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Shota Tsiskaridze

Search for Flavor-Changing Neutral Current Top Quark Decays $t \rightarrow Hq$, with $H \rightarrow b\bar{b}$, in pp Collisions at $\sqrt{s} = 8$ TeV with the ATLAS Detector

Doctoral Thesis accepted by
the Universitat Autònoma de Barcelona, Spain

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Supervisor's Foreword

This Ph.D. thesis is focused on the search for flavour-changing neutral current decays of a top quark to an up-type quark ($q = u, c$) and the Standard Model Higgs boson, $t \to Hq$. This decay mode is heavily suppressed in the Standard Model and so a measured signal would indicate the existence of new phenomena beyond the Standard Model. This analysis searches for top-antitop quark pair ($t\bar{t}$) events in which one top quark decays to Wb, with the W boson decaying leptonically, and the other top quark decays to Hq, with the Higgs boson decaying to $b\bar{b}$. It uses the full Run 1 dataset collected by the ATLAS experiment in proton-proton collisions at $\sqrt{s} = 8$ TeV at CERNs Large Hadron Collider. A very ambitious search strategy has been developed, including a novel technique to exploit kinematic differences between the signal and the dominant $t\bar{t} \to W^+bW^-\bar{b}$ background, as well as a sophisticated statistical analysis to constrain in-situ the background uncertainties. This constitutes the single most sensitive direct search for $t \to Hq$ to date. The combination of this search with other ATLAS searches in the $H \to \gamma\gamma$ and $H \to WW^*$, $\tau\tau$ decay modes further improves the sensitivity, resulting in the most restrictive direct bounds on flavour-violating tqH interactions measured so far.

Bellaterra (Barcelona), Spain — Aurelio Juste Rozas
July 2017

Abstract

In this dissertation a search for flavour-changing neutral currents in the decay of a top quark to an up-type quark ($q = u, c$) and the Standard Model Higgs boson, where the Higgs boson decays to $b\bar{b}$, is presented. The analysis searches for top quark pair events in which one top quark decays to Wb, with the W boson decaying leptonically, and the other top quark decays to Hq. The search is based on pp collisions at $\sqrt{s} = 8$ TeV recorded in 2012 with the ATLAS detector at the CERN Large Hadron Collider and uses an integrated luminosity of 20.3 fb^{-1}. Data are analyzed in the lepton+jets final state, characterized by an isolated electron or muon with moderately high transverse momentum and at least four jets. The search exploits the high multiplicity of b jets characteristic of signal events, and employs a likelihood discriminant that uses the kinematic differences between the signal and the background, which is dominated by $t\bar{t} \to WbWb$ decays. No significant excess of events above the background expectation is found. The observed (expected) upper limits on the $t \to Hc$ and $t \to Hu$ branching ratios are 0.56% (0.42%) and 0.61% (0.64%) respectively, at the 95% confidence level. The combination of this search with other ATLAS searches in the $H \to \gamma\gamma$ and $H \to WW^*, \tau\tau$ decay modes significantly improves the sensitivity yielding observed (expected) upper limits on the $t \to Hc$ and $t \to Hu$ branching ratios of 0.46% (0.25%) and 0.45% (0.29%) respectively, at the 95% confidence level. The corresponding combined observed (expected) upper limits on the $|\lambda_{tcH}|$ and $|\lambda_{tuH}|$ couplings are 0.13 (0.10) and 0.13 (0.10) respectively. These are the most restrictive direct bounds to date on tqH interactions measured so far.

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Contents

Acronyms and Naming Conventions

This section describes the naming of nuisance parameters corresponding to various systematic uncertainties in the fit output.

- Luminosity: LUMI
- Electron:
  - identification: ELE_ID
  - reconstruction: ELE_RECO
  - resolution: ELE_RES
  - energy scale: ELE_SCALE
  - trigger: ELE_TRIG
- Muon:
  - identification: MUON_ID
  - reconstruction: MUON_RECO
  - resolution in the tracker: MUON_RES_ID
  - resolution in the muon system: MUON_RES_MS
  - momentum scale: MUON_SCALE
  - trigger: MUON_TRIG
- Jet reconstruction efficiency: JEFF
- Jet vertex fraction: JVF
- Jet energy scale:
  22 independent components provided by JES group and related to the overall JES, jet ηintercalibration, jet flavour, pile-up effects and data statistics for data-driven methods: JetDet1, JetDet2, JetDet3, JetEtaModel, JetEtaStat, JetFlavB, JetFlavComp, JetFlavResp, JetMixed1, JetMixed2, JetModel1, JetModel2, JetModel3, JetModel4, JetMu, JetNPV, JetPilePt, JetPileRho, JetSinglePart, JetStat1, JetStat2, JetStat3
- Jet resolution: JER
- Missing transverse momentum: SC_SOFT, RES_SOFT

- b-tagging uncertainties:
  6 eigenvectors corresponding to b-jet p_T bins ordered from the smallest to the largest: BTAGBREAK0, BTAGBREAK1, BTAGBREAK2, BTAGBREAK3, BTAGBREAK4, BTAGBREAK5
- c-tagging uncertainties:
  4 eigenvectors corresponding to c-jet p_T bins ordered from the smallest to the largest: CTAGBREAK0, CTAGBREAK1CTAGBREAK2, CTAGBREAK3
- light-tagging uncertainties:
  12 eigenvectors corresponding to 6 light jet p_T bins and two jet ηregions ordered from the smallest to the largest: LTAGBREAK0, LTAGBREAK1, LTAGBREAK2, LTAGBREAK3, LTAGBREAK4, LTAGBREAK5, LTAGBREAK6, LTAGBREAK7, LTAGBREAK8, LTAGBREAK9, LTAGBREAK10, LTAGBREAK11
- high-p_T extrapolation uncertainty for b-, c- and light-tagging: TAGEXTRAP
- $t\bar{t}$ normalization:
  - $t\bar{t}$ inclusive cross section: ttbar_XS
  - $t\bar{t} + b\bar{b}$ normalization: ttbar_bb
  - $t\bar{t} + c\bar{c}$ normalization: ttbar_cc
- $t\bar{t}$ inclusive production:
  Uncertainties associated with the measurement of the differential cross section for $t\bar{t}$ and top p_T used to correct $t\bar{t}$ MC model:
  - Detector: ttbar-DataRw-BTagEff, ttbar-DataRw-Fragmentation, ttbar-DataRw-JER, ttbar-DataRw-JetCloseby, ttbar-DataRw-JetDet1, ttbar-DataRw-JetEtaCalibration, ttbar-DataRw-JetFlavB
  - Model: initial and final state radiation - ttbar-DataRw-IFSR, MC generator ttbar-DataRw-MCgen
- $t\bar{t}$+light:
  Parton shower model: ttbar_PartonShower
- $t\bar{t} + c\bar{c}$: MC modeling
  - Matching parameter variation in Madgraph: ttbar_cc_MG − MATCH
  - c-mass variation in Madgraph:ttbar_cc_MG − MC
  - scale variation in Madgraph:ttbar_cc_MG − Q2
  - generator choice (Powheg vs Madgraph): ttbar_cc_MG
  - parton shower model: ttbar_PartonShower-cc
  - reweighting: Uncertainties corresponding to switching top (ttbar_cc-DataRw-Notoppt) and $t\bar{t}\,p_T$ (ttbar_cc-DataRw-Nottbarpt) reweighting off

- $t\bar{t}+b\bar{b}$ +: MC modeling
  - scale variation in Sherpa: ttbbNLO_scale
  - scale functional form choice in Sherpa: ttbbNLO_QCMMPS
  - PDF uncertainties: tttbbNLO_NNPDF, ttbbNLO_MSTW
  - uncertainty due to MPI model: ttbbNLO_MPI
  - uncertainty due to FSR model: ttbbNLO_FSR
  - parton shower model: ttbar_PartonShower-bb
- Small backgrounds:
  - cross section for W+jets with ≥ 4 jets: Wjets_XS_LJETS
  - cross section for W+jets with ≥ 5 jets: Wjets_XS_jet5
  - cross section for W+jets with ≥ 6 jets: Wjets_XS_jet6
  - Wpt correction for $W+$jets : Wjets_pt
  - cross section for Z+jets with ≥ 4 jets: Zjets_XS_LJETS
  - cross section for Z+jets with ≥ 5 jets: Zjets_XS_jet5
  - cross section for Z+jets with ≥ 6 jets: Zjets_XS_jet6
  - Zpt correction for Z+jets : Zjets_pt
  - cross section for single top production with ≥ 4 jets: singleTop_XS_LJETS
  - cross section for single top production with ≥ 5 jets: singleTop_XS_jet5
  - cross section for single top production with ≥ 6 jets: singleTop_XS_jet6
  - cross section diboson production with ≥ 4 jets: Dibosons_XS_LJETS
  - cross section diboson production with ≥ 5 jets: Dibosons_XS_jet5
  - cross section diboson production with ≥ 6 jets: Dibosons_XS_jet6
  - modeling of Wt single top production (diagram subtraction scheme): SingleTop-DS
  - cross section for $t\bar{t}V, (V = Z, W, WW)$ production: ttbarV_XS
  - modeling of $t\bar{t}V, (V = Z, W)$: scale variation (ttV_scale)
  - cross section for $t\bar{t}H$ production: ttH125_XS
  - modeling of $t\bar{t}H$: scale variation (ttH − Scale_Var) and choice of functional form of scale (ttH − Scale_Dyn)
  - multijet normalization: QCDmm_EL_LJETS($e+$jets) and QCDmm_MU_LJETS($\mu+$jets)
- Signal modeling:
  - PROTOS reweighting non-closure: ttbar_ProtosNonClosureRW
  - uncertainty in Higgs branching ratios from $\Delta\alpha_s$: BR_param_alphaS
  - uncertainty in Higgs branching ratios from Δm_b: BR_param_mB
  - uncertainty on Higgs decay with from higher-order QCD corrections:

    BR_HiggsDecayWidthTHU_hqq