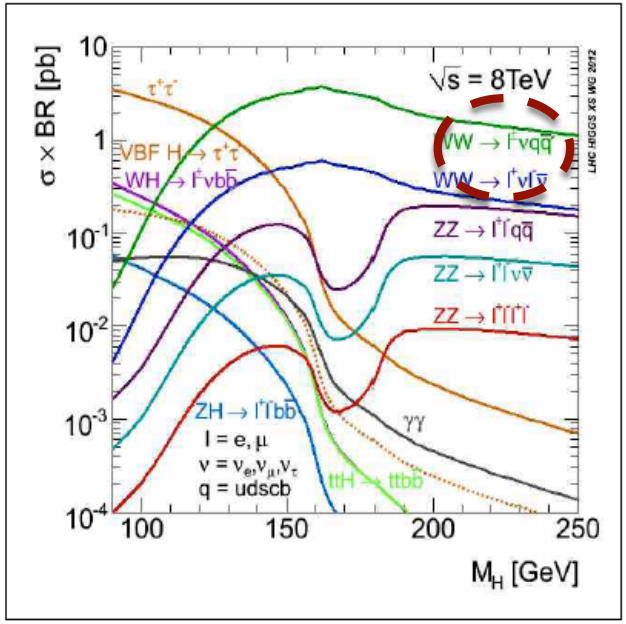
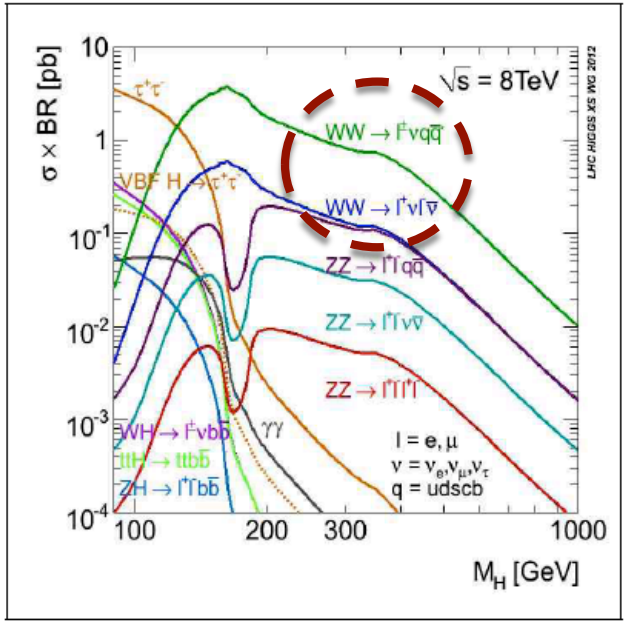
HIGGS→WW

M. Biglietti (INFN Roma3), P. Govoni (Univ. Milano Bicocca)

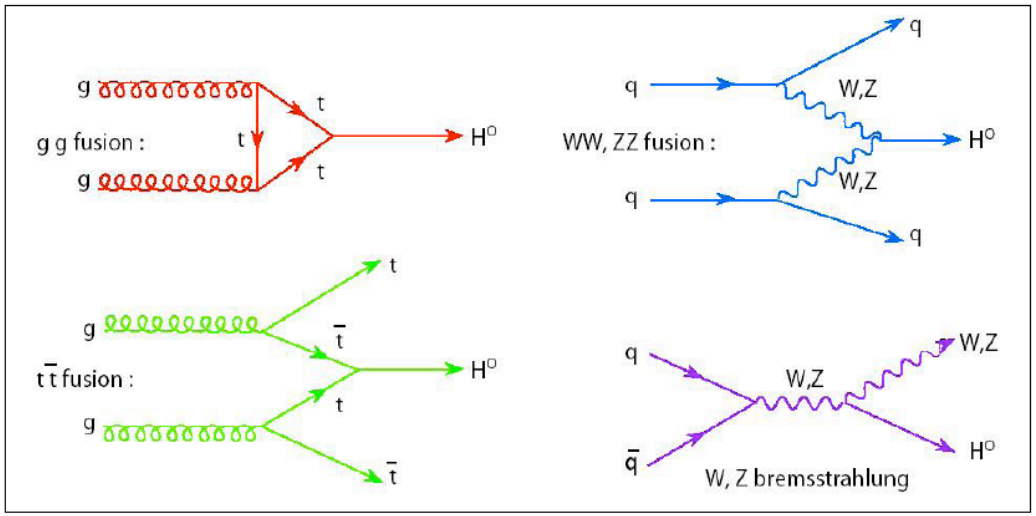
Higgs production and decay in W^+W^-

H→WW gives large yields





gg→H:
0,1 jet bin
lνlν + lνqq



VBF:
>1 jet bin
lνlν + lνqq

VH:
WWW, WWZ
lνlνlν, , lllνlν, lνlνqq

ATLAS & CMS H→WW Analyses

- Total available data (per experiment):
  - 2011 ($\sqrt{s}$ = 7 TeV, ~5/fb)
  - 2012 ($\sqrt{s}$ = 8 TeV, ~20/fb)

High sensitivity analyses

- **H→WW→2l2ν**
  - ATLAS: full dataset, 0,1jet, VBF, spin measurement, mass range 115-200 GeV
  - CMS : full dataset, 0,1jet, spin measurement, mass range 110-600GeV

Other analyses at low mass

- **WH→WWW→3l3ν**
  - ATLAS: 2011 data
  - CMS : full dataset

High mass analyses

- **H→WW→lνqq**
  - ATLAS: 2011 data ($\sqrt{s}$ = 7 TeV, 4.7/fb)
  - CMS : 2011 ($\sqrt{s}$ = 7 TeV, 4.9/fb) + 2012 ($\sqrt{s}$ = 8 TeV, 12/fb)
- **H→WW→2l2ν** (CMS)
- **2HDM**
  - ATLAS: 2012 data ($\sqrt{s}$ = 8 TeV, 13/fb)

H→WW→lνlν

→ Data 2011 ($\sqrt{s}$ = 7 TeV, ~5/fb) + 2012 ($\sqrt{s}$ = 8 TeV, ~20/fb)

- → 2011 analysis re-optimization

⇨Rates

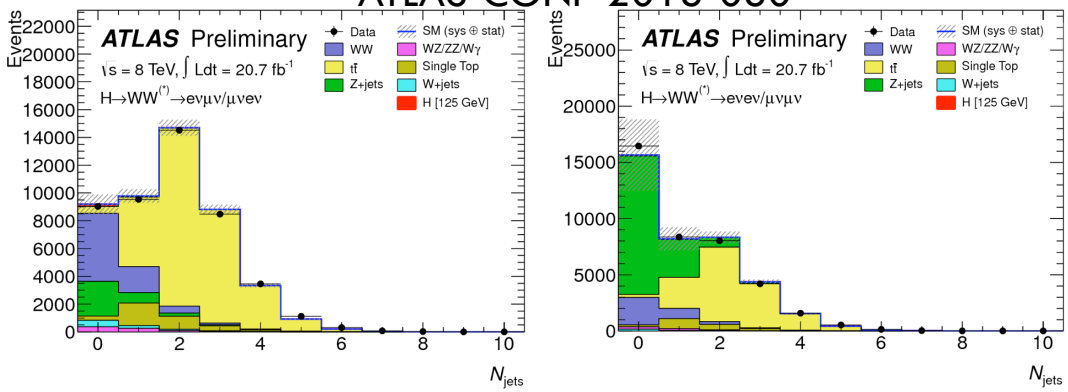
⇨ VBF/couplings

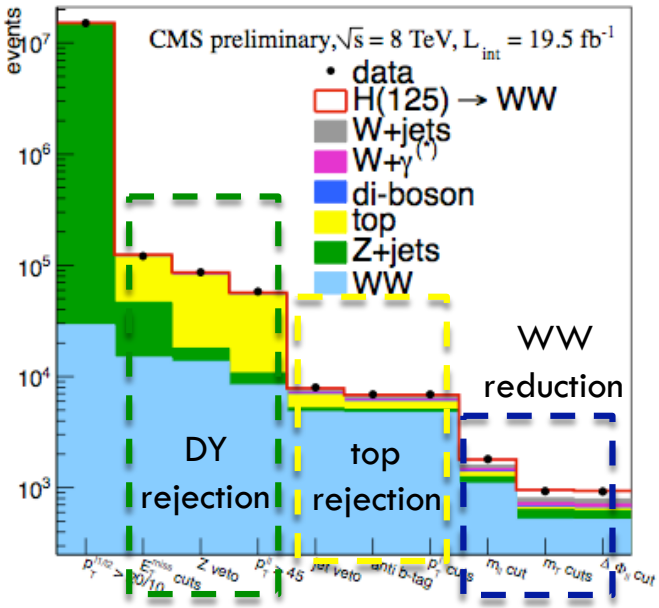
⇨ Spin

Selection & Backgrounds

- Categories with different bkg composition
  - 0jet, 1jet, >1 jets (VBF)
  - different, same flavors (em/me, ee/mm)
- Drell-Yan (lepton pair + fake MET)
  - Important in the ee/μμ channel
  - Require large missing energy, Z veto
  - Event recoil, topological selection, MVA
- Top (WW produced with bjets) in >1jet bin
  - b-jet veto (IP, soft muon)
- W+jets (lepton with MET + fake lepton)
  - Isolation / lepton identification
- WW
  - dominant in 0jet channel
  - ~reducible by topological cuts
- Other di-Bosons (WZ,ZZ,Wγ)
  - no extra leptons, conversion rejection, Z veto

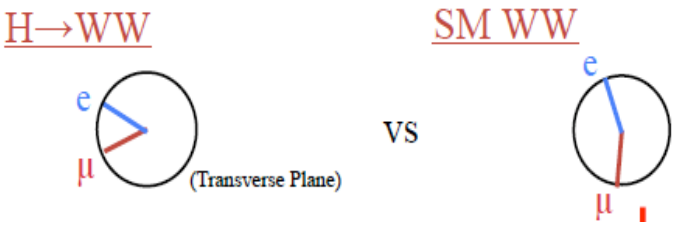
ATLAS-CONF-2013-030





Background Estimation

- non resonant WW and H→WW have very similar signature
  - exploit Spin-0 nature of the Higgs/V-A coupling of W



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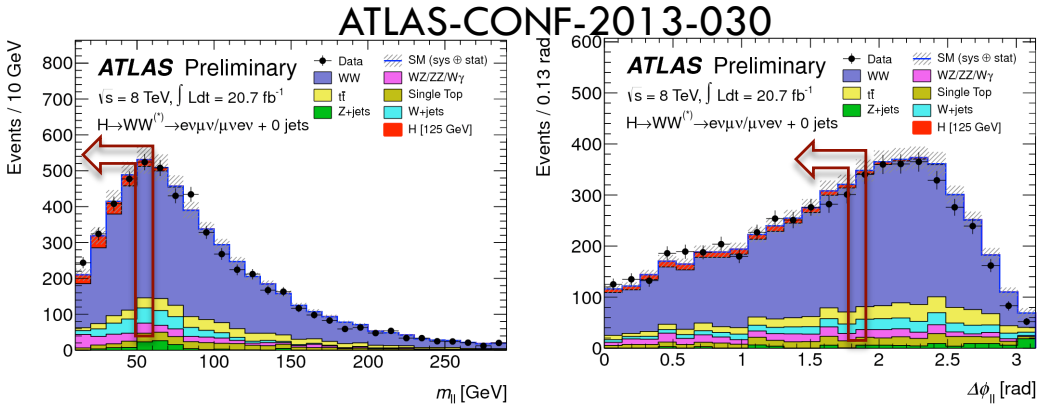


- Use data-driven estimates for main backgrounds
  - SM WW from estimated using signal free CRs
  - Zjets from system recoil studies (ATLAS)/extrapolation from Z mass peak (CMS)
  - top : from top enriched CR (ATLAS), from top-tagged events corrected for the top-tagging efficiency (CMS)
  - W+jets: control sample in which one of the two leptons satisfies relaxed identification and isolation criteria, fake factors from multi-jet samples

H→WW→lνlν, Yields @ 8TeV

ATLAS

N_{jet}	N_{obs}	N_{bkg}	N_{sig}	N_{WW}	N_{VV}	$N_{t\bar{t}}$	N_t	N_{Z/γ^*}	N_{W+jets}
= 0	831	739 ± 39	97 ± 20	551 ± 41	58 ± 8	23 ± 3	16 ± 2	30 ± 10	61 ± 21
= 1	309	261 ± 28	40 ± 13	108 ± 40	27 ± 6	68 ± 18	27 ± 10	12 ± 6	20 ± 5
≥ 2	55	36 ± 4	10.6 ± 1.4	4.1 ± 1.5	1.9 ± 0.4	4.6 ± 1.7	0.8 ± 0.4	22 ± 3	0.7 ± 0.2

CMS (cut-based @m_H=125GeV)

m_H	H → W⁺W⁻	pp → W⁺W⁻	WZ + ZZ + Z/γ* → ℓ⁺ℓ⁻	Top	W + jets	Wγ(*)	all bkg.	data
125	90 ± 19	310 ± 29	11.4 ± 1.1	20.0 ± 4.3	48 ± 13	40 ± 13	429 ± 34	505
125	56 ± 12	207 ± 19	106 ± 31	9.3 ± 2.2	28.7 ± 7.7	9.3 ± 3.8	360 ± 38	421
125	42 ± 12	80 ± 11	12.9 ± 1.2	78.9 ± 4.5	25.8 ± 6.9	11.2 ± 4.6	209 ± 14	228
125	18.0 ± 5.2	39.8 ± 5.4	21.2 ± 5.4	40.4 ± 3.1	6.6 ± 2.0	3.3 ± 1.7	111.3 ± 8.6	140

0jet eμ
0jet ee+μμ
1jet eμ
1jet ee+μμ

- ☞ CMS yields higher (looser selection on lepton p_T): 23/10GeV (CMS), 25/15GeV (ATLAS)
- ☞ Total signal uncertainty ~15% from QCD scales, PS/UE, PDF models
- ☞ Main backgrounds :

0jet bin

Total uncertainties:
- δ(WW) ~7%
- δ(W+jets) ~30%(ATLAS)/20%(CMS)

1jet bin

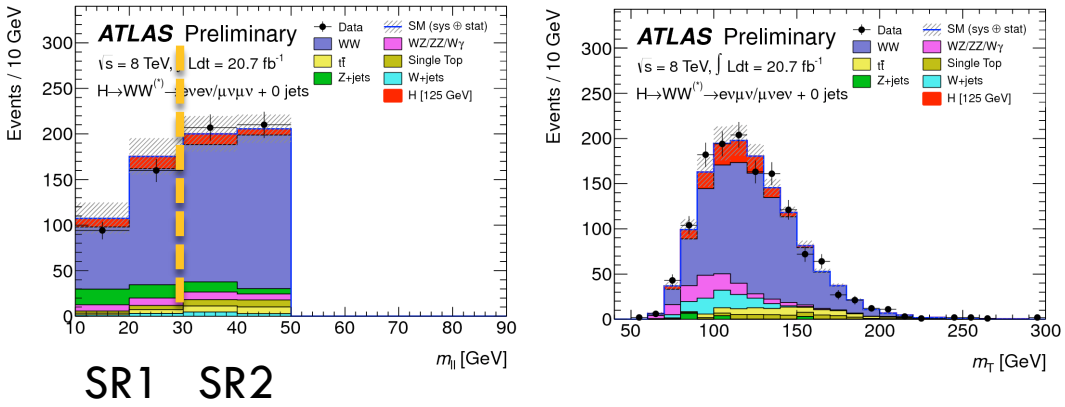
δ(WW) ~35% (ATLAS) dominated by top cross-talk, ~10% (CMS)
δ(top) ~22% (ATLAS) dominated by exp. uncertainty (JES/JER, btagging), ~5% (CMS) : dominated by the statistical uncert. on CR and by systematic on the top-tagged efficiency

Signal Extraction

ATLAS :

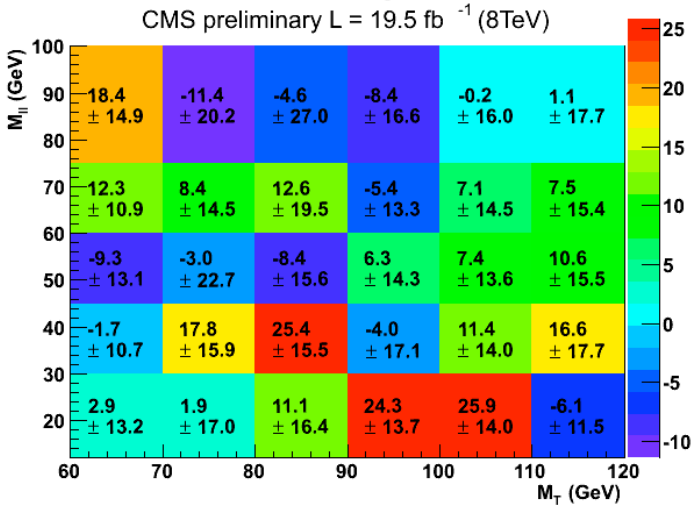
- split the SR in 2 m_{ll} bins → improved sensitivity (different S/B ratios, background composition)
- final fit on m_T

ATLAS-CONF-2013-030



SR1 SR2

CMS-PAS-HIG-13-003



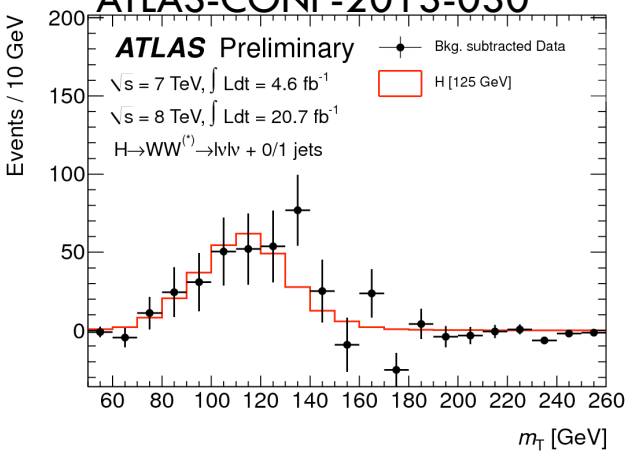
CMS:

- eμ analysis uses cut&count approach as well as a 2D shape analysis in m_{ll}-m_T plane (baseline)
- ee/μμ uses cut&count
- Cut based optimized for each m_H hypothesis

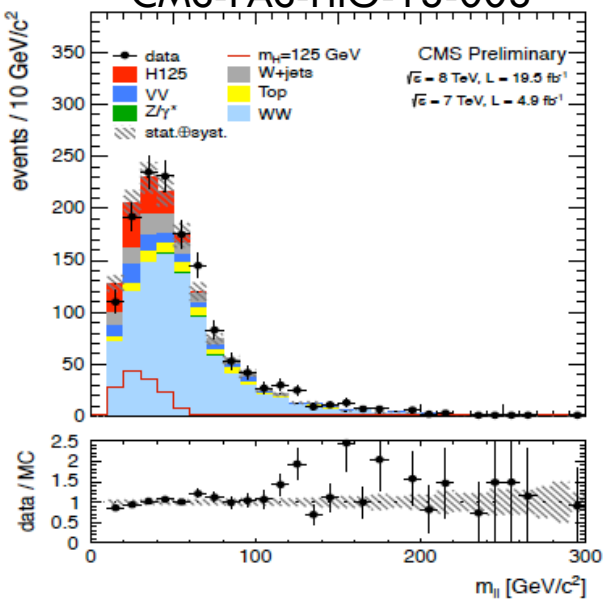
H→WW→ lνlν - Results

Excess over SM background observed!

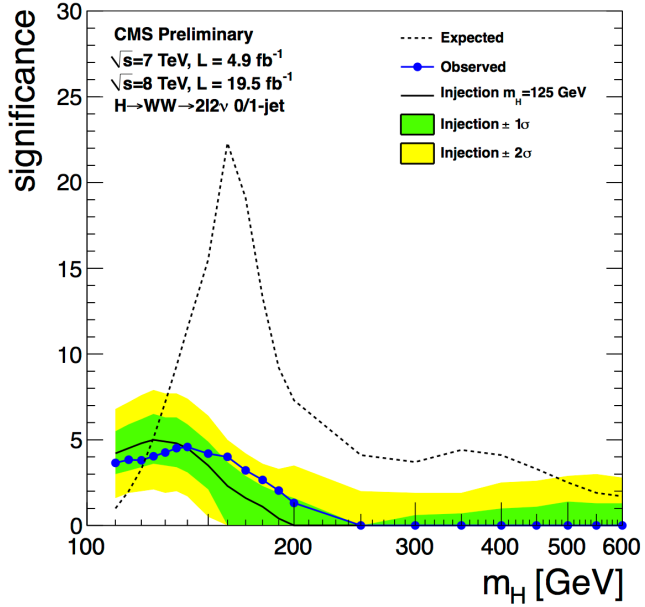
ATLAS-CONF-2013-030



CMS-PAS-HIG-13-003



CMS-PAS-HIG-13-003



- Significances @ m_H=125 GeV
  - ATLAS expected 3.5σ, observed 3.8σ
  - CMS expected 5.1σ, observed 4.0σ

Signal Strength

ATLAS :

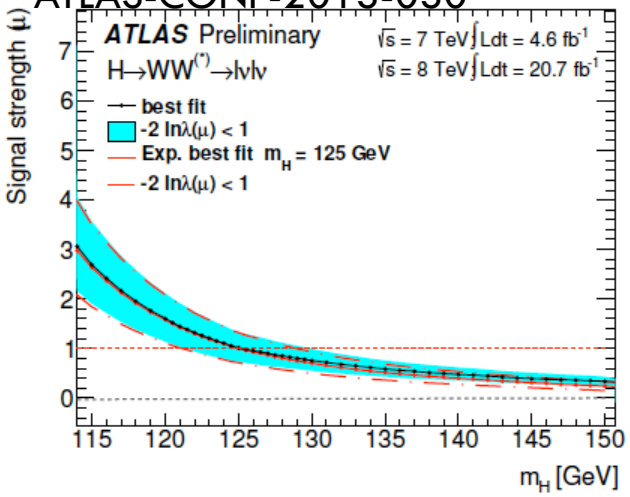
$\mu_{obs} = 1.01 \pm 0.22$ (stat.) ± 0.19 (theo. syst.)

± 0.10 (expt. syst.) ± 0.04 (lumi) $= 1.01 \pm 0.31$

CMS :

$\mu_{obs} = 0.76 \pm 0.13$ (stat.) ± 0.16 (syst.) $= 0.76 \pm 0.21$

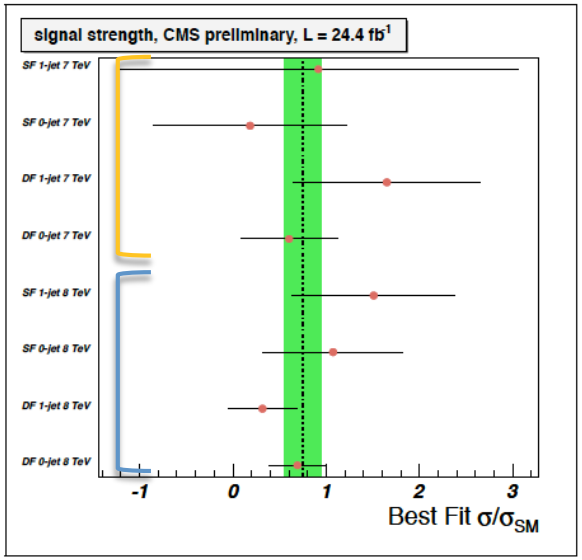
ATLAS-CONF-2013-030



CMS-PAS-HIG-13-003

7TeV

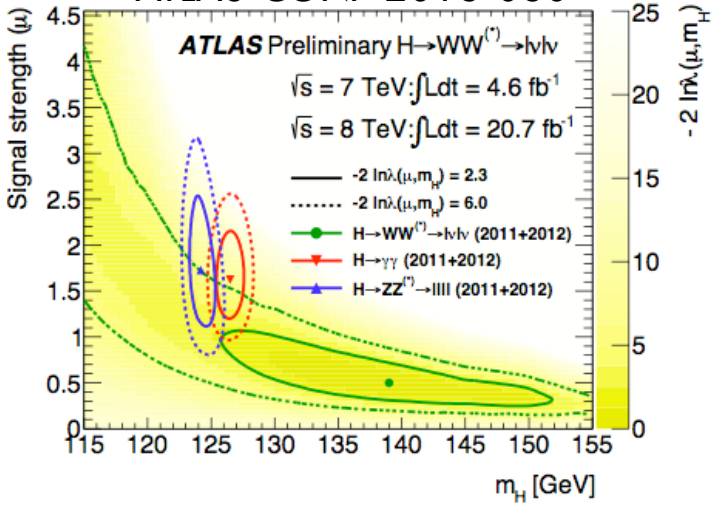
8TeV



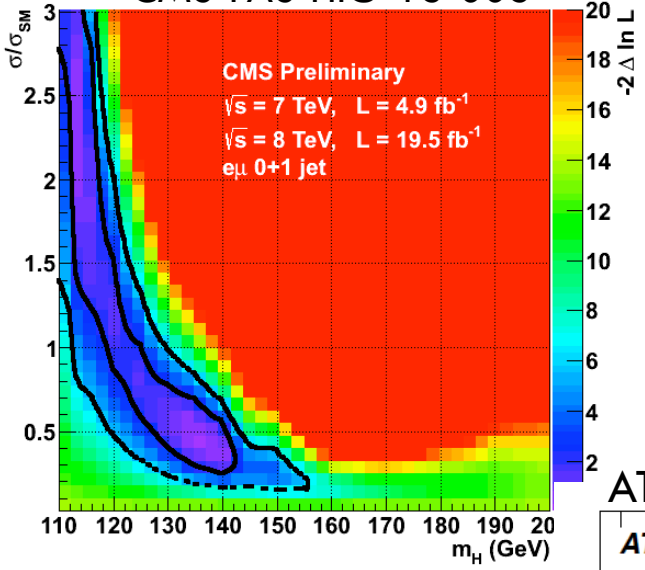
- Best fit value of the signal strength for each channel.
- Consistent results among the different exclusive final states

H→WW→ lνlν - Best Mass Fit vs Signal Strenght

ATLAS-CONF-2013-030

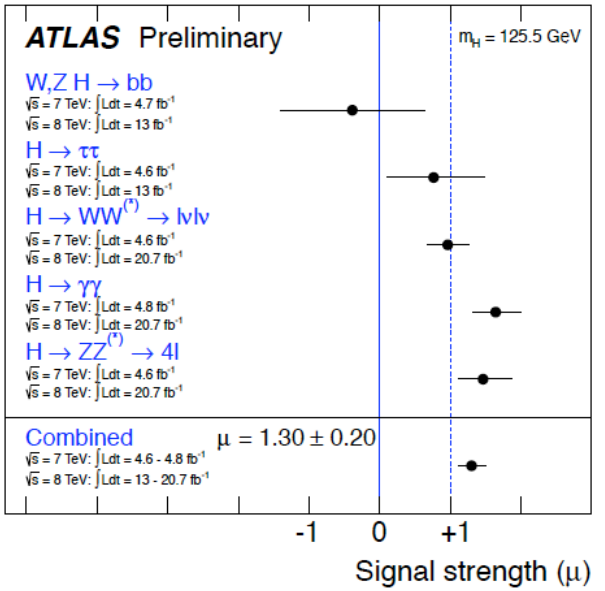


CMS-PAS-HIG-13-003



- ATLAS largest significance @ m_H=140 GeV
- CMS largest significance @ m_H=135 GeV

ATLAS-COM-CONF-2013-035

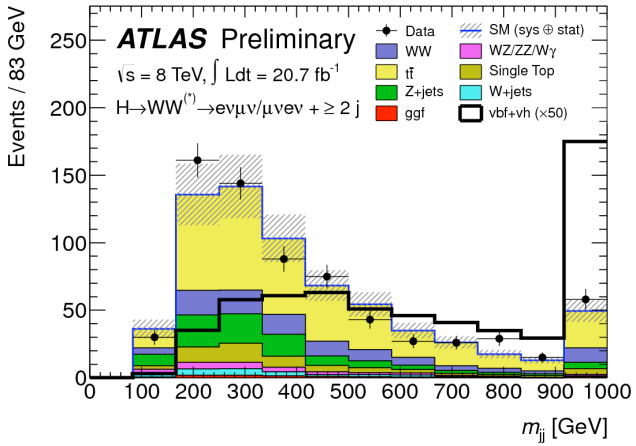


Signal strength $\mu = \sigma / \sigma_{SM}$ measured assuming m_H=125.5 GeV

VBF Results @ ATLAS

ATLAS-CONF-2013-030

- WW + 2 forward jets with large rapidity gap
- Background dominated by top and Z+jets
  - Similar background estimation to ggF analysis
- ggF included as background
- Observed significance 2.5σ (m_H=125GeV)
  - expected 1.6σ
- μ_{obs}(VBF) =1.66 ± 0.67(stat.) ± 0.42(syst.)=1.66± 0.79
- μ_{obs}(ggF) =0.82 ± 0.24 (stat.) ± 0.28 (syst.) = 0.82 ± 0.36



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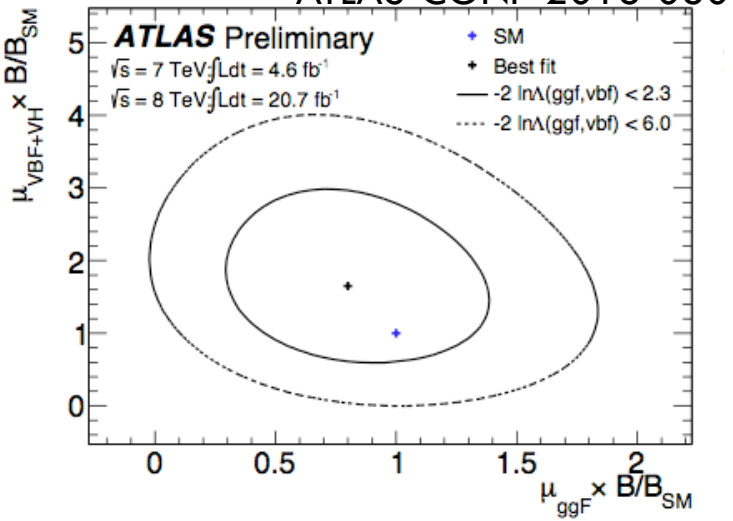
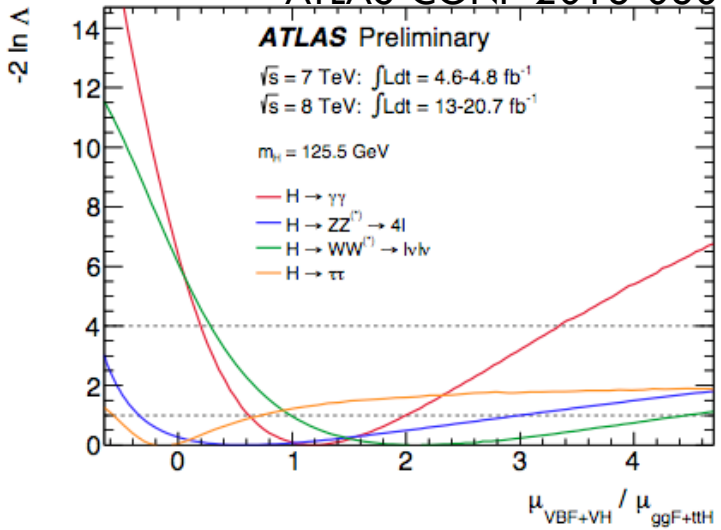
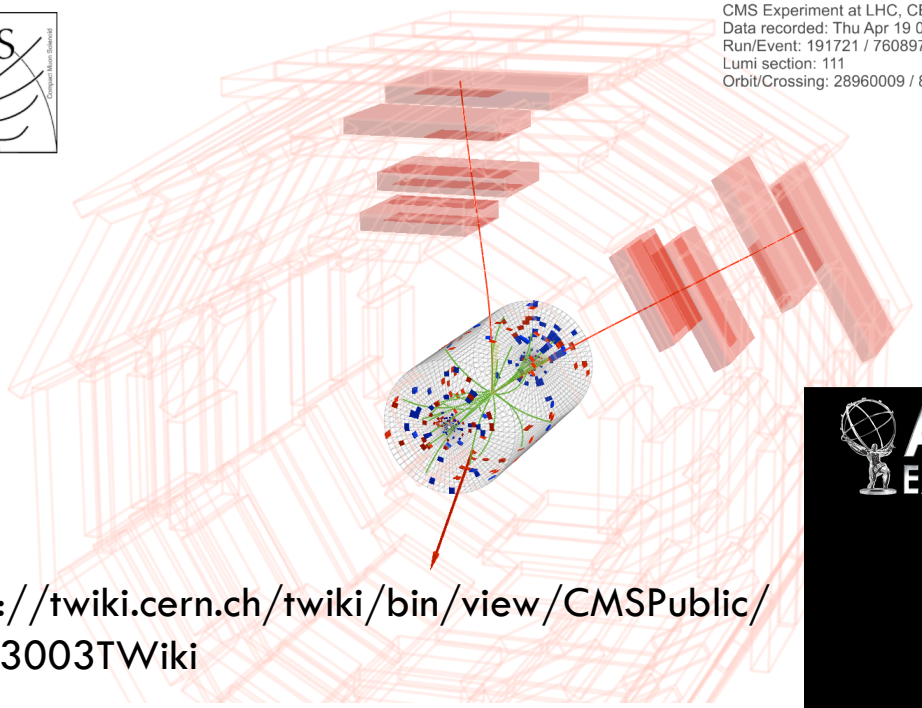


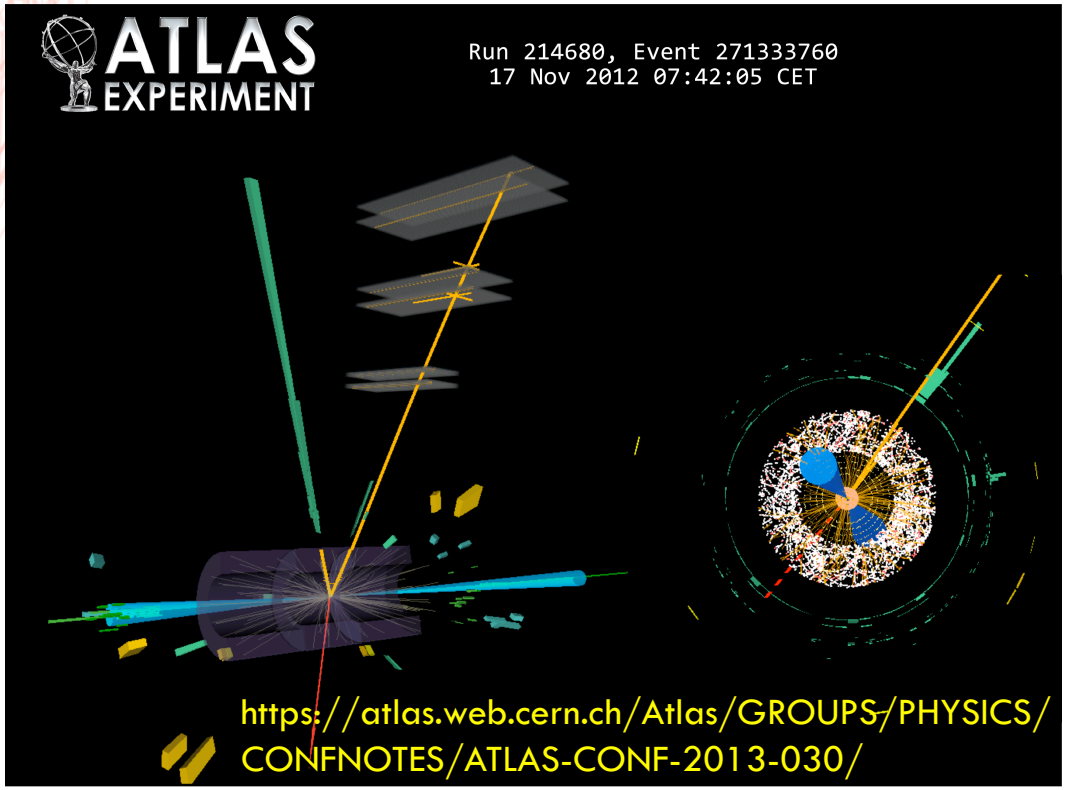
ATLAS-CONF-2013-030



di-lepton H→WW Candidates



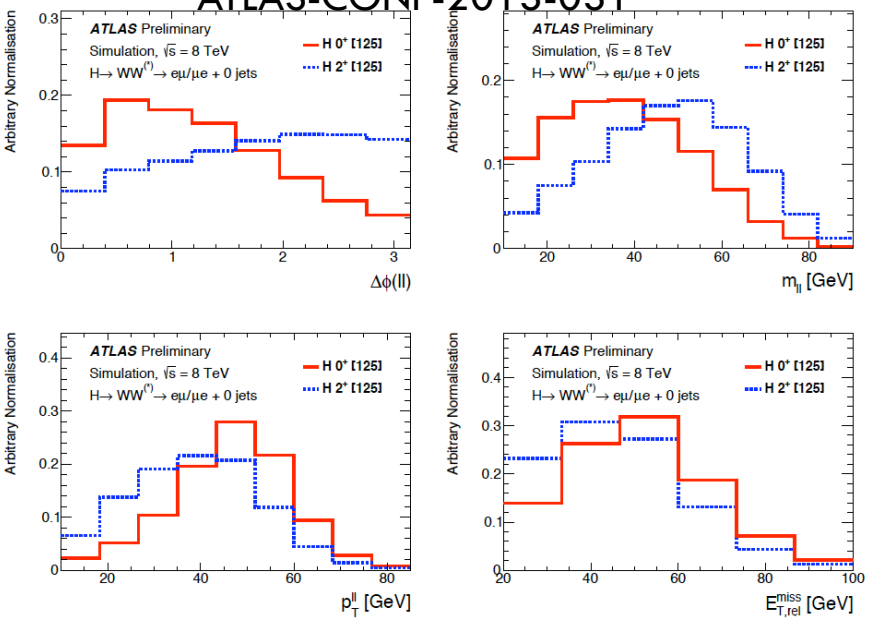
https://twiki.cern.ch/twiki/bin/view/CMSPublic/Hig13003TWiki



H→WW→ lνlν - Spin

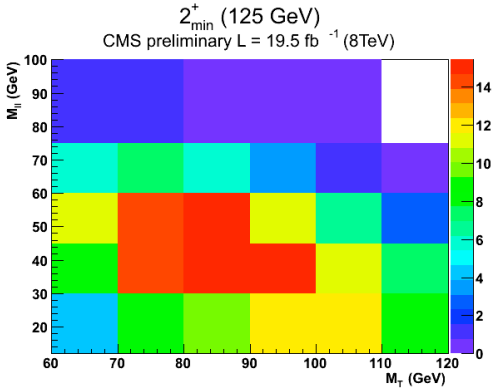
- H→WW provides large signal yield → allow for the shape analysis of sensitive distributions
- alternative general assumption is 2^+ graviton-like tensor (JHU minimal model)
- 2012 data, eμ channel (most sensitive)

ATLAS-CONF-2013-031



- ATLAS
  - 5 production modes (qq fraction=0, .25, .5, .75, 1)
  - relax cuts on MET, p_{Tll}, m_{ll} and $\Delta\Phi_{ll}$
  - 2 dedicated BDT trainings for 0^+ and 2^+
    - results use a 2D fit to BDT_0 and BDT_2
- CMS
  - ggF mode
  - implement 2^+ signal expectations in the shape-based analysis
  - 2D fit in m_{ll} - m_T

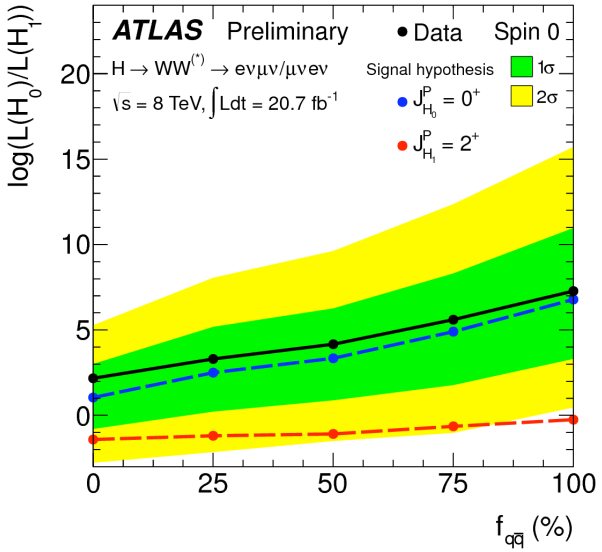
CMS-PAS-HIG-13-003

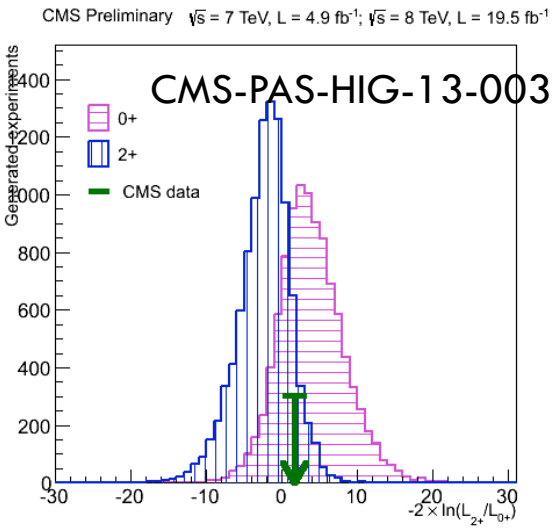


H→WW→ lνlν - Spin Results

- ATLAS
  - data compatible with 0^+ hypothesis
  - 2^+ graviton-like scenario excluded at
    - 99% CL if qq production
    - 95% CL if gg production

ATLAS-CONF-2013-031





- CMS
  - Expected separation is at the 2σ level
  - data slightly favor the SM Higgs hypothesis of 0^+ over 2^+

Other channels

- Associated production
- lvqq
- 2HDM

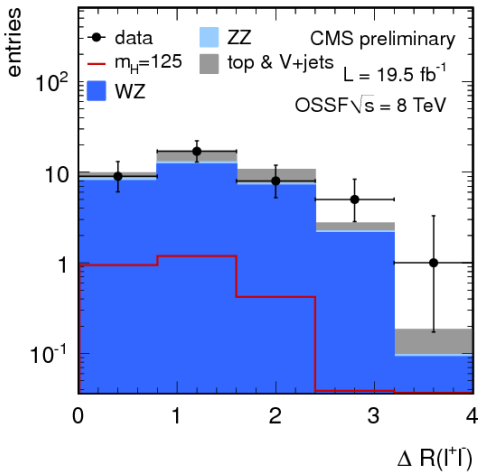
Associated Production WH→lνlνlν

- Three high p_T isolated leptons ($\Sigma q=\pm 1$) with MET, OSSF (WZ bkg) + SSSF (top bkg)

- CMS : full dataset 2011+2012
  - leptons: p_T>20, 10, 10 GeV
  - Z veto and anti b-tagging to reject WZ and top events
  - WZ normalized with 3lepton events with OS pair in Z mass window, uncertainty ~10%
  - data driven fake leptons probability to estimate Z+jet and top, uncertainty ~40%
  - Two approaches: cut-based and shape-based (using the smallest distance between OS leptons, ΔR_{ll})
    - 20% better performance with shape-based approach
  - ~3.3 σ_{SM} sensitivity at m_H=125 GeV (expected ~3σ_{SM})

- ATLAS: 2011 data (4.7/fb), sensitivity ~7σ_{SM} @m_H=125 GeV

(ATLAS-CONF-2012-078) Work in progress for updated results



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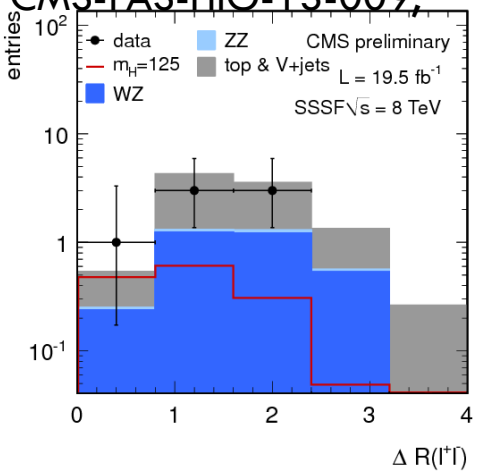

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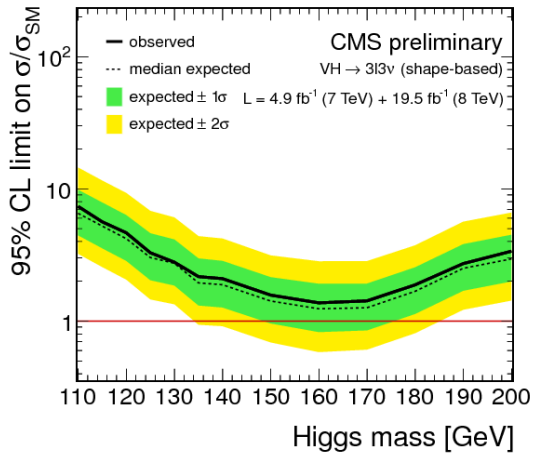
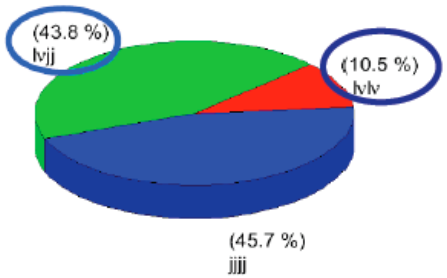
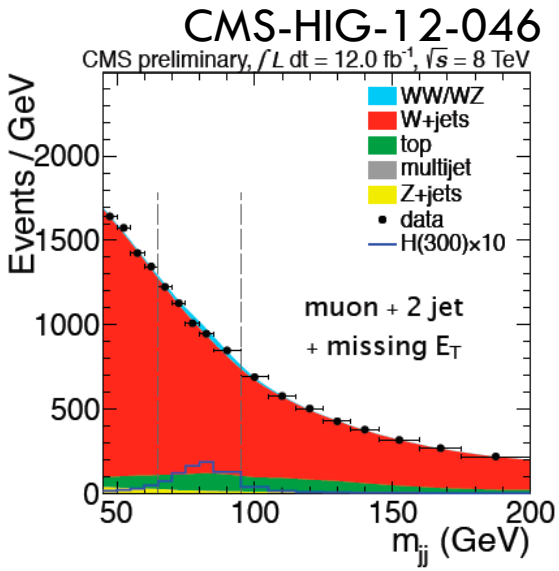


High Mass H→WW→lνjj

- Larger BR and reconstructable Higgs mass imposing $M_{l\nu}=M_W$
- Challenge : control the large W+jets background
  - falls off rapidly with increasing $M_{l\nu jj}$ → sensitivity increases



- CMS: 5/fb (2011) + 12/fb (2012)
  - lepton p_T >25/35 GeV for μ /e + 2/3 jets, MET>25/30GeV (μ /e)
  - optimization with m_H-dependent likelihood discriminant based on the expected limit for Higgs extraction
    - 5 Higgs decay angles, WW p_T and rapidity, lepton charge
  - Side-band fit to m_{jj} to obtain W+jets modelling for each mass hypothesis
  - Main systematic uncertainty from W+jets 4-body mass shape

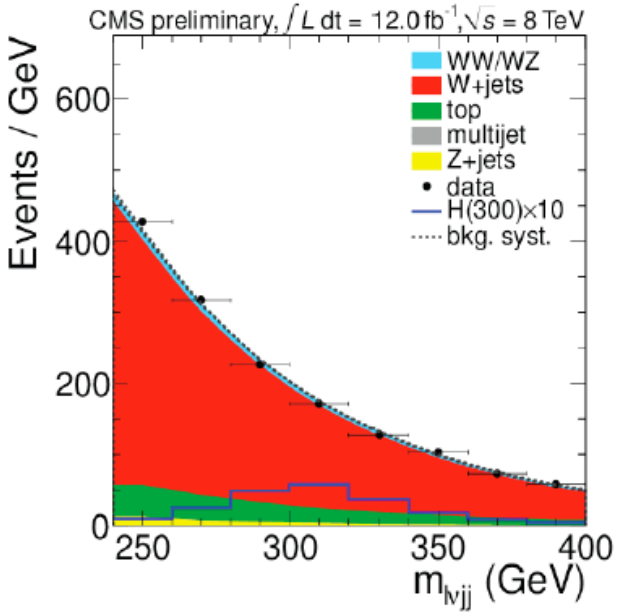


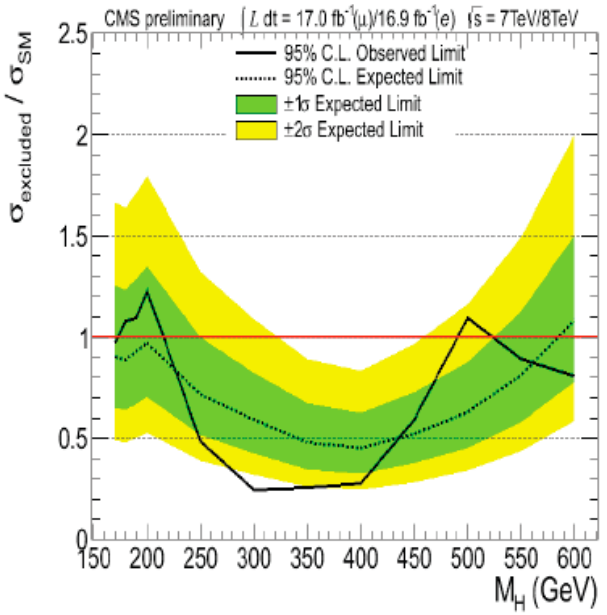
- ATLAS : results on 2011 data (4.7/fb), no exclusion, best sensitivity ~$1.6\sigma_{SM}$ @m_H=400GeV (arXiv:1109.3615)
  - Work in progress for updated results

High Mass H→WW→lνjj - Results

- final fit to the 4-body mass $m_{jjl\nu}$
- no signicant excess is seen
- 95% CL exclusion range for SM Higgs
- observed: 225-485, 550-600 GeV
  - expected: 220-560 GeV

CMS-HIG-12-046





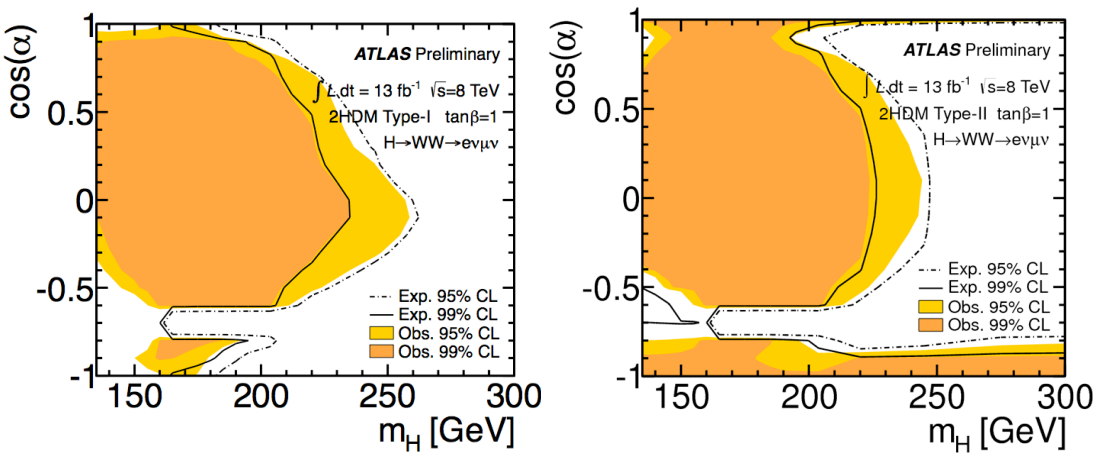
Analyses preparing for a search in higher m_H

Two-Higgs-Doublet (2HDM)

- A simple extension of the SM Higgs sector is given by the addition of a 2nd complex Higgs doublet giving rise to five Higgs bosons: *h*, *H*, *A*, $H^{\pm}$
- Is the boson at 125 GeV the lightest of 5 Higgs Bosons?

- ATLAS
  - 13/fb from collected 2012 data at $\sqrt{s}$=8TeV
  - search for 2HDM for m_h @125GeV and m_H between 135-300 GeV
  - both h/H decay to WW→eμ
  - No evidence for an additional Higgs found in the mass range of [135-300] GeV
  - Exclusions contours @95% and 99% CL are determined in the cosα-m_H plane for different values of tanβ

ATLAS-CONF-2013-027



Summary

- Analyses in H→WW mode in ATLAS/CMS contribute to the Higgs discovery and properties measurement
- di-leptons analyses fully updated
  - observation compatible with SM around m_H=125GeV
  - VBF analysis
  - sensitivity to spin 0 wrt spin 2
- Associated production into 3 leptons updated using full data (CMS)
- High mass analyses
  - semi-hadronic
  - di-lepton optimization for high mass
- 2HDM interpretation
- Expect full updates of all channels and additional improvements

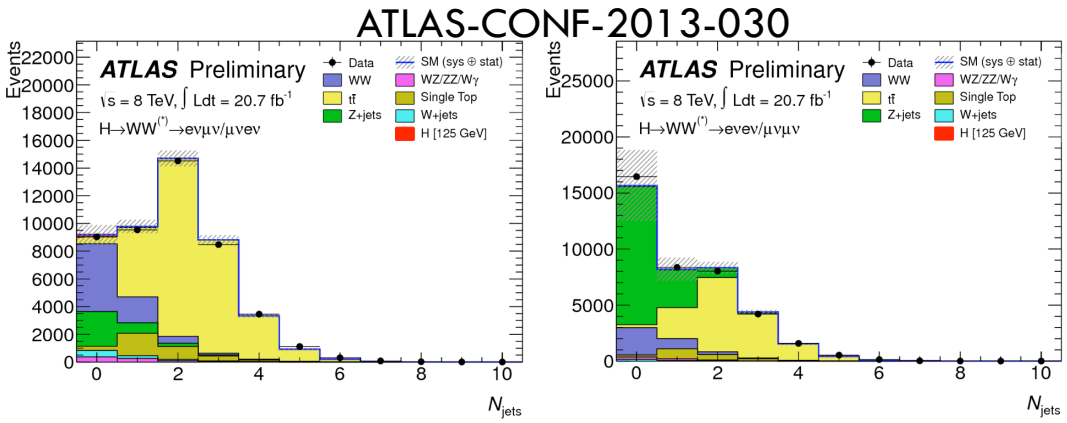
backup

2-lepton Final State: Analysis Strategy

- Data 2011 ($\sqrt{s}$ = 7 TeV, ~5/fb) + 2012 ($\sqrt{s}$ = 8 TeV, ~20/fb)
  - ➜ 2011 analysis re-optimization
- Selection criteria defined before looking at the signal region
- No mass peak → controlling background is the key

- Event basic selection: two isolated leptons (e,μ) + MET
  - ATLAS lepton p_T>25/15 GeV
  - CMS lepton p_T>20/10 GeV (optimized for m_H)
  - exploit different MET definitions

- Categories with different bkg composition
  - 0jet, 1jet, >1 jets (VBF)
    - ATLAS : jet p_T>25(30) GeV for η <2.4 (2.4-4.5)
    - CMS: jet p_T>30 GeV for η < 4.7
  - different, same flavors (eμ/μe, ee/μμ)



WW Control Region

- Mostly estimated by extrapolating the observed yields in CR to signal region
  - ATLAS in 0,1jet CR : eμ, $d\phi_{ll}$ cut removed, $50<m_{ll}<100$ GeV (0jet), $m_{ll}>80$ GeV (1jet)
    - reduction of theoretical uncertainty in 0jet bin reducing the extrapolation
    - total uncertainties : 7% (0jet), 37% (>0jet)
  - CMS: for low mass $m_H<200$ GeV, CR: $m_{ll}>100$GeV
    - total uncertainty ~ 10%

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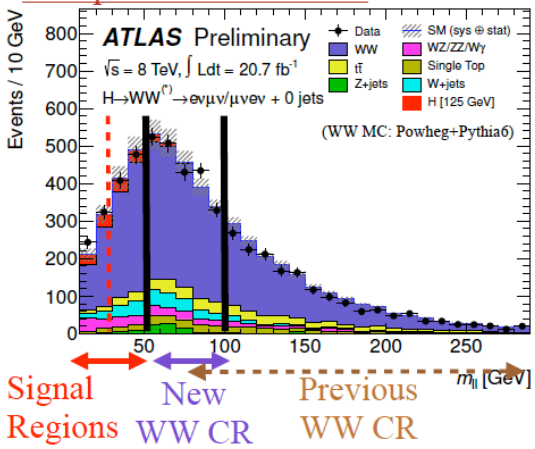
WW Extrapolation Systematics

source	old	new
scale	2.5%	0.9%
pdf	3.7%	1.1%
Parton Shower	4.5%	0.8%
MC model	3.5%	1.4%
Total	~7.2%	~2.1%

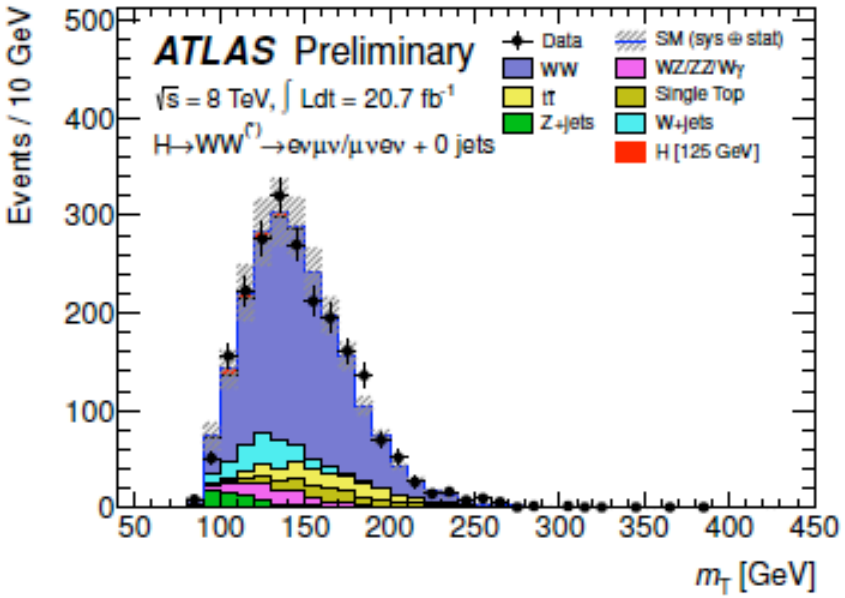
(*MC model compares Powheg+Pythia to MCFM)

Di-lepton Invariant Mass

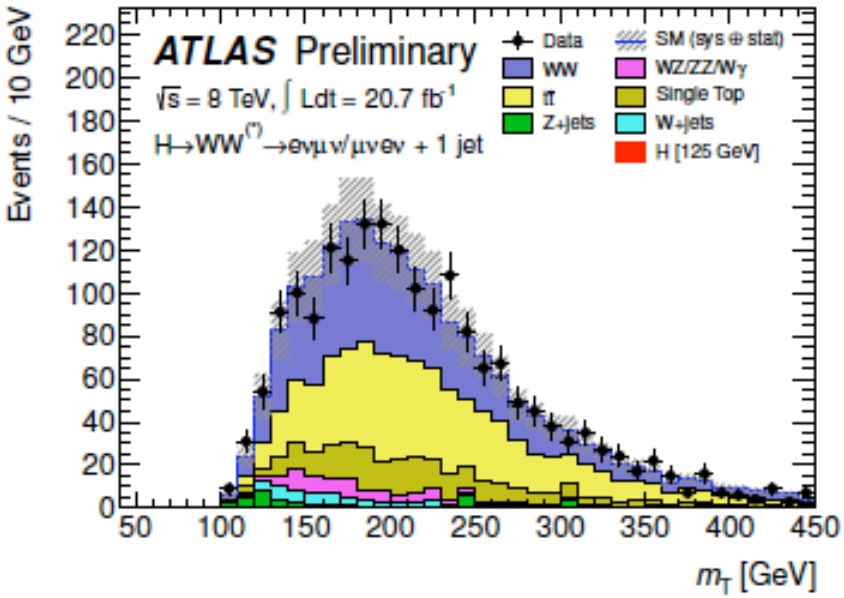


Smaller extrapolation, smaller associated systematic.
Use events w/M_{ll} > 100 GeV to validate extrapolation

WW Constrol Region -2



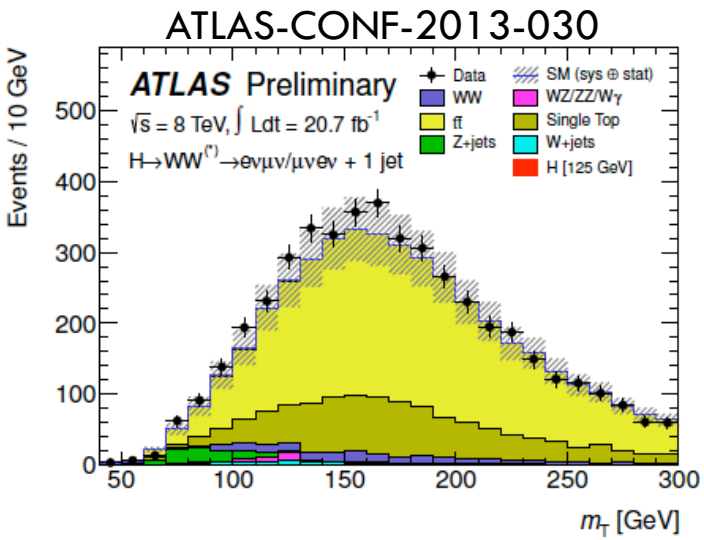
(a) m_{T} for $N_{\mathrm{jet}} = 0$



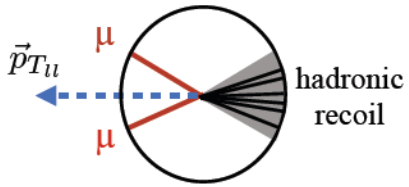
(b) m_{T} for $N_{\mathrm{jet}} = 1$

Top – Drell Yan

- Top
  - ATLAS
    - 0jet : jet veto survival probability in top enriched data, total uncertainy ~10%
    - njet>0 : normalization using a control sample with 1 b-jet, total uncert 30% (njet=1) and 40% (njet>1)
  - CMS: from top-tagged data events corrected for the top-tagged efficiency, total uncertainties ~20% (0jet), ~6% (1jet)

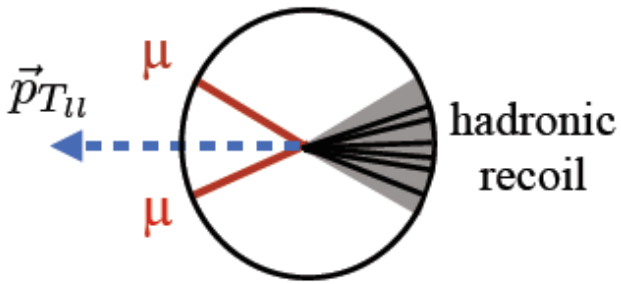


- DY : MET resolution degraded by the pileup, difficult to model with MC the tails in detector response
  - ATLAS: MET from pilup in uncorrelated with dilepton system, hadronic recoil energy (also for estimation)
  - CMS : MVA using missing E_T + kinematic and topological variables



Zjets – Hadronic Recoil

Met from pile-up is uncorrelated with di-lepton system
Hadronic activity providing P_{Tll} "Hadronic recoil"



Quadrant opp. P_{Tll}

pile-up weight

$$f_{\text{recoil}} = \frac{\sum_{\text{soft jets}} w_i \times \vec{p}_{T_i}}{\vec{p}_{Tll}}$$

Further suppress Z/γ* after MeT requirements
Used for data-driven estimate of Z/γ* background ("*Pacman method*")

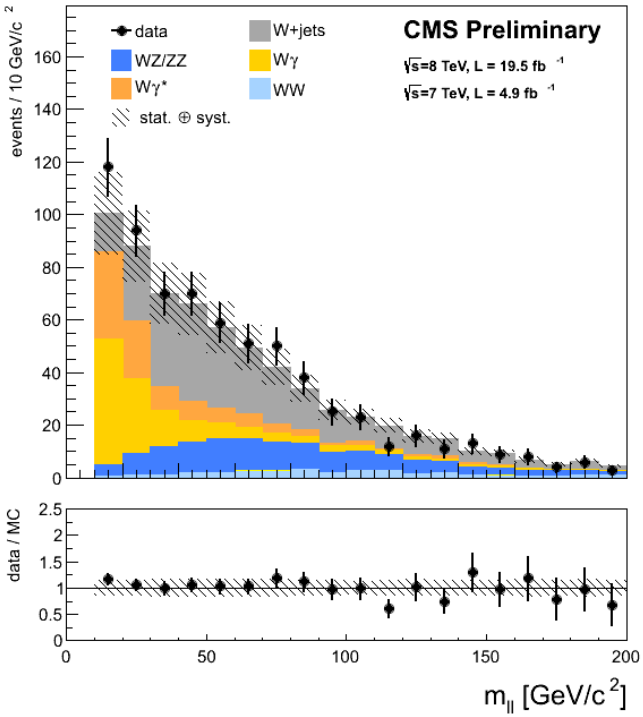
Fit Observed f_{recoil} for Z/γ* and non-Z/γ* component
- Z/γ* from same flavor Z-peak
- non-Z/γ* from opposite flavor events

~60 % total uncertainty on Z/γ* in the SF 0-jet chs.

W+jets – Wγ*

- W+jets
  - Small but not suppressed with event selection
    - arises from lepton mis-ID
    - important at low pt
  - Difficult to model lepton fake rate in MC → use data driven method
    - extrapolate from CR in which one of the two leptons satisfies relaxed identification and isolation criteria
    - fake factor from multi-jet samples
  - total uncertainty (mainly from systematics on the fake factor) ~30%
  - validation with same-charge samples

CMS-PAS-HIG-13-003



- Wγ*
  - ATLAS: from MC and validated in region enriched in W γ ($\gamma \rightarrow$ ee) that removes the anti-conversion selection for one electron
  - CMS: CR with 3 reconstructed leptons

H→WW→lνlν, Yields @ 8TeV

ATLAS

N_{jet}	N_{obs}	N_{bkg}	N_{sig}	N_{WW}	N_{VV}	$N_{t\bar{t}}$	N_t	N_{Z/γ^*}	N_{W+jets}
= 0	831	739 ± 39	97 ± 20	551 ± 41	58 ± 8	23 ± 3	16 ± 2	30 ± 10	61 ± 21
= 1	309	261 ± 28	40 ± 13	108 ± 40	27 ± 6	68 ± 18	27 ± 10	12 ± 6	20 ± 5
≥ 2	55	36 ± 4	10.6 ± 1.4	4.1 ± 1.5	1.9 ± 0.4	4.6 ± 1.7	0.8 ± 0.4	22 ± 3	0.7 ± 0.2

CMS (cut-based @m_H=125GeV)

m_H	H → W⁺W⁻	pp → W⁺W⁻	WZ + ZZ + Z/γ* → ℓ⁺ℓ⁻	Top	W + jets	Wγ(*)	all bkg.	data
125	90 ± 19	310 ± 29	11.4 ± 1.1	20.0 ± 4.3	48 ± 13	40 ± 13	429 ± 34	505
125	56 ± 12	207 ± 19	106 ± 31	9.3 ± 2.2	28.7 ± 7.7	9.3 ± 3.8	360 ± 38	421
125	42 ± 12	80 ± 11	12.9 ± 1.2	78.9 ± 4.5	25.8 ± 6.9	11.2 ± 4.6	209 ± 14	228
125	18.0 ± 5.2	39.8 ± 5.4	21.2 ± 5.4	40.4 ± 3.1	6.6 ± 2.0	3.3 ± 1.7	111.3 ± 8.6	140

0jet eμ
0jet ee+μμ
1jet eμ
1jet ee+μμ

- CMS yields higher (looser selection on lepton p_T)
- Total signal uncertainty ~15% from QCD scales, PS/UE, PDF models
- Main backgrounds :

VBF

Z+jets (~65%) estimated using MET-mll distributions to extrapolate from the Z peak to the SR

top (15%) from top enriched CR

Total uncertainties:

- δ(Z+jets) ~13%
- δ(top) ~ 33%

ATLAS – BKG Systematics

Estimate	Stat. (%)	Theory (%)	Expt. (%)	Crosstalk (%)	Total (%)
WW					
$N_{\text{jet}} = 0$	2.9	1.6	4.4	5.0	7.4
$N_{\text{jet}} = 1$	6	5	4	36	37
Top					
$N_{\text{jet}} = 1$	2	8	22	16	29
$N_{\text{jet}} \geq 2$	10	15	29	19	39

ATLAS 7TeV + 8TeV Results

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Event Yields

Numbers quoted for 0.75 mH < mT < mH w/mH =125 GeV
(mT < 1.2 mH for 2-jet ch)

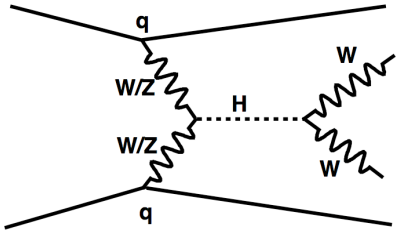
8 TeV	Signal Expectation	Total Bkg	Data
0 jet	97 ± 20	739 ± 39	831
1 jet	40 ± 13	261 ± 28	309
2 jet	10.6 ± 1.4	36 ± 4	55

7 TeV	Signal Expectation	Total Bkg	Data
0 jet	25 ± 5	161 ± 11	154
1 jet	7 ± 2	47 ± 6	62
2 jet	1.4 ± 0.2	4.6 ± 0.8	2

Source	Signal processes (%) $N_{jet}=0$	$N_{jet}=1$	$N_{jet}\geq 2$	Background processes (%) $N_{jet}=0$	$N_{jet}=1$	$N_{jet}\geq 2$
Theoretical uncertainties						
QCD scale for ggF signal for $N_{jet}\geq 0$	13	-	-	-	-	-
QCD scale for ggF signal for $N_{jet}\geq 1$	10	27	-	-	-	-
QCD scale for ggF signal for $N_{jet}\geq 2$	-	15	4	-	-	-
QCD scale for ggF signal for $N_{jet}\geq 3$	-	-	4	-	-	-
Parton shower and UE model (signal only)	3	10	5	-	-	-
PDF model	8	7	3	1	1	1
$H\rightarrow WW$ branching ratio	4	4	4	-	-	-
QCD scale (acceptance)	4	4	3	-	-	-
WW normalisation	-	-	-	1	2	4
Experimental uncertainties						
Jet energy scale and resolution	5	2	6	2	3	7
b-tagging efficiency	-	-	-	-	7	2
f_{recoil} efficiency	1	1	-	4	2	-

The VBF process contributes 2%, 12%, and 81% of the signal events expected in the signal region of the *Njet = 0, = 1, 2 jets*

Vector Boson Fusion



- WW + 2 forward jets with large rapidity gap
- Background dominated by top and Z+jets
- ATLAS
  - Selection
    - b-tag veto
    - $DY_{jj}>2.8$, $M_{jj}>500GeV$
    - Central jet veto
    - Require central leptons
  - Similar background estimation to ggF analysis
    - top : constrained in control region
    - WW : from theory
    - DY : MC corrected with control region
  - Standalone signal extracted
    - ggF "signal" as part of the background

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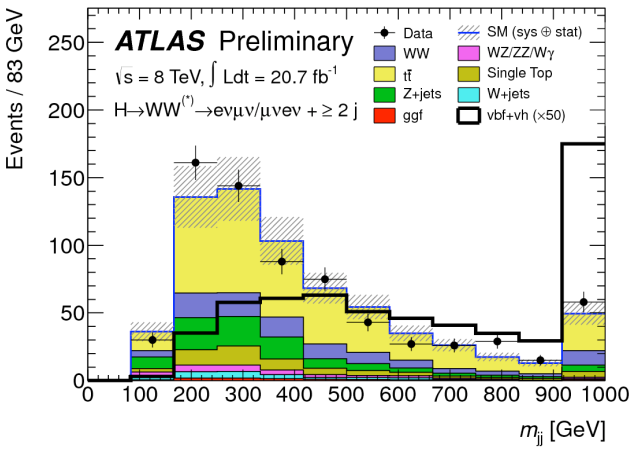
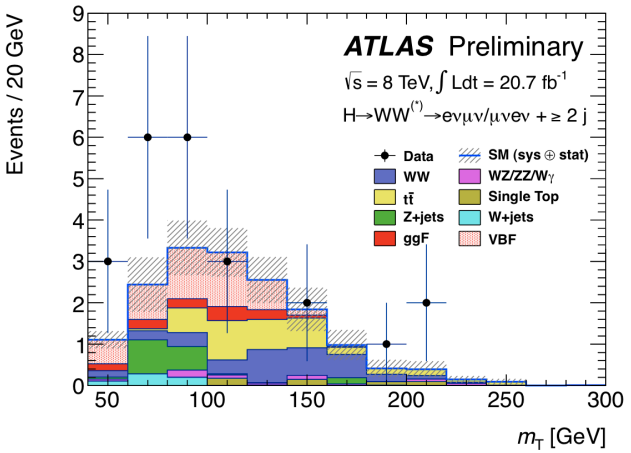
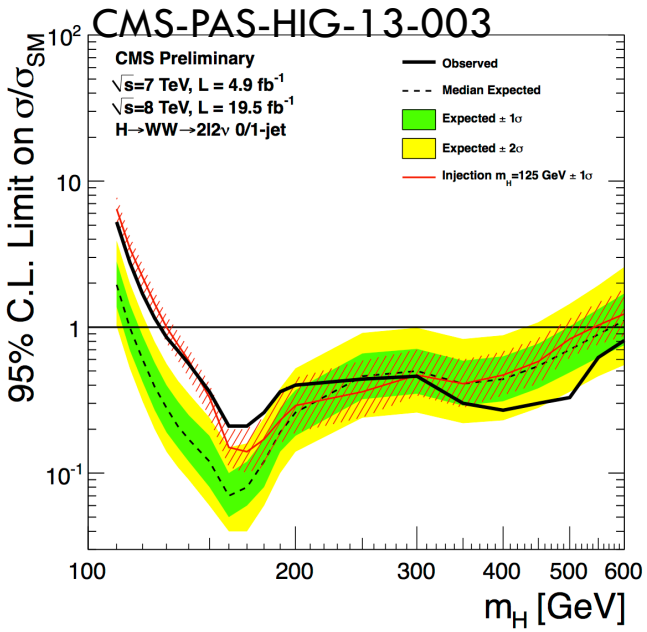




High Mass Exclusion



- CMS exclusion for SM Higgs in 128-600 GeV at 95% C.L.
  - Expected exclusion is 115-575 GeV