ATLAS H→WW

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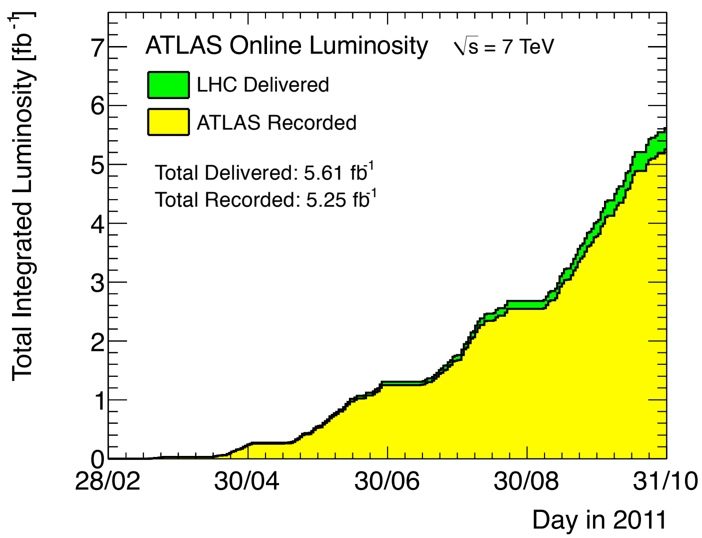
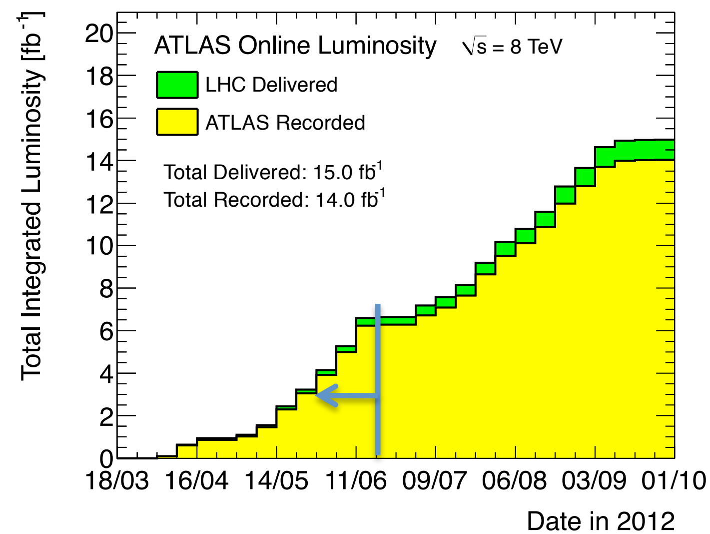
Outline

- ATLAS Higgs to WW
  - Summer 2012 analysis
  - Discovery results
- Property measurements
  - Couplings
- Compare to other Higgs decay channels
- Future plans

LHC Luminosity

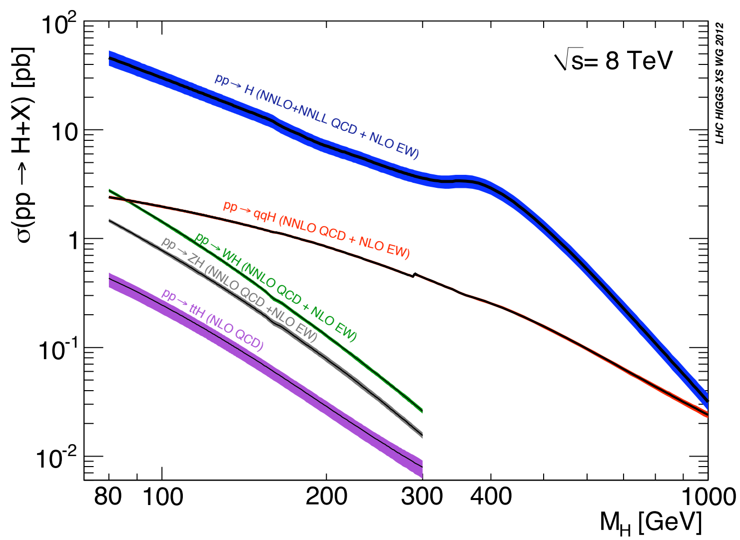


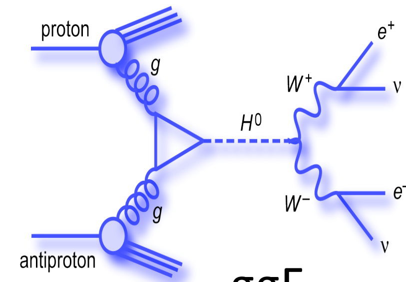


- ATLAS continues to collect data with high efficiency and good data quality
- ICHEP results combine 4.7 fb^{-1} of 2011 7TeV and 5.8 fb^{-1} of 2012 8 TeV data
- Now have double the dataset to analyze!

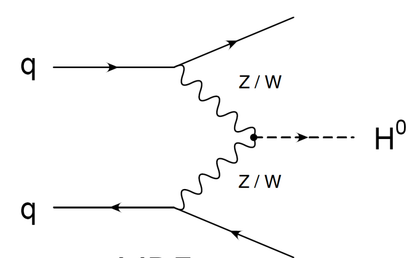
Higgs Production on the LHC

- Main production is gluon-gluon fusion (ggF)
  - Sensitive to new physics in loop
- Vector boson fusion (VBF) and associated production
  - Sensitive to direct vector boson couplings
- Sensitivity to spin and couplings to W/Z and t
  - Can measure direct WW to Higgs coupling in the qq'→*qq'H* (VBF) channel

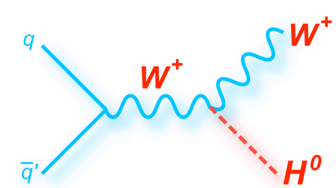




ggF



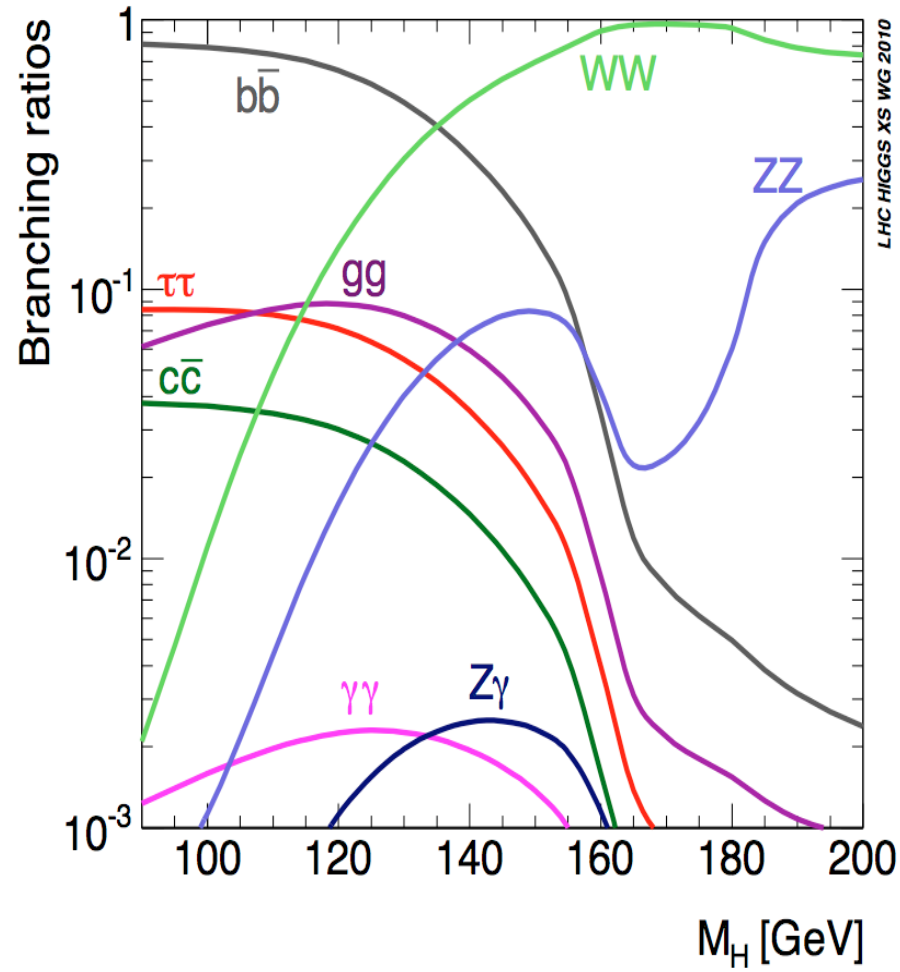
VBF



Associated Production

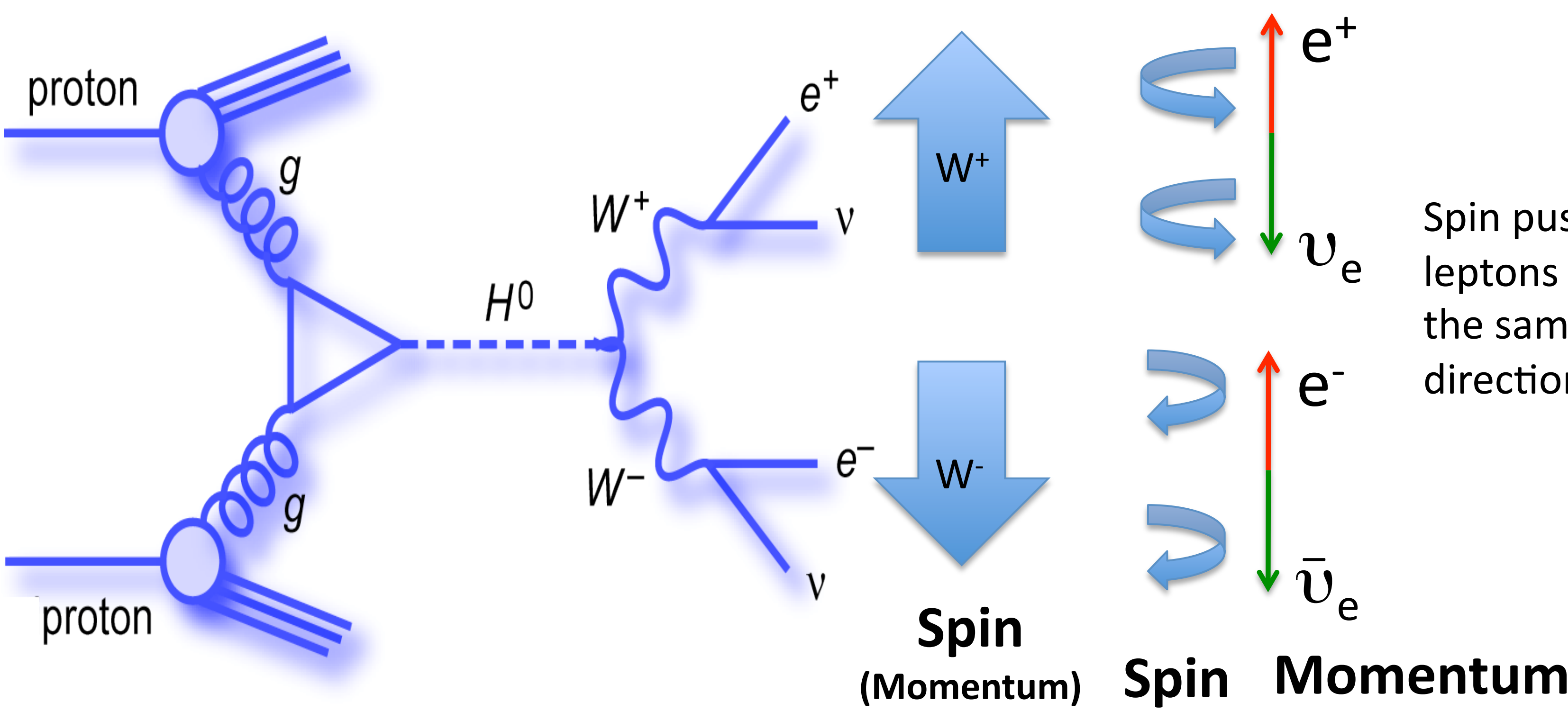
Why Look for H→WW?

- *Violates Unitarity:* Without the Higgs, the WW cross-section increases with s
- Large branching ratio
  - Best measurement of cross-section and signal strength (μ)
- Clean simple signature
  - 2 leptons
  - Missing transverse energy (MET))
- First channel on the TeVatron to make SM Higgs exclusion



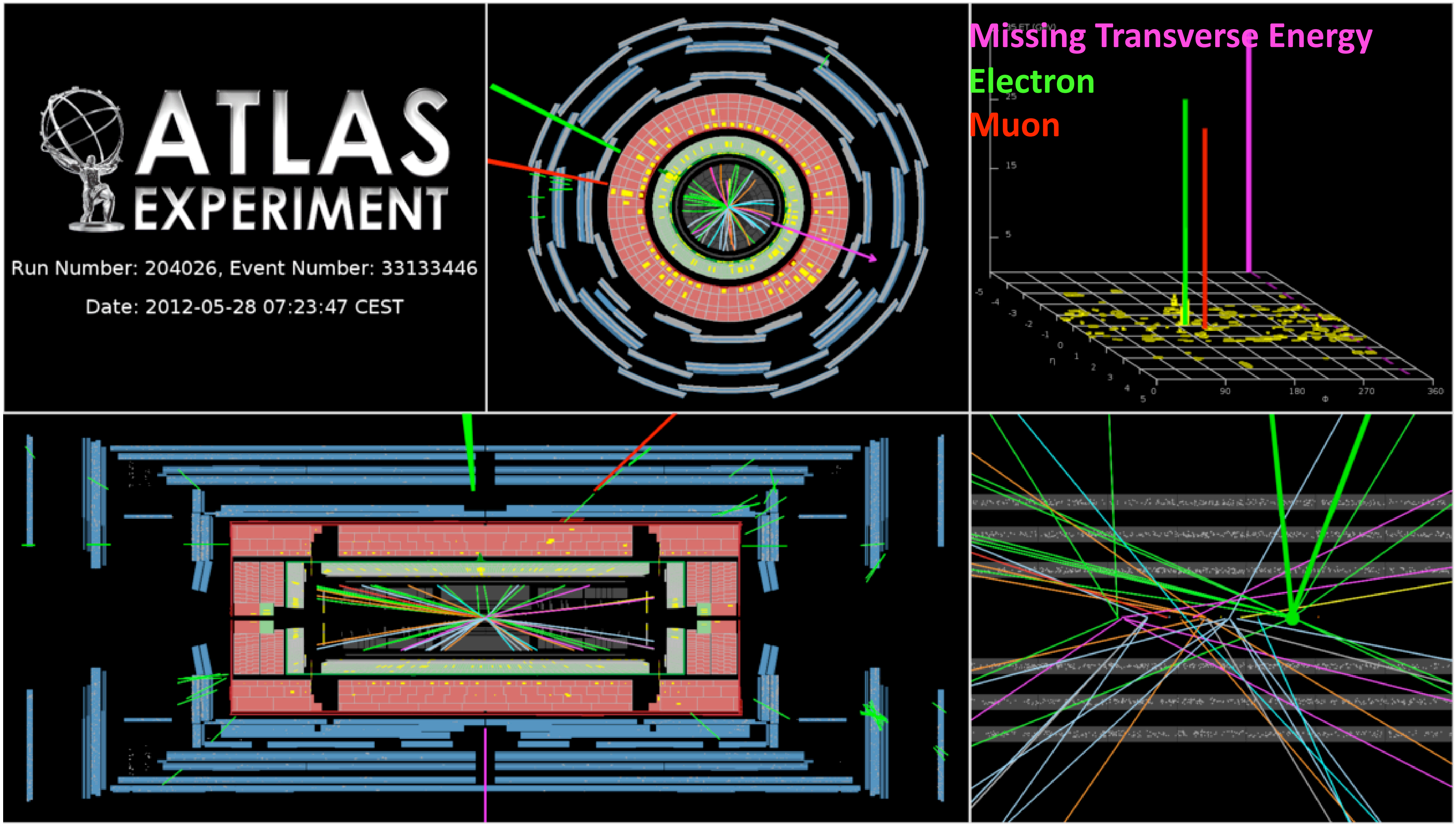
Analysis Hinges on Spin

- Most cuts are motivated by the spin 0 of the Higgs
  - Weak (V-A) decays cause the leptons to be collinear
  - One lepton (e,μ) is opposite W momentum



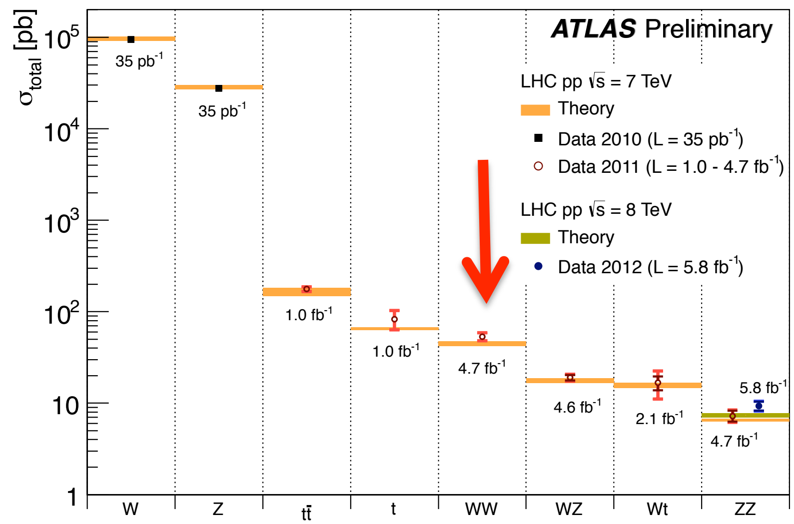
Spin pushes the leptons to be in the same direction

eμ Event Display



Many Backgrounds With Which to Contend

- Ordered list of most important backgrounds for 0 jet Higgs with m_H=126 GeV/c^2 in the opposite flavor channel
  - WW → lνlν
  - W+Jet → lν jet (jet fakes lepton)
  - Wγ (photon conversion)
  - WZ (lose lepton)
  - ttbar → blν blν (lose b's)
  - Wt → lν blν (lose b)
  - ZZ (irreducible, small)
  - Z+Jet (Drell Yan) → ll (lose jet, fake MET)
    - Z->ττ (has real MET)



WW is 70% of the 0 jet background

- Has identical final state

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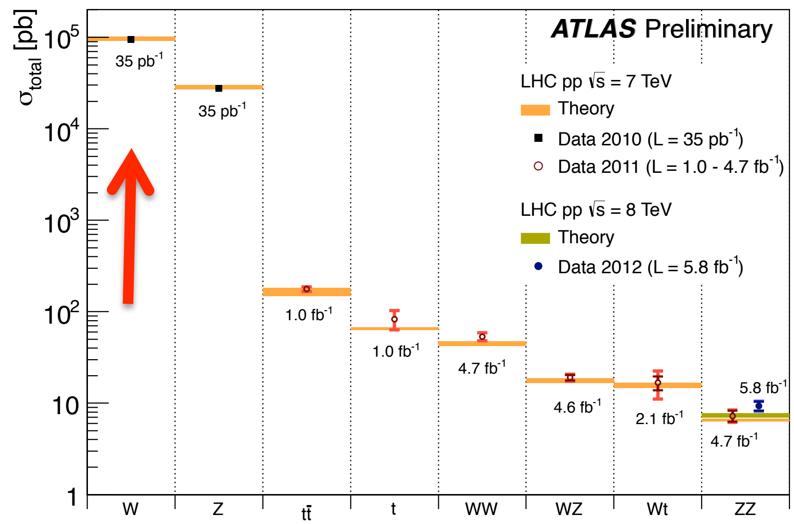

W+Jets is extremely important for low Higgs mass searches

- Large uncertainty

- Soft lepton

- Similar kinematics to signal

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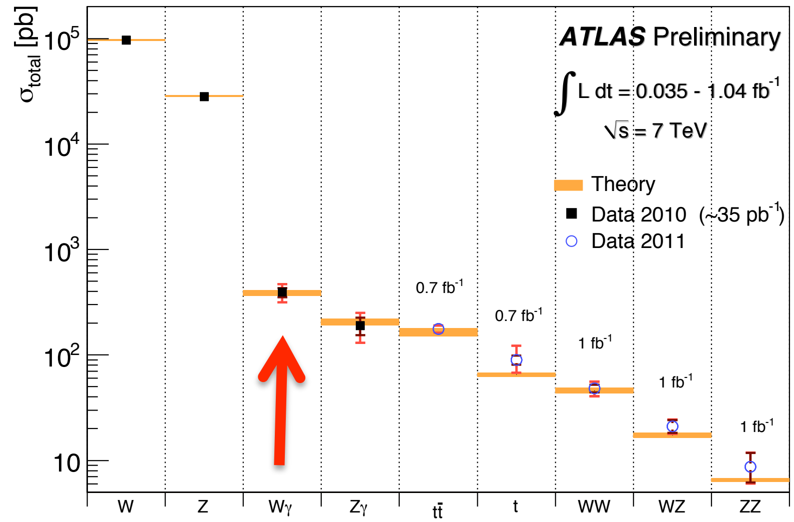


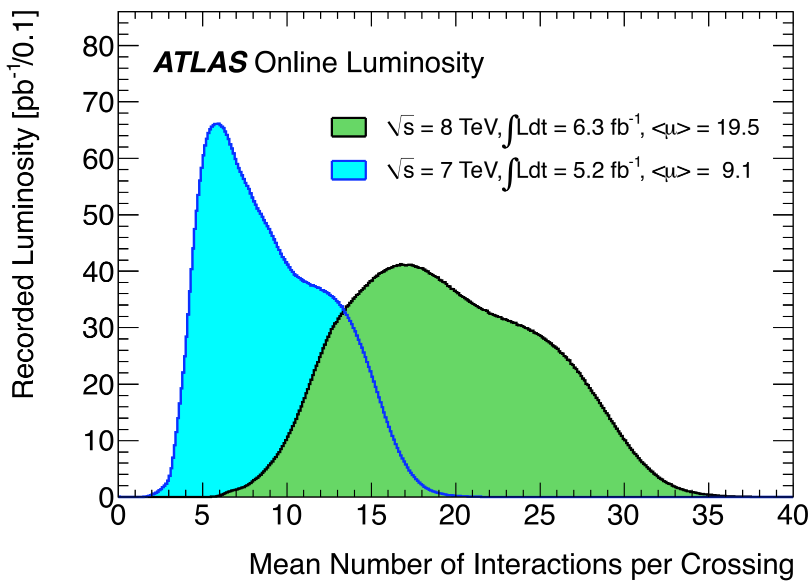
Wγ

- Large uncertainties

- Dependent on material modeling

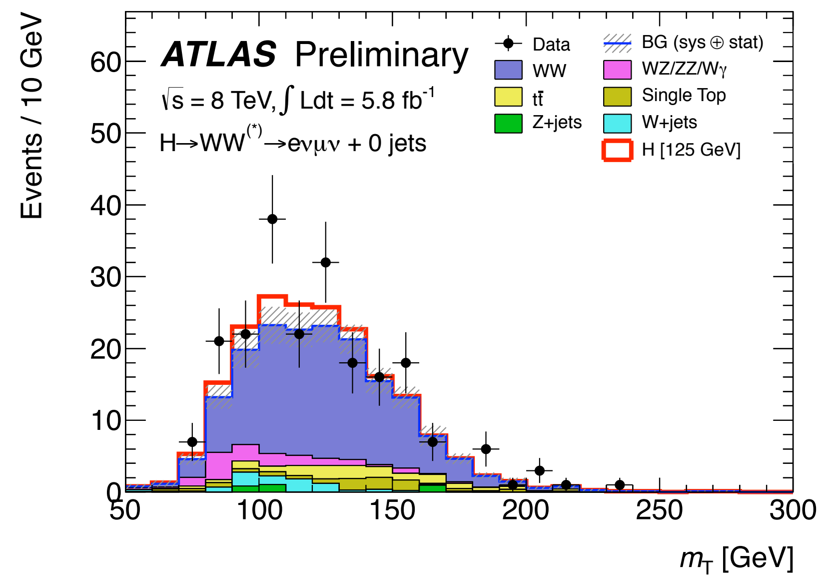
Event Selection

- In 2011, same and opposite flavor channels were used
- In 2012, increase interactions per proton bunch crossing adversely affected the missing transverse energy (MET) resolution
    - Only opposite flavor channel is used
- The following slides show the event selection for 2012 8 TeV data eμ channel



Binned Liklihood M_T Fit

- Final produce: Fit M_T distribution
  - Provides shape information
- One background model for Higgs mass from 110-200
  - Avoids look elsewhere effects
- How do get to this final distribution?



$$m_{\mathrm{T}} = \sqrt{(E_{\mathrm{T}}^{\ell\ell} + E_{\mathrm{T}}^{\mathrm{miss}})^2 - |\mathbf{p}_{\mathrm{T}}^{\ell\ell} + \mathbf{E}_{\mathrm{T}}^{\mathrm{miss}}|^2}$$

Object Selections

- Dileptons pairs (muons and electrons)
  - Lead $P_T > 25$ GeV
  - Subleading $P_T > 15$ GeV
  - Muons $|\eta|<2.5$
  - Electron $|\eta|<2.47$, excluding barrel-endcap gap
  - Track and calorimeter isolation and impact parameter cuts
- Missing tranverse energy (MET)
- Jets
  - $P_T > 25$ GeV
  - $|\eta|<4.5$
- Analysis is binned in the number of jets

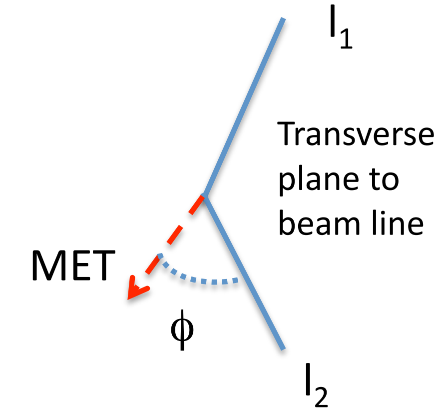
Missing Transverse Energy (MET) Cut

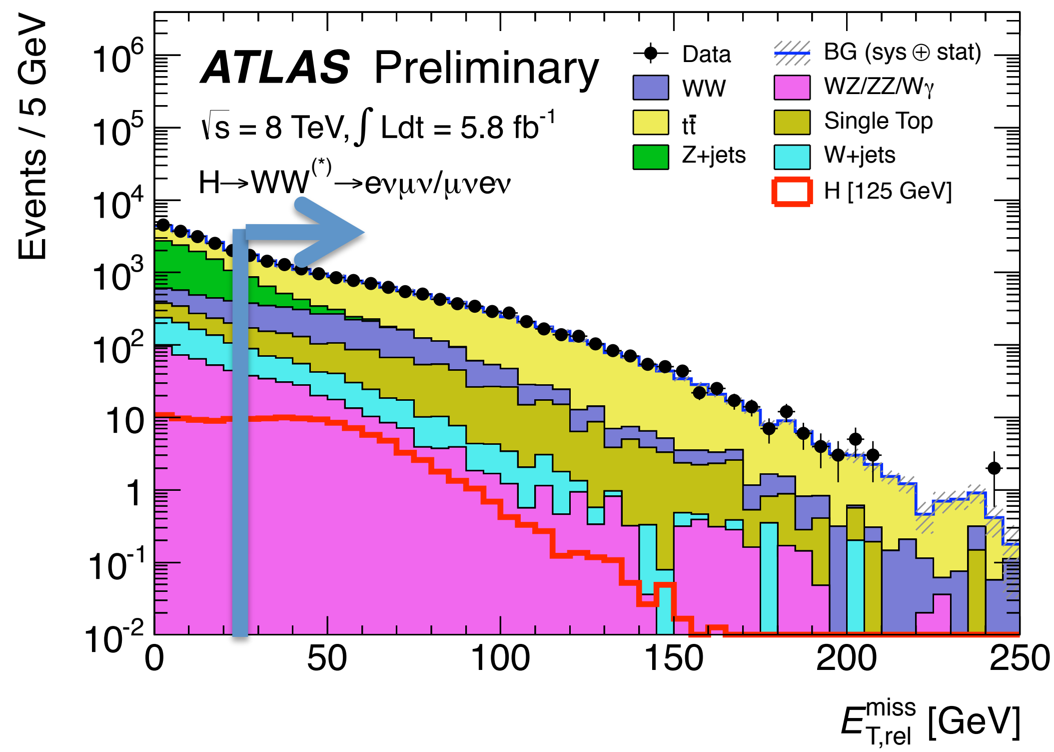
- Cut on the relative missing transverse energy (MET)
- Removes backgrounds without hard neutrinos
  - QCD
  - Drell Yan
- Effective at removing events with poorly measured objects

$\mathbf{E_{rel}^{miss}}$**=MET**

If closest object within 90°,

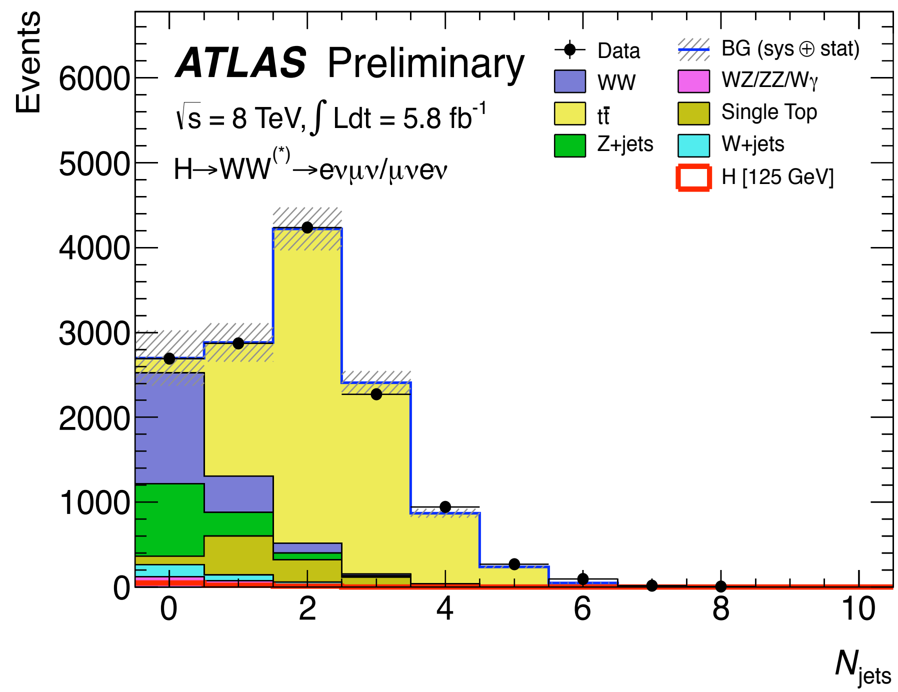
$\mathbf{E_{rel}^{miss}}$**=MET sin** $\boldsymbol{\phi}$





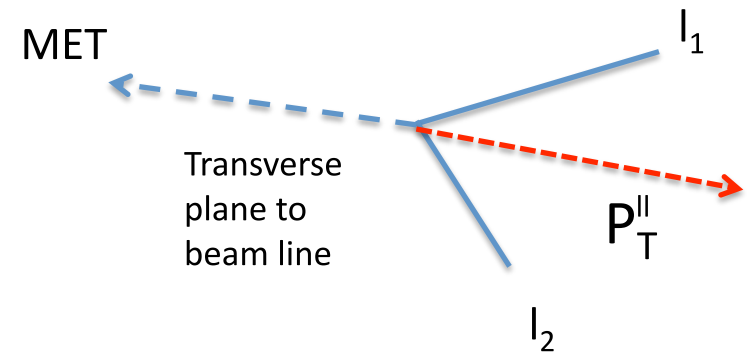
Reduce the Top Background

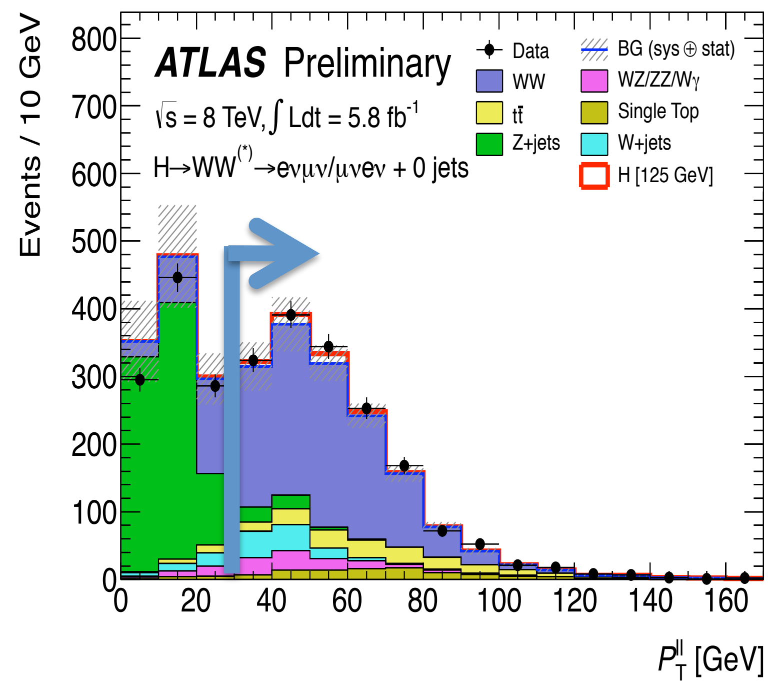
- Most of the ggF signal has 0 additional jets
  - Top increased ~15% more than the Higgs in moving from 7-8 TeV
  - Most sensitivity in 0 jet bin
- Bin analysis in 0, 1, and ≥2 jets
- Veto events with a b jet



Reduce Drell Yan Background

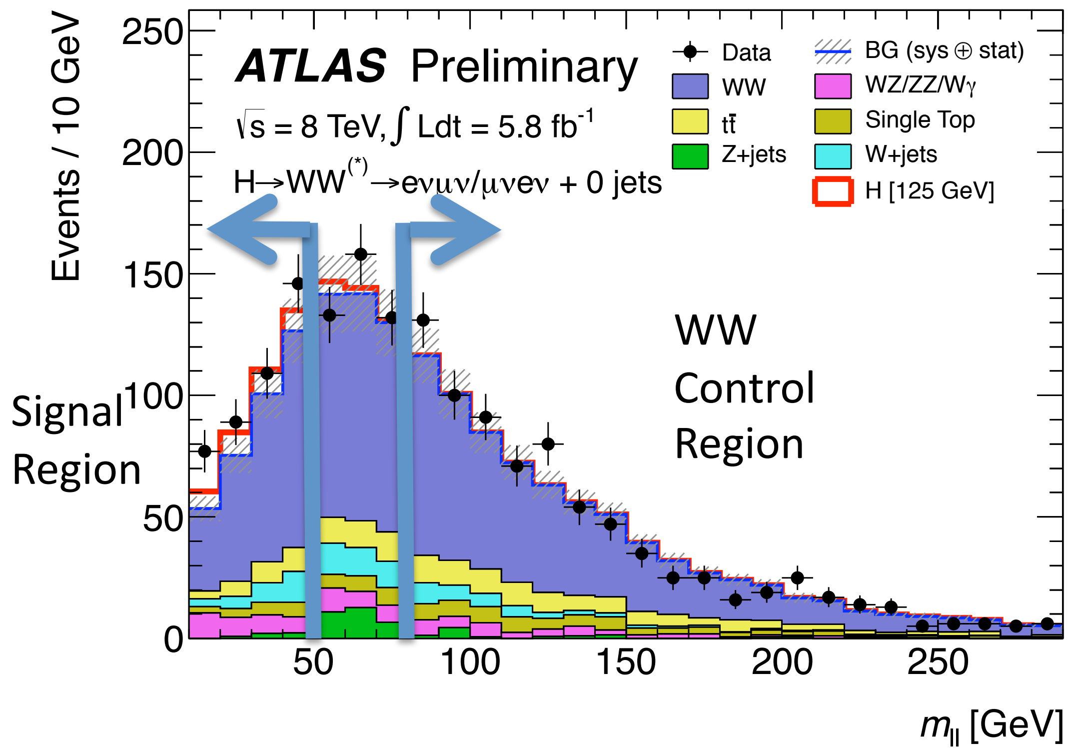
- Spin 0 Higgs has means the lepton's momentum should be in the same direction
  - Gives a transverse momentum to the lepton system
- Remove more Drell Yan, which tend to have back to back leptons



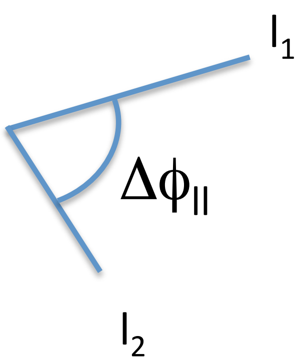


Reduce WW Background

- Off shell W in $H \rightarrow WW^*$ and the spin give a much smaller invariant mass of the leptons
- Provides a natural control region for WW



Transverse plane to beam line



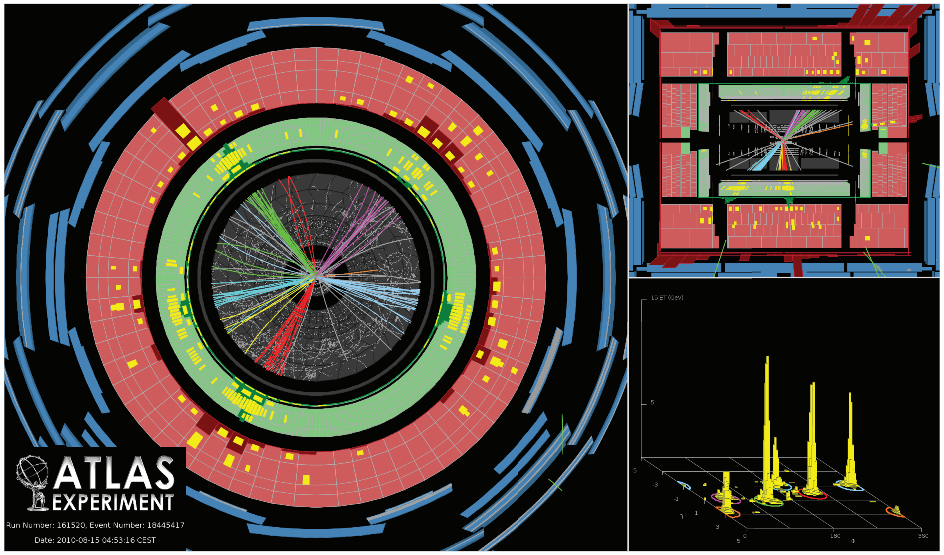
Finally, in the signal region

Require $|\Delta\phi_{ll}|<1.8$

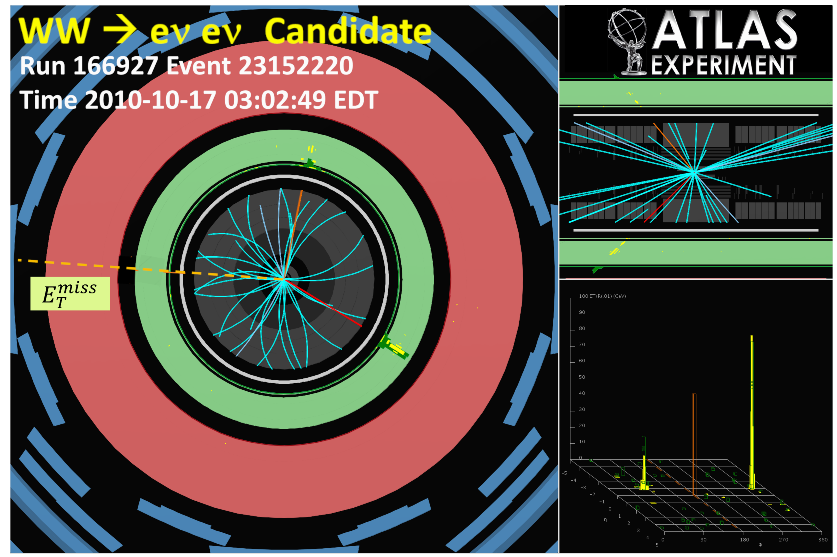
Modeling for Important Backgrounds

- Discuss background estimations in more detail for:
  - W+Jets
  - WW
  - Top

W+Jet Modeling



Multi-Jet Event

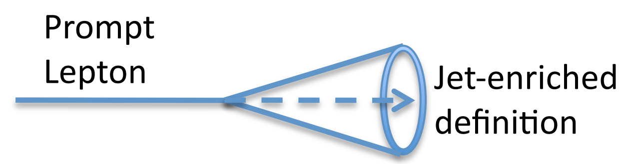


Electron Candidates

- W+Jet→lν jet (jet fakes lepton)
- Gluon and quark showering (jets) can mimic the signature of an isolated electron or muon
- Does not happen very often, but we have a lot of jets!

W+Jet Modeling (continued)

$$N_{W+Jets} = \sum_{i}^{Events} f_{jet}\left(\quad \right)$$



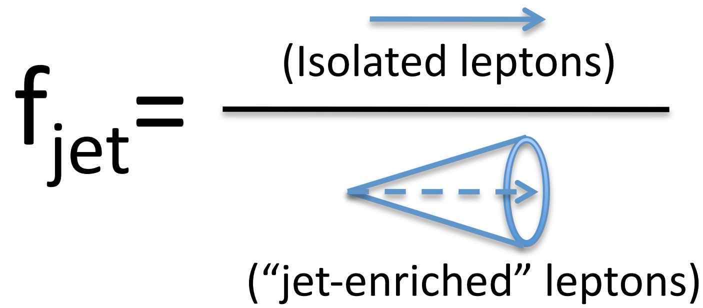
f_{jet} is the "transfer factor" from jet enriched leptons to our isolation definitions.

- Important background
  - Kinematics are very similar to low mass Higgs
  - Not modeled well by simulation (MC)
- Data driven method
  - Model jets imitating prompt leptons using a "transfer factor"
  - Predict all kinematic distributions
  - Make the same event selections to these events

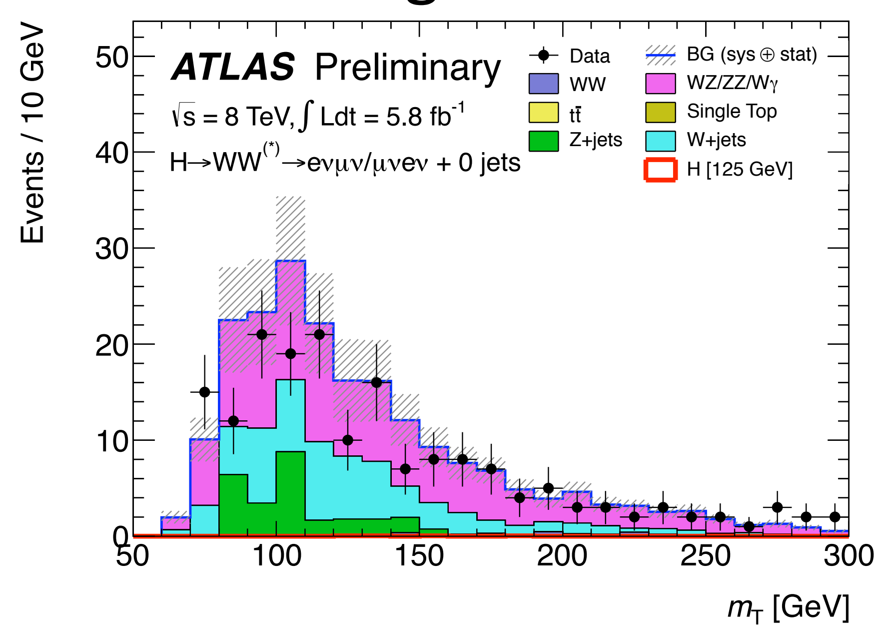
W+Jet Modeling (continued)

- ~45% uncertainties in "transfer factor"
  – Differences in jet P_T spectrum
  – Differences in jet flavor composition
- Modeling is validated with same sign lepton pairs

Measure in a multi-jet sample



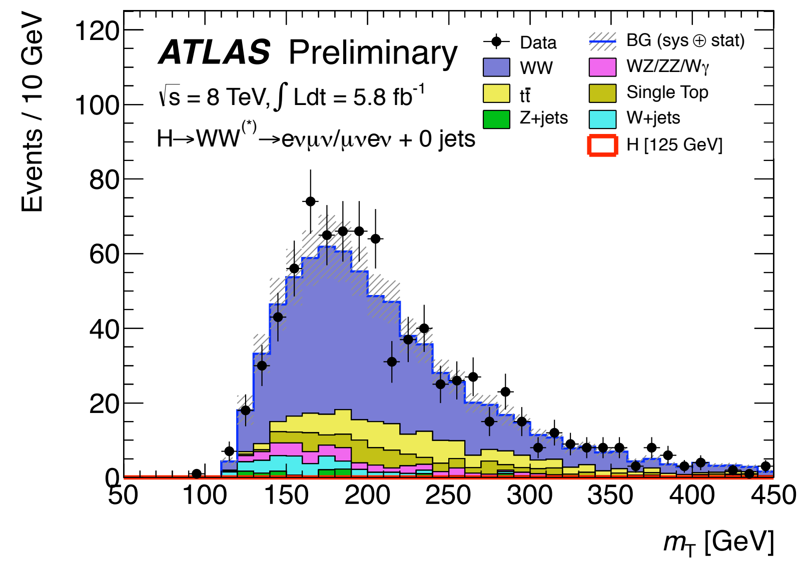
Same Sign Validation

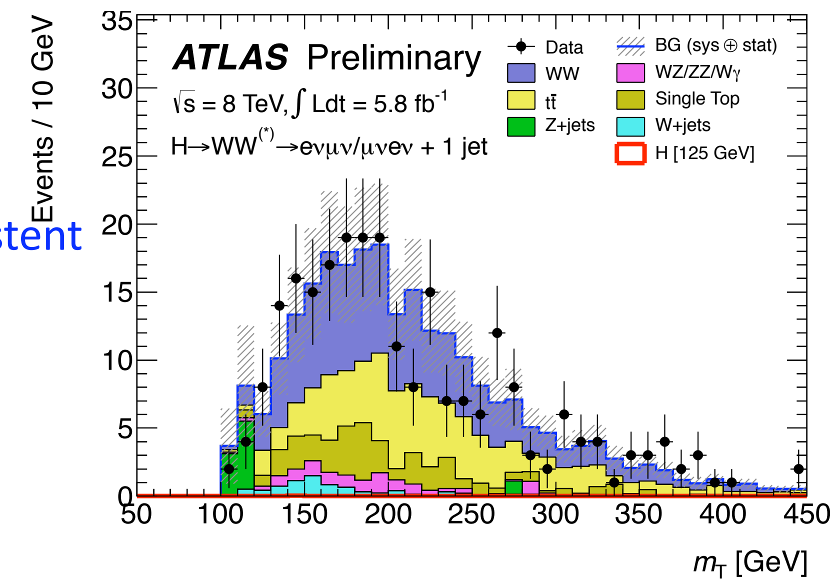


WW Modeling

- WW control region using m_{ll}>80 GeV events and removing $\Delta\phi_{ll}$ cut
- WW is 70% of 0 jet and 45% of 1 jet background in the signal region
- Obtain a normalization factor of data/mc in the control region
  - 1.06 +/- 0.06 (stat) in 0 jet
  - 0.99 +/- 0.15 (stat) in 1 jet

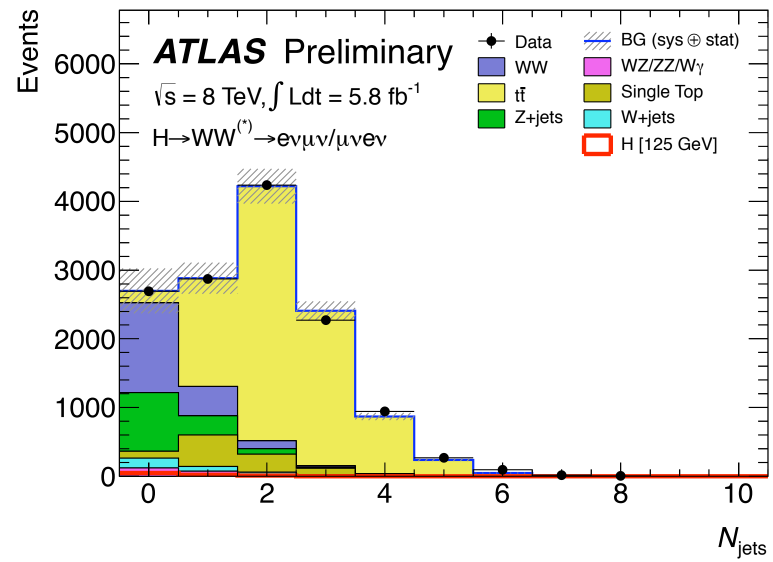
  Consistent with 1
- Theoretical and statistical shape uncertainties on WW is 13%





Top Estimate

- 0 jet top estimate is simulation corrected using jet veto survival probability (JVSF)
  - b jet control region is very pure in data
  - Measure jet survival probability in data and simulation
- JSVF Probability is small but has large uncertainty (17%)
- Ratio to simulation is 1.11+/- 0.19



In the b tag control region,

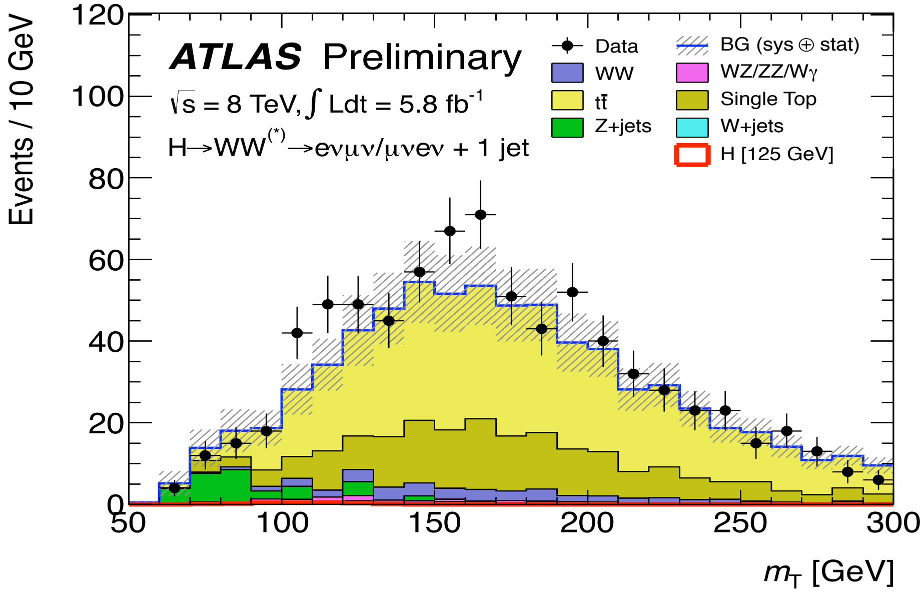
$$P^{b\text{-tag}} = \text{Prob(no additional jets)} = \frac{\text{No additional jets}}{\text{1 or more b tags}}$$

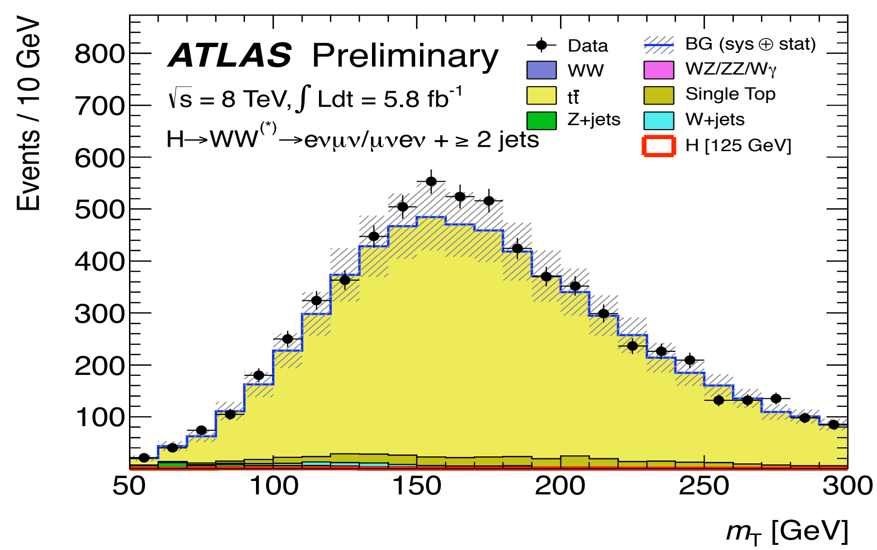
For the 0 jet top estimate,

$$Top\ estimate = N_{MC} * \left(\frac{P^{b-tag,\,Data}}{P^{b-tag,\,MC}}\right)^2$$

Top Estimate (continued)

- 1 and 2 jet analyses use b tagged jet events as a control region
  - Reverse m_{ll} and $\Delta\phi_{ll}$ cuts
  - Kinematics are well modeled
  - Very pure top sample
  - Top background is normalized to the control region
    - 1.11 +/- 0.05 (stat) in 1 jet
    - 1.01 +/- 0.26 (stat) in 2 jet
  - Ratio of ttbar and single top is fixed by the simulation





Uncertainties on Signal and Background

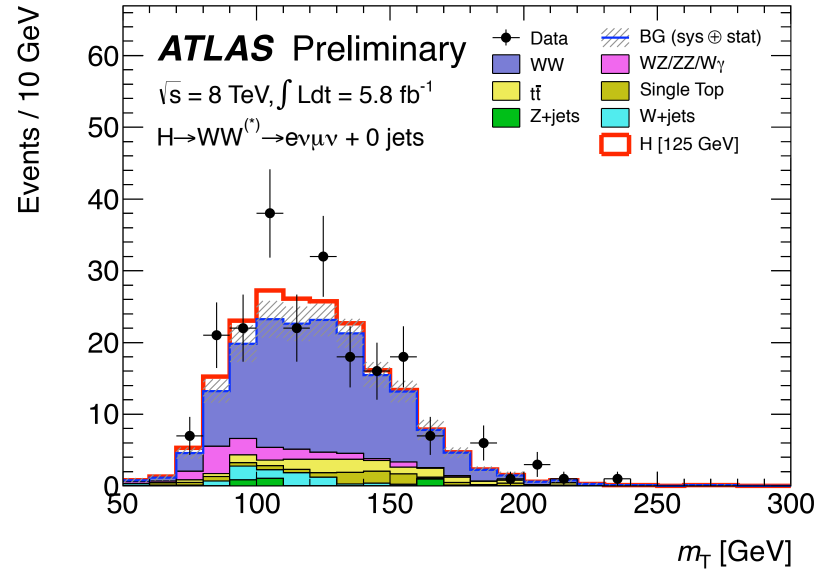
- Dominant systematics are signal theoretical uncertainties
- Largest detector systematic is WW normalization and W+Jets uncertainty

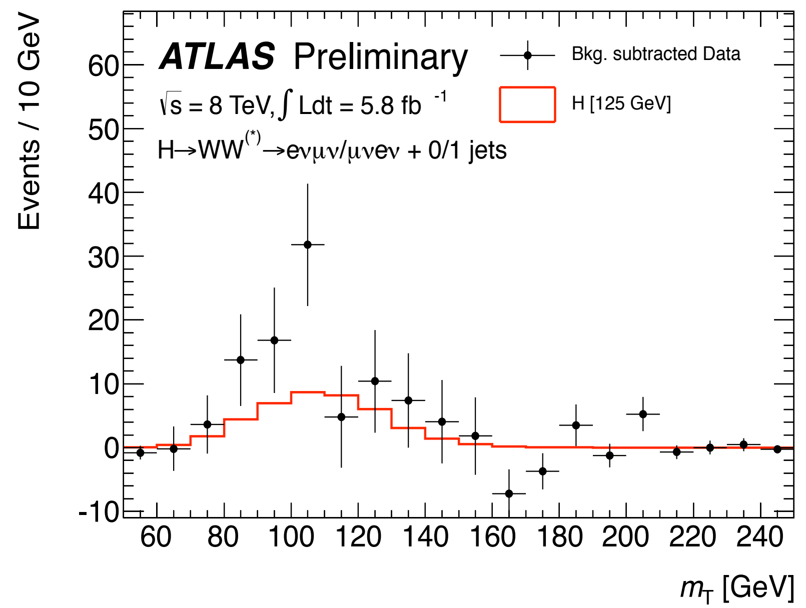
Source (0-jet)	Signal (%)	Bkg. (%)
Inclusive ggF signal ren./fact. scale	13	-
1-jet incl. ggF signal ren./fact. scale	10	-
Parton distribution functions	8	2
Jet energy scale	7	4
WW normalisation	-	7
WW modelling and shape	-	5
W+jets fake factor	-	5
QCD scale acceptance	4	2
Source (1-jet)	**Signal (%)**	**Bkg. (%)**
1-jet incl. ggF signal ren./fact. scale	28	-
WW normalisation	0	25
2-jet incl. ggF signal ren./fact. scale	16	-
b-tagging efficiency	-	10
Parton distribution functions	7	1
W+jets fake factor	0	5

2012 Binned Liklihood M_T Fit

$$m_T = \sqrt{(E_T^{\ell\ell} + E_T^{miss})^2 - |\mathbf{p}_T^{\ell\ell} + \mathbf{E}_T^{miss}|^2}$$

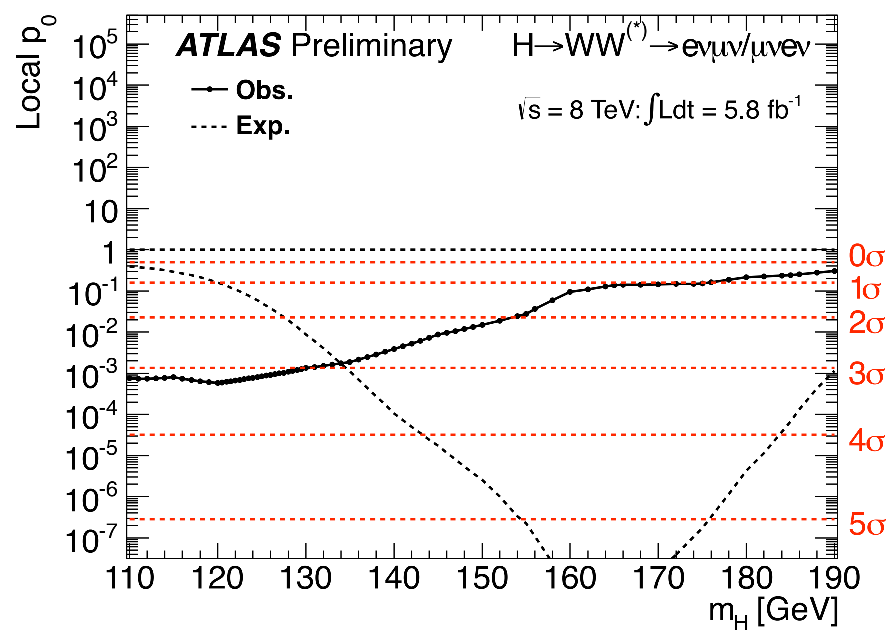
- Split jet bins (0j, 1j, 2j)
- Split lead lepton flavors
  - Lead electron – subleading muon
  - Lead muon– subleading electron
  - Different backgrounds
- *Bottom Right:* m_T subtracting away the standard model backgrounds





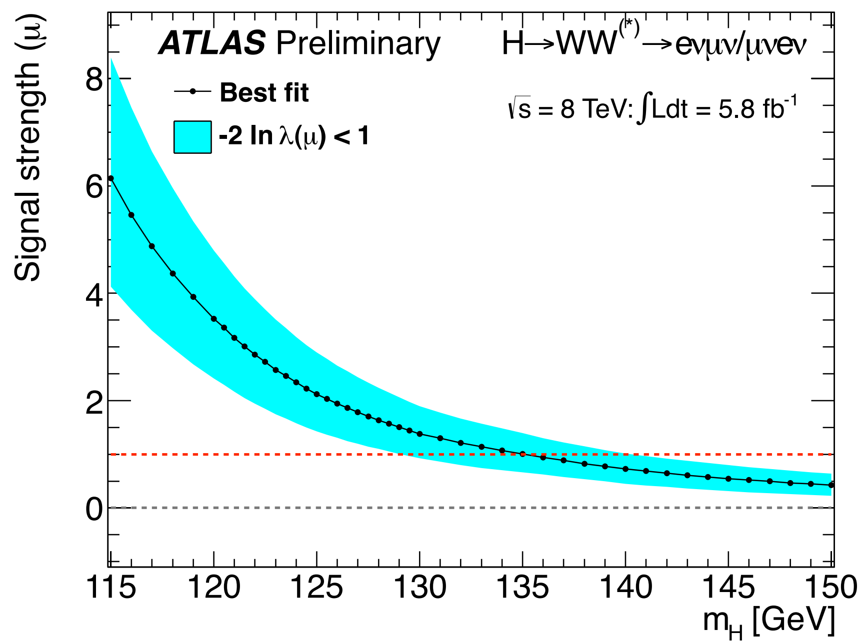
2012 Results

- Limited mass resolution
- *Expected* assumes a standard model Higgs for each m_H
  - Expected exclusion is 129
- *Observed* tests the probability of background only hypothesis
  - Best p_0 is 3.2 σ_{SM} at m_H = 120 GeV/c²
  - Reject the no Higgs hypothesis at 3.1 σ_{SM} at m_H = 125 GeV/c²



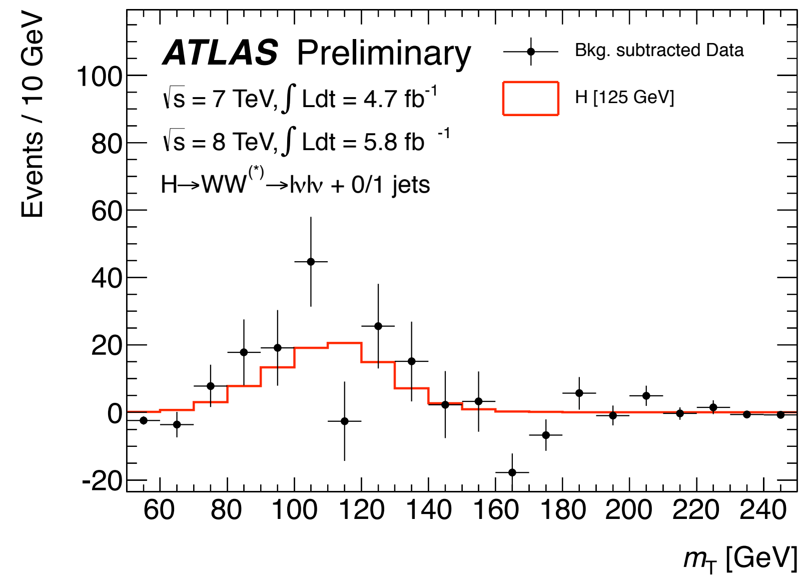
2012 Results

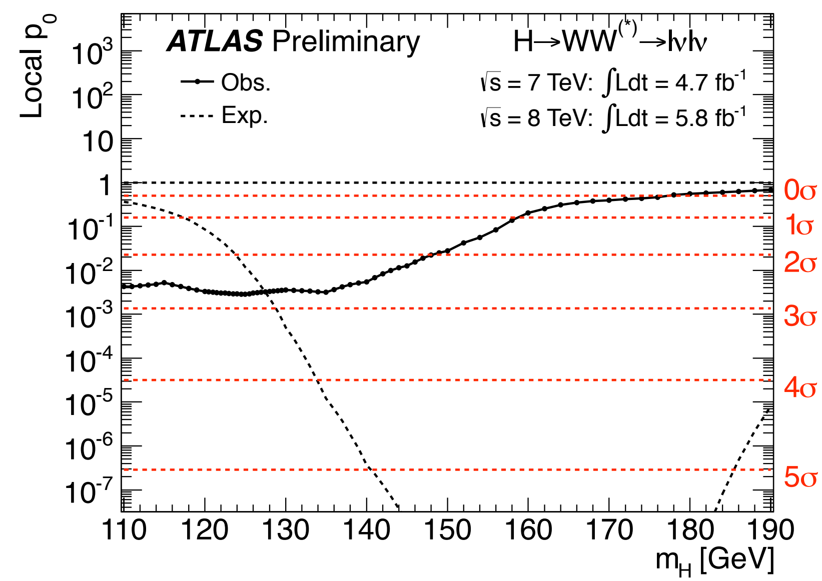
- Define signal strength parameter (μ)
  - 1 for the SM Higgs
  - 0 for no Higgs
- Measure the signal strength as a function of Higgs mass
- Signal strength at m_H = 126 GeV/c^2 is 1.9 +/- 0.7



Combined 2011 and 2012 Results

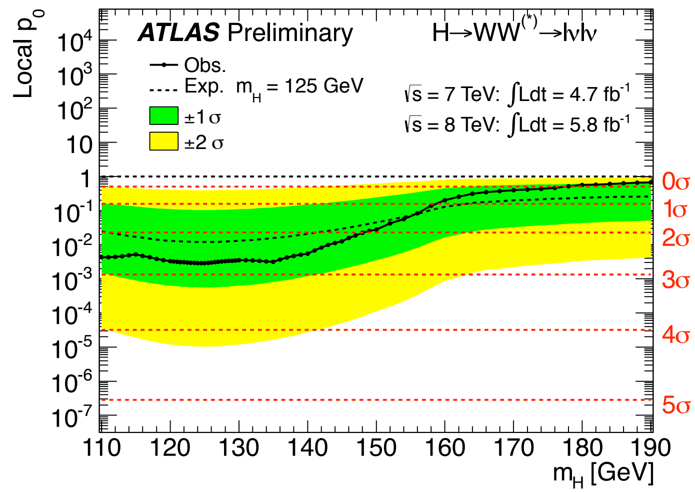
- *Top Right:* m_T subtracting away the standard model backgrounds
  - Large diboson excess observed
- ***Bottom Right:***
  Observed: Best p_0 is 2.8 σ_{SM} at $m_H = 125$ GeV/c^2

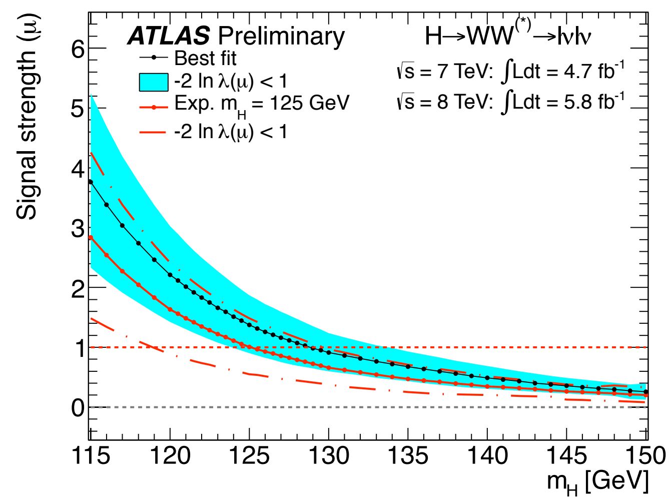




Is this the Standard Model Higgs?

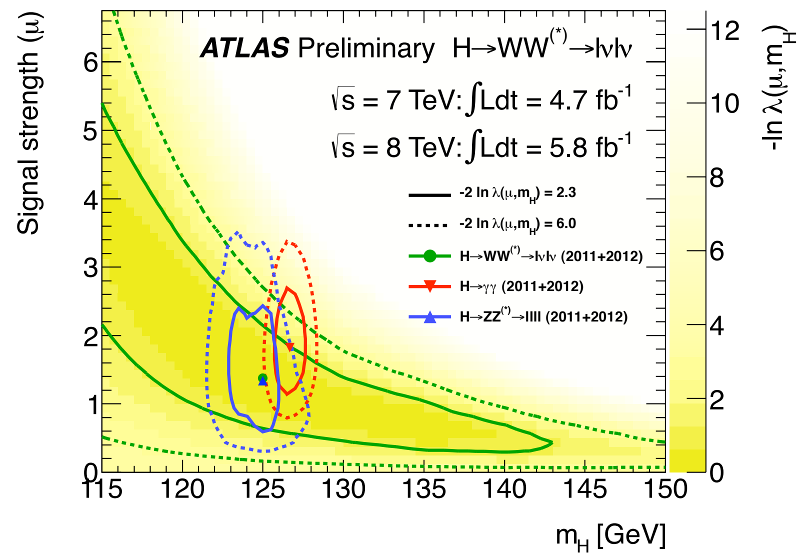
- *Top Right:* Add m_H = 125 standard model Higgs into the to the background model (*expected)*
  - Excess is consistent with m_H = 125
  - Broad excess, so mass resolution is poor
- *Bottom Right:* Measure the signal strength as a function of Higgs mass
- Define signal strength parameter (μ)
  - 1 for the SM Higgs
  - 0 for no Higgs
- Signal strength is:
  - 1.3 +/- 0.5
  - Consistent with a 125 Higgs!

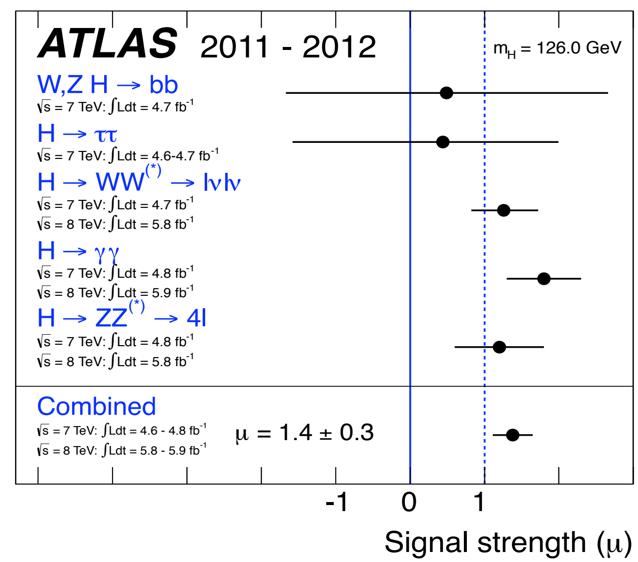




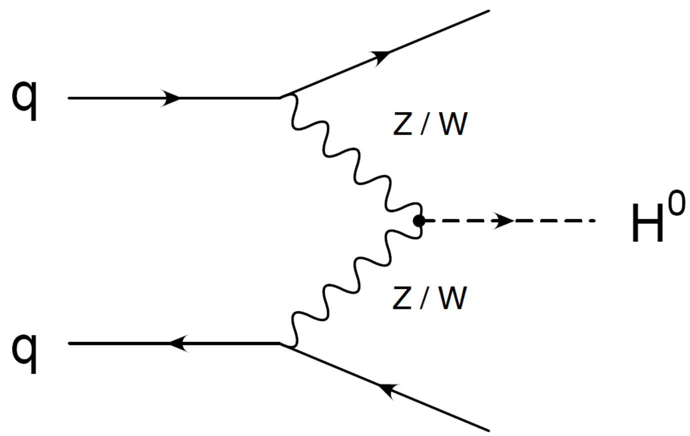
Signal Strength Across Analyses

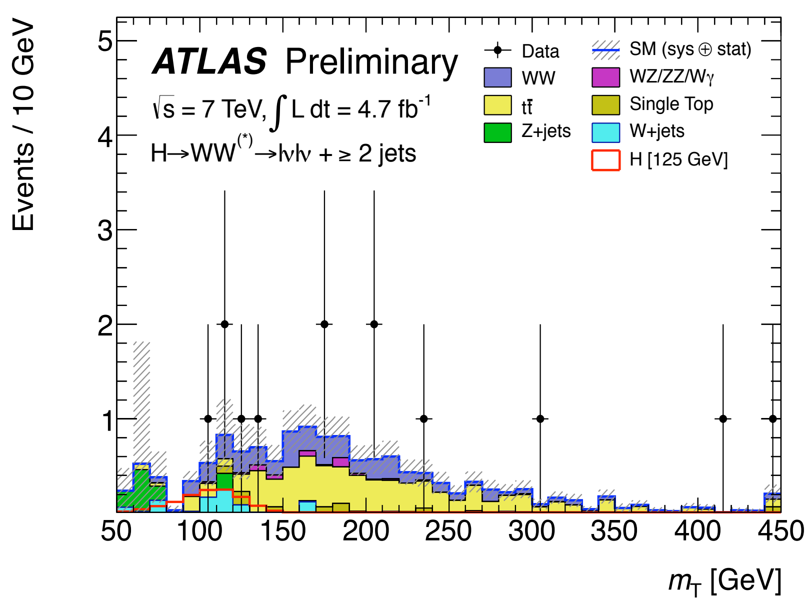
- Combine 2011 and 2012 data
- H->WW
  - Does not have mass resolution
  - Has the best estimate of signal strength because of the large branching fraction
- All analyses are consistent with a standard model Higgs



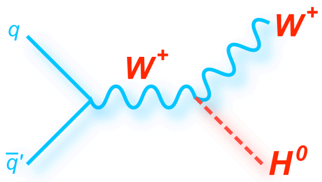


qq'→qq'H (VBF) Specific Analysis



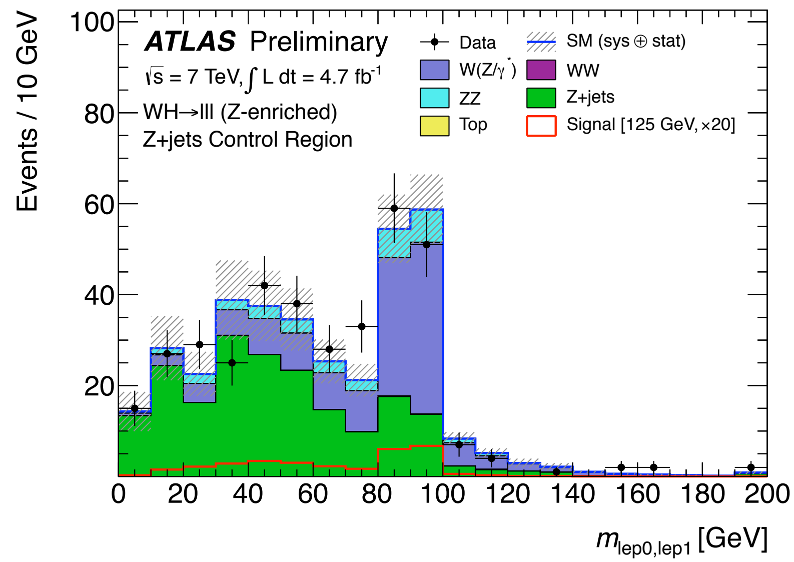


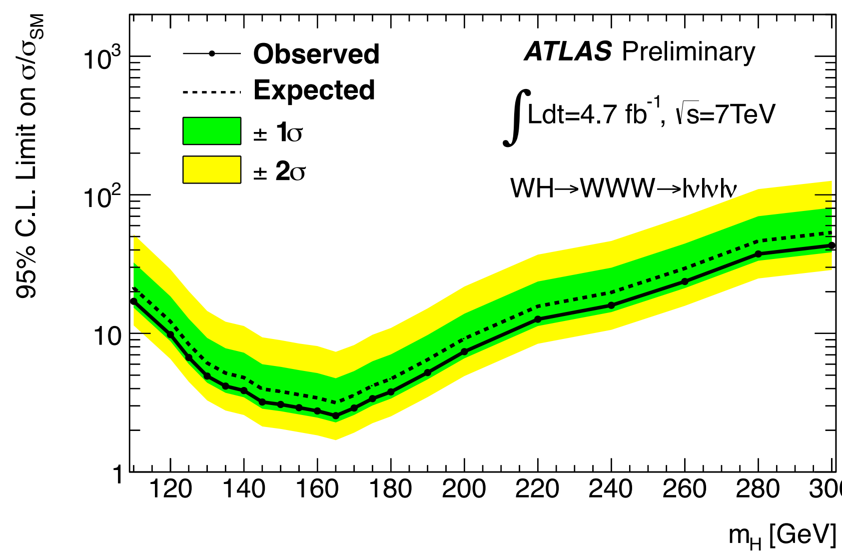
- Separates W/Z coupling from the top/W/etc loop production in ggF (no loops)
- Distinct kinematics reduce major backgrounds like top
  - Two forward jets
  - MET
  - 2 prompt leptons
- 2011 ATLAS analysis:
  - 0.6 VBF
  - 1.0 background
- Has expected sensitivity ~3.5 σ_{SM} with 10 fb^{-1} (~2σ_{SM} with 30 fb^{-1})
- Lots of room for optimization



WH Higgs Strahlung Analysis

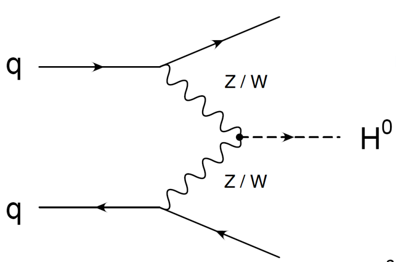
- Sensitive to direct Higgs to W coupling (no loops)
- WH→$l\nu\, ll$
    - Search for 3 isolated leptons
- 4.7 fb^{-1} of 7TeV data
- Split analysis into WZ dominated region and Z +Jet dominated region
- Current limit is ~7 σ_{SM} at m_H = 125 (~3 σ_{SM} with 30 fb^{-1})



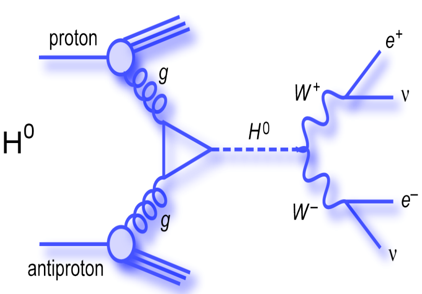


Compare ggF to VBF

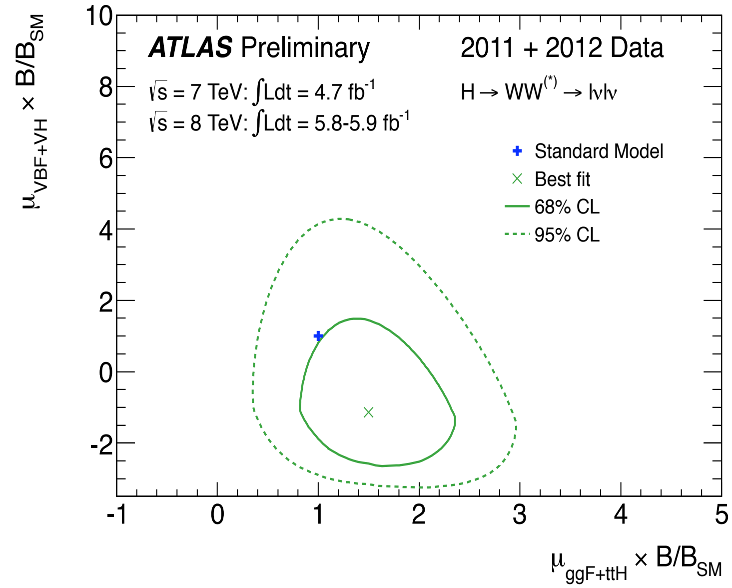
- Currently, we have more sensitivity to the gluon-gluon fusion (ggF)
  - ggF is sensitive to new physics
- VBF limit is dominated by the 2 jet limit

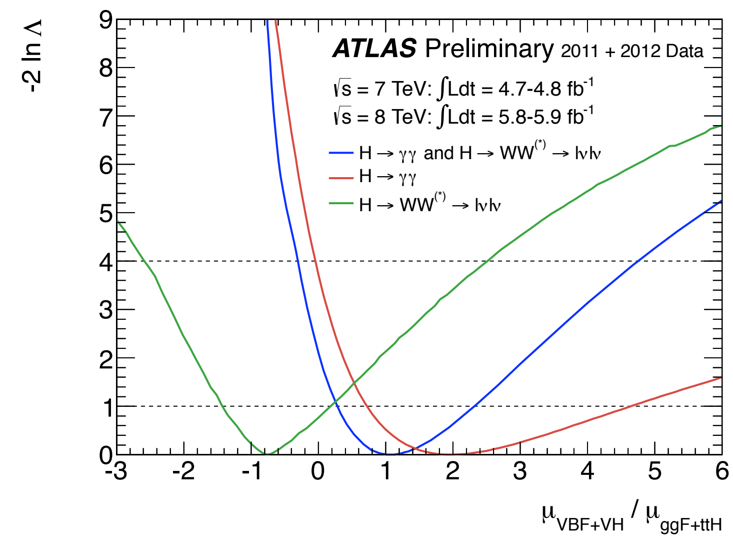


VBF



ggF





Summary

- We see a large 2.8 σ_{SM} excess in WW
- The cross-section and signal strength are consistent with the standard model Higgs
- Too early to compare ggF and VBF production modes
- Watch for more studies
  - ggF versus VBF
  - Spin
  - Couplings
  - Fermiophobic

Bibliography

- The ATLAS Collaboration, *Search for the Standard Model Higgs boson in the H → WW(∗) → ℓνℓν decay mode with 4.7 fb−1 of ATLAS data at √s = 7 TeV, arXiv:1206.0756,* submitted to Phys. Lett. B (2012) .
- The ATLAS Collaboration, *Observation of Excess Events in the Search for the Standard Model Higgs Boson H → WW(∗) → ℓνℓν channel with the ATLAS Detector* (2012) .

Spin?

- Signal strength and signal selection depend on spin-0
- Effort to place limits on the spin-2 graviton

Z+Jet Modeling

- Used in same flavor channels
- Signal Region (A) = B*(C/D)