ATLAS sensitivity to top decays beyond the SM

Nuno Castro

Nuno.Castro@cern.ch

ATLAS Collaboration

Flavour in the era of the LHC, CERN, 9th November 2005

Outline

- Physics motivation
- The ATLAS experiment at the LHC
- Physics beyond the SM with top quark
  - MC generation and simulation
  - New physics in the decay $t \rightarrow bW$
  - Top quark FCNC decays
    - $t \rightarrow qZ, t \rightarrow q\gamma, t \rightarrow qg$
- Conclusions

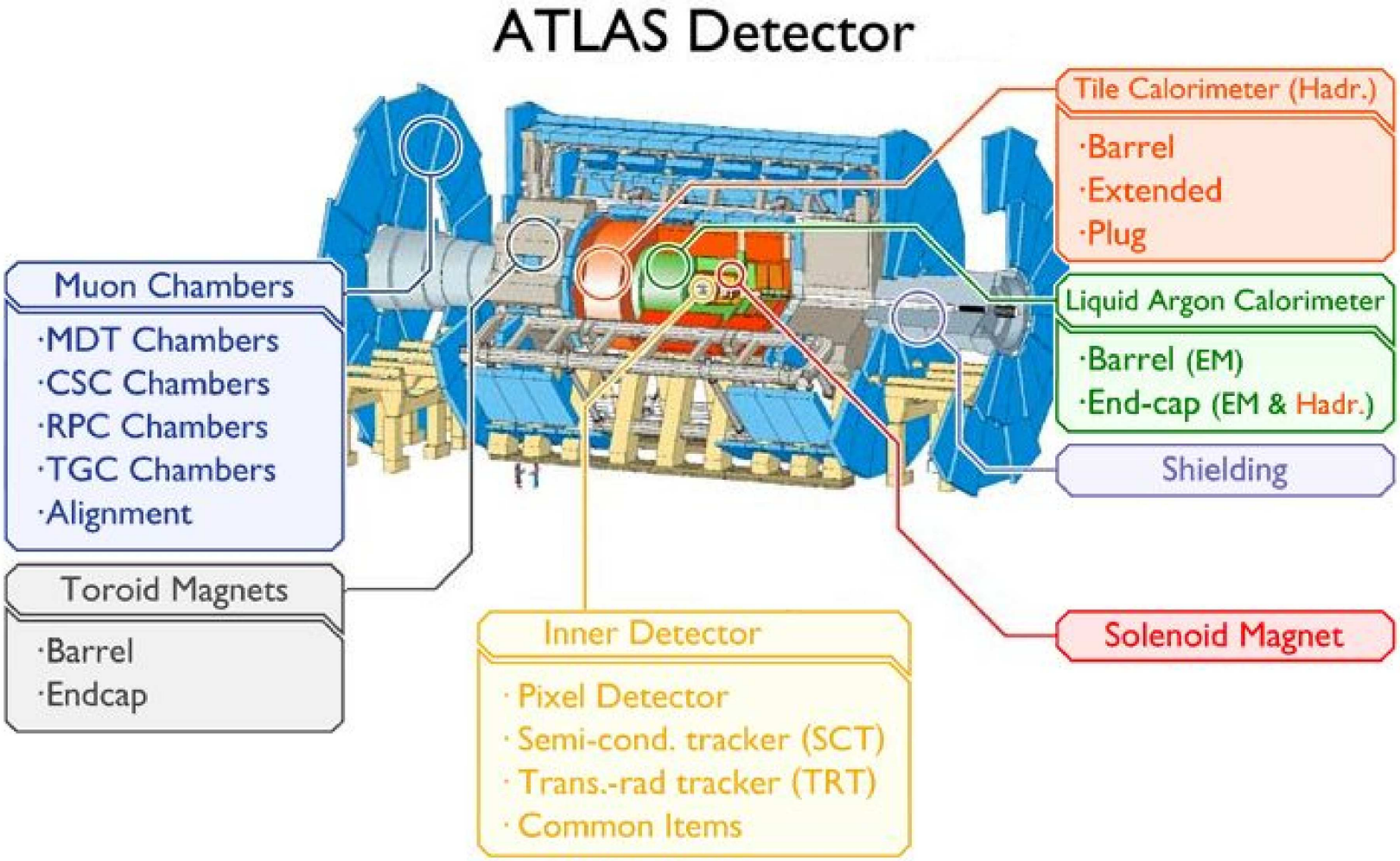
Physics motivation

- Top is the least studied quark in the SM
- The LHC will be a top factory

  $\sigma(pp \to t\bar{t}) = 833$ pb

  ($L = 10$ fb^{-1} $\longrightarrow \sim 8$ million of $t\bar{t}$ pairs per year)
- Top decays can be a window to physics beyond the SM:
  - new physics in $t \to bW$ decay
  - top quark FCNC decays: $t \to qZ$, $t \to q\gamma$, $t \to qg$

The ATLAS experiment at the LHC



MC generation and simulation

- MC generation:
  - SM backgrounds:
    - QCD ($b\bar{b}$), W+jets, Z+jets, WW, ZZ, ZW (PYTHIA, HERWIG)
    - $t\bar{t}_{SM}$, single t production (TopReX, ALPGEN, ONETOP, PYTHIA)
  - signal
    - $t\bar{t}$ production (TopReX, PYTHIA)
      - SM t decay: $t \rightarrow bW \rightarrow b\ell\nu_\ell(\ell = e, \mu)$
      - FCNC t decays: $t \rightarrow qZ, t \rightarrow q\gamma, t \rightarrow qg$
  - different versions of CTEQ PDFs sets used
- ATLAS simulation:
  - ATLFAST
  - ATLFASTB ($\varepsilon_{btag} = 60\%$)

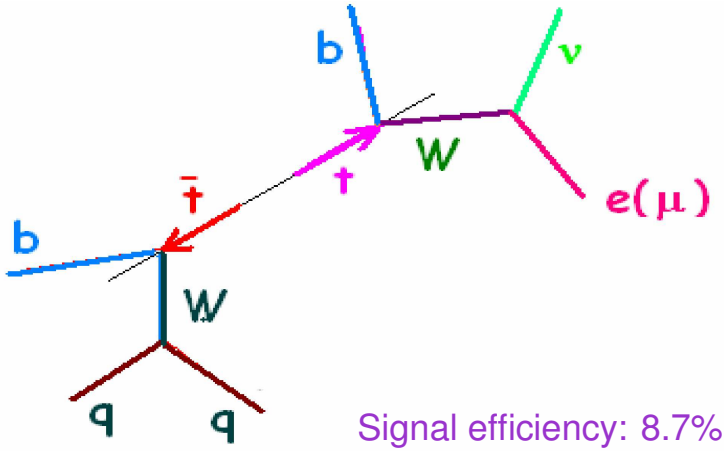
New physics in $t \longrightarrow bW$ decay

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

m_b taken into account [PRD 67 (2003) 014009]

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

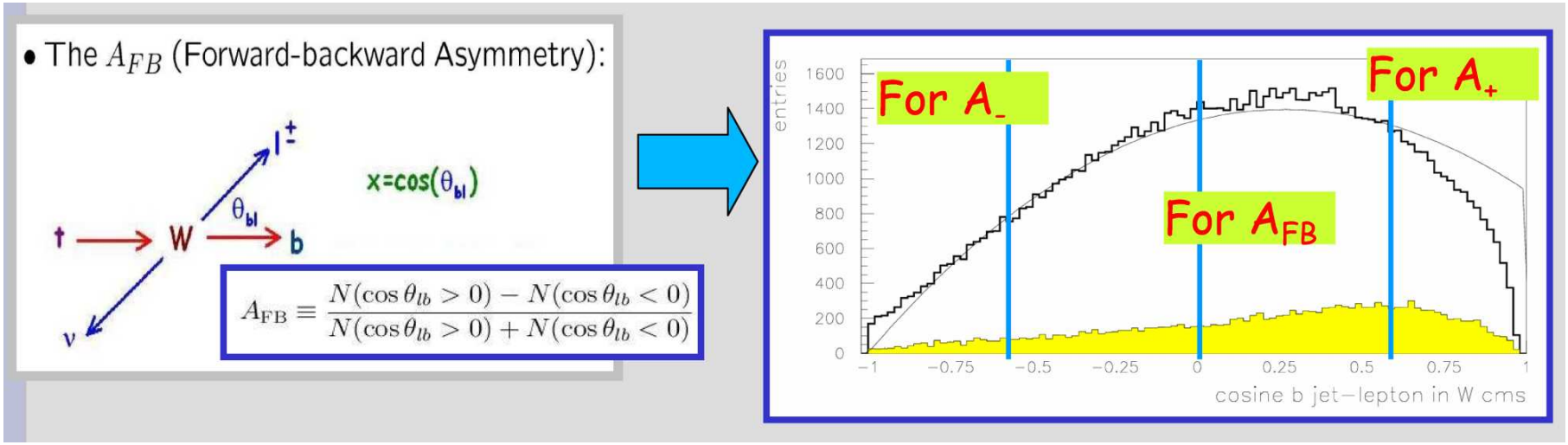


Signal efficiency: 8.7%

SM background: ~ 40k events

($L = 10$ fb^{-1})

New physics in $t \longrightarrow bW$ decay



$$A_{FB} = 0.2232 \pm 0.0035(\text{stat}) \pm 0.0130(\text{sys}) \quad [\sigma/A_{FB} = 6.0\%]$$

$$A_{+} = -0.5472 \pm 0.0032(\text{stat}) \pm 0.0099(\text{sys}) \quad [\sigma/A_{+} = 1.9\%]$$

$$A_{-} = 0.8385 \pm 0.0018(\text{stat}) \pm 0.0028(\text{sys}) \quad [\sigma/A_{-} = 0.4\%]$$

L=10 fb^{-1}

New physics in $t \longrightarrow bW$ decay

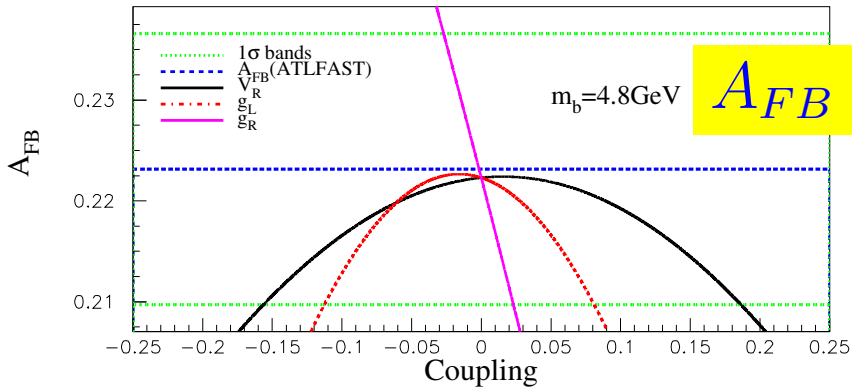
Limits on the anomalous couplings (1σ):

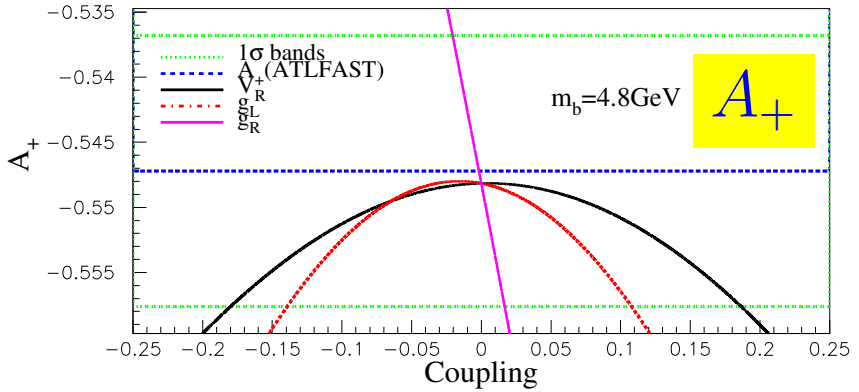
$V_R \in [-0.10, 0.16]$

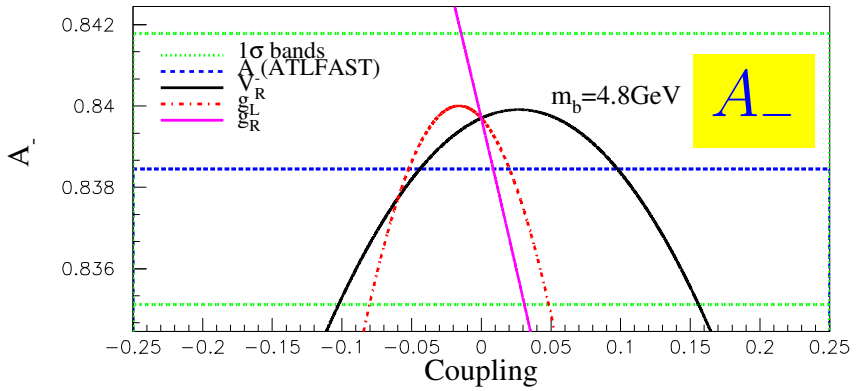
$g_L \in [-0.08, 0.05]$

$g_R \in [-0.02, 0.02]$

[results compatible with SN-ATLAS-2005-052]







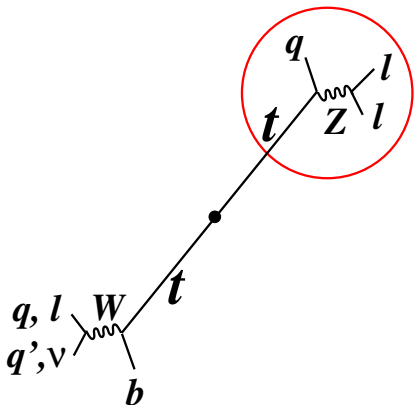
Top quark FCNC decays

	BR in SM	2-Higgs	SUSY	exotic quarks
$t \to qZ$	$\sim 10^{-13}$	$\sim 10^{-6}$	$\sim 10^{-4}$	$\sim 10^{-2}$
$t \to q\gamma$	$\sim 10^{-13}$	$\sim 10^{-7}$	$\sim 10^{-5}$	$\sim 10^{-5}$
$t \to qg$	$\sim 10^{-11}$	$\sim 10^{-5}$	$\sim 10^{-3}$	$\sim 10^{-4}$

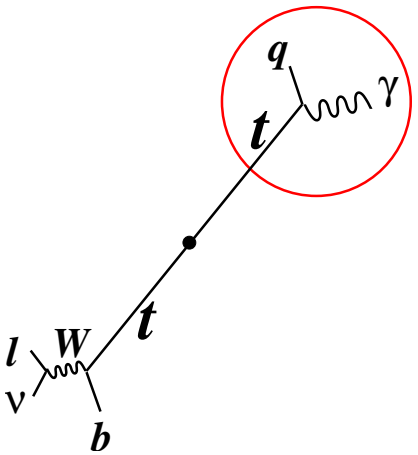
- GIM suppressed in the SM
- higher BR in some SM extensions

  (2-Higgs doublet, SUSY, exotic fermions, . . .)
- 3 top decay channels studied:

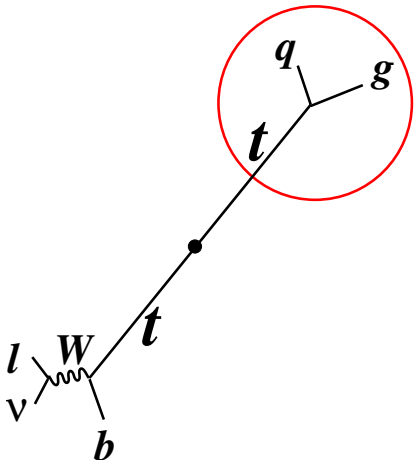
$t \to qZ$



$t \to q\gamma$

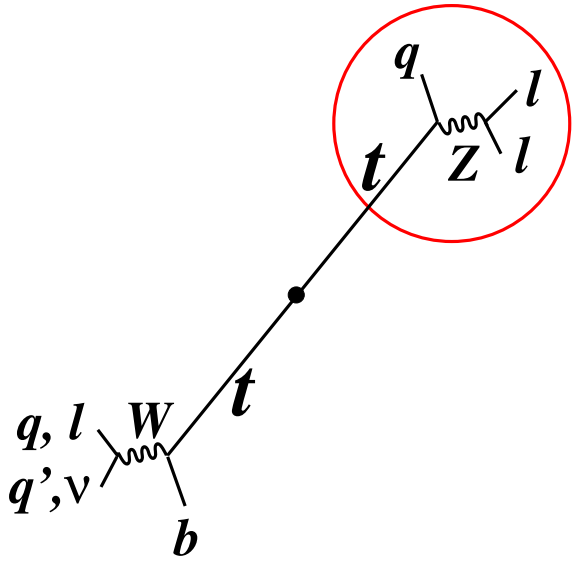


$t \to qg$



Top quark FCNC decays

$t \rightarrow qZ$



Analysis strategy:

1) Sequential analysis

- $Z \rightarrow ll, W \rightarrow l\nu$ (2jets+3l+missing)
- $Z \rightarrow ll, W \rightarrow qq'$ (4jets+2l)

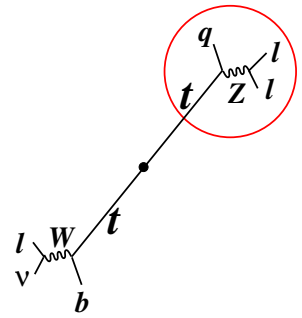
2) Probabilistic analysis

- $Z \rightarrow ll, W \rightarrow l\nu$ (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

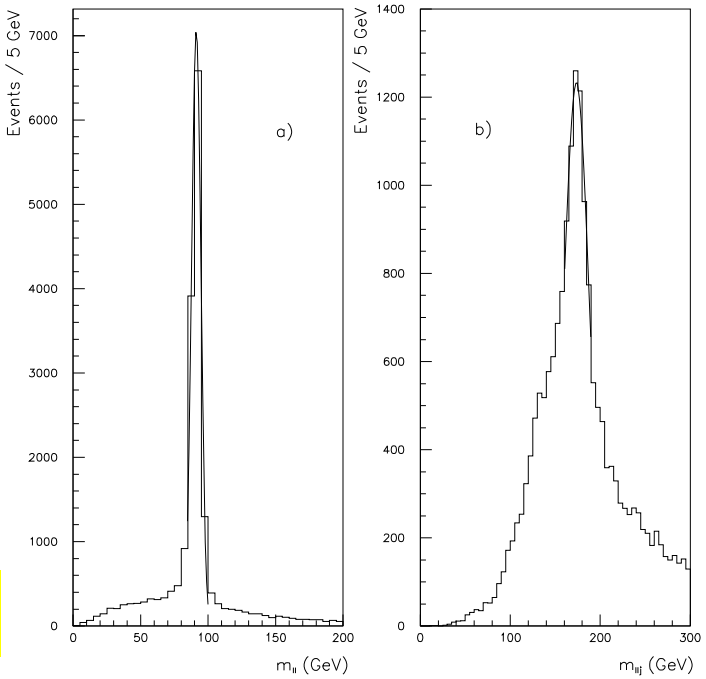
$|M(\ell^+\ell^- j) - M_t| < 24$ GeV/c^2:

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

$\varepsilon \times BR$ = 0.08%

L=10 fb^{-1}

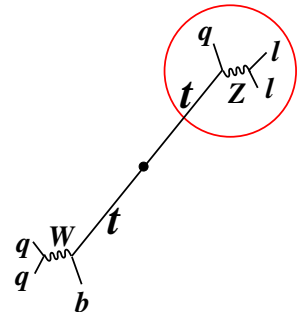
$m_{\ell^+\ell^-}$ $m_{\ell^+\ell^- j}$



Top quark FCNC decays

$t \rightarrow qZ$

Sequential analysis: $Z \rightarrow ll, W \rightarrow qq'$



- ≥ 4 jets with $p_T > 50$ GeV/c and $|\eta| < 2.5$
- only 1 b-tagged jet
- ≥ 2 leptons:
  - $p_T > 20$ GeV/c and $|\eta| < 2.5$
  - $\ell^+\ell^- = e^+e^-, \mu^+\mu^-$
  - $|M(\ell^+\ell^-) - M_Z| < 6$ GeV/c^2
- $|M(j1j2) - M_W| < 16$ GeV/c^2
- $|M(j1j2b) - M_t| < 8$ GeV/c^2

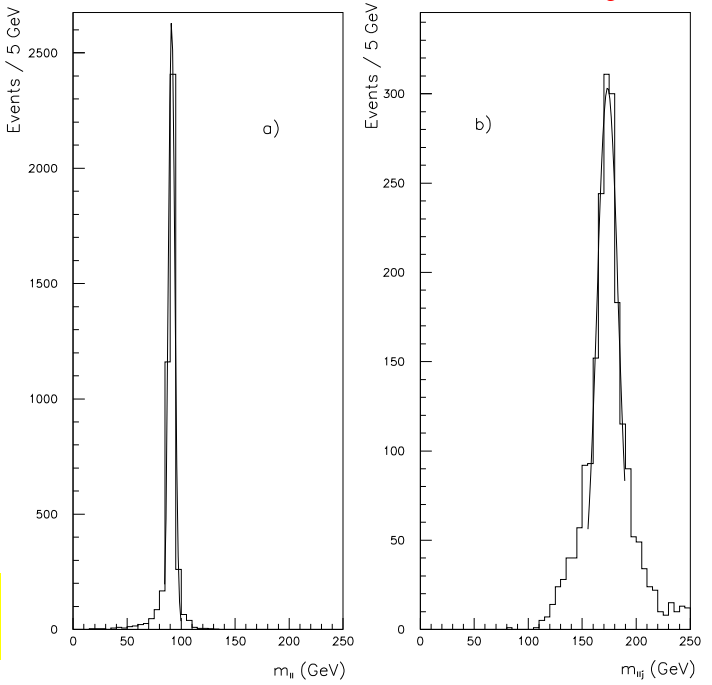
$|M(\ell^+\ell^- j) - M_t| < 24$ GeV/c^2:

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

$\varepsilon \times BR$ = 0.02%

L=10 fb^{-1}

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



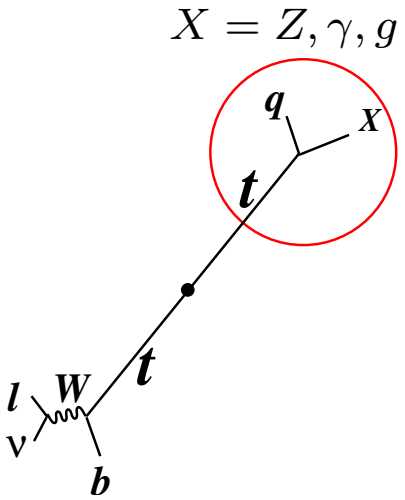
Top quark FCNC decays

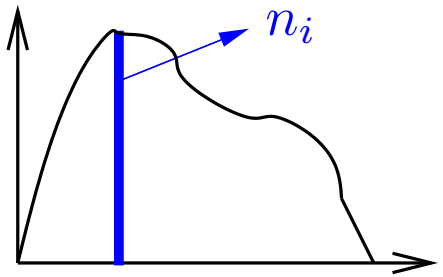
Probabilistic Analysis:

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

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

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

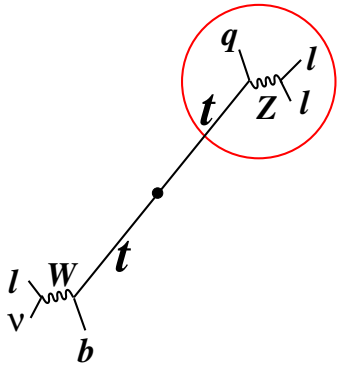




$$P_i = \frac{n_i}{n_{total}}$$

Top quark FCNC decays:

$t \rightarrow qZ$



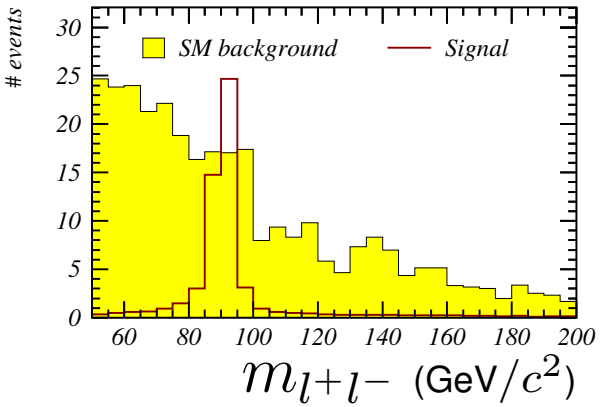
specific criteria:

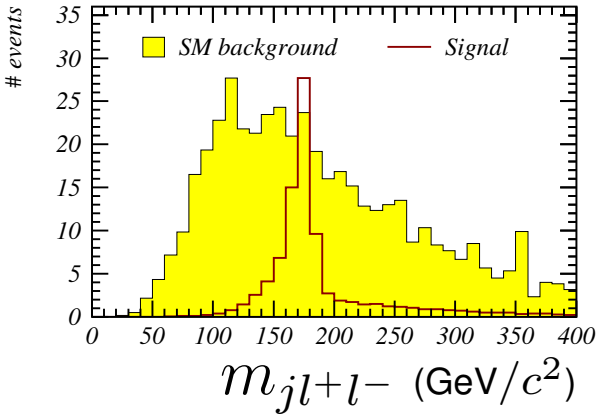
- ≥ 3 leptons:
  - $p_T^{l2,l3} > 10$ GeV$/c$ and $|\eta| < 2.5$)
  - 2 leptons with same flavour and opposite charges ($\ell^+\ell^- = e^+e^-, \mu^+\mu^-$)
- $p_T^{j1} > 30$ GeV$/c$
- only 1 b-tagged jet

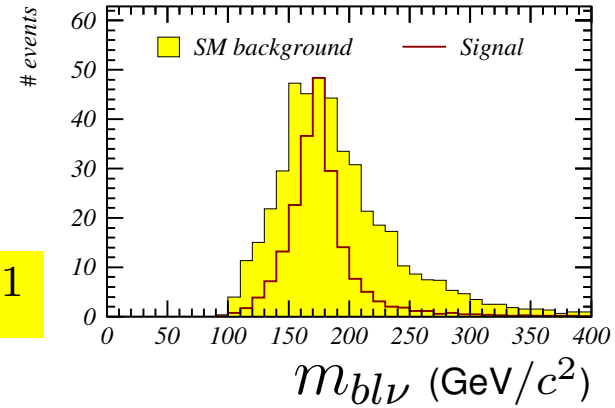
453.8 back. events (mainly $t\bar{t}$)

$\varepsilon \times BR$ = 0.23%

L=10 fb^{-1}







Top quark FCNC decays

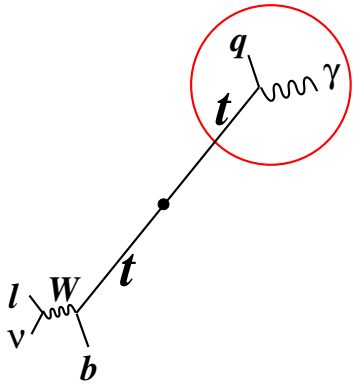
$t \to q\gamma$

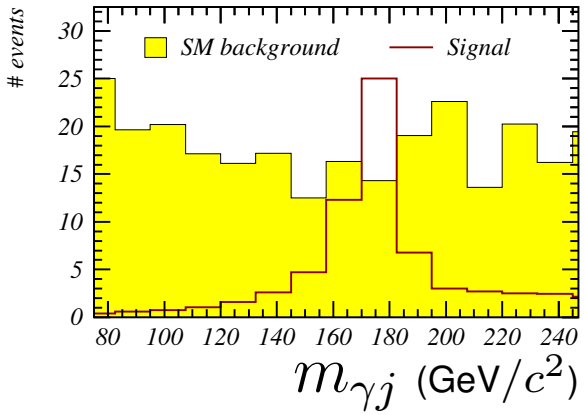
specific criteria:

- 1 photon
  - $p_T > 75$ GeV$/c$, $|\eta| < 2.5$
- only 1 b-tagged jet
- < 3 leptons

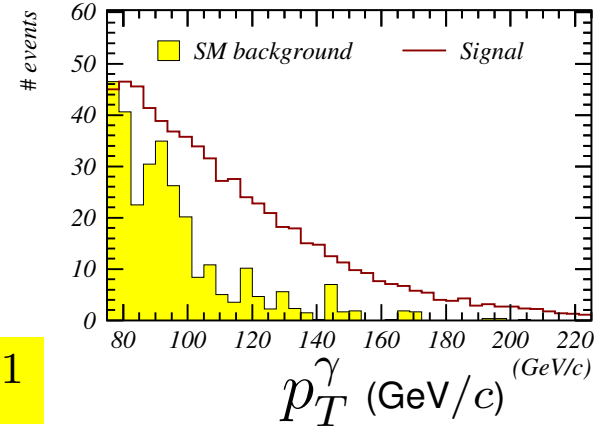
290.7 back. events (mainly $t\bar{t}$)

$\varepsilon \times BR$ = 1.88%





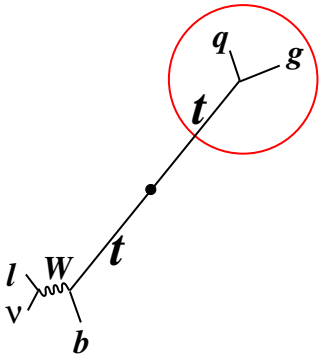
L=10 fb^{-1}

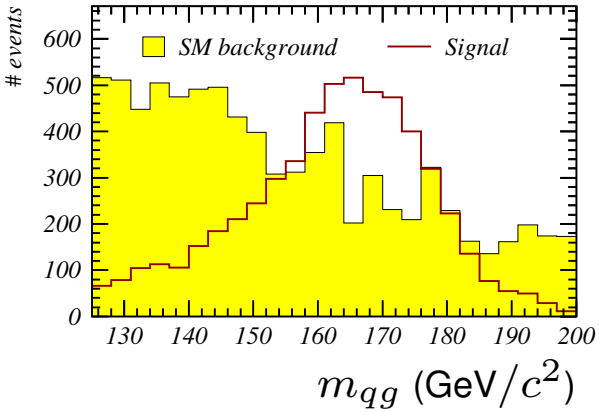


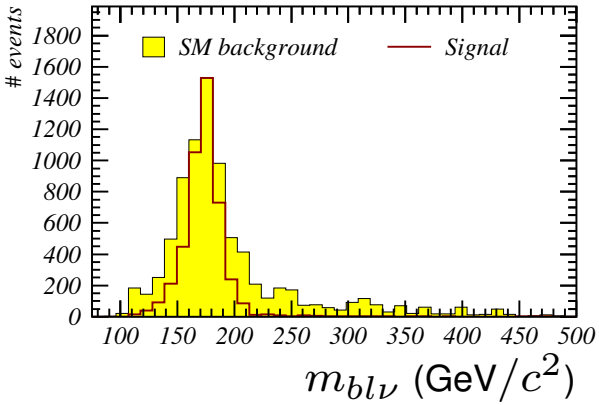
Top quark FCNC decays: $t \rightarrow qg$

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 $|\eta| < 2.5$)
- only 1 b-tagged jet
- $p_T^g > 75$ GeV$/c$
- $125 < m_{qg} < 200$ GeV$/c^2$







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

$\varepsilon \times BR$ = 0.39%

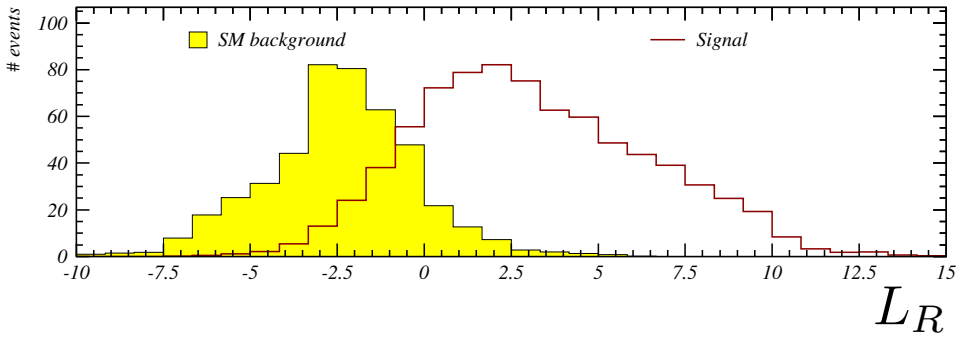
L=10 fb^{-1}

gluon is the non-b jet with highest p_T

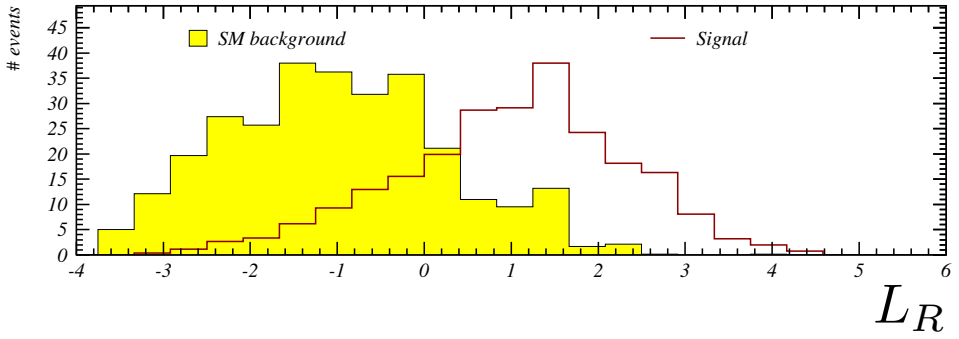
Top quark FCNC decays

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

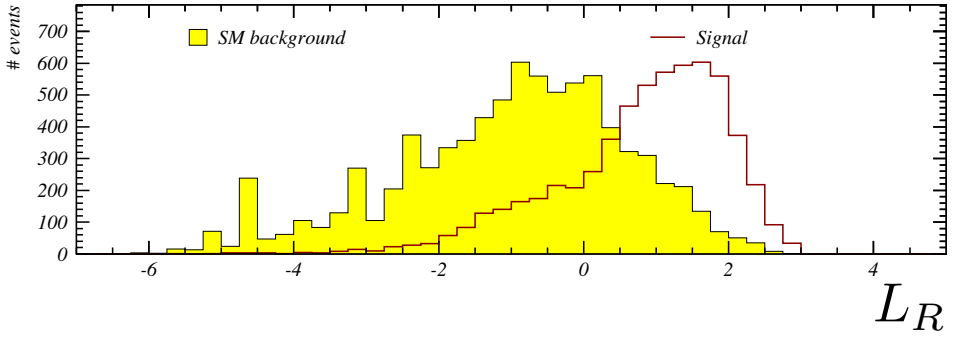
qZ **channel** $\rightarrow$



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



qg **channel** $\rightarrow$



L=10 fb^{-1}

Top quark FCNC decays

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

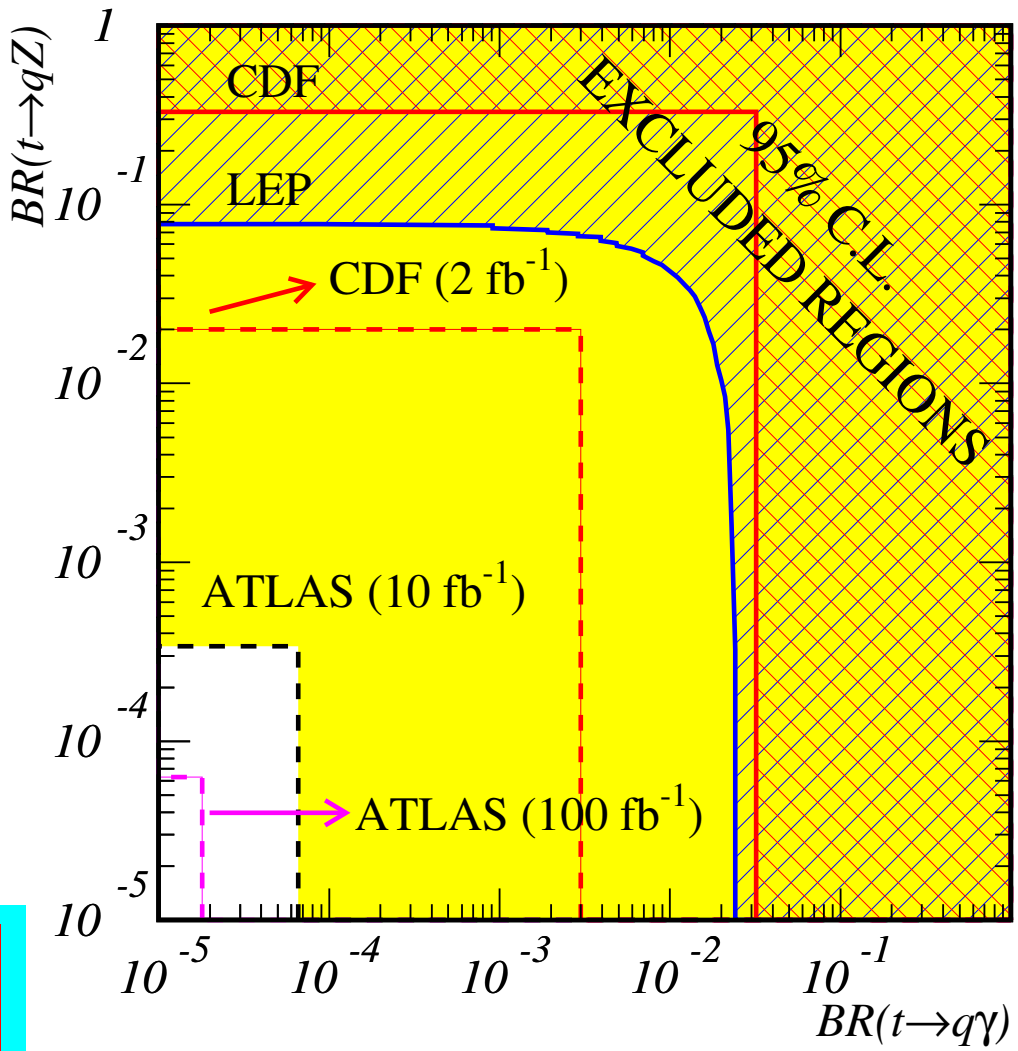
	$t \to qZ$ $(Z \to ll, W \to l\nu)$	$t \to qZ$ $(Z \to ll, W \to qq')$
$L = 100$ fb^{-1}	6.3×10^{-5}	2.8×10^{-4}

  - **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



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

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

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

(thanks to Oleg Yushchenko)

Conclusions

- Study of ATLAS sensitivity to new physics in the $t \longrightarrow bW$ decay:

  $g_R \in [-0.02, 0.02]$

- Study the ATLAS sensitivity to top quark FCNC decays

  for $L = 10$ fb^{-1} (5σ significance):

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

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

  $BR(t \rightarrow qg) \sim 10^{-3}$

  – Scientific note in preparation

  (analyses from ATL-PHYS-PUB-2005-009 and ATL-PHYS-2001-007 included)

Backup Slides

Probability Density Functions ($t \rightarrow qZ$ probabilistic analysis)