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Search for the 4th Generation Quark b' at CMS

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New energy regime of LHC allows to extend the search region for 4th generation of quarks and leptons beyond existing constraints. Feasibility studies are performed on both of the low-mass $b' \to cW$ search region, with the flavor-changing neutral-current (FCNC) decay $b' \to bZ$ is allowed, as well as the high-mass $b' \to tW$ production. Using leading order (LO) cross section for b' production, expected significance with up to 1/fb data at $\sqrt{s} = 10$ TeV and 95% confidence level (C.L.) exclusion limits are studied.

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1. Introduction

The possible existence of a 4th generation of elementary fermions, a new replica of the known three generations of chiral matter including the top-like quark t' and the bottom-like quark b', has recently regained interest. [1] Within the framework of the Standard Model (SM), the masses of the quarks of a fourth generation are constrained to be below approximately 550 GeV, by unitarity conditions. The existence of the fourth generation suggested in the context of TeV baryon genesis, as it may provide a sufficiently large CP violation (CPV), and can lead to a prediction of $\sin 2\beta_s$ value of the B_s decay [2]. Recent analyses based on data from B-factories give hints for possible New Physics (NP) beyond the SM in the CP-violation sector [3]. This could be due to a New Physics CPV phase in the electroweak penguin operator, which could arise from a 4th generation t' quark. The recent new results from the Tevatron experiments show the continuous interests on the 4th generation quarks searches [4].

2. Low Mass b' Search

For the case of b' mass less than tW mass threshold, $b' \to tW$ is kinematically suppressed. The leading charged current process $b' \to cW$, which is doubly Cabibbo-suppressed, would be the dominant one with a finite $|V_{cb'}|/|V_{tb'}|$. we consider instead the possibility of a sizable FCNC decay channel $b' \to bZ$ (an electroweak penguin loop process) at the level of 10%. With this assumption the signal is relatively clean and one can fully reconstruct the b' in the leptonic decay channel of the vector bosons.

The searching signature of this channel is to look for three isolated leptons, missing transverse energy (MET) and two jets. The signal event can be easily triggered by one high-p_T electron or muon. Lepton candidates are required to be within the sensitive area of the detector. Lepton isolation requirements are based on the near-by charged tracks p_T and calorimeter energy depositions within certain ΔR cores. The invariant mass mass window requirement on $Z \to \ell\ell$ candidates can easily suppress the QCD and most of the SM backgrounds. Further requirement on the transverse mass window: $m_T(W) = \sqrt{2 \cdot MET \cdot E_T^{\ell}(1 - \cos\Delta\phi)}$ where $\Delta\phi$ is the direction difference in ϕ-direction of the MET and the W daughter lepton.

We use the transverse energy sum observable: $H_T = \sum E_T^{jet} + \sum p_T^{trk} + \text{Missing } E_T$, where E_T and p_T are transverse energies and transverse momenta of the final state particles of the b' candidate daughters. From the following figures, one can find that the jet multiplicity plays an crucial role in the separating the signal from the $W+Z$ backgrounds. We further reconstruct the $b'(bZ)$ invariant mass by finding the most back-to-back b' candidates. The following figures shows the distributions of these variables with 1 fb^{-1} data assumed. The number of jets to be greater or equal than two is required in the final event counting.

3. High Mass b' Search

As the b' mass approaches the tW threshold, the $b' \to t^{(*)}W^{(*)}$ decay mode is expected to be dominant. In this scenario, both leptonic ($W \to \ell\nu$) and hadronic ($W \to q\bar{q}$) decay channels are considered for the $b'\bar{b'} \to tW^-\bar{t}W^+$ daughters. Final states containing same-sign (SS) dileptons and trilepton plus jets are rare in standard model processes. Therefore, one can expect clean background and unique signature in this high-mass b' production search. The draw back of these two channels is the difficulty of b' mass reconstruction.

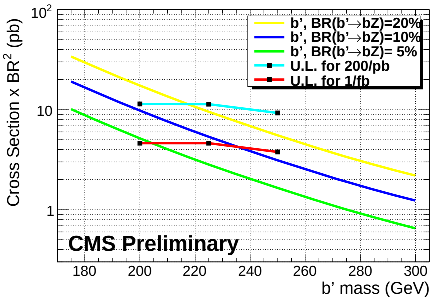
For both of the W decay channels of heavy b' search, lepton-jet separation is required to reject doubly-reconstructed electrons and muons (sharing the same tracks). For the tri-lepton channel, an event is rejected if the invariant mass of two oppositely-charged muons or electrons is within the Z-boson mass region.

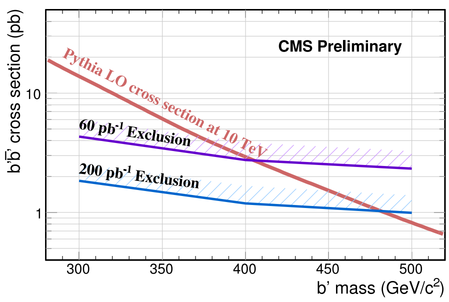
The jet multiplicity for same-signed dilepton and trilepton channels are shown separately in the figures. One can see very clear difference on the signal and background after the selection cuts optimized with genetic algorithm. Events are further required to have at least four or more jets in the final state for the same-sign dilepton channel; for the trileptonic channel, at least two or more jets are required. In addition to these criteria on the number of lepton and jet candidates, at least a hard lepton and at least a hard jet are required in the events. The above selection criteria are optimized assuming a $b' \to tW$ signal at 400 GeV. The only observable used here is the total transverse energy H_T, which sums up the transverse momentum of jets, leptons and the MET.

The signal yields b' production is based on the estimated background contribution in the total events that pass all the selection cuts. To estimate the background independent of the Monte Carlo (MC), a two-box method is used in both light b' and heavy b' study. The former checks the lepton isolation requirement of the W-boson daughter, while the later makes use the opposite-signed and same-sign leptons combination of the W daughters. The validation with MC samples shows very good agreements.

4. Conclusion

For the light b' search, due to the low $b' \to bZ$ branching fraction assumed, one will need 1 fb^{-1} data to see significant signal yields. While for the heavy b' case, one can get strong evidence if $m(b')$ is below 400 GeV with only 200 pb^{-1} data. For either cases, upper limits of 95% C. L are also shown in the following figures. The details can be found in CMS Physics Anaylsis Summaries (PAS) notes [5, 6].





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