Flavour and top physics

— experimental summary —

Working Group 1

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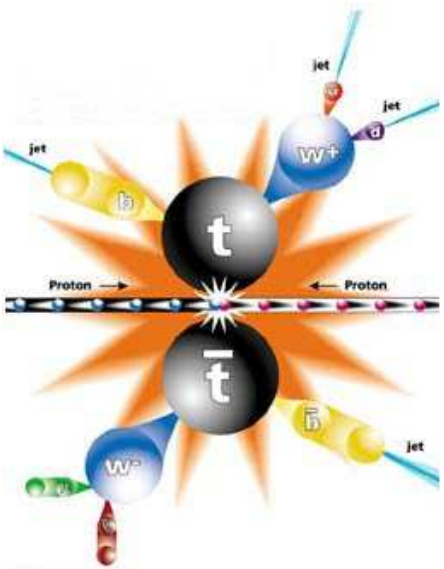


Flavour in the era of the LHC (final meeting)

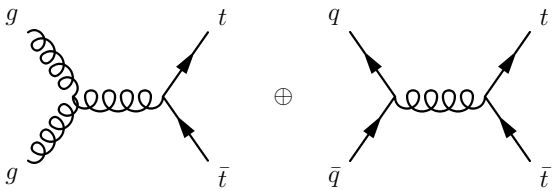
CERN, 26th March 2007

Summary

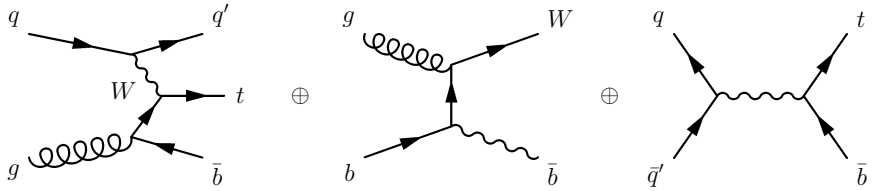
1. Motivation: flavour and top physics at LHC
2. *Wtb* vertex
   - constraints from *B*-physics (see theory summary by G. Burdman) (M. Misiak)
   - ATLAS sensitivity to *Wtb* anomalous couplings (J.A. Aguilar-Saavedra, J. Carvalho, N. Castro, A. Onofre and F. Veloso)
3. Non-standard contributions to $t\bar{t}$ production (J.A. Aguilar-Saavedra, J. Carvalho, N. Castro, A. Onofre and F. Veloso)
4. FCNC interactions
   - top quark production via strong FCNC (P. Ferreira and R. Santos)
   - LHC sensitivity to top FCNC decays (L. Benucci, J. Carvalho, N. Castro, A. Giammanco, C. Karafasoulis, A. Kyriakis, A. Onofre, F. Palla, F. Veloso and G. Vermisoglou)

Motivation: flavour and top physics at LHC

- The LHC will be a top factory



$\sigma(pp \to t\bar{t}) \sim 8 \times 10^2$ pb



$\sigma(\text{single top production}) \sim 3 \times 10^2$ pb

- $t \to bW$ is the dominant decay mode
  - $BR(t \to sW) < 0.18\%$
  - $BR(t \to dW) < 0.02\%$
- $\Gamma_t^{SM} = 1.42$ GeV (including m_b, m_W, α_s, EW corrections)
  - $\tau_t < 10^{-23}$ s $\Rightarrow$ top decays before hadronization
- Top can be a window to new flavour phenomena
  - Wtb vertex
  - $t\bar{t}$ production
  - FCNC phenomena (t production and decay)

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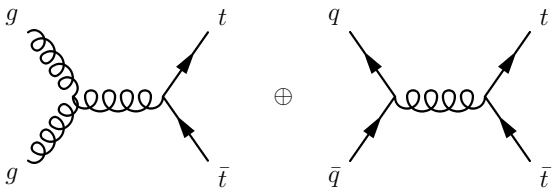

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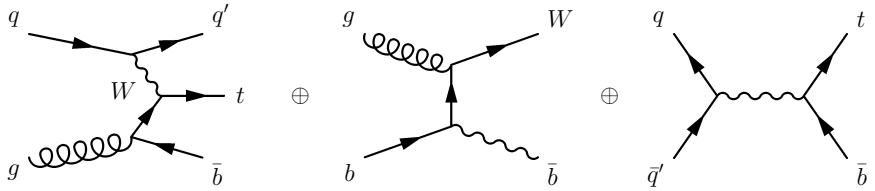

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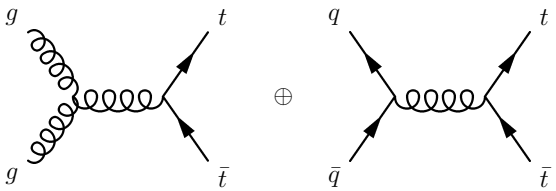

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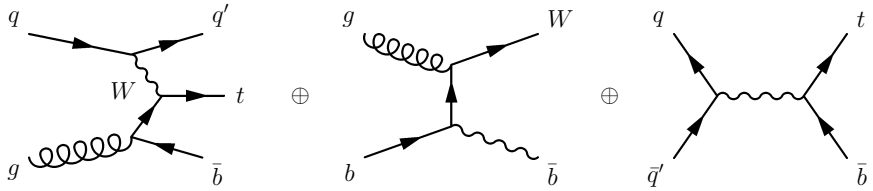

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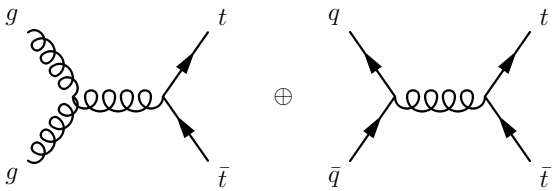

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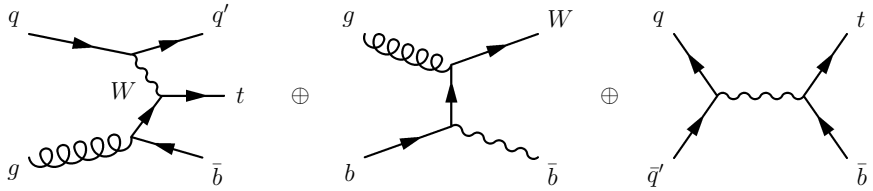

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Wtb vertex

Most general *Wtb* vertex

$$\mathcal{L} = -\frac{g}{\sqrt{2}}\bar{b}\,\gamma^{\mu}\,(V_L P_L + V_R P_R)\,t\,W_{\mu}^{-}$$
$$-\frac{g}{\sqrt{2}}\bar{b}\,\frac{i\sigma^{\mu\nu}q_{\nu}}{M_W}\,(g_L P_L + g_R P_R)\,t\,W_{\mu}^{-} + \text{h.c.}$$

$V_L \equiv V_{tb} \sim 1$ (within SM)

$V_R, g_R, g_L \Rightarrow$ anomalous couplings

How to probe *Wtb* anomalous couplings?

- constraints from B-physics
- angular distributions of the t decays:
  - in the W rest frame (helicity fractions of the W)
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Wtb vertex: constraints from *B*-physics

- experimental results from *B*-physics:

$$BR(\bar{B} \to X_s\gamma) = \left(3.55 \pm 0.24\,^{+0.09}_{-0.10} \pm 0.03\right) \times 10^{-4}$$

[hep-ex/0603003]

$\hookrightarrow$ constraints on the anomalous *Wtb* couplings

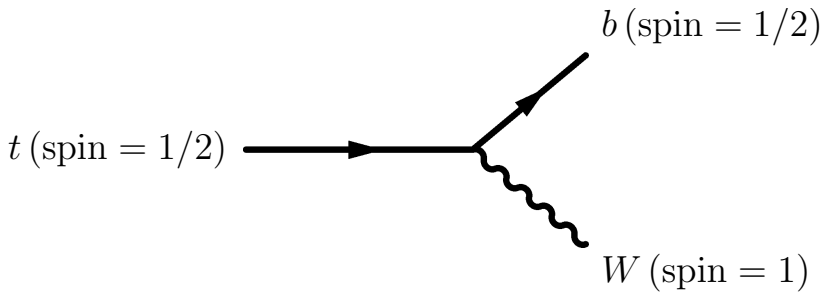
95% CL limits:

	$V_L - V_{tb}$	V_R	g_L	g_R
upper bound	**0.04**	**0.0024**	**0.003**	**0.08**
lower bound	**−0.24**	**-0.0004**	**−0.018**	**−0.46**

$\Rightarrow$ Only one coupling $\neq 0$ at a time

(see theory summary by G. Burdman)

Wtb vertex: *W* helicity fractions



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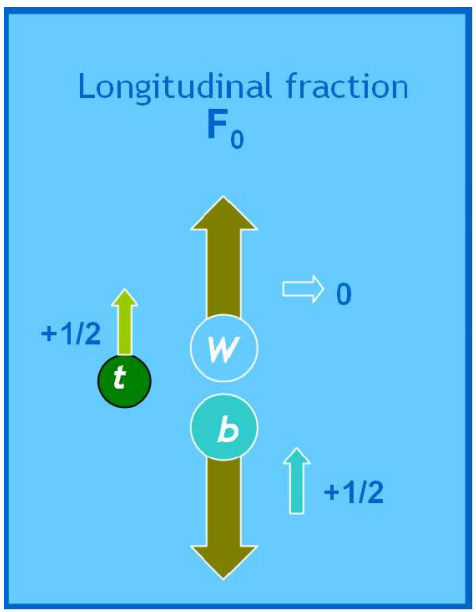
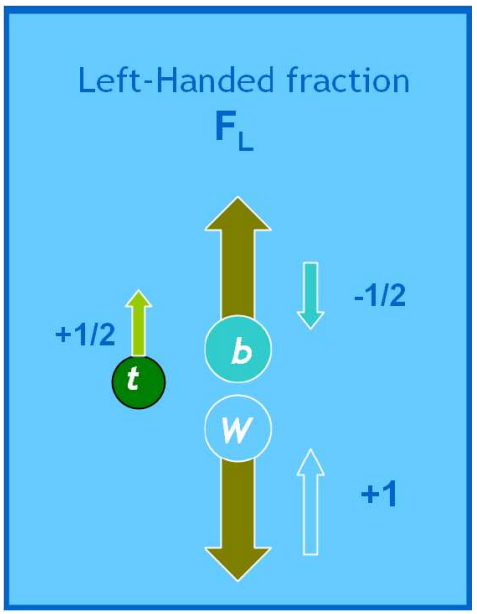
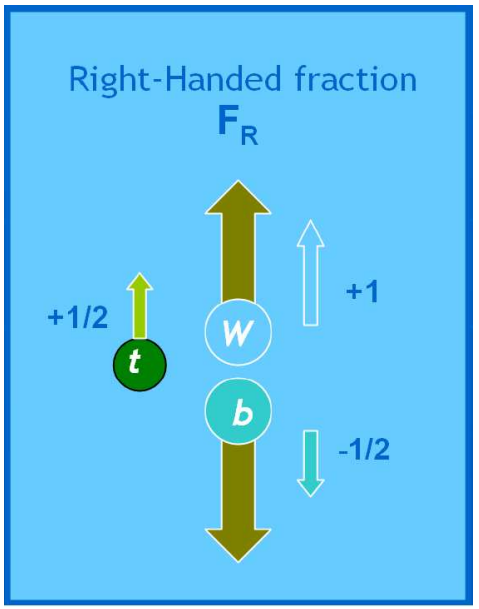




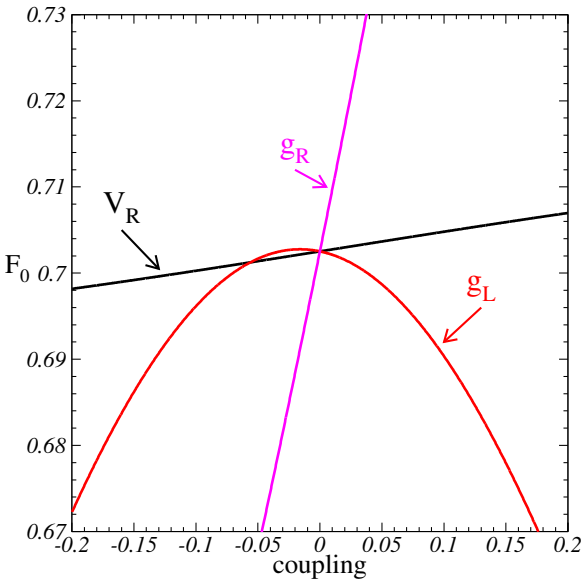


SM: $F_0 = 0.703$ $F_L = 0.297$ $F_R = 0.00036$

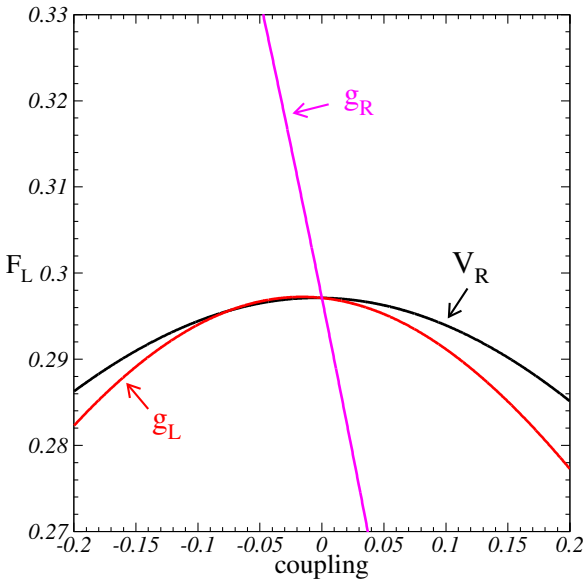
Wtb vertex: *W* helicity fractions

anomalous couplings ⇒ deviations in *W* helicity fractions

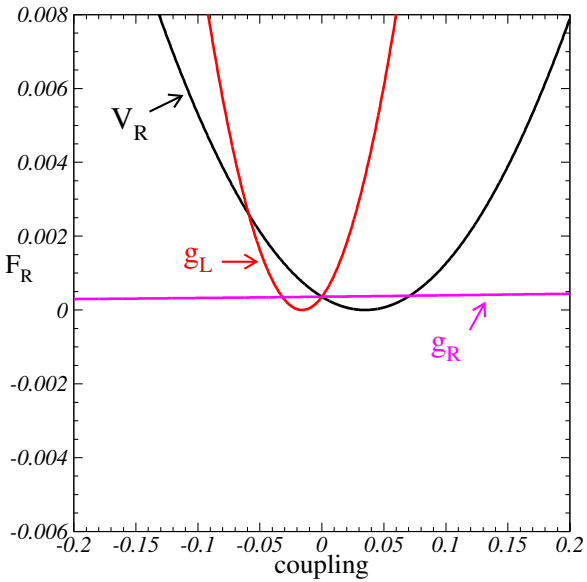
F_0



F_L



F_R



[hep-ph/0605190]

Wtb vertex: angular distributions of t decays

How to test the anomalous couplings?

- Angular distributions of t decays depend on the W polarisation (i.e. on anomalous couplings)

$t \to bW \to b\ell\nu$

W rest frame

$$\frac{1}{\Gamma}\frac{d\Gamma}{d\cos\theta_\ell^*} = \frac{3}{4}\sin^2\theta_\ell^* F_0 + \frac{3}{8}(1-\cos\theta_\ell^*)^2 F_L + \frac{3}{8}(1+\cos\theta_\ell^*)^2 F_R$$

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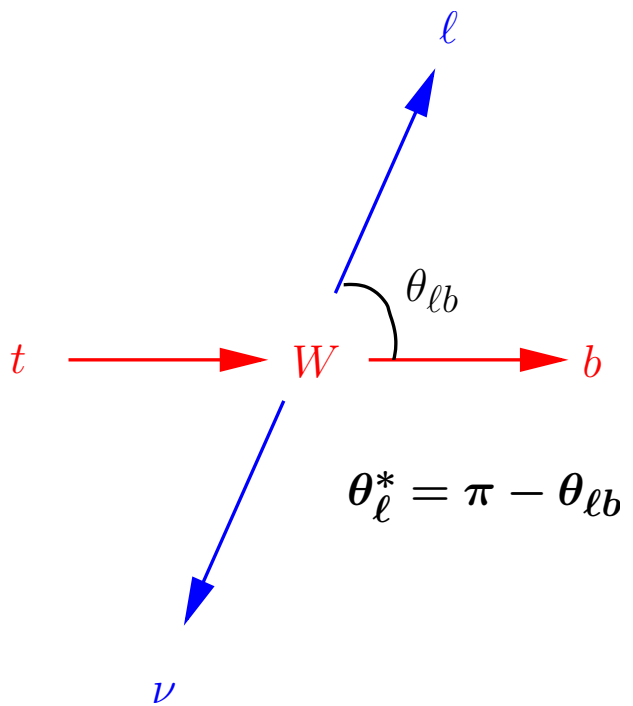

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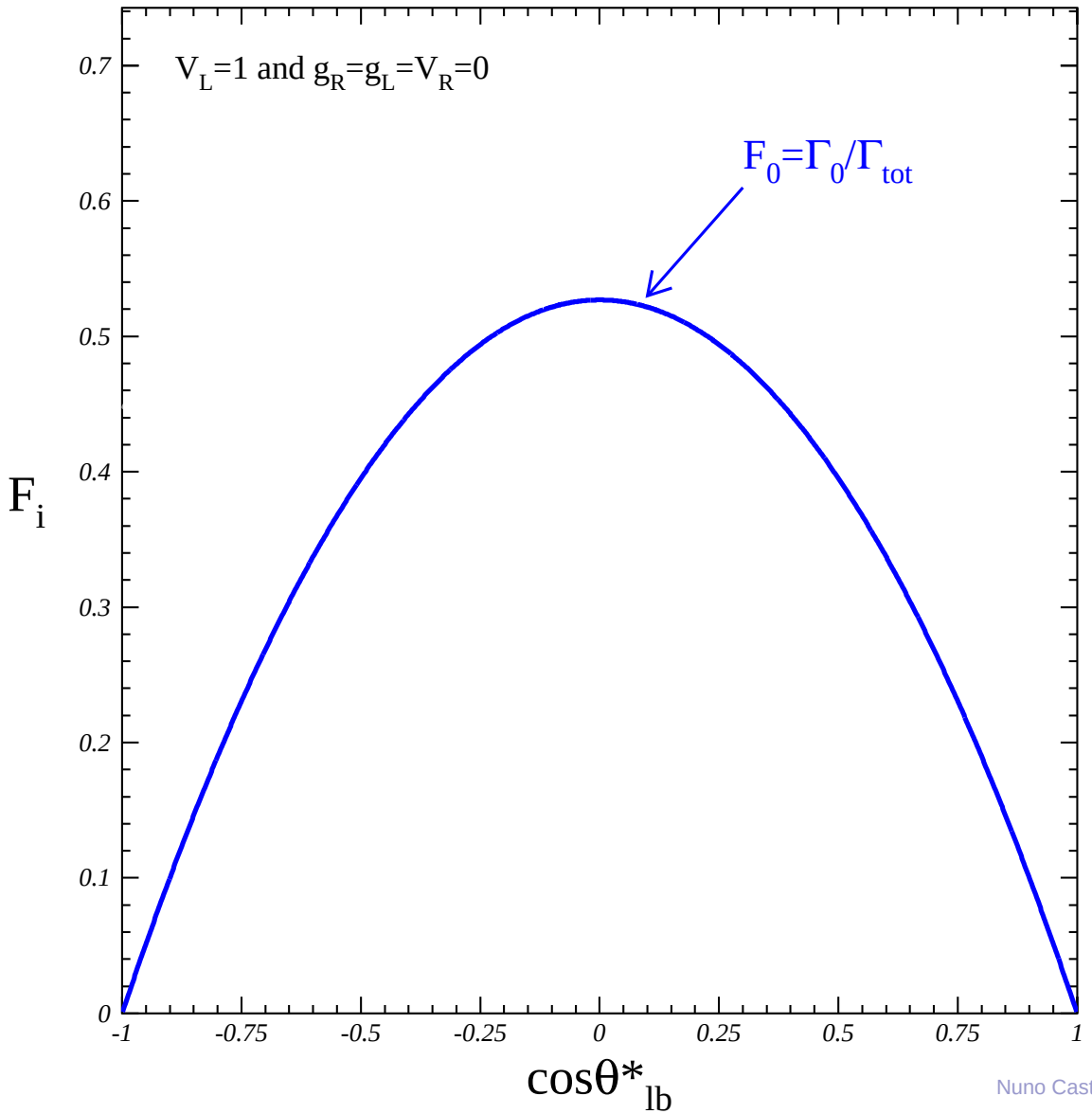

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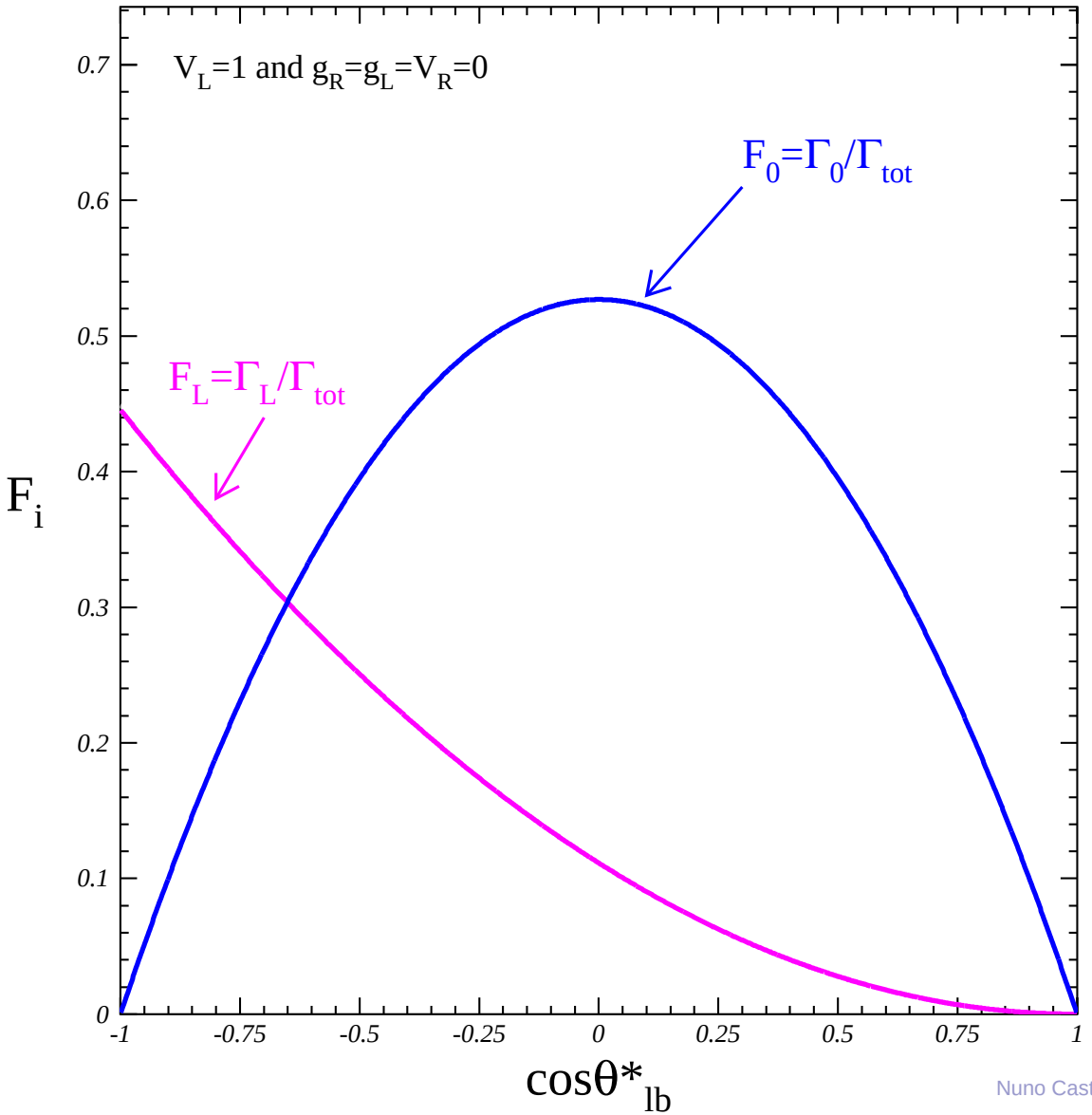

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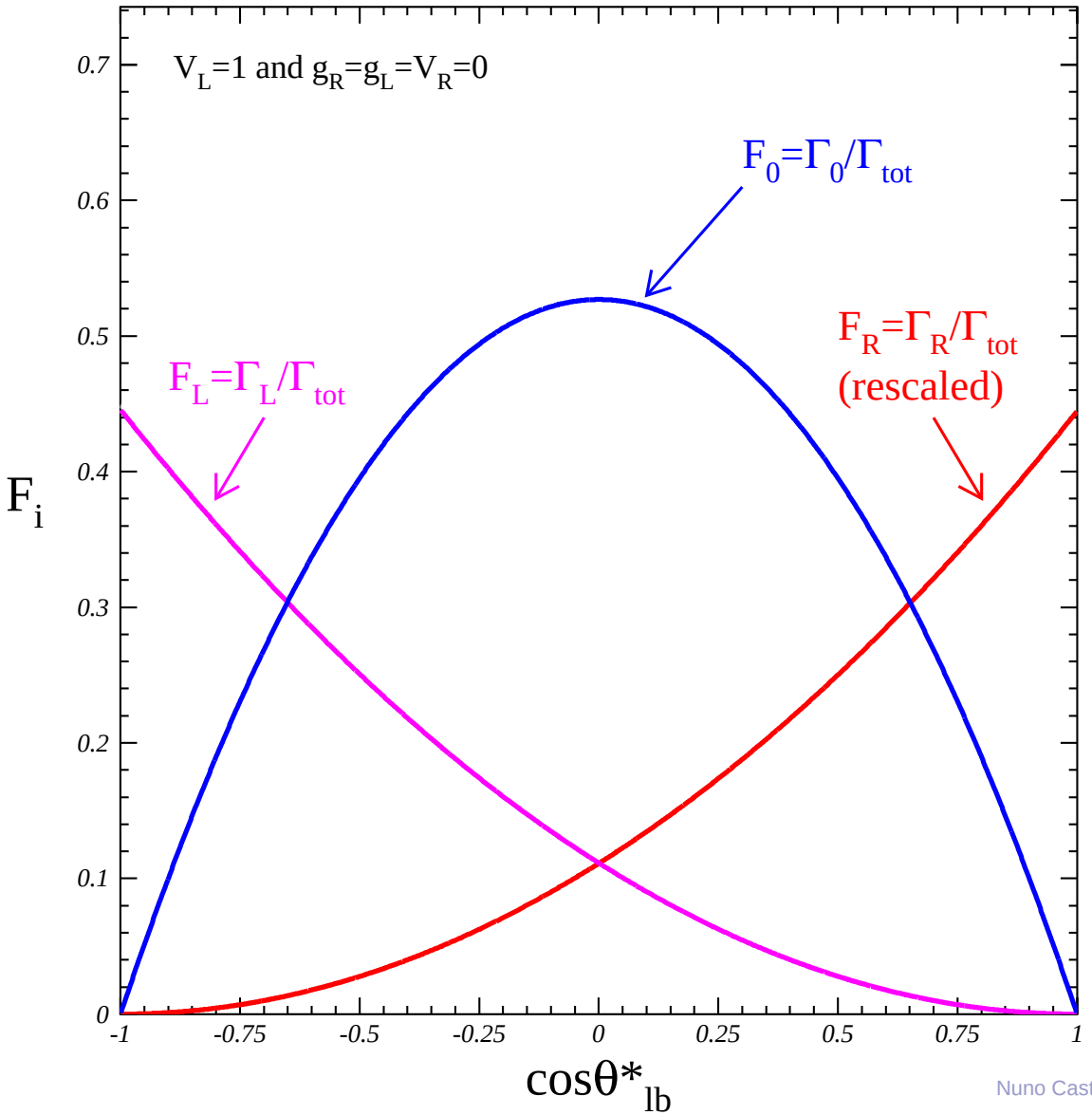

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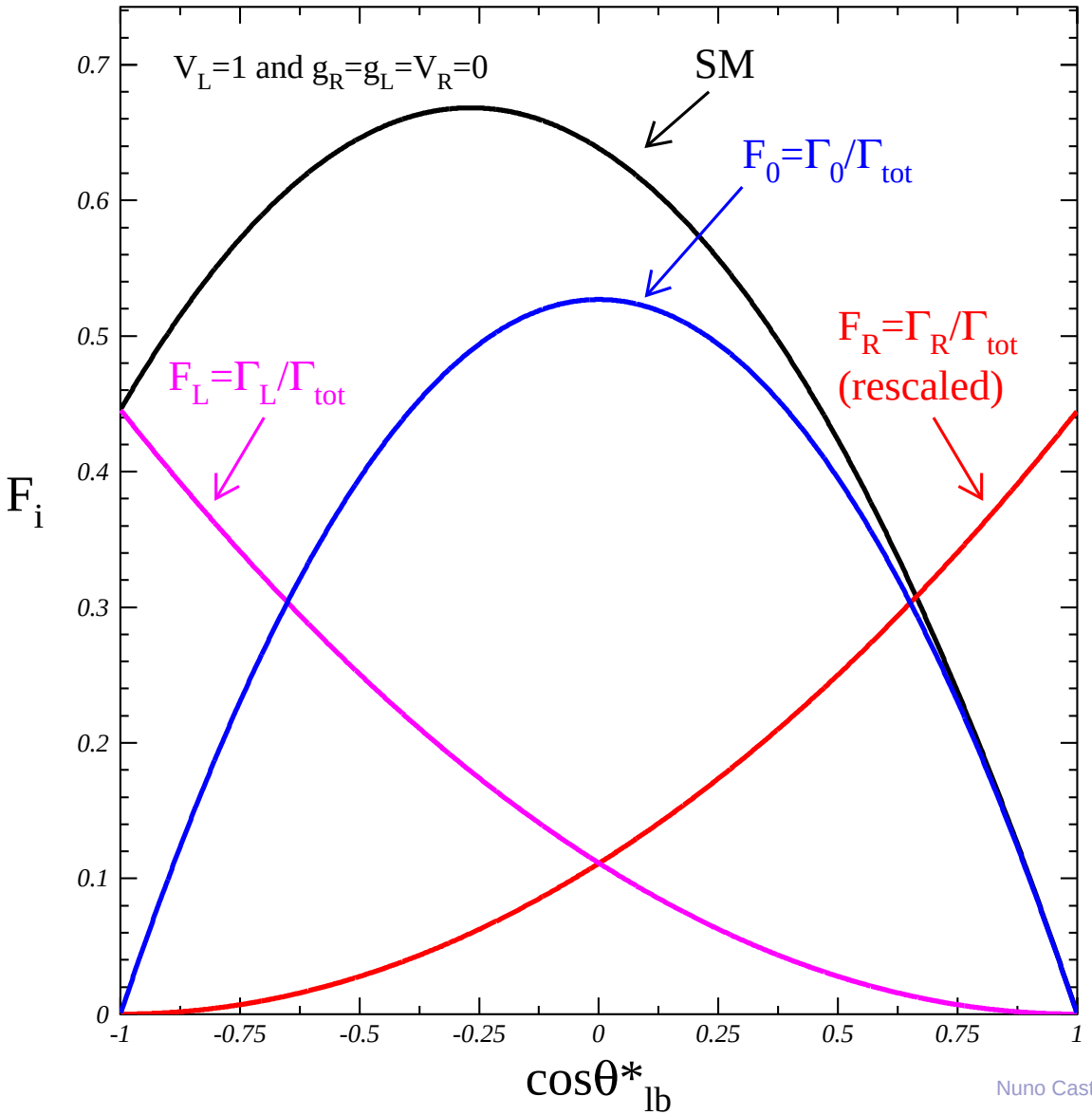

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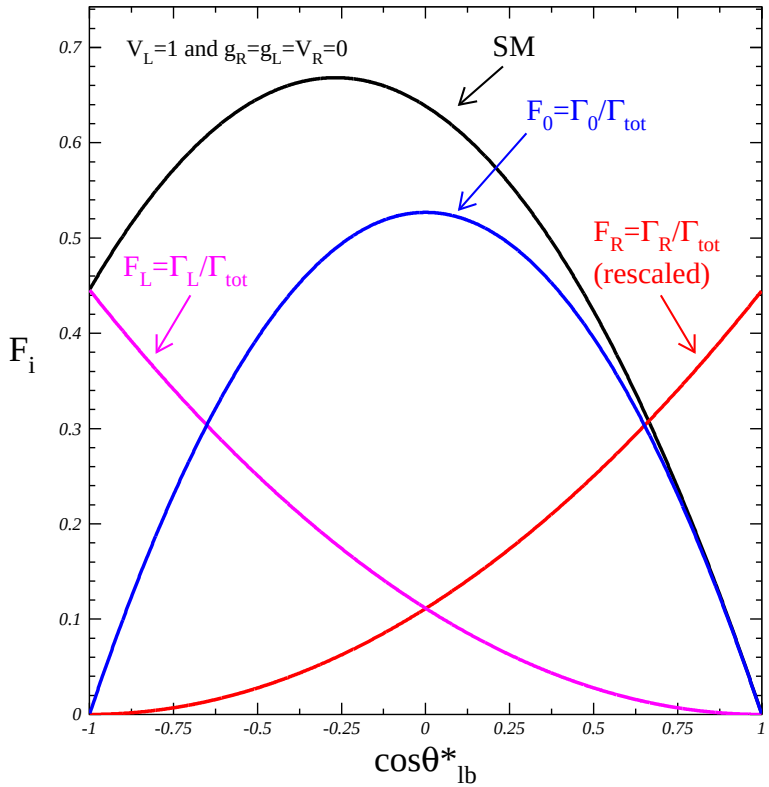

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$$z = 0 \quad \rightarrow A_z = A_{FB} = 3/4[F_R - F_L] = -0.2225\,(\text{SM, LO})$$

$$z = -(2^{2/3} - 1) \quad \rightarrow A_z = A_+ = 3\beta[F_0 + (1+\beta)F_R] = 0.5482\,(\text{SM, LO})$$

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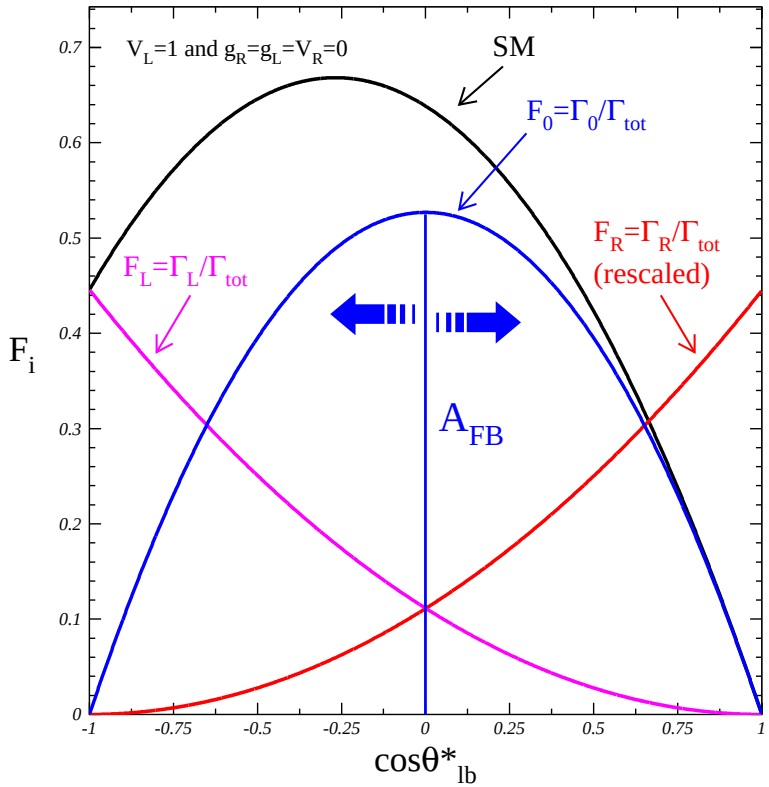

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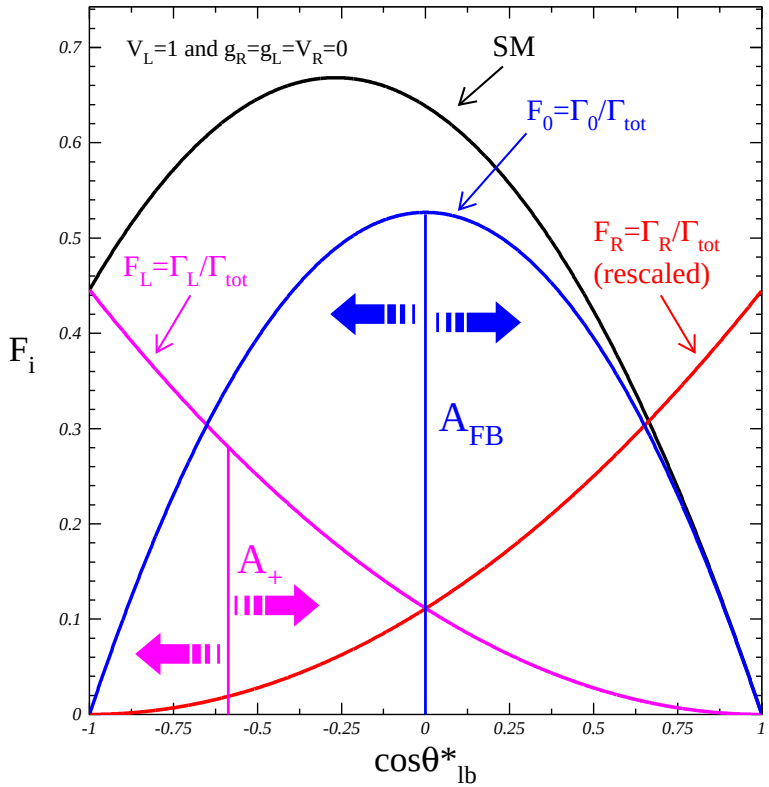

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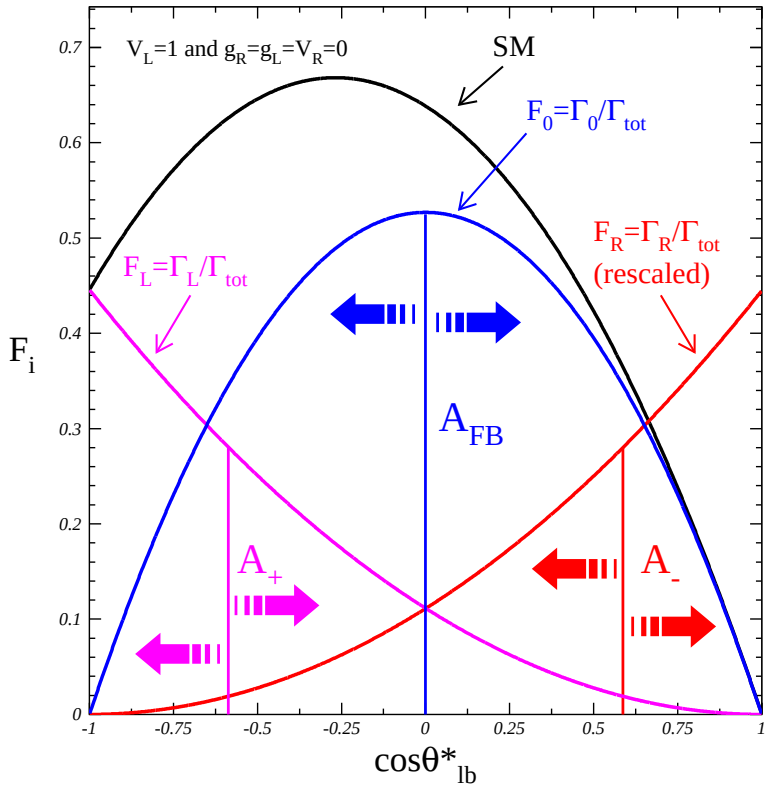

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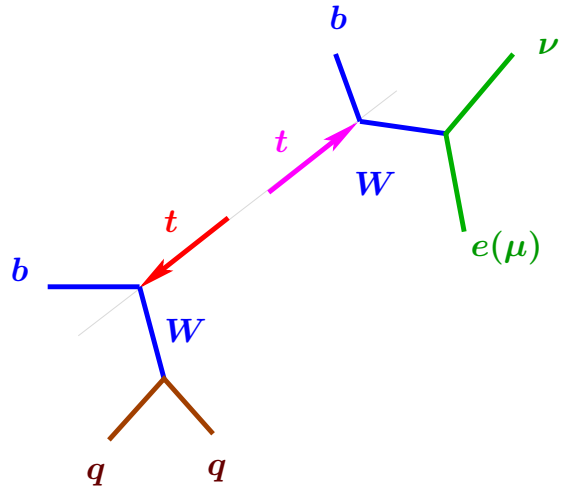
Wtb vertex: ATLAS sensitivity to anomalous couplings

How to measure the anomalous couplings?

- $t\bar{t}$ production at the LHC: $pp \rightarrow t\bar{t}$
  - $t \rightarrow bW^+$ ($\bar{t} \rightarrow W^-\bar{b}$)
  - one W decays to hadrons;
    the other decays to charged leptons (e, μ)
    (*semileptonic* topology)
- Preselection (cut-based):
  - 1 lepton
  - $\geq$ 4 jets (2 b-tagged, 2 non b)
  - missing transverse energy
- Probabilistic analysis:
  - p.d.f.s based on physical distributions:
    masses, transverse momenta, ...
  - discriminant variable: $L_R = L_S / L_B$

$$L_S = \Pi_{i=1}^{N} P_i^{signal}$$
$$L_B = \Pi_{i=1}^{N} P_i^{back}.$$

(final selection: cut on L_R – best $S/\sqrt{B}$)



signal background

selected events (L=10 fb^{-1}):
signal: 220k ($\varepsilon = 9\%$)
background: 36k

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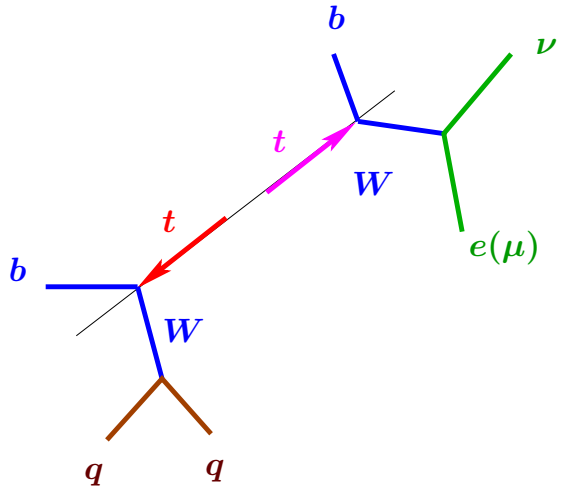
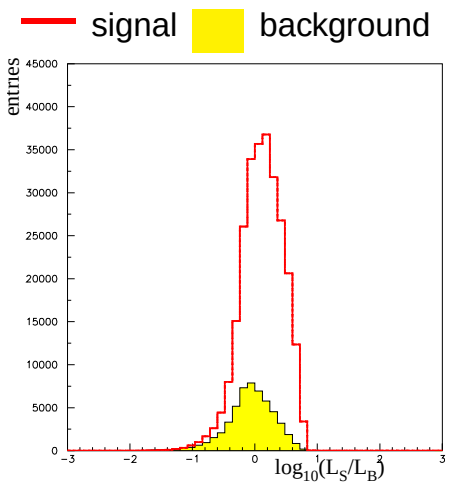
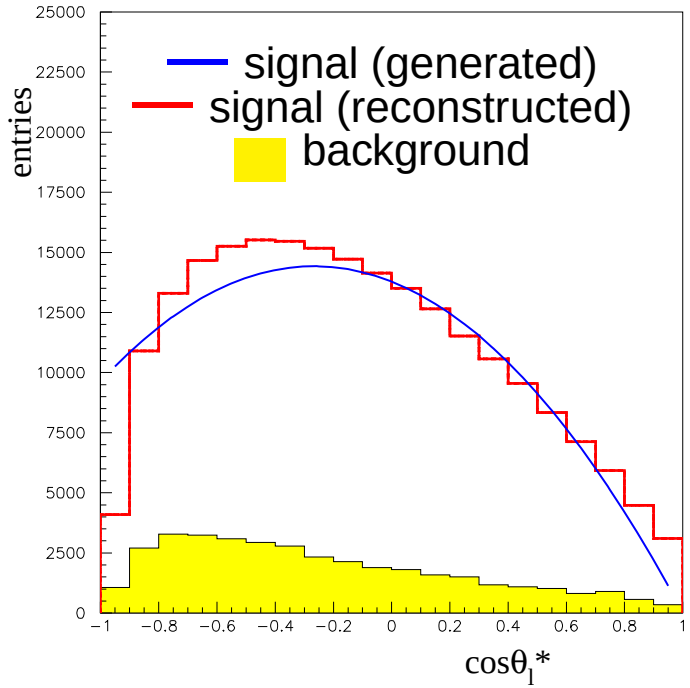




selected events (L=10 fb^{-1}):
signal: 220k ($\varepsilon = 9\%$)
background: 36k

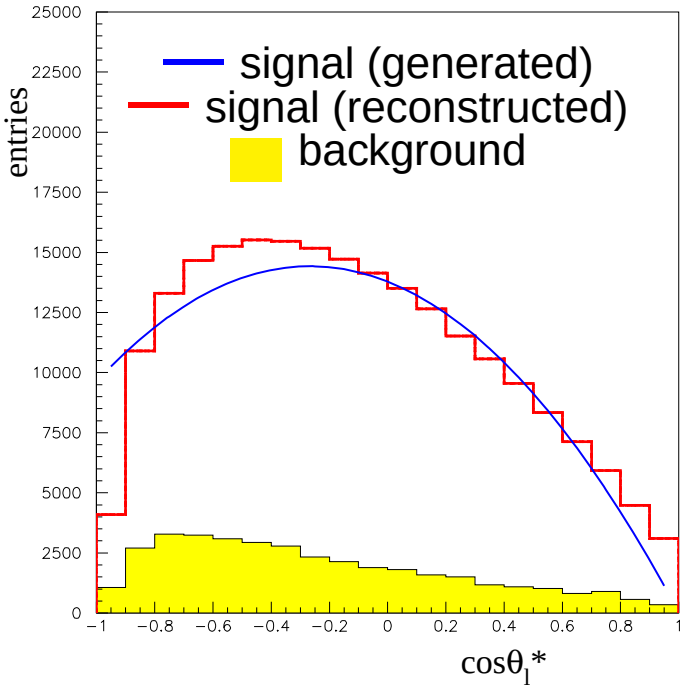
Wtb vertex: ATLAS sensitivity to anomalous couplings

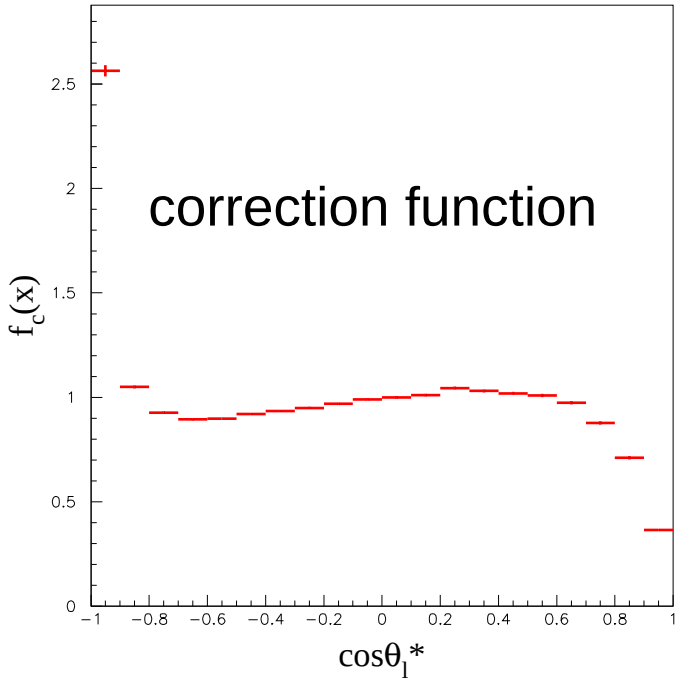


Observable		Result (L=10 fb^{-1})	
F_0	0.699	± 0.004 (stat)	± 0.020 (sys)
F_L	0.299	± 0.004 (stat)	± 0.019 (sys)
F_R	0.0021	± 0.003 (stat)	± 0.003 (sys)
ρ_L	0.4274	± 0.008 (stat)	± 0.036 (sys)
ρ_R	0.0004	± 0.002 (stat)	± 0.002 (sys)
A_{FB}	-0.2231	± 0.004 (stat)	± 0.013 (sys)
A_+	0.5472	± 0.003 (stat)	± 0.010 (sys)
A_-	-0.8387	± 0.002 (stat)	± 0.003 (sys)

☞ $\rho_{R,L} = \frac{F_{R,L}}{F_0}$

Wtb vertex: ATLAS sensitivity to anomalous couplings





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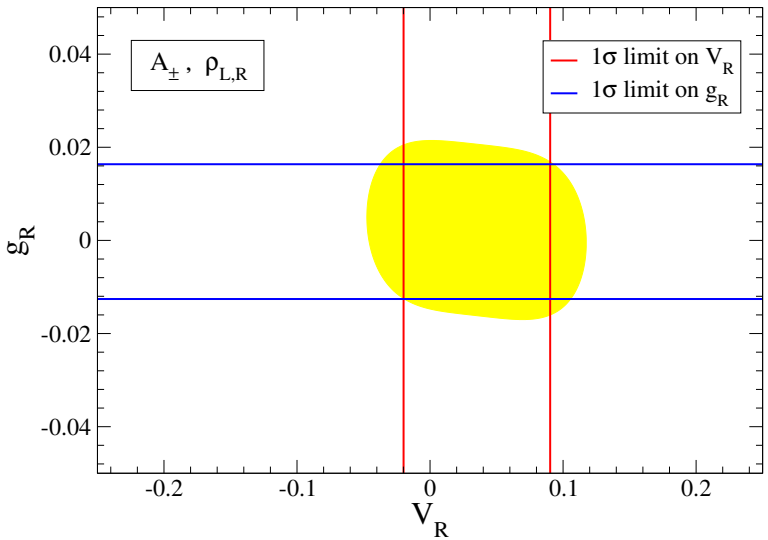
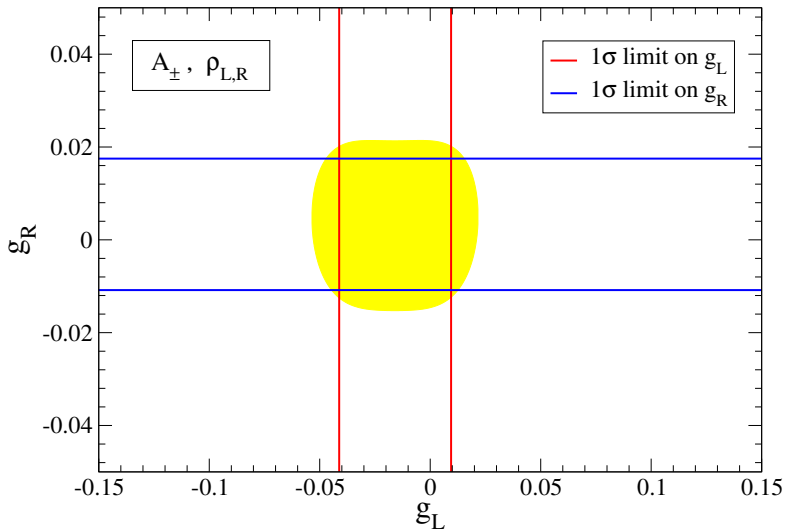
Wtb vertex: ATLAS sensitivity to anomalous couplings

1σ limits

L=10 fb^{-1}

obtained using `TopFit`

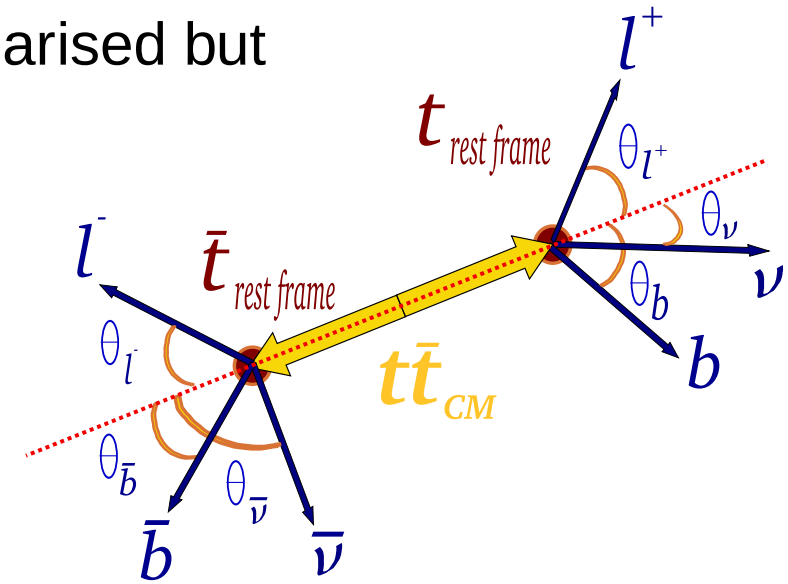




	V_R	g_L	g_R
$A_\pm$, $\rho_{R,L}$	$[-0.0195, 0.0906]$	$\times$	$\times$
$A_\pm$, $\rho_{R,L}$	$\times$	$[-0.0409, 0.00926]$	$\times$
$A_\pm$, $\rho_{R,L}$	$\times$	$\times$	$[-0.0112, 0.0174]$
$A_\pm$, $\rho_{R,L}$	$\times$	$[-0.0412, 0.00944]$	$[-0.0108, 0.0175]$
$A_\pm$, $\rho_{R,L}$	$[-0.0199, 0.0903]$	$\times$	$[-0.0126, 0.0164]$

Non-standard contributions to $t\bar{t}$ production

- $t\bar{t} \Rightarrow$ produced (almost) unpolarised but their spins are correlated



double distribution in helicity basis

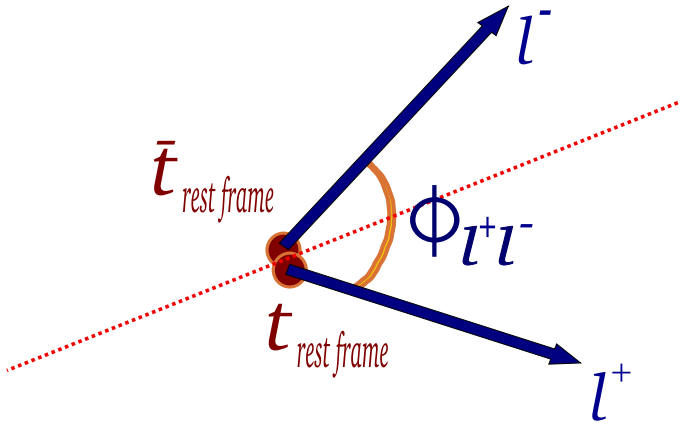
$$\frac{1}{\sigma}\frac{d^2\sigma}{d\cos\theta_X\, d\cos\theta_{\bar{X}'}} = \frac{1}{4}(1 + C\,\alpha_X\,\alpha_{\bar{X}'}\cos\theta_X\cos\theta_{\bar{X}'})$$

compare distribution of $\begin{cases} X \text{ from } t \text{ decay} \\ \bar{X}' \text{ from } \bar{t} \text{ decay} \end{cases}$

spin analysing power of X: $\alpha_{\ell^+} = \alpha_{\bar{q}'} = 1, \quad \alpha_\nu = \alpha_q = -0.31, \quad \alpha_{W^+} = -\alpha_b = 0.41$

$$C \equiv \frac{\sigma(t_R\bar{t}_R) + \sigma(t_L\bar{t}_L) - \sigma(t_R\bar{t}_L) - \sigma(t_L\bar{t}_R)}{\sigma(t_R\bar{t}_R) + \sigma(t_L\bar{t}_L) + \sigma(t_R\bar{t}_L) + \sigma(t_L\bar{t}_R)} \simeq 0.31 \quad \text{(SM tree-level)}$$

Non-standard contributions to $t\bar{t}$ production



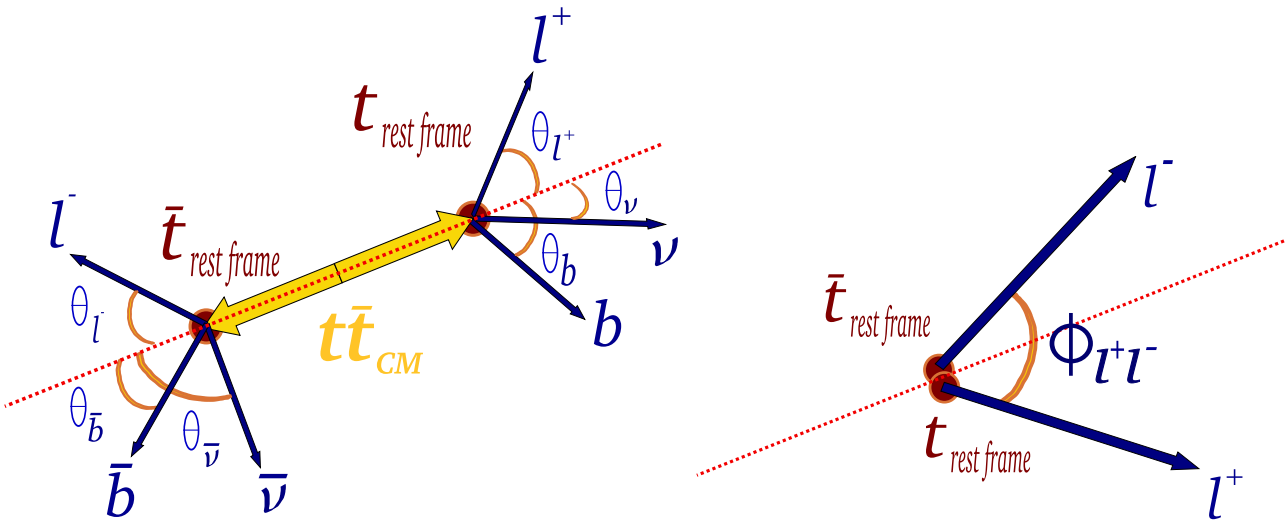
relative distribution of t and $\bar{t}$ spin analysers

$$\frac{1}{\sigma}\frac{d\sigma}{d\cos\varphi_{X\bar{X}'}} = \frac{1}{2}(1 + D\,\alpha_X\,\alpha_{\bar{X}'}\cos\varphi_{X\bar{X}'})$$

$\varphi_{X\bar{X}'}$ angle between $\left[\begin{array}{l} X \text{ momentum in } t \text{ rest frame} \\ \bar{X}' \text{ momentum in } \bar{t} \text{ rest frame} \end{array}\right.$

$D \simeq -0.217$ (SM tree-level)

Non-standard contributions to $t\bar{t}$ production



spin asymmetries

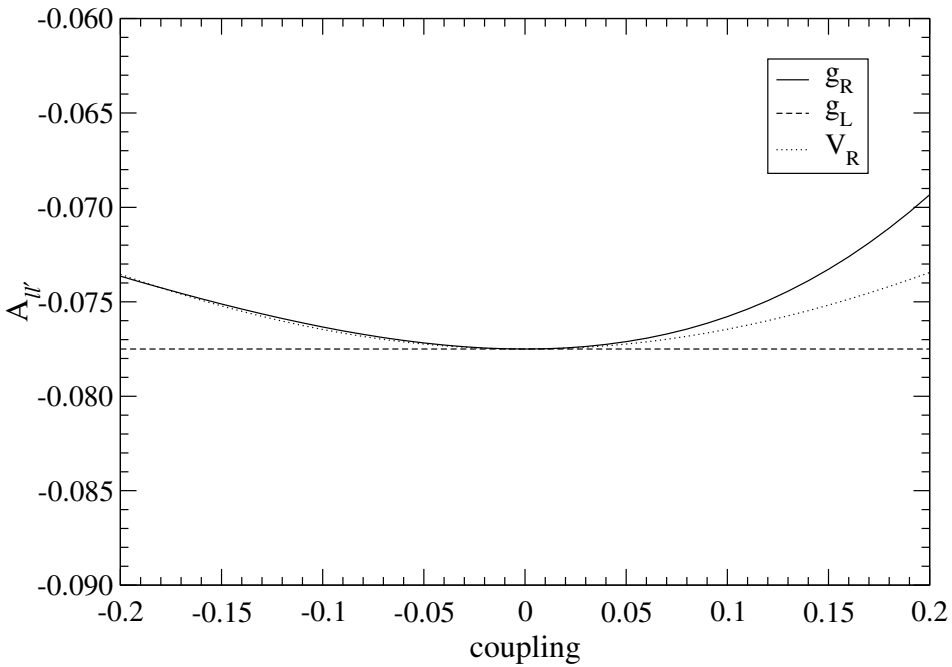
$$A_{X\bar{X}'} \equiv \frac{N(\cos\theta_X \cos\theta_{\bar{X}'} > 0) - N(\cos\theta_X \cos\theta_{\bar{X}'} < 0)}{N(\cos\theta_X \cos\theta_{\bar{X}'} > 0) + N(\cos\theta_X \cos\theta_{\bar{X}'} < 0)} = \frac{1}{4} C \alpha_X \alpha_{\bar{X}'}$$

$$\tilde{A}_{X\bar{X}'} \equiv \frac{N(\cos\varphi_{X\bar{X}'} > 0) - N(\cos\varphi_{X\bar{X}'} < 0)}{N(\cos\varphi_{X\bar{X}'} > 0) + N(\cos\varphi_{X\bar{X}'} < 0)} = \frac{1}{2} D \alpha_X \alpha_{\bar{X}'}$$

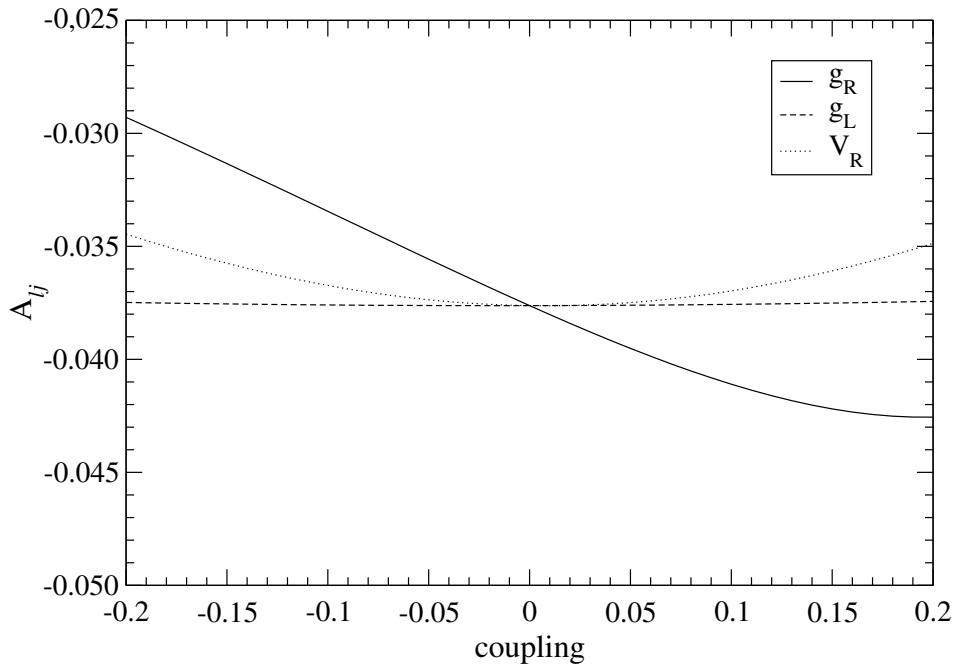
Non-standard contributions to $t\bar{t}$ production

- spin asymmetries depend on anomalous couplings (although less sensitive than angular asymmetries)

(dileptonic channel)



(semileptonic channel)



Non-standard contributions to $t\bar{t}$ production

expected ATLAS sensitivity

$$A_{\ell\ell'} = -0.0775 \pm 0.0060, \quad A_{\ell j} = -0.0376 \pm 0.0058$$

$$\tilde{A}_{\ell\ell'} = 0.1088 \pm 0.0056, \quad \tilde{A}_{\ell j} = 0.0554 \pm 0.0061$$

[ATL-PHYS-PUB-2006-018, EPJC44S2(2005)13]

$$A_{\ell\ell'} \rightarrow C = 0.310 \pm 0.024\,(\text{exp})\ {}^{+0.}_{-0.0043}\,(\delta V_R)\ {}^{+1\times10^{-5}}_{-3\times10^{-6}}\,(\delta g_L)\ {}^{+7\times10^{-6}}_{-0.0004}\,(\delta g_R)$$

$$A_{\ell j} \rightarrow C = 0.310 \pm 0.045\,(\text{exp})\ {}^{+0.}_{-0.0068}\,(\delta V_R)\ {}^{+0.0001}_{-0.0008}\,(\delta g_L)\ {}^{+0.0004}_{-0.0009}\,(\delta g_R)$$

$$\tilde{A}_{\ell\ell'} \rightarrow D = -0.217 \pm 0.011\,(\text{exp})\ {}^{+0.0031}_{-0.}\,(\delta V_R)\ {}^{+2\times10^{-6}}_{-8\times10^{-6}}\,(\delta g_L)\ {}^{+0.0003}_{-0.}\,(\delta g_R)$$

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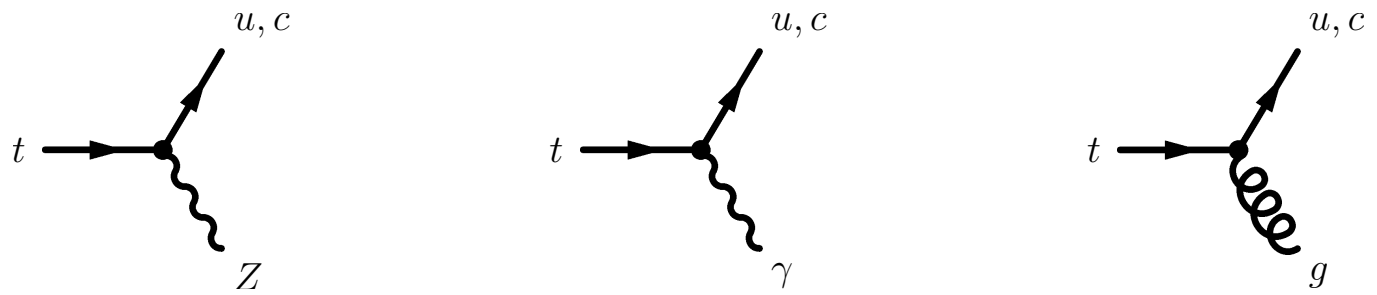
FCNC interactions: single and $t\bar{t}$ production



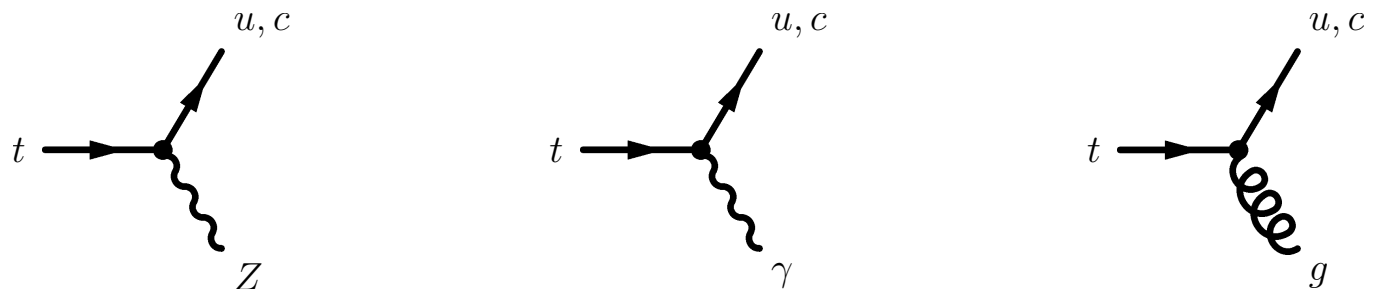
- FCNC: GIM suppressed in the SM

- higher BR in some SM extensions
  (2-Higgs doublet, SUSY, exotic fermions, . . .)

	BR in SM	2HDM	MSSM	$\not{R}$ SUSY	QS
$t \to qZ$	$\sim 10^{-14}$	$\sim 10^{-7}$	$\sim 10^{-6}$	$\sim 10^{-5}$	$\sim 10^{-4}$
$t \to q\gamma$	$\sim 10^{-14}$	$\sim 10^{-6}$	$\sim 10^{-6}$	$\sim 10^{-6}$	$\sim 10^{-9}$
$t \to qg$	$\sim 10^{-12}$	$\sim 10^{-4}$	$\sim 10^{-5}$	$\sim 10^{-4}$	$\sim 10^{-7}$

- Effects on t production and decay
  ☞ signature for new physics

FCNC interactions: single and $t\bar{t}$ production



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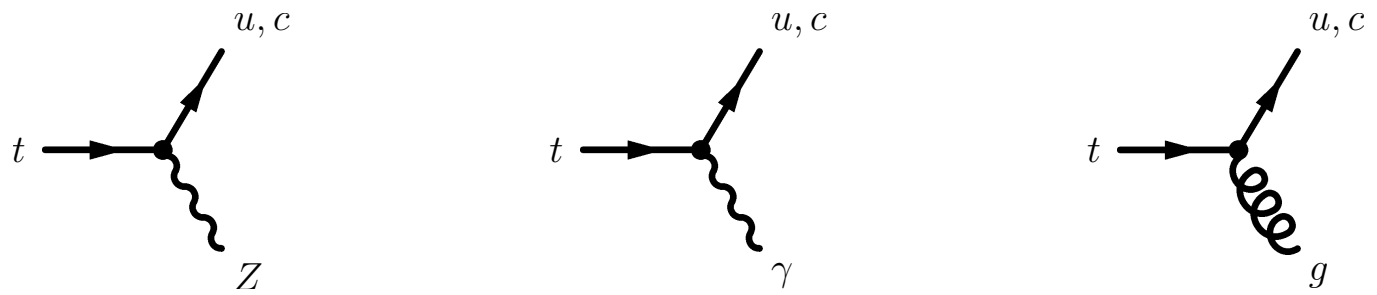

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- Effects on t production and decay
  ☞ signature for new physics

FCNC interactions: single top production

- Single top production can be an important probe to strong FCNC

direct production	$g\ q \to t + X$
top + jet production $(pp \to t + \text{jet})$	$g\ g \to \bar{q}\ t + X$ $g\ q \to g\ t + X$ $q\ q \to \bar{q}\ t + X$
top + gauge boson production $(pp \to t + \gamma/Z/W)$	$g\ q \to \gamma\ t + X$ $g\ q \to Z\ t + X$ $g\ q \to Wt + X$
top + Higgs production $(pp \to t + h)$	$g\ q \to h\ t + X$

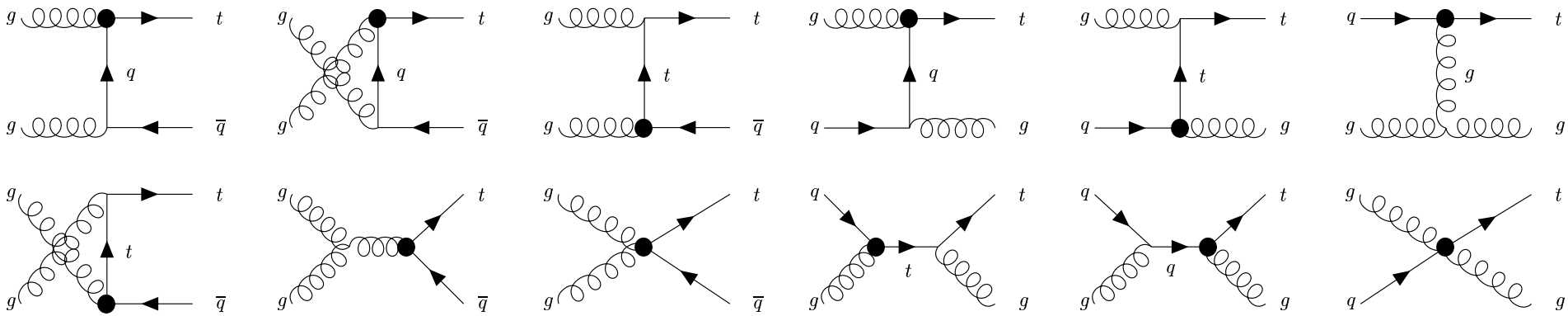
- Processes depend on anomalous couplings $\rightsquigarrow \alpha, \beta$

[PRD73(2006)034011, PRD73(2006)054025, PRD74(2006)014006]

FCNC interactions: single top production

- top + jet production ($g\,g \to \bar{q}\,t + X$ and $g\,q \to g\,t + X$)

  many diagrams:

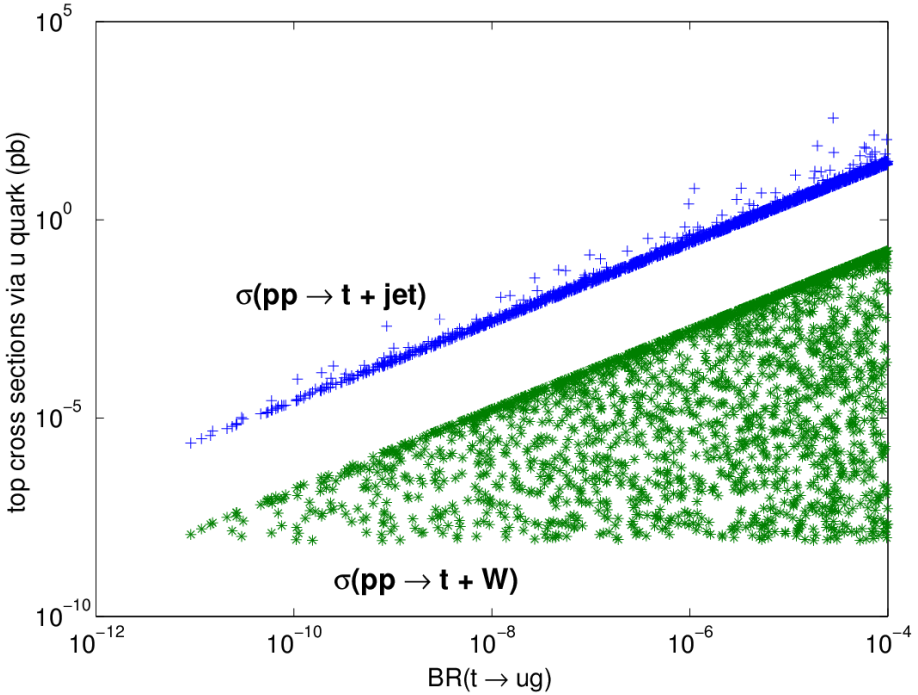


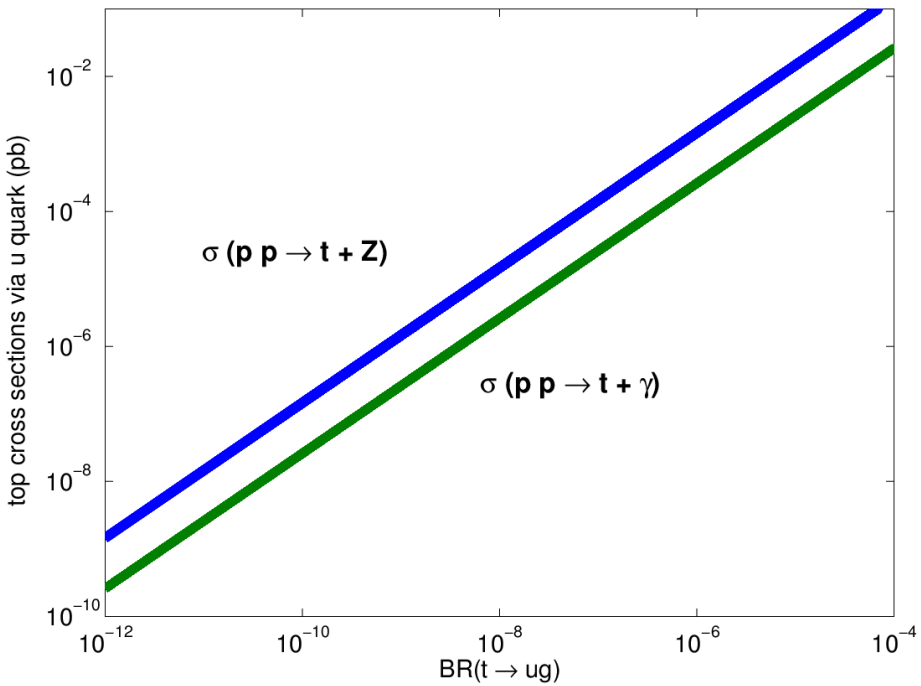
cross-sections proportional to $BR(t \to ug, cg)$:

$$\sigma(g\,g \to t\,\bar{q}) = [0.5\,BR(t \to u\,g) + 0.5\,BR(t \to c\,g)]\,|V_{tb}|^2\,10^4$$
$$\sigma(g\,q \to g\,t) = [8.2\,BR(t \to u\,g) + 0.8\,BR(t \to c\,g)]\,|V_{tb}|^2\,10^4$$
$$\sigma(g\,\bar{q} \to g\,\bar{t}) = [1.5\,BR(t \to u\,g) + 0.8\,BR(t \to c\,g)]\,|V_{tb}|^2\,10^4$$

FCNC interactions: single top production

- varying the anomalous *tqg* couplings (α and β) in the range $10^{-6} \rightarrow 1$:





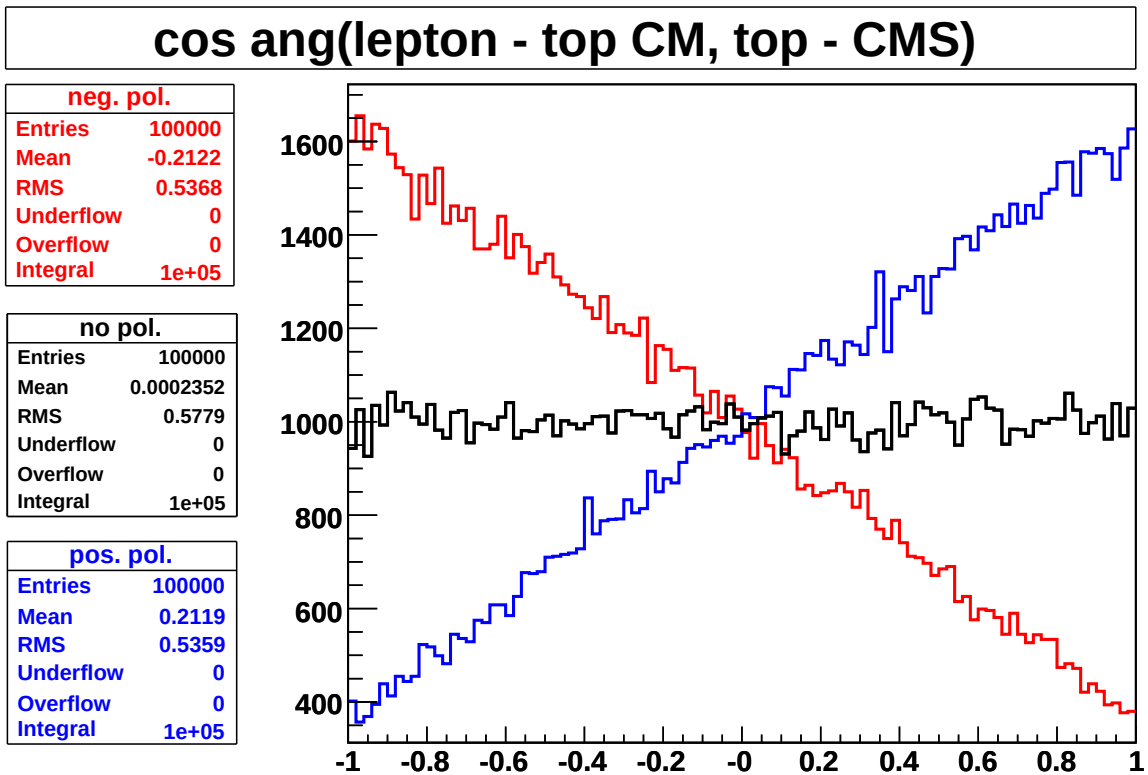
(four-fermion operators contribution not included)

FCNC interactions: single top production

TopReX 4.20

process 31: $q\bar{q} \to t\bar{u}(\bar{c})$
process 32: $gg \to t\bar{u}(\bar{c})$
process 33: $gu(c) \to tg$

$$q\bar{q} \to t\bar{u}(\bar{c}) \oplus gg \to t\bar{u}(\bar{c}) \oplus gu(c) \to tg$$



positive polarization (pure V-A): $\beta_{tc} = 1$, $\beta_{ct} = 0$
negative polarization (pure V+A): $\beta_{tc} = 0$, $\beta_{ct} = 1$
no polarization: $\beta_{tc} = 1$, $\beta_{ct} = 1$
[$\alpha_{ij} = 0$ in all cases]

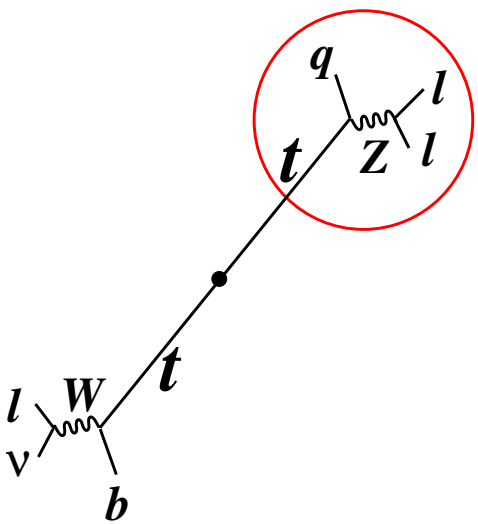
top-rest frame,
angle between lepton
and top direction of flight

FCNC interactions: $t\bar{t}$ production

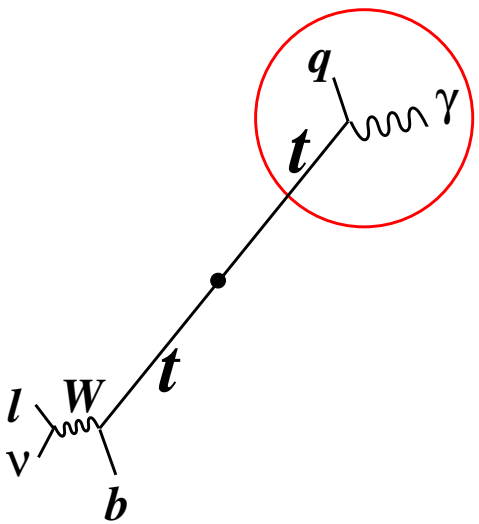
- $t\bar{t}$ production at the LHC will probe t FCNC decays

- ATLAS and CMS studies:

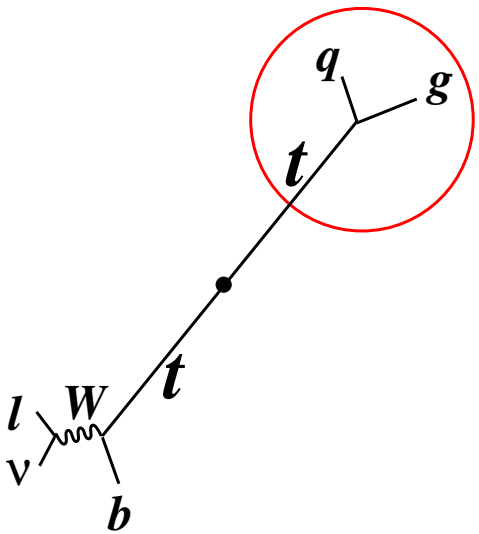
$t \to qZ$
(2jets+3l+missing)



$t \to q\gamma$
(2jets+1l+1γ+missing)



$t \to qg$
(3jets+1l+missing)

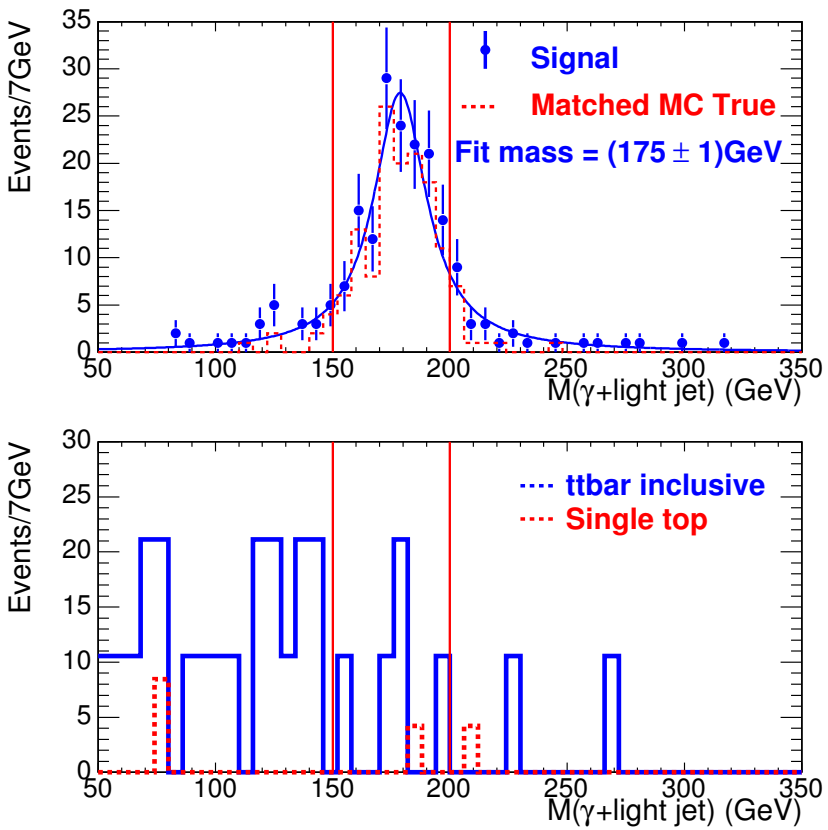


FCNC interactions: $t\bar{t}$ production

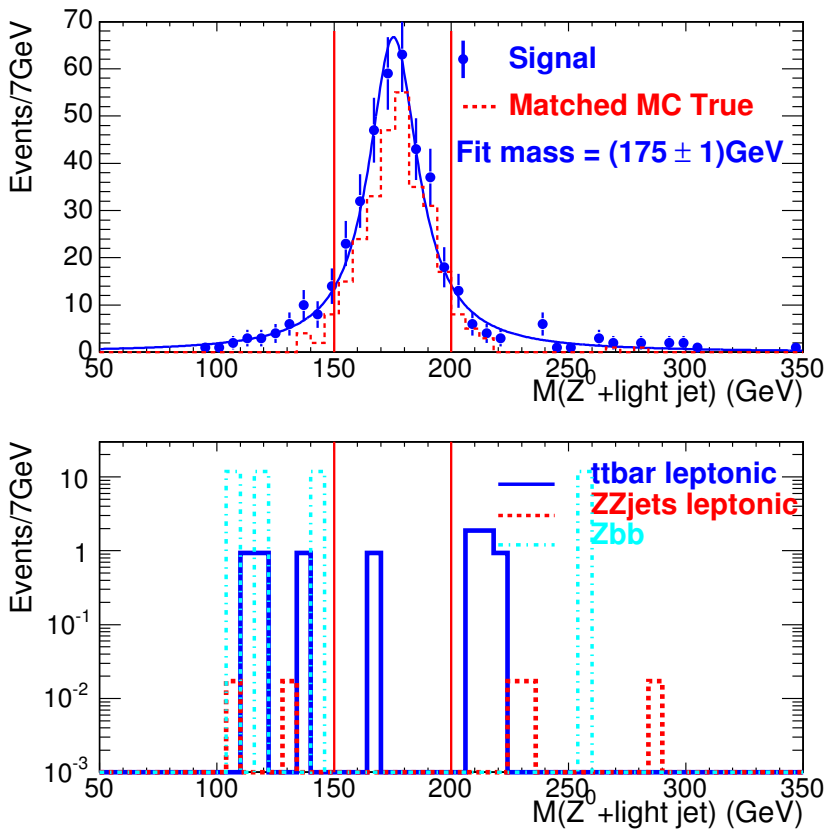
CMS analysis [CMS NOTE-2006/093]

- FULL simulation
- cut-based analysis

$q\gamma$ channel



qZ channel



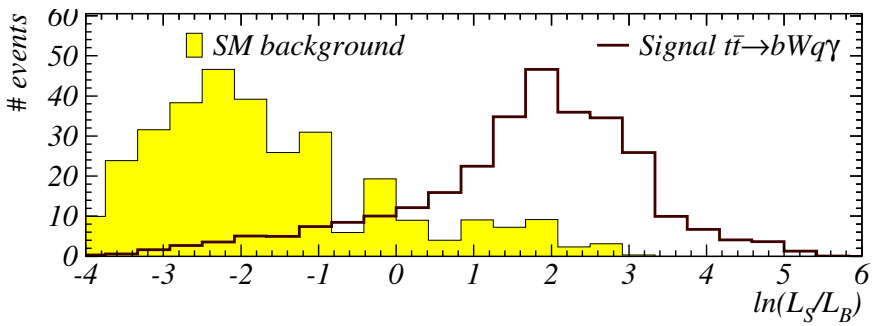
FCNC interactions: $t\bar{t}$ production

ATLAS analysis [SN-ATLAS-2007-059]

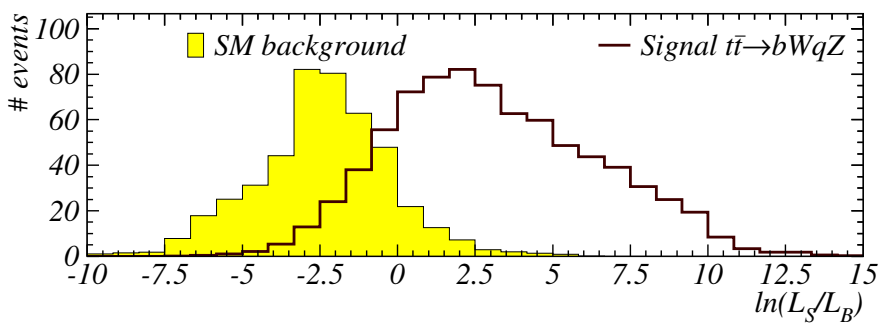
- ATLFAST simulation
- probabilistic analysis (after a cut-based preselection)
  ☞ $L_R = L_S/L_B$

$$L_S = \Pi_{i=1}^{N} P_i^{signal}$$
$$L_B = \Pi_{i=1}^{N} P_i^{back}.$$

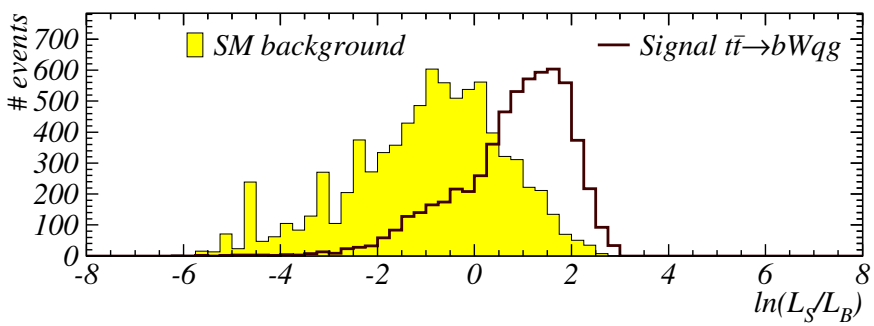
$q\gamma$ channel



qZ channel



qg channel



FCNC interactions: $t\bar{t}$ production

ATLAS/CMS results (preliminary) combination

- signal discovery: 5σ significance (L=10 fb^{-1})

	$t \to qZ$		$t \to q\gamma$	
	$BR\ (\mathcal{S}_1)$	$BR\ (\mathcal{S}_2)$	$BR\ (\mathcal{S}_1)$	$BR\ (\mathcal{S}_2)$
ATLAS	4.4×10^{-4}	13.0×10^{-4}	9.4×10^{-5}	1.6×10^{-4}
CMS	5.1×10^{-4}	11.4×10^{-4}	4.9×10^{-4}	5.7×10^{-4}

significance definition: $\mathcal{S}_1 = S/\sqrt{B}$; $\mathcal{S}_2 = 2(\sqrt{B+S} - \sqrt{B})$

- absence of signal: 95% CL (MFLM method)

luminosity	$BR(t \to qZ)$	$BR(t \to q\gamma)$
10 fb^{-1}	2.0×10^{-4}	3.6×10^{-5}
100 fb^{-1}	4.2×10^{-5}	1.0×10^{-5}

- systematic uncertainties:
  m_t, b-tag, lepton id. and back. levels are dominant ($\sim 20 - 30\%$)

FCNC interactions: $t\bar{t}$ production

ATLAS/CMS results (preliminary) combination

- signal discovery: 5σ significance (L=10 fb^{-1})

	$t \to qZ$		$t \to q\gamma$	
	$BR\ (\mathcal{S}_1)$	$BR\ (\mathcal{S}_2)$	$BR\ (\mathcal{S}_1)$	$BR\ (\mathcal{S}_2)$
ATLAS	4.4×10^{-4}	13.0×10^{-4}	9.4×10^{-5}	1.6×10^{-4}
CMS	5.1×10^{-4}	11.4×10^{-4}	4.9×10^{-4}	5.7×10^{-4}

significance definition: $\mathcal{S}_1 = S/\sqrt{B}$; $\mathcal{S}_2 = 2(\sqrt{B+S} - \sqrt{B})$

- absence of signal: 95% CL (MFLM method)

luminosity	$BR(t \to qZ)$	$BR(t \to q\gamma)$
10 fb^{-1}	2.0×10^{-4}	3.6×10^{-5}
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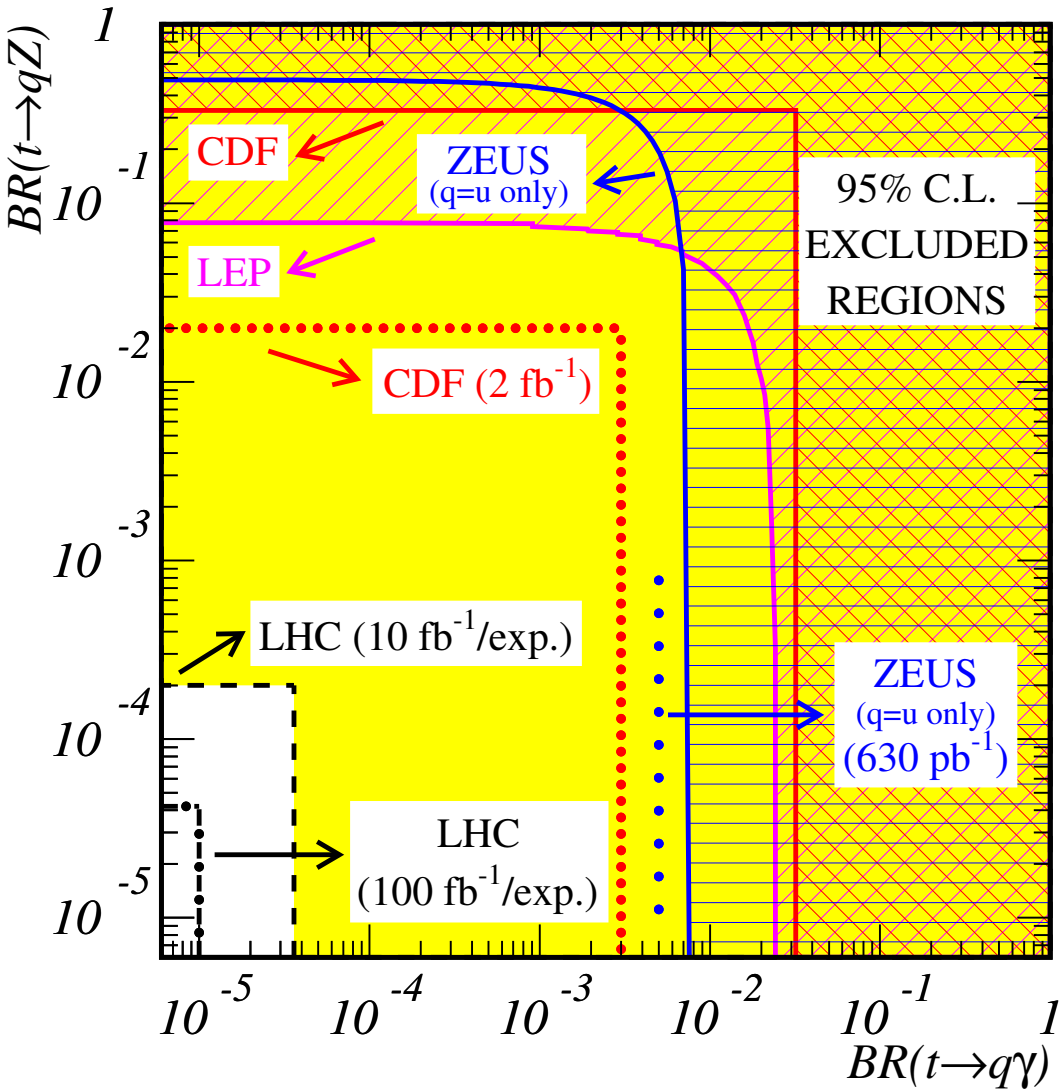

$BR(t \to qg)$ (from $t\bar{t}$ production)
ATLAS ($L = 10\ \text{fb}^{-1}$): 0.13%

new results from D0 ($L = 230\ \text{fb}^{-1}$)
single t production via gtq FCNC
[FERMILAB-PUB-07-031-E]

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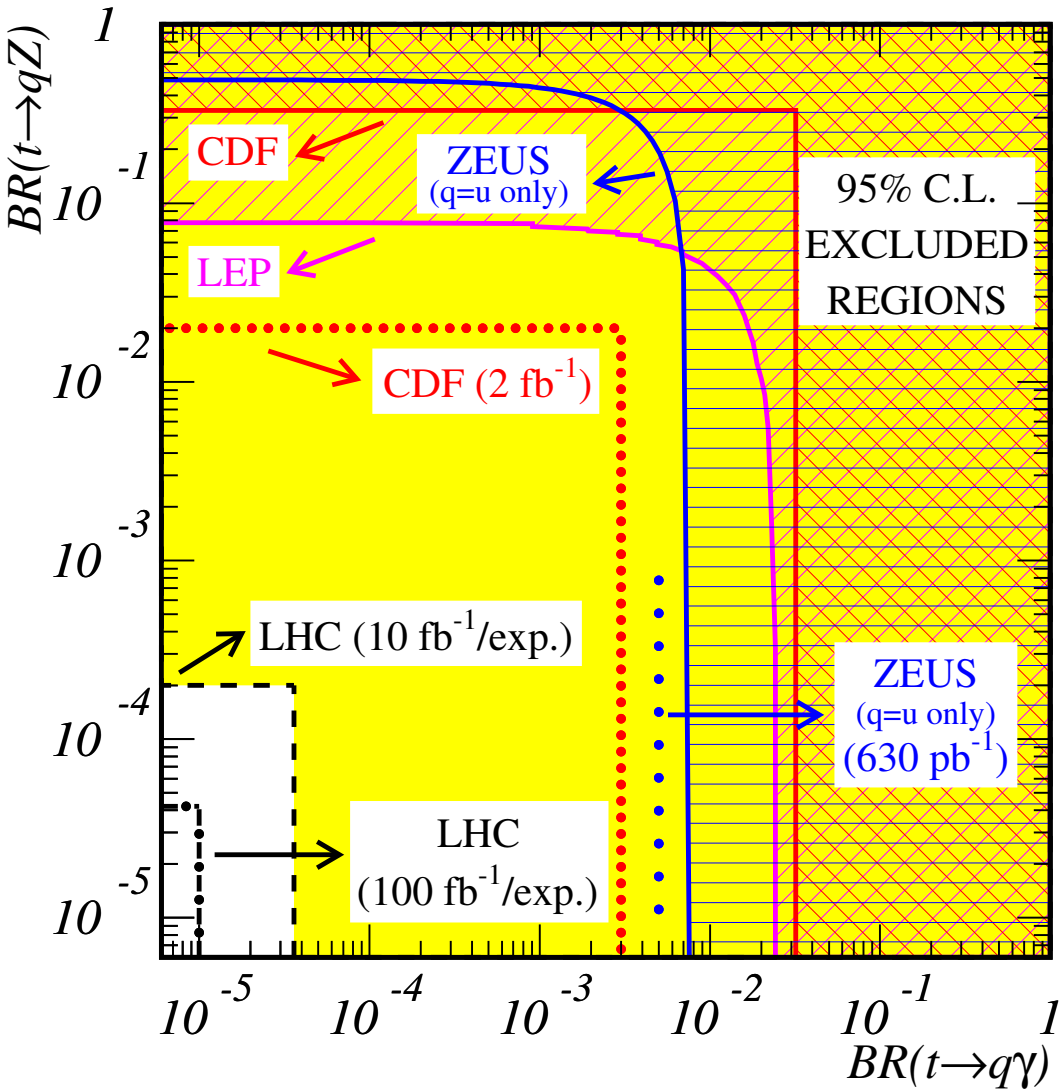

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Conclusions

- LHC will be a top factory, allowing to test new flavour phenomena
  - **Wtb vertex: anomalous couplings**
    Direct measurements and constraints from B-factories are complementary
    $|V_R| \lesssim 10^{-3}$; $|g_L| \lesssim 10^{-3}$; $|g_R| \lesssim 10^{-2}$
    `TopFit` was developed
  - **$t\bar{t}$ production**
    additional information on the anomalous couplings
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Backup Slides

B-physics constraints to Wtb vertex

$$BR(\bar{B} \to X_s\gamma) = \left(3.55 \pm 0.24\ ^{+0.09}_{-0.10} \pm 0.03\right) \times 10^{-4}$$

[hep-ex/0603003]

$$\begin{aligned} BR(B \to X_s\gamma) \times 10^4 &= (3.15 \pm 0.23) - 4.14\,(V_L - V_{tb}) + 411\,V_R \\ &- 53.9\,g_L - 2.12\,g_R - 8.03\,C_7^{(p)}(\mu_0) \\ &+ \mathcal{O}\left[\left(V_L - V_{tb}, V_R, g_L, g_R, C_7^{(p)}\right)^2\right] \end{aligned}$$

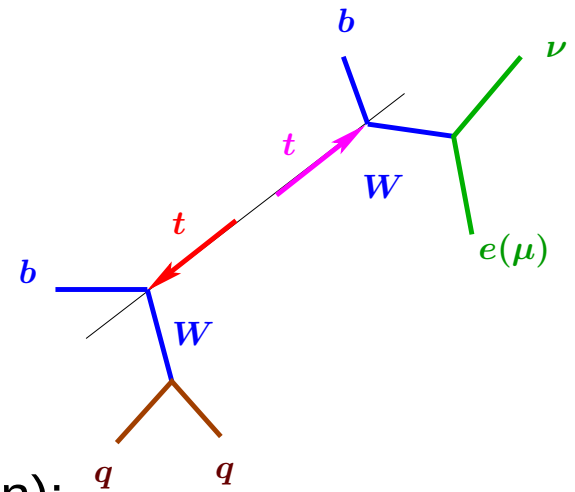
$$\mathcal{O}\left[(V_L - V_{tb}, V_R, \ldots)^2\right] \simeq 1.32(V_L - V_{tb})^2 - 262(V_L - V_{tb})V_R + 12970V_R^2 + \ldots$$

	$V_L - V_{tb}$	V_R	g_L	g_R	$C_7^{(p)}(\mu_0)$
upper bound	0.04	0.0024	0.003	0.08	0.02
lower bound	−0.24	−0.0004	−0.018	−0.46	−0.12

back

Wtb vertex: ATLAS sensitivity to anomalous couplings

- $t\bar{t}$ production at the LHC: $pp \rightarrow t\bar{t}$
  - $t \rightarrow bW^+$ ($\bar{t} \rightarrow W^-\bar{b}$)
  - one W decays to hadrons; the other decays to leptons (*semileptonic* topology)

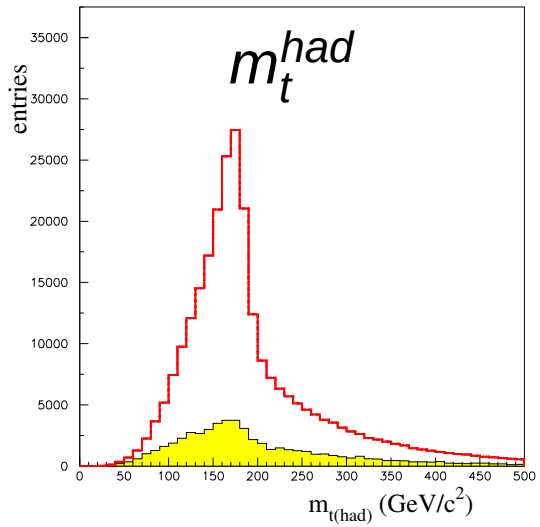


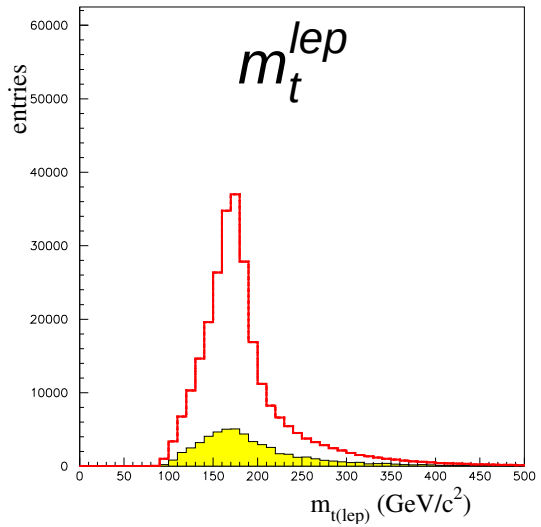
- events were required to have (preselection):
  - 1 lepton ($p_T > 25$ GeV; $|\eta| < 2.5$)
  - ≥ 4 jets ($p_T > 20$ GeV; $|\eta| < 2.5$) 2 b-tagged, 2 non b
  - MET > 20 GeV
  - solution for neutrino p_z

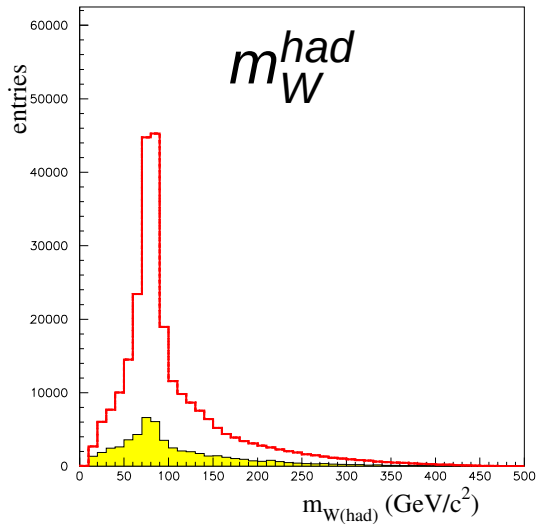
- solution for neutrino p_z:
  - $m_W = 80.4$ GeV assumed $\Rightarrow$ quadratic ambiguity (2 solutions)
  - hadronic t reconstruction: hadronic W + closer b jet
  - leptonic t reconstruction: leptonic W + remaining b jet
  - neutrino p_z solution: minimum lep./had. top mass difference

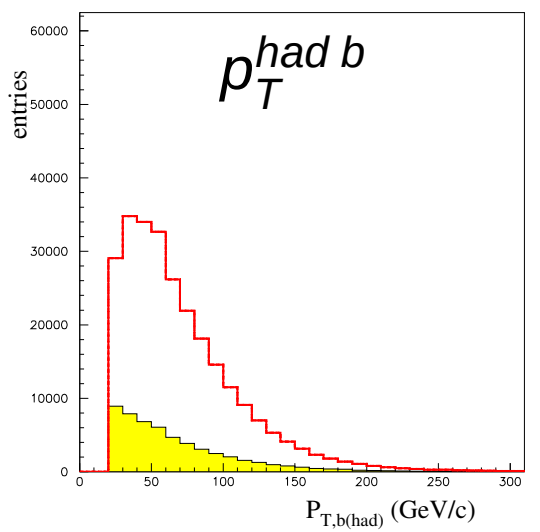
Wtb vertex: ATLAS sensitivity to anomalous couplings

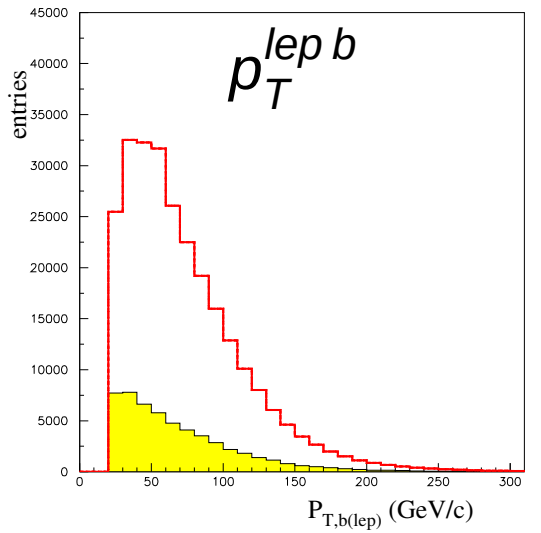
Distributions used to build the p.d.f.s:

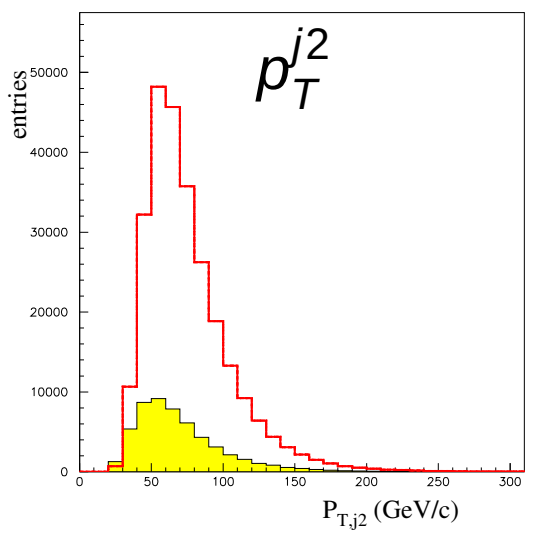












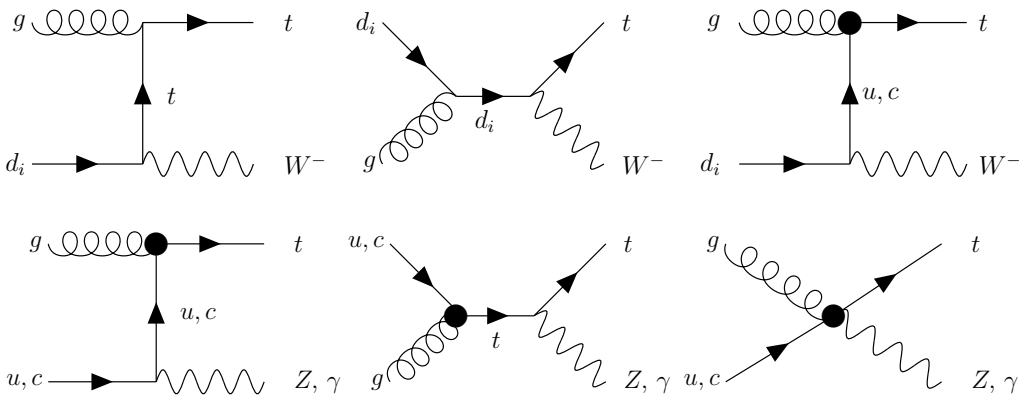
Wtb vertex: ATLAS sensitivity to anomalous couplings

Sources of systematic errors for the semileptonic channel:

source	F_0	F_L	F_R	ρ_L	ρ_R	A_{FB}	A_+	A_-
MC generator	0.0018	0.0014	0.0004	0.0006	0.0000	0.0035	0.0015	0.0006
PDFs	0.0045	0.0017	0.0027	0.0046	0.0008	0.0021	0.0005	0.0014
Top mass	0.0065	0.0060	0.0006	0.0124	0.0007	0.0034	0.0039	0.0005
ISR+FSR	0.0142	0.0131	0.0011	0.0218	0.0001	0.0046	0.0049	0.0011
b tag eff.	0.0080	0.0069	0.0011	0.0126	0.0003	0.0039	0.0046	0.0004
E_b scale	0.0019	0.0024	0.0004	0.0061	0.0002	0.0021	0.0017	0.0005
E_j scale	0.0030	0.0038	0.0005	0.0074	0.0002	0.0038	0.0023	0.0014
Back.	0.0002	0.0000	0.0002	0.0001	0.0000	0.0001	0.0000	0.0001
Pile-up	0.0087	0.0084	0.0003	0.0175	0.0002	0.0080	0.0051	0.0006
b frag.	0.0012	0.0015	0.0004	0.0078	0.0011	0.0045	0.0000	0.0012
Total Δsys.	0.0206	0.0188	0.0033	0.0356	0.0016	0.0130	0.0099	0.0028

FCNC interactions: single top production

- top + gauge boson production:



$$\frac{d\,\sigma(g\,q \to t\,\gamma)}{dt} = \frac{e^2}{18\,m_t^2\,s^2\,t\,(t+u)^2}\,(m_t^6 - t\,m_t^4 + s^2\,m_t^2 + 3\,s\,t\,m_t^2 - 2\,s^2\,t)\,u\;\Gamma(t \to q\,g)$$

$$\frac{d\,\sigma(g\,u \to t\,Z)}{dt} = \frac{e^2\,m_t^2}{1728\,\pi\,\Lambda^4\,S_{2w}^2}\,\frac{F_{tZ}^1\,|\alpha_{ut}+\alpha_{tu}^*|^2 + F_{tZ}^2\,Im[(\alpha_{ut}+\alpha_{tu}^*)\,\beta_{tu}] + F_{tZ}^3\,|\beta_{tu}|^2 + F_{tZ}^4\,|\beta_{ut}|^2}{m_z^2\,s^2\,t\,(t+u)^2}$$

$$\frac{d\,\sigma^{NEW}(g\,d \to t\,W^-)}{dt} = \frac{e^2\,|V_{qd}|^2\,\left(m_t^2 - t\right)\,\left(s\,t + 2\,m_w^2\,u\right)\,v^2}{24\,m_w^2\,\pi\,s^2 S_w^2\,t}\,\frac{|\beta_{qt}|^2}{\Lambda^4}$$

Top quark chapter

Flavour phenomena in top quark physics

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