Higgs Properties Measurement using $H \rightarrow ZZ^* \rightarrow 4\ell$ Decay Channel

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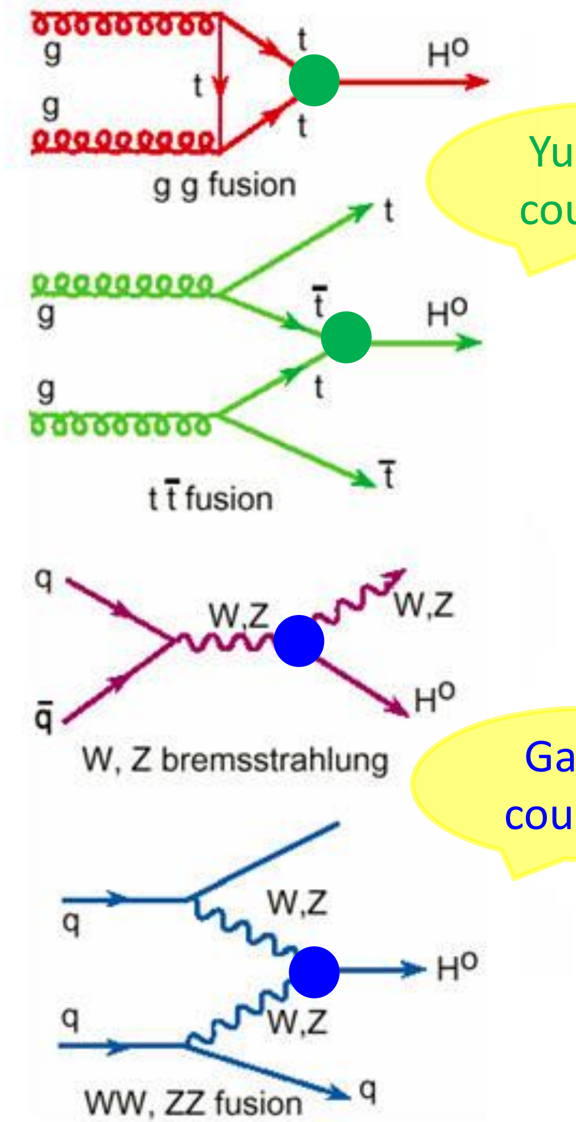
The 23rd ATLAS Chinese Cluster Meeting

IHEP, Beijing, 2013. 3. 3

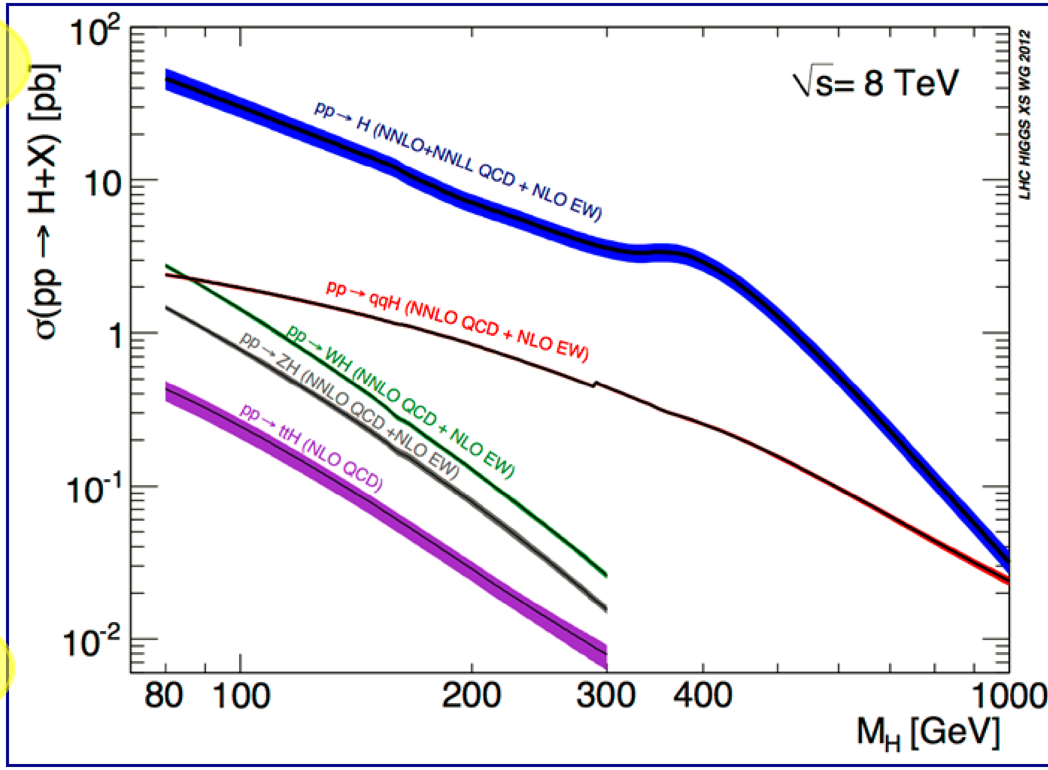
Higgs Boson Production at LHC



Yukawa coupling

Gauge coupling

Gluon-gluon fusion gg→H and vector-boson fusion qq→qqH are dominant



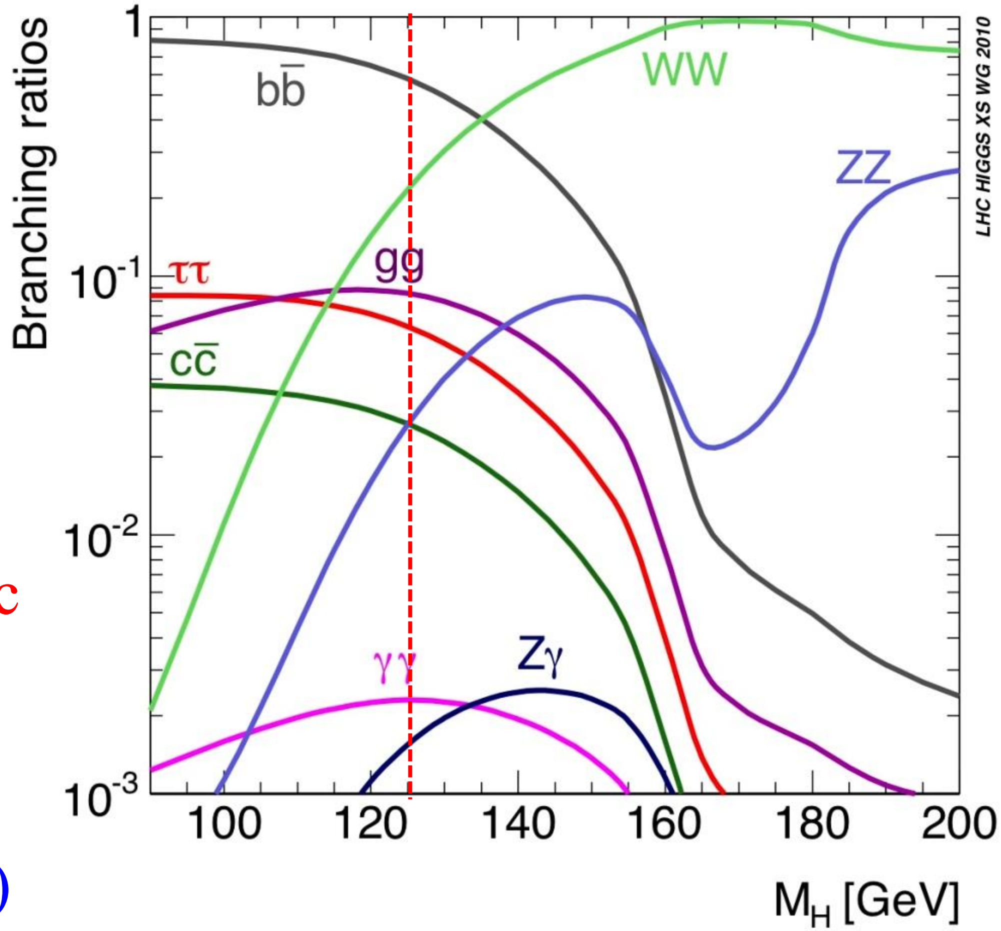
$$@125\text{ GeV: } \sigma_{ggH} = 19.5\text{ pb}, \sigma_{VBF} = 1.6\text{ pb},$$
$$\sigma_{WH} = 0.70\text{ pb}, \sigma_{ZH} = 0.39\text{ pb}, \sigma_{ttH} = 0.13\text{ pb}$$

Inelastic pp cross section at 7 TeV is ~ 60 mb

Higgs Boson Decay

Higgs decay branching ratio at m_H=125 GeV

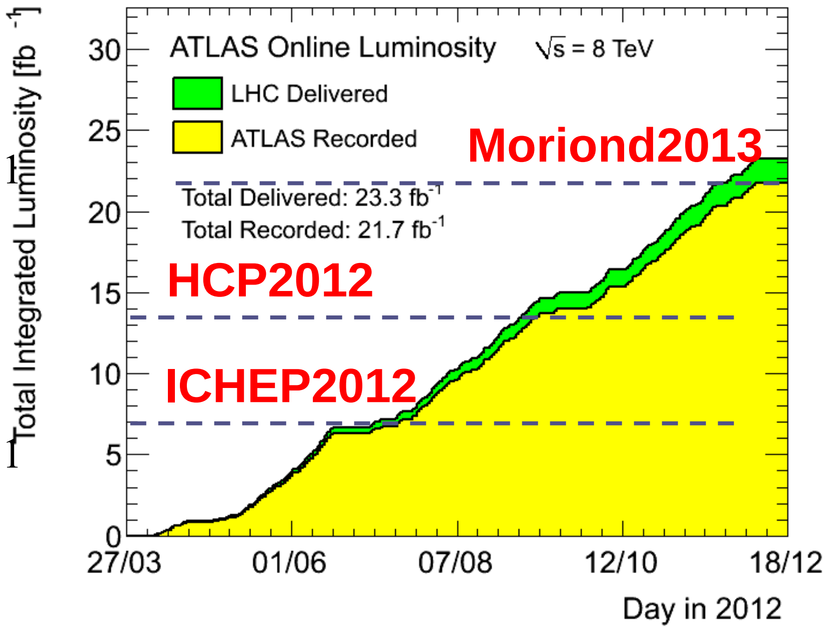
- bb: 57.7% (huge QCD background)
- WW: 21.5% (easy identification in di-lepton mode, complex background)
- ττ: 6.3% (complex final states with τ leptonic and/or hadronic decays)
- ZZ*: 2.6% ("gold-plated", clean signature of 4-lepton, high S/B, excellent mass peak)
- γγ: 0.23% (excellent mass resolution, high sensitivity)

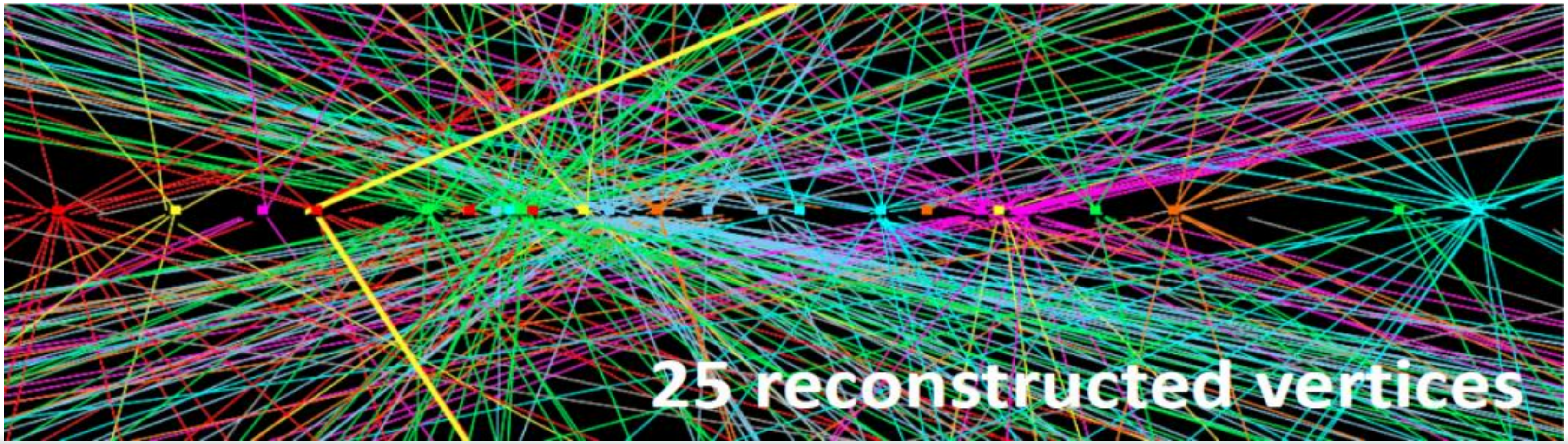


Higgs boson production rate:
1 out of 10^{12} collision events

ATLAS Data Samples

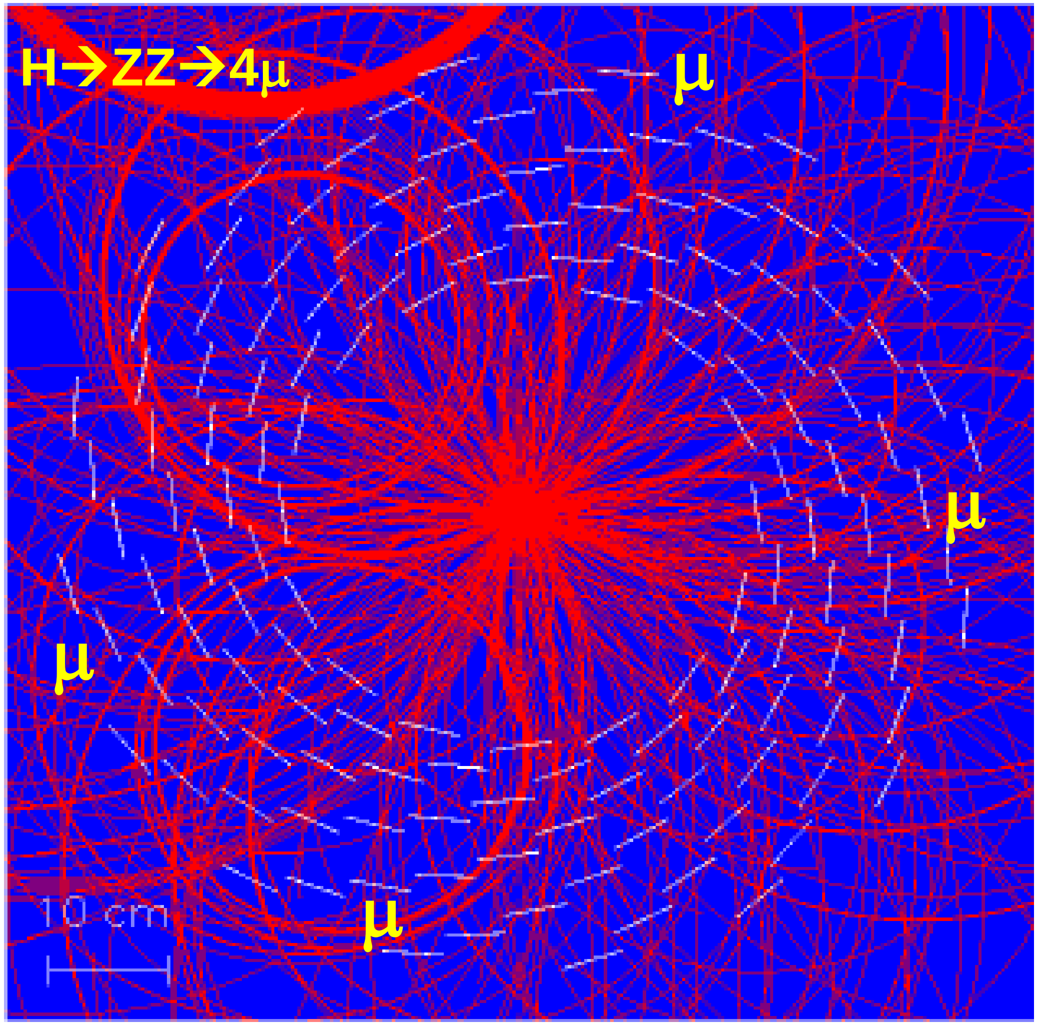
- **7 TeV data samples (2011)**
  - 4.8 fb^{-1} for physics analysis
  - Peak luminosity $3.6\times10^{33}cm^{-2}s^{-1}$
- **8 TeV data samples (2012)**
  - 20.7 fb^{-1} for physics analysis
  - Peak luminosity $7.7\times10^{33}cm^{-2}s^{-1}$
- **Data-taking efficiency: ~94%**
- **Significant pileup events**



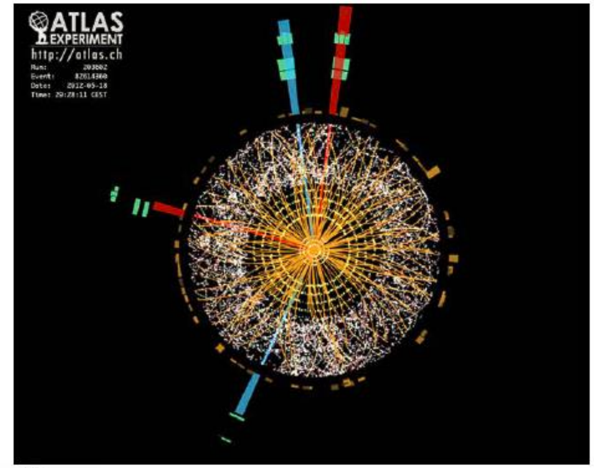


Major Challenge

- Large pileup events result in big challenge to the detector, reconstruction and particle identification !



Higgs → ZZ* → 4ℓ



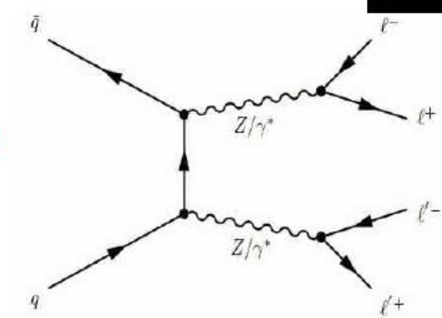
The gold-plated channel over a wide range of potential Higgs mass.

Clean signature:

- 4 isolated leptons, full reconstruction;
- Mass peak over backgrounds, good mass resolution.

Small backgrounds:

Irreducible SM ZZ* production and reducible Z+jets, top, …



$$\ell = e, \mu$$

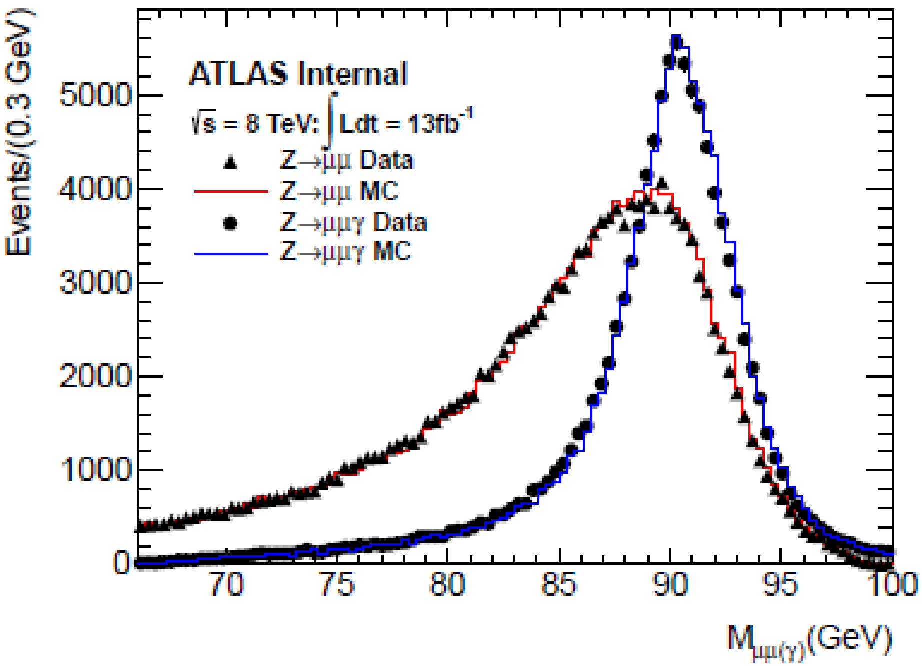
But even smaller signal rate: @125 GeV

$$\mathrm{BR}\left(ZZ \to 4\ell\right) = 0.45\%,\ \mathrm{BR}\left(H \to ZZ^*\right) = 2.6\%$$
$$\Rightarrow\ \sigma_H \times \mathrm{BR}\left(H \to ZZ \to 4\ell\right) = 2.6\ \mathrm{fb}$$

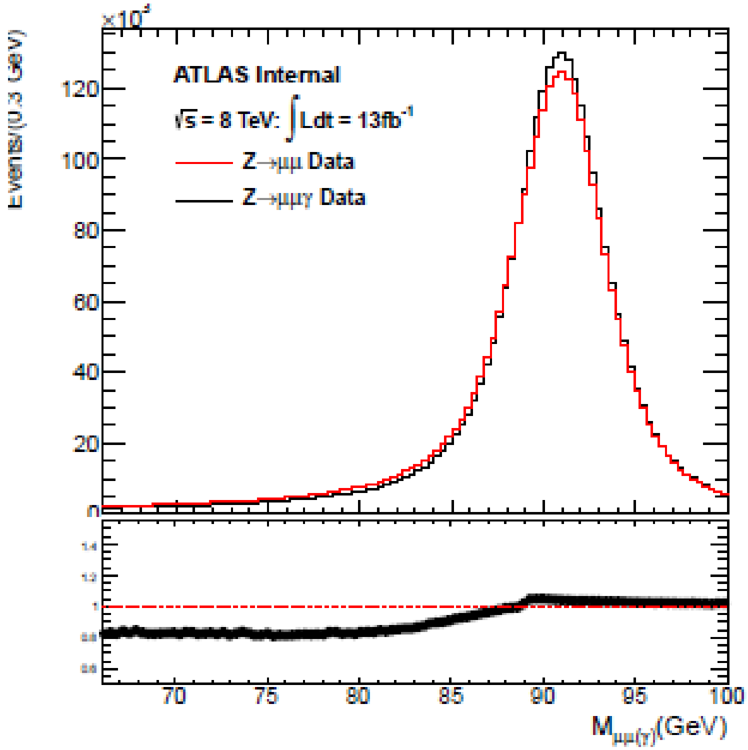
Selection efficiency to the 4th power of lepton efficiency:

$0.7^4 \sim 0.25$, $0.8^4 \sim 0.41 \Rightarrow$ critical to improve lepton selection!

Impact of the FSR Correction



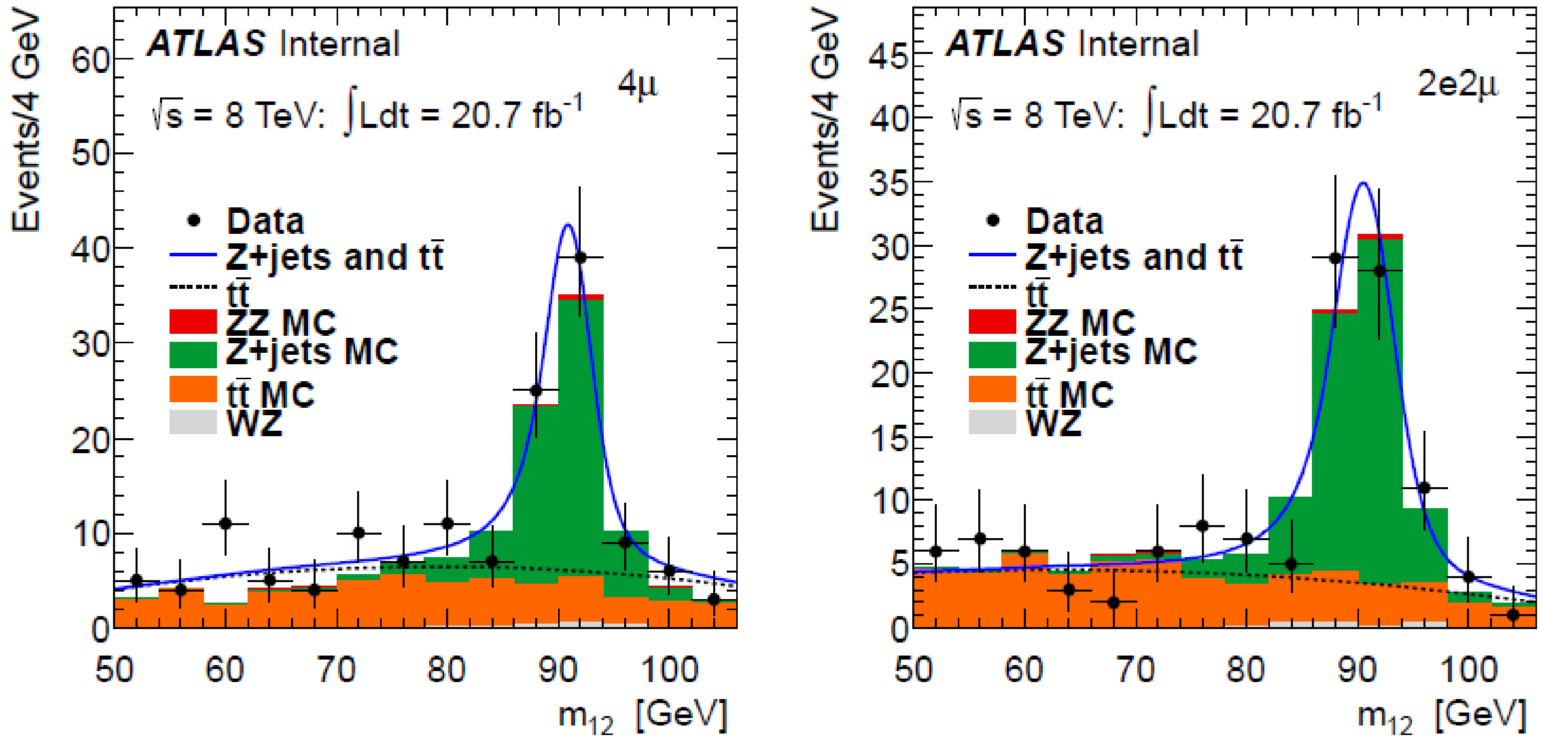
(a) Impact of the FSR correction on the invariant mass of the Z boson candidates.



(b) Comparison of the invariant mass spectra of $Z \to \mu\mu$ candidate events without and with reconstructed FSR photons after FSR correction.

- Photon energy > 1 GeV

Estimation of ttbar, Zbb background



- The control region: four-lepton analysis selection except for isolation requirements on the sub-leading pair and at least one sub-leading leptons is required to fail the IP significance requirement, to suppress *ZZ*.

Estimation of ttbar, Zbb background

- Ttbar and Zbb background estimation using a fit on m_{12} distribution (2^{nd} order Chebychev polynomial for ttbar, Briet-Wigner line shape with Crystal-Ball resolution function for Zbb)

	$t\bar{t}$	$Z+b\bar{b}$
4μ data fit	$0.141 \pm 0.028 \pm 0.028$	$2.028 \pm 0.489 \pm 0.509$
4μ MC	$0.091 \pm 0.012 \pm 0.018$	$1.030 \pm 0.158 \pm 0.258$
$2e2\mu$ data fit	$0.096 \pm 0.020 \pm 0.019$	$2.102 \pm 0.444 \pm 0.527$
$2e2\mu$ MC	$0.107 \pm 0.013 \pm 0.021$	$0.910 \pm 0.140 \pm 0.228$

Summary of Inclusive Backgrounds

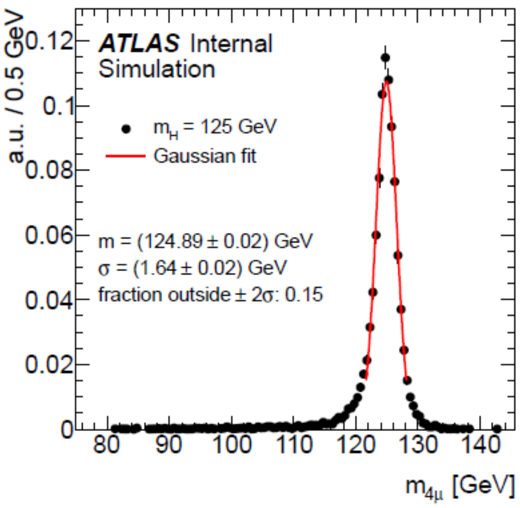
7 TeV, 4.6fb^{-1}

Method	Estimate
4μ	
m_{12} fit: $Z+$jets contribution	$0.226 \pm 0.074 \pm 0.025$ †
m_{12} fit: $t\bar{t}$ contribution	$0.028 \pm 0.009 \pm 0.012$ †
$2e2\mu$	
m_{12} fit: $Z+$jets contribution	$0.186 \pm 0.061 \pm 0.021$ †
m_{12} fit: $t\bar{t}$ contribution	$0.028 \pm 0.009 \pm 0.012$ †
$2\mu 2e$ OS	
$\ell\ell + ee$ OS in (p_T, η) bins	$1.8 \pm 0.3 \pm 0.4$ †
$2\mu 2e$ SS	
$3\ell + e$ average	$2.8 \pm 0.4 \pm 0.5$
$4e$ OS	
$\ell\ell + ee$ OS in (p_T, η) bins	$1.4 \pm 0.3 \pm 0.4$ †
$4e$ SS	
$3\ell + e$ average	$2.5 \pm 0.3 \pm 0.5$

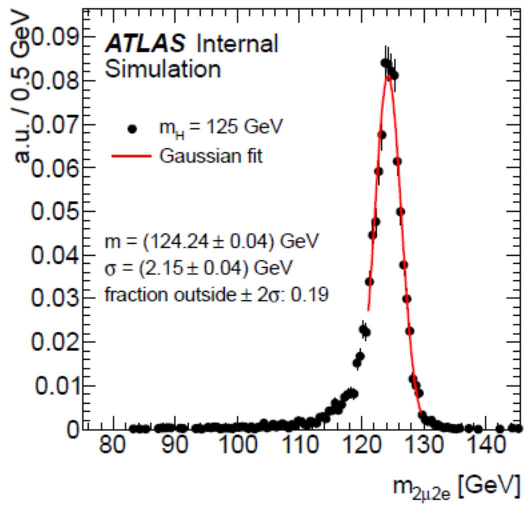
8 TeV, 20.7fb^{-1} →

Method	Moriond 2013
4μ	
m_{12} fit: $Z+$jets contribution	$2.340 \pm 0.479 \pm 0.587$ †
m_{12} fit: $t\bar{t}$ contribution	$0.141 \pm 0.028 \pm 0.028$ †
$t\bar{t}$ from $e\mu + \mu\mu$	$0.098 \pm 0.054 \pm 0.004$
$2e2\mu$	
m_{12} fit: $Z+$jets contribution	$2.484 \pm 0.494 \pm 0.623$ †
m_{12} fit: $t\bar{t}$ contribution	$0.096 \pm 0.020 \pm 0.019$ †
$t\bar{t}$ from $e\mu + \mu\mu$	$0.120 \pm 0.066 \pm 0.005$
$2\mu 2e$ OS	
$\ell\ell + ee$ OS in (p_T, η) bins	$5.2 \pm 0.4 \pm 0.5$ †
fake factor	$3.8 \pm 0.6 \pm 0.6$
$2\mu 2e$ SS	
$\ell\ell + ee$ SS in (p_T, η) bins	$3.5 \pm 0.6 \pm 0.5$
fake factors	$2.9 \pm 0.3 \pm 0.6$
$3\ell + e$ average	$4.3 \pm 0.6 \pm 0.5$
$3\ell + e$ in p_T bins	$3.4 \pm 0.7 \pm 0.3$
$4e$ OS	
$\ell\ell + ee$ OS in (p_T, η) bins	$3.2 \pm 0.5 \pm 0.5$ †
fake factors	$2.7 \pm 0.4 \pm 0.4$
$\ell\ell + ee$ SS in (p_T, η) bins	$2.4 \pm 0.4 \pm 0.5$
fake factors	$2.0 \pm 0.3 \pm 0.6$
$3\ell + e$ average	$4.2 \pm 0.5 \pm 0.5$
$3\ell + e$ in p_T bins	$3.5 \pm 0.7 \pm 0.3$

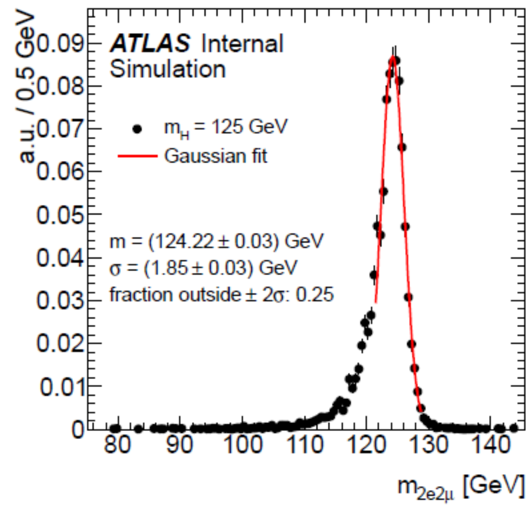
Higgs Mass Resolution



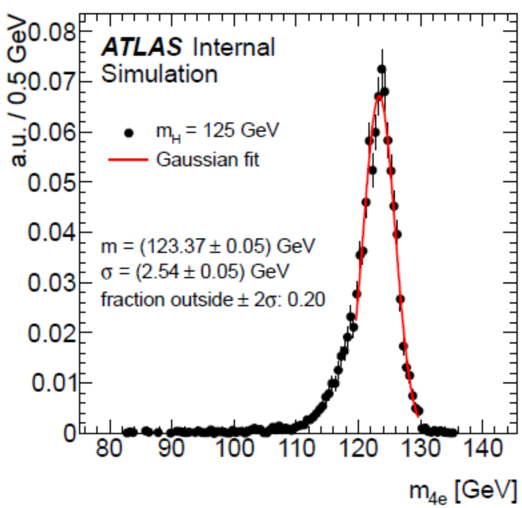
(a)

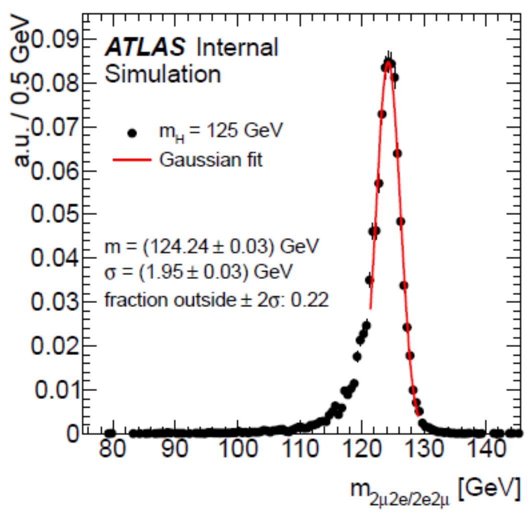


(b)



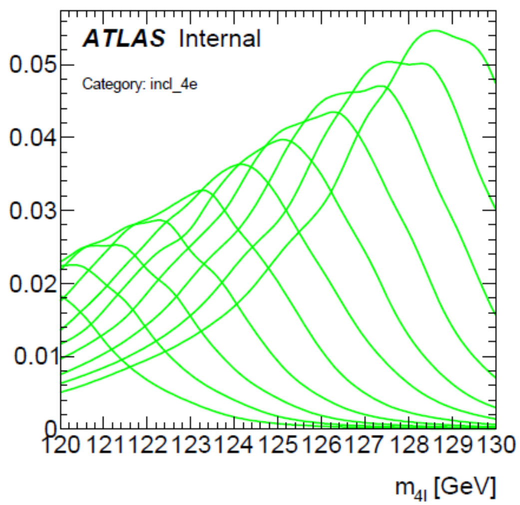
(c)



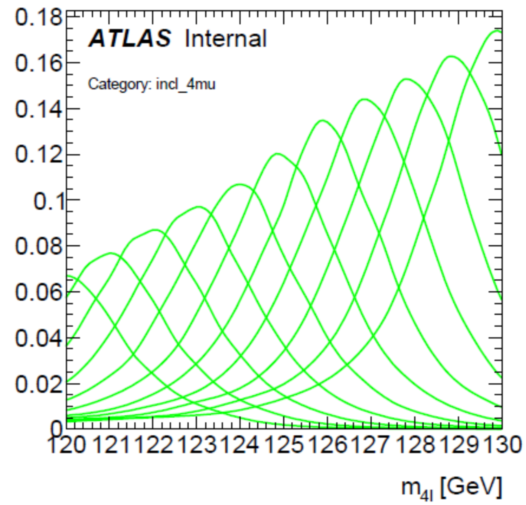


➔ Gaussian fit: FSR correction & Z mass constraint

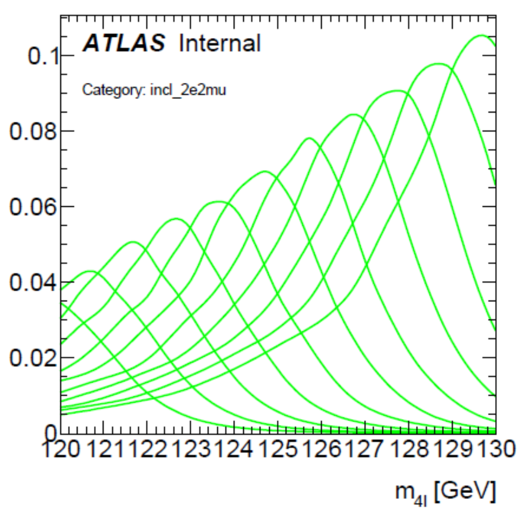
Simulated Higgs Signal Shapes



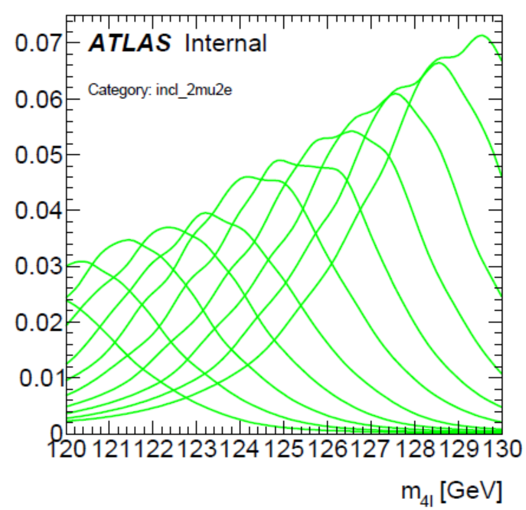
(a) $H \to 4e$



(b) $H \to 4\mu$



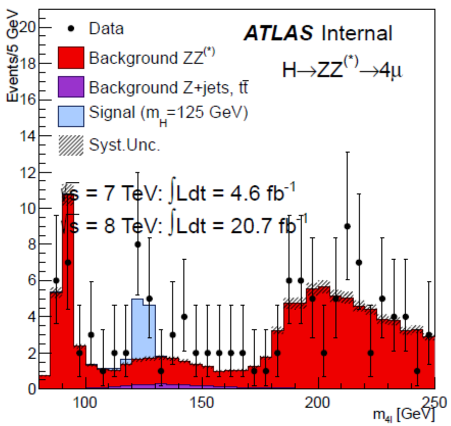
(c) $H \to 2e2\mu$



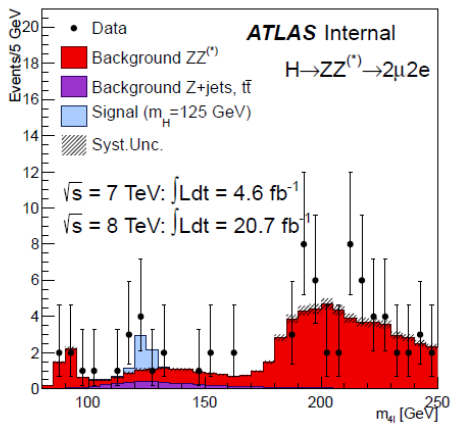
(d) $H \to 2\mu 2e$

Figure 30: Continuous parametrization in m_H. The signal shapes for 2012 ggF sampled in 1 GeV steps between 120 and 130 GeV.

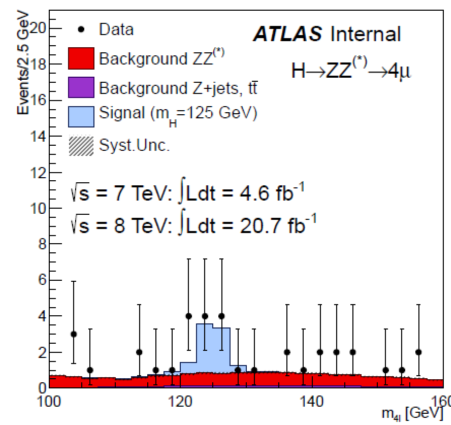
$M_{4\ell}$ of Four Different Final States (4μ, 2μ2e, 2e2μ, 4e)



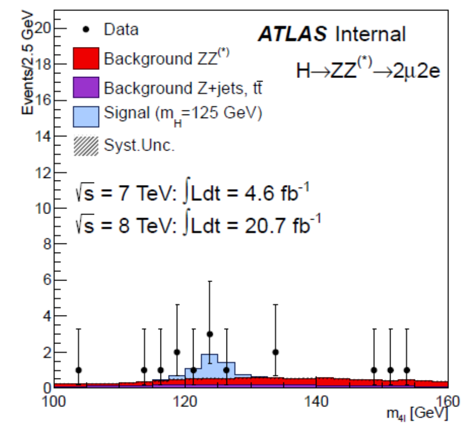
(a)



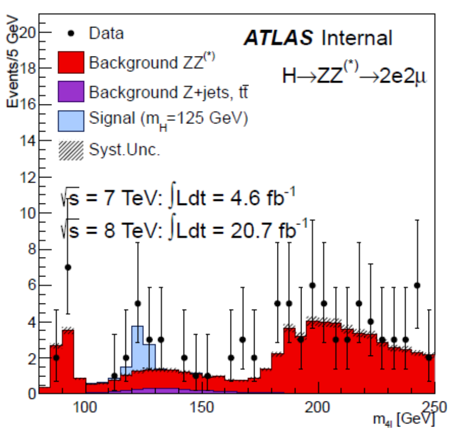
(b)



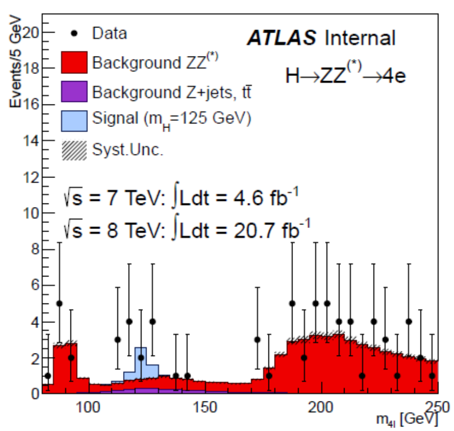
(a)



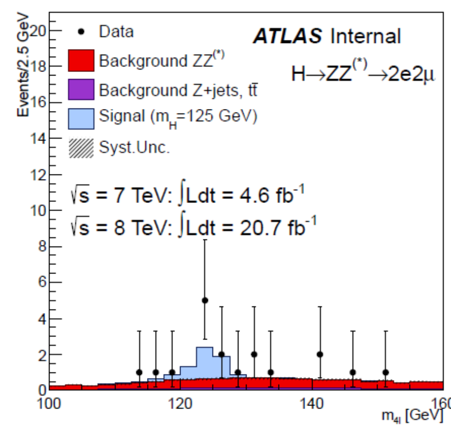
(b)



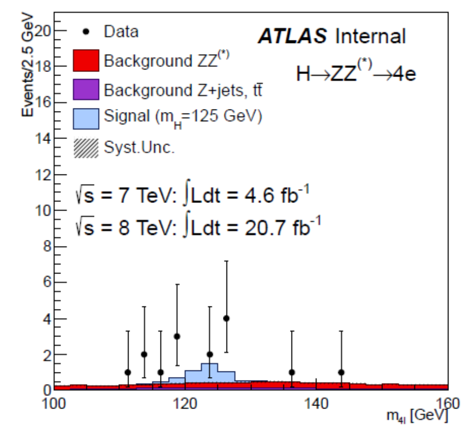
(c)



(d)

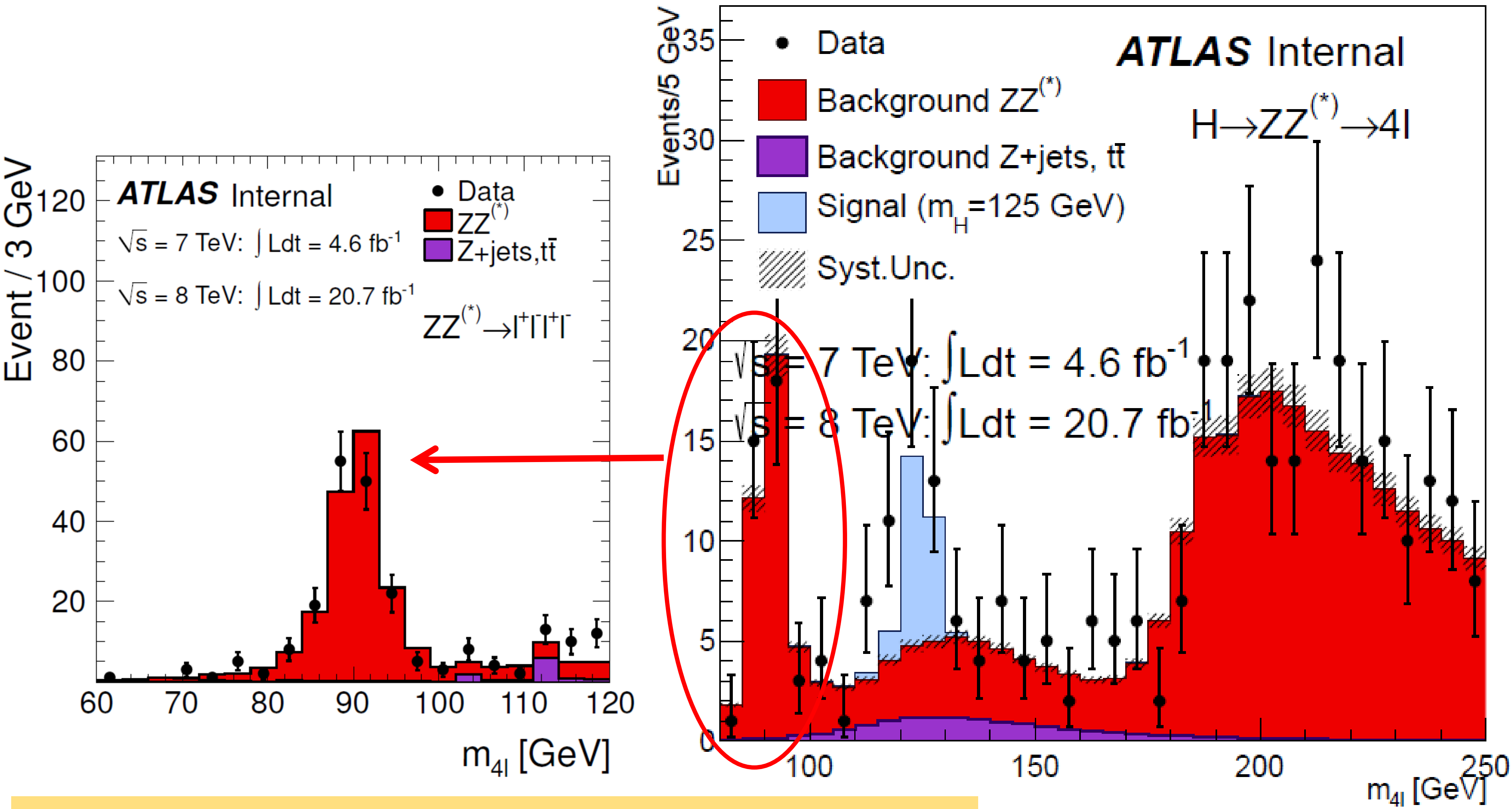


(c)



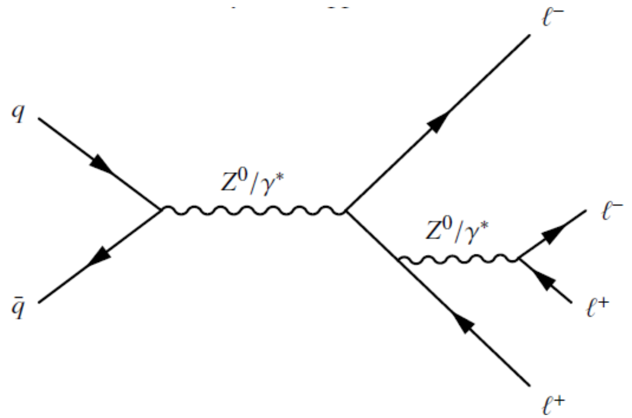
(d)

H→ZZ*→4l mass spectrum



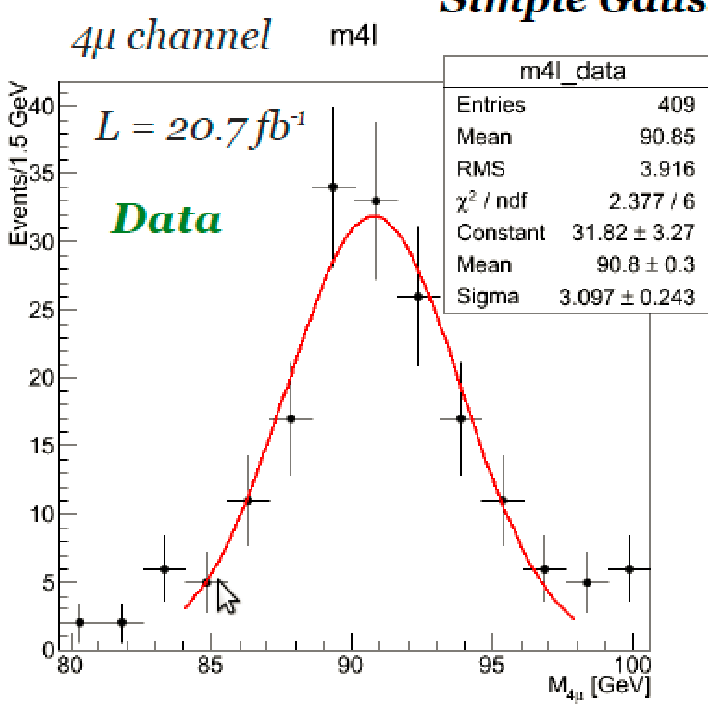
Single resonant Z→4l enhanced by relaxing mass and P_T requirements (21 + 141 = 162)

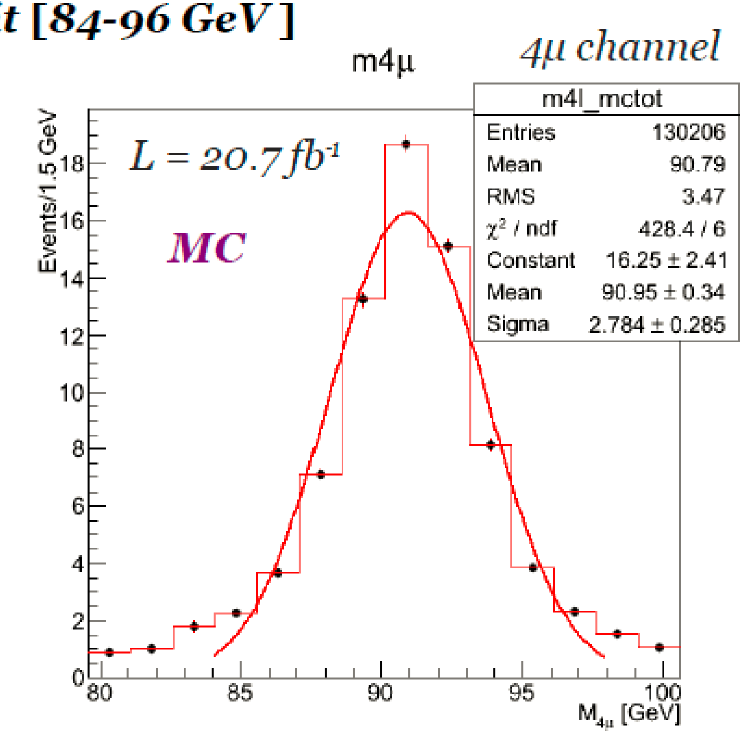
Single Z → 4l Resonance



Expected quantity		7 TeV	8 TeV
Total cross-section of $pp \to Z$		27.66×10^6 fb	32.24×10^6 fb
Phase space cross-section of $pp \to Z \to 4\ell(e,\mu)$		132.04 ± 1.60 fb	153.83 ± 1.85 fb
Branching ratio of $Z \to 4\ell(e,\mu)$		$(4.36 \pm 0.22) \times 10^{-6}$	$(4.21 \pm 0.21) \times 10^{-6}$
Fiducial cross-section of	$Z \to 4\ell(e,\mu)$	69.4 ± 0.7 fb	79.2 ± 0.8 fb
"	$Z \to 4e$	17.6 ± 0.2 fb	20.2 ± 0.2 fb
"	$Z \to 2e2\mu$	16.9 ± 0.2 fb	19.4 ± 0.2 fb
"	$Z \to 2\mu 2e$	17.0 ± 0.2 fb	19.1 ± 0.2 fb
"	$Z \to 4\mu$	18.0 ± 0.2 fb	20.4 ± 0.2 fb

Simple Gaussian Fit [84-96 GeV]





Cross Section of Z → 4ℓ

- ATLAS-COM-PHYS-2013-169

Final States	Theoretical cross section σ (fb)	Measured cross section σ (fb)
	2011 Data - 7 TeV (4.6 fb^{-1})	
$4e$	17.57 ± 0.18	10.56 ± 10.40(stat) ± 2.15(syst) ± 0.19(lumi)
$2e2\mu$	16.87 ± 0.17	15.79 ± 6.48(stat) ± 1.13(syst) ± 0.28(lumi)
$2\mu 2e$	17.00 ± 0.17	27.26 ± 12.45(stat) ± 3.84(syst) ± 0.49(lumi)
4μ	17.99 ± 0.18	12.57 ± 4.38(stat) ± 0.39(syst) ± 0.23(lumi)
Combined	69.44 ± 0.70	66.18 ± 7.15(stat) ± 7.15(syst) ± 1.19(lumi)
	2012 Data - 8 TeV (20.7 fb^{-1})	
$4e$	20.25 ± 0.24	17.56 ± 4.87(stat) ± 3.97(syst) ± 0.49(lumi)
$2e2\mu$	19.40 ± 0.23	20.73 ± 3.09(stat) ± 1.45(syst) ± 0.58(lumi)
$2\mu 2e$	19.10 ± 0.23	14.06 ± 3.76(stat) ± 2.05(syst) ± 0.39(lumi)
4μ	20.42 ± 0.25	20.81 ± 2.51(stat) ± 0.66(syst) ± 0.58(lumi)
Combined	79.15 ± 0.95	73.16 ± 7.32(stat) ± 7.52(syst) ± 2.05(lumi)

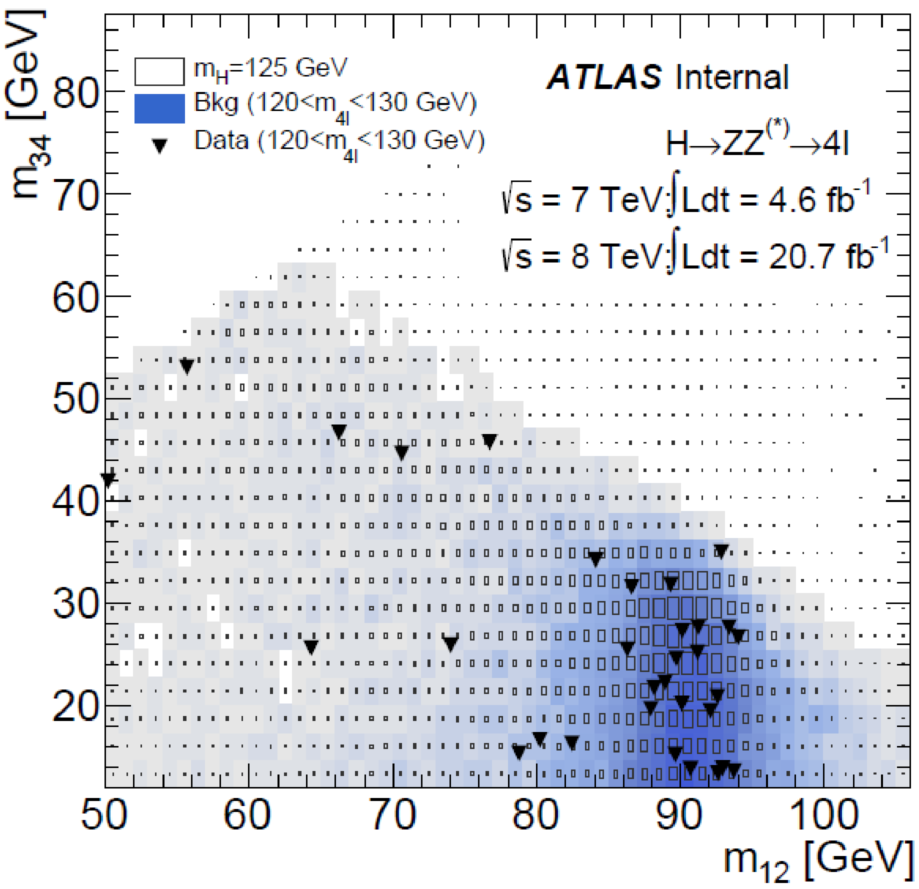
H→ZZ*→4ℓ Events Selection

- The number of expected Higgs signal and background events for 4ℓ mass in a ±5 GeV mass window around 125 GeV, for 7 TeV and 8 TeV data.

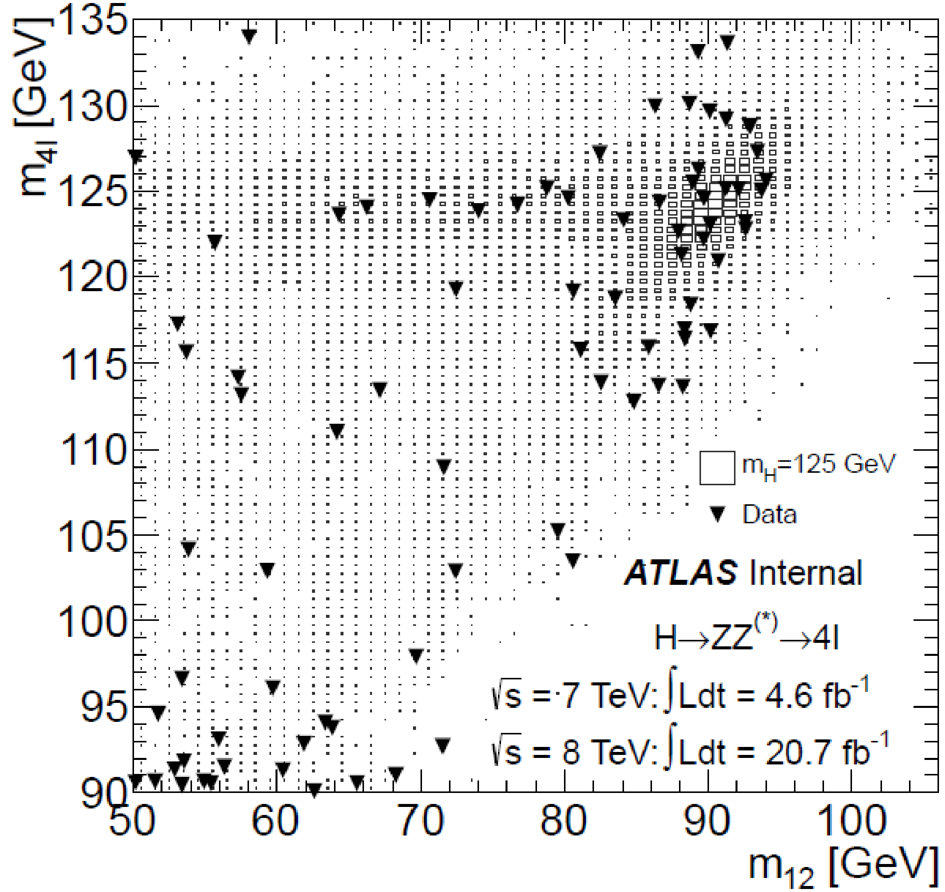
	Signal	$ZZ^{(*)}$	$Z+$jets, $t\bar{t}$	Observed
4μ	6.30±0.81	2.82±0.13	0.49±0.14	13
$2\mu 2e$	3.00±0.43	1.37±0.11	0.77±0.12	5
$2e2\mu$	3.91±0.51	2.05±0.10	0.53±0.14	8
$4e$	2.49±0.36	1.14±0.11	0.55±0.15	6
Total	15.71±2.11	7.38±0.45	2.35±0.27	32

H→ZZ*→4l Candidates

M_{12} vs M_{34}

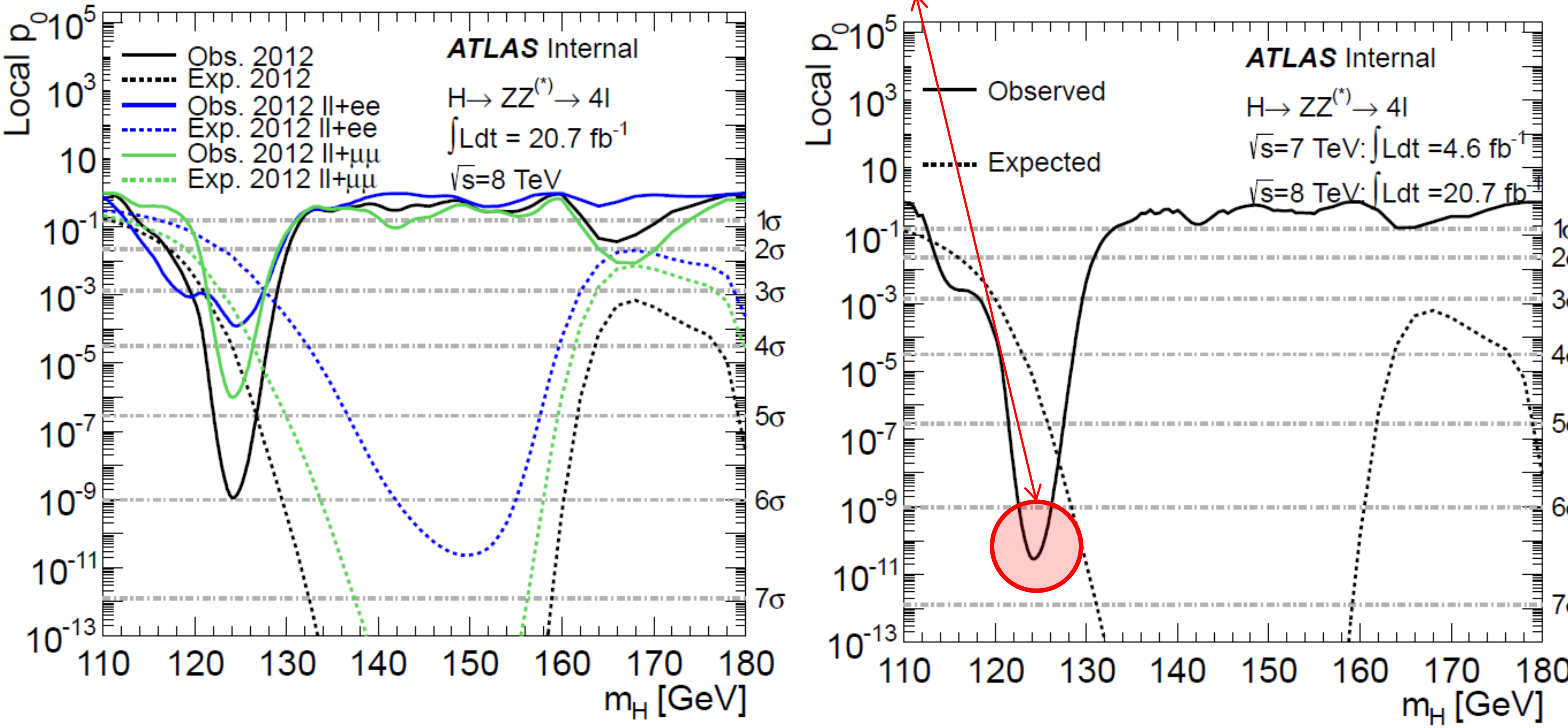


M_{12} vs M_{4l}

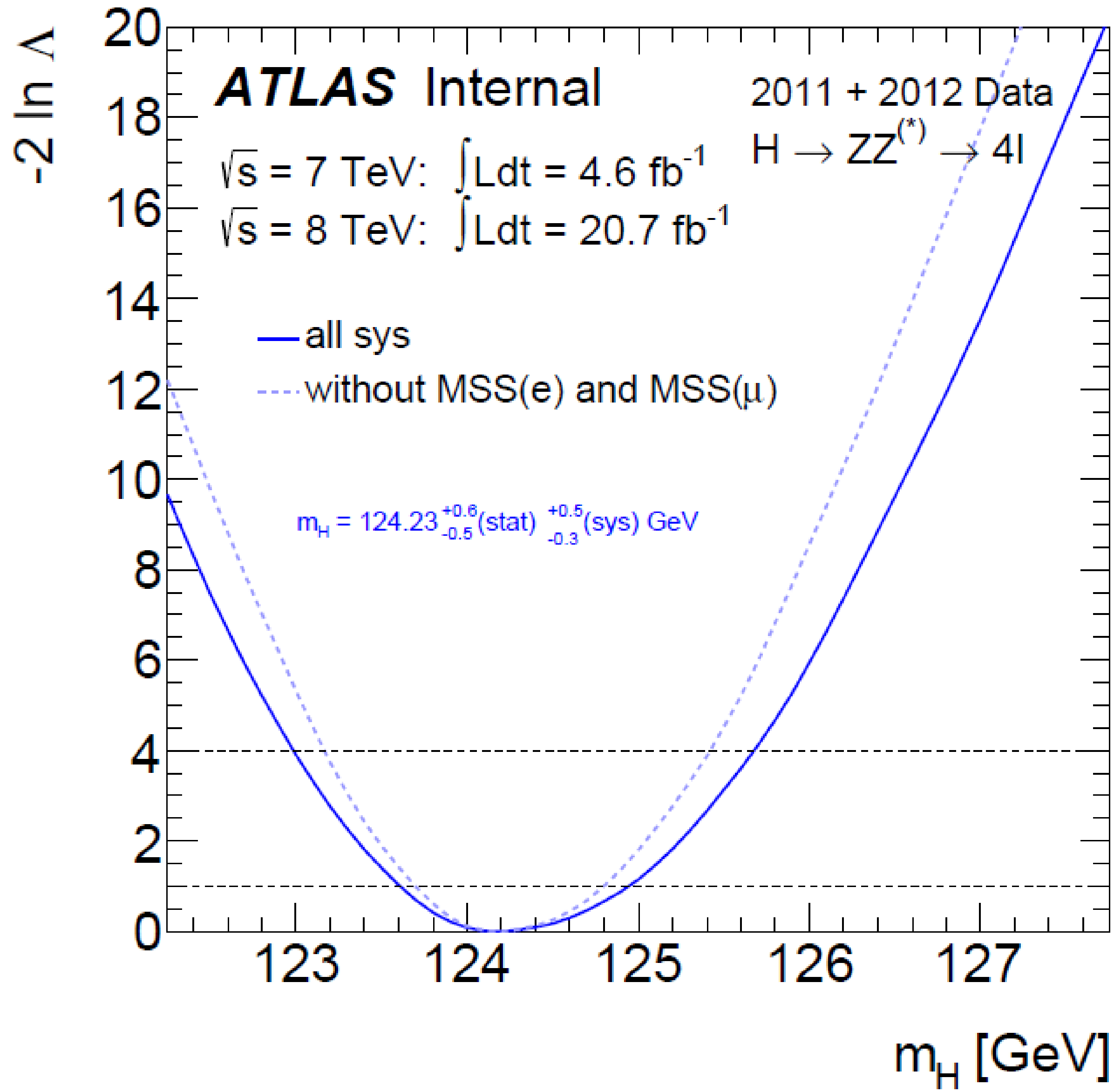


Significance of H→ZZ*→4ℓ

Dataset	$m_H(\min p_0)$ [GeV]	min p_0	Signif [σ]	expected p_0	exp signif [σ]
2011	125.6	2.5e-03	2.8	3.7e-02	1.8
2012	124.1	1.1e-09	6.0	3.0e-05	4.0
Combined	124.2	2.9e-11	6.6	5.7e-06	4.4

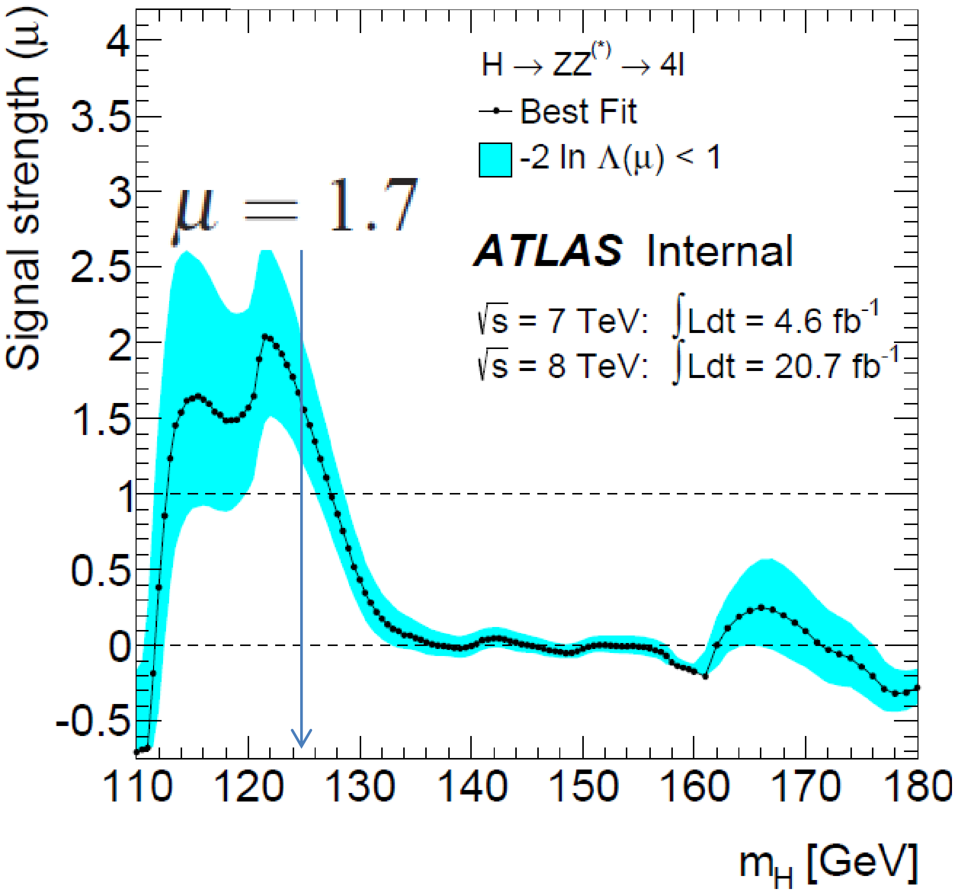


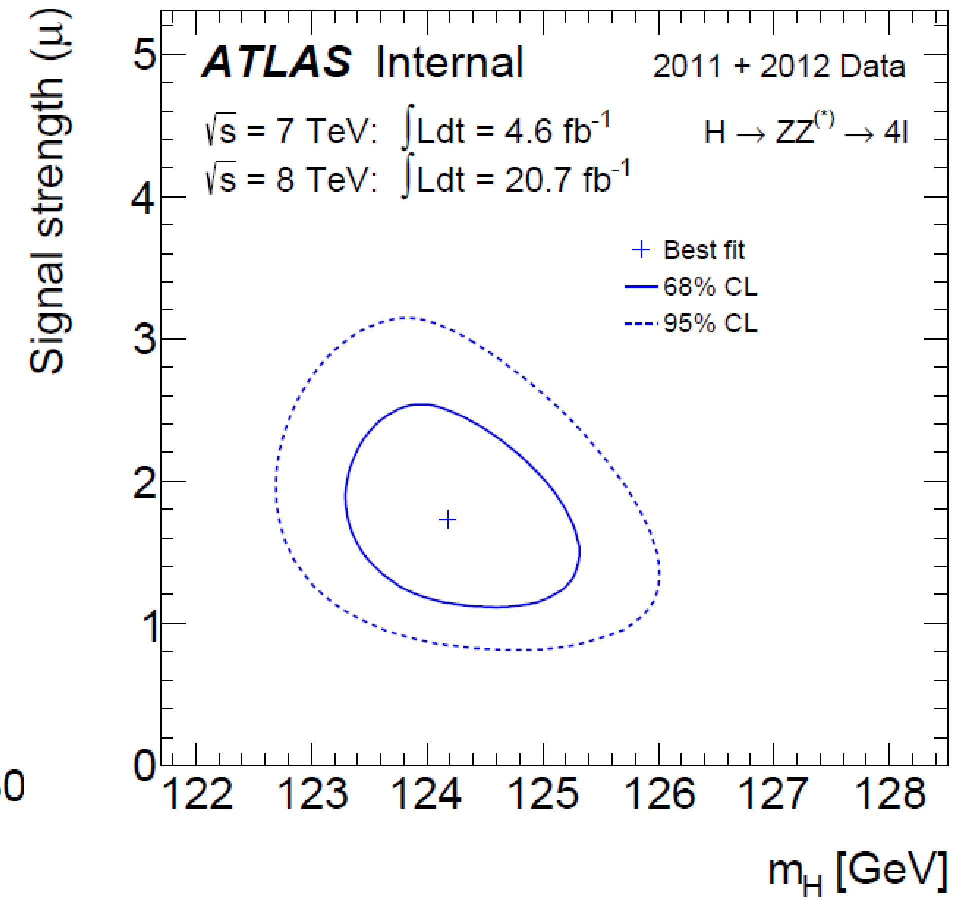
Best Fitted Higgs Mass



H→ZZ*→4l Signal Strength vs. Mass

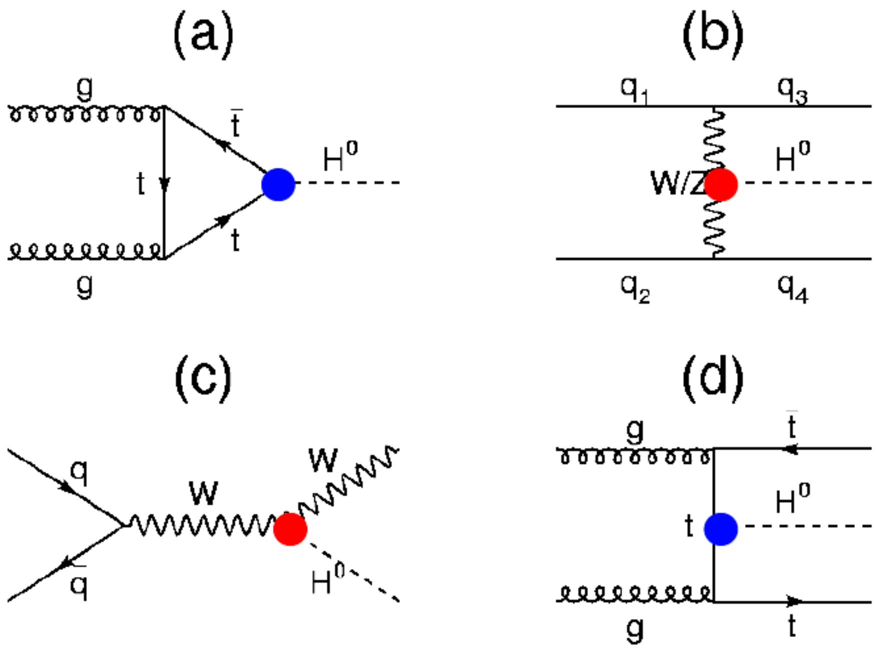
Channel	Mass [GeV]
Combined 2011+2012	$124.23^{+0.6}_{-0.5}(\text{stat})^{+0.5}_{-0.3}(\text{syst})$

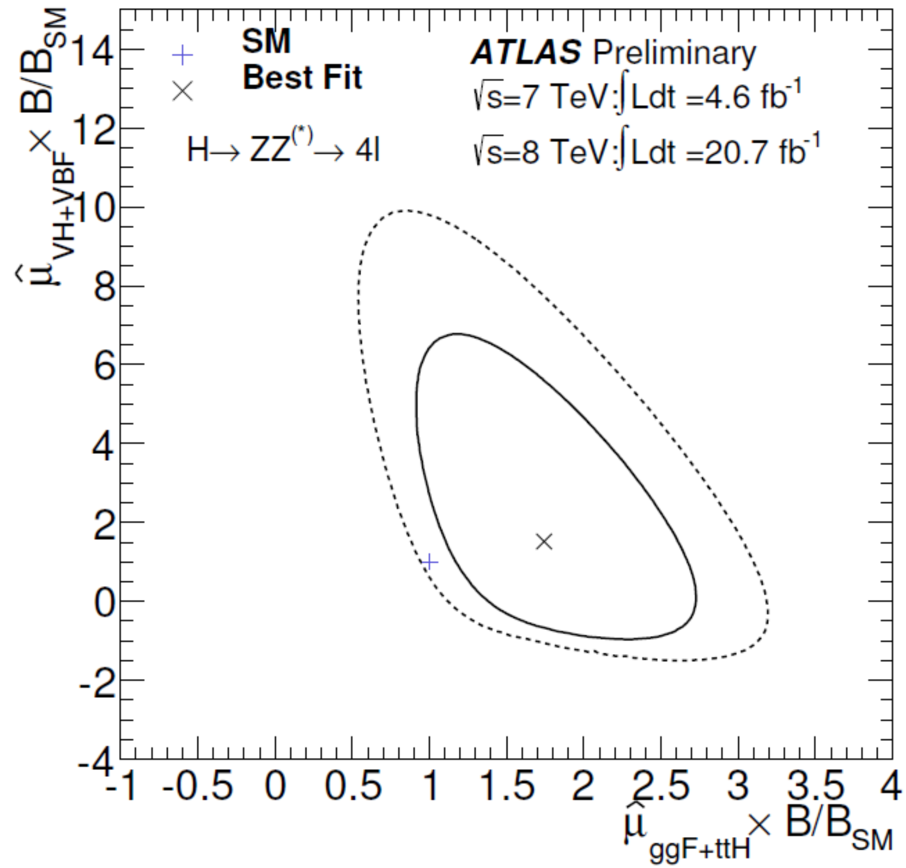




Higgs → ZZ* → 4ℓ

- **Higgs has two types of couplings**
  - “Gauge” couplings (to bosons)
  - Yukawa couplings (to fermions)





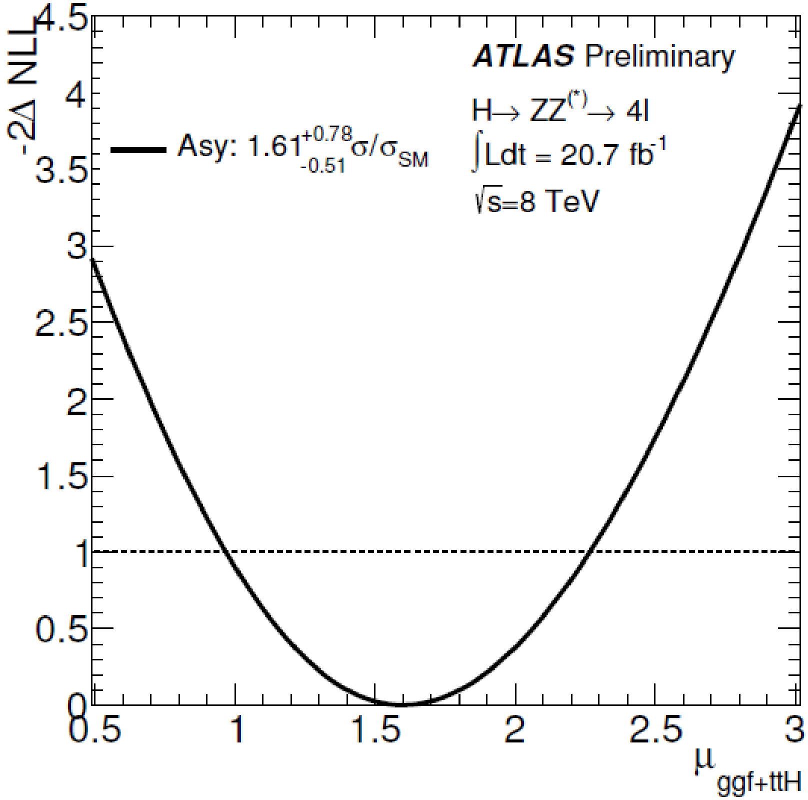
- Explore tension between SM value and observation from different Higgs production modes: μ_{VBF+VH} **vs.** $\mu_{ggF+ttH}$

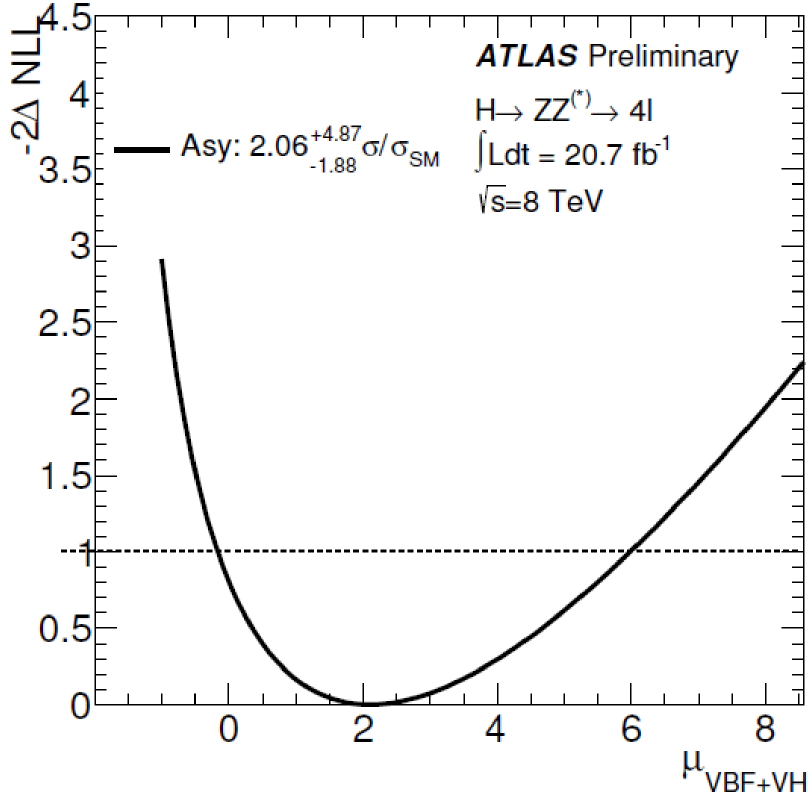
Signal Strength for ggF and VBF Productions

- 1D projections on the $\mu_{ggF+ttH}$ and μ_{VBF+VH} with m_H fixed as its best fitted mass.

  $\mu_{ggF+ttH}$=1.61+0.78(-0.51) σ/σ_{SM}

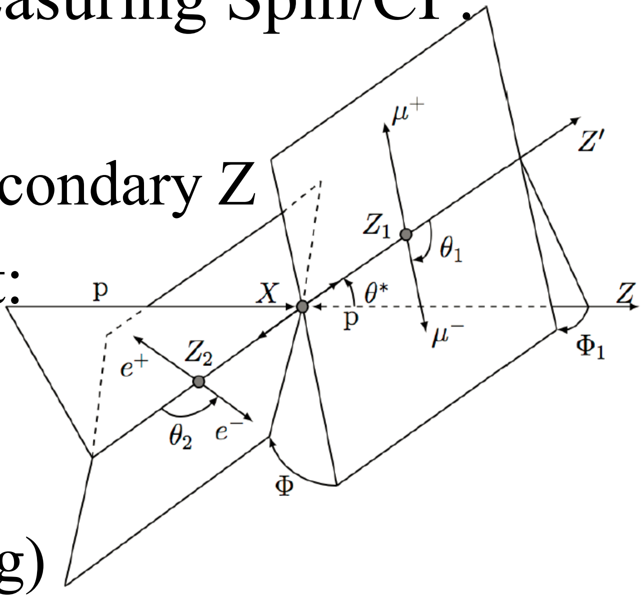
  μ_{VBF+VH}=2.06+4.87(-1.88) σ/σ_{SM}

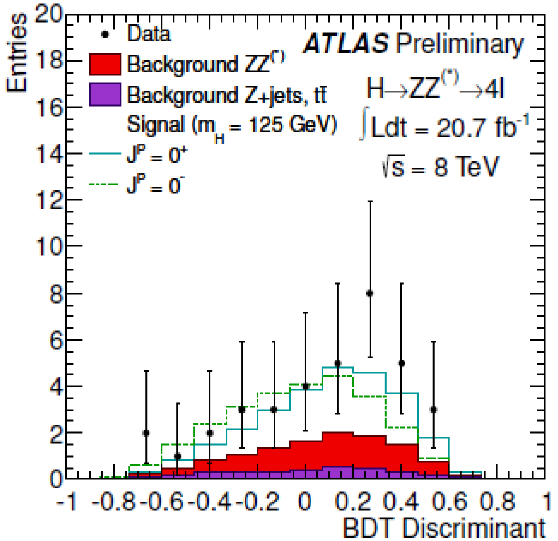


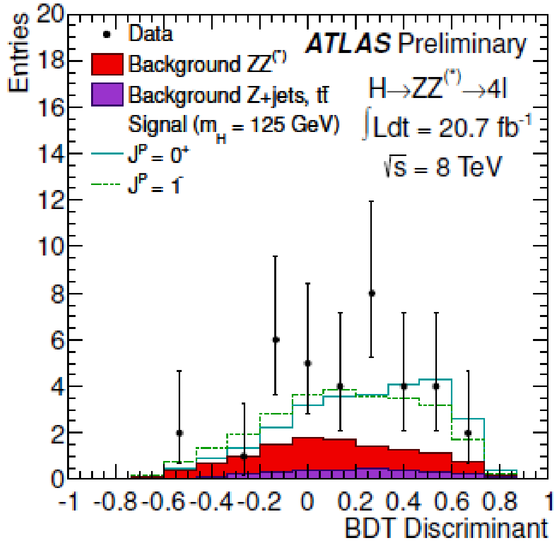


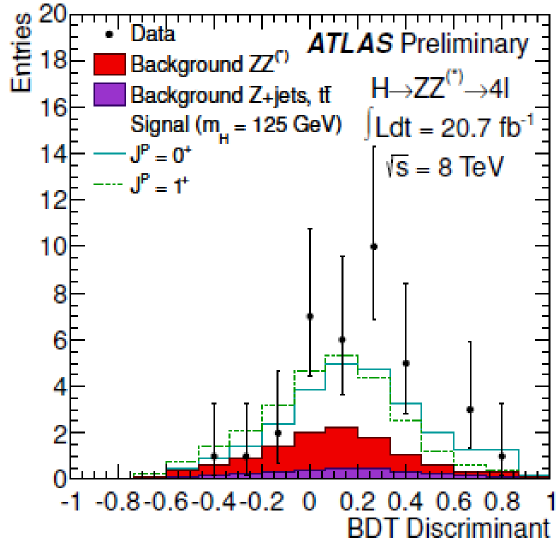
H→ZZ*→4l : Spin and Parity

- Fully reconstructed final state allows measuring Spin/CP:
  - Five kinematic angles (production, decay)
  - Invariant mass of the primary Z and the secondary Z
- Discriminate 0^+ (SM) hypothesis against:
  - 0^- (CP odd), 1^+, 1^-
  - 2^- (pseudo-tensor)
  - 2^+_m (graviton-like tensor, minimal coupling)



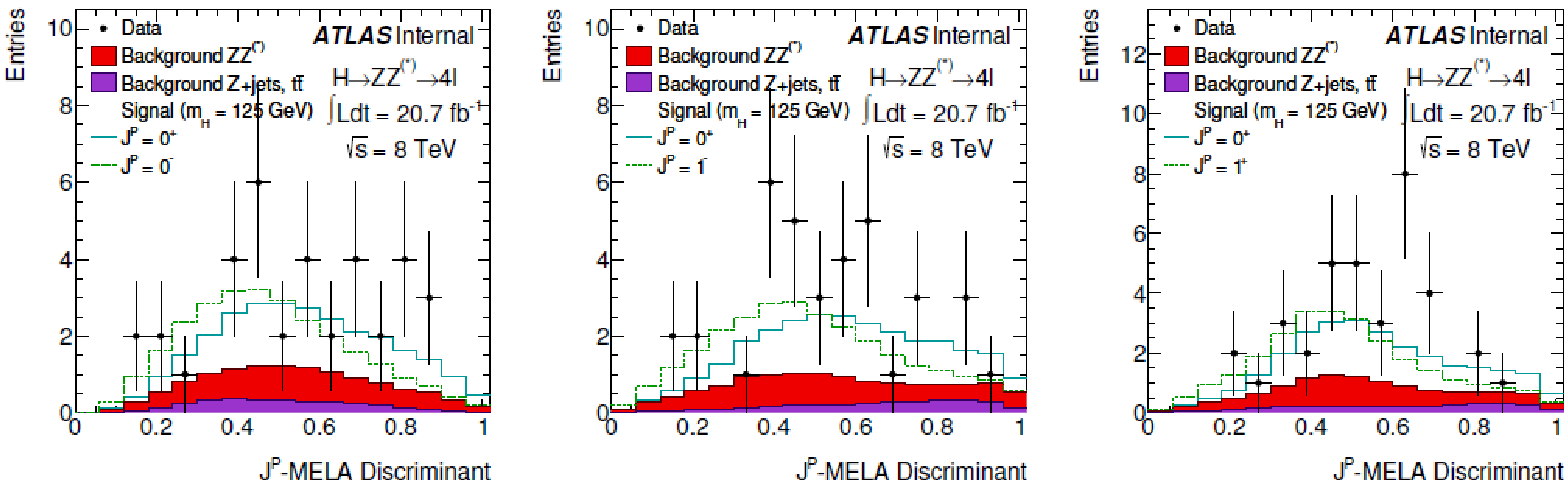






H→ZZ*→4l : Spin and Parity

- Two multivariate discriminants used:
  - Boosted Decision Trees (BDT)
  - Matrix-Element calculation for each spin / CP (J^p-MELA)



➔ **Data strongly favour 0^+ vs 0^-:**
0^- hypothesis is excluded at 98.7% C.L., (2.2σ ,expected 2.17σ)

➔ 0^+ vs 1^+ : observed separation 99.9% C.L. (3.05σ, expected 2.31σ)

➔ 0^+ vs 1^- : observed separation 99.6% C.L. (2.66σ, expected 3.86σ)

➔ 0^+ vs 2^- : observed separation 78.7% C.L. (0.8σ, expected 2.09σ)

➔ 0^+ vs 2^+ is excluded at 92.7% C.L. (1.45σ, expected 1.09σ)

Contributions to ATLAS Physics Analyses

H→ZZ→4l Mass, Signal Strength, Spin, Parity etc.

- ATLAS-COM-PHYS-2013-144
- ATLAS-COM-PHYS-2013-145
- ATLAS-COM-PHYS-2013-146

Z→4l Single Resonance Cross Section and BR

- ATLAS-COM-PHYS-2013-169

Plan of SJTU Group

Muon New Small Wheel Detector Upgrade (collaborate with USTC, SDU and UM)

- Development of sTGC segment finding algorithm including simulation, look-up table preparation and performance studies
- Participation in NSW test beam experiments to study new detector performance and signal characteristics

Liang Li is visiting CERN from March 2 – May 25 for EE chambers installation and NSW simulation work.

ATLAS NOTE

February 17, 2013

Updated results and measurements of properties of the new Higgs-like particle in the four lepton decay channel with the ATLAS detector. Spin and CP measurement.

C. Anastopoulos[1], M. Antonelli[34], Ludovica Aperio Bella[18], O. Baker[35], E. Benhar Noccioli[12], S. Borroni[25], K. Brendlinger[24], P. Catastini[41], L. R. Flores Castillo[3], T. Cao[8], F. Cerutti[14], A Calandri[7], D. Charfeddine[9], L. Chevalier[7], F. Conventi[31], P.J. Clark[16], K. Cranmer[15], G. Cree[10], T. Cuhadar Donszelmann[4], T. Dai[17], J. Dandoy[40], A. Daniells[18], A. Di-Mattia[22], F. DiValentino[10], C. Dionisi[1,13], K. Ecker[6], D. Fassouliotis[5], E. Feng[26], M. Franklin[41], A. Gabrielli[13], F. Garay[16], S. Giagu[1,13], J. Guimaraes da Costa[41], E. Gkougkousis[9], D. Grinszpun[22], E. Gozani[22], M. Goblirsch-Kolb[6], T. Guillemin[9], R.D. Harrington[16], S. Hassani[7], S. Heim[24], S. Hou[37], L. Iconomidou-Fayard[9], K. Iordanidou[5,27], V. Ippolito[1,13], L. Jeanty[41], X. Ju[3], T. Koffas[10], R. Konoplich[15], O. Kortner[6], C. Kourkoumelis[5], A. Krasznahorkay[15], S. Kreiss[15], J. Kroll[24], T. Lagouri[35], C. Leonidopoulos[16], D. Levin[17], L. Liu[17], X. Li[17], B. Li[36,37], B. Lopez-Paredes[4], L. Lu[17], B. Mansoulie[7], C. Maiani[7], E. Meoni[23], E. Monnier[11], A. Morley[1], G. Carrillo Montoya[32], E. Mountricha[27], R. D. Mudd[18], R. Di Nardo[34], R. Nicolaidou[7], K. Nikolopoulos[18], S. Oda[19], G. Pásztor[12], E. Paganis[4], L. E. Pedersen[28], L. Pontecorvo[13], K. Prokofiev[15], J. Pilcher[40], D. Rebuzzi[29,30], M. Rescigno[2,13], S. Rosati[13], E. Rossi[1,13], Y. Rozen[22], A. Salvucci[39], A. Schaffer[9], S. Sekula[8], K. Selbach[16], F. Sforza[6], R. Stroynowski[8], G. Sciolla[21], W. Spearman[41], J. Stahlman[24], S. Sun[24], F. Tarrade[10], E. Tiouchichine[11], J. Tojo[19], T. Vickey[32], G. Volpi[34], K. Whalen[10], A. Wilson[17], H. Williams[24], S. L. Wu[3], Y. Wu[17], J. Webster[40], B. Wynne[16], M. Xiao[7], L. Xu[17], H. Yang[38], S. Zambito[21], B. Zhou[17], Z. Zhao[36]

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ATLAS NOTE

February 17, 2013

Updated results and measurements of properties of the new Higgs-like particle in the four lepton decay channel with the ATLAS detector. Mass and signal strength measurement.

C. Anastopoulos[1], M. Antonelli[34], Ludovica Aperio Bella[18], O. Baker[35], E. Benhar Noccioli[12], S. Borroni[25], K. Brendlinger[24], A Calandri[7], T. Cao[8], G. Carrillo Montoya[32], P. Catastini[41], L. R. Flores Castillo[3], F. Cerutti[14], D. Charfeddine[9], L. Chevalier[7], F. Conventi[31], P.J. Clark[16], K. Cranmer[15], G. Cree[10], T. Cuhadar Donszelmann[4], T. Dai[17], J. Dandoy[40], A. Daniells[18], A. Di-Mattia[22], D. Di Valentino[10], C. Dionisi[1,13], K. Ecker[6], D. Fassouliotis[5], E. Feng[26], M. Franklin[41], A. Gabrielli[13], F. Garay[16], S. Giagu[1,13], J. Guimaraes da Costa[41], E. Gkougkousis[9], D. Grinszpun[22], E. Gozani[22], M. Goblirsch-Kolb[6], T. Guillemin[9], R.D. Harrington[16], S. Hassani[7], S. Heim[24], S. Hou[37], L. Iconomidou-Fayard[9], K. Iordanidou[5,27], V. Ippolito[1,13], L. Jeanty[41], X. Ju[3], T. Koffas[10], R. Konoplich[15], O. Kortner[6], C. Kourkoumelis[5], A. Krasznahorkay[15], S. Kreiss[15], J. Kroll[24], T. Lagouri[35], C. Leonidopoulos[16], D. Levin[17], L. Liu[17], X. Li[17], B. Li[36,37], B. Lopez-Paredes[4], L. Lu[17], B. Mansoulie[7], C. Maiani[7], E. Meoni[23], E. Monnier[11], A. Morley[1], E. Mountricha[27], R. D. Mudd[18], R. Di Nardo[34], R. Nicolaidou[7], K. Nikolopoulos[18], S. Oda[19], G. Pásztor[12], E. Paganis[4], L. E. Pedersen[28], L. Pontecorvo[13], K. Prokofiev[15], J. Pilcher[40], D. Rebuzzi[29,30], M. Rescigno[2,13], S. Rosati[13], E. Rossi[1,13], Y. Rozen[22], A. Salvucci[39], A. Schaffer[9], S. Sekula[8], K. Selbach[16], F. Sforza[6], R. Stroynowski[8], G. Sciolla[21], W. Spearman[41], J. Stahlman[24], S. Sun[24], F. Tarrade[10], E. Tiouchichine[11], J. Tojo[19], T. Vickey[32], G. Volpi[34], K. Whalen[10], A. Wilson[17], H. Williams[24], S. L. Wu[3], Y. Wu[17], J. Webster[40], B. Wynne[16], M. Xiao[7], L. Xu[17], H. Yang[38], S. Zambito[21], B. Zhou[17], Z. Zhao[36]

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ATLAS NOTE

February 22, 2013

Four lepton decay channel with production mechanism specific signatures: study of the Higgs-like particle at 125 GeV and searches for additional resonances.

C. Anastopoulos[1], M. Antonelli[34], L. Aperio Bella[18], O. Baker[35], E. Benhar Noccioli[12], F. Bernlochner[42], S. Borroni[25], K. Brendlinger[24], A Calandri[7], T. Cao[8], G. Carrillo Montoya[32], P. Catastini[41], L. R. Flores Castillo[3], F. Cerutti[14], D. Charfeddine[9], L. Chevalier[7], F. Conventi[31], P.J. Clark[16], K. Cranmer[15], G. Cree[10], T. Cuhadar Donszelmann[4], T. Dai[17], J. Dandoy[40], A. Daniells[18], A. Di-Mattia[22], D. Di Valentino[10], C. Dionisi[1,13], K. Ecker[6], D. Fassouliotis[5], E. Feng[26], M. Franklin[41], A. Gabrielli[13], F. Garay[16], S. Giagu[1,13], D. Gilberg[1], J. Guimaraes da Costa[41], E. Gkougkousis[9], D. Grinszpun[22], E. Gozani[22], M. Goblirsch-Kolb[6], T. Guillemin[9], R.D. Harrington[16], S. Hassani[7], S. Heim[24], S. Hou[37], L. Iconomidou-Fayard[9], K. Iordanidou[5,27], V. Ippolito[1,13], L. Jeanty[41], X. Ju[3], T. Koffas[10], R. Konoplich[15], O. Kortner[6], C. Kourkoumelis[5], A. Krasznahorkay[15], S. Kreiss[15], J. Kroll[24], T. Lagouri[35], C. Leonidopoulos[16], D. Levin[17], L. Liu[17], X. Li[17], B. Li[36,37], B. Lopez-Paredes[4], L. Lu[17], B. Mansoulie[7], C. Maiani[7], E. Meoni[23], E. Monnier[11], A. Morley[1], E. Mountricha[27], R. D. Mudd[18], R. Di Nardo[34], R. Nicolaidou[7], K. Nikolopoulos[18], S. Oda[19], G. Pásztor[12], E. Paganis[4], L. E. Pedersen[28], L. Pontecorvo[13], K. Prokofiev[15], J. Pilcher[40], D. Rebuzzi[29,30], M. Rescigno[2,13], S. Rosati[13], E. Rossi[1,13], Y. Rozen[22], A. Salvucci[39], A. Schaffer[9], S. Sekula[8], K. Selbach[16], F. Sforza[6], R. Stroynowski[8], G. Sciolla[21], W. Spearman[41], J. Stahlman[24], S. Sun[41], R. Tanaka[9], F. Tarrade[10], E. Tiouchichine[11], J. Tojo[19], T. Vickey[32], G. Volpi[34], K. Whalen[10], A. Wilson[17], H. Williams[24], S. L. Wu[3], Y. Wu[17], J. Webster[40], B. Wynne[16], M. Xiao[7], L. Xu[17], H. Yang[38], S. Zambito[21], G. Zevi Della Porta[41], B. Zhou[17], Z. Zhao[36]

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ATLAS NOTE

February 14, 2013

Cross-section measurements of Single Resonance $Z \to 4\ell$ in pp collisions at 7 TeV and 8 TeV with the ATLAS Detector

J.R. Batley[1], M. Baumer[1], T. Dai[2], A. Daniells[3], H. Feng[2], S. French[1], S. Hou[4], D. Levin[2], B. Li[5,4], X. Li[2], J. Liu[2], N. Lu[2], E. Mountricha[6], R. Mudd[3], K. Nikolopoulos[3], F. Tarrade[7], A. Wilson[2,4], Y. Wu[2,5], L. Xu[2,5], H. Yang[8], Z. Zhao[5], B. Zhou[2]

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上海交通大学ATLAS实验组招聘

- 招聘1-2名特别研究员
- 招聘2名 博士后或助理研究员，从事探测器升级和物理分析
- 招聘1名计算机管理人员
- 招收多名研究生和本科生

Backup

Plan of SJTU Group

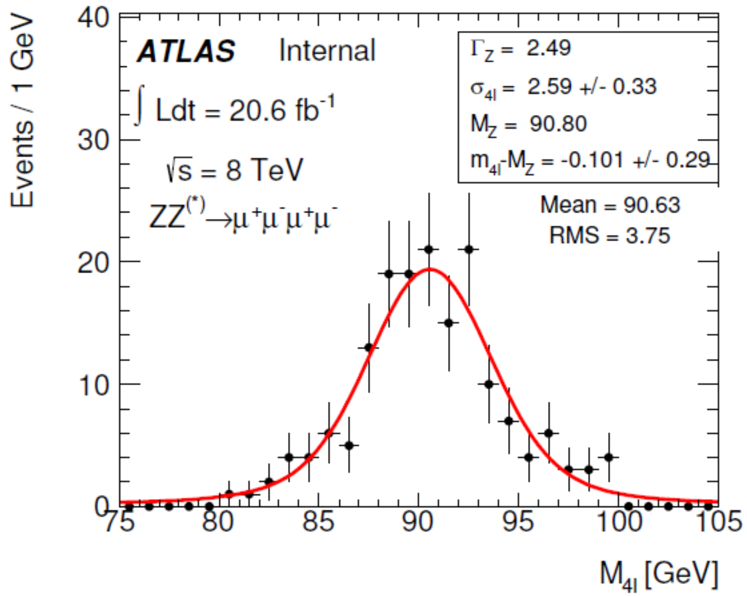
Physics Analyses:

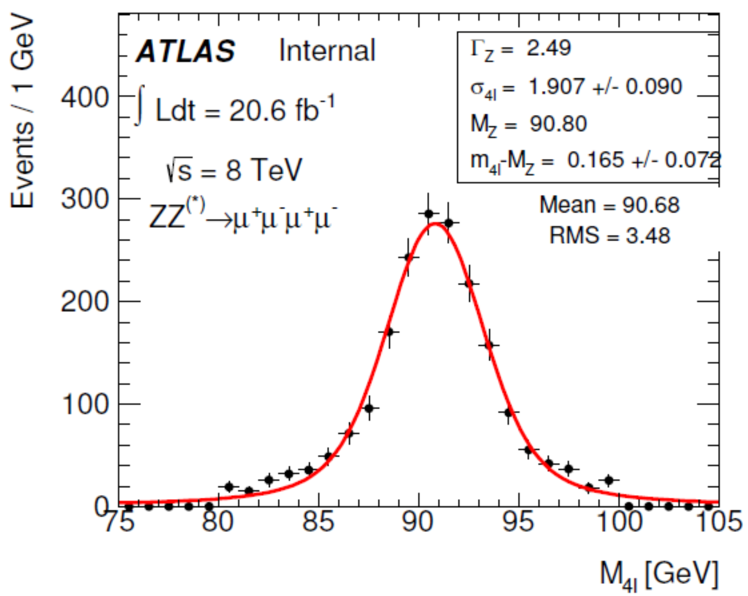
- Search for Higgs via H→ZZ*→4l final states
- Determination of Higgs spin and CP using H→ZZ*→4l events
- Cross section measurement of single resonant Z→4l
- Cross section measurement and aTGC (WW, WZ, ZZ)
- Search for new physics using diboson final states
- Precise measurements of Single top quark production
- New physics search related to top quark production and properties

Fit of 4ℓ Mass Distribution

- Fit using a Breit-Wigner line shape convoluted with a Gaussian distribution

$$\mathrm{BW}(x, M_Z, \Gamma_Z) * \mathrm{Gauss}(x, m_{4\ell}, \sigma_{4\ell})$$





Selected H → ZZ* → 4l Events

	$\mu\mu\mu\mu$		$ee\mu\mu$		$eeee$	
	Low mass	High mass	Low mass	High mass	Low mass	High mass
Luminosity	20.7 fb^{-1}		20.7 fb^{-1}		20.7 fb^{-1}	
$ZZ^{(*)}$	28.52±1.27	91.53±6.65	24.56±1.50	141.83±10.82	11.47±1.13	55.21±4.43
Z, $Zb\bar{b}$, and $t\bar{t}$	1.88±0.62	0.56±0.18	5.00±1.17	1.43±0.34	2.11±0.70	0.59±0.20
Total Background	30.40±1.42	92.09±6.65	29.56±1.90	143.26±10.82	13.59±1.33	55.79±4.43
Data	40.00	93.00	40.00	169.00	20.00	55.00
$m_H = 123$ GeV	4.44±0.60		5.44±0.78		2.26±0.35	
$m_H = 125$ GeV	5.88±0.75		6.99±0.94		2.82±0.41	
$m_H = 127$ GeV	6.71±0.90		8.46±1.20		3.40±0.52	
$m_H = 130$ GeV	8.74±1.11		11.48±1.55		4.54±0.66	
$m_H = 400$ GeV	13.08±1.66		22.90±3.10		9.61±1.42	
$m_H = 600$ GeV	2.68±0.33		4.83±0.63		2.04±0.29	

	$\mu\mu\mu\mu$		$ee\mu\mu$		$eeee$	
	Low mass	High mass	Low mass	High mass	Low mass	High mass
Luminosity	4.6 fb^{-1}		4.6 fb^{-1}		4.6 fb^{-1}	
$ZZ^{(*)}$	5.30±0.24	16.64±1.20	4.22±0.26	26.27±1.99	1.54±0.15	9.24±0.74
Z, $Zb\bar{b}$, and $t\bar{t}$	0.41±0.14	0.13±0.04	1.11±0.26	0.32±0.08	0.47±0.16	0.13±0.04
Total Background	5.72±0.27	16.77±1.20	5.33±0.36	26.59±1.99	2.01±0.22	9.37±0.74
Data	11.00	23.00	7.00	23.00	3.00	13.00
$m_H = 125$ GeV	1.06±0.14		1.13±0.15		0.39±0.06	
$m_H = 400$ GeV	2.11±0.28		3.61±0.50		1.44±0.21	
$m_H = 600$ GeV	0.40±0.05		0.71±0.10		0.31±0.05	

Is it the SM Higgs ?

➔Verify the new observed particle

✓ Spin-0 particle

- Spin-1: excluded by H→γγ
- Spin-2: look at angular correlation

Spin of particle	γγ	ZZ*	ττ	bb
Spin 0	☺	☺	☺	☺
Spin 1	☹	☺	☺	☺
Spin 2	☺	☺	☹	☺
Seen?	Yes	Yes	Not yet	Not yet

✓ CP-nature

- SM Higgs CP-even, extended Higgs sectors has CP-odd or mixed states
- Look at angular correlations

✓ Couplings

- Gauge / Yukawa couplings → g_{vvH}, $g_{ffH} \propto m$
- Unitarity in $W_L W_L$ scattering → $g_{WWH} \propto m_W$
- Higgs self-couplings, determine shape of Higgs potential via trilinear and quartic couplings, $V = \mu^2|\Phi|^2 + \lambda|\Phi|^4$ + constant

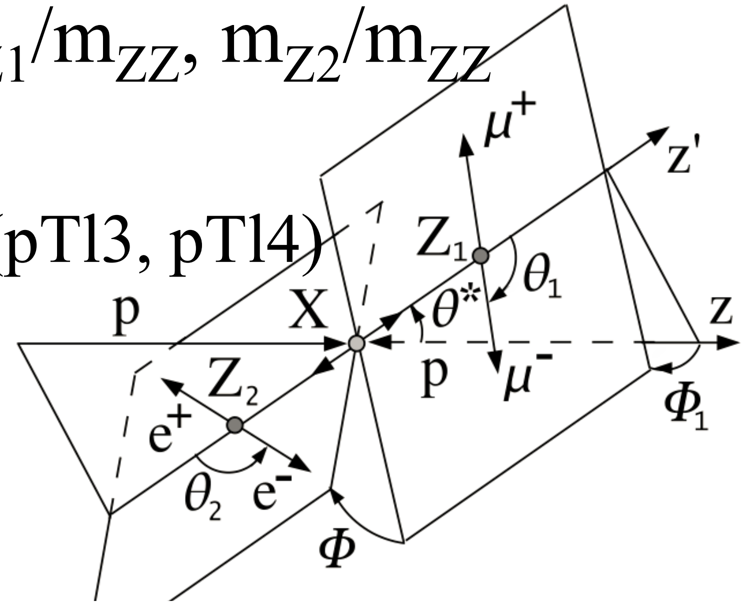
Higgs Production Cross Section and BR

m_H [GeV]	$\sigma(gg \to H)$ [pb]	$\sigma(qq' \to Hqq')$ [pb]	$\sigma(q\bar{q} \to WH)$ [pb]	$\sigma(q\bar{q} \to ZH)$ [pb]	$\text{BR}\left(H \to ZZ^{(*)} \to 4\ell\right)$ $[10^{-3}]$
$\sqrt{s} = 7$ TeV					
123	$15.8^{+2.3}_{-2.4}$	1.25 ± 0.03	$0.60^{+0.02}_{-0.03}$	0.33 ± 0.02	0.103
125	15.3 ± 2.3	1.22 ± 0.03	0.57 ± 0.02	0.32 ± 0.02	0.125
127	14.9 ± 2.2	1.20 ± 0.03	0.54 ± 0.02	0.30 ± 0.02	0.148
400	$2.05^{+0.30}_{-0.29}$	0.18 ± 0.01	–	–	1.21
600	$0.34^{+0.06}_{-0.05}$	$0.062^{+0.005}_{-0.002}$	–	–	1.23
$\sqrt{s} = 8$ TeV					
123	20.2 ± 3.0	1.61 ± 0.05	0.73 ± 0.03	0.42 ± 0.02	0.103
125	19.5 ± 2.9	$1.58^{+0.04}_{-0.05}$	0.70 ± 0.03	0.39 ± 0.02	0.125
127	18.9 ± 2.8	1.55 ± 0.05	$0.66^{+0.02}_{-0.03}$	0.37 ± 0.02	0.148
400	$2.92^{+0.41}_{-0.40}$	0.25 ± 0.01	–	–	1.21
600	$0.52^{+0.08}_{-0.07}$	0.097 ± 0.004	–	–	1.23

Higgs Spin and Parity Measurement

Variables sensitive to spin and parity

- Mass related variables: m_{ZZ}, m_{Z1}/m_{ZZ}, m_{Z2}/m_{ZZ}
- Kinematics variables
  - Pt_H, η_H, $\phi_{H,}$, lepton pT of second Z (pTl3, pTl4)
  - $\Delta R(l_3, l_4)$, $\Delta\eta(l_3,l_4)$, $\Delta R(Z_1, Z_2)$
- Angular variables
  - $\cos\theta_1$, $\cos\theta_2$, $\cos\theta^*$, ϕ_1, ϕ_2, ϕ_{12}



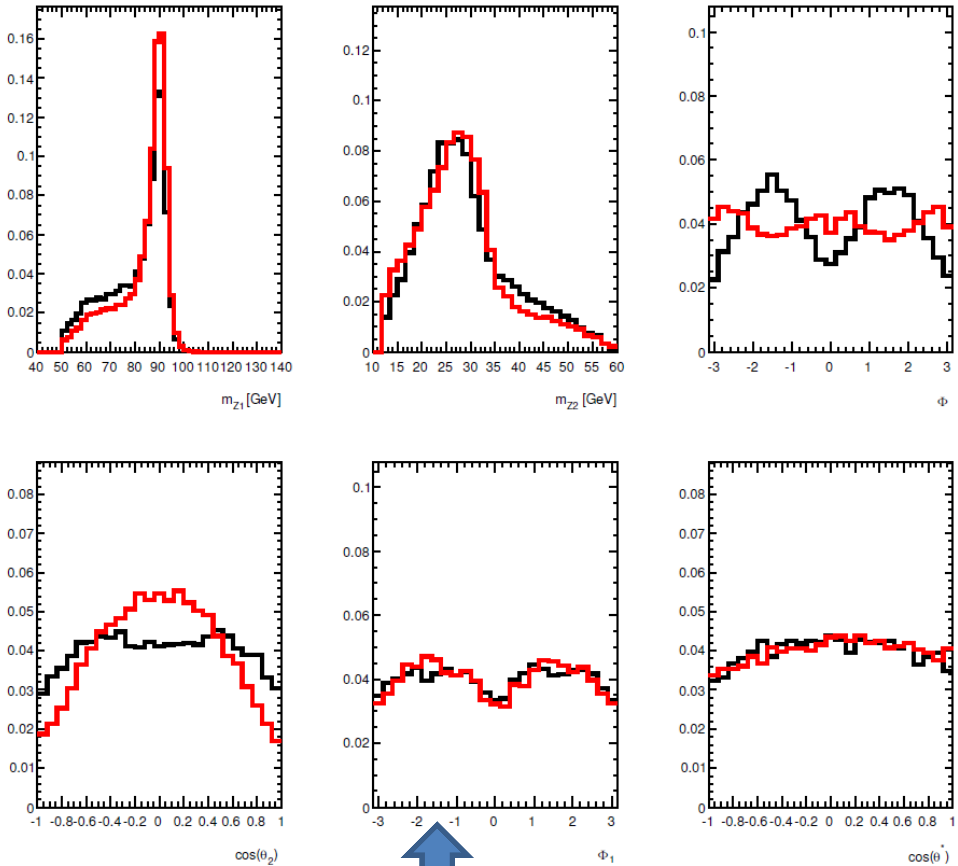
- θ_1 and θ_2 are the angles between negative final state leptons and the direction of flight of their respective Z-bosons. The 4-vectors of leptons are calculated in the rest frame of the corresponding Z-bosons.

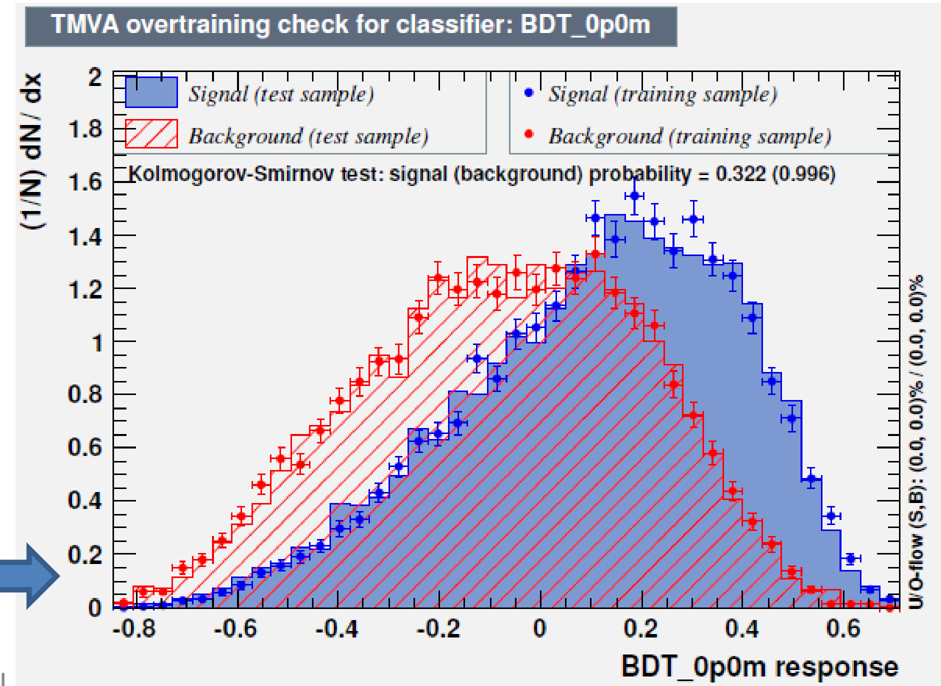
- ϕ is the angle between the decay planes of four final state leptons expressed in the four leptons rest frame.

- ϕ_1 is the angle defined between the decay plane of the first lepton pair and a plane defined by the vector of the Z_1 in the four lepton rest frame and the positive direction of the collision axis.

- θ^* is the production angle of the Z_1 defined in the four lepton rest frame.

Multivariate Method: BDT





BDT Input / Output

Expected and Observed Exclusions

Tested	Assumed					
	0^+	0^-	1^+	1^-	2^+_m	2^-
0^+		0.015 (2.17)	0.021 (2.02)	0.708 (-0.55)	0.138 (1.09)	0.021 (2.04)
0^-	0.015 (2.17)		0.004 (2.68)	()	0.014 (2.20)	0.038 (1.78)
1^+	0.010 (2.31)	0.001 (3.16)		0.060 (1.55)	0.007 (2.46)	0.001 (3.02)
1^-	0.000 (3.86)	()	0.051 (1.63)		0.005 (2.60)	0.009 (2.35)
2^+_m	0.137 (1.09)	0.019 (2.08)	0.018 (2.10)	0.009 (2.37)		0.009 (2.35)
2^-	0.018 (2.09)	0.036 (1.80)	0.004 (2.62)	0.017 (2.11)	0.007 (2.46)	

Table 19: The expected exclusion fof different spin and parity hypotheses with respect to each other for the multivariate analysis. The exclusion is given in terms of p-value with the corresponds number of Gaussian in parentheses. Result with the nominal binning in $m_{4\ell}$. Presented values are for 7 TeV and 8 TeV combined.

Tested	Assumed					
	0^+	0^-	1^+	1^-	2^+_m	2^-
0^+		0.304 (0.51)	0.508 (-0.02)	0.465 (0.09)	0.536 (-0.09)	0.038 (1.77)
0^-	0.013 (2.22)		0.070 (1.47)	()	0.184 (0.90)	0.201 (0.84)
1^+	0.001 (3.05)	0.016 (2.14)		0.000 (3.69)	0.000 (3.38)	0.000 (3.41)
1^-	0.004 (2.66)	()	0.944 (-1.59)		0.085 (1.37)	0.014 (2.19)
2^+_m	0.073 (1.45)	0.038 (1.77)	0.571 (-0.18)	0.046 (1.68)		0.007 (2.44)
2^-	0.213 (0.80)	0.078 (1.42)	0.368 (0.34)	0.258 (0.65)	0.281 (0.58)	

Table 44: The observed exclusion for 7 and 8 TeV combined of different spin and parity hypotheses with respect to each other for the multivariate analysis. The exclusion is given in terms of p-value with the corresponds number of Gaussian in parentheses. Result with the nominal binning in $m_{4\ell}$. Presented values are for the 7 TeV and 8 TeV combined.

Contributions to ATLAS Physics Analyses

Search for Higgs through H→ZZ→4l final state

- 4.7 fb^{-1}(7TeV), ATL-COM-PHYS-2012-530
- 3.2 fb^{-1}(8TeV), ATL-COM-PHYS-2012-721
- 5.8 fb^{-1}(8TeV), ATL-COM-PHYS-2012-835
- **"Observation of a New Particle in the Search for the Standard Model Higgs Boson with the ATLAS Detector at the LHC", Phys. Lett. B 716 (2012) 1-29**

- **Current works on Higgs spin and CP measurement**
  - Higgs Spin/Parity Determination based on BDT, ATLAS HSG2 MVA Meeting, August 6, 2012
  - JHU MC Validation and Higgs Spin/Parity Determination based on BDT, ATLAS HSG2 MVA Meeting, July 30, 2012

Modeling Spin and Parity States

- CP-even and CP-odd resonances with spins 0, 1, and 2 are considered.

Table 1: Choice of coupling parameters for the spin-0, spin-1, spin-2 models considered in the current analysis. For the $q\bar{q}$ channel the unique choice of coupling parameters was made across all the spin and parity states: $g_1 = 1$.

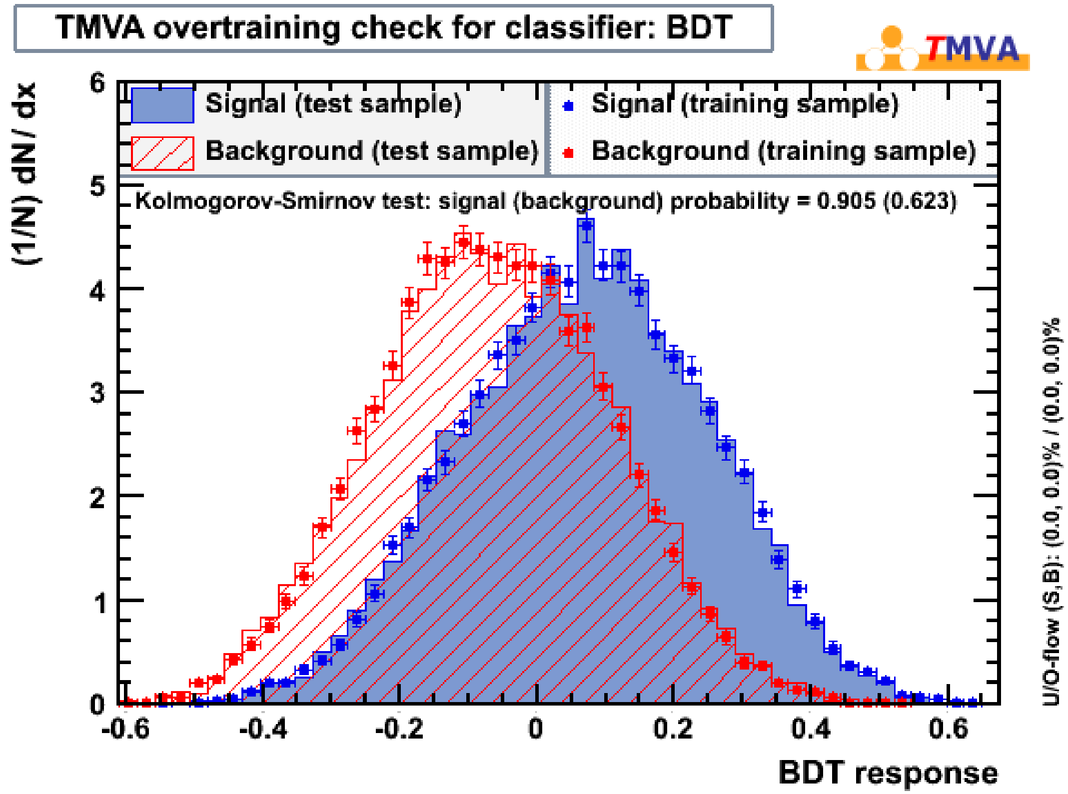
J^P	Production configuration	Decay configuration	Comments
0^+	$gg \to X$:	$g_1 = 1$ $g_2 = g_3 = g_4 = 0$	
0^-	$gg \to X$:	$g_4 = 1$ $g_1 = g_2 = g_3 = 0$	
1^+	$q\bar{q} \to X$:	$g_1 = 0$ $g_2 = 1$	
1^-	$q\bar{q} \to X$:	$g_1 = 1$ $g_2 = 0$	
2^+_m	$gg \to X$: $g_1 = 1$	$g_1 = g_5 = 1$	Graviton-like tensor with minimal couplings
2^+_m	$q\bar{q} \to X$: $g_1 = 1$	$g_1 = g_5 = 1$	Graviton-like tensor with minimal couplings
2^-	$gg \to X$: $g_1 = 1$	$g_8 = g_9 = 1$	"Pseudo-tensor"

BDT Training and Test Results

- About 28K JHU H(0+) and 28K H(0-) events, one half for BDT training and another half and SM ZZ for test.

Selection Cuts:

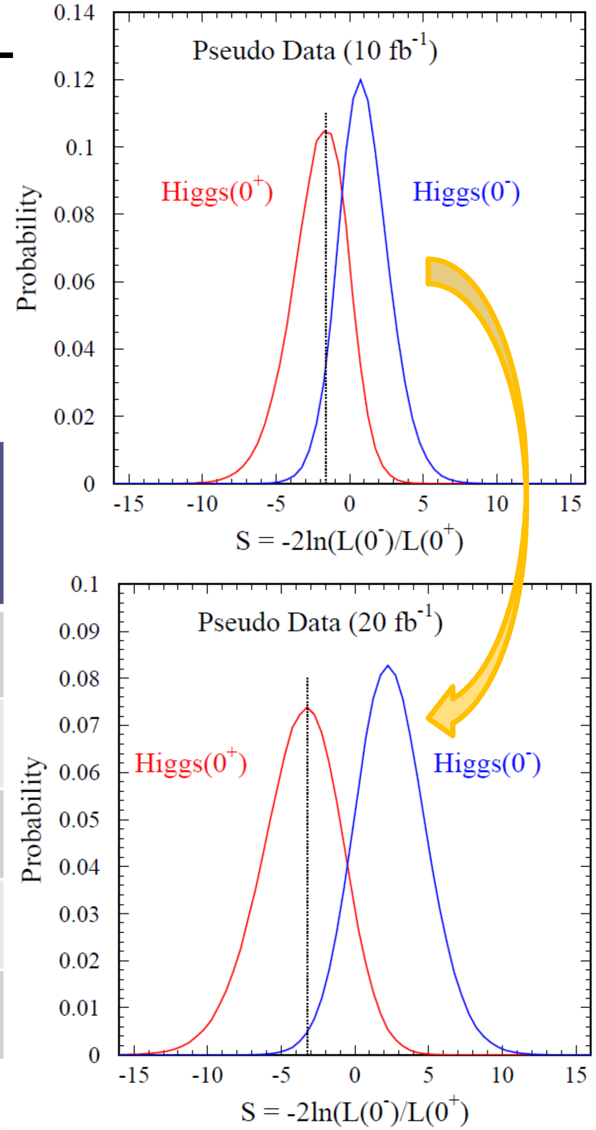
- 50 GeV < MZ1 < 106 GeV
- 17.5 GeV < MZ2 < 115 GeV
- Lepton pT:
  pT1 > 20 GeV, pT2 > 15 GeV,
  pT3 > 10 GeV, pT4 > 7 GeV
- |Eta| < 2.5
- dR > 0.1 (0.2) for same (different) flavor di-lepton
- **120 GeV < M_{ZZ} < 130 GeV**



Log-likelihood Ratio and Separation Power

- Using Binned Log-likelihood Ratio method to determine the separation power between Higgs 0+ and 0-
- 1M MC trials based on Poisson statistics
- Log-likelihood Ratio distributions
- Expected significance vs int. luminosity

Int. Luminosity (fb^{-1})	Significance (no ZZ, BDT)	Significance (with ZZ, BDT)
10 (N_s=6, N_b=5.5)	1.97 σ	1.45 σ
20 (N_s=12, N_b=11)	2.74 σ	1.98 σ
30 (N_s=18, N_b=16.5)	3.36 σ	2.40 σ
40 (N_s=24, N_b=22)	3.85 σ	2.77 σ
50 (N_s=30, N_b=27.5)	4.26 σ	3.10 σ



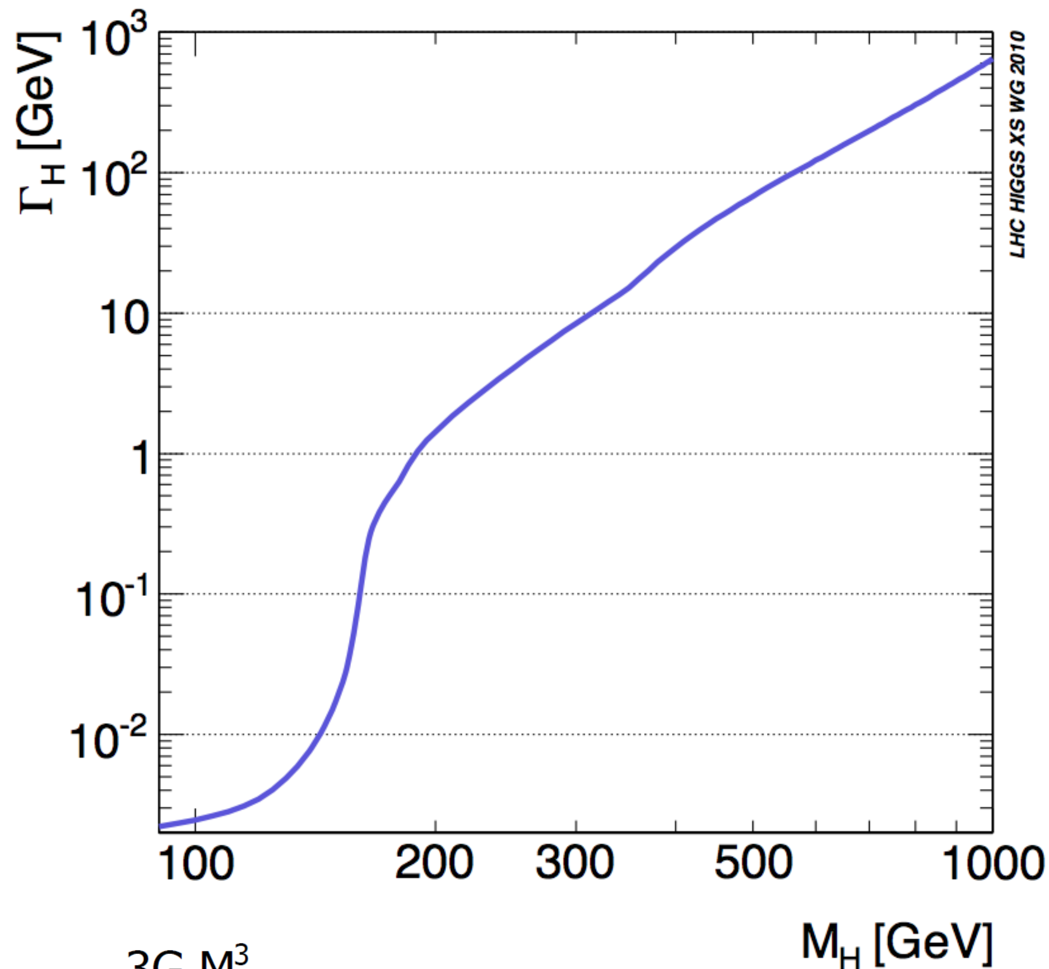
Higgs Boson Width

- **Strong mass dependent**

Γ_H = 3.5 MeV @ 120 GeV
1.4 GeV @ 200 GeV
8.4 GeV @ 300 GeV
68.0 GeV @ 500 GeV

- At low mass region (<200 GeV), detector resolution dominates mass resolution

- At high mass, intrinsic width becomes dominant



$$\Gamma_H \approx \frac{3G_F M_H^3}{16\pi\sqrt{2}}$$

$$\approx 500\ \text{GeV} \cdot \left(\frac{M_H}{1\ \text{TeV}}\right)^3$$