Search for $H^\pm$ decaying to top and bottom quarks with Single Leptonic Final State at 13 TeV using the CMS Detector

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on behalf of the CMS collaboration
Overview

- Higgs boson discovery provides last piece of the Standard Model
- Further investigations are underway to verify if this is really a SM Higgs
- Two Higgs Doublet Model (2HDM) extends the Standard Model (SM) and expects Charged Higgs
- Largest branching ratio of the charged Higgs in top and bottom quark channel
- Exclusion limit on $\tan \beta$ results from 8 TeV
Signatures

• Charged Higgs decays to top and bottom quarks

• The top quark decays to b quark and W boson

• Extra top quark and b quark from strong interactions

• Two W bosons are produced
  • One decays leptonically and other decays hadronically

• Only one lepton, electron or muon in the final state

• At least 3 b tagged jets, 1 lepton, and 2 other jets in the final state
**Backgrounds**

- Pair produced top quarks (TTbar) decaying single leptonically
  - Dominate background in signal and control regions, over ~80%

  - Categorization by flavor for jets from extra radiation
    - ttbar+2B : one additional b jet containing two b hadrons
    - ttbar+bb : at least two additional b jets, independent of the number of b hadrons in each b jets
    - ttbar+b : one additional b jet containing a single b hadron
    - ttbar+cc : at least one additional c jet, independent of the number of c hadrons in each c jets
    - ttbar + lf : no additional b or c jets

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8/3/17

Jangbae Lee


### Backgrounds

- **W+jets**
  - Leptonically decaying W boson
  - At least two b quarks produced

- **Single top**
  - At least 1 W boson and 1 b-quark
  - Mistagged Jets + Leptonically decaying W boson could mimic signal-like events

- **Diboson, Drell-Yan, and QCD multi-jet backgrounds**
Data and MC sets

- 2016 data with integrated luminosity 35.9 fb\(^{-1}\) collected by CMS detector
- Monte Carlo (MC) samples were generated with 25ns bunch spacing
- Event generators used for the MC samples
  - MADGRAPH5\_aMC@NLO 2.2.2 : Signals, W+Jets, QCD-multijet, TOP DY+Jets, Diboson
  - POWHEG 2.6 : ttbar, TOP, Diboson
  - PYTHIA8.212
- GEANT4 was used for detector simulation
- Background MC samples are grouped into ttbar, TOP, EWK, and QCD multi-jet
Triggers

• Single lepton triggers used for increasing events selection efficiency

• All the triggers were used in logical ‘OR’ operation

• Electron triggers
  • Electron $p_T > 27$ GeV, $|\eta| < 2.1$, and Tight ID
  • Electron $p_T > 35$ GeV and Loose ID
  • Electron $p_T > 105$ GeV and Tight ID
  • Photon $p_T > 165$ GeV

• Muon triggers
  • Muon $p_T > 24$ GeV with isolation
  • Muon $p_T > 24$ GeV, reconstructed with hits in tracker
  • Muon $p_T > 50$ GeV

Recovering event selection efficiency in high $p_T$
Object Selections

- Electron
  - Multivariate Analysis (MVA) based Tight ID with custom working point, 88% efficiency in ttbar
  - Transverse Momentum ($p_T$) $> 35$ GeV and $|\eta| < 2.1$
  - Mini-Isolation $< 0.1$, The cone size depends on pT to increase efficiency at high energy
  - Electron veto: Loose ID where 95% efficiency in ttbar, $p_T > 10$ GeV, $|\eta| < 2.1$, Mini-Isolation $< 0.4$

- Muon
  - “Medium2016” ID, $p_T > 30$ GeV, $|\eta| < 2.4$, and Mini-Isolation $< 0.1$
  - Muon veto: Loose ID, $p_T > 10$ GeV, $|\eta| < 2.4$, and Mini-Isolation $< 0.4$

- Tau
  - Hadron plus Strip (HPS) algorithm based Tau, $p_T > 20$ GeV, $|\eta| < 2.3$, and $\Delta R$ with lepton $> 0.4$
  - Used for veto in e/\mu channels

- Jet
  - Reconstructed Jets with the anti-kT algorithm with a distance parameter of 0.4
  - Loose particle flow jet ID, $p_T > 40$ GeV, $|\eta| < 2.4$, Angular separation ($\Delta R$) with lepton $> 0.4$

- B-tagging
  - $pfCombinedInclusiveSecondaryVertexV2$ (CSVv2) $> 0.8484$ where mistag rate is less $\sim 1\%$

- Missing Transverse Momentum (MET)
  - Negative vector sum of transverse energy from all particle flow object in an event
Baseline Event Selection

- Select events only passing logical ‘AND’ operation of following conditions
  - Exactly single electron or muon
  - Electron pT > 35 GeV and $|\eta| < 2.1$
  - Muon pT > 30 GeV and $|\eta| < 2.4$
  - Jet pT > 40 GeV
  - MET > 30 GeV
  - Number of jets $\geq 3$ and Number of b-tagged jet $\geq 1$
  - Minimum $\Delta \phi$ between MET and Jet $> 0.05$ in control regions of electron channel -> Suppressing QCD events leak
  - No Tau in electron and muon channels
Event Categorization

- Define control regions and maximization on signal sensitivity

**4 Control Regions**

1b/4j  
1b/5j  
1b/≥6j  
2b/4j

**5 Signal Regions**

2b/5j  
2b/≥6j  
≥3b/4j  
≥3b/5j  
≥3b/≥6j

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**Expected U.L. (95% CL) (pb)**

CMS  
35.9 fb$^{-1}$ (13 TeV)

**Work in Progress**

**CMS**

35.9 fb$^{-1}$ (13 TeV)

**Work in Progress**

500

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**CMS**

35.9 fb$^{-1}$ (13 TeV)

250

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**CMS**

35.9 fb$^{-1}$ (13 TeV)

**Work in Progress**
Data/MC comparison in CR

- Good agreement between Data and MC in control regions within uncertainty.
Multivariate Analysis

- Boosted Decision Tree with adaptive boost method used

- BDT discriminator is trained to distinguish signal from TTbar background which is main background

- Due to limited statistics in low mass signals two mass region defined
  - Low : 180, 200, 220, 250, and 300 GeV
  - Medium : 350, 400, and 500 GeV

- High mass signals were trained separately, 800, 1000, 2000, and 3000 GeV

- 20 kinematic input variables used for developing BDT discriminators

- Training in inclusive signal regions

- Randomly split signal sample into Train/Test/Application with 25%/25%/50%

- For TTbar background two samples used for Train/Test and Application

- Optimization in depth and number of tree performed to obtain receiver operating characteristics (ROC)
Multivariate Analysis

- the scalar sum of the all jet transverse momenta, $H_T$
- minimum mass of lepton and b-jet, $\min[M(\ell, b)]$
- the mass of the b-jet pair with minimum separation, $M(b, b)$ with $\min[\Delta R(b, b)]$
- the separation between the lepton and b-jet with maximum $p_T$, $\Delta R(\ell, b)$ with $\max[p_T, \ell, b]$
- the separation between the lepton and leading jet, $\Delta R(\ell, j_1)$
- the separation between the lepton and sub-leading jet, $\Delta R(\ell, j_2)$
- the separation between the lepton and third leading jet, $\Delta R(\ell, j_3)$
- the separation between the lepton and leading b-jet, $\Delta R(\ell, b_1)$
- the separation between the lepton and b-jet pair where the separation between b-jet pair is minimum, $\Delta R(\ell, bb)$ with $\min[\Delta R(b, b)]$
- Centrality, the ratio of the sum of the transverse momentum and total energy of all jets
- the separation in $\eta$ between furthest b-jet pair, $\max[\Delta \eta(b, b)]$
- averageCSV: this is $p_T$ weighted average discriminator of the non b-tagged jets.
- average separation of b-jet pairs, ave[$\Delta R(b, b)$]
- The second Fox-Wolfram moment where all jets are included in the calculation, $2^{nd}$ FW moment
- the mass of the three jet system with maximum $p_T$, $M(jjj)$ with $\max[p_T(jjj)]$
- the transverse momentum of leading b-jet, $p_T(b_1)$
- minimum separation between b-jet pairs, $\min[\Delta R(b, b)]$
- minimum separation between the lepton and b-jet, $\min[\Delta R(\ell, b)]$
- the transverse mass of the leading lepton and the missing transverse energy, $M_T(\ell, E_T^{miss})$
- missing transverse energy, $E_T^{miss}$
Templates in SR/CR

Templates for other regions are in backup
Templates binning and Statistical Uncertainty

- Template binning choice
  - BDT template for Signal regions
    - Start from 200 uniform bins and rebin to have < 30% statistical uncertainty
  - HT template for Control regions
    - Start from 500 uniform bins and rebin to have < 30% statistical uncertainty

- Statistical Uncertainties in MC
  - Balow-Beeston lite methods used
  - Add additional nuisances on each bin if statistical uncertainty > 10%
  - Calculate uncertainty of the total background and assign to the dominant process
  - Advantage in reducing number of nuisances
Systematic Uncertainties

- Rate and Shape uncertainties are considered

- Renormalization and Factorization, Top pT, and b-tagging are most impact uncertainties

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<td>Top $p_T$</td>
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<td>HT</td>
<td>env(upper fit, lower fit)</td>
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<td>EWK</td>
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</table>
Expected Results

- 95% CL expected upper limits on cross section of a charged Higgs boson production
  - Asymptotic approximation used for limits
  - BDT (HT) discriminant for SR (CR)
  - QCD multi-jet excluded since its yield less than 5%
  - The expected limit varies between 2 pb and 0.01 pb for Charged Higgs mass between 180 and 3000 GeV
Backup
Templates in SR/CR

< Events / 1.0 units >

35.9 fb⁻¹ (13 TeV)

CMS

SR

Work in Progress

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Work in Progress

35.9 fb⁻¹ (13 TeV)

CMS

CR
## Data and MC samples

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### QCD

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