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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, $t \rightarrow Hq$. 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 CERN's 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 $t\bar{t} \rightarrow W^+ bW^- \bar{b}$ background, as well as a sophisticated statistical analysis to constrain in-situ the background uncertainties. This constitutes the single most sensitive direct search for $t \rightarrow Hq$ to date. The combination of this search with other ATLAS searches in the $H \rightarrow \gamma\gamma$ and $H \rightarrow WW^*$, $\tau\tau$ decay modes further improves the sensitivity, resulting in the most restrictive direct bounds on flavour-violating tqH interactions measured so far.

Bellaterra (Barcelona), Spain
July 2017

Aurelio Juste Rozas

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 $t\bar{t} \rightarrow WbWb$ decays. No significant excess of events above the background expectation is found. The observed (expected) upper limits on the $t \rightarrow Hc$ and $t \rightarrow Hu$ 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 $H \rightarrow \gamma\gamma$ and $H \rightarrow WW^*$, $\tau\tau$ decay modes significantly improves the sensitivity yielding observed (expected) upper limits on the $t \rightarrow Hc$ and $t \rightarrow Hu$ 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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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 η intercalibration, 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, CTAGBREAK1, CTAGBREAK2, CTAGBREAK3
- light-tagging uncertainties:
12 eigenvectors corresponding to 6 light jet p_T bins and two jet η regions 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: `tbbNLO_scale`
 - scale functional form choice in Sherpa: `tbbNLO_QCMMPS`
 - PDF uncertainties: `tbbNLO_NNPDF`, `tbbNLO_MSTW`
 - uncertainty due to MPI model: `tbbNLO_MPI`
 - uncertainty due to FSR model: `tbbNLO_FSR`
 - parton shower model: `tbar_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`
 - W pt 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`
 - Z pt 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: `tbarV_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(μ + jets)`
- Signal modeling:
 - Protos reweighting non-closure: `tbar_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`