ATLAS Higgs Results

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On behalf of the ATLAS collaboration

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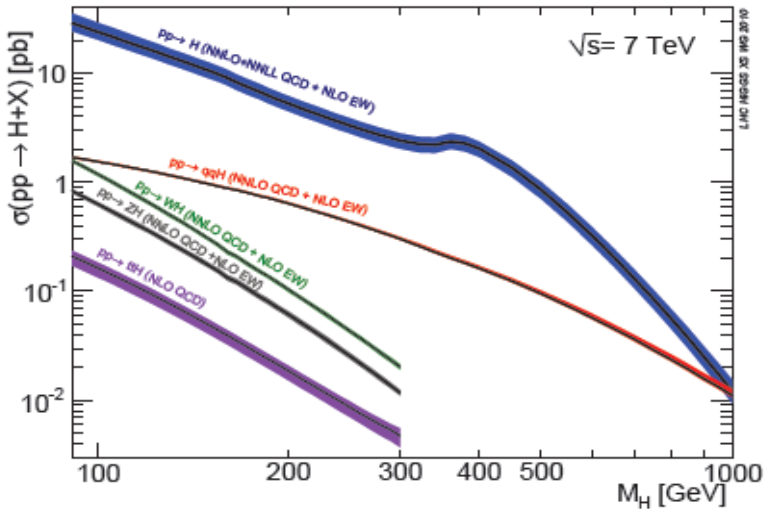
Introduction

- **ATLAS / LHC operation**
  - -- Proton-proton collisions @ 7 TeV
  - -- Recorded data by ATLAS detector: 45 pb^{-1} in 2010, 404 pb^{-1} until 27th May 2011. Data taking efficiency ~95%.

- **In this talk, we will address Standard Model Higgs searches with 2011 data if results are available, otherwise, address results with 2010 data.**
  - -- $H \rightarrow \gamma\gamma$
  - -- $H \rightarrow WW \rightarrow l\nu l\nu / l\nu qq$
  - -- $H \rightarrow ZZ \rightarrow 4l / ll\nu\nu / llqq$
  - -- Higgs combination results
  - -- Summary and prospects

Higgs @ LHC

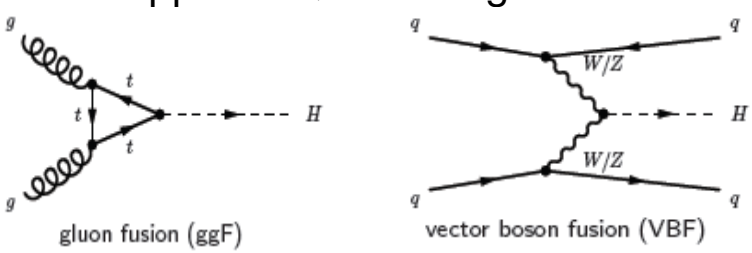
https://twiki.cern.ch/twiki/bin/view/LHCPhysics/CrossSections
"Handbook of LHC Higgs Cross Sections: 1. Inclusive Observables"(arXiv:1101.0593)

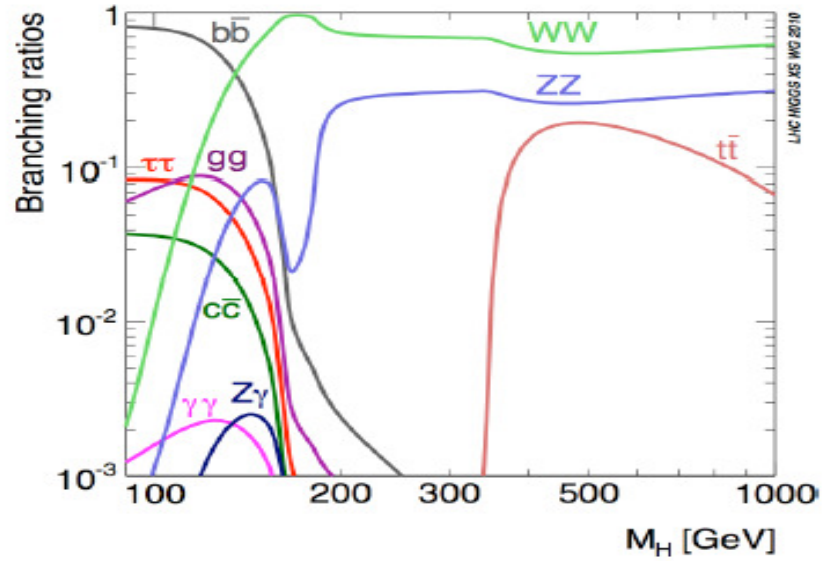


Dominant production processes:

-- ggF: an order of magnitude higher than the sum of the other processes

-- VBF: channel can be explored by tagging 2 forward jets and central jet veto to suppress QCD backgrounds.





-- $H \to bb$: dominant channel at low mass, but high QCD backgrounds

-- $H \to \tau\tau$: typically VBF

-- $H \to \gamma\gamma$: small Branching ratio (Br)

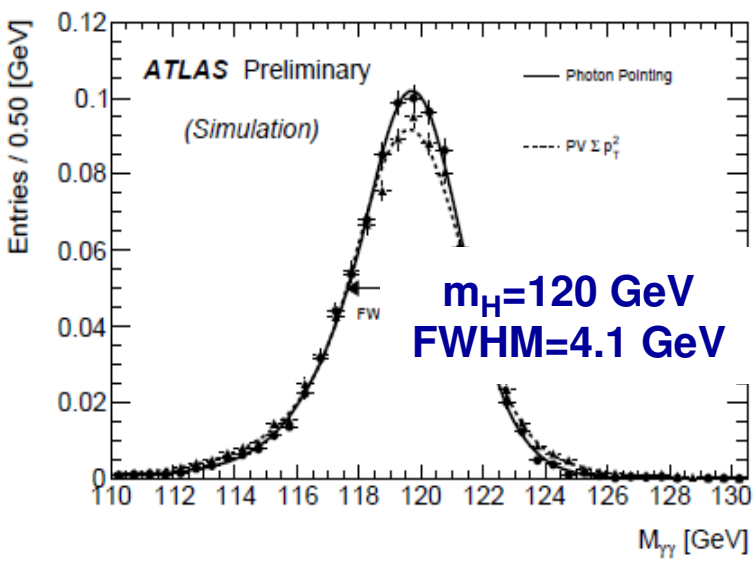
-- $H \to WW$: dominant one in intermediate and high mass region

-- $H \to ZZ \to 4l$: clean final state.
$H \to ZZ \to ll\nu\nu/llqq$: higher Br than 4l, on-shell Z bosons are assumed to reduce bkgs.

H→ γγ with 209 pb^{-1} (2011 data)

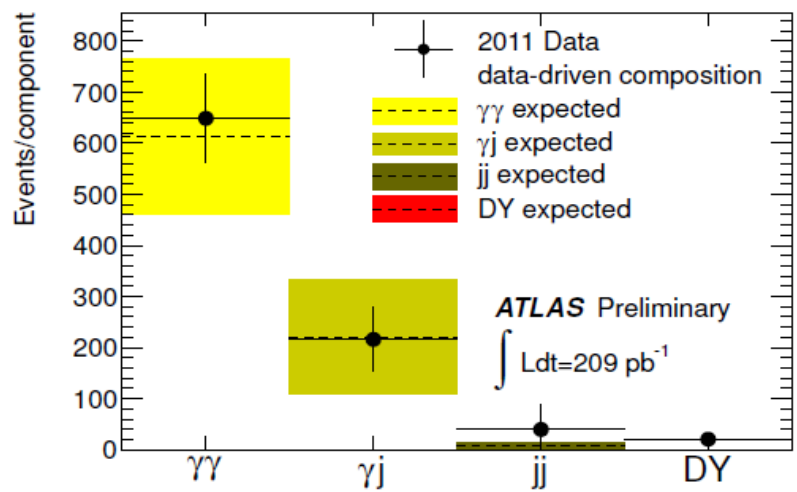
- **Selection:** 2 isolated photons, $p_{T\gamma_1} > 40\text{GeV}, p_{T\gamma_2} > 25\text{GeV}$; cut on photon isolation energy is relaxed to 5GeV mainly due to more pileup in 2011 data

- **Signal:**
  - -- small branching ratio (~ 0.002), but excellent mass resolution expected.
  - -- Mass shape is described by **Crystal Ball + Gaussian**
  - -- Primary vertex reconstruction is crucial to the invariant mass resolution.



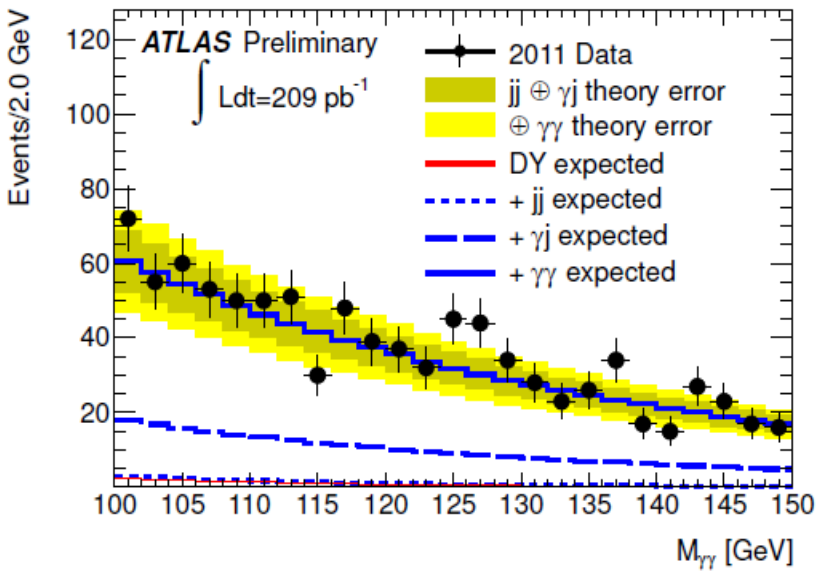
- **Backgrounds:**
  - -- γγ, γ–jet (jet faking as γ), di-jet and small Drell-Yan (electron misidentified as γ)
  - -- Each individual background has been estimated using data-driven methods (with reversed cuts control regions and Z→ee for the DY component

MC prediction v.s. estimation from data



- $M_{\gamma\gamma}$ distributions for data (**926** candidates) and the expected backgrounds from MC (862 $\pm$207).

A reasonable agreement

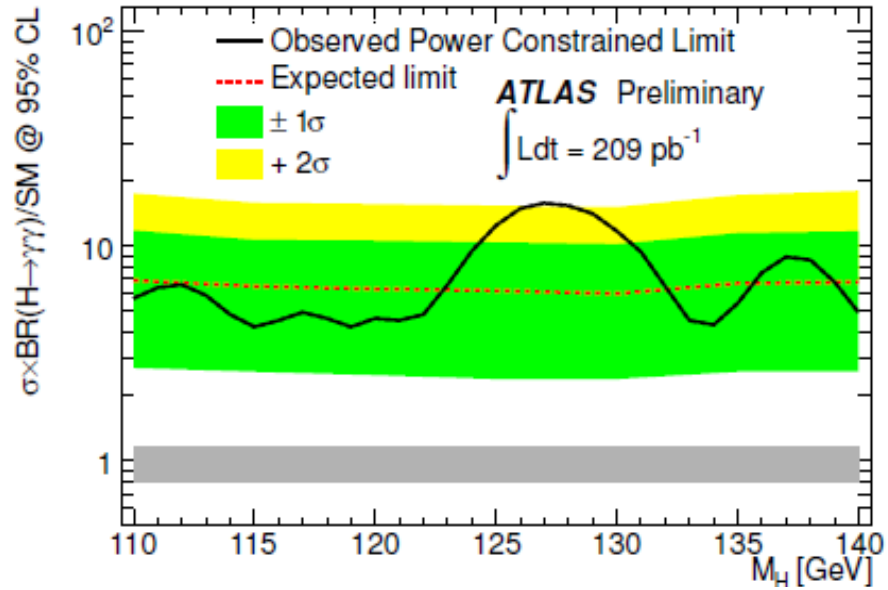


- Signal systematic uncertainties

Source	Uncertainty
Luminosity	$\pm$4.5 %
Photon identification	$\pm$10.8%
Photon Isolation	$\pm$3%
Trigger	$\pm$1%
Energy resolution	$\pm$13% on σ_M

95% C.L. exclusion limit

Background is modeled by exponential shape with two nuisance parameters



Higgs boson mass	110 (GeV)	115 (GeV)	120 (GeV)	130 (GeV)	140 (GeV)
Expected Signal	$3.5\pm0.4^{+0.7}_{-0.5}$	$3.6\pm0.4^{+0.7}_{-0.5}$	$3.6\pm0.4^{+0.7}_{-0.5}$	$3.2\pm0.4^{+0.7}_{-0.5}$	$2.5\pm0.3^{+0.5}_{-0.4}$
$1-CL_b$	55%	65%	65%	10%	52%
Expected σ_{95}/σ_{SM}	6.9	6.5	6.4	6.0	6.9
Observed σ_{95}/σ_{SM}	5.7	4.2	4.6	11.7	4.9

Fluctuations of the observed limit are compatible with expected statistical fluctuations of the background.

H→ WW→lνlν with 35 pb^{-1} (2010 data)

- Separate search into 0,1,2 jet bins p_T^{jet}>25 GeV
  - H+0j: dominated by gluon fusion
  - H+1j: primarily gluon fusion, some VBF
  - H+2j: dominated by VBF

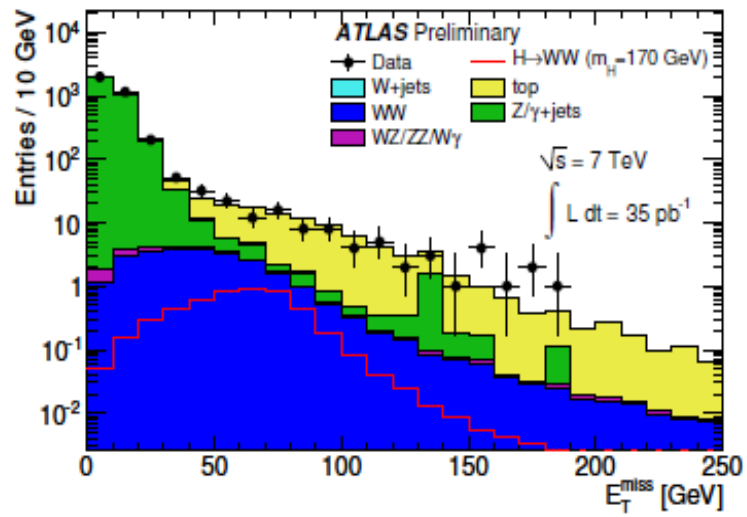
- Selection:
  - 2 leptons (e,μ), p_T>20(15) GeV
  - M_{ll} >15, $|M_Z-M_{ll}|$>10GeV (ee,μμ)
  - MET>30 GeV
  - 0 jet: pT(ll)>30 GeV(DY supression)

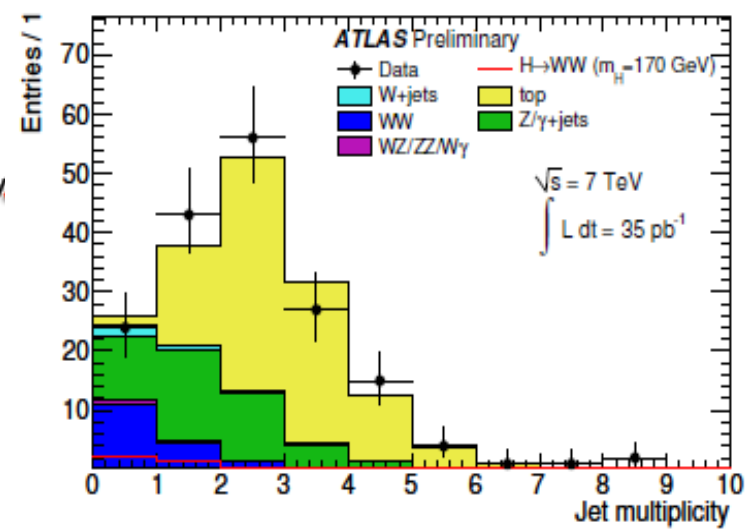
    1 jet: *b*-jet veto to suppress top backgrounds.
    P_T(total) < 30 GeV.
    Z→ττ veto ($|M_{\tau\tau}-M_Z|$ < 25 GeV).

    2 jets *b*-jet veto to suppress top backgrounds.
    P_T(total) < 30 GeV.
    Z→ττ veto ($|M_{\tau\tau}-M_Z|$ < 25 GeV).
    "VBF" cuts: $\eta_{j1}\cdot\eta_{j2} < 0$; $\Delta\eta(j1,j2) > 3.8$; $M_{jj} > 500$ GeV
    No additional jet in $|\eta|$<3.2.

  - $\Delta\phi_{ll}$ <1.3 (1.8) for M_H<170 (>=170GeV)
    (see ATLAS-CONF-2011-005 for details)
  - Transverse mass: $0.75 \cdot M_H < M_T < M_H$

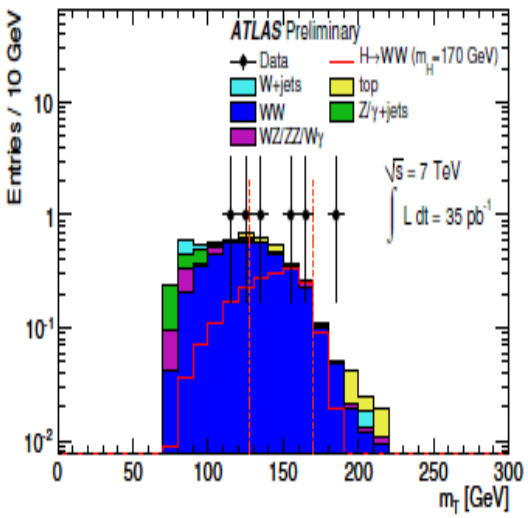
$$m_T = \sqrt{(E_T^{\ell\ell} + E_T^{miss})^2 - (\mathbf{P}_T^{\ell\ell} + \mathbf{P}_T^{miss})^2}$$





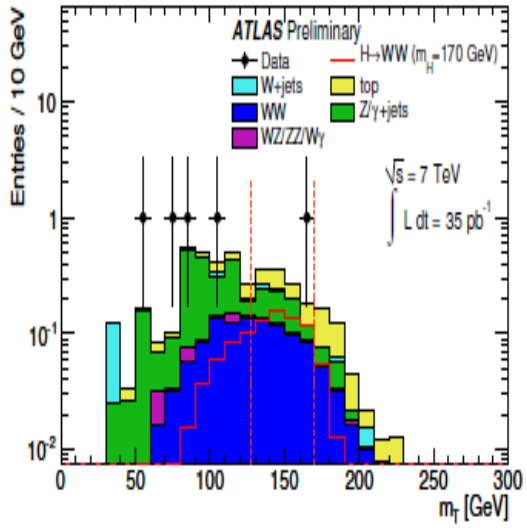
➢ Main backgrounds WW, W+jets, Z+jets, top …

- Measure number of observed events in dedicated control regions(CR) for main bkgs.
- Bkg. estimates in signal regions (SR) derived from CRs with scales estimated from data/MC
- Combine background estimated in SRs, along with uncertainties to obtain exclusion limit on signal



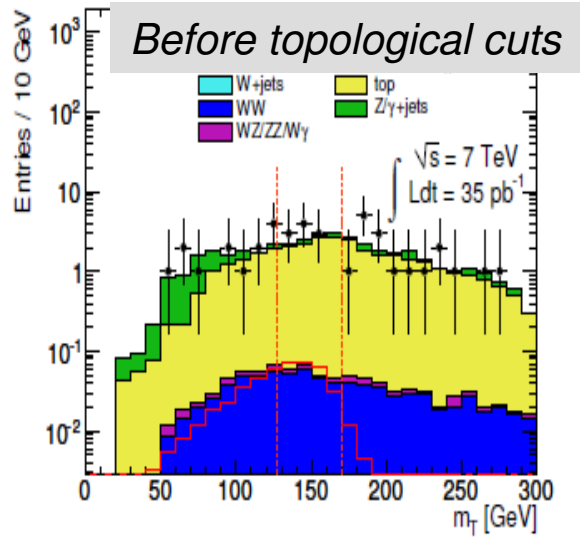
Observed	3
Bkg.	1.7±0.1
Signal	1.26±0.02

Bkgs in 0jet channel:
80% WW; 11% top;
7% Wjets; 2% di-boson



Observed	1
Bkg.	1.26±0.1
Signal	0.6±0.01

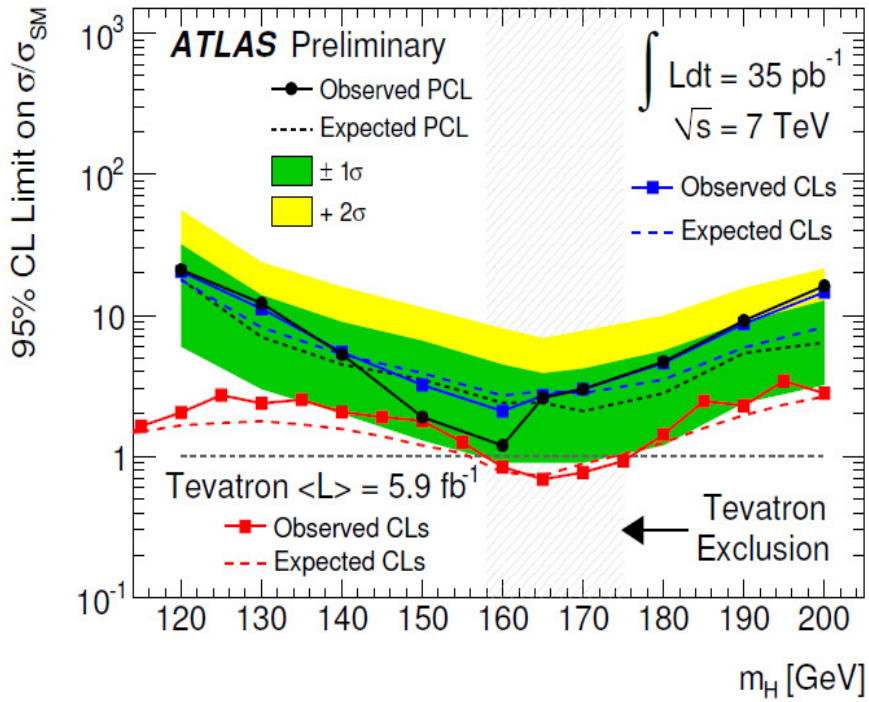
Bkgs in 1jet channel:
42% top; 32% WW;
25% Wjets; 1% di-boson



Observed	0
Bkg.	0.02±0.01
Signal	0.06±0.01

Bkgs in 2jets channel:
O(50%) top
O(50%) WW

95% C.L. exclusion limit presented in the mass range of 120-200 GeV



- ATLAS: at m_H=160 GeV, expected limit using PCL method is 2.4 X σ_{SM}

- Tevatron yield a 95% C.L. exclusion for Higgs boson masses in 158 ~ 175 GeV

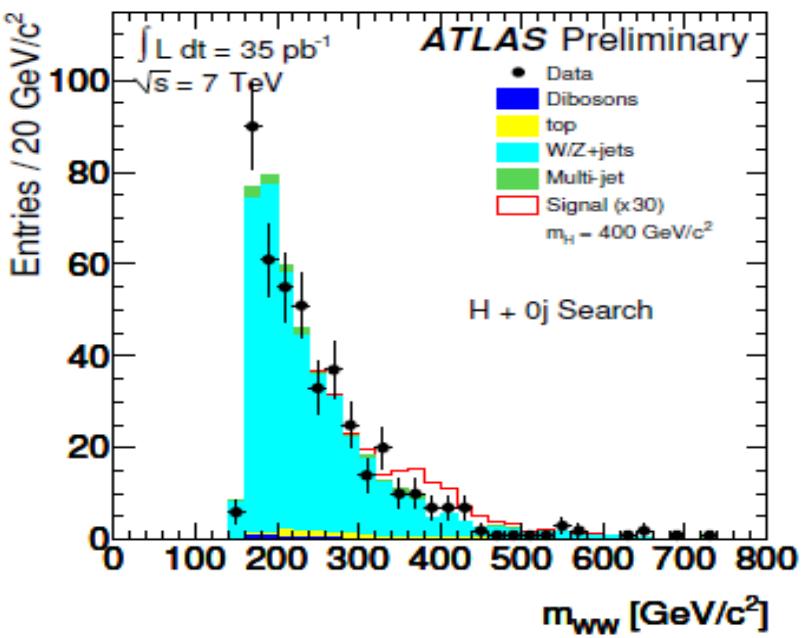
H→ WW→lνqq with 35 pb^{-1} (2010 data)

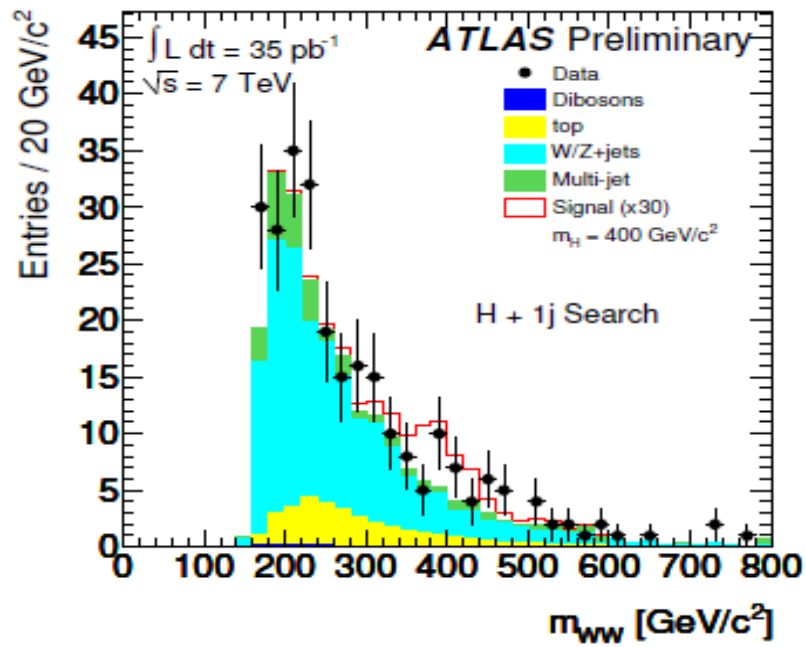
- Selections:

- One lepton with p_T>30 GeV, veto events with additional lepton with p_T>20 GeV
- MET>30 GeV
- Exactly two/three jets in |eta|<4.5; The pair of jets with invariant mass closest to the W boson are required to satisfy $71<M_{qq}<91$ GeV with |eta|<2.8; b-jet veto

- Mass reconstruction :

- $m_{l\nu qq}$ is reconstructed with a W boson mass constraint on the lepton-neutrino systerm giving rise to a quadratic equation. If two solutions, the lower longitudinal momentum one is taken; if complex solution, the real part is taken.





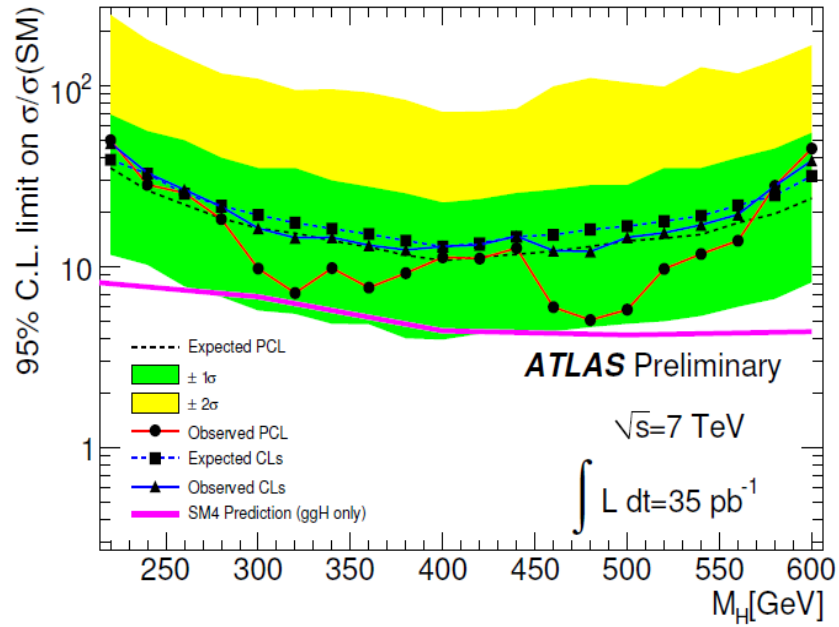
- Expected and observed event yields in H+0j and H+1j

	H($e\nu qq$) + 0j	H($\mu\nu qq$) + 0j	H($e\nu qq$) + 1j	H($\mu\nu qq$) + 1j	H + 0j or 1j
W/Z+jets	157 ± 22	259 ± 34	39.1 ± 6.2	119 ± 12	574 ± 43
Multi-jet	11.1 ± 1.6	4.5 ± 0.6	17.7 ± 2.8	13.3 ± 1.3	46.7 ± 3.5
Top	5.3 ± 1.7	7.7 ± 2.5	15.5 ± 5.0	18.2 ± 5.8	46.7 ± 14.9
Dibosons	1.8 ± 0.3	3.0 ± 0.4	0.6 ± 0.1	0.9 ± 0.1	6.3 ± 0.9
Expected Background	175 ± 22	275 ± 34	72.9 ± 8.4	151 ± 13	674 ± 45.7
Observed	177	273	87	176	713
Signal (m_H = 400 GeV)	0.5 ± 0.2	0.6 ± 0.2	0.5 ± 0.2	0.5 ± 0.2	2.1 ± 0.7

- Systematic uncertainties on the signal efficiency

Source	Uncertainty on Signal Efficiency
Electron Efficiency	±5%
Muon Efficiency	±2%
Jet Energy Scale	±26%
Luminosity Measurement	±11%
Theory Error on $\sigma(gg \to H)$	±19%

95% C.L. exclusion limit

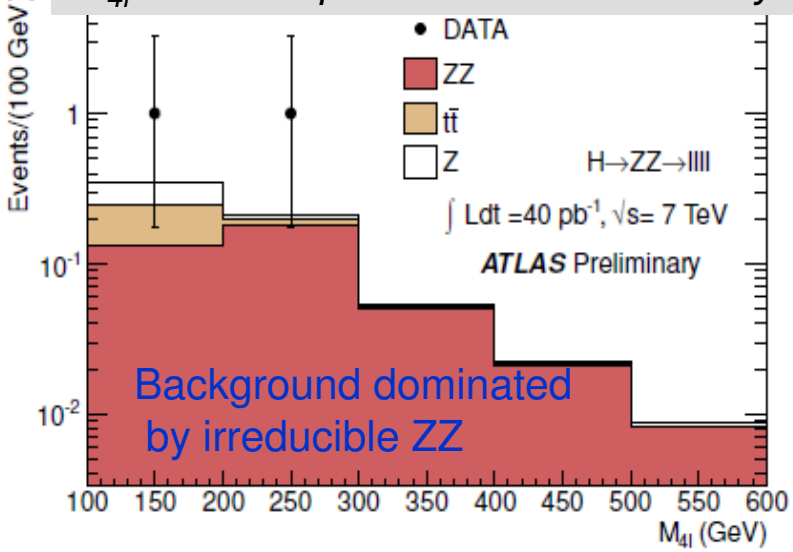


- At m_H=400 GeV, using PCL method excludes: 10.8 x σ_{SM} (exp)

H→ ZZ→4l with 40 pb^{-1} (2010 data)

- Experimentally cleanest channel
- Low leptonic branchings penalize its event yield
- Selections: - two pairs of opposite sign and same flavor leptons (e,μ)
  - at least two leptons with p_T>20 GeV
  - requirements on the di-lepton masses

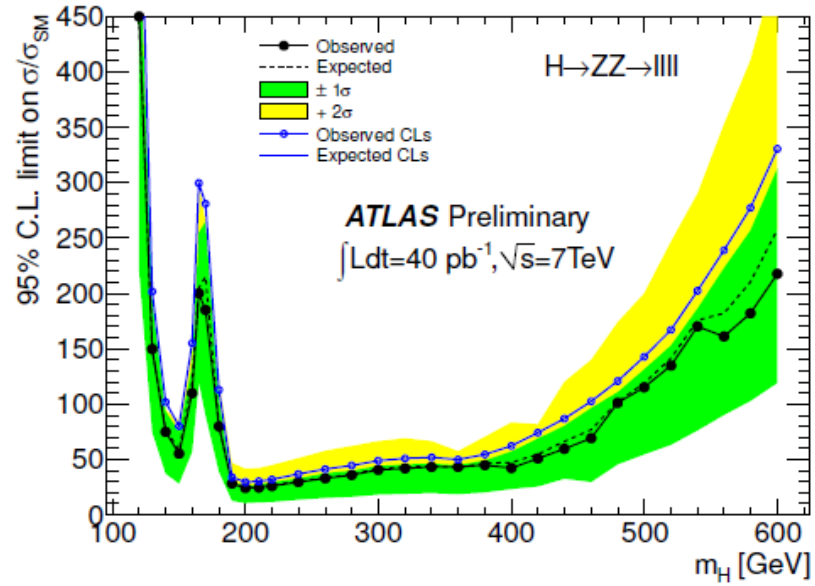
M_{4l} after di-lepton kinematic cuts only



m_H (GeV)	130	200
Total background	0.010±0.002	0.090±0.014
$H \to ZZ^{(*)} \to \ell\ell\ell\ell$	0.015±0.003	0.095±0.017
Observed	0	0

No candidates survive the final selections

95% C.L. exclusion limit



-- With 2010 integrated luminosity, not the most sensitive channel at any m_H

-- At m_H=200 GeV, 24xσ_{SM} excluded.

H→ ZZ→llqq/llνν with 35 pb^{-1} (2010 data)

- Less clean but a higher signal expectation than 4l channel
- Selections:

  -- 2 leptons (e,μ) with p_T>20GeV, 76 GeV < M_{ll} <106 GeV

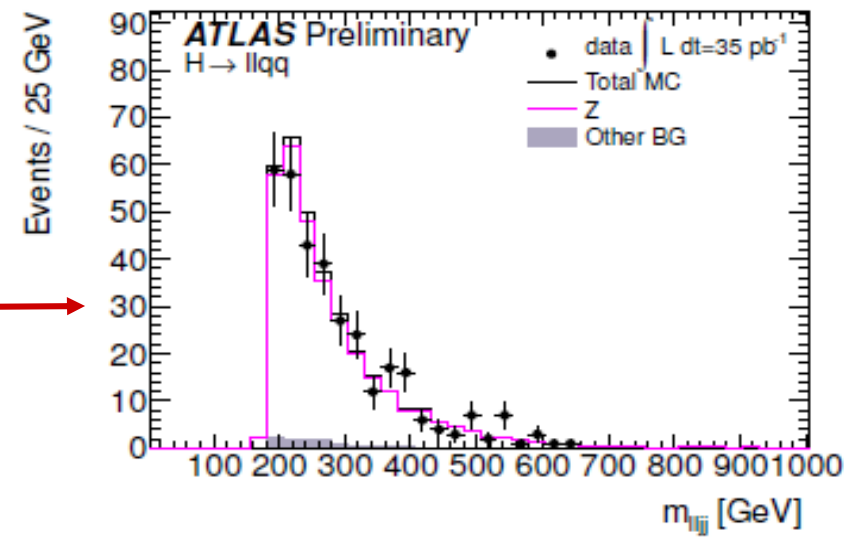
  -- llqq: MET<50 GeV , 70< Mjj<105 GeV, M_H>360 GeV: p_T(jets)>50GeV; $\Delta\phi_{ll}, \Delta\phi_{jj} < \pi/2$

  -- llνν: MET>66/82 GeV, b-jet veto, $\Delta\phi_{ll}$ <2.64/2.25 for M_H</⩾ 260 GeV

- Backgrounds: ZZ/WZ from MC; other background contributions are controlled by means of control samples

  -- Z+jet: checked in jet-jet sidebands:
  40 < m_{jj} < 70 GeV or 105 < m_{jj} < 150 GeV

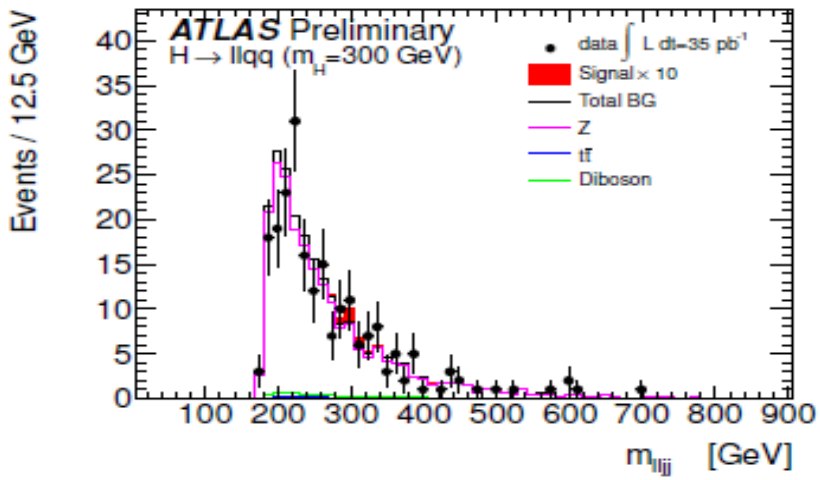
Invariant mass of lljj system for Z+jets control region



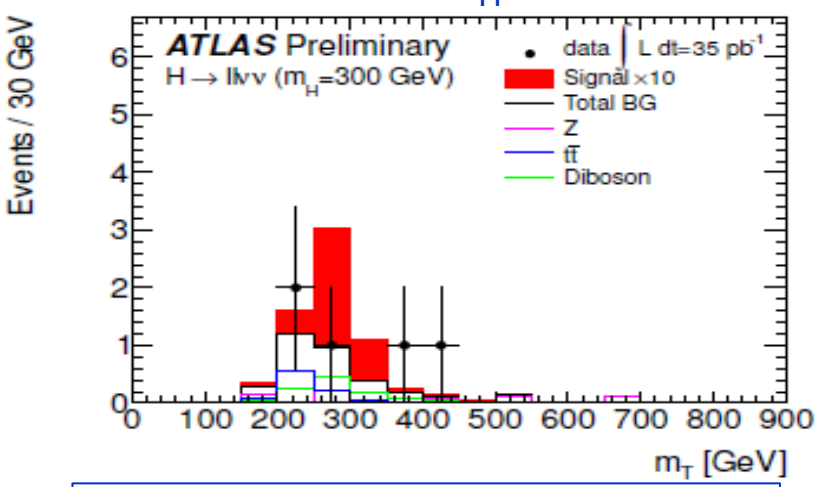
-- ttbar: checked in lepton-lepton sidebands: m_{ll} below and above Z peak

-- ...

- Invariant mass distribution of lljj system after all selection cuts for m_H=300 GeV

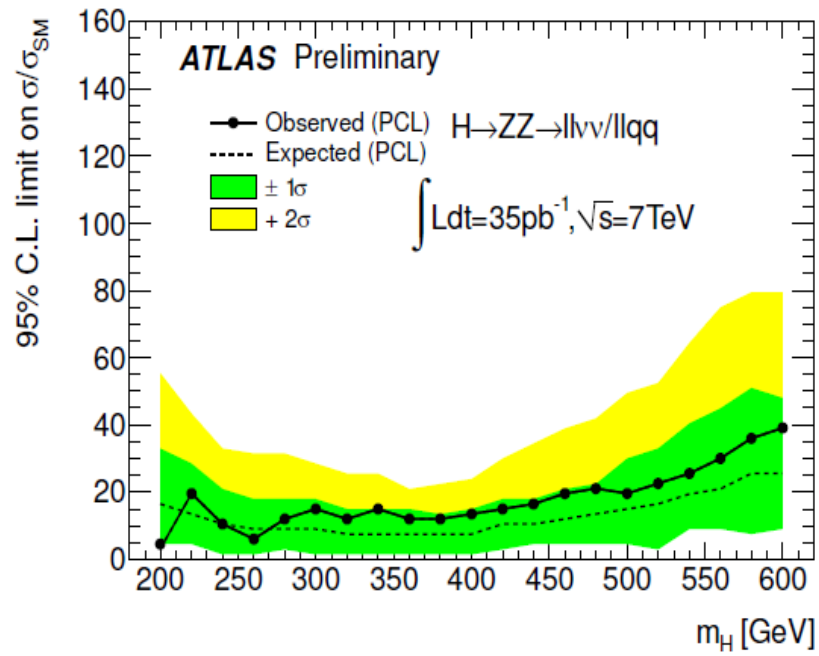


- Dilepton transverse mass distribution in H->ZZ->llvv for m_H=300 GeV



$$m_T^2 \equiv \left[\sqrt{m_Z^2 + |\vec{p}_T^{\,\ell\ell}|^2} + \sqrt{m_Z^2 + |\vec{p}_T^{\,\mathrm{miss}}|^2}\right]^2 - \left[\vec{p}_T^{\,\ell\ell} + \vec{p}_T^{\,\mathrm{miss}}\right]^2$$

95% C.L. exclusion limit

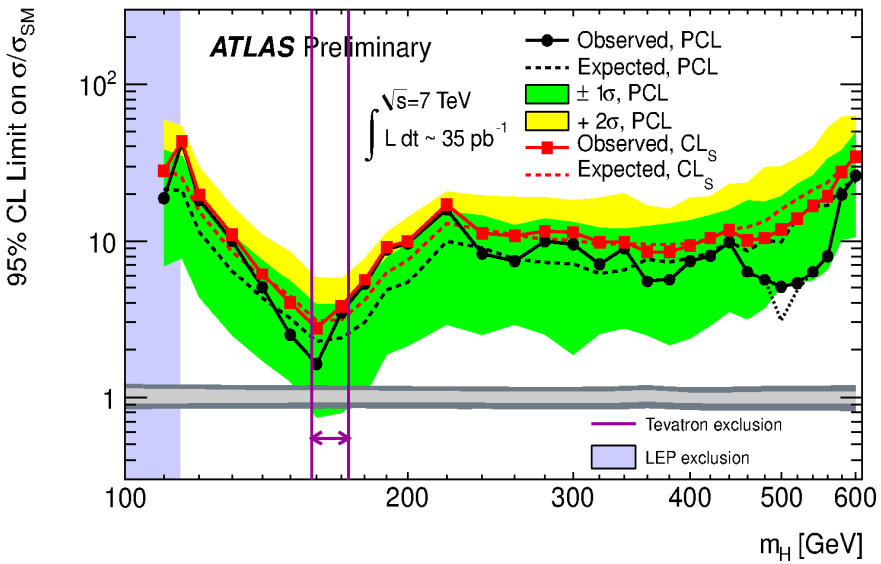


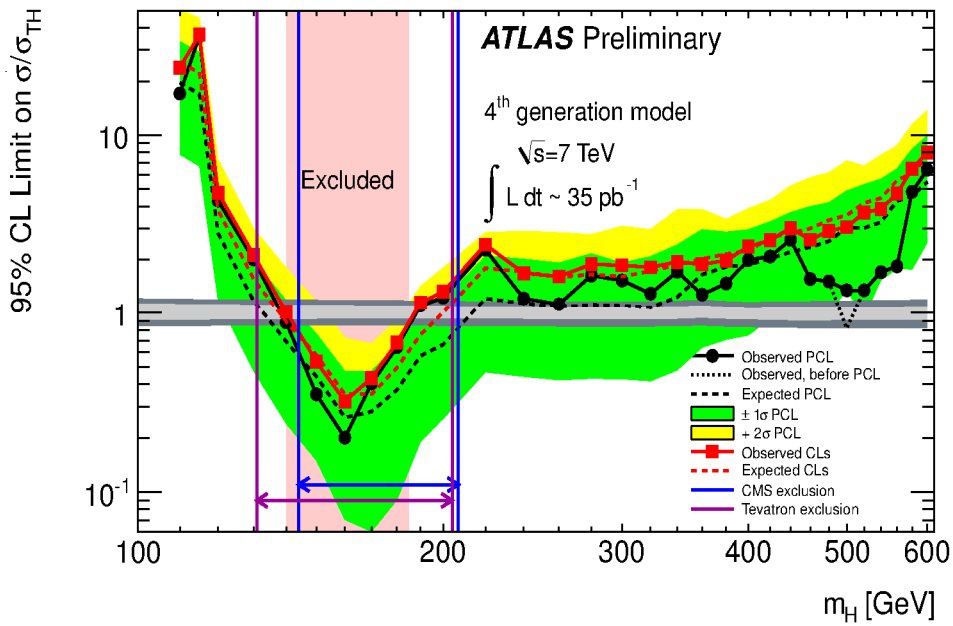
Expected upper limit on the combined H->ZZ->llvv/llqq signal rate:

6.5 ~ 24.5 σ_{SM} depending on mass!

Higgs Combination

Mode	Mass range, GeV
$H \to \gamma\gamma$	110 – 140
$H \to WW^{(*)} \to \ell\nu\ell\nu$	120 – 200
$H \to WW \to \ell\nu qq$	220 – 600
$H \to ZZ^{(*)} \to \ell\ell\ell\ell$	120 – 600
$H \to ZZ \to \ell\ell\nu\nu$	200 – 600
$H \to ZZ \to \ell\ell qq$	200 – 600





- Limit on the total cross section divided by the expected Standard Model Higgs boson cross section.
- Highest sensitivity is in the mass range 160-170 GeV. Exclusion limit @ 95% C.L. is 2.3 X SM prediction for a 160 GeV Higgs

- Limit on the total cross section divided by the expected one when a 4th Generation of high mass quarks and leptons with SM-like coupling to the Higgs boson are included In the cross section calculations.
- Excluded for a Higgs mass in range 140 - 185GeV.

Summary Prospects

❖ ATLAS detector performs very well.
ATLAS has measured most possible SM channels : H->γγ, H->WW->lvlv/lvqq, H->ZZ->4l,llvv/llqq.

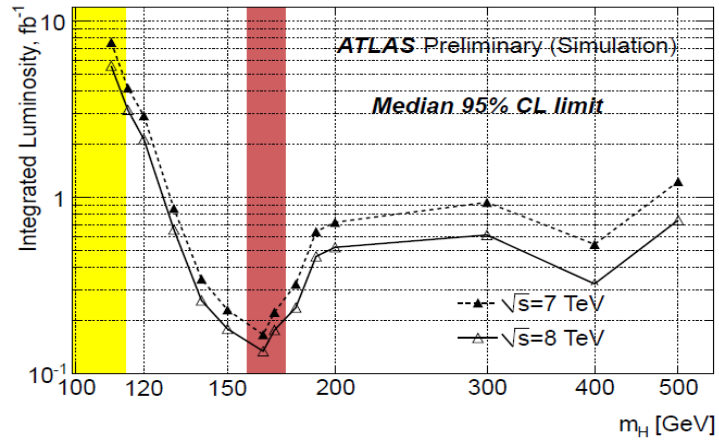
Dominant background contributions determined with data-driven methods.

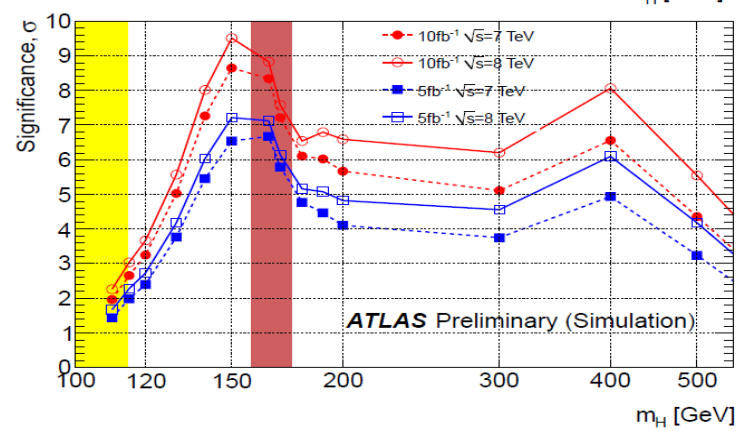
No evidence for SM Higgs boson yet!

❖ 95% C.L. exclusion limit
H->γγ search excludes 6~7X σ_{SM}.

H->WW->lvlv search excludes a 160 GeV SM Higgs with $2.4\times\sigma_{SM}$ (exp)

Limit is expected to be improved with more than 1fb^{-1} data by the end of 2011!





❖ **ATLAS Prospects:**
- with 1 fb^{-1} @ 7TeV, expects to exclude a SM Higgs in 130<m_H<460 GeV.
- with 5-10 fb^{-1} @ 8TeV: 3σ evidence or 5σ discovery is expected in 120<m_H<500 GeV

More results with SM/non-SM Higgs , see Marc Escalier's plenary talk: "*Recent Higgs results from ATLAS*"

Backup Slides

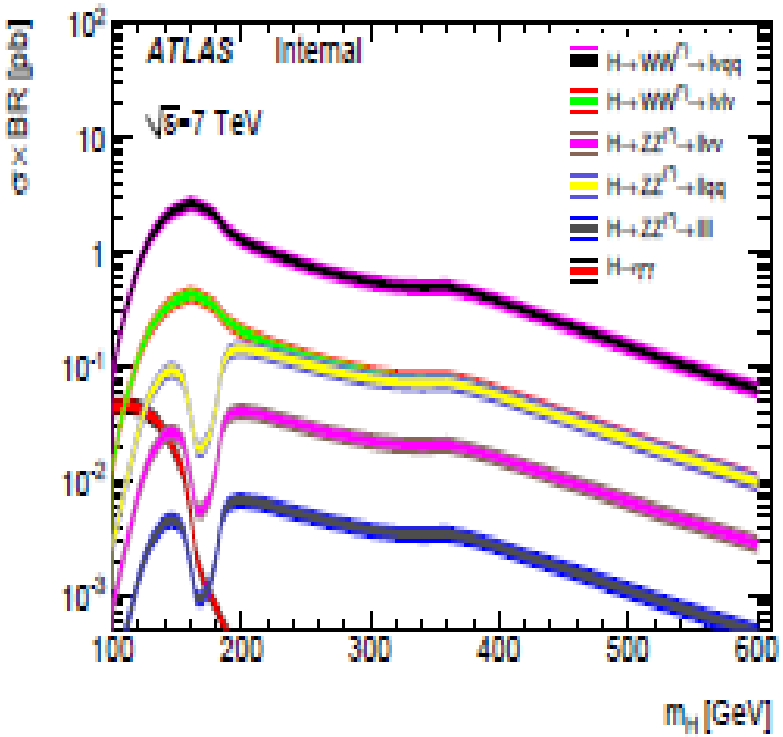
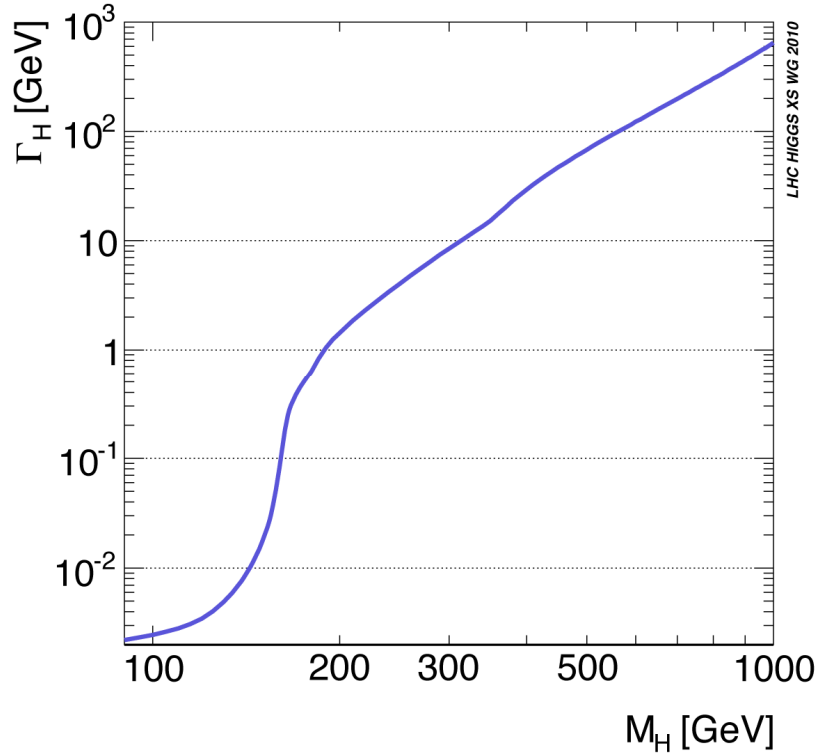


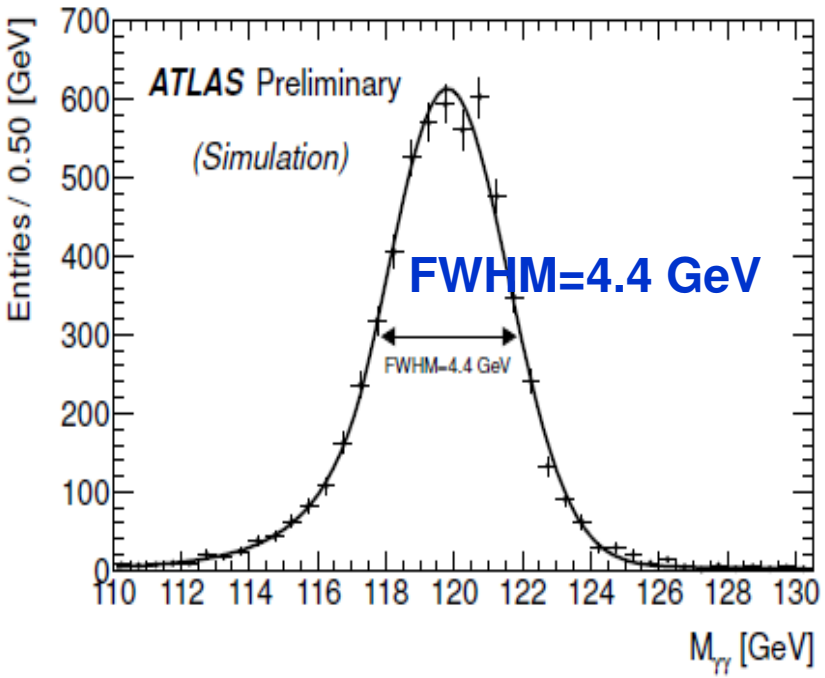
Fig. 1. The production cross section multiplied by decay branching ratios for Standard Model Higgs boson production in *pp* collisions at a 7 TeV centre-of-mass energy. All production modes are summed, and only final states which are studied in this paper are shown. Two bands are shown for each curve; the inner represents the QCD scale uncertainty and the outer also includes the PDF uncertainty.



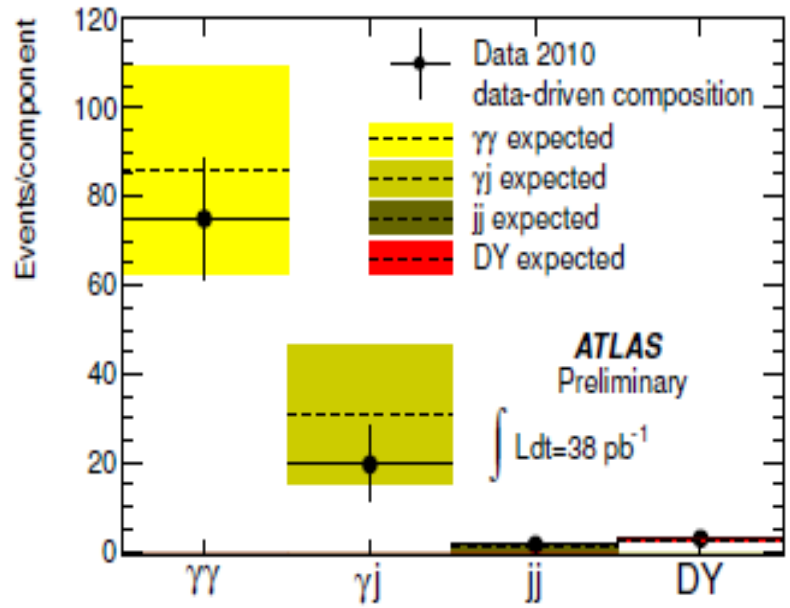
SM Higgs total width as a function of Higgs boson mass.

$H \rightarrow \gamma\gamma$ Channel (2010 data)

-- **Selection: 2 isolated photons, $p_{T\gamma_1} > 40GeV, p_{T\gamma_2} > 25GeV$**
-- **Signal: small branching ratio, but excellent mass resolution expected.**
-- **Backgrounds: $\gamma\gamma, \gamma jet$ (jet faking as photon), di-jet and small DY (electron misidentified as photon)**

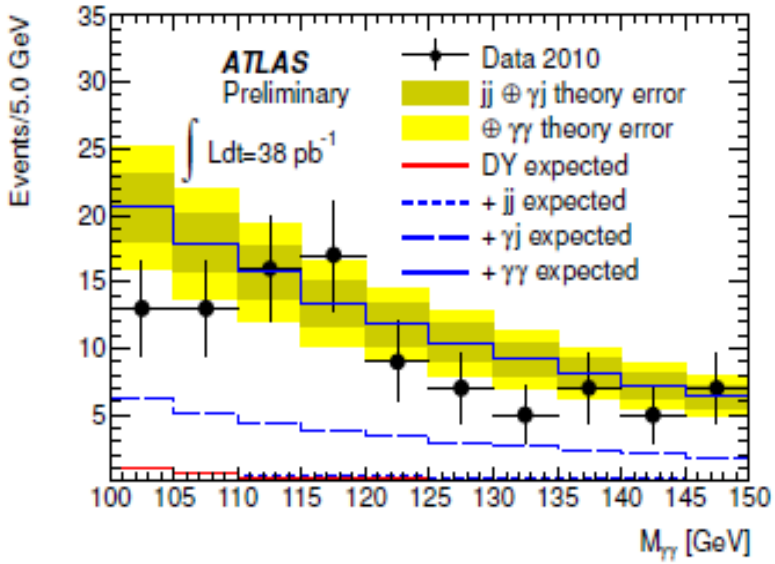


Primary vertex reconstruction is crucial to the invariance mass reconstruction.



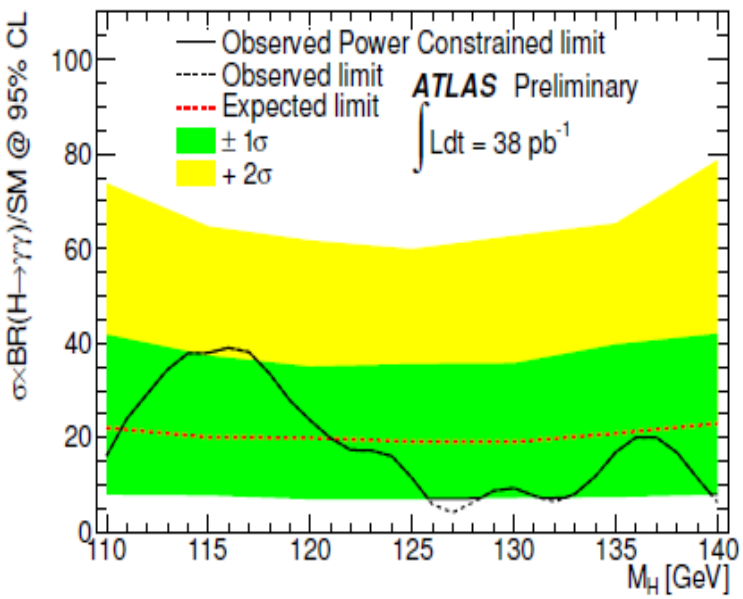
Each individual background component has been estimated using data-driven methods (with reversed cuts control regions) and Z→ee for the DY component

$H \rightarrow \gamma\gamma$ Channel (2010 data)



Diphoton invariance mass distributions for data Data and the expected backgrounds from MC.

Comparison with data shows a reaonable agreement



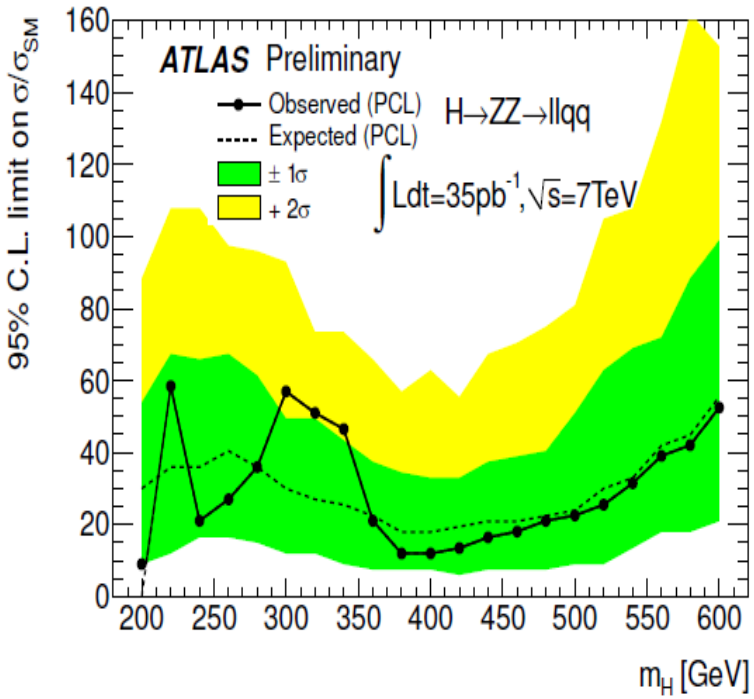
-- Limits are set using a Power Constrained Limit (PCL) method.

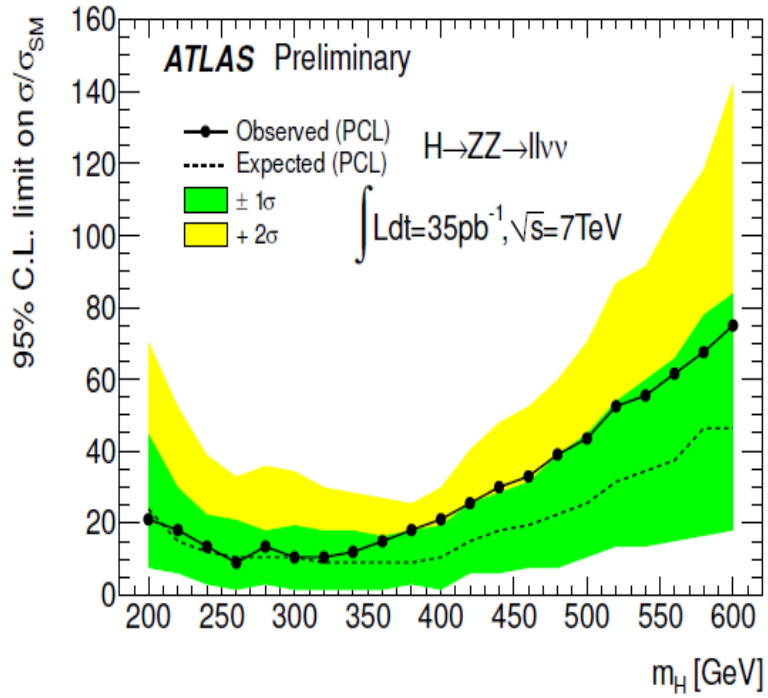
-- The exclusion limit ranges from $8\times\sigma_{SM}$ at m_H=127 GeV to $38\times\sigma_{SM}$ at m_H =116 GeV

-- Observed limit taking into account systematics is Comparable with 2010 results of Tevatron.

H->ZZ->llqq/llvv with 35pb^{-1} (2010 data)

95% C.L. exclusion limit in llqq and llvv channel, **separately**





- **H->ZZ->llqq: Observed limit is 8.5 ~ 52.5 x σ_{SM} depending on mass!**
- **H->ZZ->llvv: Observed limit is 21.0 ~ 75.0 x σ_{SM} depending on mass!**