Searches for Higgs Boson Decays with ATLAS

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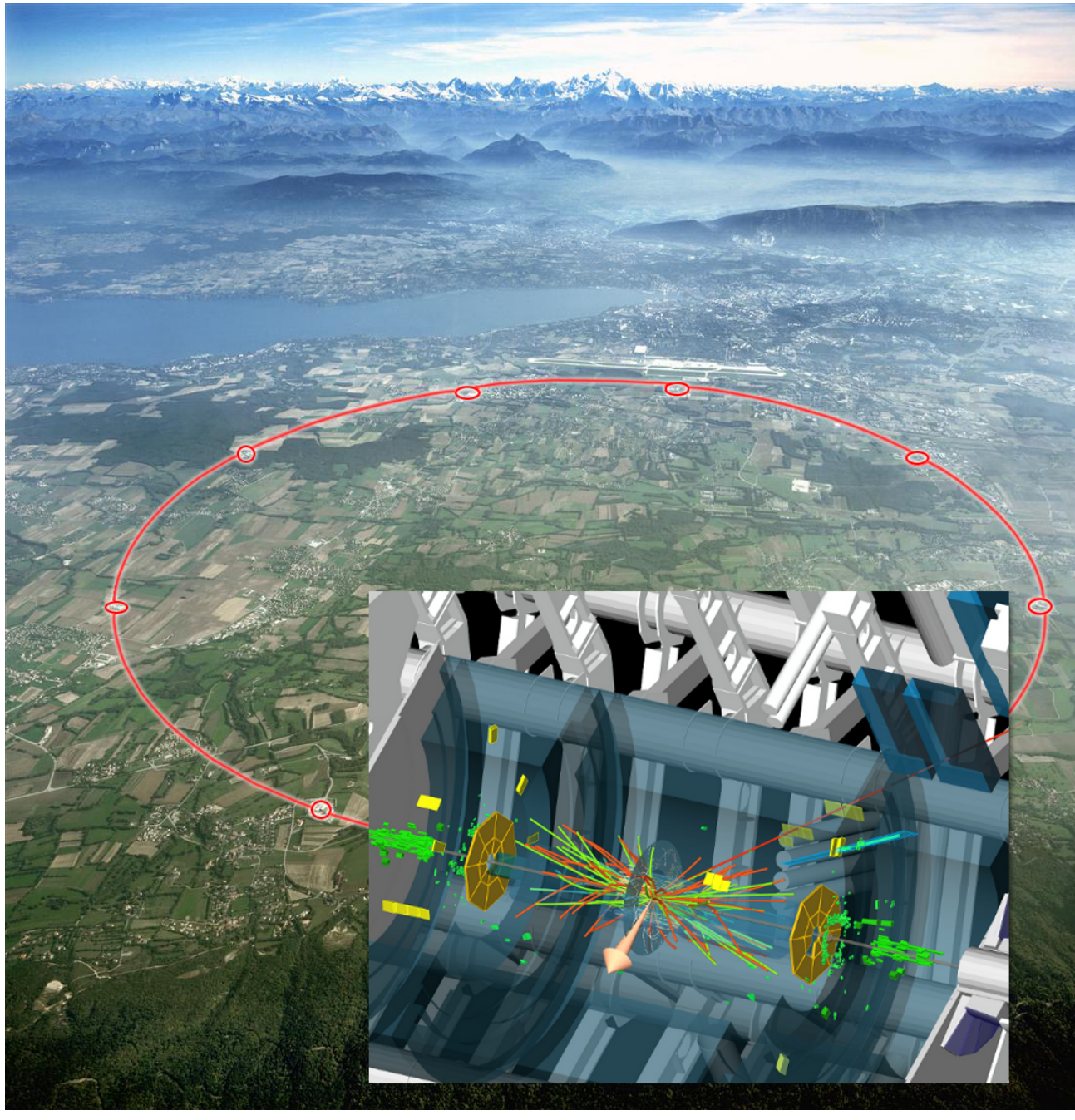
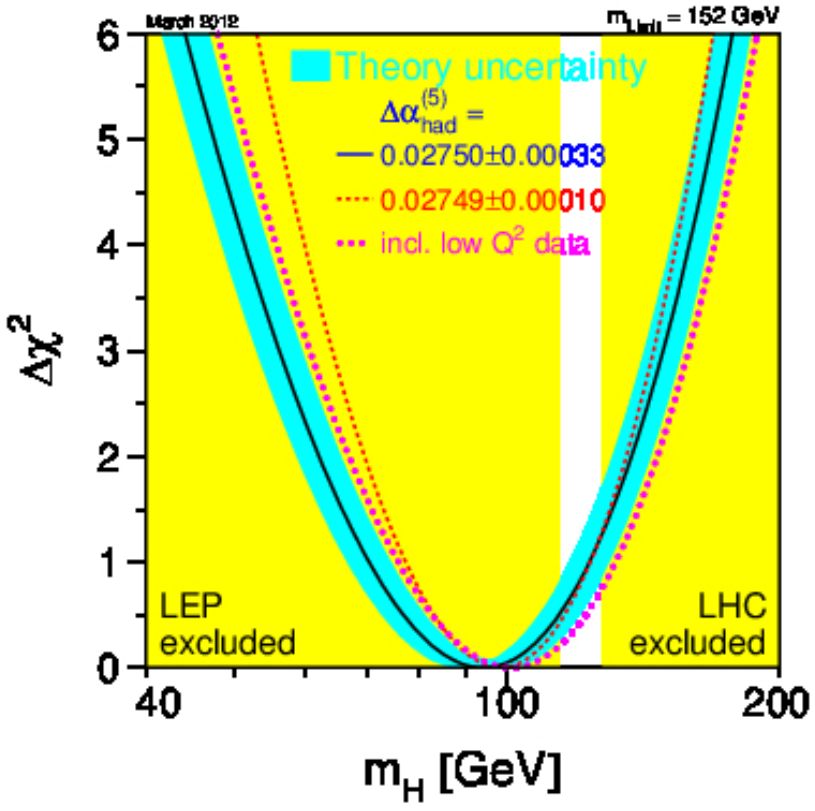
- Overview
- SM Higgs searches
- SM Higgs combination
- MSSM Higgs searches



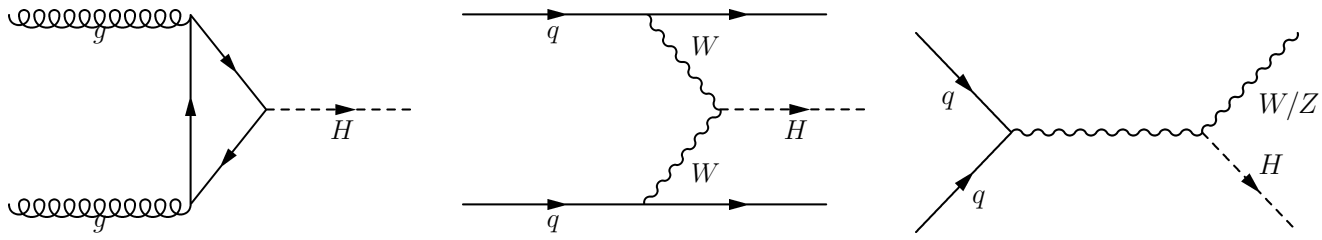
SM Higgs boson

- Higgs mechanism provides an explanation for the Electroweak Symmetry breaking and generation of the W and Z masses
- Predicts a not yet observed neutral scalar particle with unknown mass and small cross-section
- Direct searches at LEP set lower bound $m_H > 114.4$ GeV at 95% CL
- Tevatron excludes $100 < m_H < 106$ GeV and $147 < m_H < 179$ GeV at 95% CL



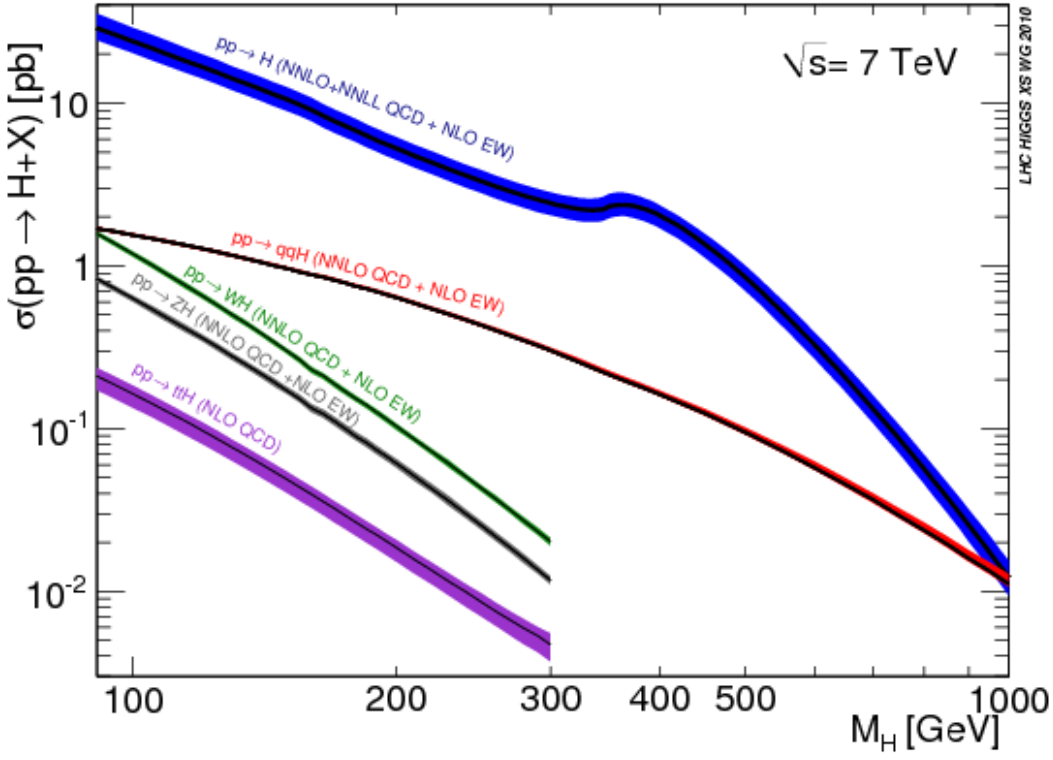
- Searching for the Higgs boson is one of the primary goals of LHC
- Higgs searches require sophisticated detectors designed to stringent performance requirements for particle identification, object energy/momentum measurements, E_T^{miss} measurement, b-tagging, etc

Higgs production



arXiv:1101.0593

- Gluon-gluon fusion (ggF)
  - POWHEG+PYTHIA
  - p_T with HqT v2.0
- Vector boson fusion (VBF)
  - POWHEG+PYTHIA
- Associated production:
  - WH/ZH
  - $t\bar{t}$H
  - PYTHIA
- Mass line shape uncertainty:
  - $(150\%) \times (\frac{m_H}{TeV})^3$

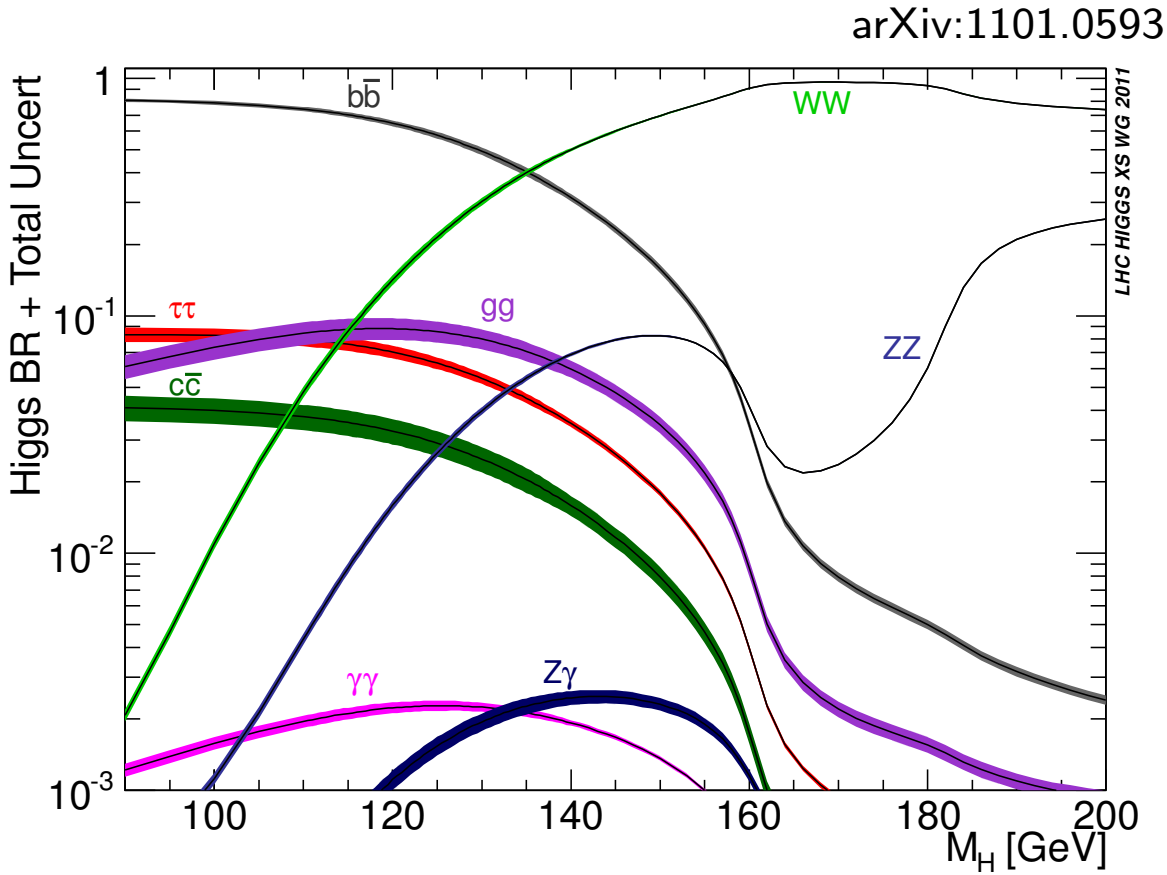


Theory uncertainties:

	ggF	VBF	WH/ZH	$t\bar{t}$H
QCD scale	$+12\%\ -8\%$	$\pm 1\%$	$\pm 1\%$	$+3\%\ -9\%$
PDF+α_S	$\pm 8\%$	$\pm 4\%$	$\pm 4\%$	$\pm 8\%$

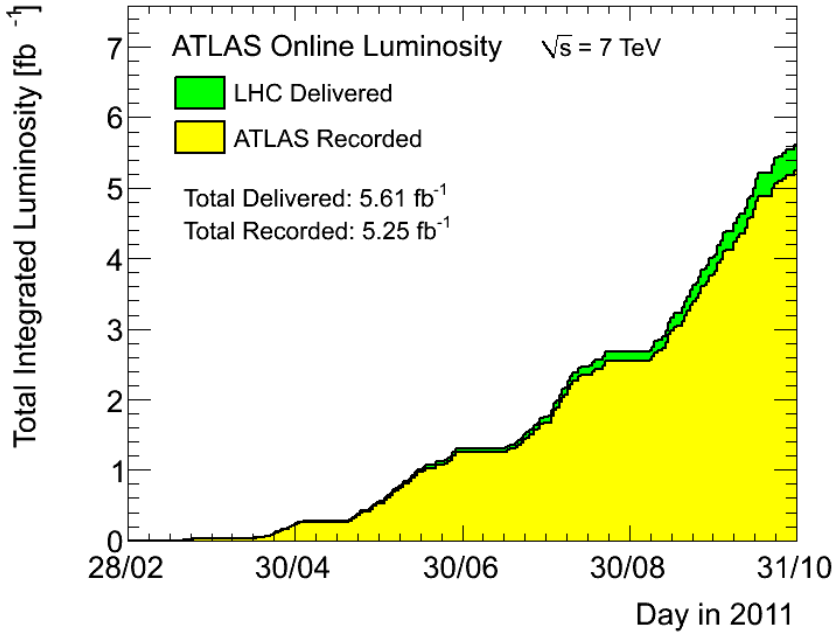
Higgs decays

- Higgs couples to mass
- WW and ZZ dominate when kinematically allowed
- Many competing channels for $m_H < 160$ GeV
- SM backgrounds inhibit searches in channels with jets and/or neutrinos
- $B(W \to l\nu) = 10.8\%$
  $B(Z \to ll) = 3.4\%$
- Width for $m_H < 170$ GeV:
  $\Gamma_H < 100$ MeV



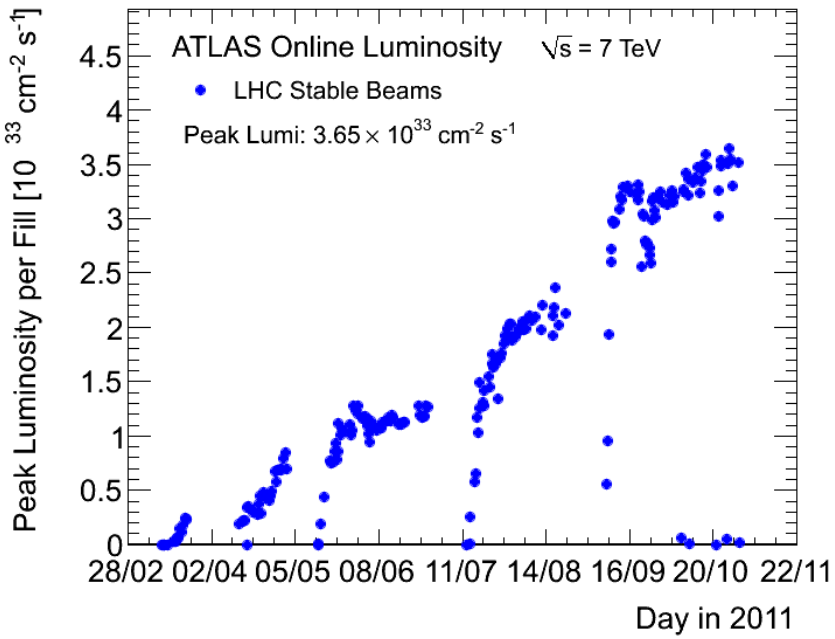
ATLAS experiment

- ATLAS is 93.5% efficient during stable LHC collisions
- Recorded $\int \mathcal{L} = 5.25\ fb^{-1}$
- Luminosity uncertainty is 3.9%
- High trigger efficiency for Higgs searches
  - Single lepton, di-lepton and di-photon triggers



LHC peak luminosity in 2011:

- $\mathcal{L}_{peak} \approx 3.6 \times 10^{33} cm^{-2} s^{-1}$
- pp inelastic $\approx 210\ MHz$
- $Z \to \mu\mu \approx 3\ Hz$
- $H[125\ GeV] \to WW \to l\nu l\nu \approx 0.0003\ Hz$



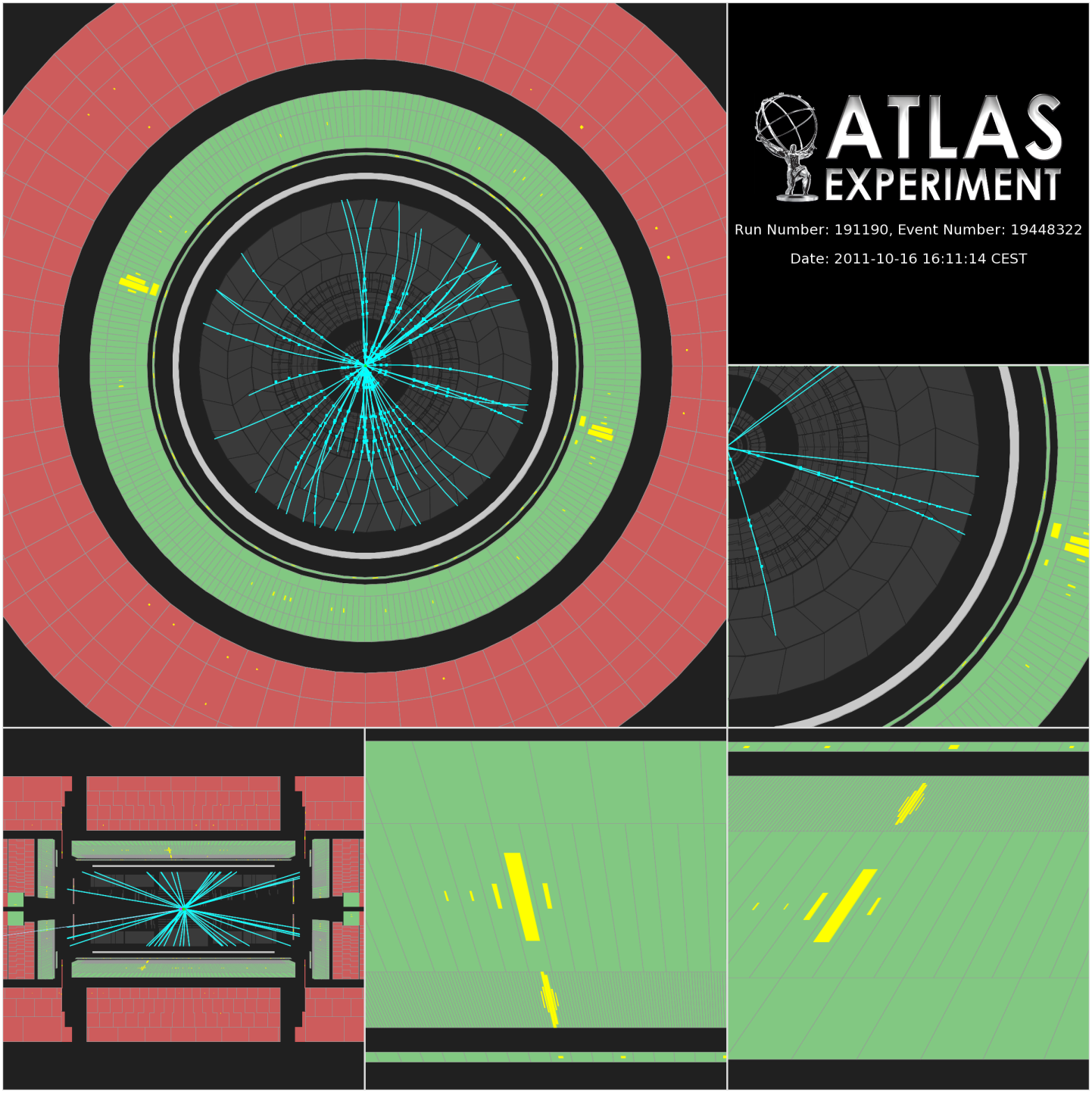
SM Higgs Boson Decays

Channel	m_H range (GeV)	$\int \mathcal{L}$ (fb^{-1})	Reference
$H \to \gamma\gamma$	$110 - 150$	4.9	arXiv:1202.1414
$H \to ZZ \to 4l$	$110 - 600$	4.8	arXiv:1202.1415
$H \to ZZ \to ll\nu\nu$	$200 - 600$	4.7	CONF-2012-016
$H \to ZZ \to llqq$	$200 - 500$	4.7	CONF-2012-017
$H \to WW \to l\nu l\nu$	$110 - 600$	4.7	CONF-2012-012
$H \to WW \to l\nu qq$	$300 - 600$	4.7	CONF-2012-018
$H \to \tau\tau$	$100 - 150$	4.7	CONF-2012-014
$VH \to Vbb$	$110 - 130$	4.7	CONF-2012-015
SM H combination	$100 - 600$	4.6-4.9	CONF-2012-019

- A mass resonance search for $H \to \gamma\gamma$, $H \to ZZ \to 4l$
- A counting experiment for final states with neutrinos
- Limited mass resolution for final states with jets

Statistical procedure:

- Profile likelihood ratio to test signal strength $\mu = \sigma/\sigma_{SM}$ (Eur.Phys.J.C71:1554,2011)
- Exclusion limits on μ are set at a 95% confidence level with the CLs method (J. Phys. G 28 (2002) 2693-2704)
- Look Elsewhere Effect for resonance searches (Eur.Phys.J.C70:525,2010)



$H \rightarrow \gamma\gamma$

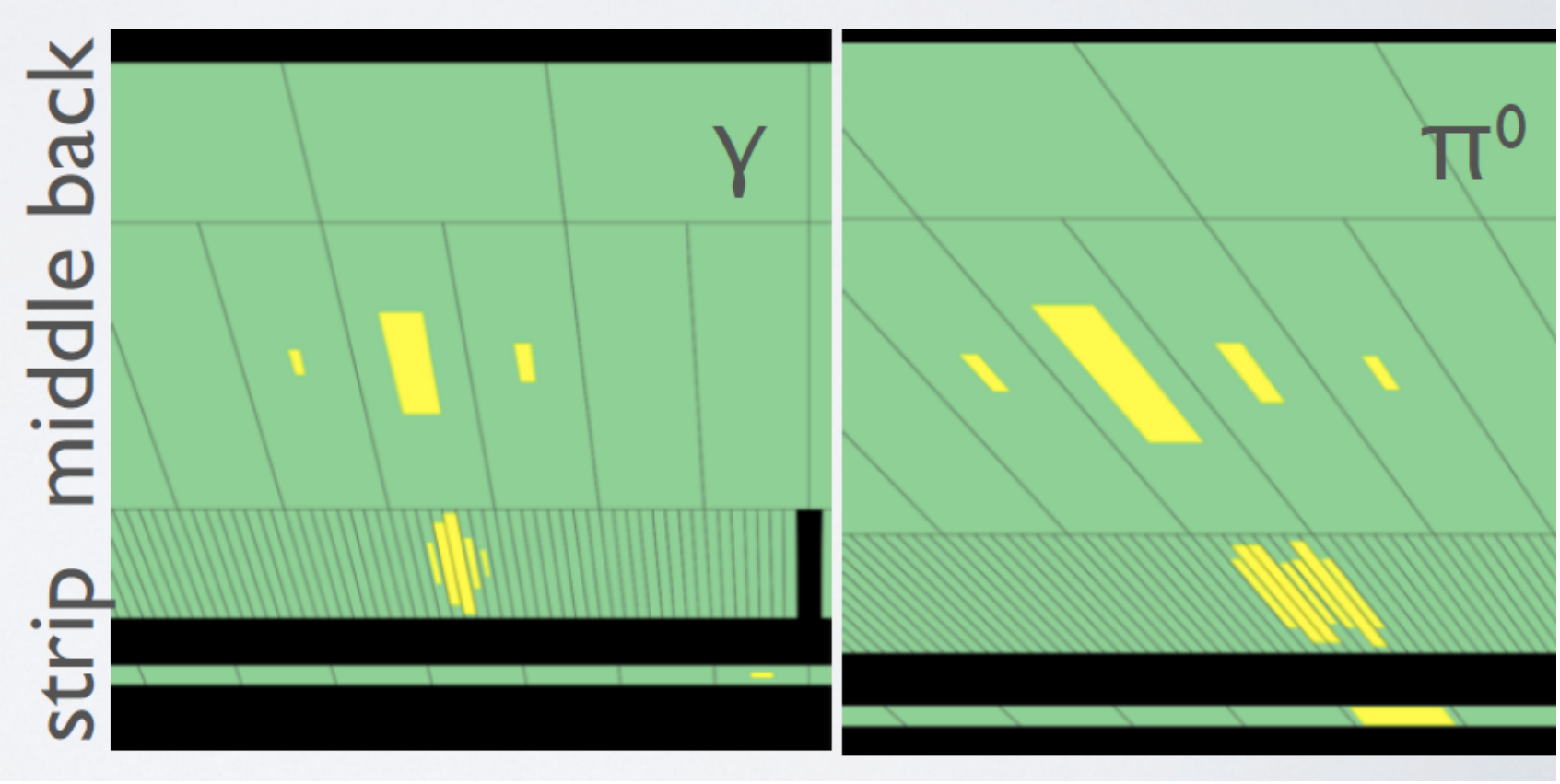
$\sigma \approx 40\ fb$

≈ 70 signal events expected in $4.9\ fb^{-1}$

ggF: 87%
VBF: 7%
W/ZH: 5%

$m^2_{\gamma\gamma} = 2E_1E_2(1 - cos\alpha)$

$H \to \gamma\gamma$: photon identification

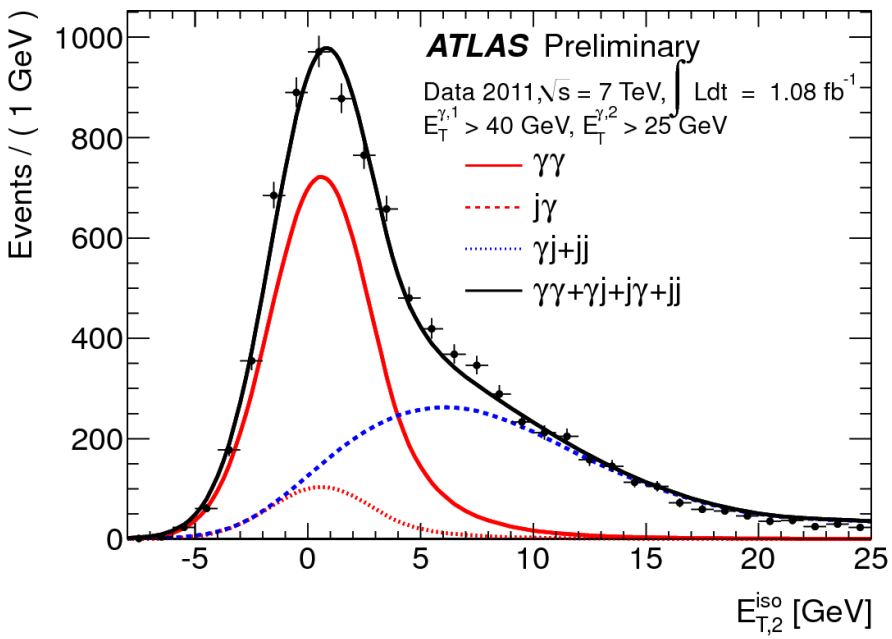


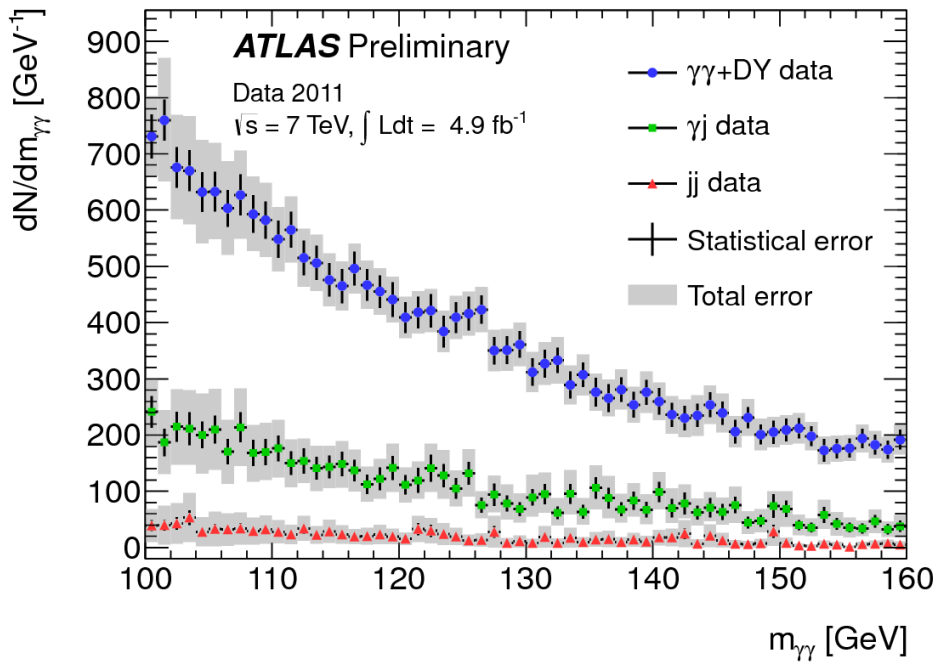
- Fine η granularity in the strip layer to reject π^0
- EM shower shape to reject fake photons from jets $\approx O(8000)$ jet rejection 85% photon efficiency
- Longitudinal segmentation to measure shower direction and to improve energy measurement

$H \to \gamma\gamma$: analysis strategy

- Two isolated photons with $p_T > 40, 25$ GeV
- Search for a narrow mass peak in di-photon mass spectrum
- Requires excellent EM energy resolution
- Split events in 9 categories to optimize signal/background
- Irreducible SM backgrounds are fitted from sidebands
  - Background composition measured from data (for cross-checks)

$\gamma\gamma$	$j\gamma$	jj	Z/γ^*
$71 \pm 5\%$	$23 \pm 4\%$	$5 \pm 3\%$	$0.7 \pm 0.1\%$

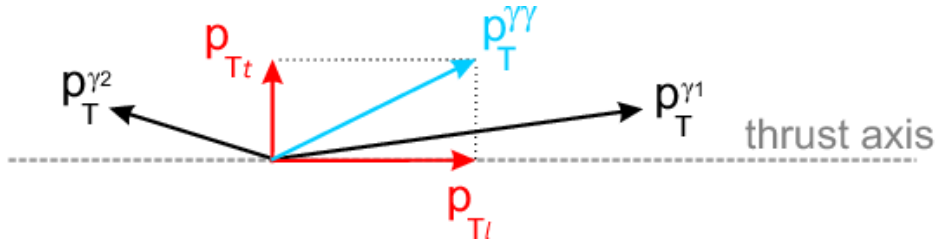


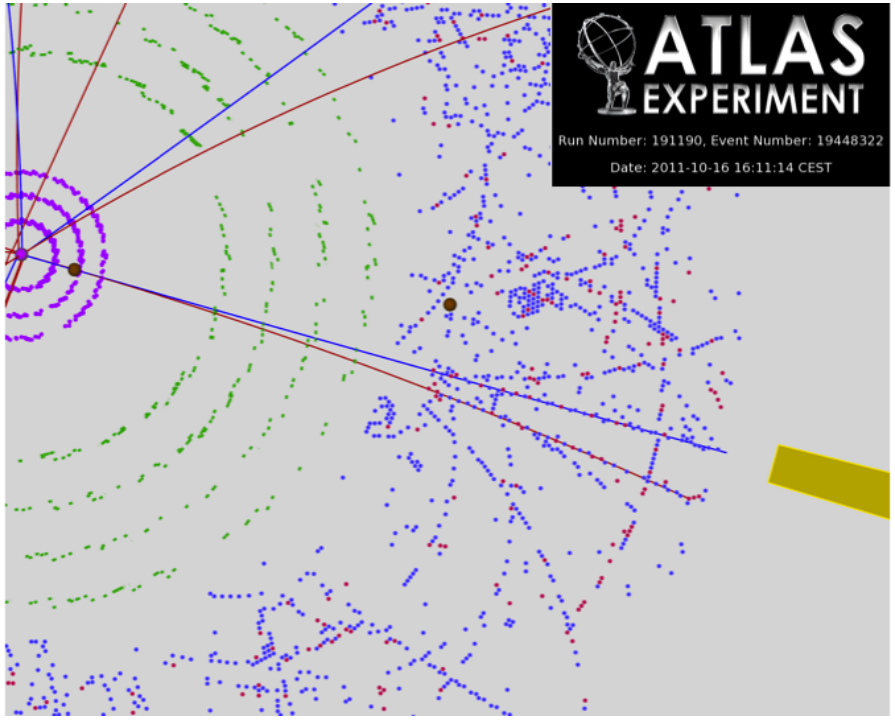


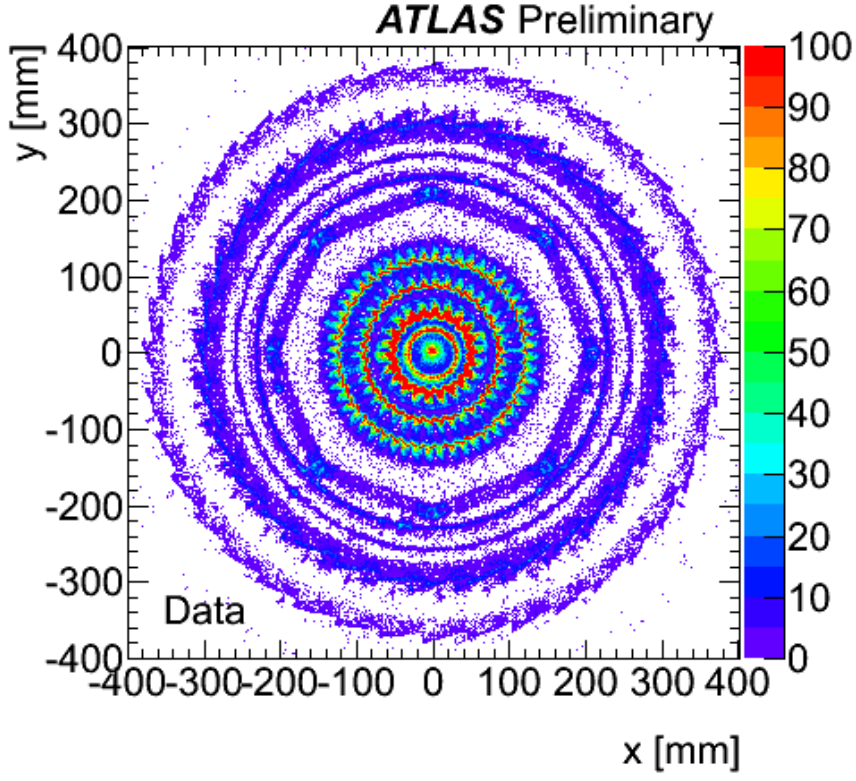
$H \to \gamma\gamma$: analysis categories

9 photon categories:

- Converted and unconverted
- Central, transition region and rest
- High and low $p_T(\gamma\gamma)$ orthogonal to the thrust axis divided at 40 GeV







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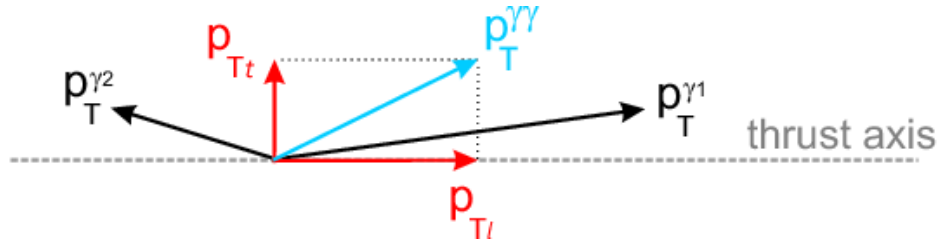
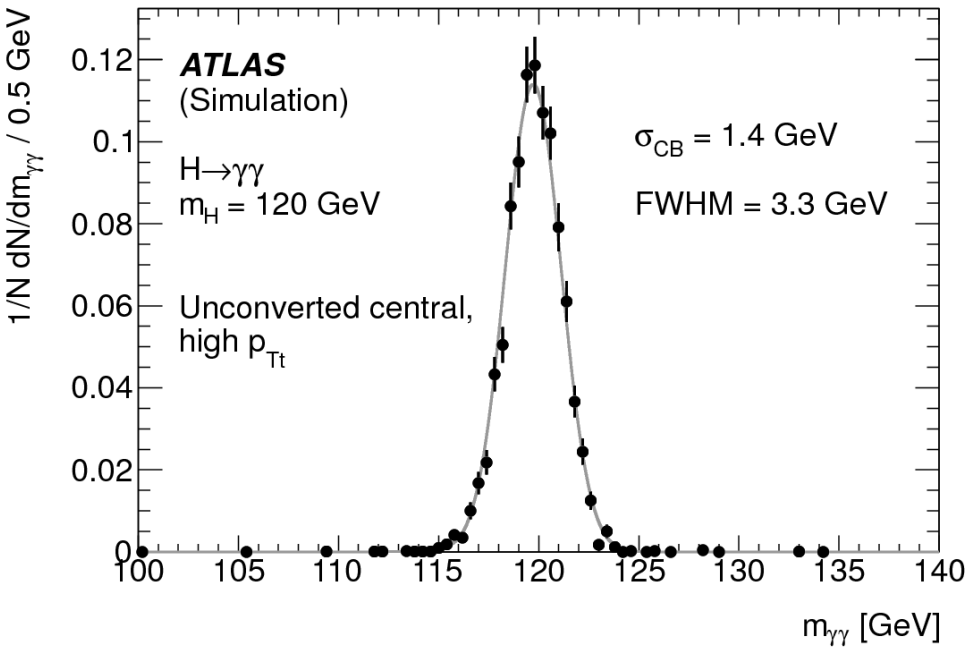
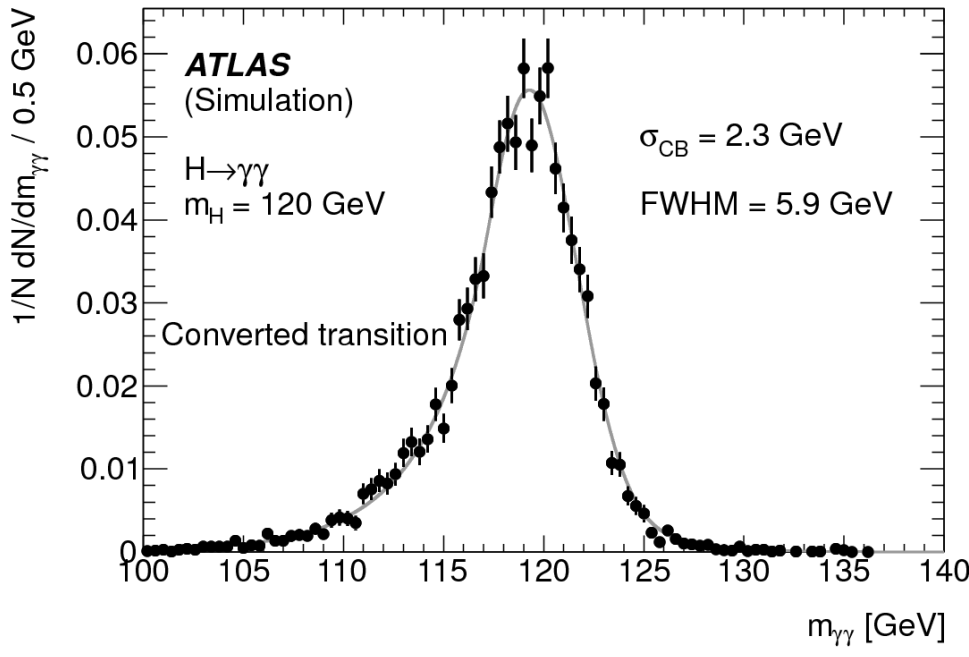


Best: $\sigma = 1.4$ GeV, S/B=0.11

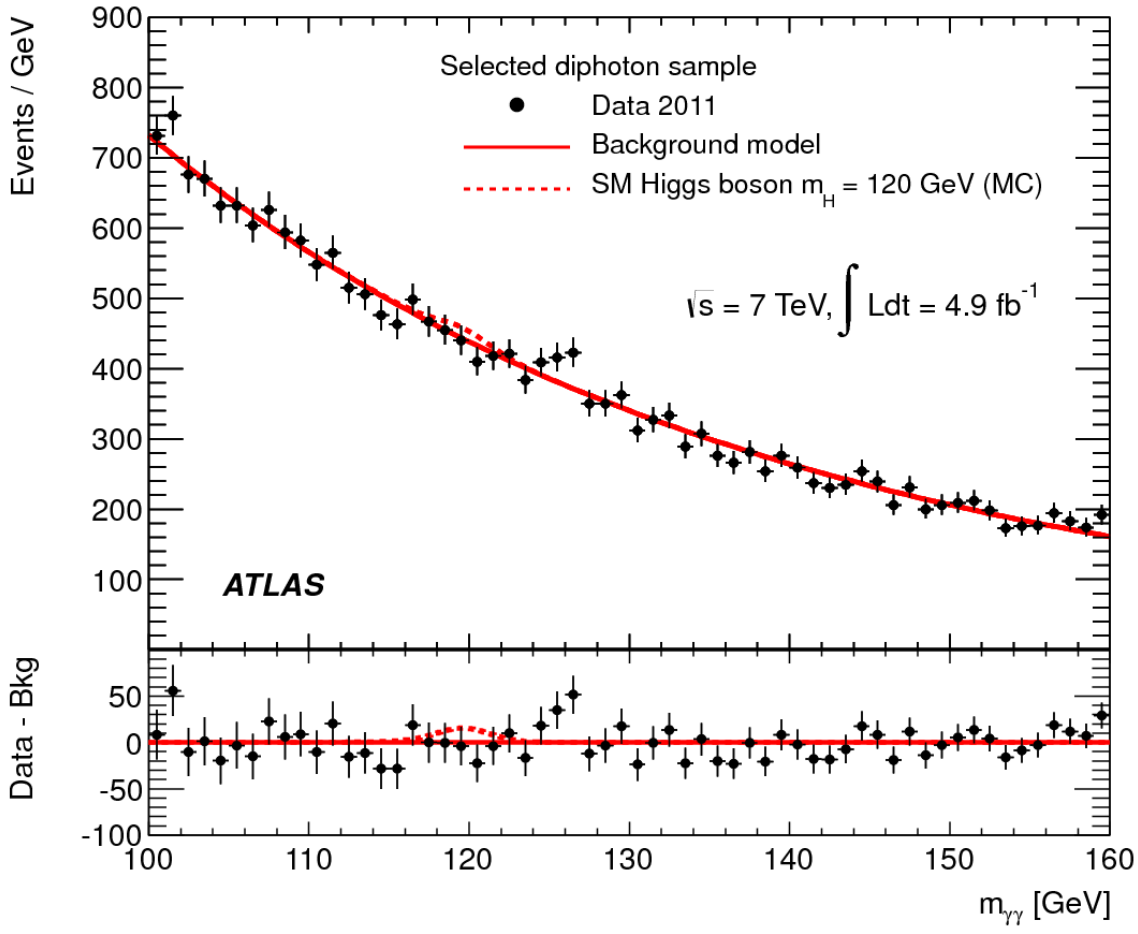


Worst: $\sigma = 2.3$ GeV, S/B=0.01



$H \to \gamma\gamma$

- Selected 22489 events
- $m_H = 125$ GeV:
  - Expect 69 signal events
  - Signal efficiency is 35%
- Fit signal with Crystal Ball + Gaussian
- Fit background with exponential
- Background modeling uncertainty is $\pm 0.1 - 7.9$ events depending on photon category



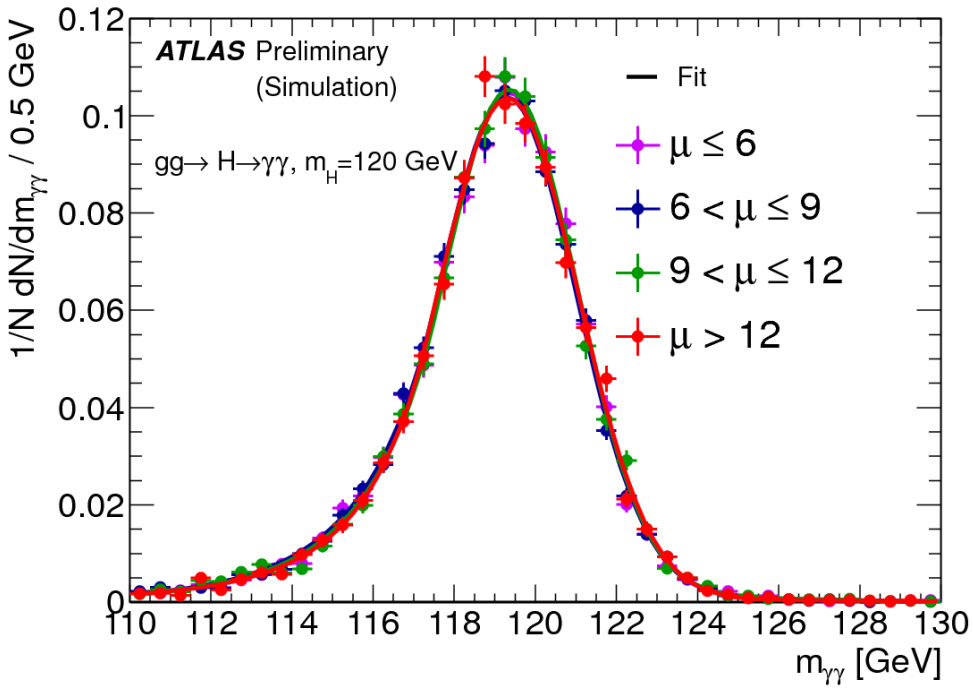
$H \to \gamma\gamma$: systematic uncertainties

Event yield:

Efficiency	$\pm 11\%$
Pileup effects	$\pm 4\%$
Isolation	$\pm 5\%$
Trigger efficiency	$\pm 1\%$
Cross-section	$+15\% \ -11\%$
Higgs p_T modeling	$\pm 1\%$
Total	$\approx 20\%$

Mass resolution:

Calorimeter energy resolution	$\pm 12\%$
Photon energy calibration	$\pm 6\%$
Pileup effect	$\pm 3\%$
Photon angle	$\pm 1\%$
Total	$\approx 14\%$

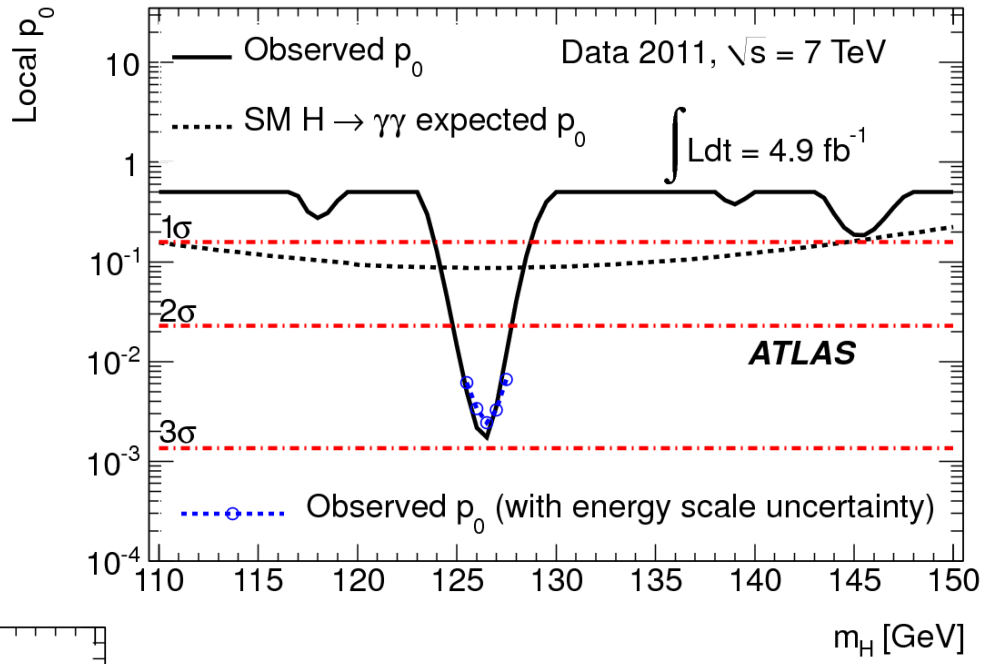


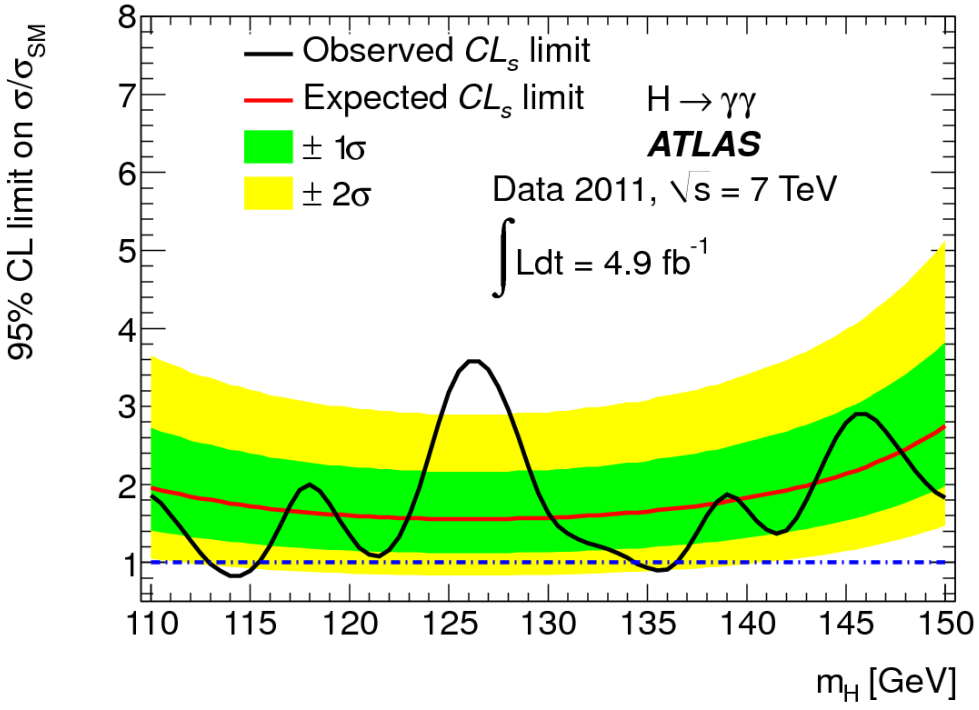
- Energy scale known to $\approx 0.5\%$ at m_Z
- Linear response at $< 1\%$
- Electron response in data is transferred to photons with MC

$H \to \gamma\gamma$: results

Consistency of observed data with background only hypothesis:

- The largest excess is at 126.5 GeV with local significance of 2.8 σ
- 1.5 σ with look-elsewhere effect in the range 110-150 GeV

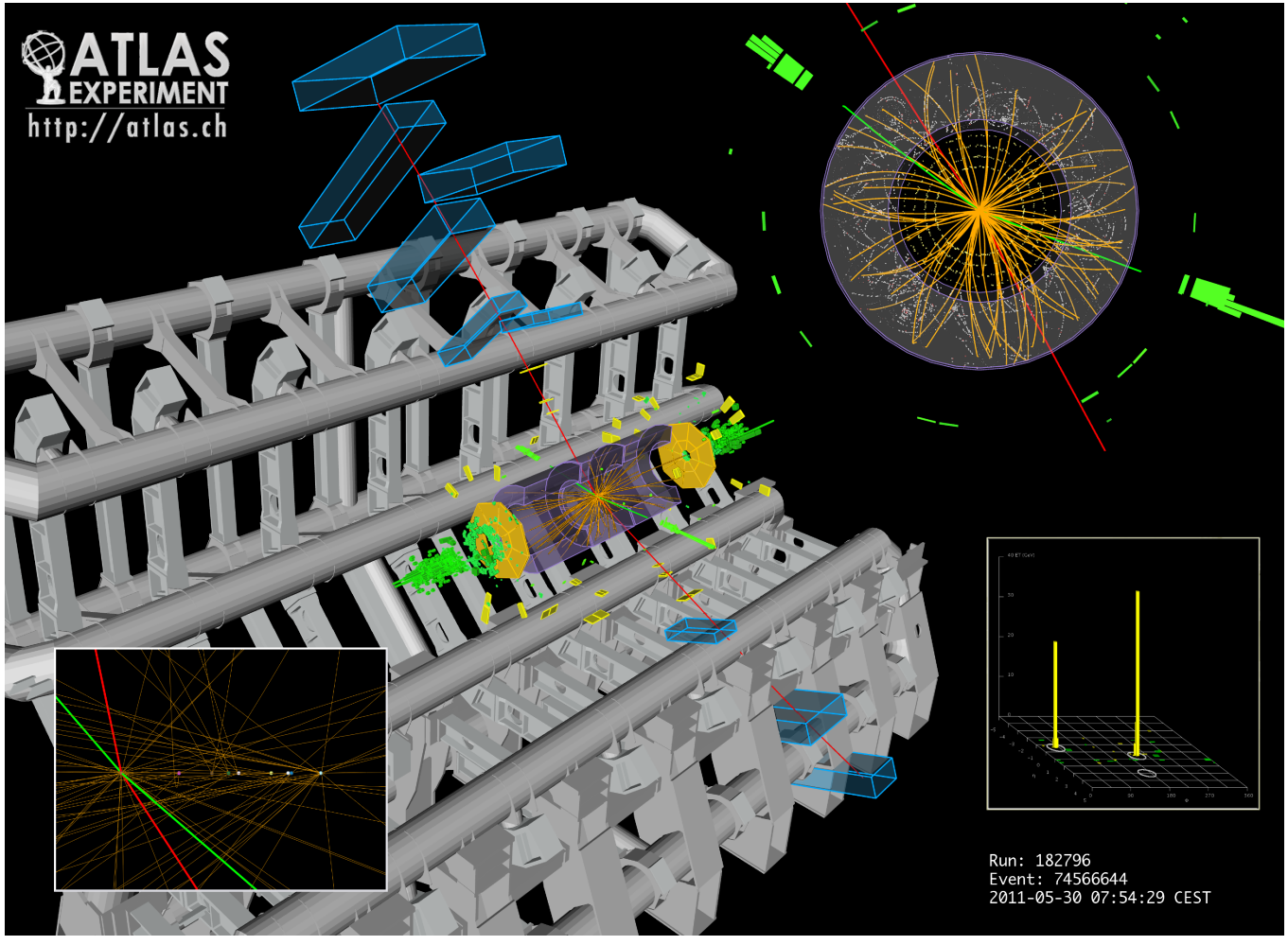




Exclusion limits:

- SM Higgs excluded at 95% confidence level in the ranges 113-115 GeV and 134.5-136 GeV
- Effect from the energy scale uncertainty on the Higgs mass is $\approx$ 0.7 GeV

$H \to ZZ \to 4l$



$m_H = 130\ GeV$:

$\sigma \approx 3\ fb$

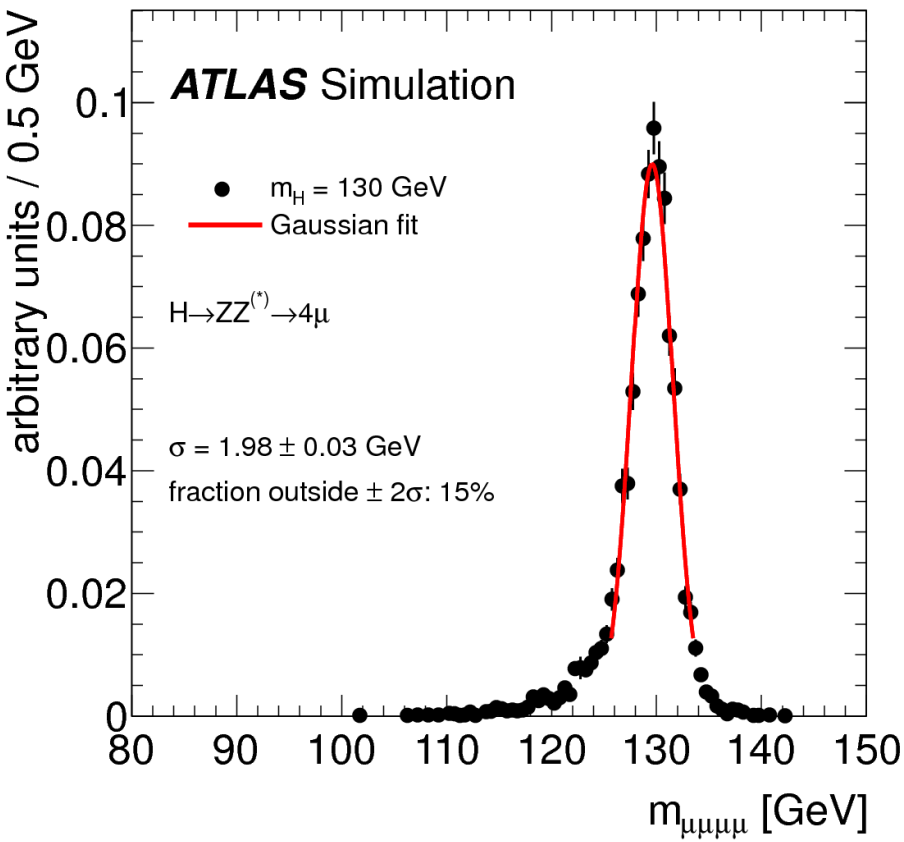
≈ 2.6 signal events expected in 4.9 fb^{-1}

ggF: 88%
VBF: 7%
W/ZH: 5%

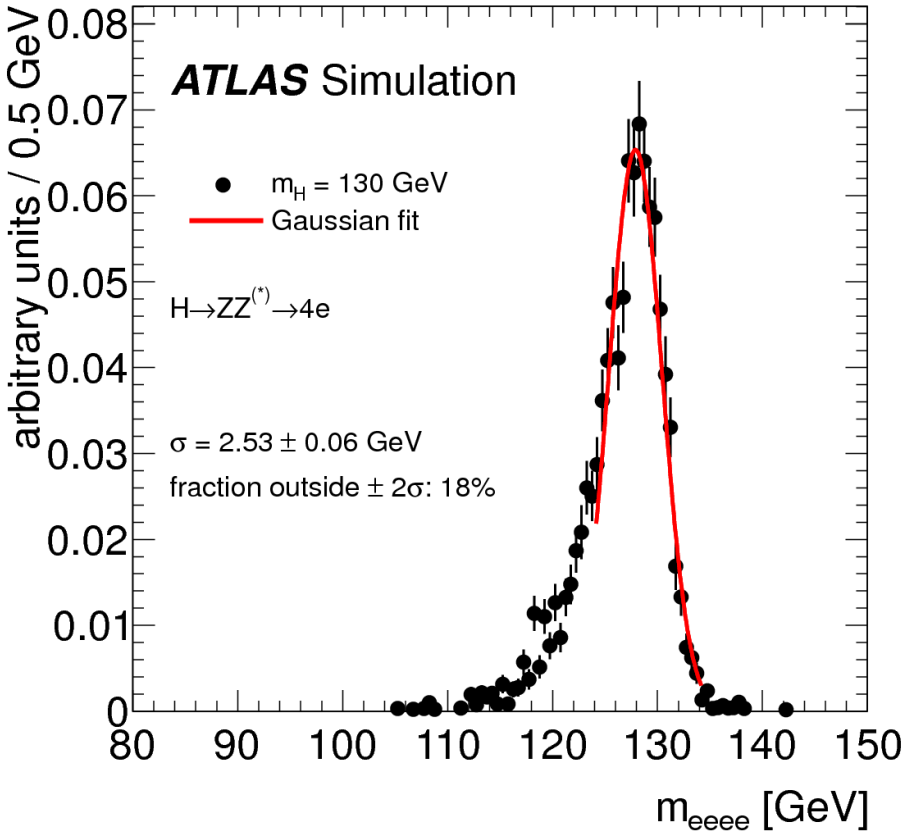
$H \to ZZ \to 4l$: analysis strategy

- Four isolated electrons or muons with $p_T > 20, 20, 7, 7$ GeV
- One pair of leptons must come from Z decay
- Search for a narrow mass resonance
- 4 event categories: $4e$, $2e2\mu$, 4μ
- Irreducible SM ZZ^* background
- Reducible Z+jets and $t\bar{t}$ backgrounds

4μ : $\sigma = 2.0$ GeV

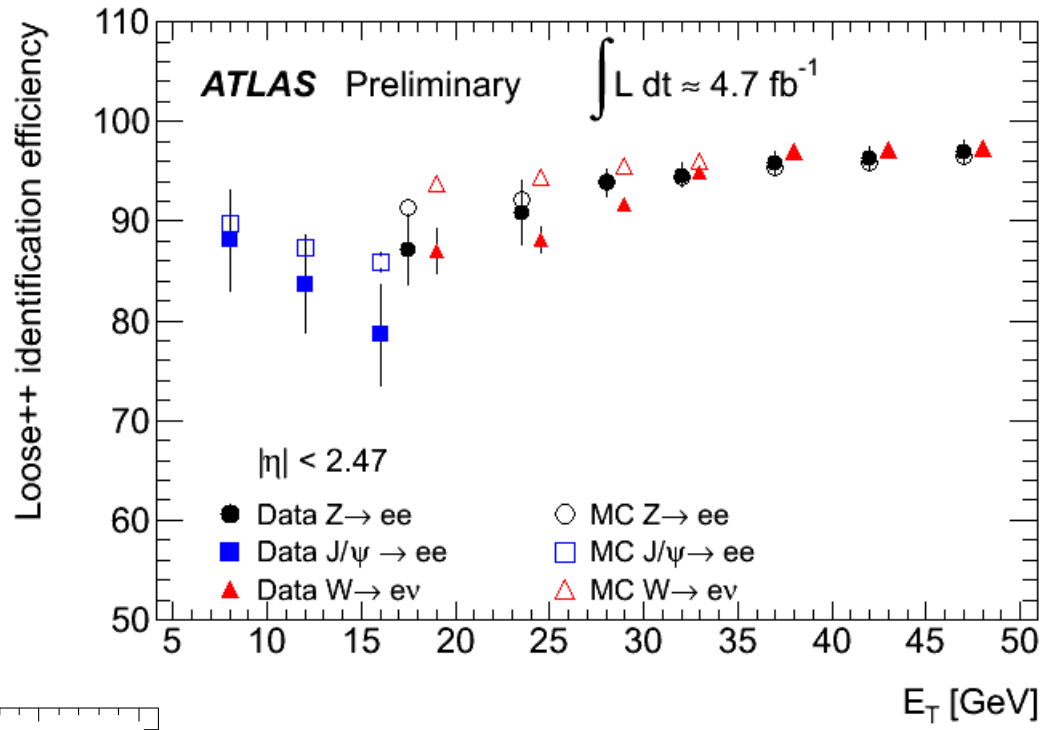


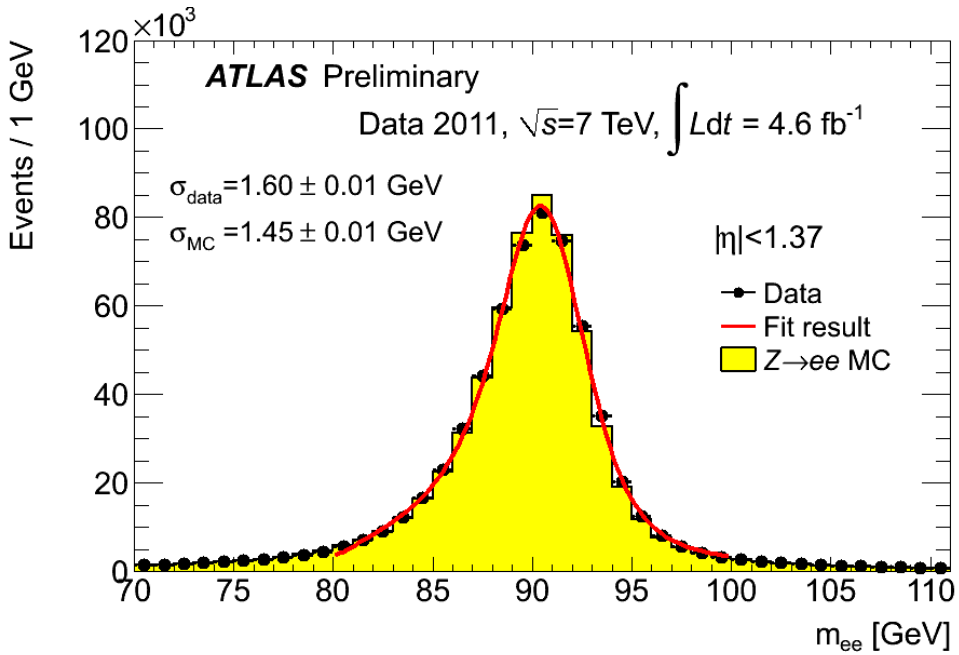
$4e$: $\sigma = 2.5$ GeV



Electrons

- Electron reconstruction and identification efficiency $85 - 90\%$
- Understand electron performance with benchmark data processes: $J/\psi \to ee$, $Z \to ee$ and $W \to e\nu$
- Track and calorimeter based isolation



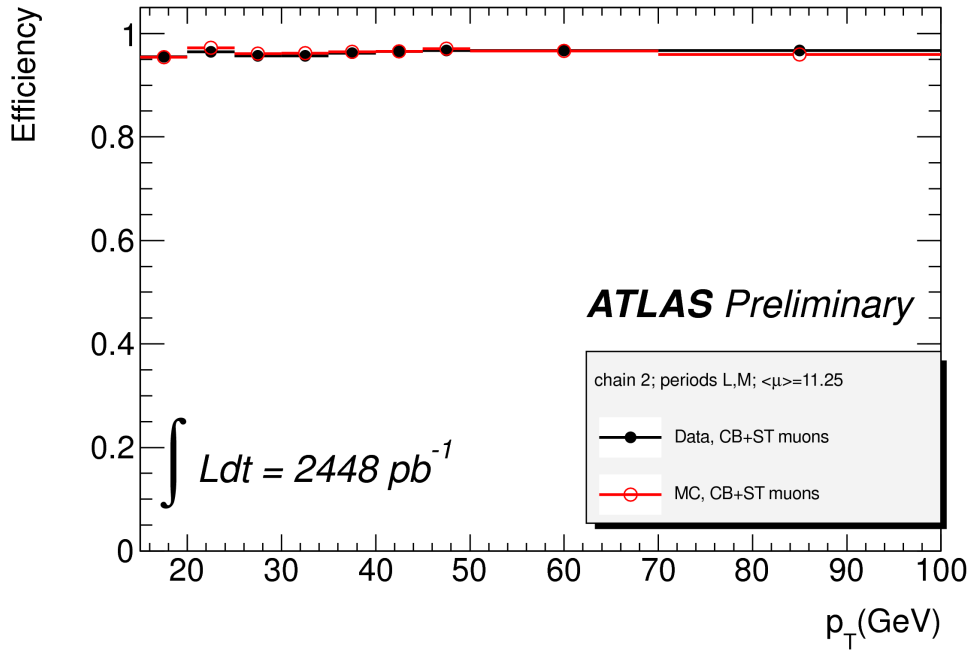


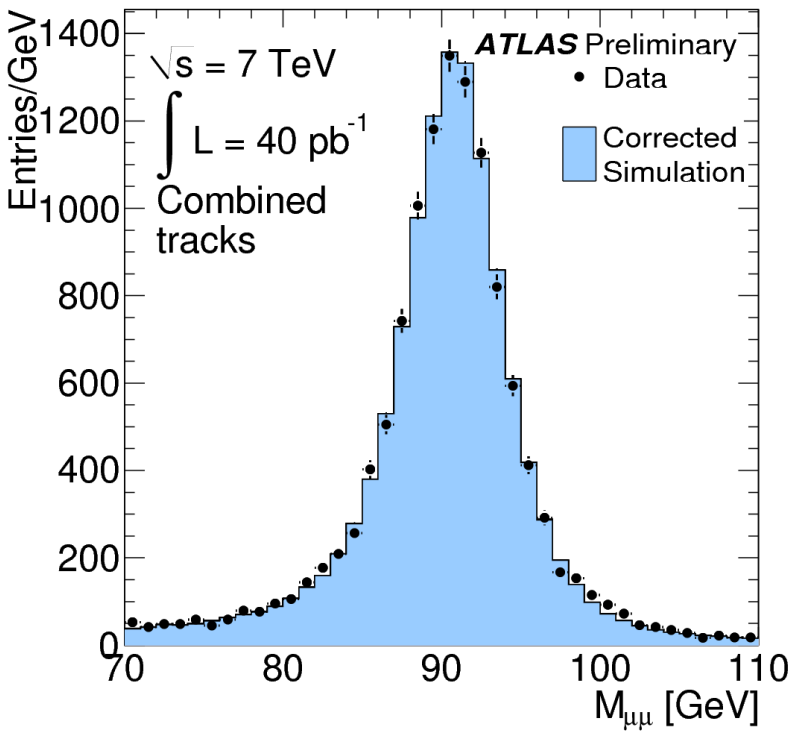
Systematic uncertainties:

- Efficiency: $< 3\%$
- Energy scale: $< 1\%$
- Energy resolution: $< 0.5\%$

Muons

- Muon reconstruction and identification efficiency $> 95\%$
- Accurate alignment of inner detector and muon system (MS)
- Combined momentum measurement using ID and MS





Systematic uncertainty:

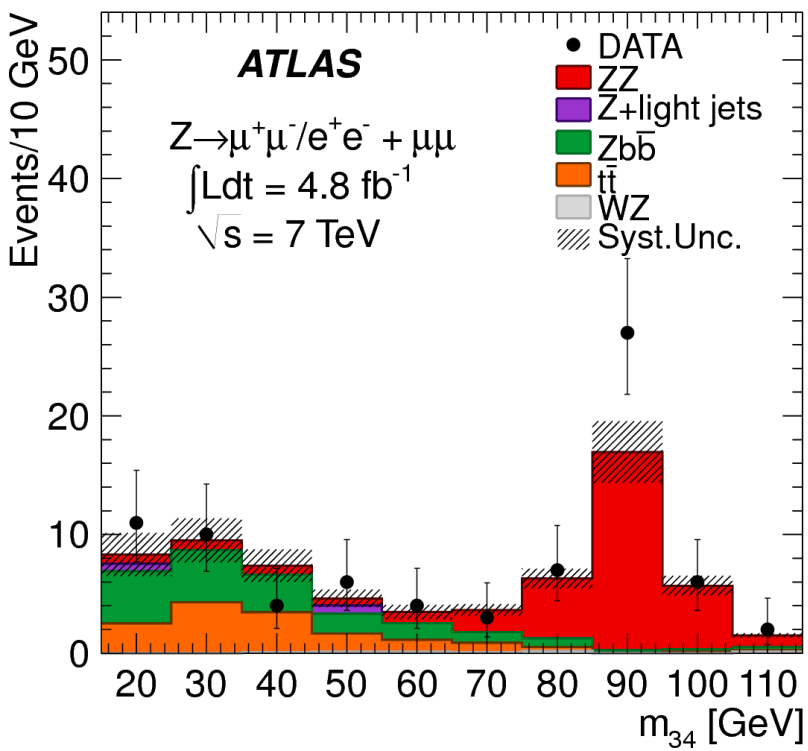
- Efficiency: $< 1\%$
- Momentum resolution: $< 1\%$

$H \to ZZ \to 4l$: backgrounds

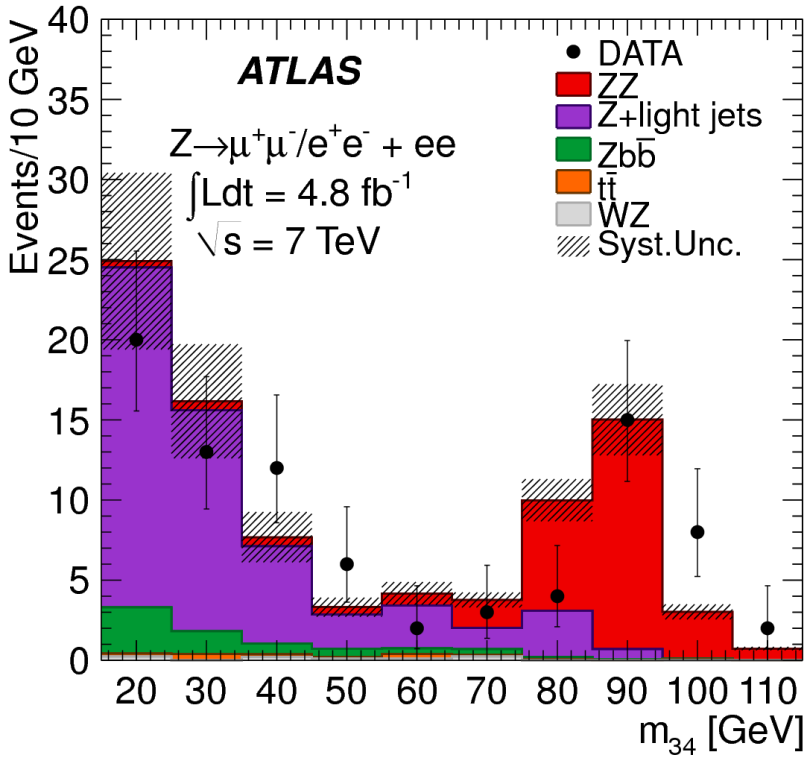
- Normalize $ZZ^{(*)}$ from simulation
- Normalize reducible backgrounds from control regions
  - Z+jets background - relax lepton selection cuts
  - $t\bar{t}$ - $e\mu$ channel

$m_{4l} < 180\ GeV$	4μ	$2e2\mu$	$4e$
$ZZ^{(*)}$	2.1 ± 0.3	2.8 ± 0.6	1.2 ± 0.3
$Z + jet$ and $t\bar{t}$	0.16 ± 0.06	1.4 ± 0.5	1.6 ± 0.7

Relax impact parameter for $Z + \mu\mu$



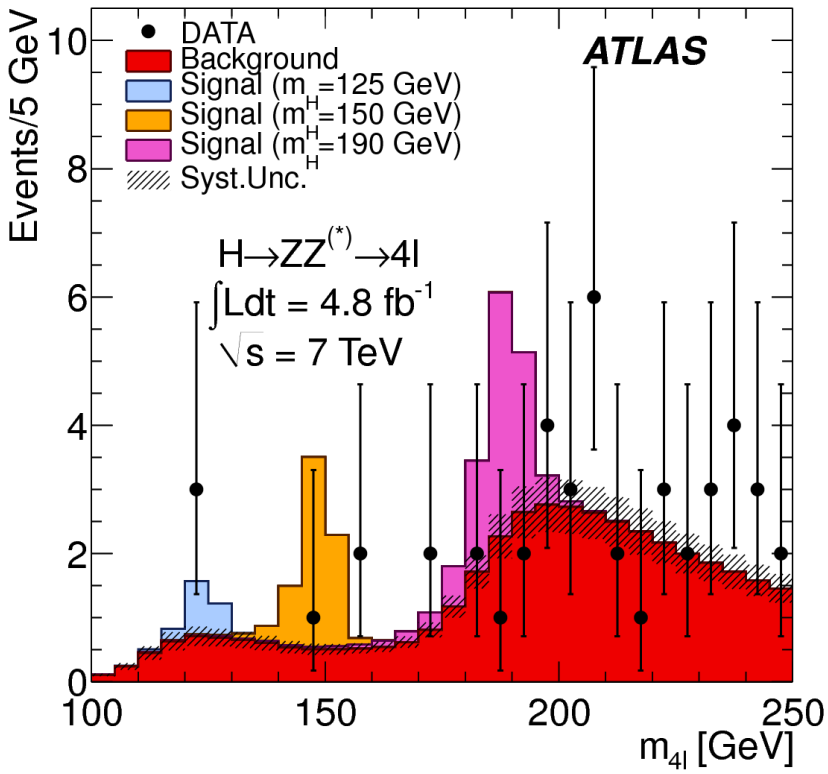
Relax isolation cut for $Z + ee$

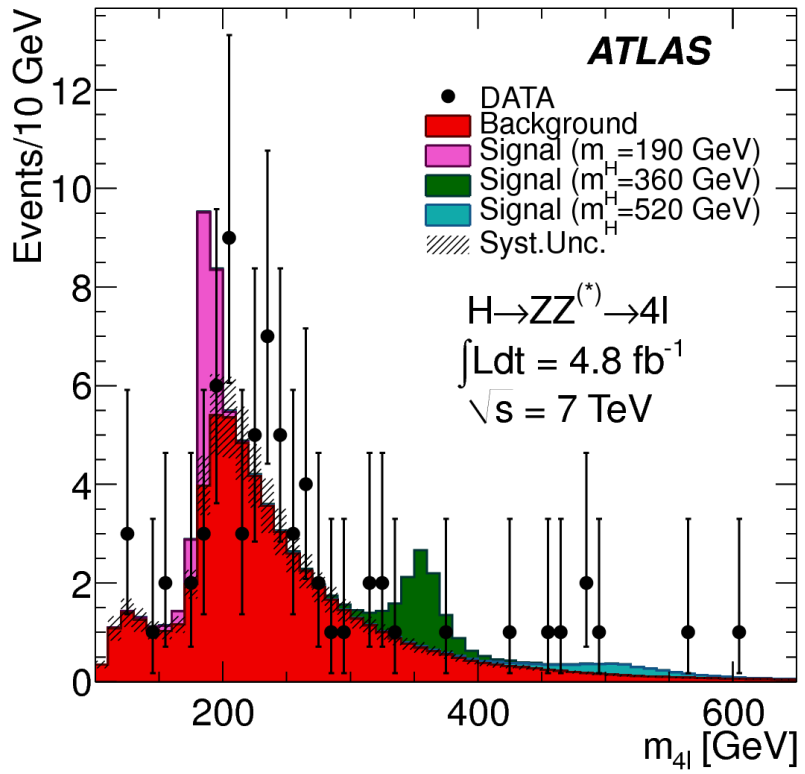


$H \to ZZ \to 4l$: four-lepton invariant mass

- Selected 71 candidate events
- Expect 62 ± 9 background events
- Fit four-lepton mass spectrum for Higgs signal

$m_{4l} < 180$ GeV	4μ	$2e2\mu$	$4e$
Total Bkg.	2.2 ± 0.3	4.3 ± 0.8	2.8 ± 0.8
$m_H = 130$ GeV	1.00 ± 0.17	1.22 ± 0.21	0.43 ± 0.08
Data	3	3	2





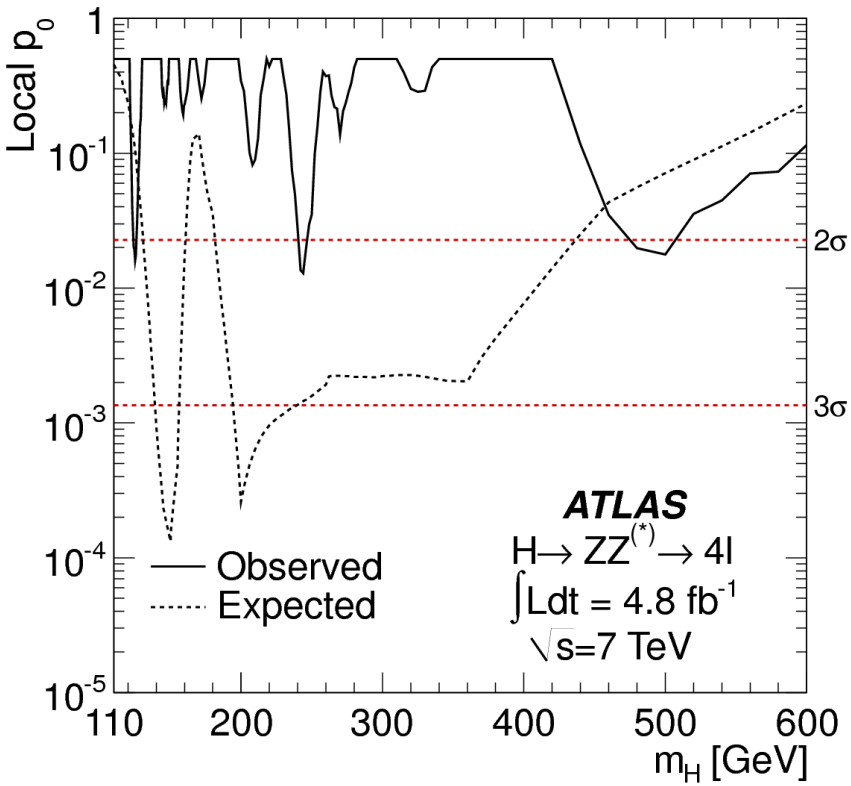
$H \to ZZ \to 4l$: results

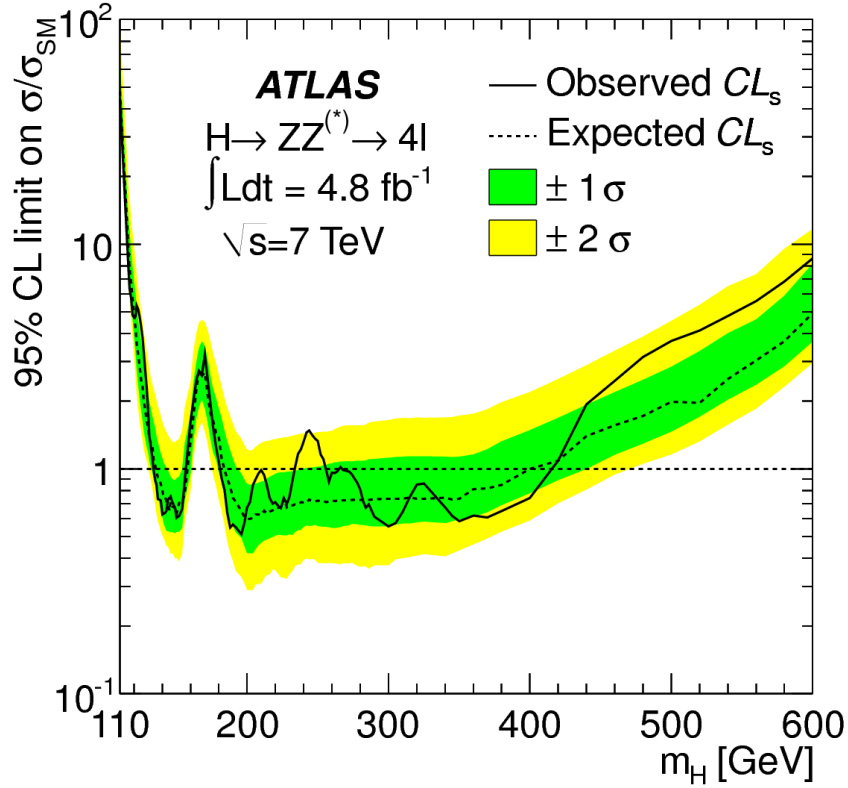
Consistency of observed data with background only hypothesis:

- Excesses at 125 GeV, 244 GeV and 500 GeV with local significances of 2.1, 2.2 and 2.1 σ
- None of these excesses is significant with the look-elsewhere effect included

Exclusion limits:

- SM Higgs is excluded in the mass ranges 134-156 GeV, 182-233 GeV, 256-265 GeV and 268-415 GeV at the 95% confidence level





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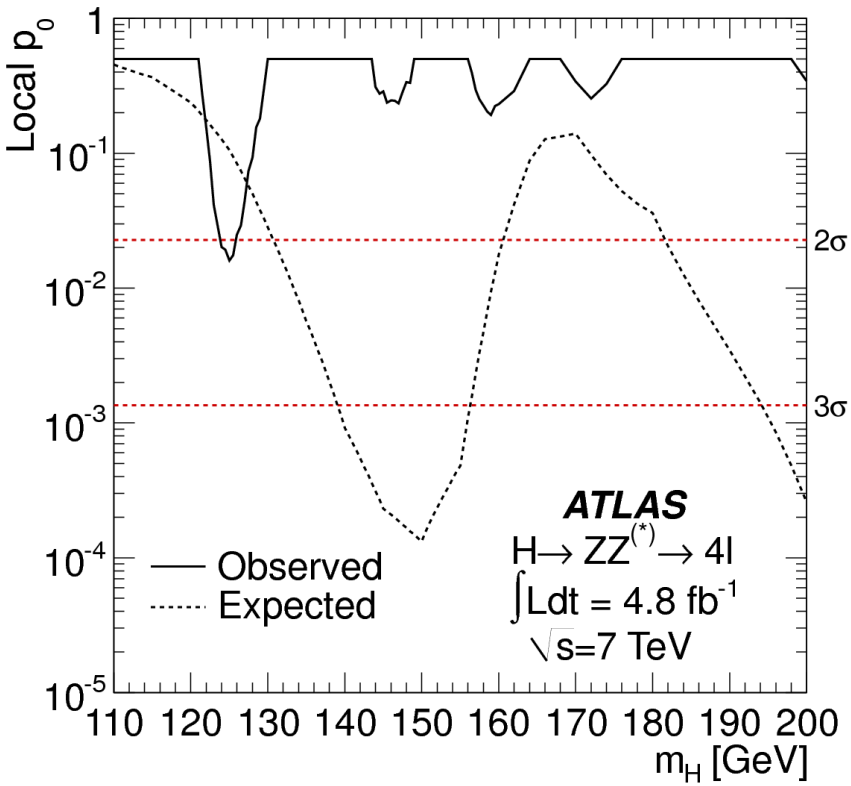
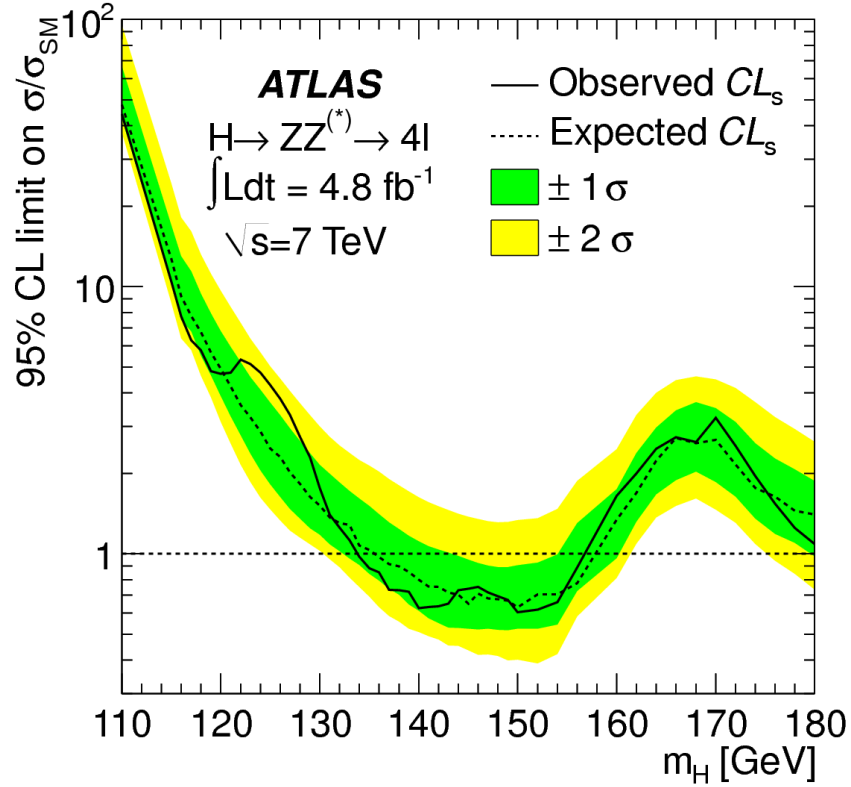
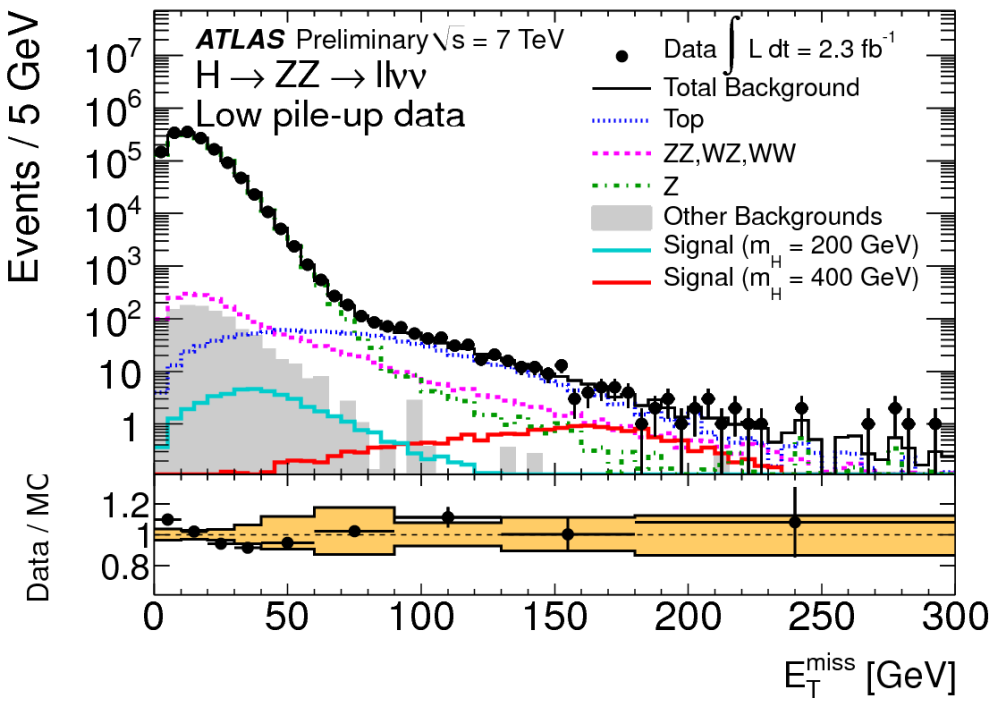




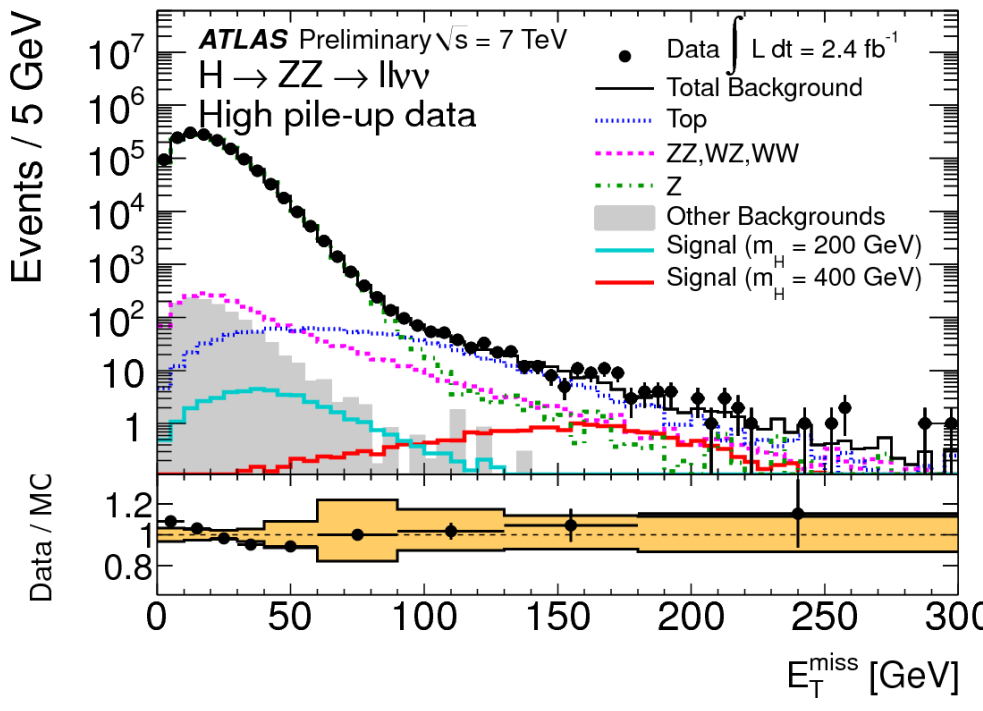
$H \to ZZ \to ll\nu\nu$: analysis strategy

- Pair of isolated electrons or muons consistent with Z decay
- Require lepton $p_T > 20$ GeV and significant missing transverse energy
- Several analysis categories to improve signal sensitivity
- Control regions for main backgrounds
  - Top, di-bosons, Z+jets/W+jets
- Search for an excess of events in transverse mass distribution

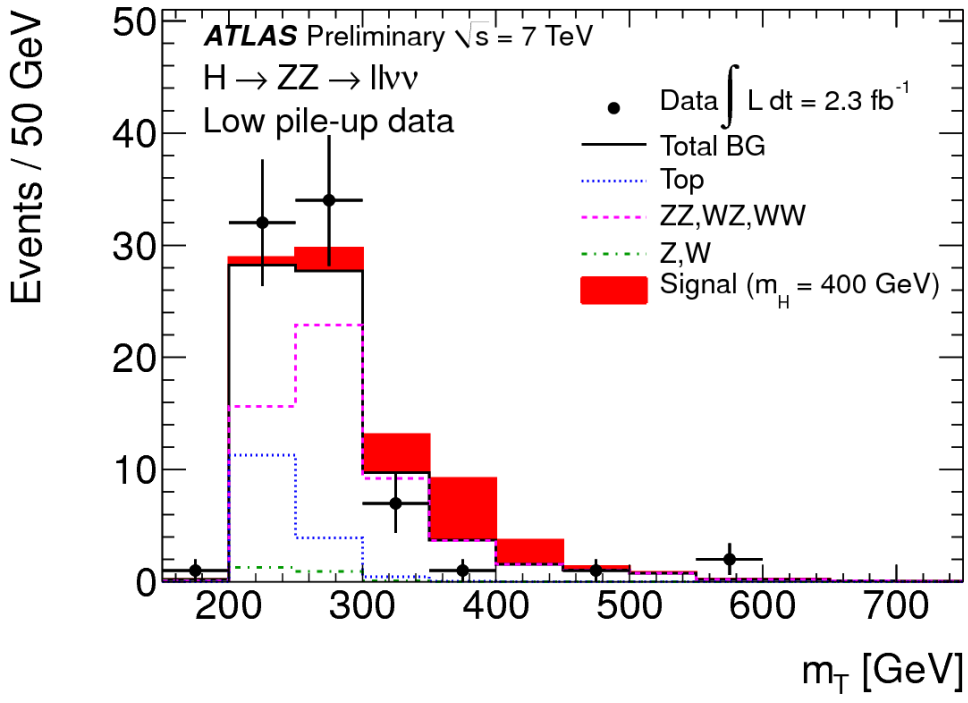
Lower pileup

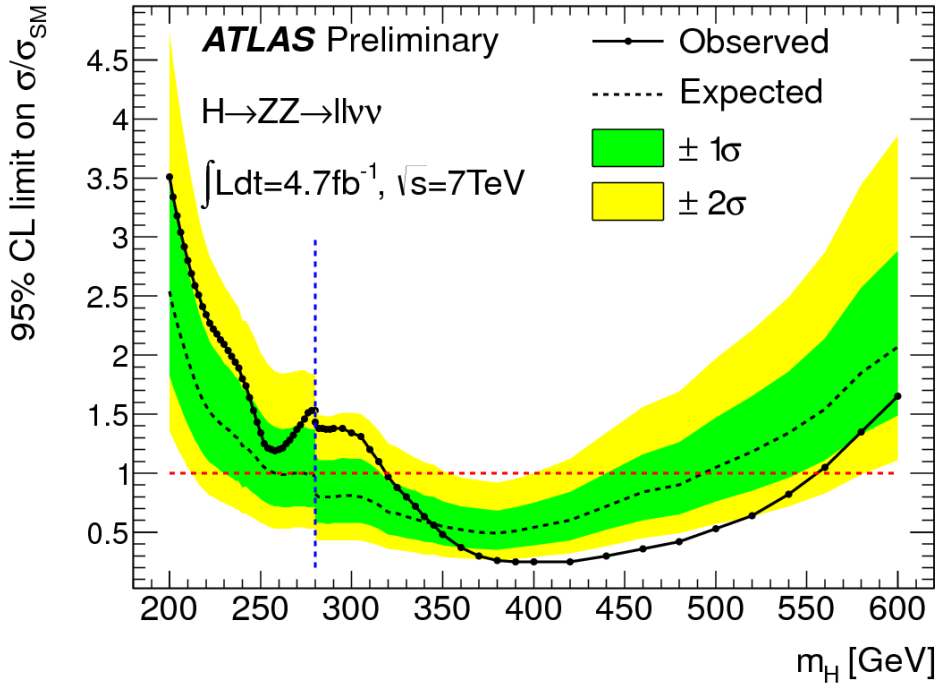


Higher pileup



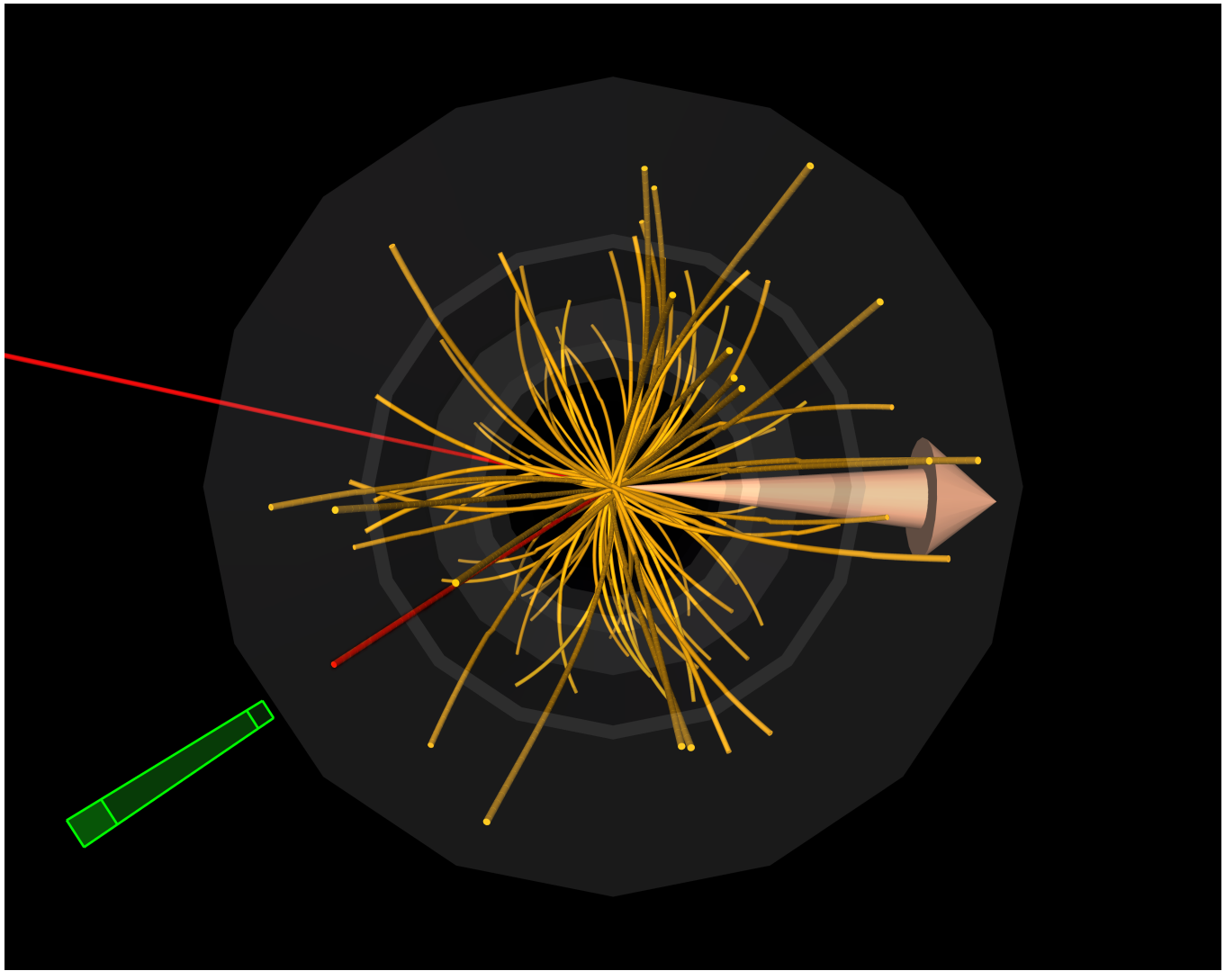
$H \to ZZ \to ll\nu\nu$: results





- Search for an excess of events in transverse mass distribution
- Split the analysis at $m_H = 280$ GeV
- SM Higgs is excluded in the mass range 320-560 GeV at the 95% confidence level
- Main uncertainties are from background normalizations which are estimated from data

$H \to WW \to l\nu l\nu$



$m_H = 125\ GeV$:

$\sigma \approx 100\ fb$

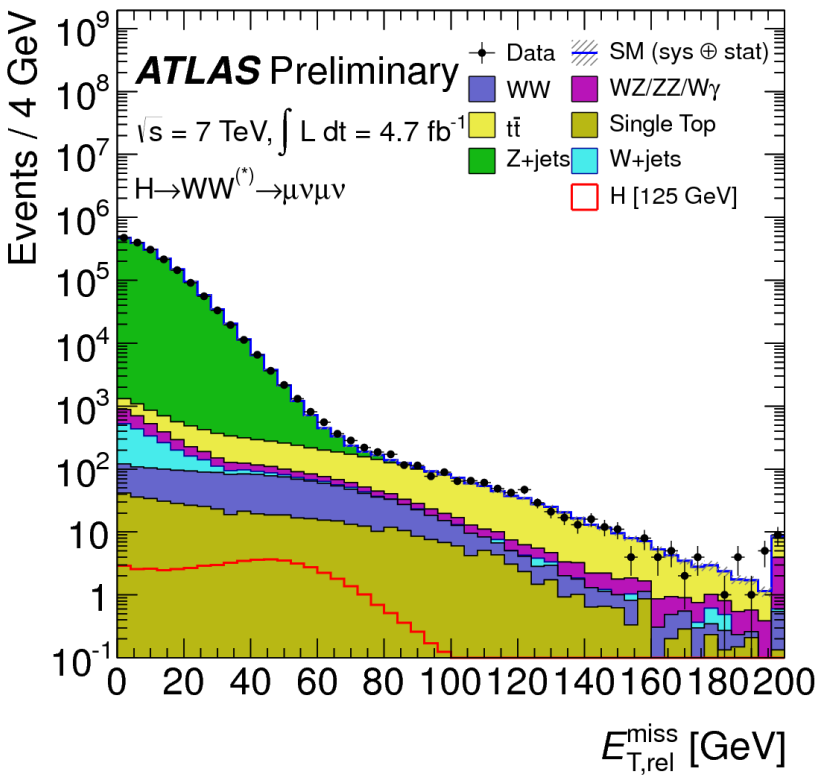
≈ 181 signal events expected in 4.9 fb^{-1}

A larger rate but difficult and diverse backgrounds

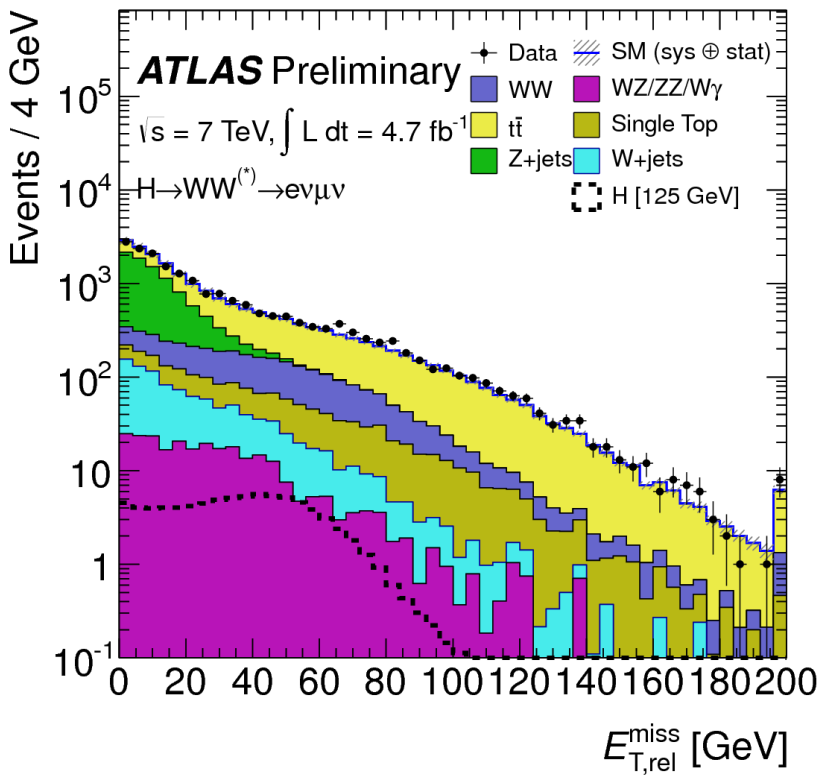
$H \to WW \to l\nu l\nu$: analysis strategy

- Pair of isolated opposite sign leptons ($p_T > 25, 15$ GeV)
- Veto Z with mass window $|m_{ll} - m_Z| < 15$ GeV for $ee, \mu\mu$
- Three lepton flavor channels plus jet multiplicity bins:
  - ee, $e\mu$ and $\mu\mu$
  - $E_{T,miss}^{rel} > 45\ GeV (25\ GeV)$ for ee and $\mu\mu$ ($e\mu$)
- Irreducible background from SM WW
- Reducible backgrounds from SM processes with mis-identified objects: W+jets, Z+jets, $t\bar{t}$, single top, $W + \gamma$, $W + \gamma^*$, WZ, ZZ

$\mu\mu$



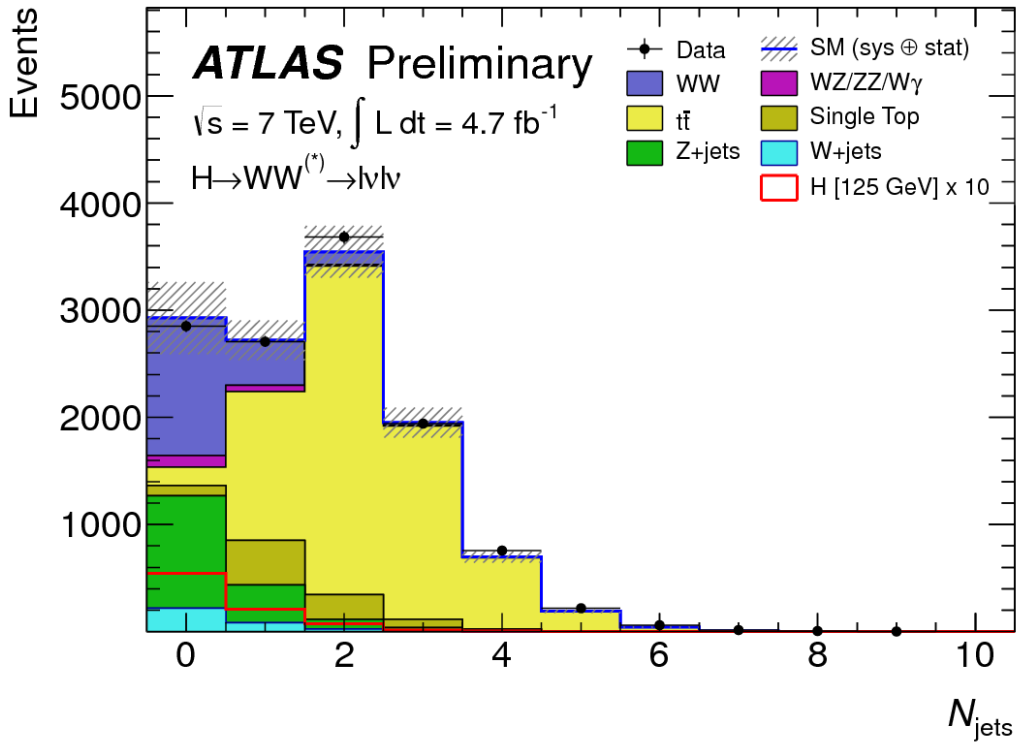
$e\mu$



$H \to WW \to l\nu l\nu$: jet multiplicity

Split by jet multiplicity:

- 0-jet: ggF vs. SM WW
  $\pm 25\%$ for $\sigma_{ggF}(m_H = 125\ GeV)$
- 1-jet: ggF vs. SM WW and top
  $\pm 37\%$ for $\sigma_{ggF}(m_H = 125\ GeV)$
- 2-jet: VBF vs. SM WW and top
  $\pm 5\%$ for $\sigma_{VBF}(m_H = 125\ GeV)$

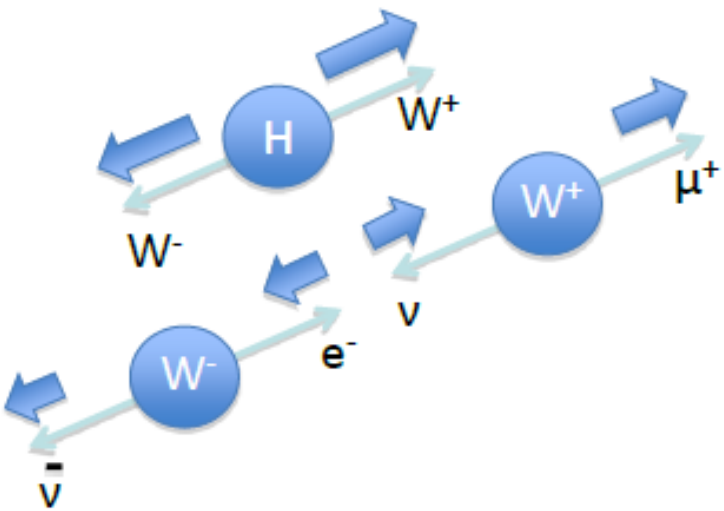


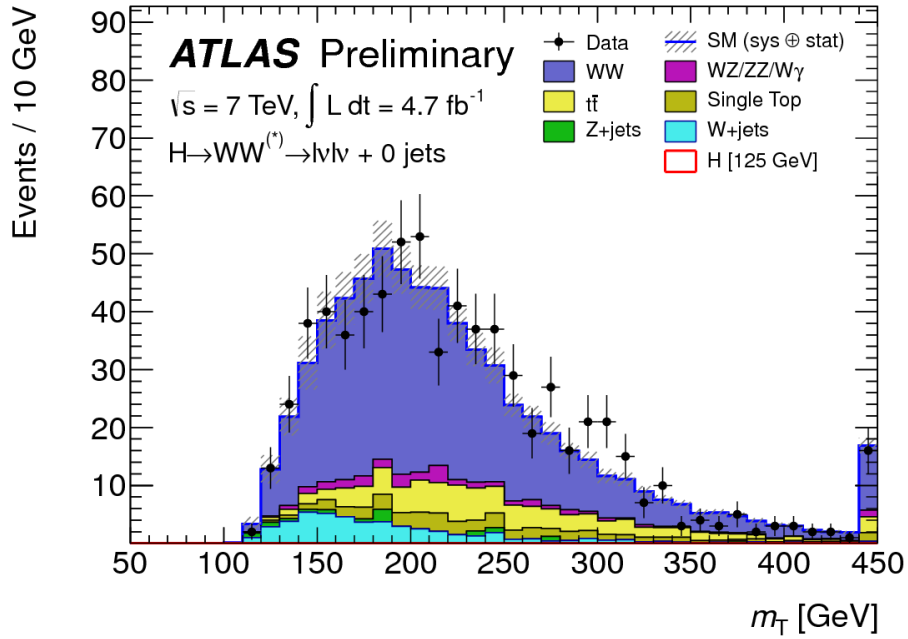
Main detector uncertainties:

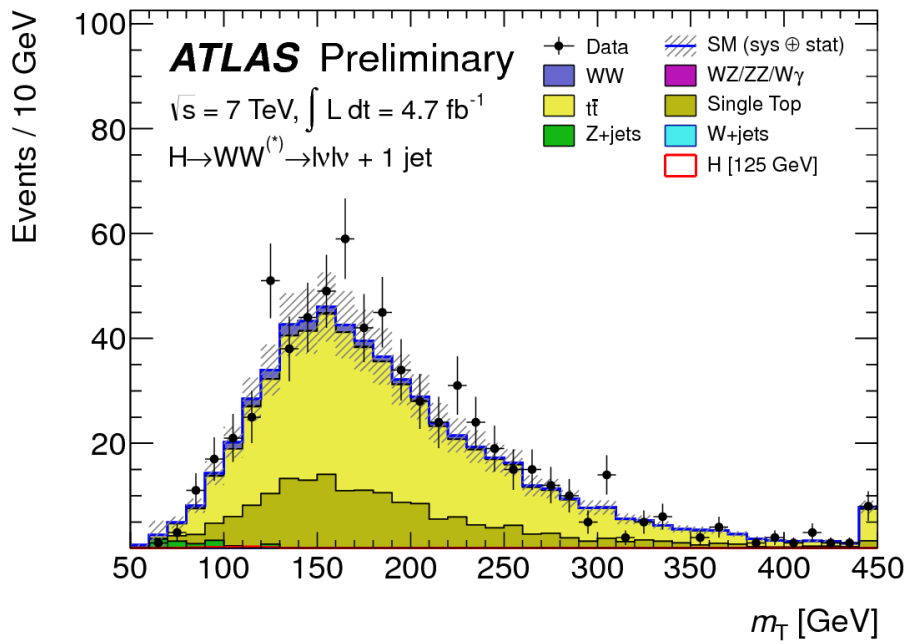
- Jet energy scale: $2 - 14\%$ as a function of jet p_T and η
- Jet energy from pileup: $< 5\%$ for jet $p_T > 25$ GeV
- B-tagging: $5 - 14\%$ as a function of jet p_T
- Missing energy: estimated by varying amount of pileup

$H \to WW \to l\nu l\nu$: selections

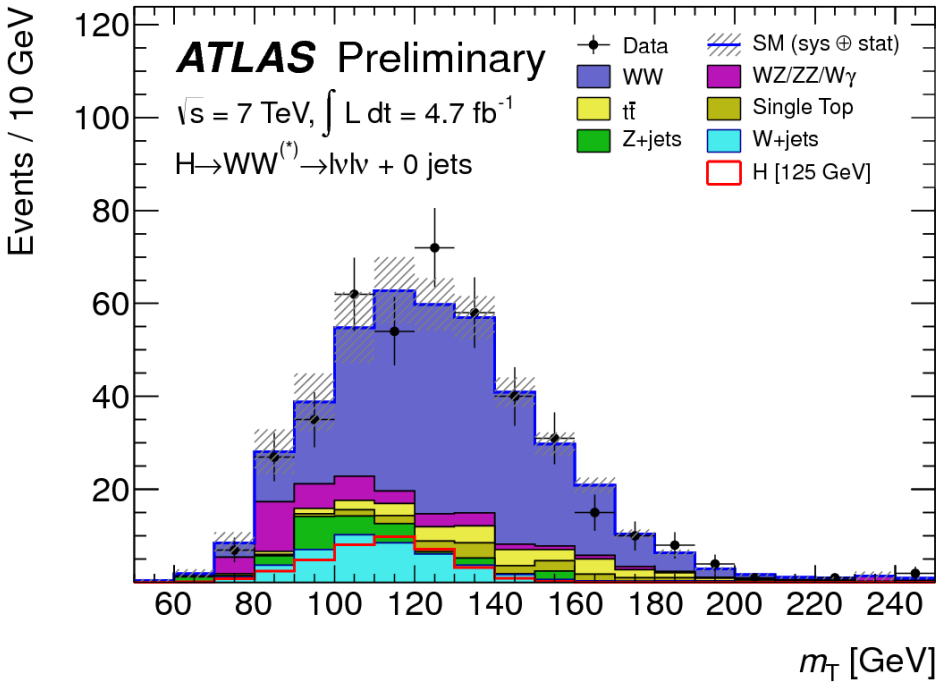
- 0-jet: $p_{T,\mu\mu,ee} > 45$ *GeV* to suppress Z+jet
- 1-jet: veto events with b-jets and high p_T^{total}
- 2-jet: forward tag jets for VBF
- Kinematic cuts to reduce SM WW
- SM WW normalized from data for $m_H < 200$ GeV
- Top normalized from data b-tagged samples
- W+jet is taken fully from data
- Z/γ^*+jet normalized from data
- $W\gamma$, $W\gamma^*$, WZ and ZZ from MC

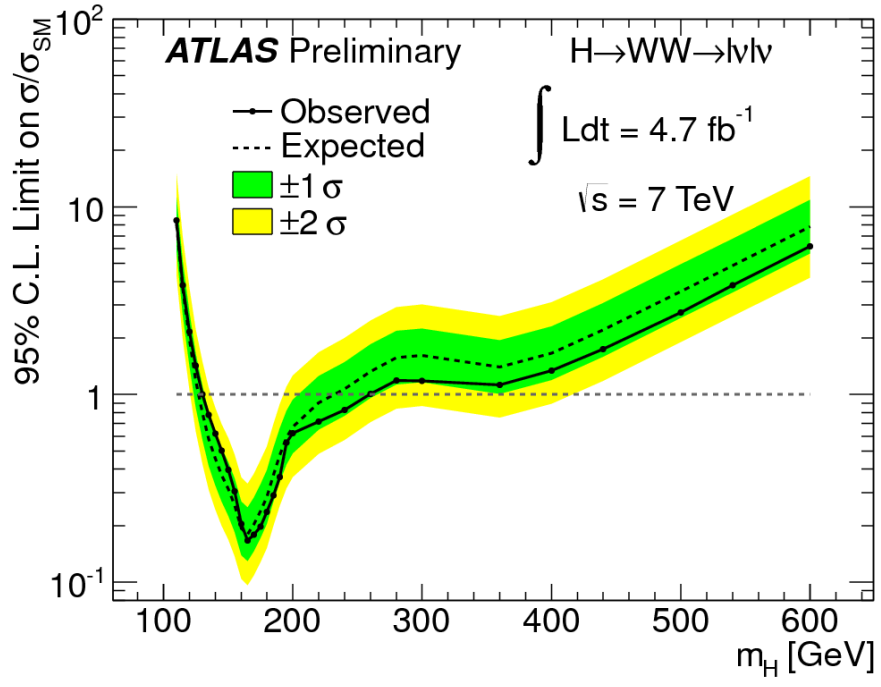






$H \to WW \to l\nu l\nu$: results

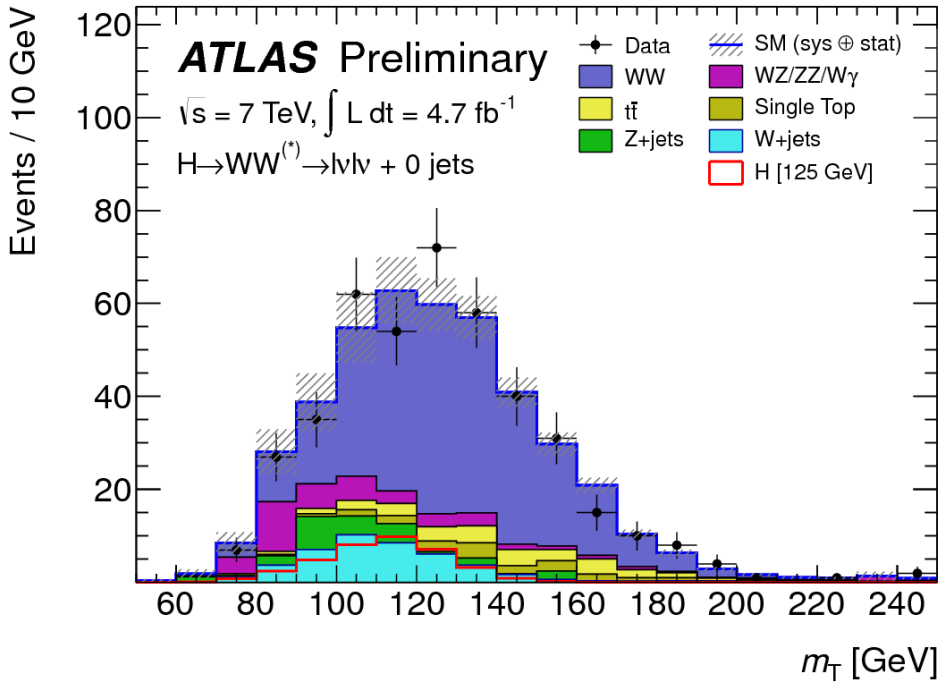


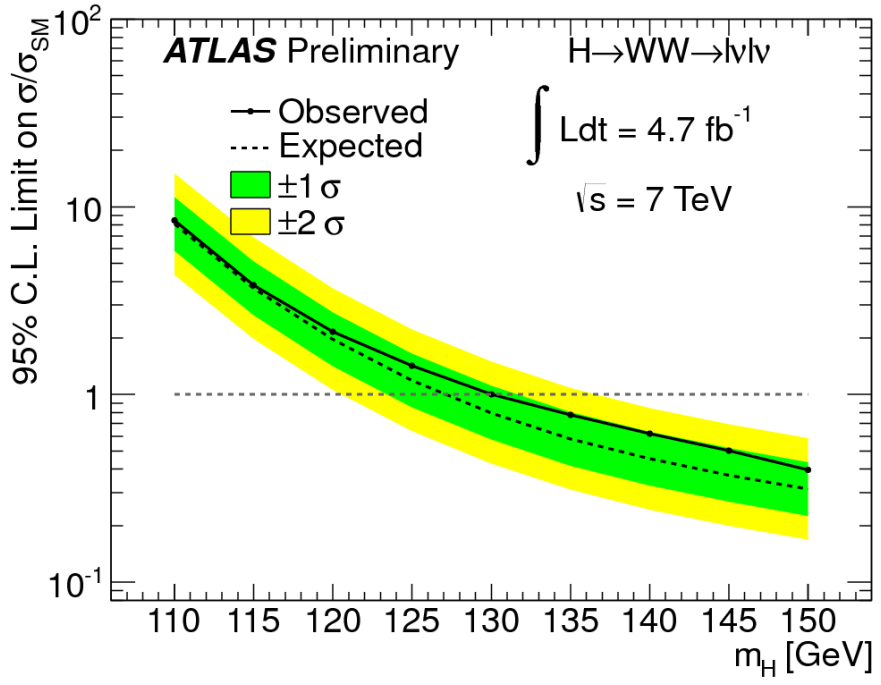


- Fit transverse mass distribution
- SM Higgs boson is excluded in the range 130-260 GeV at the 95% confidence level

Stat only errors:	0-jet	1-jet	2-jet
$m_H = 125\ GeV$	37.7 ± 0.2	9.4 ± 0.1	0.8 ± 0.1
Total Bkg.	429 ± 27	134 ± 13	1.8 ± 0.4
Obs.	427	145	1

$H \to WW \to l\nu l\nu$: results





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Total Bkg.	429 ± 27	134 ± 13	1.8 ± 0.4
Obs.	427	145	1

$H \to \tau\tau$: analysis strategy

- Directly tests Higgs couplings to leptons
- Collinearity of boosted tau decay products allows mass reconstruction

$H \to \tau\tau \to ll + 4\nu$ (12%)

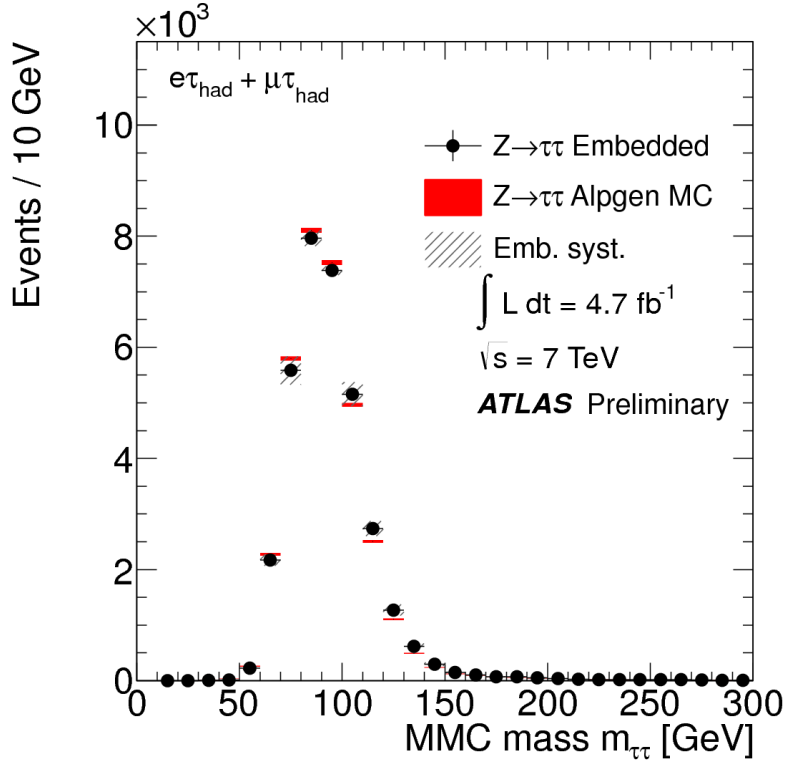
- $p_{T,\mu} > 10\ GeV$, $p_{T,e} > 15\ GeV$
- $e\mu$ only, 0-jet, 1-jet, 2-jet VH, 2-jet VBF
- Collinear mass approximation

$H \to \tau\tau \to l\tau_{had} + 3\nu$ (46%)

- $p_{T,\mu} > 20\ GeV$, $p_{T,e} > 25\ GeV$, $p_{T,\tau} > 20\ GeV$
- 0-jet (4), 1-jet (2) and 2-jet VBF
- Missing mass calculator - NIM A654 (2011) 481

$H \to \tau\tau \to \tau_{had}\tau_{had} + 2\nu$ (42%)

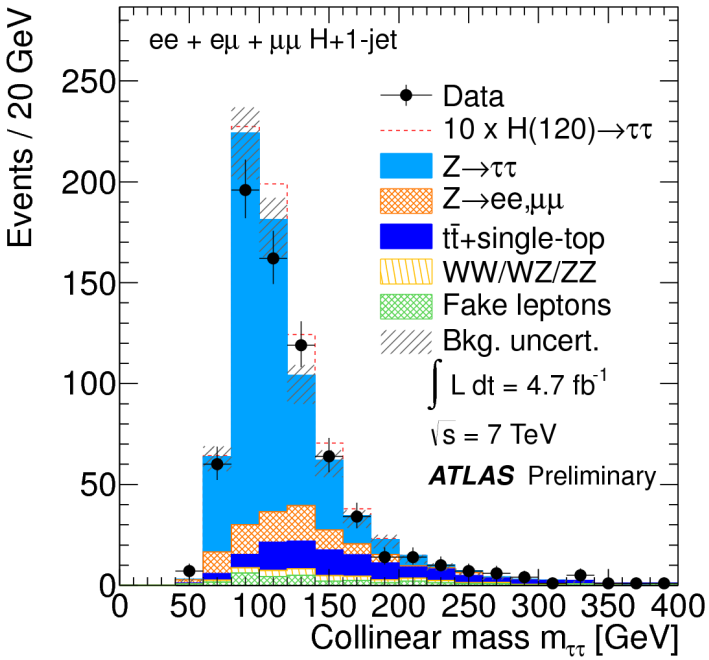
- $p_{T,\tau} > 35\ GeV$, $p_{T,\tau} > 25\ GeV$
- 1 category: $p_{T,jet} > 40\ GeV$, $E_{T,miss} > 40\ GeV$
- Collinear mass approximation

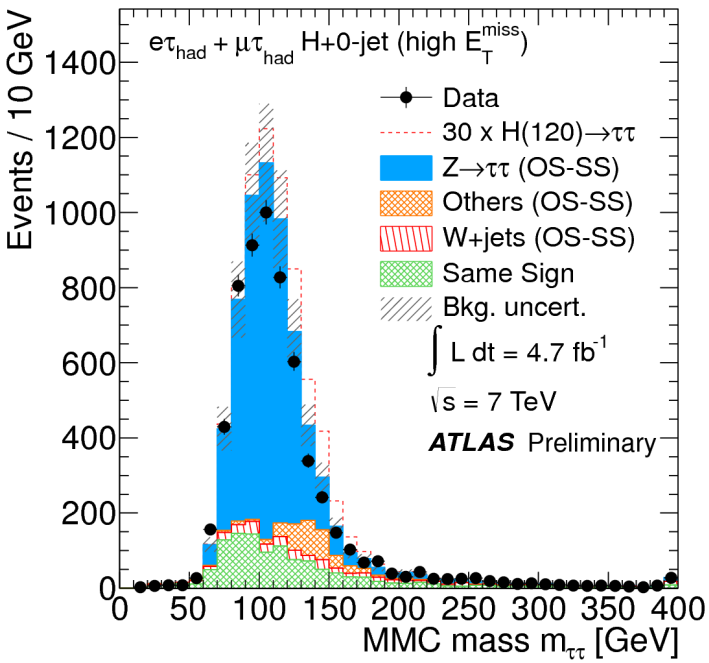


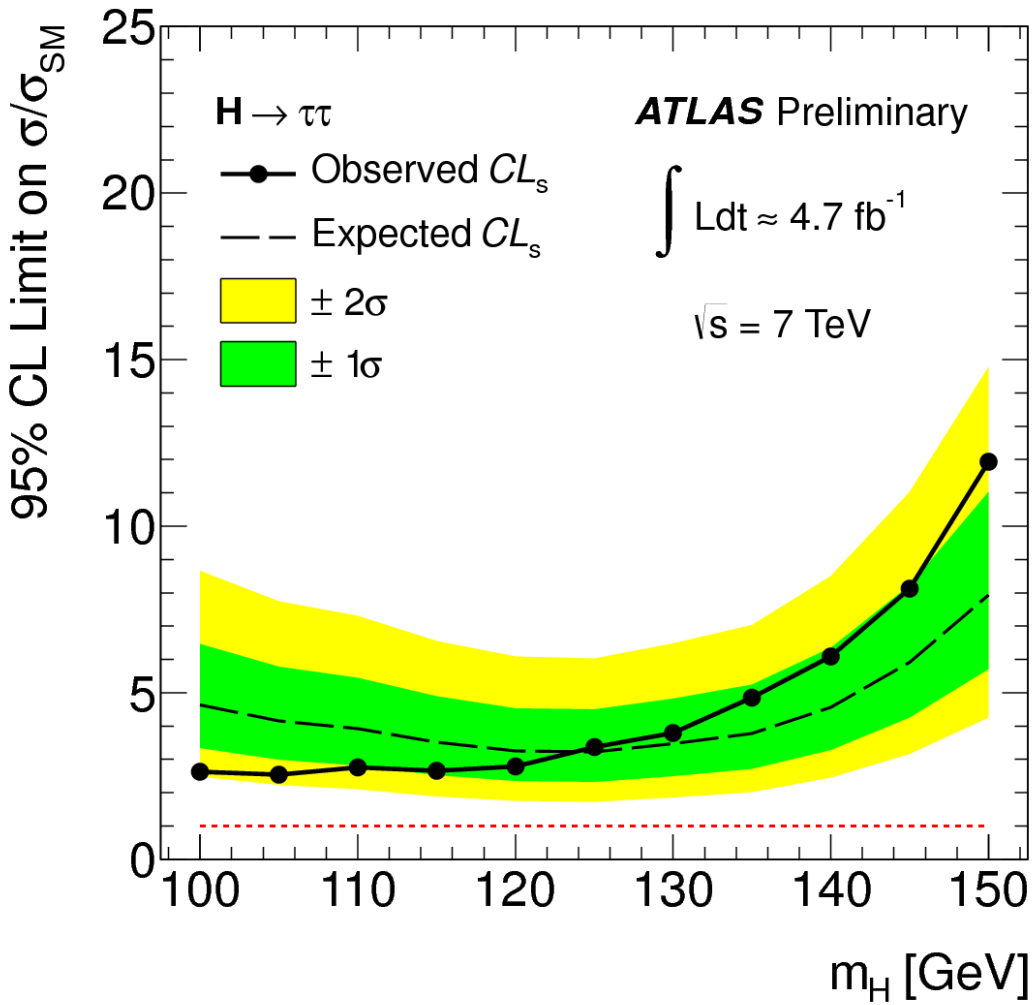
$Z \to \tau\tau$:
Normalized from theory and modeled from data using taus embedded in $Z \to \mu\mu$ data (6-10% uncertainty)

Fake leptons and tau-jets:
$ll + 4\nu$: reverse lepton isolation (30-40%)
$l\tau_{had} + 3\nu$: same sign events (20%)
$\tau\tau_{had} + 2\nu$: fit N^{jet}_{track} distribution (20%)

$H \to \tau\tau$: results







- Fit $m_{\tau\tau}$ distribution in 12 channels
- Observed limits are 2.5 to 11.9 times the SM prediction

$VH \to Vbb$: analysis strategy

- Directly tests Higgs couplings to quarks
- W/Z associated production to suppress QCD backgrounds
- W/Z and Higgs recoil with significant pt

$ZH \to llbb$:

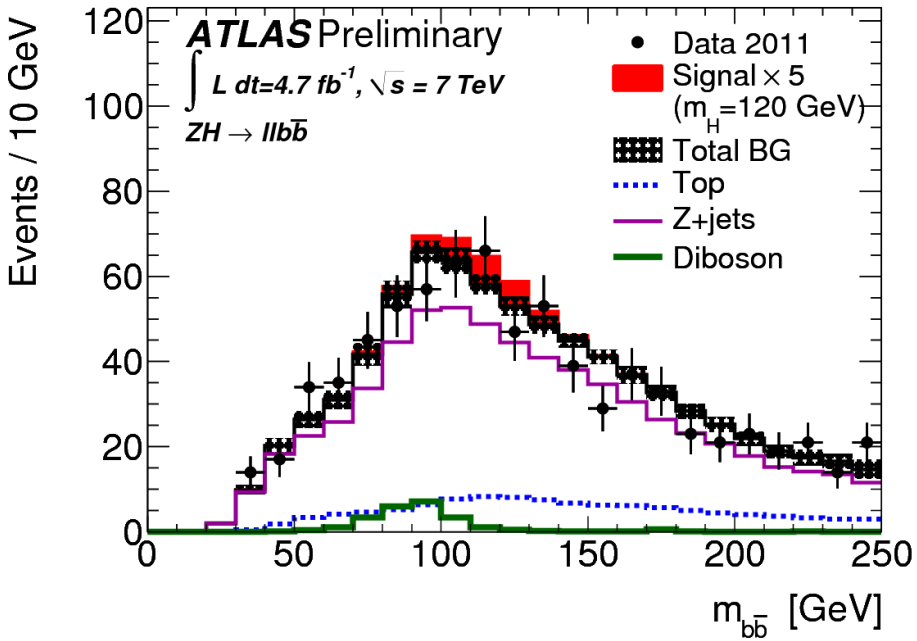
- p_T^Z: < 50, $(50, 100)$, $(100, 200)$, > 200 GeV
- $p_T^l > 20\ GeV$, $E_{T,miss} < 50\ GeV$, $83\ GeV < m_{ll} < 99\ GeV$

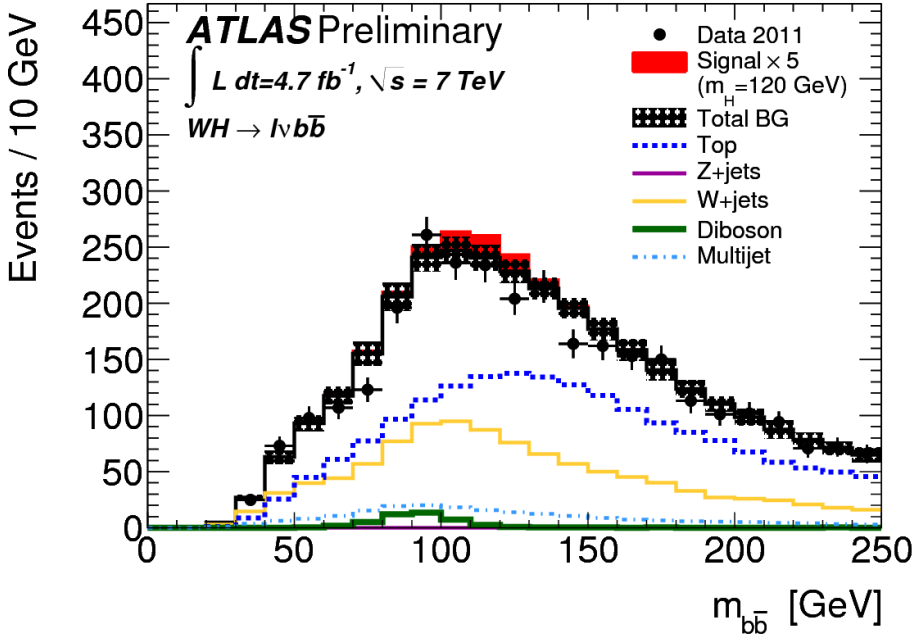
$WH \to l\nu bb$+0-jet:

- p_T^W: < 50, $(50, 100)$, $(100, 200)$, > 200 GeV
- $p_{T,lep} > 25\ GeV$, $E_{T,miss} > 25\ GeV$, $m_T > 40\ GeV$

$ZH \to \nu\nu bb$+0-jet:

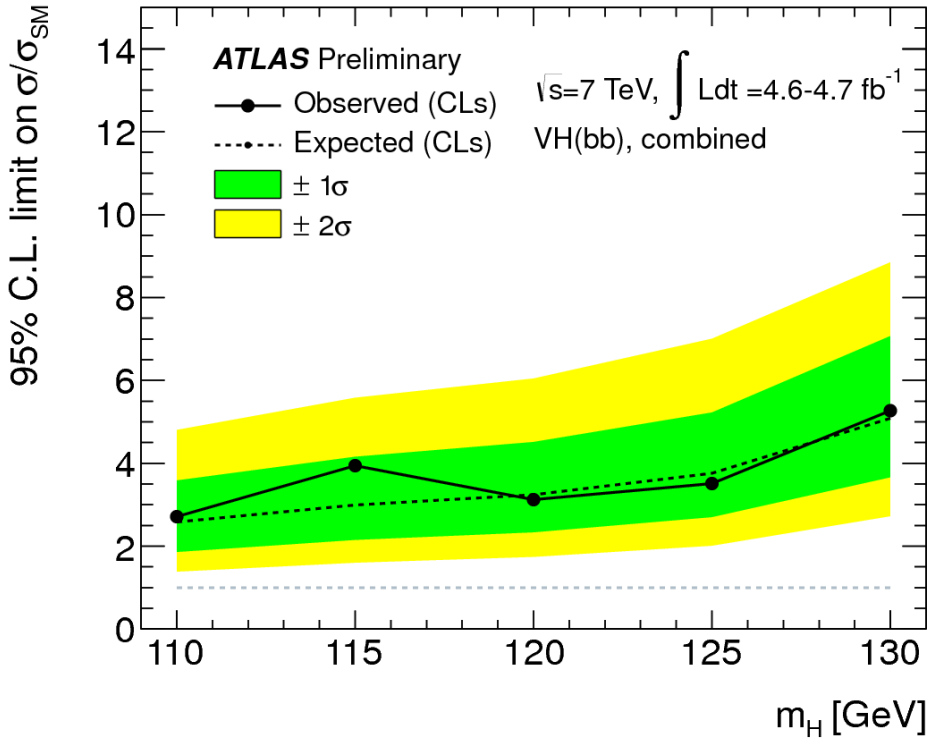
- $E_{T,miss}$: $(120, 160)$, $(160, 200)$, > 200 GeV
- Missing charged particle momentum: $p_{T,miss} > 30\ GeV$





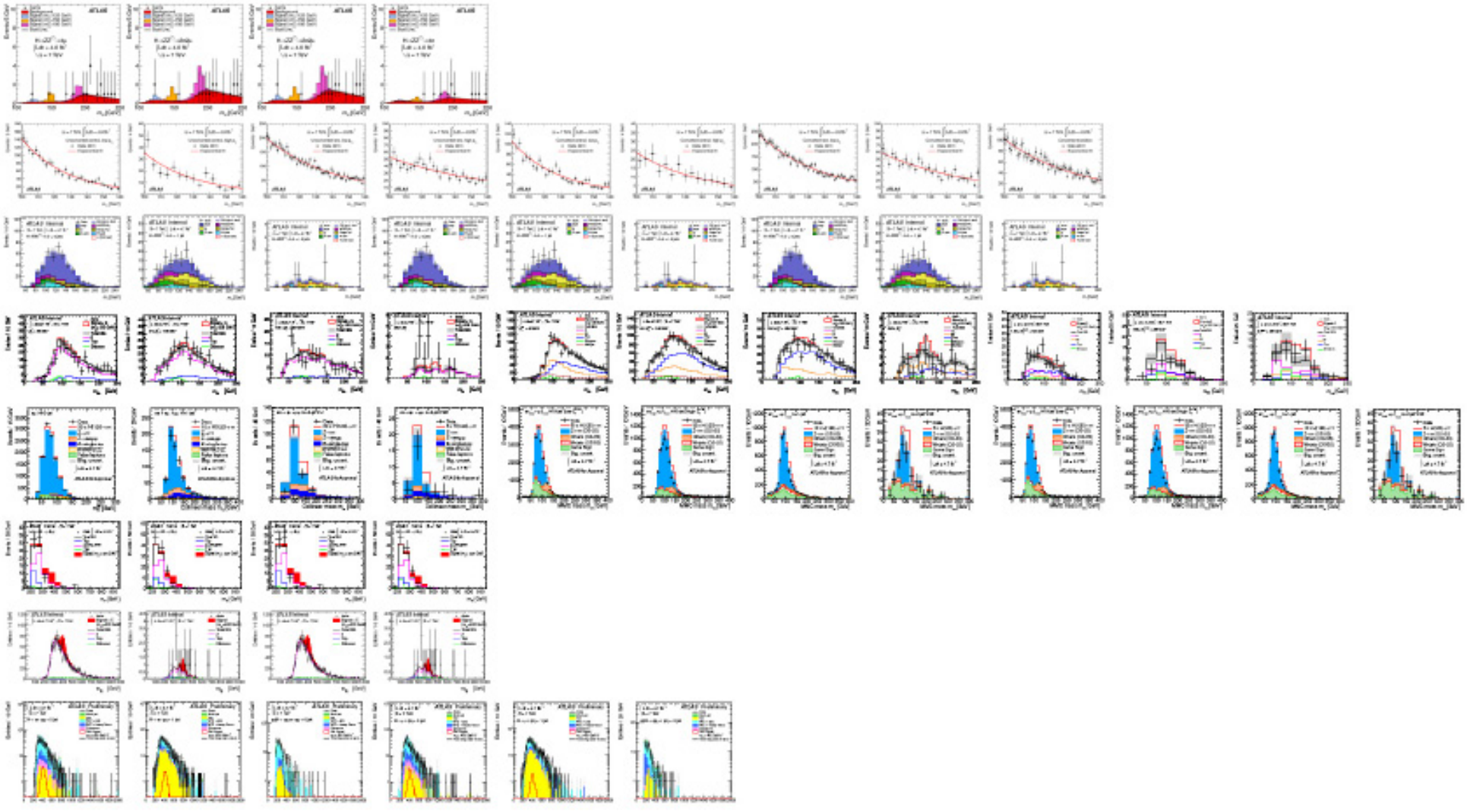
$VH \to Vbb$: results

- W/Z+jet shape taken from simulation and normalized from W/Z+2jet (1 b-jet) and m_{bb} sidebands
- Top shape taken from simulation and normalized to 2 bjet region and m_{bb} sidebands
- $llbb$ and $l\nu bb$: multi-jets normalized from region with reversed lepton ID
- $\nu\nu bb$: multi-jets normalized using $\Delta\phi(E_T^{miss}, p_T^{miss})$ and $\Delta\phi(E_T^{miss}, \text{b-jet})$



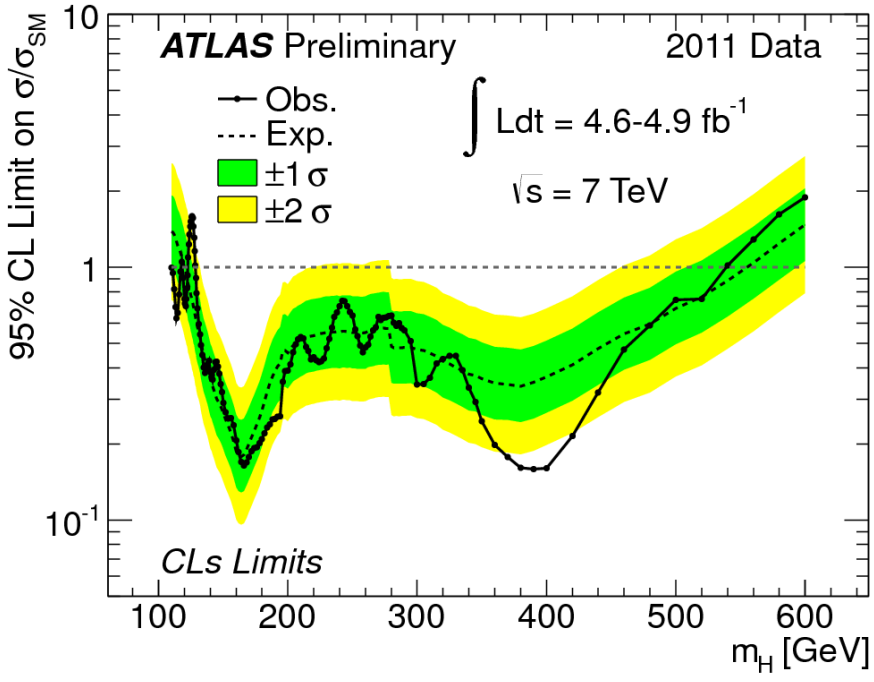
Bin	$ZH \to \ell^+\ell^- b\bar{b}$ p_T^Z[GeV]				$WH \to \ell\nu b\bar{b}$ p_T^W[GeV]				$ZH \to \nu\bar{\nu} b\bar{b}$ E_T^{miss}[GeV]		
	0-50	50-100	100-200	>200	0-50	50-100	100-200	>200	120-160	160-200	>200
Number of events for $80 < m_{b\bar{b}} < 150$ [GeV]											
Data	139	164	62	13	622	597	276	15	103	22	24
Signal	1.4 ± 0.2	2.0 ± 0.3	1.7 ± 0.3	0.4 ± 0.1	4.7 ± 0.9	5.2 ± 1.0	4.1 ± 0.9	1.4 ± 0.3	2.3 ± 0.5	1.3 ± 0.3	1.8 ± 0.5
Top	18	25	7	0	260	383	219	8.6	42	9	4
W+jets	-	-	-	-	285	181	72	12	13	7	4
Z+jets	132	126	58	5.6	0.4	0.3	0.1	0.0	33	12	7
Diboson	8	6	4	1	13	13	8	1	5	5	4
Multijet	-	-	-	-	64	42	4	1	1.2	0.2	0.4
Total Bkg	157 ± 15	157 ± 11	70 ± 7	6 ± 2	625 ± 36	620 ± 24	303 ± 13	23 ± 4	94 ± 10	33 ± 5	20 ± 5

SM Higgs combination

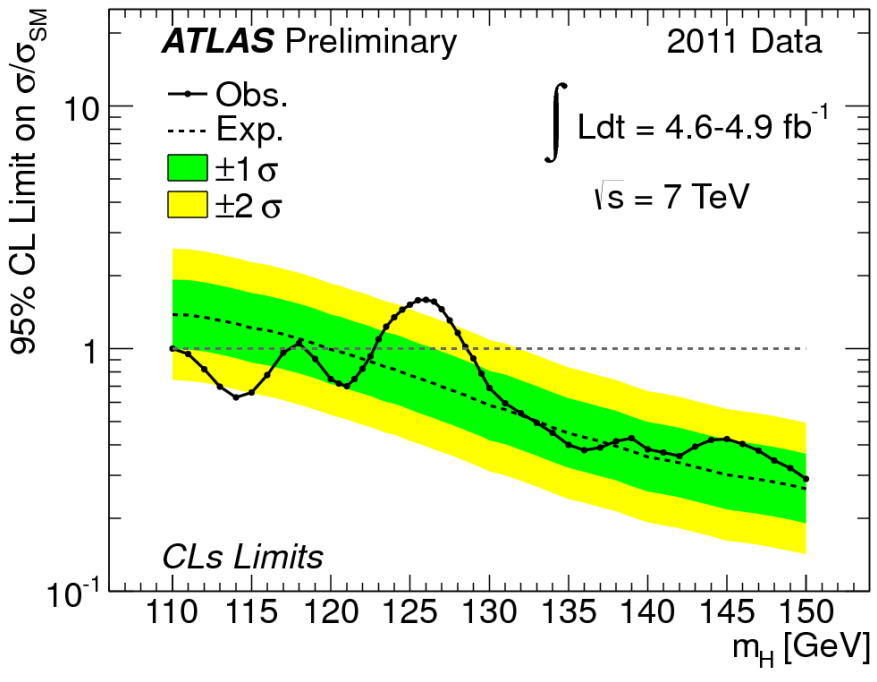


SM Higgs combination

Combined upper limits



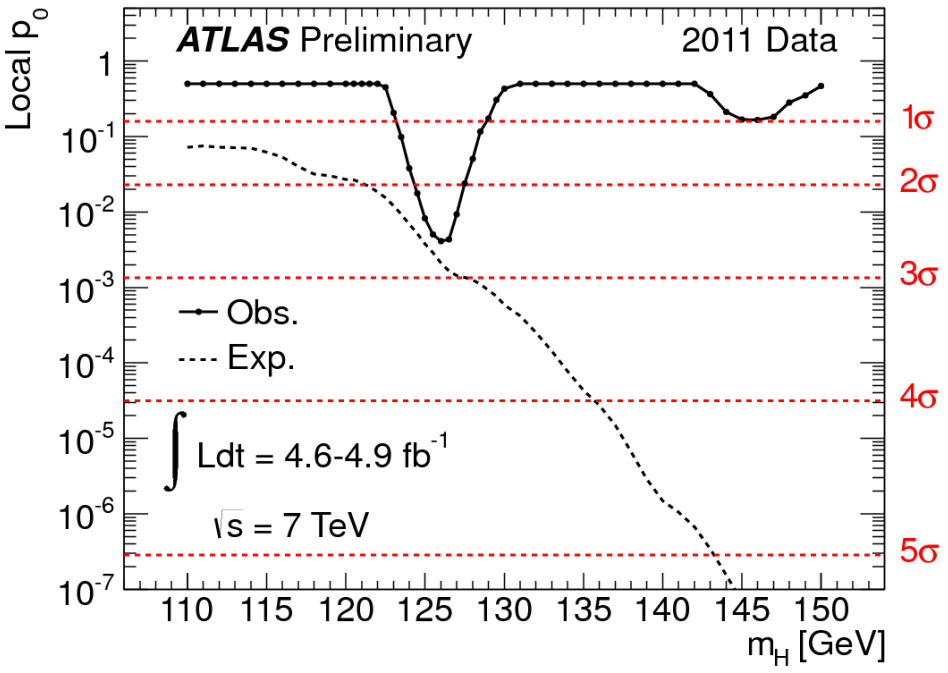
Zoom at the low mass



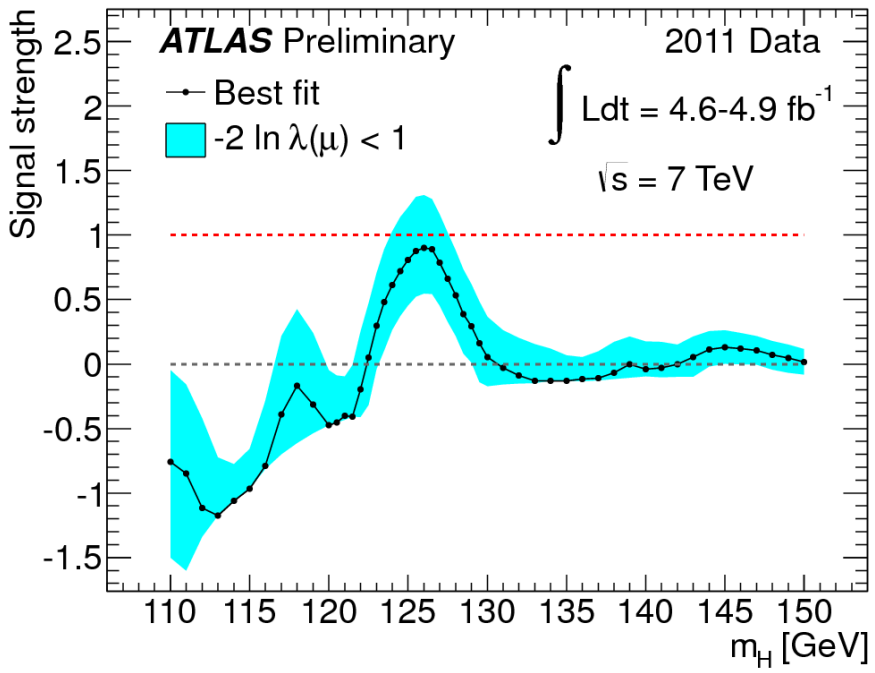
- SM Higgs boson is excluded in the ranges:
  110-117.5, 118.5-122.5, 129-539 GeV at the 95% CL
- The combination includes additional channels:
  $H \to WW \to l\nu qq$, $H \to ZZ \to llqq$

SM Higgs combination

Background-only probability



Best-fit signal strength $\mu = \sigma/\sigma_{SM}$



- An excess of events at $m_H \approx 126.5$ with a local significance 2.5 σ

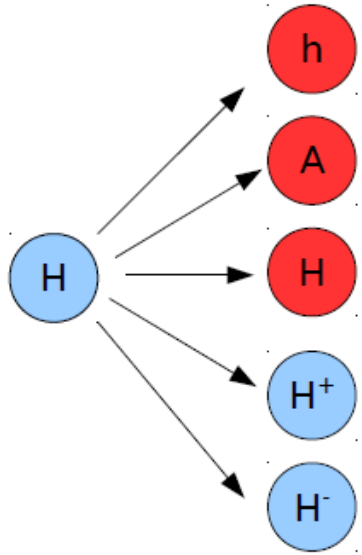
  Expected significance for SM Higgs 2.9 σ

  Best-fit signal strength $\mu = 0.9 + 0.4 - 0.3$

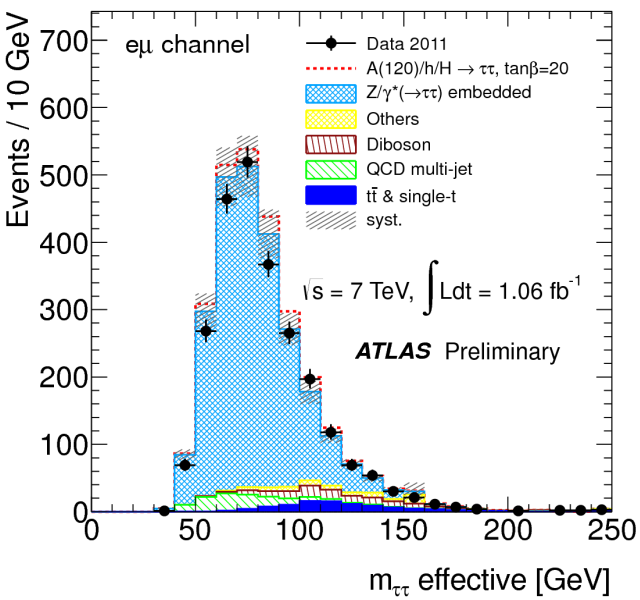
- Global probability for such background fluctuation:
  $\approx 30\%$ in the range $110 - 600$ GeV
  $\approx 10\%$ in the range $110 - 146$ GeV

MSSM $H \to \tau\tau$

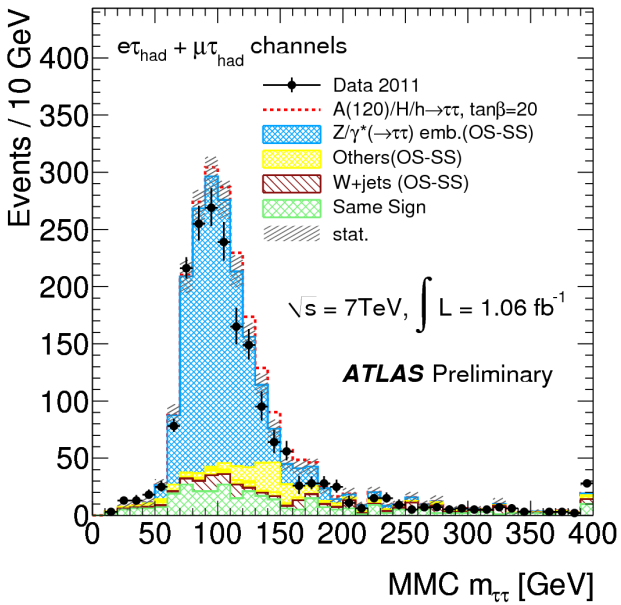
- Higgs sector in MSSM contains 3 neutral scalars and 2 charged scalars
- Decays to WW and ZZ can be suppressed or absent
- Decays to third generation fermions are enhanced for large regions of MSSM parameter space
- Selections and background estimation procedures are similar to SM $H \to \tau\tau$ searches
- $\int \mathcal{L} = 1.06\ fb^{-1}$ ATLAS-CONF-2011-132



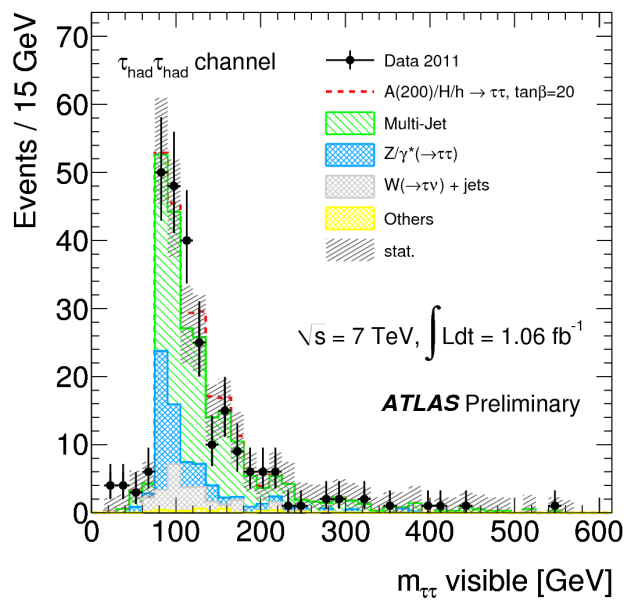
$H \to \tau\tau \to ll + 4\nu$



$H \to \tau\tau \to l\tau_{had} + 3\nu$

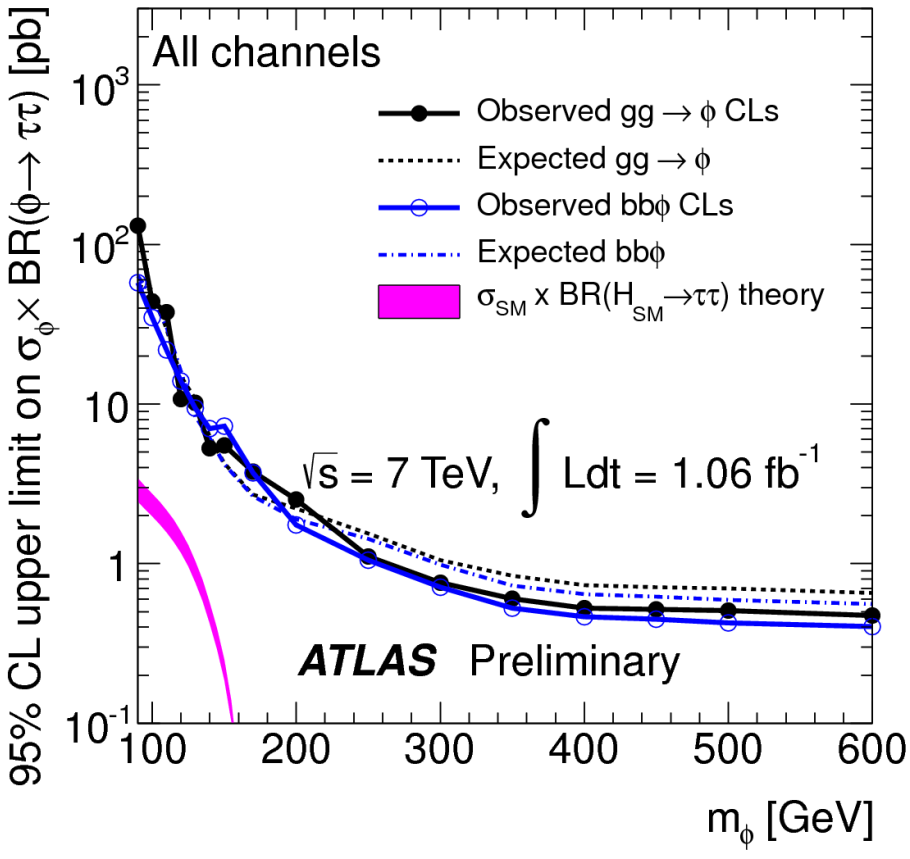


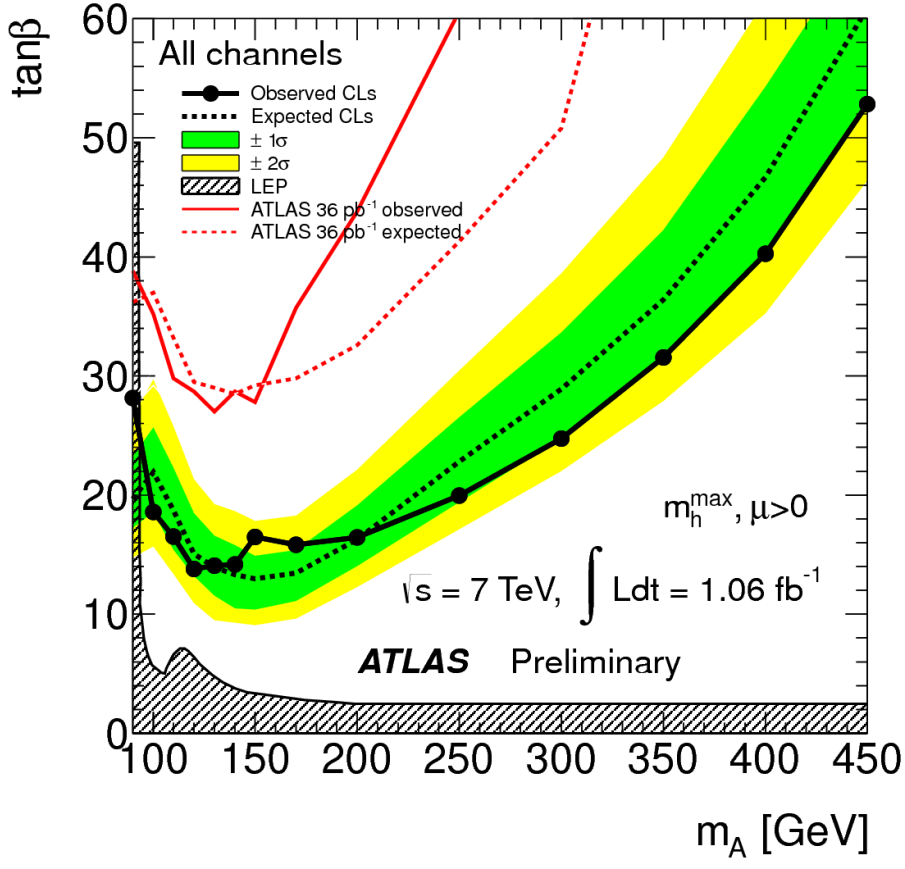
$H \to \tau\tau \to \tau_{had}\tau_{had} + 2\nu$



MSSM $H \to \tau\tau$: results

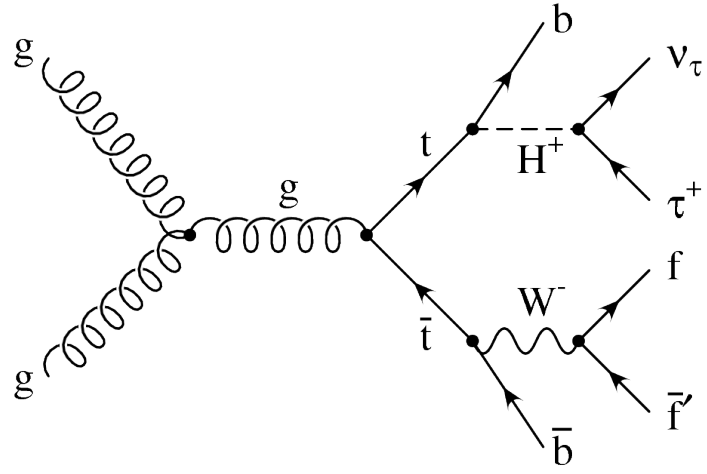
- Set limits on a production rate of a heavy neutral scalar decaying to taus
- Complimentary approach to dedicated SUSY searches



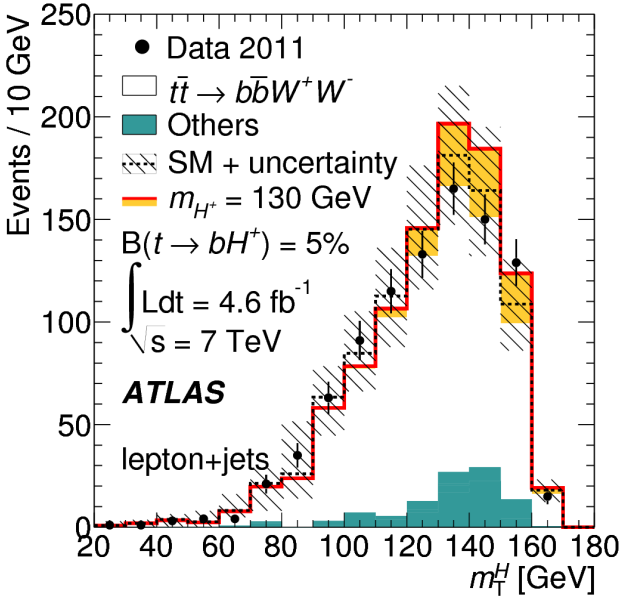


MSSM $H+ \to \tau\tau$

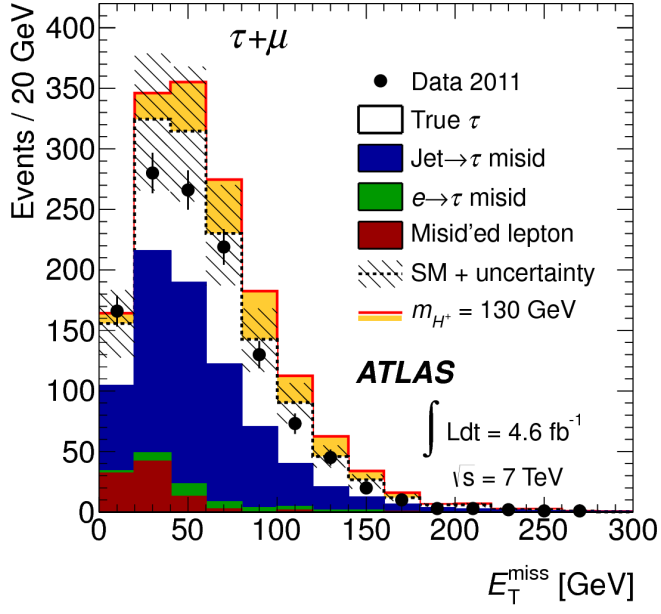
- 90 $GeV < m_H <$ 160 GeV: charged Higgs is produced in top pair decays
- Search for heavy charged particle decaying to taus in association with bjets
- $\int \mathcal{L} = 4.7\ fb^{-1}$ ATLAS-CONF-2012-011



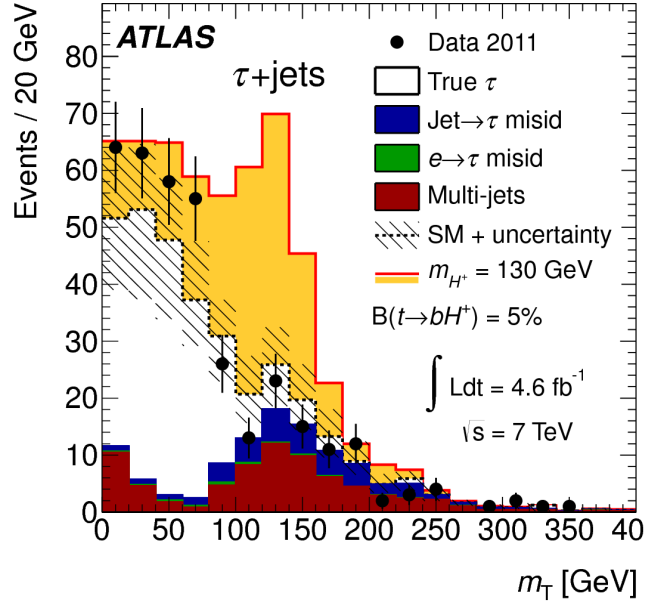
leptons+jets



tau+lepton

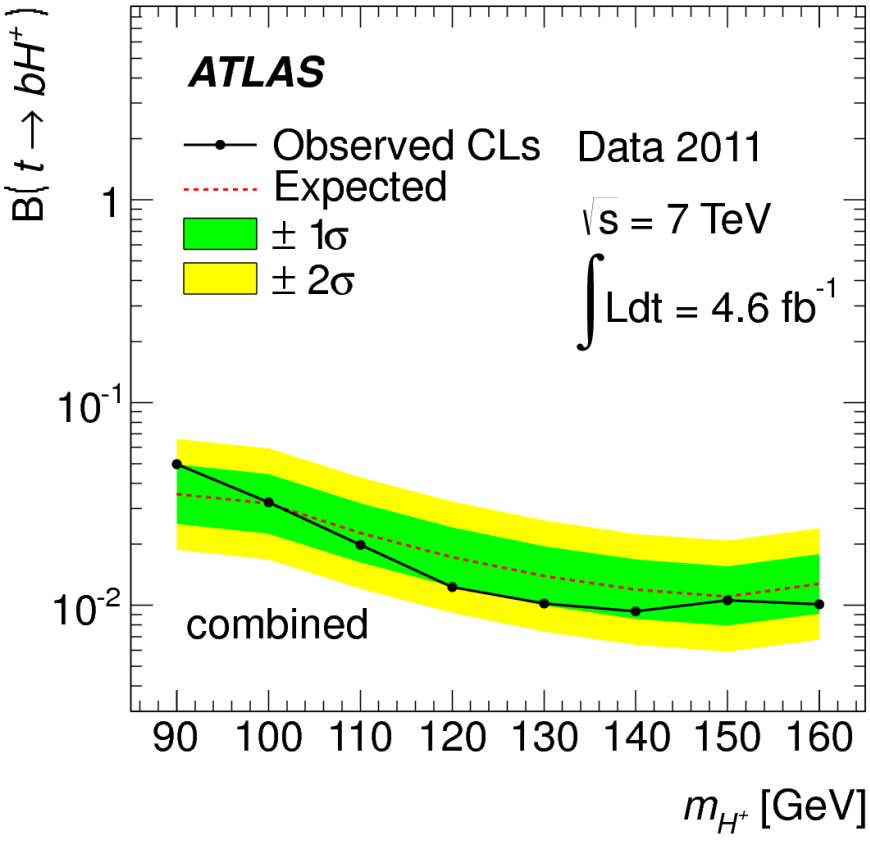


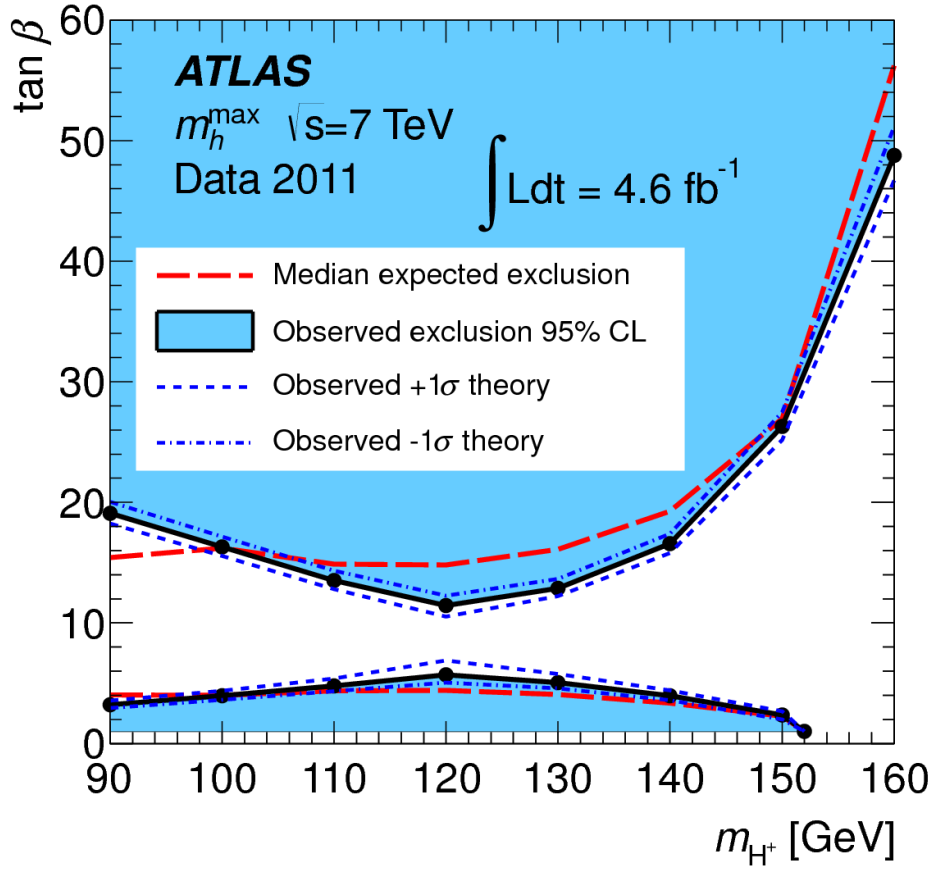
tau+jets



MSSM $H+ \to \tau\tau$: results

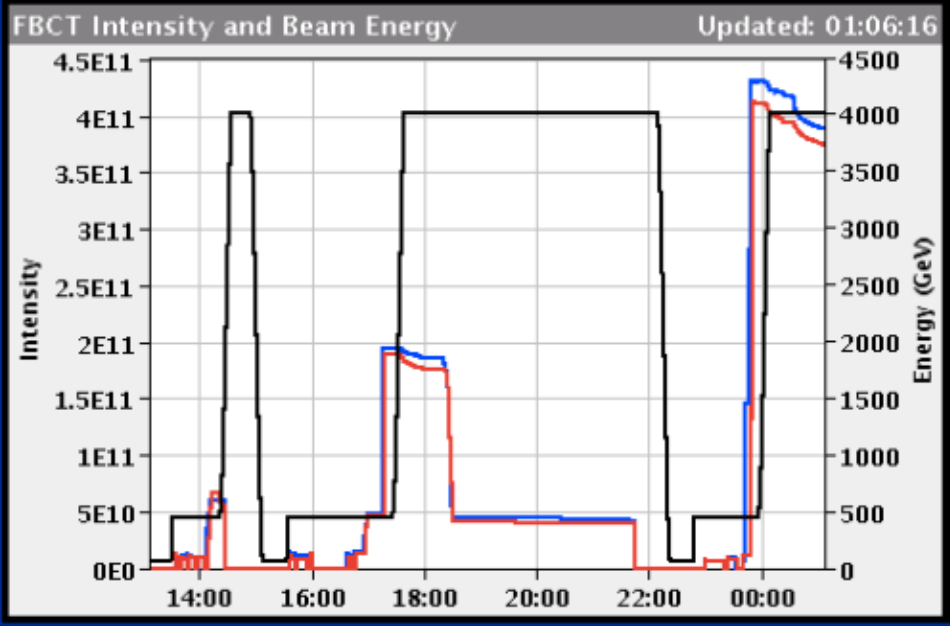
- Set limits on the branching ratio for $t \to bH^+$
- Complimentary approach to dedicated SUSY searches

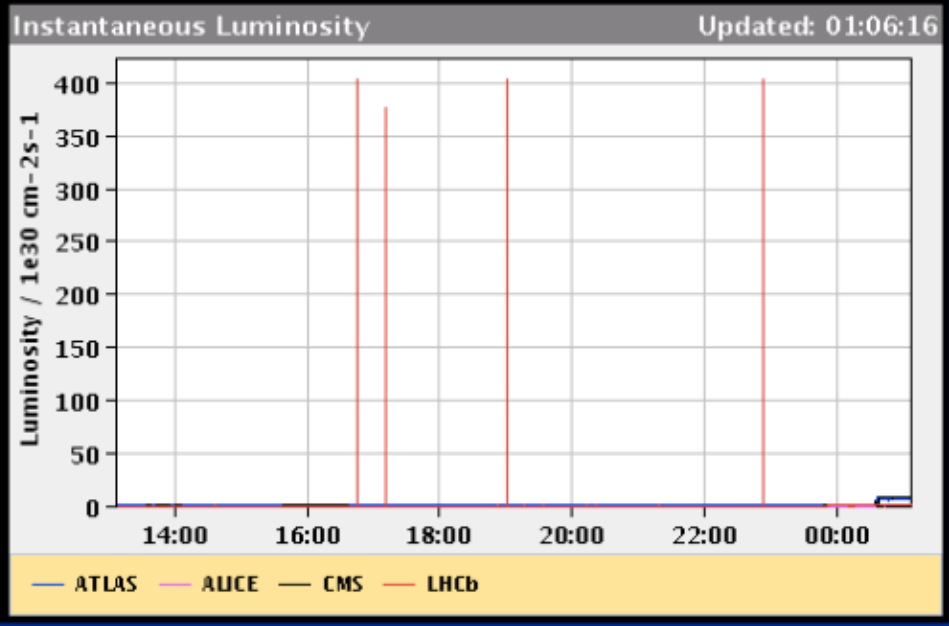




PROTON PHYSICS: STABLE BEAMS

Energy:	4000 GeV	I(B1):	3.86e+11	I(B2):	3.76e+11





Comments 05-04-2012 01:05:02 :

(optimizations done)

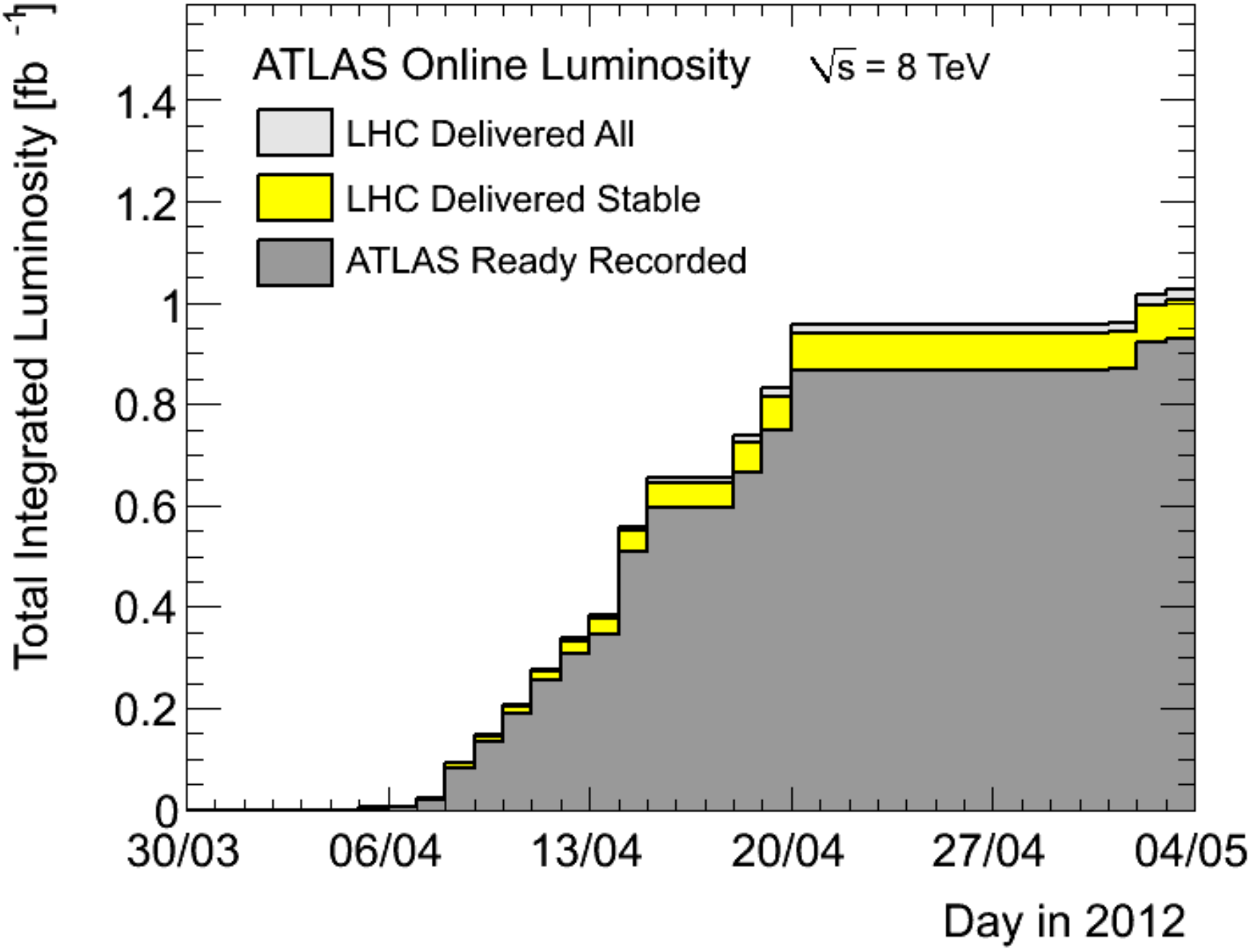
first stable beams of 2012!

BIS status and SMP flags	B1	B2
Link Status of Beam Permits	true	true
Global Beam Permit	true	true
Setup Beam	false	false
Beam Presence	true	true
Moveable Devices Allowed In	true	true
Stable Beams	true	true

AFS: Single_3b_2_2_2

PM Status B1: ENABLED

PM Status B2: ENABLED


ATLAS Online Luminosity
√s = 8 TeV
LHC Delivered All
LHC Delivered Stable
ATLAS Ready Recorded
Total Integrated Luminosity [fb -1]
0
0.2
0.4
0.6
0.8
1
1.2
1.4
30/03
06/04
13/04
20/04
27/04
04/05
Day in 2012

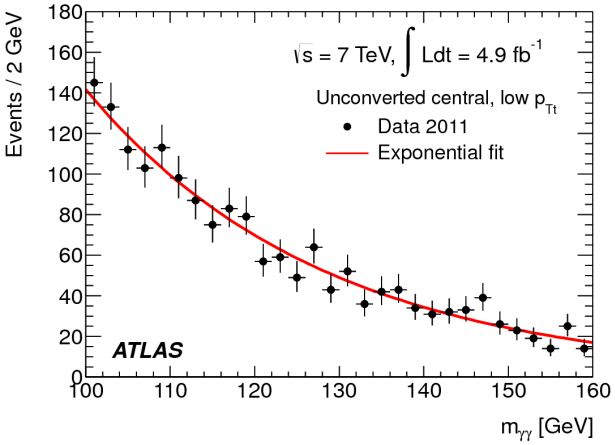
Conclusions and outlook

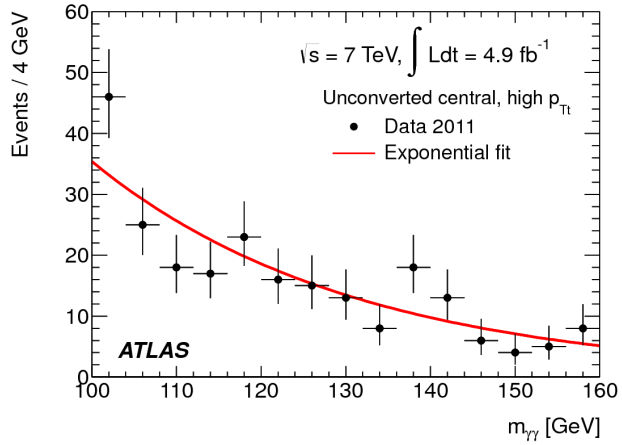
Congratulations to CERN for the fantastic LHC performance!

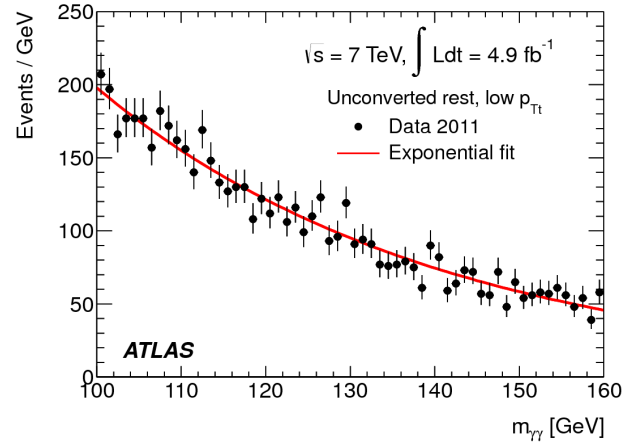
- ATLAS released SM Higgs boson searches in 12 distinct channels using full 2011 dataset
- Allowed Higgs mass is the ranges 117.5-118.5 GeV and 122.5-129 GeV at the 95% CL
- Observed an excess of events consistent with $m_H \approx 126.5$ GeV
- This year we will know if this is the SM Higgs boson!

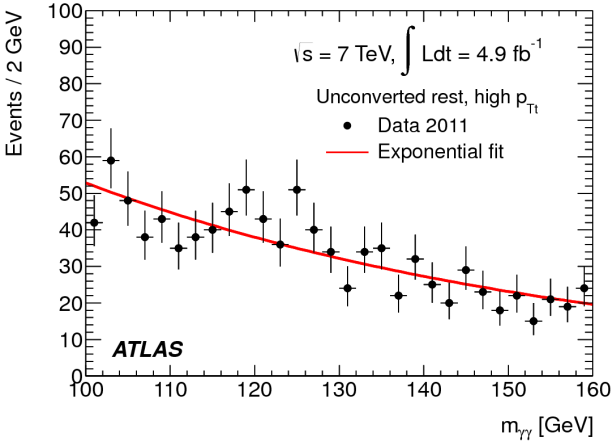
Backup

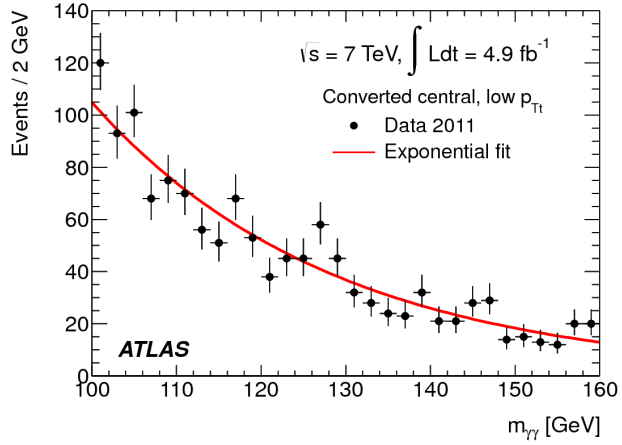
$H \to \gamma\gamma$

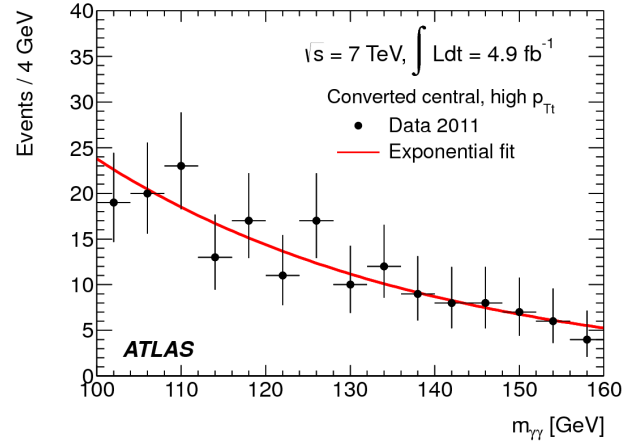


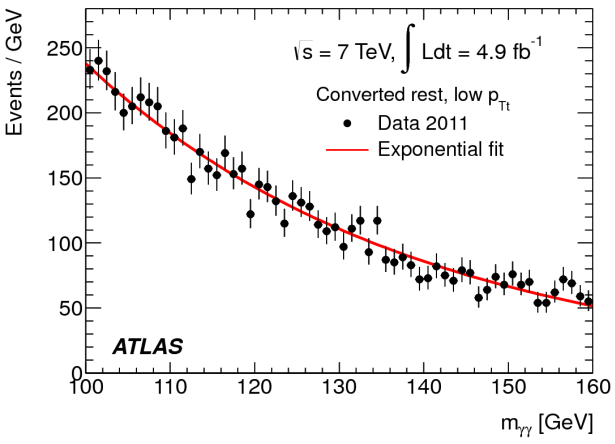


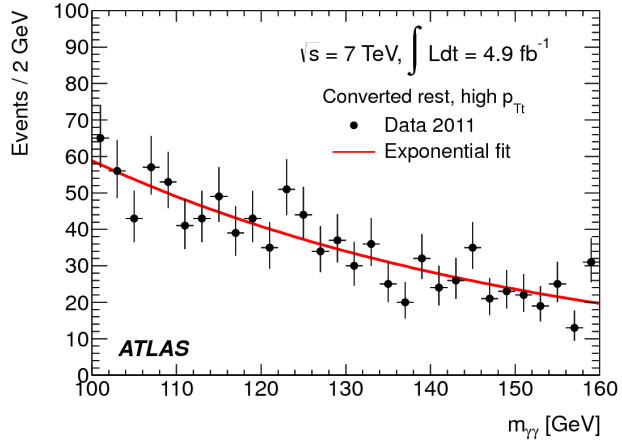


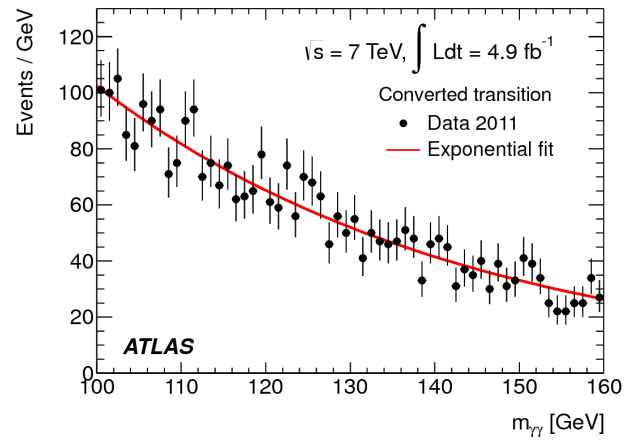




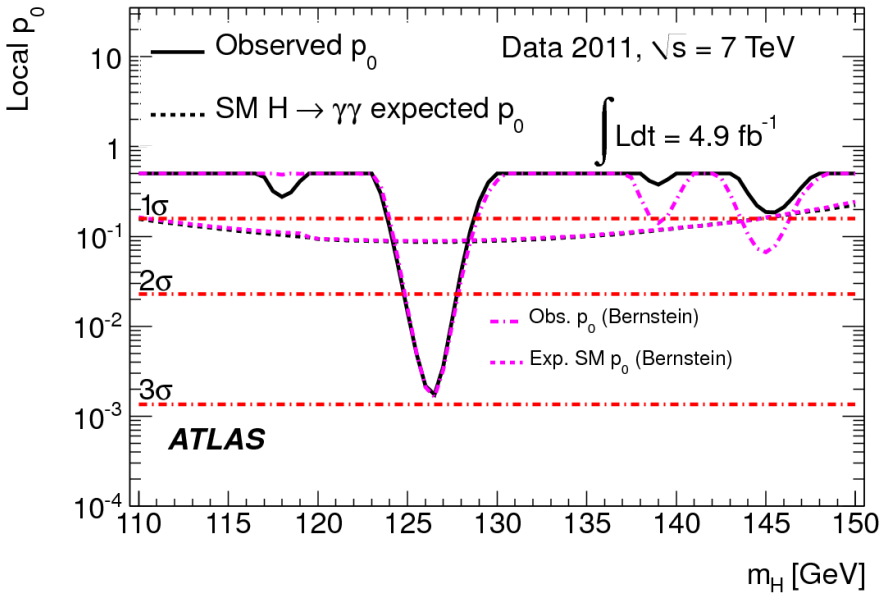


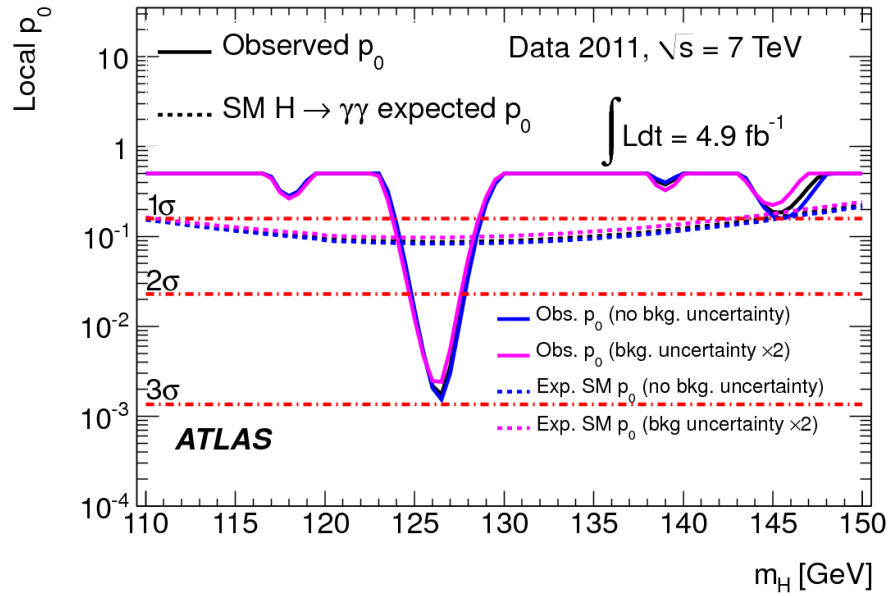


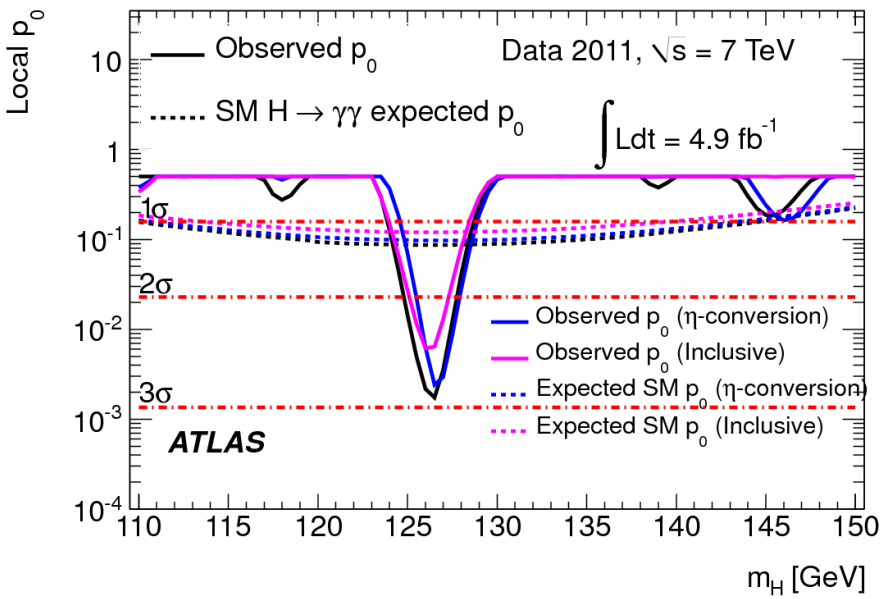


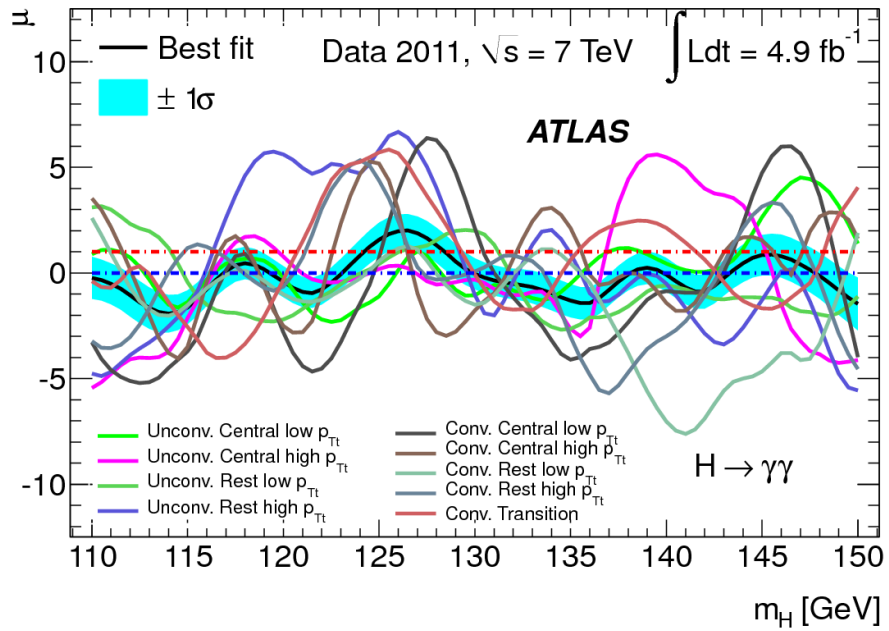


$H \to \gamma\gamma$



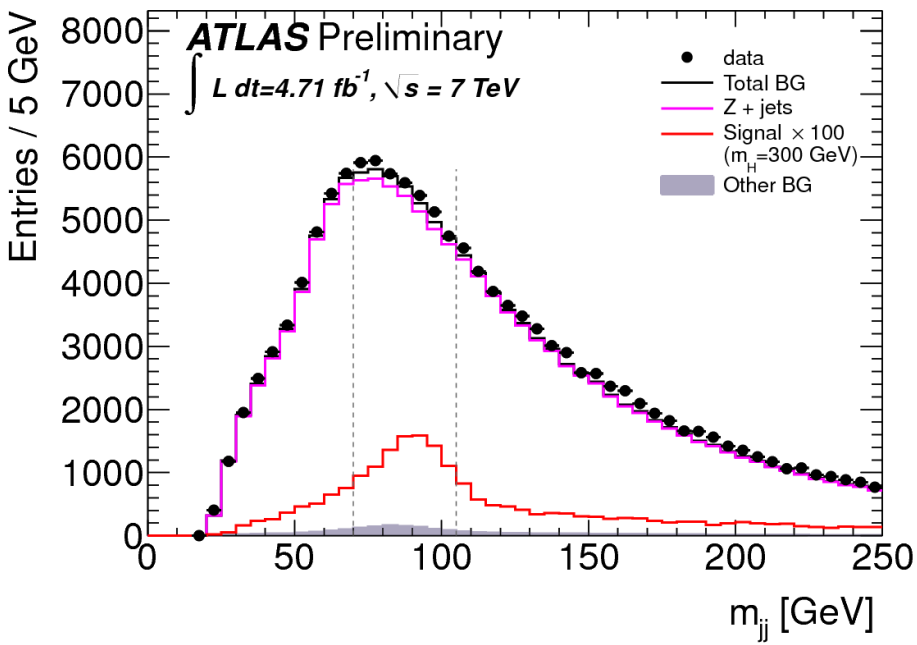


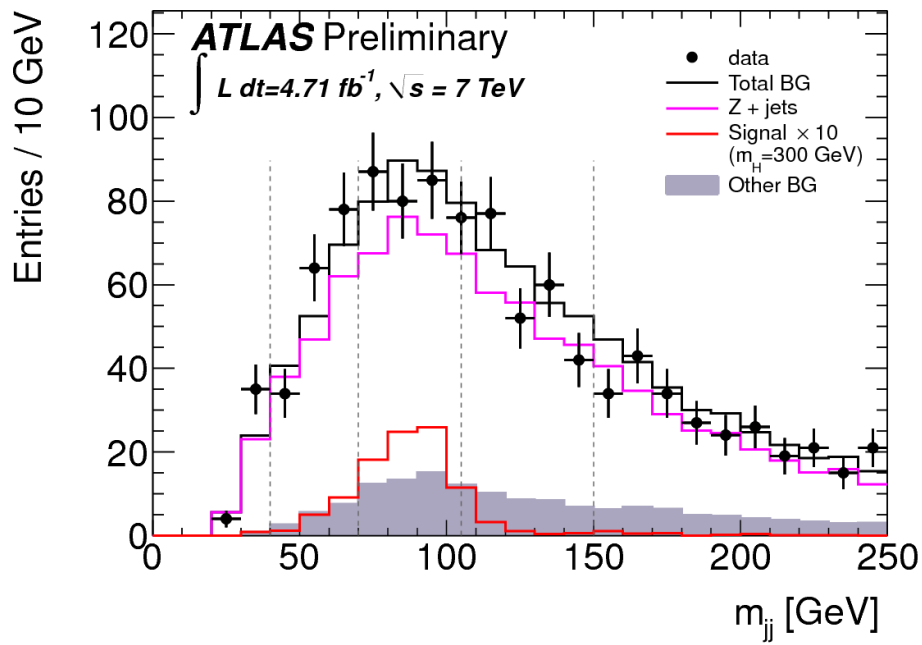




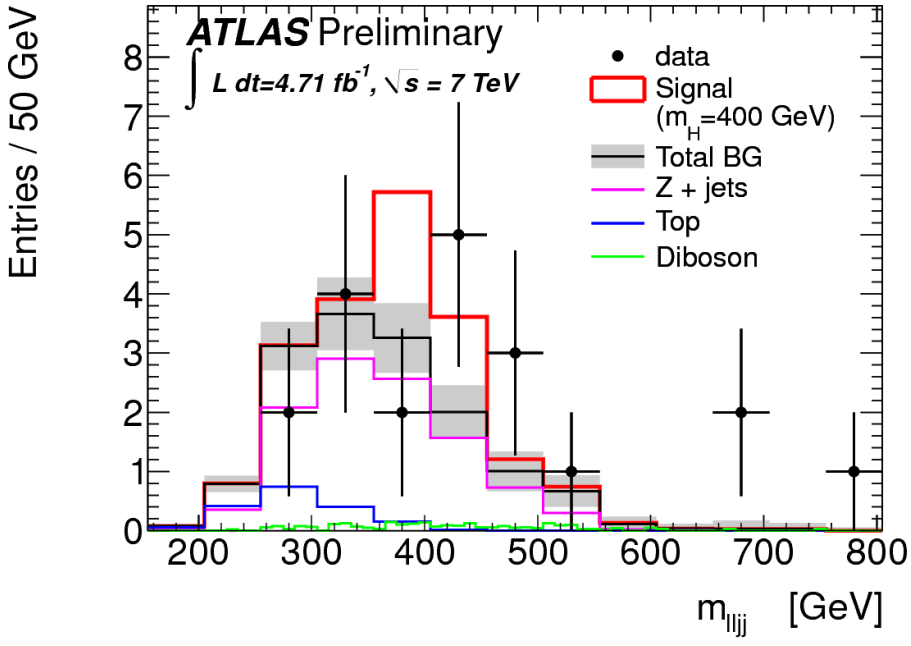
$H \to ZZ \to llqq$

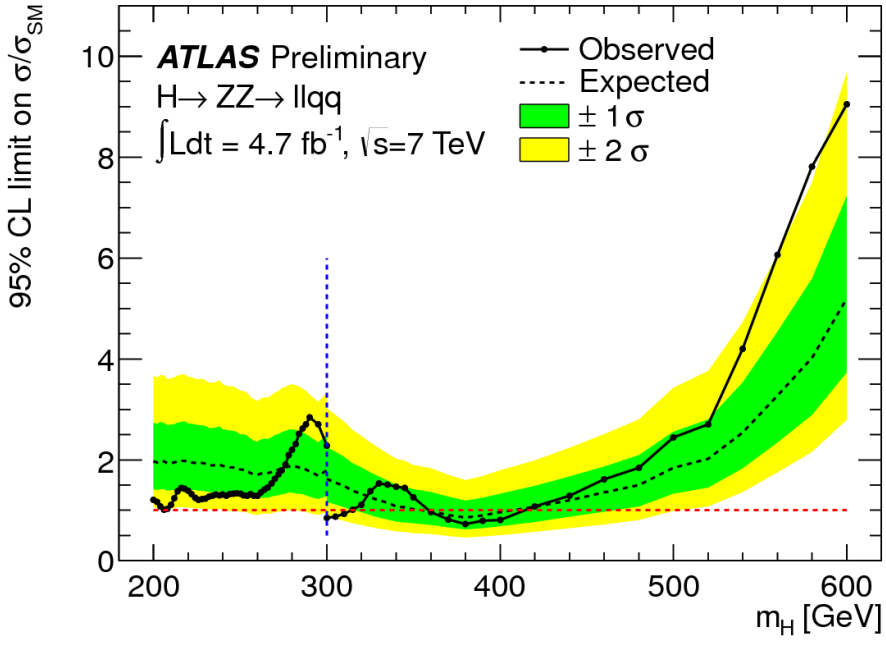
- Pair of isolated electrons or muons ($p_T > 20$ GeV) consistent with Z decay
- Two central jets from the same vertex as leptons
- Separate light jets and b-jets to improve signal sensitivity
- Z+jet and $t\bar{t}$ background shapes taken from MC and checked with data
- Z+jet and $t\bar{t}$ normalizations taken from sidebands





$H \to ZZ \to llqq$: results

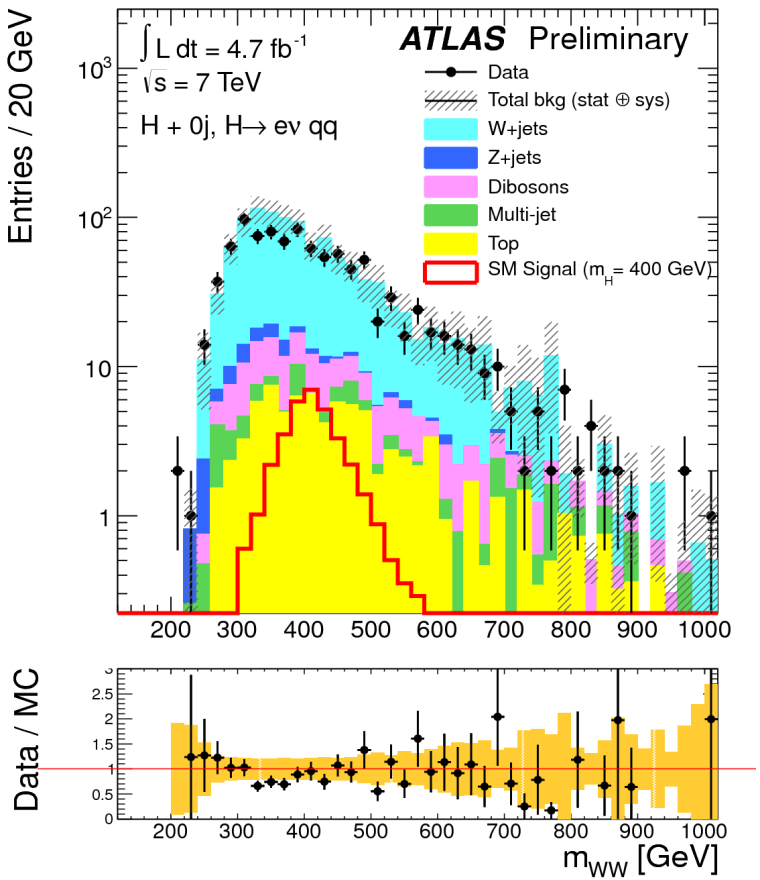


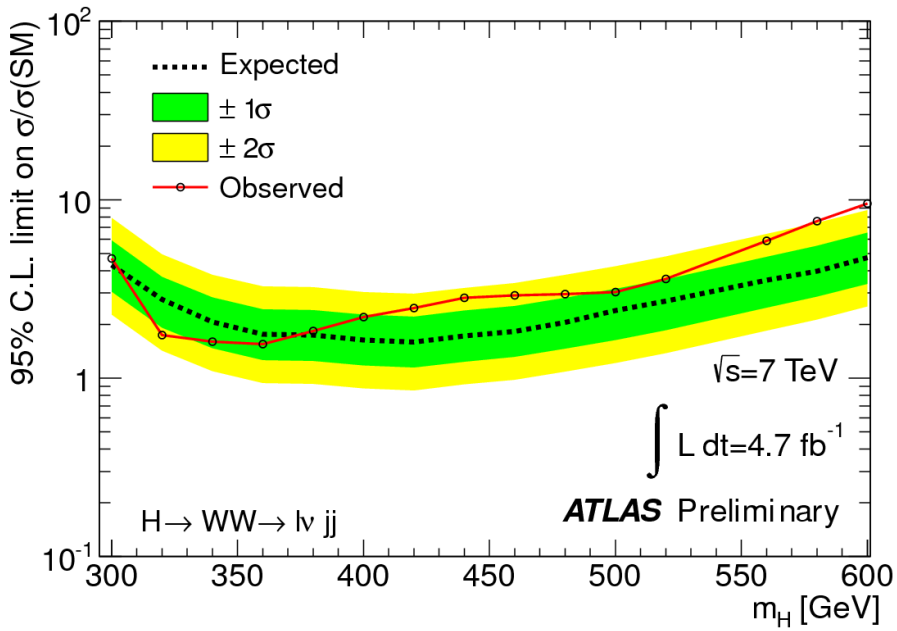


- Search for an excess of events using invariant mass distribution of two leptons and two jets
- Split the analysis at $m_H = 300$ GeV
- SM Higgs boson is excluded in the ranges 300-310 GeV and 360-400 GeV at the 95% confidence level

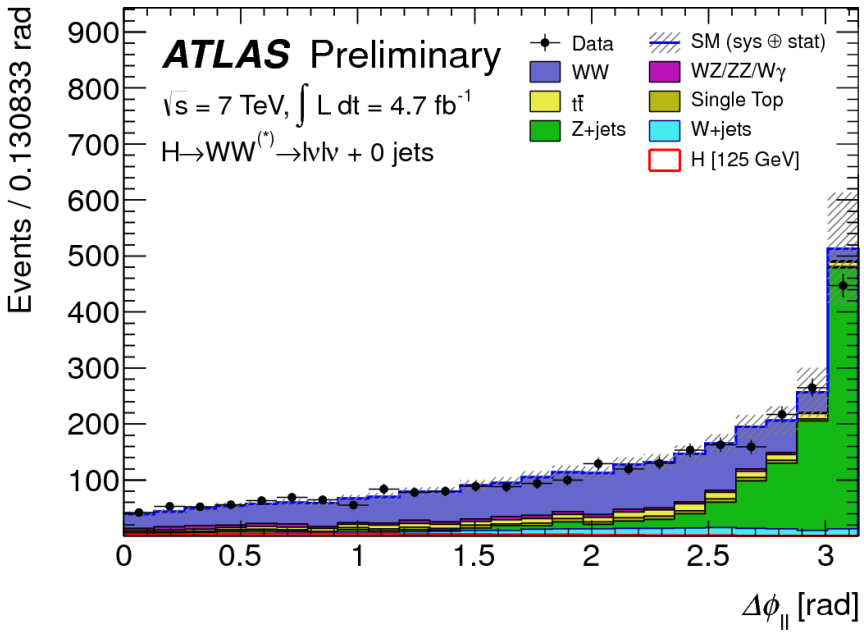
$H \to WW \to l\nu qq$

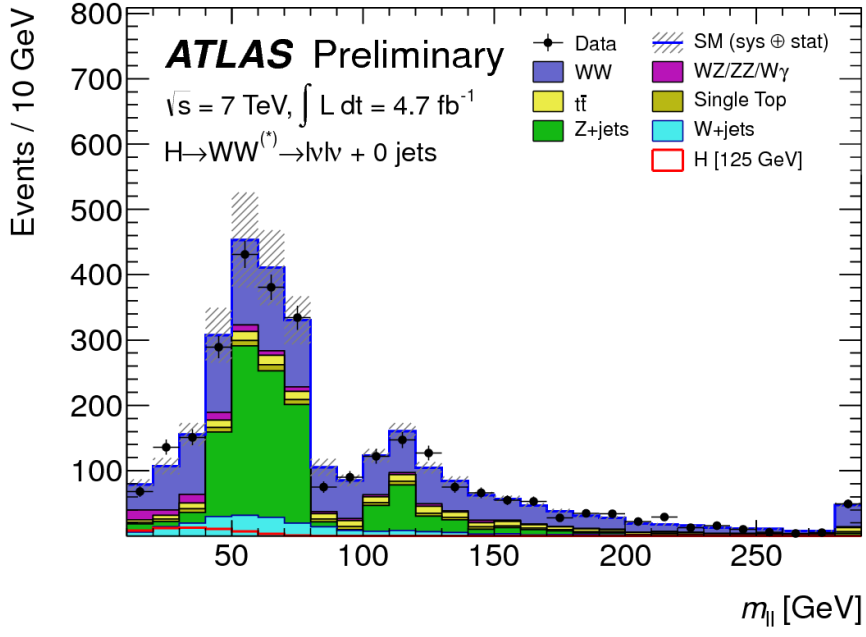
- Exactly one isolated electron or muon with $p_T > 40$ GeV
- Two central jets consistent with W decay
- Separate events by multiplicity of additional jets (ggF vs VBF)
- Search for an excess in event invariant mass distribution
- SM backgrounds are fitted from sidebands
- Approaching SM Higgs sensitivity





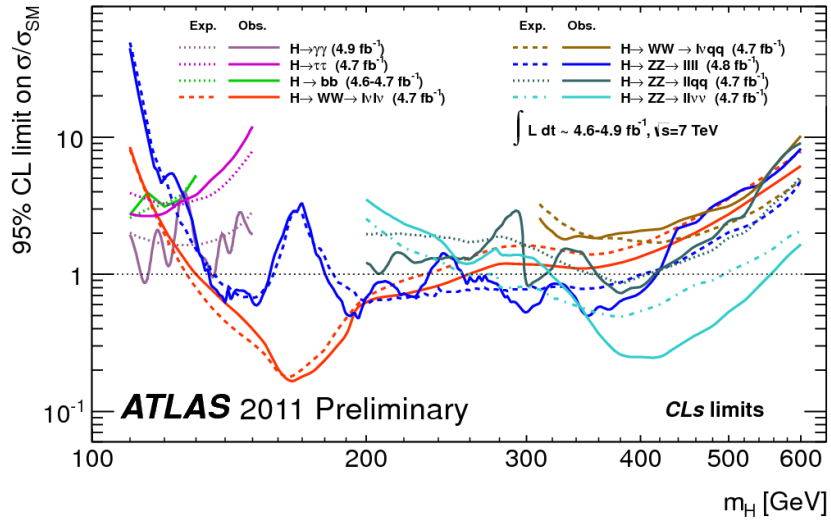
$H \to WW \to l\nu l\nu$: topological selections

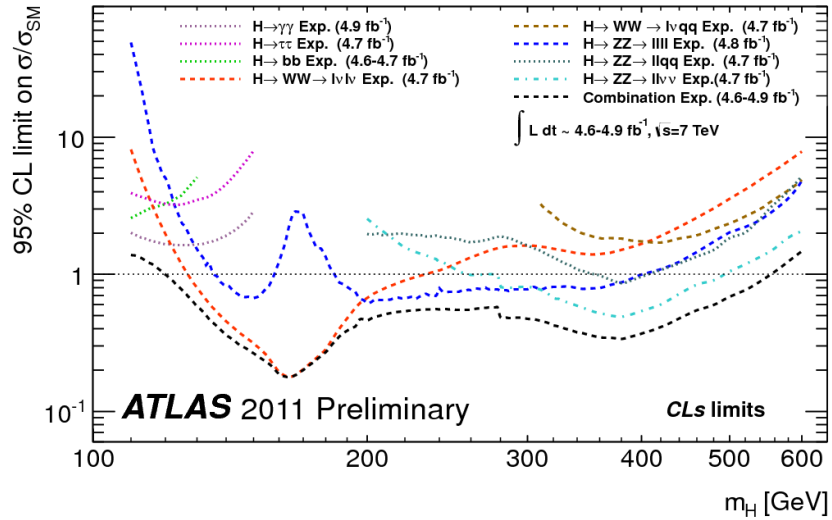


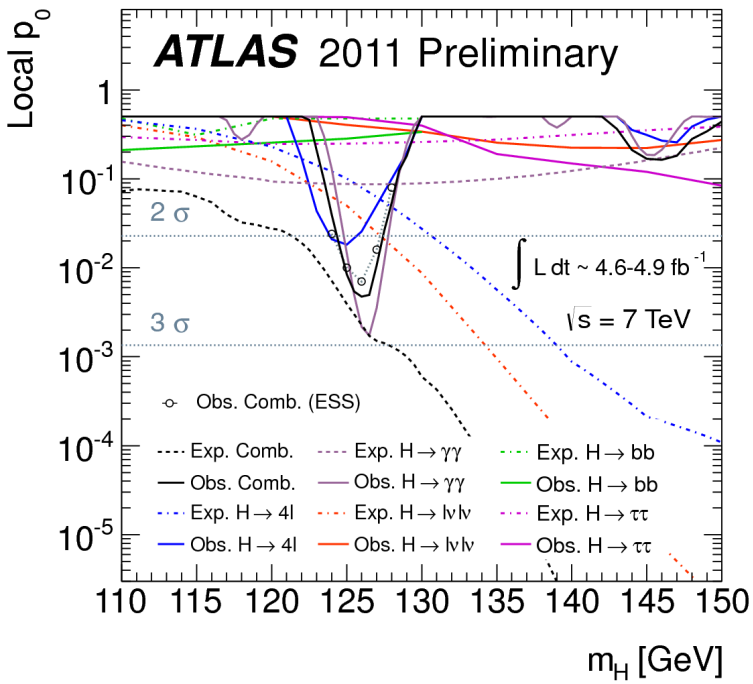


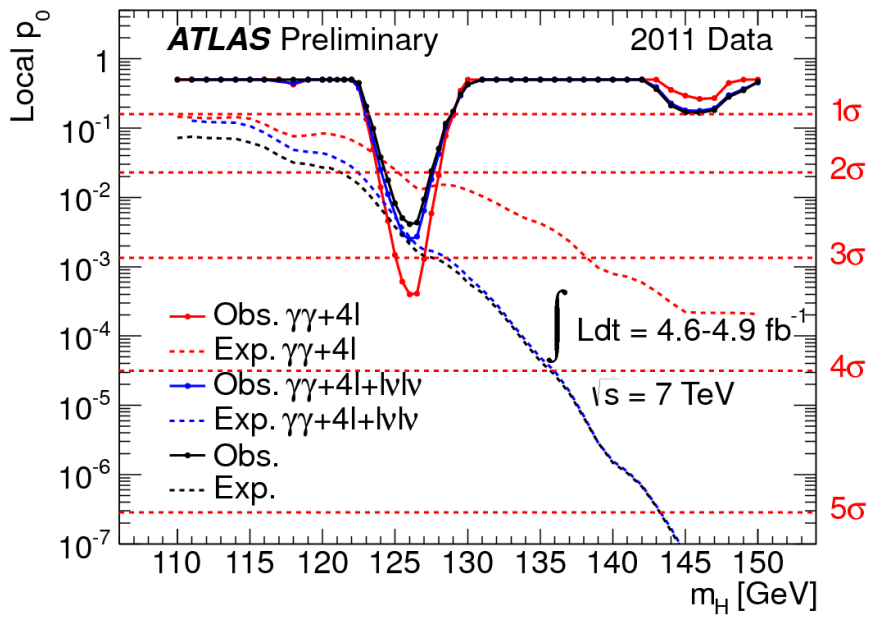
- Require small opening between two leptons for low mass Higgs
- Apply di-lepton invariant mass cut for low mass Higgs

Combination









Combination