Search for the Higgs Boson in the ZZ Decay Channels in ATLAS

LHC@BNL Workshop
October 1, 2012

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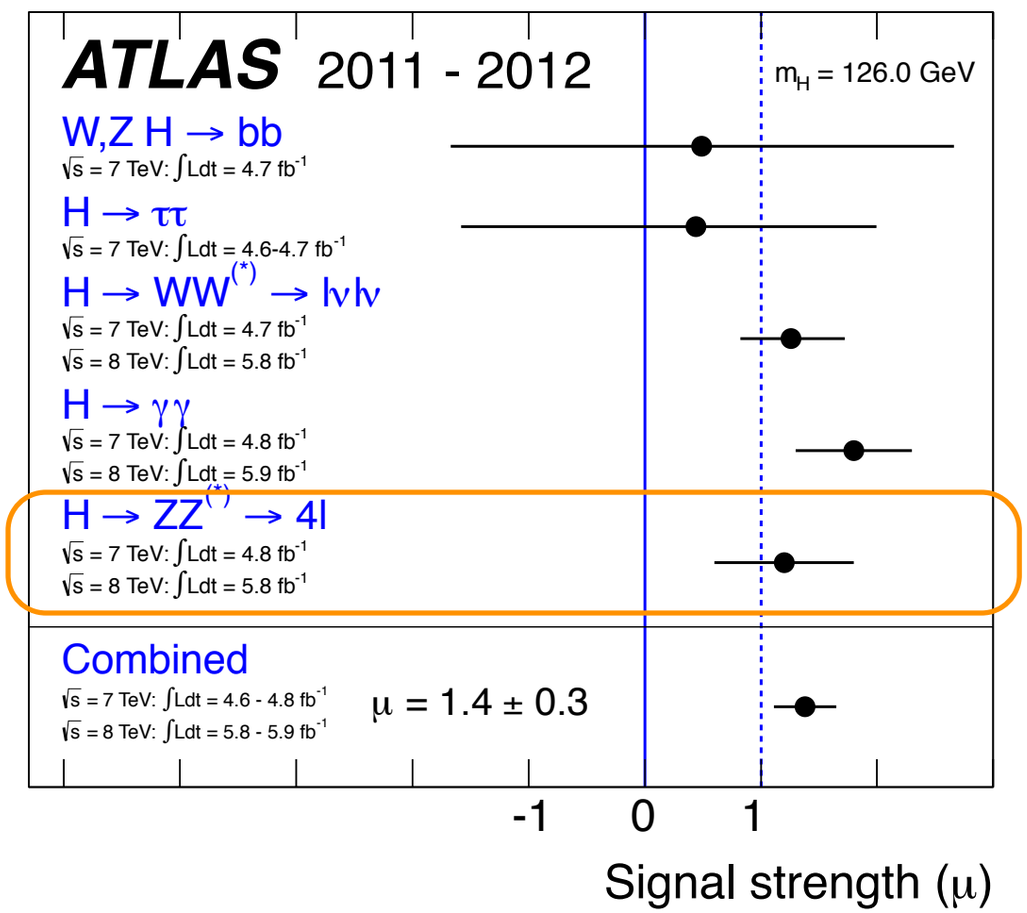
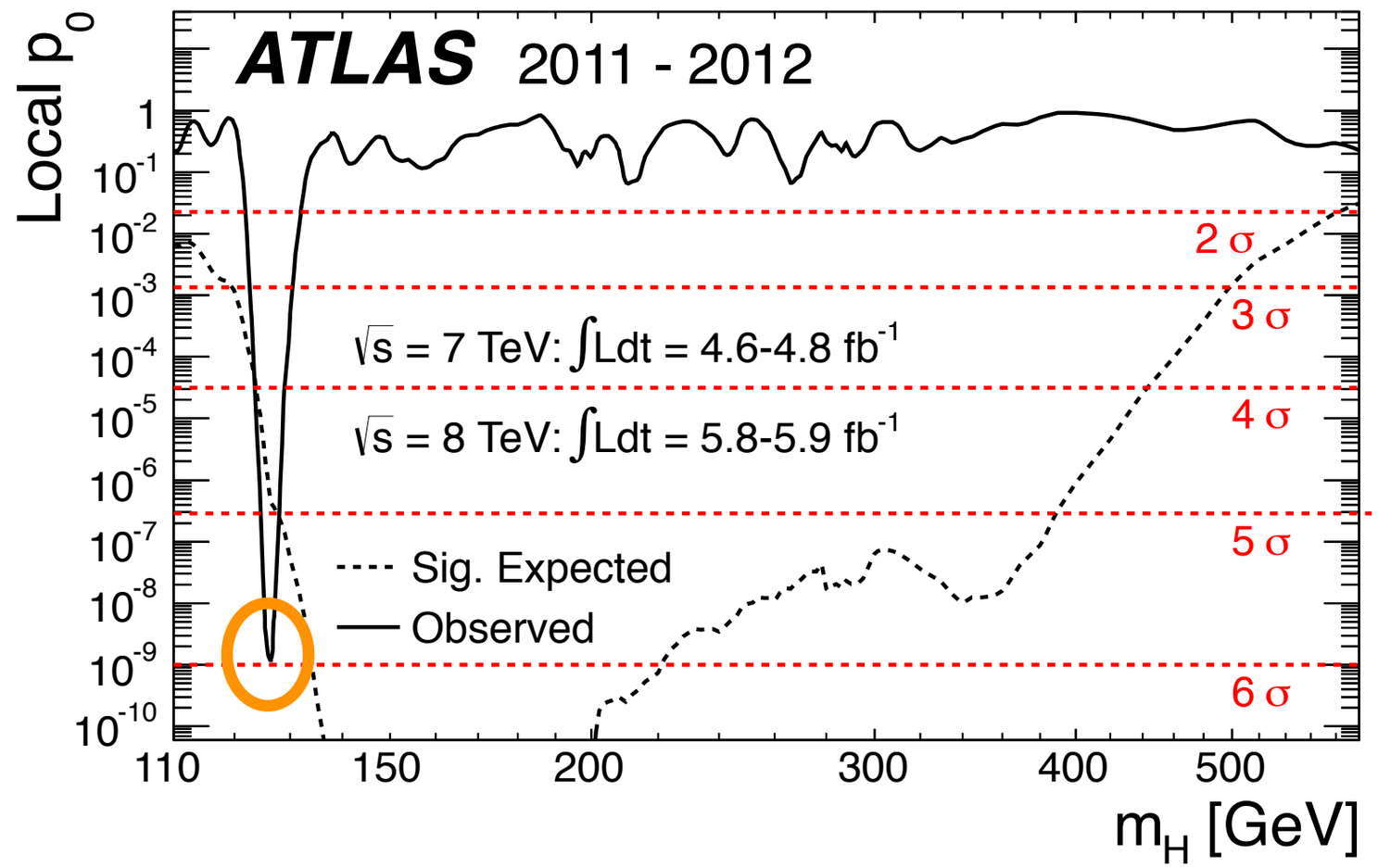
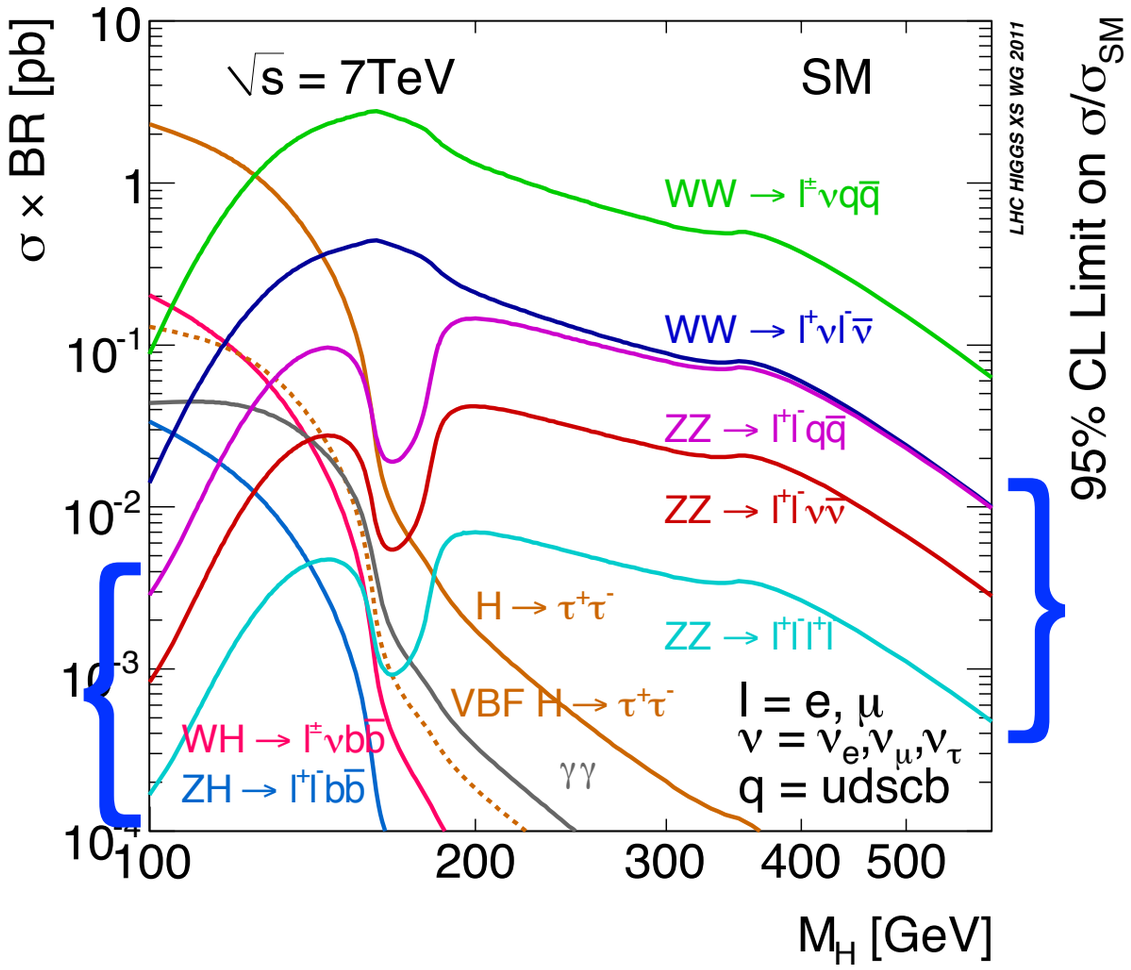
~ Dawn of the New Era ~

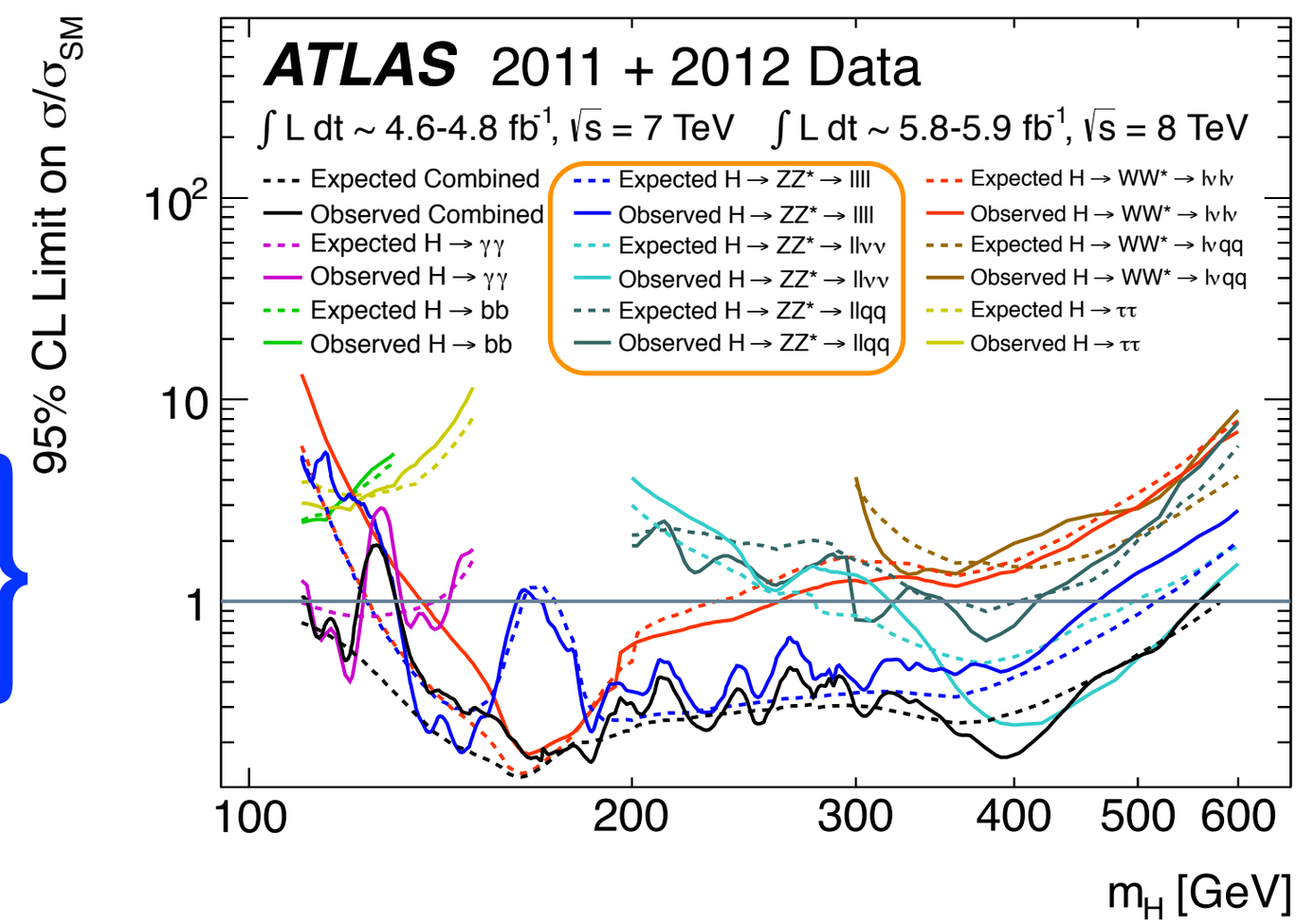




- **Observation of a new particle at ~126 GeV**
- **ATLAS observed a 5.9σ deviation with combined results (3.6σ from H→ZZ(*)→4l only) compatible with SM Higgs boson**

H→ZZ(*)

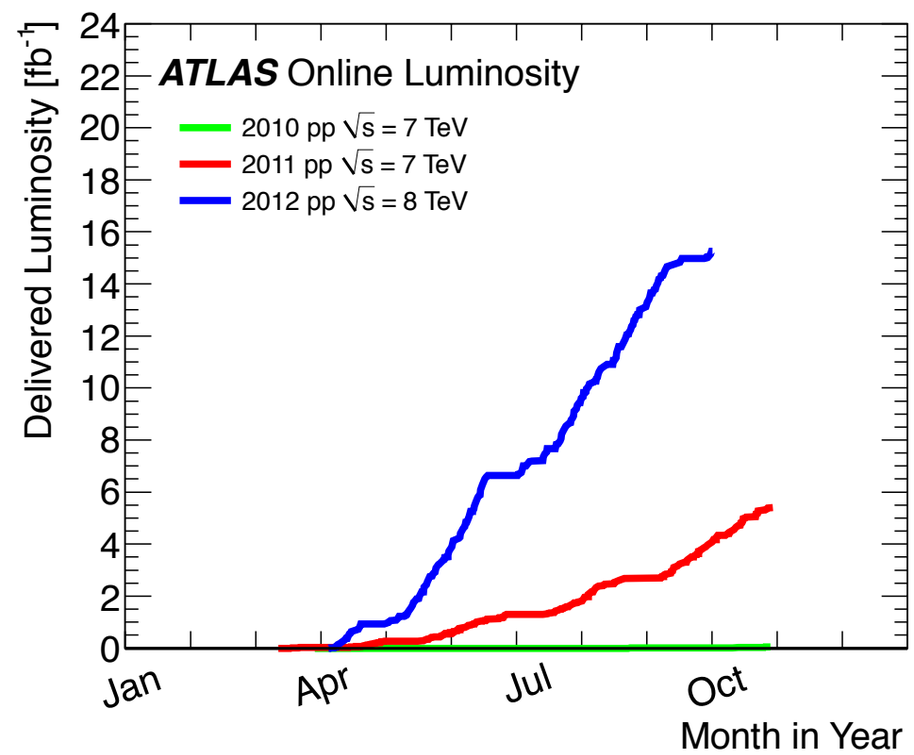


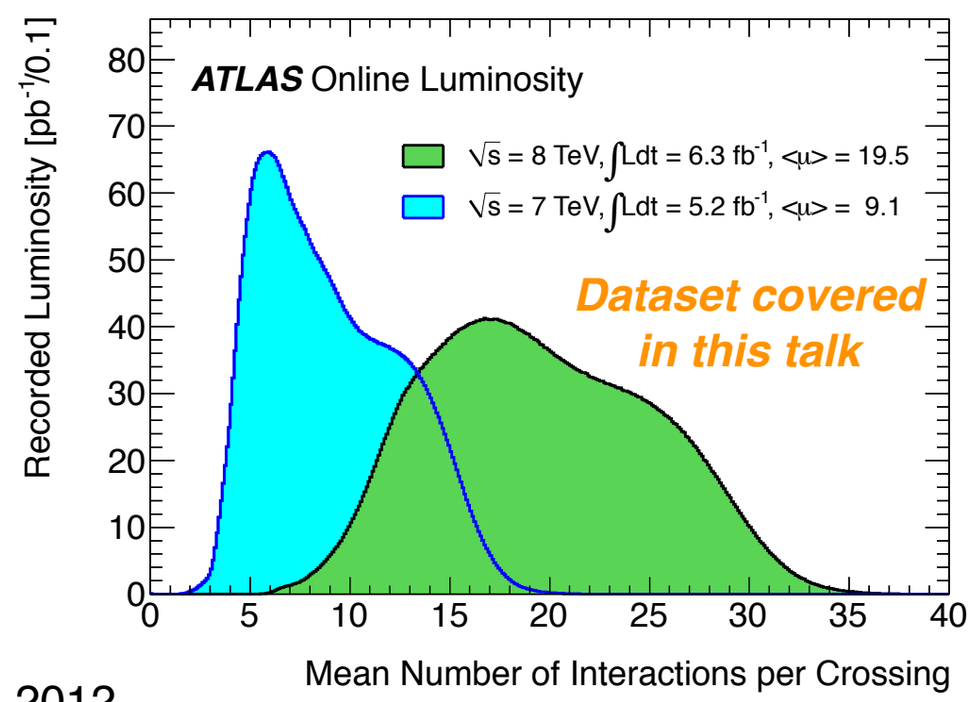


- H→ZZ(*) channels have high sensitivities over wide mass ranges
- **H→ZZ(*)→4l :** a very good mass resolution with clean signature.
  llqq : high event yield but challenging for low mass region due to large BG.
  llνν : one of the best sensitivities in high mass region.

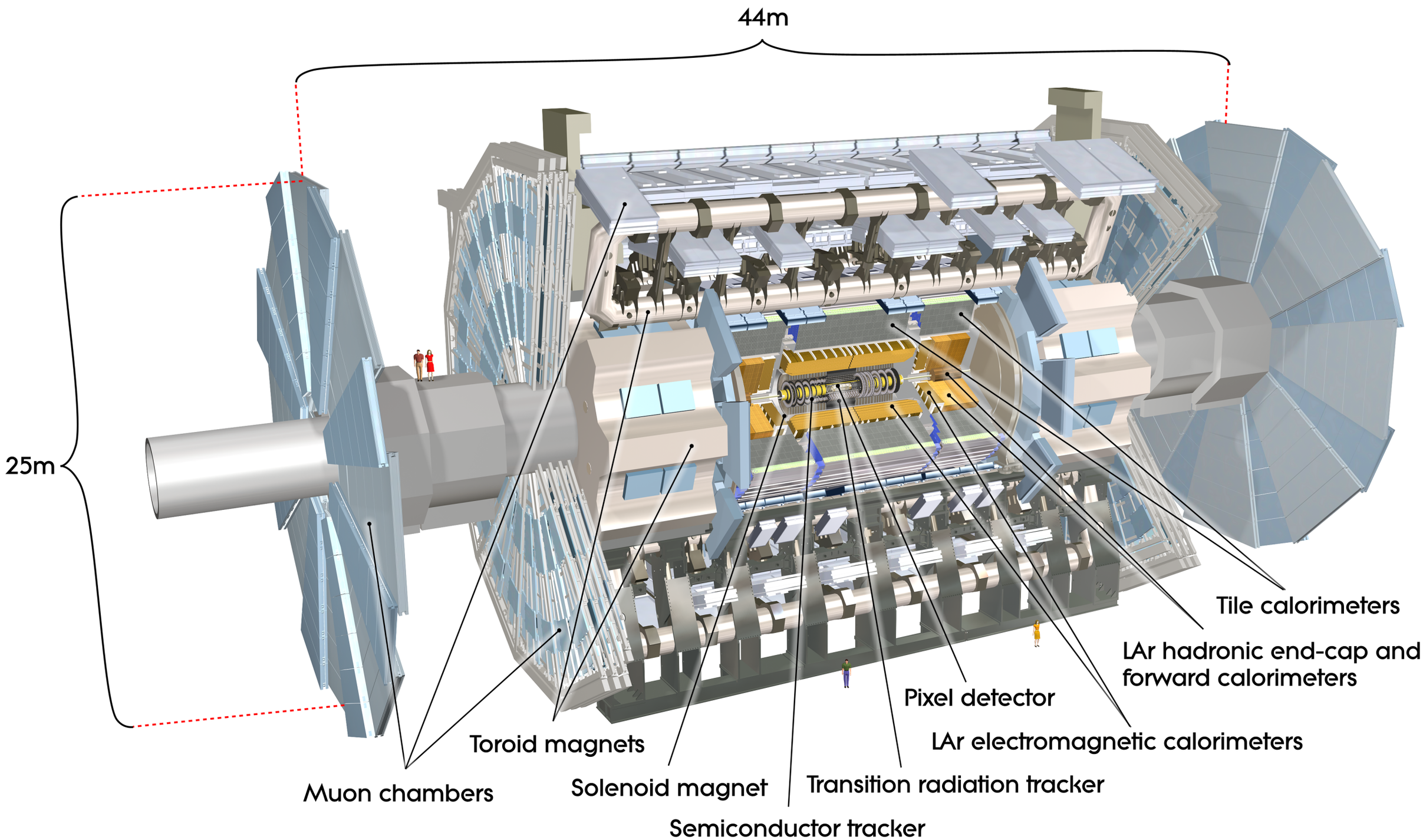
LHC & Dataset

- **√s=7 TeV data (2011)**
  - 5.2 fb^{-1} recorded, **4.7-4.8 fb^{-1} for analyses** (~90%)
  - Peak stable luminosity $3.6 \times 10^{33} cm^{-2} s^{-1}$
- **√s=8 TeV data (2012)**
  - 6.3 fb^{-1} recorded until Jun. 18, **5.8 fb^{-1} for analyses** (~92%)
  - Peak stable luminosity $6.8 \times 10^{33} cm^{-2} s^{-1}$
  - The latest is recorded luminosity is 14.0 fb^{-1} as of Sep. 17, 2012
- It is crucial that the performance is under control even with the high pileup conditions





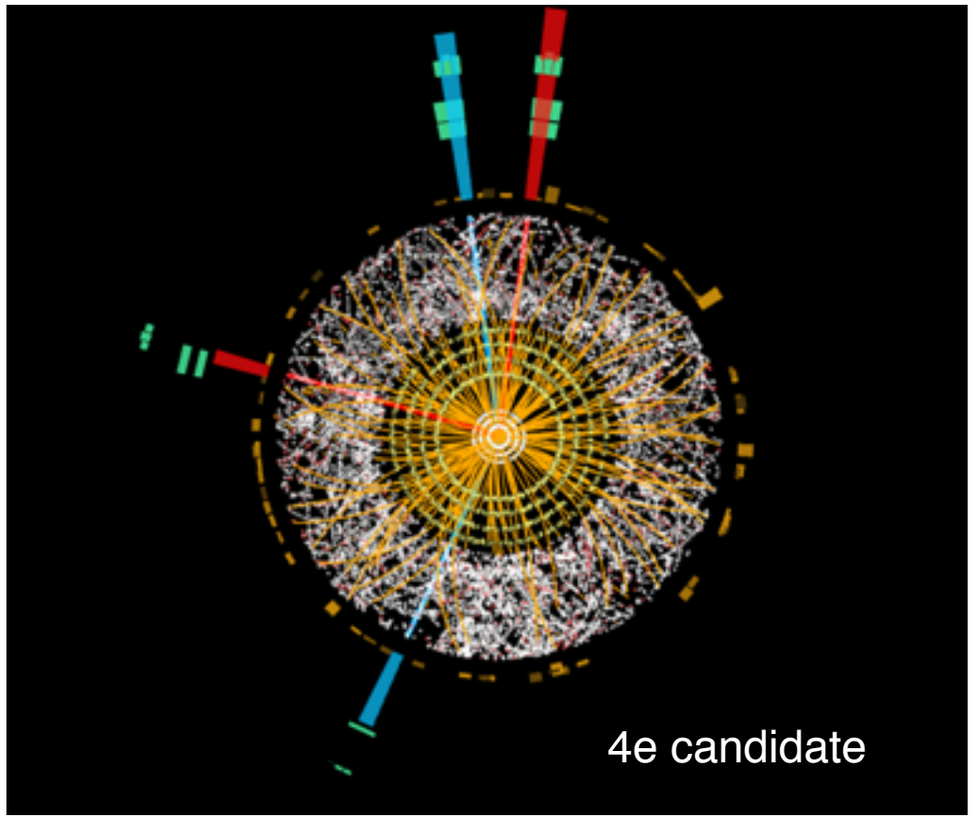
ATLAS Detector



$H \rightarrow ZZ^{(*)} \rightarrow 4l$

(2011+2012)

$H \rightarrow ZZ^{(*)} \rightarrow 4l$ Event Selection



- Single & dilepton triggers
- Require two same-flavor opposite lepton pairs
  - Electrons: p_T>7 GeV, $|\eta|$<2.47; isolated; from IP
  - Muons: p_T>6 GeV, $|\eta|$<2.7; isolated; from IP
- Leading lepton $p_T^{1,2,3}$>20,15,10 GeV

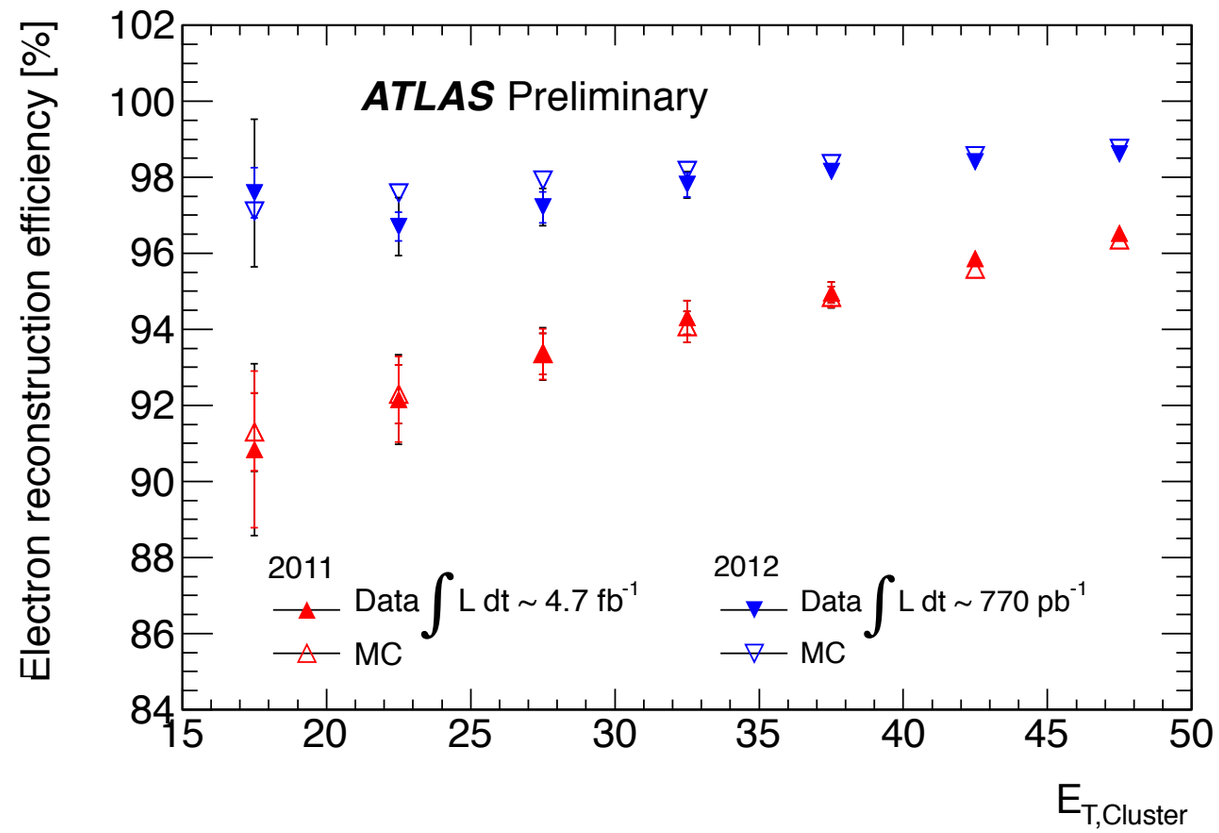
- 50 GeV < m_{12} < 106 GeV, $m_{thr}(m_{4l})$< m_{34} < 115 GeV, m_{thr}=17.5-50 GeV
- All same-flavor opposite sign pairs m_{ll}>5 GeV
- dR(l,l') > 0.1 (0.2) for all same (opposite)-flavor

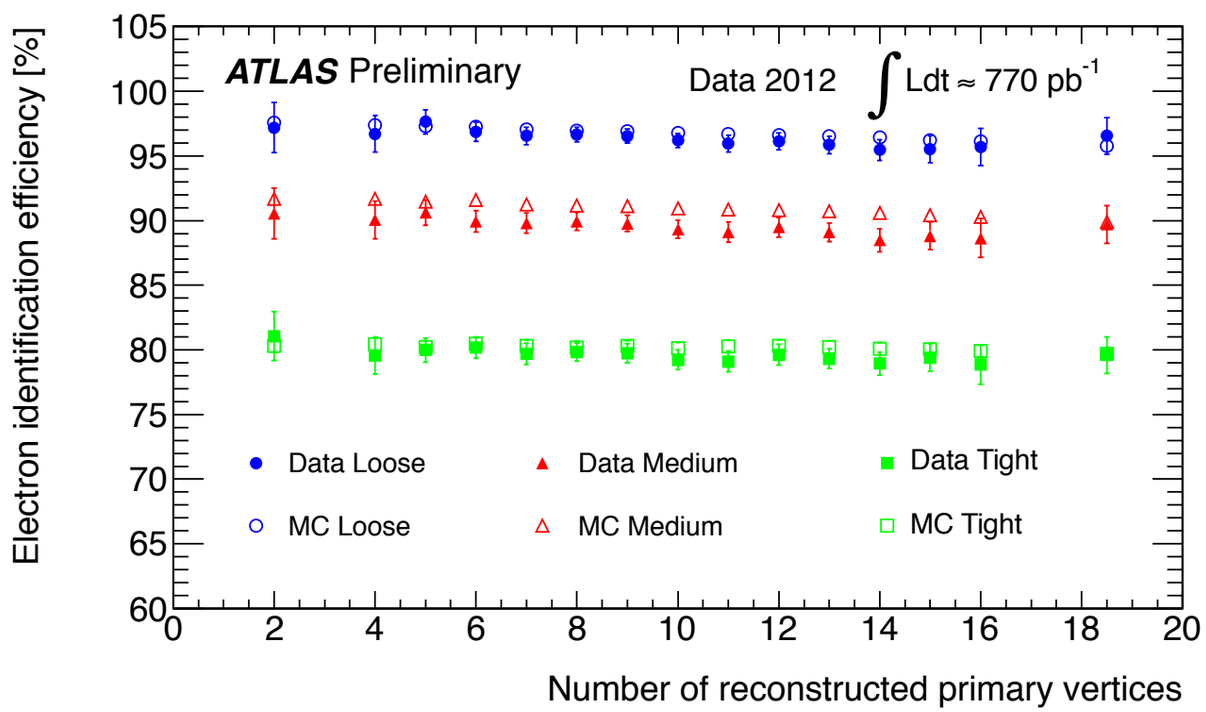
Main BG: irreducible $ZZ^{(*)}$, reducible Z+jets & ttbar

Electron Reconstruction

Electrons

- Improvement in the electron reconstruction in 2012. Better recovery of bremsstrahlung especially in the low-p_T region.



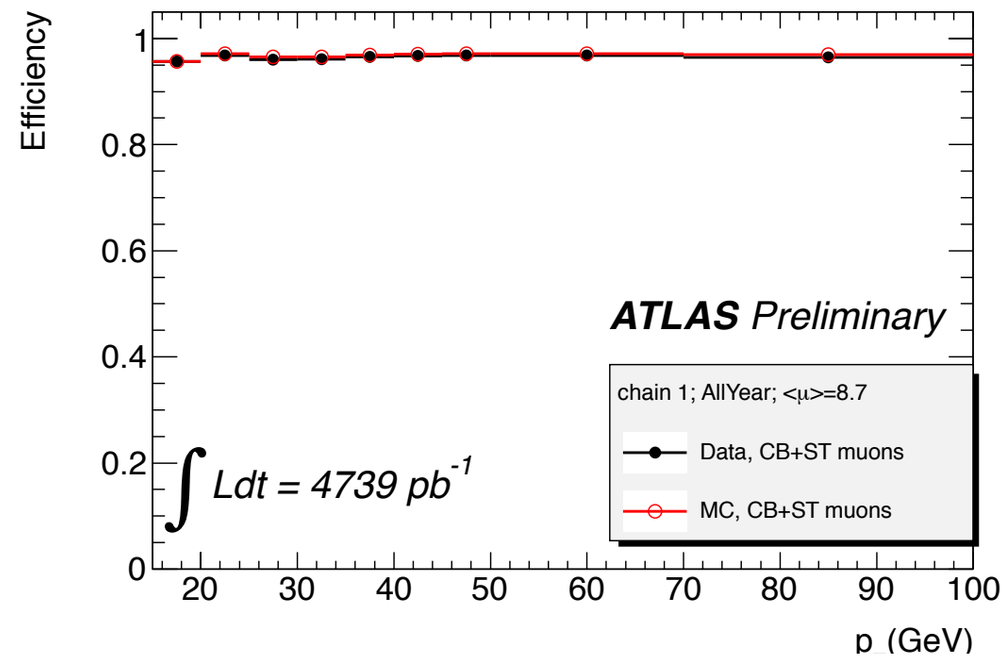


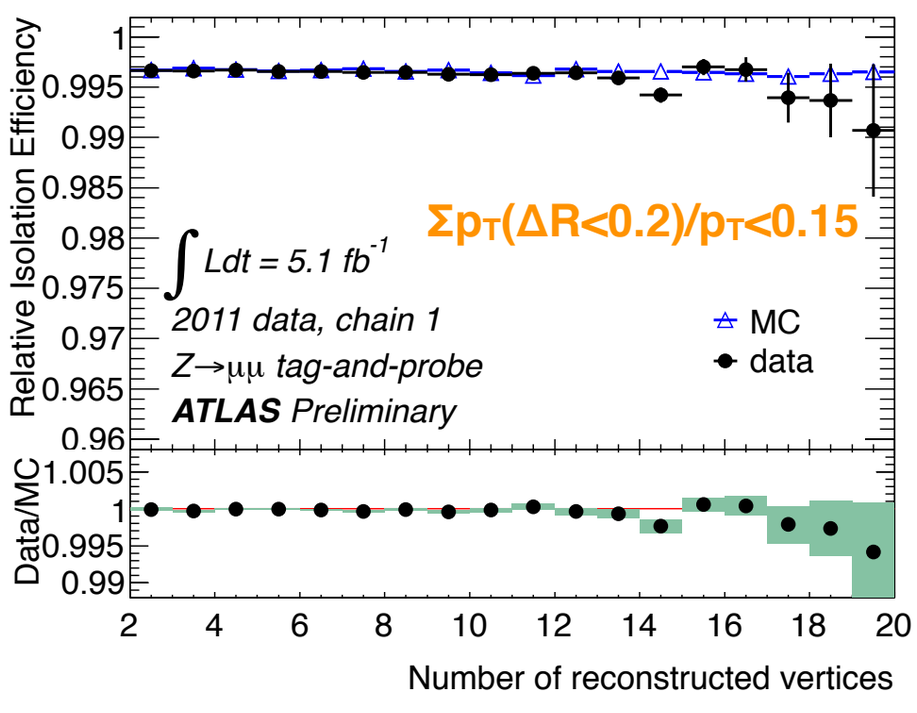
- Electron identification efficiency is stable against pileup

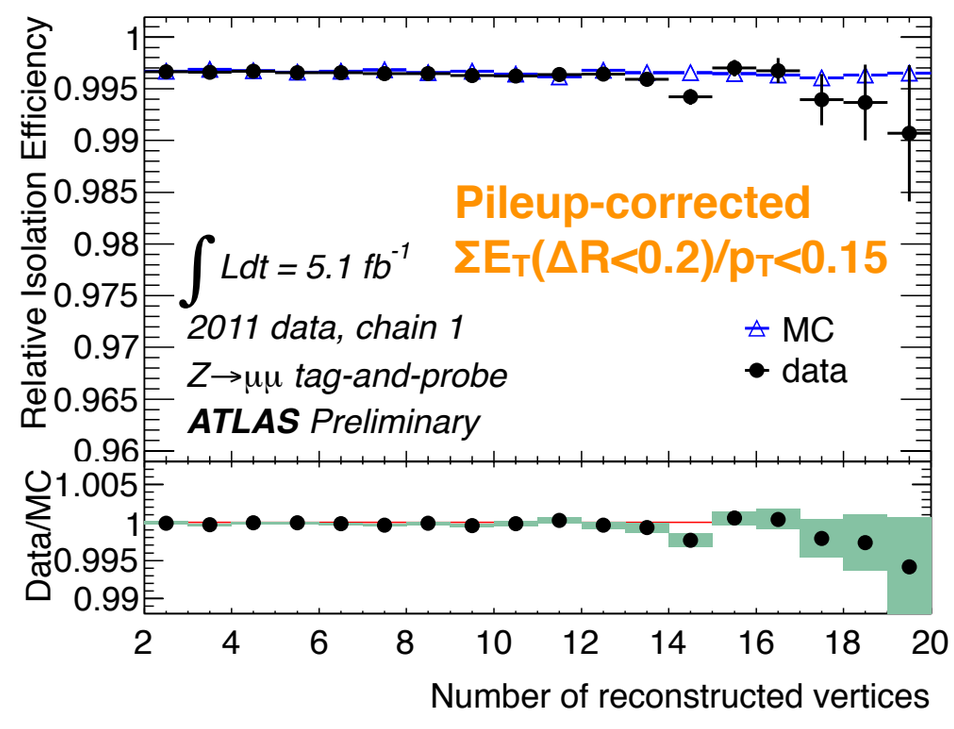
Muon Reconstruction

Muons (Staco)

- Very good & flat efficiency throughout the p_T range
- Track & calorimeter isolations are stable against pileup

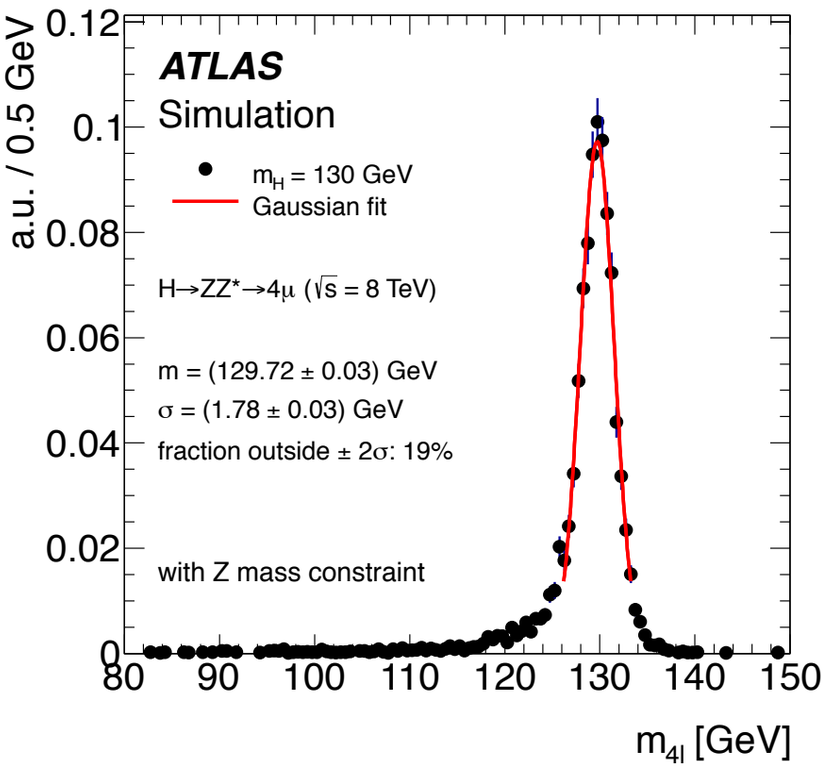




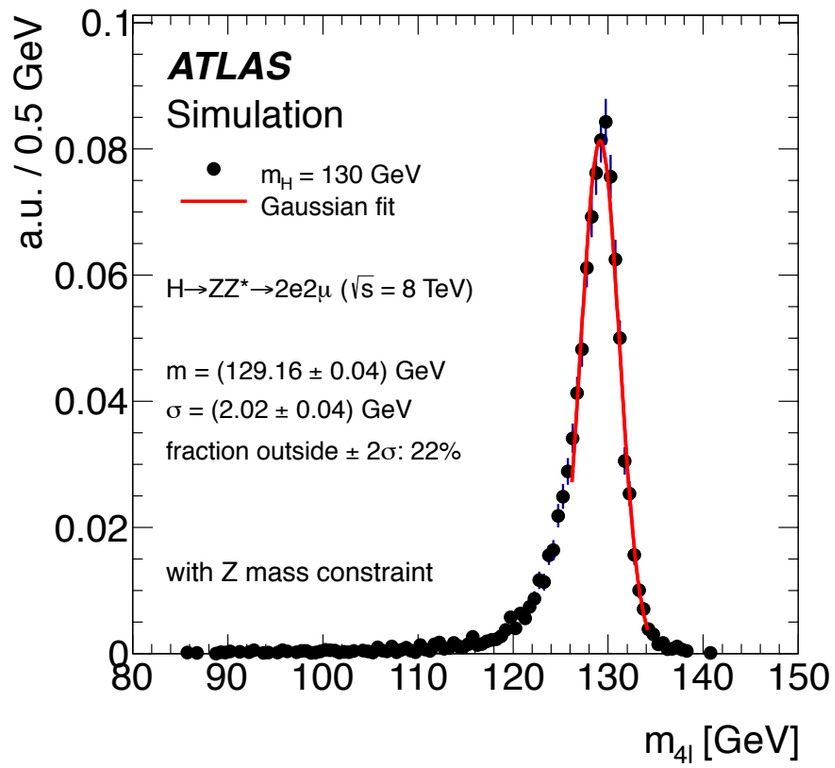


Mass Resolution

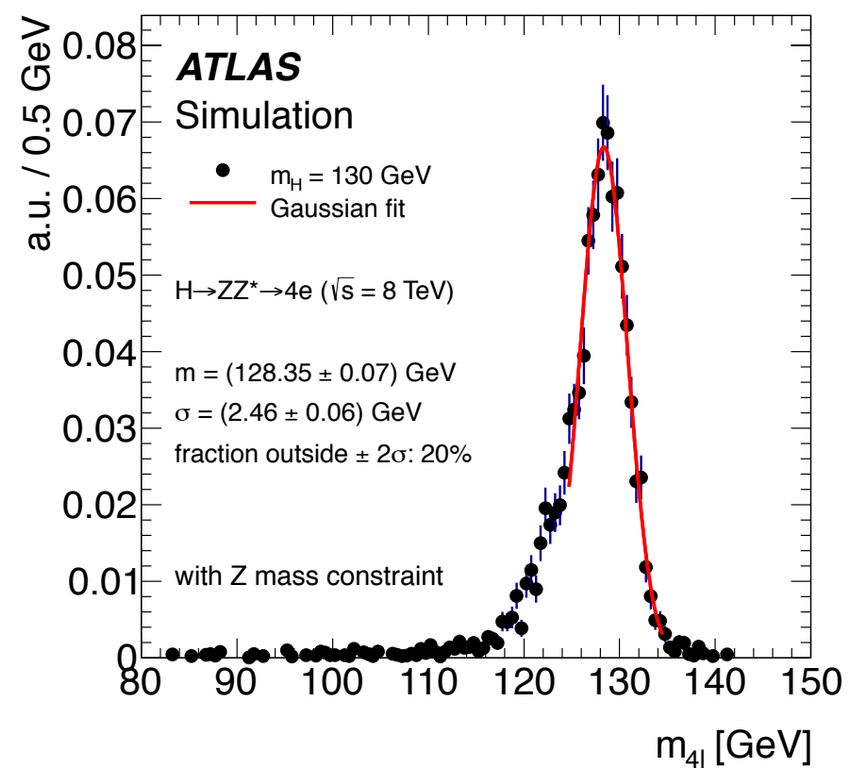
$H \rightarrow ZZ^{(*)} \rightarrow 4\mu$



$H \rightarrow ZZ^{(*)} \rightarrow 2e2\mu/2\mu2e$



$H \rightarrow ZZ^{(*)} \rightarrow 4e$



- Excellent mass resolution allowing for good sensitivity
- Relative mass resolution of ~1-2% for m_H=130 GeV
- Further improved by applying m_Z constraint on the leading dilepton

2l+2μ Background

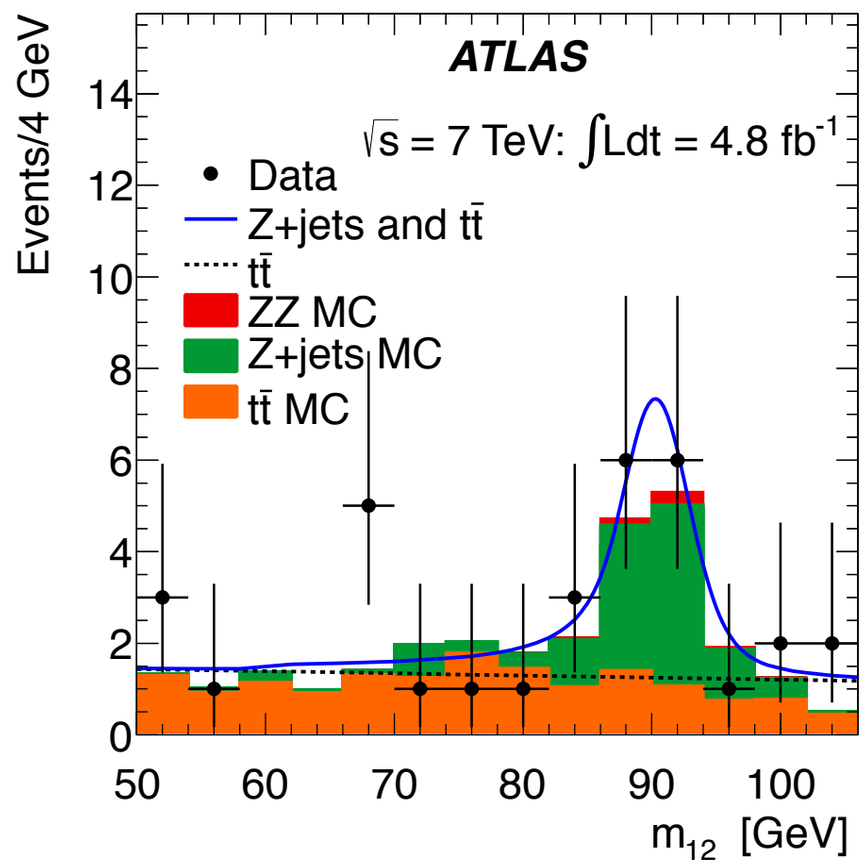
Main contributions:
Zbb & ttbar

Control Region:

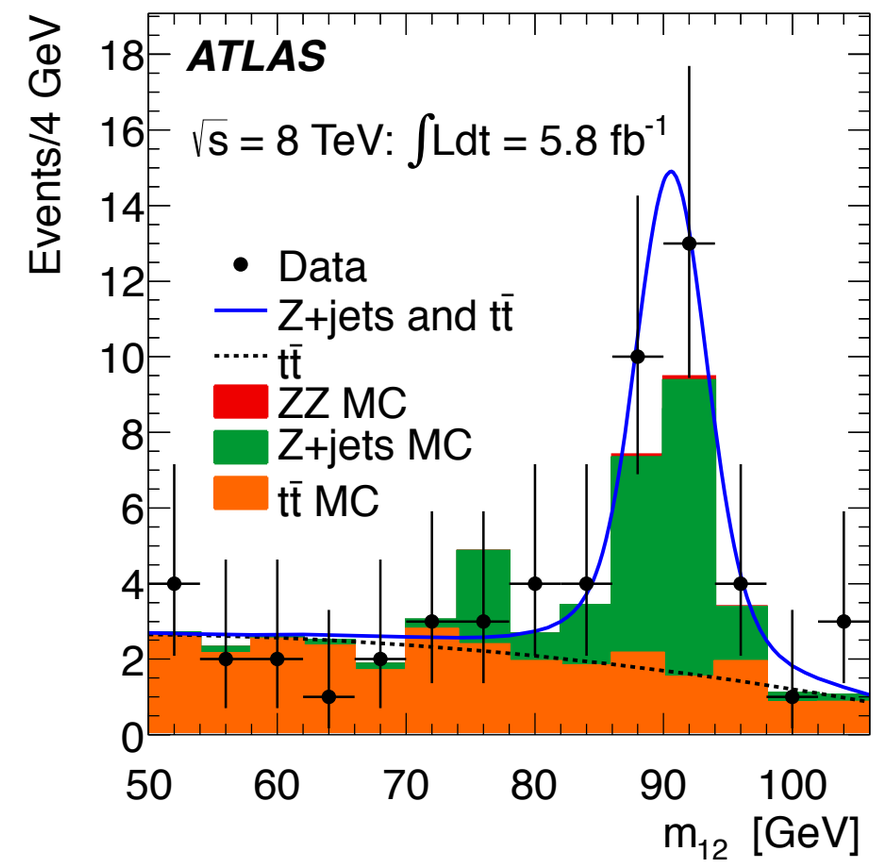
For sub-leading dimuon

- Remove isolation requirements
- Remove IP significance cut (suppress ZZ contribution)

7 TeV



8 TeV



- The shapes from MC are used for the fits, and transfer factor is appied to the MC in the signal region.
- Alternative method to use eμ+2μ control region for ttbar

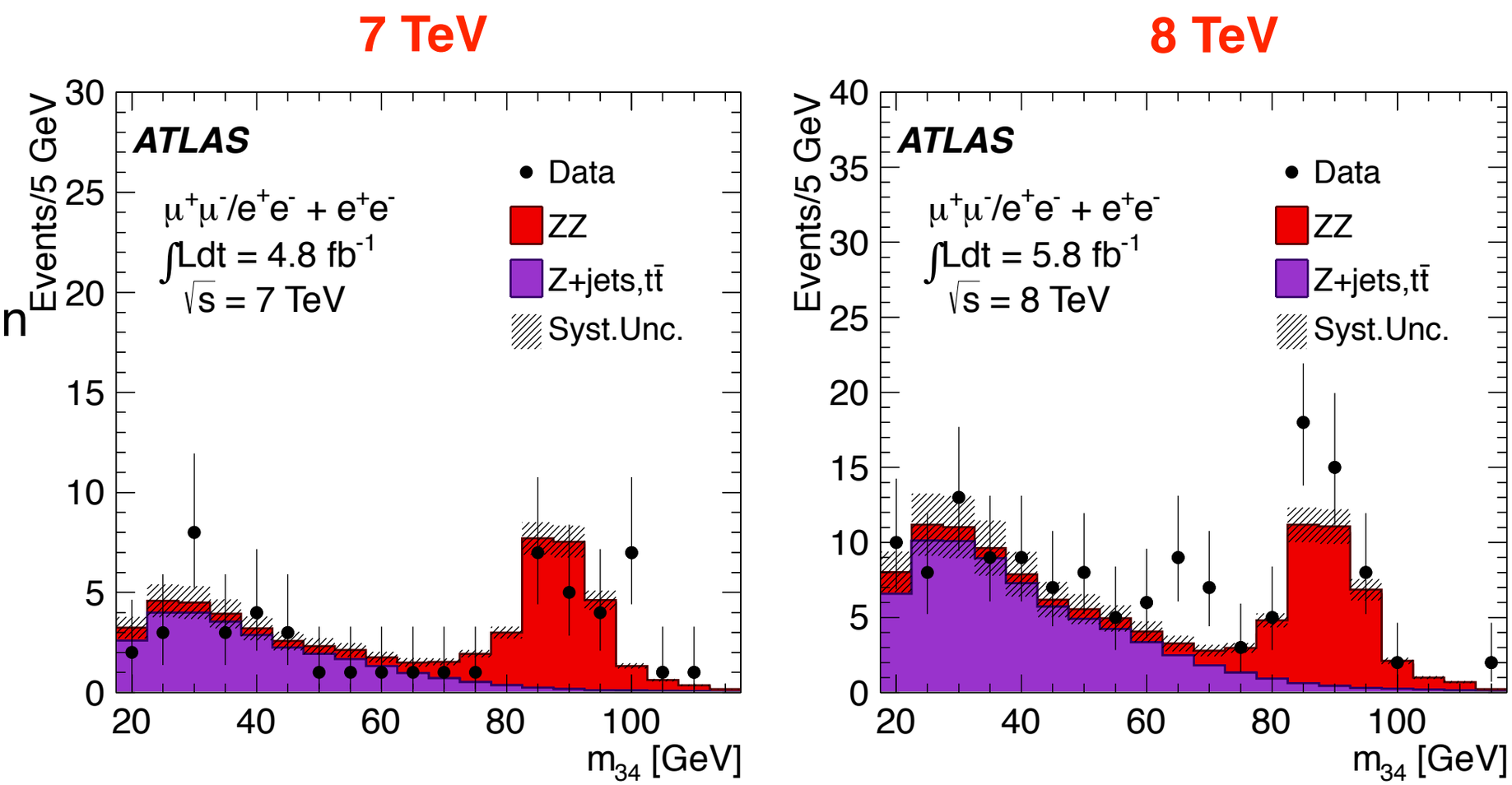
2l+2e Background

Main contributions: Z+jets

Control Region:

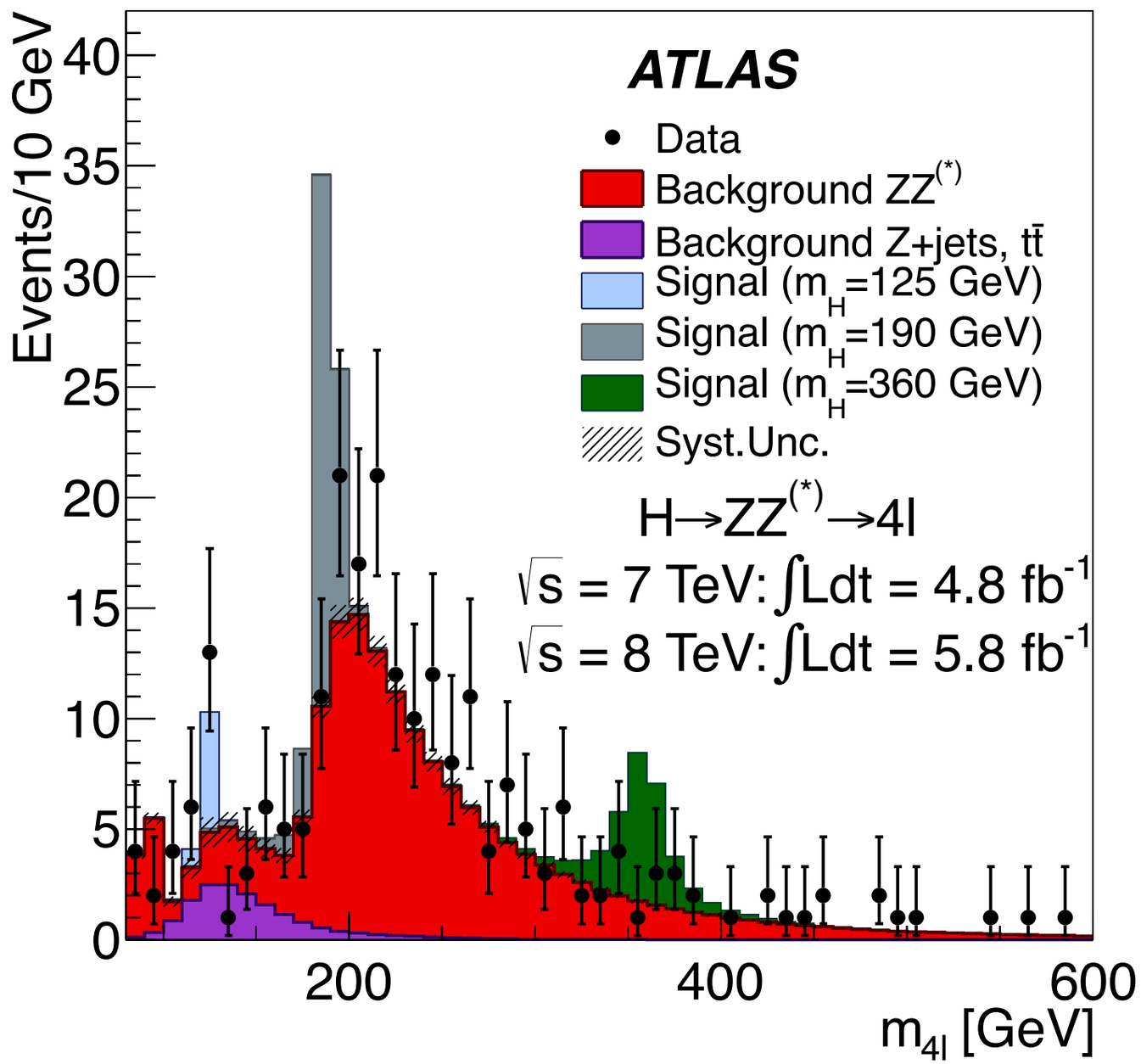
For sub-leading electron

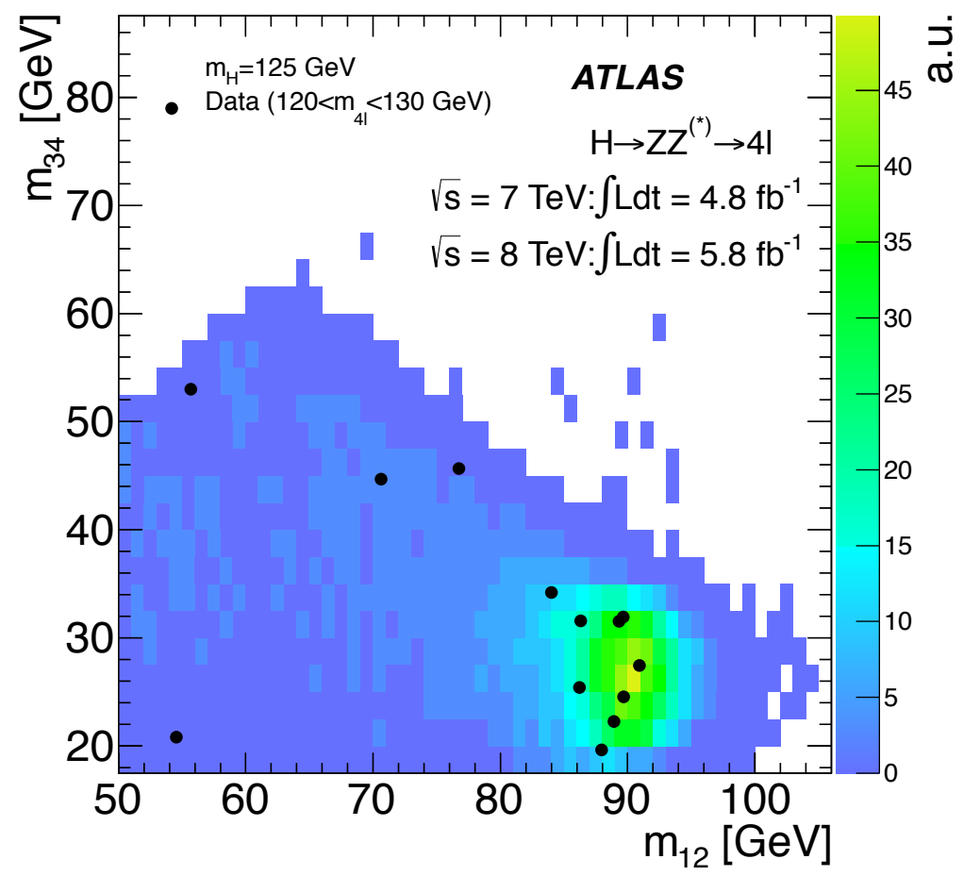
- Remove isolation requirements
- Remove IP significance cut (suppress ZZ contribution)



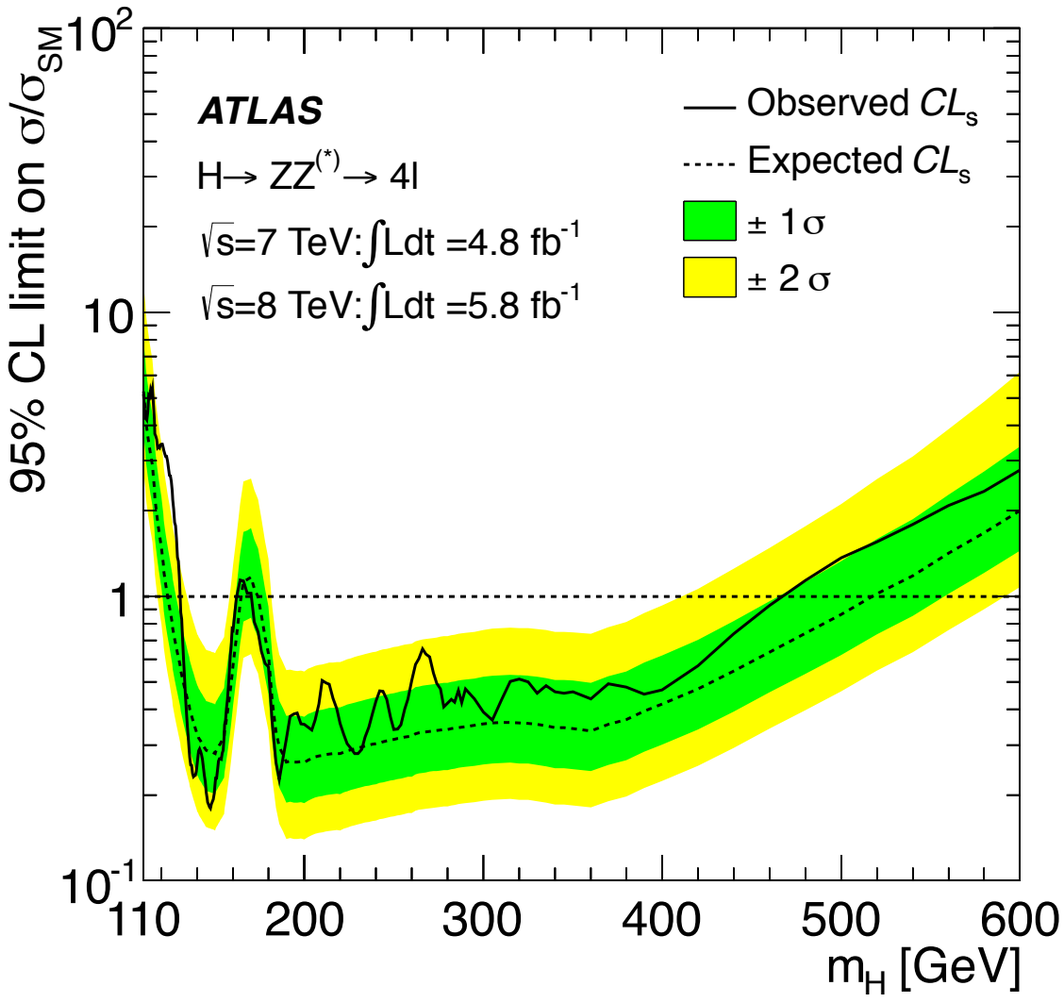
- Electron BG can be categorized to (1) heavy-flavor (2) photon conversion (3) light-flavor jets
- These contributions are extracted from simultaneous fit to # B-layer hits & TRT ratio

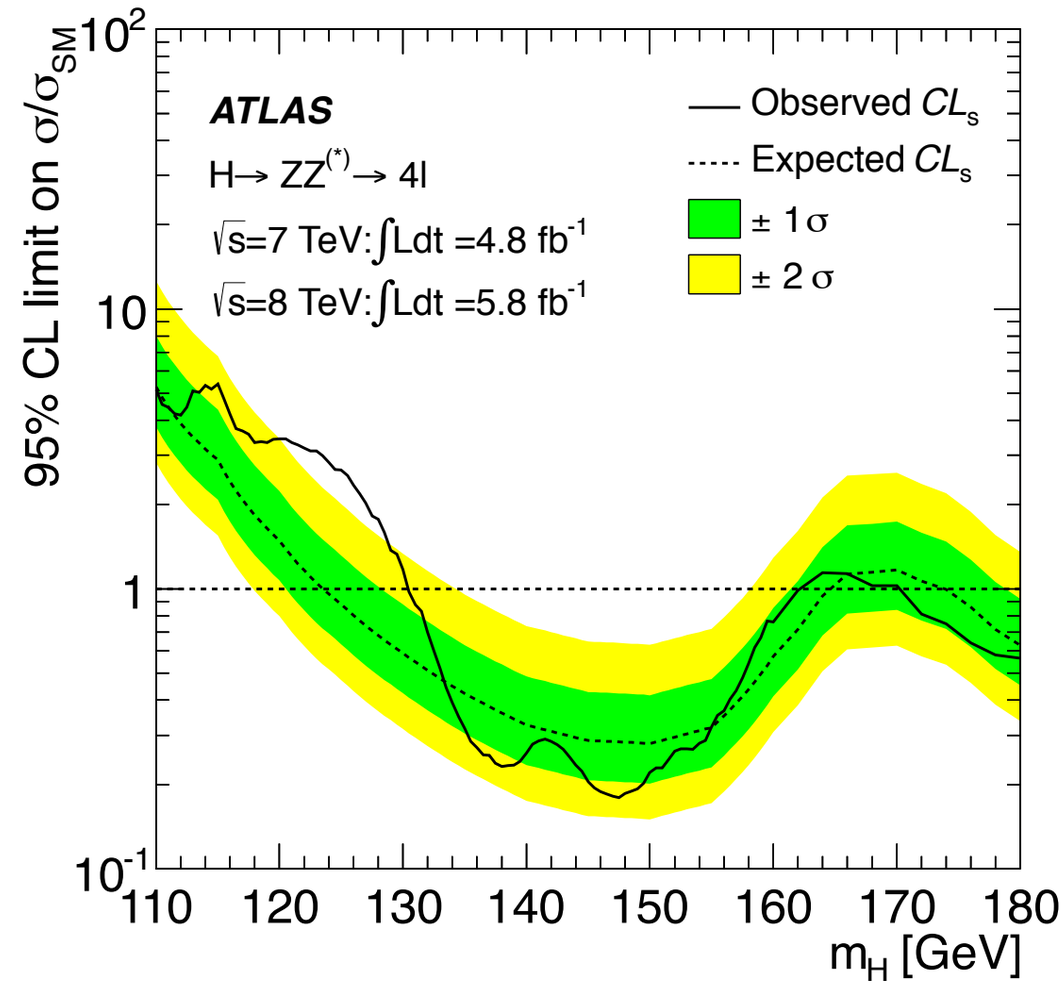
Events in Signal Region





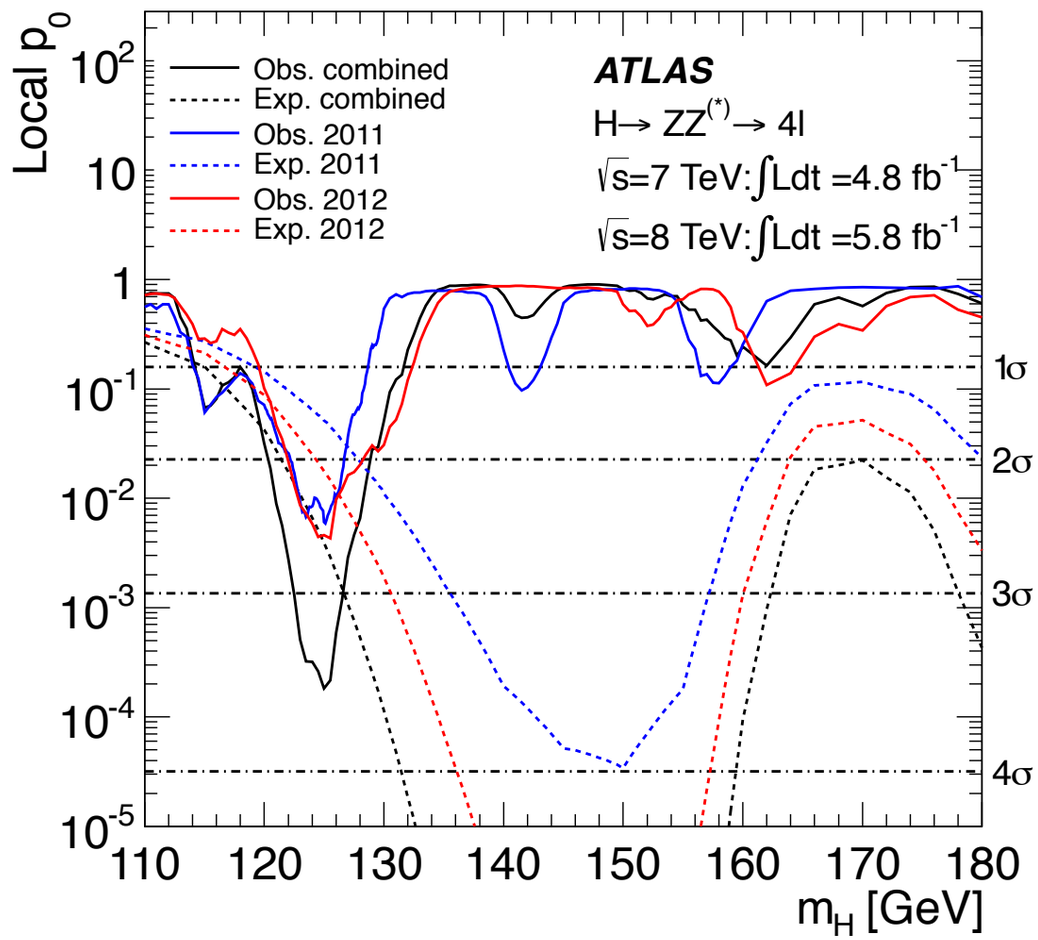
Exclusions

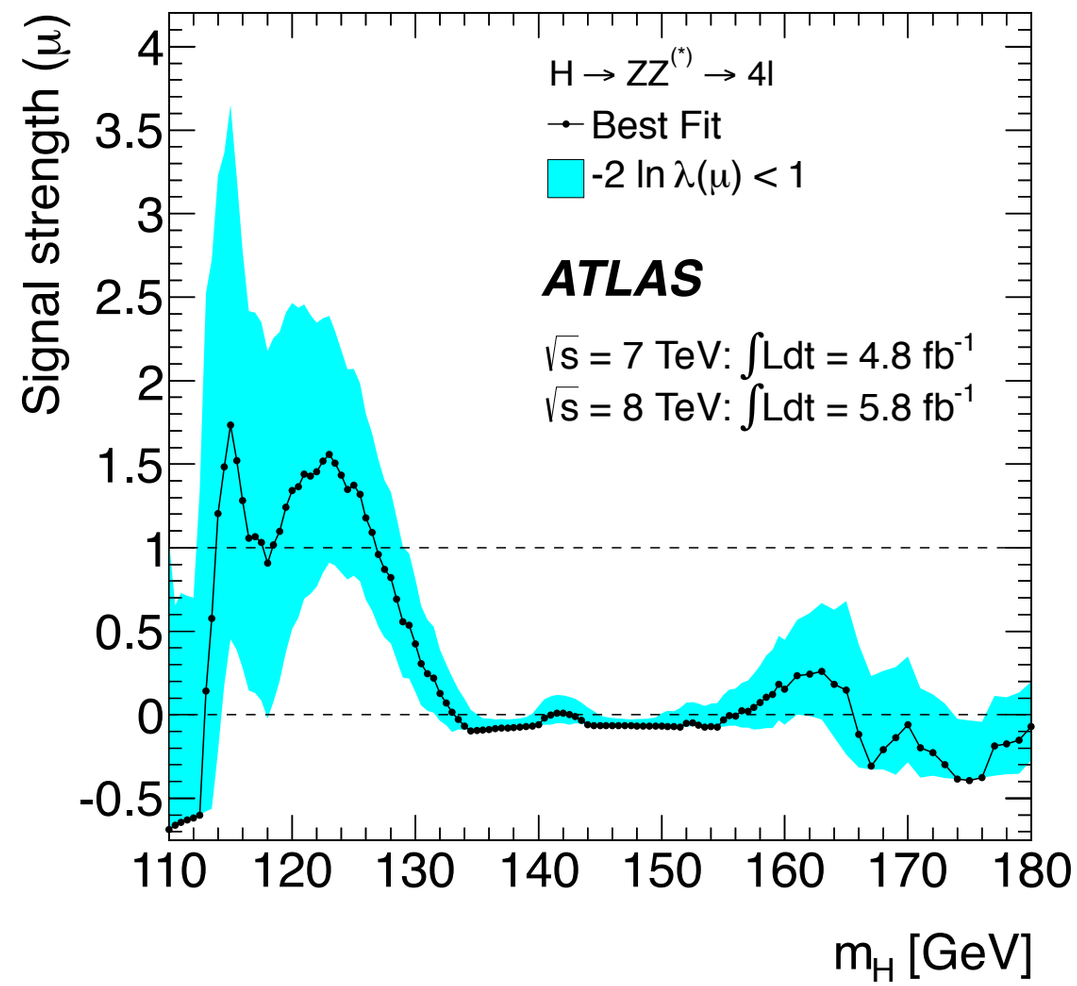




- Set limits on σ/σ_{SM} at 95% CL using CLs modified frequentist method with profile likelihood test statistics
- **Observed exclusion: $131 \leq m_H \leq 162$ GeV & $170 \leq m_H \leq 460$ GeV**
- Expected exclusion: $124 \leq m_H \leq 164$ GeV & $176 \leq m_H \leq 500$ GeV

Significance & Signal Strength



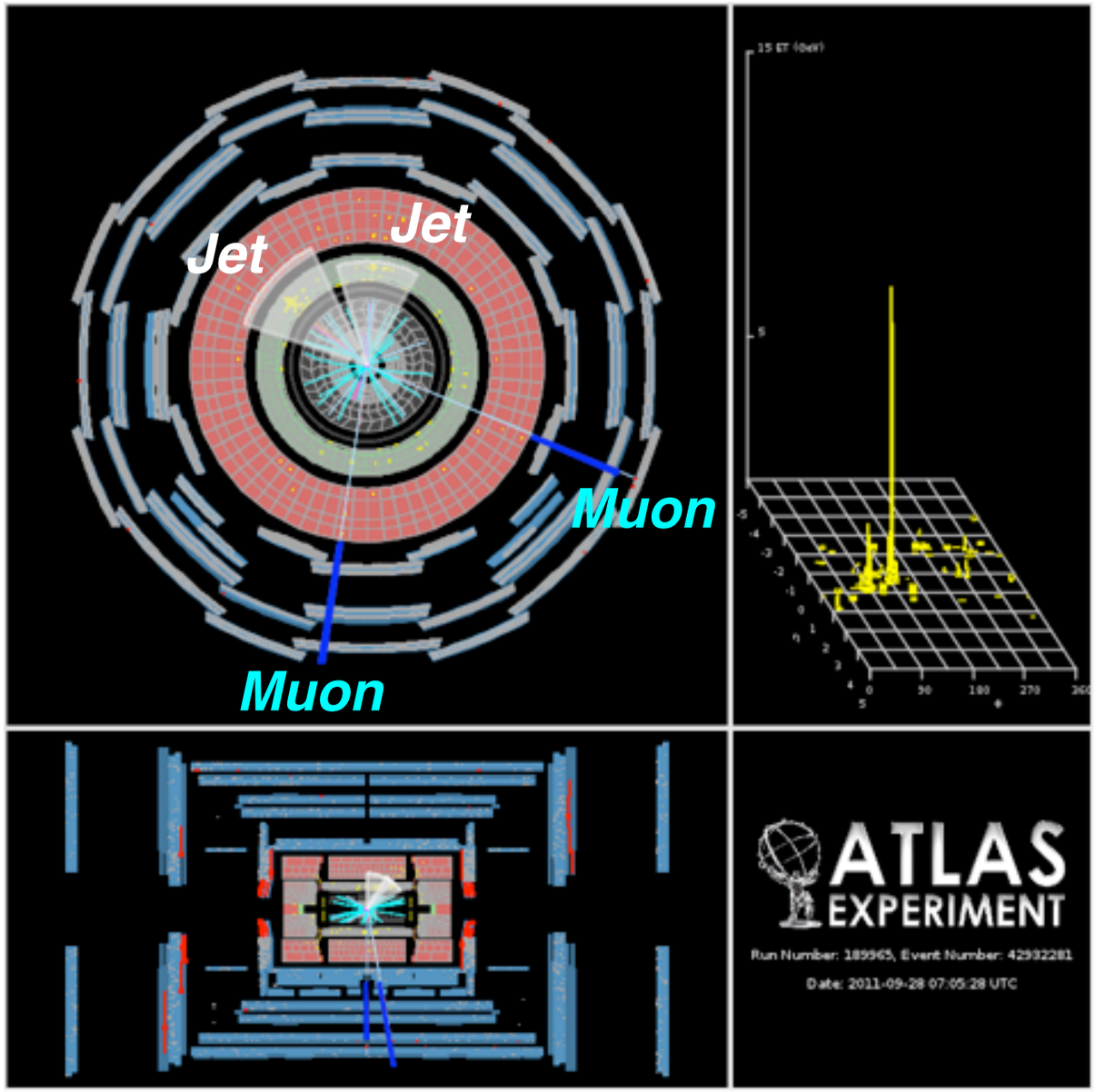


$H \rightarrow ZZ^{(*)} \rightarrow llqq$

(2011)

$H \rightarrow ZZ \rightarrow llqq$ Event Selection

- Single & dilepton triggers
- Dilepton (e,μ) & ≥2 jets
  ($83<m_{ll}<99$ GeV; $70<m_{jj}<105$ GeV; $\Delta R_{jj}>0.7$)
  - Leptons: $p_T>20$ GeV, $|\eta|<2.5$
  - Jets: $p_T>25$ GeV, $|\eta|<2.5$
- Missing $E_T < 50$ GeV
- Two signal regions
  - "Tagged": 2 b-tagged jets
  - "Untagged": # of b-jets < 2



- For $m_H>300$ GeV, jet $p_T>45$ GeV, $\Delta\Phi_{ll}<\pi/2$, $\Delta\Phi_{jj}<\pi/2$

Main BG: Z+jets & ttbar

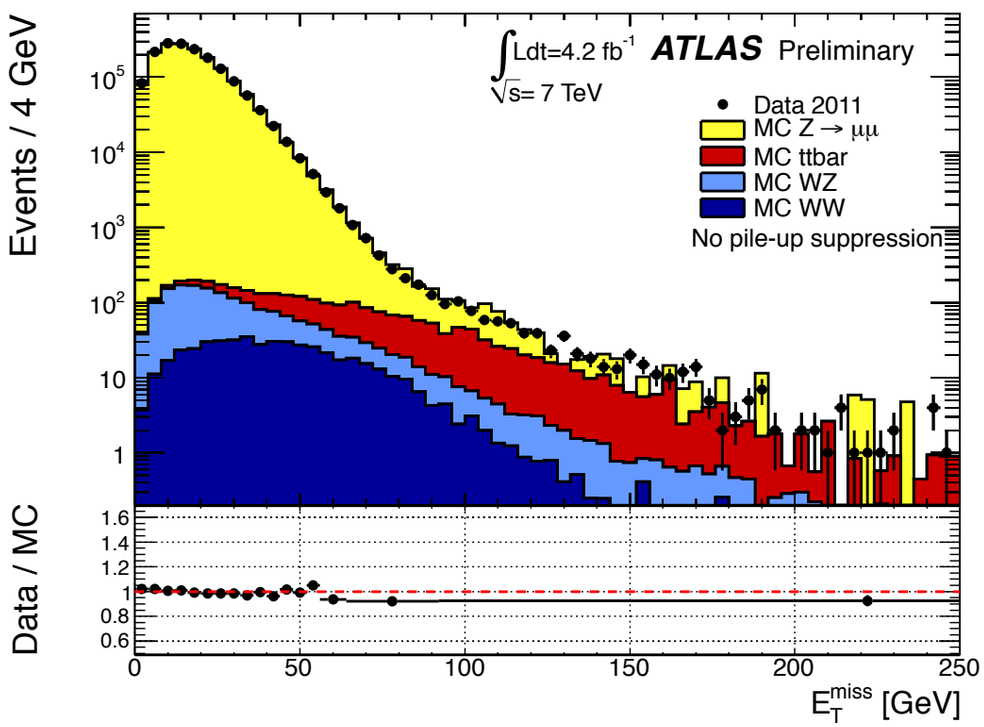
Jets & Missing E_T

Jets

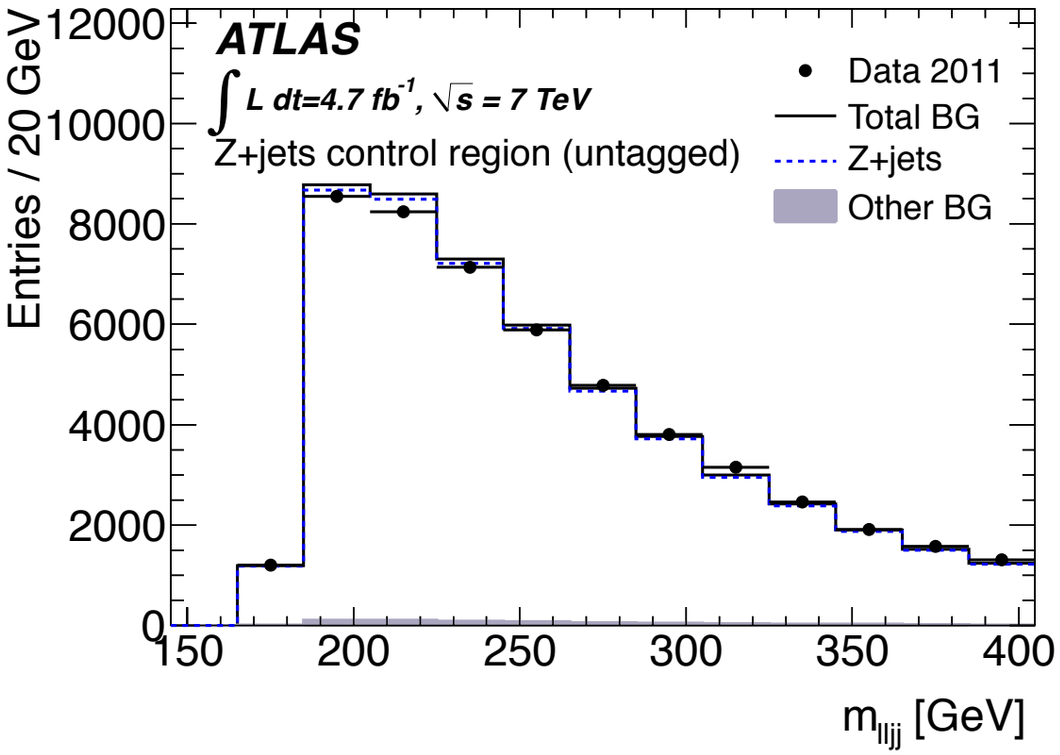
- Jet finding with the Anti-k_T algorithm using noise suppressed calorimeter clusters (topological clusters) with R=0.4
- Jet energy scale derived from in-situ methods

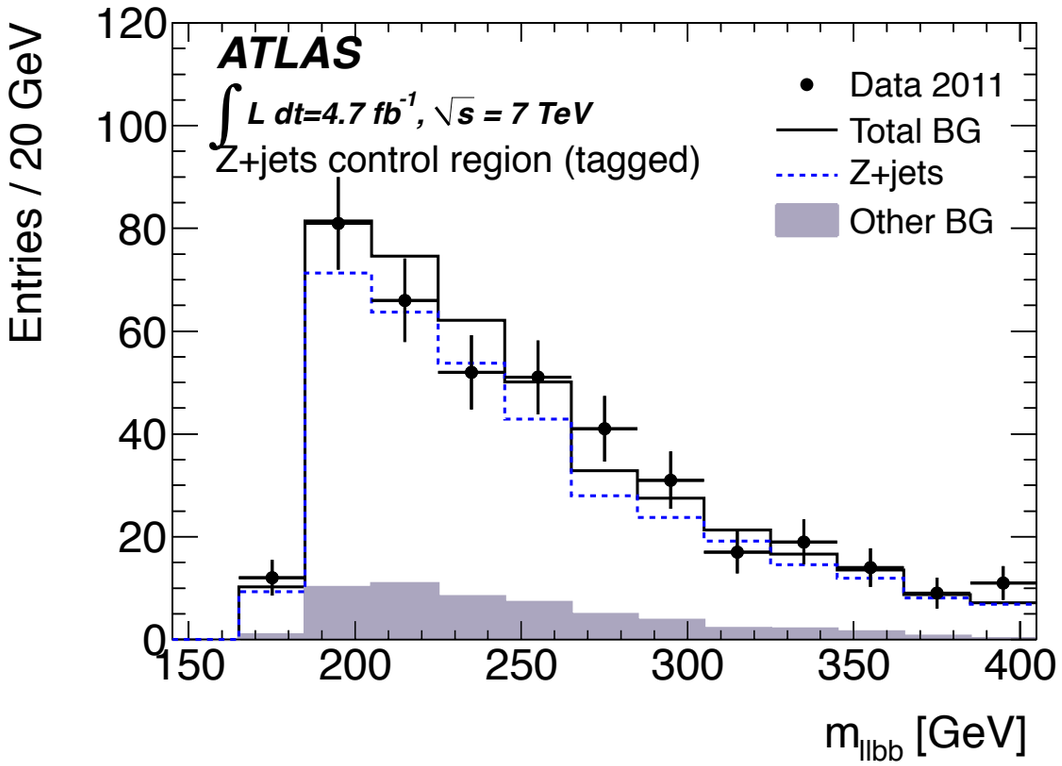
Missing E_T (E_T^{miss})

- Calculated from all the cells in the topological clusters.
- Cell energy is calibrated based on its association to physics objects (e, γ, τ, jets, μ, or unassociated)



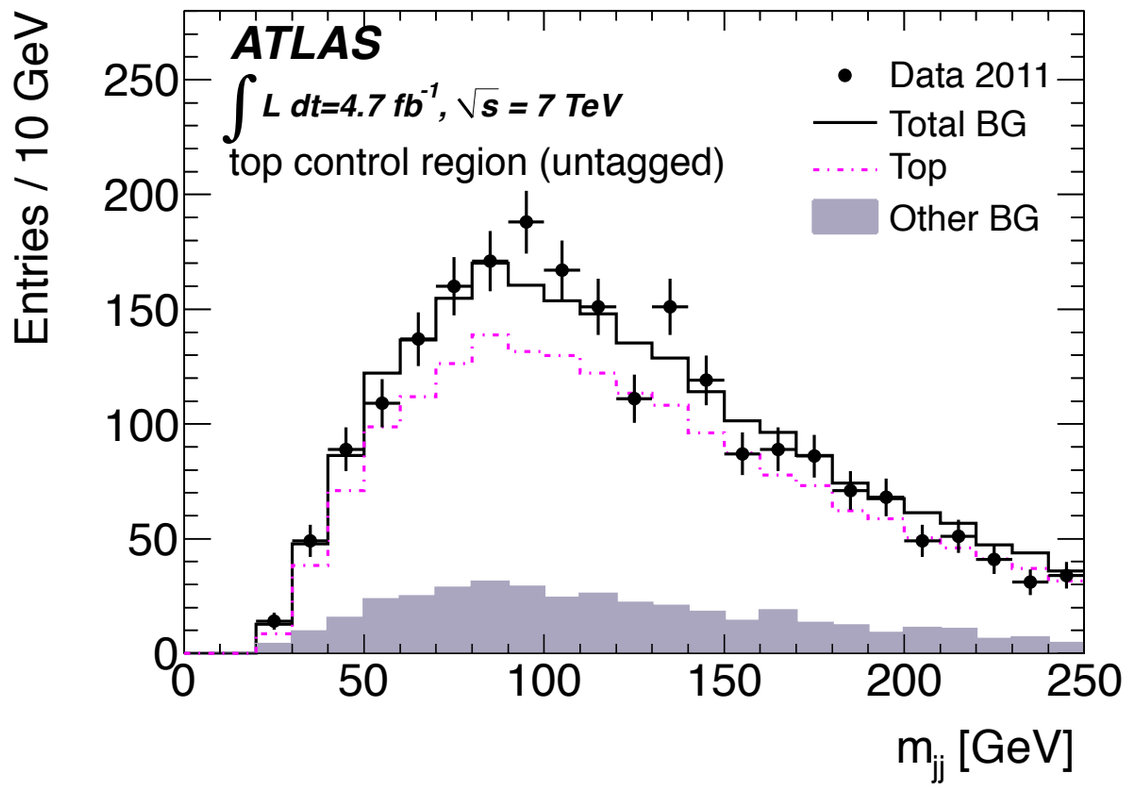
H→ZZ→llqq Z+jets BG

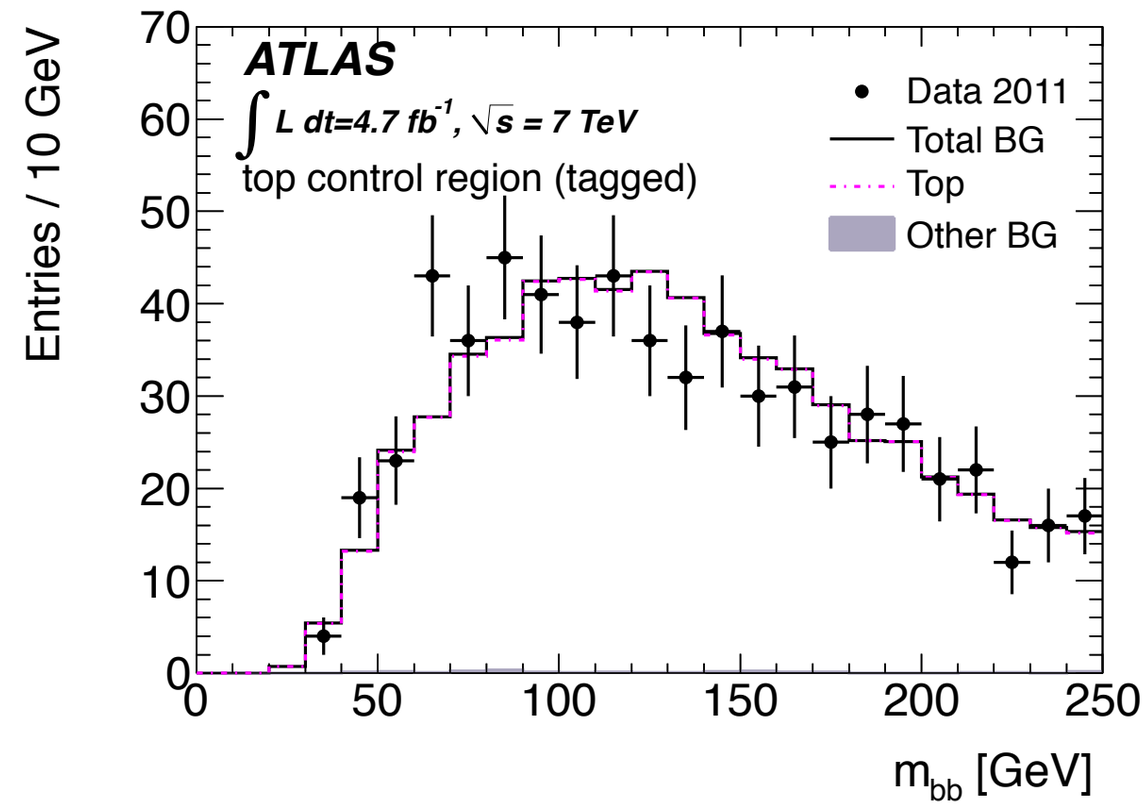




- Alpgen for Z+light-flavor jets & Sherpa for Z+heavy-flavor jets
- Fraction of light flavor/c/b is determined by the fit to b-tagging discriminants in data
- Normalization of Z+jets is extracted from mjj side-bands (40 GeV<m_{jj}<70 GeV & 105 GeV<m_{jj}<150 GeV)
  - However, no correction was needed for the high m_H selection.

H→ZZ→llqq Top BG

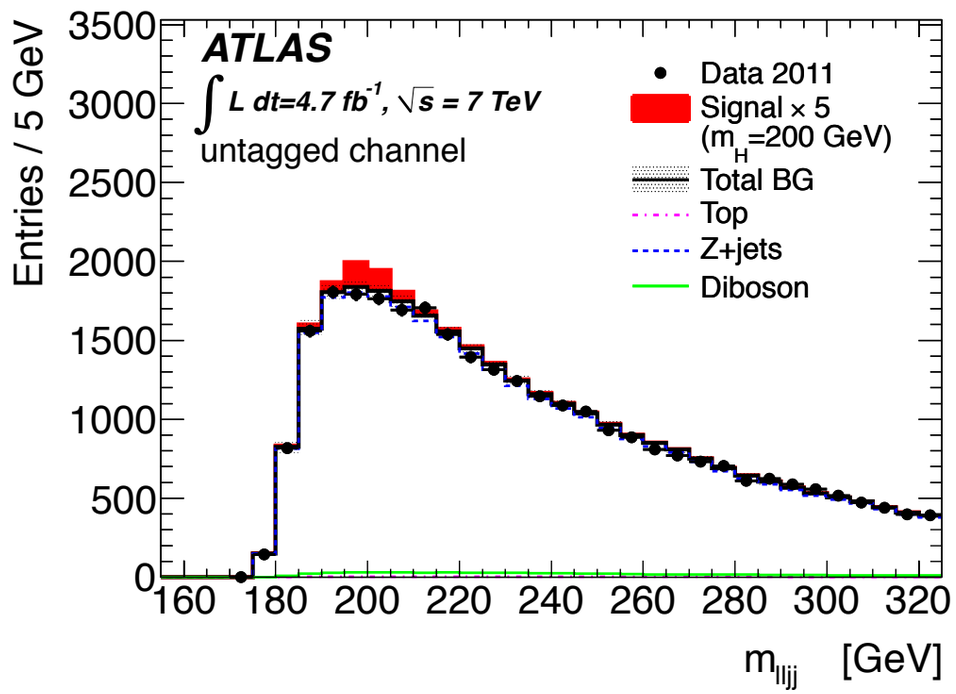


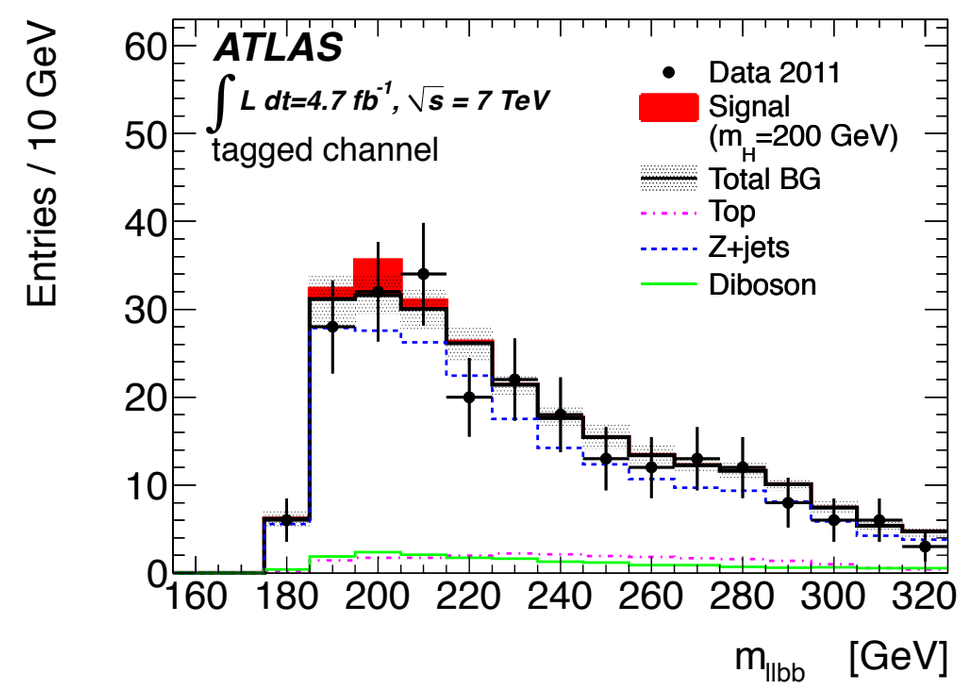


- MC@NLO interfaced with Herwig is used for the Top BG
- Normalization of the Top BG is extracted from mjj side-bands (40 GeV<m_{jj}<70 GeV & 105 GeV<m_{jj}<150 GeV) with reverted E_T^{miss} cut
- WZ/ZZ are directly estimated from MC. QCD multijet is estimated with loosened electron ID in the m_{ll} sidebands. W+jets is negligible.

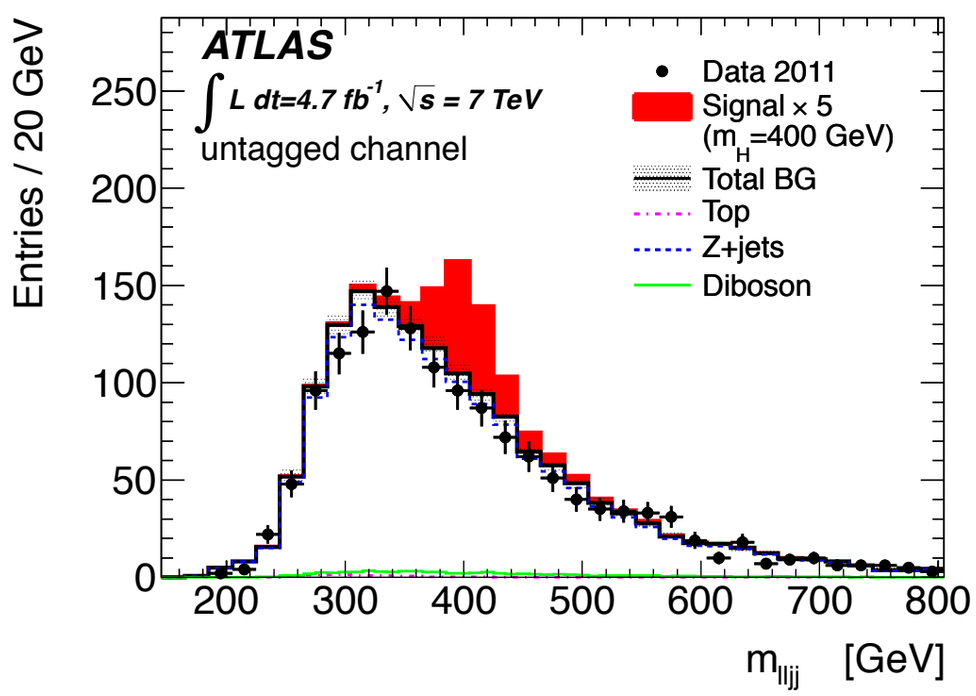
H→ZZ→llqq Signal Region

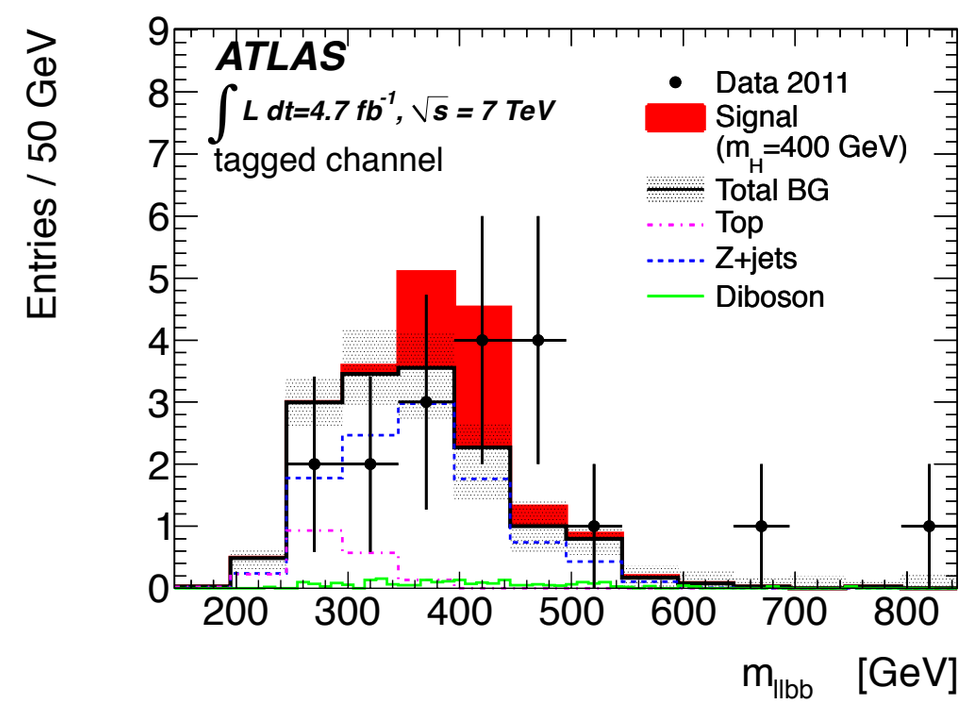
Low m_H Signal Region





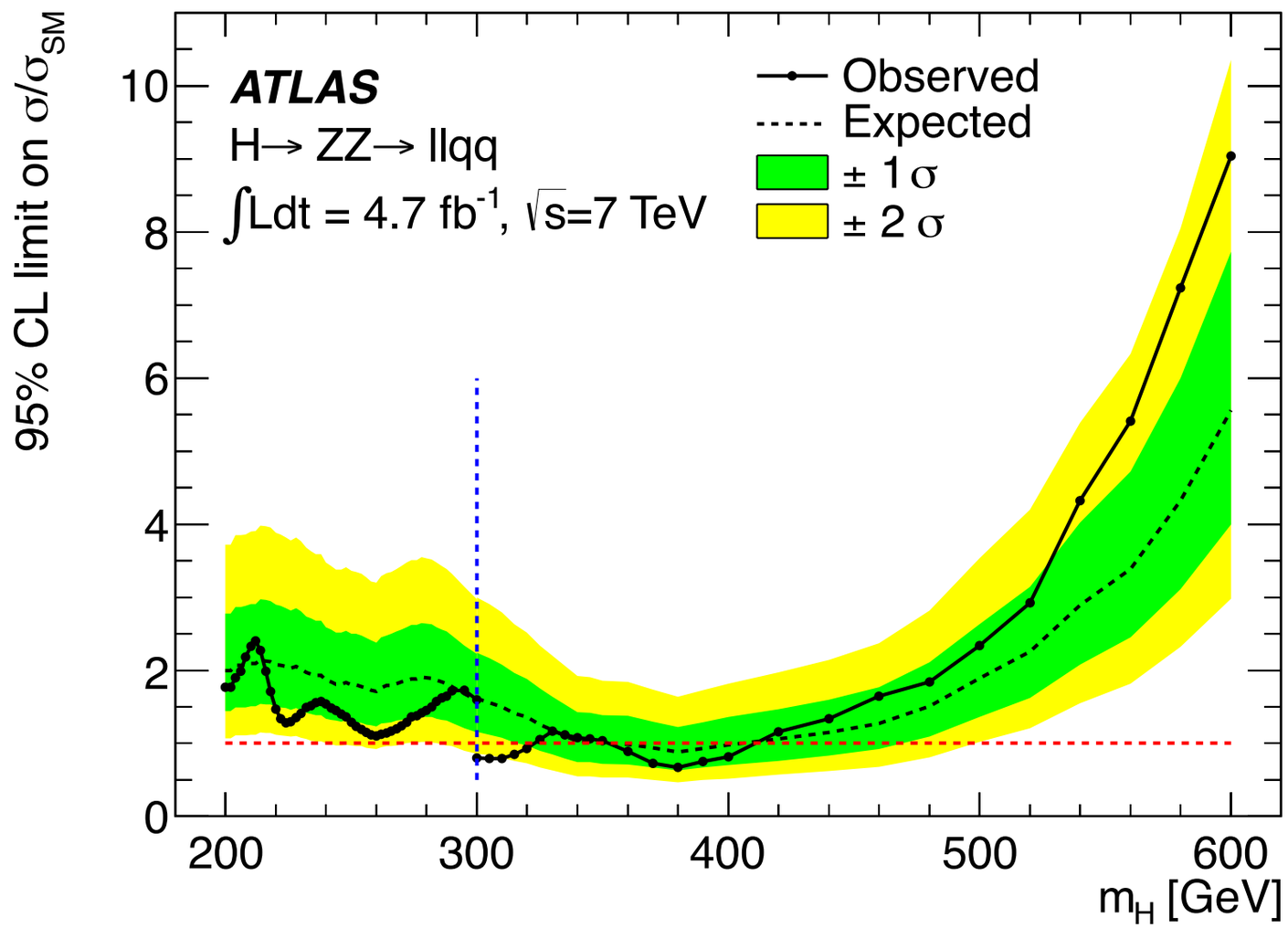
High m_H Signal Region





H→ZZ→llqq Results

- Set limits on σ/σ_{SM} at 95% CL using CLs modified frequentist method with profile likelihood test statistics

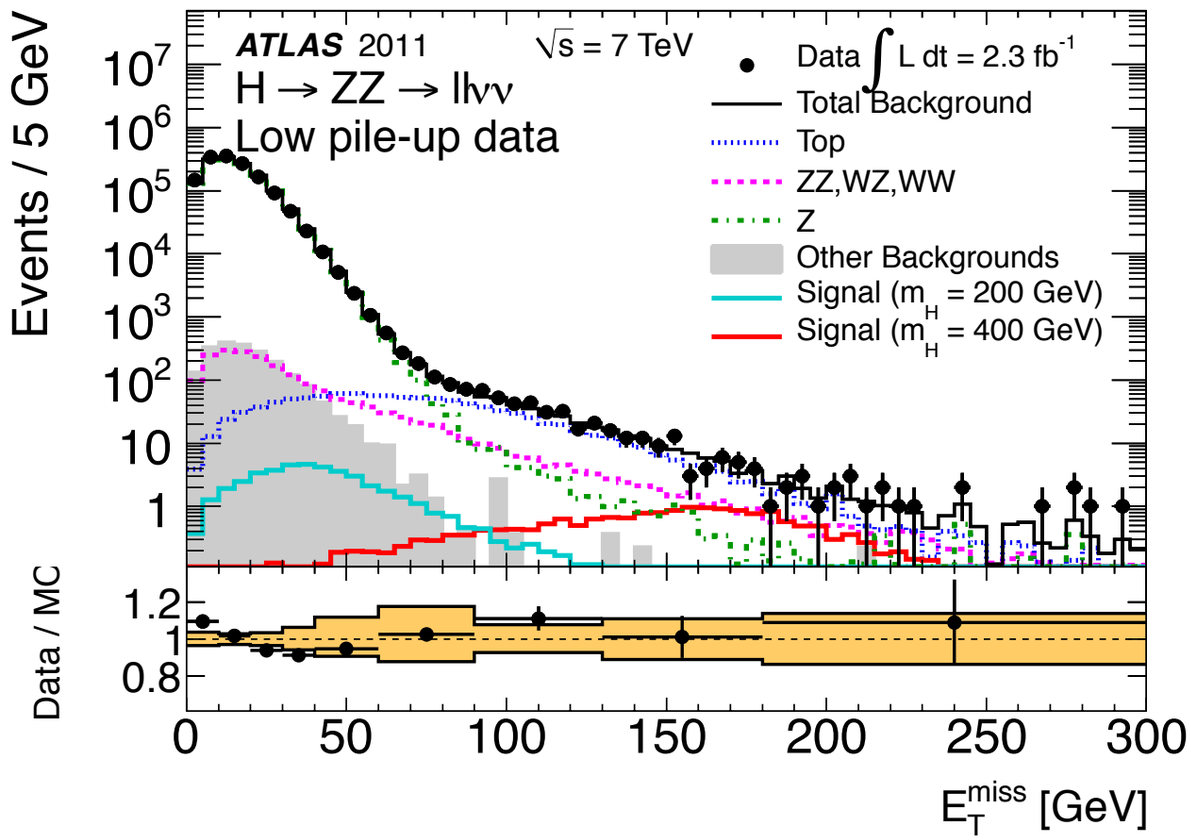


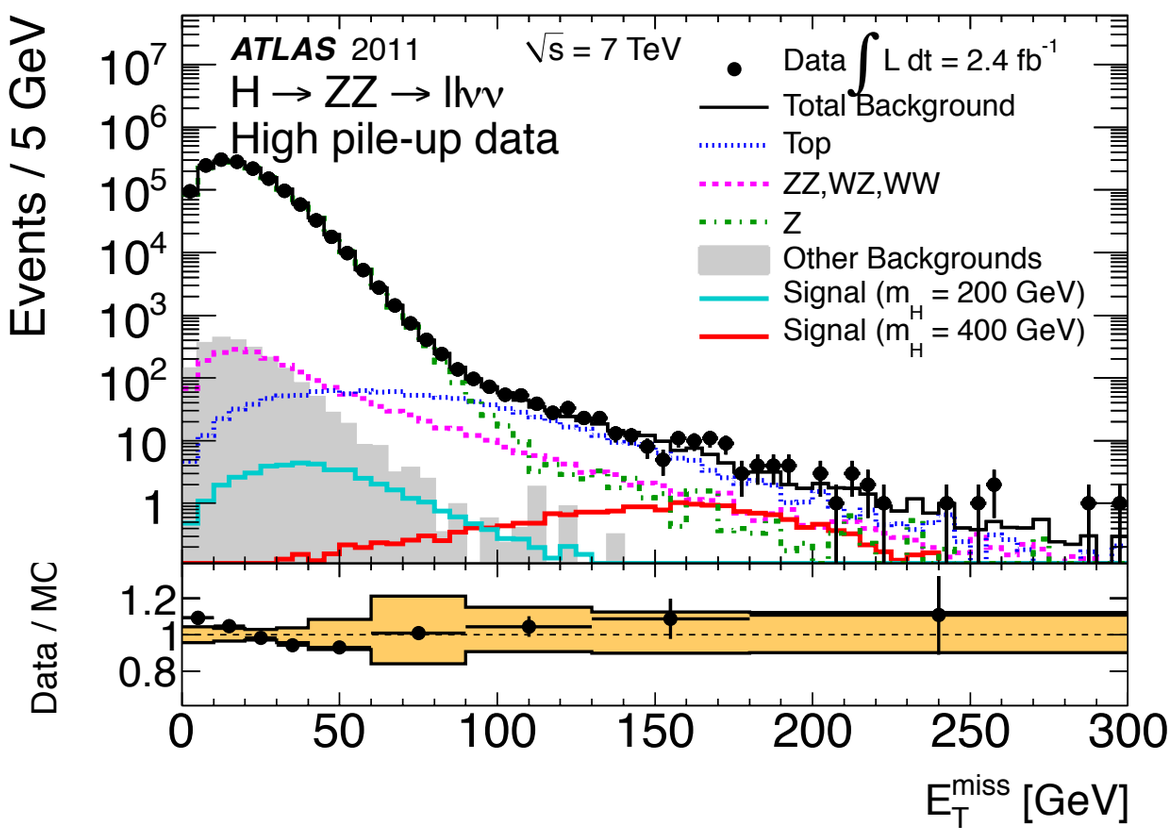
- **Observed exclusion: $300 \leq m_H \leq 322$ GeV & $353 \leq m_H \leq 410$ GeV**
- Expected exclusion: $351 \leq m_H \leq 404$ GeV

$H \rightarrow ZZ^{(*)} \rightarrow llvv$

(2011)

H→ZZ→llνν Event Selection





- Two opposite-sign leptons (e,μ) in the m_Z window (±15 GeV)

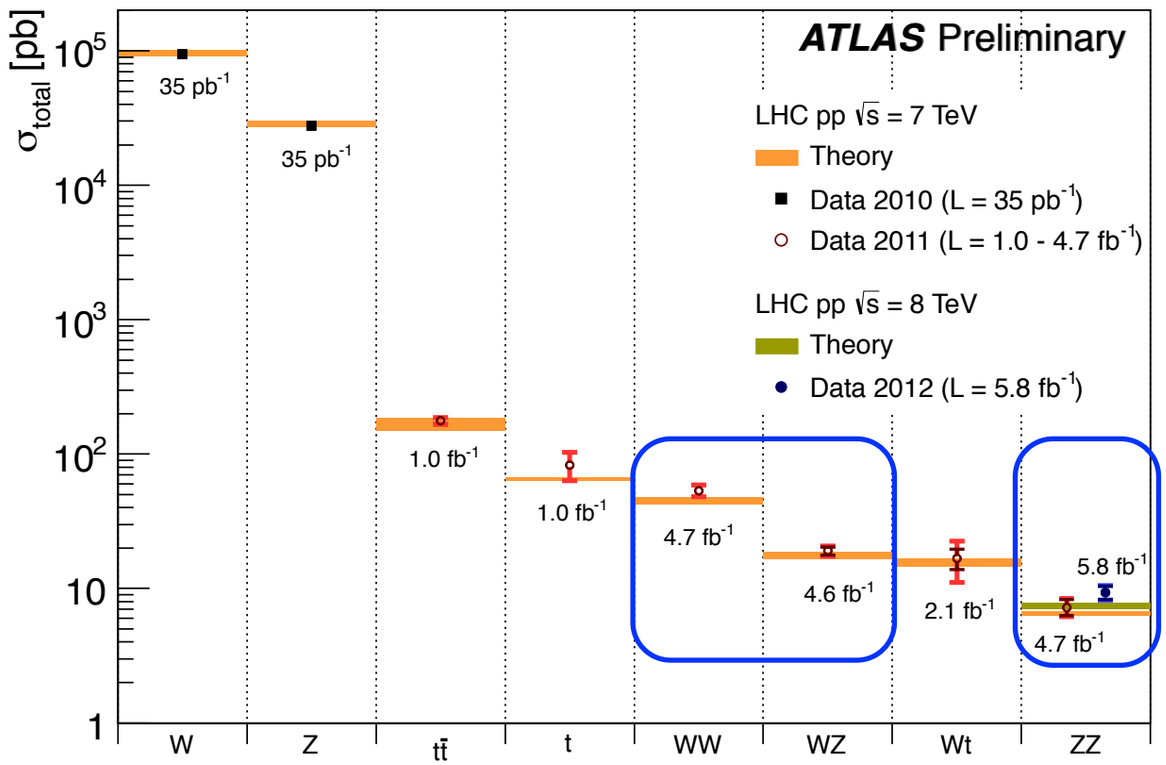
Low m_H Selection

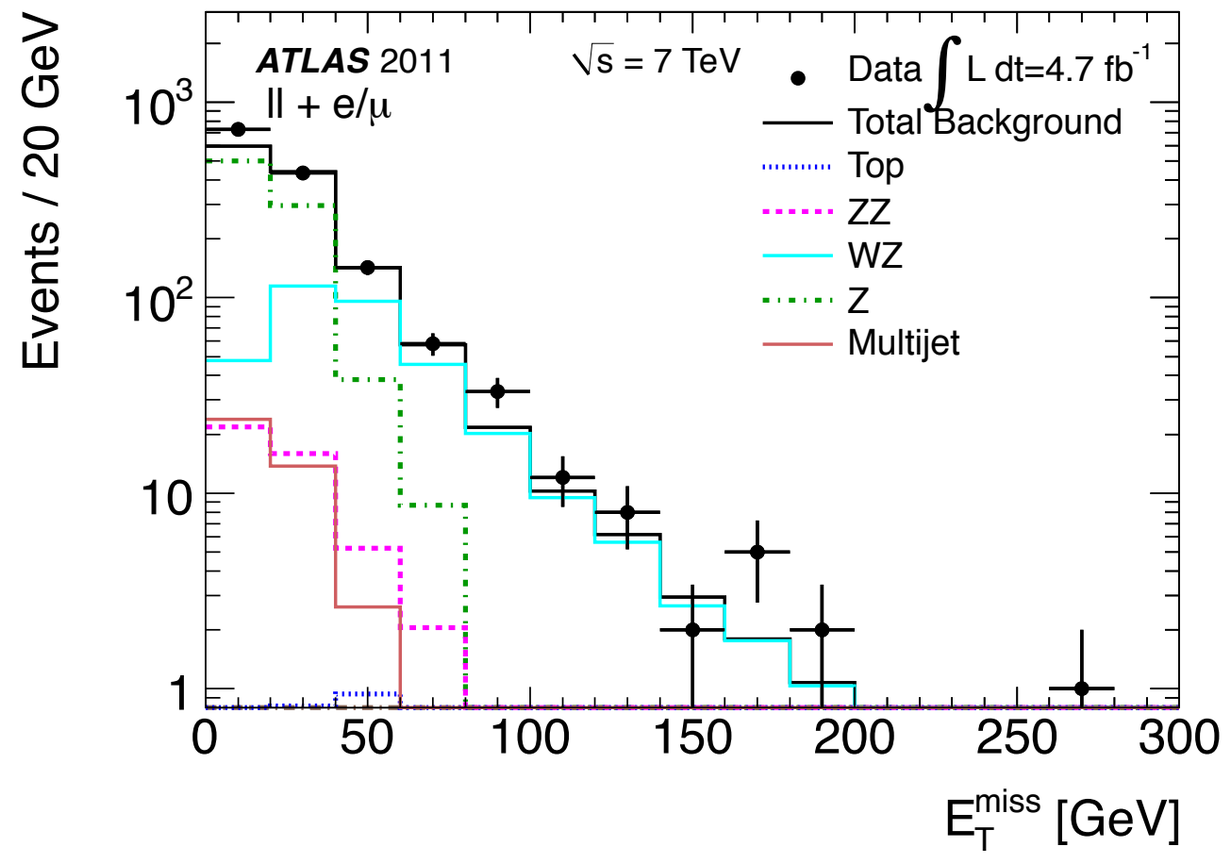
- $E_T^{miss} > 66$ GeV
- $1 < \Delta\Phi(l,l) < 2.64$
- $\Delta\Phi(p_T^{miss}, p_T^{jet}) < 1.5$

High m_H Selection

- $E_T^{miss} > 82$ GeV
- $\Delta\Phi(l,l) < 2.25$, $\Delta\Phi(p_T^{miss}, p_T^{ll}) \geq 1$
- $\Delta\Phi(p_T^{miss}, p_T^{jet}) < 0.5$

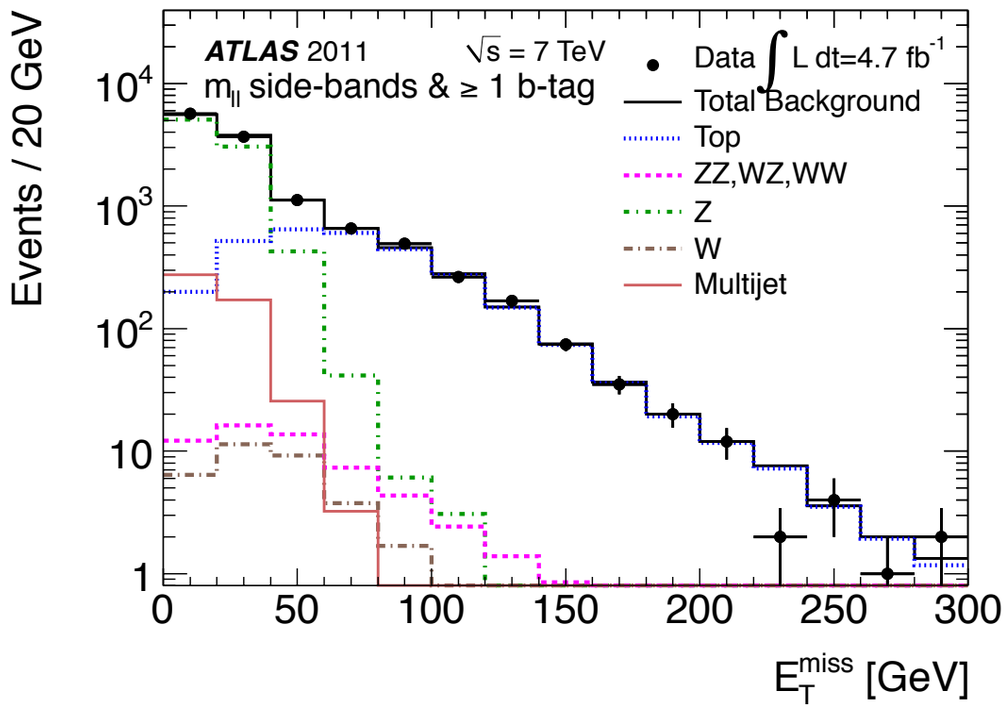
H→ZZ→llvv Diboson BG

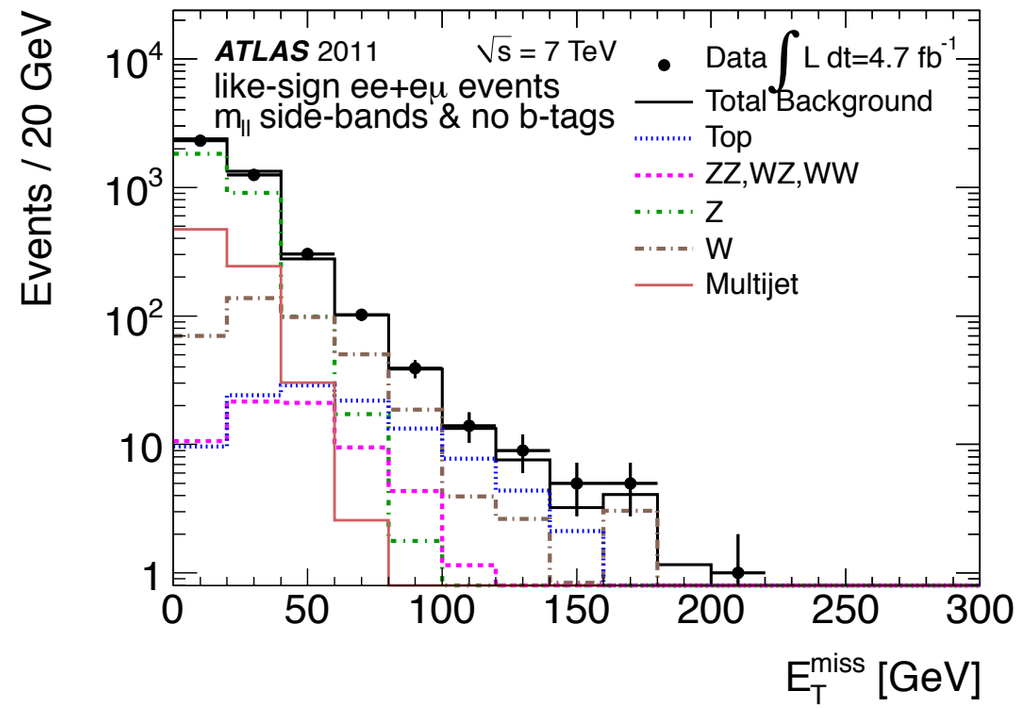




- WW/ZZ BG is estimated from theory → cross section measurements are well consistent with theory in 2011
  - ZZ shape uncertainty is estimated using various generators
- WZ normalization is checked in the 3-lepton control region

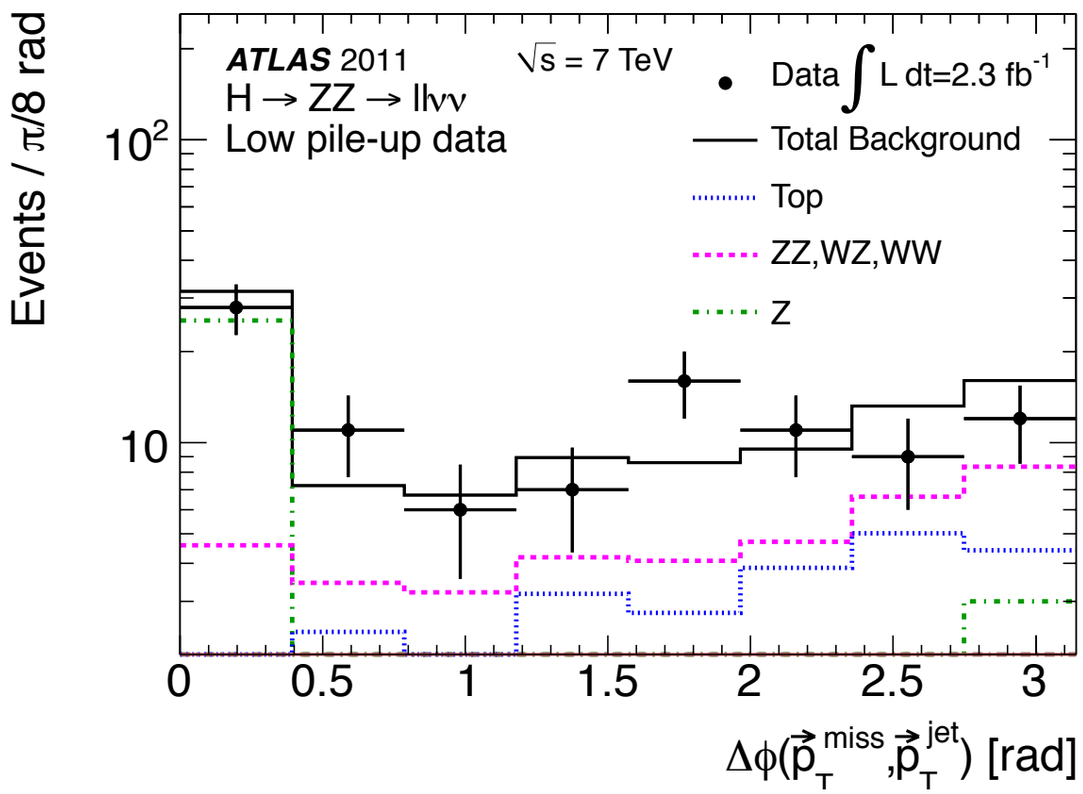
H→ZZ→llνν Top/W BG

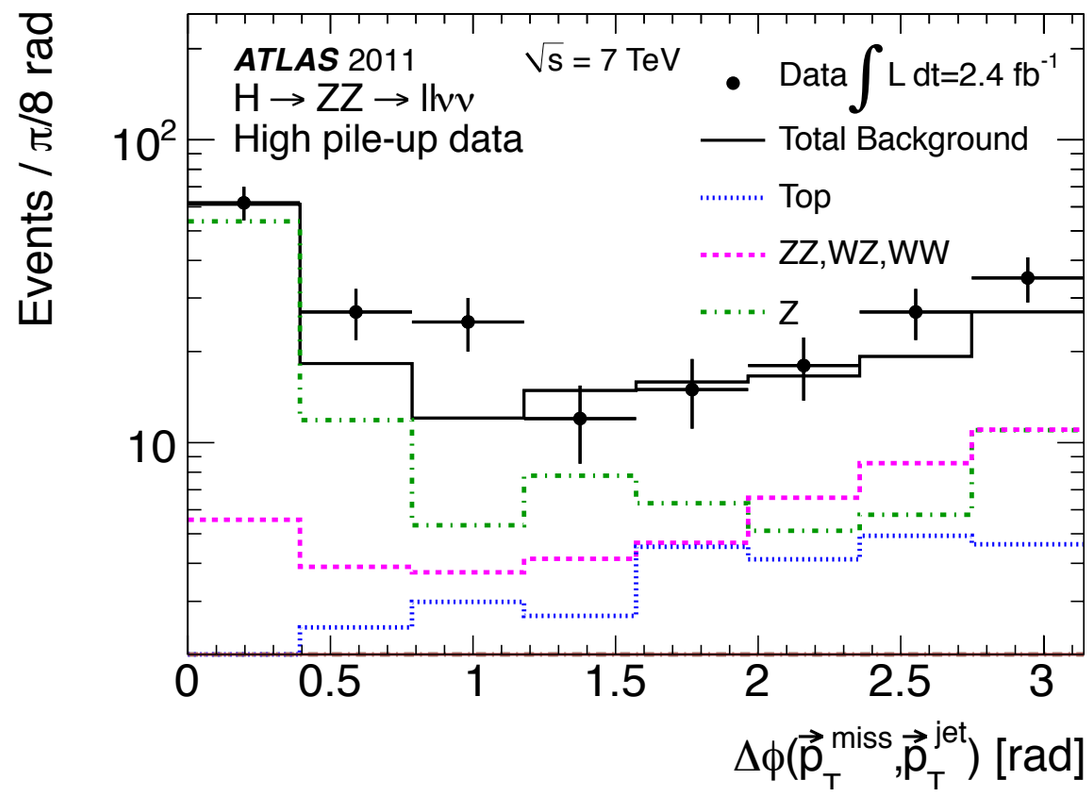




- Top BG normalization is checked in two control regions (m_{ll} side-bands with a b-tagged jet & eμ final state)
- Estimation is in very good agreement
- W+jets BG is checked in the like-sign ee & eμ control regions without b-tagged jets
- QCD multijet is found to be negligible

H→ZZ→llνν Z+jets BG



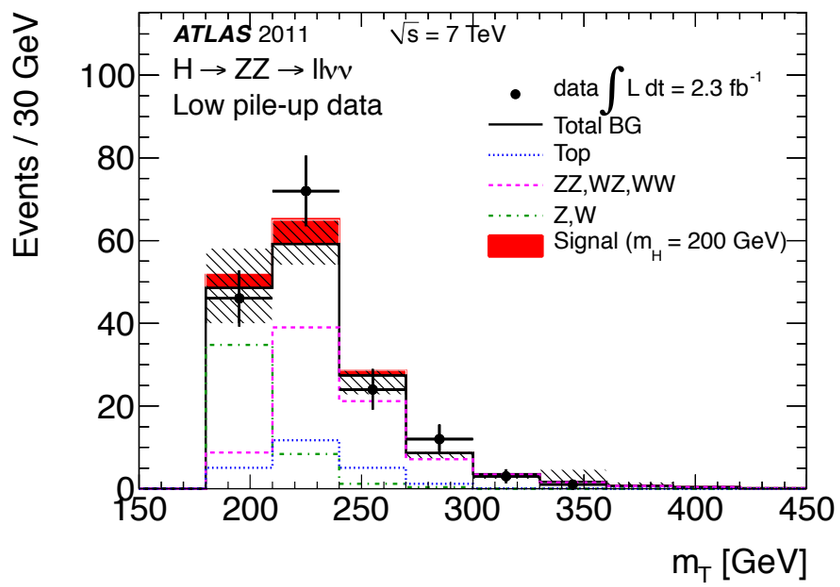


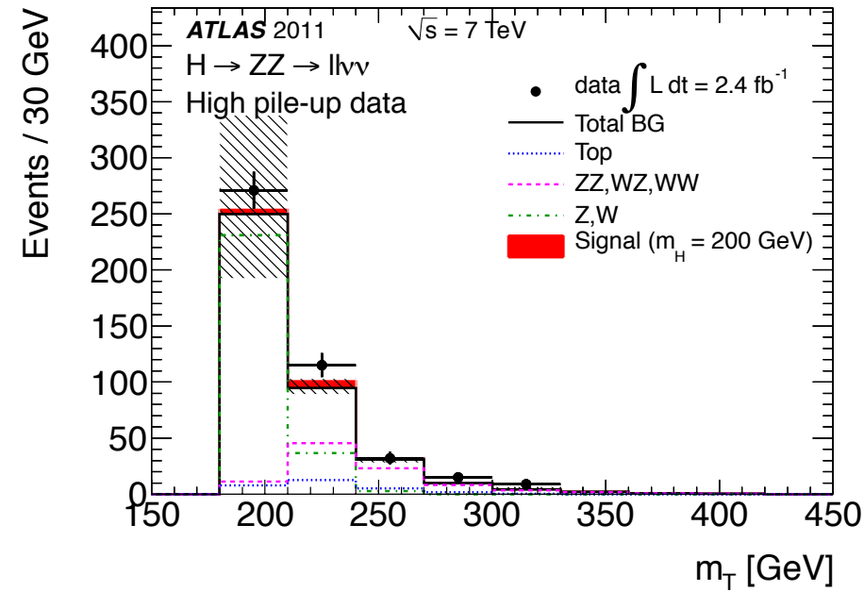
- Normalization was validated with reverting the $\Delta\Phi(p_T^{miss}, p_T^{jet})$ cut
- Shape uncertainty was extracted from different generators

H→ZZ→llνν Results

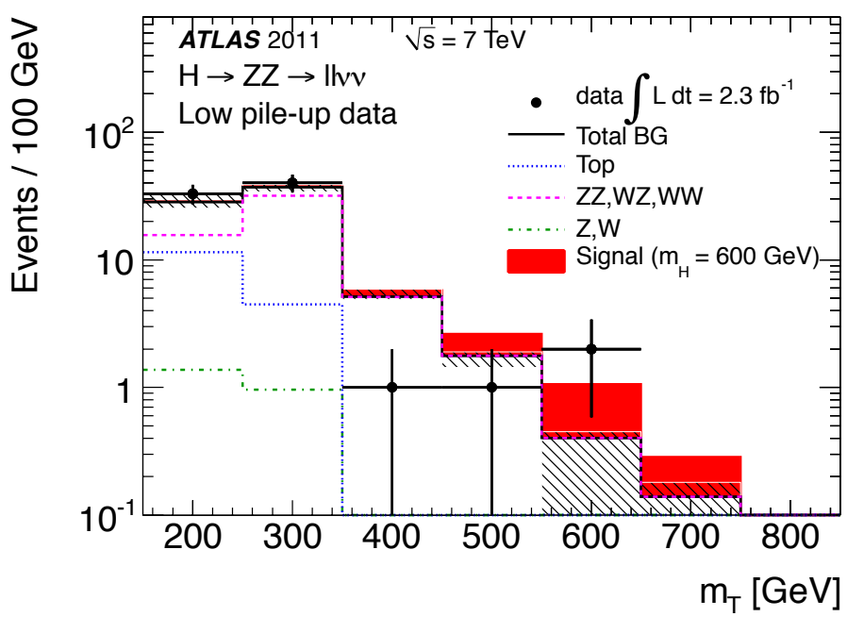
$$m_{\mathrm{T}}^2 \equiv \left[\sqrt{m_{\mathrm{Z}}^2 + |\vec{p}_{\mathrm{T}}^{\,\ell\ell}|^2} + \sqrt{m_{\mathrm{Z}}^2 + |\vec{p}_{\mathrm{T}}^{\,\mathrm{miss}}|^2}\right]^2 - \left[\vec{p}_{\mathrm{T}}^{\,\ell\ell} + \vec{p}_{\mathrm{T}}^{\,\mathrm{miss}}\right]^2$$

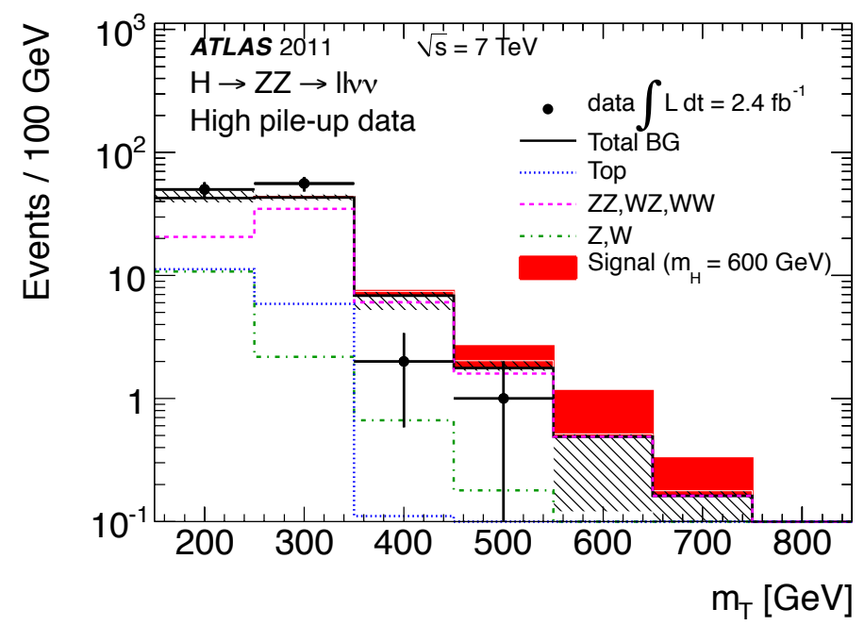
Low m_H Signal Region





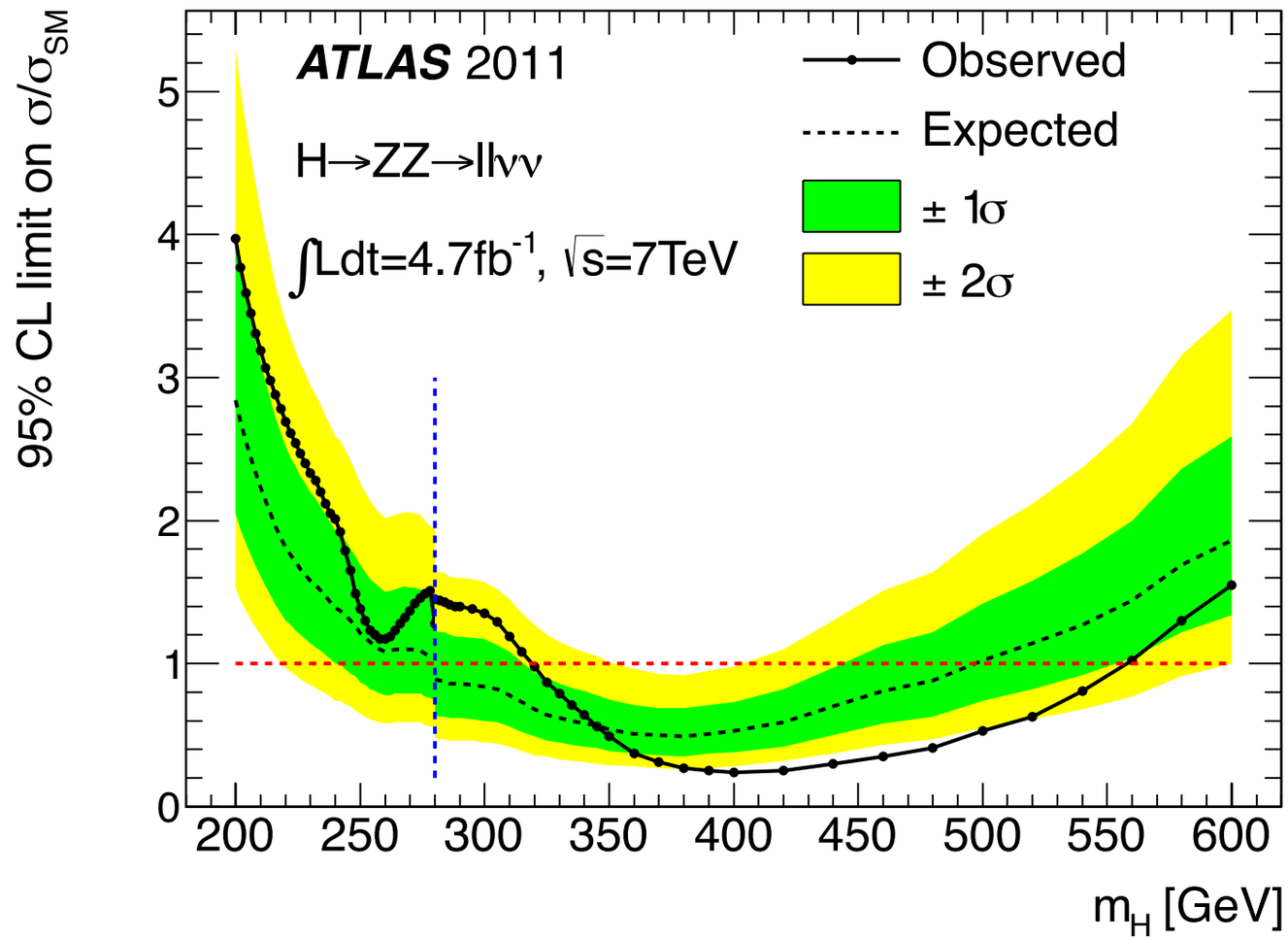
High m_H Signal Region





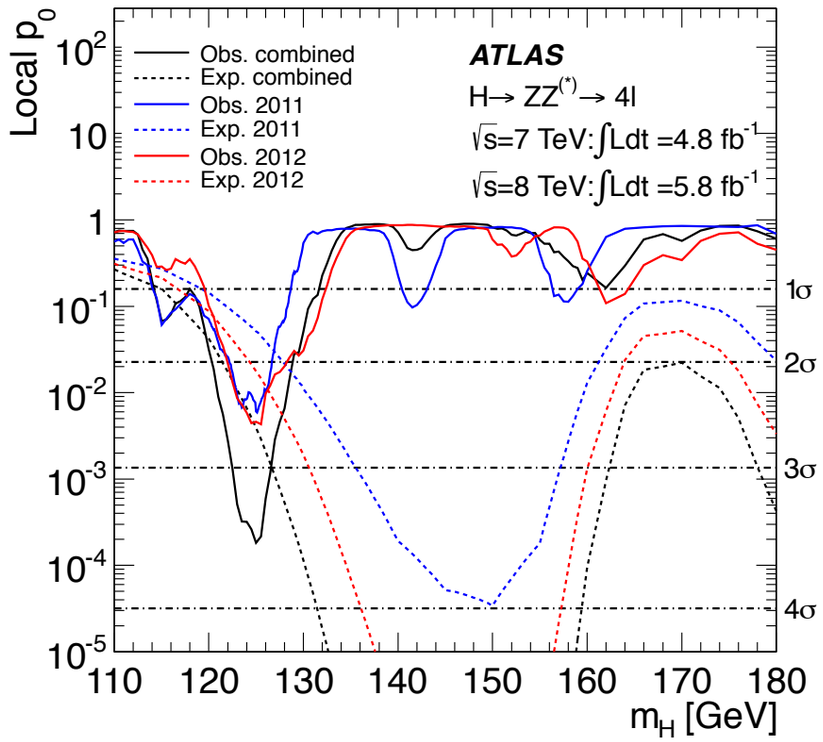
H→ZZ→llνν Results

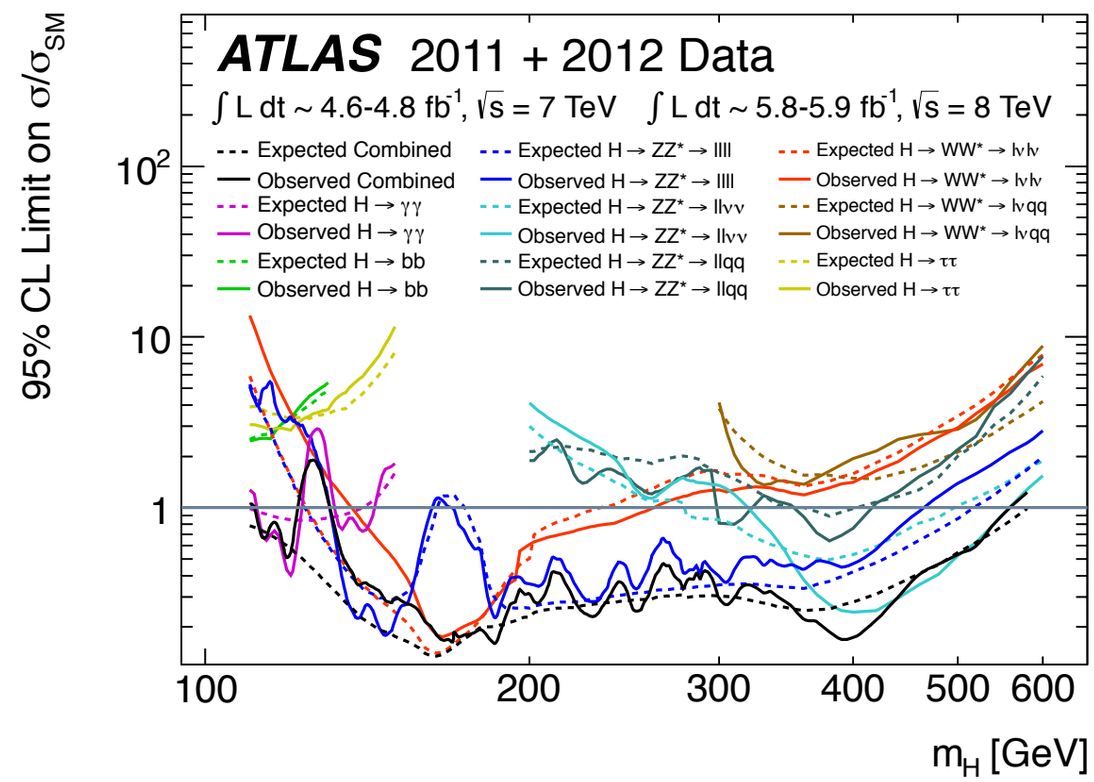
- Set limits on σ/σ_{SM} at 95% CL using CLs modified frequentist method with profile likelihood test statistics



- **Observed exclusion: 319 GeV ≤ m_H ≤ 558 GeV** (currently the highest mass exclusion among the ATLAS Higgs search channels)
- Expected exclusion: 280 GeV ≤ m_H ≤ 497 GeV

Summary





- We have observed a new particle with a mass~126 GeV
- High mass SM Higgs is excluded up to 558 GeV
- There are investigations ongoing to reveal the properties of this new particle. Stay tuned!

Backups

ATLAS Data Quality

ATLAS p-p run: April-June 2012										
Inner Tracker			Calorimeters		Muon Spectrometer				Magnets	
Pixel	SCT	TRT	LAr	Tile	MDT	RPC	CSC	TGC	Solenoid	Toroid
100	99.6	100	96.2	99.1	100	99.6	100	100	99.4	100
All good for physics: 93.6%										

Luminosity weighted relative detector uptime and good quality data delivery during 2012 stable beams in pp collisions at $\sqrt{s}$=8 TeV between April 4th and June 18th (in %) – corresponding to 6.3 fb^{-1} of recorded data. The inefficiencies in the LAr calorimeter will partially be recovered in the future.

ATLAS 2011 p–p run												
Inner Tracking			Calorimeters				Muon Detectors				Magnets	
Pixel	SCT	TRT	LAr EM	LAr HAD	LAr FWD	Tile	MDT	RPC	CSC	TGC	Solenoid	Toroid
99.8	99.6	99.2	97.5	99.2	99.5	99.2	99.4	98.8	99.4	99.1	99.8	99.3

Luminosity weighted relative detector uptime and good quality data delivery during 2011 stable beams in pp collisions at $\sqrt{s}$=7 TeV between March 13th and October 30th (in %), after the summer 2011 reprocessing campaign

H→ZZ→llqq Results

	Untagged		Tagged	
	Low-m_H	High-m_H	Low-m_H	High-m_H
Z+jets	$36190 \pm 80 \pm 640$	$1450 \pm 14 \pm 35$	$239 \pm 6 \pm 15$	$11 \pm 1 \pm 2$
Top	$85 \pm 3 \pm 10$	$7.1 \pm 0.7 \pm 0.8$	$23 \pm 1 \pm 3$	$1.9 \pm 0.4 \pm 0.5$
Multijet	$15 \pm 0 \pm 8$	$0.2 \pm 0.0 \pm 0.1$	< 0.1	< 0.1
ZZ	$348 \pm 3 \pm 47$	$25 \pm 1 \pm 3$	$22 \pm 1 \pm 4$	$2.3 \pm 0.3 \pm 0.4$
WZ	$434 \pm 4 \pm 70$	$45 \pm 1 \pm 7$	$0.7 \pm 0.2 \pm 0.3$	< 0.2
Total background	$37070 \pm 80 \pm 670$	$1530 \pm 14 \pm 37$	$285 \pm 6 \pm 18$	$15 \pm 1 \pm 2$
Data	36898	1444	286	18
Signal				
$m_H = 200$ GeV	$118 \pm 2 \pm 19$		$6.4 \pm 0.4 \pm 1.3$	
$m_H = 300$ GeV		$24.3 \pm 0.7 \pm 4.1$		$2.1 \pm 0.2 \pm 0.4$
$m_H = 400$ GeV		$40.5 \pm 0.5 \pm 6.4$		$4.4 \pm 0.2 \pm 1.0$
$m_H = 500$ GeV		$18.5 \pm 0.2 \pm 3.1$		$2.0 \pm 0.1 \pm 0.5$
$m_H = 600$ GeV		$6.3 \pm 0.1 \pm 1.1$		$0.7 \pm 0.0 \pm 0.2$