Higgs results in the WW -> lνlν channel in ATLAS and CMS

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on behalf of the ATLAS and CMS Collaborations

9.4.2013
Standard Model at LHC, Freiburg, GE

Overview

- latest updates from ATLAS and CMS Collaborations on H->WW->lvlv are presented
- data 2011 ($\sqrt{s}$ = 7 TeV, L_{int} ~4.9 fb^{-1}) + data 2012 ($\sqrt{s}$ = 8 TeV, L_{int} ~20.6 fb^{-1}) analyzed
  - 0+1+2jet by ATLAS
    - ATLAS-CONF-2013-030:
      - https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/CONFNOTES/ATLAS-CONF-2013-030/
  - 0+1jet by CMS (with spin)
    - CMS-HIG-13-003-PAS:
      - https://twiki.cern.ch/twiki/bin/view/CMSPublic/Hig13003TWiki
- associated WH production measured by CMS:
  - CMS-HIG-13-009-PAS:
    - https://twiki.cern.ch/twiki/bin/view/CMSPublic/Hig13009TWiki
- Spin measurement performed
  - ATLAS-CONF-2013-31:
    - https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/CONFNOTES/ATLAS-CONF-2013-031/
- last VH measurement by ATLAS (July 2012):
  - https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/CONFNOTES/ATLAS-CONF-2012-078/
- last 2jet measurement by CMS (November 2012):
  - https://twiki.cern.ch/twiki/bin/view/CMSPublic/Hig12042TWiki

ATLAS & CMS @ LHC

C_{LHC} = 26.7 km

$\sqrt{s}_{2011}$ = 7 TeV

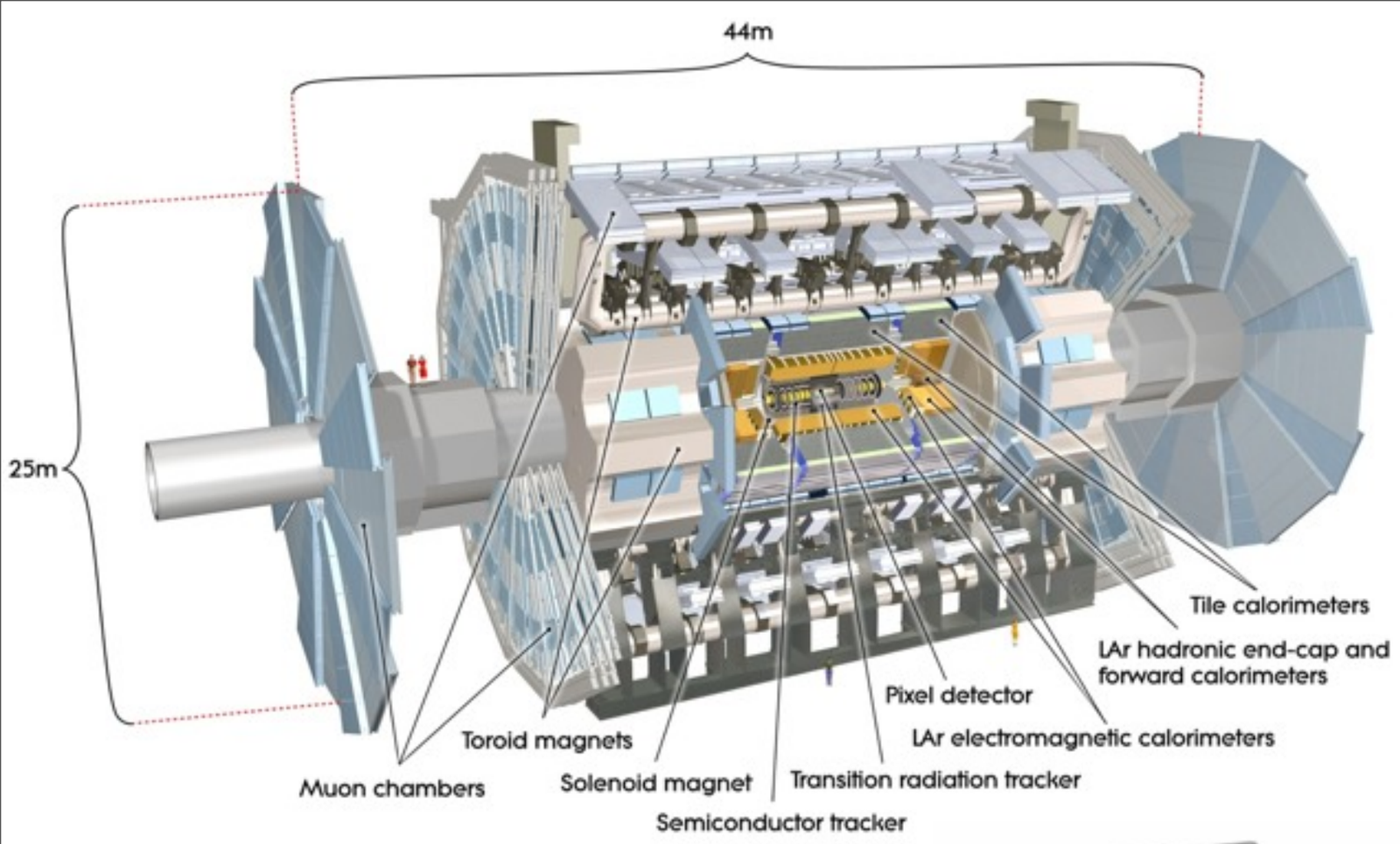
$\sqrt{s}_{2012}$ = 8 TeV

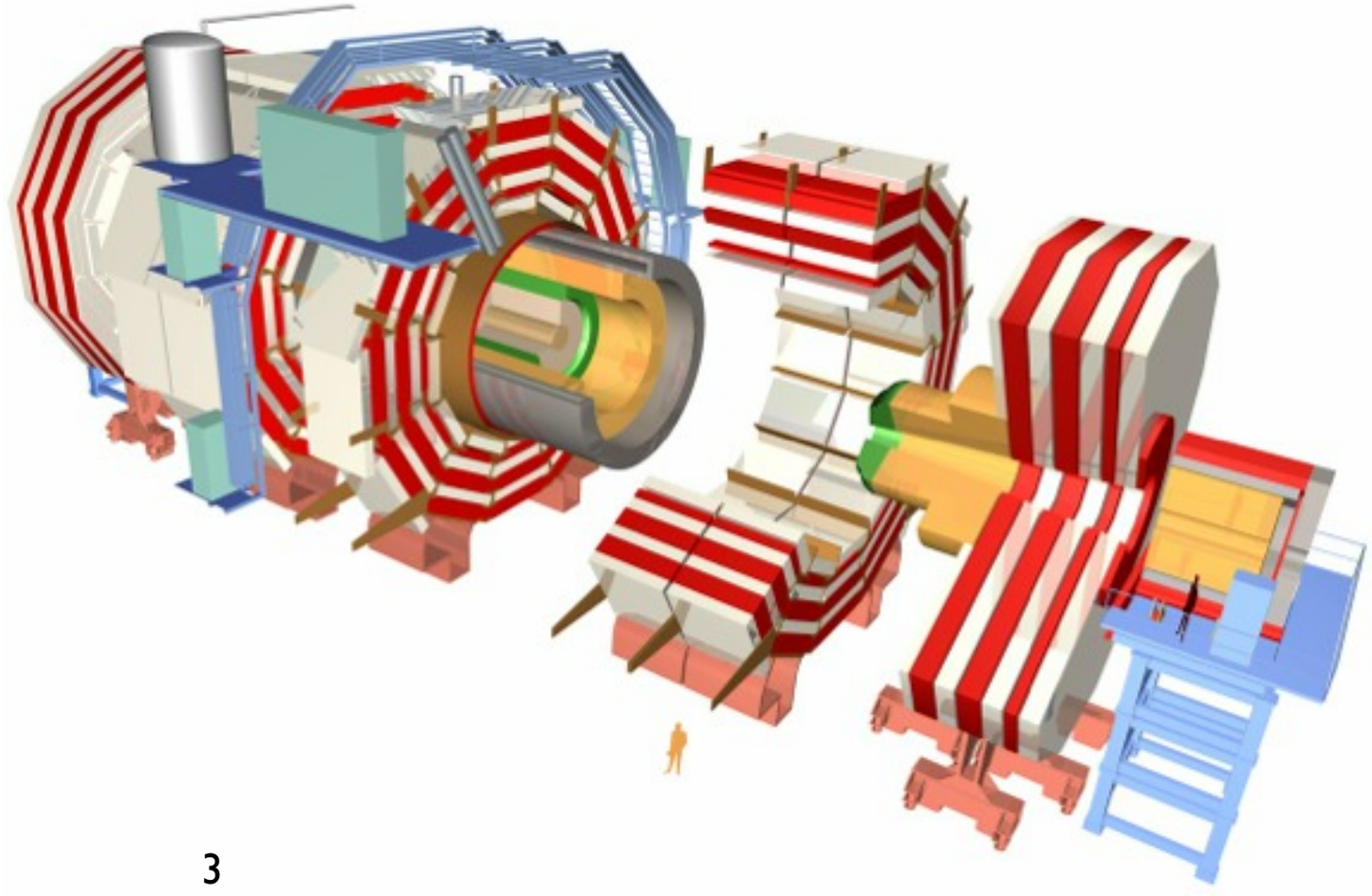
collisions 50 ns

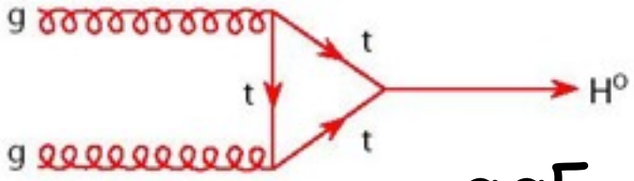
bunch intensity ~10^{11}

1368 bunches colliding

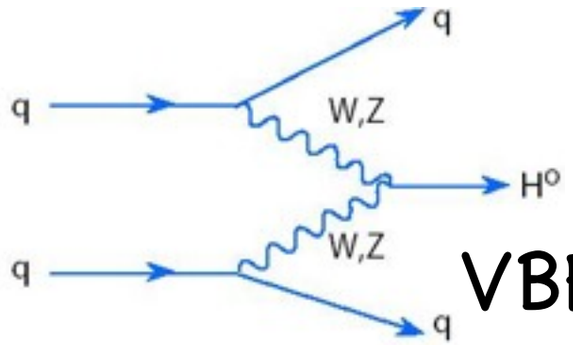
-> unprecedented pile-up



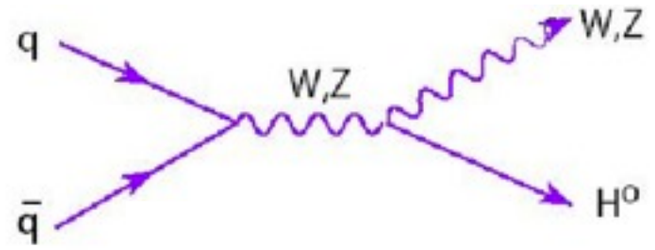




ggF



VBF



VH

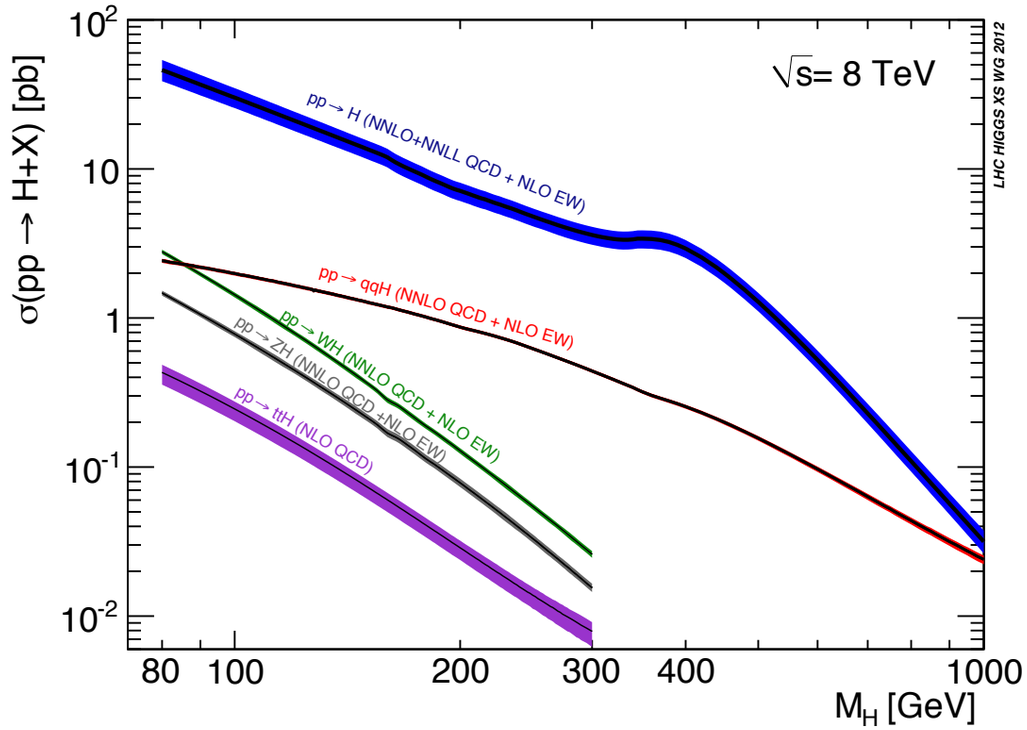
Analysis Strategy

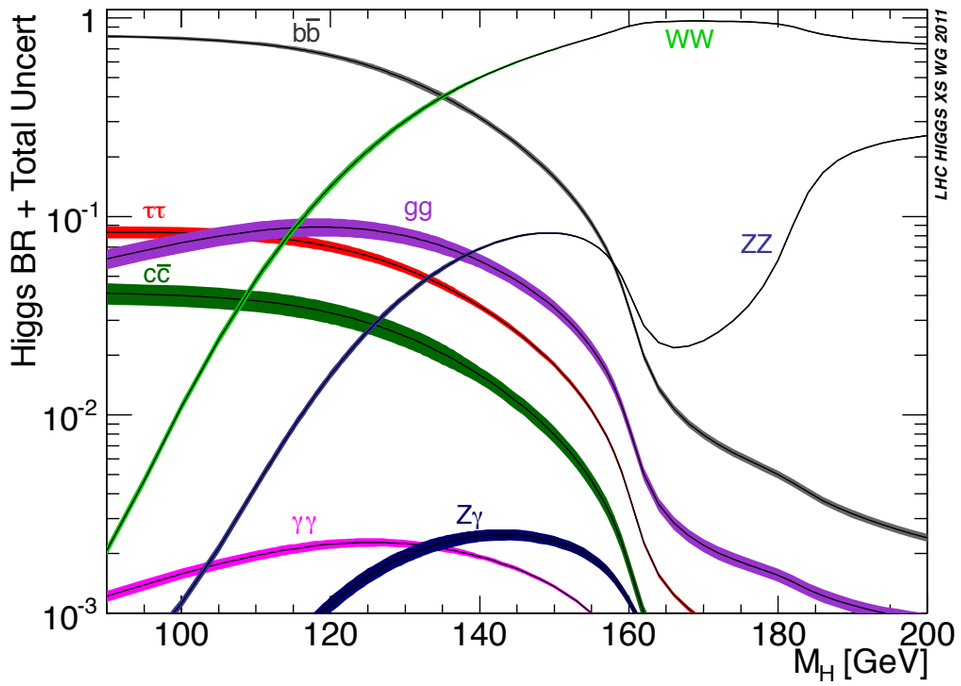
- \+ large BR over wide range of m_H
- \- poor mass resolution

- Event Characteristics:
  - two opposite sign leptons (e,μ) + E_T^{miss}

- 4 lepton channels:
  - ee, $\mu\mu$ .... same flavour (SF)
  - $e\mu$, μe .... different flavour (DF)

- binned in jet multiplicity:
  - 0 + 1j ... optimized for ggF
  - 2j .... optimized for VBF

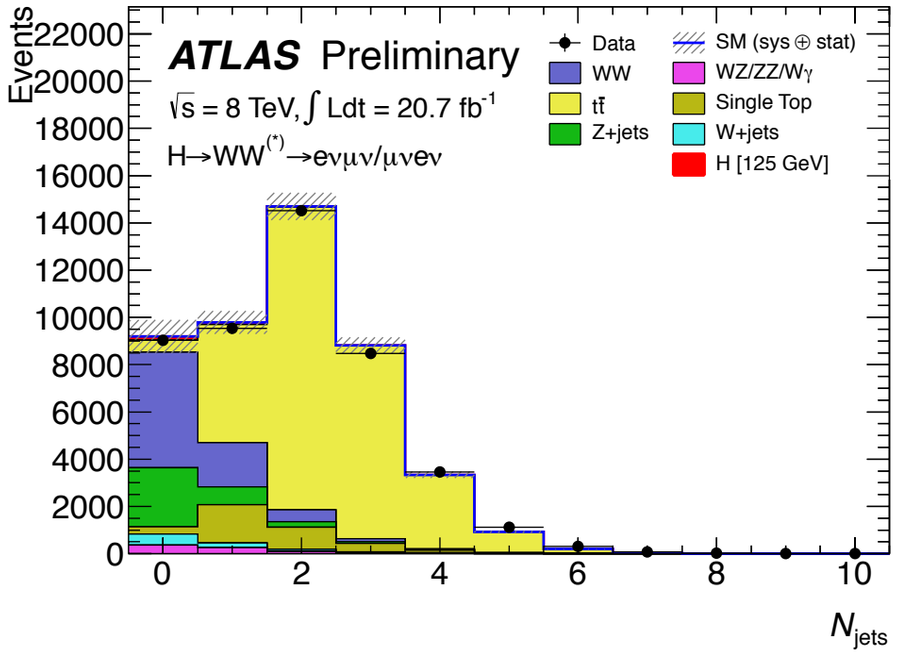




Object definition

Cut/Definition	ATLAS	CMS
Lepton ID	cut-based	Multivariate Analysis (MVA)
Lepton p_T	25/15 GeV	20/10 GeV
Jets	Anti-k_T, $\Delta R = 0.4$	Anti-k_T, $\Delta R = 0.5$
Jets p_T	$p_{Tjet} > 25$ GeV for $\|\eta\| < 2.4$ $p_{Tjet} > 30$ GeV for $2.4 < \|\eta\| < 4.5$	$p_{Tjet} > 30$ GeV for $\|\eta\| < 4.7$
pile up suppression	calibration+tracking	calibration+MVA (jet shapes...)
E_T^{miss}	relative to jets and leptons E_T^{miss} based on tracking for SF	relative to leptons E_T^{miss} based on tracking for all channels

Backgrounds



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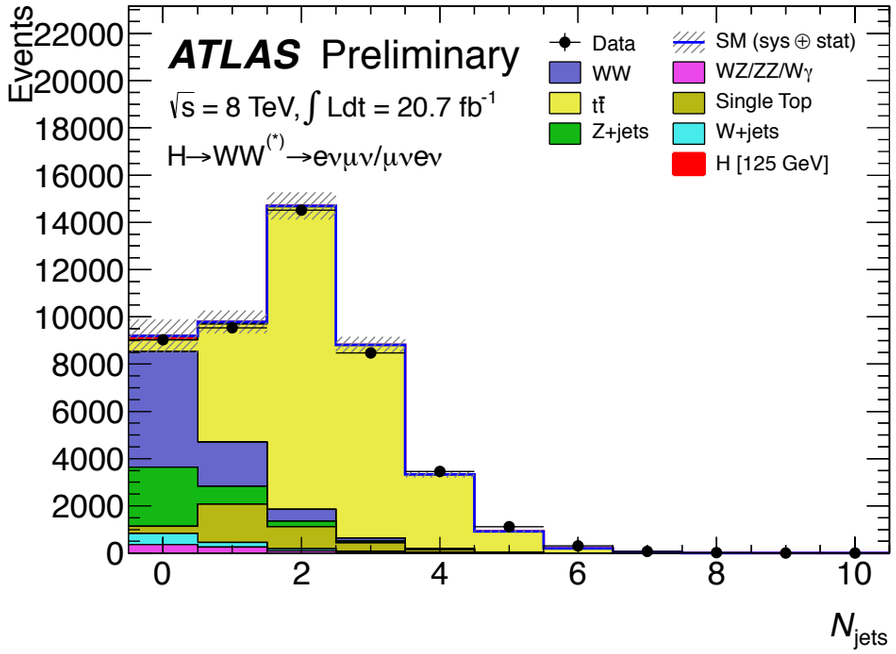
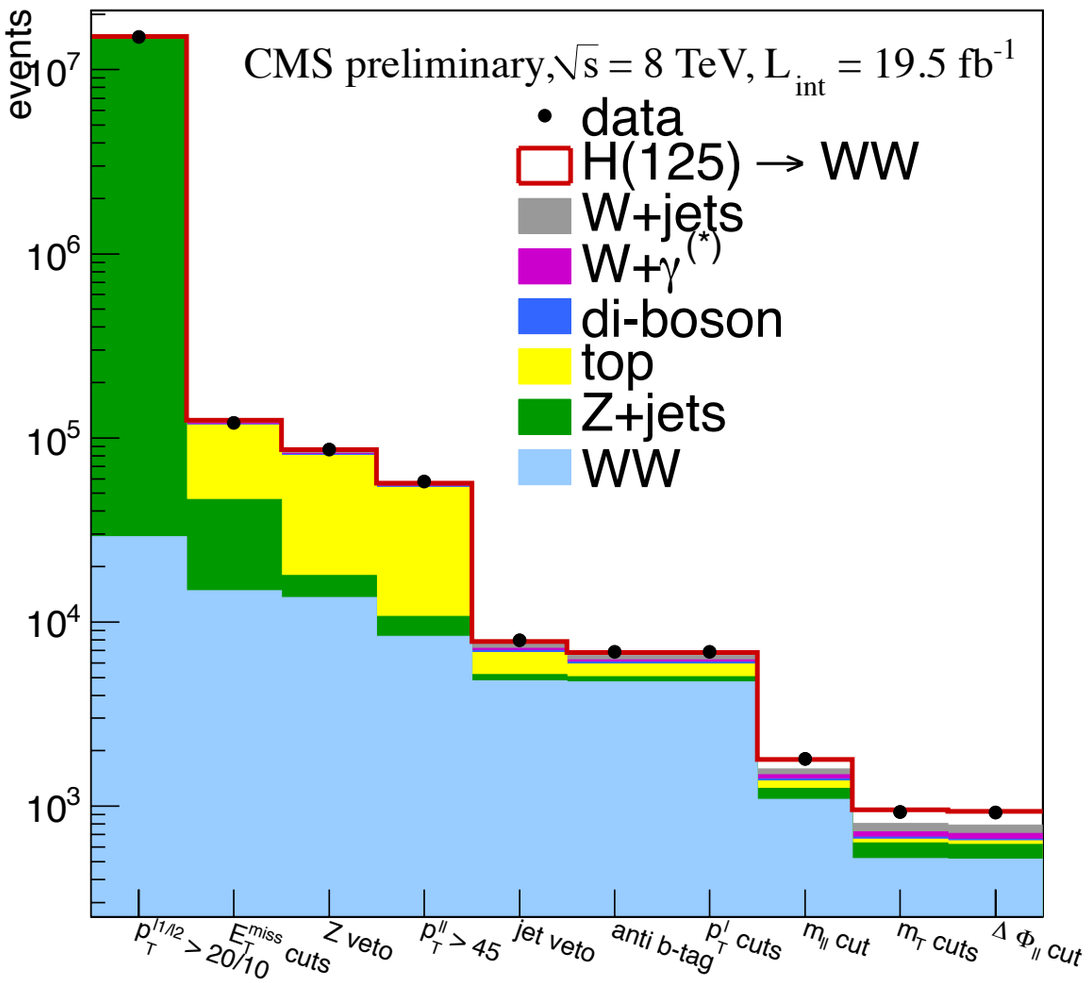


- **W+jets:** (lepton+ E_T^{miss} +fake lepton)
  - isolation / lepton ID
  - small, important at low p_T, data-driven method, p_{Tll} cut



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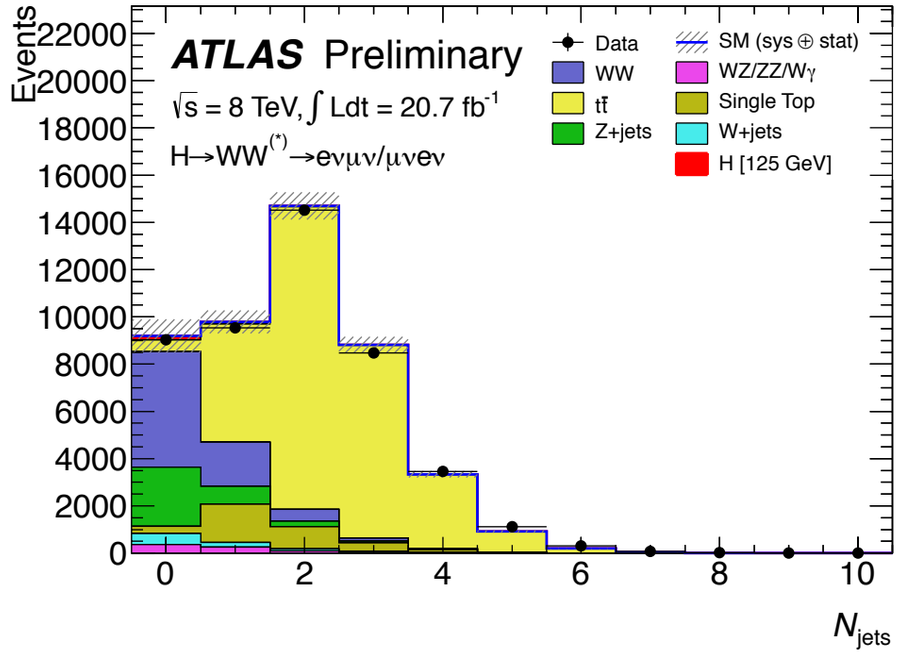

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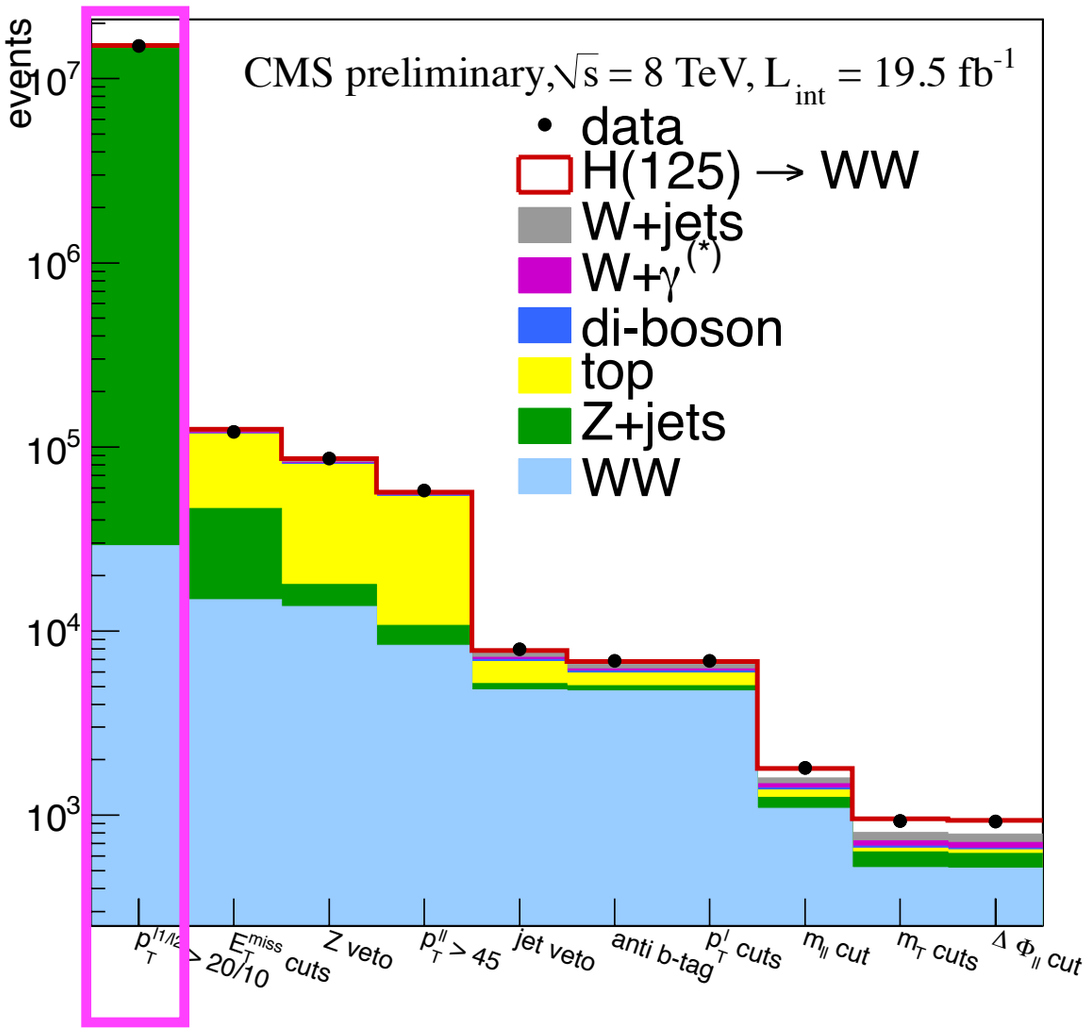
- **di-bosons (WZ, ZZ, Wγ):**
  - exactly 2 leptons



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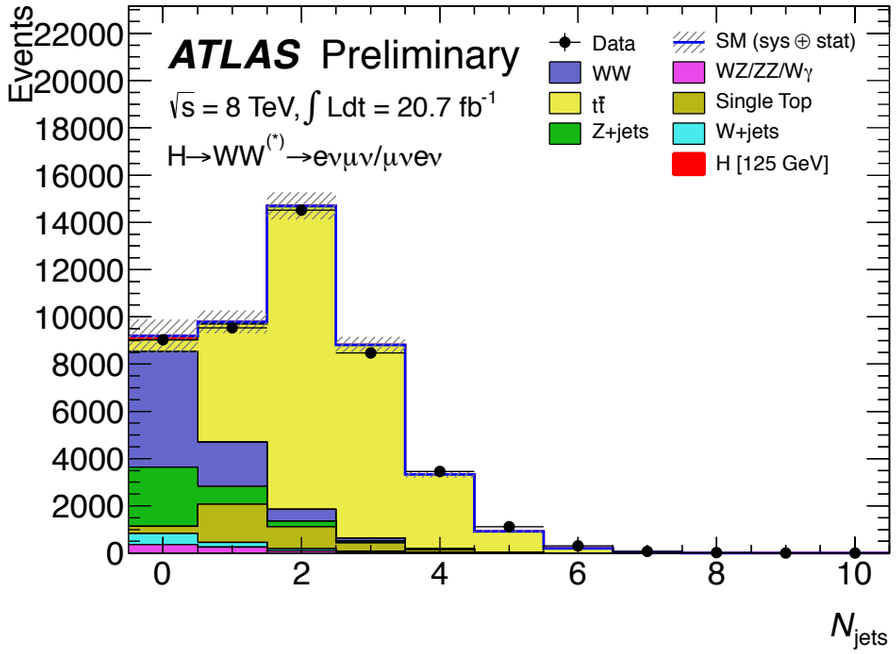

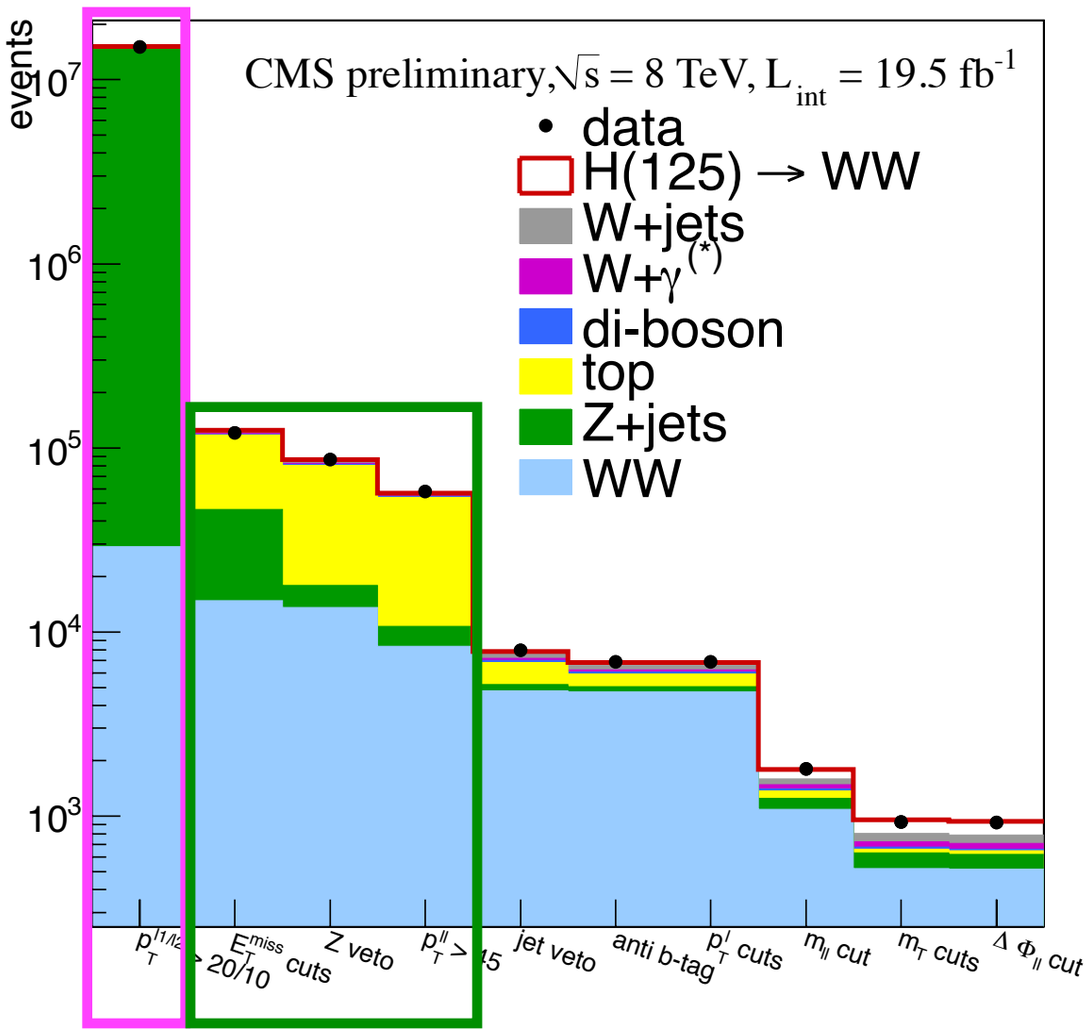

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  - large, reducible with cuts, modeled by MC, correction to data from Control Regions (CRs)
  - Z-veto, E_T^{miss} cuts, p_{Tll}

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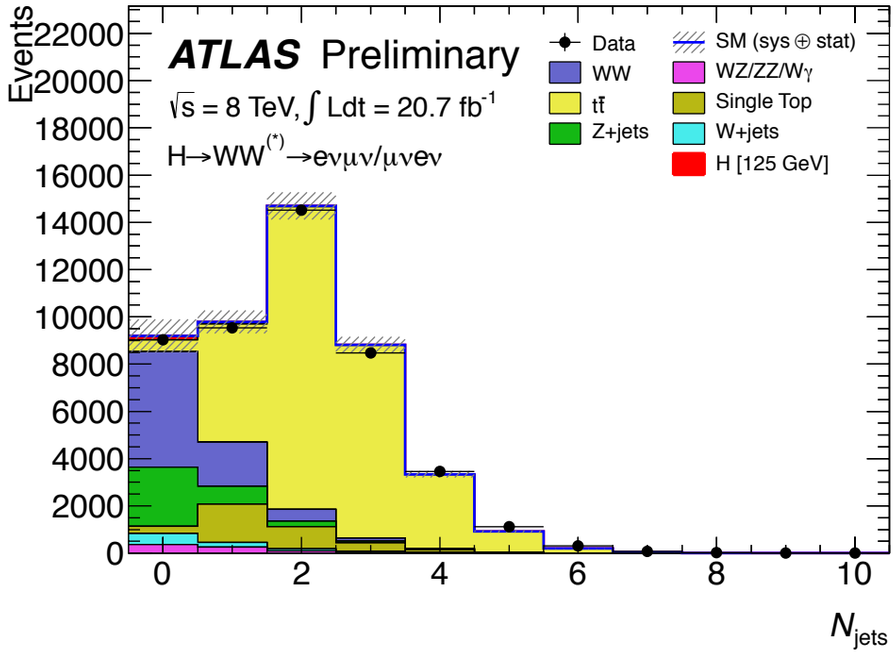

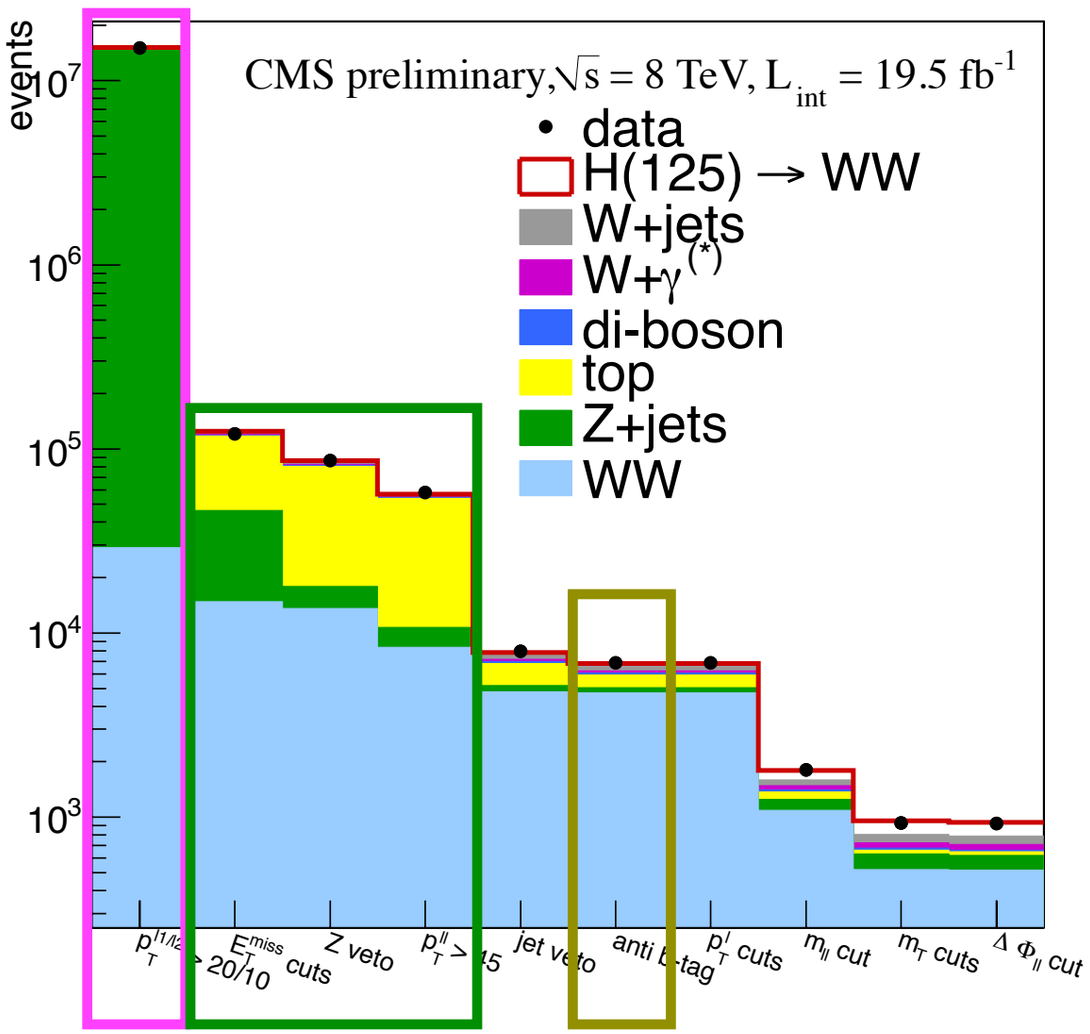

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- **ttbar, single top:**
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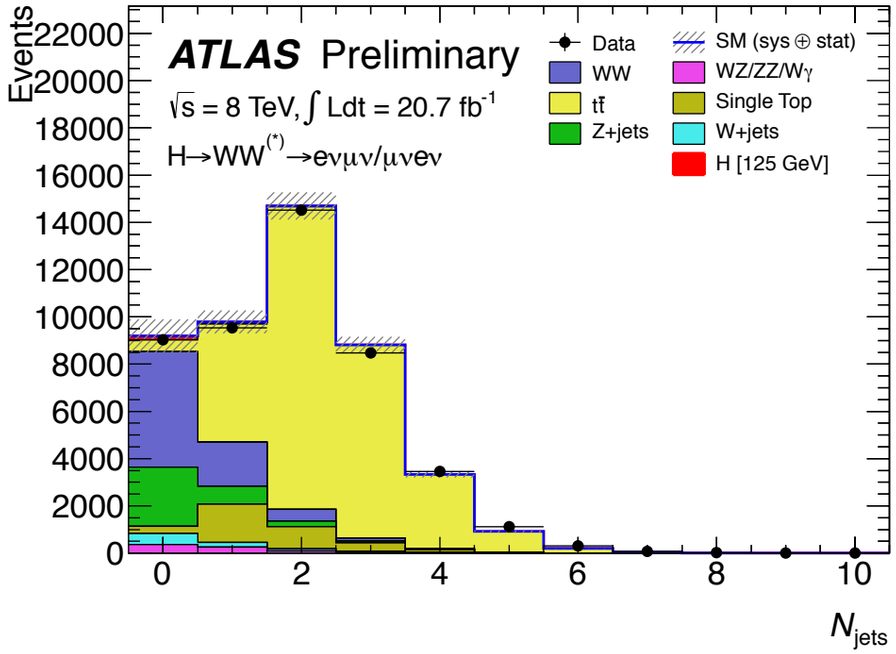
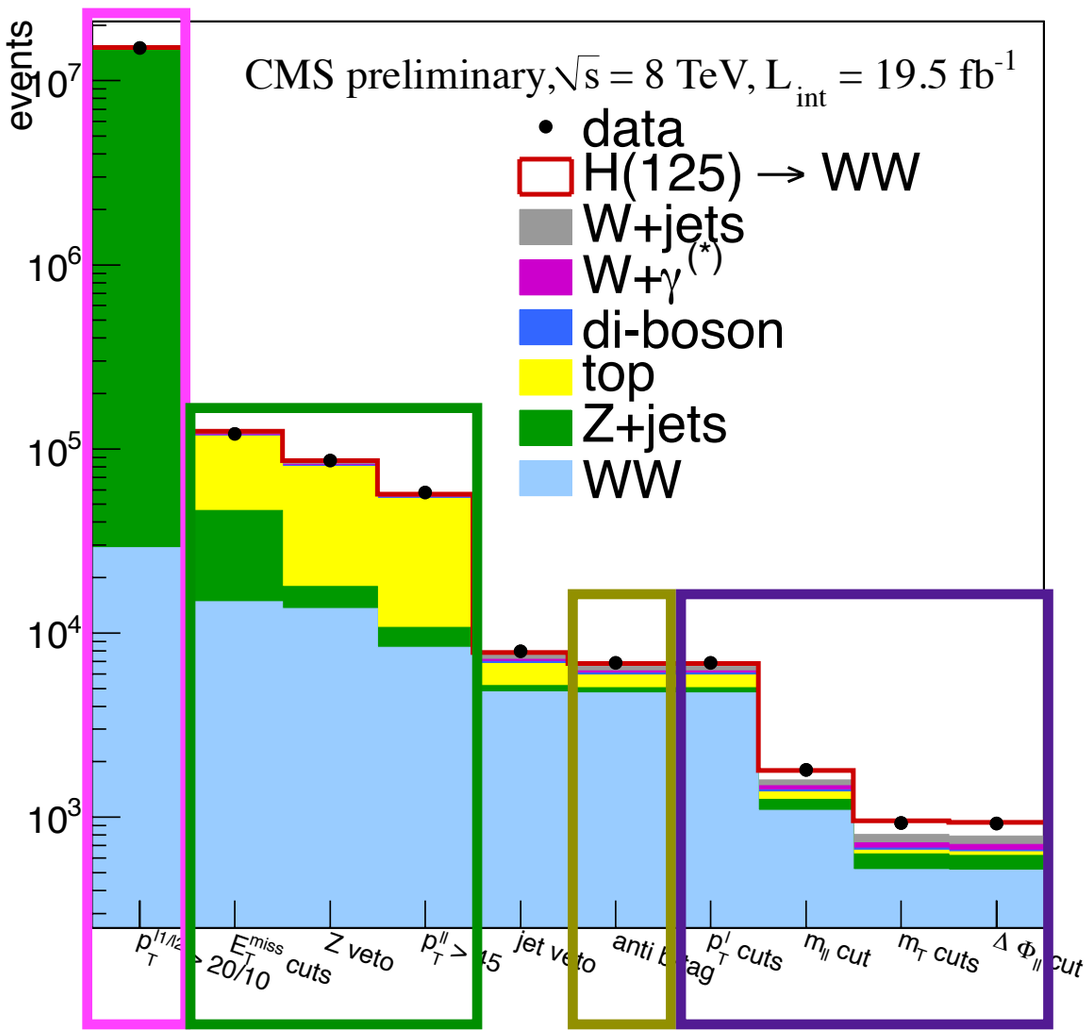
  - for 0j data driven estimate by CMS
  - b-Jet veto

Backgrounds





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- **ttbar, single top:**
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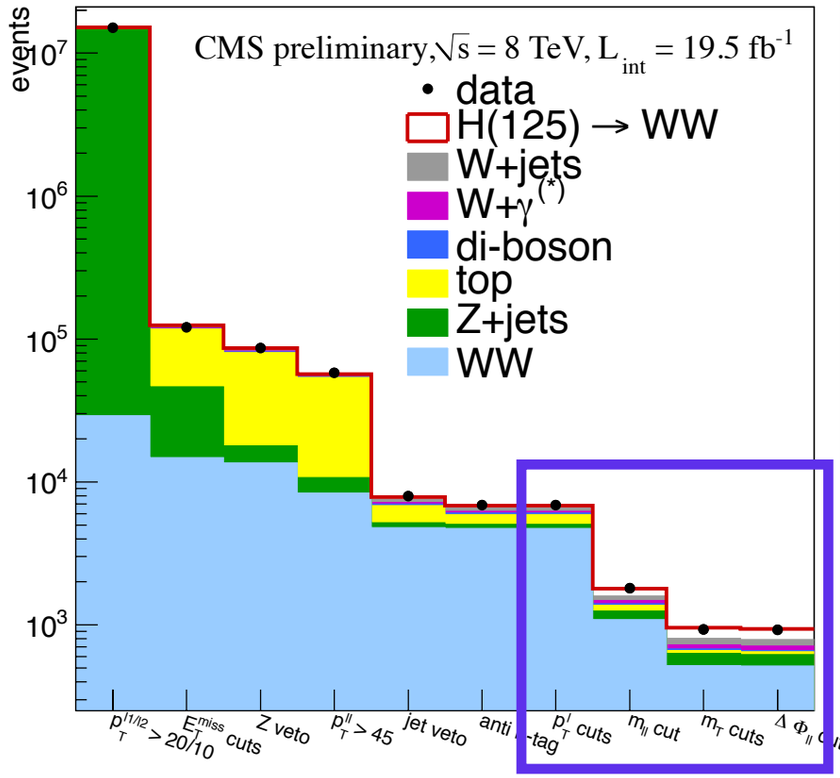
  - for 0j data driven estimate by CMS
  - b-Jet veto
- **WW:** (non resonant)
  - dominant in 0j channel
  - reducible by topological cuts

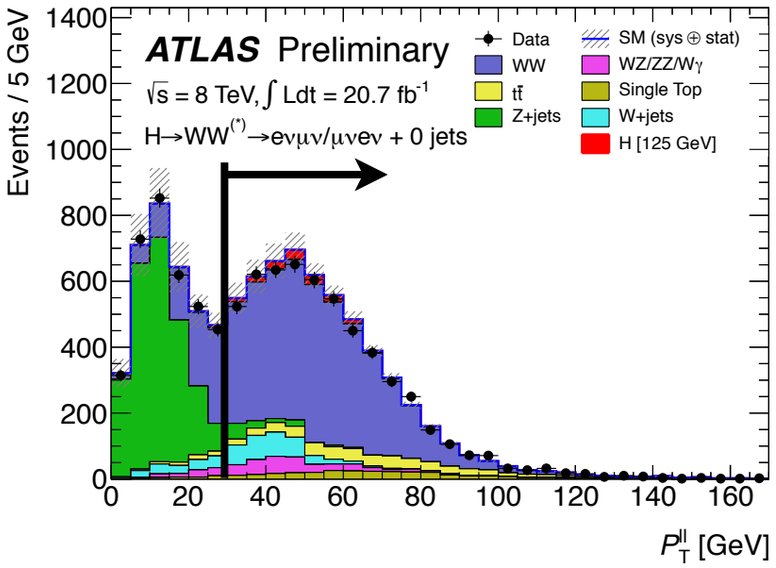
WW Background

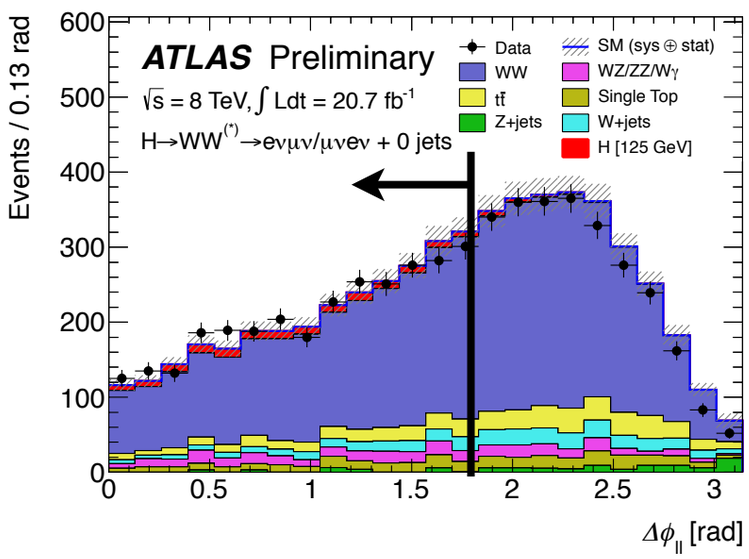
- non resonant WW and H->WW have very similar signature
- kinematics of the final state leptons show differences in angular correlation:
  - pp -> H -> WW -> lνlν ..... small opening angle between leptons
  - pp -> WW -> lνlν ... more uniform
- topological cuts applied only for the cut-based analysis @ CMS

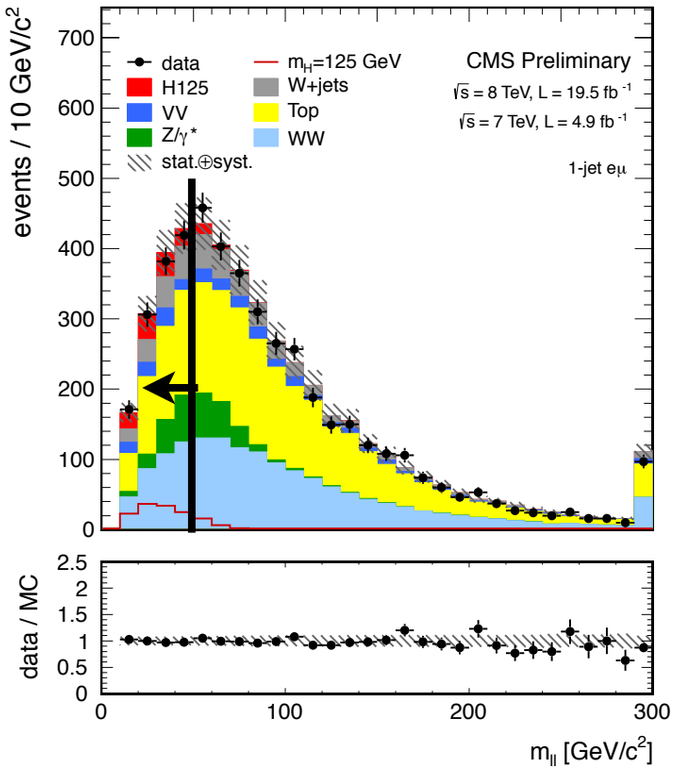


ATLAS

Category	$N_{jet} = 0$	$N_{jet} = 1$
$H \to WW^{(*)} \to \ell\nu\ell\nu$ topology	$m_{\ell\ell} < 50$ $\|\Delta\phi_{\ell\ell}\| < 1.8$ $e\mu + \mu e$: split $m_{\ell\ell}$ Fit m_T	$m_{\ell\ell} < 50$ $\|\Delta\phi_{\ell\ell}\| < 1.8$ $e\mu + \mu e$: split $m_{\ell\ell}$ Fit m_T

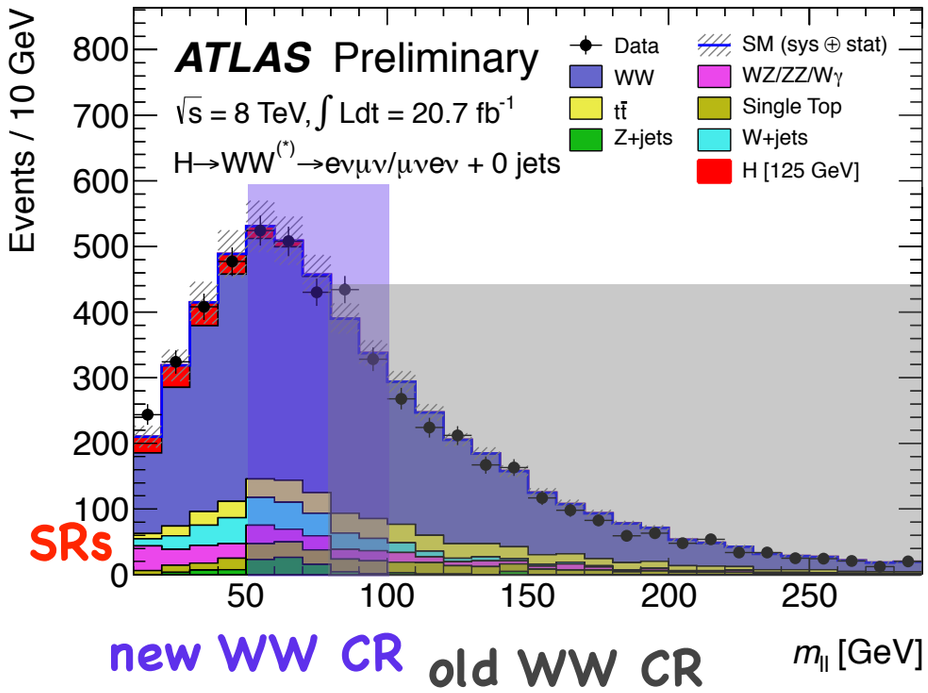






Signal Extraction - ATLAS

- WW background is dominant and crucial to understand (WW CR = Signal Region (SR) for high mass m_{ll}) - smaller m_{ll} range results in smaller extrapolation systematics



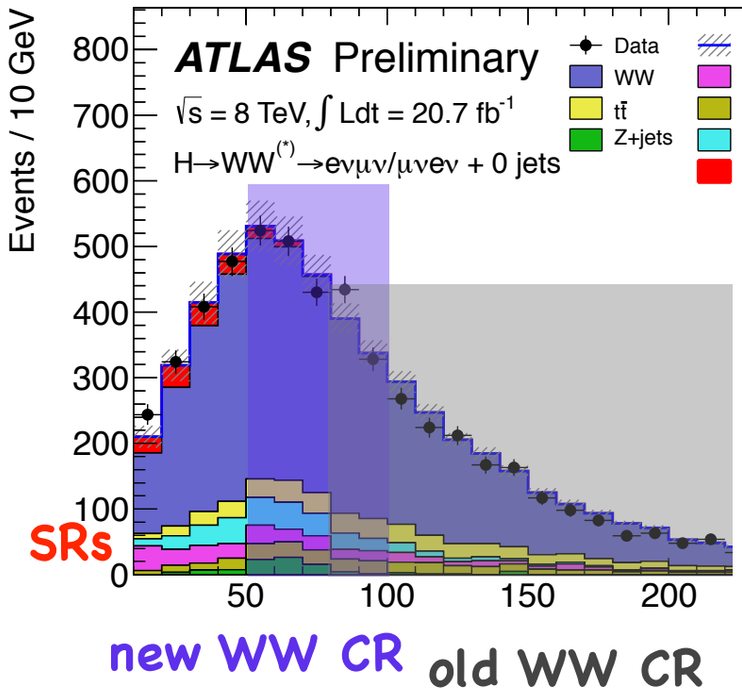
- cut-based analysis

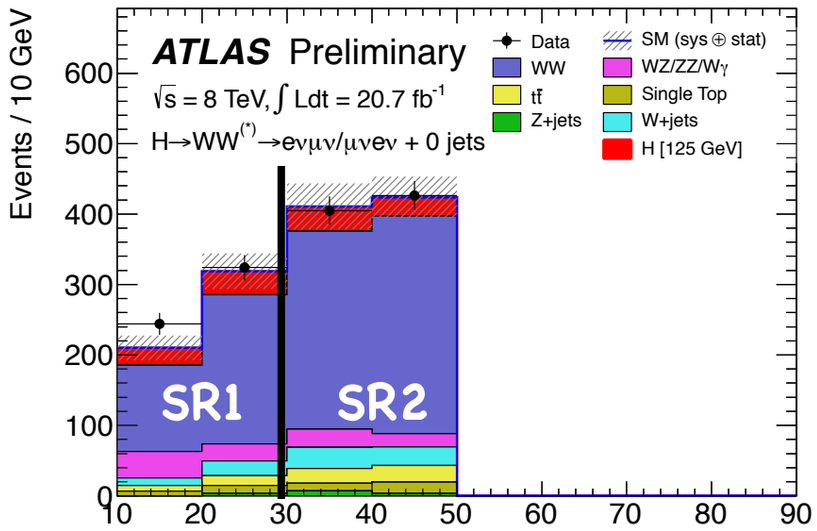
m_H = 125 GeV focused

source:	scale	PDF	parton shower	Powheg+Pythia vs MCFM	total
old	2.5%	3.7%	4.5%	3.5%	~7.2%
new	0.9%	1.1%	0.8%	1.4%	~2.1%

Signal Extraction - ATLAS

- WW background is dominant and crucial to understand (WW CR = Signal Region (SR) for high mass m_{ll}) - smaller m_{ll} range results in smaller extrapolation systematics
- cut-based analysis
- splitting the SR in 2 m_{ll} bins improves the sensitivity (different S/B ratios, background composition)





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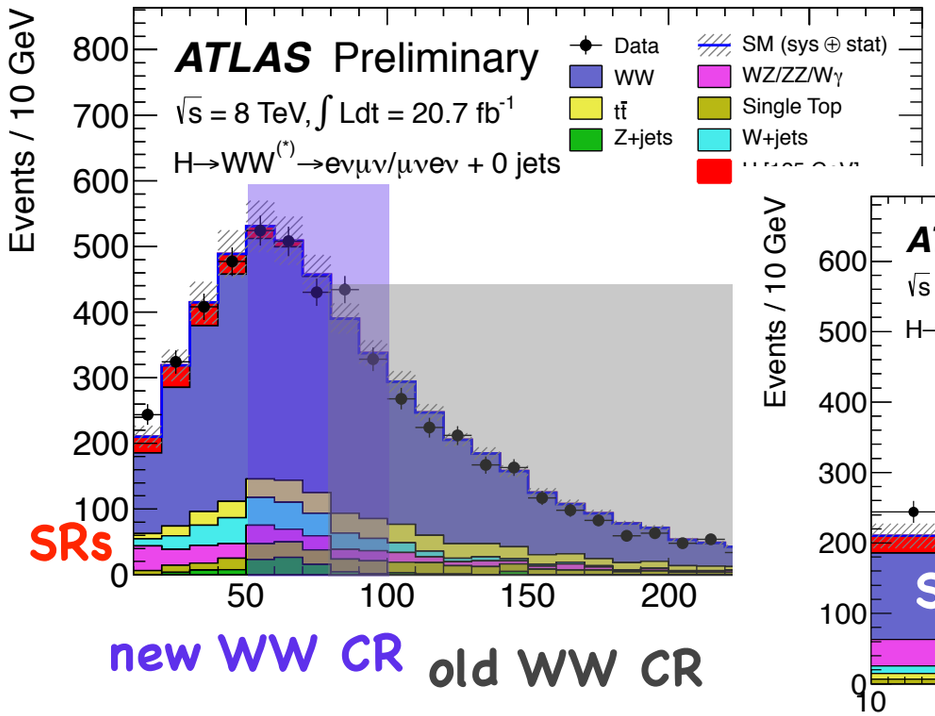
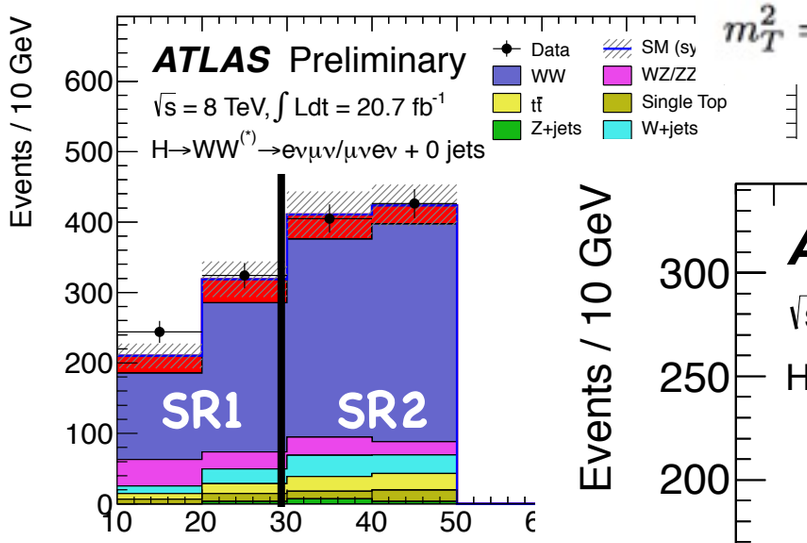
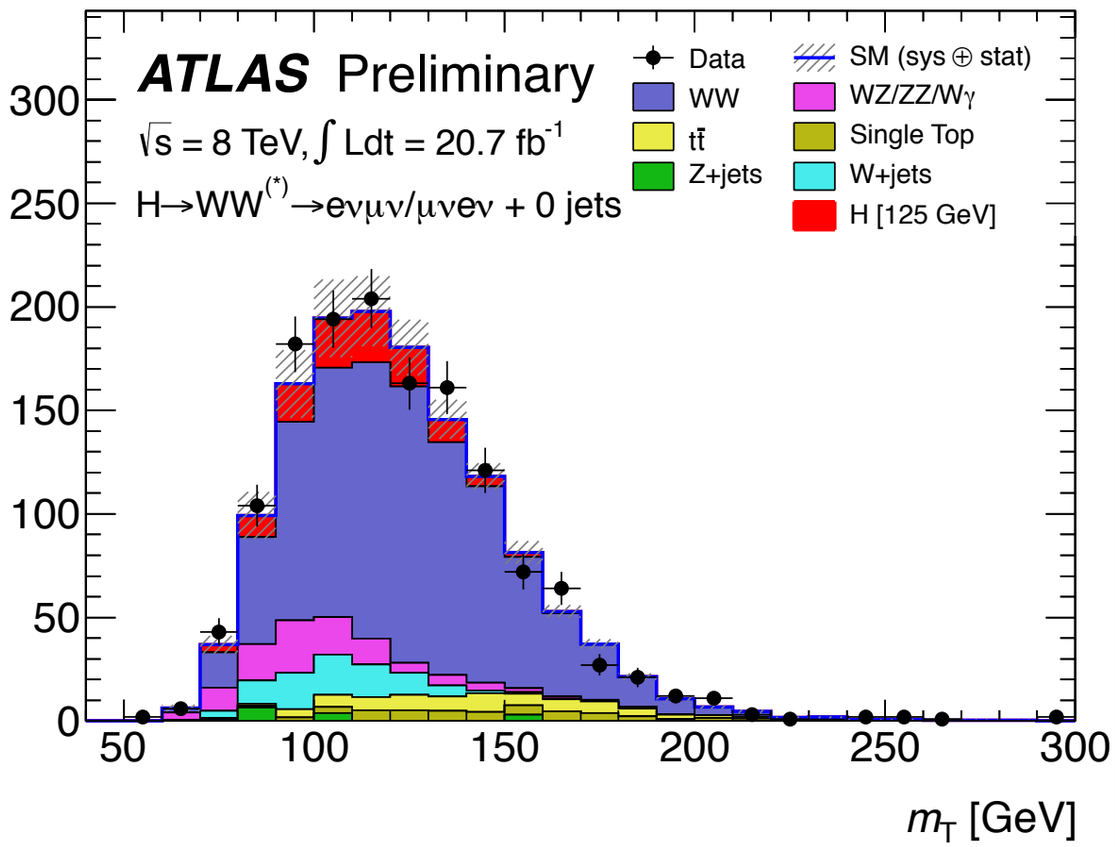




- cut-based analysis
- splitting the SR in 2 m_{ll} bins improves the sensitivity (different S/B ratios, background composition)
- final fit performed on m_T (5 bins)

$$m_T^2 = \left(\sqrt{m_{ll}^2 + |\vec{p}_{T,ll}|^2} + E_T^{\text{miss}}\right)^2 - \left(\vec{p}_{T,ll} + \vec{E}_T^{\text{miss}}\right)^2$$



m_H = 125 GeV focused

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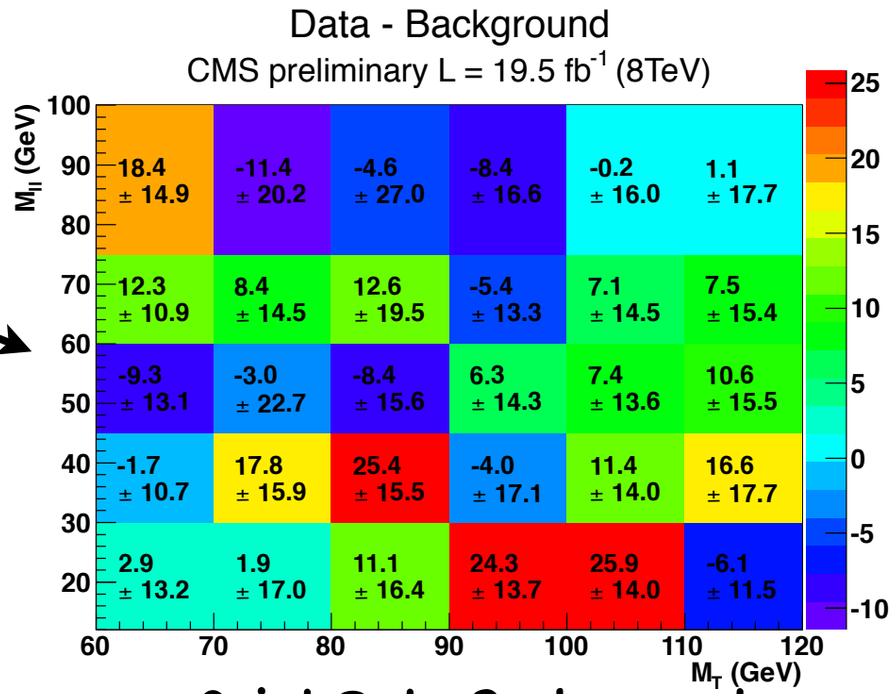
old	2.5%	3.7%	4.5%	3.5%	~7.2%
new	0.9%	1.1%	0.8%	1.4%	~2.1%

Signal Extraction - CMS

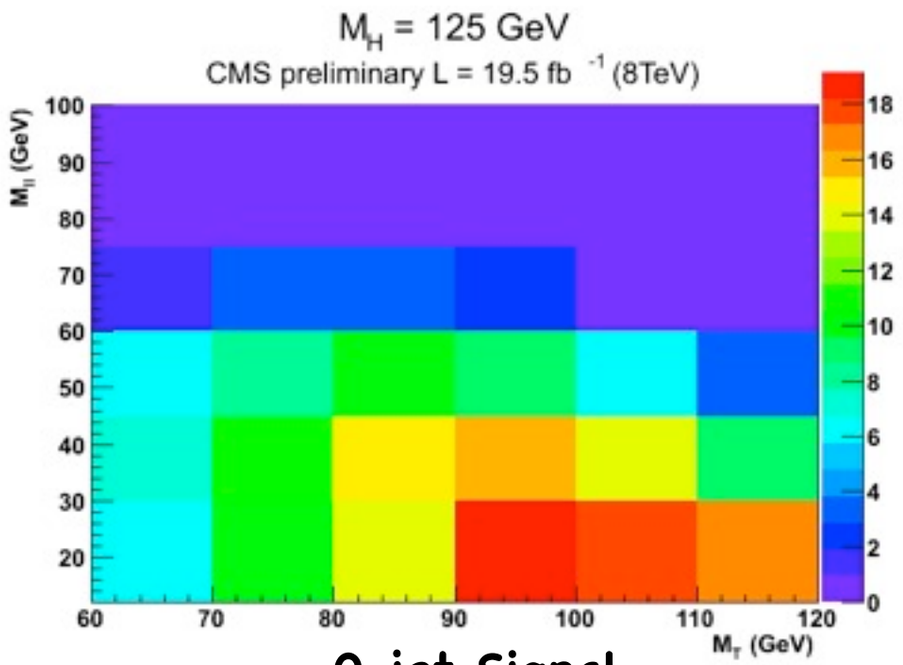
- Analysis uses cut-based approach as well as a 2D shape analysis in m_{ll}-m_T plane
  - 2D analysis is base-line due to better expected sensitivity
- WW CR defined for m_{ll} > 100 GeV
- For cut-based, optimized cut values on lepton p_T, m_{ll}, $\Delta\Phi_{ll}$ and m_T ranges are applied for different m_H:

$$M_T = \sqrt{2p_T^{\ell\ell} E_T^{miss} \cos(\Delta\phi_{\ell\ell} - E_T^{miss})}$$

m_H [GeV]	$p_T^{\ell,max}$ [GeV]	$p_T^{\ell,min}$ [GeV]	$m_{\ell\ell}$ [GeV]	$\Delta\phi_{\ell\ell}$ [°]	m_T [GeV]
	>	>	<	<	[,]
120	20	10	40	115	[80,120]
125	23	10	43	100	[80,123]
130	25	10	45	90	[80,125]
160	30	25	50	60	[90,160]
200	40	25	90	100	[120,200]
250	55	25	150	140	[120,250]
300	70	25	200	175	[120,300]
400	90	25	300	175	[120,400]



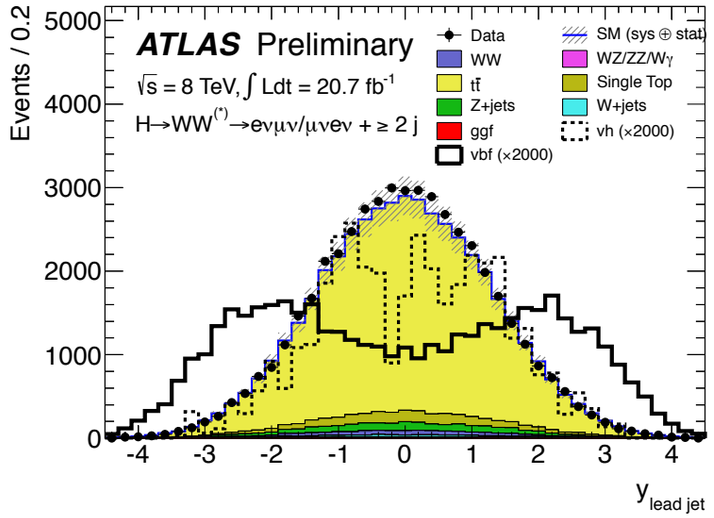
0 jet Data-Background



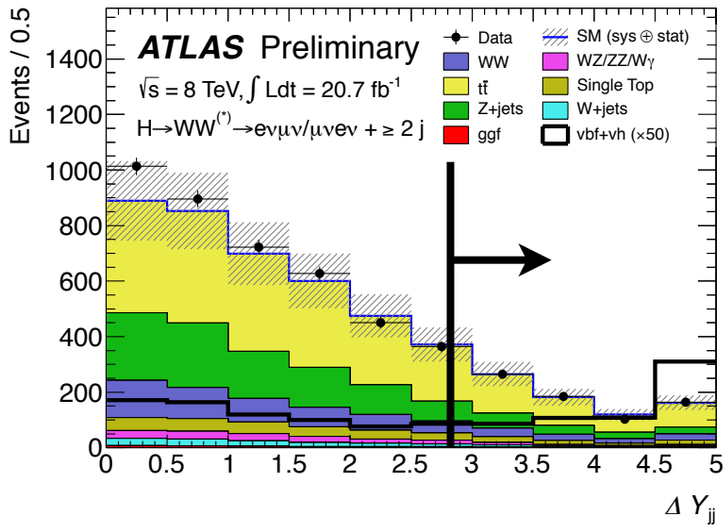
0 jet Signal

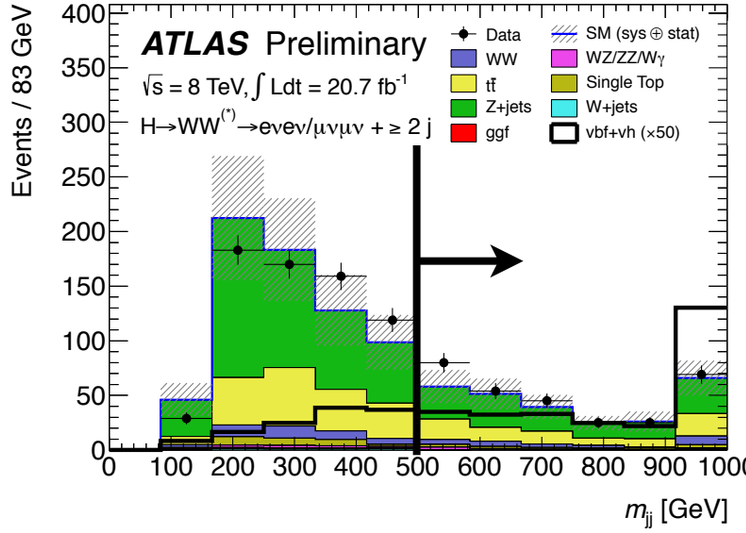
VBF @ ATLAS

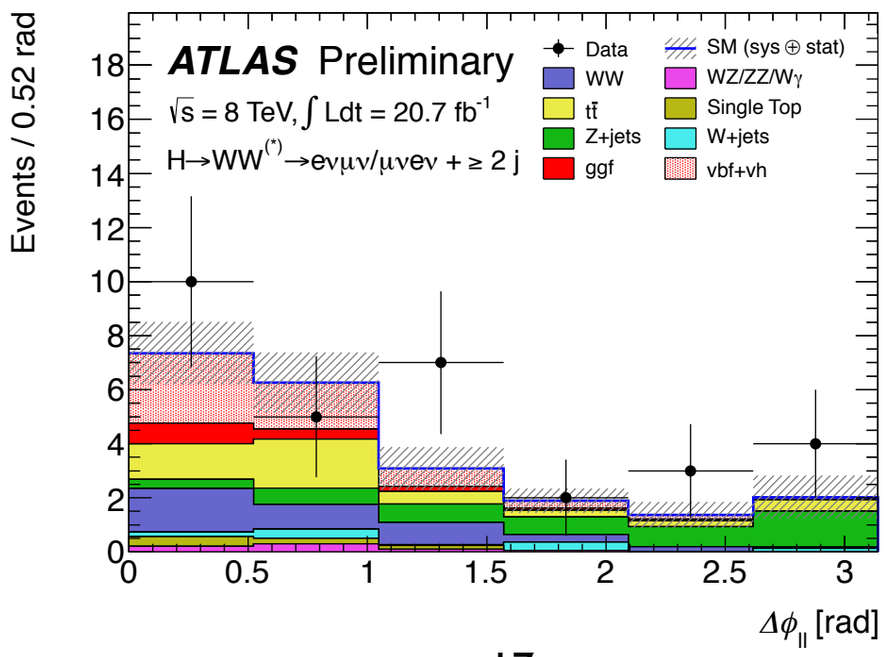
- WW + 2 leading high mass jets well separated in rapidity
- background dominated by top (constrained by CR), WW from theory (37% unc), DY from CR
- in optimizations, ggF signal considered as background

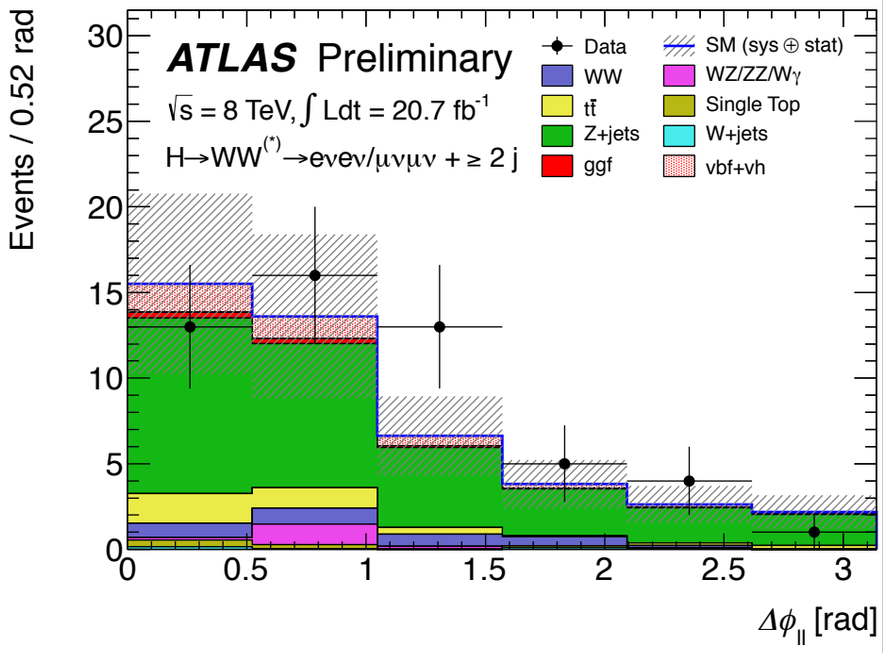


$N_{\text{jet}} \geq 2$
Two isolated leptons ($\ell = e, \mu$) with opposite charge Leptons with $p_{\text{T}}^{\text{lead}} > 25$ and $p_{\text{T}}^{\text{sublead}} > 15$ GeV $e\mu + \mu e$: $m_{\ell\ell} > 10$ GeV $ee + \mu\mu$: $m_{\ell\ell} > 12$, $\lvert m_{\ell\ell} - m_Z \rvert > 15$ GeV
$e\mu + \mu e$: $E_{\text{T}}^{\text{miss}} > 20$ GeV $ee + \mu\mu$: $E_{\text{T}}^{\text{miss}} > 45$ GeV $ee + \mu\mu$: $E_{\text{T,STVF}}^{\text{miss}} > 35$ GeV -
$N_{b\text{-jet}} = 0$ $p_{\text{T}}^{\text{tot}} < 45$ GeV $e\mu + \mu e$: $Z/\gamma^* \to \tau\tau$ veto
$m_{jj} > 500$ GeV $\lvert \Delta y_{jj} \rvert > 2.8$ No jets ($p_{\text{T}} > 20$) in rapidity gap Require both ℓ in rapidity gap
$m_{\ell\ell} < 60$ GeV $\lvert \Delta\phi_{\ell\ell} \rvert < 1.8$ - Fit m_{T}









ATLAS EXPERIMENT

CMS

CMS Experiment at LHC, CERN
Data recorded: Thu Apr 19 09:14:14 2012 CEST
Run/Event: 191721 / 76089774
Lumi section: 111
Orbit/Crossing: 28960009 / 815

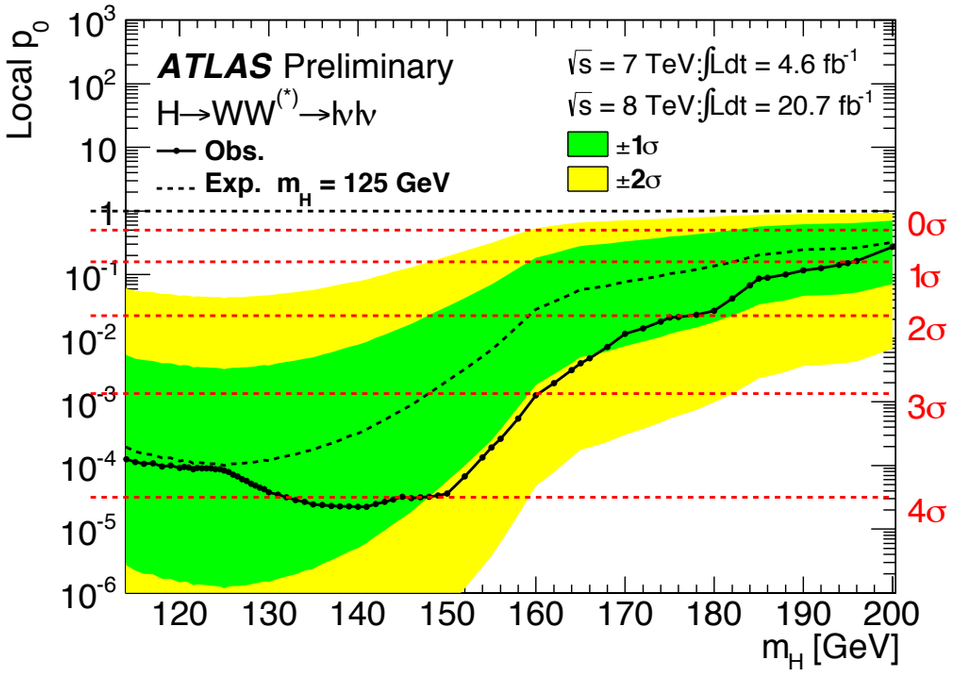
Systematics

ATLAS leading systematics in the signal region

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	-

	ATLAS δ_{tot} [%]	CMS δ_{tot} [%]
0j sig	20	21
0j bkg	4.7	7.9-11
1j sig	33.8	29
1j bkg	8.2	6.7-7.7
2j sig	11.3	
2j bkg	8.3	

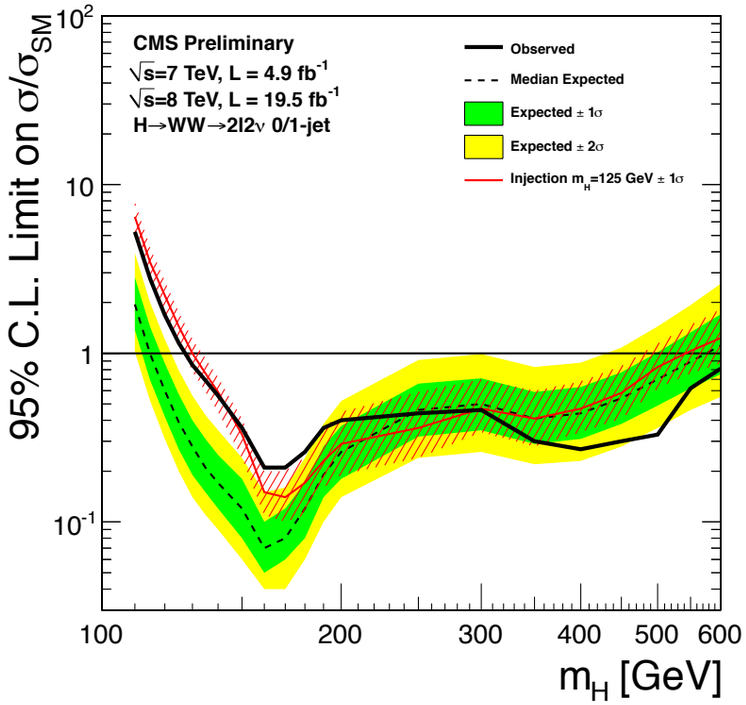
p_0 and μ @ m_H = 125 GeV

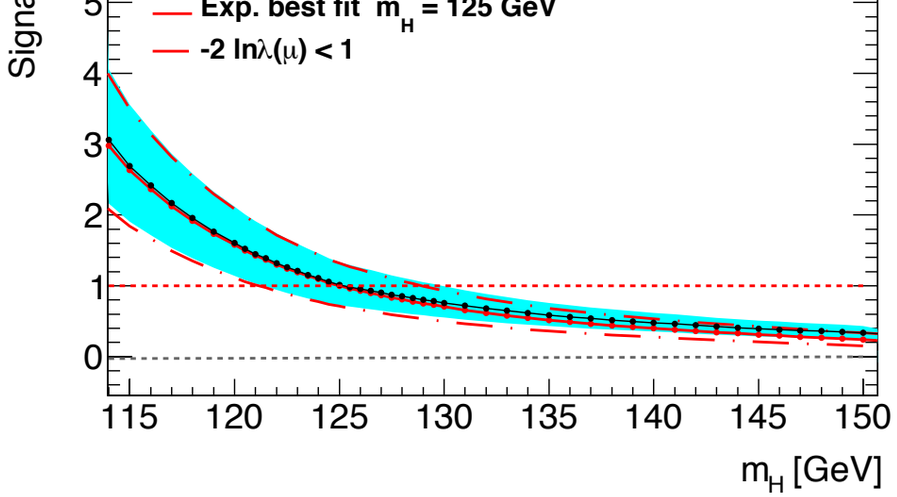


ATLAS 0+1+2j, 7+8 TeV:

exp 3.7σ, obs 3.8σ

μ_{obs} = 1.01 ± 0.12 (stat) ± 0.19 (theory) ± 0.12 (experiment) ± 0.04 (lumi) = 1.01 ± 0.31





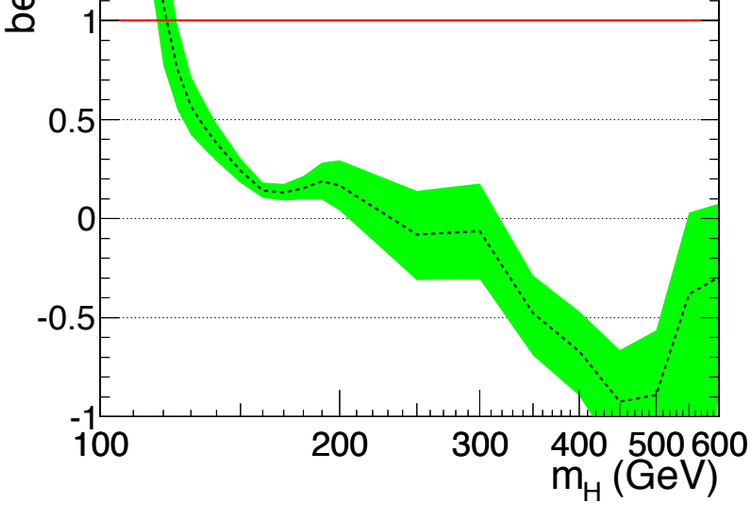
CMS 0+1j, 7+8 TeV:

cut based: exp 2.7σ, obs 2.0σ

μ_{obs} = 0.71 ± 0.37

shape based: exp 5.1σ, obs 4.0σ

μ_{obs} = 0.76 ± 0.13 (stat) ± 0.16 (syst) = 0.76 ± 0.21



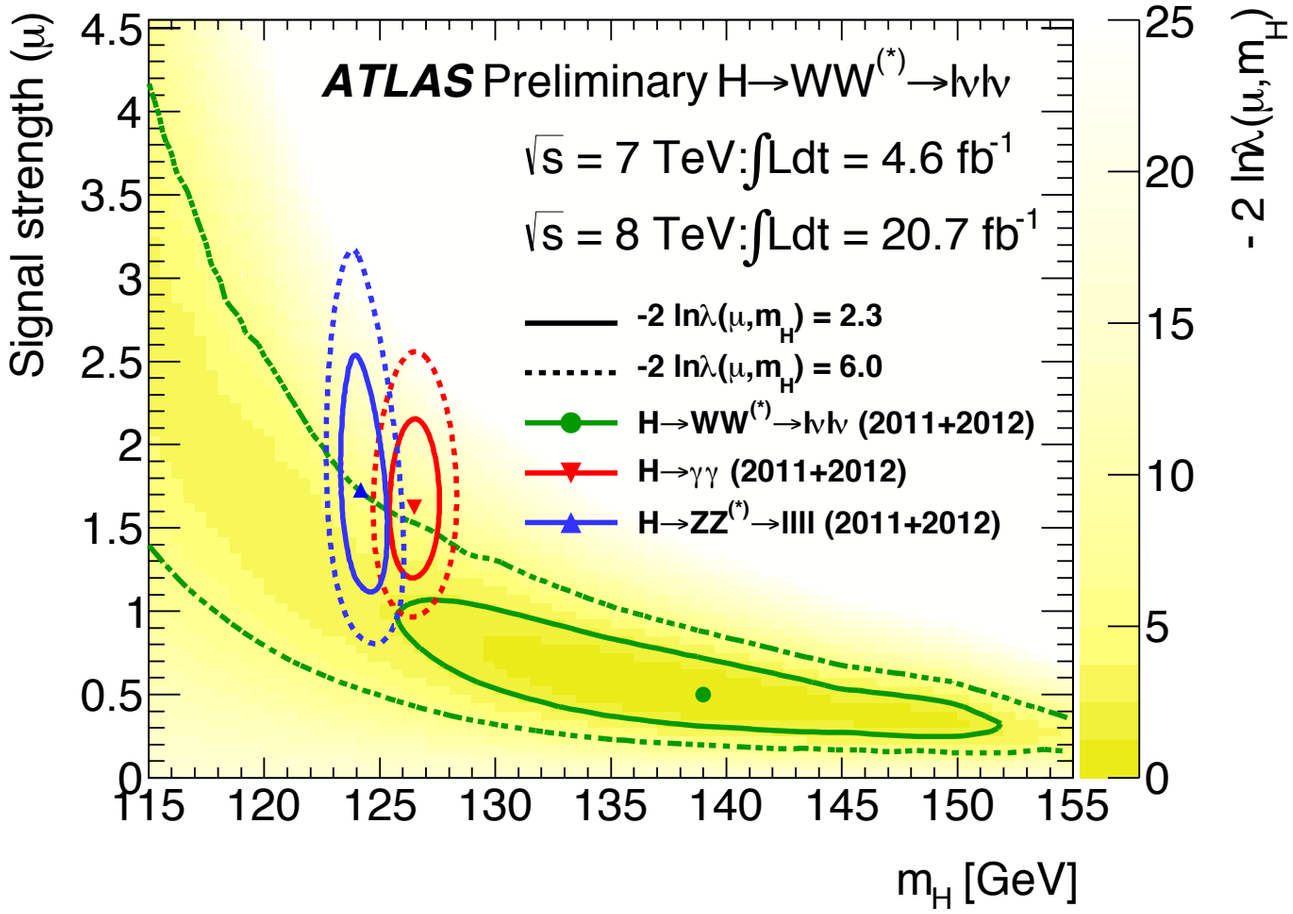
ATLAS

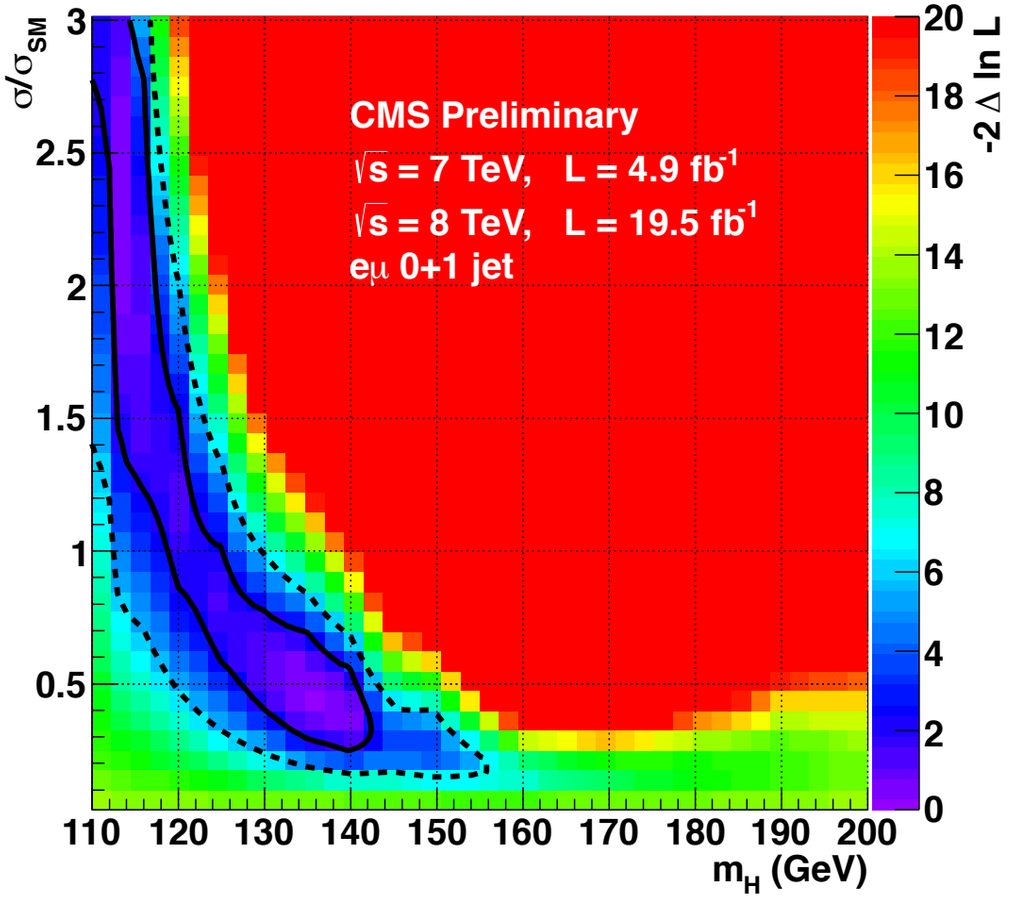
σ*Br$_{exp,8\ TeV}$ = 4.8 ± 0.6 (σ) ± 0.2 (Br) = 4.8 ± 0.7 pb

σ*Br$_{obs,8\ TeV}$ = 6.0 ± 1.1 (stat) ± 0.8 (theo) ± 0.7 (exp) ± 0.3 (lumi) = 6.0 ± 1.6 pb

good consistency with SM

Best mass fit





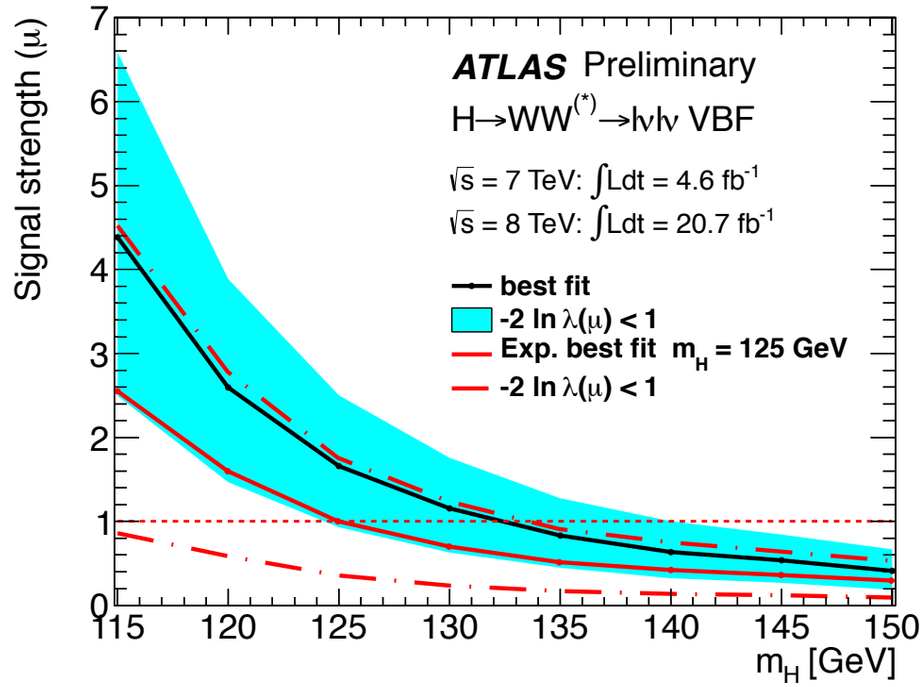
ATLAS 0+1+2j, 7+8 TeV: largest significance at m_H = 140 GeV, 4.1σ observed

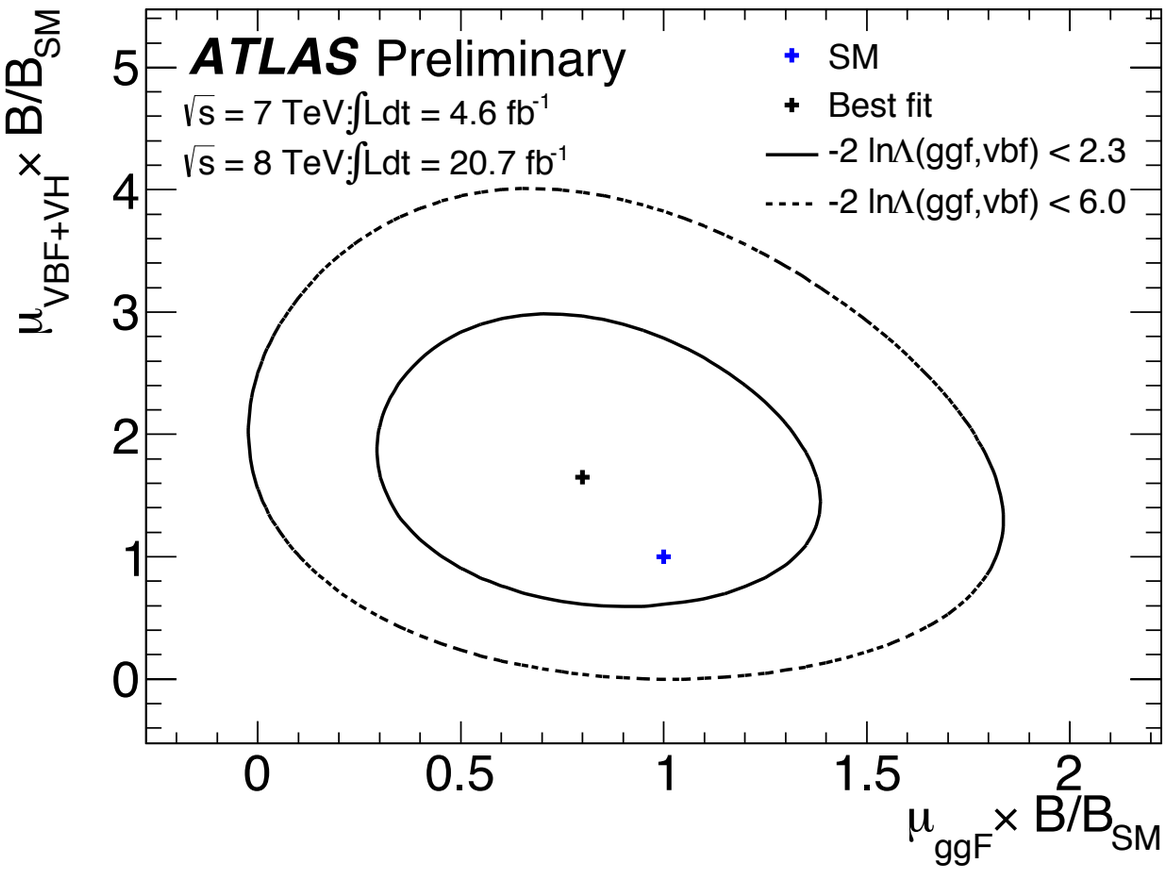
consistent with m_H = 125 GeV within 1σ

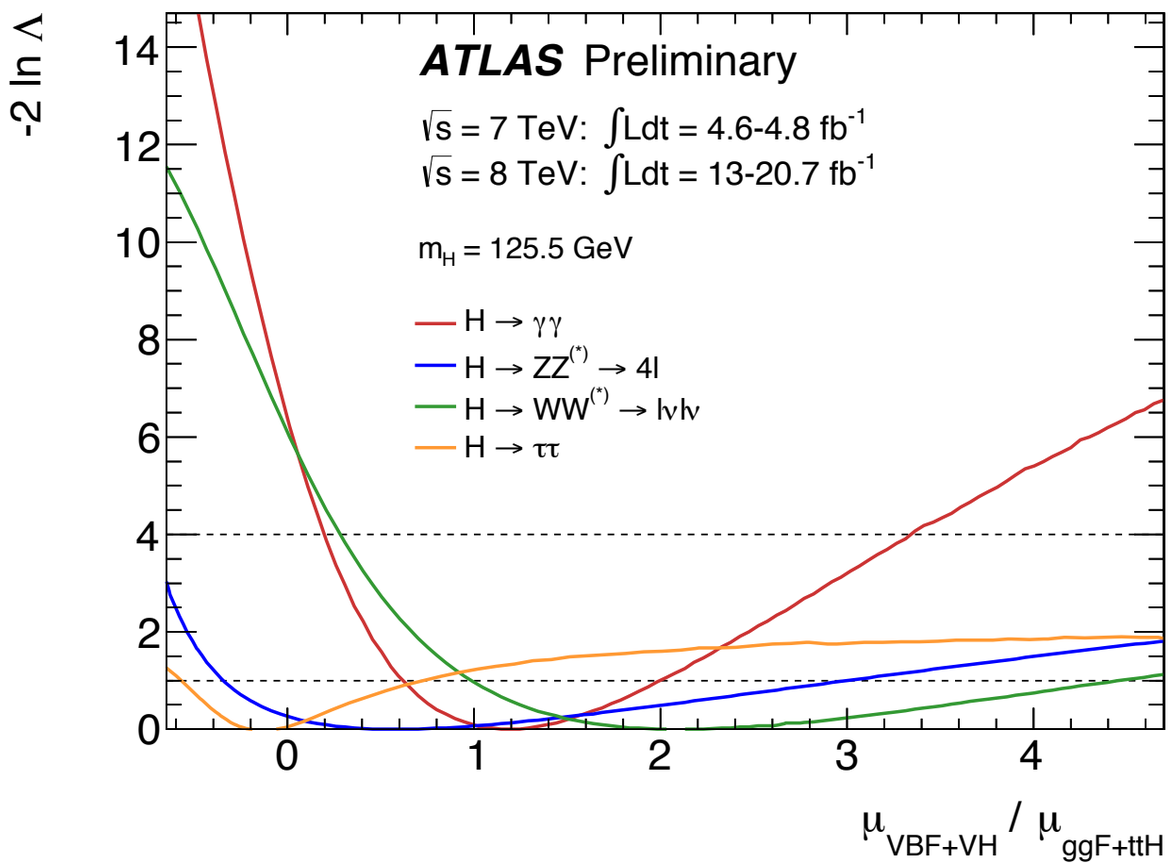
CMS 0+1j, 7+8 TeV: largest significance at m_H ~135 GeV

VBF results @ ATLAS for m_H = 125 GeV

- expected VBF signal significance is 1.6σ, observed 2.5σ
- 2D simultaneous ggF vs VBF fit
- μ_{ggF} = 0.82 ± 0.24 (stat) ± 0.28 (syst) = 0.82 ± 0.36
- μ_{VBF} = 1.66 ± 0.67 (stat) ± 0.42 (syst) = 1.66 ± 0.79





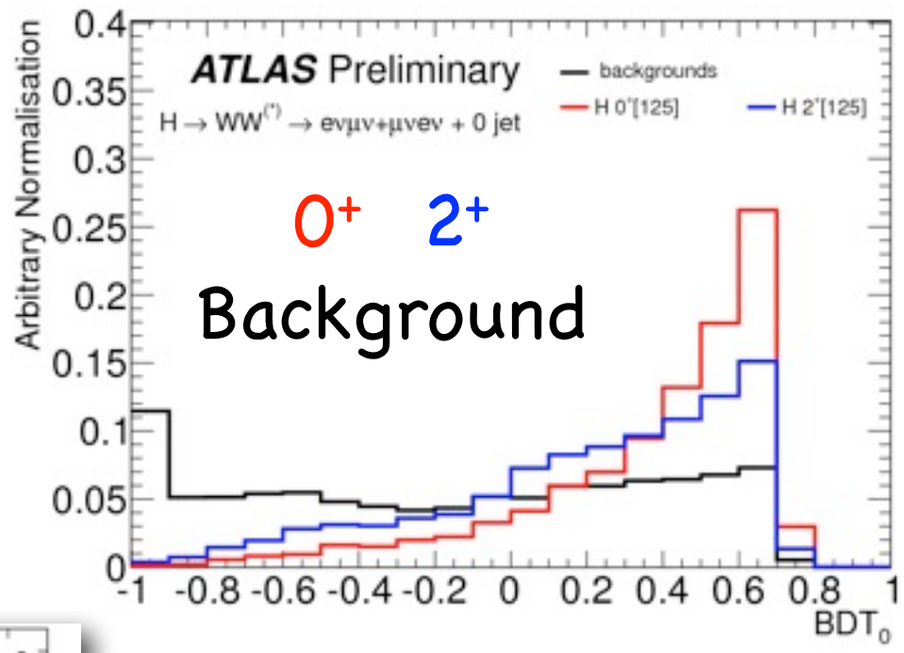


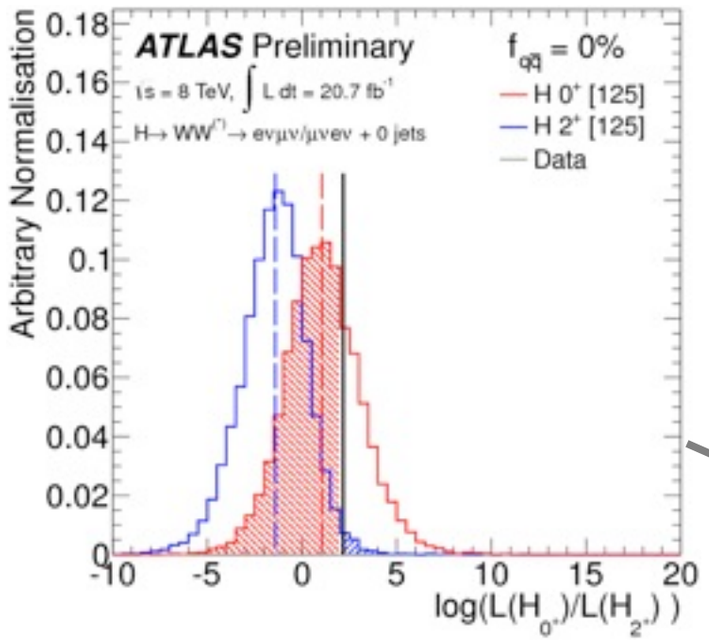
good consistency with SM

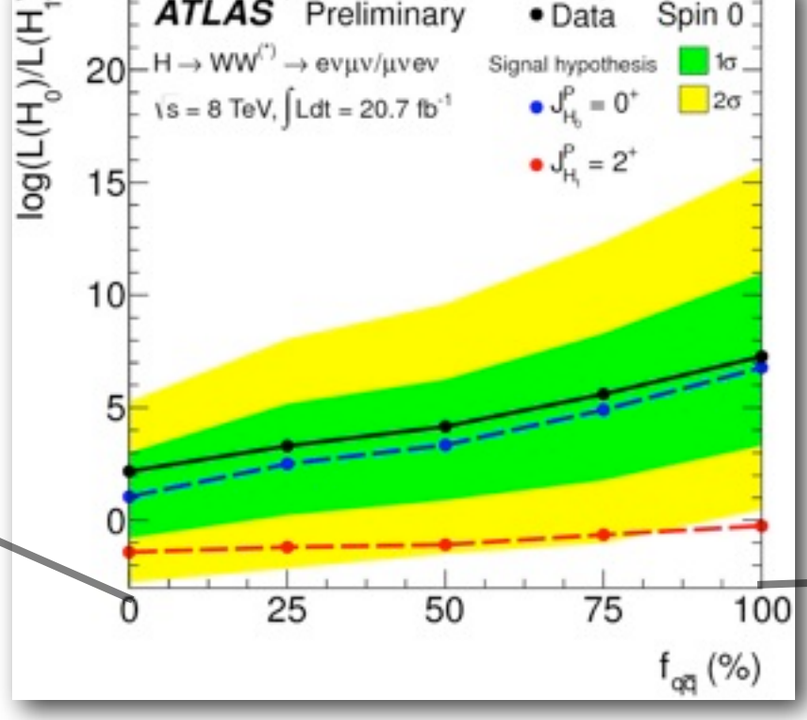
Spin @ ATLAS

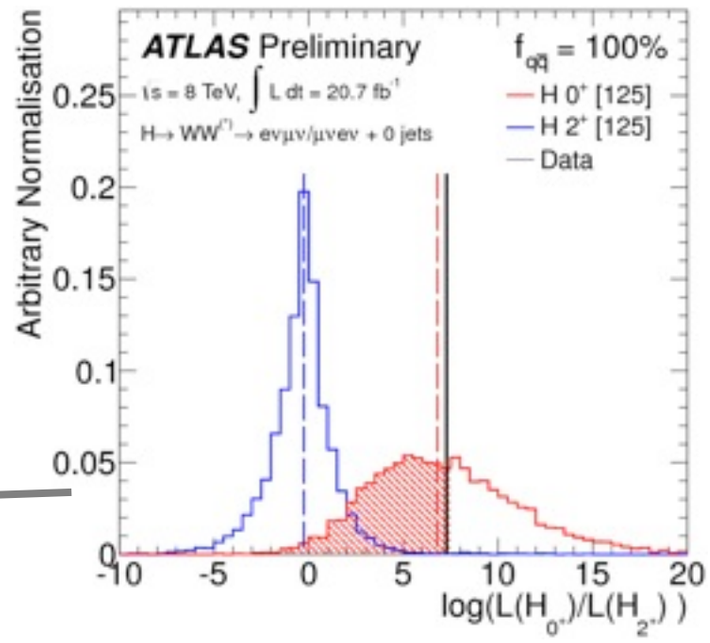
- OF 0j 2012, to distinguish $J^P = 0^+$ vs $J^P = 2^+$, relax cuts on E_T^{miss}, p_{Tll}, m_{ll} and $\Delta\Phi_{ll}$ to allow acceptance for 2^+
- general assumption is 2^+ graviton-like tensor (JHU minimal coupling model)
  - 5 production modes: 0%-25%-50%-75%-100% qq
- dedicated BDT MVA analysis:
  - 2 separate BDT trainings on relaxed variables for 0^+ and 2^+
  - results use a 2D fit to BDT_0 and BDT_2

Training for 0^+









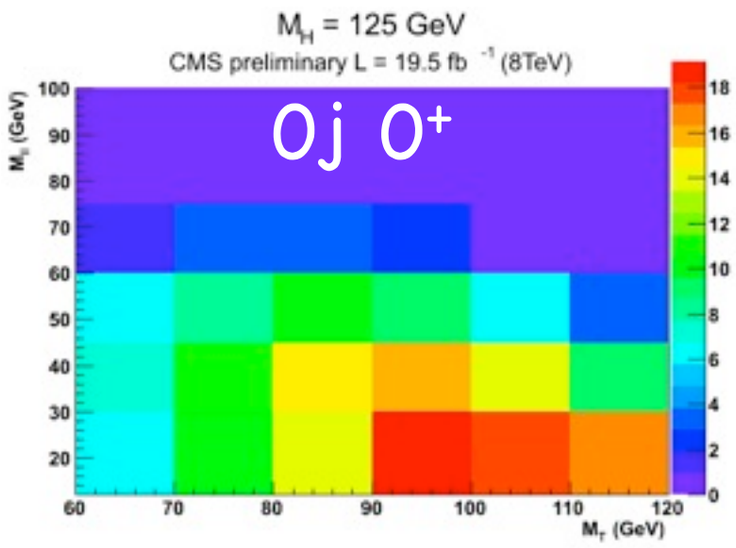
exclusion for qq = 0%	0^+	2^+
expected	1.33σ	1.58σ
observed	not excluded	2.20σ

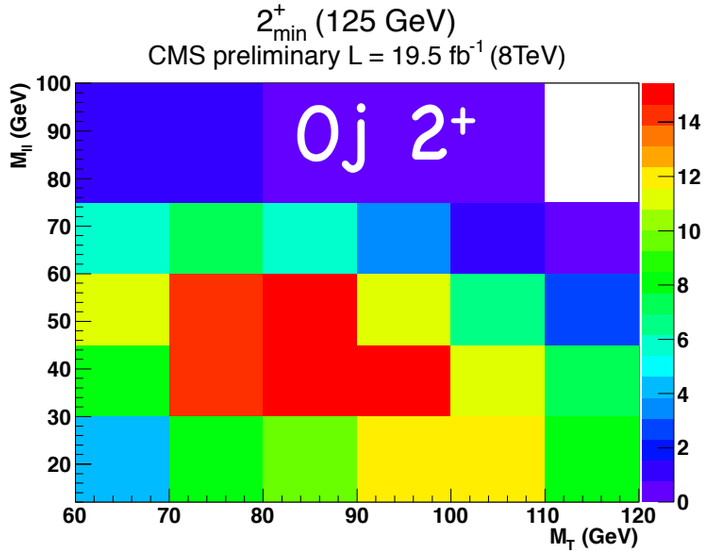
data compatible with 0^+

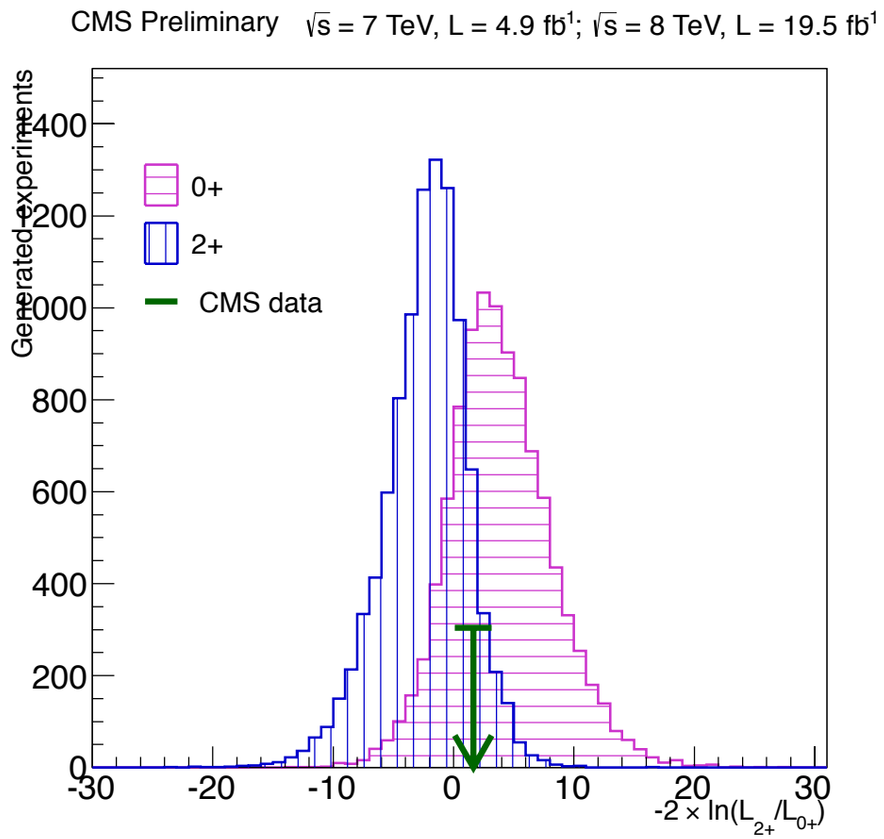
2^+ qq excluded at 99% CL, gg at 95%

Spin @ CMS

- focus on $e\mu+\mu e$ 0 + 1j channels for 2011+2012 datasets
- assumption of 2^+ graviton-like tensor in JHU minimal coupling model with 0% qq mode
- strategy:
  - implement 2^+ signal expectations in the shape-based analysis
  - 2D fit in m_{ll} - m_T







expected likelihood discriminant:

for the 0^+ hypothesis is 1.5σ away from the 2^+ hypothesis

for the 2^+ hypothesis is 1.8σ away from the 0^+ hypothesis

observed likelihood discriminant:

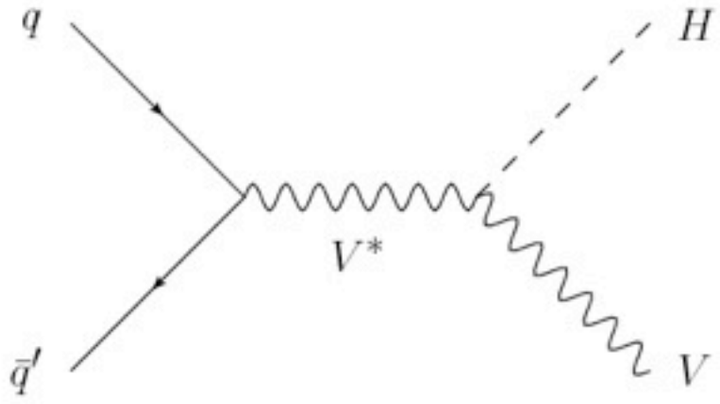
for the 0^+ hypothesis is 1.5σ away from the 2^+ hypothesis

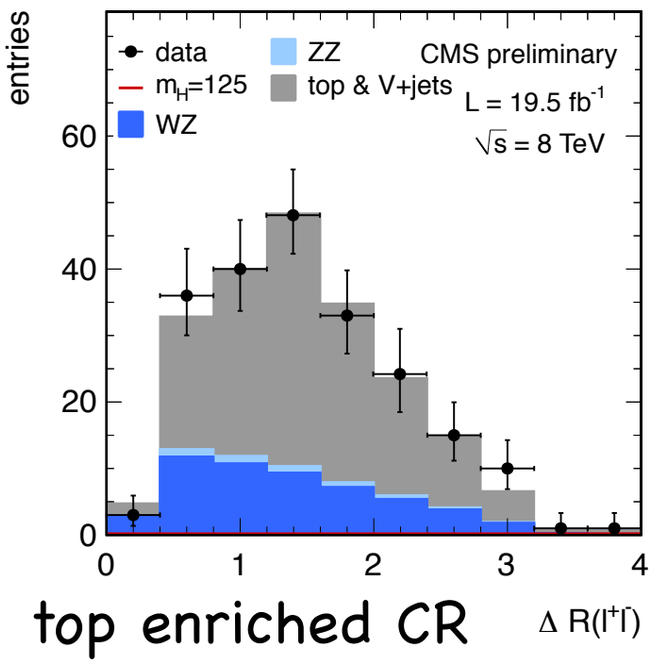
for the 2^+ hypothesis is 1.8σ away from the 0^+ hypothesis

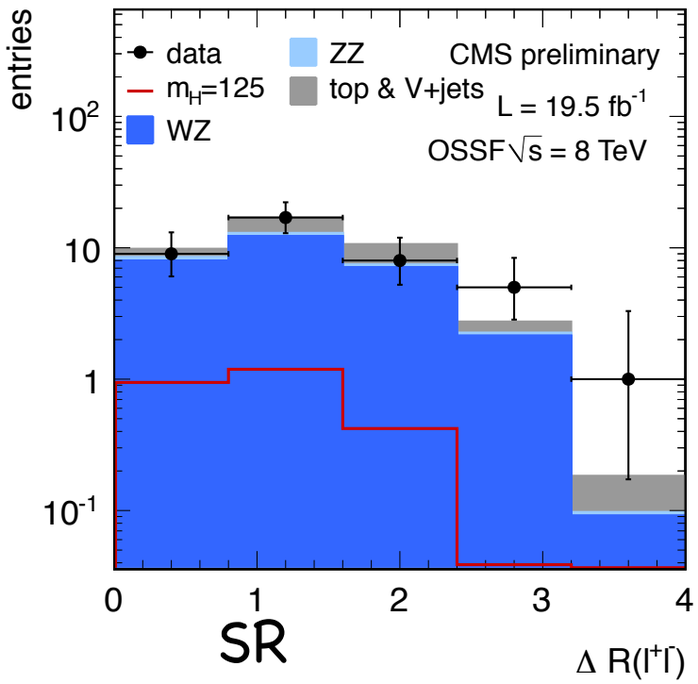
data slightly favor the SM Higgs hypothesis of $J^P = 0^+$ over 2^+ and minimal couplings to the W^+W^- pair

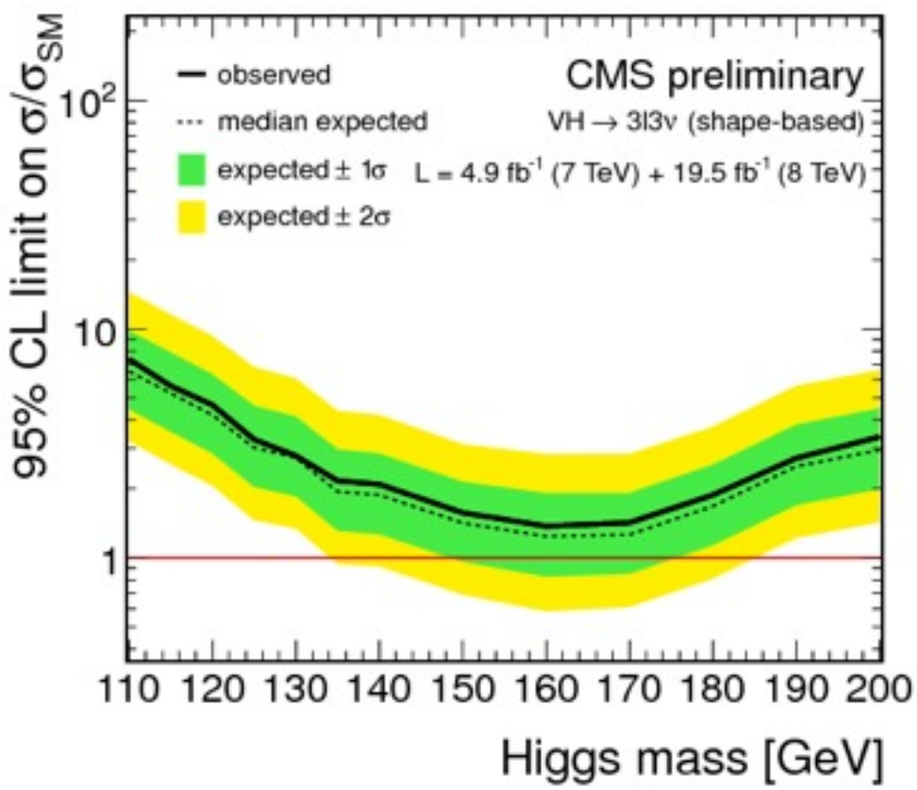
WH->3l3ν @ CMS

- associated production
- backgrounds: WZ->3lν, ZZ->4l, tribosons, Z + γ, prompt leptons
- analysis split into categories based on lepton charge and flavour
- shape-based analysis, discriminant = $\Delta R_{l^+l^-}$





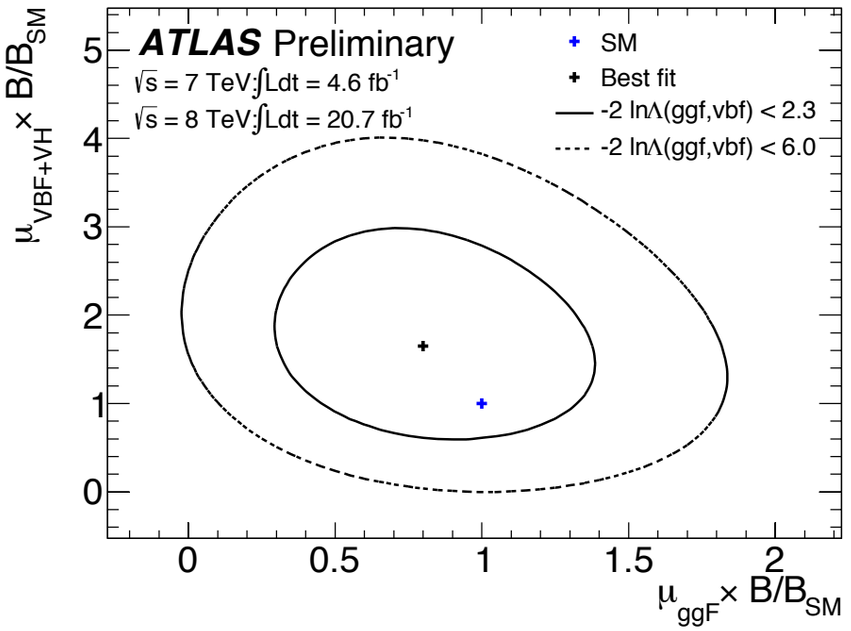


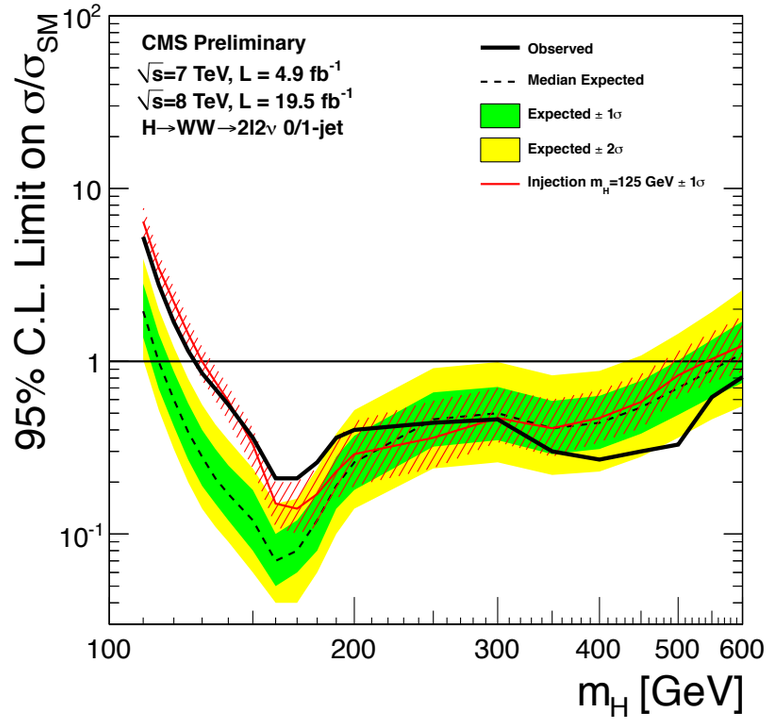


observed (expected) limit 3.3 (3.0) x σ_{SM} for m_H = 125 GeV @ 95% CL

Summary

- H->WW->lνlν channel analyzed by both ATLAS and CMS on full ~25 fb^{-1} LHC Run1 dataset
  - ATLAS: 0+1j ggF and 2j VBF cut based for m_H = 125 GeV
    - $\mu_{ggF(0+1j+2j)}$ = 1.01±0.31
    - μ_{ggF} = 0.82±0.36, μ_{VBF} = 1.66 ± 0.79
  - CMS: 0+1j ggF for m_H = 125 GeV
    - μ_{ggF} = 0.71±0.37 cut based
    - μ_{ggF} = 0.76±0.21 shape-based
- WH->lνlνlν by CMS for m_H = 125 GeV:
  - limit expected 3.0 and observed 3.3 x σ_{SM}
  - ATLAS ICHEP result: no signal observed for 110 GeV < m_H < 300 GeV with best limit @ m_H = 165 GeV - 2.7 (3.2) x σ_{SM} observed (expected) limit
- Spin:
  - ATLAS: BDT 4 variables: data are compatible with 0^+, 2^+ excluded with 99% qq and 95% gg
  - CMS: 2D m_T-m_{ll} shape fit: data slightly prefer the 0^+ hypothesis
- **ATLAS and CMS measurements are consistent with each other and with SM expectations**





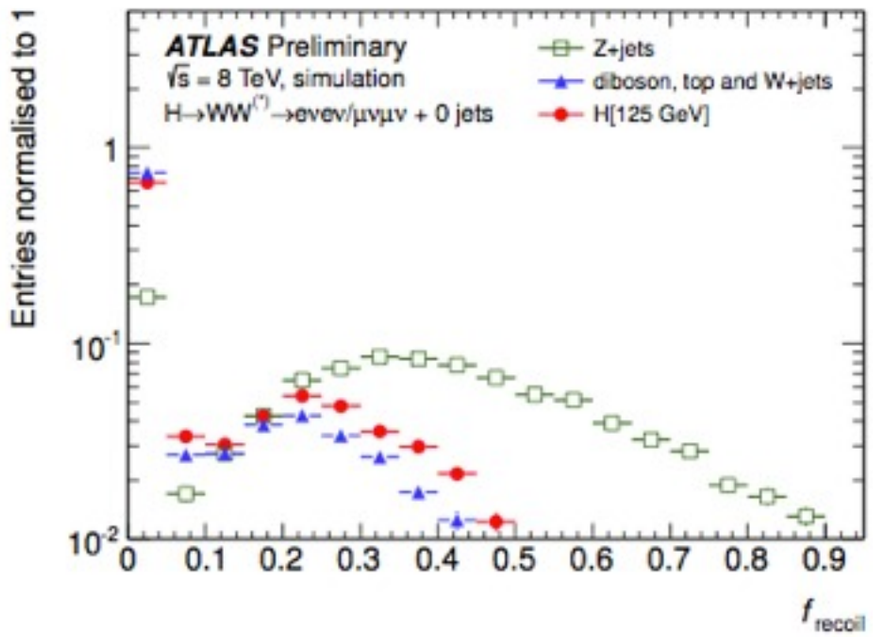
backup

all CMS cuts

- exactly 2 well isolated (MVA) opposite charge leptons
- $p_{T,l1}$ > 20 GeV, p_{Tl2} > 10 GeV, $|\eta_{e(\mu)}|$ < 2.5 (2.4), p_{Tl2} > 15 GeV for SF 2011
- particle flow
- prim vertex - highest Σp_T^2 over tracks
- jets: anti-k_T ΔR = 0.5, FastJet, PU correction (MVA)
  - discriminant: jet shapes, rel multilicity of charged and neutral components, fraction of pT carried by the hardest component
  - E_T > 30 GeV, |eta| < 4.7
- projected MET
  - projection of MET to the nearest lepton, if |phiMET - phiLep| < pi/2, else MET directly
  - MET (proj) > 20 GeV
- top bkg:
  - top tagging on soft muons and soft bJet Tagging (E_T > 15 GeV)
- p_{Tll} > 30 (45) GeV for shape (cut-based) analysis
- m_{ll} > 12 GeV, 20 GeV for SF 2011
- additional DY-suppressing cuts:
  - $|m_{ll}-m_Z|$ > 30 GeV
  - 2011:
    - METproj > (37 + Nvtx/2) GeV
    - reject event if di-leptons and hardest jet are back to back
  - 2012: MVA based on MET, kinematic and topological variables

all ATLAS cuts

- exactly 2 well isolated (MVA) opposite charge leptons
- $p_{T,l1}$ > 25 GeV, p_{Tl2} > 15 GeV, $|\eta_{e(\mu)}|$ < 2.47 (2.5)
- mll > 12 (SF) or 10 GeV (DF)
- prim vertex - highest Σp_T^2 over tracks
- jets: anti-k_T ΔR = 0.4, FastJet
  - PU suppression in the JES Calibration and dedicated application of Jet Vertex Fraction
  - p_T > 25 (30) GeV, |eta| < 2.4 (2.4 < |eta| < 4.5),
- MET
  - projection of MET to the nearest lepton/jet, if in same hemisphere, else MET directly
  - MET using tracking information
  - METs > 20-45 GeV
- top bkg:
  - top tagging on soft muons and bJet Tagging
- p_{Tll} > 30 GeV
- Z->ττ veto
- p_{Ttot} < 45 GeV (vectorial sum of all p_T in the event)
- soft hadronic recoil to reduce DY



Results

ATLAS 7 TeV eμ+μe+ee+μμ

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

ATLAS 8 TeV eμ+μe+ee+μμ

Njet	Signal	Total Bkg	Data
0	97±20	739±39	831
1	40±13	261±28	309
≥2	10.6±1.4	36±4	55

restricted m_T range (signal sensitive):

0+1j: $0.75*m_H < m_T < m_H$

≥2j: $m_T < 1.2*m_H$

CMS 7 TeV eμ+μe and ee+μμ

Selection	Signal	Total Bkg	Data
0j eμ	20.3±4.3	99.1±9.0	115
0j ee + μμ	10.1±2.2	64.1±6.7	66
1j eμ	7.9±2.3	45.0±4.3	53
1j ee+μμ	3.0±0.9	28.2±4.5	31

CMS 8 TeV eμ+μe and ee+μμ

Selection	Signal	Total Bkg	Data
0j eμ	90±19	429±34	505
0j ee + μμ	56±12	360±38	421
1j eμ	42±12	209±14	228
1j ee+μμ	18.0±5.2	111.3±8.6	140

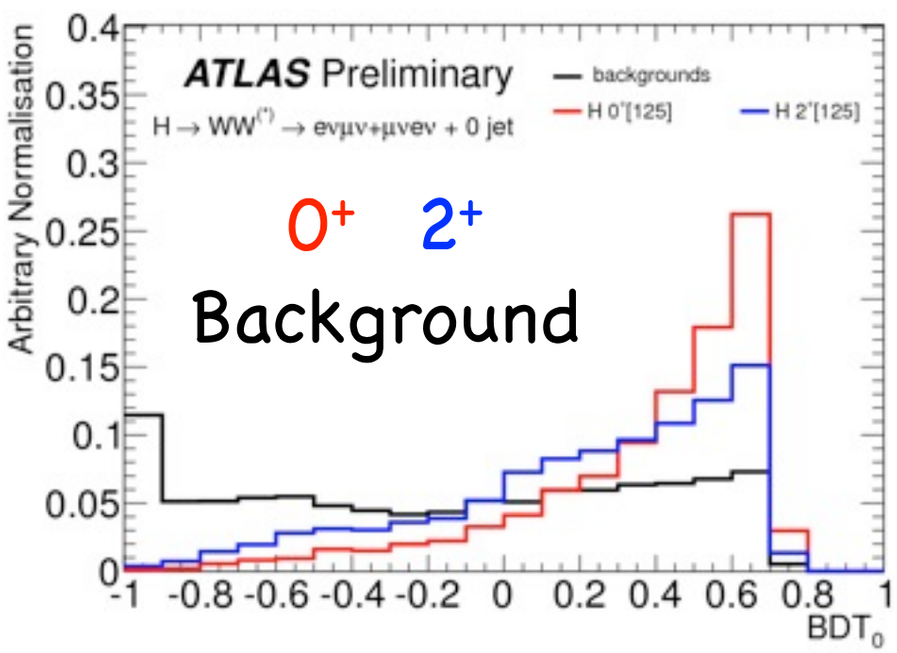
after whole selection (no m_{ll} or m_T cuts for 2D shape analysis)

Spin @ ATLAS

- possibility to distinguish between 0^+ and 2^+
- focus on $e\mu$+μe 0j channel for 2012 dataset only
- strategy: relax cuts on E_T^{miss}, p_{Tll}, m_{ll} and $\Delta\Phi_{ll}$ to allow acceptance for 2^+
- general assumption is 2^+ graviton-like tensor (JHU minimal model)
  - 5 production modes: 0%-25%-50%-75%-100% qq
- dedicated BDT MVA analysis:
  - train MC on 4 variables: m_T, $\Delta\Phi_{ll}$, m_{ll}, p_{Tll}
  - 2 separate BDT trainings for 0^+ and 2^+
  - results use a 2D fit to BDT_0 and BDT_2

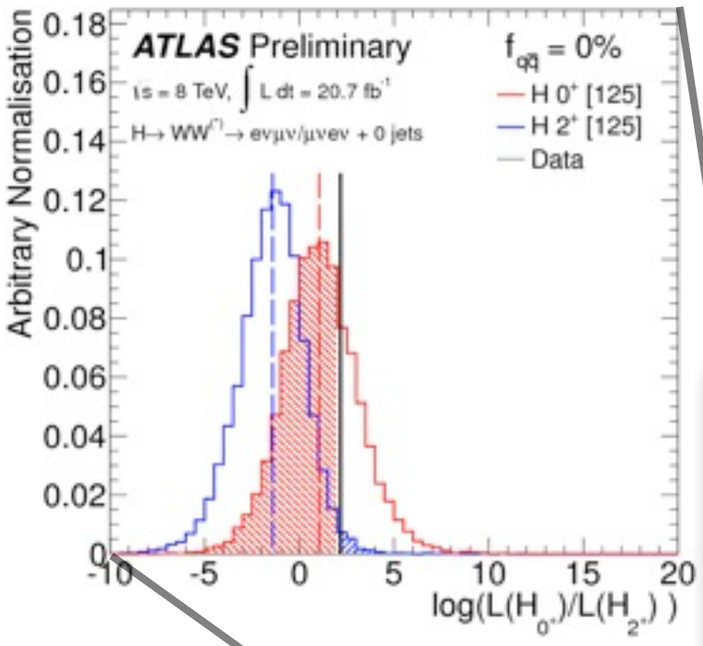
Variable	Spin analysis	Rate analysis [5]
common $e\mu/\mu e$ lepton selection		
$E_{T,rel}^{miss}$	> 20 GeV	> 25 GeV
N_{jets}	0 jets	0, 1, ≥ 2 jet selections
$p_T^{\ell\ell}$	> 20 GeV	> 30 GeV
$m_{\ell\ell}$	< 80 GeV	< 50 GeV
$\Delta\phi_{\ell\ell}$	< 2.8	< 1.8

Training for 0+



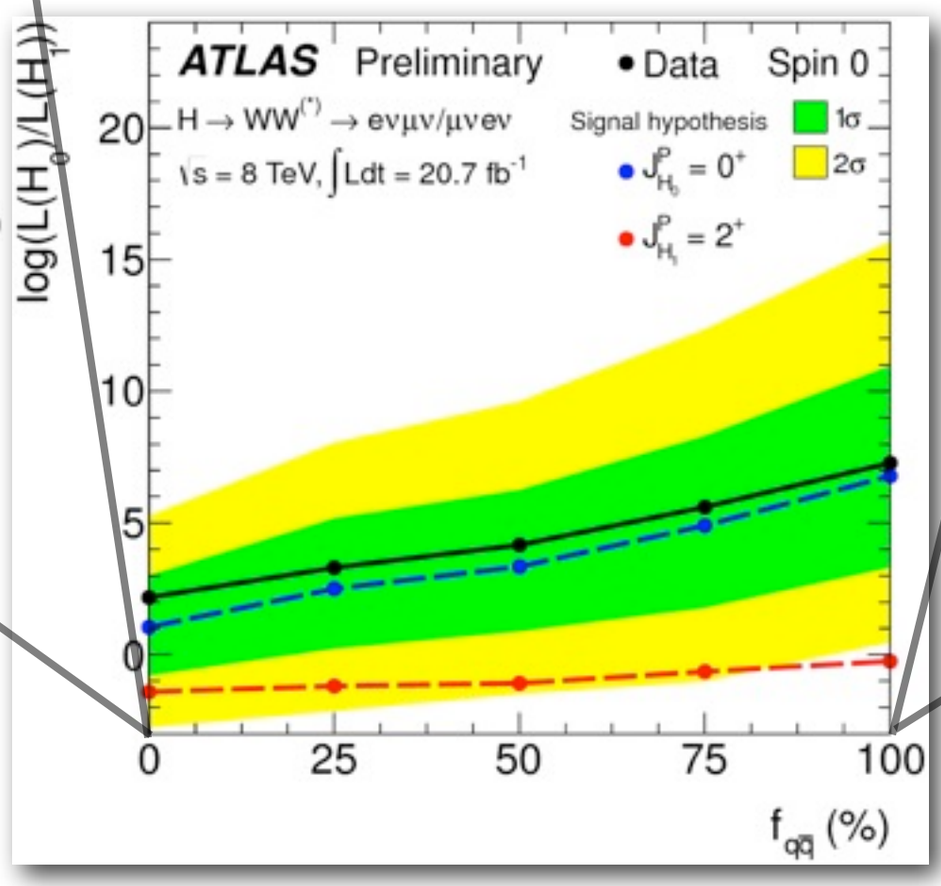
Spin @ ATLAS

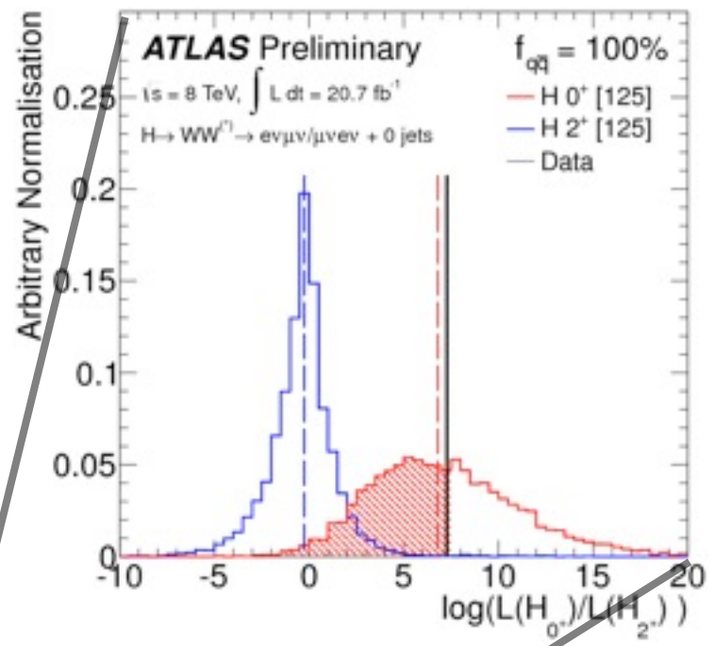
- general assumption is 2^+ graviton-like tensor (JHU minimal model)
  - 5 production modes: 0%-25%-50%-75%-100% qq



test statistics

$$q = \log \frac{\mathcal{L}(H_{0^+})}{\mathcal{L}(H_{2^+_m})} = \log \frac{\mathcal{L}(\epsilon = 1, \hat{\hat{\mu}}_{\epsilon=1}, \hat{\hat{\theta}}_{\epsilon=1})}{\mathcal{L}(\epsilon = 0, \hat{\hat{\mu}}_{\epsilon=0}, \hat{\hat{\theta}}_{\epsilon=0})}$$

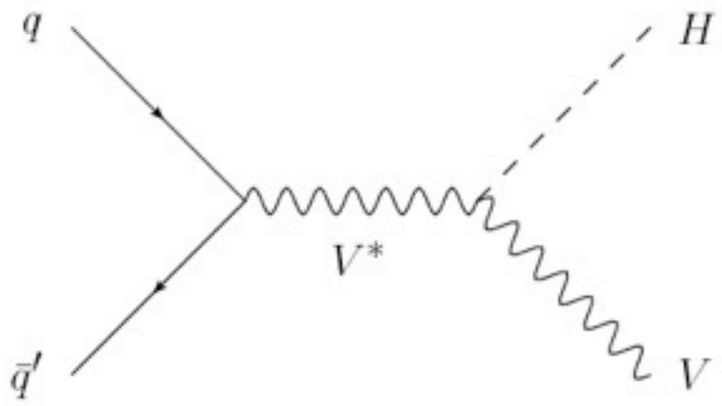


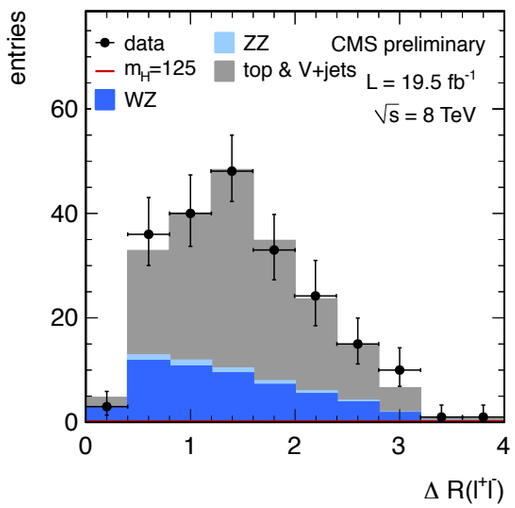


data compatible with 0^+, 2^+ qq excluded at 99% CL, gg at 95%

WH->3l3ν @ CMS

- associated production
- backgrounds: WZ->3lν, ZZ->4l, tribosons, Z + γ, prompt leptons
- analysis split into categories based on lepton charge and flavour
- shape-based analysis, discriminant = $\Delta R_{l^+l^-}$





top enriched CR

SR cutflow

	8 TeV SSSF channel					
stage	WH(→ ττ) (125)	WH(→ WW) (125)	data	all bkg.	WZ	fakes
3-lepton preselection	0.73 ± 0.08	1.65 ± 0.21	61	84.68 ± 3.03	7.92 ± 0.30	67.70 ± 2.97
min-MET > 30 GeV	0.41 ± 0.06	1.22 ± 0.18	43	60.93 ± 2.57	5.18 ± 0.24	49.06 ± 2.53
Z removal	0.41 ± 0.06	1.22 ± 0.18	43	60.93 ± 2.57	5.18 ± 0.24	49.06 ± 2.53
top veto	0.29 ± 0.05	1.02 ± 0.17	7	10.52 ± 0.99	2.86 ± 0.18	6.68 ± 0.97
$\Delta R_{\ell^+\ell^-}$ & $m_{\ell\ell}$	0.21 ± 0.04	0.92 ± 0.16	6	6.95 ± 0.85	1.72 ± 0.14	4.64 ± 0.84
	8 TeV OSSF channel					
stage	WH(→ ττ) (125)	WH(→ WW) (125)	data	all bkg.	WZ	fakes
3-lepton preselection	1.96 ± 0.13	6.11 ± 0.41	4332	4232.92 ± 20.68	2053.43 ± 4.85	1368.06 ± 13.20
min-MET > 40 GeV	0.92 ± 0.09	3.49 ± 0.31	1136	1148.15 ± 6.10	904.73 ± 3.21	152.07 ± 4.92
Z removal	0.56 ± 0.07	2.70 ± 0.27	153	156.72 ± 3.48	59.45 ± 0.82	81.02 ± 3.29
top veto	0.36 ± 0.05	1.95 ± 0.23	45	48.00 ± 1.35	35.05 ± 0.63	9.77 ± 1.19
$\Delta R_{\ell^+\ell^-}$ & $m_{\ell\ell}$	0.27 ± 0.05	1.97 ± 0.22	33	33.45 ± 1.16	24.12 ± 0.52	7.29 ± 1.03

observed (expected) limit 3.3 (3.0) x σ_{SM} for m_H = 125 GeV @ 95% CL