

# Search for Signatures of New Heavy Top Quark of the Fourth Generation at the Hadron Colliders

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## Abstract

The Fourth Generation and Vector Like Quark (VLQ) models are extensions of the Standard Model of particles physics. These models predict the existence of new heavy quarks like heavy top quark  $t'$  with electric charge  $2/3$  and heavy bottom quark  $b'$  with electric charge  $-1/3$ . The  $t'$  and  $b'$  will act the fourth generation quarks. In current work we present a search for a pair production  $t'\bar{t}'$  of a fourth generation quark,  $t'$  quark and its antiparticle, followed by their decays to  $Z$ ,  $W$  bosons followed by decays to triplepton  $e^-e^-\mu^+$  plus jets and missing transverse energy in the final state according to the process  $pp(\bar{p}) \rightarrow t'\bar{t}' \rightarrow ZtW^-b \rightarrow ZW^+bW^-b \rightarrow e^-e^-\mu^+\nu_\mu b\bar{u}\bar{d}\bar{b}$ . We use Monte Carlo simulation techniques Pythia8, MadGraph5 and CalcHEP to simulate this process at both the Large Hadron Collider at CERN (proton-proton collisions) and the Fermilab Tevatron Collider (proton-antiproton collisions). We assume that the  $t'$  quark is a narrow state that always decay to a  $W$  and  $Z$  bosons plus jets. We select 2 electrons + jets+ missing energy final states with one isolated  $\mu$  with high transverse momentum. The three charged leptons plus missing energy in the final state offer the best discovery potential at the hadron colliders for new heavy top quark mass of 500 GeV. We study the possible signals at both the LHC and the Tevatron of new quarks  $t'$  coupled to the third generation quarks in the context of fourth generation and vector like quark models under the assumption of a branching ratios  $BR(t' \rightarrow Wb) = 50\%$  and  $BR(t' \rightarrow Zt) = 50\%$ . Heavy quark pair production gives interesting signals in final states with three charged leptons plus missing energy. Finally, from our analysis the new heavy fourth generation quark  $t'$  can be discovered at both the Tevatron and the LHC with mass 500 GeV.

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## Keywords

LHC, Tevatron, Fourth Generation Model, Heavy Top, Monte Carlo Simulation

## 1. Introduction

The recent results of the SM Higgs boson at the LHC have significantly impacted the prospects and focus of heavy quark searches. In particular, the observation of a new boson by the ATLAS [1] and CMS [2] Collaborations with a mass of  $\sim 126$  GeV and couplings close to those expected for the SM Higgs boson disfavors [3] fourth-generation models. These models predict a large increase in the production rate for  $gg \rightarrow H$ , which is in tension with searches in the  $H \rightarrow WW(*)$  and  $H \rightarrow ZZ(*)$  decay Channels [4] [5].

In this work, we searched for the existence of the new heavy quark top  $t'$  fourth generation quark in the charged trilepton  $(e^+, e^-, \mu)$  plus jets and missing transverse momentum decay channel. In this channel, the  $t'$  quarks are produced in pairs  $t\bar{t}'$  and the final state contains three leptons that are produced from  $W$  and  $Z$  bosons decays, and 2 hadrons are produced from decaying the  $W$  boson and two  $b$  jets. We searched for the  $t'$  by analyzing Monte Carlo data generated by MadGraph5, CalcHEP and Pythia8. The discoveries of the top quark at the Tevatron have been many searches for a possible new generation of fermions. Those searches have found no evidence of new fermions beyond the standard model (SM). Searches for these spin-1/2 heavy top-quark partners were performed by the CDF Collaboration in proton-antiproton collisions at center of mass energy 1.96 TeV excluding at 95% confidence level (CL) top-quark partners with masses up to 400 GeV. A previous ATLAS analysis with proton-proton collisions at center of mass energy 7 TeV excludes a  $t'$  with masses up to 420 GeV. Many recent researches suggested the addition of a fourth generation of heavy chiral fermions [6], which can provide new sources of CP violation that could explain the matter-antimatter asymmetry in the universe. The new weak-isospin doublet contains heavy up-type  $t'$  and down-type  $b'$  quarks that mix with the lighter quarks via an extended CKM matrix. The Vector-Like Quarks appear in many extensions of the SM such as little Higgs or extra dimensional models. In these models, a top-partner quark, for simplicity is referred to here as  $t'$  [7].

A fourth generation of fermions is interesting since it can accommodate the baryon asymmetry in the universe, induces the heavy neutrino as a candidate for dark matter avoids the need for a light Higgs boson if the mass of the heavy quarks is large, and can relieve the tension in flavour physics results. The distribution of this variable presents a sharp kinematic limit at the  $W$  boson mass for  $t\bar{t}'$  production whereas for the signal topology it decreases slowly towards a higher mass value, due to the presence of the two additional invisible particles produced in association with the top-quark pair. A fourth generation of quarks,  $t'$  and  $b'$  would allow indirect bounds on the Higgs boson mass to be relaxed and may result in enough intrinsic matter and anti-matter asymmetry to explain the baryon asymmetry of the universe. Therefore, there is continued theoretical and experimental interest in the search for a fourth generation fermion. Discovery of the Higgs boson and recent measurements of the Higgs production cross section in various channels disfavors the chiral fourth generation.

A top quark fermionic partner  $t'$  which decays into a stable, neutral, weakly interacting particle  $A_0$  also appears in other SM extensions, such as little Higgs models or models of Universal Extra Dimensions (UED) with Kaluza-Klein parity. The production cross section at the LHC is predicted to be approximately six times higher for fermionic  $t'$  than for  $t$ .

The discovery of the top quark [8] which completed the third generation of fundamental fermions in the quark sector of the Standard Model (SM) of particle physics, and searches for heavier quarks have been of particular interest in high-energy physics research. These quarks are often present in new physics models aimed at solving some of the limitations of the SM.

## 2. The Results

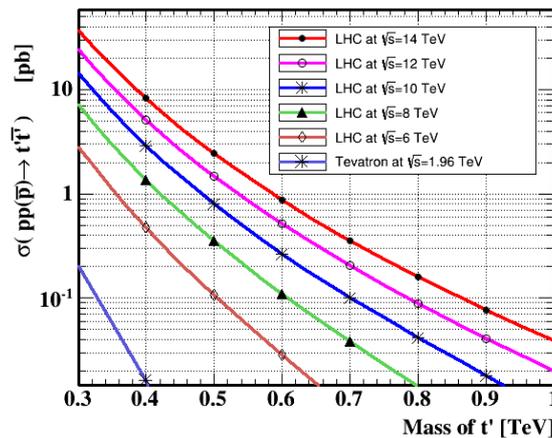
We will present an analysis for pair production and decay of  $t\bar{t}'$  fourth-generation quarks at the both the LHC (CERN) and the Tevatron (Fermi Lab.) with different center of mass energies and analyzing Monte Carlo data of event collisions produced from Pythia8, Madgraph5 and CalcHEP in the context of Fourth Generation and Vector Like Quark models. Pair production of  $t'$  quarks lead to two  $W$  bosons,  $Z$  boson and two  $b$  quarks.

ks in the final state. We will analyze the Monte Carlo data events that contain three charged leptons, jets and missing energy where one of  $W$  boson decays leptonically and the other hadronically and  $Z$  boson decays leptonically, finally we get the final state  $e^-e^-\mu^+\nu_\mu b\bar{u}d\bar{b}$ . We will calculate the production cross section of pair production, branching ratios, the decay width and different kinematics distributions of trilepton and missing energy in the final state such as transverse momentum, pseudrapidity, and also reconstructed mass of  $Z$  and  $W$  bosons from final state leptons.

## 2.1. Production of $t'$

The resulting observed and expected upper limits on the  $t\bar{t}'$  production cross section are shown in **Figure 1** as a function of  $m_{t'}$ , assuming  $BR(t' \rightarrow Wb) = 0.5$  and  $BR(t' \rightarrow Zt) = 0.5$ . **Figure 1** shows the resulting production cross sections for the signal process of the pair production  $t\bar{t}'$  as a function of the  $t'$  mass at both the LHC for energies 6, 8, 10, 12 and 14 TeV and the Tevatron for 1.96 TeV. The red line represents the prediction of the cross sections of  $t'$  quarks expected at the LHC 14 TeV which is 37 pb at  $t'$  mass 300 GeV while at 500 GeV is 2.43 pb. Also from this figure the productions cross of  $t'$  at the LHC for center of mass energy 8 TeV is 7 pb for mass 300 GeV while at 500 GeV is 0.35 pb. By comparing these results with [9] where  $e + \text{jets}$  channel happens for the 95% CL observed (expected) lower limits for a  $t'$  quark mass of 490 (540) GeV and for muon + jets channel the corresponding  $t'$ -quark mass limit is 560 (550) GeV. The combined observed (expected) limit from both channels is 570 (590) GeV. A comparable lower limit on the  $t'$  mass of 557 GeV was obtained recently by the CMS Collaboration using a dilepton channel [10] which is the most restrictive yet found and raise the lower limit on the mass of a  $t'$  quark to a region where perturbative calculations for the weak interactions start to fail and non-perturbative effects become significant. Also from the figure the production cross section of the  $t'$  at the Tevatron for mass 500 GeV is 0.0011 if we compared this with [11] with the top quark mass 172.5 GeV to the NNLO cross section with NNNLO threshold corrections in the  $s$  and  $t$ -channels of 3.3 pb [12]. Diboson samples are generated with Pythia8. Their NLO cross sections are 12.3 pb for WW, 3.7 pb for WZ, and 1.4 pb for ZZ production [13]. On the other hand the uncertainty on the cross section for  $t\bar{t}'$  production is taken from the CMS measurement of  $154 \pm 18$  pb at 7 TeV [14]. The cross section only depends on the quark  $t'$  mass. Finally The higher center-of-mass energy of the hadron collisions and the resulting larger  $t'$  production cross section at the Large Hadron Collider (LHC) are expected to improve the statistical precision compared to the Tevatron.

The expected cross section for top quark pair production at 7 TeV in proton-proton collisions is 165 pb for a top mass of 173 GeV [15]. As reference for  $t\bar{t}'$  production we use a Monte-Carlo (MC) simulation sample based on Madgraph5 [16] matched to Pythia8 [17]. The signal sample includes matrix elements describing the generation of up to four additional partons. The most relevant background processes for the trilepton channel in-

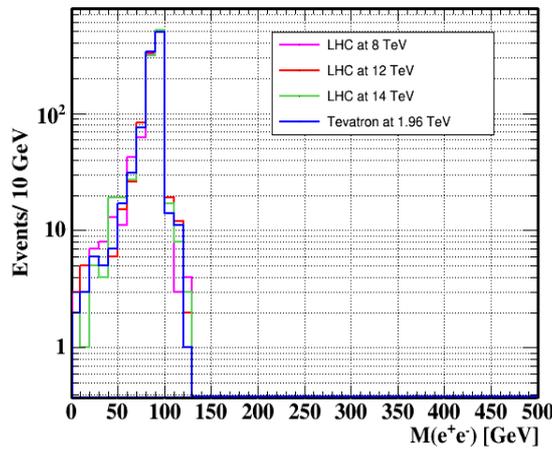


**Figure 1.** Production cross section of the fourth generation quark top-type  $t'$  as a function of  $t'$  mass at the LHC for energies 6, 8, 10, 12, 14 TeV and at the Tevatron for energy 1.96 TeV in the Vector Like Quark model using MadGraph6, CalcHEP and Pythia8.

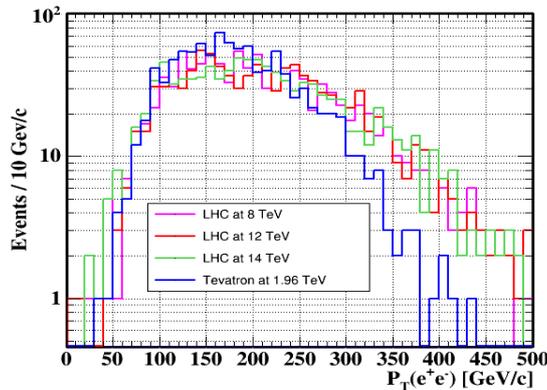
clude the production of three real isolated leptons with high transverse momentum (pT). **Figure 2** shows the Drell-Yan (DY) production of charged leptons is modeled with Madgraph8 for masses above 10 GeV. Di-boson processes are modeled with Pythia8.

For fourth-generation  $t'$  quark signals, samples are generated with Pythia8 using the CTEQ6.6 PDF set for a range of masses  $M_{t'}$  from 200 GeV to 1000 GeV in steps of 100 GeV and the Higgs boson mass is assumed to be 125 GeV. For vector-like  $t'$  signals, samples corresponding to a single  $t'$  quark decaying to  $Wb$ ,  $Zt$  and  $Ht$  are generated with Madgraph5 using the CTEQ6L1 PDF set, and interfaced to Pythia8 for the parton shower and fragmentation. **Figure 3** shows the transverse momentum of the two charged lepton from  $Z$  boson decay.

The main discriminate variable used in this search is the reconstructed Heavy quark mass built from the  $W$  mass candidate and one of the two  $b$ -jet candidates. The reconstruction of the leptonically decaying  $W$  boson usually yields two solutions, and there are two possible ways to pair the  $b$ -jet candidates with the  $W$  boson candidates to form the heavy quarks. Among the four possible combinations, the one yielding the smallest abso-



**Figure 2.** Invariant mass distribution of the two electrons in the final state (2 charged leptons from three leptons in final state) produced from  $Z$  boson decay via  $t' \rightarrow Zt$  at the LHC energies 8, 12, 14 TeV and at the Tevatron for energy 1.96 TeV in the Vector Like Quark model using Pythia8.



**Figure 3.** Transverse momentum distribution of the two electrons in the final state (2 charged leptons from three leptons in final state) produced from  $Z$  boson decay via  $t' \rightarrow Zt$  at the LHC energies 6, 8, 10, 12, 14 TeV and at the Tevatron for energy 1.96 TeV in the Vector Like Quark model using Pythia8.

lute difference between the two reconstructed heavy quark masses is chosen.

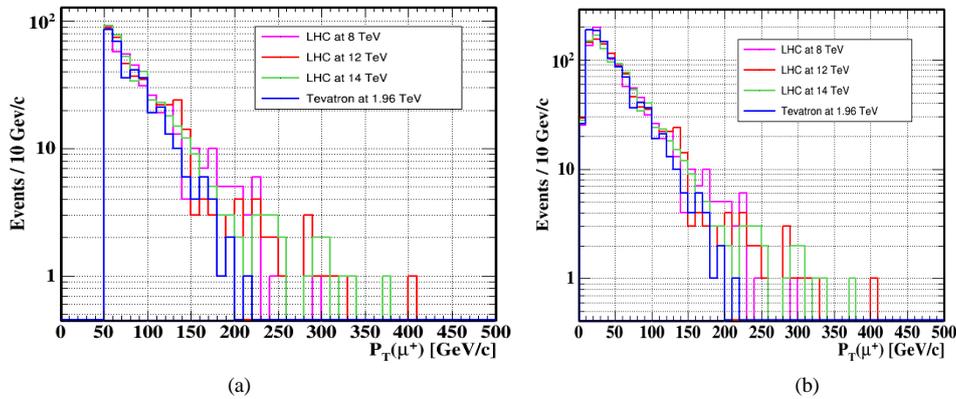
## 2.2. Event Selection

The event selection is optimized to identify the  $t\bar{t}'$  tripletonic final state which have three charged leptons with high transverse momenta, two electrons from  $Z$  boson decay and muon from  $W$  boson decay candidates are reconstructed with  $p_T > 20$  GeV/c and  $|\eta| < 2.5$ . We apply a **particle-based** isolation and require that the flux of reconstructed neutral and charged particles in a cone  $\Delta R = \sqrt{\Delta\eta^2 + \Delta\phi^2} < 0.4$  built around the lepton's thrust axis. The ambiguity is resolved by selecting the dilepton pair with opposite electric charge (from  $Z$  decay) and highest sum of transverse momenta. The event preselection criteria closely follow those used in recent ATLAS top quark studies and require exactly one isolated electron or muon with large transverse momentum at least two jets among which at least one is identified as originating from a b quark, and large missing transverse momentum  $E_T^{\text{miss}}$ . Same-flavor dileptons ( $ee$  or  $\mu\mu$ ) compatible with  $Z \rightarrow \ell\ell$  are removed by requiring  $|M_z - M_{\ell\ell}| > 30$  GeV. For all dilepton channels it is further required that  $M_{\ell\ell} > 12$  GeV in order to veto low-mass dileptons mostly produced by quarkonium decays. Directions as shown in **Figure 5** have transverse momentum  $p_T > 25$  GeV and  $|\eta| < 2.47$ , excluding the transition region ( $1.37 < |\eta| < 1.52$ ). Muon candidates are required to satisfy  $p_T > 20$  GeV and  $|\eta| < 2.5$ . For leptons satisfying these  $p_T$  requirements the efficiencies of the relevant single-lepton triggers have reached their plateau values.

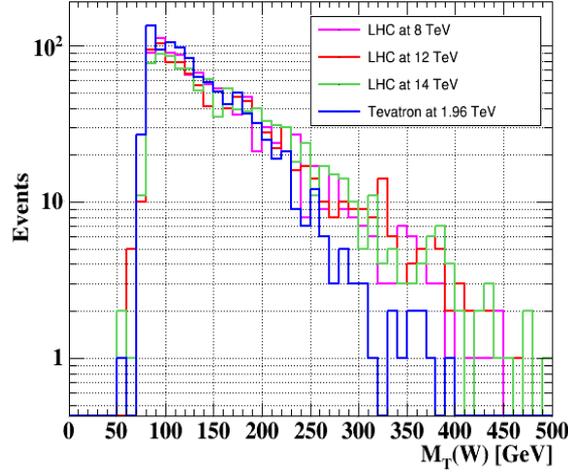
A search by the ATLAS Collaboration in the dilepton final state using 1.04 fb<sup>-1</sup> of data at  $\sqrt{s} = 7$  TeV obtained a lower 95% CL limit of  $m_{t'} > 350$  GeV. This search did not attempt to identify the flavor of the jets, making a more relaxed assumption of  $BR(t' \rightarrow Wb) = 1$ , where  $q$  could be any down type SM quark. A 95% CL limit of  $M(t') > 557$  GeV [18] assuming  $BR(t' \rightarrow Wb) = 1$ , was obtained by the CMS Collaboration using 5.0 fb<sup>-1</sup> of data at  $\sqrt{s} = 7$  TeV.

The leptonically decaying  $W$  boson is reconstructed using the lepton (muon as in **Figure 4**) and  $E_T^{\text{miss}}$  identified as the neutrino  $p_T$ . Requiring that the identified as the neutrino  $p_T$  invariant mass of the lepton-neutrino system equals the nominal  $W$  boson mass allows reconstruction of the neutrino longitudinal momentum up to a two-fold ambiguity. In case no real solution exists, the neutrino pseudorapidity is set equal to that of the lepton, since in the kinematic regime of interest for this analysis the decay products of the  $W$  boson tend to be collinear.

The transverse mass is defined by the formula  $m_T = \sqrt{2p_T^\ell E_T^\ell (1 - \cos\Delta\phi)}$  where  $p_T^\ell$  is the  $p_T$  of the lepton and  $\Delta\phi$  is the azimuthal angle separation between the lepton and  $E_T^{\text{miss}}$  directions, as in **Figure 5** for transverse mass distribution of  $W$  boson. To take advantage of the kinematic differences that exists between  $t$  quark and  $t'$  quark decays when  $M_{t'} > 400$  GeV. In particular, the hadronically decaying  $W$  boson can be reconstructed as a single isolated jet when it is sufficiently boosted, leading to a significantly improved sensitivity in comparison to previous searches. In addition, the result of this search is interpreted in the context of vector-like quark models where  $BR(t' \rightarrow Wb) = 0.5$  and  $BR(t' \rightarrow Zb) = 0.5$ . In this case the additional signals,



**Figure 4.** Transverse momentum distribution of muon in the final state (the third charged lepton from three leptons in final state) produced from  $t'$  decay followed by  $W^+ \rightarrow \mu^+ \nu_\mu$  at the LHC energies 8, 12, 14 TeV and at the Tevatron for energy 1.96 TeV in the Vector like Quark model using Pythia8. (a) Before cuts; (b) After cuts.



**Figure 5.** Transverse mass distribution of the  $W$  boson via  $t' \rightarrow Wt$  at the LHC energies 8, 12, 14 TeV and at the Tevatron for energy 1.96 TeV in the Vector Like Quark model using Pythia8.

other than  $t\bar{t} \rightarrow ZtWb$ , contribute to the signal acceptance and are accounted for in the analysis. **Figure 6** shows Mass distributions of pair production of new top at the LHC energies 8, 12, 14 TeV and at the Tevatron for energy 1.96 TeV in the Vector Like Quark mode.

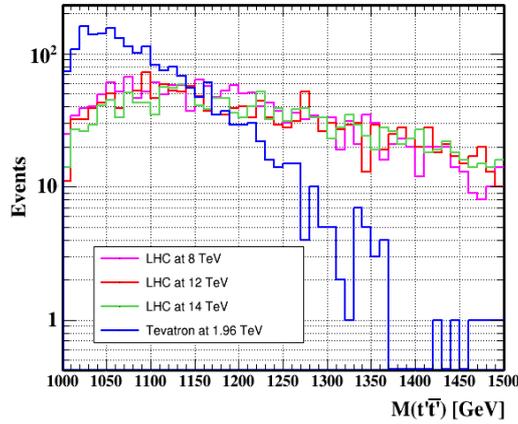
### 2.3. Branching Ratios of $t'$

Has a priori three main possible decay modes,  $t' \rightarrow Wt$ ,  $t' \rightarrow Zt$  and  $t' \rightarrow Ht$ , with branching ratios that vary **Figure 7** shows the measurement of the ratios of branching fractions of  $t'$  using CalcHEP [18]. The  $t'$  quark as a function of Mass of  $t'$  and depend on the weak isospin quantum number of the  $t'$  quark. While all three decay modes can be sizable for a weak isospin singlet, decays to only  $Zt$  and  $Ht$  are most natural for a doublet. In the case of a triplet, the  $t'$  quark can decay either as a singlet or a doublet depending on its hypercharge. The mass limits obtained for the  $t'$  quark depend on the branching ratio (BR) assumed. In current work a search for a  $t'$  decaying to  $t' \rightarrow BW$  is 25% for  $t'$  mass 300 GeV and start to decrease for higher mass of  $t'$  on contrast the decay channel to Higgs boson,  $t' \rightarrow tH$  starting to increase to reach the maximum value and become the heights one to 60% on the other hand the decay channel  $t' \rightarrow tZ$  act as 10% at 400 GeV and this value of mass is near from the expectation value of  $t'$  which is 500 GeV so we search for  $t'$  in the current work via the decay channels  $tZ$  and  $Wb$ . CMS has measured the ratio of the Branching Ratios  $R = B(t \rightarrow Wb)/B(t \rightarrow Wq)$  where  $B(t \rightarrow Wb)$  [16] is the BR of the top decaying to  $b$ 's and  $B(t \rightarrow Wq)$  where  $B(t \rightarrow Wq)$  is the branching fraction of the top quark to a  $W$  boson and a  $q$  quark ( $q = b, s, d$ ). A high-purity  $t\bar{t}$  sample in the full-leptonic decay mode, corresponding to 2.2 fb<sup>-1</sup> was used.

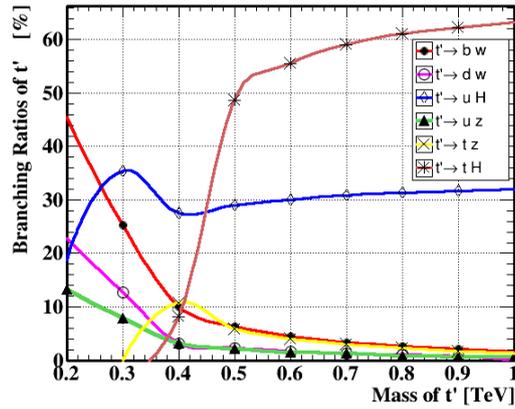
**Figure 7** shows the decay channels of  $t'$  and the branching ratios for different values of  $t'$  mass. The energy of the jets is corrected as a function of  $\eta$  and observed  $E_T$ . Extra corrections to take into account the pile-up contribution are also applied on an event-per-event basis. The number of selected jets which have resulted from the fragmentation and hadronization of  $b$  quarks. By counting the jets identified as  $b$ -jets. The heavy flavor content of the selected events (both signal and background) can be determined from the  $b$ -tagging multiplicity distribution.

Despite small contributions from other background processes, there is a non-negligible probability that at least one jet from a  $t\bar{t}$  decay is either missed because it failed the acceptance or because it was not reconstructed, and another jet is chosen instead from ISR. This will be referred to as "jet misassignment". **Figure 8** shows the transverse momentum distribution of the  $t'$  boson at the LHC energies 8, 12, 14 TeV and at the Tevatron for energy 1.96 TeV in the Vector Like Quark.

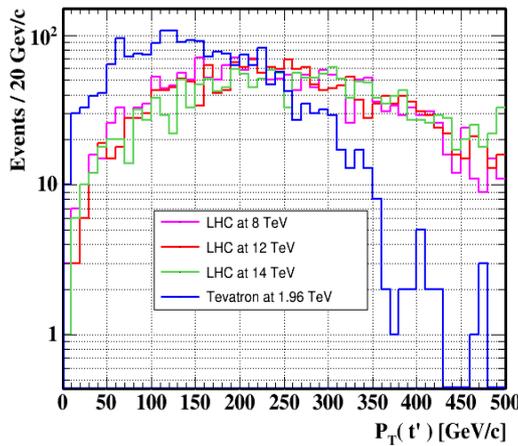
Both charged particles candidates associated to secondary vertices as well as the residual energy flux from the neutral component due to pile-up. **Figure 9** shows the pseudorapidity  $\eta$  distribution of the  $t'$  boson via  $t' \rightarrow Wt$  at the LHC energies 8, 12, 14 TeV and at the Tevatron for energy 1.96 TeV in the Vector Like Quark.



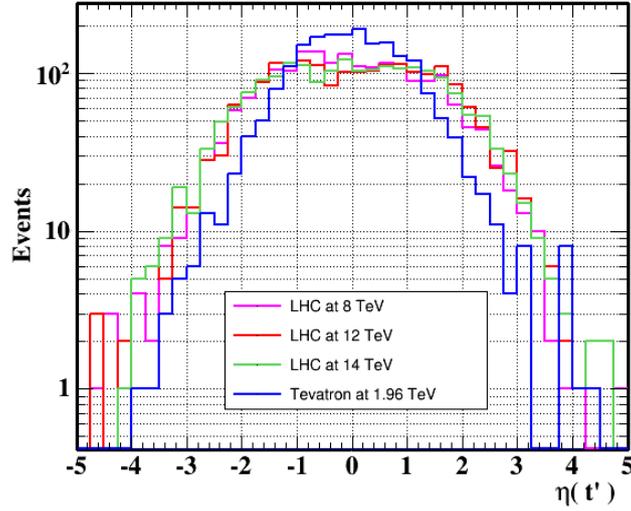
**Figure 6.** Mass distributions of pair production of new top at the LHC energies 8, 12, 14 TeV and at the Tevatron for energy 1.96 TeV in the Vector Like Quark model using Pythia8, MadGraph5.



**Figure 7.** Branching Ratios of the fourth generation quark top-type  $t'$  as a function of  $t'$  mass in the Vector Like Quark model using CalcHEP.



**Figure 8.** Transverse momentum distribution of the  $t'$  boson at the LHC energies 8, 12, 14 TeV and at the Tevatron for energy 1.96 TeV in the Vector Like Quark model using Pythia8.



**Figure 9.** Pseudorapidity distribution of the  $t'$  boson via  $t' \rightarrow Wt$  at the LHC energies 8, 12, 14 TeV and at the Tevatron for energy 1.96 TeV in the Vector Like Quark model using Pythia8.

We require the jets to have  $E_T > 30$  GeV and  $|\eta| < 3.4$ . Jet candidates are further required to be separated from the selected leptons by  $\Delta R(\text{jet}, \text{lepton}) > 0.3$  in order to remove jets which were clustered with real isolated leptons.

The missing transverse energy  $E_T$  **Figure 10** of this process comes from decay of  $W^+ \rightarrow \mu^+ \nu_\mu$  and we require  $E_T^{\text{miss}} > 30$  GeV for final state. The largest background contribution comes from DY in the same-flavor channels and it is directly estimated from data while the contribution from other processes is estimated from simulation. The distribution of the angle between the leptons  $\theta_{\ell\ell}$  is used for this purpose. The measurement requires the correct identification of  $b$  quark and light quarks, and correct association to its parent top. The  $E_T^{\text{miss}}$  is the associated high-pT object jet or electrons and including contributions from selected muon. Background from multi-jet production is suppressed by the requirement  $E_T^{\text{miss}} > 35$  (20) GeV in the electrons ( $\mu$ ) channel.

Events were none or only one top is correctly reconstructed correspond to background events or to  $t\bar{t}$  events where at least one of the jets is missed and the top is reconstructed with a wrong choice of jet.

## 2.4. Background of the Standard Model

**Figure 11** shows the SM backgrounds in this search come from like-sign lepton pairs is  $WZ$  production, and smaller sources include  $ZZ$ , like-sign  $WW$ ,  $t\bar{t}W$ , and  $t\bar{t}Z$  production. High purity sample of  $t\bar{t}$  dilepton events where the main background contamination is expected to be from Drell-Yan and single-top quark events.

After event preselection the main background is  $t\bar{t}$  production with lesser contributions from the production of a  $W$  boson in association with jets ( $W + \text{jets}$ ) and multi-jet events. Small contributions arise from single top-quark,  $Z + \text{jets}$  and diboson production.

Multi-jet events contribute to the selected sample mostly via the misidentification of a jet or a photon as an electron, or via the presence of a non-prompt lepton, e.g. from a semileptonic  $b$ - or  $c$ -hadron decay.

## 2.5. Decay Width of $t'$

**Figure 12** shows the total decay width of the  $t'$  quark using events with  $t\bar{t}$  quark pair candidates reconstructed in the final state with three charged leptons and four hadronic jets. The  $t'$  quark mass and the mass of the hadronically decaying  $W$  boson are reconstructed for each event and compared with distributions derived from simulated signal and background samples to extract the  $t'$  quark width and the energy.

We reconstruct  $t'$  quark decays in the topology of  $t' \rightarrow W^+ b$ ,  $t' \rightarrow Zt$  and  $t' \rightarrow tH$ . Events with a  $W$  bo-

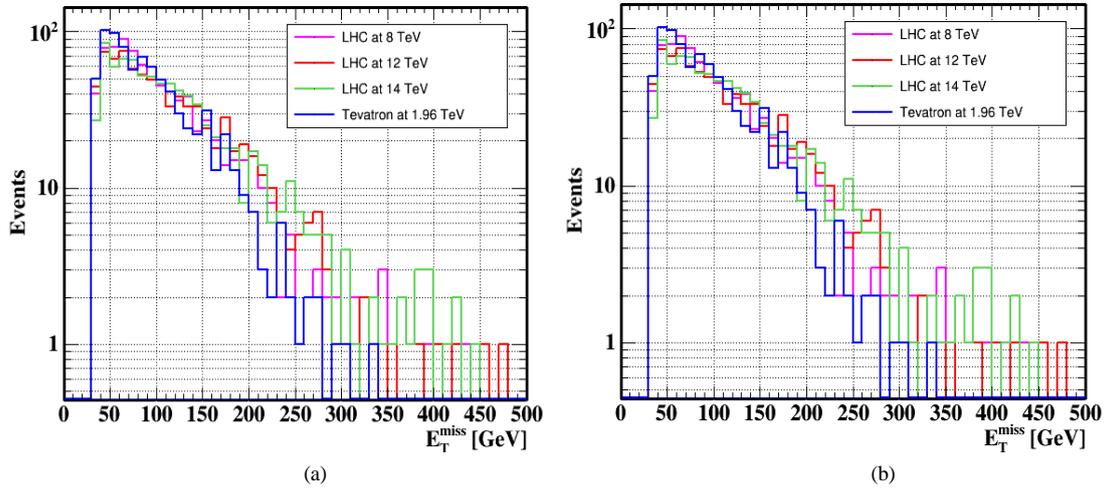


Figure 10. Missing transverse momentum distribution in the final state produced from the decay of  $t'$  followed by  $W^+ \rightarrow \mu^+ \nu_\mu$  at the LHC energies 8, 12, 14 TeV and at the Tevatron for energy 1.96 TeV in the Vector Like Quark model using Pythia8. (a) Before cuts; (b) After cuts.

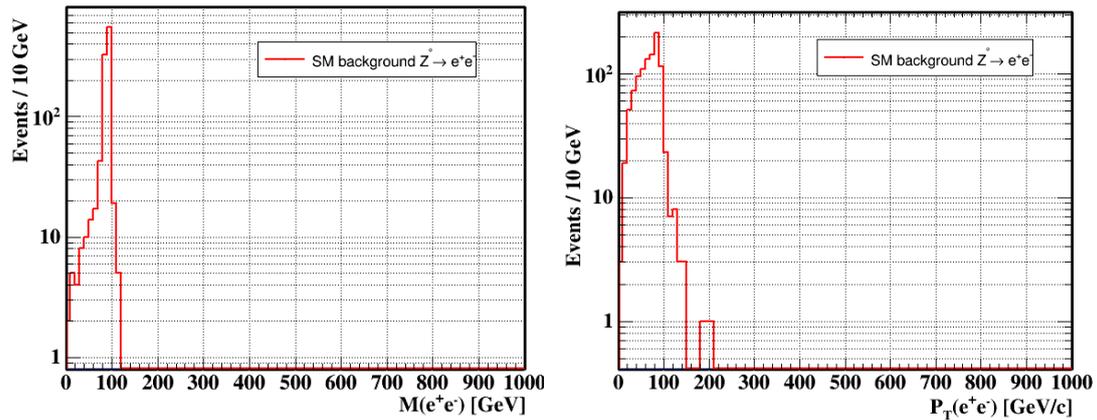


Figure 11. The Drell-Yan process background—the invariant mass of electrons produced from  $Z^0$  boson and the transverse momentum for electrons using Pythia8 and MadGraph5.

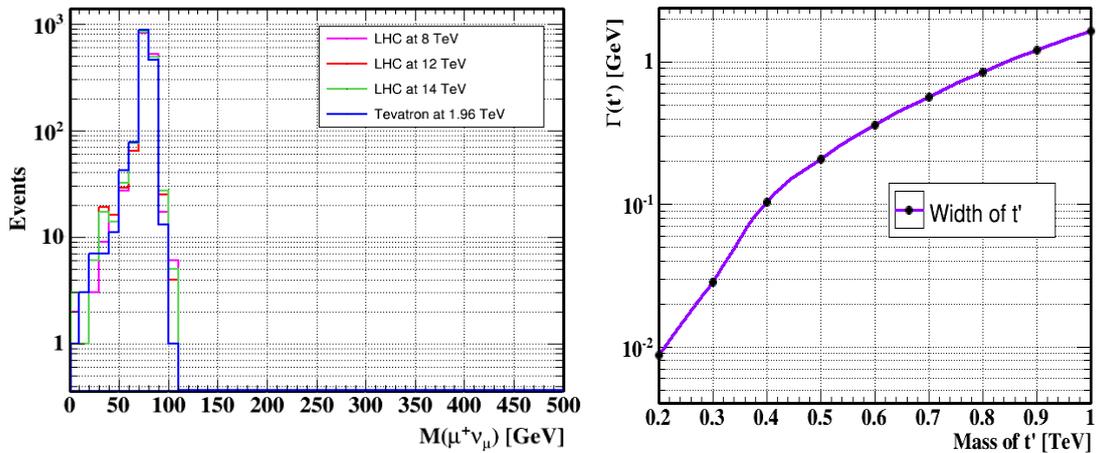


Figure 12. Decay Width of fourth generation quark top-type  $t'$  as a function of  $t'$  mass in the Vector Like Quark model using MadGraph6, CalcHEP.

son decaying into a charged lepton (electron or muon) and a neutrino  $W \rightarrow \ell \nu$  and the other  $W$  boson decaying into a pair of jets defines the lepton + jets channel.

For  $t'$  quark the partial decay widths are:

$$\begin{aligned}\Gamma(t' \rightarrow W^+ b) &= \frac{g^2}{64} |V_{t'b}|^2 \frac{m_{t'}}{M_w^2} |\lambda(m_{t'}, m_b, M_w)|^{1/2} \times \left[ 1 + \frac{M_w^2}{m_{t'}^2} - 2 \frac{m_b^2}{m_{t'}^2} - 2 \frac{M_w^4}{m_{t'}^4} + \frac{M_w^4}{m_{t'}^4} + \frac{M_w^2 m_b^2}{m_{t'}^4} \right], \\ \Gamma(t' \rightarrow Z t) &= \frac{g}{128\pi c_w^2} |X_{t't}|^2 \frac{m_{t'}}{M_z^2} |\lambda(m_{t'}, m_t, M_z)|^{1/2} \times \left[ 1 + \frac{M_z^2}{m_{t'}^2} - 2 \frac{m_t^2}{m_{t'}^2} - 2 \frac{M_z^4}{m_{t'}^4} + \frac{M_w^4}{m_{t'}^4} + \frac{M_z^2 m_t^2}{m_{t'}^4} \right], \\ \Gamma(t' \rightarrow H t) &= \frac{g^2}{128\pi} |X_{t't}|^2 \frac{m_{t'}}{M_w^2} |\lambda(m_{t'}, m_t, M_H)|^{1/2} \times \left[ 1 + \frac{m_t^2}{m_{t'}^2} - \frac{m_H^2}{m_{t'}^2} + \frac{M_H^4}{m_{t'}^4} - \frac{M_H^2 m_t^2}{m_{t'}^4} \right].\end{aligned}$$

Being  $\lambda(x, y, z) \equiv (x^4 + y^4 + z^4 - 2x^2 y^2 - 2x^2 z^2 - 2y^2 z^2)$  a kinematical function.

### 3. Conclusion

In this work we presented the production of a fourth generation heavy quark  $t'$  together with its antiparticle  $\bar{t}'$  at both the Tevatron and the LHC using Monte Carlo event generators Pythia8, MadGraph5 and CalcHEP assuming a significant branching ratios for decays into  $pp(\bar{p}) \rightarrow t'\bar{t}' \rightarrow ZtW\bar{b} \rightarrow ZW^+bW^-\bar{b} \rightarrow e^-e^-\mu^+\nu_\mu\bar{b}\bar{u}\bar{d}\bar{b}$  in the context of Fourth Generation and Vector Like Quark models under the assumption of a branching ratios  $BR(t' \rightarrow Wb) = 50\%$  and  $BR(t' \rightarrow Zt) = 50\%$ . This process has very good sensitivity to  $t'\bar{t}'$  production. The pair production of  $t'$  quarks gives final state with three leptons with branching ratios not too small. Signals in the tripleton final state involve the leptonic decay of  $Z$  and one  $W$  boson and hadronic decay for another  $W$  boson. We study the possible signals at both the LHC and the Tevatron of new quarks  $t'$  coupled to the third generation. Heavy quark pair production  $t'\bar{t}'$  gives interesting signals in final states with three charged leptons plus missing energy. We presented an analysis for the Monte Carlo events collisions at mass of  $t'$  quark 500 GeV for events contain the tripleton  $(e^+, e^-, \mu) +$  missing energy + jets in final state which characterized by a high transverse momentum for dielectron, isolated muon, large missing transverse momentum and four jets. The potential discovery of the new quarks in decay channels was obtained containing a  $Z$  and  $W$  boson, especially in the final state with one charged lepton and four  $b$ -tagged jets. It is shown that with the combination of the different channels the new top quarks  $t'$  can be identified and their charged and neutral decays established. The tripleton final state offers a good balance between signal branching ratio in  $t'\bar{t}'$  pair production and SM background. Finally, from our analysis the new heavy fourth generation quark  $t'$  can be discovered at both the Tevatron and the LHC with mass 500 GeV.

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