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# LHC sensitivity to top properties beyond the SM

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The LHC sensitivity to top quark properties beyond the Standard Model are reviewed. In particular, the anomalous couplings associated with the dominant decay ($t \to bW$) and decays through Flavour Changing Neutral Currents (FCNC) are analyzed. The LHC sensitivity to $t\bar{t}$ resonances is also discussed.

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## 1. Introduction

The three generations structure of the Standard Model (SM) was completed with the discovery of the top quark at Tevatron. With a mass of $172.7 \pm 2.9$ GeV$/c^2$ [1], the top is the heaviest and least studied quark. In the LHC low luminosity phase, several millions of top quarks per year and experiment will be produced, mainly in pairs (with a cross-section of 833 pb [2, 3]), but also through single top production (with an expected cross-section of 280 pb [4]).

Due to the structure of the Cabibbo-Cobayashi-Maskawa (CKM) matrix ($|V_{ts}|, |V_{td}| \ll |V_{tb}| \sim 1$ [5]), the top decays almost exclusively through the $t \to bW$ channel. Moreover, because of its large decay width ($\Gamma_t^{\rm SM} = 1.4$ GeV [2]), within the SM the top decays rapidly without forming hadrons or $t\bar{t}$ bound states. For these reasons, the top provides a unique laboratory to study physics beyond the SM. In the present report, the anomalous couplings associated with the dominant decay ($t \to bW$) and decays through to Flavour Changing Neutral Currents (FCNC) are analyzed. The LHC sensitivity to $t\bar{t}$ resonances is also discussed.

## 2. New physics in the $t \to bW$ decay

Within the SM the $Wtb$ vertex is purely left-handed, and its size is given by the CKM matrix element $V_{tb}$. In SM extensions, departures from the SM expectation $V_{tb} \simeq 0.999$ are possible [6], as well as new radiative contributions to the $Wtb$ vertex [7]. These deviations might be observed in top production and decay processes at LHC.

The most general $Wtb$ vertex containing terms up to dimension five can be written as [8]:

$$\mathscr{L} = -\frac{g}{\sqrt{2}} \bar{b}\, \gamma^{\mu} \left( V_L P_L + V_R P_R \right) t\, W_{\mu}^- - \frac{g}{\sqrt{2}} \bar{b}\, \frac{i \sigma^{\mu\nu} q_{\nu}}{M_W} \left( g_L P_L + g_R P_R \right) t\, W_{\mu}^- + \text{h.c.}\,, \tag{2.1}$$

with $q = p_t - p_b$. If we assume CP is conserved, the couplings can be taken to be real. Within the SM, $V_L \equiv V_{tb}$ and the other couplings vanish at tree level, while at one loop level a nonzero value $g_R = -0.00770$ is generated [9].

Top pair production takes place through QCD interactions without involving a $Wtb$ coupling. Additionally, it is likely that the top quark decays almost exclusively in the channel $t \to W^+ b$. Therefore, its cross section for production and decay $gg, q\bar{q} \to t\bar{t} \to W^+ b W^- \bar{b}$ is insensitive to the size and structure of the $Wtb$ vertex. However, the angular distributions of top decay products give information about the stucture of the vertex, and can be used to search for non-standard couplings. Angular distributions relating top and anti-top decay products probe not only the $Wtb$ interactions but also the spin correlations among the two quarks produced, and thus may be influenced by new production mechanisms as well.

The sensitivity to several angular distributions and asymmetries in the decays of top quark pairs at the LHC was studied by ATLAS [10]. The semileptonic decay channel of the $t\bar{t}$ pair, in which one of the $W$ bosons decays to leptons ($\ell\nu$, with $\ell = e, \mu$) and the other one to quarks, was considered. In this case, signal events have a final state topology characterized by one lepton with high transverse momentum ($p_T$), at least four jets (including two $b$ jets) and large transverse missing momentum. A sequential and a probabilistic analysis were developed. In the sequential analysis, specific selection criteria were applied to the most relevant kinematical variables. The event selection in the probabilistic analysis was based on the construction of a discriminant variable, taking into account the full information of the variables relevant to describe the event kinematics. The fast simulation of the ATLAS detector [11] was used.

In the sequential analysis events were accepted if they had at least one lepton (electron or muon) with $p_T > 25$ GeV/$c$ and modulus of the pseudorapidity ($|\eta|$) below 2.5. Additionally, the missing transverse momentum had to be above 20 GeV/$c$, and at least four high transverse momentum jets ($p_T > 20$ GeV/$c$), with $|\eta| < 2.5$, were required. Two of the jets had to be tagged as $b$ jets.

The $W$ which decayed hadronically was reconstructed from the two non-$b$ jets with highest transverse momentum. The parent top quark (labelled *hadronic top*) was reconstructed from these two jets and the $b$-tagged jet which maximized the hadronic top $p_T$. The momentum of the $W$ which decayed into leptons cannot be directly reconstructed due to the presence of an undetected neutrino in the final state. Nevertheless, the neutrino four-momentum can be estimated by assuming the transverse missing energy to be the transverse neutrino momentum. Its longitudinal component can then be determined, with a quadratic ambiguity, by constraining the leptonic $W$ mass (calculated as the invariant mass of the neutrino and the charged lepton) to its known on-shell value $M_W =$ 80.4 GeV/$c^2$. The corresponding top quark (labelled *leptonic top*) was reconstructed with the leptonic $W$ and the remaining $b$ jet. The ambiguity on the neutrino longitudinal momentum was eliminated by choosing the solution which minimized the difference between the masses of the hadronic and leptonic top quarks. The background was further suppressed by requiring $|M_t^{\mathrm{had}} - 175| < 200$ GeV/$c^2$, $|M_W^{\mathrm{had}} - 80.4| < 100$ GeV/$c^2$. After this criteria 209920 (8.7%) signal events and 43229 SM background events (66.7% from $t\bar{t}$ other than signal and 24.3% from single top) were selected (for $L = 10$ fb$^{-1}$).

In the probabilistic analysis, after a first level of selection similar to the sequential analysis, a discriminating variable was evaluated. For each event, signal ($\mathscr{P}_i^{signal}$) and background-like ($\mathscr{P}_i^{back.}$) probabilities were obtained using probability density functions (p.d.f.s) constructed from relevant physical variables (in the present analysis the hadronic $W$ mass, the hadronic and leptonic top masses, the $p_T$ of the $b$ jets used in the top quarks reconstruction and the $p_T$ of the jets used in the hadronic $W$ reconstruction were used). The signal $\mathscr{L}_S = \Pi_{i=1}^{n} \mathscr{P}_i^{signal}$ and background $\mathscr{L}_B = \Pi_{i=1}^{n} \mathscr{P}_i^{back.}$ likelihoods ($n$ is the number of p.d.f.s) were used to built the discriminant variable, defined as $\mathscr{L}_R = \mathscr{L}_S/\mathscr{L}_B$. The final event selection was done by applying a cut $\mathscr{L}_R > -0.2$ (corresponding to the highest $S/\sqrt{B}$) on the discriminant variable. Further details can be found in [10].

For the decay $t \to Wb \to \ell\nu b$, $\theta_{\ell b}$ is defined as the angle between the momenta of the charged lepton and the $b$ quark in the leptonic $W$ rest frame. The signal and SM background distributions of $x \equiv \cos\theta_{\ell b}$ are shown in Fig. 1. The angular asymmetry associated to this variable can be defined as:

$$A_v \equiv \frac{N(x > v) - N(x < v)}{N(x > v) + N(x < v)}, \tag{2.2}$$

where $v$ is a value chosen in the interval $[-1, 1]$ and $N$ stands for the number of events. The Forward-Backward asymmetry ($A_{FB}$) is defined by making $v = 0$. The value of this asymmetry depends on the values of the anomalous couplings $V_R$, $g_L$ and $g_R$. For $V_R = g_L = g_R = 0$, the SM

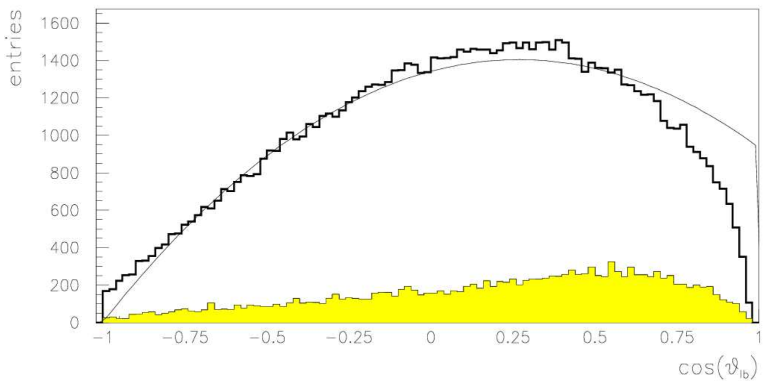


**Figure 1:** The distributions of the cosine of the angle between the $b$-tagged jet and the charged lepton, from the top semileptonic decay ($t \to Wb \to \ell\nu b$), in the leptonic $W$ rest frame are shown (normalized to $L = 10$ fb$^{-1}$). The thin line is the signal distribution at the generator level, the thick line is the signal distribution for the sequential analysis and the shadowed region represents the selected SM background.

tree-level value is $A_{FB} = 0.2226$ (assuming $M_t = 175$ GeV$/c^2$, $M_W = 80.4$ GeV$/c^2$ and $M_b = 4.8$ GeV$/c^2$). Two additional asymmetries ($A_\pm$) can be introduced by choosing $v = \pm(2^{\frac{2}{3}} - 1)$. For $V_R = g_L = g_R = 0$, the SM tree-level values are $A_+ = -0.5482$ and $A_- = 0.8397$, respectively (under the same assumptions for $M_t$, $M_W$ and $M_b$).

The angular asymmetries defined above can be related with the polarization of the $W$ bosons originated in the top decays. In the helicity basis, the $W$ bosons can be produced with right, left and longitudinal polarization, with corresponding partial widths ($\Gamma_R$, $\Gamma_L$ and $\Gamma_0$). The normalized partial widths, $F_i = \Gamma_i/\Gamma_{t\to bW}$ (with $\Gamma_{t\to bW} = \Gamma_R + \Gamma_L + \Gamma_0$), can be related with the angular asymmetries:

$$A_{FB} = \frac{3}{4}(F_L - F_R)\,, \quad A_+ = -3\beta[F_0 + (1+\beta)F_R]\,, \quad A_- = 3\beta[F_0 + (1+\beta)F_L]\,, \tag{2.3}$$

with $\beta = 2^{\frac{2}{3}} - 1$. The definition of $A_\pm$ asymmetries is now clear: they were defined in order not to depend on $F_L$ or $F_R$, respectively.

The measurement of the angular asymmetries involves counting the number of events below and above a specific value of $x \equiv \cos\theta_{\ell b}$. The simulated angular distributions, which were obtained for signal and SM background, are affected by the ATLAS resolution, reconstruction and selection criteria. After subtracting the reference background samples, the distributions were multiplied by correction functions in order to recover the generated ones (expected from SM). The correction functions were calculated for each bin, using a reference signal sample and dividing the number of events at the generator level by the number of events after the event selection.

Due to the excellent statistics achievable at the LHC, systematic errors are expected to play a crucial role in the measurement of the angular distributions and asymmetries. The following sources of systematic errors were considered: Monte Carlo generator, structure functions, top mass, initial and final state radiation, $b$-tagging efficiency, $b$ and light jets energy scale, background level, pile-up effects and parametrization of the $b$ quark fragmentation [10].

The expected values for the considered angular asymmetries (for $L = 10$ fb$^{-1}$) are:

$$\begin{aligned} A_{FB} &= 0.2234 \pm 0.0035(\text{stat}) \pm 0.0130(\text{sys}), \\ A_{+} &= -0.5472 \pm 0.0032(\text{stat}) \pm 0.0099(\text{sys}), \\ A_{-} &= 0.8387 \pm 0.0018(\text{stat}) \pm 0.0028(\text{sys}). \end{aligned} \tag{2.4}$$

These values were obtained with the probabilistic analysis, in which systematic uncertainties are smaller. The expected precision of the $A_{\pm}$ asymmetries (2% and 0.4%, respectively) is significantly better than for the $A_{FB}$ asymmetry (6%). By considering the expected values of the asymmetries, the corresponding $2\sigma$ bands and the dependence of the asymmetries with the anomalous couplings (Fig. 2), it was possible to obtain $2\sigma$ expected limits on the anomalous couplings[1]: $V_R \in [-0.14, 0.19]$, $g_L \in [-0.10, 0.07]$ and $g_R \in [-0.04, 0.04]$. These results are compatible with the ones obtained from the $W$ polarization analysis [12].

The expected value for $g_R$ was obtained from the $A_+$ asymmetry (it was found to be 30% better than the one obtained from $A_{FB}$), while the $A_-$ asymmetry was used to obtain the values for $V_R$ and $g_L$. It should be noticed that the $b$ mass ($M_b$) has an important role on the dependence of the asymmetries with $V_R$ and $g_L$. In fact if one neglects $M_b$, although the difference on the expected value of $g_R$ is small, it is up to 17% in $g_L$ and 9% in $V_R$.

## 3. Top FCNC decays

Flavour Changing Neutral Currents are strongly suppressed in the SM due to the Glashow-Iliopoulos-Maiani (GIM) mechanism. Although absent at tree level, small FCNC contributions are expected at one loop level, according to the CKM mixing matrix [13]. In the top quark sector of the SM, these contributions limit the FCNC decay branching ratios ($BR$) to the gauge bosons, $BR(t \to qZ, q\gamma, qg)$, to below $10^{-12}$ [14]. There are however extensions of the SM, like supersymmetry (SUSY), multi-Higgs doublet models and SM extensions with exotic (vector-like) quarks, which predict the presence of FCNC contributions already at tree level, and significantly enhance the FCNC decay branching ratios compared to the SM predictions (up to $BR(t \to qg) \sim 10^{-4}$ for some SUSY models) [14].

The LHC sensitivity to FCNC top quark decays in $t\bar{t}$ events was studied by ATLAS [15, 16], with one of the tops decaying via SM ($t \to bW \to b\ell\nu$, with $\ell = e, \mu$) and the other decaying through different FCNC channels into $t \to qZ, q\gamma, qg$. In the case of the $t \to qZ$ channel, only the decay $Z \to \ell^+\ell^-$ (with $\ell = e, \mu$) was analyzed. For this channel, two different types of analysis, a sequential [16] and a probabilistic type of analysis [15], were developed. For the other channels ($t \to q\gamma, qg$) a probabilistic type of analysis was adopted [15].

### 3.1 $t \to qZ$ channel

The final states for signal events are characterized by a topology with two jets (one $b$ jet from the SM top decay), three leptons (one from the leptonic decay of the $W$ and two from the $Z$ decay) and missing transverse momentum from the undetected neutrino.

[1] Only one anomalous coupling was assumed to be different from zero at each time.

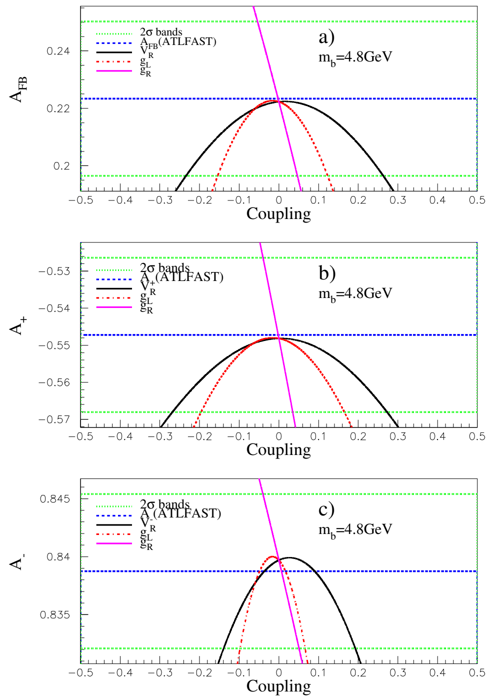


**Figure 2:** The measured a) $A_{FB}$, b) $A_+$ and c) $A_-$ asymmetries, the $\pm 2\sigma$ bands (statistical and systematic errors included) and the dependence of this asymmetry value with the anomalous couplings $V_R$, $g_L$ and $g_R$ are shown for a $b$ quark mass of 4.8 GeV$/c^2$.

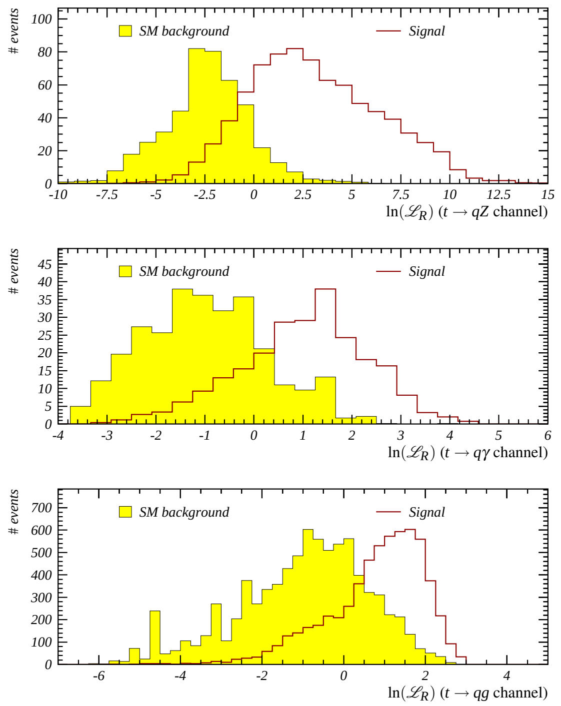


**Figure 3:** The discriminant variables for SM background (shaded histogram, normalized to $L = 10$ fb$^{-1}$) and for signal (line, with arbitrary normalization) are shown for the $t \to qZ$, $t \to q\gamma$ and $t \to qg$ channel channels.

In the sequential analysis, events were selected by requiring at least two jets (one being tagged as a $b$) with $p_T > 50$ GeV$/c$ and $|\eta| < 2.5$. Additionally, events had a missing transverse momentum above 30 GeV$/c$ and at least three charged leptons (electrons or muons) with $p_T > 20$ GeV$/c$ and $|\eta| < 2.5$, two of them with the same flavour and opposite charges ($\ell^+\ell^- = e^+e^-, \mu^+\mu^-$). The event selection was completed by requiring $|M_{\ell^+\ell^-} - M_Z| < 6$ GeV$/c^2$, with $M_Z = 91.2$ GeV$/c^2$. After this selection 0.6 background events (mainly from SM $t\bar{t}$) were selected for $L = 10$ fb$^{-1}$ and the signal efficiency (convoluted with $BR(W \to \ell\nu) \times BR(Z \to \ell\ell)$) was 0.08%.

In the probabilistic analysis, a general selection criteria (common to the $t \to q\gamma$ and $t \to qq$ channels) was adopted: events were required to have at least one charged lepton (electron or muon) with $p_T > 25$ GeV$/c$ and $|\eta| < 2.5$, at least two jets (one of them being tagged as $b$) with $p_T > 20$ GeV$/c$ and $|\eta| < 2.5$ and a missing transverse momentum above 20 GeV$/c$. After this common selection, specific criteria were used for each channel. In the $qZ$ channel, two additional leptons (with $p_T > 10$ GeV$/c$ and $|\eta| < 2.5$) were required. These leptons had to have the same flavour and opposite charged ($\ell^+\ell^- = e^+e^-, \mu^+\mu^-$). Furthermore, the non $b$ jet was required to have $p_T > 30$ GeV$/c$. At this level, 438.8 background events (mainly from SM $t\bar{t}$) were selected for $L = 10$ fb$^{-1}$ and the signal efficiency (convoluted with $BR(W \to \ell\nu) \times BR(Z \to \ell\ell)$) was 0.23%. Following this selection criteria a signal ($\mathscr{P}_i^{signal}$) and a background-like ($\mathscr{P}_i^{back.}$) probability was evaluated for each event using p.d.f.s based on relevant physical distributions (minimum invariant mass ($M_{\ell_i \ell_j}$) of the three possible combinations of two leptons, transverse momentum of the third lepton, $j\ell^+\ell^-$ invariant mass and transverse momentum of the non $b$ jet with highest $p_T$). Similarly to the analysis described in the previous section, signal $\mathscr{L}_S = \Pi_{i=1}^n \mathscr{P}_i^{signal}$ and background $\mathscr{L}_B = \Pi_{i=1}^n \mathscr{P}_i^{back.}$ likelihoods ($n$ is the number of p.d.f.s) were used to built the discriminant variable, defined as $\mathscr{L}_R = \mathscr{L}_S/\mathscr{L}_B$.

### 3.2 $t \to q\gamma$ channel

After the common selection criteria described above, the events assigned to this channel had to have one photon (with $p_T > 75$ GeV$/c$ and $|\eta| < 2.5$) and the invariant mass of the photon and the non $b$ jet ($M_{\gamma j}$) was required to be in the interval $[20, 270]$ GeV$/c^2$. At this level, 290.7 background events (mainly from SM $t\bar{t}$) were selected for $L = 10$ fb$^{-1}$ and the signal efficiency (convoluted with $BR(W \to \ell\nu)$) was 1.88%. The p.d.f.s were based on the following distributions: $M_{\gamma j}$, $p_T$ of the photon and jet multiplicity.

### 3.3 $t \to qg$ channel

The final state corresponding to this channel is characterized by the existence of three jets (one being a $b$, from the top SM decay), one lepton and missing transverse momentum. After the common selection, events were required to have the total visible energy greater than 300 GeV$/c^2$ and at least three jets with $|\eta| < 2.5$ and $p_T > 20$ GeV$/c$. Furthermore, the non $b$ jet with highest $p_T$ had $p_T > 75$ GeV$/c$ and the invariant mass of the two non $b$ jets ($M_{qg}$) was required to be in the interval $[125, 200]$ GeV$/c^2$. After this selection, 8166.1 background events ($\sim 60\%$ from SM $t\bar{t}$) were selected for $L = 10$ fb$^{-1}$ and the signal efficiency (convoluted with $BR(W \to \ell\nu)$) was 0.39%. The following distributions were used to evaluate the p.d.f.s: $M_{qg}$, $b\ell\nu$ invariant mass, $p_T$ of the $b$-jet, $p_T$ of the non $b$ jet with the second highest $p_T$ and angle between the lepton and the non $b$ jet with highest $p_T$.

### 3.4 Results

The discriminant variables obtained after the probabilistic analysis previously described are shown in Fig. 3.

Using the results obtained with the sequential and probabilistic analyses, the expected top quark FCNC decay branching ratios sensitivities of the ATLAS experiment were estimated under two different hypothesis:

- $5\sigma$ significance discovery hypothesis: in this case, the $BR$ sensitivity is given by $5\sqrt{B}/(2 \times L \times \sigma(t\bar{t}_{SM}) \times \varepsilon_t \times \varepsilon_\ell)$, where $\sigma(t\bar{t})$ is the SM cross-section for $t\bar{t}$ production, $B$ is the total number of selected background events and $\varepsilon_\ell = 0.9^n$ is the charged leptons identification efficiency ($n$ is the number of leptons required for each channel), $\varepsilon_t$ is the signal efficiency convoluted with the appropriate $BR$ and the factor 2 takes into account the $t$ and $\bar{t}$ contributions to the $BR$. In the case of the sequential analysis, further background rejection was done by applying a cut on the reconstructed top mass ($|M_{\ell^+\ell^- j} - 175| < 24$ GeV$/c^2$) and for the probabilistic analyses, a cut was applied to the discriminant variables (corresponding to the best $S/\sqrt{B}$);

| $L$ | $5\sigma$ sensitivity | | | | 95% CL expected limits | | | |
|---|---|---|---|---|---|---|---|---|
| | $t \to qZ$ | | $t \to q\gamma$ | $t \to qg$ | $t \to qZ$ | | $t \to q\gamma$ | $t \to qg$ |
| | (sequen.) | (probab.) | | | (sequen.) | (probab.) | | |
| 10 fb$^{-1}$ | — | $5.1 \times 10^{-4}$ | $1.2 \times 10^{-4}$ | $4.6 \times 10^{-3}$ | — | $3.4 \times 10^{-4}$ | $6.6 \times 10^{-5}$ | $1.4 \times 10^{-3}$ |
| 100 fb$^{-1}$ | $1.1 \times 10^{-4}$ | $1.6 \times 10^{-4}$ | $3.8 \times 10^{-5}$ | $1.4 \times 10^{-3}$ | $6.3 \times 10^{-5}$ | $6.5 \times 10^{-5}$ | $1.8 \times 10^{-5}$ | $4.3 \times 10^{-4}$ |

**Table 1:** The $5\sigma$ sensitivity and 95% CL expected limits on the *BR* for each channel are shown.

- absence of a signal hypothesis: in this case, expected 95% confidence level (CL) upper limits on the *BR* can be derived using the modified frequentist likelihood method [17]. For the discriminant analysis the $|M_{\ell^+\ell^- j} - 175| < 24$ GeV$/c^2$ cut was applied. No cuts were done in the discriminant variables of the probabilistic analysis (the full information of the distributions was used). The dominant systematic uncertainties were found to be the top mass and the $b$-tagging efficiency (the impact on the *BR* of each one of them was estimated to be below 20%).

The expected results for each hypothesis are summarized in Table 1. The present 95% CL limits and the expected sensitivity at the HERA (ZEUS, $L = 630$ pb$^{-1}$), Tevatron (CDF, run II) and LHC (ATLAS) for $BR(t \to q\gamma, qZ)$ [15, 18] are summarized in Fig 4.

The CMS Collaboration performed a preliminary study on the sensitivity to $BR(t \to qZ)$ [19]. Assuming a $b$-tagging efficiency above 50%, a signal efficiency of 5 to 6% is expected for 130 to 250 background events ($L = 100$ fb$^{-1}$). In this case, the *BR* sensitivity for a $3\sigma$ discovery ($S/\sqrt{S+B} = 3$) should be in the interval $[1.4, 2.2] \times 10^{-3}$. The CMS Physics TDR is will be released soon and new results on the $t \to qZ, q\gamma$ channels are expected.

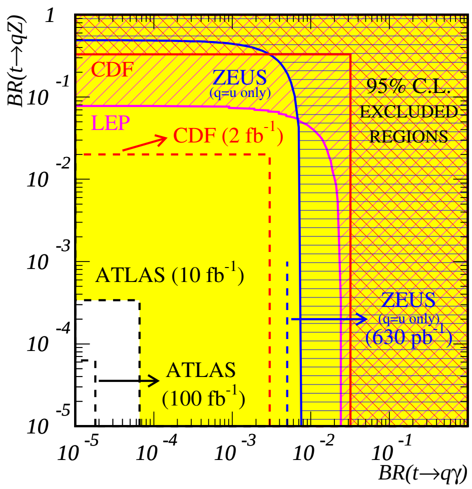


**Figure 4:** The present 95% CL limits on the $BR(t \to q\gamma)$ vs. $BR(t \to qZ)$ plane are shown (solid lines). The expected sensitivity at the HERA ($L = 630$ pb$^{-1}$), Tevatron (run II) and LHC is also represented (dashed lines) [15, 18].

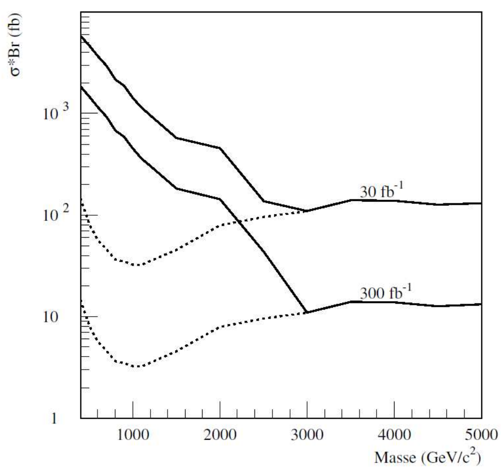


**Figure 5:** The $5\sigma$ discovery potential of narrow resonances in ATLAS is shown for $L = 30, 300$ fb$^{-1}$: $(\sigma \times BR)_{\rm res}$ (solid line) and $(\sigma \times BR)^{\rm min}_{\rm res}$ (dashed line) [20].

## 4. $t\bar{t}$ resonances

Within the SM the top has an extremely small lifetime and thus it is expected to decay before $t\bar{t}$ bound states have time to form. There are, however, SM extensions (SUSY, Technicolor), which predicts new particles which could decay into $t\bar{t}$. Consequently the $t\bar{t}$ invariant mass spectrum can be a probe for physics beyond the SM.

ATLAS has studied the sensitivity to a generic $t\bar{t}$ resonance [20]. The $t\bar{t}$ production was considered, with one of the tops decaying to leptons (electrons or muons) and the other decaying into quarks. The minimum sensitivity to a discovery ($(\sigma \times BR)^{\text{min}}_{\text{res}}$, where $\sigma$ is the cross section for the generic resonance production and $BR$ is the branching ratio for the decay into $t\bar{t}$) was computed by requiring at least 10 resonant events in a window of $\pm\Gamma_{\text{res}}$ ($\Gamma_{\text{res}}$ was assumed to be equal to the ATLAS resolution). Additionally, the $5\sigma$ discovery potential ($(\sigma \times BR)_{\text{res}}$) was also evaluated assuming $\Gamma_{\text{res}}$ to be twice the ATLAS resolution. The obtained results are shown in Fig. 5.

## 5. Conclusions

The LHC sensitivity for top properties beyond the SM was presented. In particular, the ATLAS sensitivity to new physics in the main decay mode of the top ($t \to bW$) was studied. In this case, the impact of $M_b$ in the dependence of the angular asymmetries with the anomalous couplings was found to be important. The ATLAS $2\sigma$ sensitivity to $g_R$ is expected to be in the interval $[-0.02, 0.02]$, which represents a significant improvement to the present limits from the $B$ factories [10]. Further improvements are expected from the combination of the semileptonic and the fully hadronic channels.

The LHC sensitivity to FCNC $t \to qZ, q\gamma, qg$ decays was also studied. For $L = 100$ fb$^{-1}$ the ATLAS expected sensitivity represents an improvement of more than two orders of magnitude relative to the present experimental limits and it is at the level of some SUSY and quark singlet models predictions [14, 15]. These limits will improve with the combination of the ATLAS and CMS results.

At last, the ATLAS sensitivity to $t\bar{t}$ resonances was presented. A $5\sigma$ discovery is expected to be possible for $L = 30$ fb$^{-1}$ and a generic resonance with a mass of 1 TeV$/c^2$ and $(\sigma \times BR)_{\text{res}} \sim 10^3$ fb.

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