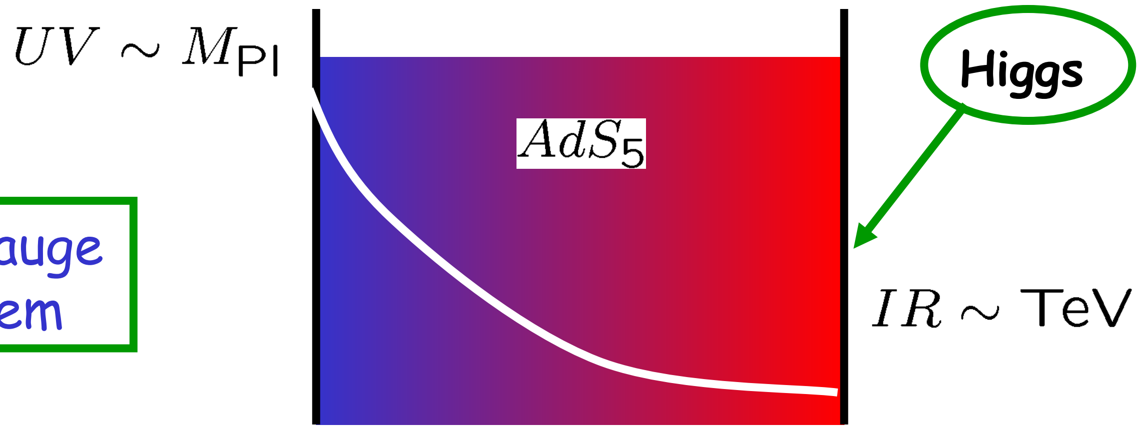
New Ideas in Randall-Sundrum Phenomenology

José Santiago

Theory Group (FNAL)

With M. Carena, E. Pontón and C. Wagner, **NPB759 (06) and hep-ph/0701055**

The goods of the old RS



Solution to the gauge hierarchy problem

Bulk fermions: Hierarchical fermion masses with FCNC and higher dim. operators suppressed for light fermions

KK excitations of bulk fields: Rich phenomenology

AdS/CFT: New insight on QCD, strongly coupled theories, ...

The bads of the old RS

BSM sector

Strongly localized towards the IR brane

Higgs

SM

Gauge bosons and heavy fermions

VERY STRINGENT BOUNDS ON THE SCALE OF NEW PHYSICS

New physics beyond the LHC reach

Little hierarchy reintroduced

Outline

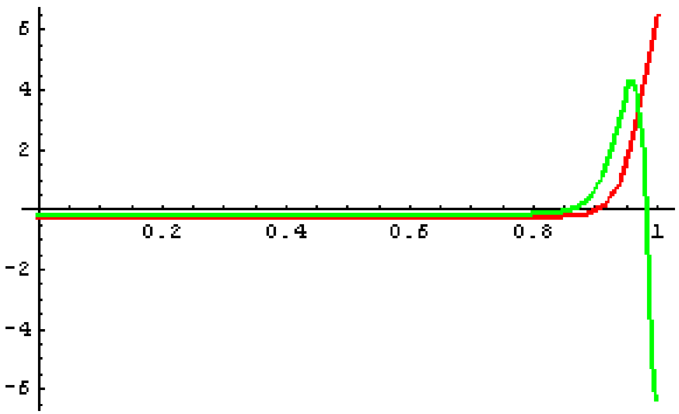
- The bads of RS:
  - T parameter
  - Zbb coupling
- New ideas: custodial protection of T and Zbb
- Calculable corrections to T and Zbb
- Models of gauge-Higgs unification
- Global fit to EW precision observables
- Spectrum
- Collider phenomenology
- Conclusions

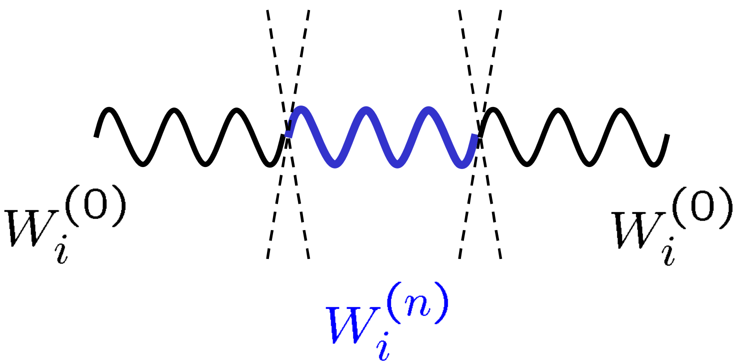
The bads of the old RS: T parameter

Gauge KK modes are localized near the IR brane

→ Large mixing with the Z and W zero modes through the Higgs

→ Large T parameter





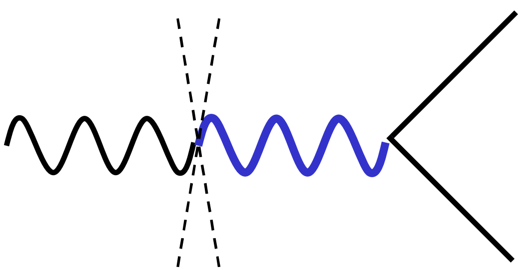
$M_{KK} \gtrsim 5 - 10\,\text{TeV}$

The bads of the old RS: Zbb coupling

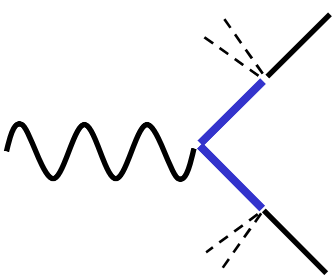
Top (bottom) zero modes are localized near the IR brane

Large gauge and Yukawa couplings to GB and fermion KK modes

Large anomalous Zbb coupling



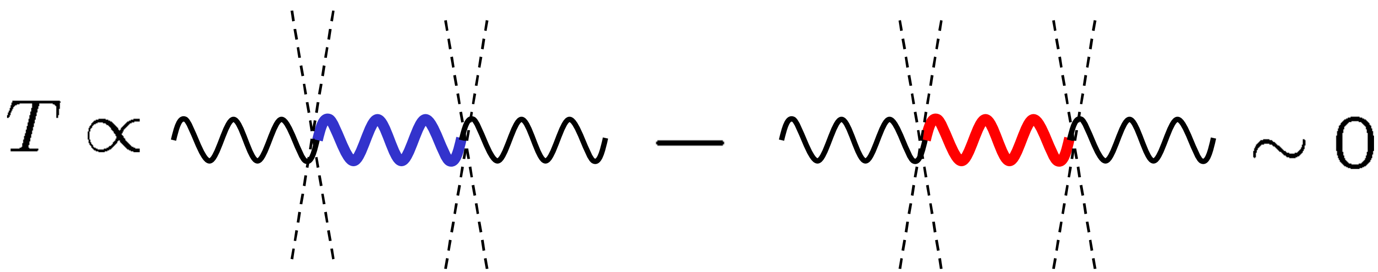
$$M_{KK} \gtrsim 7-8\,\mathrm{TeV}$$



New Ideas: custodial symmetry

- Custodial protection of Randall-Sundrum:
  - Bulk Gauge Symmetry: $SU(2)_L \times SU(2)_R \times U(1)_X \times P_{LR}$

Agashe, Delgado, May, Sundrum JHEP (03)



New Ideas: custodial symmetry

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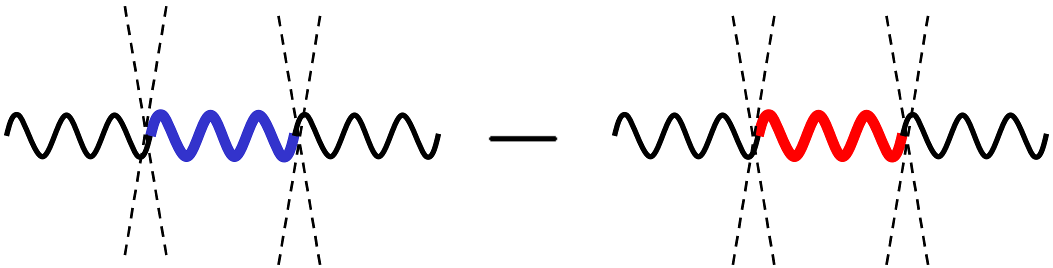
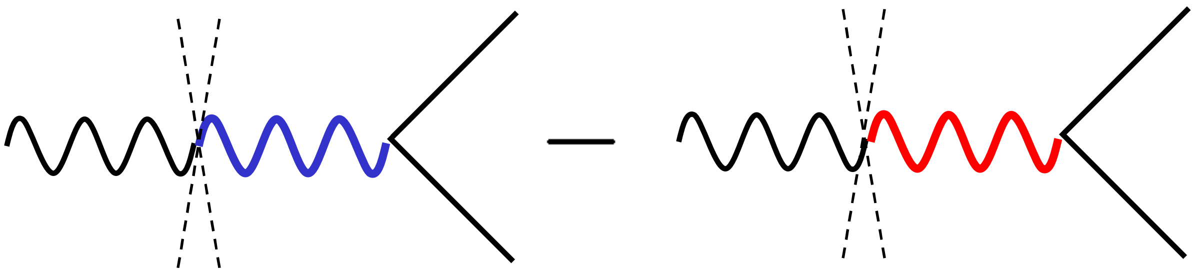
Agashe, Contino, Da Rold, Pomarol PLB (06)

$T \propto$  ~ 0

$\delta g_{b_L} \propto$  ~ 0

Custodial protection of Zbb

- Fermion coupling to Z at zero momentum

$$\frac{g}{\cos\theta_W}[Q^3_L - Q\sin^2\theta_W] Z_\mu \bar{\psi}\gamma^\mu\psi$$

- Q^3_L can be protected by the following subgroup of the custodial symmetry $U(1)_L \times U(1)_R \times P_{LR} \rightarrow U(1)_V \times P_{LR}$

$$\left.\begin{array}{r} U(1)_V \Rightarrow \delta Q^3_L + \delta Q^3_R = 0 \\ P_{LR} \Rightarrow \delta Q^3_L = \delta Q^3_R \end{array}\right\} \Rightarrow \delta Q^3_L = 0$$

$$\frac{\delta g_f}{g_f} = \frac{e^2}{s^2c^2}\left[G^f_{++} - \frac{c^2 T^3_R \frac{g_R^2}{g_L^2} + s^2 T^3_L - s^2 Q}{T^3_L - s^2 Q} G^f_{-+}\right] = \frac{e^2}{s^2c^2}\left[G^f_{++} - G^f_{-+}\right]$$

Fermion Quantum Numbers

b_L has to be eigenvector of P_{LR}

$$P_{LR} \Rightarrow T^3_R(b_L) = T^3_L(b_L)$$

The simplest option is bidoublets under $SU(2)_L \times SU(2)_R$

$SU(2)_R$

$U(1)_Q$

$$SU(2)_L \quad \begin{pmatrix} \chi^u_L(-+) & t_L(+,+) \\ \chi^d_L(-+) & b_L(+,+) \end{pmatrix}_X \sim (2,2)_{2/3} \sim \begin{pmatrix} 5/3 & 2/3 \\ 2/3 & -1/3 \end{pmatrix}$$

The Higgs is also a bidoublet with $Q_X = 0$

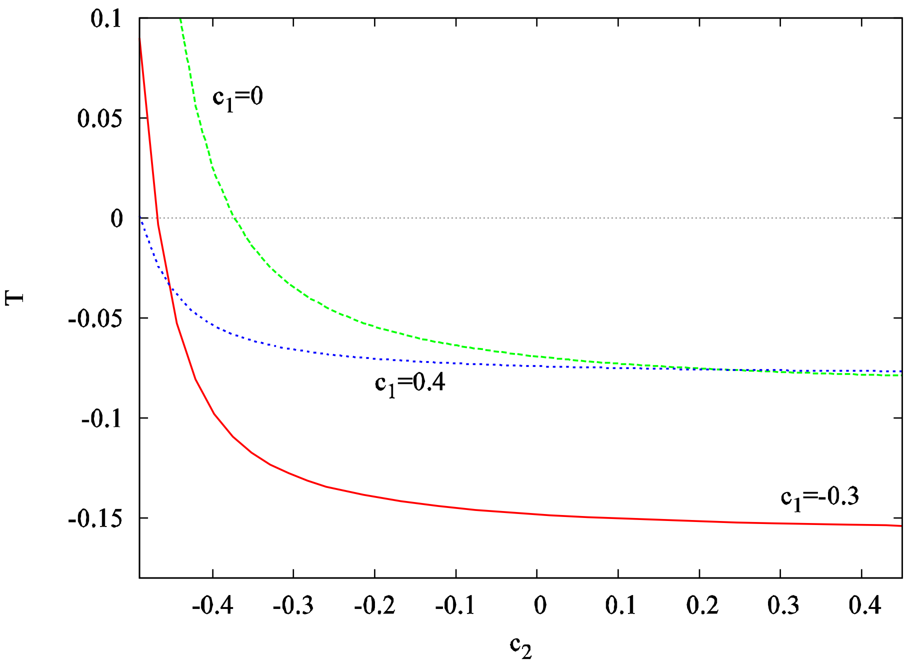
$$t_R(+,+) \sim (1,1)_{2/3}$$

Calculable corrections to T and Zbb

Carena, Pontón, J.S., Wagner NPB (06)

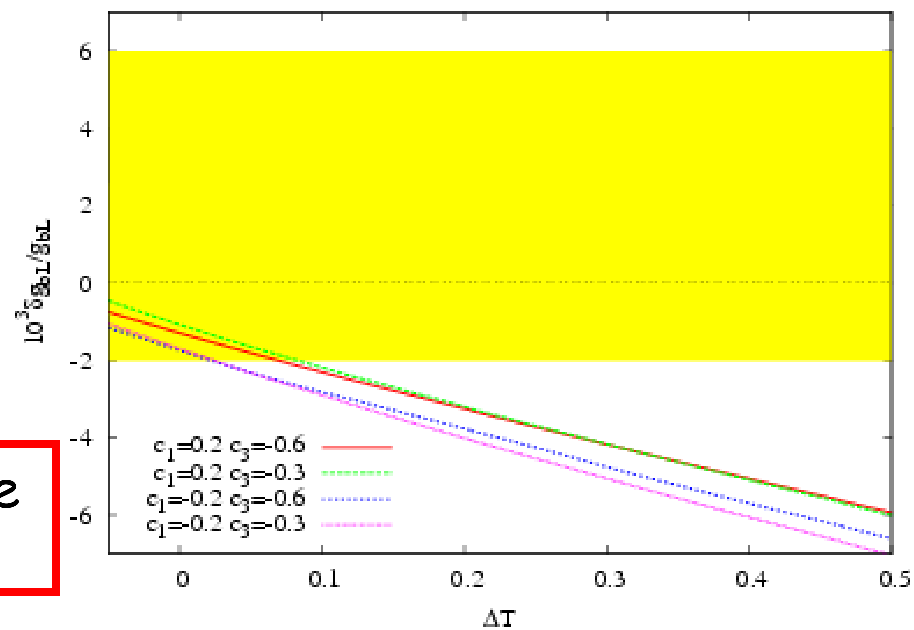
- T and Zbb protected by custodial symmetry broken by b.c. only on the UV brane: Insensitive to UV physics
  - Quantum corrections are calculable
  - T and Zbb do not receive corrections above Λ
- One loop corrections are typically sizable
  - Triplets contribute negative to T
  - Singlets contribute positive to T
  - Large positive T leads to large positive δg_{bL}

Quantum corrections to T and Zbb



T negative in most of parameter space: the RH top is almost flat (LH top/bottom near IR)

UV ← singlet localization → IR



Positive T leads to large deviations in Zbb

A model of gauge-Higgs unification

- Bulk gauge symmetry $SO(5) \times U(1)_X$, broken to $SO(4) \times U(1)_X$ at the IR brane and to the SM at the UV brane
- A_5 along $SO(5)/SO(4)$ has a zero mode, with the Higgs quantum numbers, exponentially localized toward the IR brane

Contino, Nomura, Pomarol NPB (03)

Agashe, Contino, Da Rold, Pomarol (05-06)

- Calculable Higgs potential
  - Solution to the little hierarchy problem
- Yukawa couplings from gauge couplings: Fermion masses and mixing angles through non-trivial b.c. (brane masses)
- Bidoublets embedding:

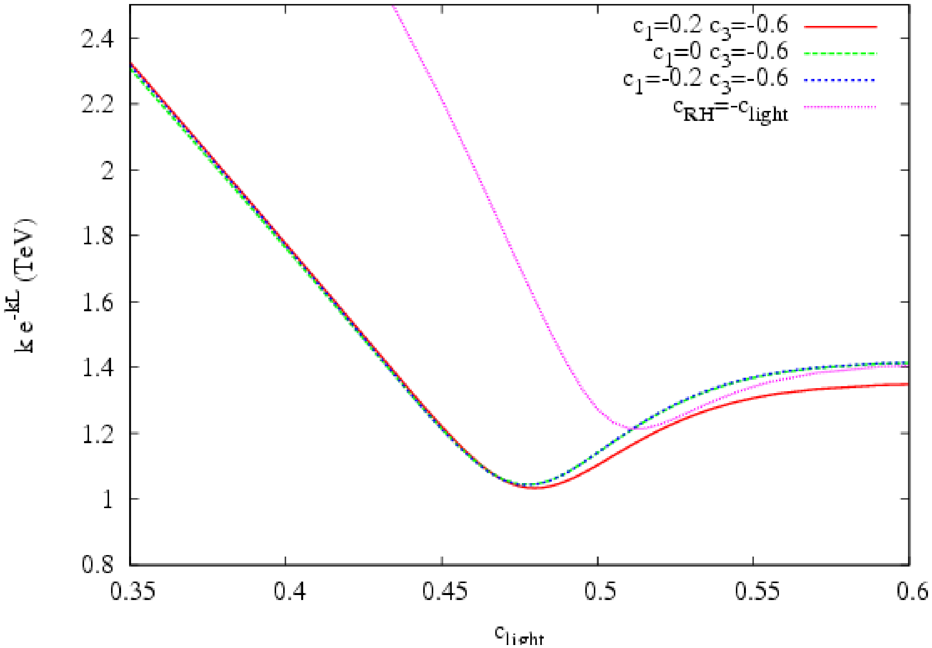
$$\underset{SO(5)}{5} = \underset{(SU(2)_L, SU(2)_R)}{(2,2) \oplus (1,1)}$$

Global Fit to Electroweak Observables

Carena, Pontón, J.S., Wagner hep-ph/0701055

- We have performed a global fit to all relevant electroweak precision observables including:
  - All tree-level effects at leading order in $\mathcal{O}(v^2/\tilde{k}^2)$
  - Leading one loop effects: S and T parameters and Zbb
- We compute the χ^2 as a function of the localization parameter of the fermion zero modes: $t_L, t_R, b_R, q^{LH}_{\text{light}}, q^{RH}_{\text{light}}$
- Zbb coupling and the S parameter are the most restrictive observables when the light fermions are near the UV brane
- Strong coupling to gauge KK modes when light fermions near IR

Result of the Global Fit

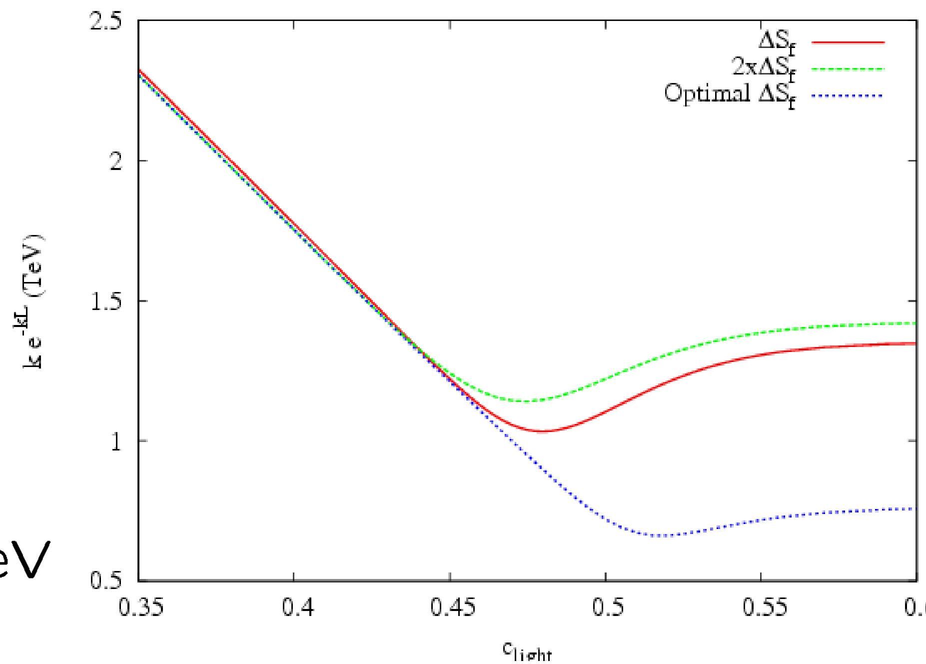


$\tilde{k} \sim 1 - 1.4$ TeV

$\Downarrow$

$M_{KK}^{\text{gauge}} \sim 2.5 - 3.5$ TeV

IR ← light localization → UV



S can receive corrections from physics above the UV cut-off

$\tilde{k} \sim 650$ GeV $\Rightarrow M_{KK}^{\text{gauge}} \sim 1.6$ TeV

Typical Spectrum

First two generation KK modes

q'	Q	$m_{q'}$ (GeV)	decay
q_1^1	$2/3$	$\sim 200-500$	$q_1^1 \rightarrow Zu$, (100%)
q_1^2	$2/3$	$\sim 200-500$	$q_1^2 \rightarrow Zc$, (100%)
q_2^1	$2/3$	$\sim 200-500$	$q_2^1 \rightarrow Hu$, (100%)
q_2^2	$2/3$	$\sim 200-500$	$q_2^2 \rightarrow Hc$, (100%)
$\chi_2^{u_1}$	$5/3$	$\sim 200-500$	$\chi_2^{u_1} \rightarrow Wu$, (100%)
$\chi_2^{u_2}$	$5/3$	$\sim 200-500$	$\chi_2^{u_2} \rightarrow Wc$, (100%)
q'^{d_1}	$-1/3$	$\sim 200-500$	$q'^{d_1} \rightarrow Wu$, (100%)
q'^{d_2}	$-1/3$	$\sim 200-500$	$q'^{d_2} \rightarrow Wc$, (100%)

Not a necessary prediction

Typical Spectrum

Third generation KK modes

Solid prediction

q'	Q	$m_{q'}$ (GeV)	decay
q_1	2/3	369	$q_1 \to Zt,$ (20%) $q_1 \to Ht,$ (60%) $q_1 \to Wb,$ (20%)
q_2	2/3	373	$q_2 \to Zt,$ (9%) $q_2 \to Ht,$ (70%) $q_2 \to Wb,$ (21%)
u_2	2/3	504	$u_2 \to Zt,$ (13%) $u_2 \to Ht,$ (40%) $u_2 \to Wb,$ (41%) $u_2 \to Zq_1,$ (1.5%) $u_2 \to Wq'^{d_3},$ (2.5%) $u_2 \to W\chi_2^{u_3},$ (2.%)
$\chi_2^{u_3}$	5/3	369	$\chi_2^{u_3} \to Wt,$ (100%)
q'^{d_3}	$-1/3$	369	$q_2'^{d_3} \to Wt,$ (100%)

Collider Phenomenology

- Tevatron
  - Searches for new quarks (including multiplicity)

$$m_q \geq \begin{cases} 325\ (410)\ \text{GeV}, & W+j \text{ with } 0.76 \text{ (projected 8) fb}^{-1}, \\ 300\ \text{GeV}, & Z+j. \end{cases}$$

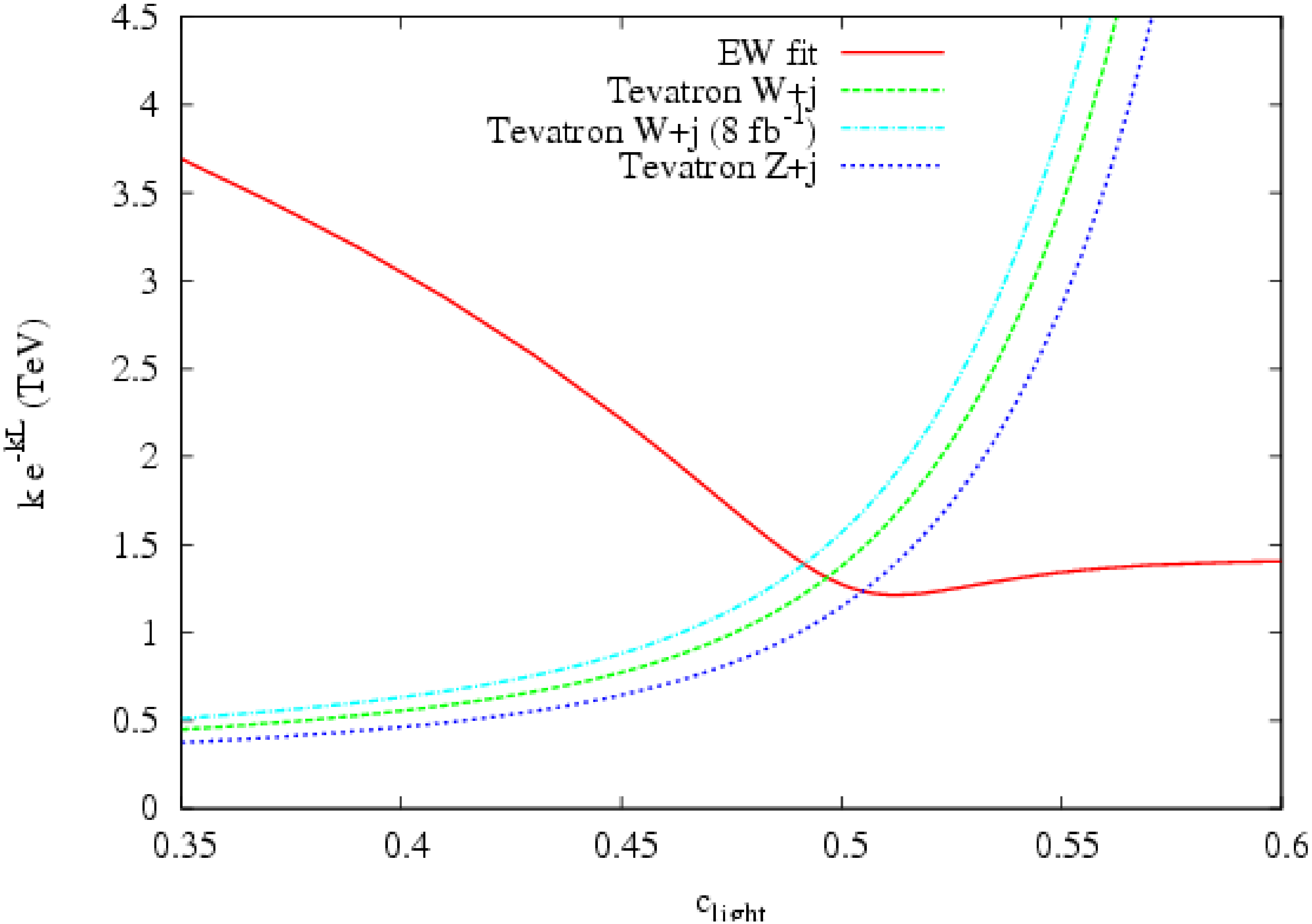
  - Interesting possibilities for Higgs physics

$$\sigma(p\bar{p} \to q'\bar{q}' \to 2H2j) \sim \sigma(gg \to H)$$

- LHC
  - q' discovery up to 1 TeV
  - Exciting Higgs physics
  - Exotic decay channels

$$pp \to q'\bar{q}' \to W^+W^-t\bar{t} \to W^+W^+W^-W^-b\bar{b}$$

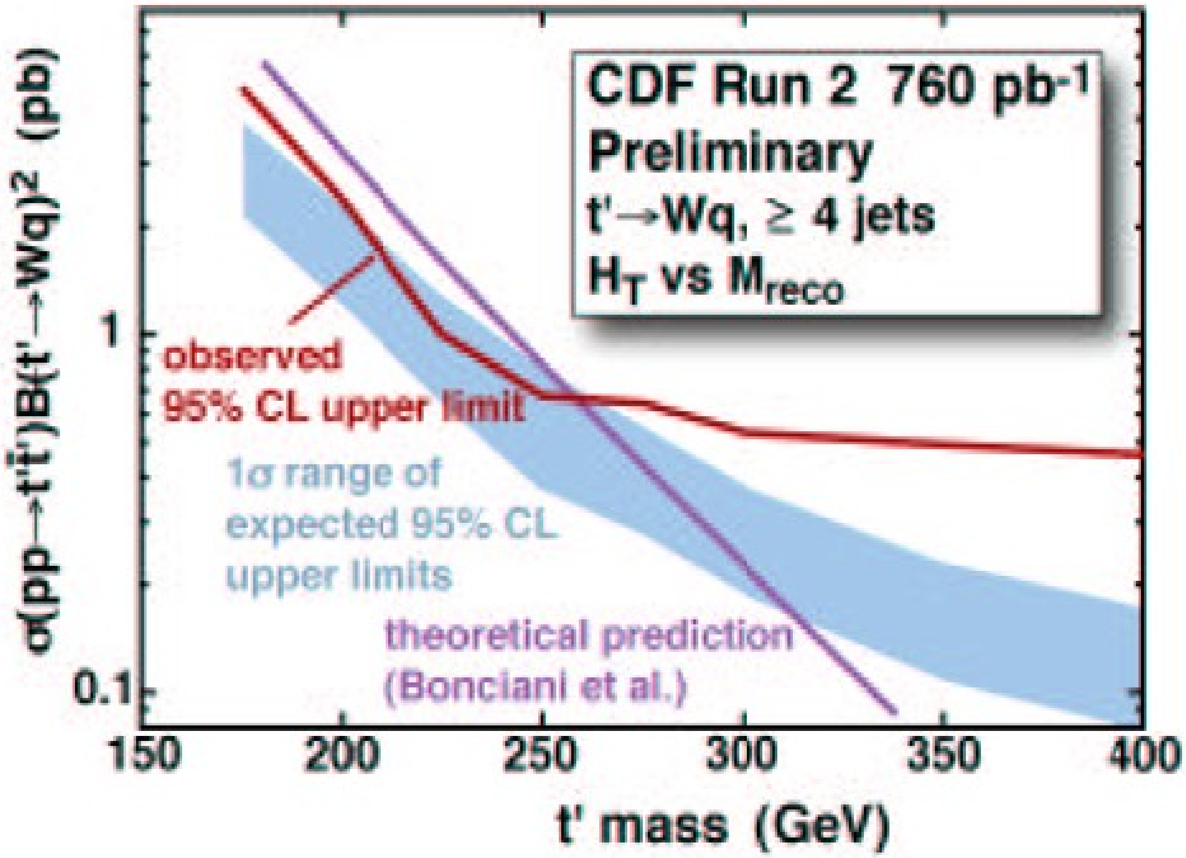
Tevatron searches



Conclusions

- Custodial protection T and Zbb in RS: Light gauge boson KK modes accessible at the LHC
- T and Zbb are insensitive to UV physics: calculable and relevant
  - Generic feature: Higgs(less), gauge-Higgs unification, ...
- Global fit to EW precision observables taking into account all relevant one loop corrections: $M_{KK}^{\mathrm{gauge}} \sim 1.5 - 3.5\ \mathrm{TeV}$
- Light quarks ~ 200-1000 GeV accessible at Tevatron and LHC
- New collider phenomenology:
  - Gauge KK mode production at LHC
  - Interesting Higgs physics
  - Exotic channels $pp \to q'\bar{q}' \to (W^+W^-)W^+W^+W^-W^-b\bar{b}$

New quarks at the Tevatron



CDF Note 8495