The Observation of a New Particle in the Search for the Standard Model Higgs Boson with the ATLAS Detector

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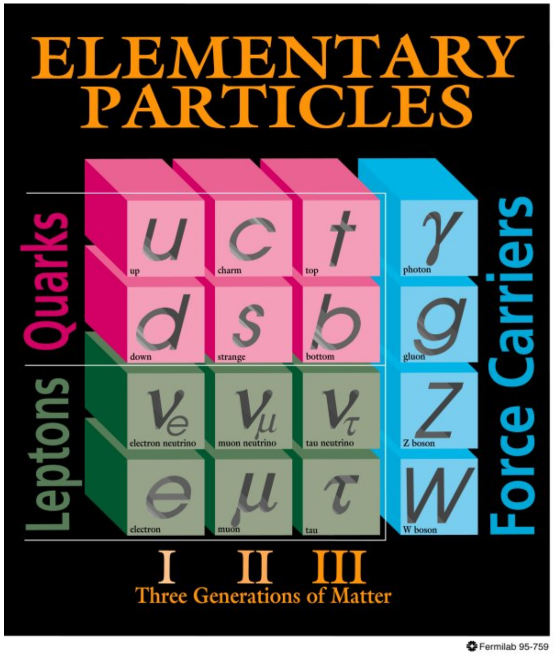
Outline

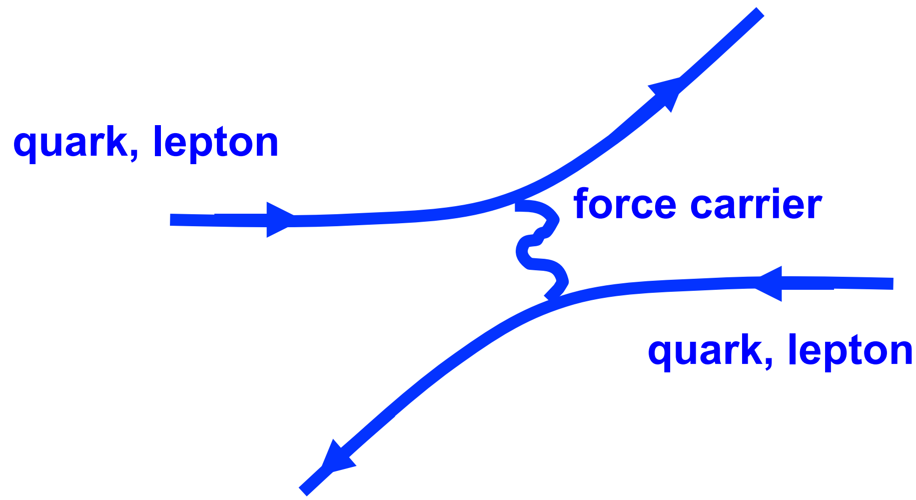
- **Introduction**
- **Summary results reported in Dec. 2011**
  - **Description of the excess**
- **The discovery (July 2012)**
  - $H \rightarrow \gamma\gamma$
  - $H \rightarrow ZZ^{(*)}$
  - $H \rightarrow WW^{(*)}$
  - $H \rightarrow \tau\tau$
  - $H \rightarrow bb$

- **New ATLAS combination**
- **The future is indeed bright!**

Standard Model of Particle Physics



- Quarks and Leptons interact via the exchange of force carriers



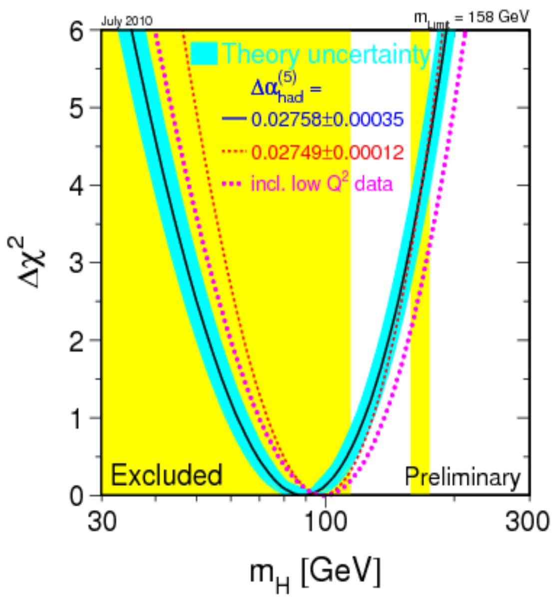
Force	Carrier
Strong	Gluons (g)
Electro-Weak	Electro-weak bosons (γ,W,Z)
Gravitation	?

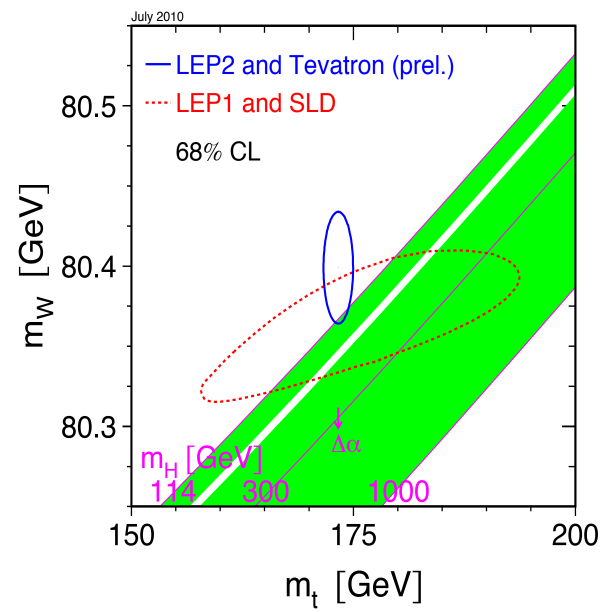
A Higgs boson in predicted and required to give mass to particles

Indirect Evidence: Electro-Weak Fits

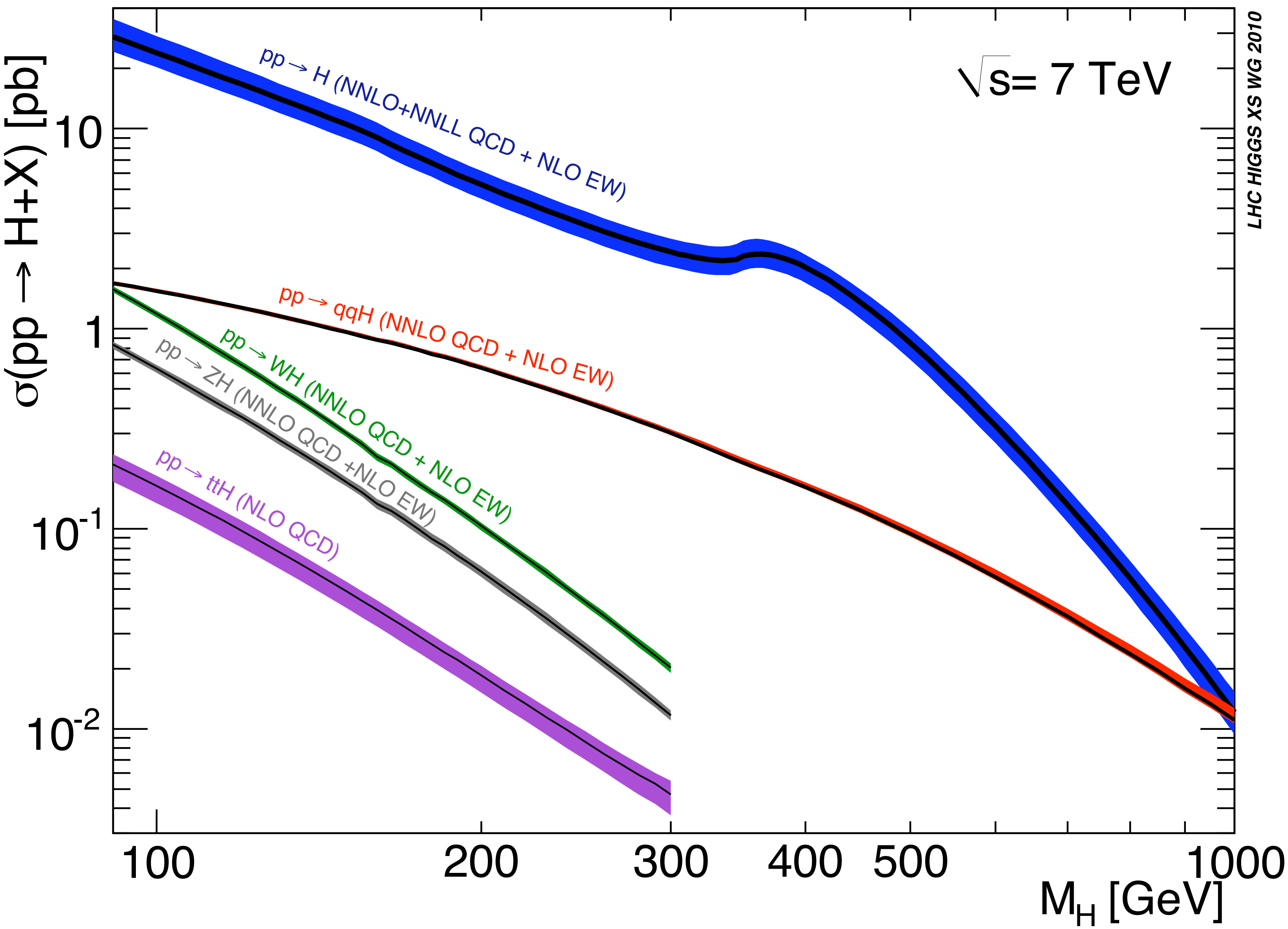
- **Experimental constraints so far:**
  - **Indirect measurements from fitting the EW data using new world average for M_{top}=172.4±1.2 GeV and M_w=80.399±0.025 GeV:**
    - **$m_H = 92^{+34}_{-26}$ GeV**
    - **m_H<161 GeV @ 95%CL** **(including LEP exclusion m_H<185 GeV)**

Data prefers low mass Higgs

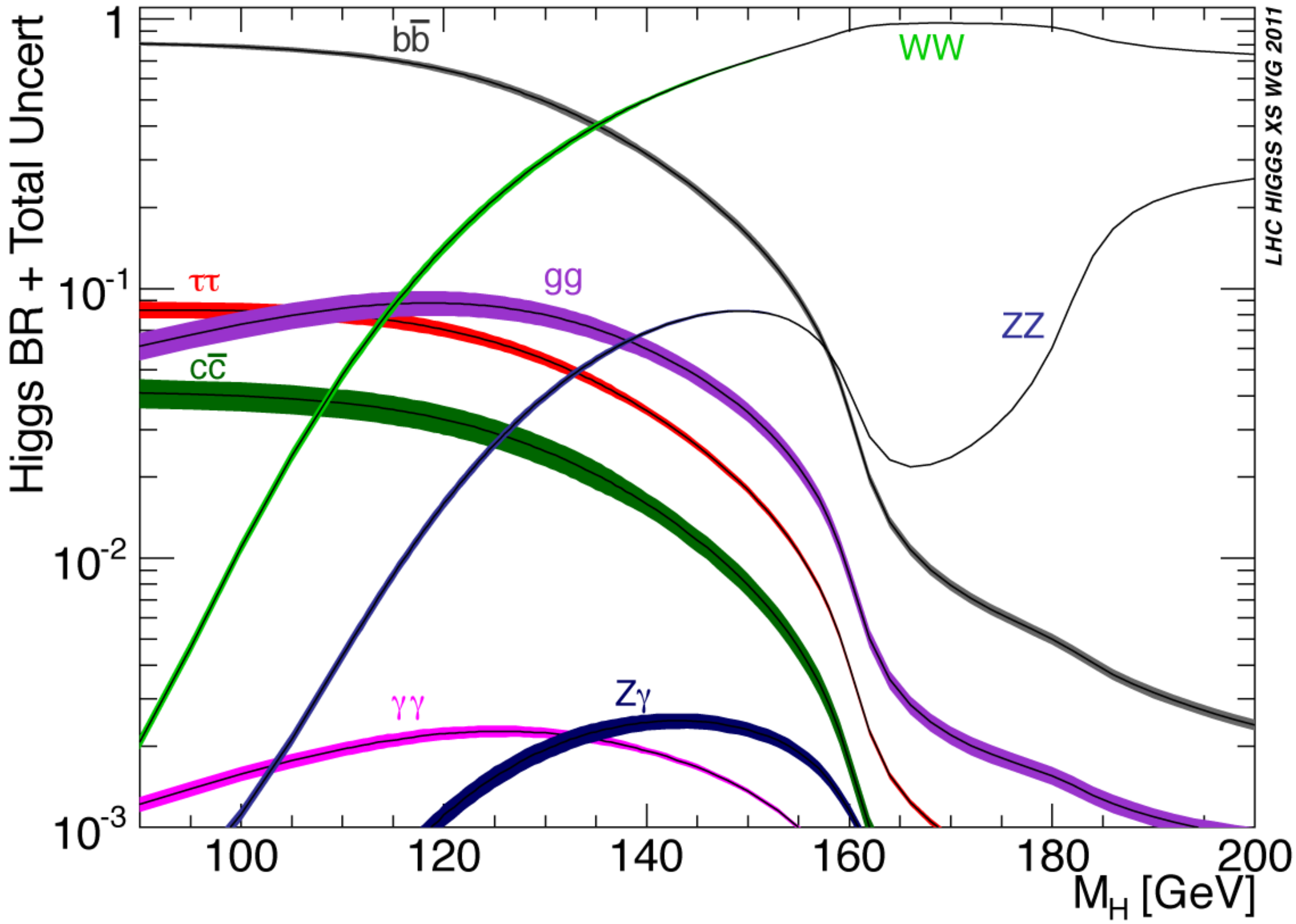




Higgs Cross-Sections at LHC



Main Decay Modes



Low Mass Higgs

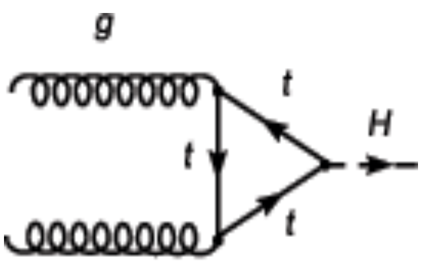
Close to LEP limit: H→γγ,ττ,bb

For M_H>140 GeV: H→WW$^{(*)}$,ZZ$^{(*)}$

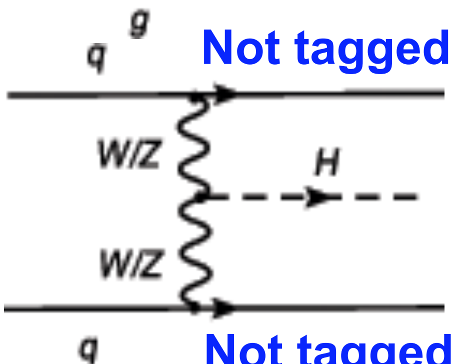
Low Mass Higgs And Jets

- Slicing phase space in regions with different S/B seems more optimal when inclusive analysis has little S/B

Inclusive



Not tagged

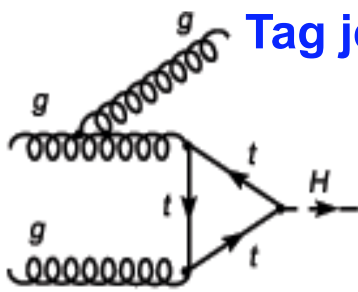


Not tagged

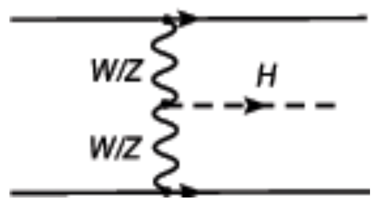
Analyses in TDR were mostly inclusive

H+1jet

Tag jet



Tag jet

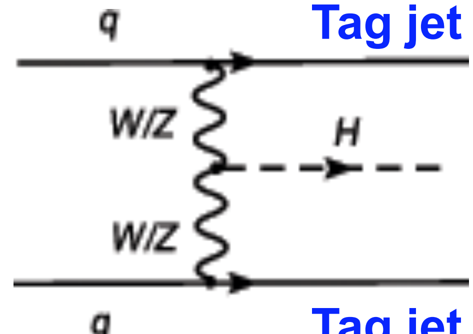


Not Tagged

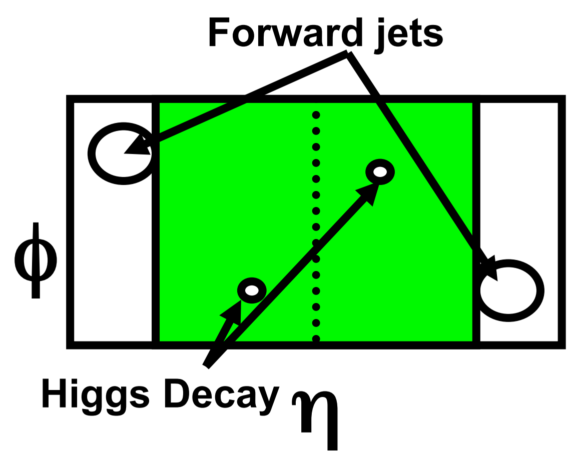
Applied to $H \to \gamma\gamma, \tau\tau, WW^{(*)}$

H+2jet

Tag jet

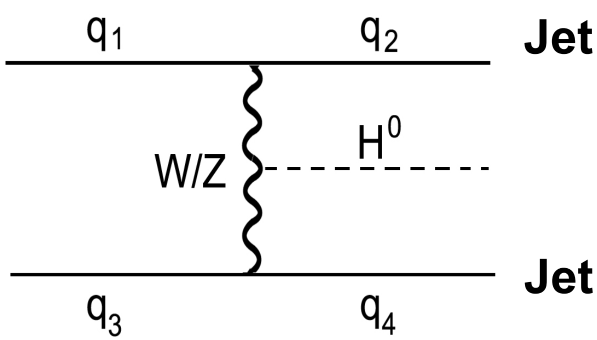


Tag jet

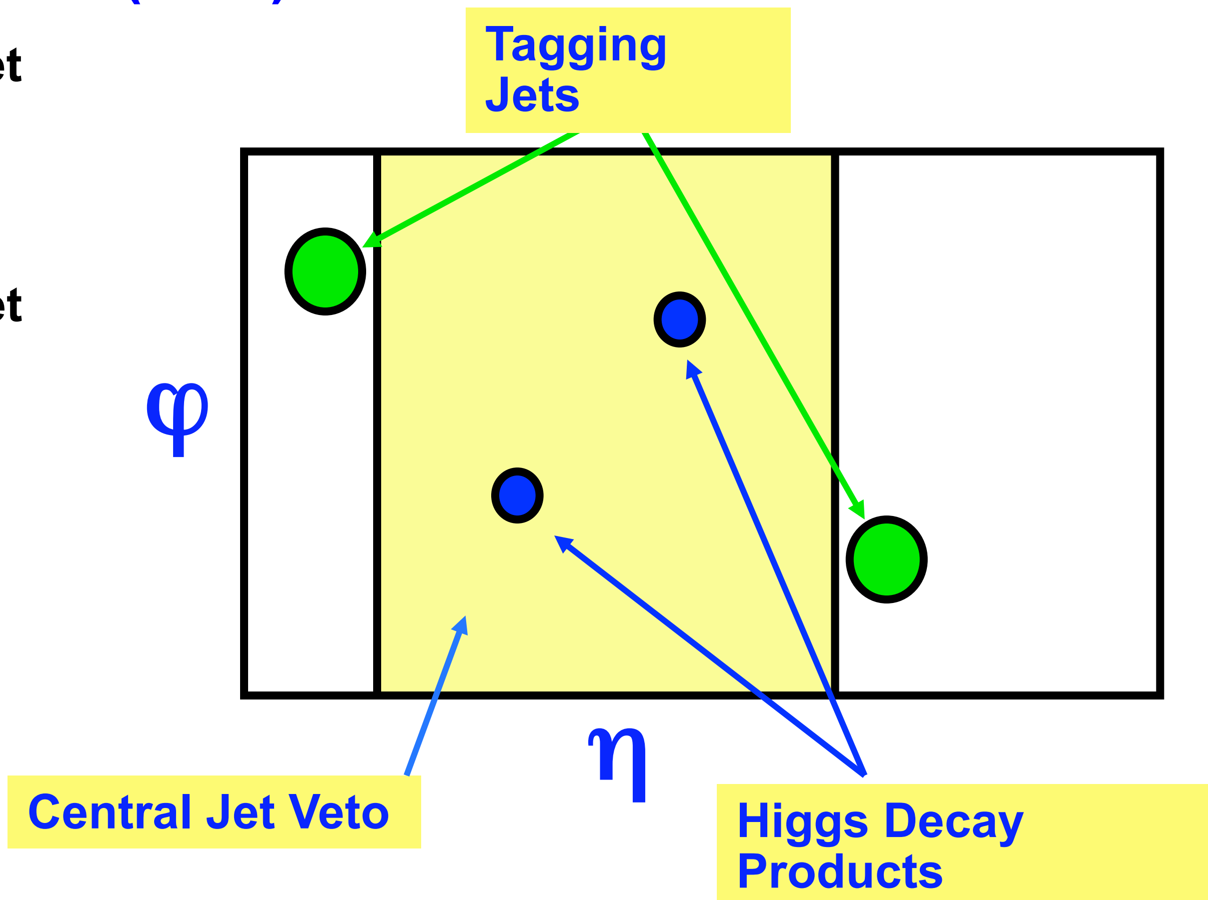


SM Higgs + ≥2jets at the LHC

- **Wisconsin Pheno (D.Zeppenfeld, D.Rainwater, et al.) proposed to search for a Low Mass Higgs in association with two jets with jet veto**
  - **Central jet veto initially suggested in V.Barger, K.Cheung and T.Han in PRD 42 3052 (1990)**



$$\eta_{J1} \cdot \eta_{J2} < 0$$
$$\Delta\eta_{JJ} > 3.5 \div 4$$
$$M_{JJ} > 500 \div 700\,\mathrm{GeV}$$
c.j.v.



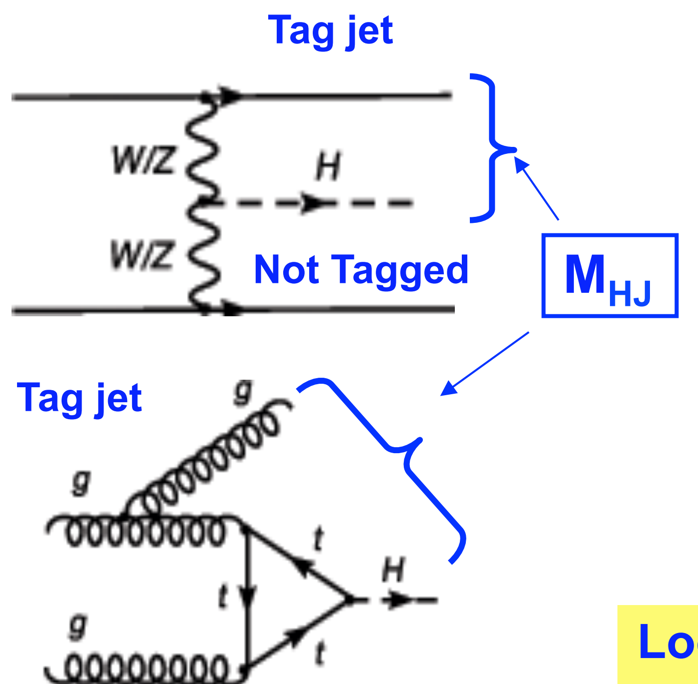
SM Higgs + ≥1jet at the LHC

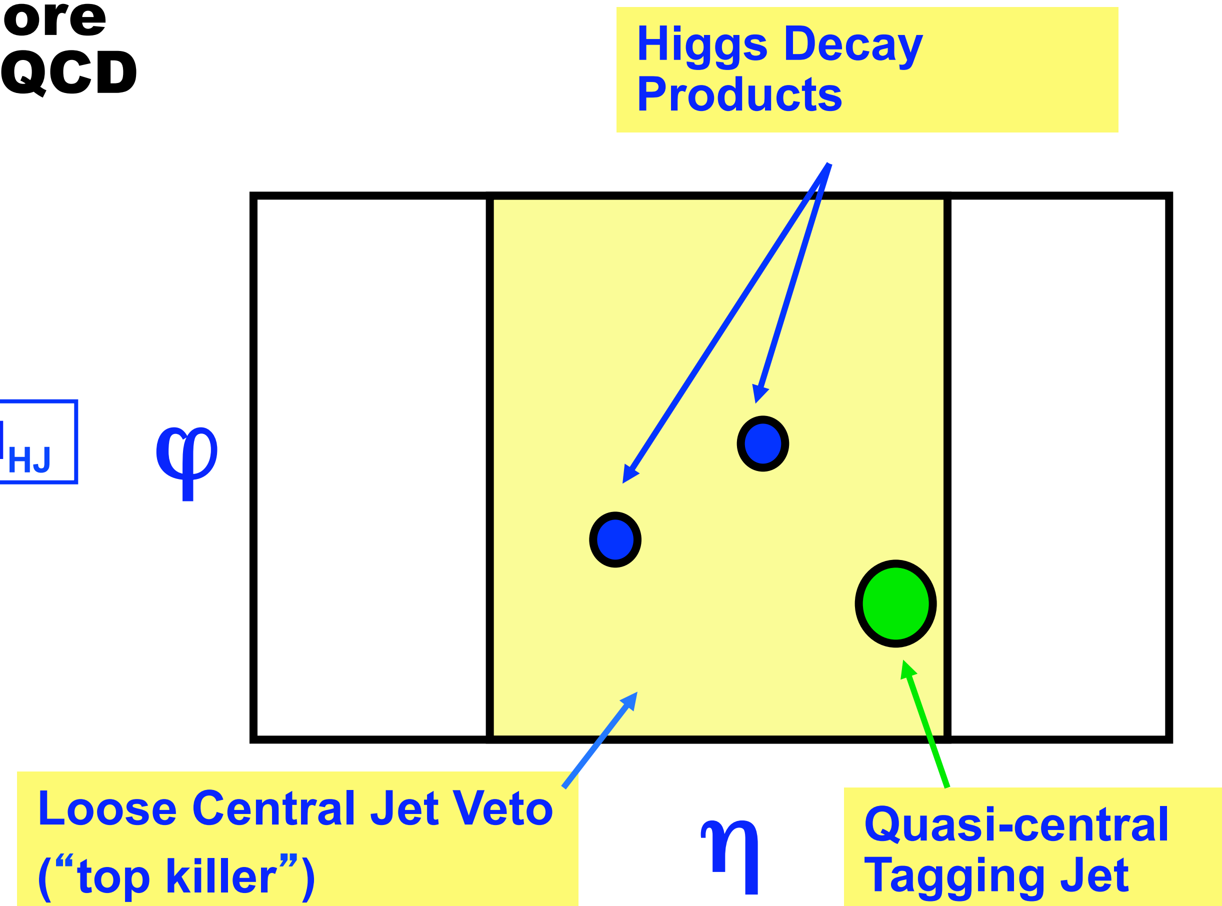
1. **Large invariant mass of leading jet and Higgs candidate**
2. **Large P_T of Higgs candidate**
3. **Leading jet is more forward than in QCD background**

S.Abdullin et al PL B431 (1998) for $H \rightarrow \gamma\gamma$

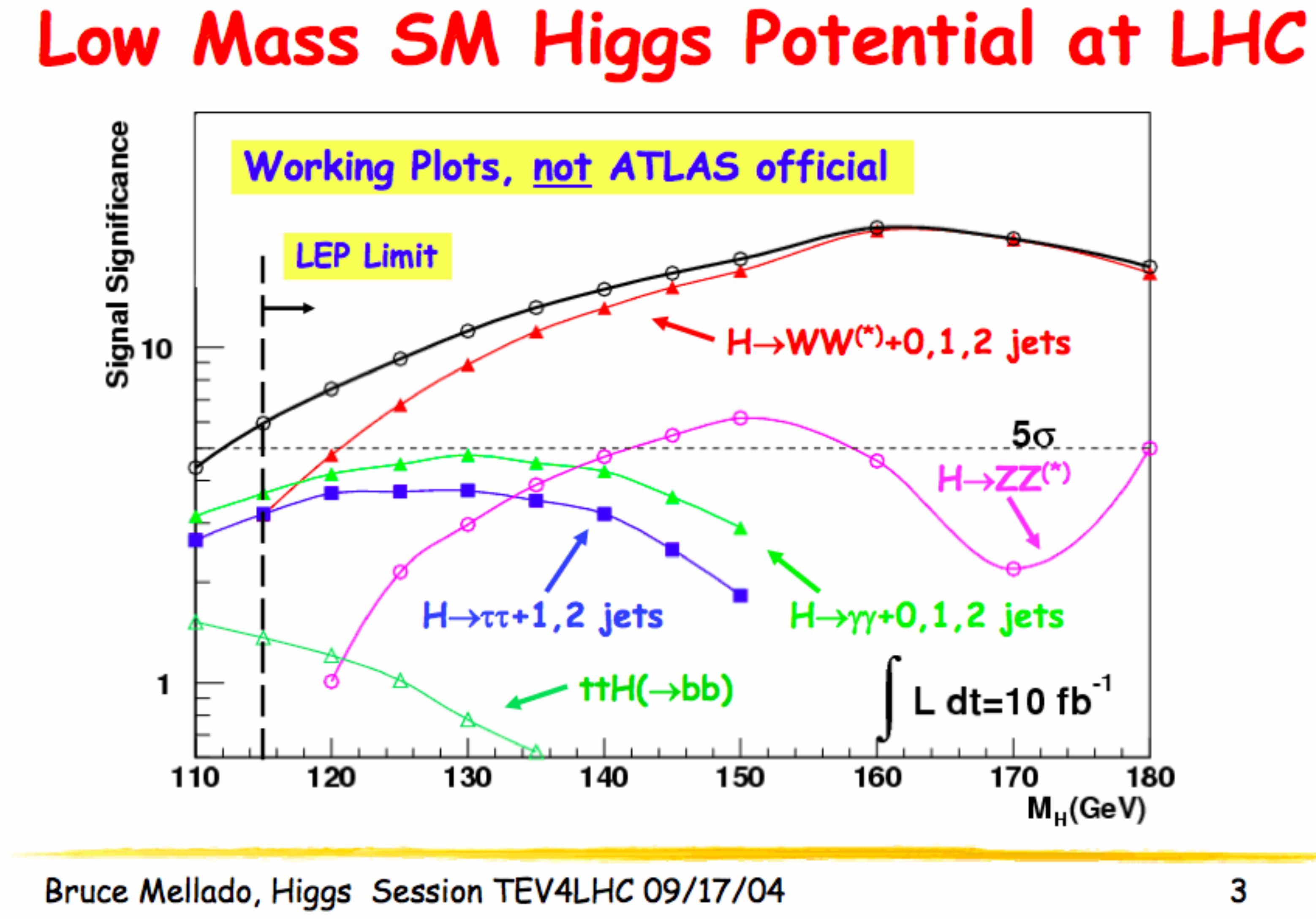
B.Mellado, W.Quayle and Sau Lan Wu Phys.Lett.B611:60-65,2005 for $H \rightarrow \tau\tau$

B.Mellado, W.Quayle and Sau lan Wu Phys.Rev.D76:093007,2007 for $H \rightarrow WW^{(*)}$





Analysis strategy of slicing phase-space according according to jet multiplicity:
B. Mellado, Tev4LHC, FermiLab, September 16-18 2004.
http://conferences.fnal.gov/tev4lhc/



Inner detector :

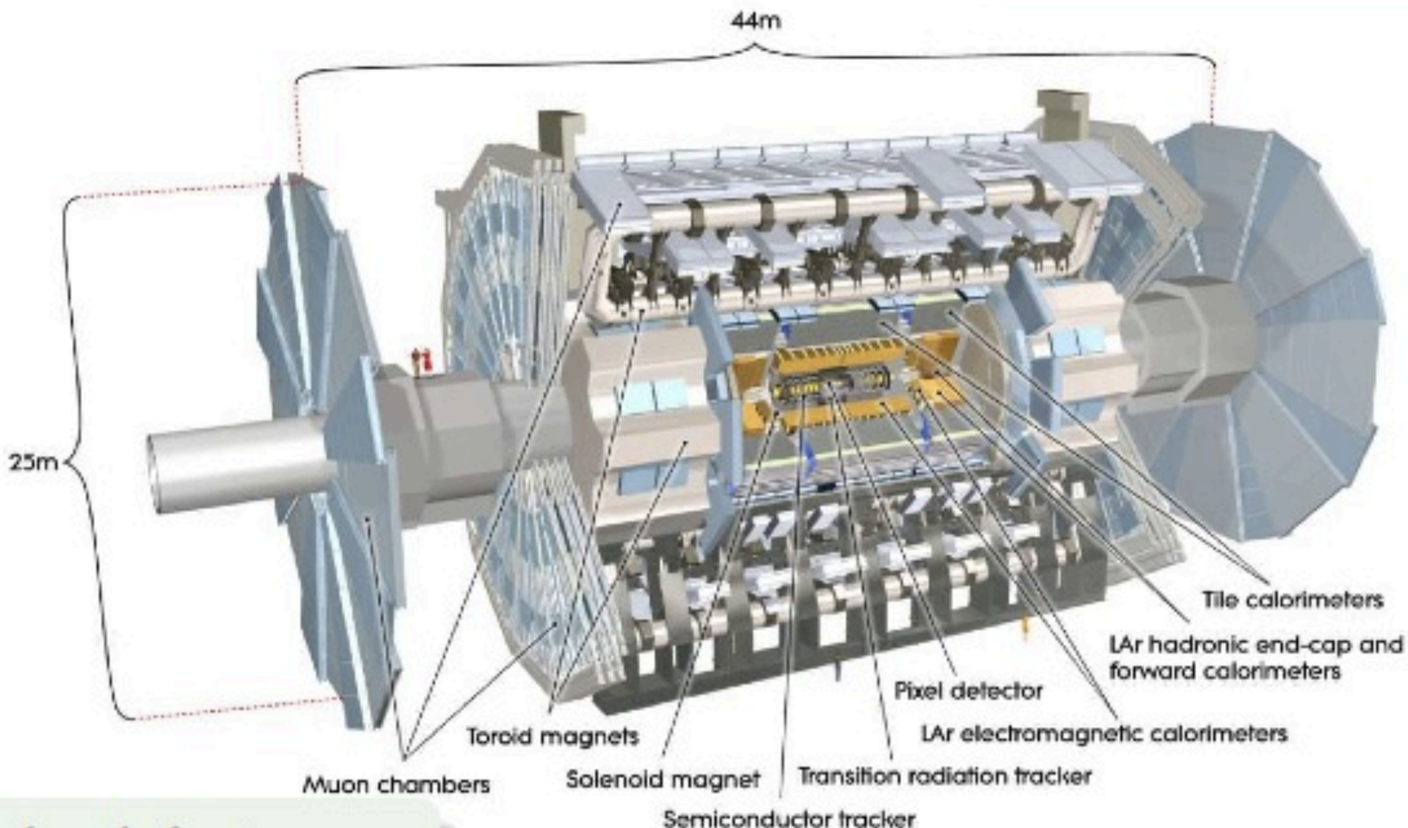
Pixel detector + SCT + TRT

$$\frac{\sigma_{p_T}}{p_T} \approx 0.05\% p_T \oplus 1\% \ , \ |\eta| < 2.5$$

EM calorimeter :

Lead-LAr sampling calo. with accordion geometry

$$\frac{\sigma_E}{E} \approx \frac{10\%}{\sqrt{E}} \oplus 0.7\% \ , \ |\eta| < 3.2$$



Hadronic calorimeter :

Steel and scintillating tiles in the barrel, copper and liquid argon in end-caps

$$\frac{\sigma_E}{E} = \frac{50\%}{\sqrt{E}} \oplus 3\%, \ |\eta| < 3.2$$

$$\frac{\sigma_E}{E} = \frac{100\%}{\sqrt{E}} \oplus 10\%, \ 3.1 < |\eta| < 4.9$$

Muon spectrometer :

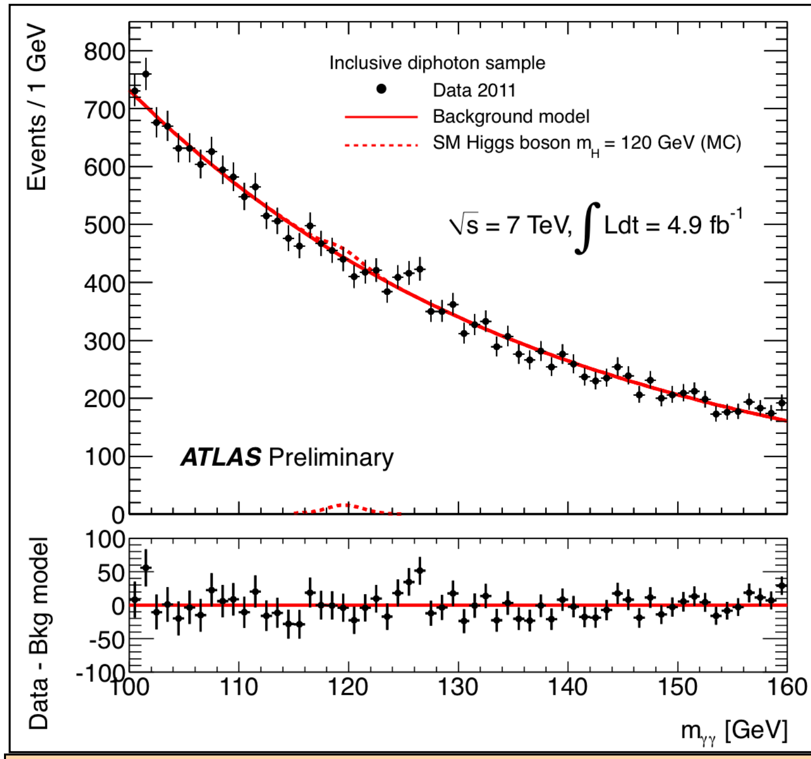
superconducting air-core toroid magnets, gaz based muon chambers

$$\frac{\sigma_{p_T}}{p_T} \approx 2\% \text{ at } 50\text{GeV to } 10\% \text{ at } 1\text{TeV}, \ |\eta| < 2.7$$

Summary of Results Reported on December 13th 2011

$H \to \gamma\gamma$

- 22489 events with $100 < m_{\gamma\gamma} < 160$ GeV observed in the data
- expected signal efficiency: ~ 35% for m_H=125 GeV



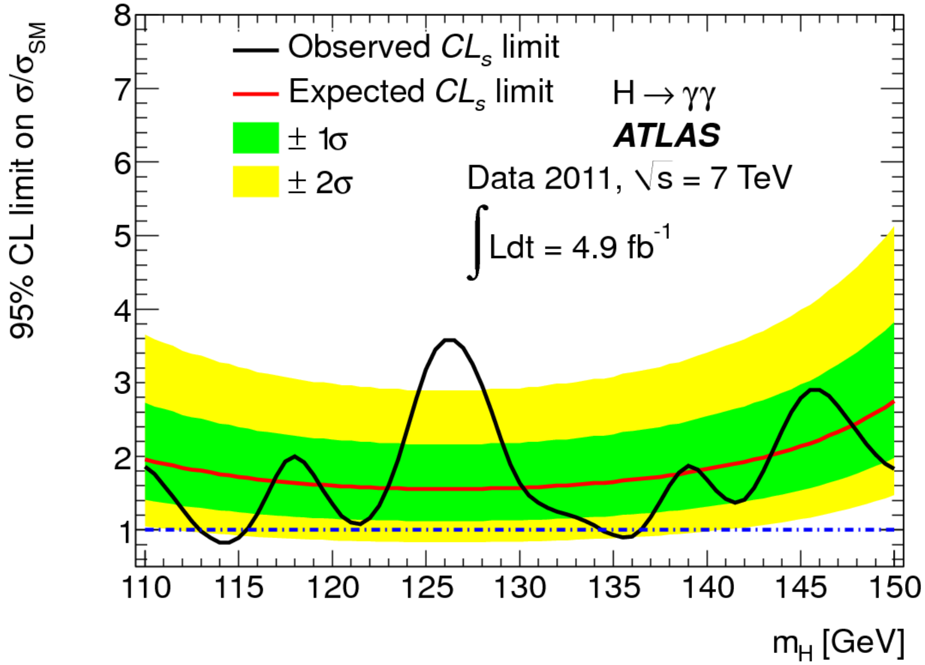
$m_{\gamma\gamma}$ spectrum fit with exponential function for background plus Crystal Ball + Gaussian for signal
→background determined directly from data

Systematic uncertainties on signal expectation

Type and source	Uncertainty
Event yield	
Photon reconstruction and identification	$\pm 11\%$
Effect of pileup on photon identification	$\pm 4\%$
Isolation cut efficiency	$\pm 5\%$
Trigger efficiency	$\pm 1\%$
Higgs boson cross section	$+15\% / -11\%$
Higgs boson p_T modeling	$\pm 1\%$
Luminosity	$\pm 3.9\%$
Mass resolution	
Calorimeter energy resolution	$\pm 12\%$
Photon energy calibration	$\pm 6\%$
Effect of pileup on energy resolution	$\pm 3\%$
Photon angular resolution	$\pm 1\%$
Migration	
Higgs boson p_T modeling	$\pm 8\%$
Conversion reconstruction	$\pm 4.5\%$

Main systematic uncertainties

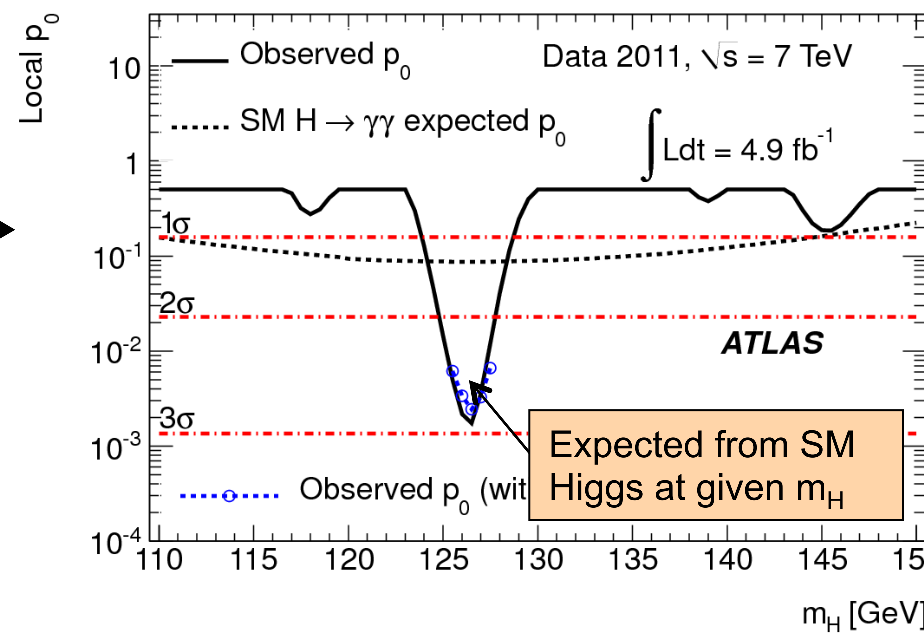
Expected signal yield : ~ 20%
H→ γγ mass resolution : ~ 14%
H→ γγ p_T modeling : ~ 8%
Background modeling : ±0.1-5.6 events



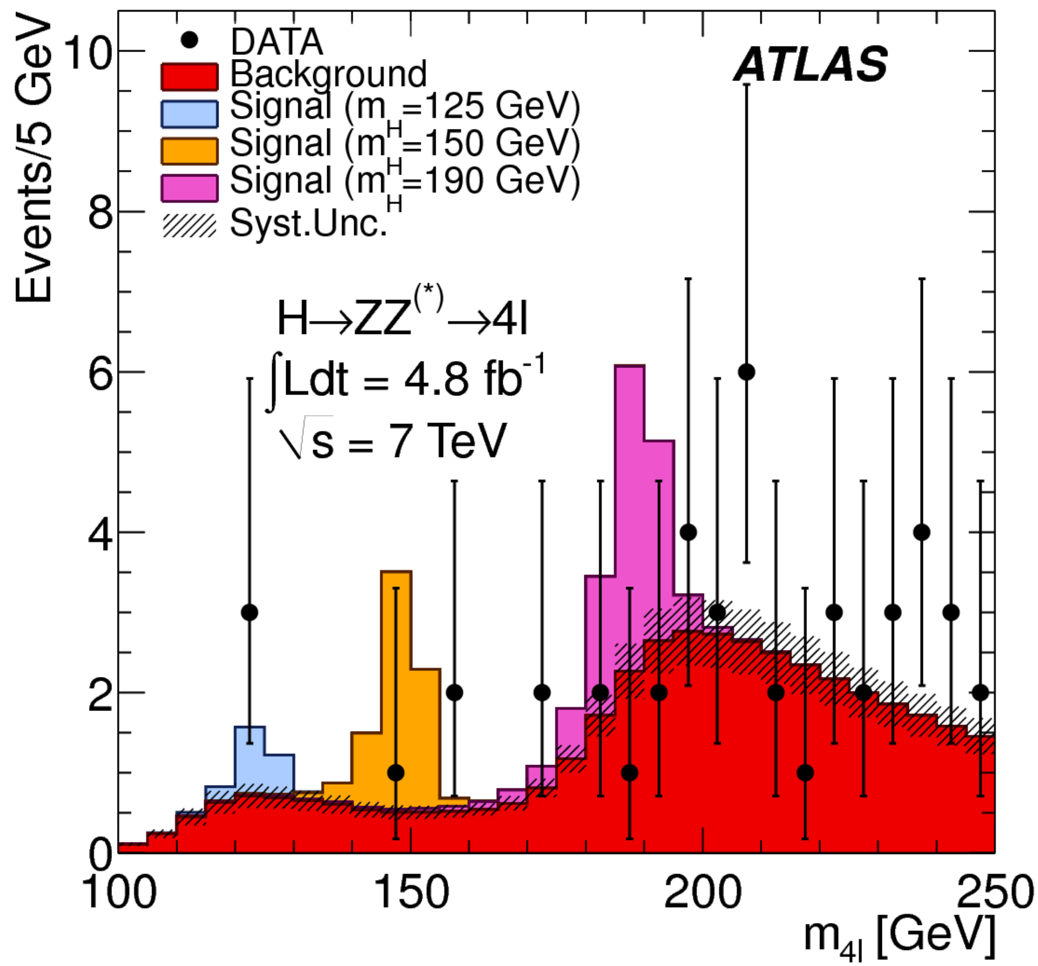
Excluded (95% CL):
$113 \le m_H \le 115$ GeV, $133.5 \le m_H \le 136$ GeV

$$H \to \gamma\gamma$$

Consistency of the data with the background-only expectation



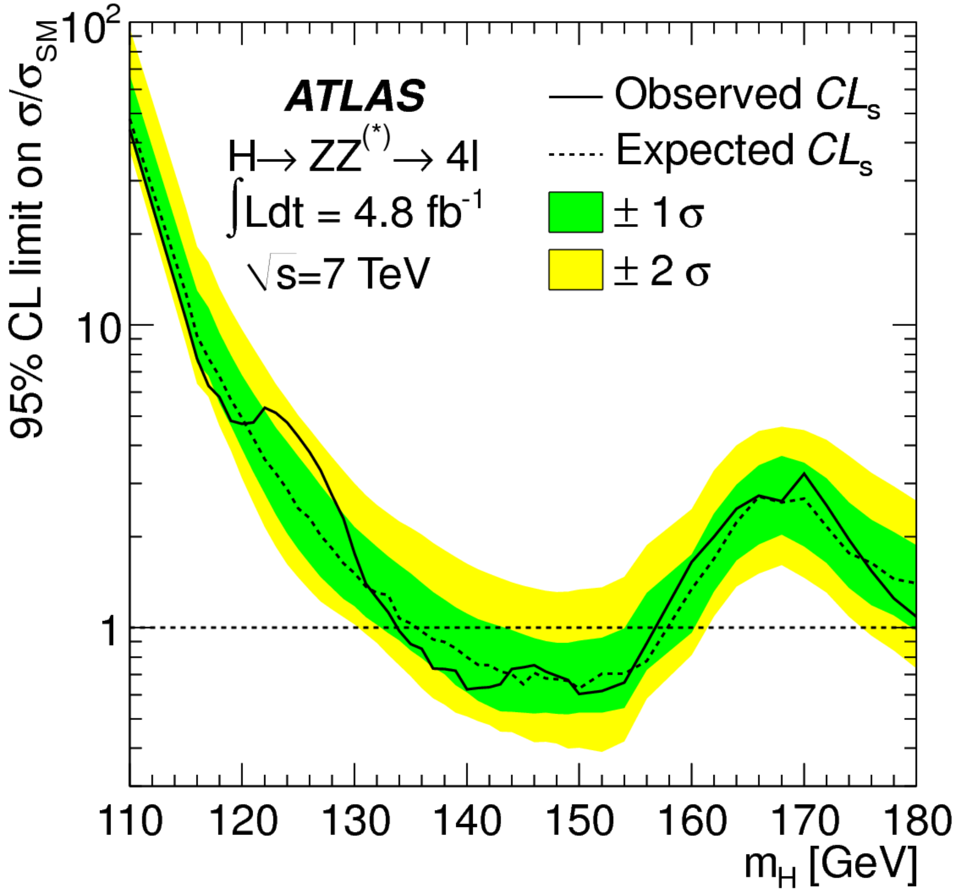
Maximum deviation from background-only expectation observed for m_H~126 GeV:
- ❑local p_0-value corresponding to 2.8σ
- ❑*expected from SM Higgs*: ~ 1.4σ local
- ❑global p_0-value: includes probability for such an excess to appear anywhere in the investigated mass range (110-150 GeV) ("Look-Elsewhere-Effect"): 1.5σ

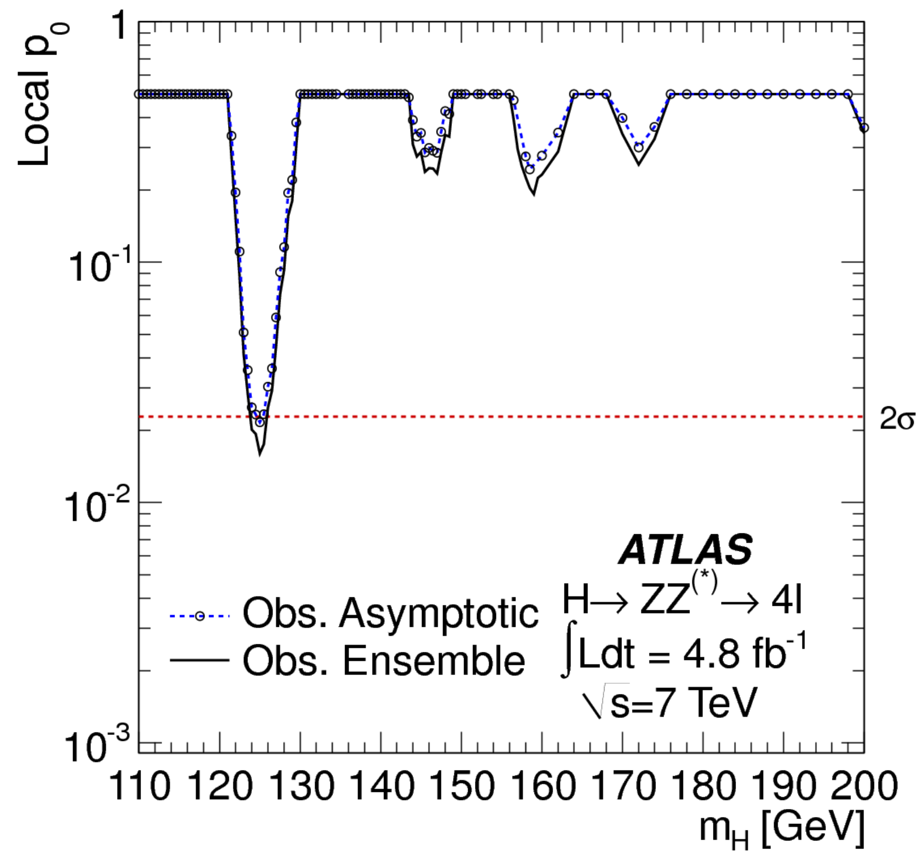


In the region 117< m_{4l} <128 GeV
(containing ~90% of a m_H=125 GeV signal):

- similar contributions expected from signal and background: ~ 1.5 events each
- S/B ~ 2 (4μ), ~ 1 (2e2μ), ~ 0.3 (4e)
- Background dominated by ZZ* (4μ and 2e2μ), ZZ* and Z+jets (4e)

Main systematic uncertainties	
Higgs cross-section	: ~ 15%
Electron efficiency	: ~ 2-8%
ZZ* background	: ~ 15%
Zbb, +jets backgrounds	: ~ 40%





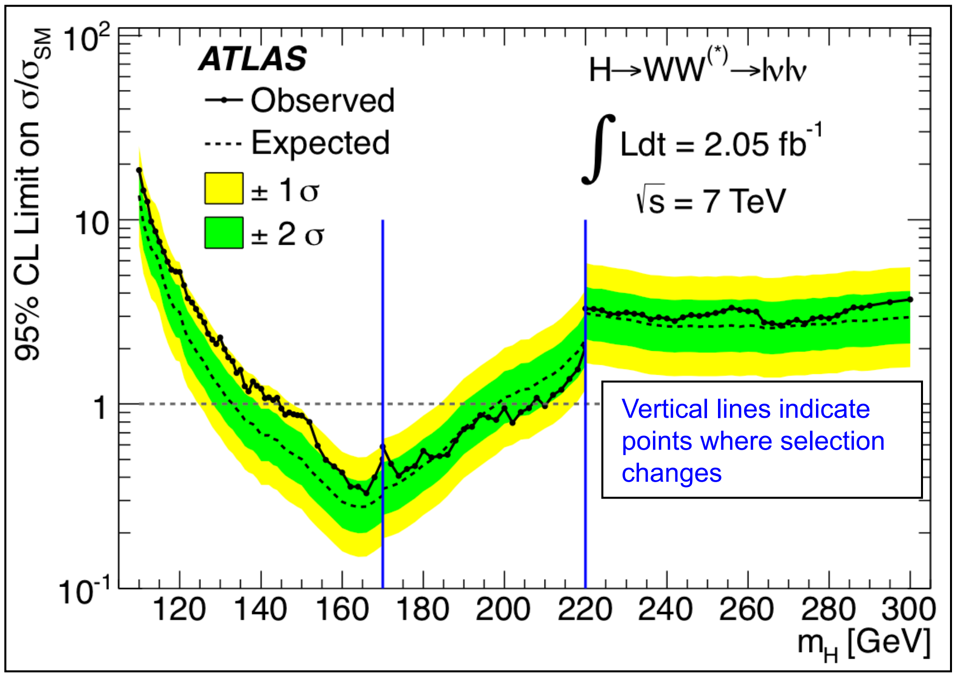
Excluded (95% CL): 134 < m_H < 156 GeV and 182 < m_H < 415 GeV (except 233-256GeV)
Expected (95% CL): 136 < m_H < 157 GeV and 184 < m_H < 400 GeV

$$H \to ZZ \to 4\ell$$

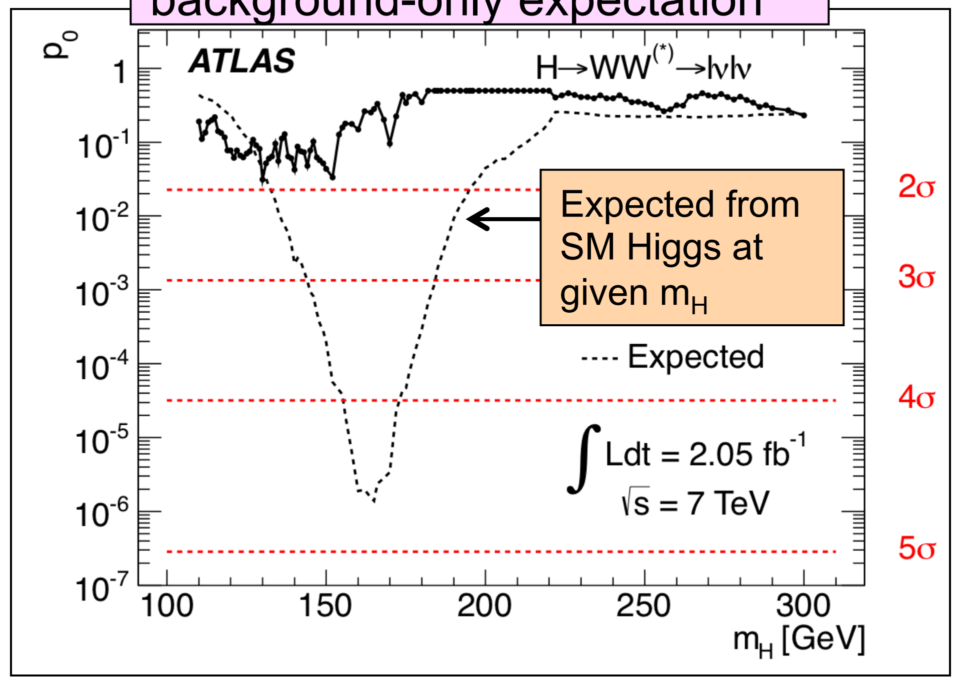
After all cuts (selection for m_H=130 GeV)

2.1 fb^{-1}

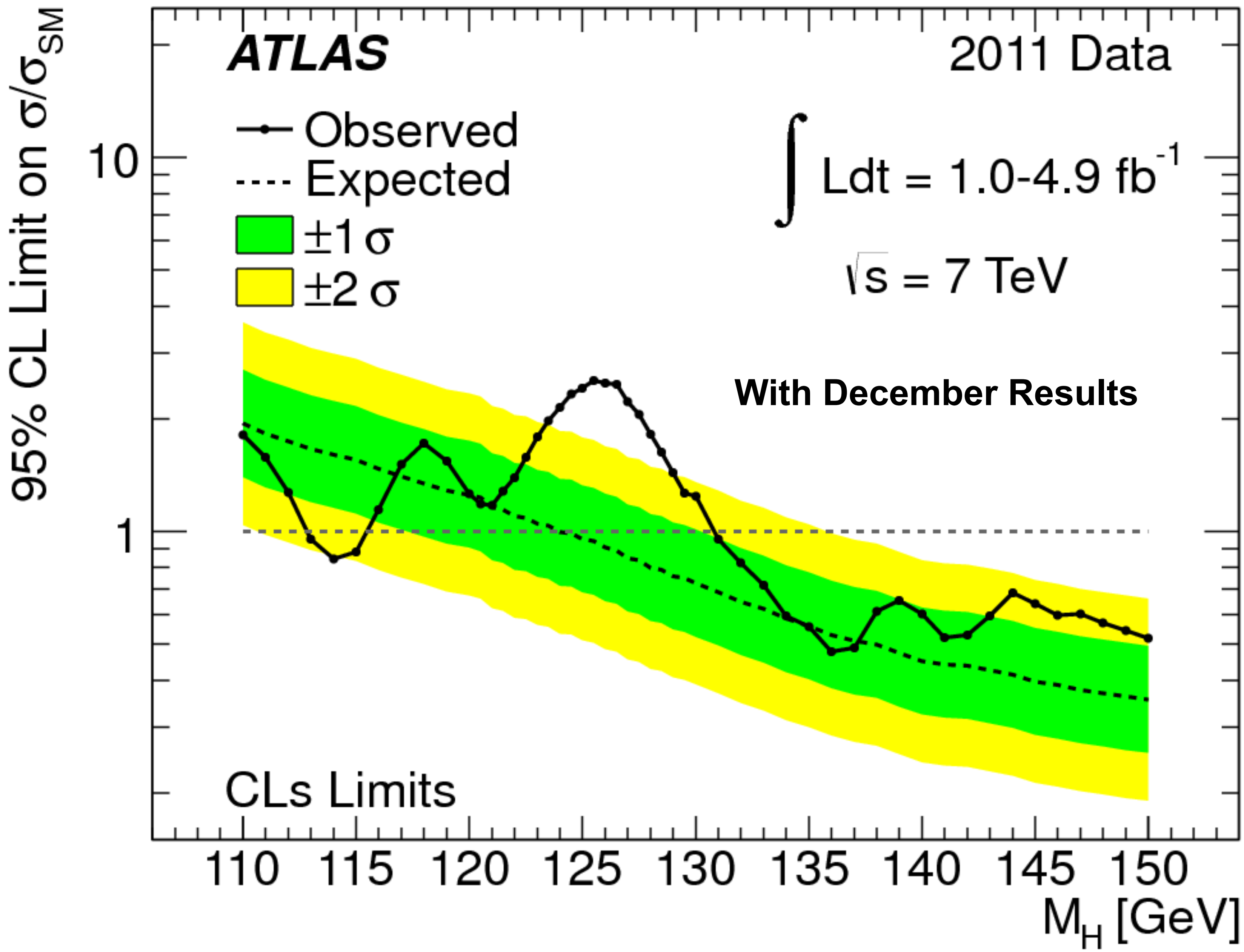
Observed in data	94 events 10 ee, 42 eμ, 42 μμ
Expected background	76 (±11)
Expected signal m_H=130 GeV	19 (±4)

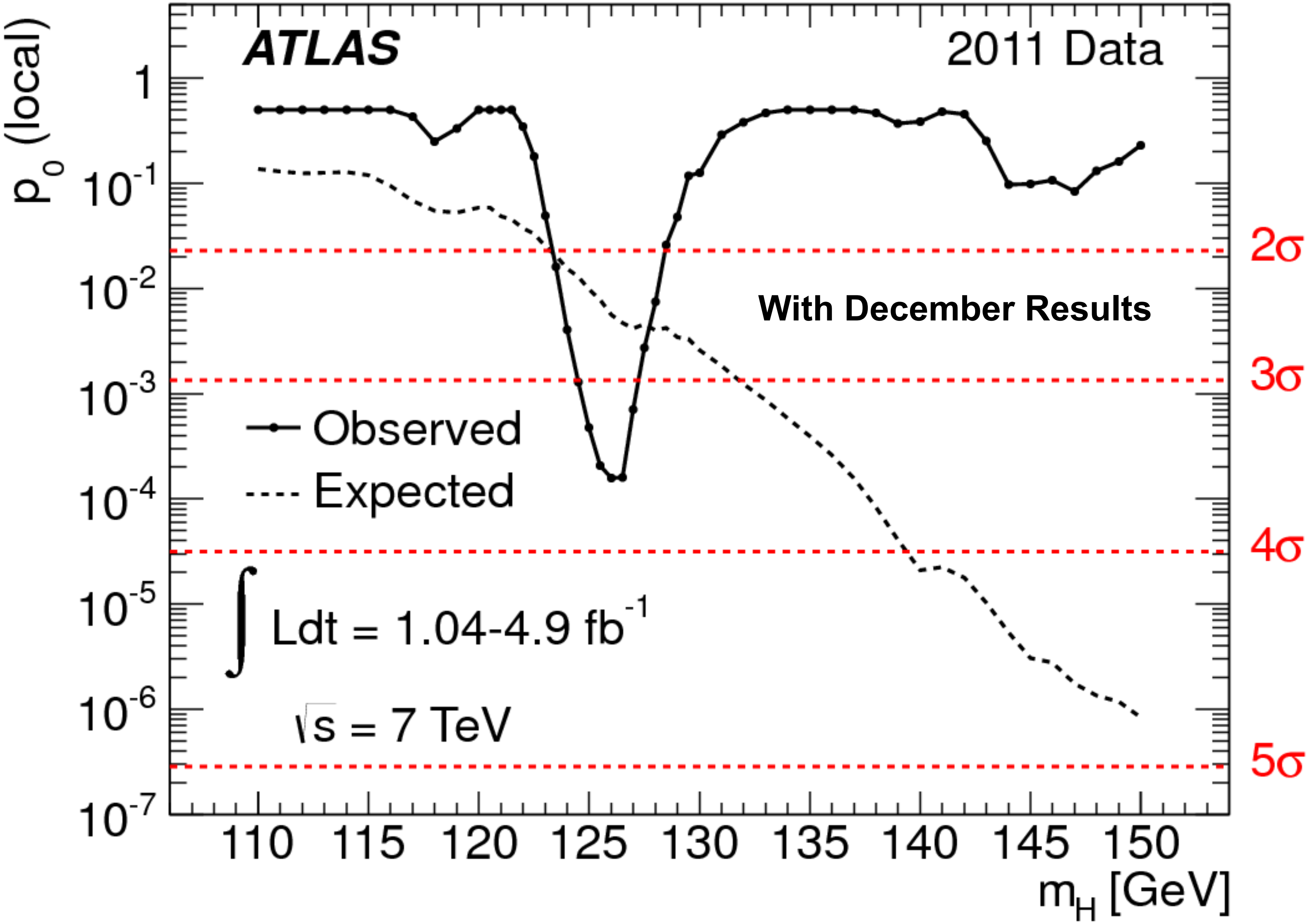


Consistency of the data with the background-only expectation

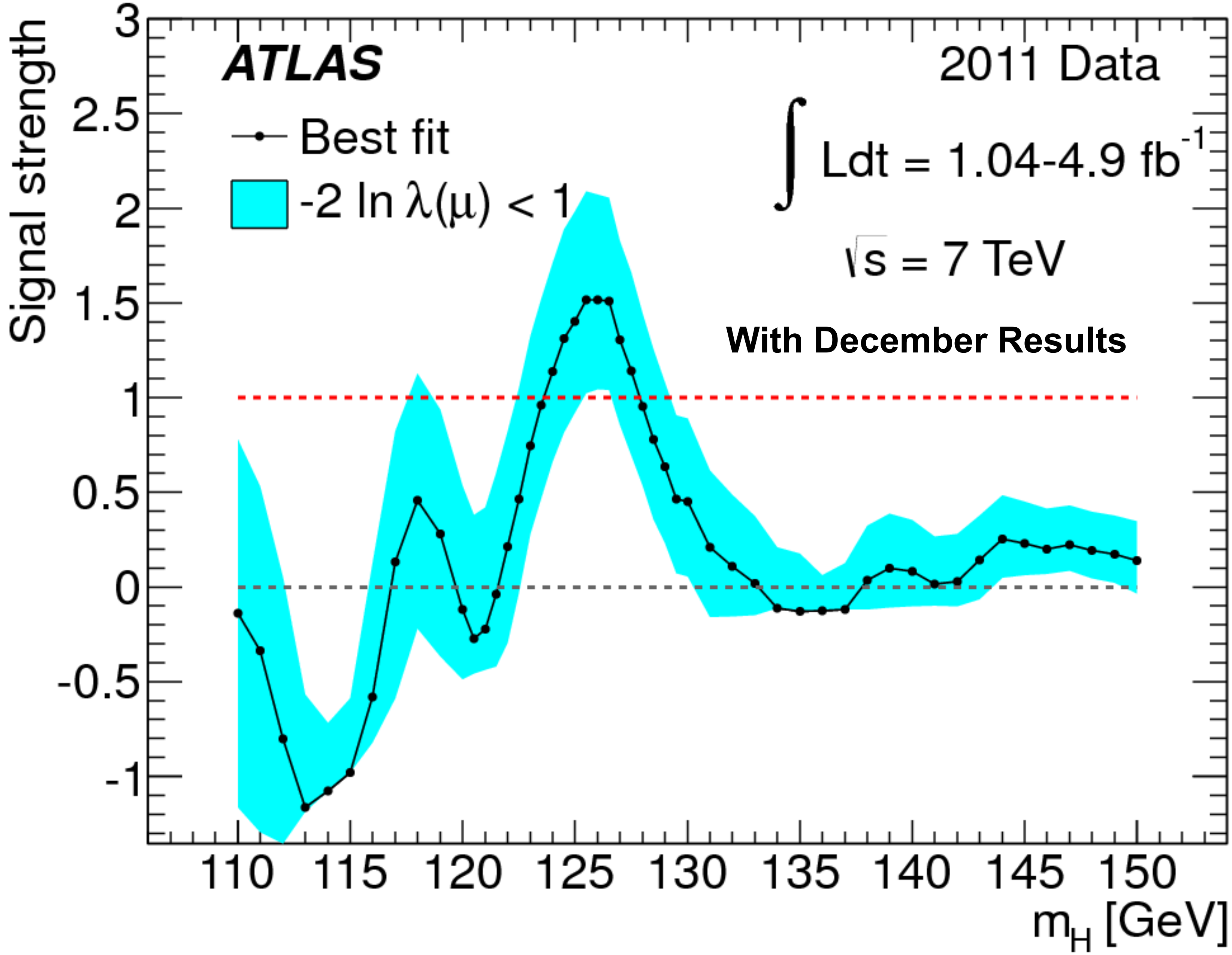


$$H \to W^+W^- \to \ell\nu\ell\nu$$


ATLAS
2011 Data
Observed
Expected
±1 σ
±2 σ
∫ Ldt = 1.0-4.9 fb⁻¹
√s = 7 TeV
With December Results
CLs Limits
95% CL Limit on σ/σ_SM
M_H [GeV]
10
1
110
115
120
125
130
135
140
145
150



ATLAS
2011 Data
With December Results
Observed
Expected
∫ Ldt = 1.04-4.9 fb^{-1}
√s = 7 TeV
p$_0$ (local)
m$_H$ [GeV]
2σ
3σ
4σ
5σ
1
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
110
115
120
125
130
135
140
145
150


ATLAS
2011 Data
Best fit
-2 ln λ(μ) < 1
∫ Ldt = 1.04-4.9 fb^-1
√s = 7 TeV
With December Results
Signal strength
m_H [GeV]
3
2.5
2
1.5
1
0.5
0
-0.5
-1
110
115
120
125
130
135
140
145
150

Conclusions from Dec. 13th 2011 Results

- ❑ **Strong enhancement of exclusion in almost entire range of 115 – 600 GeV except for:**

115.5-131 GeV

- ❑ **ATLAS sees an excess, but need more data**

126 GeV with 3.5σ (local) 2.2σ (global)

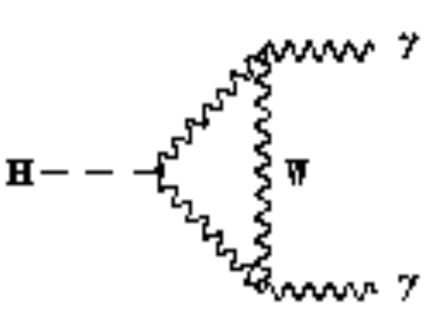
- ❑ **Three most sensitive channels seemed to give consistent results**

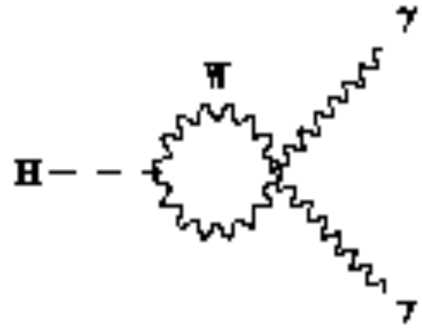
$$H \to \gamma\gamma, H \to ZZ^{(*)} \to \ell^+\ell^-\ell'^+\ell'^- \text{ and } H \to WW^{(*)} \to \ell^+\nu\ell'^-\bar{\nu},$$

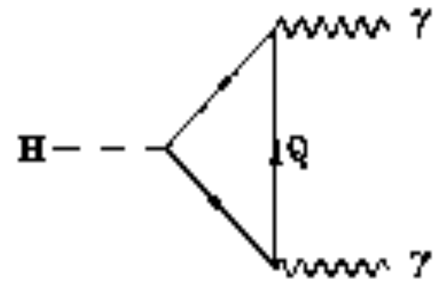
2.8σ **2.1σ** **1.4 σ**

Higgs to γγ Results with 5.9 fb^{-1} of 2012 Data

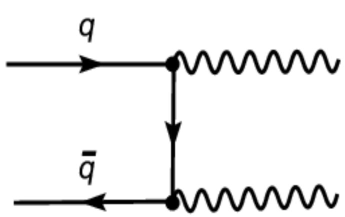
Higgs decay to γγ

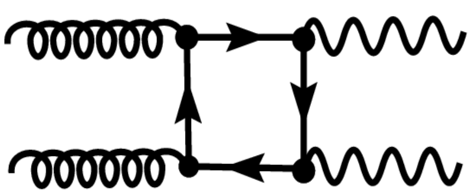


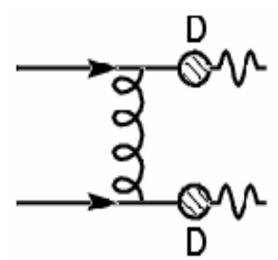


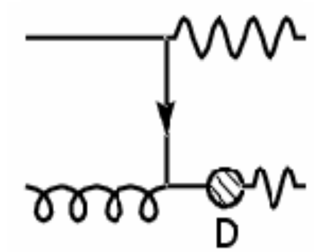


γγ Backgrounds

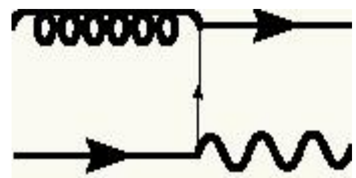


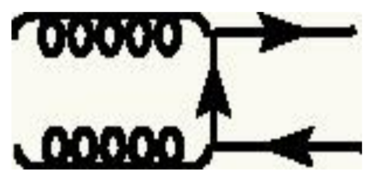






Reducible γj and jj Backgrounds

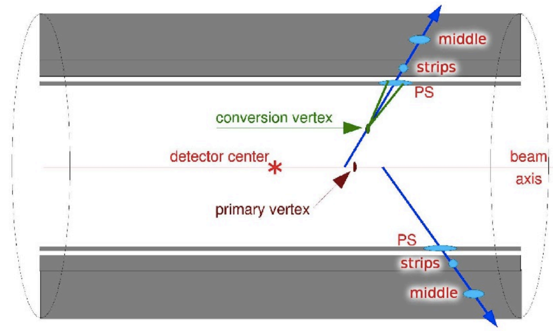




$q \rightarrow \pi^0$

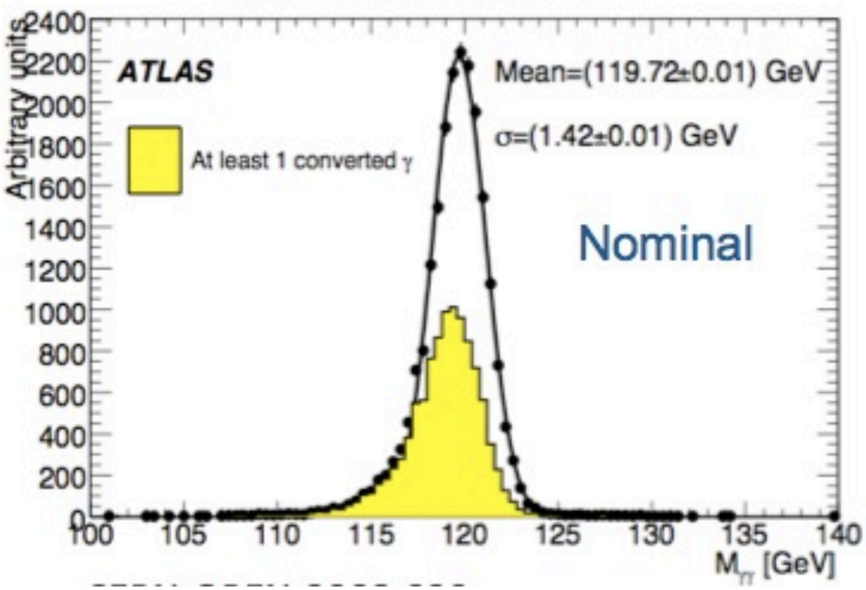
Diphoton Invariant Mass

- Primary vertex reconstruction :
    - Photon calorimeter pointing
    - Use conversion tracks when available
- Energy scale calibration from Z to electrons applied

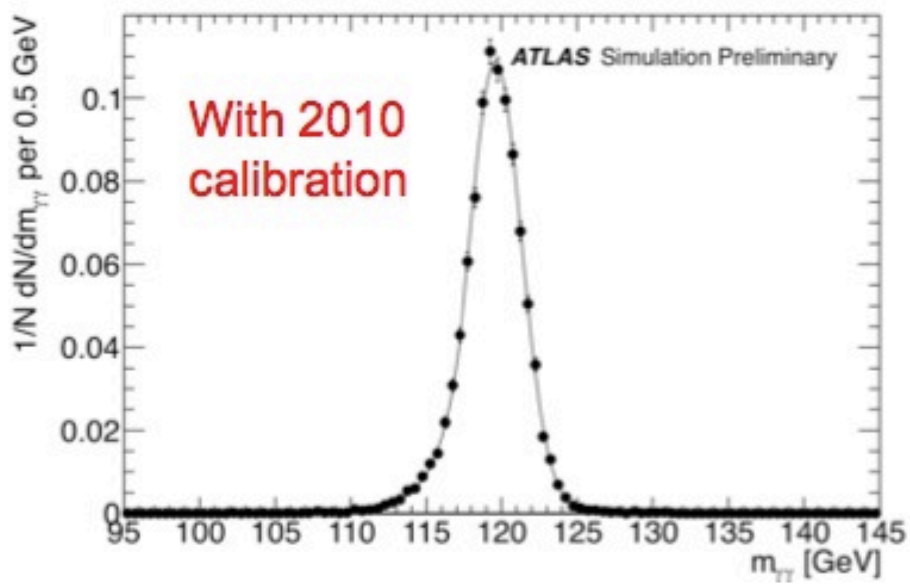


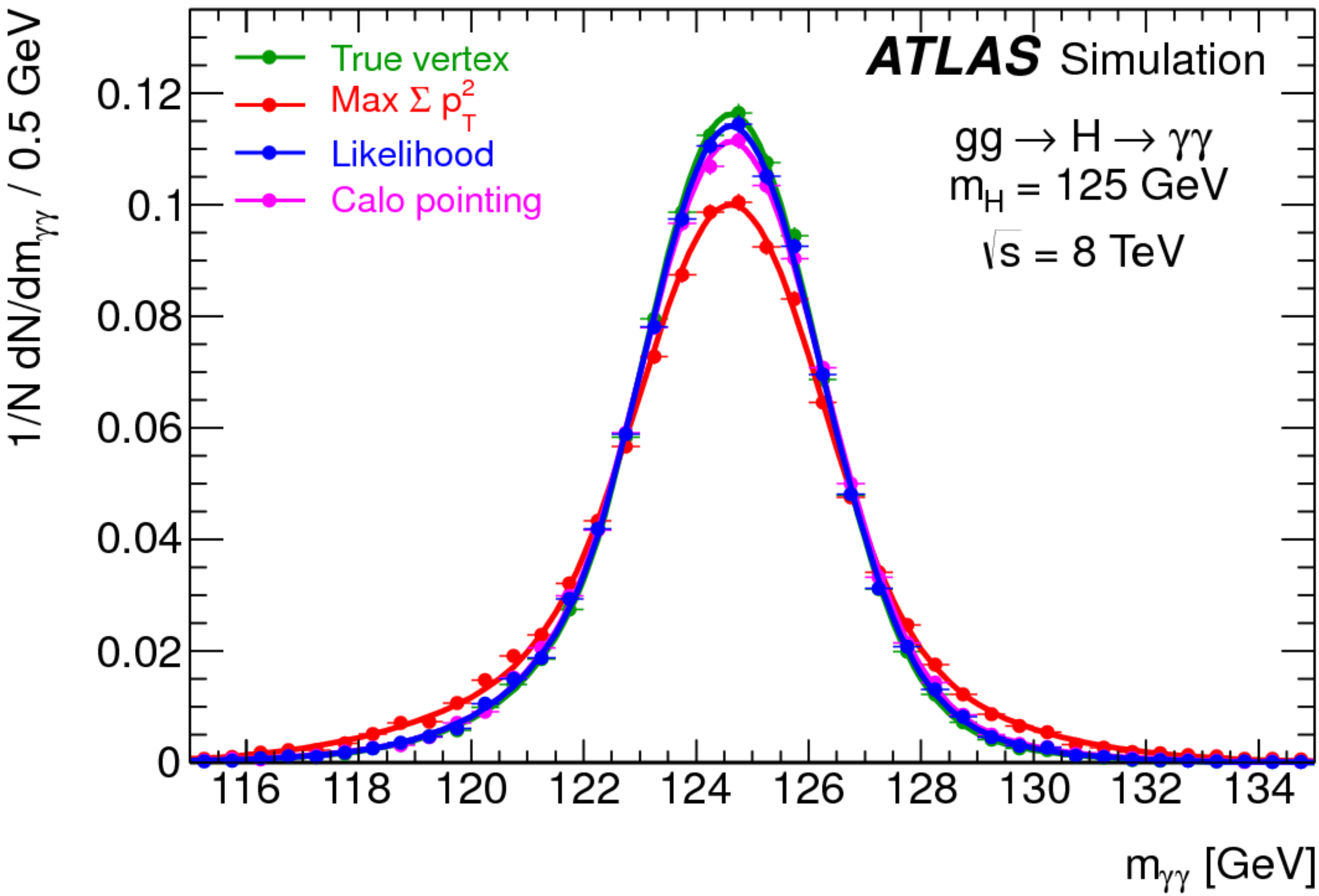
- Crystal Ball + Gaussian model with narrow widths (of the core of the distribution) :

$\sigma \sim 1.4$ GeV

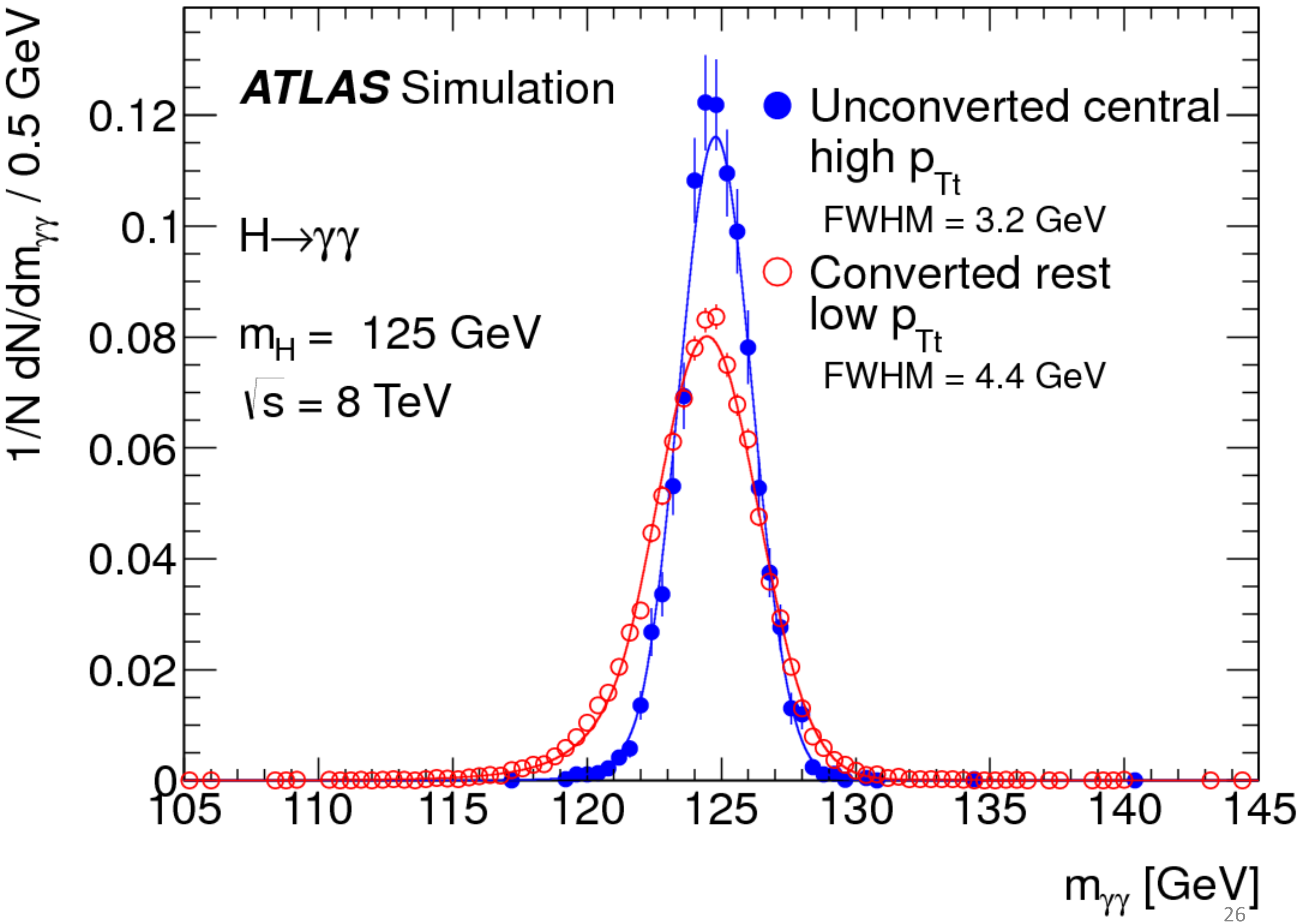


$\sigma \sim 1.7$ GeV





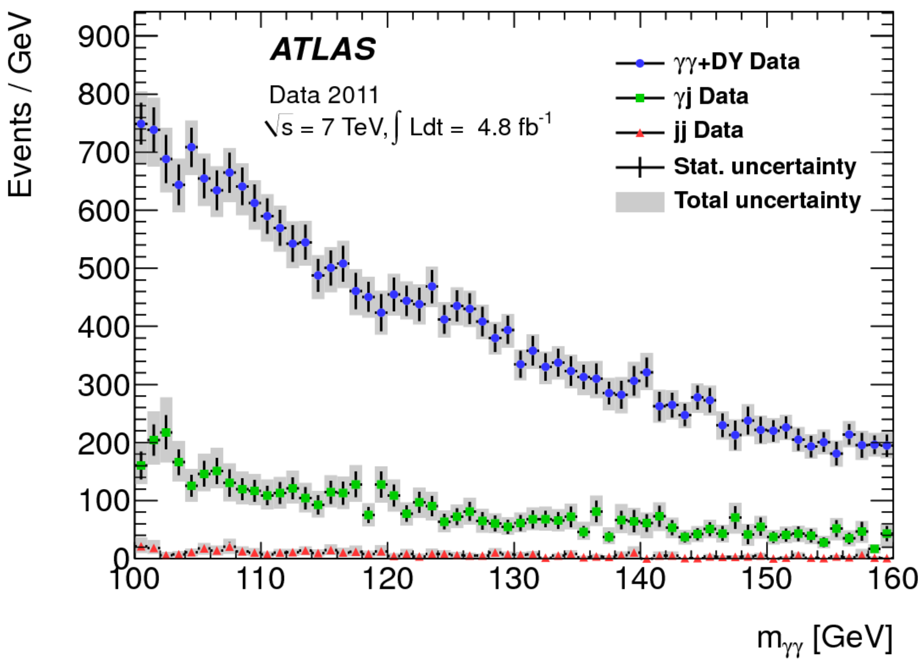
True vertex
Max Σ p_T^2
Likelihood
Calo pointing
ATLAS Simulation
gg → H → γγ
m_H = 125 GeV
$\sqrt{s}$ = 8 TeV
1/N dN/d$m_{\gamma\gamma}$ / 0.5 GeV
$m_{\gamma\gamma}$ [GeV]
0.12
0.1
0.08
0.06
0.04
0.02
0
116
118
120
122
124
126
128
130
132
134

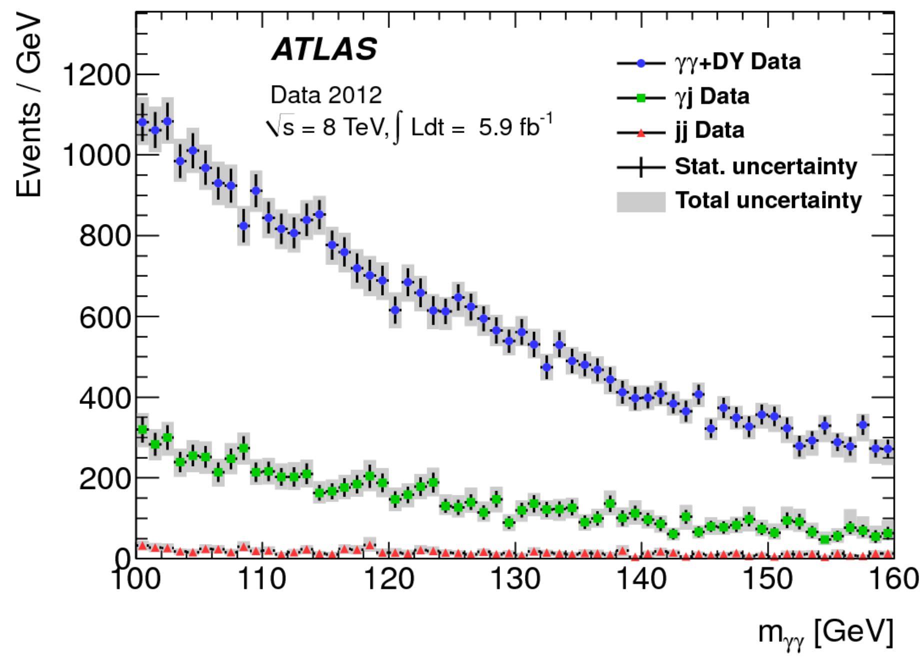


ATLAS Simulation
H→γγ
m_H = 125 GeV
√s = 8 TeV
Unconverted central high p_Tt
FWHM = 3.2 GeV
Converted rest low p_Tt
FWHM = 4.4 GeV
1/N dN/dm_γγ / 0.5 GeV
m_γγ [GeV]
0
0.02
0.04
0.06
0.08
0.1
0.12
105
110
115
120
125
130
135
140
145

Background Composition

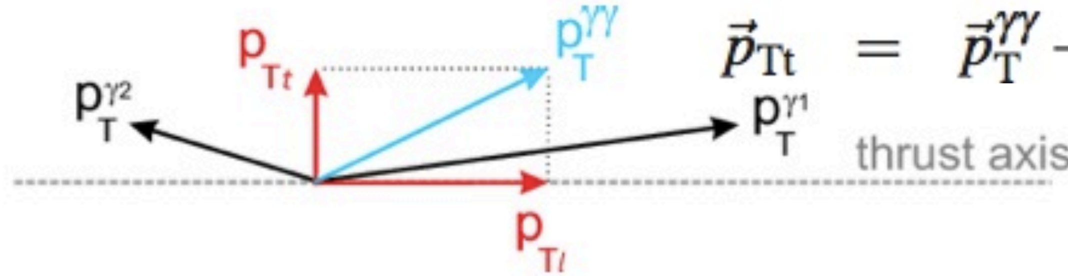
Composition	$\gamma\gamma$	γj	jj	Drell-Yan
Events	$16000 \pm 200 \pm 1100$	$5230 \pm 130 \pm 880$	$1130 \pm 50 \pm 600$	$165 \pm 2 \pm 8$
Relative fraction	$(71 \pm 5)\,\%$	$(23 \pm 4)\,\%$	$(5 \pm 3)\,\%$	$(0.7 \pm 0.1)\,\%$



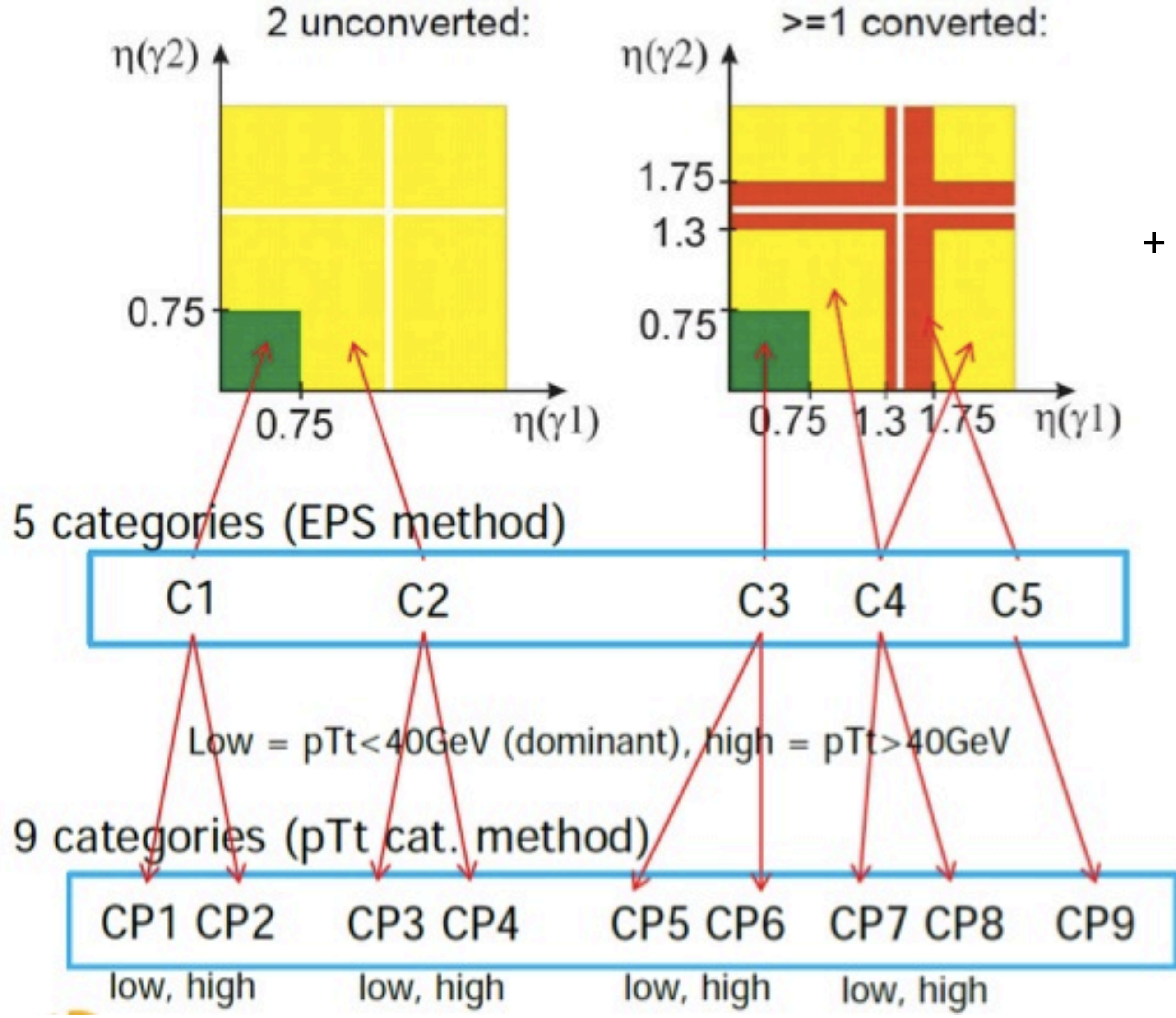


Categorization

$$\hat{t} = \frac{\vec{p}_{\mathrm{T}}^{\gamma_1} - \vec{p}_{\mathrm{T}}^{\gamma_2}}{|\vec{p}_{\mathrm{T}}^{\gamma_1} - \vec{p}_{\mathrm{T}}^{\gamma_2}|}$$



$$\vec{p}_{\mathrm{Tt}} = \vec{p}_{\mathrm{T}}^{\gamma\gamma} - (\vec{p}_{\mathrm{T}}^{\gamma\gamma} \cdot \hat{t}) \cdot \hat{t},$$



+ 2j (VBF)

First group of experimentalists who revised the parton-level study by Raiwater and Zeppenfeld. The sensitivity of this channel at ATLAS and CMS today is compatible with this study. Here an attempt for parton shower and ME merging for backgrounds was performed before these tools appeared in the field

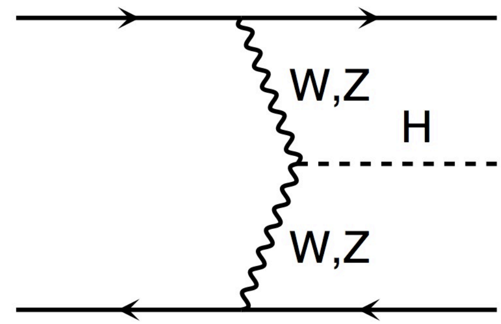
Search for Higgs Bosons Decay $H \to \gamma\gamma$ Using Vector Boson Fusion

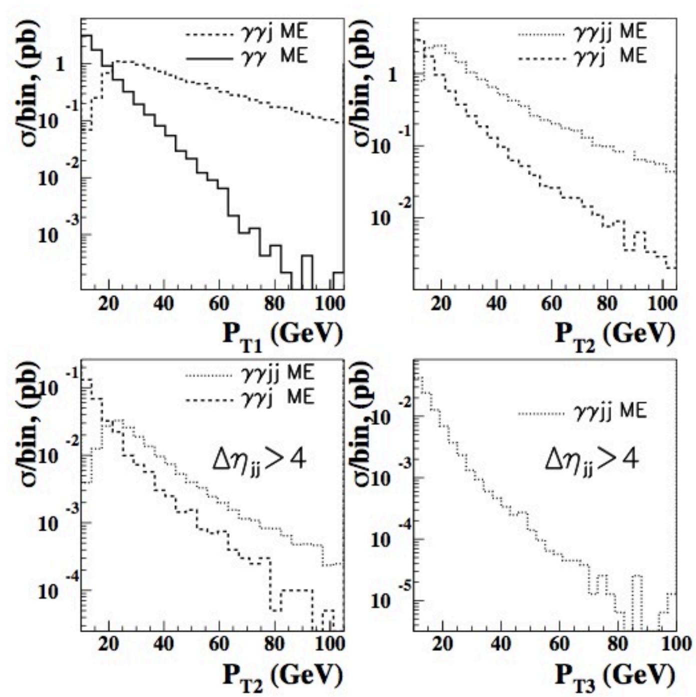
Kyle Cranmer, Bruce Mellado,
William Quayle, Sau Lan Wu

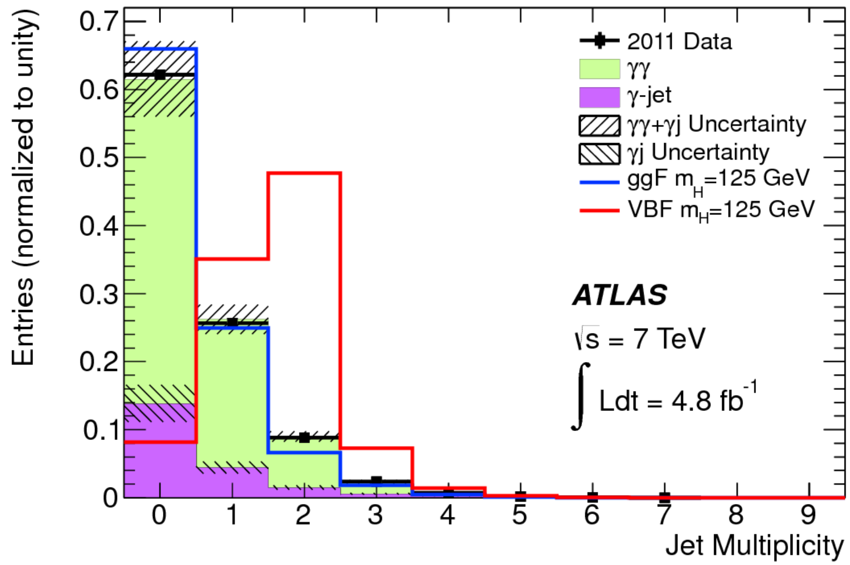
Physics Department
University of Wisconsin - Madison
Madison, Wisconsin 53706 USA

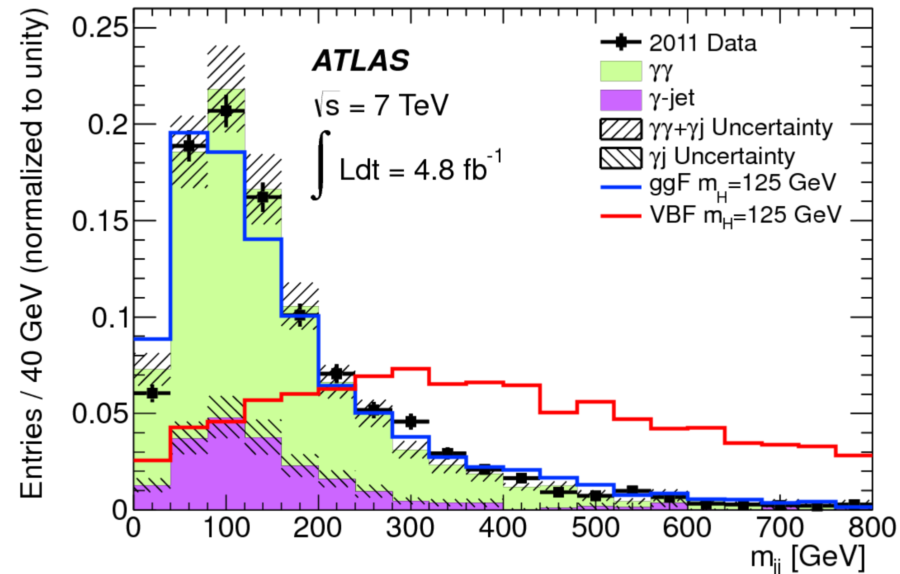
Abstract

The sensitivity of the ATLAS experiment to low mass SM Higgs produced via Vector Boson Fusion mechanism with $H \to \gamma\gamma$ is investigated. A cut based event selection has been chosen to optimize the expected signal significance with this decay mode. A signal significance of $2.2\,\sigma$ may be achieved for $M_H = 130\,\text{GeV}$ with 30 fb^{-1} of accumulated luminosity.

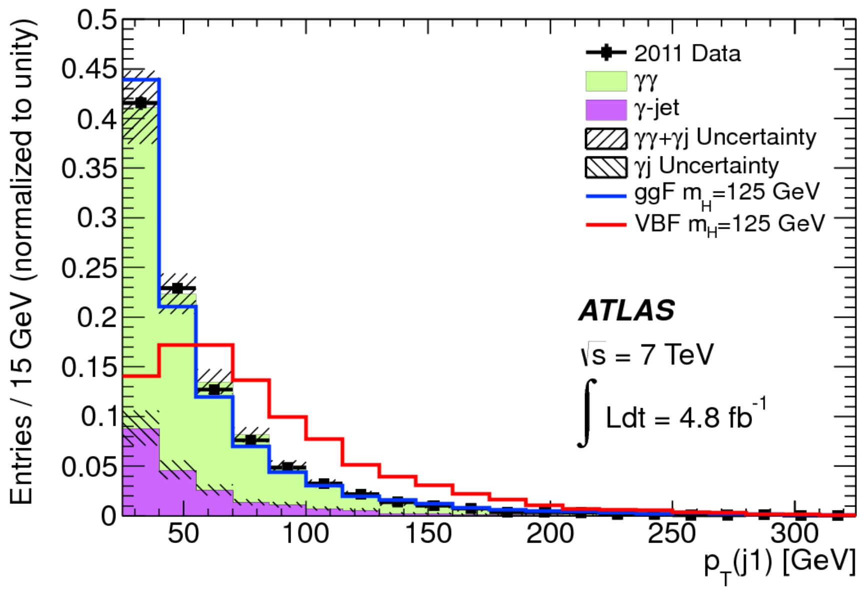


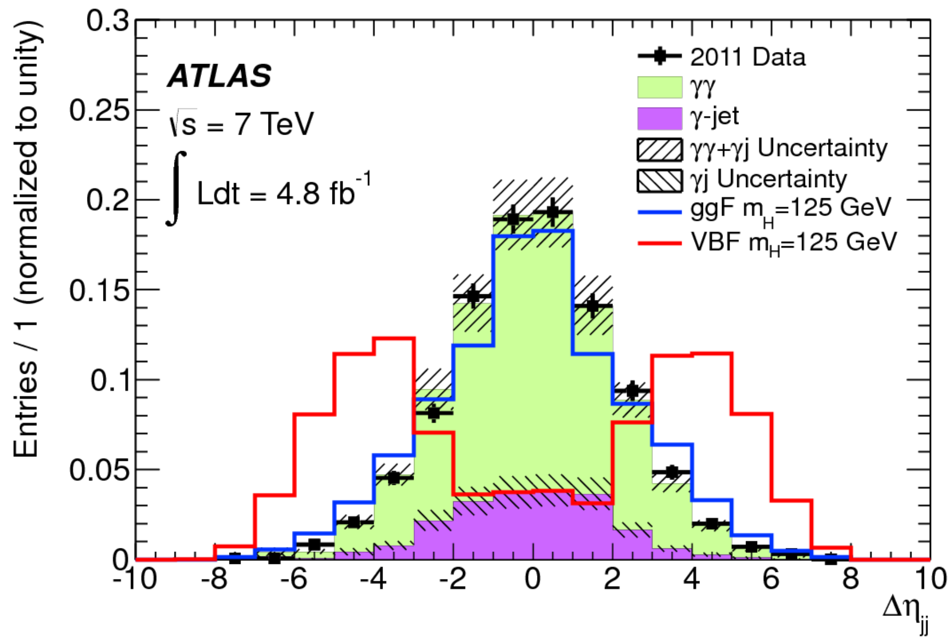


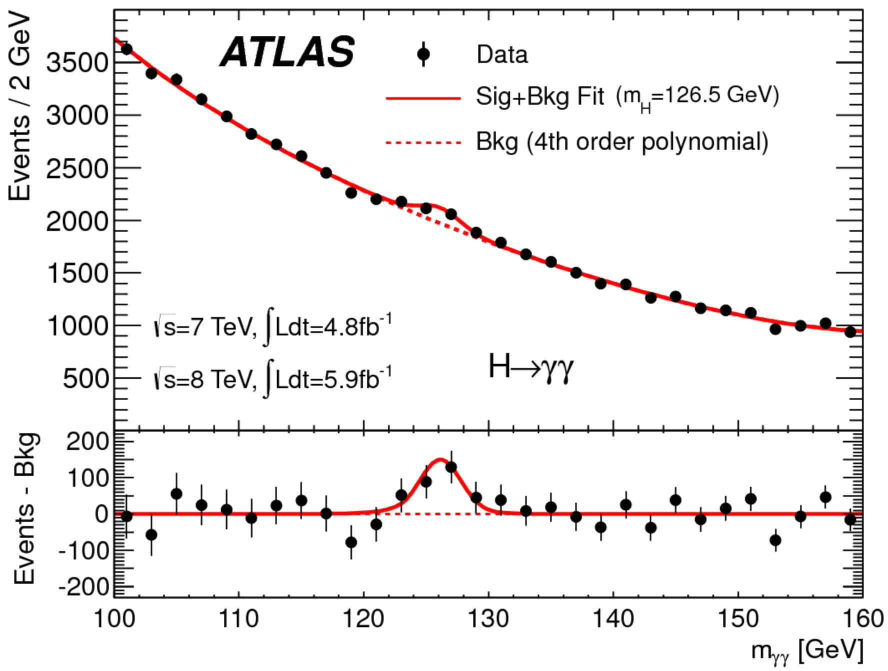




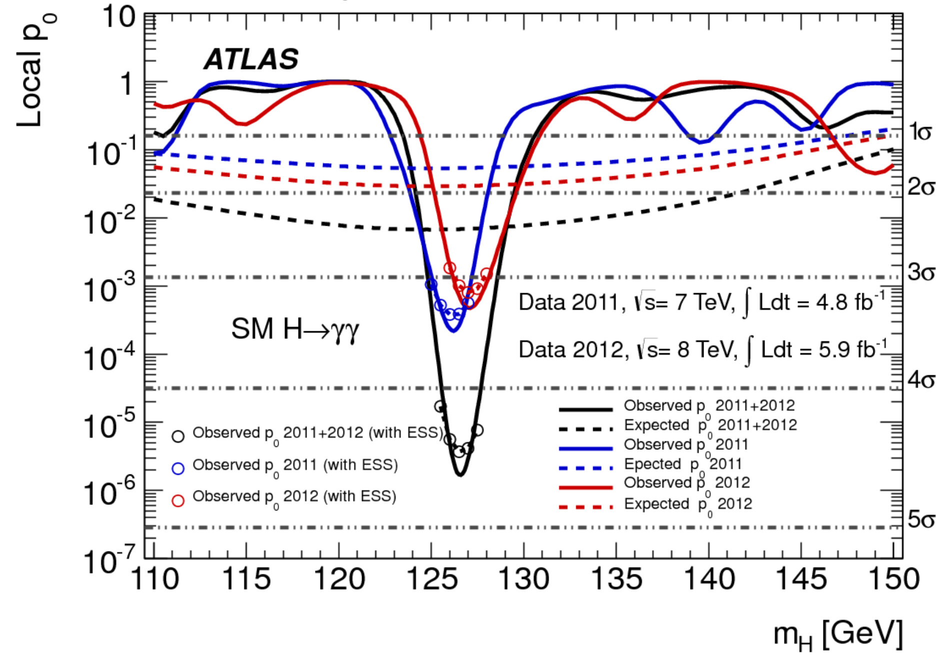
Jet variables are overall well described by tree-level ME based MC. Situation becomes more complicated when looking at well separated jets. Work in progress.

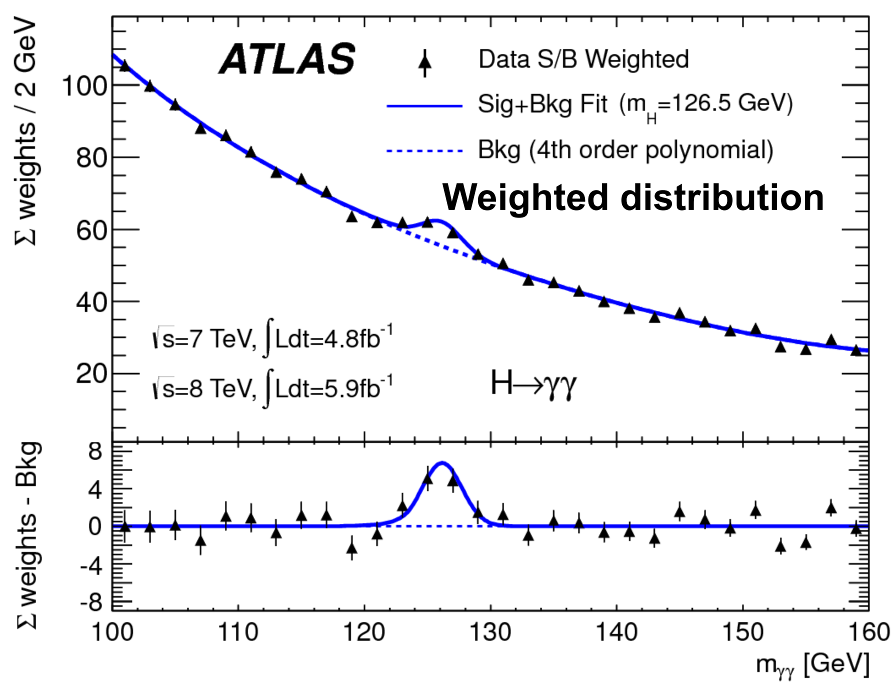




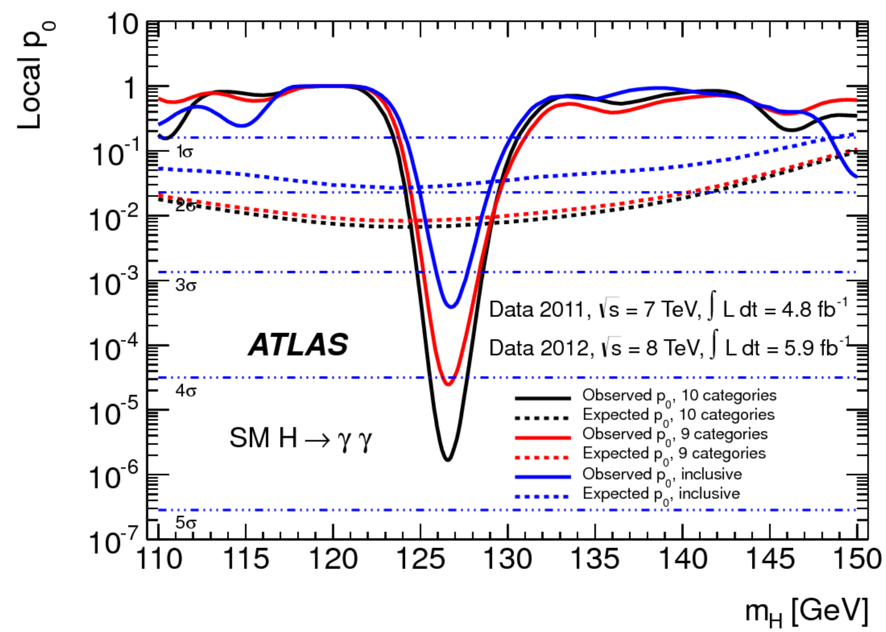


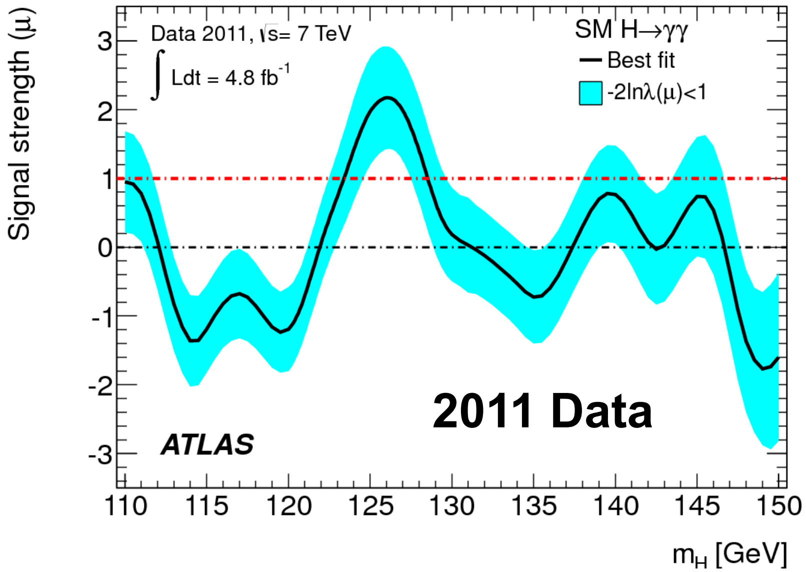
Consistency between 2011 and 2012

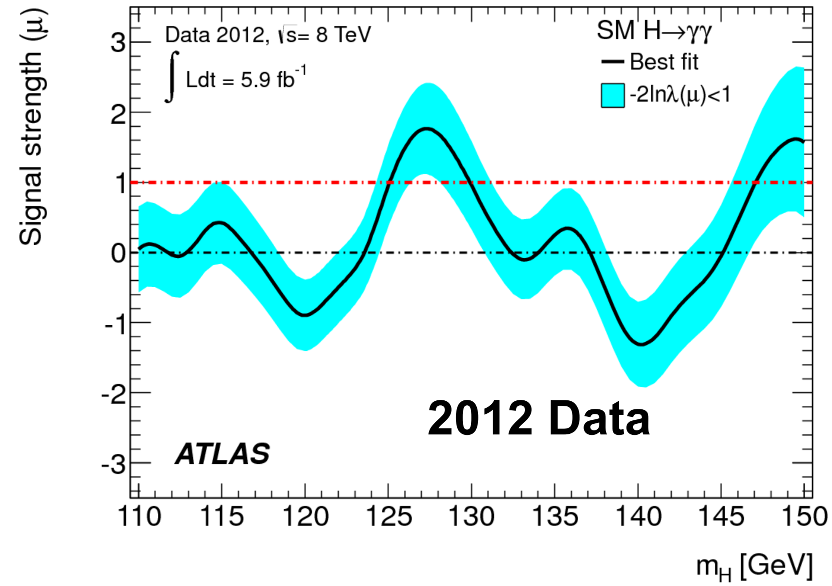


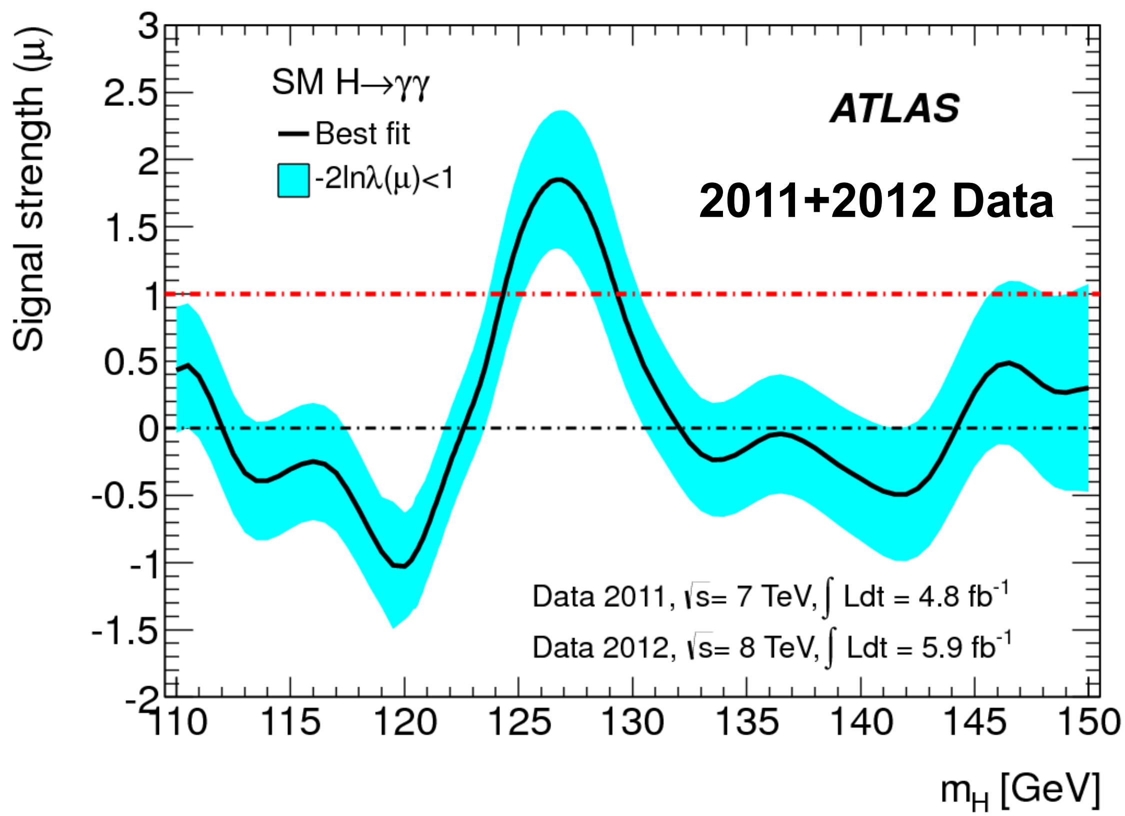


Role of categories + VBF

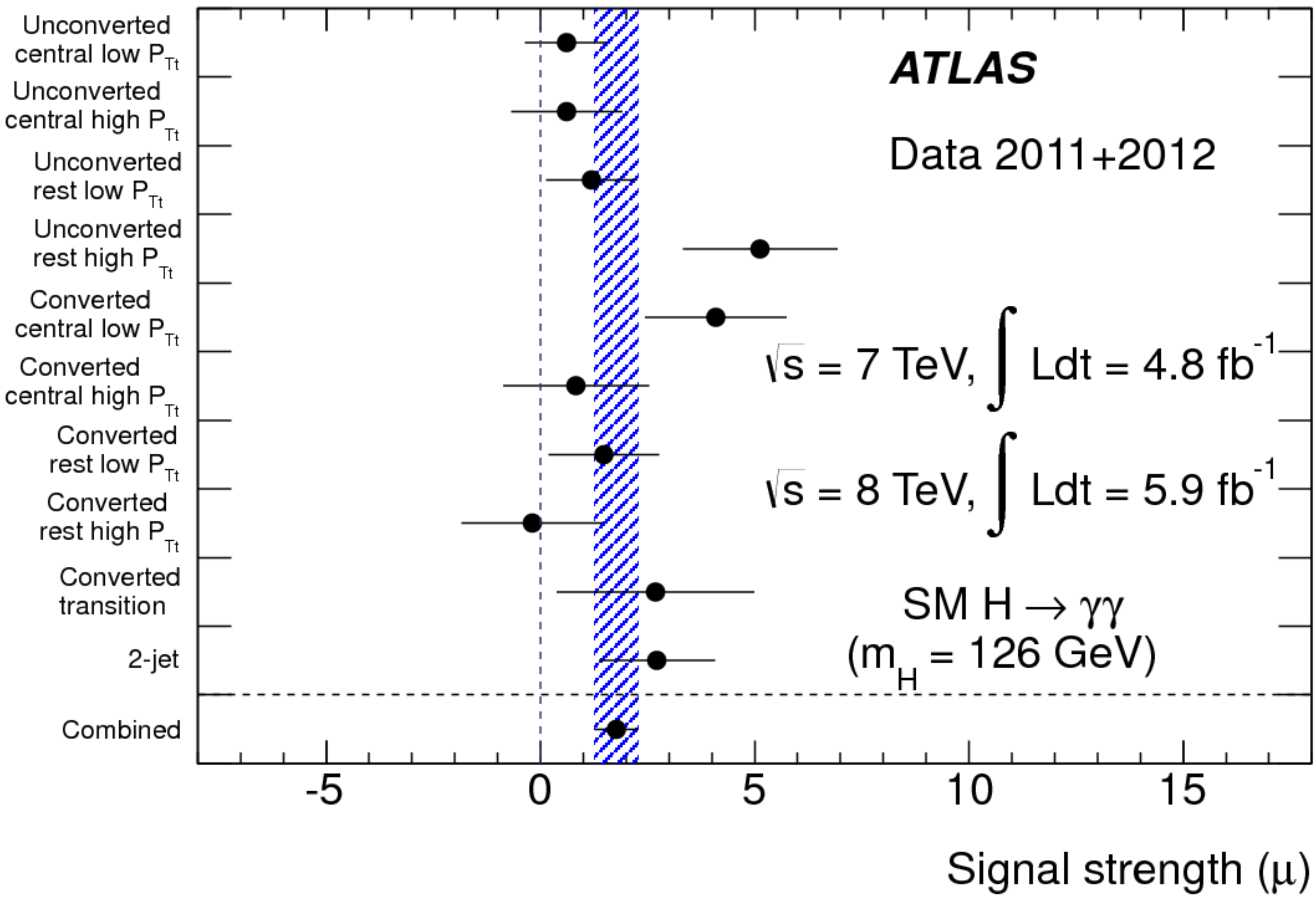



Data 2011, √s= 7 TeV
∫ Ldt = 4.8 fb-1
SM H→γγ
Best fit
-2lnλ(μ)<1
2011 Data
ATLAS
Signal strength (μ)
mH [GeV]


Data 2012, √s= 8 TeV
∫ Ldt = 5.9 fb-1
SM H→γγ
Best fit
-2lnλ(μ)<1
2012 Data
ATLAS
Signal strength (μ)
mH [GeV]

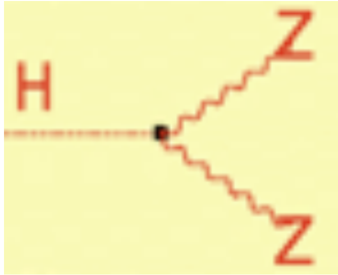

SM H→γγ
Best fit
-2lnλ(μ)<1
ATLAS
2011+2012 Data
Data 2011, √s= 7 TeV, ∫ Ldt = 4.8 fb-1
Data 2012, √s= 8 TeV, ∫ Ldt = 5.9 fb-1
Signal strength (μ)
mH [GeV]

Both ATLAS and CMS have signal strengths for the VBF higher than for ggF. Is this a hint or a statistical fluctuation? Very exciting times ahead

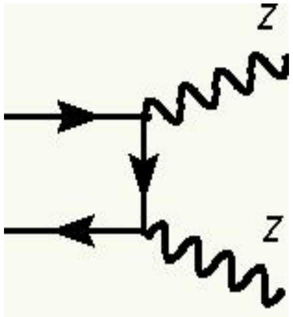


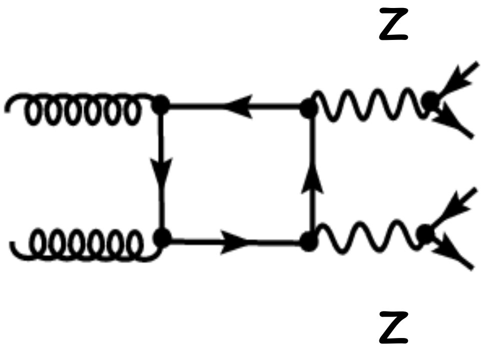
Higgs to $ZZ^{(*)}$ Results with 5.8 fb^{-1} of 2012 Data

Higgs decay to Z^0Z^0

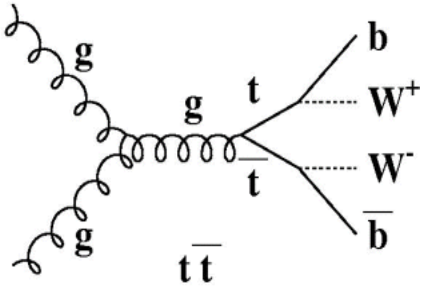


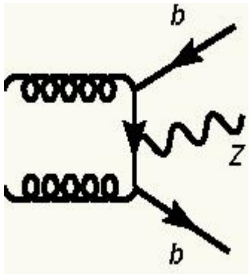
Irreducible Z^0Z^0 backgrounds



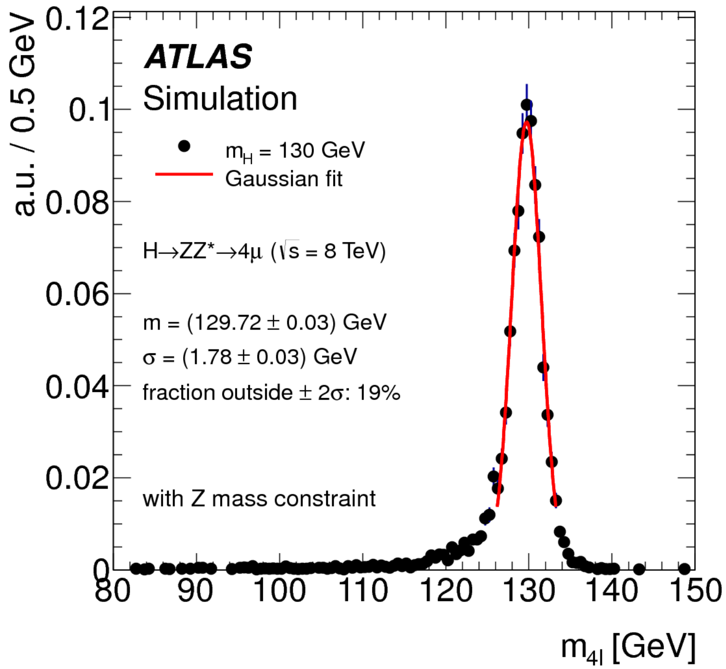


Reducible 4l backgrounds

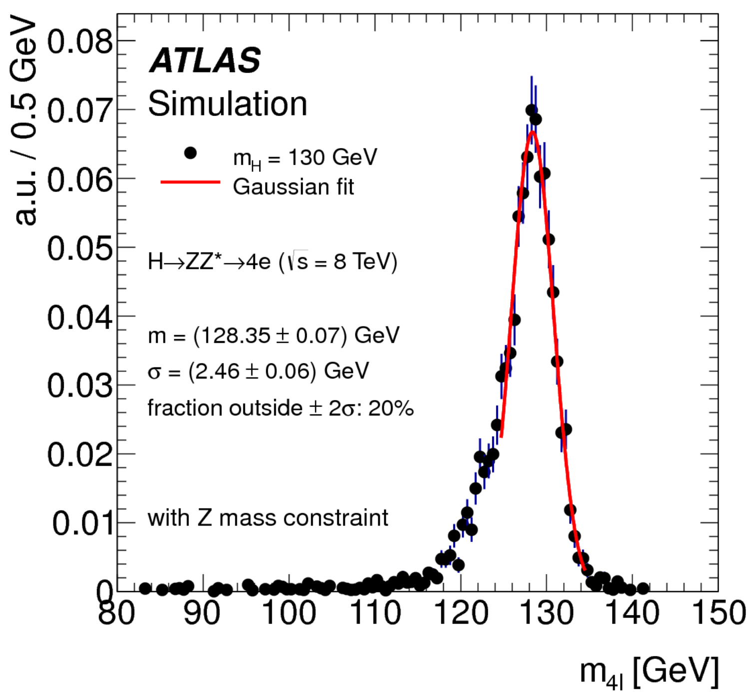


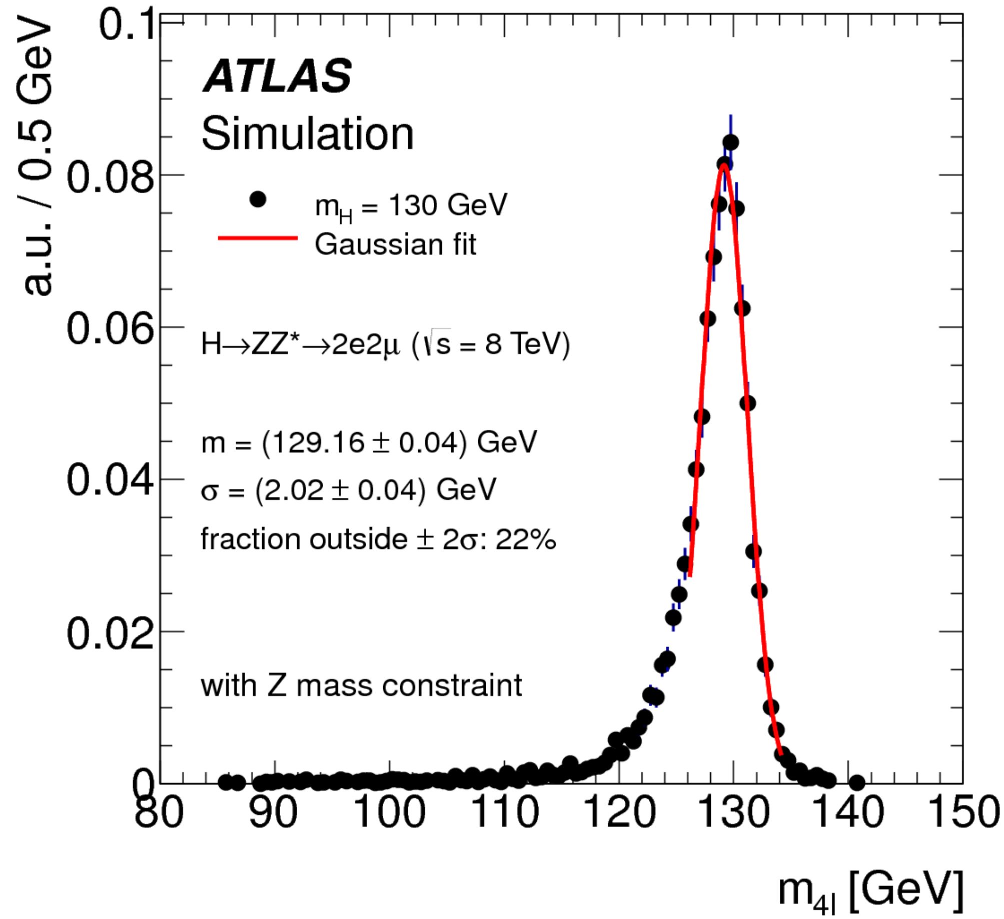


Bruce Mellado, Magurele 26/10/11

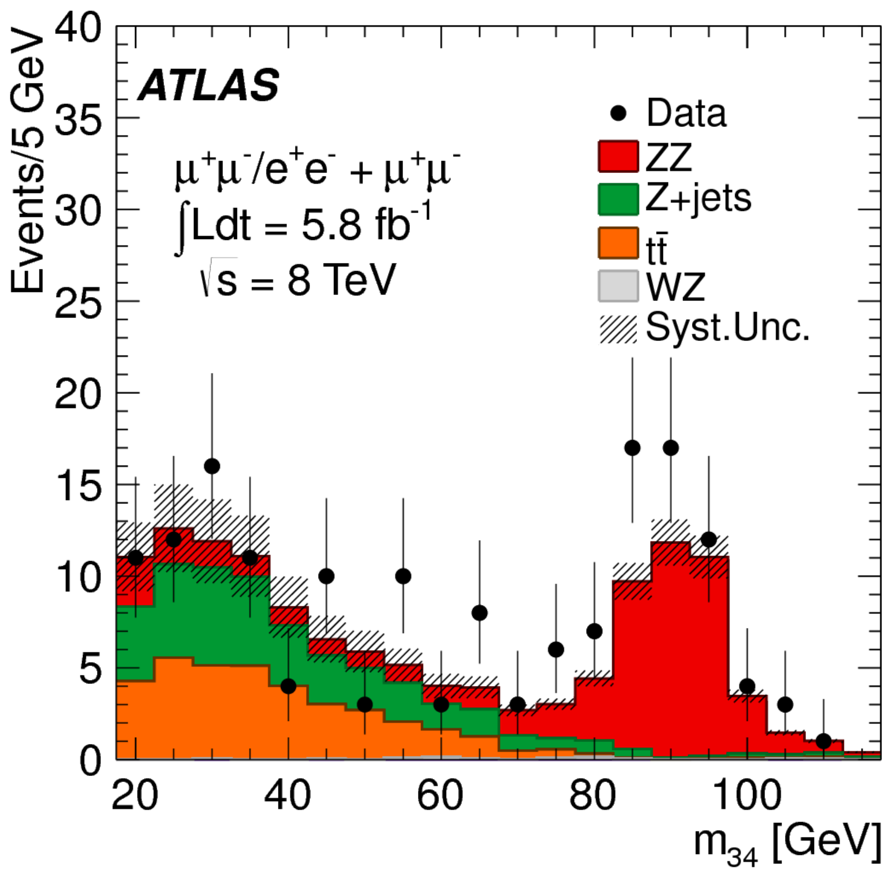


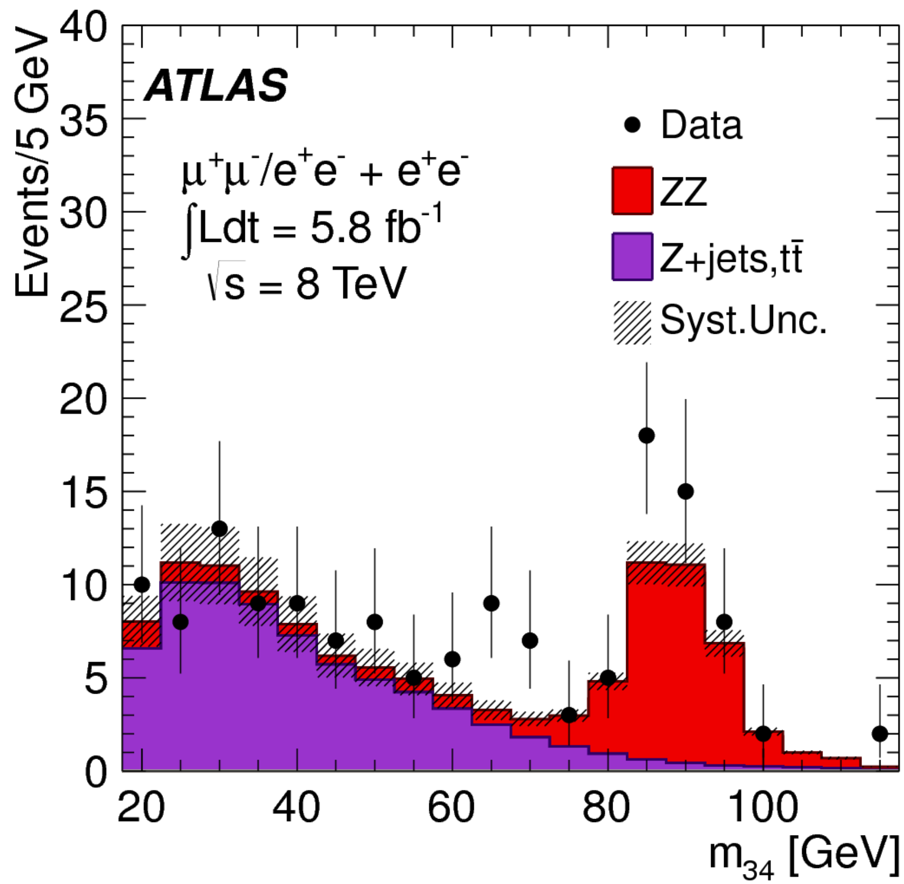
Mass resolution plots after the application of a mass constraint.
Gain in resolution ~15-20%

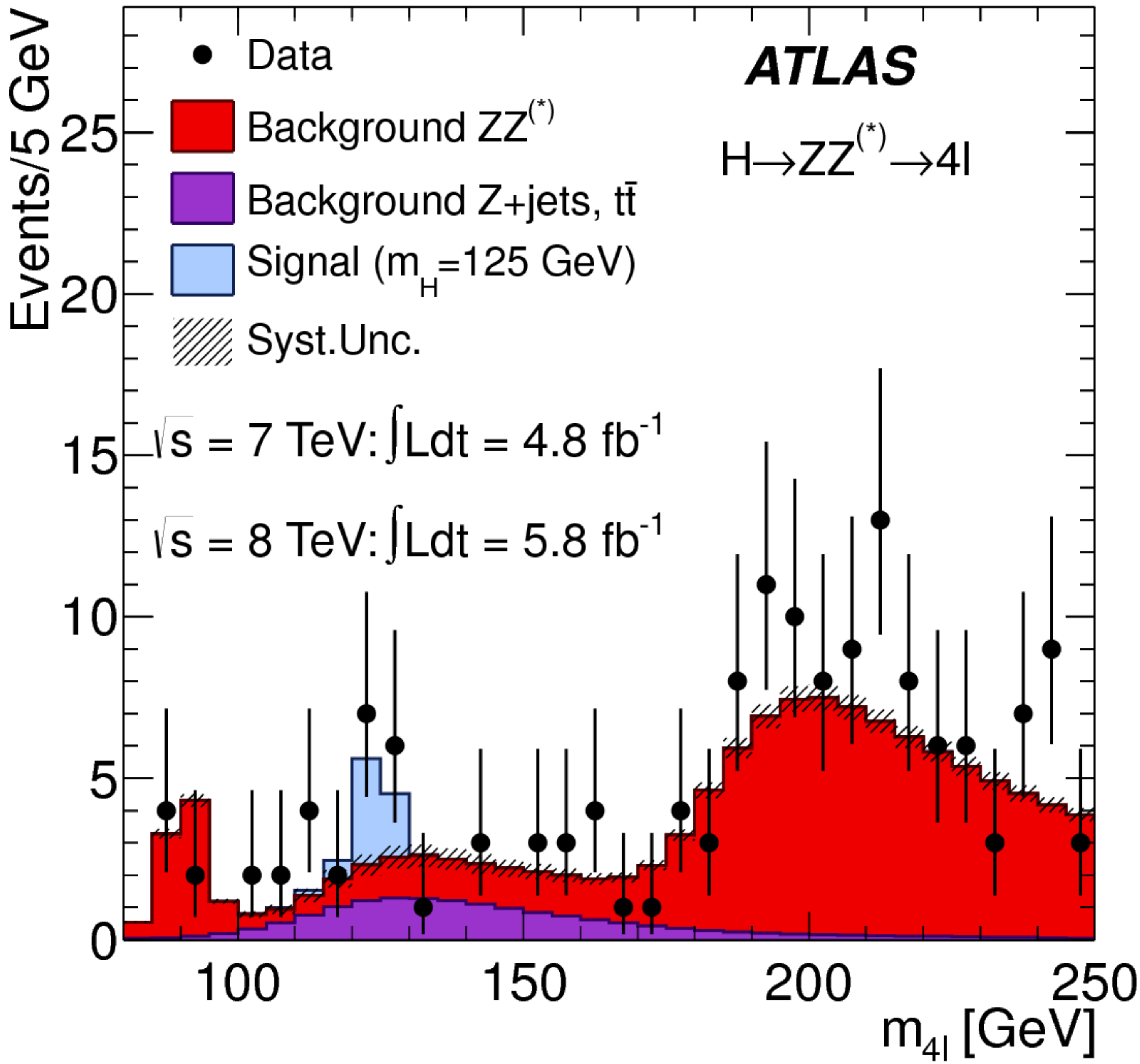




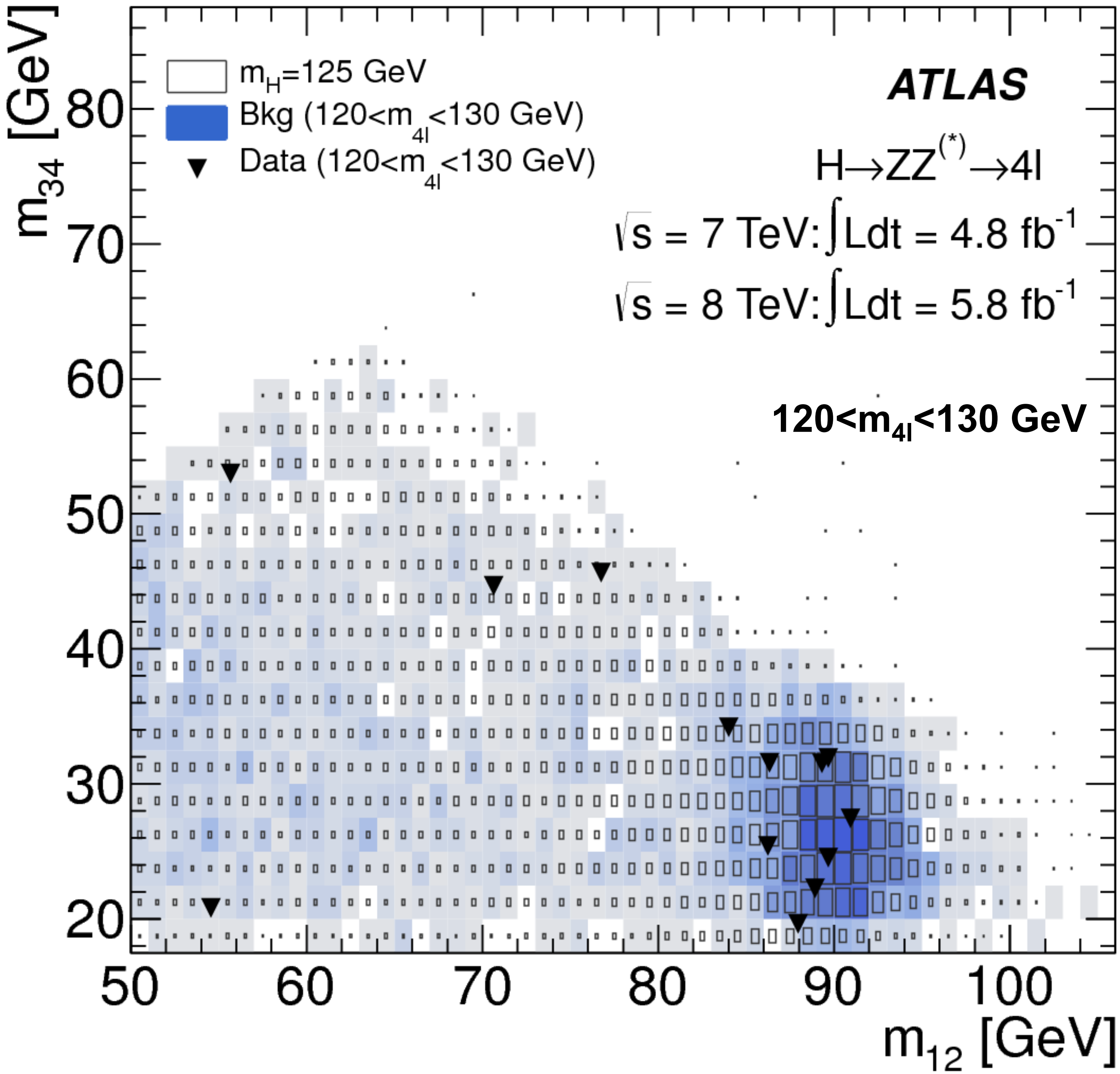
Invariant mass distribution of the second lepton pair: μμ and *ee.* The kinematic selections of the analysis have been applied. Isolation requirements have been applied on the first lepton pair. No charge requirements were applied to the second lepton pair.



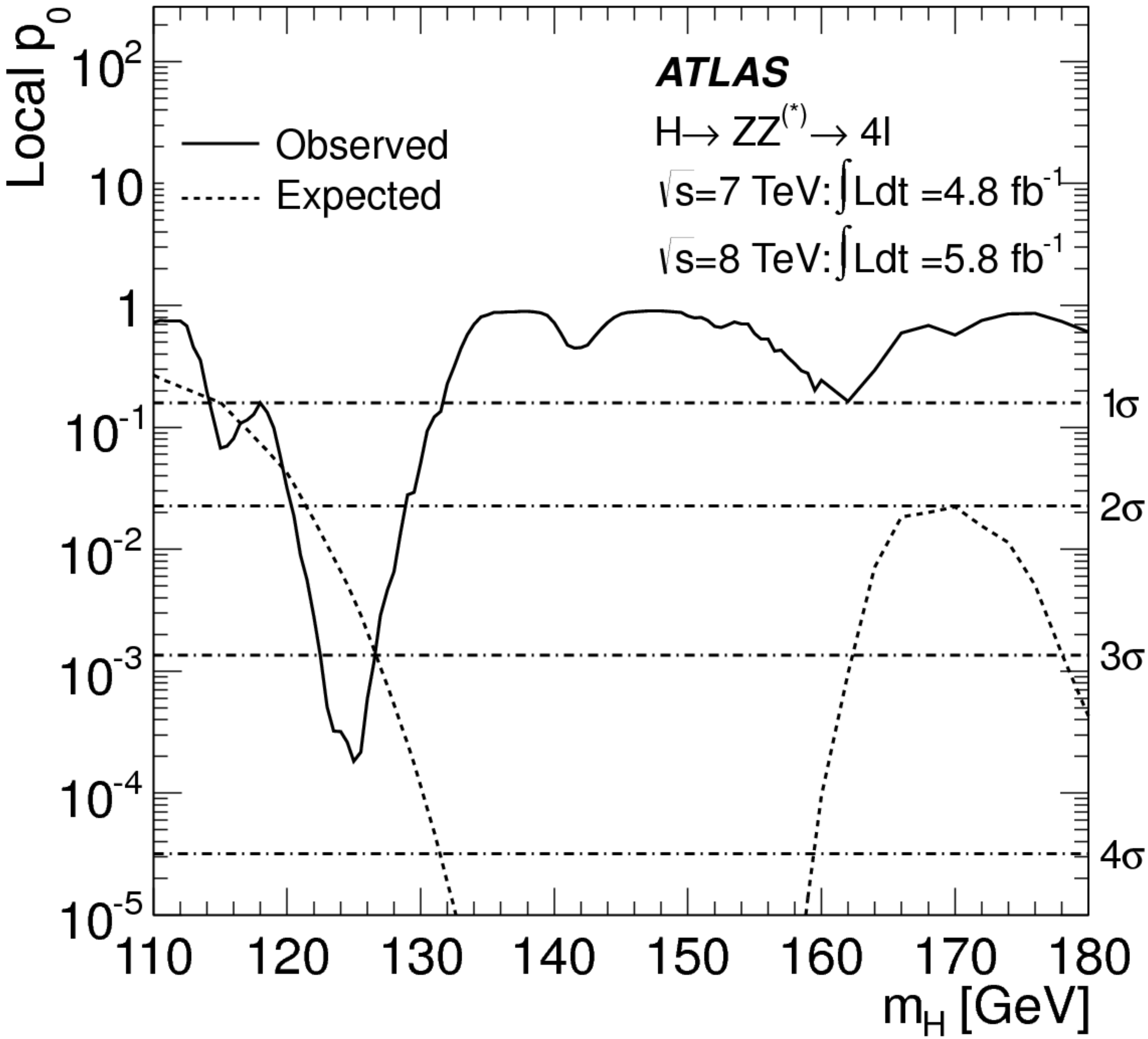




Data
Background ZZ(*)
Background Z+jets, tt̄
Signal (m_H=125 GeV)
Syst.Unc.
ATLAS
H→ZZ(*)→4l
√s = 7 TeV: ∫Ldt = 4.8 fb-1
√s = 8 TeV: ∫Ldt = 5.8 fb-1
Events/5 GeV
m4l [GeV]
0
5
10
15
20
25
100
150
200
250



m_H=125 GeV
Bkg (120<m_{4l}<130 GeV)
Data (120<m_{4l}<130 GeV)
ATLAS
$H \to ZZ^{(*)} \to 4l$
$\sqrt{s}$ = 7 TeV: $\int Ldt$ = 4.8 fb^{-1}
$\sqrt{s}$ = 8 TeV: $\int Ldt$ = 5.8 fb^{-1}
120<m_{4l}<130 GeV
m_{34} [GeV]
m_{12} [GeV]

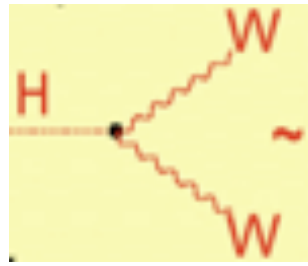


Local p_0
ATLAS
$H \rightarrow ZZ^{(*)} \rightarrow 4l$
$\sqrt{s}$=7 TeV: $\int Ldt$ = 4.8 fb^{-1}
$\sqrt{s}$=8 TeV: $\int Ldt$ = 5.8 fb^{-1}
Observed
Expected
1σ
2σ
3σ
4σ
m_H [GeV]

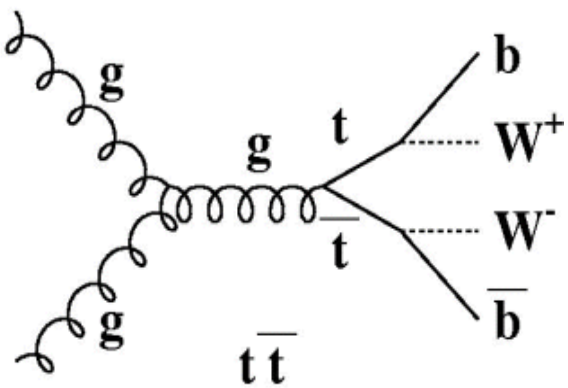
Higgs to $WW^{(*)}$ Results with 5.8 fb^{-1} of 2012 Data

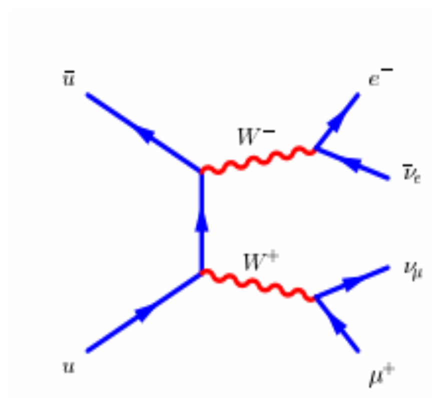
Higgs decay to W^+W^-

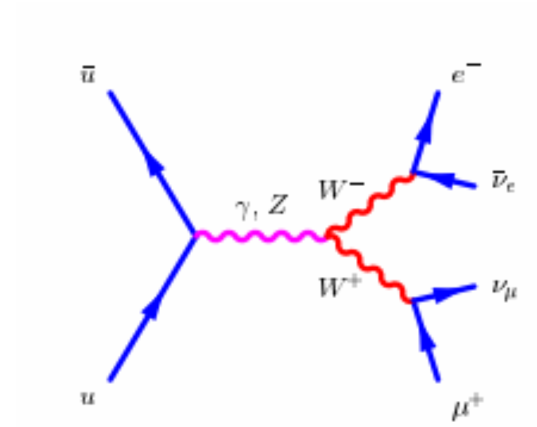
Two leptons + neutrinos
No mass peak
Event counting experiment



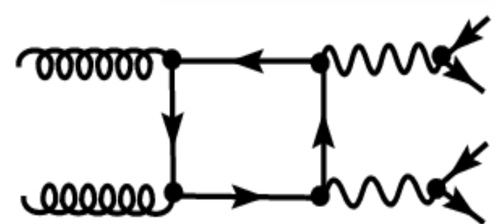
W^+W^- backgrounds







+ Single top
& non-resonant WWbb



Main References for H→WW

From the official ATLAS document ATLAS-CONF-2011-005
http://cdsweb.cern.ch/record/1328619

[16] V. Barger, G. Bhattacharya, T. Han, and B. A. Kniehl, Phys. Rev. D **43** (1991) 779.

[17] M. Dittmar and H. Dreiner, Phys. Rev. D **55** (1997) 167.

H+0 jets

[18] D. Rainwater and D. Zeppenfeld, Phys. Rev. D **60** (1999) 113004.

H+2 jets

[19] N. Kauer, T. Plehn, D. Rainwater, and D. Zeppenfeld, Phys. Lett. B **503** (2001) 113.

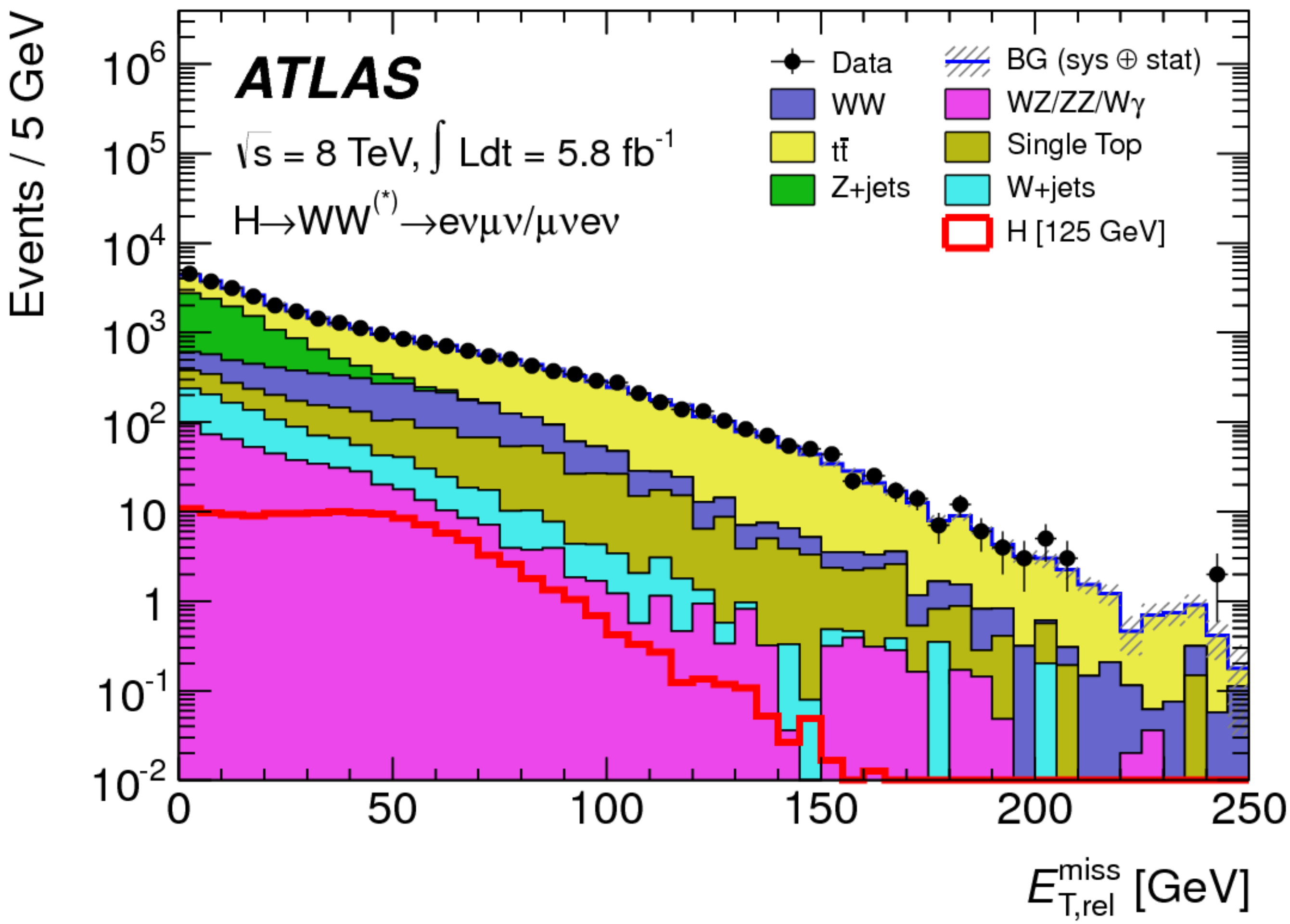
[20] B. Mellado, W. Quayle, and S. L. Wu, Phys. Rev. D **76** (2007) 093007.

H+1 jet

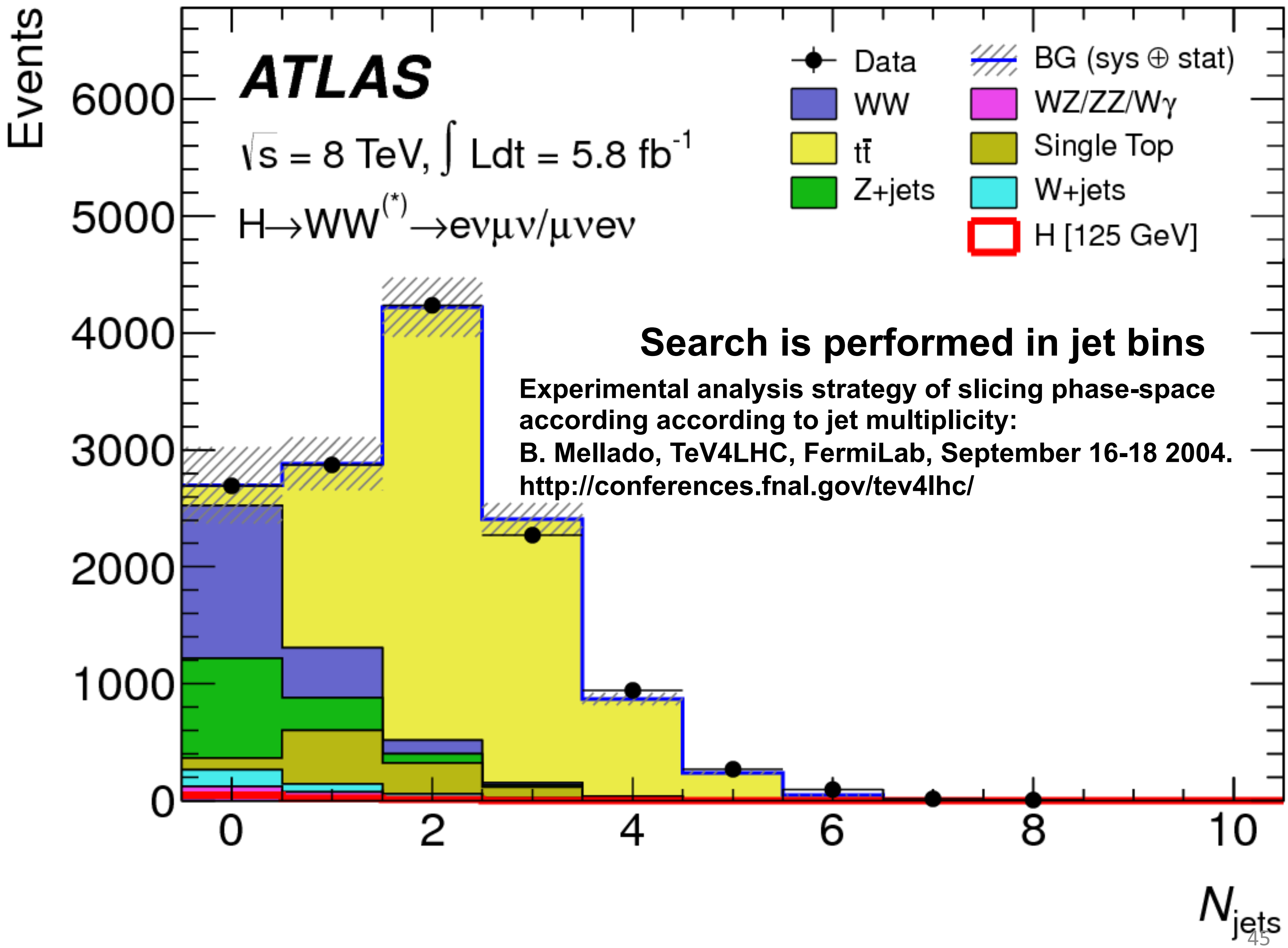
Experimental analysis strategy of slicing phase-space according according to jet multiplicity:
B. Mellado, TeV4LHC, FermiLab, September 16-18 2004.
http://conferences.fnal.gov/tev4lhc/

The reconstruction of missing energy is real is a crucial element to the search. Shown are the METRel distribution of the neutrino momenta in the presence of two charged leptons
Overall, good control of the data

$$E_{\mathrm{T,rel}}^{\mathrm{miss}} = \begin{cases} E_{\mathrm{T}}^{\mathrm{miss}} & \text{if } \Delta\phi \geq \pi/2 \\ E_{\mathrm{T}}^{\mathrm{miss}} \cdot \sin\Delta\phi & \text{if } \Delta\phi < \pi/2 \end{cases}$$

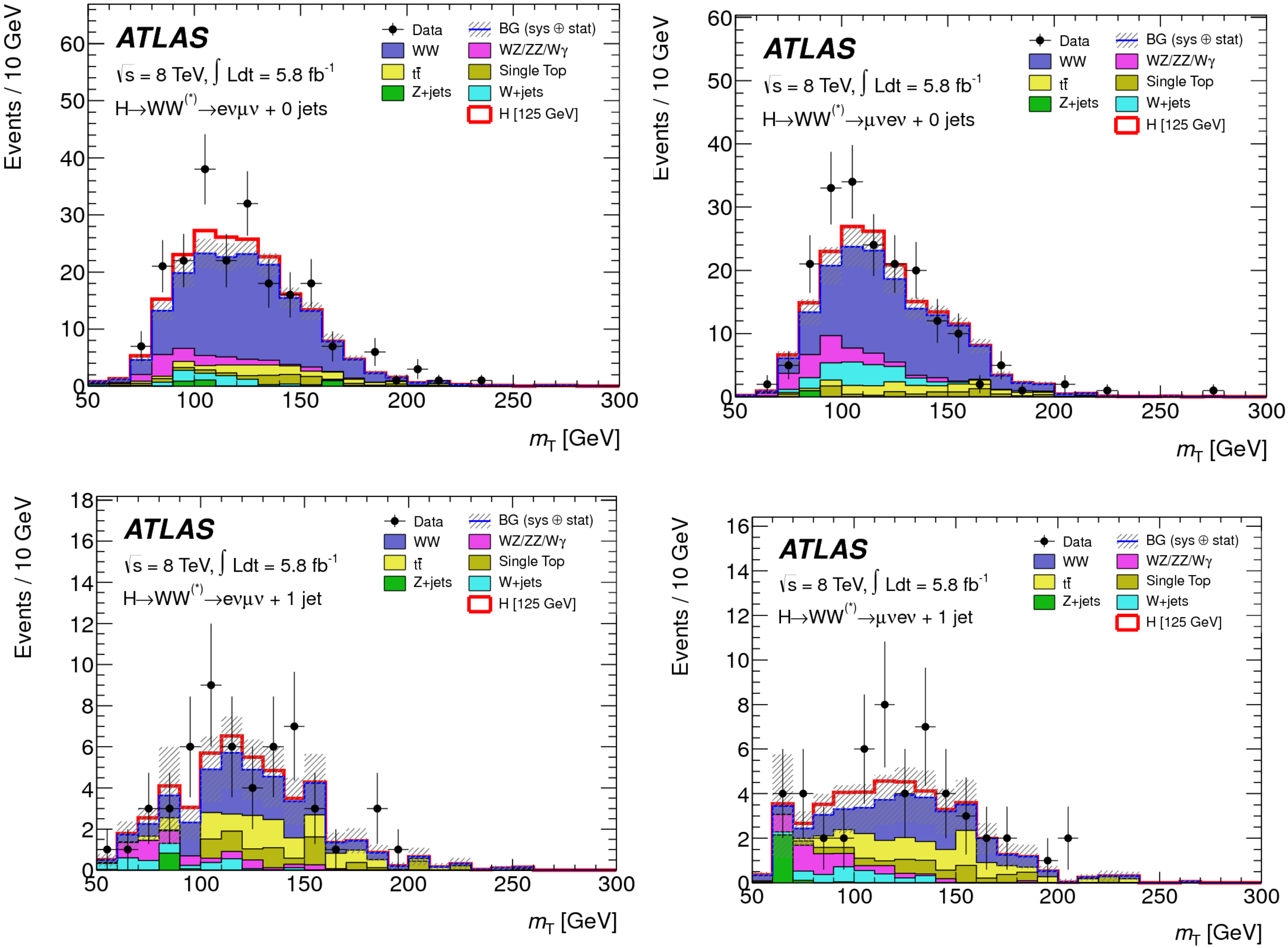


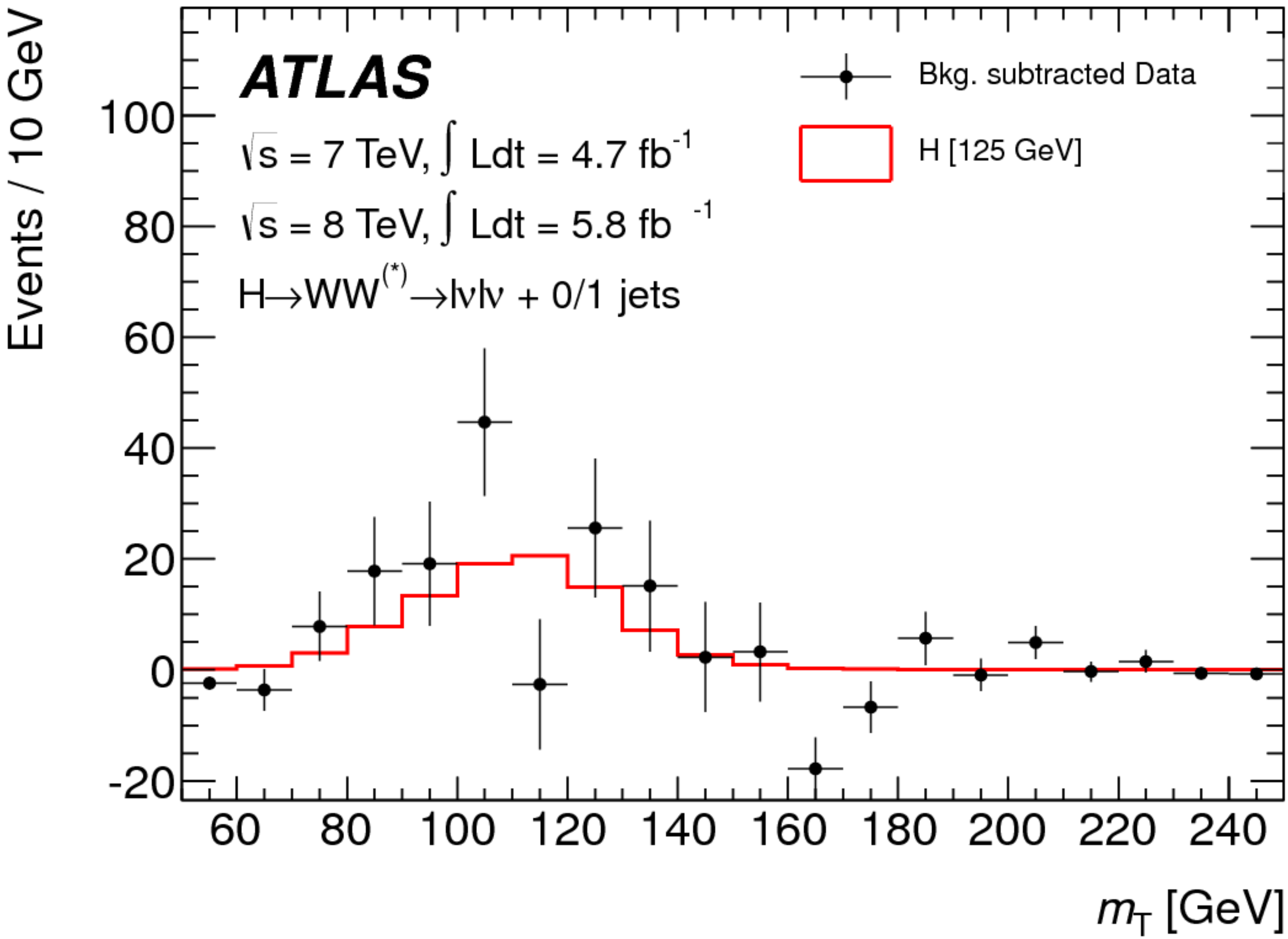
A real challenge this time around!



Search is performed in jet bins

Experimental analysis strategy of slicing phase-space according according to jet multiplicity:
B. Mellado, TeV4LHC, FermiLab, September 16-18 2004.
http://conferences.fnal.gov/tev4lhc/

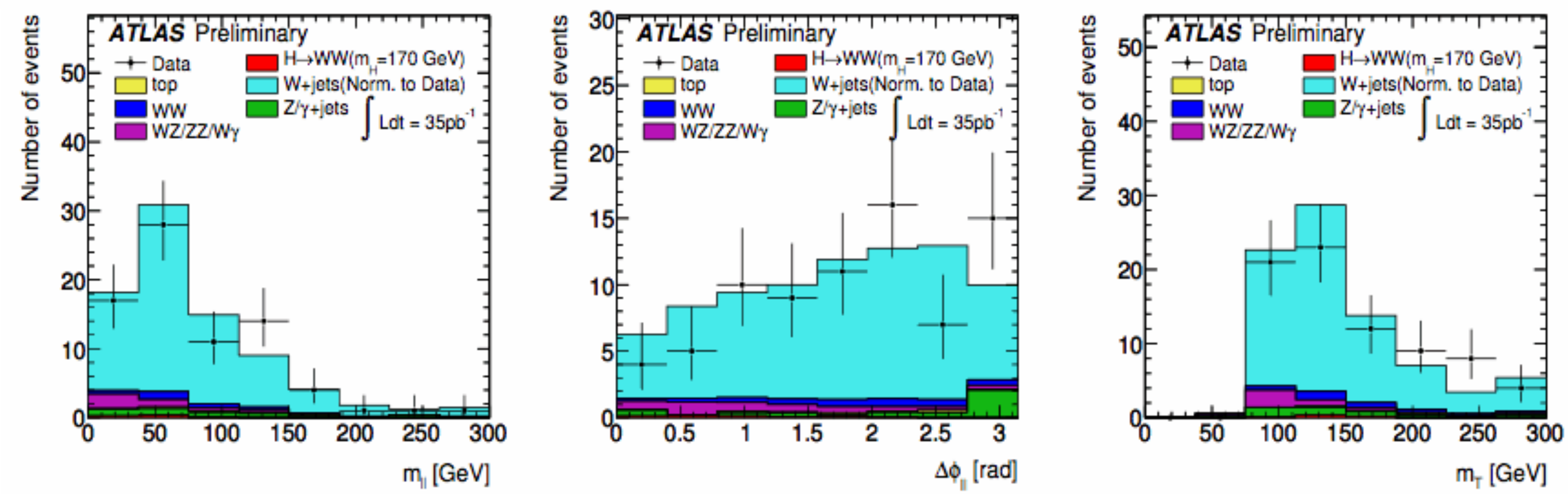

ATLAS
$\sqrt{s}$ = 8 TeV, $\int$ Ldt = 5.8 fb^{-1}
H→WW$^{(*)}$→eνμν + 0 jets
H→WW$^{(*)}$→μνeν + 0 jets
H→WW$^{(*)}$→eνμν + 1 jet
H→WW$^{(*)}$→μνeν + 1 jet
Data
WW
$t\bar{t}$
Z+jets
BG (sys ⊕ stat)
WZ/ZZ/Wγ
Single Top
W+jets
H [125 GeV]
Events / 10 GeV
m_T [GeV]


ATLAS
$\sqrt{s}$ = 7 TeV, $\int$ Ldt = 4.7 fb^{-1}
$\sqrt{s}$ = 8 TeV, $\int$ Ldt = 5.8 fb^{-1}
$H\rightarrow WW^{(*)}\rightarrow l\nu l\nu$ + 0/1 jets
Bkg. subtracted Data
H [125 GeV]
Events / 10 GeV
m_T [GeV]
100
80
60
40
20
0
-20
60
80
100
120
140
160
180
200
220
240

Extraction of W+jets

- Following similar procedure as in CDF for the H+0j and H+1j and H+2j analyses
- Define "feakable" objects for electrons/muons

Fakeable (loose) electron	Fakeable (loose) muon
$\Sigma(p_T^{calo})/p_T < 0.3$	$\Sigma(p_T^{calo})/p_T < 0.3$
$N_{Pixel}^{hits} \geq 1$	No TRT Requirement
$N_{SCT}^{hits} \geq 1$	No χ^2 cut
No Impact Parameter Requirement	No Impact Parameter Requirement
	No $(p_{MS}^{extrapol.} - p_{ID})$ Requirement



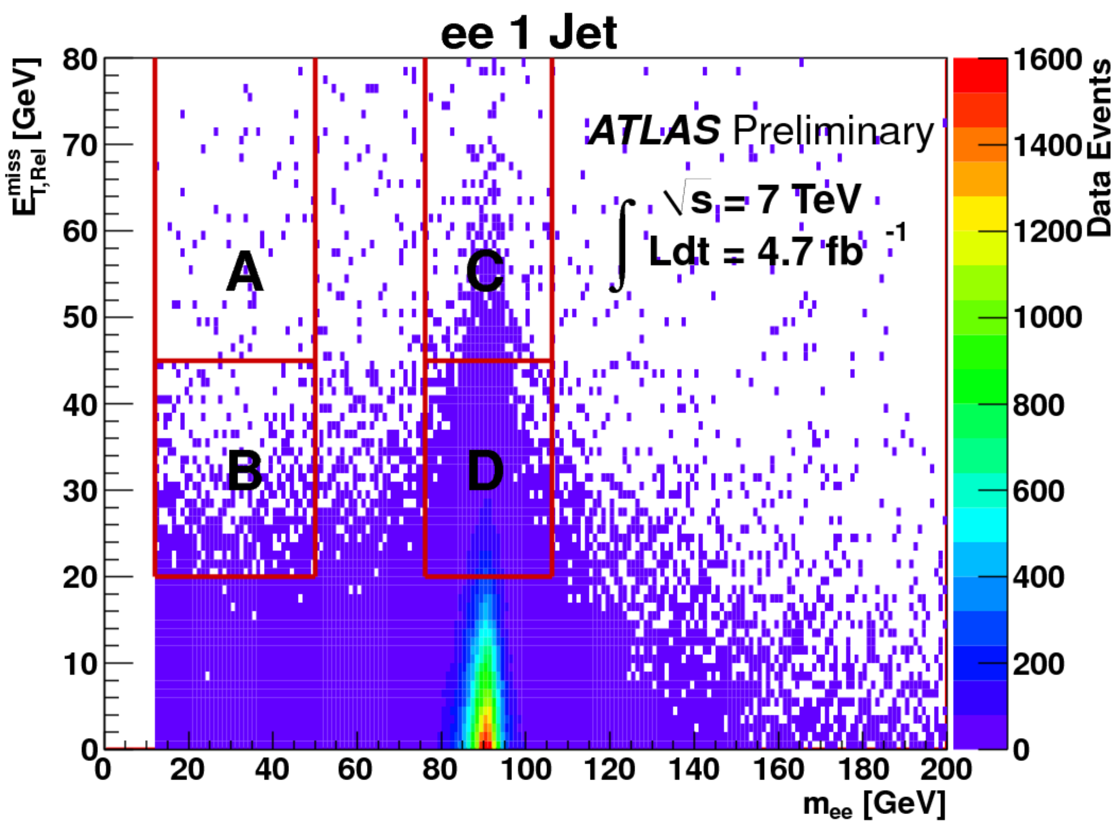
Extraction of top (H+0j)

- The extraction of top is complicated both experimentally and theoretically
  - Note that our MCs do not have the interference between double, single and non-resonant WWbb
- Adopted a quasi-data-driven method:
  - B.Mellado, X.Ruan & Z.Zhang, Phys. Rev. D 84, 096005 (2011)
  - Use a control sample with at least one b-jet to extract the jet veto efficiency in the signal region
    - Relate the jet veto efficiency in events with at least one b-jet to that without any jets

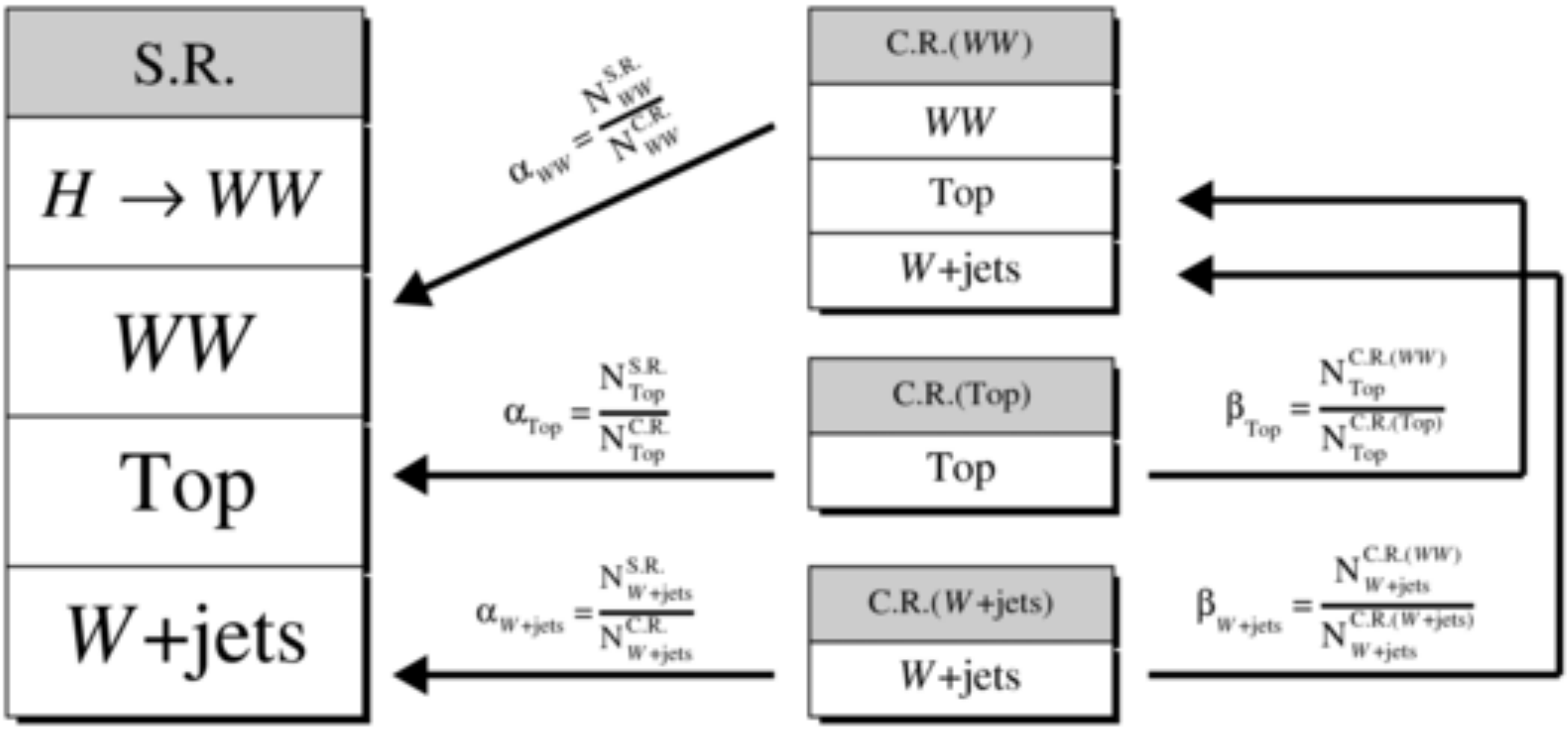
$$P_2^{\text{Estimated}} = \left(P_1^{\text{Btag,Data}}\right)^2 \frac{P_2^{\text{MC}}}{\left(P_1^{\text{Btag,MC}}\right)^2}$$

Extraction of Z+jets

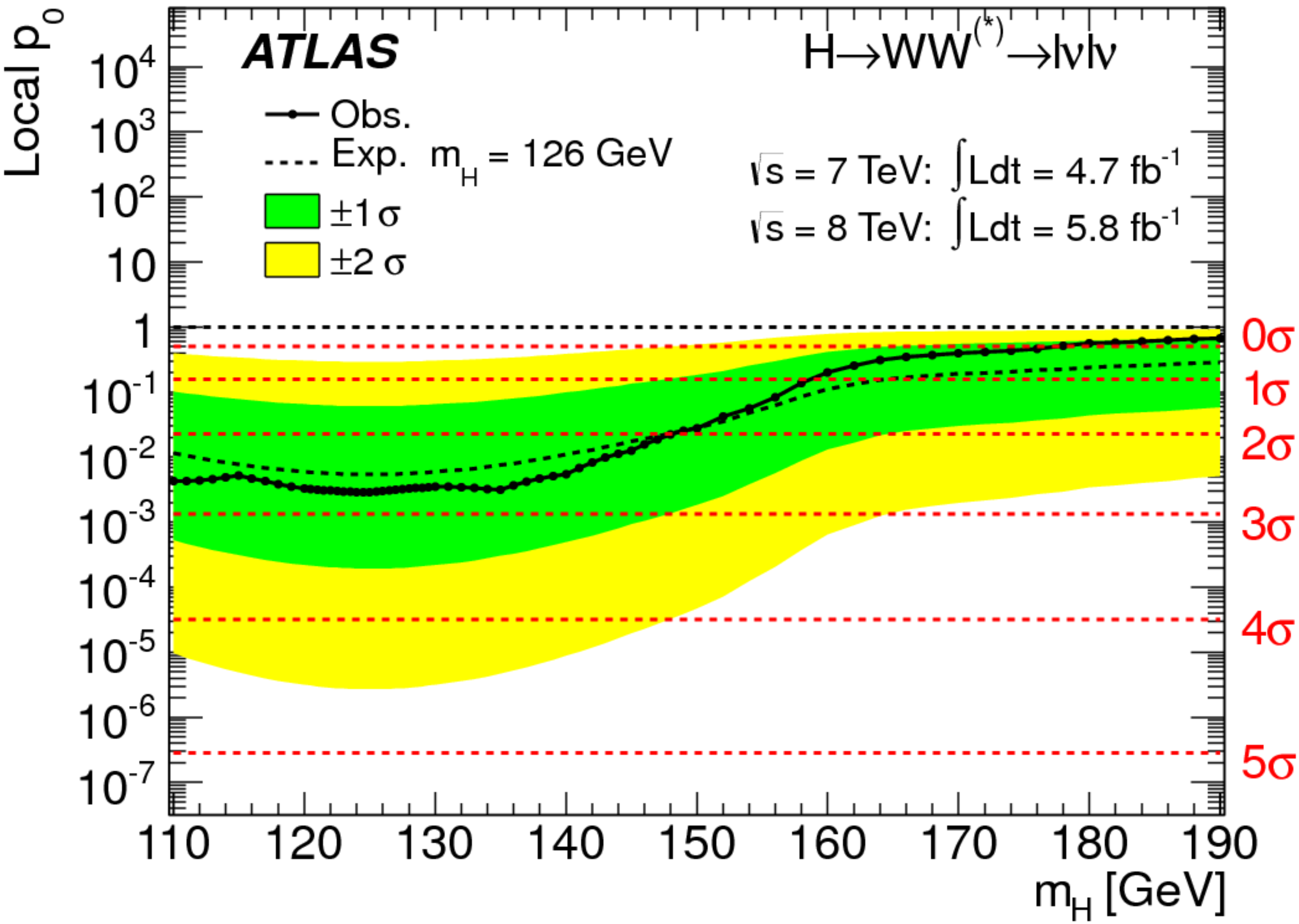
- Z+jets contributes little in the H+0j analysis but significant in H+1j. Limited statistics both in control sample and MC
- Moved to "ABCD" method used by CMS
  - Closure performed with MC



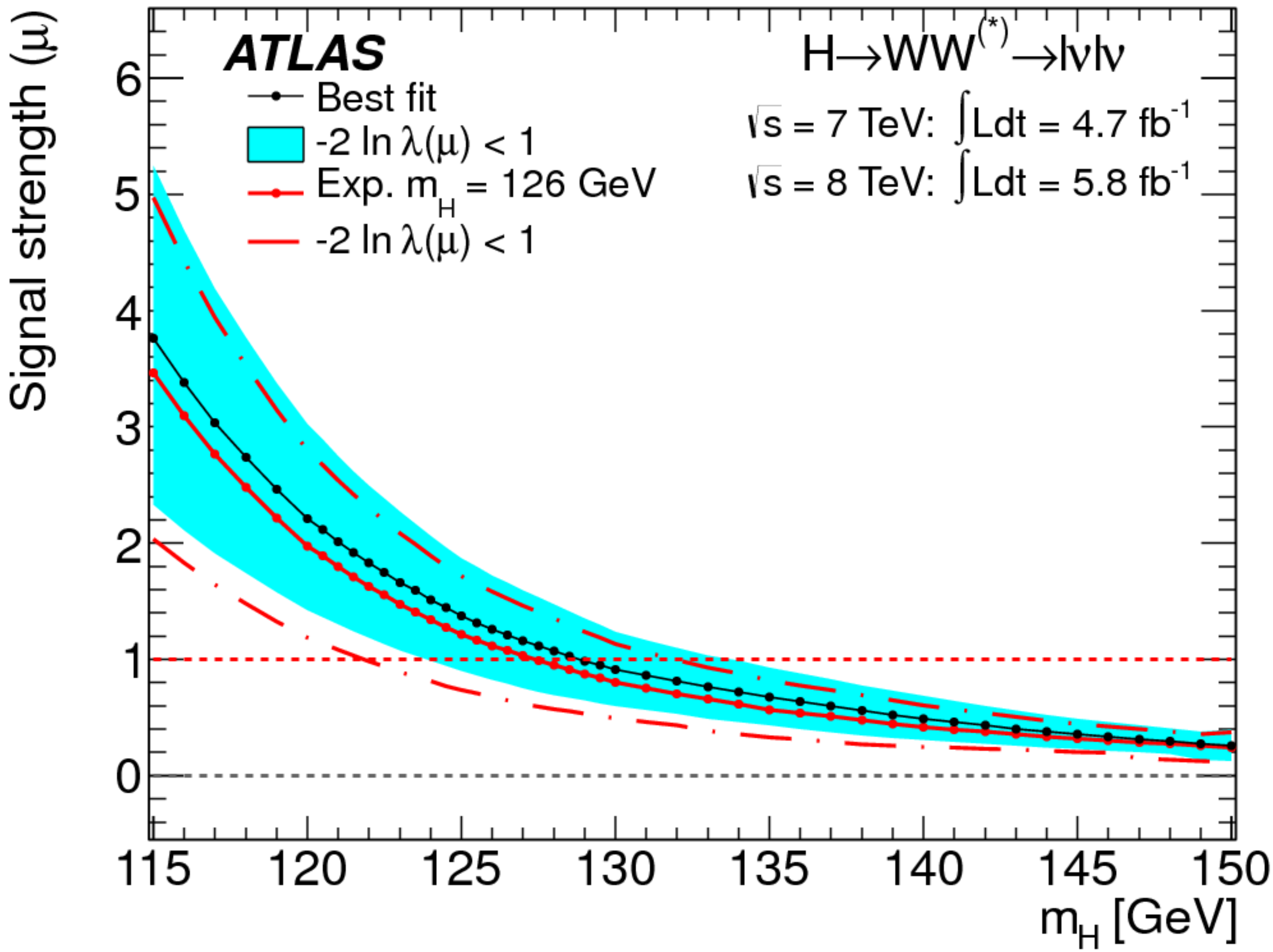
Flow chart for Back. Extraction



Complete propagation of systematic errors



Local p_0
ATLAS
$H \rightarrow WW^{(*)} \rightarrow l\nu l\nu$
Obs.
Exp. m_H = 126 GeV
$\pm 1\,\sigma$
$\pm 2\,\sigma$
$\sqrt{s}$ = 7 TeV: $\int Ldt$ = 4.7 fb^{-1}
$\sqrt{s}$ = 8 TeV: $\int Ldt$ = 5.8 fb^{-1}
10^4
10^3
10^2
10
1
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
0σ
1σ
2σ
3σ
4σ
5σ
110
120
130
140
150
160
170
180
190
m_H [GeV]



ATLAS
Best fit
-2 ln λ(μ) < 1
Exp. m_H = 126 GeV
-2 ln λ(μ) < 1
H→WW(*)→lνlν
√s = 7 TeV: ∫Ldt = 4.7 fb-1
√s = 8 TeV: ∫Ldt = 5.8 fb-1
Signal strength (μ)
m_H [GeV]

Higgs to ττ Results with 4.7 fb^{-1} of 2011 Data

Overview of Analysis

- Use the three decay modes:

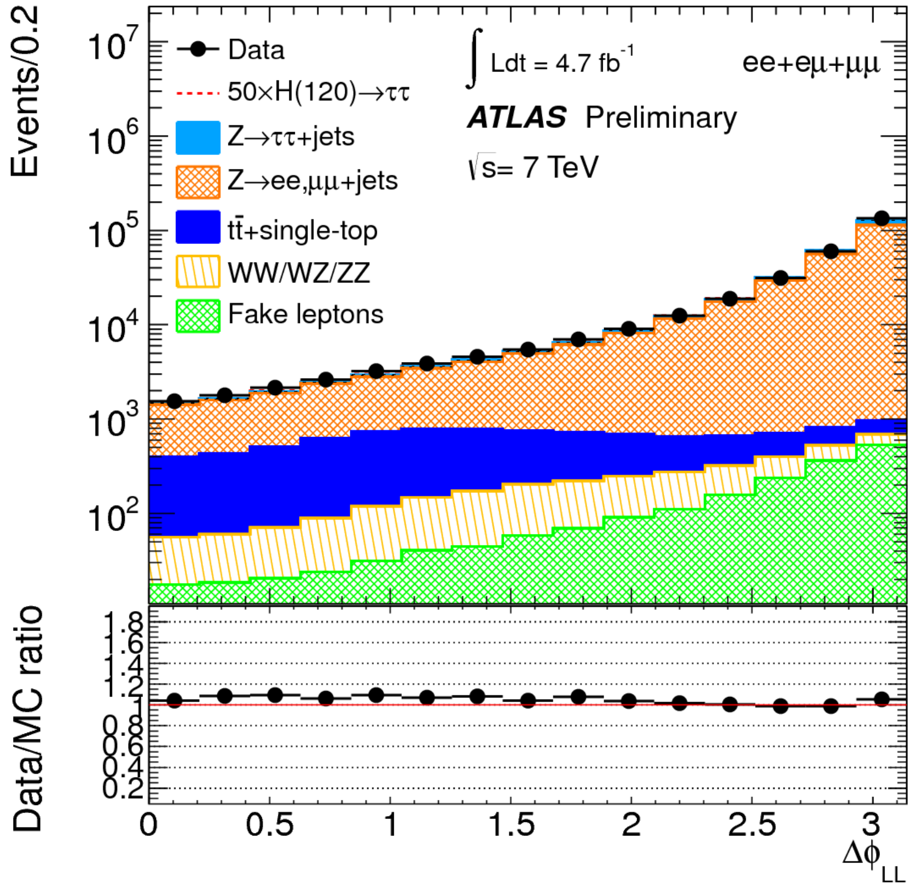
$$H \to \tau^+\tau^- \to \ell\ell 4\nu,\ \ell\tau_h 3\nu,\ \tau_h\tau_h\nu\nu$$

- Jet binning is essential to curve large backgrounds:

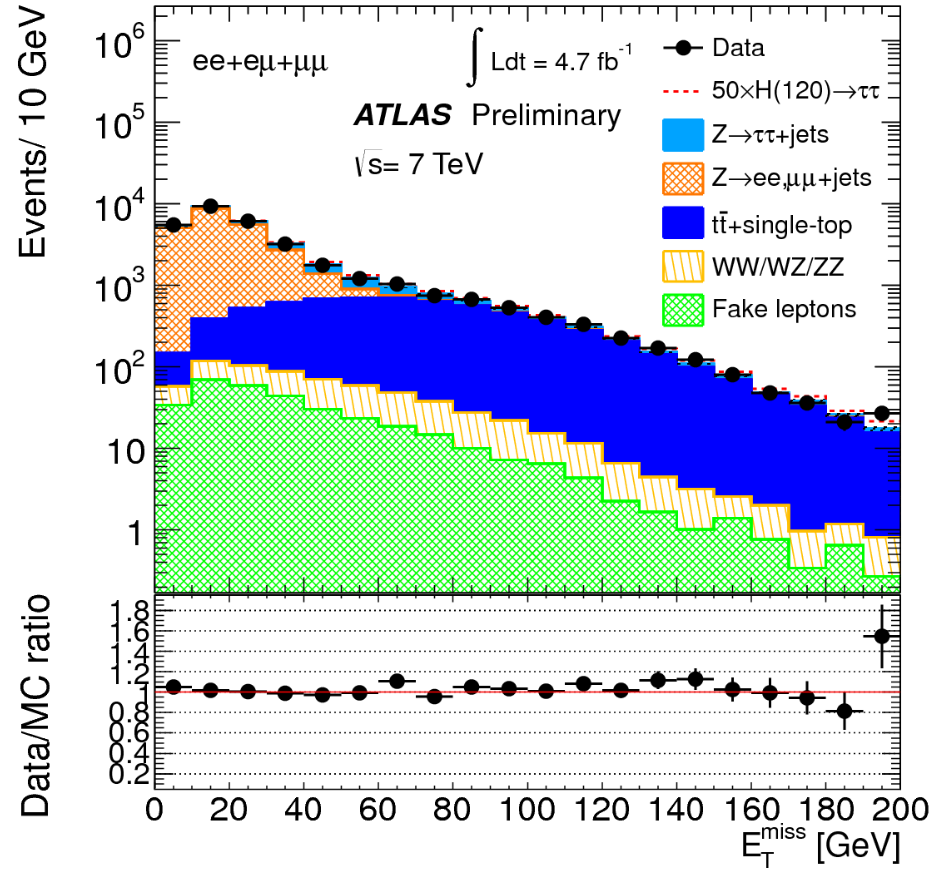
D. L. Rainwater, D. Zeppenfeld, and K. Hagiwara, Phys. Rev. **D59** (1998) 014037,

B. Mellado, W. Quayle, and S. L. Wu, Phys. Lett. **B611** (2005) 60–65,

- Main backgrounds are obtained with data
  - $Z \rightarrow \tau\tau$
    - Embedding technique with $Z \rightarrow \mu\mu$ events
  - QCD
    - Using QCD enriched samples, whether by loosening isolation of looking at SS events

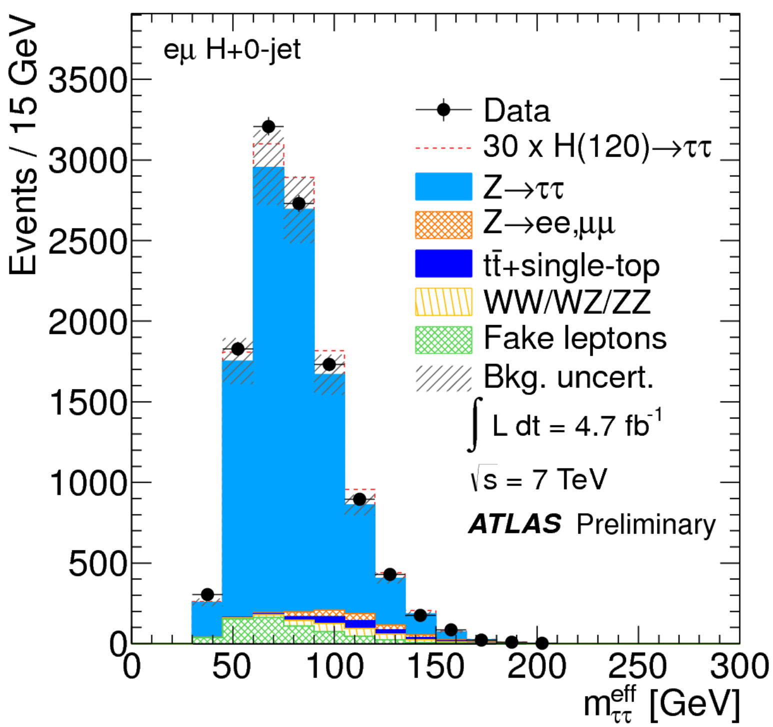


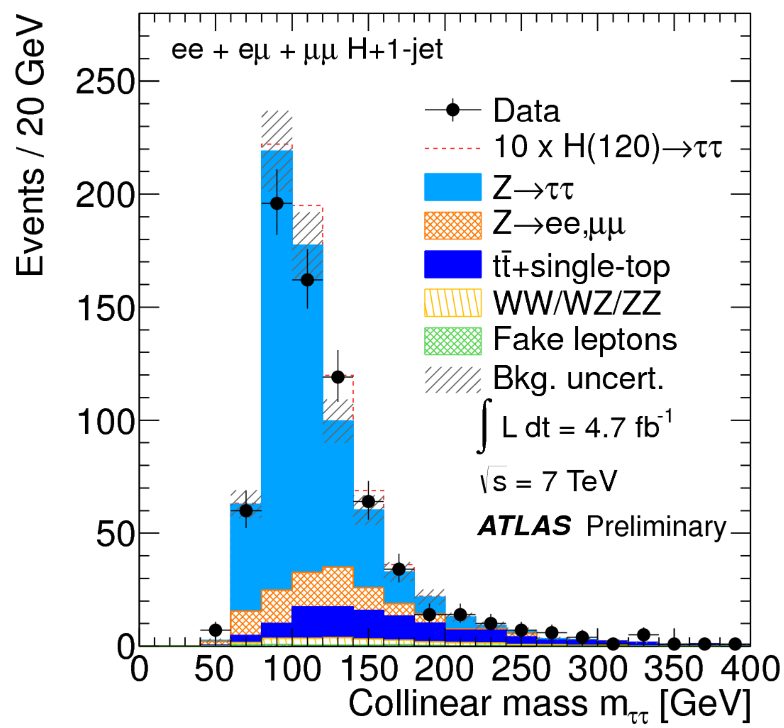
Events/0.2
Data
50×H(120)→ττ
Z→ττ+jets
Z→ee,μμ+jets
tt̄+single-top
WW/WZ/ZZ
Fake leptons
∫ Ldt = 4.7 fb⁻¹
ee+eμ+μμ
ATLAS Preliminary
√s= 7 TeV
Data/MC ratio
Δφ_LL

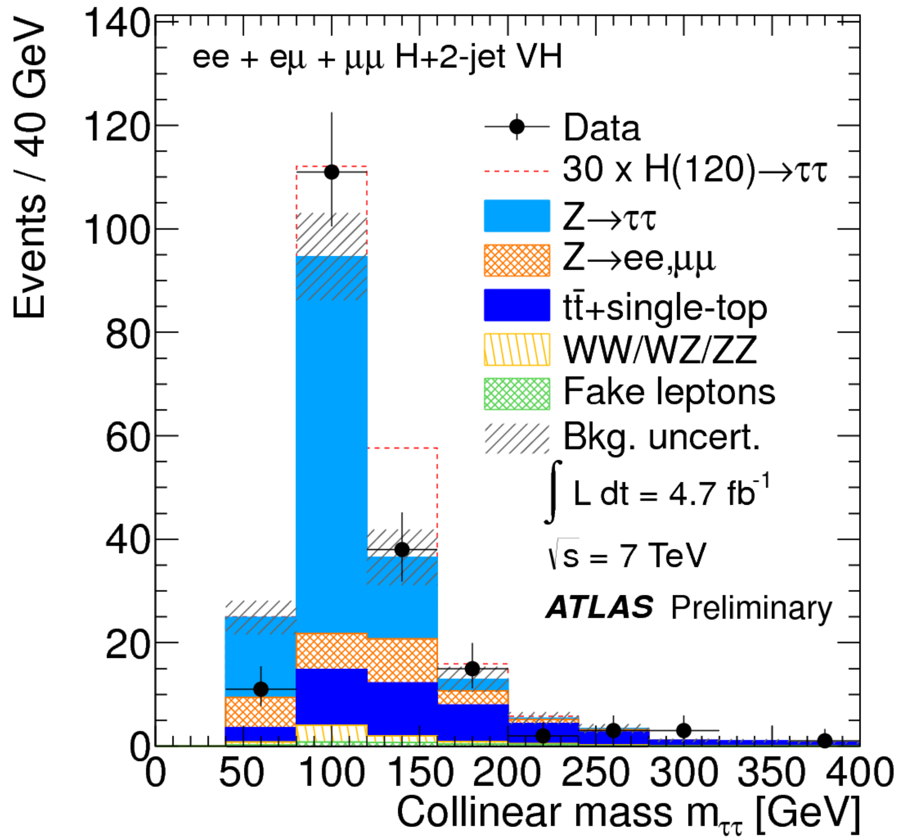


Events/ 10 GeV
ee+eμ+μμ
∫ Ldt = 4.7 fb⁻¹
ATLAS Preliminary
√s= 7 TeV
Data
50×H(120)→ττ
Z→ττ+jets
Z→ee,μμ+jets
tt̄+single-top
WW/WZ/ZZ
Fake leptons
Data/MC ratio
E_T^miss [GeV]

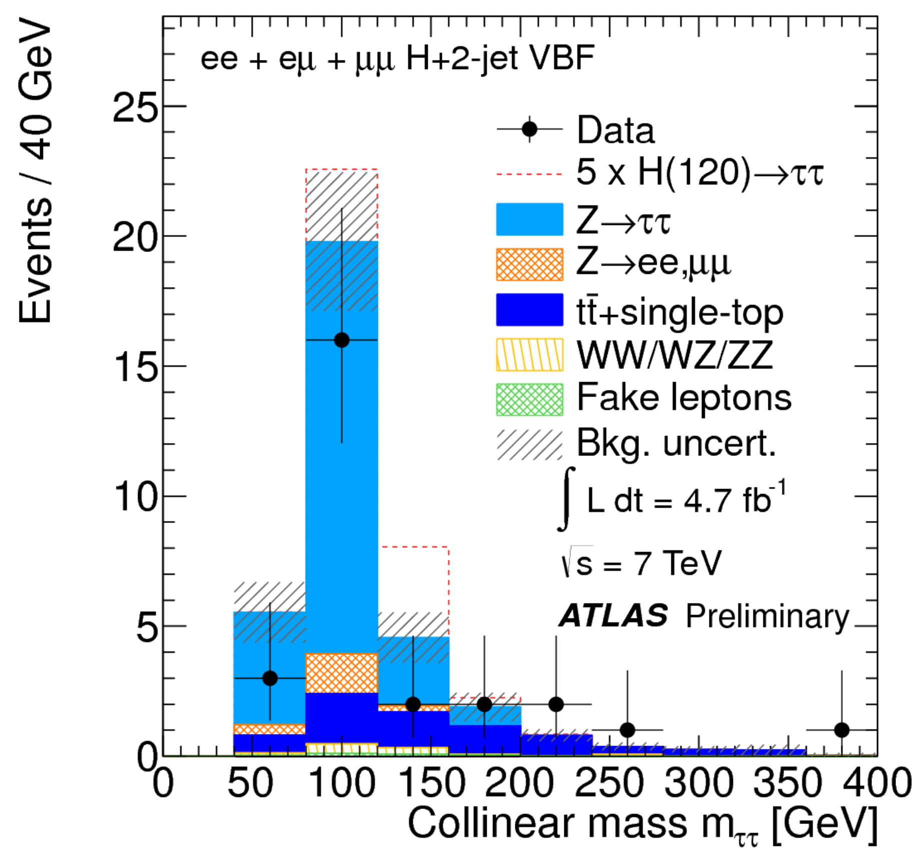
	$ee+\mu\mu+e\mu$ H +2-jet VBF	$ee+\mu\mu+e\mu$ H +2-jet VH	$ee+\mu\mu+e\mu$ H +1-jet	$e\mu$ H +0-jet
$gg\to H$ signal	0.26±0.06±0.10	0.8±0.1±0.2	3.9±0.2±1.0	23±1±3
VBF H signal	1.08±0.03±0.11	0.10±0.01±0.01	1.15±0.03±0.01	0.75±0.03±0.06
VH signal	0.01±0.01±0.01	0.53±0.02±0.07	0.40±0.02±0.03	0.52±0.02±0.04
$Z/\gamma^*\to\tau^+\tau^-$	24±3±2	107±12±9	$(0.52\pm0.01\pm0.04)\cdot10^3$	$(9.68\pm0.05\pm0.07)\cdot10^3$
$Z/\gamma^*\to\ell^+\ell^-$ (ℓ=e,μ)	2±1±1	25±4±9	80±10±30	185±11±14
$t\bar{t}$ +single top	7±1±2	41±2±6	95±3±12	169±4±14
$WW/WZ/ZZ$	0.9±0.3±0.3	6±1±1	21±1±3	221±3±18
Fake leptons	1.3±0.8±0.6	13±2±5	30±4±12	$(1.2\pm0.5)\cdot10^3$
Total background	34±3±4	191±7±20	$(0.75\pm0.01\pm0.05)\cdot10^3$	$(11.4\pm0.5)\cdot10^3$
Observed data	27	185	702	11420



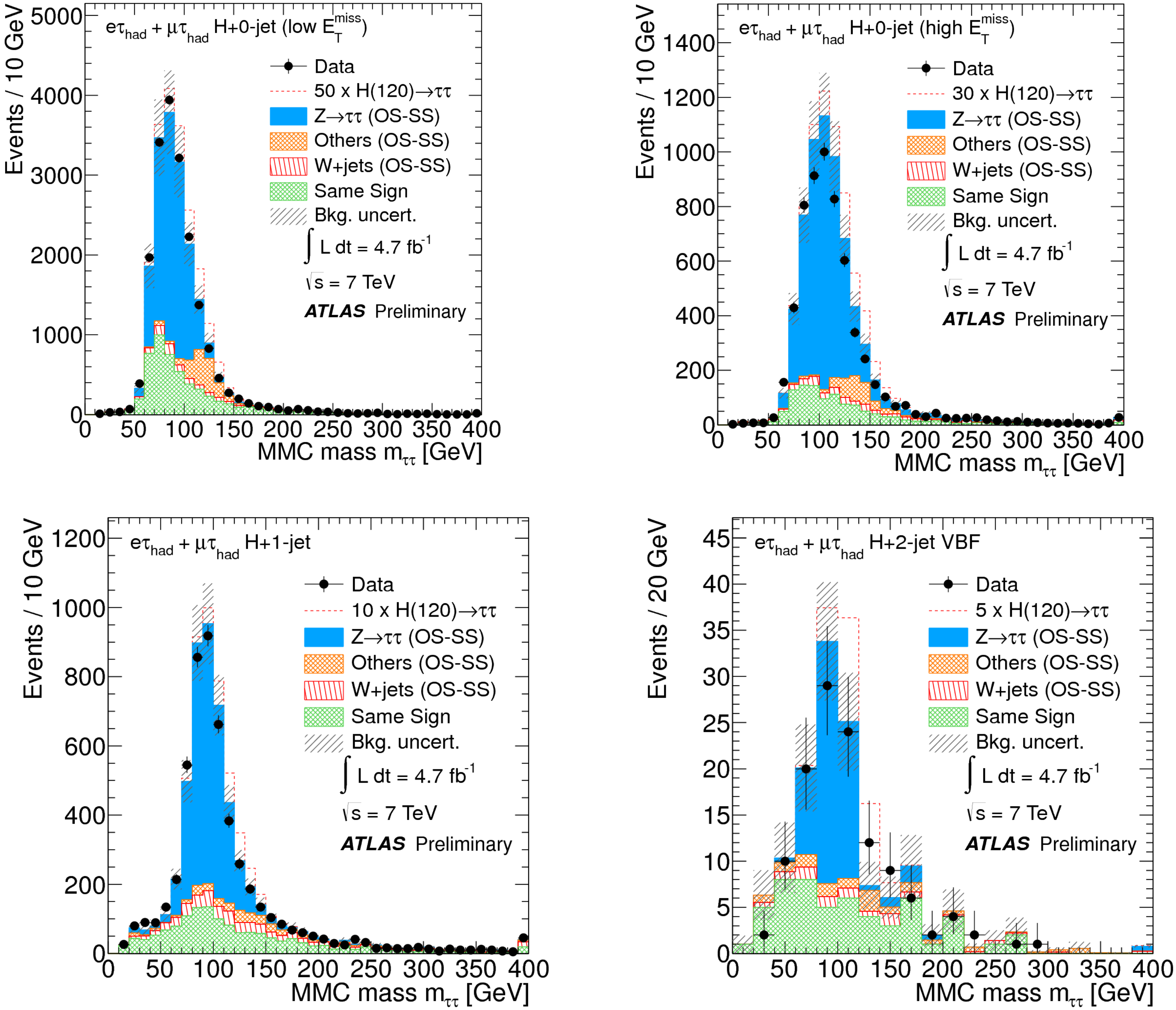




Events / 40 GeV
ee + eμ + μμ H+2-jet VH
Data
30 x H(120)→ττ
Z→ττ
Z→ee,μμ
tt̄+single-top
WW/WZ/ZZ
Fake leptons
Bkg. uncert.
∫ L dt = 4.7 fb-1
√s = 7 TeV
ATLAS Preliminary
Collinear mass mττ [GeV]

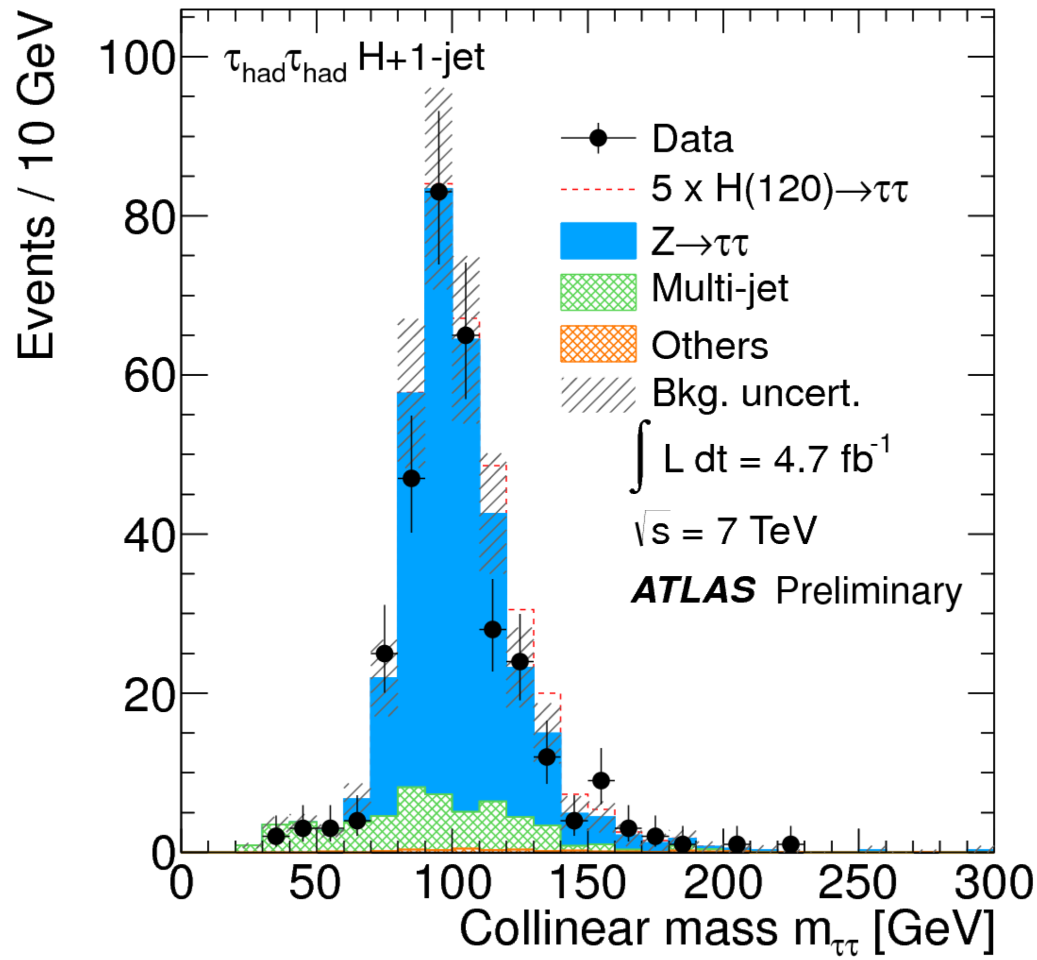


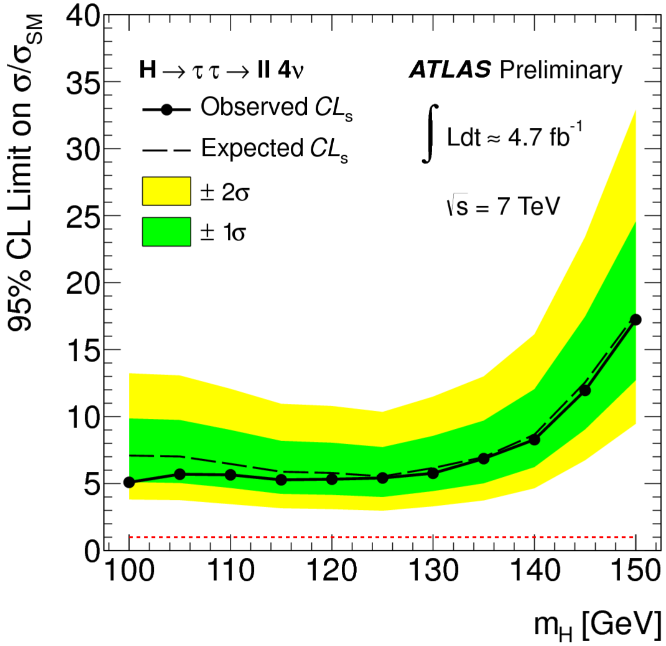
Events / 40 GeV
ee + eμ + μμ H+2-jet VBF
Data
5 x H(120)→ττ
Z→ττ
Z→ee,μμ
tt̄+single-top
WW/WZ/ZZ
Fake leptons
Bkg. uncert.
∫ L dt = 4.7 fb-1
√s = 7 TeV
ATLAS Preliminary
Collinear mass mττ [GeV]

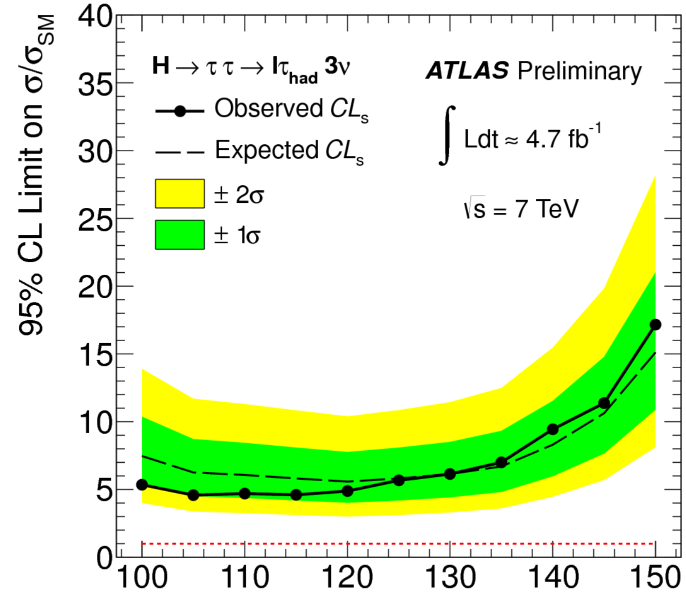

eτhad + μτhad H+0-jet (low E_T^miss)
Data
50 x H(120)→ττ
Z→ττ (OS-SS)
Others (OS-SS)
W+jets (OS-SS)
Same Sign
Bkg. uncert.
∫ L dt = 4.7 fb-1
√s = 7 TeV
ATLAS Preliminary
Events / 10 GeV
MMC mass mττ [GeV]
eτhad + μτhad H+0-jet (high E_T^miss)
30 x H(120)→ττ
eτhad + μτhad H+1-jet
10 x H(120)→ττ
eτhad + μτhad H+2-jet VBF
5 x H(120)→ττ
Events / 20 GeV

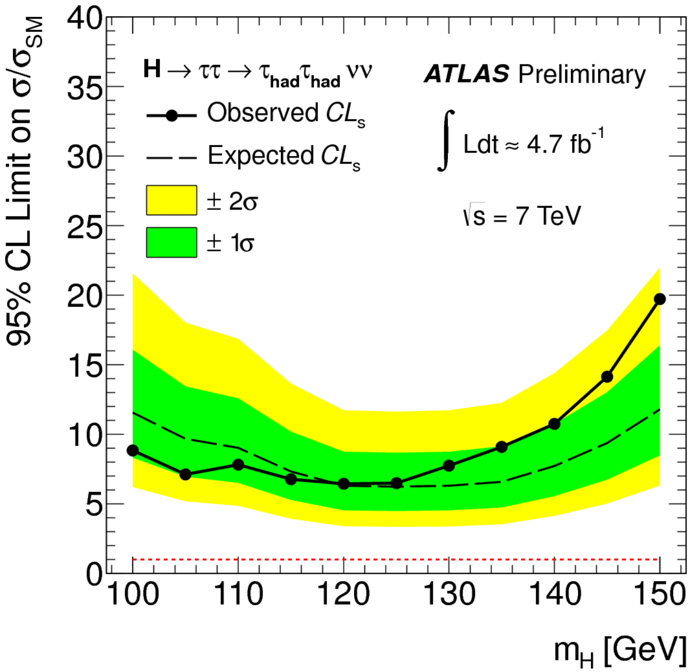
In $\tau_h\tau_h$ channel it was chosen to use one bin, an inclusive H+1j analysis

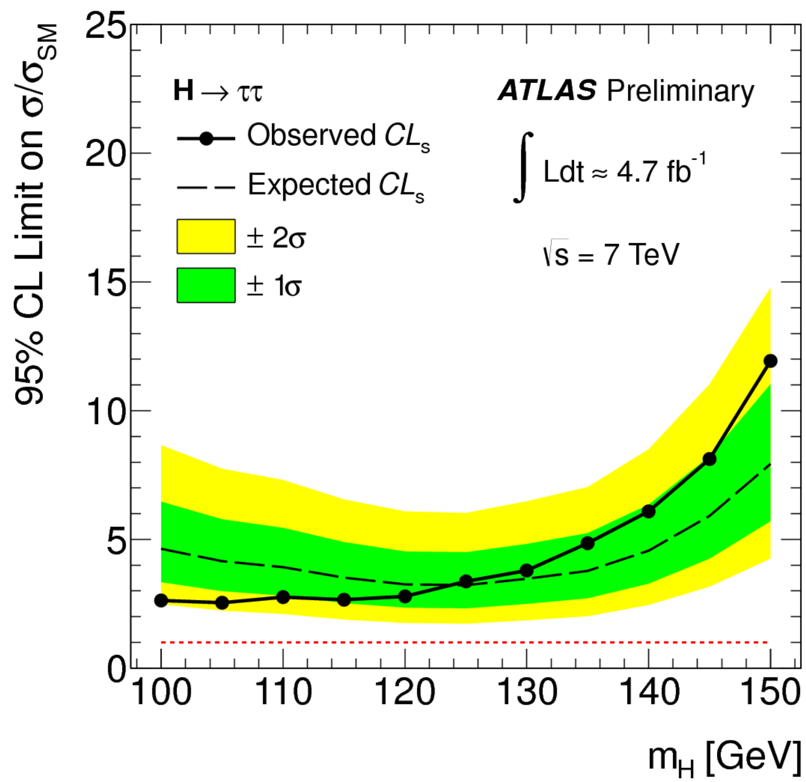
	$\tau_{\mathrm{had}}\tau_{\mathrm{had}}\,\nu\nu$ $H+1$-jet
$gg \to H$ signal	$3.1 \pm 0.2 \pm 0.6$
VBF H signal	$1.51 \pm 0.05 \pm 0.18$
VH signal	$0.61 \pm 0.04 \pm 0.06$
$Z/\gamma^* \to \tau^+\tau^-$	$287 \pm 23 \pm 34$
W+jets / Z+jets	$6.1 \pm 1.3 \pm 1.4$
$t\bar{t}$+single top	$1.9 \pm 0.3 \pm 0.4$
$WW/WZ/ZZ$	$2.1 \pm 0.4 \pm 0.4$
Multi-jet	$54 \pm 21 \pm 12$
Total background	$348 \pm 31 \pm 36$
Observed data	317




H → τ τ → ll 4ν
ATLAS Preliminary
Observed CL_s
Expected CL_s
± 2σ
± 1σ
$\int$ Ldt ≈ 4.7 fb^{-1}
√s = 7 TeV
95% CL Limit on σ/σ_{SM}
m_H [GeV]


H → τ τ → lτ$_{had}$ 3ν
ATLAS Preliminary
Observed CL_s
Expected CL_s
± 2σ
± 1σ
$\int$ Ldt ≈ 4.7 fb^{-1}
√s = 7 TeV
95% CL Limit on σ/σ_{SM}


H → ττ → τ$_{had}$τ$_{had}$ νν
ATLAS Preliminary
Observed CL_s
Expected CL_s
± 2σ
± 1σ
$\int$ Ldt ≈ 4.7 fb^{-1}
√s = 7 TeV
95% CL Limit on σ/σ_{SM}
m_H [GeV]


H → ττ
ATLAS Preliminary
Observed CL_s
Expected CL_s
± 2σ
± 1σ
$\int$ Ldt ≈ 4.7 fb^{-1}
√s = 7 TeV
95% CL Limit on σ/σ_{SM}
m_H [GeV]

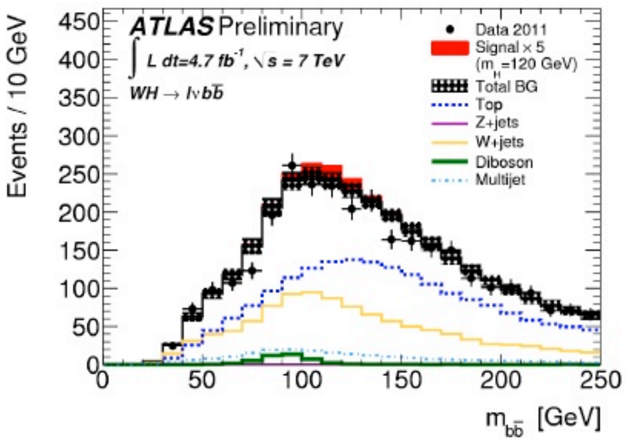
Higgs to bb Results with 4.7 fb^{-1} of 2011 Data

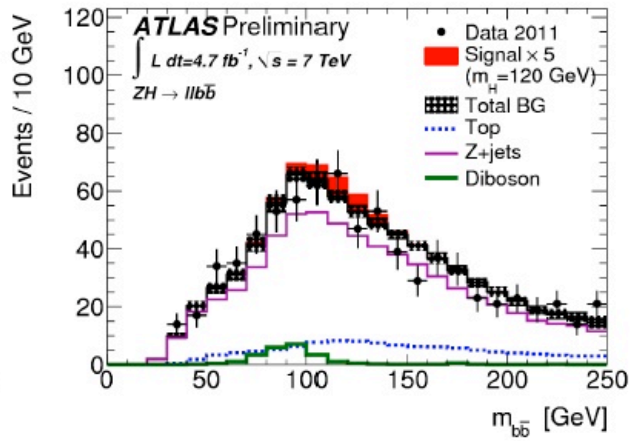
$(W/Z)H, H \to b\bar{b}$: $\ell\nu bb$, $\ell\ell bb$, $\nu\nu bb$

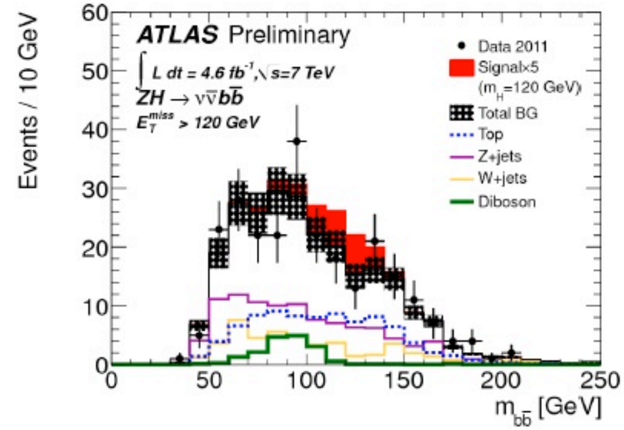
Selection requires exactly two b-tagged jets: $E_T^{b1} > 45$ GeV, $E_T^{b2} > 25$ GeV.

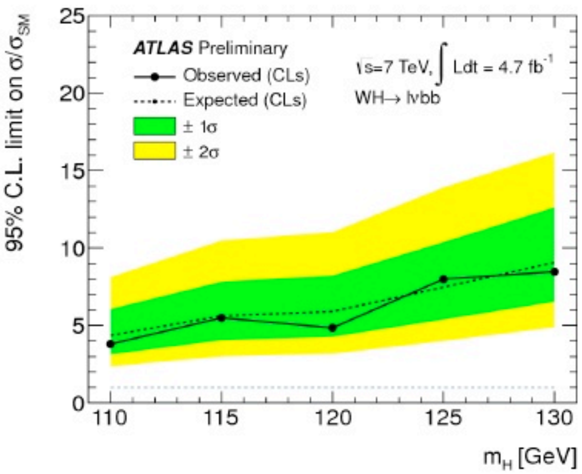
W/Z and H boson recoil away with significant p_T:

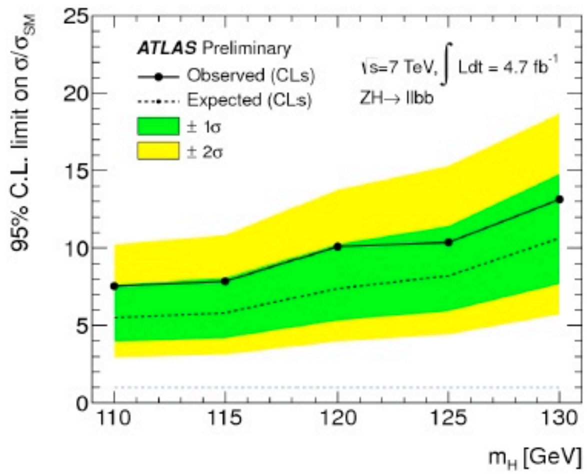
- 4 p_T^W-categories in $WH \to \ell\nu bb$: <50, [50,100), [100,200), ≥200 GeV
- 4 p_T^Z-categories in $ZH \to \ell\ell bb$: <50, [50,100), [100,200), ≥200 GeV
- 3 E_T^{miss}-categories in $ZH \to \nu\nu bb$: [120,160), [160,200), ≥200 GeV

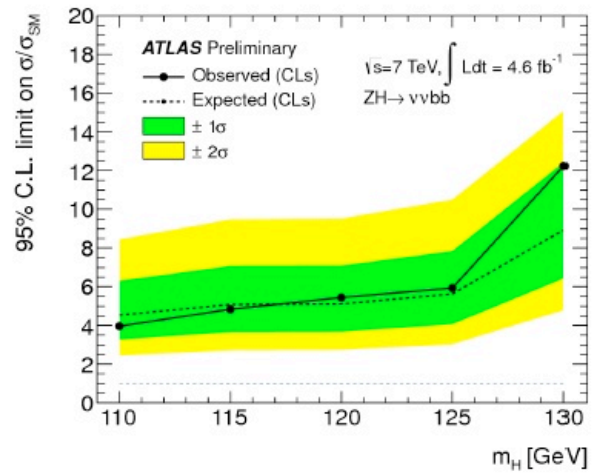


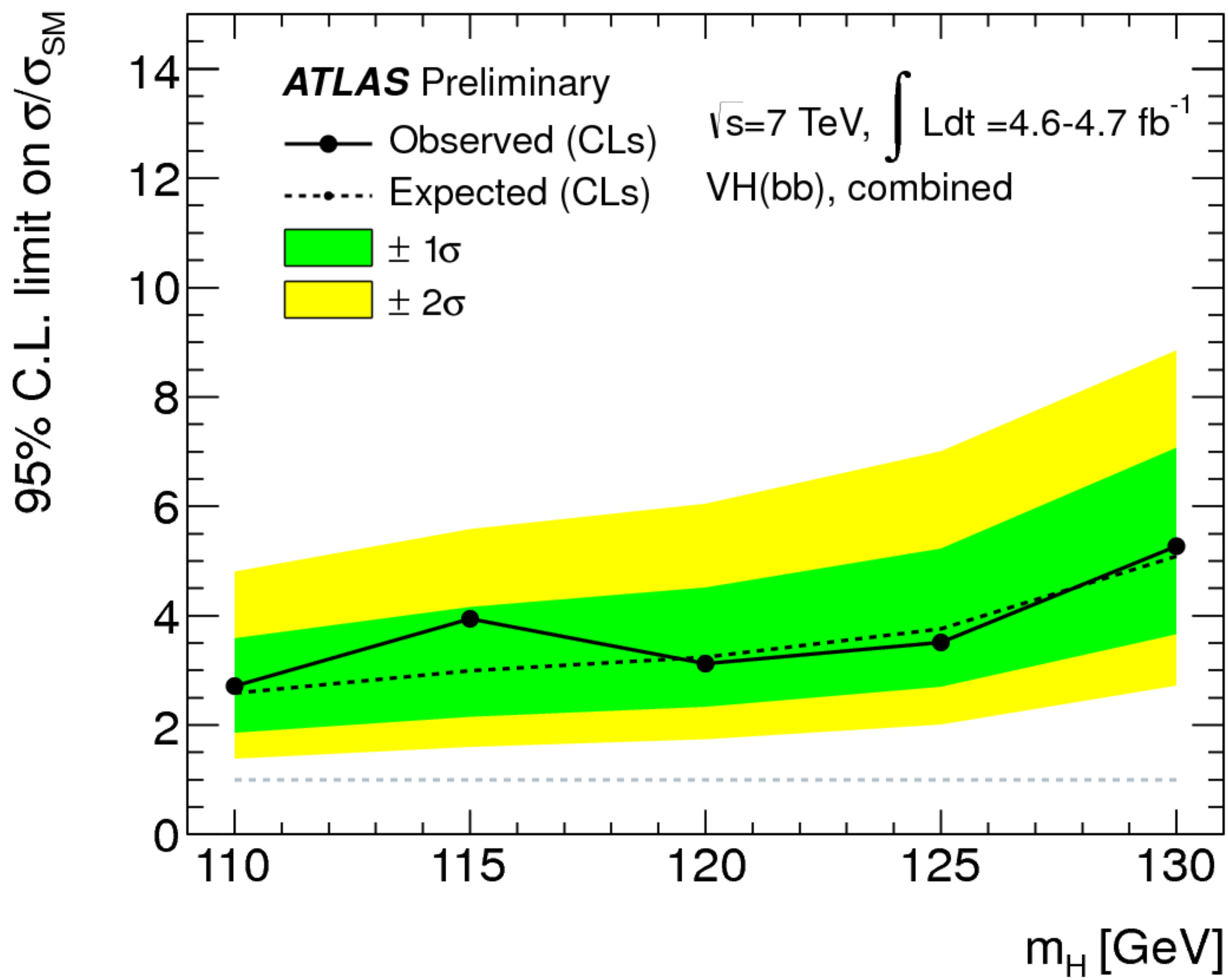








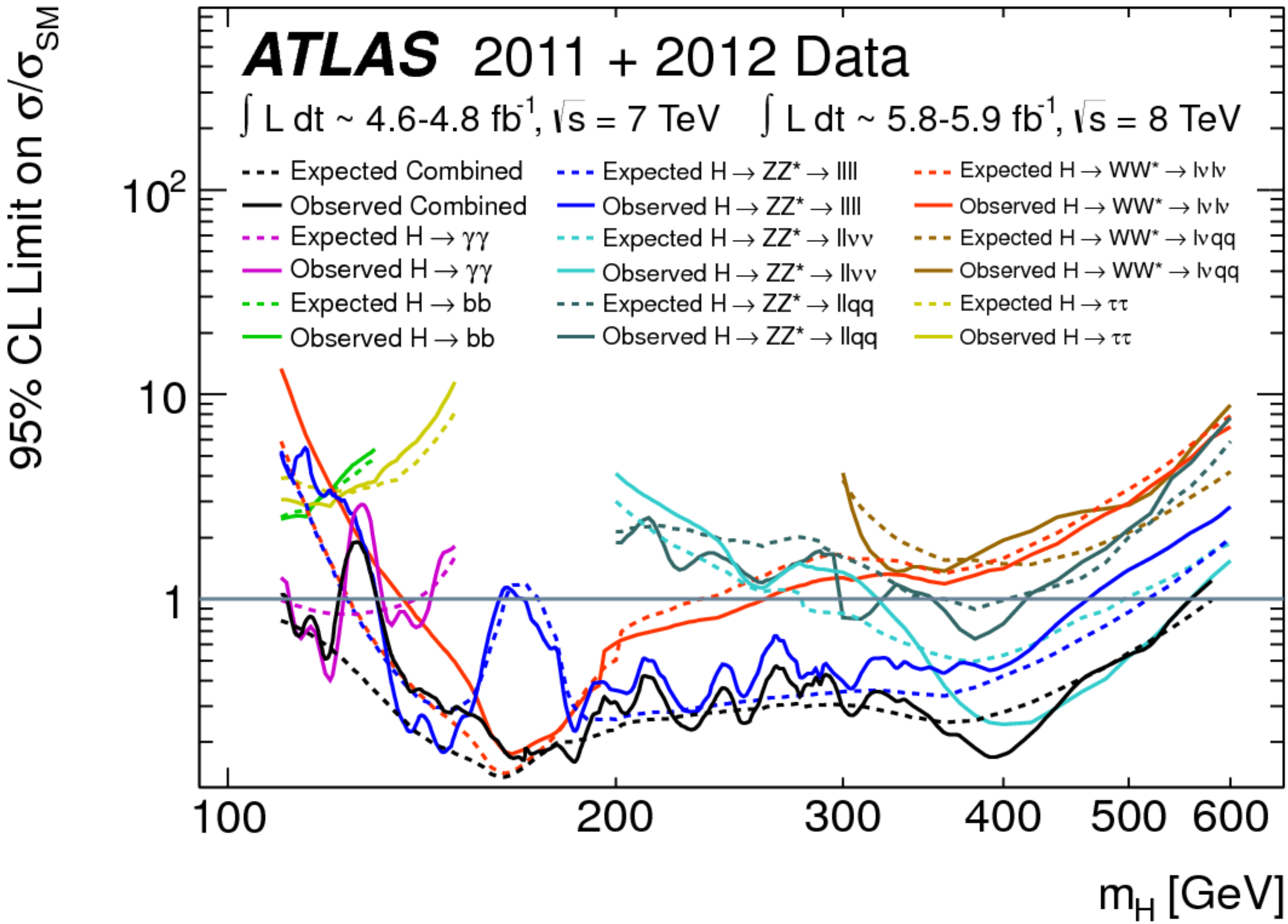


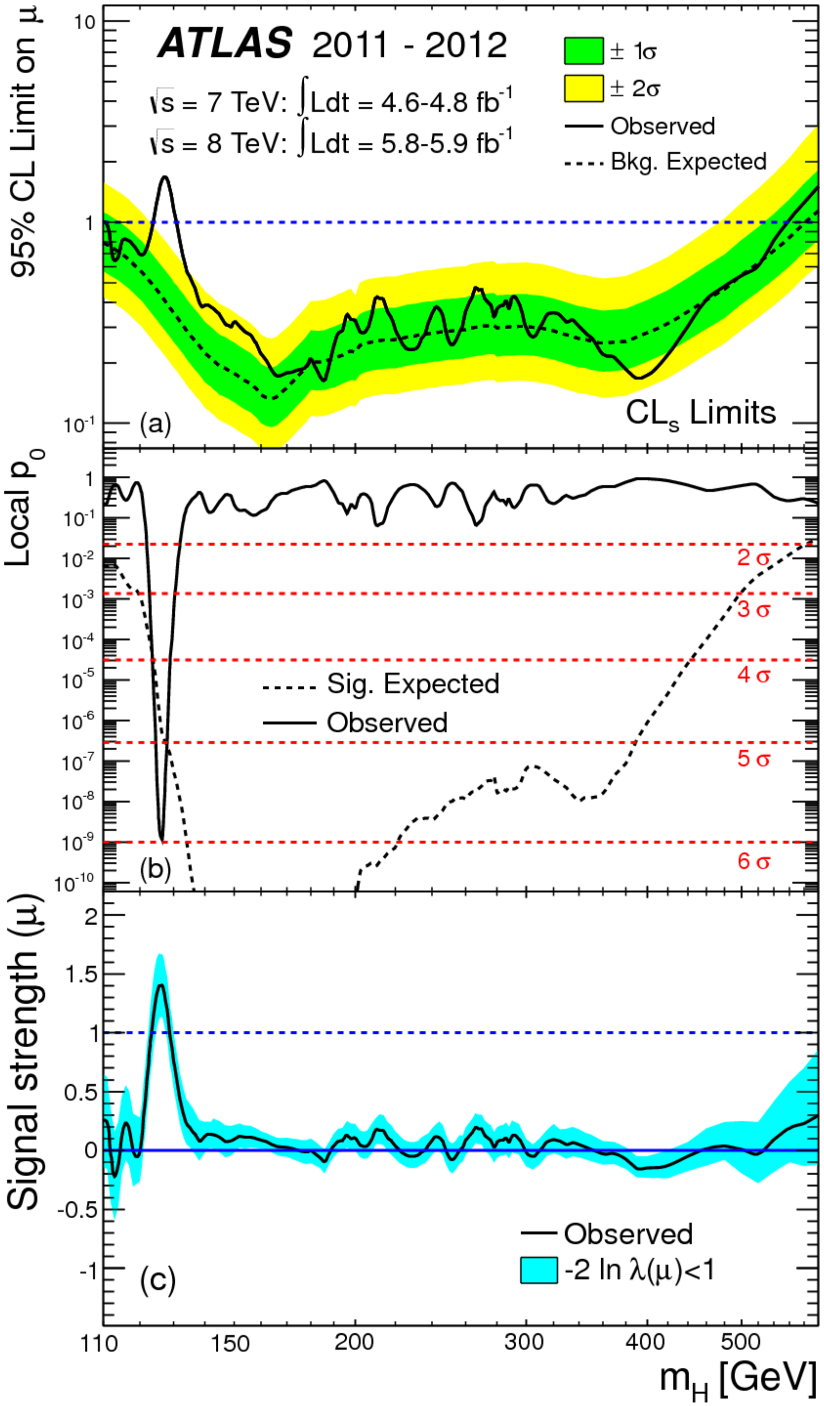

ATLAS Preliminary
Observed (CLs)
Expected (CLs)
± 1σ
± 2σ
√s=7 TeV, ∫ Ldt =4.6-4.7 fb-1
VH(bb), combined
95% C.L. limit on σ/σSM
mH [GeV]
0
2
4
6
8
10
12
14
110
115
120
125
130

Higgs Combination using results from 2011 and 2012 data

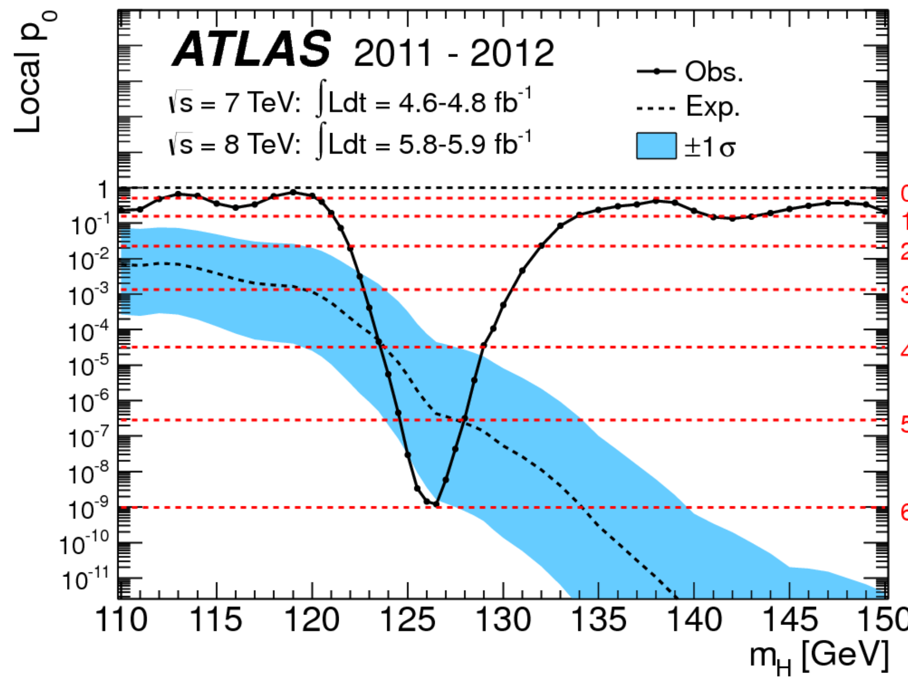
What Goes into the Combination

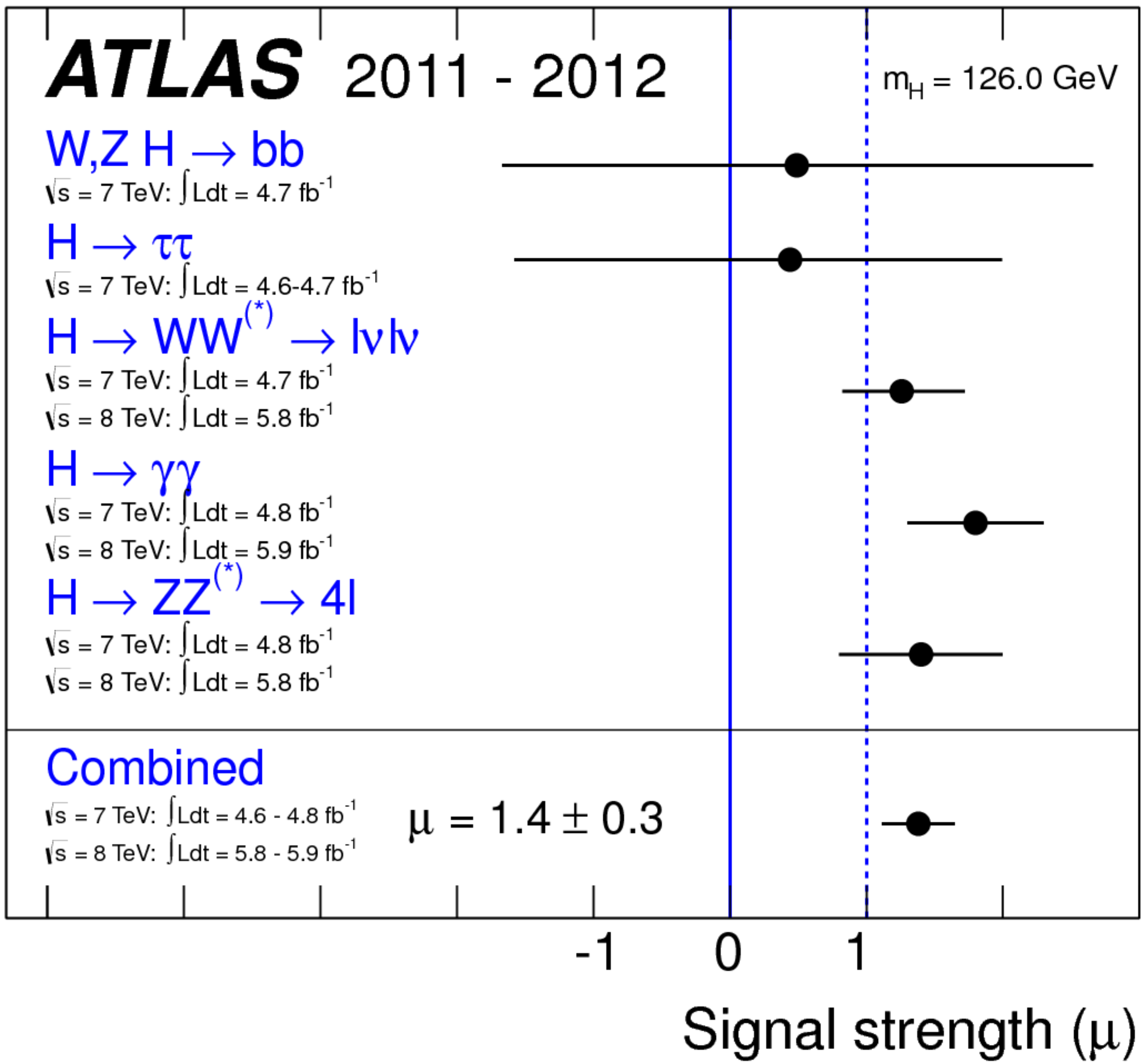
Higgs Boson Decay	Subsequent Decay	Sub-Channels	m_H Range [GeV]	$\int$ L dt [fb^{-1}]
		2011 $\sqrt{s}$ =7 TeV		
$H \to ZZ^{(*)}$	4ℓ	$\{4e, 2e2\mu, 2\mu 2e, 4\mu\}$	110–600	4.8
	$\ell\ell\nu\nu$	$\{ee, \mu\mu\} \otimes$ {low, high pile-up}	200–280–600	4.7
	$\ell\ell qq$	{b-tagged, untagged}	200–300–600	4.7
$H \to \gamma\gamma$	–	10 categories $\{p_{\mathrm{Tt}} \otimes \eta_\gamma \otimes \text{conversion}\} \oplus \{\text{2-jet}\}$	110–150	4.8
$H \to WW^{(*)}$	$\ell\nu\ell\nu$	$\{ee, e\mu/\mu e, \mu\mu\} \otimes$ {0-jet, 1-jet, 2-jet} $\otimes$ {low, high pile-up}	110–200–300–600	4.7
	$\ell\nu qq'$	$\{e, \mu\} \otimes$ {0-jet, 1-jet, 2-jet}	300–600	4.7
$H \to \tau\tau$	$\tau_{\mathrm{lep}}\tau_{\mathrm{lep}}$	$\{e\mu\} \otimes \{\text{0-jet}\} \oplus \{\ell\ell\} \otimes \{\text{1-jet, 2-jet}, VH\}$	110–150	4.7
	$\tau_{\mathrm{lep}}\tau_{\mathrm{had}}$	$\{e, \mu\} \otimes \{\text{0-jet}\} \otimes \{E_{\mathrm{T}}^{\mathrm{miss}} < 20\ \text{GeV}, E_{\mathrm{T}}^{\mathrm{miss}} \geq 20\ \text{GeV}\}$ $\oplus \{e, \mu\} \otimes \{\text{1-jet}\} \oplus \{\ell\} \otimes \{\text{2-jet}\}$	110–150	4.7
	$\tau_{\mathrm{had}}\tau_{\mathrm{had}}$	{1-jet}	110–150	4.7
$VH \to Vbb$	$Z \to \nu\nu$	$E_{\mathrm{T}}^{\mathrm{miss}} \in \{120-160, 160-200, \geq 200\ \text{GeV}\}$	110–130	4.6
	$W \to \ell\nu$	$p_{\mathrm{T}}^{W} \in \{< 50, 50-100, 100-200, \geq 200\ \text{GeV}\}$	110–130	4.7
	$Z \to \ell\ell$	$p_{\mathrm{T}}^{Z} \in \{< 50, 50-100, 100-200, \geq 200\ \text{GeV}\}$	110–130	4.7
		2012 $\sqrt{s}$ =8 TeV		
$H \to ZZ^{(*)}$	4ℓ	$\{4e, 2e2\mu, 2\mu 2e, 4\mu\}$	110–600	5.8
$H \to \gamma\gamma$	–	10 categories $\{p_{\mathrm{Tt}} \otimes \eta_\gamma \otimes \text{conversion}\} \oplus \{\text{2-jet}\}$	110–150	5.9
$H \to WW^{(*)}$	$e\nu\mu\nu$	$\{e\mu, \mu e\} \otimes$ {0-jet, 1-jet, 2-jet}	110–200	5.8


ATLAS 2011 + 2012 Data
$\int L\,dt \sim 4.6\text{-}4.8\ fb^{-1}, \sqrt{s} = 7$ TeV
$\int L\,dt \sim 5.8\text{-}5.9\ fb^{-1}, \sqrt{s} = 8$ TeV
Expected Combined
Observed Combined
Expected $H \to \gamma\gamma$
Observed $H \to \gamma\gamma$
Expected $H \to bb$
Observed $H \to bb$
Expected $H \to ZZ^* \to llll$
Observed $H \to ZZ^* \to llll$
Expected $H \to ZZ^* \to ll\nu\nu$
Observed $H \to ZZ^* \to ll\nu\nu$
Expected $H \to ZZ^* \to llqq$
Observed $H \to ZZ^* \to llqq$
Expected $H \to WW^* \to l\nu l\nu$
Observed $H \to WW^* \to l\nu l\nu$
Expected $H \to WW^* \to l\nu qq$
Observed $H \to WW^* \to l\nu qq$
Expected $H \to \tau\tau$
Observed $H \to \tau\tau$
95% CL Limit on σ/σ_{SM}
10^2
10
1
100
200
300
400
500
600
m_H [GeV]

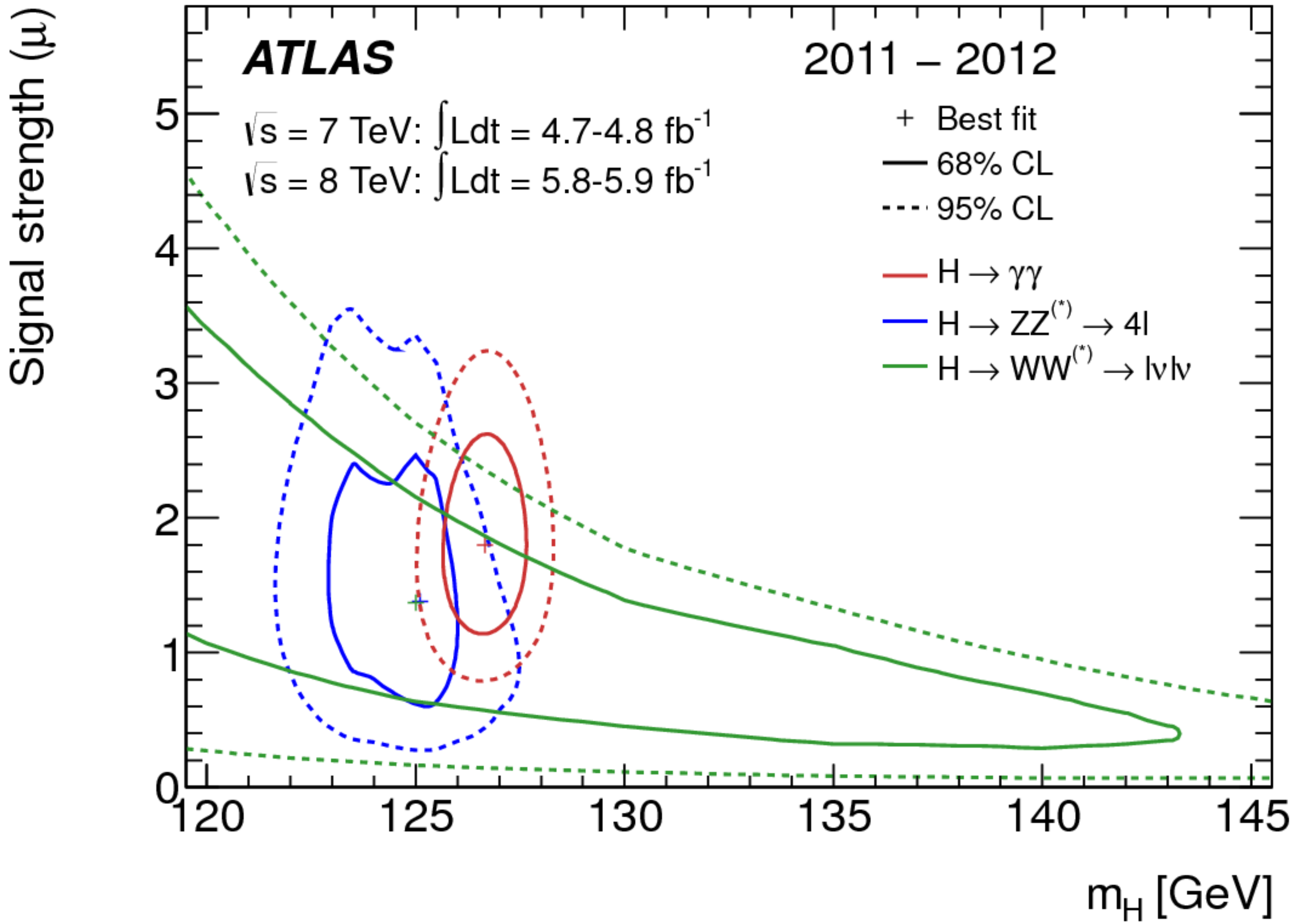


With the addition of WW a 6 sigma effect is reached





ATLAS 2011 - 2012
m_H = 126.0 GeV
W,Z H → bb
√s = 7 TeV: ∫Ldt = 4.7 fb⁻¹
H → ττ
√s = 7 TeV: ∫Ldt = 4.6-4.7 fb⁻¹
H → WW(*) → lνlν
√s = 7 TeV: ∫Ldt = 4.7 fb⁻¹
√s = 8 TeV: ∫Ldt = 5.8 fb⁻¹
H → γγ
√s = 7 TeV: ∫Ldt = 4.8 fb⁻¹
√s = 8 TeV: ∫Ldt = 5.9 fb⁻¹
H → ZZ(*) → 4l
√s = 7 TeV: ∫Ldt = 4.8 fb⁻¹
√s = 8 TeV: ∫Ldt = 5.8 fb⁻¹
Combined
√s = 7 TeV: ∫Ldt = 4.6 - 4.8 fb⁻¹
√s = 8 TeV: ∫Ldt = 5.8 - 5.9 fb⁻¹
μ = 1.4 ± 0.3
-1
0
1
Signal strength (μ)



ATLAS
2011 – 2012
√s = 7 TeV: ∫Ldt = 4.7-4.8 fb-1
√s = 8 TeV: ∫Ldt = 5.8-5.9 fb-1
+ Best fit
68% CL
95% CL
H → γγ
H → ZZ(*) → 4l
H → WW(*) → lνlν
Signal strength (μ)
0
1
2
3
4
5
120
125
130
135
140
145
mH [GeV]

**Excesses come,
excesses go.
This one stayed!
Whether it is the SM Higgs or
not the future is bright!**


My future's
so bright,
I gotta wear
shades