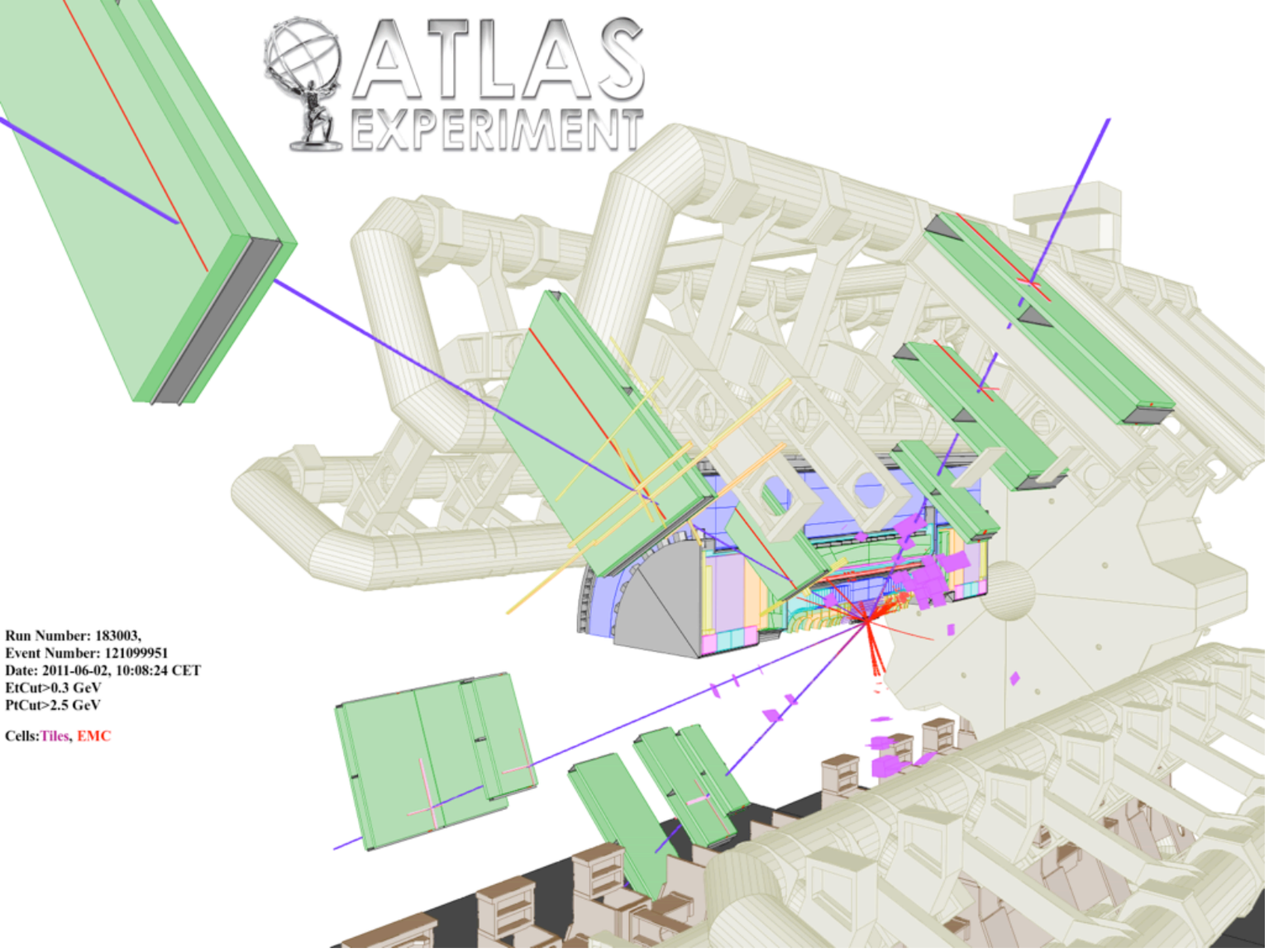


Standard Model H→ZZ searches with ATLAS

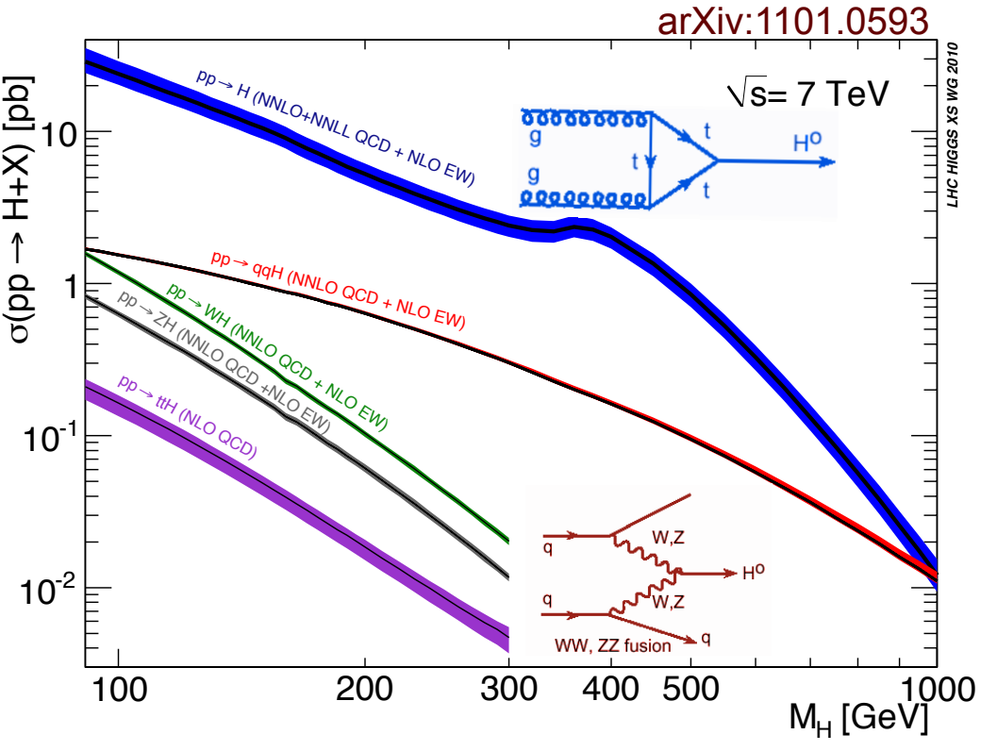
Konstantinos Nikolopoulos
Brookhaven National Laboratory

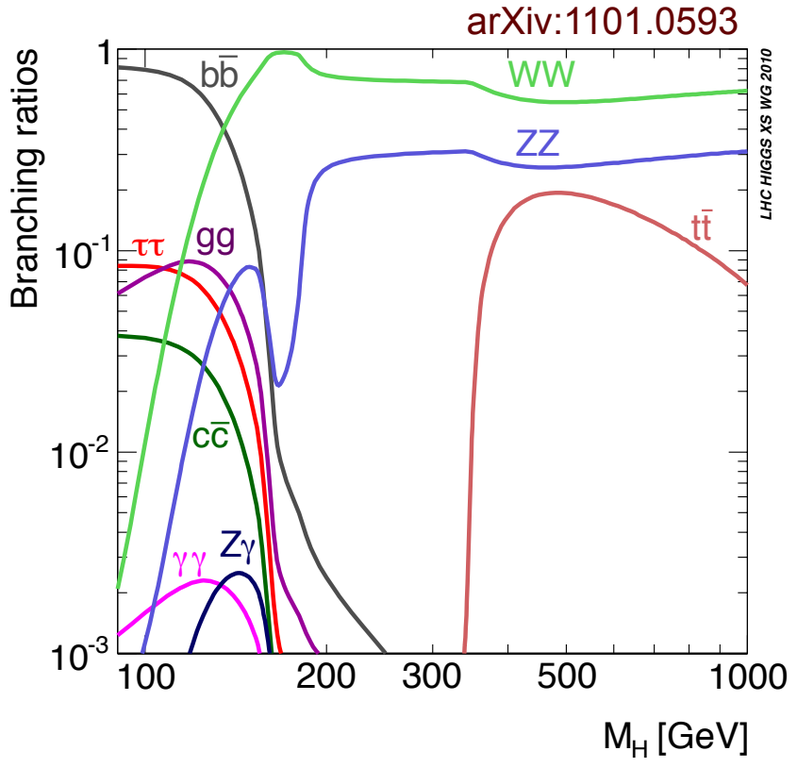
on behalf of the ATLAS collaboration

Europhysics Conference on High-Energy Physics 2011,
July 22nd 2011, Grenoble

BROOKHAVEN
NATIONAL LABORATORY

Higgs Boson Production @ LHC





SM Higgs Boson Production

⇒ gluon fusion dominates

⇒ VBF relative contribution

→ rises with m_H

SM Higgs Boson Decays

⇒ H→WW dominates m_H>130GeV

⇒ H→ZZ follows

⇒ H→γγ low BR/distinct final state

SM H→ZZ final states

⇒ llqq, llvv, llll considered

⇒ Sizeable branching ratio, especially for llqq and llvv

⇒ Presence of at least one on-shell Z → Clean final states

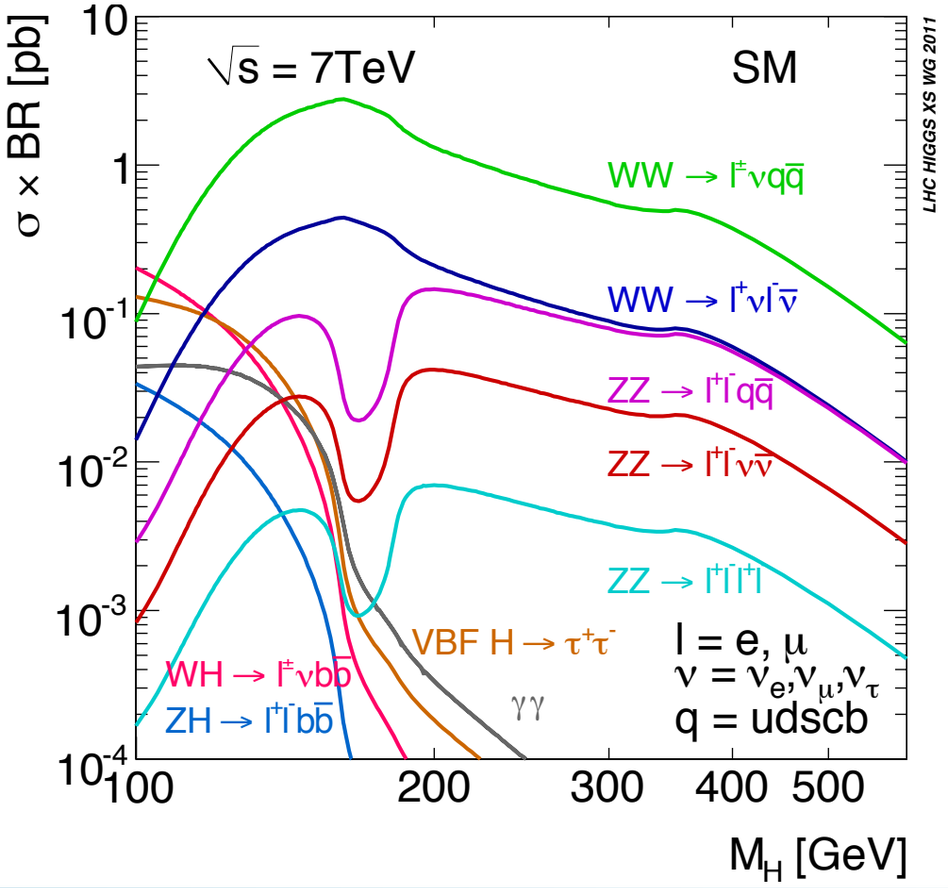
Pre-LHC SM Higgs status

⇒ LEP m_H>114.4 GeV at 95% CL

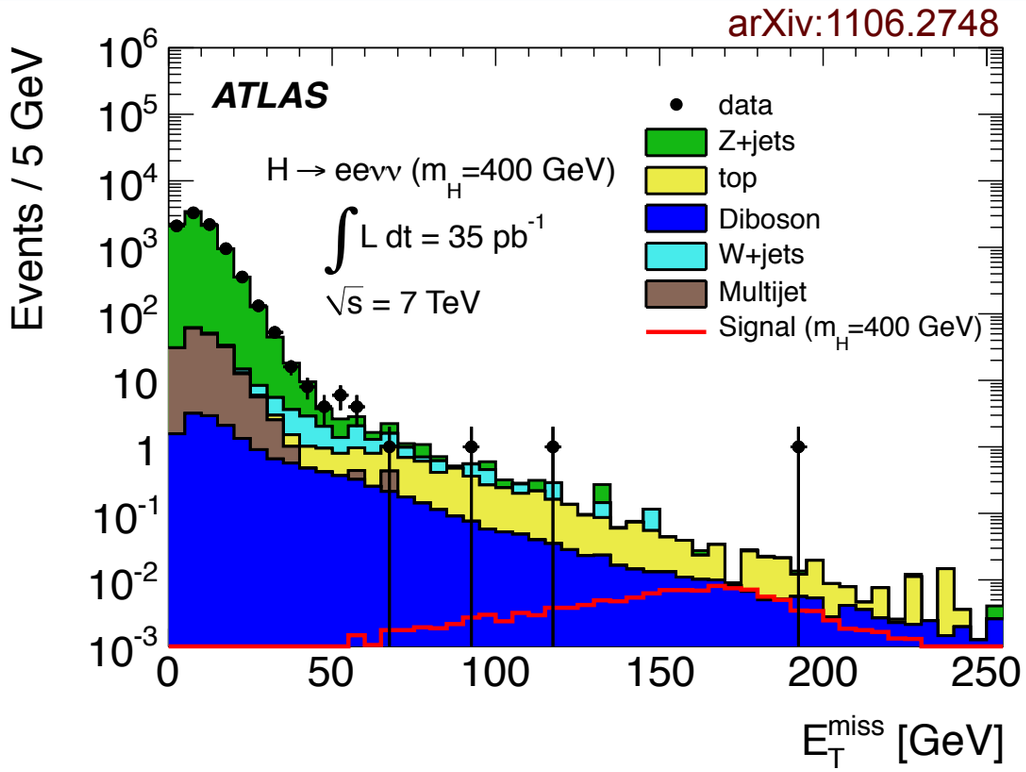
⇒ Tevatron excludes 158<m_H<163 GeV at 95% CL

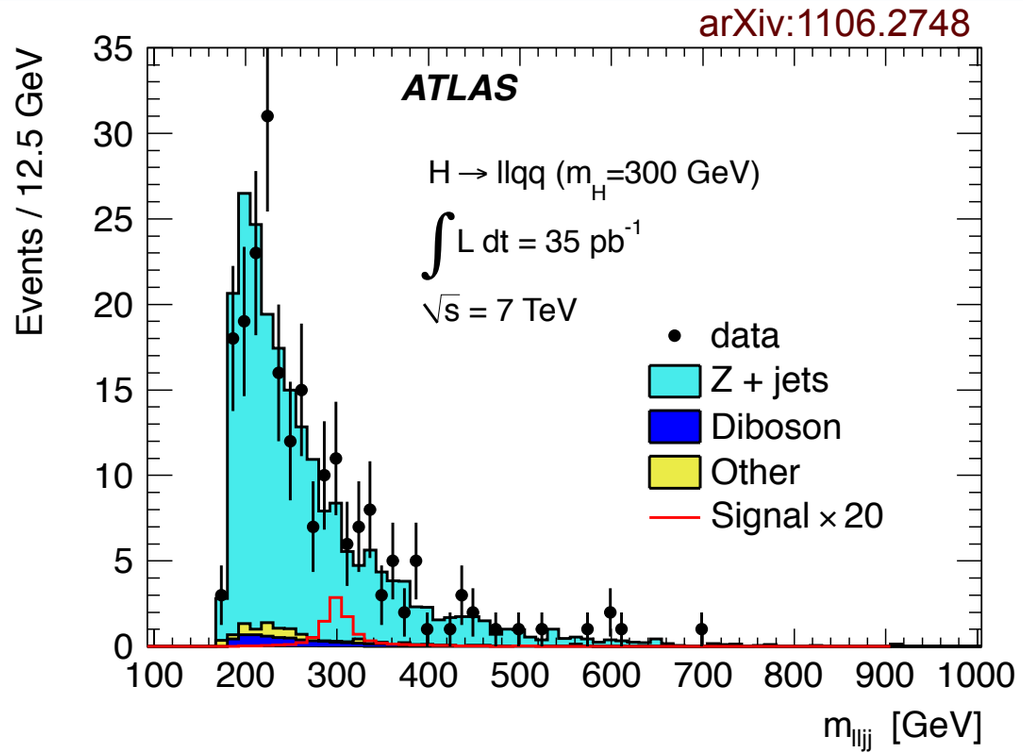
⇒ Large portion of allowed m_H still uncovered

⇒ m_H>200 GeV not considered.



Winter 2010





arXiv:1106.2748

ATLAS prepared a combined search using 2010 data (submitted to EPJC)

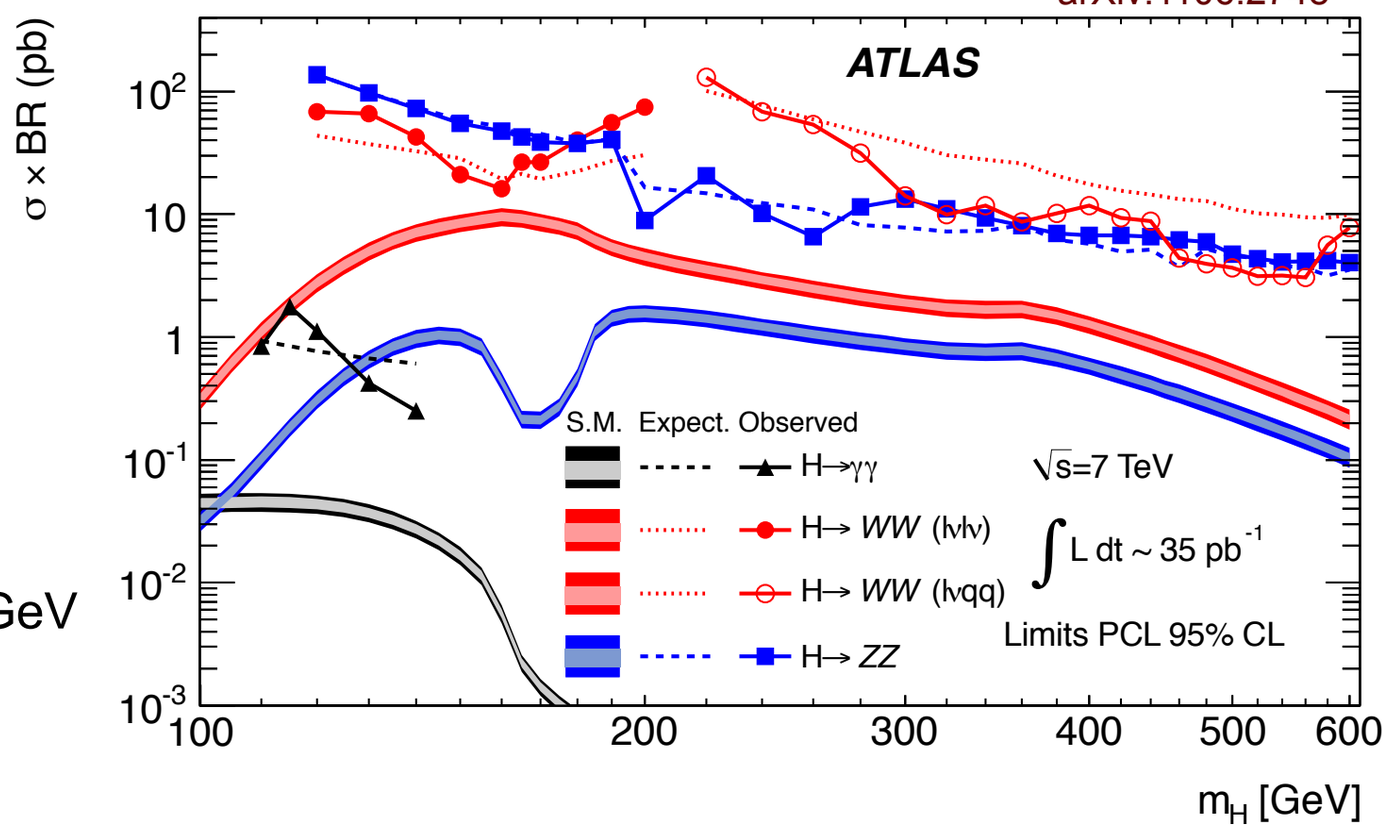
⇒ 48 pb^{-1} @ 7TeV delivered; 35-43 pb^{-1} for **physics**

⇒ Peak stable luminosity 2.1×10^{32}cm^{-2}s^{-1}

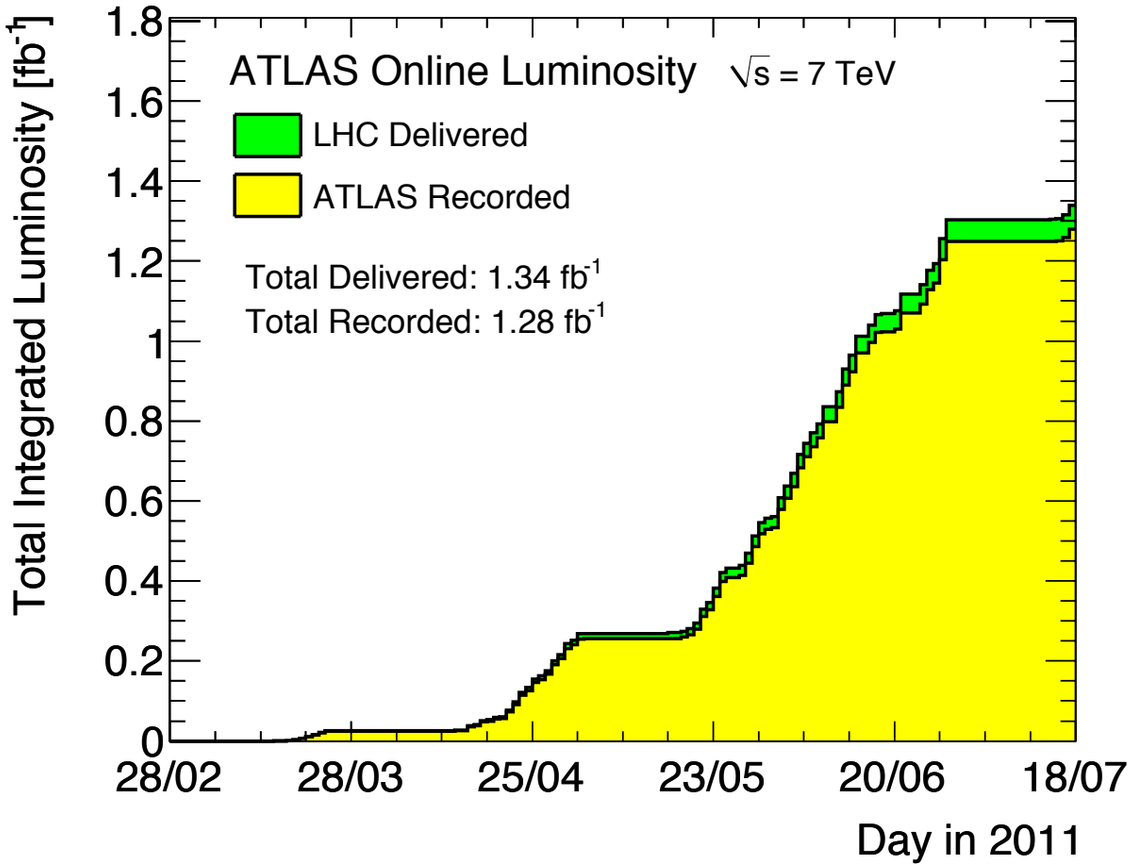
⇒ Max <interactions/bunch-crossing>=3.8

⇒ Exclusion limits (PCL) with H→ZZ

→ 5-20xSM cross section for 200 GeV≤m_H≤ 600 GeV



Summer 2011



With 1 fb^{-1} we are sensitive to the SM Higgs production for 130 GeV<m_H<500 GeV

All 95% Confidence Level (CL) upper limits presented in the following are based on CL_s

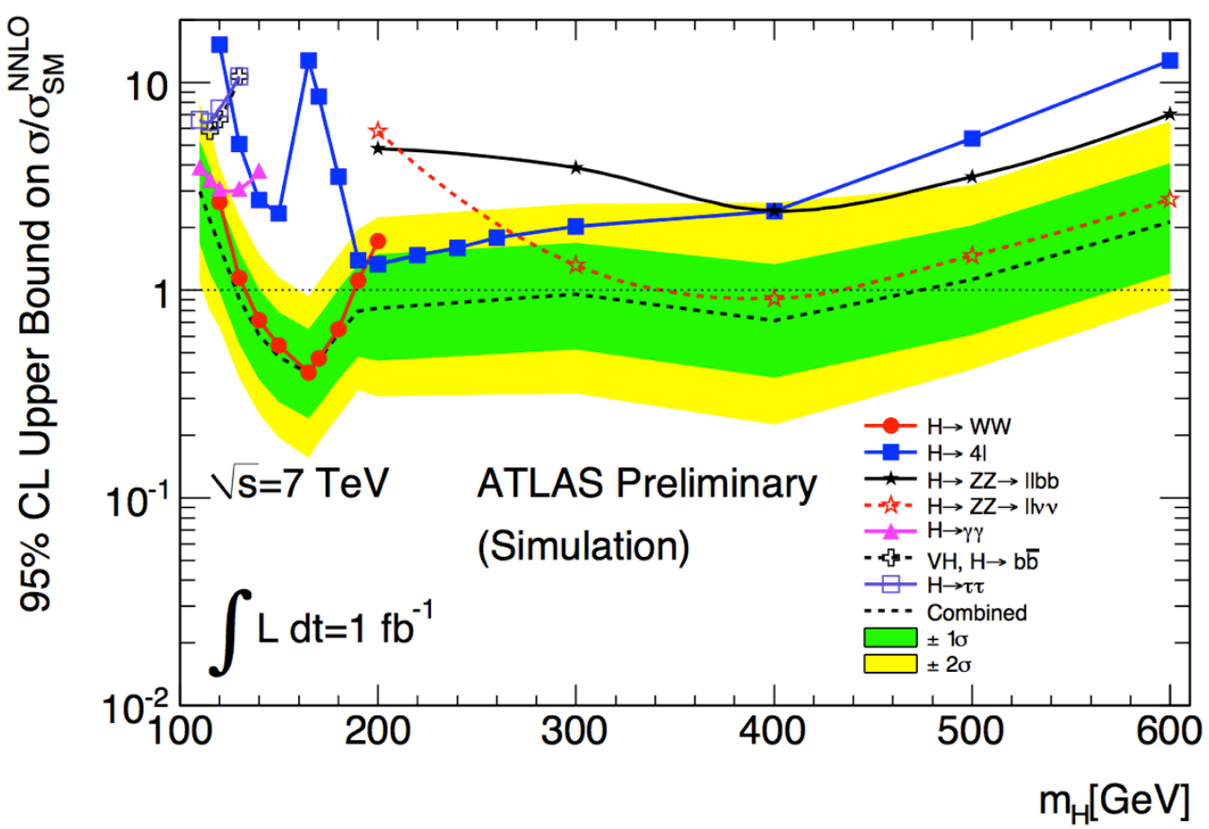
Excellent LHC performance in 2011!

→ 1.34 fb^{-1} delivered

→ 1.04 - 1.21 fb^{-1} for physics

→ Peak stable luminosity 1.28×10^{33}cm^{-2}s^{-1}

→ Max <interactions/bunch-crossing>=8.93



H→ZZ→llqq

⇒ Signature : lepton pair + 2 jets

→ Main Background: Z+jets production

⇒ Search in 200 GeV≤m_H≤600 GeV region

→ Optimized: high/low mass sub-region (m_H≥300GeV)

→ Binned: “tagged” (2 b-tags) and “un-tagged” (0/1 b-tags)

Event Selection

⇒ Same-flavor pair of isolated high pT leptons

→ pT> 20 GeV, 76 GeV < mll < 106 GeV,

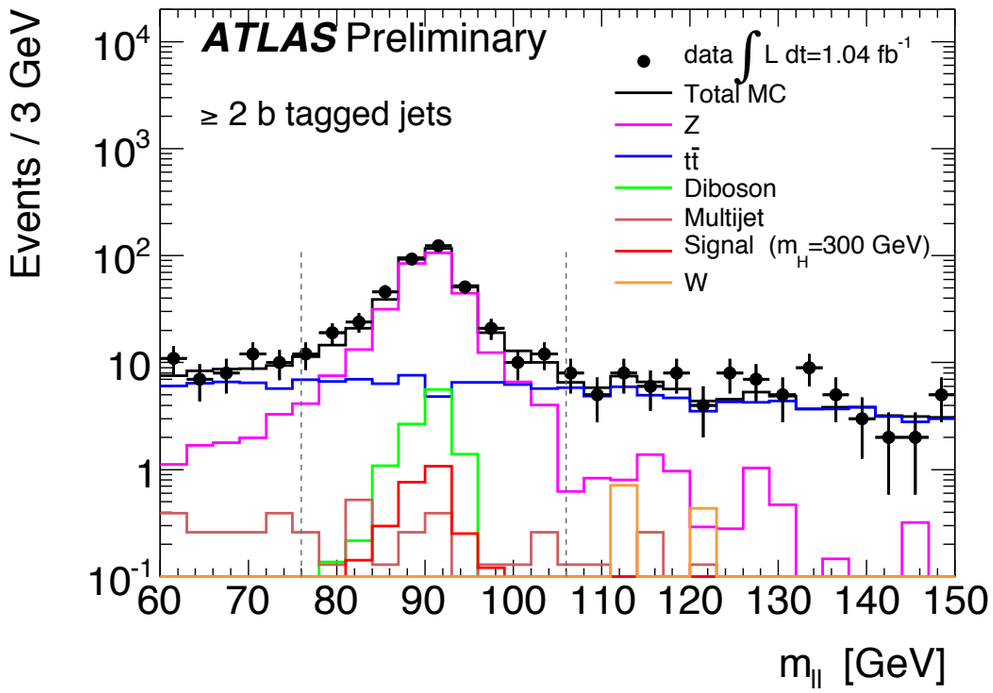
⇒ 3rd lepton veto

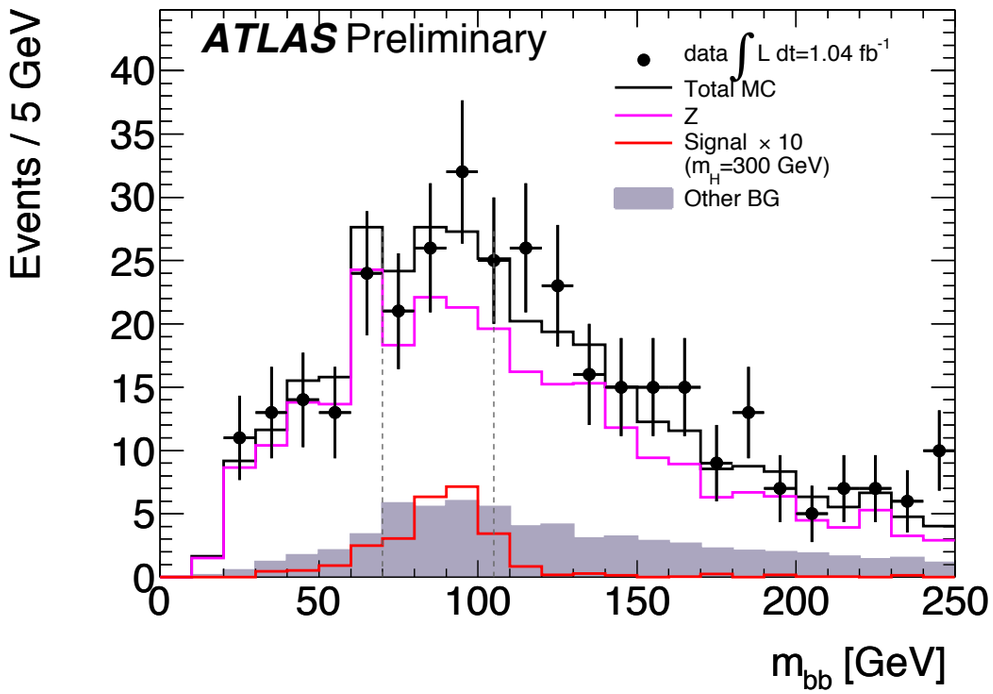
⇒ ≥2 jets, pT>25GeV, |n|<2.5, with 70< m_{jj}<105 GeV

⇒ MET<50 GeV

⇒ “high-mass” pT(jets)>50GeV, $\Delta\varphi_{ll}<\pi/2$, $\Delta\varphi_{jj}<\pi/2$

⇒ final discriminant: lljj invariant mass (m_{jj} scaled to m_Z)

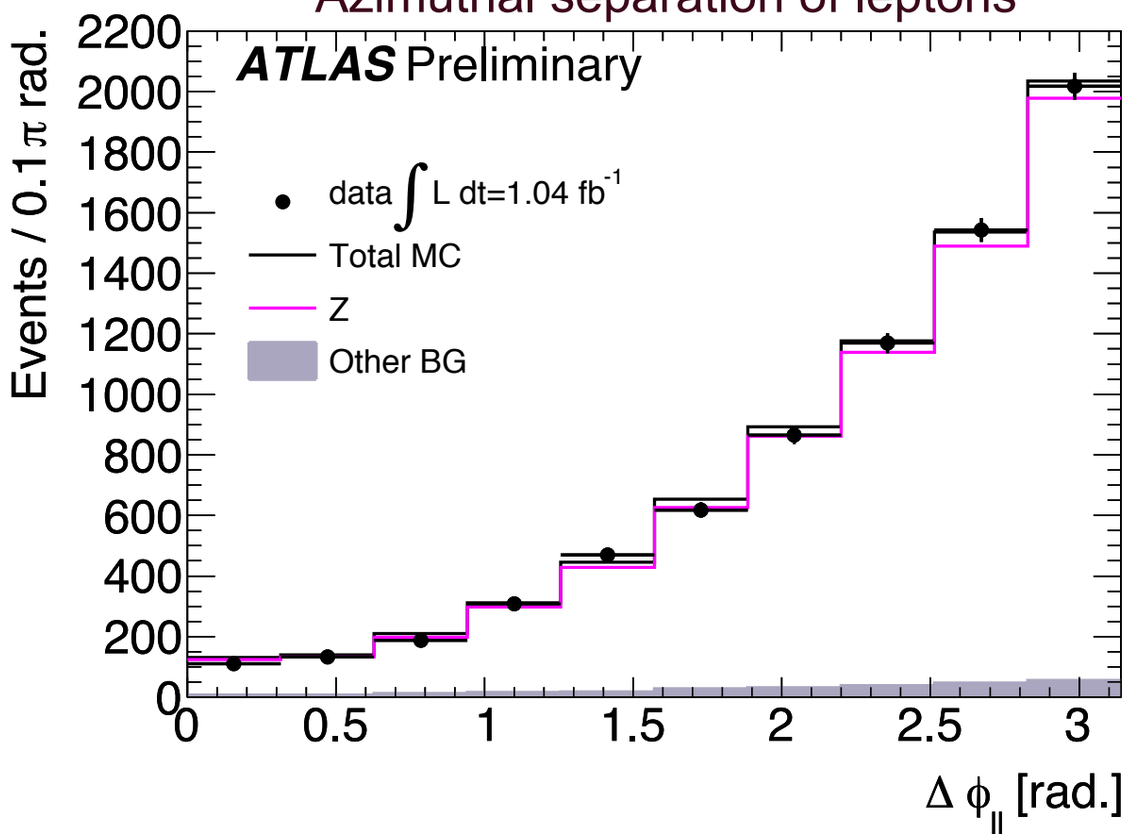




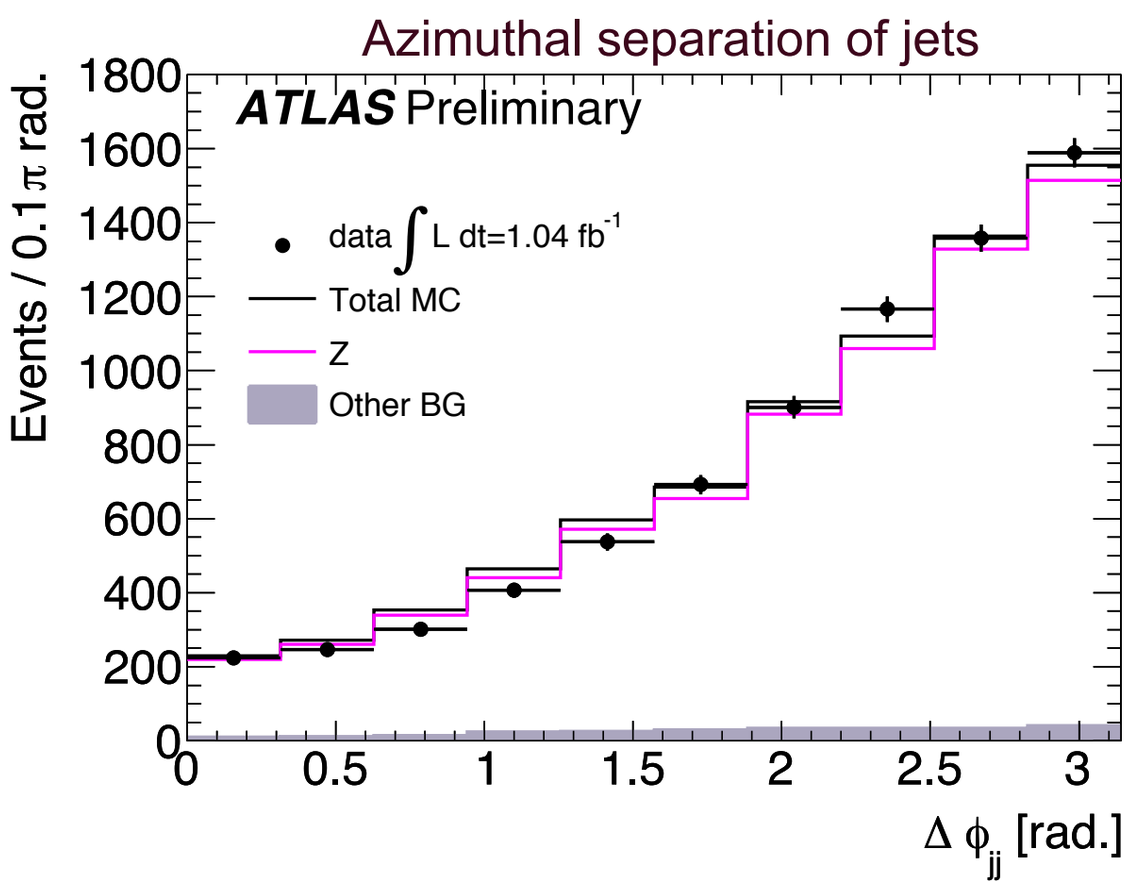
H→ZZ→llqq : Kinematic Distributions

⇒ Monte-Carlo provides reasonable description of the selection variables

Azimuthal separation of leptons

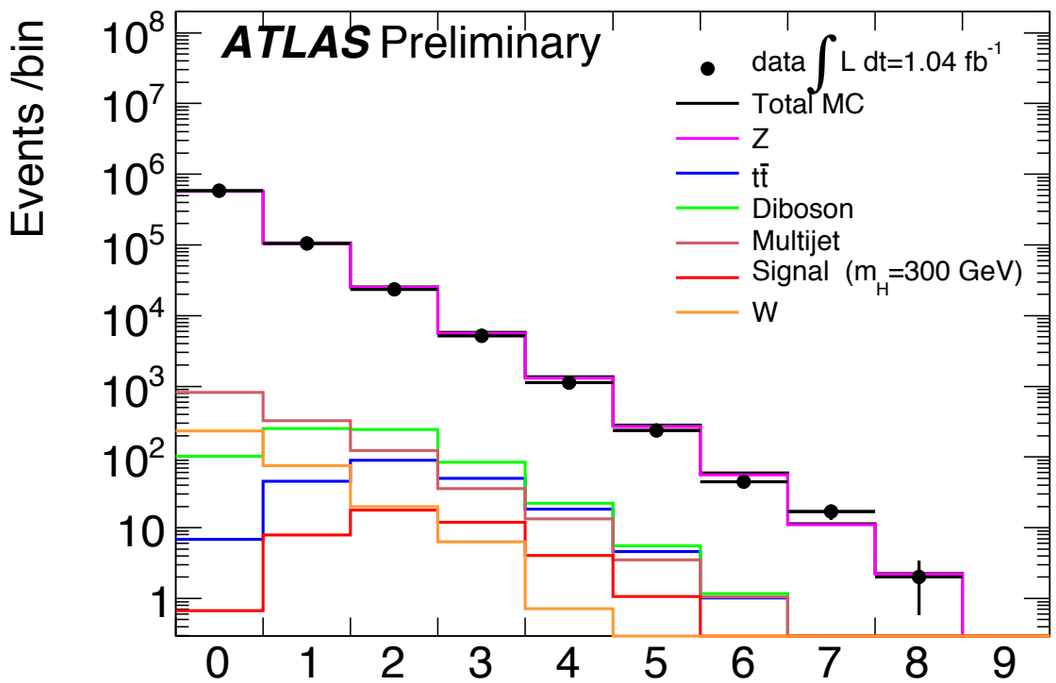


Azimuthal separation of jets



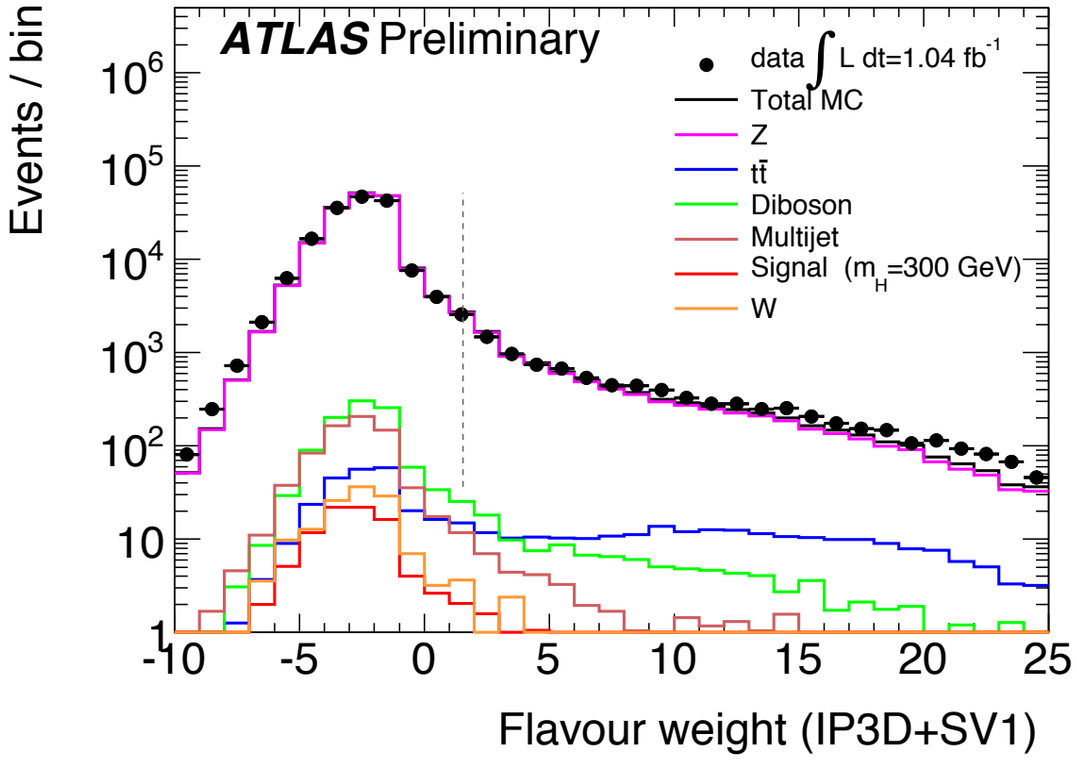
H→ZZ→llqq : Kinematic Distributions II

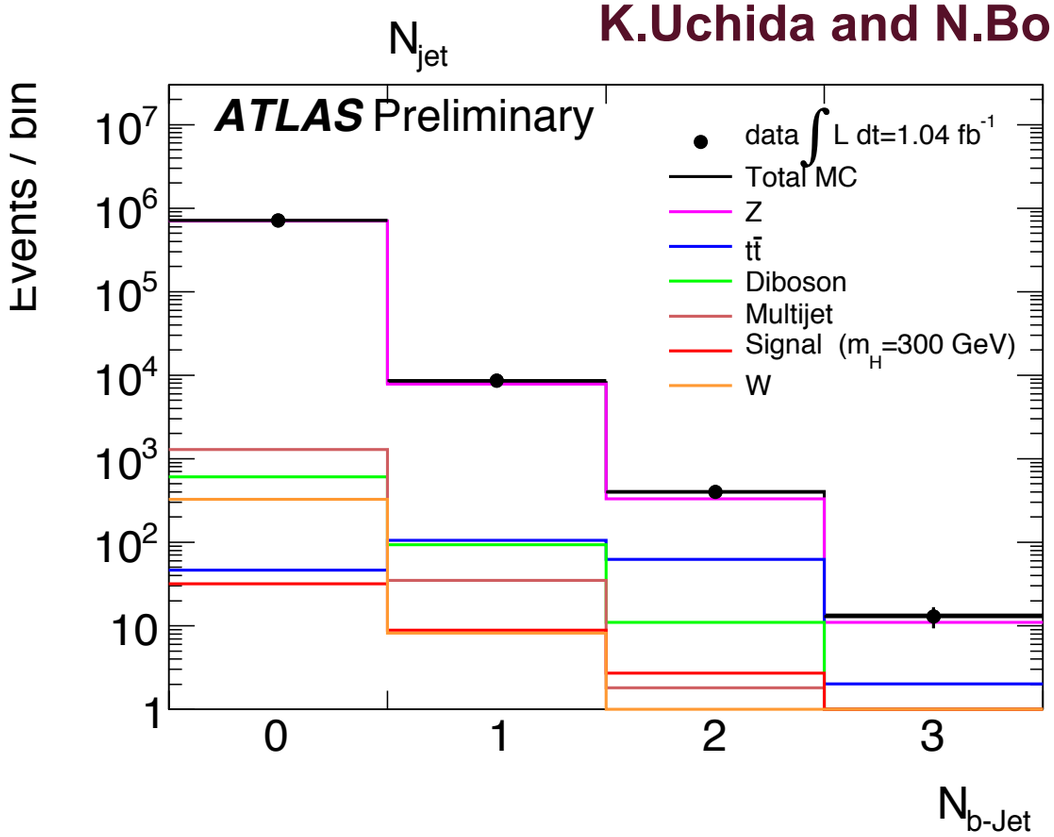
⇒ Monte-Carlo provides reasonable description of the selection variables



See also posters by:

K.Uchida and N.Bousson





H→ZZ→llqq : Backgrounds

Normalize Z+jets using sidebands of M_{jj}

⇒ uncertainty <10% for un-tagged

⇒ uncertainty ~20% for tagged

Verify top expectation using sidebands of M_{ll}

⇒ uncertainty 10% from theory

Diboson backgrounds from MC

⇒ uncertainty ~10%

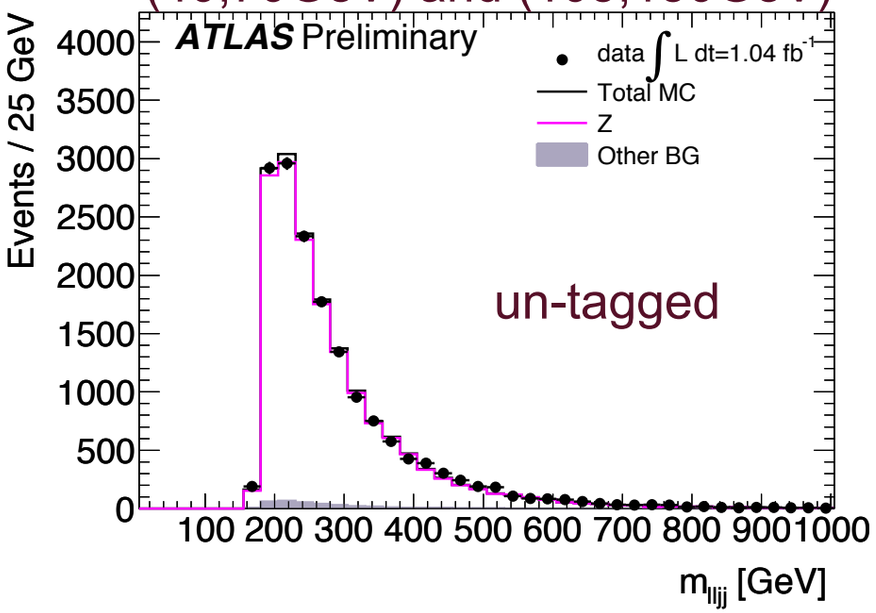
Data-Driven QCD background

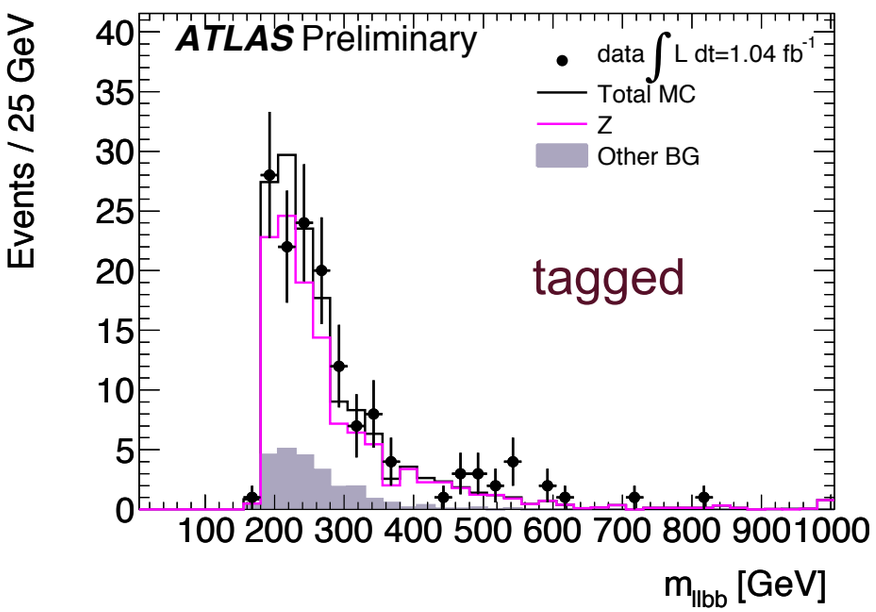
⇒ generally small contributions

⇒ ee : QCD background templates

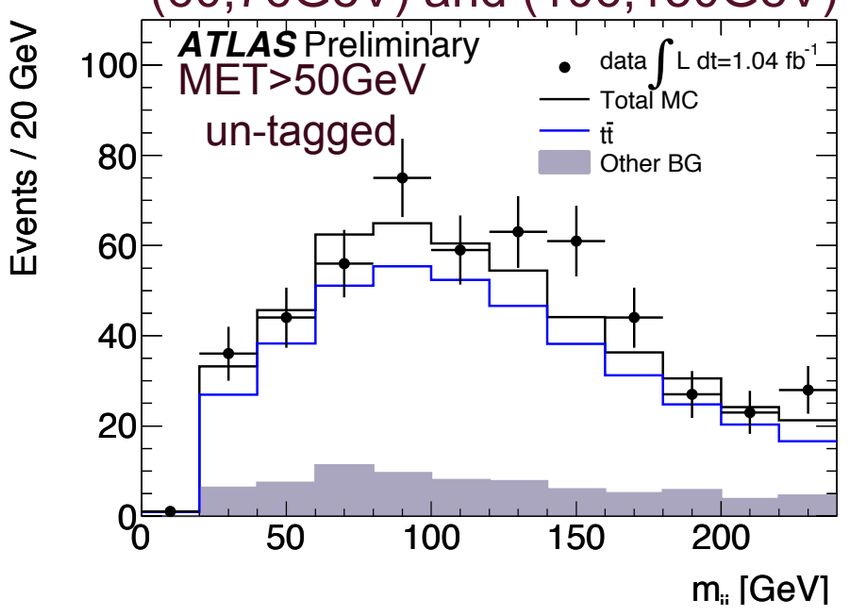
⇒ μμ : 2D sideband using isolation and invariant mass of the pair

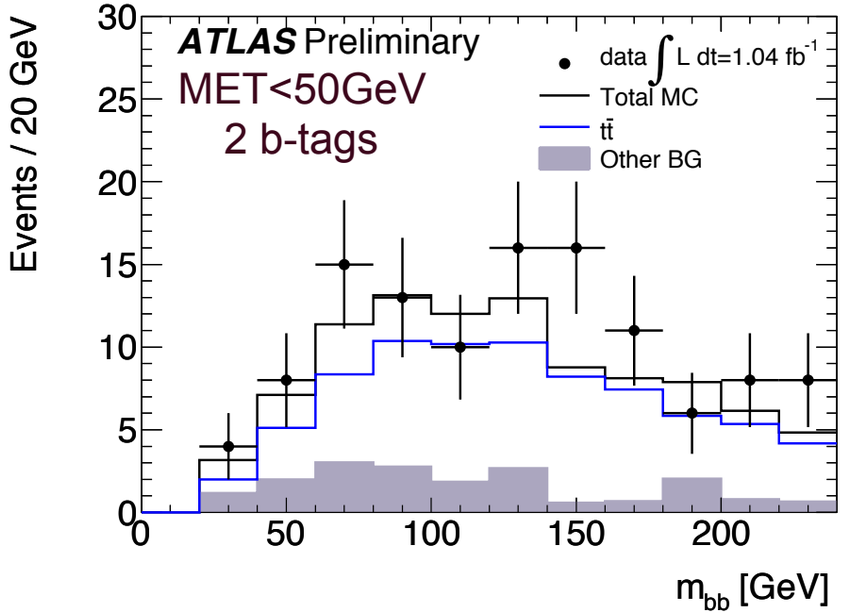
Side-bands of M_{jj}
(40,70GeV) and (105,150GeV)





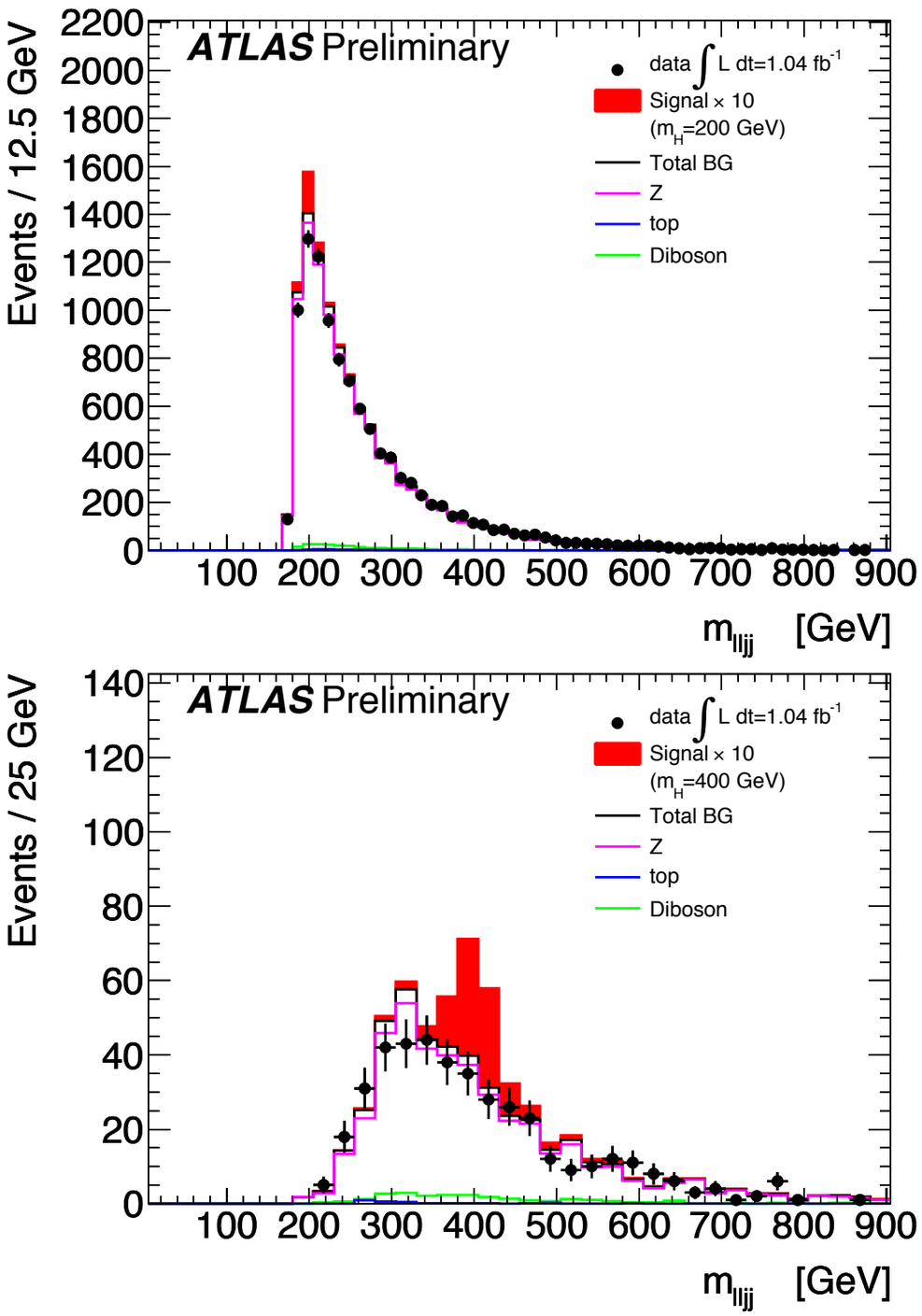
Side-bands of M_{ll}
(60,76GeV) and (106,150GeV)



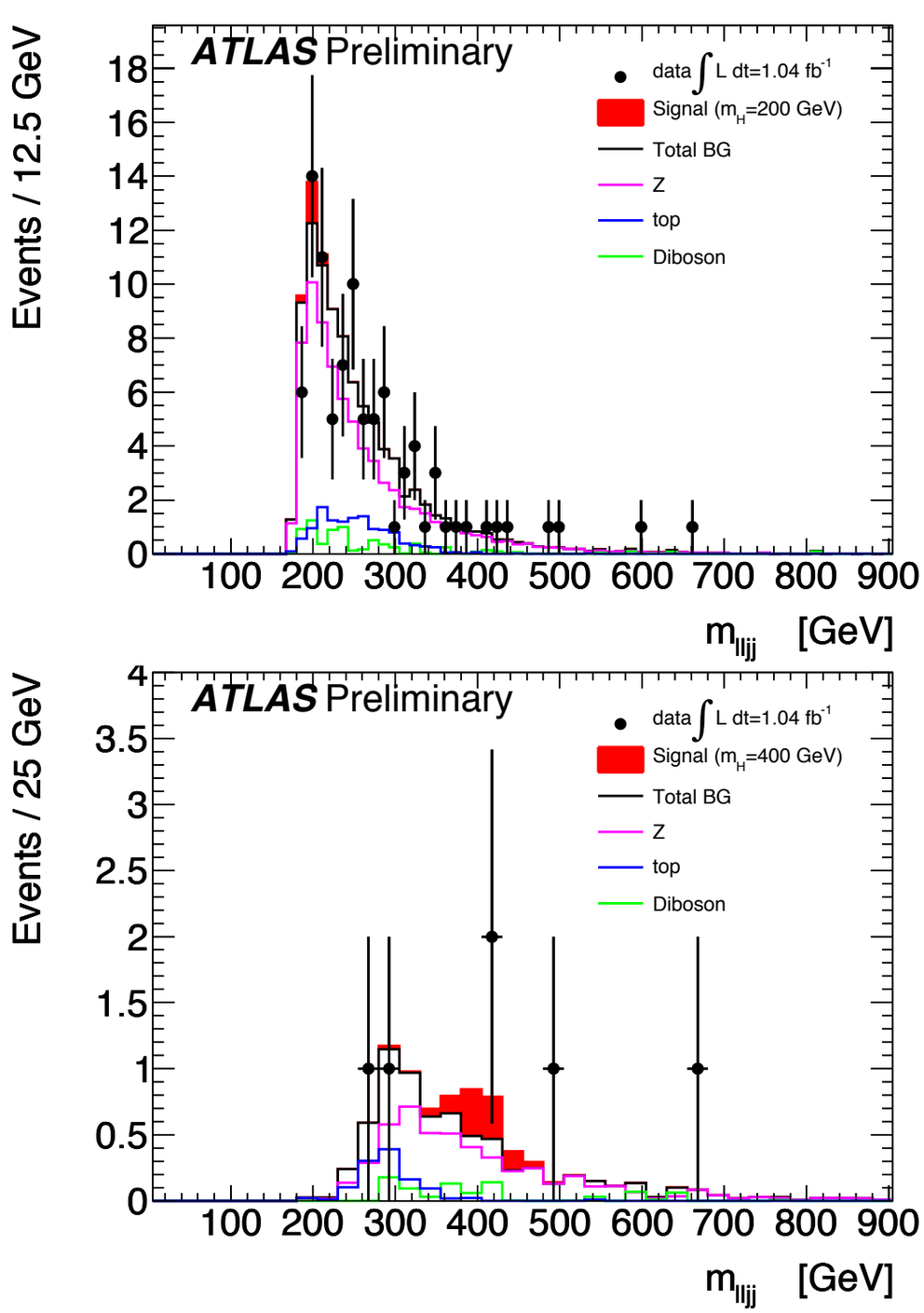


H→ZZ→llqq : Results

Un-tagged



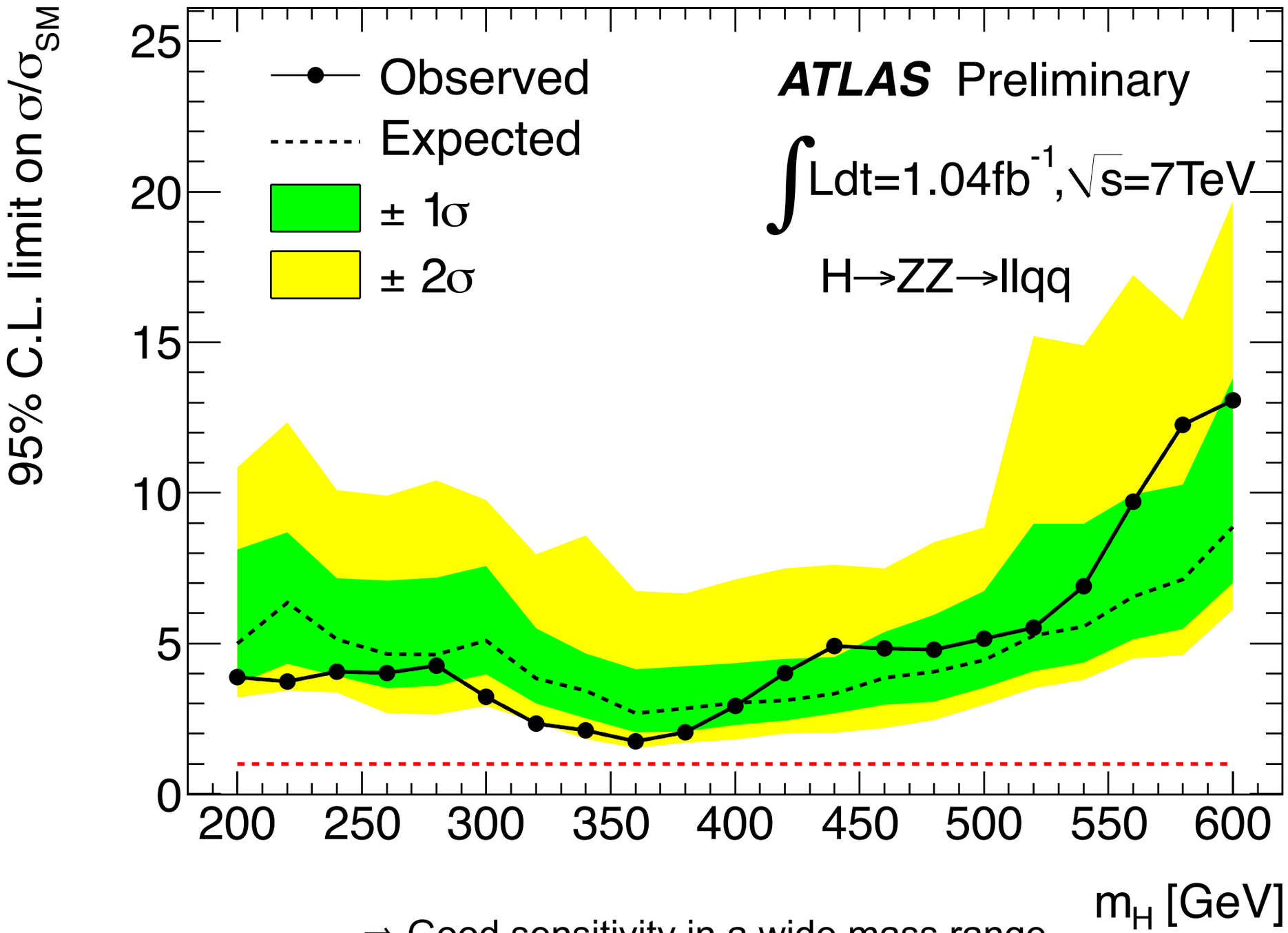
Tagged



m_H=200 GeV

m_H=400 GeV

H→ZZ→llqq : Exclusion Limits



⇒ Good sensitivity in a wide mass range

⇒ Expected limit between 2.7 - 9 x SM cross section

⇒ Observed 1.7 x SM cross section @ m_H=360GeV

H→ZZ→llνν

⇒ Signature : lepton pair + MET

→ Main backgrounds : top and diboson production
→ Signal contributions from H→WW→lνlν
→ Orthogonal to H→WW→lνlν search

⇒ Search in 200 GeV≤m_H≤600 GeV region

→ separated in high/low mass sub-region (m_H≥280GeV)

Event Selection

⇒ Same-flavor opposite-sign pair of isolated high pT leptons

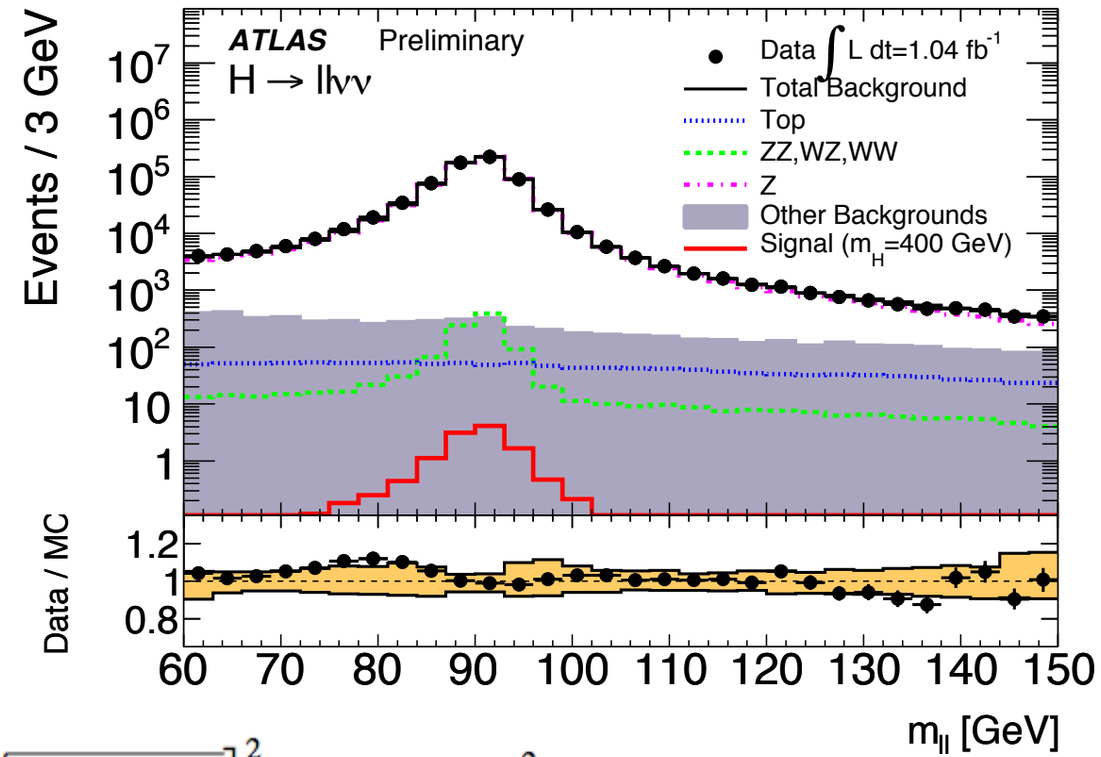
⇒ 3rd lepton veto, b-jet veto

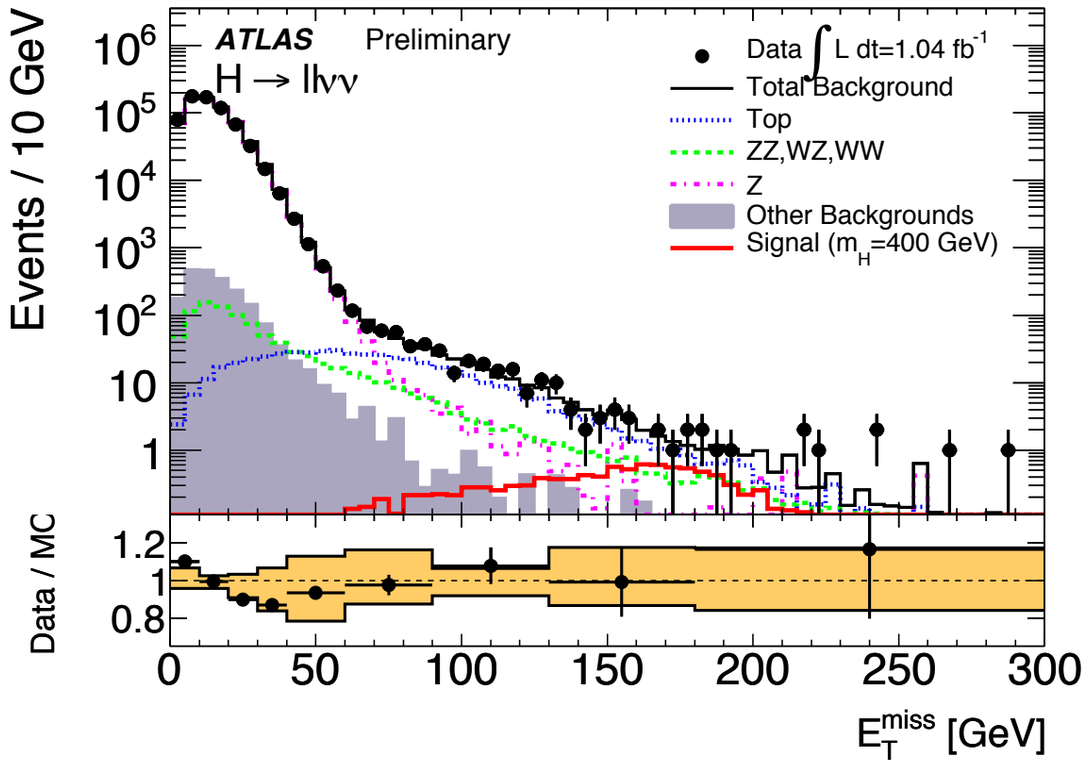
⇒ MET > 66 GeV ("high-mass" MET > 82 GeV)

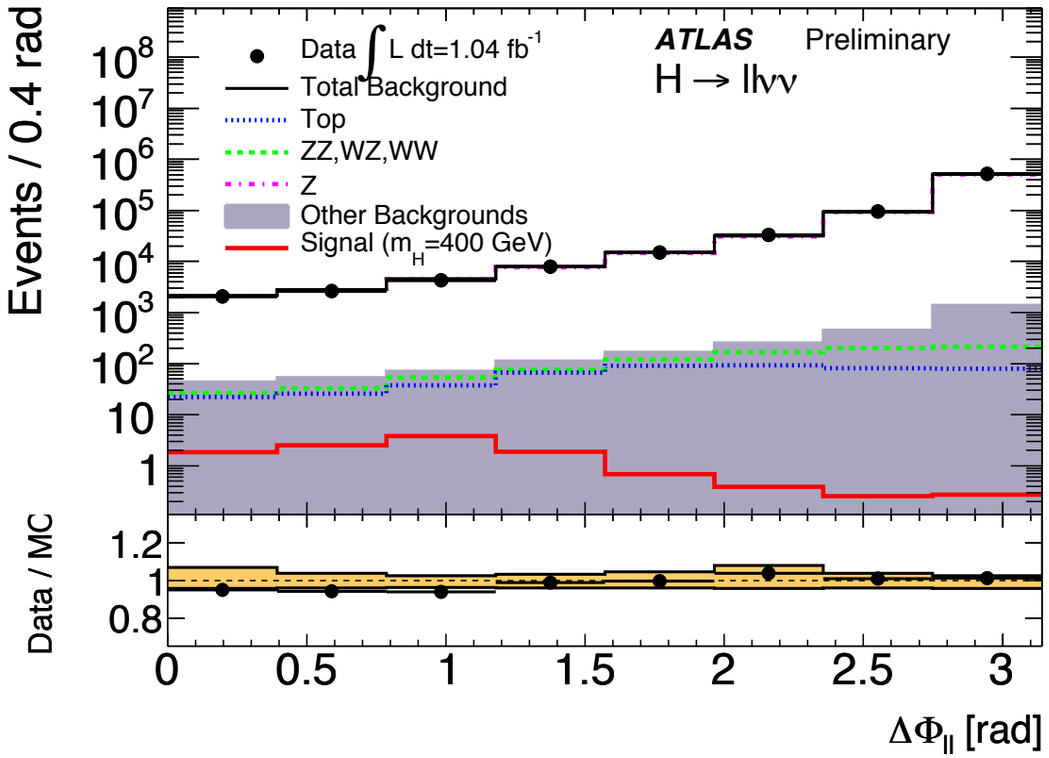
⇒ Δφ(Leading Jet,MET)>0.3, for "high-mass" also Δφ(Z,MET)>1

⇒ 1<$\Delta\varphi_{ll}$<2.64 ("high-mass" $\Delta\varphi_{ll}$<2.25)

⇒ Final discriminant is the transverse mass : $m_T^2 \equiv \left[\sqrt{m_Z^2+|\vec{P}_T^{ll}|^2}+\sqrt{m_Z^2+|\vec{P}_T^{miss}|^2}\right]^2-\left[\vec{P}_T^{ll}+\vec{P}_T^{miss}\right]^2$

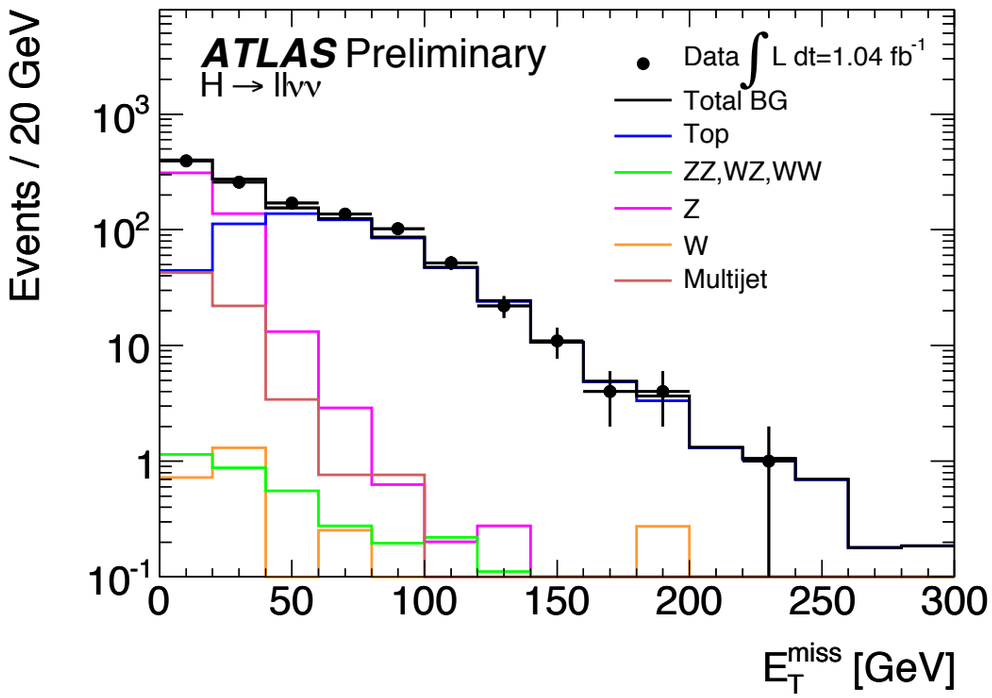




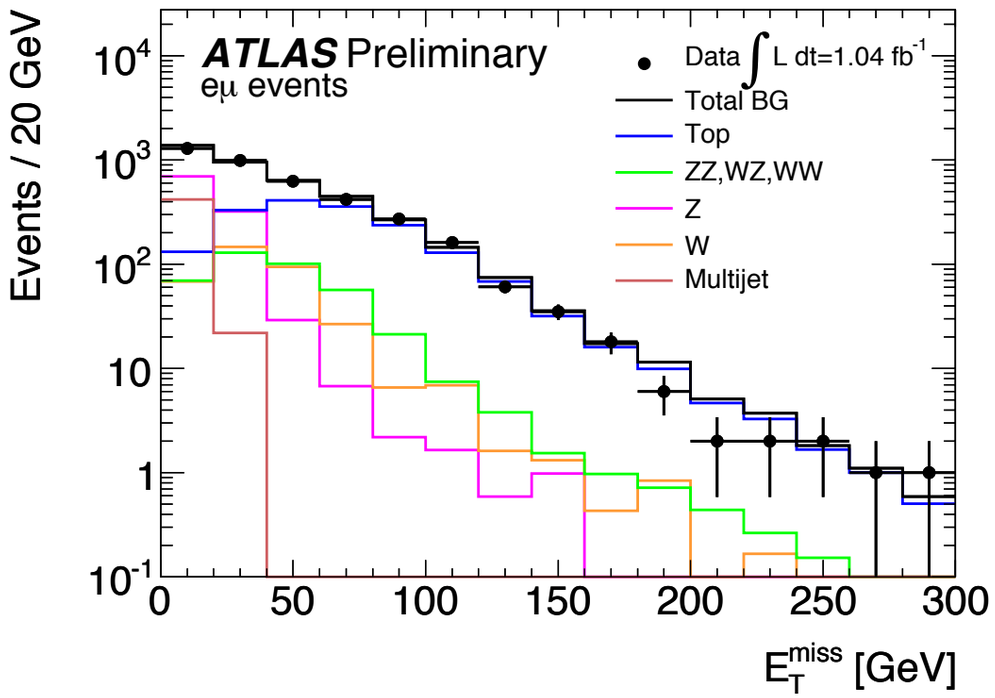


H→ZZ→llνν : Backgrounds

top M_{ll} sidebands with b-tags
(60,150 GeV) but not in Z window



top eμ



Diboson backgrounds from MC

⇒ uncertainty ~10%

Top background

⇒ MC expectation verified with data

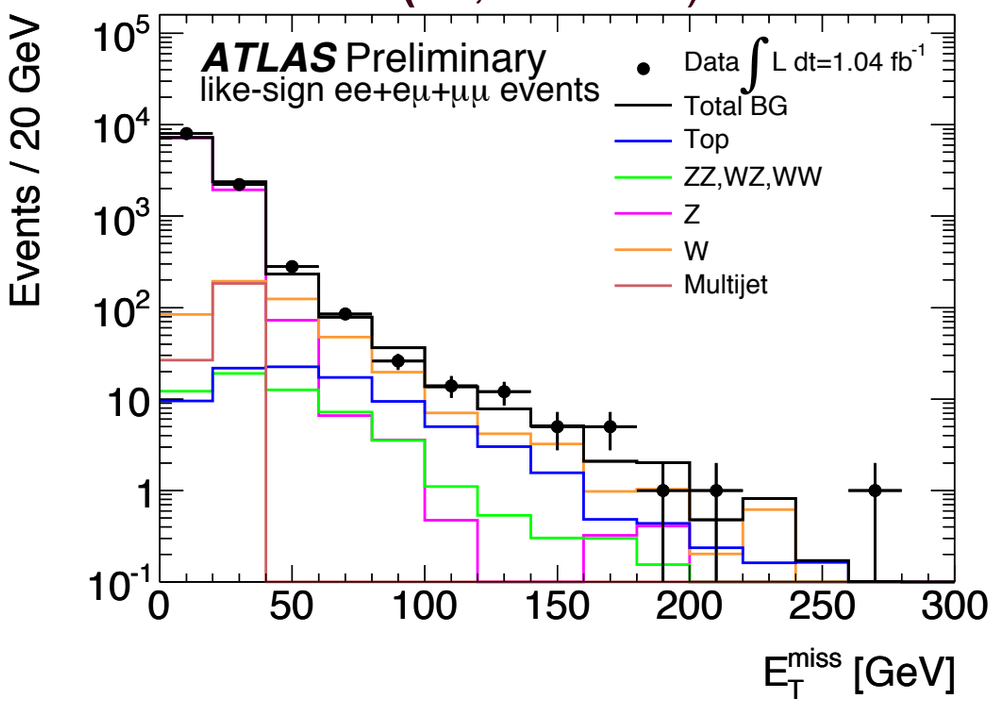
Data-driven W+jets background

⇒ taken for same-sign lepton pairs

Data-driven QCD background

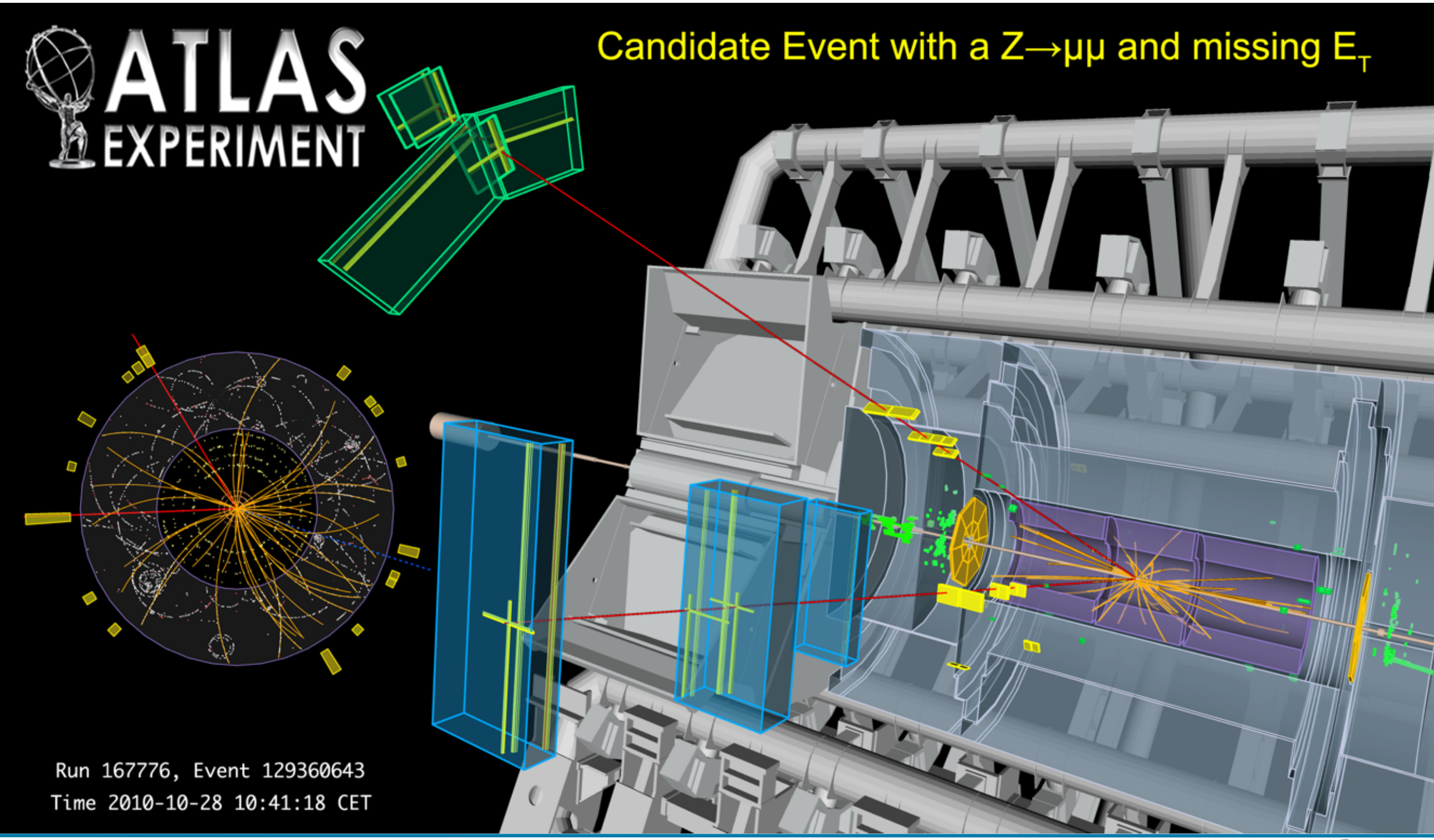
⇒ generally small contributions

W+jets same-sign lepton pairs
(60,150 GeV)

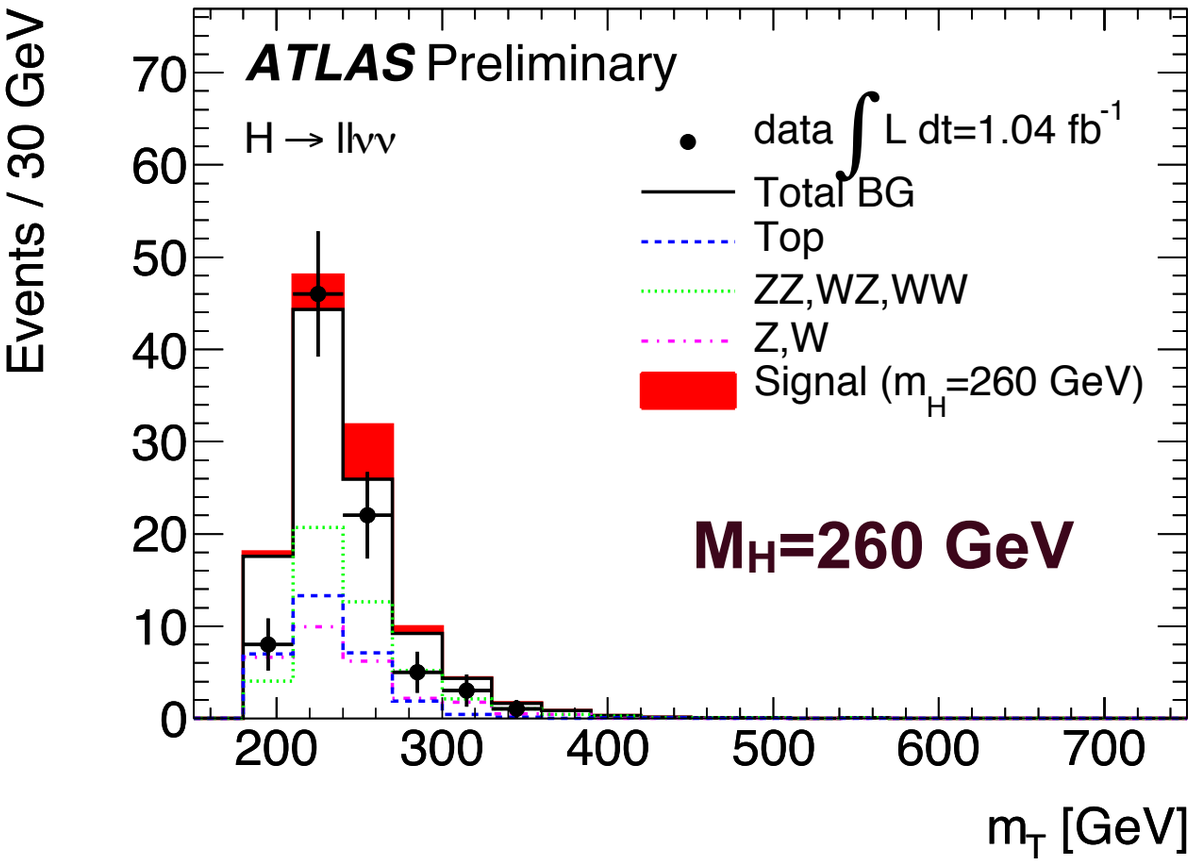


H→ZZ→llνν : Event display

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.



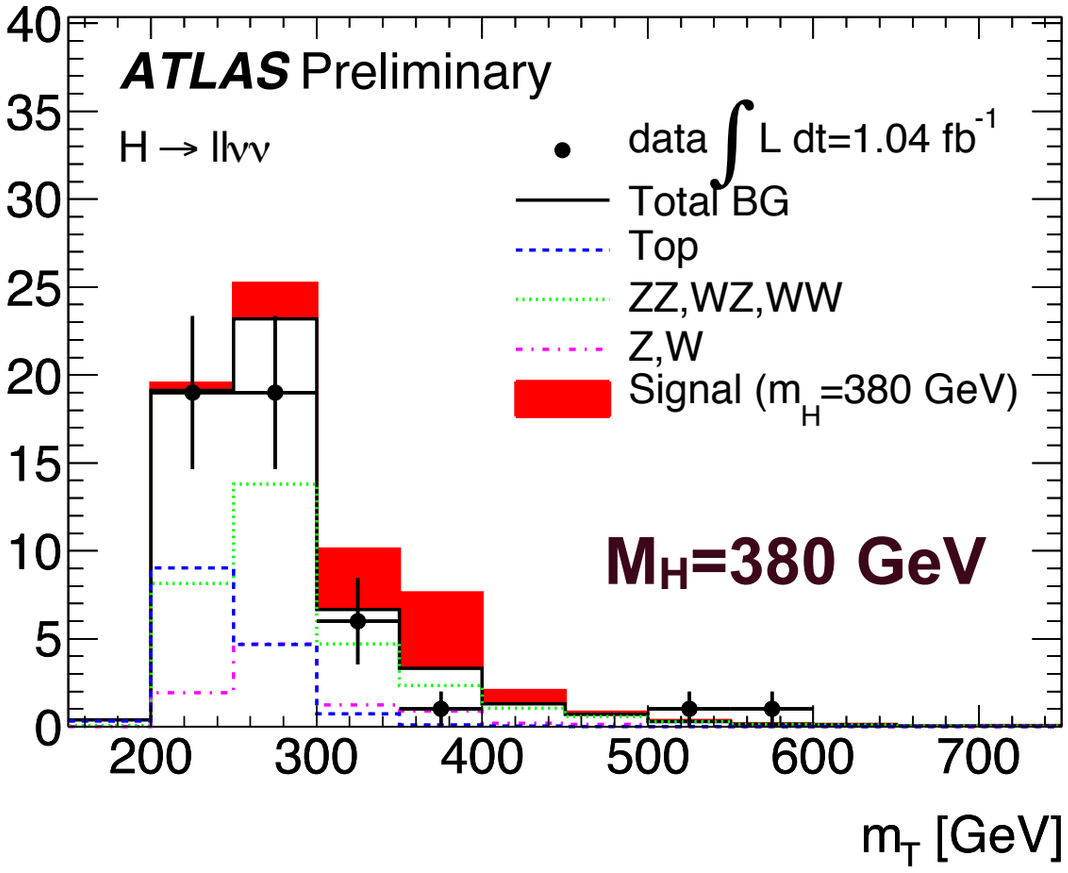
H→ZZ→llνν : Results



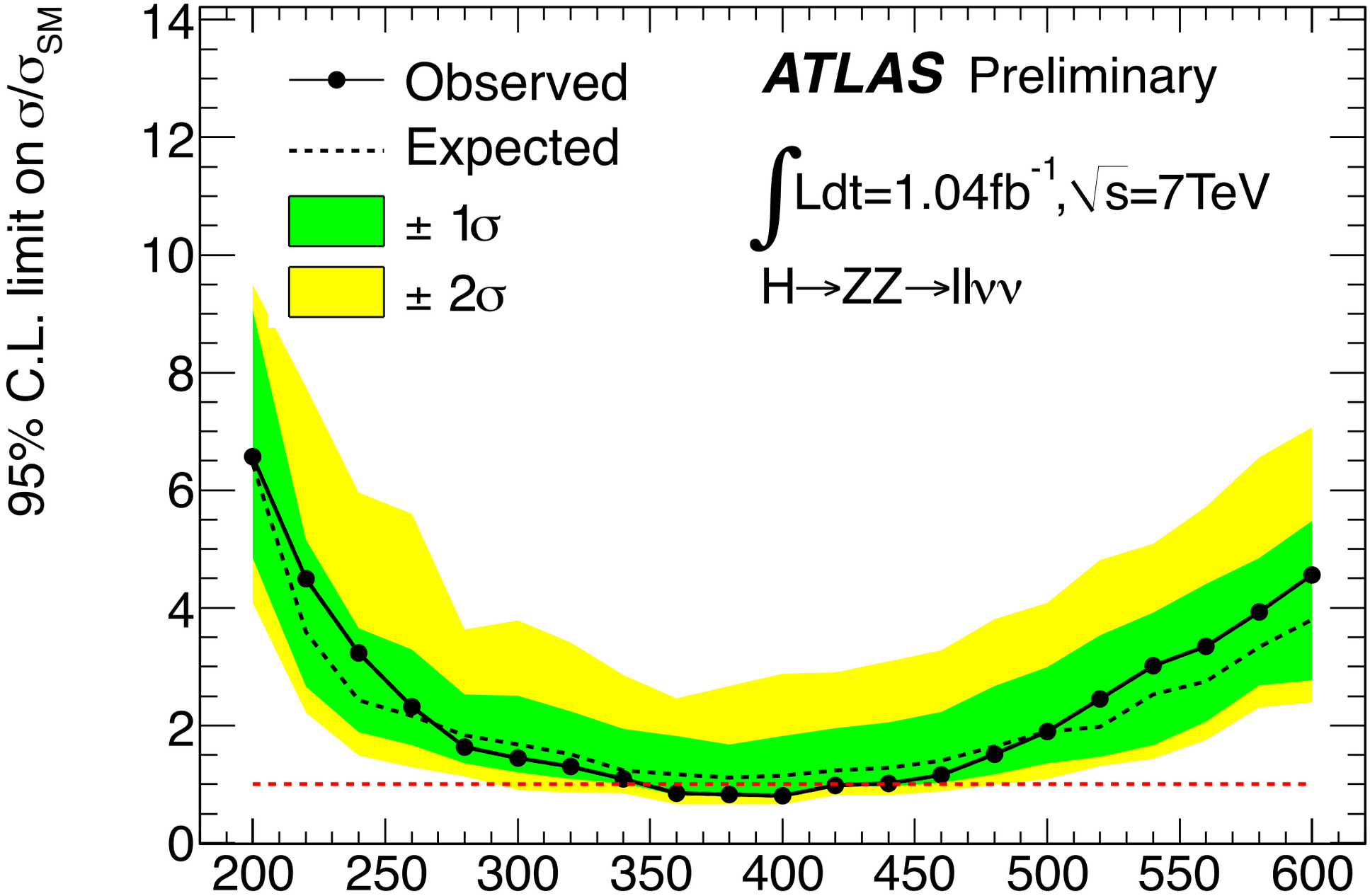
top background dominant for low mT

diboson background dominant for higher mT

No sign of the SM Higgs



H→ZZ→llνν : Exclusion limit



⇒ Sensitive in a wide mass range

⇒ Expected limit between 1.2 - 7 x SM cross section

⇒ Excluding SM Higgs between 360 and 420 GeV

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

⇒ The “gold-plated” channel : clean but small rates

⇒ Main Background: $ZZ \rightarrow 4l$

→ Z+jets/ttbar suppressed with isolation/impact parameter

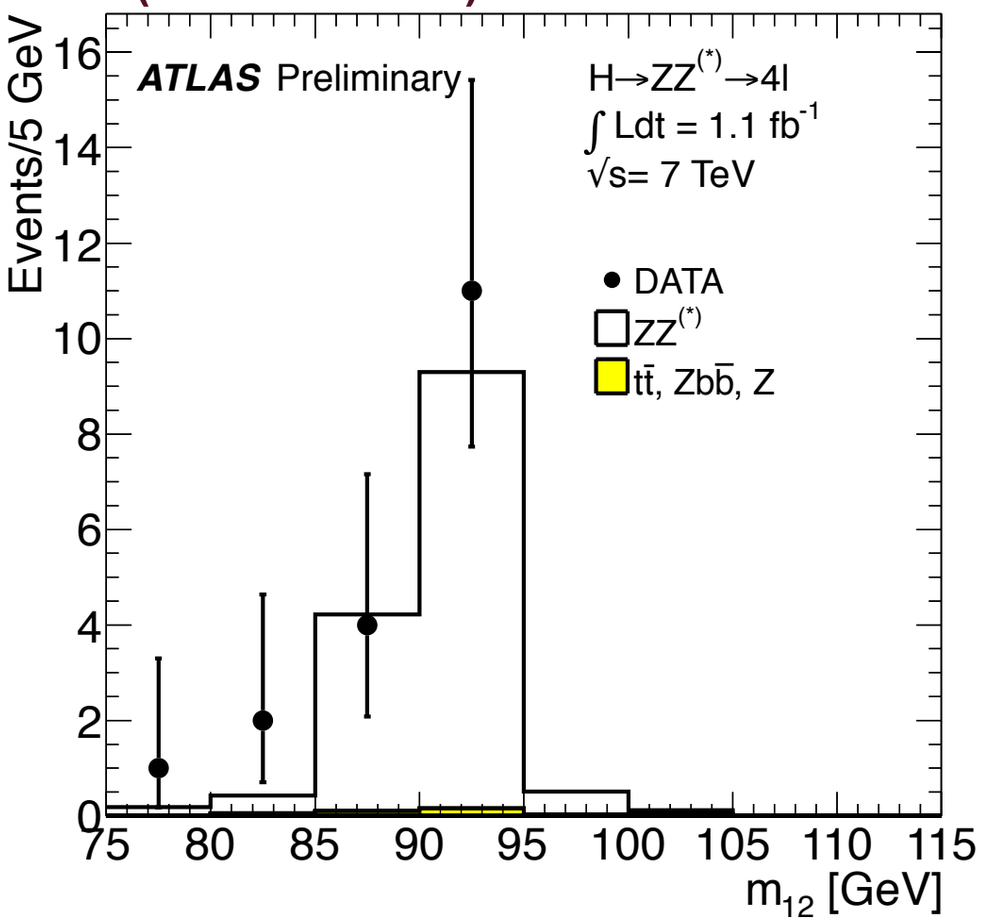
Event Selection

Two same-flavor/opposite-sign isolated lepton (e/μ) pairs,

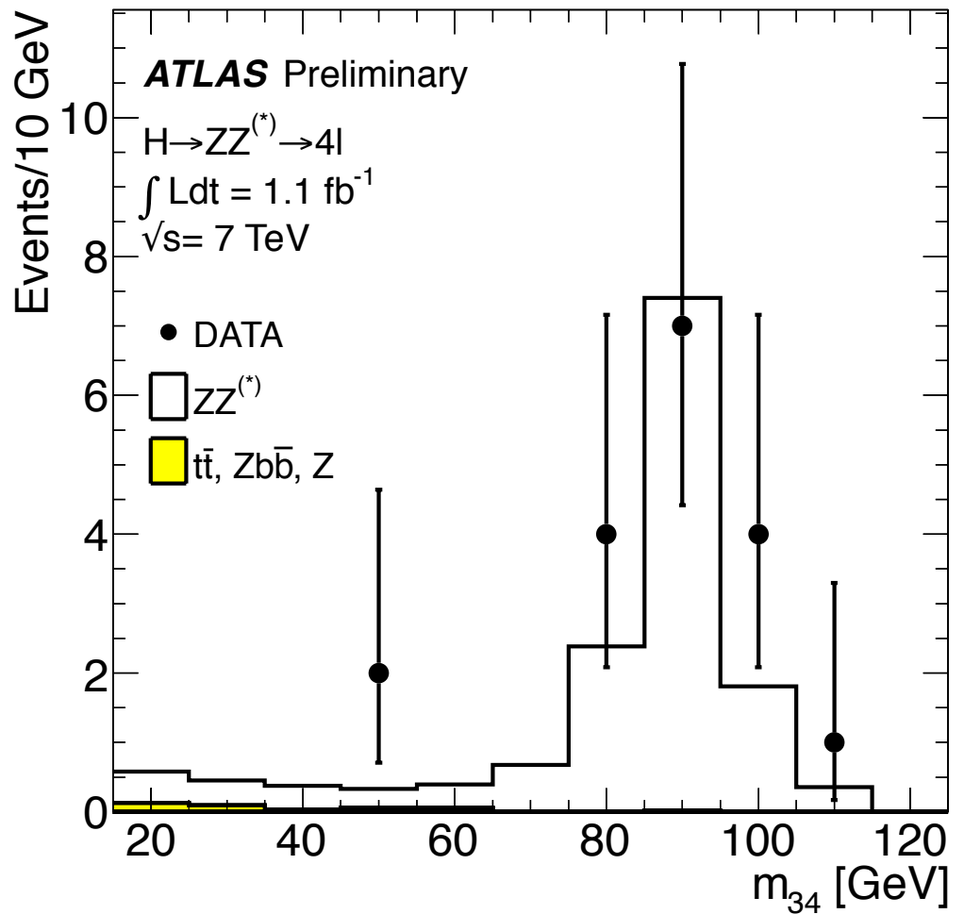
Lepton pair mass cuts : $|m_{12}-m_Z|<15$ GeV, $m_{34}<115$GeV and $m_{34}>m_{Threshold}(m_{4l})$,

For m_{4l} <190 GeV: also impact parameter requirements

Primary lepton pair (closest to m_Z) mass distribution



Second lepton pair mass distribution



H→ZZ(*)→4l : Backgrounds

Normalize ZZ production to MC expectation

⇒ Including both qq/gq→ZZ and gg→ZZ

⇒ Integrated luminosity uncertainty 3.7%

⇒ Theory uncertainty 15%

Normalize top production to MC expectation

⇒ Verified in control region

⇒ Theory normalization uncertainty 10%

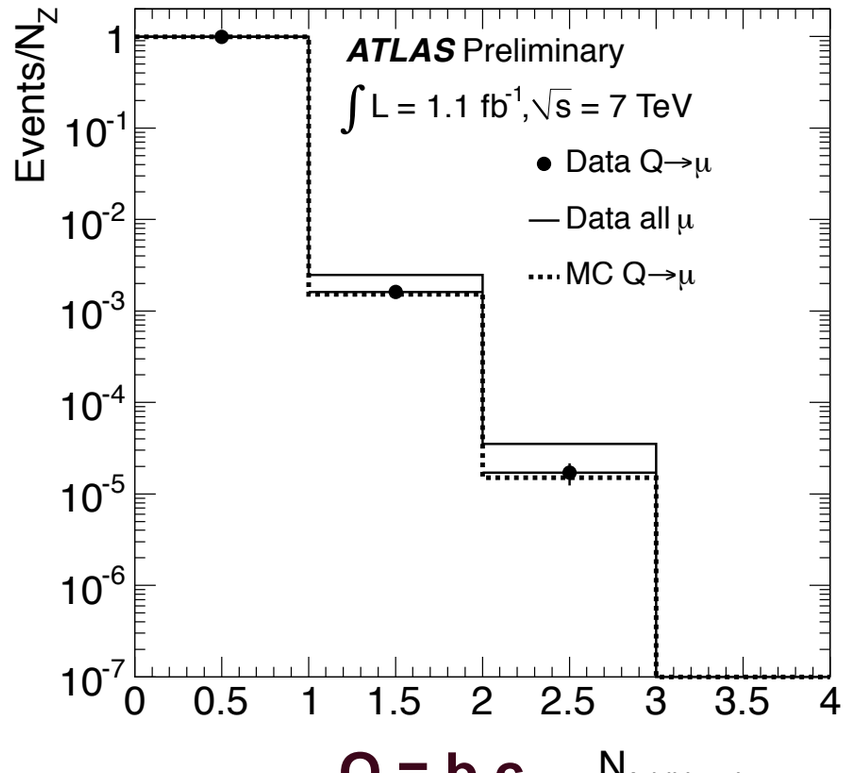
Normalize Z+jets production using control regions

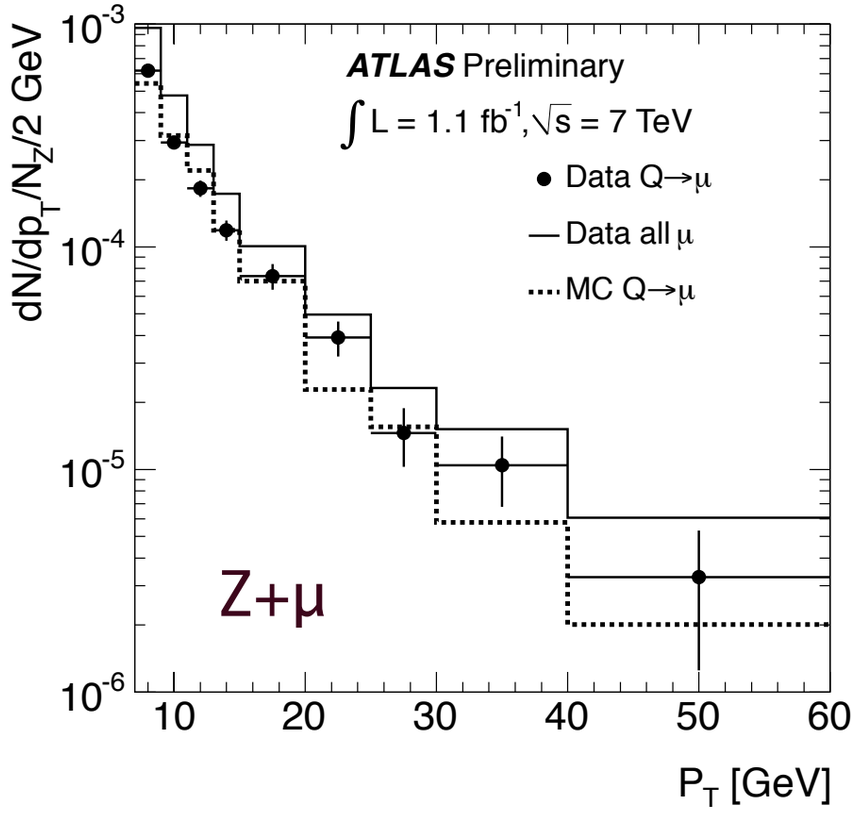
⇒ Z(→ll) + μμ/ee(→no isolation/impact parameter requirements)

→ separate different components (heavy flavour, fakes, electroweak)

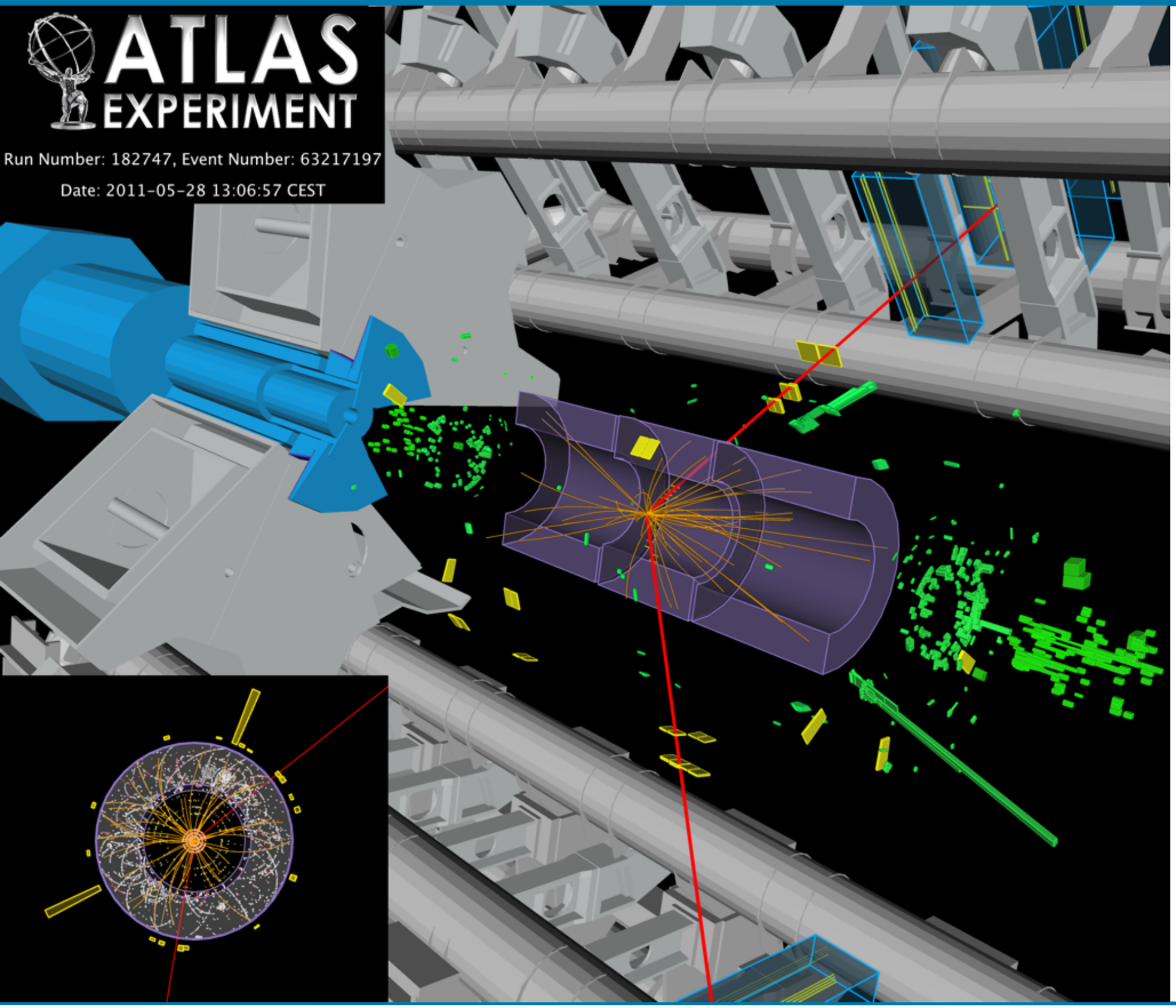
→ extrapolate to signal region

⇒ Uncertainties 20 - 40%



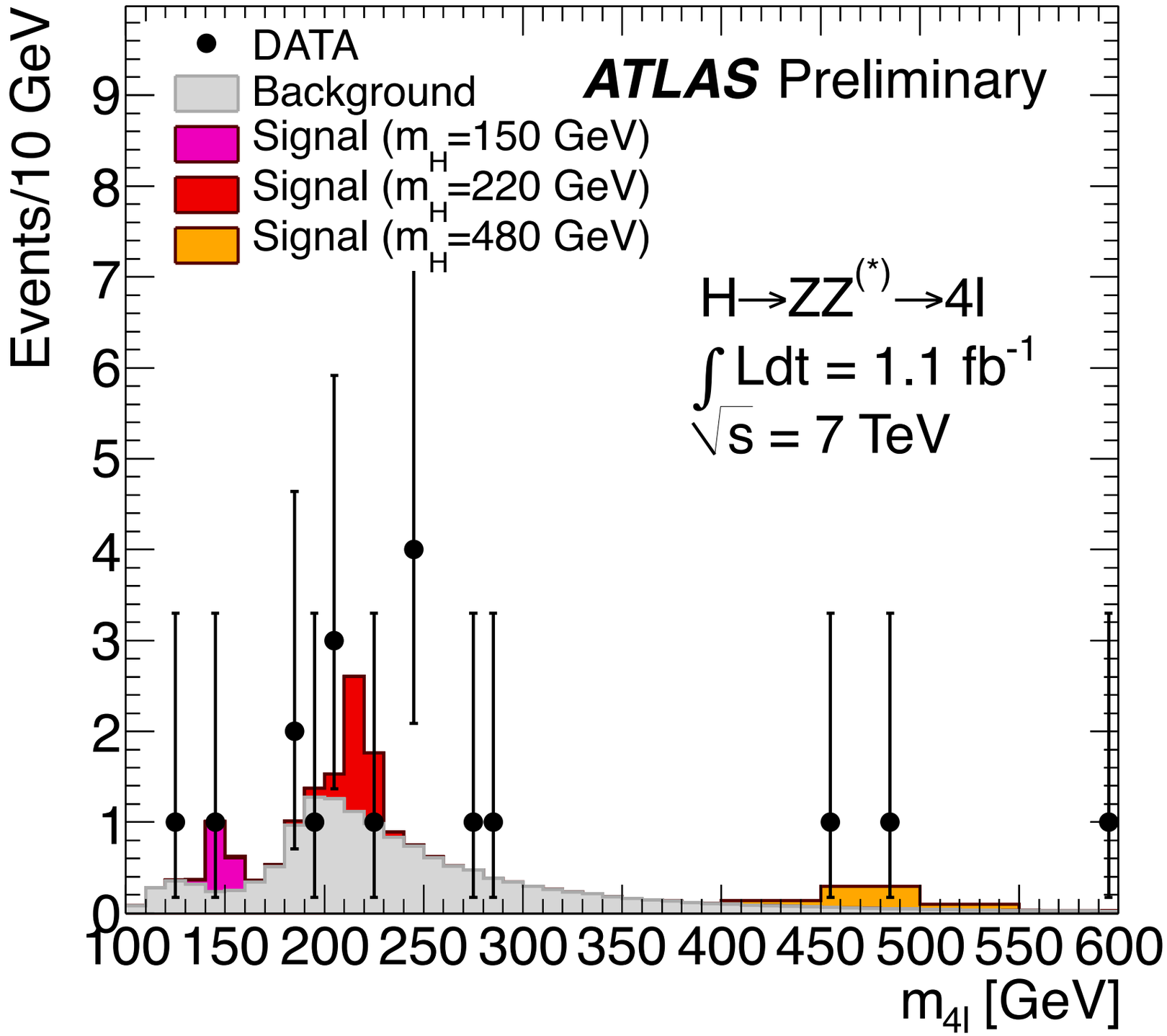


$H \rightarrow ZZ^{(*)} \rightarrow 4l$: 2μ2e event display



2μ2e candidate event
m_{12} = 85.9 GeV
m_{34} = 85.5 GeV
m_{4l}= 209.5 GeV

H→ZZ(*)→4l : Results



⇒ Event yield in four-lepton invariant mass and background expectation summarized

⇒ Shape follows expectation → local fluctuations observed

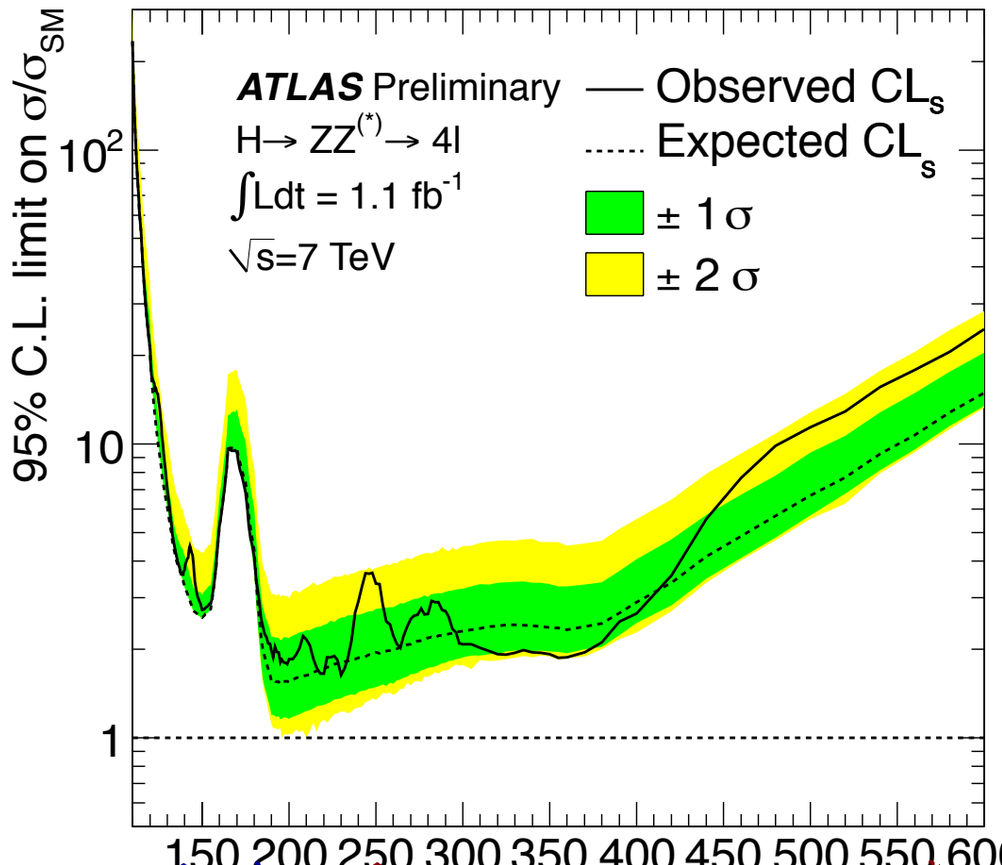
$H \rightarrow ZZ^{(*)} \rightarrow 4l$: Exclusion Limits

⇒ **Approaching SM Higgs cross section!**

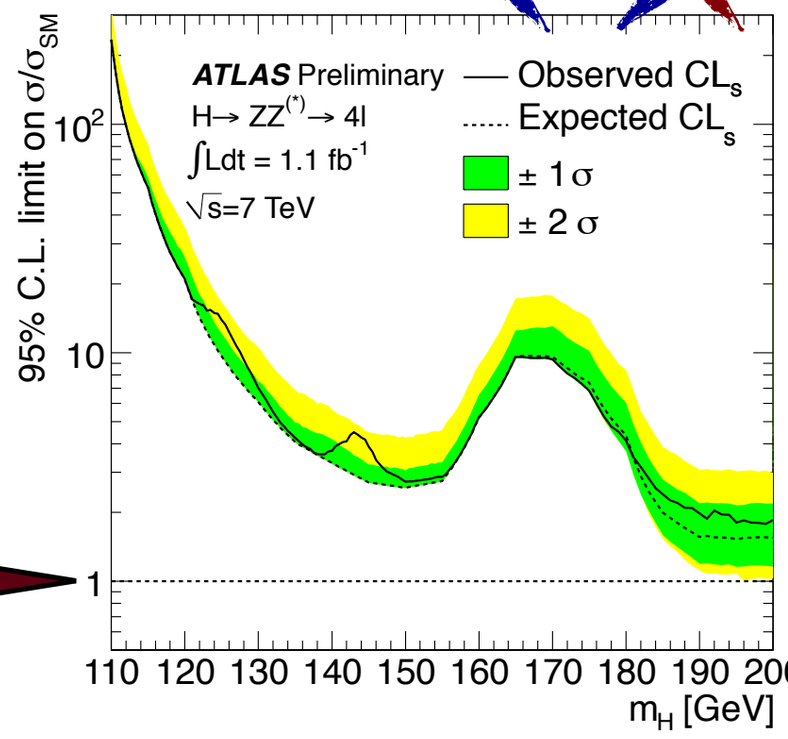
⇒ **Observed limit :**

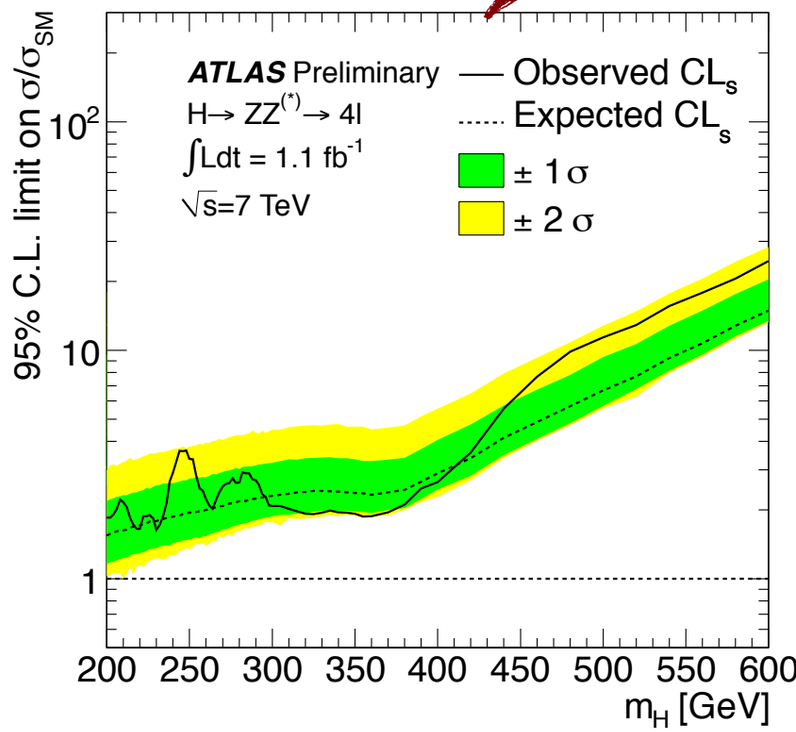
1.8 x SM expectation @ m_H=200GeV

⇒ **Localized upward fluctuations observed in a few places (mostly single events)**

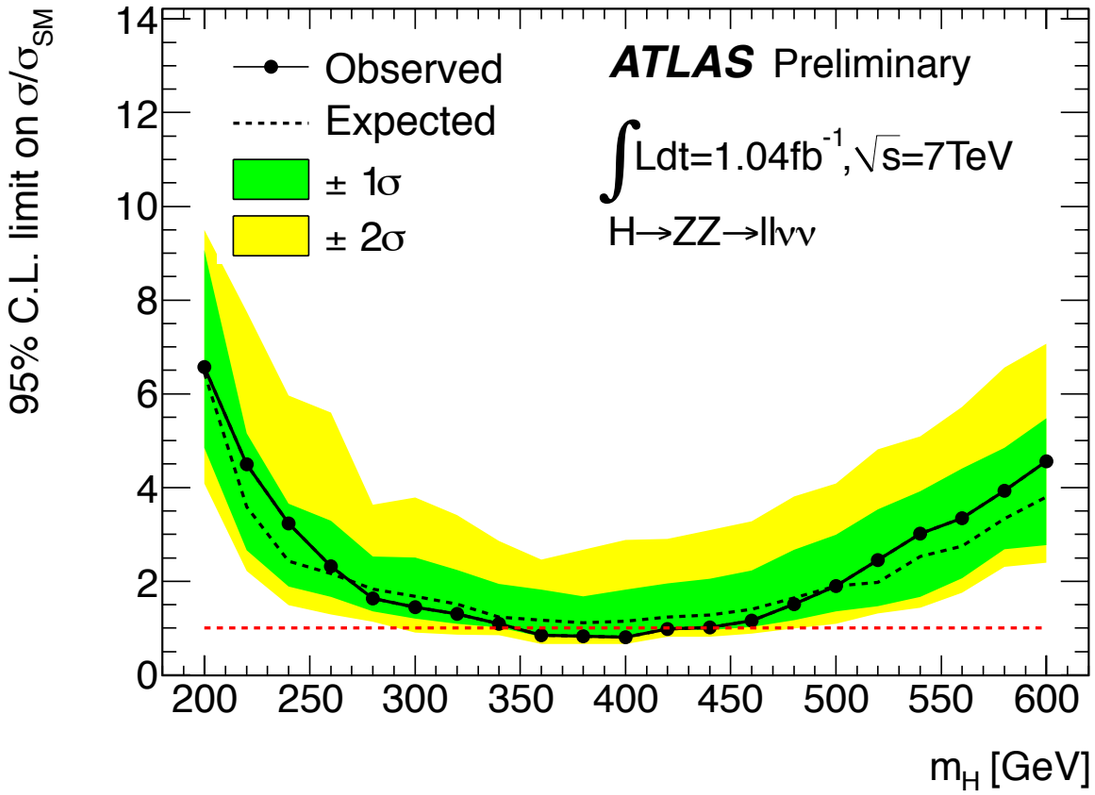


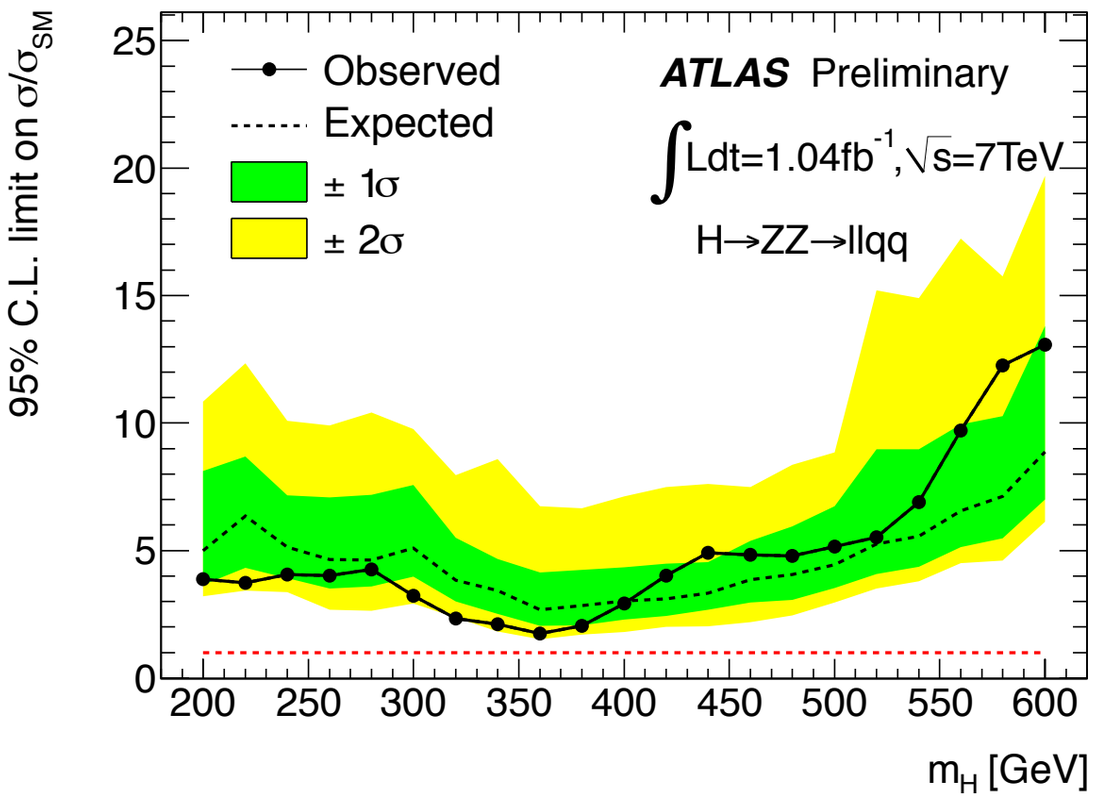
SM Expectation ➡

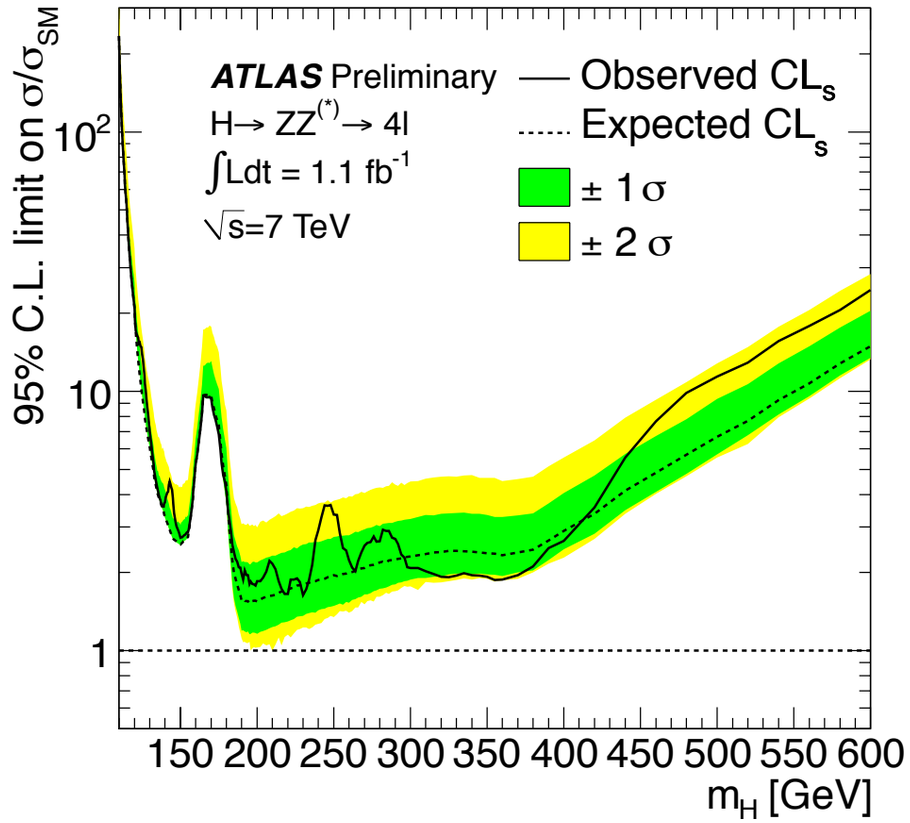




Summary







With ~1 fb^{-1} H→ZZ searches well under way in ATLAS!
Dominant for $m_H \geq 200$ GeV,
but also contributing (H→4l) to the low mass region!

⇒ <u>Sensitive to SM Higgs boson cross sections!</u>

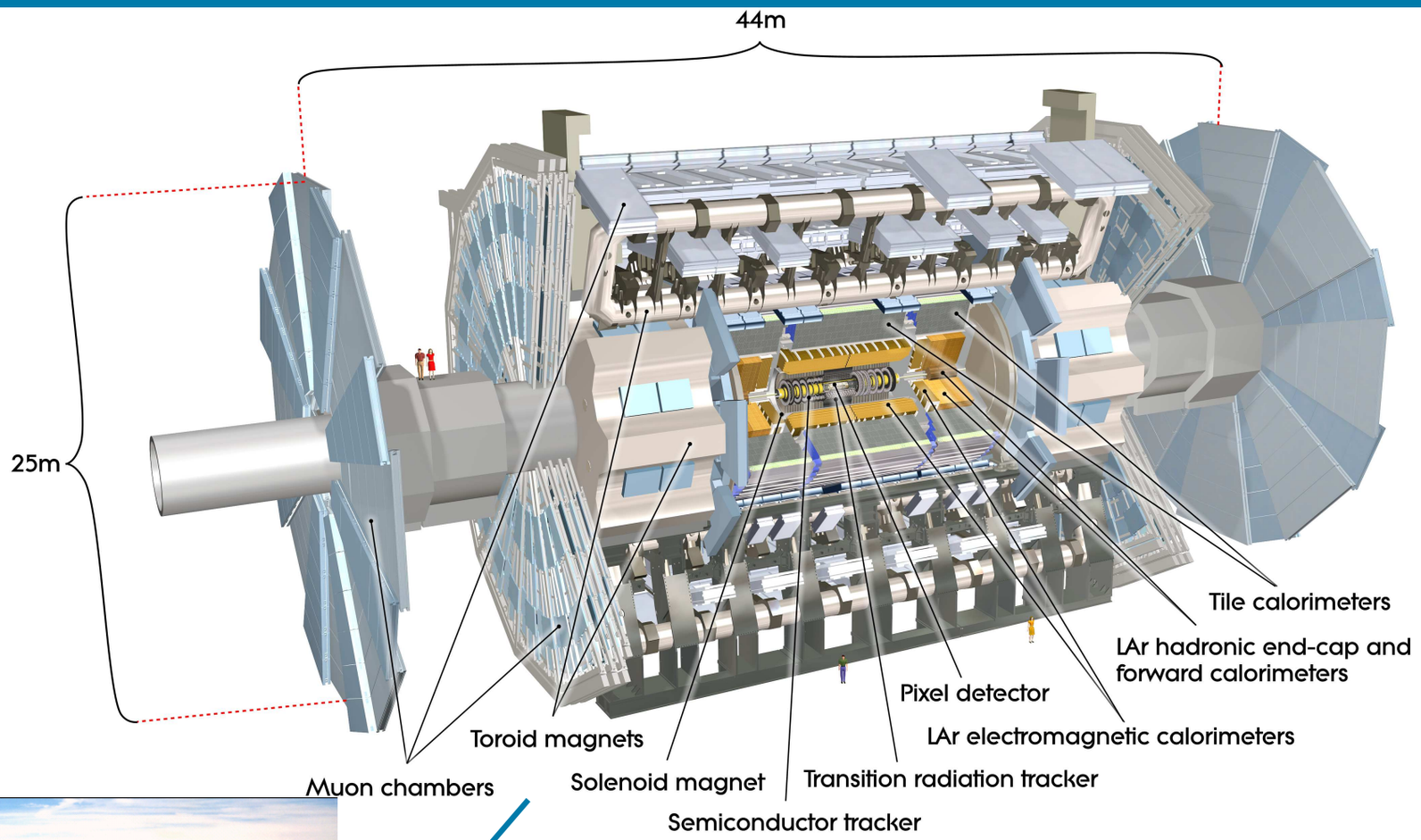
The H→ZZ→llνν already excludes at 95% CL $360 < m_H < 420$ GeV

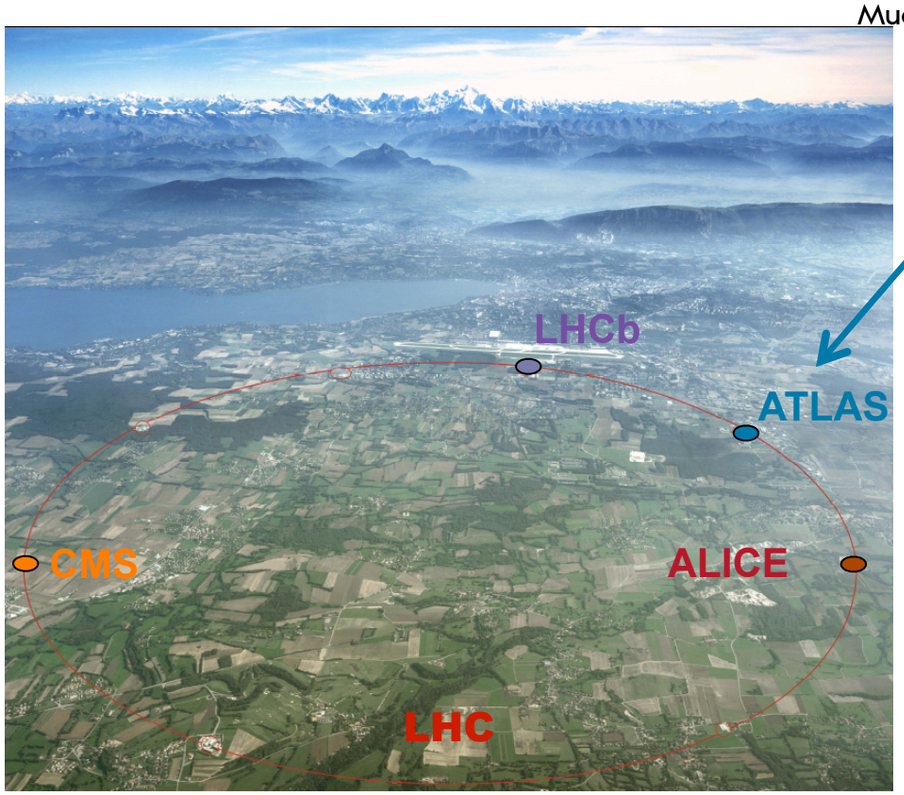
If SM Higgs not Nature's choice, we'll know very soon!

Discovery more difficult ⇒ but already interesting times!

Additional Slides

ATLAS @ LHC





⇒ General purpose detector designed for the harsh LHC environment

	ATLAS
Magnets	2T solenoid, 3 air-core toroids
Tracking	silicon + transition radiation tracker
EM Calorimetry	sampling LAr technology
Hadron Calorimetry	plastic scintillator (barrel) LAr technology (endcap)
Muon	independent system with trigger capabilities

H→ZZ→llqq : Results

ATLAS Preliminary

The expected number of signal and background candidates for the Higgs boson search for 1.04 fb^{-1} in the $H \to ZZ \to \ell\ell qq$ channel, along with the observed numbers of candidates in data. Numbers with uncertainties are ± (stat.) ± (syst.), respectively, and the statistical component assumes Gaussian uncertainties.

	Untagged		Tagged	
	Low-m_H	High-m_H	Low-m_H	High-m_H
Z+jets	10352. ± 61. ± 155.	423. ± 12. ± 30.	72. ± 1. ± 15.	4.9 ± 0.2 ± 1.0
W+jets	10. ± 2. ± 5.	0.2 ± 0.2 ± 0.1	0.0 ± 0.0 ± 0.0	0.0 ± 0.0 ± 0.0
Top	40. ± 1. ± 6.	3.0 ± 0.3 ± 0.6	13. ± 1. ± 3.	1.1 ± 0.2 ± 0.3
Multijet	64. ± 3. ± 64.	2.0 ± 0.5 ± 2.0	0.3 ± 0.2 ± 0.3	0.0 ± 0.0 ± 0.0
ZZ	107. ± 4. ± 15.	8.5 ± 1.1 ± 1.8	6.9 ± 1.0 ± 2.0	0.79 ± 0.23 ± 0.30
WZ	143. ± 3. ± 29.	17. ± 1. ± 3.	0.5 ± 0.2 ± 0.3	0.03 ± 0.02 ± 0.01
Total background	10718. ± 62. ± 173.	453. ± 13. ± 31.	92. ± 1. ± 15.	6.9 ± 0.4 ± 1.2
Data	10495	419	91	6
Signal				
$m_H = 200$ GeV	33. ± 1. ± 6.		2.2 ± 0.2 ± 0.6	
$m_H = 300$ GeV		7.0 ± 0.3 ± 1.5		0.58 ± 0.08 ± 0.19
$m_H = 400$ GeV		9.8 ± 0.3 ± 1.8		1.1 ± 0.1 ± 0.3
$m_H = 500$ GeV		5.5 ± 0.1 ± 1.0		0.63 ± 0.04 ± 0.19
$m_H = 600$ GeV		2.5 ± 0.1 ± 0.5		0.28 ± 0.02 ± 0.08

H→ZZ→llνν : Results

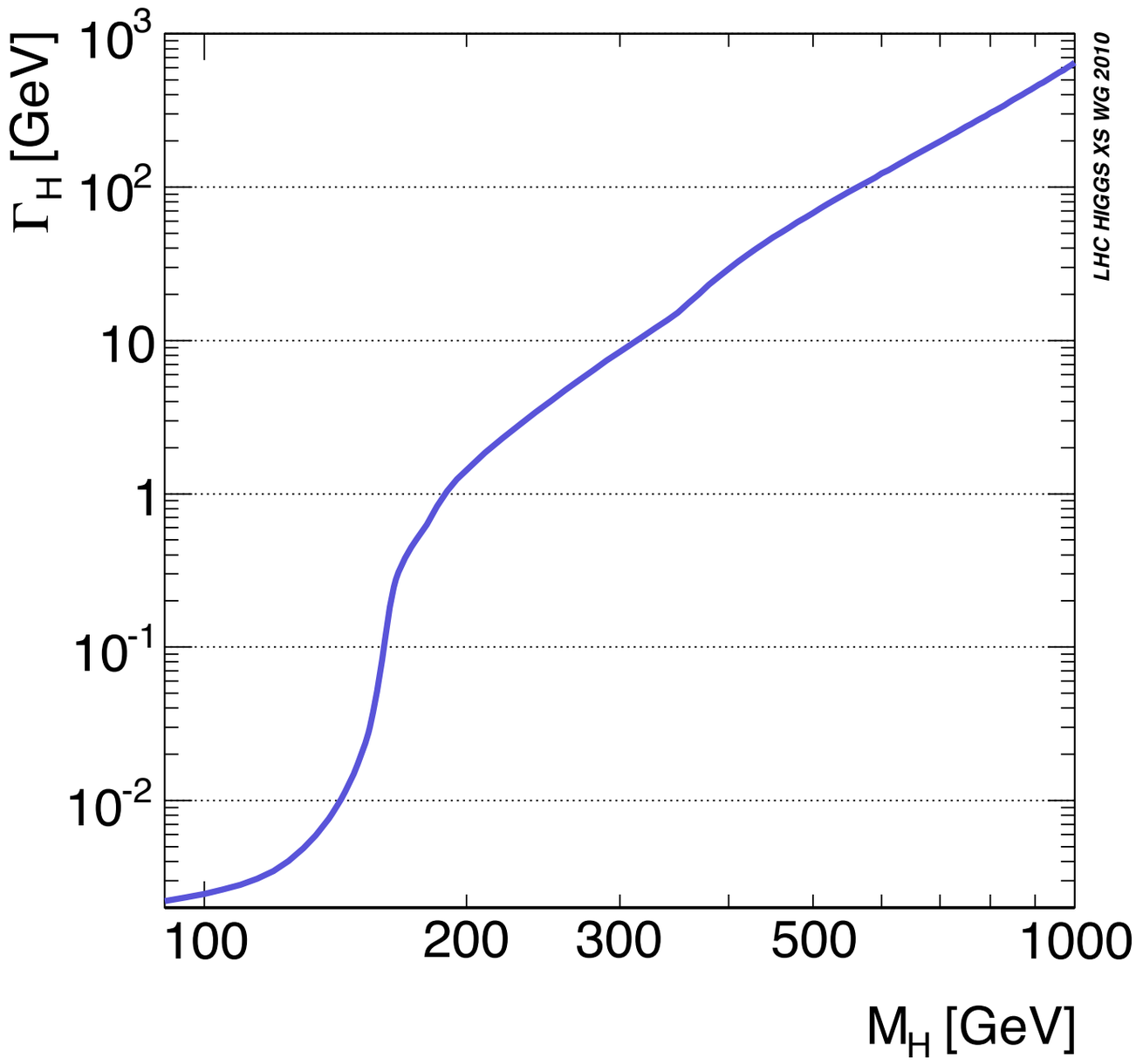
ATLAS Preliminary

Numbers of expected background events, observed events in data and expected signal events for a few representative m_H values after the full $H \to ZZ \to \ell^+\ell^-\nu\bar{\nu}$ candidate selection. The uncertainties shown on the estimated background and signal events are statistical and systematic respectively.

Source	low m_H selec.	high m_H selec.
Incl. Z	$19.1 \pm 2.6 \pm 0.9$	$6.0 \pm 1.4 \pm 1.8$
Incl. W	$8.5 \pm 2.3 \pm 8.5$	$3.1 \pm 1.0 \pm 3.1$
top	$29.9 \pm 1.3 \pm 6.0$	$14.9 \pm 0.8 \pm 3.1$
Multijet	$0.4 \pm 0.4 \pm 0.2$	$0.0 \pm 0.0 \pm 0.0$
ZZ	$17.6 \pm 0.4 \pm 2.1$	$14.7 \pm 0.4 \pm 1.7$
WZ	$16.7 \pm 0.6 \pm 2.0$	$12.1 \pm 0.5 \pm 1.4$
WW	$12.4 \pm 0.4 \pm 1.5$	$4.6 \pm 0.3 \pm 0.5$
Total	$104.6 \pm 3.8 \pm 16.0$	$55.3 \pm 2.0 \pm 7.8$
Data	85	47

m_H (GeV)	Expected number of Higgs bosons selected
200	$5.0 \pm 0.1 \pm 0.9$
300	$10.2 \pm 0.2 \pm 1.8$
400	$10.0 \pm 0.2 \pm 1.7$
500	$4.5 \pm 0.1 \pm 0.8$
600	$1.8 \pm 0.0 \pm 0.3$

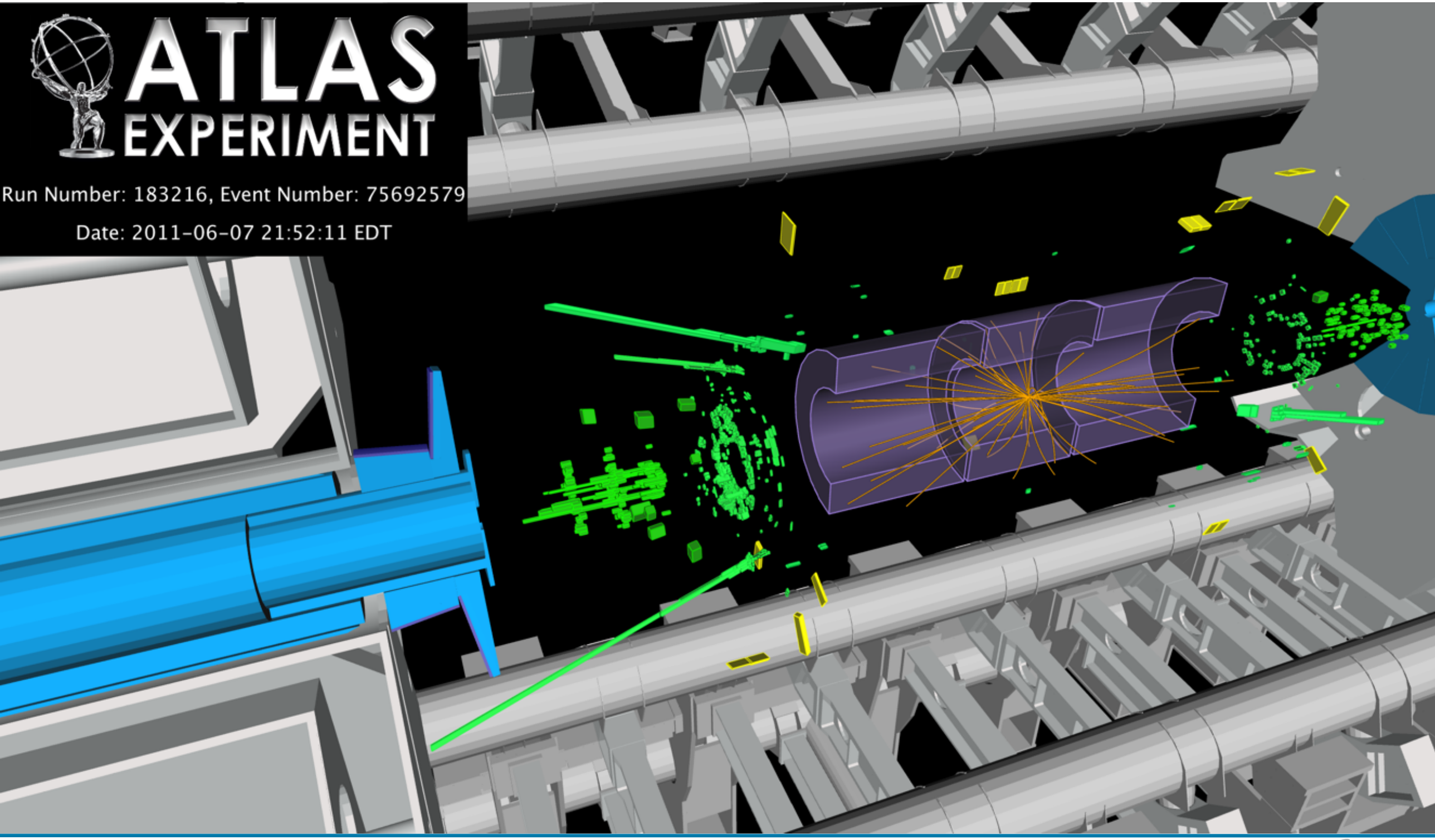
Higgs Boson Width



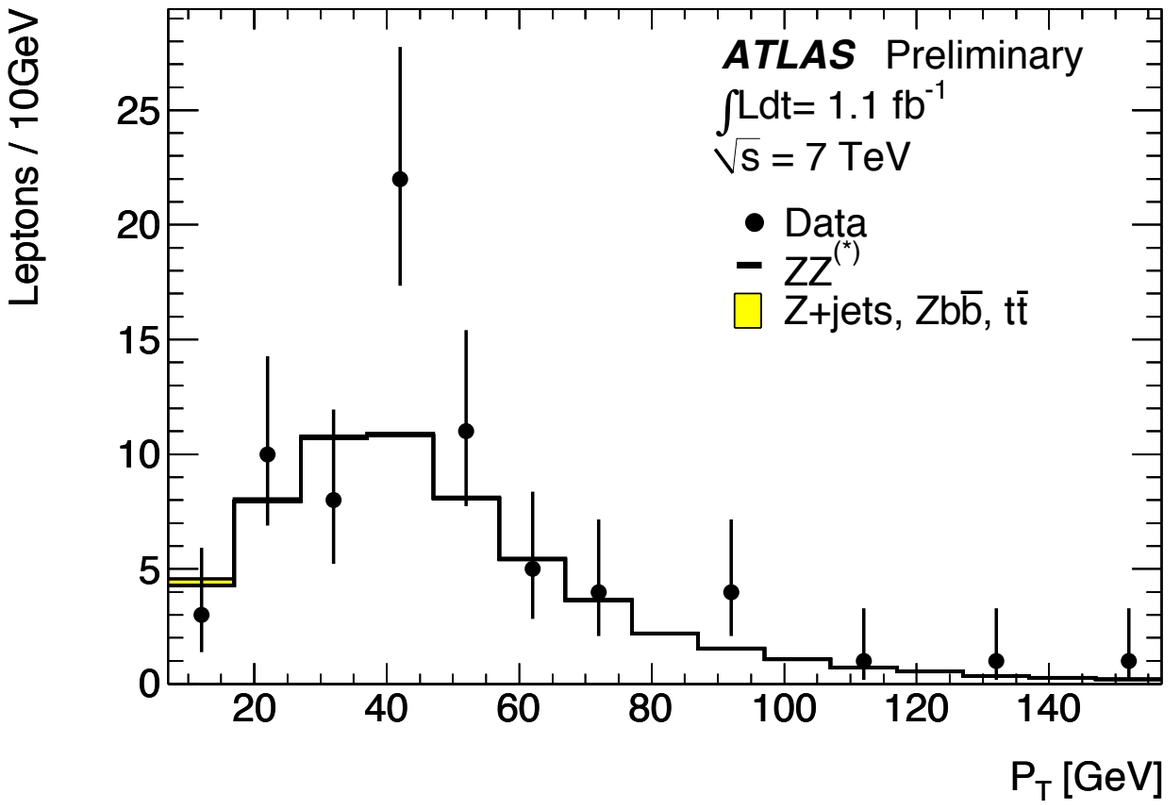
The limits presented in this search assume cross sections based on on-shell Higgs boson production and decay and use Monte Carlo generators with an ad-hoc Breit-Wigner Higgs line shape. Recently potentially important effects related to off-shell Higgs boson production and interference effects between the Higgs boson signal and backgrounds have been discussed [arXiv:1107.0683]. The inclusion of such effect may affect limits at very high Higgs masses ($m_H > 400$ GeV).

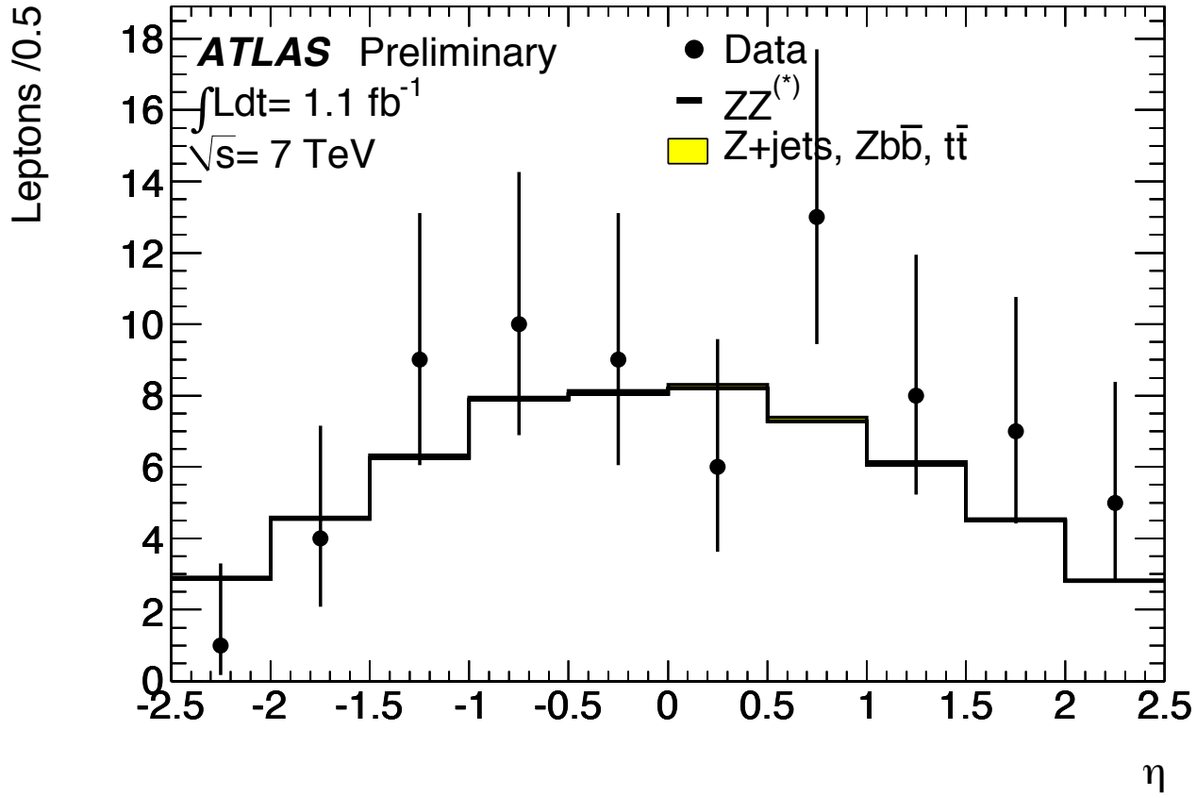
$H \rightarrow ZZ^{(*)} \rightarrow 4l$: 4e event display

4e candidate event, m_{12} = 85.8 GeV, m_{34} = 111.5 GeV, m_{4l}= 271.6 GeV

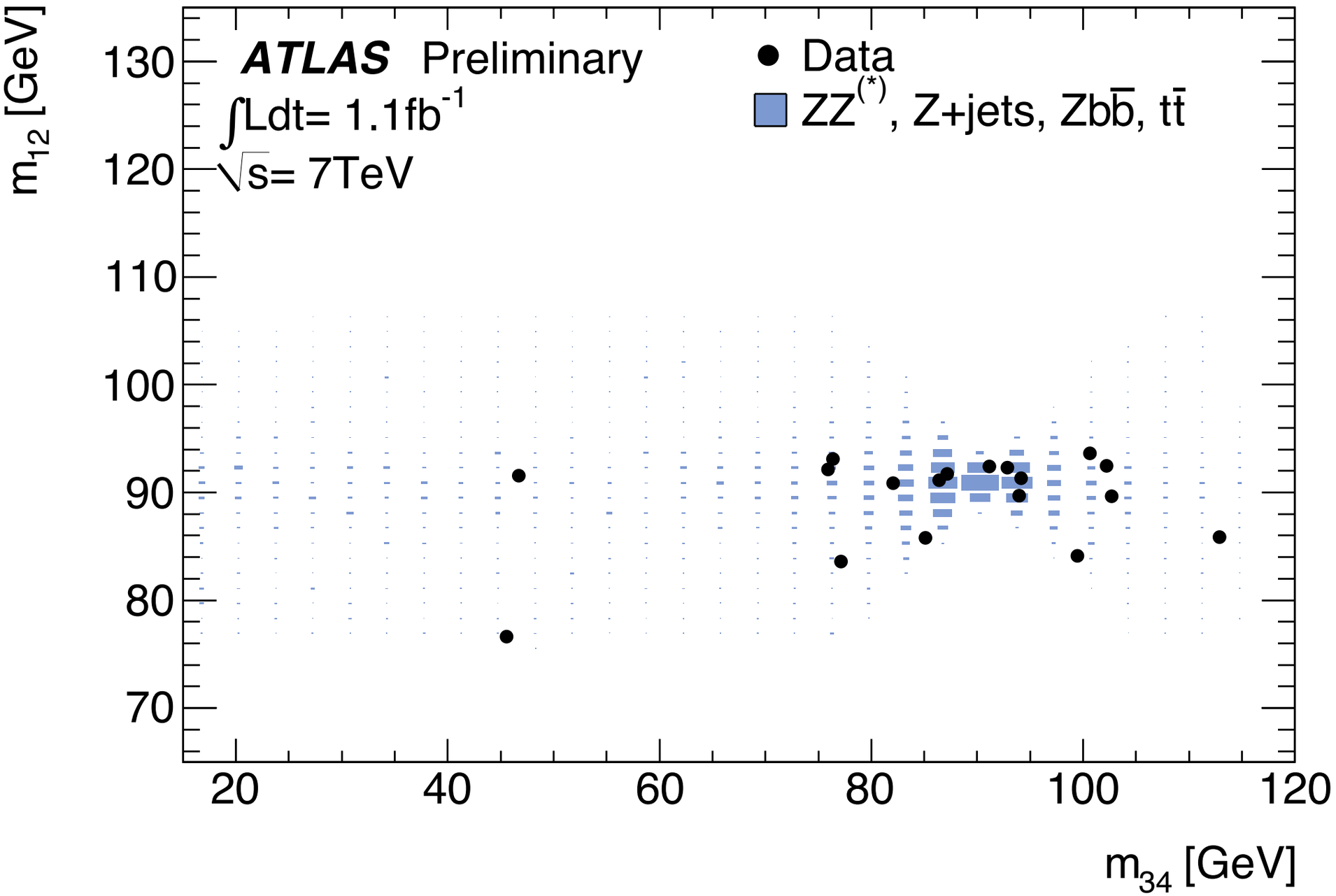


H→ZZ(*)→4l : Kinematic Distributions



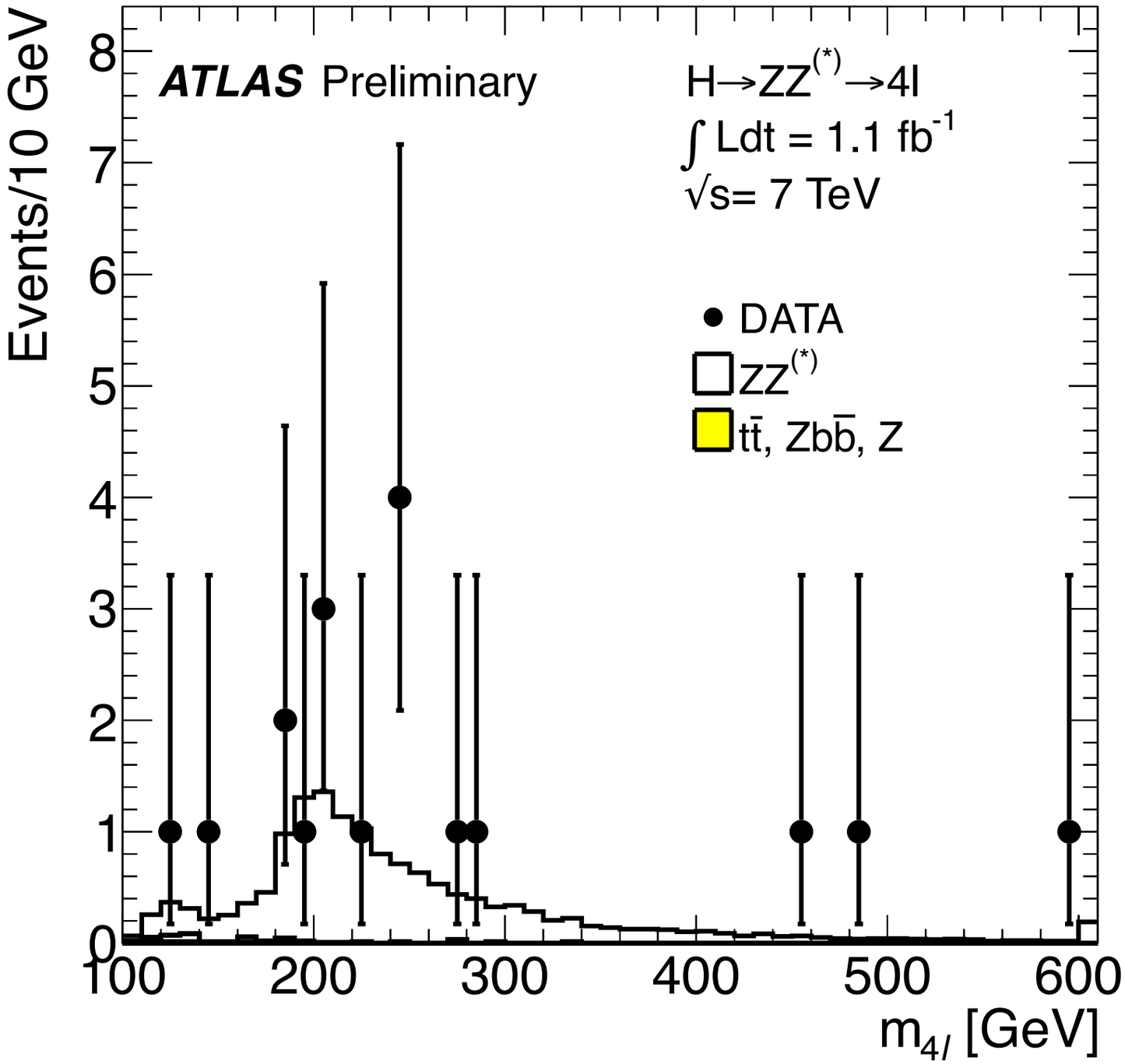


H→ZZ(*)→4l : Results



⇒ m12 - m34 correlation

H→ZZ(*)→4l : Results



⇒ Event yield in four-lepton invariant mass and background expectation summarized

H→ZZ(*)→4l : Results

ATLAS Preliminary

The expected number of signal and background events, with their systematic uncertainty, separated into "Low mass" ($m_{4\ell} < 180$ GeV) and "High mass" ($m_{4\ell} \geq 180$ GeV) regions. The observed number of events is also presented.

	$\mu\mu\mu\mu$		$ee\mu\mu$		$eeee$	
	Low mass	High mass	Low mass	High mass	Low mass	High mass
Data	1	9	1	5	0	2
$ZZ^{(*)}$	0.84±0.13	4.5±0.7	0.80±0.12	5.6±0.8	0.33±0.07	2.1±0.3
Z, $Zb\bar{b}$, and $t\bar{t}$	0.03±0.01	0.01±0.01	0.15±0.06	0.08±0.03	0.12±0.05	0.07±0.03
Total Background	0.87±0.13	4.5±0.7	0.95±0.13	5.7±0.8	0.45±0.09	2.2±0.3
$m_H = 130$ GeV	0.22 ± 0.04		0.24 ± 0.04		0.09 ± 0.02	
$m_H = 150$ GeV	0.52 ± 0.08		0.57 ± 0.09		0.22 ± 0.04	
$m_H = 200$ GeV		1.21 ± 0.18		1.52 ± 0.22		0.58 ± 0.08
$m_H = 240$ GeV		0.93 ± 0.13		1.26 ± 0.18		0.52 ± 0.07
$m_H = 300$ GeV		0.62 ± 0.09		0.91 ± 0.13		0.37 ± 0.05
$m_H = 400$ GeV		0.46 ± 0.07		0.67 ± 0.10		0.29 ± 0.04
$m_H = 600$ GeV		0.08 ± 0.01		0.12 ± 0.02		0.05 ± 0.01

$H \rightarrow ZZ^{(*)} \rightarrow 4l$: 4μ event display

4μ candidate event, m_{12} = 84 GeV, m_{34} = 100 GeV, m_{4l}= 597 GeV