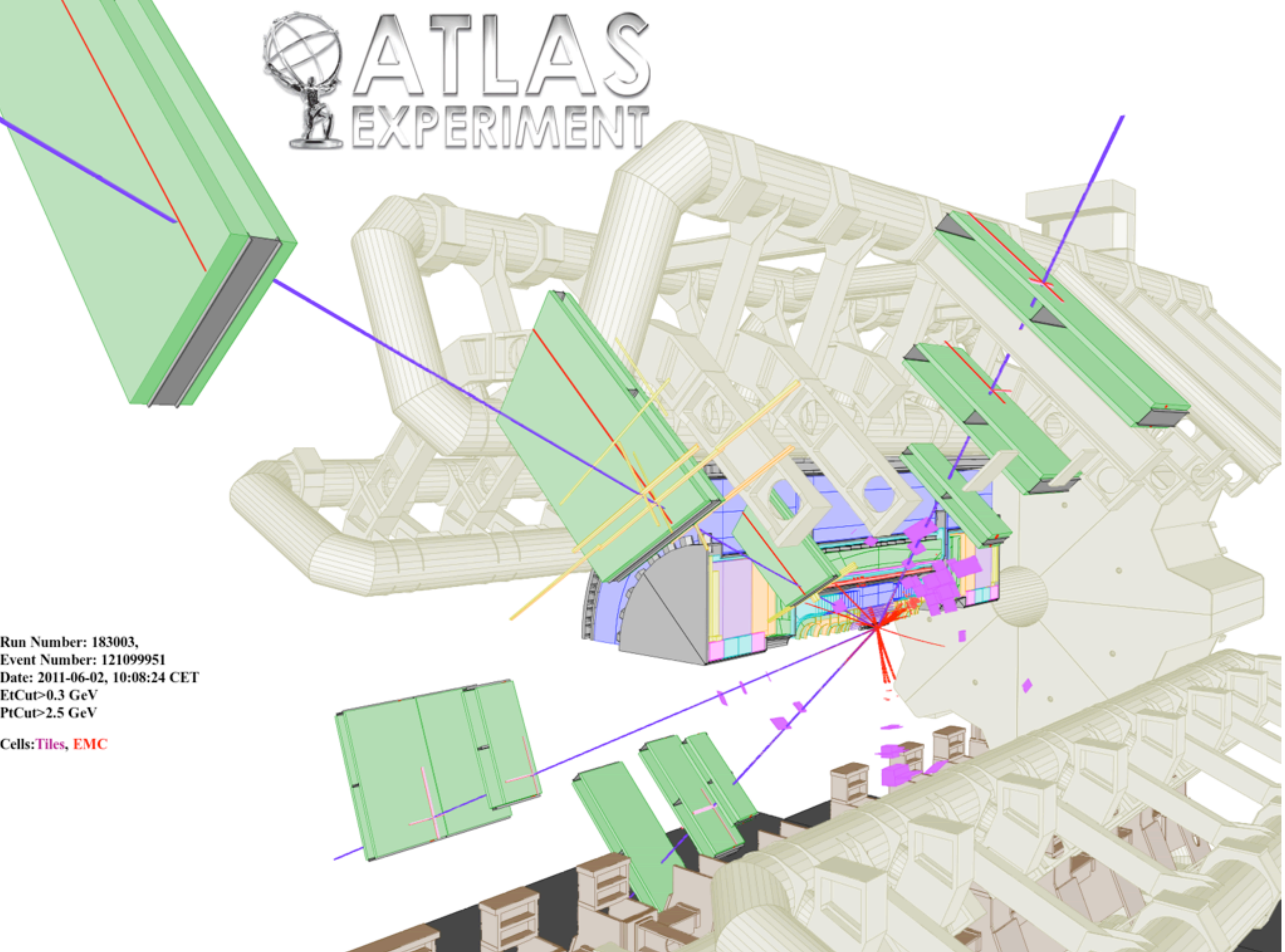


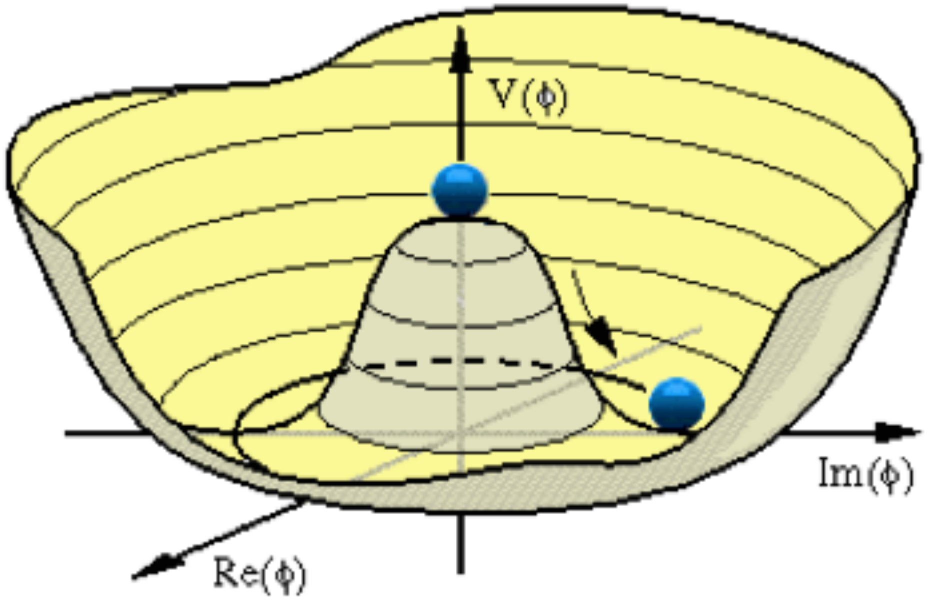
Observation of an excess of events in the Search for the Higgs Boson with ATLAS at the LHC

K. Nikolopoulos
University of Birmingham

Particle Physics Seminar
July 26th 2012, Birmingham

UNIVERSITY OF BIRMINGHAM

The Standard Model Higgs Boson



- Unification of the electromagnetic and weak interactions through the symmetry $SU(2)_L \otimes U(1)_Y \rightarrow$ massless force carriers
- The symmetry is spontaneously broken through the non-vanishing vacuum expectation value of the Higgs field (Brout-Englert-Higgs mechanism)
- Three of the four degrees of freedom of the Higgs field are becoming the longitudinal polarizations of the vector bosons, the fourth is the Higgs boson.

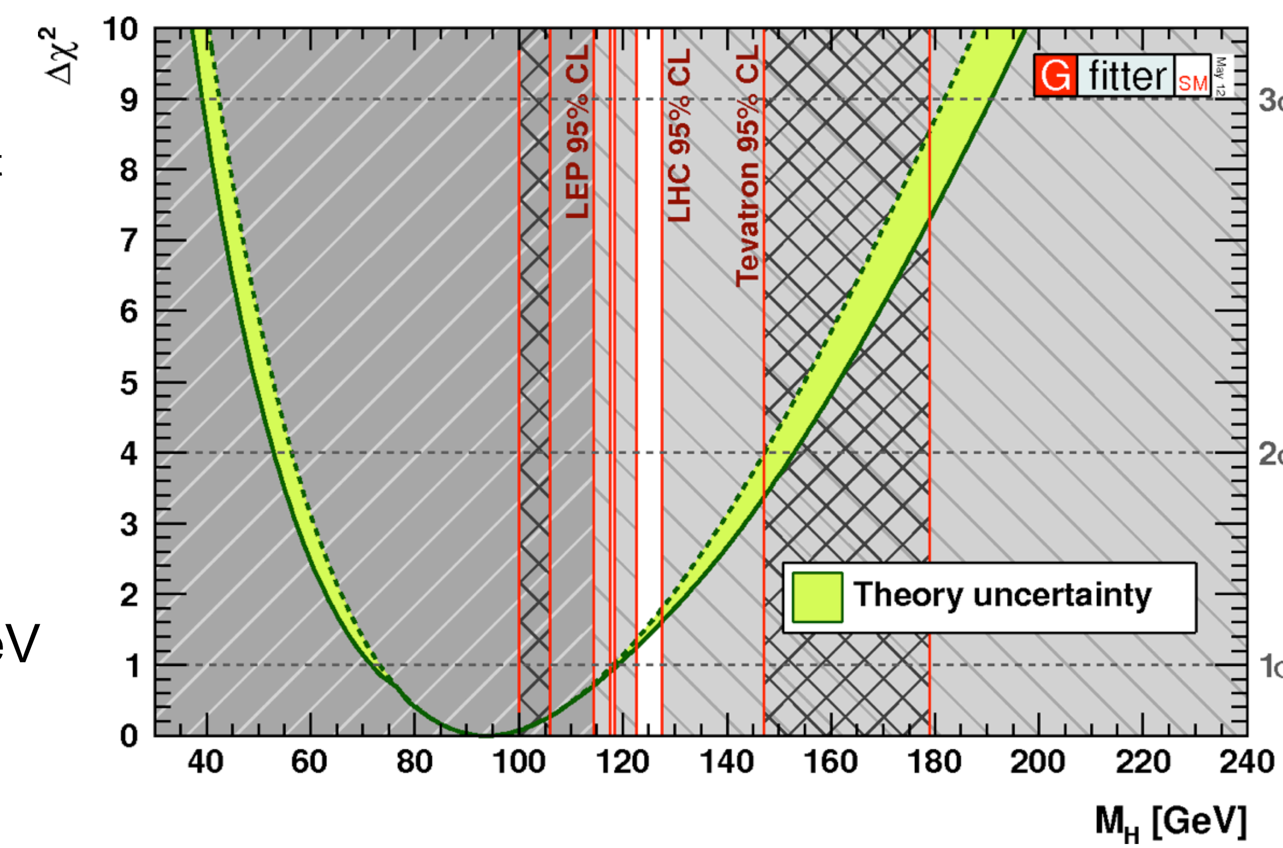
The Higgs boson has been the holy grail of particle physics for half a century!

Global Electroweak Fit

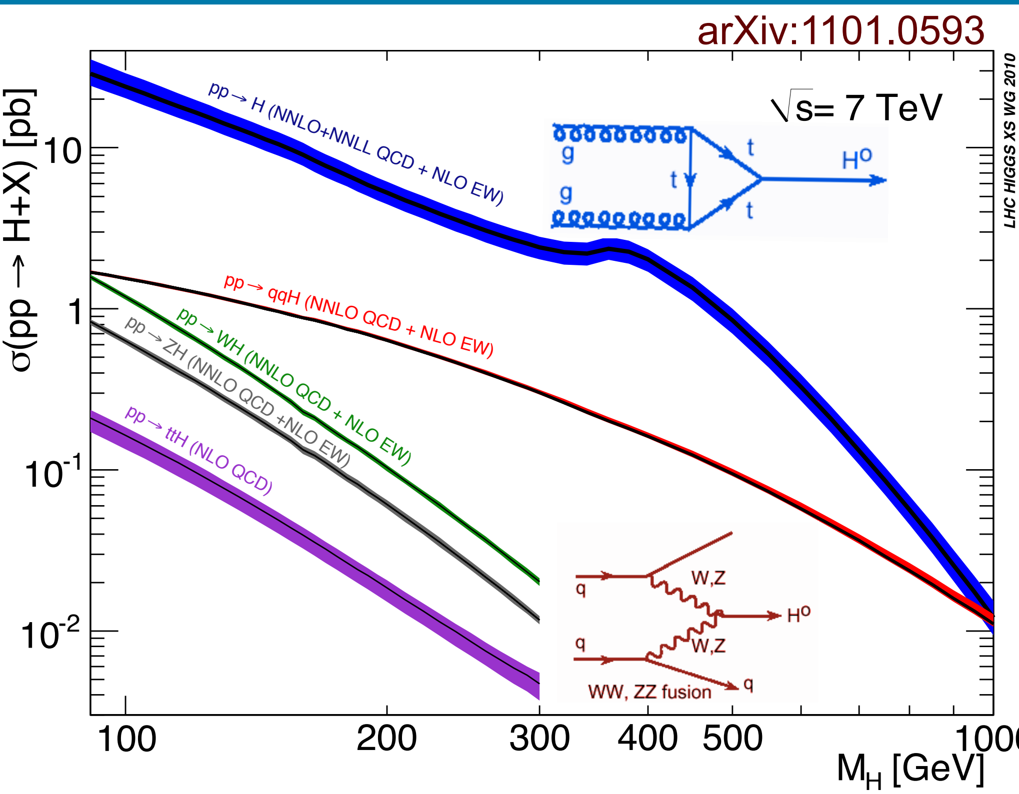
- The electroweak observables (e.g. m_W) depend on m_t and m_H through radiative corrections
- A global fit provides information on the Higgs mass assuming the validity of the SM

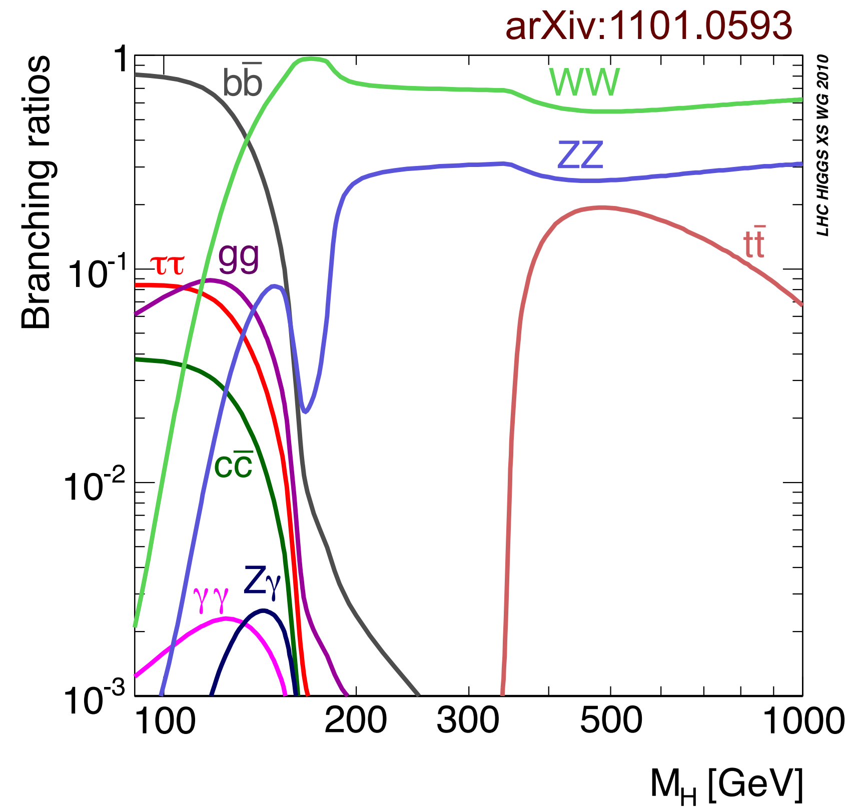
Latest Non-LHC SM Higgs status

- LEP m_H>114.4 GeV at 95% CL
- Tevatron excluded $100<m_H<103$ GeV and $147<m_H<180$ GeV at 95% CL (Summer 2012)
- Large portion of allowed m_H uncovered



Standard Model Higgs Boson Production @ LHC





SM Higgs Boson Production

⇒ gluon fusion dominates

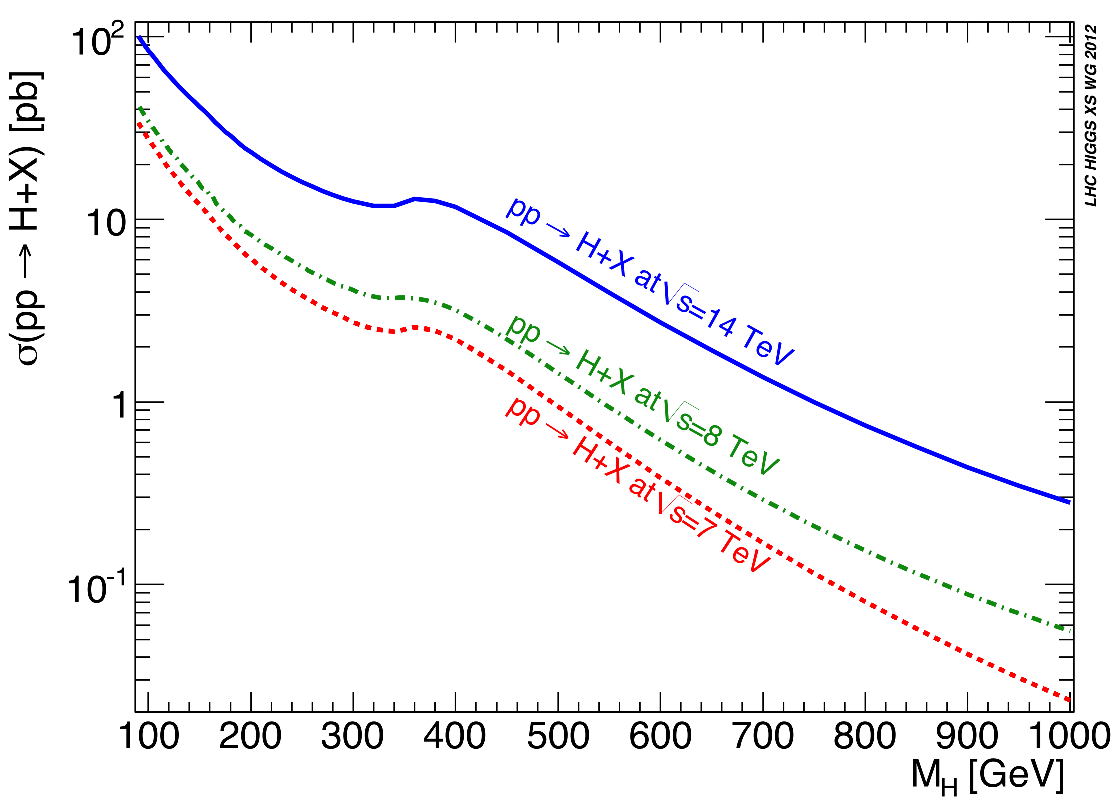
⇒ VBF relative contribution rises with m_H

SM Higgs Boson Decays

⇒ $H \rightarrow WW$ dominates m_H>130GeV

⇒ $H \rightarrow ZZ$ follows

⇒ $H \rightarrow \gamma\gamma$ low BR/distinct final state



Going from 7 to 8 TeV

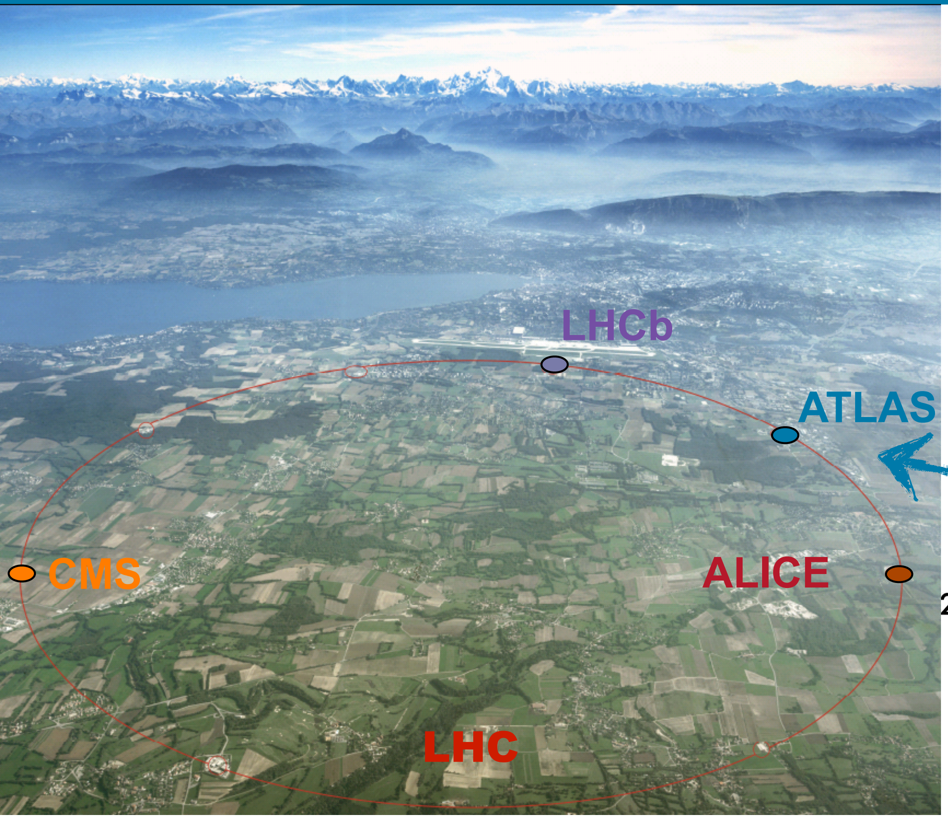
⇒ Higgs cross-section increases by ~1.3 for m_H = 125 GeV (~3.3 for 14 TeV)

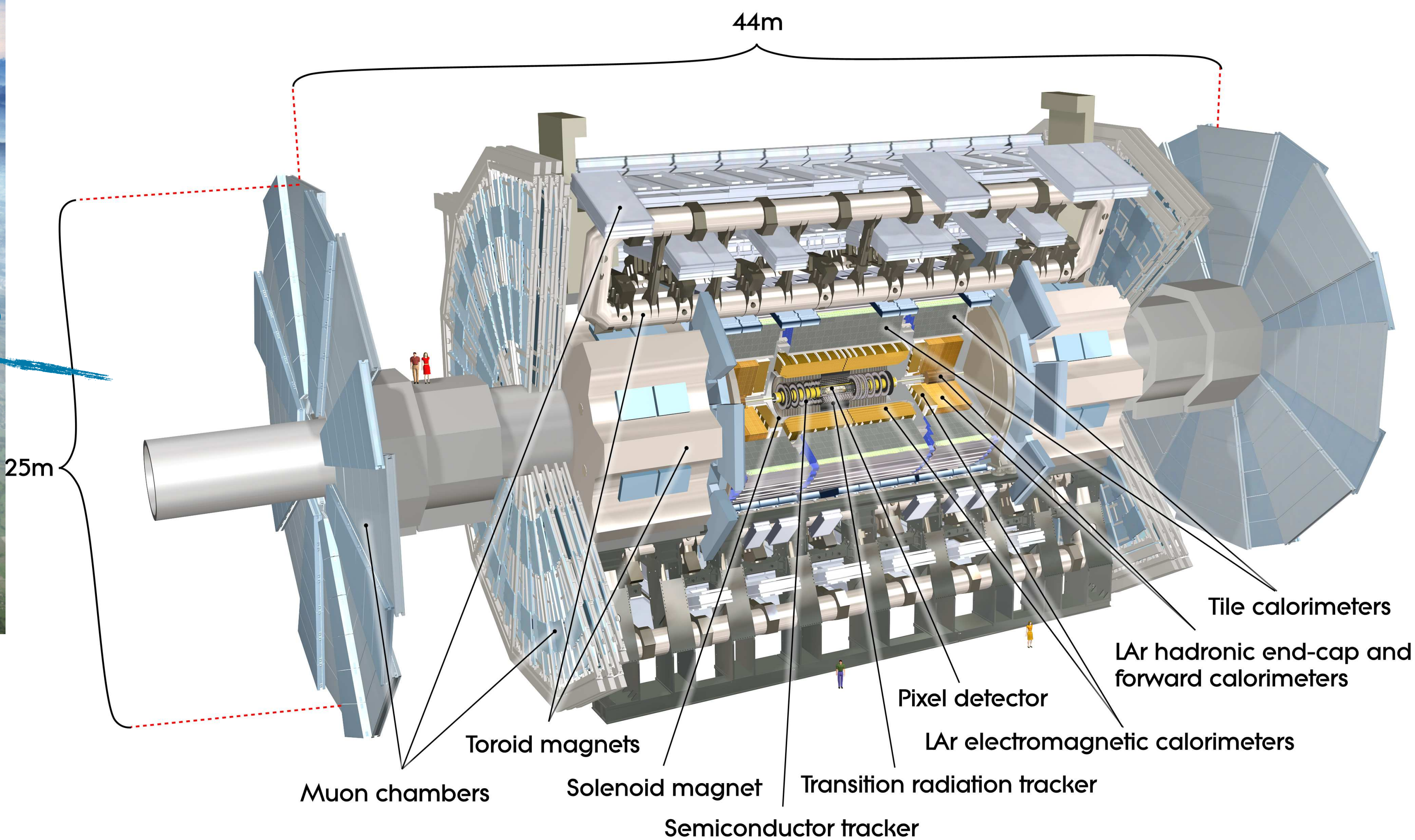
⇒ Similar effect for irreducible backgrounds γγ/di-bosons

⇒ Reducible backgrounds increase a bit more (e.g. ~1.4 for $t\bar{t}$)

⇒ Overall expected increase in sensitivity by 10-15%

A Toroidal LHC ApparatuS

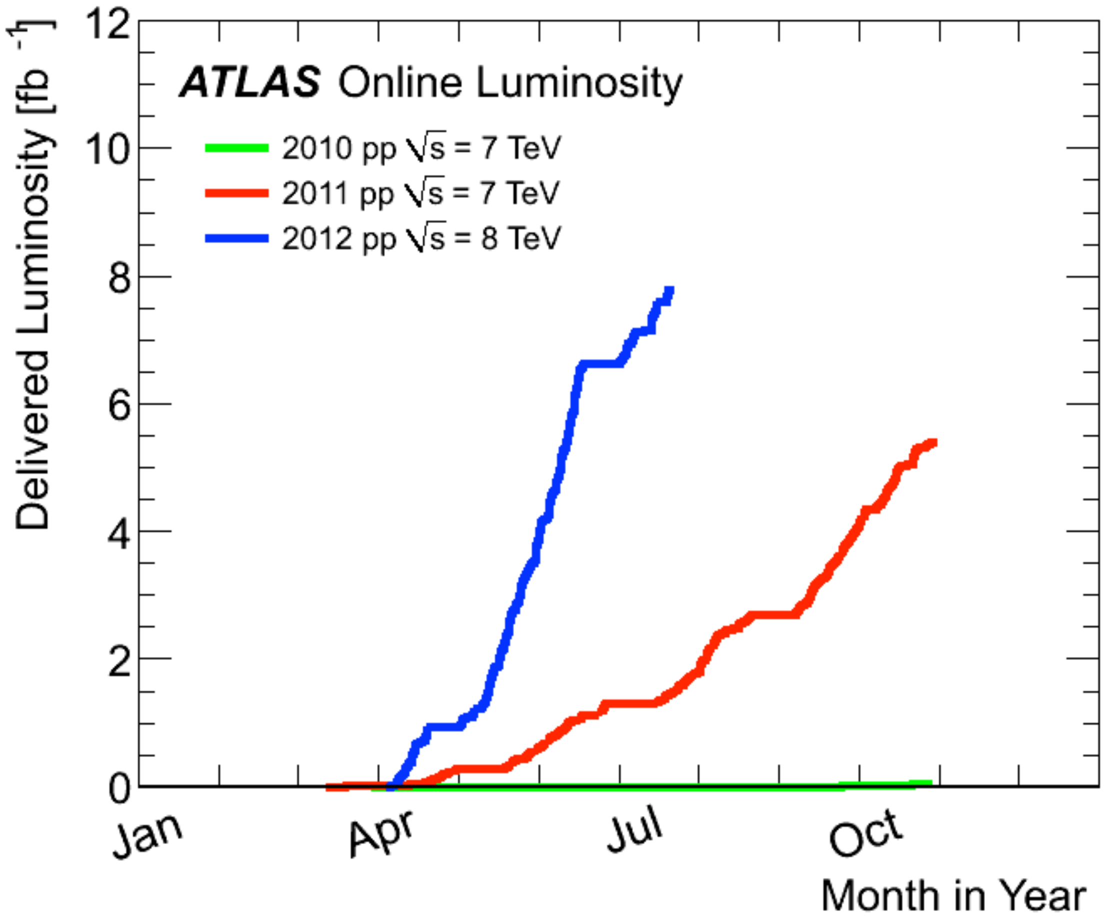




⇒ General purpose detector designed for the harsh LHC environment

	ATLAS
Magnets	2T solenoid, 3 air-core toroids
Tracking	silicon + transition radiation tracker
EM Calorimetry	sampling LAr technology
Hadron Calorimetry	plastic scintillator (barrel) LAr technology (endcap)
Muon	independent system with trigger capabilities

Integrated Luminosity vs Time



7 TeV data sample (2010)

- 0.048 fb^{-1} recorded → ~0.035 fb^{-1} for physics
- Peak stable luminosity $2.1\times10^{32}cm^{-2}s^{-1}$

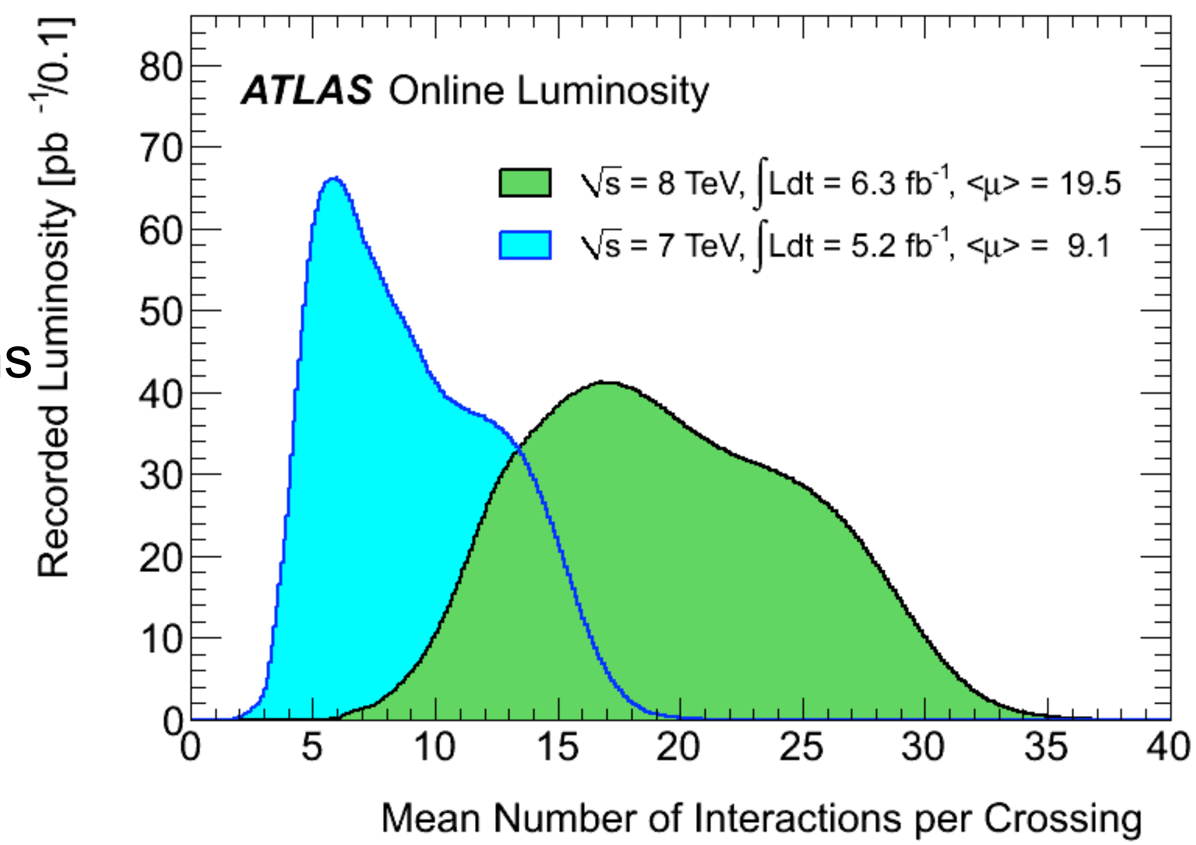
7 TeV data sample (2011)

- 5.3 fb^{-1} recorded → 4.8 fb^{-1} for physics (~90%)
- Peak stable luminosity $3.6\times10^{33}cm^{-2}s^{-1}$

8 TeV data sample (2012)

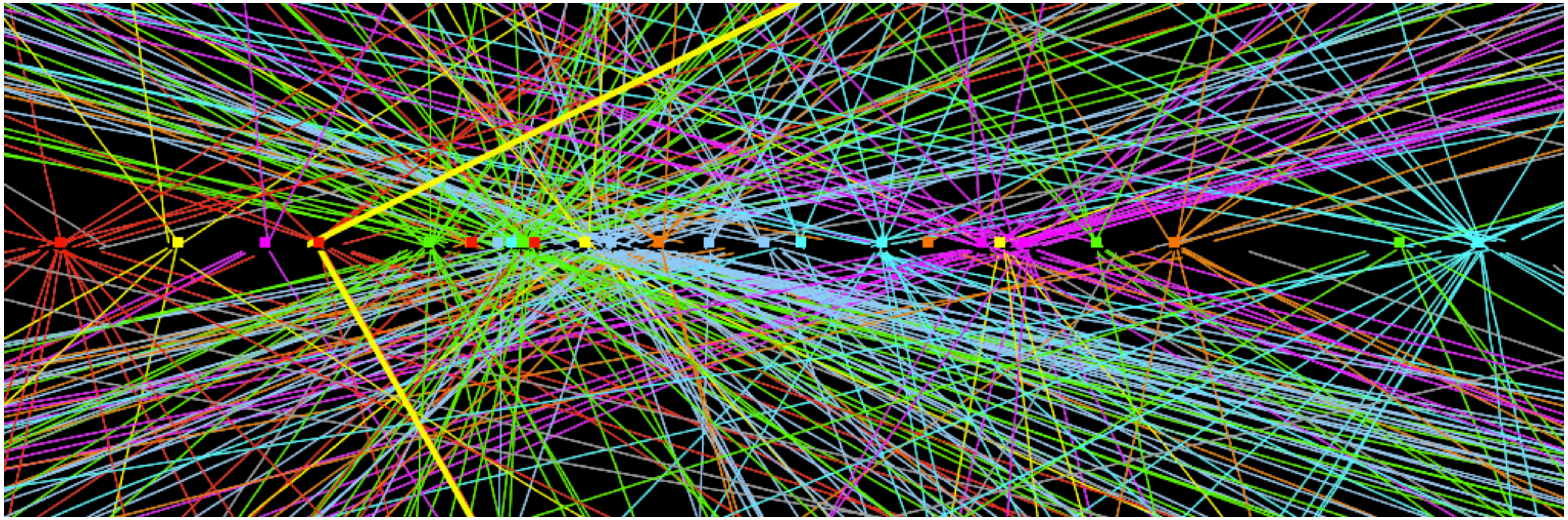
- 6.3 fb^{-1} recorded → 5.8 fb^{-1} for physics (~92%)
- Peak stable luminosity $6.8\times10^{33}cm^{-2}s^{-1}$

Pile-up in 2012 exceeding detector design specifications
→ Maintain excellent performance with improved algorithms
→ Proper modeling of conditions in simulation essential

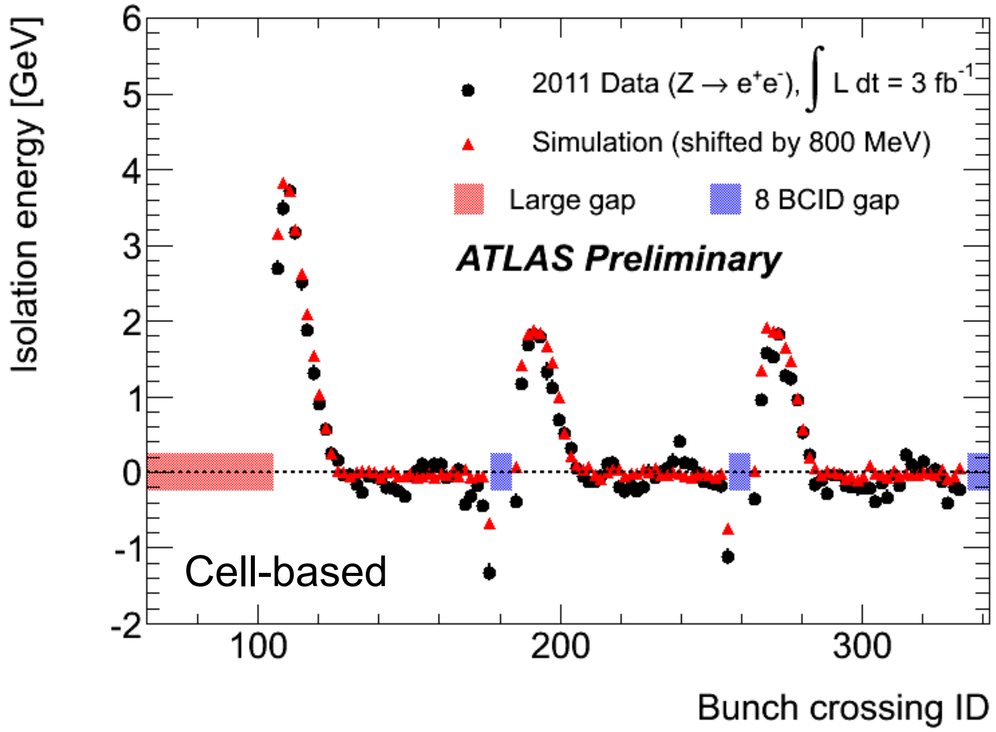


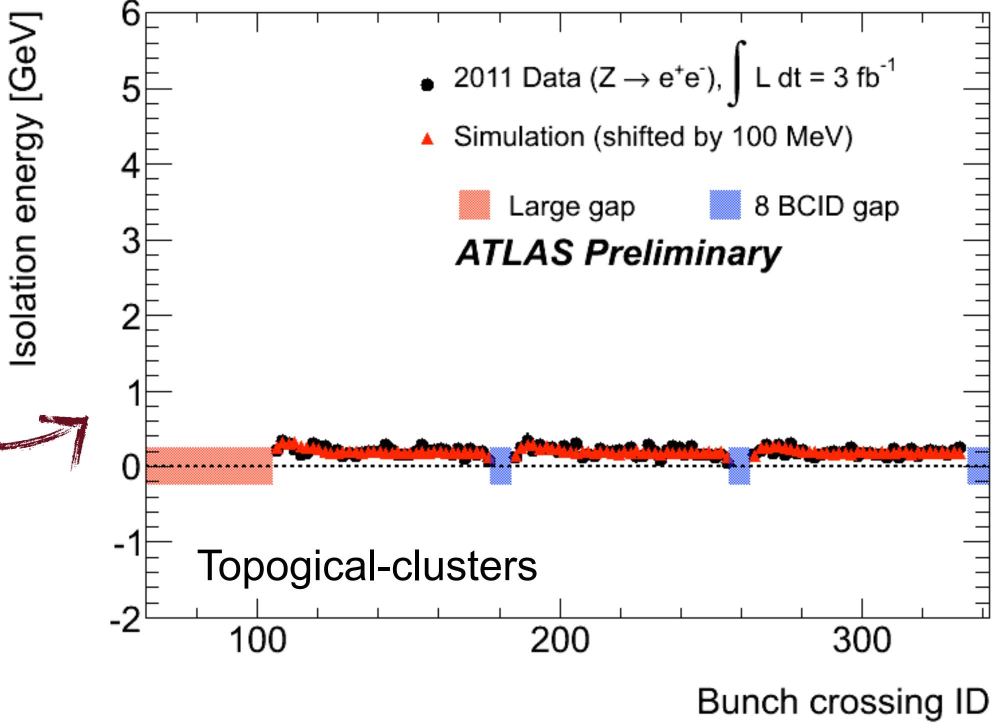
Pile-up

Z→μμ candidate with 25 reconstructed vertices from the 2012 run.
Only good quality tracks with pT>0.4GeV are shown



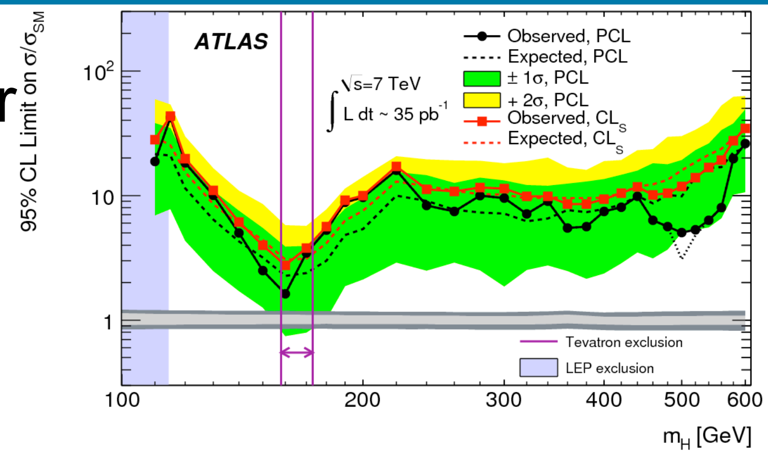
Substantial effort in ensuring detector performance is insensitive to pile-up.



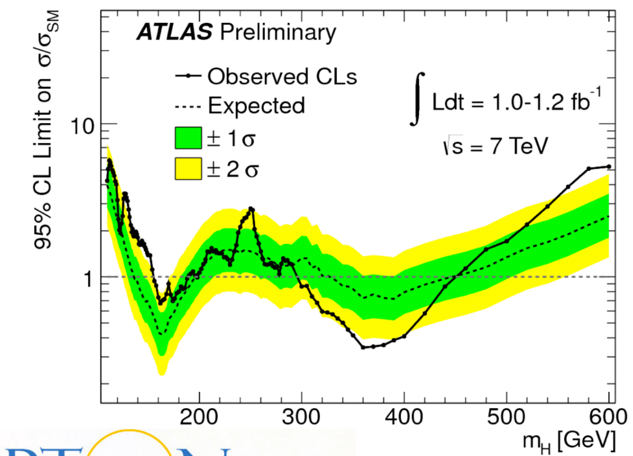


The ATLAS Higgs saga

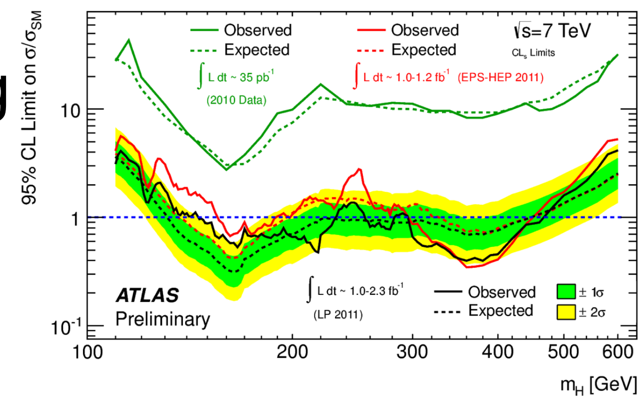
40 pb^{-1} — Apr



1 fb^{-1} — Jul

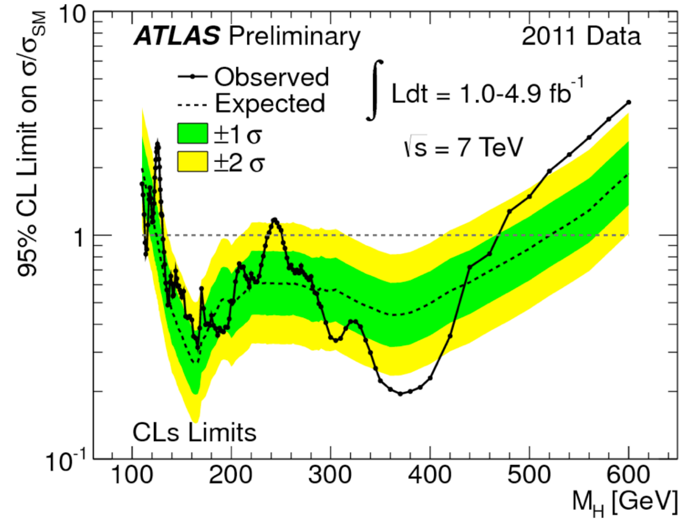


2 fb^{-1} — Aug



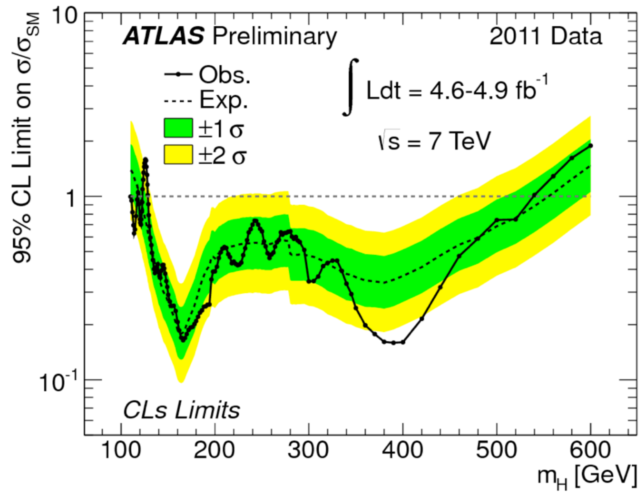
LEPTON PHOTON 2011
XXV International Symposium on Lepton and Photon Interactions at High Energies

5 fb^{-1} — Dec



2012

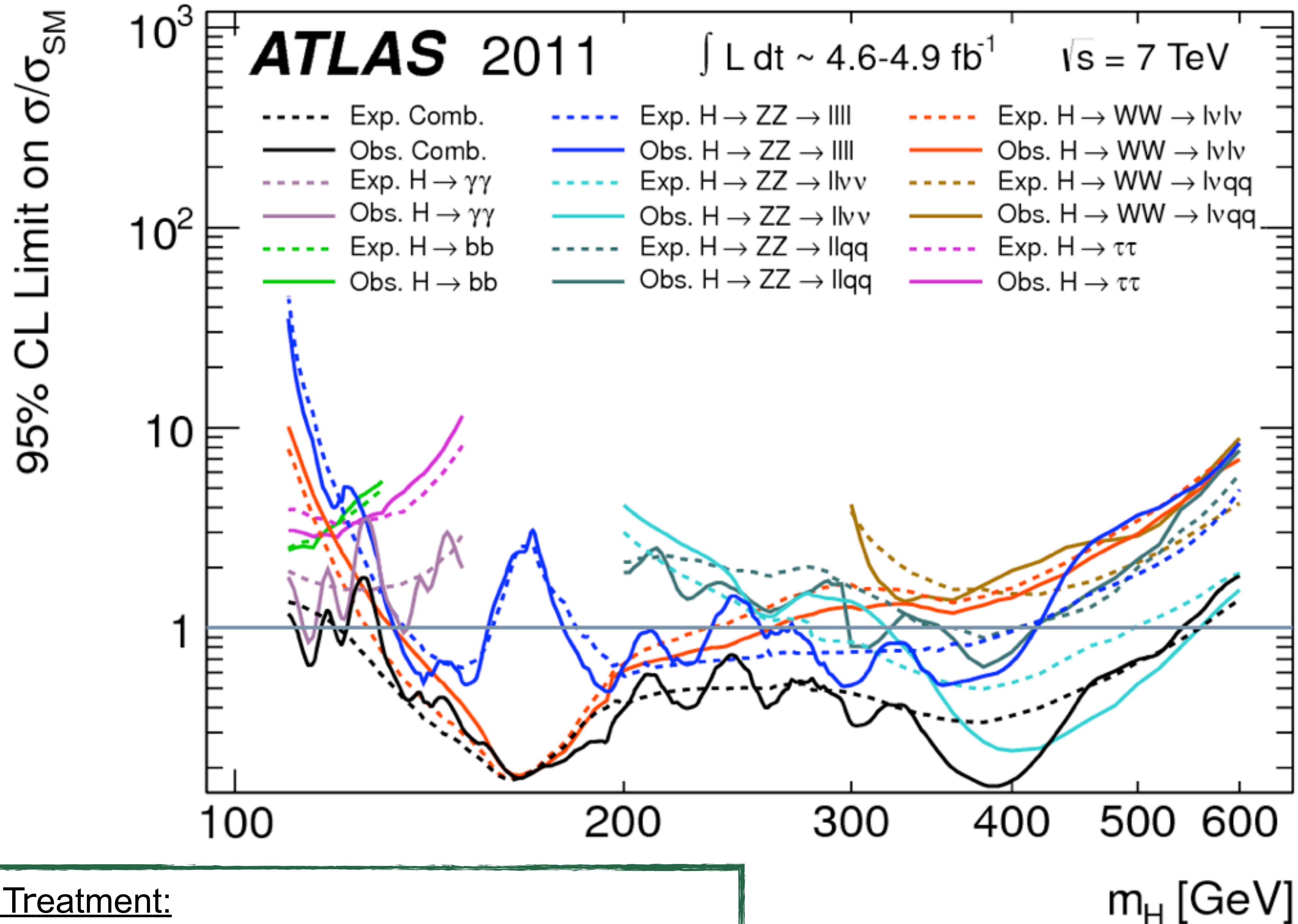
Mar



47th Rencontres de Moriond

Spring 2012

arXiv:1207.0319[hep-ex]
Accepted by Phy.Rev.D

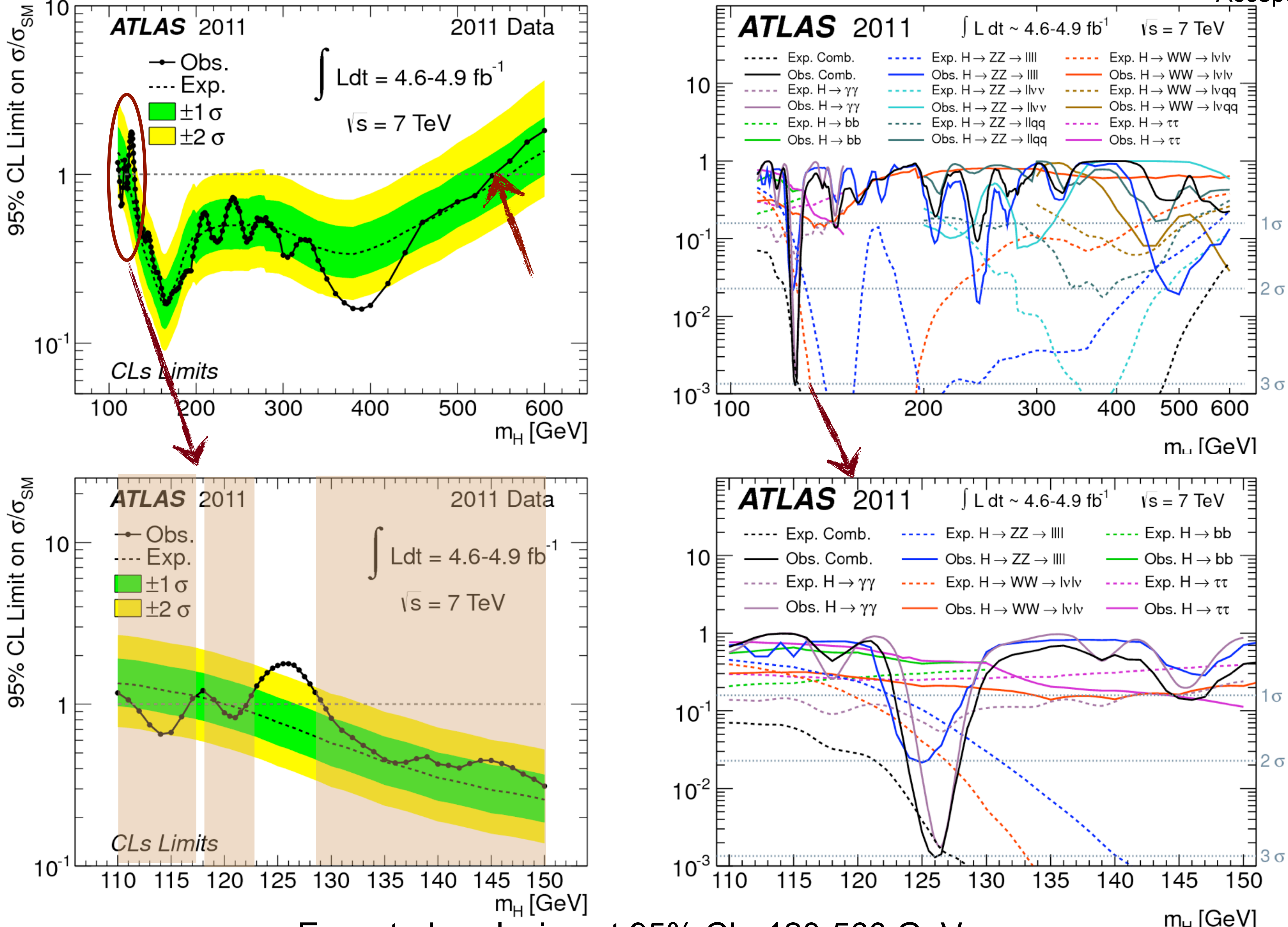


Statistics Treatment:

- profile likelihood ratio [Eur.Phys.J.C71:1554,2011]
  → nuisance parameters for systematic uncertainties
- exclusion limits using CL_S [J. Phys. G 28 (2002) 2693-2704]

Combined Results Spring 2012

arXiv:1207.0319[hep-ex]
Accepted by Phy.Rev.D



Expected exclusion at 95% CL: 120-560 GeV

Observed exclusion at 95% CL: 111.4-116.6, 119.4-122.1, 129.2-541 GeV

Observed upward flactuation at the level of 3.0σ (2.9σ with ESS) when expected 2.9σ at m_H=126 GeV

Strategy for 2012 SM Higgs Search

Huge flux of incoming data, under completely new experimental conditions.

ATLAS organized the 2012 data analysis in stages:

new results from the most sensitive high resolution channels ($H \rightarrow \gamma\gamma$ and $H \rightarrow ZZ^{(*)} \rightarrow 4l$),

while working on the understanding of the more complicated physics objects (MET, τ, b-jets)

<u>Procedure to update the analysis</u>

$\Longrightarrow$ Simulation-based optimization

$\Longrightarrow$ Study backgrounds in data

$\Longrightarrow$ Side-bands/background dominated regions

$\rightarrow$ initially on 2011 data and then 2012 data

$\Longrightarrow$ Once above studies completed look at the signal region

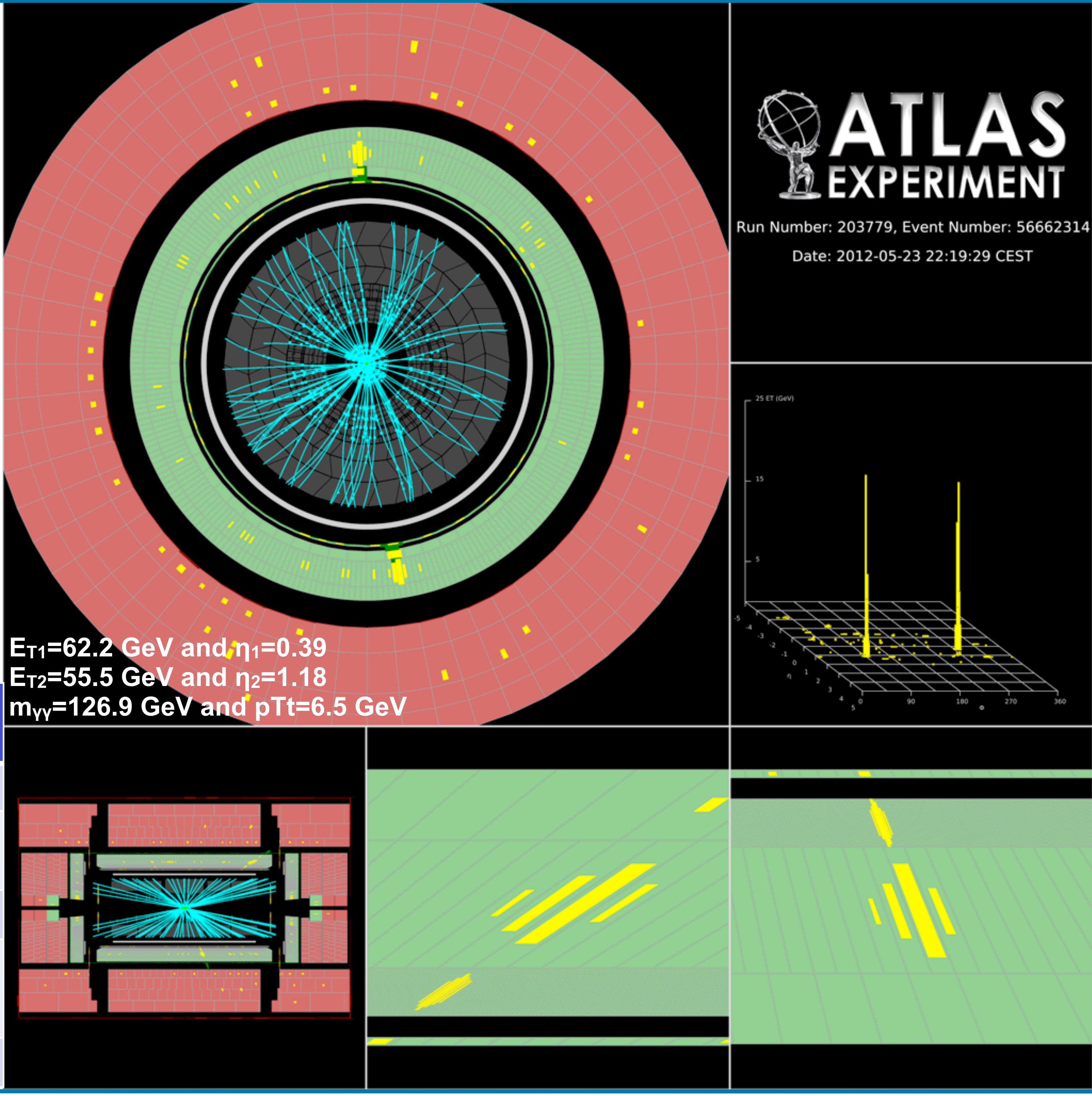
$H \rightarrow \gamma\gamma$

- Sensitive for low m_H (110 - 150 GeV)
- Search for narrow peak in $m_{\gamma\gamma}$
  - Background from data
  - Categorize wrt S/B and resolution
- Main Backgrounds:
  - → di-photon ➛ $m_{\gamma\gamma}$ resolution
  - → jj and γj ➛ photon-ID

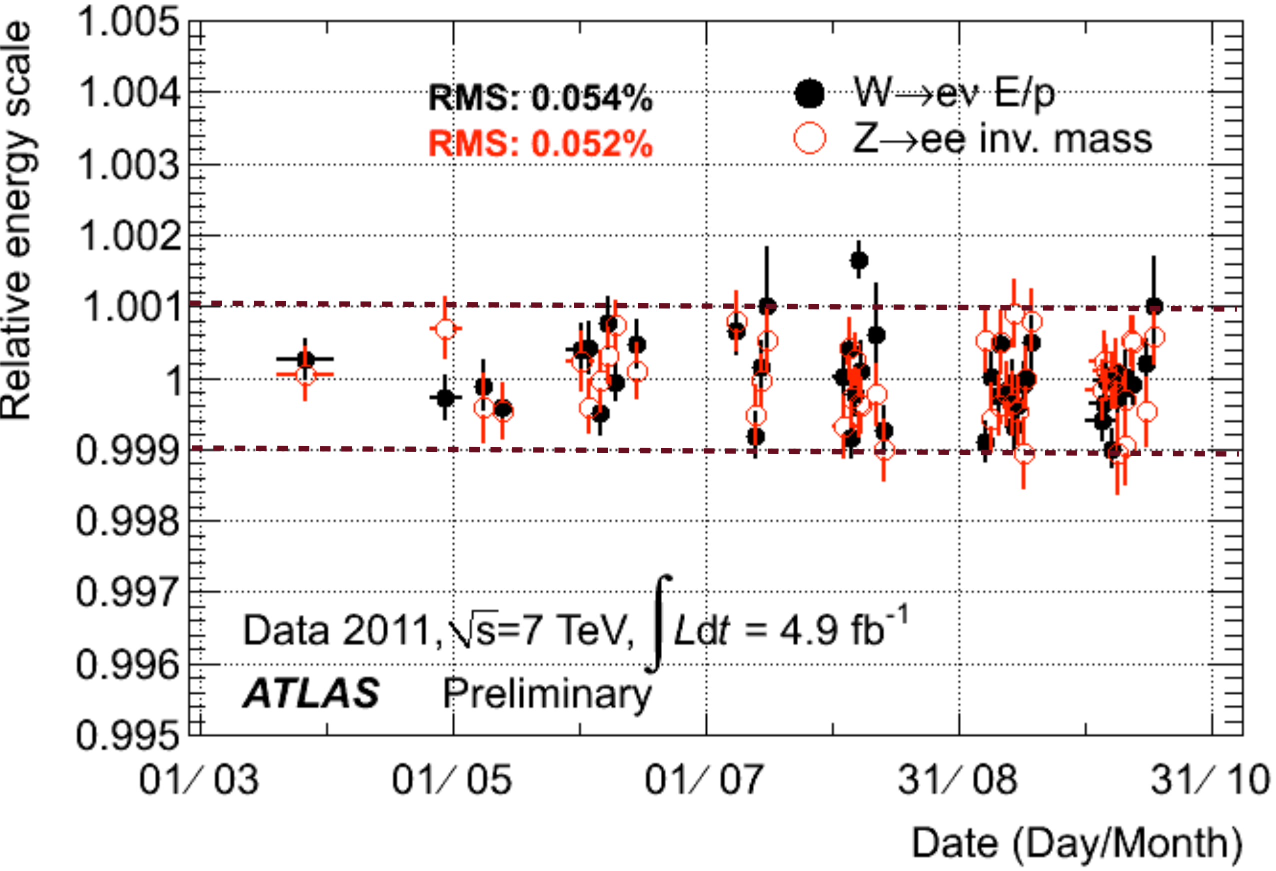
<u>Analysis optimizations</u>

- Optimised kinematic requirements
- Neural-net γ-ID for 2011 data
- Opt. γ-ID for 2012 (pile-up robust)
- Pile-up robust calorimeter isolation
- Add 2-jet category (enhance VBF)

Selection	2011	2011 Updated	2012
Trigger $p_{T\gamma}$	2γ20	2γ20	γ35γ25
Offline $p_{T\gamma}$	40,25 GeV	40,30 GeV	40,30 GeV
γ-ID	Cuts	NN	OptCuts
Isolation (ΔR=0.4)	Cell based <5 GeV	Topo based <4 GeV	Topo based <4 GeV
Categories	9	10	10

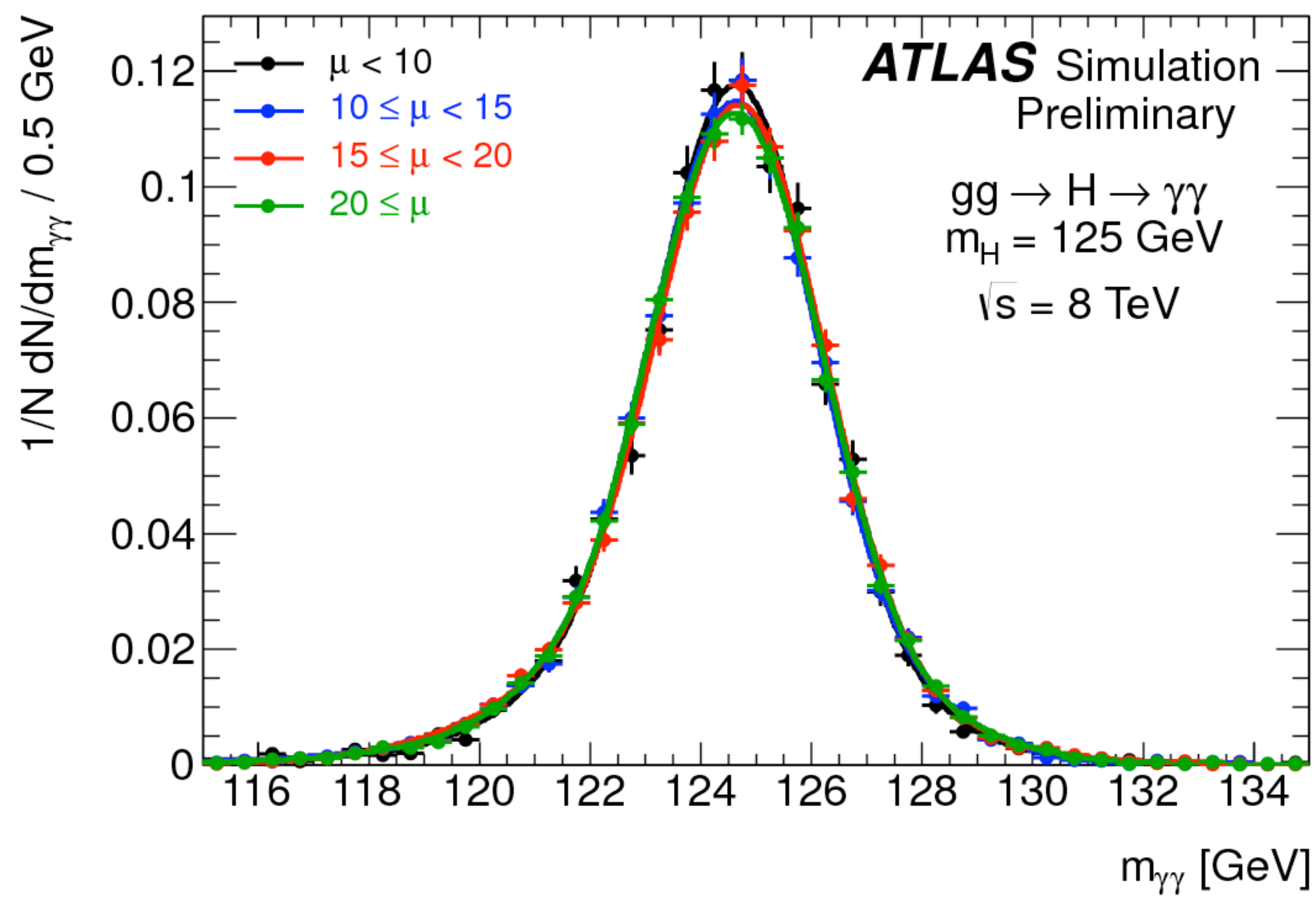


H→γγ: $m_{\gamma\gamma}$ resolution



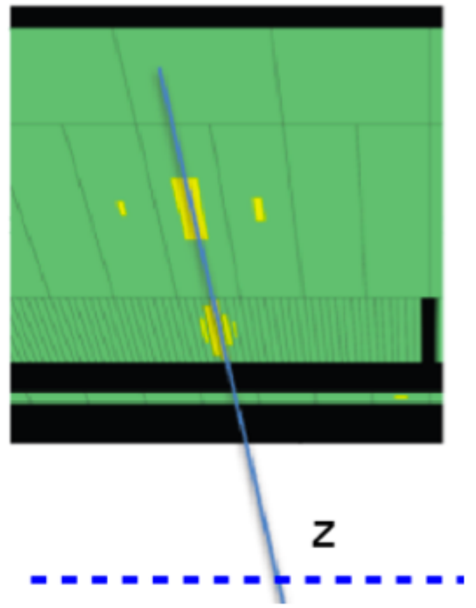
$$m^2_{\gamma\gamma}=2E_1E_2(1-\cos\alpha)$$

- Excellent stability of the EM calorimeter response!
  - Studied with Z,J/ψ→ee and W→eν events
  - Energy scale at m_Z known to ~0.3%
  - Uniformity ~1% (2.5% for 1.37< |η|<1.8)
- Resolution of inclusive sample ~1.6 GeV
  - ~90% of events within ±2σ
- Mass resolution immune to pile-up



H→γγ: $m_{\gamma\gamma}$ resolution

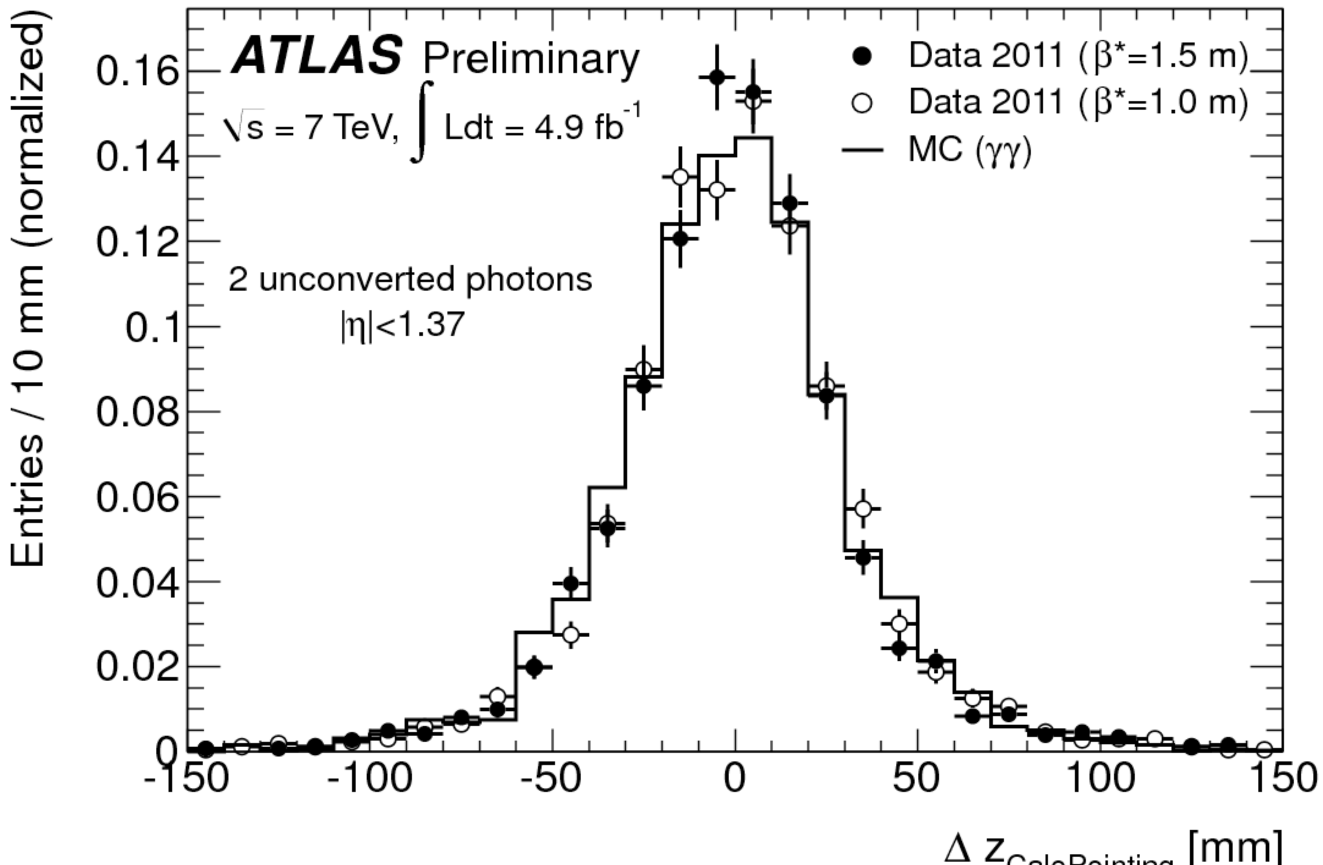
$$m^2_{\gamma\gamma}=2E_1E_2(1-\cos\alpha)$$

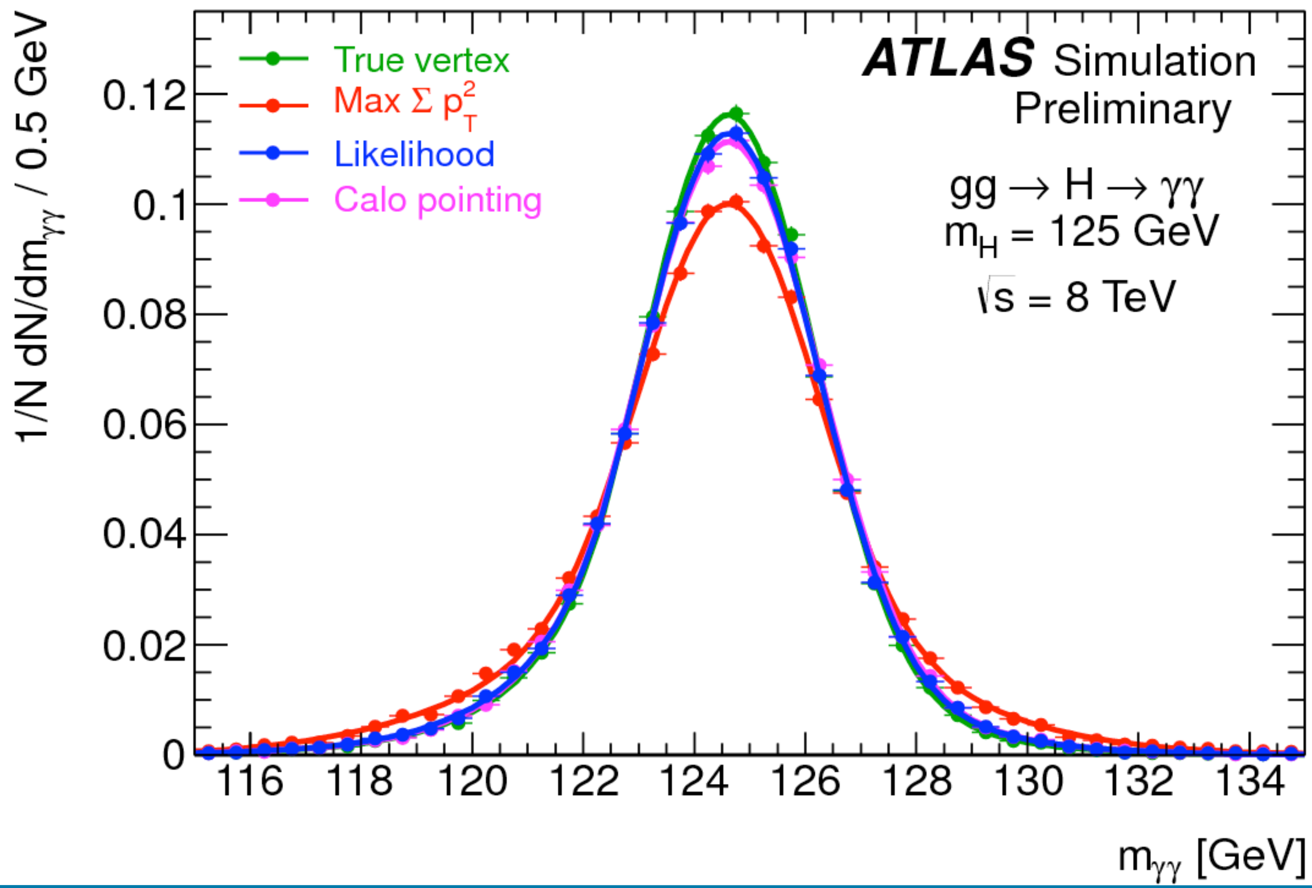


- LHC beam spot σ_z~5-6 cm and O(20) vertices
  - → difficult to identify the "primary" vertex

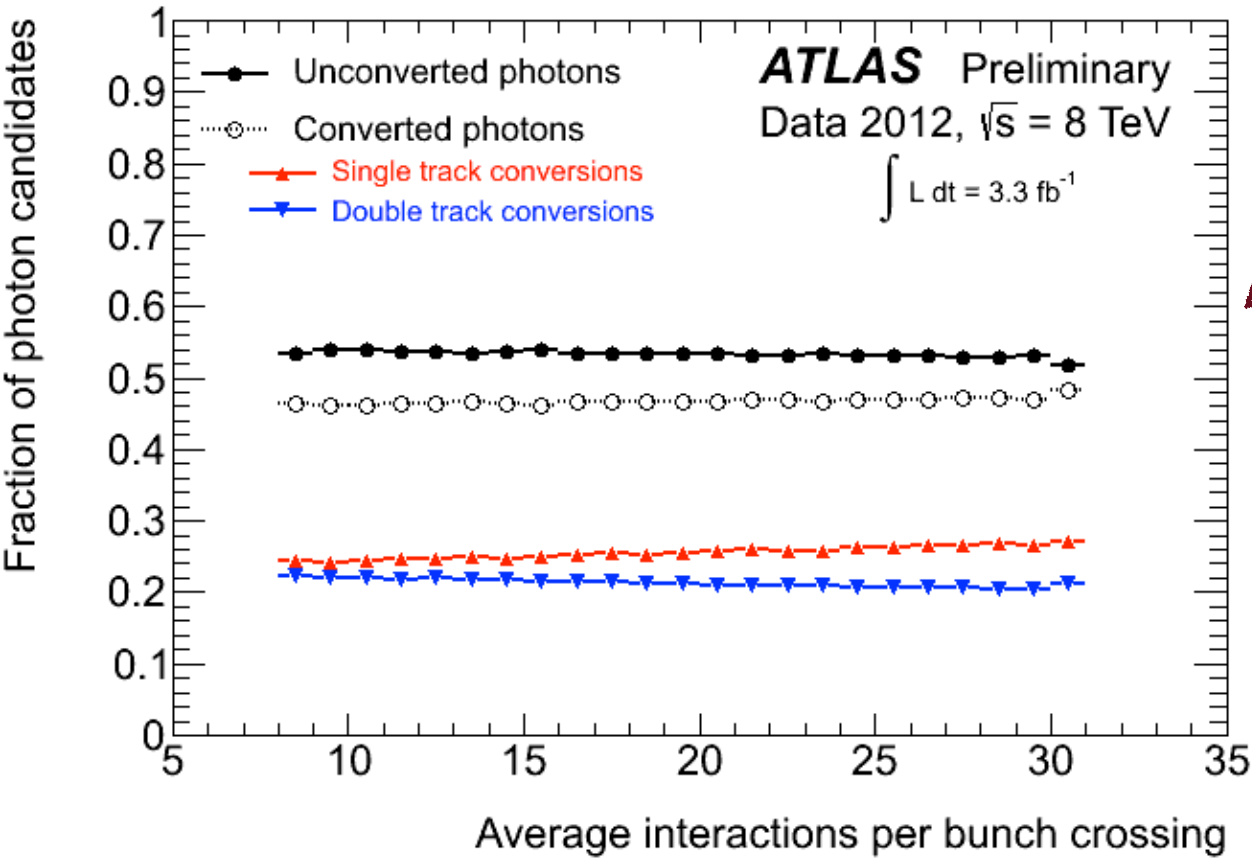
Use the strengths of the detector!

- longitudinal/lateral segmentation of EM calorimeter
  - measure photon direction with σ_z~1.5 cm
    - use beam-spot constraint/converted photon tracks
  - pile-up robust
  - contribution of angular term to $m_{\gamma\gamma}$ resolution negligible
- Build likelihood to identify the primary vertex using: Photon pointing and vertex $\Sigma(p_T)^2$





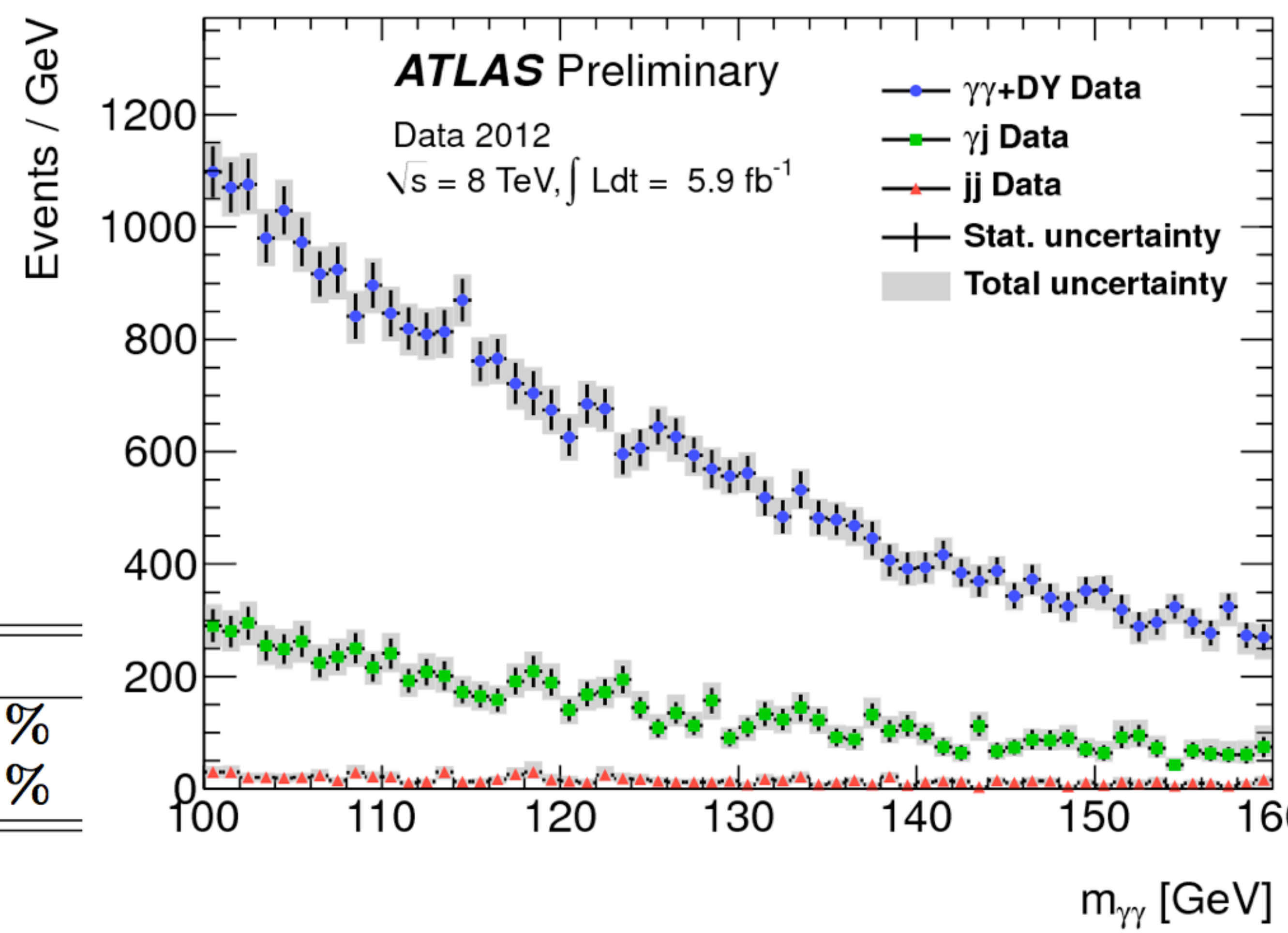
H→γγ: Background Composition



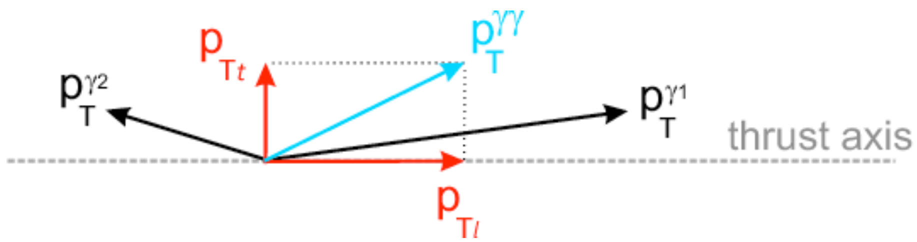
Stable photon reconstruction vs pile-up (within 1%)

- Large uncertainties jet fragmentation/cross sections
- Data-driven determination of fractional contributions for each class of events (γγ,jγ,γj,jj) using a double-sideband method (photon isolation and identification)
- Z→ee tag-and-probe used to estimate e→γ fake rate

	γγ+DY	γ-jet	jet-jet
7 TeV (NN ID)	$(80 \pm 4)\%$	$(19 \pm 3)\%$	$(1.8 \pm 0.5)\%$
8 TeV (Cut ID)	$(75 \pm 3)\%$	$(22 \pm 2)\%$	$(2.6 \pm 0.5)\%$



H→γγ: Event Categories



Categorize events based on:

direction of photons

⊗ conversion status

⊗ p_{Tt}

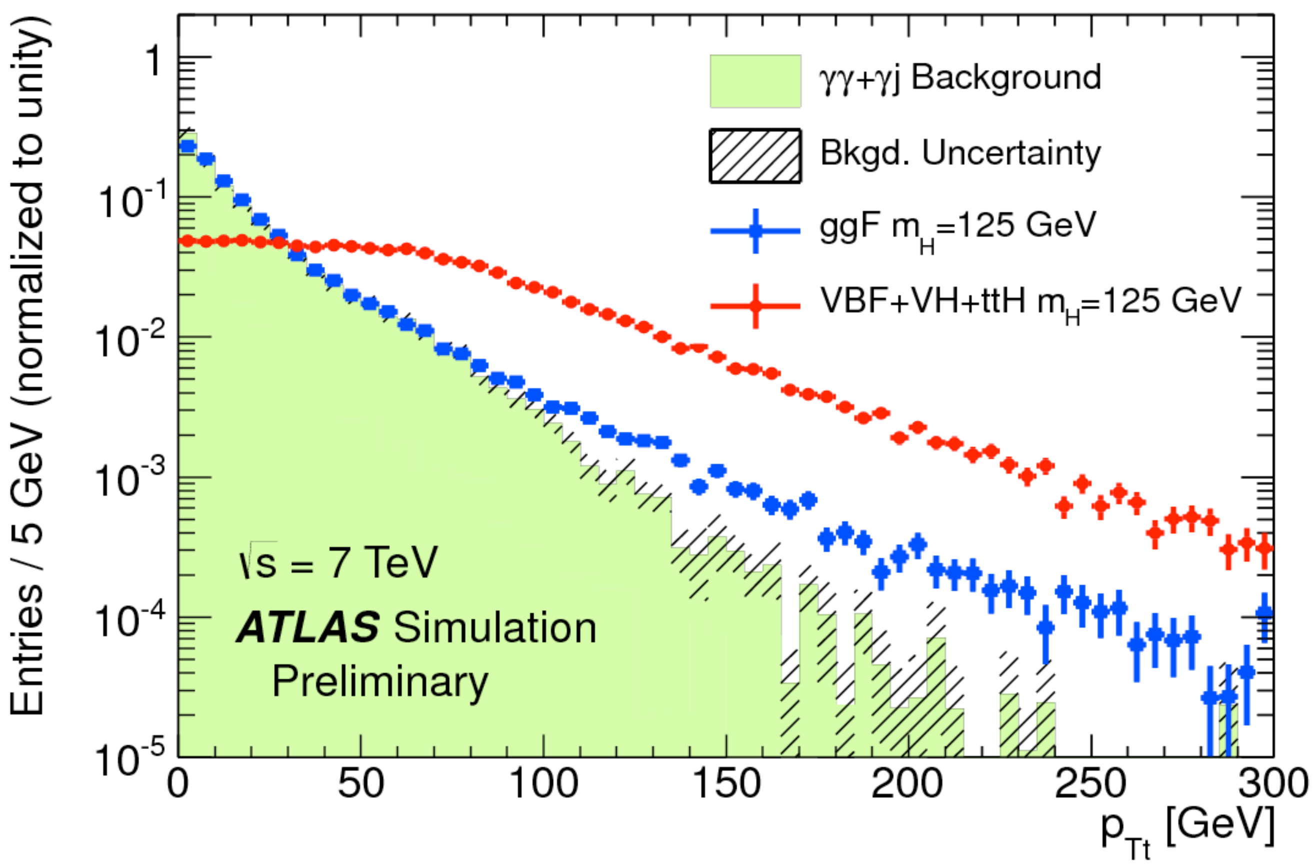
⊕ 2-jet VBF category

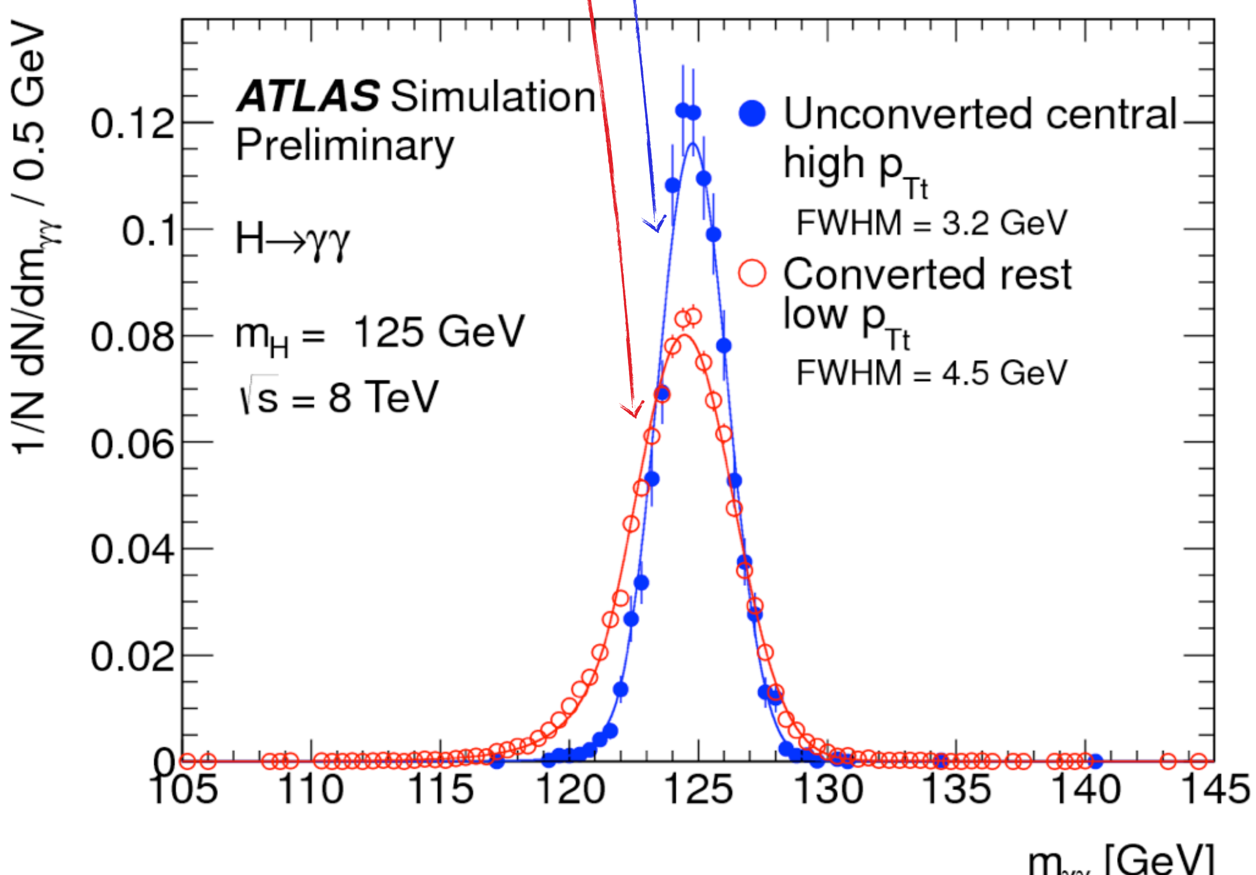
(2 jets with pT>25-30 Ge, $\Delta\eta_{jj}$>2.8, m_{jj}>400GeV, $\Delta\varphi_{jj-\gamma\gamma}$>2.6)

= 10 categories in total

8 TeV (90% signal window)

Category	σ_{CB} [GeV]	FWHM [GeV]	Observed [N_{evt}]	S [N_{evt}]	B [N_{evt}]
Inclusive	1.63	3.87	3693	100.4	3635
Unconverted central, low p_{Tt}	1.45	3.42	235	13.0	215
Unconverted central, high p_{Tt}	1.37	3.23	15	2.3	14
Unconverted rest, low p_{Tt}	1.57	3.72	1131	28.3	1133
Unconverted rest, high p_{Tt}	1.51	3.55	75	4.8	68
Converted central, low p_{Tt}	1.67	3.94	208	8.2	193
Converted central, high p_{Tt}	1.50	3.54	13	1.5	10
Converted rest, low p_{Tt}	1.93	4.54	1350	24.6	1346
Converted rest, high p_{Tt}	1.68	3.96	69	4.1	72
Converted transition	2.65	6.24	880	11.7	845
2-jets	1.57	3.70	18	2.6	12





H→γγ: Background Modeling

The background is obtained directly from data, but the fitting function used is crucial:

- Too constrained background fit function → potential shape bias
- Too many free parameters → loose sensitivity (background fits also potential signal)

Studied with high-statistics simulation before looking at data:

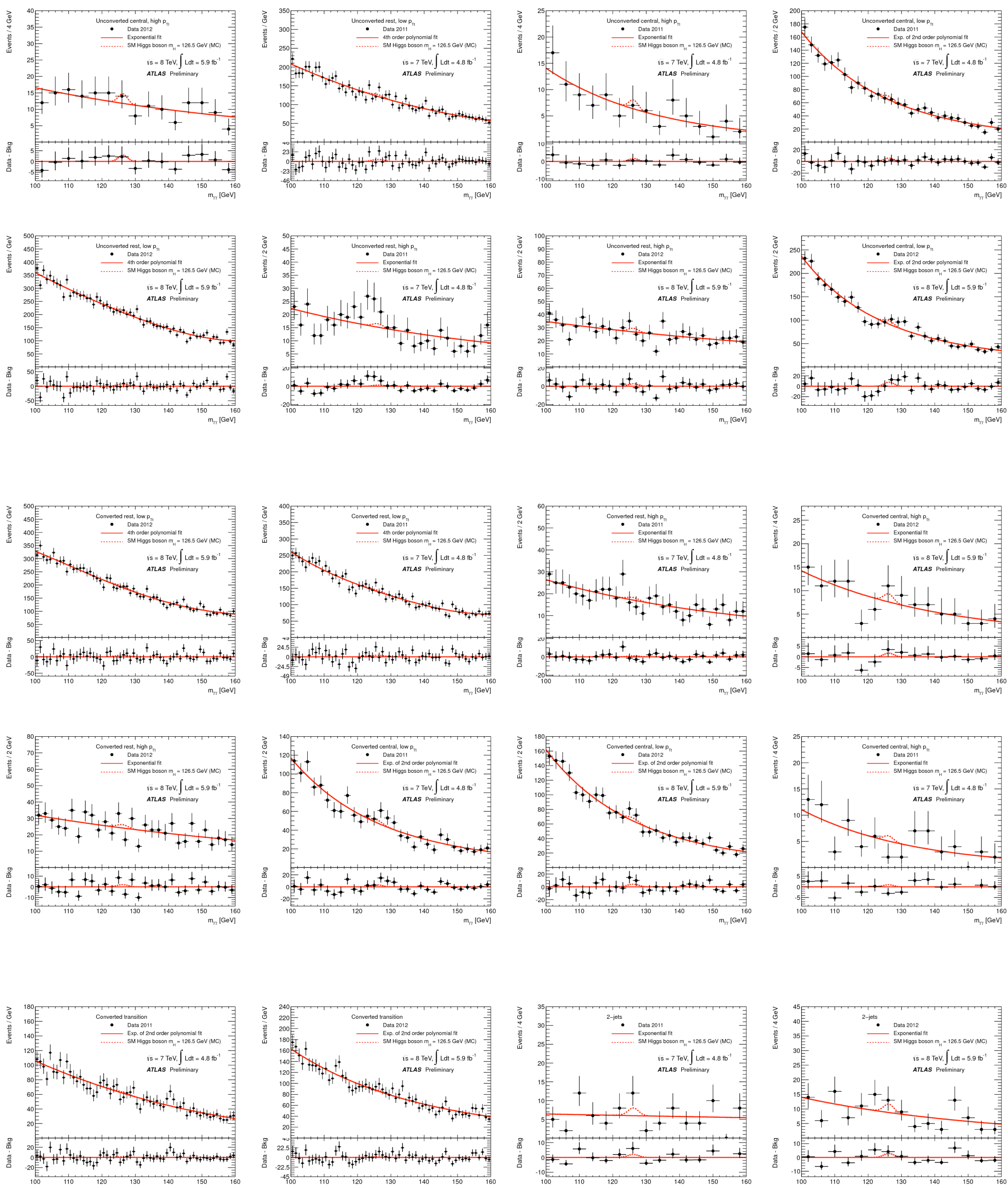
→ Modeling γγ, γ-j and jj backgrounds

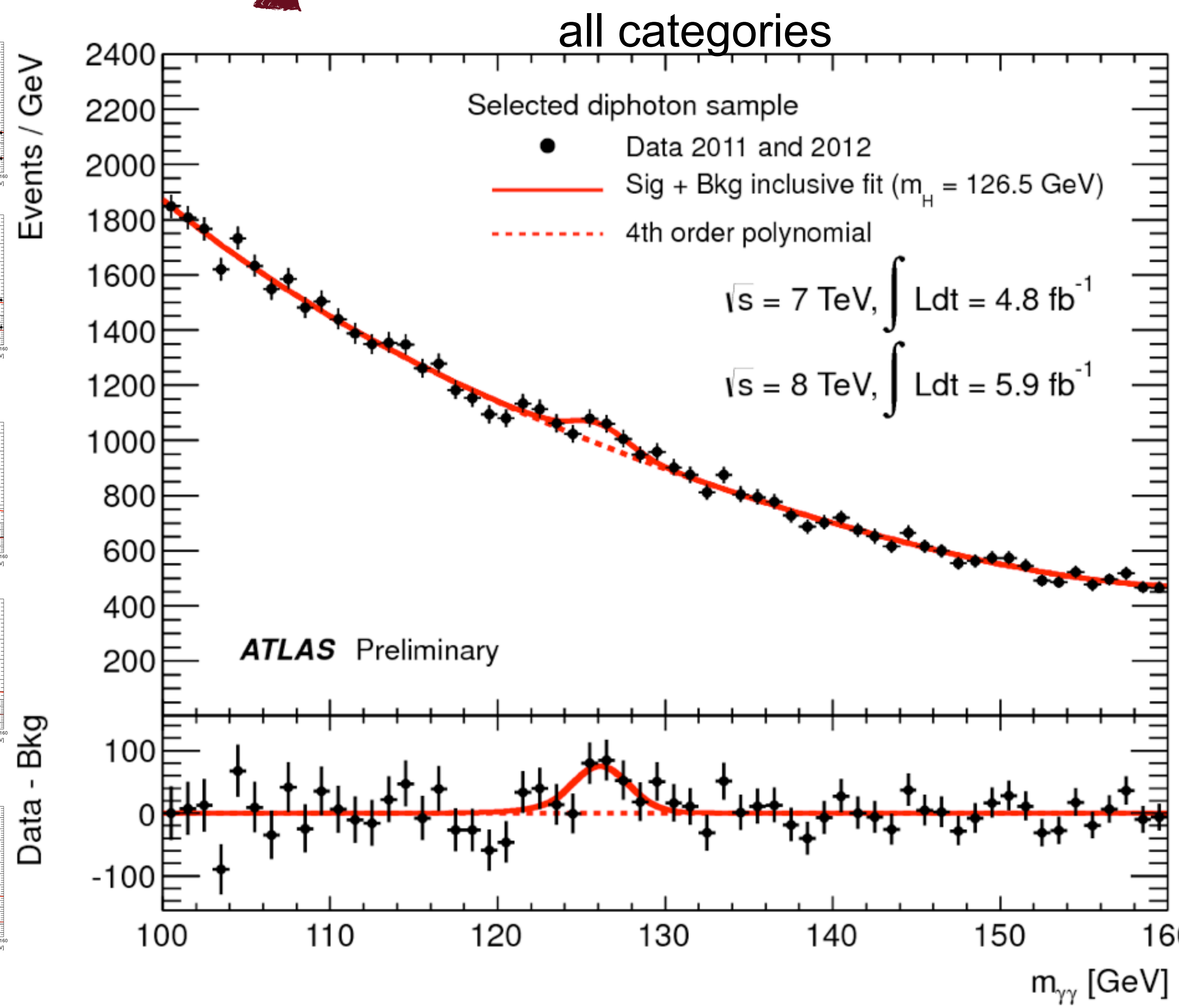
→ Consider nth-order polynomials, exponential and exponential(p2)

→ Choice based on small potential bias for 125 GeV (<20% of uncertainty on fitted signal yield or <10% of the number of expected signal events) and then on best expected significance

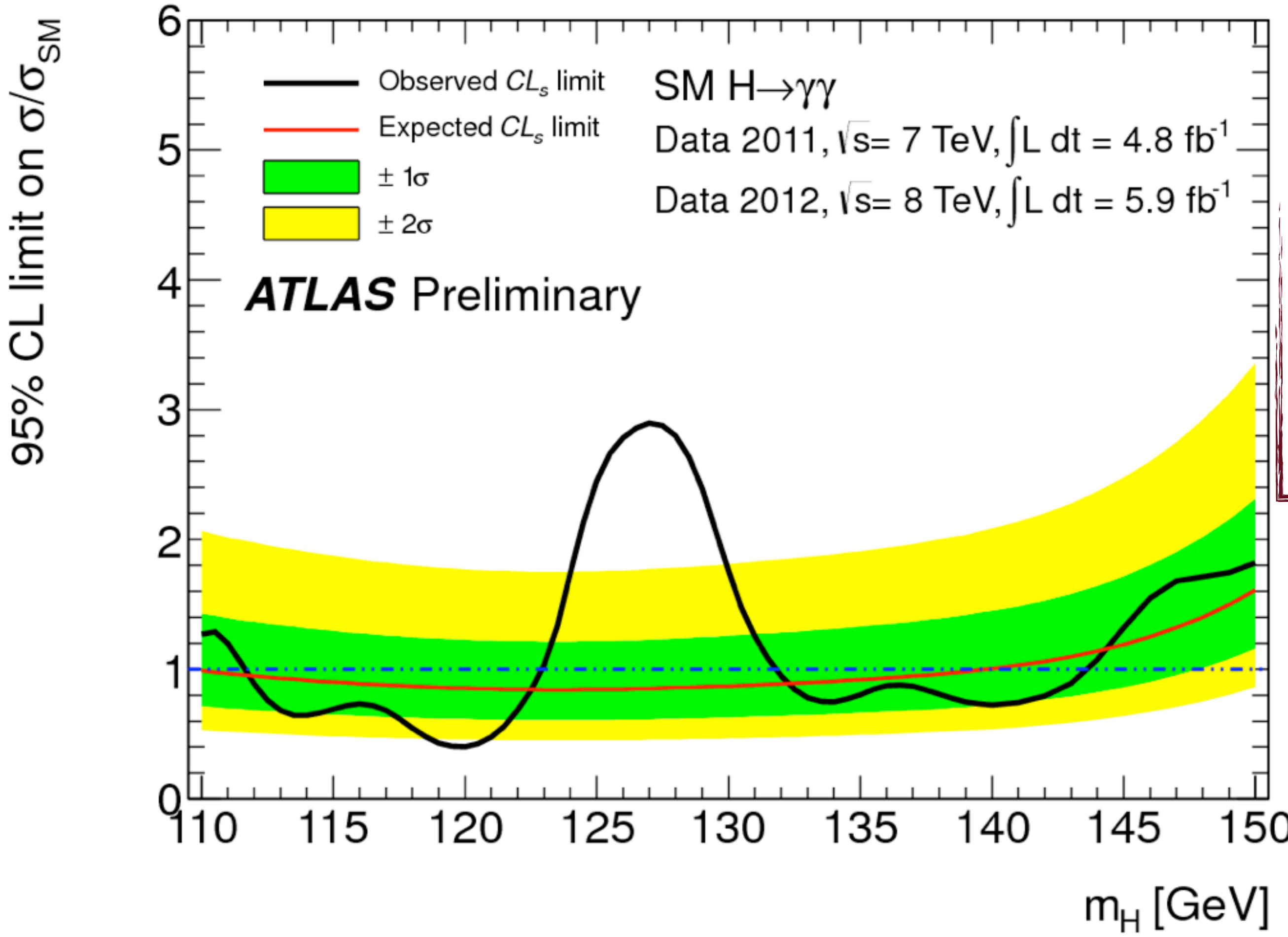
Category	Parametrization	Uncertainty [N_{evt}] $\sqrt{s}$ = 7 TeV	Uncertainty [N_{evt}] $\sqrt{s}$ = 8 TeV
Inclusive	4th order pol.	7.3	10.6
Unconverted central, low p_{Tt}	Exp. of 2nd order pol.	2.1	3.0
Unconverted central, high p_{Tt}	Exponential	0.2	0.3
Unconverted rest, low p_{Tt}	4th order pol.	2.2	3.3
Unconverted rest, high p_{Tt}	Exponential	0.5	0.8
Converted central, low p_{Tt}	Exp. of 2nd order pol.	1.6	2.3
Converted central, high p_{Tt}	Exponential	0.3	0.4
Converted rest, low p_{Tt}	4th order pol.	4.6	6.8
Converted rest, high p_{Tt}	Exponential	0.5	0.7
Converted transition	Exp. of 2nd order pol.	3.2	4.6
2-jets	Exponential	0.4	0.6

H→γγ: $m_{\gamma\gamma}$ spectra

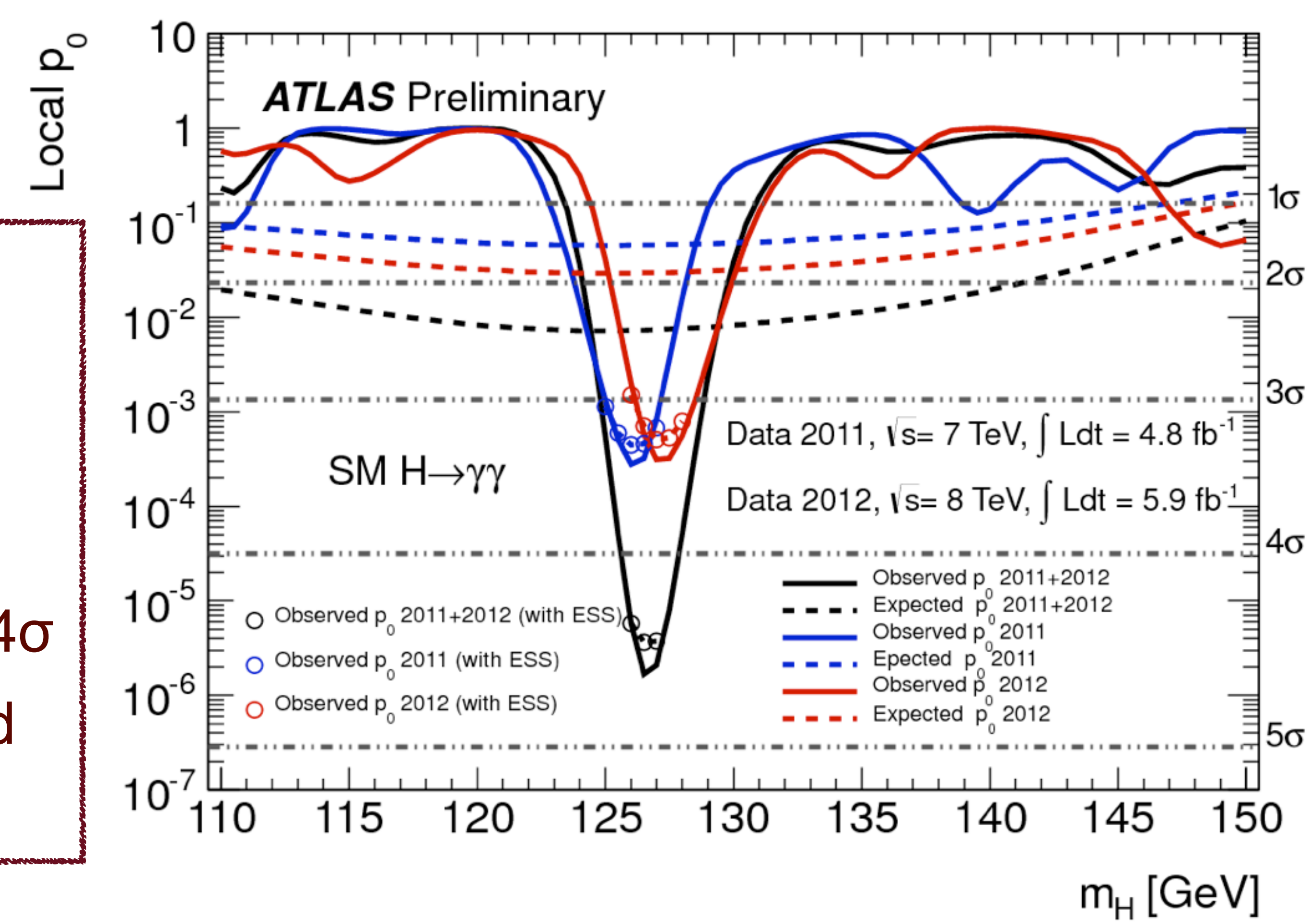




H→γγ: Results



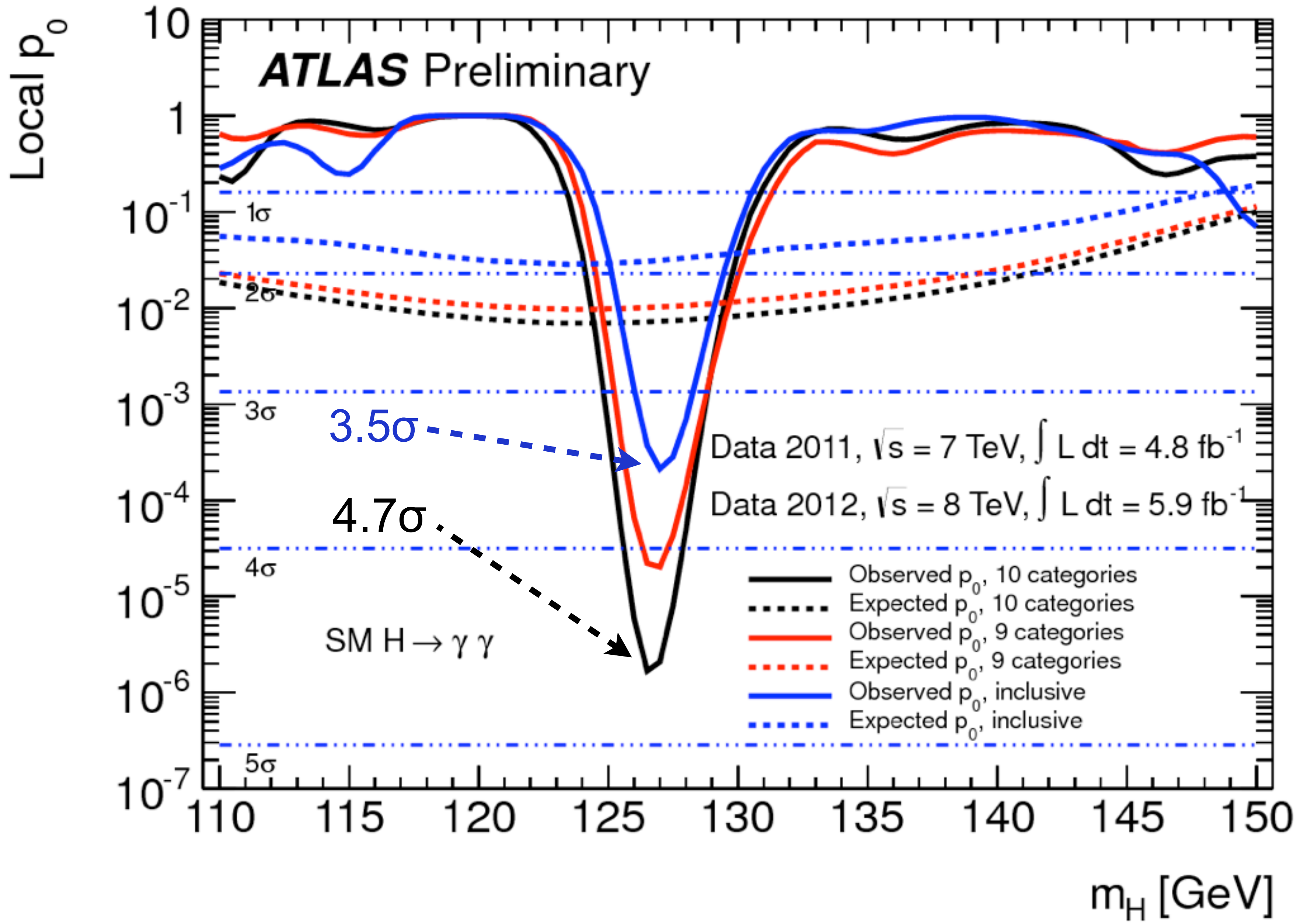
- Observed exclusion : 112-122.5 GeV and 132-143 GeV
- Expected exclusion : 110-139.5 GeV
- For m_H ~125-130 GeV much weaker limit than expected in the background-only hypothesis



<u>Most significant deviation from background only hypothesis at m_H =126.5 GeV:</u>

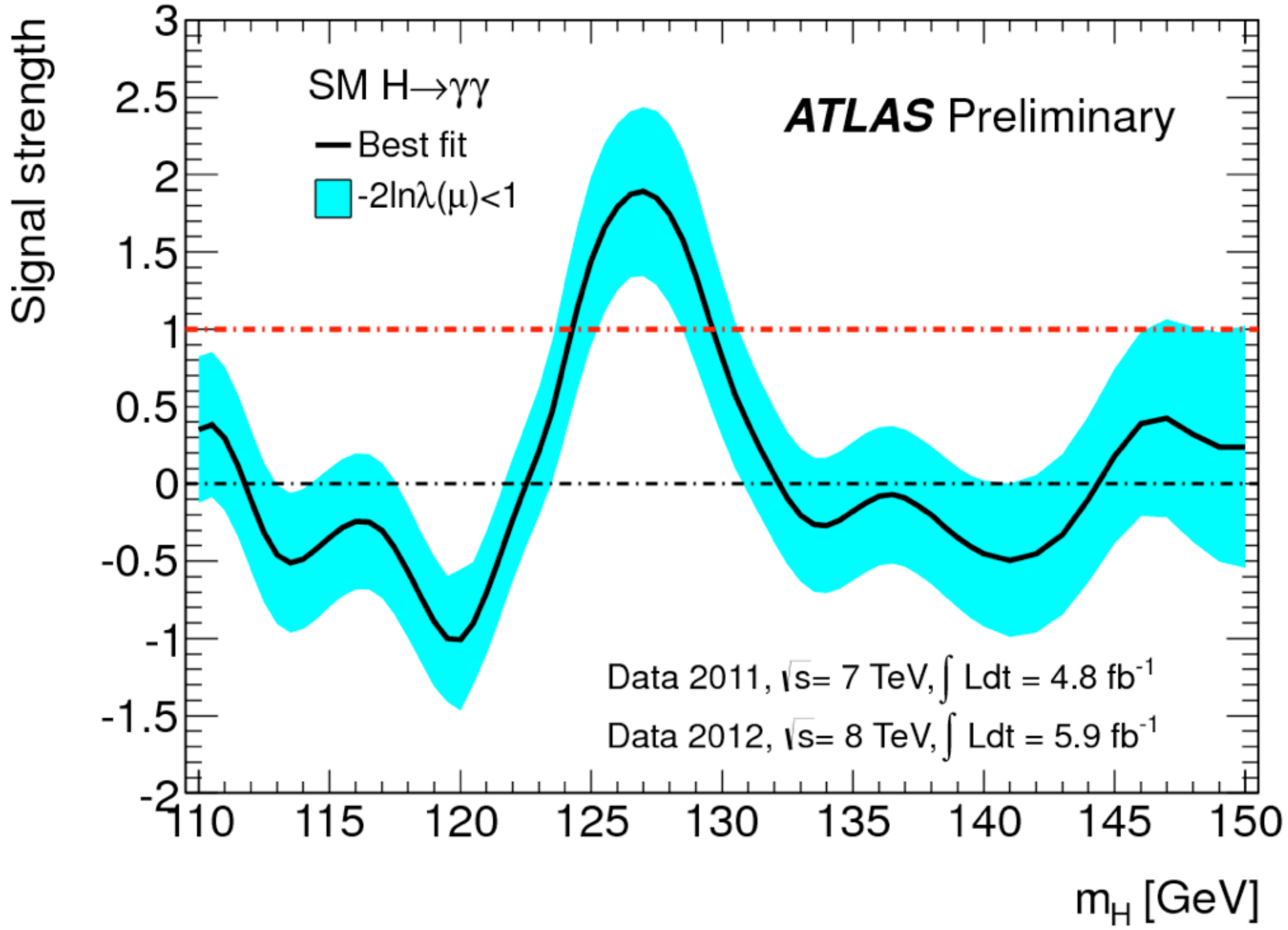
- 8 TeV (2012): 3.4σ at 127 GeV, expected 1.9σ
- 7 TeV (2011): 3.5σ at 126 GeV, expected 1.6σ
- Combined: **4.7σ** at m_H=126.5 GeV, expected 2.4σ
  - 4.5σ when Energy Scale Uncertainty included
- 3.6σ after look-elsewhere effect (110-150 GeV)

H→γγ: Effect of categories



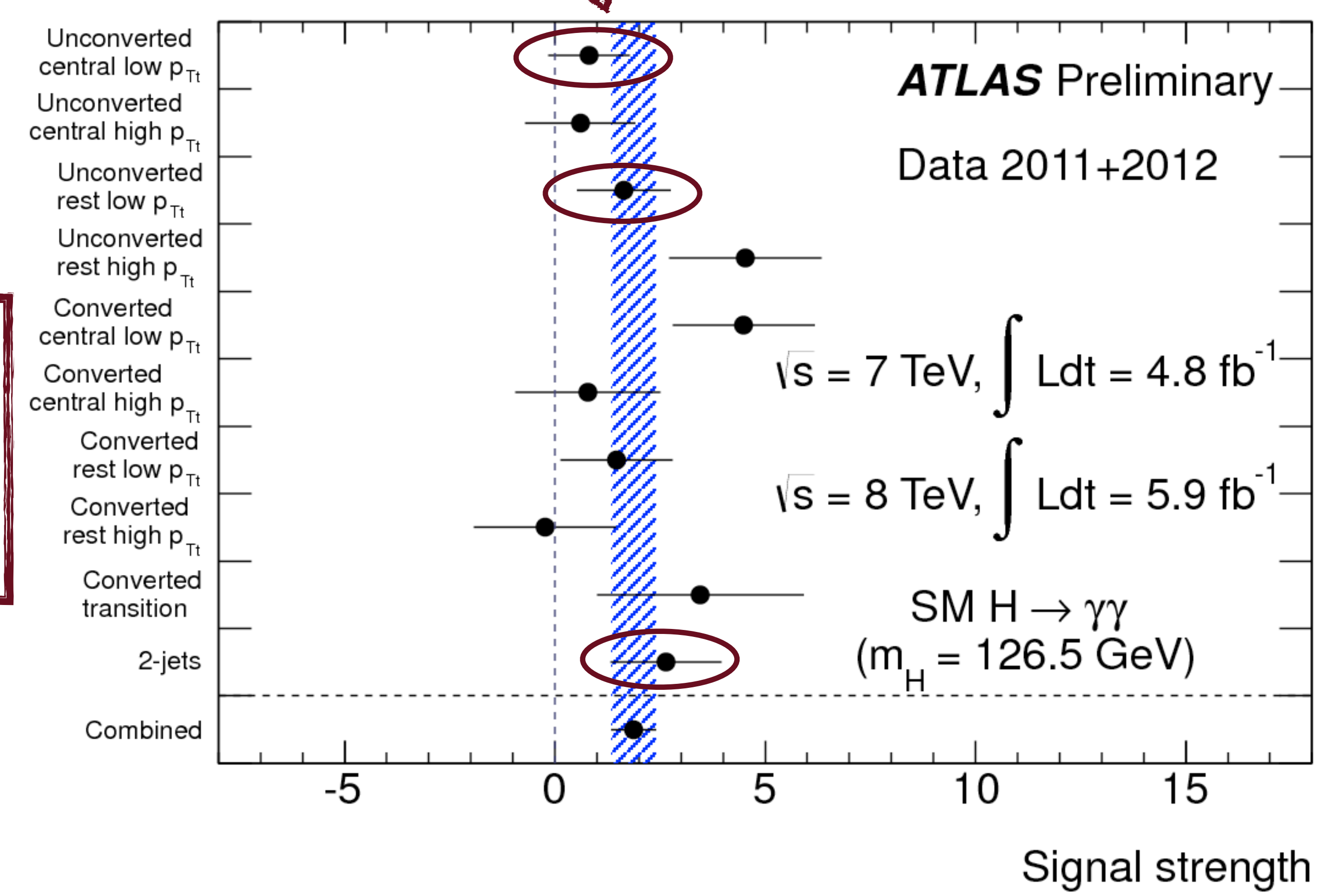
<u>Excess is robust even in simplified analysis</u>

H→γγ: Signal Strength



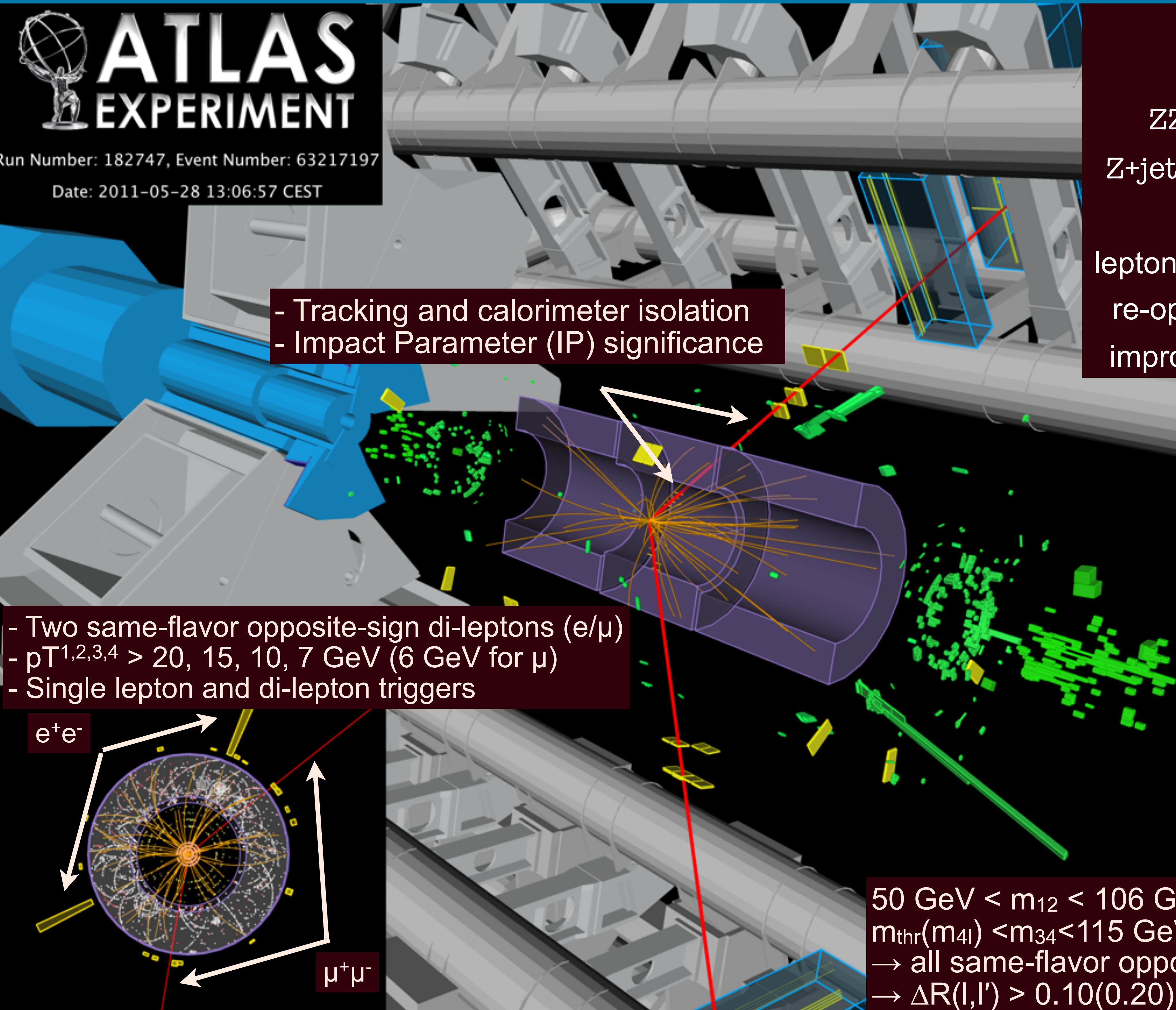
Signal strength (μ) =
(signal rate from fit to data)/
(expected SM signal rate at given m_H)

most sensitive categories



- Best-fit value for m_H =126.5 GeV: **μ=1.9 ± 0.5**
- Consistent picture obtained from all categories (within uncertainties)

$H \to ZZ^{(*)} \to 4l$



$H \to ZZ^{(*)} \to 4l$ (l=e,μ)

Backgrounds

$ZZ^{(*)} \to 4l$ and for $m_{4l} < 2m_Z$

Z+jets (Z+light jets/$Zb\bar{b}$) and $t\bar{t}$

<u>Improvements</u>

lepton performance improvements

re-optimize selection for low m_H

improved background estimates

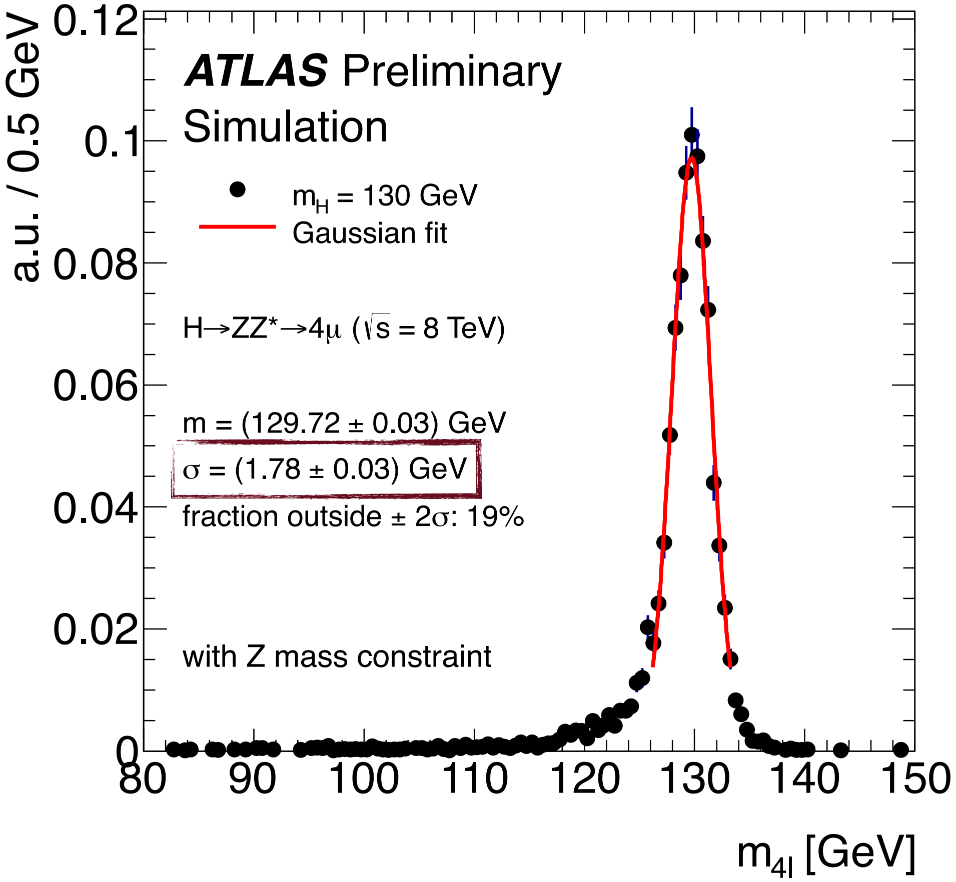
- Tracking and calorimeter isolation
- Impact Parameter (IP) significance

- Two same-flavor opposite-sign di-leptons (e/μ)
- $pT^{1,2,3,4}$ > 20, 15, 10, 7 GeV (6 GeV for μ)
- Single lepton and di-lepton triggers

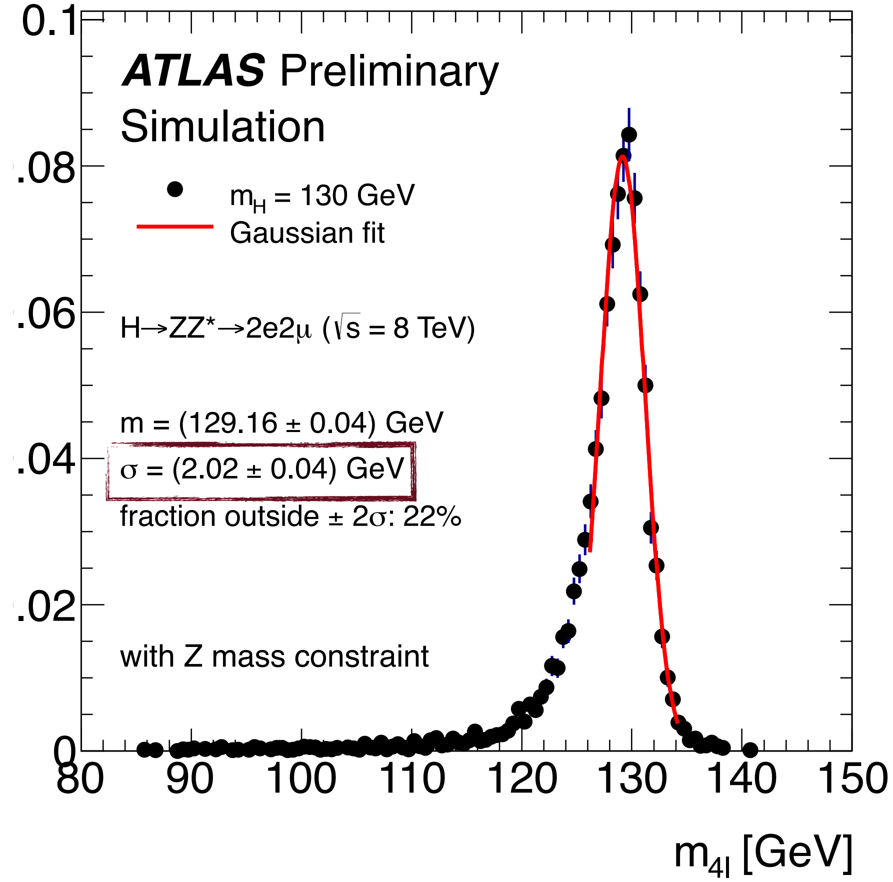
50 GeV < m_{12} < 106 GeV,
$m_{thr}(m_{4l}) < m_{34} < 115$ GeV m_{thr} =17.5 - 50 GeV
→ all same-flavor opposite-sign pairs m_{ll}>5 GeV
→ $\Delta R(l,l')$ > 0.10(0.20) for all same(different)-flavor

H→ZZ(*)→4l: Mass resolution

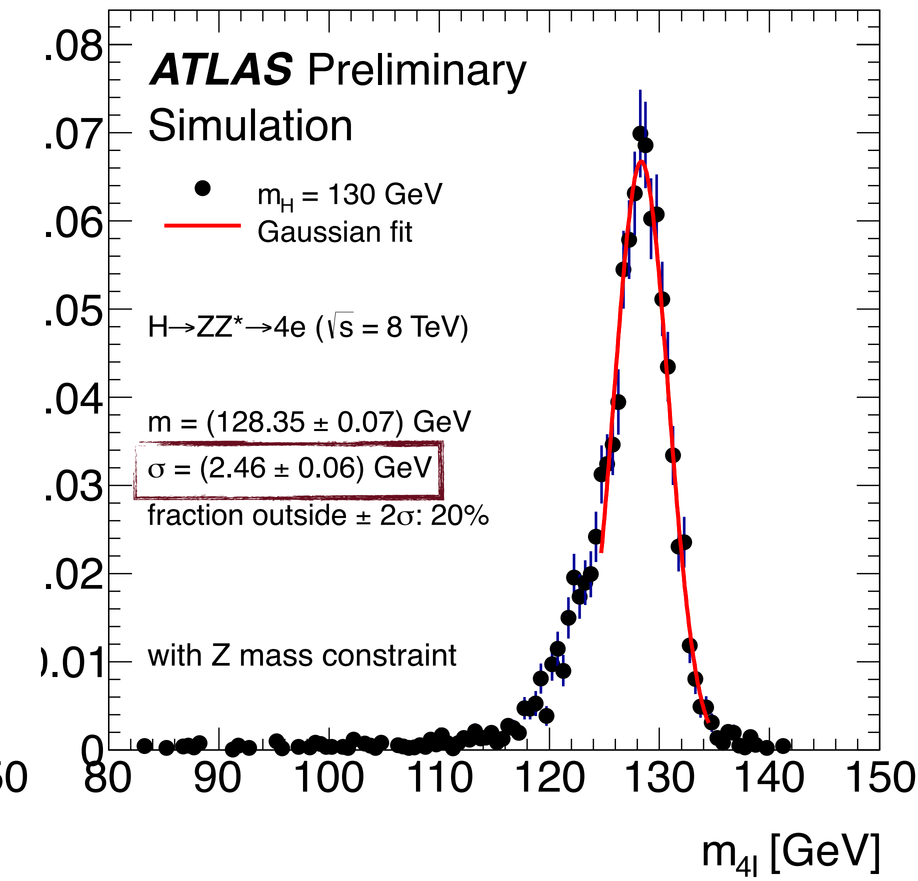
H→ZZ*→4μ



H→ZZ*→2e2μ/2μ2e



H→ZZ*→4e



Typical search for narrow peak on top of smooth background

→ Resolution crucial for sensitivity!

→ Final states separated in 4μ, 2μ2e, 2e2μ, 4e

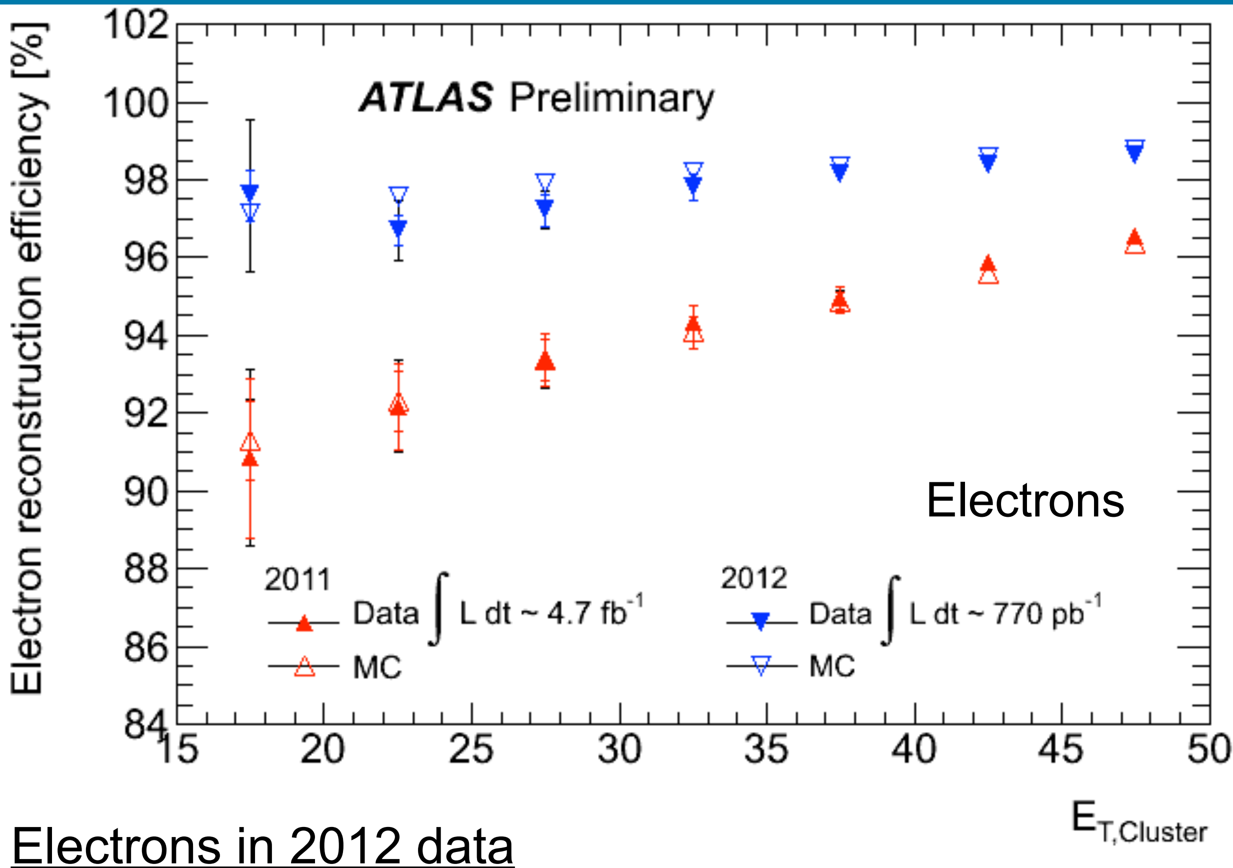
ATLAS detector provides excellent resolution!

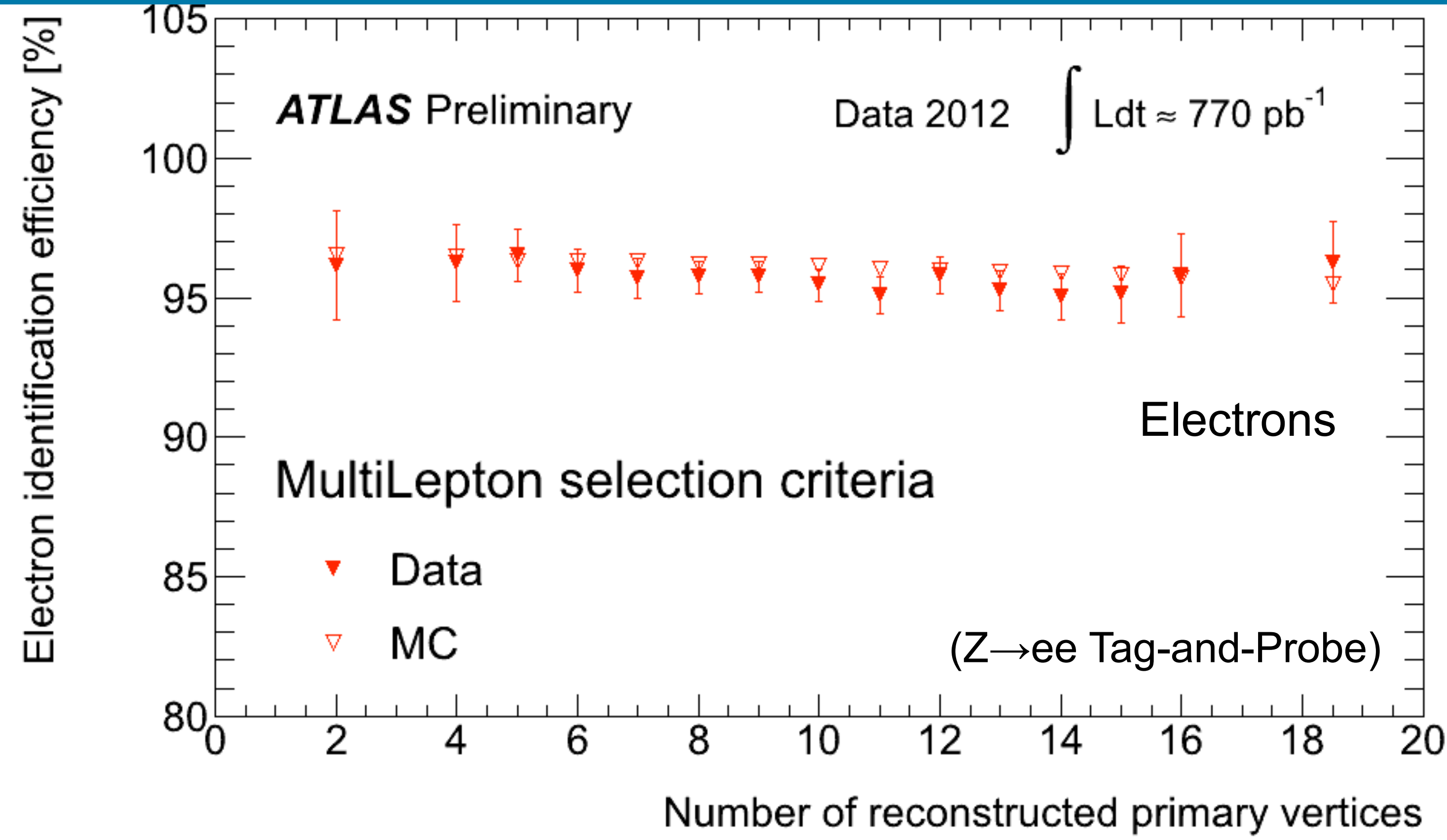
→ Relative resolution of 1.6 - 2.1% for m_H=130 GeV

Further improved by using m_Z constrained fit

→ Relative resolution of 1.3 - 1.9% for m_H=130 GeV

Lepton Reconstruction/Identification Performance



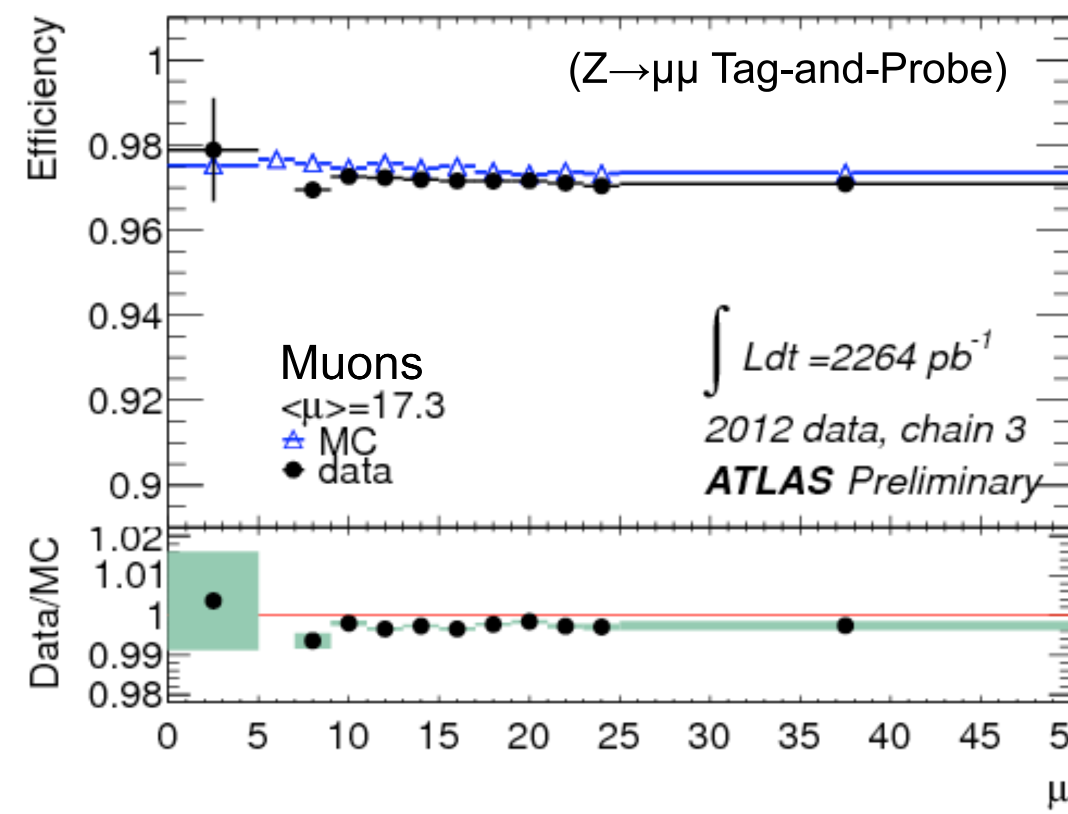


Electrons in 2012 data

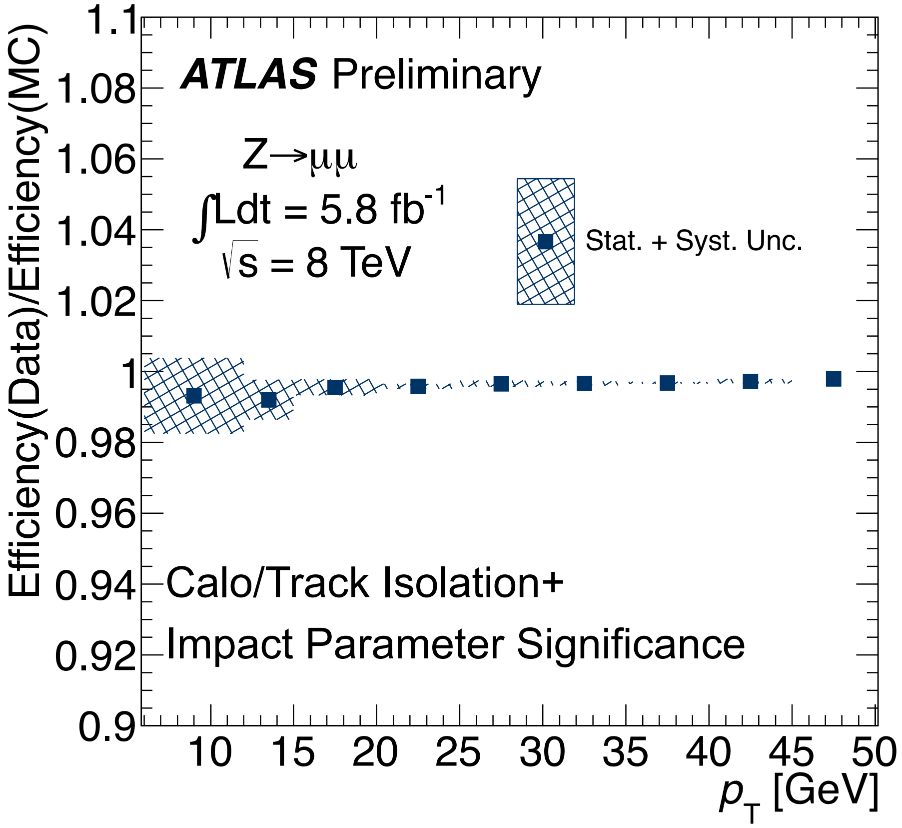
- Improved electron reconstruction!
  - New pattern finding/track-fit
- Improved electron identification!
  - Pile-up robust/Better performance wrt 2011 data
- Pile-up robust calorimeter-based isolation

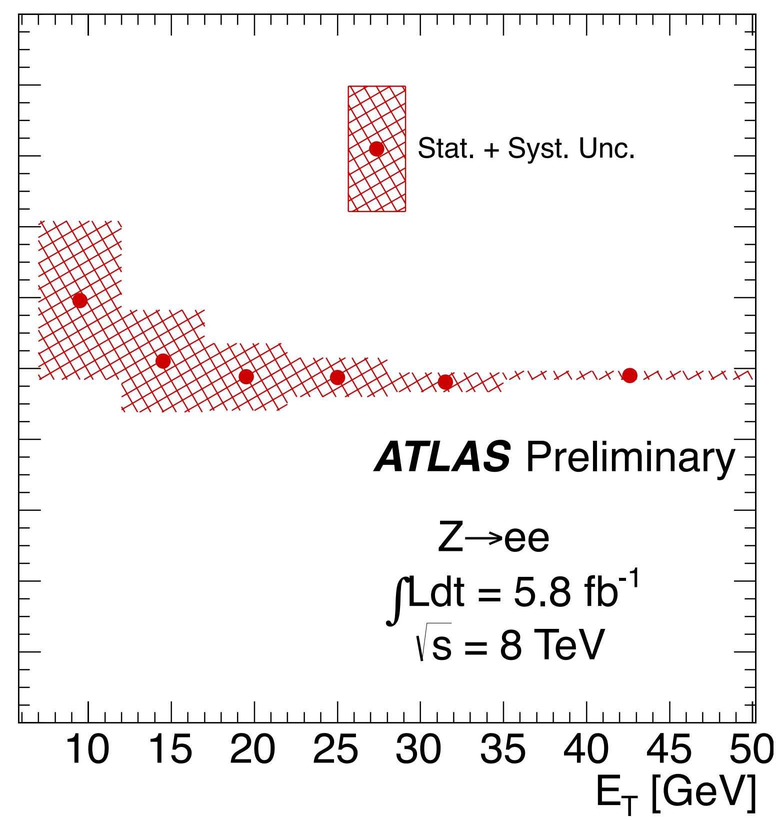
Muons

- Extended muon coverage wrt to 2011 analysis
  - Inner Detect track + energy deposit profile in calorimeter in regions of limited hardware coverage ($|\eta|<0.1$)
  - Muon Spectrometer stand-alone in regions without Inner Detector coverage ($2.5<|\eta|<2.7$)



Event Selection Performance Checks





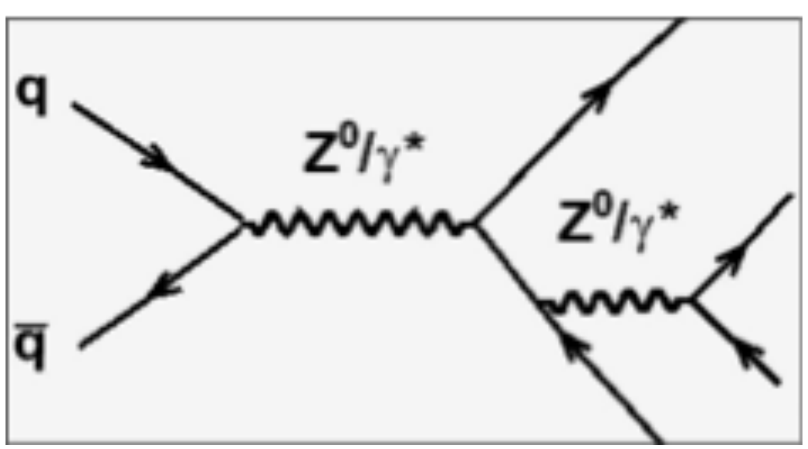
Isolation/IP requirement performance controlled from data

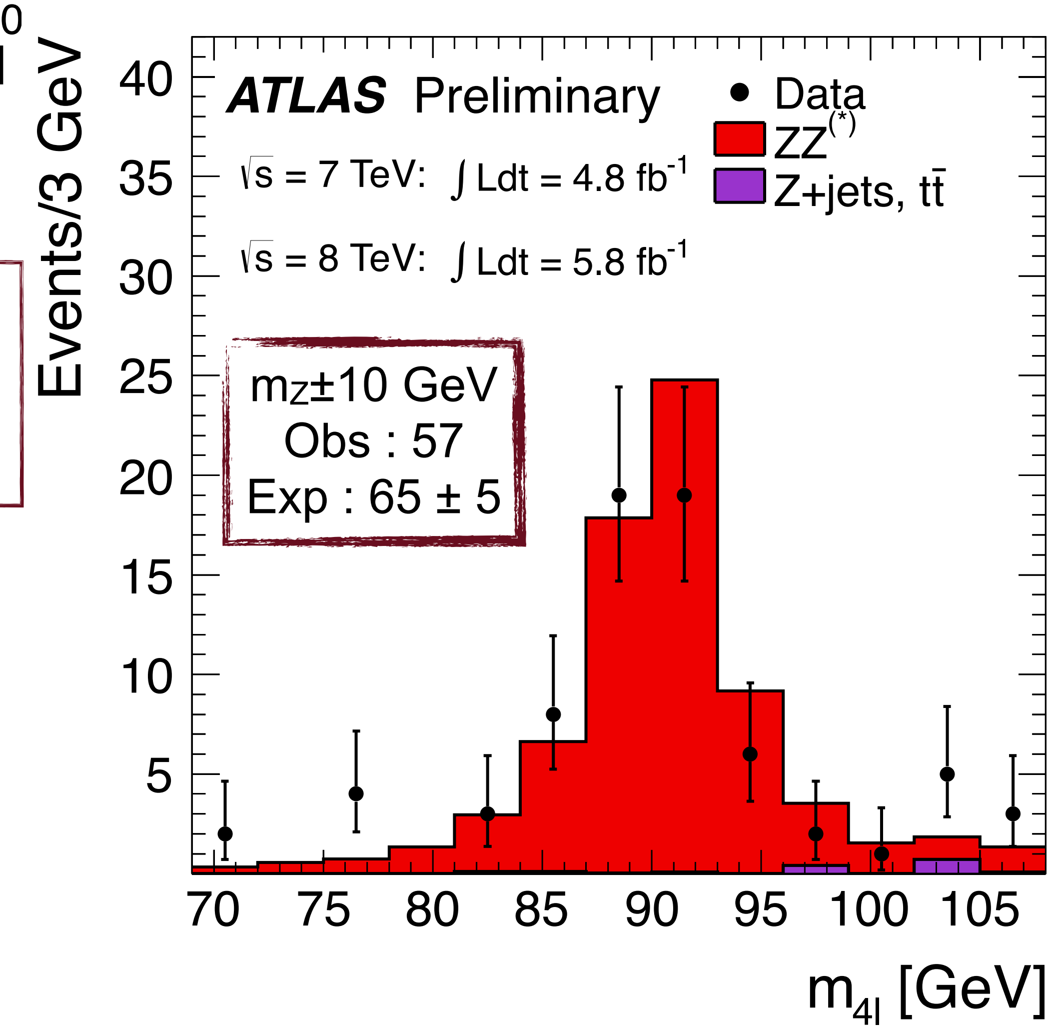
→ Signal-like leptons: Z→ll tag-and-probe

→ Background-like leptons: Z+‘μ’and Z+‘e’

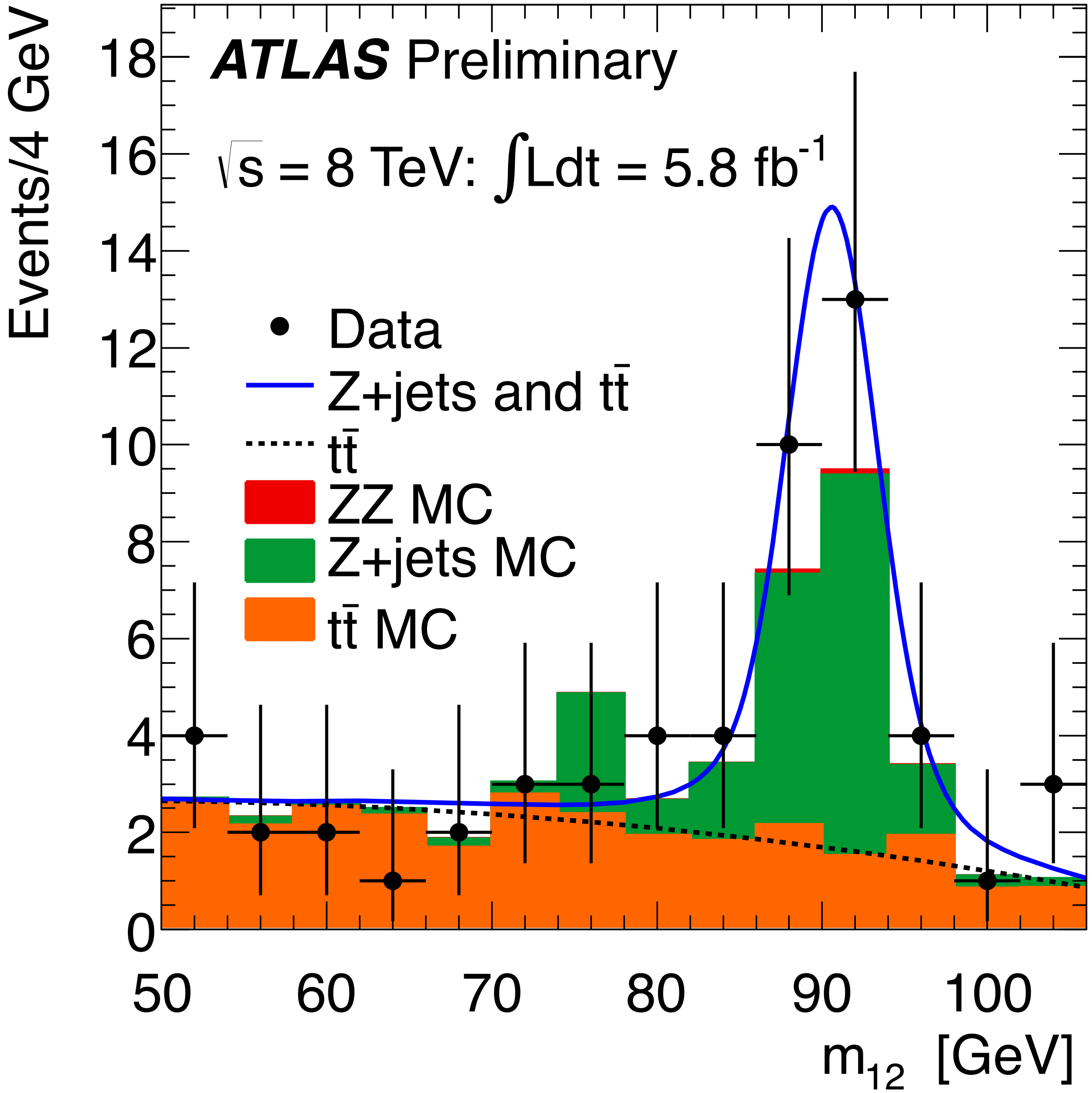
pp→Z→4l

Relax analysis requirements: m_{12}>30 GeV, m_{34}>5 GeV and lower p_T for muons (>4 GeV)





H→ZZ(*)→4l Background Estimates: ll+μμ



Main contributions from $Zb\bar{b}$ and $t\bar{t}$

m_{12} fit

- Sub-leading di-muon
  - Remove isolation requirement
  - Fail impact parameter significance requirement
- m_{12} spectrum: $Zb\bar{b}/t\bar{t}$ contributions clearly separated
- Obtain yields by fit of the two components
- Extrapolate to Signal Region
  - Transfer factors from MC
  - Cross-checked with data

$e^{\pm}\mu^{\mp}+\mu^{\pm}\mu^{\mp}$

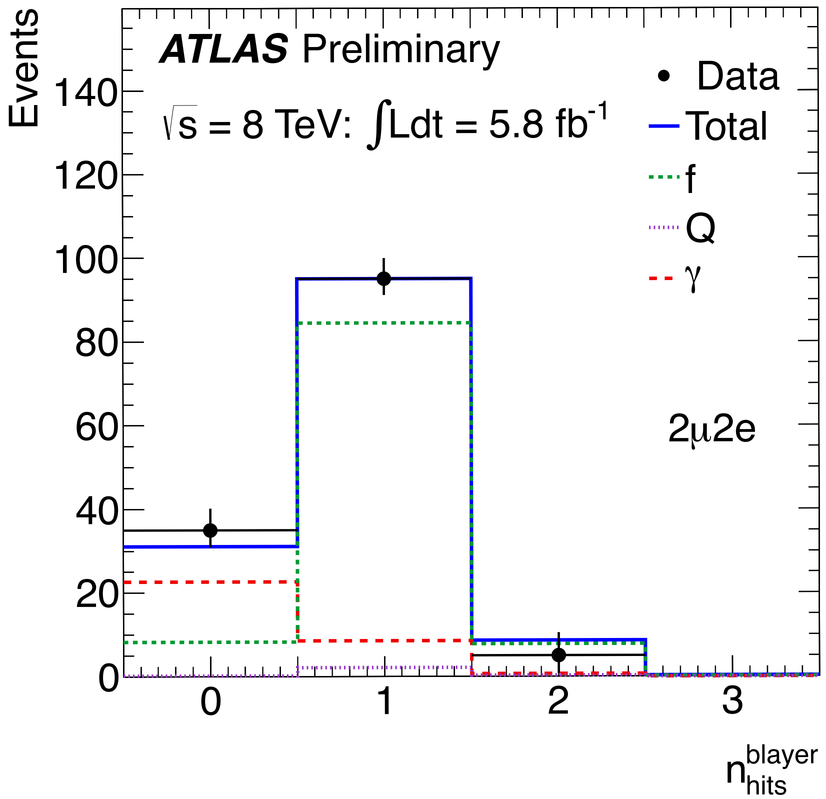
- $e^{\pm}\mu^{\mp}$ leading di-lepton with Z→ll veto → $t\bar{t}$ dominated
- Observed 16 (8) events compared to 18.9±1.1 (11.0 ± 0.6) expected in 8 (7) TeV
- Extrapolation to signal region → compatible results with m_{12} fit

H→ZZ(*)→4l Background Estimates: ll+ee

- Main contribution: Z+jets
  - Hadrons mis-identified as electrons (f)
  - Electrons from photon conversions (c/γ)
  - Electrons from semi-leptonic decays of heavy flavour (Q)
- Background composition crucial to extrapolate to Signal Region
- Use the strengths of the detector to constrain the composition
  - Transition Radiation
  - Number of B-layer hits
  - Fraction of energy in first sampling of e/m calorimeter
  - Lateral containment of cluster along φ in 2nd e/m sampling

8 TeV — Analysis phase-space, but relaxing electron identification for sub-leading di-electron

	4e		2μ2e	
	Data	MC	Data	MC
EE	32	22.7±4.8	31	24.9±5.0
EC	6	6.0±2.5	2	1.9±1.4
EF	18	19.0±4.4	26	15.3±3.9
CE	4	8.8±3.0	6	5.1±2.3
CC	1	5.3±2.3	6	4.2±2.0
CF	12	8.8±3.0	15	15.3±3.9
FE	16	5.7±2.4	12	8.4±2.9
FC	6	6.5±2.6	7	4.3±2.1
FF	12	17.4±4.2	16	33.6±5.8
Total	107	100±10	121	113±11



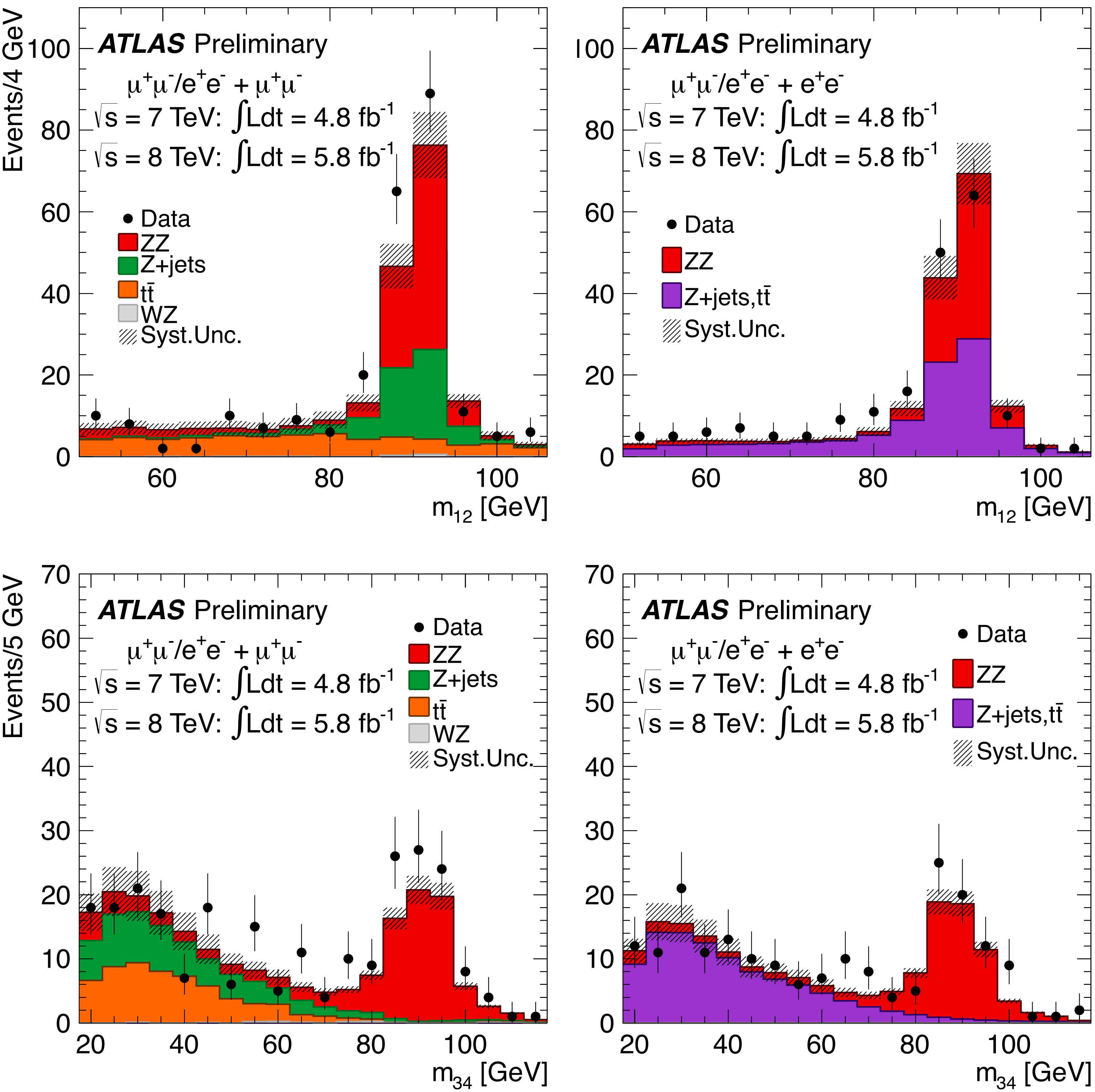
Base-line method

- Relax identification in sub-leading di-electron
- Categorize events [also check MC description]
- Extrapolate yields in each category to the signal region using MC

Alternative method in Same-Charge sub-leading di-electron

- Relax requirements on softest electron
- Composition from fit (separate Conversions/Hadrons)

$H \to ZZ^{(*)} \to 4l$ Background Estimates: Control Regions



Background-dominated Control Region

→ Remove isolation/impact parameter requirements on sub-leading di-lepton

→ Normalize to data-driven estimates

→ Normalization/shape of reducible backgrounds well described

$H \rightarrow ZZ^{(*)} \rightarrow 4l$ Background Estimates: Overview

8 TeV

Method	Estimated nr. of events
4μ	
m_{12} fit: Z + jets contribution	$0.51 \pm 0.13 \pm 0.16^{\dagger}$
m_{12} fit: $t\bar{t}$ contribution	$0.044 \pm 0.015 \pm 0.015^{\dagger}$
$t\bar{t}$ from $e^{\pm}\mu^{\mp} + \mu^{\pm}\mu^{\mp}$	$0.058 \pm 0.015 \pm 0.019$
$2e2\mu$	
m_{12} fit: Z + jets contribution	$0.41 \pm 0.10 \pm 0.13^{\dagger}$
m_{12} fit: $t\bar{t}$ contribution	$0.040 \pm 0.013 \pm 0.013^{\dagger}$
$t\bar{t}$ from $e^{\pm}\mu^{\mp} + \mu^{\pm}\mu^{\mp}$	$0.051 \pm 0.013 \pm 0.017$
$2\mu 2e$	
$\ell\ell + e^{\pm}e^{\mp}$	$4.9 \pm 0.8 \pm 0.7^{\dagger}$
$\ell\ell + e^{\pm}e^{\pm}$	$4.1 \pm 0.6 \pm 0.8$
$3\ell + \ell$ (same-sign)	$3.5 \pm 0.5 \pm 0.5$
$4e$	
$\ell\ell + e^{\pm}e^{\mp}$	$3.9 \pm 0.7 \pm 0.8^{\dagger}$
$\ell\ell + e^{\pm}e^{\pm}$	$3.1 \pm 0.5 \pm 0.6$
$3\ell + \ell$ (same-sign)	$3.0 \pm 0.4 \pm 0.4$

7 TeV

Method	Estimated nr. of events
4μ	
m_{12} fit: Z + jets contribution	$0.25 \pm 0.10 \pm 0.08^{\dagger}$
m_{12} fit: $t\bar{t}$ contribution	$0.022 \pm 0.010 \pm 0.011^{\dagger}$
$t\bar{t}$ from $e^{\pm}\mu^{\mp} + \mu^{\pm}\mu^{\mp}$	$0.025 \pm 0.009 \pm 0.014$
$2e2\mu$	
m_{12} fit: Z + jets contribution	$0.20 \pm 0.08 \pm 0.06^{\dagger}$
m_{12} fit: $t\bar{t}$ contribution	$0.020 \pm 0.009 \pm 0.011^{\dagger}$
$t\bar{t}$ from $e^{\pm}\mu^{\mp} + \mu^{\pm}\mu^{\mp}$	$0.024 \pm 0.009 \pm 0.014$
$2\mu 2e$	
$\ell\ell + e^{\pm}e^{\mp}$	$2.6 \pm 0.4 \pm 0.4^{\dagger}$
$\ell\ell + e^{\pm}e^{\pm}$	$3.7 \pm 0.9 \pm 0.6$
$3\ell + \ell$ (same-sign)	$2.0 \pm 0.5 \pm 0.3$
$4e$	
$\ell\ell + e^{\pm}e^{\mp}$	$3.1 \pm 0.6 \pm 0.5^{\dagger}$
$\ell\ell + e^{\pm}e^{\pm}$	$3.2 \pm 0.6 \pm 0.5$
$3\ell + \ell$ (same-sign)	$2.2 \pm 0.5 \pm 0.3$

value ± stat ± syst

→ Multiple methods used, yielding compatible results

→ For each channel, the "†" symbol indicates the method used for the nominal normalization

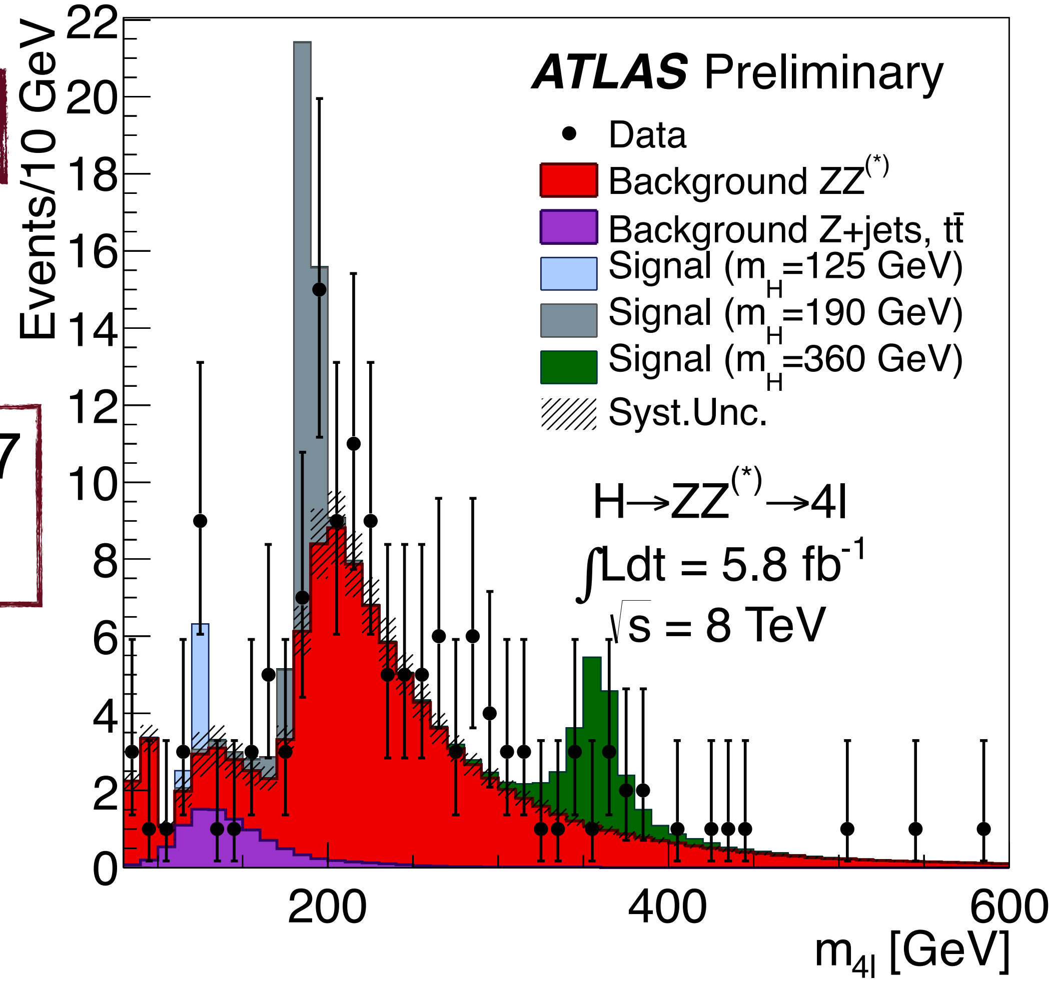
→ Uncertainties vary between 20% and 70% depending on background and data sample

H→ZZ(*)→4l: Results of Event Selection

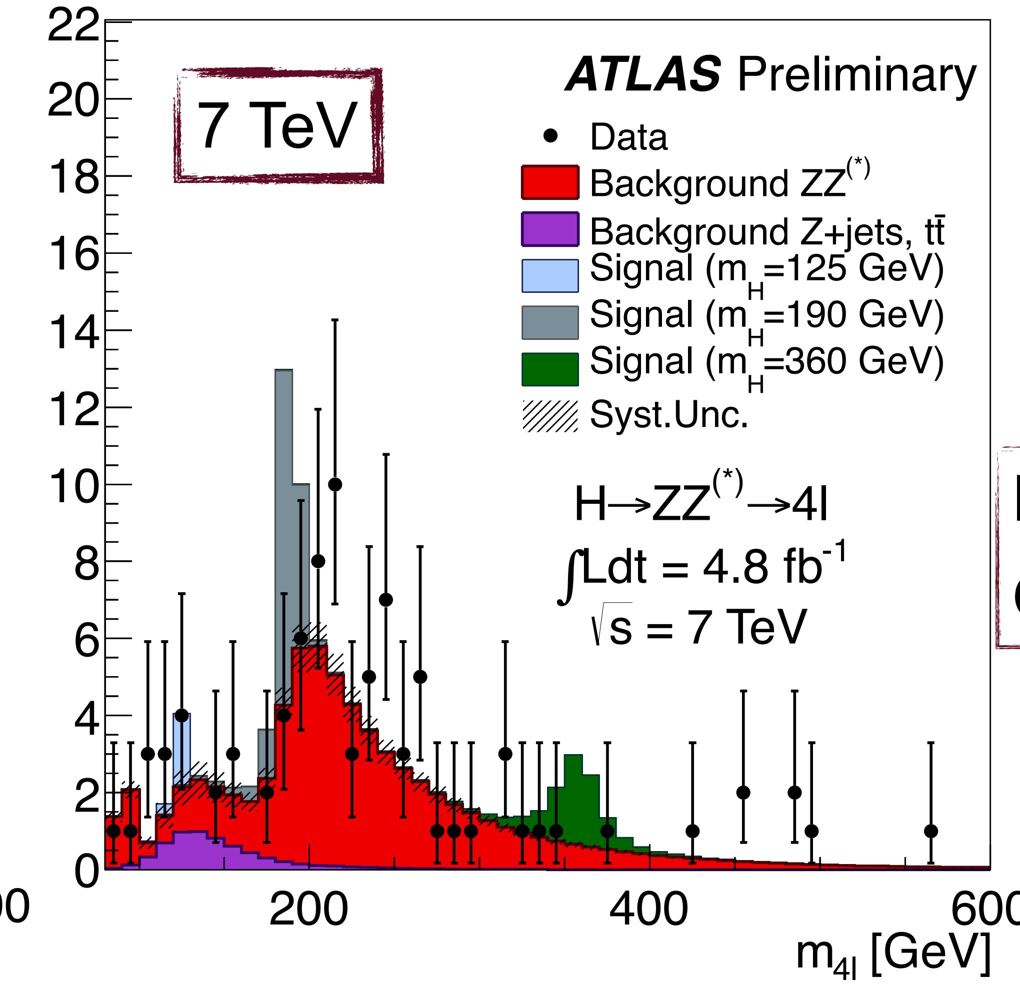
8 TeV

Exp. 109±7

Obs. 142



7 TeV



Exp. 71±5

Obs. 88

Observed events in the range $80 < m_{4l} < 600$ GeV for 7 and 8 TeV

For $m_{4l}>160$ GeV:

→ Observe ~20-30% more events than expected for 2011 and 2012

→ Events have the expected characteristics for ZZ→4l production

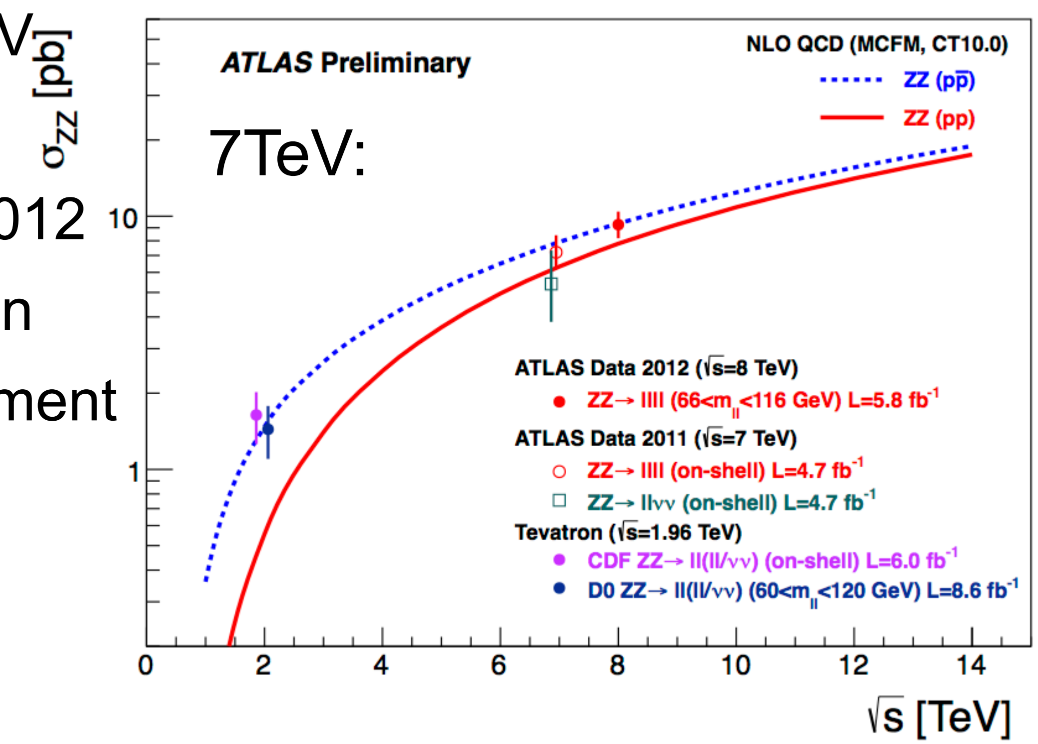
→ Reflected in the ATLAS ZZ production cross-section measurement

7 TeV Measurement: $(7.2^{+1.2}_{-1.0})$ pb

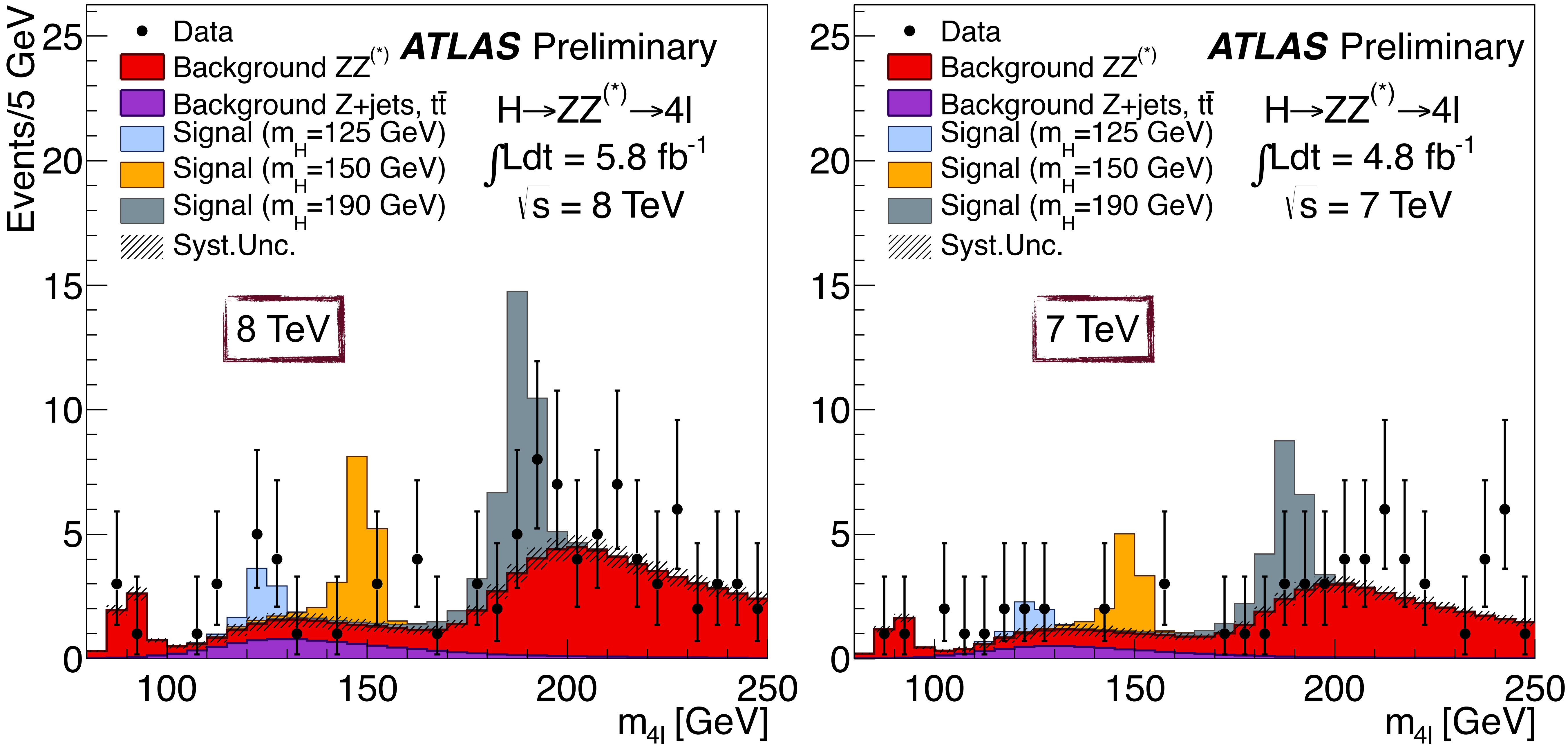
7 TeV NLO Prediction: $(6.5^{+0.3}_{-0.2})$ pb

8 TeV Measurement: $(9.3^{+1.2}_{-1.1})$ pb

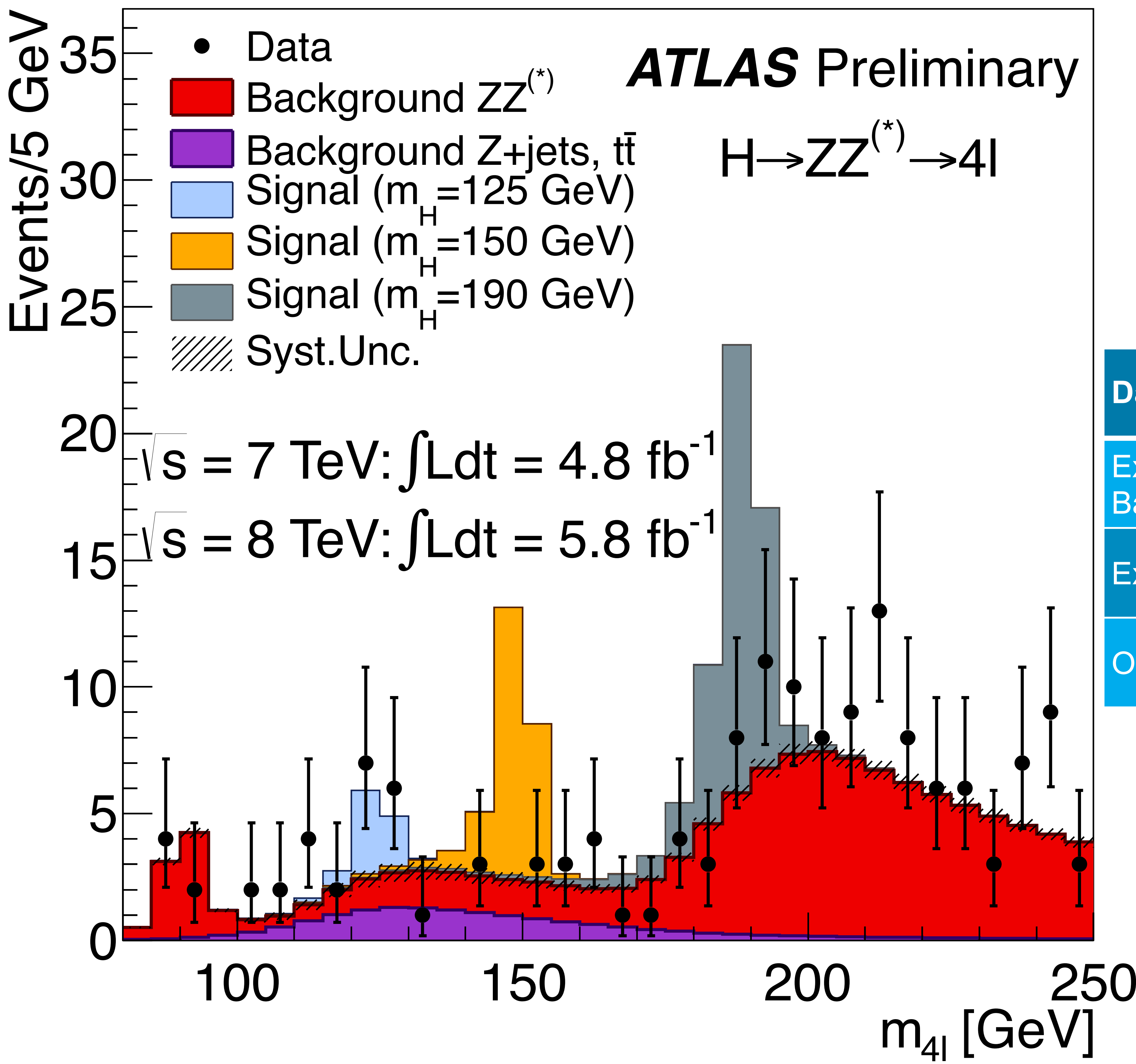
8 TeV NLO Prediction: (7.4±0.4) pb



$H \to ZZ^{(*)} \to 4l$: Results of Event Selection



H→ZZ(*)→4l: Results of Event Selection



for m_{4l} region with 125±5GeV

Dataset	2011	2012	Combined
Exp. Background	2.1±0.3	2.9±0.4	5.1±0.8
Exp. Signal	2.0±0.3	3.3±0.5	5.3±0.8
Observed	4	9	13

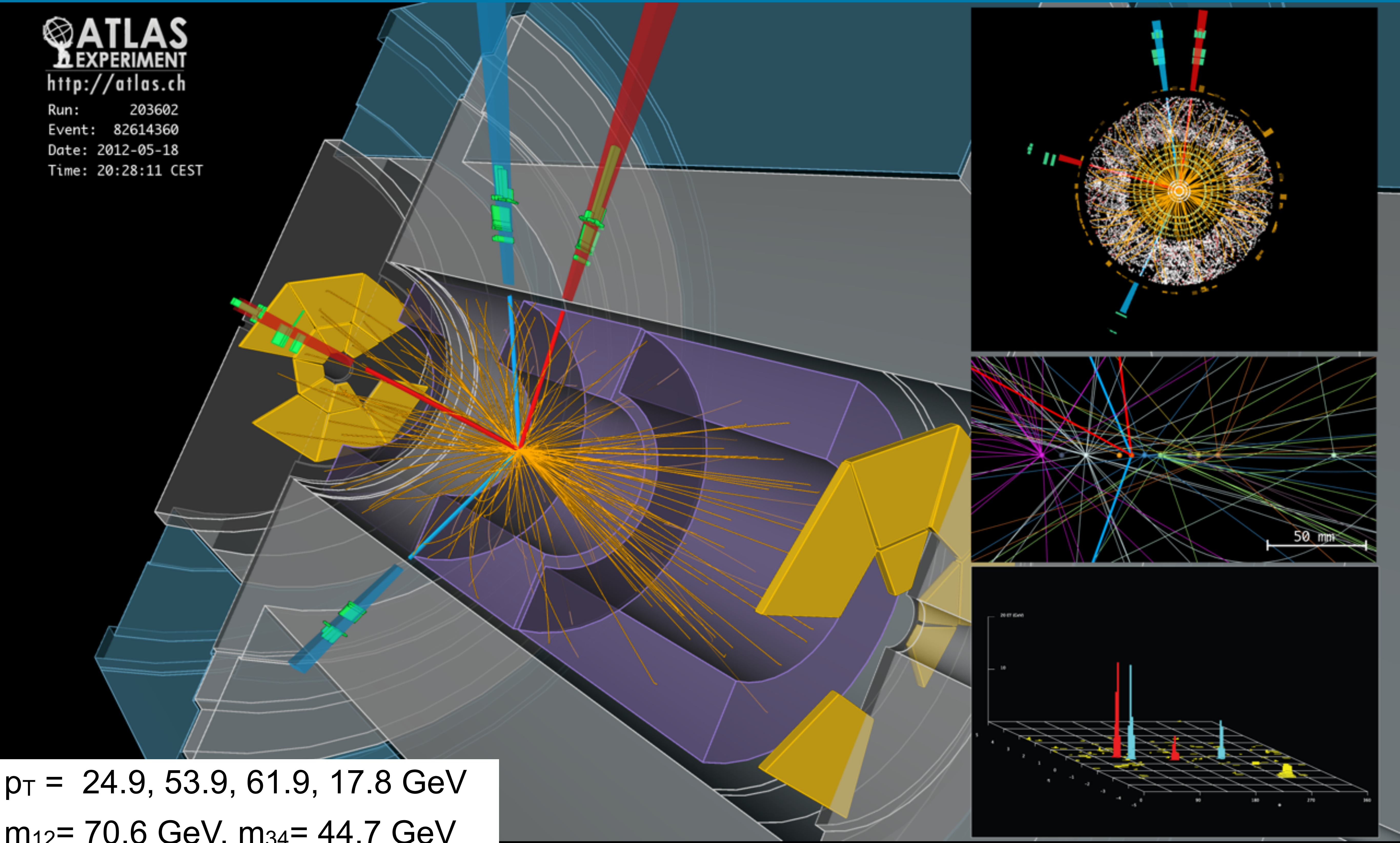
Expected S/B for m_H=125 GeV

4μ ~1.6

2e2μ/2μ2e ~1.0

4e ~0.6

eeee candidate with m_{4l} = 124.6 GeV

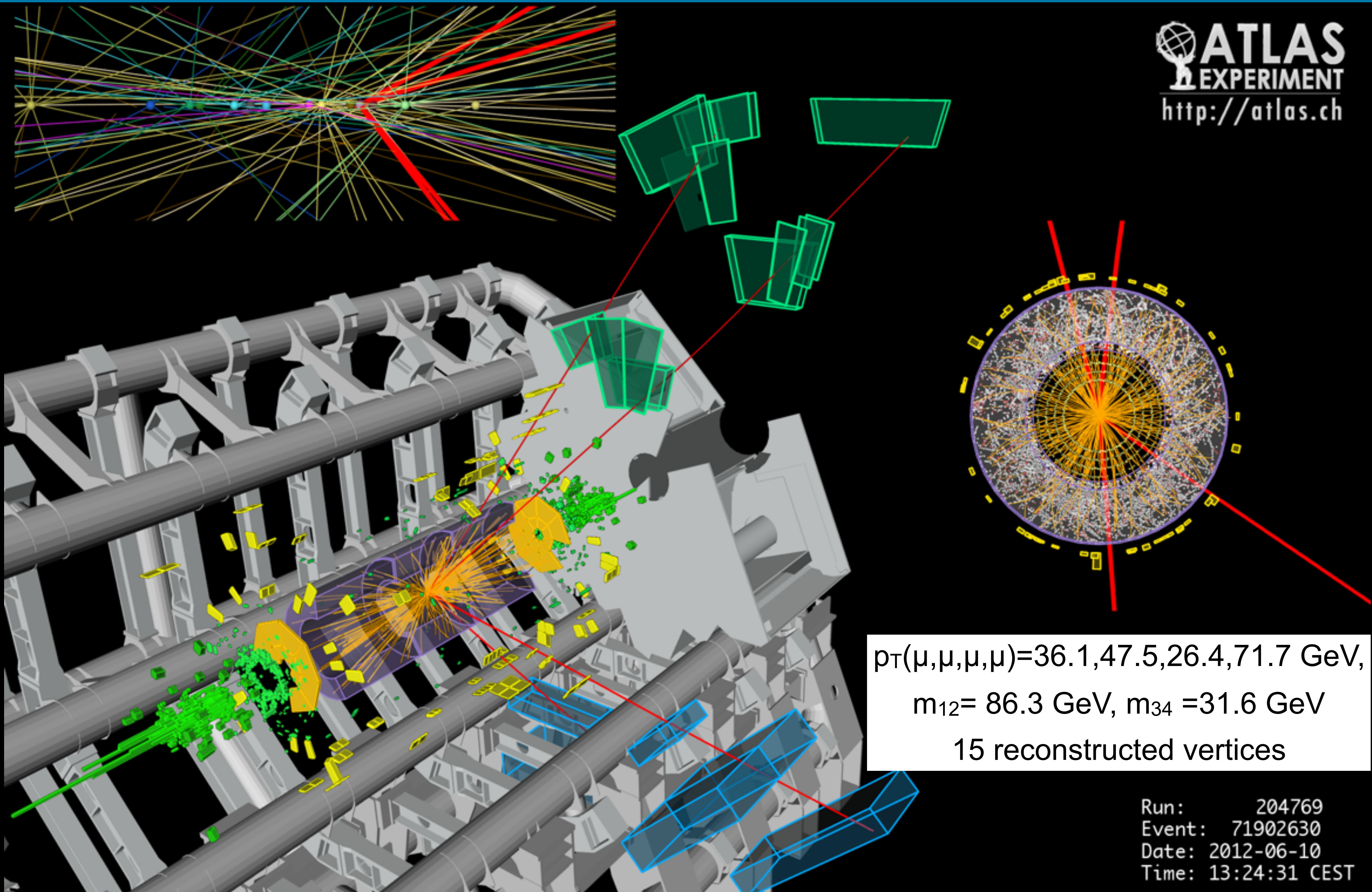


p_T = 24.9, 53.9, 61.9, 17.8 GeV

m_{12}= 70.6 GeV, m_{34}= 44.7 GeV

12 reconstructed vertices

μμμμ candidate with m_{4l} = 125.1 GeV

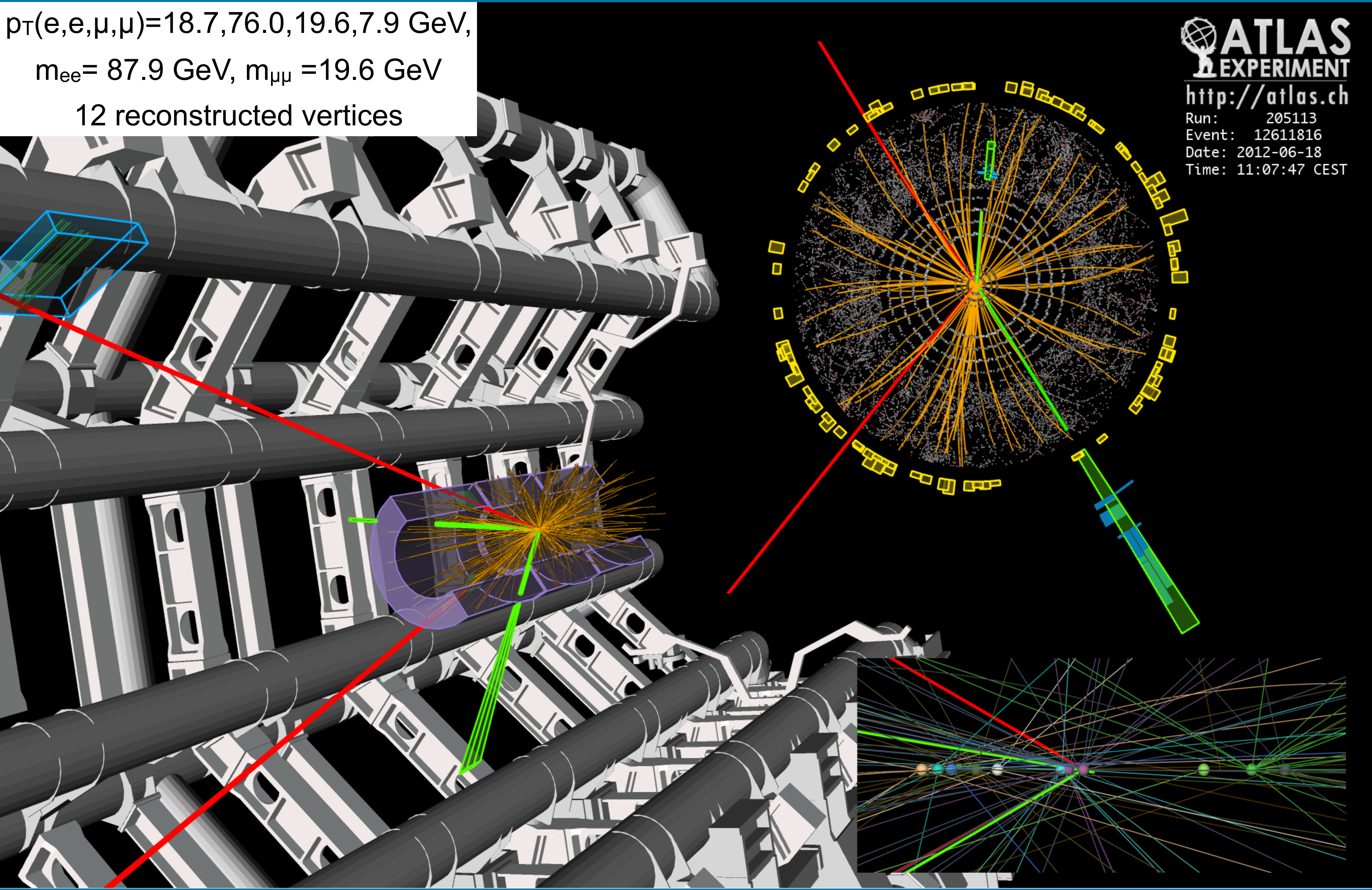


eeμμ candidate with m_{4l} = 123.9 GeV

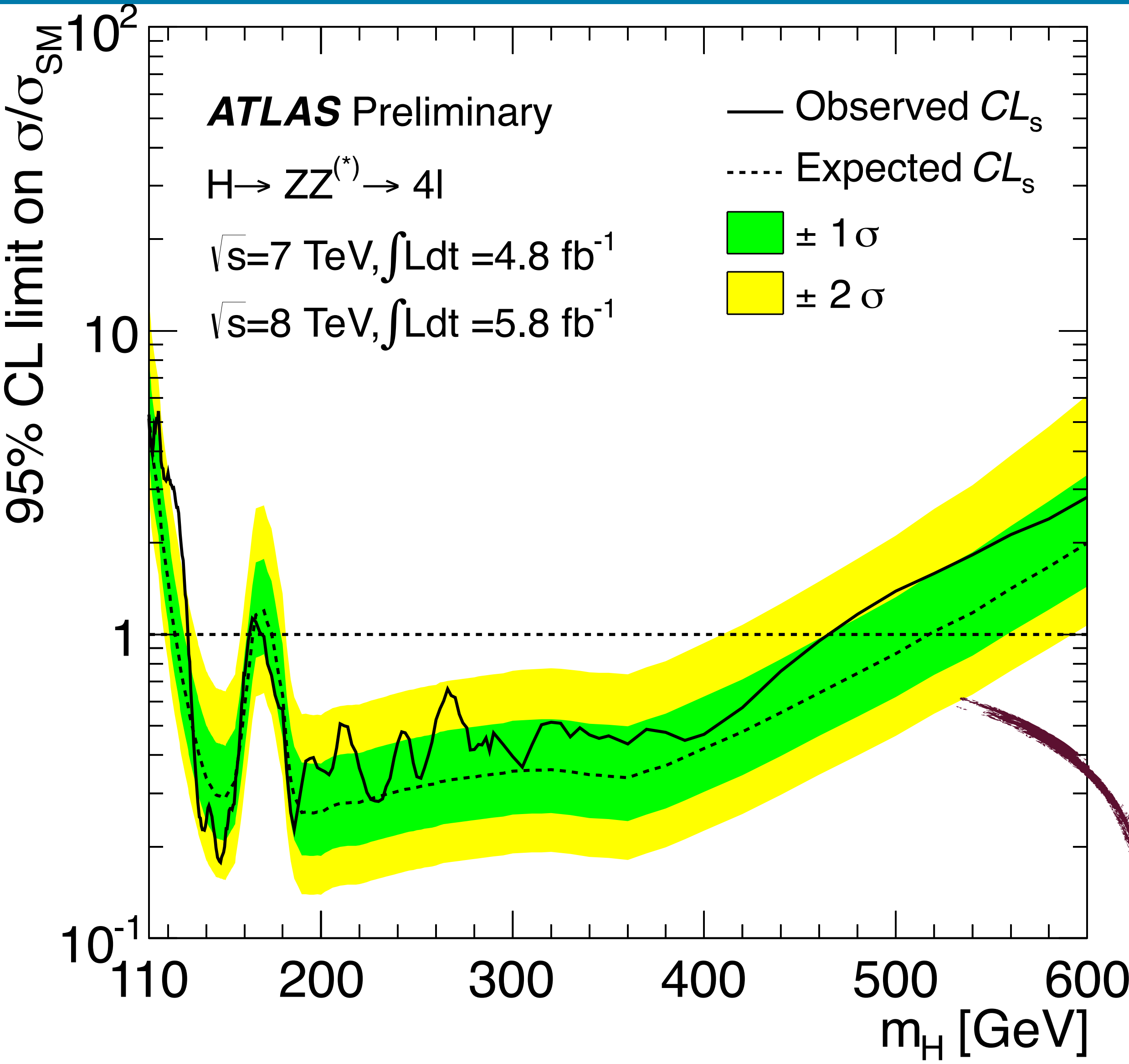
$p_T(e,e,\mu,\mu)$=18.7,76.0,19.6,7.9 GeV,

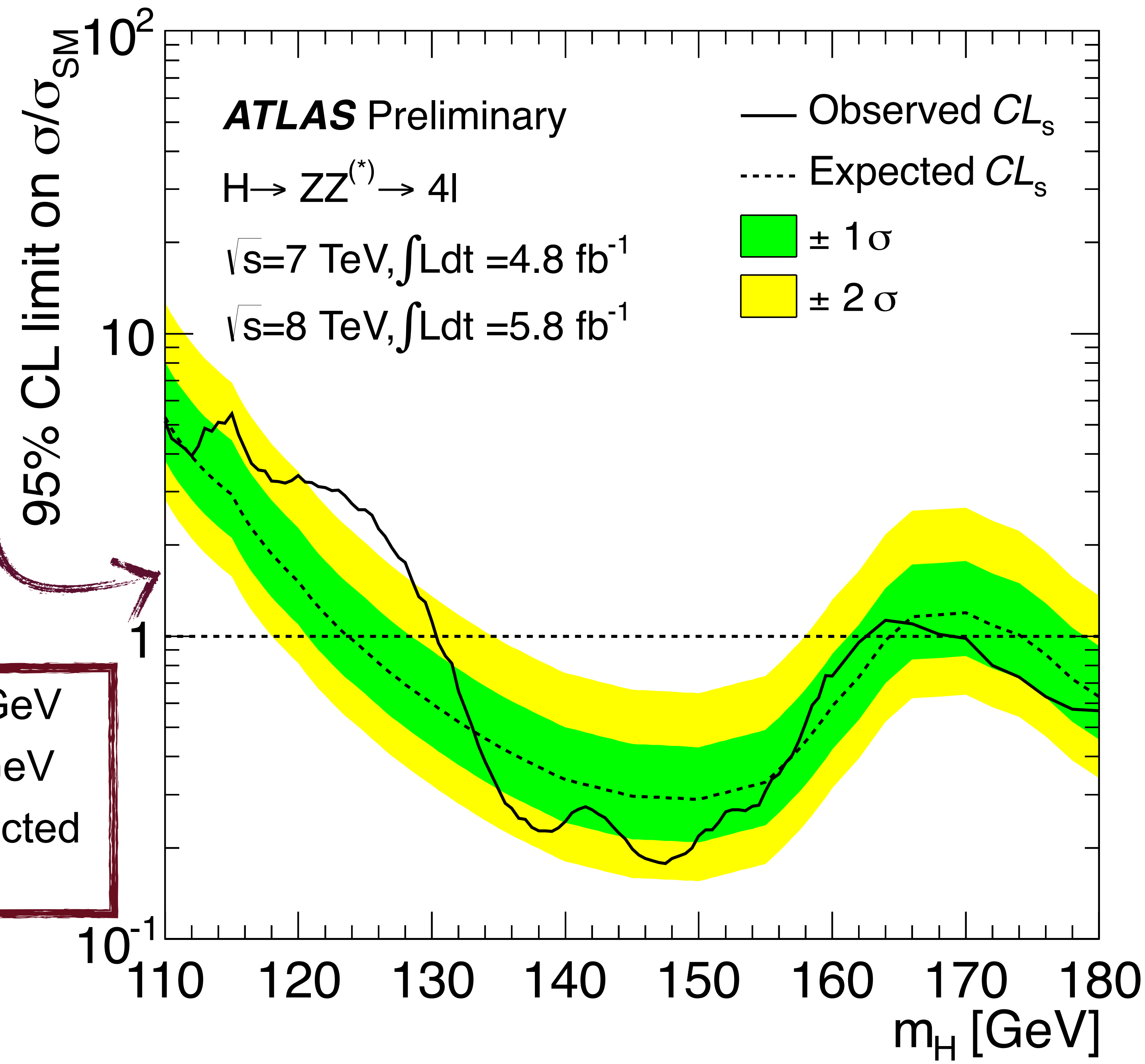
m_{ee}= 87.9 GeV, $m_{\mu\mu}$ =19.6 GeV

12 reconstructed vertices



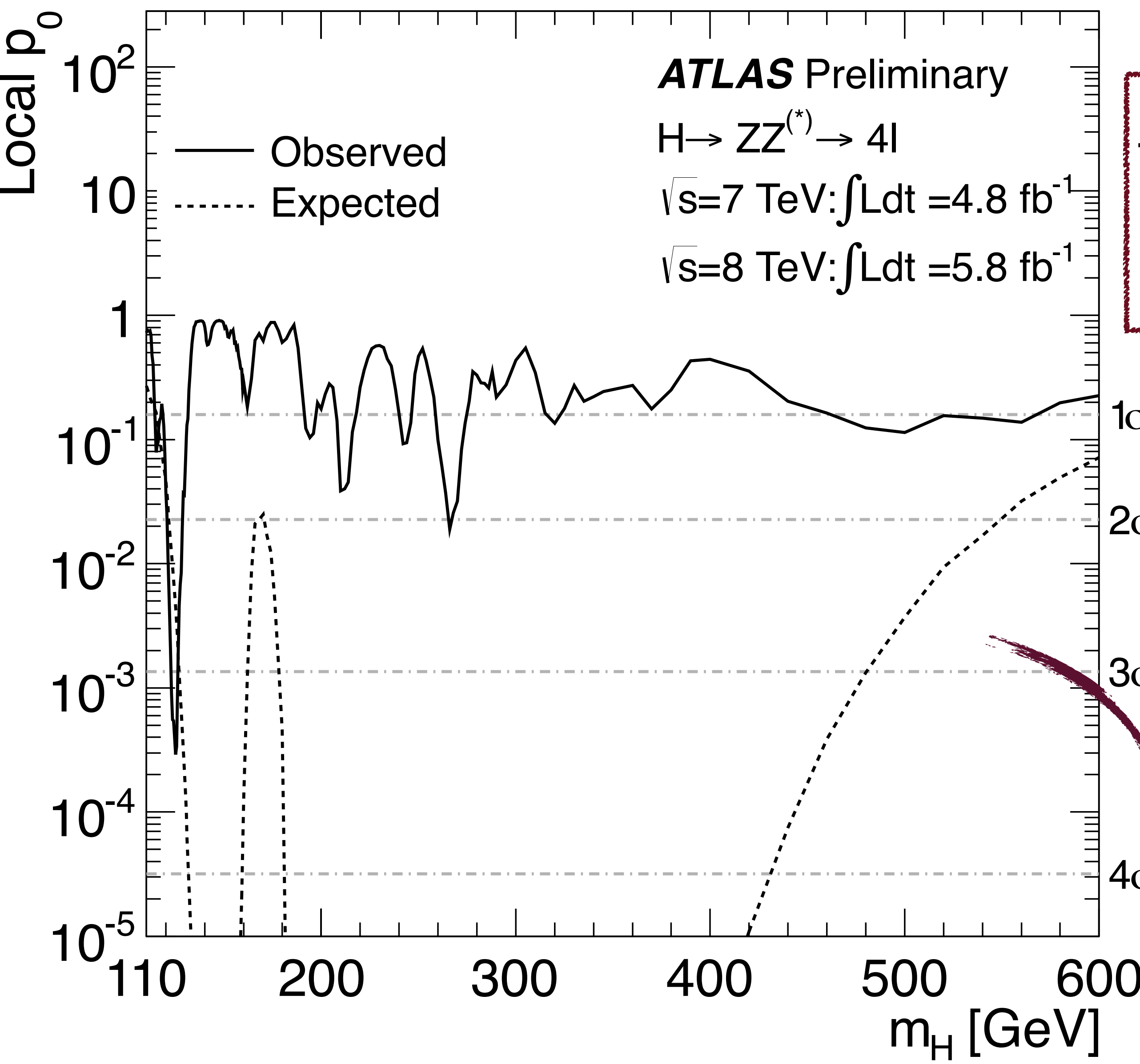
H→ZZ(*)→4l: Exclusions





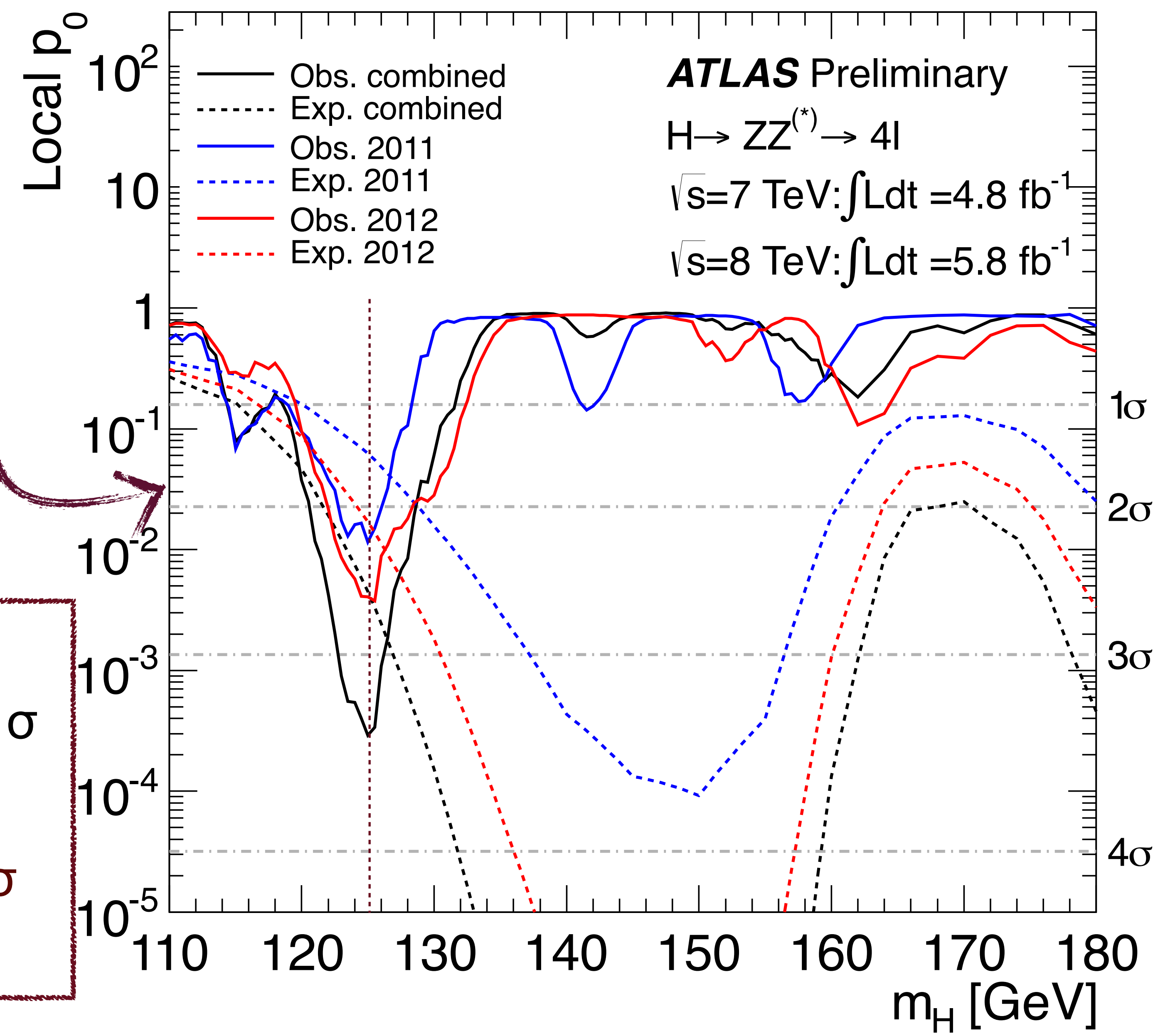
- Observed exclusion : 131-162 GeV and 170 - 460 GeV
- Expected exclusion : 124-164 GeV and 176 - 500 GeV
- For m_H ~120-130 GeV much weaker limit than expected in the background-only hypothesis

H→ZZ(*)→4l: Significance of Excesses



For high m_H:

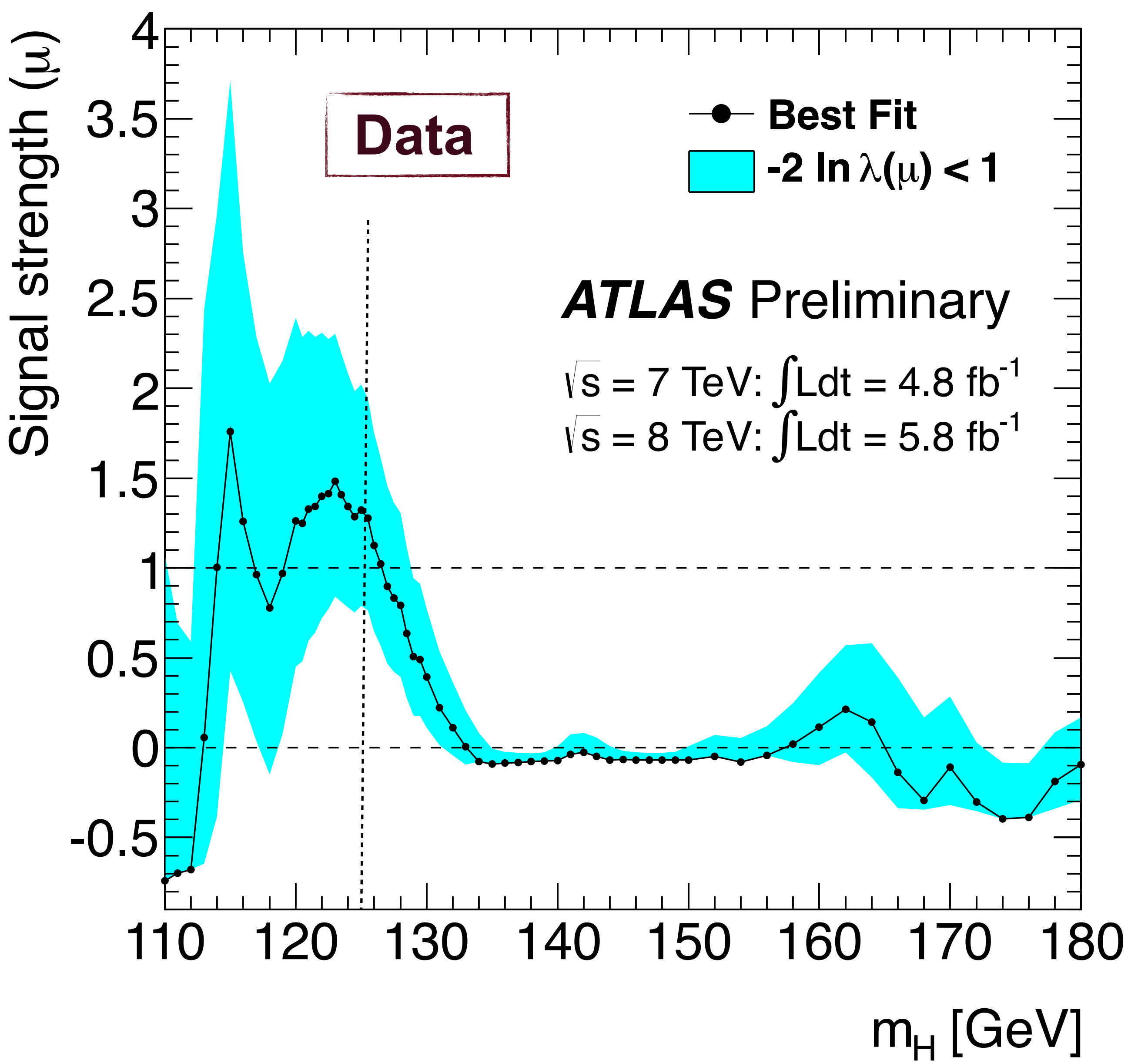
- small (<2σ) upward fluctuations are observed
- not "aligning" between 7 and 8 TeV data samples

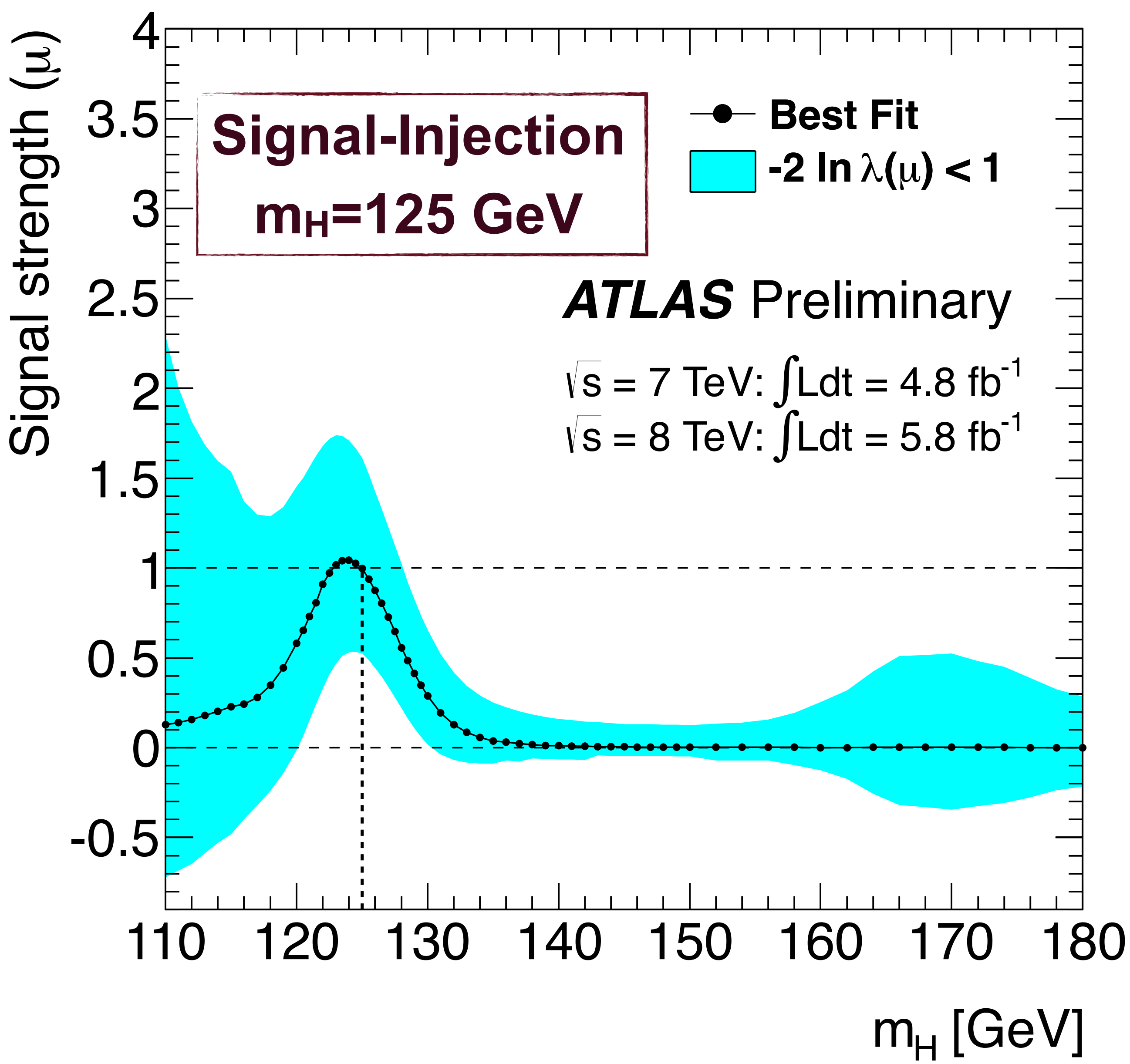


For low m_H:

- 8 TeV (2012): 2.7σ at 125.5 GeV, expected 2.1σ
- 7 TeV (2011): 2.3σ at 125 GeV, expected 1.5σ
- Combined: **3.4σ** at m_H=125 GeV, expected 2.6σ
- 2.5σ after look-elsewhere effect (110-141 GeV)

H→ZZ(*)→4l: Signal Strength

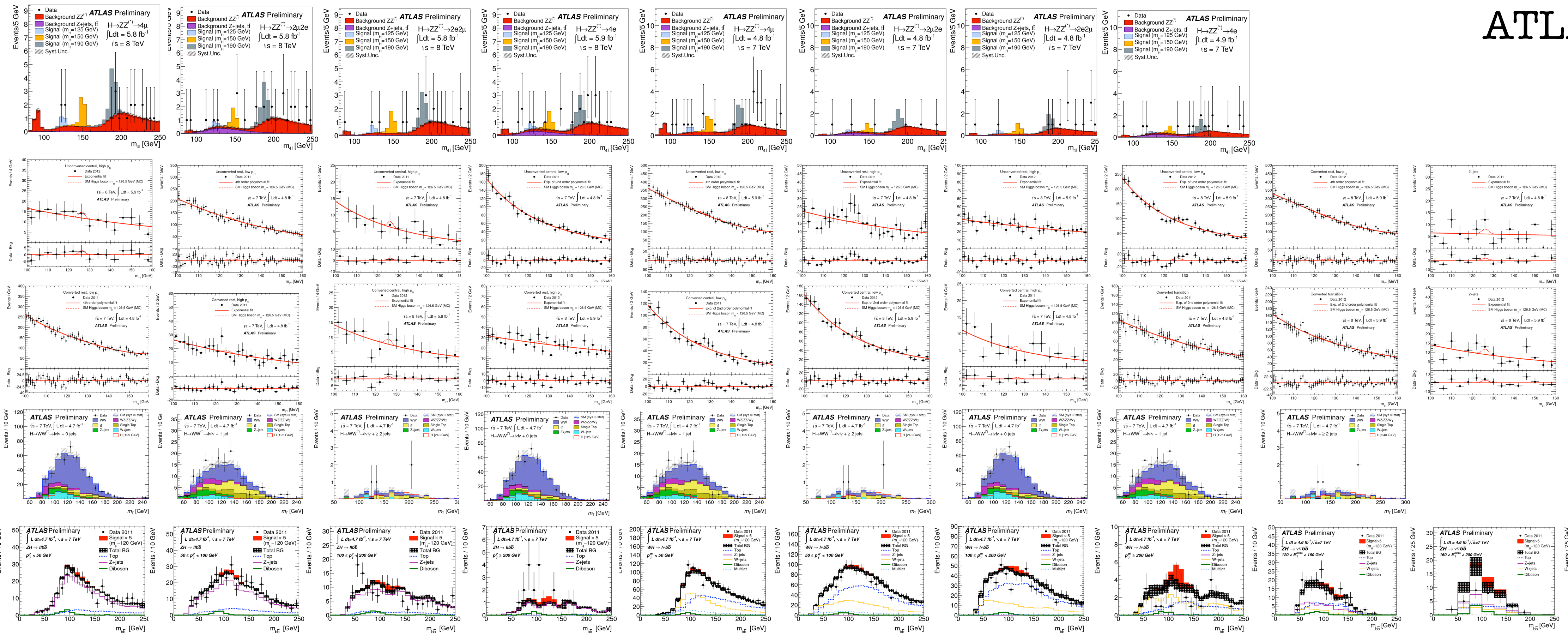


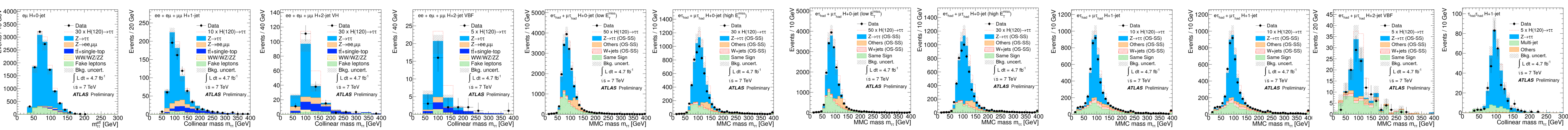


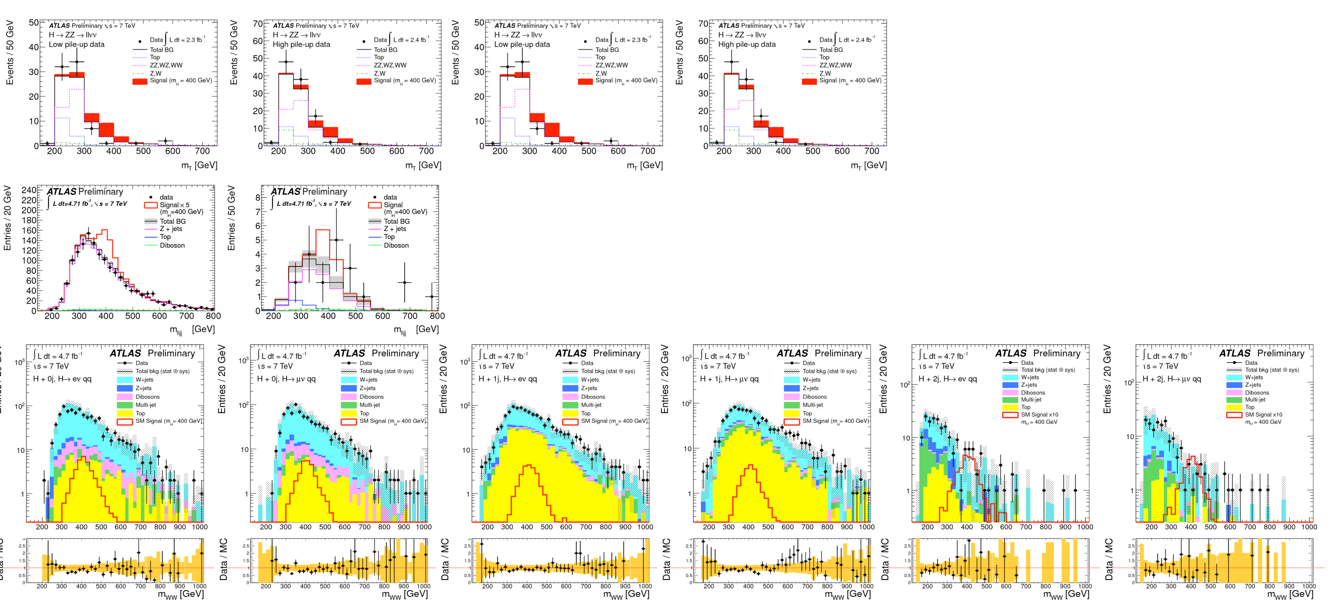
Best-fit value for m_H =125 GeV: μ=1.3 ± 0.6

Combination

ATLAS-CONF-2012-93

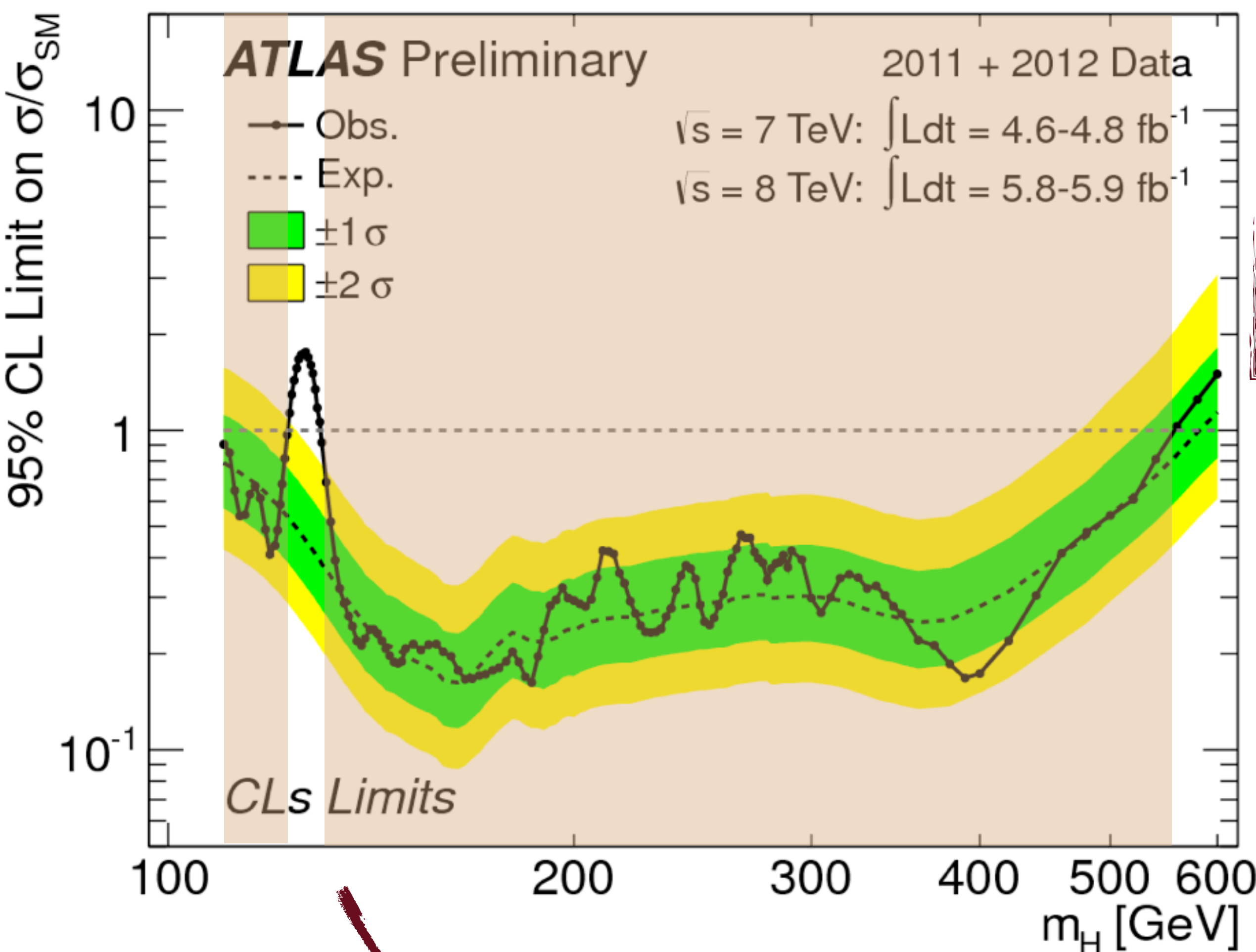




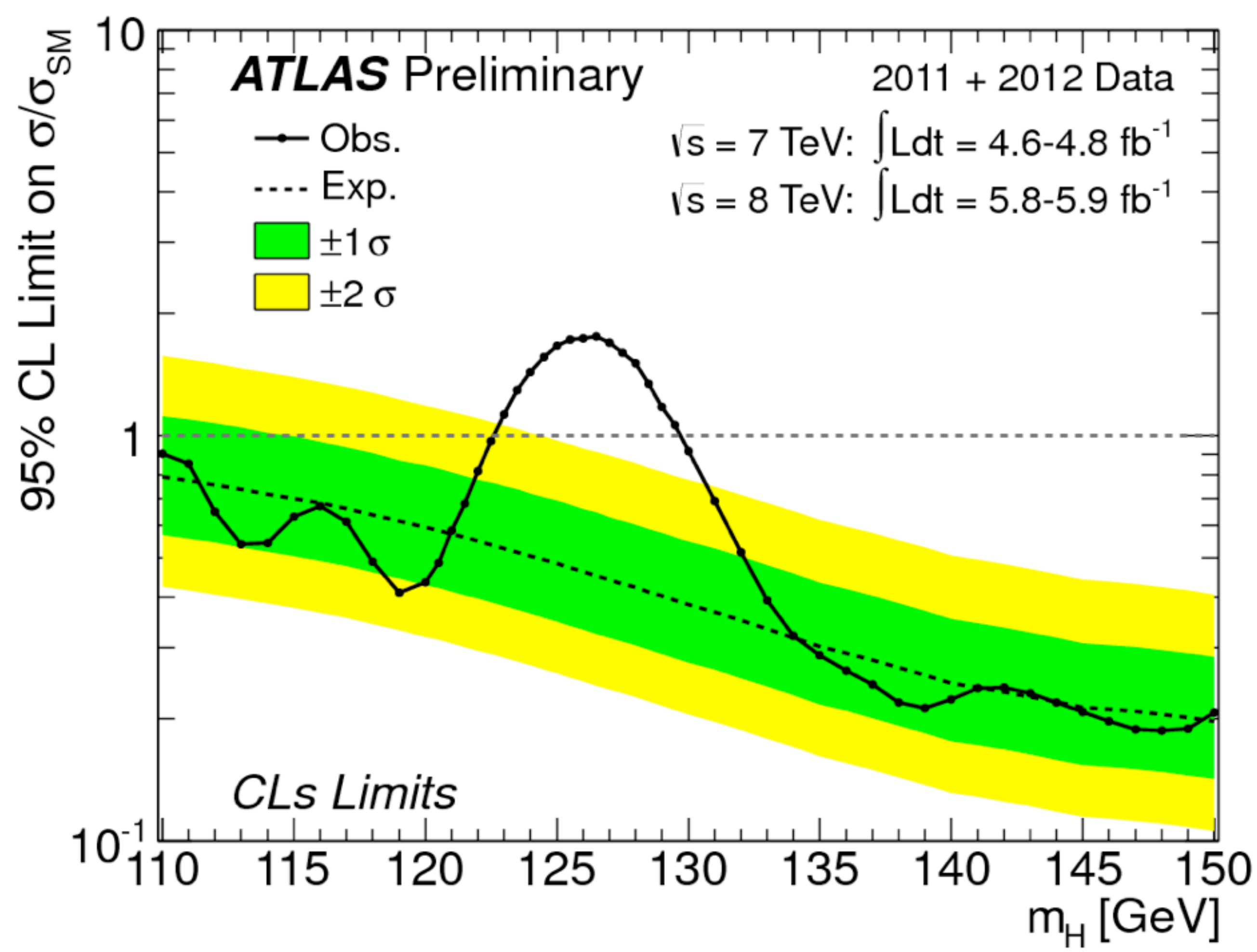


Higgs Decay	Subsequent Decay	Sub-Channels	m_H Range [GeV]	$\int L\,dt$ [fb^{-1}]
		2011 $\sqrt{s}$ =7 TeV		
$H\to\gamma\gamma$	–	9 sub-channels $\{p_{T_t}\otimes\eta_\gamma\otimes$ conversion$\}\oplus\{$2-jets$\}$	110–150	4.8
$H\to ZZ^{(*)}$	$\ell\ell\ell'\ell'$	$\{4e, 2e2\mu, 2\mu2e, 4\mu\}$	110–600	4.8
	$\ell\ell\nu\bar{\nu}$	$\{ee,\mu\mu\}\otimes\{$low, high pile-up$\}$	200–280–600	4.7
	$\ell\ell q\bar{q}$	$\{b$-tagged, untagged$\}$	200–300–600	4.7
$H\to WW^{(*)}$	$\ell\nu\ell\nu$	$\{ee, e\mu, \mu\mu\}\otimes\{$0-jets, 1-jet, 2-jets$\}\otimes\{$low, high pile-up$\}$	110–200–300–600	4.7
	$\ell\nu q\bar{q}'$	$\{e,\mu\}\otimes\{$0-jets, 1-jet, 2-jets$\}$	300–600	4.7
$H\to\tau^+\tau^-$	$\tau_{\rm lep}\tau_{\rm lep}$	$\{e\mu\}\otimes\{$0-jets$\}\oplus\{\ell\ell\}\otimes\{$1-jet, 2-jets, $VH\}$	110–150	4.7
	$\tau_{\rm lep}\tau_{\rm had}$	$\{e,\mu\}\otimes\{$0-jets$\}\otimes\{E_{\rm T}^{\rm miss}<20$ GeV, $E_{\rm T}^{\rm miss}\geq 20$ GeV$\}$ $\oplus\{e,\mu\}\otimes\{$1-jet$\}\oplus\{\ell\}\otimes\{$2-jets$\}$	110–150	4.7
	$\tau_{\rm had}\tau_{\rm had}$	$\{$1-jet$\}$	110–150	4.7
$VH\to b\bar{b}$	$Z\to\nu\bar{\nu}$	$E_{\rm T}^{\rm miss}\in\{120-160, 160-200, \geq 200$ GeV$\}$	110-130	4.6
	$W\to\ell\nu$	$p_{\rm T}^{W}\in\{<50, 50-100, 100-200, \geq 200$ GeV$\}$	110-130	4.7
	$Z\to\ell\ell$	$p_{\rm T}^{Z}\in\{<50, 50-100, 100-200, \geq 200$ GeV$\}$	110-130	4.7
		2012 $\sqrt{s}$ =8 TeV		
$H\to\gamma\gamma$	–	9 sub-channels $\{p_{T_t}\otimes\eta_\gamma\otimes$ conversion$\}\oplus\{$2-jets$\}$	110–150	5.9
$H\to ZZ^{(*)}$	$\ell\ell\ell'\ell'$	$\{4e, 2e2\mu, 2\mu2e, 4\mu\}$	110–600	5.8

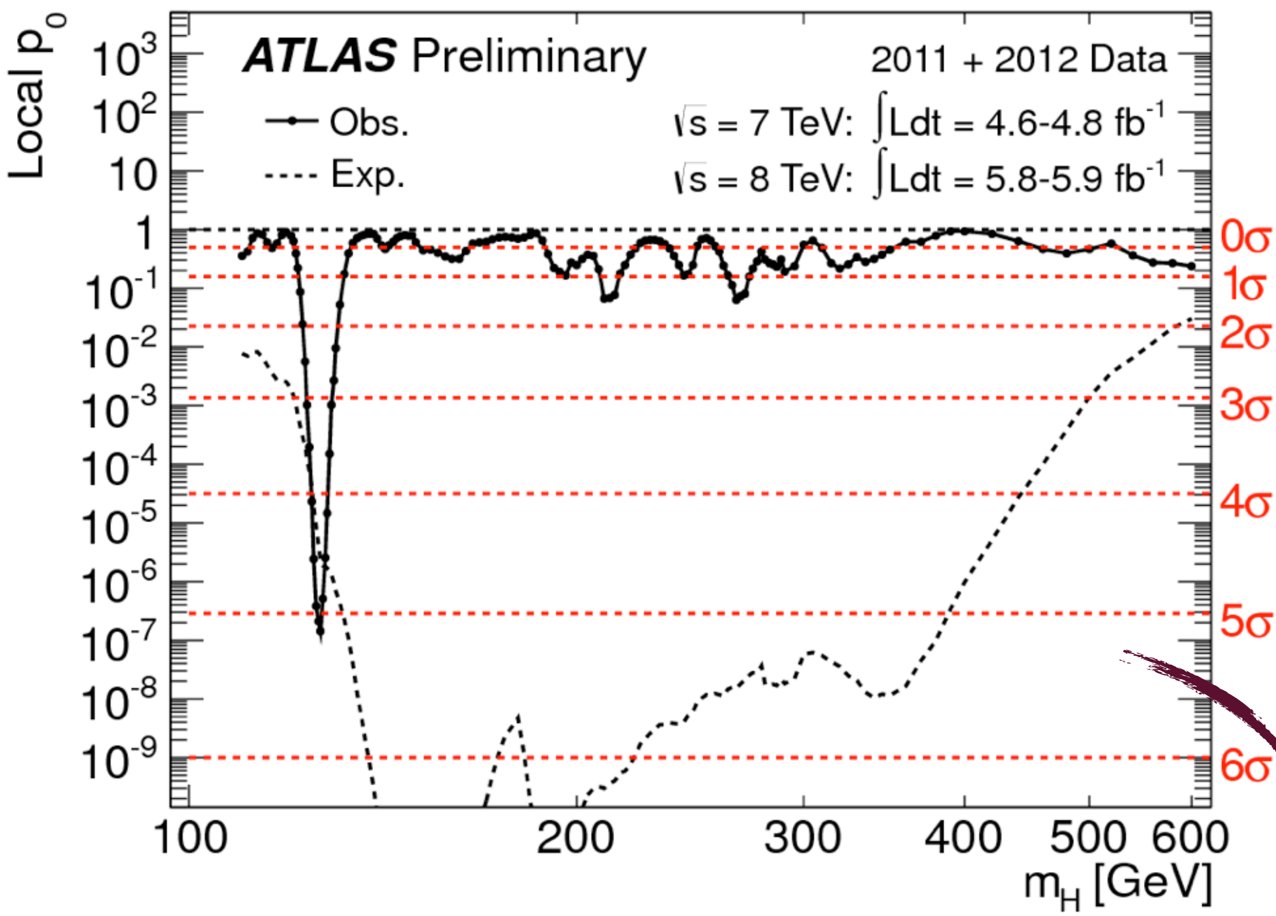
Exclusion Limits



- Observed exclusion : 110-122.6 GeV and 129.7-558 GeV
- Expected exclusion : 110-582 GeV



Significance



For high m_H:

- No significant deviation from background-only hypothesis
- All fluctuations <2σ

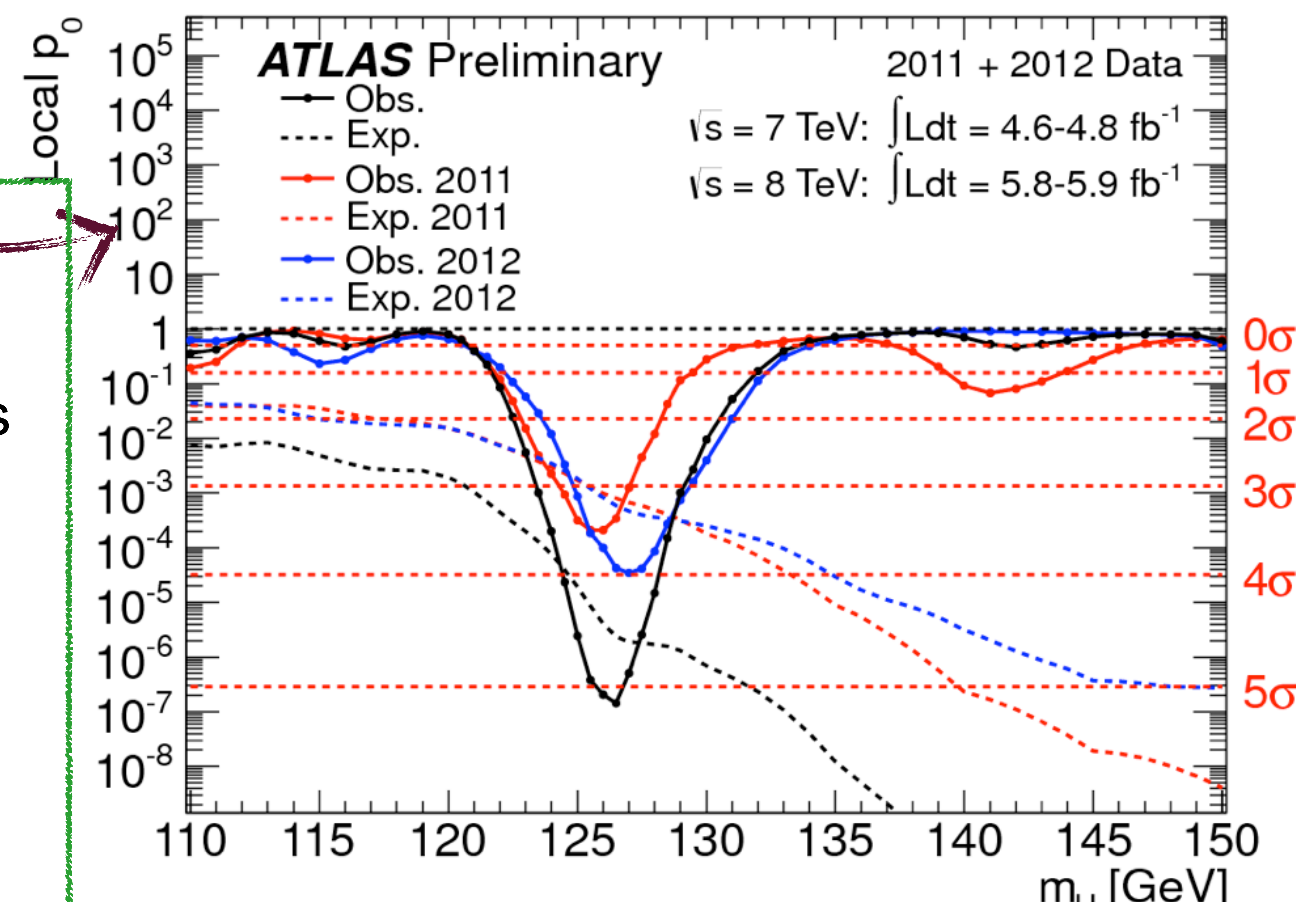
For low m_H:

The ATLAS SM Higgs search observes a significant excess of events over the background only hypothesis at m_H~126.5 GeV

→ Consistent in both 2011 and 2012 datasets.

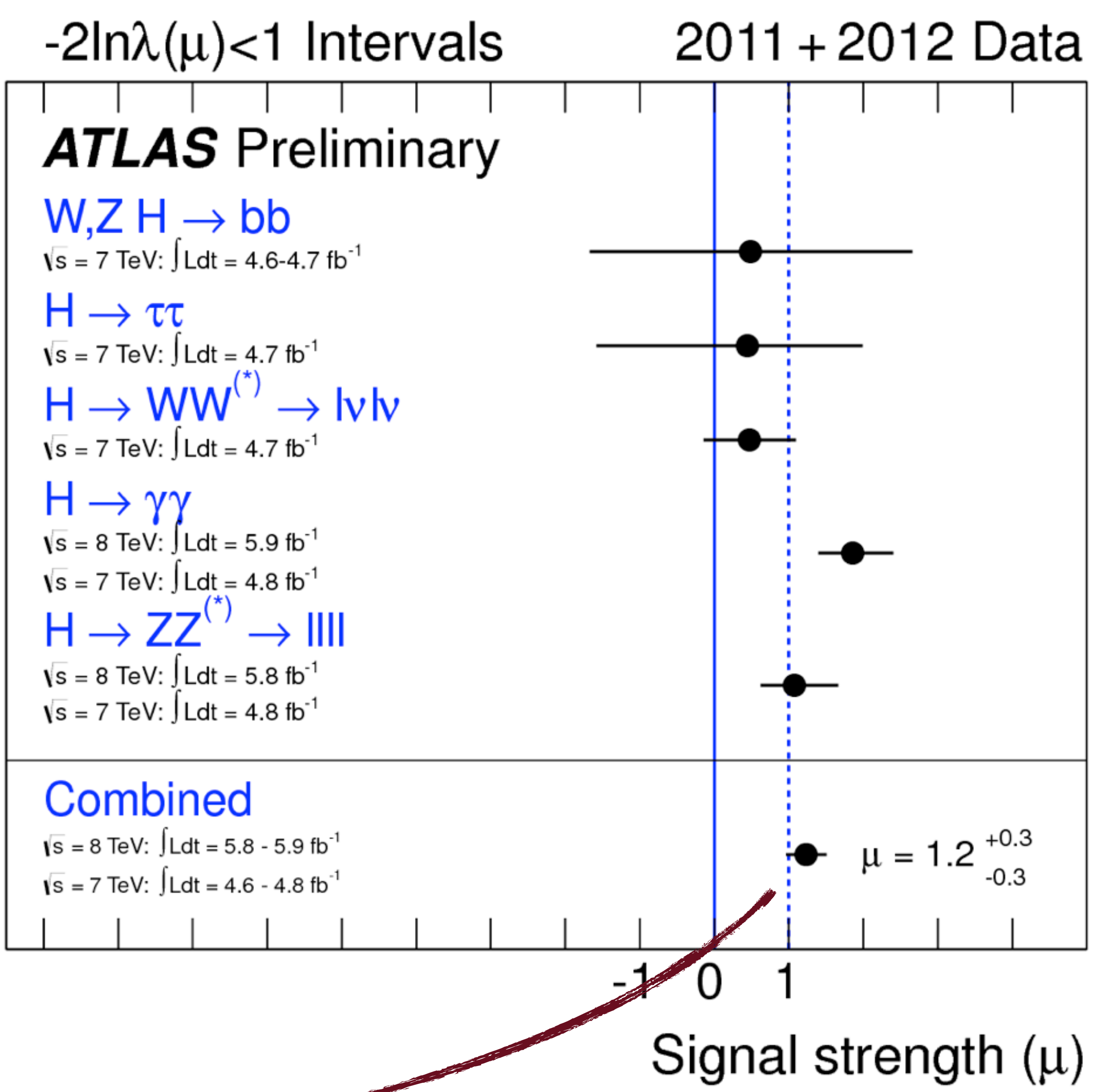
→ Combining datasets, **5.0σ** local significance
[4.3σ global significance (110-150 GeV)]

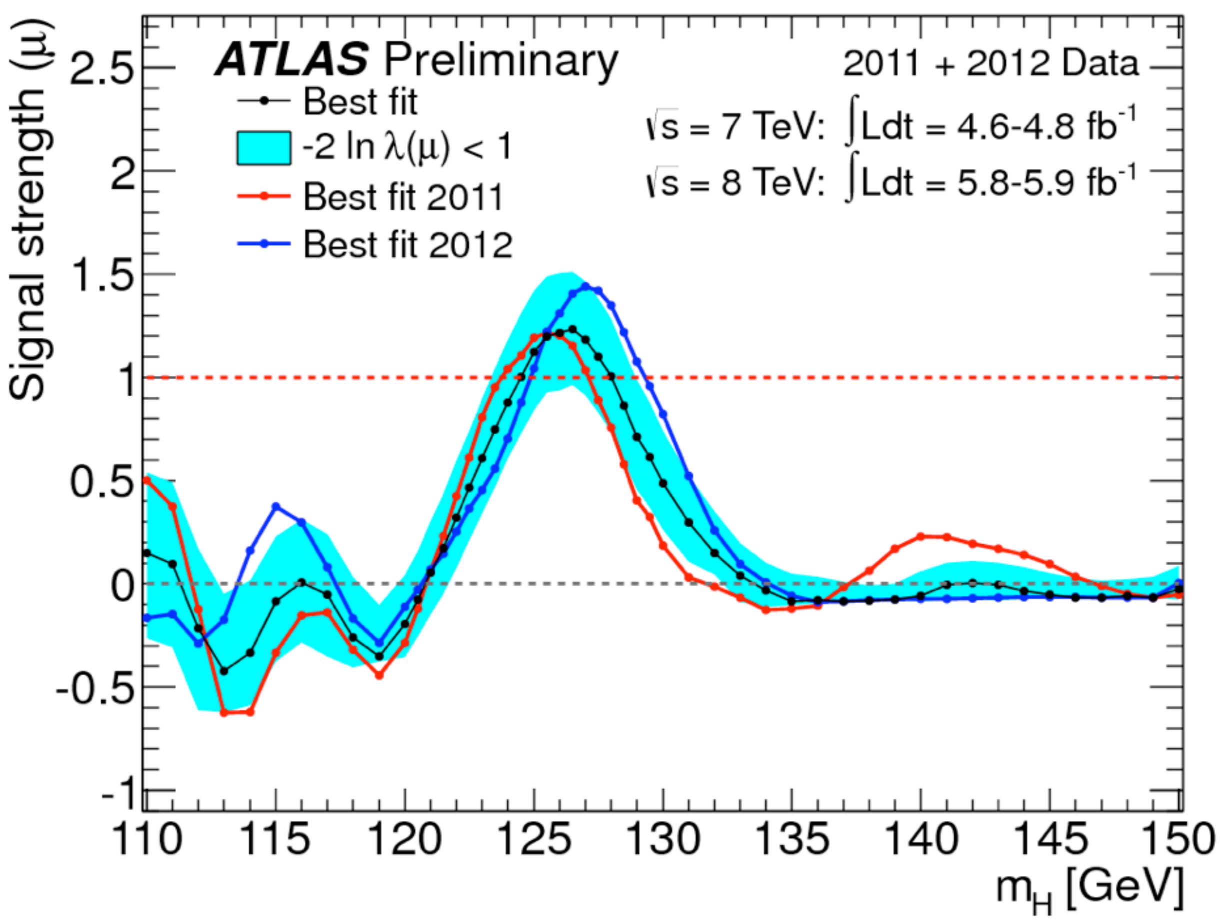
→ Expected local significance 4.6σ



Signal Strength

Contributions of different channels at 126.5 GeV



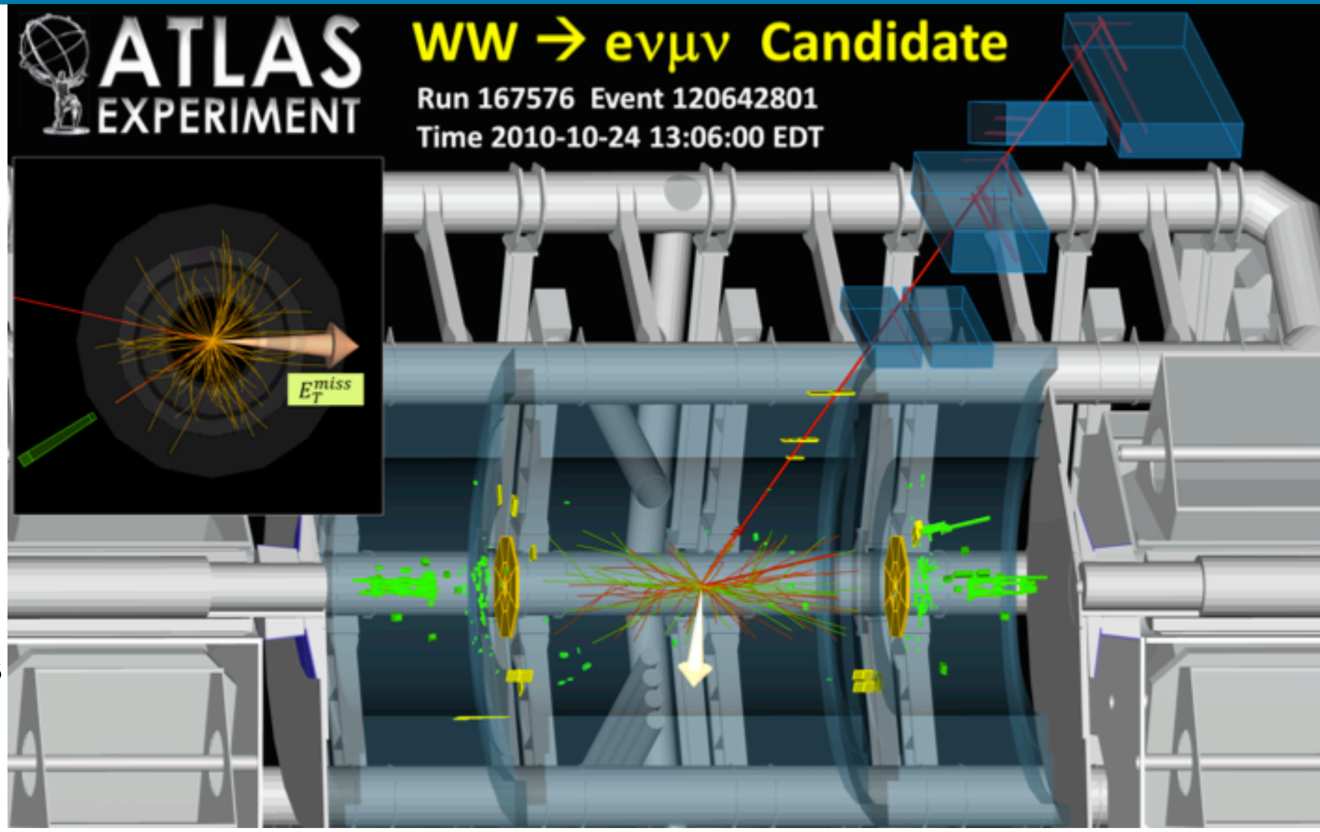


$H \rightarrow WW^{(*)} \rightarrow l\nu l\nu$

- Sensitive in wide range, in particular $120 < m_H < 200$ GeV
- Also very complicated (uses all ATLAS components!)
- ATLAS results on the 2012 dataset released on July 18th

⇒ For 2012 only eμ channel considered

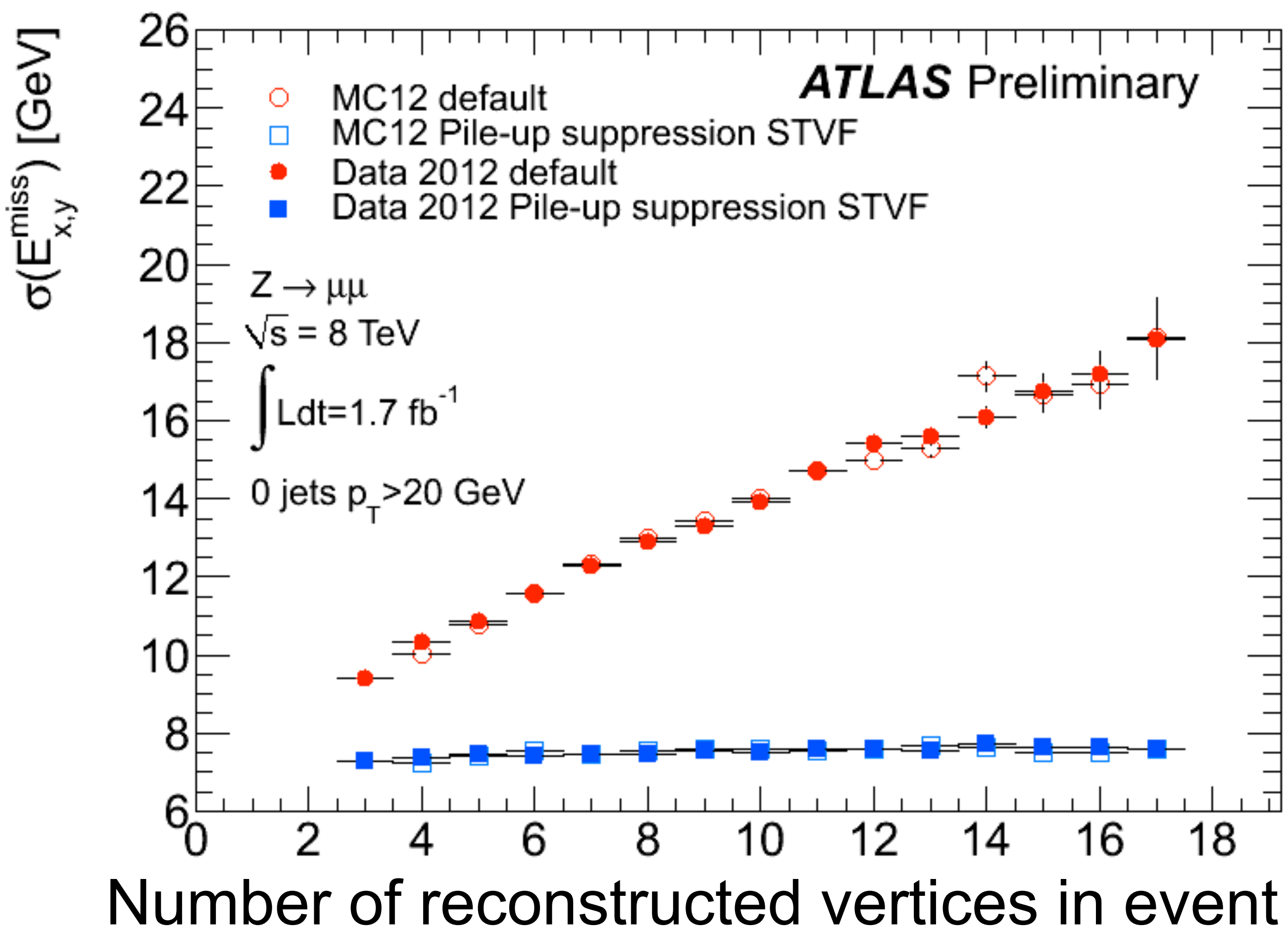
⇒ Main Backgrounds: WW, top and W/Z+jets

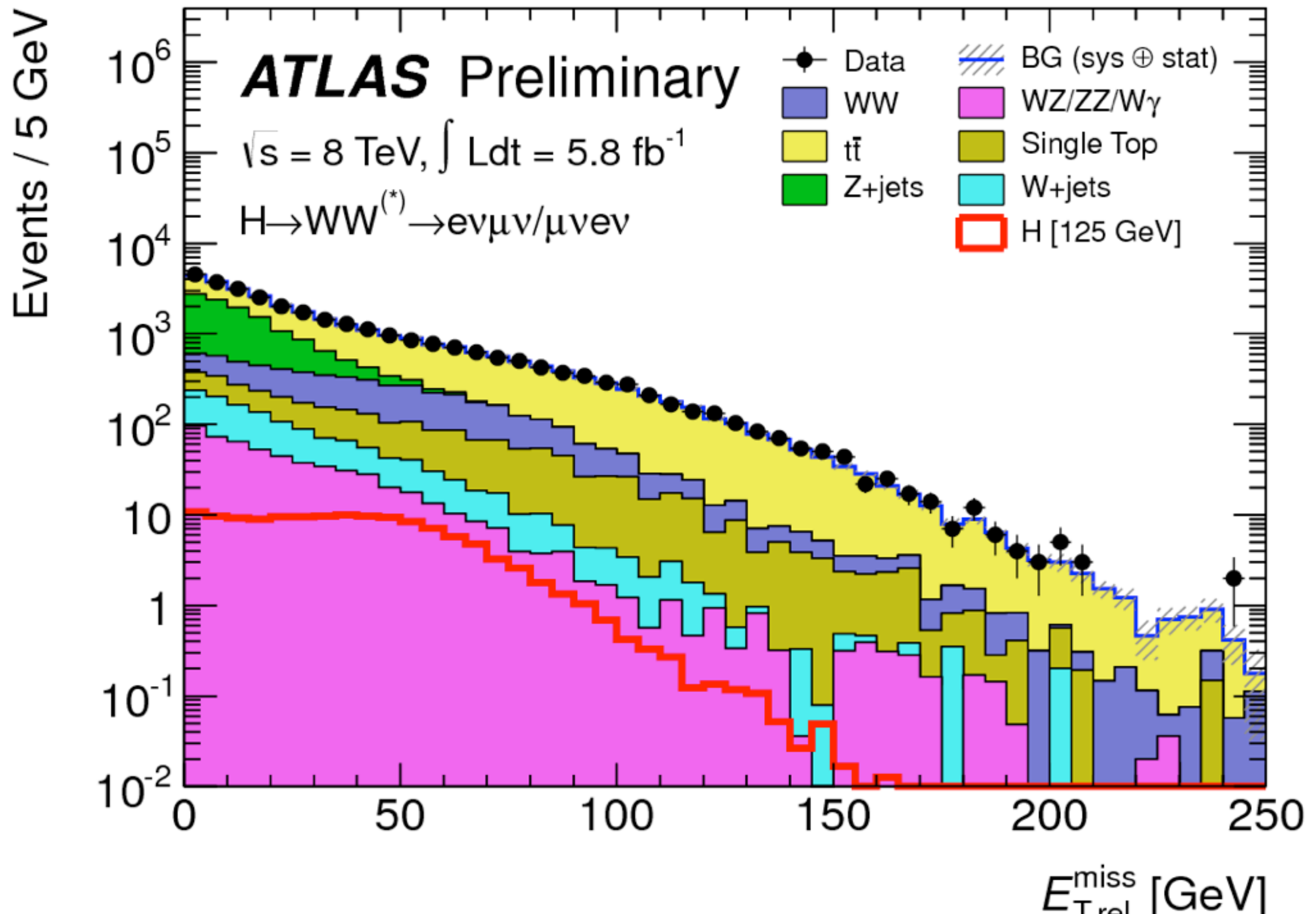


Selection

- 2 leptons pT>25,15 GeV, m_{ll}>10 GeV
- neutrinos in final state require METrel>25 GeV

METrel = MET sin(Δφmin), Δφmin=min(Δφ,π/2) Δφ of MET wrt leptons,jets





H→WW(*)→lνlν

Jet selection:

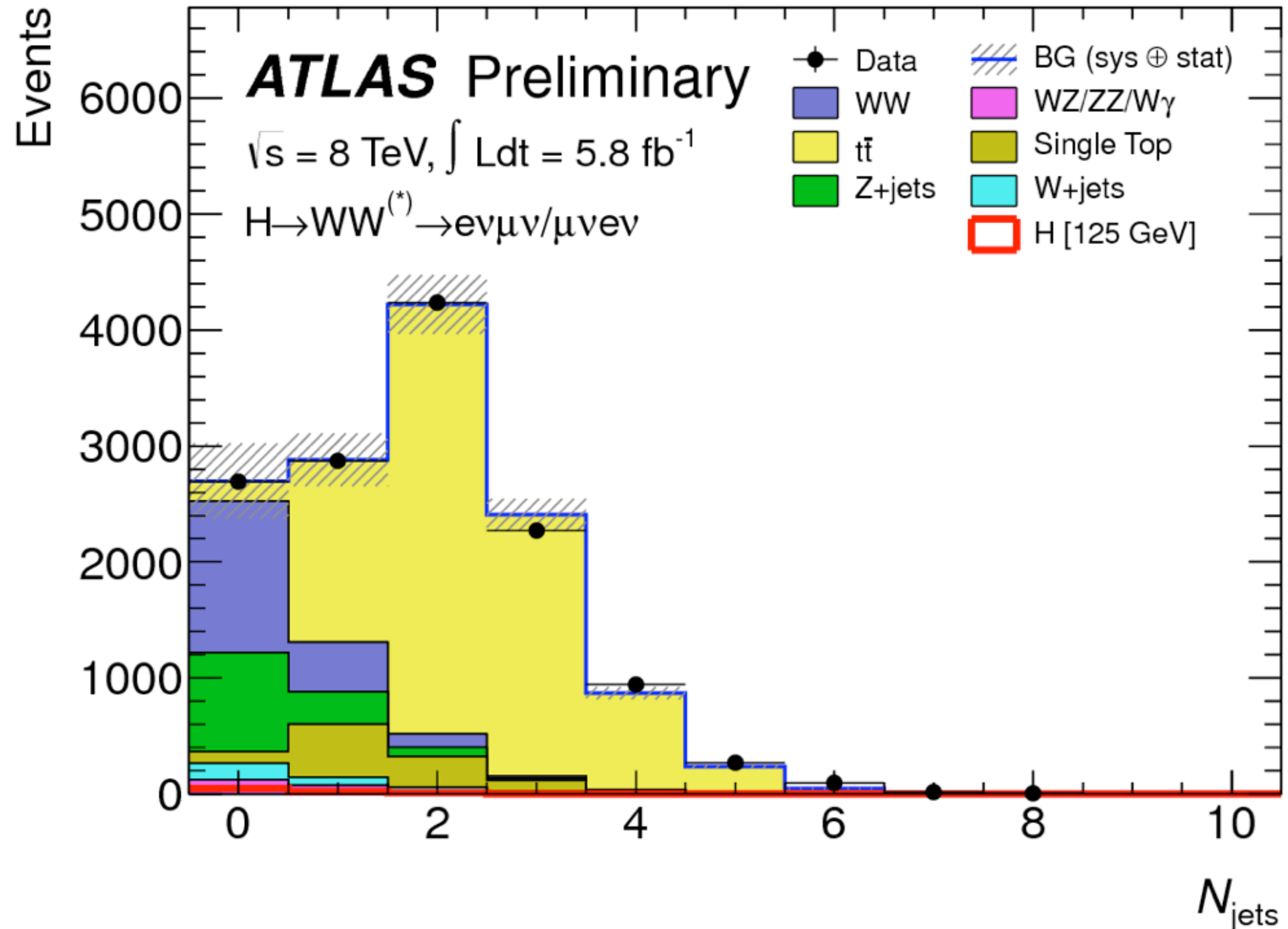
E_T>25 GeV for |η|<2.5 and ET>30 GeV for 2.5<|η|<4.5

Analysis is split in 0, 1 and 2jets

→ 0-jet highest sensitivity WW dominates background

→ 1-jet top production dominates background

→ 2-jet small statistics but sensitive to VBF



Topological cuts

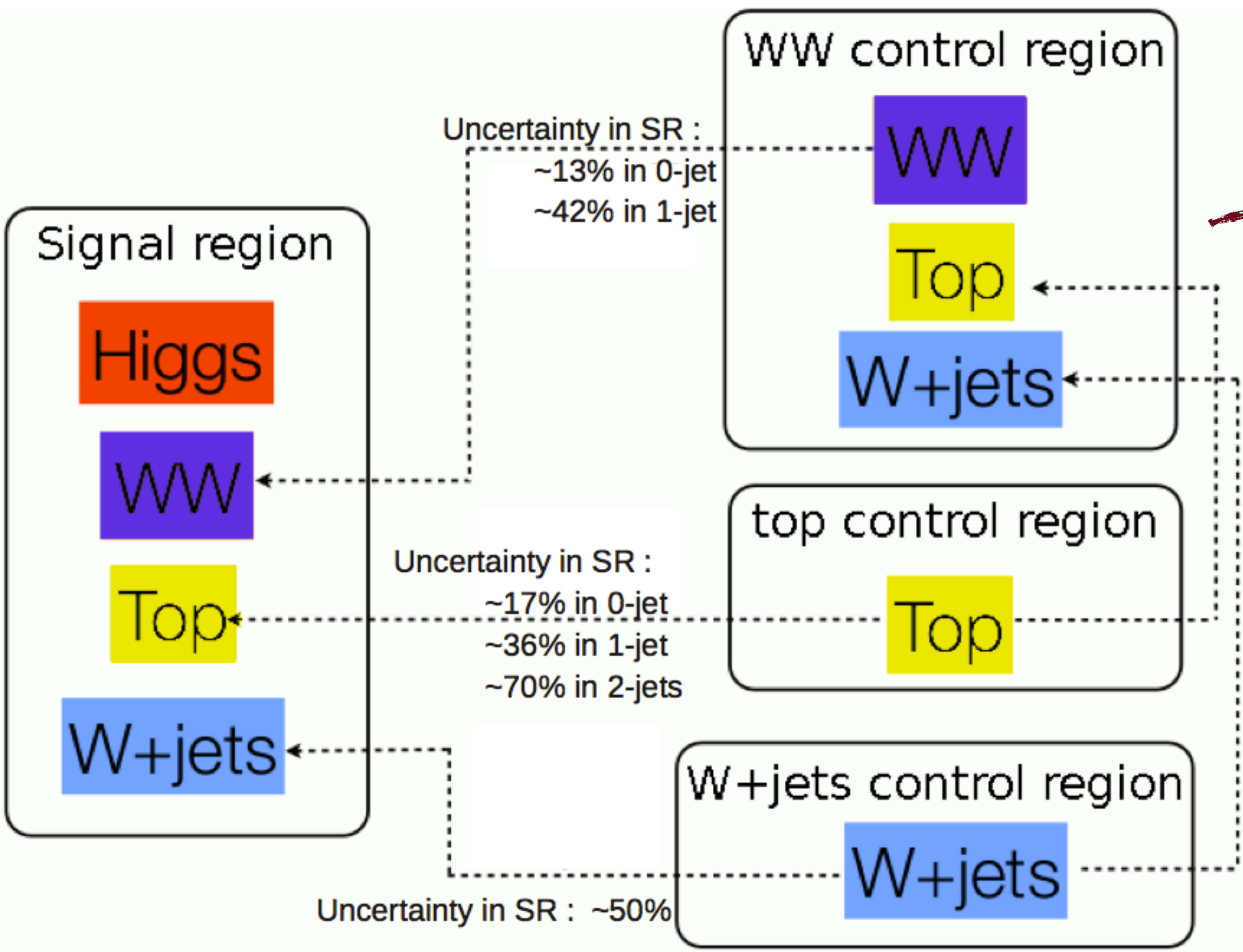
m_{ll}< 50 GeV for 0/1jet, <80 for 2jets

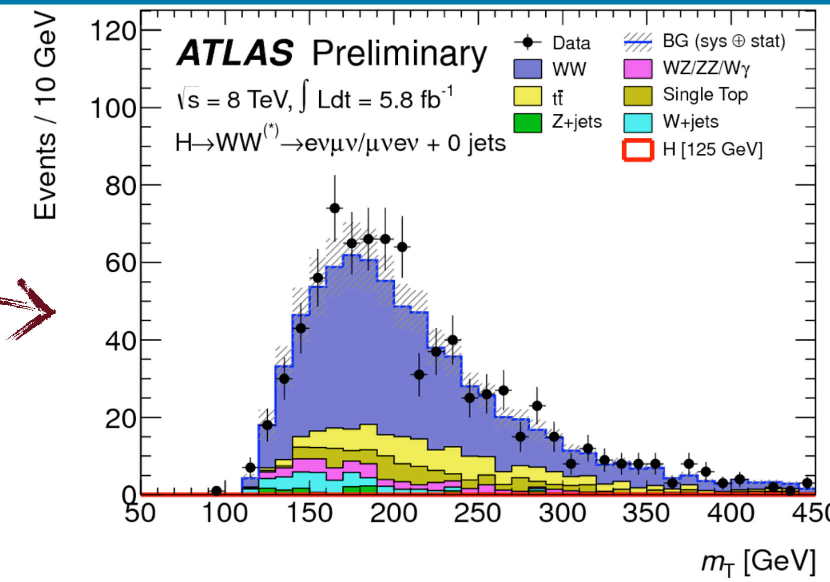
$\Delta\varphi_{ll}$ <1.8

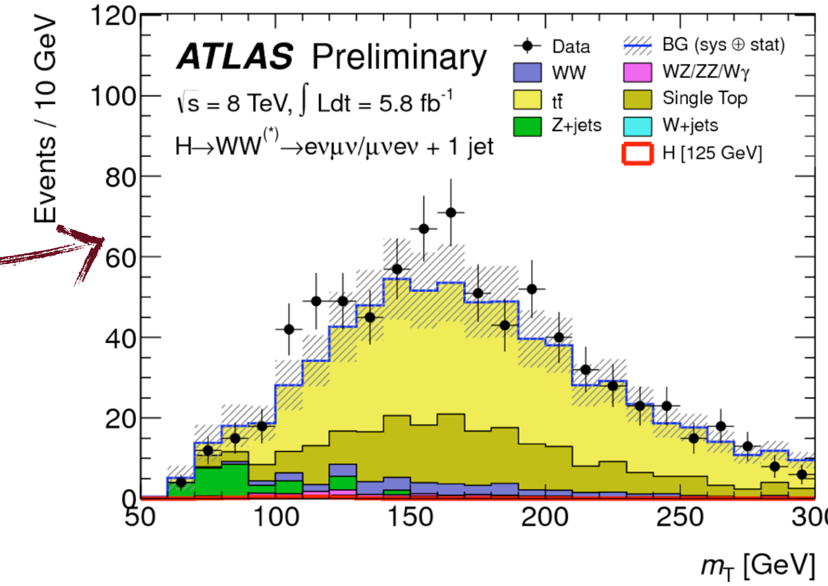
Then further jet-bin dependent requirements

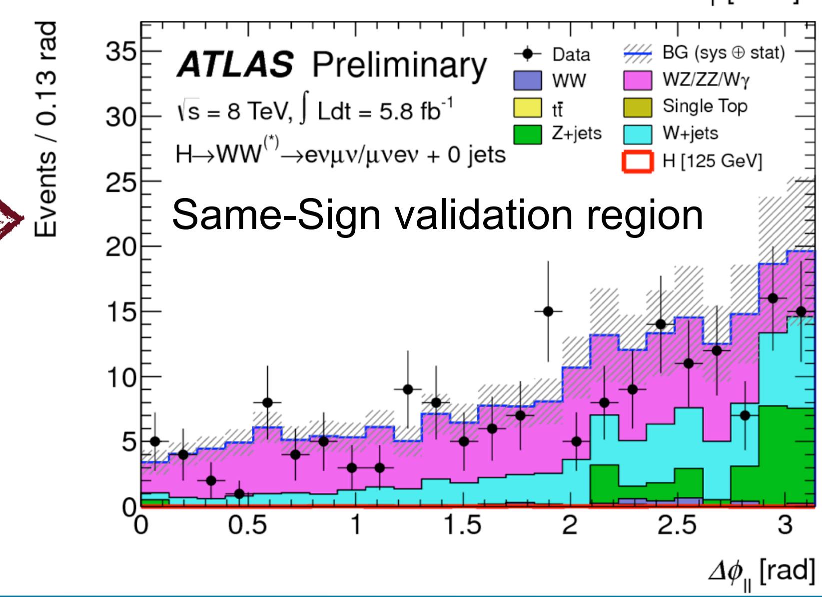
Requirement	jet-bin
pT_{ll}>30 GeV	0
b-tag veto |ptTot|<30GeV (leptons,jets, MET) |mττ-mZ|>25GeV (collinear approximation)	1
1 jet cuts tag jets (highest pT) $\|\Delta y_{jj}\|$>3.8, m_{jj}>500GeV no jet with pT>20GeV in between	2

H→WW(*)→lνlν: Backgrounds







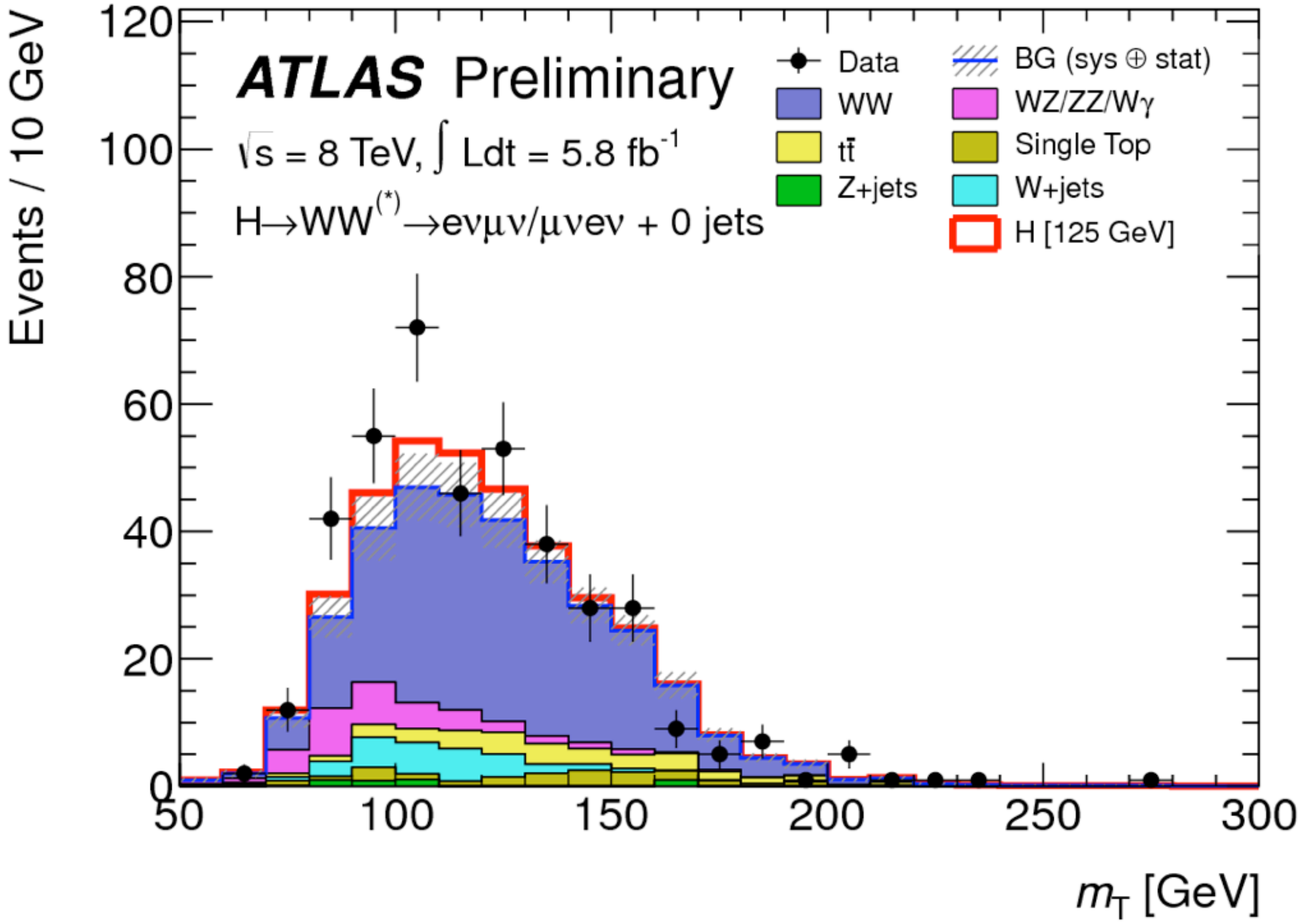


⇒ Backgrounds

→ WW : remove $\Delta\varphi_{ll}$ cut, m_{ll}>80 GeV
→ top : 0-jet use data-driven probability of top surviving jet-veto
1/2-jet use b-tag requirement
→ W+jets : control sample with loose lepton ID
(→ Z+jets : side-bands using m_{ll} and MET)

H→WW(*)→lνlν: Results

⇒ Final discriminant is m_T $$m_T = \sqrt{(E_T^{\ell\ell} + E_T^{miss})^2 - |\mathbf{p}_T^{\ell\ell} + \mathbf{p}_T^{miss}|^2}$$



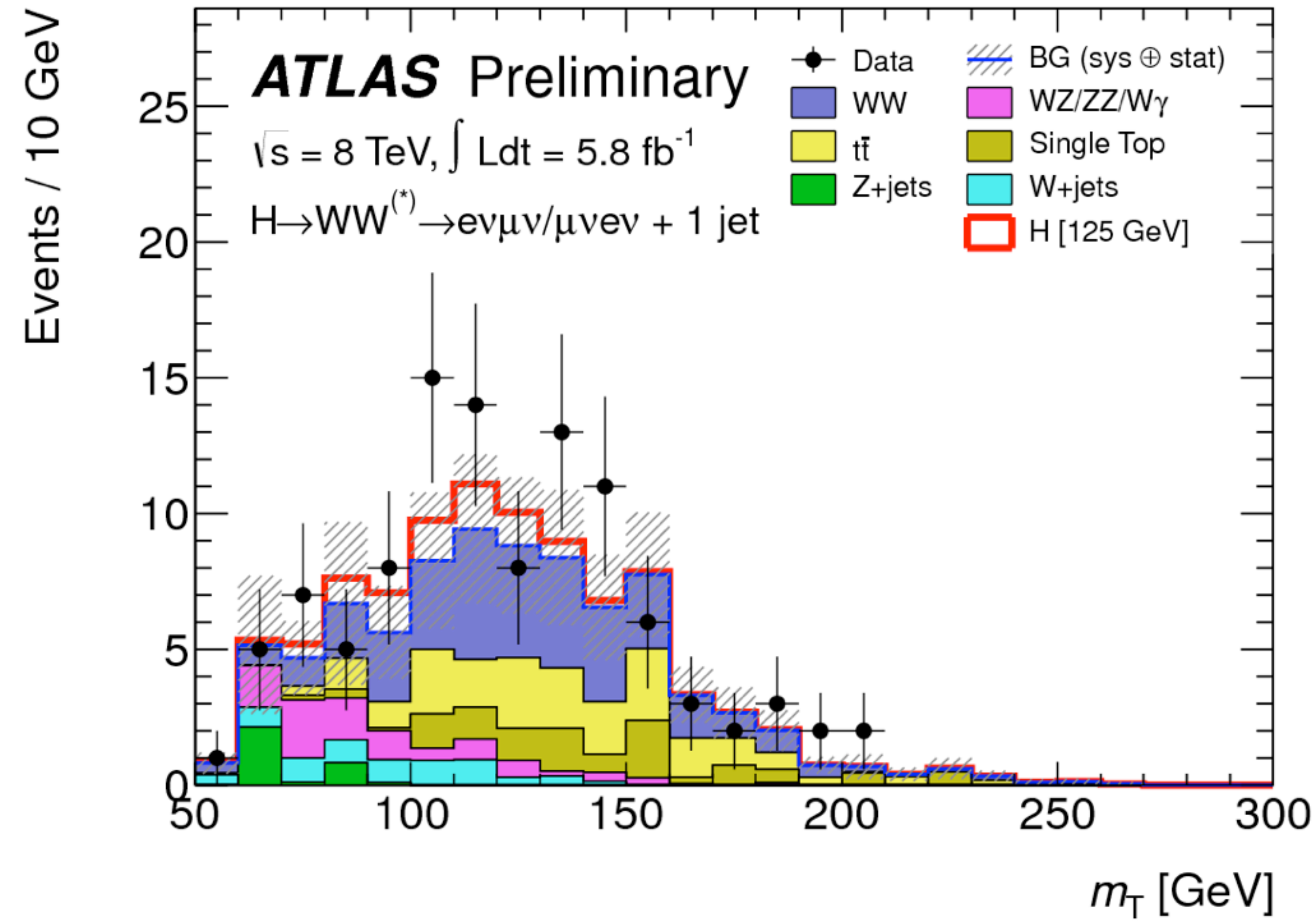
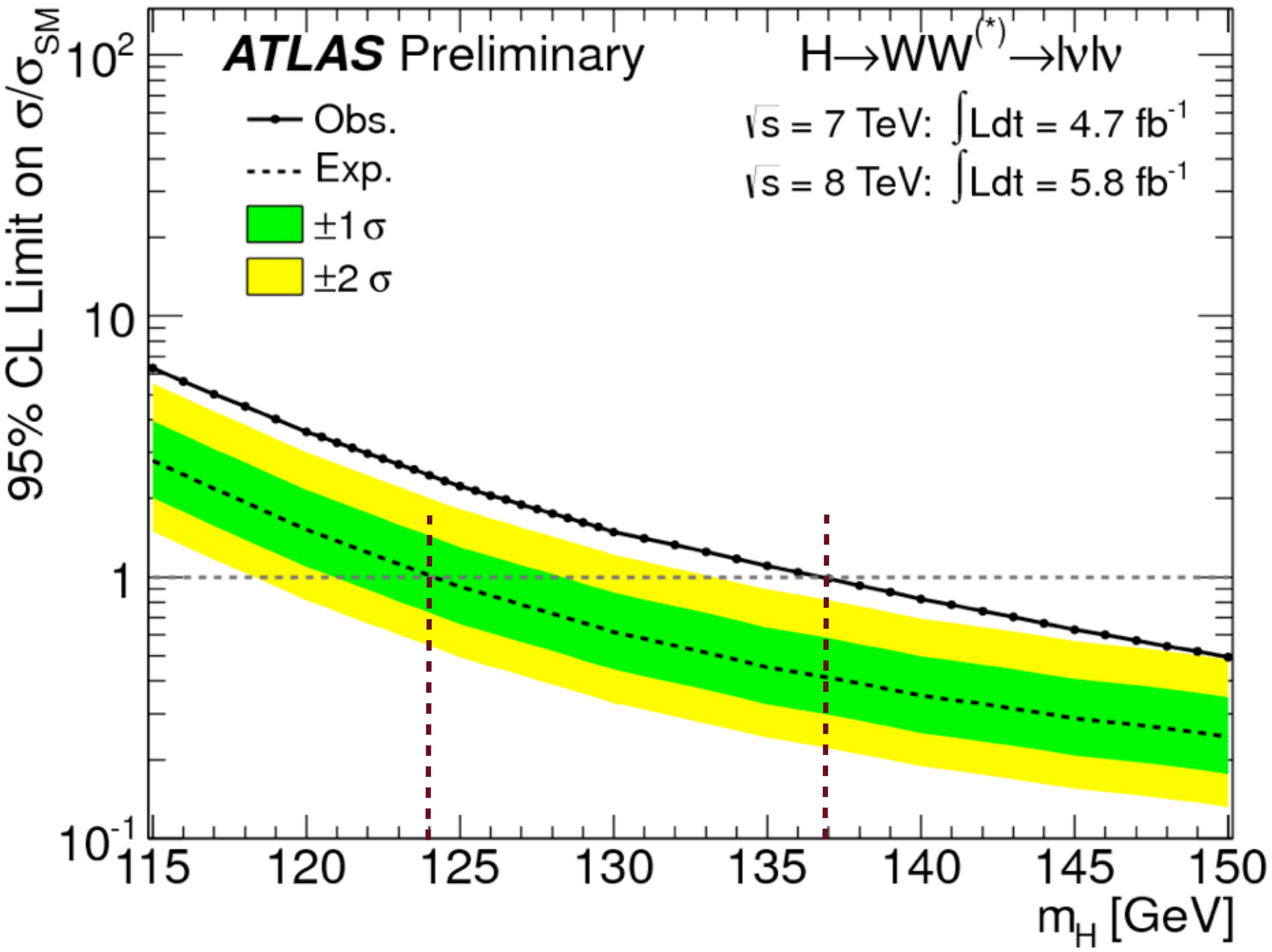


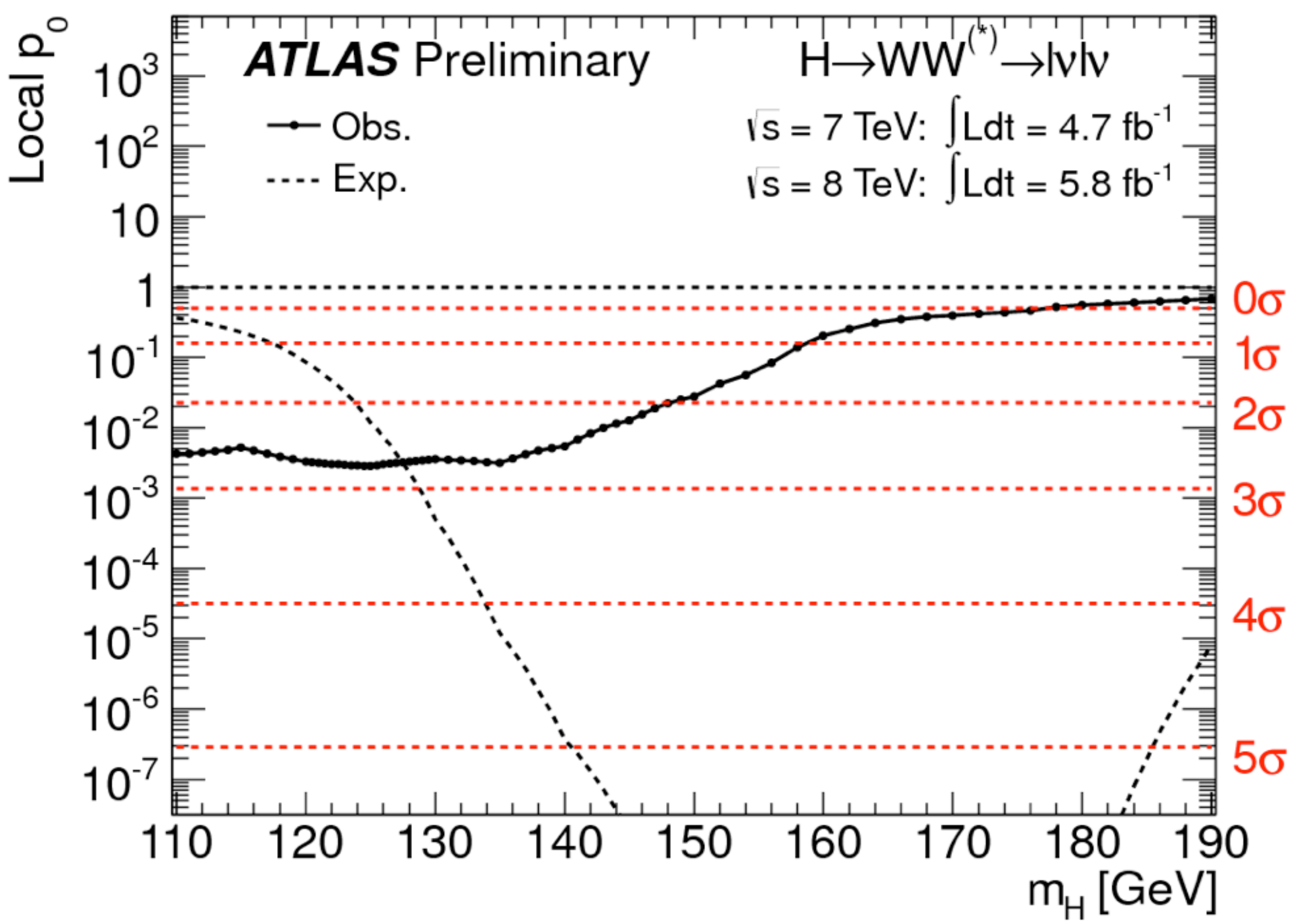
illustration only

For m_H=125 GeV including cut $0.75m_H < m_T < m_H$

	Signal	WW	$WZ/ZZ/W\gamma$	$t\bar{t}$	$tW/tb/tqb$	$Z/\gamma^* + $jets	$W + $jets	Total Bkg.	Obs.
$H+$ 0-jet	20 ± 4	101 ± 13	12 ± 3	8 ± 2	3.4 ± 1.5	1.9 ± 1.3	15 ± 7	142 ± 16	185
$H+$ 1-jet	5 ± 2	12 ± 5	1.9 ± 1.1	6 ± 2	3.7 ± 1.6	0.1 ± 0.1	2 ± 1	26 ± 6	38
$H+$ 2-jet	0.34 ± 0.07	0.10 ± 0.14	0.10 ± 0.10	0.15 ± 0.10	-	-	-	0.35 ± 0.18	0

$H \rightarrow WW^{(*)} \rightarrow l\nu l\nu$: Results 2011+2012



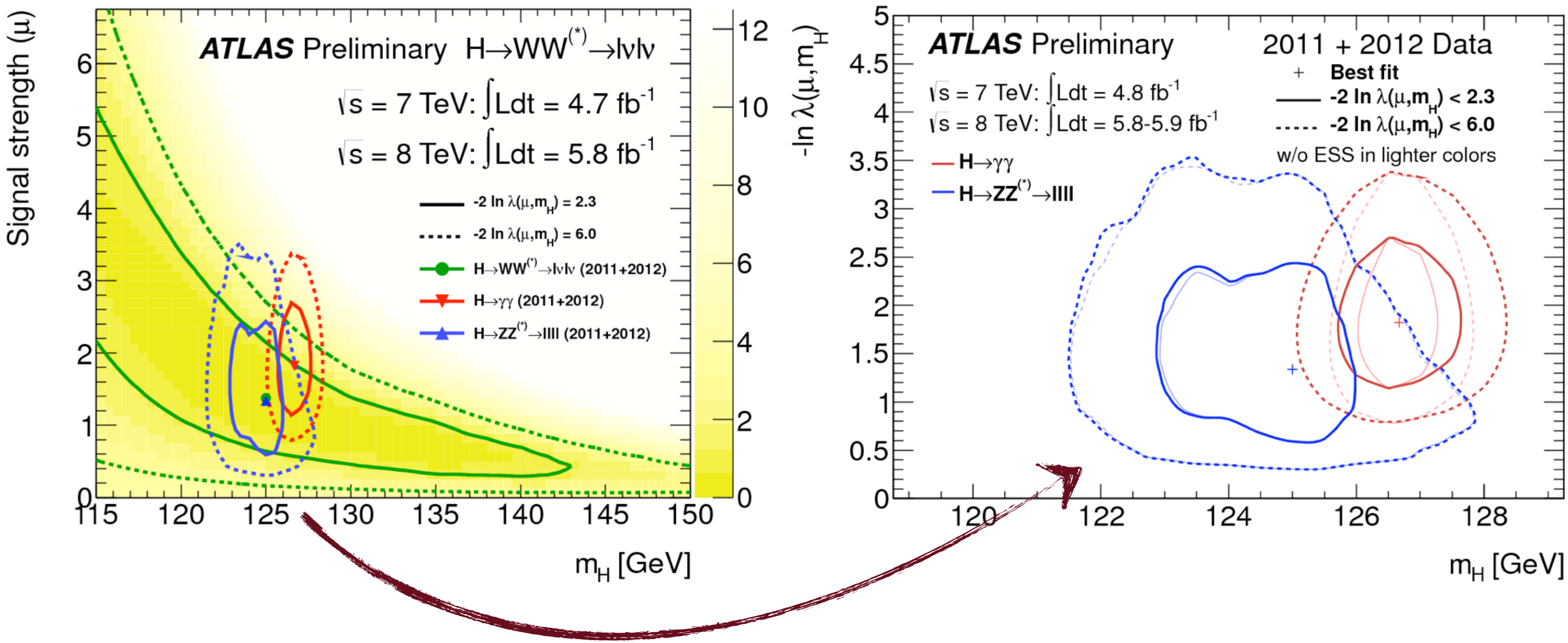


⇒ Observed significance is 2.8σ at m_H=125 GeV

⇒ Expected significance is 2.3σ at m_H=125 GeV

Likelihood Contours: Signal Strength vs m_H

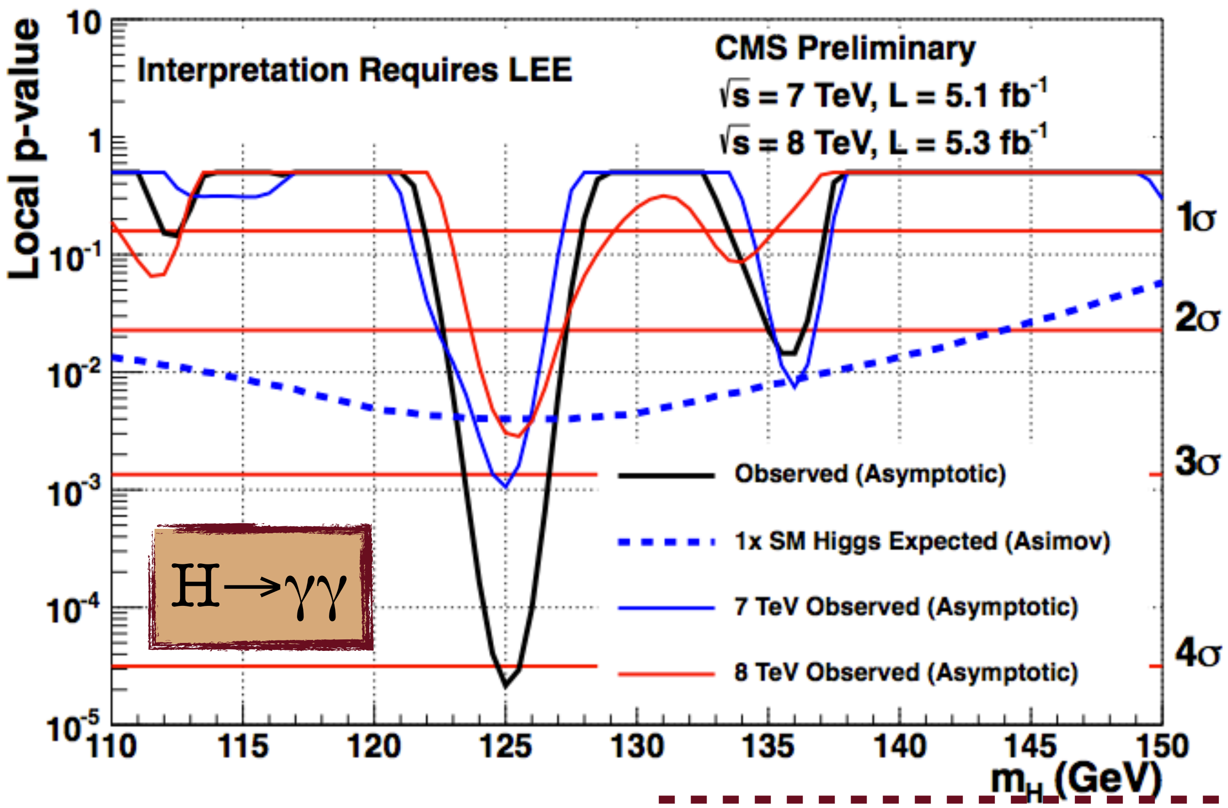
2D likelihood fit to signal mass and strength.
Curves show approximate 68% (full) and 95% (dashed) CL contours

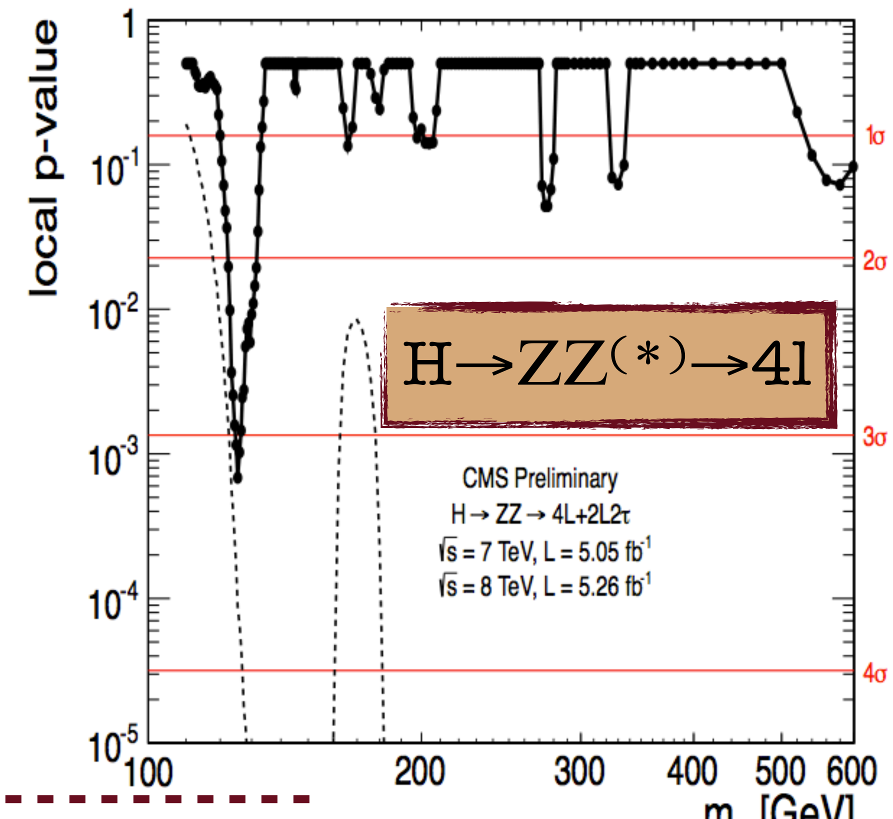


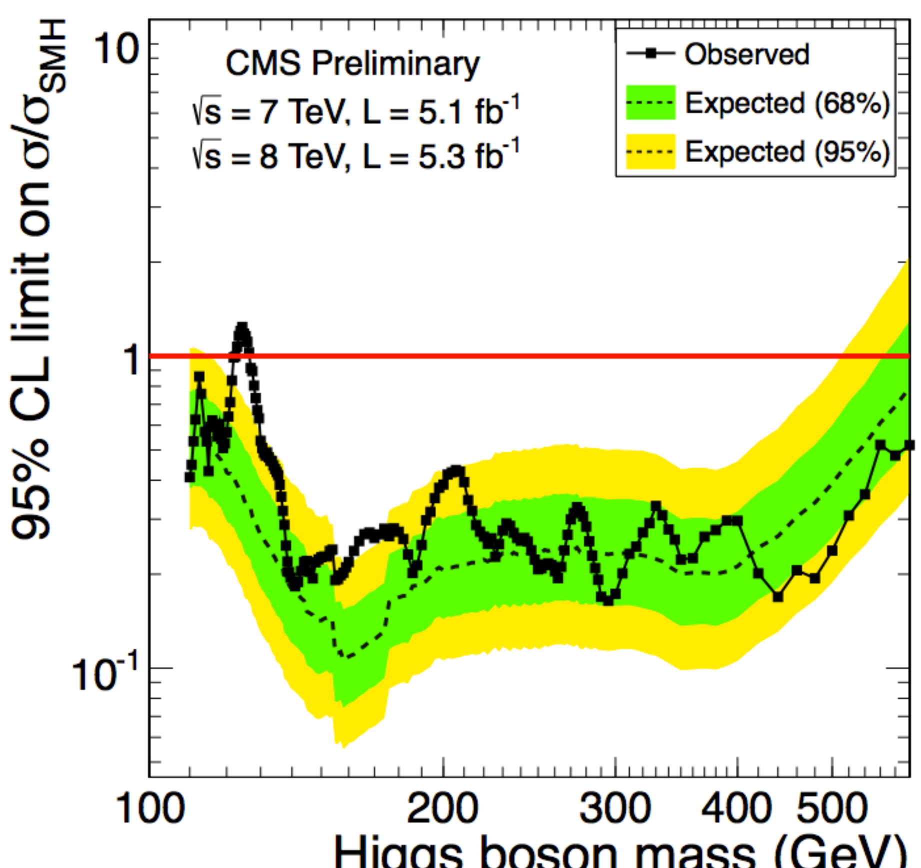
- The $H \to ZZ^{(*)} \to 4l$ and $H \to \gamma\gamma$ results are consistent within current uncertainties
- The $H \to WW \to l\nu l\nu$ given consistent results but with very large uncertainties (no mass peak)
- The effect of the Energy Scale Uncertainty is also given
- The effort to measure the mass of the new found particle is just starting

CMS Results in a nutshell

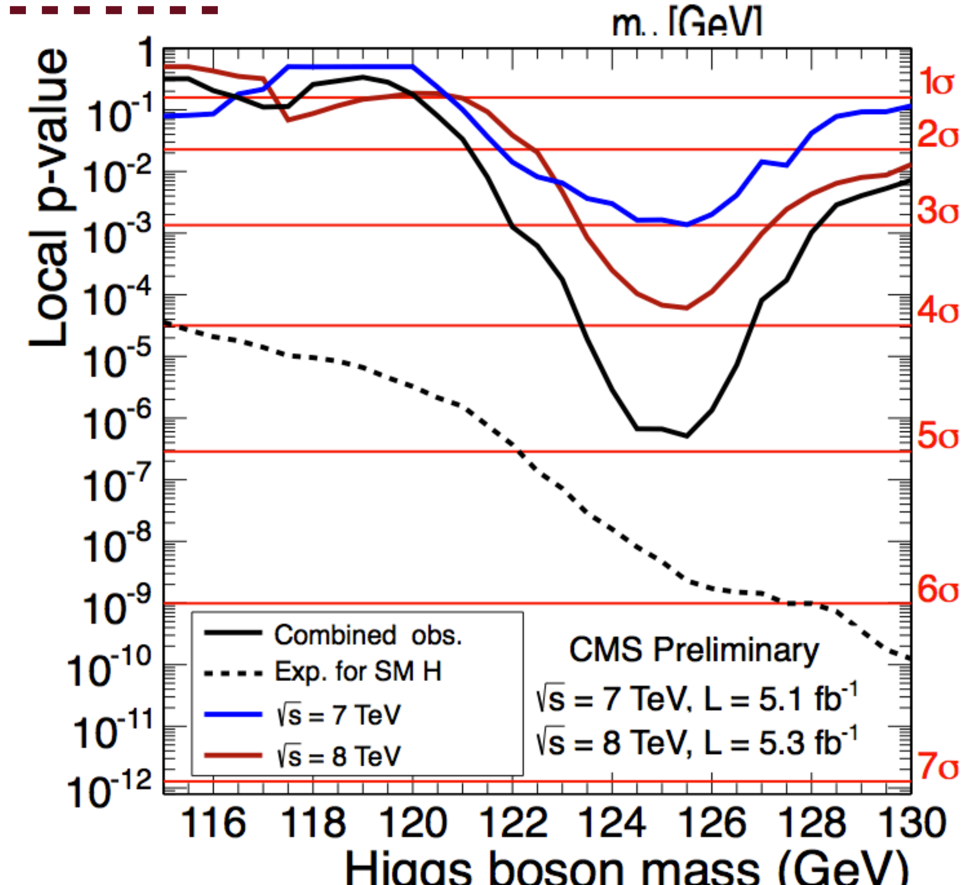
CMS updated all SM Higgs searches for the seminar on July 4th







CMS Overall Combination



Towards measurement of couplings

J. R. Espinosa et al. Higgs Hunting 2012 (arXiv:1207.1717[hep-ph])

FITS IN SM(a,c)

$\mathcal{L}$ valid at $E \sim M_t$.

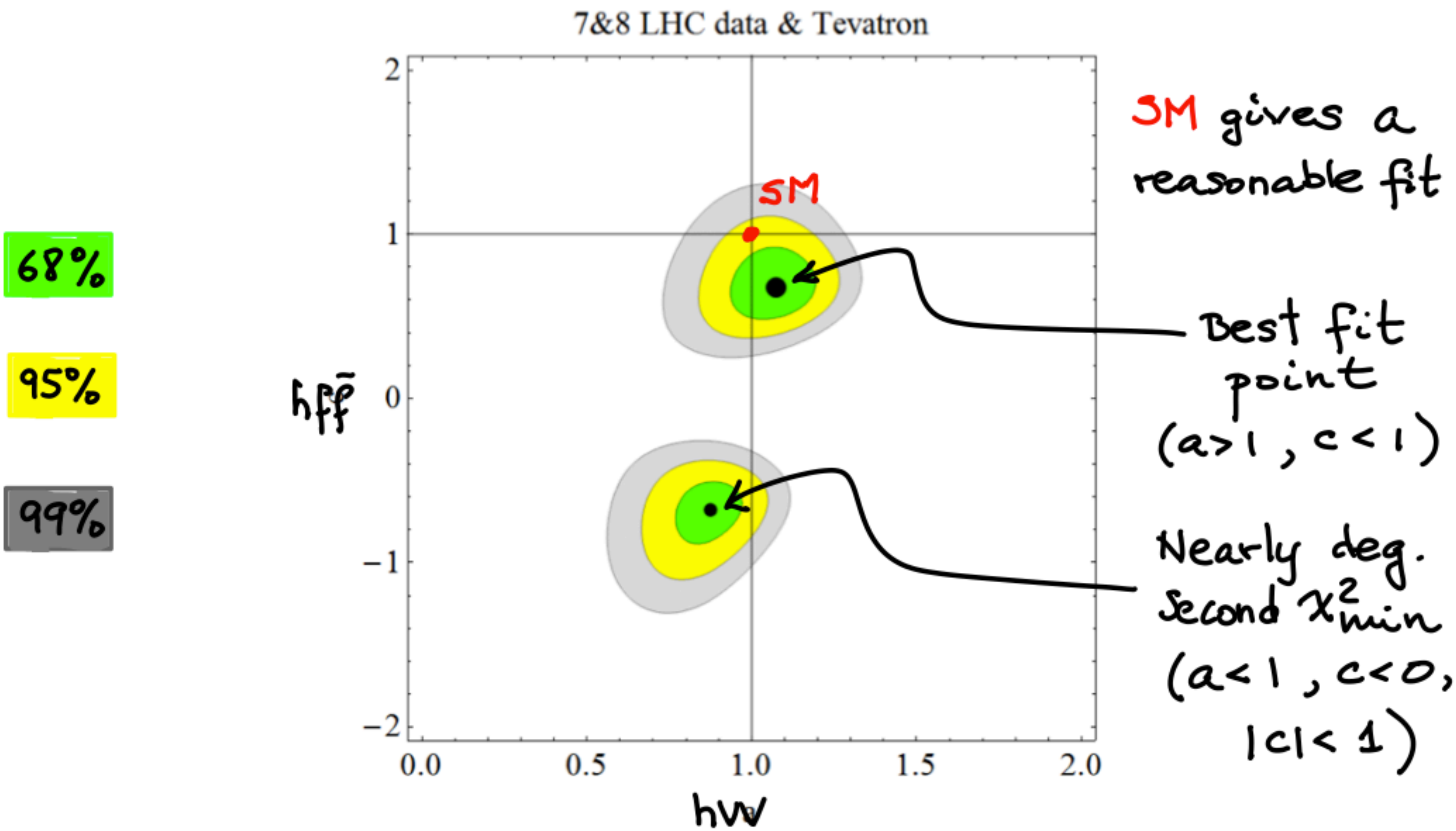
Field content: SM + scalar h (no extra light states)

$$\mathcal{L} = \mathcal{L}[h] - (M_W^2 W_\mu^+ W^{\mu -} + \frac{1}{2} M_Z^2 Z_\mu Z^\mu)\left[1 + 2a\frac{h}{v} + O(h^2)\right]$$
$$- m_{\psi_i} \bar{\psi}_i \psi_i \left[1 + c\frac{h}{v} + O(h^2)\right] + \dots$$

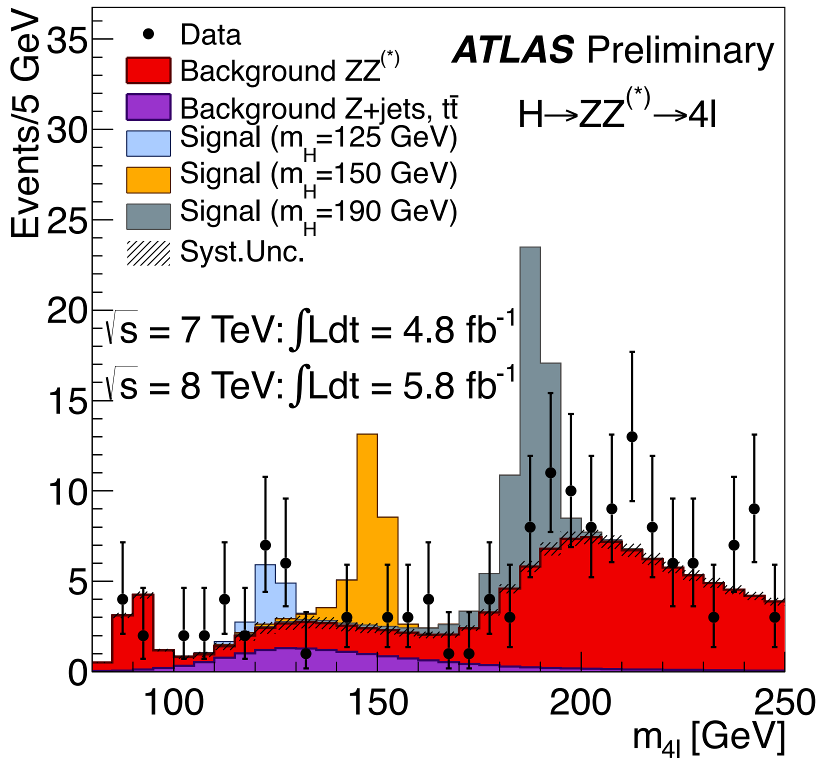
Contino et al '10 '12

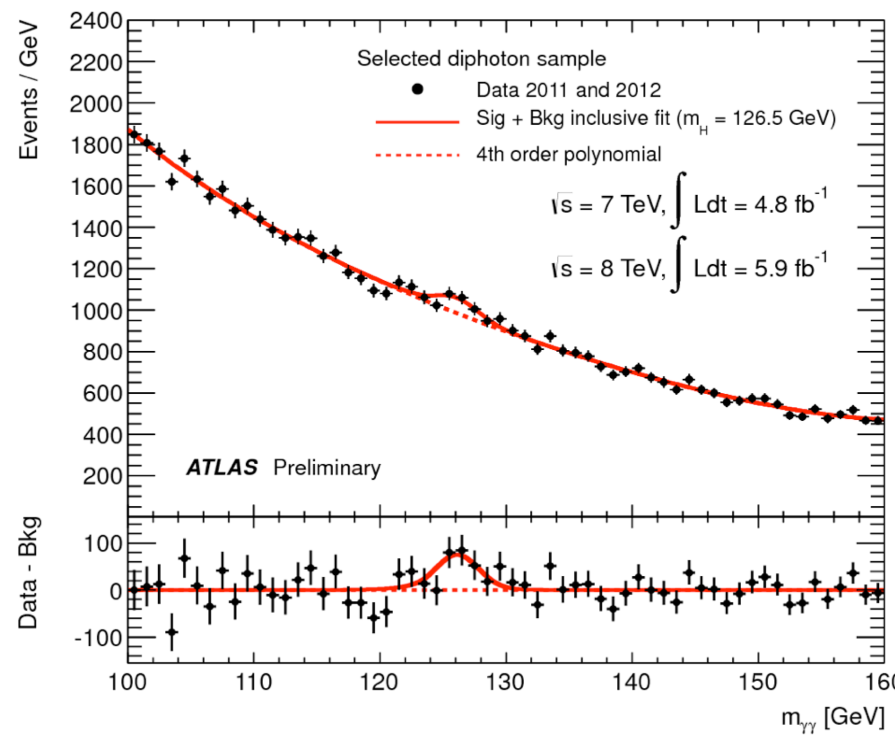
Incorporates $SU(2)_L \times U(1)_Y \to U(1)_{em}$ breaking

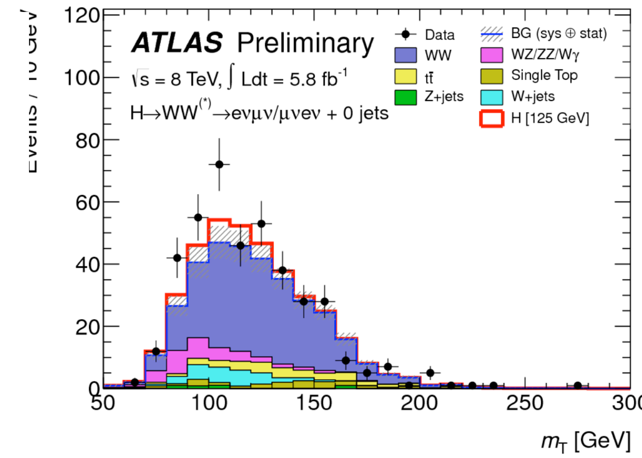
χ^2 fit to $\hat{\mu}_i \pm \sigma_i$ from 48 channels (ATLAS+CMS+Tevatron)

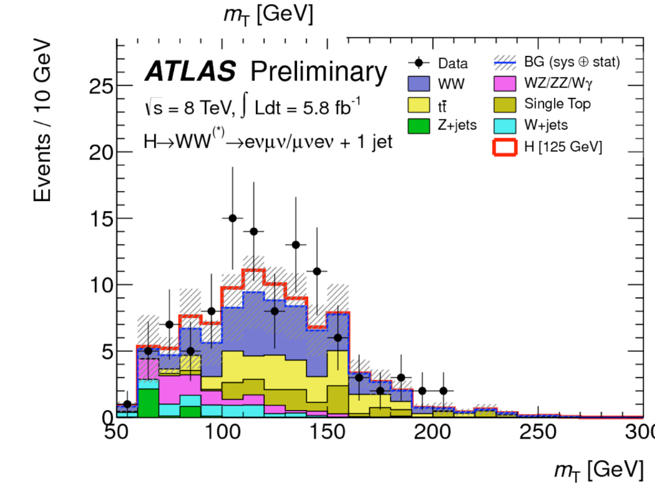


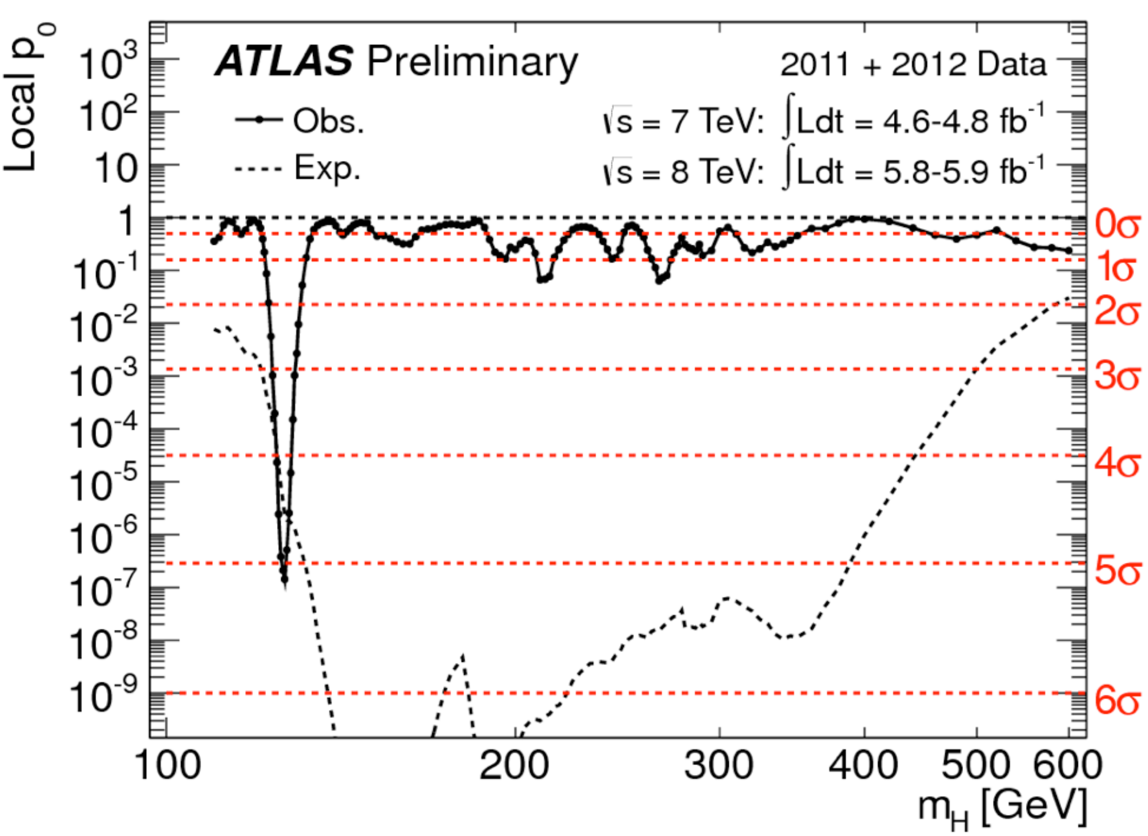
Summary











ATLAS observes a significant excess of events over the background only hypothesis at m_H~126.5 GeV

→ Consistent in both 2011 and 2012 datasets.

→ Combined: **5.0σ** at m_H=126.5 GeV, expected 4.6σ

[4.1-4.3σ global significance (110-600/110-150 GeV)]

→ H→WW→lνlν (2011+2012) observes 2.8σ

CMS observes similar excess

Now, focus on the properties of the new-found particle!

Additional Slides

Evolution of significance with time