Higgs search at ATLAS

S.M. Consonni
On behalf of the ATLAS Collaboration
Università degli Studi di Milano & INFN

Right title?

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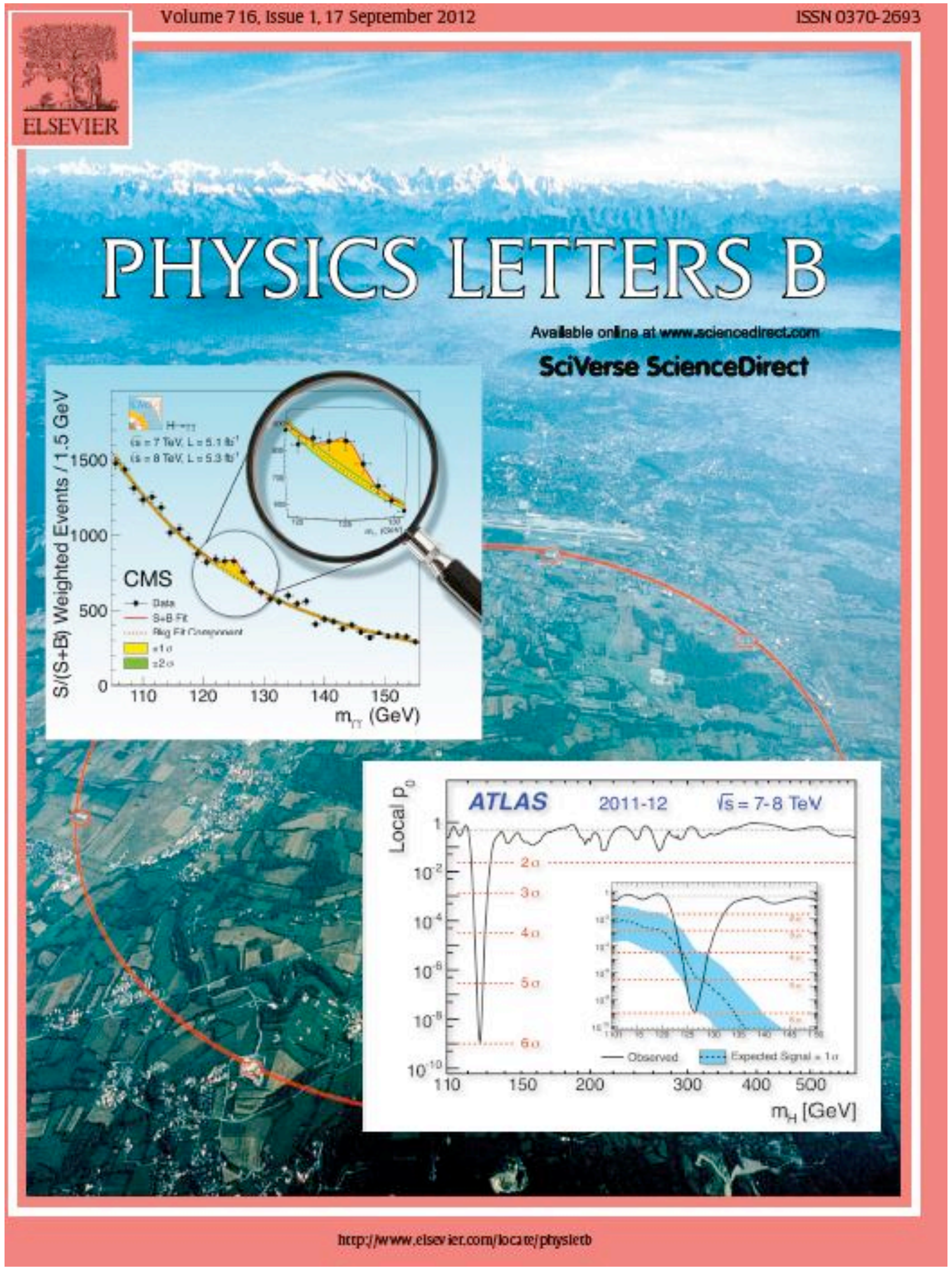

July 4th: ATLAS and CMS collaborations announce new boson discovery in the context of Higgs boson searches...

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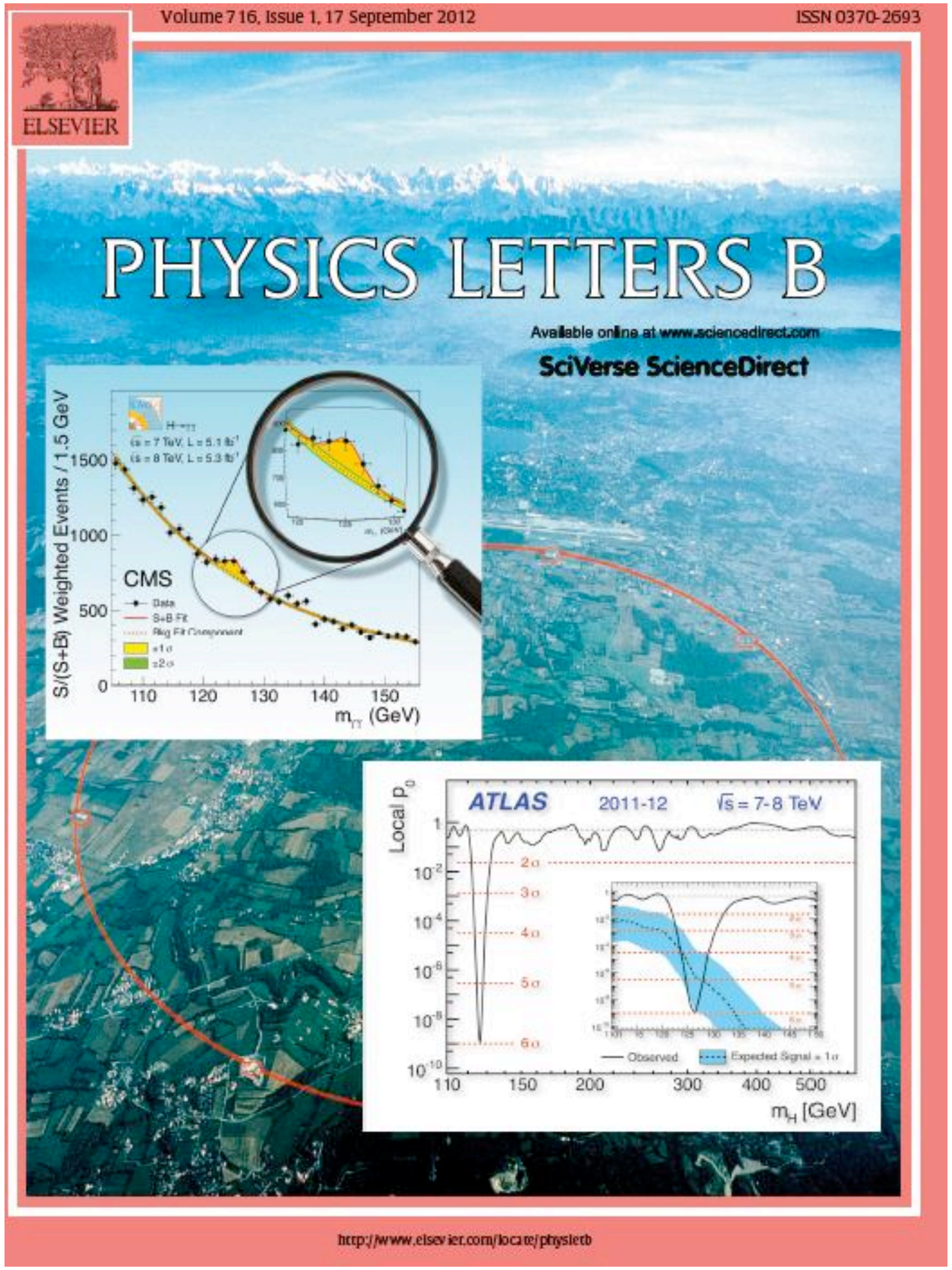


July 4th: ATLAS and CMS collaborations announce new boson discovery in the context of Higgs boson searches...

since then focus on

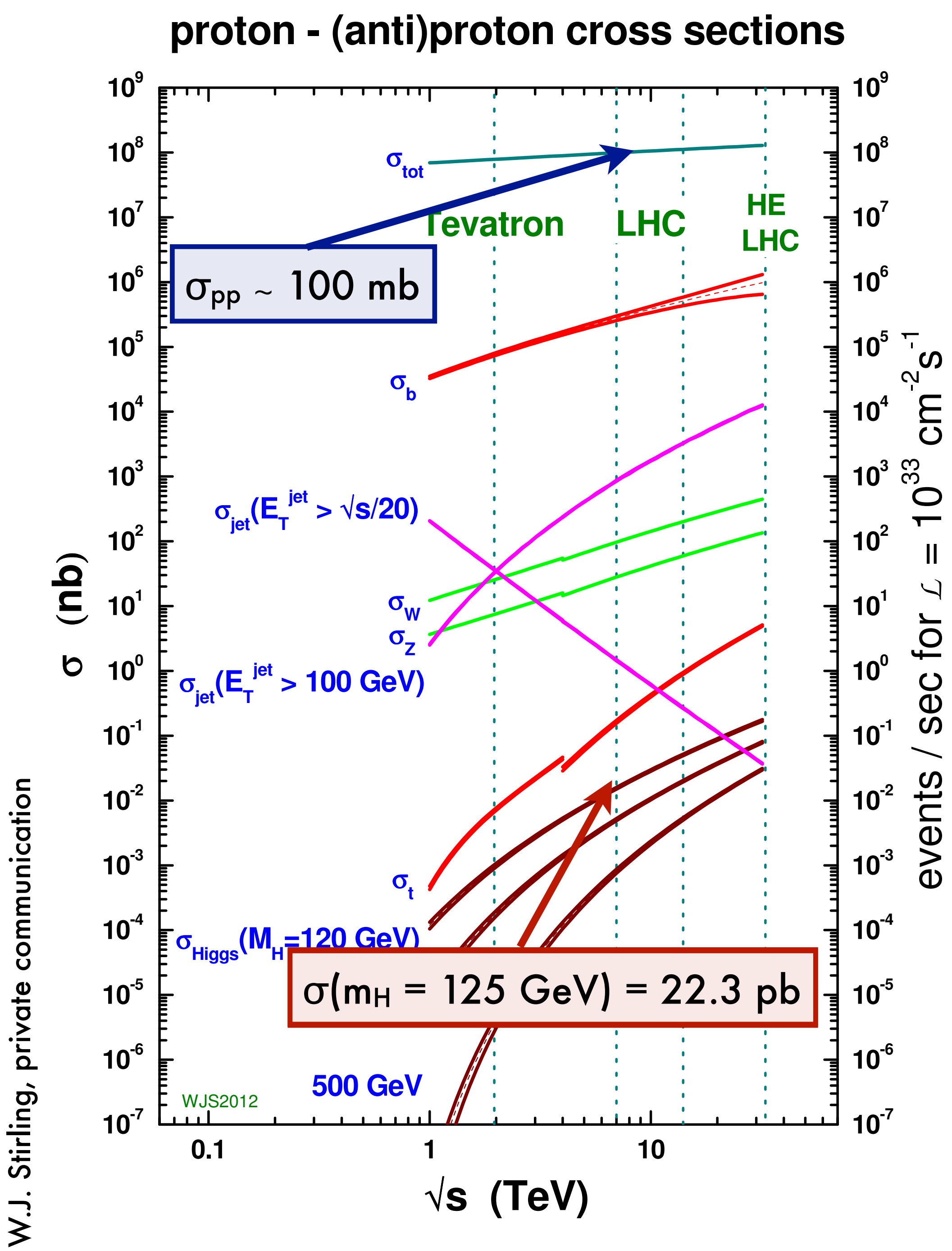
- property measurements of the new boson
- searches for other decays channels

The Higgs, LHC, Atlas

W.J. Stirling, private communication

The Higgs, LHC, Atlas

Needle in a haystack



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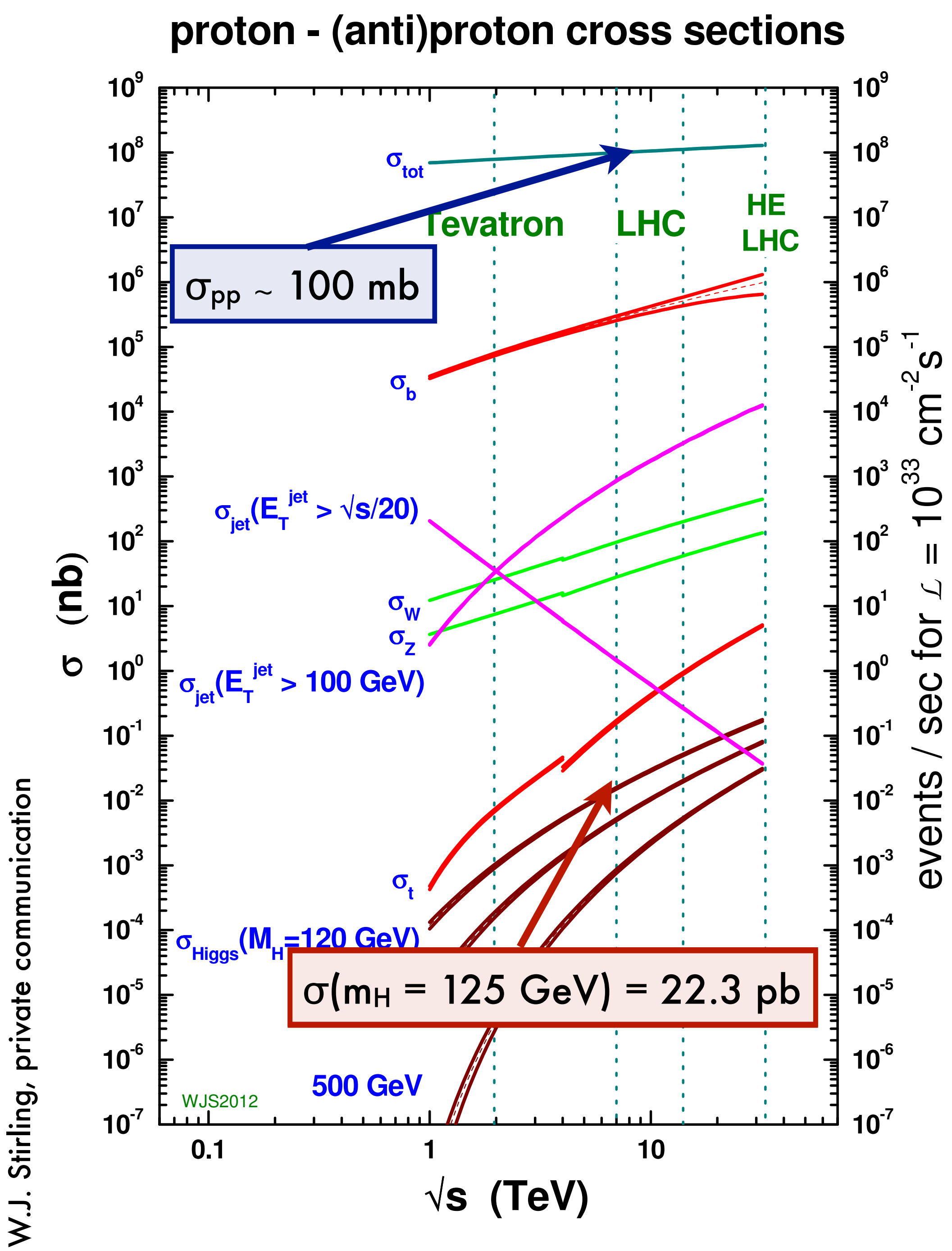
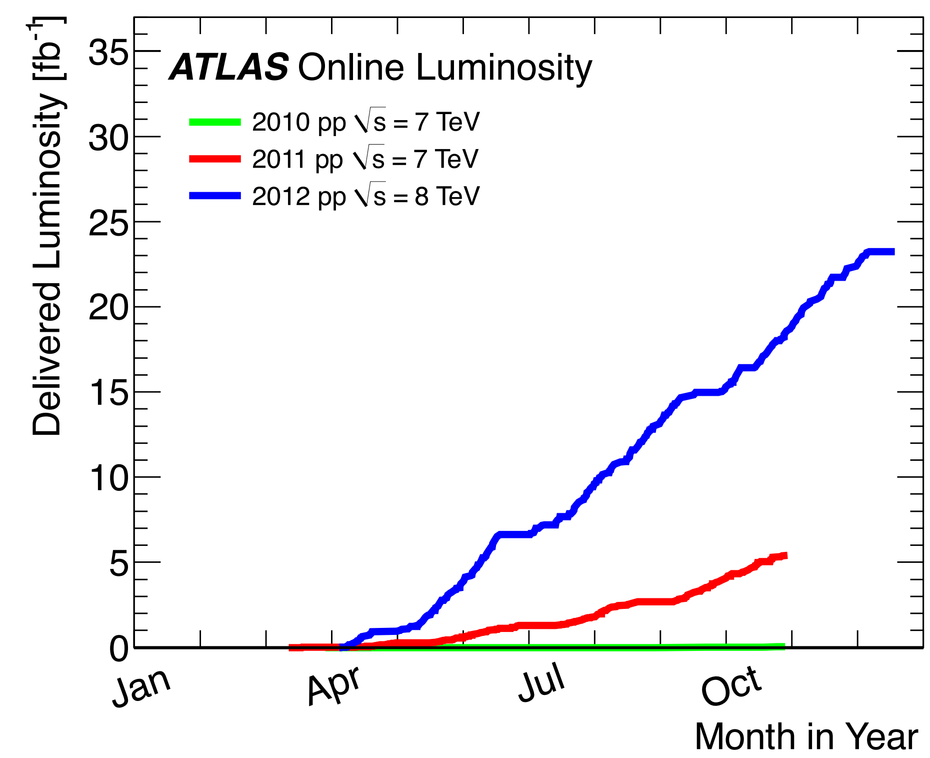


LHC
L_{peak} 7.7·10^{33} cm^{-2}s^{-1}
L_{int} ~ 29 fb^{-1}
in 2011+2012

ATLAS
~90% of delivered luminosity used in physics analyses



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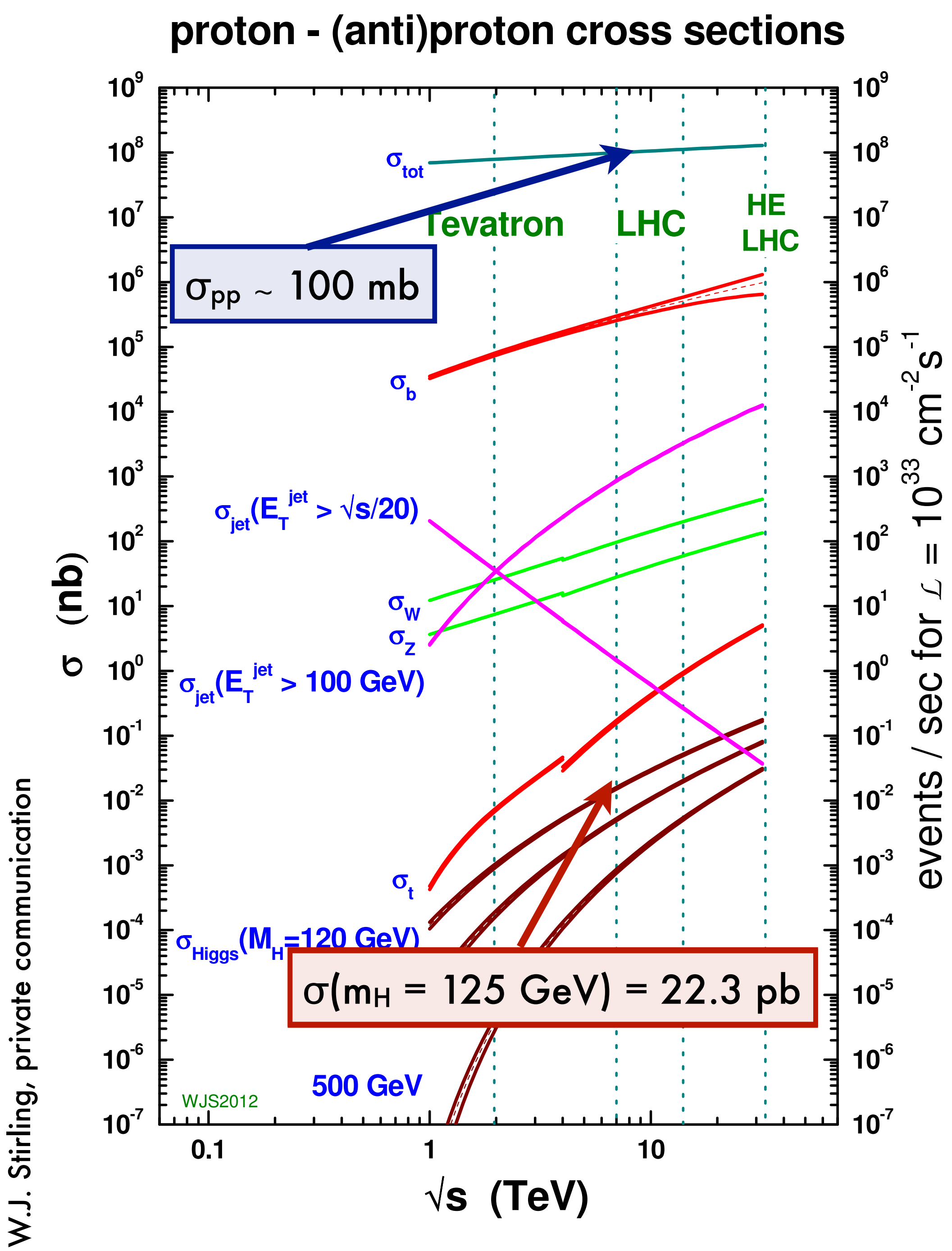

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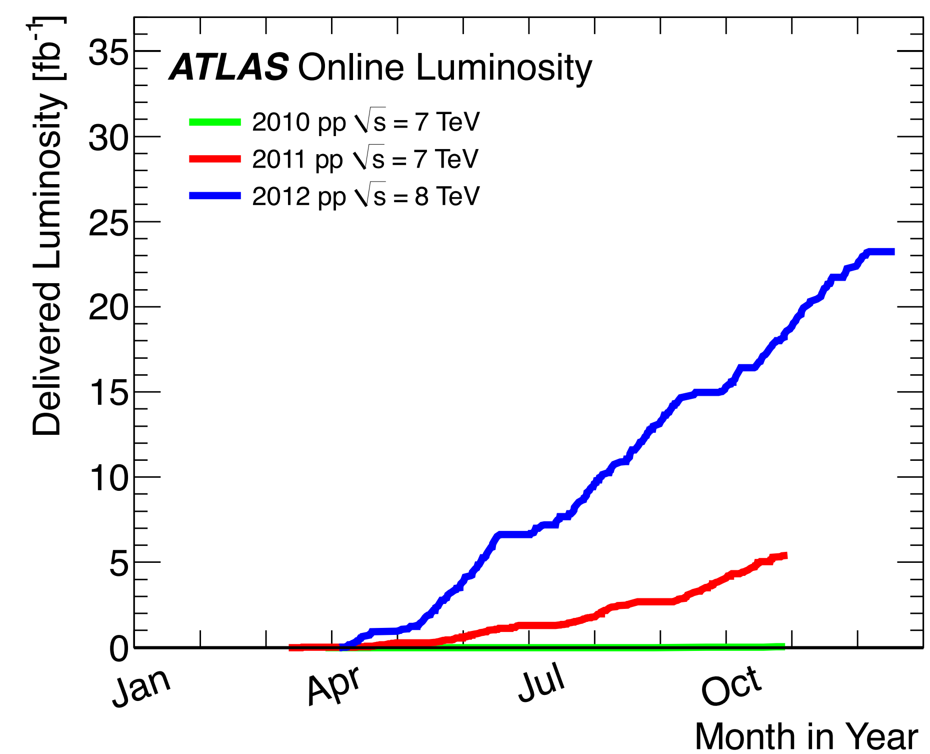
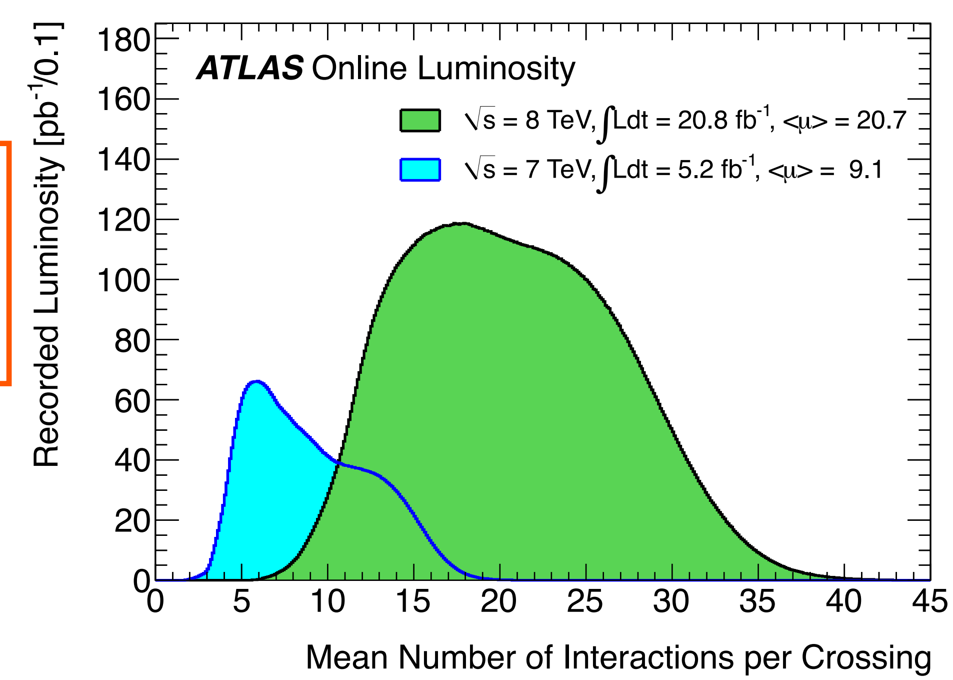
Pileup:
the price to pay…
above design values

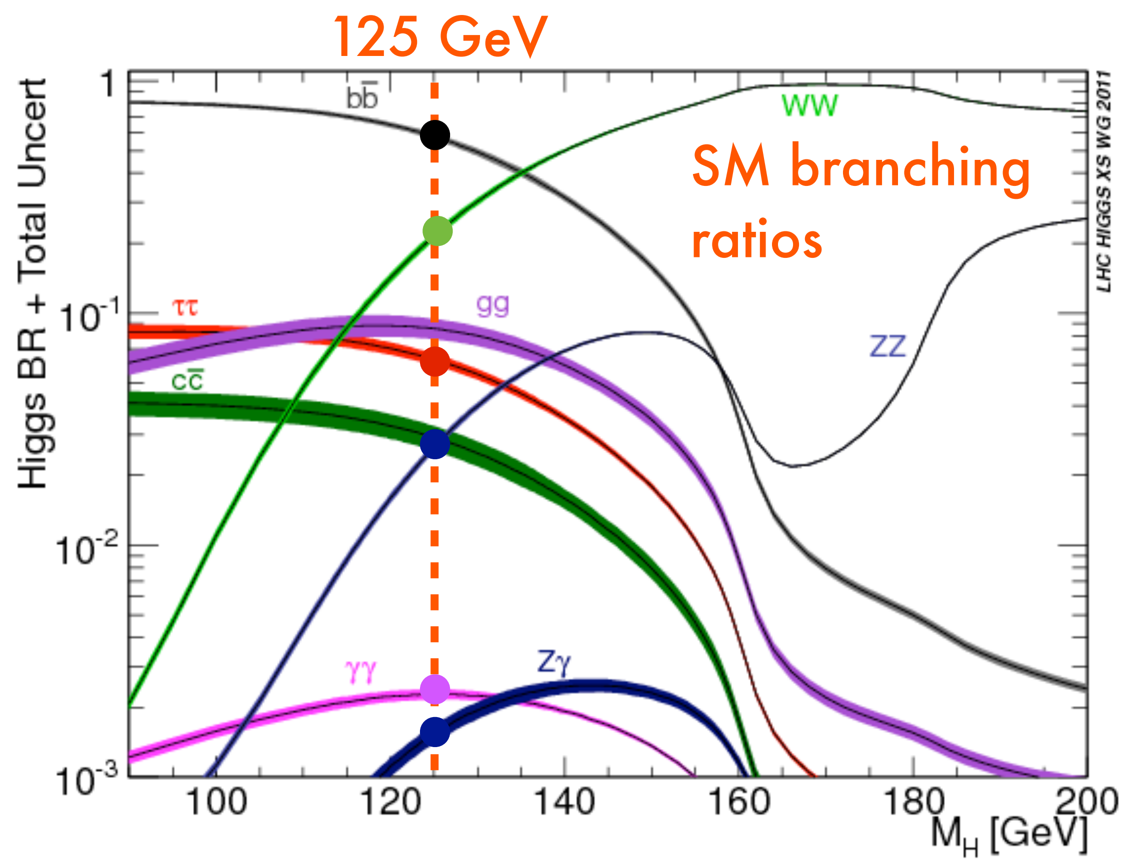




SM and BSM searches and measurements

SM and BSM searches and measurements

- Measurements and searches in the context of SM Higgs boson search
  - golden bosonic decay channels
    - γγ and ZZ→ 4l
    - WW
    - Zγ
    - more high mass devoted: ZZ→ llqq, ZZ→ llνν, WW→ lνqq
  - fermionic decay channels
    - ττ, bbar, μμ



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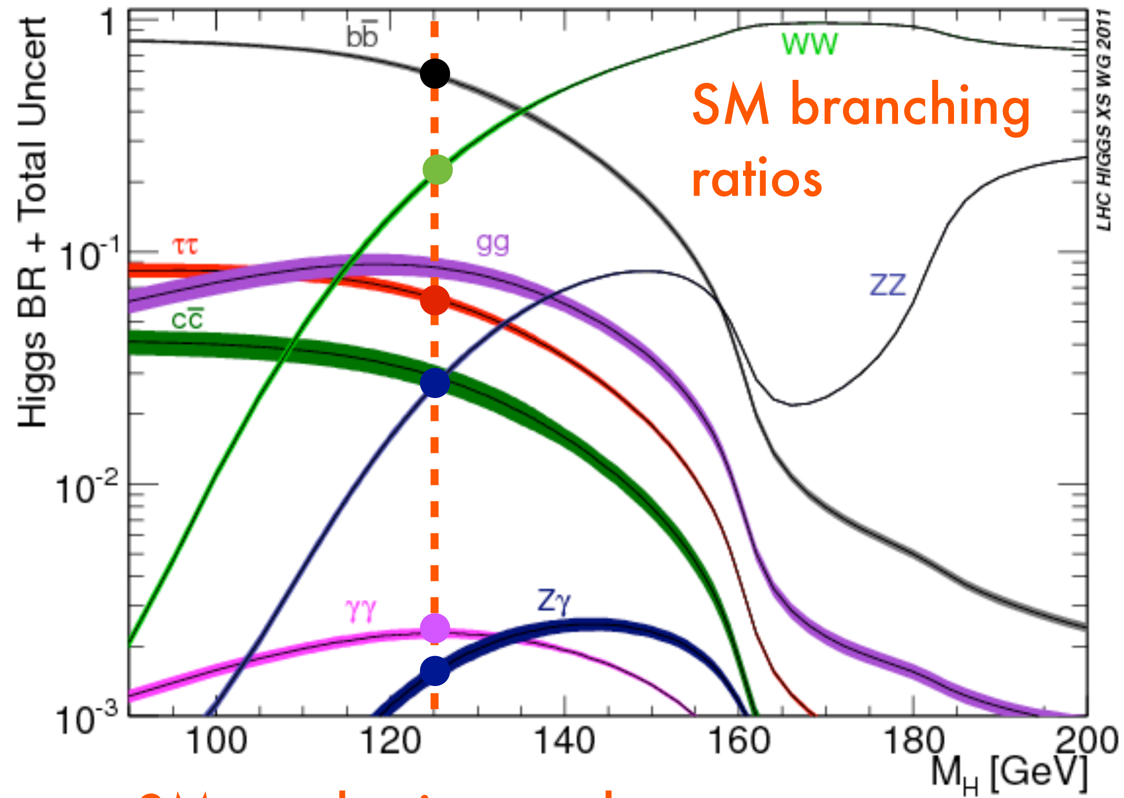
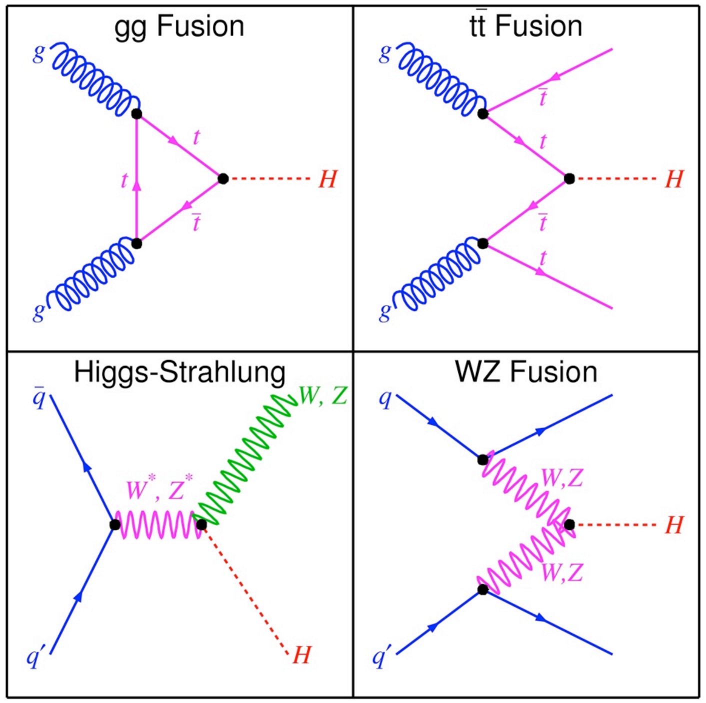
Production modes used both to enhance analysis sensitivity and to get information about couplings



SM production modes



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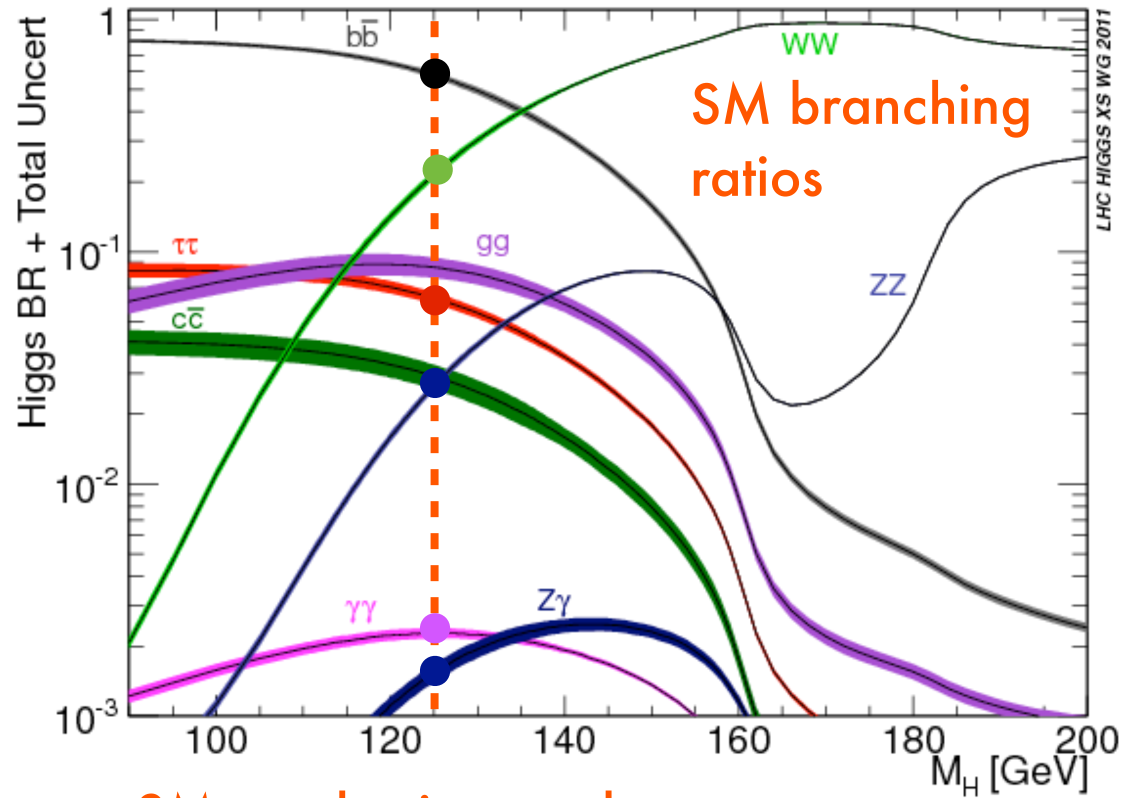

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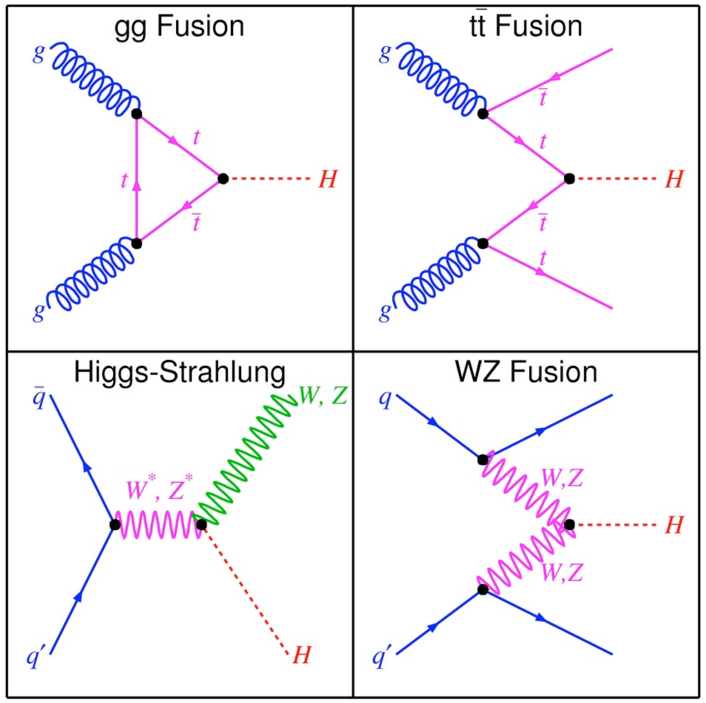


Production modes used both to enhance analysis sensitivity and to get information about couplings

Generic BSM: invisible decays
MSSM: A/H → ττ, $H^{\pm}$→τν or csbar

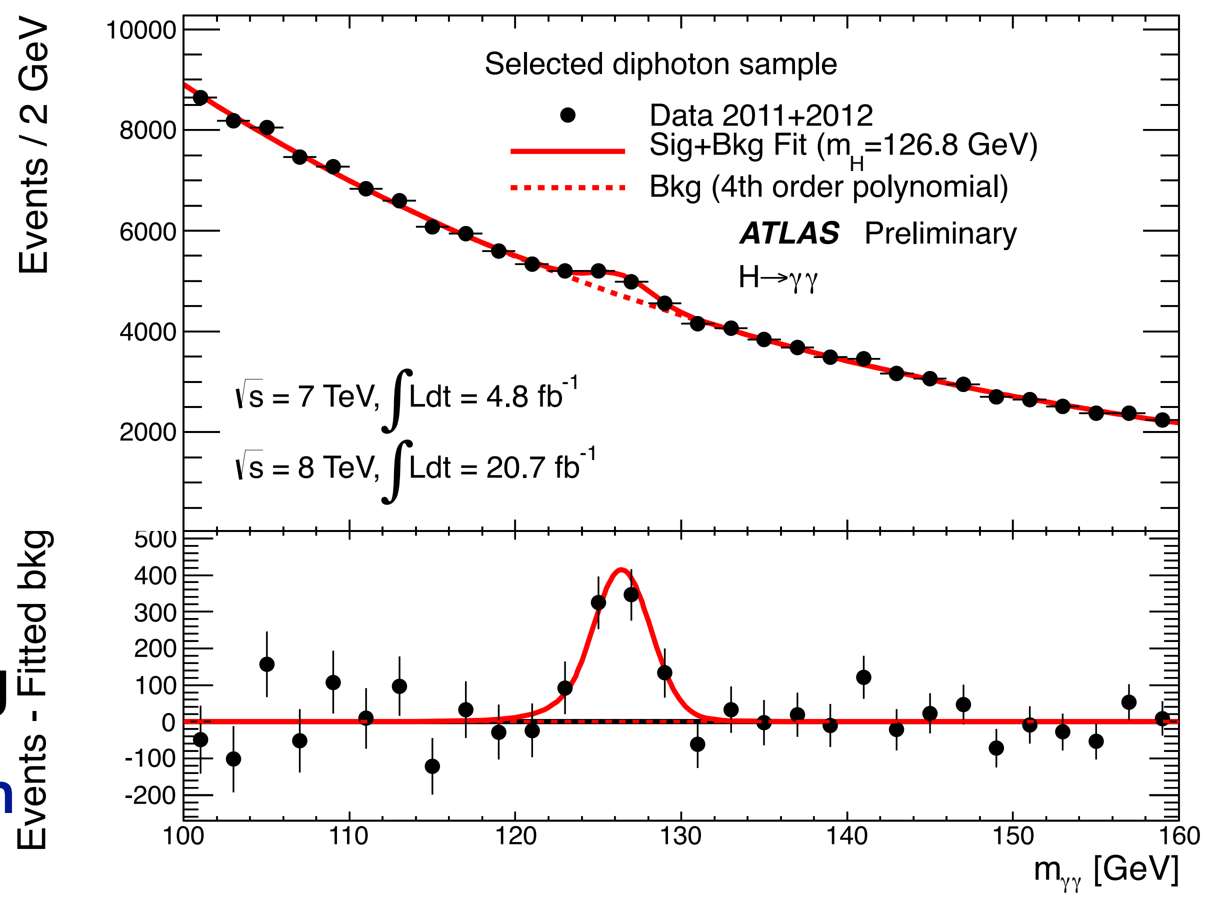
H→γγ overview

ATLAS-CONF-2013-012

H→γγ overview

ATLAS-CONF-2013-012

- Low BR (~0.2%) but very distinctive signature
- Main production mode and decay through loops: sensitive to new physics
- High mass resolution channel: σ_m ~ 1.7 GeV
  - stable against time and pileup
  - negligible uncertainty on primary vertex identification thanks to calorimeter pointing
- 14 categories targeting different production modes, VH (lepton, jets and MET) and two VBF categories. Different sensitivities and resolutions



H→γγ overview

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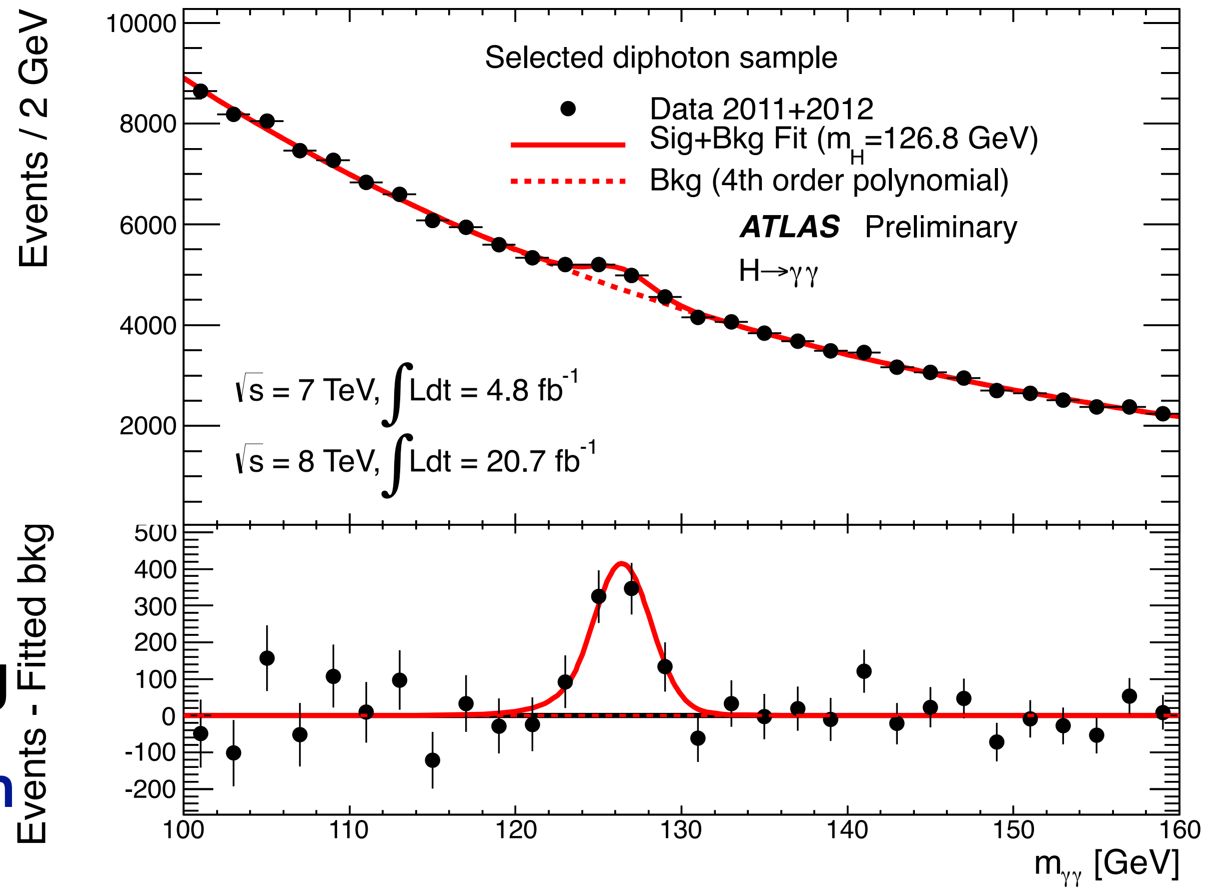


- 14 categories targeting different production modes, VH (lepton, jets and MET) and two VBF categories. Different sensitivities and resolutions
- Main backgrounds: γγ continuum (75%), γ-jet, jet-jet events (25%)
  - tight photon identification and isolation
  - background parametrised by an analytic function in each category, model chosen with MC to minimise biases
  - background extrapolated from side-bands in data
  - S/B ~ 3% in mass window

H→γγ signal strenght and mass

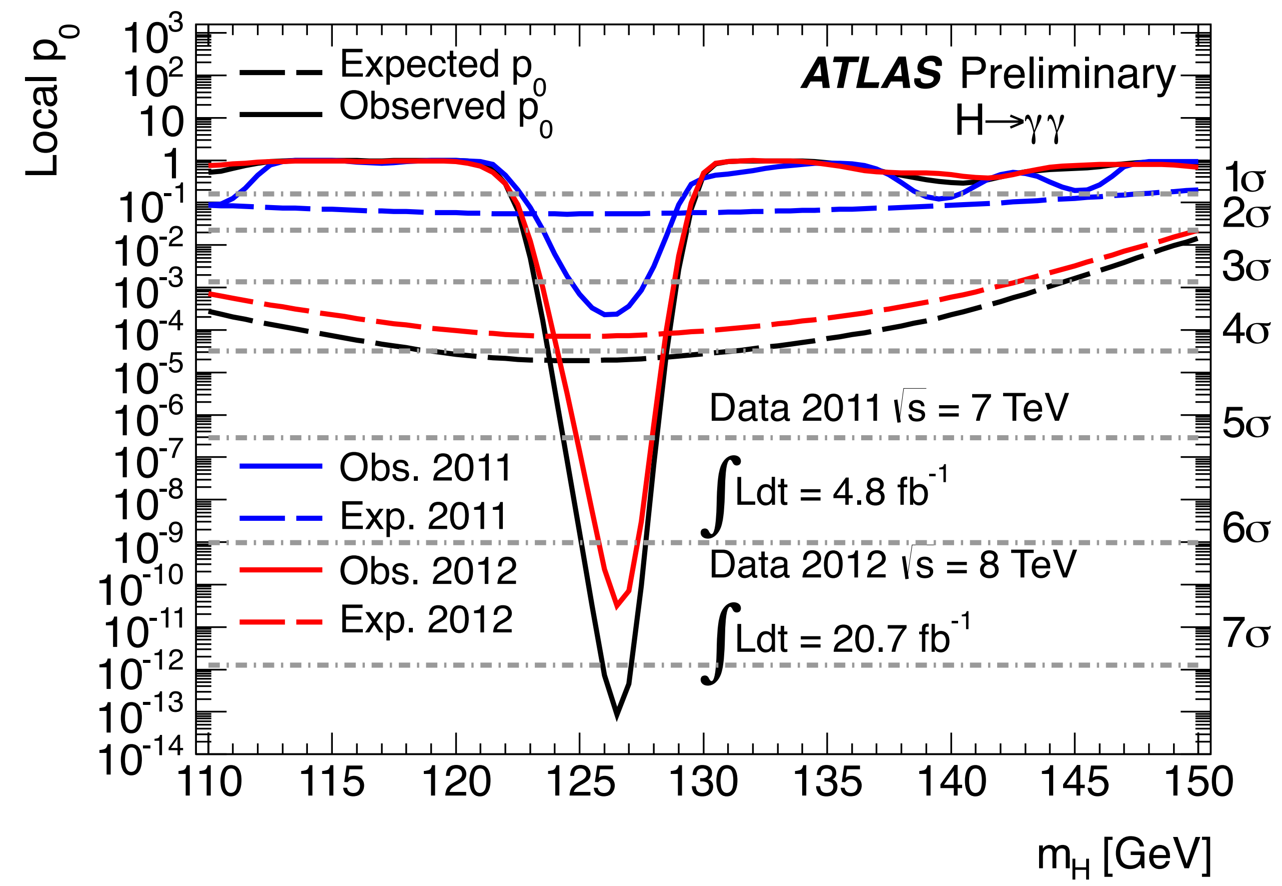
ATLAS-CONF-2013-012

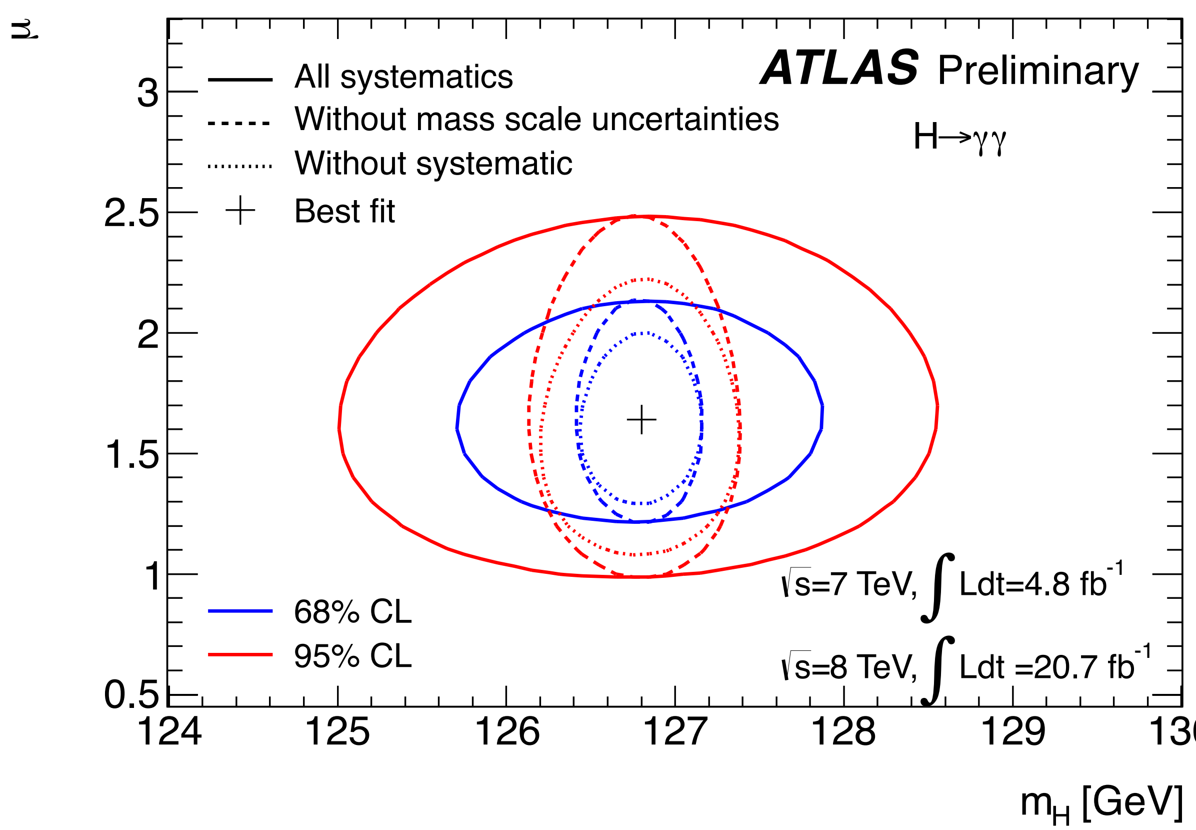
- Signal extracted by $m_{\gamma\gamma}$ fit in each category
- Observed excess local significance: 7.4σ (4.1σ SM expected)
- Signal strenght at best fit mass:

$\mu = 1.65 + 0.24(stat)\ ^{+0.25}_{-0.18}\ (syst)$

- Inclusive fiducial cross section:

$\sigma_{fid} \times BR = 56.2 \pm 12.5$ fb





- Best fit mass:

$m_H = 126.8 \pm 0.2\ (stat) \pm 0.7\ (syst)$ GeV

- Main mass sytematics:

- Extrapolation of γ energy scale from Z→ee (0.3%)
- Material modeling (0.3%)
- Presampler energy scale (0.1%)

H→γγ couplings and spin

ATLAS-CONF-2013-012
ATLAS-CONF-2013-027

H→γγ couplings and spin

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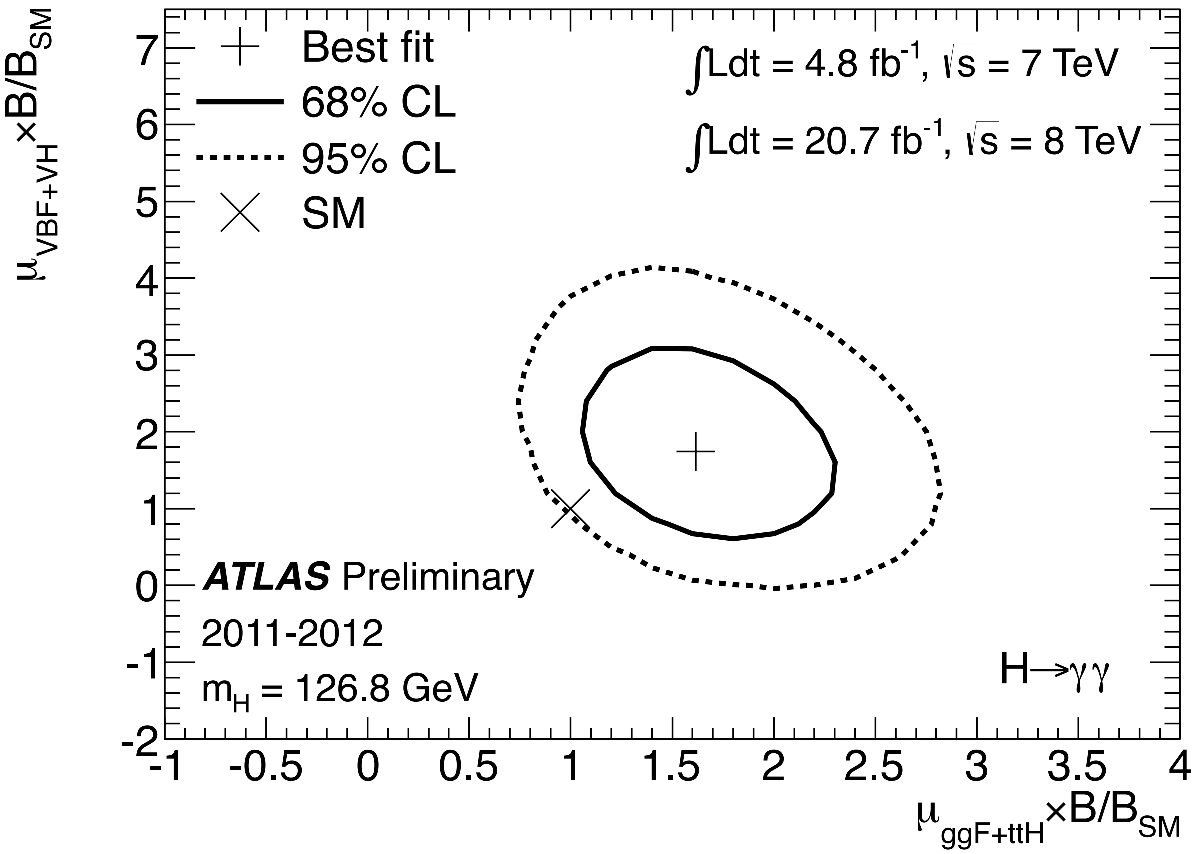
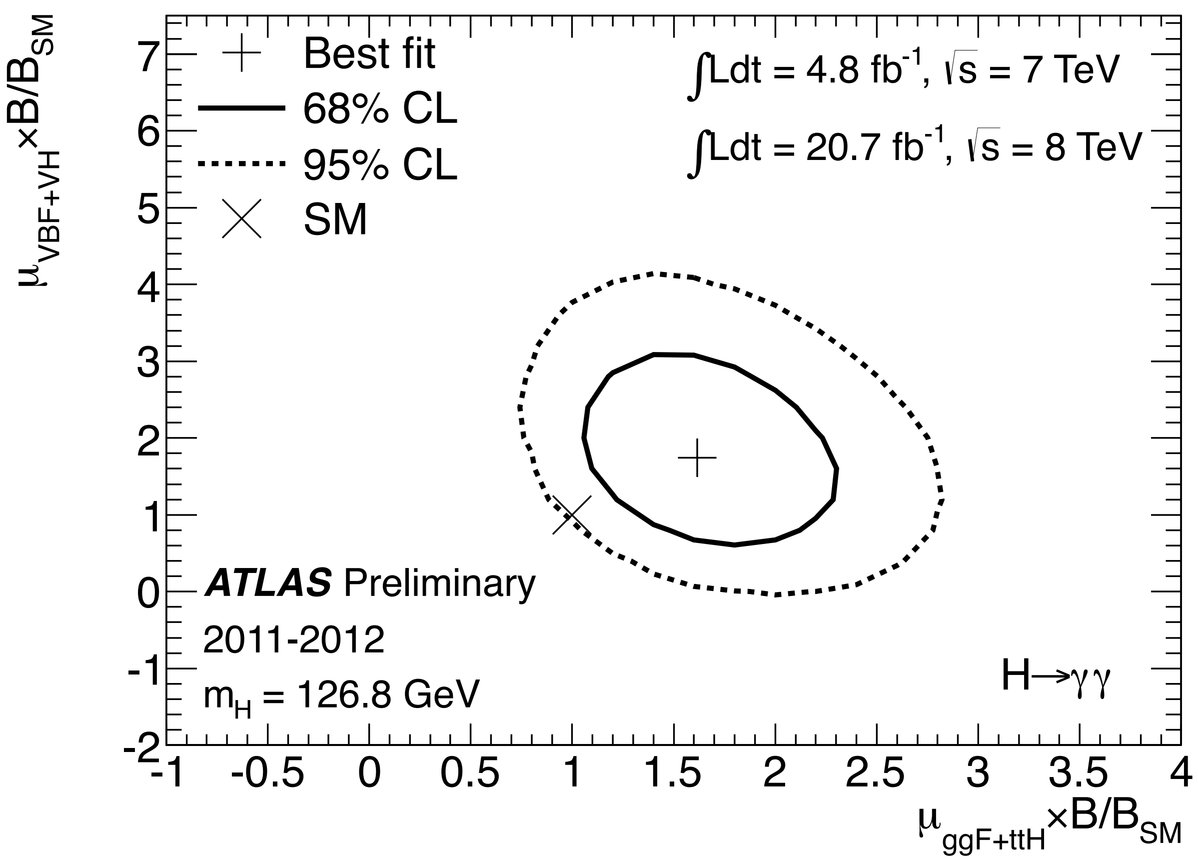
ATLAS-CONF-2013-027



- Grouped ggF+ttH and VBF+VH production modes (boson and fermion couplings)
- Compatibility with SM at 2σ level
- VBF production excess: 2σ level

H→γγ couplings and spin

ATLAS-CONF-2013-012
ATLAS-CONF-2013-027



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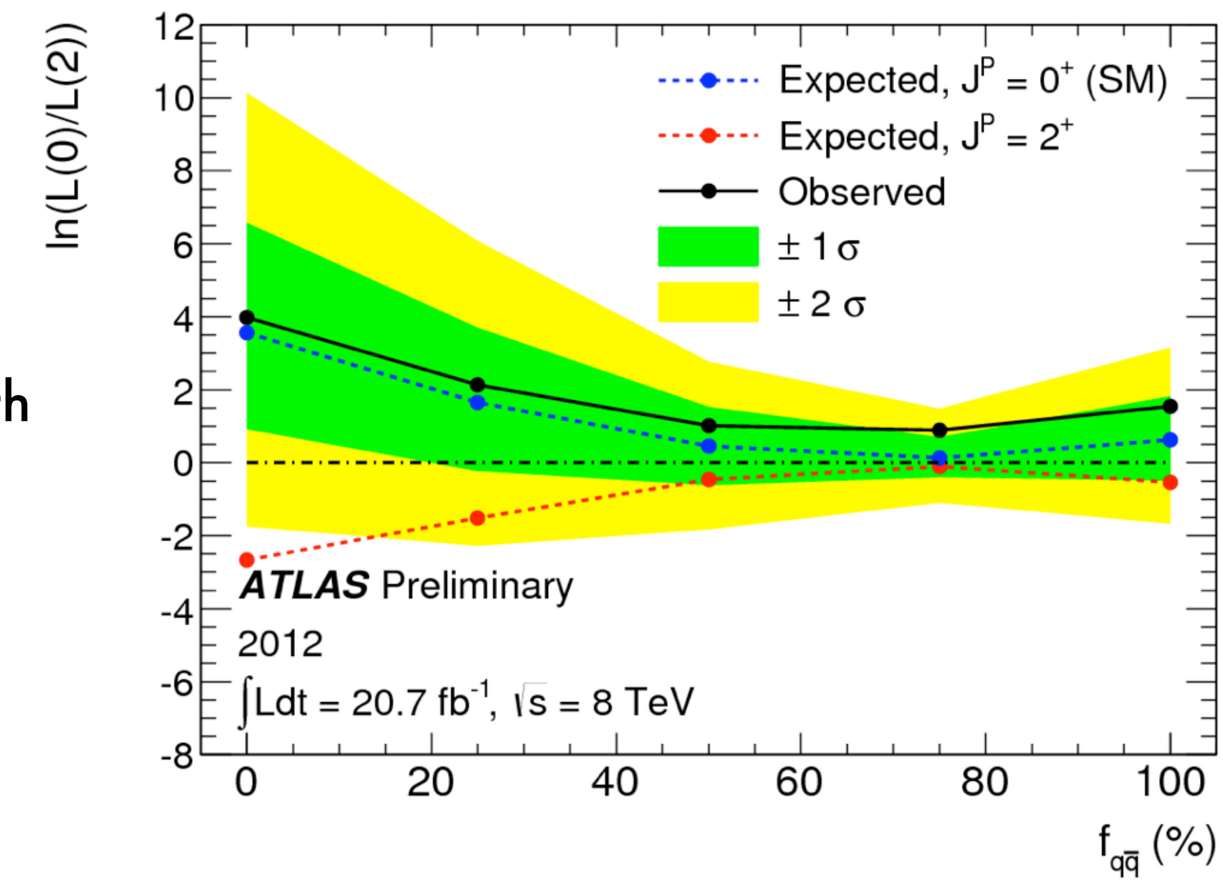
- From dN/d|cosθ*|, θ* angle of the photons in resonance rest frame
  - 0^+ → flat before cuts
  - 2^+ → $1+6\cos^2\theta^* + \cos^4\theta^*$ (graviton like model with minimal couplings, gg production)
- Inclusive analysis with different p_T cuts
- Signal region: ±1.5σ around peak
- Background from sidebands
- Five benchmarks of 2^+ production (qqbar fraction)
- Analyses based on $m_{\gamma\gamma}$ and dN/d|cosθ*|



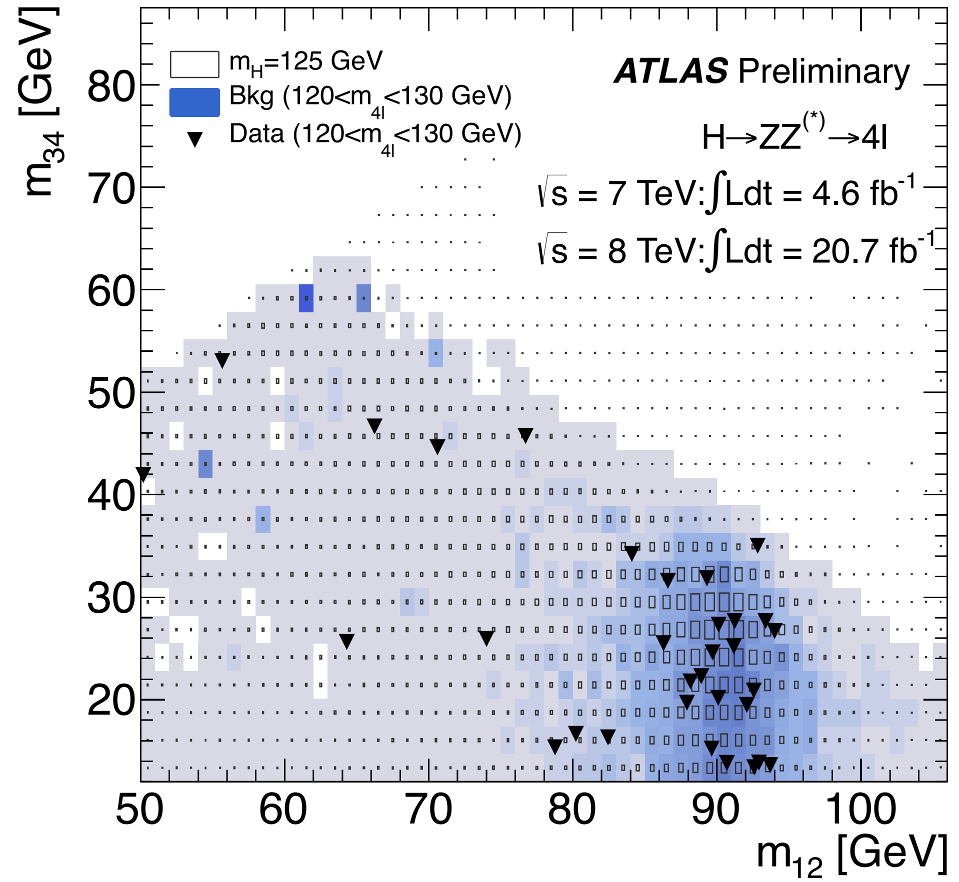
$H \rightarrow ZZ \rightarrow 4l$ overview

ATLAS-CONF-2013-013

H→ZZ→4l overview

ATLAS-CONF-2013-013

- Golden channel: small BR but very clear signature (two pairs l^+l^-) and very good mass resolution
- Maximise acceptance with high μ/e reconstruction and id efficiency down to 6/7 GeV
- FSR recovery (~ 4% of events)
- Mass resolution: 1.3%/1.9% for 4μ/4e @125 GeV



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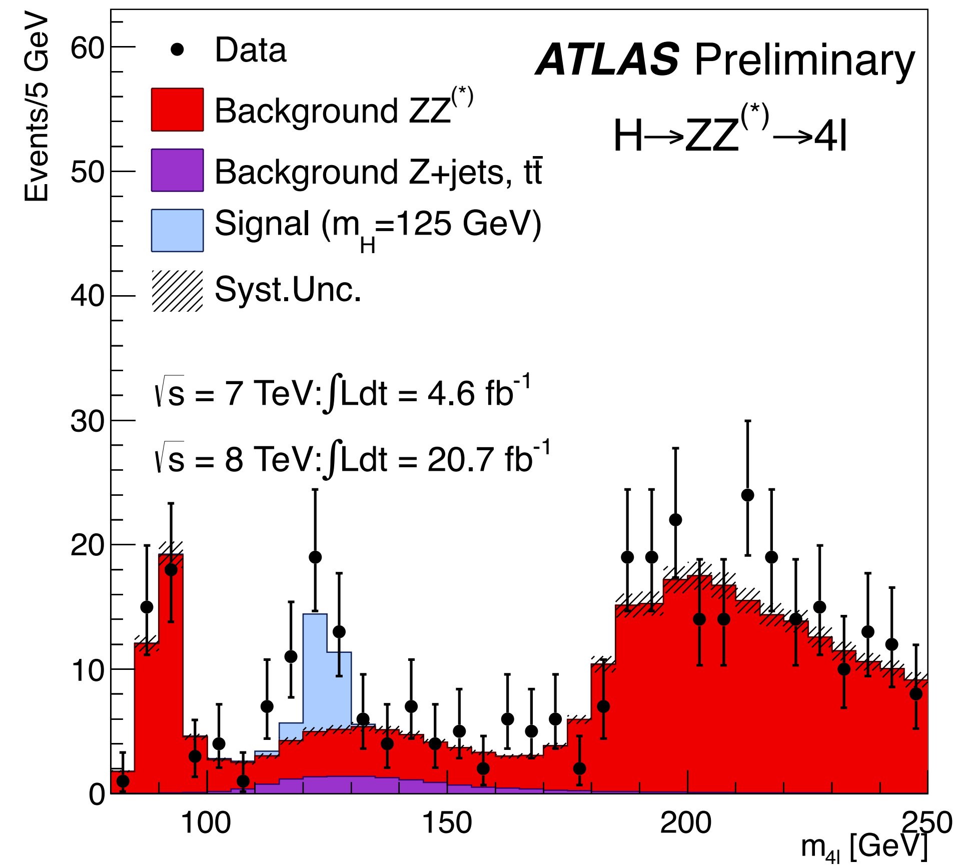
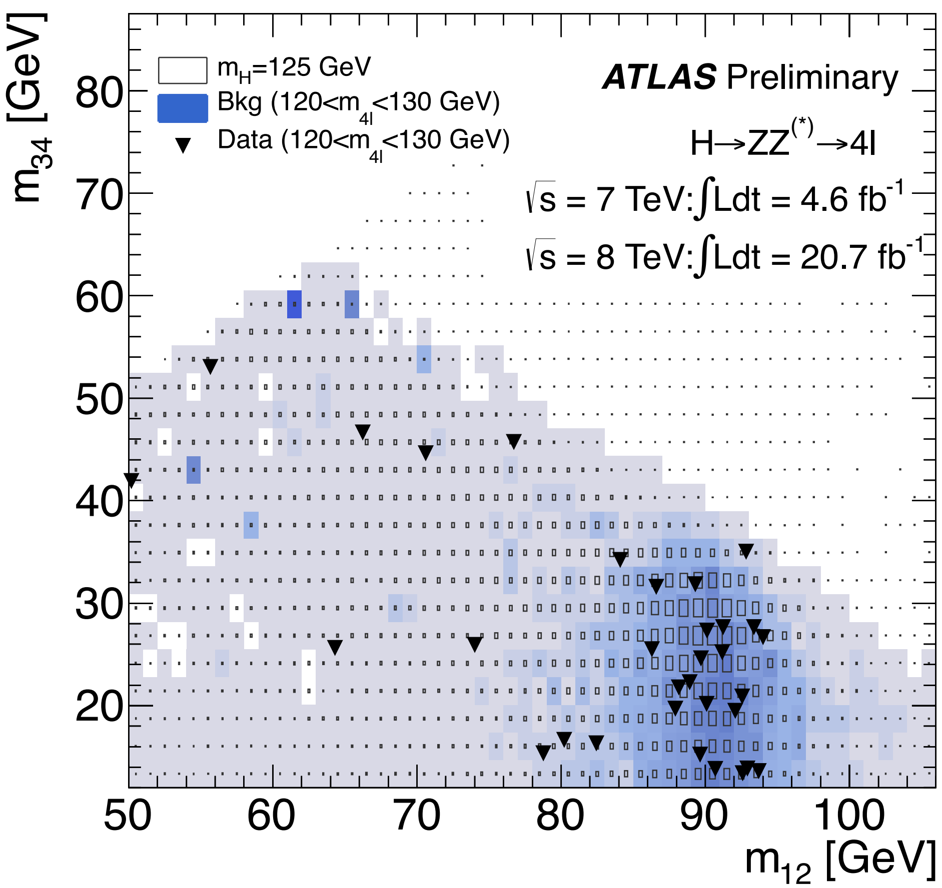


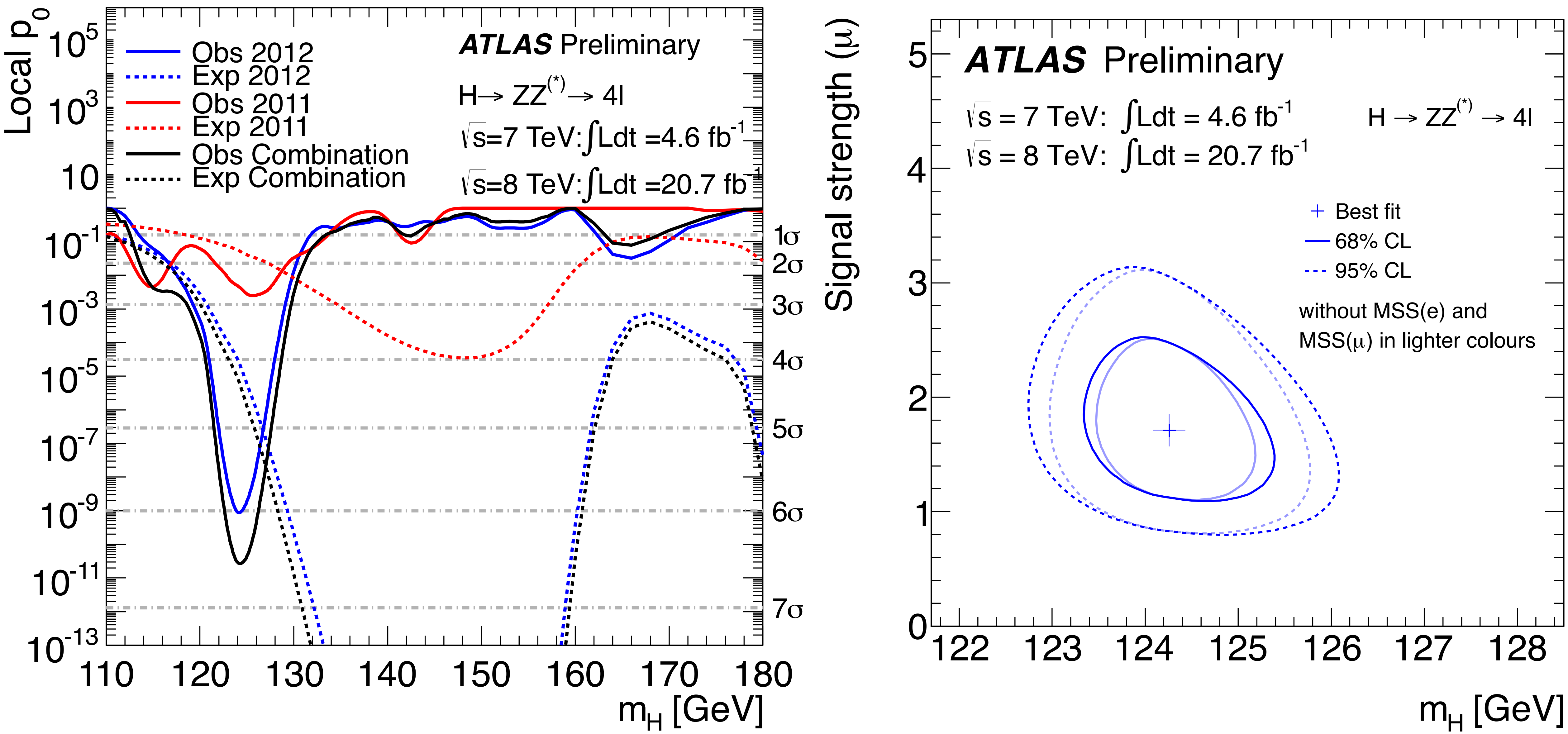


- Background
  - irreducible ZZ continuum (MC), including Z→4l
  - Z+jets, Z+bb, ttbar
    - isolation and impact parameter cuts
    - background measurement in data control regions
- Mass resolution improved by Z mass constraint
- 3 Categories reflecting different production modes

$H \rightarrow ZZ \rightarrow 4l$ mass and signal strenght

ATLAS-CONF-2013-013

- 6.6 σ local significance excess
- $m_H = 124.3^{+0.6}_{-0.5}\,(stat)^{+0.5}_{-0.3}(syst)$ GeV
- $\mu = 1.7^{+0.5}_{-0.4}$



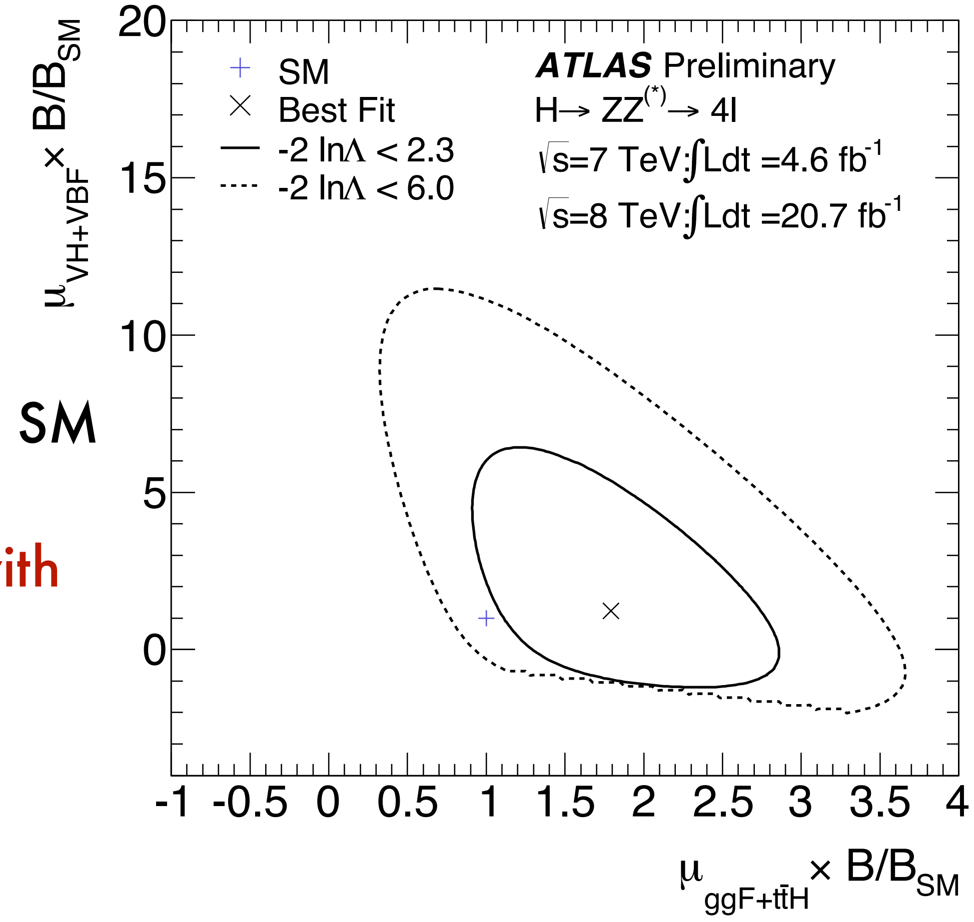
H→ZZ→4l couplings and spin

ATLAS-CONF-2013-013

H→ZZ→4l couplings and spin

ATLAS-CONF-2013-013

- Categorisation dedicated to coupling studies
  - VBF: 2 high pT jets $\Delta\eta_{jj} > 3$ $m_{jj} > 350$ GeV
  - VH: additional lepton, non VBF
  - ggF: failing other categories
- $m_{4l} > 160$ GeV: 6 VBF events observed, expected 3.8±1.3
- 120 GeV < m_{4l} < 130 GeV: 1 event observed, expected from SM Higgs 0.71±0.10
- Signal strenght per production mechanism: <2σ agreement with SM



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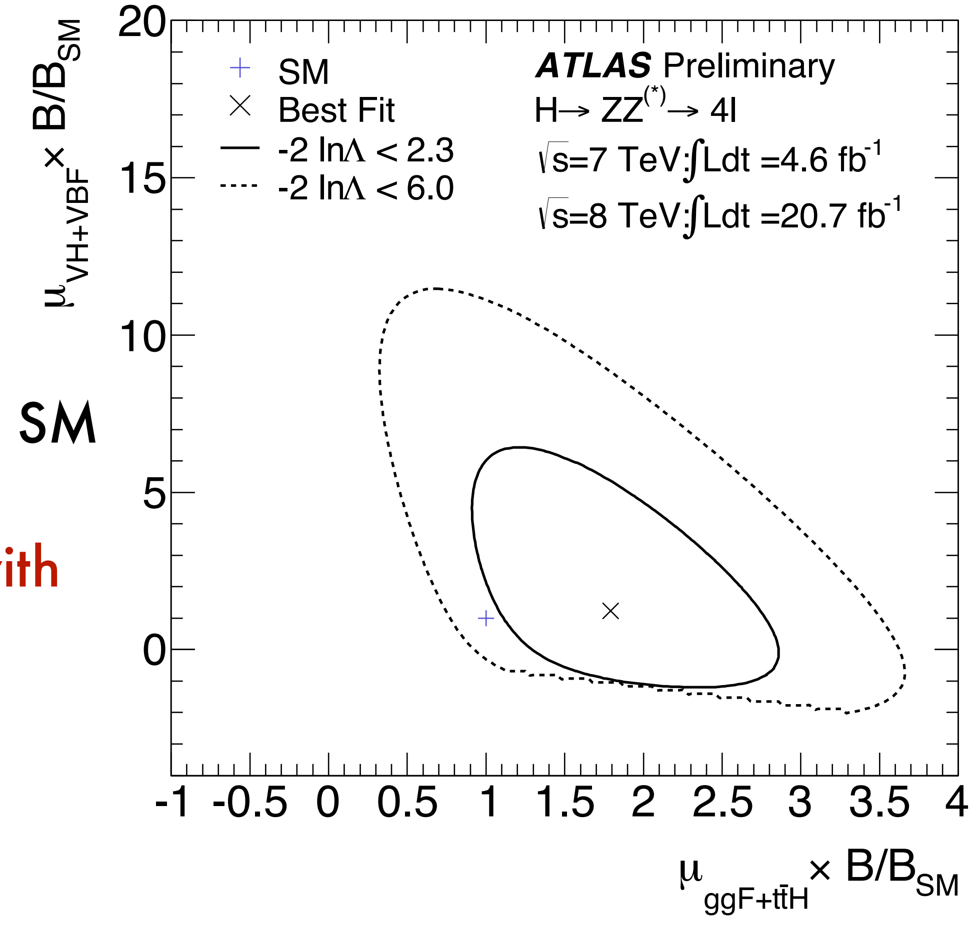
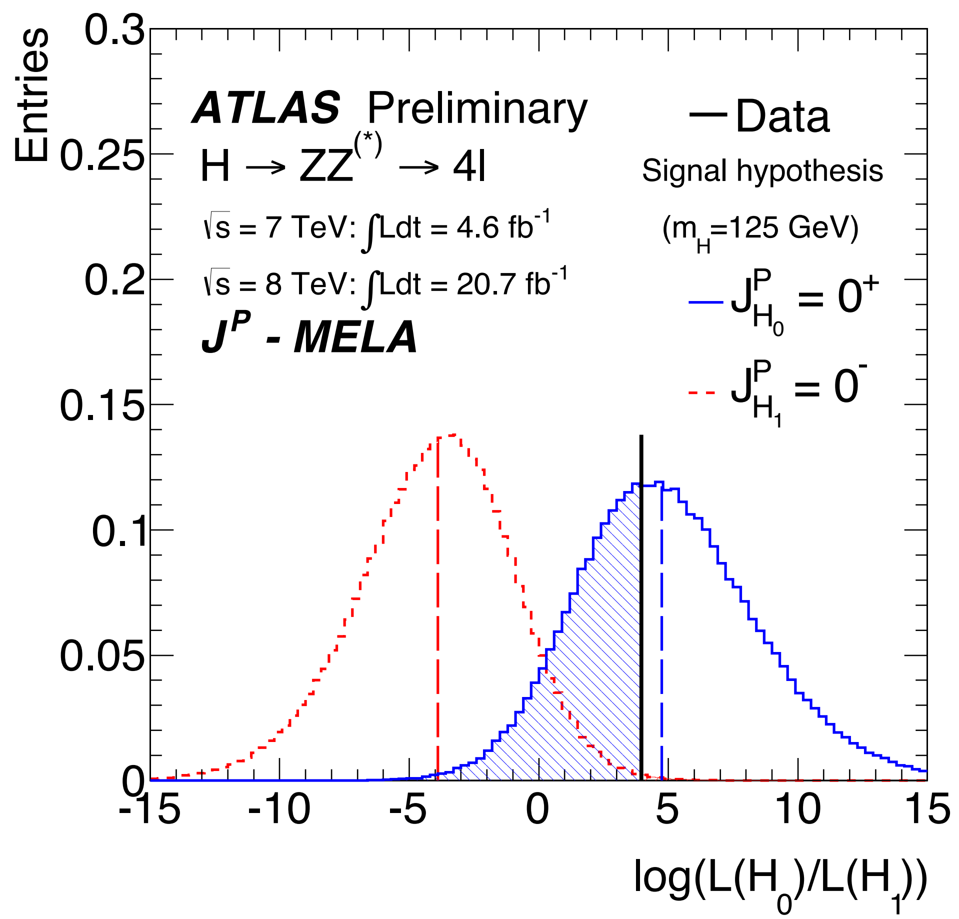
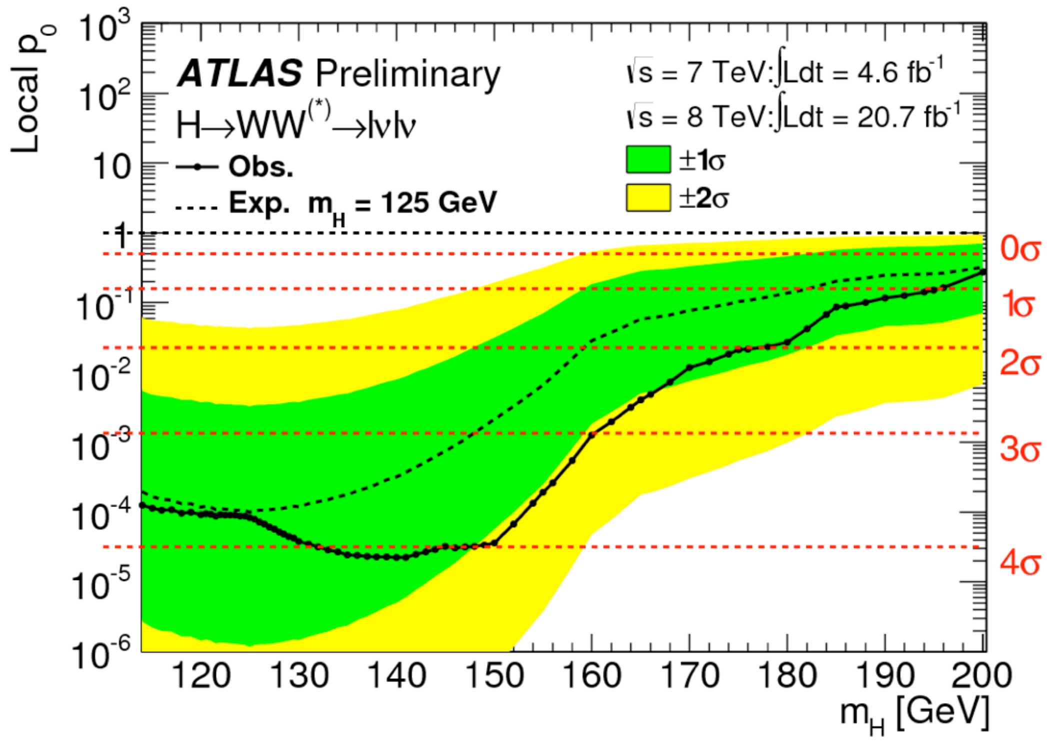


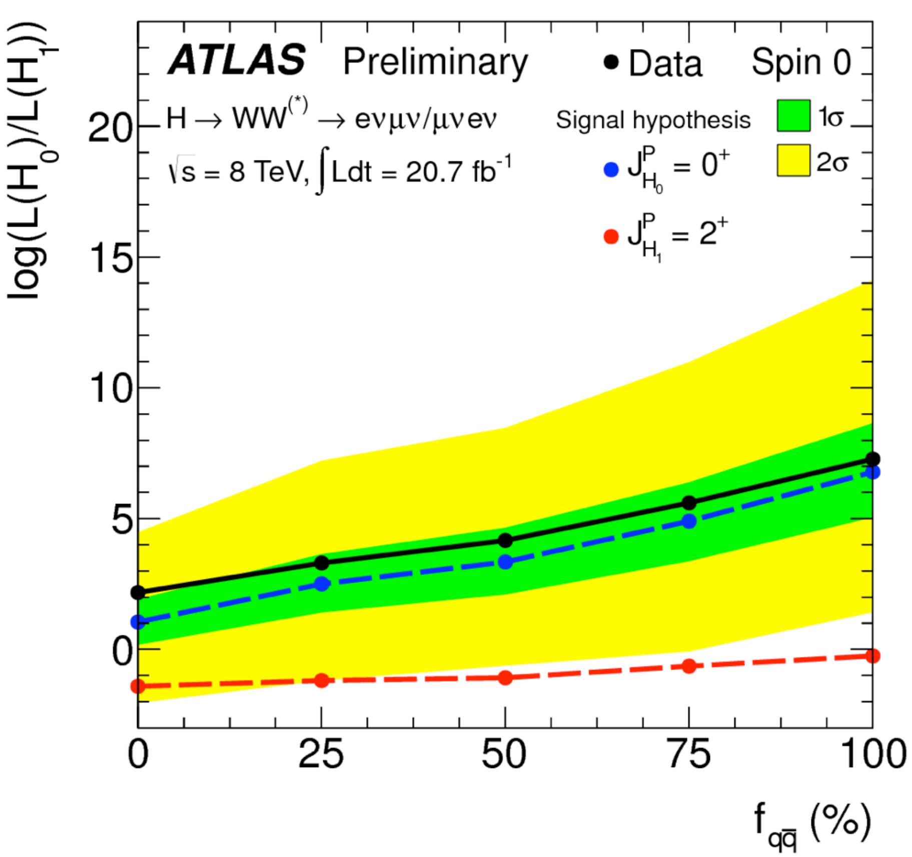


- Discriminants built from spin sensitive observables: Z_1,Z_2 masses, 1 production and 4 decay angles
- Tested on 43 events in signal region
- tested J^P 0^+, 0^-, 1^+, 1^-, 2^+, 2^-
- 0^- and 1^+ excluded at > 97.8% CL_s
- 0^+ favoured

H→WW

ATLAS-CONF-2013-030
ATLAS-CONF-2013-031





- Large BR (~ 20%) despite being below real WW decay around 125 GeV
- Full mass reconstruction not possible
- Clear dilepton signature
- VBF dedicated channels
- Main backgrounds: irreducible continuum WW , ttbar, W→lν
- Backgrounds estimated from control regions

- Observed local significance excess at m = 125 GeV of 3.8σ (expected 3.7σ)
- μ = 1.0 ± 0.3
- Measured cross section @8TeV
  σxBR = 6.0 ± 1.5 pb
  SM expected = 4.8 ± 0.7 pb

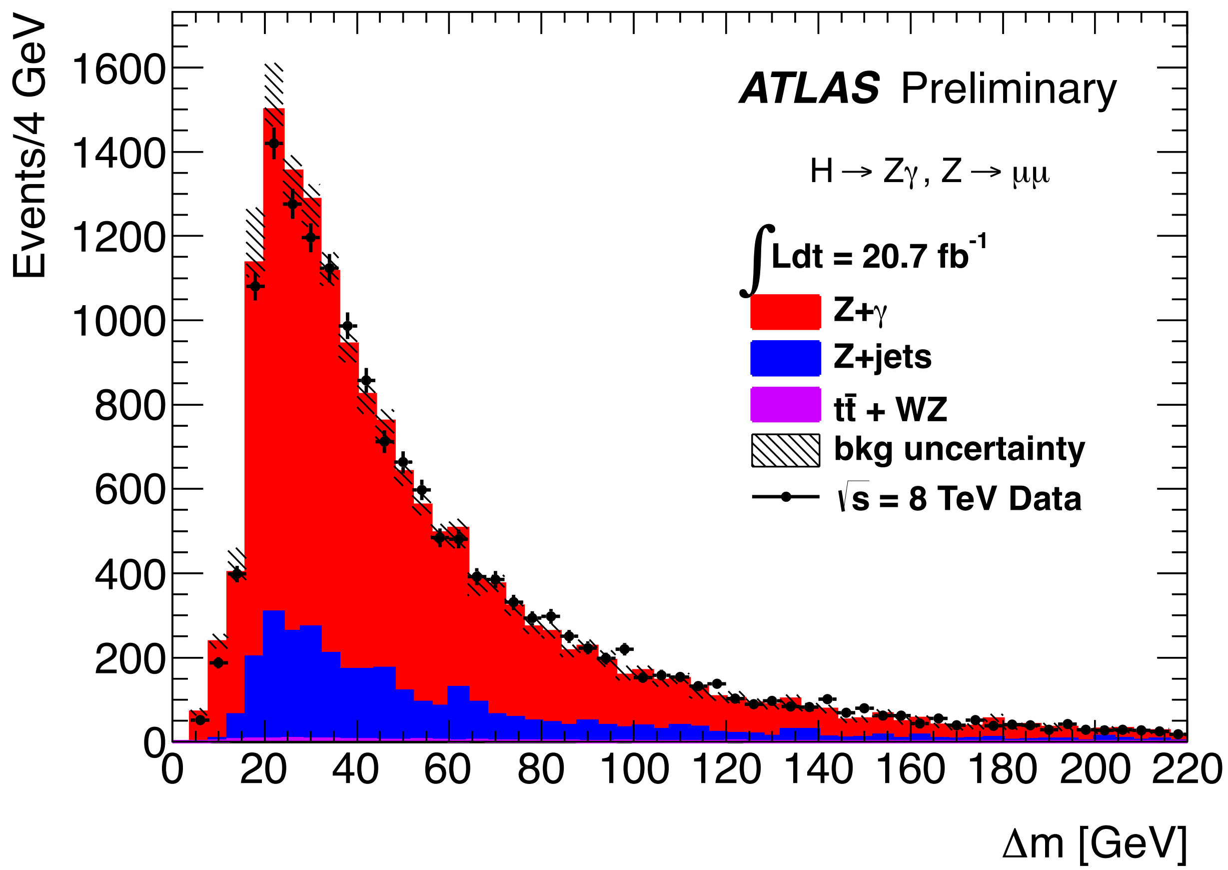
- Spin tested exploiting angular distributions, main variables m_{ll} and $\Delta\phi_{ll}$

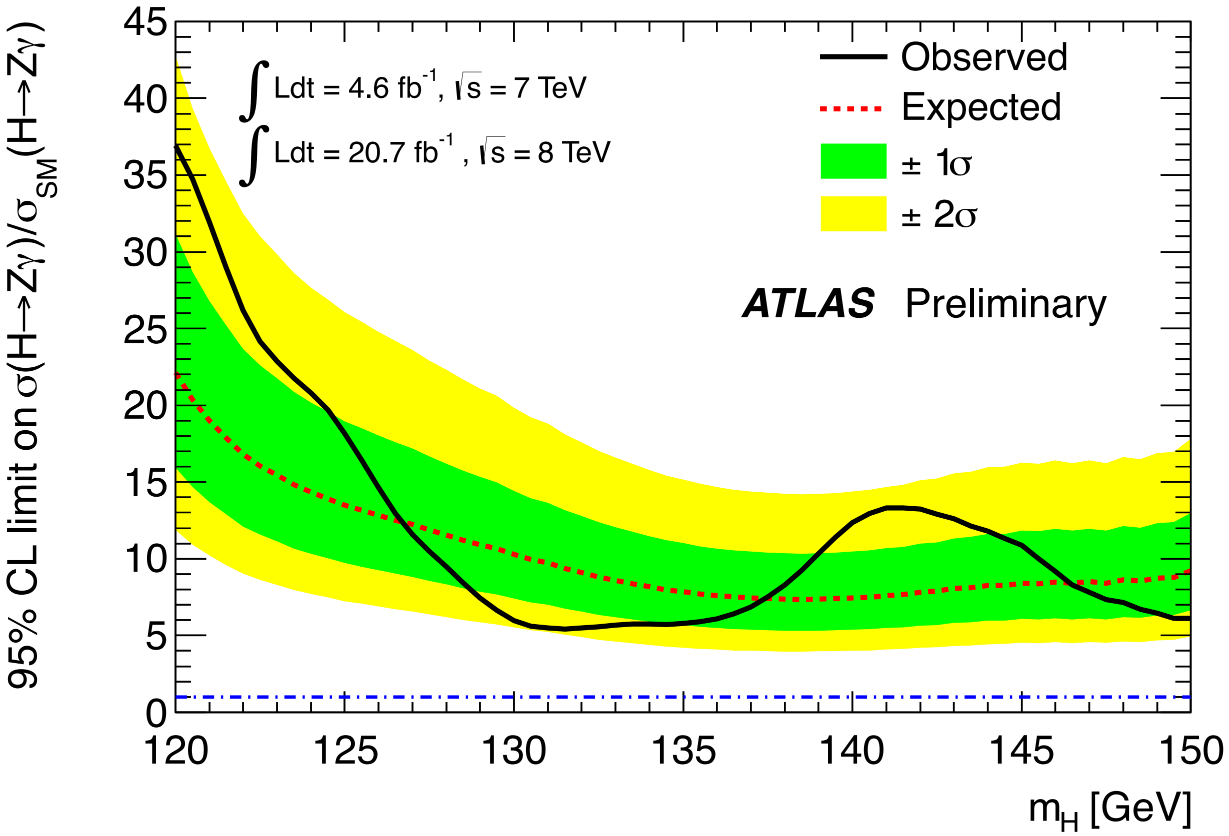
0^+ and 2^+ hypotheses tested, 0^+ favoured against 2^+ > 90% CLs

Sensitive in the f_{qqbar} region where γγ looses discrimination power

$H\to Z\gamma$

- Low BR, decay through loops → sensitivity to new physics
- Analysis with $Z\to ll$ (e/μ)
- Main backgrounds irreducible $Z+\gamma$ and Z+jets
- Discriminating variable: $\Delta m = m_{ll\gamma} - m_{ll}$
- Background estimated from sidebands fit and cross checked with data-driven methods
- No excess observed, limits set at 18.2 x σ_{SM} at 125 GeV (expected 13.5 x σ_{SM})

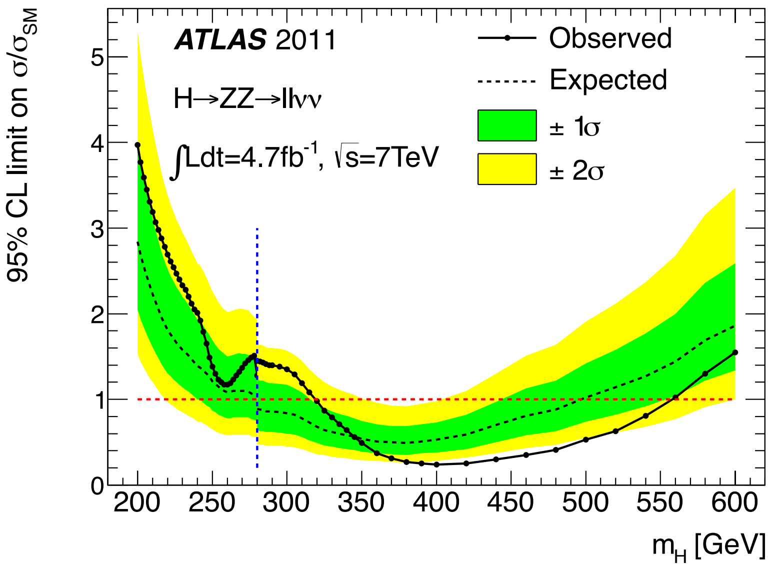




Other ZZ and WW channels

- Analyses on full 7 TeV dataset,no excesses above SM observed

PLB 717 (2012) 29



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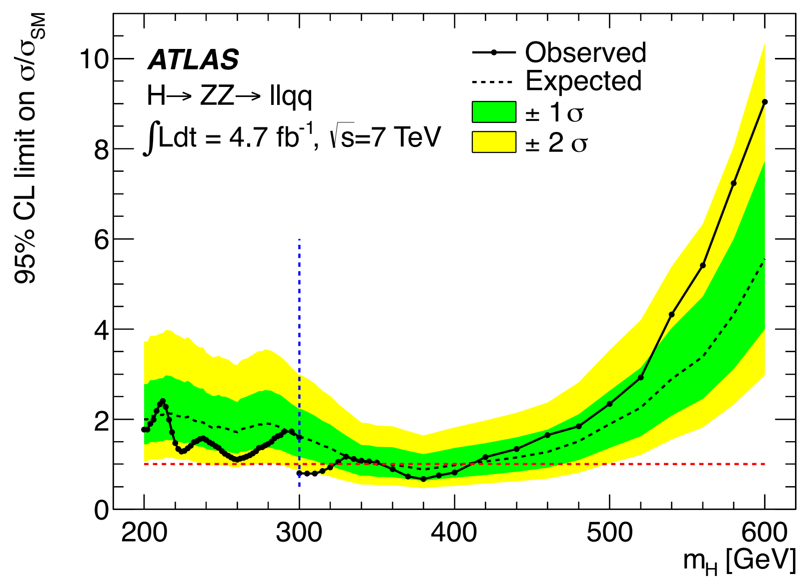

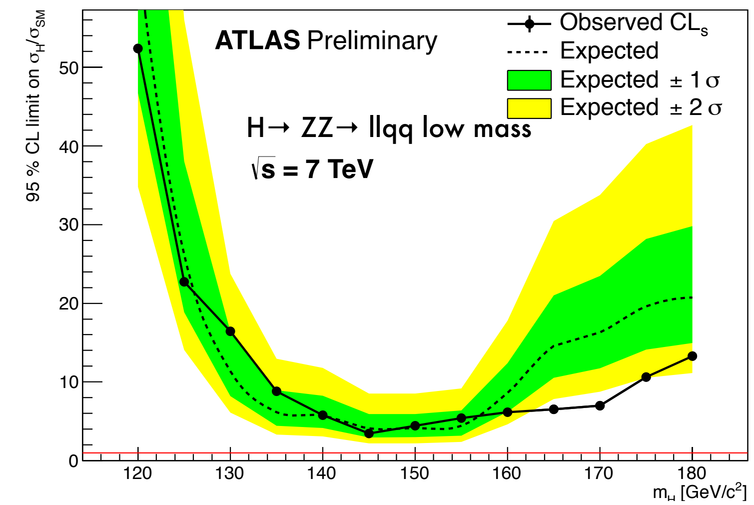

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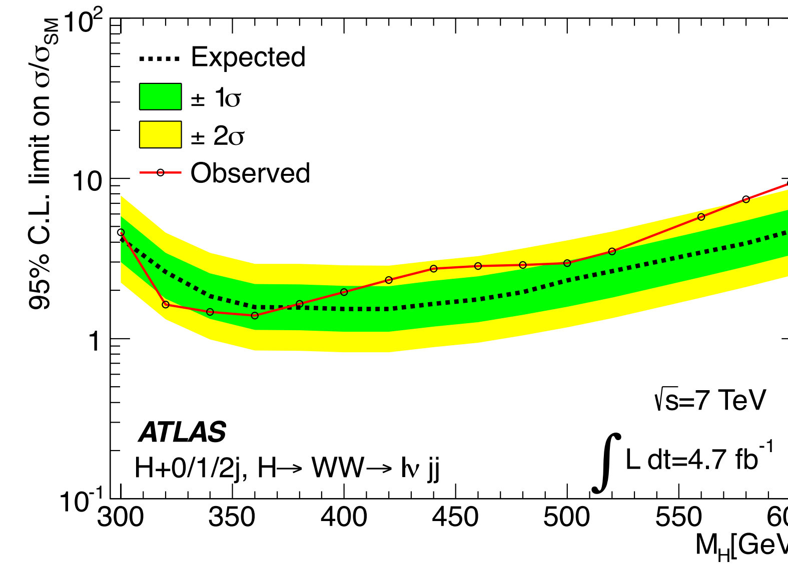

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- High mass ZZ→ 4l analysis updated with full LHC dataset

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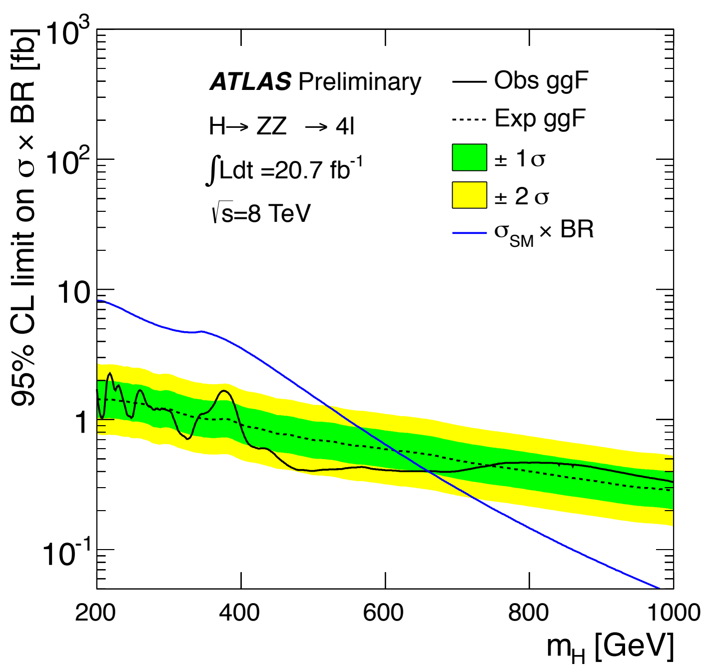
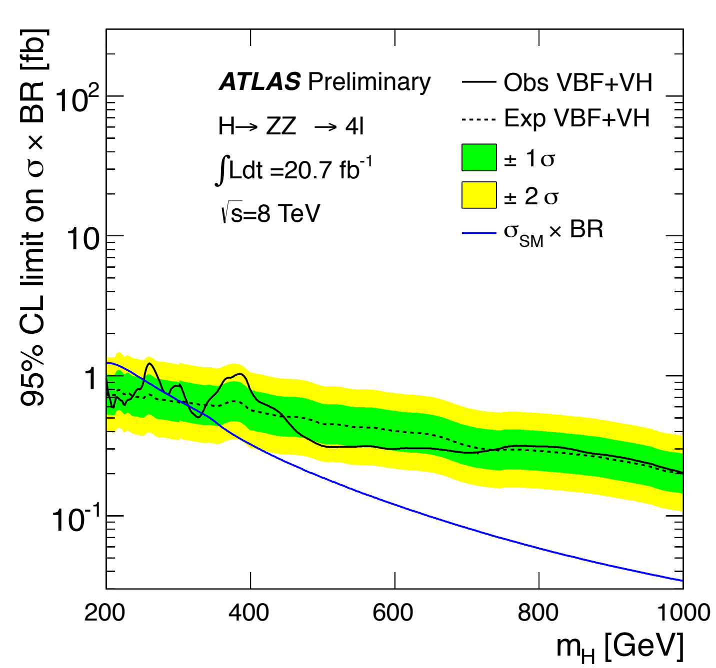
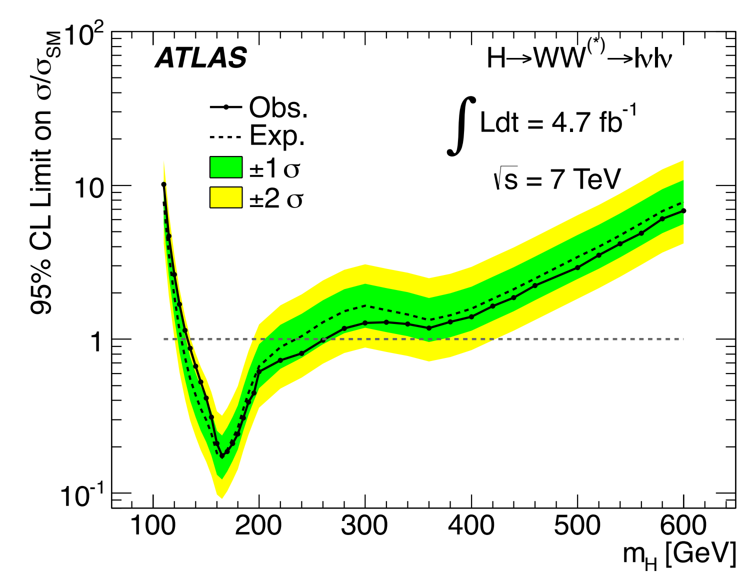




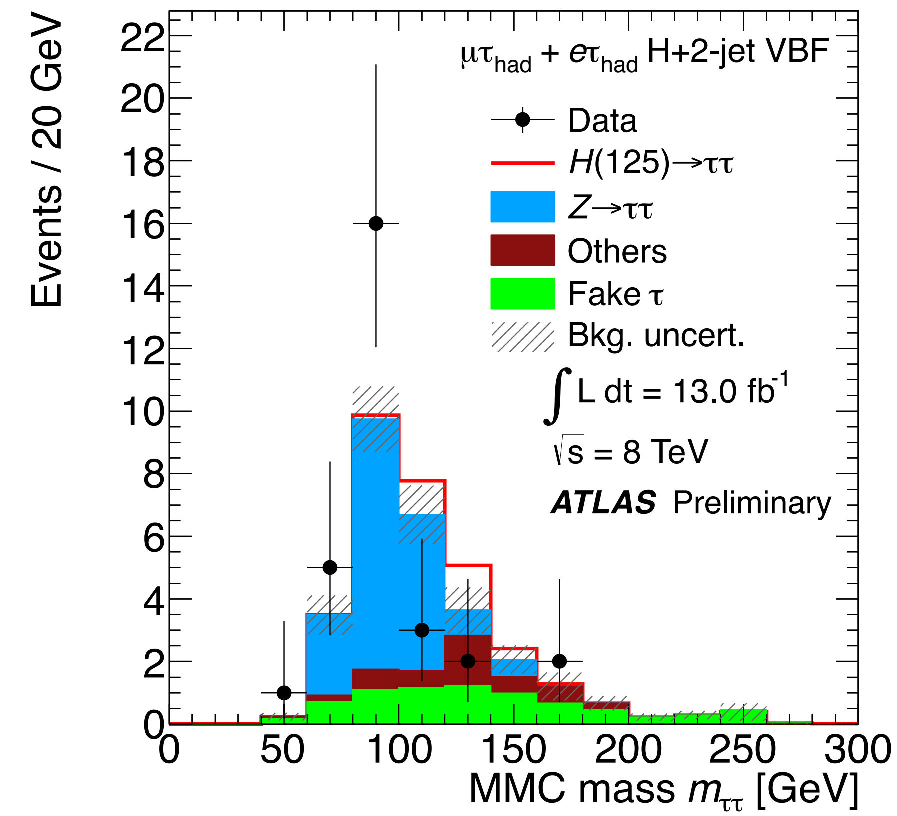


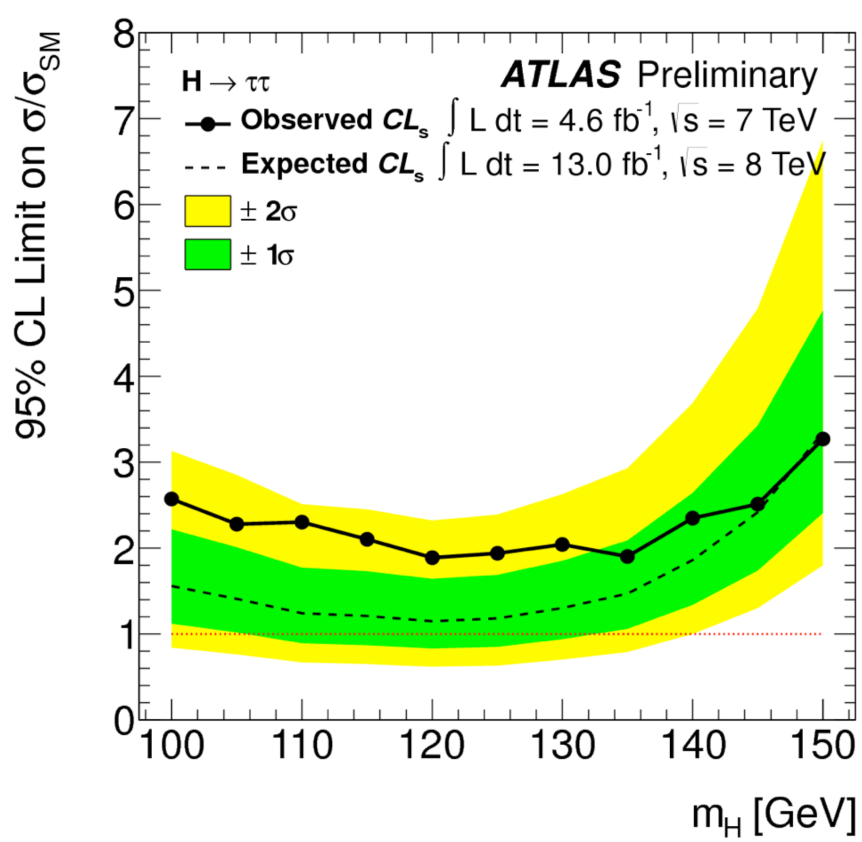
PLB 716 (2012) 62

H→ττ

ATLAS-CONF-2012-160

- Second in branching ratio for decays to fermions but highest sensitivity due to experimental signature
- Accessible thanks to VBF production mode
- Hadronic tau decays reconstructed from calorimeter jets and identified with BDT discriminator based on tracking and calorimeter information
- 10 categories based on tau decay type (ll, lhad, hadhad) and jet/event topology (targeting different production modes)



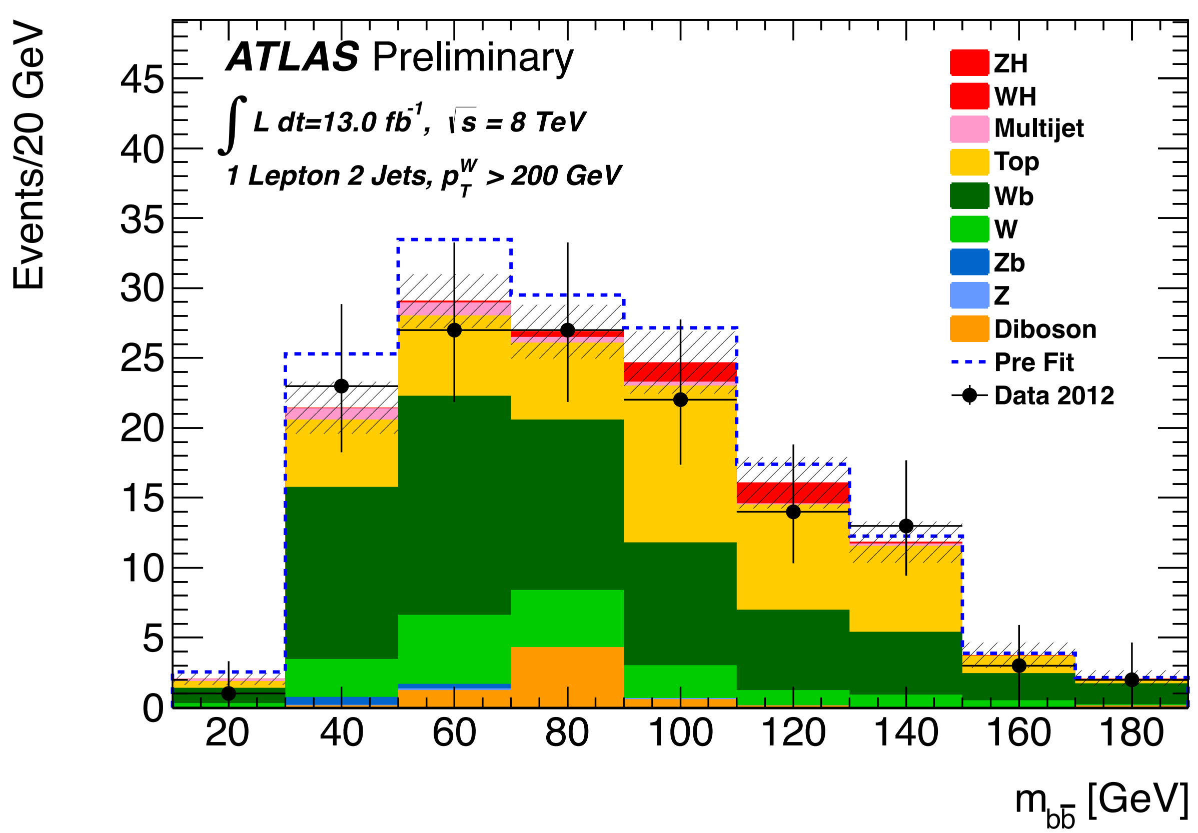


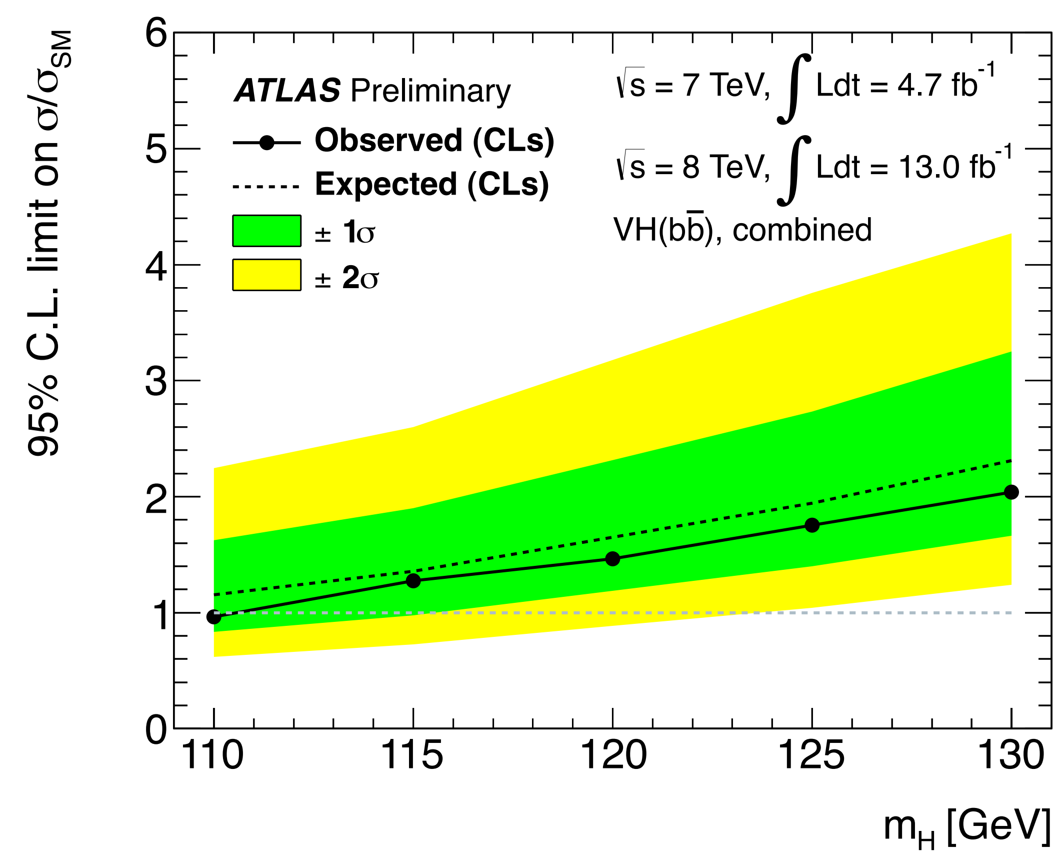
- Irreducible Z→ττ background from hybrid data-MC technique (Z→μμ data events with muons replaced by simulated taus)
- Z+jets, W+jets, top from MC, normalised/checked in data control regions, diboson from MC
- Multijet fully data driven
- Mass reconstruction exploiting knowledge of tau decay kinematics (MMC)
- No significant excess above SM is observed, limit at 125 GeV: 1.9 x σ_{SM} (expected 1.2 x σ_{SM})

VH, H→bb

ATLAS-CONF-2012-161

- H→bbar highest SM branching ratio, but experimentally difficult → need to exploit production modes
- Associated production: three channels 0, 1, 2 leptons targeting Z→νν, W→lν, Z→ll
- 13 categories targeting different Higgs boost regime
- b-jets tagged combining information from different algorithms based on track impact parameter significance and or secondary decay vertex reconstruction
- Main backgrounds: top, W+jet and Z+jet
- Backgrounds taken from MC and normalised in control region (except multijets, fully data-driven and diboson, fully MC-driven)
- No excess observed, limit at 125 GeV on σ_{SM}xBR 1.8 (1.9 expected)
- Cross checked method with 4σ observation of WZ, ZZ with Z→bbar



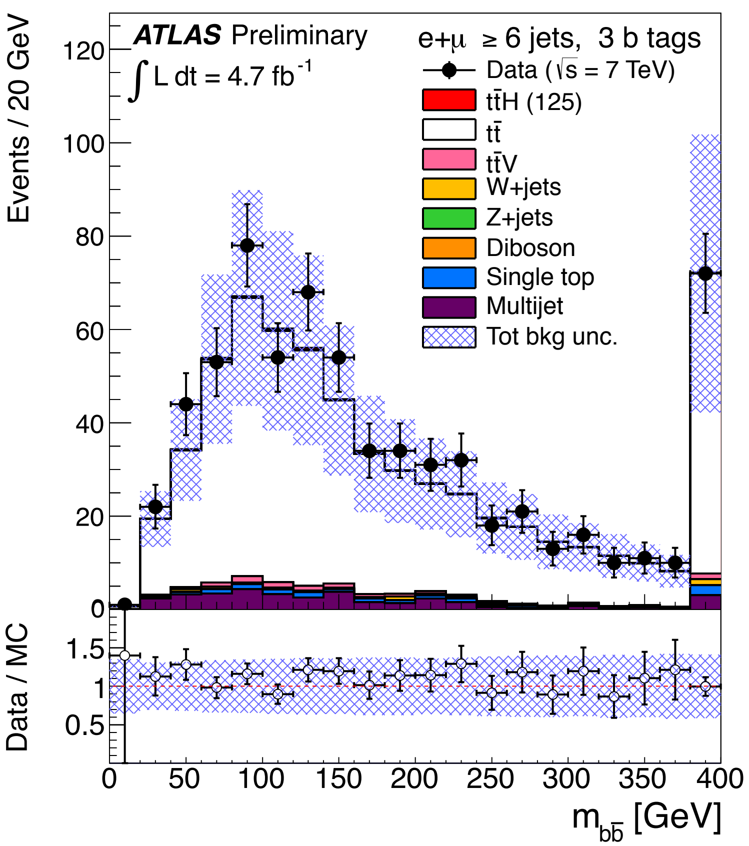


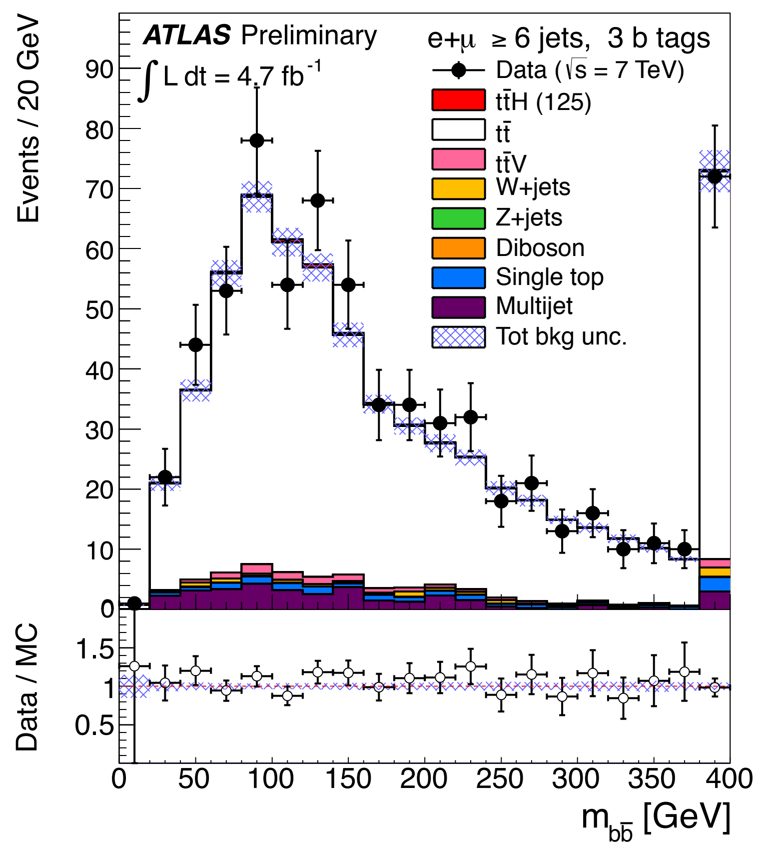
ttbarH, H→bb

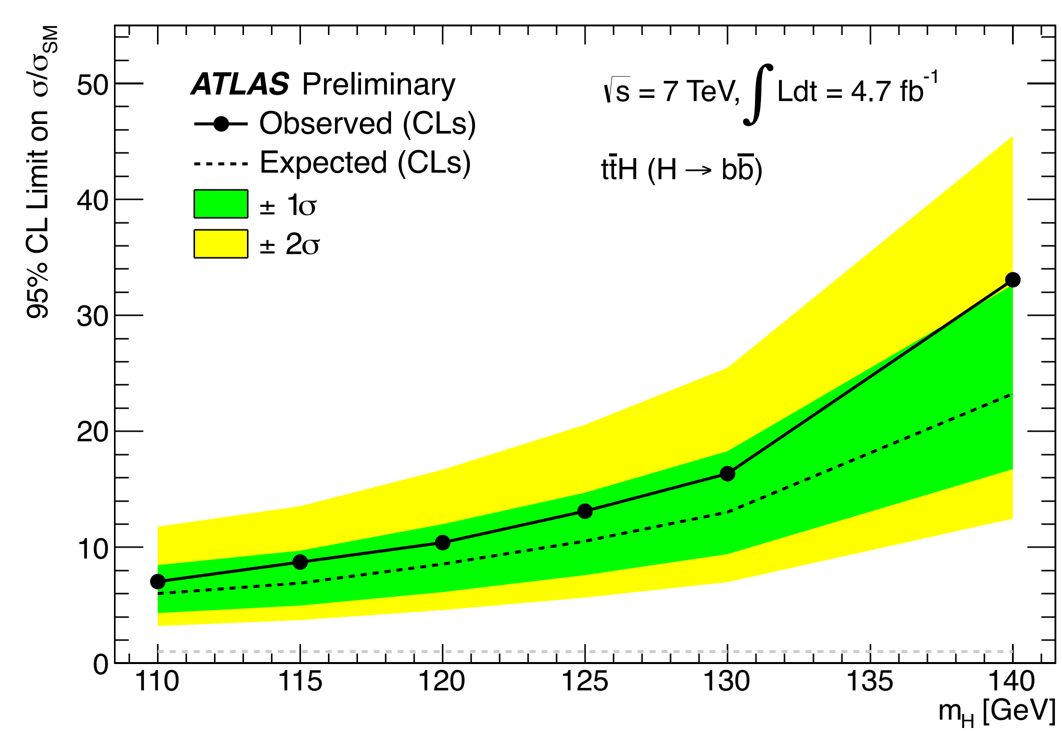
ATLAS-CONF-2012-135

$$t\bar{t}H \to W^+ b\, W^- \bar{b}\, b\bar{b} \to l^+ \nu b\, q\bar{q}\bar{b}\, b\bar{b}$$

- Events with ≥ 6 jets, of which ≥3 b-tagged
- Kinematic likelihood filter used to assign objects in the detector to the objects above
- discriminating variable: m_{bbar}
- Main background from ttbar
- Systematics due to b and c tagging efficiencies/mistag rate constrained in fit to data
- No excess observed, limit σ_{SM}xBR 13.1 (10.5 expected)



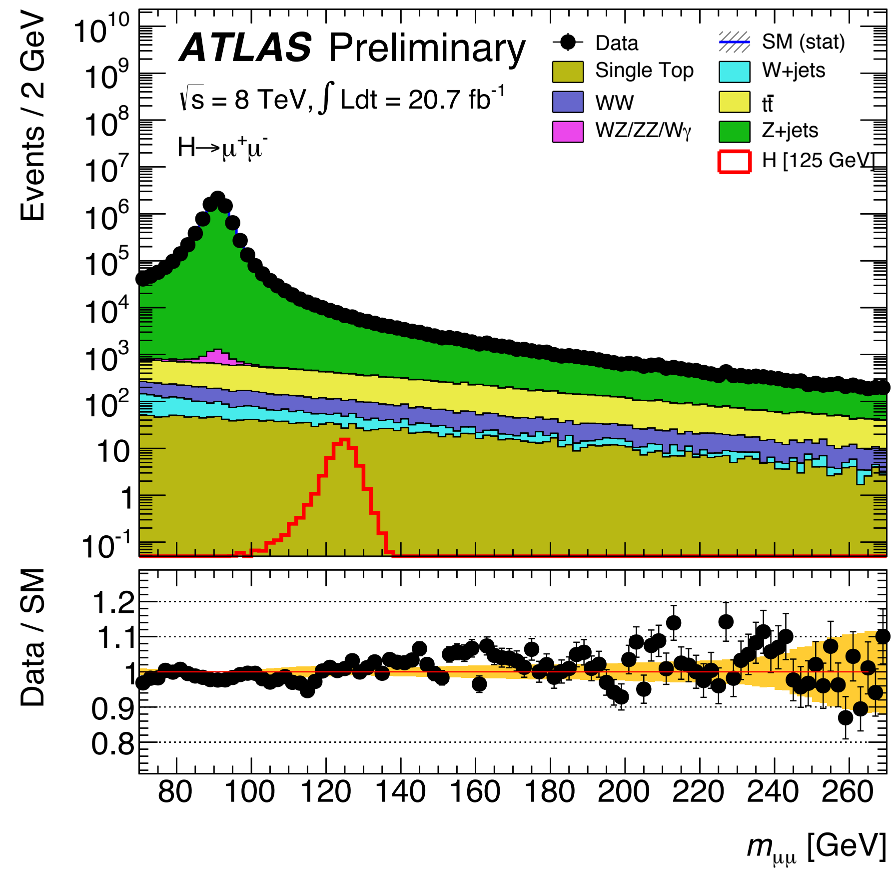


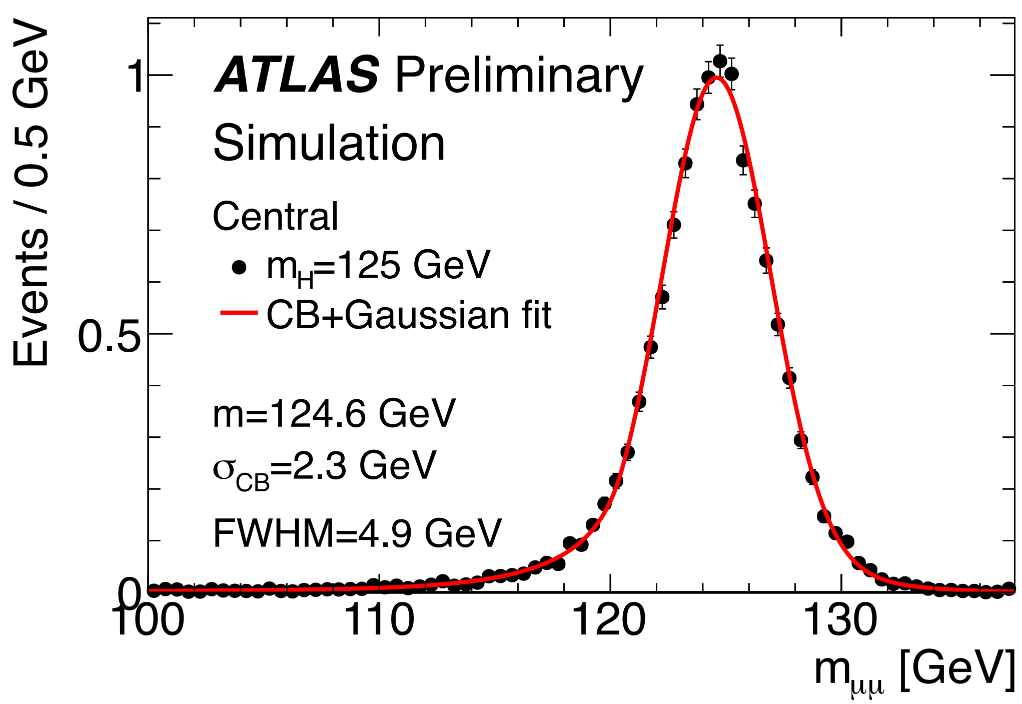


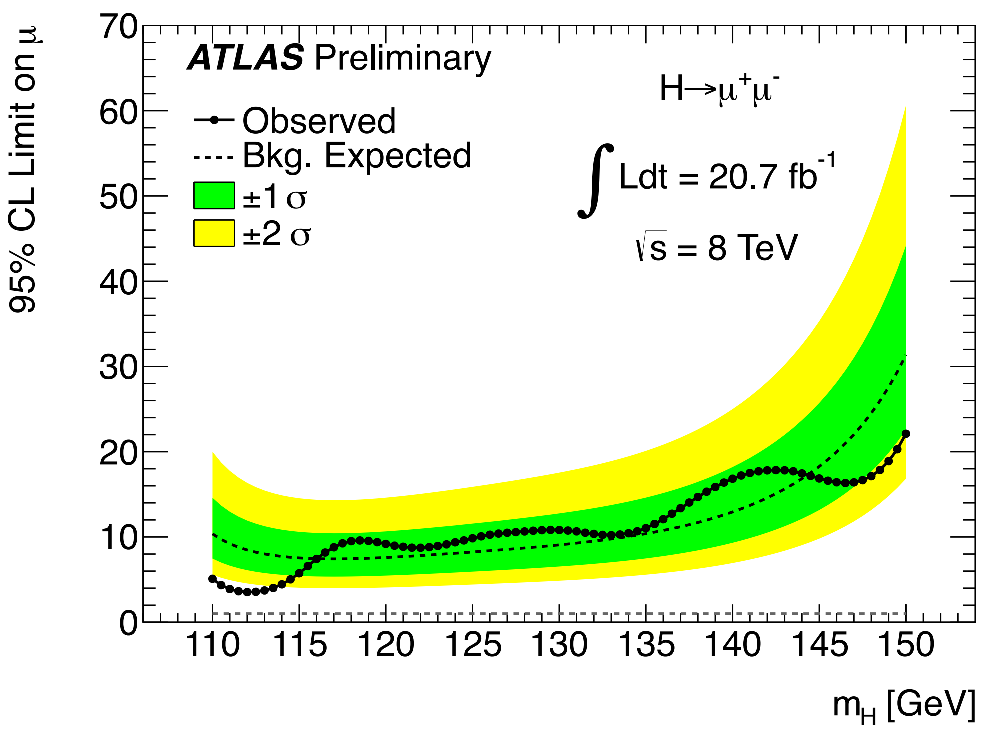
H→μμ

ATLAS-CONF-2013-010

- Clean final state signature
- Testing couplings to second generation
- Branching ratio 28×10^{-5} - 6×10^{-5}
- Dominant irreducible Drell-Yan background
- 2 analysis categories depending on muon centrality
- Binned likelihood fit
  - background BW + exponential
  - signal CrystalBall + gaussian



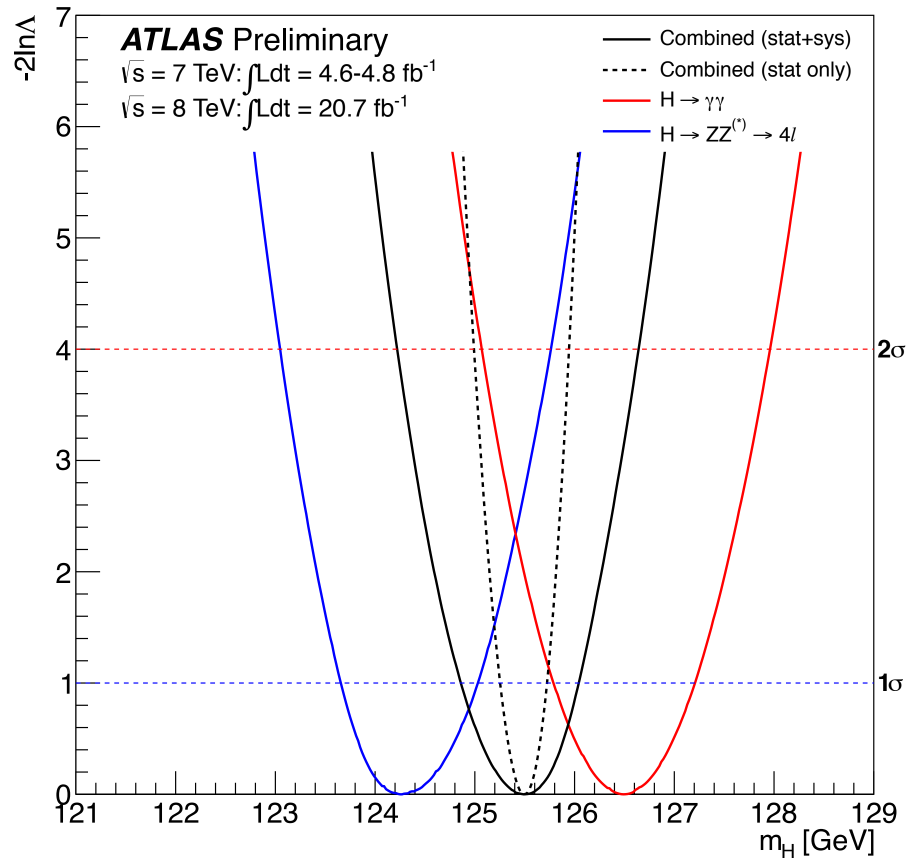


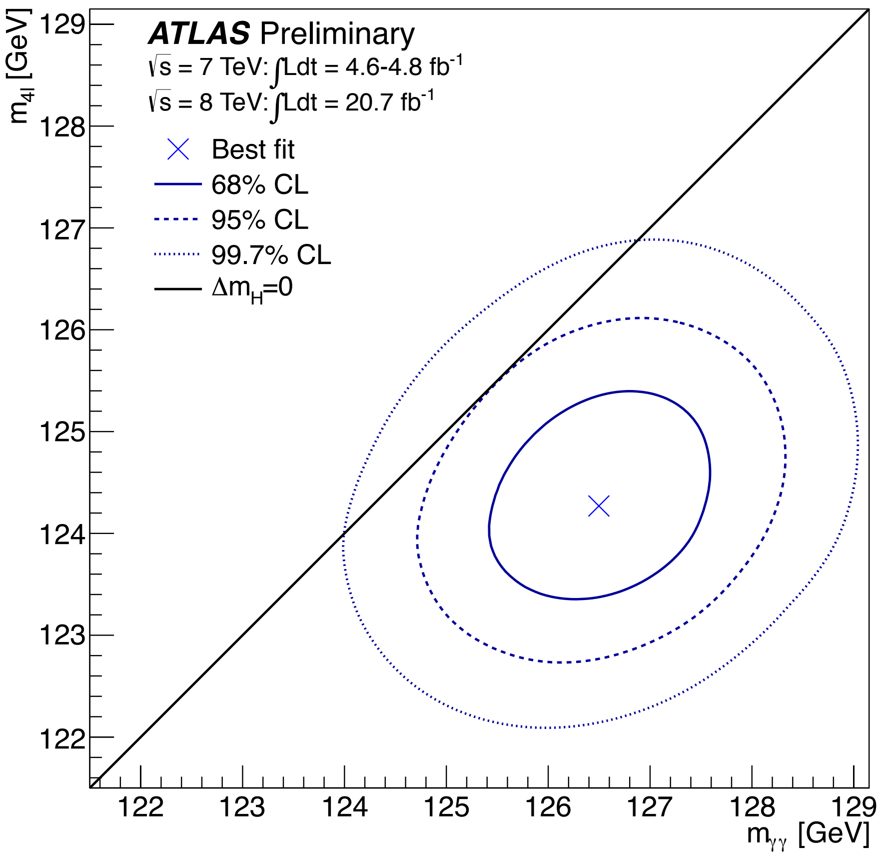


Combination: mass

ATLAS-CONF-2013-014

- From high mass resolution γγ and 4l channels
- 4l
  - dominated by 4 muons
  - muon momentum scale uncertainty 0.2%
- γγ
  - per category systematics + global uncertainty
  - global mass systematic 0.55%





- Results from profile-likelihood method
- m_H = 125.5 ± 0.2 (stat) $^{+0.5}_{-0.6}$ (syst) GeV

(was 125.2 ± 0.3 (stat) ± 0.6 (sys) GeV for Cern council in December)

- Mass difference between γγ and 4l

  Δm_H = 2.3 $^{+0.6}_{-0.7}$ (stat) ± 0.6 (syst) GeV

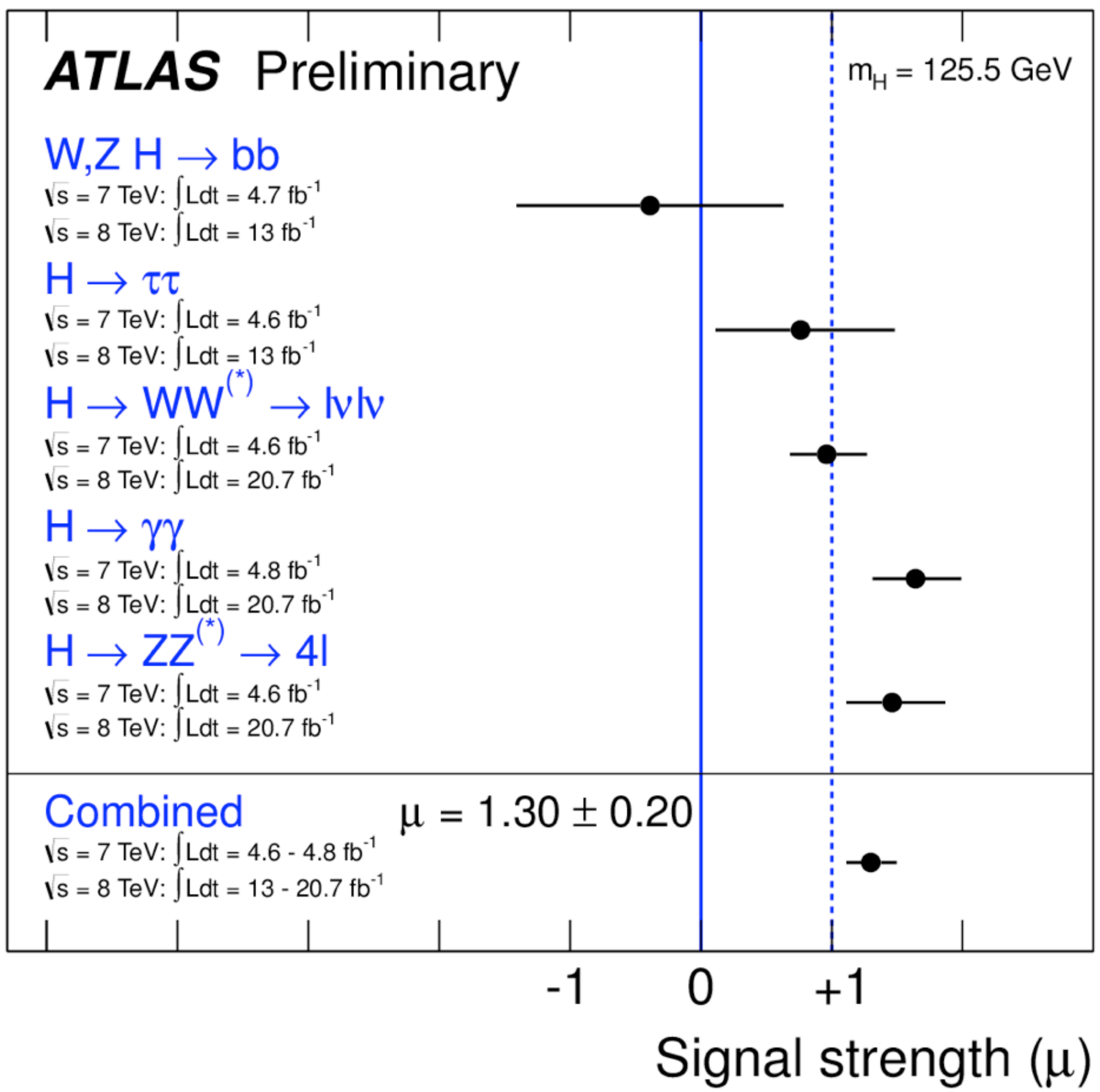
  2.4σ away from 0 (p = 1.5%, using rectangular pdfs p = 8%)

(was 3.0 ± 0.8(stat) $^{+0.7}_{-0.6}$ (sys) GeV for Cern council in December)

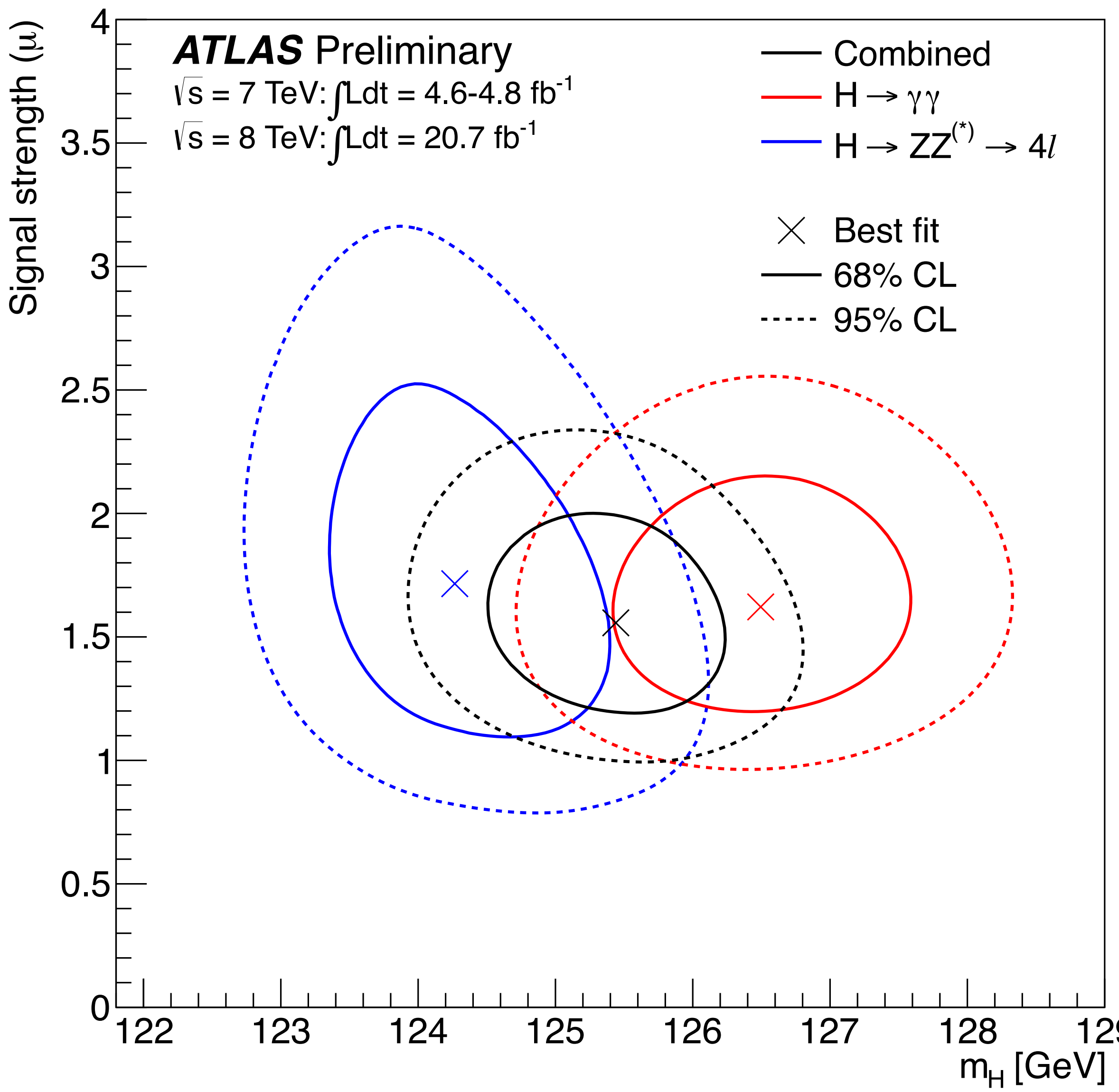
Combination: signal strenght

ATLAS-CONF-2013-014
ATLAS-CONF-2013-034

- Parameter of interest: μ (global)
- μ = 1.30 ± 0.13 (stat) ± 0.14 (sys)



- Consistency with SM
  - global μ: 9% (40% with rectangular PDFs for QCDscale and PDFs)
  - 5 single channel μ_i: 8%
- Consistency with μ = 1.43
  - 5 single channel μ_i: 13%



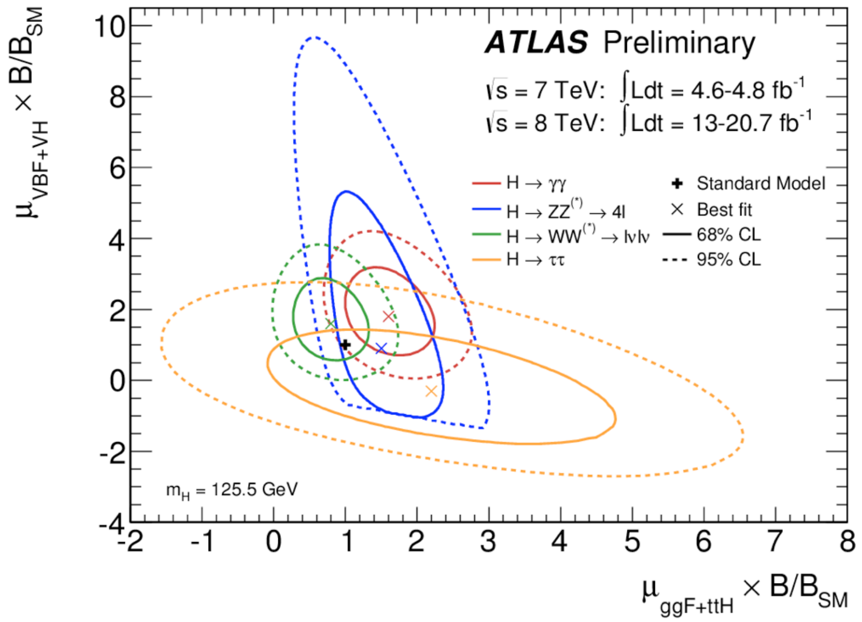
Production modes and couplings ATLAS-CONF-2013-034

Production modes and couplings

ATLAS-CONF-2013-034

- Analysis of signal strenght depending on production modes
  - grouped VBF + VH and ggF + ttH
  - $\mu_{VBF+VH}/\mu_{ggF+ttbarH} = 1.2^{+0.7}_{-0.5}$:3σ evidence for VBF production

Production modes



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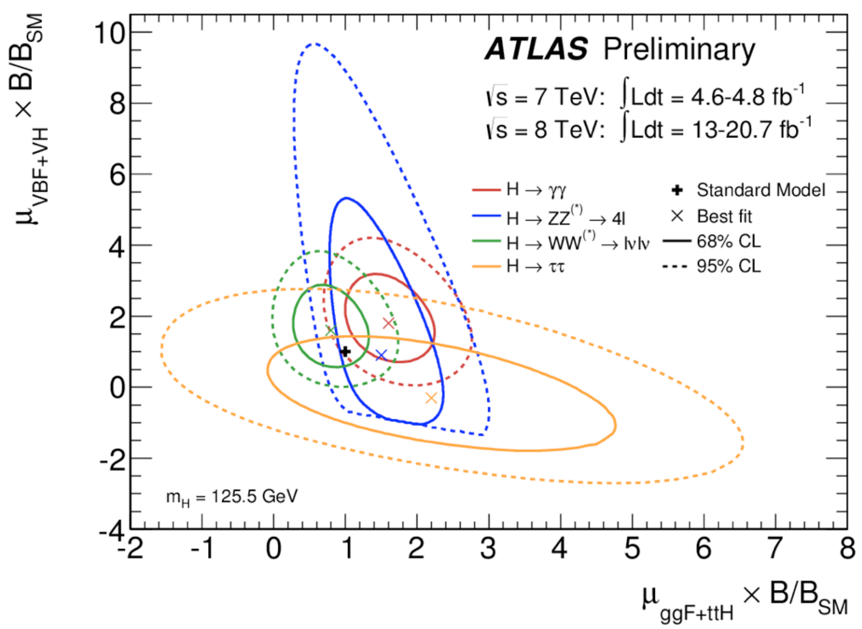
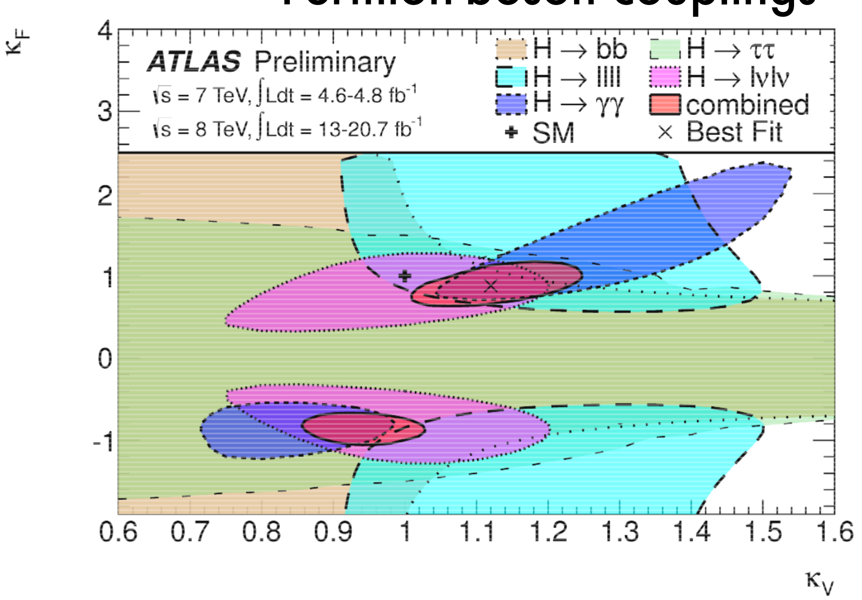
  - $k_v = k_W = k_Z$, $k_f = k_t = k_b = k_\tau$
  - assume only SM particles involved
  - compatibility with SM =8%

Production modes



Fermion-boson couplings



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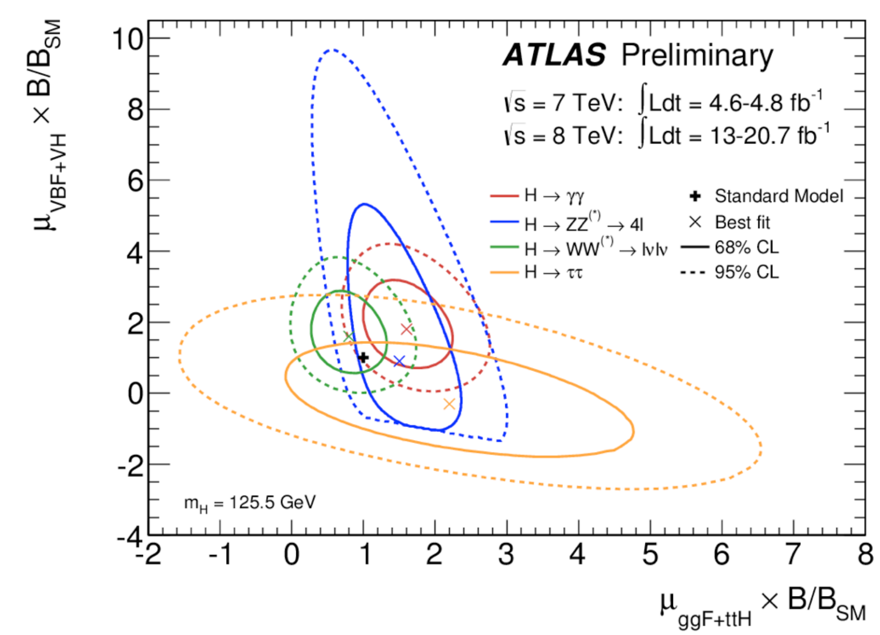
  - ungroup k_W and k_Z, $\lambda_{WZ} = k_W/k_Z = 1$ within 95% CL

Production modes



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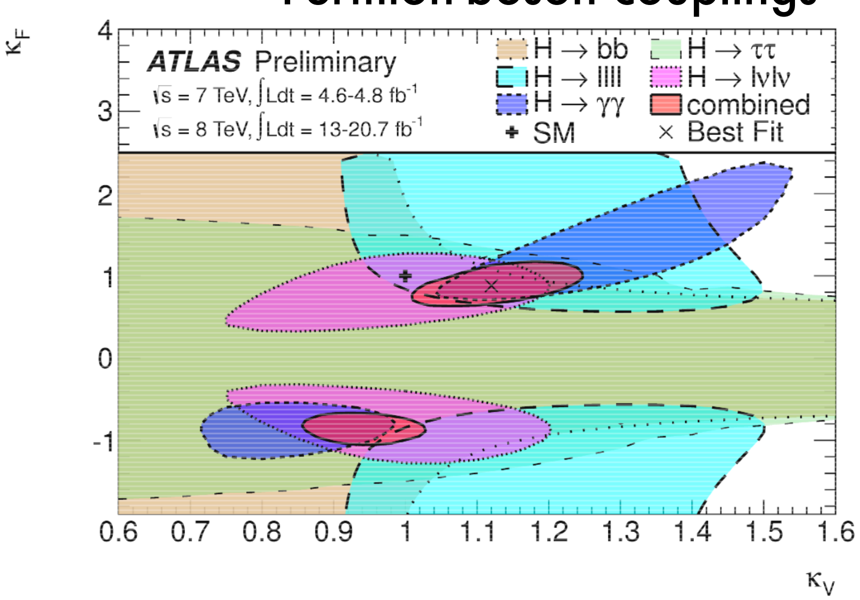

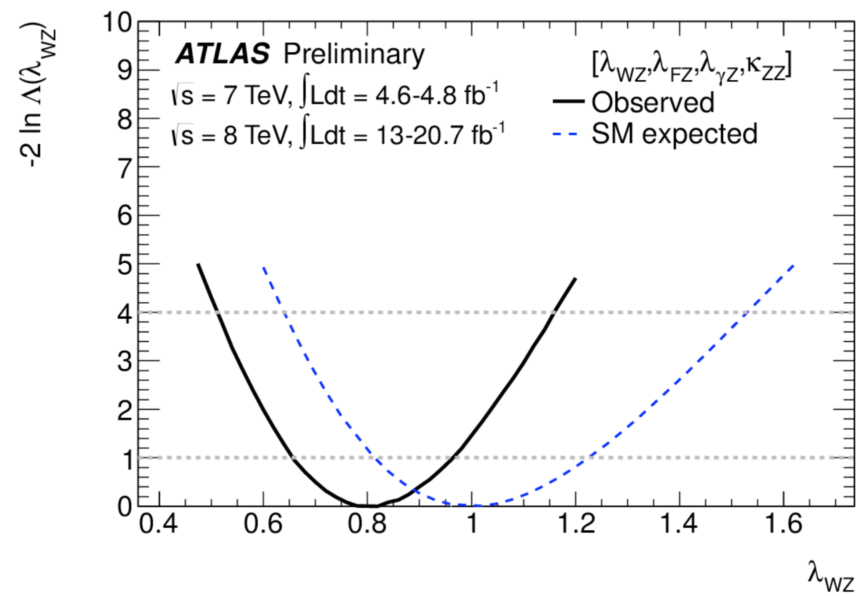

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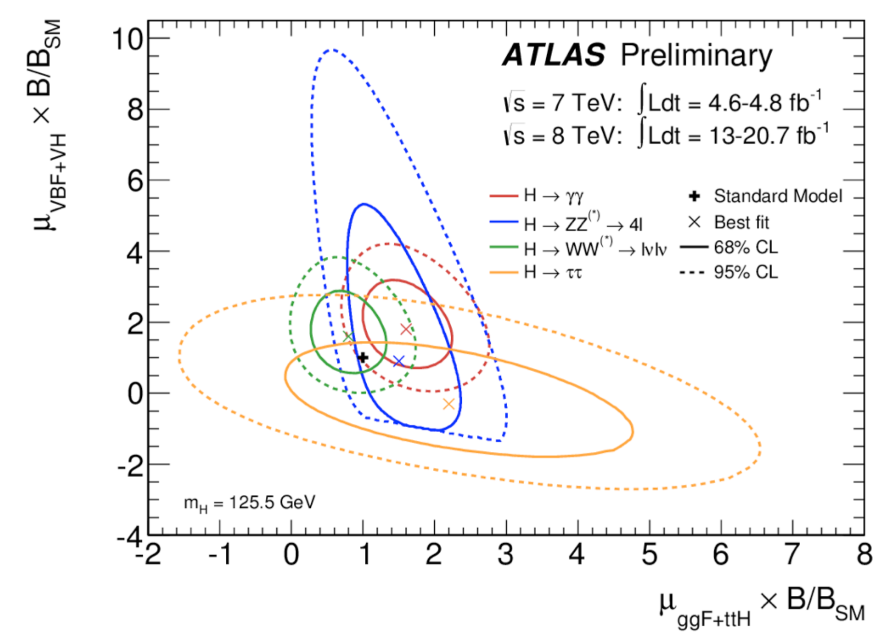
- Custodial symmetry:
  - ungroup k_W and k_Z, $\lambda_{WZ} = k_W/k_Z = 1$ within 95% CL
- Contributions from BSM particles: assume SM k_i =1, $k_g = 1.08 \pm 0.14$, $k_\gamma = 1.23^{+0.16}_{-0.13}$

Production modes



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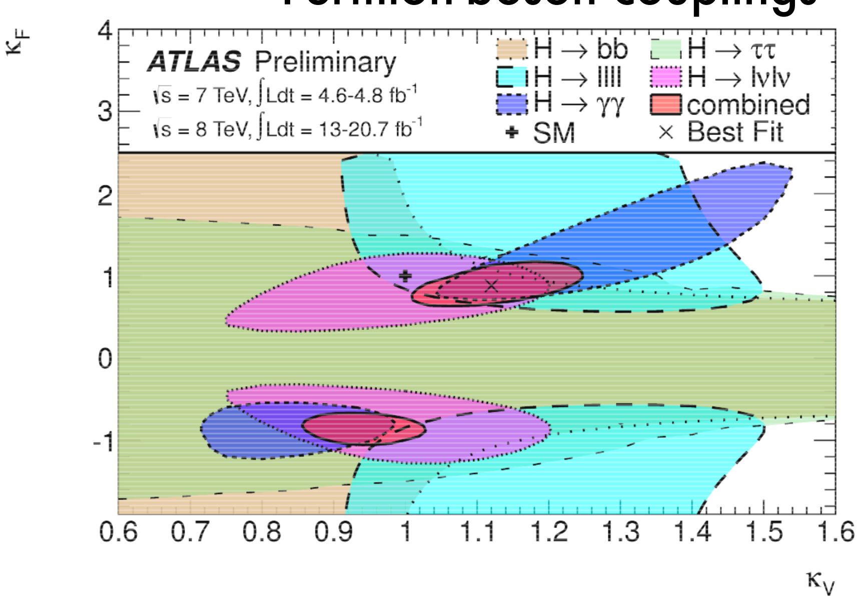
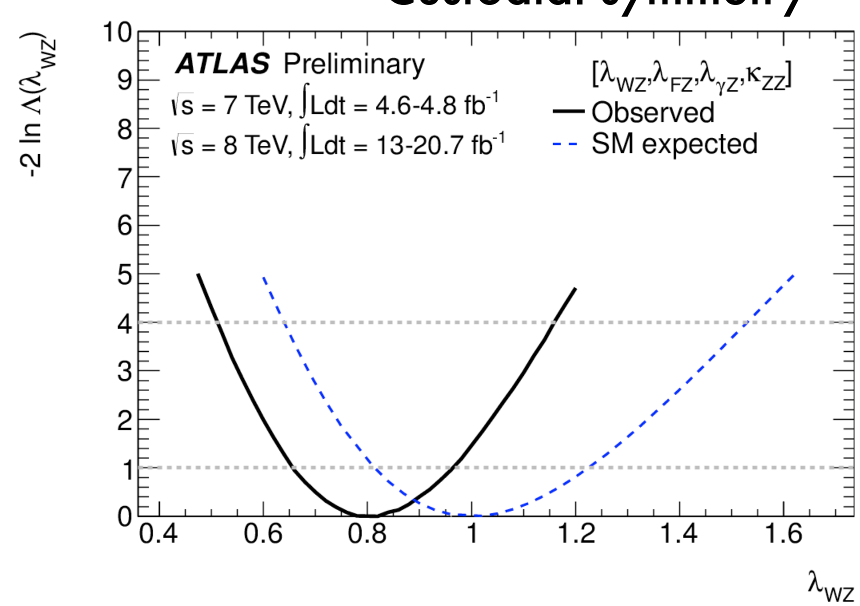
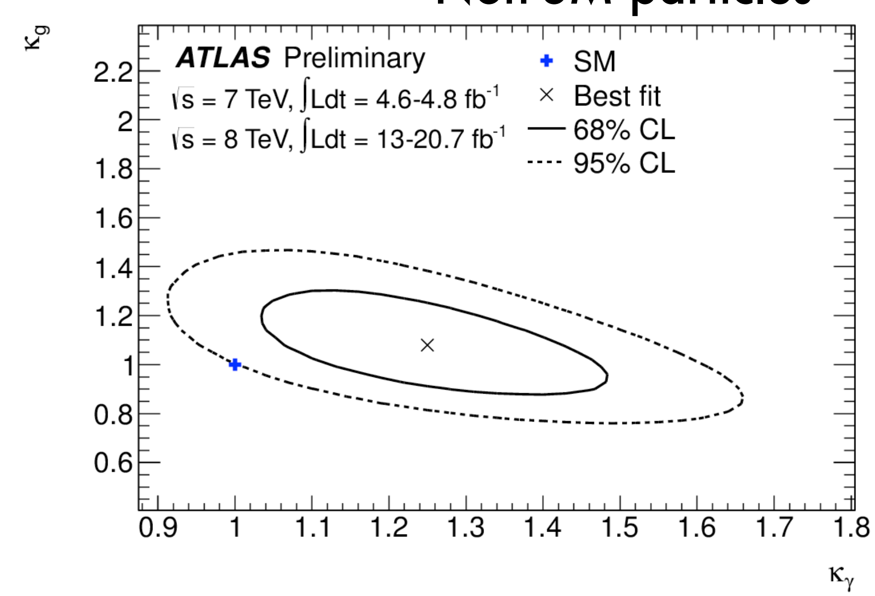


Custodial symmetry



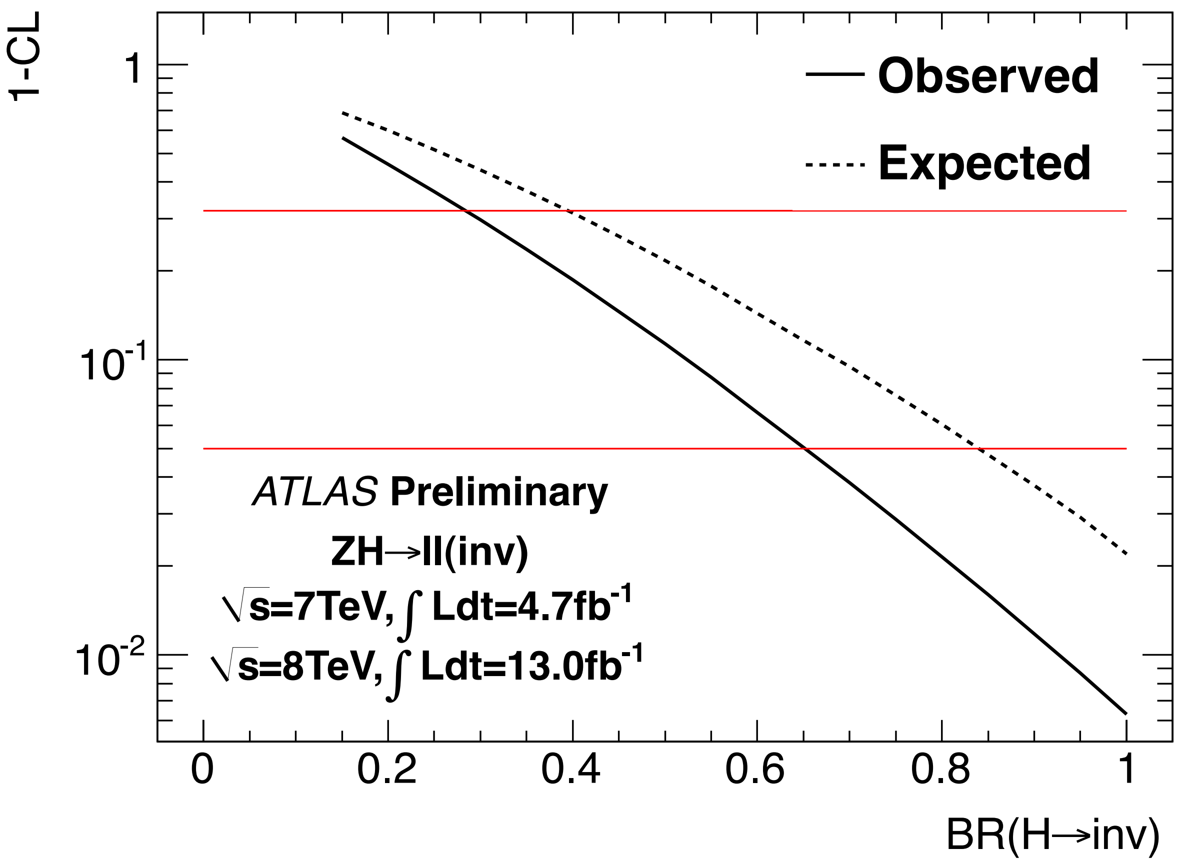
Non-SM particles

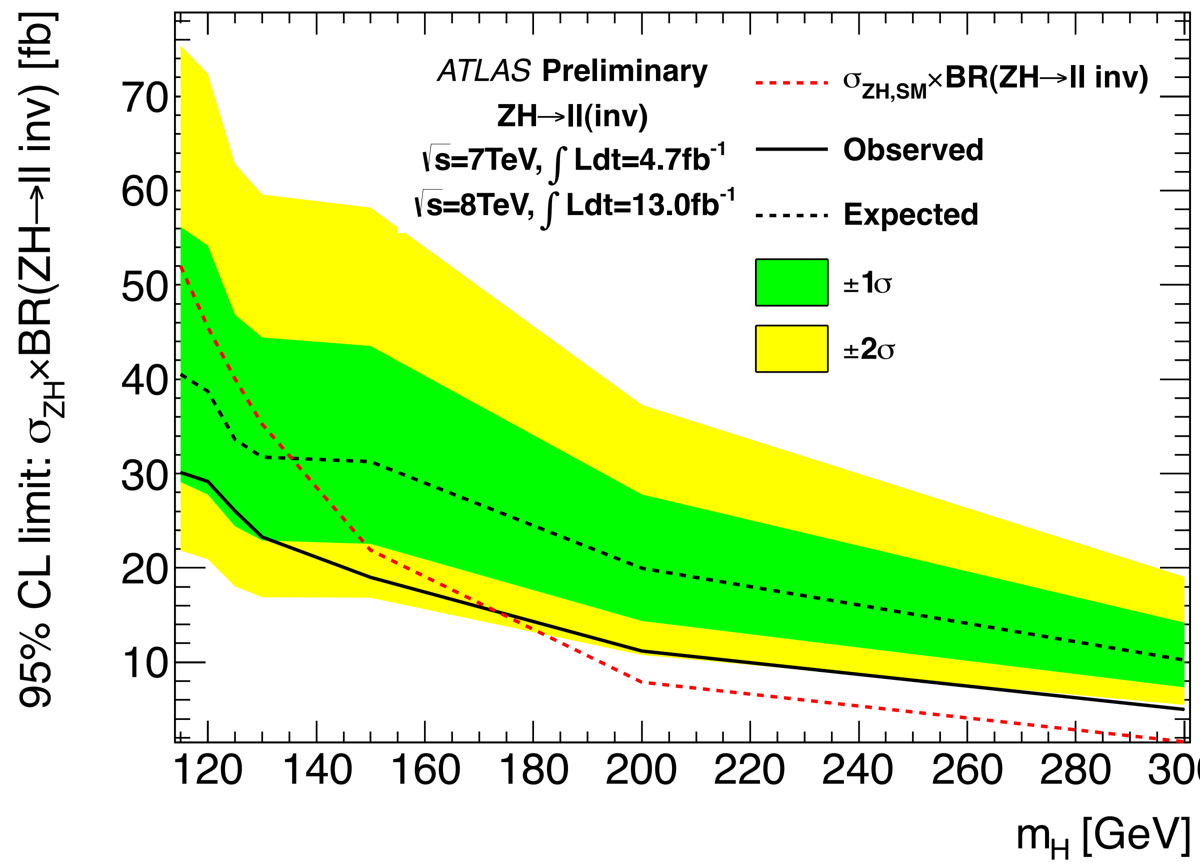


ZH, H→ invisible

ATLAS-CONF-2013-011

- For a SM Higgs BR to invisible particles is not measurable
- Could have contributions eg from dark matter particles
- Signature: Z→ee and Z→μμ with large Etmiss (> 90 GeV)
- Main backgrounds from diboson production
- Cut optimization against ZH-like events
- Two interpretations: limit for a SM Higgs invisible branching ratio
- Limit on σ(ZH) x BR(invisible) for further Higgs-like states

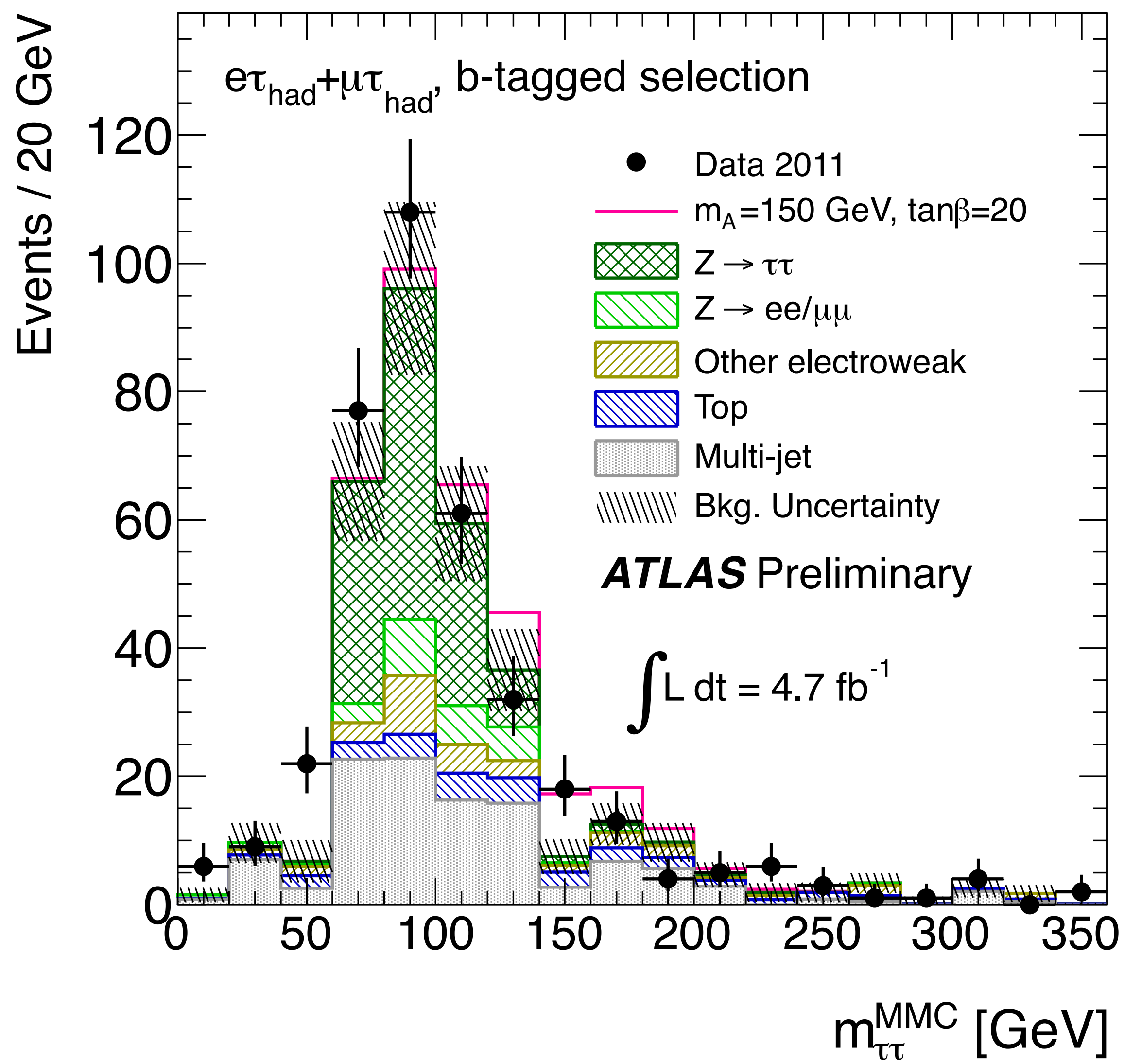


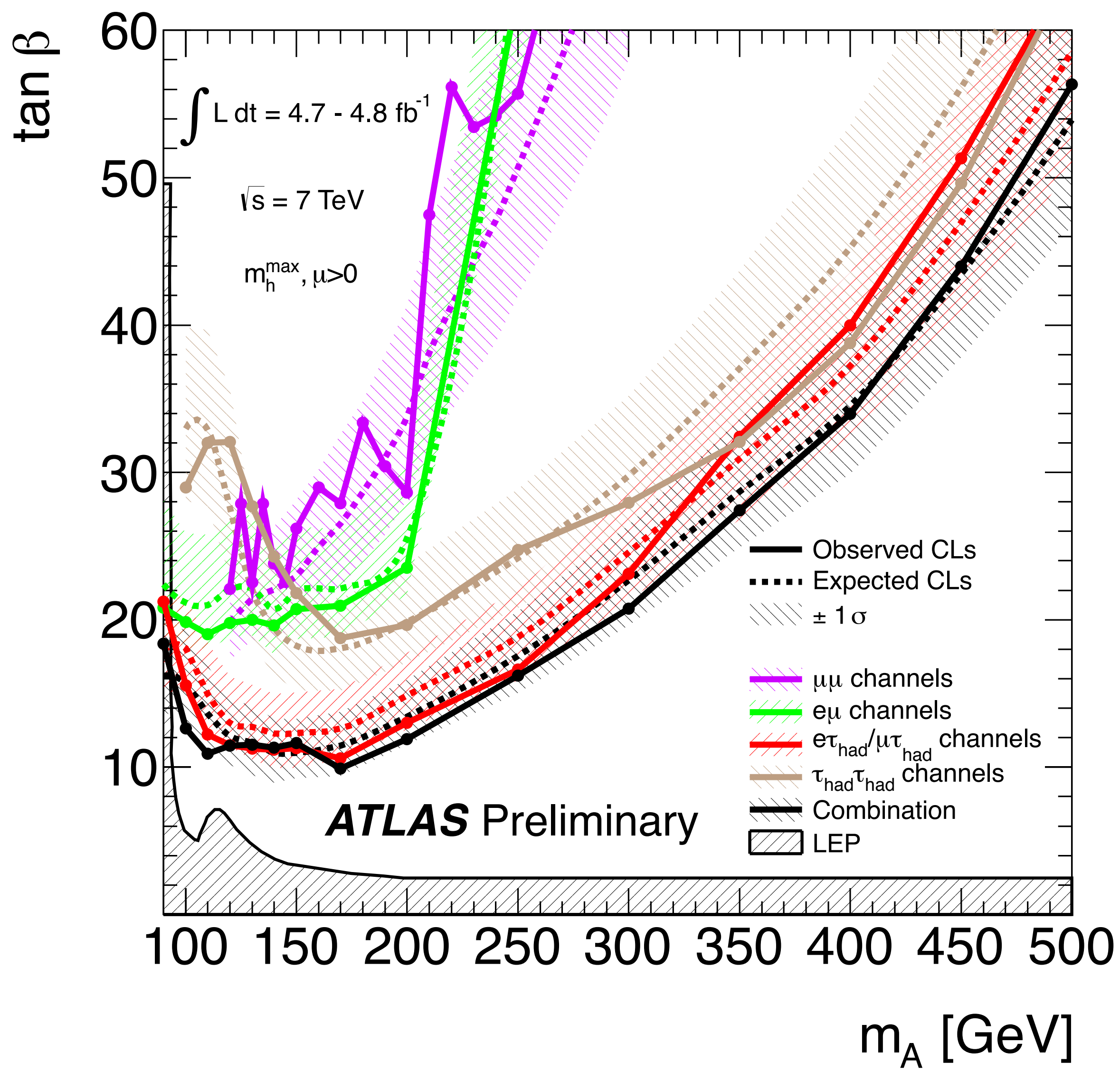


MSSM neutral Higgs searches

ATLAS-CONF-2012-094

- MSSM Higgs branching ratios similar in structure to SM, but suppressed or enhanced according to tanβ
- At high tanβ τ and μ decays of A/H highly favoured
- Decay channels considered: μμ, eμ, ehad, μhad, hadhad
- Exploiting two main MSSM production modes: ggF and b-associated production

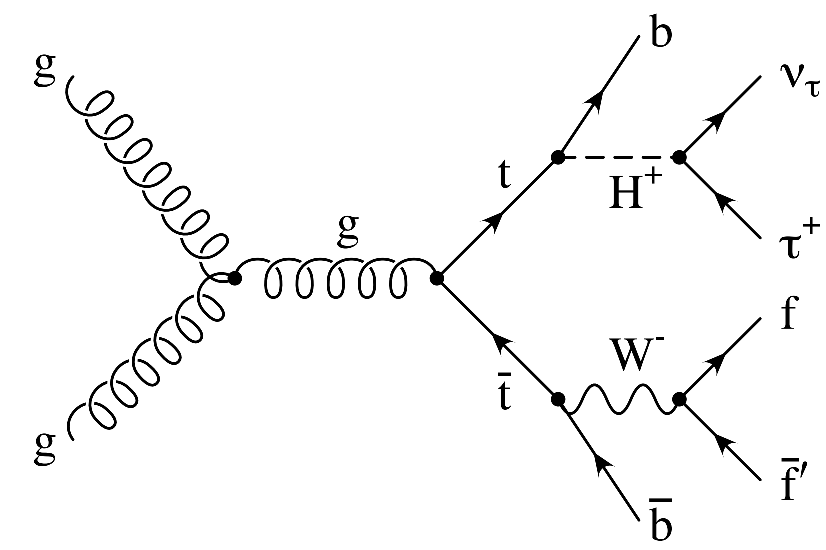




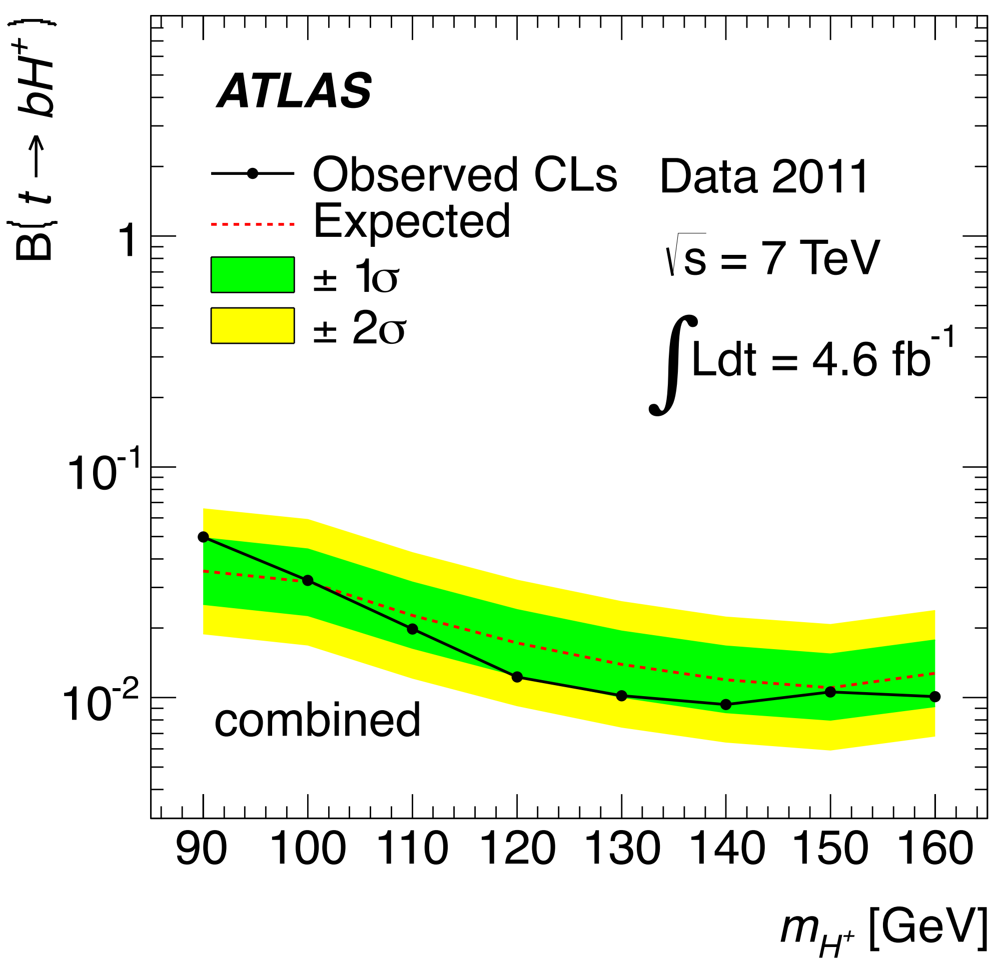
MSSM charged Higgs searches

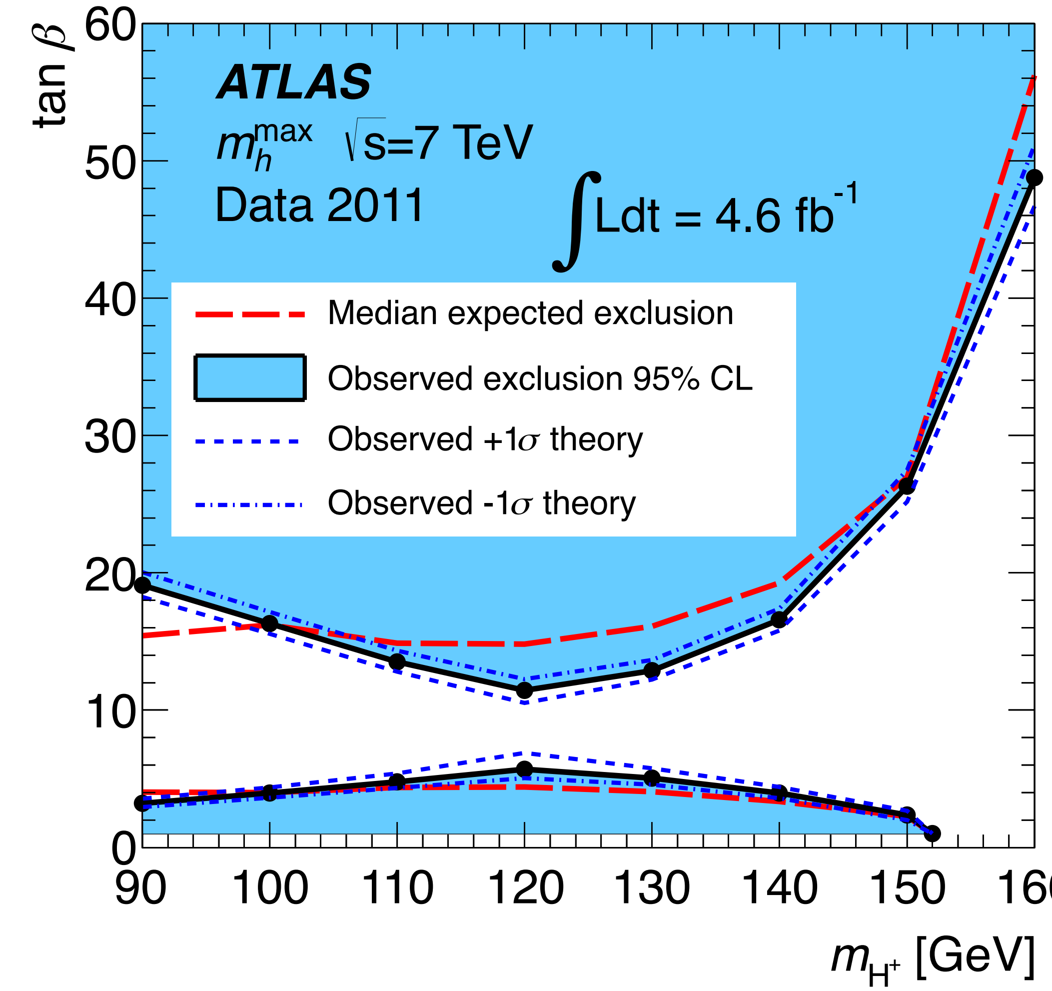
ATLAS-CONF-2012-011
ATLAS-CONF-2011-094

- Charged Higgs fundamental in SUSY Higgs sector, since at least two Higgs doublets are needed
- Main production mode through top decays
- 3 final states considered, leptonic or hadronic τ decay, Etmiss, b jets, and leptonically or hadronically decaying W boson
- Backgrounds: ttbar, single top multijet and diboson
- Mixed MC/data driven background estimation



- csbar decay search with 35 pb^{-1} performed as well





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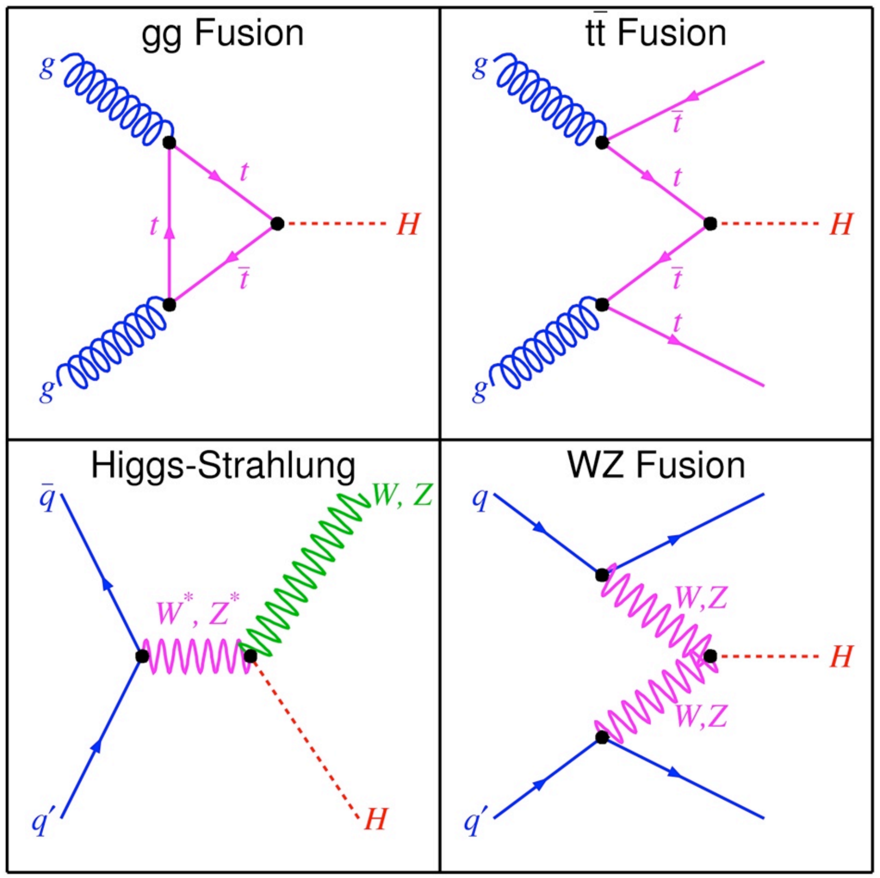
The characteristics of the observed boson are up to now compatible with those of a SM Higgs boson

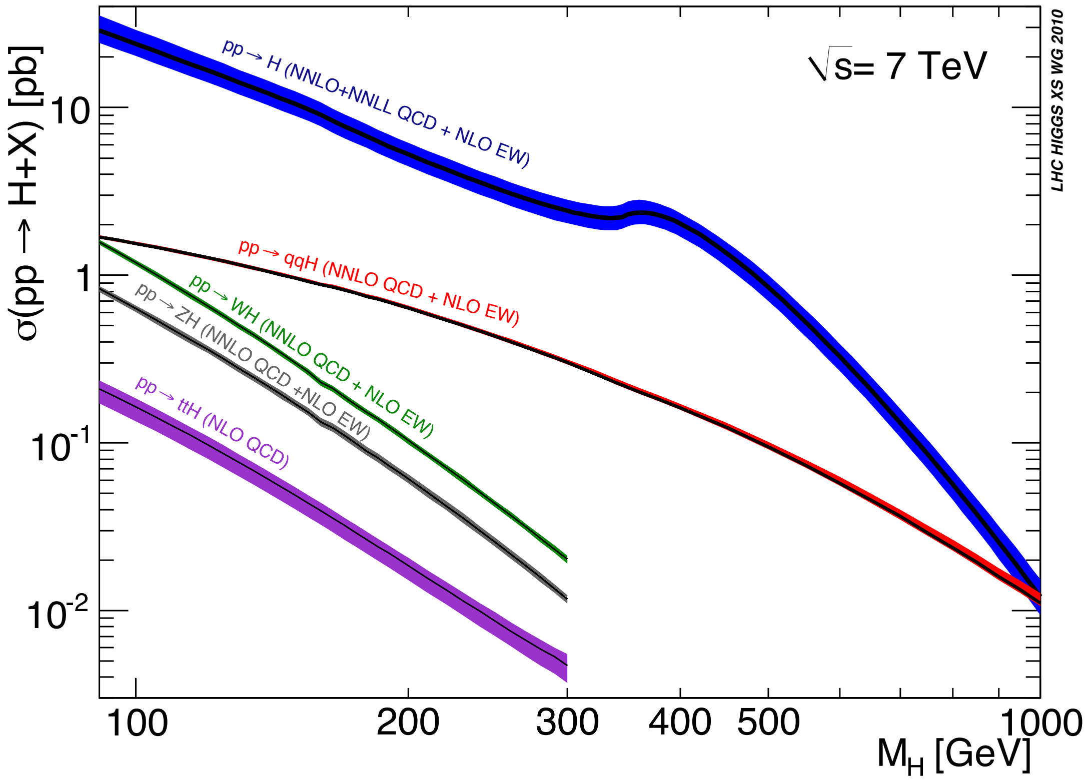
Thanks!

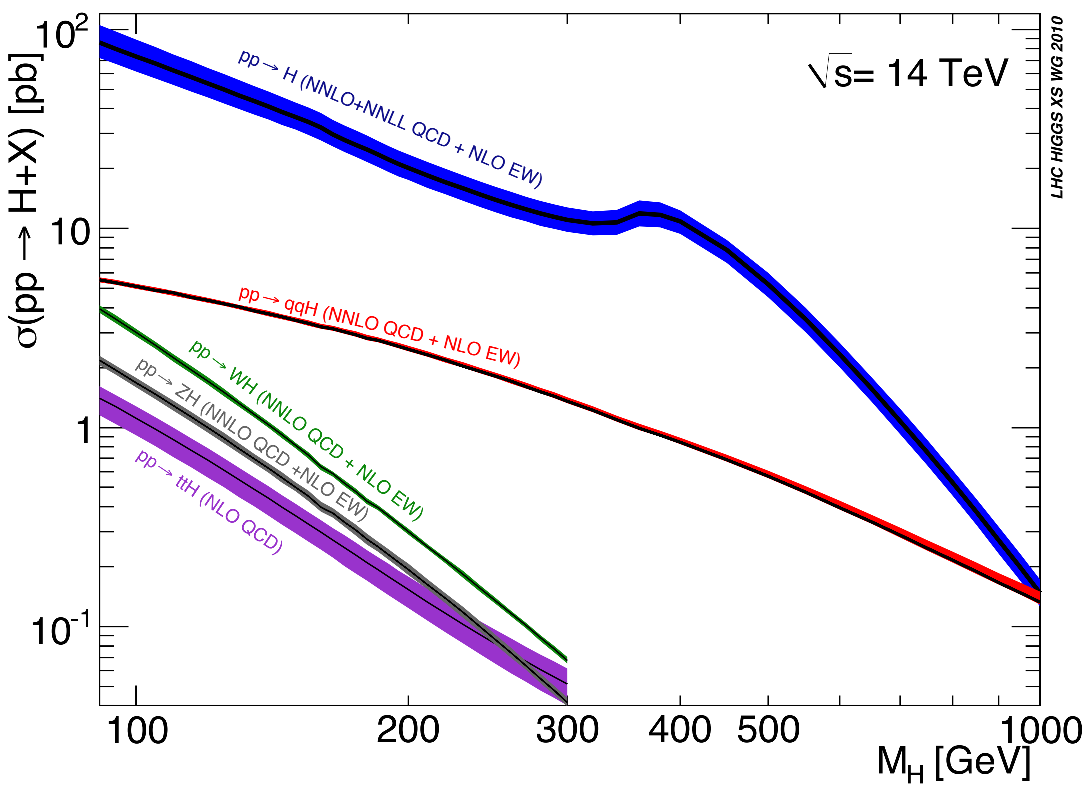
Backup

Atlas collaboration

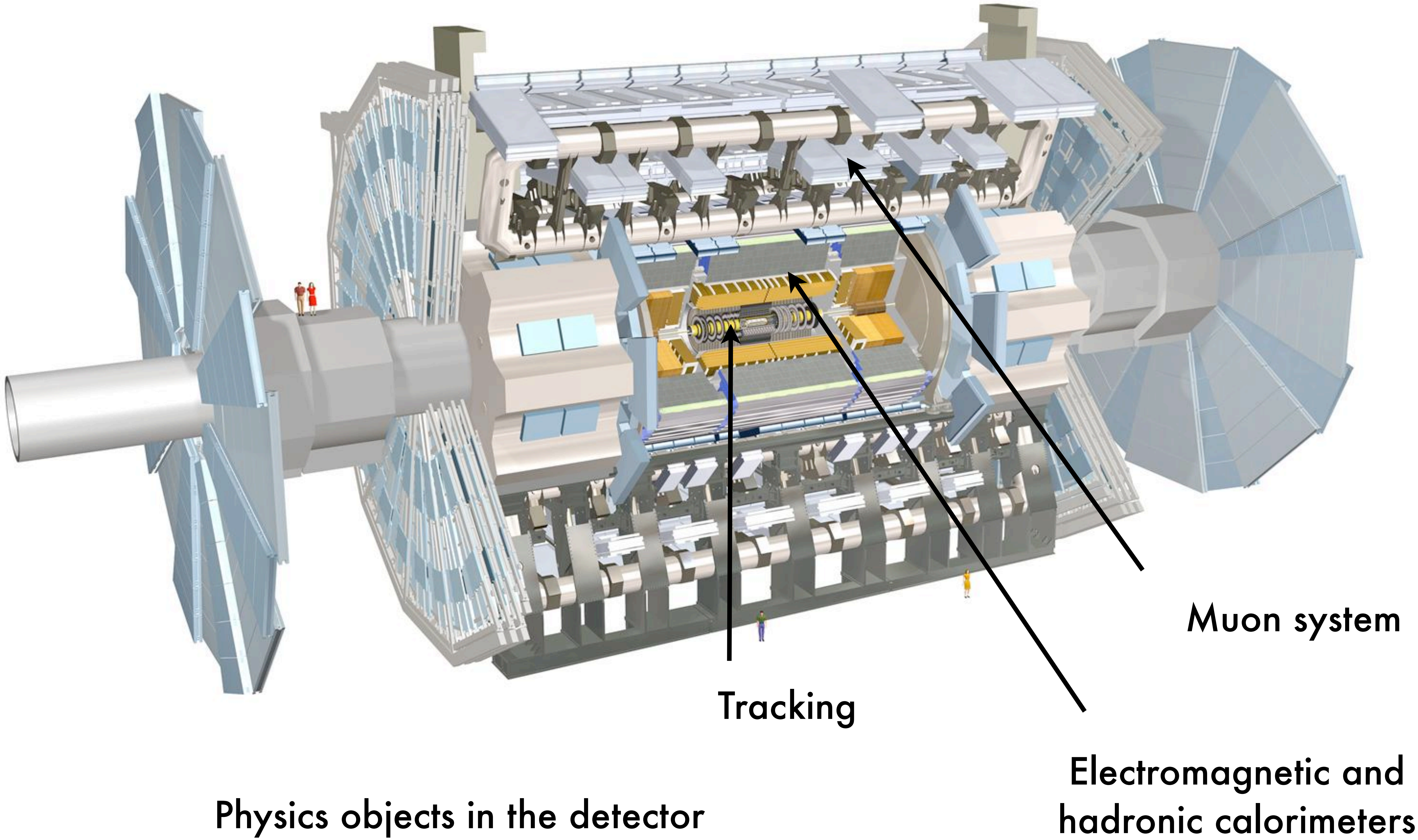
Higgs production modes





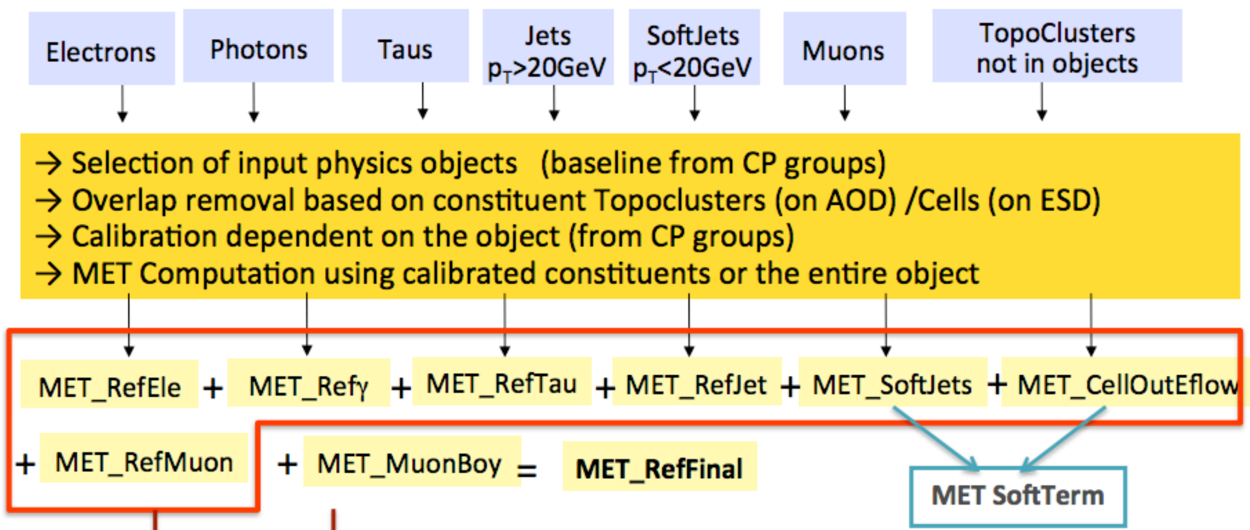


Atlas detector



Physics objects in the detector

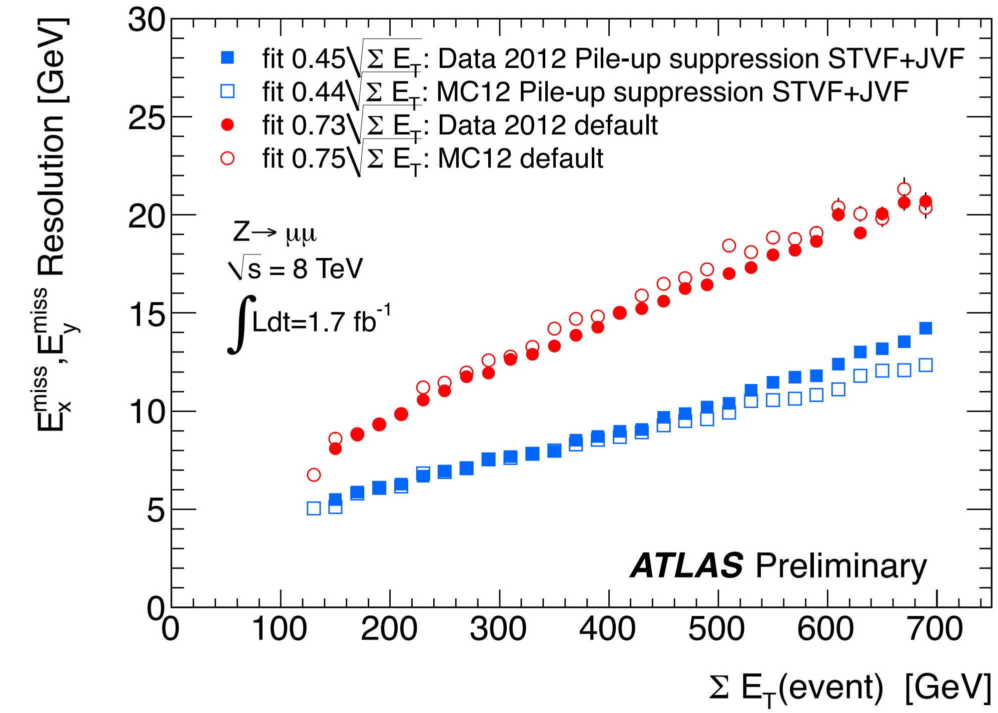
Etmiss

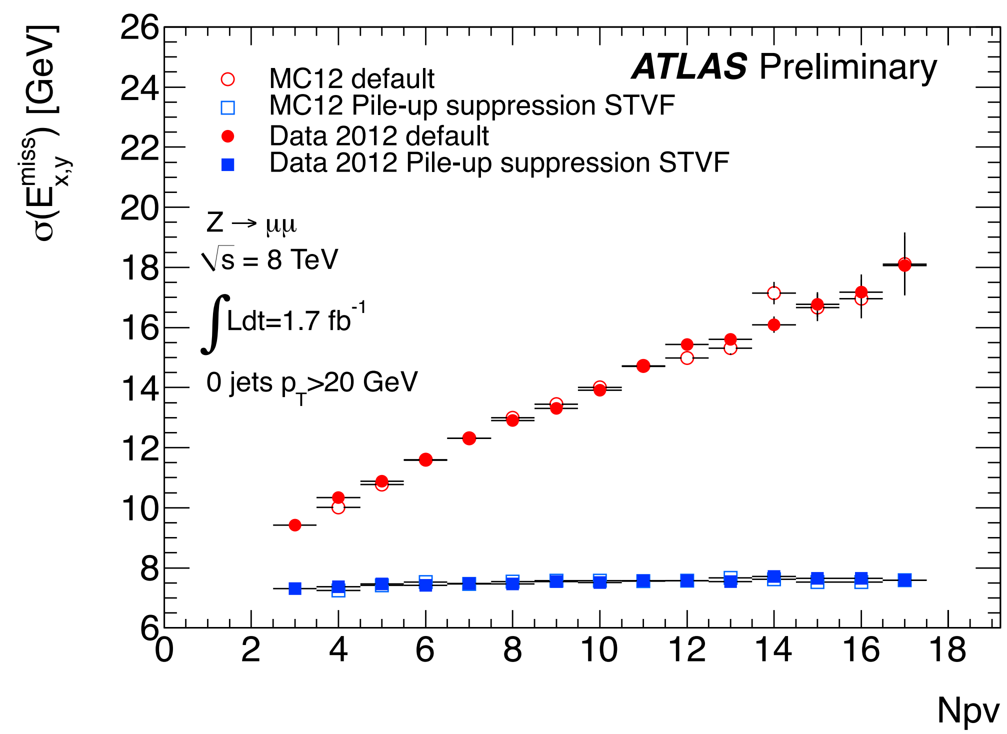


$$\vec{E}_T^{miss,calo} + \vec{E}_T^{miss,muon} = \vec{E}_T^{miss}$$

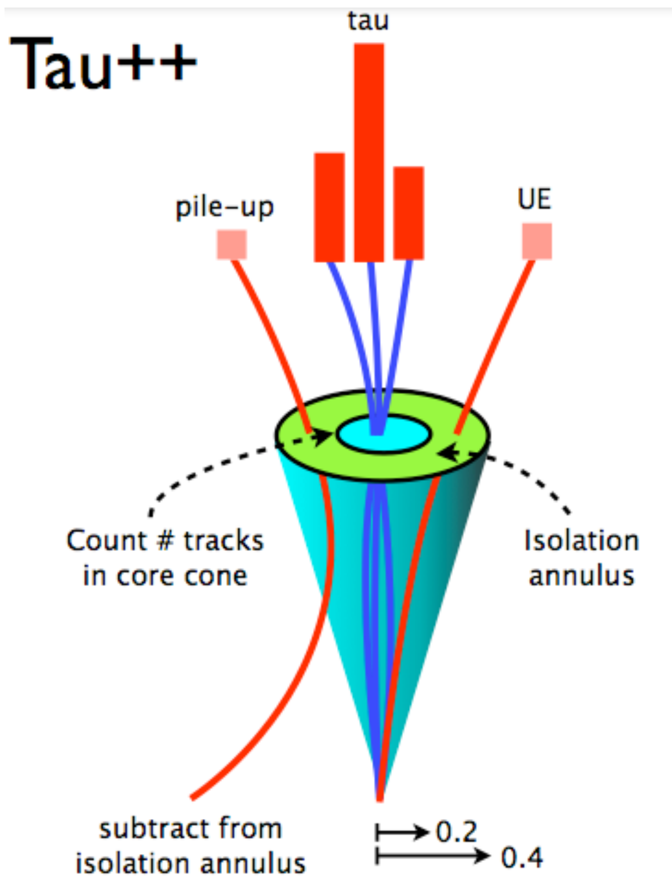
$$STVF = \left(\sum p_T^{track,PV} \Big/ \sum p_T^{track}\right)_{\substack{unmatched \\ objects}}$$

$$JVF = \left(\sum p_T^{track,PV} \Big/ \sum p_T^{track}\right)_{\substack{\text{tracks matched} \\ \text{to a jet}}}$$

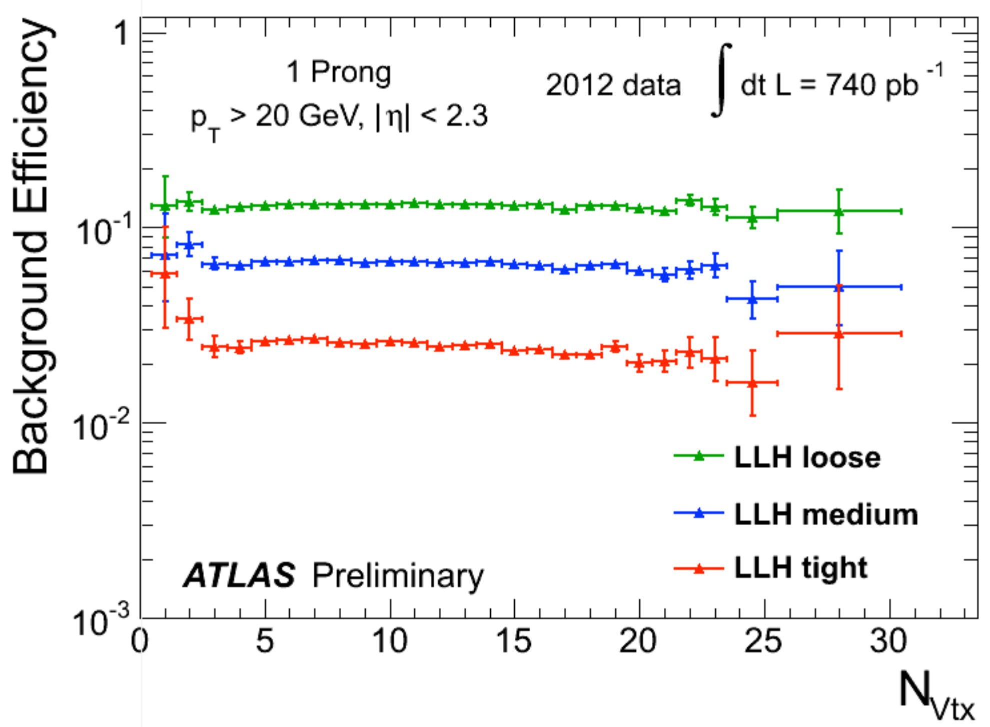




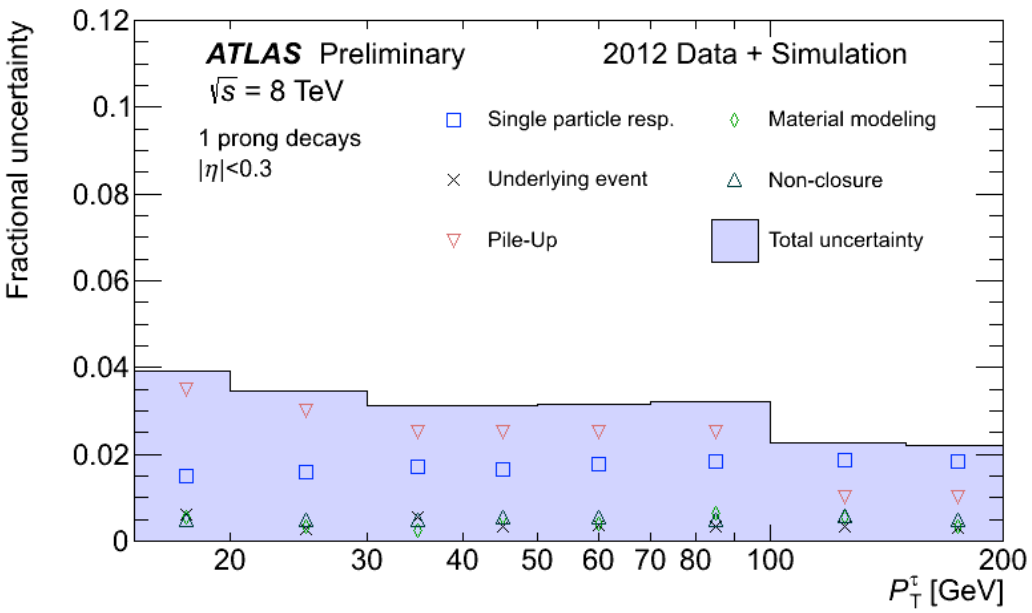
Taus



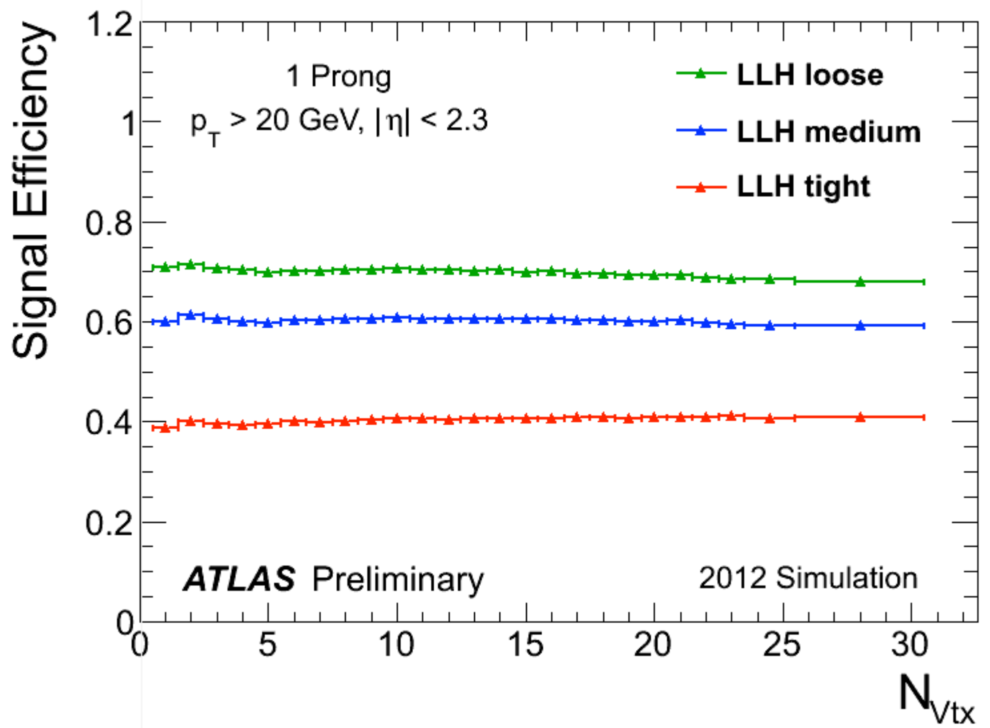
Tau++
tau
pile-up
UE
Count # tracks in core cone
Isolation annulus
subtract from isolation annulus
0.2
0.4



1 Prong
p_T > 20 GeV, |η| < 2.3
2012 data ∫dt L = 740 pb⁻¹
Background Efficiency
LLH loose
LLH medium
LLH tight
ATLAS Preliminary
N_{Vtx}



ATLAS Preliminary
2012 Data + Simulation
√s = 8 TeV
1 prong decays
|η|<0.3
Single particle resp.
Material modeling
Underlying event
Non-closure
Pile-Up
Total uncertainty
Fractional uncertainty
P_T^τ [GeV]



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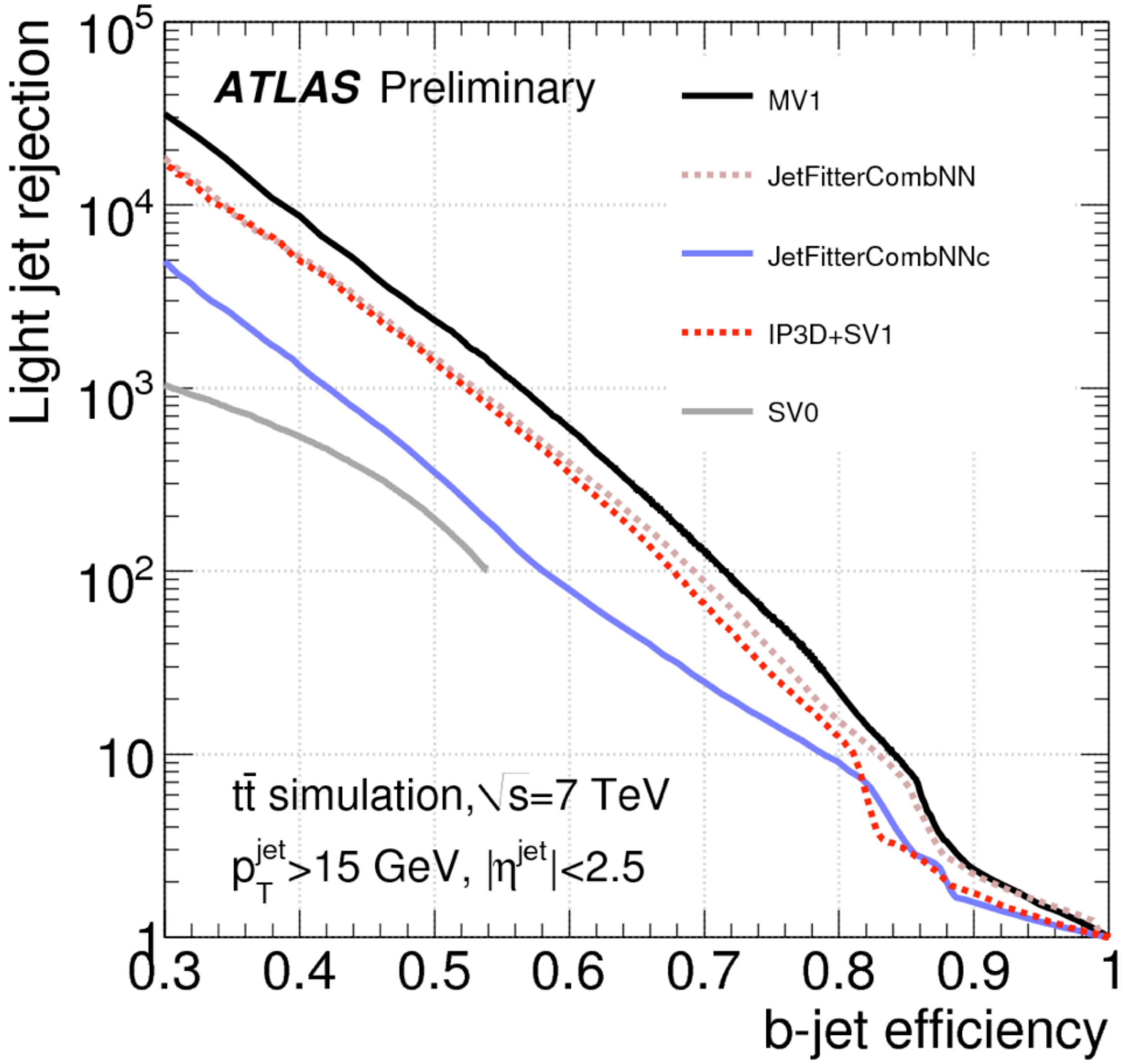
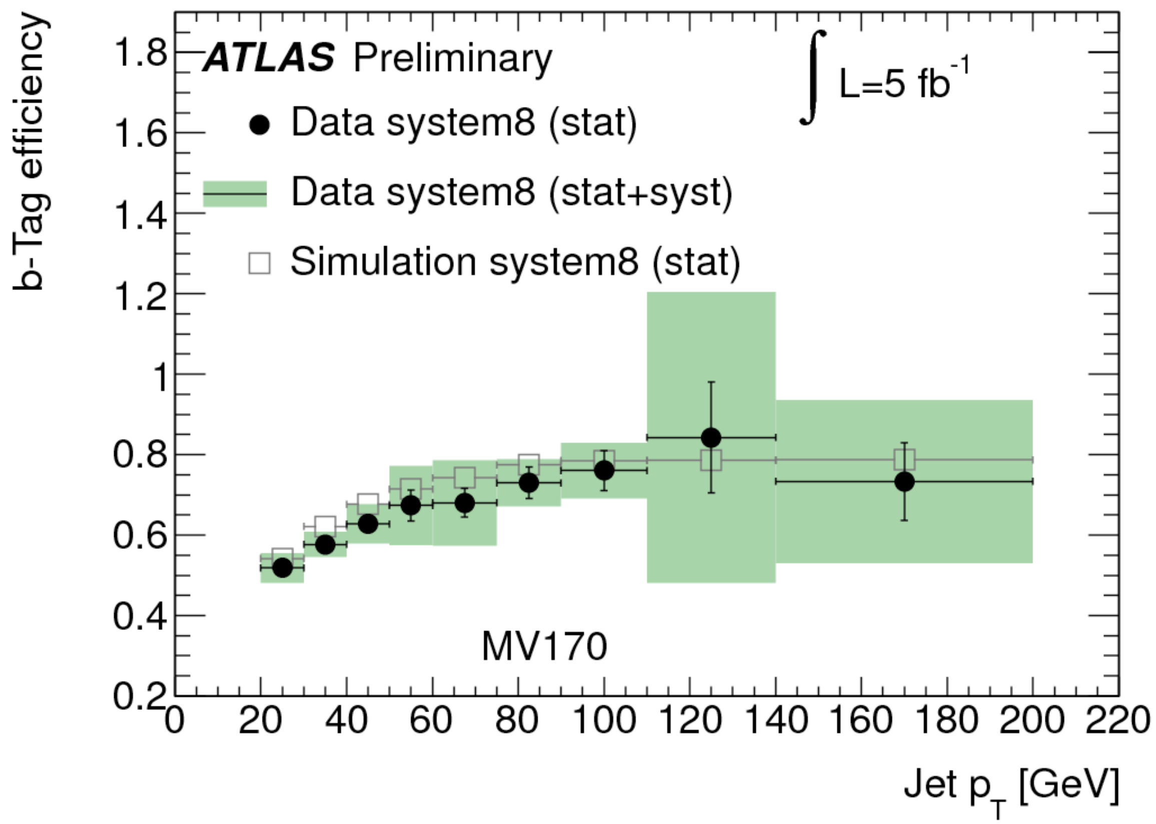
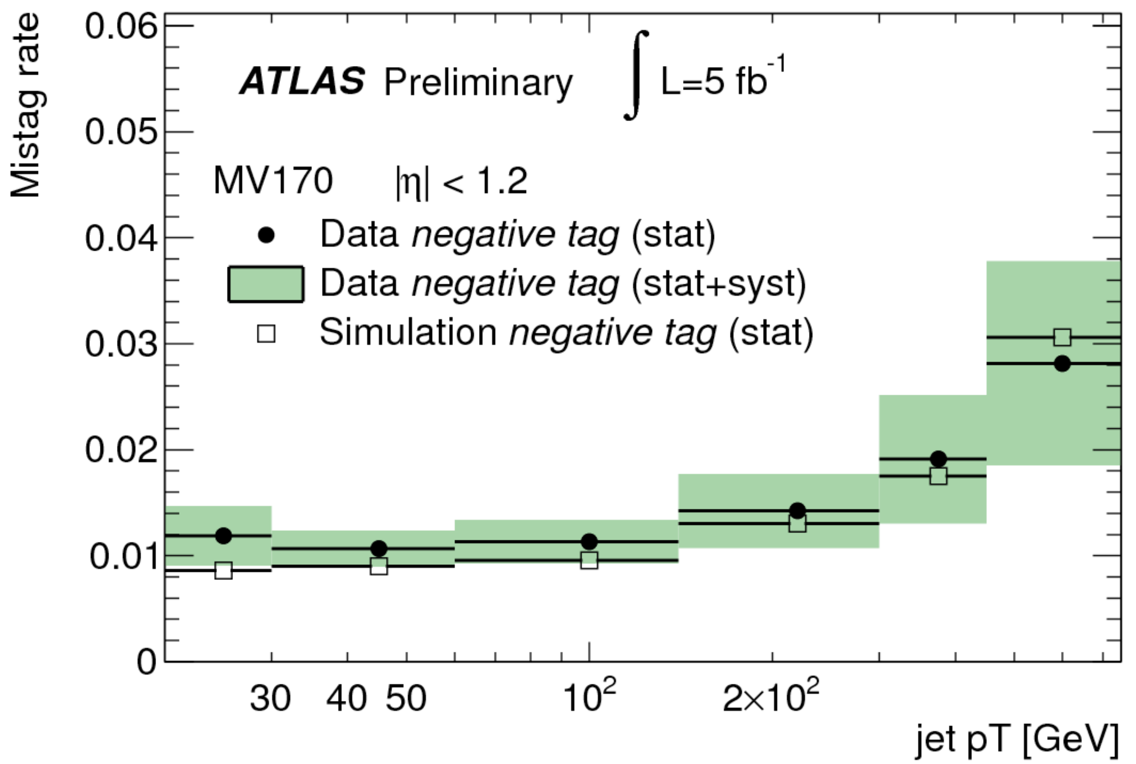
B-tagging

ATLAS-CONF-2012-040
ATLAS-CONF-2012-043
ATLAS-CONF-2012-097

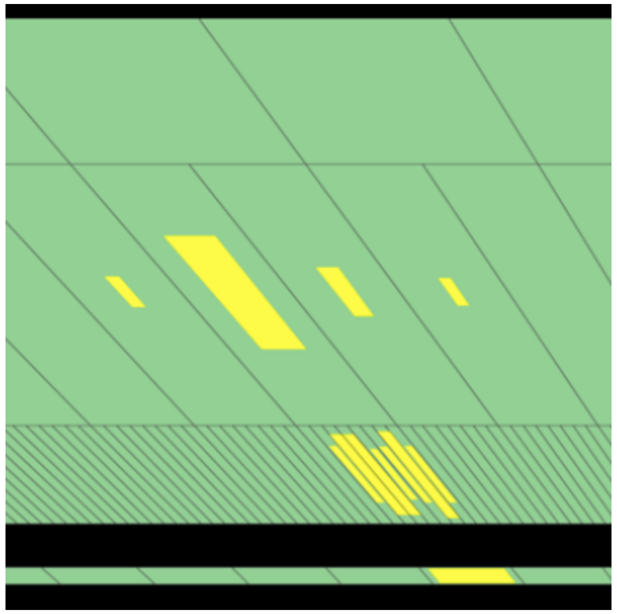




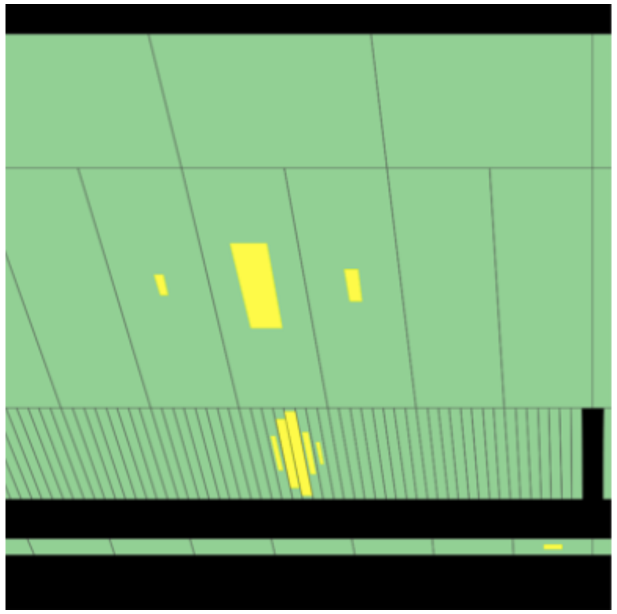


$H \rightarrow \gamma\gamma$

π^0

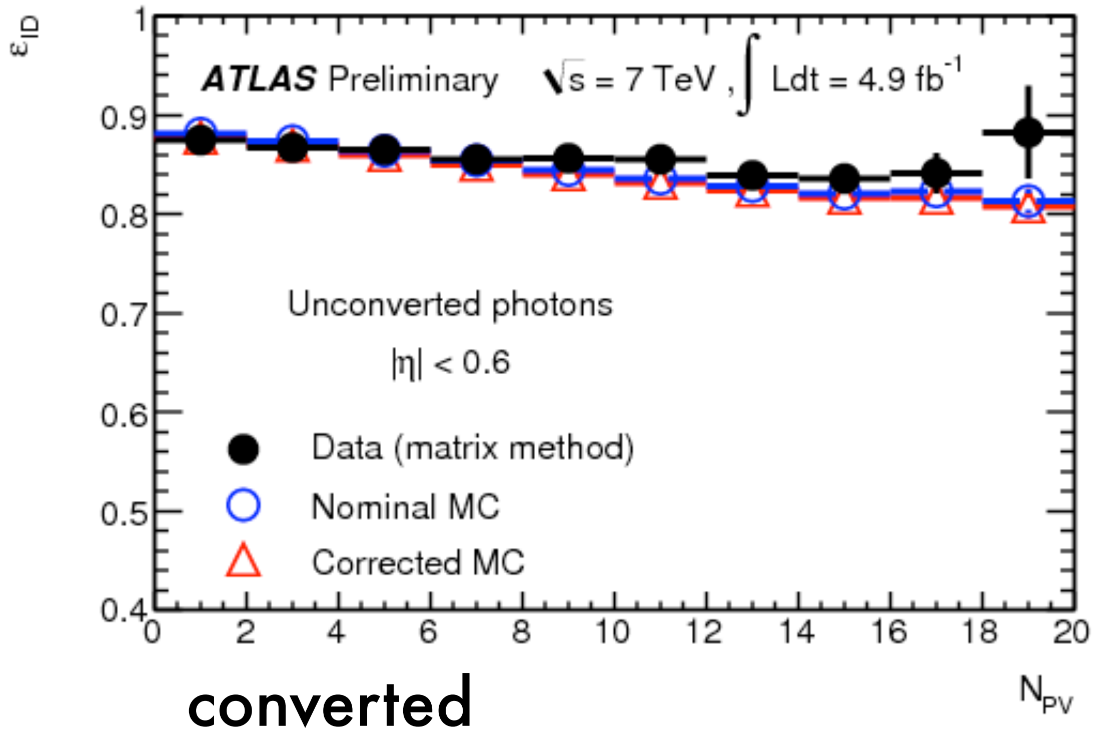


γ

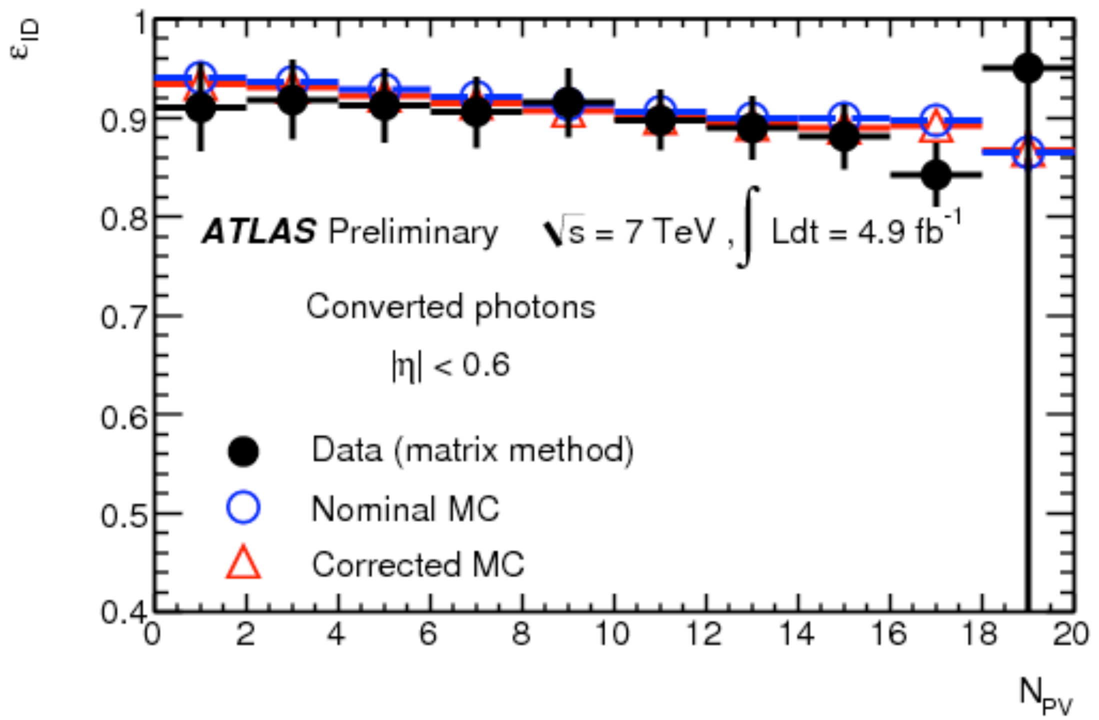


Efficiency stability with pileup

unconverted



converted



H→γγ

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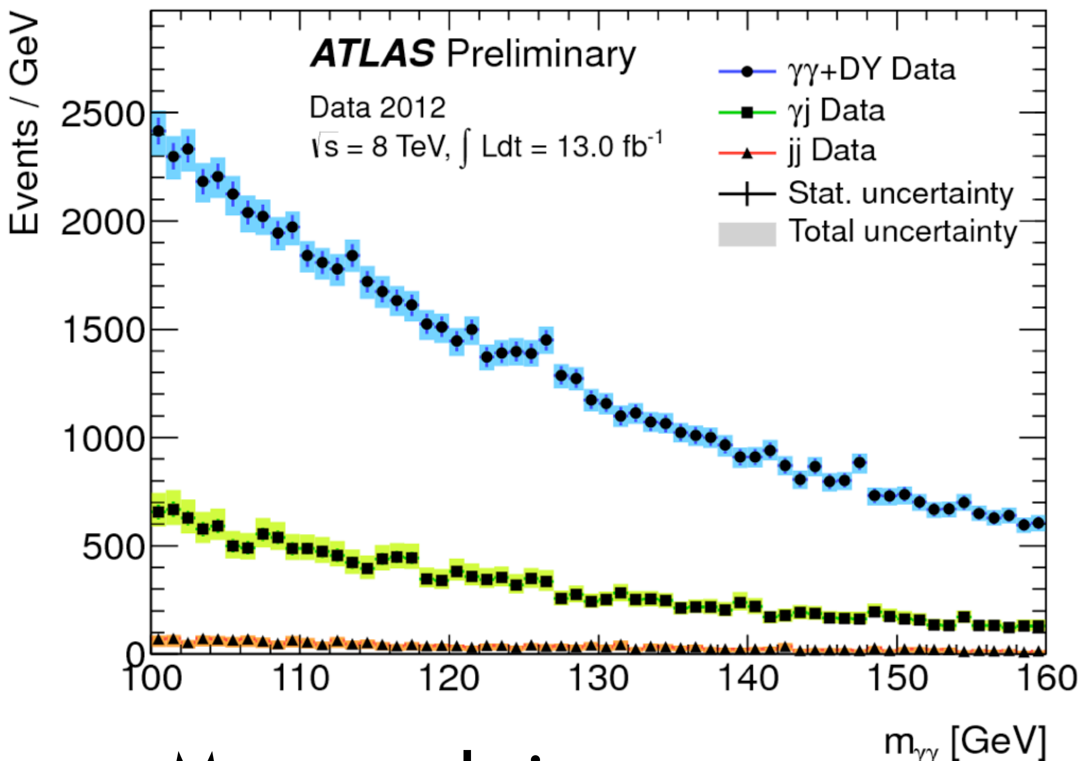
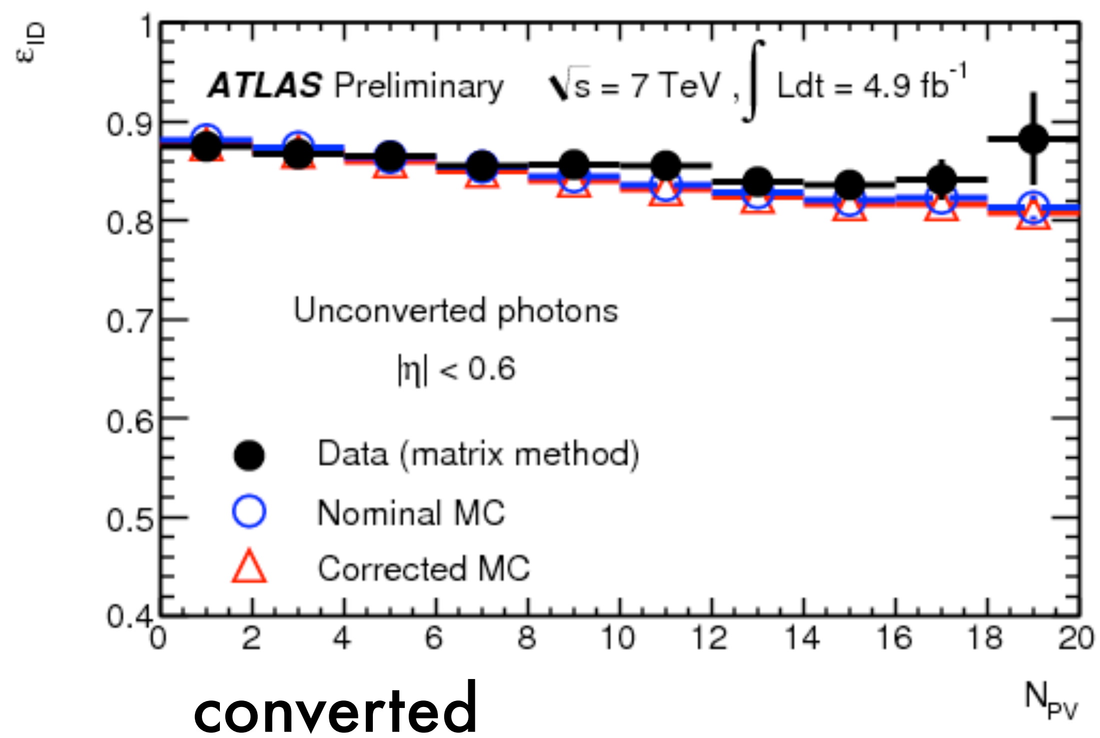
Background decomposition

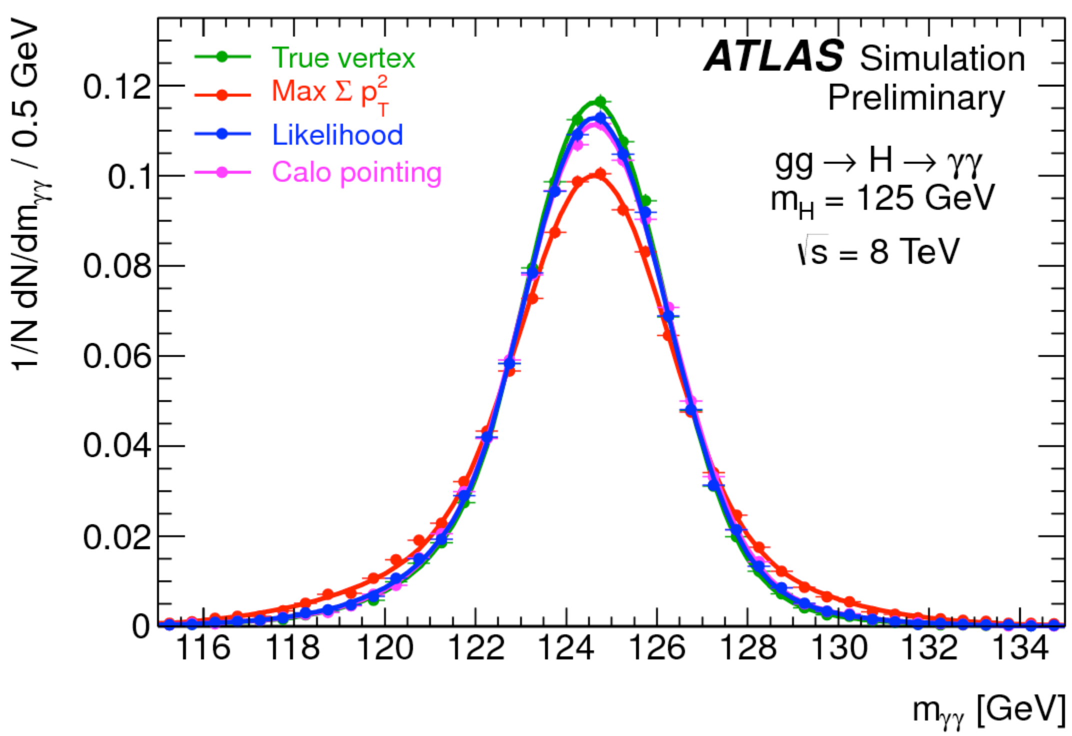


Efficiency stability with pileup

unconverted



Mass resolution



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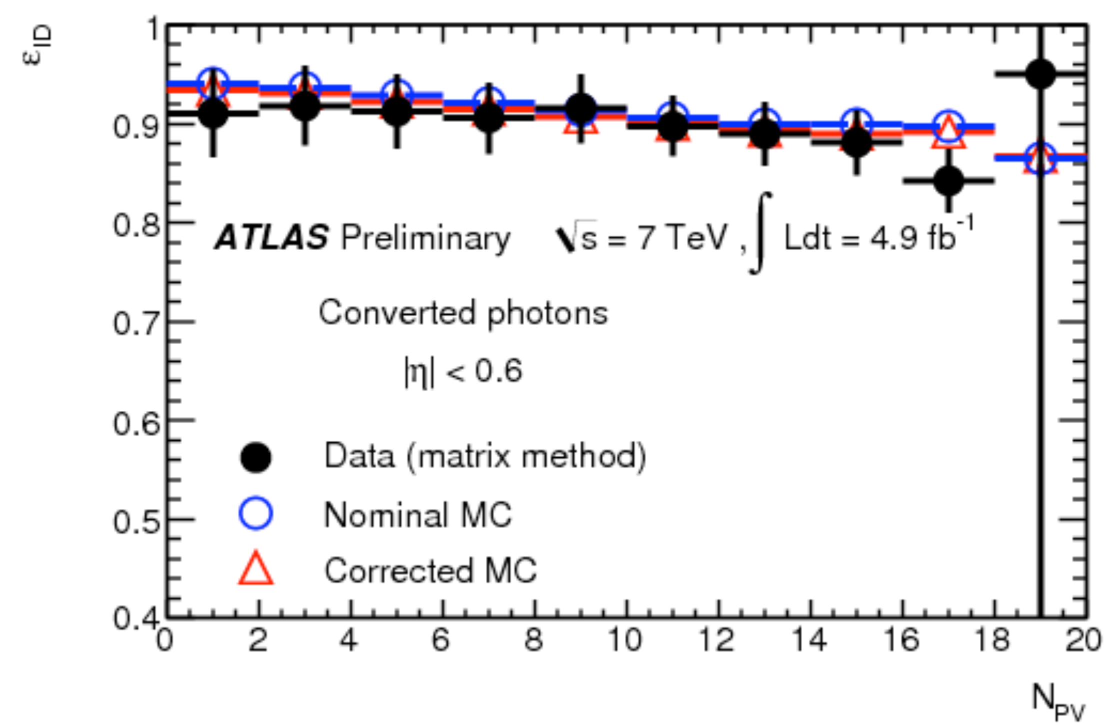

H→ γγ categories

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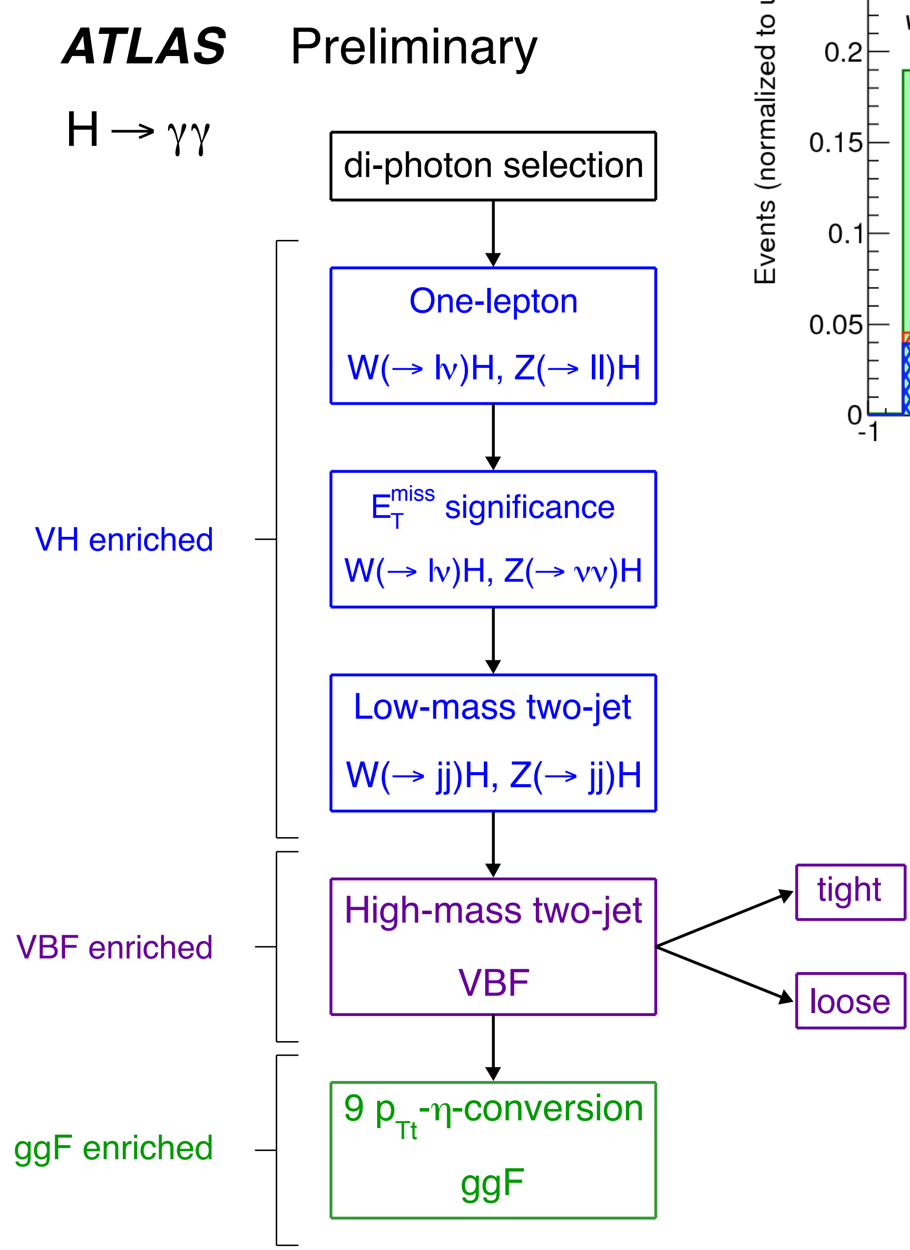

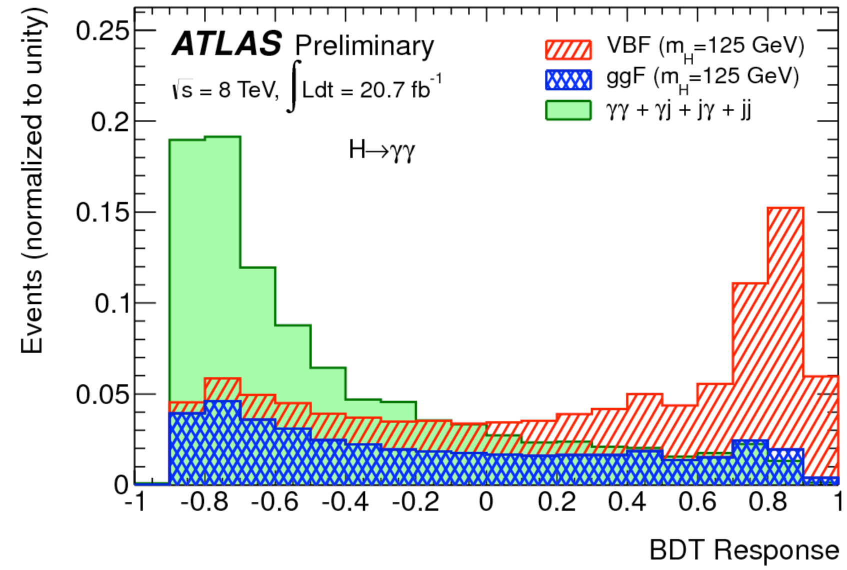

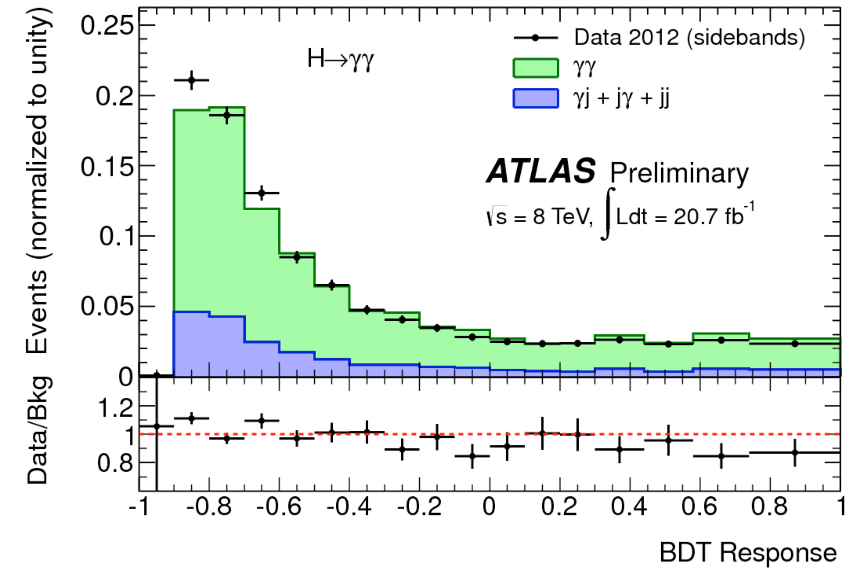

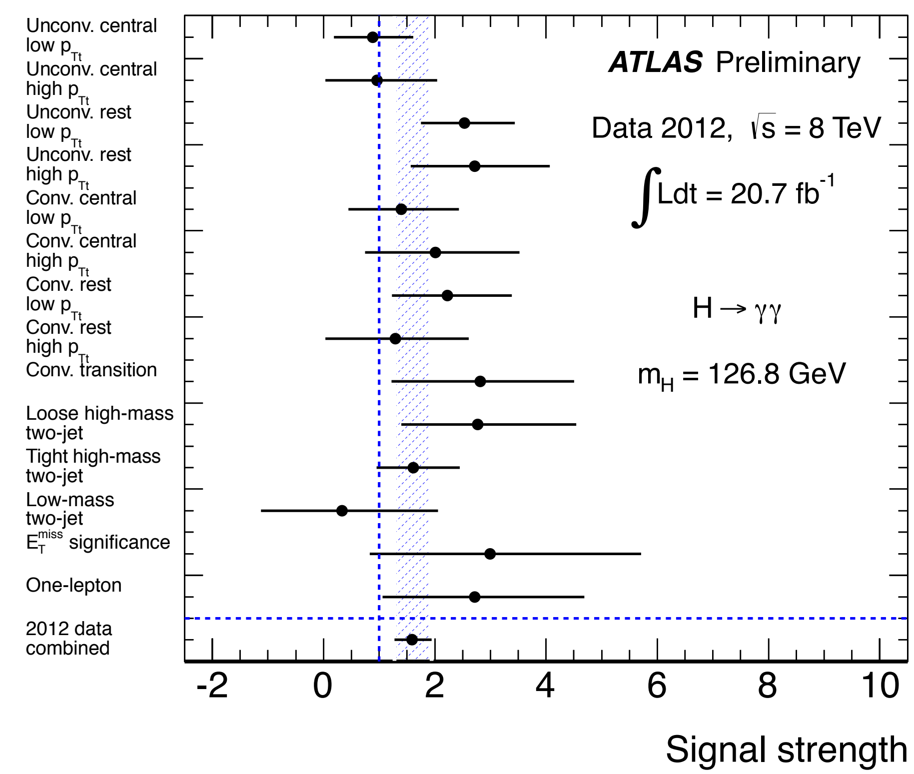

H→γγ

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Table 2: Signal mass resolution (σ_{CB}), number of observed events, number of expected signal events (N_S), number of expected background events (N_B) and signal to background ratio (N_S/N_B) in a mass window around m_H = 126.5 GeV containing 90% of the expected signal for each of the 14 categories of the 8 TeV data analysis. The numbers of background events are obtained from the background + signal fit to the $m_{\gamma\gamma}$ data distribution.

$\sqrt{s}$	8 TeV				
Category	σ_{CB}(GeV)	Observed	N_S	N_B	N_S/N_B
Unconv. central, low p_{Tt}	1.50	911	46.6	881	0.05
Unconv. central, high p_{Tt}	1.40	49	7.1	44	0.16
Unconv. rest, low p_{Tt}	1.74	4611	97.1	4347	0.02
Unconv. rest, high p_{Tt}	1.69	292	14.4	247	0.06
Conv. central, low p_{Tt}	1.68	722	29.8	687	0.04
Conv. central, high p_{Tt}	1.54	39	4.6	31	0.15
Conv. rest, low p_{Tt}	2.01	4865	88.0	4657	0.02
Conv. rest, high p_{Tt}	1.87	276	12.9	266	0.05
Conv. transition	2.52	2554	36.1	2499	0.01
Loose High-mass two-jet	1.71	40	4.8	28	0.17
Tight High-mass two-jet	1.64	24	7.3	13	0.57
Low-mass two-jet	1.62	21	3.0	21	0.14
E_T^{miss} significance	1.74	8	1.1	4	0.24
One-lepton	1.75	19	2.6	12	0.20
Inclusive	1.77	14025	355.5	13280	0.03

H→γγ uncertainties

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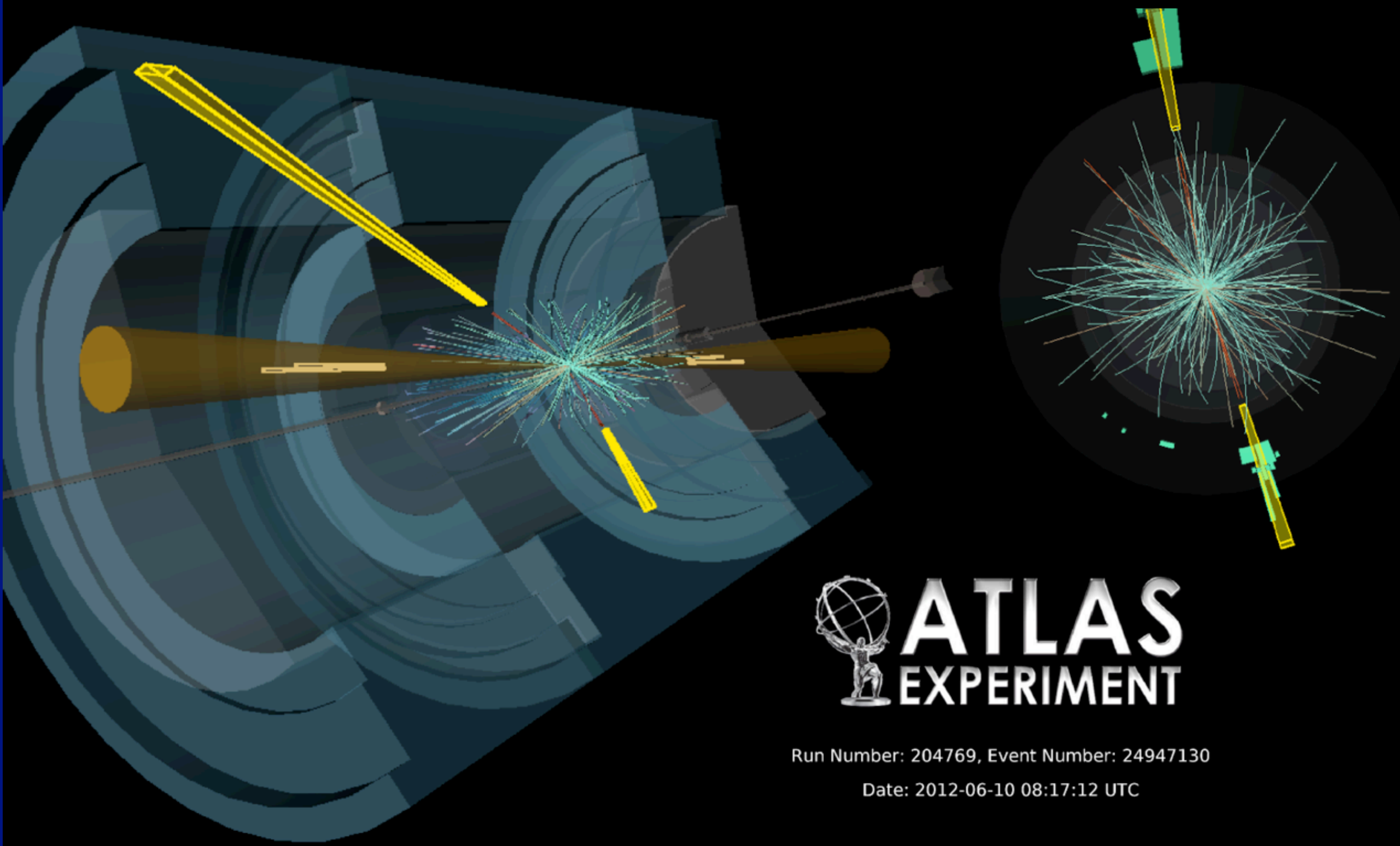
Table 5: Summary of the impact of systematic uncertainties on the signal yields for the analysis of the 8 TeV data.

Systematic uncertainties	Value(%)			Constraint
Luminosity	±3.6			
Trigger	±0.5			
Photon Identification	±2.4			Log-normal
Isolation	±1.0			
Photon Energy Scale	±0.25			
Branching ratio	±5.9% – ±2.1% (m_H = 110 - 150 GeV)			Asymmetric Log-normal
Scale	ggF: $^{+7.2}_{-7.8}$	VBF: $^{+0.2}_{-0.2}$	WH: $^{+0.2}_{-0.6}$	Asymmetric
	ZH: $^{+1.6}_{-1.5}$	ttH: $^{+3.8}_{-9.3}$		Log-normal
PDF+α_s	ggF: $^{+7.5}_{-6.9}$	VBF: $^{+2.6}_{-2.7}$	WH: ±3.5	Asymmetric
	ZH: ±3.6	ttH: ±7.8		Log-normal
Theory cross section on ggF	Tight high-mass two-jet:	±48		Log-normal
	Loose high-mass two-jet:	±28		
	Low-mass two-jet:	±30		

VBF H→γγ event display



Spin-2 model

$$A(X \to VV) = \Lambda^{-1}\Big[2g_1 t_{\mu\nu} f^{*1,\mu\alpha} f^{*2,\nu\alpha} + 2g_2 t_{\mu\nu}\frac{q_\alpha q_\beta}{\Lambda^2} f^{*1,\mu\alpha} f^{*2,\nu\alpha}$$
$$+g_3\frac{\tilde{q}^\beta \tilde{q}^\alpha}{\Lambda^2} t_{\beta\nu}(f^{*1,\mu\nu} f^{*2}_{\mu\alpha} + f^{*2,\mu\nu} f^{*1}_{\mu\alpha}) + g_4\frac{\tilde{q}^\nu \tilde{q}^\mu}{\Lambda^2} t_{\mu\nu} f^{*1,\alpha\beta} f^{*(2)}_{\alpha\beta}$$
$$+m_V^2\left(2g_5 t_{\mu\nu}\epsilon_1^{*\mu}\epsilon_2^{*\nu} + 2g_6\frac{\tilde{q}^\mu q_\alpha}{\Lambda^2} t_{\mu\nu}(\epsilon_1^{*\nu}\epsilon_2^{*\alpha} - \epsilon_1^{*\alpha}\epsilon_2^{*\nu}) + g_7\frac{\tilde{q}^\mu \tilde{q}^\nu}{\Lambda^2} t_{\mu\nu}\epsilon_1^*\epsilon_2^*\right)$$
$$+g_8\frac{\tilde{q}_\mu \tilde{q}_\nu}{\Lambda^2} t_{\mu\nu} f^{*1,\alpha\beta}\tilde{f}^{*(2)}_{\alpha\beta} + g_9 t_{\mu\alpha}\tilde{q}^\alpha \epsilon_{\mu\nu\rho\sigma}\epsilon_1^{*\nu}\epsilon_2^{*\rho} q^\sigma$$
$$+\frac{g_{10} t_{\mu\alpha}\tilde{q}^\alpha}{\Lambda^2}\epsilon_{\mu\nu\rho\sigma} q^\rho \tilde{q}^\sigma (\epsilon_1^{*\nu}(q\epsilon_2^*) + \epsilon_2^{*\nu}(q\epsilon_1^*))\Big],$$

General interaction of spin-2 particle with gauge bosons pair has 10 independent tensor couplings

- Excluding generic spin-2 model is impossible at this stage
- Start with model with minimal couplings (g1=g5=1)
- Two production modes allowed: gg and qqbar
- Study 5 different gg fractions from 0% to 100%

H→ZZ→ 4l FSR correction

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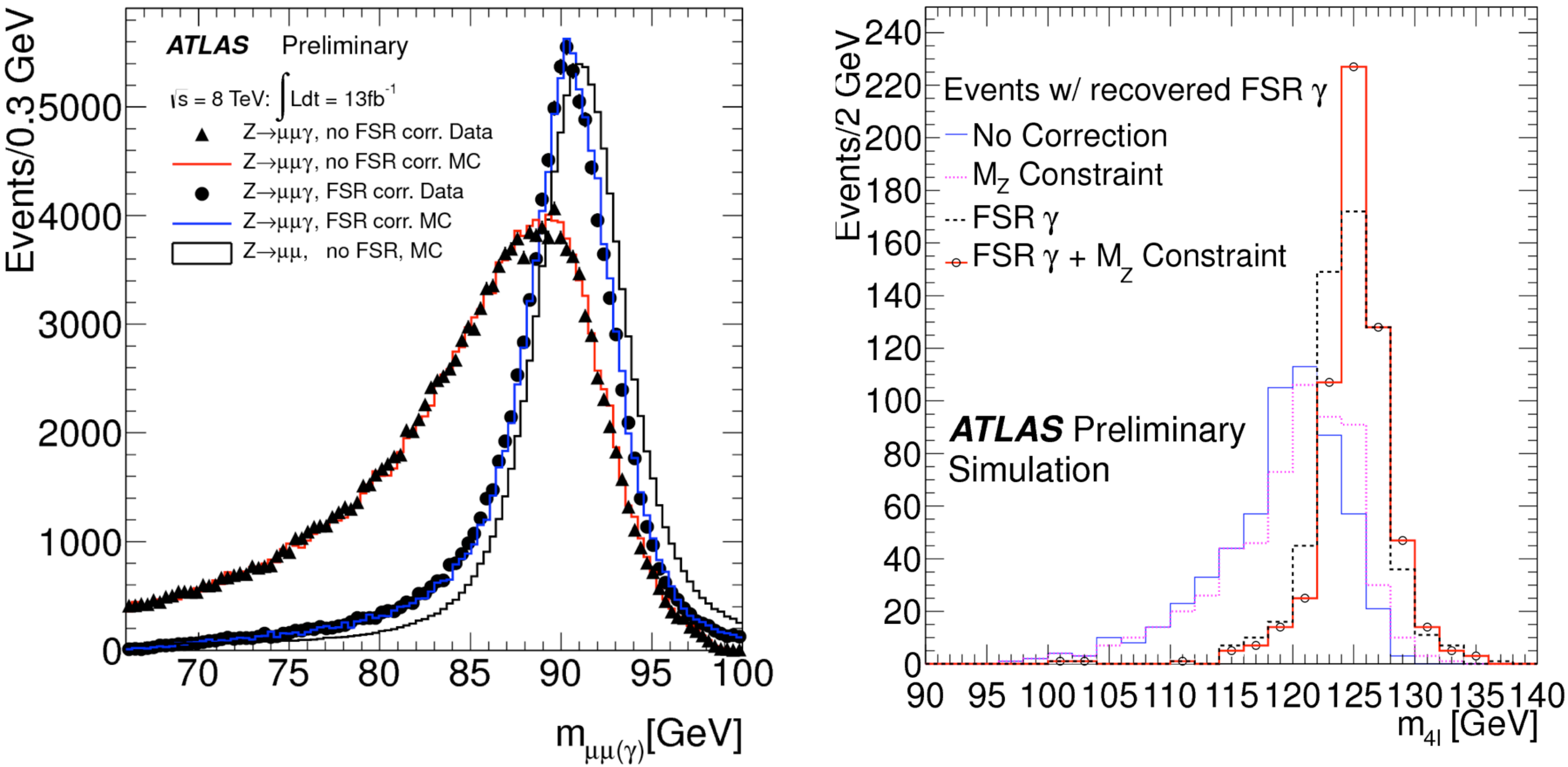

$H \to ZZ \to 4l$ categories

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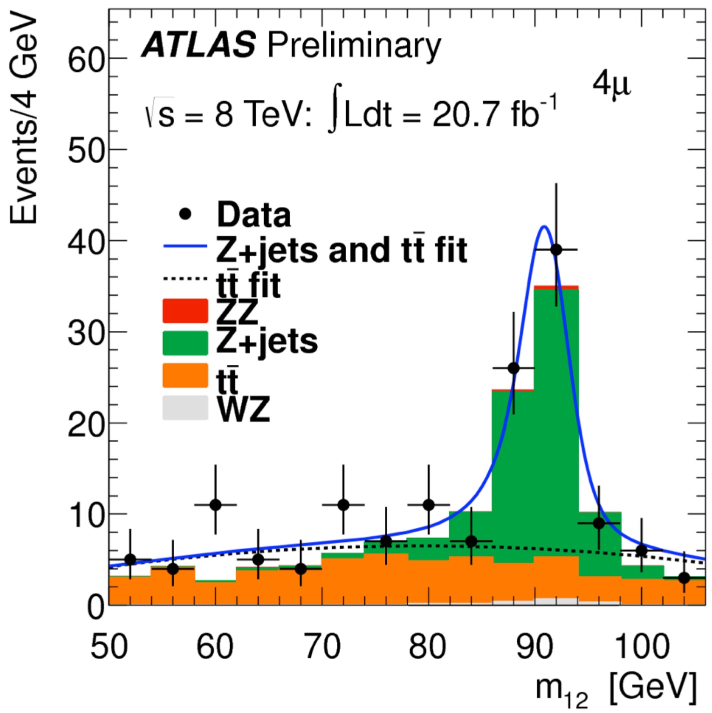
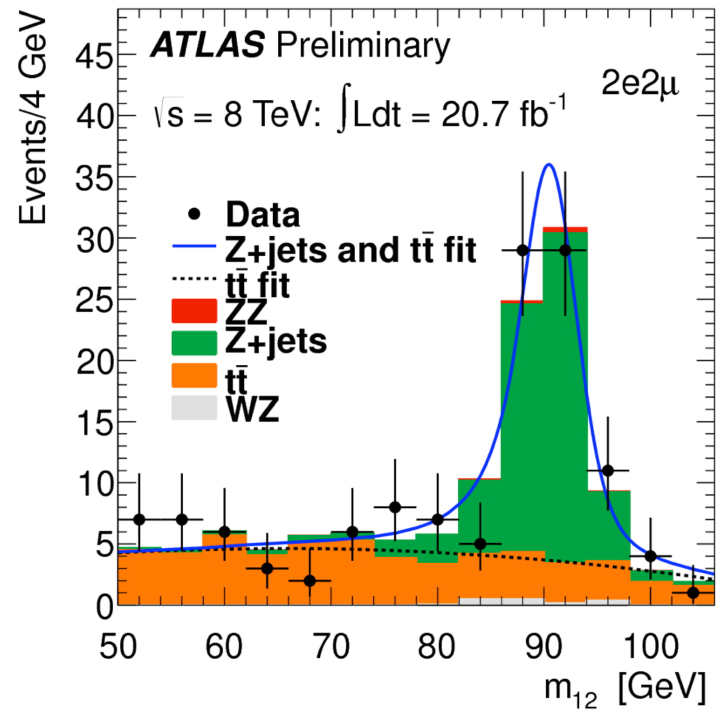
Table 2: The expected numbers of events in each category (ggF-like, VBF-like, VH-like), after all analysis criteria are applied, for each signal production mechanism (ggF/$t\bar{t}H$, VBF, VH) at m_H =125 GeV and the $ZZ^{(*)}$ background, for 20.7 fb^{-1} at $\sqrt{s}$ = 8 TeV and 4.6 fb^{-1} at $\sqrt{s}$ = 7 TeV. The requirement $m_{4\ell} > 100$ GeV is applied.

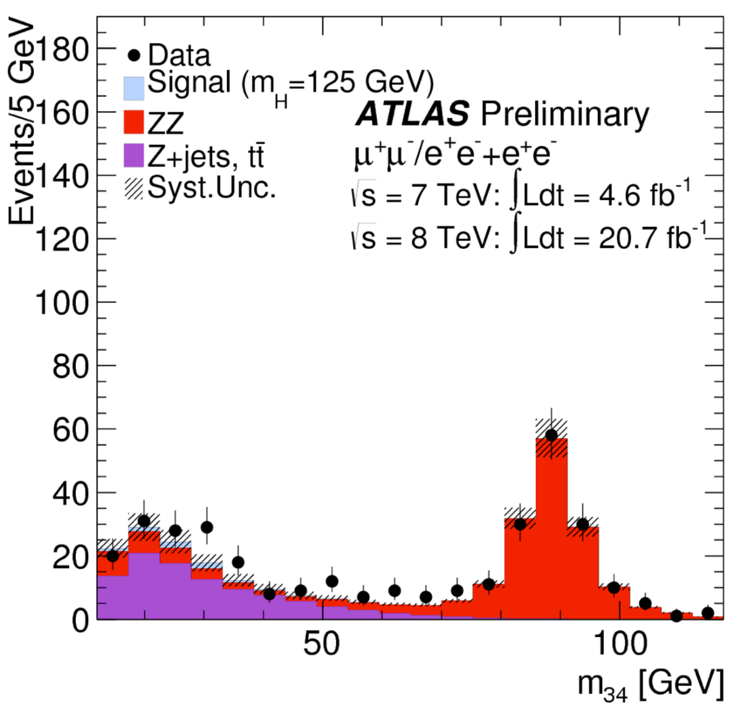
category	$gg \to H, q\bar{q}/gg \to t\bar{t}H$	$qq' \to Hqq'$	$q\bar{q} \to W/ZH$	$ZZ^{(*)}$
		$\sqrt{s} = 8$ TeV		
ggF-like	13.5	0.79	0.65	320.4
VBF-like	0.28	0.43	0.01	3.58
VH-like	0.06	-	0.14	0.69
		$\sqrt{s} = 7$ TeV		
ggF-like	2.20	0.14	0.11	57.5
VBF-like	0.03	0.06	-	0.44
VH-like	0.01	-	0.03	0.25

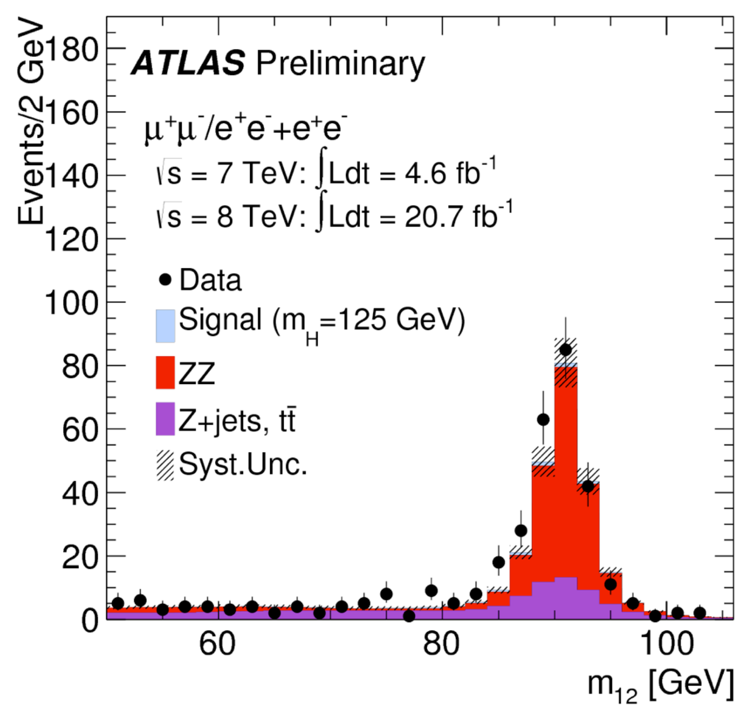
H→ZZ→ 4l background





ll+μμ background estimation
ttbar and Z+jets CR, isolation requirement on subleading dilepton removed, fail impact parameter requirement





ll+ee background estimation
various methods based on relaxed selection criteria, inverted isolation and impact parameter selections, same sign subleading di-electrons

$H \rightarrow ZZ \rightarrow$ 4l background

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Table 3: Summary of the estimated numbers of Z + jets and $t\bar{t}$ background events for the 20.7 fb^{-1} of $\sqrt{s}$ = 8 TeV data and for the 4.6 fb^{-1} of $\sqrt{s}$ = 7 TeV data for the full mass range of the analysis after the kinematic selections described in the text. The sub-leading same sign full analysis event counts are given only for $m_{4\ell} < 160$ GeV to avoid contamination from the irreducible $ZZ^{(*)}$ background with an incorrect charge measurement. Approximately 80% of the reducible background has $m_{4\ell} < 160$ GeV. The "†" symbol indicates the estimates used for the background normalisation, the others being cross-checks. The first uncertainty is statistical, the second is systematic.

method	estimate at $\sqrt{s}$ = 8 TeV	estimate at $\sqrt{s}$ = 7 TeV
	4μ	4μ
m_{12} fit: Z + jets contribution	$2.4 \pm 0.5 \pm 0.6^{\dagger}$	$0.22 \pm 0.07 \pm 0.02^{\dagger}$
m_{12} fit: $t\bar{t}$ contribution	$0.14 \pm 0.03 \pm 0.03^{\dagger}$	$0.03 \pm 0.01 \pm 0.01^{\dagger}$
$t\bar{t}$ from $e\mu + \mu\mu$	$0.10 \pm 0.05 \pm 0.004$	-
	$2e2\mu$	$2e2\mu$
m_{12} fit: Z + jets contribution	$2.5 \pm 0.5 \pm 0.6^{\dagger}$	$0.19 \pm 0.06 \pm 0.02^{\dagger}$
m_{12} fit: $t\bar{t}$ contribution	$0.10 \pm 0.02 \pm 0.02^{\dagger}$	$0.03 \pm 0.01 \pm 0.01^{\dagger}$
$t\bar{t}$ from $e\mu + \mu\mu$	$0.12 \pm 0.07 \pm 0.005$	-
	$2\mu 2e$	$2\mu 2e$
$\ell\ell + e^{\pm}e^{\mp}$ relaxed cuts	$5.2 \pm 0.4 \pm 0.5^{\dagger}$	$1.8 \pm 0.3 \pm 0.4$
$\ell\ell + e^{\pm}e^{\mp}$ inverted cuts	$3.9 \pm 0.4 \pm 0.6$	-
$3\ell + \ell$ (same-sign)	$4.3 \pm 0.6 \pm 0.5$	$2.8 \pm 0.4 \pm 0.5^{\dagger}$
sub-leading same sign full analysis events	4	0
	$4e$	$4e$
$\ell\ell + e^{\pm}e^{\mp}$ relaxed cuts	$3.2 \pm 0.5 \pm 0.4^{\dagger}$	$1.4 \pm 0.3 \pm 0.4$
$\ell\ell + e^{\pm}e^{\mp}$ inverted cuts	$3.6 \pm 0.6 \pm 0.6$	-
$3\ell + \ell$ (same-sign)	$4.2 \pm 0.5 \pm 0.5$	$2.5 \pm 0.3 \pm 0.5^{\dagger}$
sub-leading same sign full analysis events	3	2

H→ZZ→ 4l results

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Table 6: The observed numbers of events and the final estimates for the expected backgrounds, separated into "low mass" ($100 < m_{4\ell} < 160$ GeV) and "high mass" ($m_{4\ell} \geq 160$ GeV) regions. The expected numbers of signal events are also shown for various Higgs boson mass hypotheses. For the signal and background estimates the corresponding total uncertainties are given.

	4μ		$2\mu 2e/2e2\mu$		$4e$	
	low mass	high mass	low mass	high mass	low mass	high mass
$\sqrt{s} = 8$ TeV integrated luminosity 20.7 fb^{-1}						
$ZZ^{(*)}$	12.4 ± 0.6	92.6 ± 6.7	14.7 ± 0.9	144 ± 11	5.4 ± 0.5	55.9 ± 4.5
Z, $Zb\bar{b}$, and $t\bar{t}$	1.9 ± 0.6	0.5 ± 0.2	6.1 ± 1.5	1.5 ± 0.4	2.5 ± 0.6	0.6 ± 0.2
total background	14.3 ± 0.8	93.1 ± 6.7	20.8 ± 1.8	145 ± 11	8.0 ± 0.8	56.5 ± 4.5
data	27	93	28	169	13	55
$m_H = 123$ GeV	4.4 ± 0.6		5.4 ± 0.8		2.2 ± 0.4	
$m_H = 125$ GeV	5.8 ± 0.7		7.0 ± 0.9		2.9 ± 0.4	
$m_H = 127$ GeV	6.7 ± 0.9		8.4 ± 1.2		3.4 ± 0.5	
$\sqrt{s} = 7$ TeV integrated luminosity 4.6 fb^{-1}						
$ZZ^{(*)}$	2.2 ± 0.1	16.8 ± 1.2	2.5 ± 0.2	26.6 ± 2.0	0.8 ± 0.1	9.4 ± 0.8
Z, $Zb\bar{b}$, and $t\bar{t}$	0.2 ± 0.1	0.05 ± 0.02	2.4 ± 0.5	0.6 ± 0.1	2.0 ± 0.5	0.48 ± 0.1
total background	2.4 ± 0.1	16.9 ± 1.2	4.9 ± 0.6	27.1 ± 2.0	2.8 ± 0.5	9.8 ± 0.8
data	8	23	5	23	2	13
$m_H = 123$ GeV	0.7 ± 0.1		0.8 ± 0.1		0.3 ± 0.1	
$m_H = 125$ GeV	1.0 ± 0.1		1.1 ± 0.2		0.4 ± 0.1	
$m_H = 127$ GeV	1.0 ± 0.2		1.2 ± 0.2		0.4 ± 0.1	

H→ZZ→ 4l results

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Table 7: The numbers of expected signal events for the m_H=125 GeV hypothesis and background events together with the numbers of observed events, in a window of ±5 GeV around 125 GeV for 20.7 fb^{-1} at $\sqrt{s}$ = 8 TeV and 4.6 fb^{-1} at $\sqrt{s}$ = 7 TeV as well as for their combination.

	total signal full mass range	signal	$ZZ^{(*)}$	Z + jets, $t\bar{t}$	S/B	expected	observed
			$\sqrt{s}$ = 8 TeV				
4μ	5.8 ± 0.7	5.3 ± 0.7	2.3 ± 0.1	0.50 ± 0.13	1.9	8.1 ± 0.9	11
$2\mu 2e$	3.0 ± 0.4	2.6 ± 0.4	1.2 ± 0.1	1.01 ± 0.21	1.2	4.8 ± 0.7	4
$2e2\mu$	4.0 ± 0.5	3.4 ± 0.4	1.7 ± 0.1	0.51 ± 0.16	1.5	5.6 ± 0.7	6
$4e$	2.9 ± 0.4	2.3 ± 0.3	1.0 ± 0.1	0.62 ± 0.16	1.4	3.9 ± 0.6	6
total	15.7 ± 2.0	13.7 ± 1.8	6.2 ± 0.4	2.62 ± 0.34	1.6	22.5 ± 2.9	27
			$\sqrt{s}$ = 7 TeV				
4μ	1.0 ± 0.1	0.97 ± 0.13	0.49 ± 0.02	0.05 ± 0.02	1.8	1.5 ± 0.2	2
$2\mu 2e$	0.4 ± 0.1	0.39 ± 0.05	0.21 ± 0.02	0.55 ± 0.12	0.5	1.2 ± 0.1	1
$2e2\mu$	0.7 ± 0.1	0.57 ± 0.08	0.33 ± 0.02	0.04 ± 0.01	1.5	0.9 ± 0.1	2
$4e$	0.4 ± 0.1	0.29 ± 0.04	0.15 ± 0.01	0.49 ± 0.12	0.5	0.9 ± 0.1	0
total	2.5 ± 0.4	2.2 ± 0.3	1.17 ± 0.07	1.12 ± 0.17	1.0	4.5 ± 0.5	5
			$\sqrt{s}$ = 8 TeV and $\sqrt{s}$ = 7 TeV				
4μ	6.8 ± 0.8	6.3 ± 0.8	2.8 ± 0.1	0.55 ± 0.15	1.9	9.6 ± 1.0	13
$2\mu 2e$	3.4 ± 0.5	3.0 ± 0.4	1.4 ± 0.1	1.56 ± 0.33	1.0	6.0 ± 0.8	5
$2e2\mu$	4.7 ± 0.6	4.0 ± 0.5	2.1 ± 0.1	0.55 ± 0.17	1.5	6.6 ± 0.8	8
$4e$	3.3 ± 0.5	2.6 ± 0.4	1.2 ± 0.1	1.11 ± 0.28	1.1	4.9 ± 0.8	6
total	18.2 ± 2.4	15.9 ± 2.1	7.4 ± 0.4	3.74 ± 0.93	1.4	27.1 ± 3.4	32

H→ZZ→ 4l results

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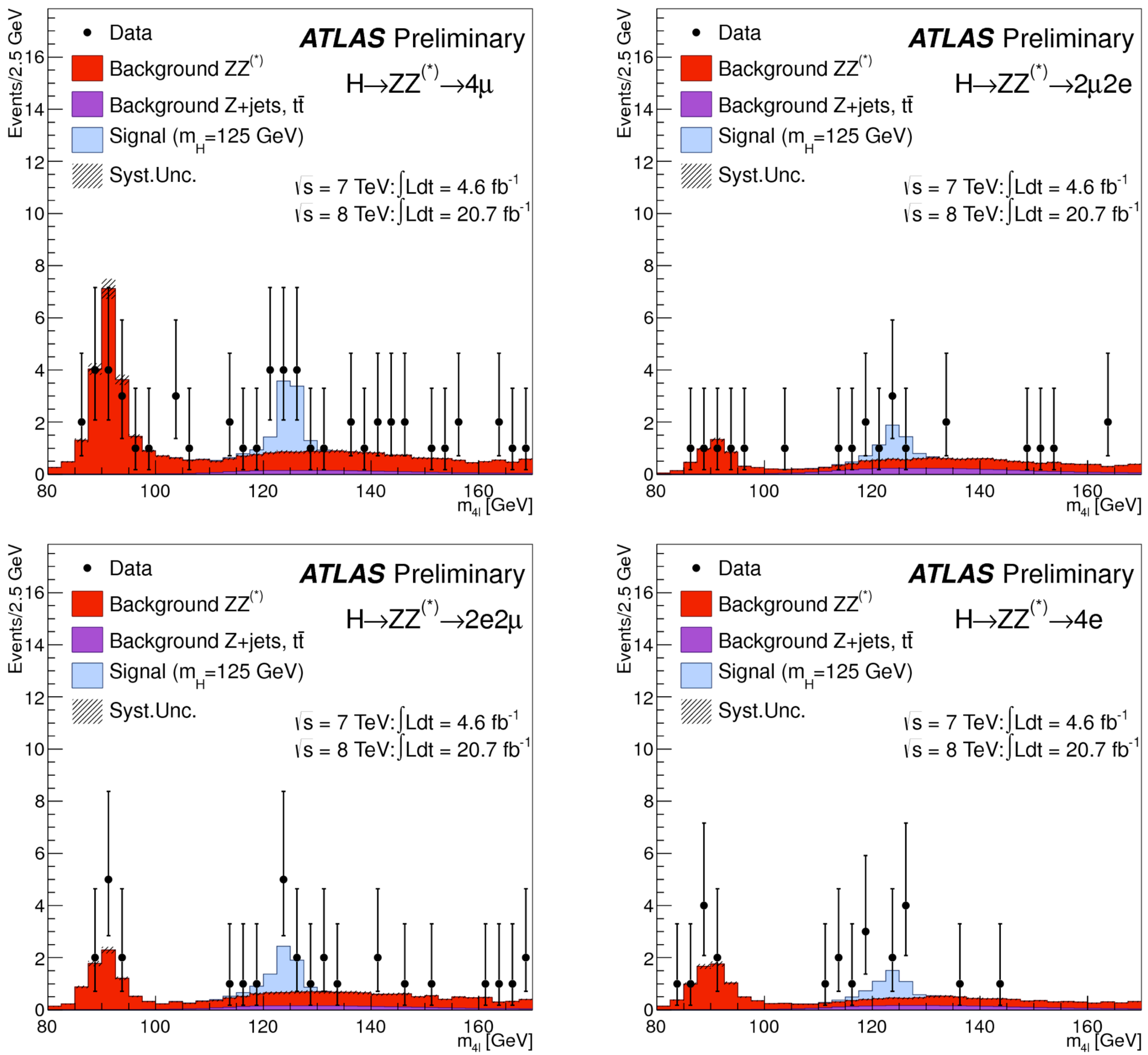

H→ZZ→4l spin

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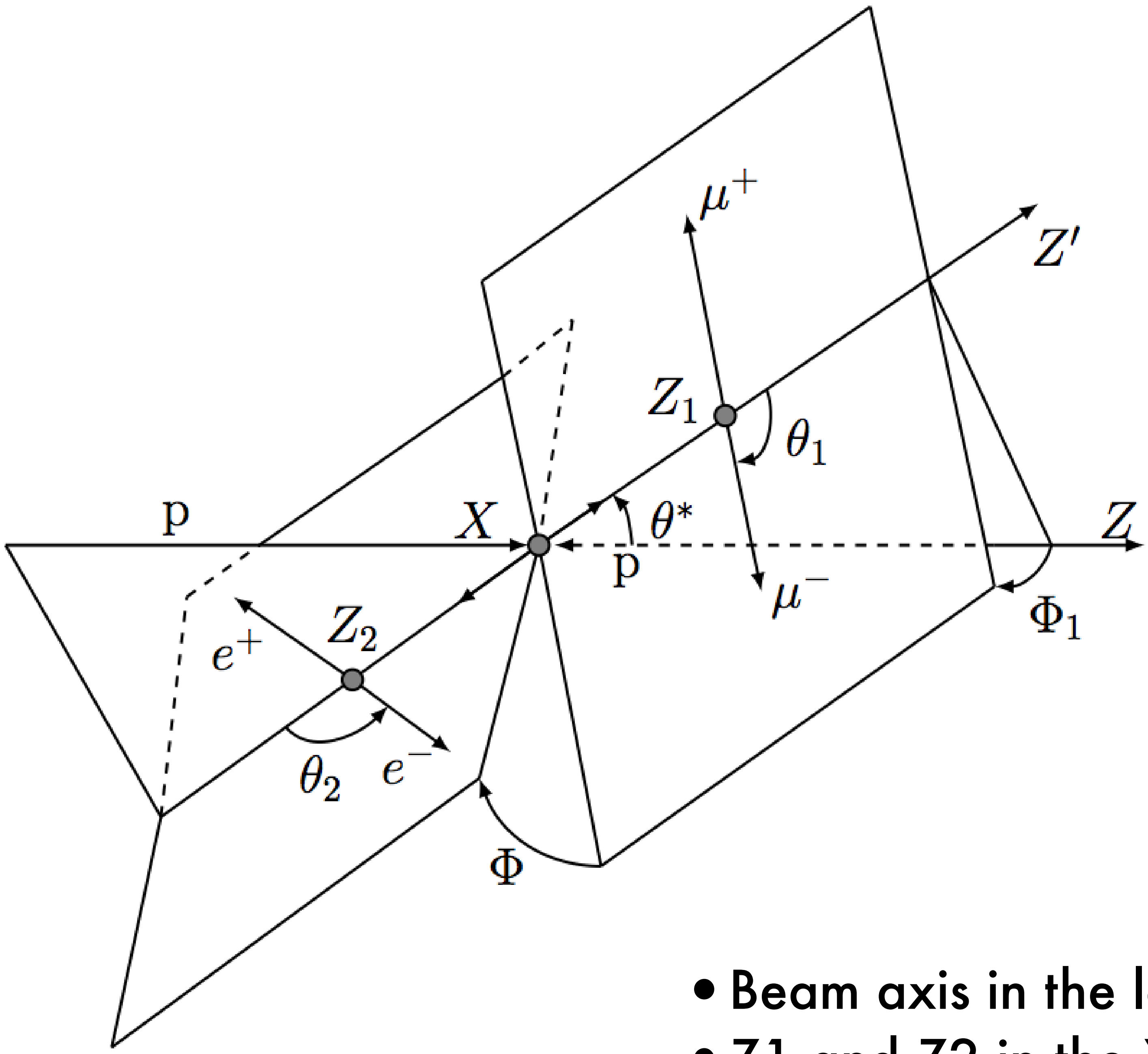

- Beam axis in the lab frame
- Z1 and Z2 in the X rest frame
- leptons in their corresponding parent rest frames

H→ZZ→4l spin

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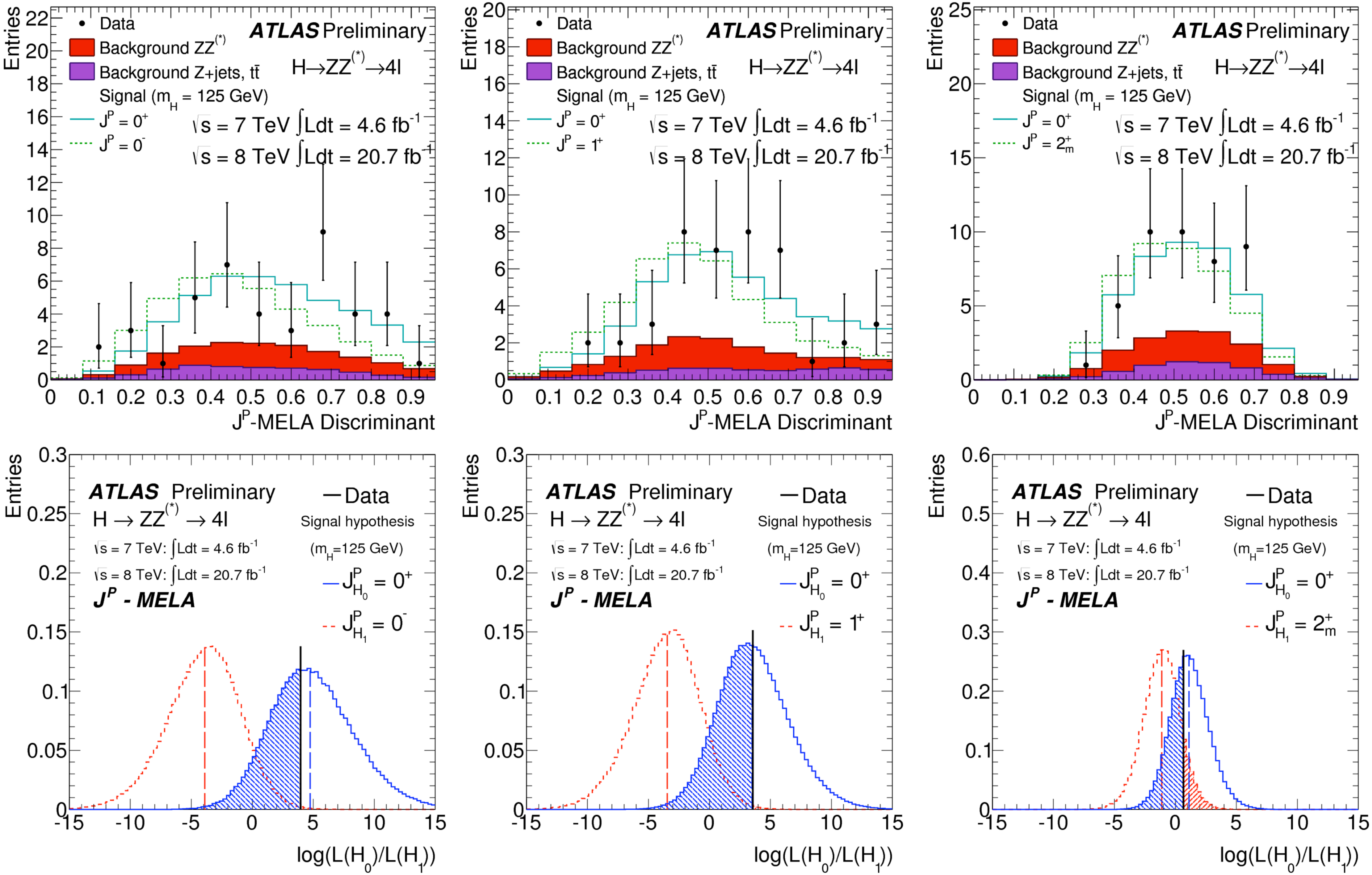

$H \to ZZ \to 4l$ spin

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Table 9: For an assumed 0^+ hypothesis H_0, the values for the expected and observed p_0-values of the different tested spin and parity hypotheses H_1 for the BDT and J^P-MELA analyses. The results are given combining the $\sqrt{s} = 8$ TeV and $\sqrt{s} = 7$ TeVdata sets. Also given is the observed p_0-value where 0^+ is the test hypothesis and the other spins states are the assumed hypothesis (observed*). These two observed p_0-values are combined to provide the CL_S confidence level for each test hypothesis. The production mode is assumed to be 100% ggF.

		BDT analysis				J^P-MELA analysis			
		tested J^P for an assumed 0^+		tested 0^+ for an assumed J^P	CL_S	tested J^P for an assumed 0^+		tested 0^+ for an assumed J^P	CL_S
		expected	observed	observed*		expected	observed	observed*	
0^-	p_0	0.0037	0.015	0.31	0.022	0.0011	0.0022	0.40	0.004
1^+	p_0	0.0016	0.001	0.55	0.002	0.0031	0.0028	0.51	0.006
1^-	p_0	0.0038	0.051	0.15	0.060	0.0010	0.027	0.11	0.031
2_m^+	p_0	0.092	0.079	0.53	0.168	0.064	0.11	0.38	0.182
2^-	p_0	0.0053	0.25	0.034	0.258	0.0032	0.11	0.08	0.116

H→ZZ→4l spin

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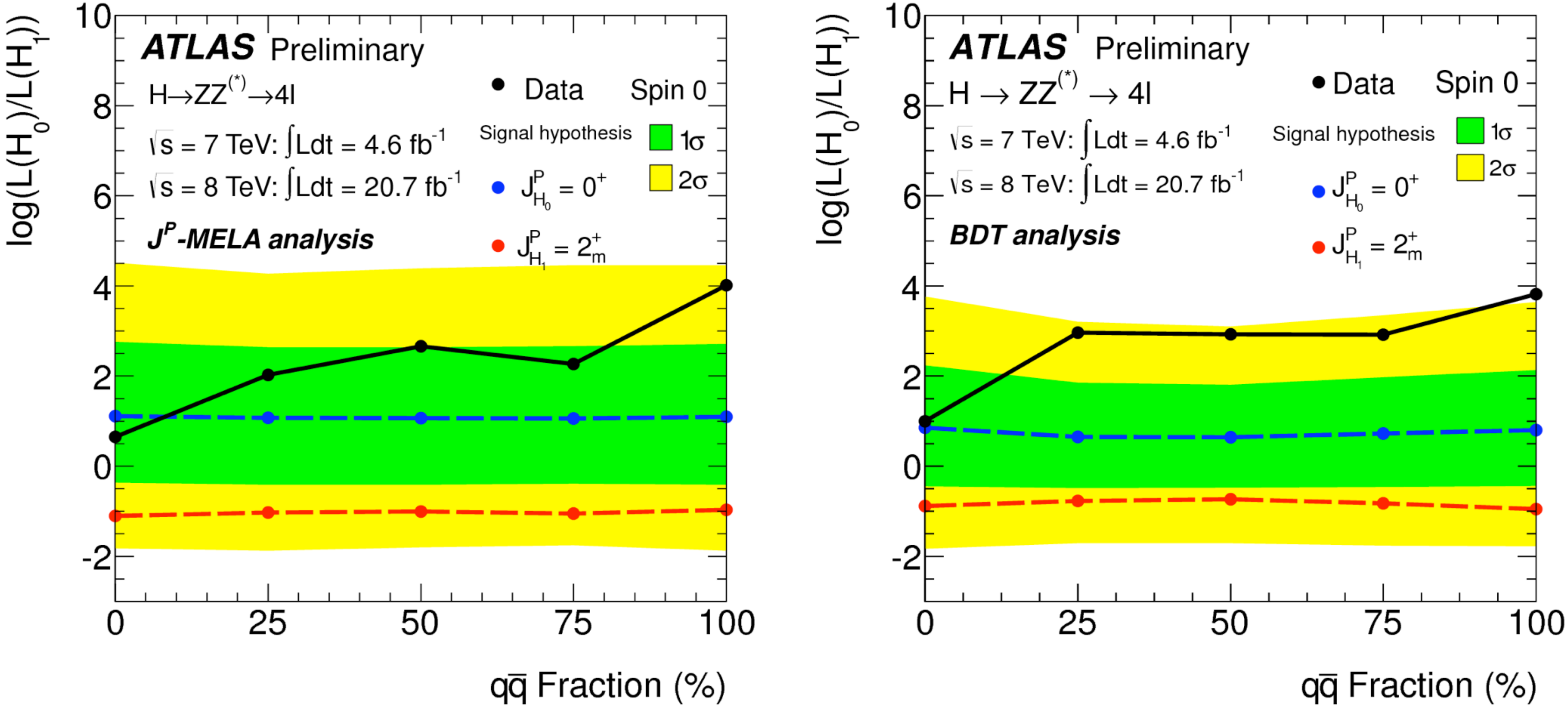

H→ZZ→4l event display

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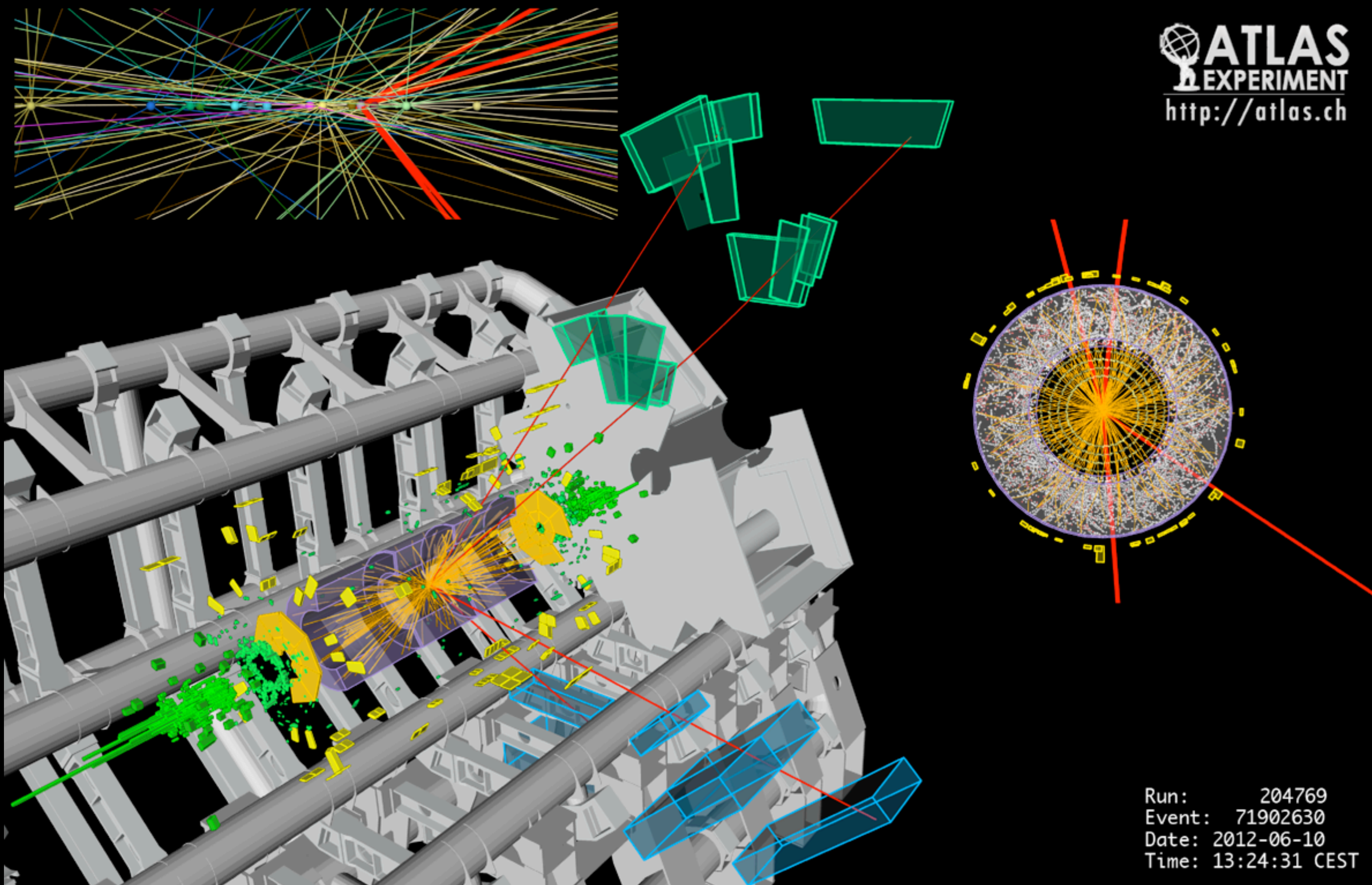


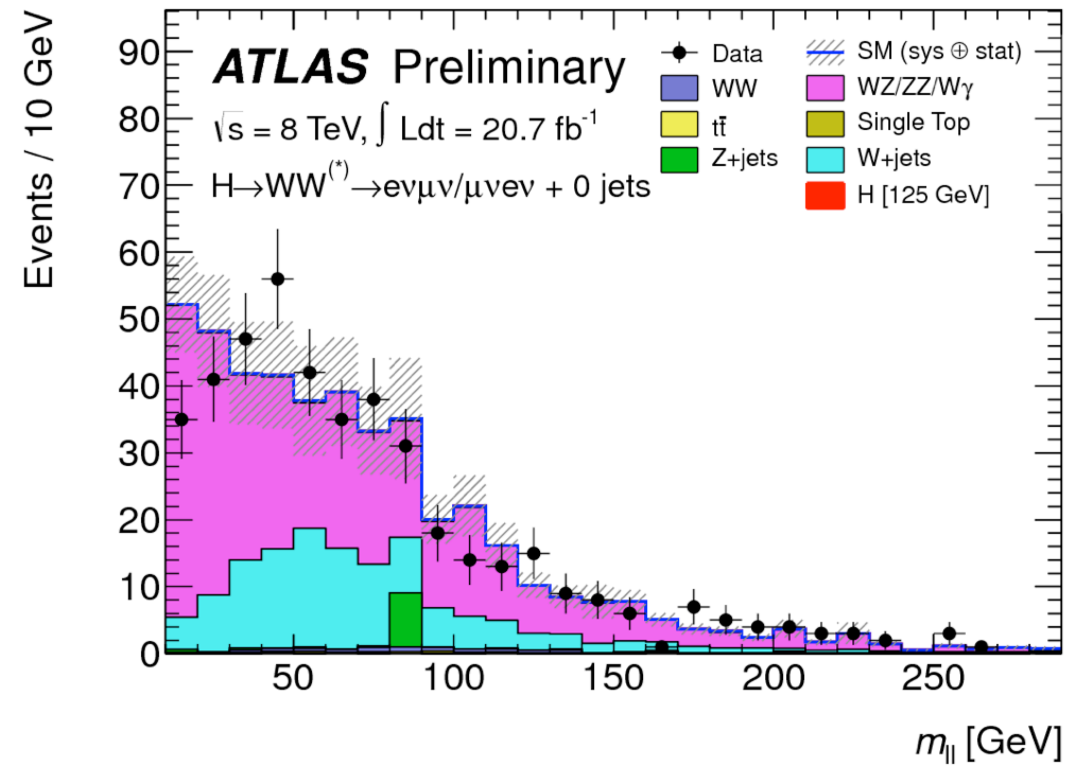
H→WW

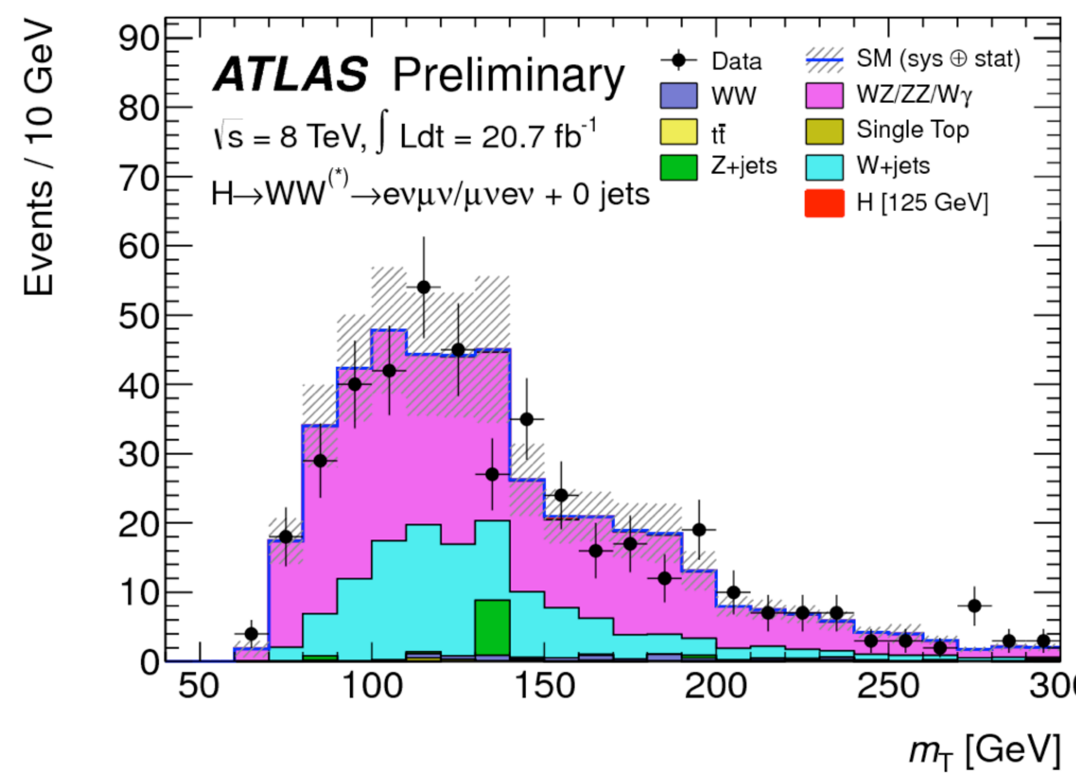
Table 2: Selection listing for 8 TeV data. The criteria specific to $e\mu + \mu e$ and $ee + \mu\mu$ are noted as such; otherwise, they apply to both. Pre-selection applies to all $N_{\rm jet}$ modes. The rapidity gap is the y range spanned by the two leading jets. The $m_{\ell\ell}$ split is at 30 GeV. The modifications for the 7 TeV analysis are given in Section 6 and are not listed here. Energies, masses, and momenta are in units of GeV.

Category	$N_{\rm jet} = 0$	$N_{\rm jet} = 1$	$N_{\rm jet} \geq 2$
Pre-selection	Two isolated leptons ($\ell = e, \mu$) with opposite charge Leptons with $p_{\rm T}^{\rm lead} > 25$ and $p_{\rm T}^{\rm sublead} > 15$ $e\mu + \mu e$: $m_{\ell\ell} > 10$ $ee + \mu\mu$: $m_{\ell\ell} > 12$, $\lvert m_{\ell\ell} - m_Z \rvert > 15$		
Missing transverse momentum and hadronic recoil	$e\mu + \mu e$: $E_{\rm T,rel}^{\rm miss} > 25$ $ee + \mu\mu$: $E_{\rm T,rel}^{\rm miss} > 45$ $ee + \mu\mu$: $p_{\rm T,rel}^{\rm miss} > 45$ $ee + \mu\mu$: $f_{\rm recoil} < 0.05$	$e\mu + \mu e$: $E_{\rm T,rel}^{\rm miss} > 25$ $ee + \mu\mu$: $E_{\rm T,rel}^{\rm miss} > 45$ $ee + \mu\mu$: $p_{\rm T,rel}^{\rm miss} > 45$ $ee + \mu\mu$: $f_{\rm recoil} < 0.2$	$e\mu + \mu e$: $E_{\rm T}^{\rm miss} > 20$ $ee + \mu\mu$: $E_{\rm T}^{\rm miss} > 45$ $ee + \mu\mu$: $E_{\rm T,STVF}^{\rm miss} > 35$ -
General selection	- $\lvert \Delta\phi_{\ell\ell,MET} \rvert > \pi/2$ $p_{\rm T}^{\ell\ell} > 30$	$N_{b\text{-jet}} = 0$ - $e\mu + \mu e$: $Z/\gamma^* \to \tau\tau$ veto	$N_{b\text{-jet}} = 0$ $p_{\rm T}^{\rm tot} < 45$ $e\mu + \mu e$: $Z/\gamma^* \to \tau\tau$ veto
VBF topology	- - - -	- - - -	$m_{jj} > 500$ $\lvert \Delta y_{jj} \rvert > 2.8$ No jets ($p_{\rm T} > 20$) in rapidity gap Require both ℓ in rapidity gap
$H \to WW^{(*)} \to \ell\nu\ell\nu$ topology	$m_{\ell\ell} < 50$ $\lvert \Delta\phi_{\ell\ell} \rvert < 1.8$ $e\mu + \mu e$: split $m_{\ell\ell}$ Fit $m_{\rm T}$	$m_{\ell\ell} < 50$ $\lvert \Delta\phi_{\ell\ell} \rvert < 1.8$ $e\mu + \mu e$: split $m_{\ell\ell}$ Fit $m_{\rm T}$	$m_{\ell\ell} < 60$ $\lvert \Delta\phi_{\ell\ell} \rvert < 1.8$ - Fit $m_{\rm T}$

$$m_T = \sqrt{(E_T^{ll} + E_T^{miss})^2 - |p_T^{ll} + E_T^{miss}|^2}$$

same sign validation region





H→WW

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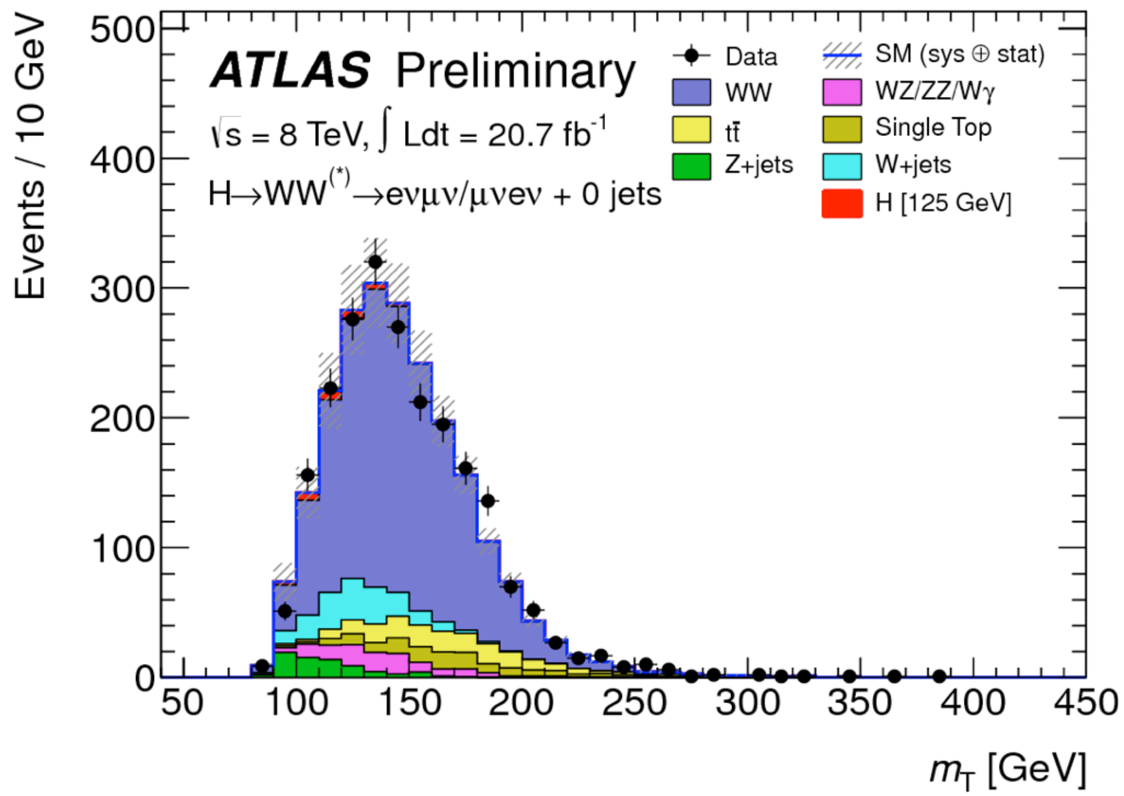
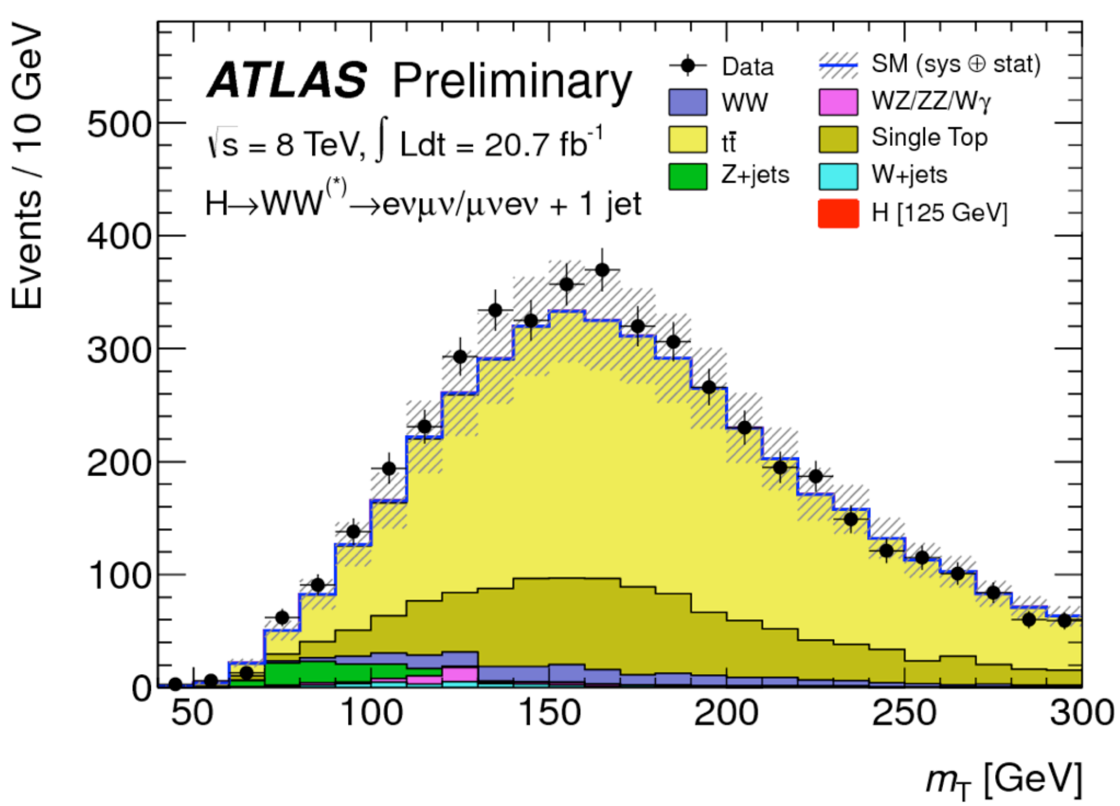
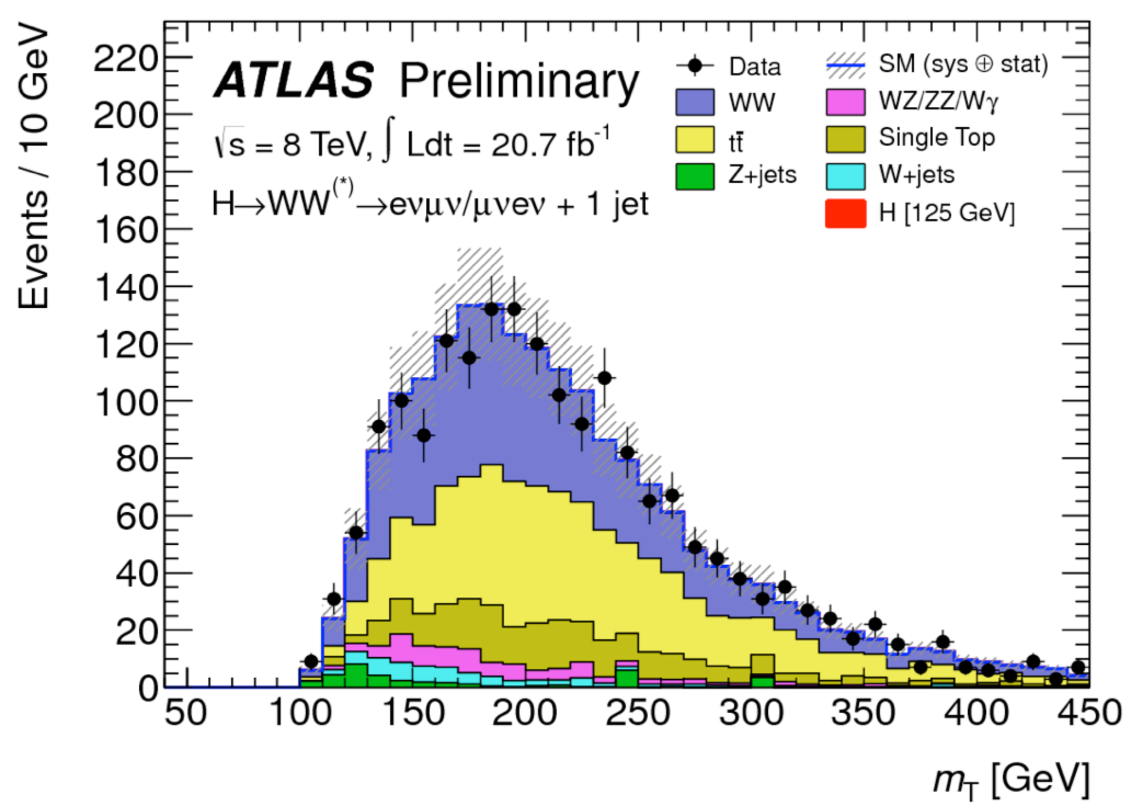
- W+jets fully estimated from data (anti-isolated lepton, fake factor from dijet sample, checked in SS region)
- top normalisation from data (b-jet veto reverted, m_{ll} and $\Delta\phi_{ll}$ cuts removed)
- WW control region: $\Delta\phi_{ll}$ removed and large m_{ll}







H→WW

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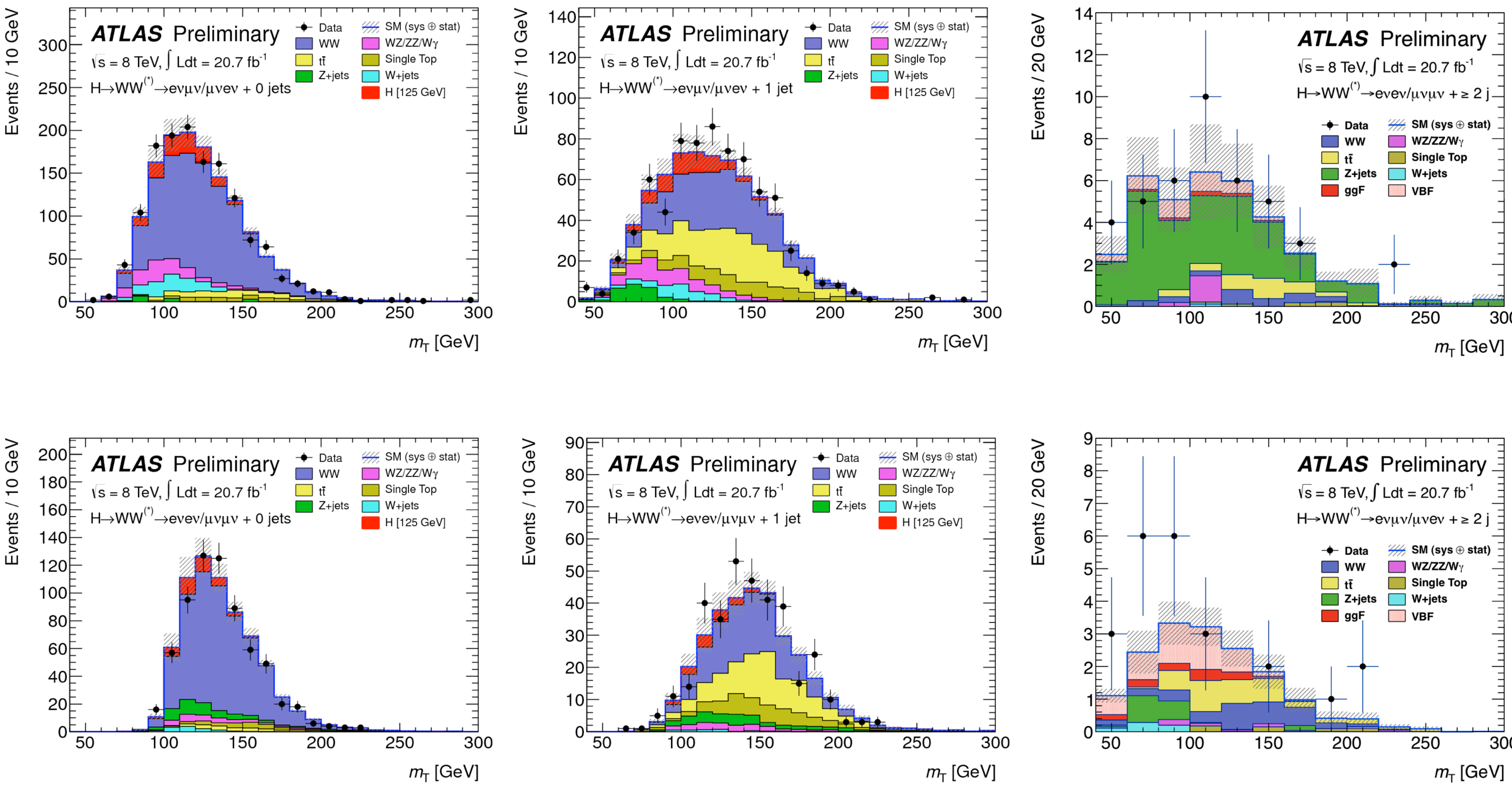
Signal region



$H \rightarrow WW$ systematics

Table 3: Summary of the systematic uncertainties on the signal yield and invariant mass distribution for $m_H = 125$ GeV, at $\sqrt{s} = 8(7)$ TeV.

Systematic Uncertainty	$H \rightarrow Z(ee)\gamma(\%)$	$H \rightarrow Z(\mu\mu)\gamma(\%)$
Signal Yield		
Luminosity	3.6 (1.8)	3.6 (1.8)
Trigger efficiency	0.4 (0.2)	0.8 (0.7)
Acceptance of kinematic selection	4.0 (4.0)	4.0 (4.0)
γ identification efficiency	2.9 (2.9)	2.9 (2.9)
electron reconstruction and identification efficiency	2.7 (3.0)	
μ reconstruction and identification efficiency		0.6 (0.7)
e/γ energy scale	1.4 (0.3)	0.3 (0.2)
e/γ isolation	0.4 (0.3)	0.4 (0.2)
e/γ energy resolution	0.2 (0.2)	0.0 (0.0)
μ momentum scale		0.1 (0.1)
μ momentum resolution		0.0 (0.1)
Signal Δm resolution		
e/γ energy resolution	5.0 (5.0)	2.4 (2.4)
μ momentum resolution		0.0 (1.5)
Signal Δm peak position		
e/γ energy scale	0.2 (0.2) GeV	0.2 (0.2) GeV
μ momentum scale		negligible

H→WW results

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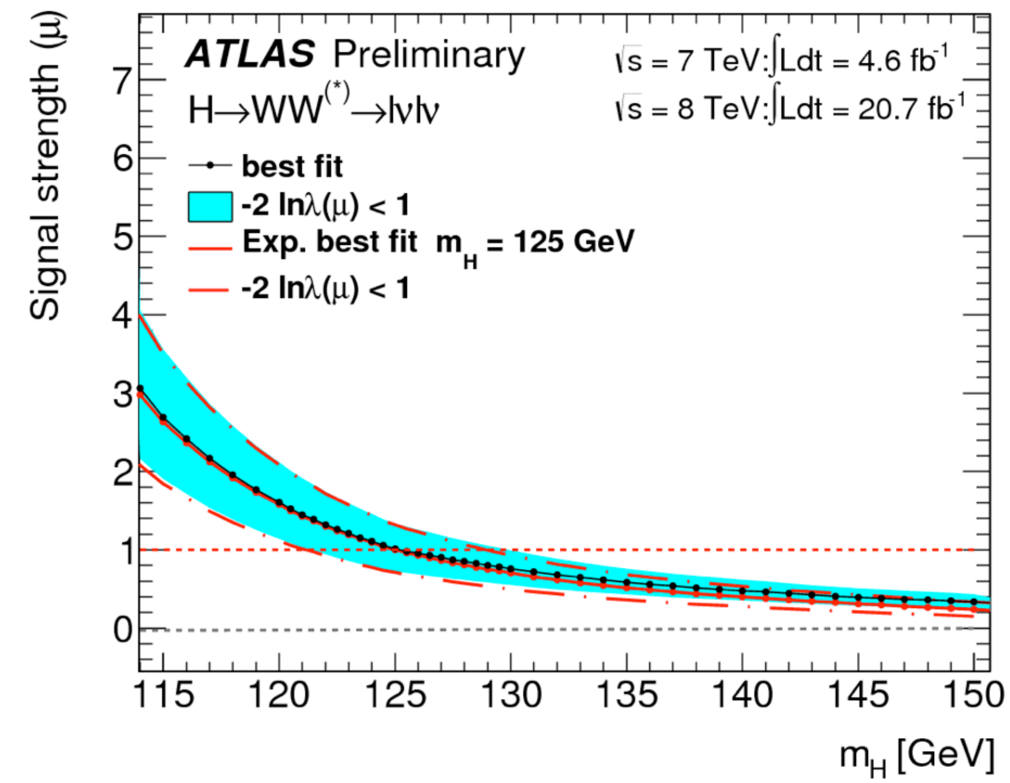

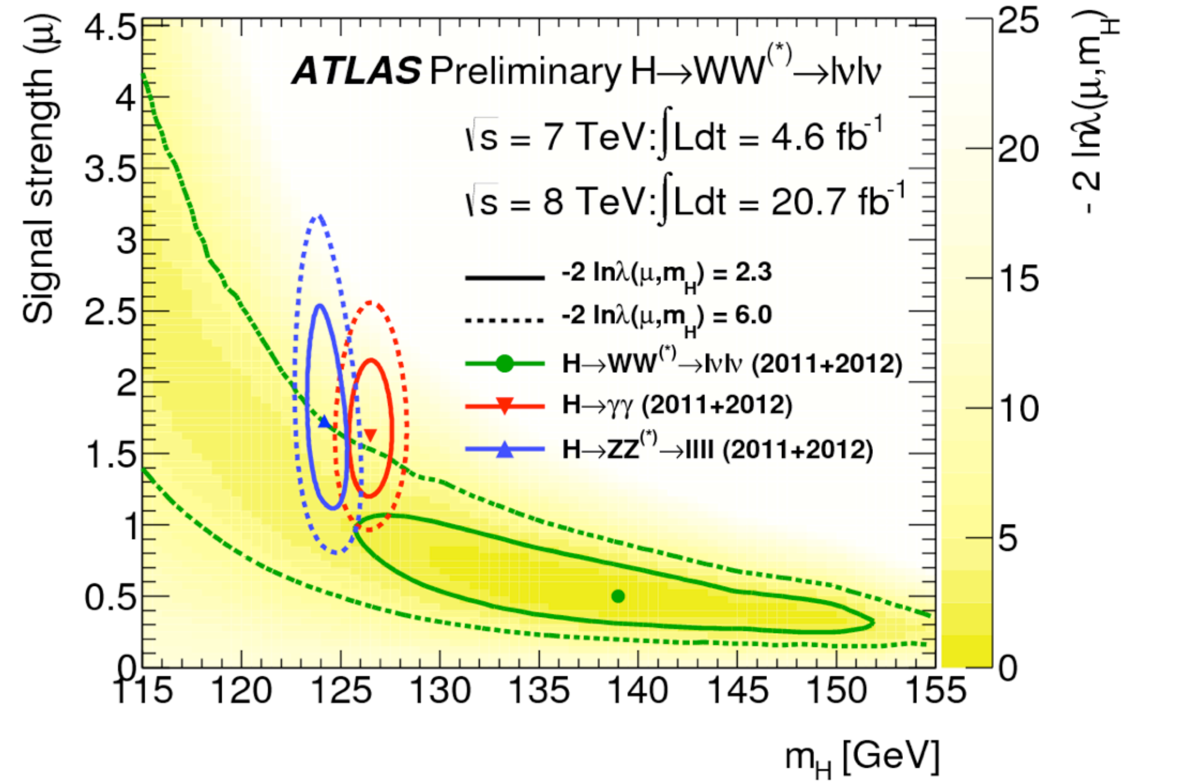

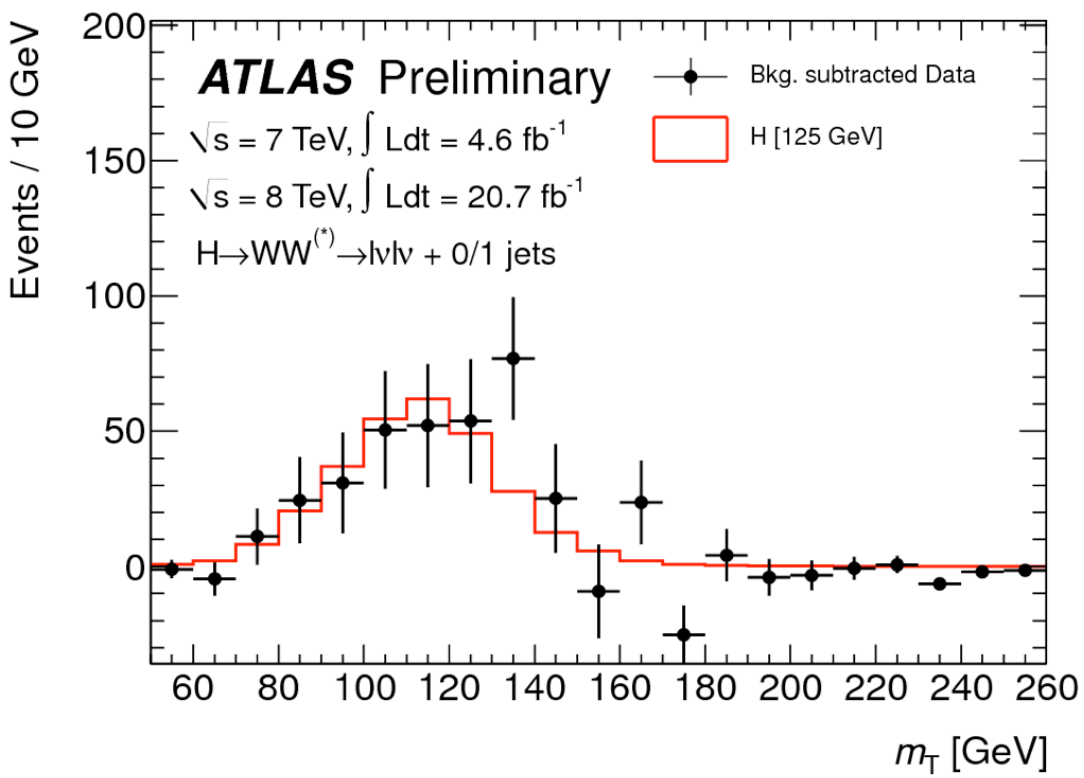

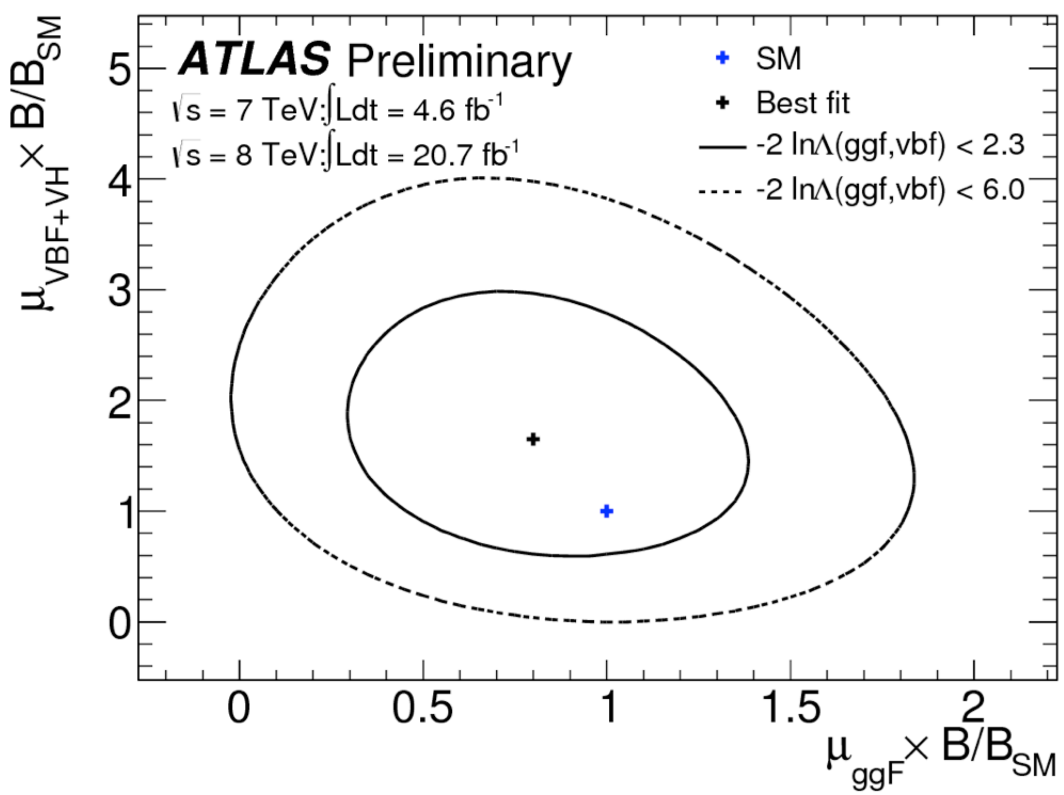

H→Zγ signal

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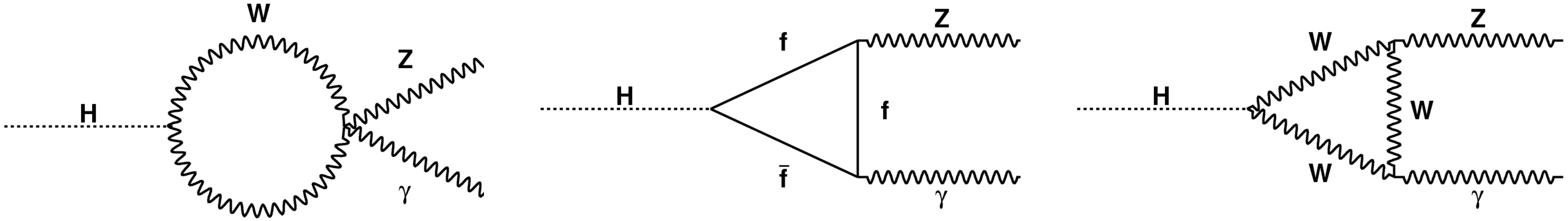

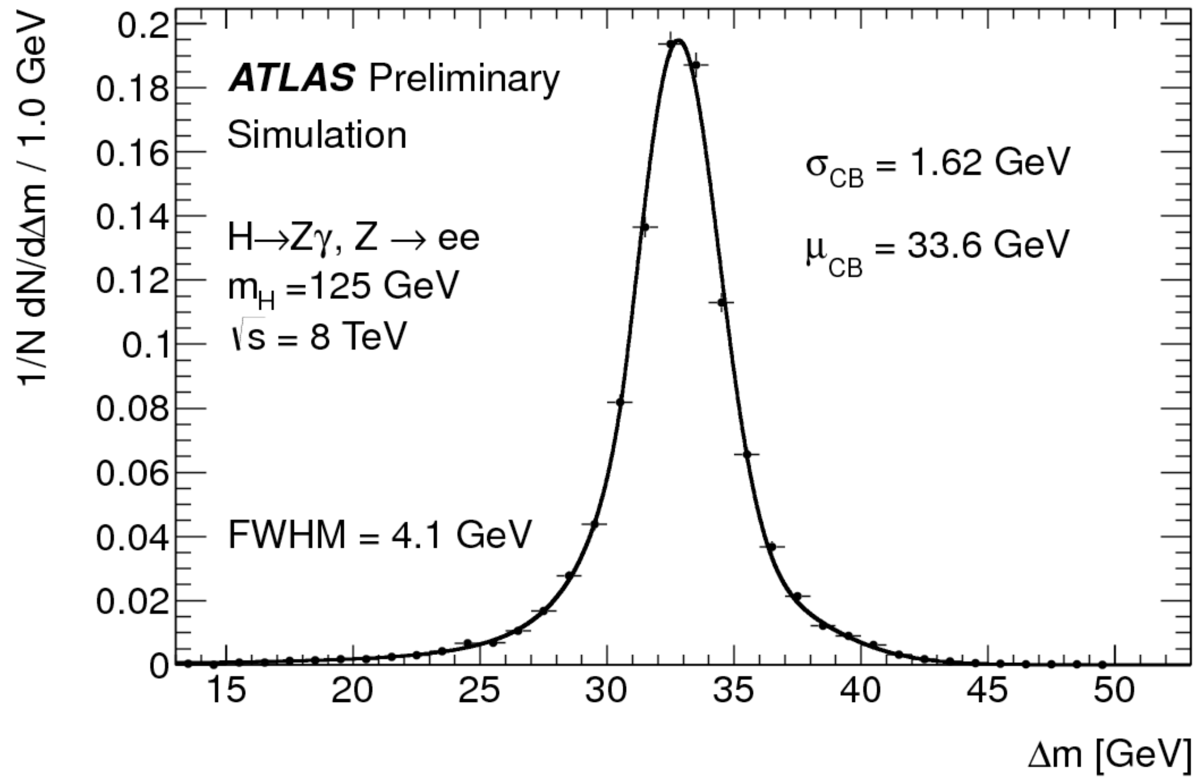

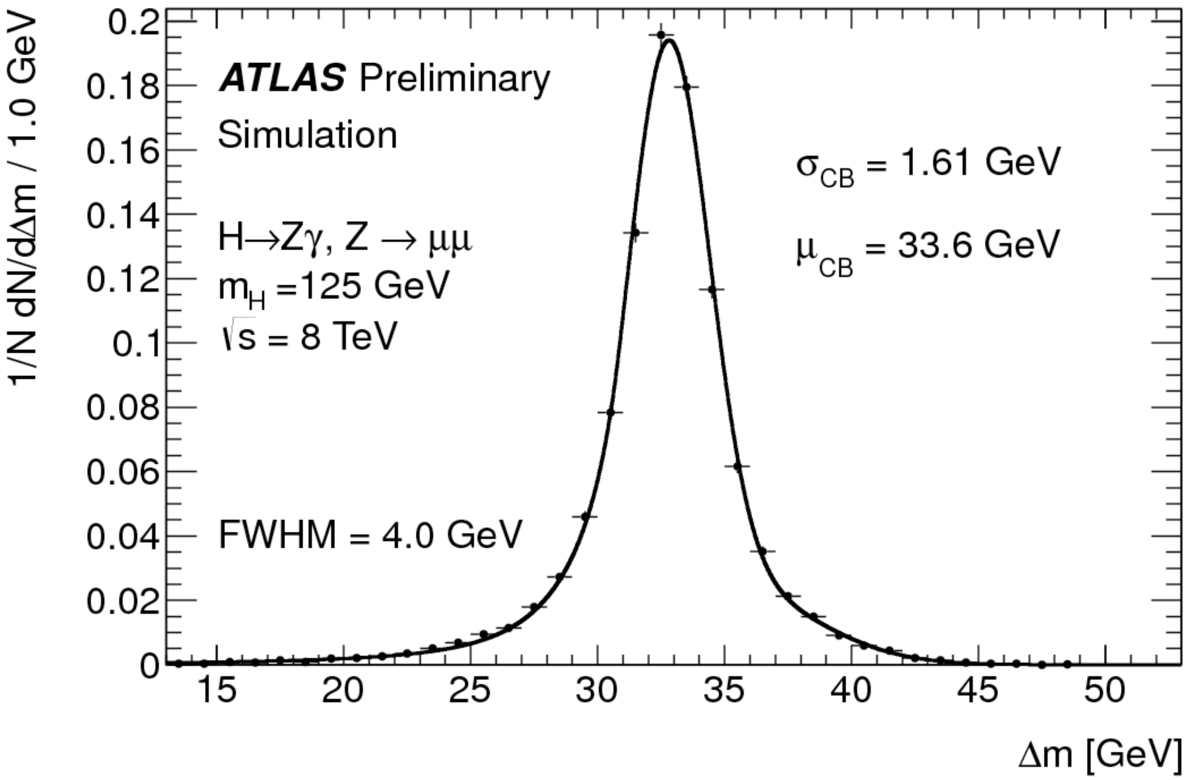

Crystal-ball + gaussian

$H \rightarrow Z\gamma$ background

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- Impact parameter requirements for leptons
- Isolation for leptons and photons
- $m_{ll\gamma} > m_Z$ - 10 GeV (suppress FSR $Z \rightarrow ll\gamma$ and $H \rightarrow \gamma\gamma$ internal conversion)
- $\Delta R_{l\gamma}$ cut to suppress FSR
- Photon η and E_T recomputed from primary vertex and impact point in the calorimeter
- Lepton 4-momenta recomputed with Z-mass constrained kinematic fit
- Background composition studied by means of 2D sideband method

H→ Zγ background

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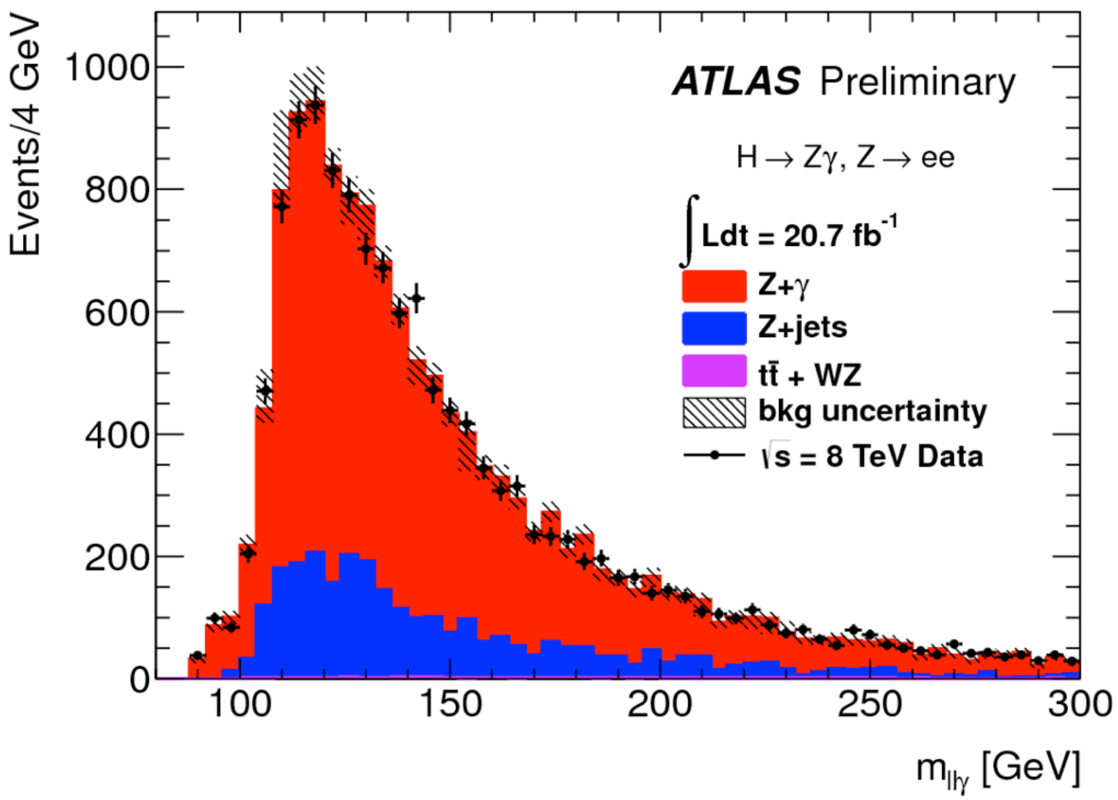
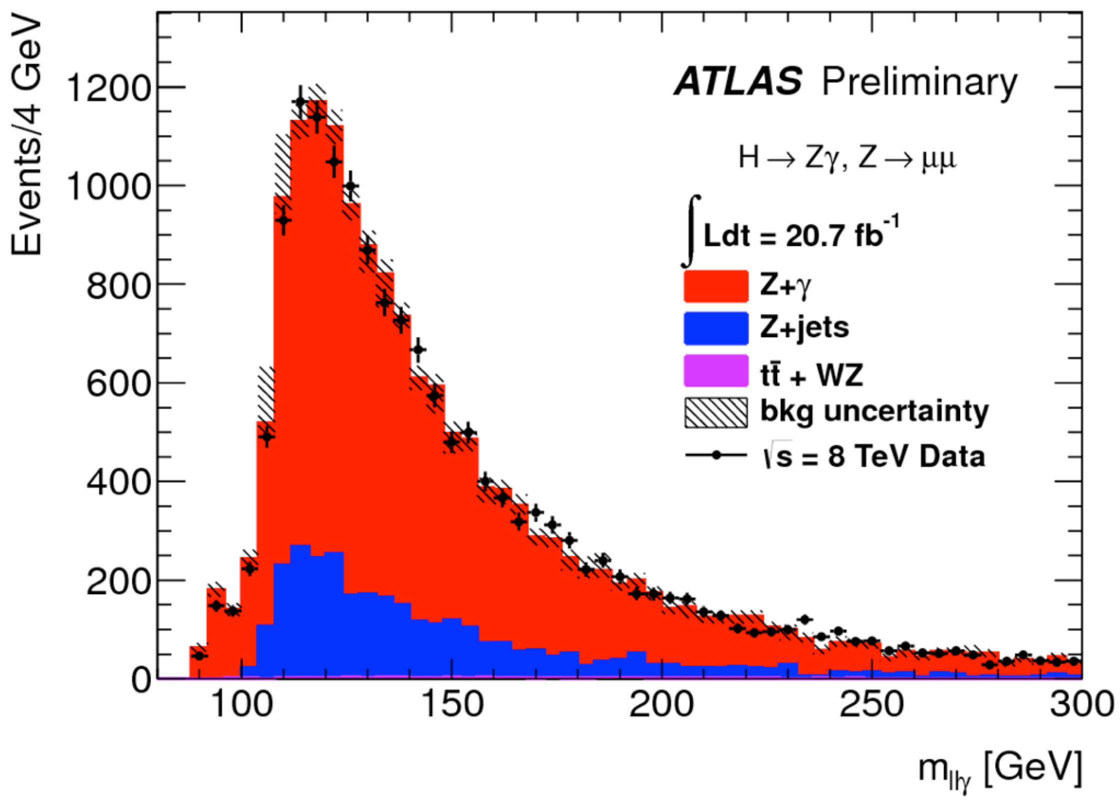
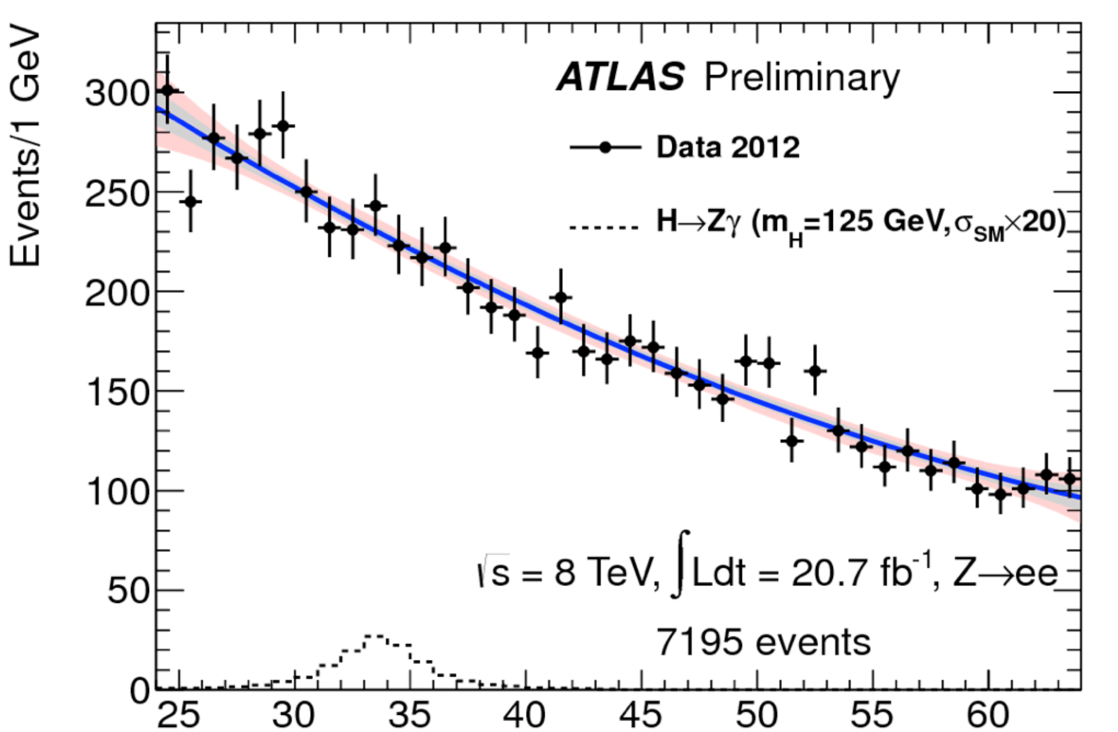
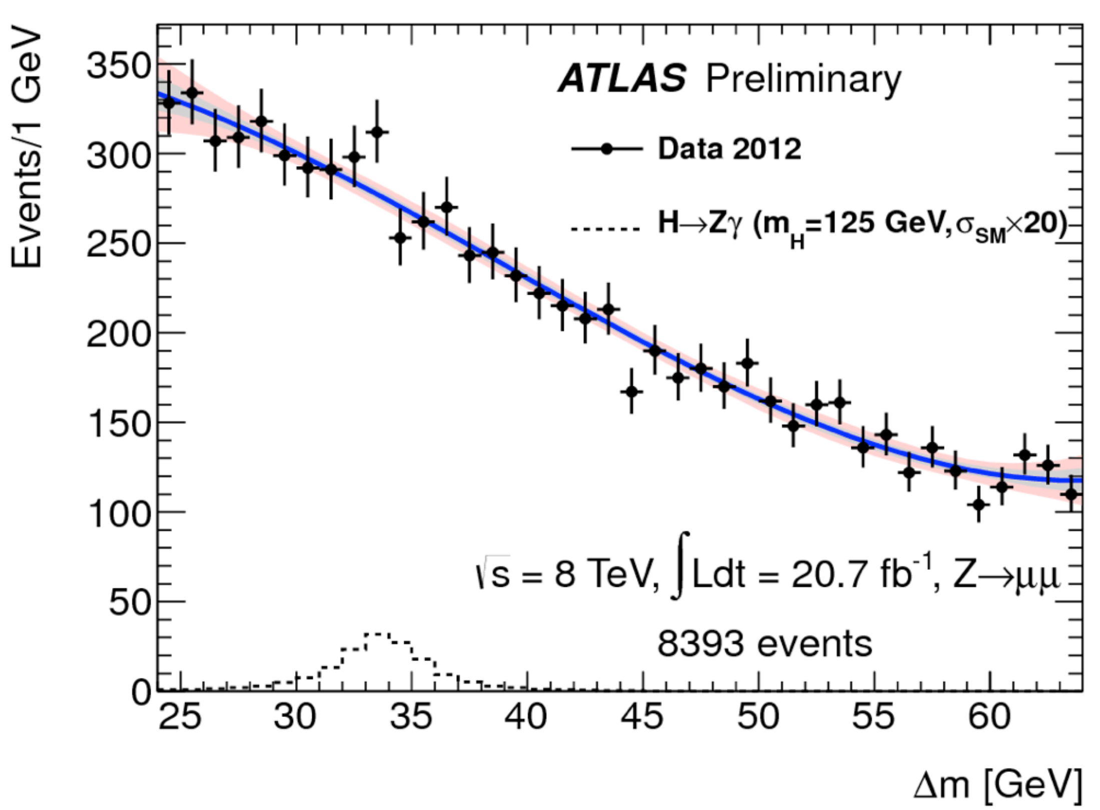








3[rd] order Chebychev polinomial

$H \rightarrow Z\gamma$ systematics

ATLAS-CONF-2013-009

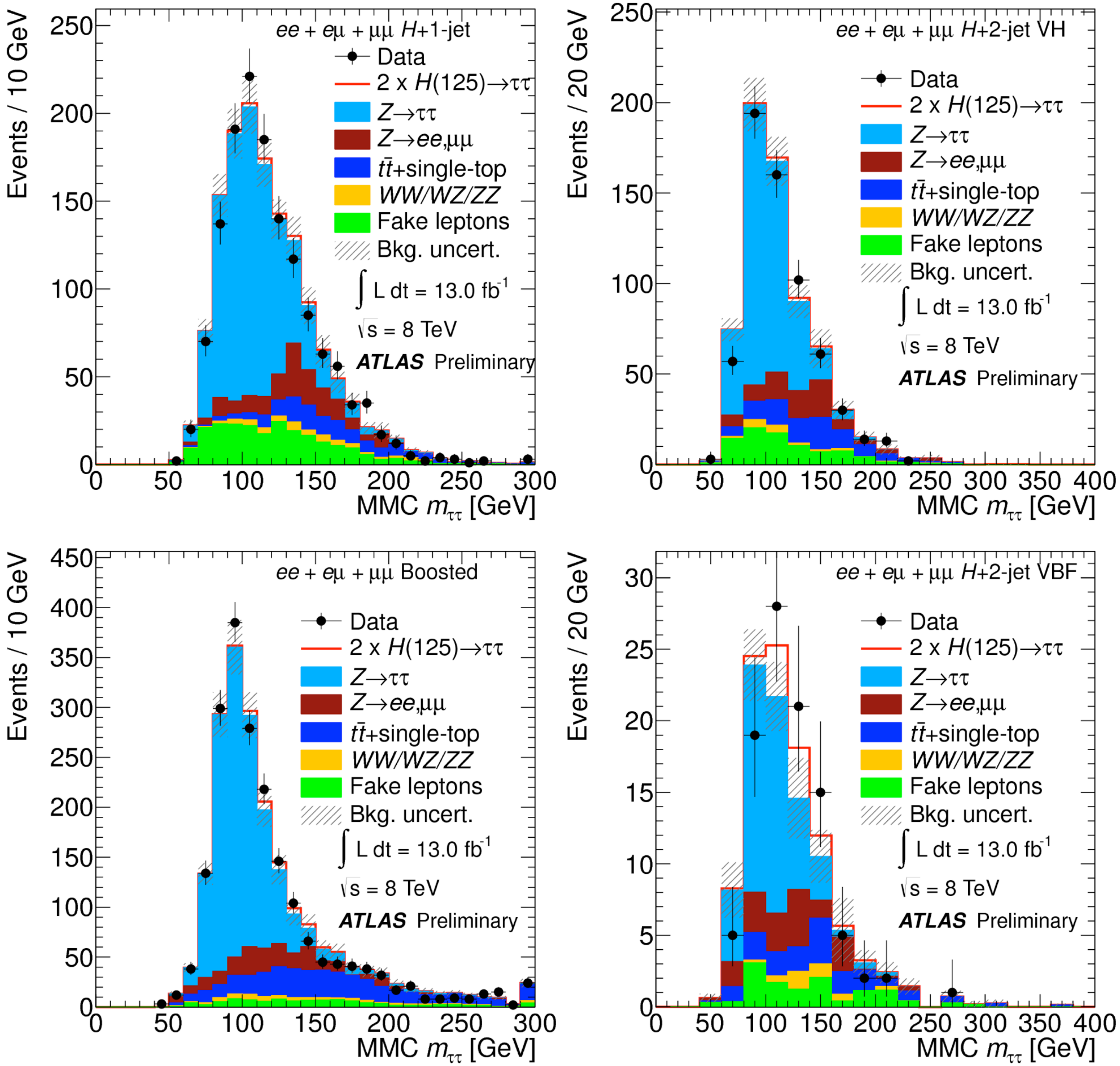
Table 2: Theoretical systematic uncertainties for the SM Higgs boson production cross section and branching fraction of the $H \rightarrow Z\gamma$ decay at $\sqrt{s}$ = 7 and 8 TeV, for a Higgs boson mass of 125 GeV.

$\sqrt{s}$	Systematic uncertainty (%)										
	$\sigma(gg \rightarrow H)$		σ(VBF)		$\sigma(WH)$		$\sigma(ZH)$		$\sigma(t\bar{t}H)$		$B(H \rightarrow Z\gamma)$
	scale	PDF	scale	PDF	scale	PDF	scale	PDF	scale	PDF	
7 TeV	$^{+7.1}_{-7.8}$	$^{+7.6}_{-7.1}$	± 0.3	$^{+2.5}_{-2.1}$	$^{+0.2}_{-0.8}$	± 3.5	$^{+1.4}_{-1.6}$	± 3.5	$^{+3.3}_{-9.3}$	± 8.5	$^{+9.0}_{-8.8}$
8 TeV	$^{+7.3}_{-7.9}$	$^{+7.5}_{-6.9}$	± 0.2	$^{+2.6}_{-2.8}$	$^{+0.1}_{-0.6}$	± 3.4	$^{+1.5}_{-1.4}$	± 3.5	$^{+3.9}_{-9.3}$	± 7.8	$^{+9.0}_{-8.8}$

Table 3: Summary of the systematic uncertainties on the signal yield and invariant mass distribution for m_H = 125 GeV, at $\sqrt{s}$ = 8(7) TeV.

Systematic Uncertainty	$H \rightarrow Z(ee)\gamma(\%)$	$H \rightarrow Z(\mu\mu)\gamma(\%)$
Signal Yield		
Luminosity	3.6 (1.8)	3.6 (1.8)
Trigger efficiency	0.4 (0.2)	0.8 (0.7)
Acceptance of kinematic selection	4.0 (4.0)	4.0 (4.0)
γ identification efficiency	2.9 (2.9)	2.9 (2.9)
electron reconstruction and identification efficiency	2.7 (3.0)	
μ reconstruction and identification efficiency		0.6 (0.7)
e/γ energy scale	1.4 (0.3)	0.3 (0.2)
e/γ isolation	0.4 (0.3)	0.4 (0.2)
e/γ energy resolution	0.2 (0.2)	0.0 (0.0)
μ momentum scale		0.1 (0.1)
μ momentum resolution		0.0 (0.1)
Signal Δm resolution		
e/γ energy resolution	5.0 (5.0)	2.4 (2.4)
μ momentum resolution		0.0 (1.5)
Signal Δm peak position		
e/γ energy scale	0.2 (0.2) GeV	0.2 (0.2) GeV
μ momentum scale		negligible

H→ττ→leplep



ee + eμ + μμ H+1-jet
ee + eμ + μμ H+2-jet VH
ee + eμ + μμ Boosted
ee + eμ + μμ H+2-jet VBF
Data
2 x H(125)→ττ
Z→ττ
Z→ee,μμ
$t\bar{t}$+single-top
WW/WZ/ZZ
Fake leptons
Bkg. uncert.
∫ L dt = 13.0 fb^{-1}
√s = 8 TeV
ATLAS Preliminary
Events / 10 GeV
Events / 20 GeV
MMC $m_{\tau\tau}$ [GeV]

H→ττ→leplep

Table 2: The categorization of the $H \to \tau_{lep}\tau_{lep}$ analysis. The JVF cut is $|JVF| > 0.75$ for 7 TeV data, the lepton centrality is not applied for 7 TeV analysis, and the 0-jet category is not used for 8 TeV data analysis.

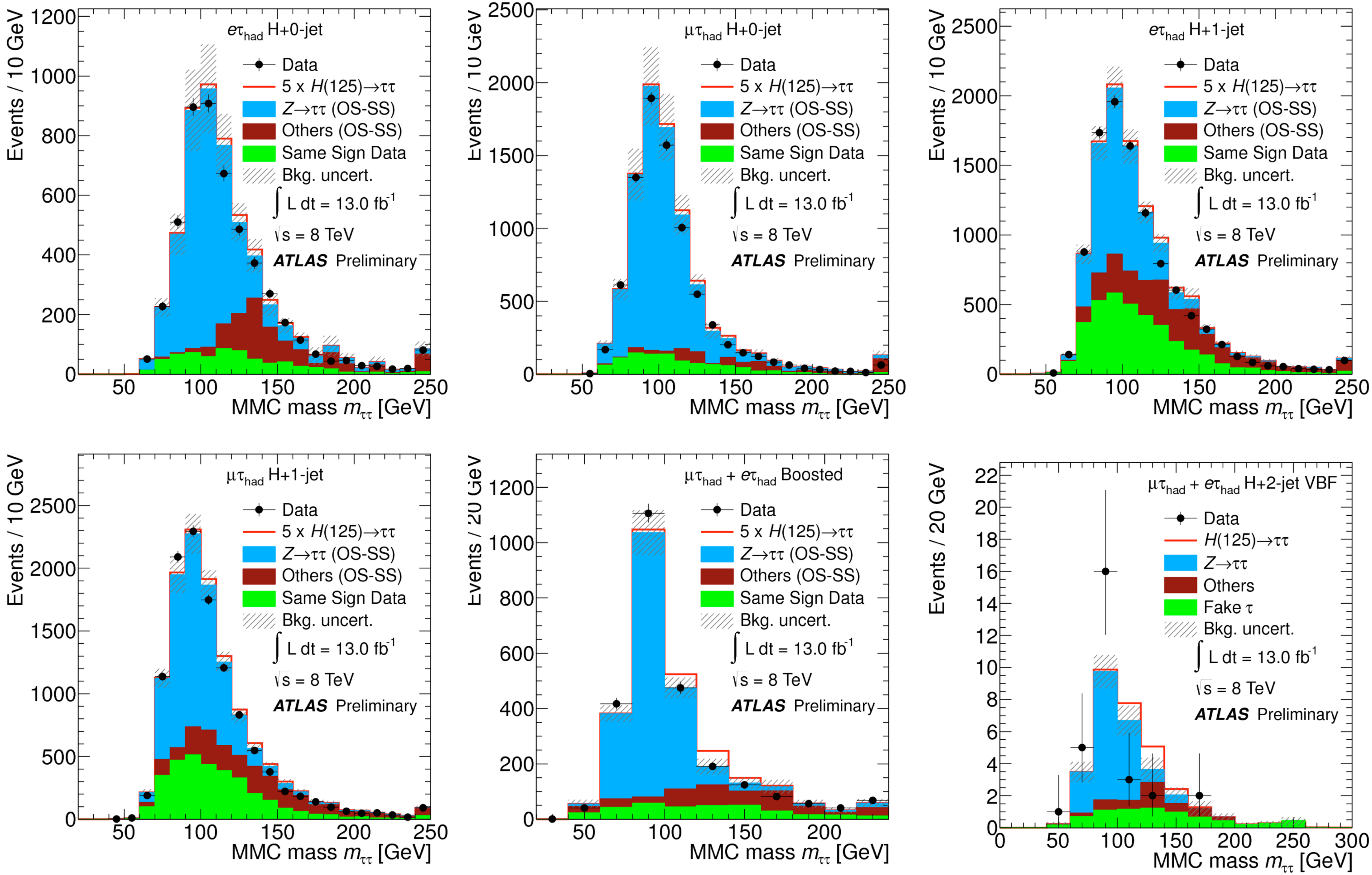
2-jet VBF	Boosted	2-jet VH	1-jet
Pre-selection: exactly two leptons with opposite charges			
30 GeV $< m_{\ell\ell} <$ 75 GeV (30 GeV $< m_{\ell\ell} <$ 100 GeV) for same-flavor (different-flavor) leptons, and $p_{T,\ell 1} + p_{T,\ell 2} >$ 35 GeV			
At least one jet with $p_T >$ 40 GeV ($|JVF_{jet}| > 0.5$ if $|\eta_{jet}| < 2.4$)			
$E_T^{miss} >$ 40 GeV ($E_T^{miss} >$ 20 GeV) for same-flavor (different-flavor) leptons			
$H_T^{miss} >$ 40 GeV for same-flavor leptons			
$0.1 < x_{1,2} < 1$			
$0.5 < \Delta\phi_{\ell\ell} < 2.5$			
$p_{T,j2} >$ 25 GeV (JVF)	excluding 2-jet VBF	$p_{T,j2} >$ 25 GeV (JVF)	excluding 2-jet VBF, Boosted and 2-jet VH
$\Delta\eta_{jj} > 3.0$	$p_{T,\tau\tau} >$ 100 GeV	excluding Boosted	$m_{\tau\tau j} >$ 225 GeV
$m_{jj} >$ 400 GeV	b-tagged jet veto	$\Delta\eta_{jj} < 2.0$	b-tagged jet veto
b-tagged jet veto	–	30 GeV $< m_{jj} <$ 160 GeV	–
Lepton centrality and CJV		b-tagged jet veto	
0-jet (7 TeV only)			
Pre-selection: exactly two leptons with opposite charges			
Different-flavor leptons with 30 GeV $< m_{\ell\ell} <$ 100 GeV and $p_{T,\ell 1} + p_{T,\ell 2} >$ 35 GeV			
$\Delta\phi_{\ell\ell} > 2.5$			
b-tagged jet veto			

H→ττ→lephad

Table 3: Event requirements applied in the different categories of the $H \to \tau_{lep}\tau_{had}$ analysis. Requirements marked with a triangle (▹) are categorization requirements, meaning that if an event fails that requirement it is still considered for the remaining categories. Requirements marked with a bullet (•) are only applied to events passing all categorization requirements in a category; events failing such requirements are discarded.

7 TeV		8 TeV	
VBF Category	Boosted Category	VBF Category	Boosted Category
▹ $p_T{}^{\tau_{had\text{-}vis}}$ >30 GeV	–	▹ $p_T{}^{\tau_{had\text{-}vis}}$ >30 GeV	▹ $p_T{}^{\tau_{had\text{-}vis}}$ >30 GeV
▹ E_T^{miss} >20 GeV	▹ E_T^{miss} >20 GeV	▹ E_T^{miss} >20 GeV	▹ E_T^{miss} >20 GeV
▹ $\geq$ 2 jets	▹ $p_T^H > 100$ GeV	▹ $\geq$ 2 jets	▹ $p_T^H > 100$ GeV
▹ $p_T{}^{j1}, p_T{}^{j2} > 40$ GeV	▹ $0 < x_1 < 1$	▹ $p_T{}^{j1} > 40$, $p_T{}^{j2}$ >30 GeV	▹ $0 < x_1 < 1$
▹ $\Delta\eta_{jj} > 3.0$	▹ $0.2 < x_2 < 1.2$	▹ $\Delta\eta_{jj} > 3.0$	▹ $0.2 < x_2 < 1.2$
▹ $m_{jj} > 500$ GeV	▹ Fails VBF	▹ $m_{jj} > 500$ GeV	▹ Fails VBF
▹ centrality req.	–	▹ centrality req.	–
▹ $\eta_{j1} \times \eta_{j2} < 0$	–	▹ $\eta_{j1} \times \eta_{j2} < 0$	–
▹ $p_T{}^{Total} < 40$ GeV	–	▹ $p_T{}^{Total} < 30$ GeV	–
–	–	▹ $p_T{}^{\ell}$ >26 GeV	–
• m_T <50 GeV	• m_T <50 GeV	• m_T <50 GeV	• m_T <50 GeV
• $\Delta(\Delta R) < 0.8$	• $\Delta(\Delta R) < 0.8$	• $\Delta(\Delta R) < 0.8$	• $\Delta(\Delta R) < 0.8$
• $\sum \Delta\phi < 3.5$	• $\sum \Delta\phi < 1.6$	• $\sum \Delta\phi < 2.8$	–
–	–	• b-tagged jet veto	• b-tagged jet veto
1 Jet Category	0 Jet Category	1 Jet Category	0 Jet Category
▹ $\geq$ 1 jet, p_T >25 GeV	▹ 0 jets p_T >25 GeV	▹ $\geq$ 1 jet, p_T >30 GeV	▹ 0 jets p_T >30 GeV
▹ E_T^{miss} >20 GeV	▹ E_T^{miss} >20 GeV	▹ E_T^{miss} >20 GeV	▹ E_T^{miss} >20 GeV
▹ Fails VBF, Boosted	▹ Fails Boosted	▹ Fails VBF, Boosted	▹ Fails Boosted
• m_T <50 GeV	• m_T <30 GeV	• m_T <50 GeV	• m_T <30 GeV
• $\Delta(\Delta R) < 0.6$	• $\Delta(\Delta R) < 0.5$	• $\Delta(\Delta R) < 0.6$	• $\Delta(\Delta R) < 0.5$
• $\sum \Delta\phi < 3.5$	• $\sum \Delta\phi < 3.5$	• $\sum \Delta\phi < 3.5$	• $\sum \Delta\phi < 3.5$
–	• $p_T^{\ell} - p_T^{\tau} < 0$	–	• $p_T^{\ell} - p_T^{\tau} < 0$

H→ττ→lephad



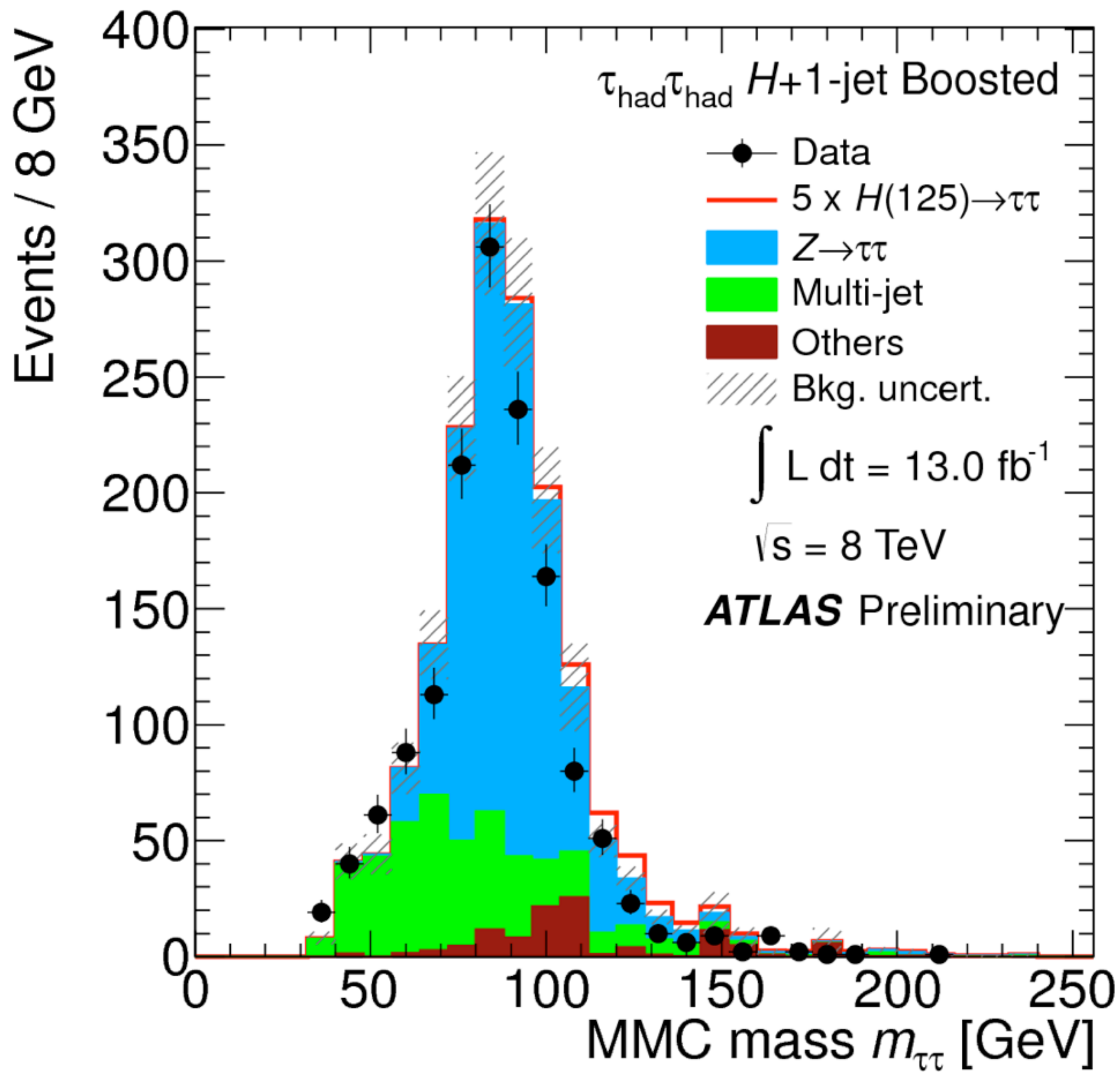
eτhad H+0-jet
μτhad H+0-jet
eτhad H+1-jet
μτhad H+1-jet
μτhad + eτhad Boosted
μτhad + eτhad H+2-jet VBF
Data
5 x H(125)→ττ
H(125)→ττ
Z→ττ (OS-SS)
Others (OS-SS)
Same Sign Data
Z→ττ
Others
Fake τ
Bkg. uncert.
∫ L dt = 13.0 fb-1
√s = 8 TeV
ATLAS Preliminary
Events / 10 GeV
Events / 20 GeV
MMC mass mττ [GeV]

$H \rightarrow \tau\tau \rightarrow$ hadhad

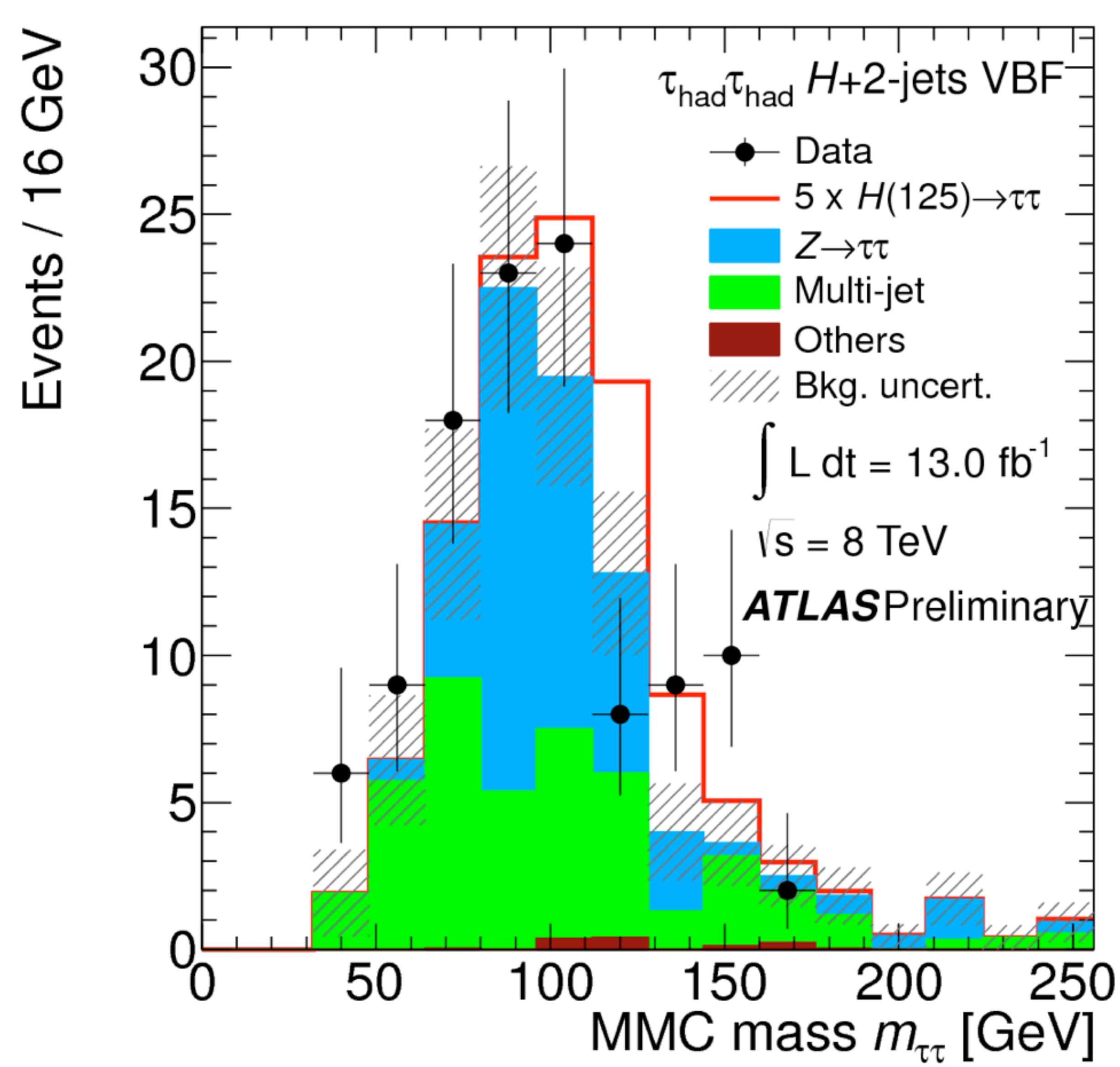
Table 4: Summary of the event selection and categories for the $H \rightarrow \tau_{had}\tau_{had}$ channel.

Cut	Description
Preselection	No muons or electrons in the event
	Exactly 2 medium τ_{had} candidates matched with the trigger objects
	At least 1 of the τ_{had} candidates identified as tight
	Both τ_{had} candidates are from the same primary vertex
	Leading $\tau_{had\text{-}vis}$ $p_T > 40$ GeV and sub-leading $\tau_{had\text{-}vis}$ $p_T > 25$ GeV, $\lvert\eta\rvert < 2.5$
	τ_{had} candidates have opposite charge and 1- or 3-tracks
	$0.8 < \Delta R(\tau_1, \tau_2) < 2.8$
	$\Delta\eta(\tau, \tau) < 1.5$
	if E_T^{miss} vector is not pointing in between the two taus, $\min\{\Delta\phi(E_T^{miss}, \tau_1), \Delta\phi(E_T^{miss}, \tau_2)\} < 0.2\pi$
VBF	At least two tagging jets, j_1, j_2, leading tagging jet with $p_T > 50$ GeV
	$\eta_{j1} \times \eta_{j2} < 0$, $\Delta\eta_{jj} > 2.6$ and invariant mass $m_{jj} > 350$ GeV
	$\min(\eta_{j1}, \eta_{j2}) < \eta_{\tau 1}, \eta_{\tau 2} < \max(\eta_{j1}, \eta_{j2})$
	$E_T^{miss} > 20$ GeV
Boosted	Fails VBF
	At least one tagging jet with $p_T > 70(50)$ GeV in the 8(7) TeV dataset
	$\Delta R(\tau_1, \tau_2) < 1.9$
	$E_T^{miss} > 20$ GeV
	if E_T^{miss} vector is not pointing in between the two taus, $\min\{\Delta\phi(E_T^{miss}, \tau_1), \Delta\phi(E_T^{miss}, \tau_2)\} < 0.1\pi$.

H→ττ→hadhad



$\tau_{had}\tau_{had}$ H+1-jet Boosted
Data
5 x H(125)→ττ
Z→ττ
Multi-jet
Others
Bkg. uncert.
∫ L dt = 13.0 fb⁻¹
√s = 8 TeV
ATLAS Preliminary
Events / 8 GeV
MMC mass $m_{\tau\tau}$ [GeV]
0
50
100
150
200
250
300
350
400



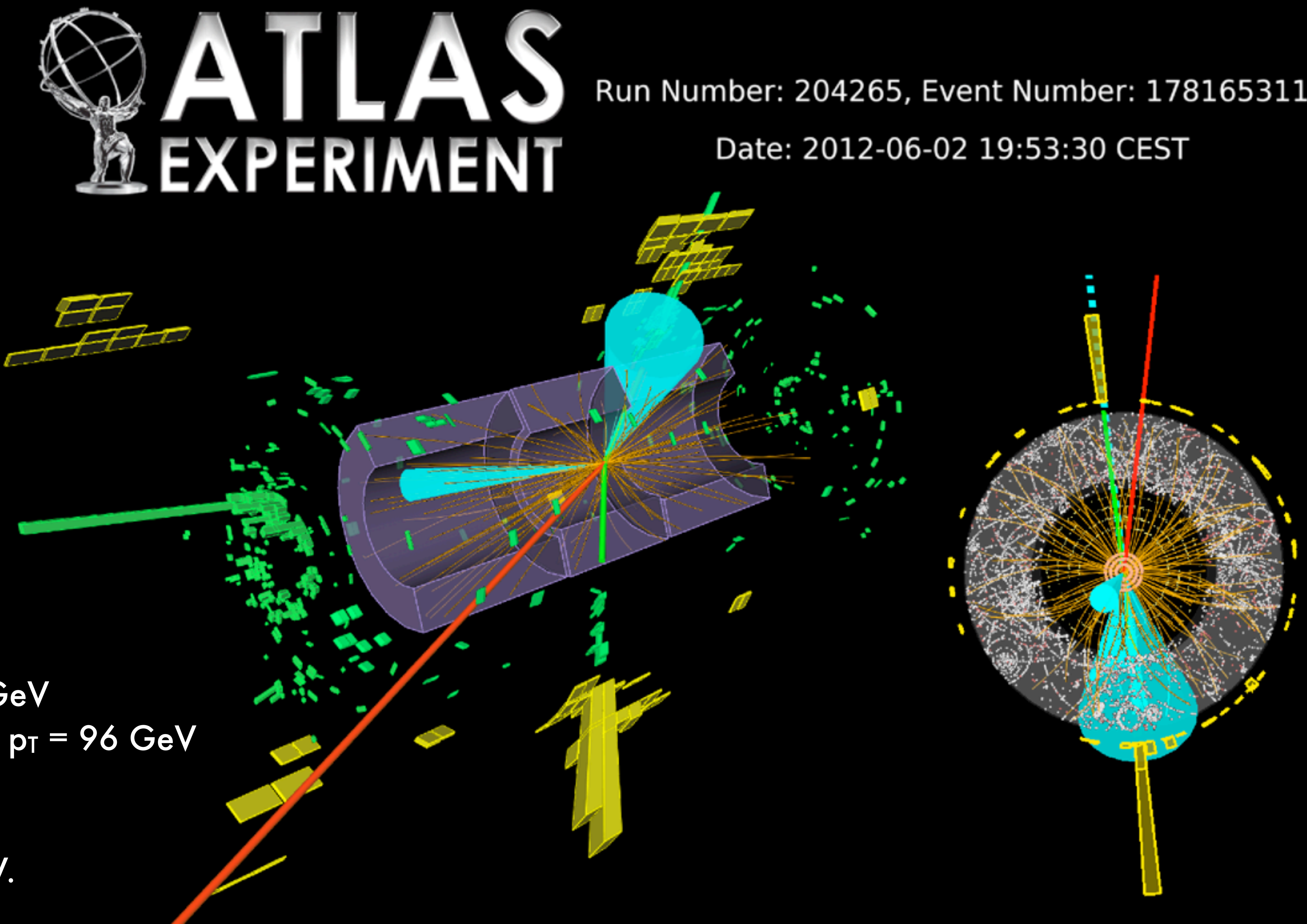
$\tau_{had}\tau_{had}$ H+2-jets VBF
Data
5 x H(125)→ττ
Z→ττ
Multi-jet
Others
Bkg. uncert.
∫ L dt = 13.0 fb⁻¹
√s = 8 TeV
ATLAS Preliminary
Events / 16 GeV
MMC mass $m_{\tau\tau}$ [GeV]
0
5
10
15
20
25
30

$H \to \tau\tau$ systematics

Table 14: Summary of $Z \to \tau^+\tau^-$ background and signal systematic uncertainties by channel. The quoted ranges refer specifically to the 8 TeV dataset, but they are similar for the 7 TeV dataset. Uncertainties indicated with (S) are also applied bin-by-bin, and therefore affect the shape of the final distributions. Signal systematic uncertainties are derived from the sum of all signal production modes.

Uncertainty	$H \to \tau_{lep}\tau_{lep}$	$H \to \tau_{lep}\tau_{had}$	$H \to \tau_{had}\tau_{had}$
		$Z \to \tau^+\tau^-$	
Embedding	1–4% (S)	2–4% (S)	1–4% (S)
Tau Energy Scale	–	4–15% (S)	3–8% (S)
Tau Identification	–	4–5%	1–2%
Trigger Efficiency	2–4%	2–5%	2–4%
Normalisation	5%	4% (non-VBF), 16% (VBF)	9–10%
		Signal	
Jet Energy Scale	1–5% (S)	3–9% (S)	2–4% (S)
Tau Energy Scale	–	2–9% (S)	4–6% (S)
Tau Identification	–	4–5%	10%
Theory	8–28%	18–23%	3–20%
Trigger Efficiency	small	small	5%

H→ττ event display



muon p_T = 63 GeV
τ_{had} candidate p_T = 96 GeV
E_T^{miss}=119 GeV
m_{jj}=625 GeV
m_{MMC}=129 GeV.

VH, H→bb selection

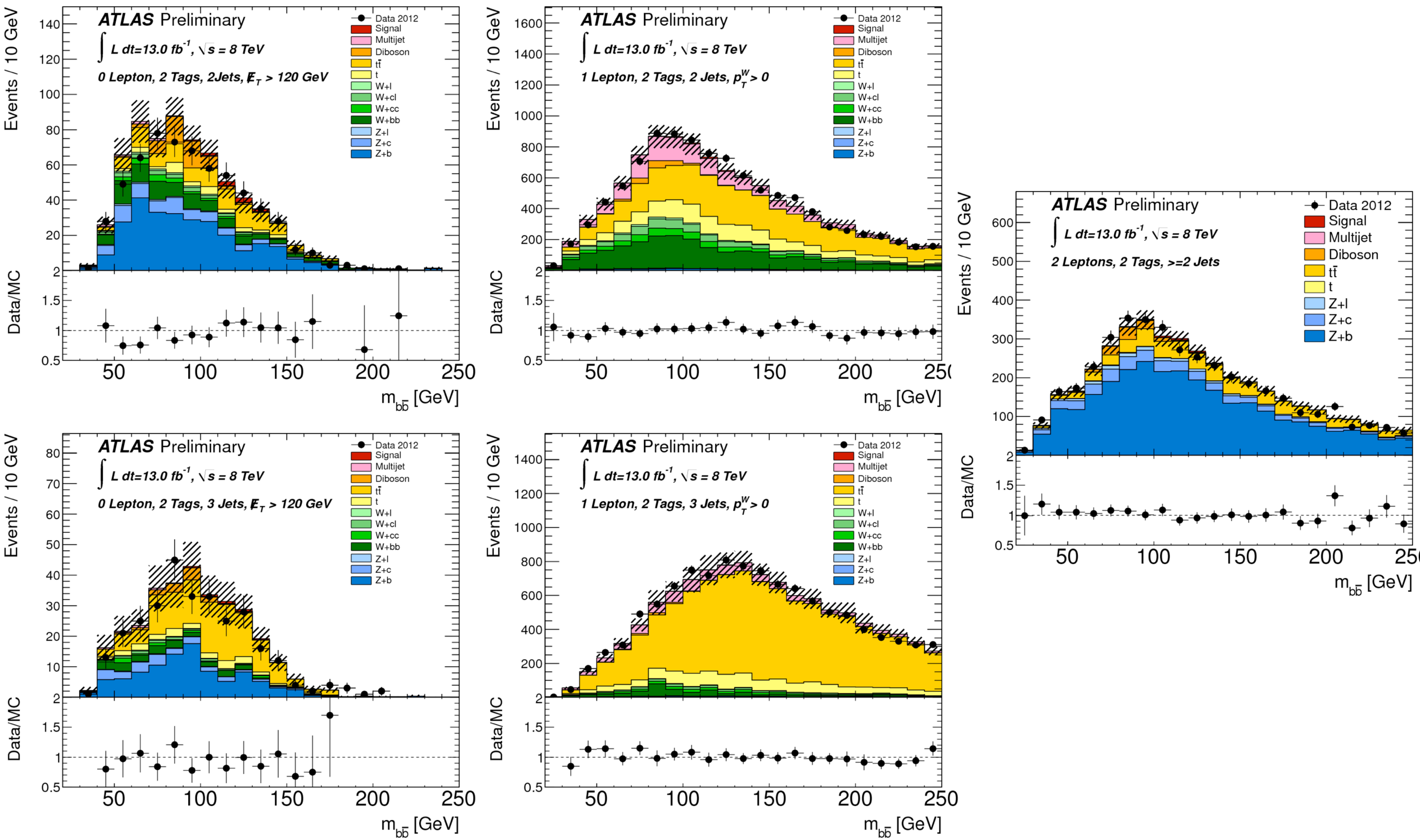
Table 1: The basic event selection of the three channels. The details of the cuts on the individual objects are summarised in the text.

Object	0-lepton	1-lepton	2-lepton
Leptons	0 loose leptons	1 tight lepton + 0 loose leptons	1 medium lepton + 1 loose lepton
Jets	2 b-tags $p_T^1 > 45$ GeV $p_T^2 > 20$ GeV $+ \leq 1$ extra jets	2 b-tags $p_T^1 > 45$ GeV $p_T^2 > 20$ GeV + 0 extra jets	2 b-tags $p_T^1 > 45$ GeV $p_T^2 > 20$ GeV -
Missing E_T	$E_T^{miss} > 120$ GeV $p_T^{miss} > 30$ GeV $\Delta\phi(E_T^{miss}, p_T^{miss}) < \pi/2$ $\text{Min}[\Delta\phi(E_T^{miss}, \text{jet})] > 1.5$ $\Delta\phi(E_T^{miss}, b\bar{b}) > 2.8$	-	$E_T^{miss} < 60$ GeV
Vector Boson	-	$m_T^W < 120$ GeV	$83 < m_{\ell\ell} < 99$ GeV

Table 2: Further topological cuts for the three channels in separate p_T^V intervals.

0-lepton channel					
E_T^{miss} (GeV)	120-160		160-200		>200
$\Delta R(b,\bar{b})$	0.7-1.9		0.7-1.7		<1.5
1-lepton channel					
p_T^W (GeV)	0-50	50-100	100-150	150-200	>200
$\Delta R(b,\bar{b})$	>0.7			0.7-1.6	<1.4
E_T^{miss} (GeV)	> 25				> 50
m_T^W (GeV)	> 40			-	
2-lepton channel					
p_T^Z(GeV)	0-50	50-100	100-150	150-200	>200
$\Delta R(b,\bar{b})$	>0.7			0.7-1.8	<1.6

VH, H→bb


ATLAS Preliminary
∫ L dt=13.0 fb⁻¹, √s = 8 TeV
0 Lepton, 2 Tags, 2Jets, E̸T > 120 GeV
1 Lepton, 2 Tags, 2 Jets, pT^W > 0
2 Leptons, 2 Tags, >=2 Jets
0 Lepton, 2 Tags, 3 Jets, E̸T > 120 GeV
1 Lepton, 2 Tags, 3 Jets, pT^W > 0
Data 2012
Signal
Multijet
Diboson
tt̄
t
W+l
W+cl
W+cc
W+bb
Z+l
Z+c
Z+b
Events / 10 GeV
Data/MC
m_bb̄ [GeV]

VH, H→bb systematics

Table 4: A summary of the size of the components of the systematic uncertainty on the total estimated background after all cuts for the three channels of the $\sqrt{s}$ = 8 TeV analysis. The uncertainties are shown as a percentage and grouped together into broad categories and are averaged over all p_T^V bins in each category. The total error is worked out by adding the individual components together in quadrature in each p_T^V bin and then averaging.

Uncertainty [%]	0 lepton	1 lepton	2 leptons
b-tagging	6.5	6.0	6.9
c-tagging	7.3	6.4	3.6
light tagging	2.1	2.2	2.8
Jet/Pile-up/E_T^{miss}	20	7.0	5.4
Lepton	0.0	2.1	1.8
Top modelling	2.7	4.1	0.5
W modelling	1.8	5.4	0.0
Z modelling	2.8	0.1	4.7
Diboson	0.8	0.3	0.5
Multijet	0.6	2.6	0.0
Luminosity	3.6	3.6	3.6
Statistical	8.3	3.6	6.6
Total	25	15	14

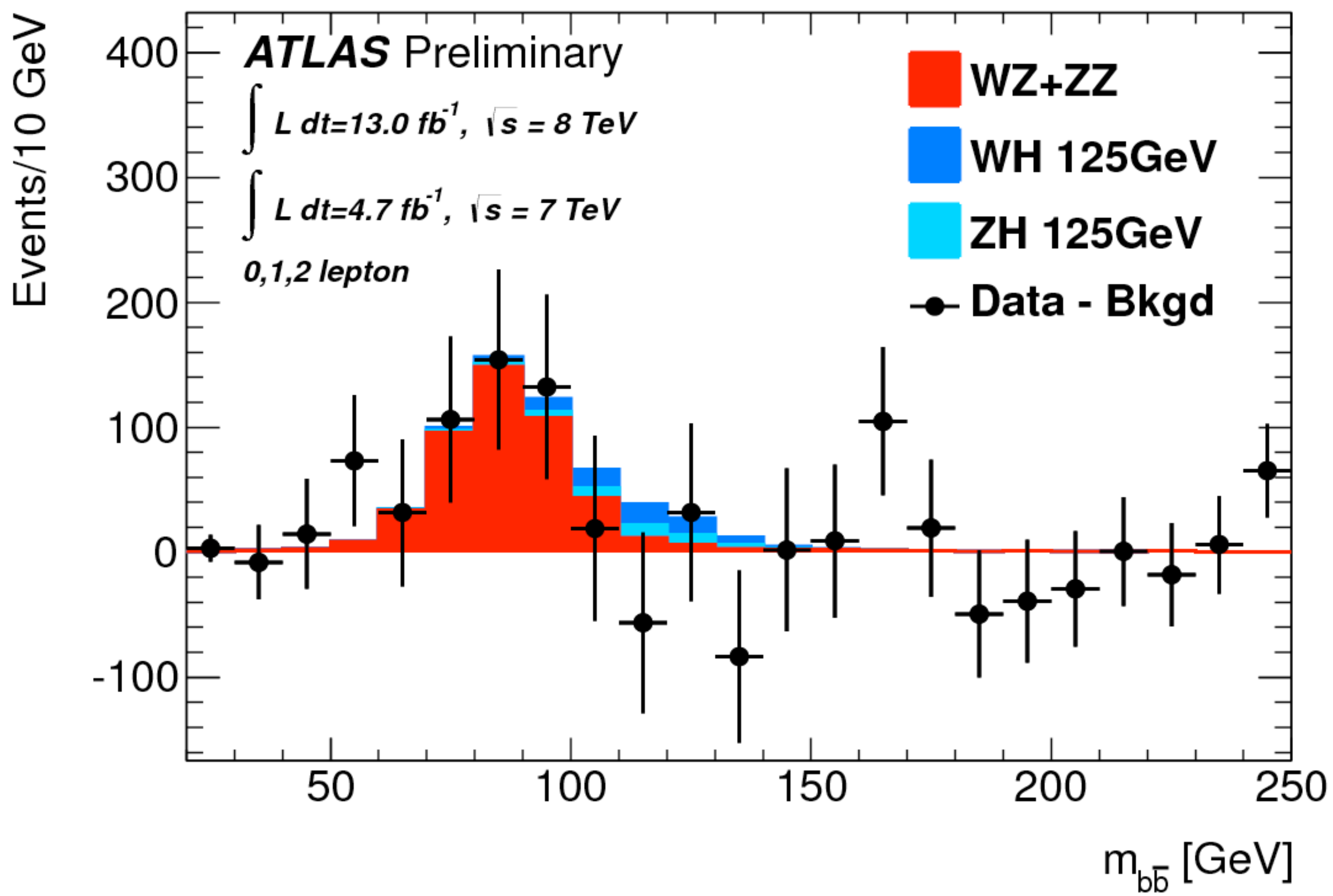
Table 5: A summary of the size of the components of the systematic uncertainty on the signal with m_H = 125 GeV for the three channels of the $\sqrt{s}$ = 8 TeV analysis. The dominant signal is shown for the 1 lepton and 2 lepton channels, while for the 0 lepton channel both *ZH* and *WH* signals are listed. The uncertainties are shown as a percentage, grouped together into broad categories and are calculated by summing in quadrature within each p_T^V bin and then averaging over all p_T^V bins in a channel.

Uncertainty [%]	0 lepton		1 lepton	2 leptons
	ZH	*WH*	*WH*	*ZH*
b-tagging	8.9	9.0	8.8	8.6
Jet/Pile-up/E_T^{miss}	19	25	6.7	4.2
Lepton	0.0	0.0	2.1	1.8
$H \to bb$ BR	3.3	3.3	3.3	3.3
VH p_T-dependence	5.3	8.1	7.6	5.0
VH theory PDF	3.5	3.5	3.5	3.5
VH theory scale	1.6	0.4	0.4	1.6
Statistical	4.9	18	4.1	2.6
Luminosity	3.6	3.6	3.6	3.6
Total	24	34	16	13

VH, H→bb: cross check VZ, Z→bb

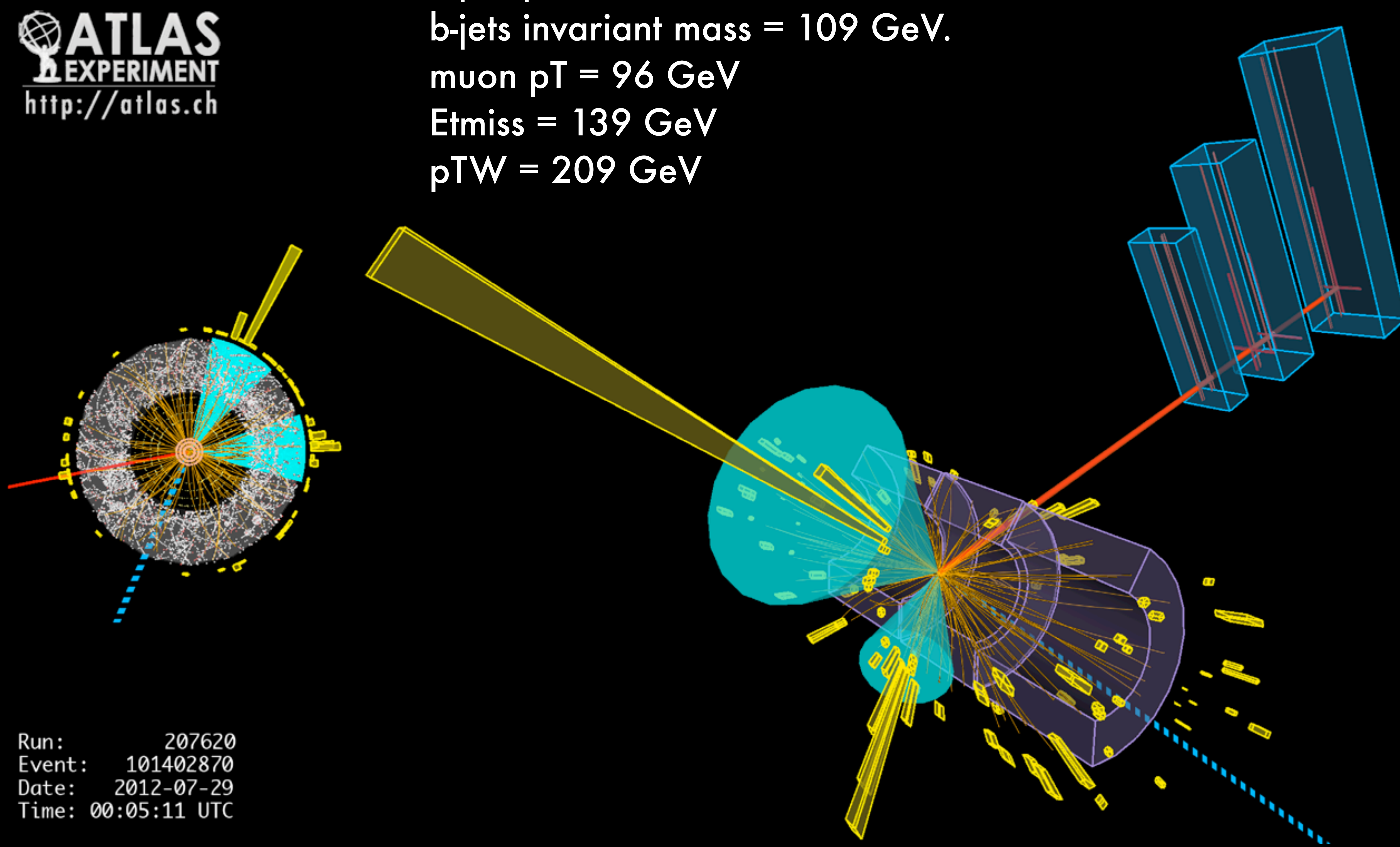
WZ, ZZ production with Z→bbar similar signature, but 5 × cross-section
Perform a separate fit to find Z→bbar and validate the analysis
Backgrounds except VZ and VH are subtracted

$\sigma/\sigma_{SM} = \mu = 1.09 \pm 0.20$ (stat) ± 0.22 (syst). Significance of 4.0σ

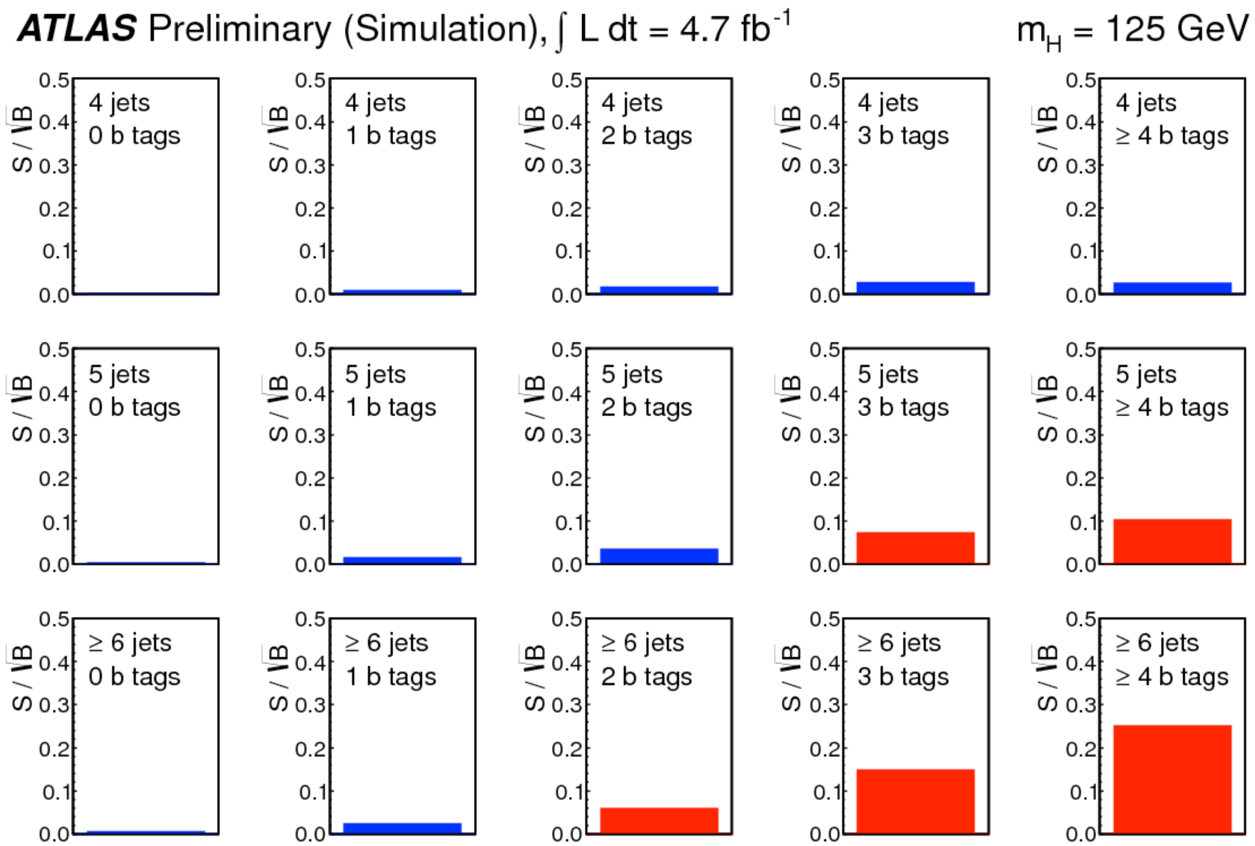


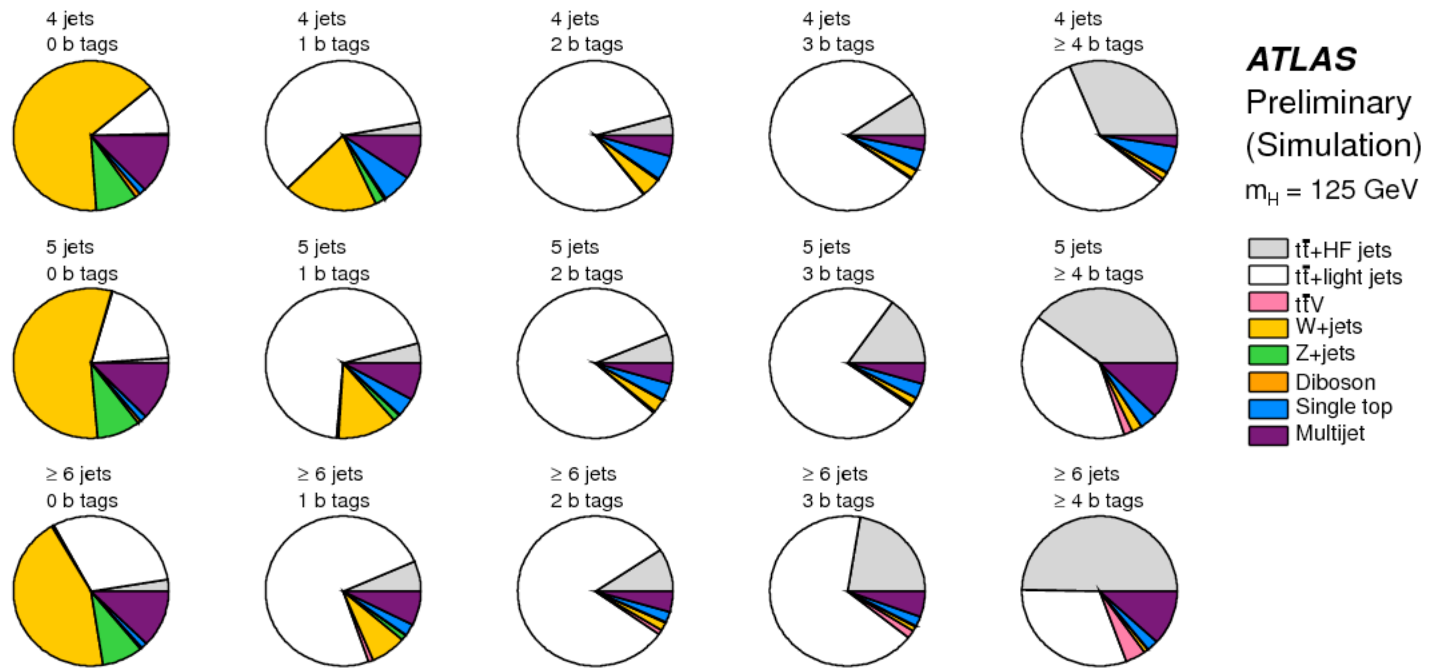
VH, H→bb event display

b-jets pT: 149 GeV and 86 GeV
b-jets invariant mass = 109 GeV.
muon pT = 96 GeV
Etmiss = 139 GeV
pTW = 209 GeV

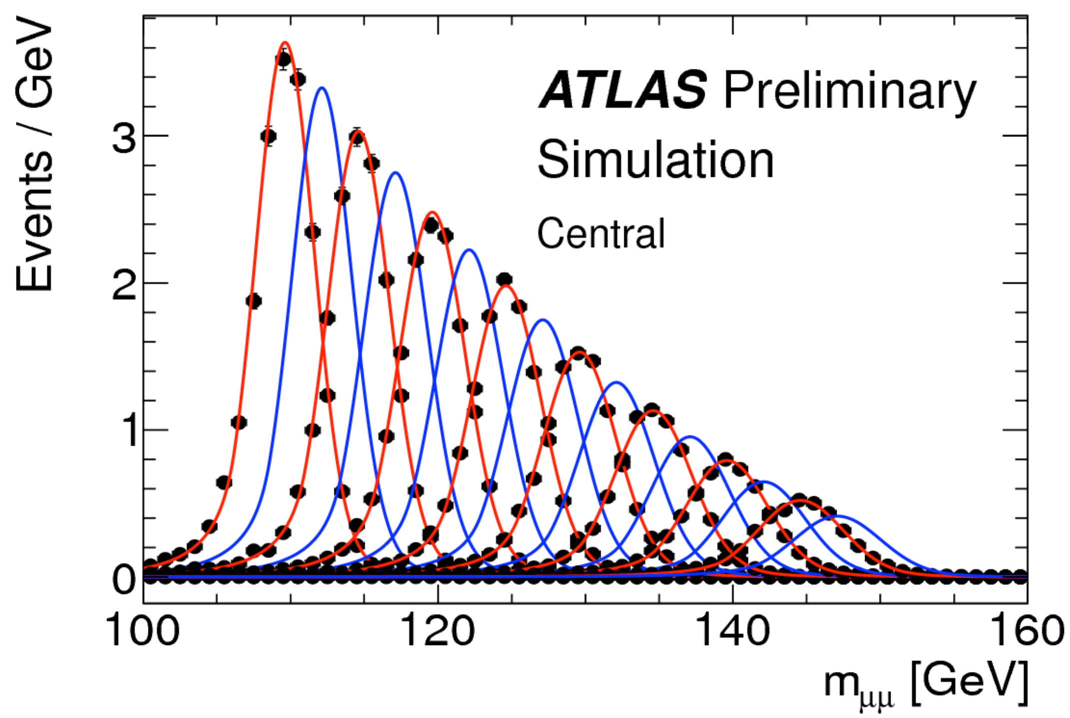


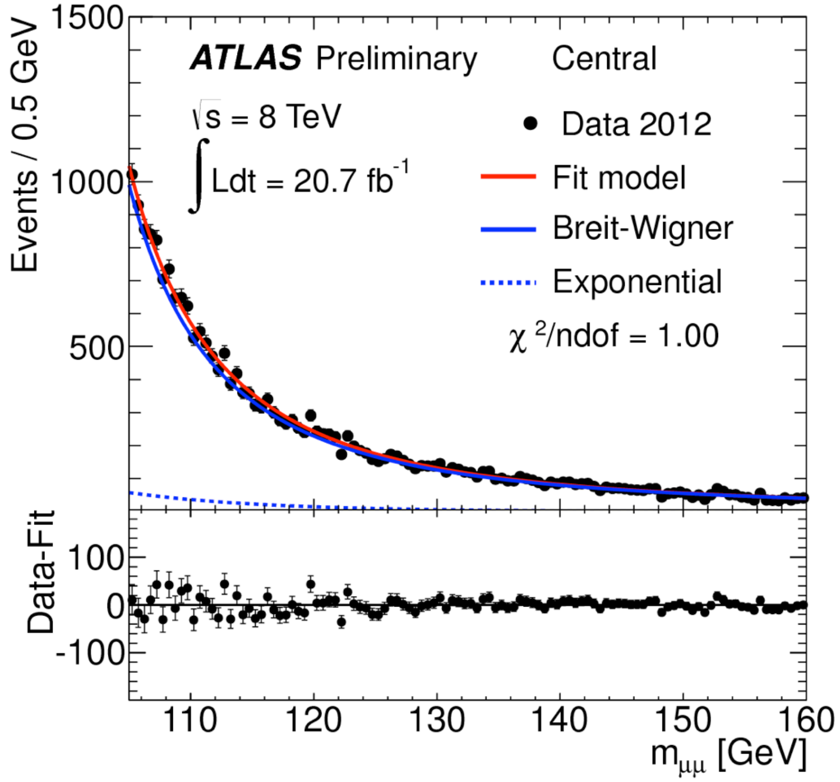
ttbarH, H→bb


ATLAS Preliminary (Simulation), ∫ L dt = 4.7 fb-1
mH = 125 GeV
S / √B
4 jets 0 b tags
4 jets 1 b tags
4 jets 2 b tags
4 jets 3 b tags
4 jets ≥ 4 b tags
5 jets 0 b tags
5 jets 1 b tags
5 jets 2 b tags
5 jets 3 b tags
5 jets ≥ 4 b tags
≥ 6 jets 0 b tags
≥ 6 jets 1 b tags
≥ 6 jets 2 b tags
≥ 6 jets 3 b tags
≥ 6 jets ≥ 4 b tags


ATLAS
Preliminary
(Simulation)
mH = 125 GeV
tt̄+HF jets
tt̄+light jets
tt̄V
W+jets
Z+jets
Diboson
Single top
Multijet

H→μμ



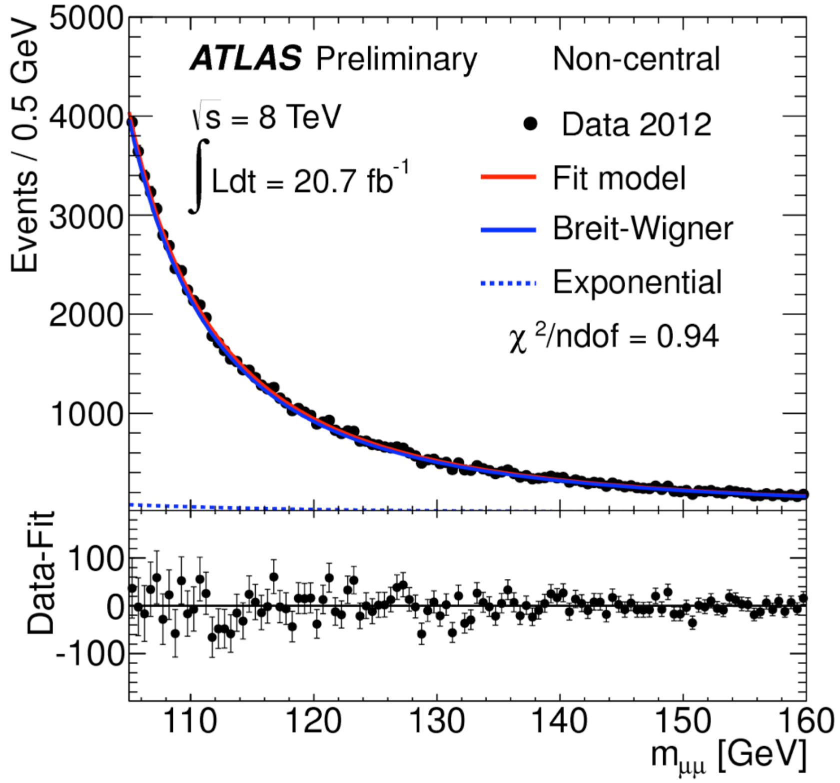


Uncertainty	Upward [%]	Downward [%]
Ren./Fac. Scale	0.1	-0.3
ISR	1.3	-2.5
FSR	-0.4	0.1
PDF	0.2	0.2
Total inclusive	+1.3	-2.6

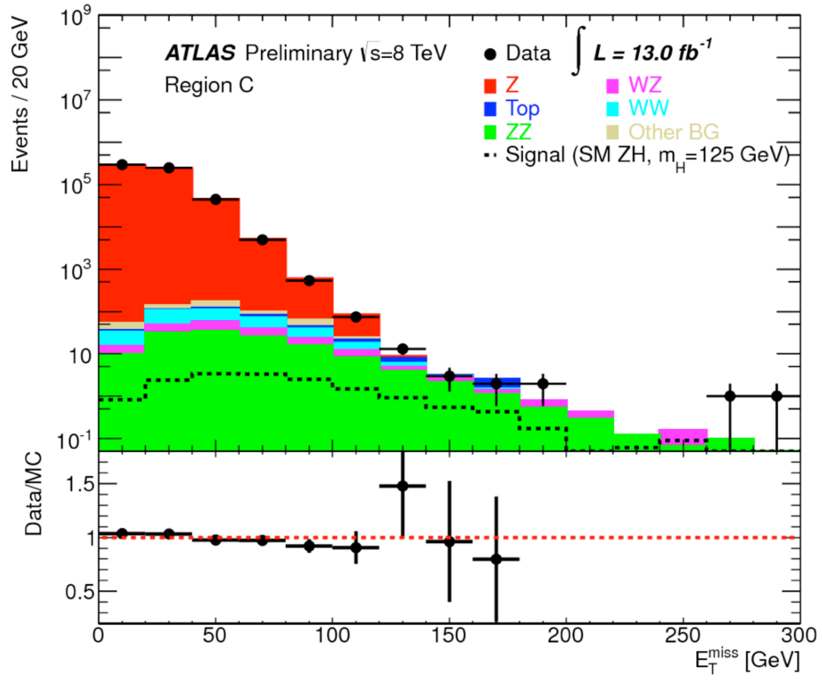
Table 3: Summary of signal acceptance uncertainties due to theoretical sources.

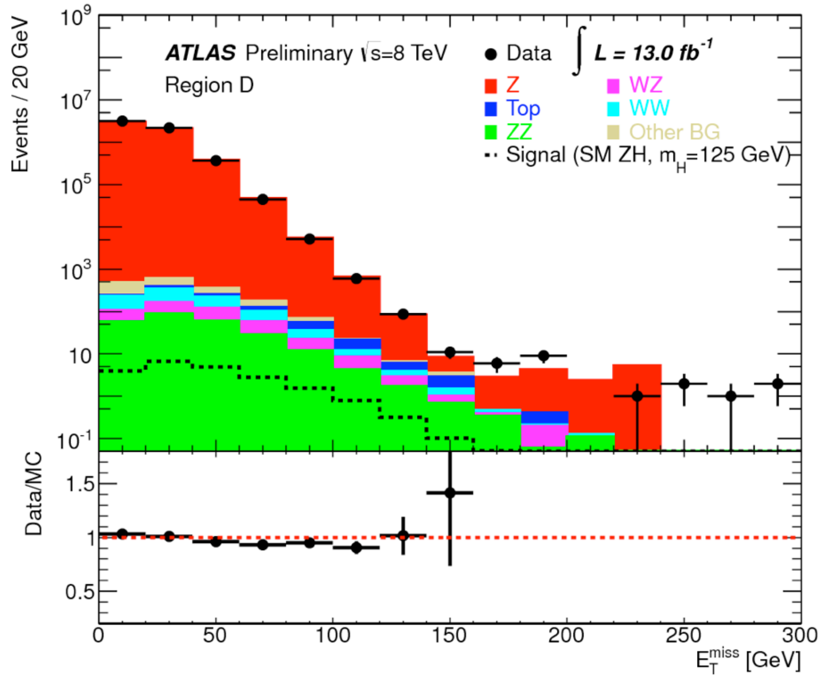
Source of Uncertainty	Treatment in the analysis
Luminosity	3.6%
Muon Selection Efficiency	0.3-1% as a function of η and p_T
Muon Momentum Scale and Resolution	$< 1\%$
Muon Trigger	$< 1\%$
Muon Track Isolation	$< 1\%$
Pile-up reweighting	$< 1\%$

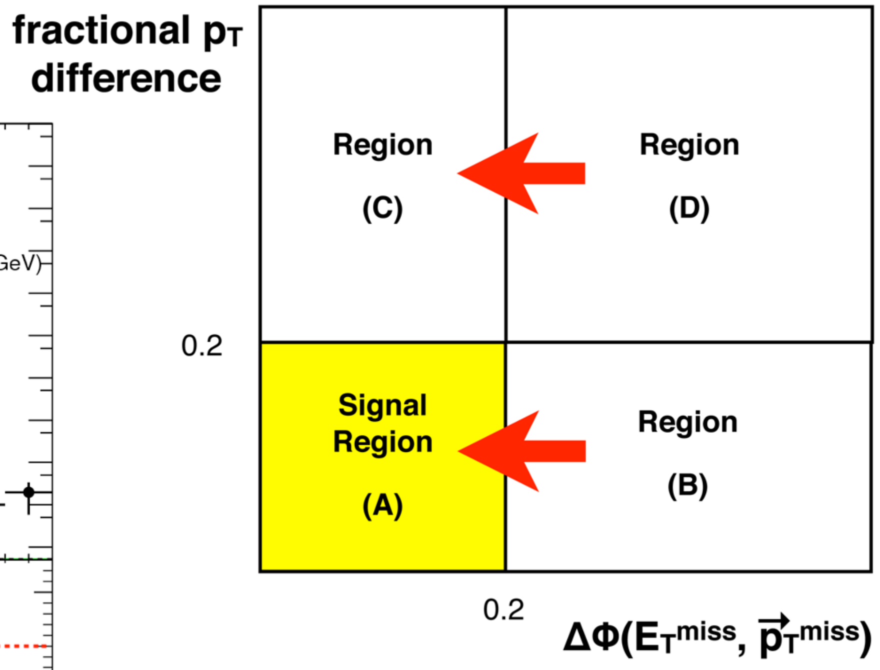
Table 4: Summary of signal normalization uncertainties due to experimental sources.

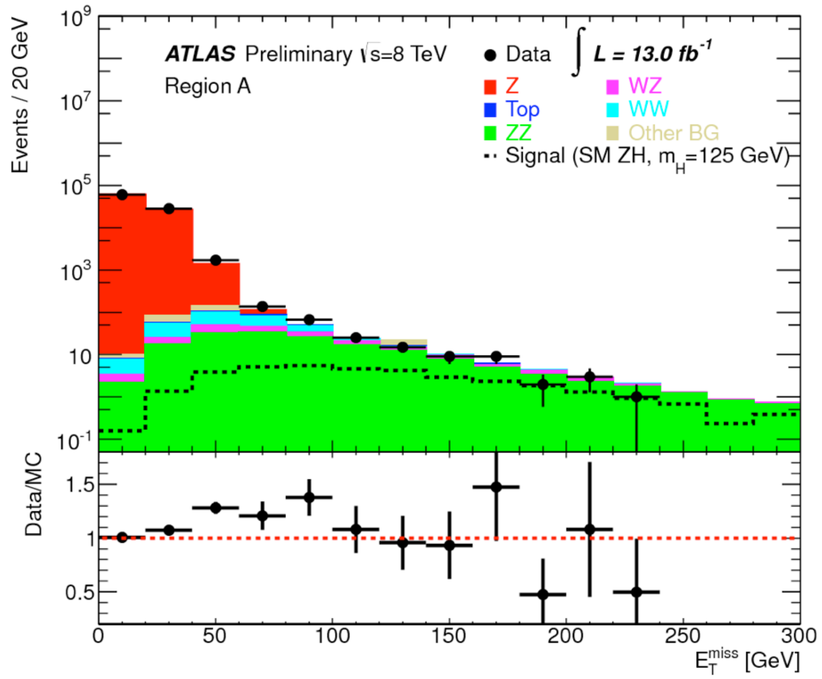


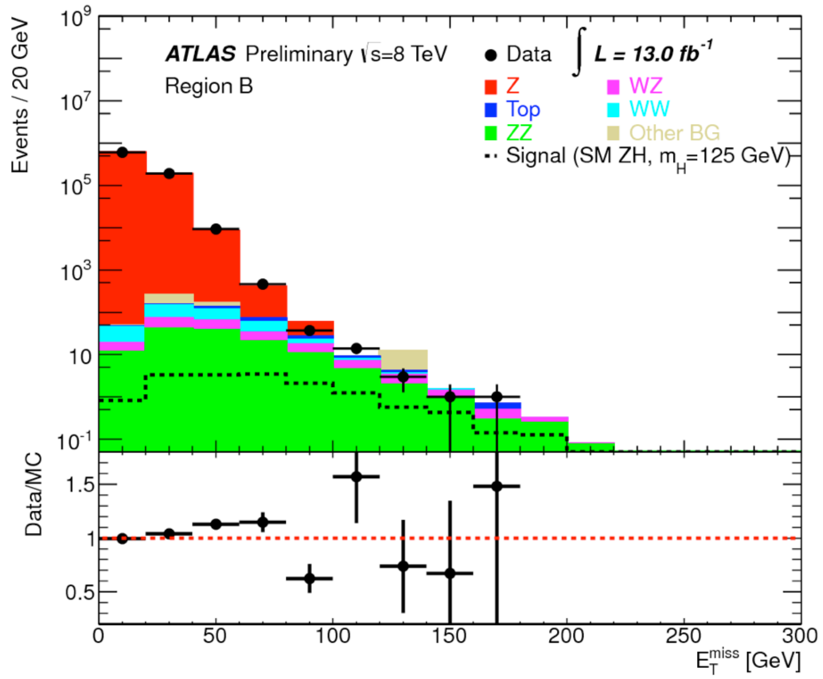
ZH, H→invisible











ZH, H→invisible

Process	Estimation method	Uncertainty (%) 2011	2012
ZH Signal	MC	7	6
ZZ	MC	11	10
WZ	MC	12	14
WW	MC	14	not used
Top quark	MC	90	not used
Top quark, WW and $Z \to \tau\tau$	$e\mu$ CR	not used	4
Z	ABCD method	56	51
W + jets, multijet	Matrix method	15	22

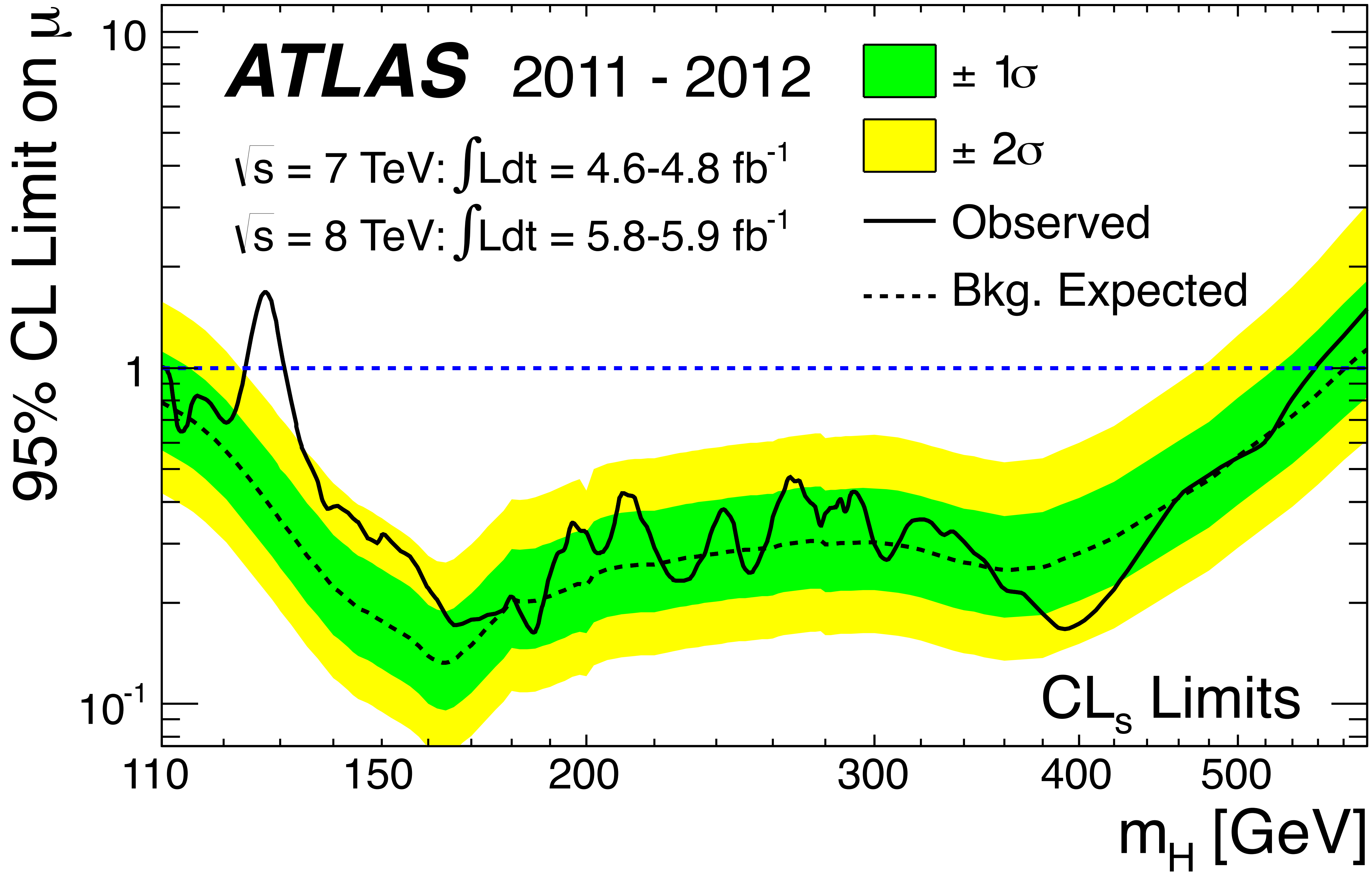
Table 2: Summary of the systematic uncertainties on each background and on the signal yield. The method used to estimate the backgrounds and the associated sources of systematic uncertainties are given. The total systematic uncertainties for each data taking period are given.

Data Period	2011 (7 TeV)	2012 (8 TeV)
ZZ	$23.5 \pm 0.8 \pm 2.5$	$56.5 \pm 1.2 \pm 5.7$
WZ	$6.2 \pm 0.4 \pm 0.7$	$13.9 \pm 1.2 \pm 2.1$
WW	$1.1 \pm 0.2 \pm 0.2$	used $e\mu$ data-driven
Top quark	$0.4 \pm 0.1 \pm 0.4$	used $e\mu$ data-driven
Top quark, WW and $Z \to \tau\tau$ ($e\mu$ data-driven)	used MC	$4.9 \pm 0.9 \pm 0.2$
Z	$0.16 \pm 0.13 \pm 0.09$	$1.4 \pm 0.4 \pm 0.7$
W + jets, multijet	$1.3 \pm 0.3 \pm 0.2$	$1.4 \pm 0.4 \pm 0.3$
Total BG	$32.7 \pm 1.0 \pm 2.6$	$78.0 \pm 2.0 \pm 6.5$
Observed	27	71

Table 3: Observed number of events and expected contributions from each background source separated into the 2011 and 2012 data taking periods. Uncertainties associated with the background predictions are presented with the statistical uncertainty first and the systematic uncertainty second.

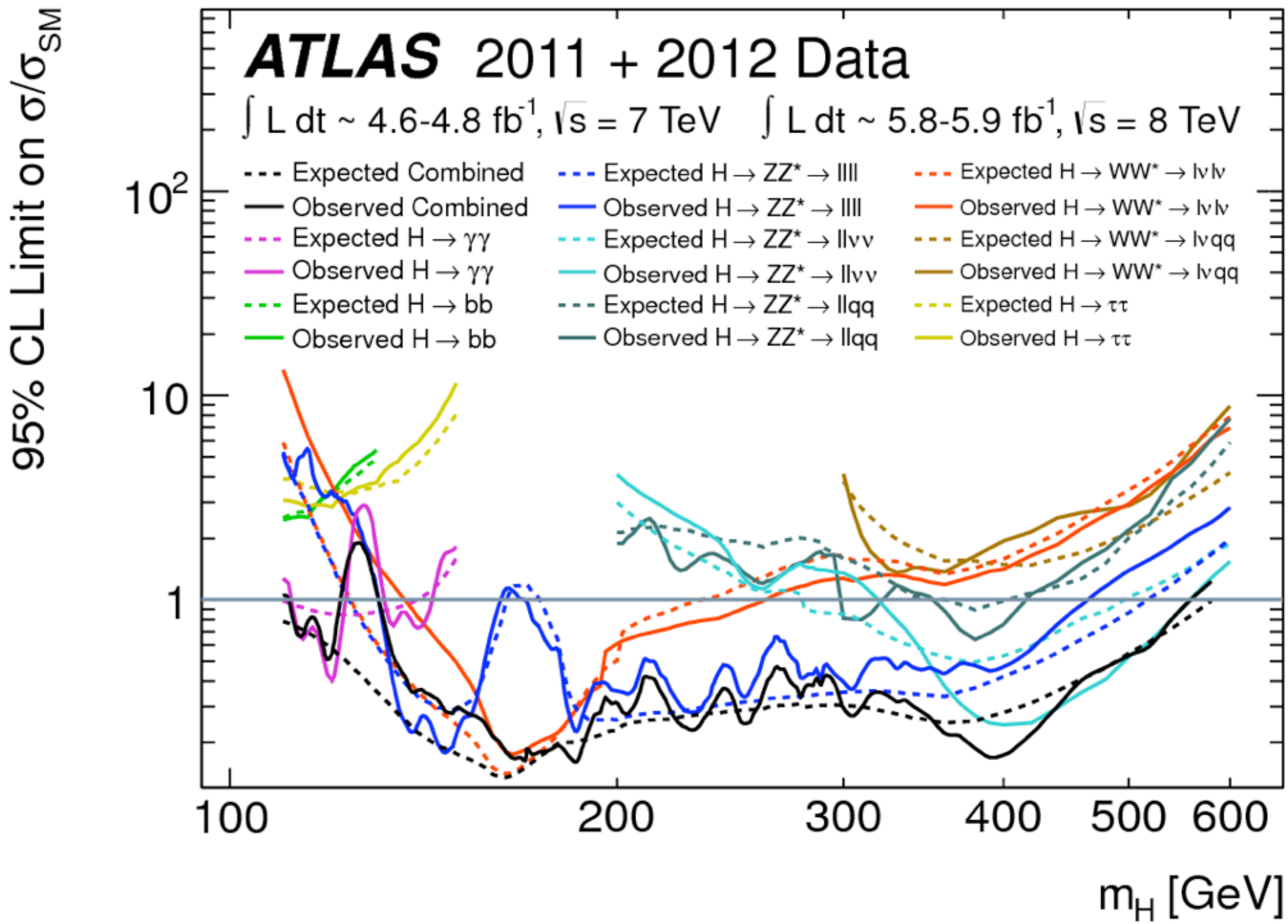
Full mass range

Phys. Lett. B 716 (2012) 1-29



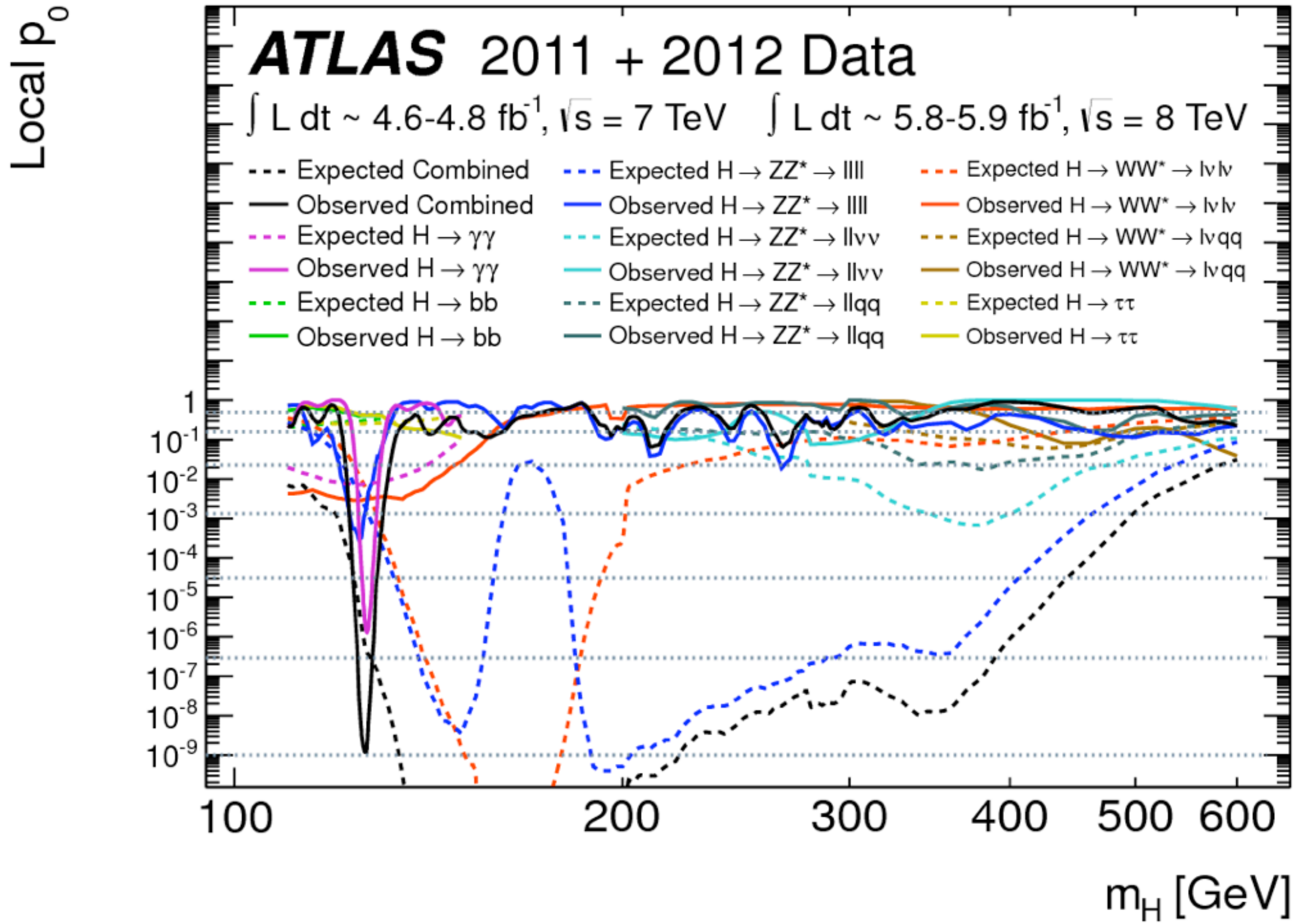
Full mass range

Phys. Lett. B 716 (2012) 1-29



Full mass range

Phys. Lett. B 716 (2012) 1-29



Statistical method

ATLAS-CONF-2013-014

- For every analysis category k the number of signal events is parametrised as

$$n^k_{signal} = \left(\sum_i \mu_i \sigma_{i,SM} \times A^k_{if} \times \epsilon^k_{if} \right) \times \mu_f \times B_{f,SM} \times \mathcal{L}^k$$

- Profile likelihood method

$$\Lambda(\mu) = \frac{L(\mu, \hat{\hat{\theta}}(\mu))}{L(\hat{\mu}, \hat{\theta})}$$

- μ parameter of interest
- θ nuisance parameters
- $L(\hat{\mu}, \hat{\theta})$ global likelihood maximum
- $L(\mu, \hat{\hat{\theta}})$ likelihood maximum for tested μ point
- $-2\mathrm{Ln}(\Lambda(\mu))$ follows a χ^2 distribution with ndof ($\mu_{1...n}$)
- Pdfs for nuisance parameters θ: gaussian, LogNormal, Poisson... (explored rectangular pdfs for some systematics as well)

Statistical method

- For m_H

$$\Lambda(m_H) = \frac{L(m_H\,,\, \hat{\hat{\mu}}_{\gamma\gamma}(m_H)\,,\, \hat{\hat{\mu}}_{4\ell}(m_H)\,,\, \hat{\hat{\theta}}(m_H))}{L(\hat{m}_H, \hat{\mu}_{\gamma\gamma}, \hat{\mu}_{4\ell}, \hat{\theta})}$$

- For Δm_H

$$\Lambda(\Delta m_H) = \frac{L(\Delta m_H\,,\, \hat{\hat{\mu}}_{\gamma\gamma}(\Delta m_H)\,,\, \hat{\hat{\mu}}_{4\ell}(\Delta m_H)\,,\, \hat{\hat{m}}_H(\Delta m_H)\,,\, \hat{\hat{\theta}}(\Delta m_H))}{L(\hat{\Delta m}_H, \hat{\mu}_{\gamma\gamma}, \hat{\mu}_{4\ell}, \hat{m}_H, \hat{\theta})}$$

Couplings combination inputs

Table 1: Summary of the individual channels entering the combined results presented here. In channels sensitive to associated production of the Higgs boson, V indicates a W or Z boson. The symbols $\otimes$ and $\oplus$ represent direct products and sums over sets of selection requirements, respectively. The abbreviations listed here are described in the corresponding References indicated in the last column. For the determination of the combined signal strength μ, reported in Section 4, the inclusive $H \to ZZ^{(*)} \to 4\ell$ analysis [8] is used.

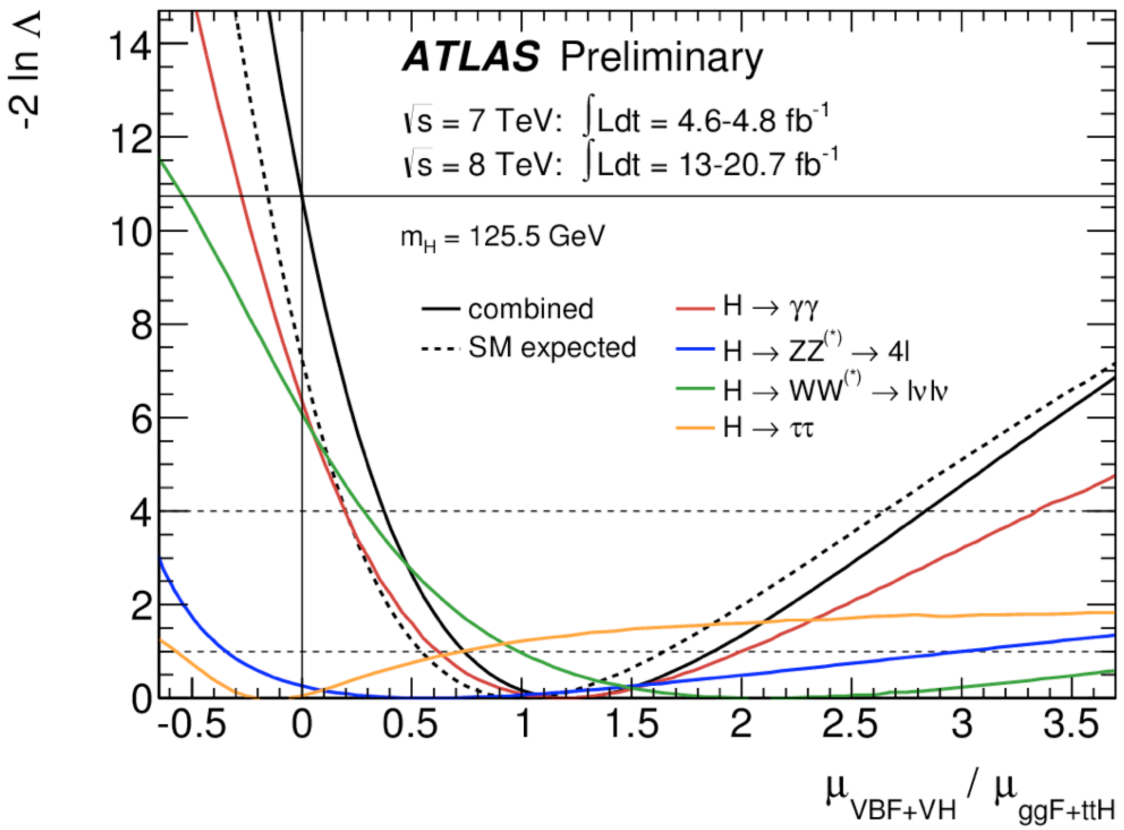
Higgs Boson Decay	Subsequent Decay	Sub-Channels	$\int L\,dt$ [fb^{-1}]	Ref.
		2011 $\sqrt{s}$ =7 TeV		
$H \to ZZ^{(*)}$	4ℓ	$\{4e, 2e2\mu, 2\mu 2e, 4\mu$, 2-jet VBF, ℓ-tag$\}$	4.6	[8]
$H \to \gamma\gamma$	–	10 categories $\{p_{\mathrm{Tt}} \otimes \eta_\gamma \otimes$ conversion$\} \oplus \{$2-jet VBF$\}$	4.8	[7]
$H \to WW^{(*)}$	$\ell\nu\ell\nu$	$\{ee, e\mu, \mu e, \mu\mu\} \otimes \{$0-jet, 1-jet, 2-jet VBF$\}$	4.6	[9]
$H \to \tau\tau$	$\tau_{\mathrm{lep}}\tau_{\mathrm{lep}}$	$\{e\mu\} \otimes \{$0-jet$\} \oplus \{\ell\ell\} \otimes \{$1-jet, 2-jet, $p_{\mathrm{T},\tau\tau} > 100$ GeV, $VH\}$	4.6	[10]
	$\tau_{\mathrm{lep}}\tau_{\mathrm{had}}$	$\{e, \mu\} \otimes \{$0-jet, 1-jet, $p_{\mathrm{T},\tau\tau} > 100$ GeV, 2-jet$\}$	4.6	
	$\tau_{\mathrm{had}}\tau_{\mathrm{had}}$	$\{$1-jet, 2-jet$\}$	4.6	
$VH \to Vbb$	$Z \to \nu\nu$	$E_{\mathrm{T}}^{\mathrm{miss}} \in \{120-160, 160-200, \geq 200$ GeV$\} \otimes \{$2-jet, 3-jet$\}$	4.6	[11]
	$W \to \ell\nu$	$p_{\mathrm{T}}^{W} \in \{< 50, 50-100, 100-150, 150-200, \geq 200$ GeV$\}$	4.7	
	$Z \to \ell\ell$	$p_{\mathrm{T}}^{Z} \in \{< 50, 50-100, 100-150, 150-200, \geq 200$ GeV$\}$	4.7	
		2012 $\sqrt{s}$ =8 TeV		
$H \to ZZ^{(*)}$	4ℓ	$\{4e, 2e2\mu, 2\mu 2e, 4\mu$, 2-jet VBF, ℓ-tag$\}\}$	20.7	[8]
$H \to \gamma\gamma$	–	14 categories $\{p_{\mathrm{Tt}} \otimes \eta_\gamma \otimes$ conversion$\} \oplus \{$2-jet VBF$\} \oplus \{\ell$-tag, $E_{\mathrm{T}}^{\mathrm{miss}}$-tag, 2-jet VH$\}$	20.7	[7]
$H \to WW^{(*)}$	$\ell\nu\ell\nu$	$\{ee, e\mu, \mu e, \mu\mu\} \otimes \{$0-jet, 1-jet, 2-jet VBF$\}$	20.7	[9]
$H \to \tau\tau$	$\tau_{\mathrm{lep}}\tau_{\mathrm{lep}}$	$\{\ell\ell\} \otimes \{$1-jet, 2-jet, $p_{\mathrm{T},\tau\tau} > 100$ GeV, $VH\}$	13	[10]
	$\tau_{\mathrm{lep}}\tau_{\mathrm{had}}$	$\{e, \mu\} \otimes \{$0-jet, 1-jet, $p_{\mathrm{T},\tau\tau} > 100$ GeV, 2-jet$\}$	13	
	$\tau_{\mathrm{had}}\tau_{\mathrm{had}}$	$\{$1-jet, 2-jet$\}$	13	
$VH \to Vbb$	$Z \to \nu\nu$	$E_{\mathrm{T}}^{\mathrm{miss}} \in \{120-160, 160-200, \geq 200$ GeV$\} \otimes \{$2-jet, 3-jet$\}$	13	[11]
	$W \to \ell\nu$	$p_{\mathrm{T}}^{W} \in \{< 50, 50-100, 100-150, 150-200, \geq 200$ GeV$\}$	13	
	$Z \to \ell\ell$	$p_{\mathrm{T}}^{Z} \in \{< 50, 50-100, 100-150, 150-200, \geq 200$ GeV$\}$	13	

Production modes

$$\begin{aligned}
\sigma(gg \to H) * \mathrm{BR}(H \to \gamma\gamma) &\sim \mu_{\mathrm{ggF}+t\bar{t}H;H\to\gamma\gamma} \\
\sigma(qq' \to qq'H) * \mathrm{BR}(H \to \gamma\gamma) &\sim \mu_{\mathrm{ggF}+t\bar{t}H;H\to\gamma\gamma} \cdot \mu_{\mathrm{VBF}+VH}/\mu_{\mathrm{ggF}+t\bar{t}H} \\
\sigma(gg \to H) * \mathrm{BR}(H \to ZZ^{(*)}) &\sim \mu_{\mathrm{ggF}+t\bar{t}H;H\to ZZ^{(*)}} \\
\sigma(qq' \to qq'H) * \mathrm{BR}(H \to ZZ^{(*)}) &\sim \mu_{\mathrm{ggF}+t\bar{t}H;H\to ZZ^{(*)}} \cdot \mu_{\mathrm{VBF}+VH}/\mu_{\mathrm{ggF}+t\bar{t}H} \\
\sigma(gg \to H) * \mathrm{BR}(H \to WW^{(*)}) &\sim \mu_{\mathrm{ggF}+t\bar{t}H;H\to WW^{(*)}} \qquad (3) \\
\sigma(qq' \to qq'H) * \mathrm{BR}(H \to WW^{(*)}) &\sim \mu_{\mathrm{ggF}+t\bar{t}H;H\to WW^{(*)}} \cdot \mu_{\mathrm{VBF}+VH}/\mu_{\mathrm{ggF}+t\bar{t}H} \\
\sigma(gg \to H) * \mathrm{BR}(H \to \tau\tau) &\sim \mu_{\mathrm{ggF}+t\bar{t}H;H\to\tau\tau} \\
\sigma(qq' \to qq'H) * \mathrm{BR}(H \to \tau\tau) &\sim \mu_{\mathrm{ggF}+t\bar{t}H;H\to\tau\tau} \cdot \mu_{\mathrm{VBF}+VH}/\mu_{\mathrm{ggF}+t\bar{t}H}
\end{aligned}$$

where $\mu_{\mathrm{ggF}+t\bar{t}H;H\to XX}$ is defined as

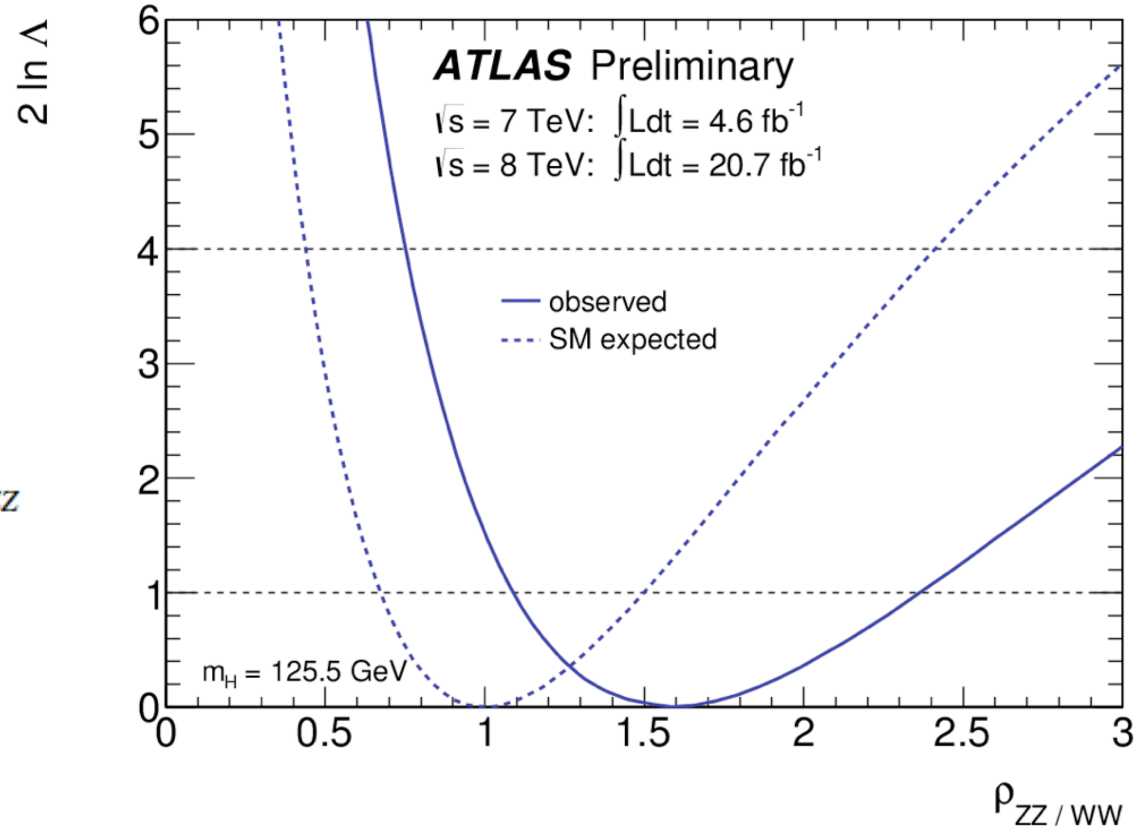
$$\mu_{\mathrm{ggF}+t\bar{t}H;H\to XX} = \frac{\sigma(\mathrm{ggF}) \cdot \mathrm{BR}(H \to XX)}{\sigma_{\mathrm{SM}}(\mathrm{ggF}) \cdot \mathrm{BR}_{\mathrm{SM}}(H \to XX)} = \frac{\sigma(t\bar{t}H) \cdot \mathrm{BR}(H \to XX)}{\sigma_{\mathrm{SM}}(t\bar{t}H) \cdot \mathrm{BR}_{\mathrm{SM}}(H \to XX)} \qquad (4)$$

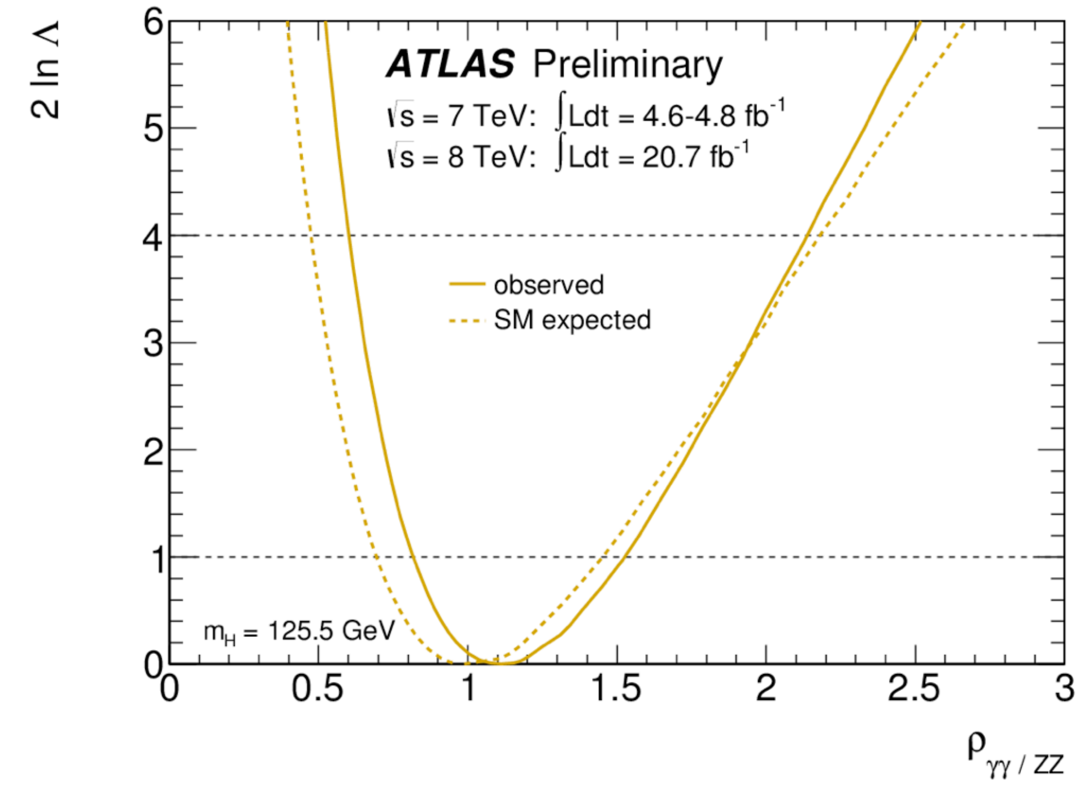


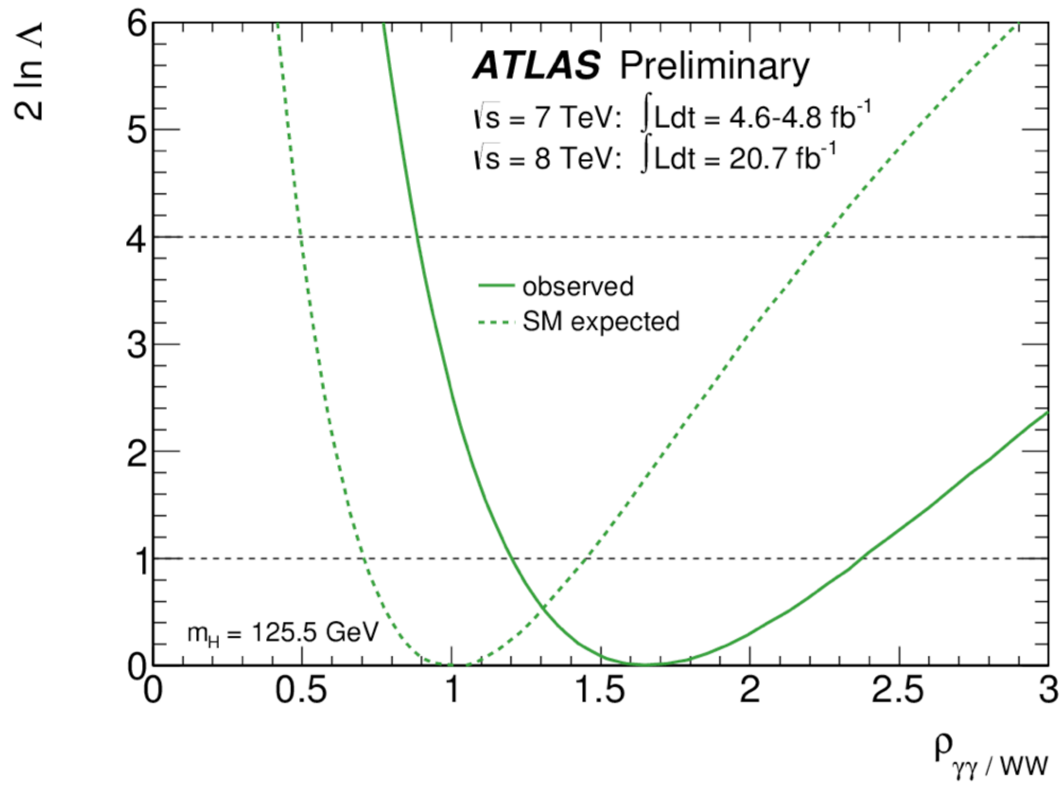
Branching ratio ratios

$$\rho_{\gamma\gamma/ZZ} = \frac{\mathrm{BR}(H\to\gamma\gamma)}{\mathrm{BR}(H\to ZZ^{(*)})} \times \frac{\mathrm{BR_{SM}}(H\to ZZ^{(*)})}{\mathrm{BR_{SM}}(H\to\gamma\gamma)} \quad ,$$

$$\begin{aligned}
\sigma(gg\to H)*\mathrm{BR}(H\to\gamma\gamma) &\sim \mu_{\mathrm{ggF}+t\bar{t}H;H\to ZZ^{(*)}}\cdot\rho_{\gamma\gamma/ZZ}\\
\sigma(qq'\to qq'H)*\mathrm{BR}(H\to\gamma\gamma) &\sim \mu_{\mathrm{ggF}+t\bar{t}H;H\to ZZ^{(*)}}\cdot\mu_{\mathrm{VBF}+VH}/\mu_{\mathrm{ggF}+t\bar{t}H}\cdot\rho_{\gamma\gamma/ZZ}\\
\sigma(gg\to H)*\mathrm{BR}(H\to ZZ^{(*)}) &\sim \mu_{\mathrm{ggF}+t\bar{t}H;H\to ZZ^{(*)}}\\
\sigma(qq'\to qq'H)*\mathrm{BR}(H\to ZZ^{(*)}) &\sim \mu_{\mathrm{ggF}+t\bar{t}H;H\to ZZ^{(*)}}\cdot\mu_{\mathrm{VBF}+VH}/\mu_{\mathrm{ggF}+t\bar{t}H}
\end{aligned}$$





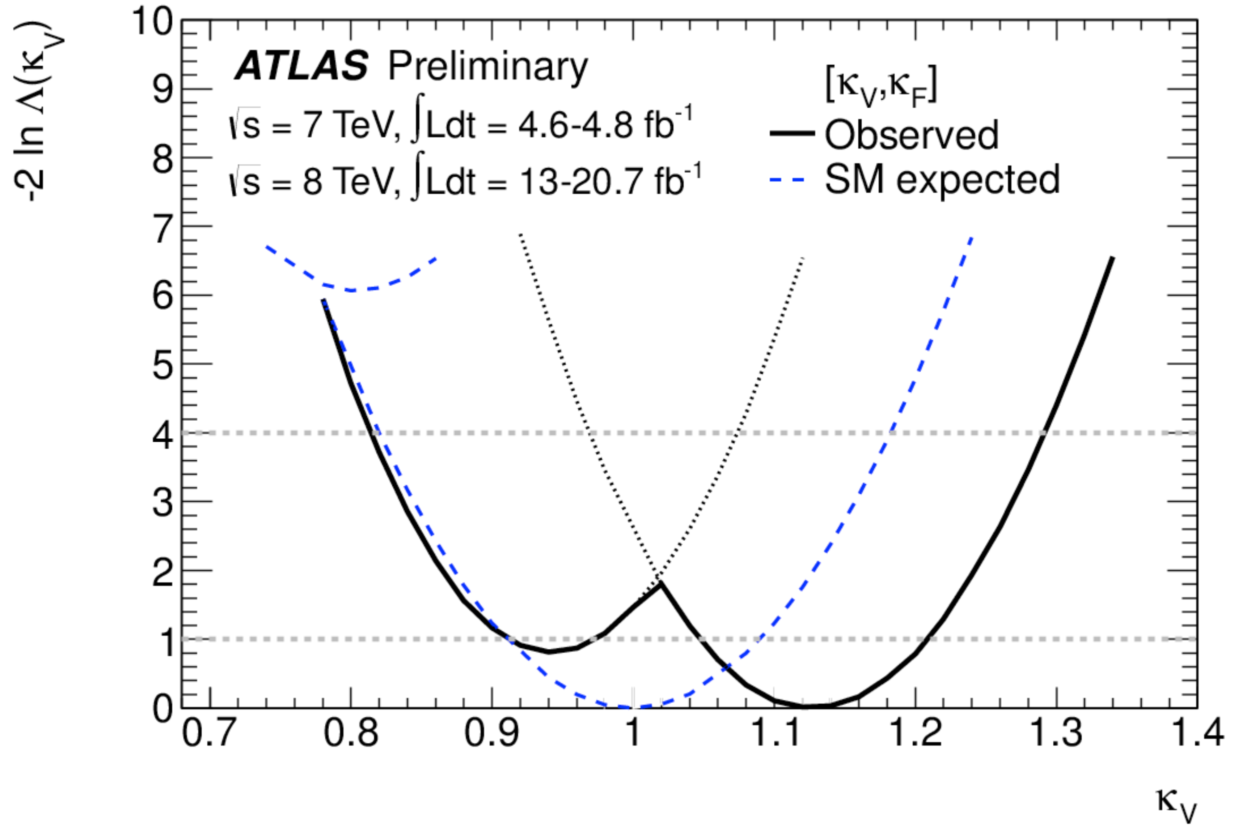


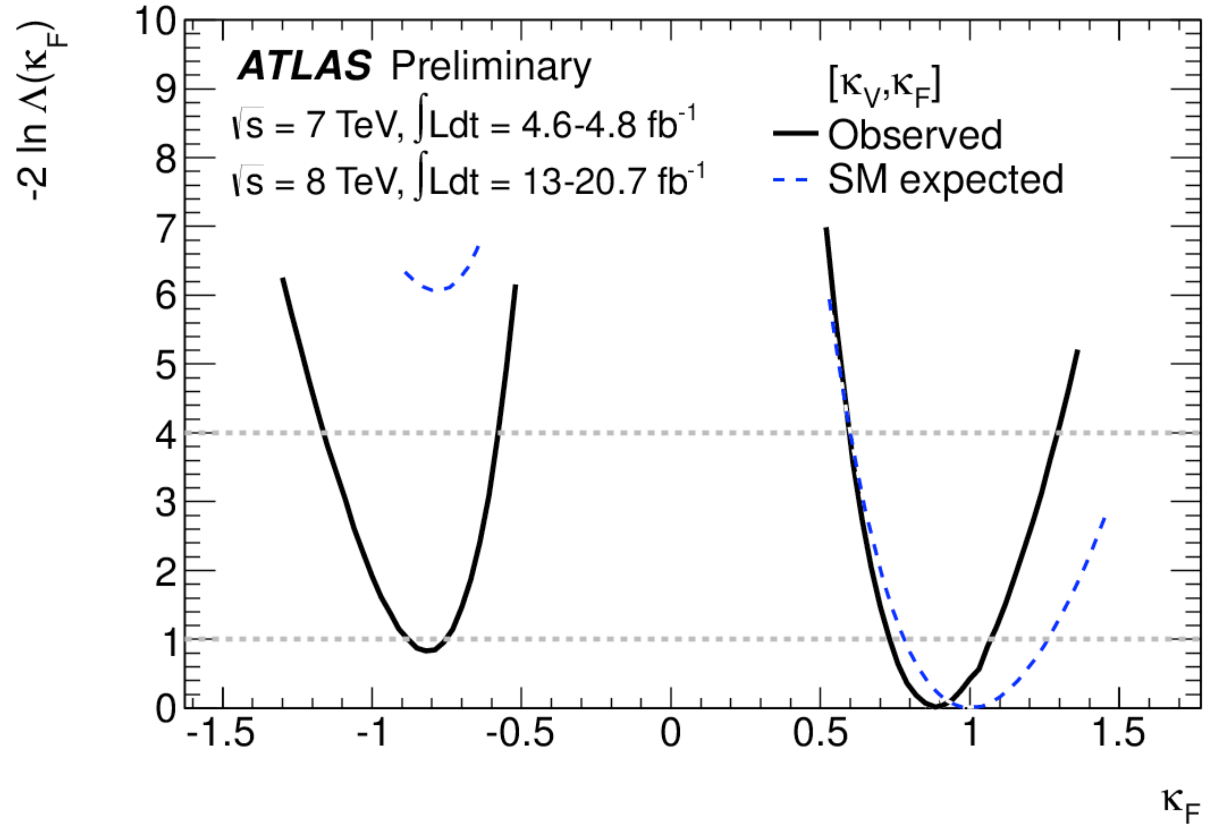
Couplings SM Γ

$$\kappa_V = \kappa_W = \kappa_Z$$
$$\kappa_F = \kappa_t = \kappa_b = \kappa_\tau = \kappa_g$$

$$\kappa_\gamma^2(\kappa_F, \kappa_V) = 1.59 \cdot \kappa_V^2 - 0.66 \cdot \kappa_V\kappa_F + 0.07 \cdot \kappa_F^2 \quad .$$

$$\begin{aligned}
\sigma(gg \to H) * \mathrm{BR}(H \to \gamma\gamma) &\sim \frac{\kappa_F^2 \cdot \kappa_\gamma^2(\kappa_F, \kappa_V)}{0.75 \cdot \kappa_F^2 + 0.25 \cdot \kappa_V^2} \\
\sigma(qq' \to qq'H) * \mathrm{BR}(H \to \gamma\gamma) &\sim \frac{\kappa_V^2 \cdot \kappa_\gamma^2(\kappa_F, \kappa_V)}{0.75 \cdot \kappa_F^2 + 0.25 \cdot \kappa_V^2} \\
\sigma(gg \to H) * \mathrm{BR}(H \to ZZ^{(*)}, H \to WW^{(*)}) &\sim \frac{\kappa_F^2 \cdot \kappa_V^2}{0.75 \cdot \kappa_F^2 + 0.25 \cdot \kappa_V^2} \\
\sigma(qq' \to qq'H) * \mathrm{BR}(H \to ZZ^{(*)}, H \to WW^{(*)}) &\sim \frac{\kappa_V^2 \cdot \kappa_V^2}{0.75 \cdot \kappa_F^2 + 0.25 \cdot \kappa_V^2} \\
\sigma(qq' \to qq'H, VH) * \mathrm{BR}(H \to \tau\tau, H \to b\bar{b}) &\sim \frac{\kappa_V^2 \cdot \kappa_F^2}{0.75 \cdot \kappa_F^2 + 0.25 \cdot \kappa_V^2} \quad ,
\end{aligned} \tag{12}$$

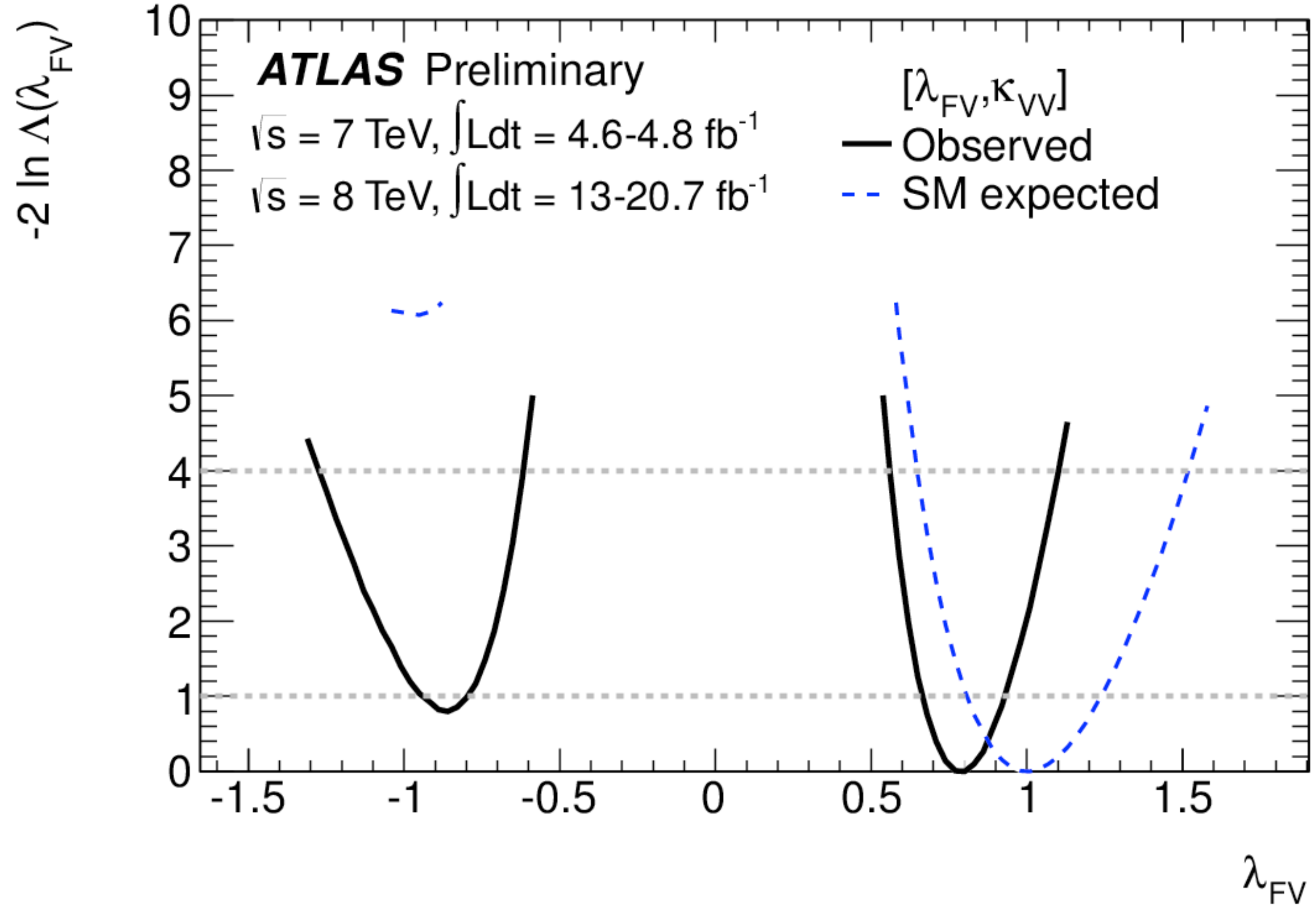




Couplings no assumption on Γ

$$\lambda_{FV} = \kappa_F/\kappa_V$$
$$\kappa_{VV} = \kappa_V \cdot \kappa_V/\kappa_H \quad .$$

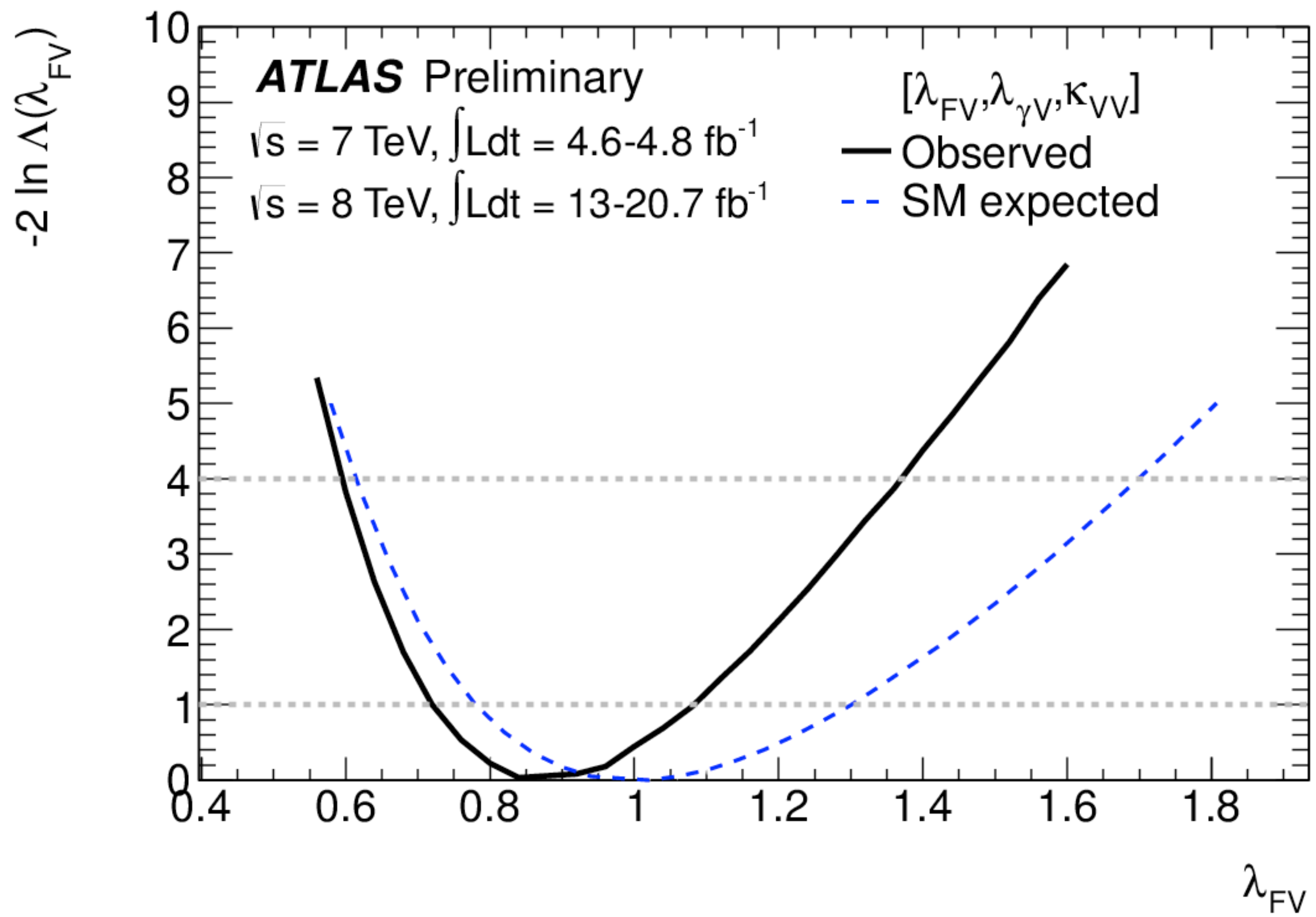
$$\begin{aligned}
\sigma(gg \to H) * \mathrm{BR}(H \to \gamma\gamma) &\sim \lambda_{FV}^2 \cdot \kappa_{VV}^2 \cdot \kappa_\gamma^2(\lambda_{FV}, 1) \\
\sigma(qq' \to qq'H) * \mathrm{BR}(H \to \gamma\gamma) &\sim \kappa_{VV}^2 \cdot \kappa_\gamma^2(\lambda_{FV}, 1) \\
\sigma(gg \to H) * \mathrm{BR}(H \to ZZ^{(*)}, H \to WW^{(*)}) &\sim \lambda_{FV}^2 \cdot \kappa_{VV}^2 \\
\sigma(qq' \to qq'H) * \mathrm{BR}(H \to ZZ^{(*)}, H \to WW^{(*)}) &\sim \kappa_{VV}^2 \\
\sigma(qq' \to qq'H, VH) * \mathrm{BR}(H \to \tau\tau, H \to b\bar{b}) &\sim \kappa_{VV}^2 \cdot \lambda_{FV}^2 \quad ,
\end{aligned}$$



Couplings no assumption Γ and γγ loop

$$\lambda_{FV} = \kappa_F/\kappa_V$$
$$\lambda_{\gamma V} = \kappa_\gamma/\kappa_V$$
$$\kappa_{VV} = \kappa_V \cdot \kappa_V/\kappa_H \quad ,$$

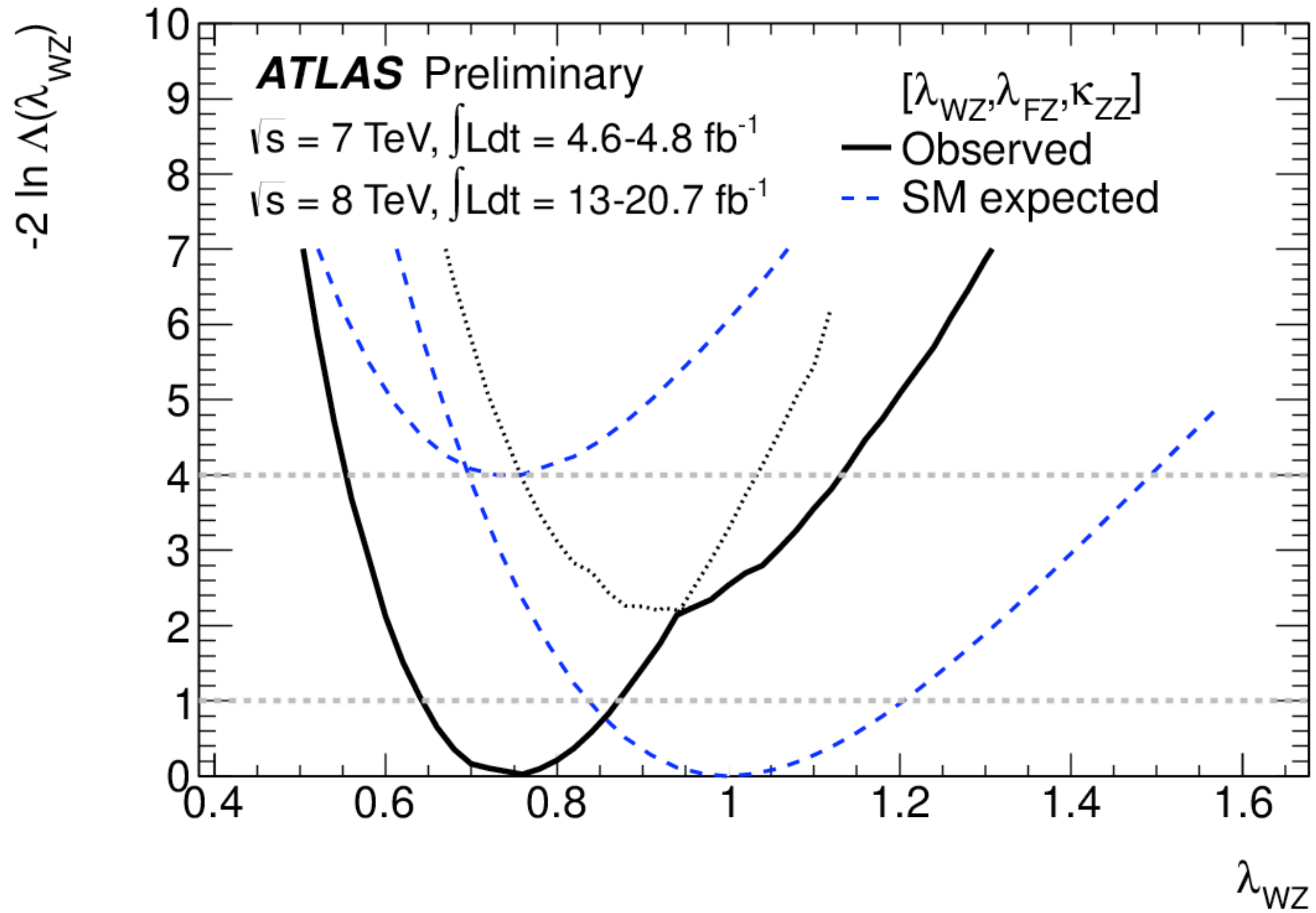
$$\sigma(gg \to H) * \mathrm{BR}(H \to \gamma\gamma) \sim \lambda_{FV}^2 \cdot \kappa_{VV}^2 \cdot \lambda_{\gamma V}^2$$
$$\sigma(qq' \to qq'H) * \mathrm{BR}(H \to \gamma\gamma) \sim \kappa_{VV}^2 \cdot \lambda_{\gamma V}^2$$
$$\sigma(gg \to H) * \mathrm{BR}(H \to ZZ^{(*)}, H \to WW^{(*)}) \sim \lambda_{FV}^2 \cdot \kappa_{VV}^2$$
$$\sigma(qq' \to qq'H) * \mathrm{BR}(H \to ZZ^{(*)}, H \to WW^{(*)}) \sim \kappa_{VV}^2$$
$$\sigma(qq' \to qq'H, VH) * \mathrm{BR}(H \to \tau\tau, H \to b\bar{b}) \sim \kappa_{VV}^2 \cdot \lambda_{FV}^2 \quad .$$



Custodial symmetry

$$\kappa_{ZZ} = \kappa_Z \cdot \kappa_Z / \kappa_H$$
$$\lambda_{WZ} = \kappa_W / \kappa_Z$$
$$\lambda_{FZ} = \kappa_F / \kappa_Z \quad .$$

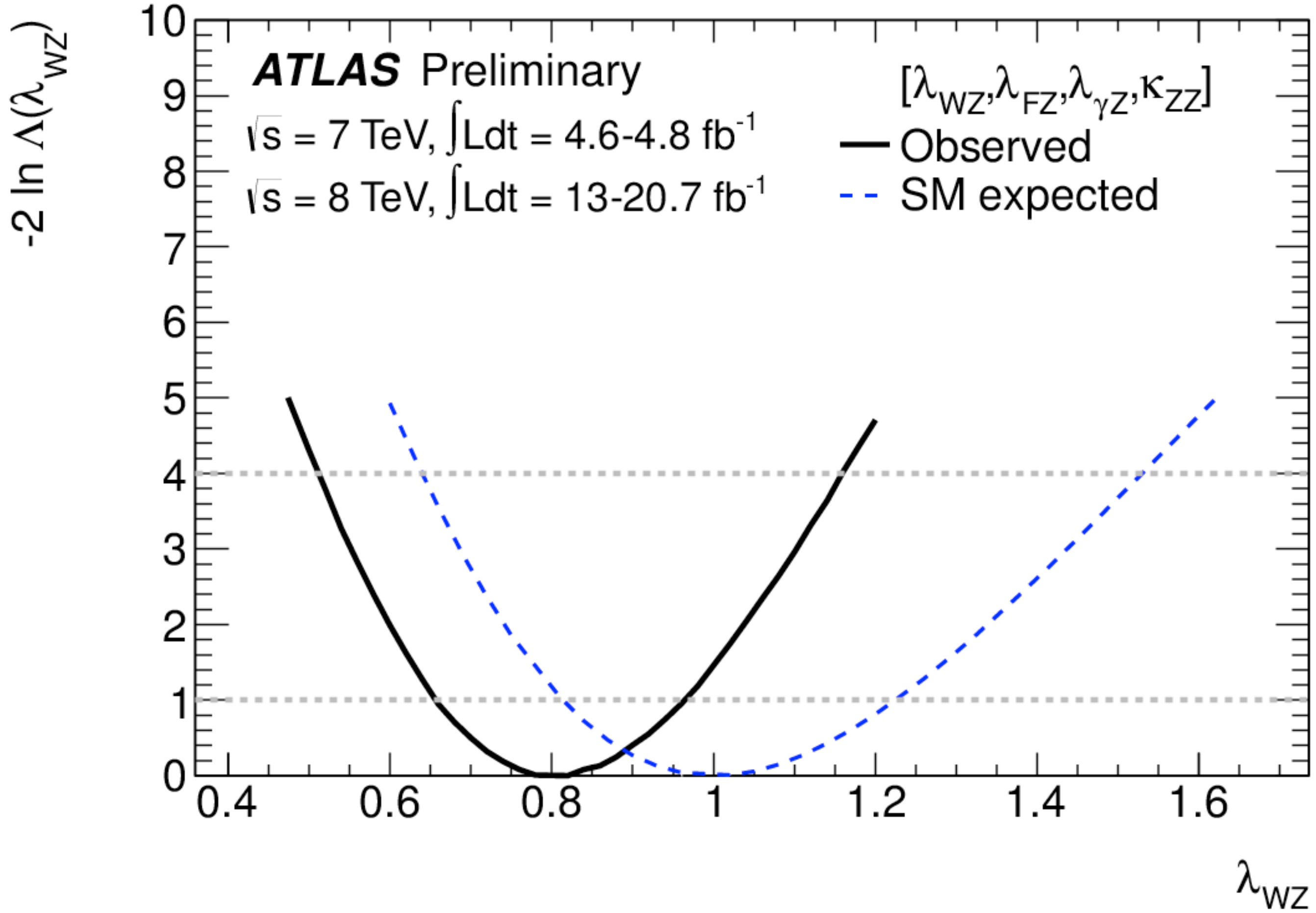
$$\begin{aligned}
\sigma(gg \to H) * \mathrm{BR}(H \to \gamma\gamma) &\sim \lambda_{FZ}^2 \cdot \kappa_{ZZ}^2 \cdot \kappa_\gamma^2(\lambda_{FZ}, 1) \\
\sigma(qq' \to qq'H) * \mathrm{BR}(H \to \gamma\gamma) &\sim \kappa_{\mathrm{VBF}}^2(\lambda_{WZ}, 1) \cdot \kappa_{ZZ}^2 \cdot \kappa_\gamma^2(\lambda_{FZ}, 1) \\
\sigma(gg \to H) * \mathrm{BR}(H \to ZZ^{(*)}) &\sim \lambda_{FZ}^2 \cdot \kappa_{ZZ}^2 \\
\sigma(qq' \to qq'H) * \mathrm{BR}(H \to ZZ^{(*)}) &\sim \kappa_{\mathrm{VBF}}^2(\lambda_{WZ}, 1) \cdot \kappa_{ZZ}^2 \\
\sigma(gg \to H) * \mathrm{BR}(H \to WW^{(*)}) &\sim \lambda_{FZ}^2 \cdot \kappa_{ZZ}^2 \cdot \lambda_{WZ}^2 \\
\sigma(qq' \to qq'H) * \mathrm{BR}(H \to WW^{(*)}) &\sim \kappa_{\mathrm{VBF}}^2(\lambda_{WZ}, 1) \cdot \kappa_{ZZ}^2 \cdot \lambda_{WZ}^2 \\
\sigma(qq' \to qq'H) * \mathrm{BR}(H \to \tau\tau) &\sim \kappa_{\mathrm{VBF}}^2(\lambda_{WZ}, 1) \cdot \kappa_{ZZ}^2 \cdot \lambda_{FZ}^2 \quad ,
\end{aligned}$$



Custodial symmetry, independent of γγ deviations

$$\begin{aligned}\kappa_{ZZ} &= \kappa_Z \cdot \kappa_Z / \kappa_H \\ \lambda_{WZ} &= \kappa_W / \kappa_Z \\ \lambda_{\gamma Z} &= \kappa_\gamma / \kappa_Z \\ \lambda_{FZ} &= \kappa_F / \kappa_Z \quad .\end{aligned}$$

$$\begin{aligned}
\sigma(gg \to H) * \mathrm{BR}(H \to \gamma\gamma) &\sim \lambda_{FZ}^2 \cdot \kappa_{ZZ}^2 \cdot \lambda_{\gamma Z}^2 \\
\sigma(qq' \to qq'H) * \mathrm{BR}(H \to \gamma\gamma) &\sim \kappa_{\mathrm{VBF}}^2(\lambda_{WZ}, 1) \cdot \kappa_{ZZ}^2 \cdot \lambda_{\gamma Z}^2 \\
\sigma(gg \to H) * \mathrm{BR}(H \to ZZ^{(*)}) &\sim \lambda_{FZ}^2 \cdot \kappa_{ZZ}^2 \\
\sigma(qq' \to qq'H) * \mathrm{BR}(H \to ZZ^{(*)}) &\sim \kappa_{\mathrm{VBF}}^2(\lambda_{WZ}, 1) \cdot \kappa_{ZZ}^2 \\
\sigma(gg \to H) * \mathrm{BR}(H \to WW^{(*)}) &\sim \lambda_{FZ}^2 \cdot \kappa_{ZZ}^2 \cdot \lambda_{WZ}^2 \\
\sigma(qq' \to qq'H) * \mathrm{BR}(H \to WW^{(*)}) &\sim \kappa_{\mathrm{VBF}}^2(\lambda_{WZ}, 1) \cdot \kappa_{ZZ}^2 \cdot \lambda_{WZ}^2 \\
\sigma(qq' \to qq'H) * \mathrm{BR}(H \to \tau\tau) &\sim \kappa_{\mathrm{VBF}}^2(\lambda_{WZ}, 1) \cdot \kappa_{ZZ}^2 \cdot \lambda_{FZ}^2 \quad .
\end{aligned}$$



BSM contribution, SM Γ

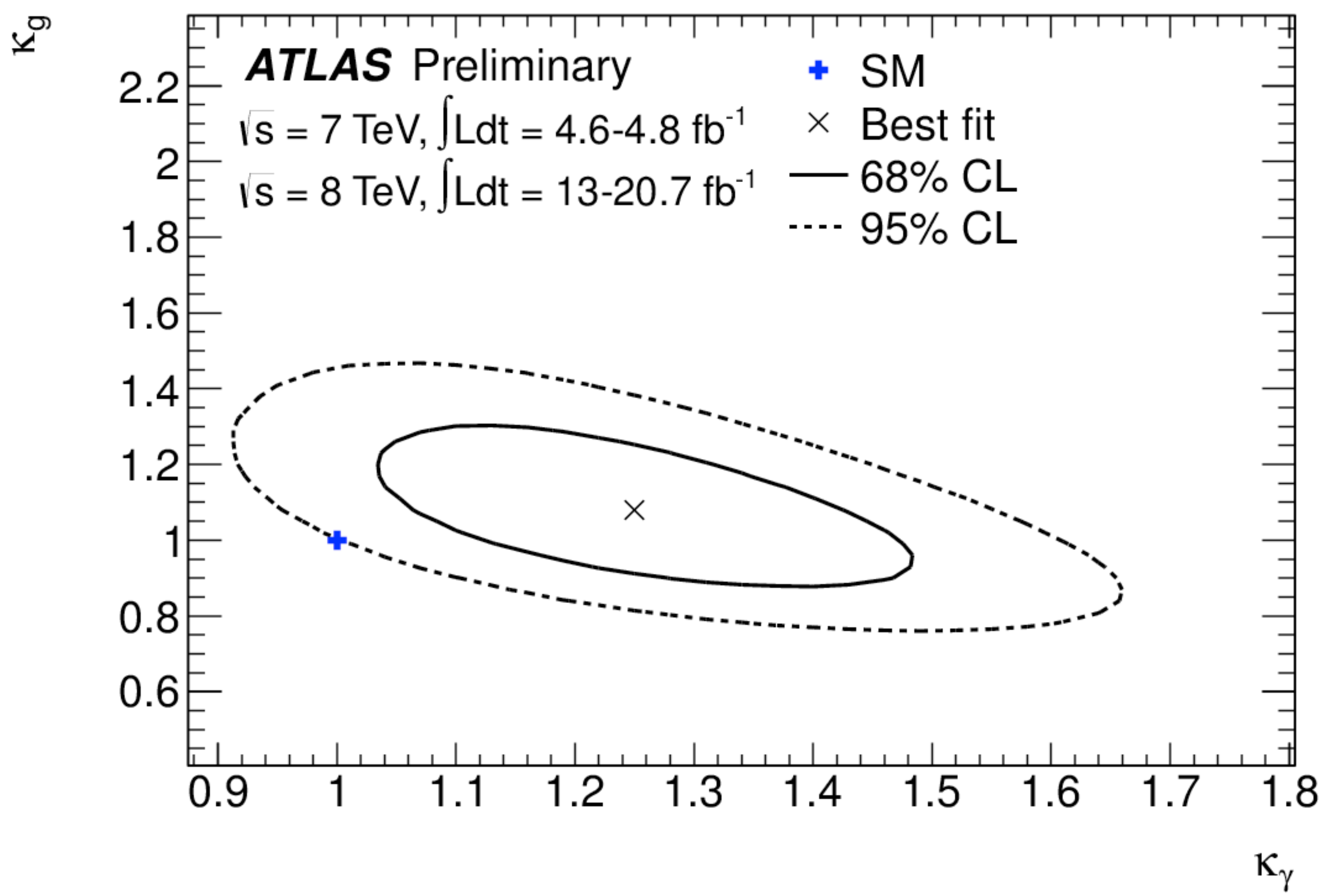
$$\sigma(gg \to H) * \mathrm{BR}(H \to \gamma\gamma) \sim \frac{\kappa_g^2 \cdot \kappa_\gamma^2}{0.085 \cdot \kappa_g^2 + 0.0023 \cdot \kappa_\gamma^2 + 0.91}$$

$$\sigma(qq' \to qq'H) * \mathrm{BR}(H \to \gamma\gamma) \sim \frac{\kappa_\gamma^2}{0.085 \cdot \kappa_g^2 + 0.0023 \cdot \kappa_\gamma^2 + 0.91}$$

$$\sigma(gg \to H) * \mathrm{BR}(H \to ZZ^{(*)}, H \to WW^{(*)}) \sim \frac{\kappa_g^2}{0.085 \cdot \kappa_g^2 + 0.0023 \cdot \kappa_\gamma^2 + 0.91}$$

$$\sigma(qq' \to qq'H) * \mathrm{BR}(H \to ZZ^{(*)}, H \to WW^{(*)}) \sim \frac{1}{0.085 \cdot \kappa_g^2 + 0.0023 \cdot \kappa_\gamma^2 + 0.91}$$

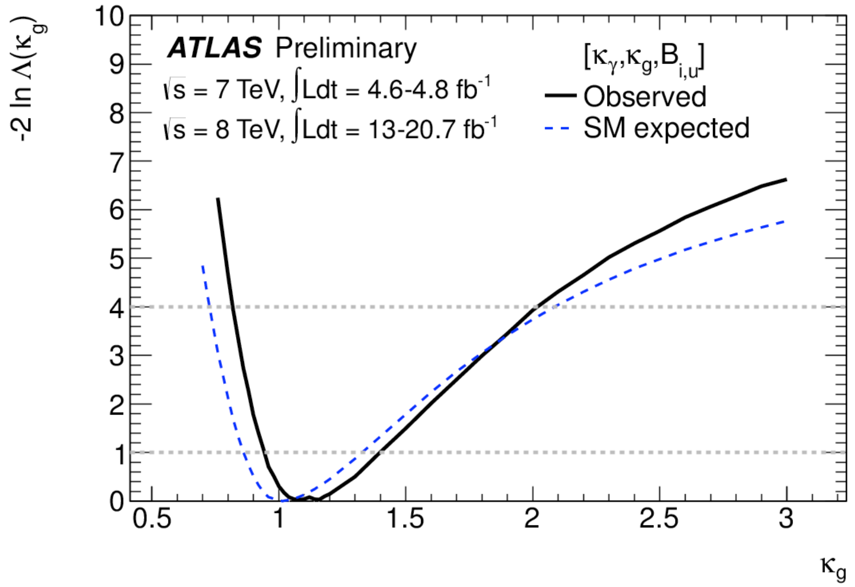
$$\sigma(qq' \to qq'H, VH) * \mathrm{BR}(H \to \tau\tau, H \to b\bar{b}) \sim \frac{1}{0.085 \cdot \kappa_g^2 + 0.0023 \cdot \kappa_\gamma^2 + 0.91} .$$

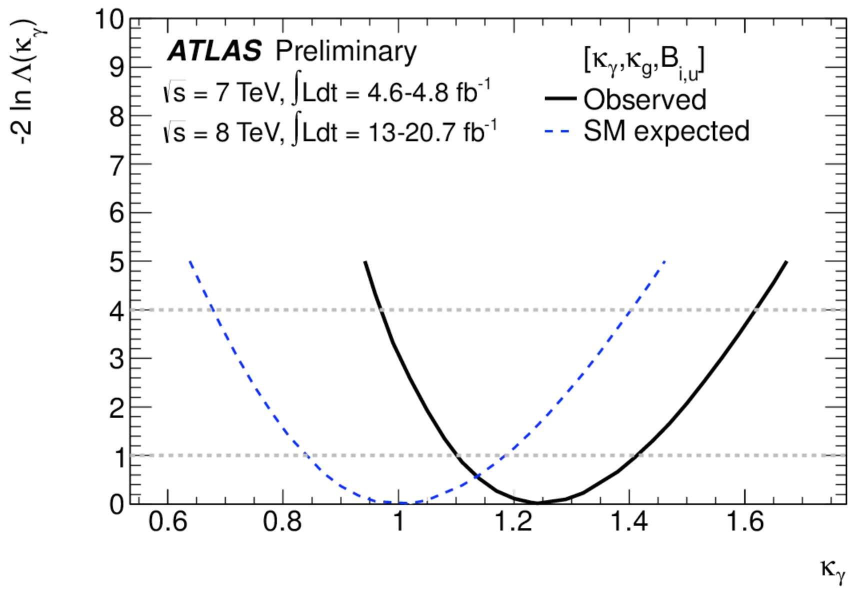


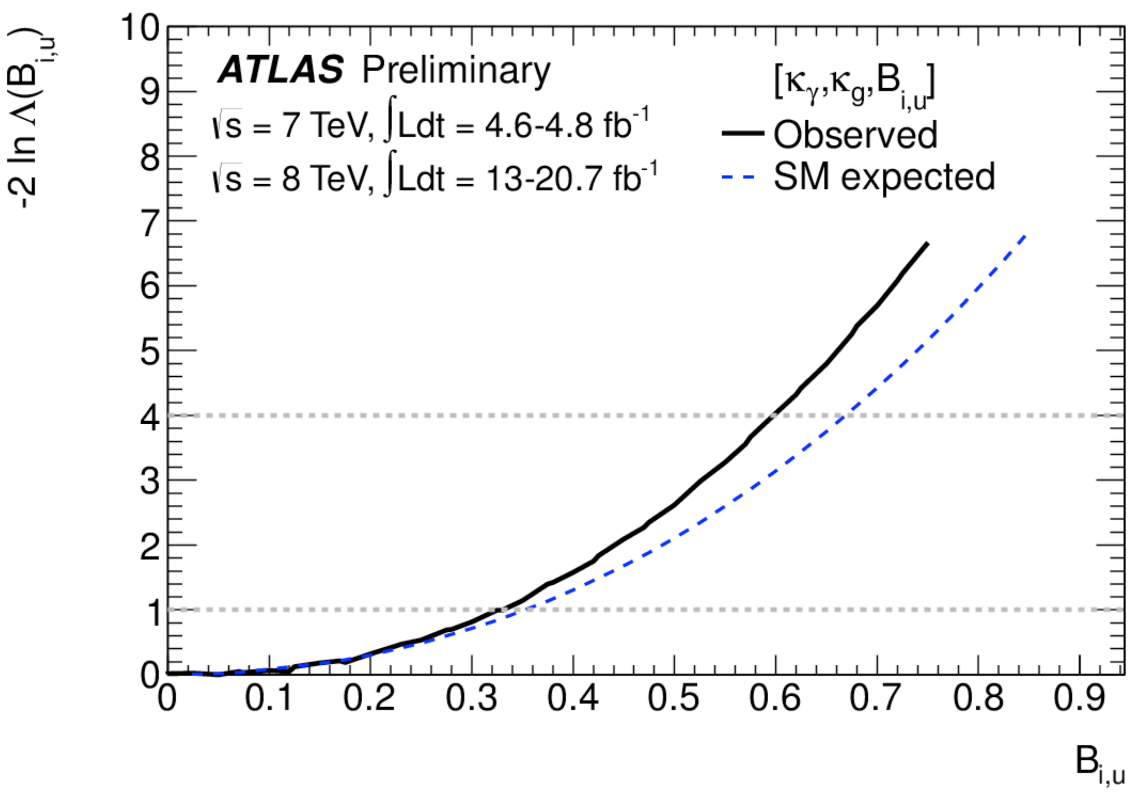
BSM contributions, $BR_{invis,undet}$

$$\Gamma_H = \frac{\kappa_H^2(\kappa_i)}{(1 - BR_{inv.,undet.})}\Gamma_H^{SM} .$$

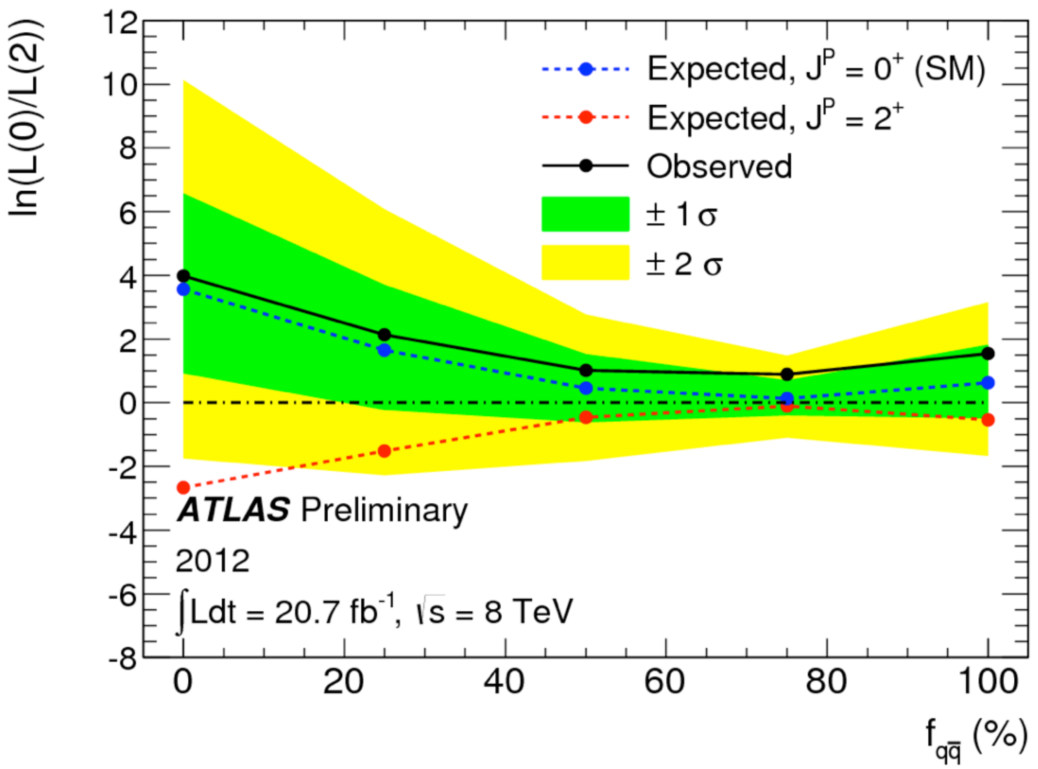
$$\begin{aligned}
\sigma(gg \to H) * BR(H \to \gamma\gamma) &\sim \frac{\kappa_g^2 \cdot \kappa_\gamma^2}{0.085 \cdot \kappa_g^2 + 0.0023 \cdot \kappa_\gamma^2 + 0.91} \cdot (1 - BR_{inv.,undet.}) \\
\sigma(qq' \to qq'H) * BR(H \to \gamma\gamma) &\sim \frac{\kappa_\gamma^2}{0.085 \cdot \kappa_g^2 + 0.0023 \cdot \kappa_\gamma^2 + 0.91} \cdot (1 - BR_{inv.,undet.}) \\
\sigma(gg \to H) * BR(H \to ZZ^{(*)}, H \to WW^{(*)}) &\sim \frac{\kappa_g^2}{0.085 \cdot \kappa_g^2 + 0.0023 \cdot \kappa_\gamma^2 + 0.91} \cdot (1 - BR_{inv.,undet.}) \quad (48) \\
\sigma(qq' \to qq'H) * BR(H \to ZZ^{(*)}, H \to WW^{(*)}) &\sim \frac{1}{0.085 \cdot \kappa_g^2 + 0.0023 \cdot \kappa_\gamma^2 + 0.91} \cdot (1 - BR_{inv.,undet.}) \\
\sigma(qq' \to qq'H, VH) * BR(H \to \tau\tau, H \to b\bar{b}) &\sim \frac{1}{0.085 \cdot \kappa_g^2 + 0.0023 \cdot \kappa_\gamma^2 + 0.91} \cdot (1 - BR_{inv.,undet.}) .
\end{aligned}$$



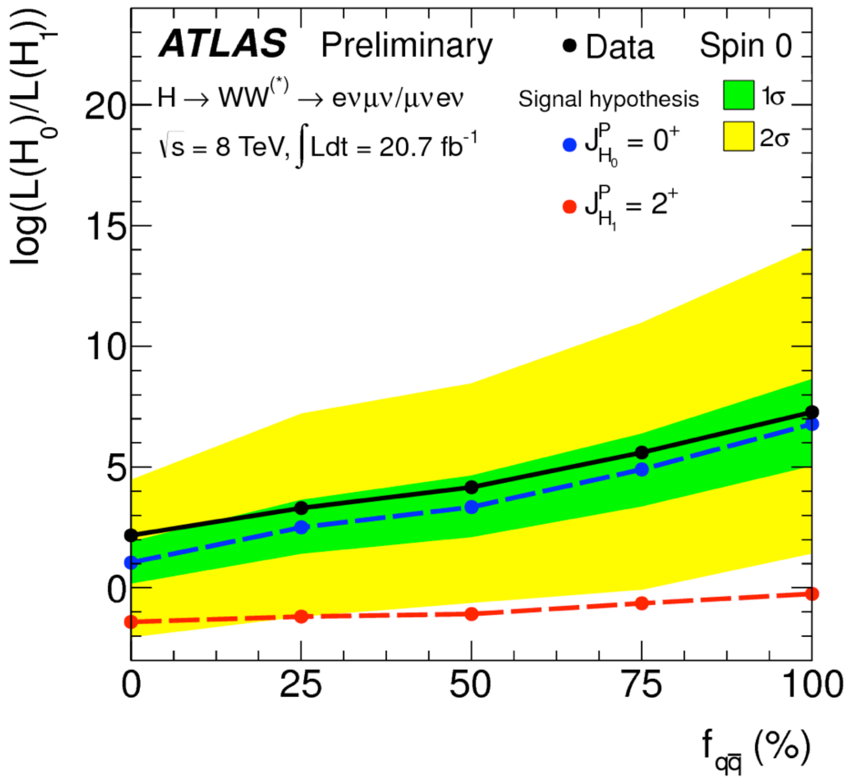




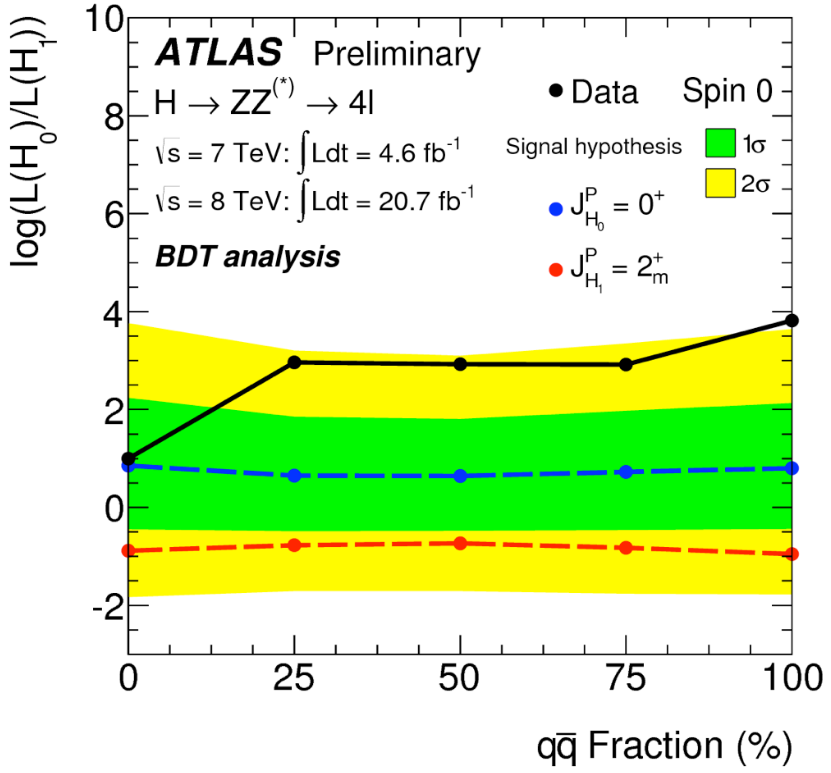
Spin



ln(L(0)/L(2))
Expected, J^P = 0^+ (SM)
Expected, J^P = 2^+
Observed
± 1 σ
± 2 σ
ATLAS Preliminary
2012
∫Ldt = 20.7 fb^-1, √s = 8 TeV
f_qq̄ (%)



log(L(H_0)/L(H_1))
ATLAS Preliminary
Data
Spin 0
H → WW^(*) → eνμν/μνeν
√s = 8 TeV, ∫Ldt = 20.7 fb^-1
Signal hypothesis
1σ
2σ
J^P_H0 = 0^+
J^P_H1 = 2^+
f_qq̄ (%)



log(L(H_0)/L(H_1))
ATLAS Preliminary
H → ZZ^(*) → 4l
√s = 7 TeV: ∫Ldt = 4.6 fb^-1
√s = 8 TeV: ∫Ldt = 20.7 fb^-1
BDT analysis
Data
Spin 0
Signal hypothesis
1σ
2σ
J^P_H0 = 0^+
J^P_H1 = 2^+_m
qq̄ Fraction (%)

Mass difference, council

ATLAS-CONF-2012-170