$H \rightarrow WW$ 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→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.

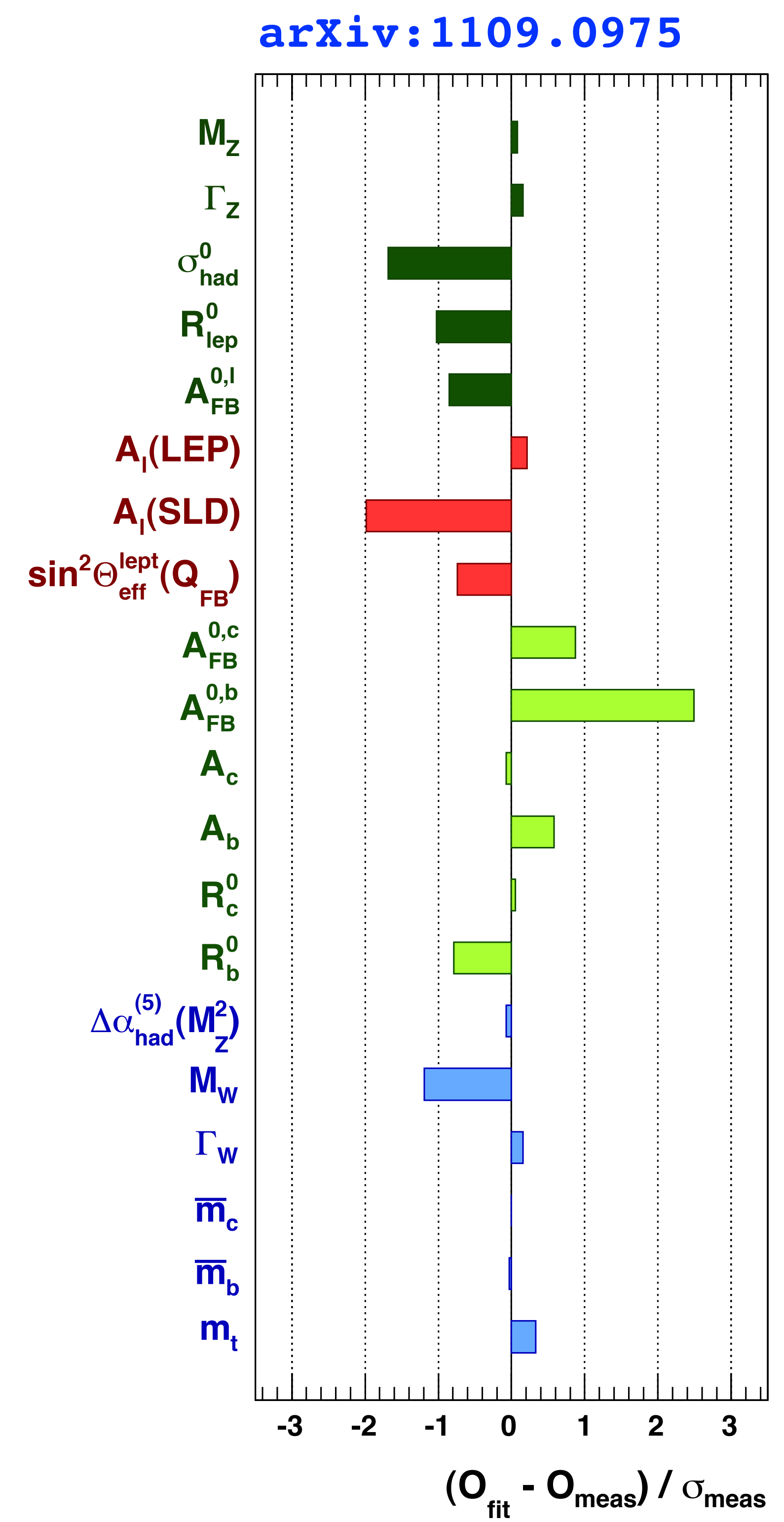
Results.

Higgs Physics

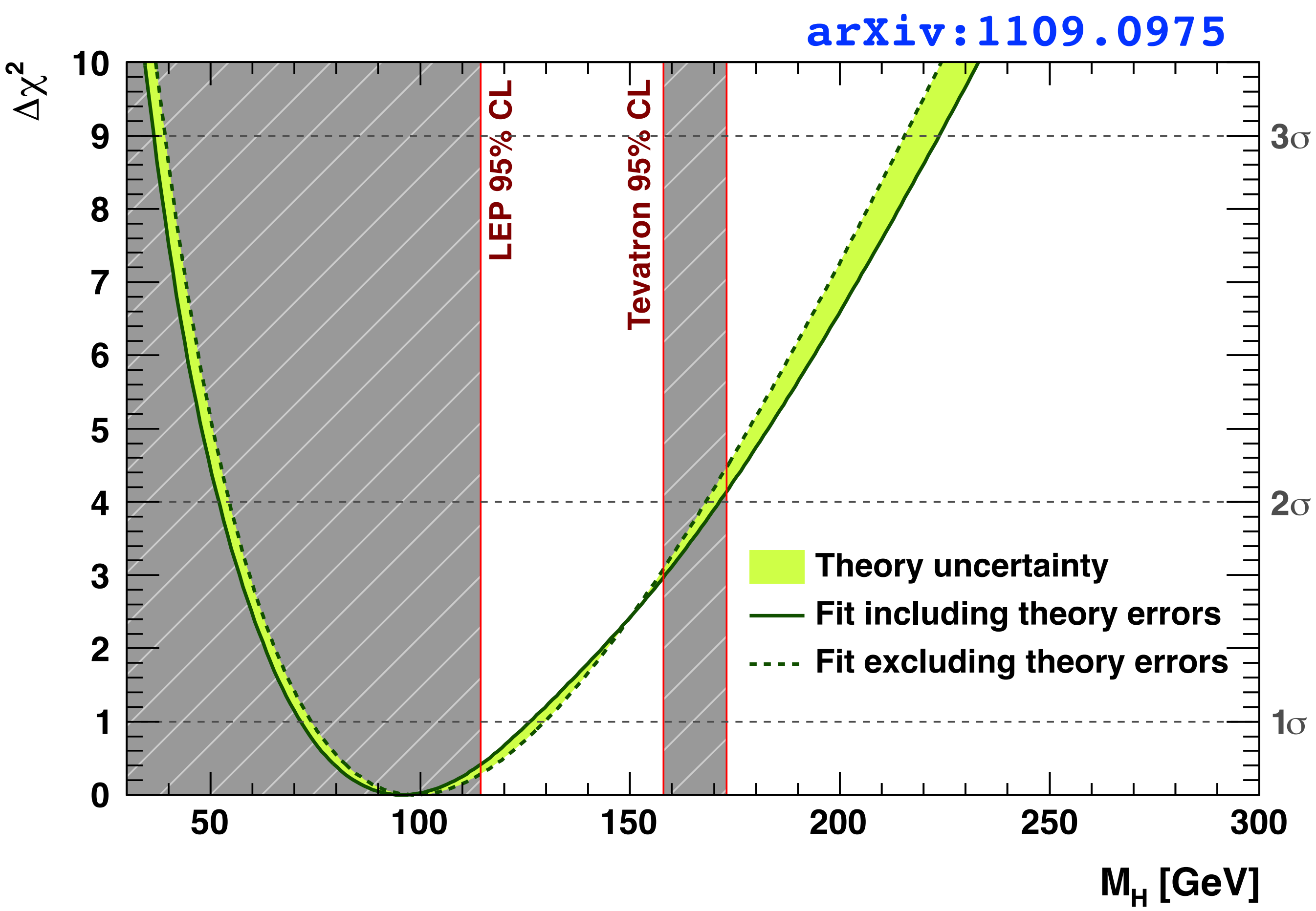
Standard Model

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

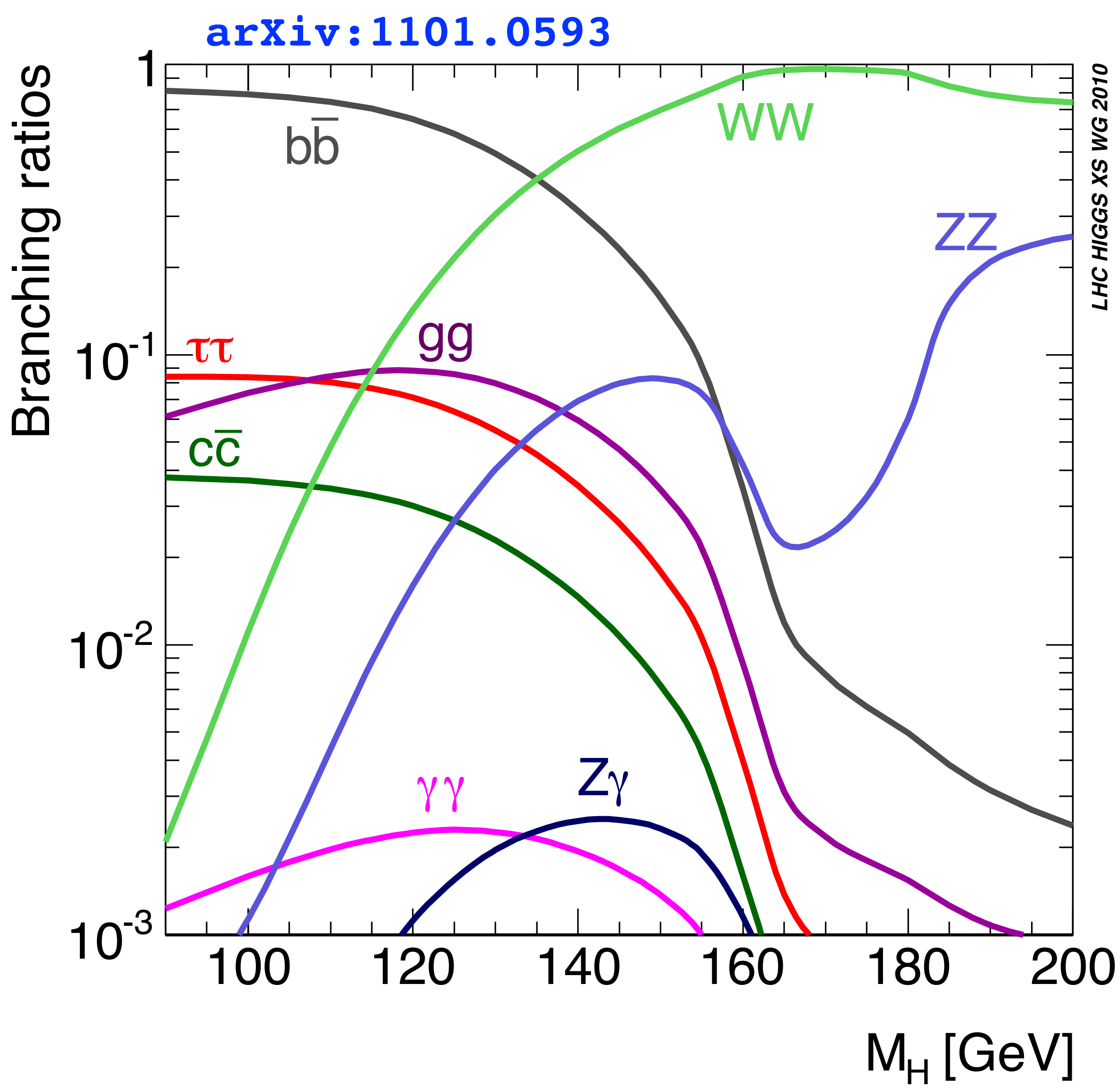
Theory vs Experiment

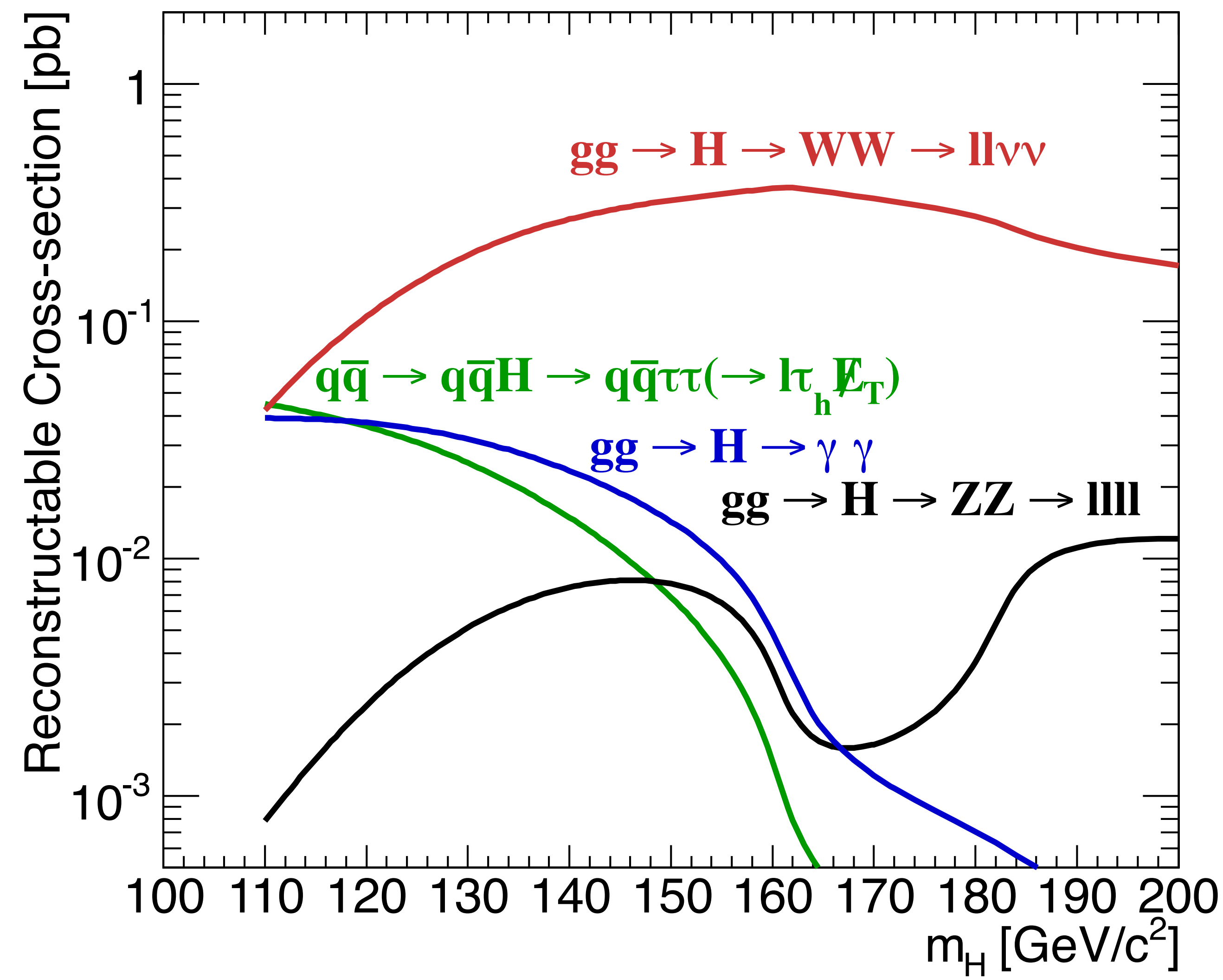


Best Fit for Higgs Mass



Searching for the Higgs

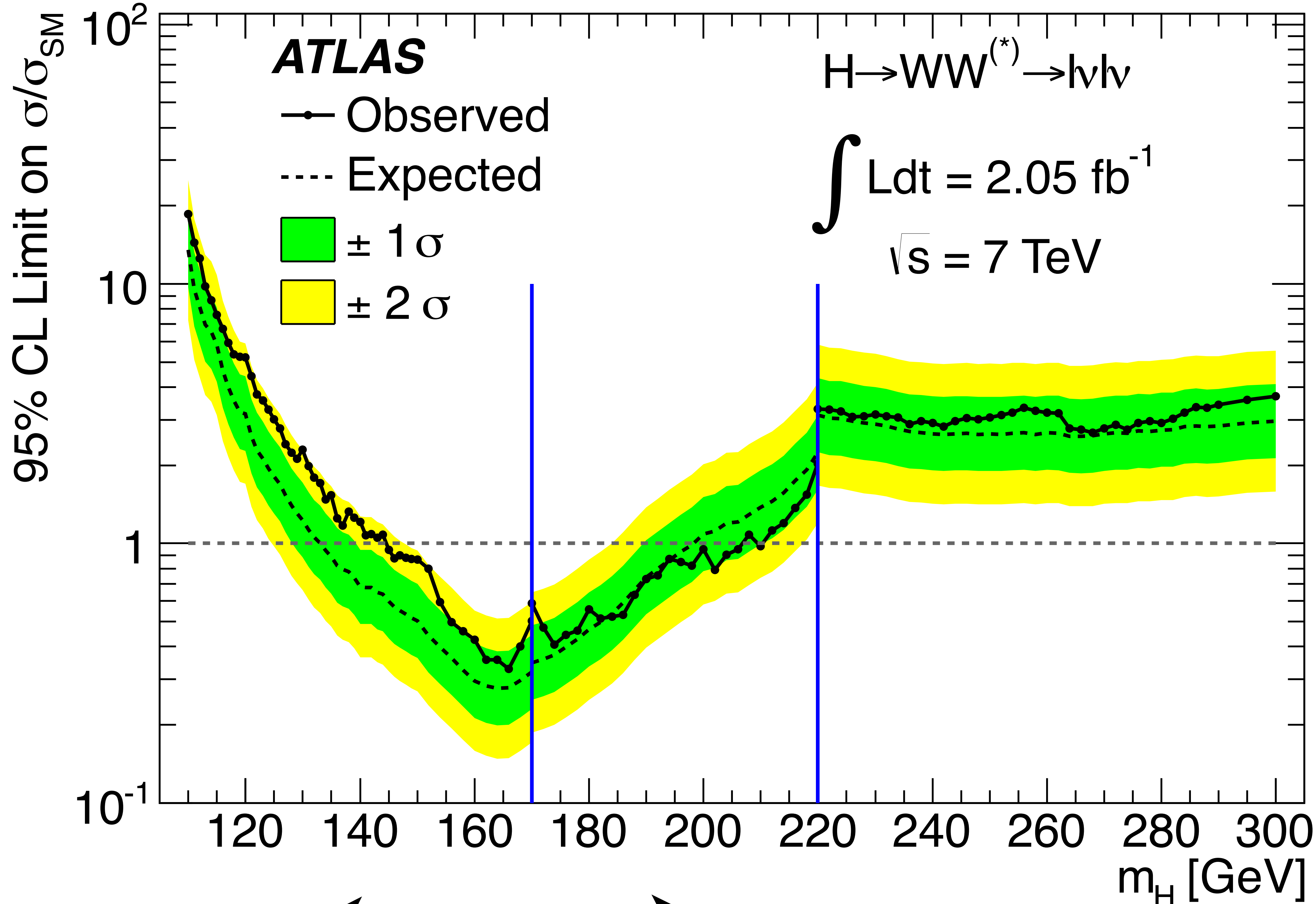




H→WW→lνlν

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

H→WW→lνlν Results

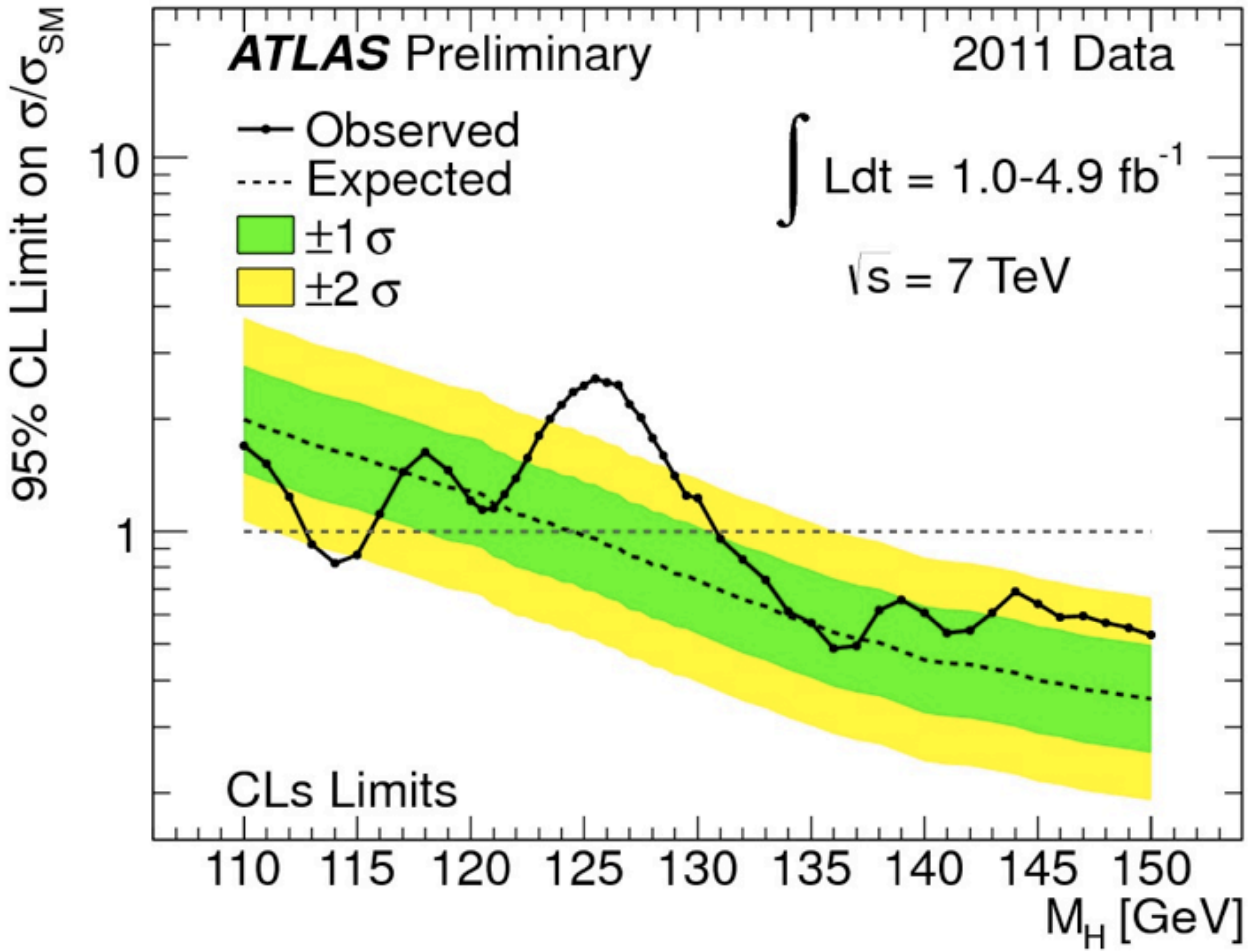


135 196

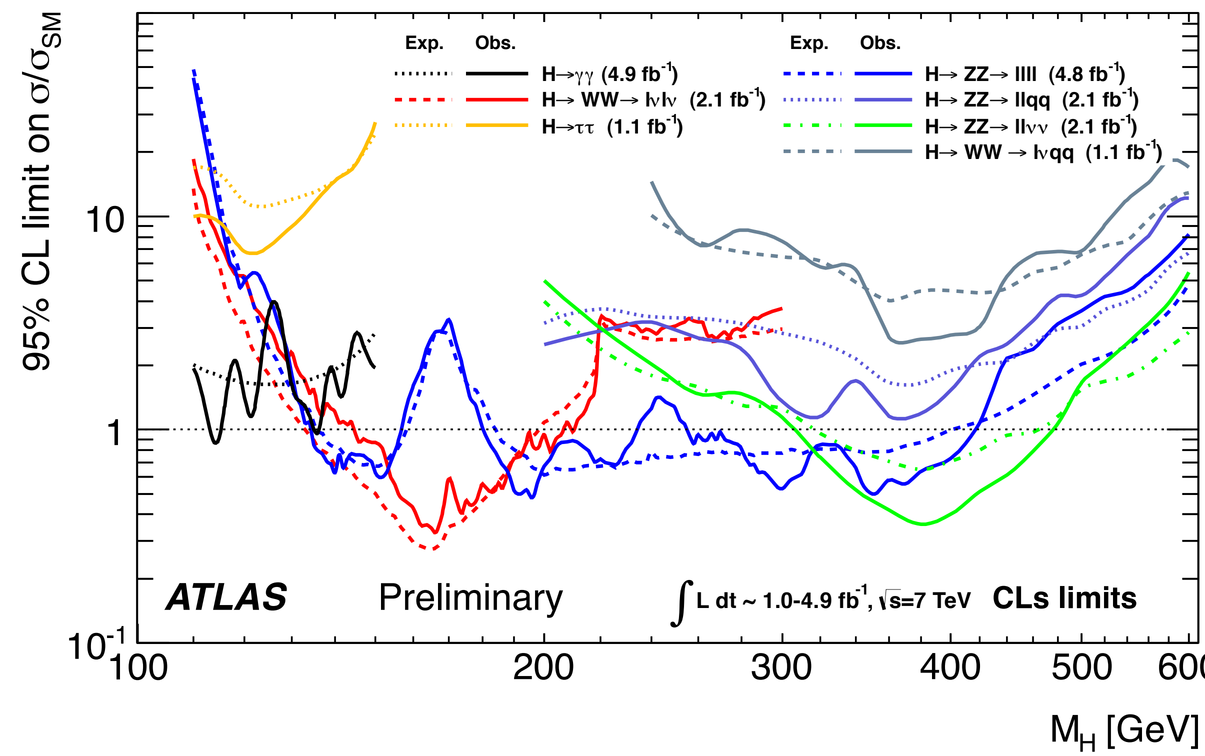
145 206

Status of the Higgs search.

Combined ATLAS Higgs limits



Status of the Higgs search.



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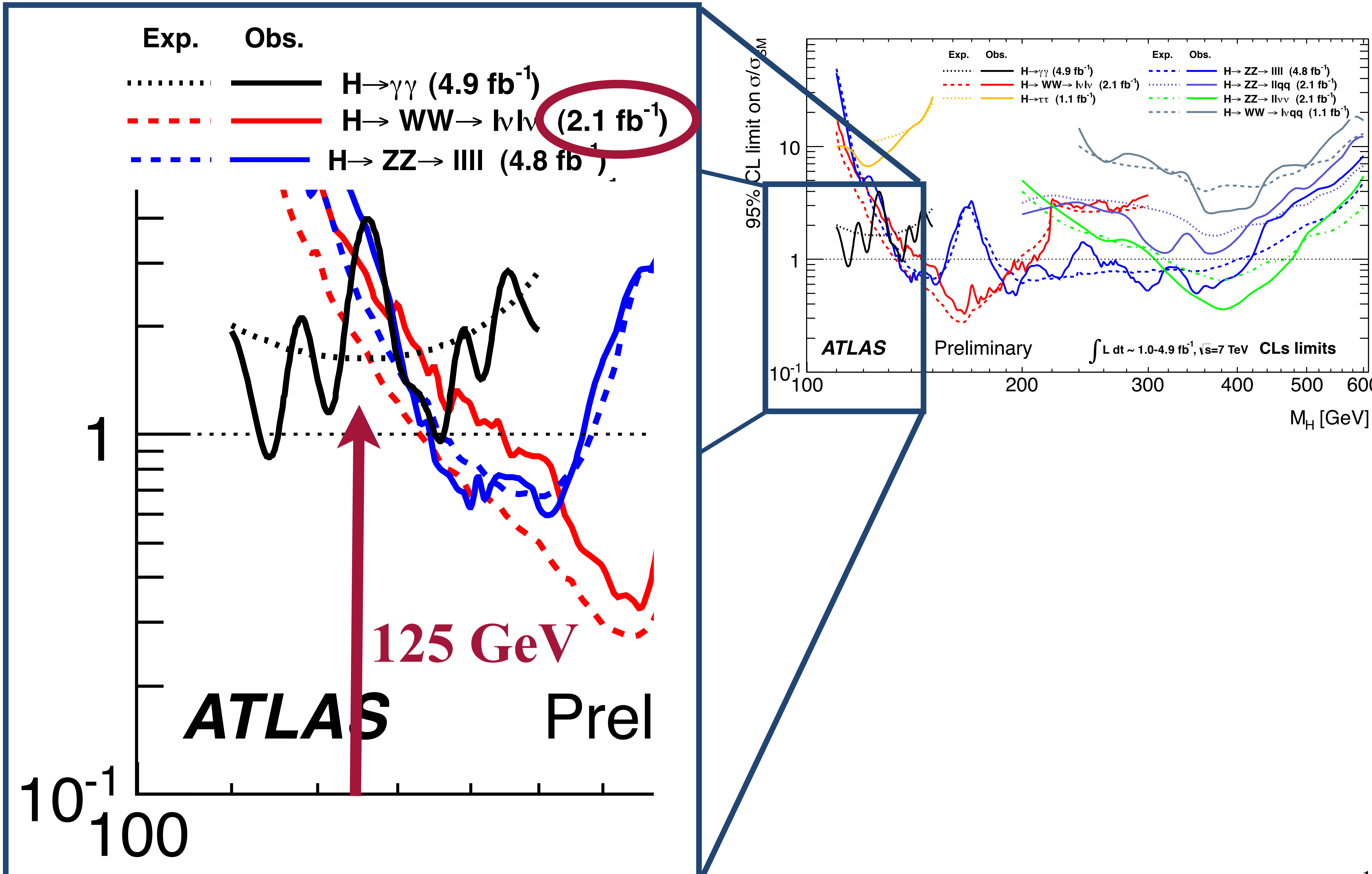

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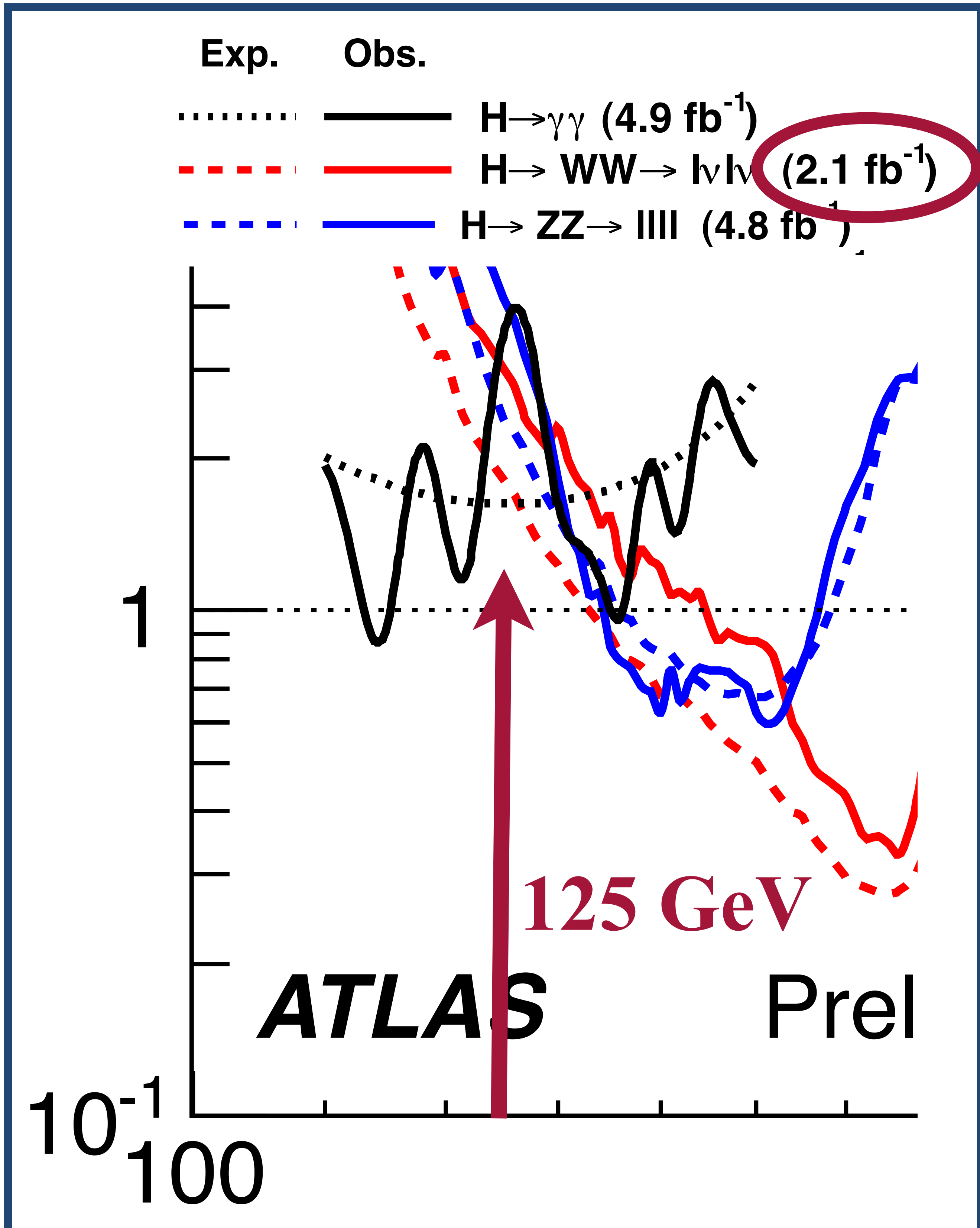
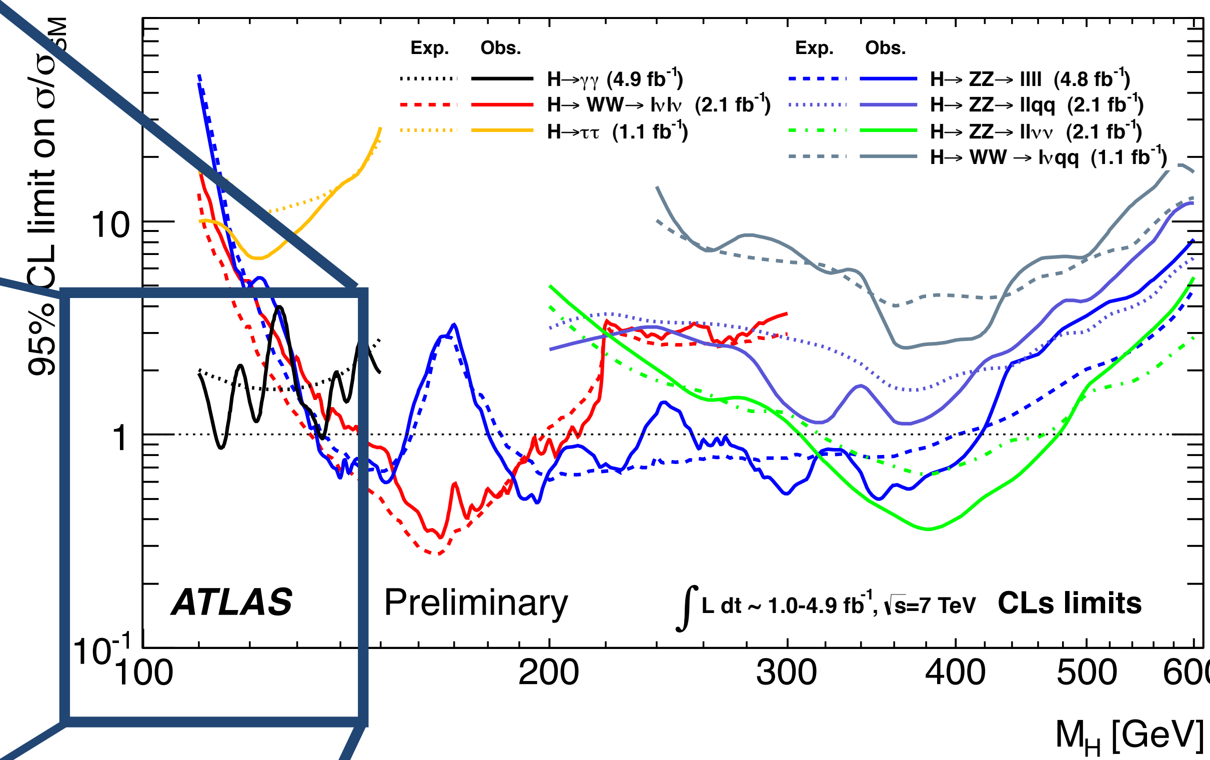
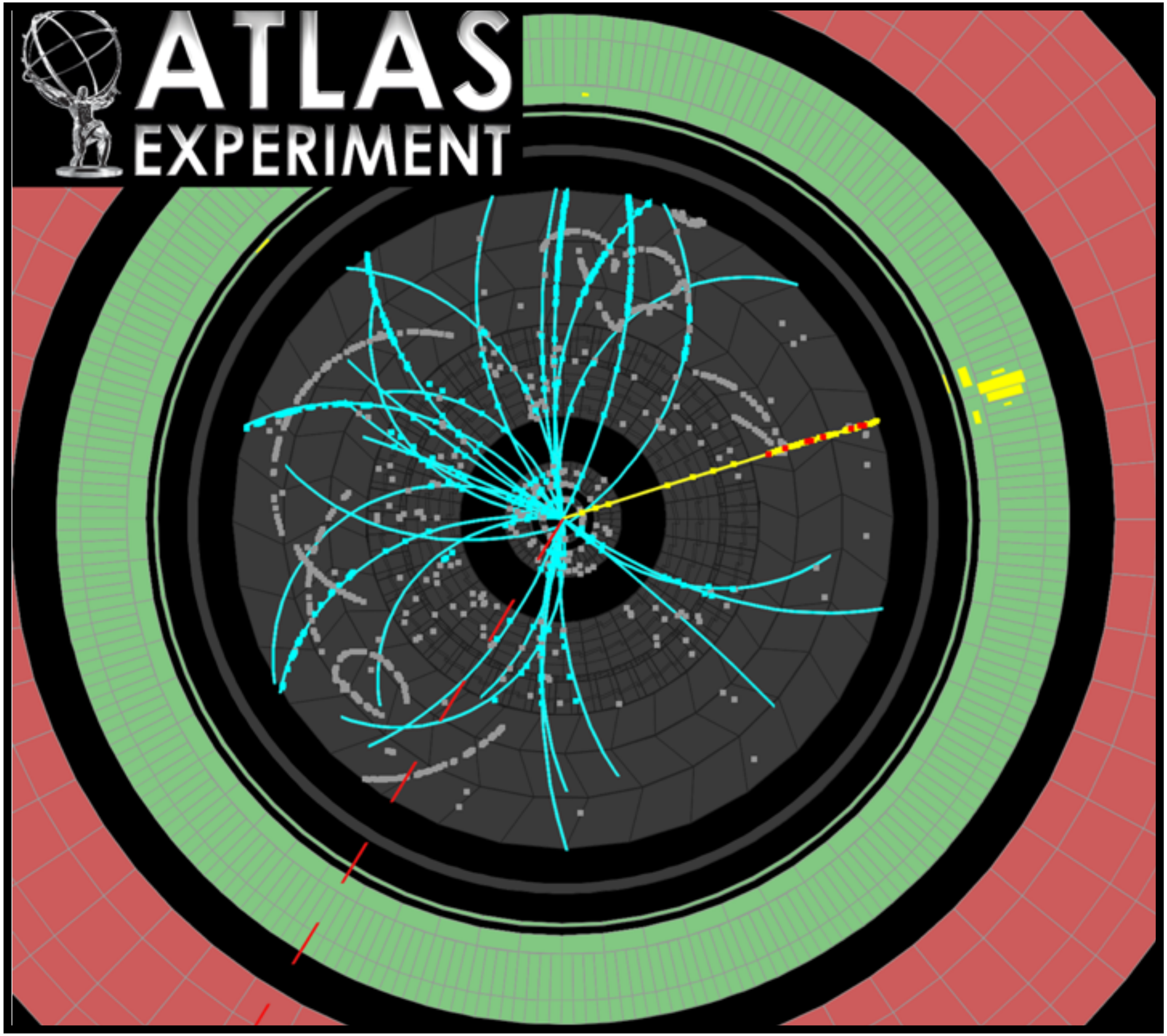




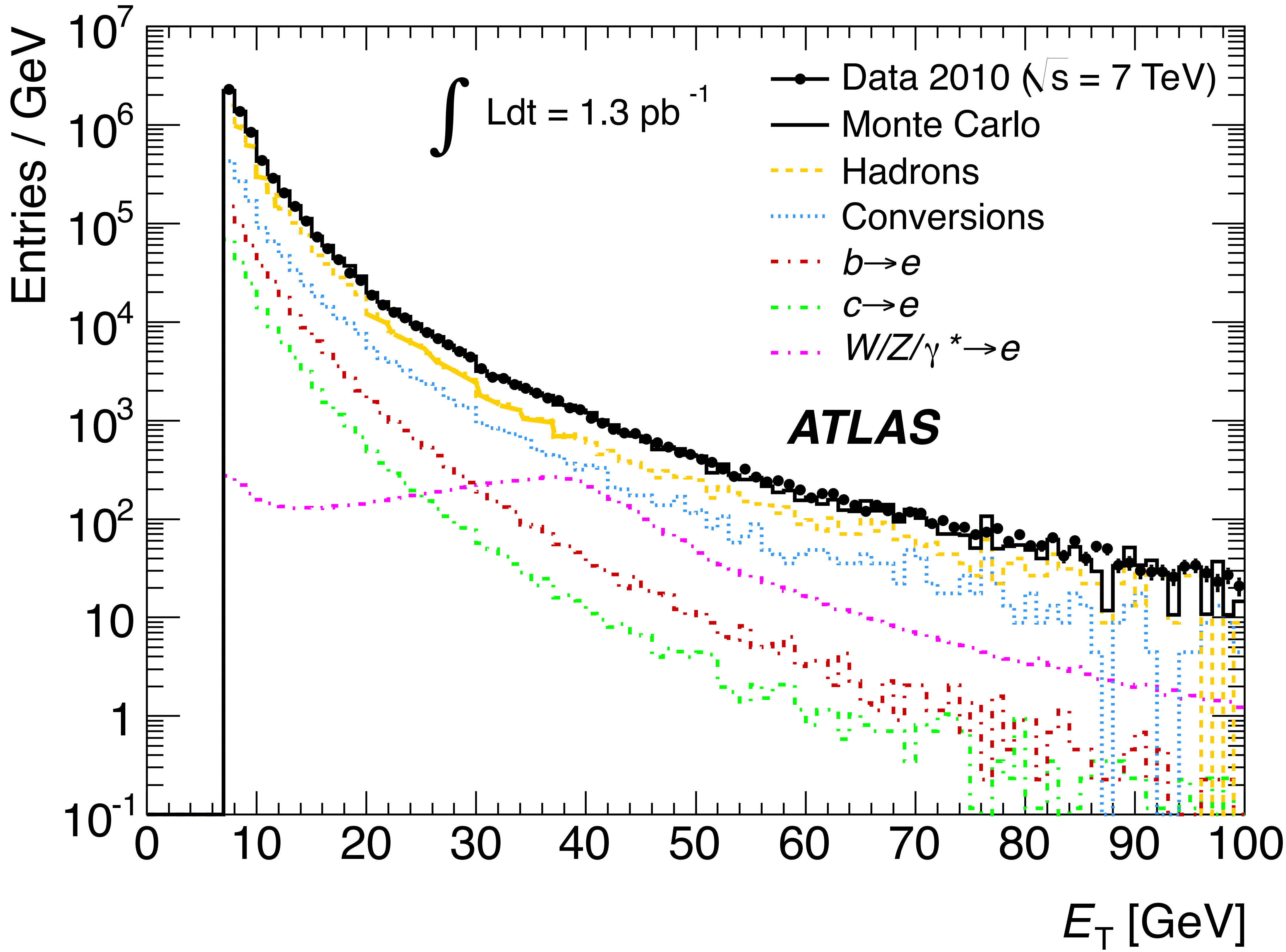
- Hww has strongest sensitivity at 125.
- Big piece of potential discovery.
- If found, will provide best cross section measurement

Electrons in ATLAS

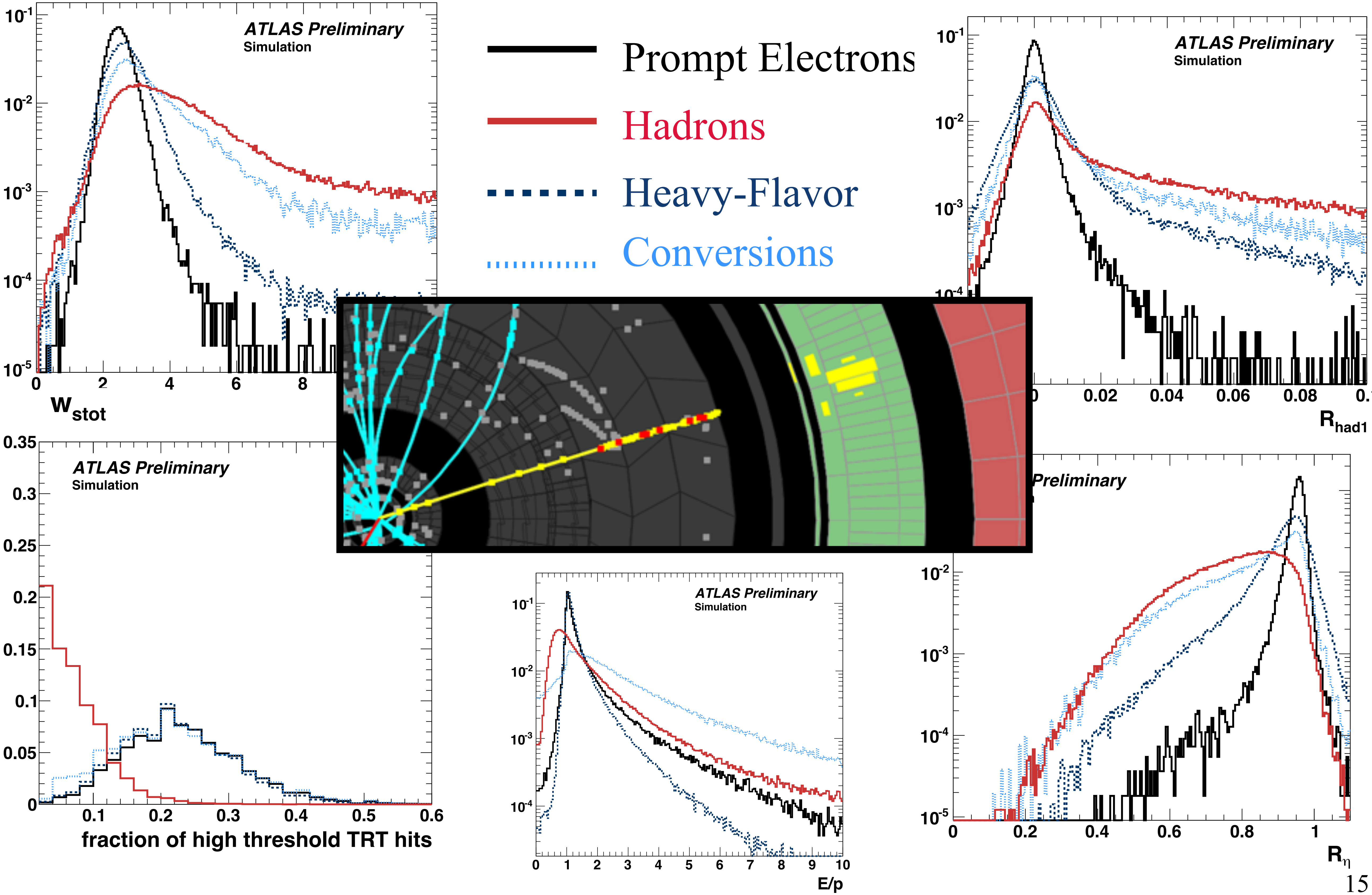
An Electron ATLAS



Electron Candidates in ATLAS



Electron Identification



Electrons in ATLAS

Operating Points:

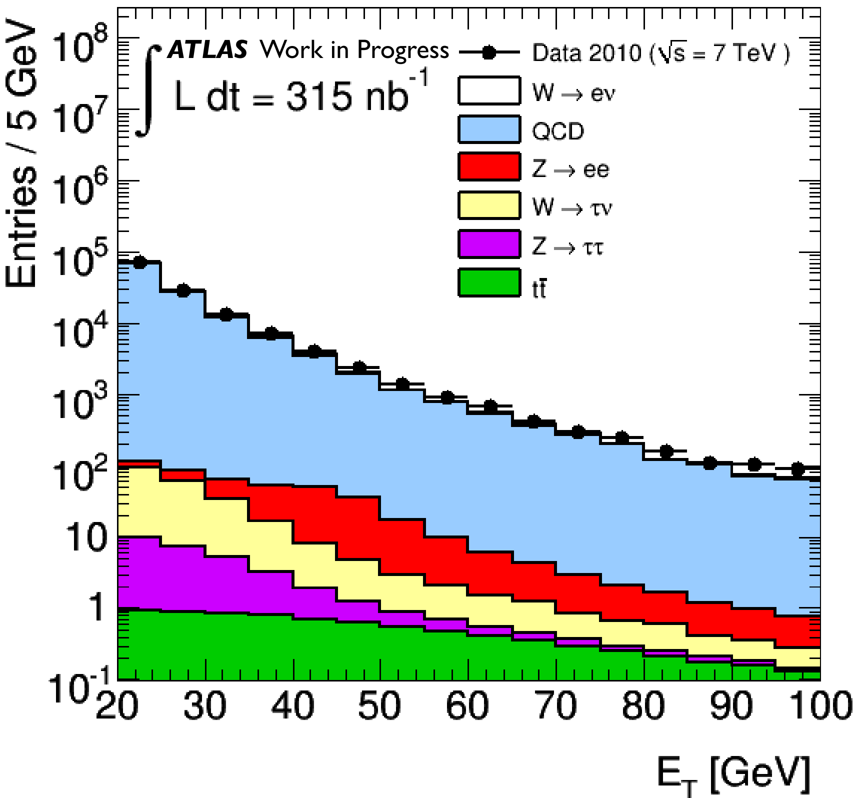
"Loose"
- Shower shapes 2nd sampling
- Hadronic Leakage.

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

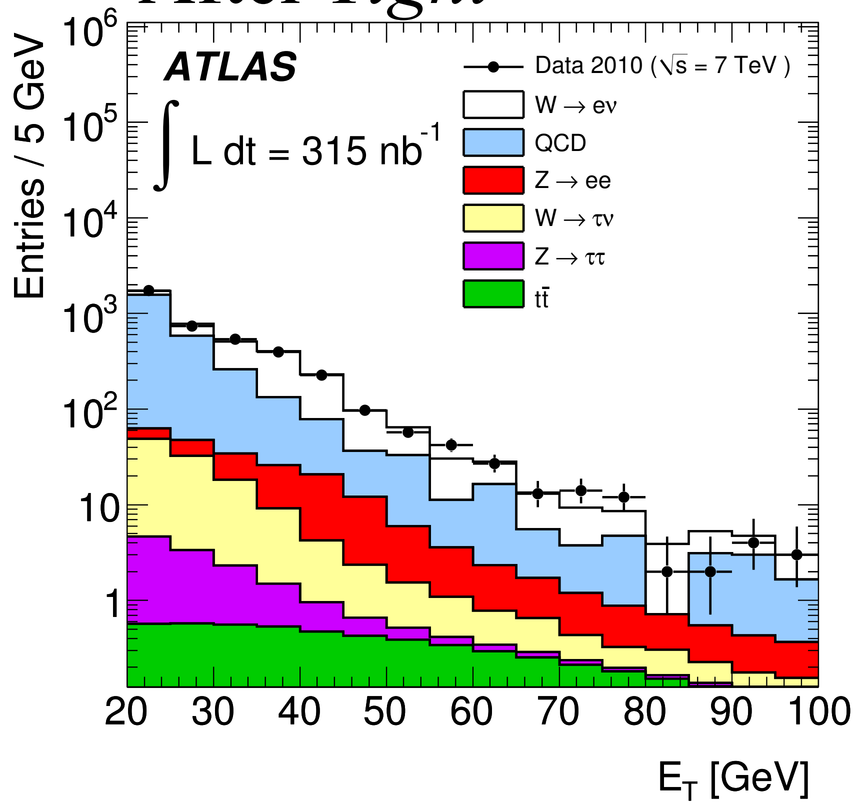
"Tight"
- All Medium requirements
- Track Cluster Matching.
- Transition Radiation.
- Conversion Rejection.

Isolation not explicitly included in operating points,
Often included in electron definition used in Analysis.

After *Loose*

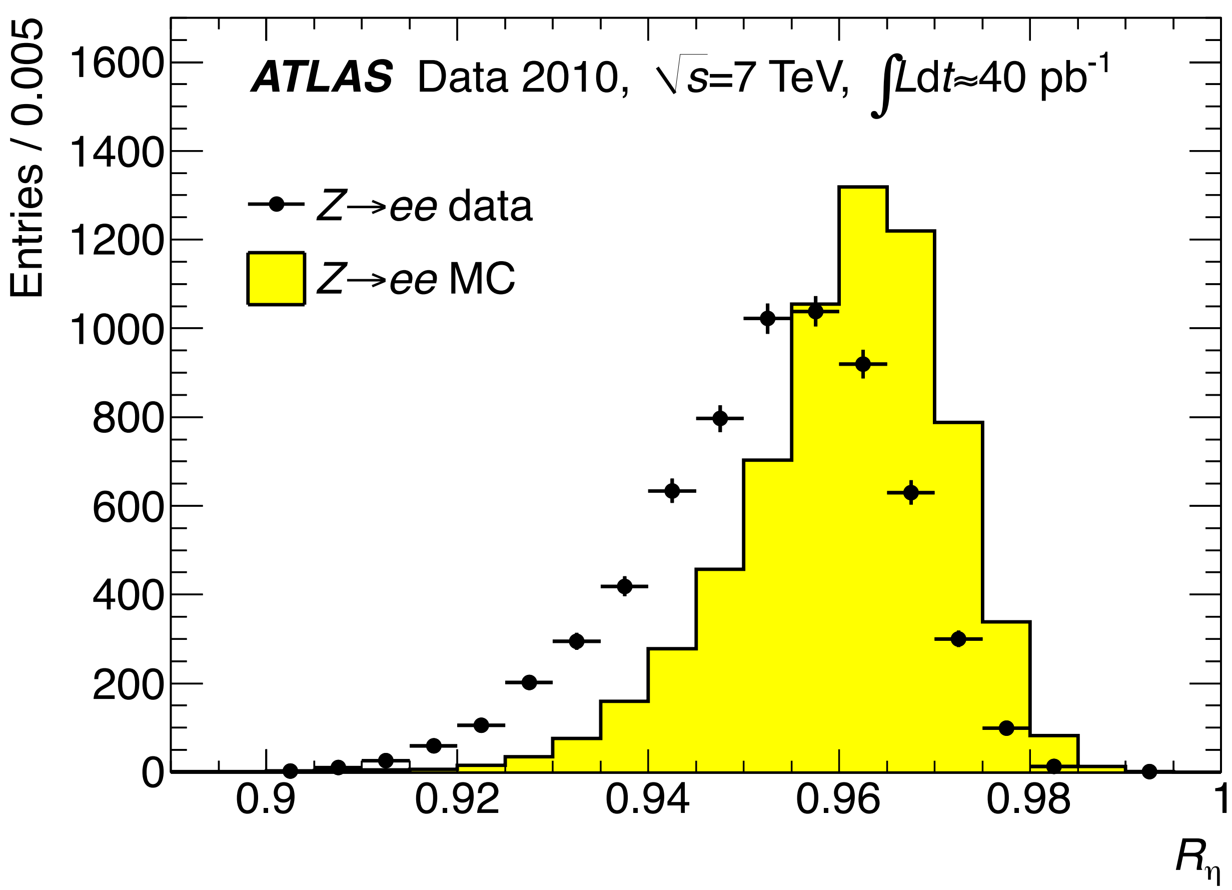


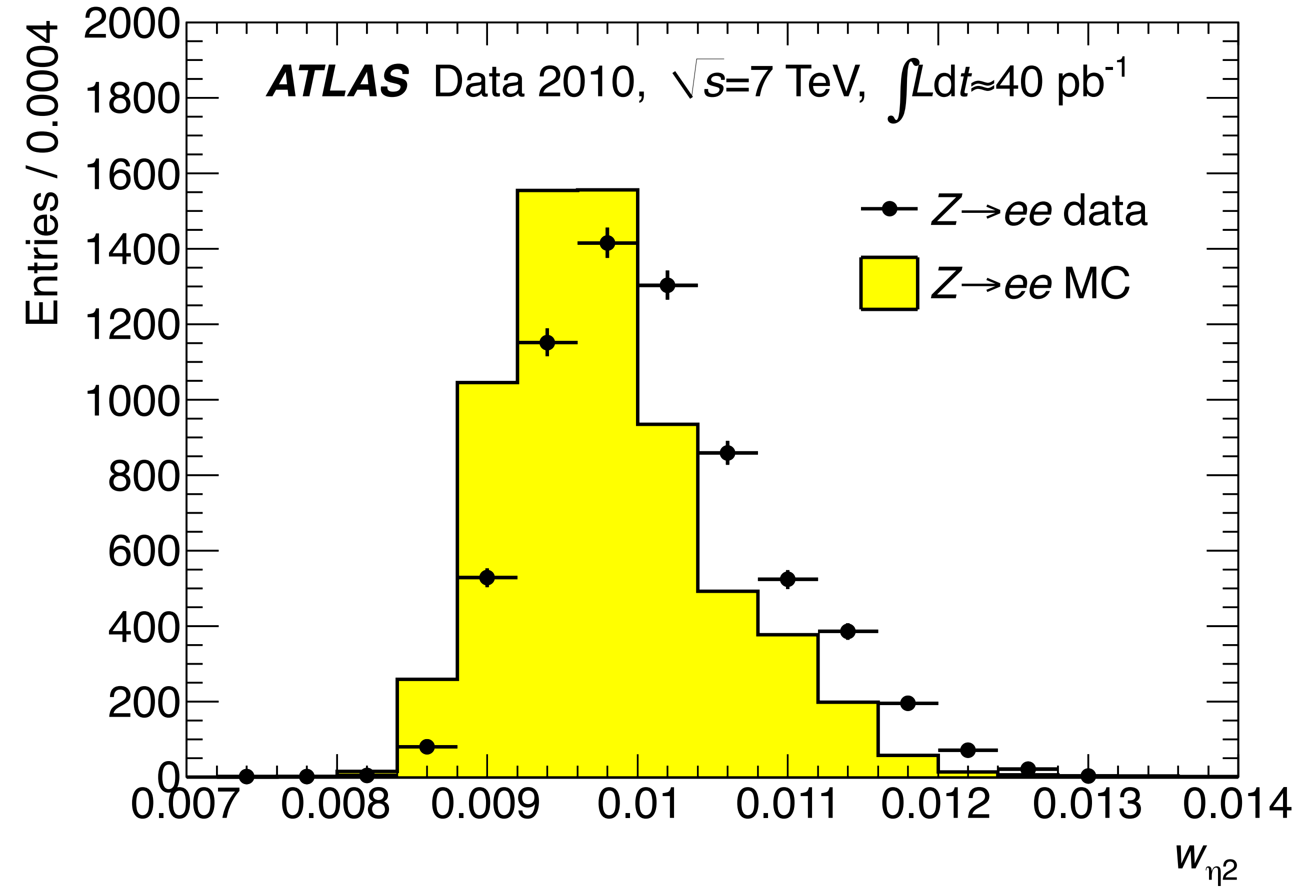
After *Tight*



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.

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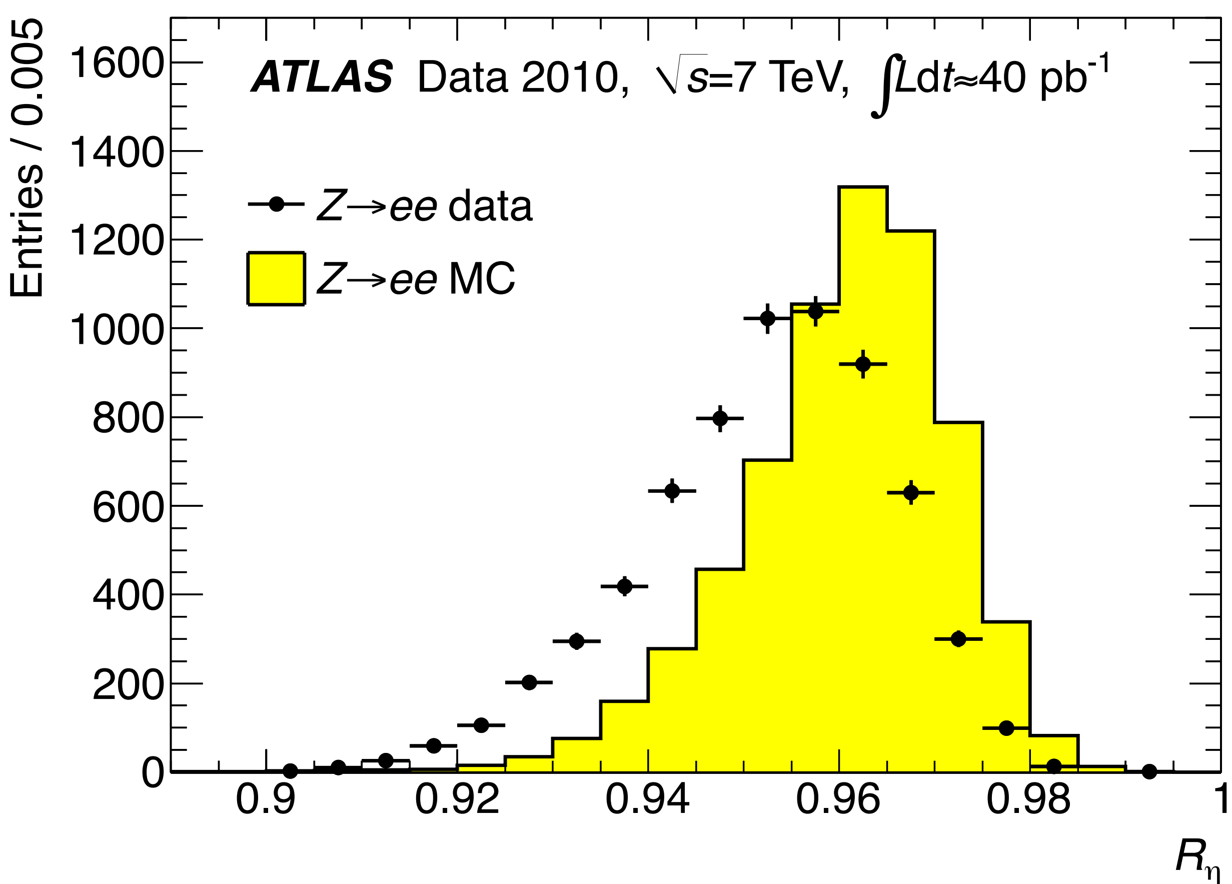

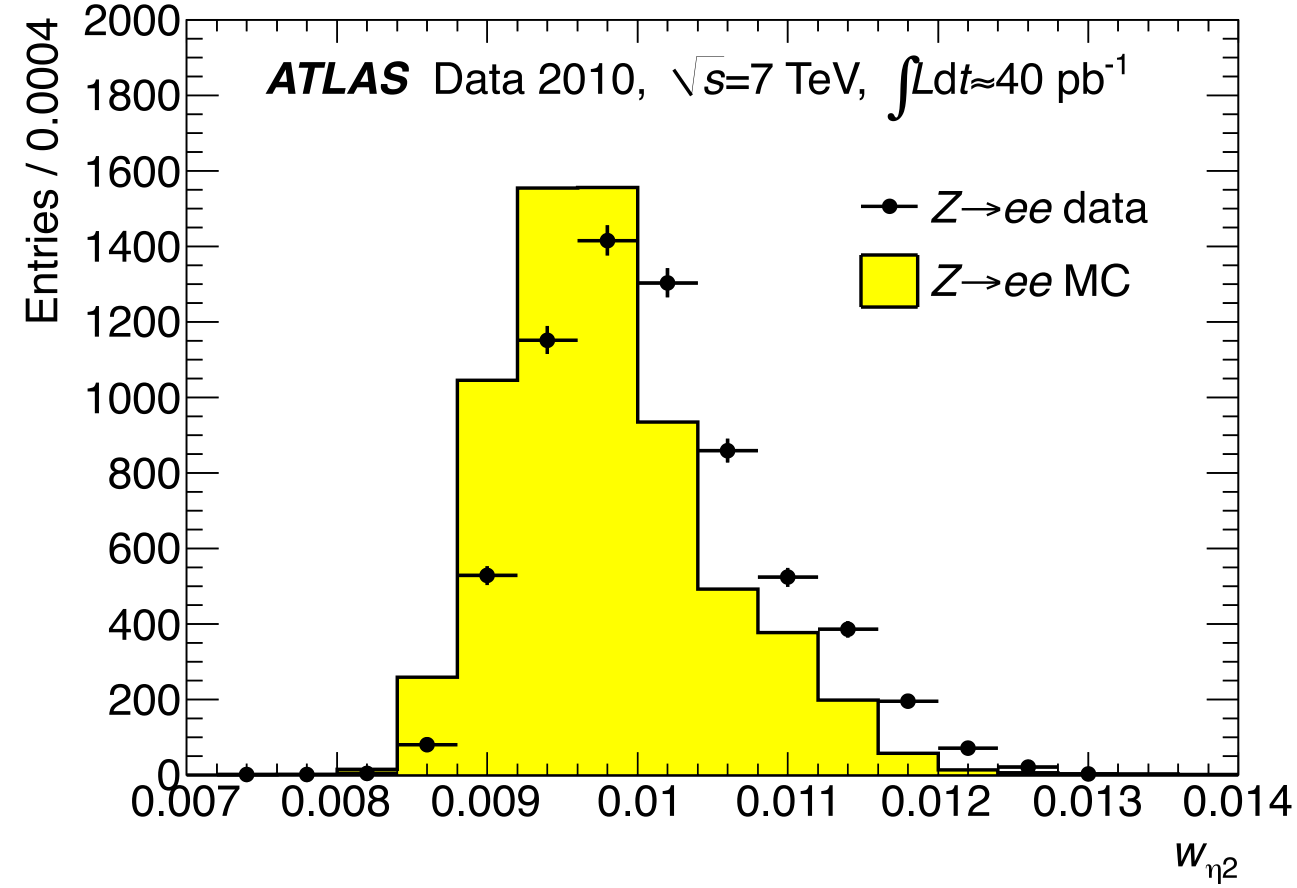

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Due primarily to approximations made in the calorimeter geometry description.
Absorber Material: Average vs Detailed description

Muons in ATLAS

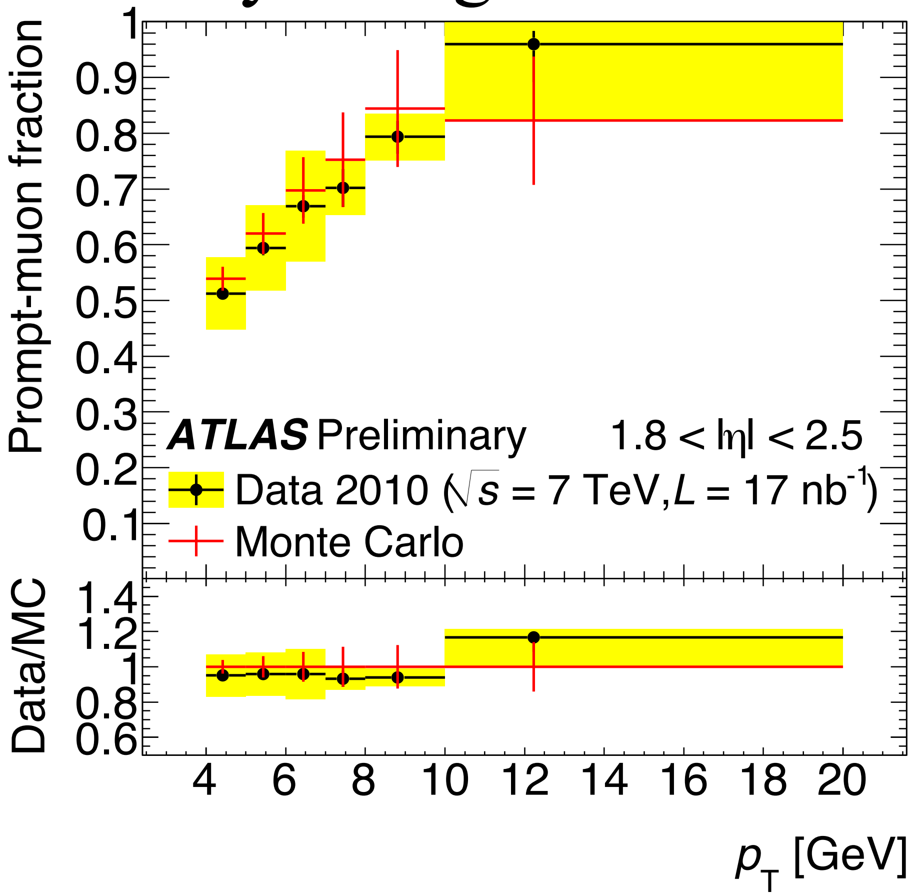
Muons in ATLAS

Identified as Tracks in the Muon Spectrometer.

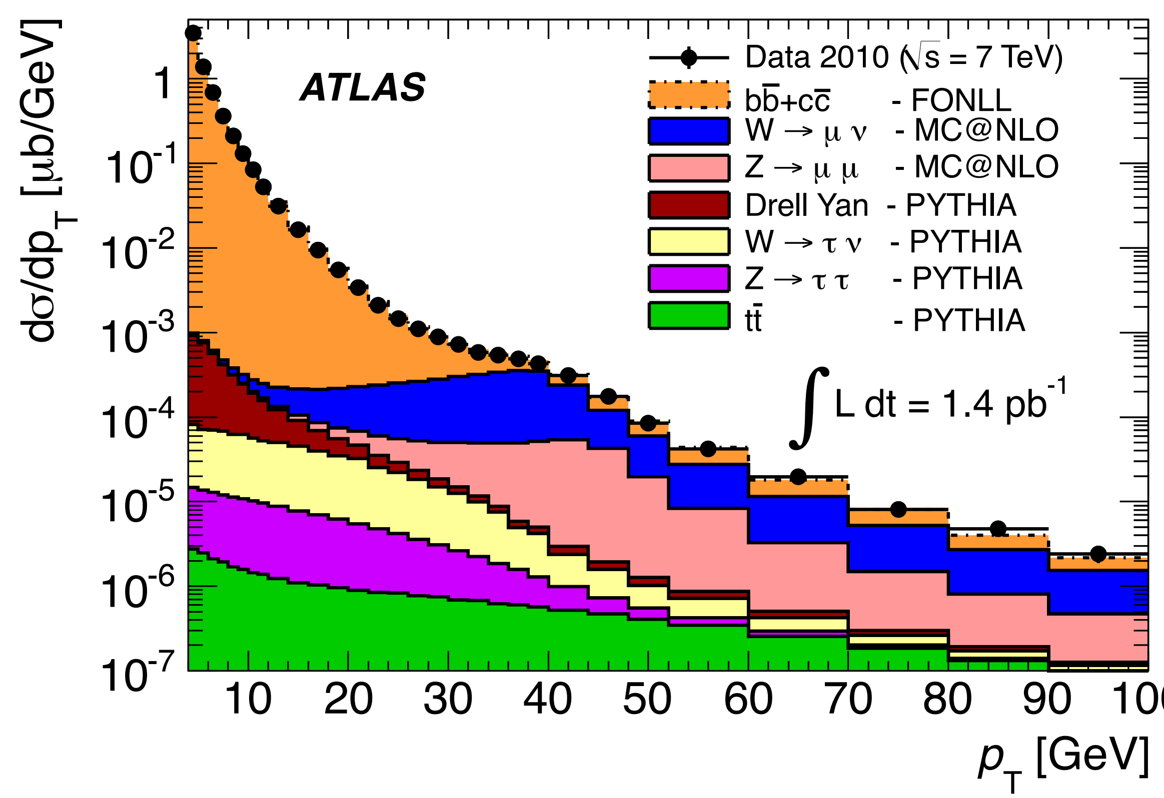
Essentially all reconstructed muons are from muons.

π/K decays / semi-leptonic heavy flavor decays / EWK bosons

Decay in flight



Inclusive muon cross section



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)

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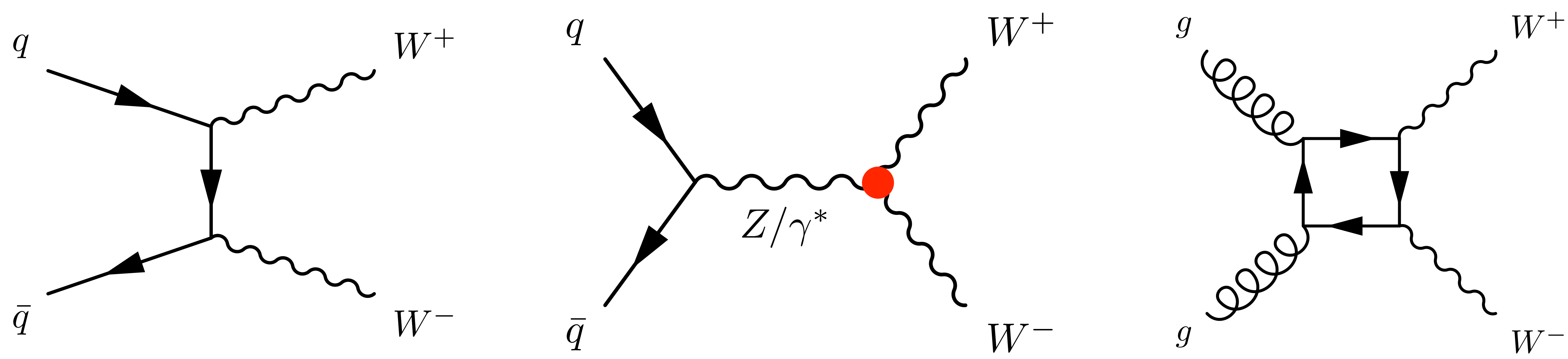
Mis-Identification Rate

How often things that are not "True" Leptons are Identified as Leptons.
hadrons / heavy flavor jets / photons

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

WW Cross Section



Motivation:

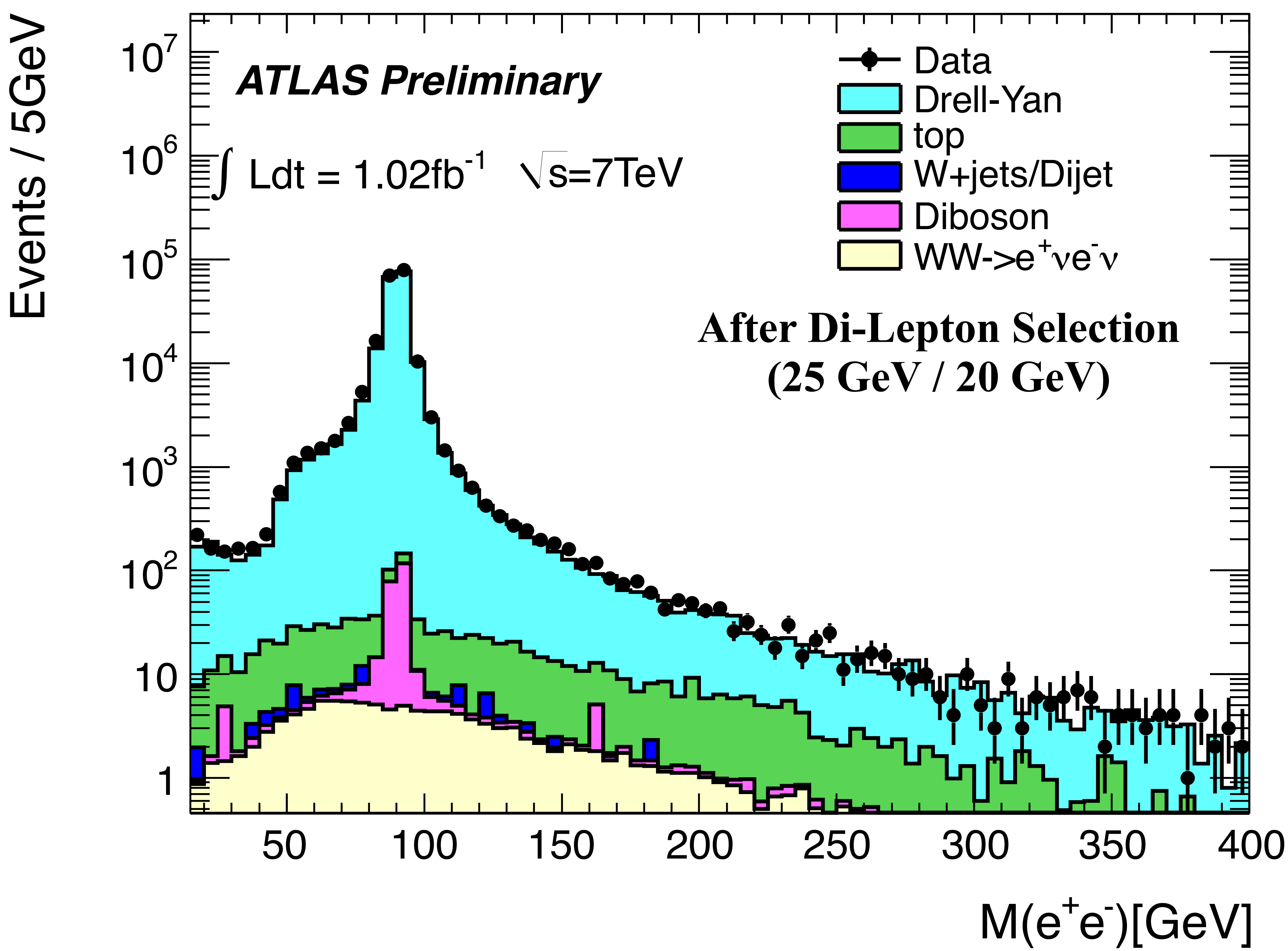
- Dominant Background to H→WW search
- Test EWK model, Sensitive to Triple Gauge Couplings

Signature:

- Performed Fully Leptonic Decays.
- 2 Opposite-Sign Leptons (e,μ)
- Large Missing Energy

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

WW Cross Section



Event Selection

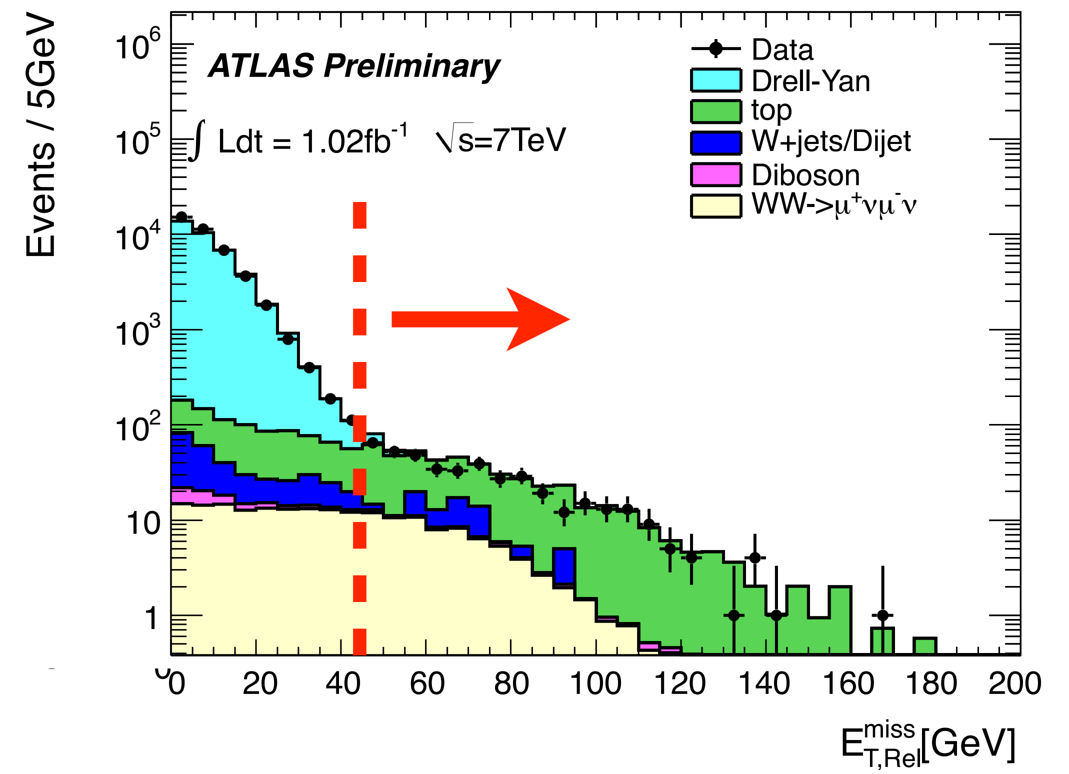
Backgrounds:

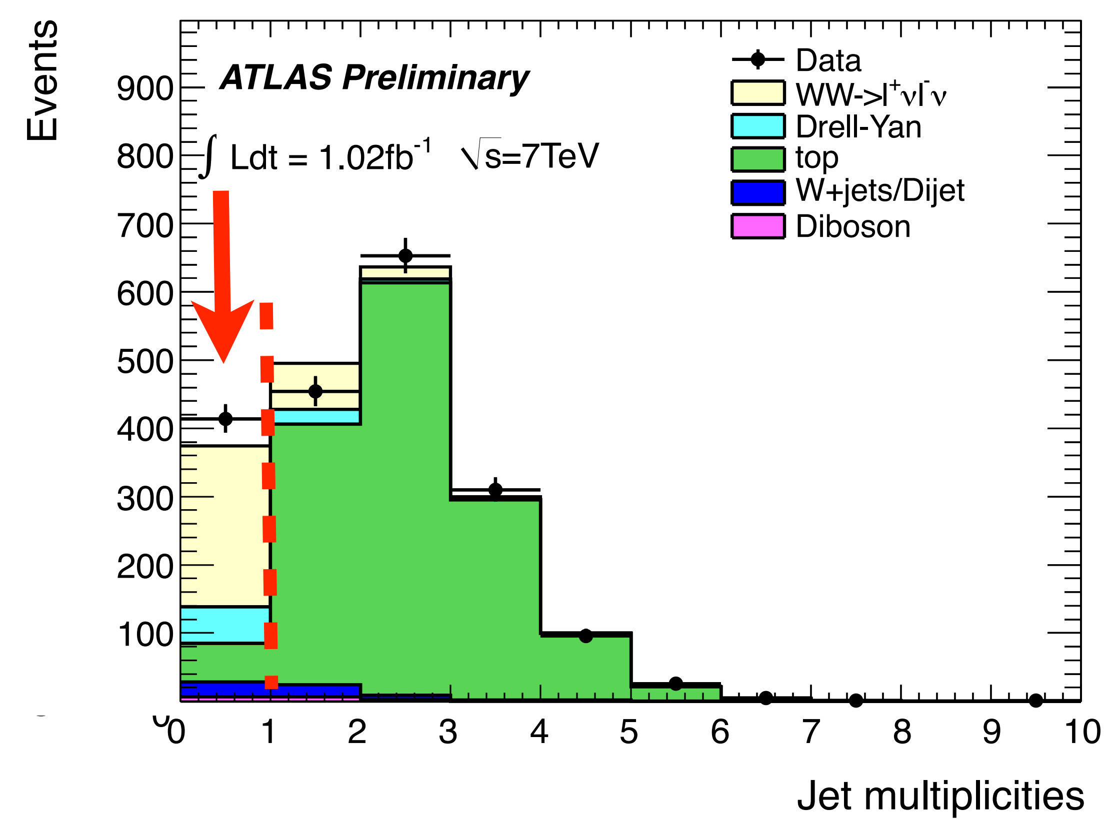
Drell-Yan: (lepton pair + ‘fake’ MeT)
- Require Large Missing Energy
- Reject events consistent w/Z mass

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.





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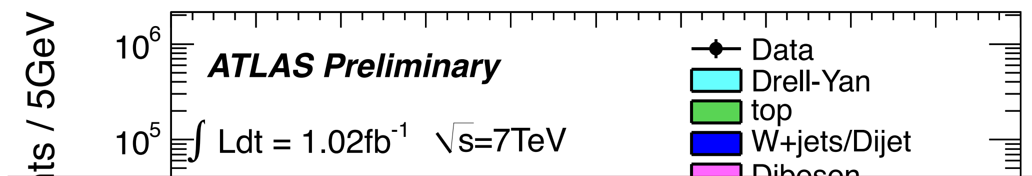
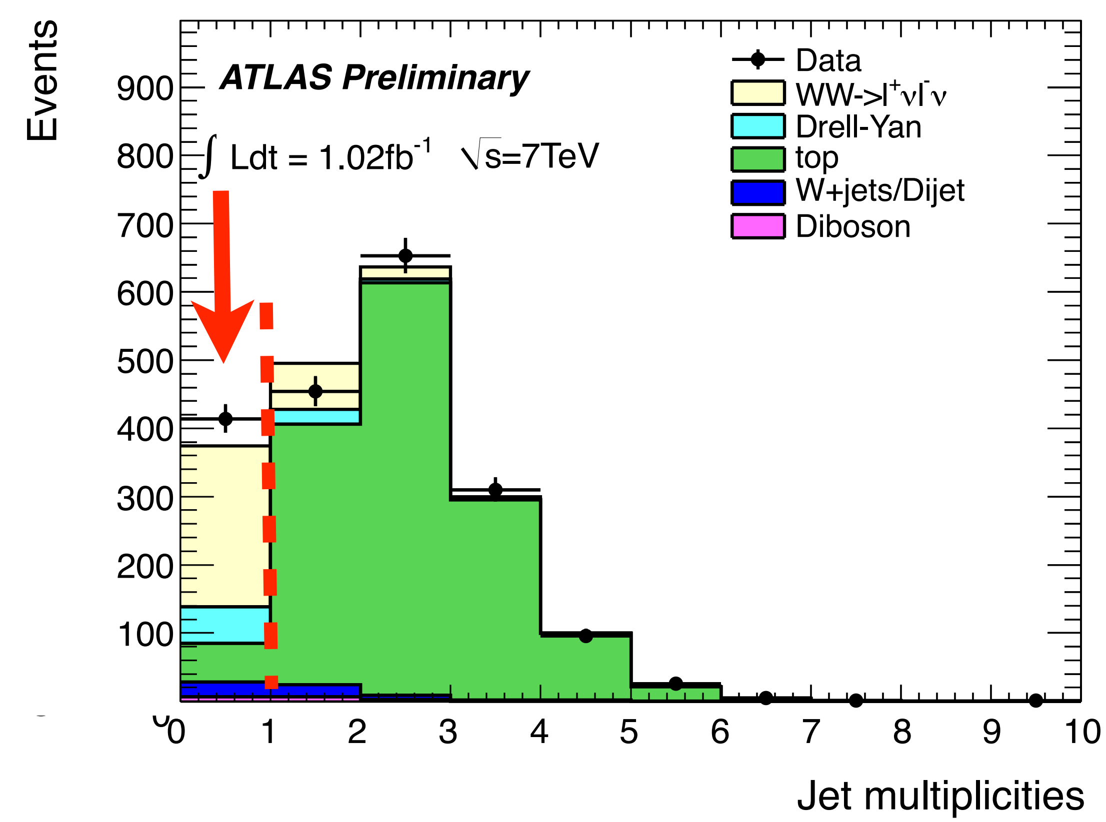


DY /Top Background
- Large, but reduced w/ Event Selection
- Well modeled by MC
- Can be corrected to Data.

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



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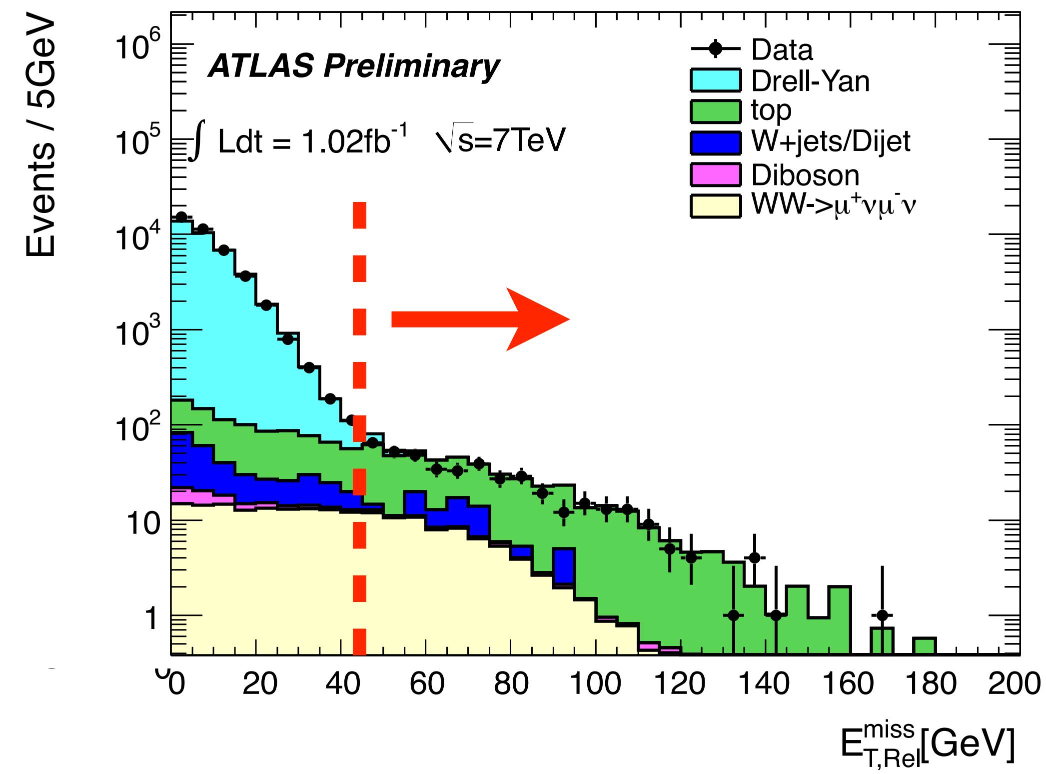
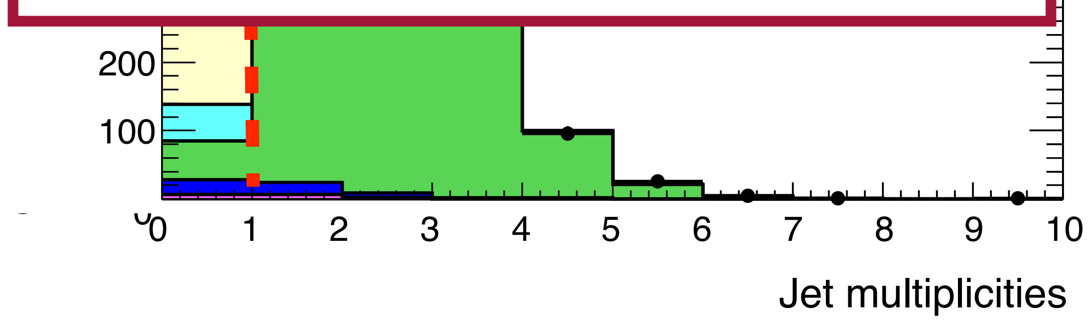


W+Jet Background
- Small, but not suppressed w/ Event Selection
- Difficult to model in MC
- Important at Low Pt.



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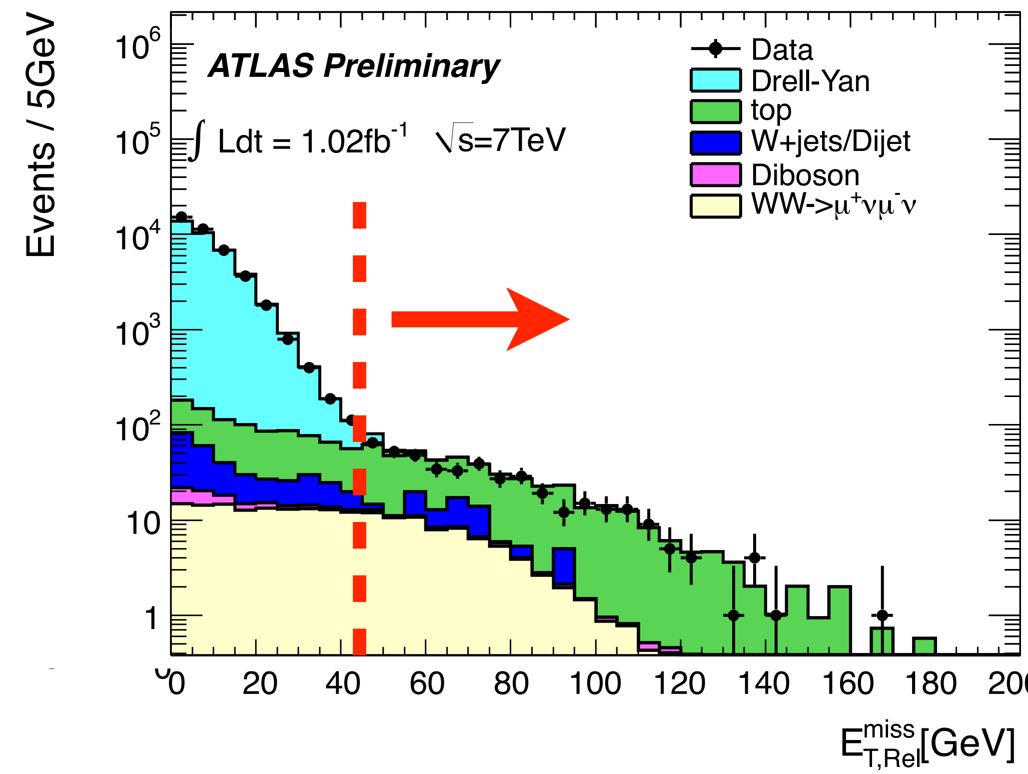
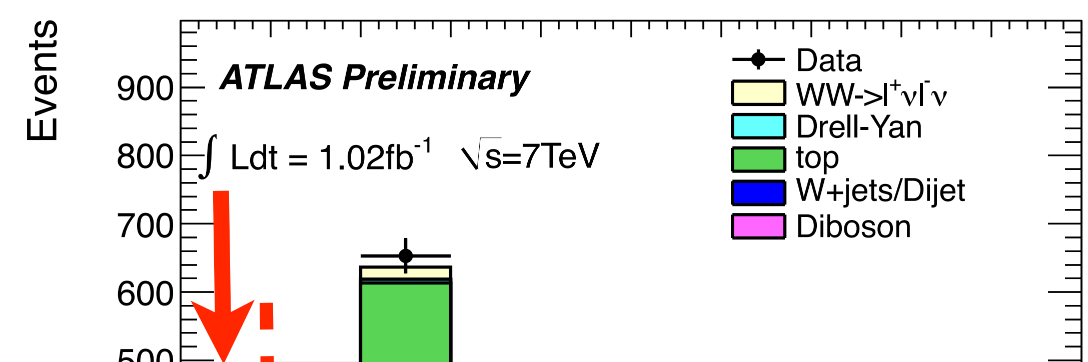
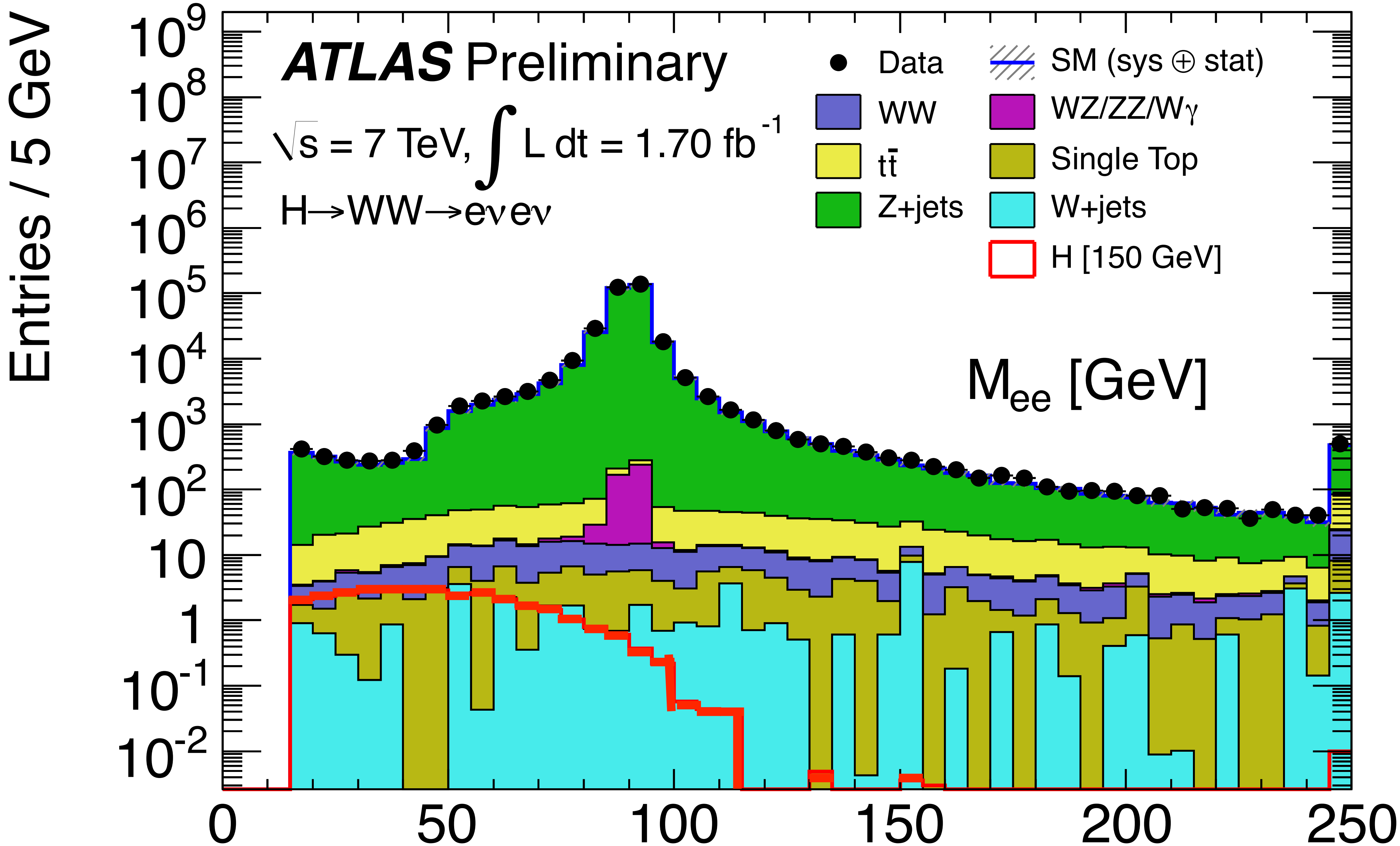




Diboson Background
- Small, and suppressed w/ Event Selection
- Well modeled by MC.

Searching for H→WW→lνlν



Separating out the H→WW

Event Selection same as for WW Cross Section.

Slightly Looser MeT cuts, add $P_{T_{ll}}$

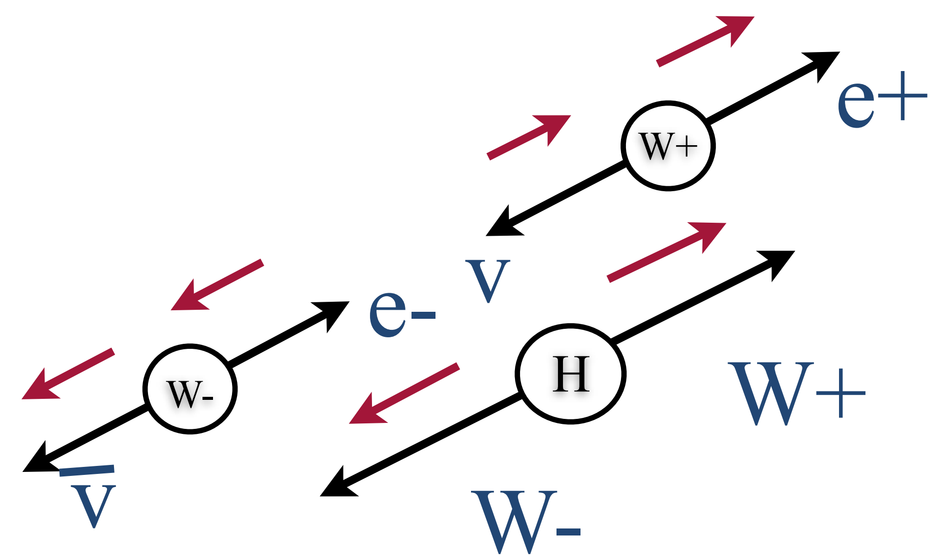
(Also includes 1-jet bin, see backup)

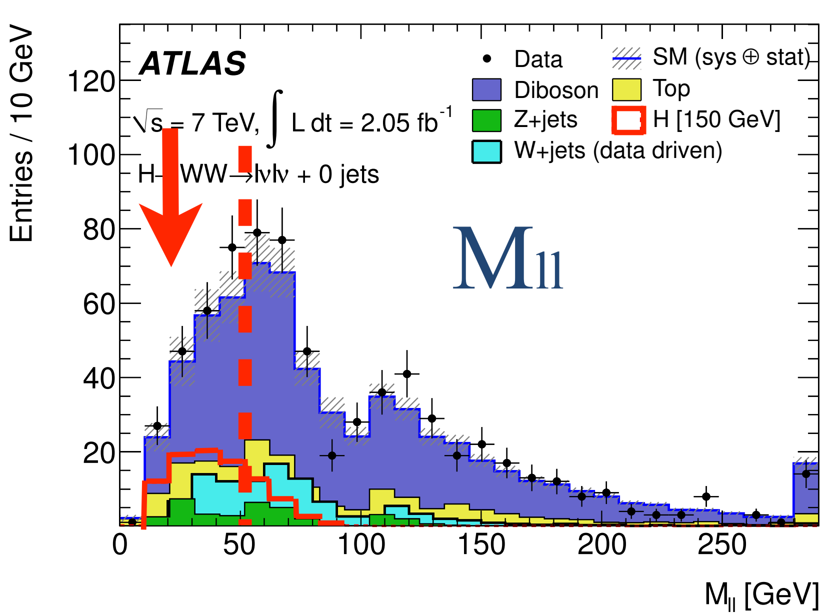
Dominated by SM WW.

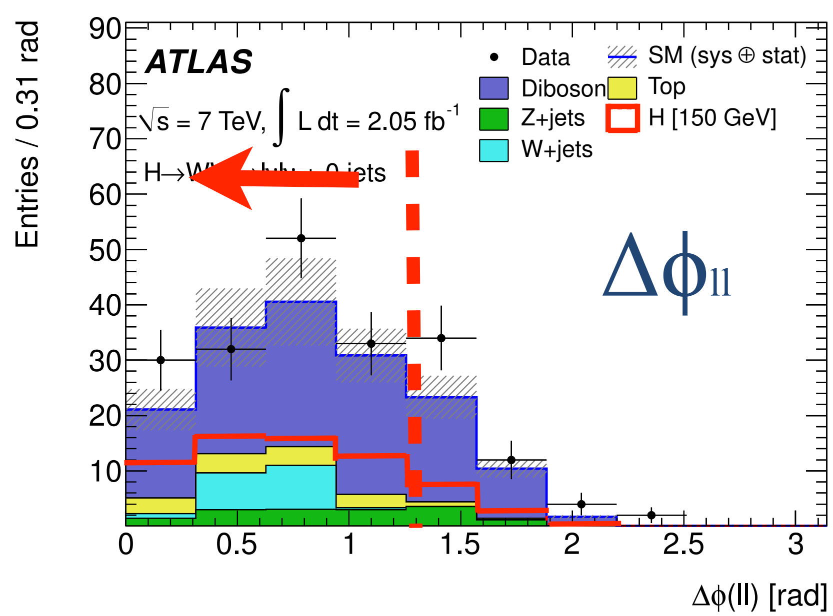
Additional cuts to suppress SM WW.

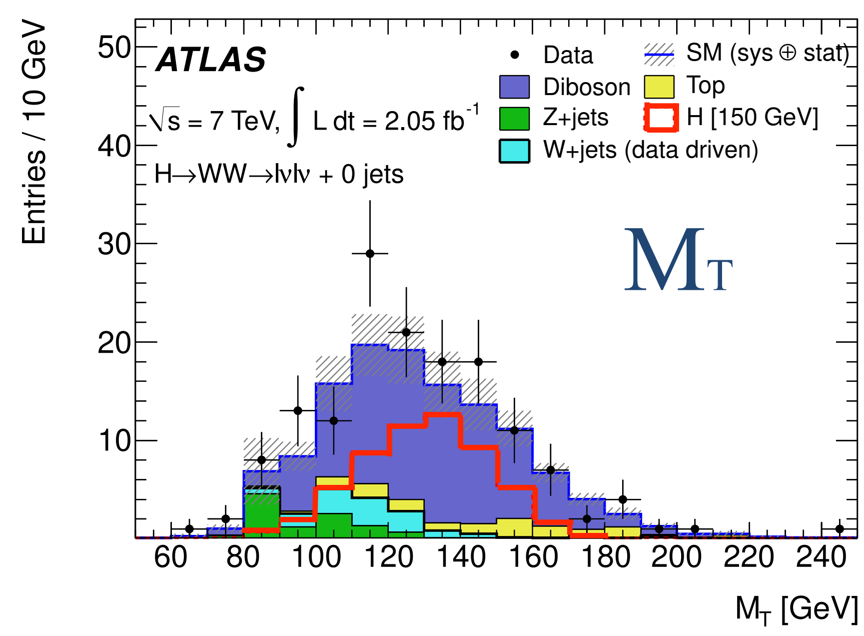
Exploit spin-0 nature of Higgs.

Optimized in 3 bins of m(H)









Background Estimation

Drell-Yan Background

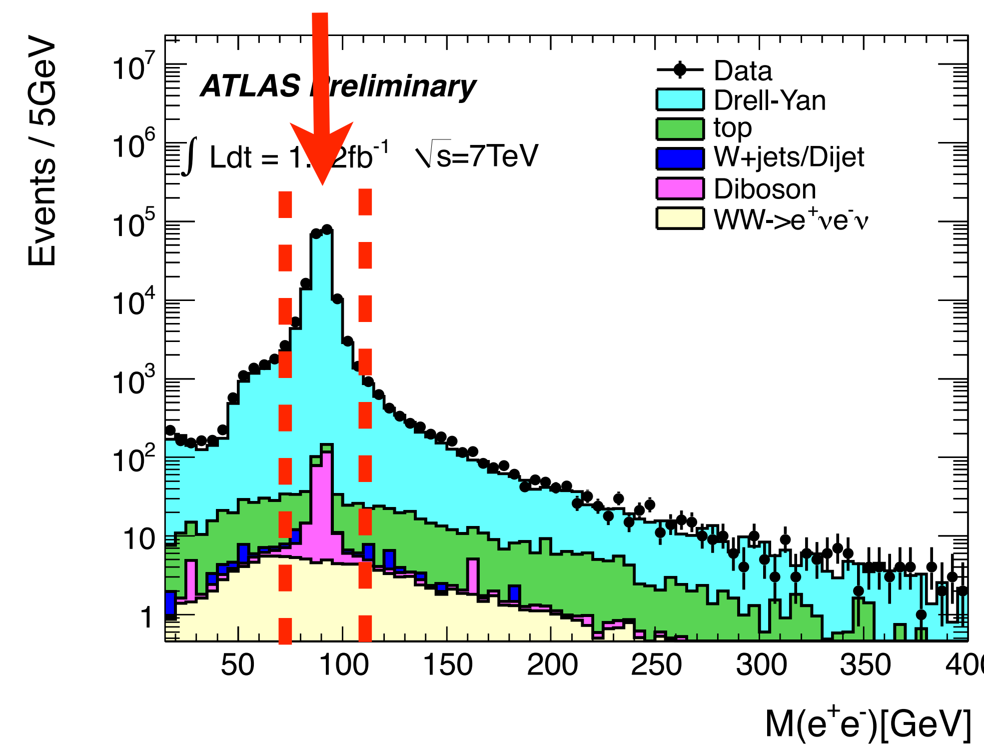
Background from DY if "fake" MeT

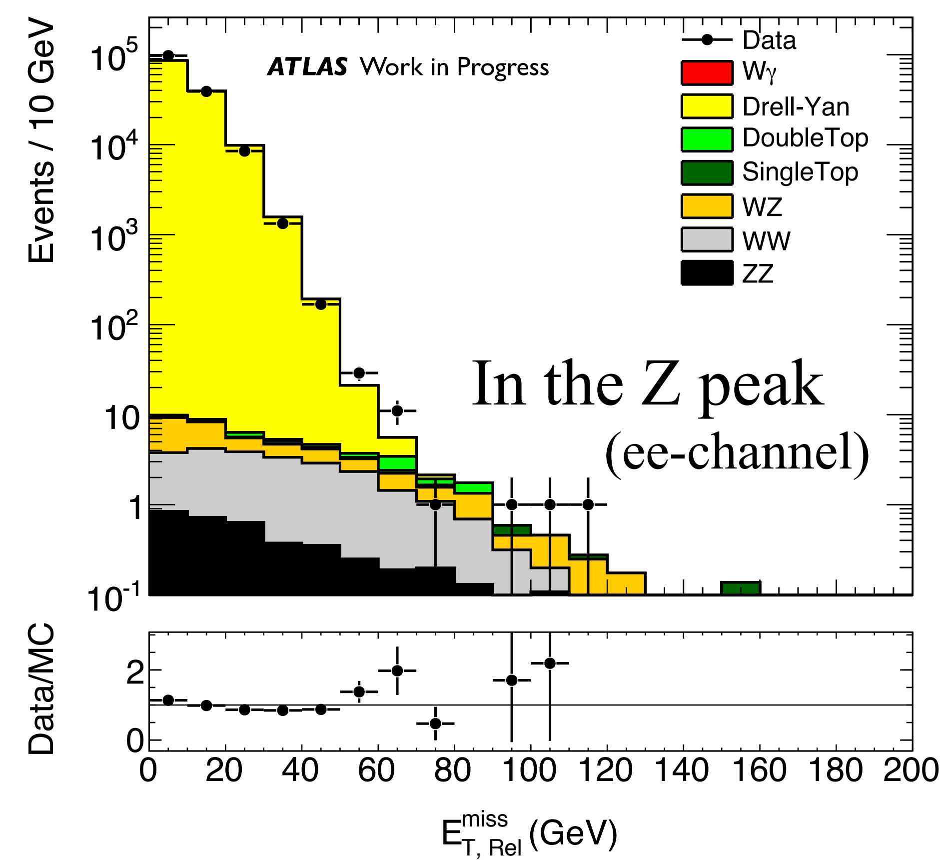
Observed momentum imbalance that is not due to the presence of neutrinos.

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:
$$S(E_T^{miss,Rel}) = \frac{\mathrm{N_{Data}} - \mathrm{N_{MC}}}{\mathrm{N_{DY}}}$$





Drell-Yan Background

Background from DY if "fake" MeT

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

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Use Data Events in the Z peak:

Quantify modeling of MeT in DY Events with:

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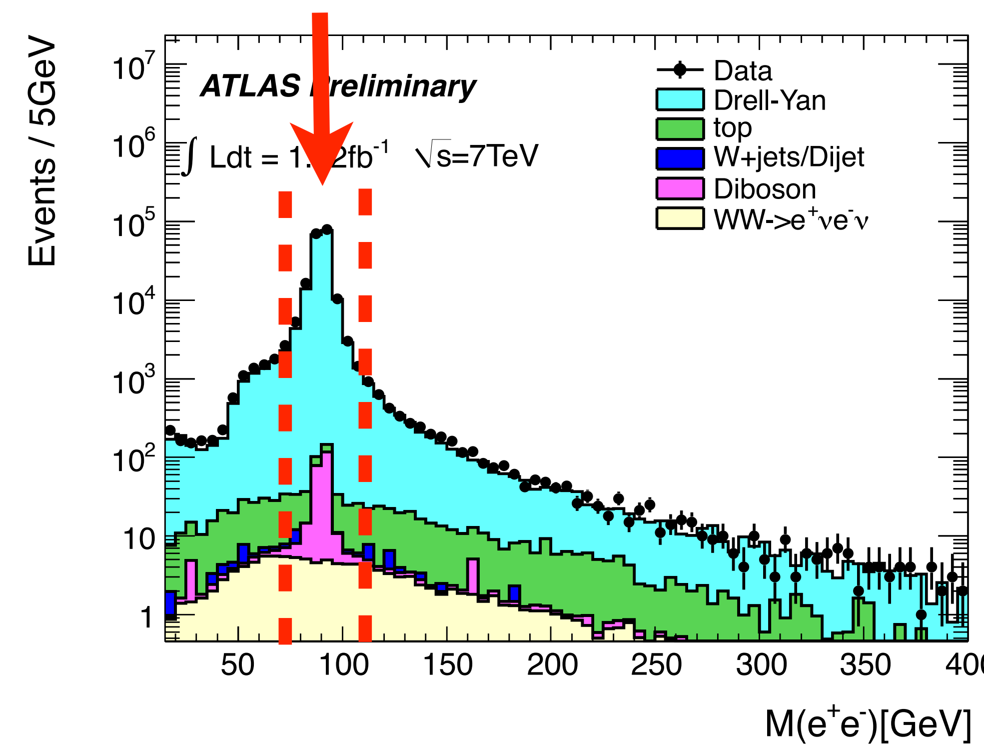
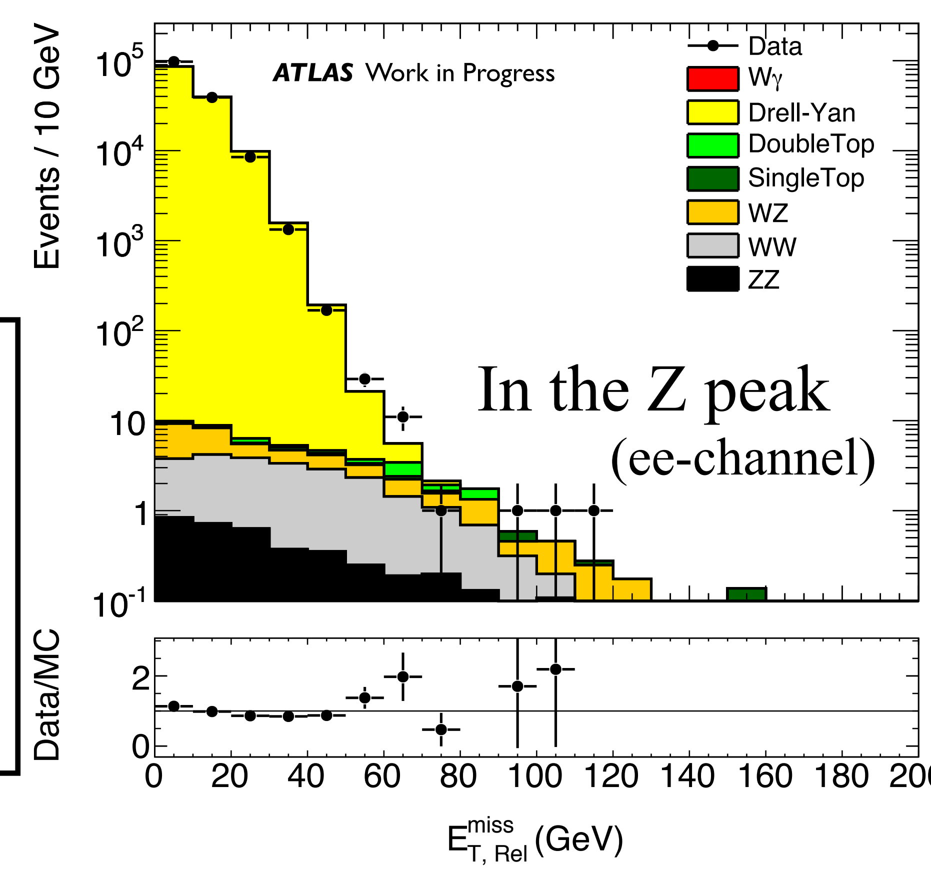




Measurement:

Channel	S
ee	0.06 ± 0.08
mm	0.05 ± 0.10

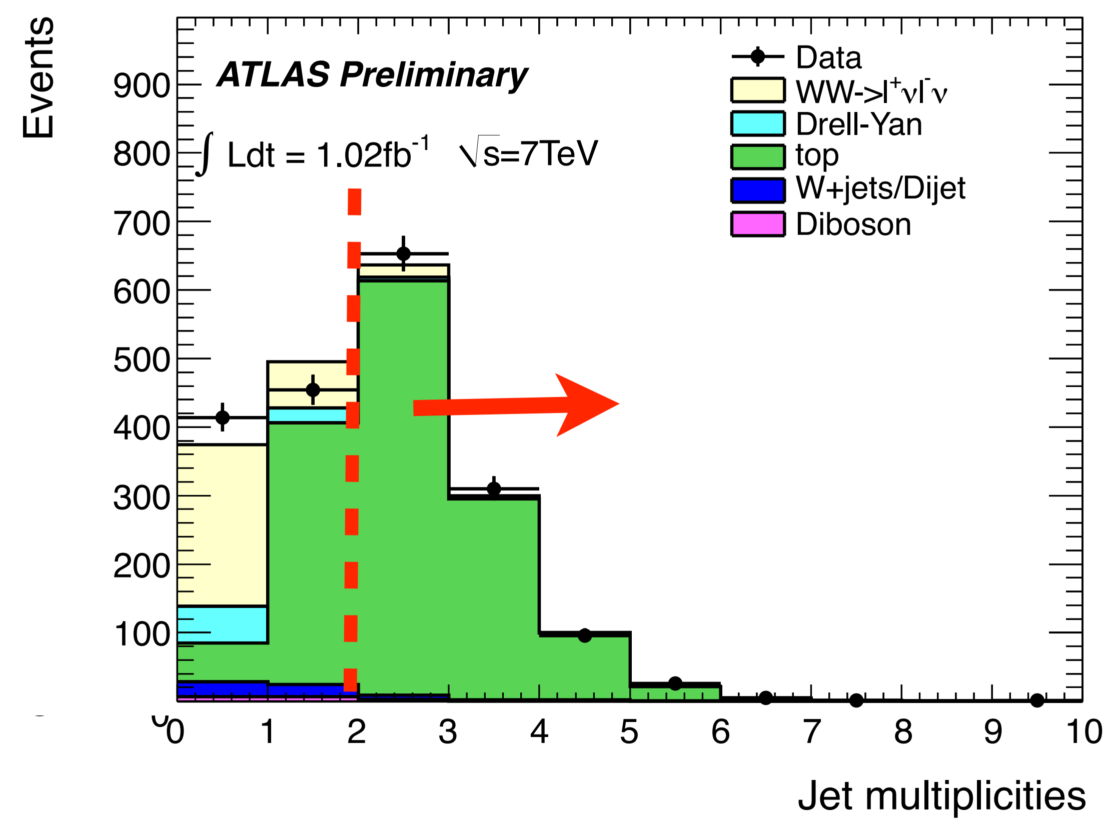
- Given Data/MC consistency do not correct prediction.
- S to assign systematic.

Top Background

Background from Top from lost Jets

Use Top control region in data

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

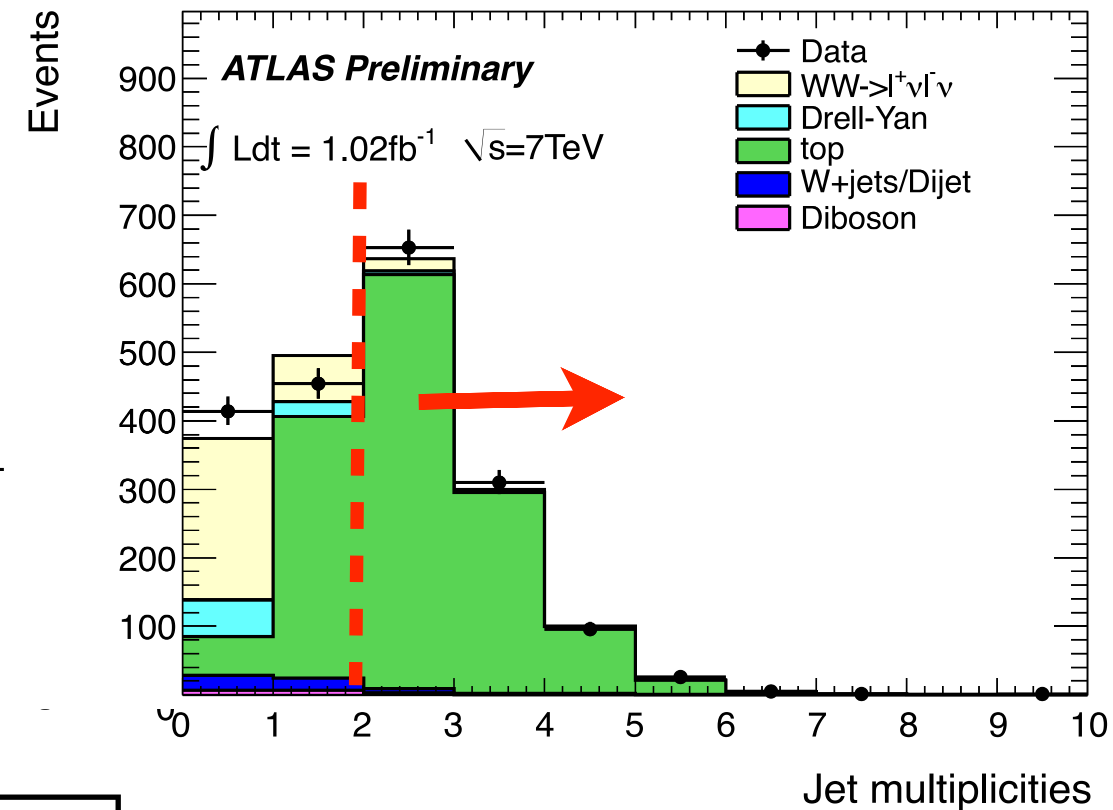


Top Background

Background from Top from lost Jets

Use Top control region in data

$$N^{\text{Bkg}}_{\text{Top}}(\text{0-jet}) = N^{\text{Data-CR}}_{\text{Top}} \times \frac{N^{\text{MC}}_{\text{Top}}(\text{0-jet})}{N^{\text{MC-CR}}_{\text{Top}}}$$



Measurement of the Top Background in agreement with MC prediction

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

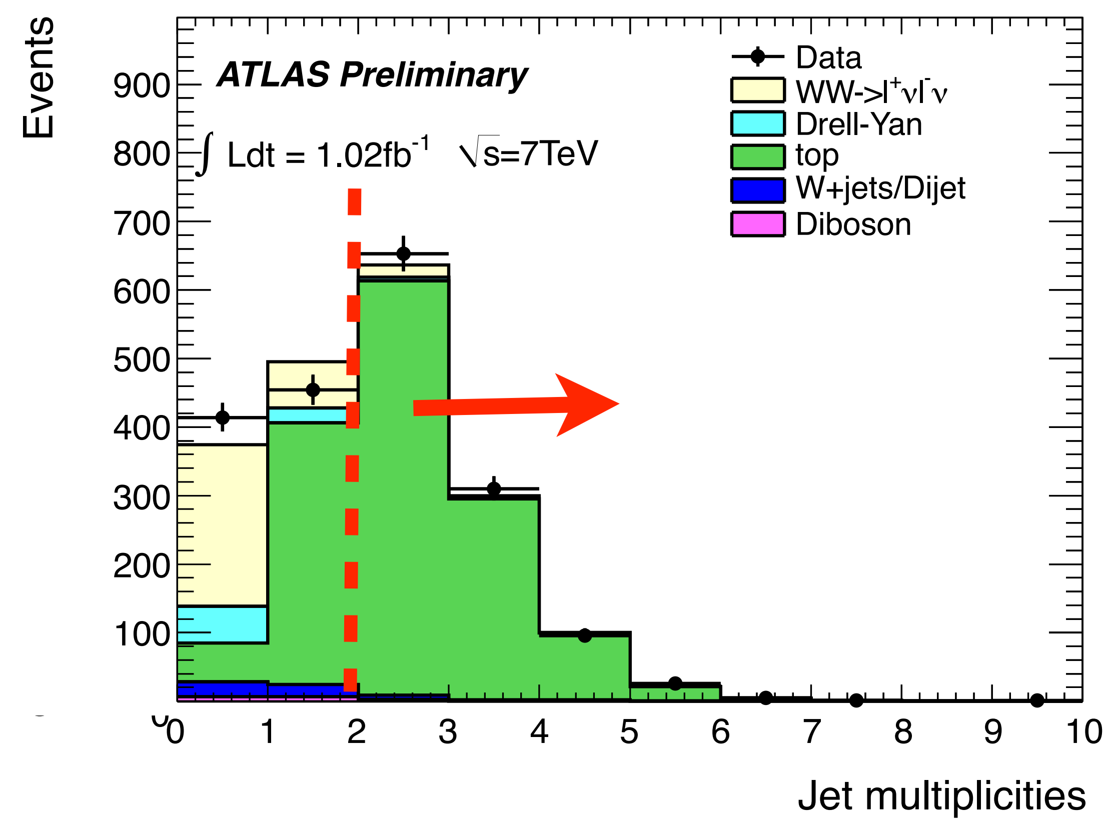
Large systematic uncertainty due to Energy scale uncertainty in MC

Top Background

Background from Top from lost Jets

Use Top control region in data

$$N^{\text{Bkg}}_{\text{Top}}(\text{0-jet}) = N^{\text{Data-CR}}_{\text{Top}} \times \frac{N^{\text{MC}}_{\text{Top}}(\text{0-jet})}{N^{\text{MC-CR}}_{\text{Top}}}$$



Reduce systematics by applying SF measured in Tag sample.

$$N^{\text{Bkg}}_{\text{Top}}(\text{0-jet}) = N^{Data}_{\text{Top}} \times \text{SF} \times \frac{N^{\text{MC}}_{\text{Top}}(\text{0-jet})}{N^{\text{MC}}_{\text{Top}}}$$

SF - scale factor from tag sample

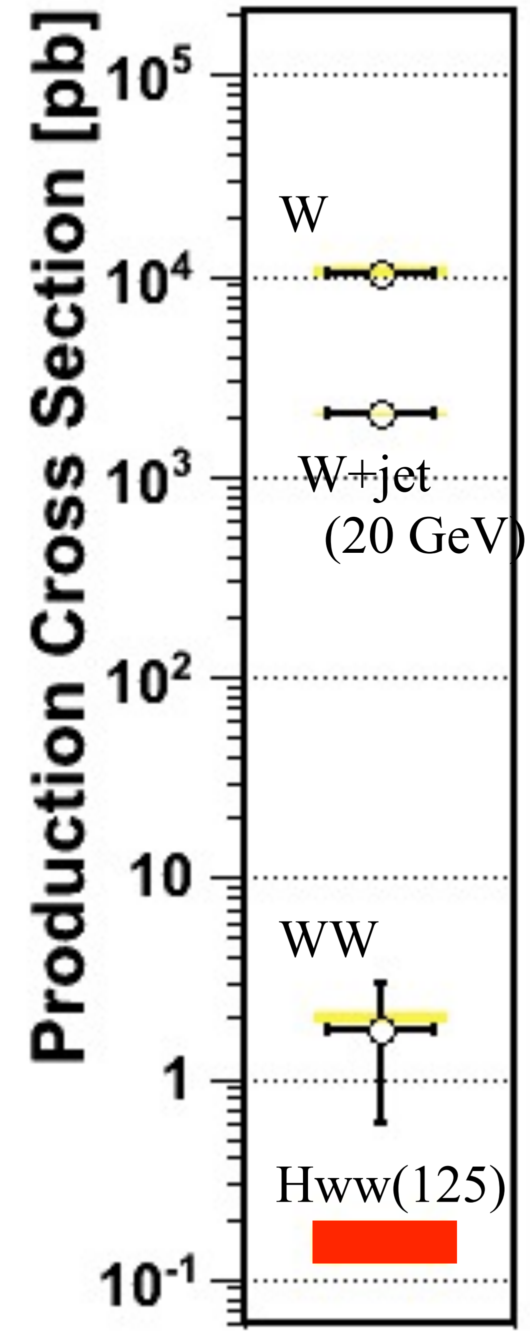
Leads to cancelation of some of the JES uncertainty in jet-veto .
~20 % systematic vs ~40 % without SF.

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.

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Control Sample.

W +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.

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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.

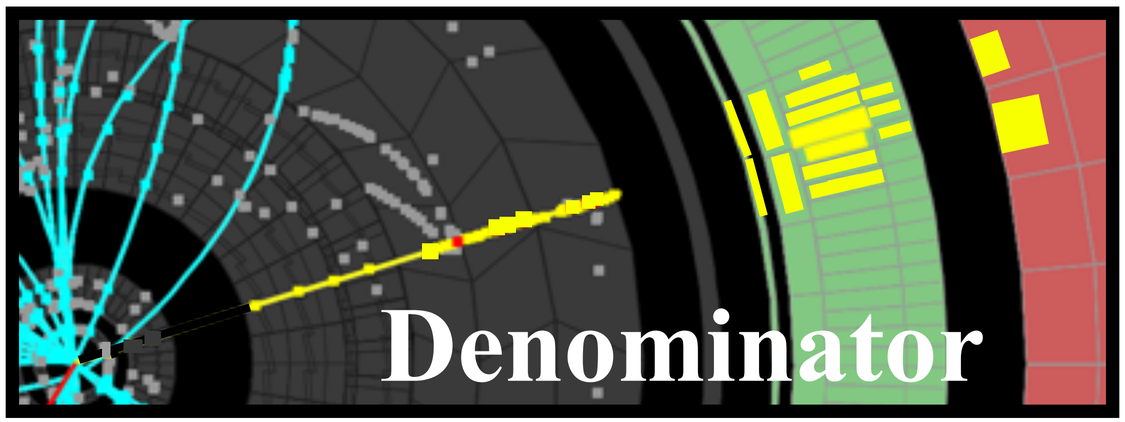
Extrapolation Factor.

Relates Control Sample to W+Jet background in signal region.

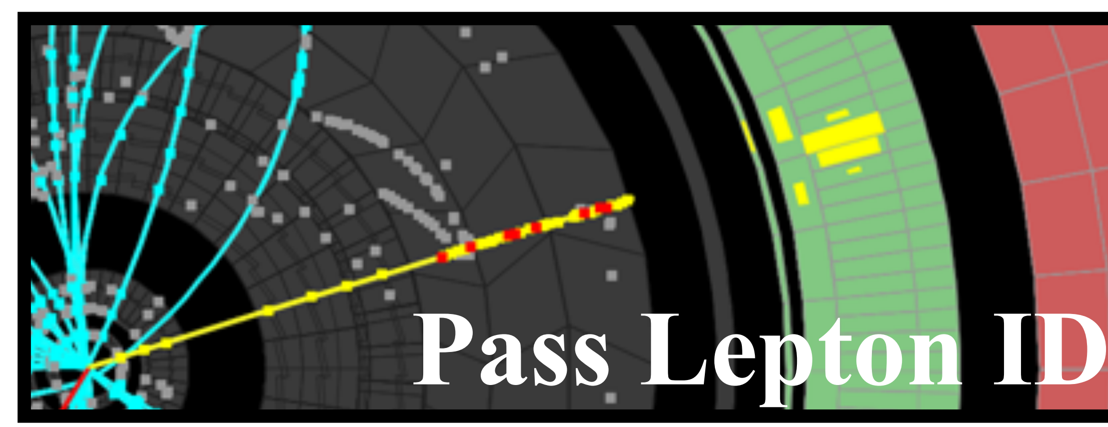
- Relates mis-ID rate of the “Denominators” identification criteria to the mis-ID rate of the Lepton identification criteria
- Property Local to mis-ID object. Measure in di-jet sample.

Fake Factor Method.

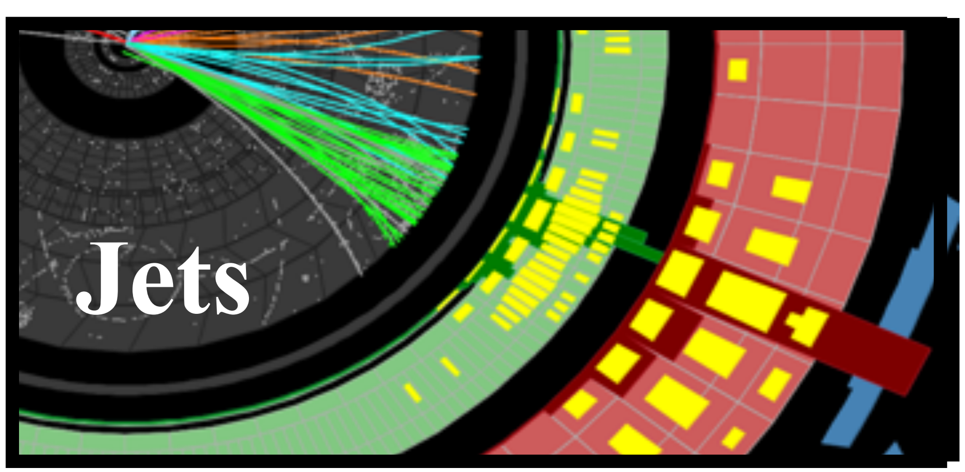
Use



To model



From



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

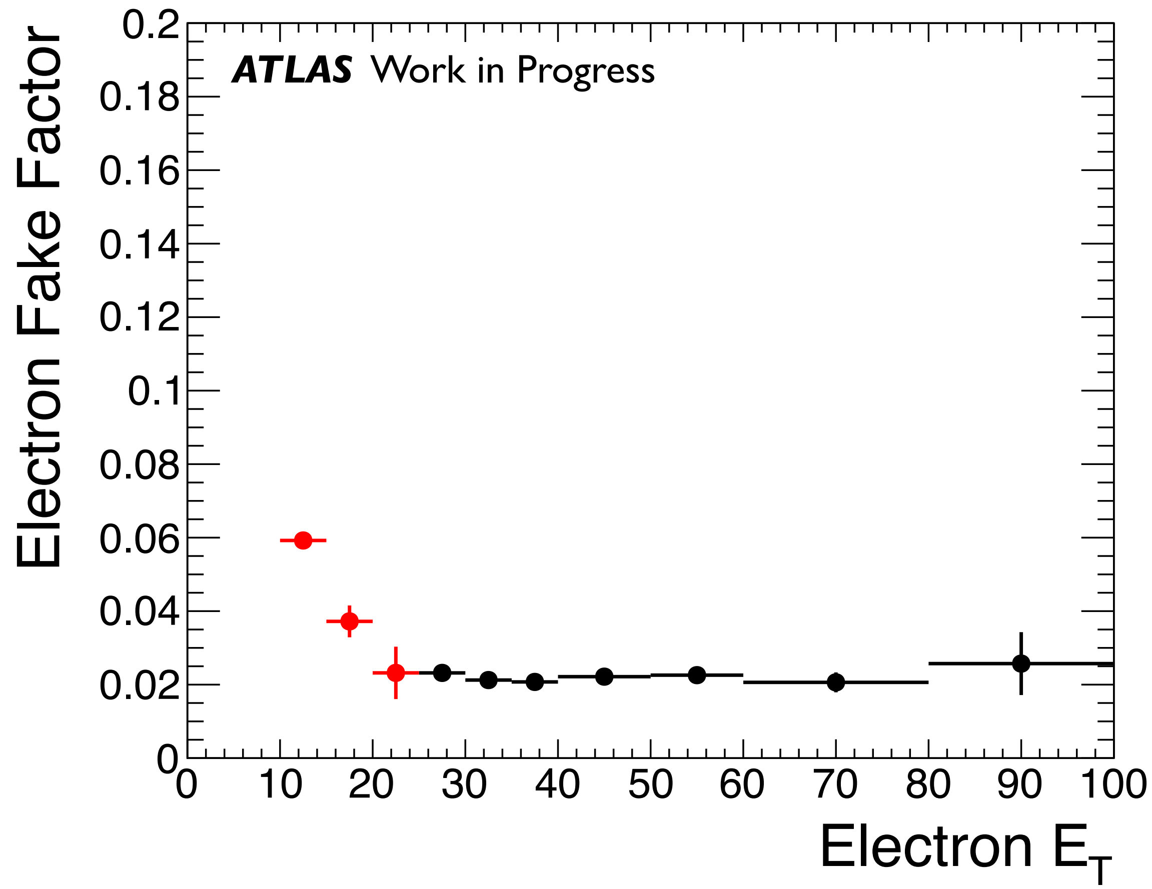
Jet Sample:

- *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.

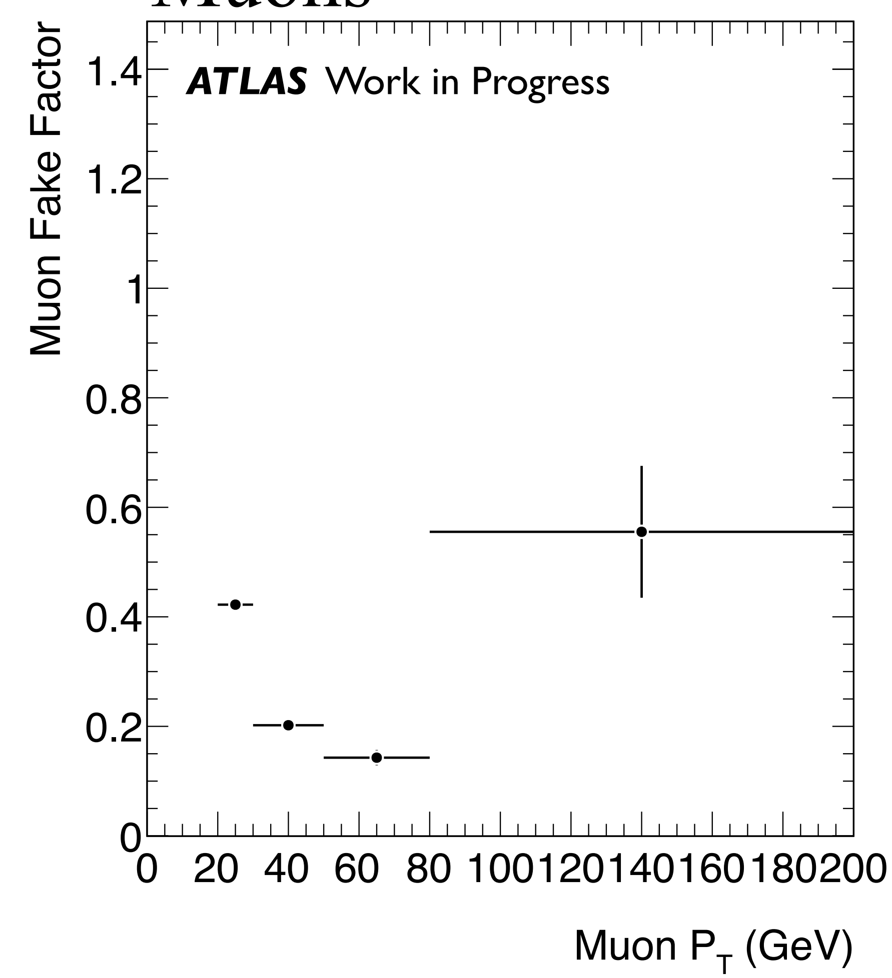
Measuring Extrapolation Factor

	Lepton Definition	Denominator Definition
Electrons:	Reconstructed Electron Pass Tight + Isolation.	Reconstructed Electron Fail Medium
Muons:	Reconstructed Muon Tight D0/Z0 + Isolation	Reconstructed Muon Loose D0/Z0 + Interm. Isolation

Electrons



Muons



Extrapolation Factor Systematics

The challenging part of measuring *f*.

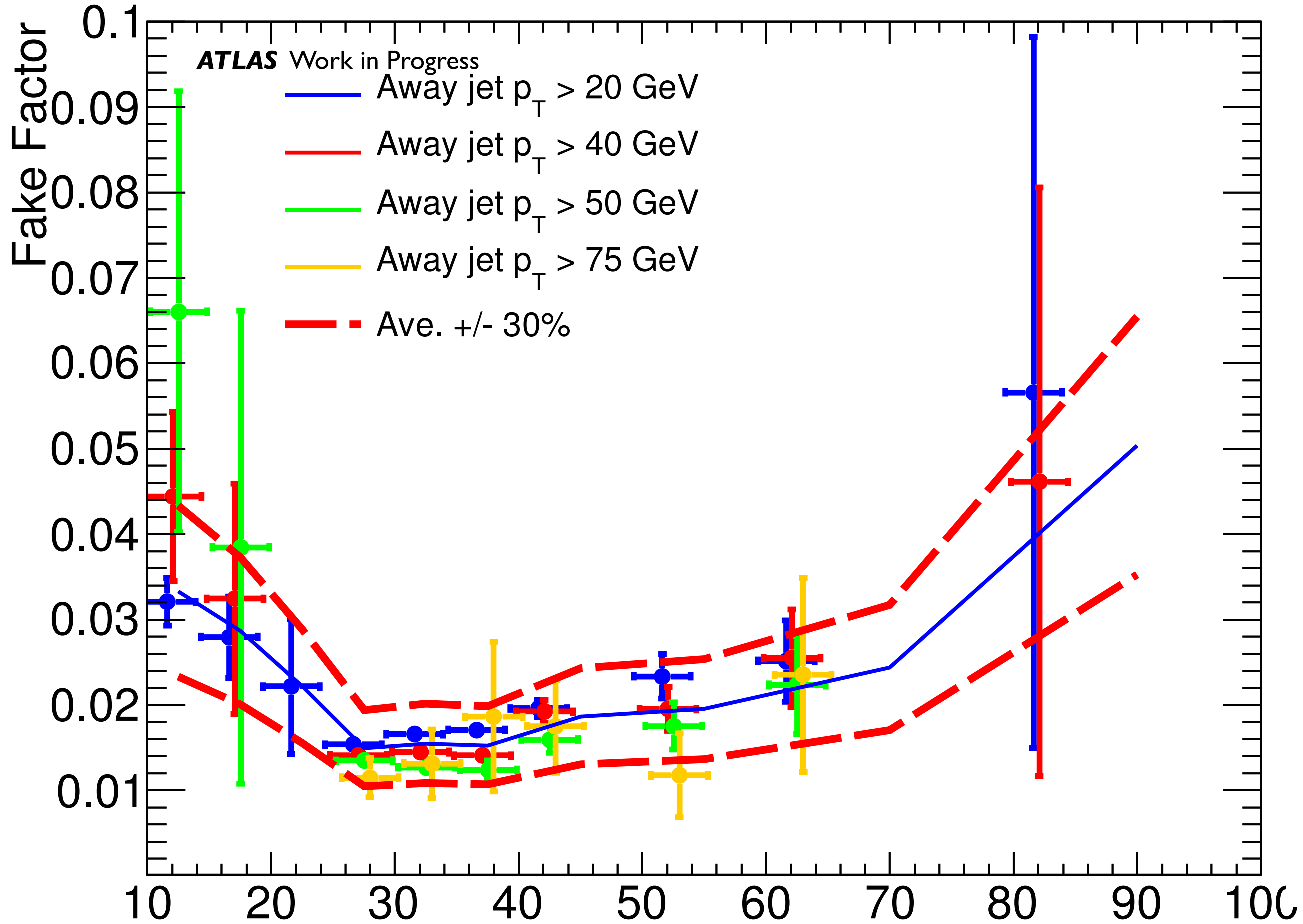
Assumption:
Measure *f* in di-jet sample and assume it applies to Control Region

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

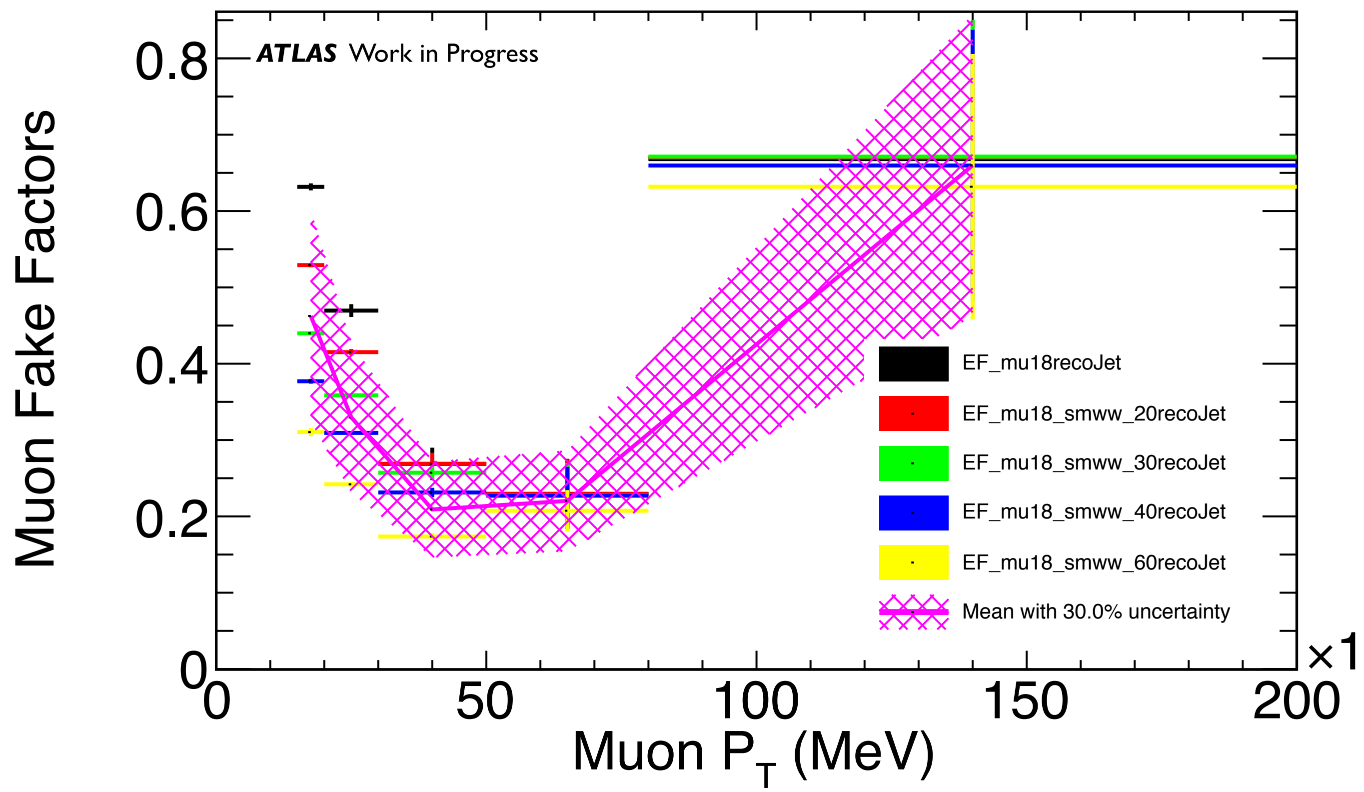
Data-Driven
Measure variation in *f* with varying jet sample:
- Varying P_T of "faking" jet by Varying away side jet P_T.
- Varying composition
  - g+jet (Away side g, enhances near side q content)
- Z+jet sample. (Jet kinematics/composition similar to W+j)

Extrapolation Factor Systematics

Electrons



Muons



Putting it all together

Observed Lepton-Denm. pairs passing event selection.

$$N_{\mathrm{Bkg}}^{\mathrm{W+Jet}} = f \times N_{(\mathrm{Lepton+Denm})}$$

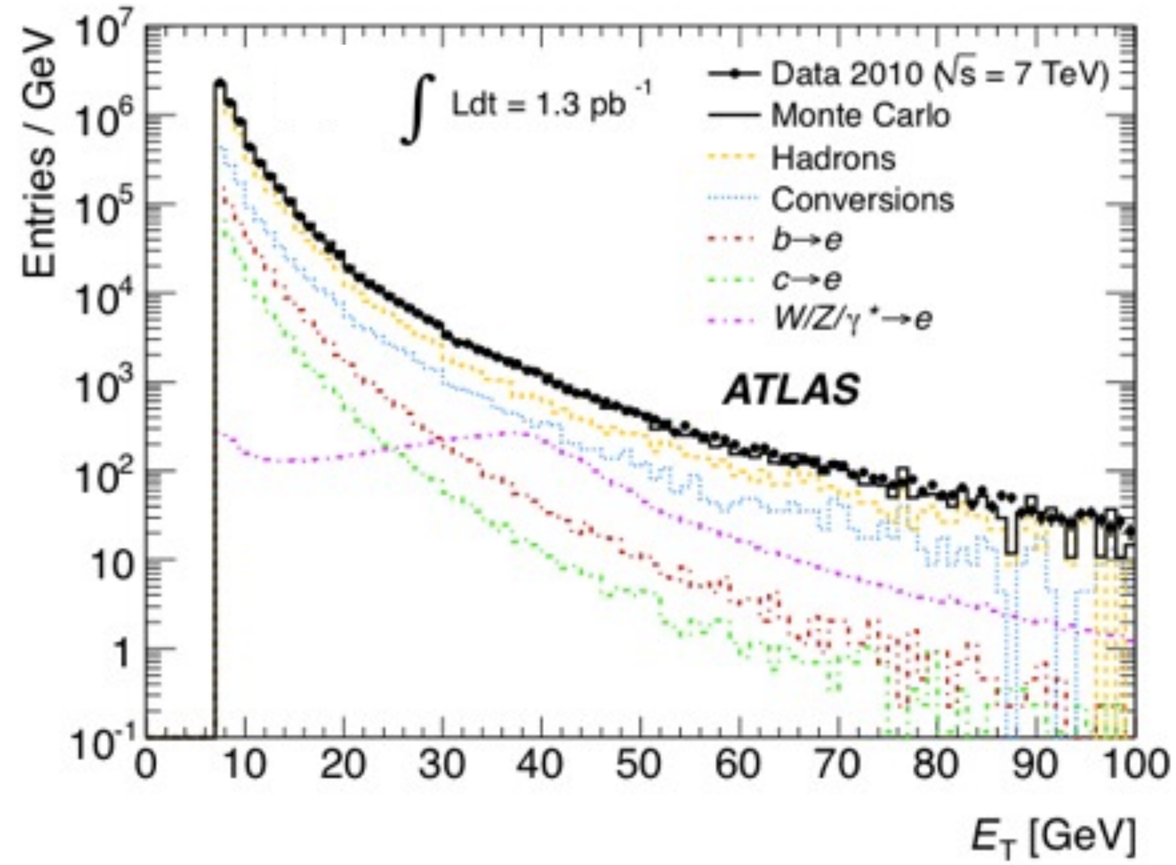
Measured in a di-jet sample

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



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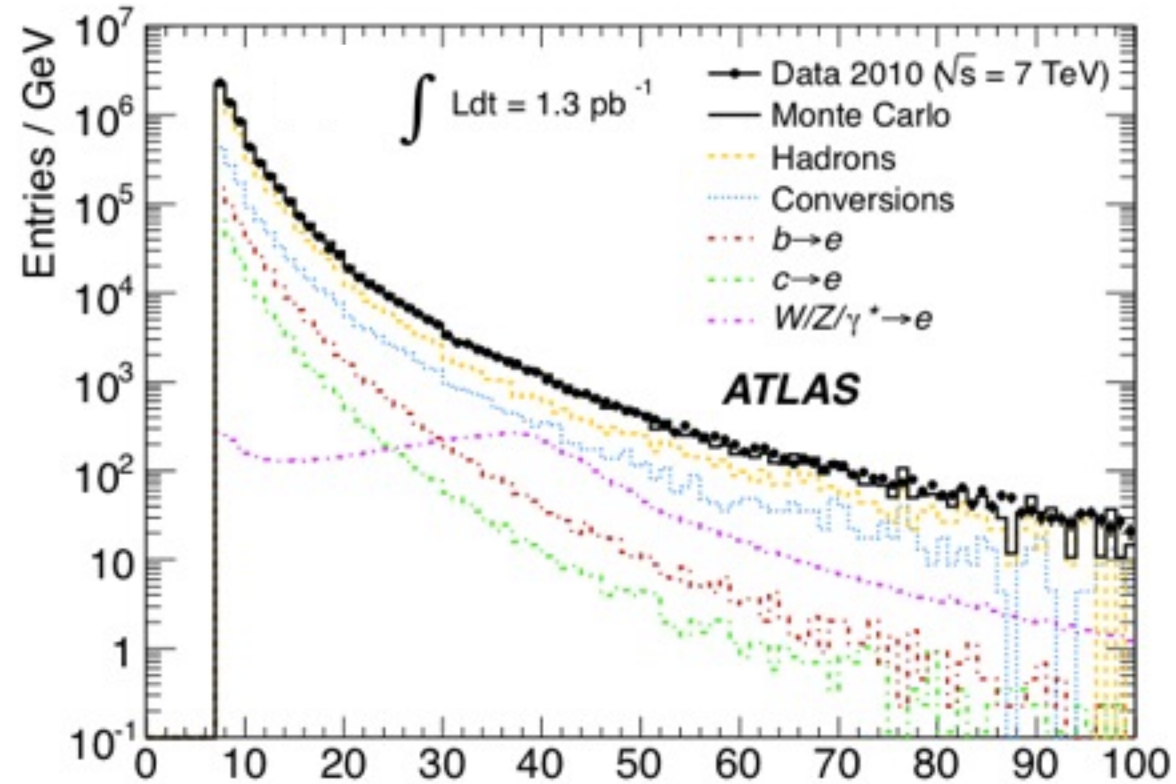
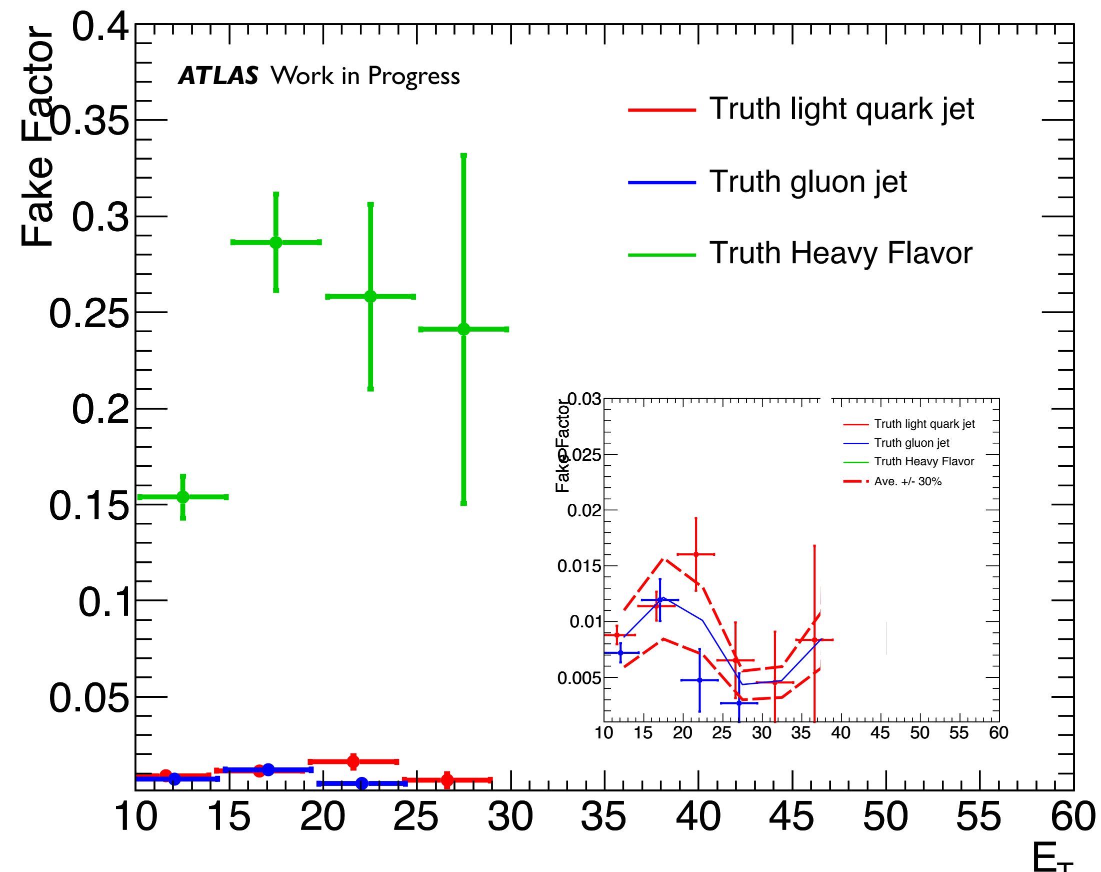
- Heavy Flavor jets (HF)
  semi-leptonic decays

Fake Factor can depend on source.

- heavy flavor significantly
  larger f than light flavor /gluon.





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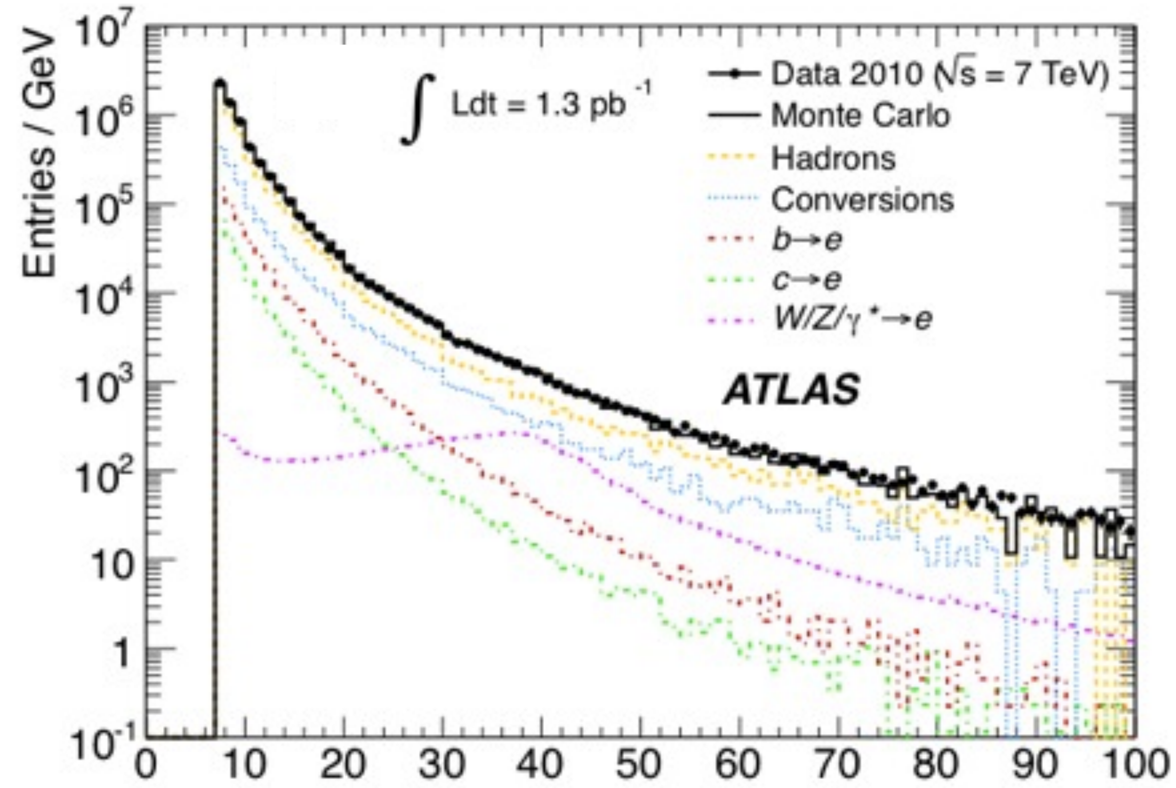
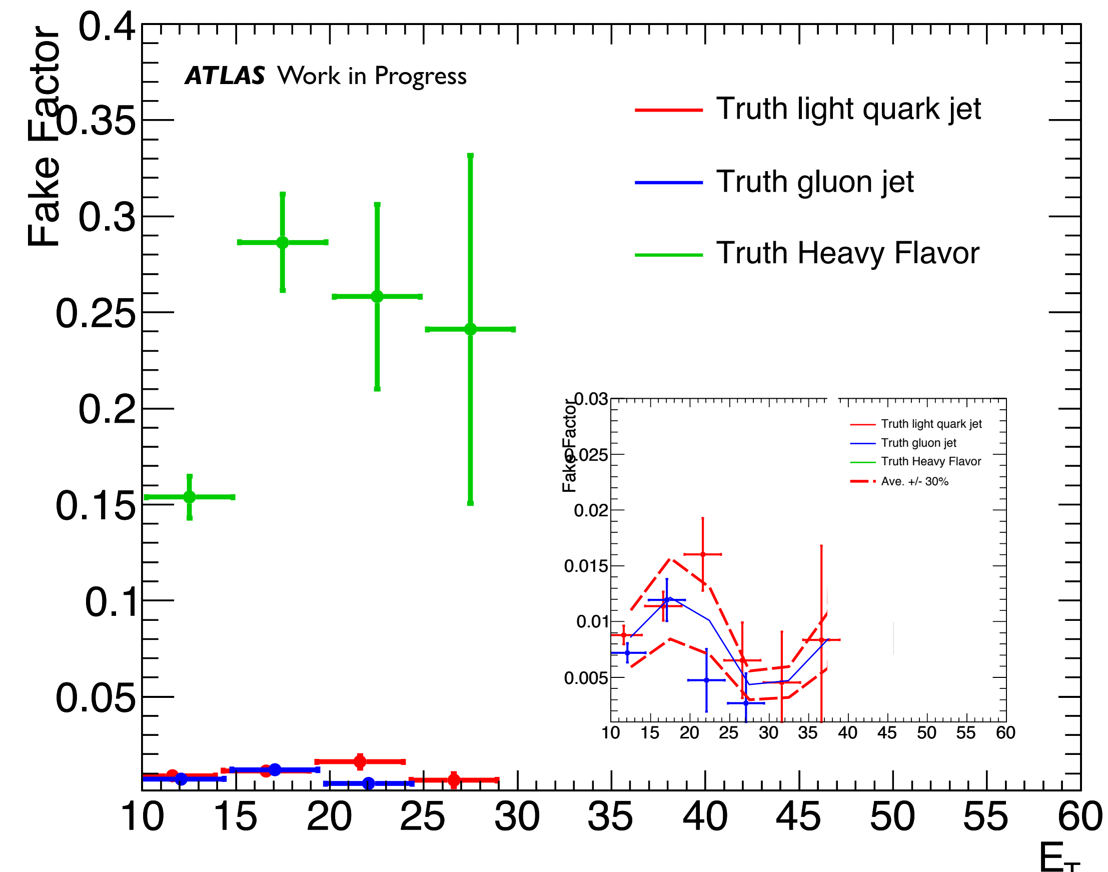


Fake Factor can depend on source.

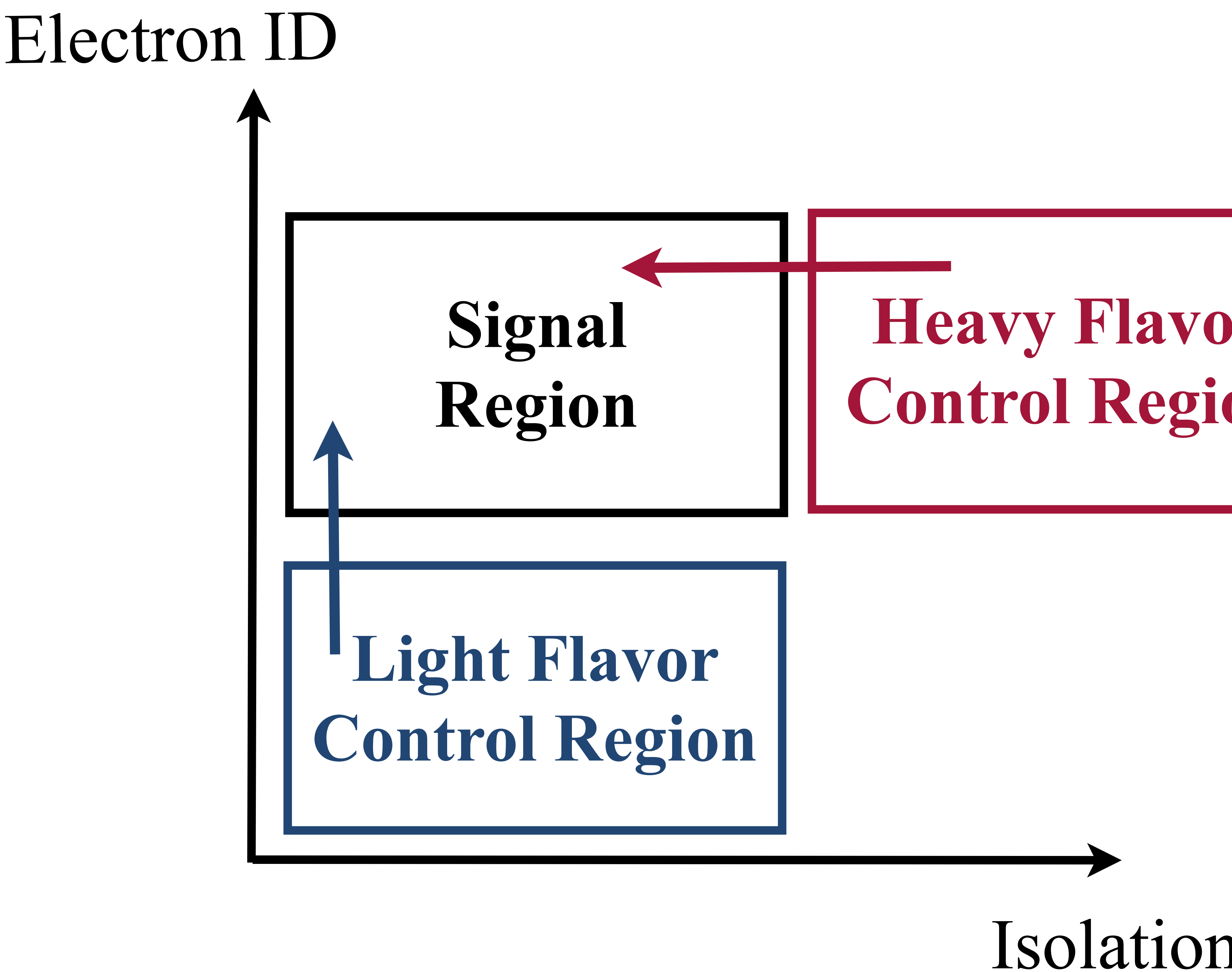
- heavy flavor significantly larger f than light flavor /gluon.



$$N_{\text{Bkg}}^{\text{W+Jet}} = f \times N_{(\text{Lepton+Denm})}$$

Differences in heavy-flavor composition in sample used to measure f and in $N_{(\text{Lepton+Denm})}$ will bias background prediction

Conceptually



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:
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- disjoint from signal region

Pass Identification
Fail Isolation

LF and HF Control Regions

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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,

$$f_{\mathrm{LF}} = \frac{N_{\text{Lepton-LF}}}{N_{\text{Denm-LF}}} \qquad \text{and} \qquad f_{\mathrm{HF}} = \frac{N_{\text{Lepton-HF}}}{N_{\text{Denm-HF}}}$$

Extending the Fake Factor Procedure

If we had,

Numerators *from* LF

Numerators *from* HF

$$f_{\mathrm{LF}} = \frac{N_{\text{Lepton-LF}}}{N_{\text{Denm-LF}}} \quad \text{and} \quad f_{\mathrm{HF}} = \frac{N_{\text{Lepton-HF}}}{N_{\text{Denm-HF}}}$$

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LF-enriched denominator ***definition***

HF-enriched denominator ***definition***

Extending the Fake Factor Procedure

If we had,

$$f_{\mathrm{LF}} = \frac{N_{\text{Lepton-LF}}}{N_{\text{Denm-LF}}} \quad \text{and} \quad f_{\mathrm{HF}} = \frac{N_{\text{Lepton-HF}}}{N_{\text{Denm-HF}}}$$

The W+Jet Bkg could be calculated as:

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

Extending the Fake Factor Procedure

If we had,

$$f_{\mathrm{LF}} = \frac{N_{\text{Lepton-LF}}}{N_{\text{Denm-LF}}} \qquad \text{and} \qquad f_{\mathrm{HF}} = \frac{N_{\text{Lepton-HF}}}{N_{\text{Denm-HF}}}$$

The W+Jet Bkg could be calculated as:

$$N^{\text{W+Jet}}_{\text{Bkg}} = \underbrace{f_{\mathrm{LF}} \times N_{(\text{Lepton+Denm-LF})}}_{\text{W+jet Bkg from Light Flavor}} + \underbrace{f_{\mathrm{HF}} \times N_{(\text{Lepton+Denm-HF})}}_{\text{W+jet Bkg from Heavy Flavor}}$$

W+jet Bkg
from Light Flavor

W+jet Bkg
from Heavy Flavor

Extracting f_{LF} and f_{HF}

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

Numerators *from* LF

Numerators *from* HF

Complication

- $N_{\text{Lepton-LF}}$ and $N_{\text{Lepton-HF}}$ are <u>not</u> observables.
- We can only measure $N_{\text{Lepton}} = N_{\text{Lepton-LF}} + N_{\text{Lepton-HF}}$ in data
- For a given N_{Lepton} we don't know if its from LF or HF

Extracting f_{LF} and f_{HF}

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Numerators *from* LF

Numerators *from* HF

Complication

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- We can only measure $N_{\text{Lepton}} = N_{\text{Lepton-LF}} + N_{\text{Lepton-HF}}$ in data
- For a given N_{Lepton} we don't know if its from LF or HF

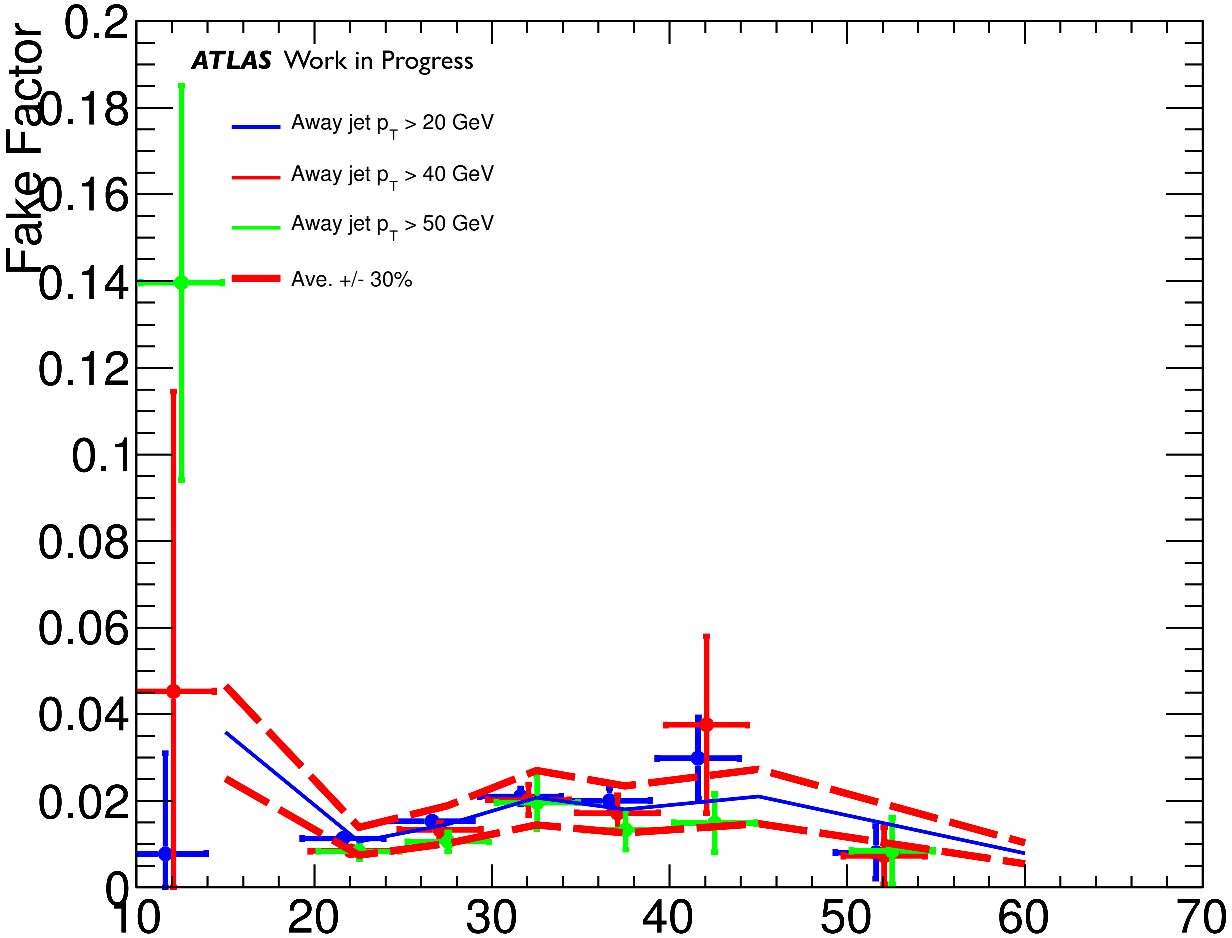
Solve for f_{LF} and f_{HF} in terms of observables.

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

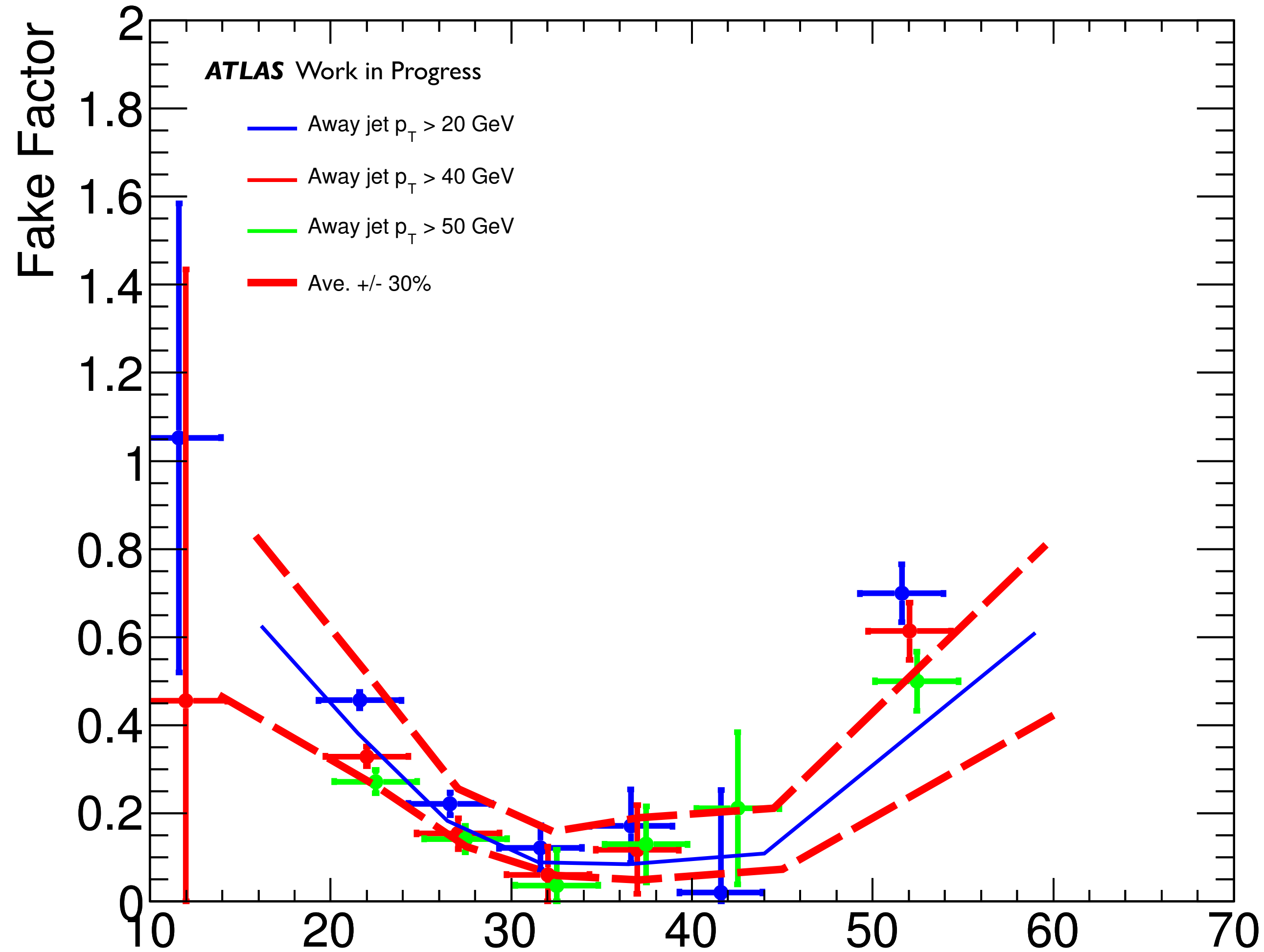
(Details in backup)

Measuring f_{LF} and f_{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.

Same Sign

Require Same-Sign Lepton+Denm.

$$N^{\mathrm{W+Jet}}_{\mathrm{Bkg}} = f \times N_{(\mathrm{Lepton+Denm})}$$

Provides a data-driven closure test of the method.

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Require Same-Sign Lepton+Denm.

$$N^{\mathrm{W+Jet}}_{\mathrm{Bkg}} = f \times N_{(\mathrm{Lepton+Denm})}$$

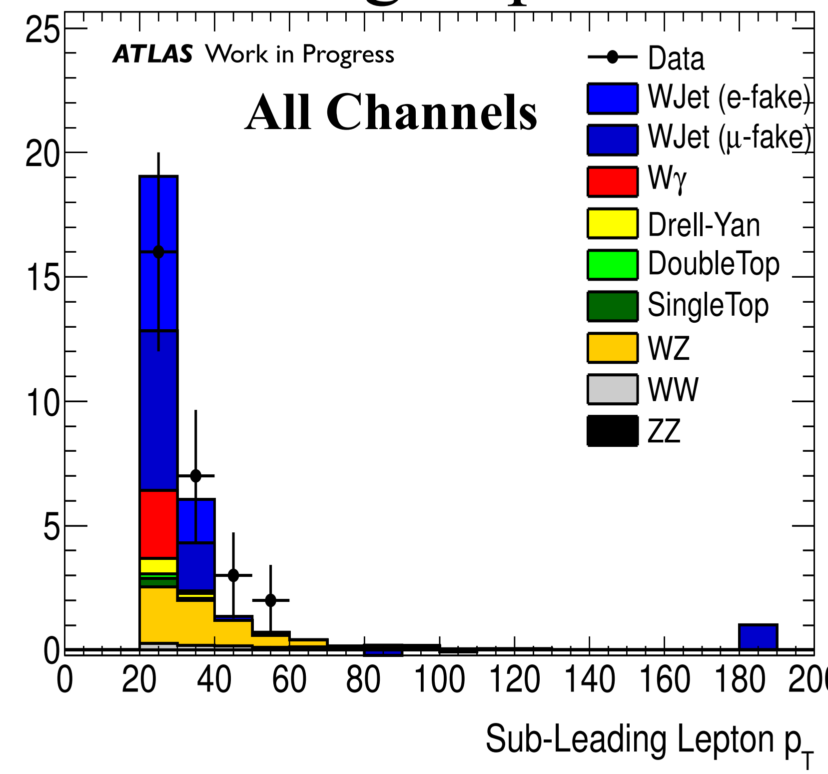
Provides a data-driven closure test of the method.

<u>Caveats</u>:
- 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)

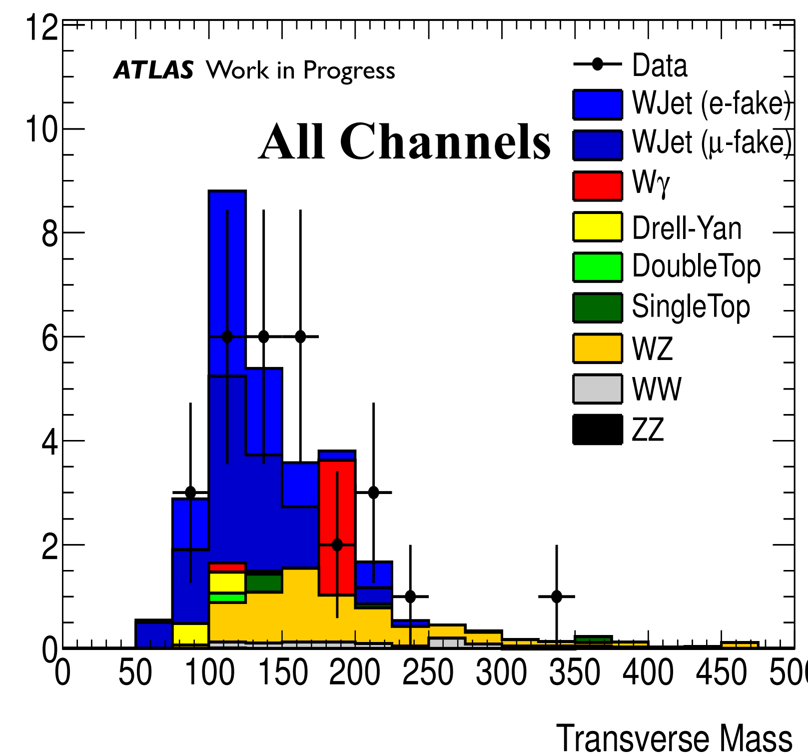
Same Sign Results

	ee	em	mm
e-fakes (LF)	2.8 ± 1.0	5.5 ± 0.8	-
e-fakes (HF)	0.0 ± 0.1	0.4 ± 0.1	-
m-fakes	-	5.3 ± 2.8	0.9 ± 1.1
non W+jet	3.6 ± 0.7	6.6 ± 0.4	2.4 ± 0.2
Total Prediction	**6.4 ± 1.2**	**17.0 ± 3.6**	**3.3 ± 1.2**
Observed	**3**	**19**	**6**

Subleading Lepton Pt



mT



W+Jet Results

	ee	em	mm
e-fakes (LF)	3.9 ± 1.4	6.0 ± 2.6	-
e-fakes (HF)	1.4 ± 0.9	2.1 ± 1.3	-
m-fakes	-	24.7 ± 9.5	12.4 ± 6.0
Total Prediction	**5.3 ± 1.7**	**32.9 ± 10.0**	**12.4 ± 6.0**

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

W+Jet Results

	ee	em	mm
e-fakes (LF)	3.9 ± 1.4	6.0 ± 2.6	-
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emu-channel: e Pt > 20 GeV
m Pt > 25 GeV

Heavy-Flavor Electron Fakes

	Opposite Sign	Same Sign
Heavy-Flavor Fraction	0.26 +/- 0.21	0.04 +/- 0.13

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

Results

WW Cross Section Results

Backgrounds	Events
Drell Yan	50.4 ± 3.7 ± 5.6
Top	58.6 ± 2.1 ± 22.3
W+Jets	50.5 ± 4.8 ± 14.7
Other Diboson (MC)	6.8 ± 0.4 ± 0.8
Total Background	**169.8 ± 6.4 ± 27.3**
Observed Events	**414**

Source	Uncertainty
Luminosity	3.7%
Background	9.6%
Acceptance	7.4%
Systematic	**13.1%**
Statistical	**8.3%**

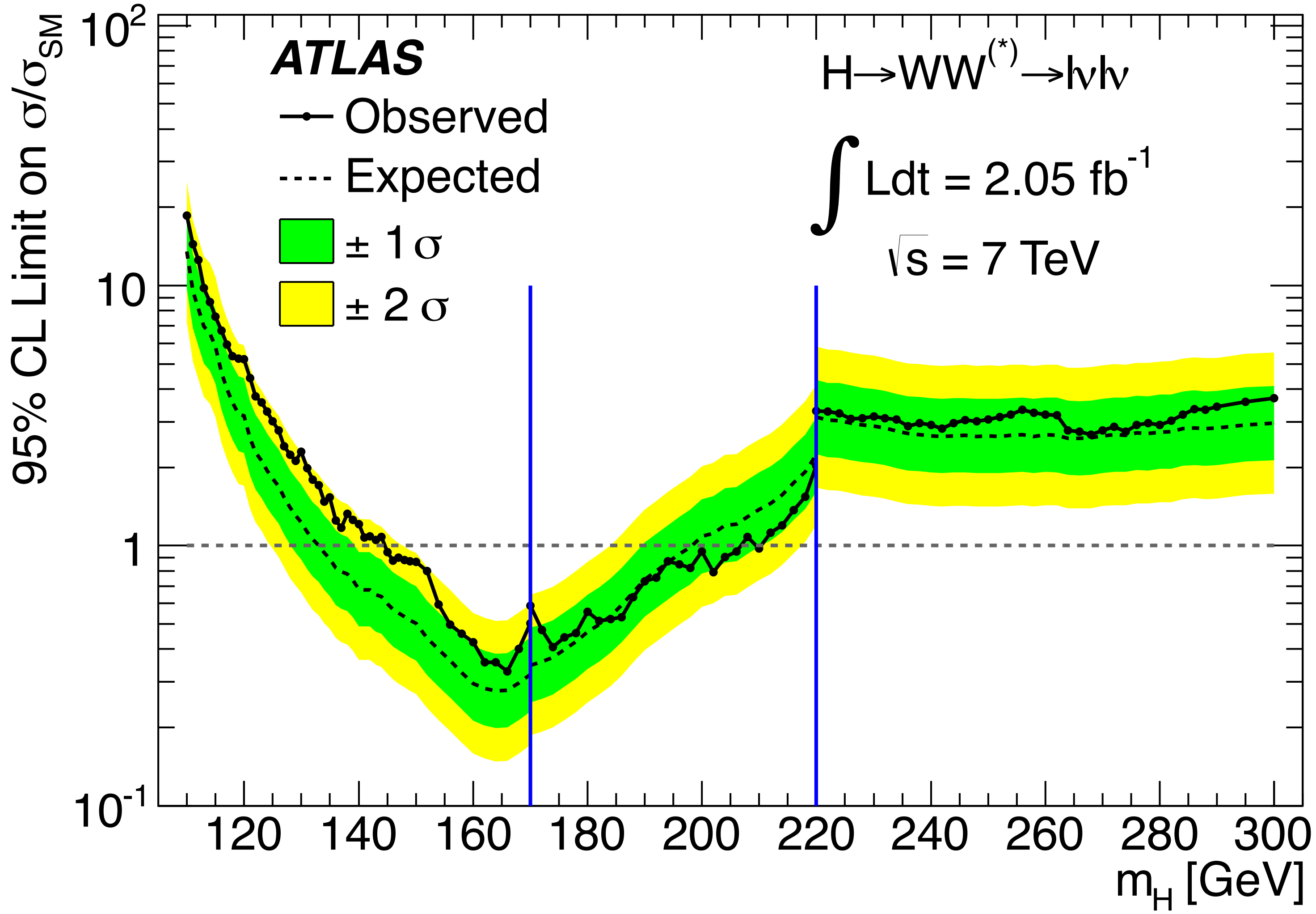
$$\sigma_{\mathrm{WW}} = 48.2 \pm 4.0(\mathrm{stat}) \pm 6.4(\mathrm{sys}) \pm 1.8(\mathrm{lumi})\mathrm{pb.}$$

NLO Prediction: 46 ± 3 pb

(MCFM with MSTW2008 (including gg))

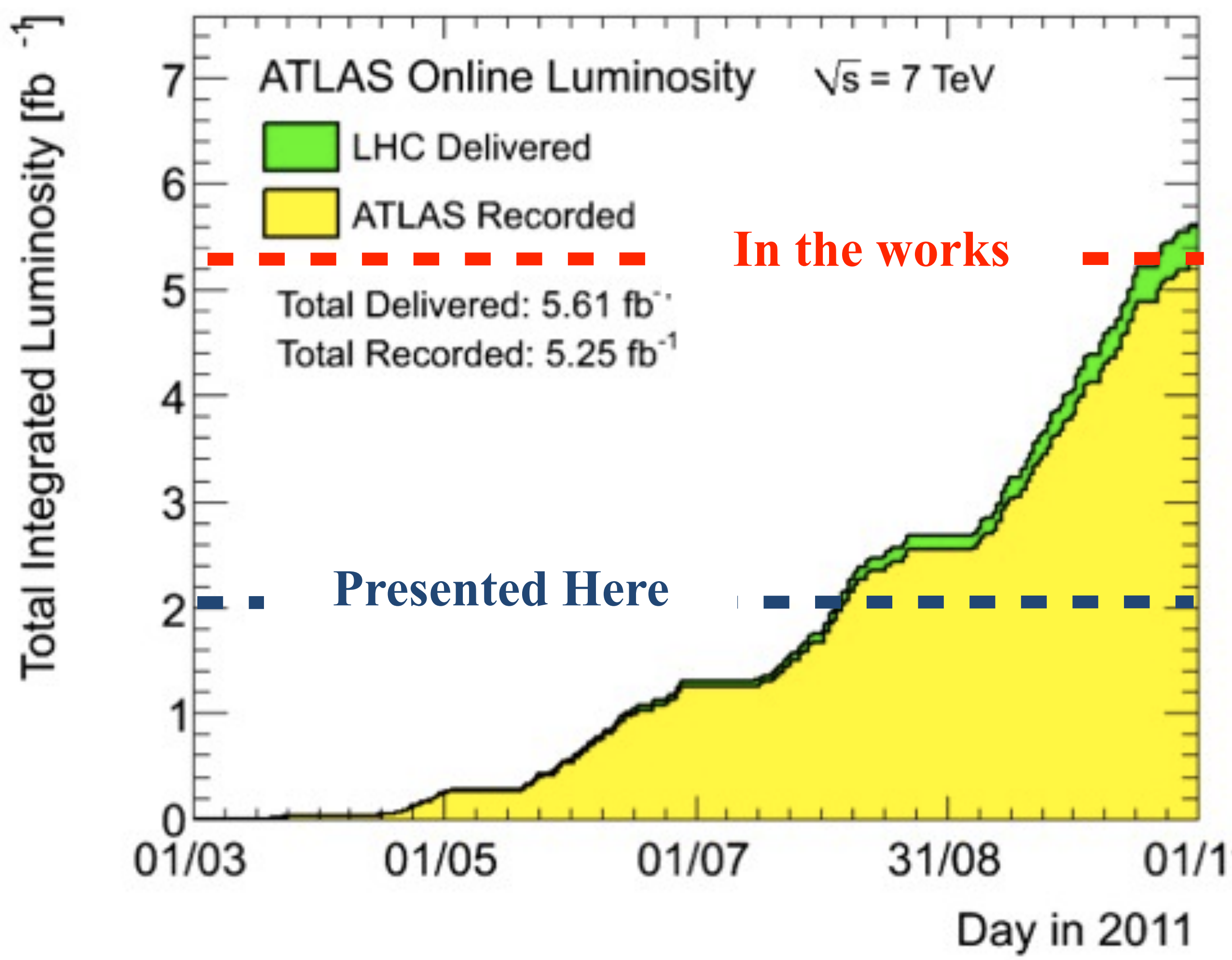
Hww Results

Backgrounds	Events
Drell Yan	2 ± 4
Top	3.9 ± 1.9
W+Jets	5 ± 2
Other Diboson (MC)	1.1 ± 0.5
WW	52 ± 7
Total Background	**63 ± 9**
Observed Events	**81**
Higgs m(H) 150	40 ± 9



The Future of the Higgs search.

Improvements



Analysis Updates Expected for winter conferences

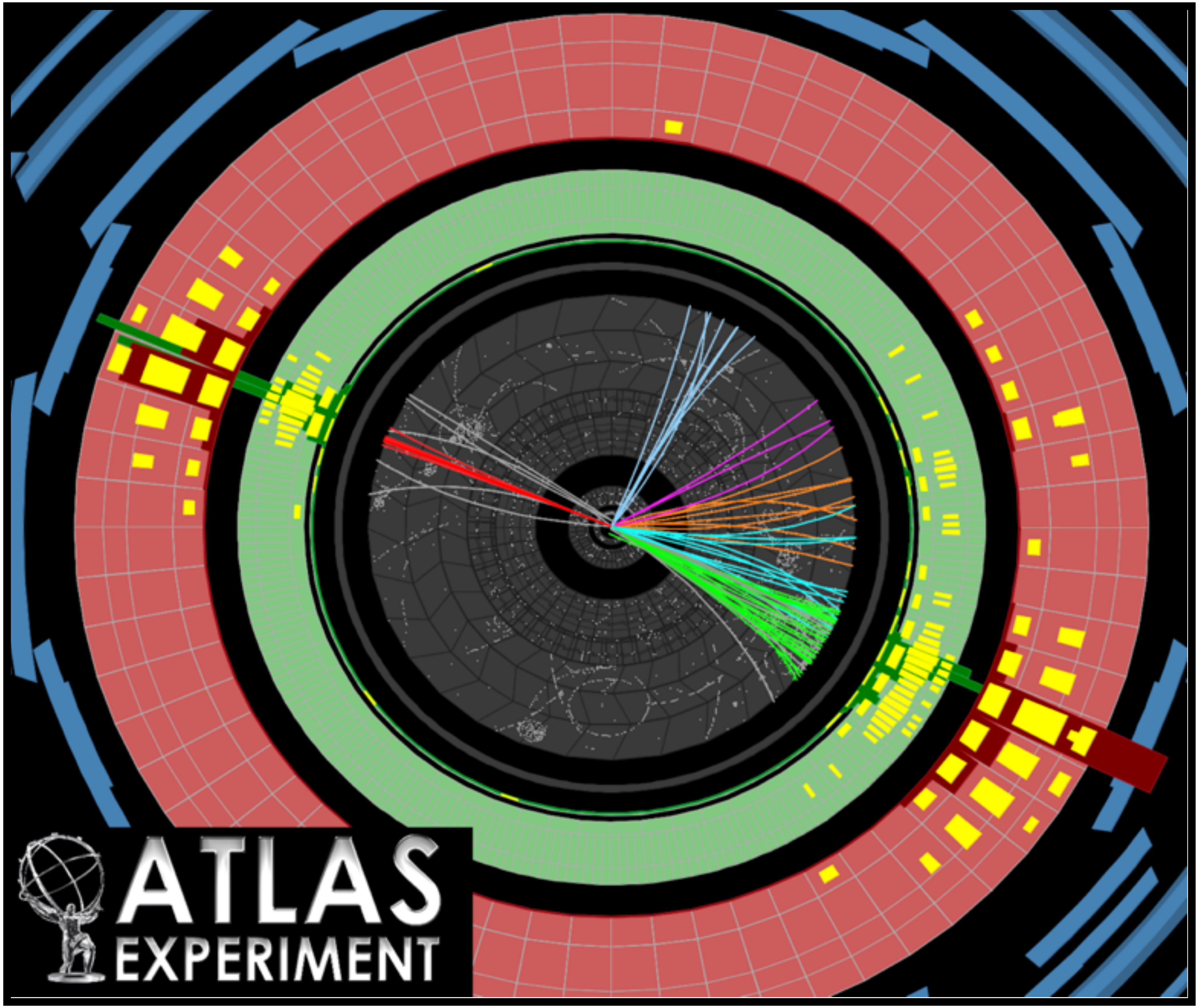
- Lowering Lepton Pt to increase low m(H) acceptance
- Use multivariate classifier separate WW and Hww

Conclusions

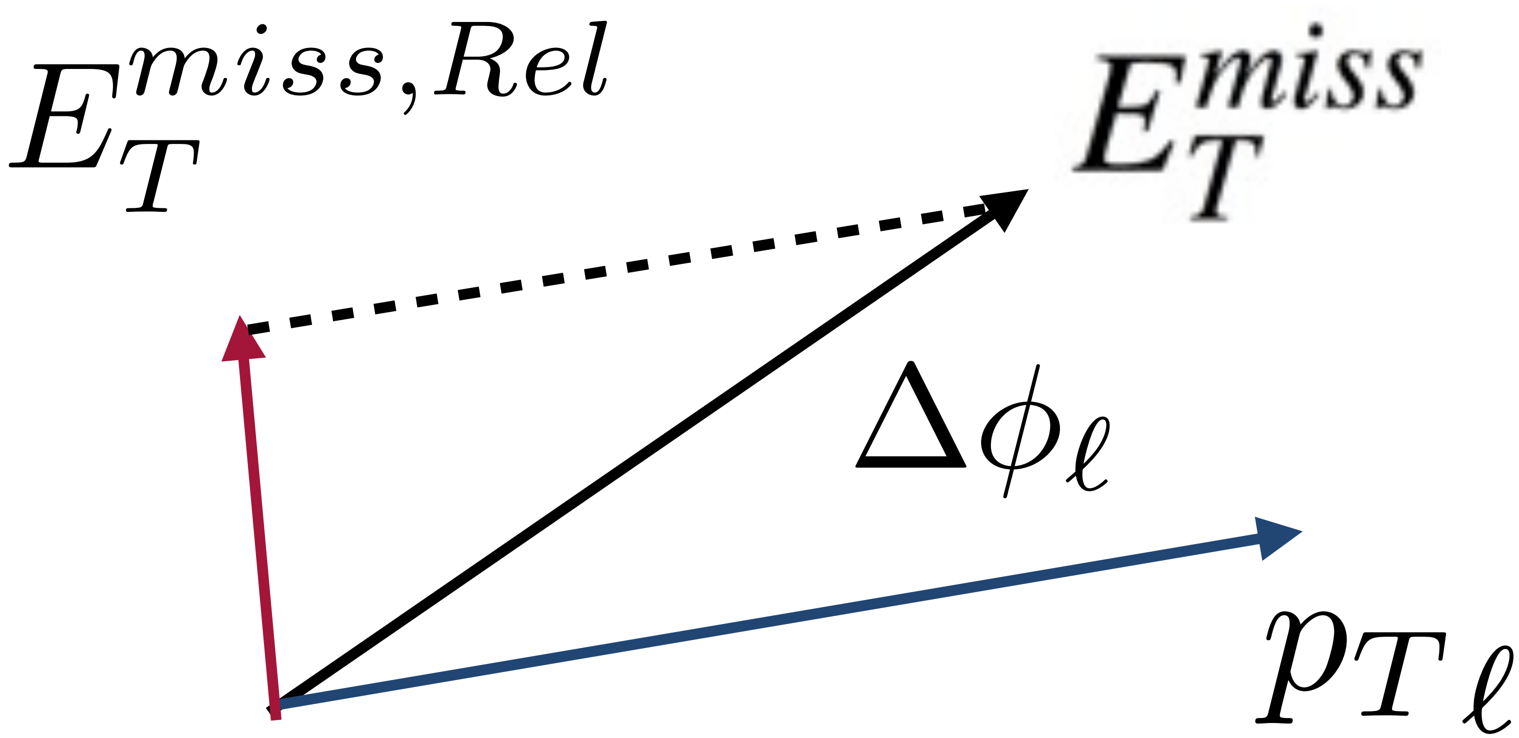
Its a great time to be doing particle physics !

Supporting Material

Not An Electron in ATLAS

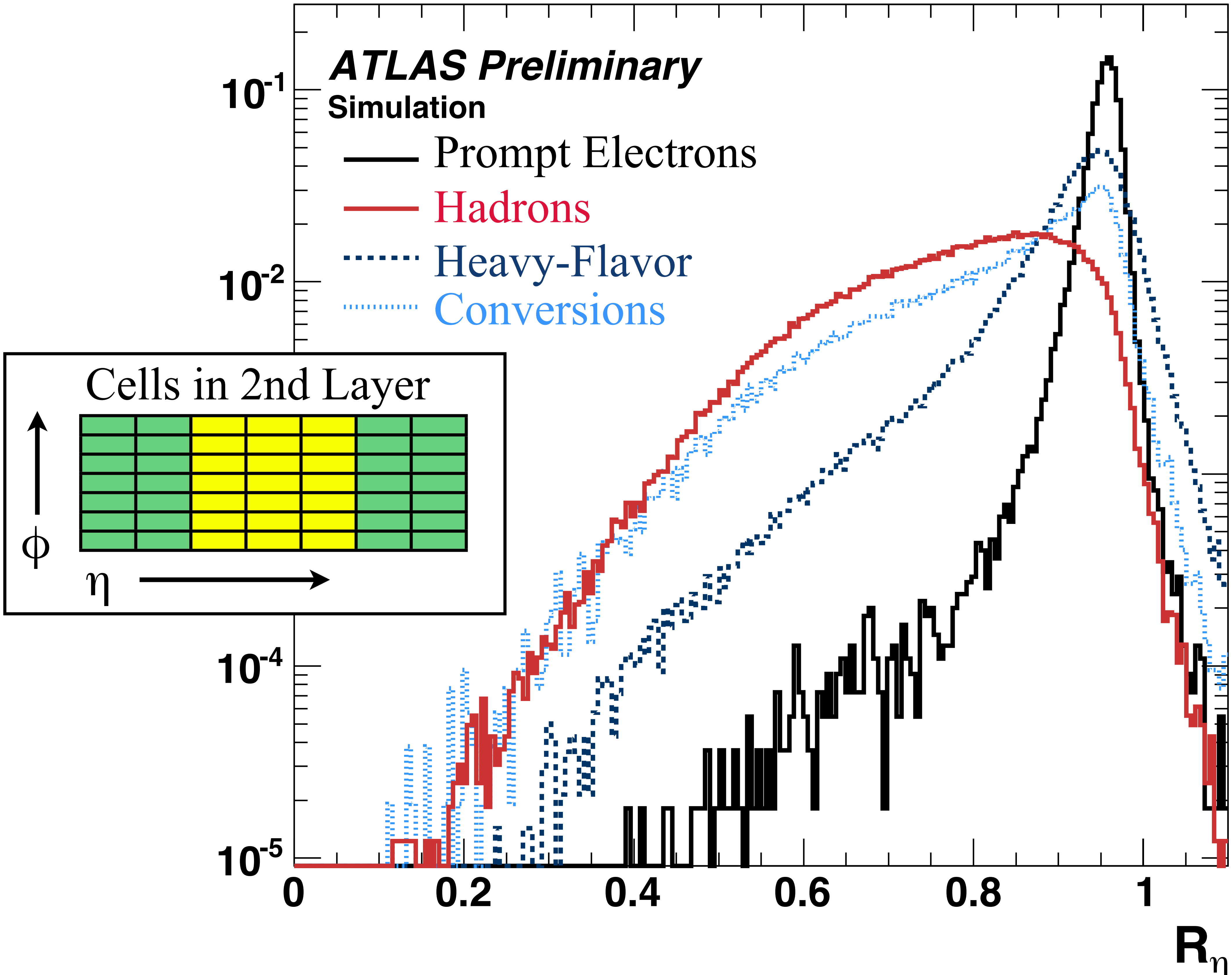


Relative Missing Energy



Electron Identification

Electron Identification

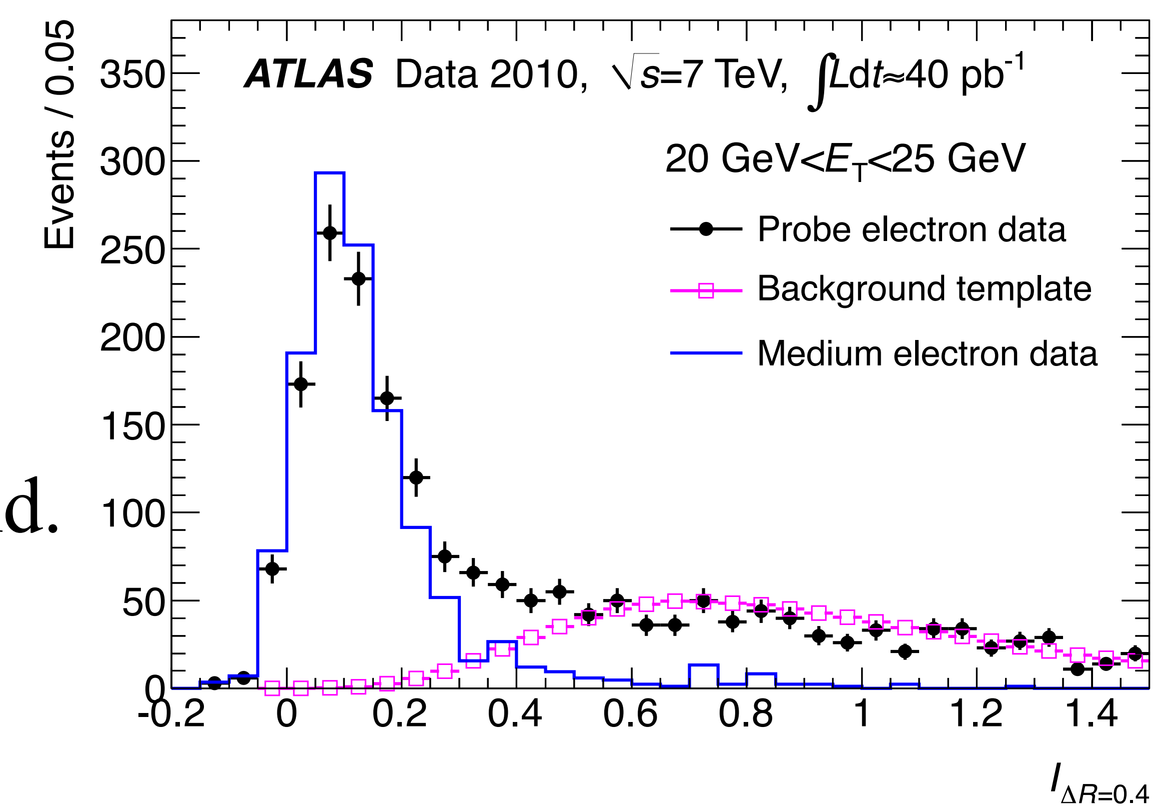


Lepton Efficiency

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

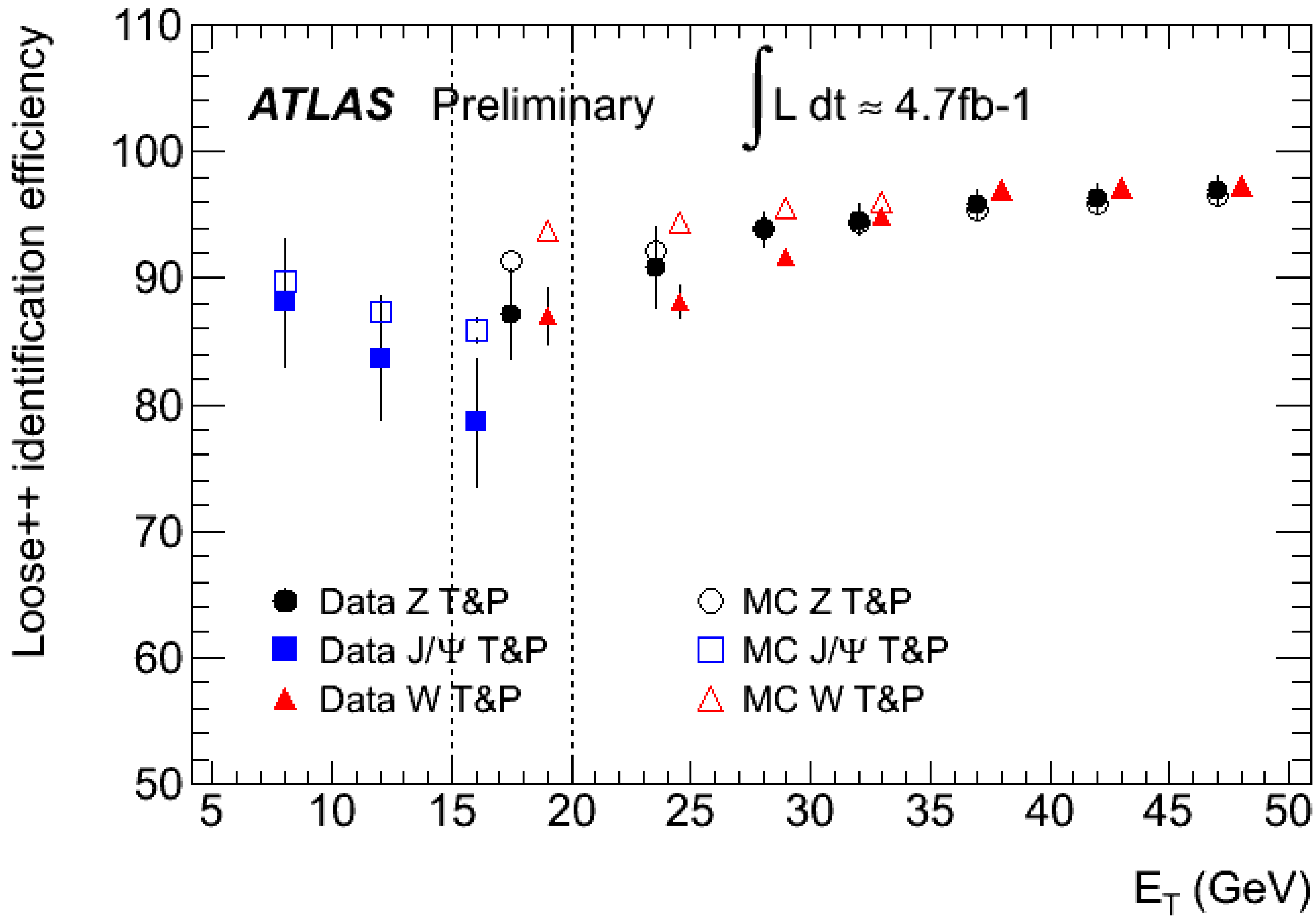
Require Tight Lepton + 2nd in Zmass

W-Bosons

Require Large MeT + High Et Lepton Cand.

Fit Isolation.

Efficiency

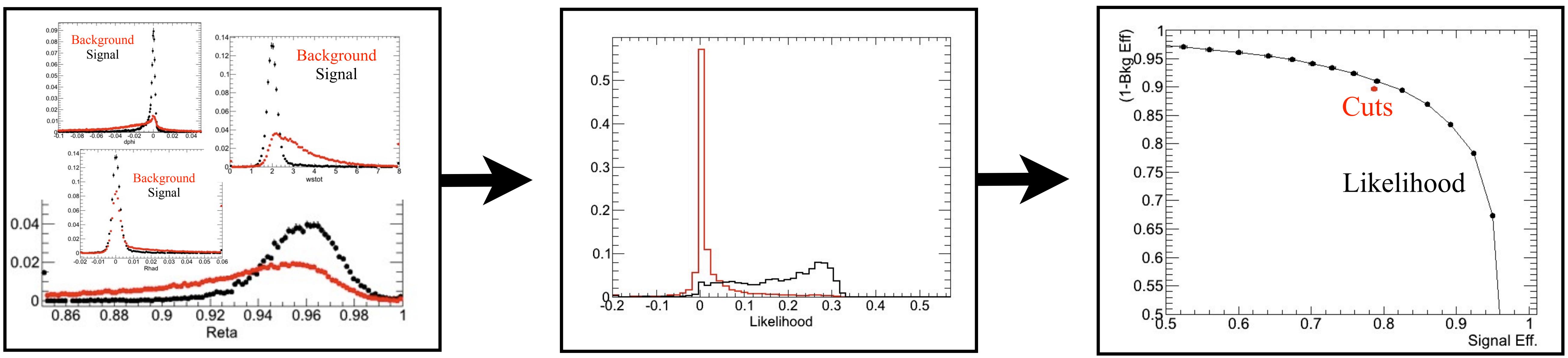


ATLAS Preliminary
∫L dt ≈ 4.7fb-1
Loose++ identification efficiency
E_T (GeV)
Data Z T&P
Data J/Ψ T&P
Data W T&P
MC Z T&P
MC J/Ψ T&P
MC W T&P
110
100
90
80
70
60
50
5
10
15
20
25
30
35
40
45
50

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.

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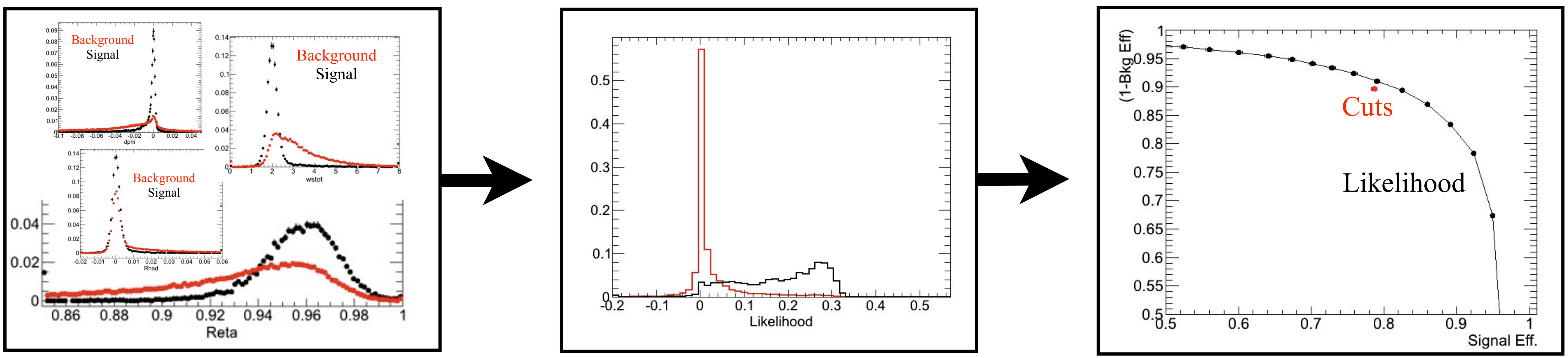

Many Advantages

- 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

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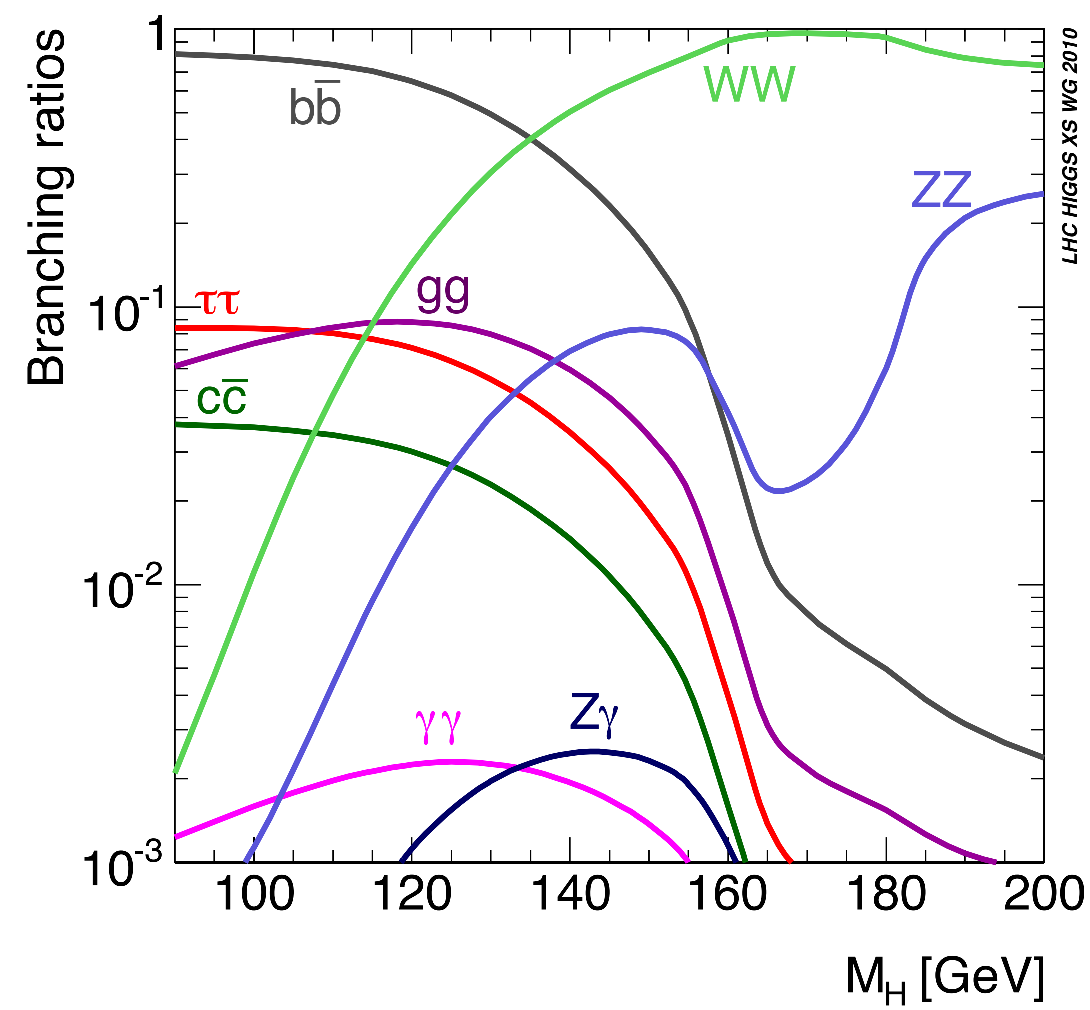
Example: Higgs Physics

- Leptons the signature of EW processes.
- Essential to understanding
Electro-Weak symmetry breaking



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.

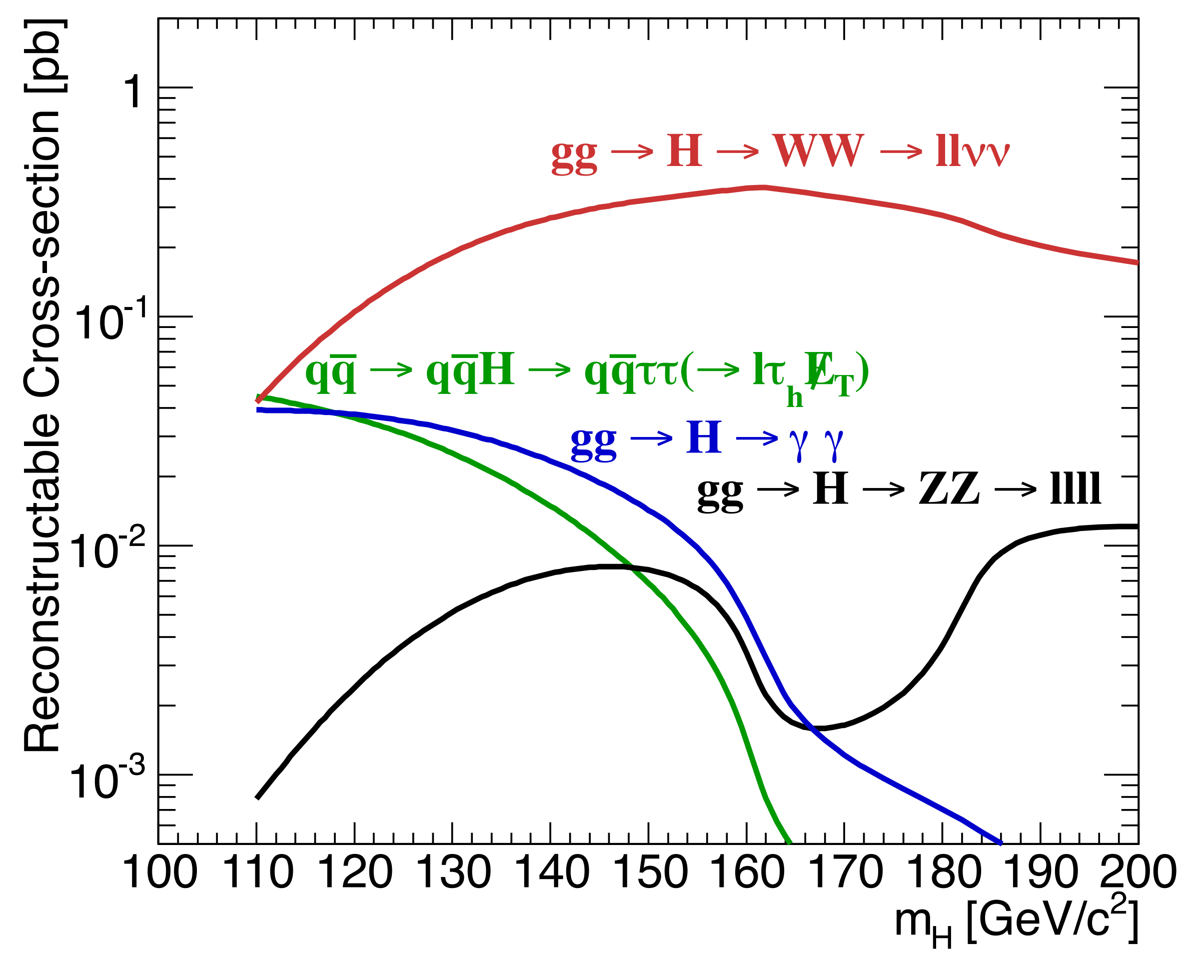
Can be used to trigger events.

Several known sources of leptons.

- Provide calibration samples

<u>Example</u>: 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

$$\begin{bmatrix} N_{TT} \\ N_{TL} \\ N_{LT} \\ N_{LL} \end{bmatrix} = \begin{bmatrix} r_1 r_2 & r_1 f_2 & f_1 r_2 & f_1 f_2 \\ r_1(1-r_2) & r_1(1-f_2) & f_1(1-r_2) & f_1(1-f_2) \\ (1-r_1)r_2 & (1-r_1)f_2 & (1-f_1)r_2 & (1-f_1)f_2 \\ (1-r_1)(1-r_2) & (1-r_1)(1-f_2) & (1-f_1)(1-r_2) & (1-f_1)(1-f_2) \end{bmatrix} \begin{bmatrix} N_{RR} \\ N_{RF} \\ N_{FR} \\ N_{FF} \end{bmatrix}$$

Invert matrix to determine:

W+jet background from N_{FR} and QCD background from N_{FF}

QCD in Fake Factor Method

Fake factor method double counts the QCD Contribution.

The W+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

$$N_{\text{QCD Bkg}} = f^2 \times N^{QCD}_{jet-rich+jet-rich}. \tag{8}$$

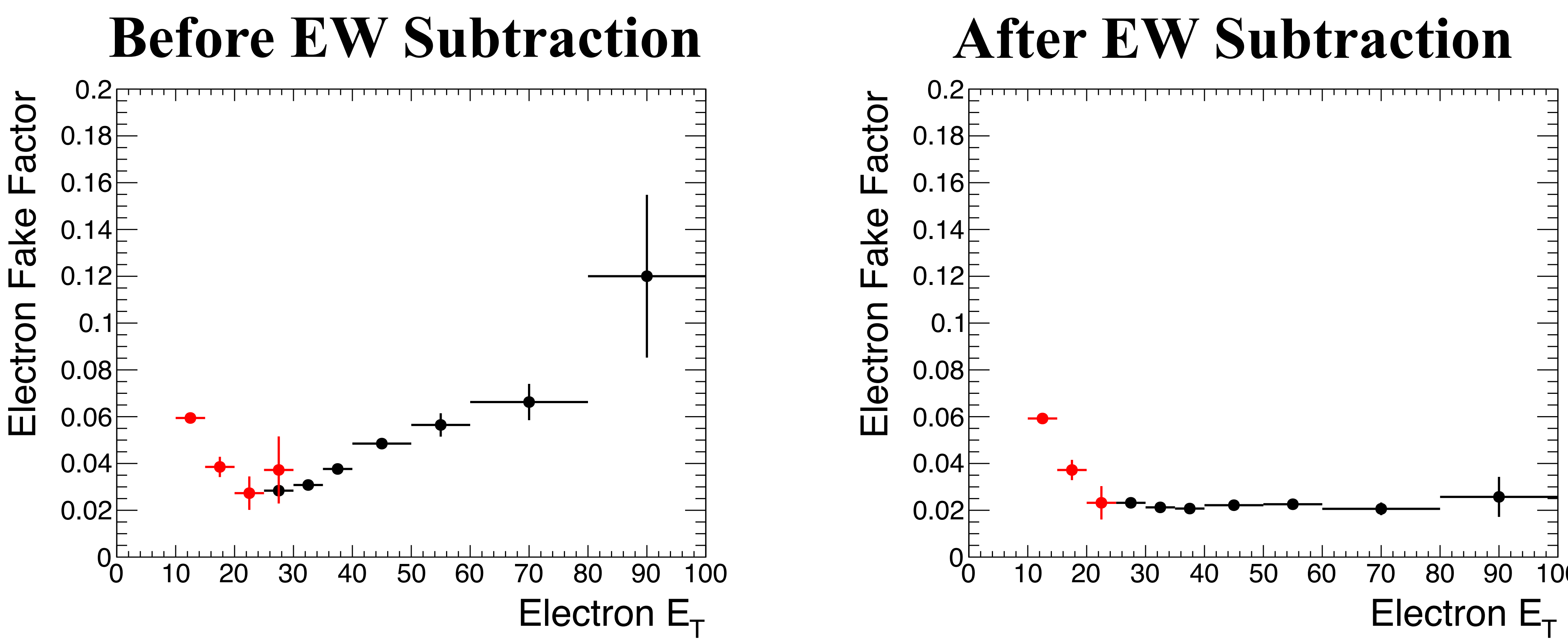
However, QCD will also contribute to the W+jet control sample with a rate given by,

$$N^{QCD}_{leptonID+jet-rich} = 2 \times f \times N^{QCD}_{jet-rich+jet-rich} \tag{9}$$

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+jet control sample by the fake factor gives,

$$f \times N^{QCD}_{leptonID+jet-rich} = 2 \times f^2 \times N^{QCD}_{jet-rich+jet-rich} = 2 \times N_{QCDBkg}. \tag{10}$$

Electron Fake Factors



(a) (b)

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.

Sample Dependence

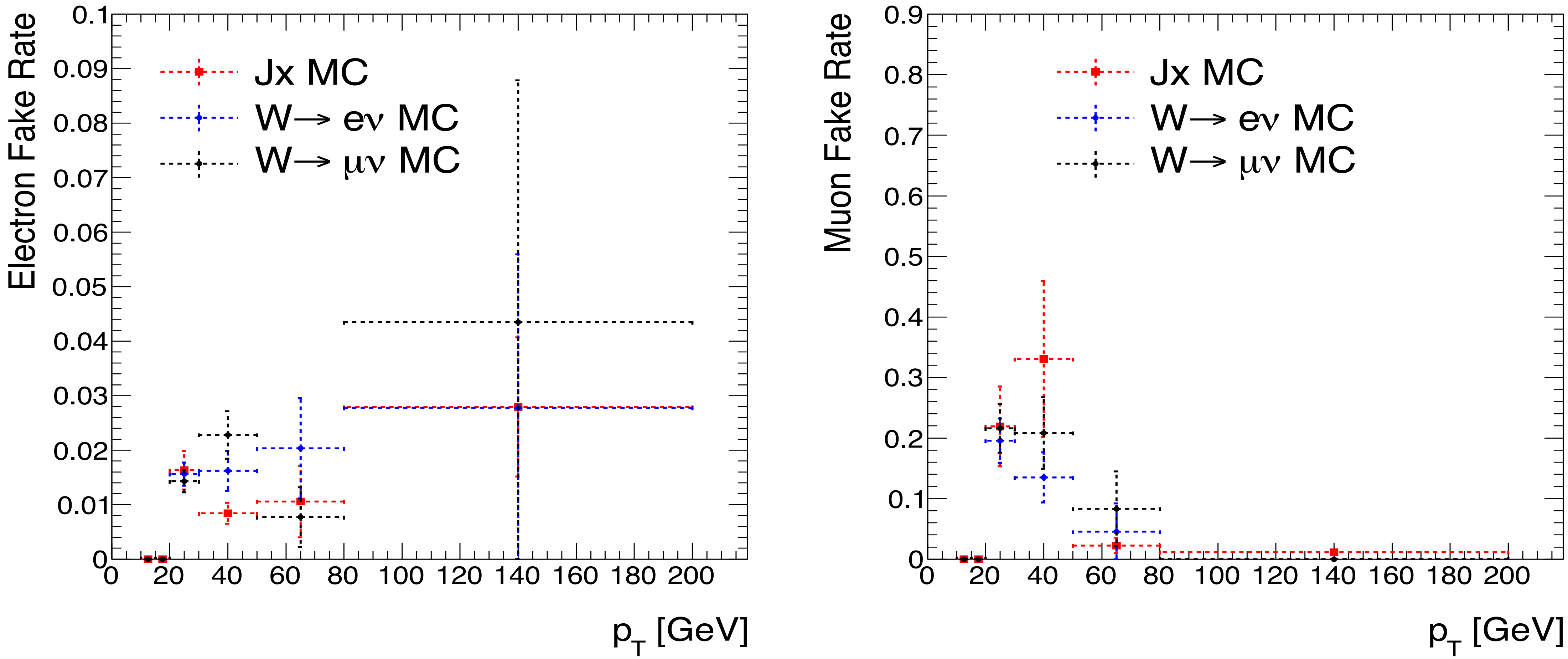


Figure 18: Left: the electron fake factor as a function of electron p_{T} from di-jet MC sample and W inclusive MC sample. Right: the muon fake factor as a function of muon p_{T}. Uncertainty shows the MC statistics of samples.

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

<u>Denominator more exclusive:</u>

- "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.

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	Lepton Definition	Denominator Definition
Electrons:	Reconstructed Electron Pass Tight + Isolation.	Reconstructed Electron Fail Medium + Loose Isolation
Muons:	Reconstructed Muon Tight D0/Z0 + Isolation	Reconstructed Muon Loose D0/Z0 + Interm. Isolation

Fake Factor Method in Equations

"Naive" Method

What we would like to do:

Number of Lepton+Jet events passing event selection

$$F_{\text{Lepton}} \times N_{(\text{Lepton + Jet})}$$

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

"Naive" Method

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Problems:

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

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- Jets are not “like” Leptons. F_{Lepton} far extrapolation.
- Multiple energy scales. (100 GeV jets can fake 20 GeV electrons.)

F_{Lepton} and, its extrapolation, would have large systematics.

Fake Factor Method

More realistically,

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

Fake Factor Method

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

Jet to Denominator Fake Rate.

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

Fake Factor Method

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

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

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

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

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,

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

or,

$$f \times \sum_{\text{Jet } E_T, \cdots} F^{ij}_{\text{Denm}}(q'/g, \cdots) \times N^{j}_{(\text{Lepton+Jet})}$$

Fake Factor Method

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

or,

$$f \times \sum_{\text{Jet } E_T,\cdots} F^{ij}_{\text{Denm}}(q'/g,\cdots) \times N^{j}_{(\text{Lepton+Jet})}$$

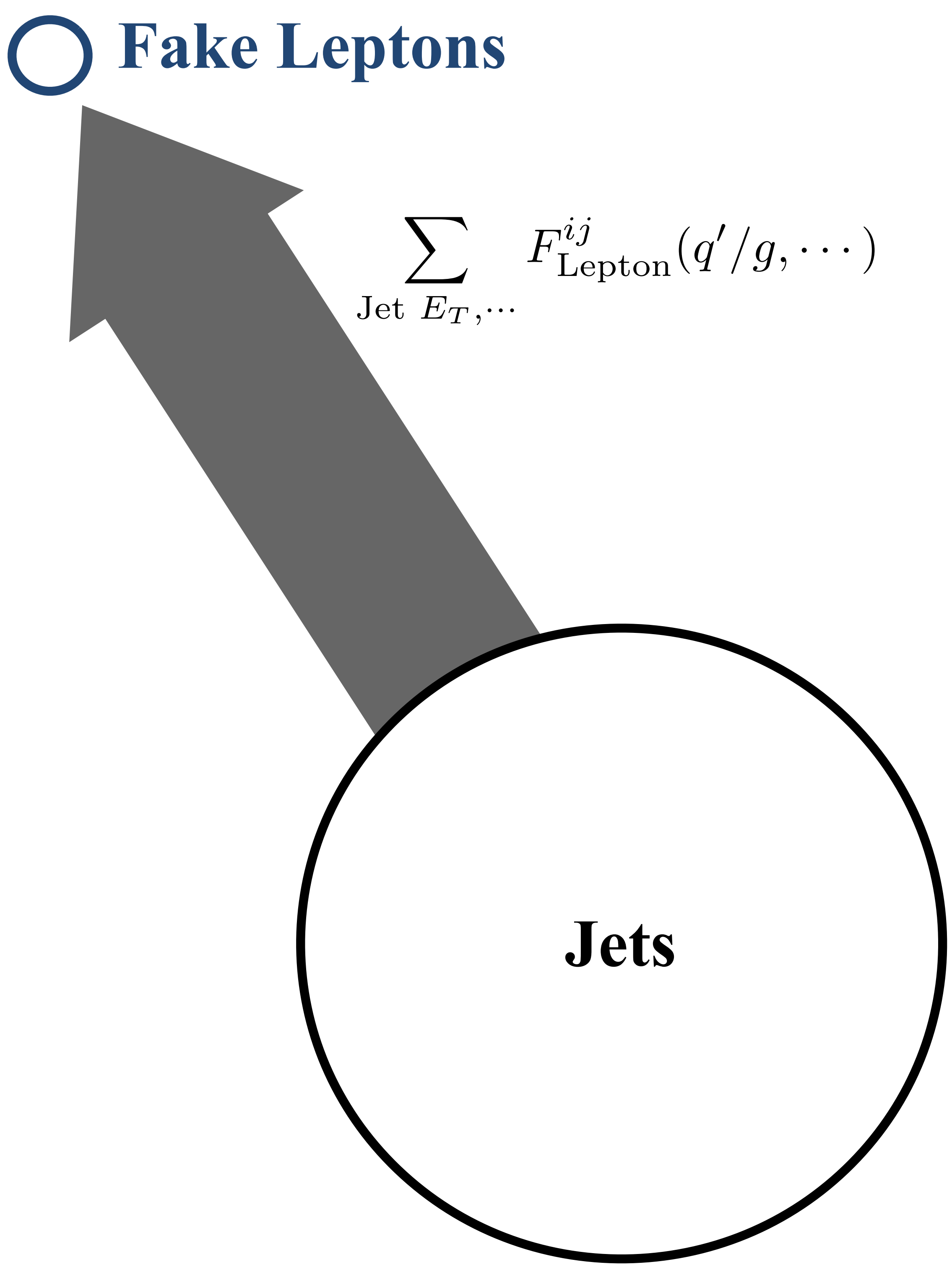
This term is an observable.

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

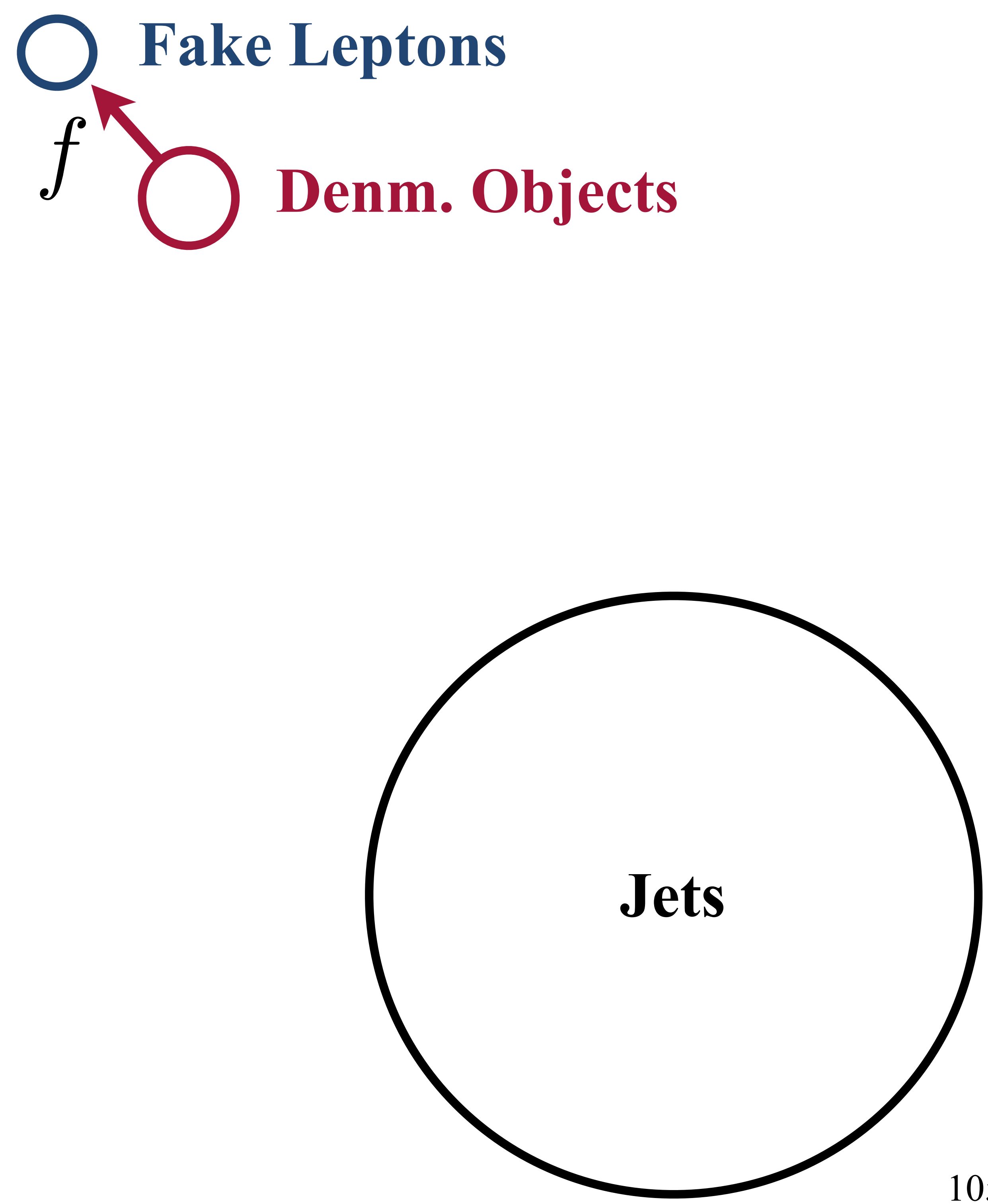
The number of observed
Lepton-Denominator Pairs

Conceptually

<u>“Naive Method”</u>



<u>Fake Factor Method</u>



Measuring Extrapolation Factor

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

$$\frac{N_{\text{Lepton}}}{N_{\text{Denm}}} = \frac{\sum\limits_{\text{Jet } E_T,\cdots} F^{ij}_{\text{Lepton}} \times N^{j}_{Jet}}{\sum\limits_{\text{Jet } E_T,\cdots} F^{ij}_{\text{Denm}} \times N^{j}_{Jet}} = \frac{\sum\limits_{\text{Jet } E_T,\cdots} f \times F^{ij}_{\text{Denm}} \times N^{j}_{Jet}}{\sum\limits_{\text{Jet } E_T,\cdots} F^{ij}_{\text{Denm}} \times N^{j}_{Jet}} = f$$

<u>Ratio of Leptons to Denominators, in jet sample, measures *f*</u>

Including Heavy Flavor

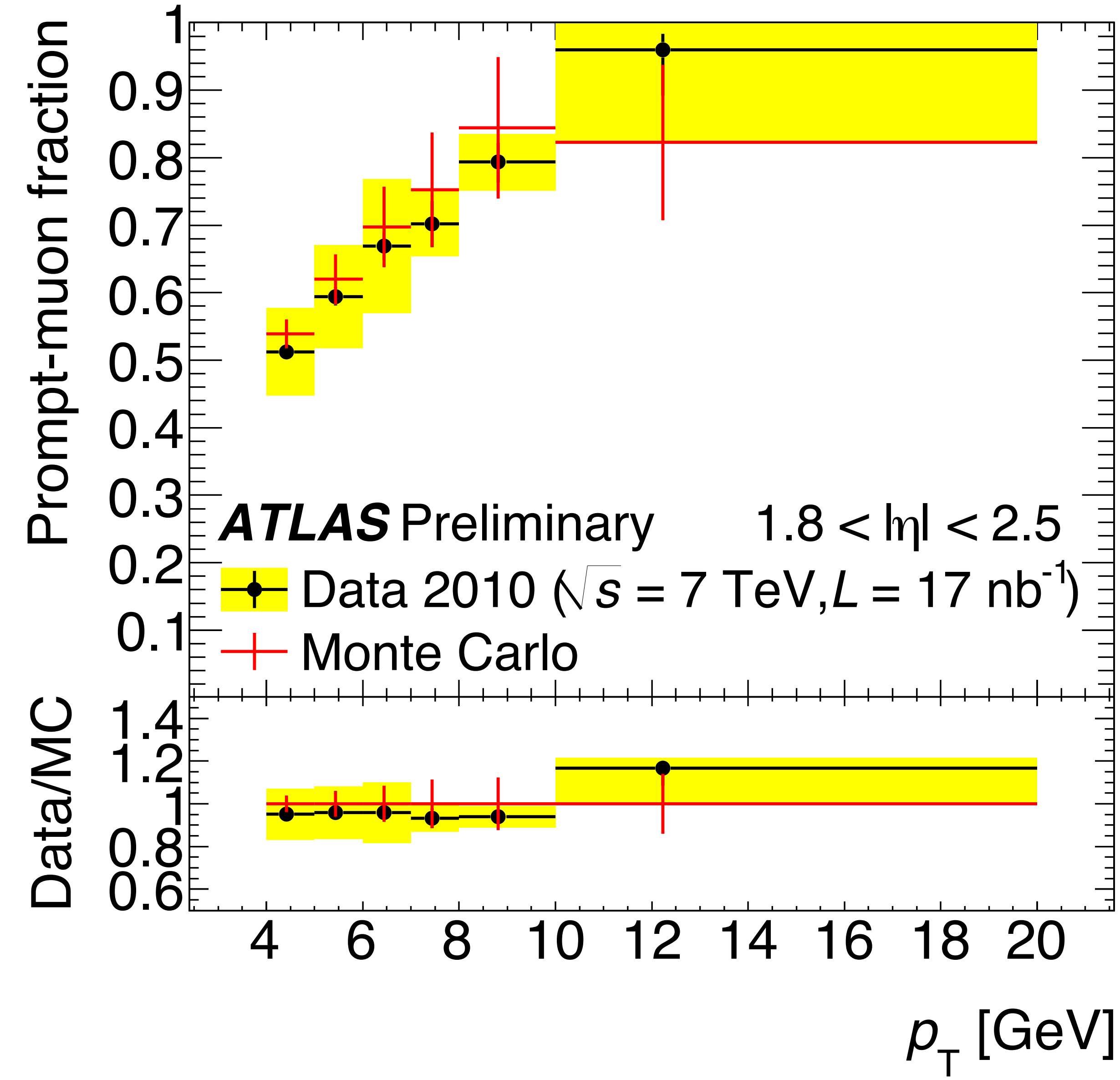
Sample Dependence: Muons

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



Calculating f(lf) and f(hf)

In a light flavor enriched sample, we can measure:

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

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

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

Calculating f(lf) and f(hf)

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

Repeat in heavy flavor enriched sample:

$$\Longrightarrow \quad f^{tag} = f_{hf} + \frac{d_{lf}^{tag}}{d_{hf}^{tag}} \times f_{hf}$$

Calculating f(lf) and f(hf)

In a light flavor enriched sample, we can measure:

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

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

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

System of equations
in terms of **observables**
that can be solved
to extract f(lf) and f(hf)

riched sample:

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

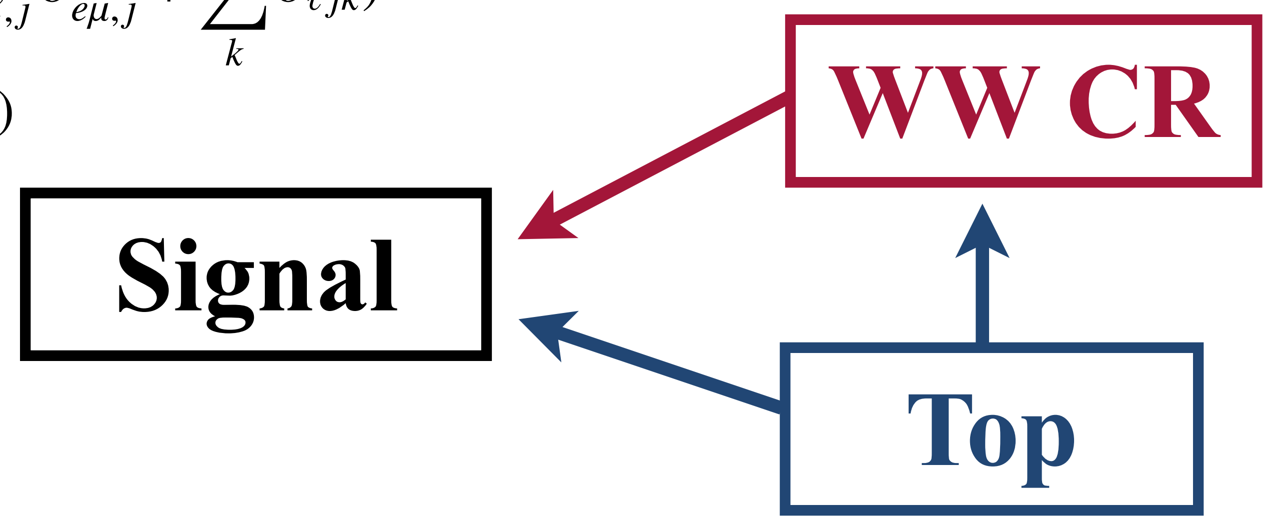
(see backup for details)

Search for Higgs in $H \rightarrow WW \rightarrow l\nu l\nu$

Limit Setting

Profile Likelihood / CLs / Asymptotic to set limits

$$\mathcal{L}(\mu,\theta) = \prod_{\ell=ee,\mu\mu,e\mu}\prod_{j=0,1} \mathrm{Poisson}(N^{SR}_{\ell j}|\mu s_{\ell j} + \alpha^{WW}_{\ell,j}\dot{b}^{WW}_{e\mu,j} + \delta^1_j\alpha^{top}_{\ell,j}\dot{b}^{top}_{e\mu,j} + \sum_k b_{\ell jk})$$
$$\mathrm{Poisson}(N^{WW}_{\ell j}|\mu s_{\ell j} + \beta^{WW}_{\ell,j}\dot{b}^{WW}_{e\mu,j} + \delta^1_j\beta^{top}_{\ell,j}\dot{b}^{top}_{e\mu,j} + \sum_k b_{\ell jk})$$
$$\mathrm{Poisson}(N^{top}_{\ell j}|\mu s_{\ell j} + \delta^1_j\dot{b}^{top}_{e\mu,j} + \sum_k b_{\ell jk})$$
$$\prod_\theta \mathrm{Gaussian}(\theta|0,1)$$

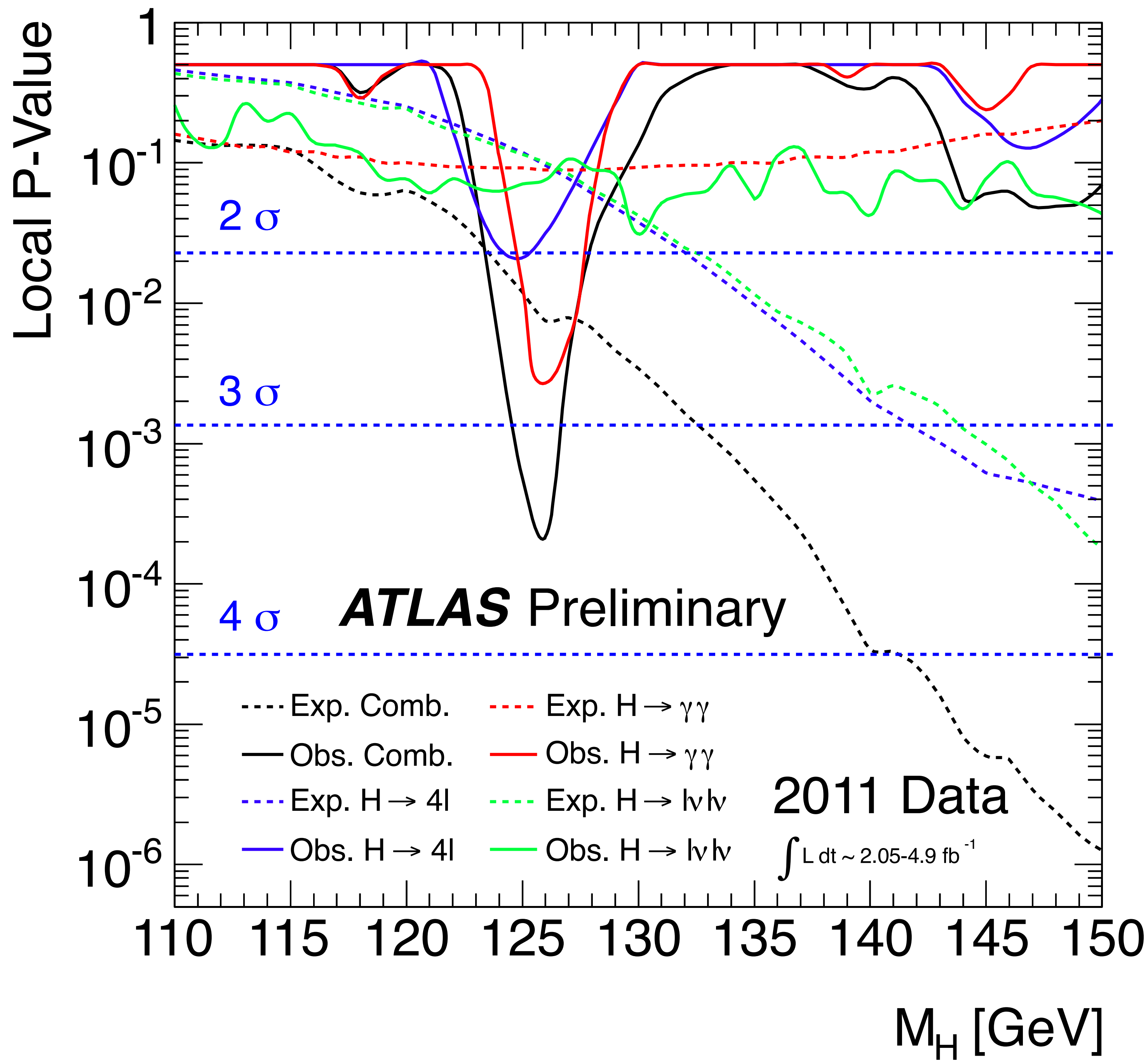


Acceptance Systematics

Process	jet bin	Scale	PDF	MC	Total
WW	0 jet	4%	3%	7%	9%
	1 jet	5%	3%	10%	12%
$t\bar{t}$	0 jet	9%	3%	8%	12%
	1 jet	4%	3%	8%	9%
$gg\to H$	0 jet	3%	3%	3%	5%
	1 jet	3%	3%	11%	12%

Systematics on A - B

	α^{0j}_{WW}	α^{1j}_{WW}	α^{1j}_{top}	β^{1j}_{top}
Q^2 Scale	2.5%	4%	9%	–
MC Modeling	3.5%	3.5%	4%	–
PDF	3.8%	3.5%	3%	–
Jet E Scale + Resolution	$^{+0.5}_{-0.6}\%$	$^{+2.3}_{-1}\%$	$^{-35}_{+32}\%$	$^{-36}_{+32}\%$
b-tagging Efficiency	–	–	$^{-23}_{+23}\%$	$^{-19}_{+20}\%$
MC Statistics	4.3%	12.9%	6%	–



Local P-Value
1
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
2 σ
3 σ
4 σ
ATLAS Preliminary
Exp. Comb.
Obs. Comb.
Exp. H → 4l
Obs. H → 4l
Exp. H → γγ
Obs. H → γγ
Exp. H → lνlν
Obs. H → lνlν
2011 Data
∫L dt ~ 2.05-4.9 fb^{-1}
110 115 120 125 130 135 140 145 150
M_H [GeV]

Top Background Estimation

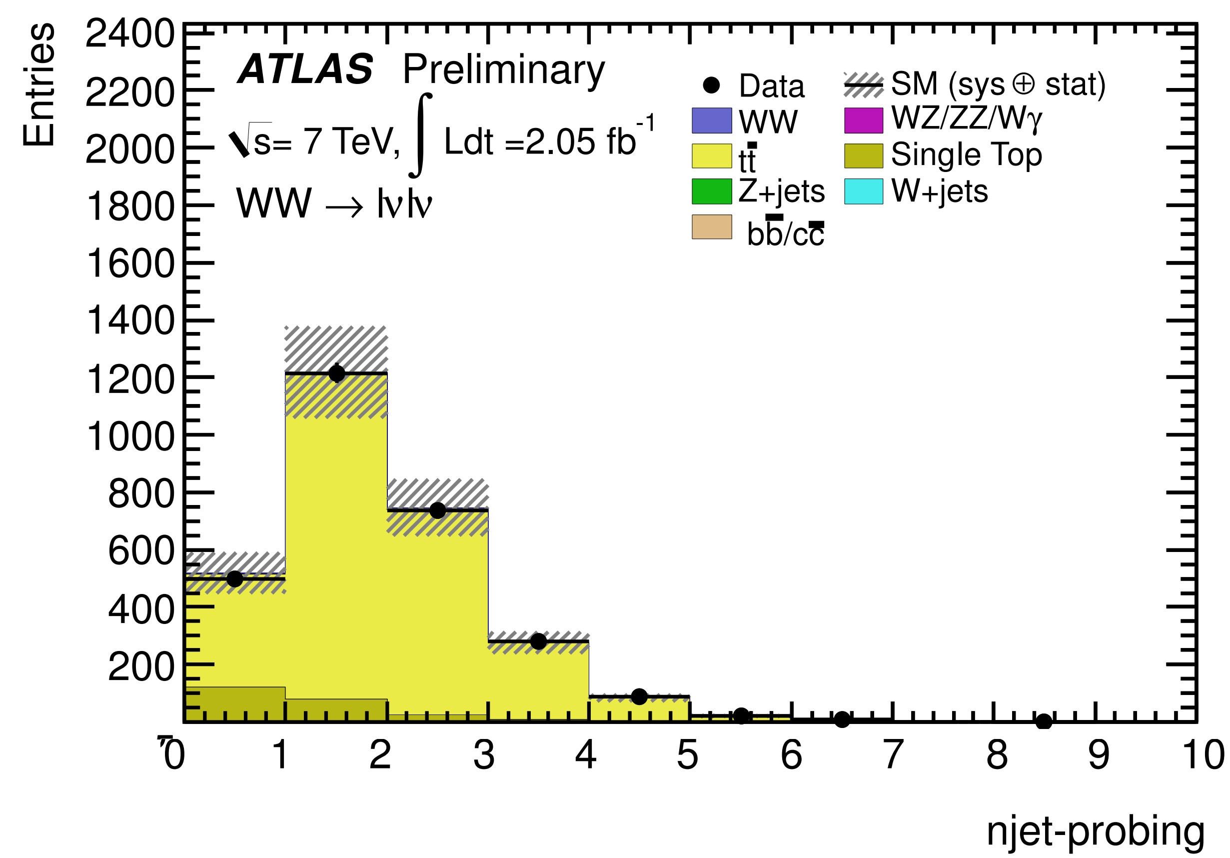
Top in the 0-jet analysis

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

SF - scale factor from tag sample

<u>After jet veto Top Estimate</u>

$65 \pm 8(stat) \pm 20(syst)$



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

Reverse b-tag after Z→ ττ veto in 1-jet analysis

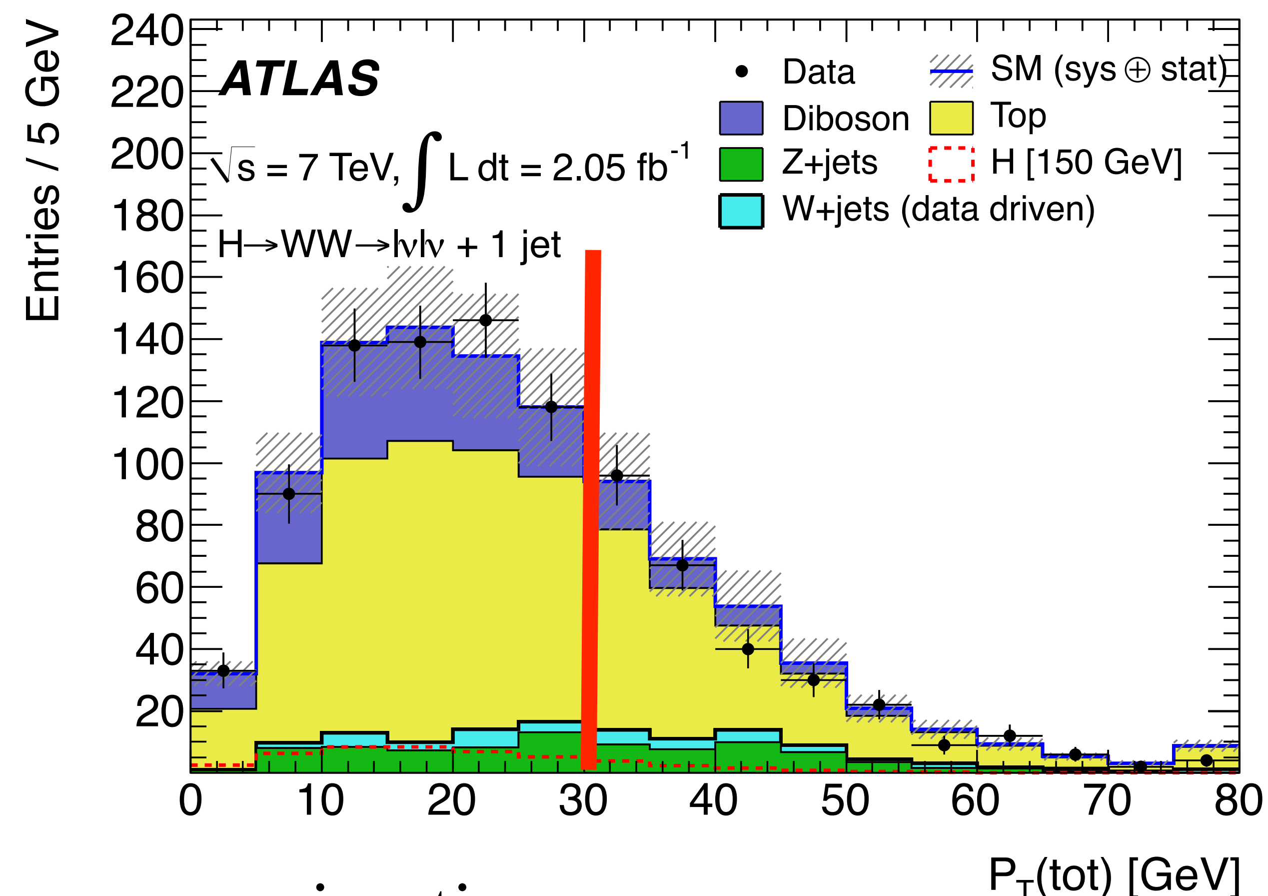
Top Control

	Top	non-Top	Prediction	Observed
ee	34 ± 8	1 ± 1	35 ± 9	32
em	163 ± 45	7 ± 2	170 ± 50	153
mm	63 ± 20	1 ± 1	64 ± 20	64

1-jet Analysis

Dominated by top After 1-jet Selection.

After 1-jet Requirement



Reduce Top Contribution:

- b-jet veto.
  CombNN at 70% eff. point
- low P_T(tot)

$$\mathbf{p}_T^{tot} = \mathbf{p}_T^{l1} + \mathbf{p}_T^{l2} + \mathbf{p}_T^{J} + \mathbf{p}_T^{miss}$$

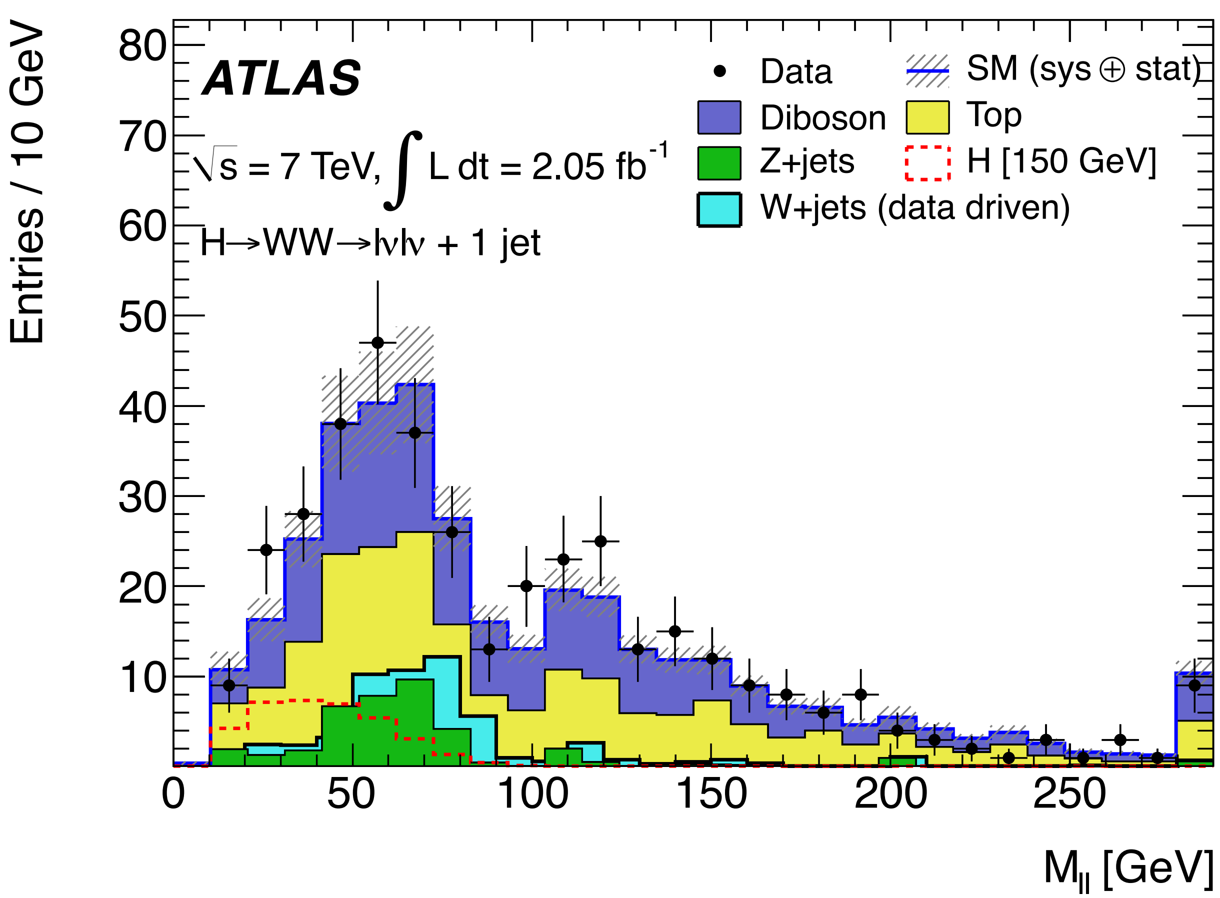
Reduce Z+jet by Z→ ττ veto

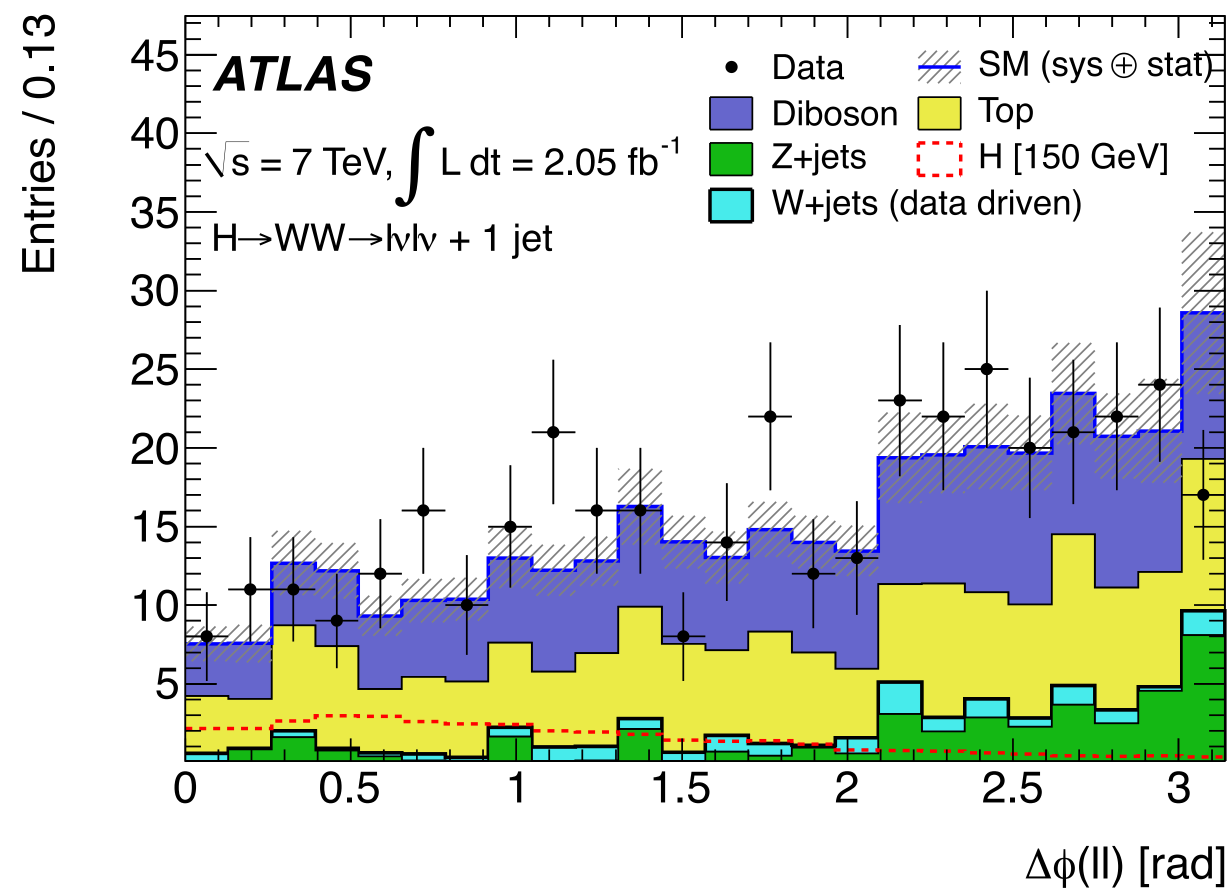
$|m_{\tau\tau} - m_Z| < 25$ GeV using the collinear approximation

Assume MeT due to neutrinos in direction of visible decay products.

1-jet Analysis

After Z⟶ ττ 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

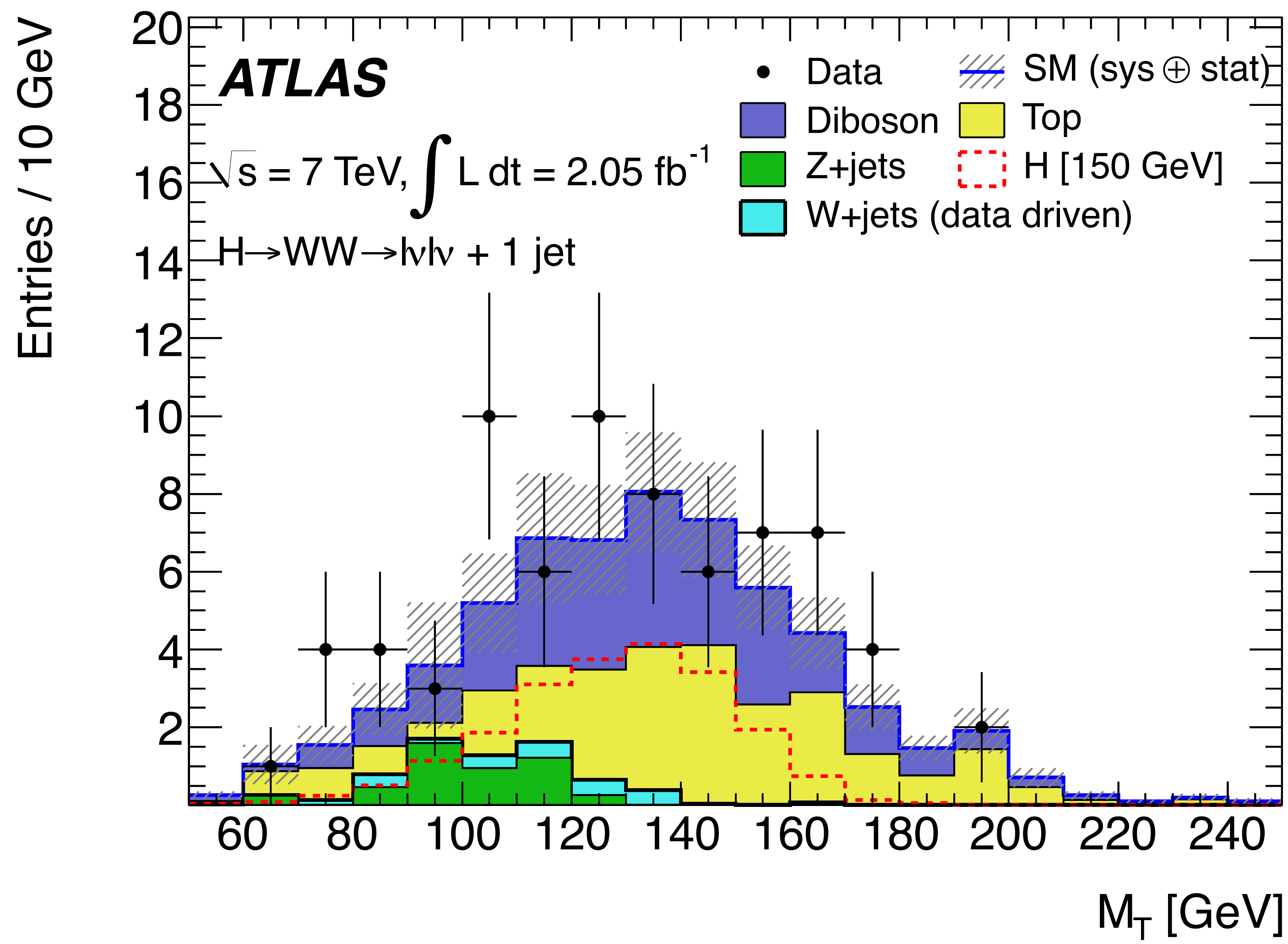
1-jet Analysis

$m_H < 170$
- mll < 50 GeV
- Δφll < 1.3
- 0.75 x mH < mT < mH

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

$m_H > 220$
- $50 < m_{ll} < 180$ GeV
- $0.6 \times m_H < m_T < m_H$

After $\Delta\phi_{ll}$ w/ low mass selection



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
- mll > 80 GeV (Low m(H))
- mll < 50 GeV || 180 GeV < mll (High m(H))

0-jet

	WW	non-WW	Prediction	Observed
ee	27 ± 4	10 ± 5	37 ± 8	52
em	150 ± 20	34 ± 12	200 ± 40	184
mm	45 ± 6	18 ± 6	63 ± 10	60