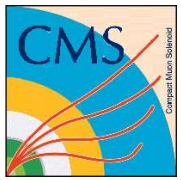
LHC sensitivity to top properties beyond the SM



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International Workshop on Top Quark Physics

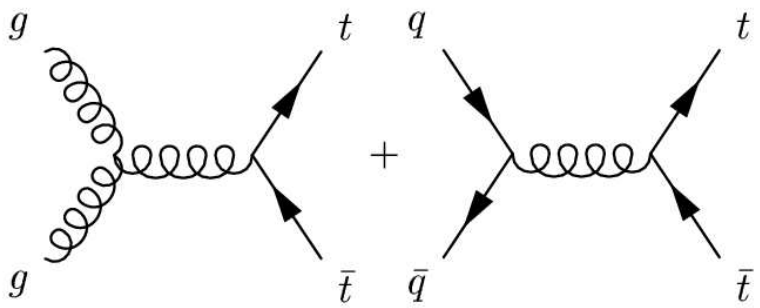
Coimbra, 14th January 2006

Outline

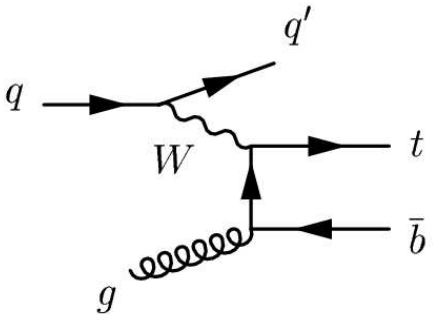
- Physics motivation
- The ATLAS and CMS experiments
- Physics beyond the SM with top quark
  - new physics in the main decay: $t \to bW$
  - top quark FCNC decays: $t \to qZ$, $t \to q\gamma$, $t \to qg$
  - $t\bar{t}$ resonances
- Conclusions

Physics motivation

- The LHC will be a top factory
  - $\sigma(pp \to t\bar{t}) \sim 800$ pb
  - $\sigma(\text{single top production}) \sim 300$ pb



- $t \to bW$ is the dominant decay mode
  - $BR(t \to sW) < 0.18\%$
  - $BR(t \to dW) < 0.02\%$

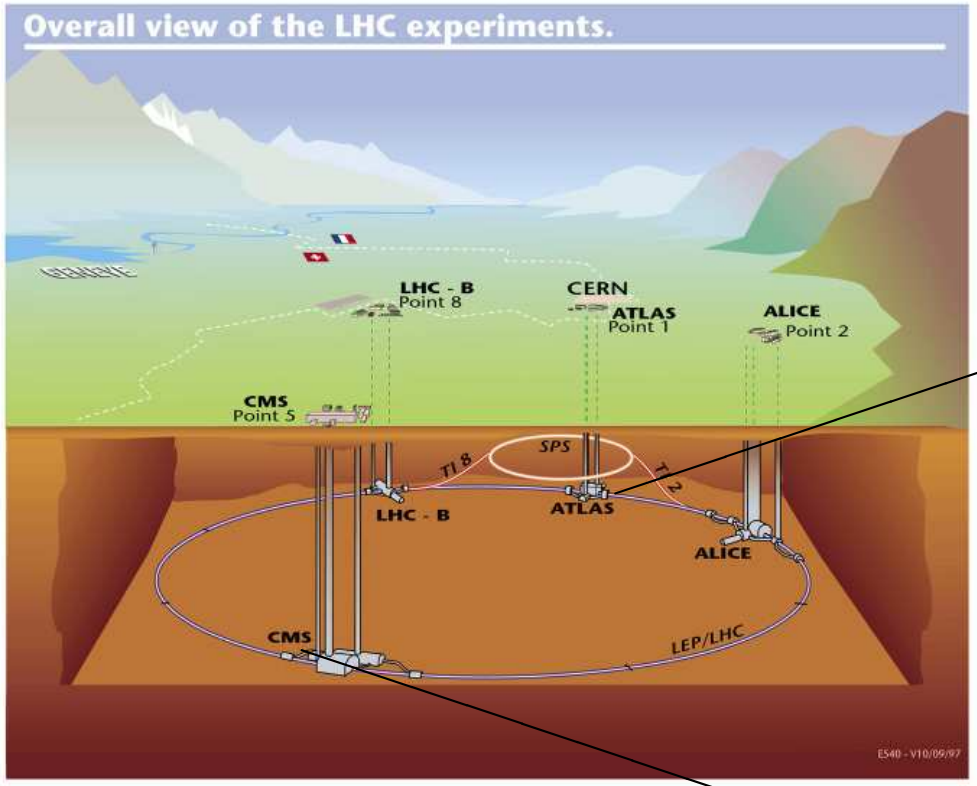


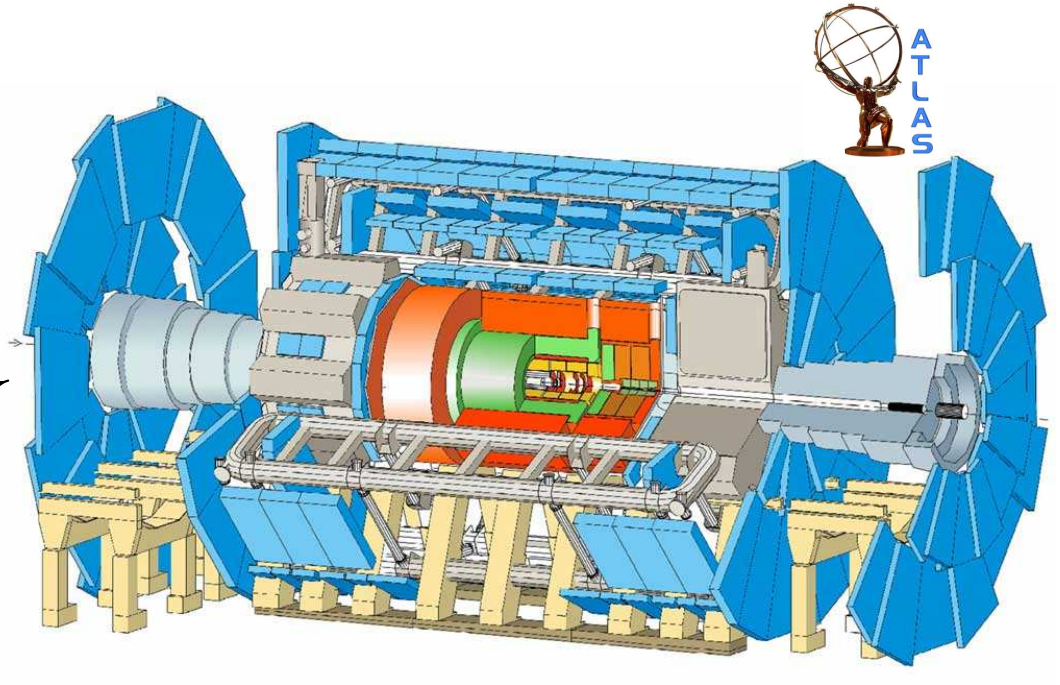
(+ Wt + s-channel)

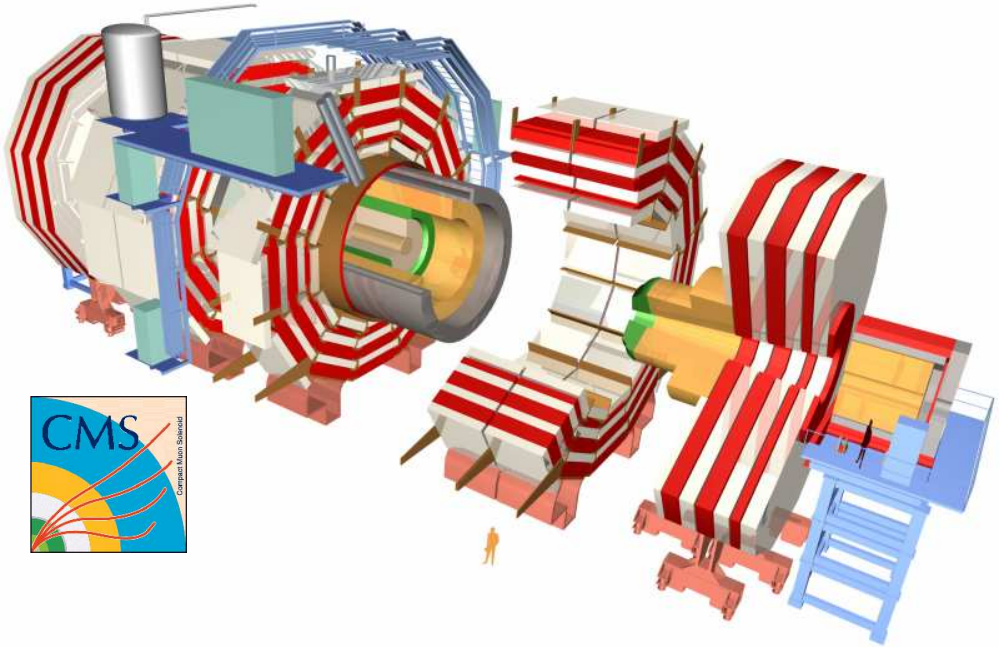
- $\Gamma_t^{SM} = 1.42$ GeV (including m_b, m_W, α_s, EW corrections)
  - $\tau_t < 10^{-23}$ s $\Rightarrow$ top decays before hadronization

- Top can be a window to physics beyond the SM

The ATLAS and CMS experiments







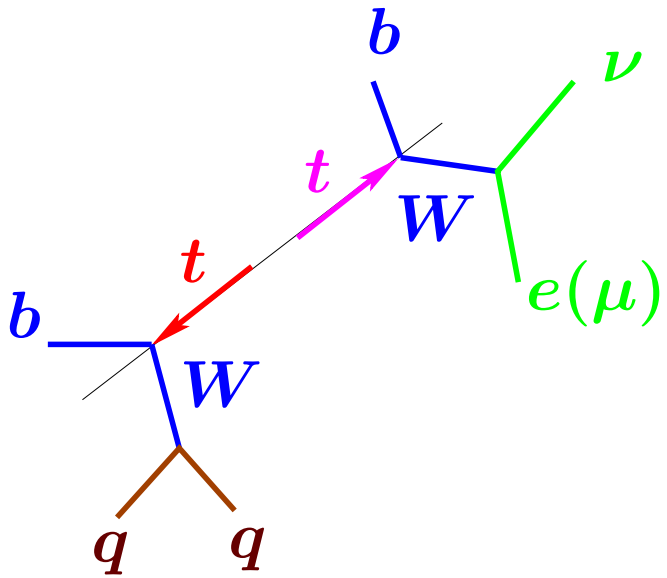
LHC: pp collisions at
$\sqrt{s} = 14$ TeV

New physics in $t \longrightarrow bW$ decay

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

PRD45 (1992) 124:

$|f_1^R| \equiv |V_R|$
$|f_2^L| \equiv |g_L|$
$|f_2^R| \equiv |g_R|$



Event selection:

- ≥ 4 jets with $p_T > 20$ GeV/c and $|\eta| < 2.5$
- 2 b-tagged jet
- ≥ 1 lepton with $p_T > 25$ GeV/c and $|\eta| < 2.5$
- $p_T^{missing} > 20$ GeV/c
- $|M(jj) - M_W| < 100$ GeV/c^2
- $|M(jjb) - M_t| < 200$ GeV/c^2

Signal efficiency: 8.7%

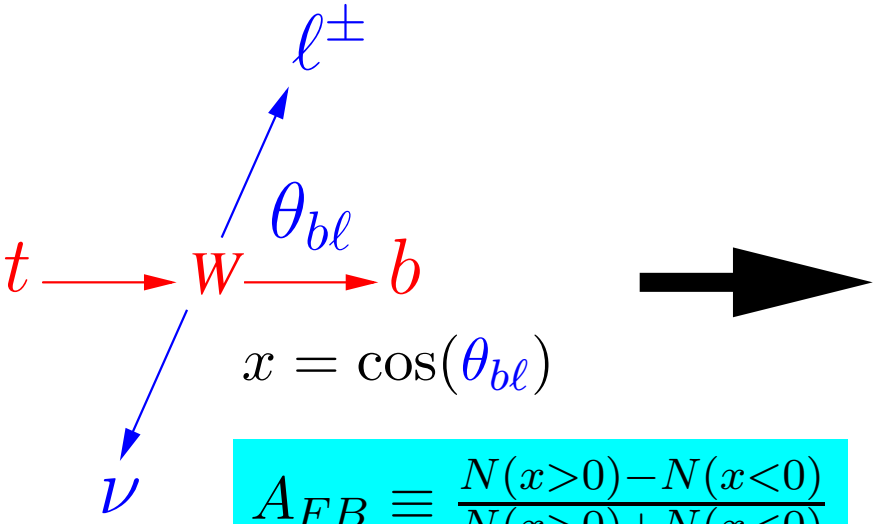
SM background: ~ 40k events

(~ 30k from $t\bar{t} \longrightarrow bqqb\tau\nu_\tau$ and ~ 10k from single top)

L=10 fb^{-1}

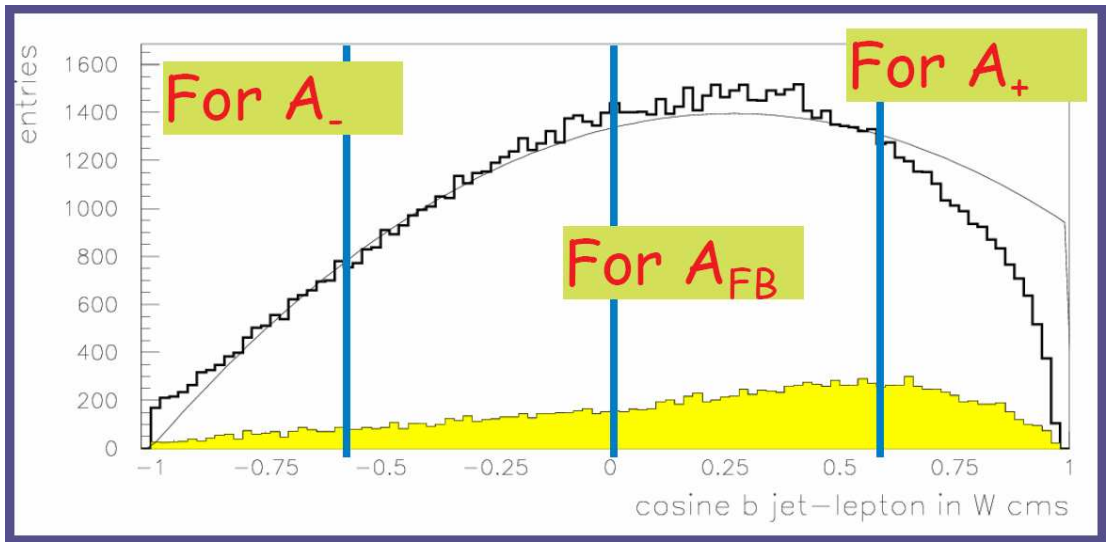
New physics in $t \to bW$ decay

- Angular asymmetries in $t \to bW$ decay



$A_{FB} \equiv \frac{N(x>0)-N(x<0)}{N(x>0)+N(x<0)}$

$\cos(\theta_{b\ell})$ in W cms



L=10 fb^{-1}

- $A_{FB} = 0.2234 \pm 0.0035(\text{stat}) \pm 0.0130(\text{sys}) \quad [\sigma/A_{FB} = 6.0\%]$
- $A_{+} = -0.5472 \pm 0.0032(\text{stat}) \pm 0.0099(\text{sys}) \quad [\sigma/A_{+} = 1.9\%]$
- $A_{-} = 0.8387 \pm 0.0018(\text{stat}) \pm 0.0028(\text{sys}) \quad [\sigma/A_{-} = 0.4\%]$

New physics in $t \longrightarrow bW$ decay

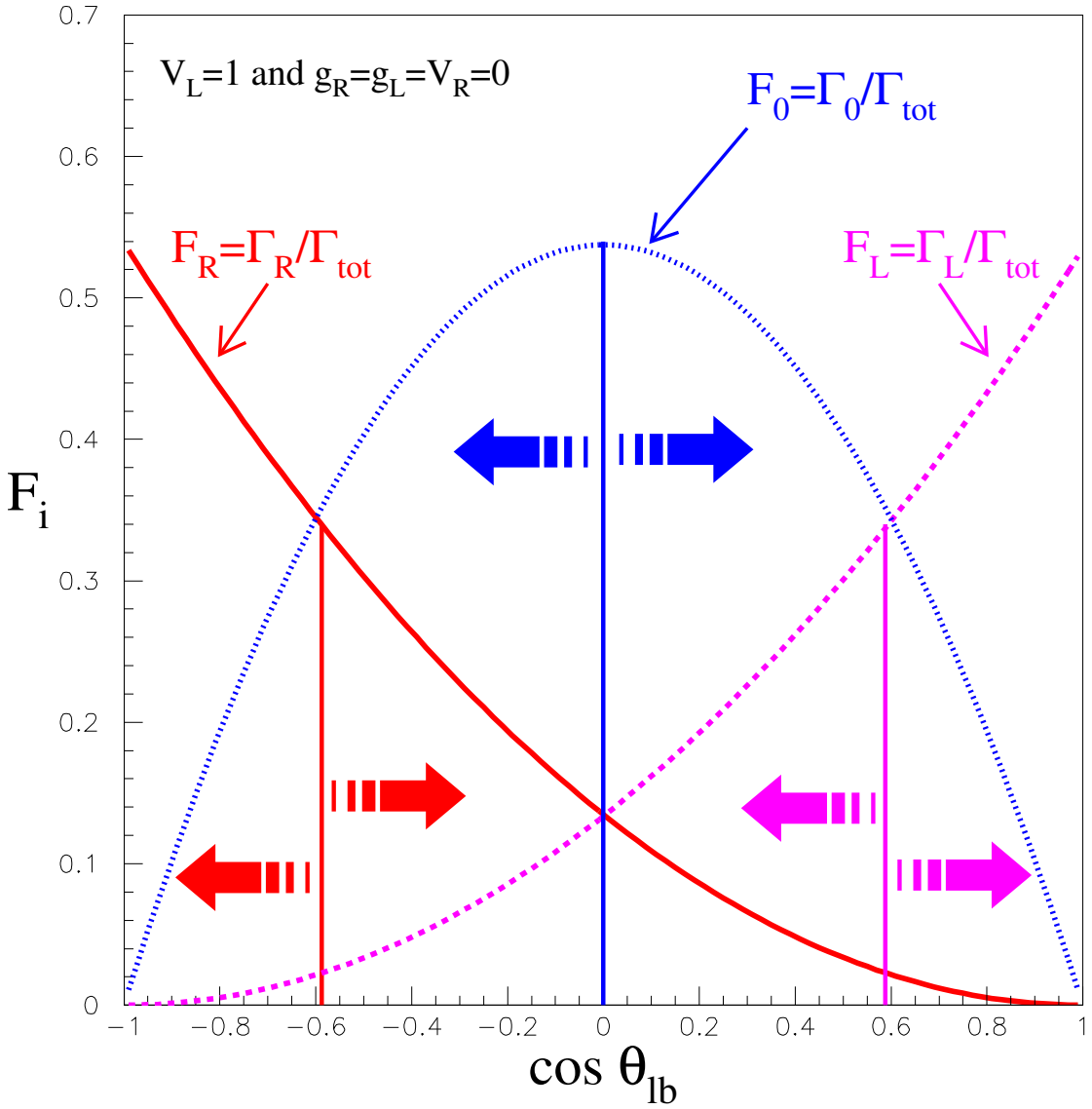
- W polarization:

$$A_{FB} = a_0(F_L - F_R) = 0.2226 \text{ (LO)}$$

$$A_+ = a_1 F_L - a_2 F_0 = -0.5482 \text{ (LO)}$$

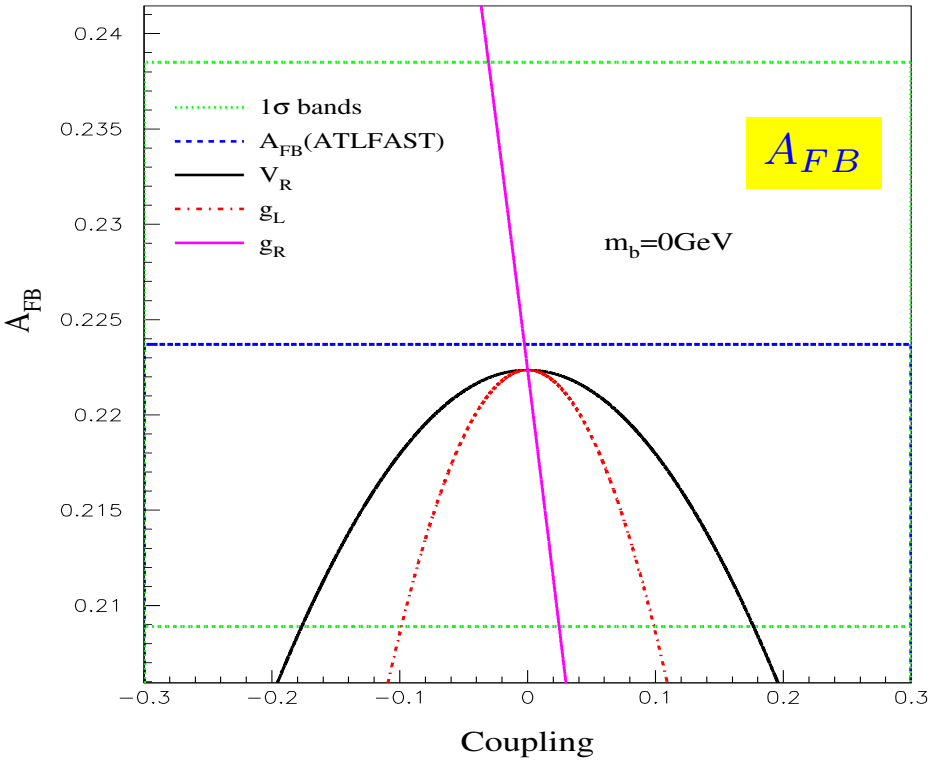
$$A_- = -a_1 F_R + a_2 F_0 = 0.8397 \text{ (LO)}$$

(F_L, F_R, F_0 defined as in SN-ATLAS-2005-052)

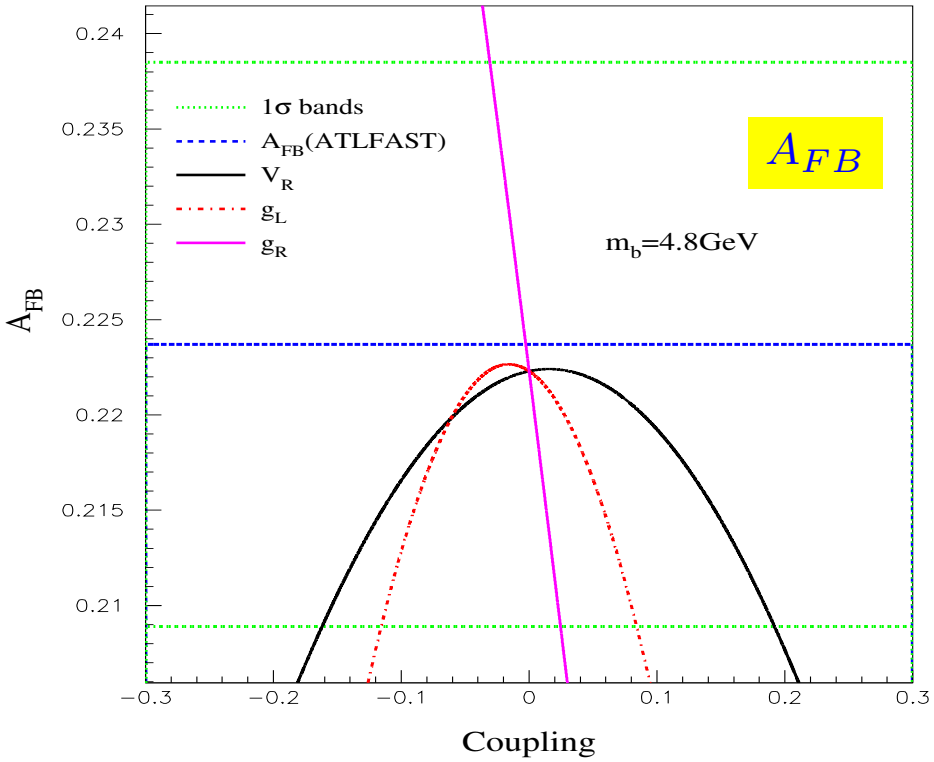


New physics in $t \rightarrow bW$ decay

- Anomalous Couplings



$m_b = 0$ GeV$/c^2$



$m_b = 4.8$ GeV$/c^2$

[PRD67 (2003) 014009]

- Differences up to 17% in g_L and up to 9% in V_R

L=10 fb^{-1}

New physics in $t \longrightarrow bW$ decay

L=10 fb^{-1}

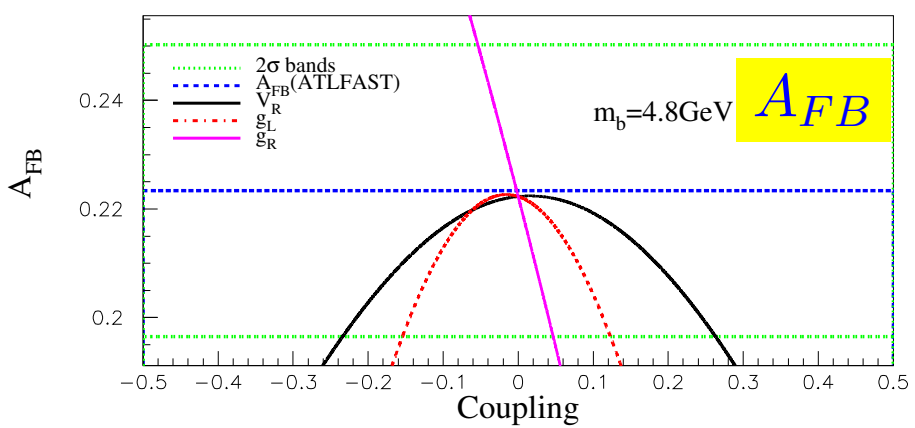
limits on the anomalous couplings:

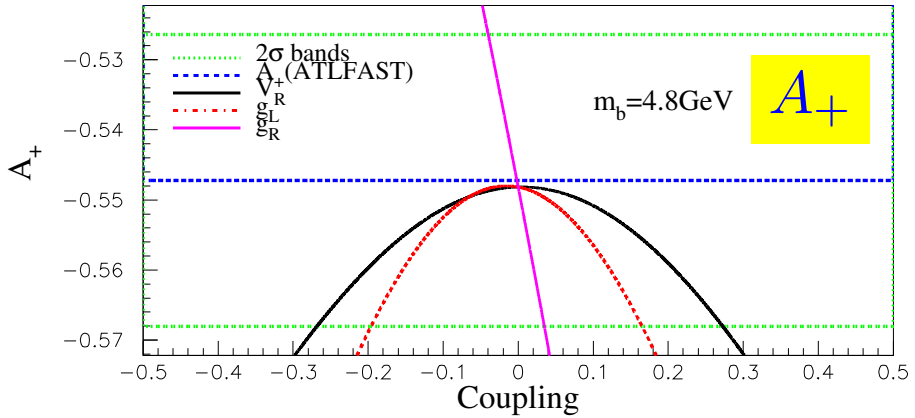
m_b taken into account

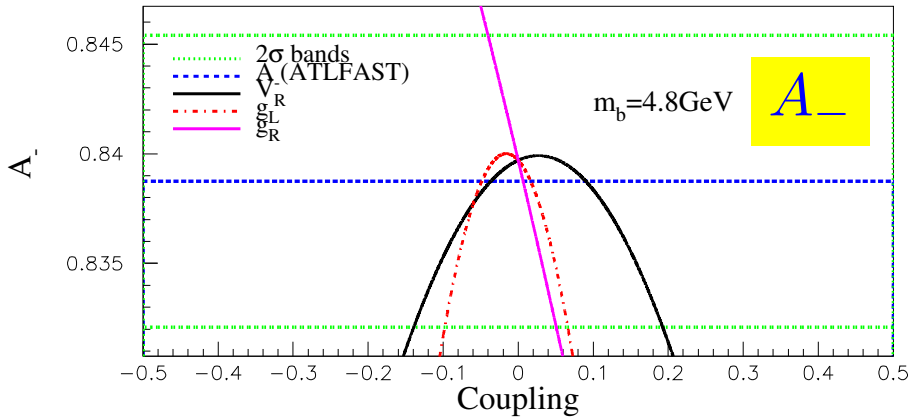
$\mathbf{1\sigma}$ limits	$\mathbf{2\sigma}$ limits
$V_R \in [-0.10, 0.15]$	$V_R \in [-0.14, 0.19]$
$g_L \in [-0.08, 0.05]$	$g_L \in [-0.10, 0.07]$
$g_R \in [-0.02, 0.02]$	$g_R \in [-0.04, 0.04]$

Compatible with results from W polarization analysis (semileptonic and dileptonic channels): SN-ATLAS-2005-052

(2σ limits considering $m_b = 0$ GeV/c^2)







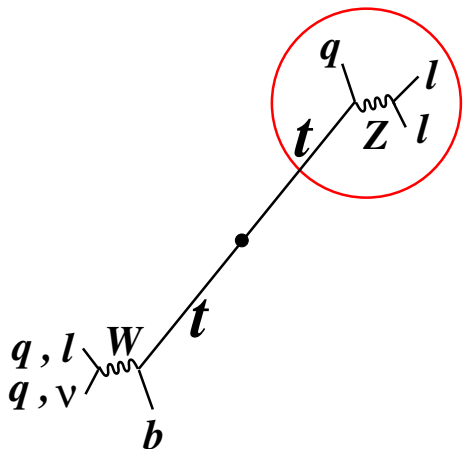
Top quark FCNC decays

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

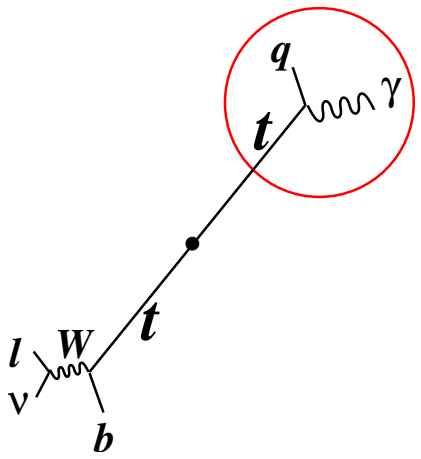
	BR in SM	2HDM	MSSM	$\not{R}$ SUSY	QS
$t \to qZ$	$\sim 10^{-14}$	$\sim 10^{-7}$	$\sim 10^{-6}$	$\sim 10^{-5}$	$\sim 10^{-4}$
$t \to q\gamma$	$\sim 10^{-14}$	$\sim 10^{-6}$	$\sim 10^{-6}$	$\sim 10^{-6}$	$\sim 10^{-9}$
$t \to qg$	$\sim 10^{-12}$	$\sim 10^{-4}$	$\sim 10^{-5}$	$\sim 10^{-4}$	$\sim 10^{-7}$

- 3 top decay channels studied:

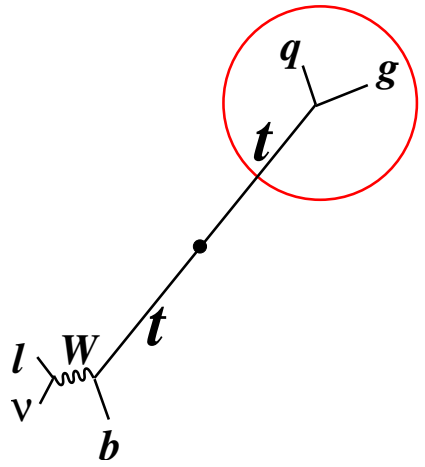
$t \to qZ$



$t \to q\gamma$

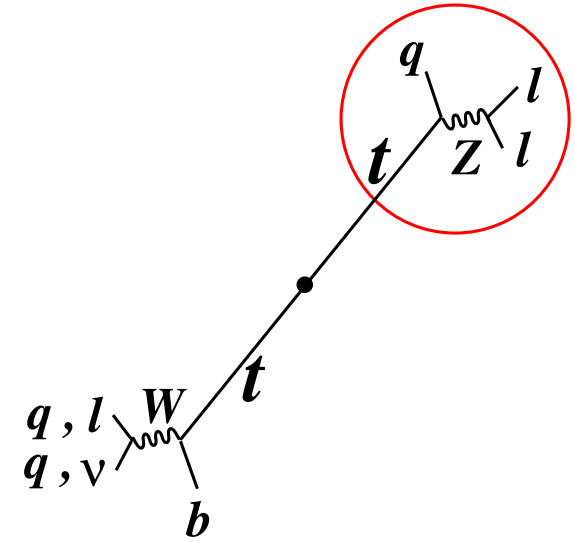


$t \to qg$



Top quark FCNC decays

$t \to qZ$



Analysis strategy:

① Sequential analysis [ATL-PHYS-2001-007]

- $Z \to ll$, $W \to l\nu$ (2jets+3l+missing)
- $Z \to ll$, $W \to qq$ (4jets+2l) → not described (see ATL note)

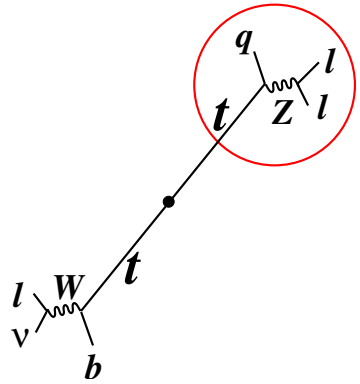
② Probabilistic analysis [ATL-PHYS-PUB-2005-009]

- $Z \to ll$, $W \to l\nu$ (2jets+3l+missing)

Top quark FCNC decays

$t \to qZ$

Sequential analysis: $Z \to ll$, $W \to l\nu$



- ≥ 2 jets with $p_T > 50$ GeV/c and $|\eta| < 2.5$
- only 1 b-tagged jet
- ≥ 3 leptons:
  - $p_T > 20$ GeV/c and $|\eta| < 2.5$
  - 2 leptons with same flavour and opposite charges ($\ell^+\ell^- = e^+e^-, \mu^+\mu^-$)
  - $|M(\ell^+\ell^-) - M_Z| < 6$ GeV/c^2
- $p_T^{missing} > 30$ GeV/c

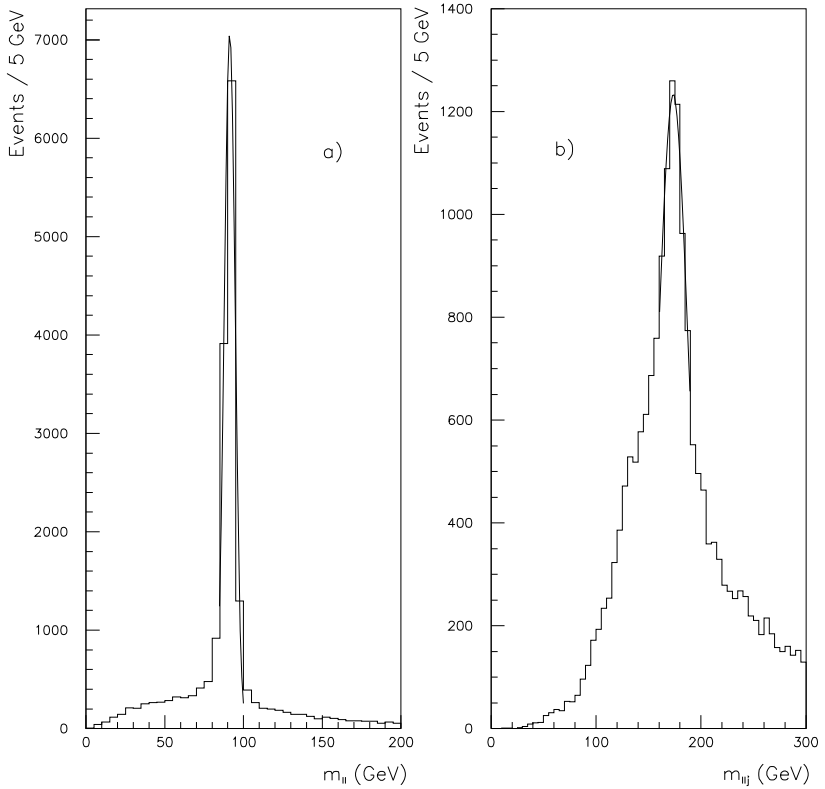
$|M(\ell^+\ell^- j) - M_t| < 24$ GeV/c^2:

0.6 back. events (mainly $t\bar{t}$)

$\varepsilon \times BR$ = 0.08%

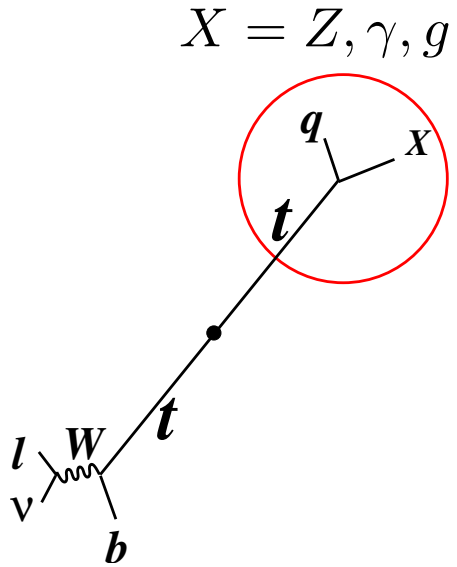
L=10 fb^{-1}

$m_{\ell^+\ell^-}$ $m_{\ell^+\ell^- j}$



Top quark FCNC decays

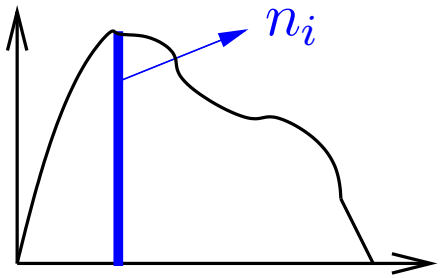
Probabilistic Analysis:



- Preselection
  - General criteria:
    - ≥ 1 lepton ($p_T > 25$ GeV$/c$ and $|\eta| < 2.5$)
    - ≥ 2 jets ($p_T > 20$ GeV$/c$ and $|\eta| < 2.5$)
    - only 1 b-tagged jet
    - $p_T^{miss.} > 20$ GeV$/c$
  - Events classified into different channels (qZ, $q\gamma$ or qg)
  - Specific criteria for each channel
- Probabilistic type of analysis after the preselection

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

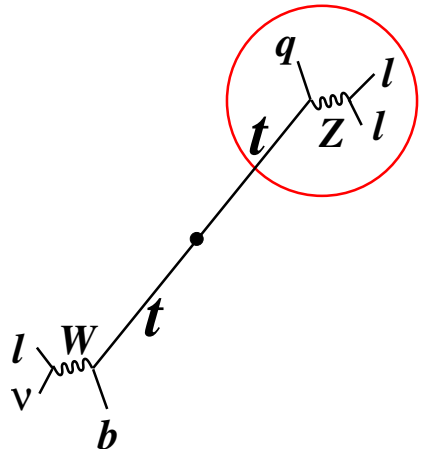
$$L_B = \Pi_{i=1}^{N} P_i^{back.}$$



$$P_i = \frac{n_i}{n_{total}}$$

Top quark FCNC decays

$t \rightarrow qZ$



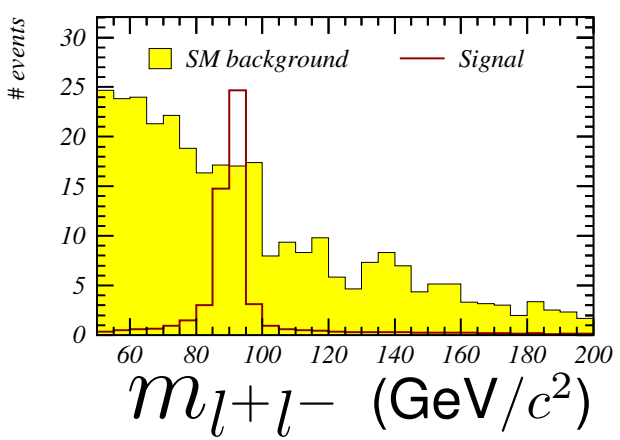
specific criteria:

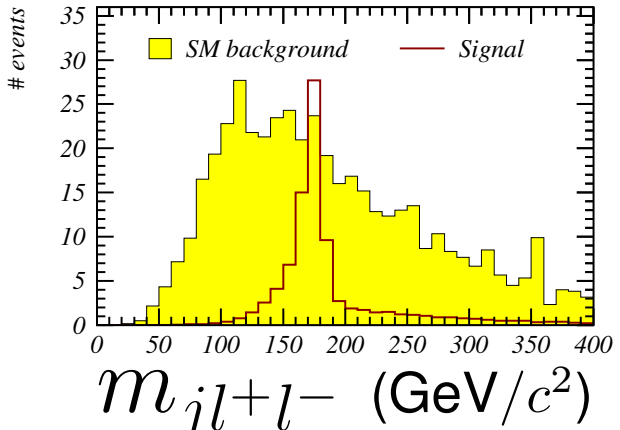
- ≥ 3 leptons:
  - $p_T^{l2,l3} > 10$ GeV$/c$ and $|\eta| < 2.5$)
  - 2 leptons with same flavour and opposite charges ($\ell^+\ell^- = e^+e^-, \mu^+\mu^-$)
- $p_T^{j1} > 30$ GeV$/c$

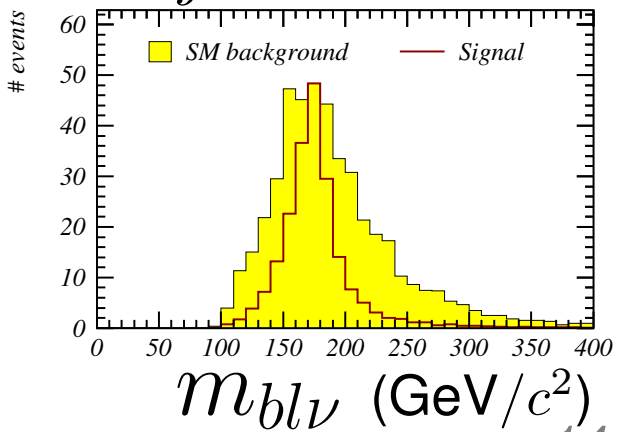
453.8 back. events (mainly $t\bar{t}$)

$\varepsilon \times BR$ = 0.23%

L=10 fb^{-1}

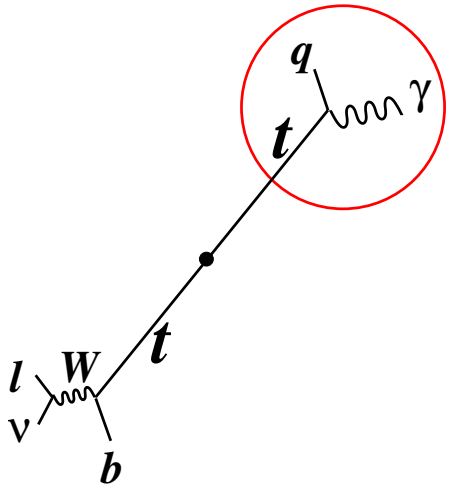






Top quark FCNC decays

$t \to q\gamma$



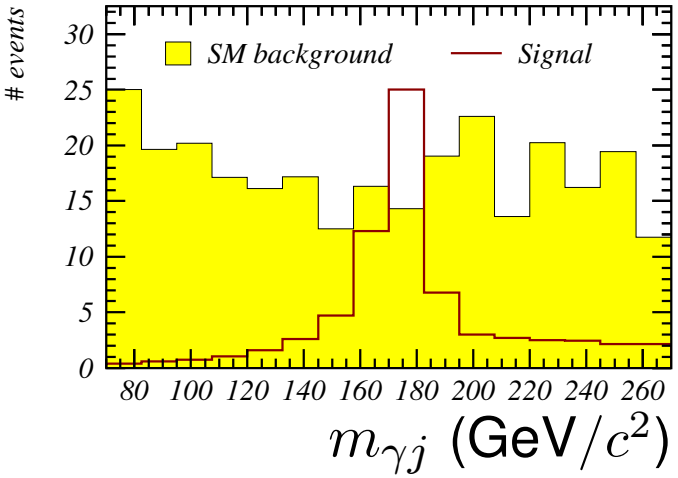
specific criteria:

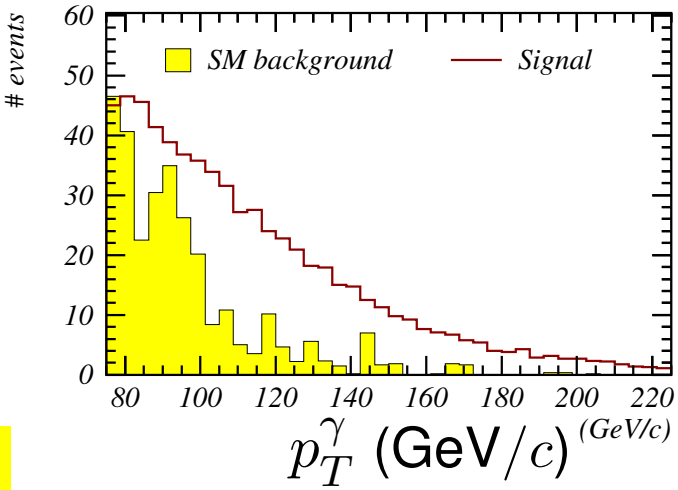
- 1 photon
  - $p_T > 75$ GeV$/c$, $|\eta| < 2.5$
- 20 GeV$/c^2 < m_{\gamma j} <$ 270 GeV$/c^2$
- < 3 leptons

290.7 back. events (mainly $t\bar{t}$)

$\varepsilon \times BR$ = 1.88%

L=10 fb^{-1}



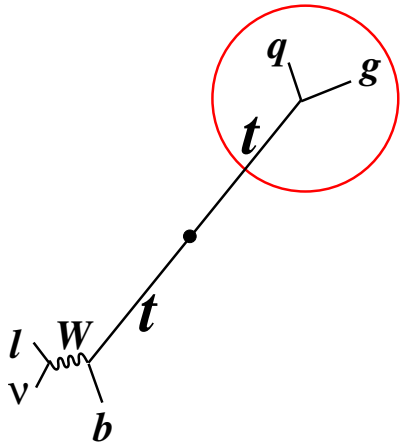


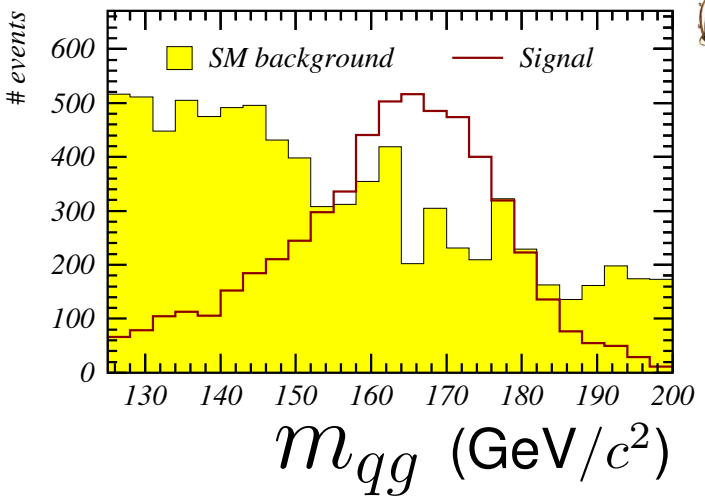
Top quark FCNC decays

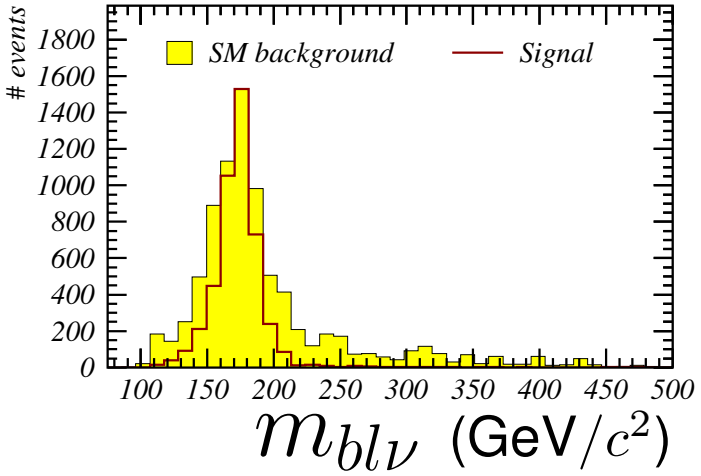
$t \rightarrow qg$

specific criteria:

- only one lepton
- no γ with $p_T > 5$ GeV$/c$
- $E_{visible} > 300$ GeV
- 3 jets ($p_T^{j1} > 40$ GeV$/c$, $p_T^{j2,3} > 20$ GeV$/c$ and $|\eta| < 2.5$)
- $p_T^g > 75$ GeV$/c$
- $125 < m_{qg} < 200$ GeV$/c^2$







8166.1 back. events ($\sim 60\%$ $t\bar{t}$)

$\varepsilon \times BR$ = 0.39%

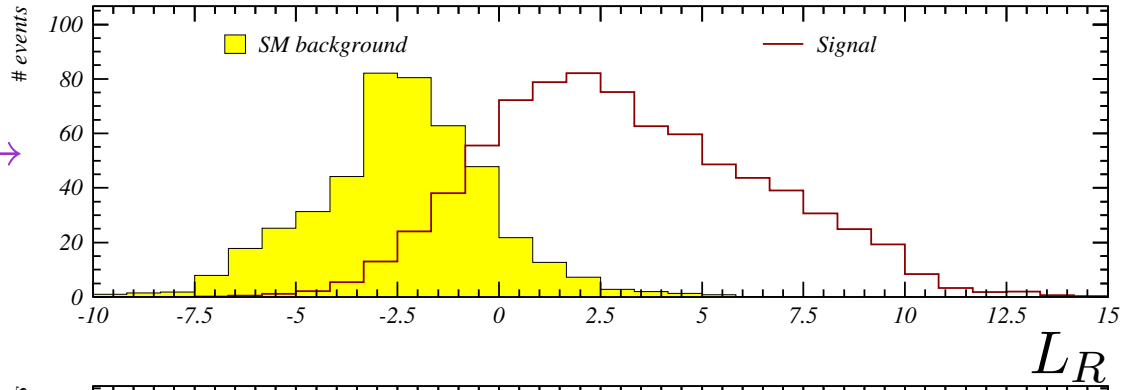
L=10 fb^{-1}

gluon is the non-b jet with highest p_T

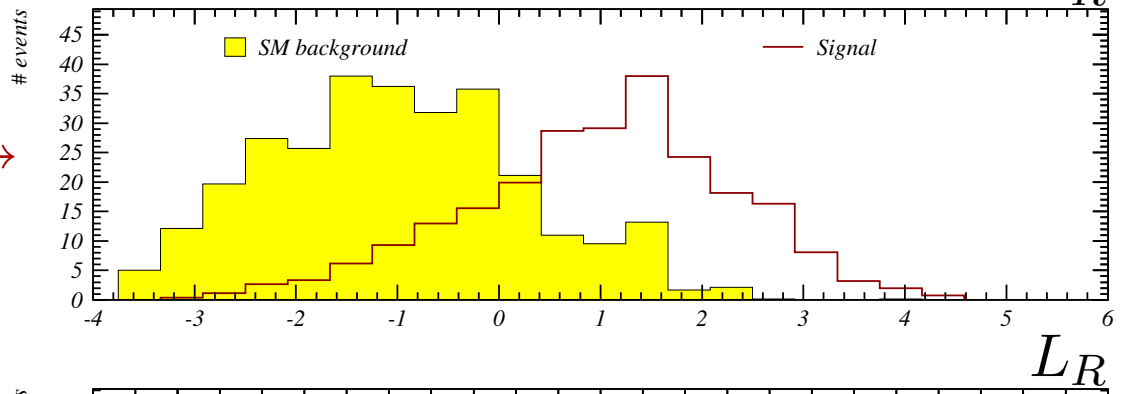
Top quark FCNC decays

- discriminant variable: $L_R = \ln(L_S/L_B)$

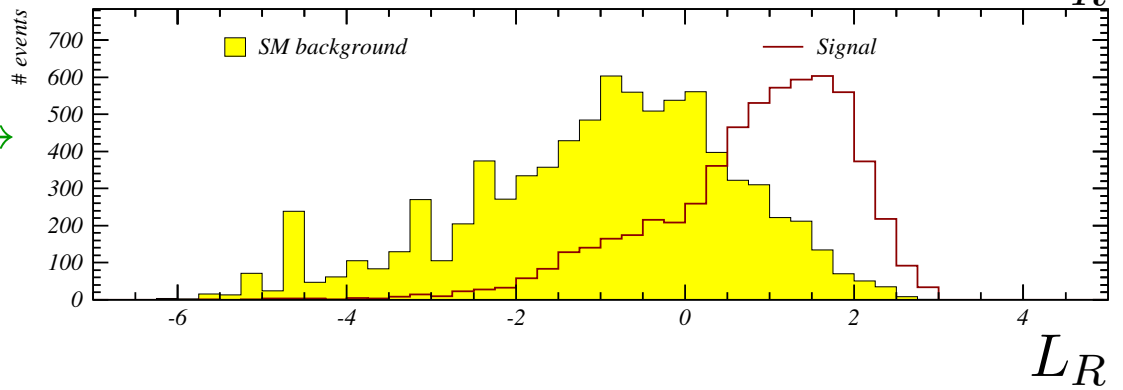
qZ **channel** $\rightarrow$



$q\gamma$ **channel** $\rightarrow$

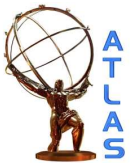


qg **channel** $\rightarrow$



L=10 fb^{-1}

Top quark FCNC decays



- **BR 5σ sensitivity**
  - $BR = \frac{5\sqrt{B}}{2 \times L \times \sigma(t\bar{t}_{SM}) \times \varepsilon_t \times \varepsilon_\ell}$ $\quad [\sigma(t\bar{t}_{SM}) = 833$ pb (NLO) $\quad \varepsilon_\ell = 0.9^{n_{leptons}}]$

- **Sequential analysis** [$|M(\ell^+\ell^- j) - M_t| < 24$ GeV/c^2 cut]:

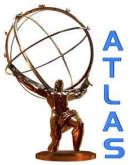
	$t \to qZ$ $(Z \to ll, W \to l\nu)$	$t \to qZ$ $(Z \to ll, W \to qq')$
$L = 100$ fb^{-1}	1.1×10^{-4}	5.0×10^{-4}

- **Discriminant analysis:**

  cut applied to the discriminant variable (best $S/\sqrt{B}$)

	$t \to qZ$	$t \to q\gamma$	$t \to qg$
$L = 10$ fb^{-1}	5.1×10^{-4}	1.2×10^{-4}	4.6×10^{-3}
$L = 100$ fb^{-1}	1.6×10^{-4}	3.8×10^{-5}	1.4×10^{-3}

Top quark FCNC decays



- **expected 95% CL limits on BR (absence of signal)**
  - **Sequential analysis** [$|M(\ell^+\ell^- j) - M_t| < 24$ GeV/c^2 cut]:

	$t \to qZ$ $(Z \to ll, W \to l\nu)$	$t \to qZ$ $(Z \to ll, W \to qq')$
$L = 100$ fb^{-1}	6.3×10^{-5}	2.8×10^{-4}

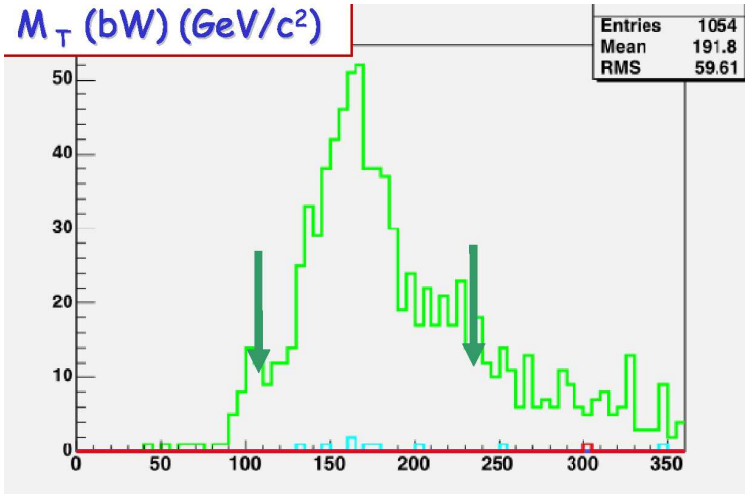
  - **Discriminant analysis:**
    - Modified frequentist likelihood method [A.L. Read, CERN report 2000-005 (2000) 81]
    - No cuts on the discriminant variable used

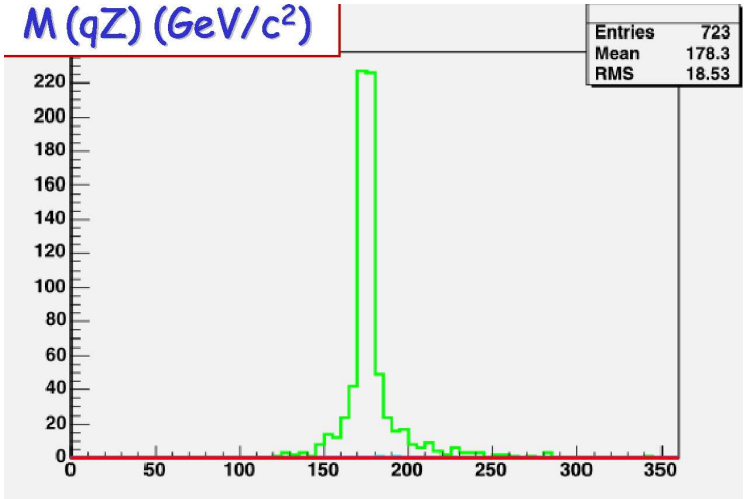
	$t \to qZ$	$t \to q\gamma$	$t \to qg$
$L = 10$ fb^{-1}	3.4×10^{-4}	6.6×10^{-5}	1.4×10^{-3}
$L = 100$ fb^{-1}	6.5×10^{-5}	1.8×10^{-5}	4.3×10^{-4}

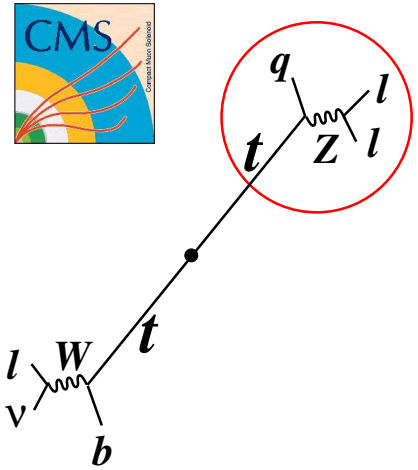
    - Dominant systematics: M_t and $\varepsilon_{btag} < 20\%$

Top quark FCNC decays

- Preliminary study at generator level





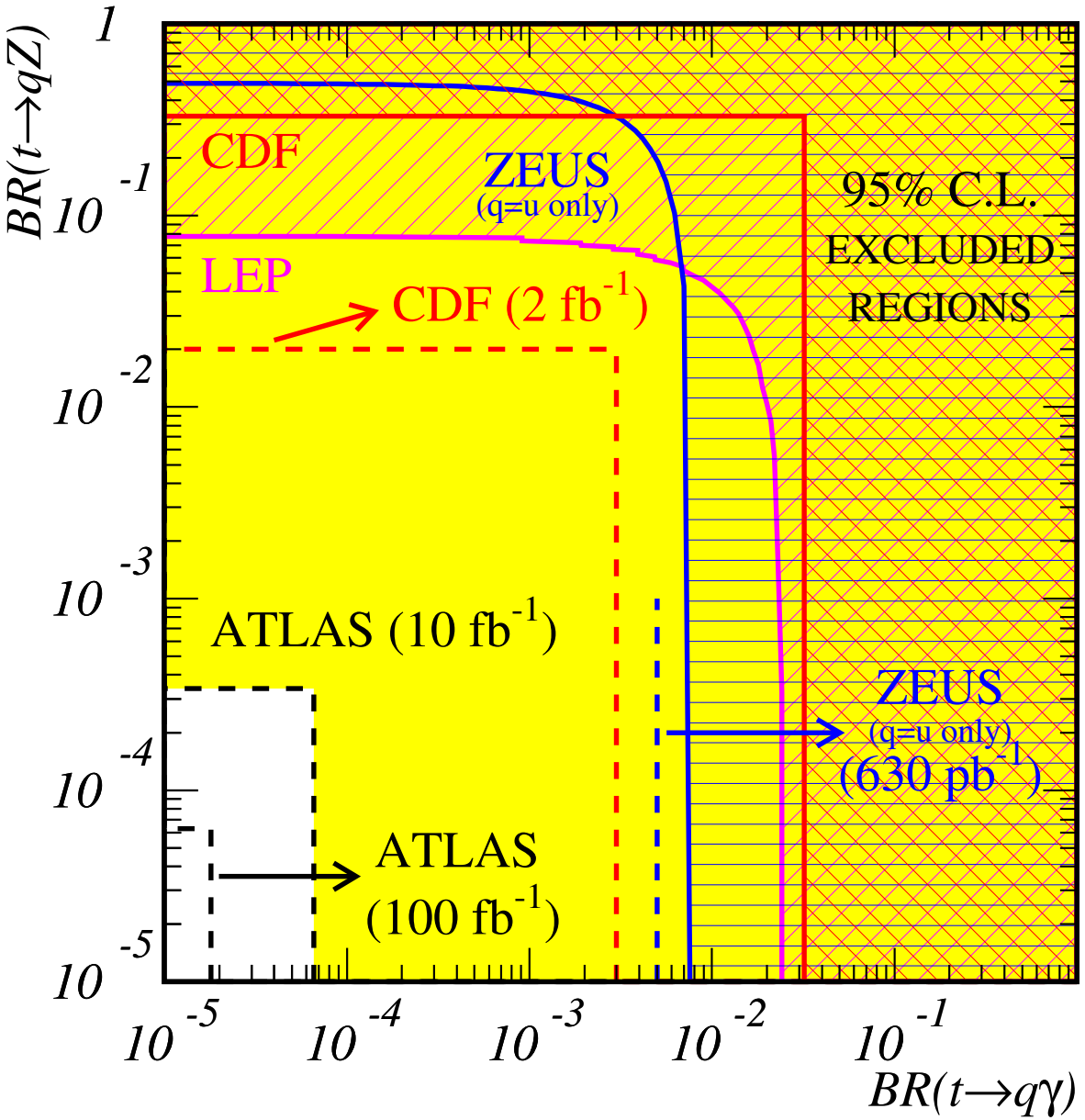


- Estimated $BR(t \to qZ)$ sensitivity for a 3σ discovery: $S/\sqrt{S+B} = 3$

	$L = 100$ fb^{-1}
expected $t\bar{t}$ SM events	[130,250]
expected signal efficiency	[5%,6%]
$BR(t \to qZ)$ sensitivity	$[\mathbf{14 \times 10^{-4}, 22 \times 10^{-4}}]$

- **CMS Physics TDR in April**
  - results on the CMS sensitivity to $t \to qZ$ and $t \to q\gamma$ FCNC decays

Top quark FCNC decays



(thanks to Lorenzo Bellagamba)

LHC combination (ATLAS/CMS) will improve the limits

$BR(t \to qg)$ (95% CL):

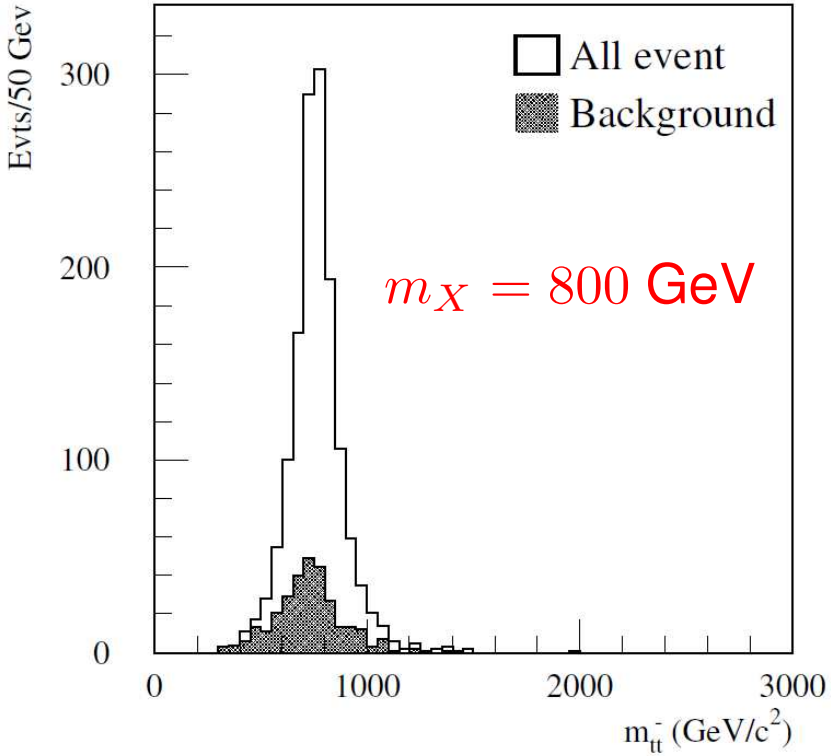
TEVATRON ($L = 2$ fb^{-1}): level of few %

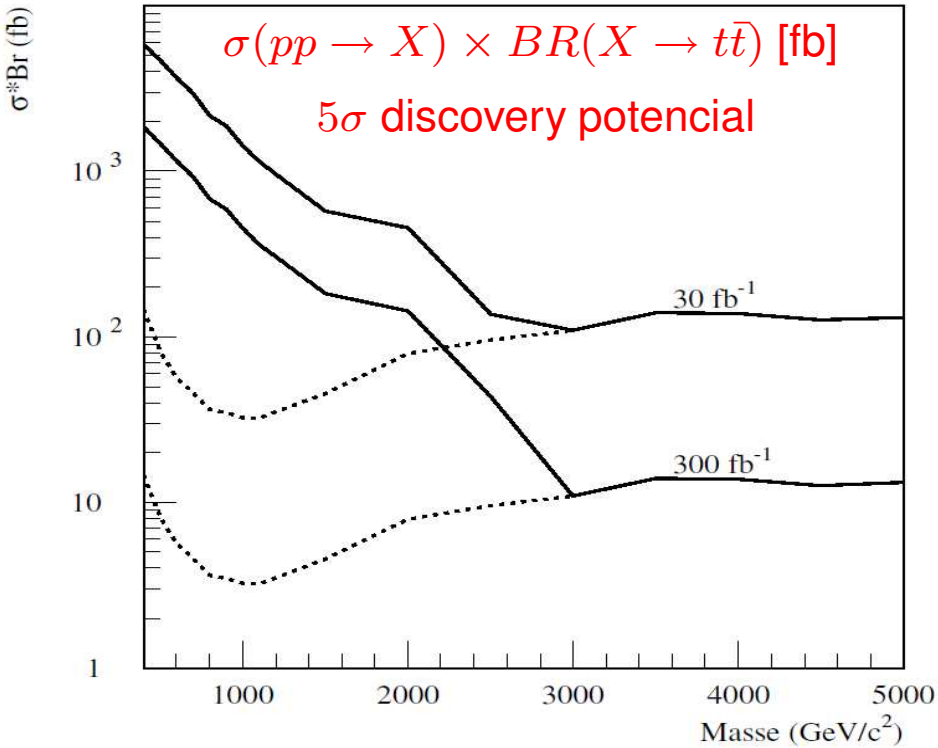
ATLAS ($L = 10$ fb^{-1}): $< 0.14\%$

$t\bar{t}$ resonances

- $\tau_t < 10^{-23}$ s $\Rightarrow$ no $t\bar{t}$ bound states within the SM
- $X \to t\bar{t}$ in several SM extensions (SUSY, Technicolor, . . .)
  - MSSM predicts $BR(H^0, A \to t\bar{t}) \sim 1$ for $m_{H^0,A} > 2m_t$ and $\tan\beta \sim 1$
- $X \to t\bar{t} \to WbW\bar{b} \to \ell\nu bjjb$ topology was studied
  (X is a 'generic', narrow resonance)

($\Gamma_X = 2\times$ ATLAS resolution)





Conclusions

- ATLAS sensitivity to new physics in the $t \to bW$ decay:
  - m_b should be taken into account
  - $g_R \in [-0.02, 0.02] \Rightarrow$ factor 2-3 better than the present limits
  - further improvements expected from the combination of the semileptonic and the fully leptonic channels
- LHC sensitivity to top quark FCNC decays ($L = 100$ fb^{-1}, 5σ significance):

  $BR(t \to qZ) \sim 10^{-4}$

  $BR(t \to q\gamma) \sim 10^{-5}$

  $BR(t \to qg) \sim 10^{-3}$
  - improvement combining ATLAS and CMS results
  - sensitivities at the level of SUSY and Quark Singlets models predictions
- ATLAS sensitivity to $t\bar{t}$ resonances:
  - 5σ discovery ($m_X = 1$ TeV$/c^2$, $L = 30$ fb^{-1}): $\sigma \times BR \sim 10^3$ fb