

# Search for the Higgs boson in $H \rightarrow ZZ^{(*)}$ decay modes on ATLAS

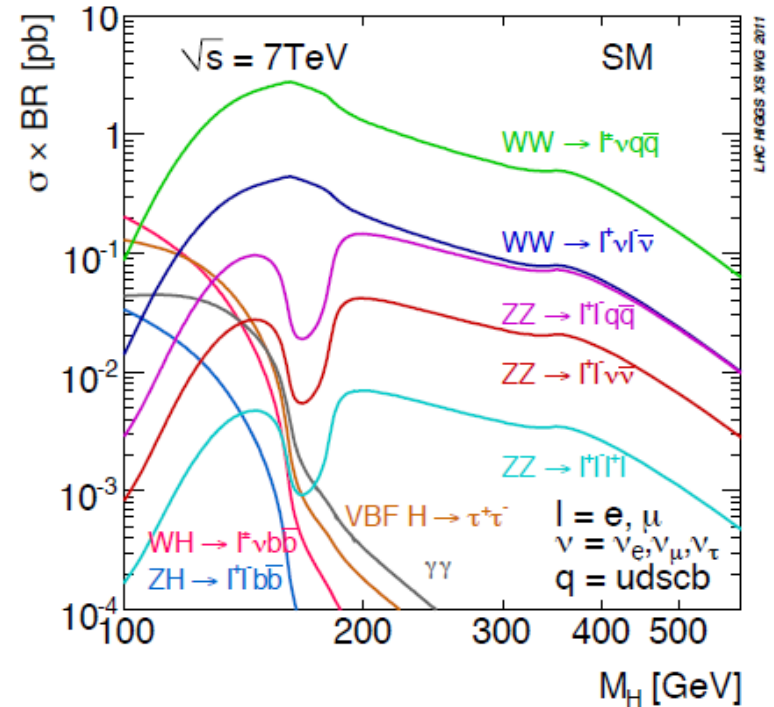
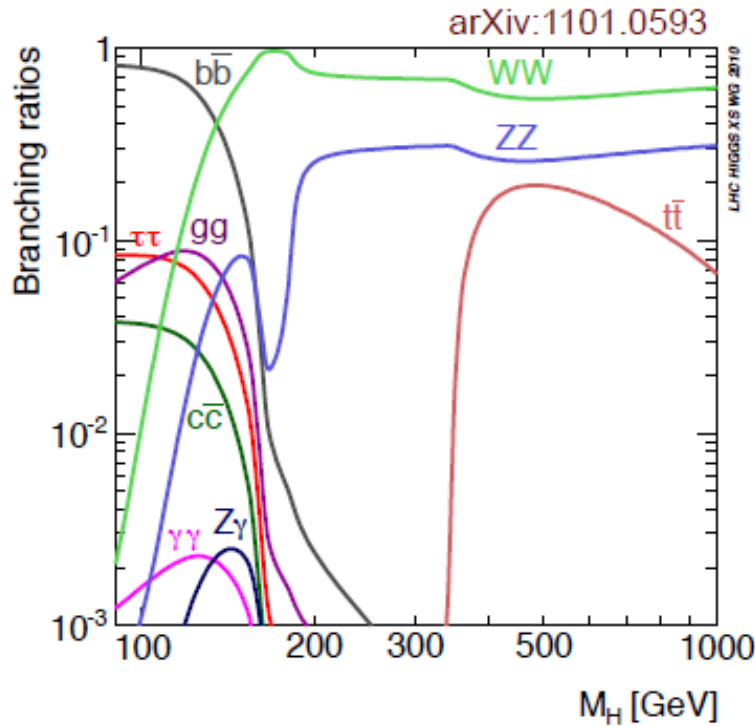
ATLAS



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University of Wisconsin-Madison  
*On behalf of the ATLAS Collaboration*

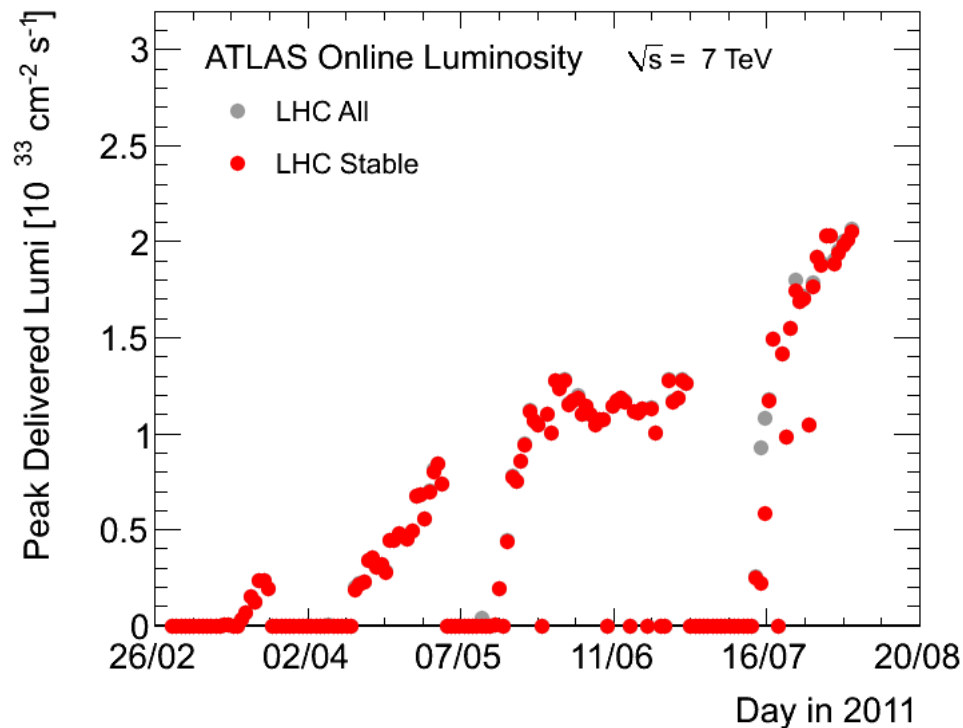
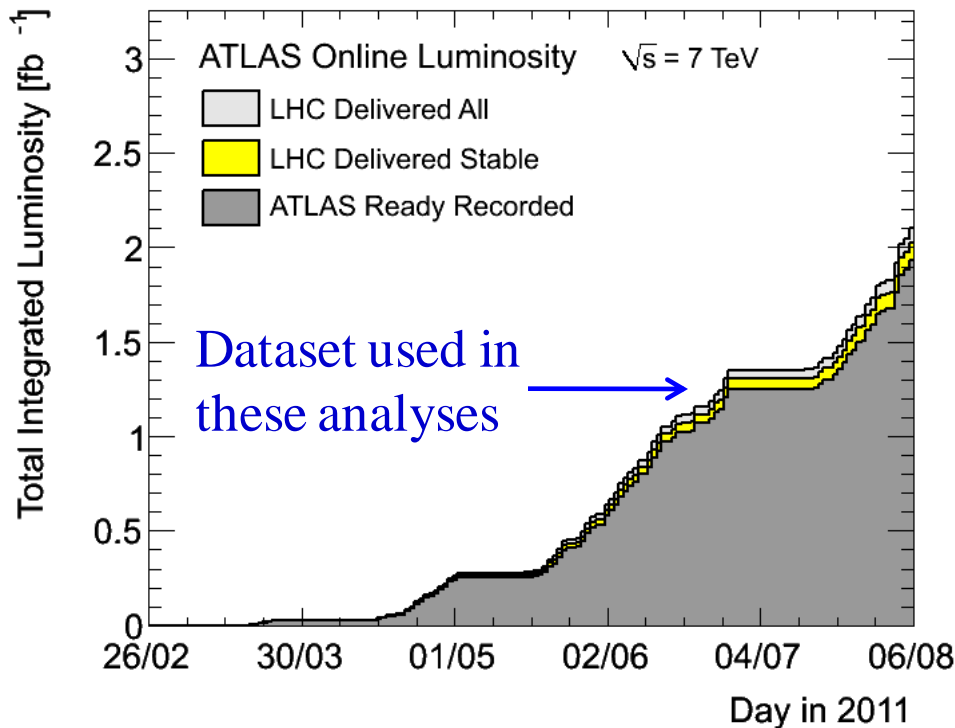
*DPF 2011, Brown University, Rhode Island*  
August 9, 2011

# Introduction



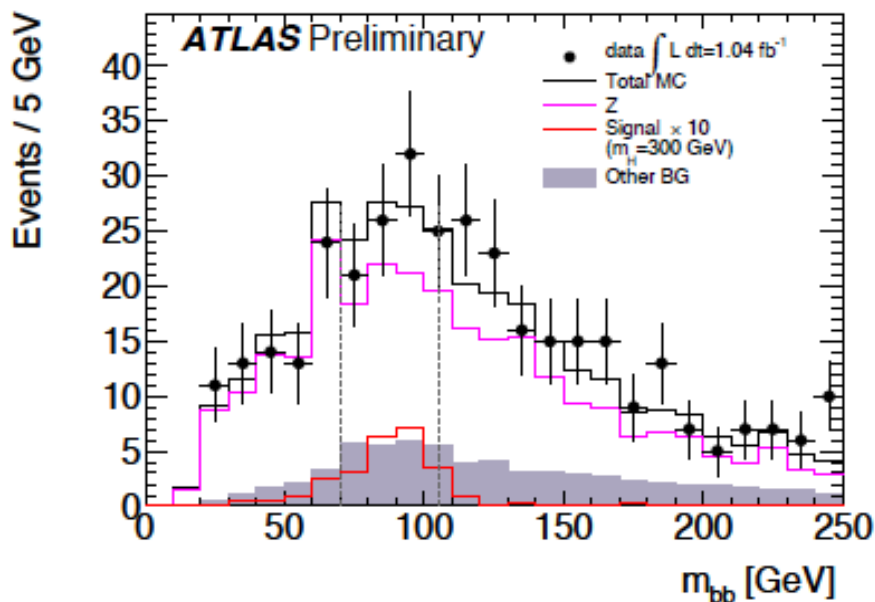
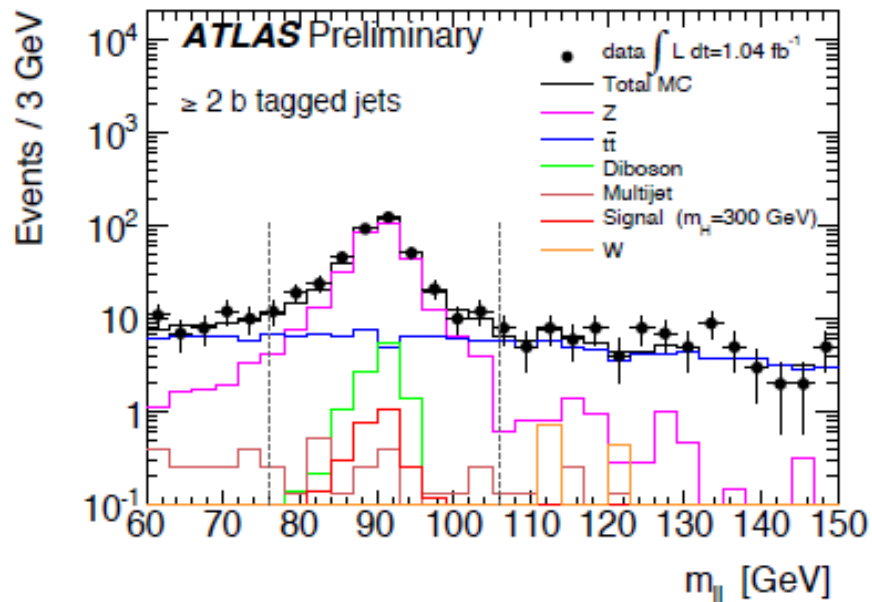
- $H \rightarrow ZZ$  branching ratio is large for  $M_H > 2 M_Z$ , second to the  $WW$  branching
- Requiring at least one real  $Z$  leads to three channels:
  - $llqq, ll\nu\nu, llll$
- For each, will summarize selection, results and limit curves with 2011 data

# Data sample



- These analyses based on  $1.04 - 1.21 \text{ fb}^{-1}$  data from March to June 2011
- Error on luminosity: 3.7%
- Already sensitive to Higgs signal in wide range  $130 \text{ GeV} < M_{\text{H}} < 500 \text{ GeV}$

# The $H \rightarrow ZZ \rightarrow llqq$ channel



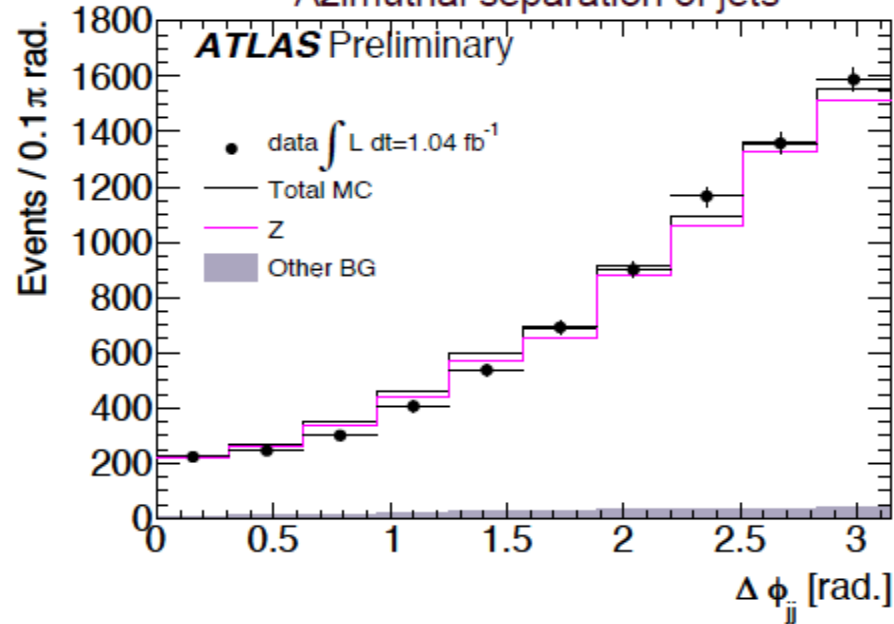
- High- $p_T$  lepton pair + 2 jets signature
- Search region:  $200 \text{ GeV} < M_H < 600 \text{ GeV}$
- Bin by  $b$ -tagging: 2  $b$  jets (tagged),  $< 2$   $b$  jets (untagged)

## Event selection

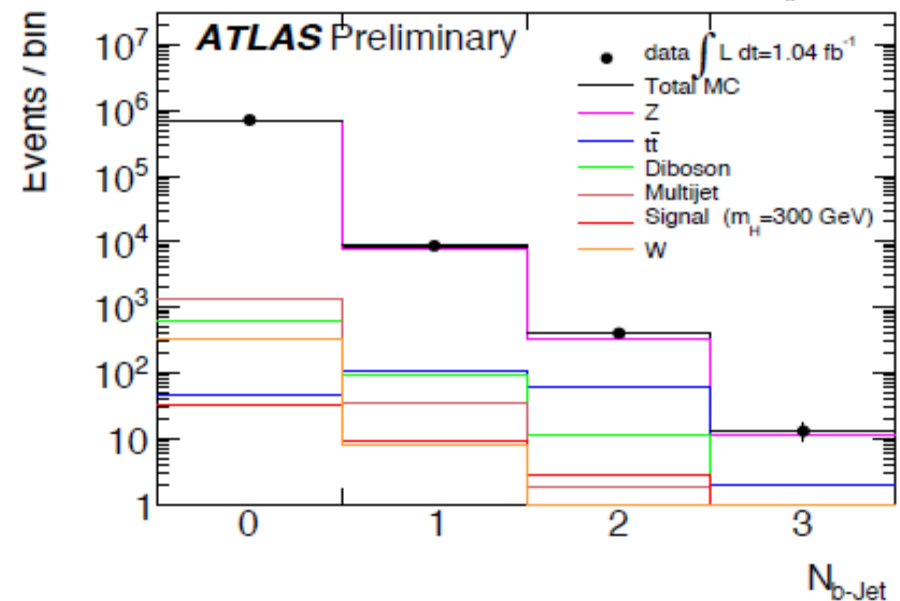
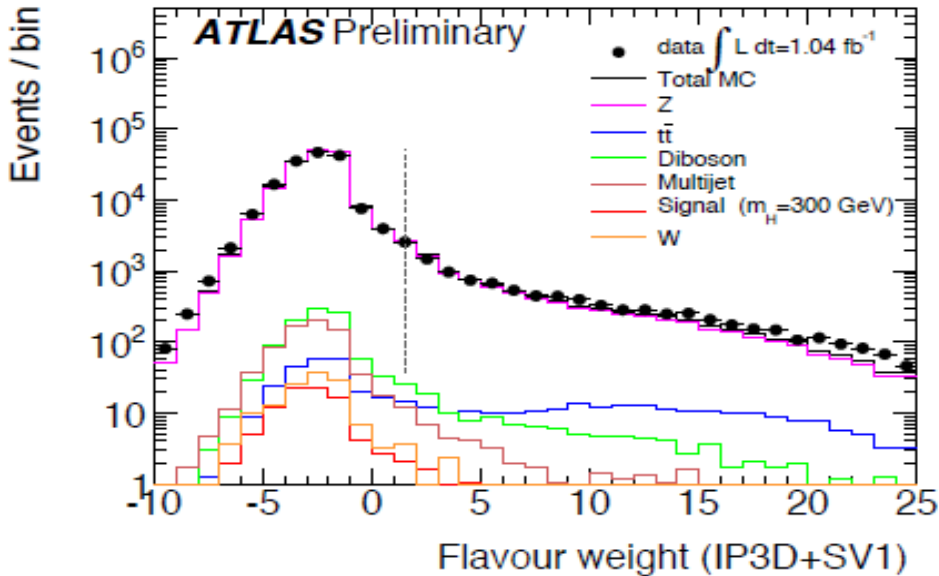
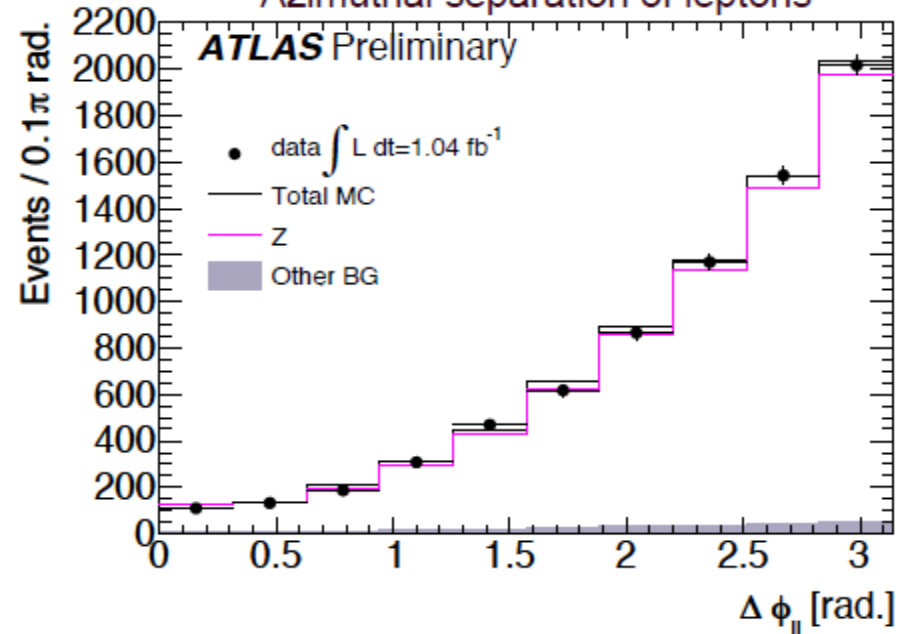
- Isolated same-flavor lepton pair
  - $p_T > 20 \text{ GeV}$ ,  $76 \text{ GeV} < m_{ll} < 106 \text{ GeV}$
- No additional lepton in event
- At least 2 jets, with  $p_T > 25 \text{ GeV}$ ,  $|\eta| < 2.5$ ,  $70 \text{ GeV} < m_{jj} < 105 \text{ GeV}$
- $E_T^{\text{miss}} < 50 \text{ GeV}$
- High mass ( $M_H > 300 \text{ GeV}$ ):
  - $p_T(\text{jets}) > 50 \text{ GeV}$ ,  $\Delta\phi_{ll} < \pi/2$ ,  $\Delta\phi_{jj} < \pi/2$

# $llqq$ : kinematics

Azimuthal separation of jets



Azimuthal separation of leptons



# $llqq$ : backgrounds

$Z + jets$ : Main background

- Normalized using sidebands in  $m_{jj}$
- Uncertainty  $<10\%$  for untagged sample,  $\sim 20\%$  for tagged sample

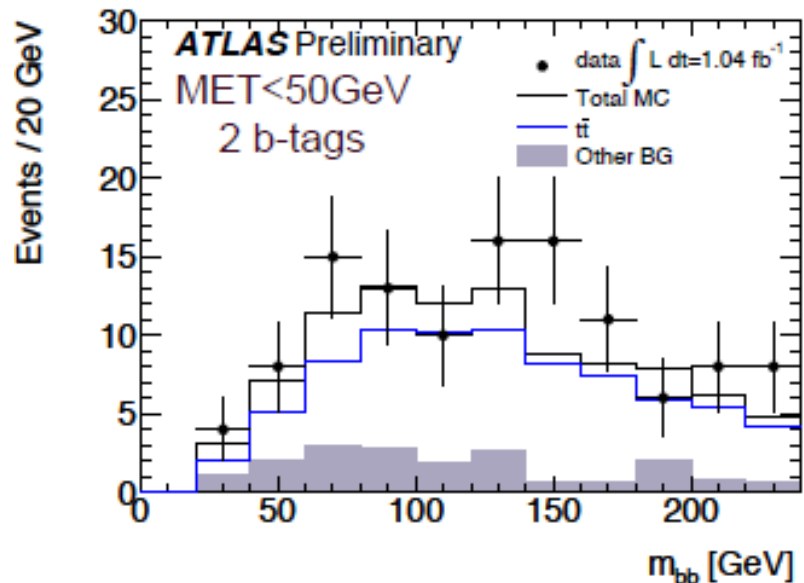
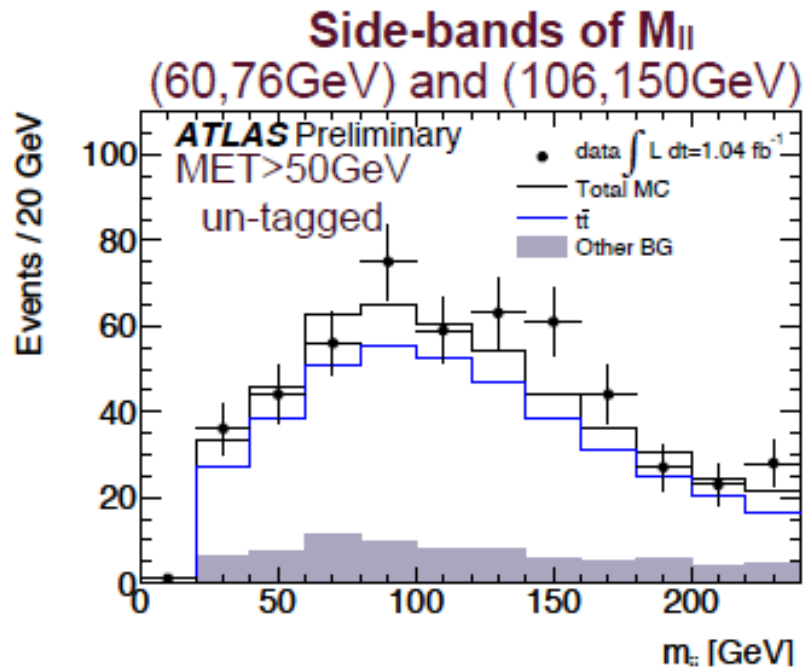
$Top$ : MC expectation validated using sidebands in  $m_{ll}$

- $\sim 10\%$  theory uncertainty

$QCD$ : data-driven techniques

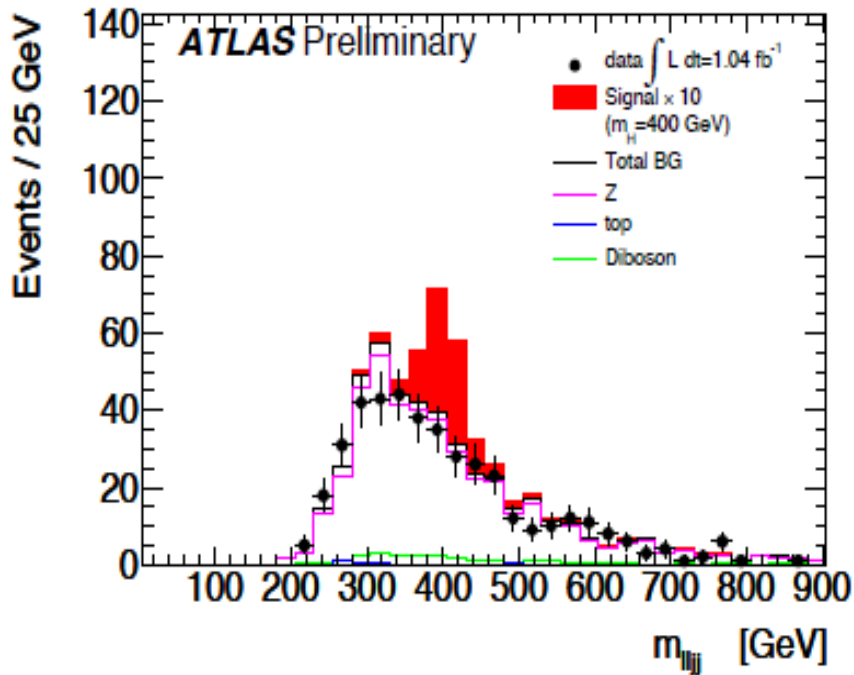
- Template fit method in  $ee$  channel
- ‘ABCD’ method in  $\mu\mu$  channel using isolation and  $m_{\mu\mu}$

$Diboson$ : MC-derived,  $\sim 10\%$  theory uncertainty

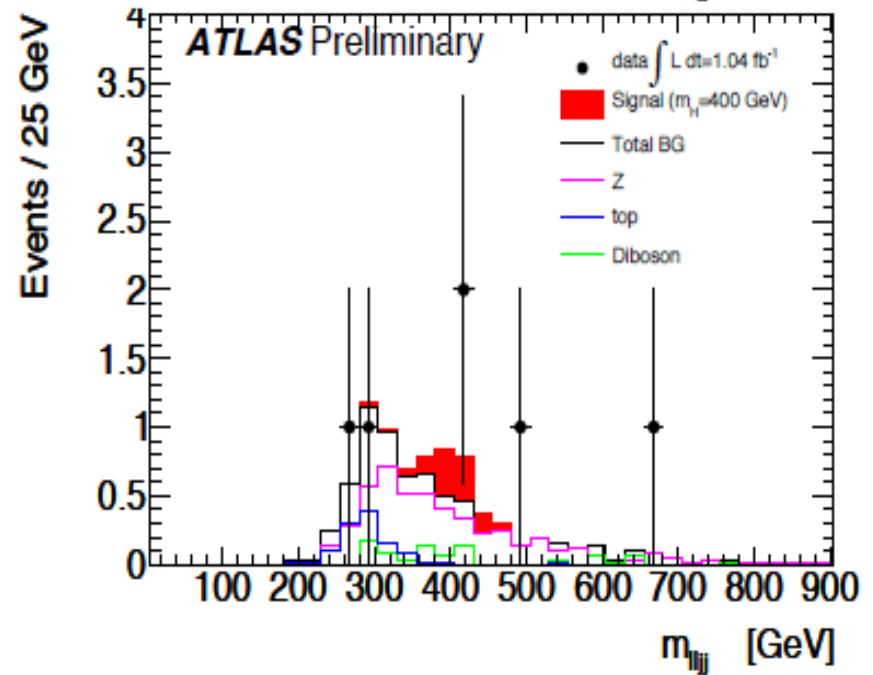


# $llqq$ : results

- Look for bump in dilepton-dijet invariant mass spectrum



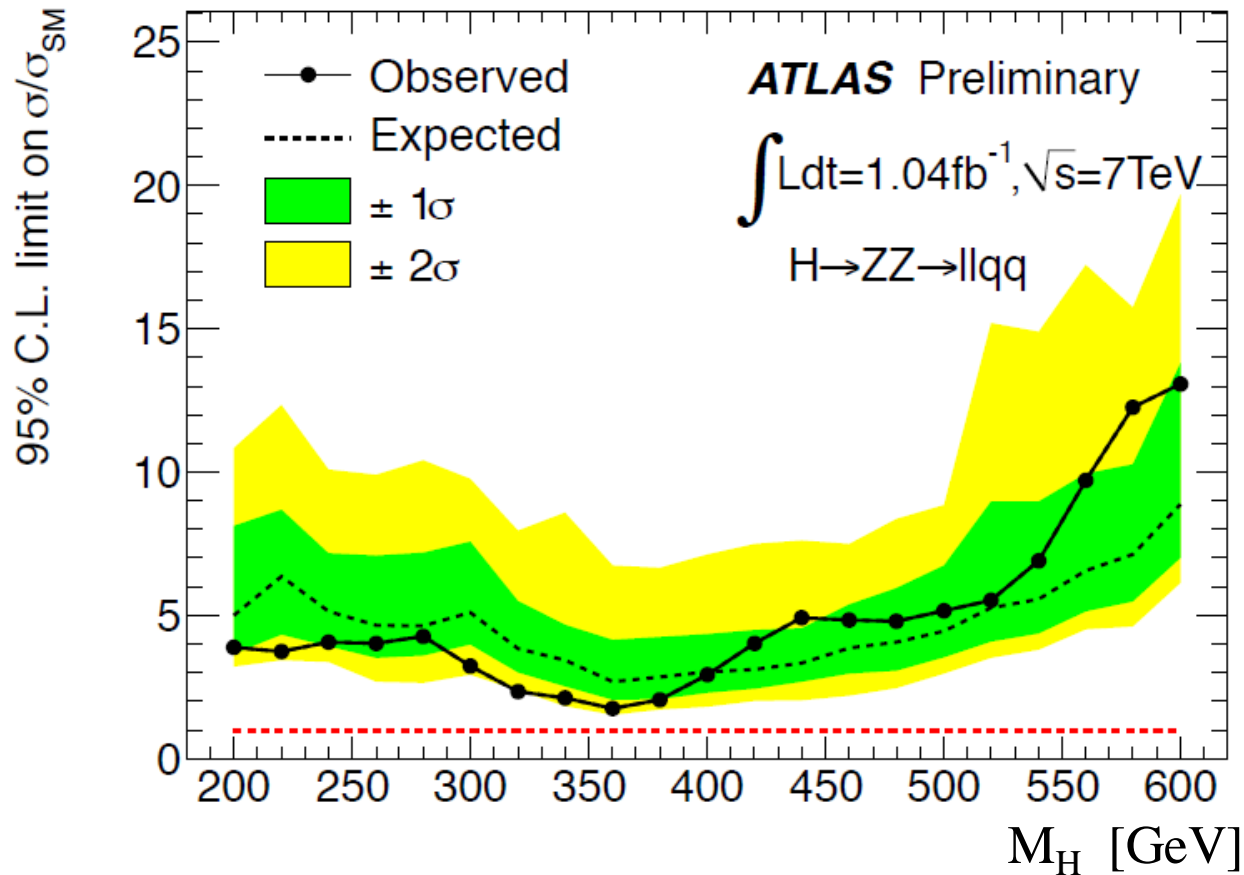
Untagged sample,  $M_H = 400$  GeV



Tagged sample,  $M_H = 400$  GeV

- Observed spectra consistent with background in both untagged and tagged samples

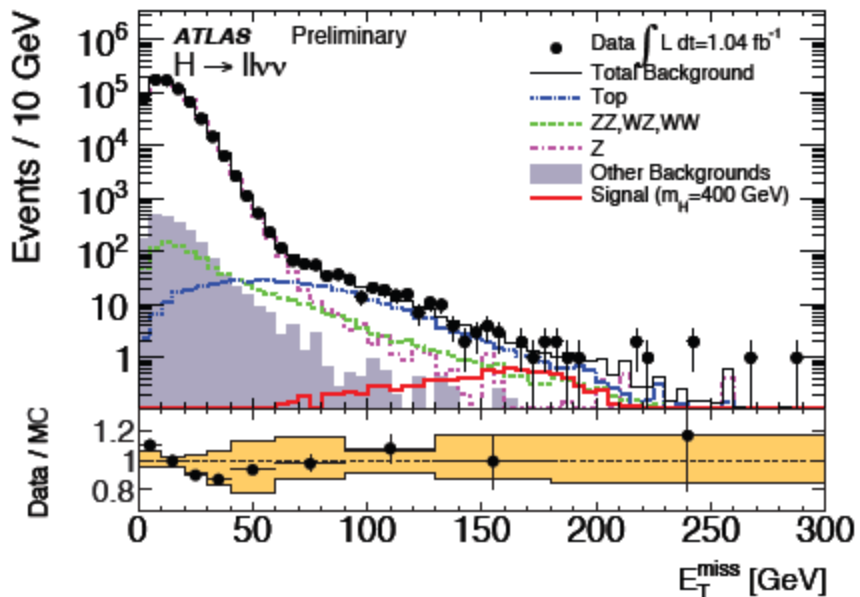
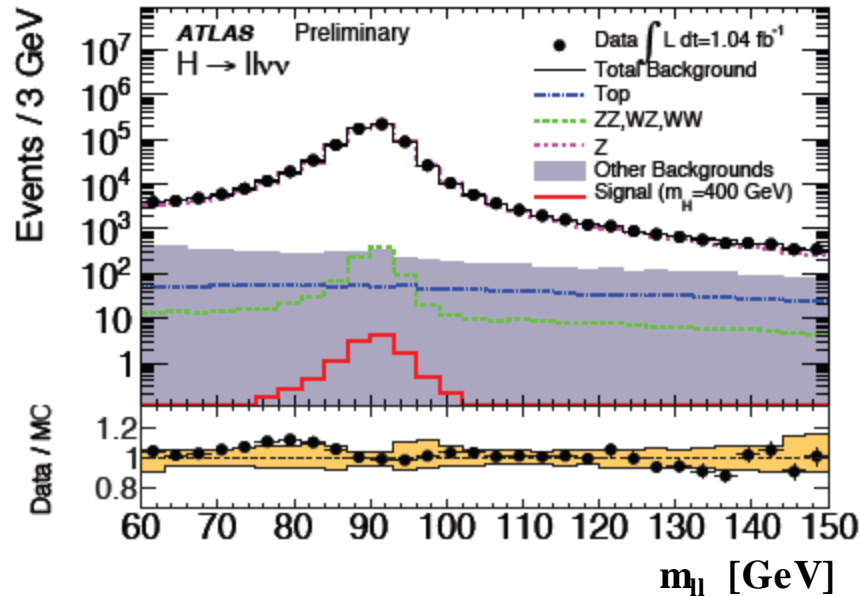
# $llqq$ : limits



- Expected limits 2.7 - 9 times SM cross-section
- Observed limit at 1.7 times SM cross-section around  $M_H = 360$  GeV



# The $H \rightarrow ZZ \rightarrow ll\nu\nu$ channel



- High- $p_T$  lepton pair +  $E_T^{\text{miss}}$  signature
- Search region:  $200 \text{ GeV} < M_H < 600 \text{ GeV}$
- Cuts optimized for low mass ( $M_H < 280 \text{ GeV}$ ) and high mass regions

## Event selection

- Isolated same-flavor lepton pair
- No additional lepton in event
- No  $b$ -tagged jet
- Low mass:  $E_T^{\text{miss}} > 66 \text{ GeV}$ ,  
 $\Delta\phi(j1, E_T^{\text{miss}}) > 0.3, 1 < \Delta\phi_{ll} < 2.64$
- High mass:  $E_T^{\text{miss}} > 82 \text{ GeV}$ ,  
 $\Delta\phi(j1, E_T^{\text{miss}}) > 0.3, \Delta\phi(Z, E_T^{\text{miss}}) > 1,$   
 $\Delta\phi_{ll} < 2.25$

# $ll\nu\nu$ : backgrounds

Main backgrounds: *Top, diboson*

*Diboson*: MC-derived,  $\sim 10\%$  theory uncertainty

*Top*: MC expectation validated in data using sidebands in  $m_{ll}$  and with  $b$ -jet requirement

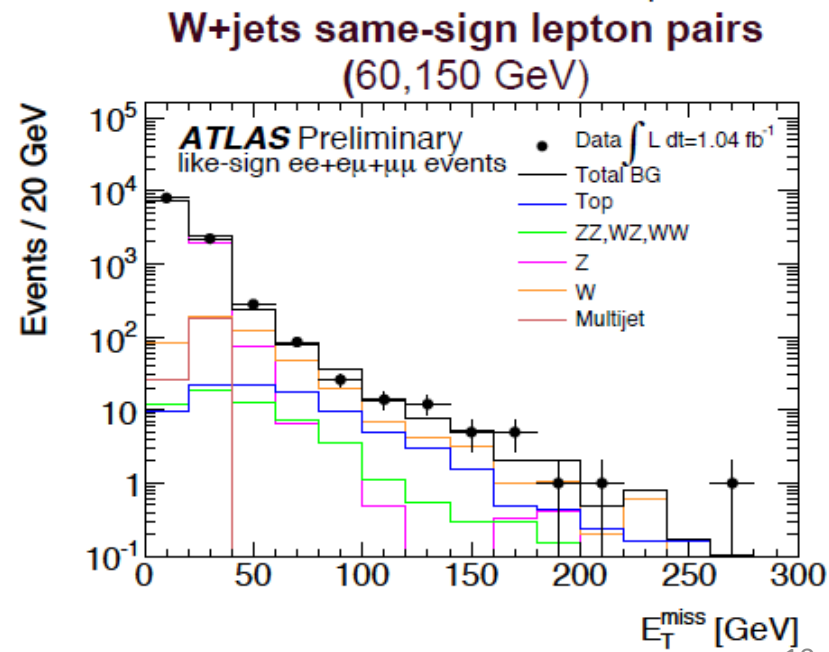
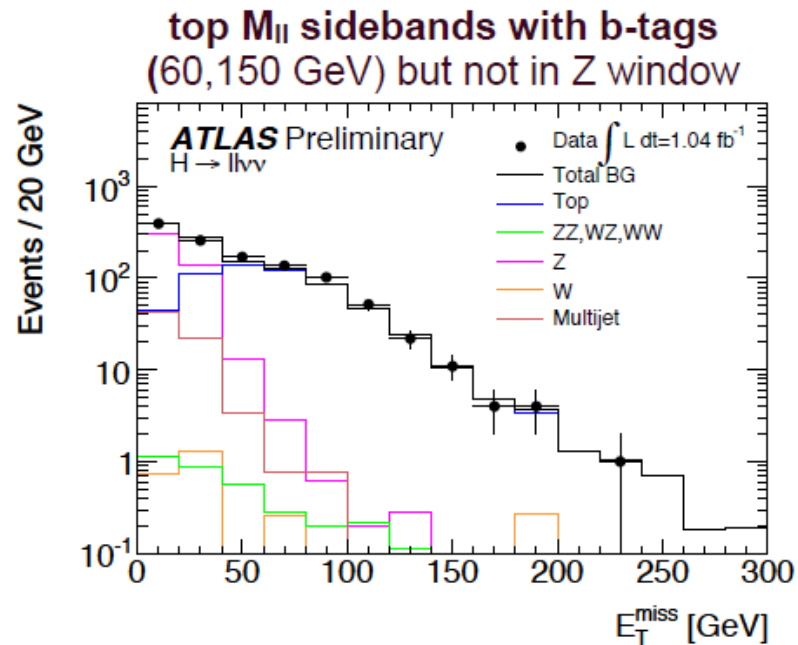
- $\sim 10\%$  theory uncertainty

$W + jets$ : partially data-driven

- MC expectation normalized using  $W + jets$  control region requiring same-sign lepton pairs

*QCD*: small contribution

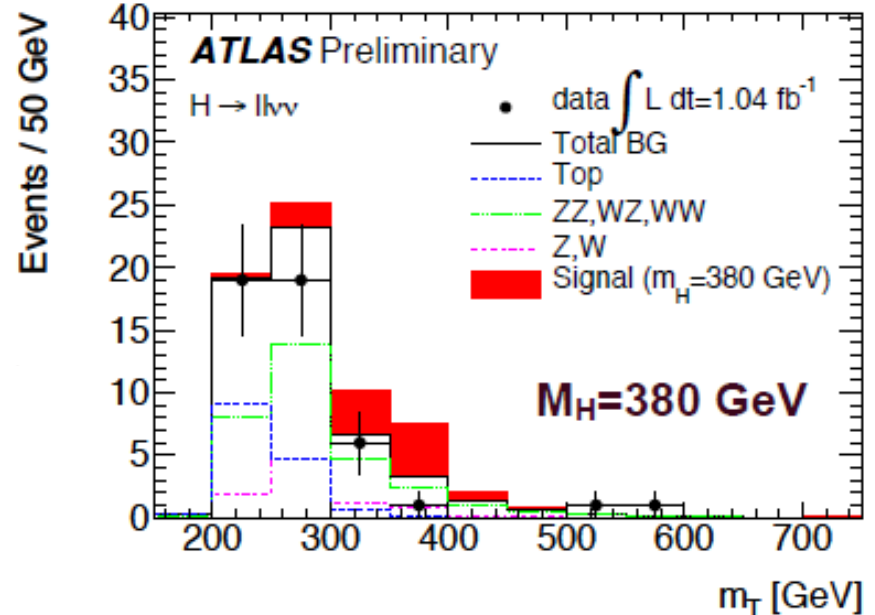
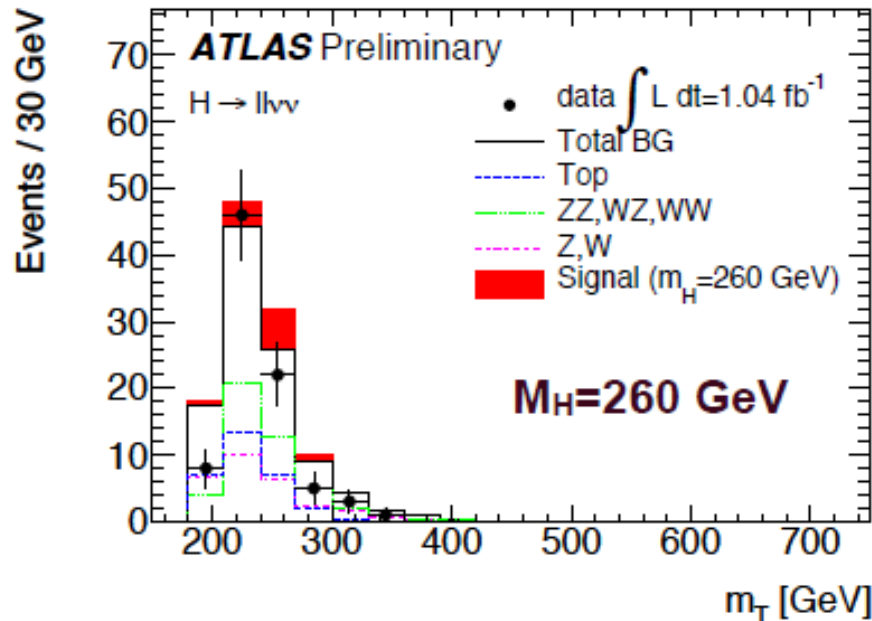
- data-driven techniques used as for  $llqq$



# $ll\nu\nu$ : results

- Look for bump in transverse mass distribution:

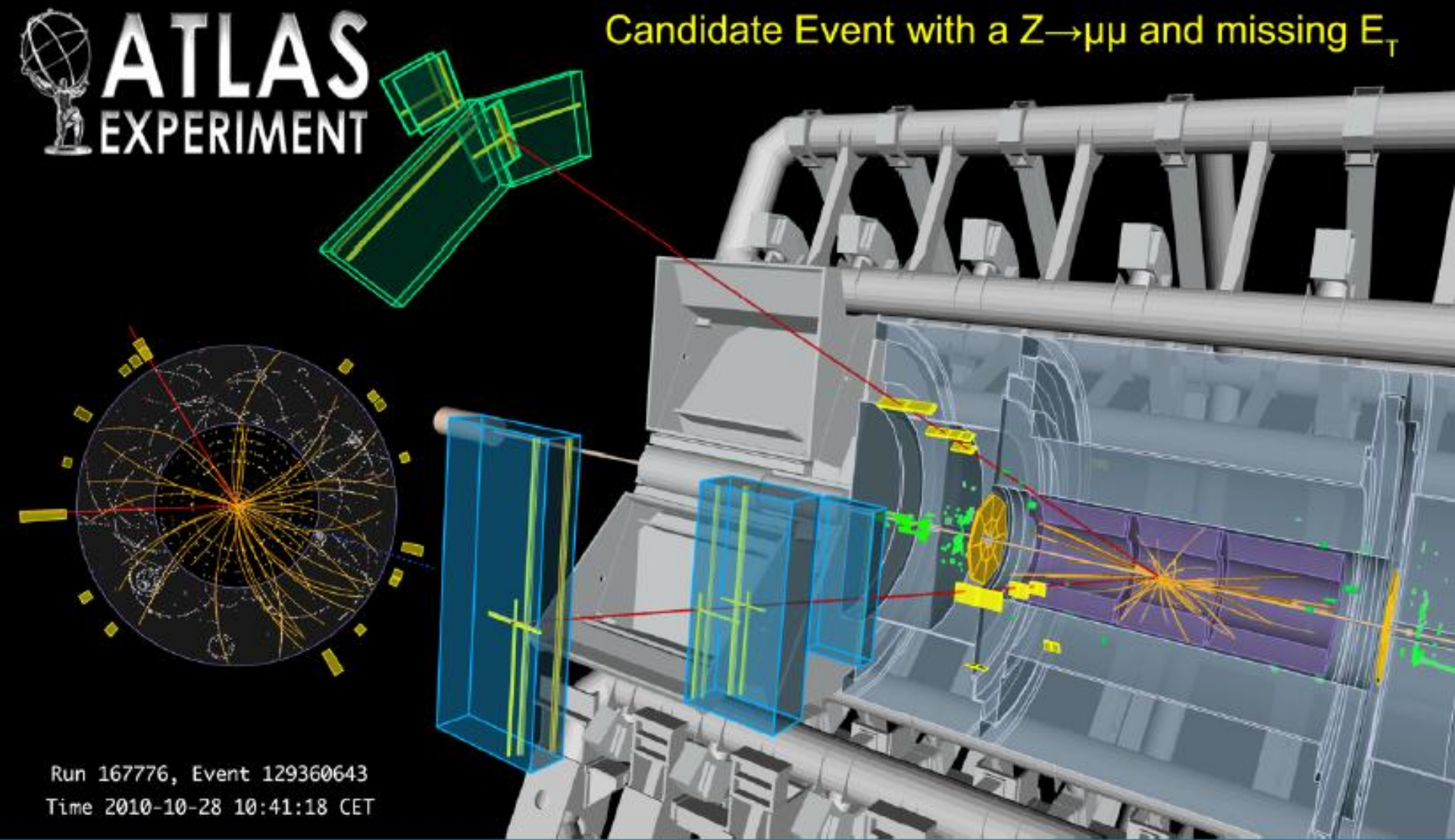
$$m_T^2 \equiv \left[ \sqrt{m_Z^2 + |\vec{P}_T^{ll}|^2} + \sqrt{m_Z^2 + |\vec{P}_T^{miss}|^2} \right]^2 - \left[ \vec{P}_T^{ll} + \vec{P}_T^{miss} \right]^2$$



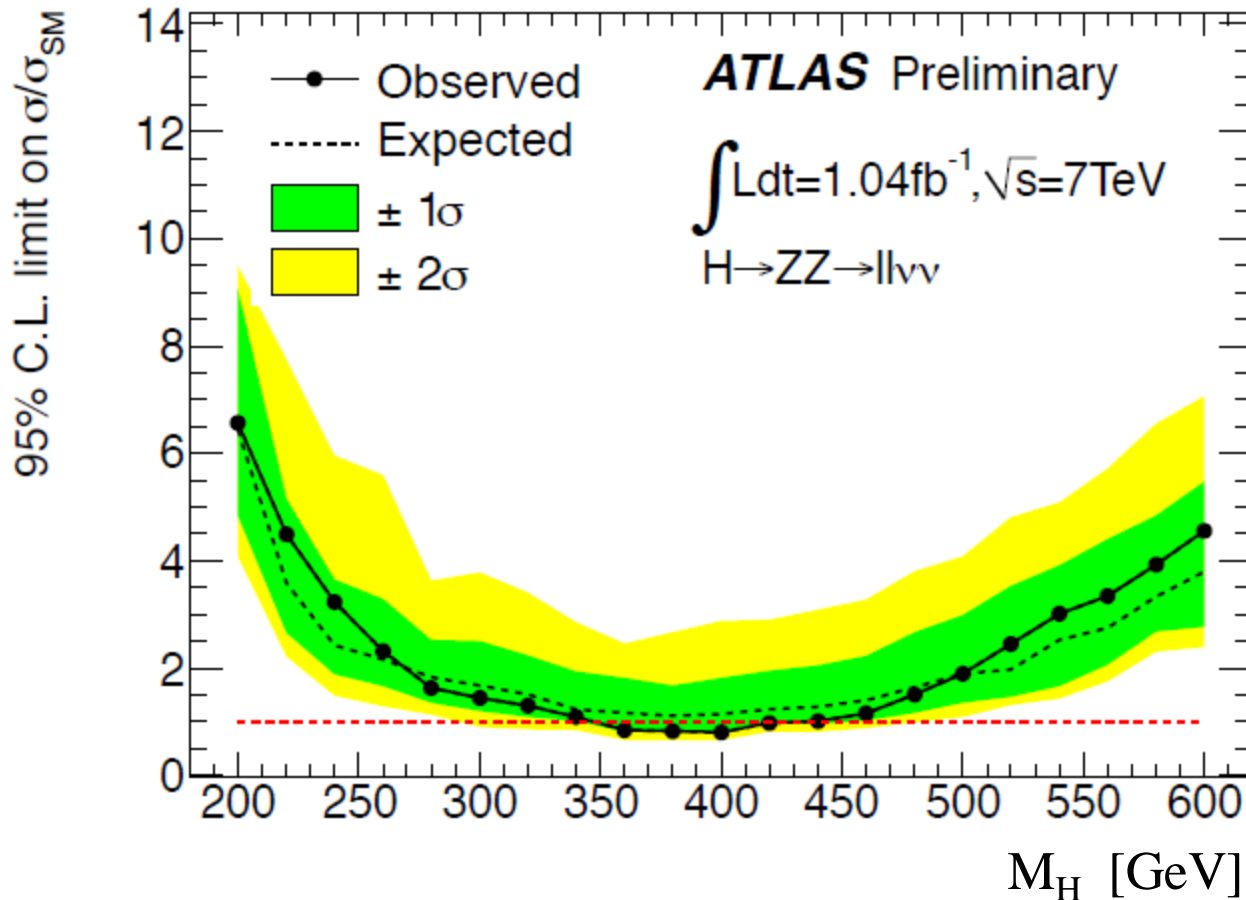
- Observed distributions consistent with background, although a few interesting  $Z + E_T^{\text{miss}}$  events seen

# $ll\nu\nu$ : an event of interest (thanks K. Nicolopoulos)

Candidate event with a Z decay to muon pairs, recoiling against missing- $E_T$ . The muon candidates have transverse momenta of 50 and 126 GeV and a dimuon invariant mass of 94 GeV; the missing  $E_T$  is measured to be 161 GeV.

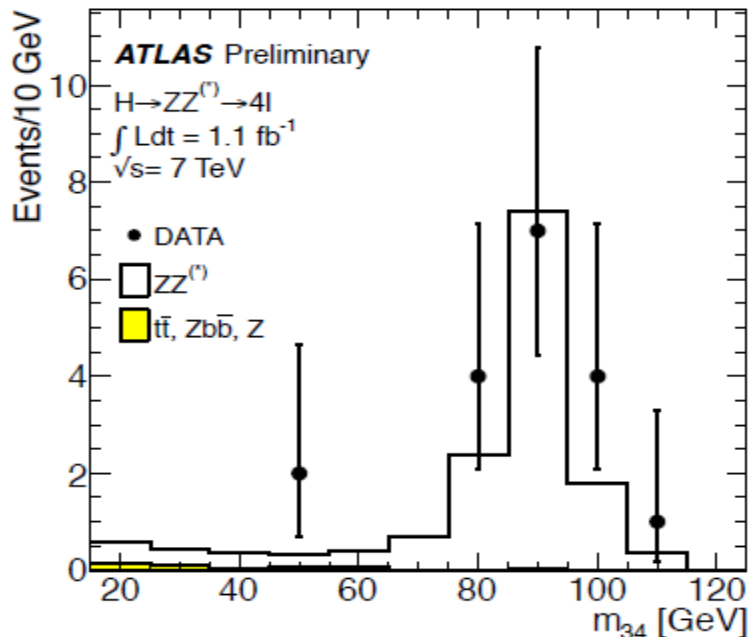
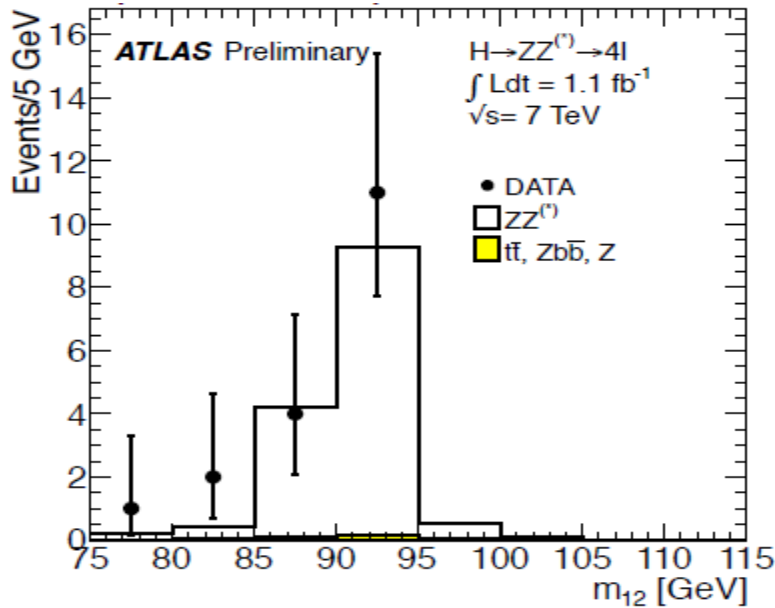


# $ll\nu\nu$ : limits



- Expected limits 1.2 - 7 times SM cross-section
- Observed limits are better: this channel excludes SM Higgs in range  $360 \text{ GeV} < M_H < 420 \text{ GeV}$  at 95% CL

# The $H \rightarrow ZZ \rightarrow llll$ channel



- So-called ‘golden’ channel: small cross-section, but very clean signature
- Search region:  $110 \text{ GeV} < M_H < 600 \text{ GeV}$

## Event selection

- Two pairs of isolated, same-flavor, opposite-sign leptons
- Label leptons with  $m_{ll}$  closest to  $m_Z$  as 1,2, and the other two leptons as 3,4
- $|m_{12} - m_Z| < 15 \text{ GeV}$
- $m_{34} < 115 \text{ GeV}, m_{34} > m_{threshold}$   
with  $m_{threshold}$  defined as a function of the 4-lepton invariant mass  $m_{llll}$
- For  $m_{llll} < 190 \text{ GeV}$ , impact parameter cuts on leptons 3,4

# llll : backgrounds

Main background:  $ZZ \rightarrow 4l$

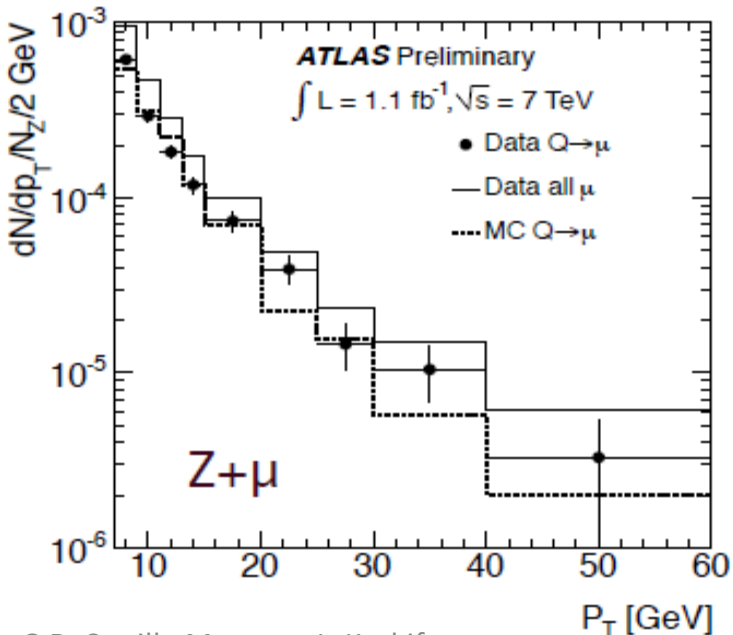
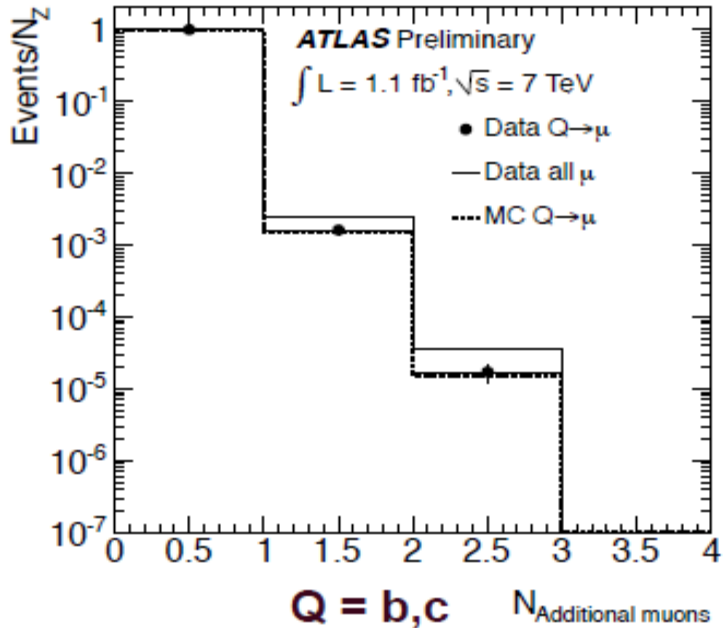
- Normalized using MC
- ~15% theory uncertainty
- Remaining backgrounds are top and  $Z + jets$ , both suppressed by lepton isolation and impact parameter cuts

*Top*: MC expectation validated in data

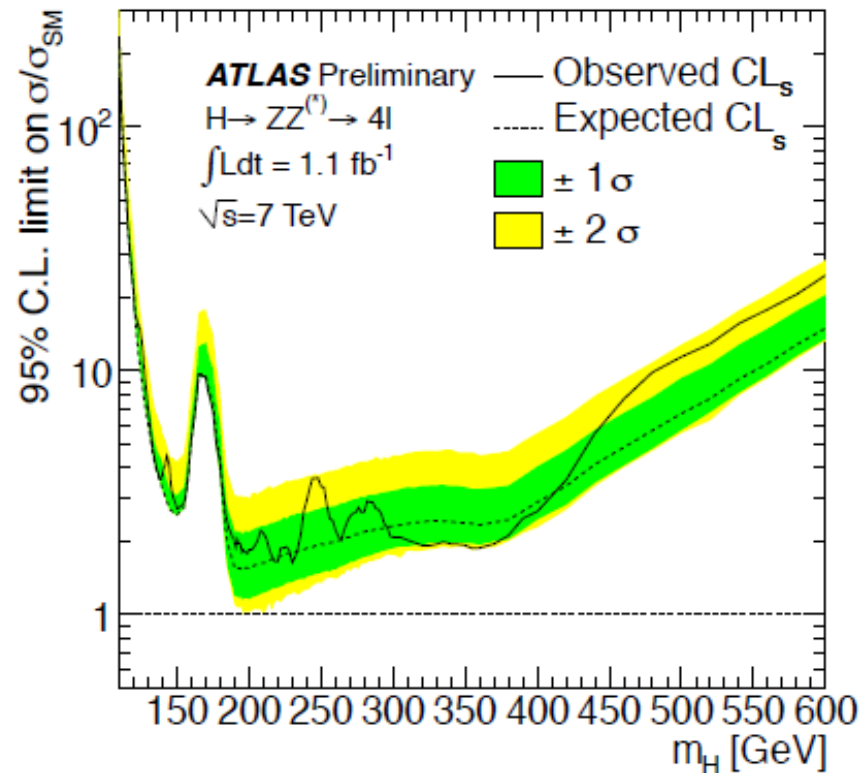
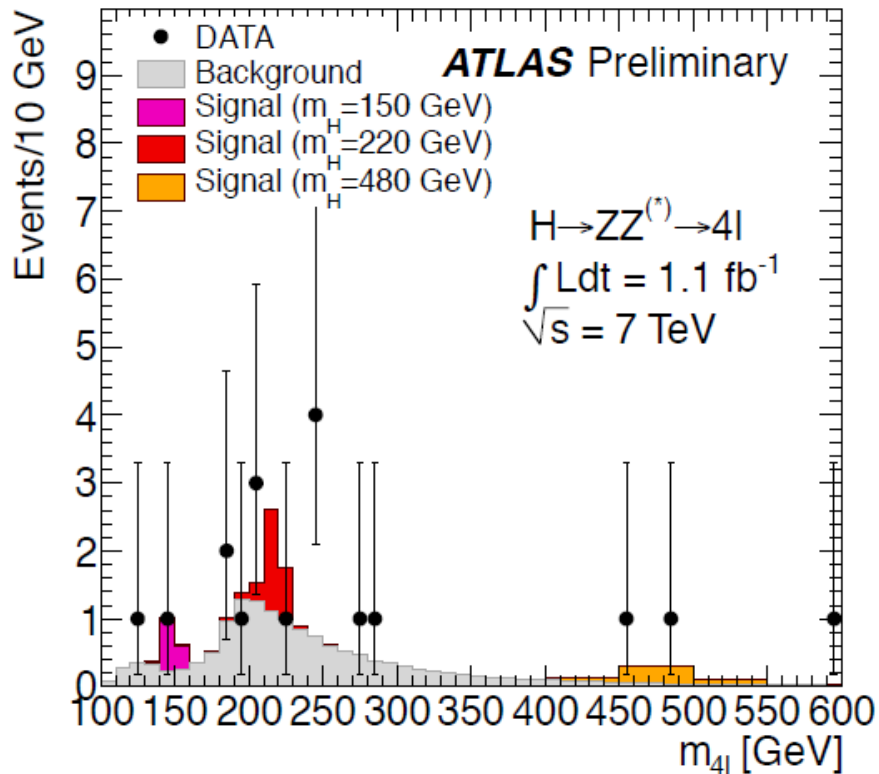
- ~10% theory uncertainty

$Z + jets$ : normalized using control regions

- Defined by eliminating isolation and impact parameter criteria on one lepton pair
- Estimated separately for heavy flavor decay leptons, fake leptons and leptons from EW sources



# llll: results and limit curve



- Observed 4-lepton invariant mass spectrum consistent with background expectation
- Expected limit  $\sim 1.8$  times SM cross-section at  $M_H = 200 \text{ GeV}$
- Some fluctuations in observed limit due to single events



# Conclusion and outlook

- We have presented ATLAS Higgs search results in three final states from the  $H \rightarrow ZZ^{(*)}$  decay
- The channels are mostly sensitive for  $M_H > 200$  GeV, except 4-lepton channel which has sensitivity at lower masses
- The  $H \rightarrow ZZ \rightarrow ll\nu\nu$  channel **excludes** Standard Model Higgs in mass range  $360 \text{ GeV} < M_H < 420 \text{ GeV}$  at 95% confidence level
- The LHC is increasing our dataset fast  
→ expect new results soon
- Analysis improvements meanwhile

ATLAS SM Higgs combination

