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Study of ATLAS Sensitivity to Rare Top Quark Decays

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1 Introduction

The LHC will be a top "factory". The NLO prediction that $\sigma(t\bar{t}) = 833$ pb in pp collisions at $\sqrt{s} = 14$ TeV [1] implies that more than 8 million $t\bar{t}$ pairs per year will be produced in low luminosity (10^{33} cm^{-2} s^{-1}) running of the LHC. Using a high-p_T isolated lepton tag, for example, to select $t\bar{t}$ events in which at least one of the produced W's decays leptonically, and assuming a b-tagging efficiency of 60%, approximately 600k single lepton plus jets events with one b-tag will be selected for an integrated luminosity of 10 fb^{-1} . Such high statistics samples will give ATLAS unprecedented sensitivity to various possible rare decay modes of the top quark, and provide a potential window to physics beyond the Standard Model.

This note describes the results of studies to quantify the ATLAS sensitivity to rare flavour changing neutral current (FCNC) and radiative decays of the top quark. Standard Model predictions for the branching ratios of FCNC decays are around 10^{-10} or less, so any observation at the LHC would be a signal of new physics. Significant increases in these branching ratios are predicted in SUSY extensions to the SM, and also arise in models including new dynamical interactions of the top quark, multi-Higgs doublets, or new exotic fermions, for example.

The "radiative" top decay $t \rightarrow WbZ$ has been suggested as a sensitive probe of the top quark mass, since the measured value of m_t is close to threshold for this decay. For $m_t = 174.3 \pm 5.1$ GeV [2, 3], the predicted branching ratio for this decay is about 5×10^{-7}, but varies by a factor of approximately three within the current uncertainty on the mass. A measurement of BR($t \rightarrow WbZ$) could therefore provide a strong constraint on m_t . Similar arguments have been made for the decay $t \rightarrow WbH$, assuming a relatively light SM Higgs ($m_H \approx m_Z$).

2 Rare Decays of the Top Quark

In the Standard Model, the dominant decay of the top quark is $t \rightarrow Wb$, which has a branching ratio of approximately 99.9%. (Note that charge conjugate decays such as $t \rightarrow W^+b$ and $\bar{t} \rightarrow W^-\bar{b}$ are not distinguished here and elsewhere in this note). Predictions for the CKM-suppressed decays are approximately 0.1% for $t \rightarrow Ws$ and 0.01% for $t \rightarrow Wd$. The large mass of the top quark implies, however, that it would tend to couple strongly to other massive particles, and determining whether it has the couplings and decays predicted by the SM is therefore a sensitive probe of physics beyond the SM.

In this note we examine the expected ATLAS sensitivity to two classes of rare decays: flavour changing neutral current decays $t \rightarrow (c,u)(Z,\gamma)$, and radiative decays $t \rightarrow WbX, (X = Z, H)$. These studies have been performed using PYTHIA 6.1 [4] and ATLFAST 1.53 or 2.0 [5]. In all cases, PYTHIA was used to generate $t\bar{t}$ pairs at $\sqrt{s} = 14$ TeV with $m_t = 175$ GeV, using CTEQ2L structure functions and including initial- and final-state radiation, hadronisation and multiple interactions corresponding to low luminosity running of the LHC. For the produced $t\bar{t}$ pairs, one of the quarks was allowed to decay via the dominant $t \rightarrow Wb$ channel, while the other was forced to decay via the rare decay mode in question. ATLFAST was used with its default parameters for low luminosity running, including jet energy corrections [5]. A 90% efficiency for reconstructing isolated leptons (e, μ) and a b-tagging efficiency of 60% (with a rejection factor of 100 against light quark jets) were assumed.

2.1 Flavour Changing Neutral Current Decays

Within the Standard Model, FCNC decays such as $t \rightarrow cZ$ are forbidden at the tree level by the GIM mechanism. They do occur at the one-loop level however, though strongly suppressed, and have expected branching ratios on the order of $10^{-12} - 10^{-10}$ [6, 7]. At such levels, no SM FCNC decays can be observed at the LHC.

Supersymmetric extensions to the SM lead to significantly larger predictions for the FCNC branching ratios [8, 9], on the level of $10^{-8} - 10^{-6}$, although these are probably still too small to be observable at the LHC. Other extensions of the SM, such as models with new dynamical interactions of the top quark, multi-Higgs doublets, or new exotic fermions, may however give rise to further significant enhancements in the FCNC branching ratios [7, 10, 11, 12, 13].

Current experimental limits on FCNC decays from CDF [14] are shown in Table 1, along with predictions for both SM and MSSM branching ratios.

FCNC decay	BR in SM	BR in MSSM	Expt. lim. (95% CL)
$t \rightarrow qZ$	$\sim 10^{-12}$	$\sim 10^{-8}$	< 0.33
$t \rightarrow q\gamma$	$\sim 10^{-12}$	$\sim 10^{-8}$	< 0.032
$t \rightarrow qg$	$\sim 10^{-10}$	$\sim 10^{-6}$	-

Table 1: SM and MSSM predictions for the branching ratios for FCNC decays of the top quark. Also shown are current experimental limits.

2.1.1 $t \rightarrow Zq (q = u, c)$

The enormous QCD backgrounds at hadron colliders make the search for the signal via hadronic decays of the W and Z ($t\bar{t} \rightarrow WbZq \rightarrow$ 6-jets) very difficult. We have chosen to study the case where the Z decays leptonically ($Z \rightarrow l^+l^-$, $l = (e, \mu)$), which significantly reduces the backgrounds and provides a relatively clean experimental signature. Given the selection of the leptonic decay mode of the Z, the final state is then determined by the decay mode of the W. If it decays leptonically ($t\bar{t}\to WbZq\to l\nu l^+l^-$ + 2-jets), the signature is three leptons (with $m_{l^+l^-} \approx m_Z$), missing E_T , and at least two jets, one of which is a b-jet. If the W decays hadronically ($t\bar{t}\to WbZq\to l^+l^-$ + 4-jets), the signature is two leptons (again with $m_{l^+l^-} \approx m_Z$), and at least four jets, one of which is tagged as a b-jet. The hadronic W decay mode has a much larger branching ratio, but suffers from larger backgrounds. We examine each in turn.

$t\bar{t}\to(l^+l^-)q(l\nu)b$

In order to reconstruct the $Z \to l^+l^-$ decay, selection cuts required a pair of opposite-sign, same-flavour (e, μ) leptons, each having $p_T > 20$ GeV and $\mid \eta \mid < 2.5$. The invariant mass of the lepton pair was required to be within 4 GeV of m_Z . Fig. 1 shows the l^+l^- invariant mass distribution from a sample of 20,000 signal events. The invariant mass distribution for each Zq combination was formed, requiring each jet to have $p_T > 30$ GeV and $\mid \eta \mid < 2.5$ (Fig. 2). Fitting this distribution with a Gaussian plus third order polynomial yields a Zq mass resolution of 6.6 GeV.

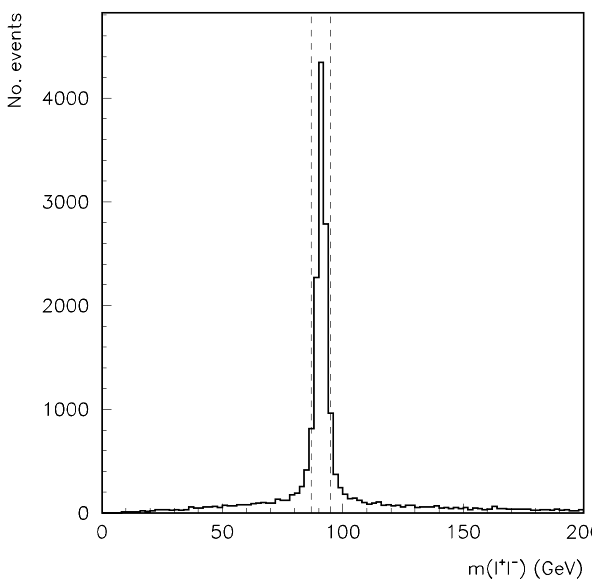

Figure 1: Invariant mass distribution of all opposite-sign, same-flavour lepton pairs, showing the Z selection cuts.

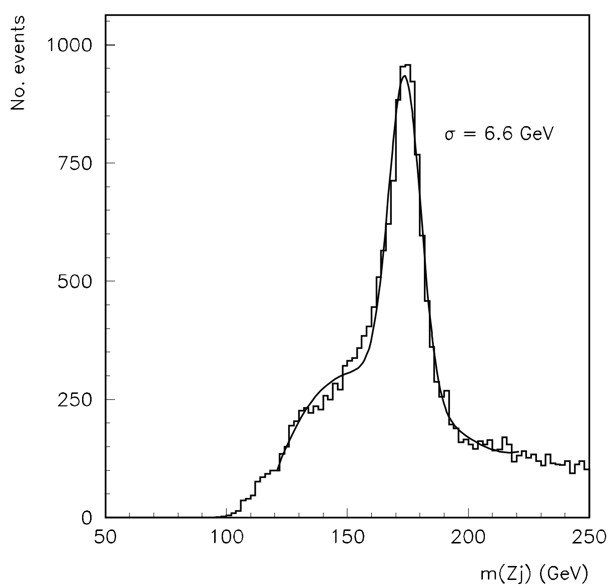

Figure 2: Invariant mass distribution of all Zj combinations. The curve shows the result of fitting a Gaussian plus third order polynomial to the distribution.

Since the $Z \to l^+l^-$ signature is rather clean, the dominant backgrounds for this search are from processes having a Z in the final state (Z+jets and $W+Z$ production), and from $t\bar{t}$ decay in which both top quarks decay to Wb where the final state includes an opposite-sign, same-flavour lepton pair with $m_{l^+l^-} \approx m_Z$.

With the selection cuts described above, the dominant background is from Z+jets. Additional cuts, based on the Wb decay of the second top quark in the event, can be used to reduce this background contribution. In the case of a leptonic decay of the W, requiring a (third) high-p_T lepton and/or large missing transverse momentum (due to the escaping neutrino) provides significant rejection against the Z+jets background. Figs. 3 and 4 show the number of leptons and missing p_T from signal and background sources. Additional cuts required a third lepton (p_T > 30 GeV, $|\eta| < 2.5$), and $p_T^{miss} > 30$ GeV. The number of jets provides additional discrimination against the Z+jets, and to a lesser extent $W + Z$, backgrounds (see Fig. 5). A second jet, with $p_T > 30$ GeV and $|\eta| < 2.5$, was required. Finally, one (and only one) b-jet, other than the jet in the Zj combination, was required. This is effective in reducing all remaining backgrounds.

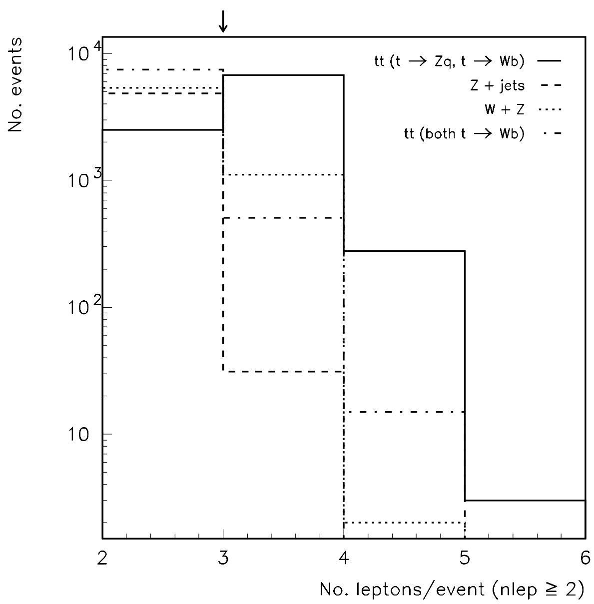

Figure 3: Number of leptons ($p_T > 20$ GeV, $|\eta| < 2.5$) per event from signal and background sources, normalised to $10k$ events. Only events with at least 2 leptons (satisfying the Z selection criteria) are shown. In all cases $Z \to l^+l^-$, and for $t\bar{t}$ events both W's decay via $W \to l\nu$.

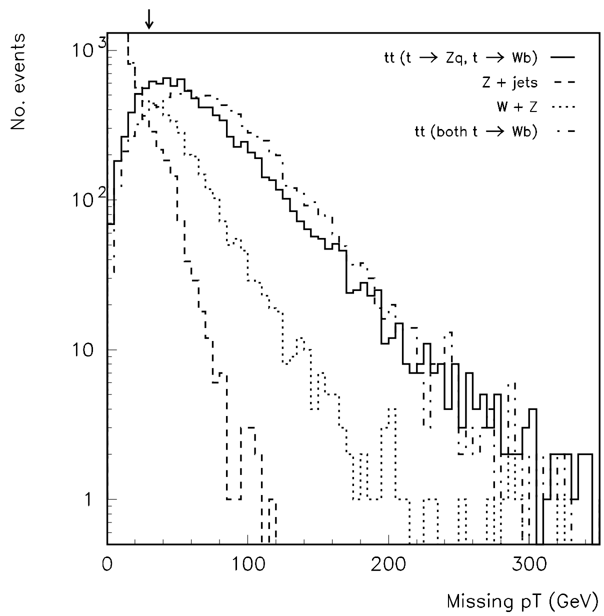

Figure 4: Missing p_T per event from signal and background sources, normalised to $10k$ events. In all cases $Z \to l^+l^-$, and and for $t\bar{t}$ events both W's decay via $W \to l\nu$.

Table 2 shows the signal efficiency and number of background events for $\int \mathcal{L} \cdot \mathrm{dt} = 10$ fb^{-1} as each successive cut is applied. The efficiencies do not include the $Z \to l^+l^-$ and $W \to l\nu$ branching ratios. A cut requiring the (llj) invariant mass to be within 15 GeV of m_t was applied in determining the backgrounds. The assumed cross-sections are those calculated by PYTHIA 6.1, except for the inclusive $t\bar{t}$ cross-section, for which the NLO prediction $\sigma_{t\bar{t}} = 833$ pb is used. The relevant cross-sections for this analysis are shown in Table 3, along with those used for the $t\to\gamma q$ and $t\to WbZ$ analyses later in this note. Since the Z+jets cross-section is large (the inclusive cross-section is about 110 nb, ignoring the γ^* and Z/γ^* interference contributions), events were generated with $\hat{p}_T > 30$ GeV, where $\hat{p}_T$ is the transverse momentum of the hard parton interaction.

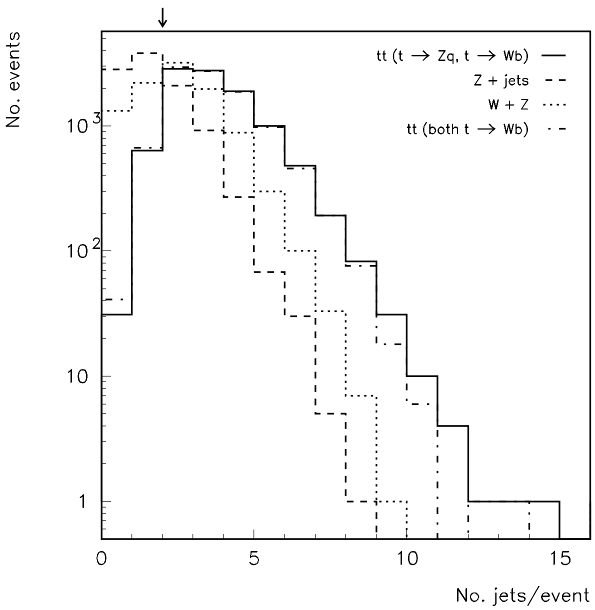

Figure 5: Number of jets ($p_T > 15$ GeV, $|\eta| < 2.5$) per event from signal and background sources, normalised to $10k$ events. In all cases $Z \to l^+l^-$, and for $t\bar{t}$ events both W's decay via $W \to l\nu$.

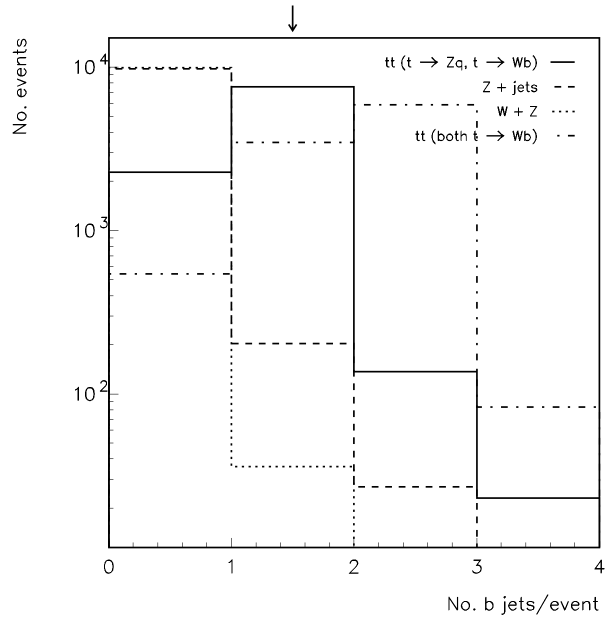

Figure 6: Number of b-jets per event from signal and background sources, normalised to $10k$ events. In all cases $Z \to l^+l^-$, and for $t\bar{t}$ events both W's decay via $W \to l\nu$.

Cut	ε (%)	# ev. per 10 fb^{-1}		
	$t{\to}qZ$	Z+jets ($\hat{p}_T > 30$ GeV)	$W+Z$	$t\bar{t}$
l^+l^-j satisfying p_T ,η cuts	27.9	553000	1690	34800
m_Z cut	22.3	446000	1350	3420
3rd (≥ 3) lepton, $p_T > 30$ GeV	13.0	13	44	15
$p_T^{miss} > 30$ GeV	9.5	4	31	12
2nd (≥ 2) jet, $p_T > 30$ GeV	8.2	1	12	10
# b-tag = 1	4.3	0	0	1

Table 2: $t{\to}qZ$ signal efficiency with the other top decaying via $t{\to}Wb$ and with $Z \to l^+l^-$ and $W \to l\nu$. Also shown are the number of surviving background events for $\int \mathcal{L} \cdot \mathrm{dt} = 10$ fb^{-1} .

Process	Cross-section (pb)
$t\bar{t}$	833
Single top: W-gluon fusion Wt s-channel	 244 60 10
WZ	28
Z+jets ($\hat{p}_T > 30$ GeV	8478
Wjj	18000
$Wb\bar{b}$	300

Table 3: Cross-sections assumed for the $t \to (Z, \gamma)q$ and $t \to WbZ$ analyses.

The branching ratio sensitivity, assuming a 5σ signal significance ($S/\sqrt{B}$) for discovery, is given by:

$$\text{Min. BR} = \frac{5\sqrt{B}}{2 \int \mathcal{L} \cdot \text{dt}\, (\sigma \times \text{BR})\, \varepsilon} \quad (1)$$

where B is the total number of background events, $\int \mathcal{L} \cdot \text{dt}$ is the integrated luminosity, $\sigma \times \text{BR}$ is the $t\bar{t}$ cross-section (including appropriate branching ratios) and ε is the reconstruction efficiency. The factor of 2 in the denominator arises since either of the two produced top quarks can decay to qZ. With the cuts described above, and assuming $\int \mathcal{L} \cdot \text{dt} = 10\ \text{fb}^{-1}$, one remaining background event is expected. Requiring at least five events for signal observation, the branching ratio sensitivity is 4.7×10^{-4} . Since the background has been reduced almost to zero, the sensitivity should improve almost linearly with integrated luminosity. An order of magnitude improvement on this limit may therefore be achievable for $\int \mathcal{L} \cdot \text{dt} = 100\ \text{fb}^{-1}$.

$t\bar{t} \to (l^+l^-)q(jj)b$

For the hadronic decay mode of the W, the final state is l^+l^- + 4-jets, one of which is a b-jet. The Z selection criteria were the same as for the leptonic mode described above, and the invariant mass distribution for each Zq combination formed, requiring each jet to have $p_T >$ 30 GeV and $|\ \eta\ | < 2.5$, as before. Fitting the invariant mass distribution with a Gaussian plus third order polynomial yields a Zq mass resolution of 6.6 GeV. In addition, at least four jets with $p_T > 30$ GeV and $|\ \eta\ | < 2.5$ were required, one being a b-jet. To reduce the Z+jets and QCD backgrounds, the other top quark was reconstructed via its decay $t \to jjb$. Pairs of non b-tagged jets were required to have an invariant mass within 20 GeV of m_W (see Fig. 7), and these W candidates then combined with the b-jet and required to have an invariant mass within 25 GeV of m_t (see Fig. 8). An increased jet p_T cut (> 50 GeV) proved effective in reducing backgrounds still further.

Table 4 shows the signal efficiency and number of background events for $\int \mathcal{L} \cdot \text{dt} = 10\ \text{fb}^{-1}$ as each successive cut is applied. The efficiencies do not include the $Z \to l^+l^-$ and $W \to jj$ branching ratios. A cut requiring the (llj) invariant mass to be within 15 GeV of m_t was applied in determining the backgrounds. With only one background event expected for an integrated

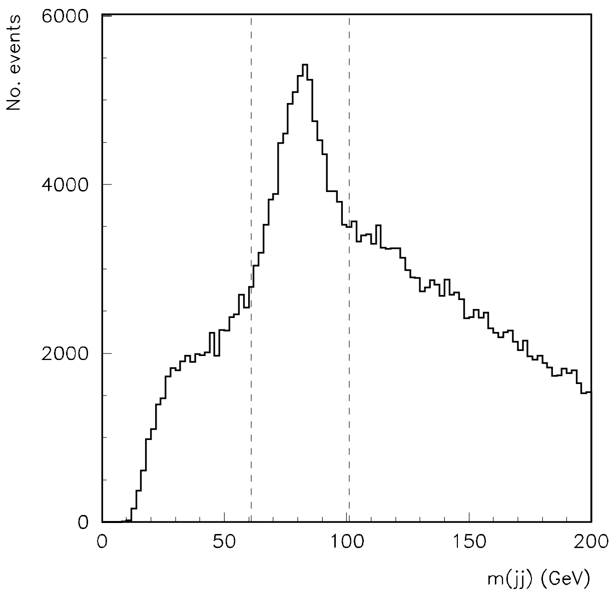

Figure 7: Invariant mass distribution of non b-tagged jet pairs, after Z selection cuts and requiring at least 4 jets. The W selection cuts are shown.

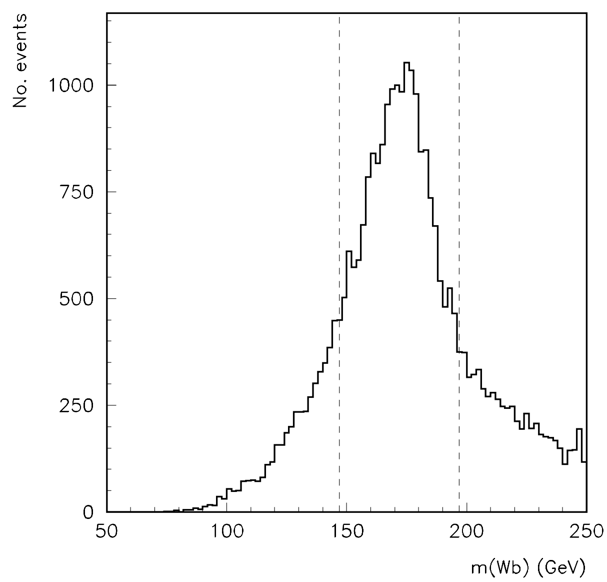

Figure 8: Invariant mass distribution of three-jet combinations, after Z and W selection cuts, and requiring at least 4 jets. The third jet was required to be tagged as a b-jet. The t selection cuts are shown.

Cut	ε (%)	# ev. per 10 fb^{-1}		
	$t \to qZ$	Z+jets ($\hat{p}_T > 30$ GeV)	$W+Z$	$t\bar{t}$
l^+l^-j satisfying p_T ,η cuts	26.5	30800	181	11500
m_Z cut	21.2	24700	148	1080
4 ($\geq$ 4) jets, $p_T > 30$ GeV	12.2	19300	113	925
# b-tag = 1	5.1	516	1	67
m_W cut	3.3	167	0	17
$m_{t \to Wb}$ cut	2.7	66	0	9
p_T (jets) > 50 GeV	0.4	0	0	1

Table 4: $t \to qZ$ signal efficiency with the other top decaying via $t \to Wb$ and with $Z \to l^+l^-$ and $W \to jj$. Also shown are the number of surviving background events for $\int \mathcal{L} \cdot \mathrm{dt} = 10$ fb^{-1} .

luminosity $\int \mathcal{L} \cdot \mathrm{dt} = 10\ \mathrm{fb}^{-1}$ and again requiring at least five events for signal observation, a branching ratio sensitivity of 1.7 $\times 10^{-3}$ is achievable. This is about a factor of three worse than the estimated sensitivity with the leptonic decay mode of the W, described above. Once again, since the background has been reduced essentially to zero, an order of magnitude improvement on this limit may be possible for $\int \mathcal{L} \cdot \mathrm{dt} = 100\ \mathrm{fb}^{-1}$.

Combining results from the leptonic and hadronic modes, a branching ratio as low as 4.5×10^{-4} for $t \to Zq$ could be discovered at the 5σ level for $\int \mathcal{L} \cdot \mathrm{dt} = 10\ \mathrm{fb}^{-1}$. An order of magnitude improvement in the sensitivity should be possible for an integrated luminosity of 100 fb^{-1} .

An analysis of the ATLAS sensitivity to $t \to Zq$ decays has also been reported in [16]. The stated values for signal reconstruction efficiencies and numbers of background events are similar to those obtained in this analysis, with the resulting branching ratio sensitivities being within a factor of 2 between the two analyses.

2.1.2 $t \to \gamma q (q = u, c)$

A signal for the FCNC decay $t \to \gamma q$ can be sought by searching for a peak above background in the $m_{\gamma j}$ spectrum in the region of m_t. The presence of a high p_T isolated photon in $t\bar{t} \to (Wb)(\gamma q)$ events is not sufficient to reduce the QCD multi-jet background to a manageable level. Therefore, the analysis considered the final state where the decay of the other top quark in the event included a leptonic decay of the resulting W boson.

Signal events with the decay chain $t\bar{t} \to (l\nu b)(\gamma q)$ (with $l = e, \mu$) were generated with PYTHIA 6.1, and simulated using ATLFAST 2.0. For selection cuts which require the presence of both a high p_T isolated photon and a high p_T isolated charged lepton, the background is dominated by events with a real $W \to l\nu$ decay and either a real or fake photon. These processes include $t\bar{t}$ and single top production, as well as W+jets and $Wb\bar{b}$ production. PYTHIA was used to generate $t\bar{t}$ events. Single top production was simulated using ONETOP for all three production processes, namely $W - gluon$ fusion, s-channel production, and the Wt process (for more details, see [18] and references therein). Finally, W+jets and $Wb\bar{b}$ production was simulated using HERWIG. The cross-sections assumed for the various processes are shown in Table 3.

Selection cuts required the presence of an isolated photon candidate with $p_T(\gamma) > 40$ GeV and $|\eta_\gamma| < 2.5$. In addition, the signature of the leptonic W decay was imposed by requiring $E_T^{miss} >$ 20 GeV and the presence of an isolated charged lepton (electron or muon) with $p_T(lep) > 20$ GeV and $|\eta_l| < 2.5$. To reduce the $t\bar{t}$ background, which tends to have more jets, the number of jets with $p_T(j) > 20$ GeV was required to be equal to 2. At least one of the two jets was further required to be tagged as a b-jet and to satisfy $p_T(j) > 30$ GeV and $|\eta_j| < 2.5$.

The analysis continued by first seeking to reconstruct the $t \to l\nu b$ decay. The neutrino momentum was measured by assigning $p_T(\nu) = p_T^{miss}$ and calculating $p_z(\nu)$ (with a quadratic ambiguity) by applying the constraint that $m_{l\nu} = m_W$. The W boson candidates resulting from the two solutions for $p_z(\nu)$ were then each combined with the b-tagged jet. A combination was accepted as a top quark candidate if the resultant $l\nu b$ invariant mass agreed with m_t within ± 20 GeV.

For events with an accepted $t \to l\nu b$ candidate, evidence for the decay $t \to \gamma q$ was sought by combining the isolated photon candidate with the additional jet, which was required to satisfy $p_T(j) > 40$ GeV and $|\eta_j| < 2.5$. Fig. 9 shows the $m_{\gamma j}$ invariant mass distribution resulting from applying this analysis to a sample of 10,000 signal events. The $m_{\gamma j}$ mass resolution was 7.7 GeV, and the overall selection efficiency (not counting branching ratios) was 3.3%, including a b-tagging efficiency of 60%.

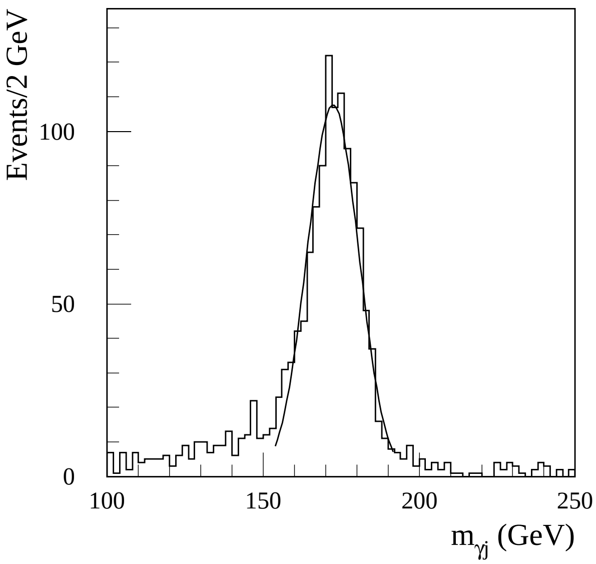

Figure 9: Invariant mass distribution of all selected γj combinations.

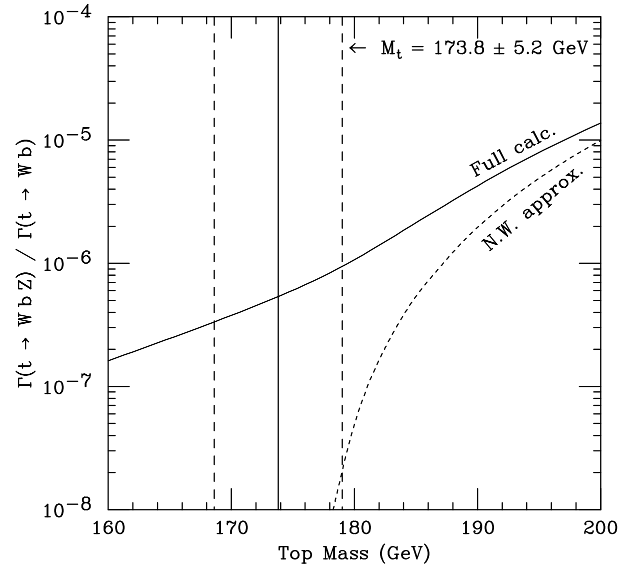

Figure 10: The ratio $\Gamma(t \to WbZ)/\Gamma(t \to Wb)$ versus m_t [19, 20]. The solid line is the full calculation including the finite W and Z widths; the dashed line shows the narrow width approximation. Also shown are the current uncertainties on m_t .

After the cuts, the total background with real photons, normalised to an integrated luminosity of 100 fb^{-1}, consisted of 50 $t\bar{t}$ events with negligible contributions from the other processes. Assuming a somewhat conservative jet rejection of about 2900 for photons with $p_T > 40$ GeV [15], larger backgrounds resulted from fake photons, namely 90 $t\bar{t}$ events, 10 events from single top production, and 5 events from W+jets including $Wb\bar{b}$. The total background was therefore 155 events, dominated by $t\bar{t}$ events. The corresponding 5σ discovery limit for an integrated luminosity of 100 fb^{-1} was BR$(t \to \gamma q) = 1.0 \times 10^{-4}$.

2.1.3 $t \to gq (q = u, c)$

A search for the decay $t \to gq$ would be overwhelmed by QCD multi-jet event background. It has been noted however that evidence for a FCNC $t - g - q$ coupling could be sought through the production of like-sign top pairs [17]. A study to search for like-sign top pair production has been performed in ATLAS and indicates that the expected branching ratio sensitivity for an integrated luminosity of 100 fb^{-1} is BR$(t \to gq) = 7.4 \times 10^{-3}$ [15].

2.2 Radiative Decays

2.2.1 $t\to WbZ$

The top quark mass $m_t = 174.3 \pm 5.1$ GeV [2, 3] is close to the threshold for the radiative decay $t\to WbZ$ ($\Sigma[m_W + m_b + m_Z] \approx 176.1$ GeV). The branching ratio for $t\to WbZ$ is therefore strongly dependent on the top mass and, if observable, might provide a powerful constraint on the value of m_t.

The partial width $\Gamma(t\to WbZ)/\Gamma(t\to Wb)$ as a function of m_t is shown in Fig. 10 [19, 20]. With the current uncertainty on the top mass, the SM prediction is BR$(t\to WbZ) = (5.4^{+4.7}_{-2.0}) \times 10^{-7}$, corresponding to a factor of ~ 3 variation in the decay rate.

Sensitivity to the $t\to WbZ$ decay has been studied using PYTHIA 6.1 and ATLFAST 1.53 to simulate $t\bar{t}\to(WbZ)(Wb)$, where the Z is reconstructed in the leptonic decay channel $Z \to l^+l^-(l = e, mu)$, and the W (from the WbZ decay) in the two-jet hadronic channel $W\to jj$. The final state for the $t\to WbZ$ decay is therefore (l^+l^-jjb). The $t\to WbZ$ decay was incorporated into PYTHIA, assuming (non-optimised) three-body phase space for the decay kinematics.

Selection cuts required an opposite-sign, same-flavour di-lepton pair, each lepton having $p_T >$ 30 GeV and $\mid \eta \mid < 2.5$, and invariant mass of the lepton pair between 60 and 100 GeV. At least three jets were also required, each jet having $p_T >$ 30 GeV and $\mid \eta \mid < 2.5$, with the invariant mass of one two-jet combination satisfying $70 \leq m_{jj} \leq 90$ GeV. A b-veto was applied to each of the two jets consistent with m_W, and a b-tag required on the third jet. The reconstruction efficiency for the WbZ exclusive channel using these selection criteria is very low, due to the soft p_T distribution of the produced b-jet. Preliminary estimates of branching ratio sensitivity in the exclusive mode indicated that it would be at least three orders of magnitude higher than that expected in the Standard Model, for an integrated luminosity of 30fb^{-1}.

In order to improve the reconstruction efficiency, the semi-inclusive measurement $t\to WZ$ has been examined. Since the $t\to WbZ$ decay is so close to threshold, the resolution of the (WZ) invariant mass distribution should not be significantly degraded with respect to the exclusive measurement. Applying the same selection cuts described above to the lepton pair and two jets, reconstructed Z and W peaks are clearly seen (shown in Figs. 11, 12 for a signal sample of 100,000 events), and also a peak in the (l^+l^-jj) invariant mass distribution (Fig. 13). The resolution $\sigma[m_{WZ}] = 7.2 \pm 0.4$ GeV, with a signal efficiency of about 3.5%.

The clean $Z \to l^+l^-$ signature for this decay means that the dominant backgrounds come from processes with a Z in the final state, primarily Z+jet production, and to a much lesser extent from $W + Z$ production and $t\bar{t}$ production. In order to reduce the Z+jet background, an additional cut requiring a third lepton with $p_T >$ 30 GeV is made. For the signal process $t\bar{t}\to(WbZ)(Wb)$, this cut selects events in which the W from the other top quark decays leptonically, with a corresponding drop in signal efficiency of ~ 5, but reduces the Z+jet background by more than three orders of magnitude. Table 5 shows the number of background events normalised to 10fb^{-1} from Z+jet, $W + Z$ and $t\bar{t}$ production with the selection cuts described above, and with a cut of $\pm$ 10 GeV about the top mass.

For an integrated luminosity of 10fb^{-1}, the total number of background events expected is one. Requiring at least five events for signal observation leads to a branching ratio sensitivity of 6.4×10^{-4}. Removing the b-veto on the two jets consistent with the W results in a 10-20%

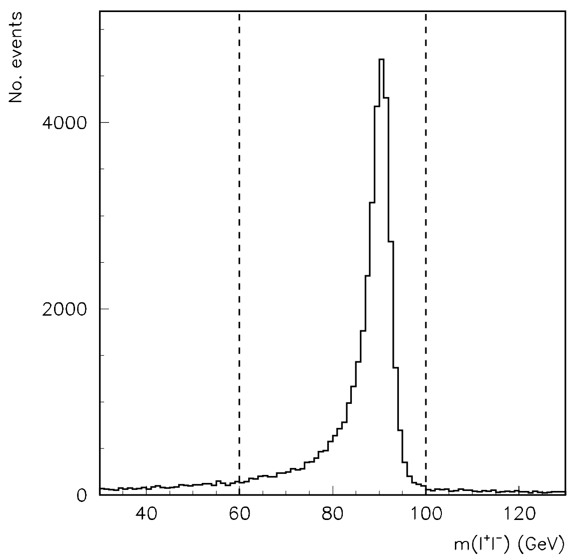

Figure 11: Invariant mass distribution of opposite-sign, same-flavour lepton pairs ($l = e, \mu$), showing the Z selection cuts.

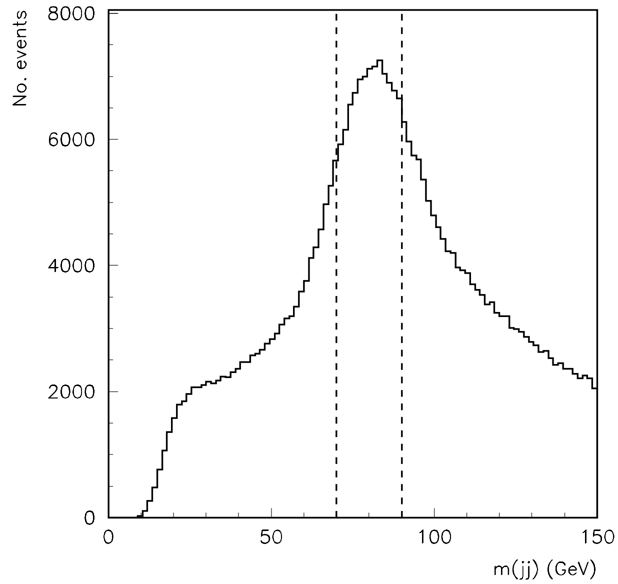

Figure 12: Invariant mass distribution of jj pairs, with a b-veto applied to both jets in the pair. The W selection cuts are also shown.

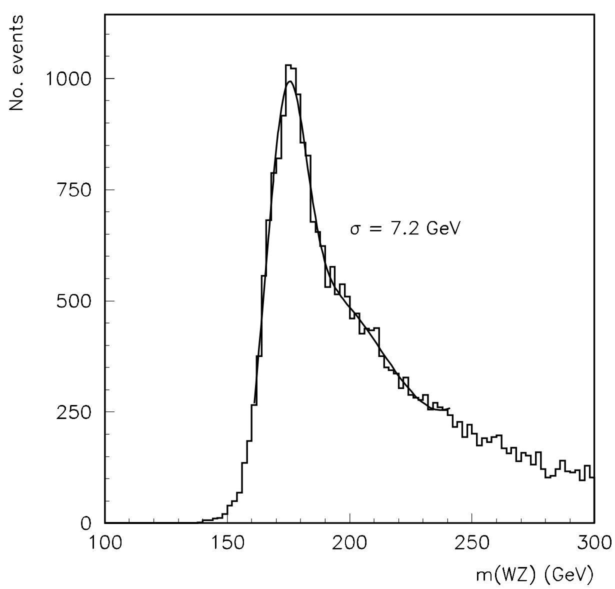

Figure 13: The (l^+l^-jj) invariant mass distribution.

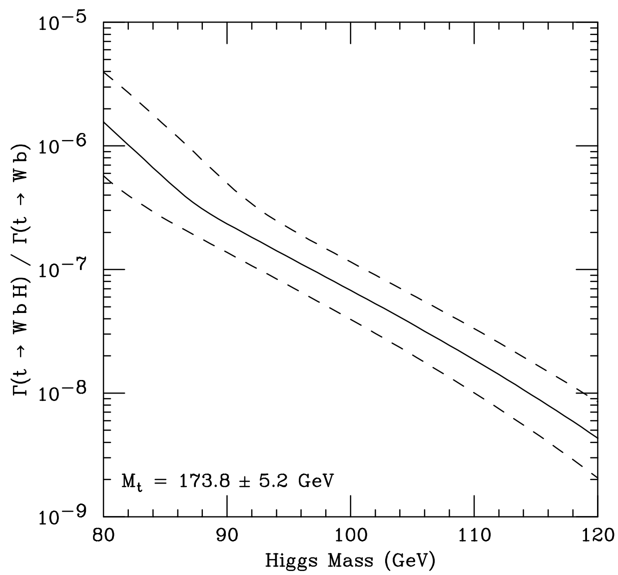

Figure 14: The ratio , $(t\to WbH)/,$ $(t\to Wb)$ versus m_H [19, 20]. The dotted lines indicate the errors on the branching ratio due to the current uncertainty on m_t .

Process	# background events per 10 fb^{-1}
Z + jets ($\hat{p}_T > 30$ GeV)	0
$W + Z$	1
$t\bar{t}$	0
Total	1

Table 5: Remaining backgrounds for $\int \mathcal{L} \cdot \mathrm{dt} = 10$ fb^{-1} after the selection cuts described in the text.

deterioration in sensitivity. With an integrated luminosity of 100fb^{-1}, a factor of ten improvement on this limit might be achievable. The branching ratio sensitivity would still be about two orders of magnitude larger than the expected SM branching ratio however, and would not allow observation of the SM decay $t \to WbZ$.

2.2.2 $t \to WbH$

Fig. 14 shows the branching ratio for $t \to WbH$ as a function of m_H [20]. With the current LEP limit on the Higgs mass $m_H > 107.7$ GeV [21], the branching ratio , $(t \to WbH)/, (t \to Wb)$ is at most approx. 5×10^{-8}. As m_H increases further, B($t \to WbH$) drops rapidly. Assuming $m_H \approx m_Z$, one would have to search for $t \to WbH$ using the dominant decay $H \to b\bar{b}$. The final state suffers much more from background than in the case of $t \to WbZ$, where the clean $Z \to l^+l^-$ signature is a key element in suppressing background. Although B($H \to b\bar{b}$) in this m_H range is much larger than B($Z \to l^+l^-$), the large increase in background will more than compensate for the increased signal acceptance, and so it is clear that the sensitivity to B($t \to WbH$) will be worse than for B($t \to WbZ$). The decay $t \to WbH$ has therefore not been studied in further detail.

3 Conclusion

A study of the expected ATLAS sensitivity to the flavour changing neutral current decays $t \to (c,u)(Z,\gamma)$ and radiative decays $t \to Wb(Z,H)$ of the top quark has been performed. For an integrated luminosity $\int \mathcal{L} \cdot \mathrm{dt} = 100$ fb^{-1} the expected branching ratio sensitivities for the FCNC decays are 4.5×10^{-5} ($t \to Zq$) and 1.0×10^{-4} ($t \to \gamma q$), and 6.4×10^{-5} for the radiative decay $t \to WbZ$. Detection of the SM decays $t \to WbZ$ and $t \to WbH$ does not appear possible.

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