Search for the Standard Model Higgs Boson in the Decay Mode $H \to \gamma\gamma$ with ATLAS

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On behalf of the ATLAS Collaboration

Beyond The Standard Model of Particle Physics
Quy Nhon, Vietnam
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pre 2012 status

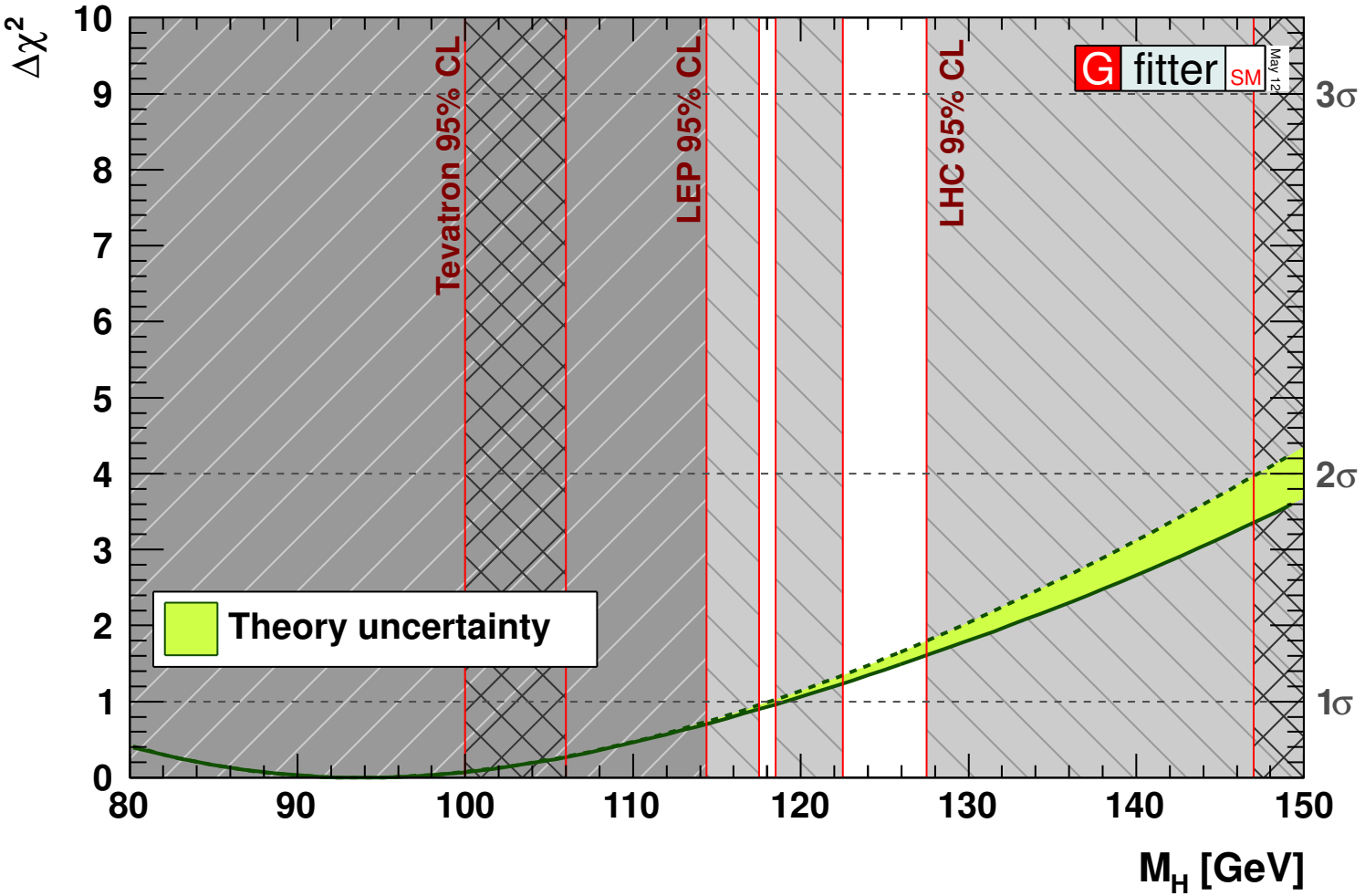
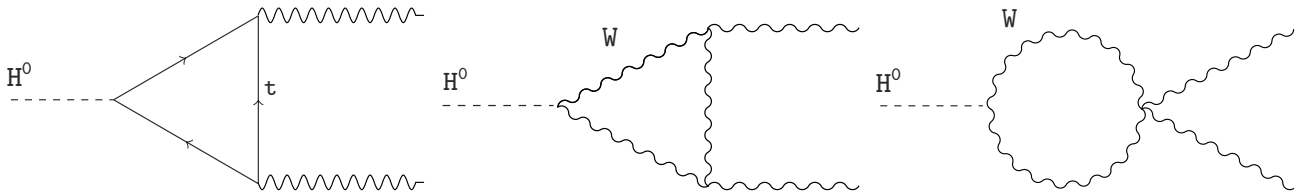
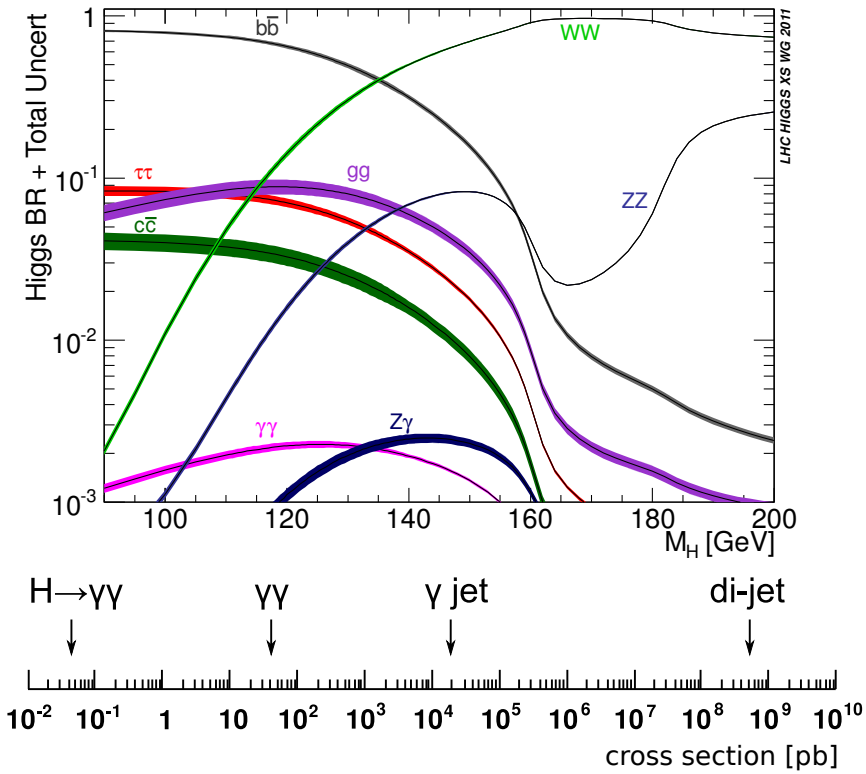


Figure: ATLAS (2011 combined) + CMS: (2010 + 2011 combined)

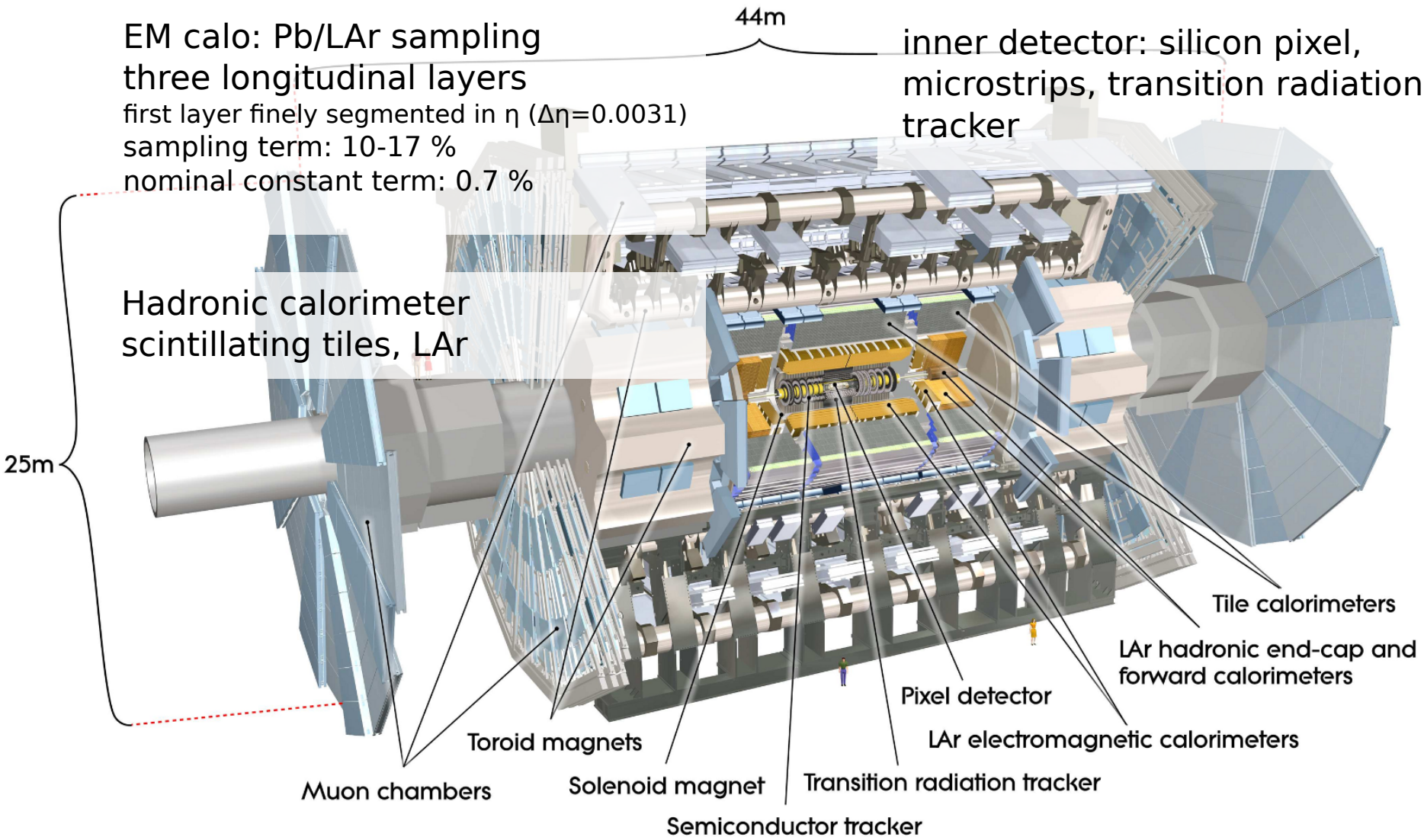
$H \to \gamma\gamma$



- small branching ratio ($\sim 10^{-3}$)
- simple signature: two energetic isolated photons
- very good mass resolution
- huge background
  - $\gamma\gamma$ from QCD (irreducible)
  - γj with one mis-identified jet as photon
  - jj with two mis-identified jets
  - Drell-Yan with electrons mis-identified as photons
- very high sensitivity in the low mass range, best one up to 125 GeV



The ATLAS detector



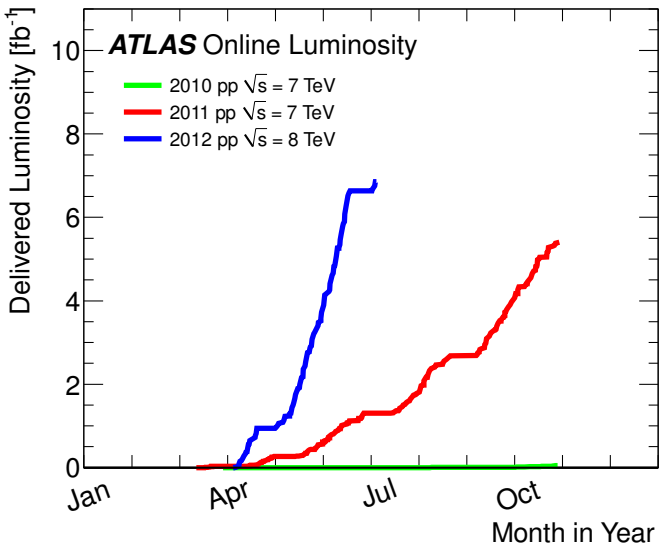
Data and selection

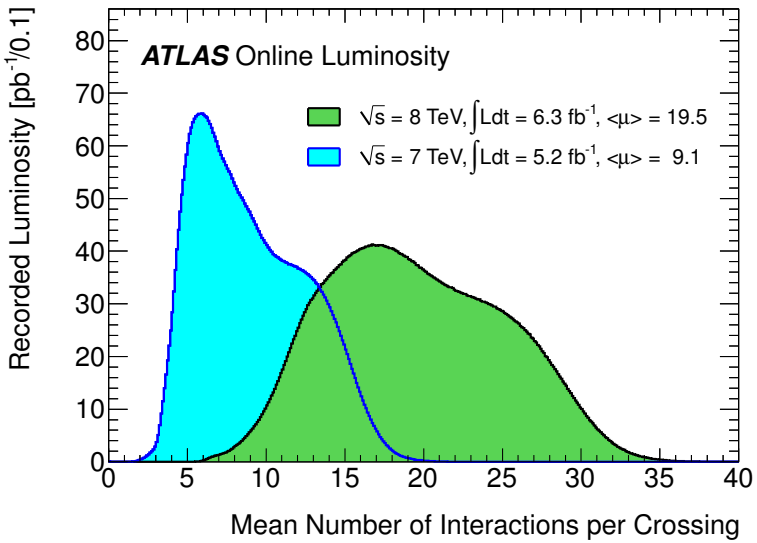
$\sqrt{s} = 7$ TeV (2011)

- $L = 4.8\,\text{fb}^{-1}$
- $\langle \#$ interaction per crossing$\rangle = 9.1$
- $p_T^{(1)} > 40$ GeV, $p_T^{(2)} > 30$ GeV
- $|\eta| < 2.37$ except $1.52 < |\eta| < 1.52$
- neural net photon identification
- calorimetric isolation
- 23 788 diphoton candidate selected in $100\,\text{GeV} < m_{\gamma\gamma} < 160\,\text{GeV}$

$\sqrt{s} = 8$ TeV (Jan-Jun 2012)

- $L = 5.9\,\text{fb}^{-1}$
- $\langle \#$ interaction per crossing$\rangle = 19.5$
- $p_T^{(1)} > 40$ GeV, $p_T^{(2)} > 30$ GeV
- $|\eta| < 2.37$ except $1.52 < |\eta| < 1.52$
- cut based photon identification
- calorimetric isolation
- 35 271 diphoton candidate selected in $100\,\text{GeV} < m_{\gamma\gamma} < 160\,\text{GeV}$



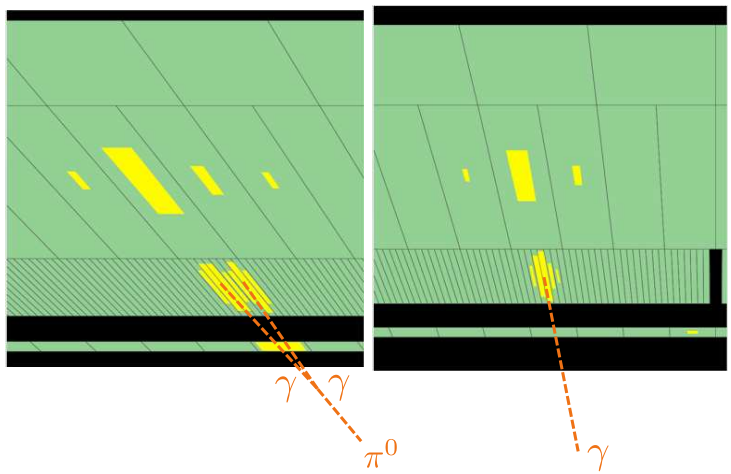


Photon reconstruction and identification

- seeded from cluster energy deposits in the electromagnetic calorimeter
- photon candidates classified as converted or unconverted looking at the matching between tracks and clusters
- MC-based calibration using as input the energy in the three longitudinal layers and the radius of conversion for converted photon
- improved with energy scale based on $Z \to ee$, $W \to e\nu$, $J/\Psi \to ee$
- tracking, vertexing and matching to cluster have been improved for 2012 to ensure that the reconstruction of converted photons is robust against pileup
- new photon reconstruction efficiency for photons is 96.5 % from Higgs MC

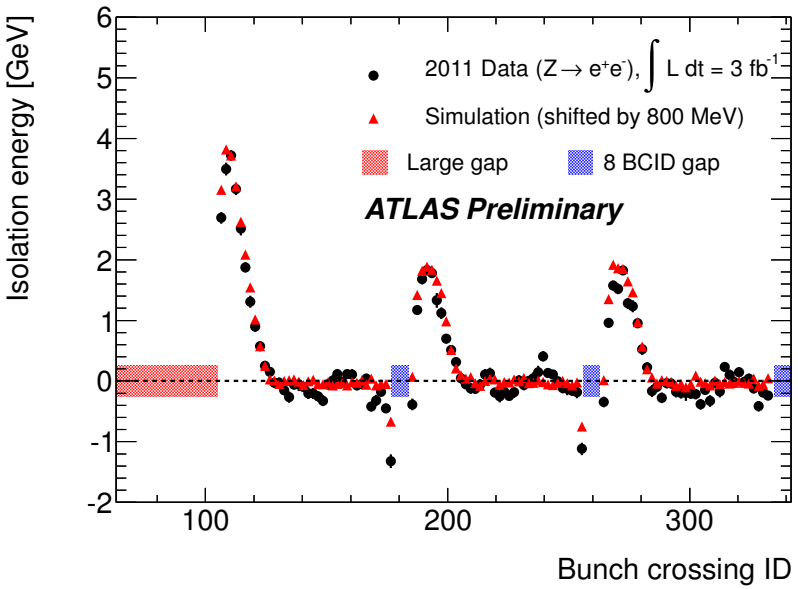
Need powerful jet-rejection

- shower shapes using the electromagnetic calorimeter
  - lateral width of the shower
  - hadronic leakage
  - secondary maxima from the finely segmented first layer
- photon efficiency 85 $\div$ 95 %

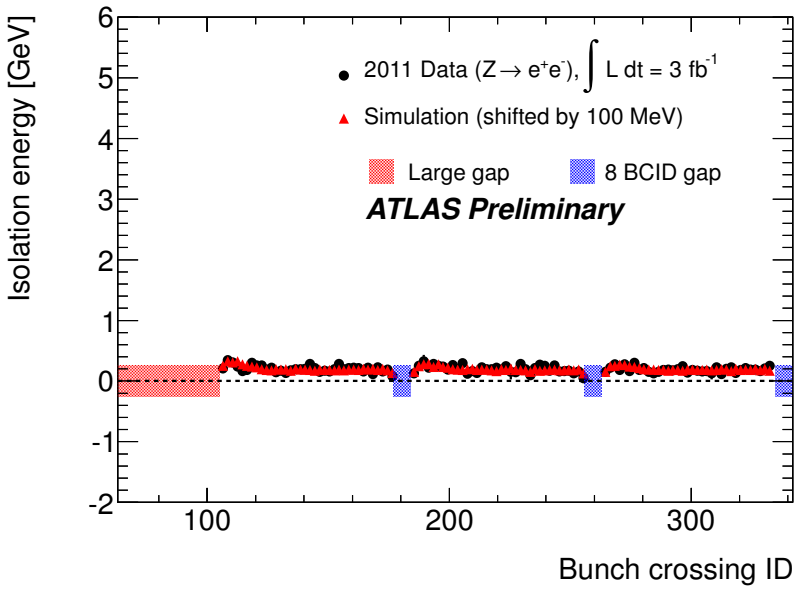


Isolation selection

- isolation $< 4\,\text{GeV}$: sum of the transverse energy of positive-energy topological clusters reconstructed in the electromagnetic and hadronic calorimeters in a cone of $\Delta R = 0.4$ around the candidate
  - corrected for photon leakage
  - corrected for ambient energy
  - agreement between MC and $Z \to ee$ and $Z \to ee\gamma$ data



previous 2011 analysis



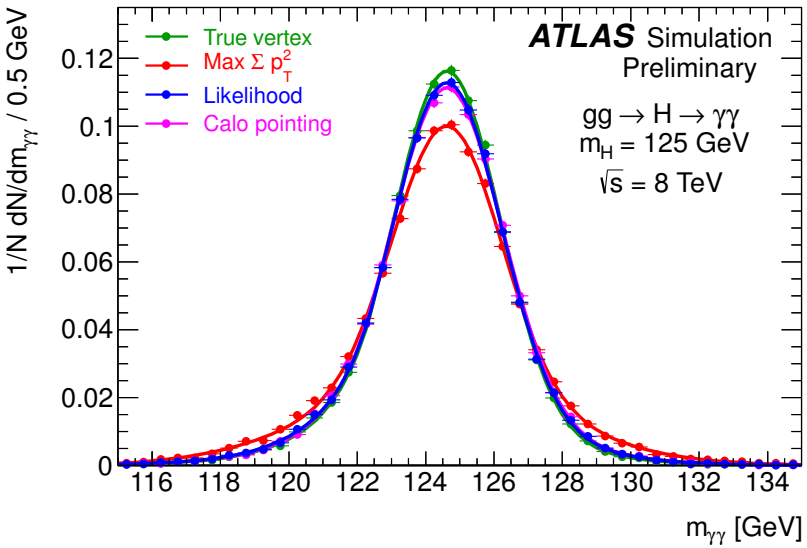
current analysis 2011+2012

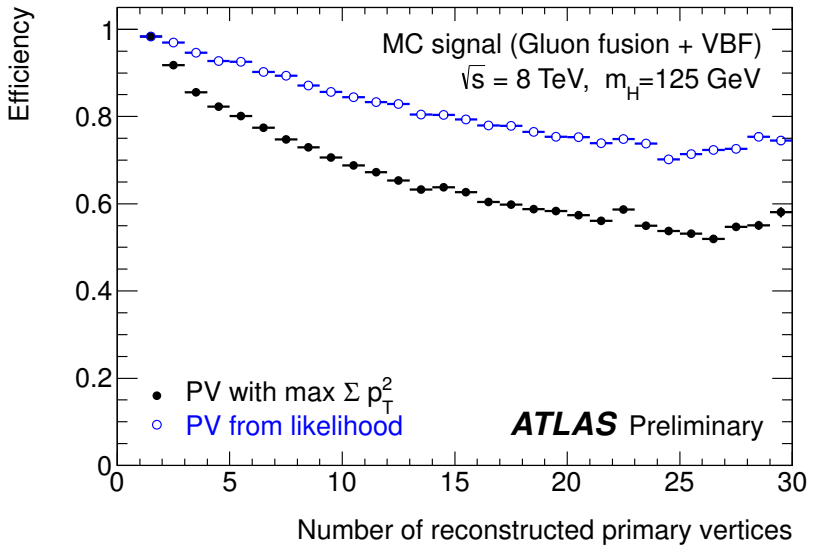
- correction has been optimized to be more stable with respect to the position of the bunch in the train (and hence in-time pileup)

Photon pointing and primary vertex selection

The selection of the primary vertex is relevant for the estimation of the invariant mass and the selection of the jets associated with the hard interaction. The primary vertex is identified using a likelihood combining:

- photon pointing from:
  - photon direction measured from calorimeter using longitudinal segmentation $\rightarrow \sigma_z \sim 15\,\text{mm}$
  - conversion vertex for converted photons (only for $\sqrt{s} = 7\,\text{TeV}$) $\rightarrow \sigma_z \sim 6\,\text{mm}$
  - constraint to LHC beam spot
- $\sum_i p_T^2$ over the tracks (needed for jet selection, main improvement in the resolution from the pointing)



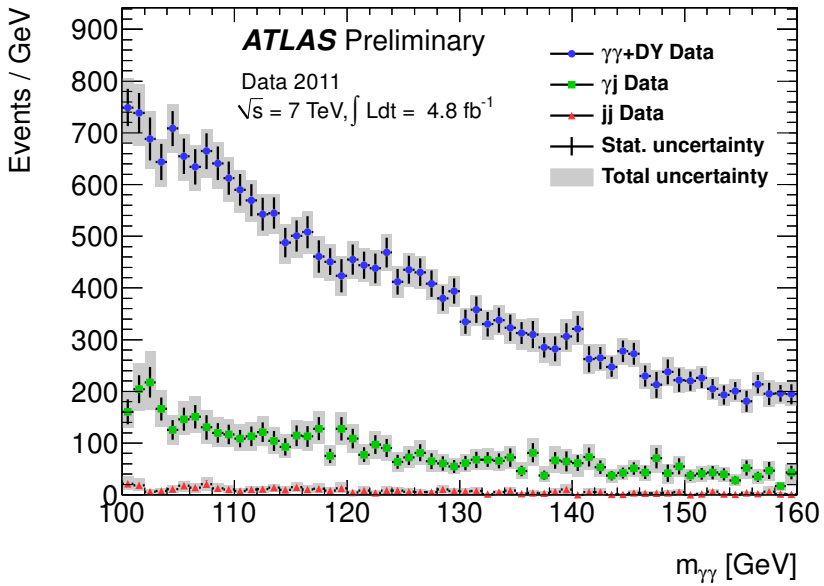


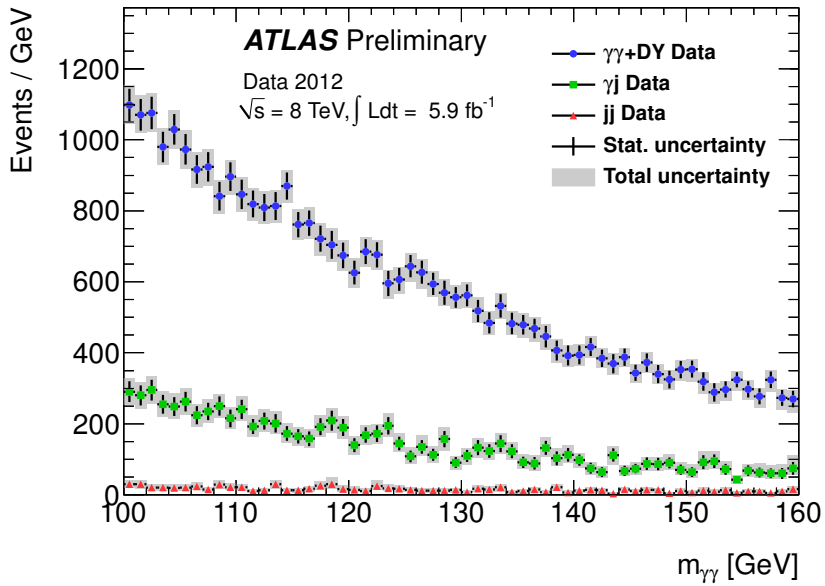
- very close to the optimal

Background decomposition

- Four methods to decompose the $\gamma\gamma$, γj, jj background
  - from control region using the isolation and shower shapes variables
- Drell-Yan background from the misidentification of electron from $Z \to ee$
  - very small in the region 100 GeV–160 GeV
  - less DY in 8 TeV because of better reconstruction of converted photons.

	$\gamma\gamma$ + DY	γj	jj	DY
$\sqrt{s} = 7$ TeV	$(80 \pm 4)\,\%$	$(19 \pm 3)\,\%$	$(1.8 \pm 0.5)\,\%$	$(1.4 \pm 0.1)\,\%$
$\sqrt{s} = 8$ TeV	$75^{+3}_{-2}\,\%$	$(22 \pm 2)\,\%$	$(2.6 \pm 0.5)\,\%$	$(0.76 \pm 0.07)\,\%$



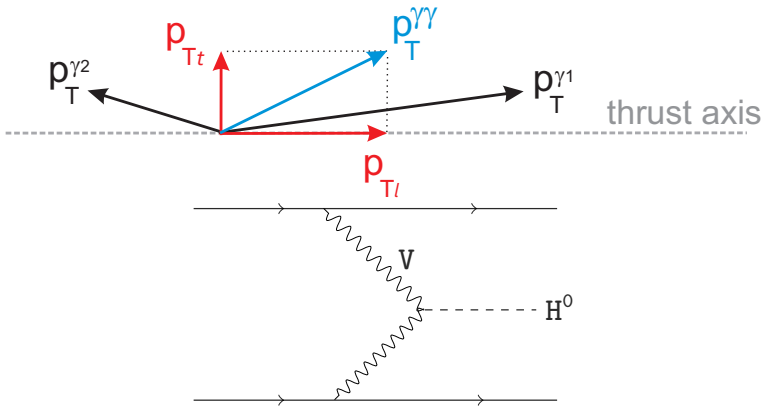


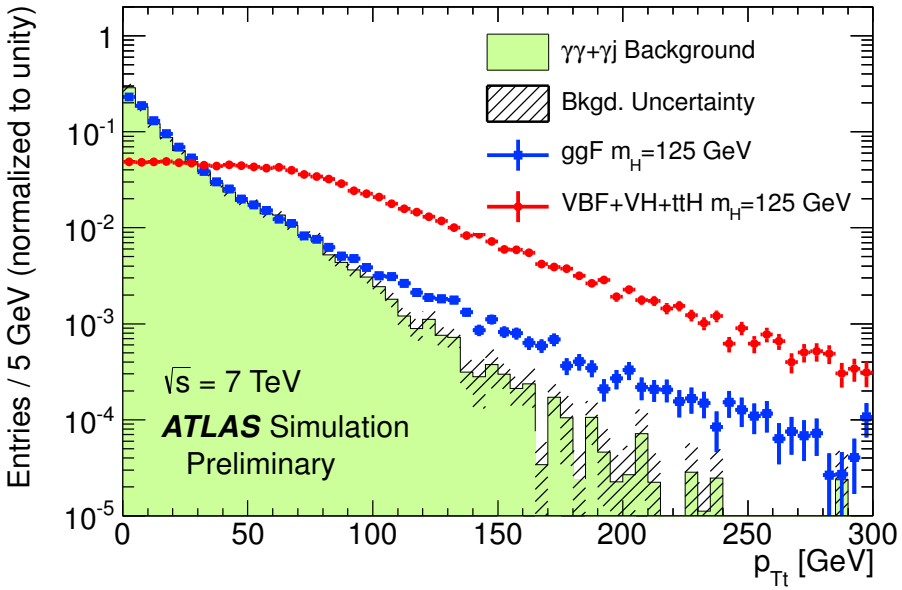
- good understanding of the background.
- the decomposition is not used in the analysis

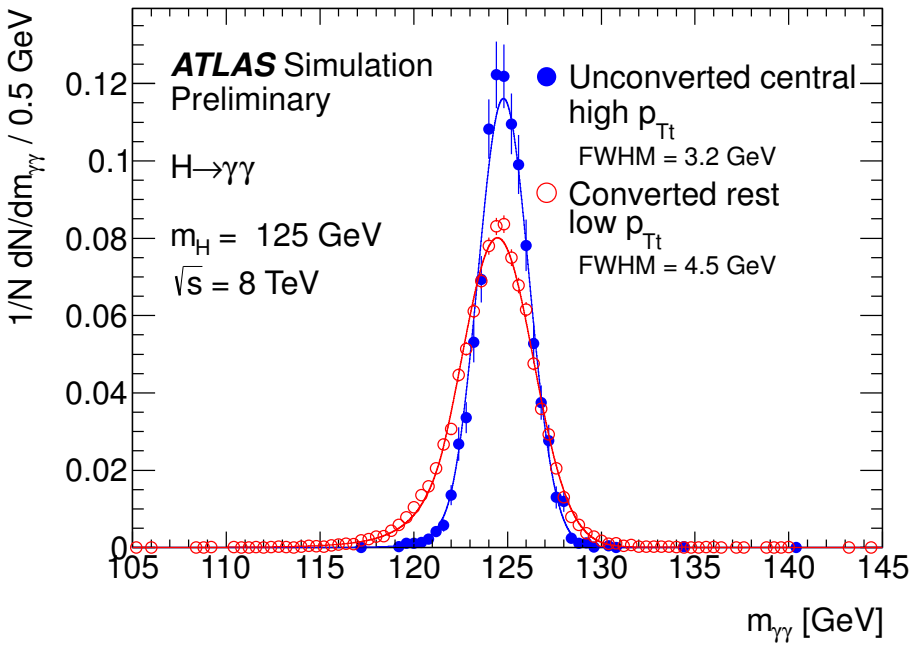
Categories

To increase sensitivity 10 categories are introduced:

- categories using the conversion status $\otimes$ $|\eta|$
- $\otimes$ $p_{Tt} \gtrless 60\,\text{GeV}$ (strongly correlated with the diphoton transverse momentum, but it has a better detector resolution)
- $\oplus$ 2 jets category requiring 2 energetic and well separated hadronic jets







Signal model

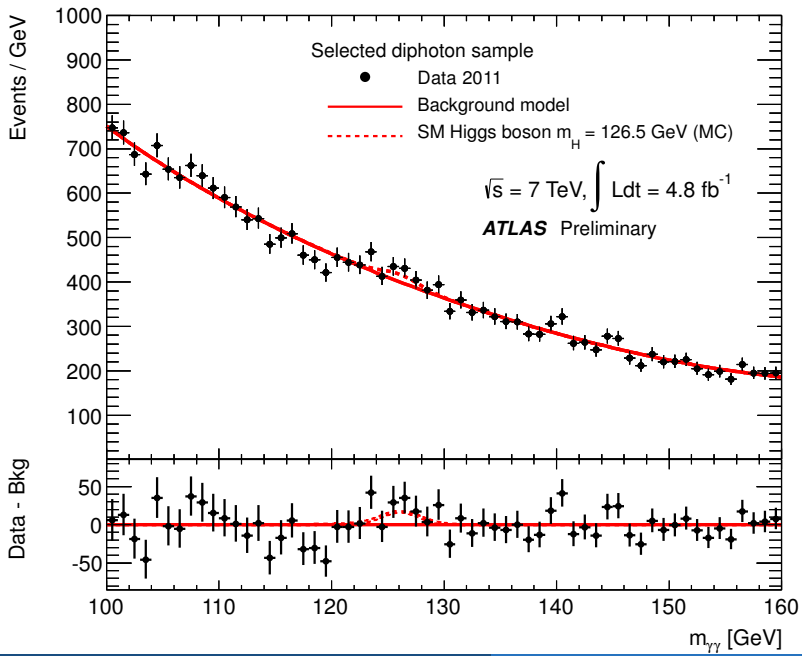
- from POWHEG interfaced to PYTHIA6(8) for $\sqrt{s} = 7(8)$ TeV for gluon fusion and VBF. PYTHIA6(8) for associated production with Z/W and $t\bar{t}$ for $\sqrt{s} = 7(8)$ TeV
- invariant mass modeled as the sum of Crystall Ball and a small wide Gaussian

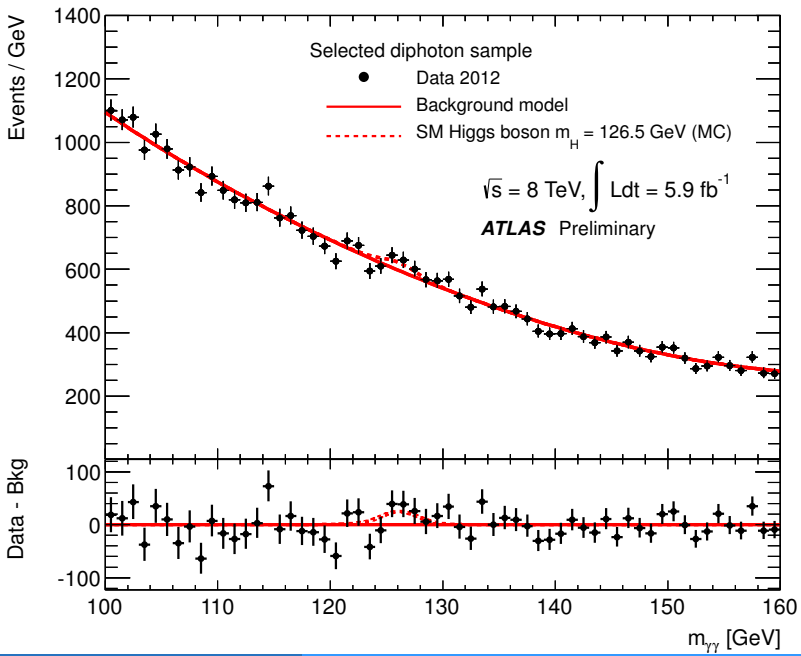
Systematic uncertainties	$\sqrt{s} = 7$ TeV [%]	$\sqrt{s} = 8$ TeV [%]
Signal event yield		
Photon identification	± 8.4	± 10.8
Effect of pileup on photon rec/ID	± 4	
Trigger	± 1	
Higgs boson cross section	depends on the process, $\sim 10\%$ (25% for VBF)	
Higgs boson branching ratio	± 5	
Higgs boson pt modeling	low p_{Tt}: ± 1.1, high p_{Tt}: ∓ 12.5, 2-jets: ∓ 9	
Underlying Event (2-jets)	VBF: ± 6, Others: ± 30	
Luminosity	± 1.8	± 3.6
Signal mass resolution		
Calorimeter energy resolution	± 12	
Photon energy scale	± 6	
Effect of pileup on energy resolution	± 4	
Signal mass position		
Photon energy scale	± 0.6	

Background model

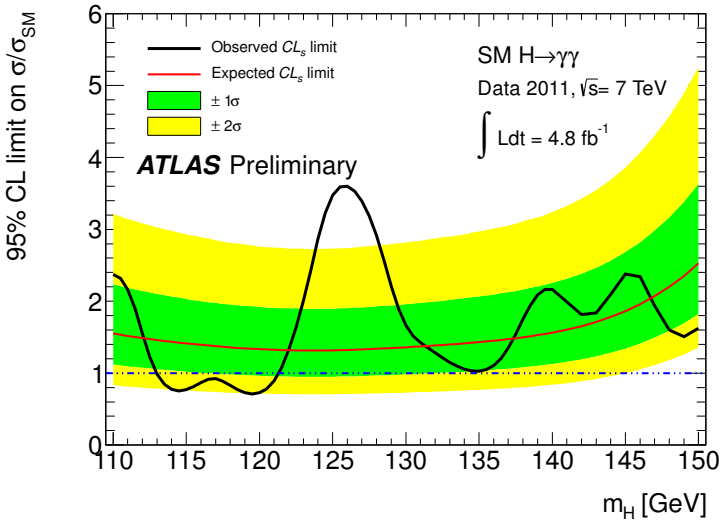
Background obtained from fits to the observed diphoton invariant mass distribution:

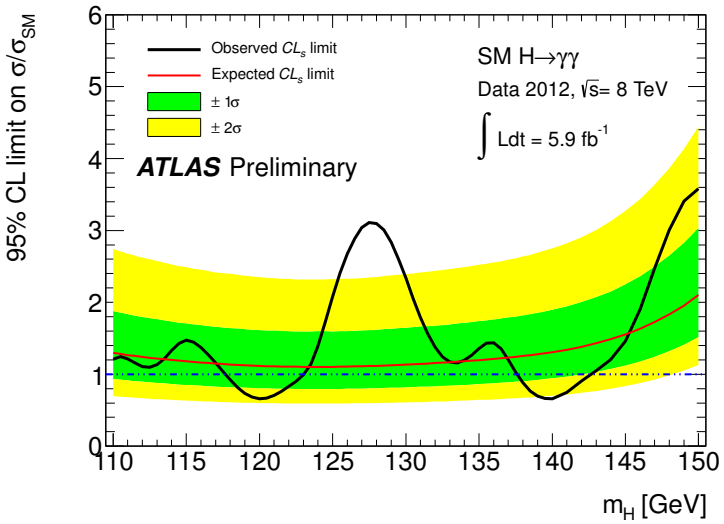
- different functions for different categories (exponential, fourth-order Bernstein polynomial, 4th order polynomial, exponential function of a second-order polynomial)
- parametrization chosen to limit potential bias while keeping good statistical power
- uncertainty estimated with high-statistics samples Sherpa, Diphox and Resbos ($\gamma\gamma$), Sherpa (γj), Pythia (jj)
- uncertainty express in term of spurious signal. The categories mainly affected by background parametrization bias are the high-statistics categories, which also have a lower signal to background ratio, for example inclusive gives ~ 11 events uncertainty on the spurious signal for $\sqrt{s} = 8\,\text{TeV}$ ($\sim 110\ H \to \gamma\gamma$ expected) at 126.5 GeV





Results


95% CL limit on σ/σSM
Observed CLs limit
Expected CLs limit
± 1σ
± 2σ
SM H→γγ
Data 2011, √s= 7 TeV
∫ Ldt = 4.8 fb-1
ATLAS Preliminary
mH [GeV]


95% CL limit on σ/σSM
Observed CLs limit
Expected CLs limit
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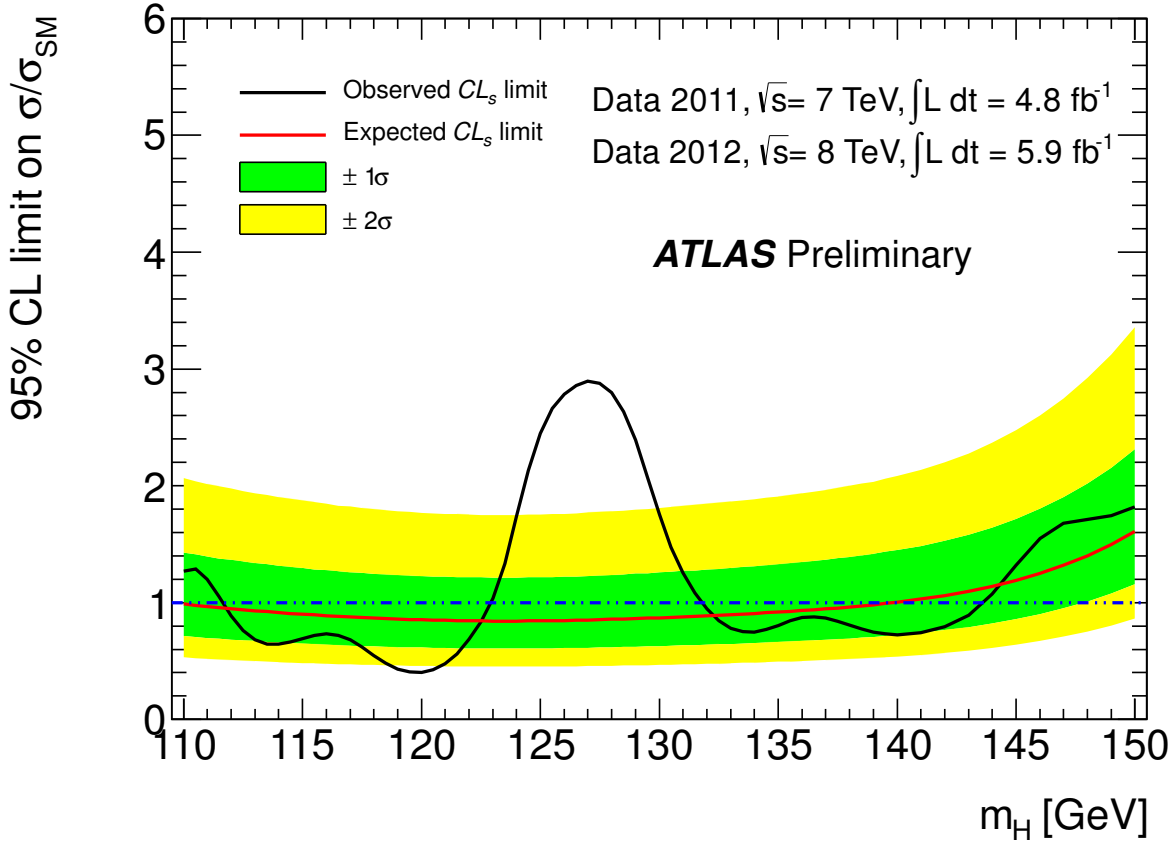
SM H→γγ
Data 2012, √s= 8 TeV
∫ Ldt = 5.9 fb-1
ATLAS Preliminary
mH [GeV]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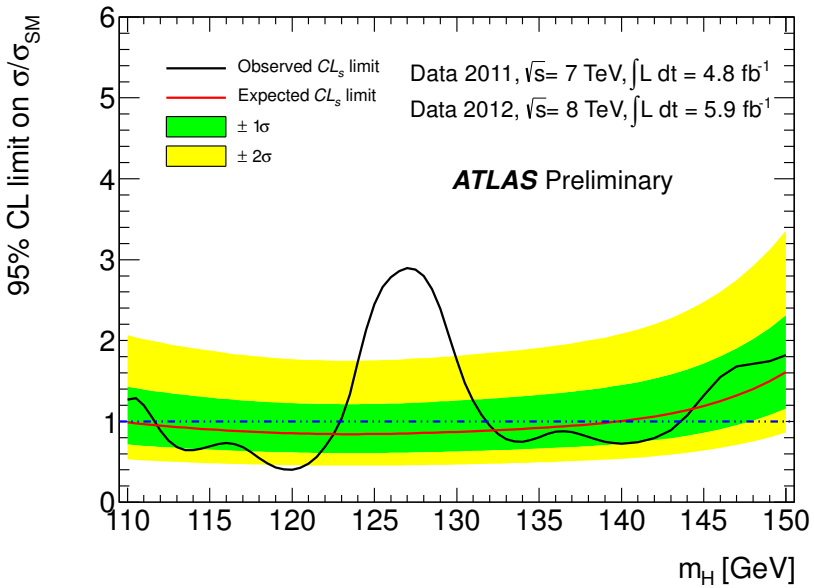
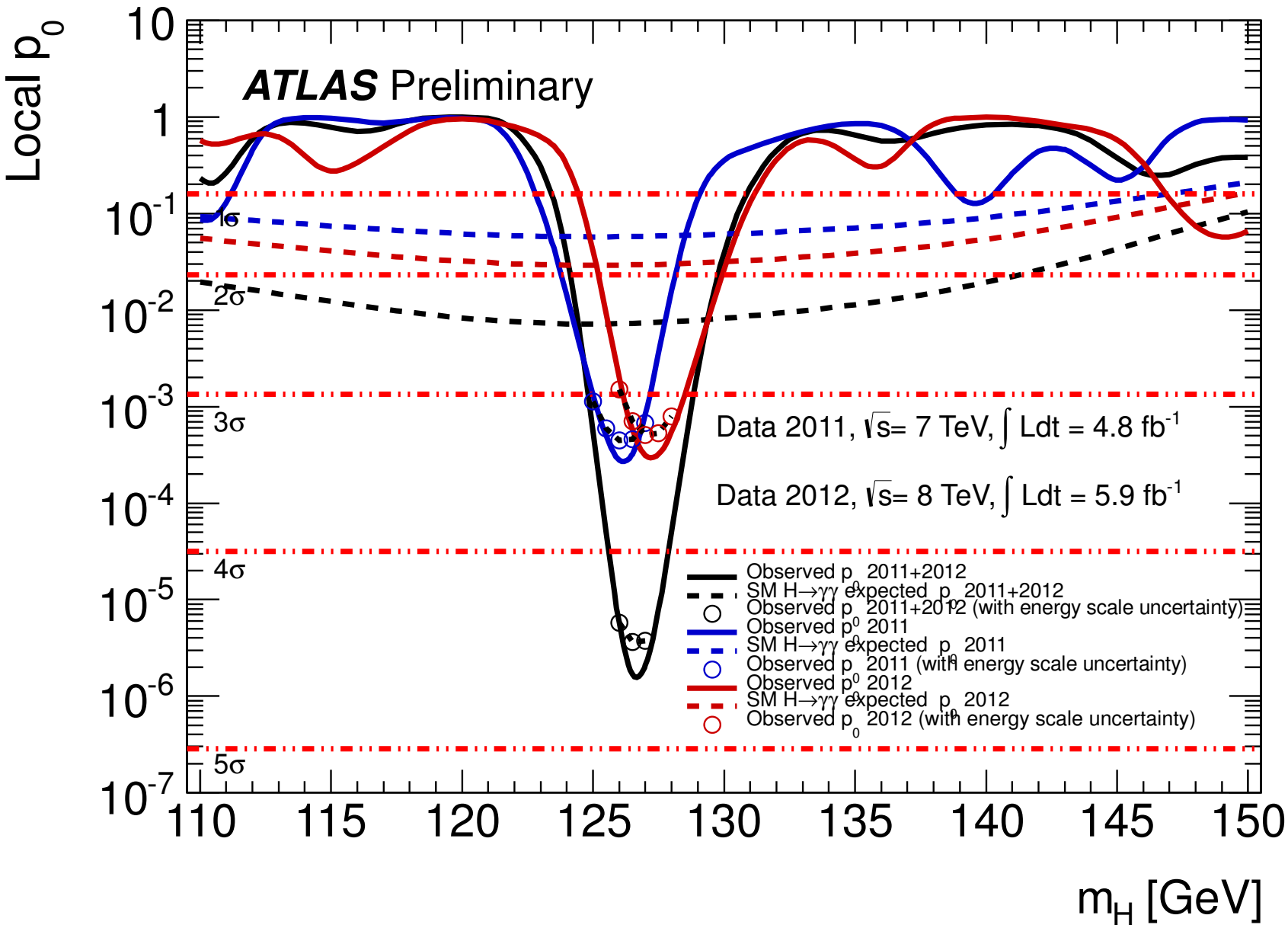
Data 2012, √s= 8 TeV, ∫L dt = 5.9 fb-1
ATLAS Preliminary
mH [GeV]

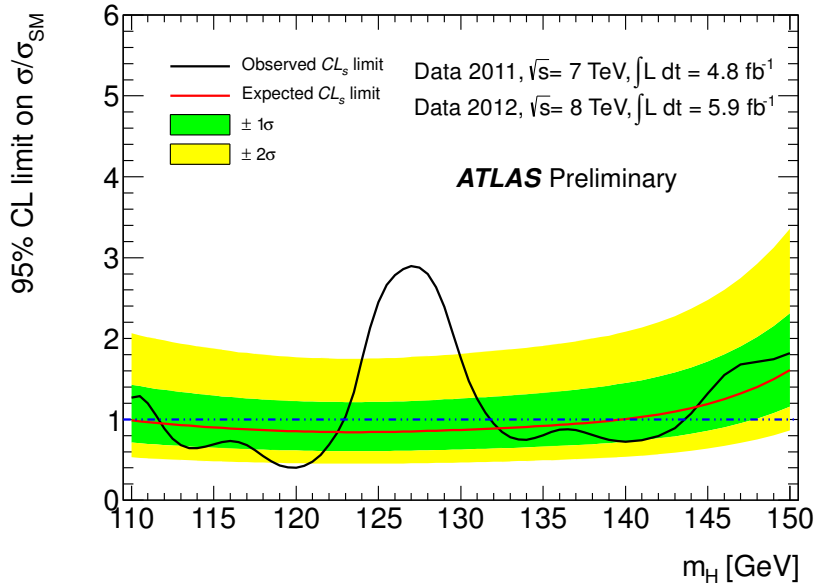
Results

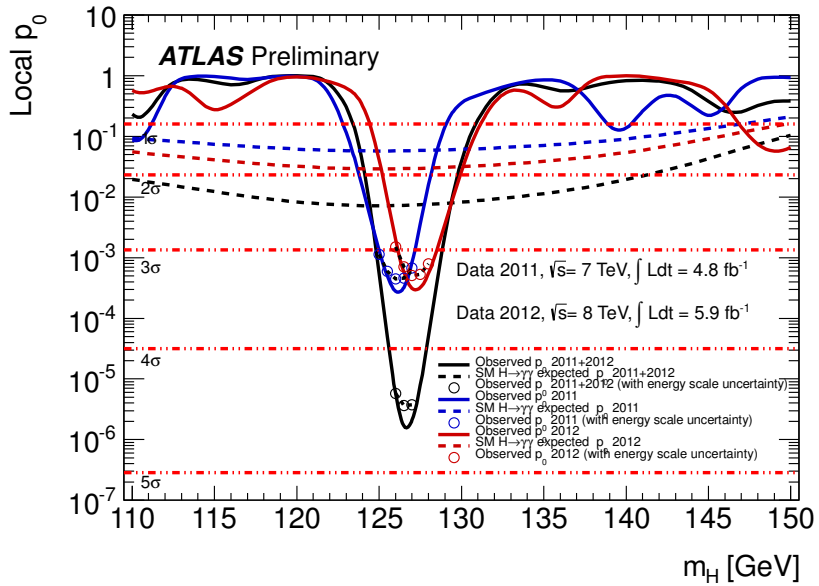


- combined exclusion region at 95% CL: 112 GeV to 122.5 GeV and 132 GeV to 143 GeV


ATLAS Preliminary
Local p0
10
1
10-1
10-2
10-3
10-4
10-5
10-6
10-7
1σ
2σ
3σ
4σ
5σ
Data 2011, √s= 7 TeV, ∫ Ldt = 4.8 fb-1
Data 2012, √s= 8 TeV, ∫ Ldt = 5.9 fb-1
Observed p0 2011+2012
SM H→γγ expected p0 2011+2012
Observed p0 2011+2012 (with energy scale uncertainty)
Observed p0 2011
SM H→γγ expected p0 2011
Observed p0 2011 (with energy scale uncertainty)
Observed p0 2012
SM H→γγ expected p0 2012
Observed p0 2012 (with energy scale uncertainty)
110
115
120
125
130
135
140
145
150
mH [GeV]

Results





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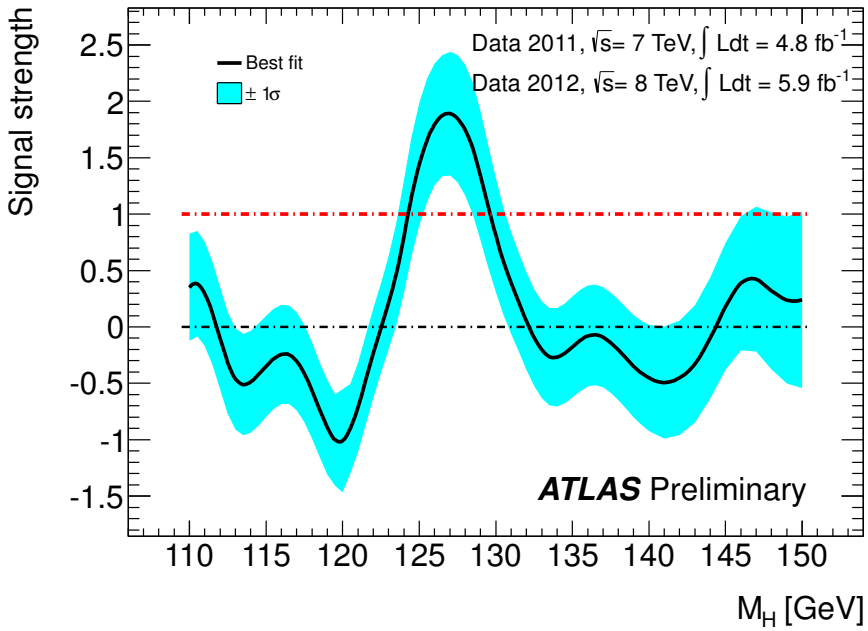
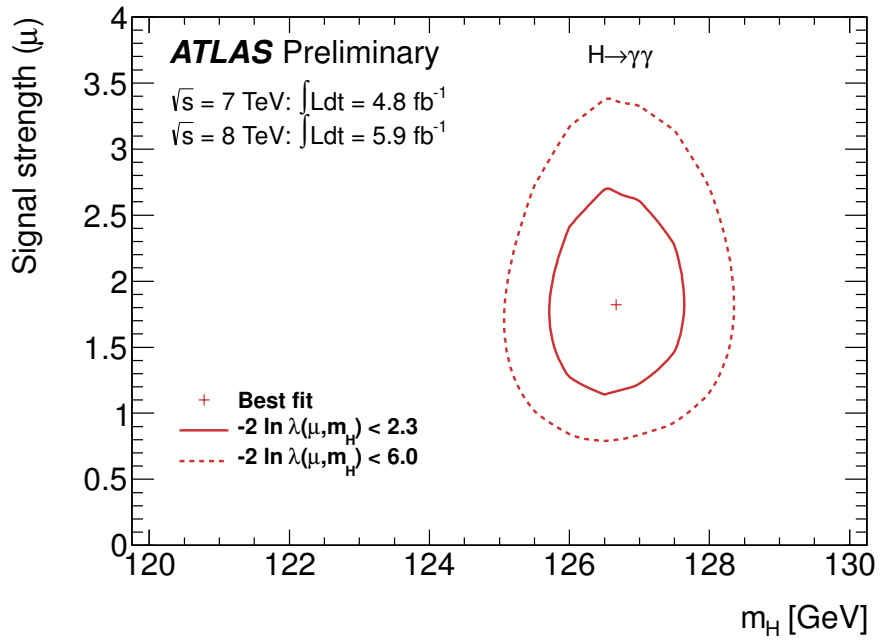
dataset	m_H max deviation	local obs (exp) significance	global significance
$\sqrt{s} = 7$ TeV	126 GeV	3.5 (1.6)	2.2
$\sqrt{s} = 8$ TeV	127 GeV	3.4 (1.9)	2.2
combined	126.5 GeV	4.5 (2.4)	3.6

- toy MC with energy scale systematics
- as cross check an analysis without categories gives a local observed significance of 3.5σ
- 15% improvement on the expected sensitivity with respect to the previous analysis

Results
best μ, best m_H

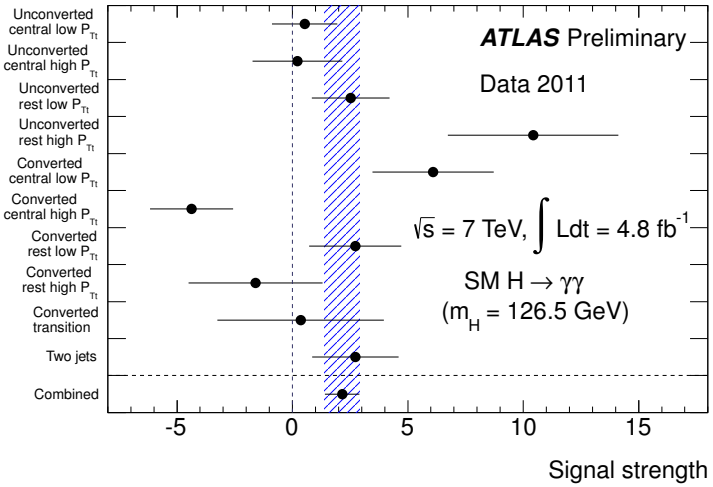


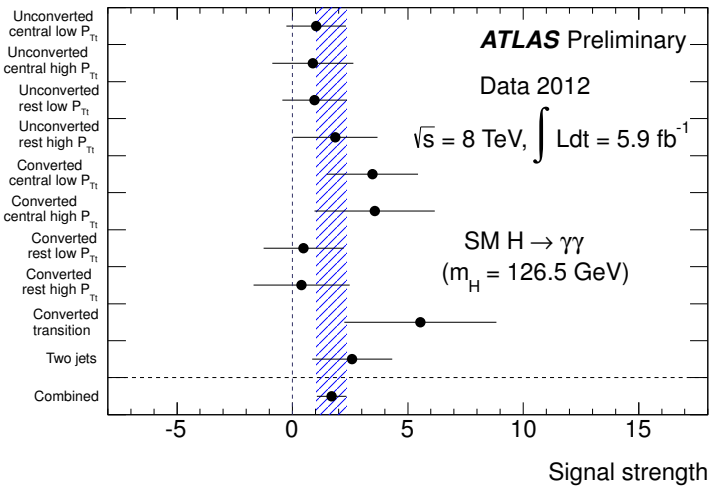
$\hat{\mu} = \hat{\sigma}/\sigma_{SM} = 1.9 \pm 0.5$ at $m_H = 126.5$ GeV

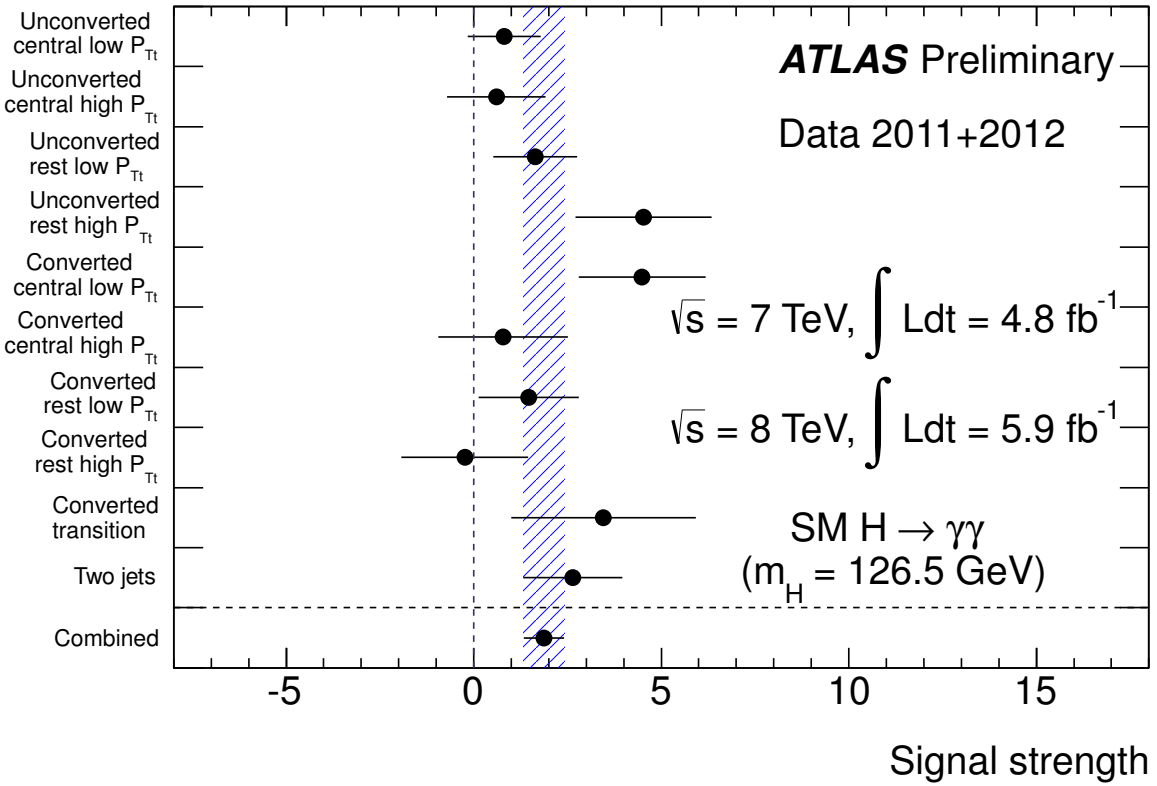


$(\hat{\mu}, \hat{m_H})$ contours from a bidimensional likelihood

Results
$\hat{\mu}$ for the all the categories







- consistent results from different categories

Conclusions

- combining $4.8\,\text{fb}^{-1}$ at $\sqrt{s} = 7\,\text{TeV}$ and $5.9\,\text{fb}^{-1}$ at $\sqrt{s} = 8\,\text{TeV}$
- the observed exclusion ranges for a SM Higgs boson are 112 GeV to 122.5 GeV and 132 GeV to 143 GeV at 95% CL.
- an excess over the expected background is observed around 126.5 GeV and corresponds to a local significance of 4.5σ.
- compatible excess between $\sqrt{s} = 7\,\text{TeV}$ and $\sqrt{s} = 8\,\text{TeV}$ datasets
- signal strength with respect to SM: 1.9 ± 0.5

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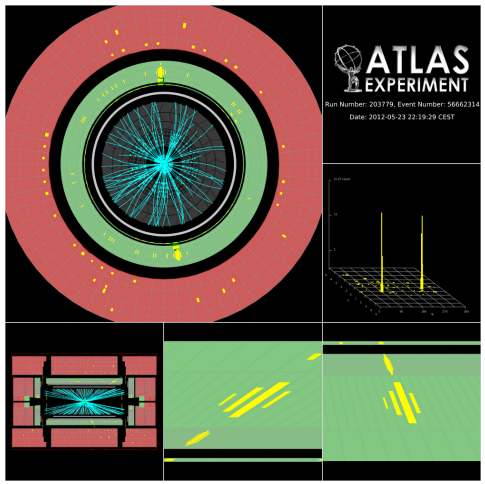
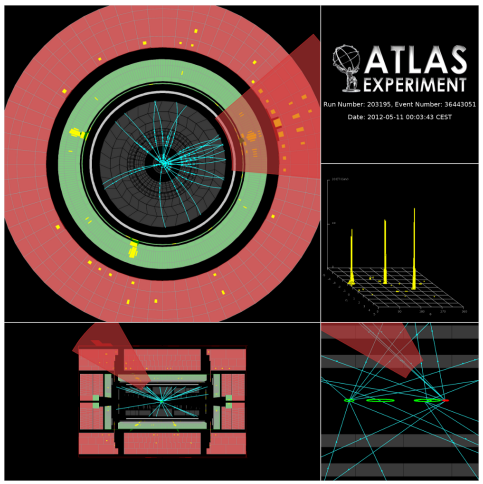
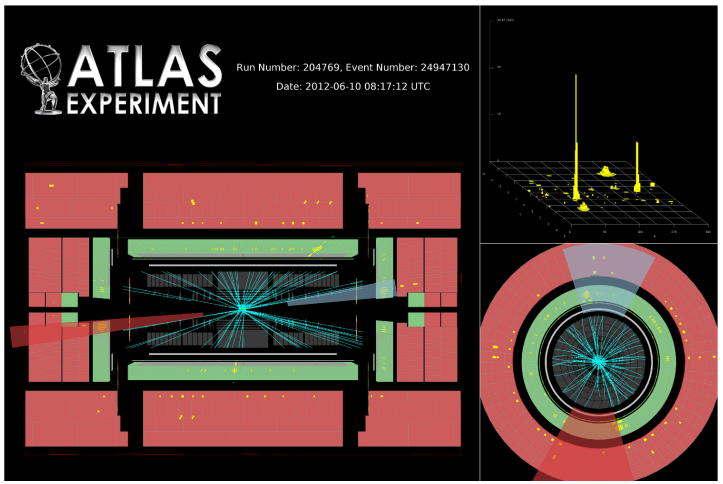
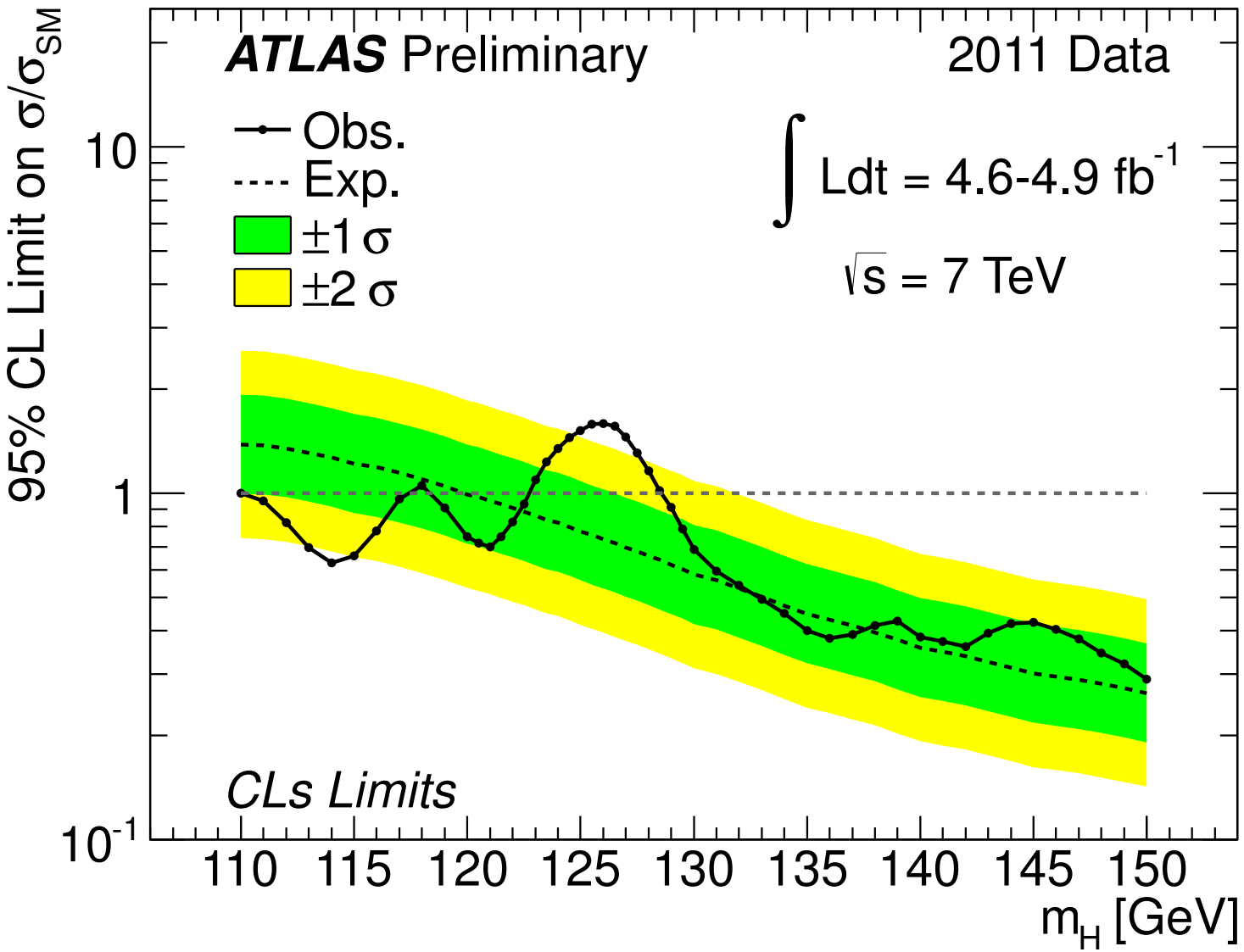
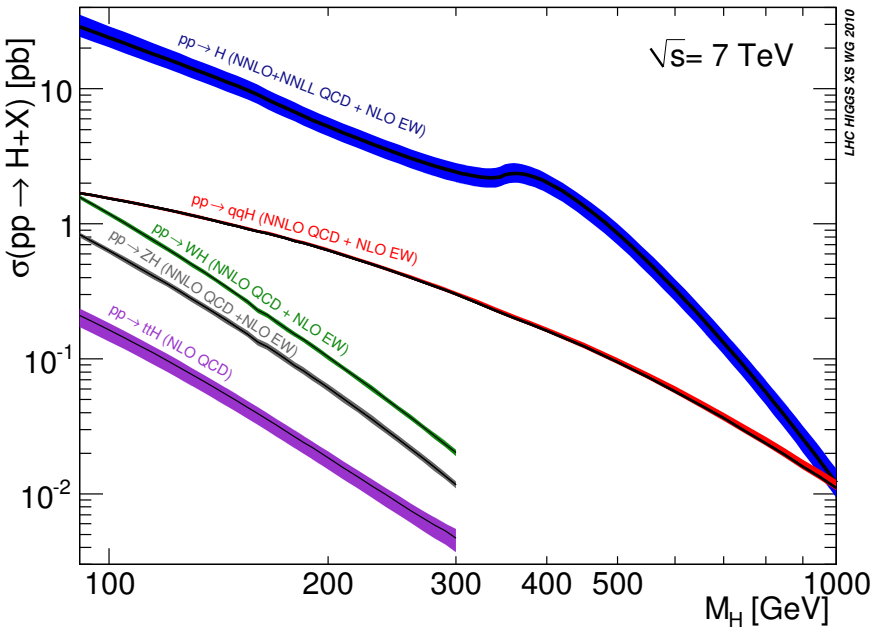


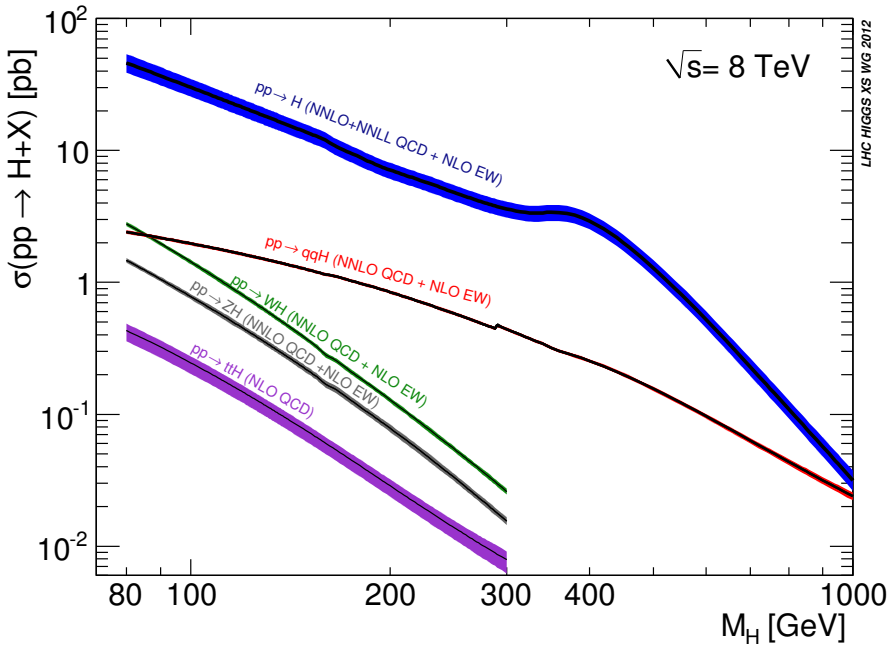




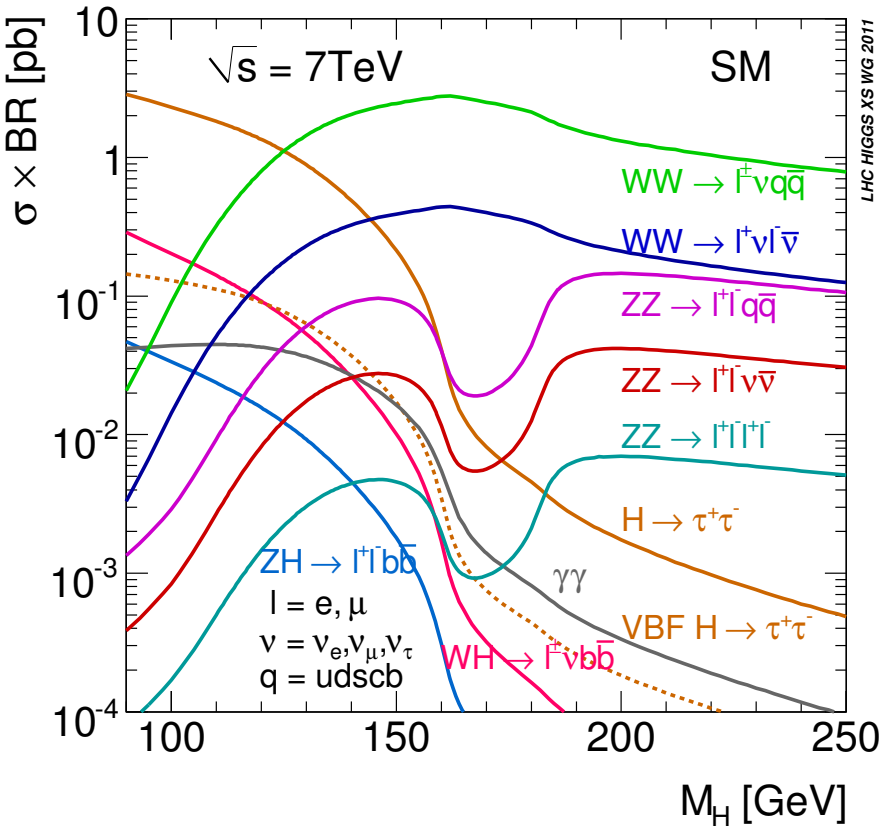
"Observation of an excess of events in the search for the Standard Model Higgs boson in the gamma-gamma channel with the ATLAS detector", ATLAS-CONF-2012-091

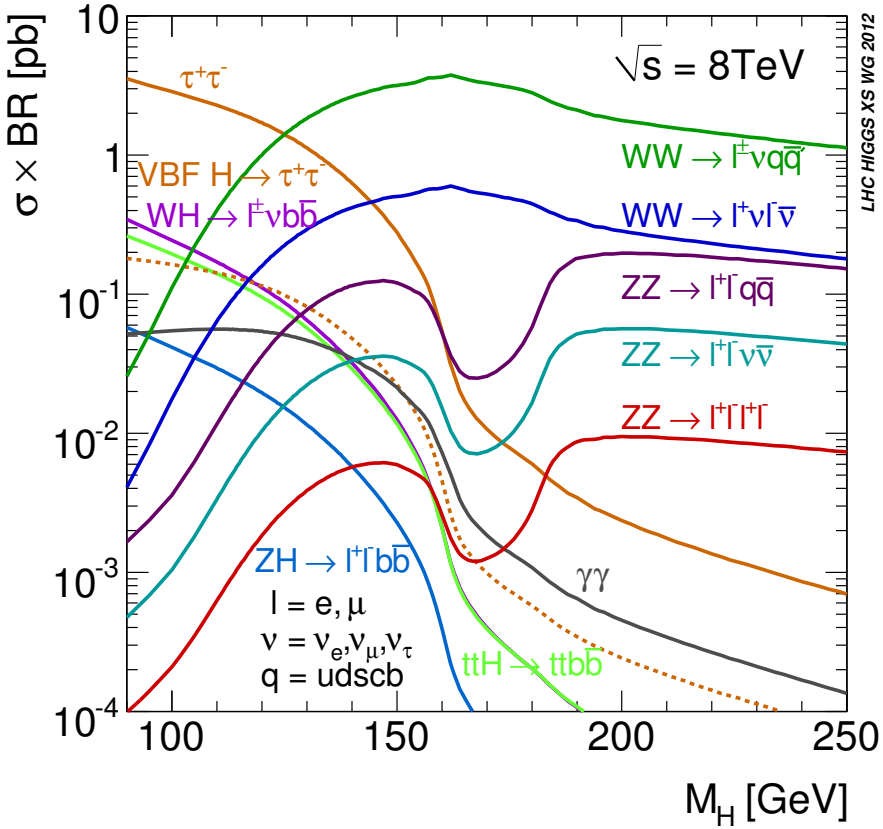

ATLAS Preliminary
2011 Data
Obs.
Exp.
±1 σ
±2 σ
∫ Ldt = 4.6-4.9 fb-1
√s = 7 TeV
95% CL Limit on σ/σSM
10
1
10-1
CLs Limits
110 115 120 125 130 135 140 145 150
mH [GeV]


√s= 7 TeV
LHC HIGGS XS WG 2010
pp → H (NNLO+NNLL QCD + NLO EW)
pp → qqH (NNLO QCD + NLO EW)
pp → WH (NNLO QCD + NLO EW)
pp → ZH (NNLO QCD +NLO EW)
pp → ttH (NLO QCD)
σ(pp → H+X) [pb]
M_H [GeV]

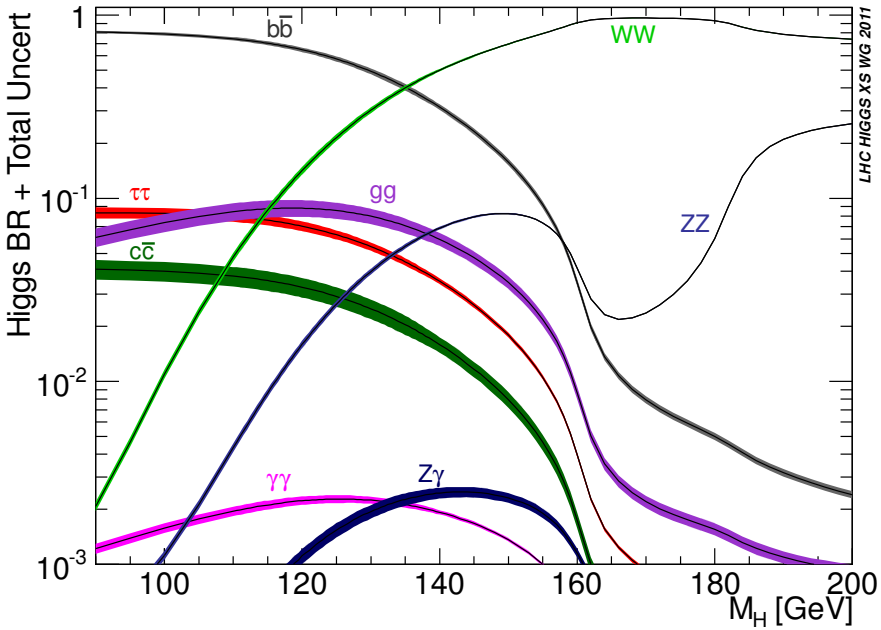

√s= 8 TeV
LHC HIGGS XS WG 2012
pp → H (NNLO+NNLL QCD + NLO EW)
pp → qqH (NNLO QCD + NLO EW)
pp → WH (NNLO QCD + NLO EW)
pp → ZH (NNLO QCD +NLO EW)
pp → ttH (NLO QCD)
σ(pp → H+X) [pb]
M_H [GeV]

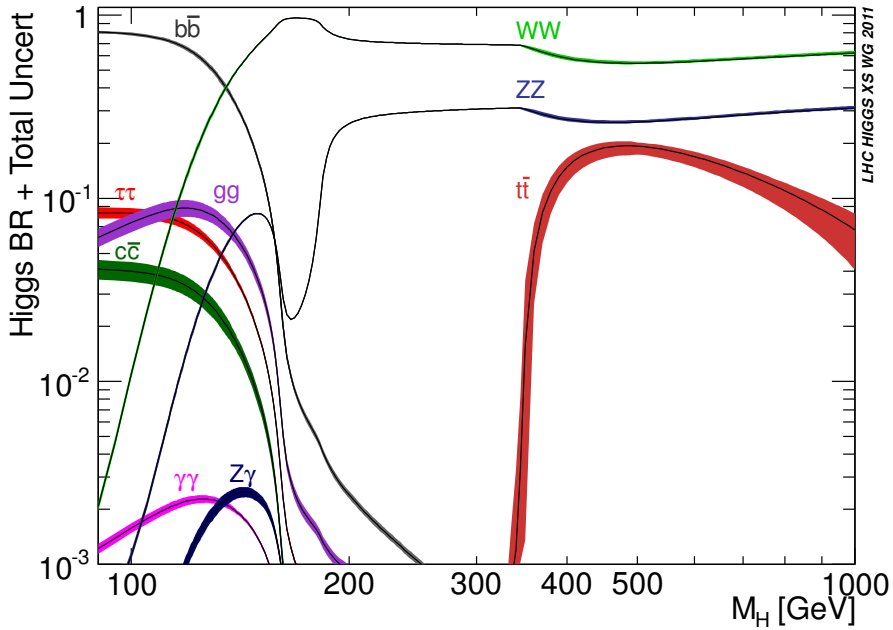
$\sigma \times Br$



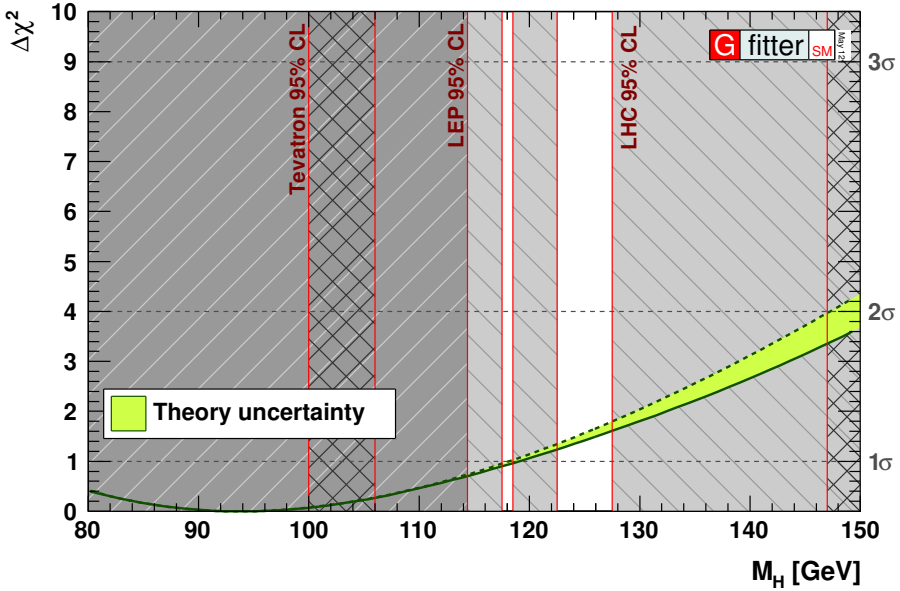


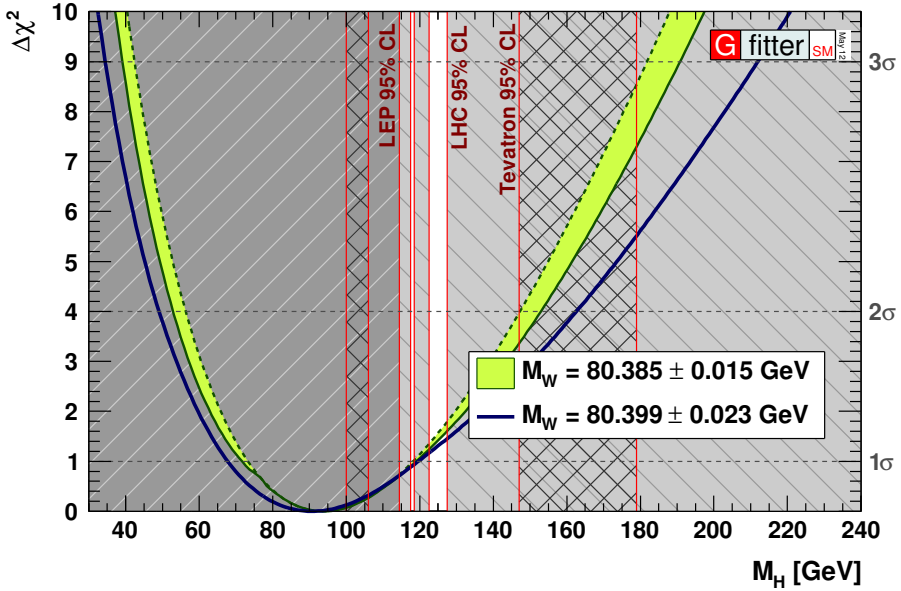
Br


Higgs BR + Total Uncert
1
10^{-1}
10^{-2}
10^{-3}
$b\bar{b}$
WW
ZZ
$\tau\tau$
gg
$c\bar{c}$
$\gamma\gamma$
$Z\gamma$
100
120
140
160
180
200
M_H [GeV]
LHC HIGGS XS WG 2011

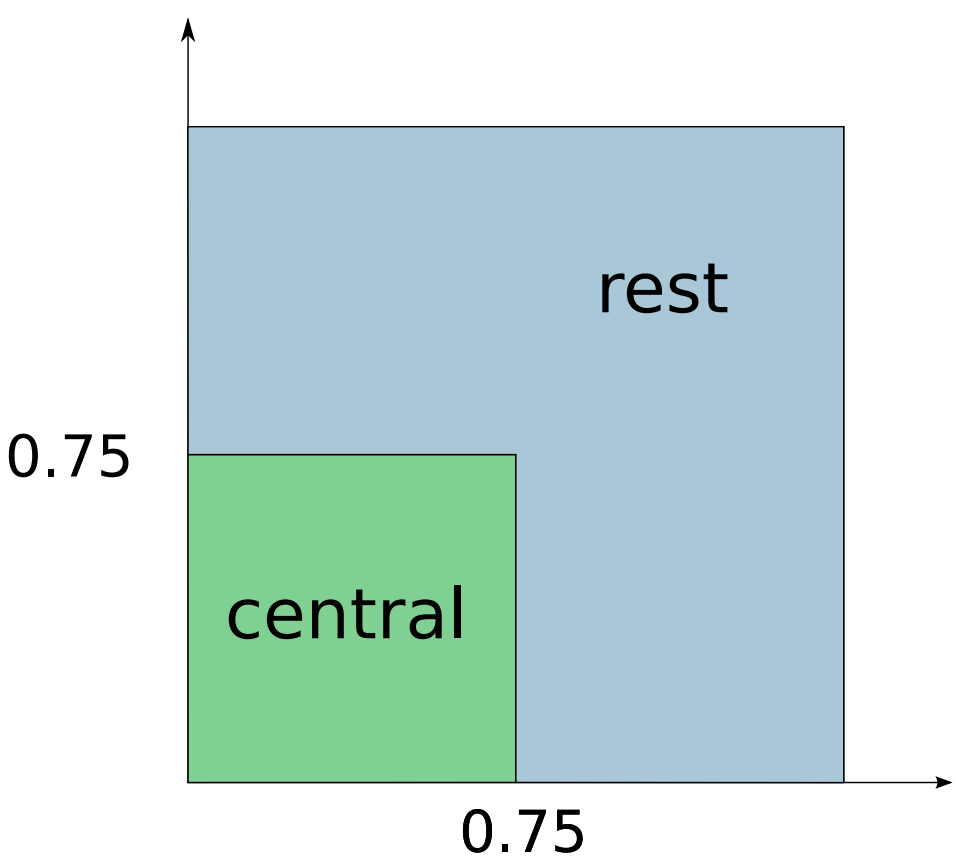

Higgs BR + Total Uncert
1
10^{-1}
10^{-2}
10^{-3}
$b\bar{b}$
WW
ZZ
$\tau\tau$
gg
$t\bar{t}$
$c\bar{c}$
$\gamma\gamma$
$Z\gamma$
100
200
300
400
500
1000
M_H [GeV]
LHC HIGGS XS WG 2011

EW fit

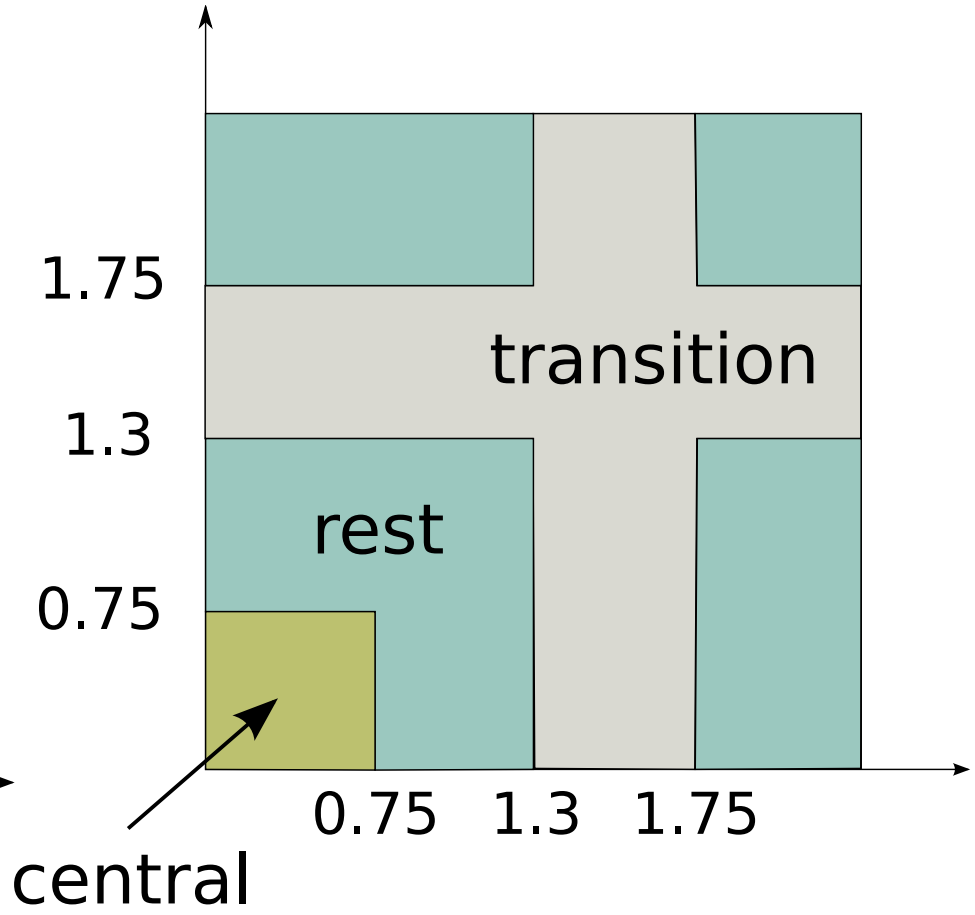

$\Delta\chi^2$
Tevatron 95% CL
LEP 95% CL
LHC 95% CL
G fitter SM
May 12
3σ
2σ
1σ
Theory uncertainty
M_H [GeV]


$\Delta\chi^2$
LEP 95% CL
LHC 95% CL
Tevatron 95% CL
G fitter SM
May 12
3σ
2σ
1σ
M_W = 80.385 ± 0.015 GeV
M_W = 80.399 ± 0.023 GeV
M_H [GeV]

non-VBF categories



unconverted



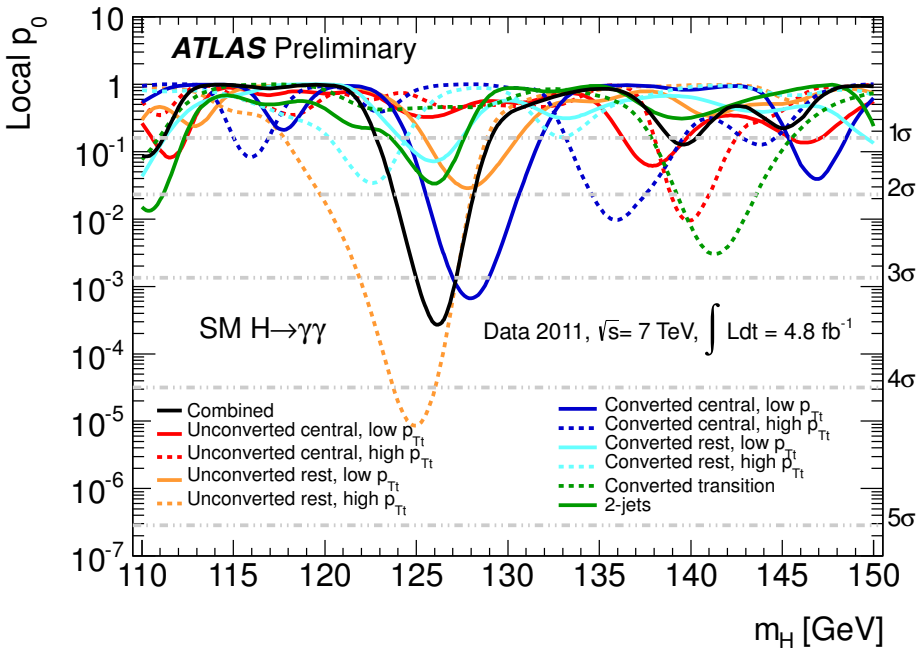
converted

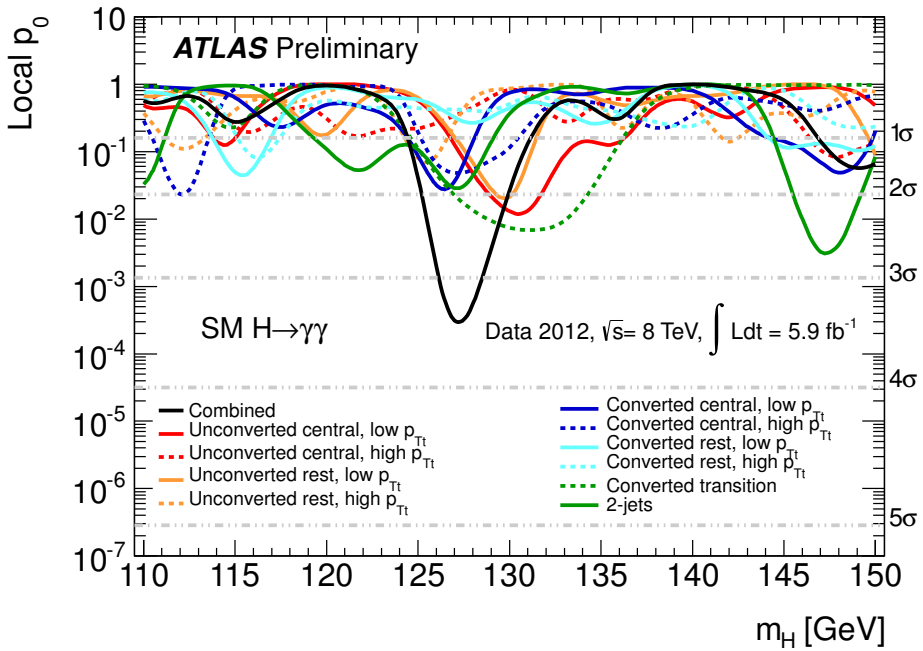
VBF category

High S/B category, requiring two hadronic jets:

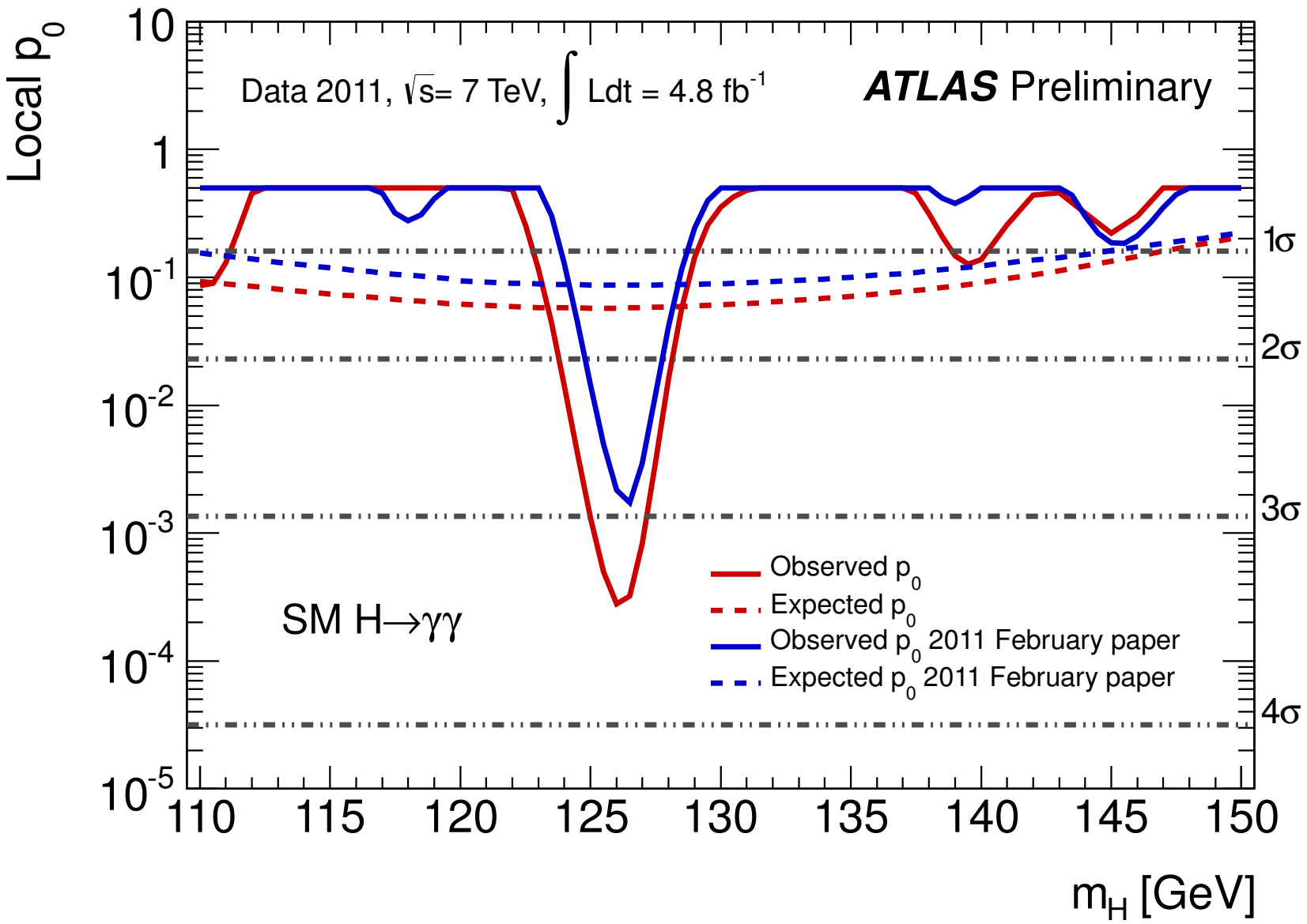
- $|\eta_j| < 4.5$
- $|JVF| > 0.5$
- $p_T > 25\,\text{GeV}$ (and $p_T > 30\,\text{GeV}$ for $|\eta| > 2.5$ for $\sqrt{s} = 8\,\text{TeV}$)
- $\Delta\eta_{jj} > 2.8$
- $M_{jj} > 400\,\text{GeV}$
- $\Delta R_{\gamma j} > 0.4$
- $\Delta\Phi_{jj-\gamma\gamma} > 2.6$

Categories comparison

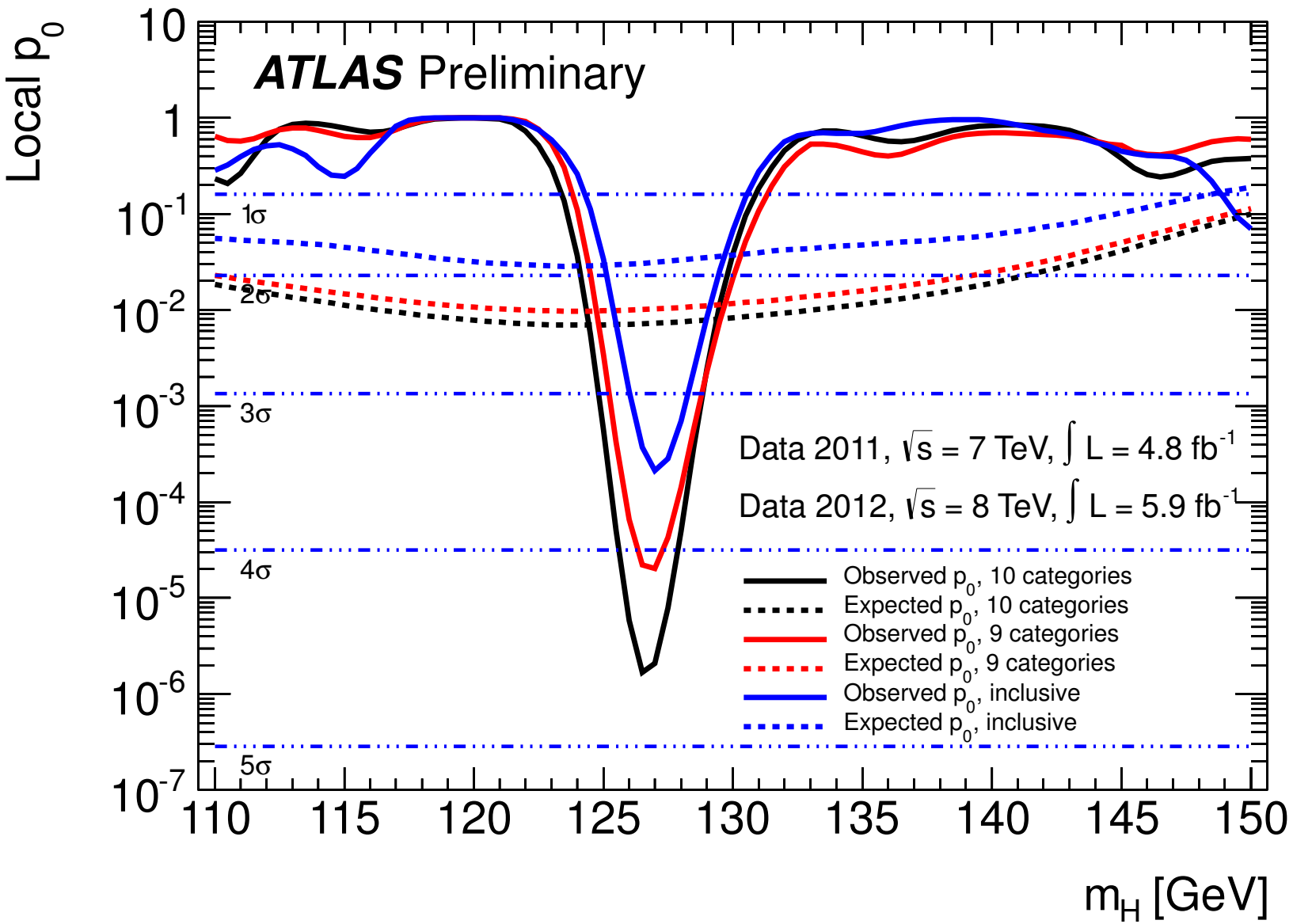


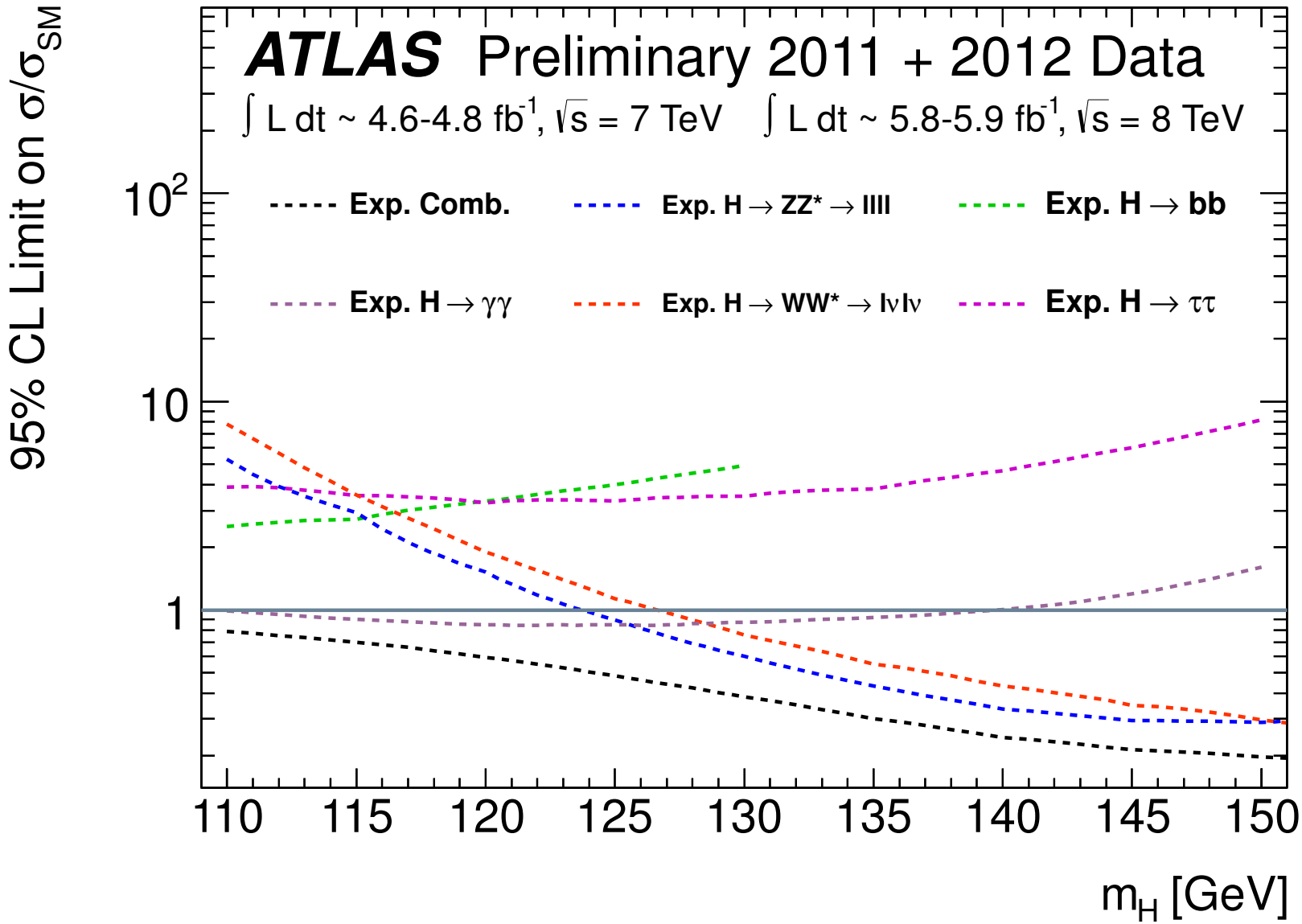


Comparison with previou analysis ($\sqrt{s} = 7$ TeV)



categories improvement




ATLAS Preliminary 2011 + 2012 Data
∫ L dt ~ 4.6-4.8 fb-1, √s = 7 TeV
∫ L dt ~ 5.8-5.9 fb-1, √s = 8 TeV
Exp. Comb.
Exp. H → ZZ* → llll
Exp. H → bb
Exp. H → γγ
Exp. H → WW* → lνlν
Exp. H → ττ
95% CL Limit on σ/σSM
10²
10
1
110
115
120
125
130
135
140
145
150
mH [GeV]

comparison with other channels