Top Flavor Violation

from the B-Factories to the LHC

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Outline

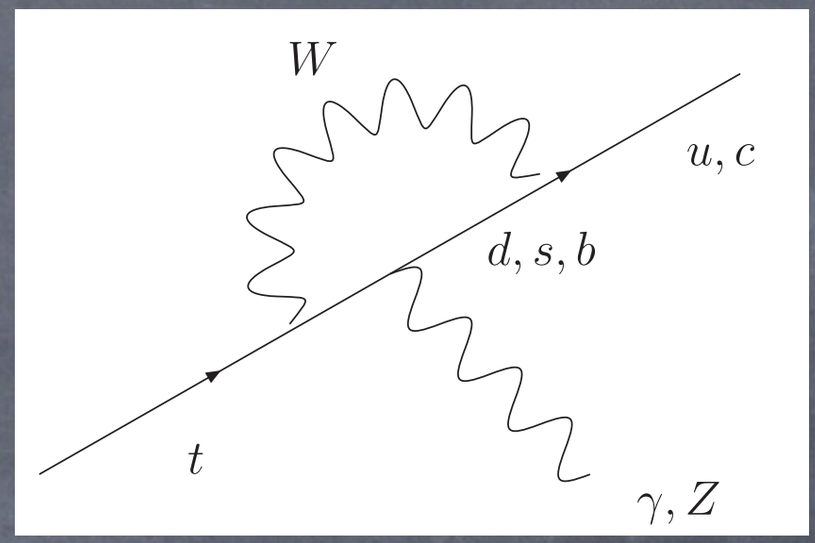
- FCNCs in top decays
- Motivations
- Direct searches (past & future)
- Indirect bounds from B-physics experiments
- Conclusions

FCNC in top decays

Top rare decays:

- $t \to q\, Z$ q=u,c
- $t \to q\, \gamma$

} ⟵ this talk



- $t \to q\, g$ ⟵ e.g. ph/0603131
- $t \to q\, h$ ⟵ more model dep'
- …

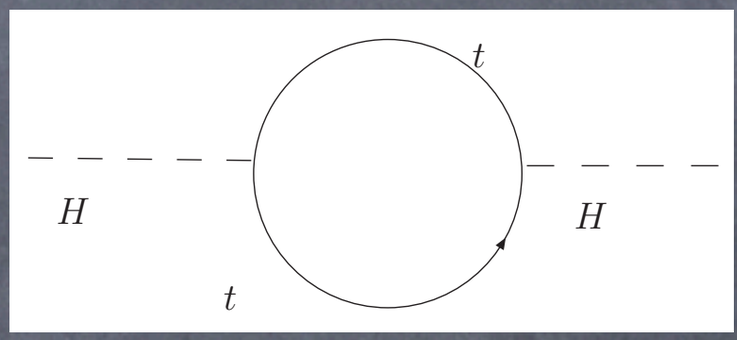
SM: BR ~ 10^{-14}

"SM free" → good place to check for New Physics

New Physics in the top sector?

- NP @ TeV to stabilize the ElectroWeak scale

...NP may interact with the top



Possible new source of flavor violation if

NP ⇔ 3rd gen' ≠ NP ⇔ 1st-2nd gen'

Search for Flavor viol' in the Top sector

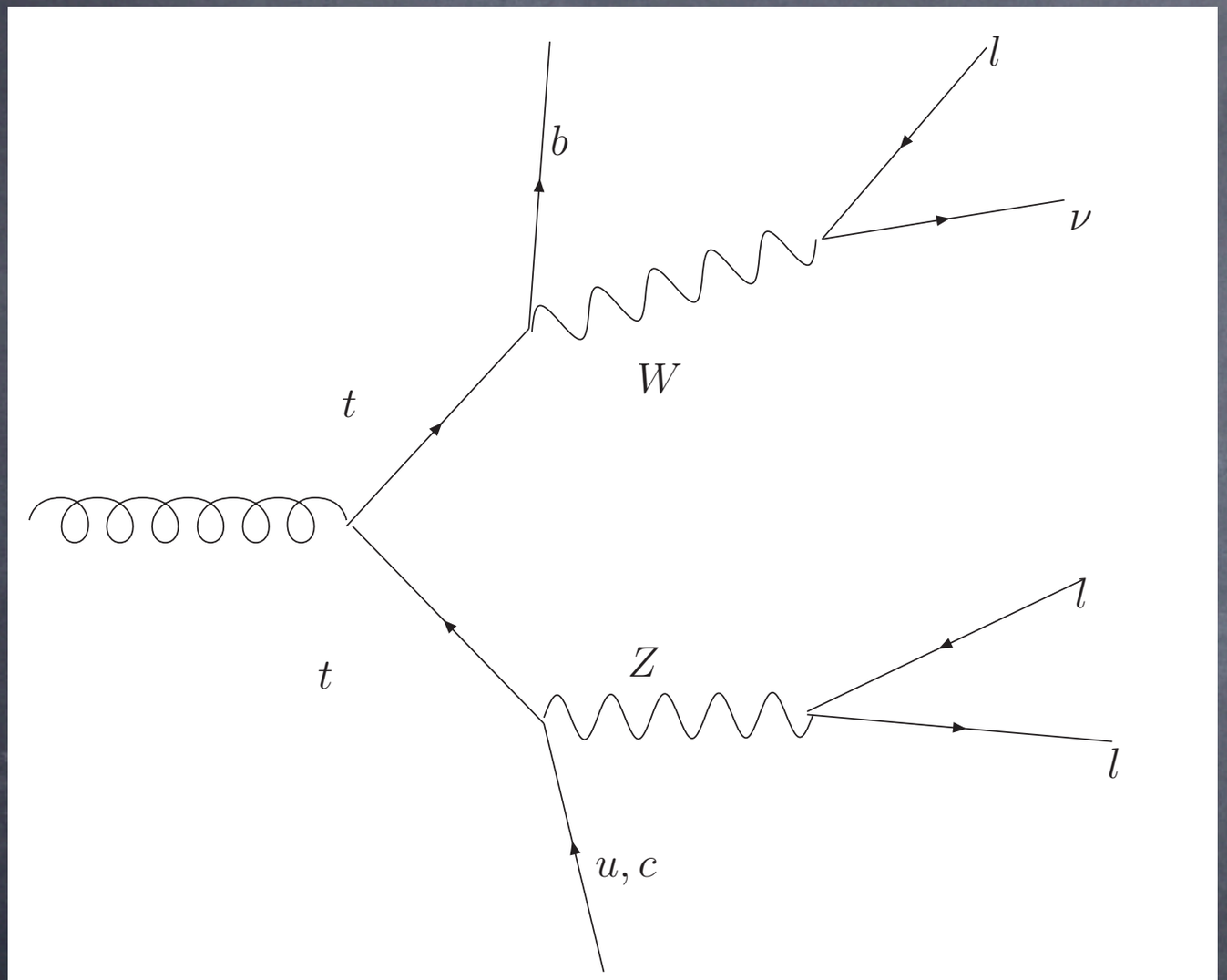
($t_L \leftrightarrow b_L \Rightarrow$ search in bottom sector, but no NP there...)

Direct bounds on top FCNCs

- LEP2:
  - e+ e- → t c : BR(t→qZ)<13.7% @ 95%CL
- Hera:
  - e- p → t e- : BR(t→uγ)<0.6% @ 95%CL
- CDF:
  - BR(t→qZ)<33% @ 95%CL

We need a top factory...

The LHC: 1 $t\bar{t}$ pair $s^{-1}\mathrm{exp}^{-1}$



the perfect place...

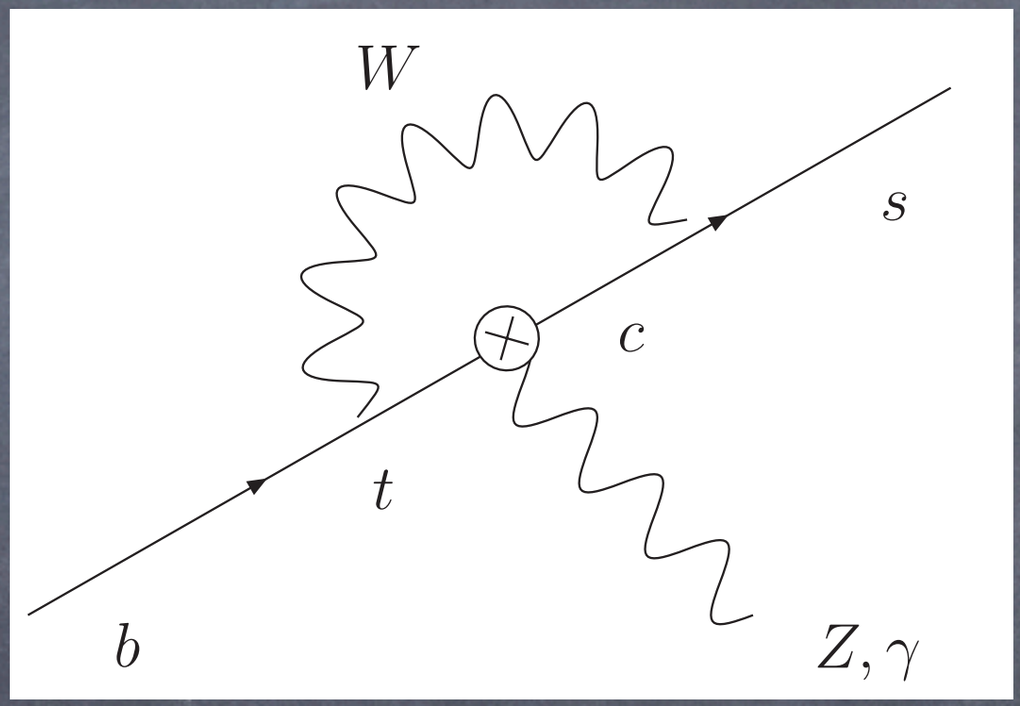
...to probe FCNC top decays

channel	$t \to Zu(c)$	$t \to \gamma u(c)$	$t \to gu(c)$		
			(3 jets)	(4 jets)	(combined)
upper limit on BR ($L = 10$ fb^{-1})	3.4×10^{-4}	6.6×10^{-5}	1.7×10^{-3}	2.5×10^{-3}	1.4×10^{-3}
upper limit on BR ($L = 100$ fb^{-1})	6.5×10^{-5}	1.8×10^{-5}	5.0×10^{-4}	8.0×10^{-4}	4.3×10^{-4}

(Carvalho, Castro, Onofre, Veloso 2005)

Indirect constraints?

- Top FCNCs can affect other observables:



What are the present bounds?
Is the LHC window still open?

A Model-Indep' analysis

- Write SM + all possible dim-6 operators contributing to top FCNCs. (Buchmuller Wyler '86)
- Assume a valid perturbative expansion in v/Λ_{NP}
- Assume SU(2)xU(1) invariance
- "No CP violation" (~ be conservative with CPV)
- Look at all the possible indirect bounds...

The main players:

- 2 LL operators:

$$\mathcal{O}^u_{LL} = i\left[\overline{Q}_3\tilde{H}\right]\left[\left(\not{D}\tilde{H}^\dagger\right)Q_i\right] - i\left[\overline{Q}_3\left(\not{D}\tilde{H}\right)\right]\left[\tilde{H}^\dagger Q_i\right] + \text{h.c.}$$

$$\mathcal{O}^h_{LL} = i\left[\overline{Q}_3\gamma^\mu Q_i\right]\left[H^\dagger D_\mu H\right] + \text{h.c.}$$

- 4 LR,RL operators:

$$\mathcal{O}^W_{LR} = g\left[\overline{Q}_3\sigma^{\mu\nu}\tau^a\tilde{H}\right]u_i W^a_{\mu\nu} + \text{h.c.}$$

$$\mathcal{O}^B_{LR} = g'\left[\overline{Q}_3\sigma^{\mu\nu}\tilde{H}\right]u_i B_{\mu\nu} + \text{h.c.}$$

+ LR ↔ RL

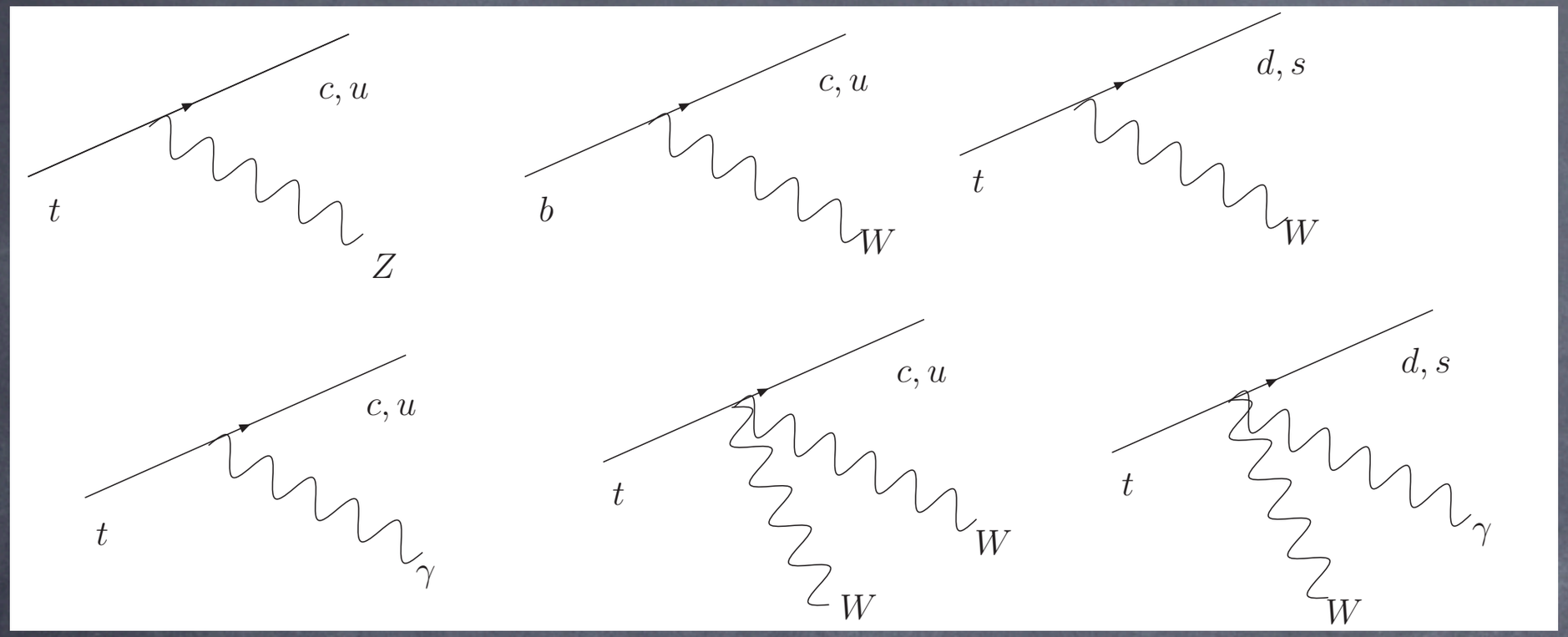
- 1 RR operator:

$$\mathcal{O}^u_{RR} = i\overline{u}_3\gamma^\mu u_i\left[H^\dagger D_\mu H\right] + \text{h.c.}$$

- 4-fermions operators (many)

The plot

- After EWSB:



+...

→ Look at constraints coming from:

- semileptonic B decays
- $b \to s\gamma$ & $b \to s l^+ l^-$ & $b \to \rho\gamma$
- $\Delta F=2$ (Unitarity)
- T,U,V (EWPT)

LHC reach

- In terms of the previous operators, the LHC reach corresponds to:
  - $t \to q\gamma$: $\Lambda <$ 2.6TeV
  - $t \to qZ$: $\Lambda <$ 1.2TeV for op' involving $B_{\mu\nu}$

    $\Lambda <$ 2.3TeV others

Semileptonic B-decays

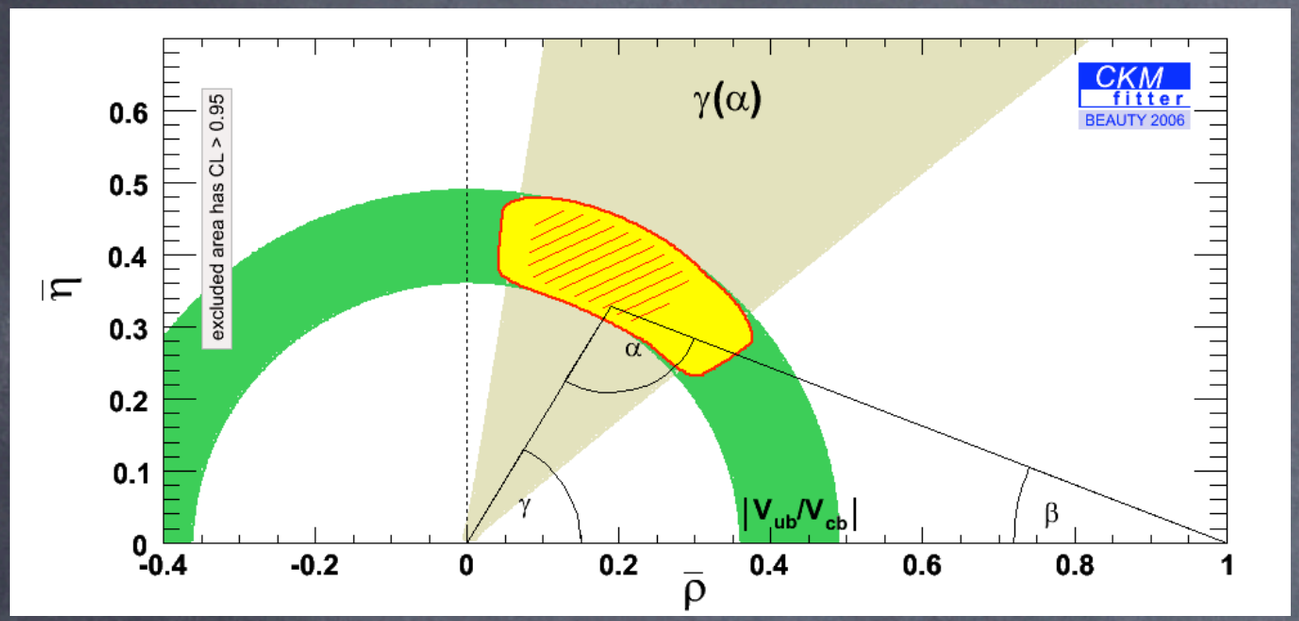
- Tree level bWc & bWu couplings
  - LL operator: same structure of the SM
    - shift of V_{cb} and V_{ub}
    - constrained only by unitarity / $\Delta F=2$ (later)
- $b_L c_R$ & $b_L u_R$ couplings can be constrained by present data

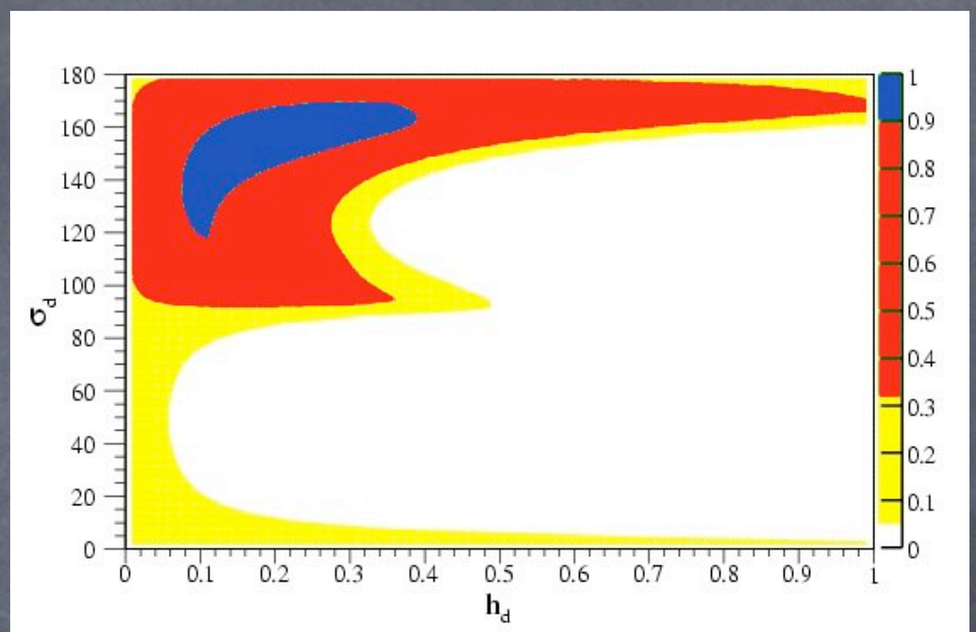
Semileptonic B-decays (cont'd)

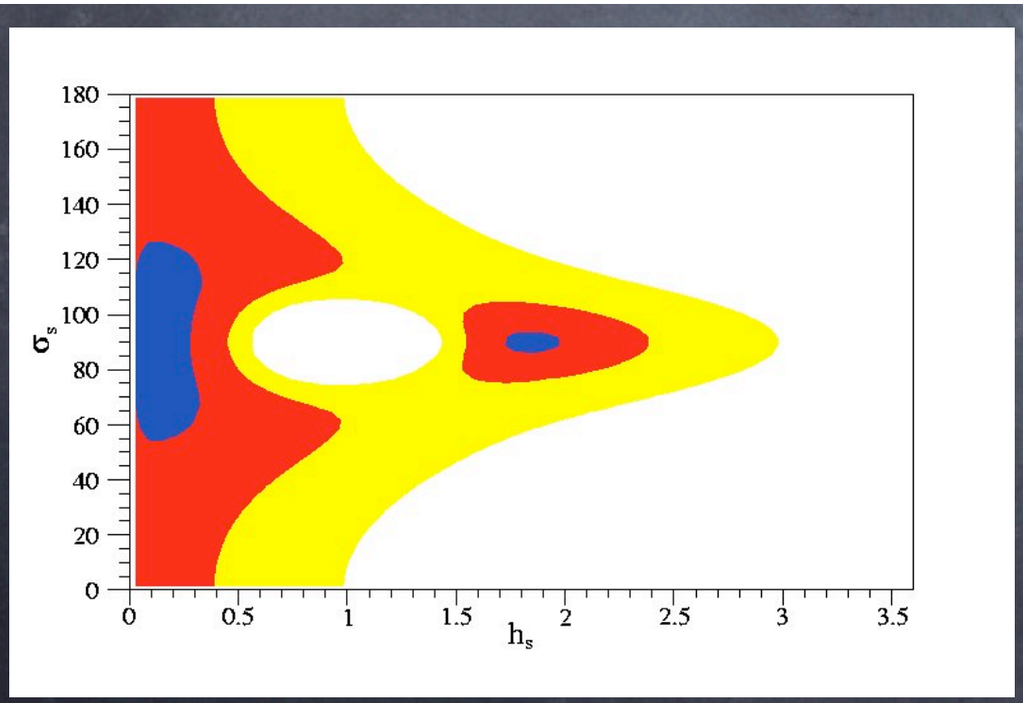
- For $t \to c$: $\Lambda > 1$ TeV @ 95%CL
  - inclusive $B \to X_c l \nu$ partial rates and lepton energy moments (BaBAR '04)
  - $B \to D^* l \nu$ form factors and $B \to D l \nu$ / $B \to D^* l \nu$ ratio
- For $t \to u$: $\Lambda > 1$ TeV @ 95%CL
  - inclusive $B \to X_u l \nu$ measurements ("BLL" method)
  - exclusive $B \to \pi l \nu$

Unitarity & New Physics

- We have enough data to constrain SM V_{CKM} + NP:







SM NP in b->d

NP in b->s

Assumptions: V_{CKM} unitary, NP affects "loop" observ'

Unitarity & LL operators

- LL NP is indistinguishable from the SM in bWc, bWu and modify V_{CKM} at tree level...
  - redefine:

$$V_{cb}^{exp}=V_{cb}^{SM}+NP \;\&\; V_{ub}^{exp}=V_{ub}^{SM}+NP$$

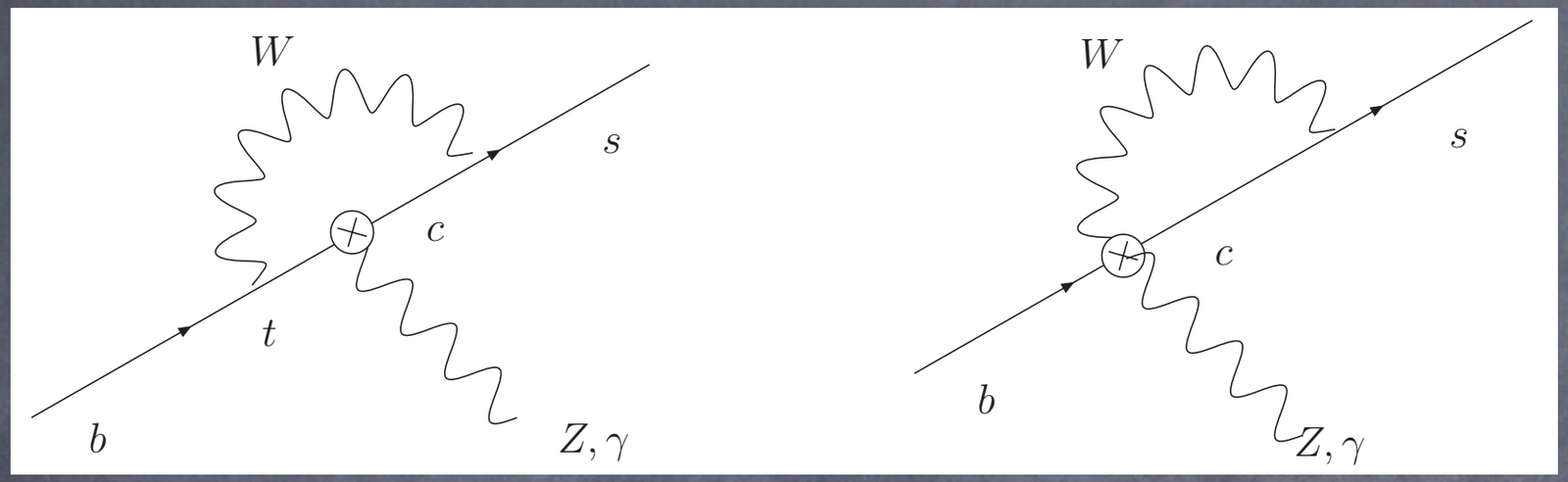
- In the CKM fit we are now fitting a different unitary matrix containing the measured V_{ub}^{exp} and V_{cb}^{exp} and corresponding " V_{ts}^{fit}" & "V_{td}^{fit}"
- Compute $\Delta F=2$ contrib' SM+NP and reexpress them in term of V_{td}^{fit} and V_{ts}^{fit} as $SM^{fit}+NP'$
- constrain NP'

$\Delta F=2$

- Constraints on op' involving $t_L q_L$ (tree level + 1-loop):
  - Λ>1-1.6 TeV for O_{LL}^{u} & Λ>8 TeV for O_{LL}^{h}
- Constraints on op' involving $t_R q_L$ and W's (1-loop)
  - Λ>0.7,1.7 TeV

$b \to s l^+ l^-$ & $b \to s \gamma$

- NP contributions to C_3, $C_{7\gamma}$, C_{9V}, C_{10A} @ M_W:



+...

- Contributions from:
  - $t_L c_L$ operators (tree level + 1-loop)
    - $\Lambda > 7.5$ TeV & $\Lambda > 2.6$ TeV
  - $t_R c_L$ operators at 1-loop
    - $\Lambda_- > 1.9$ & $\Lambda_+ > 2.6$ TeV for $W_{\mu\nu}$ op′
    - $\Lambda > 1.6$ TeV for $B_{\mu\nu}$ op′

...The rest

- ElectroWeak Precision Tests:
  - At order v^2/Λ^2 only charged gauge bosons self energies are corrected (T, U, V) by $t_L q_L$ and $t_R q_L$
  - Constraints are very weak: Λ>400-500 GeV
- 4-fermions op':
  - LEP2 constrained contact terms involving top and a light quark
  - $\mathrm{BR}(t \to c e^+ e^-)\,|_{M_{ee}=80\div100\mathrm{GeV}}$ from contact terms is beyond LHC reach

Results

Λ [TeV]	O_{LL}^u	O_{LL}^h	O_{RL}^W	O_{RL}^B	O_{LR}^W	O_{LR}^B	O_{RR}^u
$t\to cZ$ (Λ<...)	2.3	2.3	2.3	1.2	2.2	1.2	2.3
$t\to c\gamma$ (Λ<...)	–	–	2.6	2.6	2.6	2.6	–
$b\to s\gamma$ +$b\to sl^+l^-$	2.6	7.5	$1.9_{(2.6)}$	1.6	–	–	–
$\Delta F=2$	1.4	8	0.8	–	–	–	–
EWPT	0.5	–	–	–	–	–	–
$b\to cl\nu$	–	–	–	–	1	–	–
LHC window	closed	closed	ajar	ajar	open	fully open	fully open

and similar for $t\to u$...

Conclusions

- New Physics involved in EWSB may induce new source of flavor violation in top decays
- LHC can probe FCNCs top decays up to BR~10^{-4}-10^{-5}
- Present data from B-factories constrain these decays (in some cases beyond LHC reach)
- B-factories & the LHC together can probe the nature of NP inducing Top FCNCs

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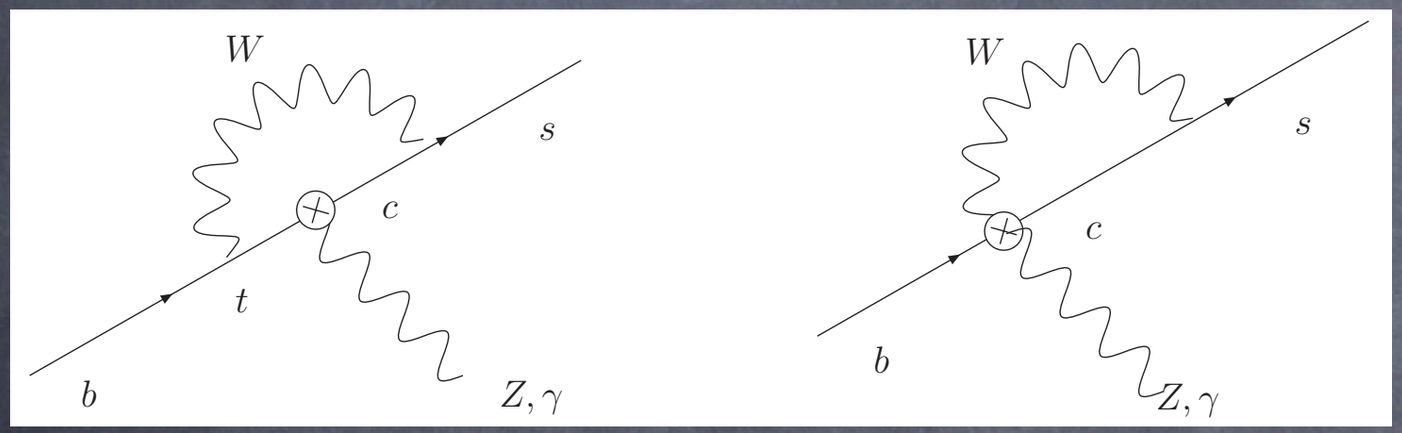
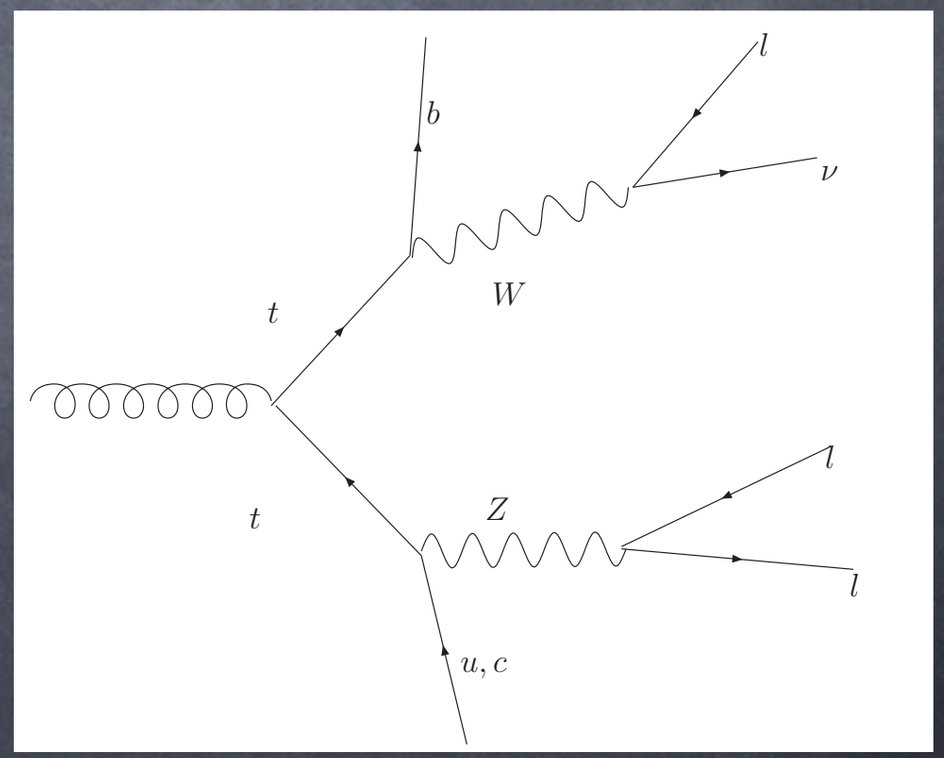
from the B-Factories to the LHC





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