Top quark tensor couplings

Gabriel González-Sprinberg

Facultad de Ciencias,

Universidad de la República, Uruguay

XL International Meeting on Fundamental Physics

Benasque, May 2012

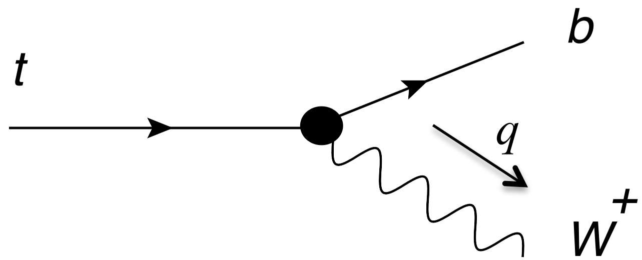
Top quark tensor couplings

Outline

- What: Top quark decay vertex
- Why: SM BSM
- How: Observables
- Where: Tevatron, LHC and future accelerators
- When: Summary/Future

Top quark tensor couplings

Top decay:



$$\mathcal{M}_{tbW^+} = -\frac{e}{\sin\theta_W\sqrt{2}}\,\varepsilon^{\mu *}\,\bar{u}_b\left[(V_{tb}+f_L)\gamma_\mu P_L + f_R\gamma_\mu P_R + \frac{i\sigma_{\mu\nu}q^\nu}{m_W}(g_L P_L + g_R P_R)\right]u_t$$

Most general parametrization for the decay

Top quark tensor couplings

WHAT

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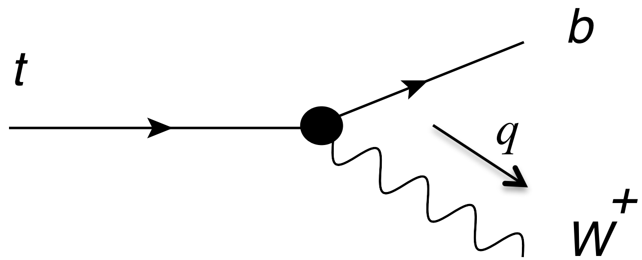

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Most general parametrization for the decay

particles on-shell

complex couplings

both g are chirality-flipping couplings

Top quark tensor couplings

WHAT

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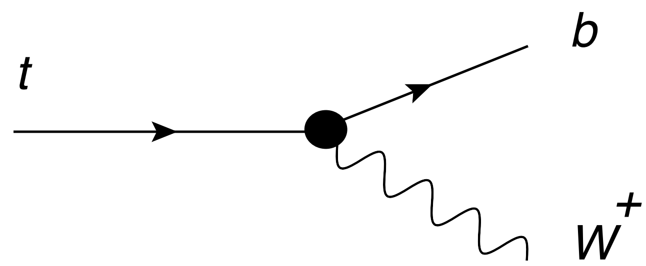

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Most general parametrization for the decay

Effective Lagrangian approach:

- suitable for BSM where all new particles are heavy
- simulate low energy effects coming from higher scales

$M_{new} \approx \Lambda >> m_t$, momentum scale << Λ, …… new "light" scalars?

Top quark tensor couplings

WHAT

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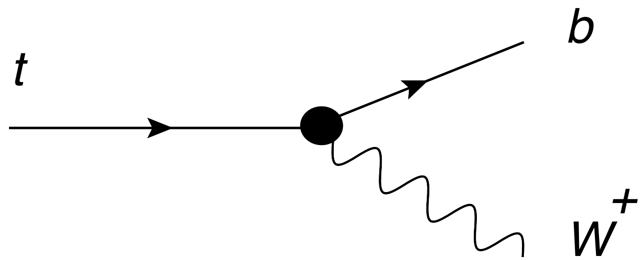

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Tree level SM: $f_L = 0$ $f_R = 0$ $g_L = 0$ $g_R = 0$

Top quark tensor couplings

WHAT

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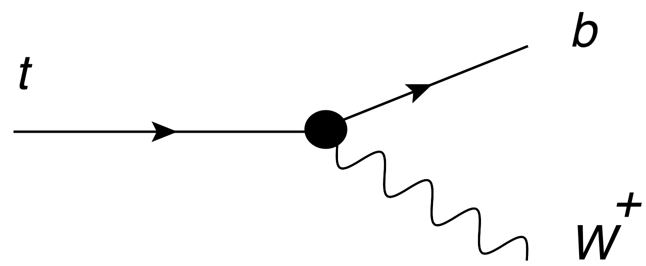

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Loop induced SM: $f_L \neq 0$ $f_R \neq 0$ $g_L \neq 0$ $g_R \neq 0$

Top quark tensor couplings

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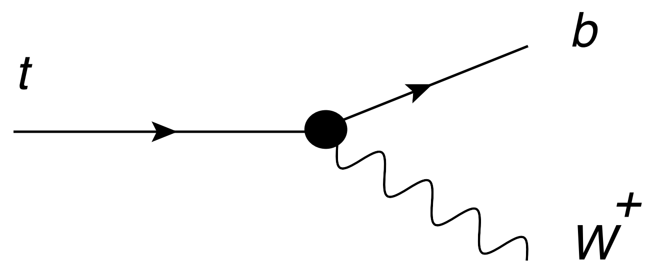

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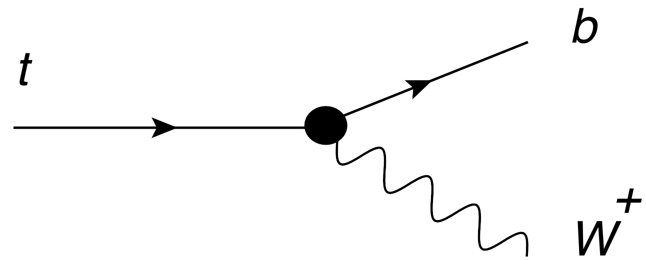
Loop induced SM: $f_L \neq 0$ $f_R \neq 0$ $g_L \neq 0$ $g_R \neq 0$

tensor/transition/anomalous/magnetic

Top quark tensor couplings

WHAT

Top decay:



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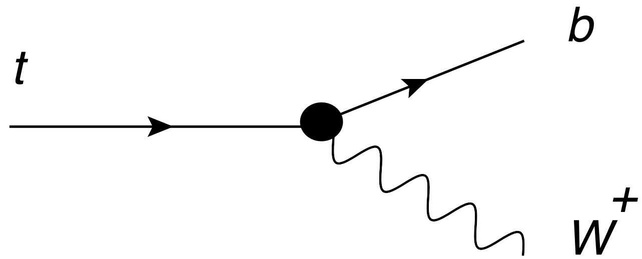
Loop induced SM: $f_L \neq 0$ $f_R \neq 0$ $g_L \neq 0$ $g_R \neq 0$

BSM: New physics contribution to be distinguished from loop induced SM ones

Top quark tensor couplings

Vertex:



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Top quark tensor couplings

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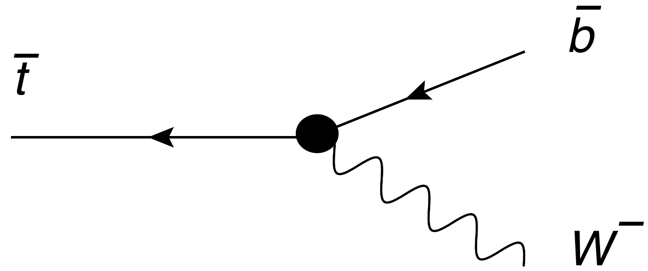

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Top quark tensor couplings

WHAT

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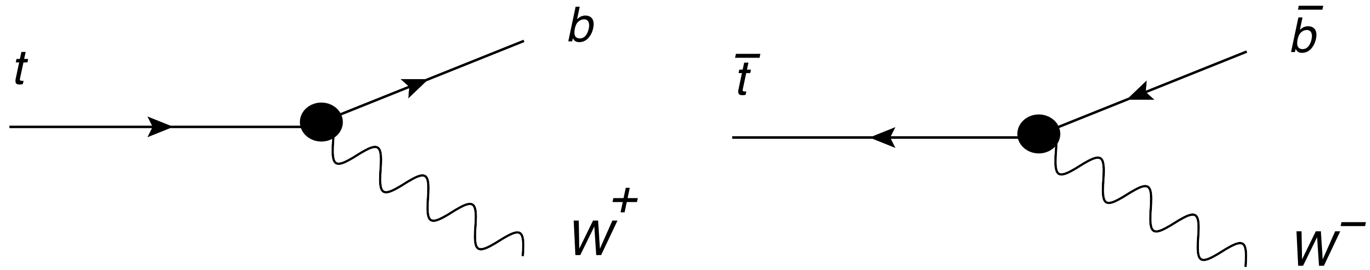

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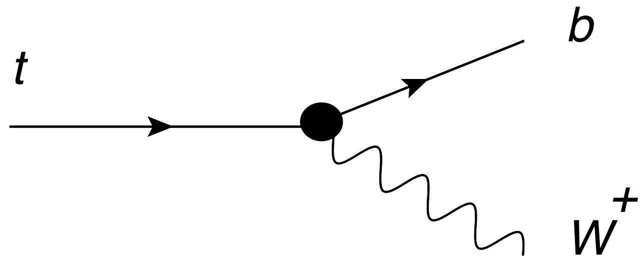
CP invariance: both L,R $f' = f$ $g' = g$

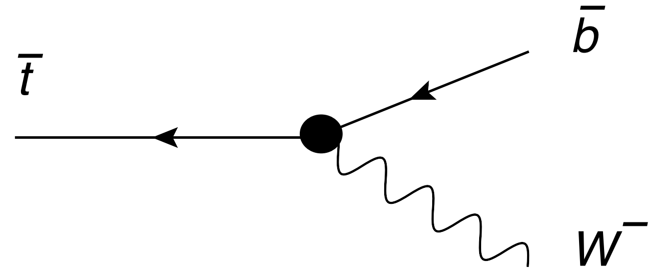
CPV induce: both L,R $Im\, f' = -\, Im\, f$ $Im\, g' = -\, Im\, g$

Top quark tensor couplings

WHAT

Vertex:





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CP invariance: both L,R $f' = f$ $g' = g$

CPV induce: both L,R $Im\, f' = -\, Im\, f$ $Im\, g' = -\, Im\, g$

CKM-induced CPV is unobservably small

Top quark tensor couplings

WHAT

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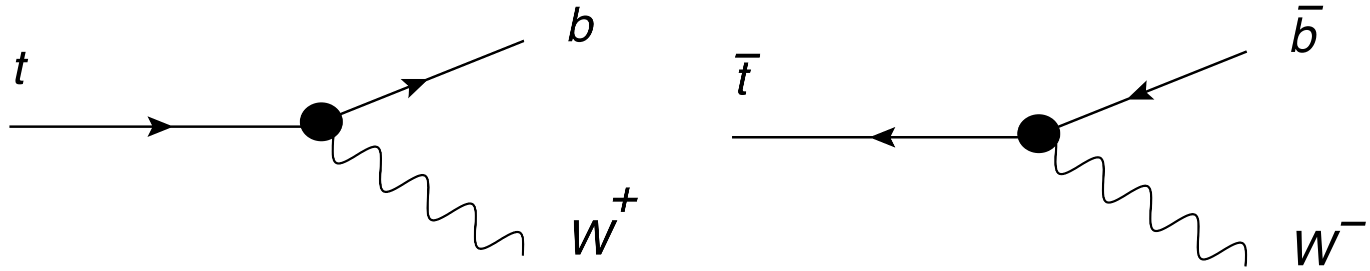

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CP invariance: both L,R $f' = f$ $g' = g$

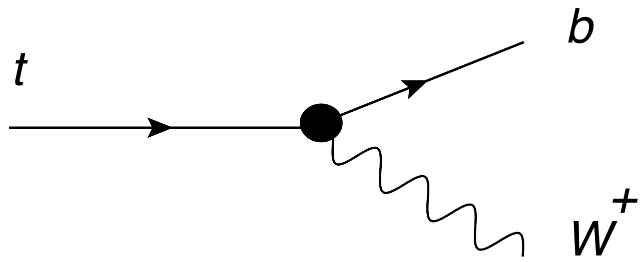
CPV induce: both L,R $\mathrm{Im}\, f' = -\,\mathrm{Im}\, f$ $\mathrm{Im}\, g' = -\,\mathrm{Im}\, g$

Absorptive parts generate $\mathrm{Im}\, g' = \mathrm{Im}\, g$

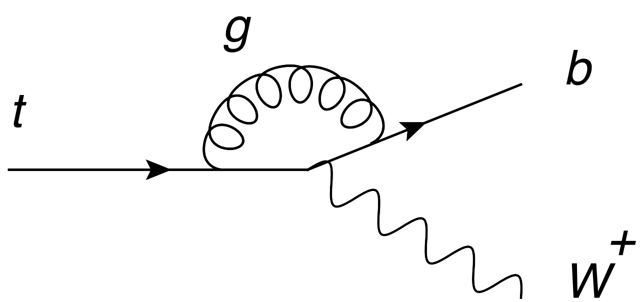
Top quark tensor couplings

WHY

SM:



One loop QCD

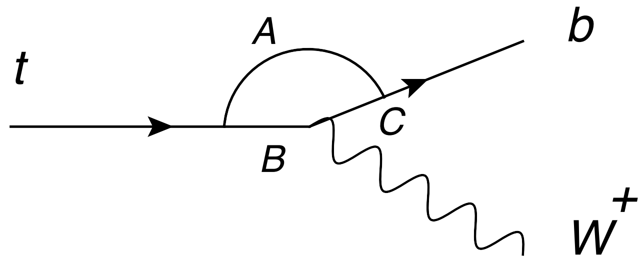


$g_R^{QCD} = -\,6.61 \times 10^{-3}$ $g_L^{QCD} = -\,1.12 \times 10^{-3}$

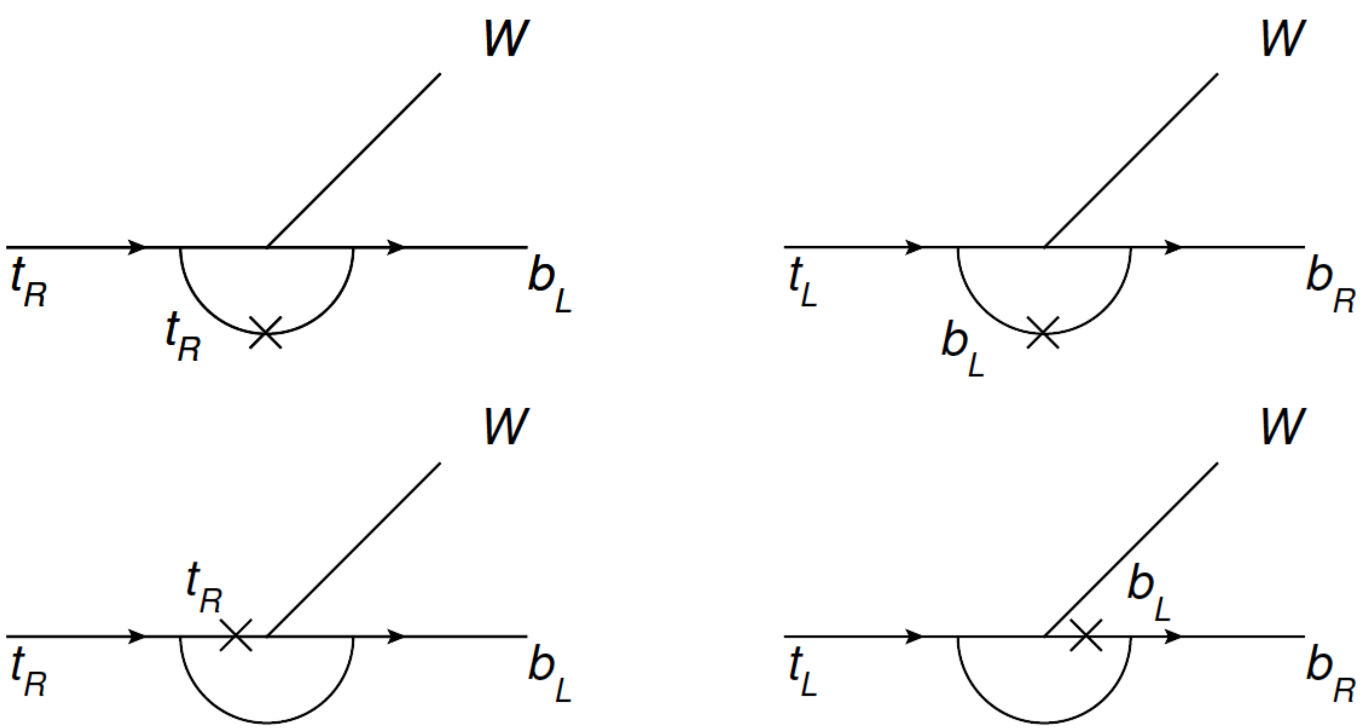
Top quark tensor couplings

WHY

One loop EW



g_R



$g_L \approx m_b$

Top quark tensor couplings

WHY

One loop EW

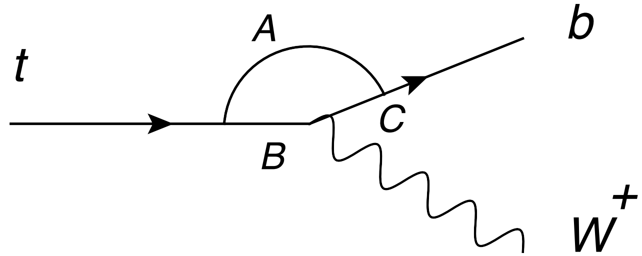
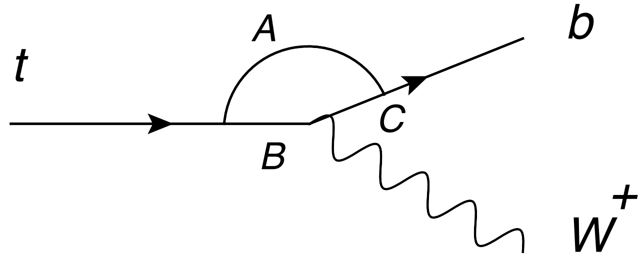


Diagram	$g_R\ \times 10^3$	$g_L\ \times 10^3$
tZW	-1.176	-0.0141
thW	0.220	0
tw^0w^-	0.344	0.0051
thw^-	0.462	-0.0088
tZw^-	-0.050	-0.0012
$t\gamma W + t\gamma w^-$	0.572	-0.0094
bWZ	$-0.623 - 0.664i$	$-0.0201 - 0.0214i$
bWh	0	$0.0086 - 0.0120i$
bw^+w^0	$(1.5 + 11.0i) \times 10^{-4}$	$-0.0029 - 0.0167i$
bw^+h	$(-4.3 + 8.6i) \times 10^{-4}$	$-0.0019 + 0.0111i$
bw^+Z	$-0.088 - 0.062i$	$-0.00039 - 0.00028i$
$bW\gamma + bw^+\gamma$	$0.114 - 0.509i$	$-0.0270 + 0.0250i$
Ztb	-0.397	-0.0067
γtb	0.068	0.0115
w^0tb	-6.8×10^{-4}	-0.0109
htb	-6.2×10^{-4}	-0.0135
$\Sigma(EW)$	$-0.56 - 1.23i$	$-(0.092 + 0.014i)$
g t b	-6.61	-1.12
Total	$-7.17 - 1.23i$	$-1.212 - 0.014i$

Top quark tensor couplings

WHY

One loop EW



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Top quark tensor couplings

WHY

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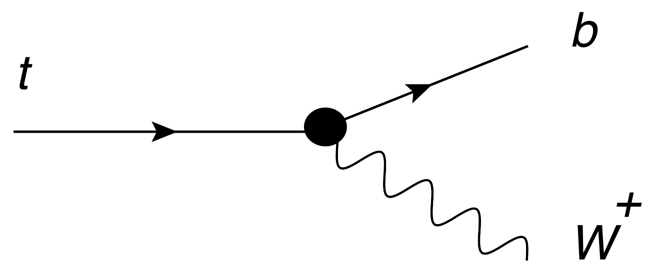
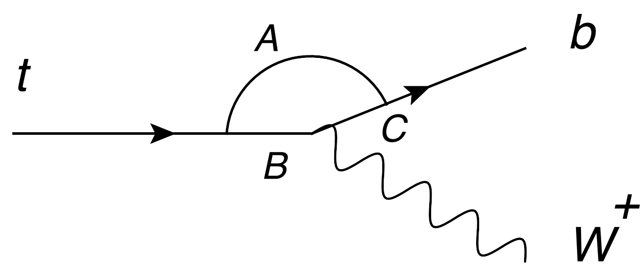


One loop EW



$$g_R^{EW} = -(0.56 + 1.23\, i) \times 10^{-3} \qquad g_L^{EW} = -(0.92 + 0.14\, i) \times 10^{-4}$$

G.A.González-Sprinberg, R.Martínez and J.Vidal, JHEP 1107 (2011) 094.

Top quark tensor couplings

WHY

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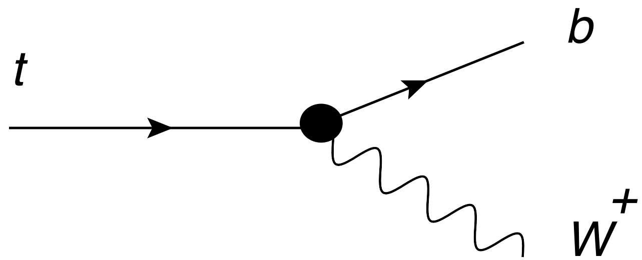

One loop QCD

$g_R^{QCD} = -\,6.61 \times 10^{-3}$

$g_L^{QCD} = -\,1.12 \times 10^{-3}$

One loop EW

$g_R^{EW} = -\,(\,0.56 + 1.23\,i\,) \times 10^{-3}$

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Top quark tensor couplings

WHY

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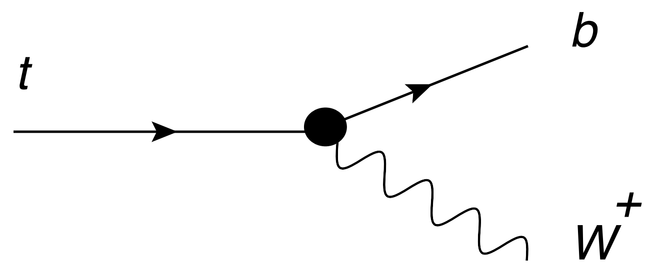

One loop QCD

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One loop EW

10 %

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Top quark tensor couplings

WHY

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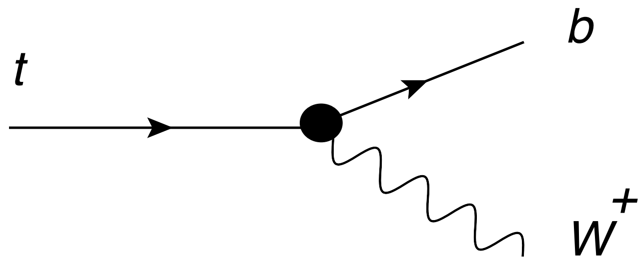

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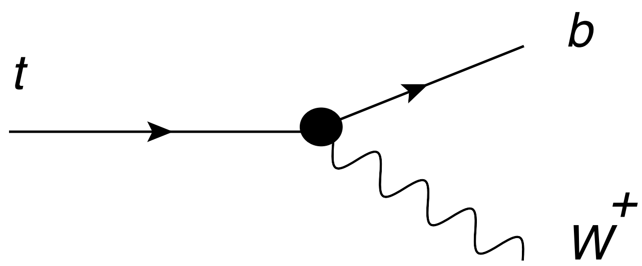
Top quark tensor couplings

WHY

SM:



One loop SM

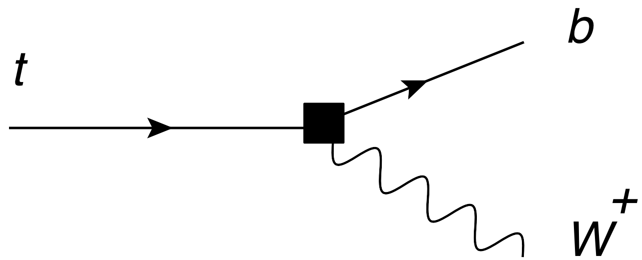
$$g_R^{SM} = g_R^{QCD} + g_R^{EW} = -(7.17 + 1.23\, i) \times 10^{-3}$$

$$g_L^{SM} = g_L^{QCD} + g_L^{EW} = -(1.21 + 0.01\, i) \times 10^{-3}$$

Top quark tensor couplings

WHY

BSM:



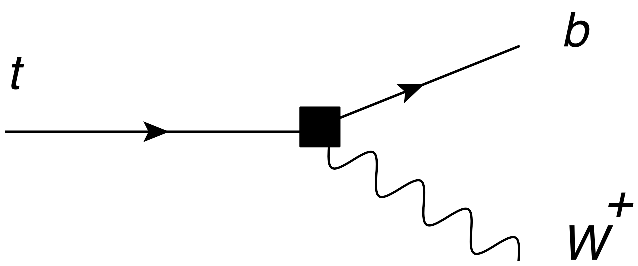
- tree level (f_L , f_R) and/or loop induced contributions (g_L , g_R)
- new CP-odd interactions may contribute
- real and imaginary parts may show up

Top quark tensor couplings

WHY

W.Bernreuther etal 2009 EPJC60

BSM:



General type-II 2HDM

Higgs potencial CP-even

Generic features

$| g_R | >> | g_L |$ (flow of chirality)

$|Re\, g_R | >> | Im\, g_R |$ (only 2/7 diagrames)

Top quark tensor couplings

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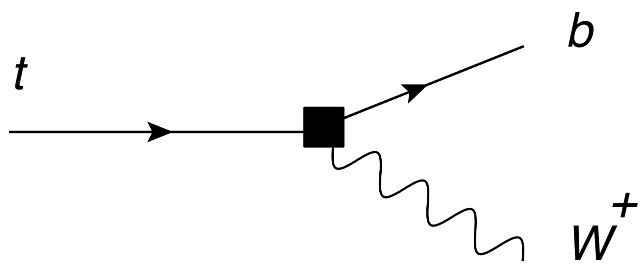
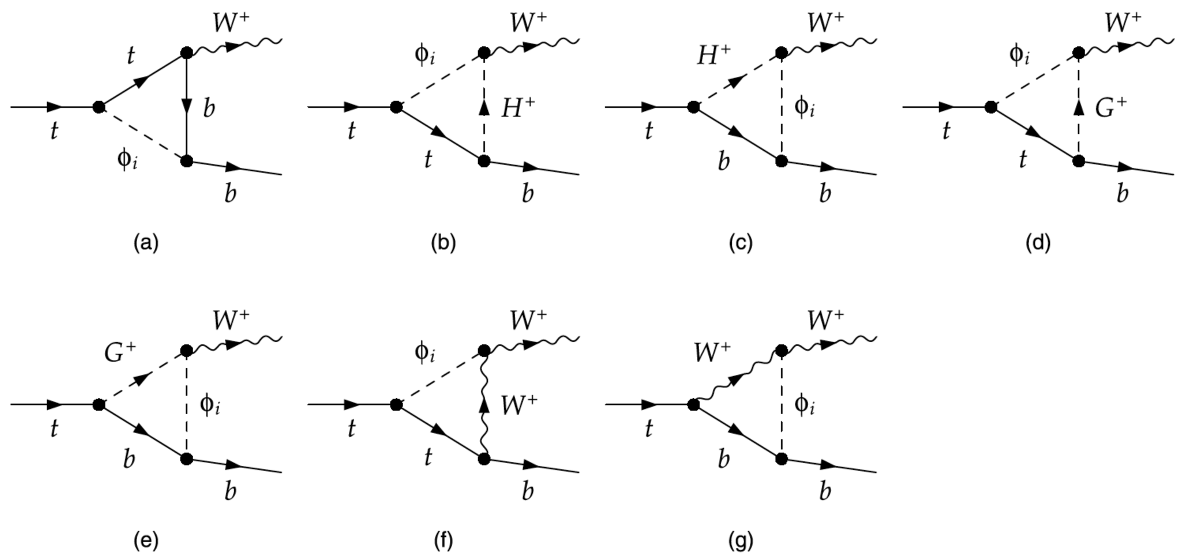


General type-II 2HDM

Higgs potential CP-even



Top quark tensor couplings

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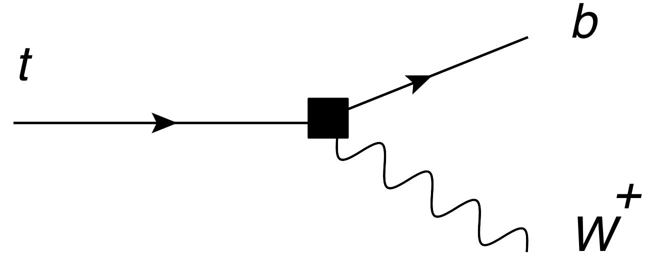

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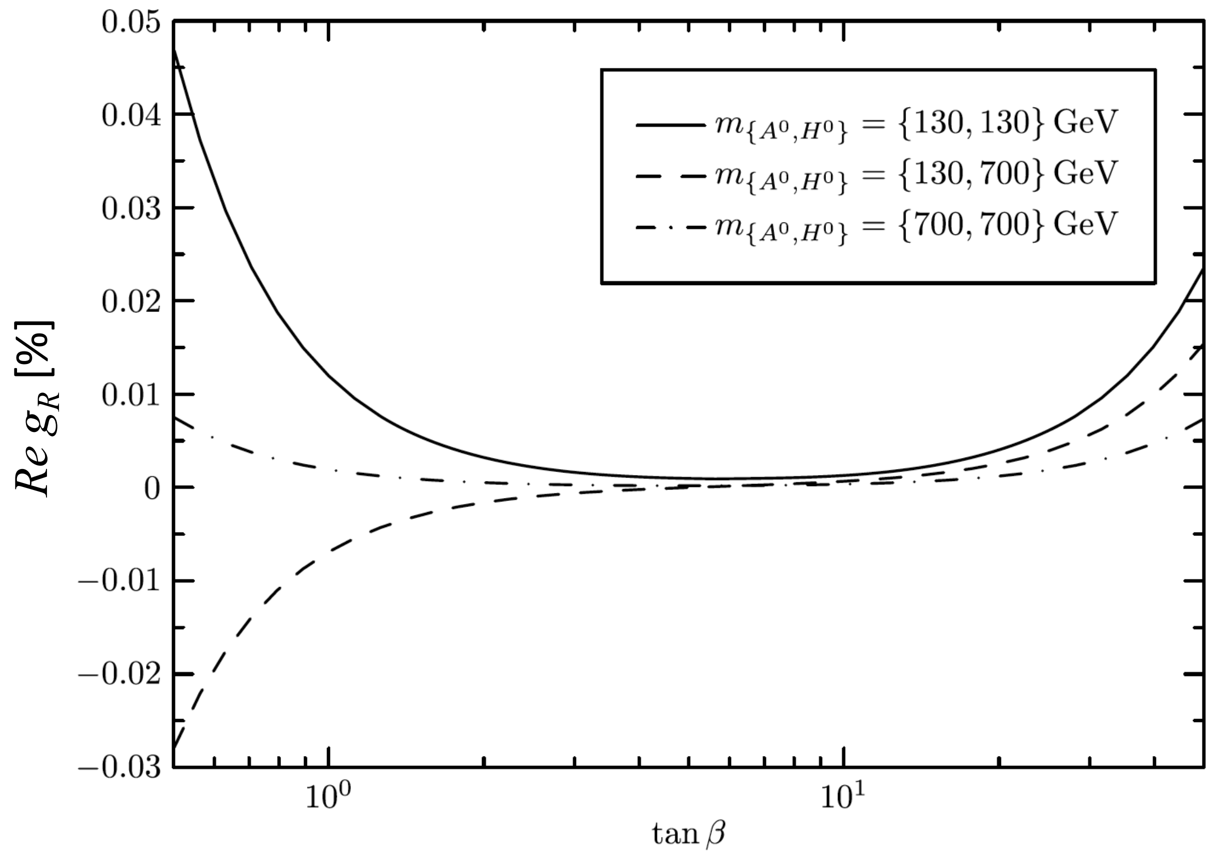

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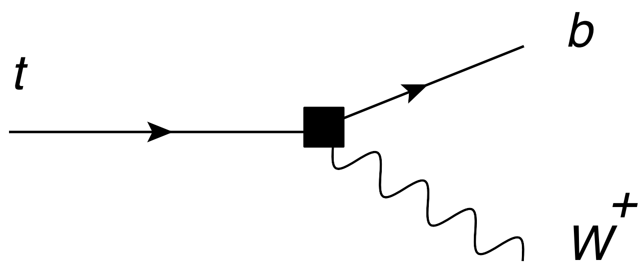
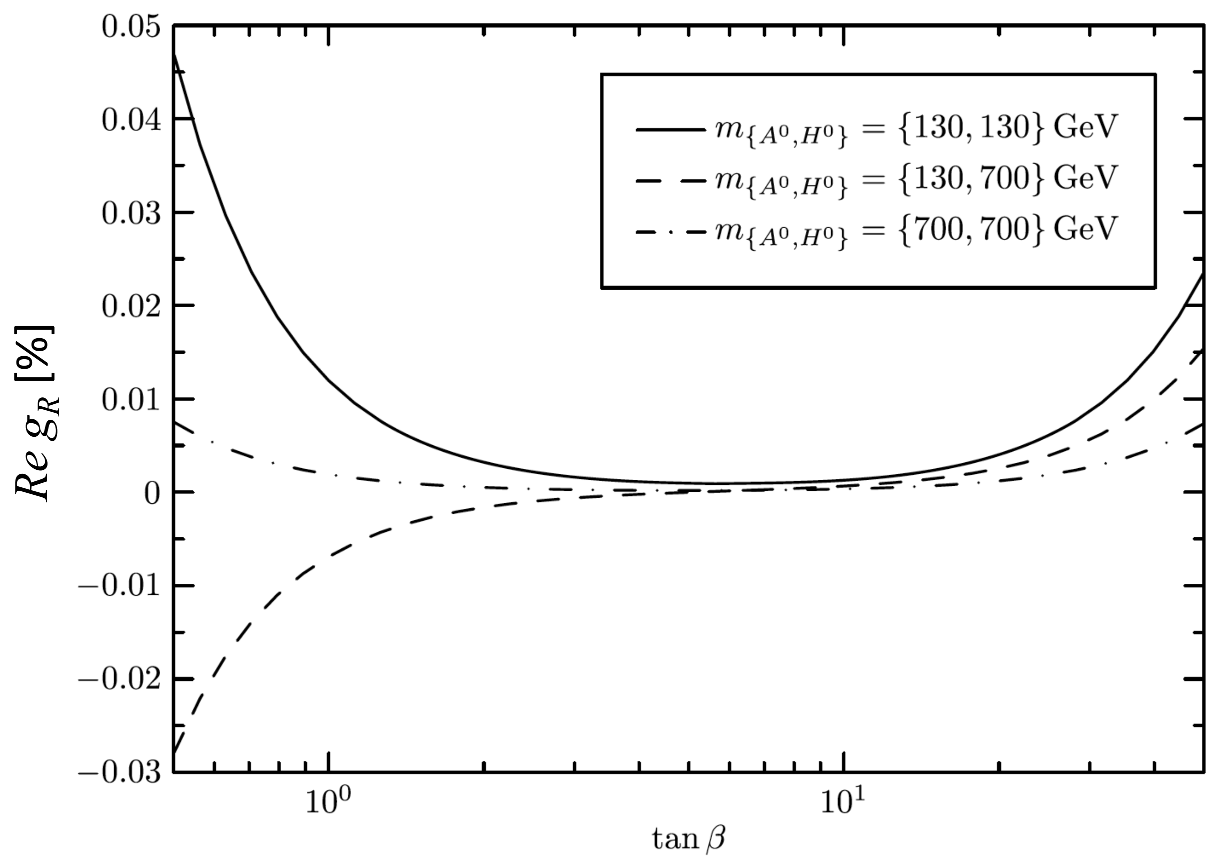


General type-II 2HDM

Higgs potential CP-even

CP-odd potential:

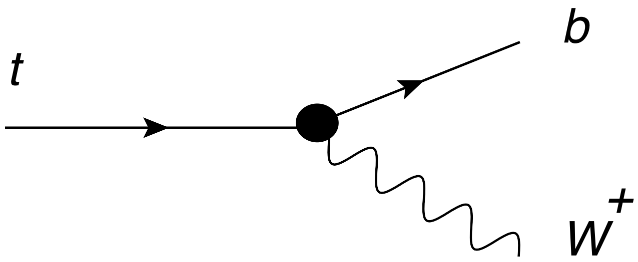
$| Im\, g_R | < 3.5 \times 10^{-4}$



Top quark tensor couplings

HOW

Observables:



- Top width Γ_t (not particular sensitivity to tensor couplings)
- $b \longrightarrow s\gamma$ in $Br(\overline{B} \longrightarrow X_s\ \gamma)$ (indirect limit, m_t/m_b enhancement for g_L)
- branching fractions $Br(t \longrightarrow b\ W_\lambda^+)$ for polarized W
- angular asymmetries
- single Top production cross section
- normal and transverse W polarization fractions

F. del Águila and J.A.Aguilar-Saavedra 2003 Phys.Rev. D67 014009

J.A. Aguilar-Saavedra etal since 2003

B. Grzadkowski and M.Misiak 2008 Phys.Rev. D78 077501, Erratum-ibid. D84 (2011) 059903

J.A.Aguilar-Saavedra and J.Bernabéu 2010 Nucl.Phys. B840 349-378

……

Top quark tensor couplings

HOW

- W helicity fractions for the Top decay $F_i = \Gamma_i / \Gamma$, $i = +, 0, -$

$\Gamma = \Gamma_0 + \Gamma_+ + \Gamma_-$ (NNLO QCD)

- Top decay asymmetries

$$A_\pm = \frac{N(\cos\theta^*_\ell > z_\pm) - N(\cos\theta^*_\ell < z_\pm)}{N(\cos\theta^*_\ell > z_\pm) + N(\cos\theta^*_\ell < z_\pm)}$$

θ^*_ℓ angle between the charged lepton momentum in the W rest frame and the W momentum in the Top quark rest frame

$z^\pm = \pm(1 - 2^{2/3})$ good choice

(f_L, f_R dependence cancelled)

Top quark tensor couplings

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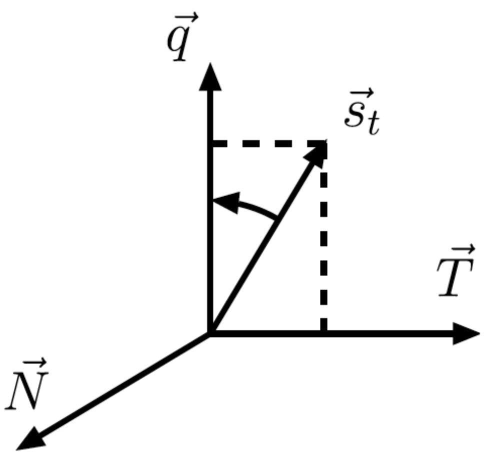
Top polarized decays: new asymmetries for normal and transverse W polarization.



New sets of polarized partial widths

Γ_i^{T} and Γ_i^{N} for i= +, 0, −.

$\Gamma_-^{N} \neq \Gamma_+^{N}$ for CPV in the $t \longrightarrow bW$ decay

$$P_t = \frac{N_\uparrow - N_\downarrow}{N_\uparrow + N_\downarrow}$$

$$A_z = \frac{N(\cos\theta > z) - N(\cos\theta < z)}{N(\cos\theta > z) + N(\cos\theta < z)}$$

$z = 0$

$$\boxed{A_{\mathrm{FB}}^{T,N} = \frac{3}{4} P \left[F_+^{T,N} - F_-^{T,N} \right]}$$

$$A_{\mathrm{FB}}^{N} \approx Im\, g_R$$

Top quark tensor couplings

WHERE

(assuming real couplings)

J.A.Aguilar-Saavedra etal Phys.Rev. D83 (2011) 117301

Early LHC data and Tevatron:

- Helicity fractions at Tevatron
- Single top production measured @ CMS
- Top decay asymmetries measured in ATLAS

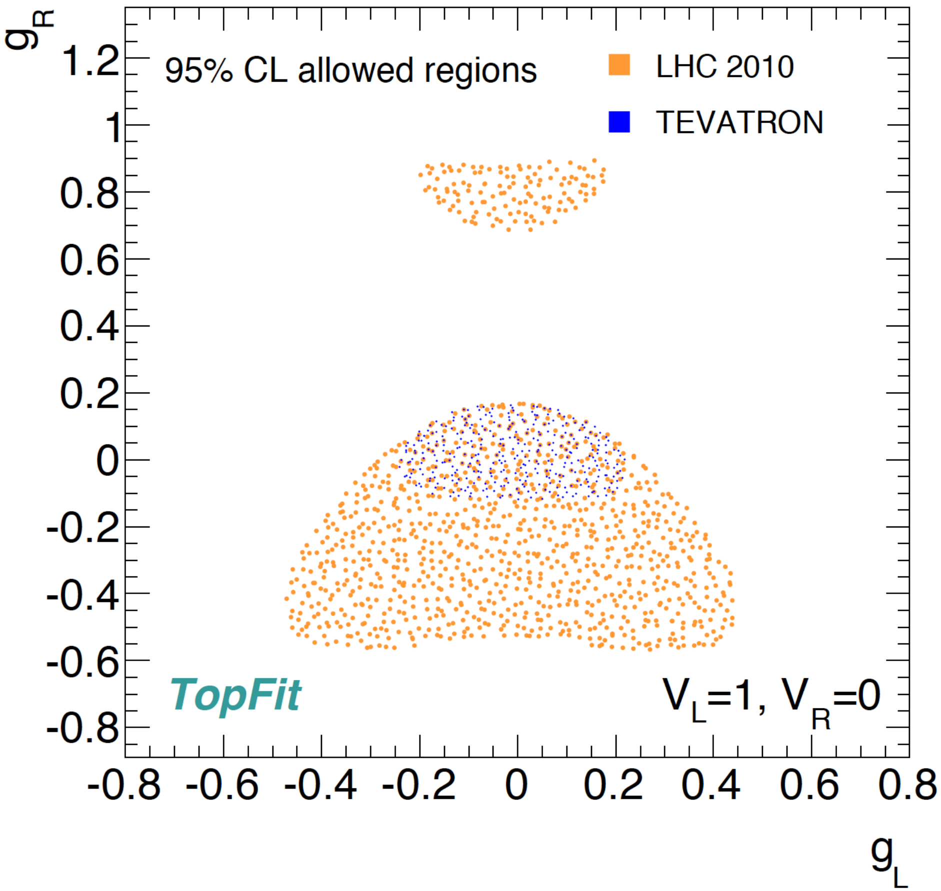
(2010 data, 35 pb^{-1})

Top quark tensor couplings

WHERE

(assuming real couplings)

J.A.Aguilar-Saavedra etal Phys.Rev. D83 (2011) 117301

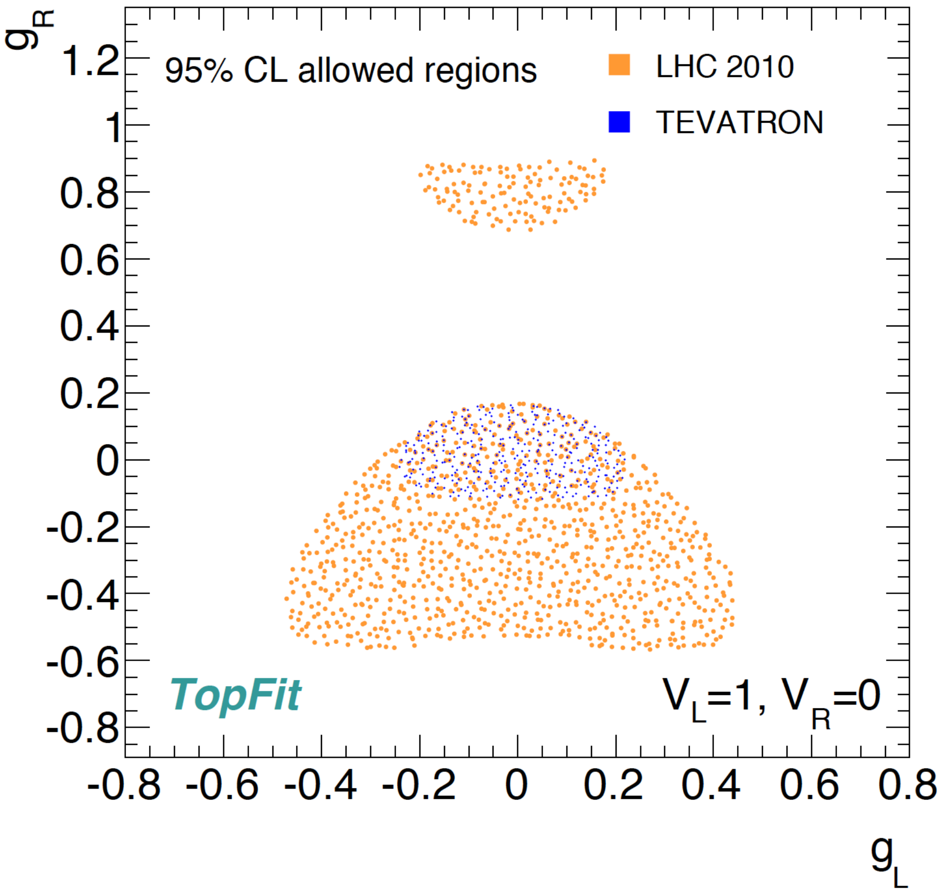


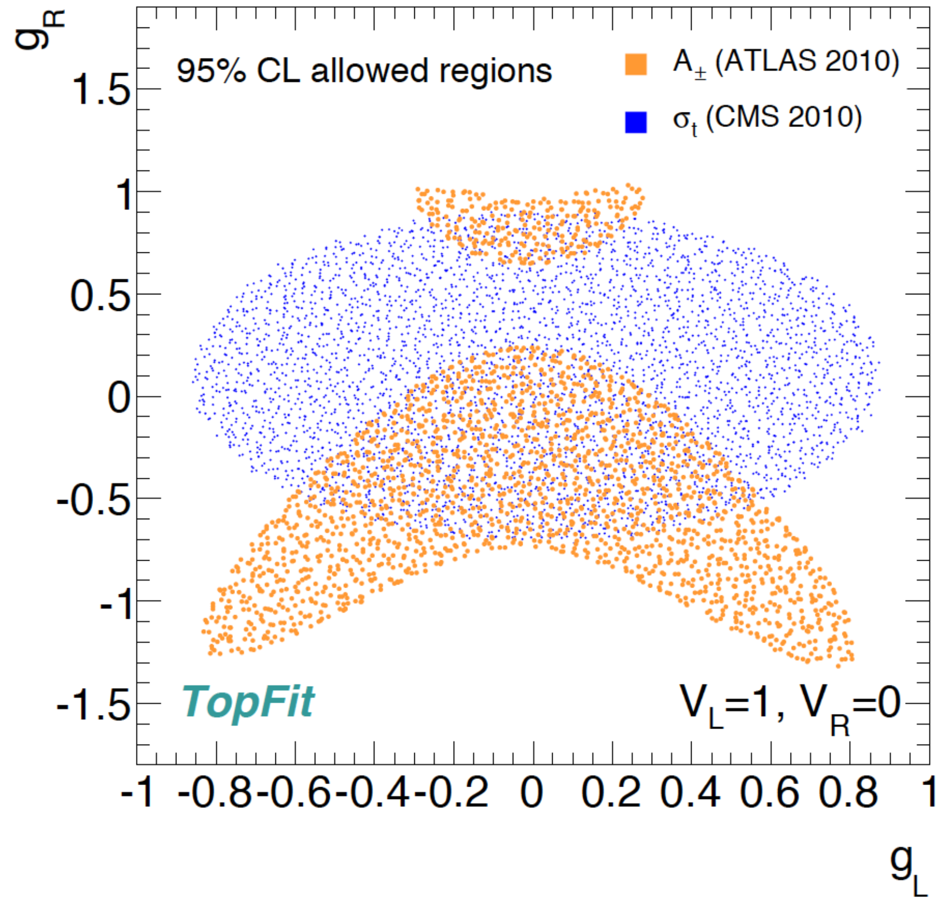
Top quark tensor couplings

WHERE

(assuming real couplings)

J.A.Aguilar-Saavedra etal Phys.Rev. D83 (2011) 117301

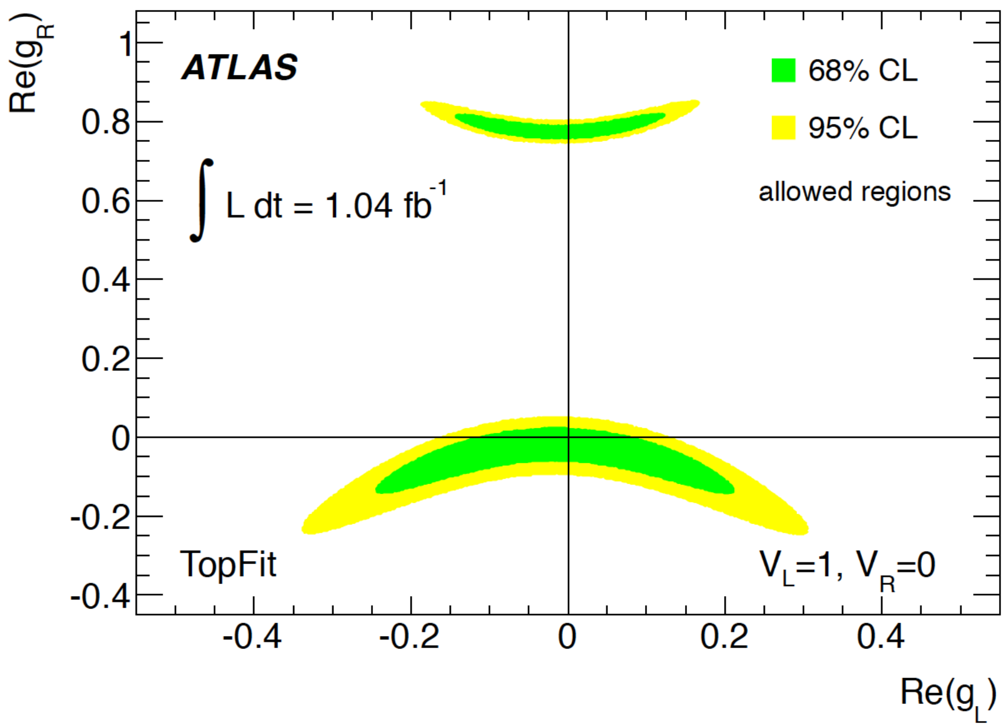




Top quark tensor couplings

ATLAS hep-ph/1205.2484

1.04 fb^{-1} single and dilepton channel, March-June 2011, 95% CL



$$\mathrm{Re}\,(g_\mathrm{L}) \in [-0.14, 0.11]$$

$$\mathrm{Re}\,(g_\mathrm{R}) \in [-0.08, 0.04]$$

Top quark tensor couplings

WHERE

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	Reference		g_R bound	g_L bound
$b \longrightarrow s\gamma$	[22]	95%C.L.	$-0.15 < g_R < 0.57$	-0.00[illegible]$ < g_L < 0.0004$
ATLAS	[15]	2σ	$-0.026 \leq g_R \leq$ [illegible]	$-0.058 \leq g_L \leq 0.026$
Single Top	[9]	1σ	$-0.012 \leq g_R \leq 0.024$	$-0.16 \leq g_L \leq 0.16$
			g_R discovery limit	g_L discovery limit
Aguilar-S. Bernabéu $\longrightarrow$	[16]	3σ	$\lvert Re(g_R)\rvert \geq 0.056$	$Re(g_L) \geq 0.051$ or $Re(g_L) \leq -0.083$
			$\lvert Im(g_R)\rvert \geq$ [illegible]	$\lvert Im(g_L)\rvert \geq 0.065$
$\longrightarrow$	[16, 22]	3σ	$Re(g_R) \geq 0.76$ or $Re(g_R) \leq -0.33$	$Re(g_L) \geq 0.0009$ or $Re(g_L) \leq -0.0019$
				$\lvert Im(g_L)\rvert \geq 0.006$

Table 1. Bounds on g_R and g_L. The first line shows the indirect limits from $b \to s\gamma$. The second and third lines are limits obtained from simulations for the LHC. The last two lines show 3 σ discovery limits intervals: fourth line limits are from simulations for the LHC and the last one is from $b \to s\gamma$.

One coupling ≠ 0 at a time

Either real or imaginary

10 fb^{-1} at 14 TeV

Top quark tensor couplings

WHERE

J.A.Aguilar-Saavedra and J.Bernabéu 2010 Nucl.Phys. B840 349-378

	Reference		g_R bound	g_L bound
b $\rightarrow$ s γ	[22]	95%C.L.	$-0.15 < g_R < 0.57$	$-0.0015 < g_L < 0.0004$
ATLAS	[15]	2σ	$-0.026 \leq g_R \leq 0.031$	$-0.058 \leq g_L \leq 0.026$
Single Top	[9]	1σ	$-0.012 \leq g_R \leq 0.024$	$-0.16 \leq g_L \leq 0.16$
			g_R discovery limit	g_L discovery limit
LHC	[16]	3σ	$\lvert Re(g_R)\rvert \geq 0.056$	$Re(g_L) \geq 0.051$ or $Re(g_L) \leq -0.083$
			$\lvert Im(g_R)\rvert \geq 0.115$	$\lvert Im(g_L)\rvert \geq 0.065$
Aguilar-S. Bernabéu	[16, 22]	3σ	$Re(g_R) \geq 0.76$ or $Re(g_R) \leq -0.33$	$Re(g_L) \geq 0.0009$ or $Re(g_L) \leq -0.0019$
b $\rightarrow$ s γ				$\lvert Im(g_L)\rvert \geq 0.006$

Table 1. Bounds on g_R and g_L. The first line shows the indirect limits from $b \to s\gamma$. The second and third lines are limits obtained from simulations for the LHC. The last two lines show 3 σ discovery limits intervals: fourth line limits are from simulations for the LHC and the last one is from $b \to s\gamma$.

Top quark tensor couplings

WHERE

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-0.0013

b → s γ

ATLAS

Single Top

LHC →

Aguilar-S. Bernabéu →

b → s γ

Reference		g_R bound	g_L bound
[22]	95%C.L.	$-0.15 < g_R < 0.57$	$\cancel{-0.0015} < g_L < 0.0004$
[15]	2σ	$-0.026 \leq g_R \leq 0.031$	$-0.058 \leq g_L \leq 0.026$
[9]	1σ	$-0.012 \leq g_R \leq 0.024$	$-0.16 \leq g_L \leq 0.16$
		g_R discovery limit	g_L discovery limit
[16]	3σ	$\lvert Re(g_R)\rvert \geq 0.056$	$Re(g_L) \geq 0.051$ or $Re(g_L) \leq -0.083$
		$\lvert Im(g_R)\rvert \geq 0.115$	$\lvert Im(g_L)\rvert \geq 0.065$
[16, 22]	3σ	$Re(g_R) \geq 0.76$ or $Re(g_R) \leq -0.33$	$Re(g_L) \geq 0.0009$ or $Re(g_L) \leq -0.0019$
			$\lvert Im(g_L)\rvert \geq 0.006$

SM:
- 0.0012 !

Table 1. Bounds on g_R and g_L. The first line shows the indirect limits from $b \to s\gamma$. The second and third lines are limits obtained from simulations for the LHC. The last two lines show 3 σ discovery limits intervals: fourth line limits are from simulations for the LHC and the last one is from $b \to s\gamma$.

Top quark tensor couplings

WHEN

Summary

- SM predictions for g_R and g_L computed up to one loop
- Im g_R and Re g_L same order of magnitude
- SM predictions still to be measured
- SM Re g_L very close to 3σ limits from $b \longrightarrow s\,\gamma$
- BSM quite below sensitivity of expected measurements limits
- Work on progress…

  CPV in general 2HDM

  New accelerators bounds and observables

Top quark tensor couplings

CODA

Many thanks to the organizers for include my talk in the schedule

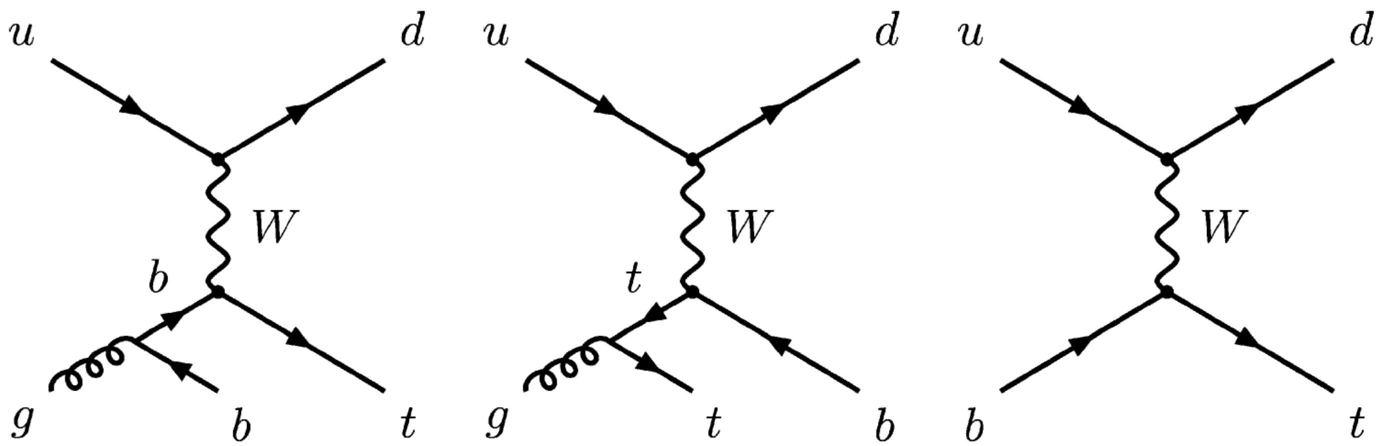
and to

Jordi Vidal
Pepe Bernabéu
Arcadi Santamaría

Top quark tensor couplings

BACKUP

Single Top t-channel, some diagrams



W, t and/or b are off-shell

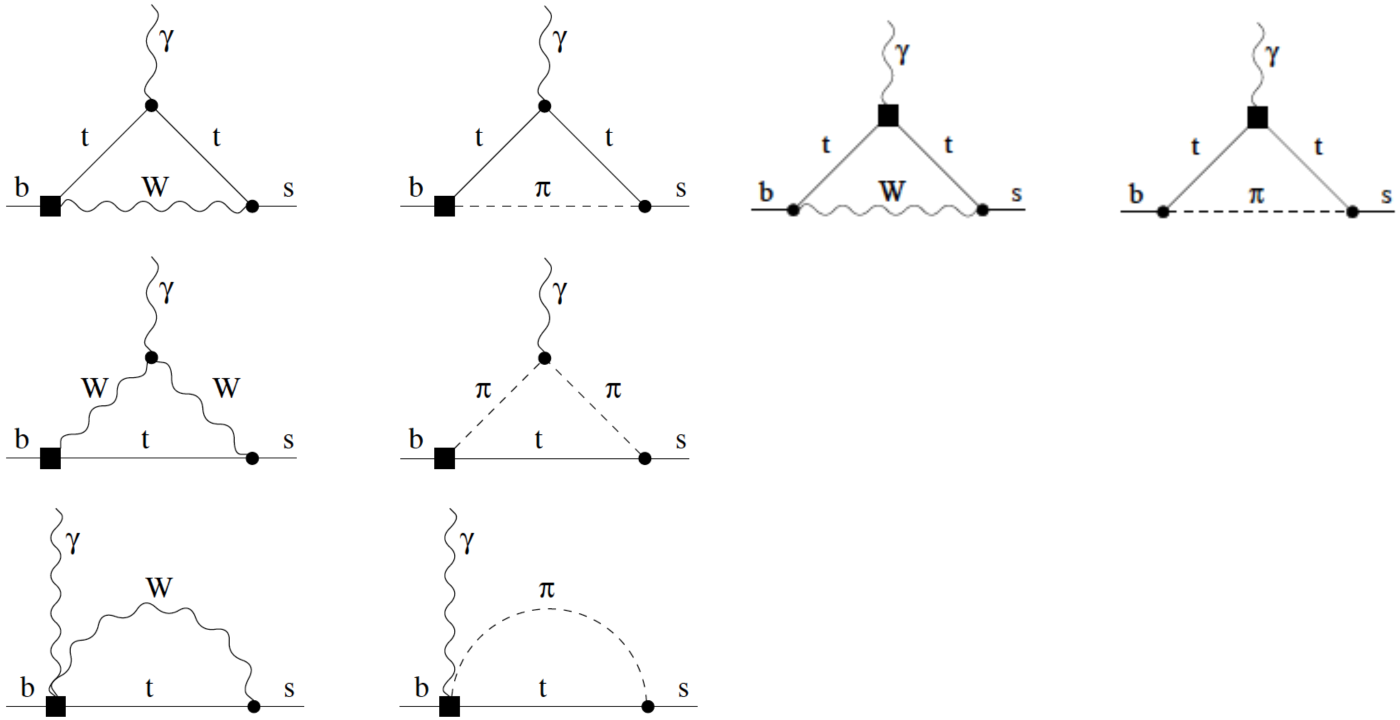
Anyway, by the magic of Gordon identities and gauge invariance, no new form factors enter into the game.

Top quark tensor couplings

BACKUP

B. Grzadkowski and M.Misiak 2008 Phys.Rev. D78 077501, Erratum-ibid. D84 (2011) 059903

$b \longrightarrow s\,\gamma$



$$
\begin{aligned}
\mathcal{B} \;=\;& (3.15 \pm 0.23) - 8.2\,\delta v_L + 427\, v_R - 837\, g_L \\
&+\; 1.9\, g_R - 8.0\, C_7^{(p)}(\mu_0) - 1.9\, C_8^{(p)}(\mu_0) \\
&+\; \mathcal{O}\left[\left(\delta v_L, v_R, g_L, g_R, C_i^{(p)}\right)^2\right].
\end{aligned}
$$