New Ideas in Randall-Sundrum Phenomenology

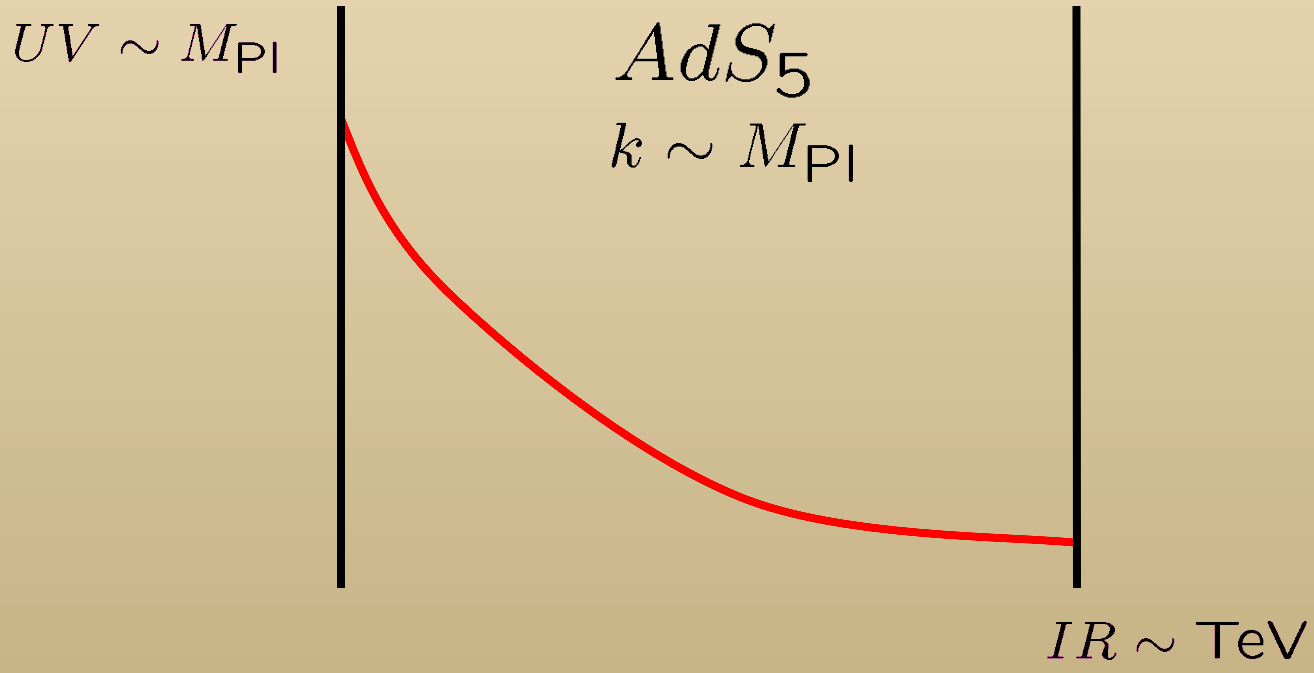
José Santiago
Fermilab

work with M. Carena, E. Pontón, C. Wagner

NPB (06) [ph/0607106]
and hep-ph/0701055
+ work in progress

Randall-Sundrum 101

- RS offers a nice solution to the hierarchy problem



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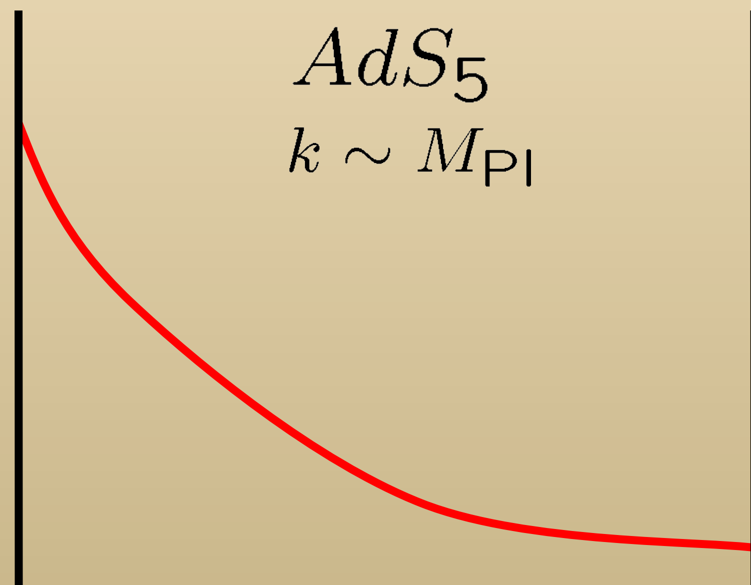

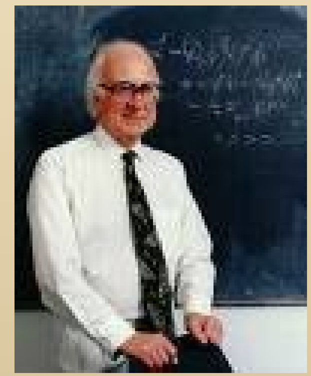

Randall-Sundrum 101

- Fermions (and gauge bosons) in the bulk
  - nice flavor theory: hierarchical masses + ~~FCNC~~
  - Higher-dimensional operators suppressed

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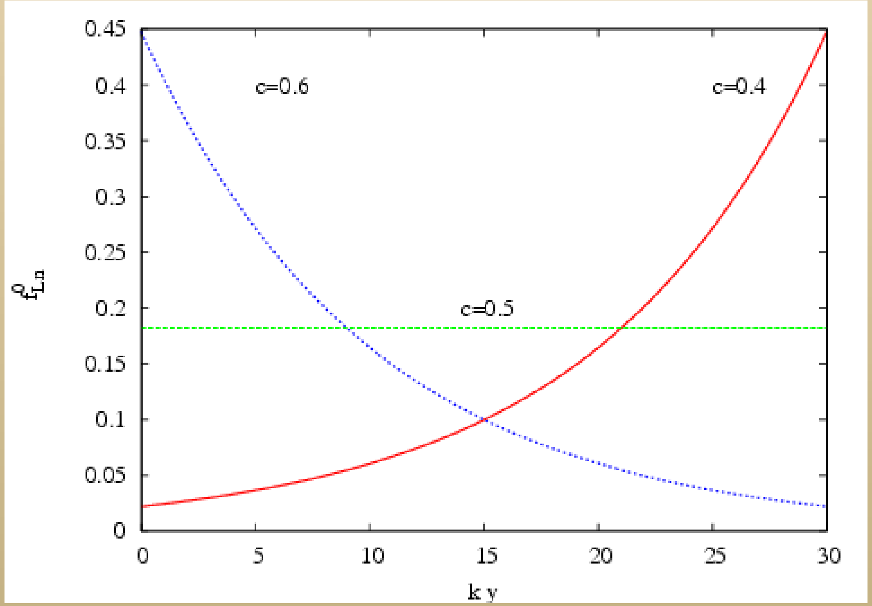
  - nice flavor theory: hierarchical masses + ~~FCNC~~
  - Higher-dimensional operators suppressed
- Fermion localization from bulk mass $\mathcal{L}_m = c_\Psi k \bar{\Psi}\Psi$



$+\ +$ b.c. zero mode

It is also possible to use different b.c.

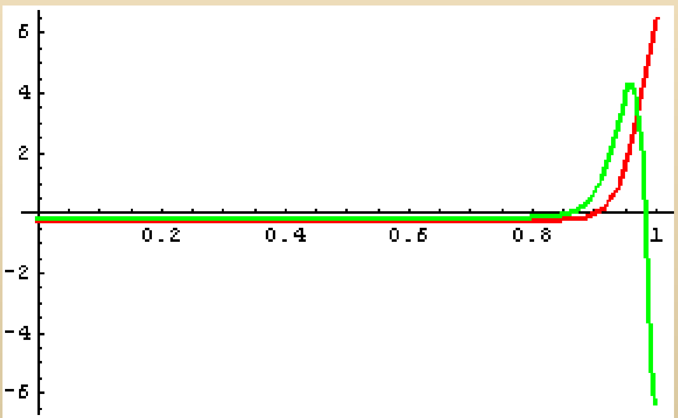
$-\ +$ b.c. ~~zero mode~~

KK modes might be light

Agashe, Servant JCAP (05)

Randall-Sundrum faces reality

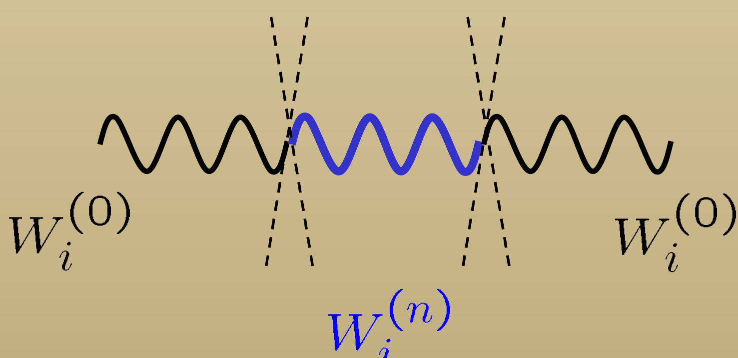
- Gauge boson KK modes localized towards IR brane



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

Large T parameter

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

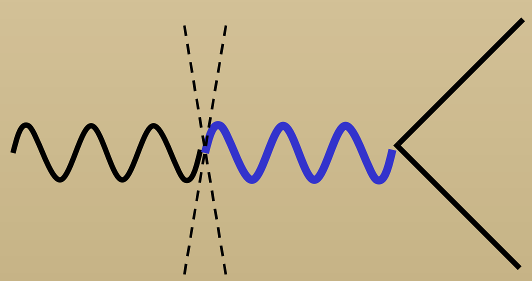


Randall-Sundrum faces reality

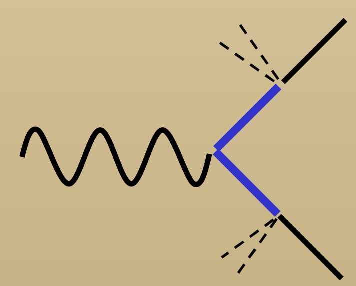
- Top (bottom) zero modes localized towards IR brane

Large gauge and Yukawa couplings to GB and fermion KK modes

Large anomalous Zbb coupling



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



Randall-Sundrum faces reality

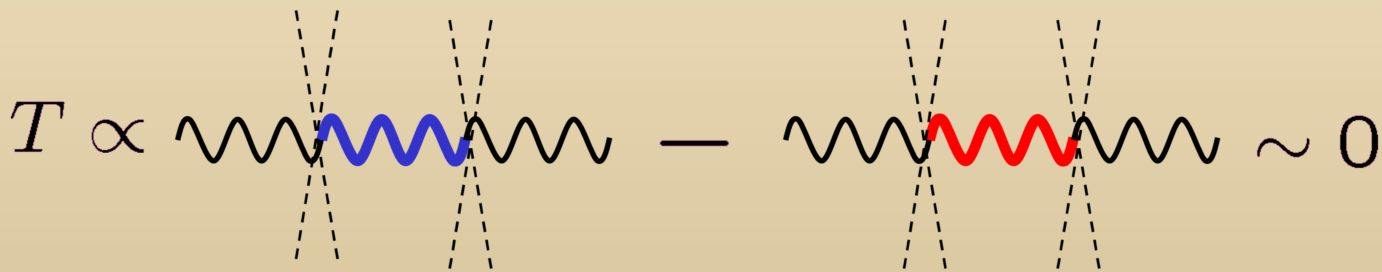
Large corrections to the T parameter and the Zbb coupling force $\tilde{k}$ to be beyond the LHC reach

- No Randall-Sundrum physics at the LHC
- The model becomes very fine-tuned

RS needs protection: call custodial symmetry

Agashe, Delgado, May, Sundrum JHEP (03)

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



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

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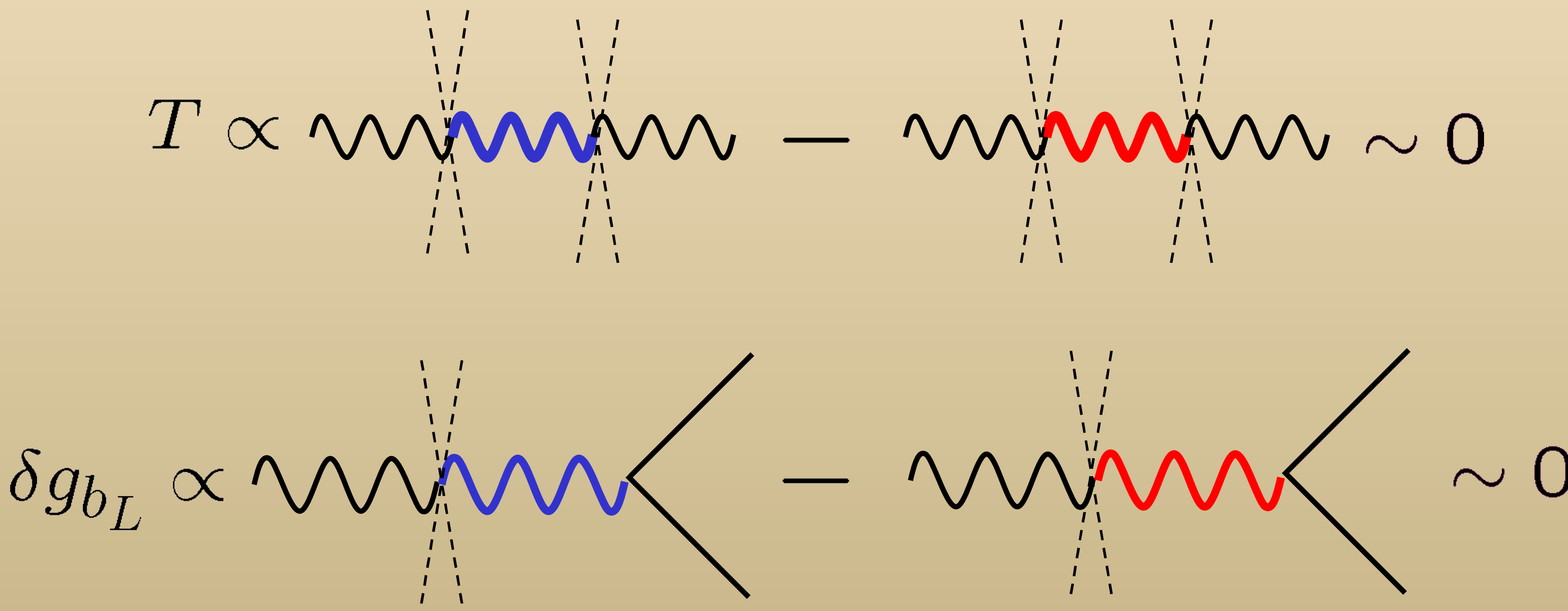


Symmetry broken by b.c. to $SU(2)_L \times U(1)_Y$ on the UV

Fermion Quantum Numbers

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

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

$$SU(2)_R$$

$$U(1)_Q$$

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

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

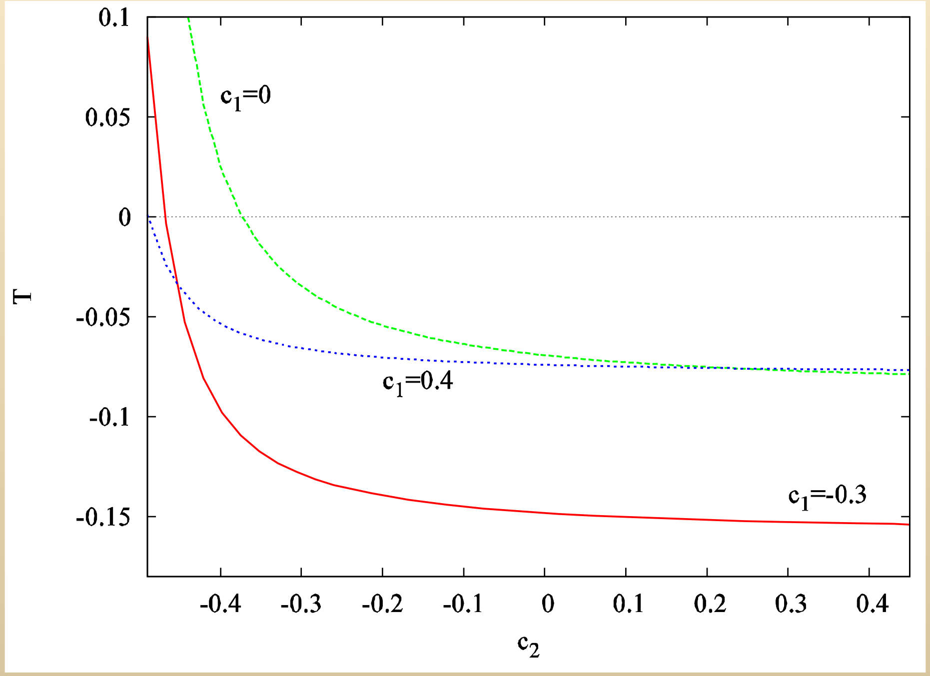
$$t_R(+,+) \sim (1,1)_{2/3}$$

Calculable corrections to T and Zbb

Carena, Pontón, J.S., Wagner NPB (06)

- T and Zbb protected (at tree level) by custodial symmetry broken on the UV brane:
  - Quantum corrections are calculable (finite)
  - T and Zbb are insensitive to physics above Λ
- One loop corrections are important
  - Bidoublets contribute negative to T
  - Singlets contribute positive to T
  - Large positive T leads to large positive δg_{bL}

Calculable 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

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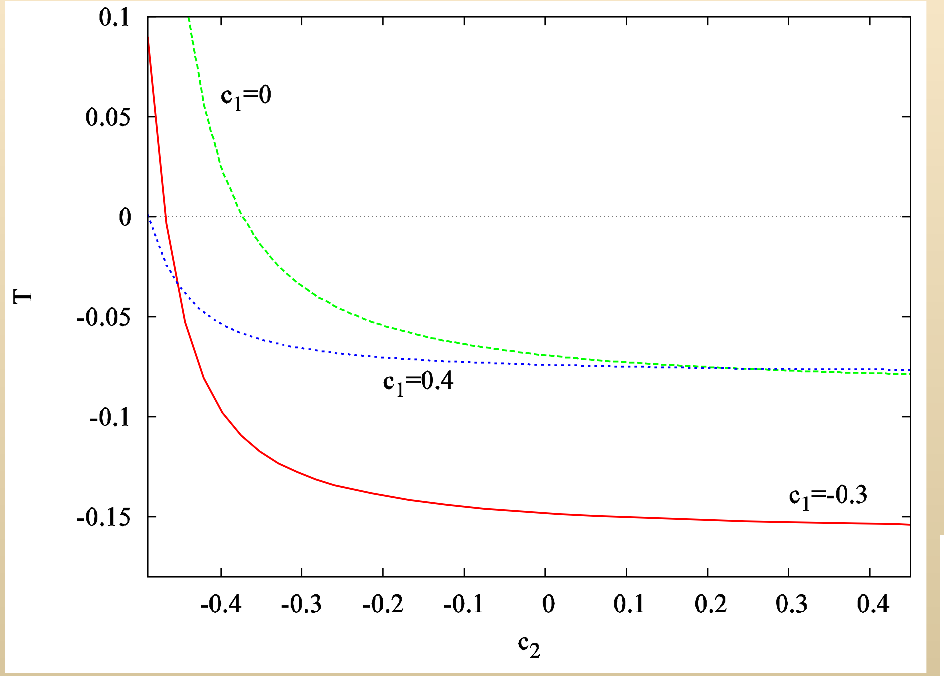

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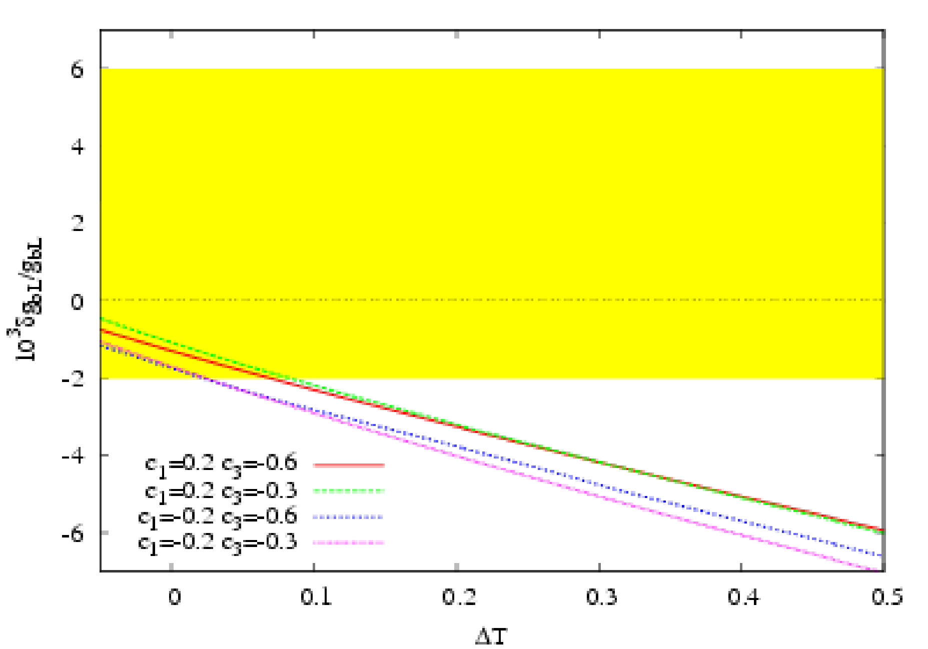
UV ⟵ singlet localization ⟶ IR



Positive T leads to large deviations in Zbb

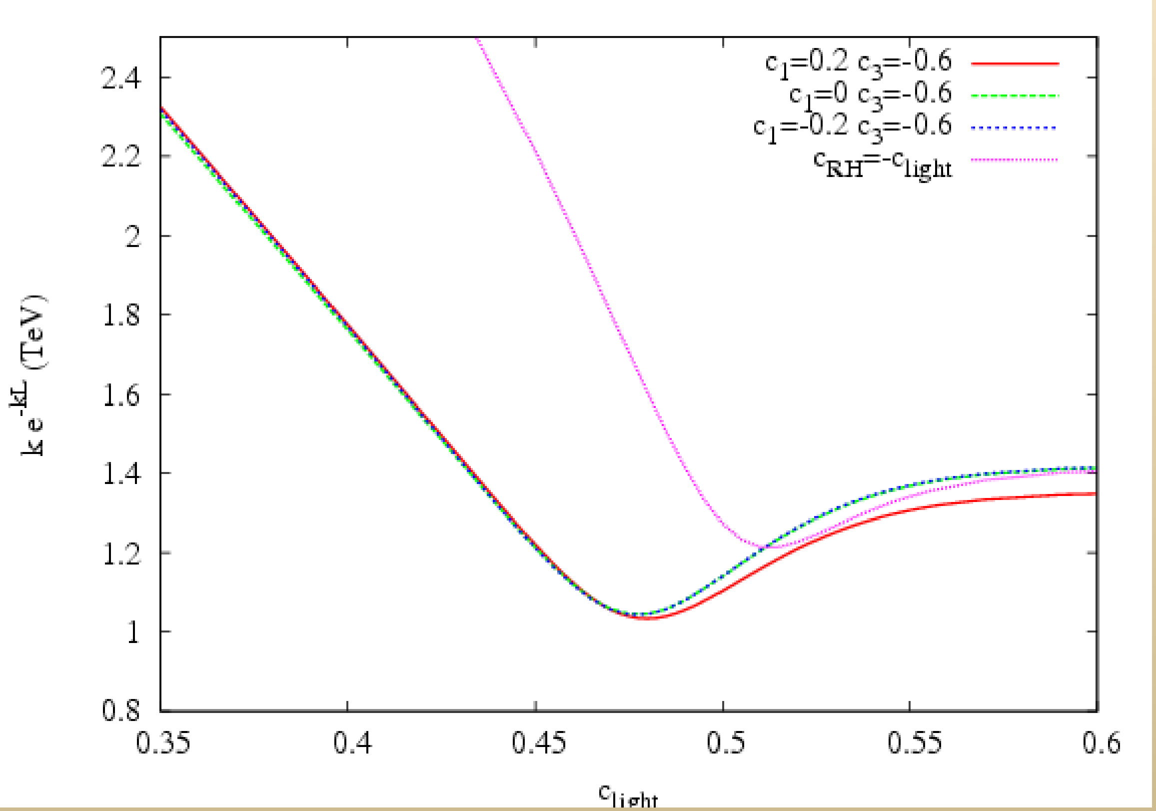
Gobal Fit to Electroweak Observables

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

Han, Skiba PRD (05-06)

- We have performed a global fit to all EW observables including:
  - All tree-level effects at leading order in $\mathcal{O}(v^2/\tilde{k}^2)$
  - Leading one loop effects on: T, Zbb and S
- We compute the χ^2 as a function of the localization parameter of the fermions $t_L, t_R, b_R, f^{LH}_{\text{light}}, f^{RH}_{\text{light}}$ and $\tilde{k}$
- To reduce number of parameters we optimize with respect to $t_R, f^{RH}_{\text{light}}$

Gobal Fit to Electroweak Observables



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

$\Downarrow$

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

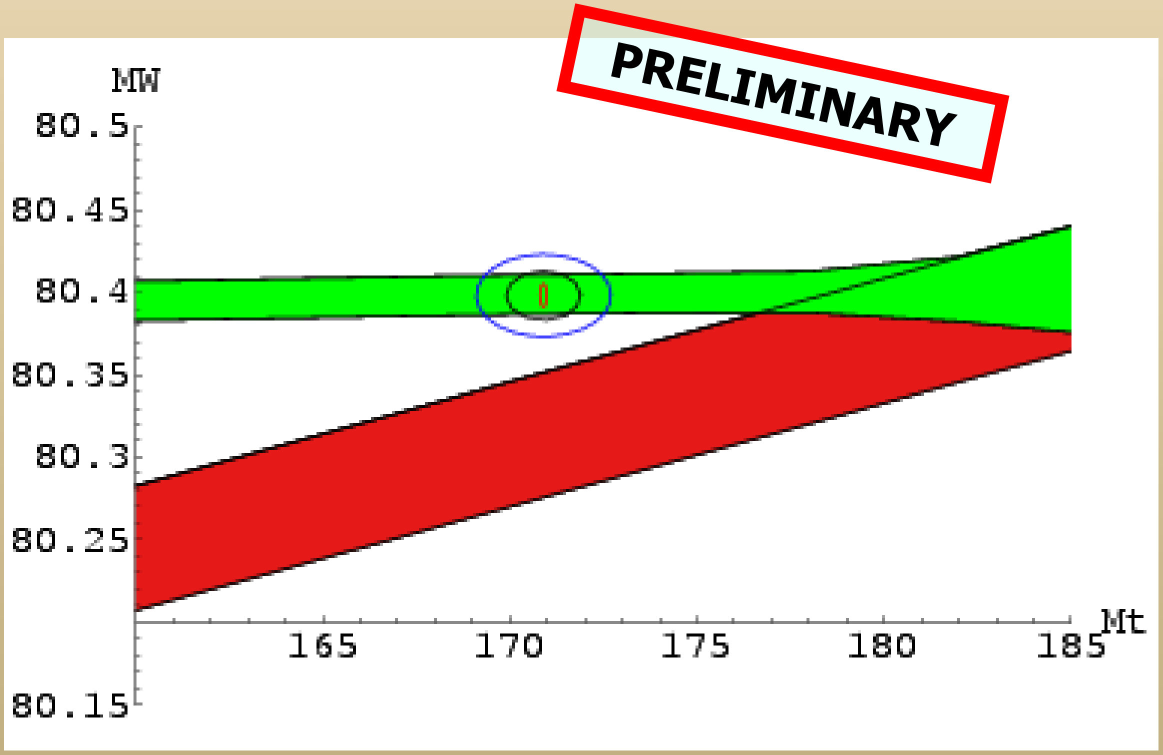
IR ← light localization → UV

Gobal Fit to Electroweak Observables

- New measurements of m_t and m_W generate a tension in the SM
- The contribution in our model goes in the right direction

$$M_w = 80.398 \pm 0.025\,\text{GeV}$$

$$M_{\text{top}} = 170.9 \pm 1.8\,\text{GeV}$$



Fermion Spectrum

First two generation KK modes

q'	Q	$m_{q'}$ (GeV)	decay
q_1^1	$2/3$	$\sim 200 - 500$	$q_1^1 \to Zu, \quad (100\%)$
q_1^2	$2/3$	$\sim 200 - 500$	$q_1^2 \to Zc, \quad (100\%)$
q_2^1	$2/3$	$\sim 200 - 500$	$q_2^1 \to Hu, \quad (100\%)$
q_2^2	$2/3$	$\sim 200 - 500$	$q_2^2 \to Hc, \quad (100\%)$
$\chi_2^{u_1}$	$5/3$	$\sim 200 - 500$	$\chi_2^{u_1} \to Wu, \quad (100\%)$
$\chi_2^{u_2}$	$5/3$	$\sim 200 - 500$	$\chi_2^{u_2} \to Wc, \quad (100\%)$
q'^{d_1}	$-1/3$	$\sim 200 - 500$	$q'^{d_1} \to Wu, \quad (100\%)$
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Not a necessary prediction

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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.%)
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Collider Phenomenology

- Tevatron
  - Searches for new quarks
  - Interesting possibilities for Higgs physics

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

- LHC
  - GB KK modes discovery up to ~5 TeV
  - Exotic decay channels

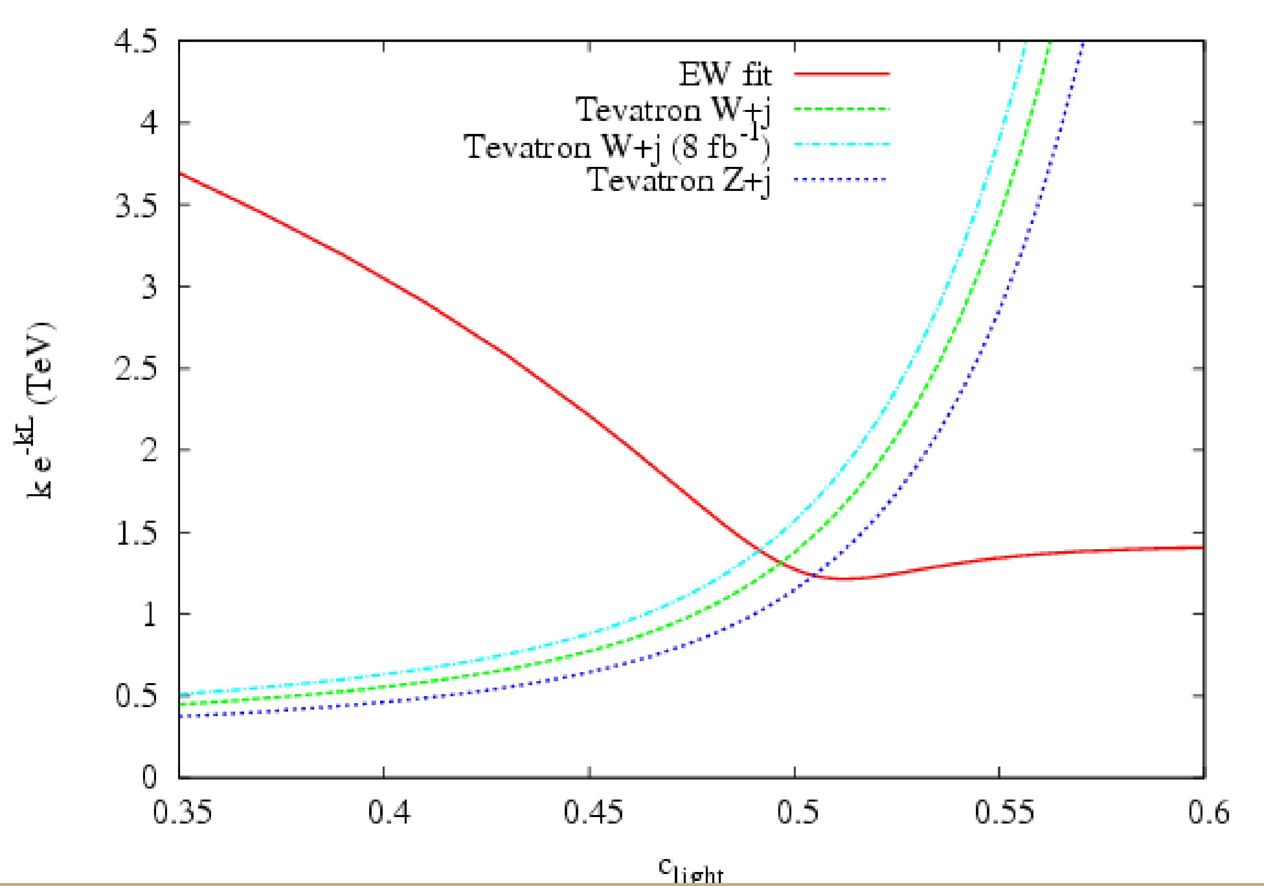
$$pp \to q'\bar{q}' \to W^+W^-t\bar{t} \to W^+W^+W^-W^-b\bar{b}$$

  - t′ discovery up to ~1 TeV
  - Exciting Higgs physics

Tevatron searches

New quark searches

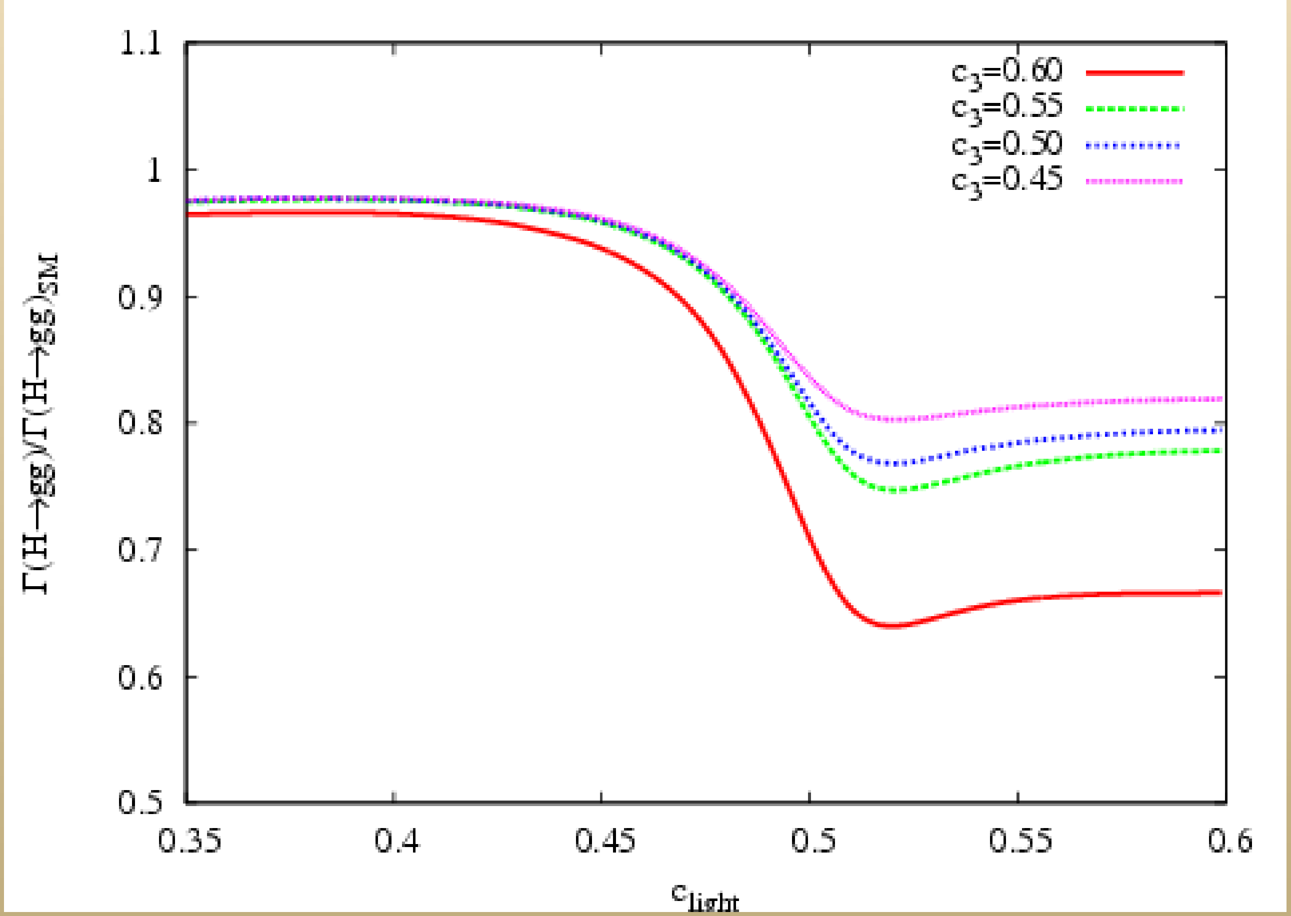
$$m_q \geq \begin{cases} 325\ (410)\ \text{GeV}, & W+j \text{ with } 0.76 \text{ (projected 8) fb}^{-1} \\ 300\ \text{GeV}, & Z+j \end{cases}$$



Tevatron searches

Higgs physics

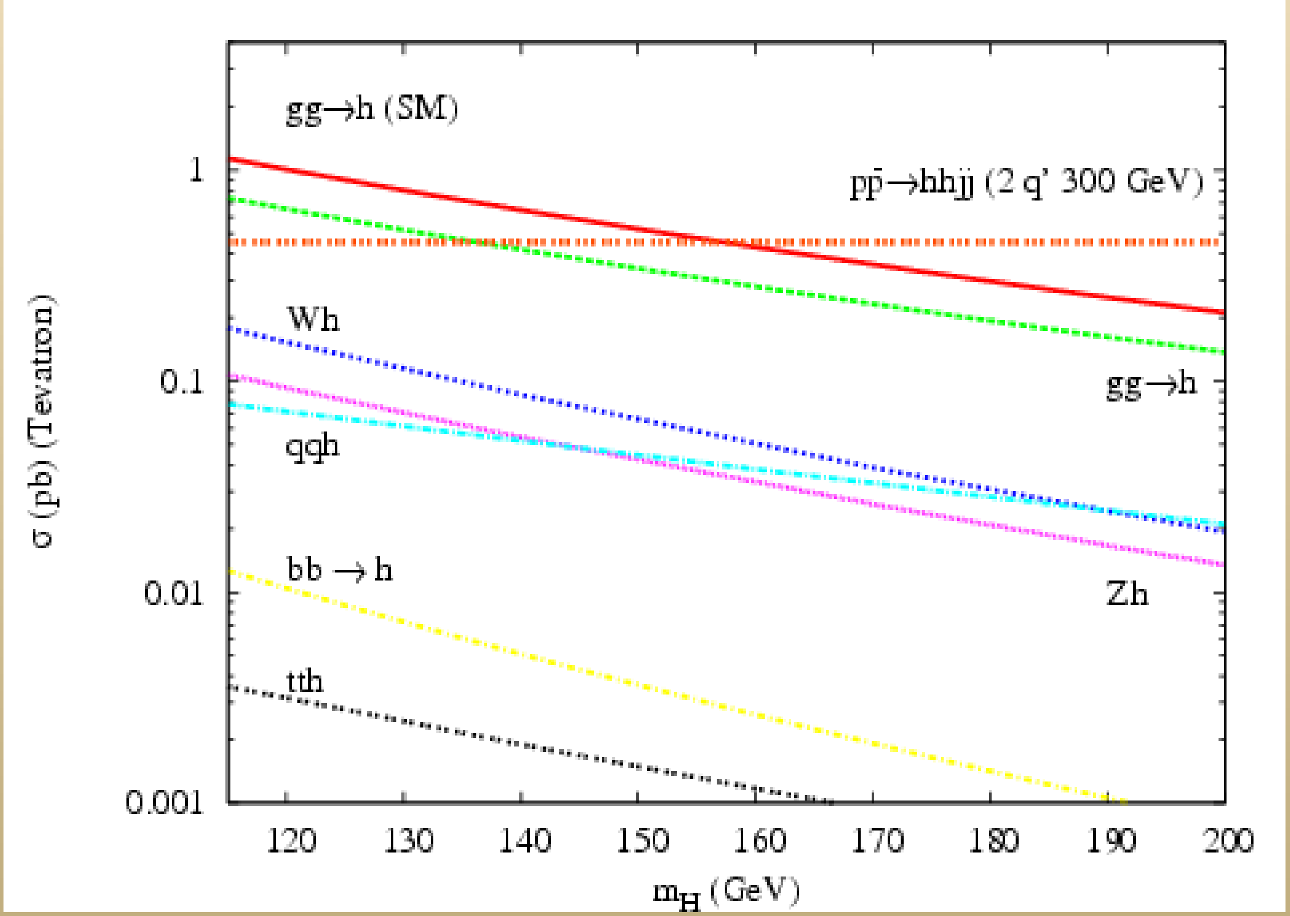
Top mixing with KK modes ⇒ reduced top Yukawa



Tevatron searches

Higgs physics

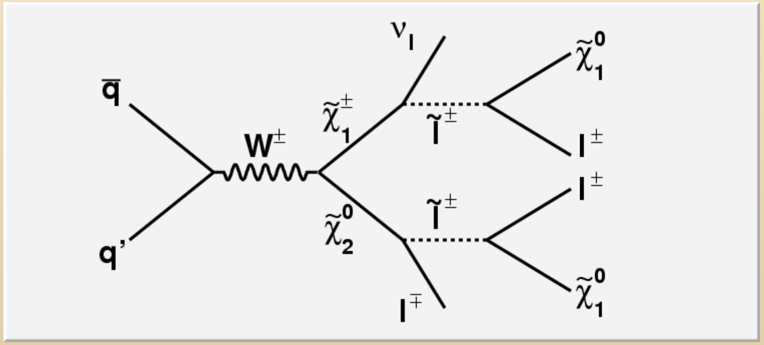
But new production mechanism mediated by q'

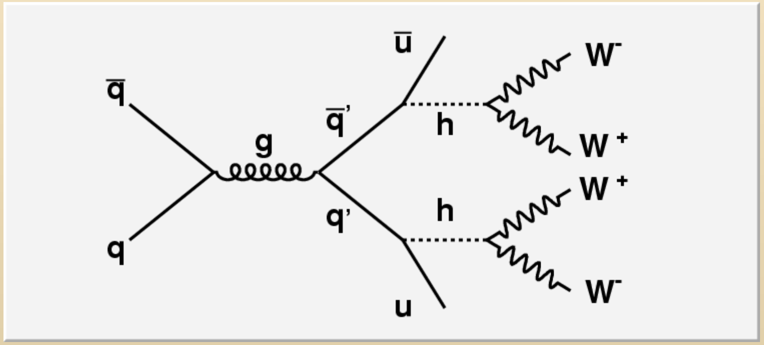


Tevatron searches

LS dileptons: SUSY vs q' (M_H=170 GeV)

D0 Note 5126-CONF (1fb^{-1})





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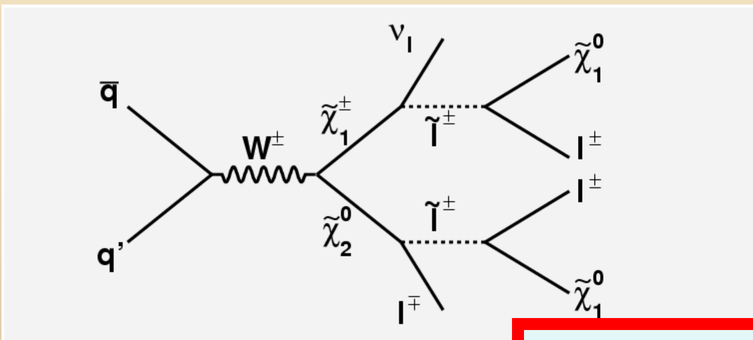
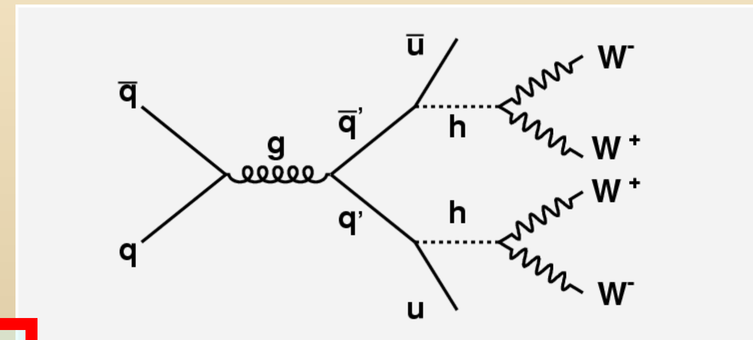
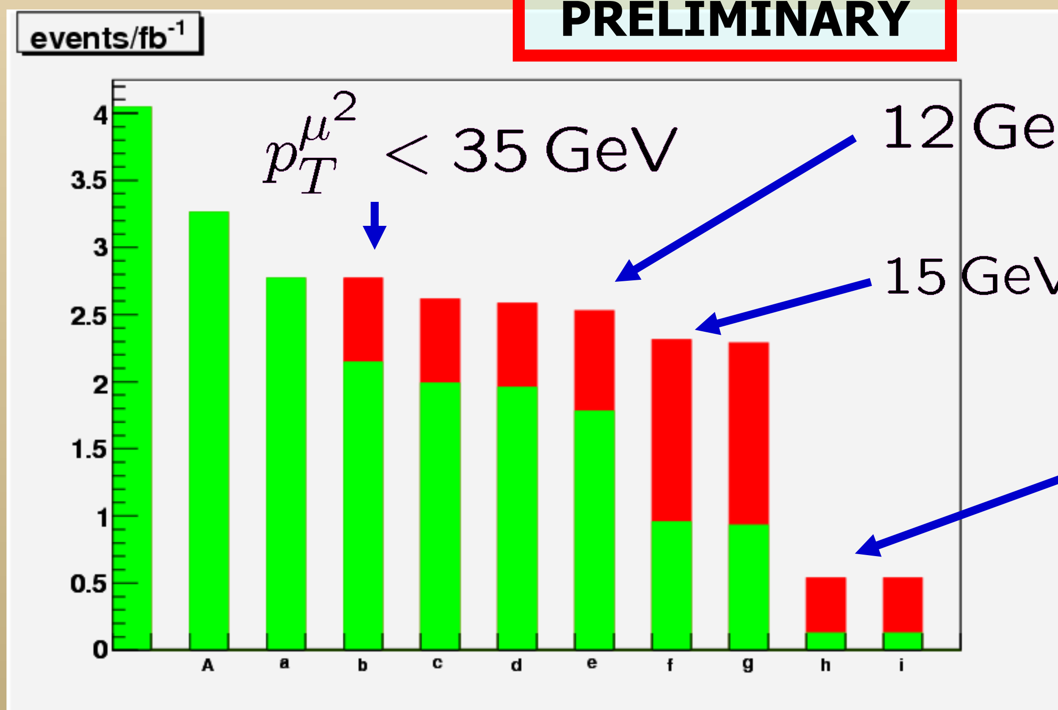




PRELIMINARY



$12\,\mathrm{GeV} < M_{\mu\mu} < 110\,\mathrm{GeV}$

$15\,\mathrm{GeV} < M_T(\not{E}_T, p_T^{\mu^2}) < 65\,\mathrm{GeV}$

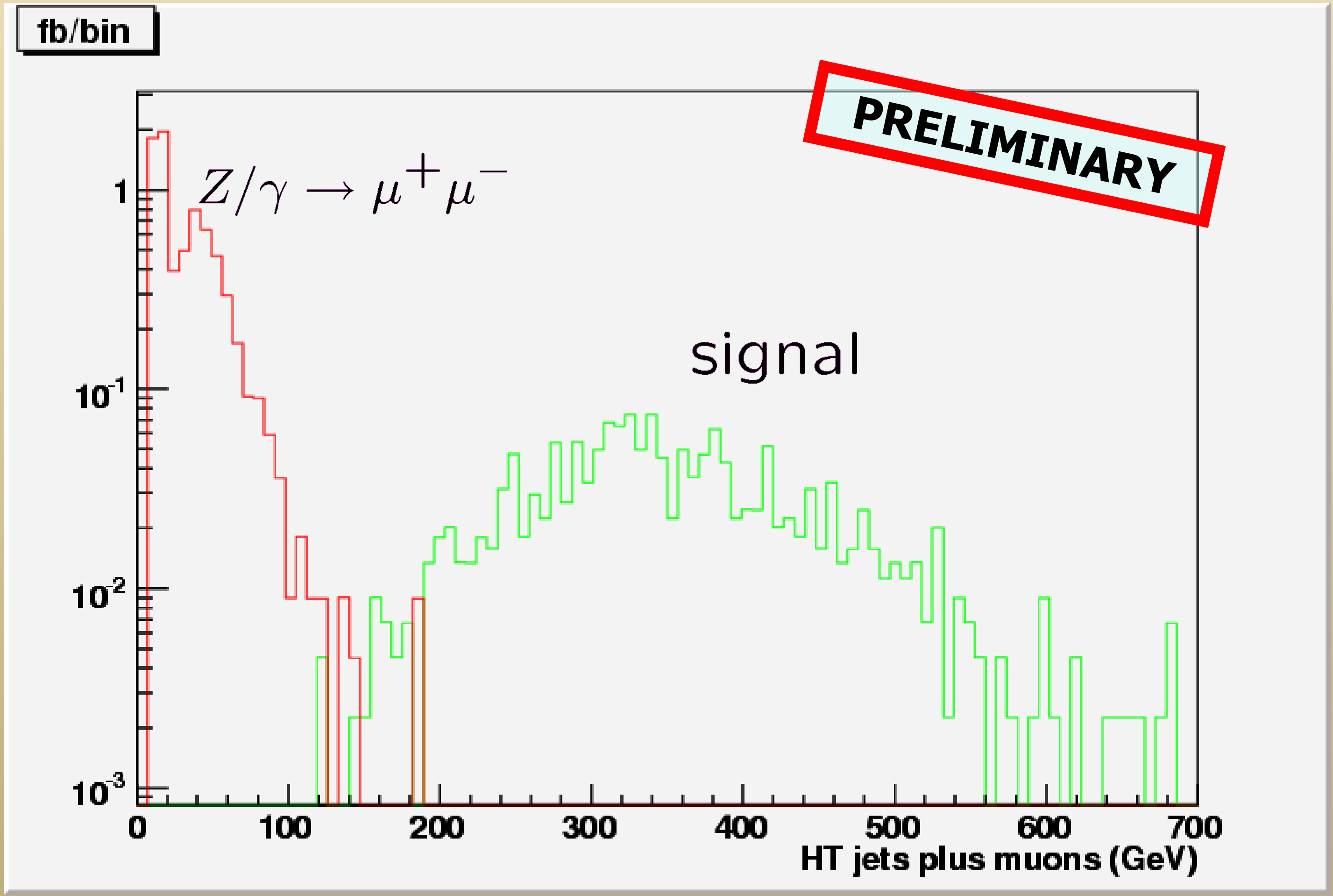
$Sig(\not{E}_T)$

Simulations using MG/ME+Pythia+PGS4

Tevatron searches

LS dileptons: SUSY vs q' (M_H=170 GeV) D0 Note 5126-CONF (1fb^{-1})

Alternative cuts: signal is harder than backgrounds



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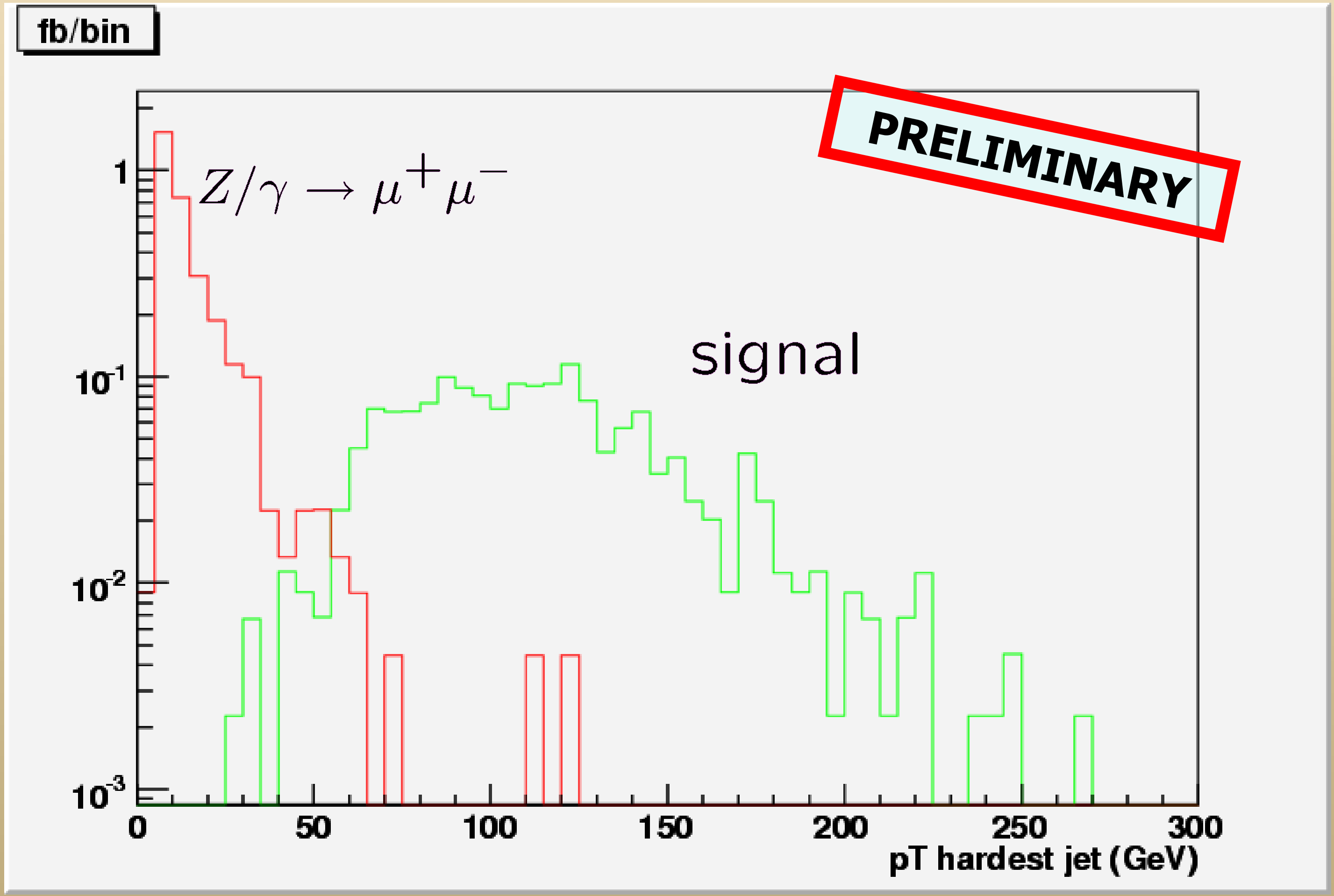

Tevatron searches

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Main backgrounds considered

$$\mathrm{QCD}, WZ, ZZ, Z/\gamma + \text{jet(s) and } W + \text{jet(s)}$$

Result of the analysis for 1 fb^{-1}

	sum	data
selection $\mathcal{B}$	14922±981	15234
$M_{\mu^{\pm}\mu^{\mp}} \in [25-65]$ GeV/c^2(a)	3479±232	3569
$p_T^{\mu^2} < 35$ GeV/c (b)	3479±232	3358
$p_T^{\mu^2} > 8$ GeV/c (c)	8.9±1.8	10
$p_T^{\mu^1} > 13$ GeV/c (d)	6.5±1.4	6
$M_{\mu^{\pm}\mu^{\pm}} \in [12-110]$ GeV/c^2(e)	4.9±1.2	2
$M_T(\not{E}_T, p_T^{\mu^2}) \in [15-65]$ GeV/c^2(f)	2.9±0.8	2
$\not{E}_T > 10$ GeV (g)	2.3±0.7	1
Sig($\not{E}_T$) > 12 GeV$^{1/2}$ (h)	1.7±0.6	1
$\not{E}_T \times p_T^{\mu^2} > 160$ GeV^2/c (i)	1.1±0.4	1

Our signal, assuming improved analysis is 2.5 events per fb^{-1}

In the absence of signal ~2 fb^{-1} could set a 95% C.L. bound

LHC searches

- $Z^{(1)}, \gamma^{(1)}$ accessible at the LHC in Drell-Yan up to

  $M_{Z^{(1)},\gamma^{(1)}} \sim 6\,\text{TeV}$

  Ledroit, Moreau, Morel ph/0703262

- KK gluons require careful treatment of *top jets* and improved fake jet efficiencies but

  $M_{g^{(1)}} \sim 4-5\,\text{TeV},\ 100\,\text{fb}^{-1}$

  Agashe, Belyaev, Krupovnickas, Perez, Virzi ph/0612015

  Lillie, Randall, Wang ph/0701166

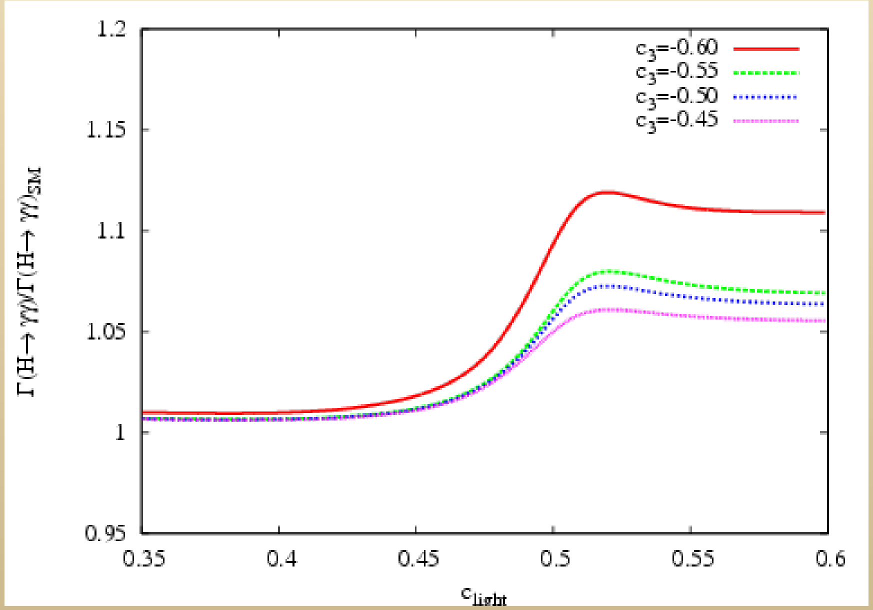
- Exotic decay channels with 4 or more W's may allow early discovery of q' with $M_{q'}$=500 GeV with 10 fb^{-1}

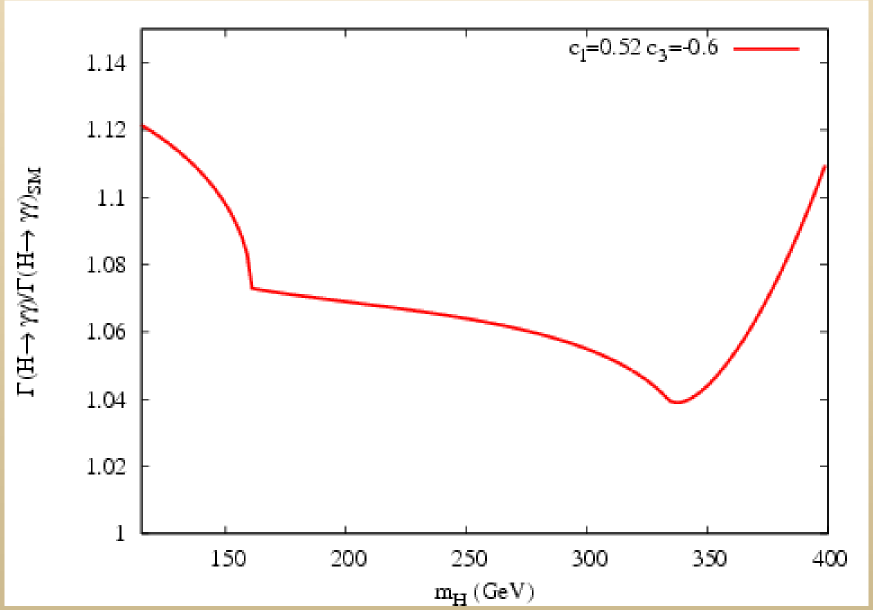
  Dennis, Ünel, Servant, Tseng ph/0701158

- t' with masses $\sim 1\,\text{TeV}$ can be discovered at the LHC

LHC Higgs physics

- Gluon fusion production reduced up to a factor 0.65
- $H \to \gamma\gamma$ slightly enhanced (up to 1.12 for light Higgs)





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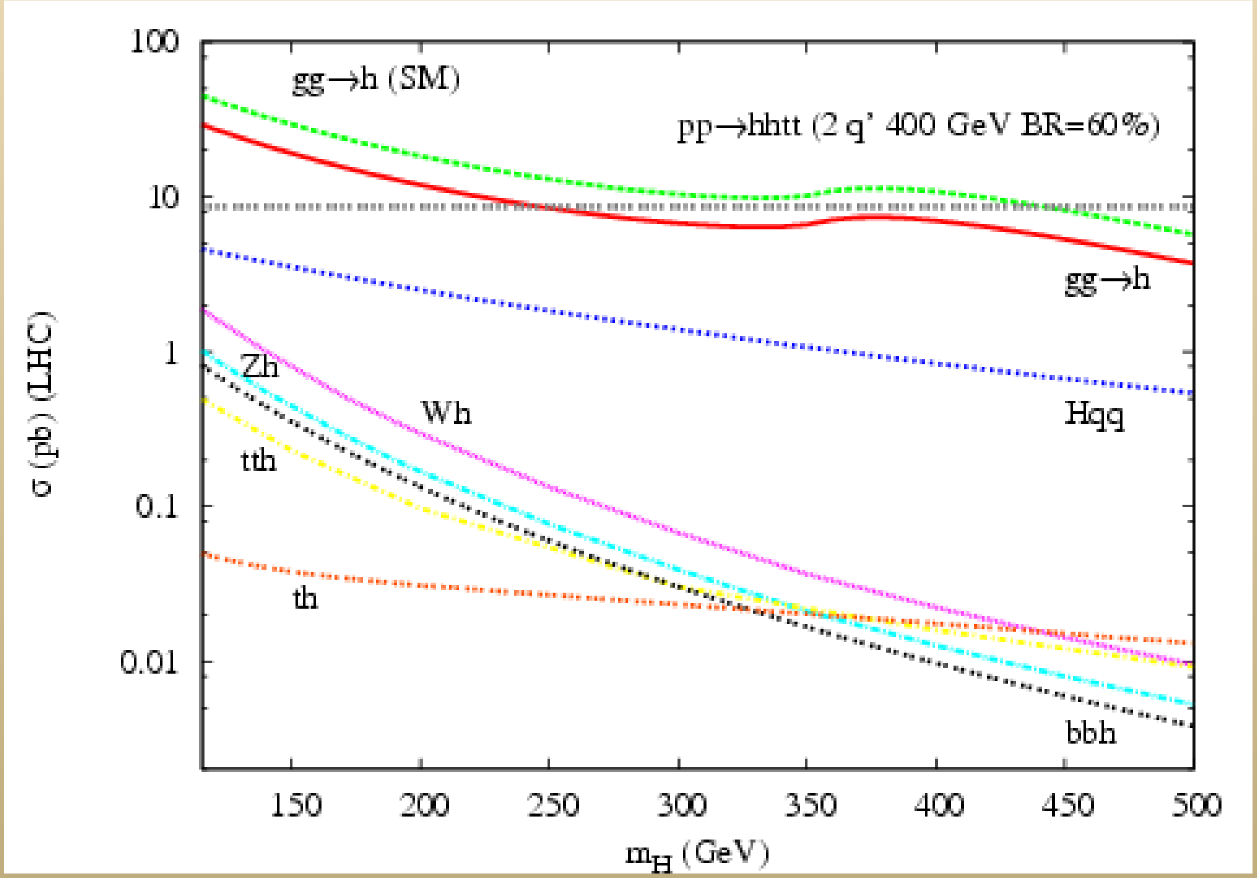

LHC Higgs physics

- Gluon fusion production reduced up to a factor 0.65
- $H \to \gamma\gamma$ slightly enhanced (up to 1.12 for light Higgs)
- But new production mechanism mediated by q'
- New possibilities for early discovery

Aguilar-Saavedra JHEP (06)

$$pp \to T\bar{T} \to W^+ bH\bar{t}/HtW^-\bar{b} \to W^+ bW^-\bar{b}H$$
$$pp \to T\bar{T} \to HtH\bar{t} \to W^+ bW^-\bar{b}HH$$

5σ discovery for m_T=500 GeV and m_H=115 GeV with 8 fb^{-1}

T is a vector-like singlet $\Rightarrow BR(T \to Ht) \approx 25\%$

But need dedicated analysis!

Conclusions

- Custodial protection of T and Zbb: new opportunities for Randall-Sundrum models
- Quantum corrections calculable and relevant:
  - Fix some features of the model (t_L, b_L near IR brane)
  - Help ease the tension after new M_{top}, M_W measurements
- Very rich,interesting and new phenomenology
  - Light ($\sim 2-3\,\mathrm{TeV}$) gauge boson KK modes
  - Light ($\sim 0.4-1\,\mathrm{TeV}$) quarks, some with exotic charges
  - Spectacular signatures: multigauge bosons, LS leptons, ...
  - Important effects in Higgs physics