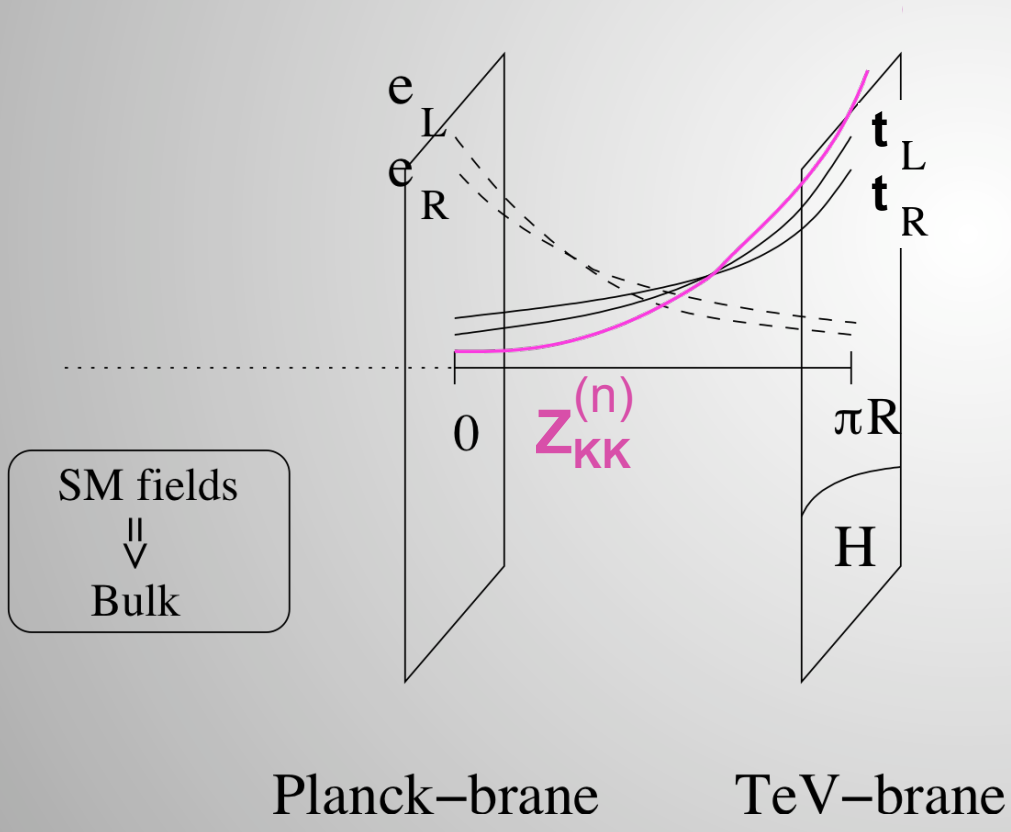
~> Bulk flavor structure

EW BOUNDS IN WARPED ED SCENARIOS / DUAL MODELS

5D holographic version	RS with bulk fields	gauge-Higgs unification	Higgsless models
4D dual [in AdS/CFT] interpretation	composite Higgs boson	composite Higgs pseudo-Goldstone boson of a global symmetry *(as for little Higgs with T parity)*	technicolor models
EW constraints {with a custodial symmetry}	S,T within 95%C.L. [S>0 ; T>0 ; U ≈0] for $M_{KK} \approx 3$TeV, $m_h \approx 115-500$ GeV *(without custodial: e.g. $M_{KK} \approx 6.4$TeV , $m_h \approx 1$TeV)*	S,T within 95%C.L. [S>0 ; T>0, <0 ; U ≈ 0] for $M_{KK} \approx 3$TeV, $m_h \approx 115-190$ GeV	S=1.15 (excess by factor 5) ; T ≈ 0 ; U ≈0, for $M_{KK} \approx 1.2$TeV

II) Comparison of EW fits in RS/SM

The RS model with bulk fields:



- **RS addresses the gauge *hierarchy* :**

$$M_{grav} \approx TeV \approx Q_{EW}$$

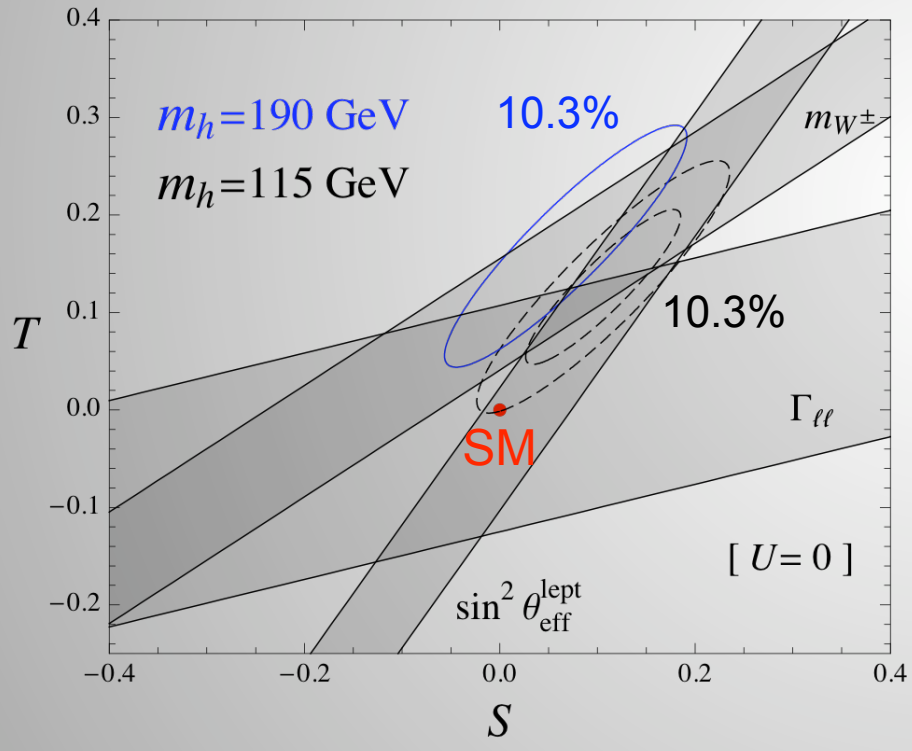
- **RS generates the mass *hierarchies* :**

$$m_e << m_t$$

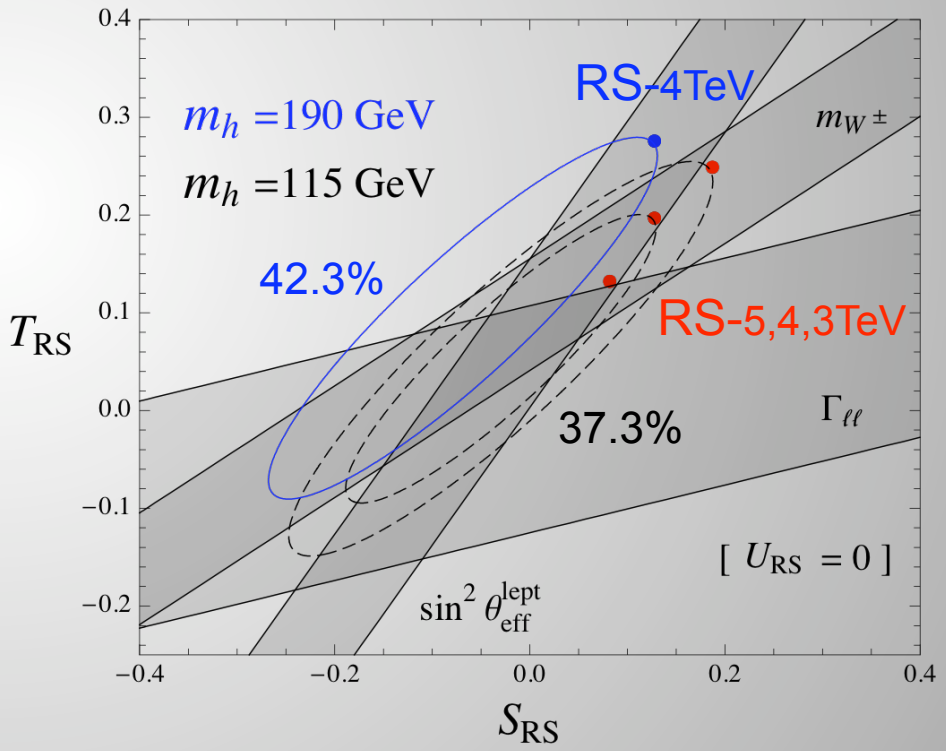
Improved goodness-of-fit

EW observables are expressed in terms of oblique parameters encoding the New Physics...

$$S_{\rm RS} \simeq 2\pi \left(\frac{2.4v}{M_{KK}}\right)^2 \qquad T_{\rm RS} \simeq k\pi^2 R_c \frac{\tilde{g}^2}{8e^2}\frac{\tilde{M}^2}{k^2}\left(\frac{2.4v}{M_{KK}}\right)^2$$



p-value 10.3% ⇔ χ^2/11 =1.56



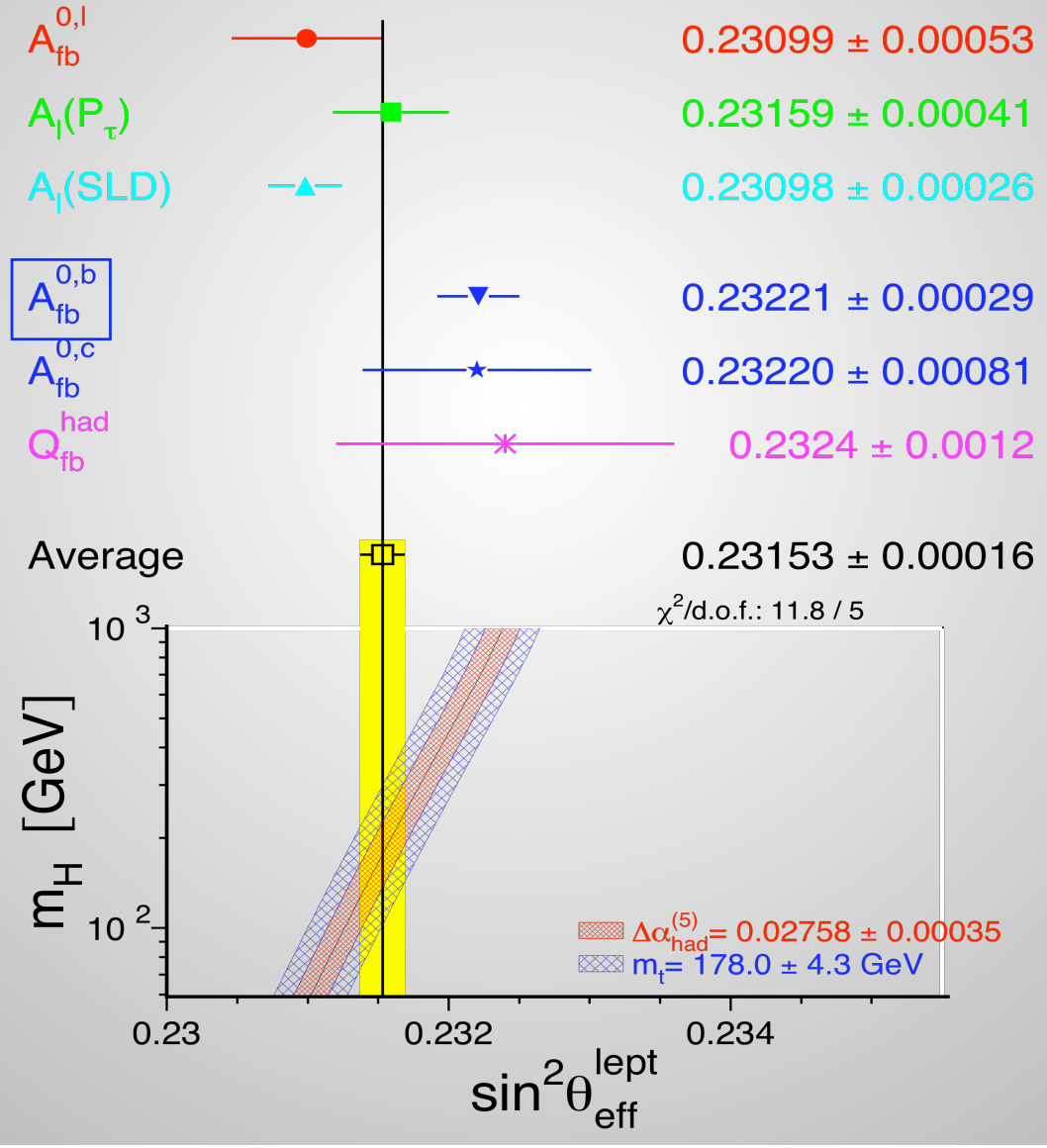
p-value 37.3% ⇔ χ^2/10 =1.08

Better quality of fit in RS than in SM cause..

1) **positive contribution T_{RS}** *(custodial symmetry breaking)*

2) **SM fit degraded by the $\sin^2\theta_W$ measurement derived** *directly* **from A^b_{FB} :**

SM →



Best-fit Higgs mass

- RS fit can be better for any m_h>115GeV (e.g. m_h=190GeV => h->Z^0Z^0)

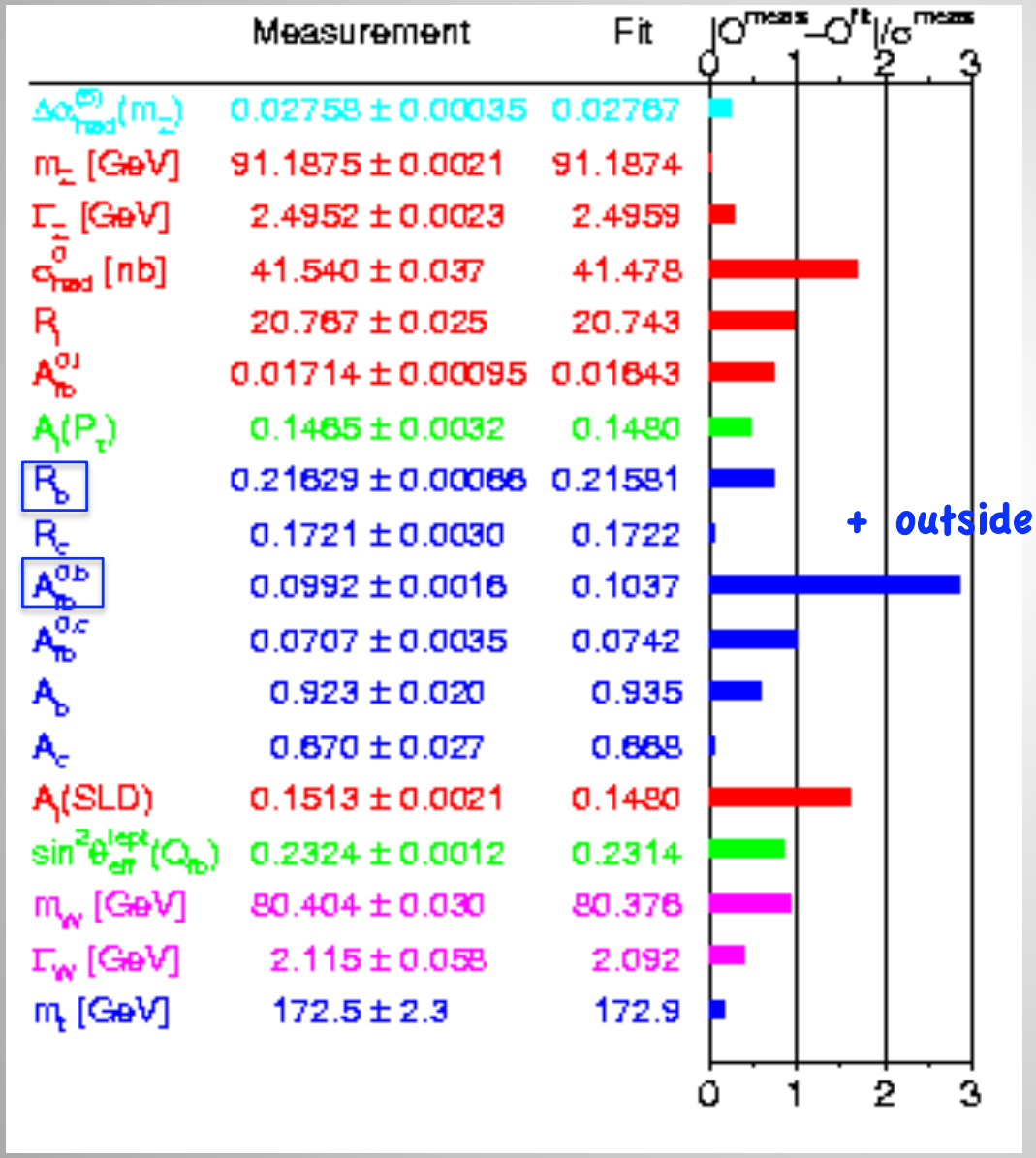
- for m_h= 500 GeV
  - p-value can be @ 25.3% in RS if M_{KK}= 4 TeV
  - p-value is only @ 2.5 10^{-9} in SM
  - m_h excluded in gauge-Higgs unification & SUSY

=> the discovery of a heavy Higgs would constitute a sign for RS

- the best-fit m_h value is possibly larger than the LEP2 direct limit of 115GeV

in contrast with the SM where the best-fit m_h is 76^{-24}_{+33} GeV
(getting even smaller by excluding A^b_{FB})

III) The case of heavy flavors



A^b_{FB} : a NP effect in the b sector ?

$$A^b_{FB}(p\hat{o}le) \equiv \frac{\int_0^{+1}\sigma_\theta d\cos\theta - \int_{-1}^{0}\sigma_\theta d\cos\theta}{\sigma_0(e^+e^- \to \gamma/Z \to b\bar{b})}$$

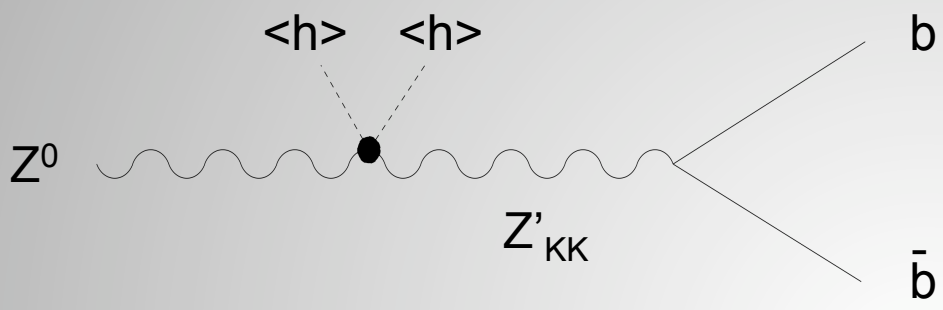
$$= \frac{3}{4}\frac{(Q_Z^{e_L})^2-(Q_Z^{e_R})^2}{(Q_Z^{e_L})^2+(Q_Z^{e_R})^2}\frac{(Q_Z^{b_L})^2-(Q_Z^{b_R})^2}{(Q_Z^{b_L})^2+(Q_Z^{b_R})^2}$$

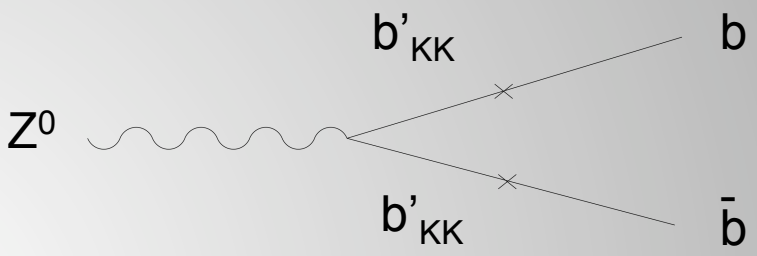
+ outside Z pôle !

$$R_b \equiv \frac{\Gamma(Z \to b\bar{b})}{\Gamma(Z \to hadrons)}$$

$$= \frac{(Q_Z^{b_L})^2+(Q_Z^{b_R})^2}{\sum_{q\neq t}[(Q_Z^{q_L})^2+(Q_Z^{q_R})^2]}$$

Interpretation in a generic *extra-dimensional model:*





$$\left|\delta Q_Z^{f_l}\right| \approx 1‰ \;<<\; \left|\delta Q_Z^{b_{L/R}}\right| \approx |-1.5/30\%|$$

$$m_{b'}(c_{t_R}) \;<<\; m_{f'}(c_{\text{light}})$$

$$\text{Coupling } Z_{KK} f_l \bar{f}_l \;<<\; \text{Coupling } Z_{KK} b\bar{b}$$

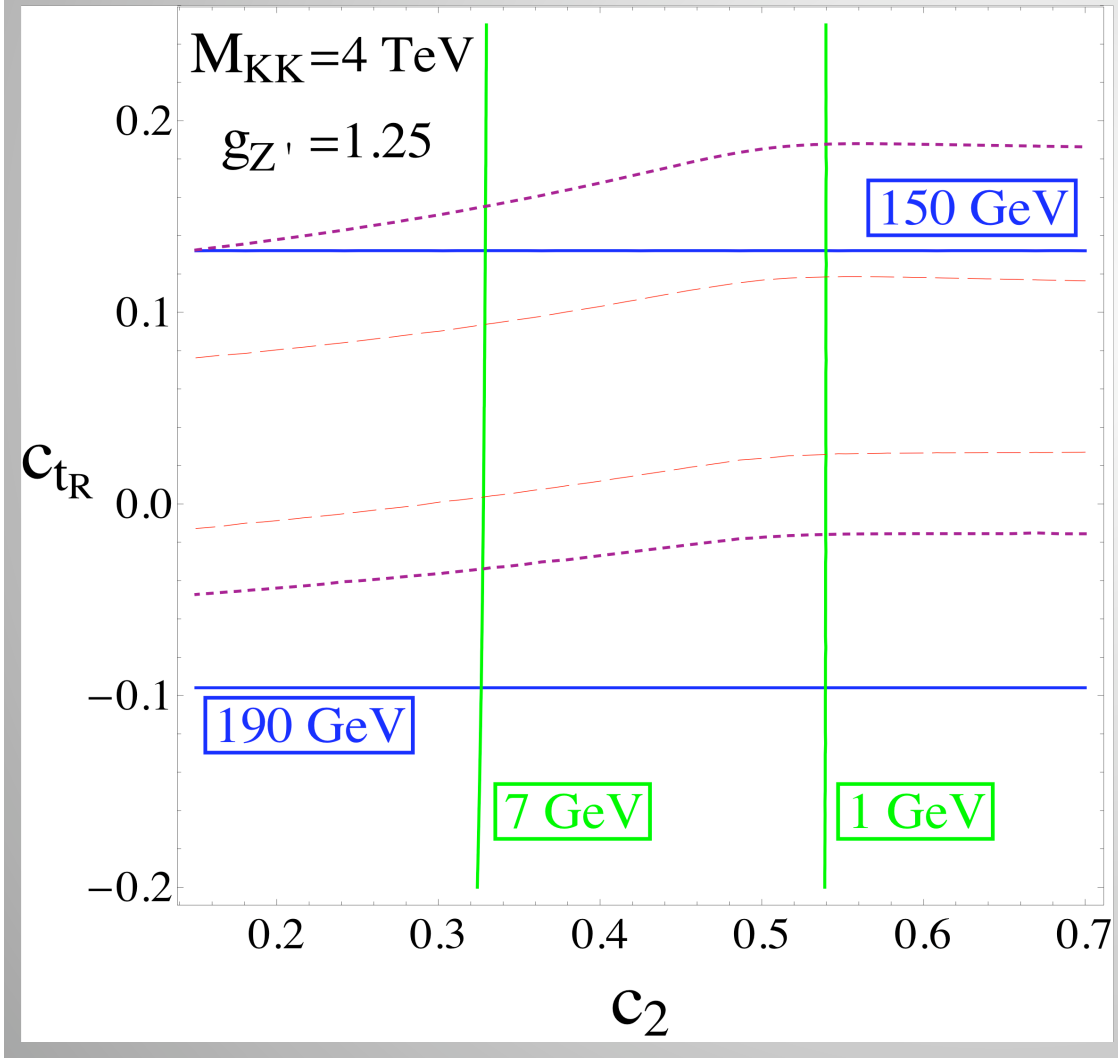
$$m_t(c_{t_R}) \uparrow \;\Rightarrow\; m_{b'}(c_{t_R}) \downarrow$$

natural conditions within the RS model

Example of possible quark representations:

$$\{Q_{1L}\} \equiv (\mathbf{2},\mathbf{3})_{1/6} = \begin{pmatrix} q'_{(5/3)L} & t_{1L} & b'_L \\ t'_L & b_{1L} & q'_{(-4/3)L} \end{pmatrix} \quad \{t^c_R\} \equiv (\mathbf{3},\mathbf{2})_{1/6} = \begin{pmatrix} q^{c\prime}_{(5/3)R} & t^{c\prime}_R \\ t^c_R & b^{c\prime\prime}_R \\ b^{c\prime}_R & q^{c\prime}_{(-4/3)R} \end{pmatrix}$$

$$\{Q_{2L}\} \equiv (\mathbf{2},\mathbf{3})_{-5/6} = \begin{pmatrix} t_{2L} & b''_L & q'''_{(-4/3)L} \\ b_{2L} & q''_{(-4/3)L} & q'_{(-7/3)L} \end{pmatrix} \quad \{b^c_R\} \equiv (\mathbf{1},\mathbf{2})_{-5/6} = \begin{pmatrix} b^c_R & q^{c\prime\prime}_{(-4/3)R} \end{pmatrix}$$



Fit of R_b + 8 data for $A^b_{FB}(\sqrt{s})$

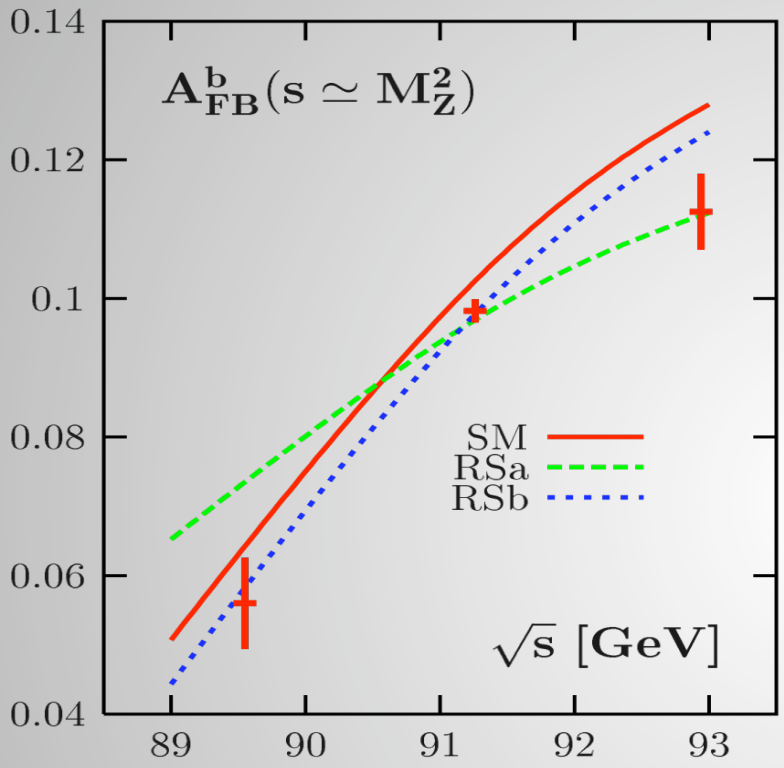
→ p-value 10% ⇔ $\chi^2/9 = 1.63$

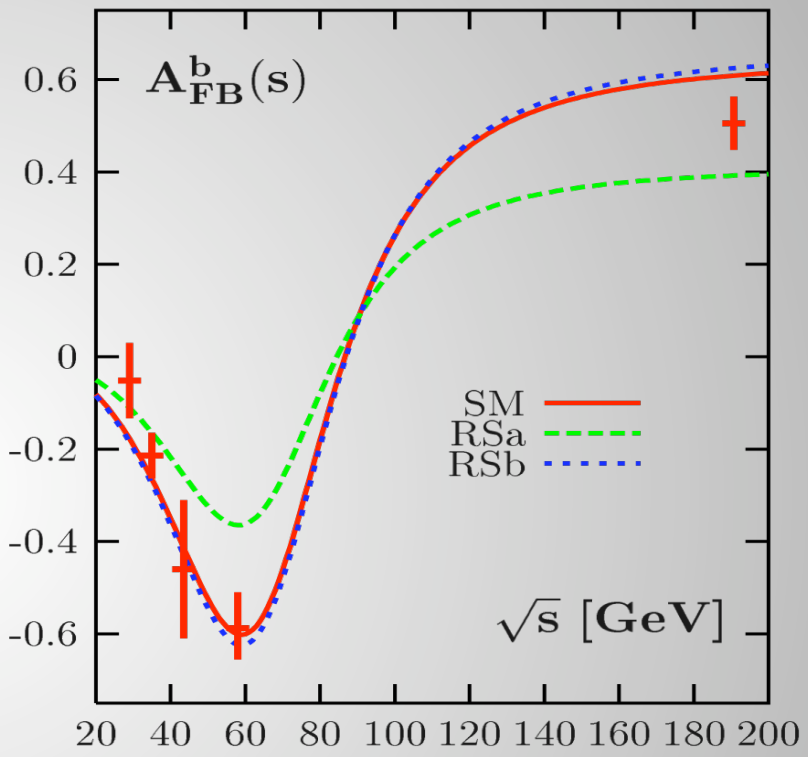
→ p-value 8% ⇔ $\chi^2/9 = 1.71$

[SM: p-value 0.8% ⇔ $\chi^2/9 = 2.47$]

$$\begin{cases} \lambda_t^{5D} k = 1 & c_1 = 0 \quad c_{bR} = 0.27 \\ \lambda_b^{5D} k = 1 & \cos\theta_{12} = 0.1 \end{cases}$$

Global A^b_{FB} fit @ and off the Z pôle :





$$\text{SM}: \quad \chi^2 = 24 \qquad \text{RSa}: \quad \chi^2 = 20 \qquad \text{RSb}: \quad \chi^2 = 14$$

b_R under $SU(2)_L \times SU(2)_R \times U(1)_X$:

$$\begin{cases} Q_X = (B-L)/2 \Rightarrow I_R^3 = -1/2 & \text{RSa} \\ Q_X = -5/6 \Rightarrow I_R^3 = +1/2 & \text{RSb} \end{cases}$$

IV) Testing warped ED models at ILC

Indirect effects mainly in the heavy quark sector

(b,t couplings to KK bosons up to $\times \sqrt{2\pi\, kR_c} \approx 8$)

- Giga-Z: more data on A^b_{FB} / R_b to confirm or invalidate the anomaly (and its possible ***RS*** interpretation)

- contribution from s-channel exchange of KK Z, KK photon to top pair production in ***RS*** → ILC sensitivity on M_{KK} ($\delta\sigma \approx 1\%$, $A^t_{LR} \approx 0.002$) :

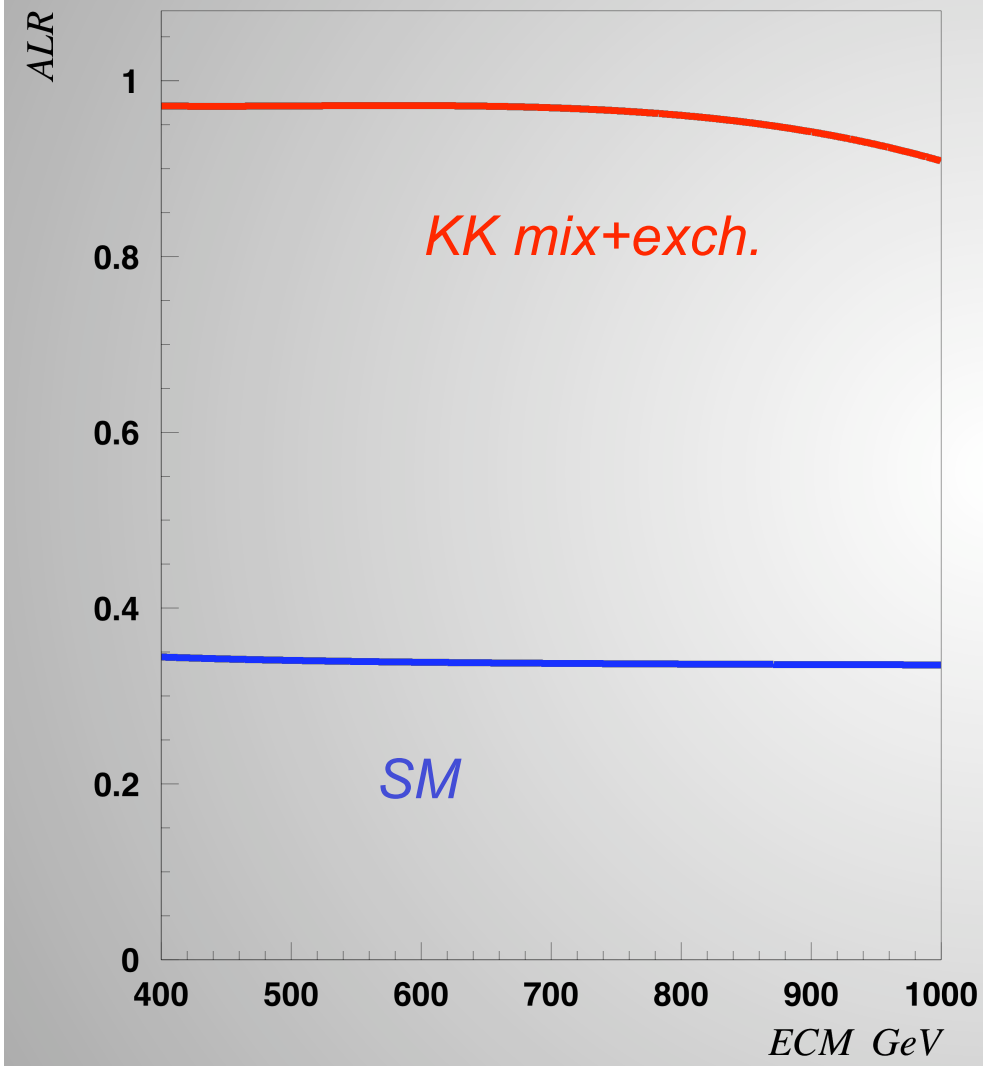
  ~ 10-20 TeV ! ***…out of LHC reach*** {little hierarchy}

[De Pree, Sher 06]

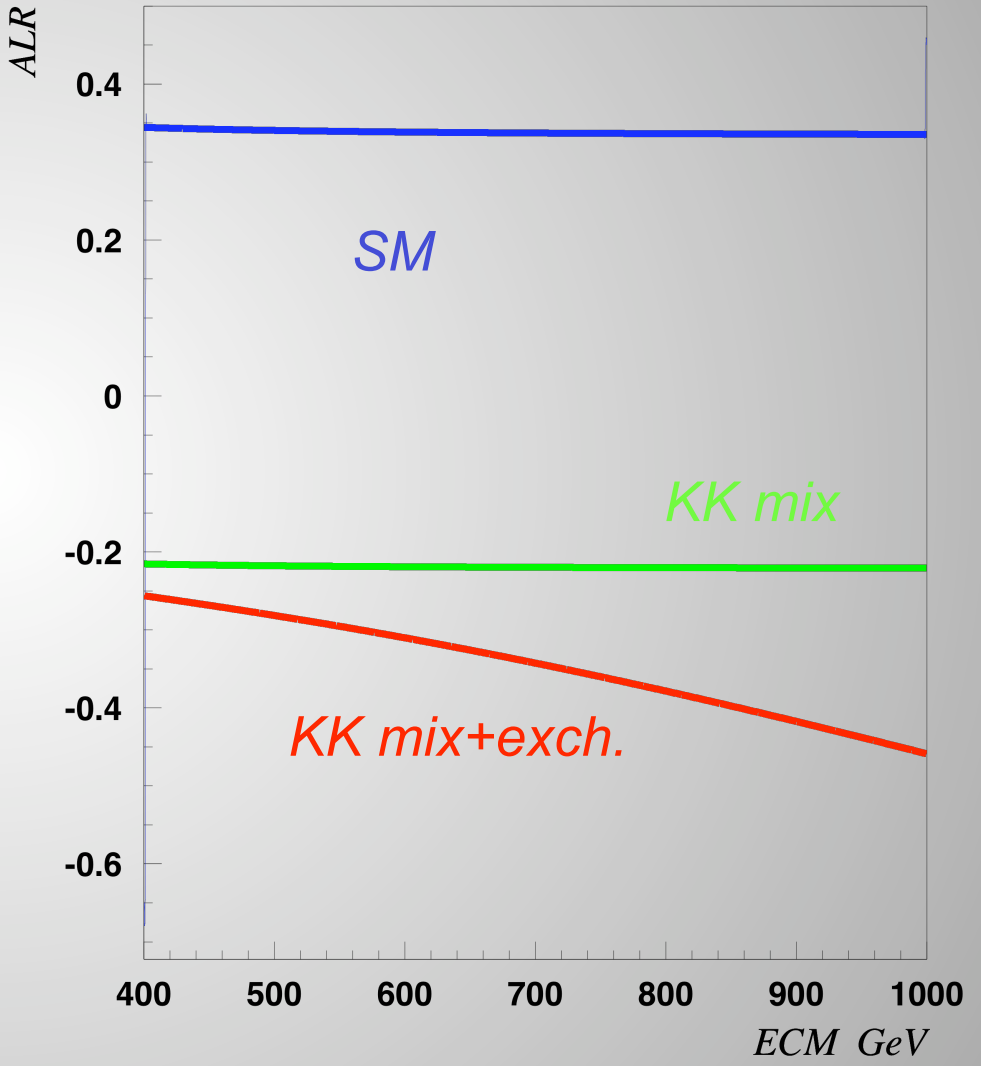
A^t_{LR}

$$e\bar{e} \to \gamma / Z^{(n)}_{KK} \to t\bar{t}$$

M_{KK} = 3 TeV



RSa



RSb

THROUGH FCNC...

- tree-level FCNC process $e^+e^- \to t\bar{c}$ through Z^0-KK's mixing in *RS* :

$$\sigma_{tc}/\sigma_{\mu\bar{\mu}} \cong 2\,10^{-5} \quad \text{at} \quad \sqrt{s} \cong 200\ \text{GeV}$$

(+ angular distributions @ ILC can probe the prediction of Right-handed coupling dominance)

[Agashe, Perez, Soni 06]

Through the Higgs...

- Higgs compositeness effects / KK gauge boson mixings
  ⇒ h^0 vertex corrections
  ⇒ deviations in $\sigma(ff \to h^0) \times B(h^0 \to ...)$ [model-independent study]

[Giudice, Grojean, Pomarol, Rattazzi]

  ⇒ testable at LHC when deviations reach 20-60 % (m_h<150GeV)
  testable at ILC already @ the level of a few %

- Gravity-induced EWSB scenario in *URS* :
  ⇒ corrections testable at ILC in $g_{h^0WW}/g^{SM}_{h^0WW} \approx 0.5-0.7$ (m_h<1TeV)

[Davoudiasl, Lillie, Rizzo 05]

- precise m_h reconstruct. @ILC
  VEV measurement (h^0Z^0 prod.)
  } $m_h^2/2xVEV^2 = \lambda_h$ experimental estimation

→ *to be compared with e.g.* VEV_{RS}

- *Higgs-radion mixing effects ...*

Possibly even ***direct*** effects

- within composite pseudo-GB Higgs scenarios where $m_{custodians} \sim 500GeV$ [<< $M_{KK} \sim 3TeV$] can be compatible with precision EW constraints :

  [Contino, Da Rold, Pomarol 06]

  the ***single production*** of these `custodians' (exotic colored fermions like b' , $q_{5/3}$ ...) becomes accessible by a 1TeV e^+e^- machine..

- KK Higgs excitation in *URS* :
  possible/difficult in a 1TeV ILC ($\approx 10^{-1}$ reduced $h^{(1)}$-boson couplings)

  [Davoudiasl, Lillie, Rizzo 05]

V) Conclusion

We have shown how, thanks to the custodial symmetry, flavor structure and quark representations, the ***RS*** model can simultaneously:

- solve the forward-backward **Anomaly** for the bottom
- improve the **quality** of precision EW fits *w.r.t. SM*
- for a best-fit Higgs mass above the **LEP2 limit.**

There exist various precision tests of warped ED models at ILC, mostly in the third generation quark sector.

& another model for m_h = 500 GeV …