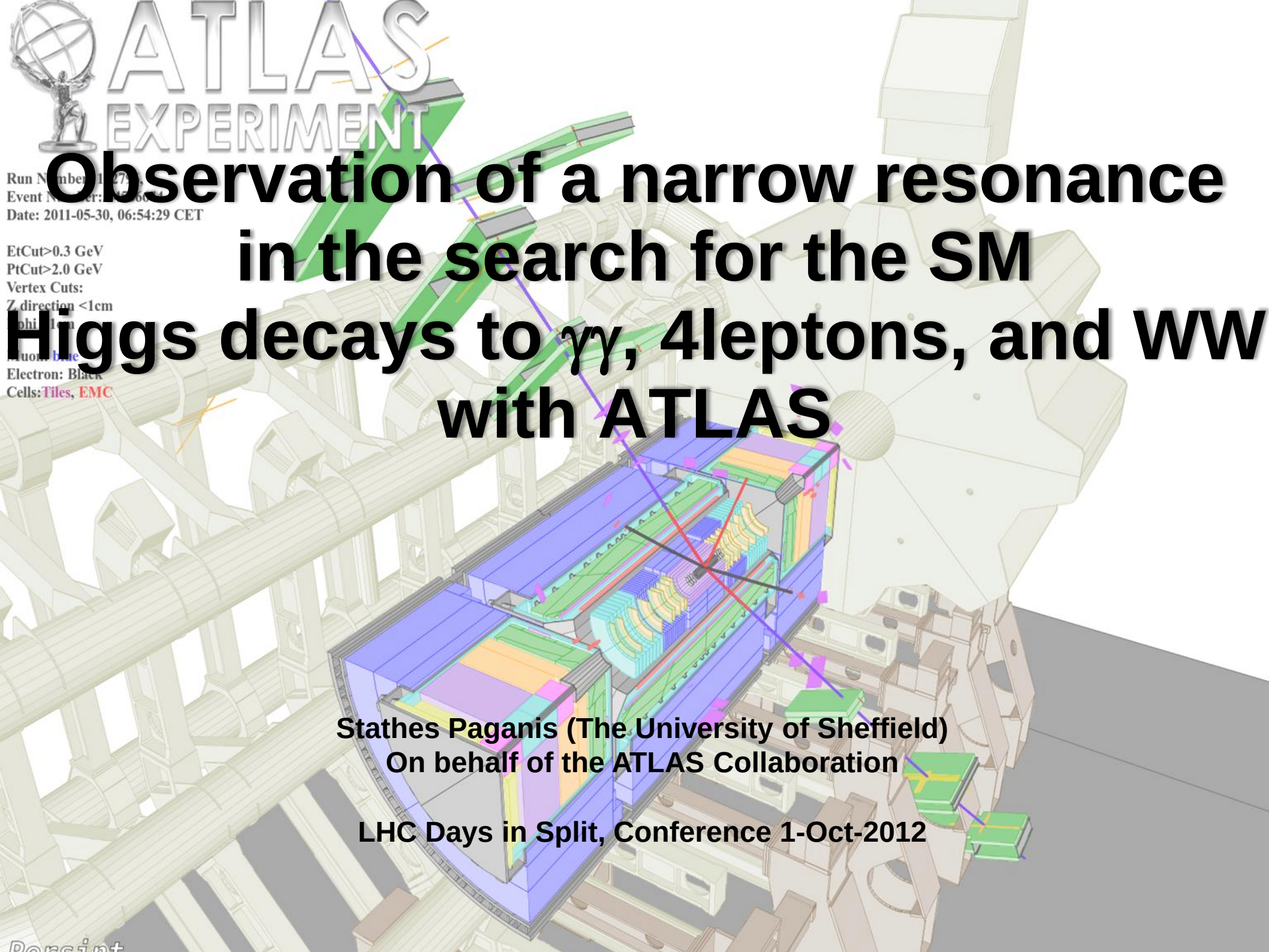


Observation of a narrow resonance in the search for the SM Higgs decays to $\gamma\gamma$, 4leptons, and WW with ATLAS

Stathes Paganis (The University of Sheffield)
On behalf of the ATLAS Collaboration

LHC Days in Split, Conference 1-Oct-2012

Introduction/Outline

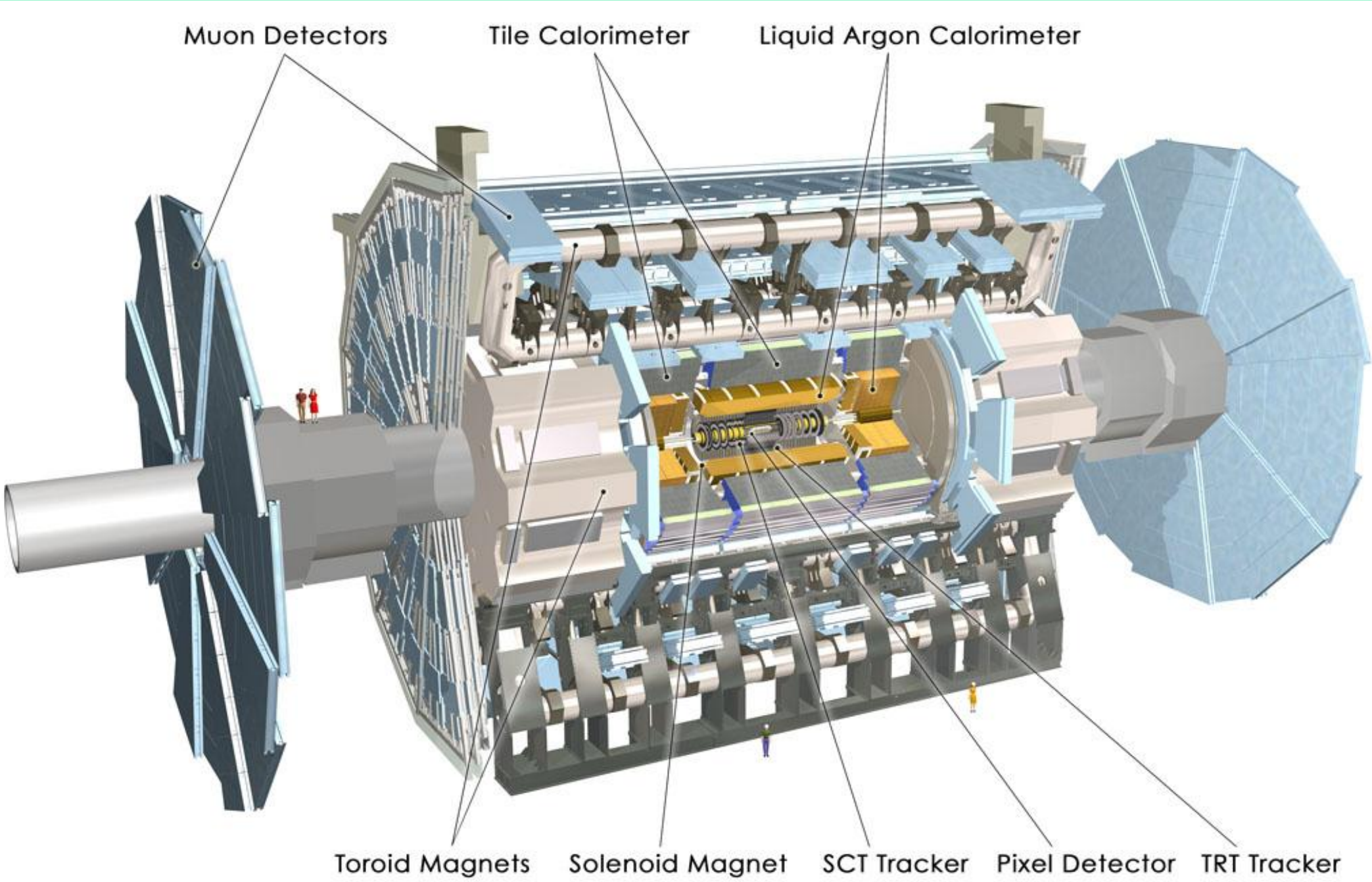
On the 4th of July 2012, ATLAS and CMS experiments announced the observation of a new narrow resonance at a mass of ~125-126 GeV. Studies of the properties of this particle are now in full force with the aim to establish if the particle is the long sought Higgs boson of the Higgs mechanism responsible for the EW gauge symmetry breaking.

Here we present the latest results from ATLAS with a focus in $\gamma\gamma$, ZZ→4l and WW→lνl'ν final states, for an integrated luminosity of ~10.7 fb^{-1}.

- H→$\gamma\gamma$
- H→ZZ→4 leptons (e,μ)
- H→WW→lνl'ν
- Coupling Measurements → covered later by Sven Kreiss

Phys. Lett. B 716 (2012) 1-29

The ATLAS Detector



$$H \rightarrow \gamma\gamma$$

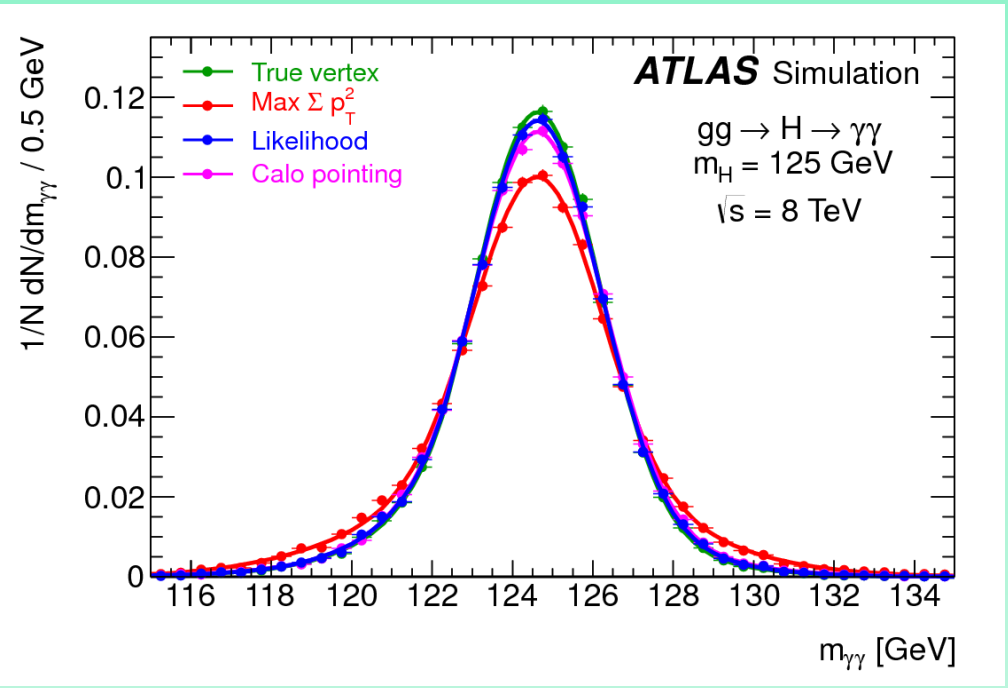
$\gamma\gamma$ event selection summary

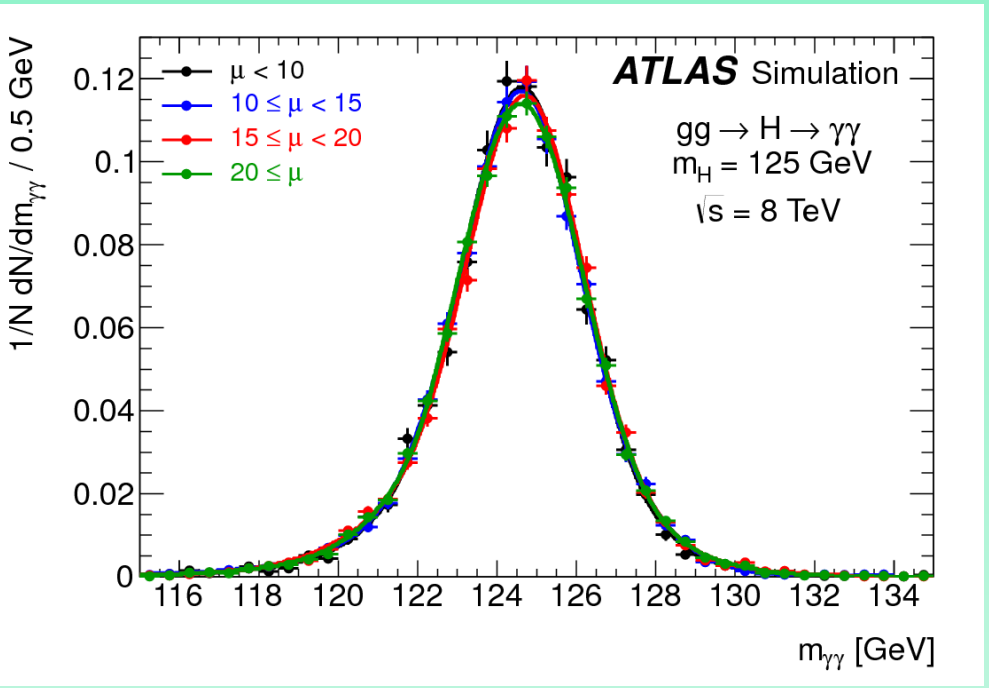
Uncertainty	Description
Fiducial cuts	$E_{T,\gamma 1} > 40$ GeV, $E_{T,\gamma 2} > 30$ GeV, $\|\eta\|<2.37$, excluding $1.37<\|\eta\|<1.52$
Photon ID	EM shower-shape based. NeuralNet-based for 2011
Photon Isolation	Summed E_T in a calo cone $\Delta R<0.4$ around photon excluding the photon cluster, not to exceed 4GeV.
Categories	10 categories based on photon η, $P_{T,t}$, converted, unconverted, dijet.

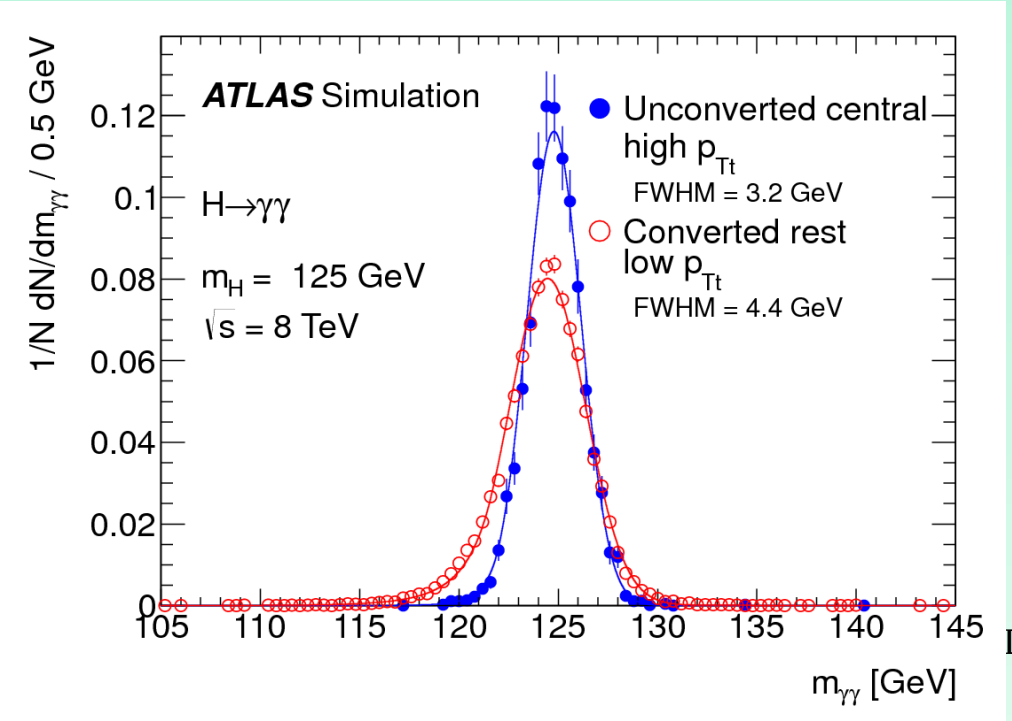
Photons: converted, unconverted.
Photon energy: from LAr EM cluster energy
Photon position: η from calorimeter and the primary vertex, ϕ from calorimeter
Dijet category improves sensitivity to VBF.

Search performed in the 110-150 GeV $\gamma\gamma$ mass range.

$\gamma\gamma$ signal mass resolution







Higgs Mass Resolution:

for different methods of longitudinal vertex position reconstruction. Calorimetric pointing and likelihood lead to improved resolution.

Not affected by increased levels of pileup.

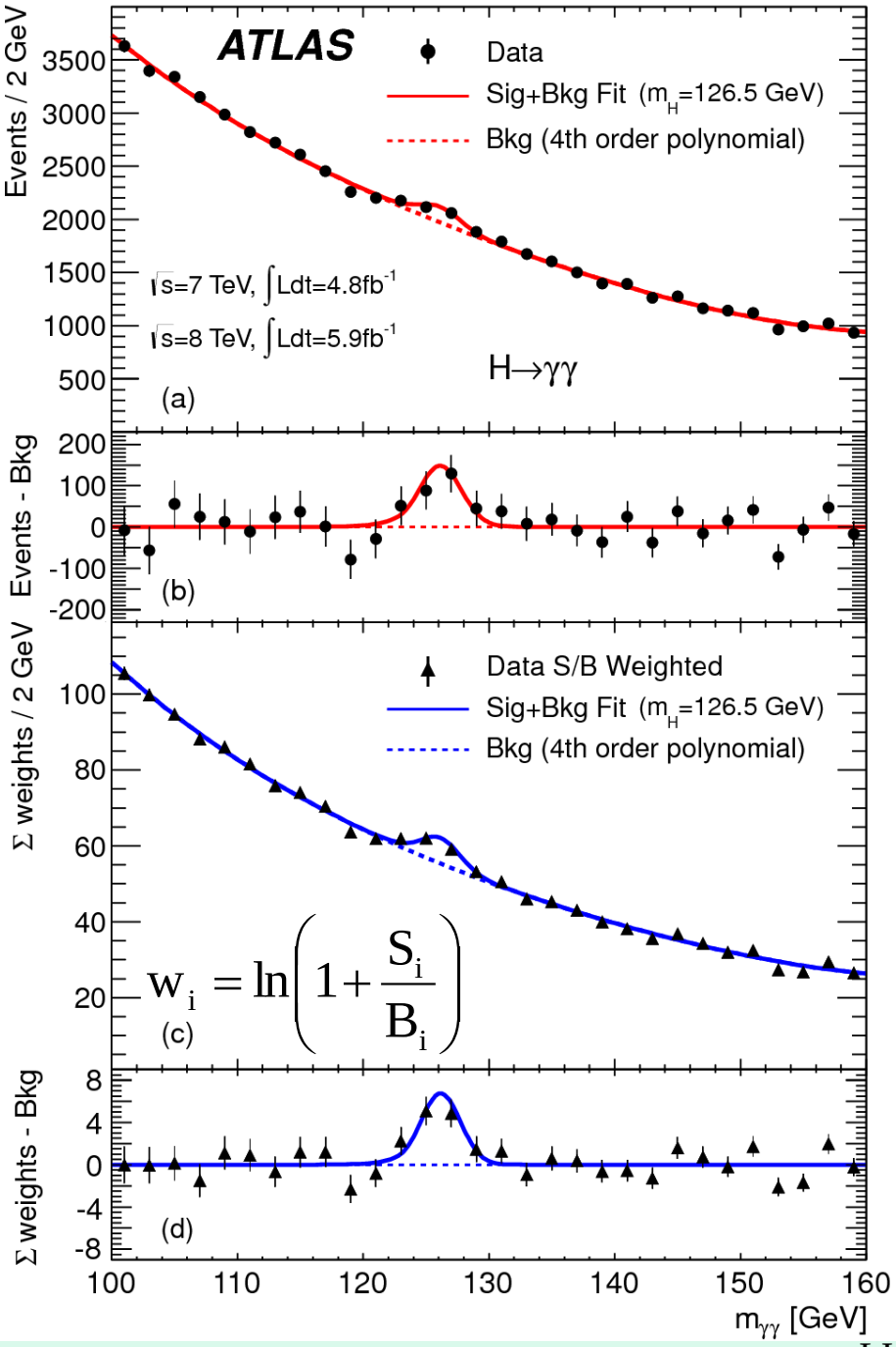
Varies from category to category.

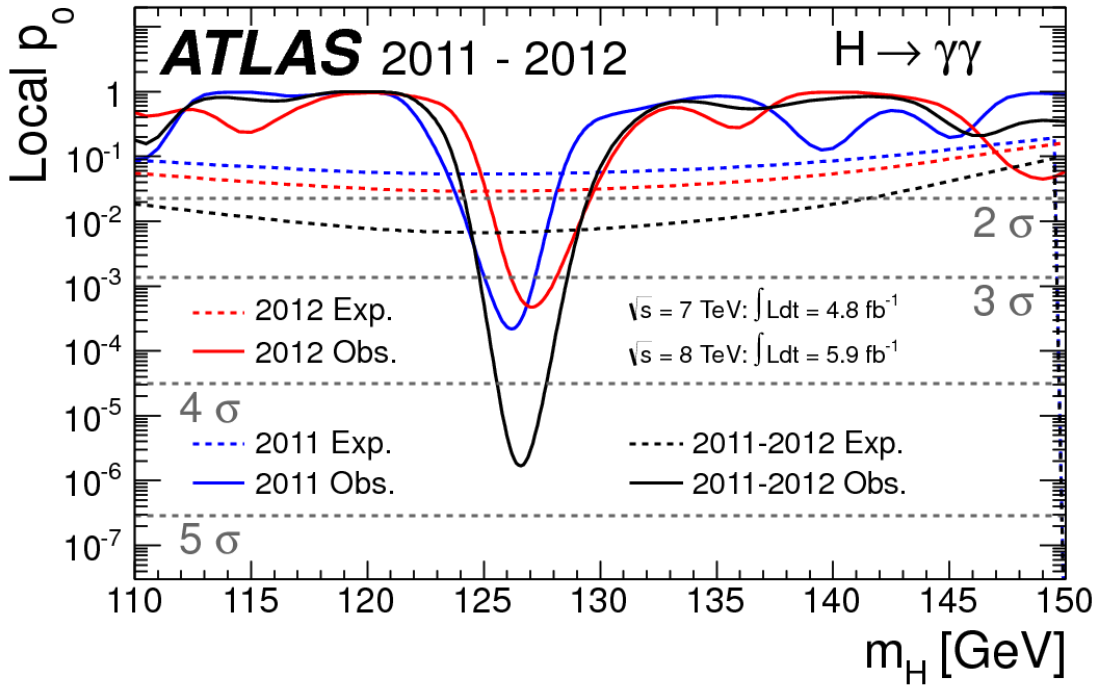
Systematic Uncertainties

Uncertainty	Description
Signal yield uncertainty from γ ID efficiency	±8% , ±11% (7TeV, 8TeV)
Pile-up modelling	±4%
Theory uncertainties in Higgs kinematics (affecting event migration between categories)	±9%
Signal resolution uncertainty	±14%
Trigger	±1%
Photon isolation	±0.4% , ±0.5% (7TeV, 8TeV)
Luminosity	±1.8% , ±3.6% (7TeV, 8TeV)

Uncertainties in the expected fractions of events per category (includes migrations) due to material effects, jet energy scale, pile-up effects, PDFs and jet vertex fraction, have been included.

γγ invariant mass and local Significance

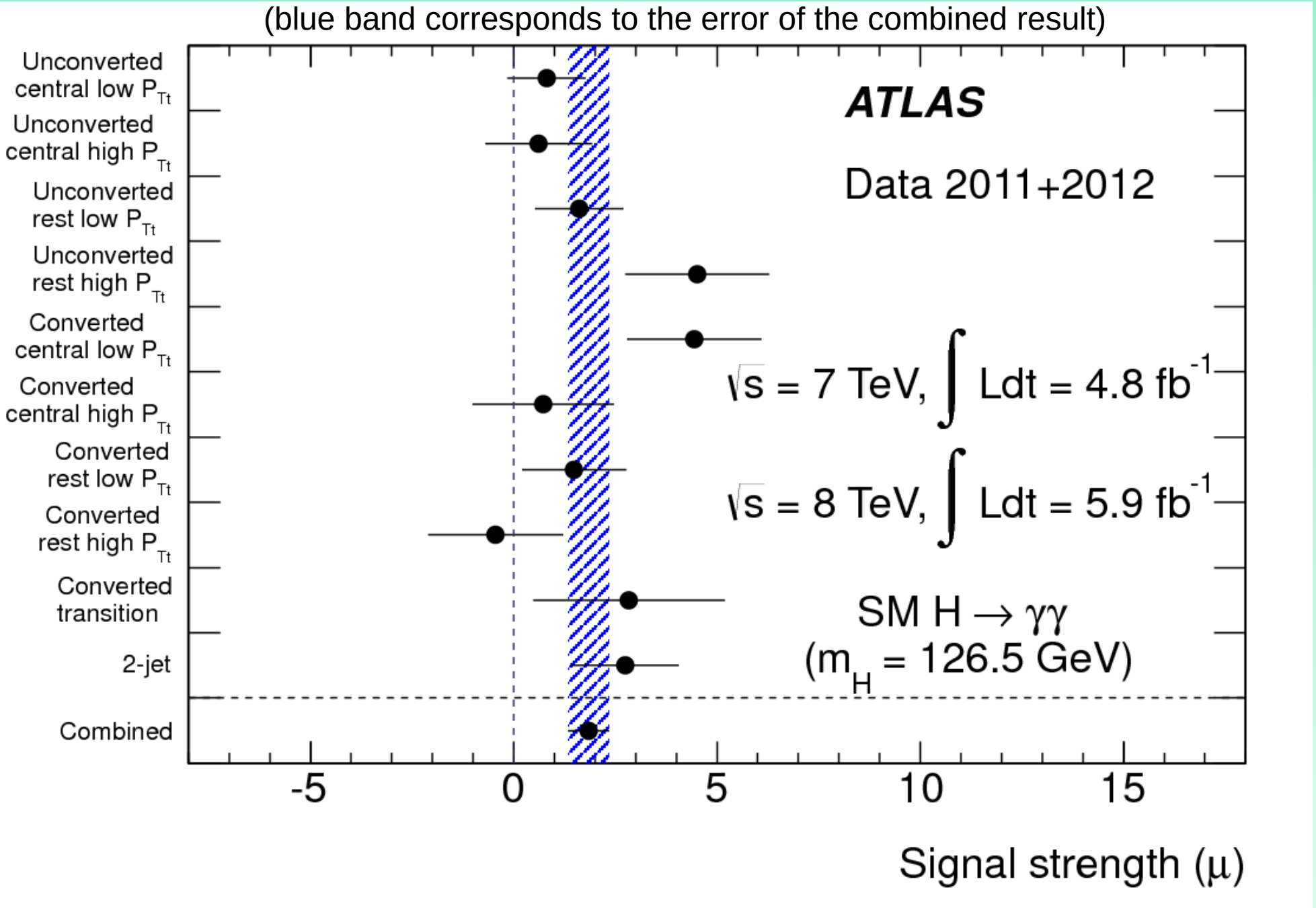




Combination of all categories leads to a 4.5σ significance.

$\gamma\gamma$ signal strength per category (at 126.5 GeV)

(blue band corresponds to the error of the combined result)



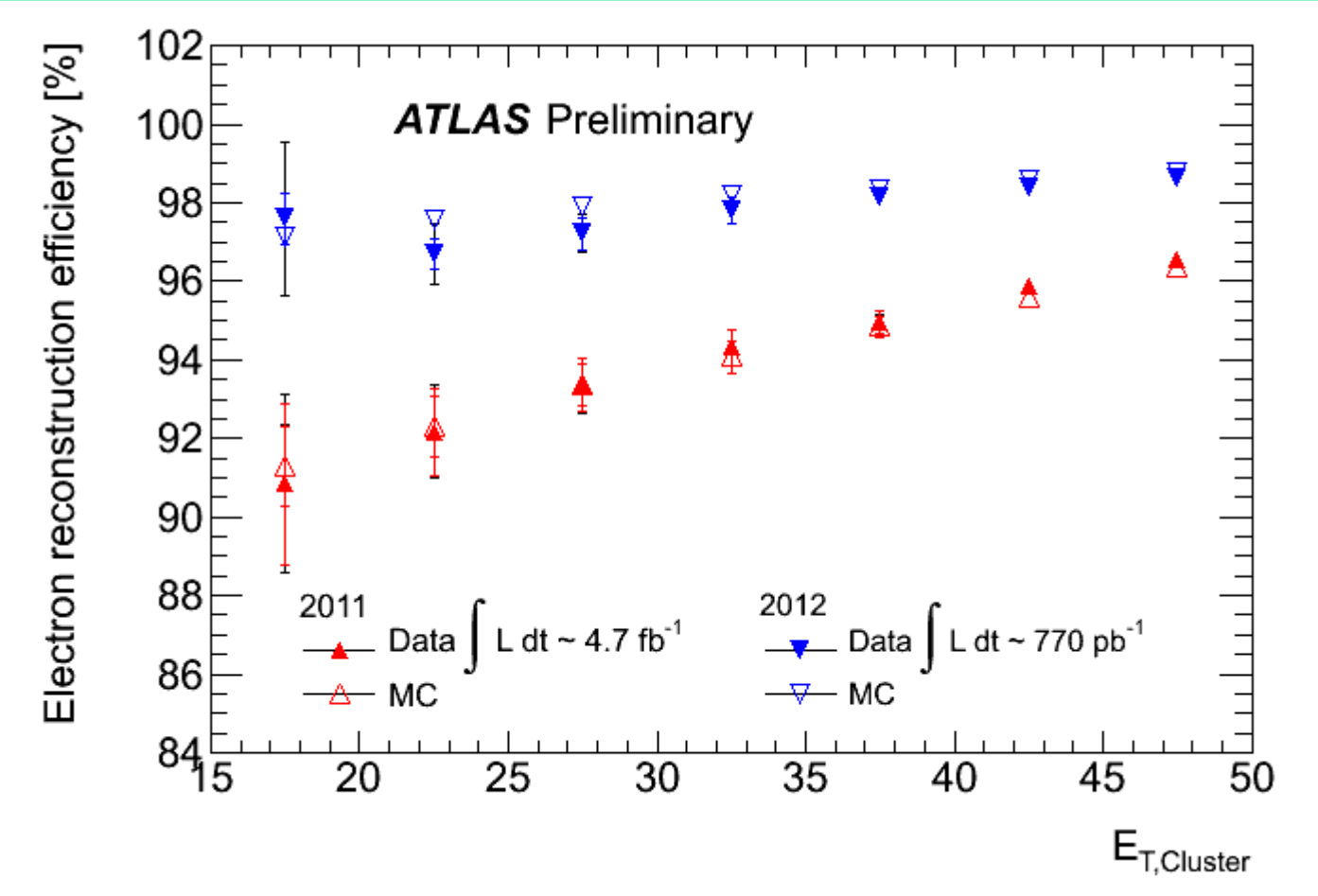
$$H \rightarrow ZZ^{(*)} \rightarrow l^+l^-l^+l^-$$

$$\sigma \times \mathrm{BR} = 2.8\,\mathrm{fb}\,(8\,\mathrm{TeV})$$

4-lepton event selection summary

Selection	Description
Final states	$e^+e^-e^+e^-$, $\mu^+\mu^-\mu^+\mu^-$, $\mu^+\mu^-e^+e^-$, $e^+e^-\mu^+\mu^-$
Fiducial cuts	All leptons $p_{T,\mu} > 6$ GeV, $p_{T,e} > 7$ GeV, Leading $p_T > 20$ GeV Subleading $p_T > 15$ GeV Third $p_T > 10$ GeV $\lvert\eta_\mu\rvert < 2.7$, $\lvert\eta_e\rvert < 2.47$
Lepton Isolation	Track sum ET and Calo sum ET inside a $\Delta R<0.2$ cone around the Z leptons.
e (μ) Impact Parameter	$d0/\sigma_{d0} < 6.5$ (3.5)
Leading dilepton (12)	Same flavour opposite charge with M closest to 91.18 GeV. Pairs must satisfy $m_{12}>50$ GeV, $m_{34}>17.5$ GeV.
Leading Z mass cut	$50 < m_{12} < 106$ GeV
Subleading Z mass cut	$M_{min}(m_{4l}) < m_{34} < 115$ GeV (M_{min} is a minimum mass cut that depends on the 4-lepton mass)

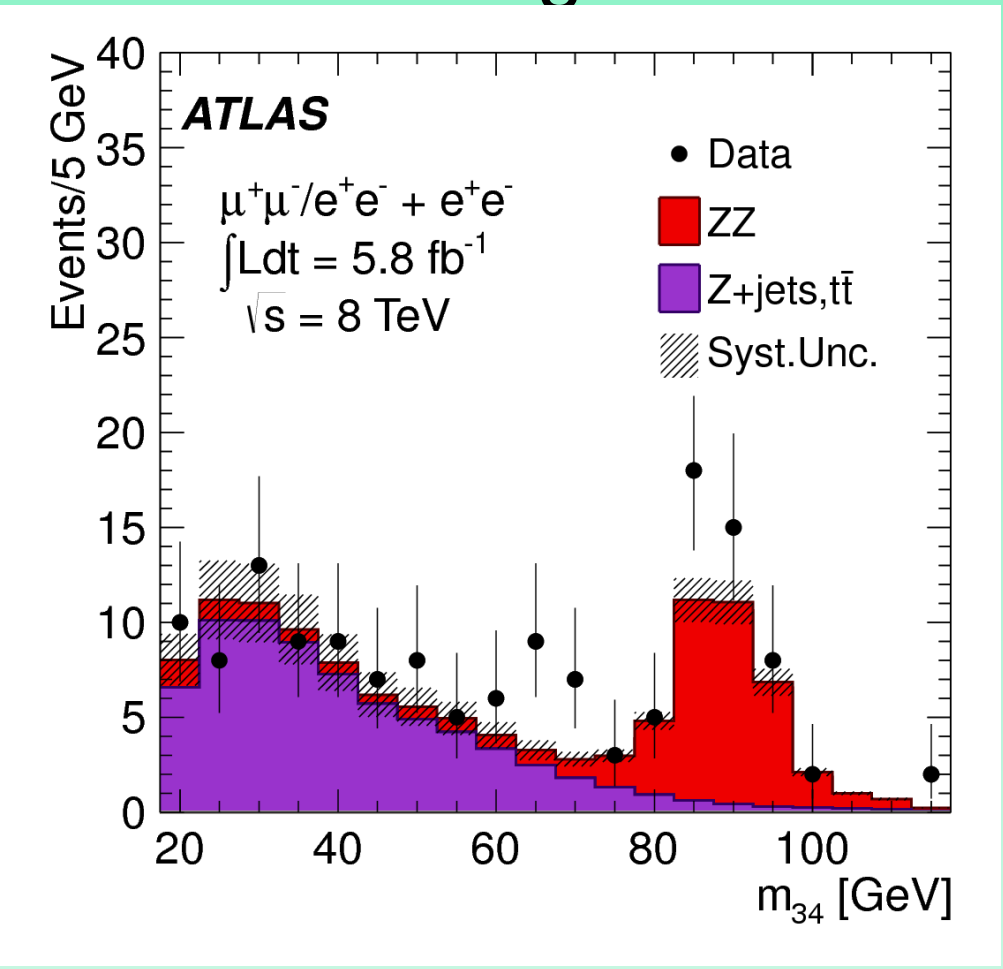
Lepton Reconstruction

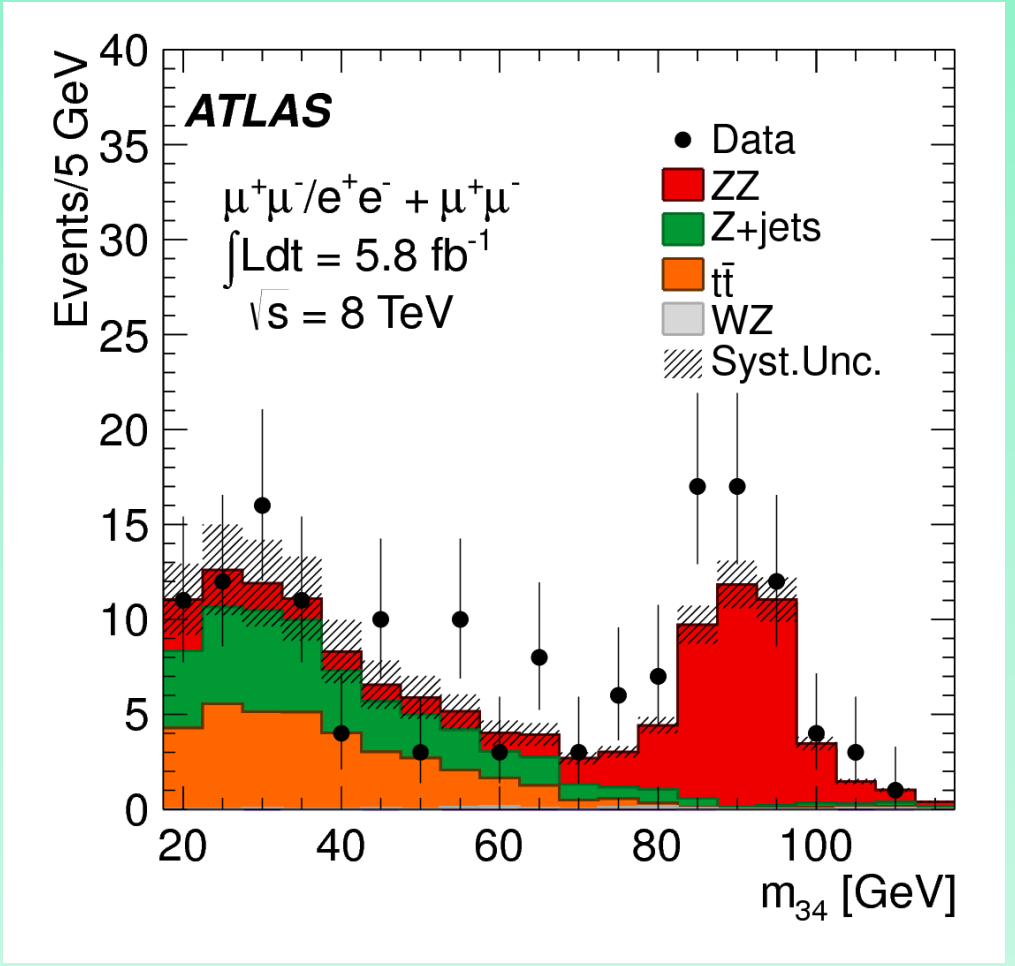


Electron reconstruction/identification improved in 2012: New pattern finding/track fitting, Improved track-cluster matching, to recover electrons undergoing hard bremsstrahlung , GSF.

Muon reconstruction: use ID tracks matched with partial or complete track segments in the muon spectrometer, and ID tracks+energy deposits in the calo ($|\eta|<0.1$ $pt>15GeV$). Standalone muons ($2.5<|\eta|<2.7$).

Background measurements from data





A number of methods was used to determine the various backgrounds using data. A subset of the analysis cuts is applied to define a control region.

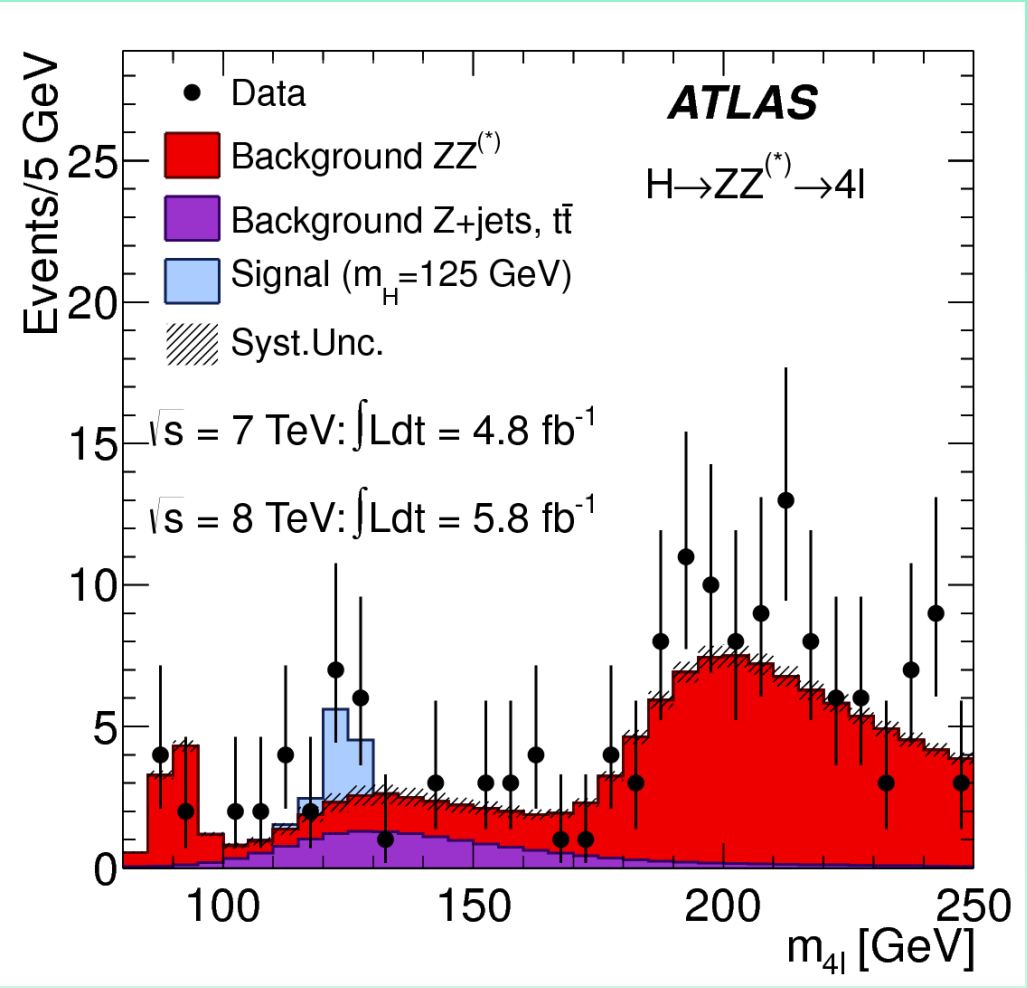
One example is to use the invariant mass of the subleading dilepton M34 to control the Z+jets and ttbar backgrounds. For these leptons the isolation and impact parameter cuts are not applied. All other analysis cuts are applied.

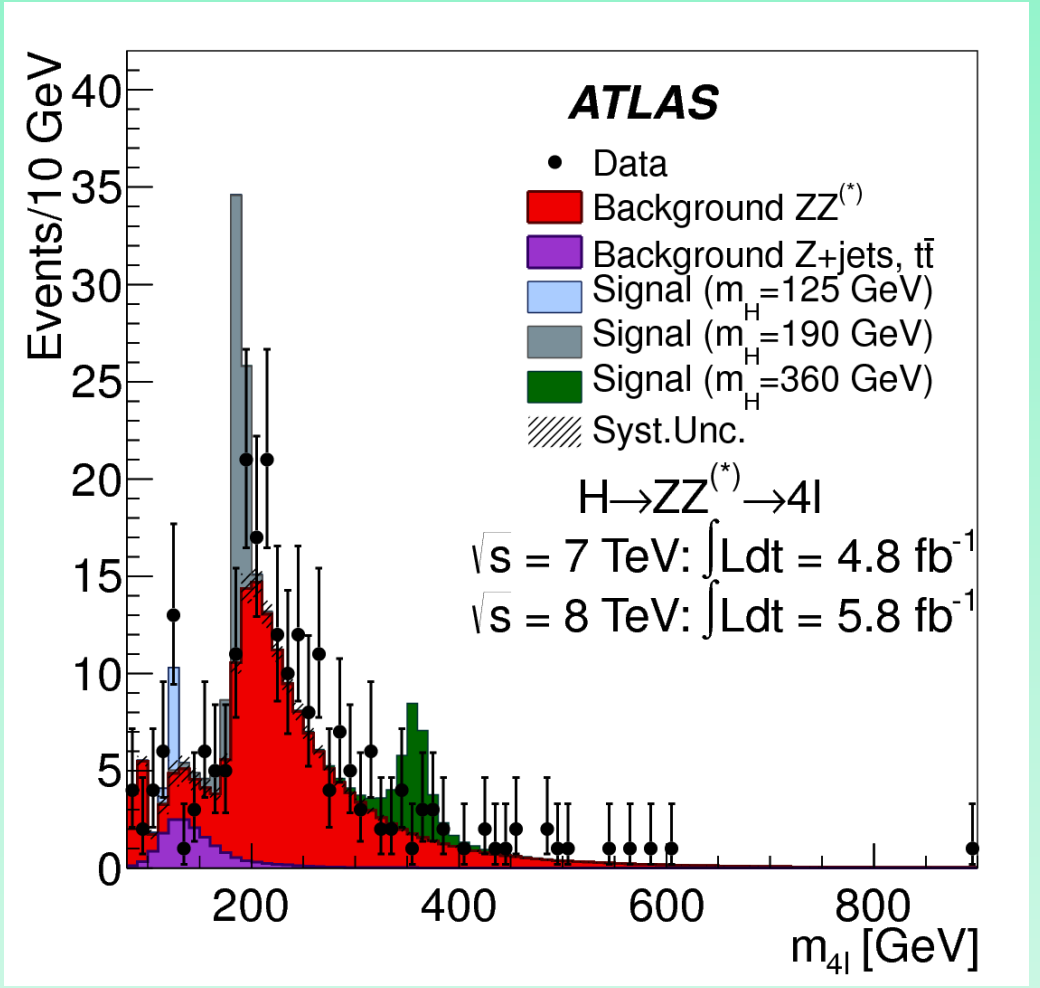
Systematic Uncertainties

Uncertainty	Description
μ acceptance uncertainty due to reco and ID efficiency uncertainties	from ±0.7% (±0.5%,±0.5%) for 4μ (2e2μ,2μ2e) at 600GeV to ±0.9% (±0.8%,±0.5%) for 4μ (2e2μ,2μ2e) at 115GeV
e acceptance uncertainty due to reco and ID efficiency uncertainties	from ±2.6% (±1.7%,±1.8%) for 4e (2e2μ,2μ2e) at 600GeV to ±8.0% (±2.3%,±7.6%) for 4e (2e2μ,2μ2e) at 115GeV
ZZ* bkg uncertainty (QDC scale)	±5%
ZZ* bkg uncertainty (α_s + PDF)	±4% (±8%) for processes initiated by quarks (gluons)
Z+jets and ttbar backgrounds	estimated from control regions

ZZ normalization comes from MC.
Dependence of ZZ* uncertainties on m_{4l} has been taken into account

4-lepton invariant mass

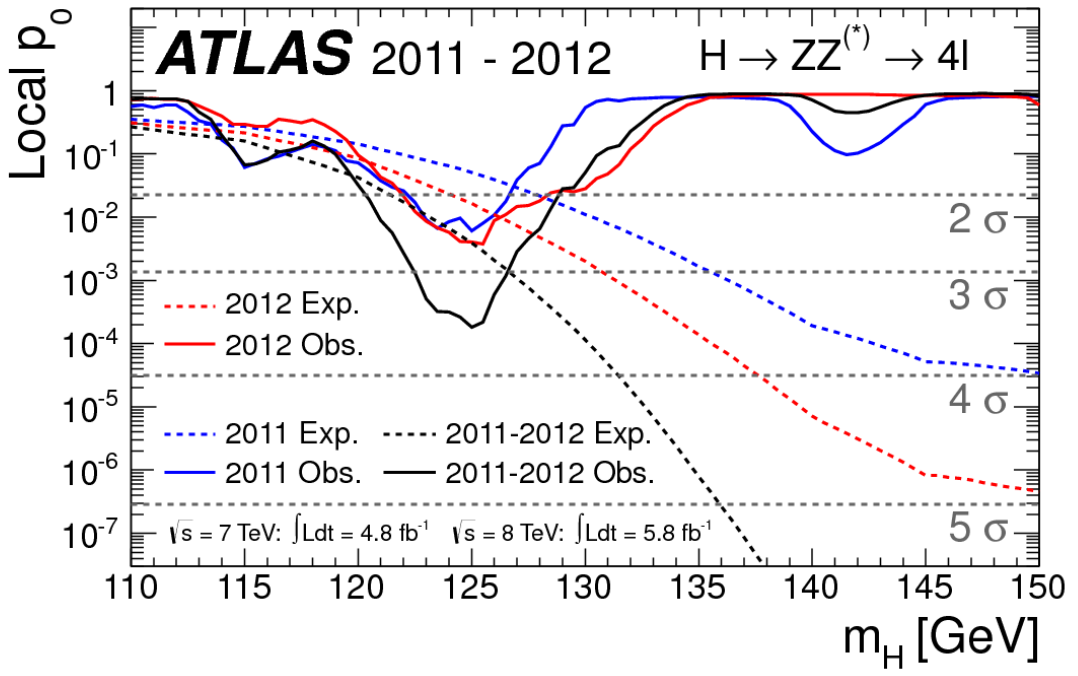




Observed excess in 120-130 GeV

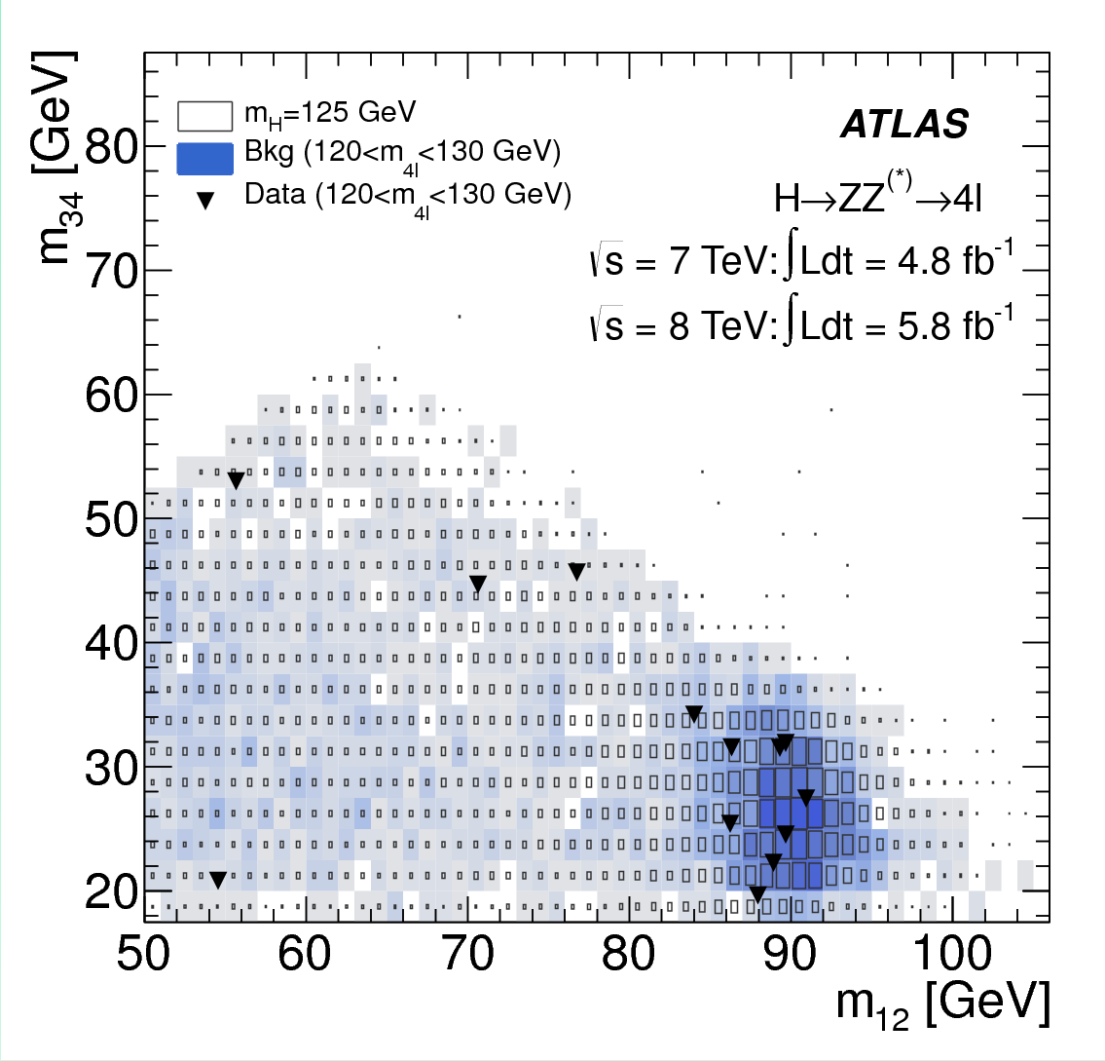
4-lepton expected and observed events: 120-130GeV

m_H [GeV]	exp. signal	exp. $ZZ^{(*)}$	exp. Z + jets, $t\bar{t}$	obs
		4μ		
120	1.16± 0.16	0.91±0.04	0.12± 0.04	4
125	2.09± 0.30	1.12±0.05	0.13± 0.04	6
130	3.25± 0.46	1.25±0.05	0.13± 0.04	3
		$2e2\mu$ and $2\mu2e$		
120	1.29± 0.19	0.69±0.05	1.13± 0.17	3
125	2.29± 0.33	0.80±0.05	1.27± 0.19	5
130	3.52± 0.51	0.82±0.05	1.31± 0.19	3
		$4e$		
120	0.49± 0.07	0.36±0.03	0.97± 0.19	2
125	0.90± 0.14	0.44±0.04	1.09± 0.20	2
130	1.33± 0.21	0.51±0.05	1.13± 0.21	1



Maximum local significance of 3.6σ observed at 125 GeV.
No other significant excess is observed in m_H.

m_{34} vs m_{12} for $120<m_{4l}<130$ GeV



Distribution of the m_{34} versus the m_{12} invariant mass for the selected candidates in the m_{4l} range 120 to 130 GeV. The expected distributions for a SM Higgs with m_H = 125 GeV and for the total background are shown. The sizes and intensity of the boxes indicate the relative density.

$$H \rightarrow WW^{(*)} \rightarrow l^{+}\nu\, l^{-'}\bar{\nu}$$

Focus in 2012 data: eμ,μe final states

$\sigma \times \mathrm{BR} = 112\,\mathrm{fb}\,(8\,\mathrm{TeV})$

WW event selection summary

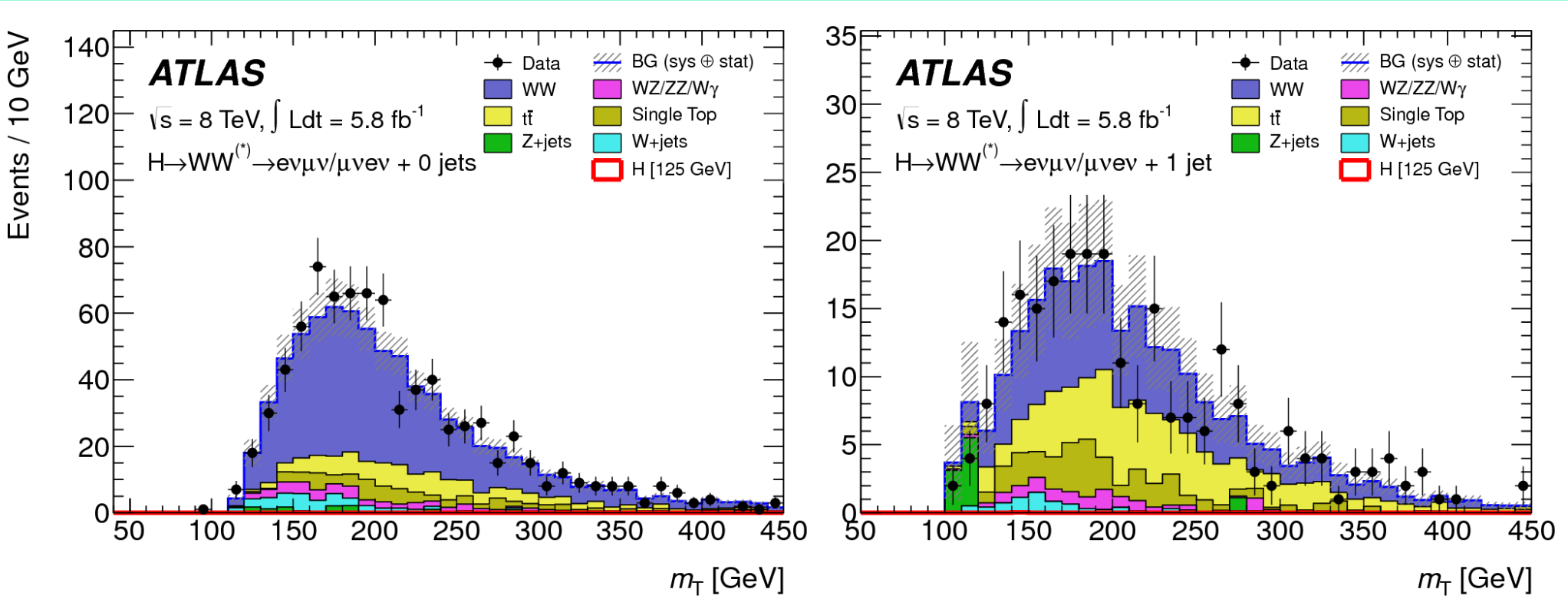
Fiducial cuts	$p_{T,l1} > 25$ GeV, $p_{T,l2} > 15$ GeV, $\lvert\eta_\mu\rvert<2.5$, $\lvert\eta_e\rvert<2.47$, excluding $1.37<\lvert\eta_e\rvert<1.52$
Lepton Isolation	Track sum ET and Calo sum ET inside a $\Delta R<0.3$ cone around the Z leptons.
Dilepton Invariant mass	$m_{ll} < 50\,(80)\,\text{GeV},\ \text{for}\ 0\text{-}1\,(2)\ \text{jet channels}$
Dilepton PT (0-jet channel)	$\left\lvert\vec{p}_{\mathrm{T}}^{\,ll}\right\rvert = \left\lvert\vec{p}_{\mathrm{T}}^{\,l1} + \vec{p}_{\mathrm{T}}^{\,l2}\right\rvert > 30\,\text{GeV}$
Missing ET (relative)	ET,rel>25 GeV
Categories	H + 0 jets, H + 1 jet, H + 2 jets
For 2012 (8TeV) only the eμ final state is used (5.8 fb^{-1})	

Transverse mass is the discriminant used in the search:

$$m_{\mathrm{T}} = \sqrt{\left(E_{\mathrm{T}}^{\ell\ell} + E_{\mathrm{T}}^{\mathrm{miss}}\right)^2 - \left\lvert\vec{p}_{\mathrm{T}}^{\,\ell\ell} + \vec{E}_{\mathrm{T}}^{\mathrm{miss}}\right\rvert^2}$$

$$E_{\mathrm{T}}^{\ell\ell} = \sqrt{\left\lvert\vec{p}_{\mathrm{T}}^{\,\ell\ell}\right\rvert^2 + m_{\ell\ell}^2}$$

Background measurements from data

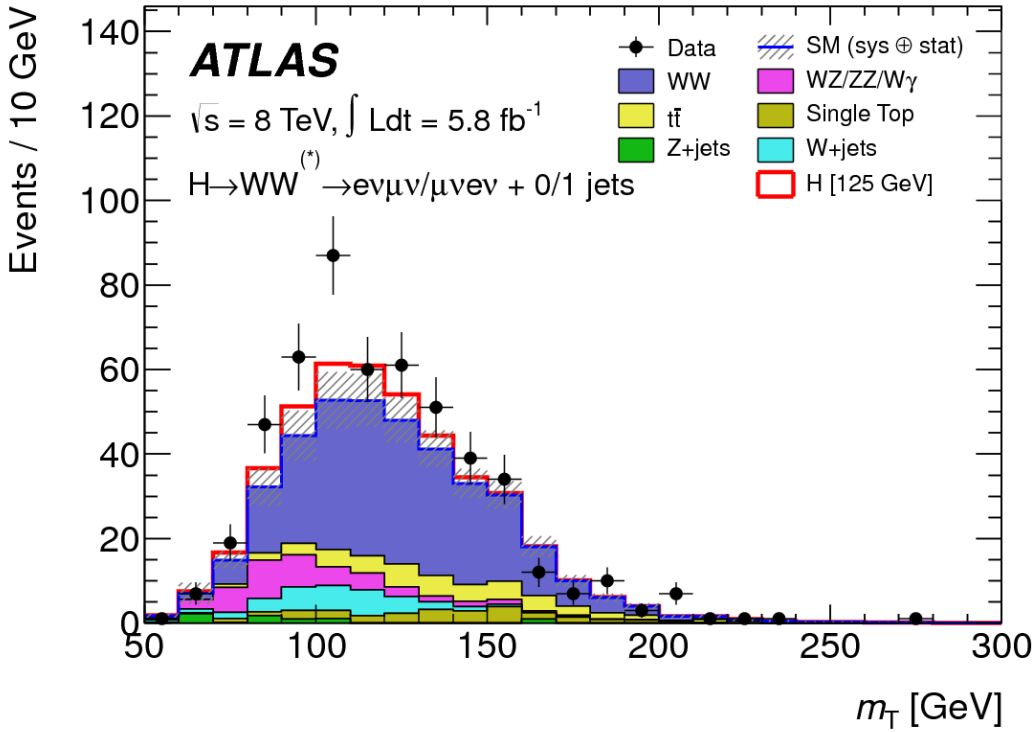


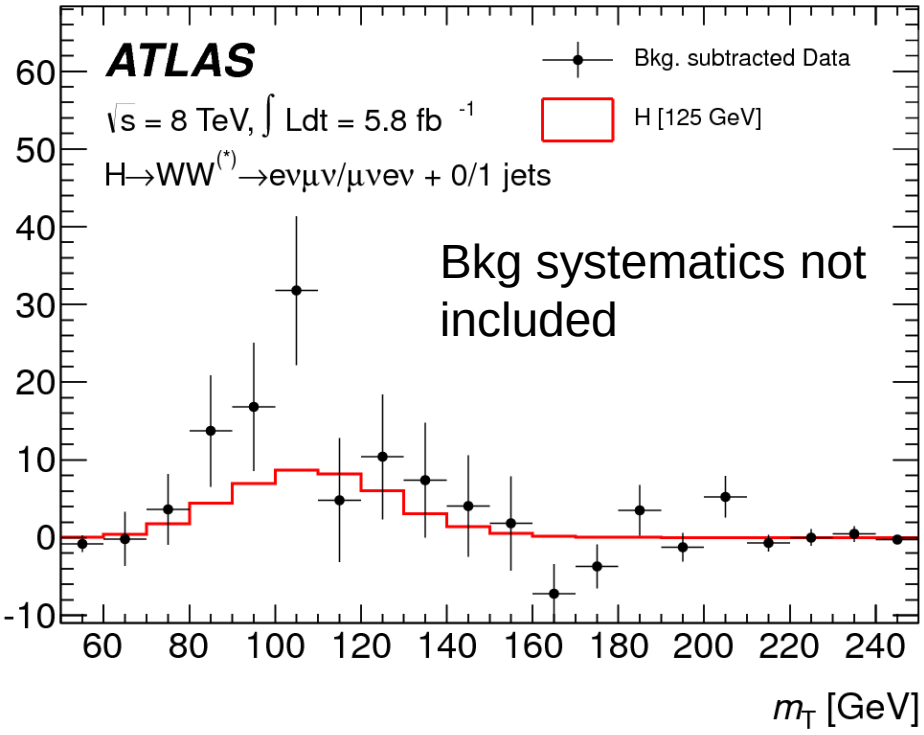
Example control regions
for WW + 0 jets (mostly WW)
and WW + 1 jet (large ttbar + single top fraction).

Systematic Uncertainties

Uncertainty	Description
Theoretical uncertainties associated to the **signal**	±17% (0-jets), ±36% (1-jet)
Jet energy scale (max effect on **signal**)	±7% in W+0jet
Jet energy scale (max effect on bkg)	±4% in W+1jet
Jet energy resolution (max effect on **signal**)	±4% in W+1jet
Jet energy resolution (max effect on bkg)	±2% in W+1jet
Pile-up to JES (max effect on **signal**)	±4% in W+1jet
Pile-up to JES (max effect on bkg)	±2% in W+1jet
Missing ET effect in total yield	±3% (±3%) signal (bkg)
b-jet tagging efficiency	±10% in W+1jet
W+jet prediction effect in the total bkg	±5%

WW Observed and expected events





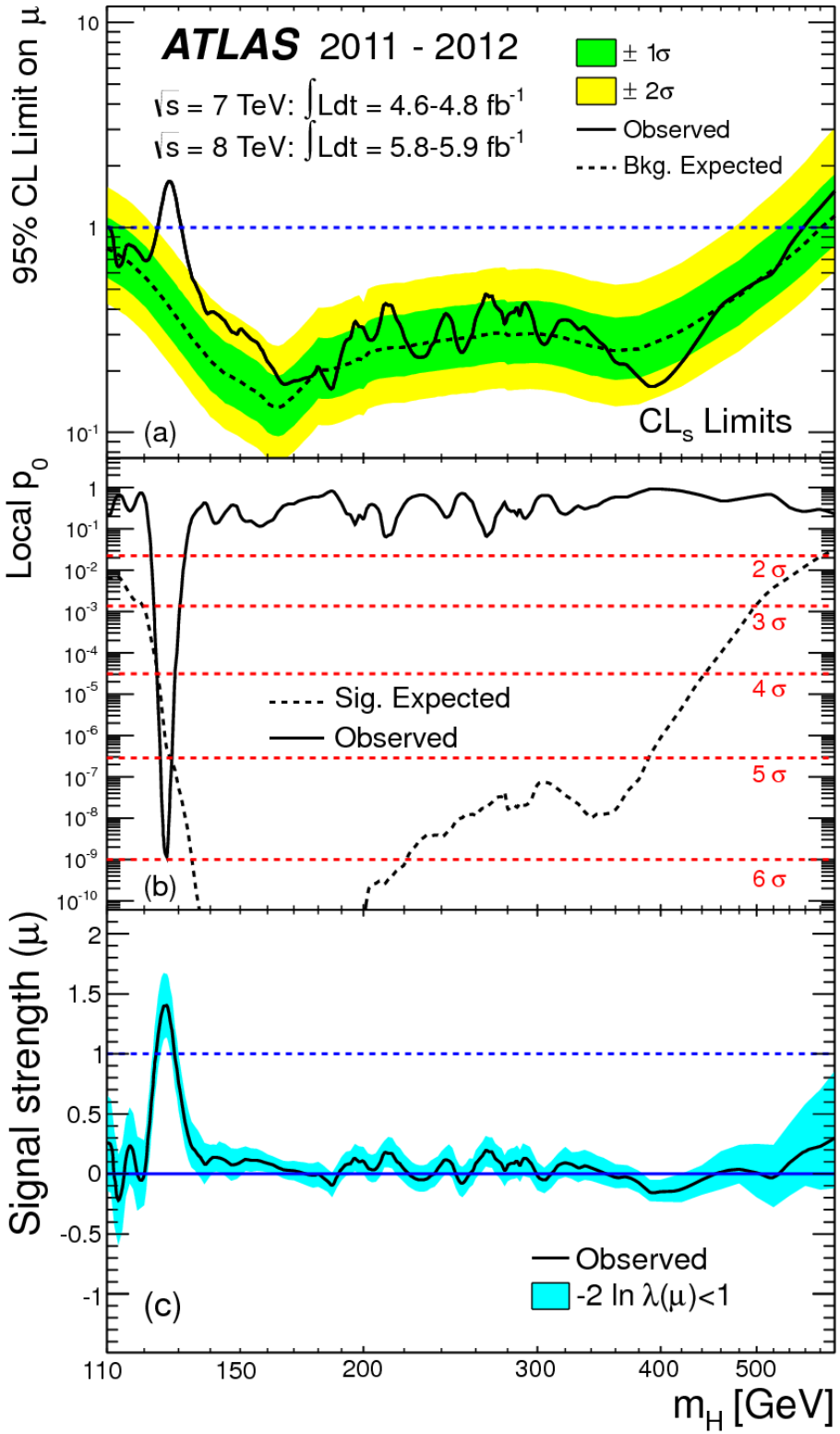
$0.75m_H < m_T < m_H$ for $m_H = 125$ GeV.

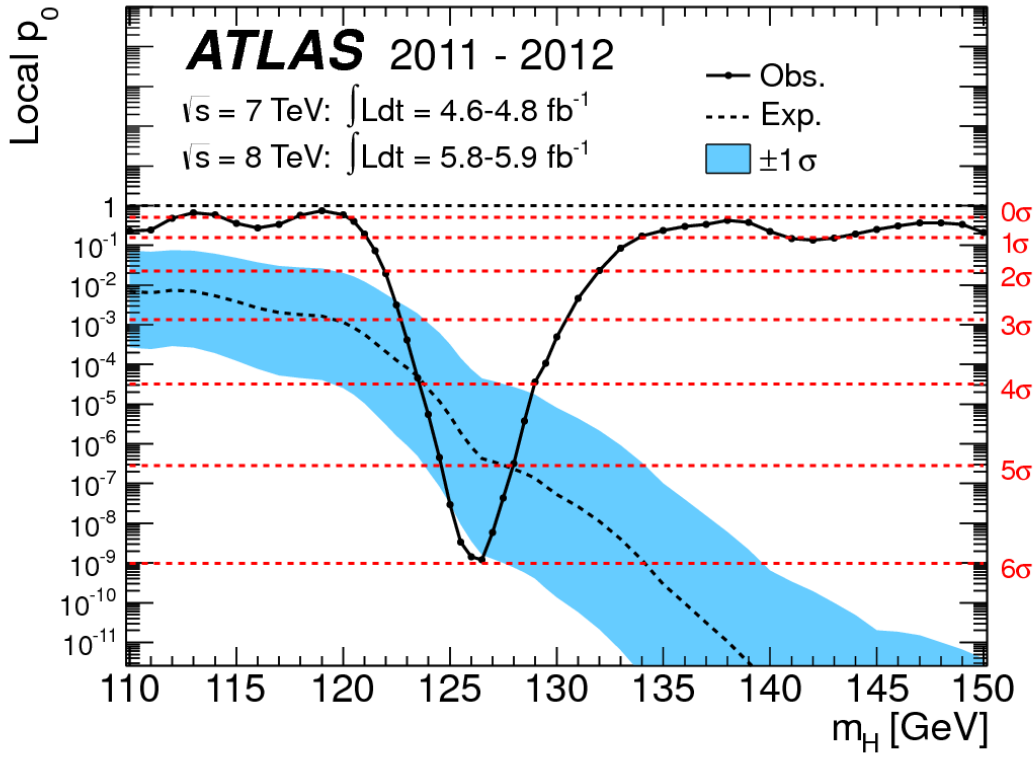
	0-jet	1-jet	2-jet
Signal	20 ± 4	5 ± 2	0.34 ± 0.07
WW	101 ± 13	12 ± 5	0.10 ± 0.14
$WZ^{(*)}/ZZ/W\gamma^{(*)}$	12 ± 3	1.9 ± 1.1	0.10 ± 0.10
$t\bar{t}$	8 ± 2	6 ± 2	0.15 ± 0.10
$tW/tb/tqb$	3.4 ± 1.5	3.7 ± 1.6	–
$Z/\gamma^* + \text{jets}$	1.9 ± 1.3	0.10 ± 0.10	–
$W + \text{jets}$	15 ± 7	2 ± 1	–
Total background	142 ± 16	26 ± 6	0.35 ± 0.18
Observed	185	38	0

Combination

More on Sven Kreiss' talk

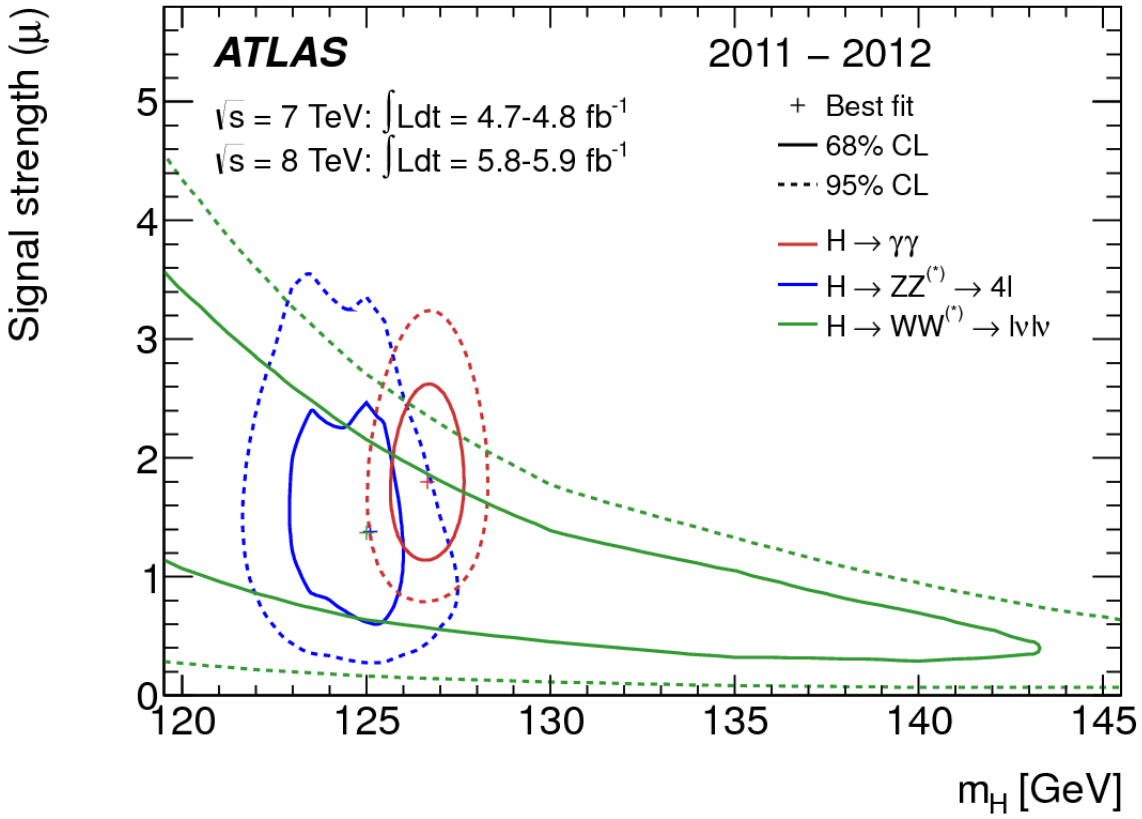
Exclusion Region and Combined Significance

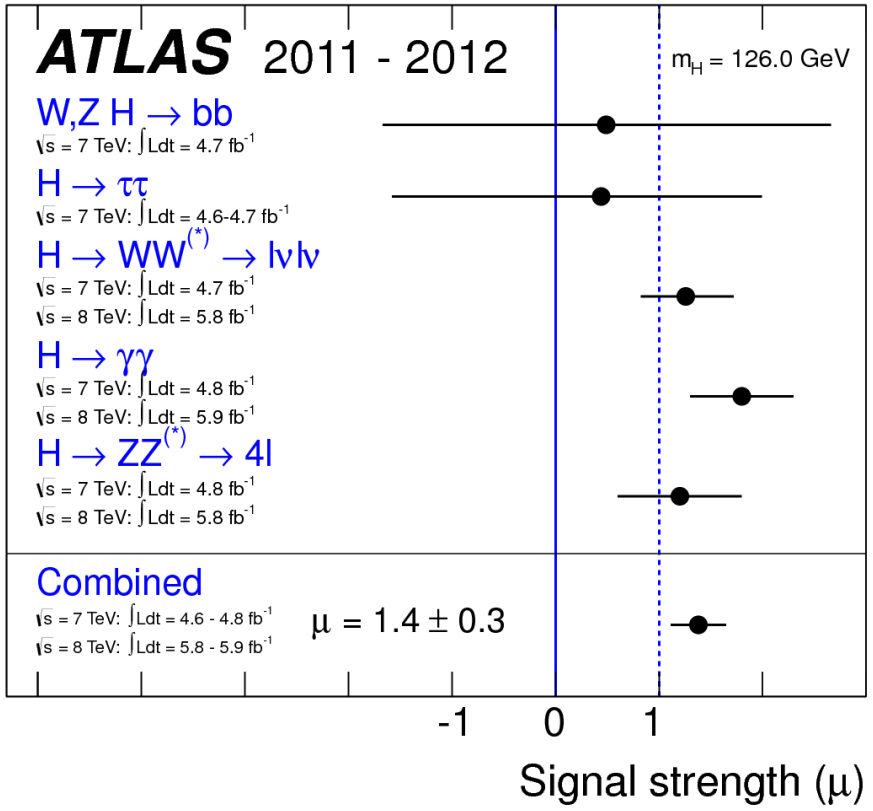




Combination of all channels (including 2011 ττ, bb, etc) leads to a 5.9σ significance.

Mass and Signal strength μ wrt Standard Model





Extracted mass:126 ± 0.4(stat) ± 0.4(syst) GeV
(using only 4-lepton and γγ channels)

Combined Signal Strength:1.4 ± 0.3

Conclusions

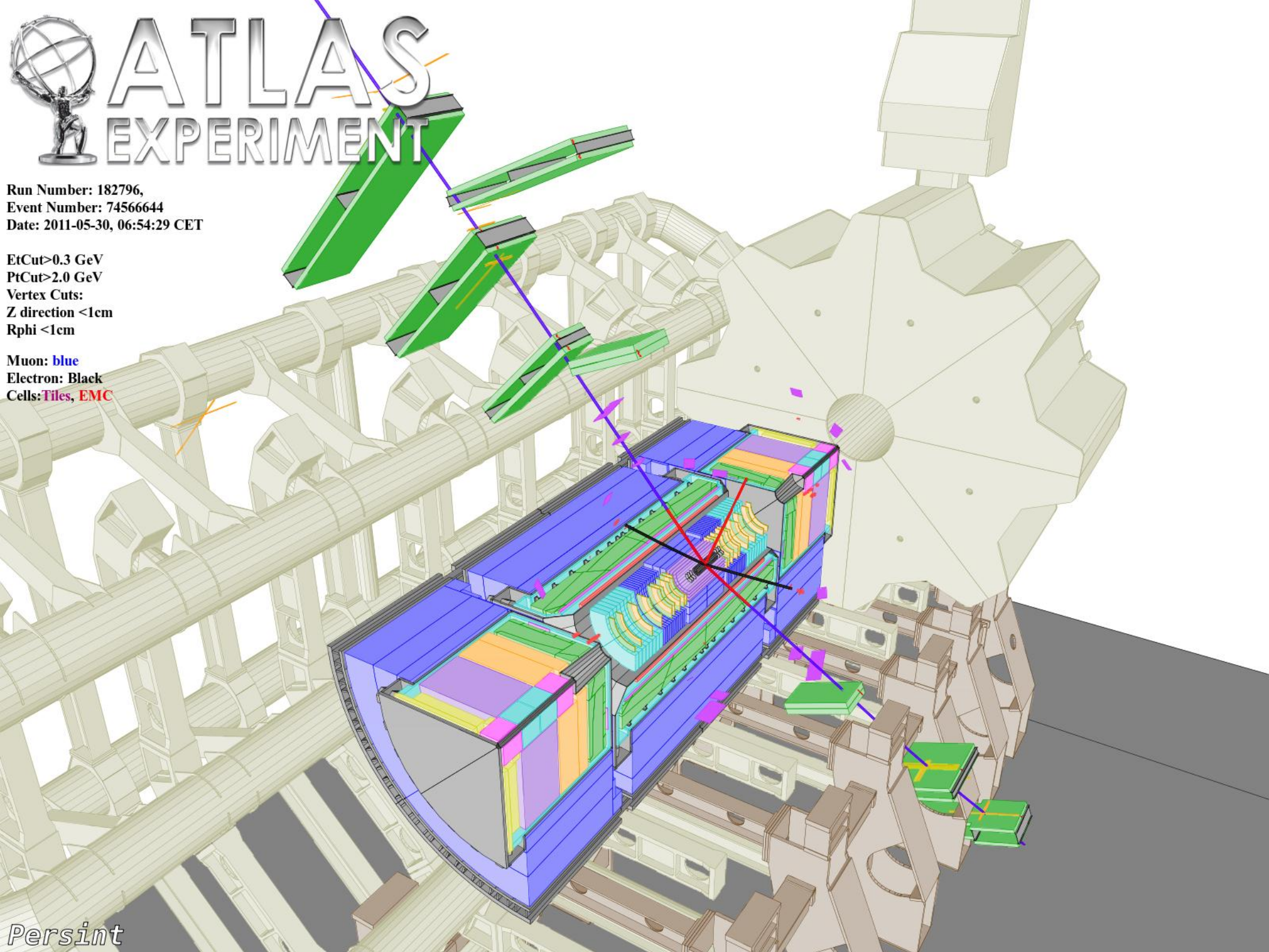
ATLAS has performed a search for the SM Higgs boson with an integrated luminosity of ~10.7 fb^{-1}.

A 5.9σ excess of events is observed in the region 121-131 GeV. The excess is dominated by the high mass resolution channels $H \rightarrow \gamma\gamma$ and $H \rightarrow ZZ \rightarrow 4l$ in addition to $H \rightarrow WW \rightarrow l\nu l'\nu$.

The SM Higgs boson is excluded at the 95% or higher CL in 111-559 GeV apart from the narrow range 121-131 GeV where a clear excess is observed.

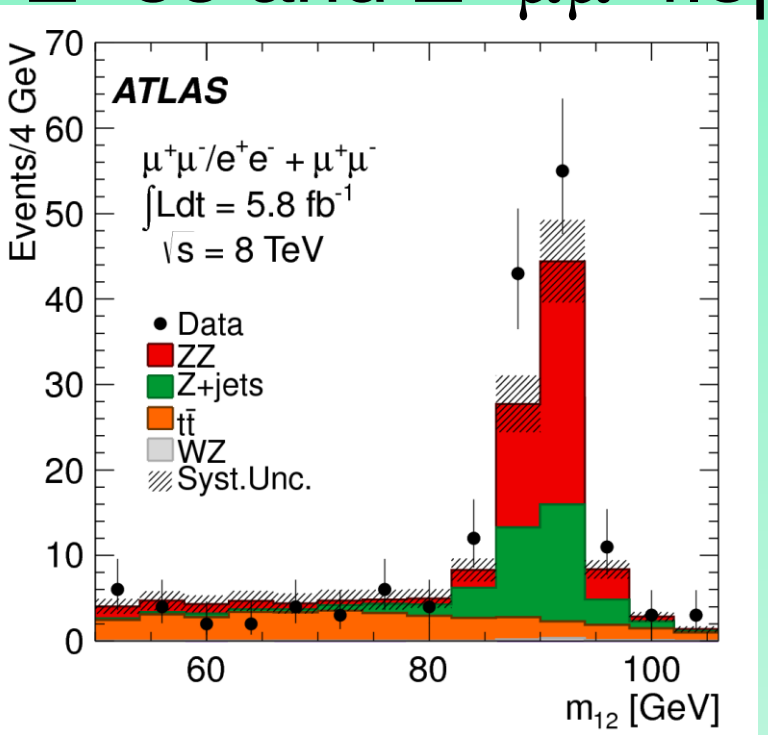
The measured invariant mass of the new particle is:

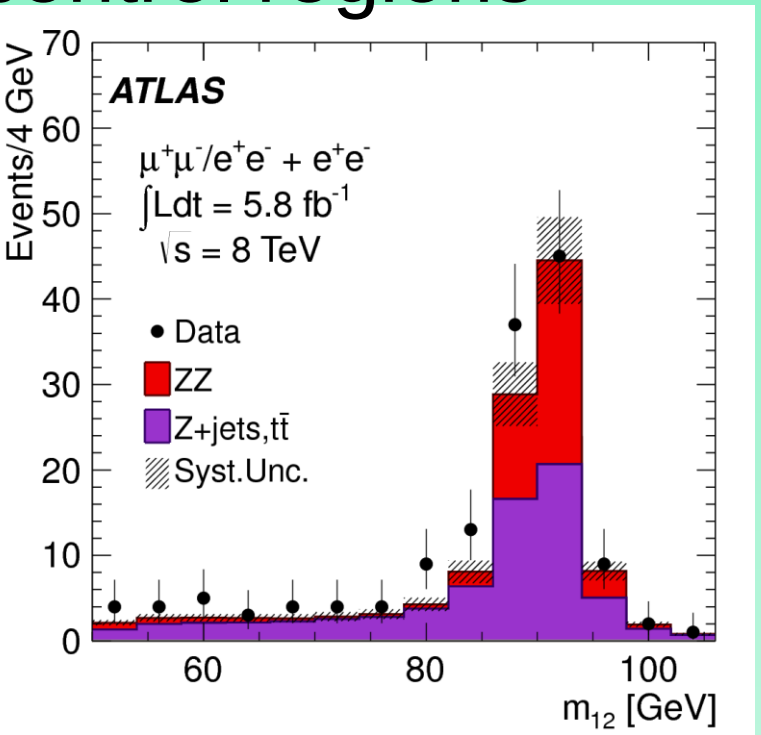
$$126 \pm 0.4(\text{stat}) \pm 0.4(\text{syst}) \text{ GeV}$$

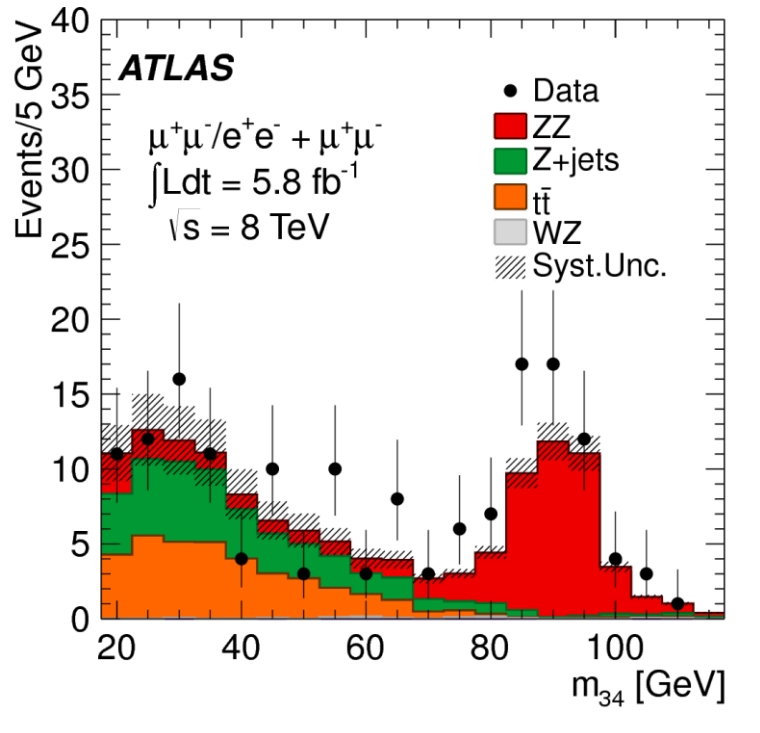

ATLAS
EXPERIMENT
Run Number: 182796,
Event Number: 74566644
Date: 2011-05-30, 06:54:29 CET
EtCut>0.3 GeV
PtCut>2.0 GeV
Vertex Cuts:
Z direction <1cm
Rphi <1cm
Muon: blue
Electron: Black
Cells:Tiles, EMC
Persint

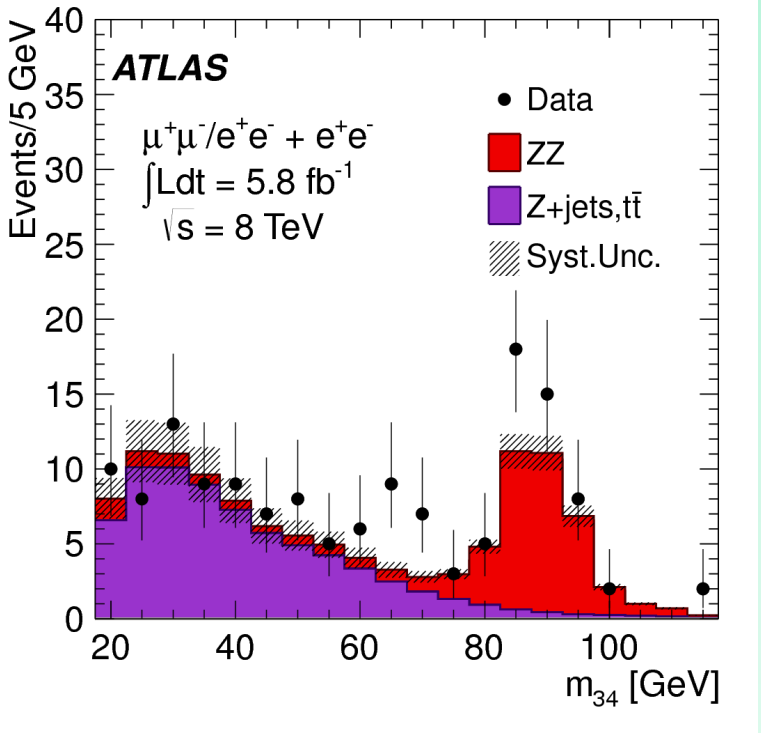
Additional Slides

Z+ee and Z+μμ 4lepton control regions







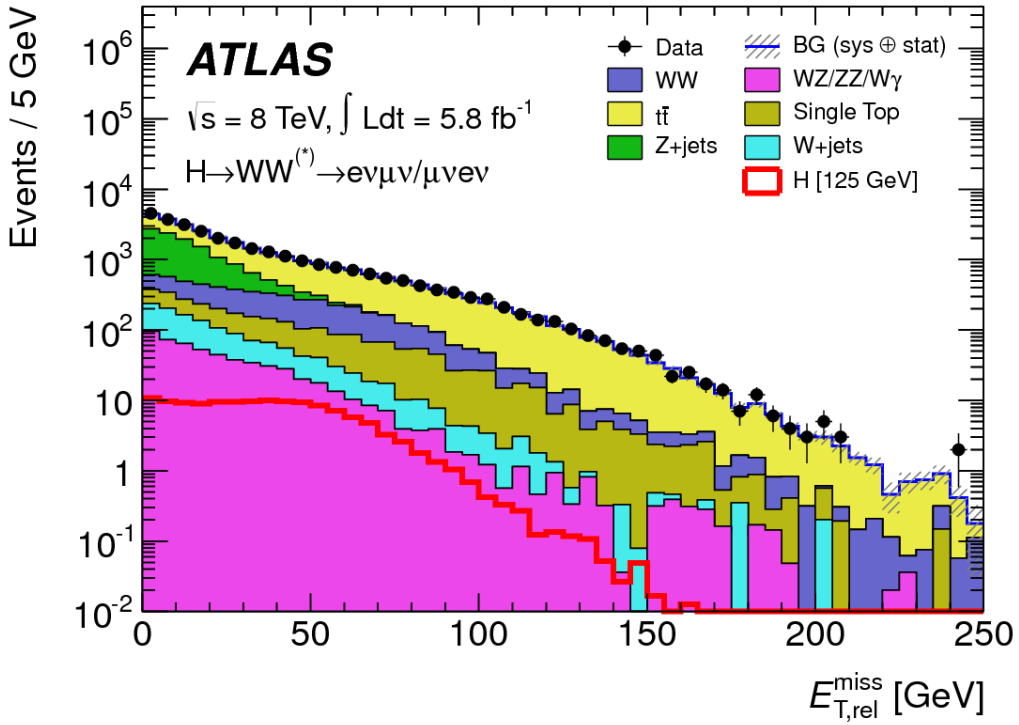


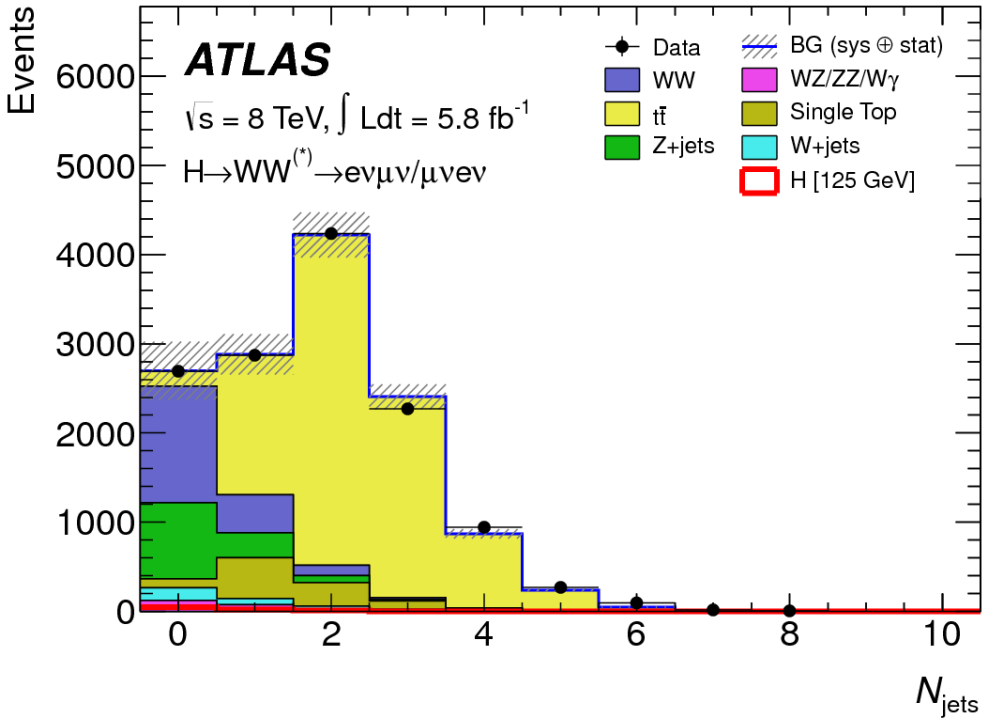
Summary of characterization of excess

Table 7
Characterisation of the excess in the $H \to ZZ^{(*)} \to 4\ell$, $H \to \gamma\gamma$ and $H \to WW^{(*)} \to \ell\nu\ell\nu$ channels and the combination of all channels listed in Table 6. The mass value m_{max} for which the local significance is maximum, the maximum observed local significance Z_l and the expected local significance $E(Z_l)$ in the presence of a SM Higgs boson signal at m_{max} are given. The best fit value of the signal strength parameter $\hat{\mu}$ at $m_H = 126$ GeV is shown with the total uncertainty. The expected and observed mass ranges excluded at 95% CL (99% CL, indicated by a *) are also given, for the combined $\sqrt{s} = 7$ TeV and $\sqrt{s} = 8$ TeV data.

Search channel	Dataset	m_{max} [GeV]	Z_l [σ]	$E(Z_l)$ [σ]	$\hat{\mu}(m_H = 126$ GeV)	Expected exclusion [GeV]	Observed exclusion [GeV]
$H \to ZZ^{(*)} \to 4\ell$	7 TeV	125.0	2.5	1.6	1.4 ± 1.1		
	8 TeV	125.5	2.6	2.1	1.1 ± 0.8		
	7 & 8 TeV	125.0	3.6	2.7	1.2 ± 0.6	124–164, 176–500	131–162, 170–460
$H \to \gamma\gamma$	7 TeV	126.0	3.4	1.6	2.2 ± 0.7		
	8 TeV	127.0	3.2	1.9	1.5 ± 0.6		
	7 & 8 TeV	126.5	4.5	2.5	1.8 ± 0.5	110–140	112–123, 132–143
$H \to WW^{(*)} \to \ell\nu\ell\nu$	7 TeV	135.0	1.1	3.4	0.5 ± 0.6		
	8 TeV	120.0	3.3	1.0	1.9 ± 0.7		
	7 & 8 TeV	125.0	2.8	2.3	1.3 ± 0.5	124–233	137–261
Combined	7 TeV	126.5	3.6	3.2	1.2 ± 0.4		
	8 TeV	126.5	4.9	3.8	1.5 ± 0.4		
	7 & 8 TeV	126.5	6.0	4.9	1.4 ± 0.3	110–582 113–532 (*)	111–122, 131–559 113–114, 117–121, 132–527 (*)

H→WW, missing Et and Jet multiplicity





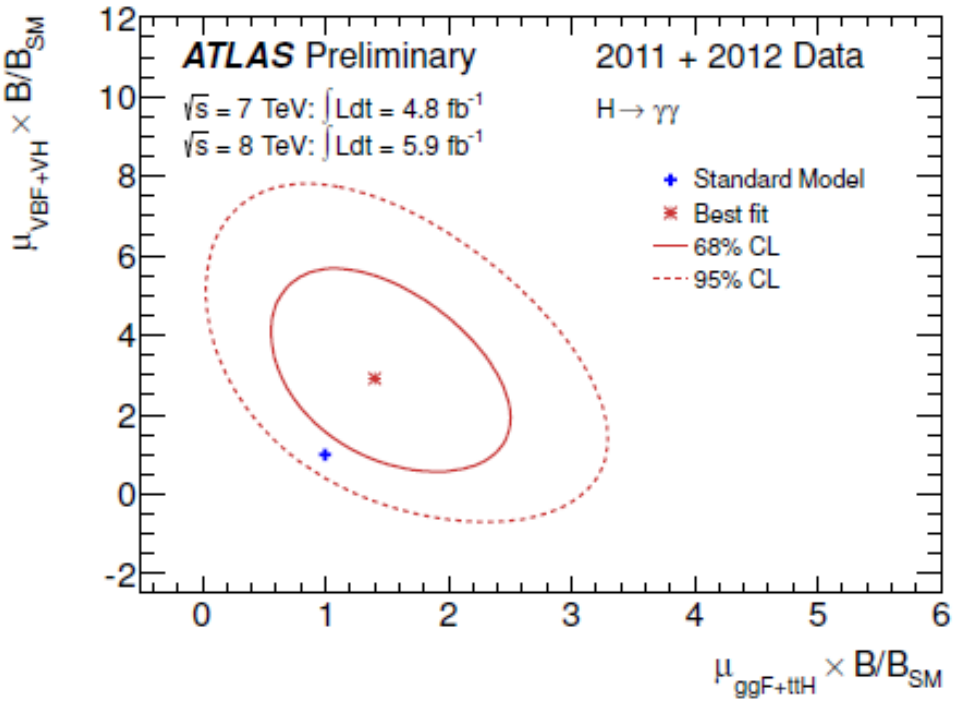
Numbers of observed and expected SM signal events

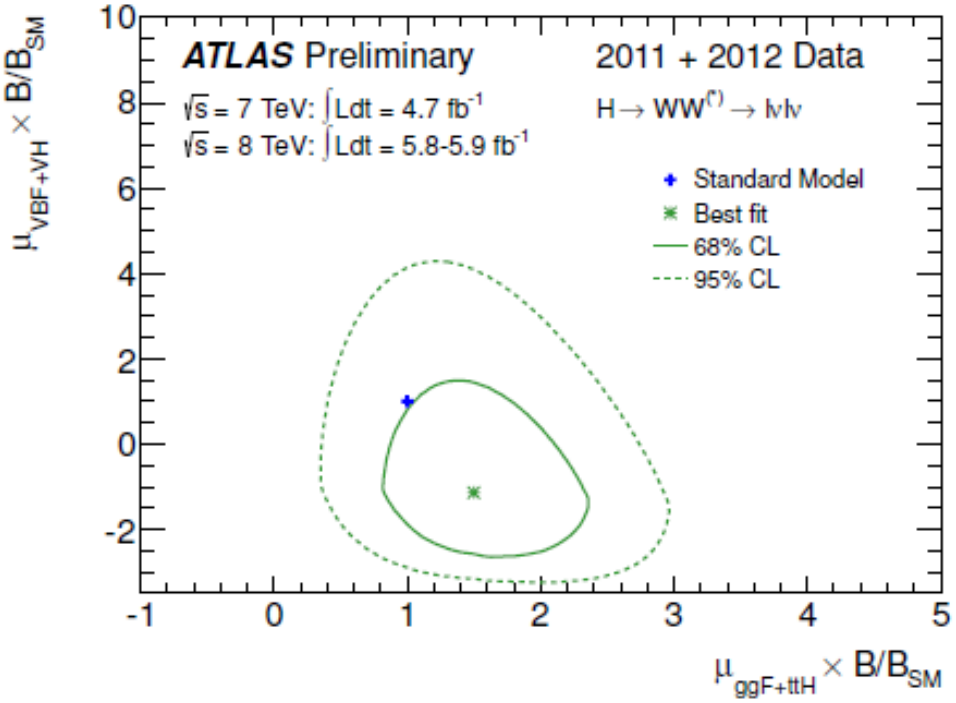
Decay	Sub-channel	N_{obs}	$\langle N_B \rangle$	$\langle N_{ggF} \rangle$	$\langle N_{VBF} \rangle$	$\langle N_{WH} \rangle$	$\langle N_{ZH} \rangle$	$\langle N_{ttH} \rangle$
$H \to \gamma\gamma$	low-p_{Tt}	7013	6820.3	138.0	6.3	3.1	1.8	0.4
	high-p_{Tt}	320	290.6	14.0	2.9	1.8	1.0	0.4
	2-jet	36	24.2	1.3	3.4	0.0	0.0	0.0
$H \to ZZ^{(*)} \to 4\ell$	–	14	5.4	5.6	0.5	0.1	0.1	0.0
$H \to WW^{(*)} \to \ell\nu\ell\nu$	0-jet	667	573.5	75.3	0.8	0.3	0.4	0.0
	1-jet	183	140.8	16.7	1.7	0.3	0.2	0.0
	2-jet	3	3.7	0.3	1.3	0.0	0.0	0.0
$H \to \tau^+\tau^-$	0-jet	9277	9304.8	17.6	0.6	0.1	0.3	0.0
	1-jet	393	406.2	3.6	1.0	0.1	0.2	0.0
	2-jet	22	28.2	0.3	0.9	0.0	0.0	0.0
	VH	164	151.9	0.7	0.1	0.2	0.3	0.0
$H \to b\bar{b}$	ZH	322	320.7	0.0	0.0	0.0	4.0	0.0
	WH	1266	1311.4	0.0	0.0	11.1	0.0	0.0

Number of selected events, bkg and expected SM signal contribution for a 126GeV Higgs boson from various production modes satisfying all selection requirements.

These numbers refer to mass windows that contain about 90% of the signal. Categories that do not provide significant discrimination for the production mode are merged.

Likelihood contours for H→γγ and H→WW→lνlν VBF+VH vs ggF+ttH





Likelihood contours for the $H \to \gamma\gamma$ and $H \to WW^{(*)} \to \ell\nu\ell\nu$ in the $(\mu_{ggF+t\bar{t}H}, \mu_{VBF+VH})$ plane including the BR factor B/B_{SM}. The quantity $\mu_{ggF+t\bar{t}H}$ (μ_{VBF+VH}) is a common scale factor for the ggF and $t\bar{t}H$ (VBF and VH) production cross sections.