The Compact Muon Solenoid Experiment
Conference Report

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25 September 2009 (v3, 29 September 2009)

Search for fourth generation quarks

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Abstract

It is still a mystery why the Standard Model as we know it has three families. At new high energy colliders it is worthwhile to search for a new additional family – which obviously would have a heavy neutrino to avoid the LEP bounds. This presentation discusses new studies made with the CMS detector for the search of new heavy b-like quarks in several different decay modes and for different possible mass regions. These studies are based on detailed detector simulation, including all Standard Model backgrounds. Particular emphasis is given to possible early discoveries, i.e. with 100 pb⁻¹ or less. Projected 95

Presented at *SUSY09: 17th International Conference On Supersymmetry And The Unification Of Fundamental Interactions*

Search for Fourth Generation Quarks

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Abstract. It is still a mystery why the Standard Model as we know it has only three families. At new high energy colliders it is worthwhile to search for a new additional family which obviously would have a heavy neutrino to avoid the LEP bounds. This paper discusses new studies made with the CMS detector for the search of new heavy b-like quarks in several different decay modes and for different possible mass regions. These studies are based on detailed detector simulation, including all Standard Model backgrounds. Particular emphasis is given to possible early discoveries, i.e. with 100pb^{-1} or less. Projected 95% CL exclusion limits as a function of luminosity are presented as well.

Keywords: Fourth generation quarks, CMS

PACS: 14.65.-q

INTRODUCTION

The Standard Model (SM) describes successfully most of the physics phenomena with three generations of quarks. The precision measurements at Z pole in the Large Electron-Positron Collider (LEP) experiment exclude light fourth generation neutrino with mass less than half of Z mass. However, it does not exclude the existence of fourth generation neutrino.

The existence of an irreducible phase in the quark mixing matrix provides the only source of CP violation in the SM. This source of CP violation is too small to account for the asymmetry between matter and antimatter in the universe. The existence of fourth generation quarks may rescue the model [1].

CDF at the Tevatron has performed searches for the fourth generation quarks. For b' quark decays into tW , CDF has announced their result [2]. The study consists of searching for same-sign dilepton pair. The limit on the b' mass is 325 GeV at 95% confidence level. CDF also performs a search for $t' \rightarrow qW$ and the lower limit on t' mass is 311 GeV at 95% confidence level [3]. For $b' \rightarrow bZ$ channel, the lower limit on the b' mass (> 268 GeV at 95% confidence level) is provided by CDF [4]. The result is obtained by assuming 100% $b' \rightarrow bZ$ decay branch fraction.

With different assumptions of the relative strength of $|V_{cb'}|$ and $|V_{tb'}|$, both $b' \rightarrow cW$ and $b' \rightarrow t^{(*)}W$ (or $tW^{(*)}$) could be the major b' decays if $M_{b'} < 255$ GeV. For the case of $M_{b'} > 255$ GeV, the decay channel $b' \rightarrow tW$ is expected to be dominant and the transition $b' \rightarrow cW$ would be suppressed except for $|V_{cb'}| \gg |V_{tb'}|$. The decay $b' \rightarrow t'$ should be suppressed if $M_t < M_{t'} < M_{b'}$ [5] and $b' \rightarrow b$ mode only occurs through second order loop diagrams.

This paper only focuses on bottom-like fourth generation quark (b') with $M_{b'} > 300$ GeV and the branch ratio of $b' \rightarrow tW$ is assumed 100%. When both b' quarks decay into top quark and W boson, the final state contains four W bosons. Each boson can either decay leptonically or hadronically. The same-sign dileptonic (Figure 1) and trileptonic channels are selected in final state. The signature of same-sign dileptonic channels is very rare for SM processes, and therefore the backgrounds are negligible small. The branch ratio of trileptonic mode is much smaller than the dileptonic channels and thus is free from most of the SM backgrounds.

A dataset corresponding to 100 pb^{-1} integrated luminosity at 14 TeV is assumed for the search and exclusion limits. The Monte Carlo (MC) samples, produced with a fast simulation of the CMS detector [6], are used in this analysis.

FIGURE 1. The leading order Feynman diagram for $b' \rightarrow tW$ same-sign dileptonic channel.

EVENT SELECTIONS AND EVENT YIELD

The events are selected to pass either single non-isolated electron trigger or single non-isolated muon trigger. Four types of objects are used in this analysis: electrons, muons, jets and missing transverse energy (MET). These selections are optimized by Genetic Algorithm and the optimization is based on 300 GeV b' . The detail selections could be found in Ref. [7].

Signal events can be characterized with the variable, H_T , which is defined as:

$$H_T = \sum P_T(\text{jets}) + \sum P_T(\text{leptons}) + \text{MET}.$$

H_T is the most effective variable that carries the information of b' mass, since b' mass cannot be reconstructed in this analysis. The distributions of H_T with 100 pb^{-1} integrated luminosity are shown in Figure 2.

FIGURE 2. The distributions of H_T for three signal b' mass. The opening histograms are expected signal for 300 GeV (left), 400 GeV (middle) and 500 GeV (right) b' mass.

The signal is significant for the low b' mass (300 ~ 400 GeV). The expected signal and background yields are listed in Table 1. The background to signal is expected to be small, but a data-driven method is still introduced for the background estimation.

The study of systematic uncertainties on the cross-section measurement is also performed. The contributions contain integrated luminosity, background estimation, jet energy scale, jet reconstruction efficiency, MET, pile-up jets, lepton identification, lepton trigger, PDF, and MC statistics. The main contributions are background estimation, jet energy scale and MET. The overall uncertainties (syst. + stat.) are +39%/-42%, +45%/-62%, and +88%/-144% for 300 GeV, 400 GeV, and 500 GeV b' mass. If b' mass is 300 GeV, the significance is 7.5σ . The detail description is in Ref. [7].

TABLE 1. Summary of expected signal and background yields for 100pb^{-1} integrated luminosity.

Process	Yield		Sum
	Same-sign dilepton	trilepton	
$b'b', M(b') = 300 \text{ GeV}$	44.7	23.6	68.2
$b'b', M(b') = 400 \text{ GeV}$	14.6	7.6	22.2
$b'b', M(b') = 500 \text{ GeV}$	5.1	2.9	8.0
$t\bar{t}+\text{jets}$	4.7	1.0	5.7
$t\bar{t}W+\text{jets}$	0.43	0.32	0.75
$t\bar{t}Z+\text{jets}$	0.31	0.38	0.69
$t\bar{t}WZ+\text{jets}$	0.02	0.014	0.035
$Z+\text{jets}$	<0.4	<0.4	<0.4
$W+\text{jets}$	<1.4	<1.4	<1.4
ZZ	<0.03	<0.03	<0.03
WZ	<0.1	0.21	0.21
Background Sum	5.4	1.9	7.3

EXCLUSION LIMIT

The exclusion limit on the b' mass is estimated using Bayesian statistics for null hypothesis. Comparing to the Pythia LO cross section, we are able to exclude the production of $pp \rightarrow b'b'$ up to 480 (420) GeV at 95% confidence level with 100 (30) pb^{-1} integrated luminosity (see Figure 3).

CONCLUSION

We have performed the feasibility study for a search of fourth generation bottom-like quark, $b' \rightarrow tW$ (branch ratio = 100%) with 100 pb^{-1} at 14TeV at CMS. If b' mass is 300 GeV, the significance is 7.5σ . If the observed events are consistent with Standard Model background processes, we could exclude $b' \rightarrow tW$ up to $M(b') > 480$ (420) GeV at 95% confidence level with 100 (30) pb^{-1} integrated luminosity.

FIGURE 3. The exclusion limit at 95% confidence level on the cross-section measurement of b' . Comparing to the Pythia LO cross section, b' mass less than 480 GeV can be excluded with 100pb^{-1} integrated luminosity for a null hypothesis.

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