Update on Higgs HCP results

B. Di Micco
CERN
Università degli Studi di Roma Tre

On behalf of the ATLAS collaboration

Introduction

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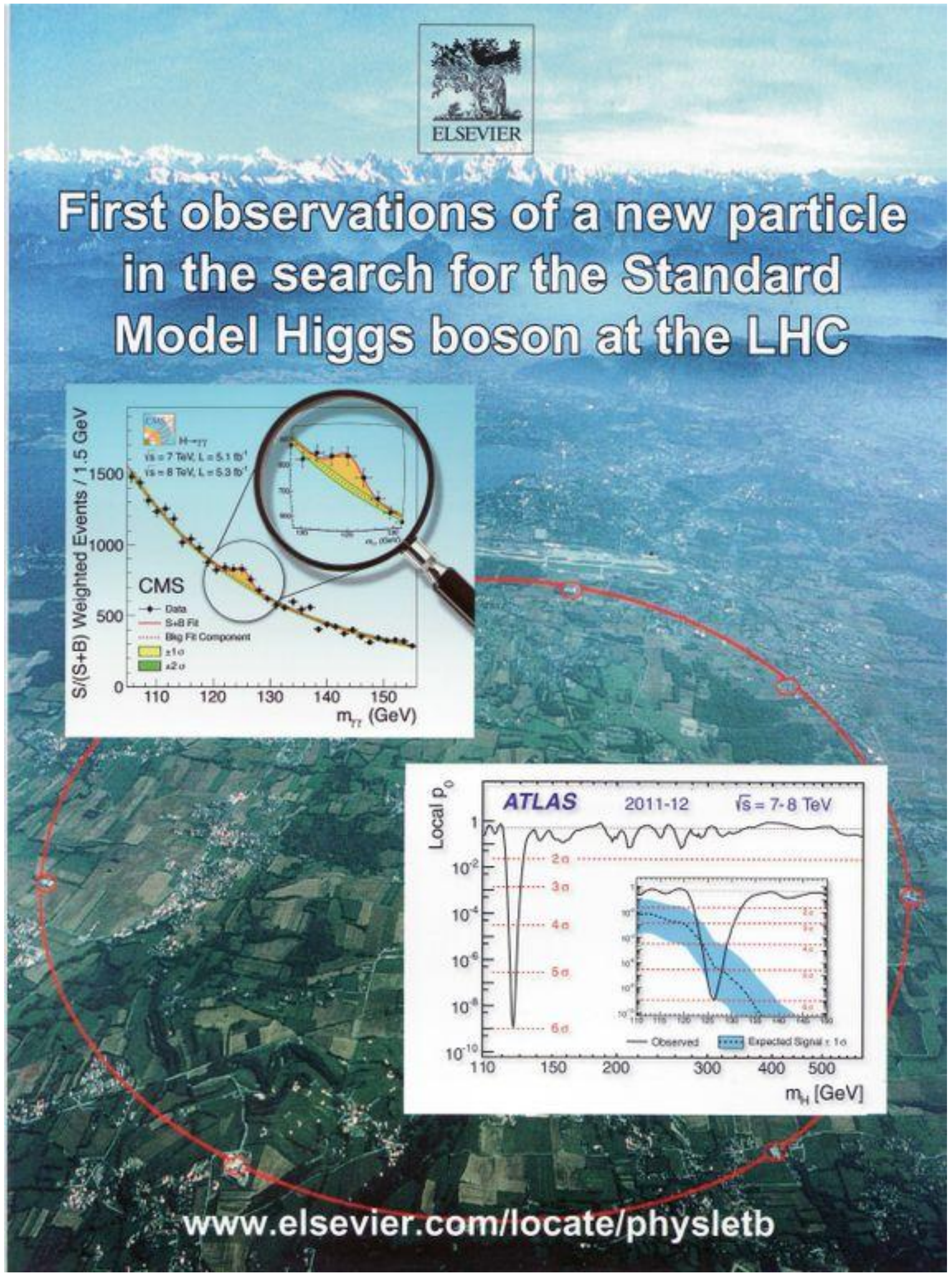
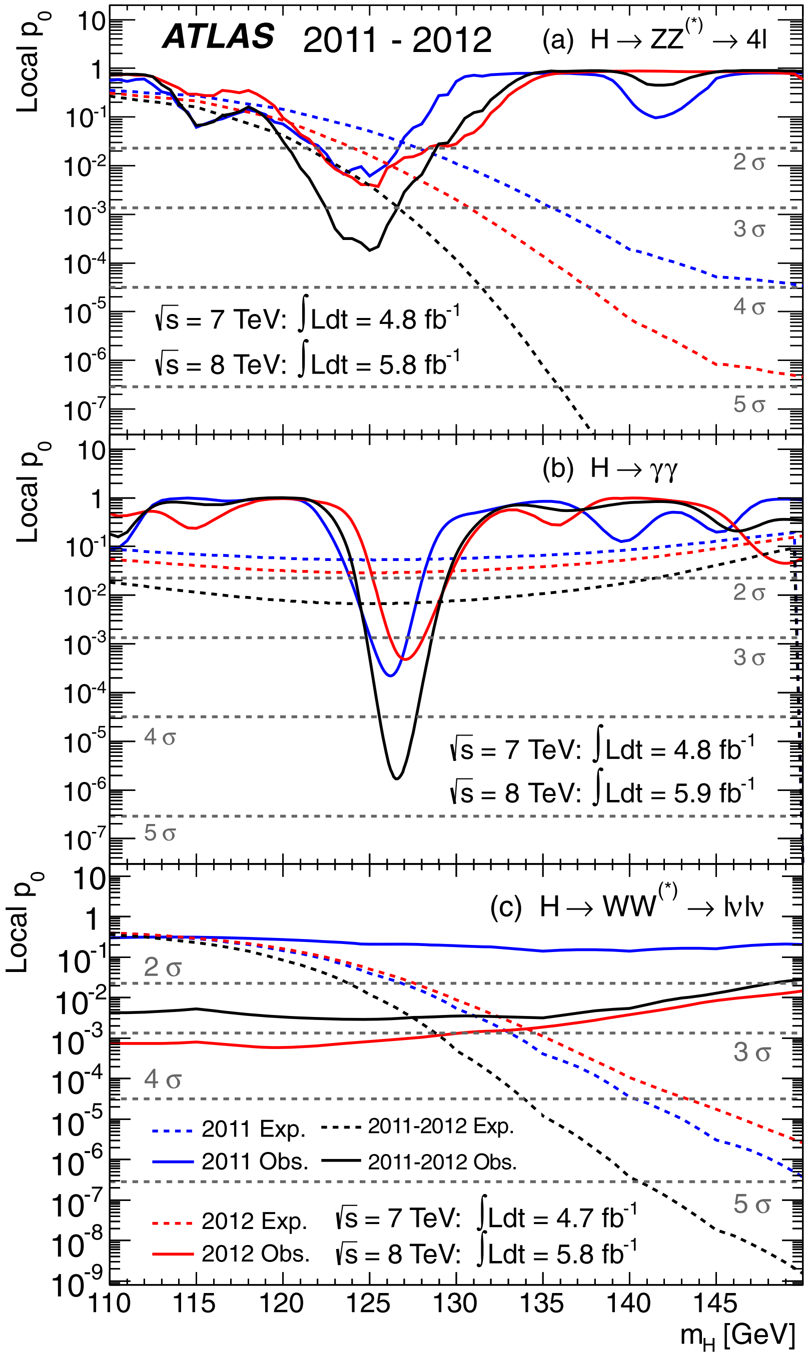


ELSEVIER

First observations of a new particle in the search for the Standard Model Higgs boson at the LHC

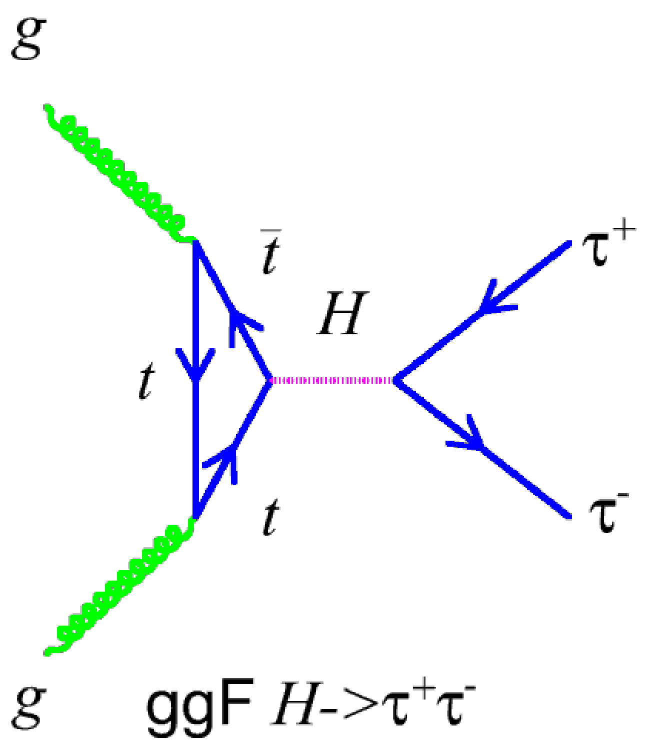
www.elsevier.com/locate/physletb

- Higgs discovered this summer
- Observation in the most sensitive channels $\gamma\gamma$, ZZ, WW
- 6σ observed, 5σ expected.



What we know today.

- It is a non spin 1 boson (observed in $\gamma\gamma$);
- It couples to both W and Z (needed to explain the EWSB);
- It’s production cross section is consistent with the SM ggF process (at least at order 1), so it most likely couples to top.
- Does it couple to other fermions (bb) and leptons? SM lepton sector looks a bit triky, one single Higgs is just economic, neutrino masses imply several order of magnitude difference in the couplings



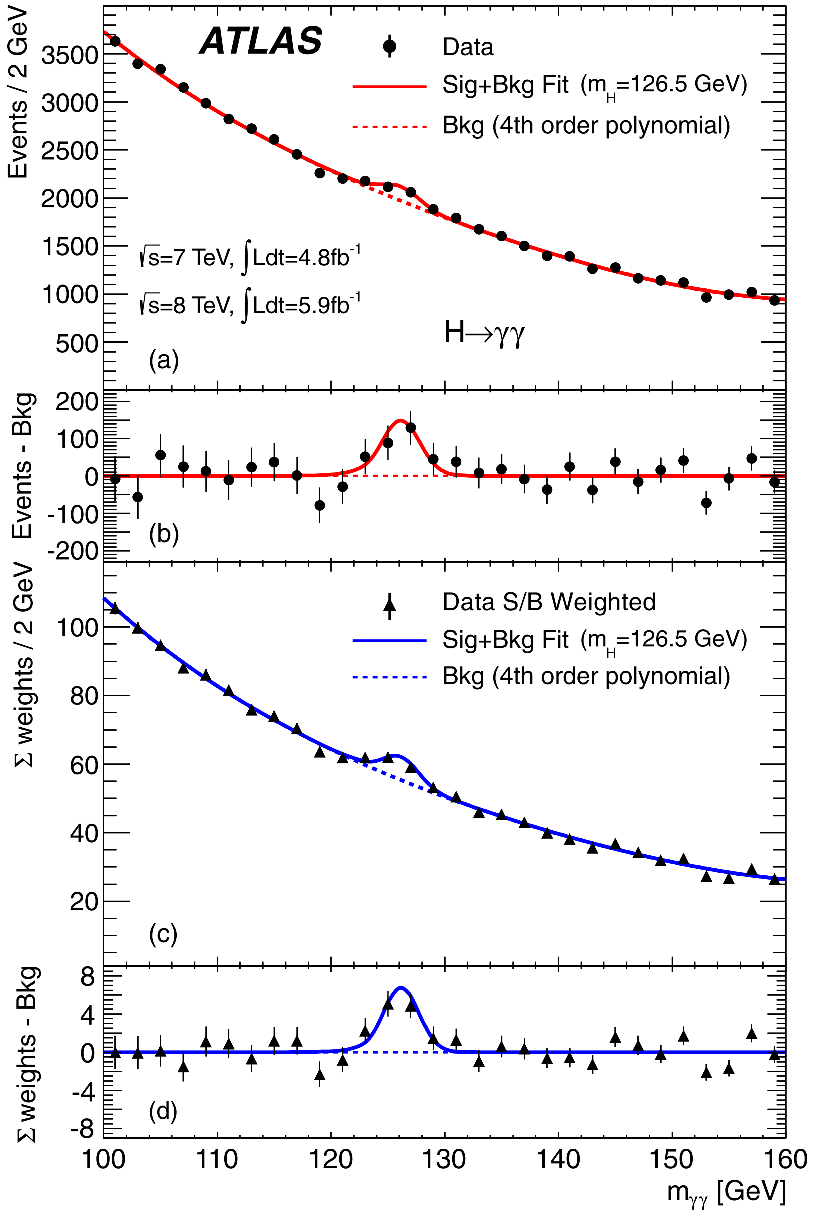
ggF H->$\tau^+\tau^-$

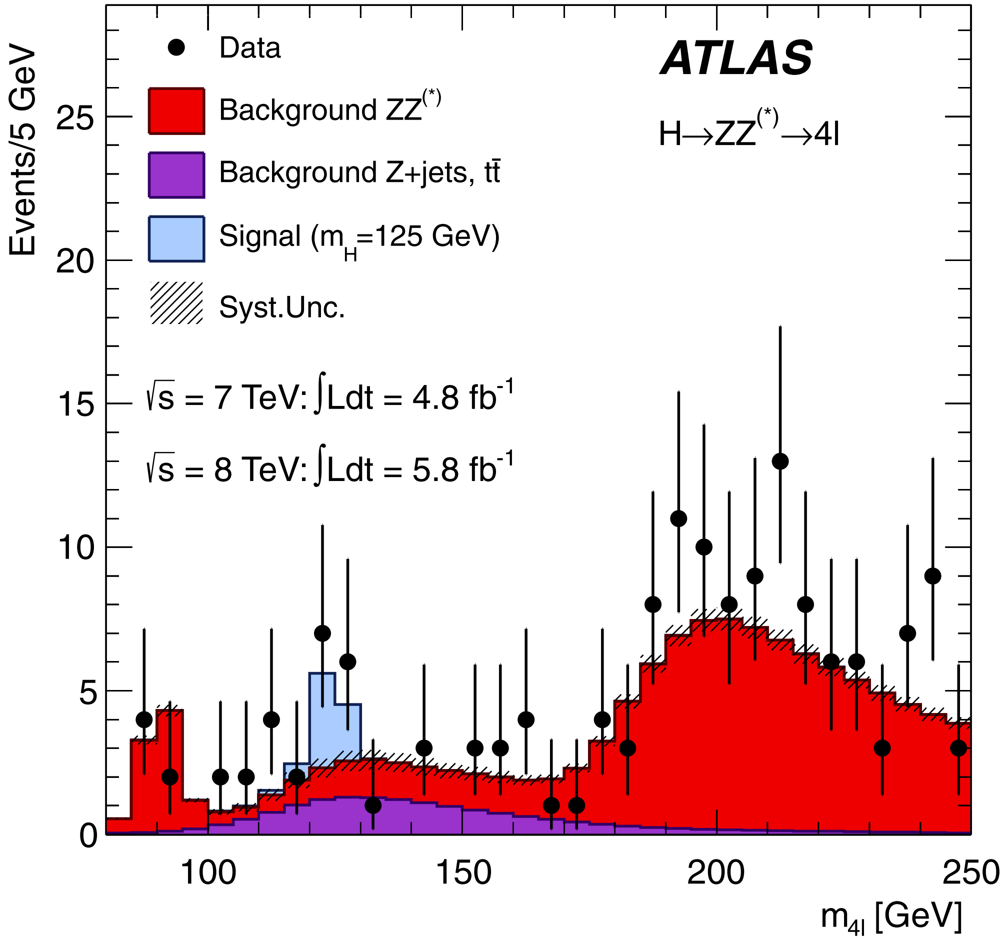
HCP results.

- dedicated to search in $\tau\tau$ and bb;
- mass measurment;
- coupling measurement;
- first attempt to provide cross section measurements unfolded from the theoretical error

ZZ, γγ

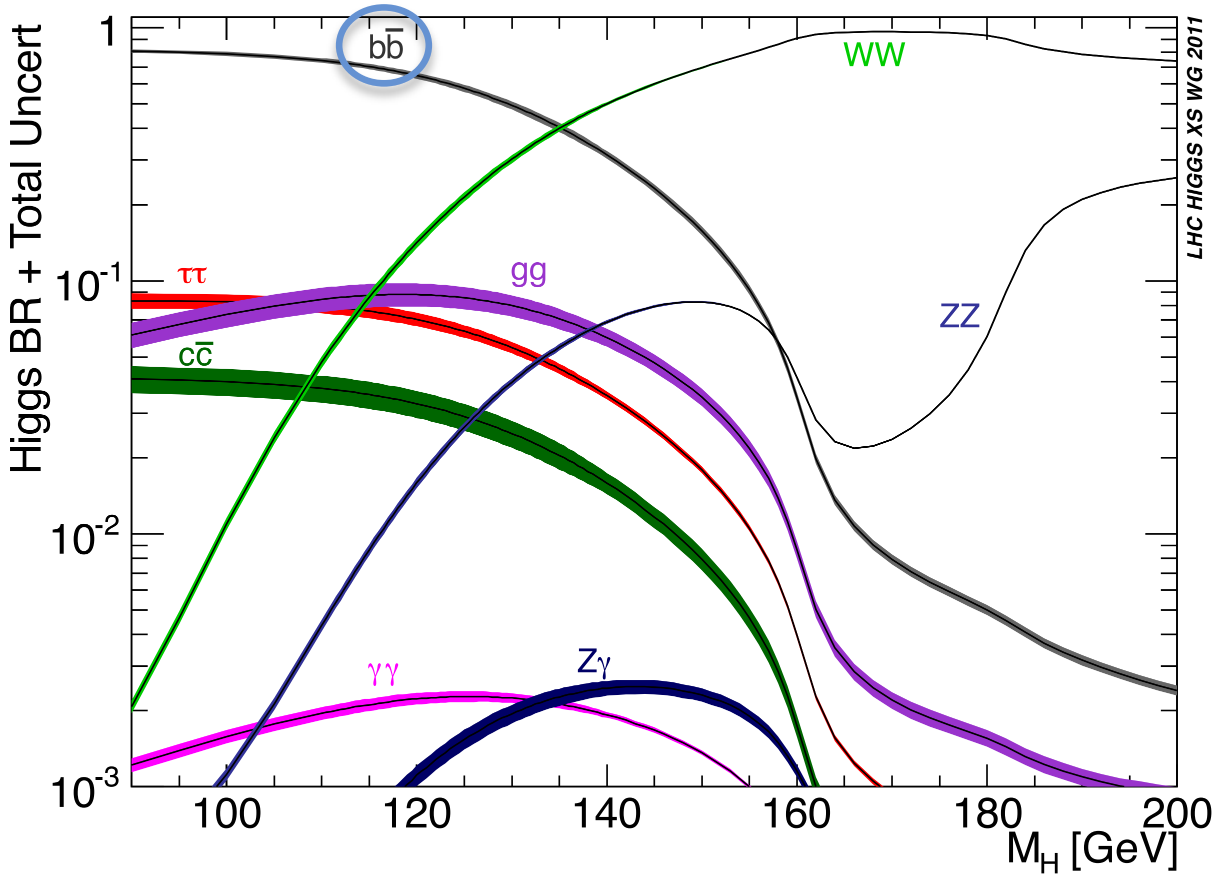
- Missing from HCP;
  - don't worry, they are still there...
  - High statistics is now probing the detector calibration at % level, we need hard work to understand calibrations without a reference point different than the Higgs itself..
  - Possible update in December...





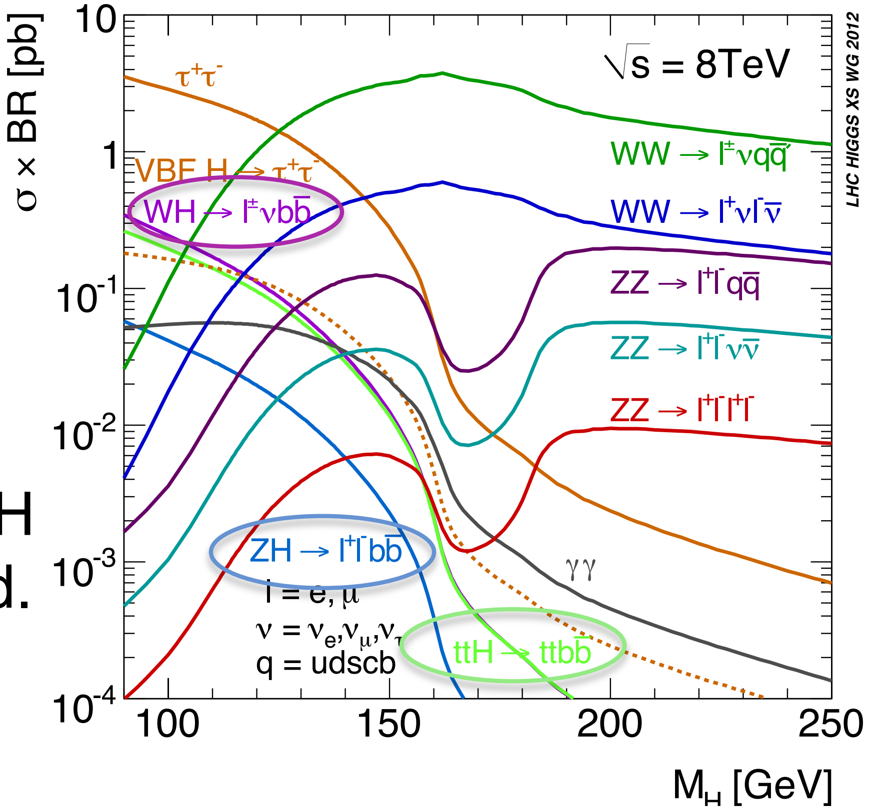
$$H \rightarrow b\bar{b}$$

Higgs production and decay.



- The search for H → bb is important to understand if new particle is SM
- Most prevalent SM Higgs decay
  - At m_H ~125 GeV: BR(H→bb) ~ 58%
  - Direct constraint on coupling to fermions
- Input to measuring VH & tH couplings

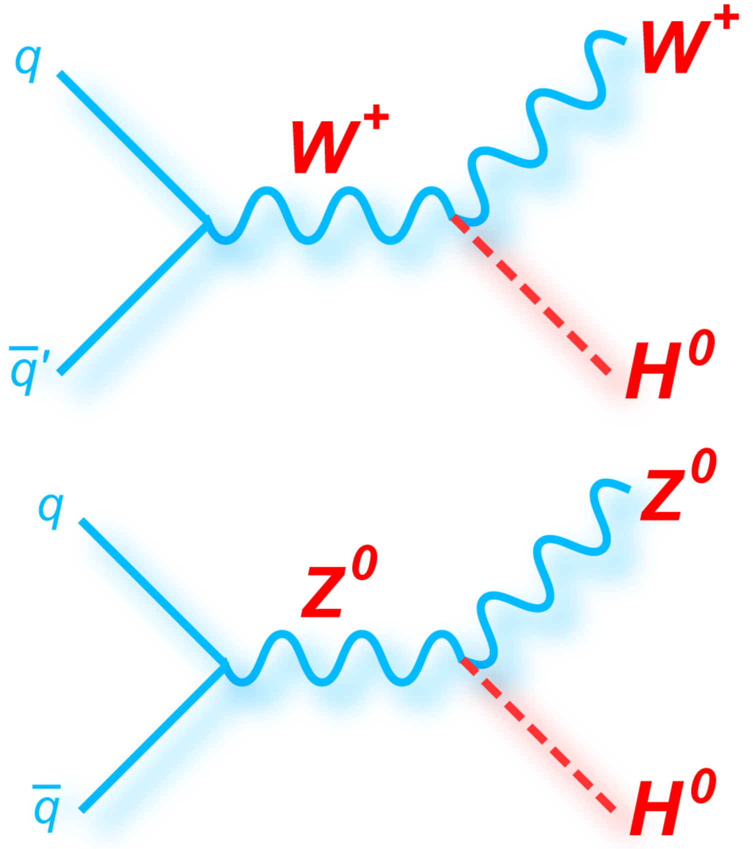
- Very challenging jet backgrounds
  - 7-8 orders of magnitude greater
- Utilise associated production V=W,Z and tt
  - Clean leptonic decay signatures for trigger and offline analysis to reject background events
  - This talk will focus the new VH results. Recent ttH analysis results (7 TeV) are mentioned at the end.



Analysis selection.

Search in ggF and VBF impossible due to the huge QCD multi-jet background
Associate production allows better background rejection through isolated leptons and high missing E_T (reducing QCD)

- Search for Higgs decaying to pair of b-quarks
  - Associated production to reduce backgrounds
- The analysis is divided into three channels
  - Two (llbb), one (lνbb) or zero (ννbb),) (l=e,μ)
- Cuts common to all channels
  - Two or three jets: 1st jet $p_T > 45$ GeV
    other jets $p_T > 20$ GeV
  - Two b-tags: 70% efficiency per tag (mistag ~1%)



Two lepton

ZH → llbb
- No additional leptons
- $E_t^{miss} < 60$ GeV
- $83 < m_Z < 99$ GeV
- Single & di-lepton trigger

One lepton

WH → lνbb
- No additional leptons
- $E_t^{miss} > 25$ GeV
- $40 < M_T^W < 120$ GeV
- Single lepton trigger

Zero lepton

ZH → ννbb
- No leptons
- $E_t^{miss} > 120$ GeV
- E_t^{miss} trigger

Analysis improvements

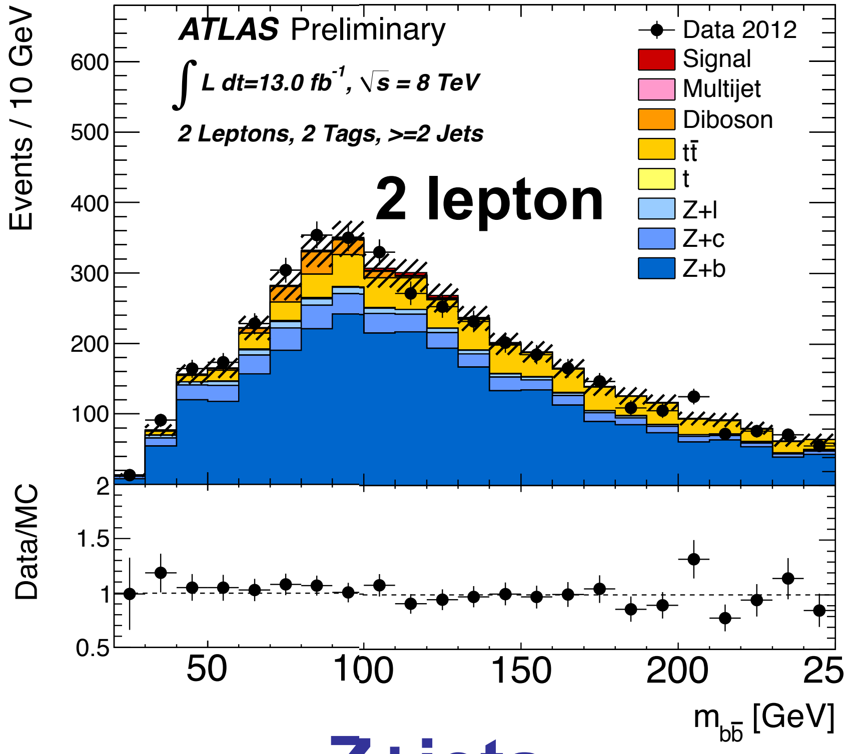
- Data used: 4.7fb^{-1} $\sqrt{s}$ = 7 TeV (2011) & 13fb^{-1} $\sqrt{s}$ = 8 TeV (2012)
  - S/B increases with higher p_T^{bb};
  - The analysis is catgorised as a function of p_T^V
- 16 signal categories with cuts optimised for each
  - ➢ 0-lepton: E_T^{miss} [120-160] [160-200] [>200] GeV x (2 jets or 3 jets)
  - ➢ 1 & 2 lepton: $p_T^{W/Z}$ [0-50],[50,100],[100-150],[150-200] [>200] GeV
- Some other improvements
  - ➢ Muon energy (p_T > 4 GeV) added for b-jets (increased resolution)
  - ➢ Apply ttbar based b-tagging calibration (reduces systematic at high p_T)

Background and MC

- ● Data 2012
- 🟥 Signal
- 🟪 Multijet
- 🟧 Diboson
- 🟨 $t\bar{t}$
- 🟨 t
- 🟩 W+l
- 🟩 W+c
- 🟩 W+b
- 🟦 Z+l
- 🟦 Z+c
- 🟦 Z+b

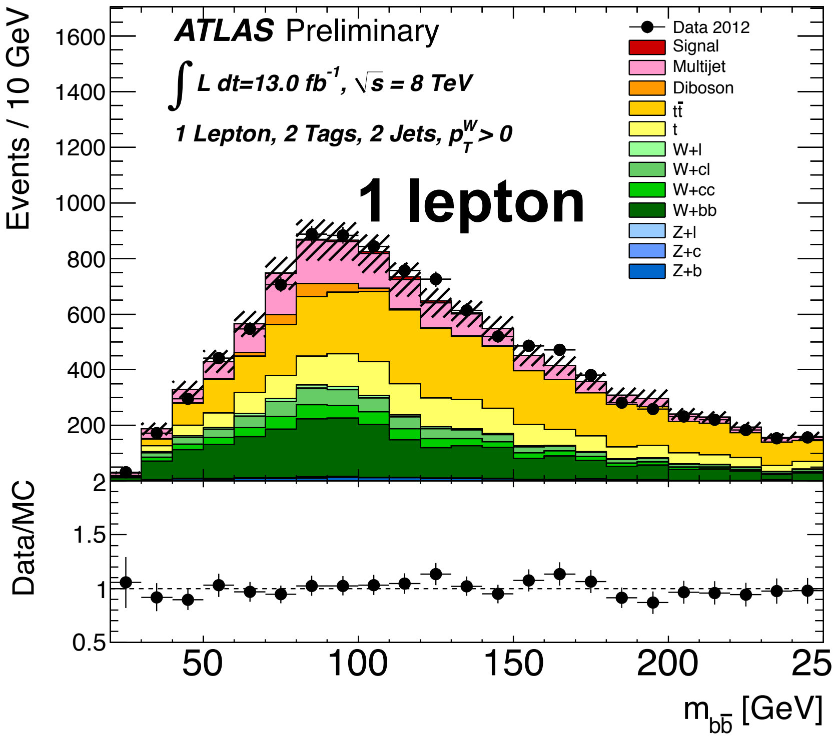
Signal:	WH/ZH Pythia8
Diboson	WW/WZ/ZZ Herwig
Multijet:	Data driven
Ttbar:	MC@NLO
Single Top	Acer/MC@NLO
W+b	Powheg
W+c/light-jets	Alpgen
Z+ b/c/light-jets	Alpgen/Sherpa

- Background shapes from simulation and normalised using data (flavour & signal fit)
- Multi-jet bkg determined by data-driven techniques
- WZ(Z→bb) & ZZ(Z→bb) resonant bkg normalisation and shape from simulation



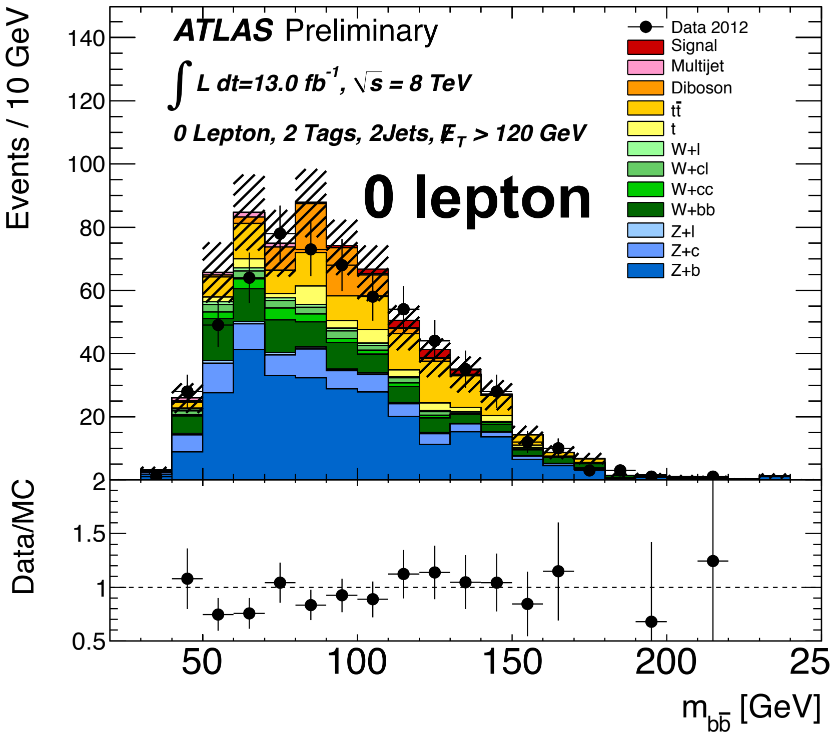
Z+jets

Top CR: m_{ll} outsede Z window, $E_T^{miss} > 60$



Top/W+jets

Top CR: require extra jets (t→Wb→jjb)

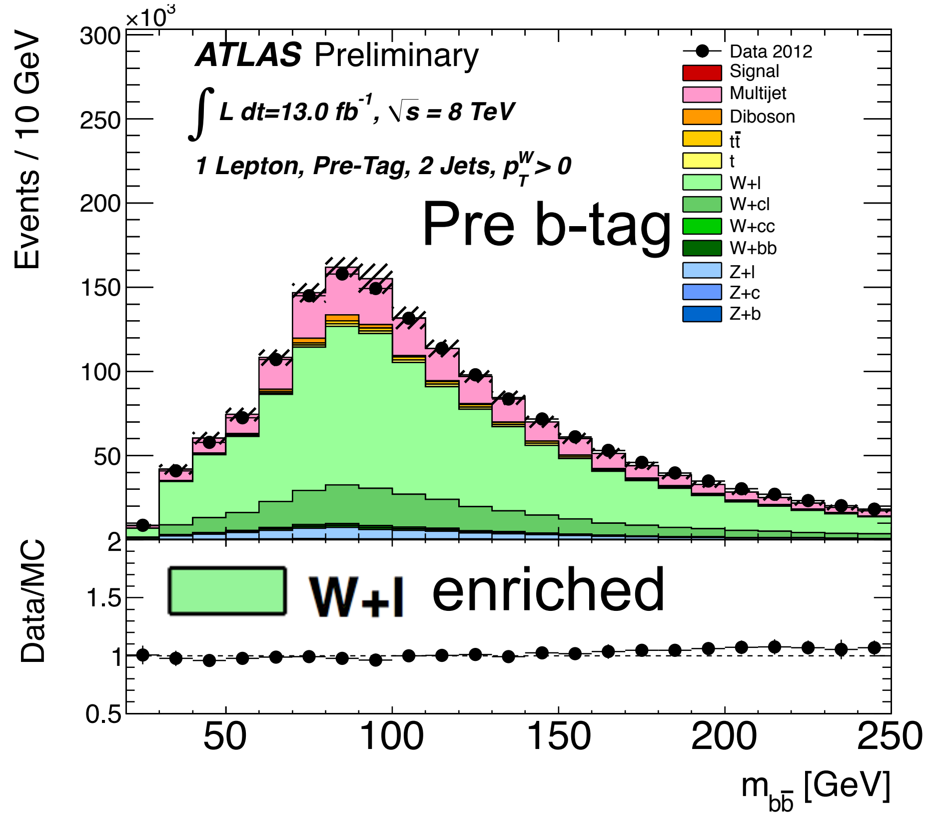


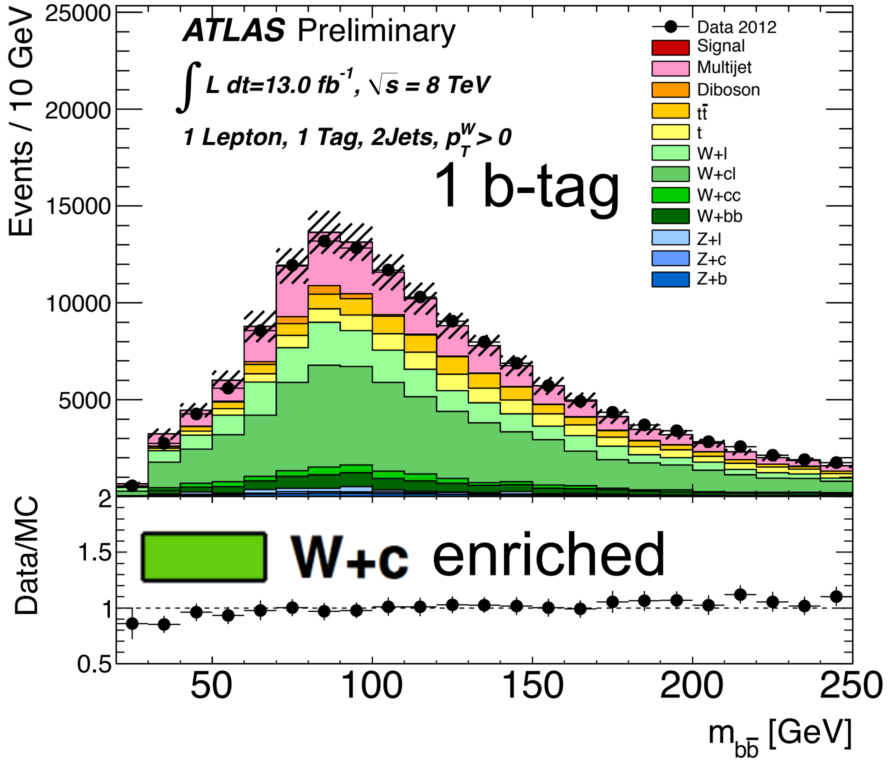
Z+jets/W+jets/Top

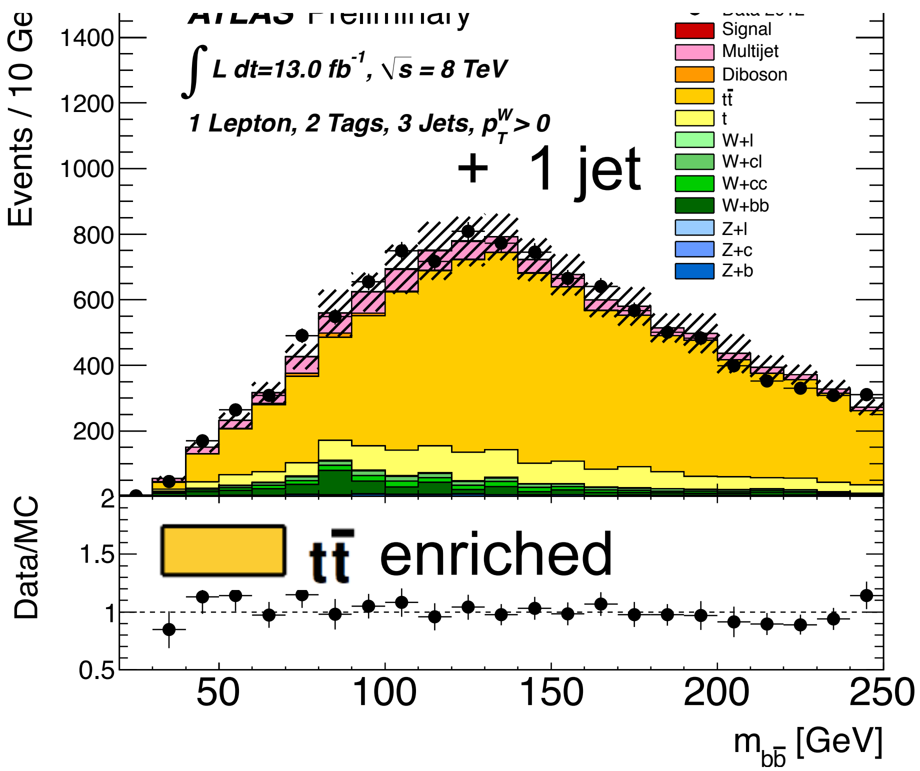
V+jets CR: using pre-tag, 0 and 1 tag region in the pre-tag we expect negligible signal contamination, used to correct p_T^V

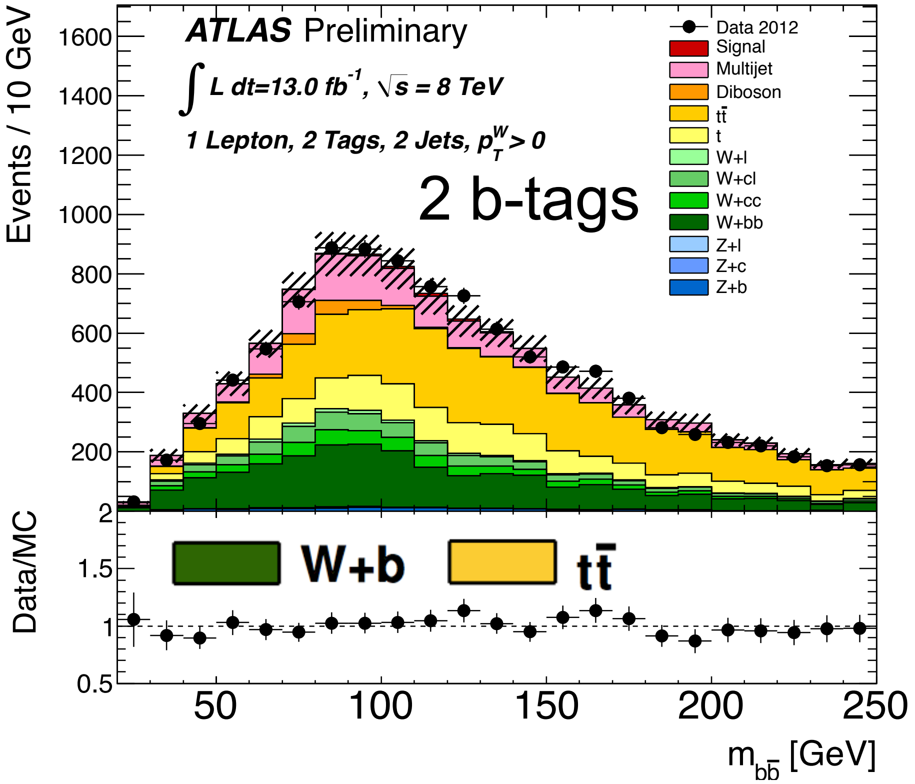
Flavour fit

Events with 0, 1 and 2 b tag jets have different flavour contributions. This allows to fit the normalisation of the several components.









Flavours and signal fit

1. Flavour maximum likelihood fit
    - One scale factor applied for each bkg
    - Determine V+light and V+c scale factors
    - Z+c factor changes due to MC treatment

	$\sqrt{s}$ = 7 TeV	$\sqrt{s}$ = 8 TeV
$Z + c$	1.99 ± 0.51	0.71 ± 0.23
$Z+$ light	0.91 ± 0.12	0.98 ± 0.11
$W + c$	1.04 ± 0.23	1.04 ± 0.24
$W+$ light	1.03 ± 0.08	1.01 ± 0.14

- Improved understanding of bkg V pT
    - Correction from the pre-tag sample applied to both top and V+jets p_T^V distribution.
    - W + jets and Z + jets: ~5-10% correction required
    - Top background: ~15% correction required

Flavour fit produces excellent MC/data agreement in 12 data regions

2. Binned profile likelihood fit to 16 signal regions & top control regions
    - W+b, Z+b and top bkg are floated in fit
    - Rescaling factors from the fit ➠

	$\sqrt{s}$ = 7 TeV	$\sqrt{s}$ = 8 TeV
Top	1.10 ± 0.14	1.29 ± 0.16
$Z + b$	1.22 ± 0.20	1.11 ± 0.15
$W + b$	1.19 ± 0.23	0.79 ± 0.20

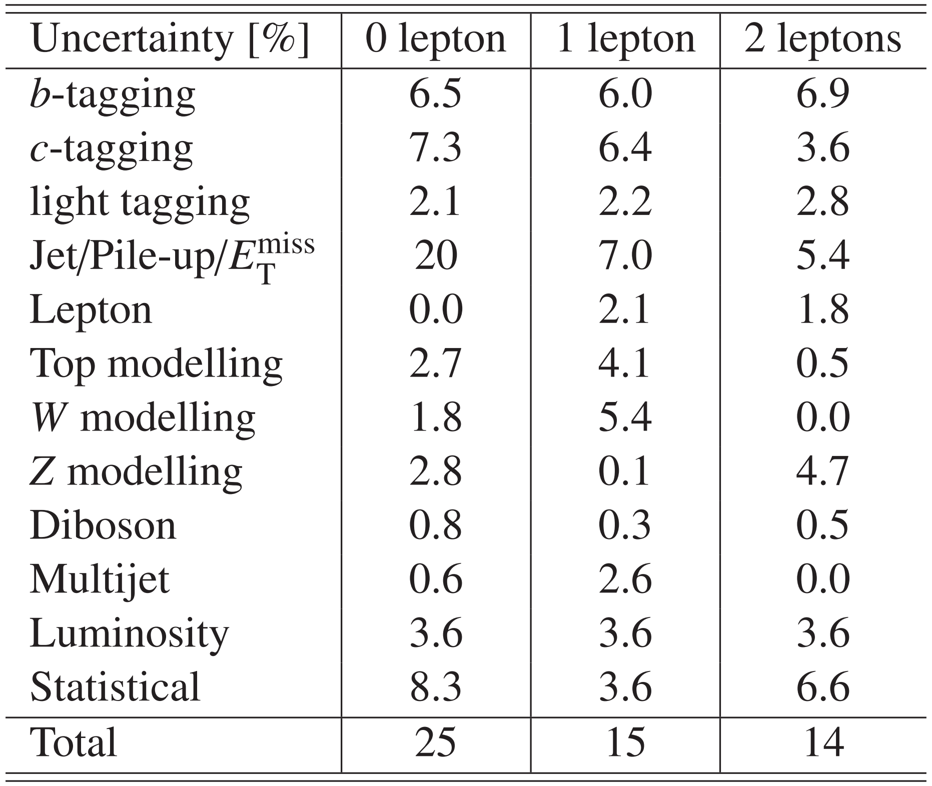
- L(μ,θ) fit to signal strength μ (= σ/σ_{SM})
    - Nuisance parameters θ for systematics

Systematics uncertainties

- **Main experimental uncertainties**

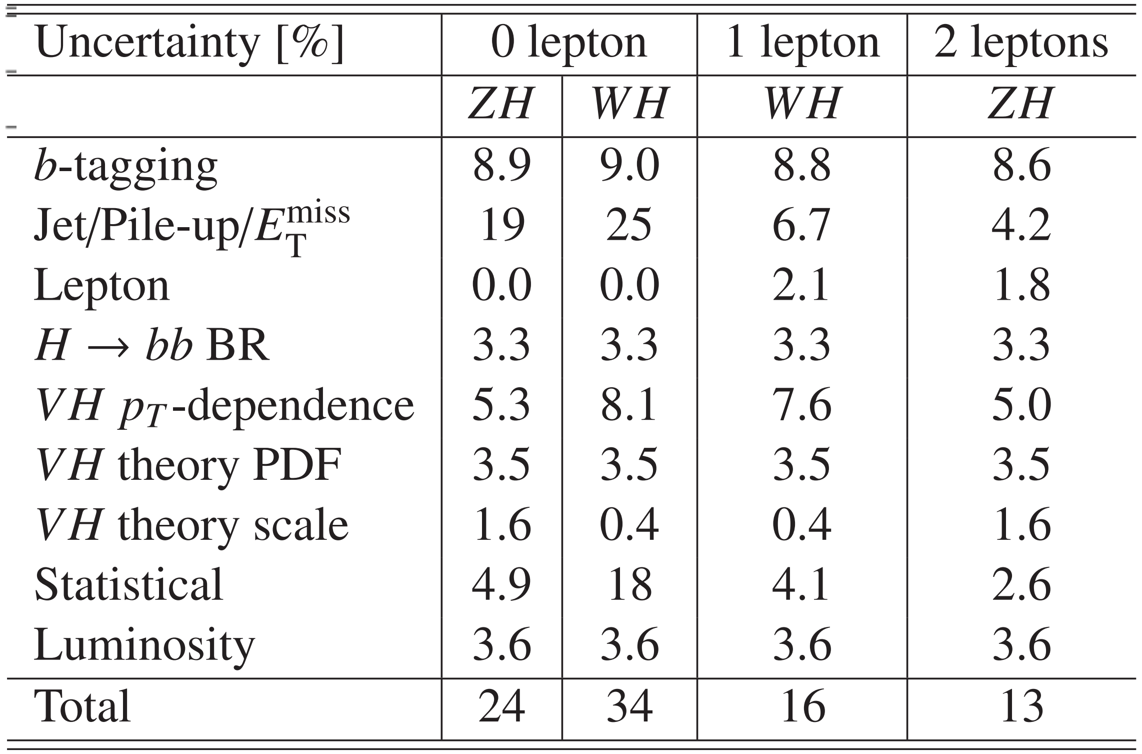
  b-tagging and **jet energy** dominate

  - Jets: components (7 JES, 1 p_T^{Reco}, resol.)
  - E_T^{miss} – scale and resolution
  - bTagging – light, c & 6 p_T efficiency bins
  - Top, W, Z background modelling
  - Lepton/ Multijet / diboson / Luminosity
  - MC statistics



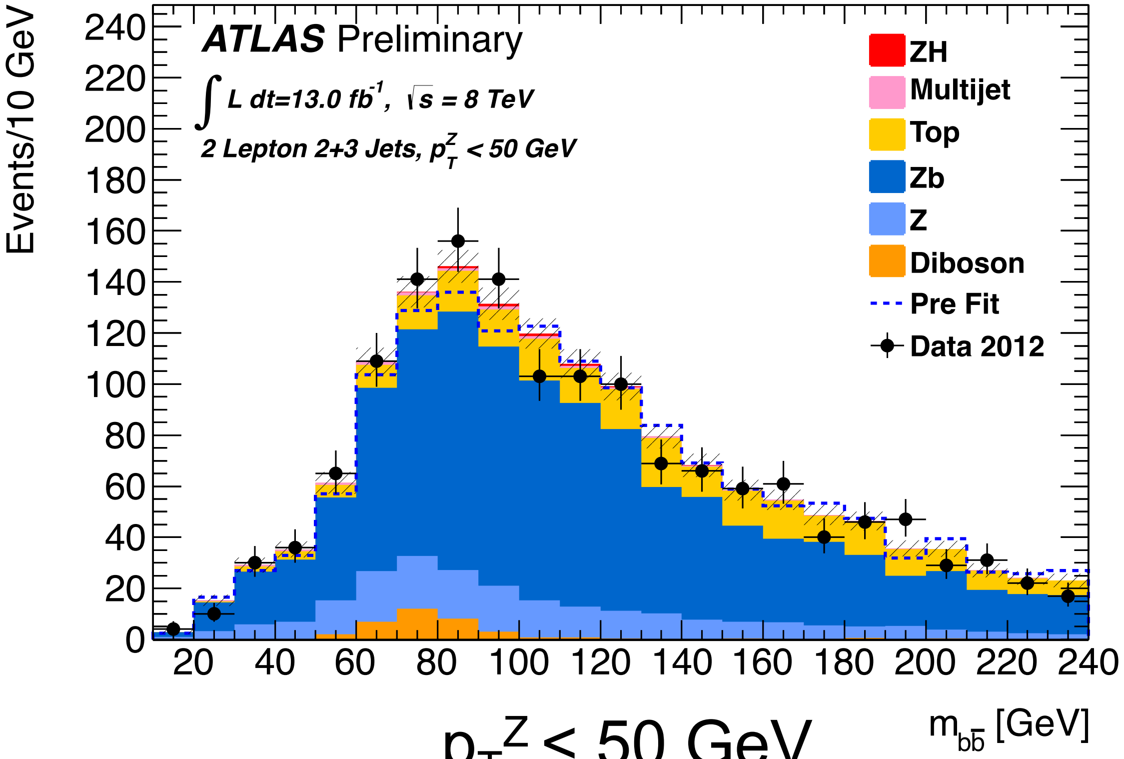
Uncertainty [%]	0 lepton	1 lepton	2 leptons
b-tagging	6.5	6.0	6.9
c-tagging	7.3	6.4	3.6
light tagging	2.1	2.2	2.8
Jet/Pile-up/E_T^{miss}	20	7.0	5.4
Lepton	0.0	2.1	1.8
Top modelling	2.7	4.1	0.5
W modelling	1.8	5.4	0.0
Z modelling	2.8	0.1	4.7
Diboson	0.8	0.3	0.5
Multijet	0.6	2.6	0.0
Luminosity	3.6	3.6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

- **Main theoretical uncertainties**
  - W/Z+jet m_{bb} and V pT
  - BR(H→bb) @ mH=125 GeV
  - Signal cross-sections include pT-dependent electroweak correction factors
  - Single top/top normalisation
  - W+c, Z+c

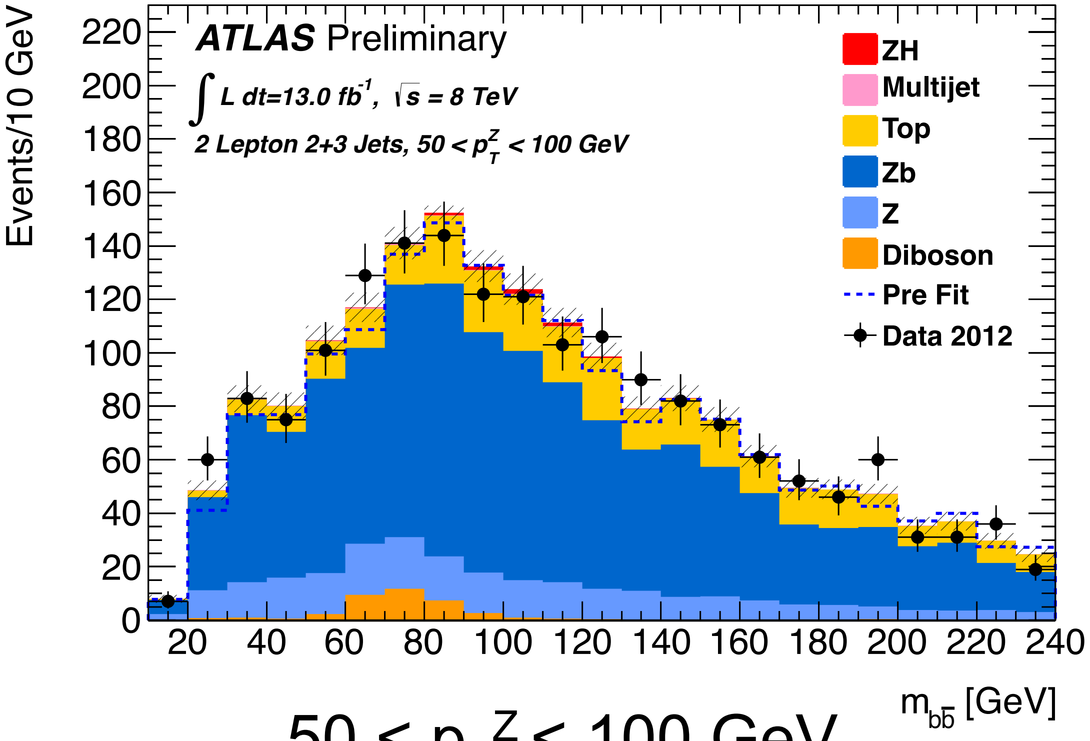


Uncertainty [%]	0 lepton		1 lepton	2 leptons
	ZH	*WH*	*WH*	*ZH*
b-tagging	8.9	9.0	8.8	8.6
Jet/Pile-up/E_T^{miss}	19	25	6.7	4.2
Lepton	0.0	0.0	2.1	1.8
$H \rightarrow bb$ BR	3.3	3.3	3.3	3.3
VH p_T-dependence	5.3	8.1	7.6	5.0
VH theory PDF	3.5	3.5	3.5	3.5
VH theory scale	1.6	0.4	0.4	1.6
Statistical	4.9	18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

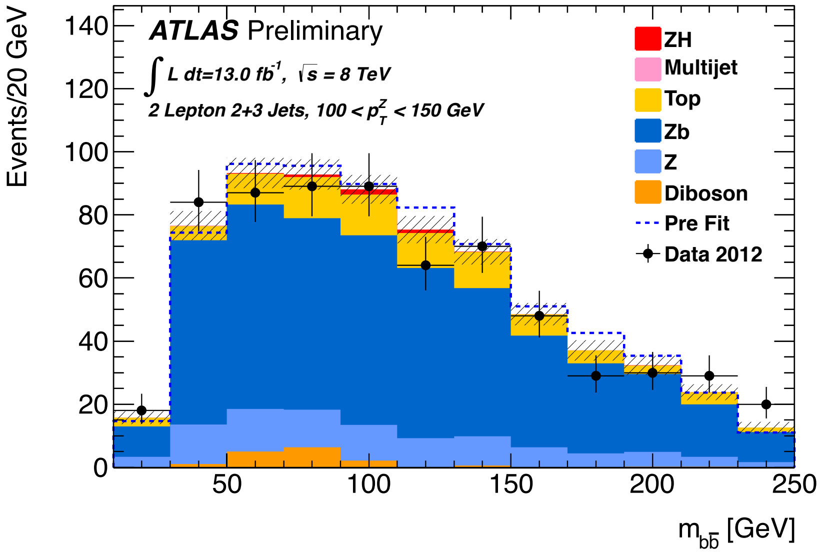
m_{bb} distributions 2-leptons



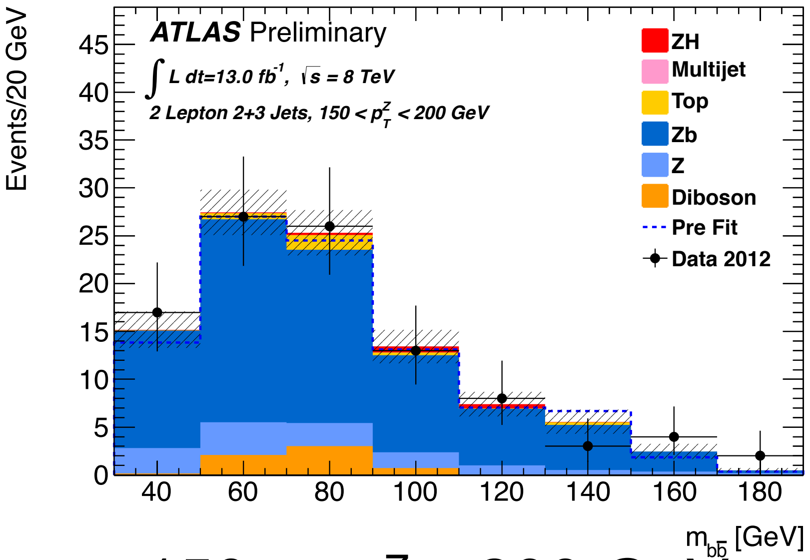
$p_T^Z < 50$ GeV



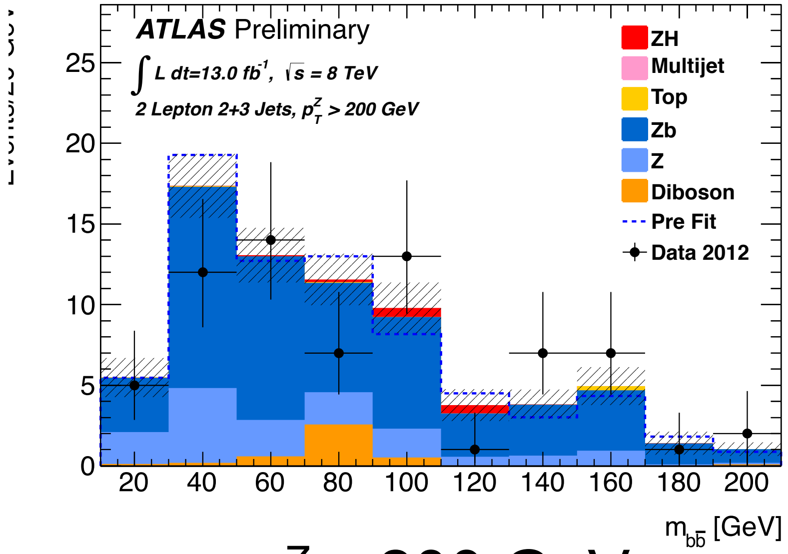
$50 < p_T^Z < 100$ GeV



$100 < p_T^Z < 150$ GeV

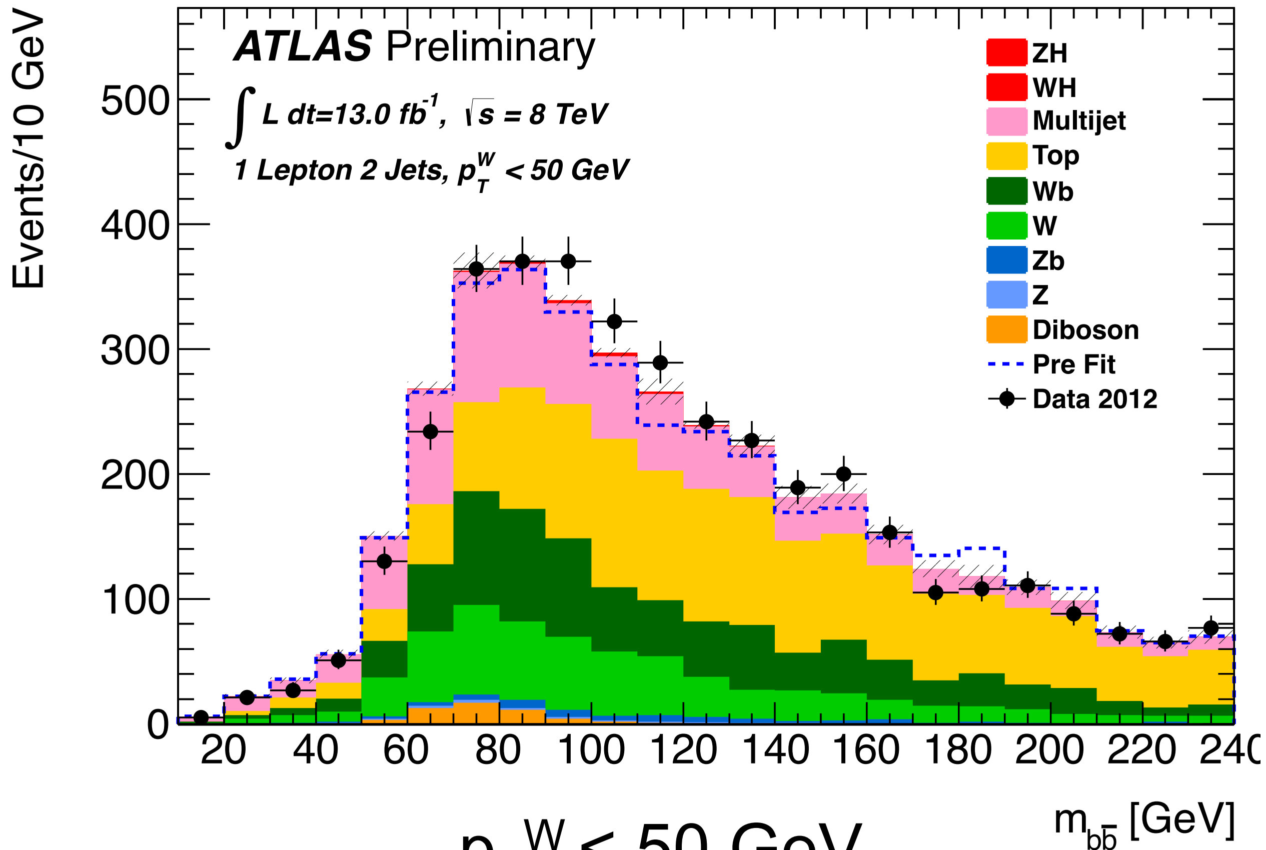


$150 < p_T^Z < 200$ GeV

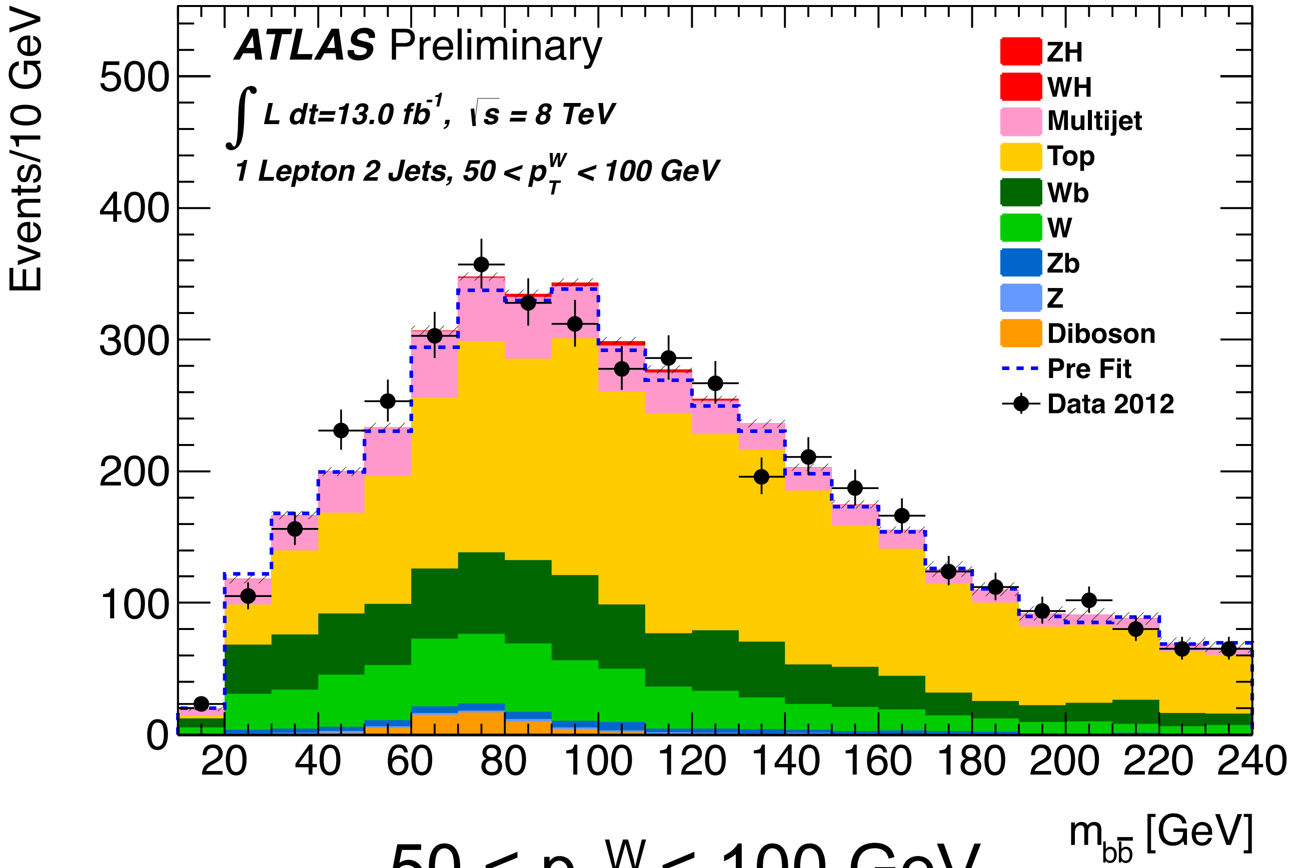


$p_T^Z > 200$ GeV

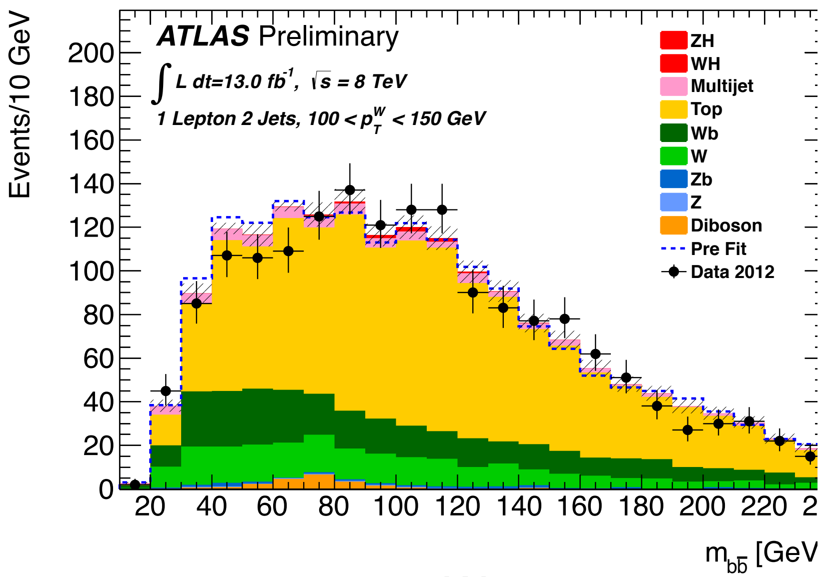
m_{bb} distributions 1-lepton



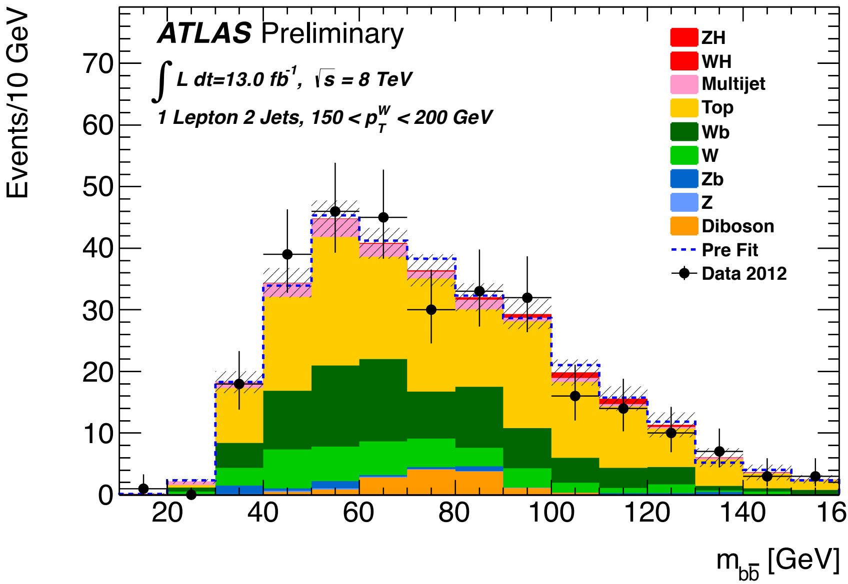
$p_T^W < 50$ GeV



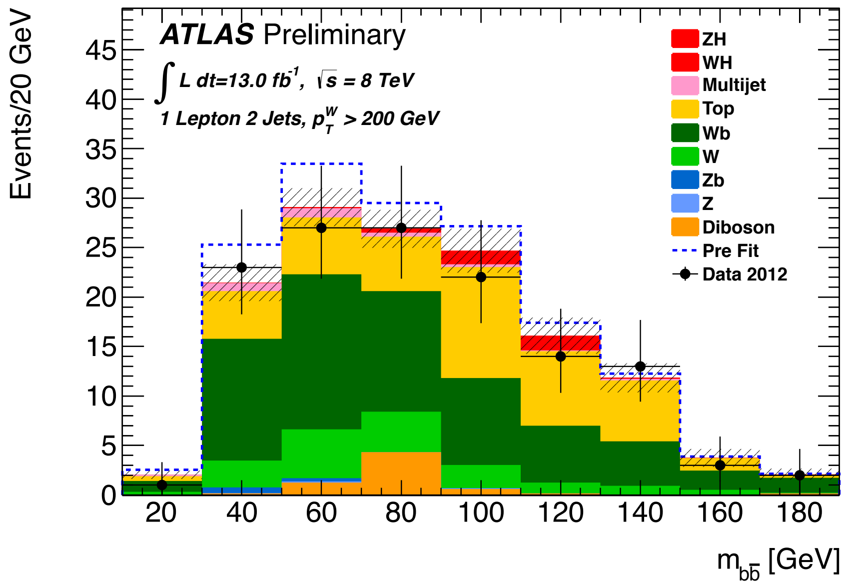
$50 < p_T^W < 100$ GeV



$100 < p_T^W < 100$ GeV



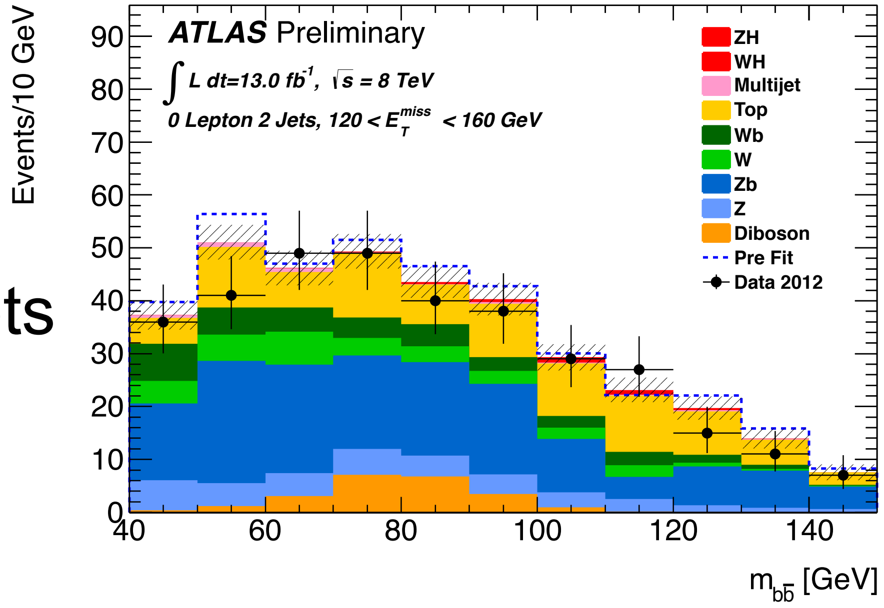
$150 < p_T^W < 200$ GeV



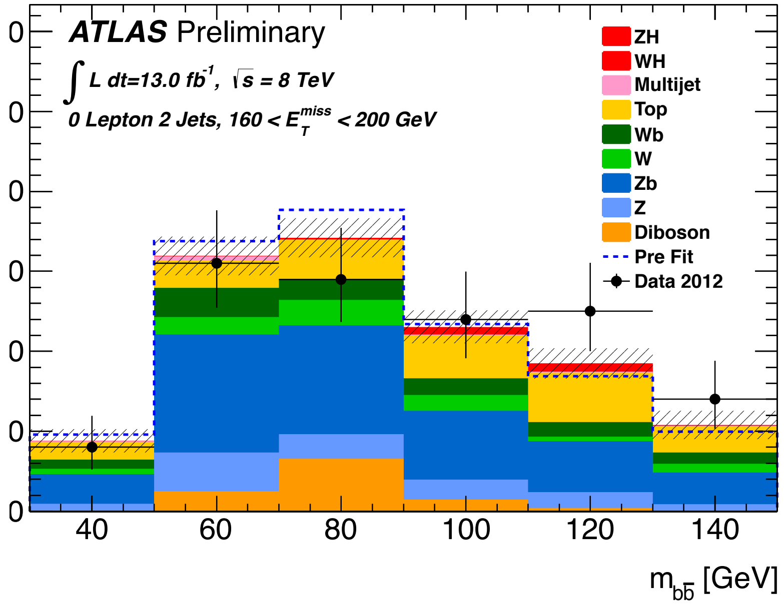
$p_T^W > 200$ GeV

m_{bb} distributions 0-leptons

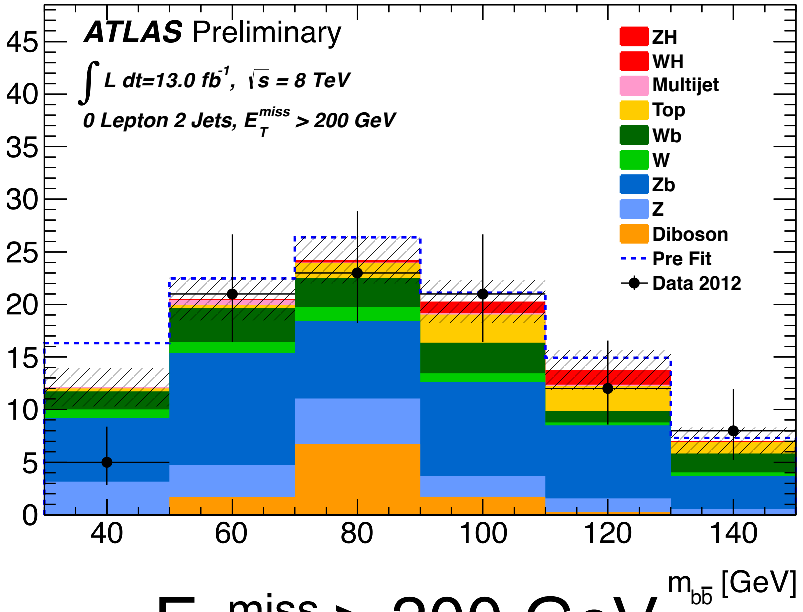
2 jets



$120 < E_T^{miss} < 160$ GeV

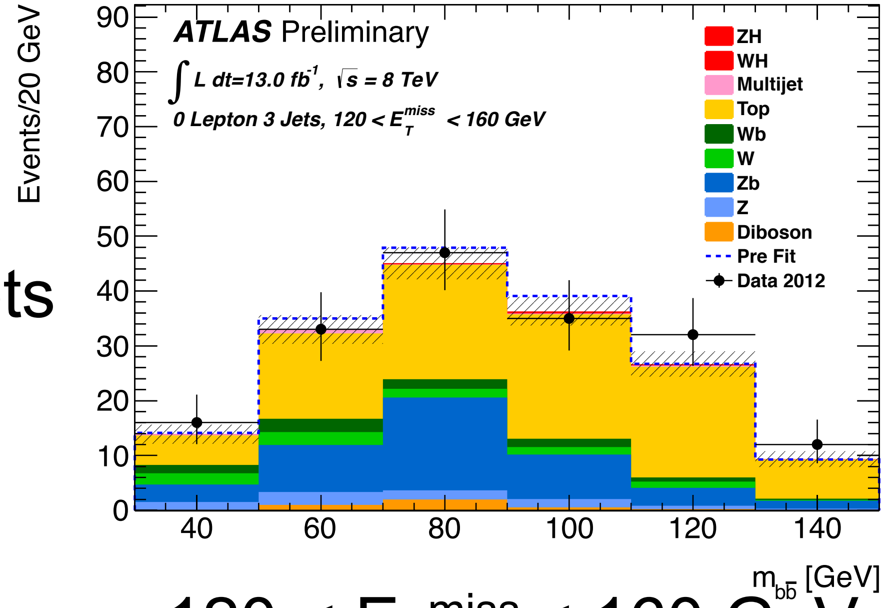


$160 < E_T^{miss} < 200$ GeV

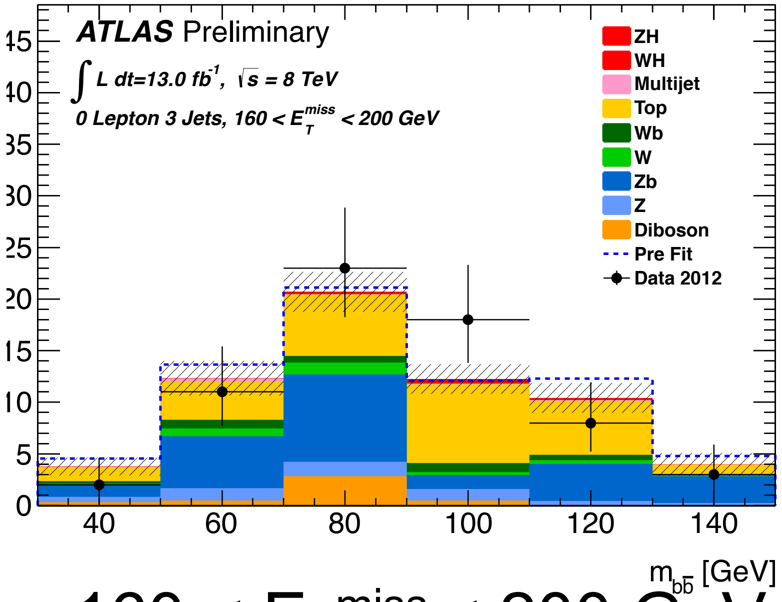


$E_T^{miss} > 200$ GeV

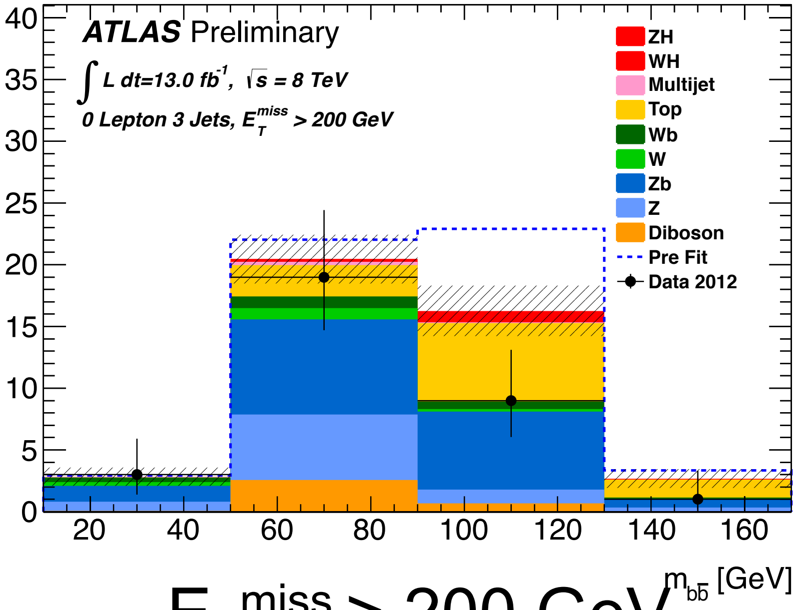
3 jets



$120 < E_T^{miss} < 160$ GeV

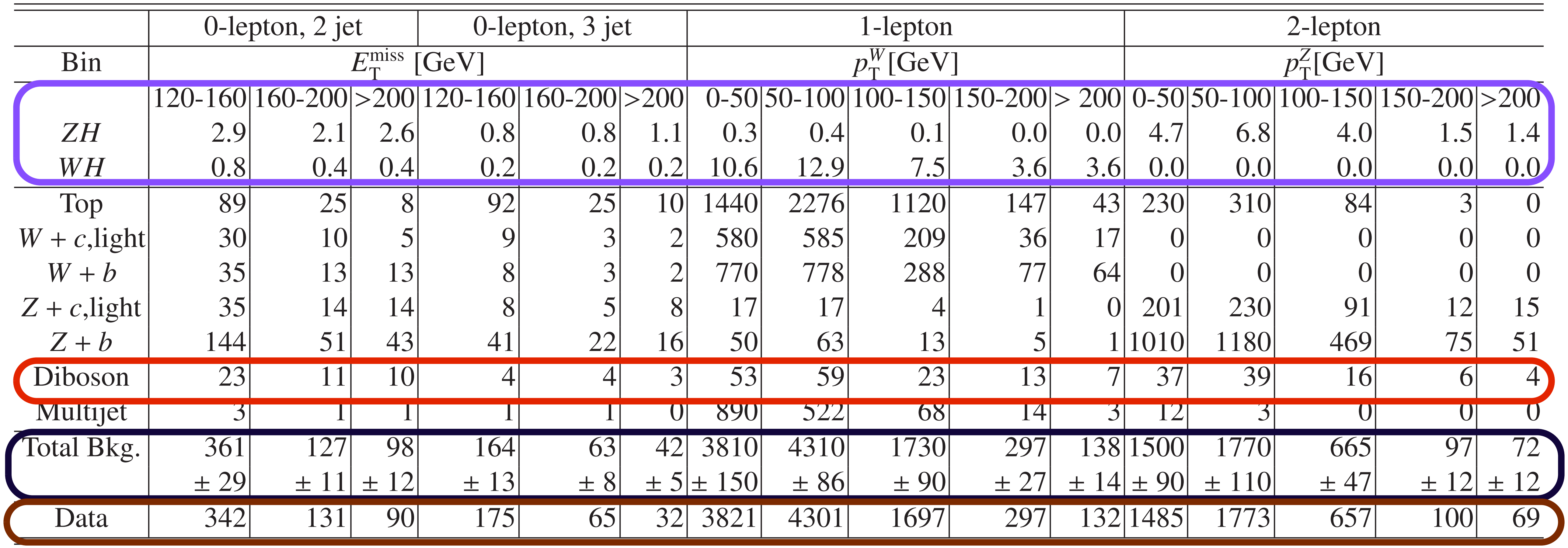


$160 < E_T^{miss} < 200$ GeV



$E_T^{miss} > 200$ GeV

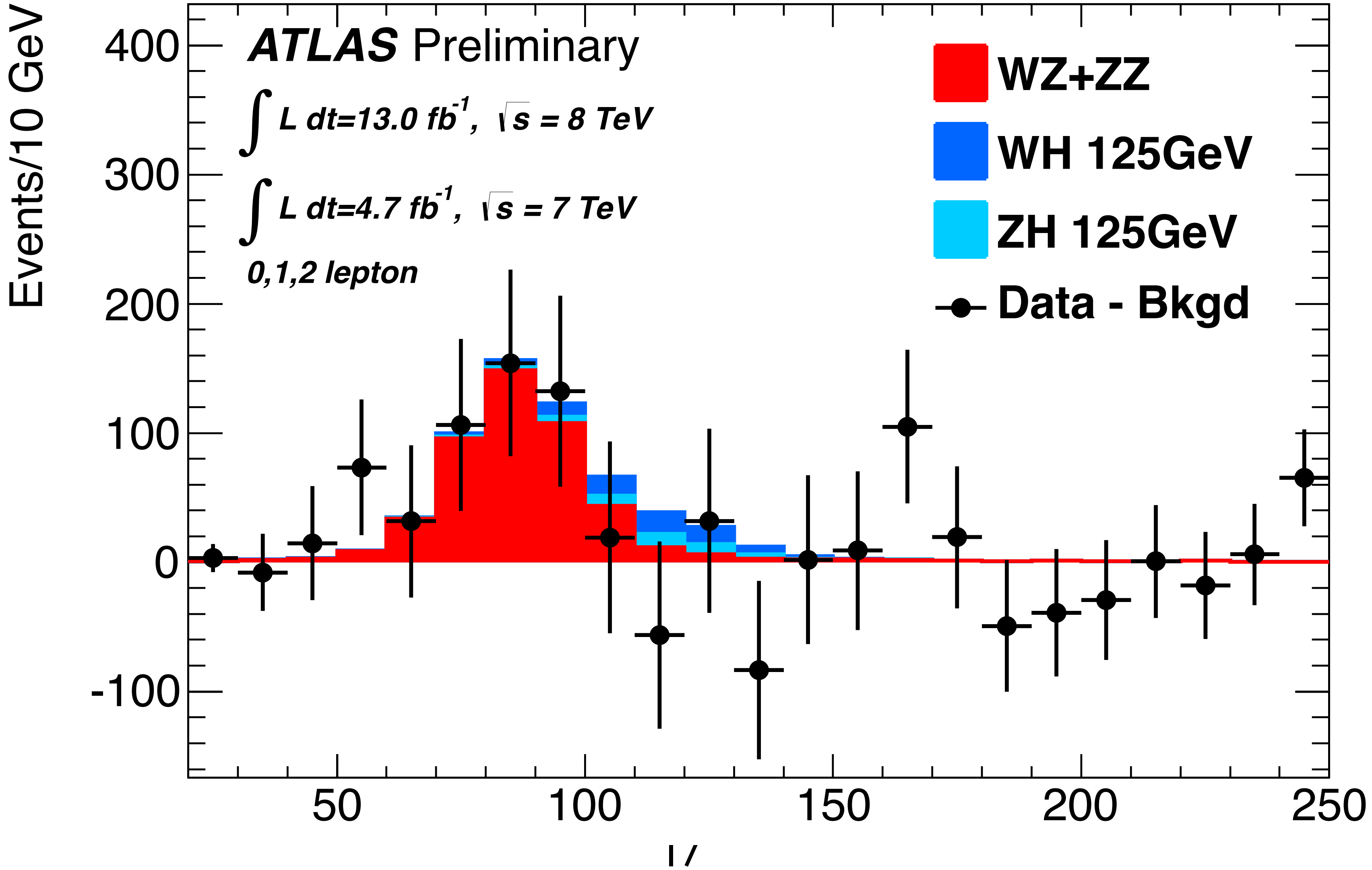
Cut flow in each category.



	0-lepton, 2 jet			0-lepton, 3 jet			1-lepton					2-lepton				
Bin	E_T^{miss} [GeV]						p_T^W[GeV]					p_T^Z[GeV]				
	120-160	160-200	>200	120-160	160-200	>200	0-50	50-100	100-150	150-200	> 200	0-50	50-100	100-150	150-200	>200
ZH	2.9	2.1	2.6	0.8	0.8	1.1	0.3	0.4	0.1	0.0	0.0	4.7	6.8	4.0	1.5	1.4
WH	0.8	0.4	0.4	0.2	0.2	0.2	10.6	12.9	7.5	3.6	3.6	0.0	0.0	0.0	0.0	0.0
Top	89	25	8	92	25	10	1440	2276	1120	147	43	230	310	84	3	0
$W + c$,light	30	10	5	9	3	2	580	585	209	36	17	0	0	0	0	0
$W + b$	35	13	13	8	3	2	770	778	288	77	64	0	0	0	0	0
$Z + c$,light	35	14	14	8	5	8	17	17	4	1	0	201	230	91	12	15
$Z + b$	144	51	43	41	22	16	50	63	13	5	1	1010	1180	469	75	51
Diboson	23	11	10	4	4	3	53	59	23	13	7	37	39	16	6	4
Multijet	3	1	1	1	1	0	890	522	68	14	3	12	3	0	0	0
Total Bkg.	361 ± 29	127 ± 11	98 ± 12	164 ± 13	63 ± 8	42 ± 5	3810 ± 150	4310 ± 86	1730 ± 90	297 ± 27	138 ± 14	1500 ± 90	1770 ± 110	665 ± 47	97 ± 12	72 ± 12
Data	342	131	90	175	65	32	3821	4301	1697	297	132	1485	1773	657	100	69

Complex analysis, discriminant power not obvious from the cut flow, a standard candle is needed to understand if everything is under control…

- WZ & ZZ production with Z→bb similar signature, but 5 times larger cross-section
- Perform a separate fit to search for it and to validate the analysis procedure
  - ➢ Profile likelihood fit performed (with full systematics)
  - ➢ All backgrounds (except diboson) subtracted
  - ➢ Uses full $p_T^{W,Z}$ range, done individually for each channel & year (see backup)
- Clear excess is observed in data at expected mass (all lepton channels combined)
- Results: $\sigma/\sigma_{SM} = \mu_D = 1.09 \pm 0.20$ (stat) ± 0.22 (syst). The significance is 4.0σ



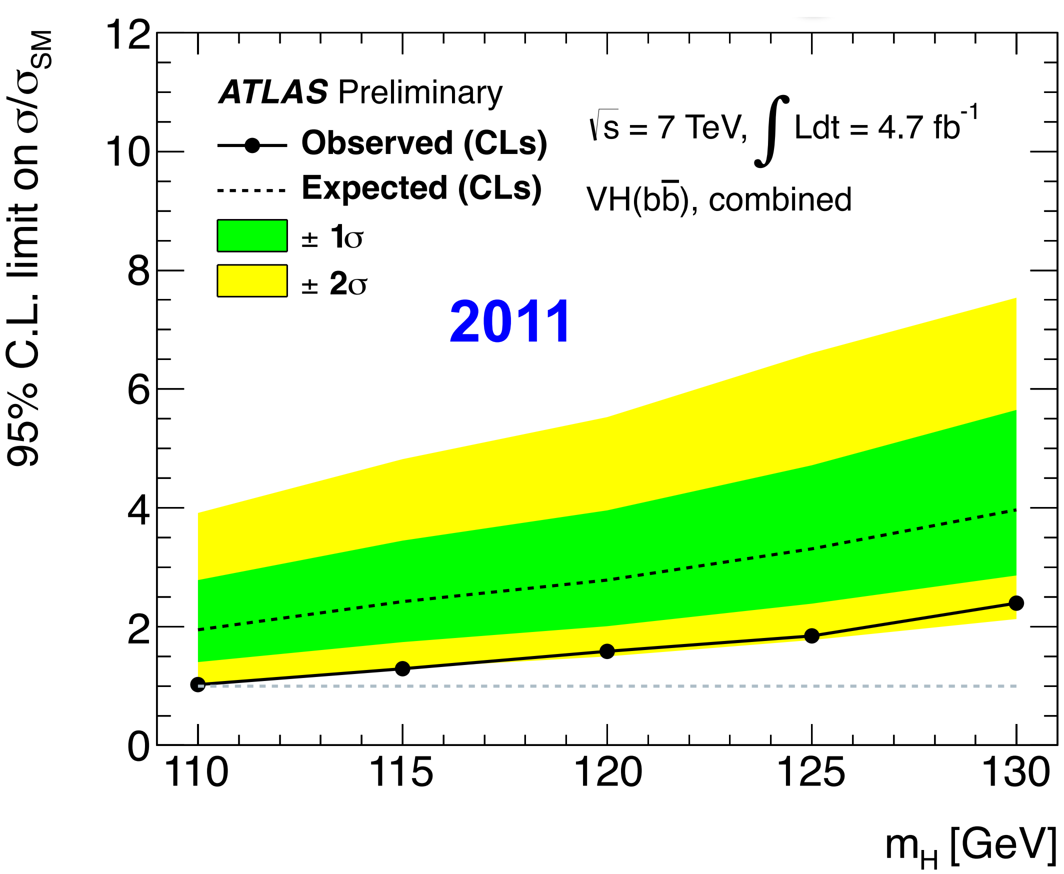
CL$_s$ limit results.

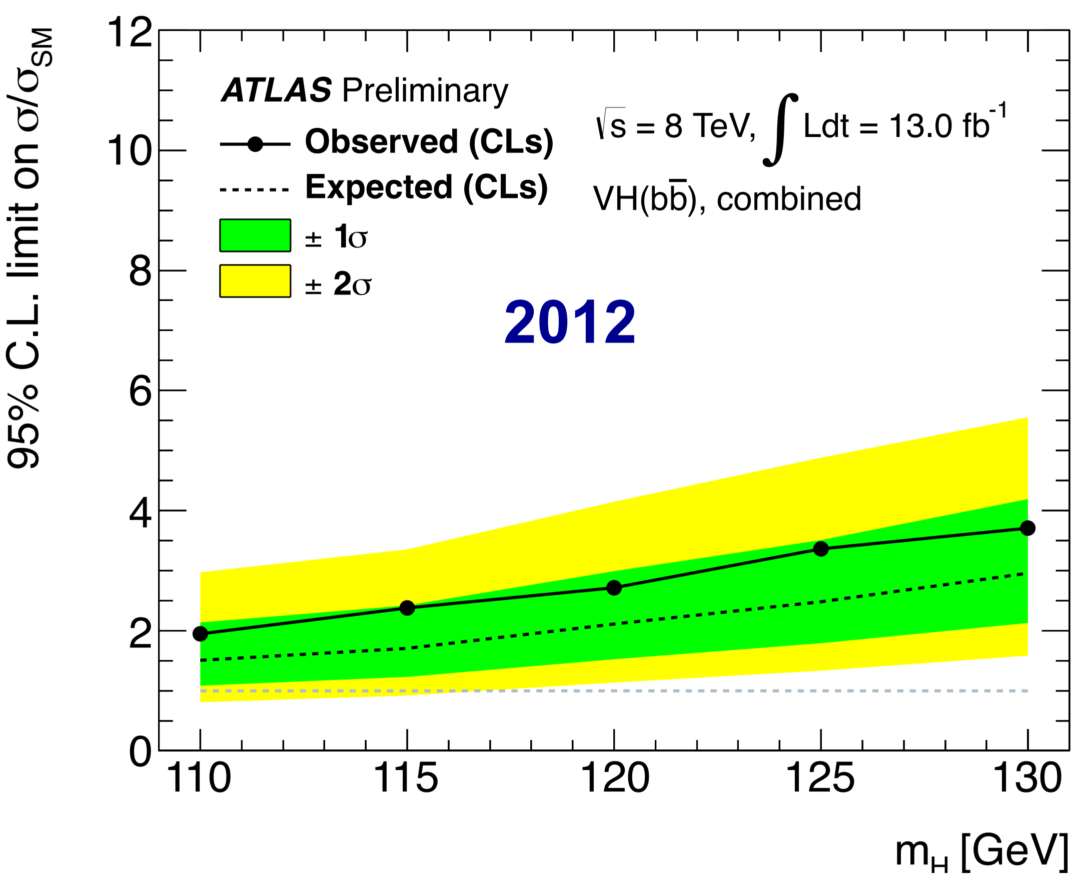
$\mathcal{L}(\mu, \theta)$

Poisson term constructed for each category, with a scale factor μ to apply to the MC predicted yield.

$q_\mu = 2\ln(\mathcal{L}(\mu, \hat{\hat{\theta}}_\mu)/\mathcal{L}(\hat{\mu}, \hat{\theta}))$

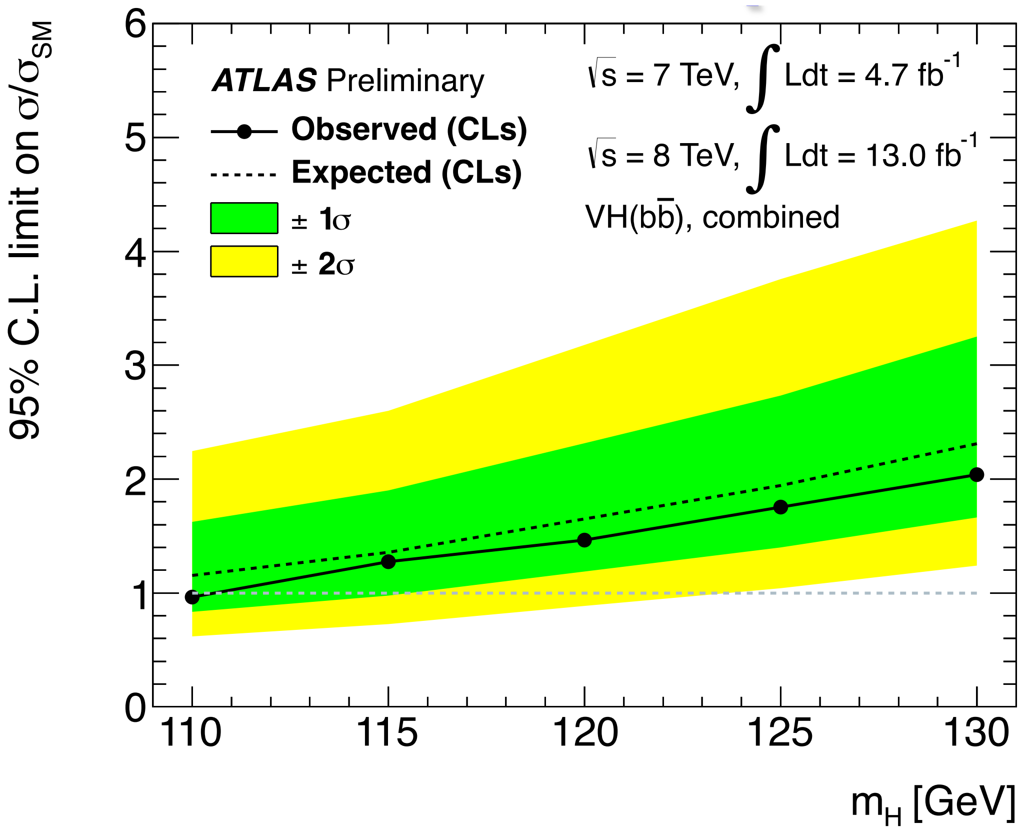
Test statisitics built to evaluate upper limit, using asymptotic approximation.

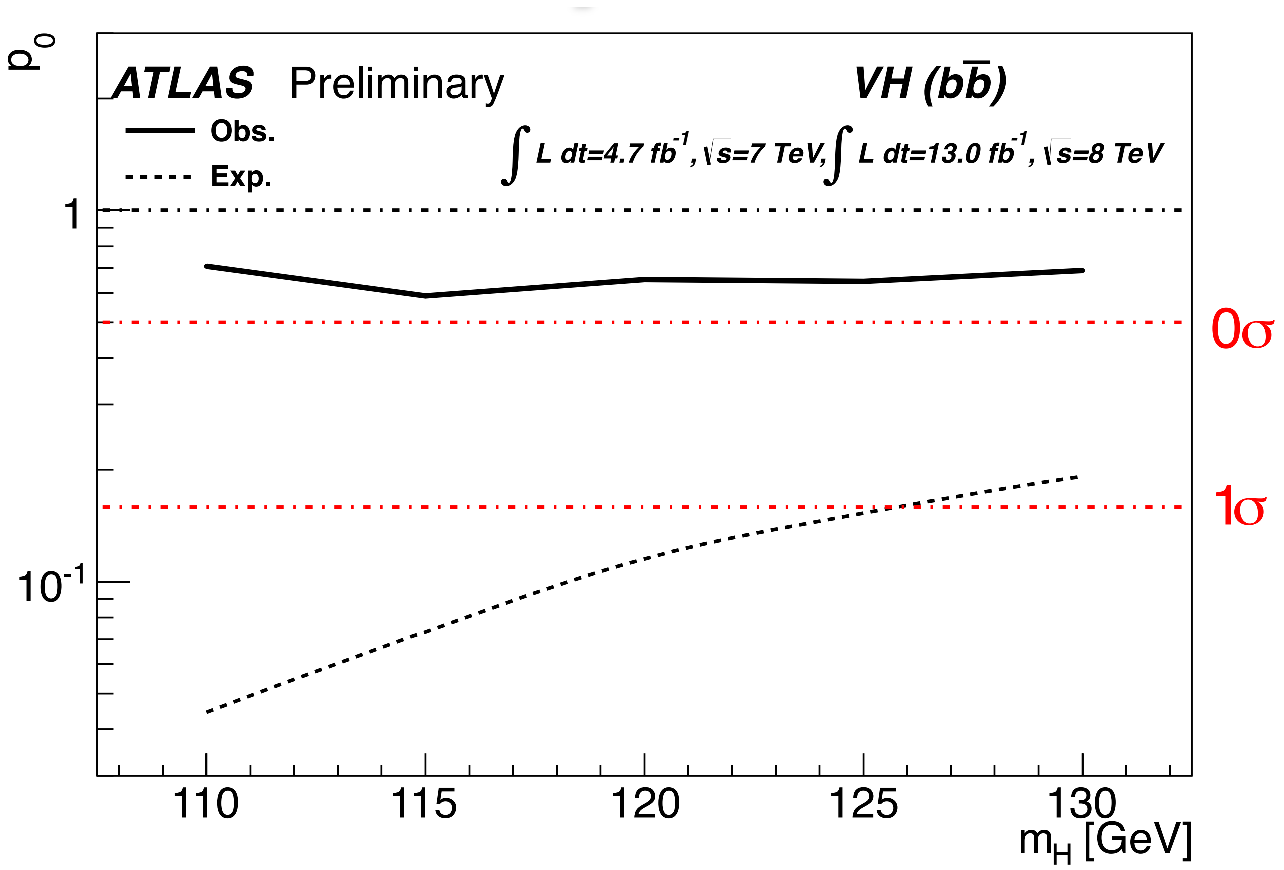




- Observed & expected CL$_S$ limit on normalised signal strength as function of Higgs Boson mass (0,1,2 lepton combined)
- Observed (expected) values at m_H =125 GeV
  - ➢ Limits 1.8 (3.3) & 3.4 (2.5) times the Standard Model
  - ➢ p_0 values: 0.97 (0.26) & 0.17 (0.20)
  - ➢ σ/σ_{SM}: $\mu = -2.7 \pm 1.1$(stat.) ± 1.1(syst.) & $\mu = 1.0 \pm 0.9$(stat.) ± 1.1(syst.)

Combined 2011+2012 results.

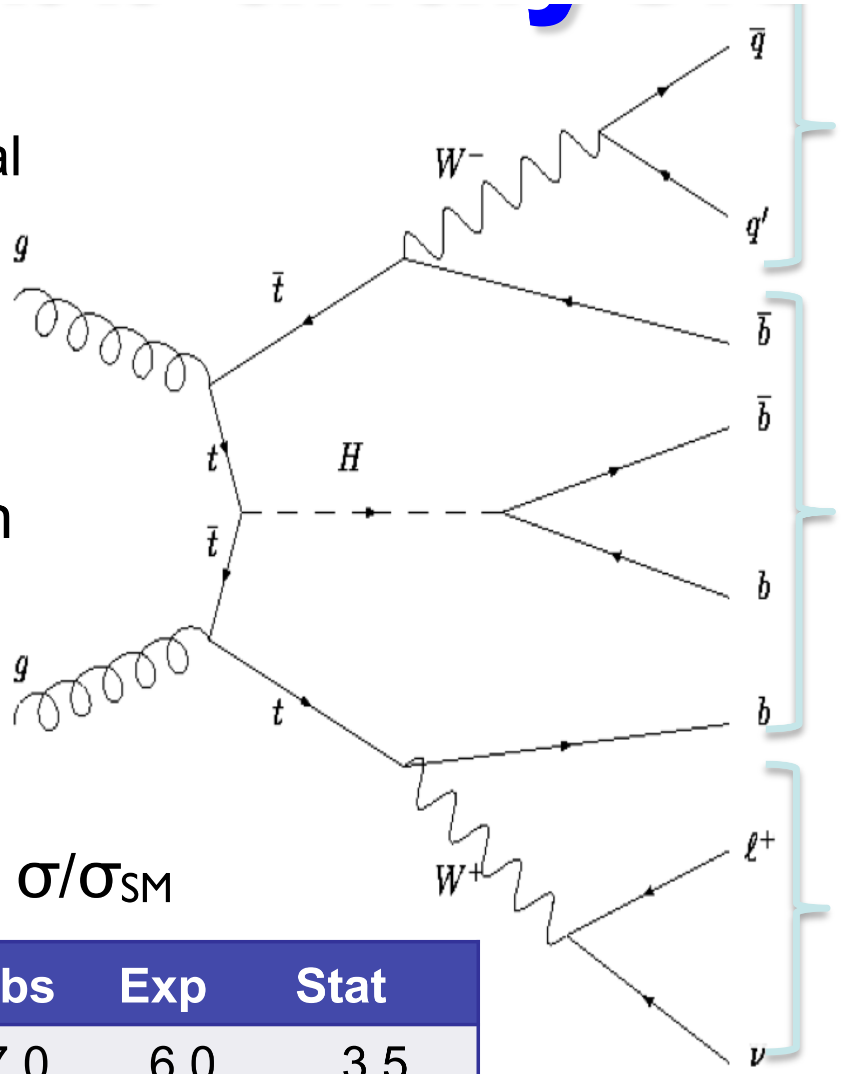




- Observed (expected) limit at m_H =125 GeV
  - ➢ 1.8 (1.9) x SM prediction
  - ➢ $\sigma/\sigma_{SM} = \mu = -0.4 \pm 0.7(\text{stat.}) \pm 0.8(\text{syst.})$
- Observed (expected) p_0 value: 0.64 (0.15)
- Exclusion at m_H ~ 110 GeV

ttH analysis.

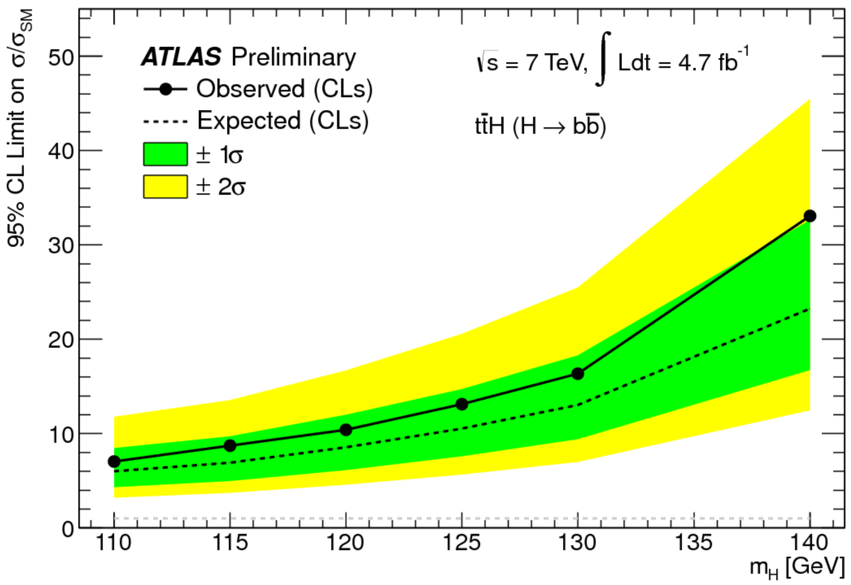
- Very challenging analysis!
  - High combinatorial background and small signal
  - Important for the measurement of top coupling
- Data: 4.7fb^{-1} at √s = 7 TeV (2011)
- 9 categories based on jet & b-tag multiplicity
  - Signal enriched (≥5 jets and ≥3 b-tags)
  - Others used for background determination
- Main discriminants
  - m_{bb} for ≥6 jets and (≥3 b-tag) categories
  - H_t^{had} ($\sum p_{T,jet}$) for other samples
- Results:



2 light jets (mostly)

Up to 4 b-tags

e or μ, E_T^{miss}, M_T^W



σ/σ_{SM}

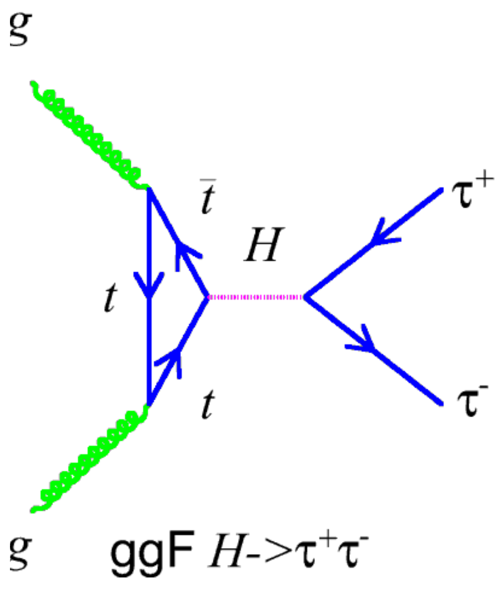
m_H (GeV)	Obs	Exp	Stat
110	7.0	6.0	3.5
115	8.7	6.9	4.0
120	10.4	8.5	4.9
125	13.1	10.5	6.1
130	16.4	13.0	7.8
140	33.0	23.2	14.2

ATLAS-CONF-2012-135 https://cdsweb.cern.ch/record/1478423

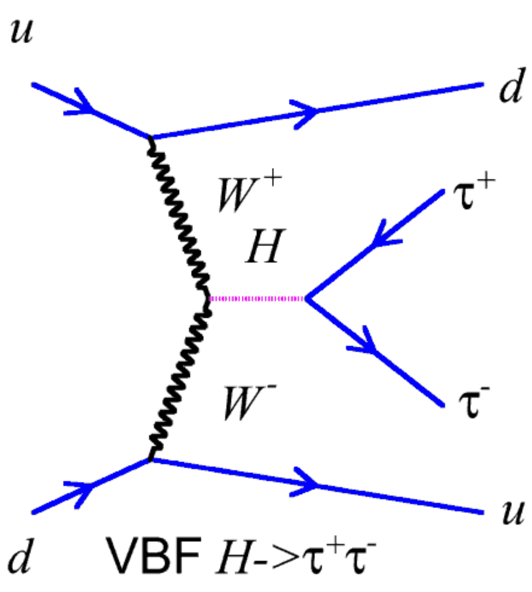
From quarks to leptons
$H \rightarrow \tau\tau$ search

H→ττ searches

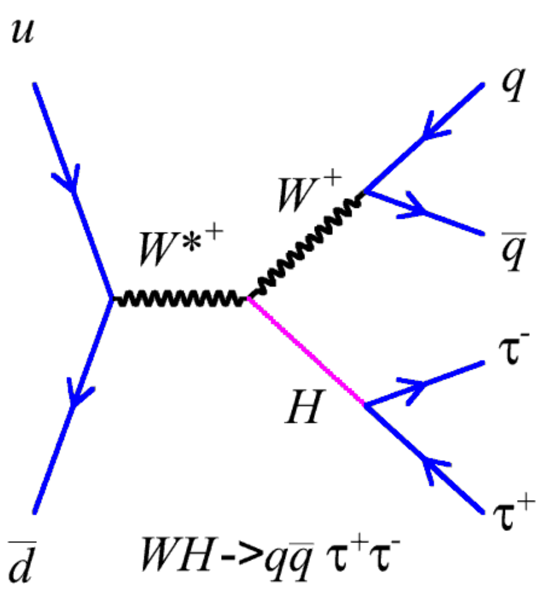
- Three Higgs production processes are considered in this analysis.



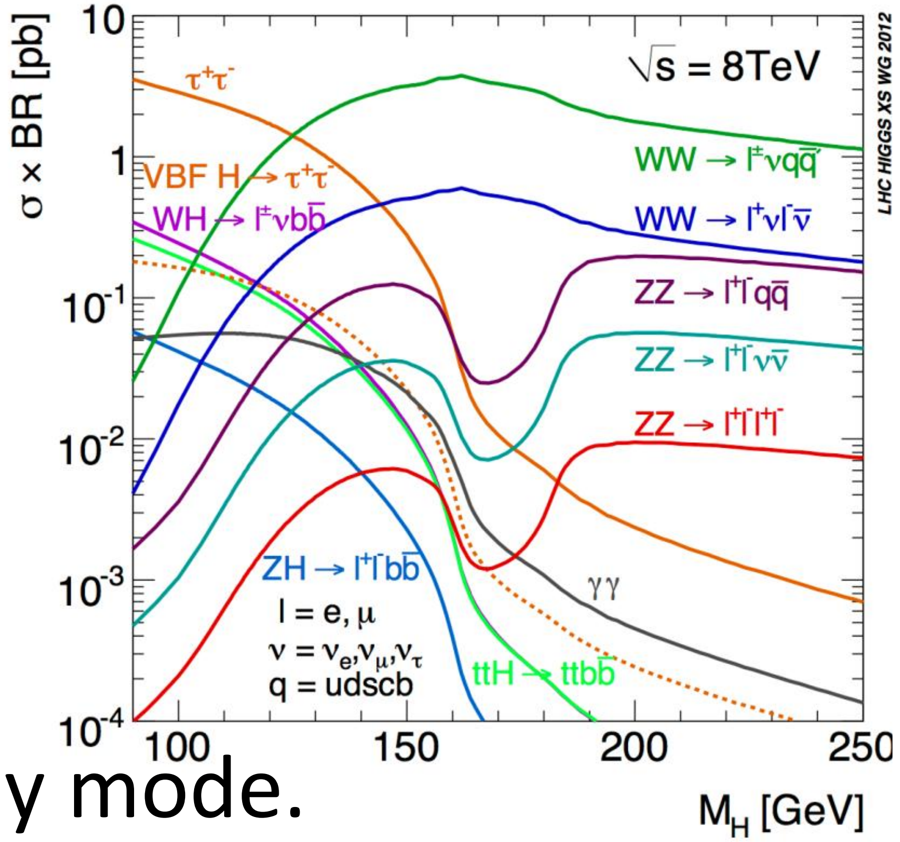
ggF $H\text{->}\tau^+\tau^-$



VBF $H\text{->}\tau^+\tau^-$

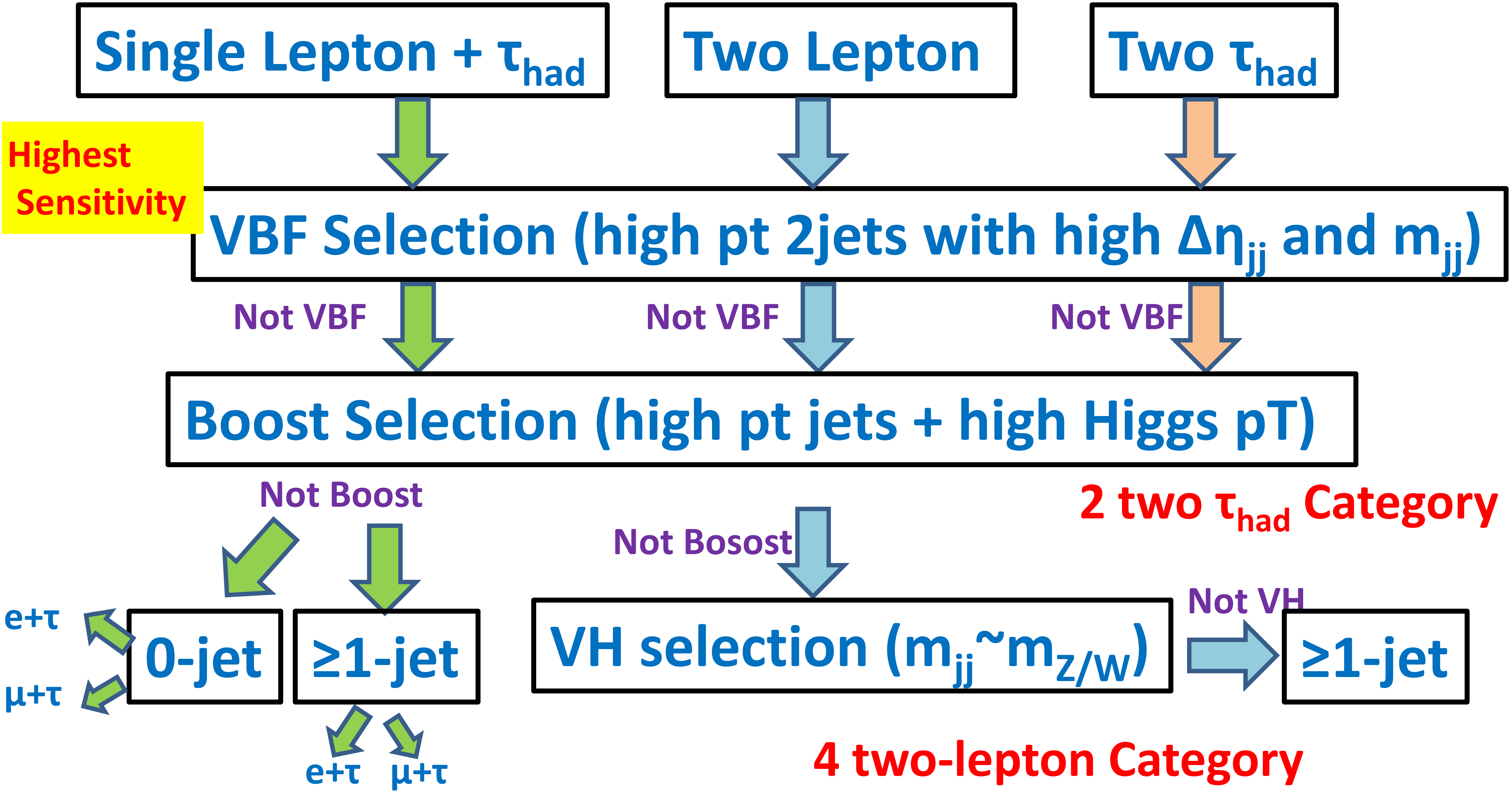


$WH\text{->}q\bar{q}\ \tau^+\tau^-$



- Separate analysis for three different ττ decay mode.
  - lep-lep = ll4ν : (ee)+eμ+μμ
  - lep-had = $l\tau_{had}3\nu$: $e\tau_{had}+\mu\tau_{had}$
  - had-had = $\tau_{had}\tau_{had}\nu\nu$: $(\tau_{had}\tau_{had})$
- Combined all three channels to search for H→ττ signature.

Analysis strategy (8 TeV)



Single Lepton + τ_{had}

Two Lepton

Two τ_{had}

Highest Sensitivity

VBF Selection (high pt 2jets with high $\Delta\eta_{jj}$ and m_{jj})

Not VBF

Not VBF

Not VBF

Boost Selection (high pt jets + high Higgs pT)

Not Boost

Not Bosost

2 two τ_{had} Category

e+τ

μ+τ

0-jet

≥1-jet

e+τ μ+τ

VH selection (m_{jj}~$m_{Z/W}$)

Not VH

≥1-jet

4 two-lepton Category

6 Single lepton Category

Quite similar categorization for 2011.
2011 and 2012 data were treated as separate categ.

Di-tau mass reconstruction.

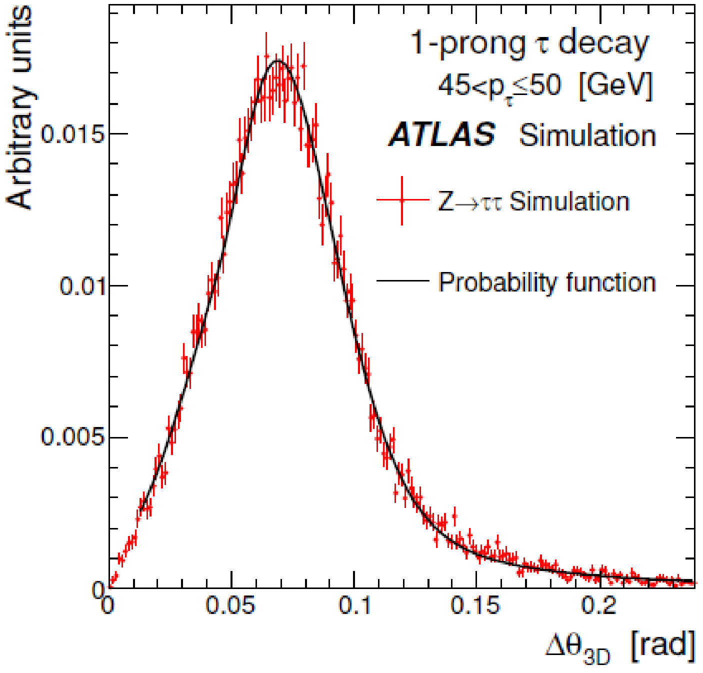
- $m_{\tau\tau}$ can be reconstructed using some approximations (due to the missing neutrino informations).
- for high p_T taus we can assume that the neutrino direction is along the visible decay product, it allows to reconstruct the $m_{\tau\tau}$ (collinear approximation)
- better resoultion can be achieved "guessing" the 3D angle between the visibe decay product of the τ and the "sum" of neutrino momenta;
- the $\Delta\theta_{3D}$ distribution is taken from simulation, and the $\Delta\theta_{3D}$ comes from a likelihood maximisation linked to the event topology and the $\Delta\theta_{3D}$ pdf assuming the τ decay kinematic

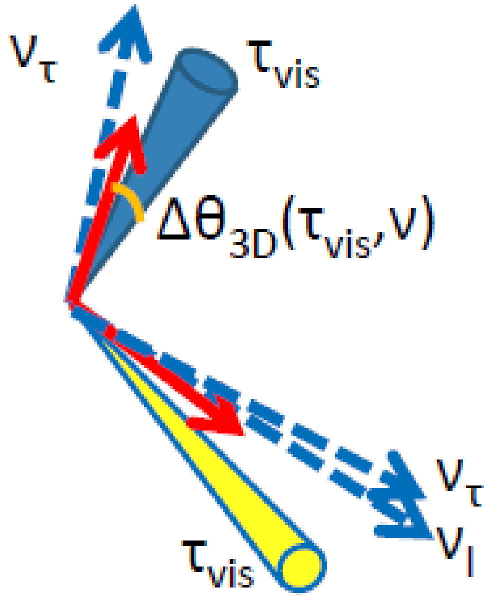
Event by Event estimator of true di-τ mass likelihood.

Full reconstruction of event kinematics.

Missing Mass Calculator(MMC)

- Solve τ, E_T^{miss} in $\Delta\phi(\tau_{vis},\nu)$ parameter space using $\Delta\theta_{3D}(\tau_{vis},\nu)$ template from simulation as PDF.





Selection $\tau_{\mathrm{lep}}\tau_{\mathrm{lep}}$

<table>
<tr><th>2-jet VBF</th><th>Boosted</th><th>2-jet VH</th><th>1-jet</th></tr>
<tr><td colspan="4">Pre-selection: exactly two leptons with opposite charges</td></tr>
<tr><td colspan="4">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</td></tr>
<tr><td colspan="4">At least one jet with $p_T > 40$ GeV ($|JVF_{\mathrm{jet}}| > 0.5$ if $|\eta_{\mathrm{jet}}| < 2.4$)</td></tr>
<tr><td colspan="4">$E_{\mathrm{T}}^{\mathrm{miss}} > 40$ GeV ($E_{\mathrm{T}}^{\mathrm{miss}} > 20$ GeV) for same-flavor (different-flavor) leptons</td></tr>
<tr><td colspan="4">$H_{\mathrm{T}}^{\mathrm{miss}} > 40$ GeV for same-flavor leptons</td></tr>
<tr><td colspan="4">$0.1 < x_{1,2} < 1$</td></tr>
<tr><td colspan="4">$0.5 < \Delta\phi_{\ell\ell} < 2.5$</td></tr>
<tr><td>$p_{T,j2} > 25$ GeV (JVF)</td><td>excluding 2-jet VBF</td><td>$p_{T,j2} > 25$ GeV (JVF)</td><td>excluding 2-jet VBF, Boosted and 2-jet VH</td></tr>
<tr><td>$\Delta\eta_{jj} > 3.0$</td><td>$p_{T,\tau\tau} > 100$ GeV</td><td>excluding Boosted</td><td>$m_{\tau\tau j} > 225$ GeV</td></tr>
<tr><td>$m_{jj} > 400$ GeV</td><td>b-tagged jet veto</td><td>$\Delta\eta_{jj} < 2.0$</td><td>b-tagged jet veto</td></tr>
<tr><td>b-tagged jet veto</td><td rowspan="2">–</td><td>30 GeV < m_{jj} < 160 GeV</td><td rowspan="2">–</td></tr>
<tr><td>Lepton centrality and CJV</td><td>b-tagged jet veto</td></tr>
<tr><td colspan="4">0-jet (7 TeV only)</td></tr>
<tr><td colspan="4">Pre-selection: exactly two leptons with opposite charges</td></tr>
<tr><td colspan="4">Different-flavor leptons with 30 GeV < $m_{\ell\ell}$ < 100 GeV and $p_{T,\ell 1} + p_{T,\ell 2} > 35$ GeV</td></tr>
<tr><td colspan="4">$\Delta\phi_{\ell\ell} > 2.5$</td></tr>
<tr><td colspan="4">b-tagged jet veto</td></tr>
</table>

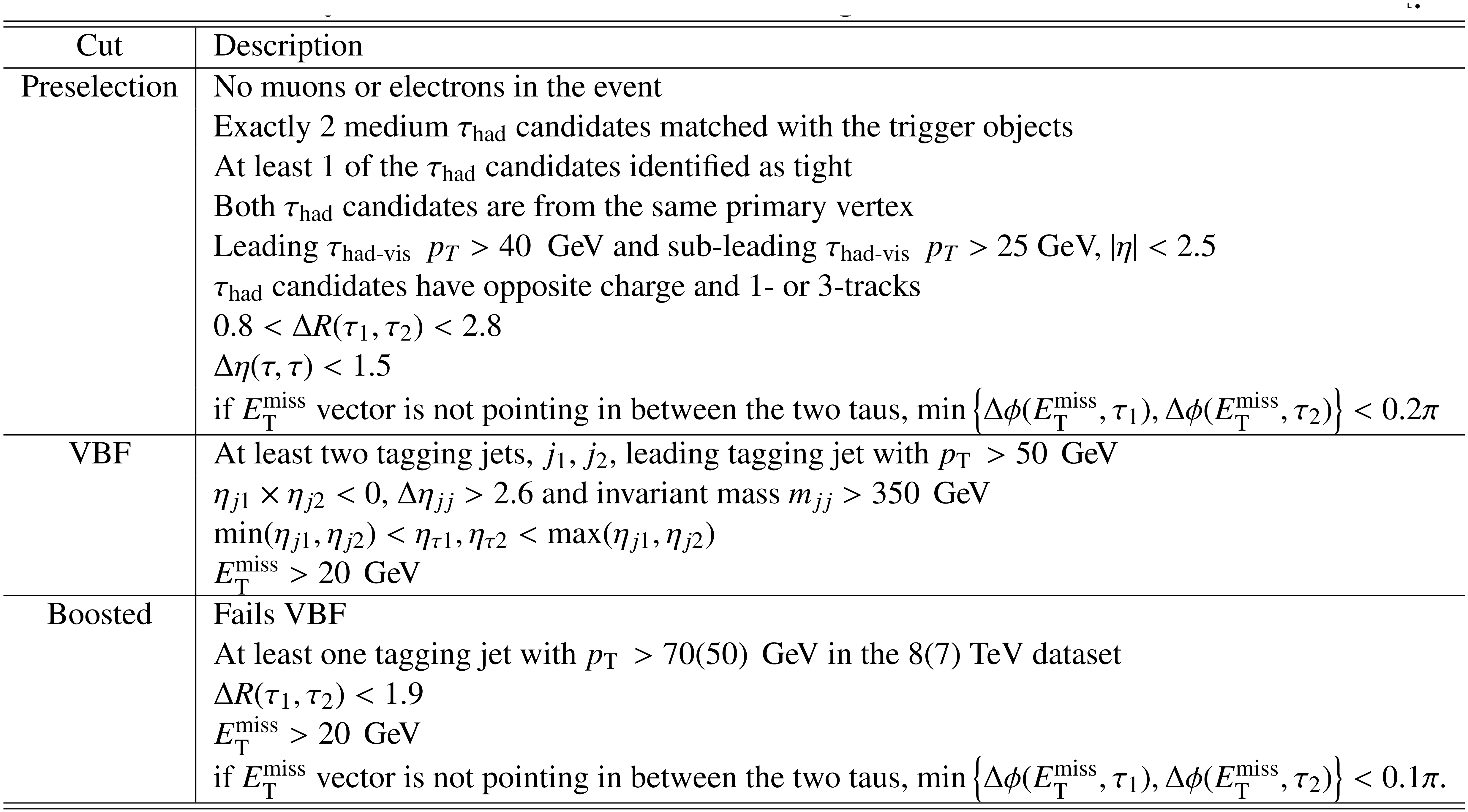
Selection $\tau_{lep}\tau_{had}$

7 TeV		8 TeV	
VBF Category	Boosted Category	VBF Category	Boosted Category
▹ $p_{\mathrm{T}}{}^{\tau_{\text{had-vis}}}$ >30 GeV	–	▹ $p_{\mathrm{T}}{}^{\tau_{\text{had-vis}}}$ >30 GeV	▹ $p_{\mathrm{T}}{}^{\tau_{\text{had-vis}}}$ >30 GeV
▹ $E_{\mathrm{T}}^{\text{miss}}$ >20 GeV	▹ $E_{\mathrm{T}}^{\text{miss}}$ >20 GeV	▹ $E_{\mathrm{T}}^{\text{miss}}$ >20 GeV	▹ $E_{\mathrm{T}}^{\text{miss}}$ >20 GeV
▹ ≥ 2 jets	▹ $p_{\mathrm{T}}^{\mathrm{H}} > 100$ GeV	▹ ≥ 2 jets	▹ $p_{\mathrm{T}}^{\mathrm{H}} > 100$ GeV
▹ $p_{\mathrm{T}}{}^{j1}, p_{\mathrm{T}}{}^{j2} > 40$ GeV	▹ $0 < x_1 < 1$	▹ $p_{\mathrm{T}}{}^{j1} > 40, p_{\mathrm{T}}{}^{j2}$ >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.	–
▹ $\eta_{j1} \times \eta_{j2} < 0$	–	▹ $\eta_{j1} \times \eta_{j2} < 0$	–
▹ $p_{\mathrm{T}}{}^{\text{Total}} < 40$ GeV	–	▹ $p_{\mathrm{T}}{}^{\text{Total}} < 30$ GeV	–
–	–	▹ $p_{\mathrm{T}}{}^{\ell}$ >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
▹ ≥ 1 jet, p_{T} >25 GeV	▹ 0 jets p_{T} >25 GeV	▹ ≥ 1 jet, p_{T} >30 GeV	▹ 0 jets p_{T} >30 GeV
▹ $E_{\mathrm{T}}^{\text{miss}}$ >20 GeV	▹ $E_{\mathrm{T}}^{\text{miss}}$ >20 GeV	▹ $E_{\mathrm{T}}^{\text{miss}}$ >20 GeV	▹ $E_{\mathrm{T}}^{\text{miss}}$ >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
• $\Delta(\Delta R) < 0.6$	• $\Delta(\Delta R) < 0.5$	• $\Delta(\Delta R) < 0.6$	• $\Delta(\Delta R) < 0.5$
• $\sum \Delta\phi < 3.5$	• $\sum \Delta\phi < 3.5$	• $\sum \Delta\phi < 3.5$	• $\sum \Delta\phi < 3.5$
–	• $p_{\mathrm{T}}^{\ell} - p_{\mathrm{T}}^{\tau} < 0$	–	• $p_{\mathrm{T}}^{\ell} - p_{\mathrm{T}}^{\tau} < 0$

$$x_{1,2} = \frac{|p_{\text{vis}1,2}|}{|(p_{\text{vis}1,2} + p_{\text{mis}1,2})|} \, .$$

1 leptonic visible momentum fraction in the collinear approx.
2 hadronic visible momentum fraction in the collinear approx.

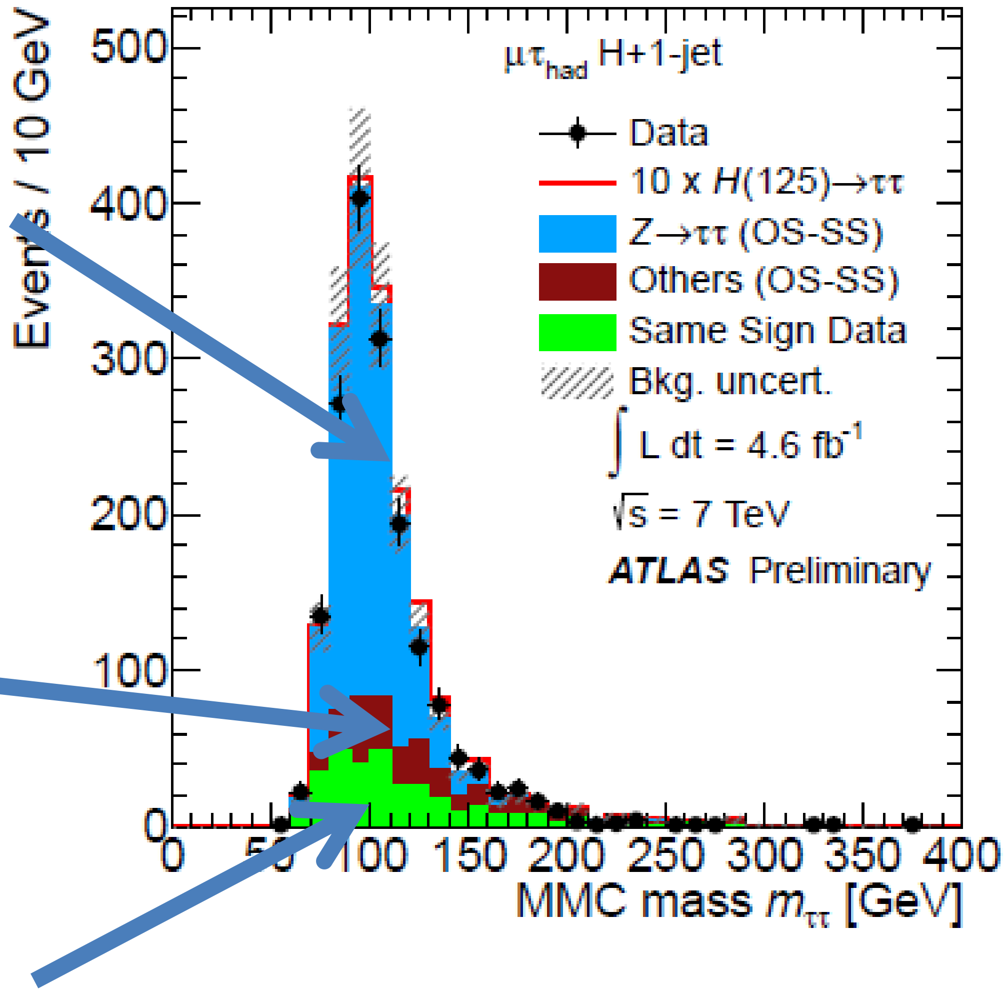
Selection $\tau_{\mathrm{had}}\tau_{\mathrm{had}}$



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 $\tau_{\text{had-vis}}$ $p_T > 40$ GeV and sub-leading $\tau_{\text{had-vis}}$ $p_T > 25$ 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 $E_{\mathrm{T}}^{\mathrm{miss}}$ vector is not pointing in between the two taus, $\min\left\{\Delta\phi(E_{\mathrm{T}}^{\mathrm{miss}}, \tau_1), \Delta\phi(E_{\mathrm{T}}^{\mathrm{miss}}, \tau_2)\right\} < 0.2\pi$
VBF	At least two tagging jets, j_1, j_2, leading tagging jet with $p_{\mathrm{T}} > 50$ GeV
	$\eta_{j1} \times \eta_{j2} < 0$, $\Delta\eta_{jj} > 2.6$ and invariant mass $m_{jj} > 350$ GeV
	$\min(\eta_{j1}, \eta_{j2}) < \eta_{\tau 1}, \eta_{\tau 2} < \max(\eta_{j1}, \eta_{j2})$
	$E_{\mathrm{T}}^{\mathrm{miss}} > 20$ GeV
Boosted	Fails VBF
	At least one tagging jet with $p_{\mathrm{T}} > 70(50)$ GeV in the 8(7) TeV dataset
	$\Delta R(\tau_1, \tau_2) < 1.9$
	$E_{\mathrm{T}}^{\mathrm{miss}} > 20$ GeV
	if $E_{\mathrm{T}}^{\mathrm{miss}}$ vector is not pointing in between the two taus, $\min\left\{\Delta\phi(E_{\mathrm{T}}^{\mathrm{miss}}, \tau_1), \Delta\phi(E_{\mathrm{T}}^{\mathrm{miss}}, \tau_2)\right\} < 0.1\pi$.

Background estimation.

- Opposite sign tau decay products are required.
- High Missing ET and low MT cuts are added.



Z→ττ estimated by embedding+MC

-- used Z→μμ data and replace μ by full simulated τ, so that all the objects except tau decay product are obtained by real data.

-- Used high statistics MC for VBF channel with correction by data.

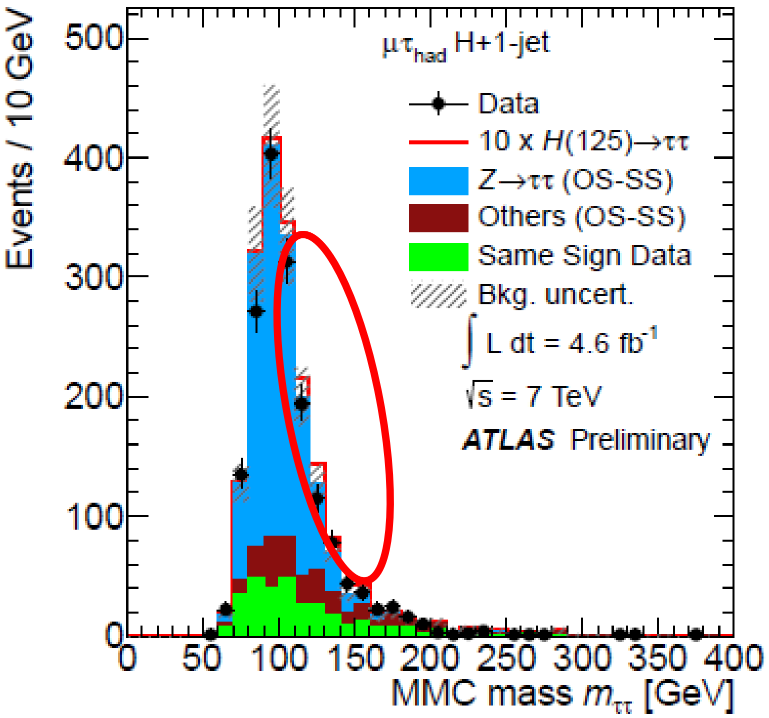
Z→ee/μμ + jets, Top, di-boson Estimated by MC with correction.

QCD and W+Jets – Estimated from Same Sign events(lephad)

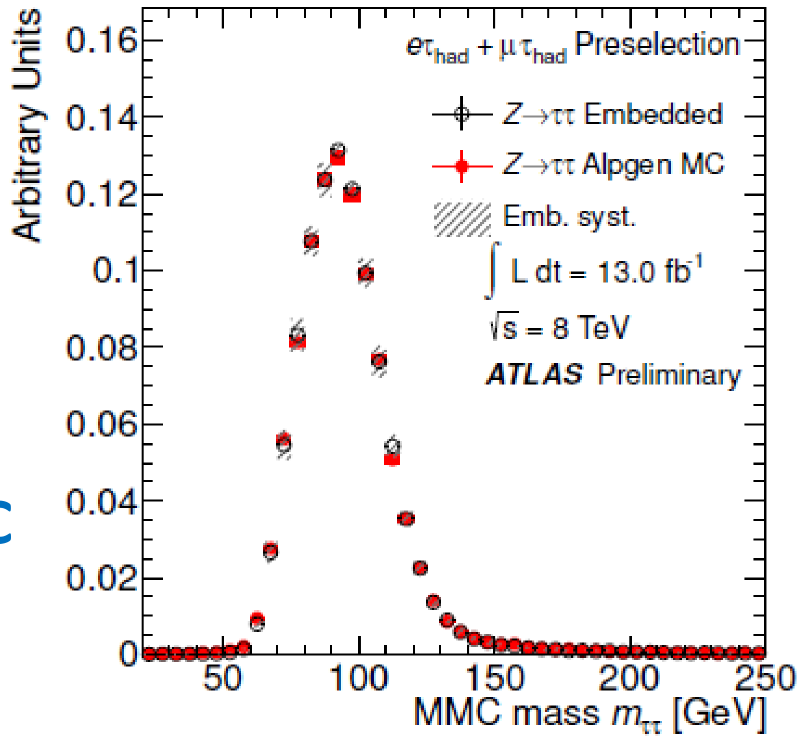
-- Template fit by loose selection (lep-lep,hadhad)

Z→ττ validation

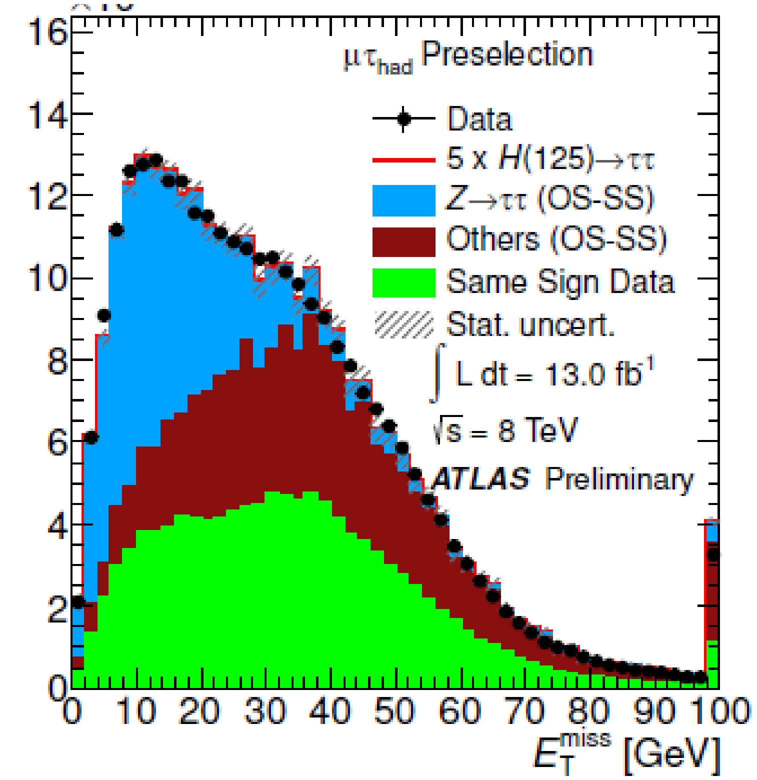
Higgs Signal is on the right hand side tail of Z.
Need carful varidation of the Z→ττ shape.



MMC distribution embedding vs MC



MET distribution. estimation vs data



Non-VBF channel : Embedding

- → **Checked with MC sample**
- → **Assigned systematics by varying condition.**

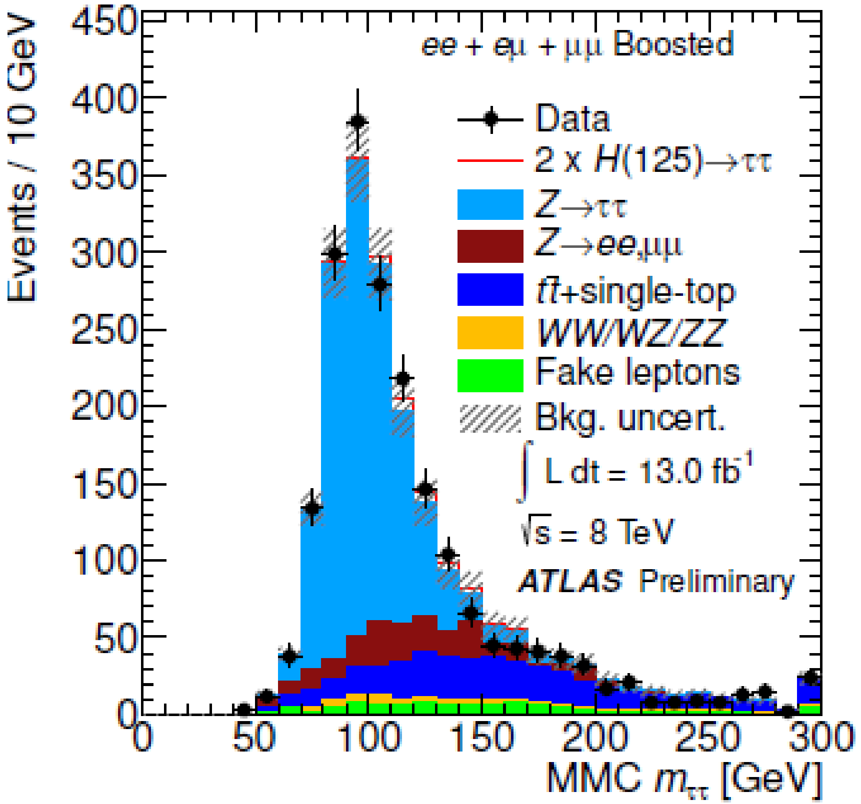
VBF channel : High statistics MC

- → **Jet kinematics are validated by Zee/μμ data.**
- → **Reweighted kinematics for MC mismodeling.**

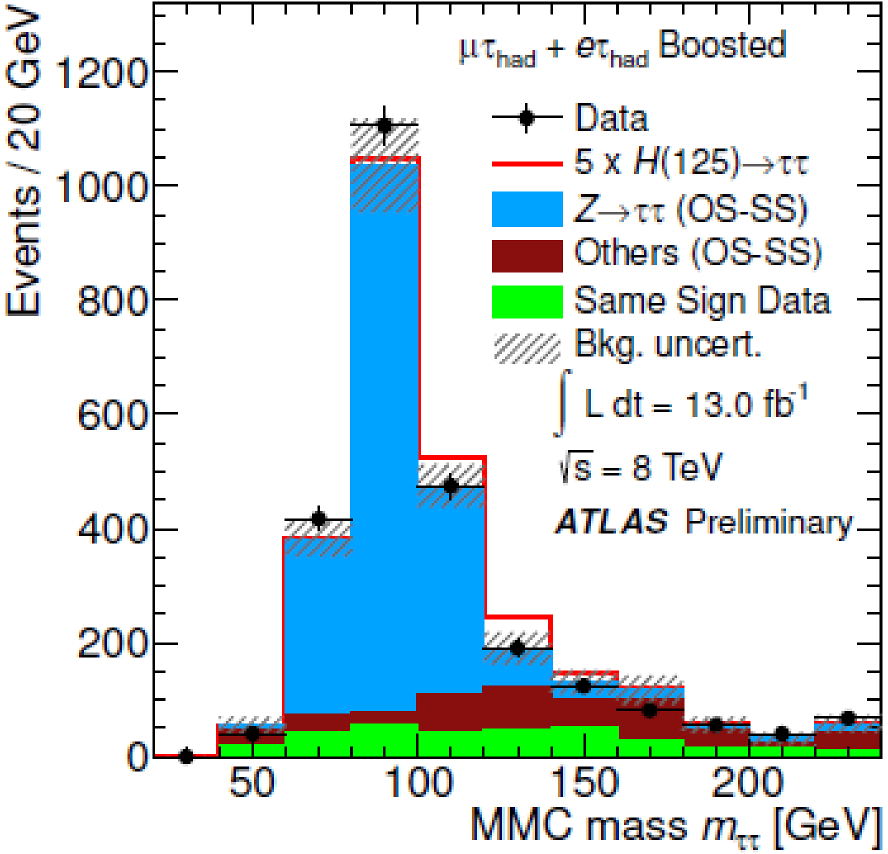
ggF categories.

- Boost category is the best sensitivity in non-VBF category.
- 0/1 jet non-boost events also used for limit calculation.

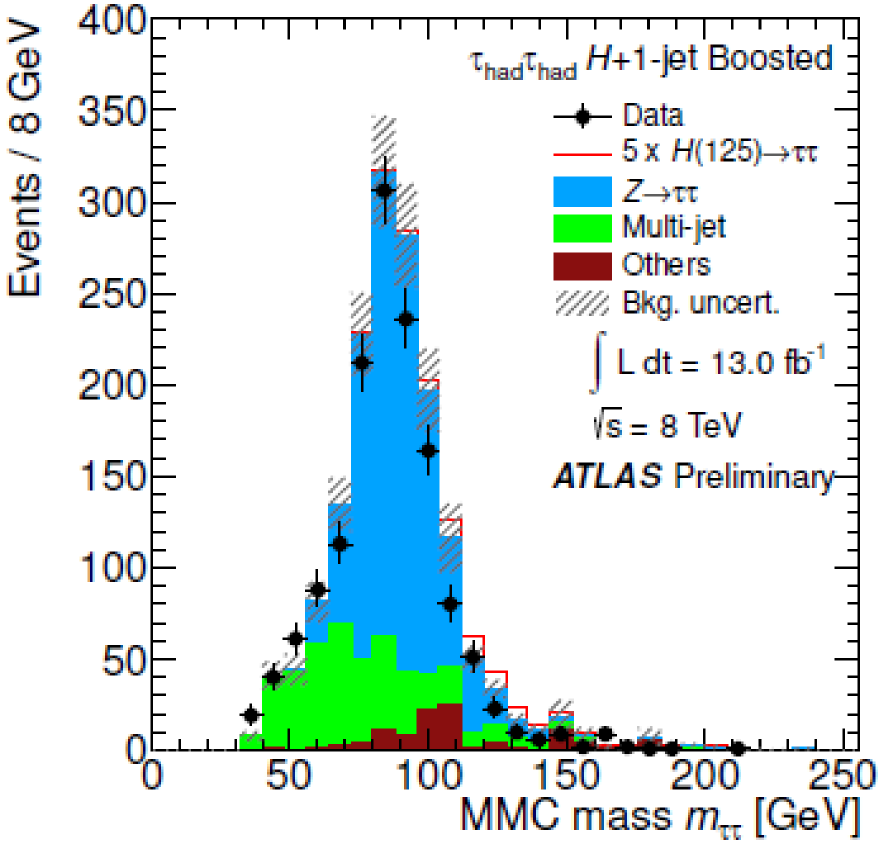
leplep



lephad



hadhad

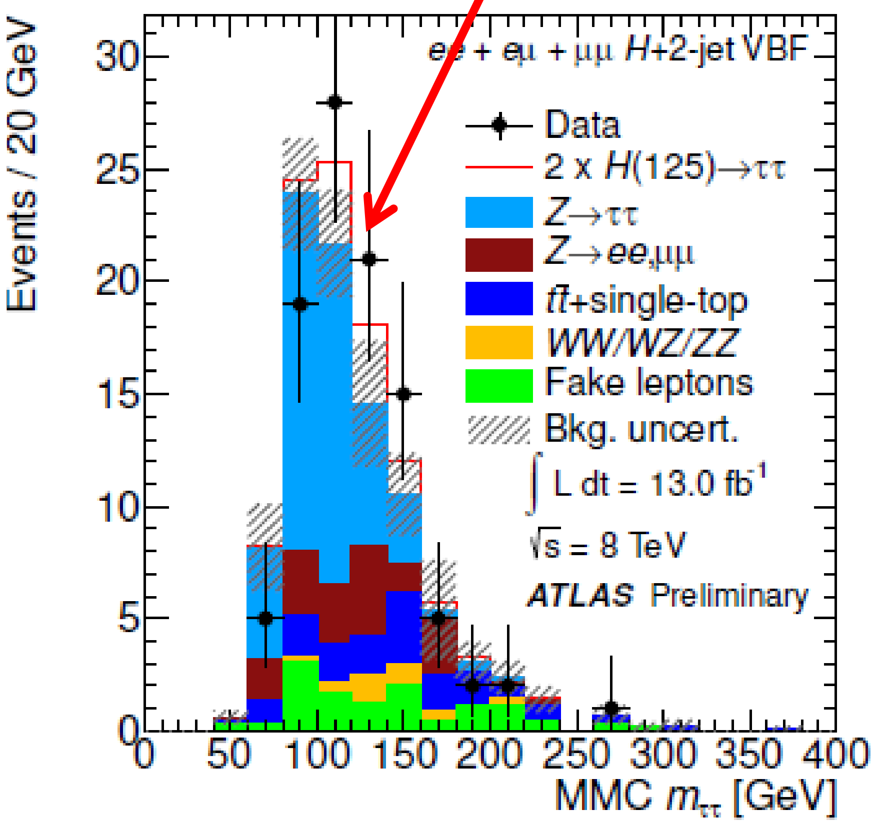


VBF categories.

- Highest sensitivity channels are VBF category.
- Limited statistics but Good S/B ratio.

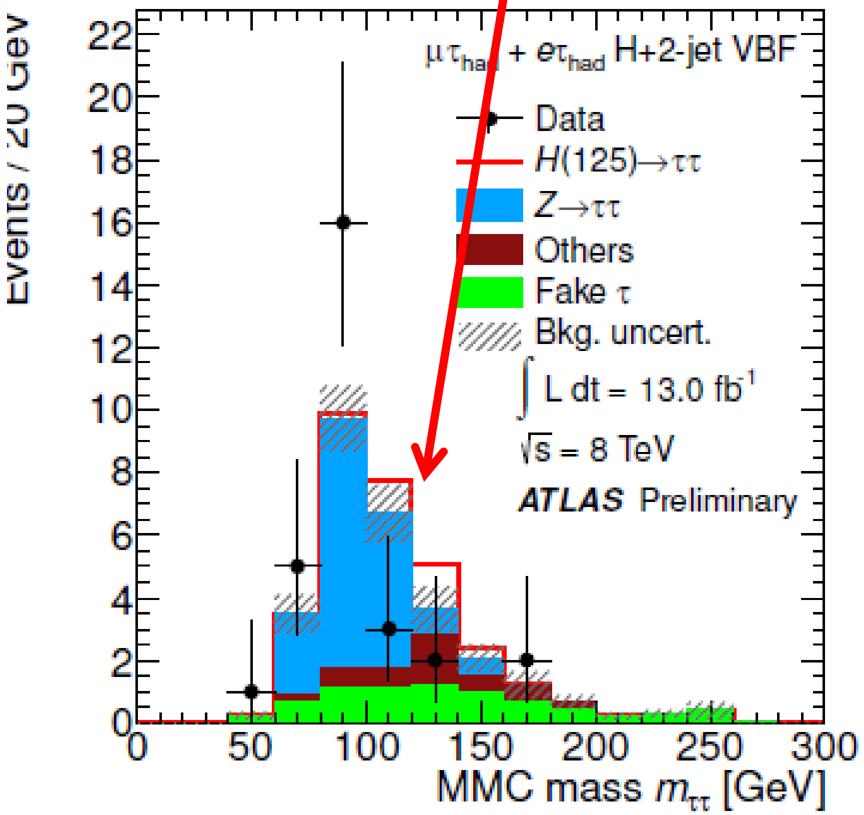
leplep

2xSM signal



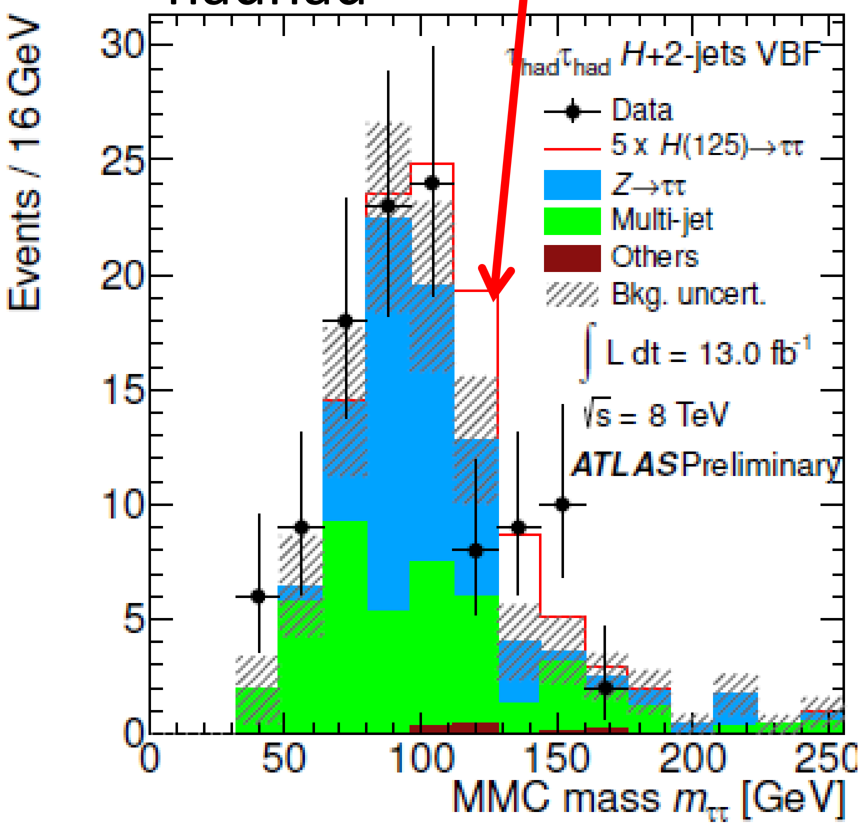
lephad

1xSM signal



hadhad

5xSM signal

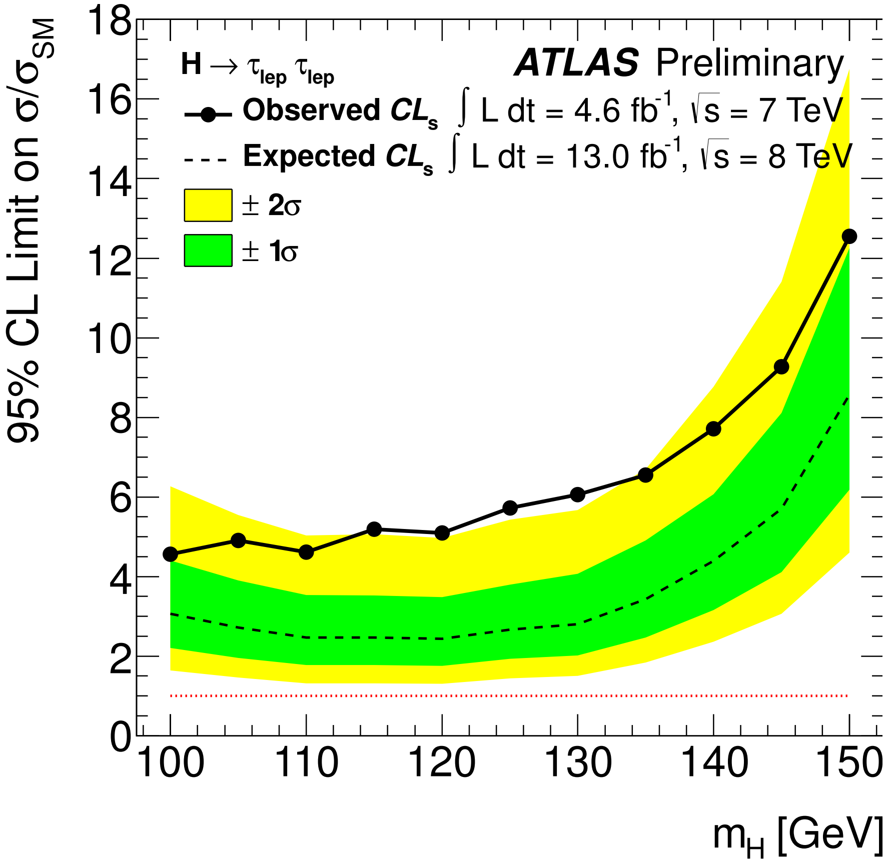


Systematic uncertainties

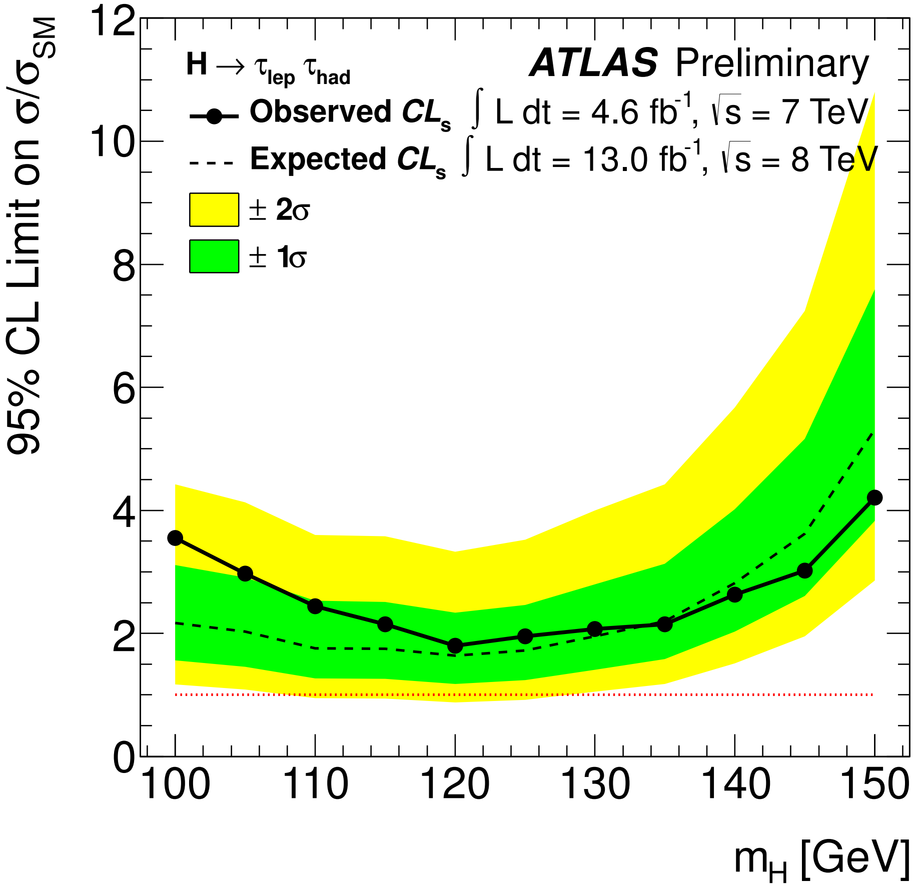
- Systematic uncertainties for Z→ττ background and Signal.
- Dominant systematics are Embedding, Tau Energy Scale and Jet Energy Scale. Both Shape and Normalization variation are taken into account.

Uncertainty	$H \to \tau_{\mathrm{lep}}\tau_{\mathrm{lep}}$	$H \to \tau_{\mathrm{lep}}\tau_{\mathrm{had}}$	$H \to \tau_{\mathrm{had}}\tau_{\mathrm{had}}$
		$Z \to \tau^+\tau^-$	
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%

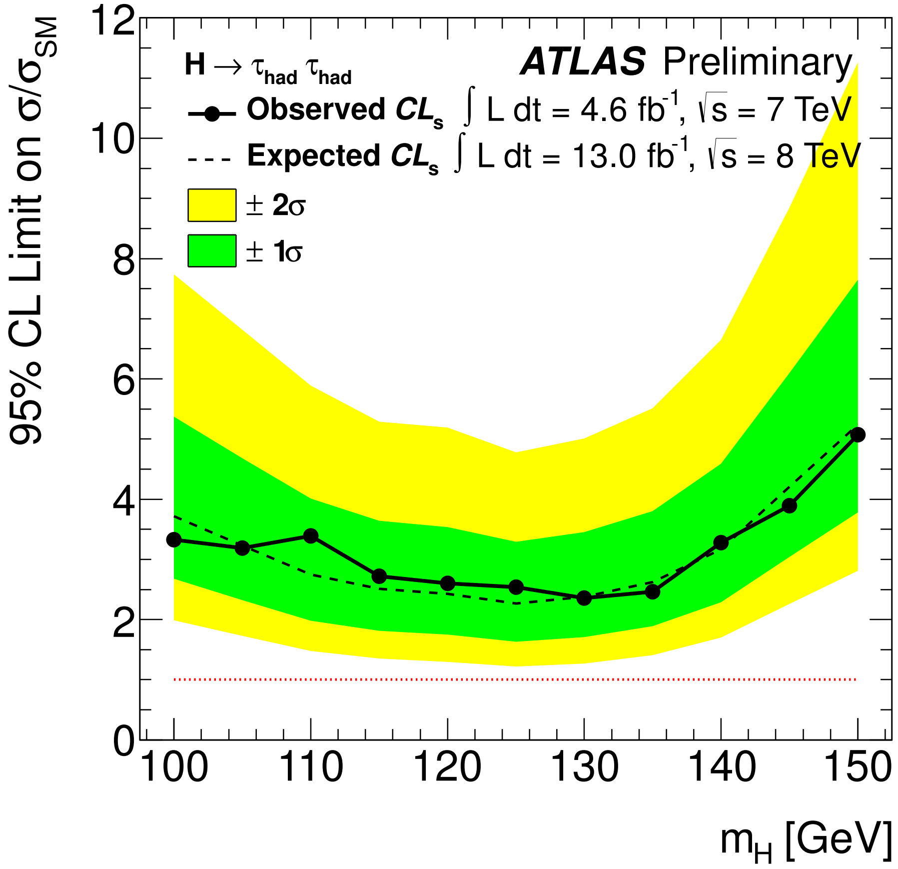
Per channel CL_s



(a) Combined $H \rightarrow \tau_{\text{lep}}\tau_{\text{lep}}$

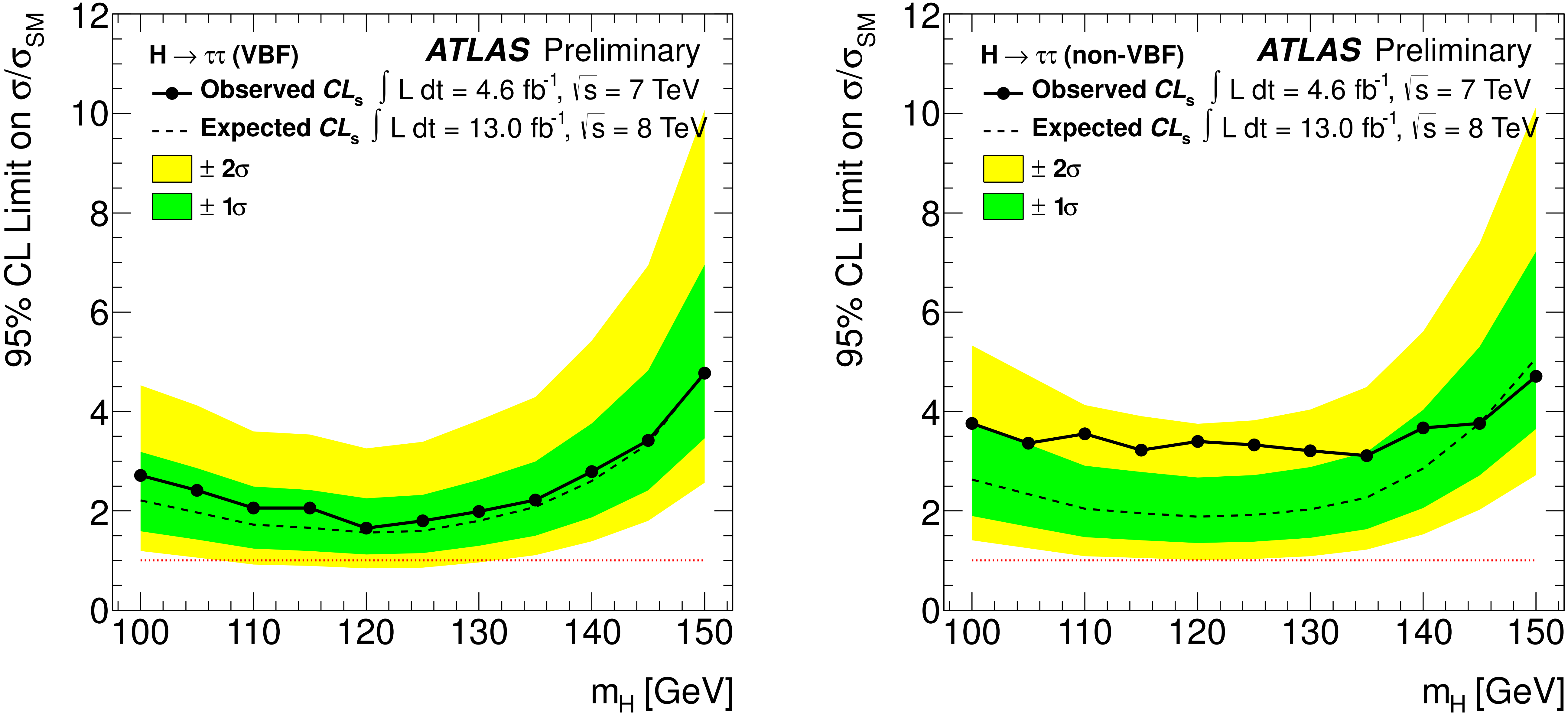


(b) Combined $H \rightarrow \tau_{\text{lep}}\tau_{\text{had}}$



(c) Combined $H \rightarrow \tau_{\text{had}}\tau_{\text{had}}$

Production mode categories CL$_s$

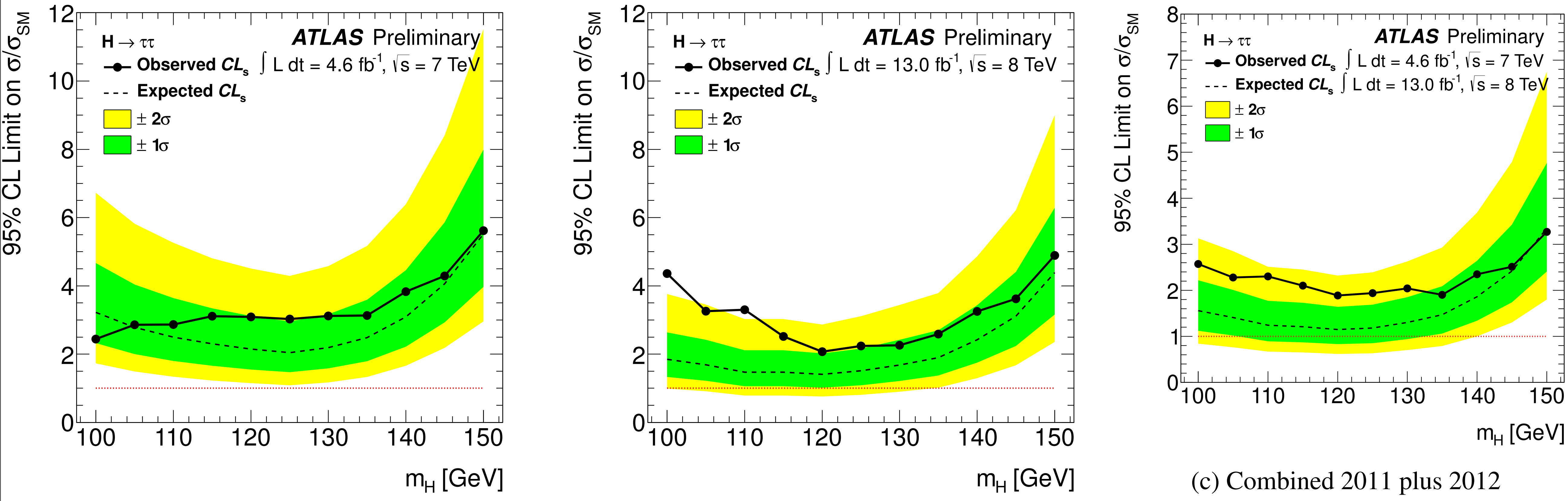


(a) VBF categories

(b) Non-VBF categories

Combined Results

- Calculated limit and significance using MMC distribution as the discriminant.
- To extract signal, Profile likelihood was used.

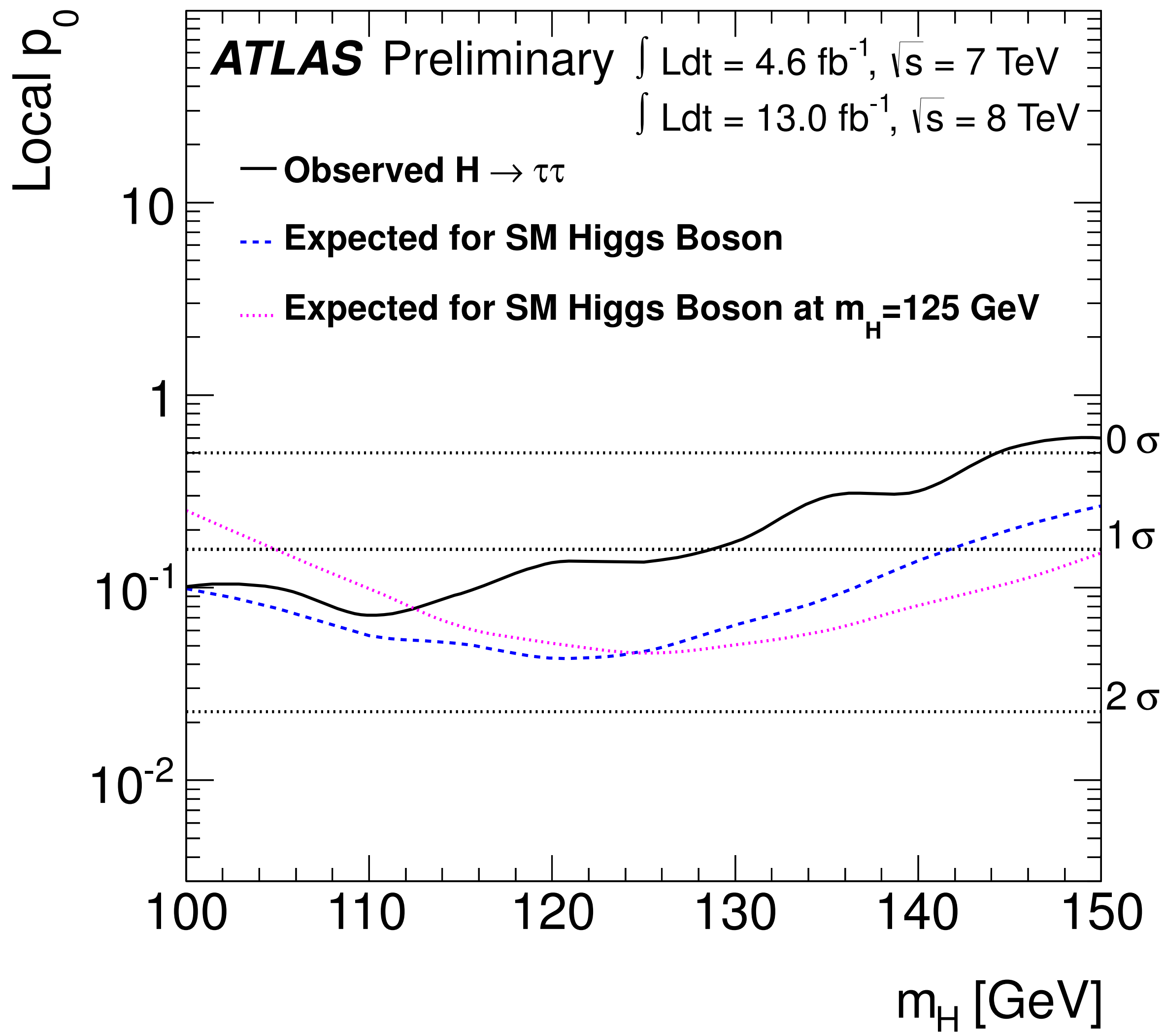


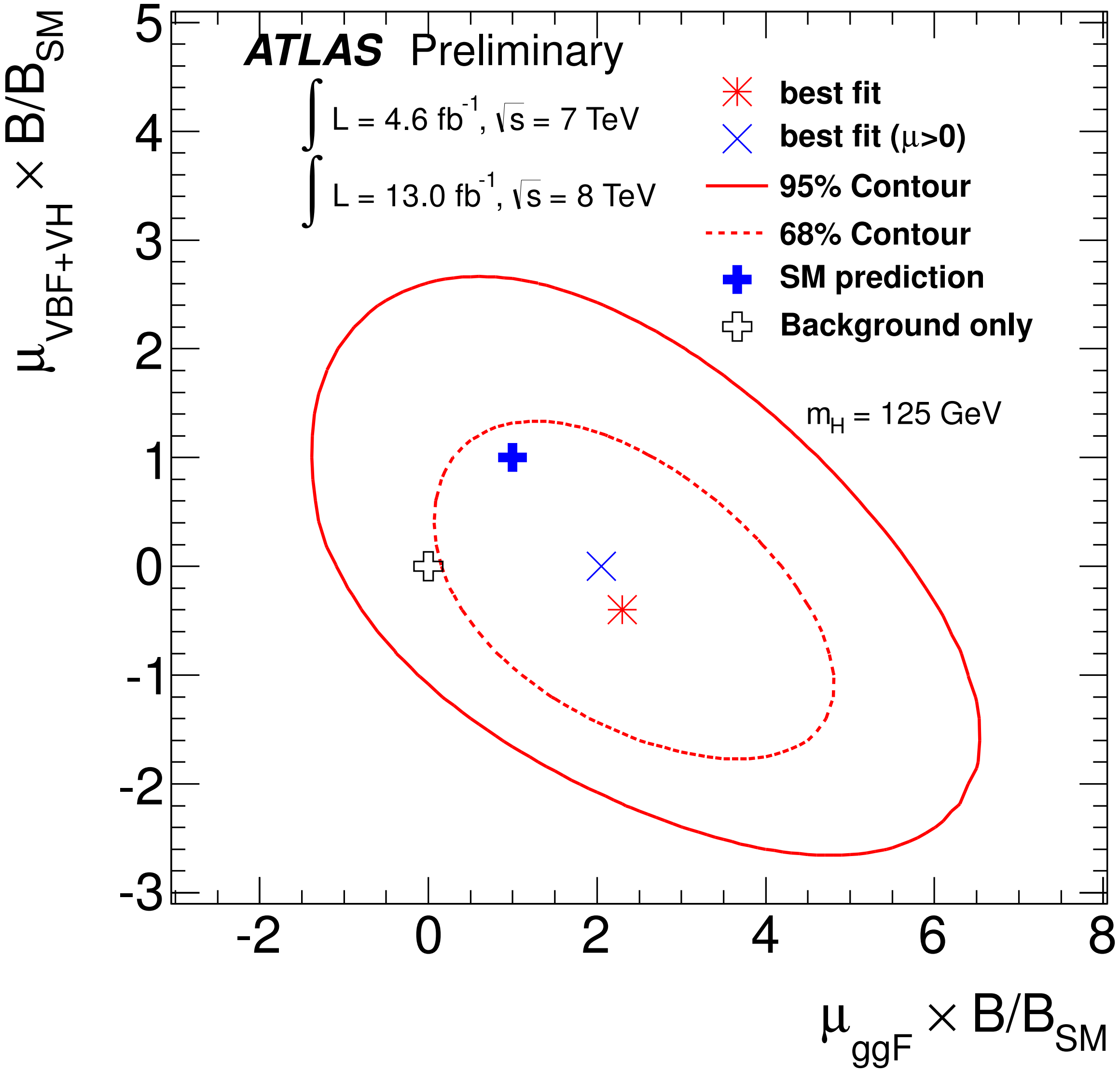
(c) Combined 2011 plus 2012

Expected:1.2xSM (μ=0) **Observed:1.9xSM** **Expected:1.7σ** (μ=1) **Observed:1.1σ**

Best fit value of Signal Strength (μ) is 0.7 ±0.7

p_0 and process dependence



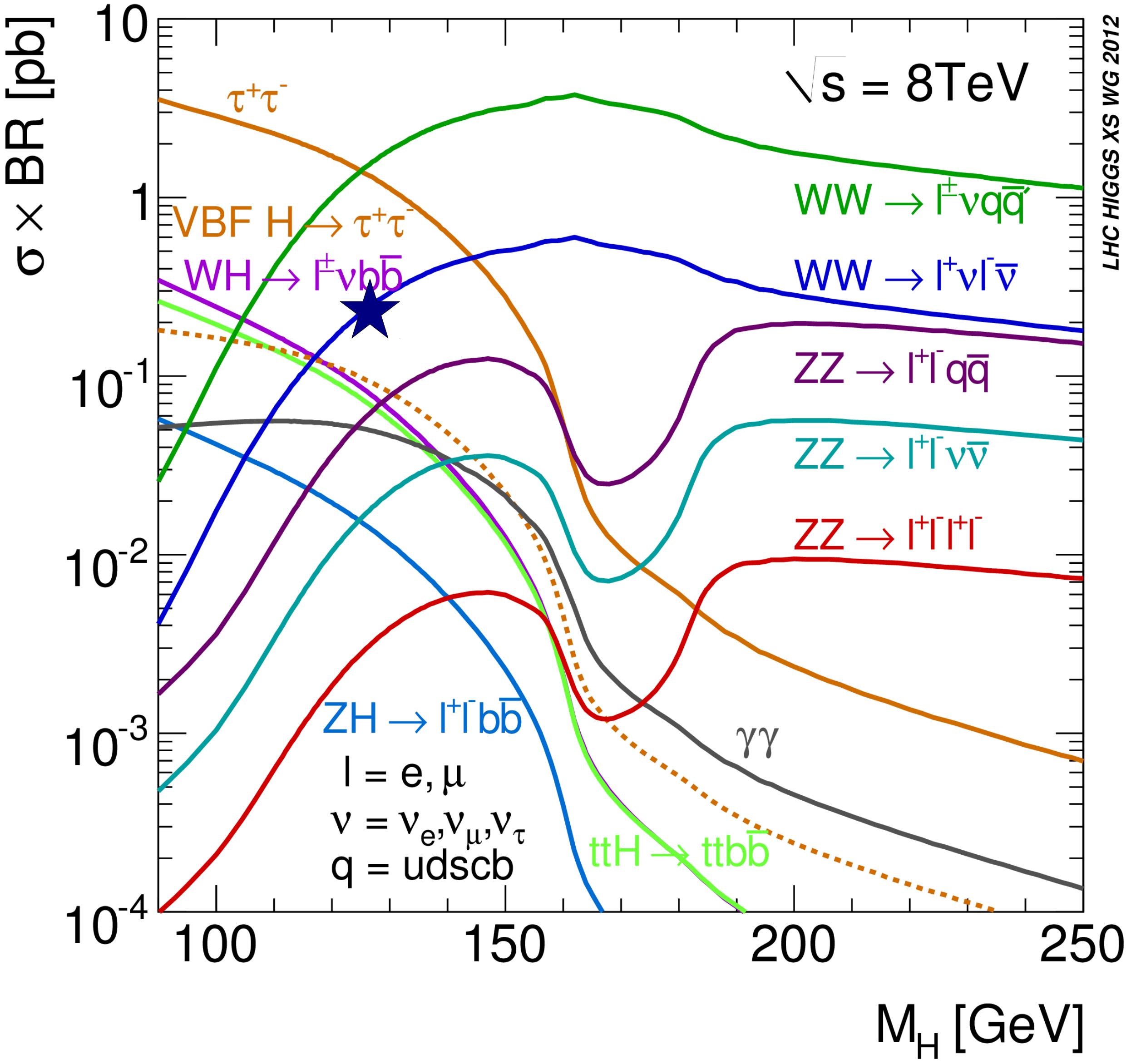


Still not enough sensitive to probe SM prediction, but it provides good constraint in VBF and ggF plane

$H \rightarrow WW$

H→WW

- $H \rightarrow WW \rightarrow \ell\nu\ell\nu$ is one of the more abundant Higgs final states at 125 GeV
- Provides best current probe of HWW coupling
- In July: 2.8 σ evidence for signal using 7 and 8 TeV data (expected 2.3 σ)
- Today: an updated measurement of the $H \rightarrow WW$ production rate with **13 fb^{-1}** of 8 TeV data



H→WW→lνlν Search

- Signature: $\ell\ell\not{E}_T$
  - Major backgrounds are continuum WW, top production, W+jets with a fake lepton, Z/γ* + fake $\not{E}_T$, $W\gamma^{(*)}$
- We use only the "different flavor" channel eνμν to avoid the contamination of $Z/\gamma^* \longrightarrow ee, \mu\mu$
  - Pileup ⟶ bad $\not{E}_T$ resolution for Z/γ^* rejection
- Higgs decays kinematically different from backgrounds, allows definition of signal-rich and control regions
  - Most signal-rich region blinded until control regions understood
  - Higgs mass proxy: transverse mass variable

$$m_T \equiv \sqrt{\left(\sqrt{p_T^{\ell\ell 2} + m_{\ell\ell}^2} + \not{E}_T\right)^2 - |\vec{\mathbf{p}}_T^{\ell\ell} + \vec{\not{\mathbf{E}}}_T|^2}$$

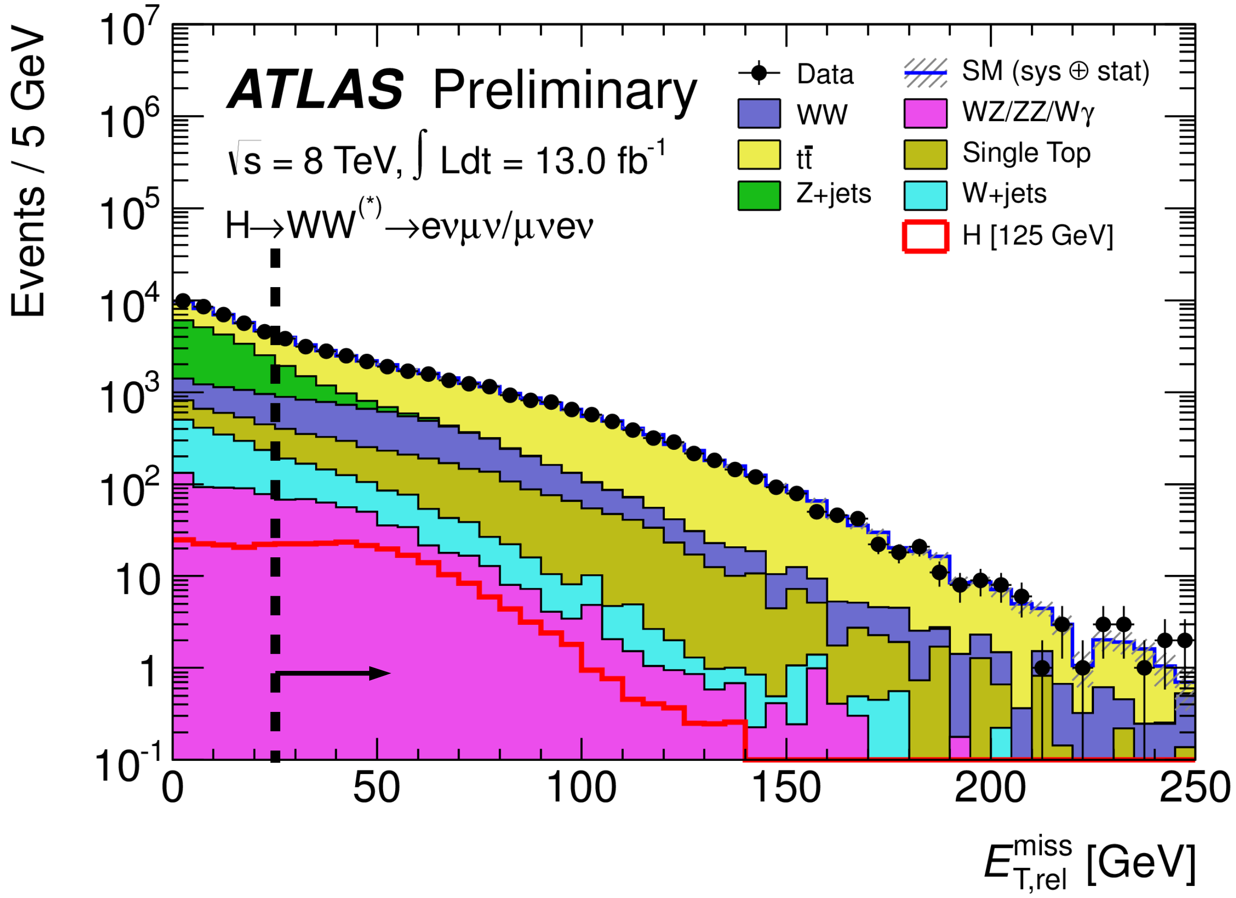
blind region of $93.75 < m_T < 125$ GeV after all other cuts

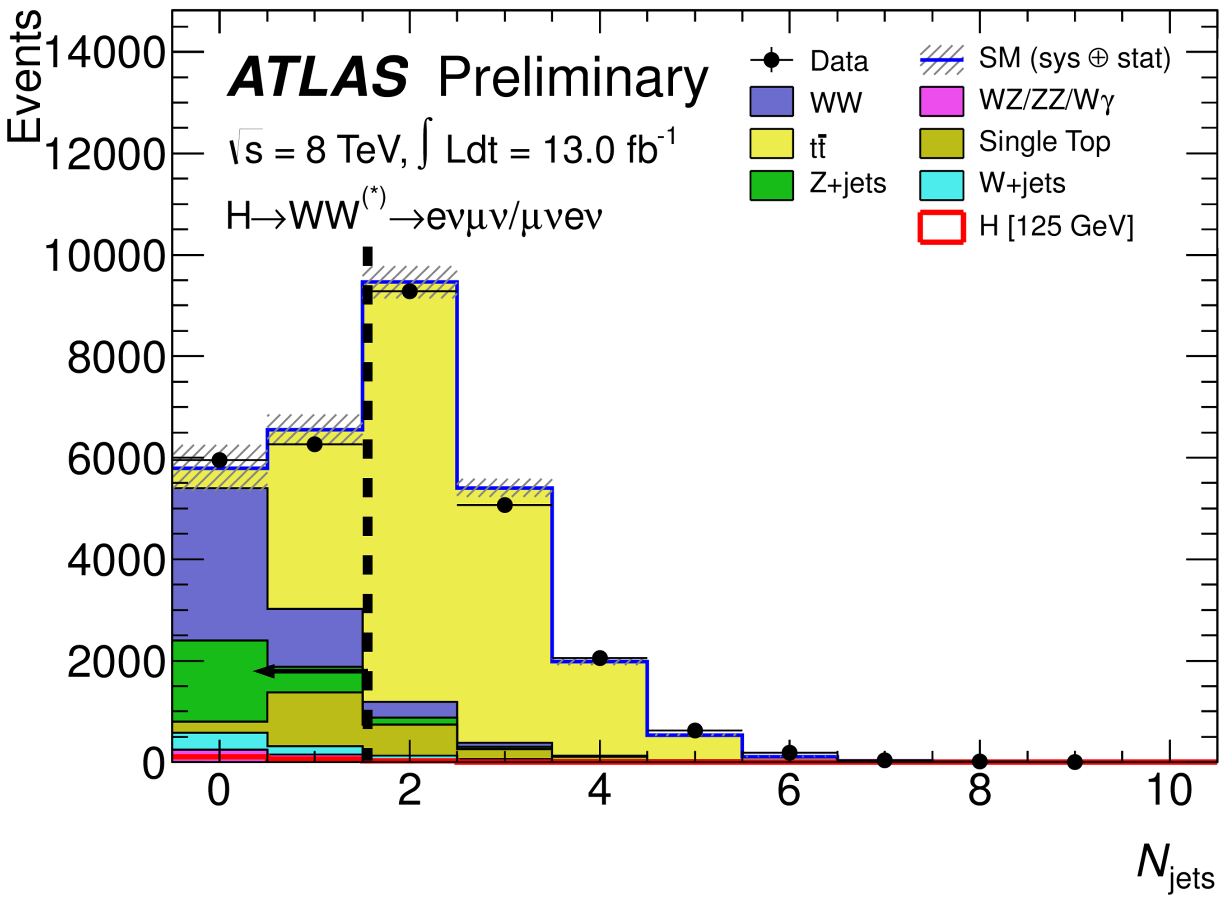
Event selection.

- opposite sign eμ candidates, M(ℓℓ) > 10 GeV
- $\not{E}_T^{rel} > 25$ GeV to remove Z → ττ
- ≤ 1 jet to remove top quark background

$$\not{E}_T^{rel} = \not{E}_T \sin\min(\Delta\phi_m, \pi/2)$$
$$\Delta\phi_m \equiv \min\Delta\phi(\ell \text{ or } j, \not{E}_T)$$

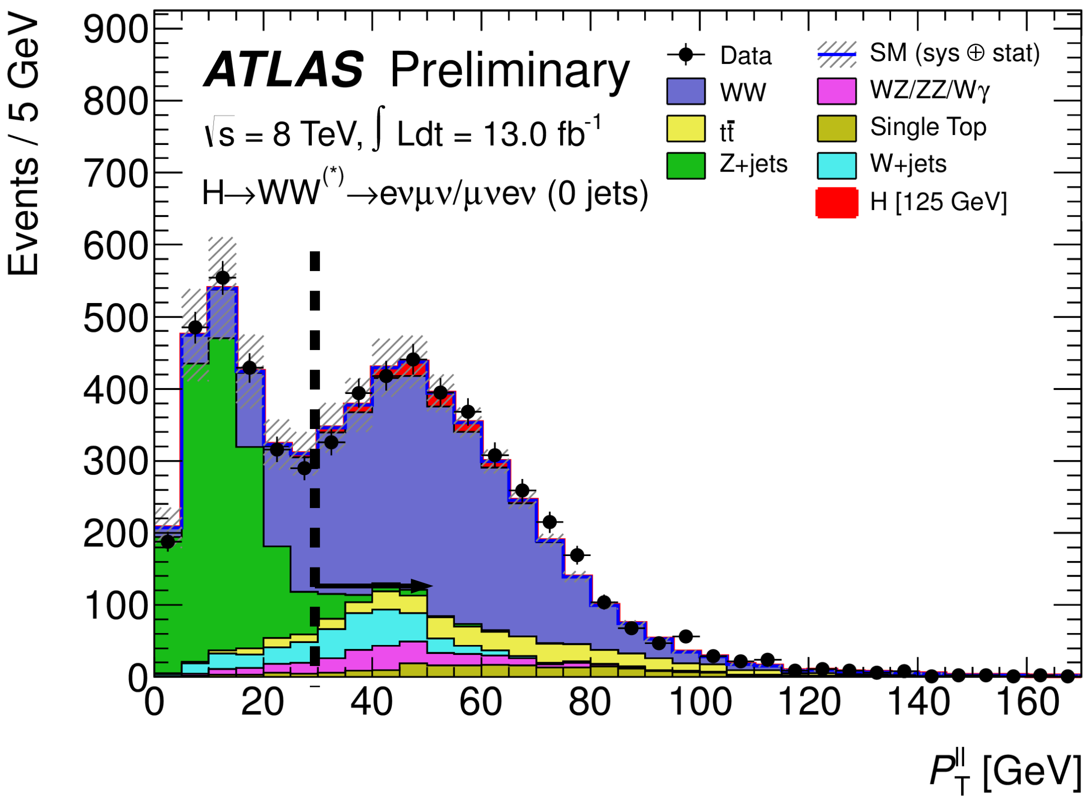
clean up E_T^{Miss} from object mis-reconstruction

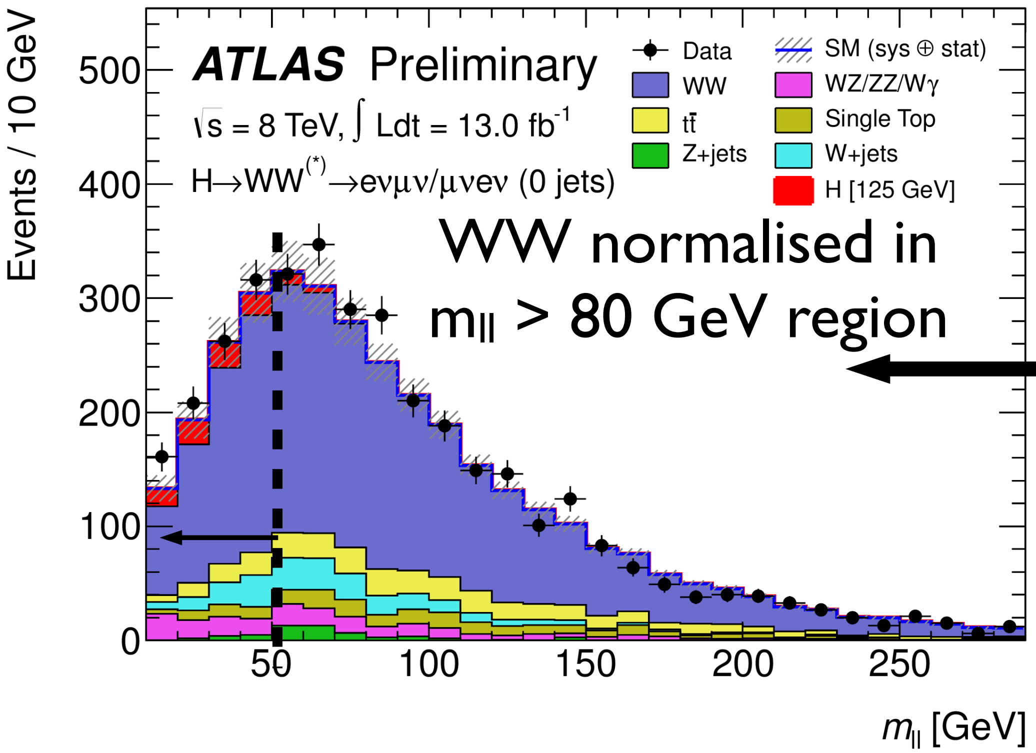




Higgs candidate selection 0 jet

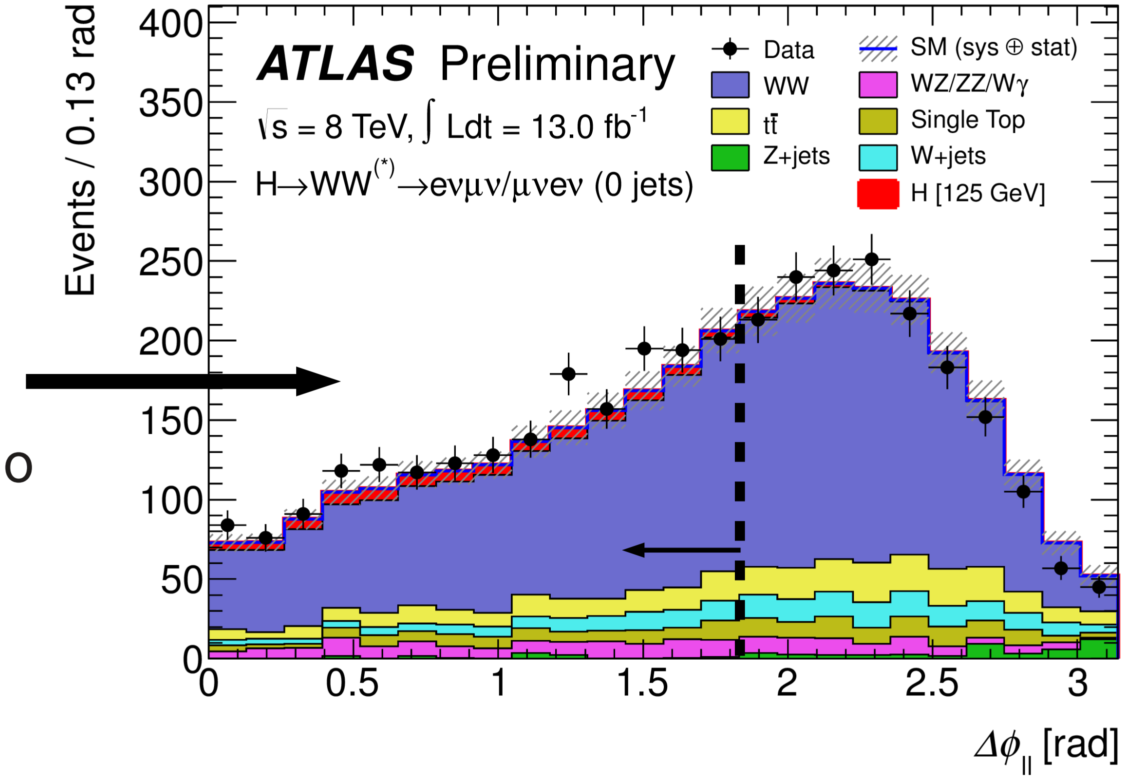
- Expect leptons to preferentially have small separation
  - high total momentum, small azimuthal separation, small invariant mass
  - Require $\not{E}_T$ in opposite hemisphere from dilepton system





WW normalised in m_{ll} > 80 GeV region

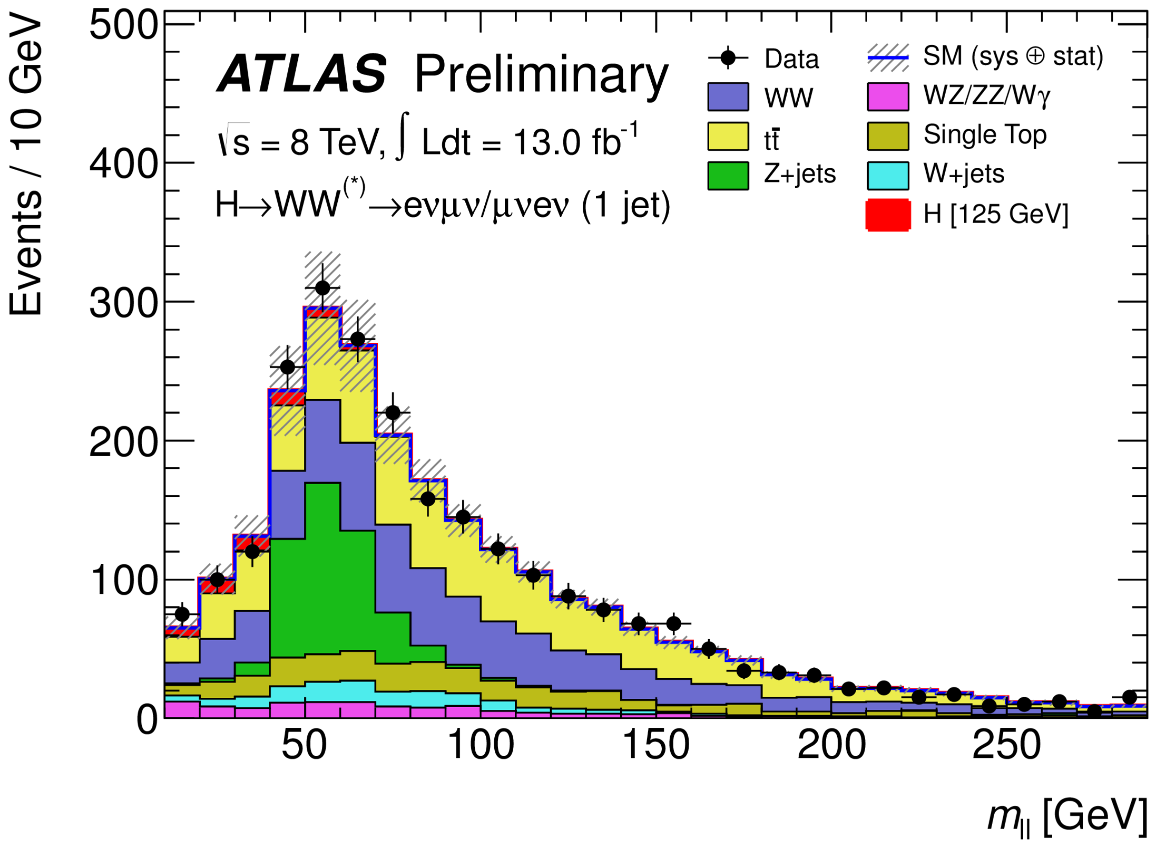
after pT(ℓℓ) > 30



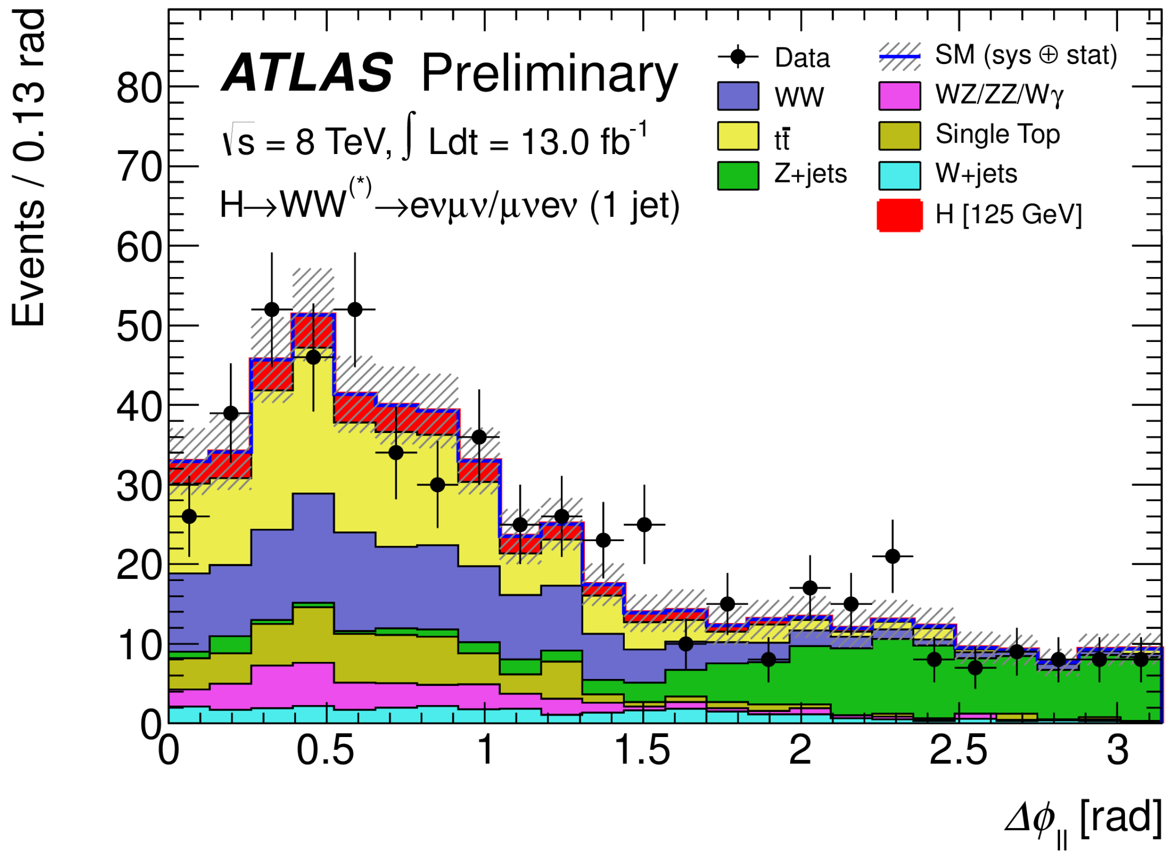
1 jet selection

- jet cannot be b-tagged
- $Z \rightarrow \tau\tau$ veto using collinear approximation
- Require small $m(\ell\ell)$ and $\Delta\phi(\ell,\ell)$ as in 0 jet bin

after b veto, $Z \rightarrow \tau\tau$ veto

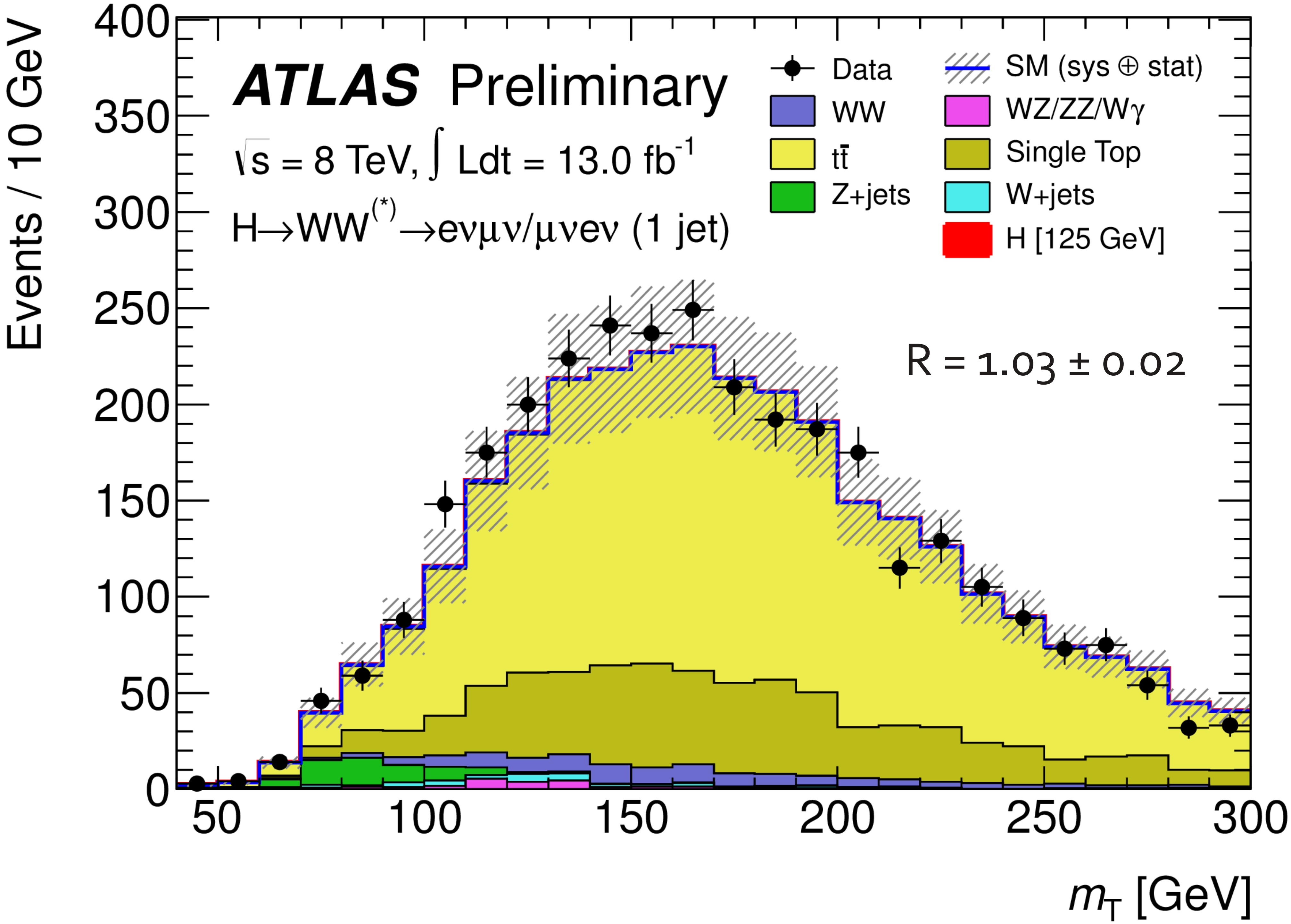


+ $m(\ell\ell) < 50$ GeV



Top Control Region.

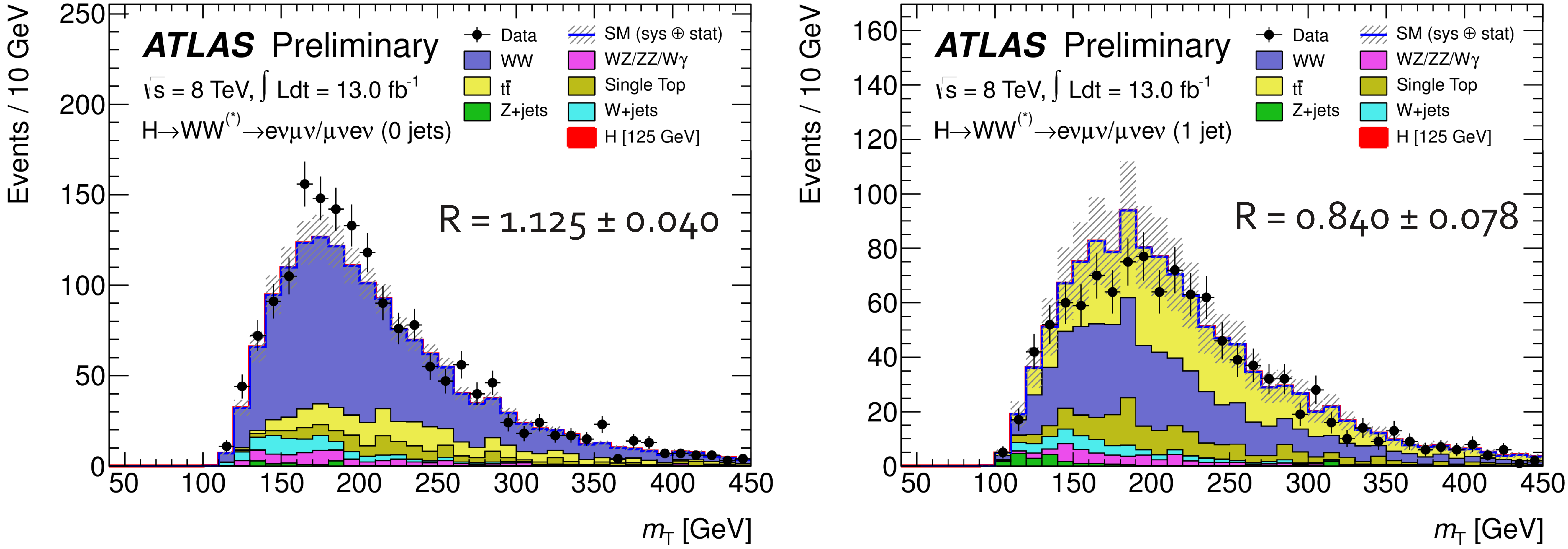
Reverse b-jet veto in 1 jet bin. Nice agreement out of the box.



WW normalisation.

- Normalization differences to MC evident, taken into account in the signal yield fit
  - Top contribution normalized via top CR

worse absolute normalisation with Powheg+Pytha8 than MC@NLO+Herwig (ICHEP)
but better description of m_{ll} and $\Delta\varphi_{ll}$ variables used for extrapolaton

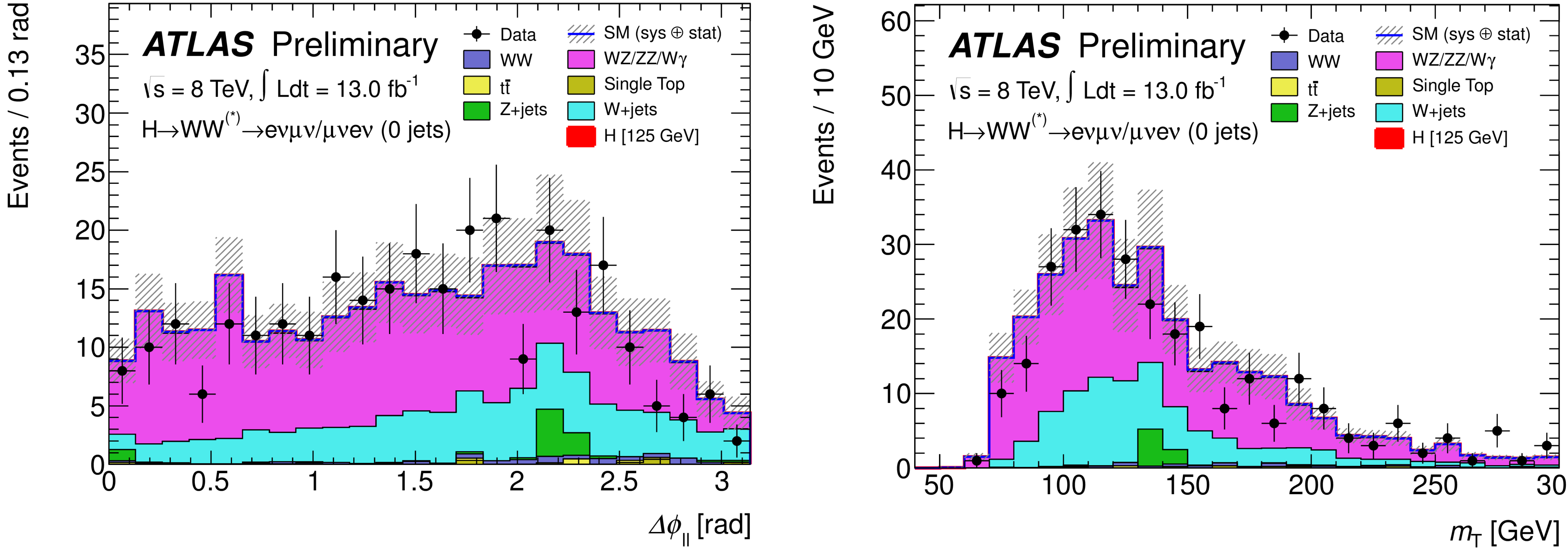


Nominal WW MC: Powheg+Pythia 8

Same sign validation.

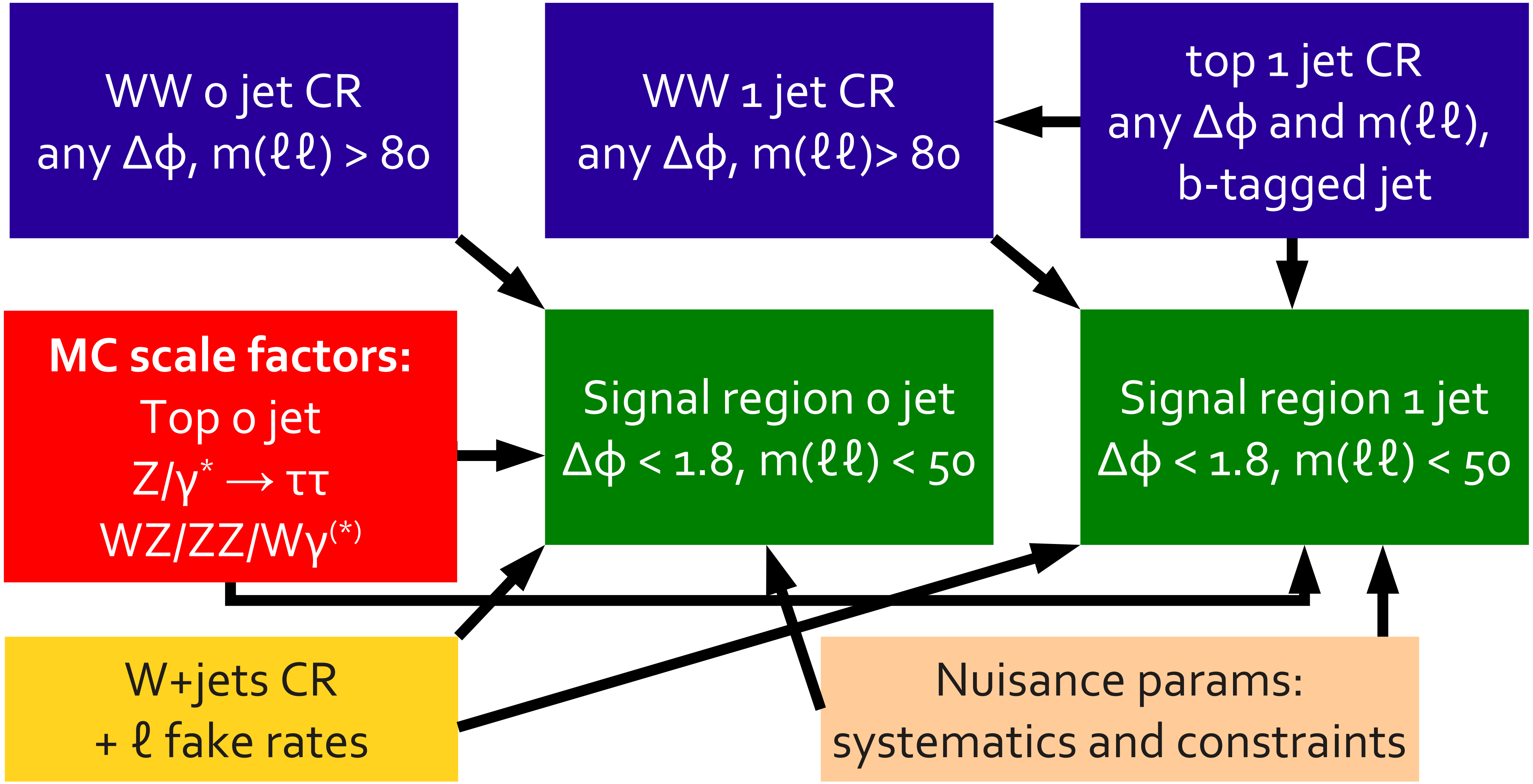
- Checks W+jets and non-WW diboson processes (in particular $W\gamma^{(*)}$)

Same sign events, 0 jet bin, $p_T(\ell\ell) > 30$ GeV



Fit model

- Fit the m_T spectrum of the signal region and the normalizations of (blue) control regions
  - systematics included as nuisance parameters



WW 0 jet CR
any Δϕ, m(ℓℓ) > 80

WW 1 jet CR
any Δϕ, m(ℓℓ)> 80

top 1 jet CR
any Δϕ and m(ℓℓ),
b-tagged jet

MC scale factors:
Top 0 jet
$Z/\gamma^* \rightarrow \tau\tau$
$WZ/ZZ/W\gamma^{(*)}$

Signal region 0 jet
Δϕ < 1.8, m(ℓℓ) < 50

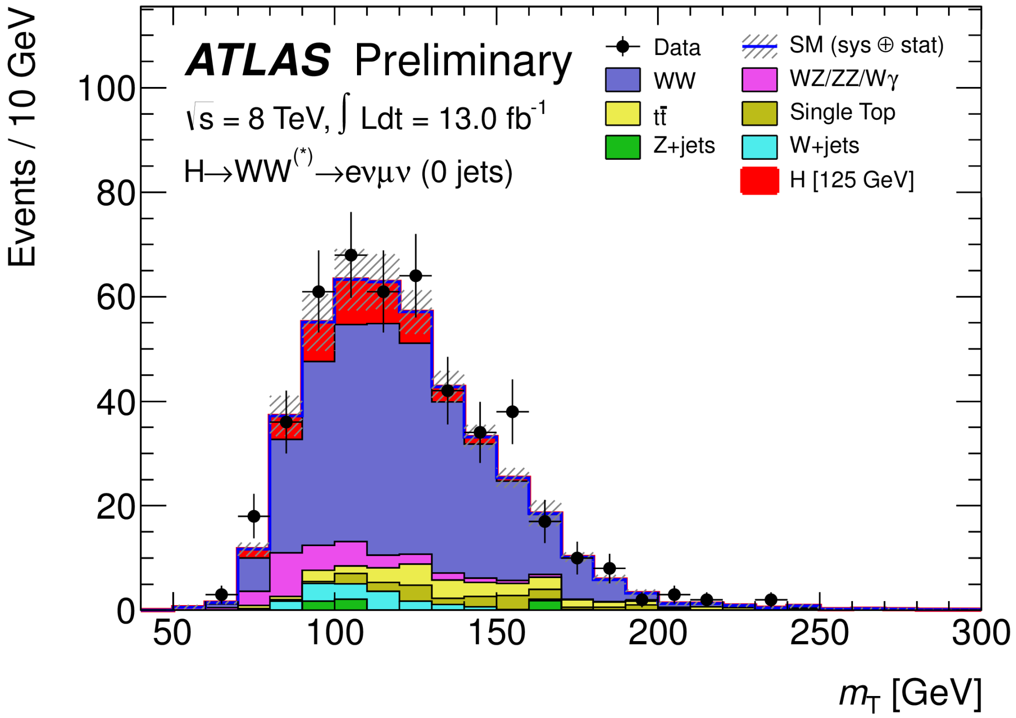
Signal region 1 jet
Δϕ < 1.8, m(ℓℓ) < 50

W+jets CR
+ ℓ fake rates

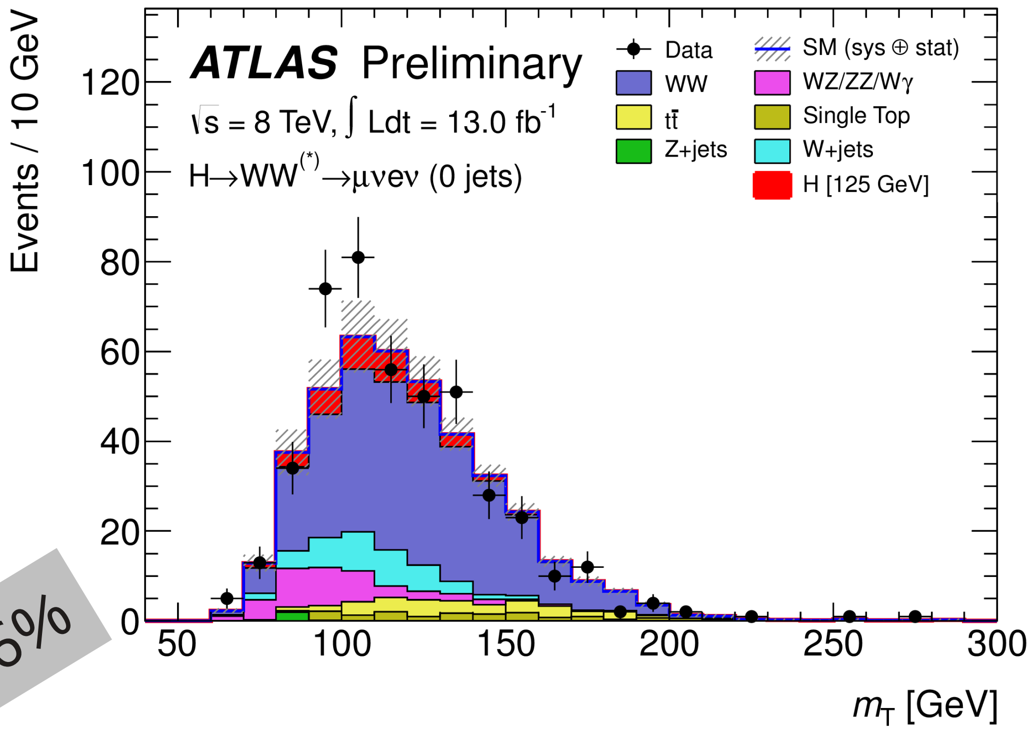
Nuisance params:
systematics and constraints

Signal region plots

e has higher p_T

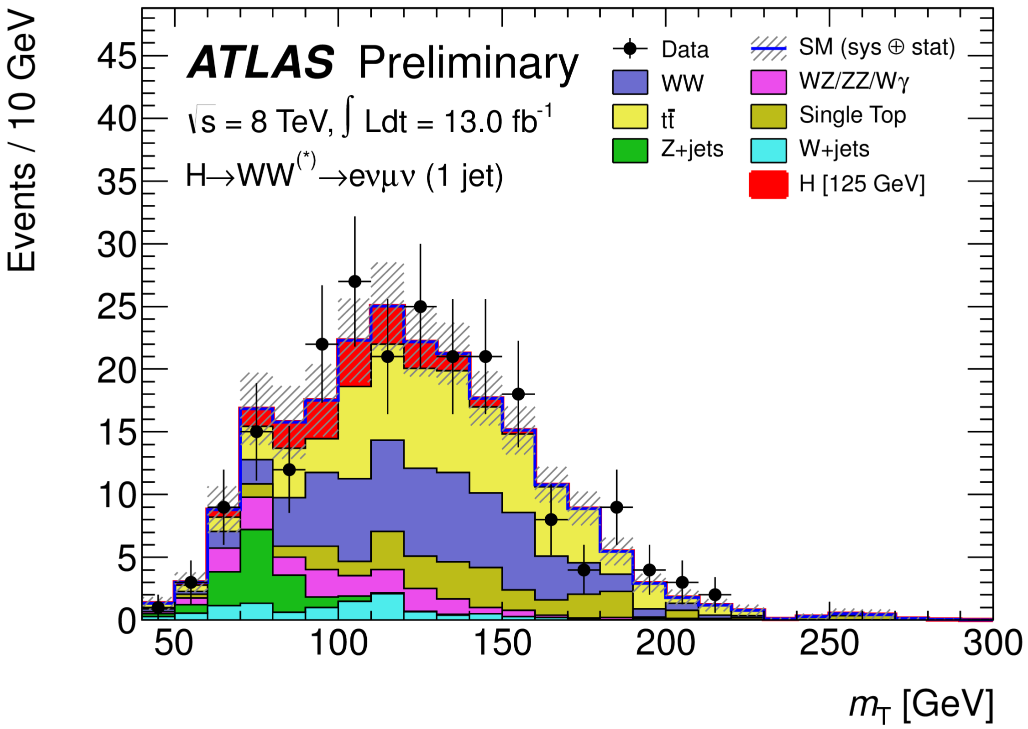


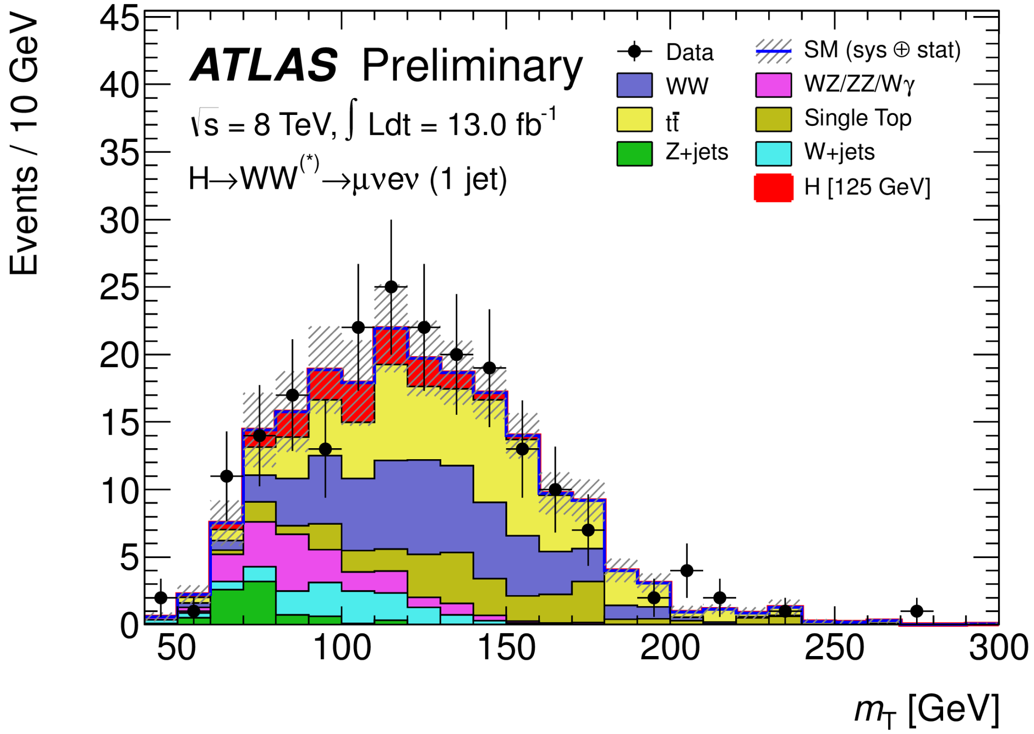
μ has higher p_T



0 jet

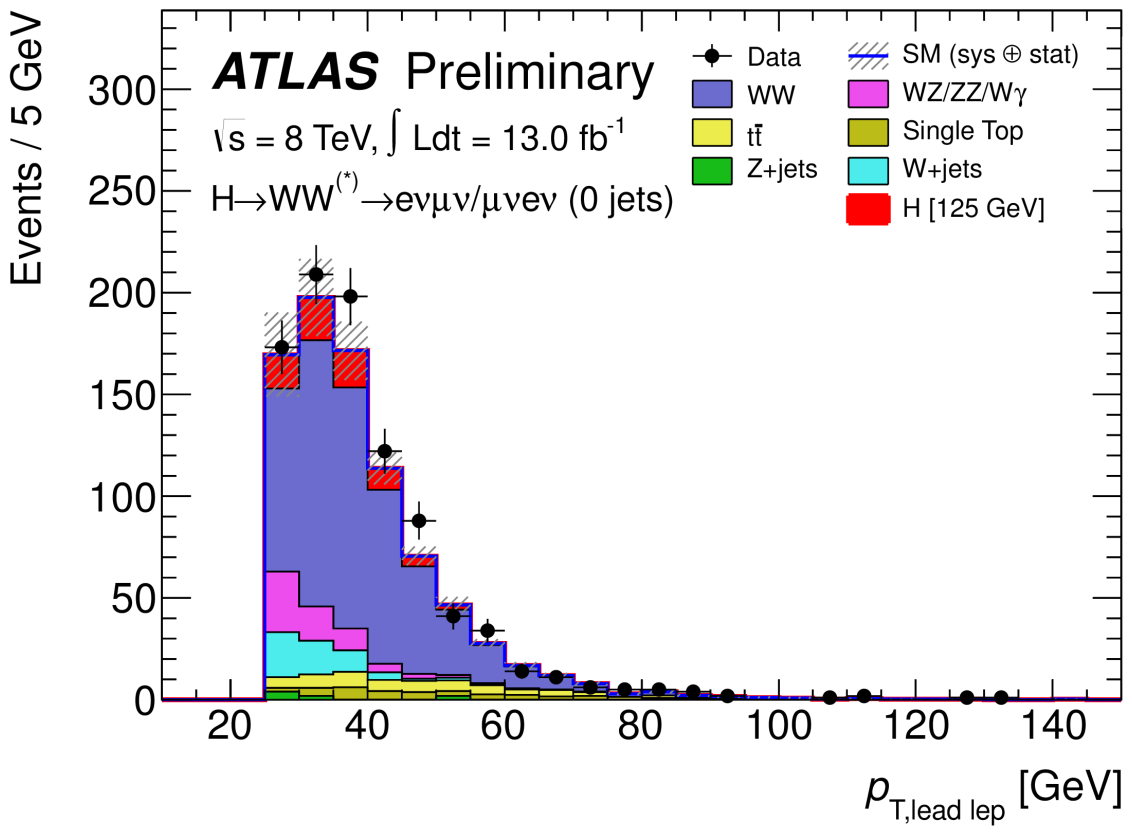
S/B: 13-16%

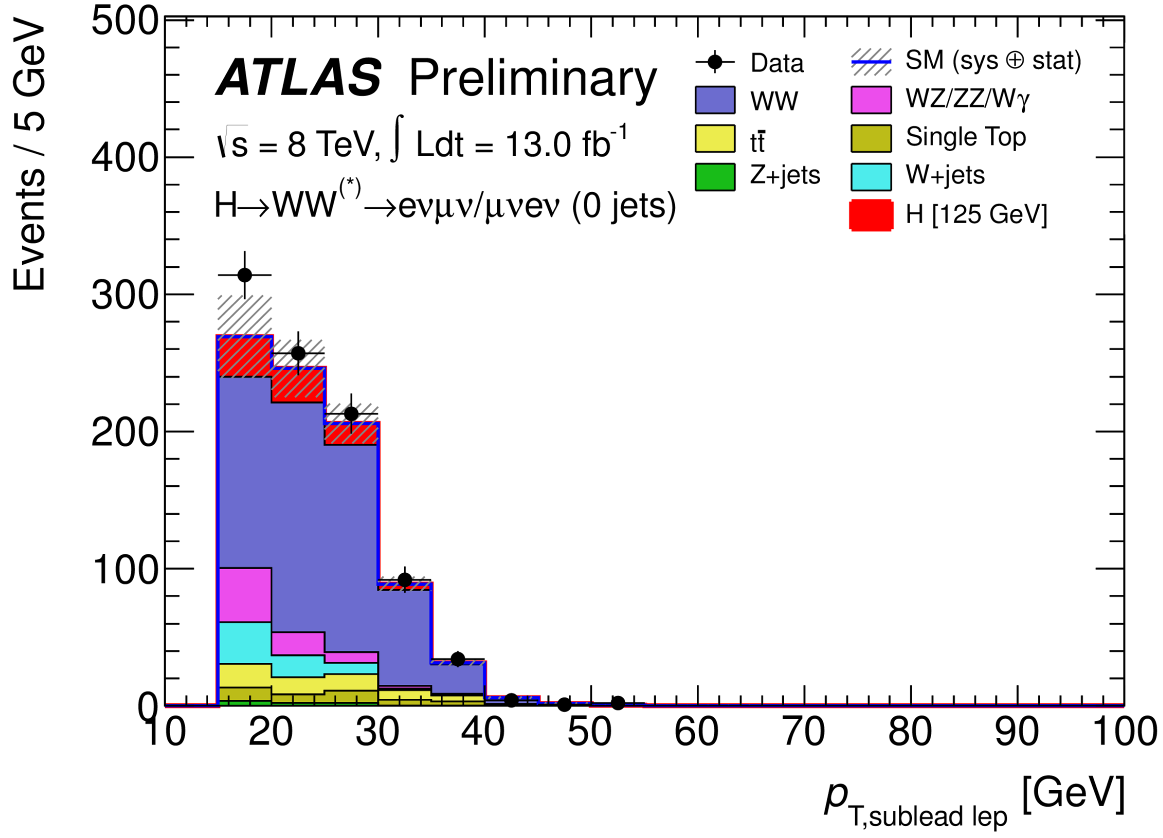


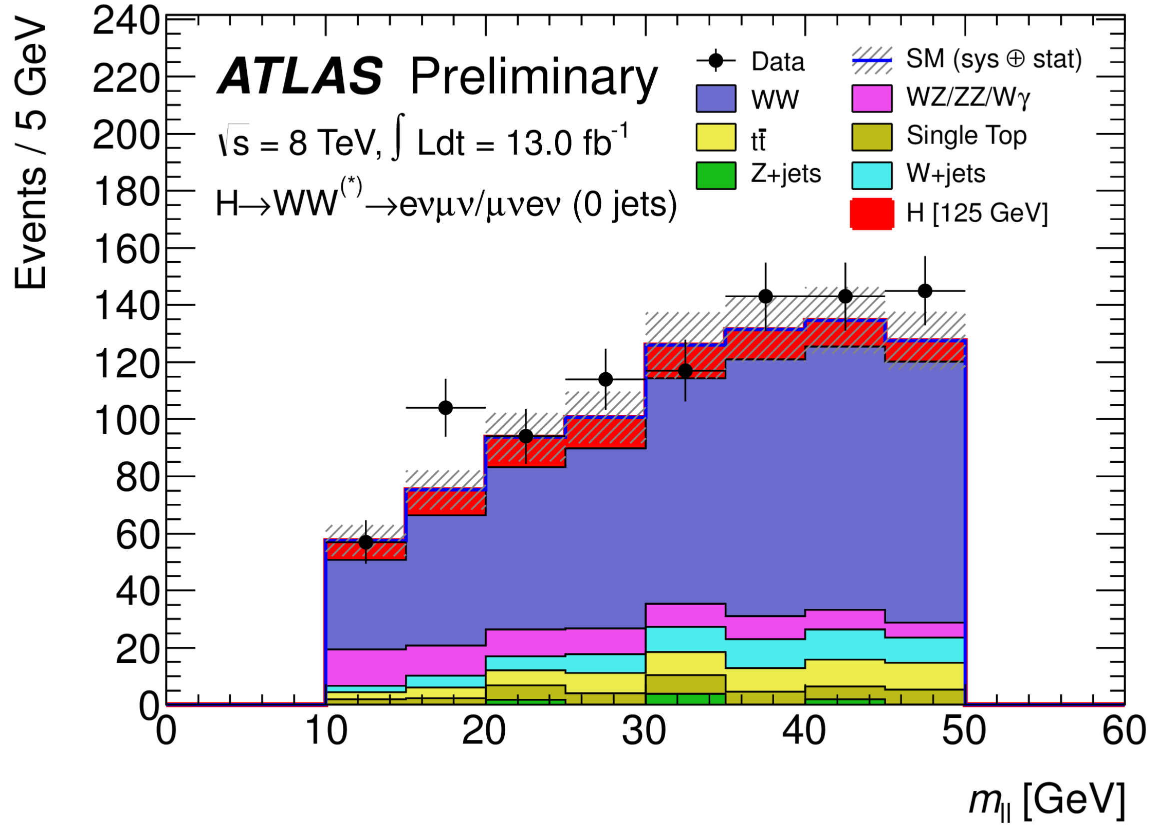


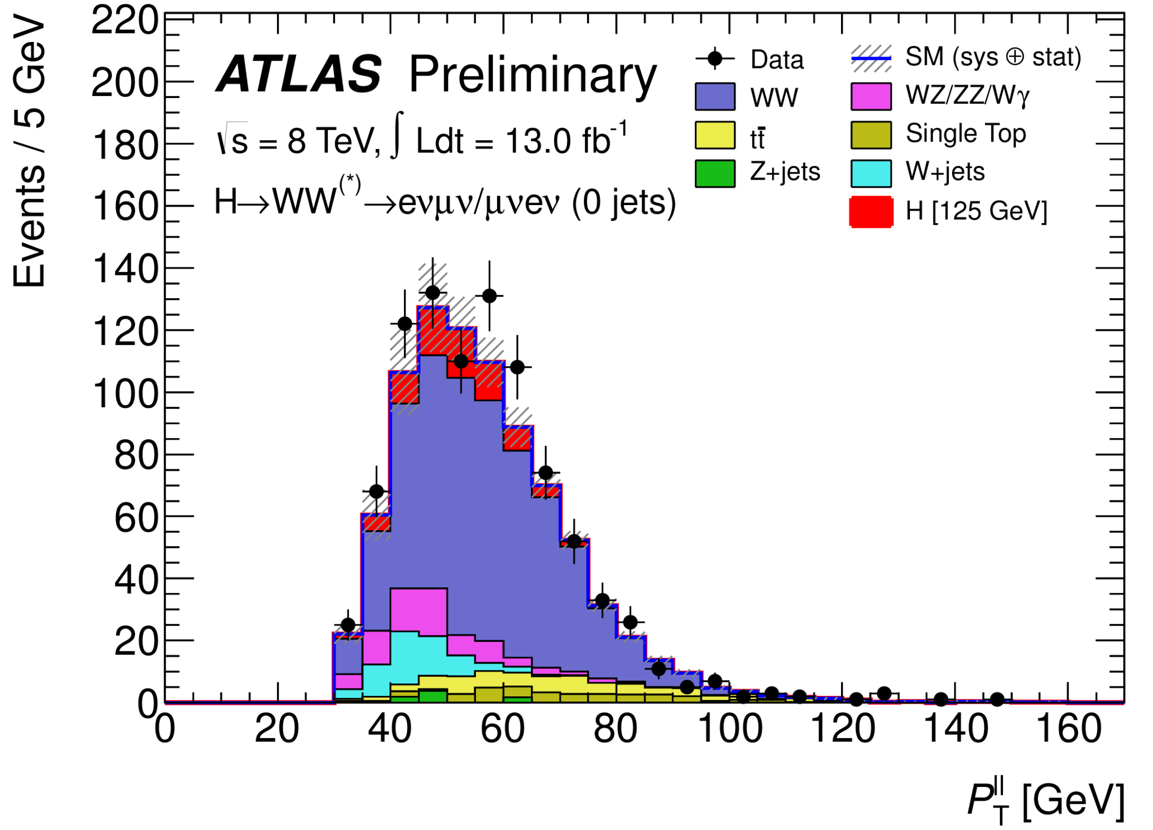
1 jet

A picture to the signal.









Results

@125 signal significance 2.6σ (expected 1.9σ)

signal strength (ratio to SM rate) $\mu = 1.5 \pm 0.6$

} $m_H = 125$ GeV

---

assumes SM ratio of production mechanisms

backgrounds & signal acceptance

$$\sigma(pp \to H) \cdot Br(H \to WW) = 7.0^{+1.7}_{-1.6}\ (\mathrm{stat})^{+1.7}_{-1.6}\ (\mathrm{theory})^{+1.3}_{-1.3}\ (\mathrm{exp}) \pm 0.3\ (\mathrm{lum})\ \mathrm{pb}$$

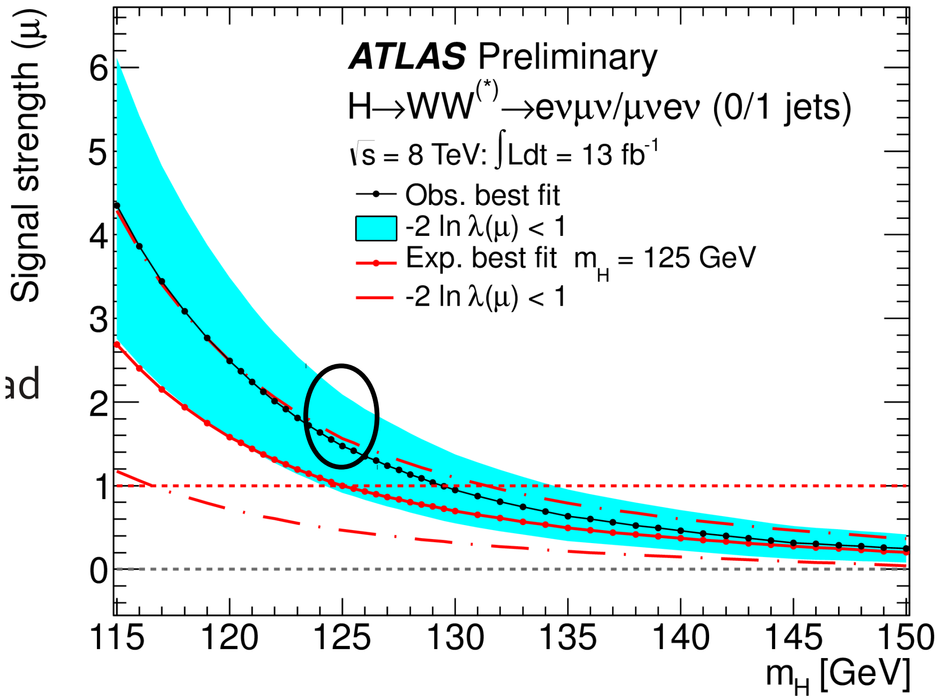
SM expectation: $\sigma(pp \to H) \cdot Br(H \to WW) = 4.77 \pm 0.64\ (\mathrm{xsec}) \pm 0.2\ (\mathrm{BR})\ \mathrm{pb}$

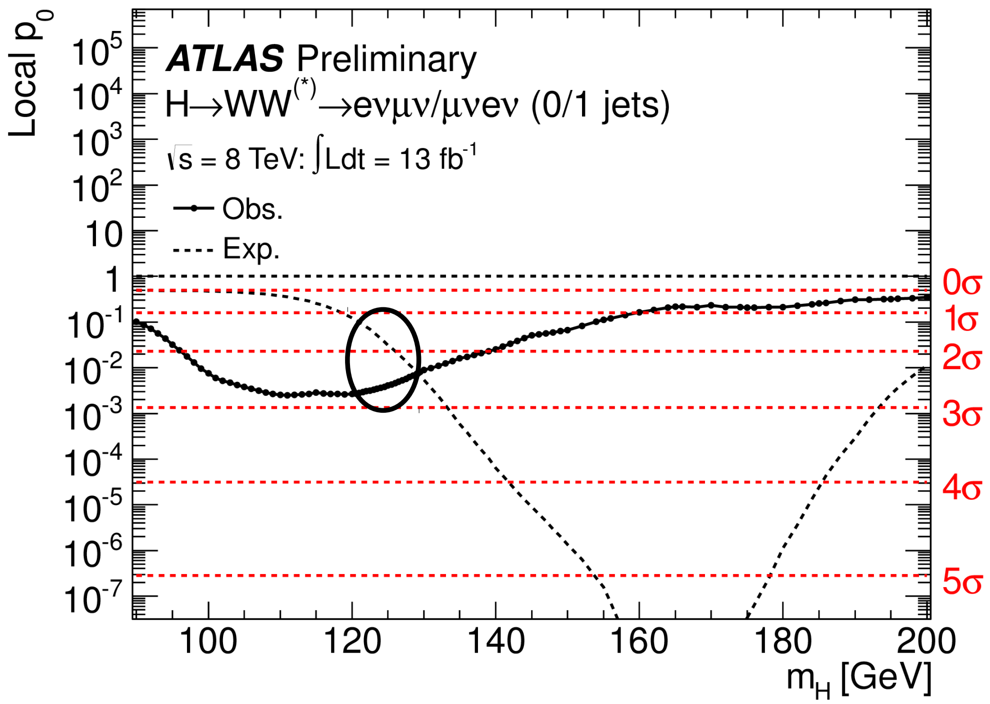
LHC Higgs XS WG

minimum p0

corresponding

to 2.8 σ





NOT COMBINED WITH 2011 RESULTS

Is it time to stop the μ saga and give a measurement? $d\sigma/dm_H = -0.25$ pb/GeV
(much more stable than μ, μ still usefull for 2011+2012 combination and channel combinations)

Systematics

Systematic uncertainty on the signal and background yield.

Source (0-jet)	Signal (%)	Bkg. (%)
Inclusive ggF signal ren./fact. scale	13	-
1-jet incl. ggF signal ren./fact. scale	10	-
PDF model (signal only)	8	-
QCD scale (acceptance)	4	-
Jet energy scale and resolution	4	2
W+jets fake factor	-	5
WW theoretical model	-	5
Source (1-jet)	**Signal (%)**	**Bkg. (%)**
1-jet incl. ggF signal ren./fact. scale	26	-
2-jet incl. ggF signal ren./fact. scale	15	-
Parton shower/ U.E. model (signal only)	10	-
b-tagging efficiency	-	11
PDF model (signal only)	7	-
QCD scale (acceptance)	4	2
Jet energy scale and resolution	1	3
W+jets fake factor	-	5
WW theoretical model	-	3

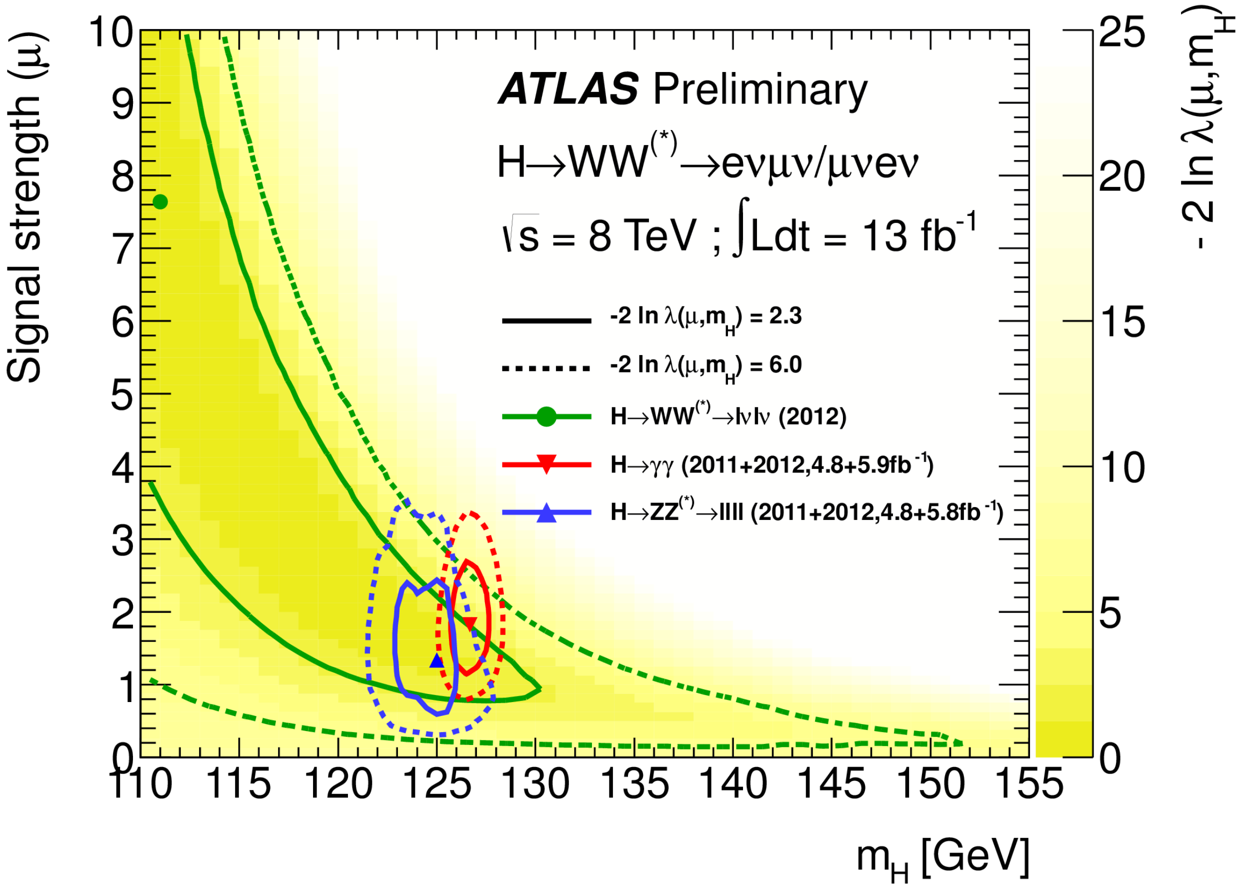
Systematic uncertainty on μ.

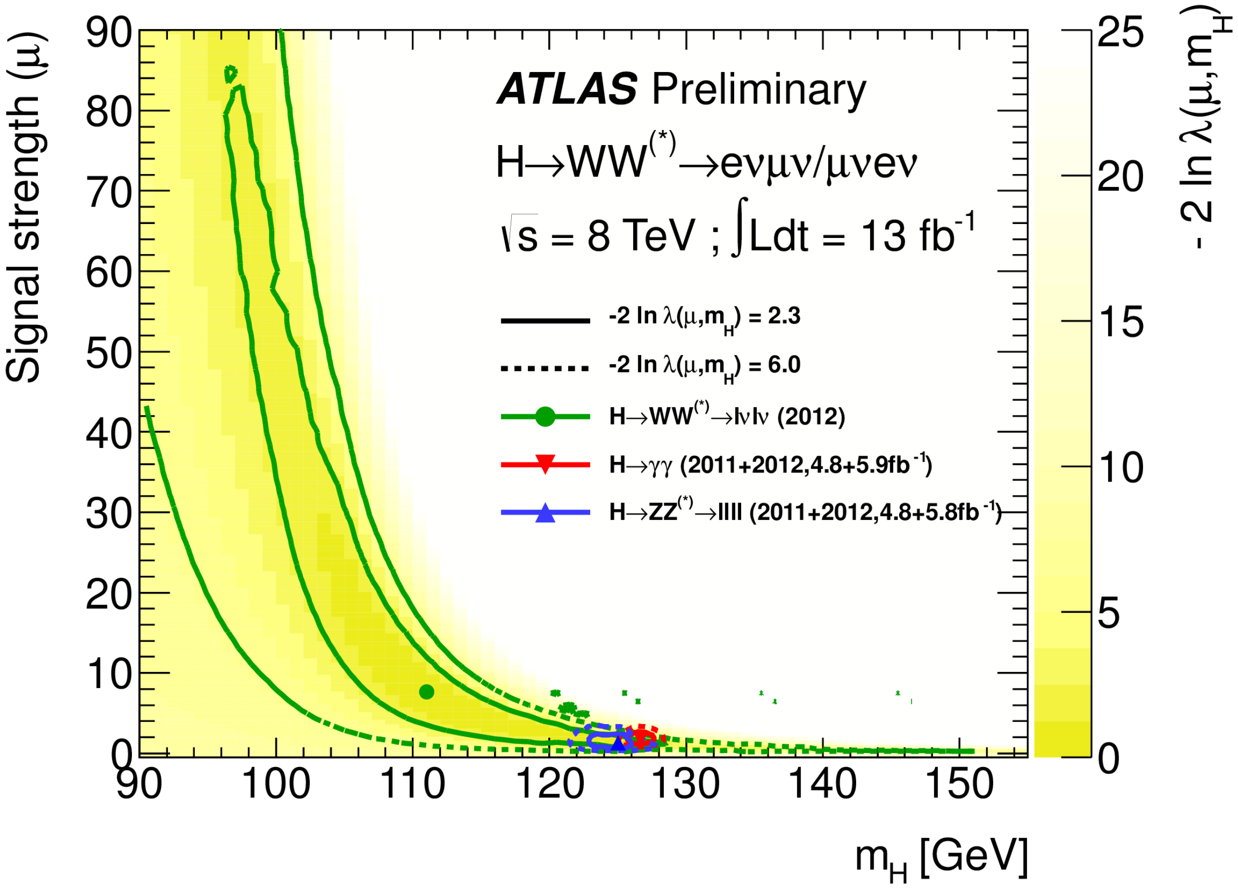
Source	Upward uncertainty (%)	Downward uncertainty (%)
Statistical uncertainty	+23	-22
Signal yield ($\sigma \cdot \mathcal{B}$)	+14	-9
Signal acceptance	+9	-6
WW normalisation, theory	+20	-20
Other backgrounds, theory	+9	-9
W+jets fake rate	+11	-12
Experimental + bkg subtraction	+14	-11
MC statistics	+8	-8
Total uncertainty	+41	-38

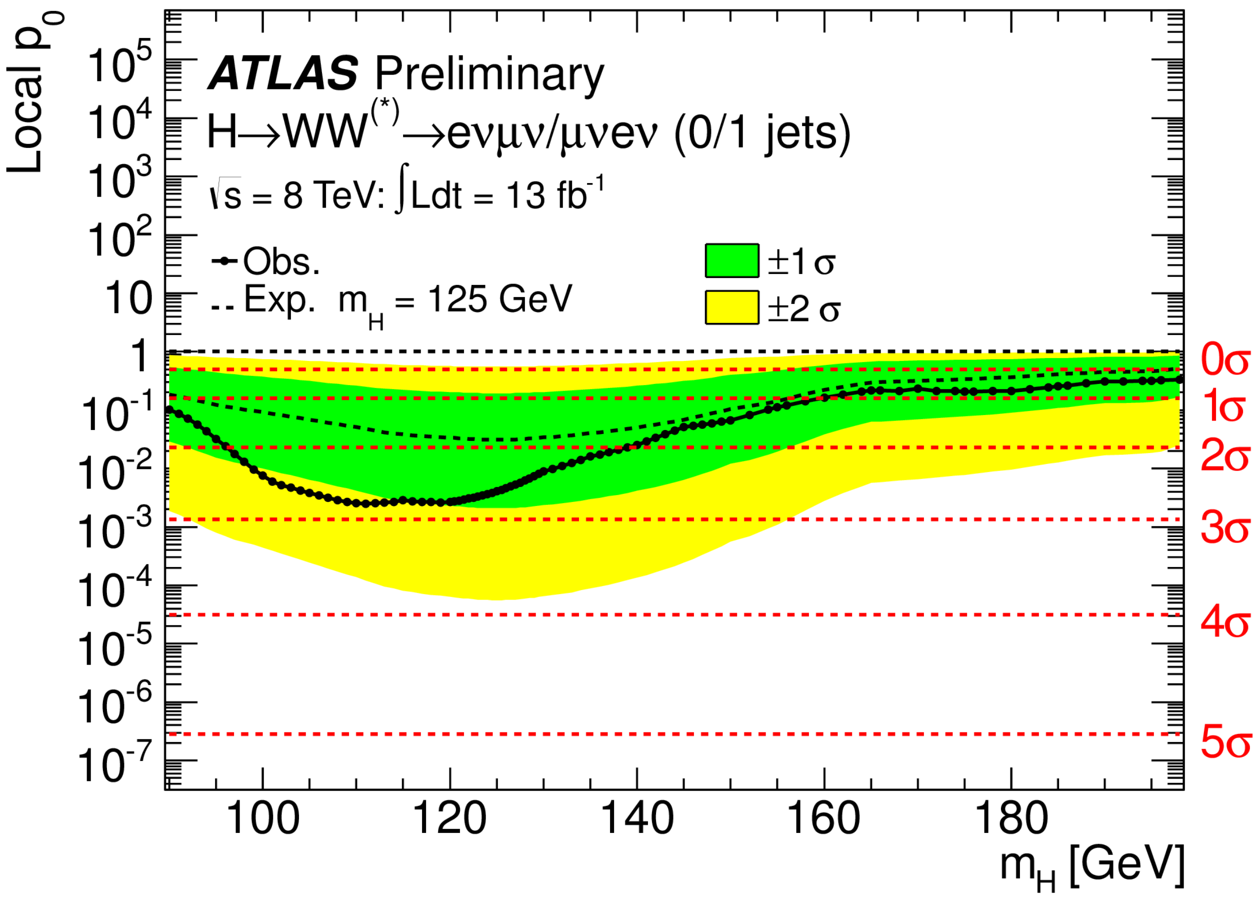
WW background extrapolation uncertainties				
	Scale	PDFs	PS/UE	Modelling
α_{WW}^{0j}	2.5%	3.7%	4.5%	3.5%
α_{WW}^{1j}	4%	2.9%	4.5%	3.5%

The result is systematically dominated, we need to change strategy for Moriond...

m_H-μ correlation.







Why we don’t combine with 2011?

1. We discovered it, why should we combine? :-)
2. We changed the WW modeling, this affects μ_{2012} by ~ $0.5\sigma_{sys}$ (reanalysis 2011 with the same modelling)
3. We realised that the high statistics in the CR was constraining systematics (this is a not desired effect of the profiling, 2012 analysis has been corrected by reducing the numbers of CR, we need to do the same for 2011)
4. The profiling doesn’t impact so much μ (0.01 effect in 2012) but artificially reduces the systematics, also when combining with 2011.

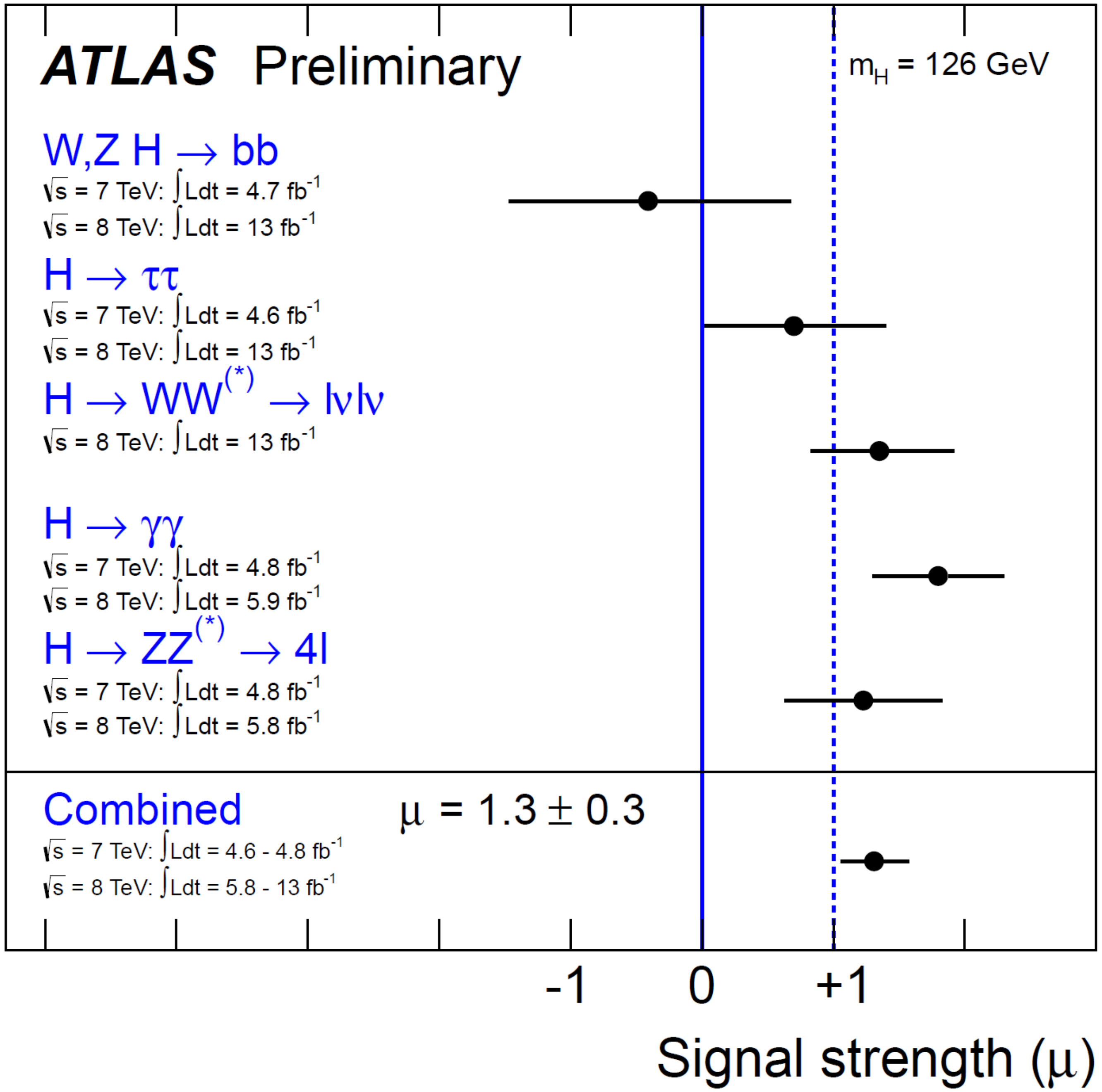
Combination

ATLAS combination.

- ☐ H→bb, ττ and WW* analyses have been updated using 13fb^{-1} data collected at 8 TeV in 2012.
- ☐ Higgs decays to γγ, ZZ* and WW* are established, but H → bb, ττ still lack of statistics to draw definitive conclusion.

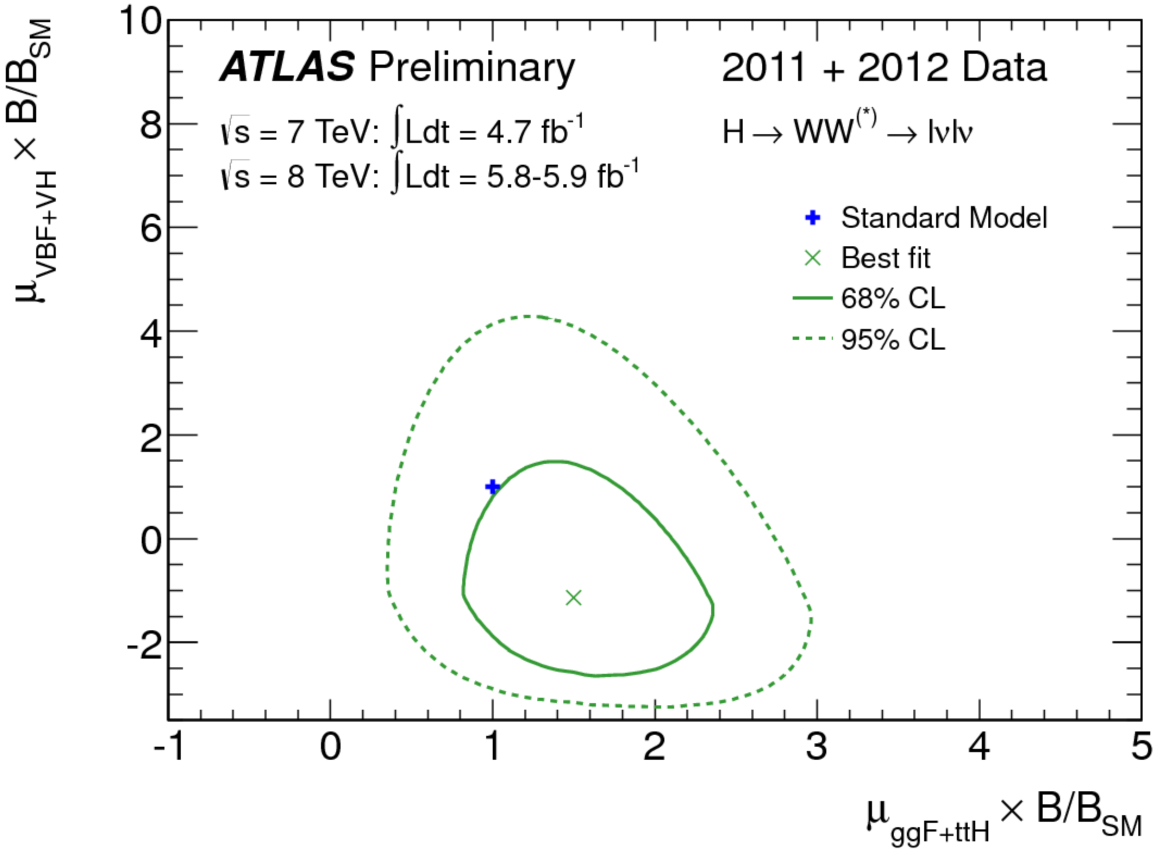
Best–fit Higgs mass m_H :
126.0 ± 0.4 (stat) ± 0.4 (syst) GeV

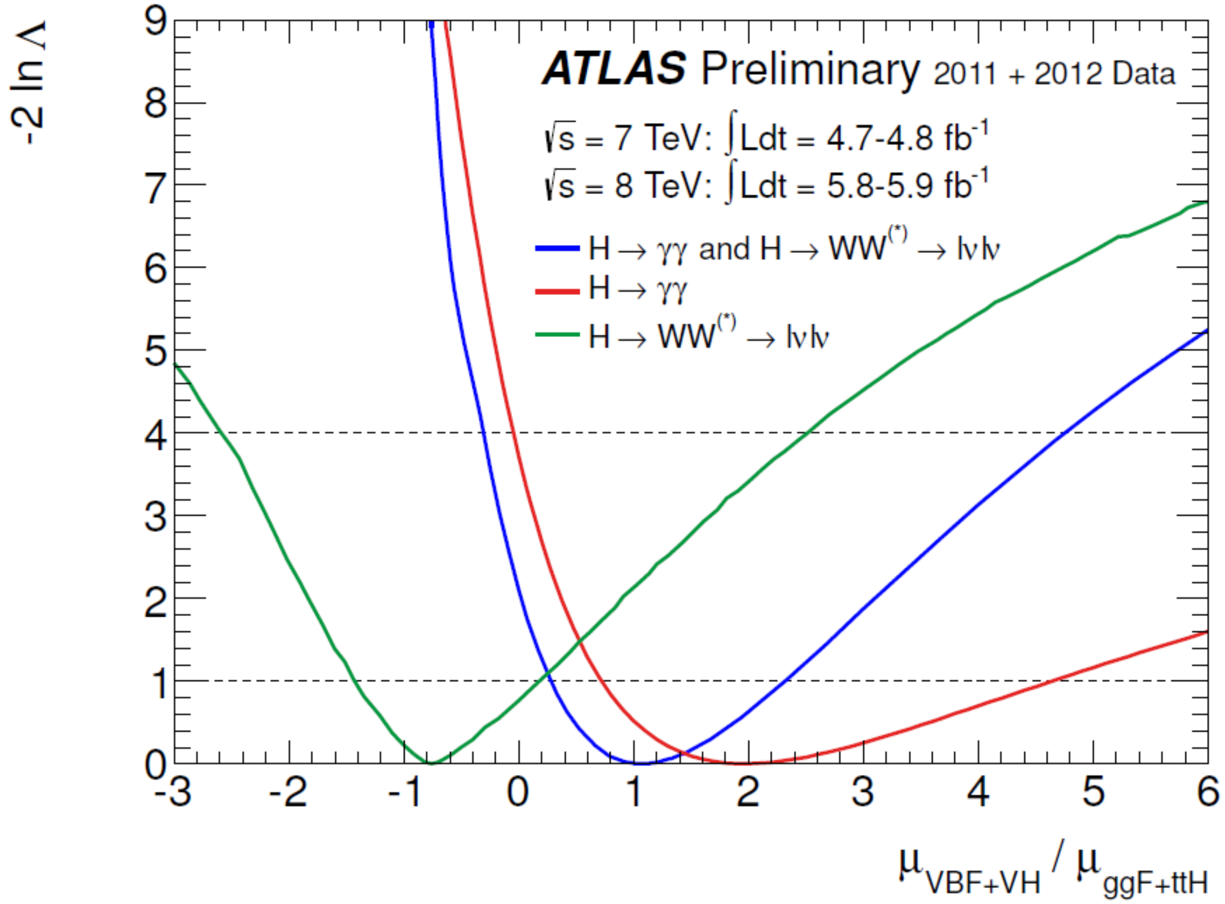
Best-fit signal strength:
$\mu = 1.3 \pm 0.3$



VBF/ggF prod mode.

- ❑ Model independent coupling studies which are directly related to experimental observables. 2D contour: μ_{VBF+VH} vs. $\mu_{ggF+ttH}$
- ❑ H→ZZ*→4l has low statistics and uses inclusive analysis





➔The signal strength ratios cancel the branching ratios of different channels so that the results can be compared directly.

Measuremet of Higgs couplings

- ☐ **Assumptions (LHC HXSWG, arXiv:1209.0040):**
  - The signal observed in different channels originate from a single narrow resonance with mass near 125 GeV.
  - The width of the assumed Higgs boson near 125 GeV is neglected, hence the signal cross section can be decomposed in the following for all channels:

$$(\sigma \cdot \mathrm{BR})\,(ii \to \mathrm{H} \to ff) = \frac{\sigma_{ii} \cdot \Gamma_{ff}}{\Gamma_{\mathrm{H}}}$$

  - Only modifications of couplings strengths are taken into account, while the tensor structure of the couplings is assumed to be same as in the SM prediction (CP-even scalar). **[ATLAS-CONF-2012-127]**

Higgs coupling structure

- Depending on the benchmark model, κ$_g$, κ$_\gamma$ and κ$_H$ are either functions of other couplings or independent parameters.
- Notation for gg→H→γγ

Zero Width Approximation

$$(\sigma\cdot\mathrm{BR})(gg\to H\to\gamma\gamma) = \sigma_{\mathrm{ggF}} \cdot \frac{\Gamma_{\gamma\gamma}}{\Gamma_H}$$

$$\frac{\sigma_{\mathrm{ggF}}}{\sigma_{\mathrm{ggF}}^{\mathrm{SM}}} = \kappa_g^2 \qquad \frac{\Gamma_{\gamma\gamma}}{\Gamma_{\gamma\gamma}^{\mathrm{SM}}} = \kappa_\gamma^2 \qquad \frac{\Gamma_H}{\Gamma_H^{\mathrm{SM}}} = \kappa_H^2$$

$$= \kappa_g^2\,\sigma_{\mathrm{SM}}(gg\to H)\cdot\frac{\kappa_\gamma^2}{\kappa_H^2}\mathrm{BR}_{\mathrm{SM}}(H\to\gamma\gamma)$$

fixed

Higgs couplings..

- ☐ No BSM particle contributions to gg→H, H→γγ and the total width. Two coupling scale factors κ_F for fermions and κ_V for bosons,

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

68% CL intervals

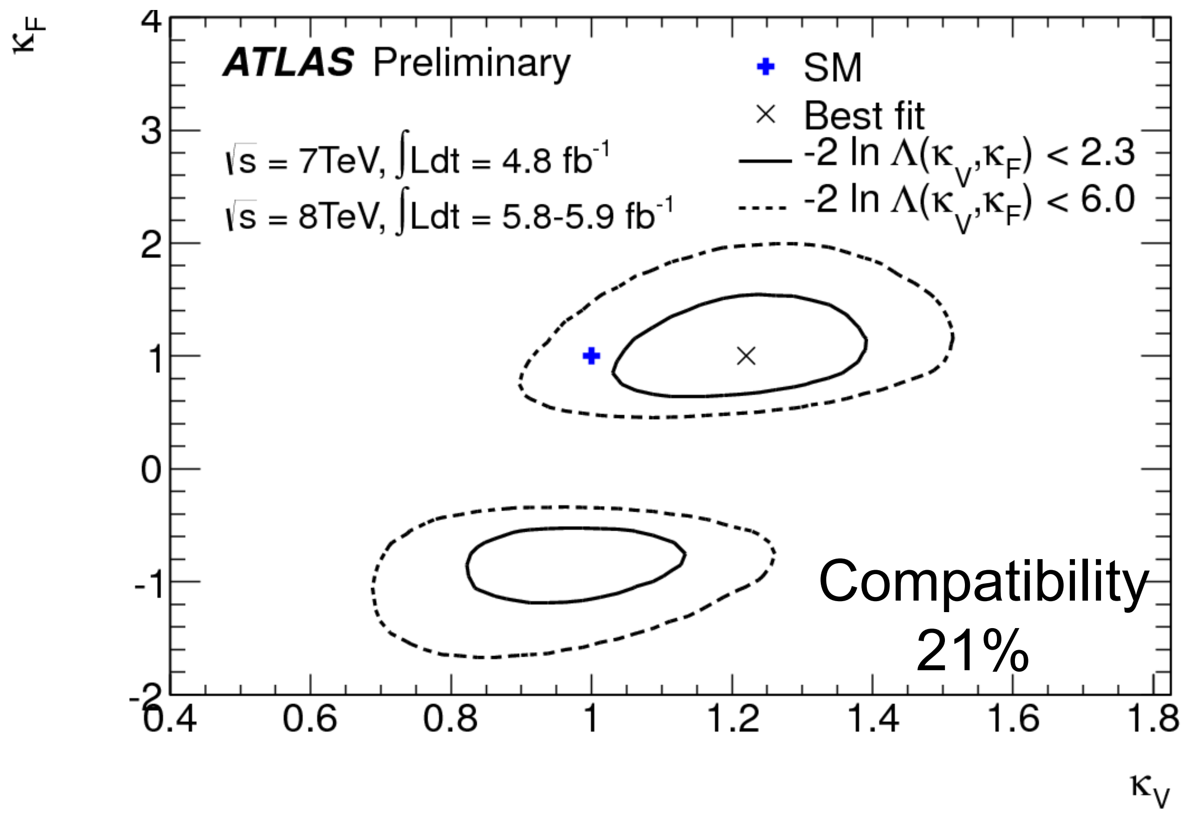
$$\boxed{\begin{aligned} \kappa_F &\in [-1.0, -0.7] \cup [0.7, 1.3] \\ \kappa_V &\in [0.9, 1.0] \cup [1.1, 1.3] \end{aligned}}$$

- ☐ Same as above, but without the assumption on the total width

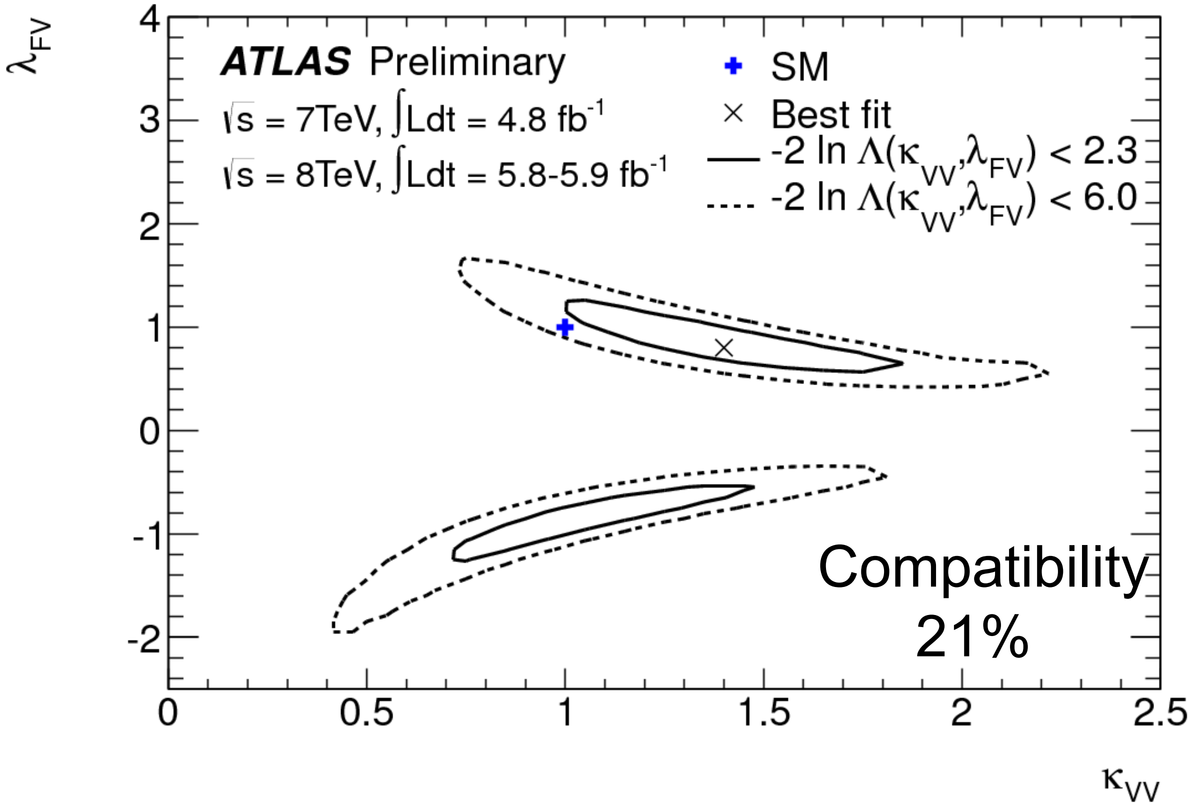
$\lambda_{FV}=\kappa_F/\kappa_V$, $\kappa_{VV}=\kappa_V \cdot \kappa_V/\kappa_H$

68% CL intervals

$$\lambda_{FV} \in [-1.1, -0.7] \cup [0.6, 1.1]$$
$$\kappa_{VV} = 1.2^{+0.3}_{-0.6}$$



Compatibility 21%

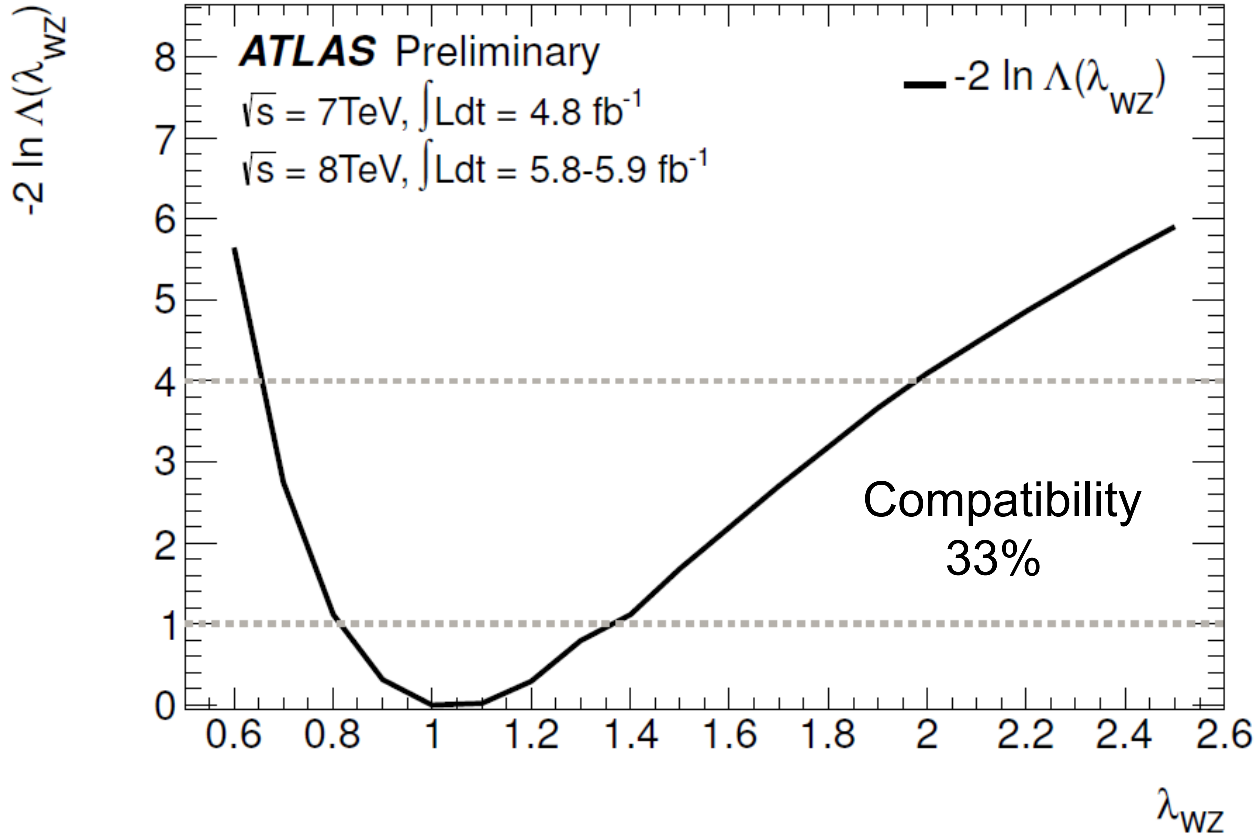


Compatibility 21%

Probing custodial symmetry.

- ☐ Similar to previous benchmark model, but $\kappa_V \rightarrow \kappa_W$ and κ_Z, so there are three free parameters κ_W , κ_Z and κ_F. Identical couplings scale factors for the W and Z are required within tight bounds by SU(2) custodial symmetry and ρ parameter.
- ☐ The VBF process is parametrized with κ_W and κ_Z according to the Standard Model.

$$\lambda_{WZ} = \frac{\kappa_W}{\kappa_Z} = 1.07^{+0.35}_{-0.27}$$

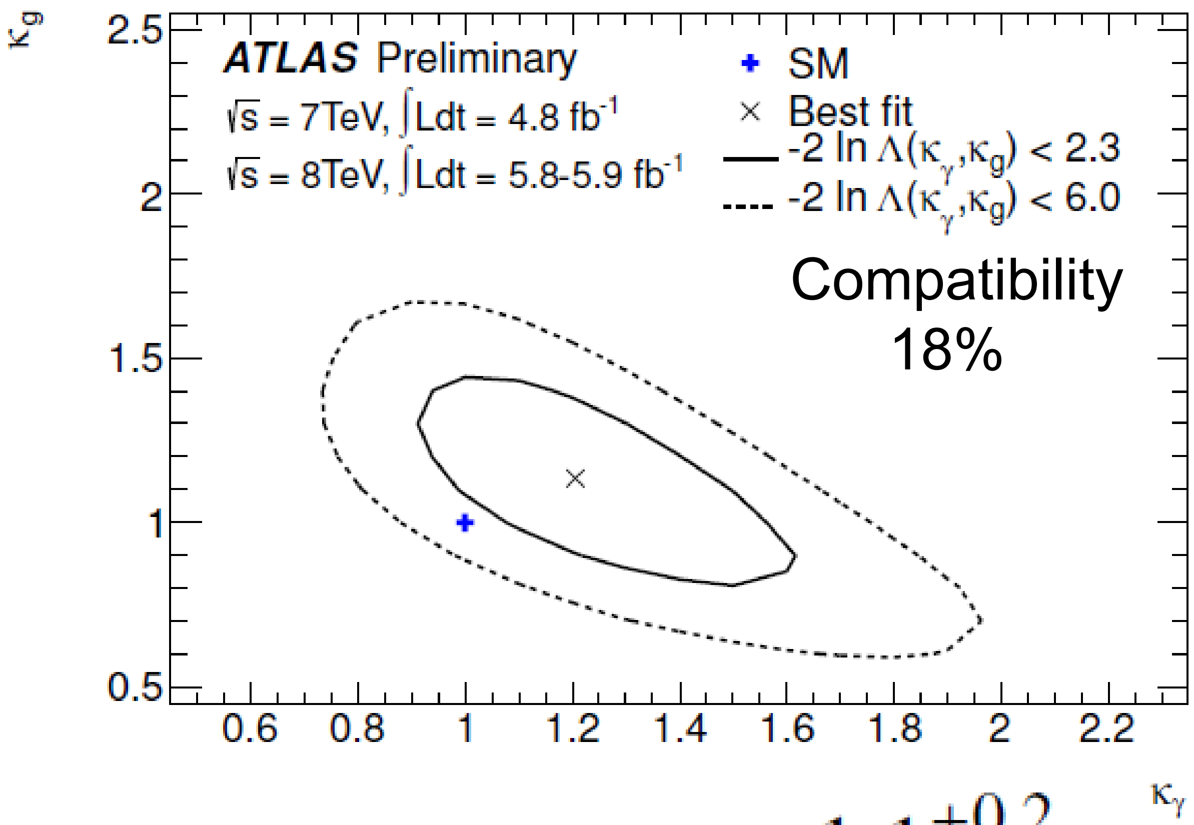


Probing potential BSM contrbutions

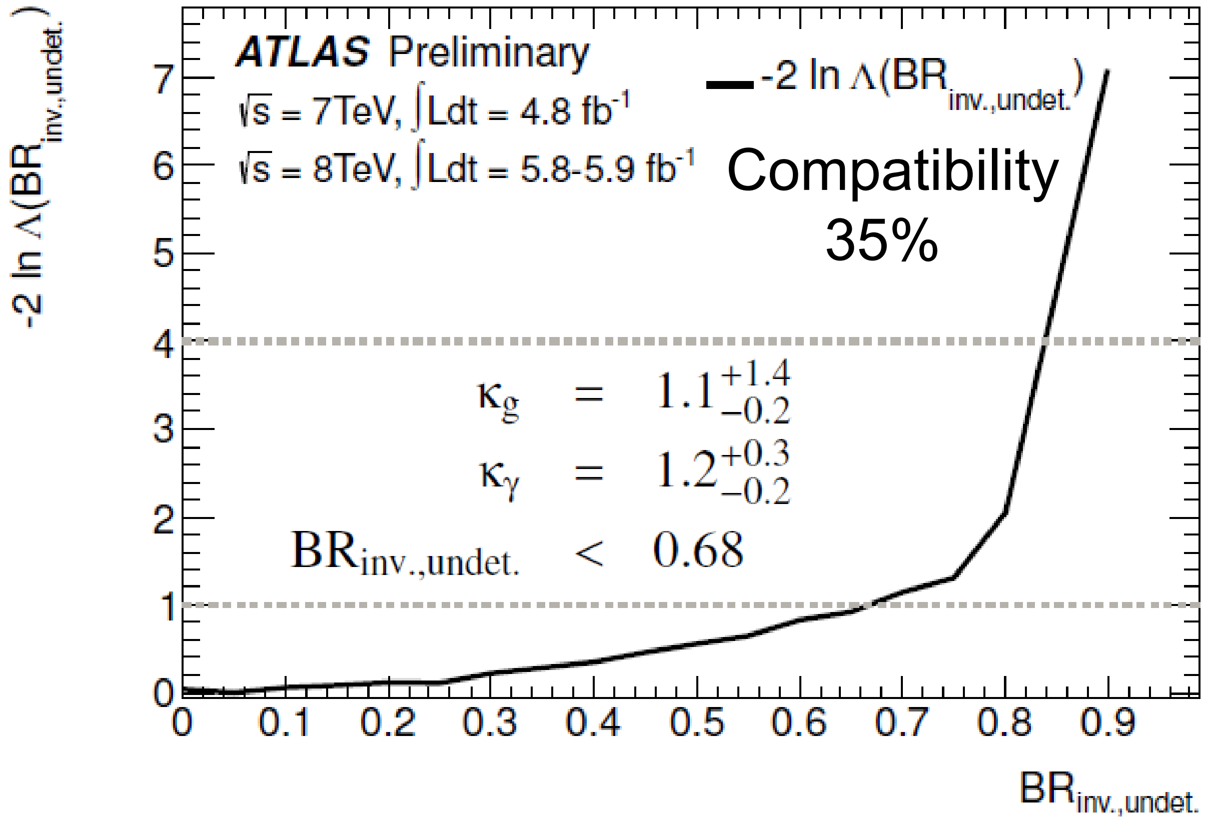
- ☐ For H→γγ and gg→H vertices, effective scale factors κ_γ and κ_g are introduced (two free parameters). Non-SM particles can contribute to H→γγ and gg→H loops or in new final states.

assuming only SM contributions to total width and $\kappa_i = 1$ for all SM particles

no assumption on total width, but $\kappa_i = 1$ for all SM particles



Compatibility 18%



Compatibility 35%

$$\kappa_g = 1.1^{+1.4}_{-0.2}$$
$$\kappa_\gamma = 1.2^{+0.3}_{-0.2}$$
$$\mathrm{BR}_{\mathrm{inv.,undet.}} < 0.68$$

68% CL
$$\kappa_g = 1.1^{+0.2}_{-0.3}$$
$$\kappa_\gamma = 1.2^{+0.3}_{-0.2}$$

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

Conclusions...

- Stay tuned for ZZ and γγ
- Moriond we will hopefully see something in the fermionic channels
- The combination of 2011+2012 WW, plus reorganisation of the analysis (we need to reduce the impact of the systematics)
- The search time has gone, now we are in the measurement phase... (plus VBF and fermionic channel observation)