H→WW search and WW Cross Section Measurement with ATLAS

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on behalf of the ATLAS Collaboration.
Introduction

Projects on ATLAS

- Basic Tracking / Commissioning with Cosmic-Rays
- TRT Tracking Performance
- Inner Detector Alignment (TRT)
- Electron Identification
  - Designing HLT Trigger / Offline Electron Definitions
- Electron Efficiency
- Multivariate Electron Identification

Physics on ATLAS

- W/Z Cross section
- WW Cross section
- Search for Hww
- W+jet Background
Physics Goals

Motivation is Higgs.

Why $H\rightarrow WW$?
   Important over broad mass range.
   Challenging, but important, at low mass.
   Hint of signal there from ZZ and gamma-gamma at 125 GeV.
   Large branching fraction for WW

Why WW?
   Important to understand WW and its backgrounds for Hww.

Why leptons?
   Rare in proton collisions compared to jets.
   Provide trigger & well-reconstructed.
Outline

Introduction/Motivation

Leptons at ATLAS
  - Electrons.

WW Cross Section / H→WW Search.
  - Fake Leptons.

Results.
Higgs Physics

Standard Model
Remarkably Accurate Description Data.
One Remaining Piece: Higgs Boson.
Data predict m(H) below ~200 GeV

Best Fit for Higgs Mass

Theory vs Experiment

arXiv:1109.0975
Searching for the Higgs

**H → WW → llvv**

Strongest sensitivity over broad range of m(H)
Critical in the region between LEP and SM EWK exclusion
H→WW→llll Results

95% CL Limit on σ/σ_{SM}

ATLAS

- Observed
- Expected

± 1σ
± 2σ

\( \int L dt = 2.05 \text{ fb}^{-1} \)
\( \sqrt{s} = 7 \text{ TeV} \)

m_{H} [GeV]

120 140 160 180 200 220 240 260 280 300

135 196

145 206
Status of the Higgs search.

Combined ATLAS Higgs limits

ATLAS Preliminary 2011 Data

\[ \int L dt = 1.0 - 4.9 \text{ fb}^{-1} \]
\[ \sqrt{s} = 7 \text{ TeV} \]
Status of the Higgs search.
Status of the Higgs search.

Exp. Obs.

\[ \text{H} \rightarrow \gamma \gamma \ (4.9 \text{ fb}^{-1}) \]

\[ \text{H} \rightarrow \text{WW} \rightarrow l^+l^- \nu \nu \ (2.1 \text{ fb}^{-1}) \]

\[ \text{H} \rightarrow \text{ZZ} \rightarrow 4l \ (4.8 \text{ fb}^{-1}) \]

95% CL limit on \( m_{\text{H}} \)
Status of the Higgs search.

- Hww has strongest sensitivity at 125.
- Big piece of potential discovery.
- If found, will provide best cross section measurement
Electrons in ATLAS
An Electron ATLAS
Electron Candidates in ATLAS

\[ \int \text{Ldt} = 1.3 \text{ pb}^{-1} \]

- Data 2010 (\(\sqrt{s} = 7 \text{ TeV}\))
- Monte Carlo
- Hadrons
- Conversions
- \(b\to e\)
- \(c\to e\)
- \(W/Z/\gamma^*\to e\)

ATLAS
Electron Identification

- Prompt Electrons
- Hadrons
- Heavy-Flavor Conversions

ATLAS Preliminary Simulation

Prompt Electrons
Hadrons
Heavy-Flavor Conversions

Electron Identification

fraction of high threshold TRT hits

ATLAS Preliminary Simulation

0 0.1 0.2 0.3 0.4 0.5 0.6

0 0.05 0.1 0.15 0.2 0.25 0.3 0.35

0 10^5 10^6 10^7 10^8 10^9

0 1 2 3 4 5 6 7 8 9 10

0 0.1 0.2 0.4 0.6 0.8 1

0 0.02 0.04 0.06 0.08 0.1

0 0 2 4 6 8 10 12

-5 10 -4 10 -3 10 -2 10 -1 10

0 10^1 10^2 10^3 10^4 10^5 10^6

0 0.2 0.4 0.6 0.8 1

10 100 1000 10000 100000 1000000

0 0.05 0.1 0.15 0.2 0.25 0.3

0 1 2 3 4 5 6 7 8 9 10

0 0.2 0.4 0.6 0.8 1
Electrons in ATLAS

Operating Points:

“Loose”
- Shower shapes 2nd sampling
- Hadronic Leakage.

“Medium”
- All Loose requirements
- Track quality
- Shower shapes in 1st sampling.

“Tight”
- All Medium requirements
- Track Cluster Matching.
- Transition Radiation.
- Conversion Rejection.

Isolation not explicitly included in operating points,
Often included in electron definition used in Analysis.
- Electron ID criteria (including that used in trigger) based on MC expectation.
- Had to be re-optimized using more realistic shower shapes.
- **Problem:** Became critical before collected enough W/Z’s. Use Corrected MC.
- Efficiency Measurements couldn’t rely on the simulation.
Shower Shape Mis-modeling

Challenge with the Electron Identification.

- Electron ID criteria (including that used in trigger) based on MC expectation.
- Had to be re-optimized using more realistic shower shapes.
- **Problem:** Became critical before collected enough W/Z’s. Use Corrected MC.
- Efficiency Measurements couldn’t rely on the simulation.

Due primarily to approximations made in the calorimeter geometry description.

Absorber Material: Average vs Detailed description
Muons in ATLAS
Muons in ATLAS

Identified as Tracks in the Muon Spectrometer.
Essentially all reconstructed muons are from muons.

\[ \pi/K \text{ decays} / \text{semi-leptonic heavy flavor decays} / \text{EWK bosons} \]

Heavy Flavor decays dominate above 15 GeV.
Isolation Energy / Displacement from Collision point, means of suppression
Physics with Leptons

Once you have a way of identifying leptons, two key issues.

**Efficiency**

How often are “True” Leptons are correctly identified.

Important for:
- Correcting predictions from Simulation
- Cross section measurement / Limit Setting.

Need a known, unbiased, source of “real” leptons to measure.

(Use: Z’s, J/Phi, and Ws)
Physics with Leptons

Once you have a way of identifying leptons, two key issues.

**Efficiency**
How often are “True” Leptons are correctly identified.
Important for:
- Correcting predictions from Simulation
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Need a known, unbiased, source of “real” leptons to measure.

**Mis-Identification Rate**
How often things that are not “True” Leptons are Identified as Leptons.

mis-ID Reduces purity of sample/measurement
Can lead to biases, if not modeled correctly.
Rate is small, sensitive tails of the simulation.
Physics with Leptons
**Motivation:**
- Dominant Background to $H \rightarrow WW$ search
- Test EWK model, Sensitive to Triple Gauge Couplings

**Signature:**
- Performed Fully Leptonic Decays.
- 2 Opposite-Sign Leptons ($e, \mu$)
- Large Missing Energy

\[
\sigma_{WW} = \frac{N - N_{Bkg}}{\epsilon \times A \times L}
\]
WW Cross Section

$\int \text{Ldt} = 1.02\text{fb}^{-1} \quad \sqrt{s}=7\text{TeV}$

**ATLAS Preliminary**

After Di-Lepton Selection
(25 GeV / 20 GeV)
Event Selection

Backgrounds:

**Drell-Yan:** (lepton pair + ‘fake’ MeT)
- Require Large Missing Energy
- Reject events consistent w/Z mass

**Top:** (WW produced w/2 b-jets)
- Jet Veto

**W+Jets:** (lepton w/MeT + ‘fake’ lepton)
- Isolation / lepton Identification

**Other Diboson:** (WZ, ZZ, Wγ)
- remove events w/ > 2 leptons.
Event Selection

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**DY /Top Background**
- Large, but reduced w/ Event Selection
- Well modeled by MC
- Can be corrected to Data.
Event Selection

Backgrounds:

**Drell-Yan:** (lepton pair + ‘fake’ MeT)
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**Other Diboson:** (WZ, ZZ, Wγ)
- remove events w/ > 2 leptons.

**W+Jet Background**
- Small, but not suppressed w/ Event Selection
- Difficult to model in MC
- Important at Low Pt.
Event Selection

**Backgrounds:**

**Drell-Yan:** (lepton pair + ‘fake’ MeT)
- Require Large Missing Energy
- Reject events consistent w/Z mass

**Top:** (WW produced w/2 b-jets)
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**Other Diboson:** (WZ, ZZ, Wγ)
- remove events w/ > 2 leptons.

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**Diboson Background**
- Small, and suppressed w/ Event Selection
- Well modeled by MC.
Searching for $H \rightarrow WW \rightarrow \ell\ell\ell\ell$

$\sqrt{s} = 7$ TeV, $\int L \, dt = 1.70$ fb$^{-1}$

$H \rightarrow WW \rightarrow e\nu e\nu$

ATLAS Preliminary

- Data
- SM (sys $\oplus$ stat)
- WW
- WZ/ZZ/W$\gamma$
- $t\bar{t}$
- Single Top
- Z+jets
- W+jets
- H [150 GeV]

$M_{ee}$ [GeV]
Separating out the $H \rightarrow WW$

Event Selection same as for WW Cross Section.
Slightly Looser MeT cuts, add $P_{T_{ll}}$

(Also includes 1-jet bin, see backup)

Dominated by SM WW.

Additional cuts to suppress SM WW.
Exploit spin-0 nature of Higgs.
Optimized in 3 bins of $m(H)$
Background Estimation
Drell-Yan Background

Background from DY if “fake” MeT

Observed momentum imbalance that is not due to the presence of neutrinos.

Causes of fake MeT not necessarily expected to be reproduced by MC.

Use Data Events in the Z peak:

Quantify modeling of MeT in DY Events with:

\[ S(E_{T,\text{miss},\text{Rel}}) = \frac{N_{\text{Data}} - N_{\text{MC}}}{N_{\text{DY}}} \]
Drell-Yan Background

Background from DY if “fake” MeT
Observed momentum imbalance that is not due to the presence of neutrinos.

Causes of fake MeT not necessarily expected to be reproduced by MC.

Use Data Events in the Z peak:
Quantify modeling of MeT in DY Events with:

\[ S(\varepsilon_{T,rel}) = \frac{N_{\text{Data}} - N_{\text{MC}}}{N_{\text{DY}}} \]

**Measurement:**

<table>
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<tr>
<th>Channel</th>
<th>( S )</th>
<th>- Given Data/MC consistency do not correct prediction.</th>
<th>- ( S ) to assign systematic.</th>
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Top Background

Background from Top from lost Jets

Use Top control region in data

\[ N_{Top}^{Bkg}(0\text{-jet}) = N_{Top}^{Data-CR} \times \frac{N_{Top}^{MC}(0\text{-jet)}}{N_{Top}^{MC-CR}} \]
Top Background

Background from Top from lost Jets

Use Top control region in data

\[ N_{\text{Top}}^{\text{Bkg}}(0\text{-jet}) = N_{\text{Top}}^{\text{Data-CR}} \times \frac{N_{\text{Top}}^{\text{MC}}(0\text{-jet})}{N_{\text{Top}}^{\text{MC-CR}}} \]

Measurement of the Top Background in agreement with MC prediction

Bkg Prediction: 58.6 ± 2.1 (stat) ± 22.3 (sys)
MC Prediction: 56.7

Large systematic uncertainty due to Energy scale uncertainty in MC
Top Background

Background from Top from lost Jets

Use Top control region in data

\[ N_{\text{Top}}^{\text{Bkg}}(0\text{-jet}) = N_{\text{Top}}^{\text{Data-CR}} \times \frac{N_{\text{Top}}^{\text{MC}}(0\text{-jet})}{N_{\text{Top}}^{\text{MC-CR}}} \]

Reduce systematics by applying SF measured in Tag sample.

\[ N_{\text{Top}}^{\text{Bkg}}(0\text{-jet}) = N_{\text{Top}}^{\text{Data}} \times SF \times \frac{N_{\text{Top}}^{\text{MC}}(0\text{-jet})}{N_{\text{Top}}^{\text{MC}}} \]

SF - scale factor from tag sample

Leads to cancelation of some of the JES uncertainty in jet-veto.

\(~20\%\) systematic vs \(~40\%\) without SF.
W + Jet Background.

W+jet events can give rise to background to WW.
- True lepton and real MeT from W
- Jet mis-IDed as Lepton

Large W+jet cross section gives significant contribution despite small lepton fake rate.

Cannot Rely on MC
- Simulation would have to get W+jet physics right.
- Simulation would have to get the Jet → Lepton piece right.
  Hadrons / Conversions/ Heavy Flavor
  (Requires precise modeling of tails)

Fake Factor Method Data Driven Technique
Fake Factor Method.

Basic Idea.
- Select a control sample of $W+$jet events in data.
- Use an extrapolation factor ("fake factor") that allows us to model the $W+$jet background with the control sample.
Fake Factor Method.

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- Select a control sample of W+jet events in data.
- Use an extrapolation factor ("fake factor") that allows us to model the W+jet background with the control sample.

Control Sample.

\[ W + \text{Jet background is same as signal, except for mis-Identified Lepton.} \]

- Use an alternative Lepton definition, intended to:
  - enhance mis-Identification rate
  - suppress efficiency for True Leptons
- Apply full Signal Selection, treating the Denm. as a Lepton

“Denominators”
Fake Factor Method.

Basic Idea.
- Select a control sample of $W+\text{jet}$ events in data.
- Use an extrapolation factor ("fake factor") that allows us to model the $W+\text{jet}$ background with the control sample.

Extrapolation Factor.

*Relates Control Sample to $W+\text{Jet}$ background in signal region.*

- Relates mis-ID rate of the “Denominators” identification criteria to the mis-ID rate of the Lepton identification criteria
- Property Local to mis-ID object. Measure in di-jet sample.
Fake Factor Method.

Use

From

Denominator

Jets

To model

Pass Lepton ID

Other good reasons not to use reconstructed Jets for extrapolation. See Details in back-up
Measuring Extrapolation Factor

Extrapolation Factor ($f$) can be measured in a data using a sample with no True Leptons.

All identified Leptons and Denm. in this sample are due to mis-identification.

Ratio of identified Leptons to Denominators measures $f$
Measuring Extrapolation Factor

Extrapolation Factor \( (f) \) can be measured in a data using a sample with no True Leptons.

All identified Leptons and Denm. in this sample are due to mis-identification.

Ratio of identified Leptons to Denominators measures \( f \)

Jet Sample:
- *Unbiased* sample of reconstructed electrons/muons.
  - Unbiased with respect to Lepton or Denm. Defintion
  - Trigger on lepton ("etcut" triggers) or away side Jet.
  - Veto W and Z candidates. (small \( m_T \) and \( m_{ll} \) away from Z)
  - Residual ElectroWeak correction subtracted using MC.
Measuring Extrapolation Factor

Lepton Definition

Muons: Reconstructed Muon Tight D0/Z0 + Isolation

Denominator Definition

Electrons: Reconstructed Electron Fail Medium
Muons: Reconstructed Muon Loose D0/Z0 + Interm. Isolation

Electrons

Muon Fake Factor

Electron ET

Muons

Muon Fake Factor

Muon PT (GeV)
The challenging part of measuring $f$.

**Assumption:**
Measure $f$ in di-jet sample and assume it applies to Control Region

**MC-Driven**
Closure Test using $W+$jet and di-jet MC.
(MC statistics is a limitation.)

**Data-Driven**
Measure variation in $f$ with varying jet sample:
- Varying $P_T$ of “faking” jet by Varying away side jet $P_T$.
- Varying composition
  - $g+$jet (Away side $g$, enhances near side $q$ content)
  - $Z+$jet sample. (Jet kinematics/composition similar to $W+$j)
Extrapolation Factor Systematics

Electrons

![Electrons Graph]

Muons

![Muons Graph]
Putting it all together

\[ N_{W+Jet}^{W+Jet} = f \times N_{Lepton+Denm}(Lepton+Denm) \]

1) Define Denominator Definition
2) Measure \( f \) and its uncertainty in di-jet control sample
3) Select (Lepton-Denm.) pairs passing the Event selection
4) Subtract non-W+jet contribution to (Lep-Denm) pairs, with MC
5) Scale by \( f \) to predict W+jet event yields / kinematics.
The Heavy Flavor Complication

Several Sources of “fake” electrons
- Light-Flavor or gluon jets (LF) hadrons/conversions mis-IDed.
- Heavy Flavor jets (HF) semi-leptonic decays
The Heavy Flavor Complication

Several Sources of “fake” electrons
- Light-Flavor or gluon jets (LF) hadrons/conversions mis-IDed.
- Heavy Flavor jets (HF) semi-leptonic decays

Fake Factor can depend on source.
- heavy flavor significantly larger $f$ than light flavor /gluon.
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- Light-Flavor or gluon jets (LF) hadrons/conversions mis-IDed.
- Heavy Flavor jets (HF) semi-leptonic decays

Fake Factor can depend on source.
- heavy flavor significantly larger f than light flavor /gluon.

\[ N^{W+Jet}_{Bkg} = f \times N^{(Lepton+Denm)} \]

Differences in heavy-flavor composition in sample used to measure f and in N^{(Lepton+Denm)} will bias background prediction.

ATLAS Work in Progress
Conceptually

Electron ID

- Signal Region
- Heavy Flavor Control Region
- Light Flavor Control Region

Isolation
LF and HF Control Regions

**Light-Flavor Denominator:**
- enriched in light-flavor
- disjoint from signal region

**Heavy-Flavor Denominator:**
- enriched in heavy-flavor
- disjoint from signal region
LF and HF Control Regions

Light-Flavor Denominator:
- enriched in light-flavor
- disjoint from signal region

\{ \}
Fail Identification
Pass Isolation

Heavy-Flavor Denominator:
- enriched in heavy-flavor
- disjoint from signal region

\{ \}
Pass Identification
Fail Isolation
LF and HF Control Regions

**Light-Flavor Denominator:**
- enriched in light-flavor
- disjoint from signal region

{ Fail Identification
  Pass Isolation
}

**Heavy-Flavor Denominator:**
- enriched in heavy-flavor
- disjoint from signal region

{ Pass Identification
  Fail Isolation
}

**Light-Flavor enriched sample**
  di-jet sample with opposite b-veto

**Heavy-Flavor enriched sample**
  di-jet sample with opposite side b-tag
Extending the Fake Factor Procedure

If we had,

\[ f_{\text{LF}} = \frac{N_{\text{Lepton-LF}}}{N_{\text{Denm-LF}}} \quad \text{and} \quad f_{\text{HF}} = \frac{N_{\text{Lepton-HF}}}{N_{\text{Denm-HF}}} \]
Extending the Fake Factor Procedure

If we had,

\[ f_{LF} = \frac{N_{Lepton-LF}}{N_{Denm-LF}} \quad \text{and} \quad f_{HF} = \frac{N_{Lepton-HF}}{N_{Denm-HF}} \]
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**LF-enriched denominator definition**

**HF-enriched denominator definition**
Extending the Fake Factor Procedure

If we had,

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The W+Jet Bkg could be calculated as:

\[ N_{\text{W+Jet}}^{\text{Bkg}} = f_{LF} \times N_{(\text{Lepton+Denm-LF})} + f_{HF} \times N_{(\text{Lepton+Denm-HF})} \]
Extending the Fake Factor Procedure

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\[ N_{\text{Bkg}}^{W+\text{Jet}} = f_{LF} \times N_{(\text{Lepton+Denm-LF})} + f_{HF} \times N_{(\text{Lepton+Denm-HF})} \]

\[ \text{W+jet Bkg from Light Flavor} \]

\[ \text{W+jet Bkg from Heavy Flavor} \]
Extracting $f_{\text{LF}}$ and $f_{\text{HF}}$

$$f_{\text{LF}} = \frac{N_{\text{Lepton-LF}}}{N_{\text{Denm-LF}}}$$

$$f_{\text{HF}} = \frac{N_{\text{Lepton-HF}}}{N_{\text{Denm-HF}}}$$

Complication

- $N_{\text{Lepton-LF}}$ and $N_{\text{Lepton-HF}}$ are not observables.
- We can only measure $N_{\text{Lepton}} = N_{\text{Lepton-LF}} + N_{\text{Lepton-HF}}$ in data.
- For a given $N_{\text{Lepton}}$ we don’t know if it’s from LF or HF.
**Extracting $f_{LF}$ and $f_{HF}$**

\[ f_{LF} = \frac{N_{Lepton-LF}}{N_{Denm-LF}} \quad \quad f_{HF} = \frac{N_{Lepton-HF}}{N_{Denm-HF}} \]

**Complication**

- $N_{Lepton-LF}$ and $N_{Lepton-HF}$ are **not** observables.
- We can only measure $N_{Lepton} = N_{Lepton-LF} + N_{Lepton-HF}$ in data.
- For a given $N_{Lepton}$ we don’t know if it’s from LF or HF.

**Solve for $f_{LF}$ and $f_{HF}$ in terms of observables.**

By measuring $\frac{N_{Lepton}}{N_{Denm-LF}}$ and $\frac{N_{Lepton}}{N_{Denm-HF}}$ in LF and HF-rich samples.

*(Details in backup)*
Measuring $f_{\text{LF}}$ and $f_{\text{HF}}$

Light Flavor Extrapolation

Heavy Flavor Extrapolation
Same Sign Control Region

Same Sign di-lepton Events passing the WW signal selection are enriched in W+jet events.

Can use the fake factor procedure to predict the same sign yield.

To predict SS background, Apply $f$ to SS Lepton-Denm pairs.

\[ N_{W+Jet}^{W+Jet} = f \times N_{(Lepton+Denm)} \]

Provides a data-driven closure test of the method.
Same Sign Control Region

Same Sign di-lepton Events passing the WW signal selection are enriched in W+jet events.

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Provides a data-driven closure test of the method.

Caveats:
- W+jet component which is not charge symmetric. (eg: W+c)
- Can’t be used if your signal is Same Sign! (Z+fake / OS Low Pt)
Same Sign Results

<table>
<thead>
<tr>
<th></th>
<th>ee</th>
<th>em</th>
<th>mm</th>
</tr>
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<tbody>
<tr>
<td>e-fakes (LF)</td>
<td>2.8 ± 1.0</td>
<td>5.5 ± 0.8</td>
<td>-</td>
</tr>
<tr>
<td>e-fakes (HF)</td>
<td>0.0 ± 0.1</td>
<td>0.4 ± 0.1</td>
<td>-</td>
</tr>
<tr>
<td>m-fakes</td>
<td>-</td>
<td>5.3 ± 2.8</td>
<td>0.9 ± 1.1</td>
</tr>
<tr>
<td>non W+jet</td>
<td>3.6 ± 0.7</td>
<td>6.6 ± 0.4</td>
<td>2.4 ± 0.2</td>
</tr>
<tr>
<td><strong>Total Prediction</strong></td>
<td><strong>6.4 ± 1.2</strong></td>
<td><strong>17.0 ± 3.6</strong></td>
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</tr>
<tr>
<td><strong>Observed</strong></td>
<td>3</td>
<td>19</td>
<td>6</td>
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# W+Jet Results

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emu-channel: e Pt > 25 GeV
m Pt > 20 GeV
W+Jet Results

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emu-channel: e Pt > 20 GeV
m Pt > 25 GeV

Heavy-Flavor Electron Fakes

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<th>Heavy-Flavor Fraction</th>
<th>Opposite Sign</th>
<th>Same Sign</th>
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<td>0.04 +/- 0.13</td>
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</tbody>
</table>

- Important confirm this using the data. (Potential failure mode in method.)
- Critical for analyses with significant b-bar background.
Results
# WW Cross Section Results

<table>
<thead>
<tr>
<th>Backgrounds</th>
<th>Events</th>
<th>Source</th>
<th>Uncertainty</th>
</tr>
</thead>
<tbody>
<tr>
<td>Drell Yan</td>
<td>$50.4 \pm 3.7 \pm 5.6$</td>
<td>Luminosity</td>
<td>3.7%</td>
</tr>
<tr>
<td>Top</td>
<td>$58.6 \pm 2.1 \pm 22.3$</td>
<td>Background</td>
<td>9.6%</td>
</tr>
<tr>
<td>W+Jets</td>
<td>$50.5 \pm 4.8 \pm 14.7$</td>
<td>Acceptance</td>
<td>7.4%</td>
</tr>
<tr>
<td>Other Diboson (MC)</td>
<td>$6.8 \pm 0.4 \pm 0.8$</td>
<td>Systematic</td>
<td>13.1%</td>
</tr>
<tr>
<td><strong>Total Background</strong></td>
<td><strong>$169.8 \pm 6.4 \pm 27.3$</strong></td>
<td>Statistical</td>
<td>8.3%</td>
</tr>
<tr>
<td>Observed Events</td>
<td><strong>414</strong></td>
<td>Statistical</td>
<td>8.3%</td>
</tr>
</tbody>
</table>

$$\sigma_{WW} = 48.2 \pm 4.0\text{(stat)} \pm 6.4\text{(sys)} \pm 1.8\text{(lumi)}\text{pb}.$$  

**NLO Prediction:** $46 \pm 3$ pb  
(MCFM with MSTW2008 (including gg))
Hww Results

<table>
<thead>
<tr>
<th>Backgrounds</th>
<th>Events</th>
</tr>
</thead>
<tbody>
<tr>
<td>Drell Yan</td>
<td>2 ± 4</td>
</tr>
<tr>
<td>Top</td>
<td>3.9 ± 1.9</td>
</tr>
<tr>
<td>W+Jets</td>
<td>5 ± 2</td>
</tr>
<tr>
<td>Other Diboson (MC)</td>
<td>1.1 ± 0.5</td>
</tr>
<tr>
<td>WW</td>
<td>52 ± 7</td>
</tr>
<tr>
<td><strong>Total Background</strong></td>
<td><strong>63 ± 9</strong></td>
</tr>
<tr>
<td><strong>Observed Events</strong></td>
<td><strong>81</strong></td>
</tr>
<tr>
<td><strong>Higgs m(H) 150</strong></td>
<td><strong>40 ± 9</strong></td>
</tr>
</tbody>
</table>

**Observed Events:**

- Drell Yan: 2 ± 4
- Top: 3.9 ± 1.9
- W+Jets: 5 ± 2
- Other Diboson (MC): 1.1 ± 0.5
- WW: 52 ± 7

**Higgs m(H) 150:**

- Observed Events: 40 ± 9
The Future of the Higgs search.

Improvements

Analysis Updates Expected for winter conferences
- Lowering Lepton Pt to increase low m(H) acceptance
- Use multivariate classifier separate WW and Hww
Conclusions

It's a great time to be doing particle physics!
Supporting Material
Not An Electron in ATLAS
Relative Missing Energy

\[ \Delta \phi_\ell \]

\[ E_{T}^{miss, Rel} \]

\[ E_{T}^{miss} \]

\[ p_{T \ell} \]
Electron Identification
Lepton Efficiency

Lepton Efficiency Needed for cross section measurement

\[ \sigma_{WW} = \frac{N - N_{Bkg}}{\epsilon \times A \times L} \]

Obtained from unbiased sample of “True” Leptons

Z-Bosons
- Require Tight Lepton + 2nd in Zmass

W-Bosons
- Require Large MeT + High Et Lepton Cand.
- Fit Isolation.
Efficiency

ATLAS Preliminary $\int L \, dt \approx 4.7\text{fb}^{-1}$

Loose++ identification efficiency

Data Z T&P
Data J/ψ T&P
Data W T&P
MC Z T&P
MC J/ψ T&P
MC W T&P
Electron Identification lends itself to multi-variate techniques:
- Large number of discriminating variables
- Many correlations.
- Get pure training/testing samples from data.

Many Advantages
- Gain separation. / Include more variables
- Easily tunable operating points / Output more than y/n decision.
The Future of Electrons

Electron Identification lends itself to multi-variate techniques:
- Large number of discriminating variables
- Many correlations.
- Get pure training/testing samples from data.

Many Advantages
- Gain separation. / Include more variables
- Easily tunable operating points / Output more than y/n decision,

(Simplifies Fake Factor Interpretation:
  Defines the space (MVA output) on which the extrapolation is done.)
Leptons
Leptons in Hadron Collisions

A lot of interesting physics signatures involve leptons

Electroweak Measurements.
Top Physics.
Higgs Physics.
Supersymmetry.
Exotics.

Leptonic final states provide rich physics potential
Leptons in Hadron Collisions

A lot of interesting physics signatures involve leptons

Electroweak Measurements.
Top Physics.
Higgs Physics.
Supersymmetry.
Exotics.

Leptonic final states provide rich physics potential

**Example: Higgs Physics**
- Leptons the signature of EW processes.
- Essential to understanding
  
  **Electro-Weak symmetry breaking**
  
  ![Branching ratios graph]

- Branching ratios
- Leptonic final states
- Electroweak measurements
- Higgs physics
- Top physics
- Supersymmetry
- Exotics
Leptons in ATLAS

ATLAS was designed to do physics with leptons.

- Efficiency to reconstruct Leptons is high.
- Purity of the reconstructed Leptons is high.

Can be used to trigger events.

Several known sources of leptons.

- Provide calibration samples
Leptons in ATLAS

ATLAS was designed to do physics with leptons.

- Efficiency to reconstruct Leptons is high.
- Purity of the reconstructed Leptons is high.

Can be used to trigger events.

Several known sources of leptons.
- Provide calibration samples

Example: Higgs Physics

Essentially sensitive Higgs final states involve leptons
Fake Factor Method
Matrix Method

1) Define Loose Lepton Definition. (triggerable)
2) Select pairs of leptons satisfying Tight or Loose definitions
3) Use:
   lepton efficiency \( r = \frac{N_T^\text{lepton}}{N_L^\text{lepton}} \) and fake efficiency \( f = \frac{N_T^\text{jet}}{N_L^\text{jet}} \)

Define system of equations
Relate: observed Tight/Loose pairs to true Real/Fake pairs

\[
\begin{bmatrix}
N_{TT} \\
N_{TL} \\
N_{LT} \\
N_{LL}
\end{bmatrix} =
\begin{bmatrix}
r_1r_2 & r_1f_2 & f_1r_2 & f_1f_2 \\
(1 - r_1)r_2 & (1 - f_1)f_2 & (1 - f_1)r_2 & (1 - f_1)f_2 \\
(1 - r_1)(1 - r_2) & (1 - r_1)(1 - f_2) & (1 - f_1)(1 - r_2) & (1 - f_1)(1 - f_2)
\end{bmatrix}
\begin{bmatrix}
N_{RR} \\
N_{RF} \\
N_{FR} \\
N_{FF}
\end{bmatrix}
\]

Invert matrix to determine:
W+jet background from \( N_{FR} \) and QCD background from \( N_{FF} \)
The \( W + \text{jet} \) background estimation includes a prediction of the QCD multijet background, where both leptons are due to mis-identified jets. The background due to double fakes from QCD is given by

\[
N_{\text{QCD Bkg}} = f^2 \times N_{\text{QCD jet-rich+jet-rich}}. 
\]

However, QCD will also contribute to the \( W + \text{jet} \) control sample with a rate given by,

\[
N_{\text{leptonID+jet-rich}}^{\text{QCD}} = 2 \times f \times N_{\text{jet-rich+jet-rich}}^{\text{QCD}}
\]

with the factor of two being due to the fact that either of the jets in the dijet event can be mis-identified as a lepton. Scaling the QCD component of the \( W + \text{jet} \) control sample by the fake factor gives,

\[
f \times N_{\text{leptonID+jet-rich}}^{\text{QCD}} = 2 \times f^2 \times N_{\text{jet-rich+jet-rich}}^{\text{QCD}} = 2 \times N_{\text{QCD Bkg}}.
\]
Electron Fake Factors

Before EW Subtraction

Electron Fake Factor

After EW Subtraction

Electron Fake Factor

Figure 14: Measured electron fake factors as a function of electron $E_T$, before (left) and after (right) the electroweak subtraction. The fake factors shown in red were measured using the EF_g11_etcut trigger, while those in black use a combination of the EF_g20_etcut and EF_e20_medium triggers.
Figure 18: Left: the electron fake factor as a function of electron $p_T$ from di-jet MC sample and $W$ inclusive MC sample. Right: the muon fake factor as a function of muon $p_T$. Uncertainty shows the MC statistics of samples.
Control Sample Definition

**More exclusive:**
- “Nearer” to signal region (smaller extrapolation)
- More True lepton contamination.
- Smaller control sample

**Less exclusive:**
- “Further” from signal region (larger extrapolation)
- Less True lepton contamination.
- Larger control sample
Control Sample Definition

Freedom in definition of the control sample. Trade off between statistical and systematic uncertainties.

**Advantage of the Fake Factor Method is this freedom.**

“Denominator” vs Reconstructed Jets

**Denominator more exclusive:**
- “Nearer” to signal region (smaller extrapolation)
- Smaller Systematics.
Control Sample Definition

Freedom in definition of the control sample. Trade off between statistical and systematic uncertainties:

Advantage of the Fake Factor Method is this freedom.

“Denominator” vs Reconstructed Jets

Denominator more exclusive:
- “Nearer” to signal region (smaller extrapolation)
- Smaller Systematics.

<table>
<thead>
<tr>
<th>Electrons:</th>
<th>Lepton Definition</th>
<th>Denominator Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Reconstructed Electron Pass Tight + Isolation.</td>
<td>Reconstructed Electron Fail Medium + Loose Isolation</td>
</tr>
<tr>
<td>Muons:</td>
<td>Reconstructed Muon Tight D0/Z0 + Isolation</td>
<td>Reconstructed Muon Loose D0/Z0 + Interm. Isolation</td>
</tr>
</tbody>
</table>
Fake Factor Method in Equations
“Naive” Method

What we would like to do:

\[ F_{\text{Lepton}} \times N(\text{Lepton} + \text{Jet}) \]

Fake Rate: How often a Jet is identified as a Lepton

Number of Lepton+Jet events passing event selection
What we would like to do:

\[ F_{\text{Lepton}} \times N(\text{Lepton + Jet}) \]

**Fake Rate:** How often a Jet is identified as a Lepton

**Problems:**
- A lot of different kinds of Jets, with different \( F_{\text{Lepton}} \)
- Jets are not “like” Leptons. \( F_{\text{Lepton}} \) far extrapolation.
- Multiple energy scales. (100 GeV jets can fake 20 GeV electrons.)
“Naive” Method

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\[ F_{\text{Lepton}} \times N(\text{Lepton} + \text{Jet}) \]

Fake Rate: How often a Jet is identified as a Lepton

Problems:
- A lot of different kinds of Jets, with different \( F_{\text{Lepton}} \)
- Jets are not “like” Leptons. \( F_{\text{Lepton}} \) far extrapolation.
- Multiple energy scales. (100 GeV jets can fake 20 GeV electrons.)

\( F_{\text{Lepton}} \) and, its extrapolation, would have large systematics.
Fake Factor Method

More realistically,

\[ \sum_{\text{Jet } E_T, \cdots} F_{\text{Lepton}}^{ij}(q'/g, \cdots) \times N^j_{(\text{Lepton}+\text{Jet})} \]
Fake Factor Method

More realistically,

\[
\sum_{\text{Jet } E_T, \ldots} F_{\text{Lepton}}^{ij} \left( q'/g, \cdots \right) \times N_j^{(\text{Lepton+Jet})}
\]

Use an alternative, Jet-enriched, Lepton definition to do the extrapolation. (“Denominator” Objects)

\[
\sum_{\text{Jet } E_T, \ldots} \frac{F_{\text{Lepton}}^{ij}}{F_{\text{Denm}}^{ij}} \left( q'/g, \cdots \right) F_{\text{Denm}}^{ij} \left( q'/g, \cdots \right) \times N_j^{(\text{Lepton+Jet})}
\]
Fake Factor Method

More realistically, 

$$\sum_{\text{Jet } E_T, \cdots} F_{\text{Lepton}}^{ij}(q'/g, \cdots) \times N^j_{(\text{Lepton+Jet})}$$

Use an alternative, Jet-enriched, Lepton definition to do the extrapolation. (“Denominator” Objects)

$$\sum_{\text{Jet } E_T, \cdots} \frac{F_{\text{Lepton}}^{ij}(q'/g, \cdots)}{F_{\text{Denm}}^{ij}(q'/g, \cdots)} F_{\text{Denm}}^{ij}(q'/g, \cdots) \times N^j_{(\text{Lepton+Jet})}$$

**Assumption:** We assume we can define the Denominator such that:

$$F_{\text{Lepton}}^{ij}(q'/g, \cdots) = f \times F_{\text{Denm}}^{ij}(q'/g, \cdots)$$

ie: Assume all the Fake Rate variation due to the underlying jet-physics, is the same for Leptons and Denominators, up to a numerical constant.

This is not quite right, we assign systematics to cover this approximation.
Fake Factor Method

Taking the assumption,

\[
\sum_{\text{Jet } E_T, \ldots} f \times \frac{F_{ij}^{\text{Denm}}(q'/g, \cdots)}{F_{ij}^{\text{Denm}}(q'/g, \cdots)} F_{\text{Denm}}^{ij}(q'/g, \cdots) \times N^j_{(\text{Lepton}+\text{Jet})}
\]

or,

\[
f \times \sum_{\text{Jet } E_T, \ldots} F_{\text{Denm}}^{ij}(q'/g, \cdots) \times N^j_{(\text{Lepton}+\text{Jet})}
\]
Fake Factor Method

Taking the assumption,

\[
\sum_{\text{Jet } E_T, \cdots} f \times \frac{F_{\text{Denm}}^{ij}(q'/g, \cdots)}{F_{\text{Denm}}^{ij}(q'/g, \cdots)} F_{\text{Denm}}^{ij}(q'/g, \cdots) \times N^j_{(\text{Lepton+Jet})}
\]

or,

\[
f \times \sum_{\text{Jet } E_T, \cdots} F_{\text{Denm}}^{ij}(q'/g, \cdots) \times N^j_{(\text{Lepton+Jet})}
\]

This term is an observable.

\[
= f \times N_{(\text{Lepton+Denm})}
\]

The number of observed Lepton-Denominator Pairs
Conceptually

**“Naive Method”**

- Fake Leptons

\[ \sum_{\text{Jet } E_T, \ldots} F_{\text{Lepton}}^{ij}(q'/g, \ldots) \]

**Fake Factor Method**

- Fake Leptons

\[ f \]

- Denm. Objects
Measuring Extrapolation Factor

Can measure $f$ in a data using a jet control sample.

$$\frac{N_{\text{Lepton}}}{N_{\text{Denm}}} = \frac{\sum_{\text{Jet } E_T} F_{\text{Lepton}}^{ij} \times N_{\text{Jet}}^j}{\sum_{\text{Jet } E_T} F_{\text{Denm}}^{ij} \times N_{\text{Jet}}^j} = \frac{\sum_{\text{Jet } E_T} f \times F_{\text{Denm}}^{ij} \times N_{\text{Jet}}^j}{\sum_{\text{Jet } E_T} F_{\text{Denm}}^{ij} \times N_{\text{Jet}}^j} = f$$

Ratio of Leptons to Denominators, in jet sample, measures $f$
Including Heavy Flavor
Sample Dependence: Muons

For muons situation is simpler.

Nearly all high pT “fake” muons are from heavy flavor.

Both the di-jet and the W+jet control samples.

Heavy flavor already included in fake factor procedure for muons.

References


In a light flavor enriched sample, we can measure:

\[
f = \frac{n}{d_{lf}} = \frac{n_{lf} + n_{hf}}{d_{lf}} = f_{lf} + \epsilon_{hf} \times f
\]

\[
f^c = \frac{n}{d_{hf}} = \frac{n_{lf} + n_{hf}}{d_{hf}} = f_{hf} + (1 - \epsilon_{hf}) \times f^c
\]

\[
f = f_{lf} + \frac{d_{hf}}{d_{lf}} \times f_{hf}
\]
Calculating $f(lf)$ and $f(hf)$

In a light flavor enriched sample, we can measure:

$$ f = \frac{n}{d_{lf}} = \frac{n_{lf} + n_{hf}}{d_{lf}} = f_{lf} + \epsilon_{hf} \times f $$

$$ f_c = \frac{n}{d_{hf}} = \frac{n_{lf} + n_{hf}}{d_{hf}} = f_{hf} + (1 - \epsilon_{hf}) \times f_c $$

$$ f = f_{lf} + \frac{d_{hf}}{d_{lf}} \times f_{hf} $$

Repeat in heavy flavor enriched sample:

$$ f^{tag} = f_{hf} + \frac{d_{lf}^{tag}}{d_{hf}^{tag}} \times f_{hf} $$
Calculating $f(\text{lf})$ and $f(\text{hf})$

In a light flavor enriched sample, we can measure:

$$f = \frac{n}{d_{lf}} = \frac{n_{lf} \, + \, n_{hf}}{d_{lf}} = f_{lf} + \varepsilon_{hf} \, \times \, f$$

$$f_c = \frac{n}{d_{hf}} = \frac{n_{lf} \, + \, n_{hf}}{d_{hf}} = f_{hf} + (1 - \varepsilon_{hf}) \, \times \, f$$

System of equations in terms of observables that can be solved to extract $f(\text{lf})$ and $f(\text{hf})$

(see backup for details)
Search for Higgs
in H \rightarrow WW \rightarrow l\nu l\nu
Table 15: Numbers of expected events after all cuts for the signal region using the control region. A set of extrapolated values are also shown. The nominal numbers correspond to the background-only events in the signal region after their acceptances before their acceptances were included. Also shown are the signal and background values rescaled to the SM cross-sections. The systematic uncertainty that applies to the channel, i.e., the number of background events given a particular set of values for the nuisance parameters, is estimated from the theory and from the MC simulation, describe the theoretical knowledge on the ratio obtained from MC simulation, which is used to evaluate the PDFs rather than using an asymptotic approximation. Using the PDFs, two pseudo-experiments are performed, as it is a less CPU intensive calculation. Since the signal is positive and the upper bound to guarantee a one-sided limit is obtained from the fit for two different hypotheses.

\begin{align*}
\mathcal{L}(\mu, \theta) &= \prod_{\ell=ee, \mu\mu} \prod_{j=0,1} \text{Poisson}(N_{\ell j}^{SR} | \mu s_{\ell j} + \alpha_{\ell j}^{WW} b_{\ell j}^{WW} + \delta_{j}^{1} \alpha_{\ell j}^{top} b_{\ell j}^{top} + \sum_{k} b_{\ell j k}) \\
\text{Poisson}(N_{\ell j}^{WW} | \mu s_{\ell j} + \beta_{\ell j}^{WW} b_{\ell j}^{WW} + \delta_{j}^{1} \beta_{\ell j}^{top} b_{\ell j}^{top} + \sum_{k} b_{\ell j k}) \\
\text{Poisson}(N_{\ell j}^{top} | \mu s_{\ell j} + \delta_{j}^{1} b_{\ell j}^{top} + \sum_{k} b_{\ell j k}) \\
\prod_{\theta} \text{Gaussian}(\theta|0, 1)
\end{align*}

Acceptance Systematics

<table>
<thead>
<tr>
<th>Process</th>
<th>jet bin</th>
<th>Scale</th>
<th>PDF</th>
<th>MC</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>WW</td>
<td>0 jet</td>
<td>4%</td>
<td>3%</td>
<td>7%</td>
<td>9%</td>
</tr>
<tr>
<td></td>
<td>1 jet</td>
<td>5%</td>
<td>3%</td>
<td>10%</td>
<td>12%</td>
</tr>
<tr>
<td>t\bar{t}</td>
<td>0 jet</td>
<td>9%</td>
<td>3%</td>
<td>8%</td>
<td>12%</td>
</tr>
<tr>
<td></td>
<td>1 jet</td>
<td>4%</td>
<td>3%</td>
<td>8%</td>
<td>9%</td>
</tr>
<tr>
<td>gg \rightarrow H</td>
<td>0 jet</td>
<td>3%</td>
<td>3%</td>
<td>3%</td>
<td>5%</td>
</tr>
<tr>
<td></td>
<td>1 jet</td>
<td>3%</td>
<td>3%</td>
<td>11%</td>
<td>12%</td>
</tr>
</tbody>
</table>

Systematics on A - B

<table>
<thead>
<tr>
<th></th>
<th>(\alpha_{WW}^{0j})</th>
<th>(\alpha_{WW}^{1j})</th>
<th>(\alpha_{top}^{1j})</th>
<th>(\beta_{top}^{1j})</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Q^2) Scale</td>
<td>2.5%</td>
<td>4%</td>
<td>9%</td>
<td>–</td>
</tr>
<tr>
<td>MC Modeling</td>
<td>3.5%</td>
<td>3.5%</td>
<td>4%</td>
<td>–</td>
</tr>
<tr>
<td>PDF</td>
<td>3.8%</td>
<td>3.5%</td>
<td>3%</td>
<td>–</td>
</tr>
<tr>
<td>Jet E Scale + Resolution</td>
<td>+0.5%</td>
<td>+2.3%</td>
<td>-35%</td>
<td>-36%</td>
</tr>
<tr>
<td>(b)-tagging Efficiency</td>
<td>-0.6%</td>
<td>-1</td>
<td>+32%</td>
<td>+32%</td>
</tr>
<tr>
<td>MC Statistics</td>
<td>4.3%</td>
<td>12.9%</td>
<td>6%</td>
<td>–</td>
</tr>
</tbody>
</table>
Local P-Value

2 σ

3 σ

4 σ

ATLAS Preliminary

2011 Data

Exp. Comb.  Exp. H → γγ
Obs. Comb.  Obs. H → γγ
Exp. H → 4l  Exp. H → ℓνℓν
Obs. H → 4l  Obs. H → ℓνℓν

$\int_{L dt} \sim 2.05-4.9 fb^{-1}$
Top Background Estimation

Top in the 0-jet analysis

\[ N_{\text{Top}}^{\text{Bkg}}(0\text{-jet}) = N_{\text{Top}}^{\text{Data}} \times \text{SF} \times \frac{N_{\text{Top}}^{\text{MC}}(0\text{-jet})}{N_{\text{MC}}^{\text{Top}}} \]

SF - scale factor from tag sample

After jet veto Top Estimate

\[ 65 \pm 8(\text{stat}) \pm 20(\text{syst}) \]

Top in 1-jet analysis is normalized to data using control region

Top Control

Reverse b-tag after \( Z \rightarrow \tau\tau \)

Veto in 1-jet analysis

<table>
<thead>
<tr>
<th></th>
<th>Top</th>
<th>non-Top</th>
<th>Prediction</th>
<th>Observed</th>
</tr>
</thead>
<tbody>
<tr>
<td>ee</td>
<td>34 ± 8</td>
<td>1 ± 1</td>
<td>35 ± 9</td>
<td>32</td>
</tr>
<tr>
<td>em</td>
<td>163 ± 45</td>
<td>7 ± 2</td>
<td>170 ± 50</td>
<td>153</td>
</tr>
<tr>
<td>mm</td>
<td>63 ± 20</td>
<td>1 ± 1</td>
<td>64 ± 20</td>
<td>64</td>
</tr>
</tbody>
</table>
1-jet Analysis

Dominated by top After 1-jet Selection.

Reduce Top Contribution:
- b-jet veto.
  CombNN at 70% eff. point
- low \( P_T(tot) \)

\[
\mathbf{p}_T^{tot} = \mathbf{p}_T^{l1} + \mathbf{p}_T^{l2} + \mathbf{p}_T^1 + \mathbf{p}_T^{miss}
\]

Reduce Z+jet by \( Z \rightarrow \tau \tau \) veto

\(|m_{\tau\tau} - m_Z| < 25 \text{ GeV} \) using the collinear approximation

Assume MeT due to neutrinos in direction of visible decay products.
1-jet Analysis

After $Z \rightarrow \tau\tau$ veto WW and Top Dominate.

Cut on $m_{ll}$, $\Delta\phi_{ll}$, and $m_T$ to separate Hww from WW and Top

Analysis divided in to “low”/“high” higgs mass regions
1-jet Analysis

\( m_H < 170 \)
- \( m_{ll} < 50 \) GeV
- \( \Delta \phi_{ll} < 1.3 \)
- \( 0.75 \times m_H < m_T < m_H \)

\( 170 < m_H < 220 \)
- \( m_{ll} < 65 \) GeV
- \( \Delta \phi_{ll} < 1.8 \)
- \( 0.75 \times m_H < m_T < m_H \)

\( m_H > 220 \)
- \( 50 < m_{ll} < 180 \) GeV
- \( 0.6 \times m_H < m_T < m_H \)
Background Estimation

Same DY, Top, and W+Jet background estimated as in WW cross section measurement

WW MC prediction is normalized to data using WW control region

**WW Control Region**
- after PT_{ll}
- m_{ll} > 80 GeV (Low m(H))
- m_{ll} < 50 GeV || 180 GeV < m_{ll} (High m(H))

<table>
<thead>
<tr>
<th></th>
<th>WW</th>
<th>non-WW</th>
<th>Prediction</th>
<th>Observed</th>
</tr>
</thead>
<tbody>
<tr>
<td>ee</td>
<td>27 ± 4</td>
<td>10 ± 5</td>
<td>37 ± 8</td>
<td>52</td>
</tr>
<tr>
<td>em</td>
<td>150 ± 20</td>
<td>34 ± 12</td>
<td>200 ± 40</td>
<td>184</td>
</tr>
<tr>
<td>mm</td>
<td>45 ± 6</td>
<td>18 ± 6</td>
<td>63 ± 10</td>
<td>60</td>
</tr>
</tbody>
</table>