Study of the Standard Model
Higgs boson in $ZH \rightarrow l^+l^-bb$ at DØ

Jiaming Yu (University of Michigan)
On behalf of the DØ collaboration
Higgs Hunting 2013, Orsay - France
Overview

The Search for the Brout-Englert-Higgs Boson

New Results from the DØ Experiment

Joseph Haley
Northeastern University
On Behalf of the DØ Collaboration
Rencontres de Moriond
7 March 2012, La Thuile, Italy

For \( m_H = 125 \text{ GeV} \), the observed (expected) limit is \( 7.1 \) (\( 5.1 \) \( \times \) SM cross section

Two papers with 9.7\,fb\(^{-1}\) data:

**DØ reprocessed data**

**DØ Reprocessed dataset**
- \(8.6\text{fb}^{-1}\) (RunIIb) after data quality requirements
- Improvements: lepton tracking, vertex algorithm
- New b-jet tagging tools

**Analysis goals with reprocessed data:**
- Perform the analysis with new version of dataset and MC samples; optimize the analysis strategy
- Higgs production cross section measurement
Event Selection

\[ Z \rightarrow \mu^+\mu^- \text{ or } Z \rightarrow e^+e^- \text{ with } 70 < m_{ll} < 110 \text{ GeV} \]

- at least two jets with \( p_T > 20 \text{ GeV} \) and \( |\eta| < 2.5 \)
- The primary vertex has at least three associated tracks

\( \mu^+\mu^- \):
- at least one isolated muon with \( p_T > 15 \text{ GeV} \) and \( |\eta| < 1.5 \)
- at least one more isolated muon with \( p_T > 10 \text{ GeV} \), \( |\eta| < 2.0 \)

\( e^+e^- \):
- at least one isolated electron with \( p_T > 10 \text{ GeV} \) and \( |\eta| < 1.1 \)
- at least one more isolated electron with \( p_T > 15 \text{ GeV} \), \( |\eta| < 1.1 \) or \( 1.5 < |\eta| < 2.5 \)
SM background

- Multijet backgrounds are estimated from control samples in data:
  - Di-muon: events with same-sign charge muons
  - Di-electron: inverting the electron isolation and shower shape requirements
- Normalization – global fit to the $m_{ll}$ distribution:
  - Multijet samples normalized in the **low-mass tail** of the $m_{ll}$ distribution
  - MC backgrounds normalized in the **Z peak**
Pre-btag selection

DØ work in progress, 8.6 fb⁻¹

Events / Bin

Leading Jet $p_T$ [GeV]

Second Jet $p_T$ [GeV]

Dijet Mass [GeV]

Dilepton Mass [GeV]

Data
- Z+LF
- Z+b$b$
- $Z+c\bar{c}$
- Top
- Diboson
- Multijet
- $ZH \times 100$

DØ work in progress, 8.6 fb⁻¹

Events / Bin

July 25 2013

Jiaming Yu (UMich)
b-jet tagger

- Improved MVA technique based b-tagging algorithm [12 Operating Points (OPs)]

<table>
<thead>
<tr>
<th>Operating Point</th>
<th>L6</th>
<th>Old Loose</th>
<th>Very Tight</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cut value</td>
<td>0.45</td>
<td>0.75</td>
<td>0.88</td>
</tr>
<tr>
<td>Efficiency to tag b-jet</td>
<td>~82%</td>
<td>~68%</td>
<td>~58%</td>
</tr>
<tr>
<td>Chance to tag light jet</td>
<td>~10%</td>
<td>~2%</td>
<td>~0.8%</td>
</tr>
</tbody>
</table>

- Two b-tagging categories selection:
  - Double Tag (DT): TightOP && LooseOP
  - Single Tag (ST): SingleTightOP && !(DT)

- In DT, if more than 2 b-tagged jets, form a Higgs candidate with highest \( p_T \) tagged jets
- In ST, use the tagged jet and the highest \( p_T \) untagged jet
Optimize b-tag category

Expected limits $M_H=125$ GeV

Winner:

- DT : VeryTight && L6
- ST : oldLoose && !(DT)

Pre-btag | ST | DT
---|---|---
Signal/Background | ~1/2800 | ~1/360 | ~1/130
A kinematic fit is adopted to improve the resolution of the dijet invariant mass:

- Lepton energies are measured more precisely than jet energies
- The $p_T$ boost of the ZH system is moderate, and no neutrinos in the final state
- Three constrains:
  \[ \sum_{\text{lep,jets}} p_x = 0, \text{ with Gaus width of 7 GeV} \]
  \[ \sum_{\text{lep,jets}} p_y = 0, \text{ with Gaus width of 7 GeV} \]
  \[ M_{ll} = M_Z, \text{ with Breit-Wigner } \Gamma_Z = 2.49 \text{ GeV} \]
- Improving the dijet mass resolution by 10~15% depending on $M_H$
- The resolution for $M_H=125$ GeV is approximately 15 GeV after the kinematic fit
A multivariate analysis strategy based on Random Forest discriminants (RF) is used to improve the separation of the signal from the background.

- **Tagged events**
  - Cut on ttbar RF

- **ttbar depleted**
  - Cut on Z+bb RF

- **ttbar, Z+bb depleted**
  - Cut on Z+cc/LF RF

- **ttbar, Z+bb, Z+cc/LF depleted**
  - Cut on diboson RF

- **Region 5**
  - ttbar, Z+bb, Z+cc/LF, diboson depleted

- **Region 1**
  - ttbar enriched

- **Region 2**
  - ttbar depleted
  - Z+bb enriched

- **Region 3**
  - ttbar, Z+bb depleted
  - Z+cc/LF enriched

- **Region 4**
  - ttbar, Z+bb, Z+cc/LF depleted
  - Diboson enriched

- Four intermediate RFs (trained with all tagged events): ttbar vs. ZH, Z+bb vs. ZH, Z+cc/LF vs. ZH, diboson vs. ZH
- Cuts used to define the enriched/depleted region is optimized
- In each final region, a global RF(all Bkg vs. ZH) is trained independently
- 5 regions × 2 post b-tagging bins = 10 final discriminants in each sub-channel
Multivariate analysis

Intermediate RF : ST

Cut @ 0.633
Cut @ 0.504
Cut @ 0.544
Cut @ 0.599

Intermediate RF : DT

Cut @ 0.602
Cut @ 0.594
Cut @ 0.733
Cut @ 0.638

DØ work in progress, 8.6 fb⁻¹
Preliminary analysis results

Final discriminant

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ST

- DØ work in progress, 8.6 fb⁻¹

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DT

- DØ work in progress, 8.6 fb⁻¹

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95% C.L.

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<th>@ m_H = 125GeV</th>
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<th>Reprocessed</th>
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<td>Expected limit (8.6fb⁻¹)</td>
<td>5.9</td>
<td>5.8</td>
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The analysis with 8.6fb⁻¹ reprocessed data is validated

- The analysis is performed in di-muon and di-electron sub-channels
- All the improvements in the reprocessed data are adopted
- b-tag category is optimized
- A MVA strategy with four intermediate RFs is well studied

Future plan

- Higgs boson production cross section measurement
Back up
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DØ Detector

[Diagram of DØ Detector showing various components like Muon Scintillators, Muon Chambers, Calorimeter, Toroid, Shielding, and η values at different distances.]
Di-electron: inclusive, efficiency consistent with 100%

Di-muon: inclusive

For di-muon sub-channel: a trigger efficiency correction is derived from the ratio of the inclusive data to SingleMu_OR trigger data (parameterized in four variables), then applied to the MC samples.
MVA BL* tagger

Additional primary vertex information in the MVA training
New electron scenario

Electron selection in di-electron sub-channel

- CC electron Point0 \( p_T > 15 \text{GeV} \)
- CC electron Point0 \( p_T > 10 \text{GeV} \)
- EC electron Point05 \( p_T > 15 \text{GeV} \)
- EC electron Point0 + HoR \( p_T > 15 \text{GeV} \)

- Cut on HoR for EC:
  \( \geq 1.2 \) for SMT only
  \( \geq 2.2 \) for SMT&&CFT
- No cut on HoR for CC