

$H \rightarrow WW^* \rightarrow l\nu l\nu$ in ATLAS+CMS



The only French group in ATLAS working in the channel. No CMS French group currently active in the channel

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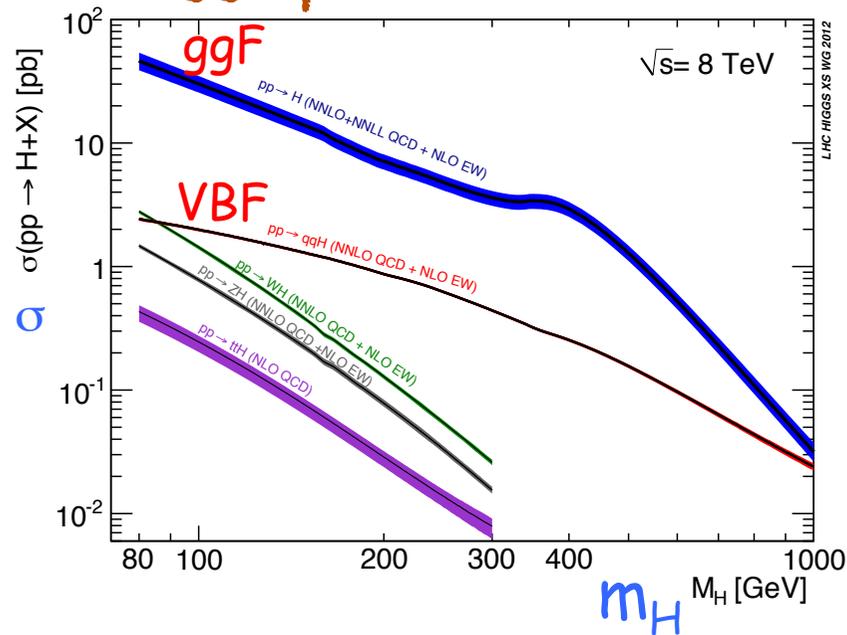
Comprendre le monde,
construire l'avenir®

Outline

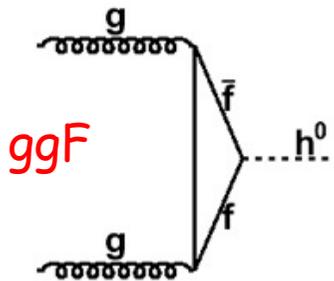
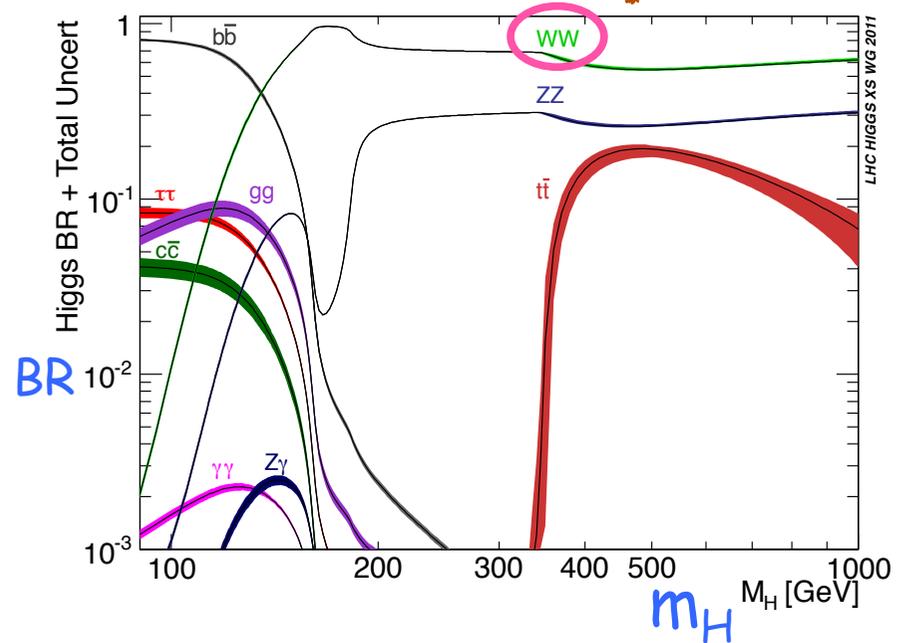
- Introduction
- Challenges
- Analysis (strategy)
- Results

Introduction

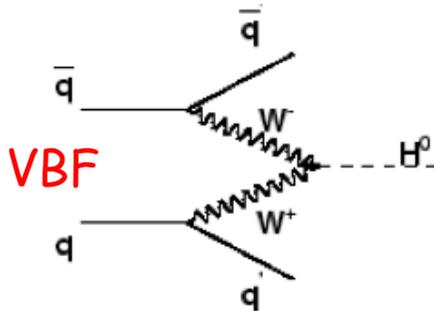
Higgs production @8TeV



Higgs decays



@125GeV,
 $\sigma_{ggF}/\sigma_{VBF} = 12.4$

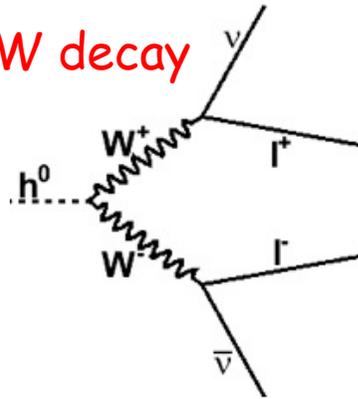


Over a large mass range,
 $WW^{(*)}$ has the largest BR and
 search sensitivity

This is why early exclusions at
 Tevatron & LHC were mostly
 from WW

Introduction (continued)

Leptonic WW decay



→ Simple experimental signature:

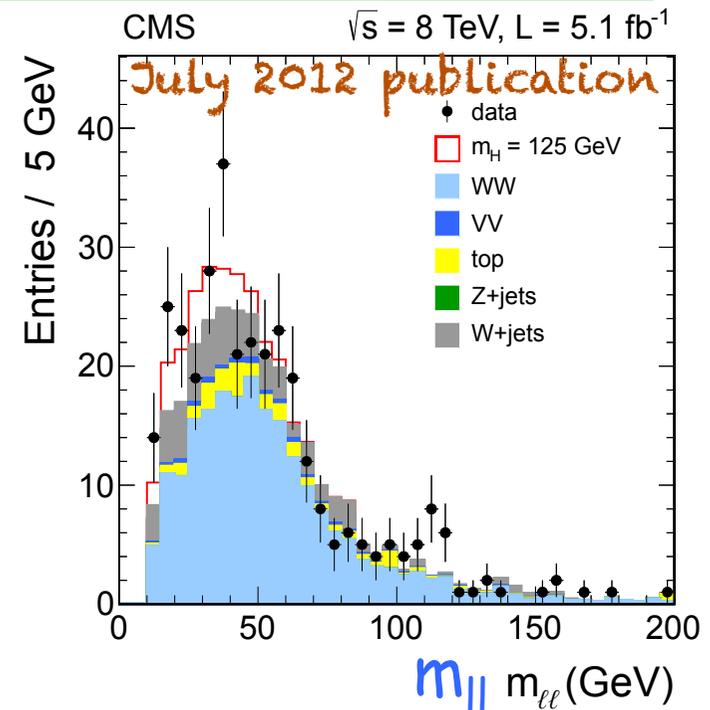
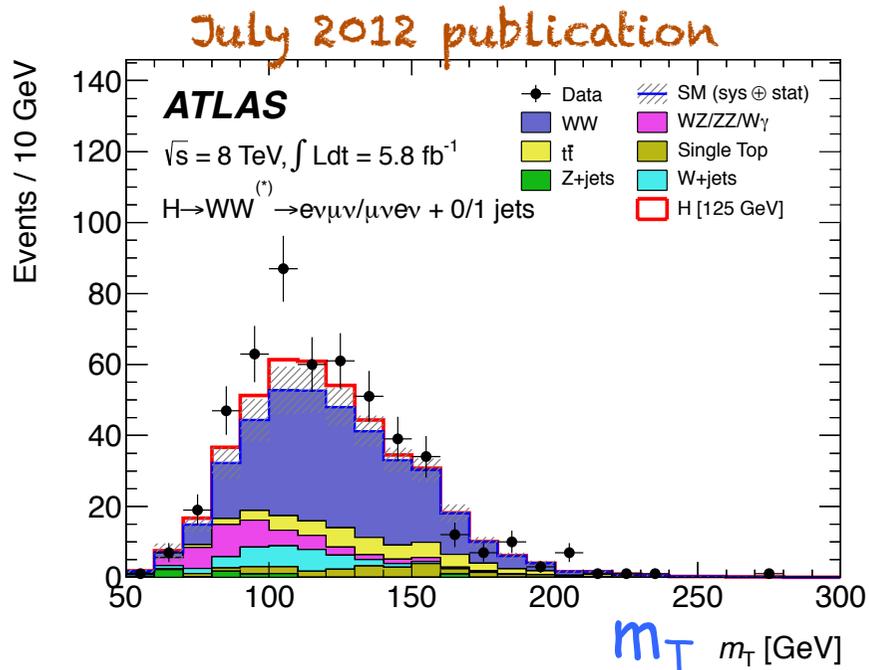
$l^+l^- + E_T^{\text{miss}}$ (0/1 jet, **ggF**)

$l^+l^- + E_T^{\text{miss}} + 2\text{jets}$ (**VBF**)

→ Missing neutrinos

→ Dilepton invariant mass (m_{ll}) or transverse mass (m_T) with limited resolution

WW* has been one of the 3 discovery channels ($\gamma\gamma$, ZZ^* , WW^*)

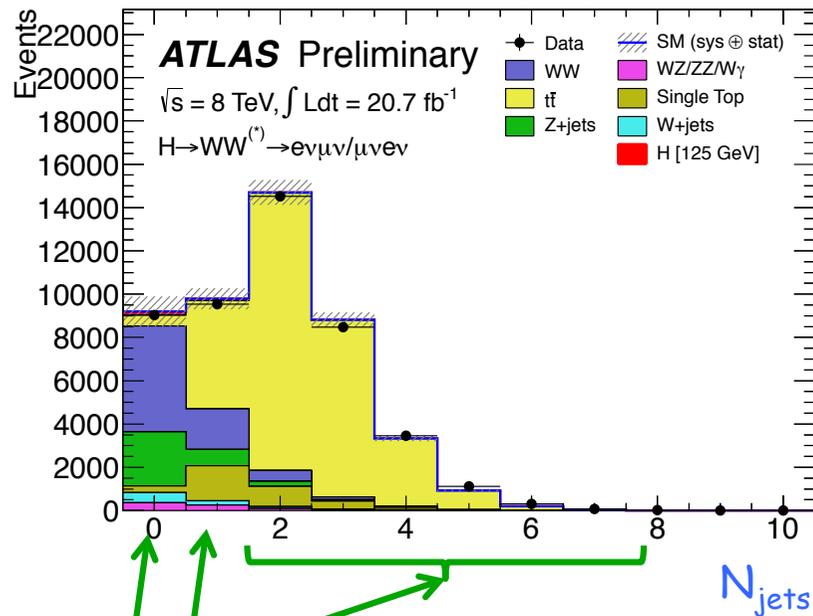


Challenge No. 1

How to suppress and reliably estimate various background contributions which are flavor and jet category dependent?

Different Flavor (DF)

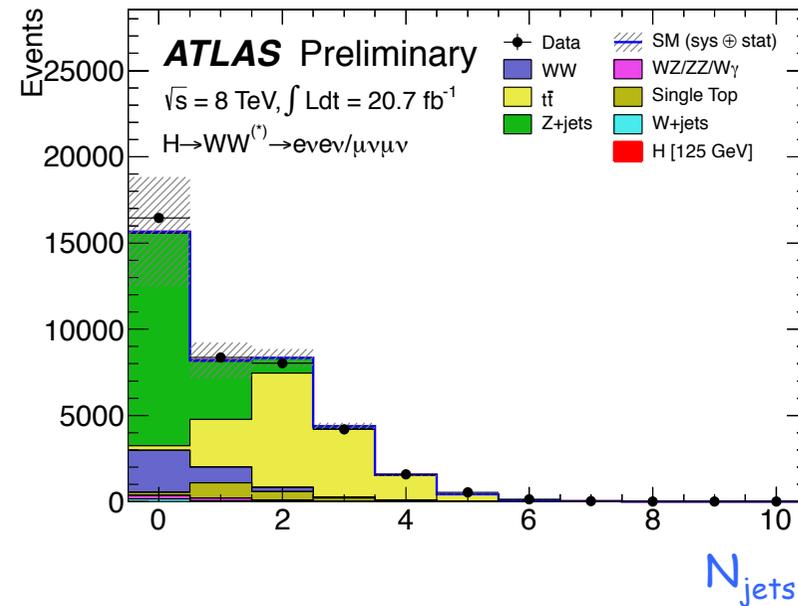
$H \rightarrow WW^* \rightarrow e\nu\mu\nu/\mu\nu e\nu$



0, 1, ≥ 2 jet categories

Same Flavor (SF)

$H \rightarrow WW^* \rightarrow e\nu e\nu/\mu\nu\mu\nu$

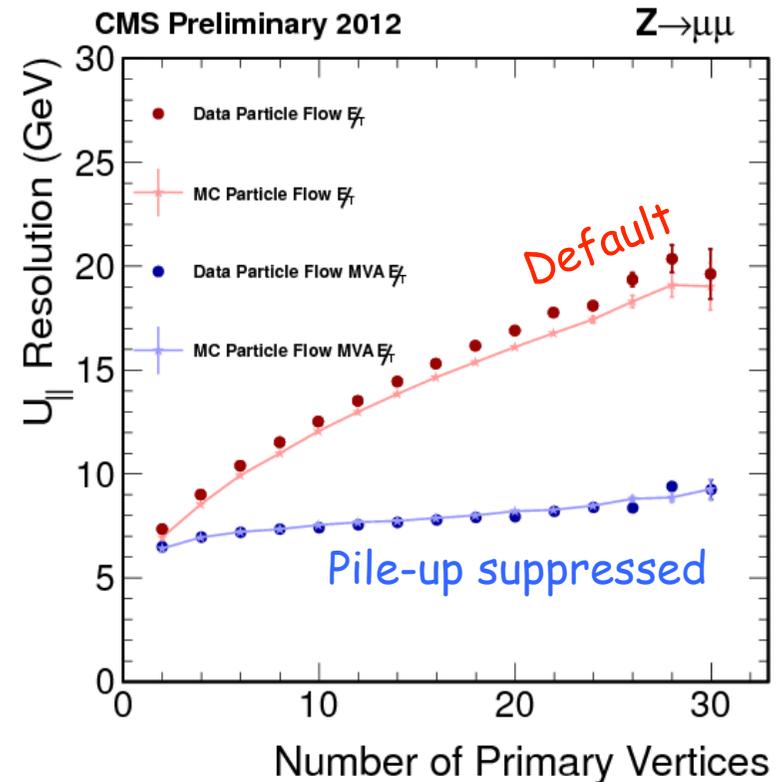
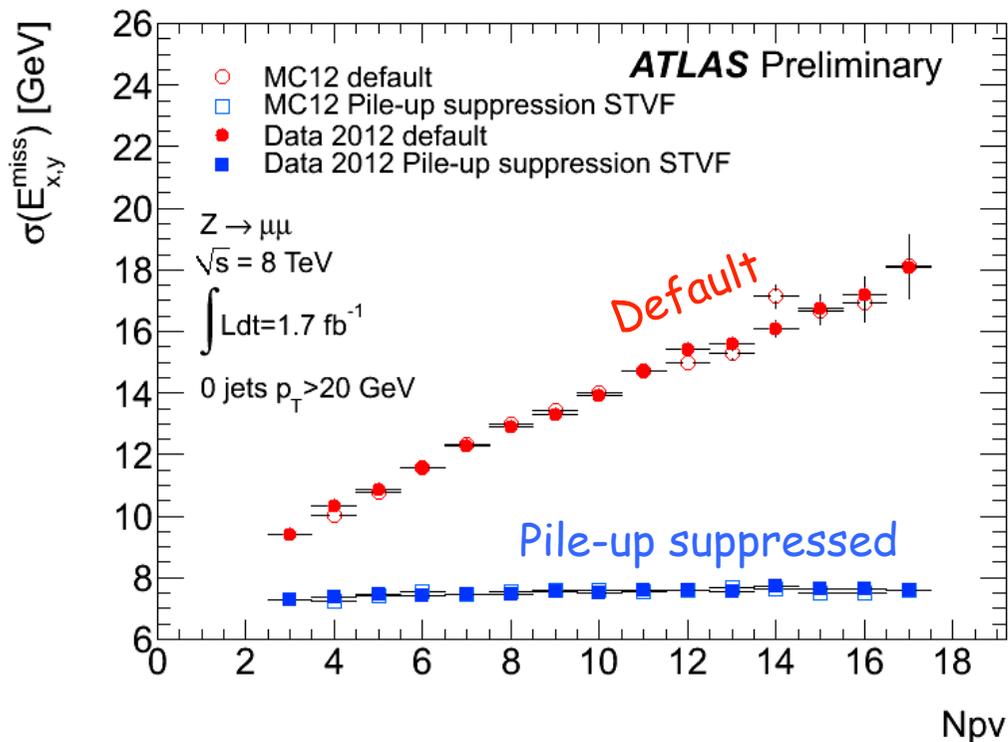


The dominant backgrounds:
 Top
 Drell-Yan Z+jets (mainly for SF)
 Nonresonant WW (irreducible)

Challenge No. 2

Default missing E_T (MET) resolution degrades as pile-up increases
 → Background contribution (e.g. Drell-Yan) increases

How to reduce the pile-up dependence?



A MET relative to lepton (CMS) and/or jet (ATLAS) is used if $\Delta\phi(\text{MET}, l/j) < \pi/2$, and the MET can be calo/PF or track based, the latter has much reduced pile-up dependence

Comparison of Latest Moriond Results

	ATLAS	CMS
Mass Range (GeV)	115-200	110-600
DF and SF	Yes	Yes
0/1 jet	Yes	Yes
VBF (≥ 2 jets)	Yes	No update
ggF/VBF μ	Yes	No
8 TeV cross section	Yes	No
Spin ($0^+/2^+$)	Both gg/qq	gg only

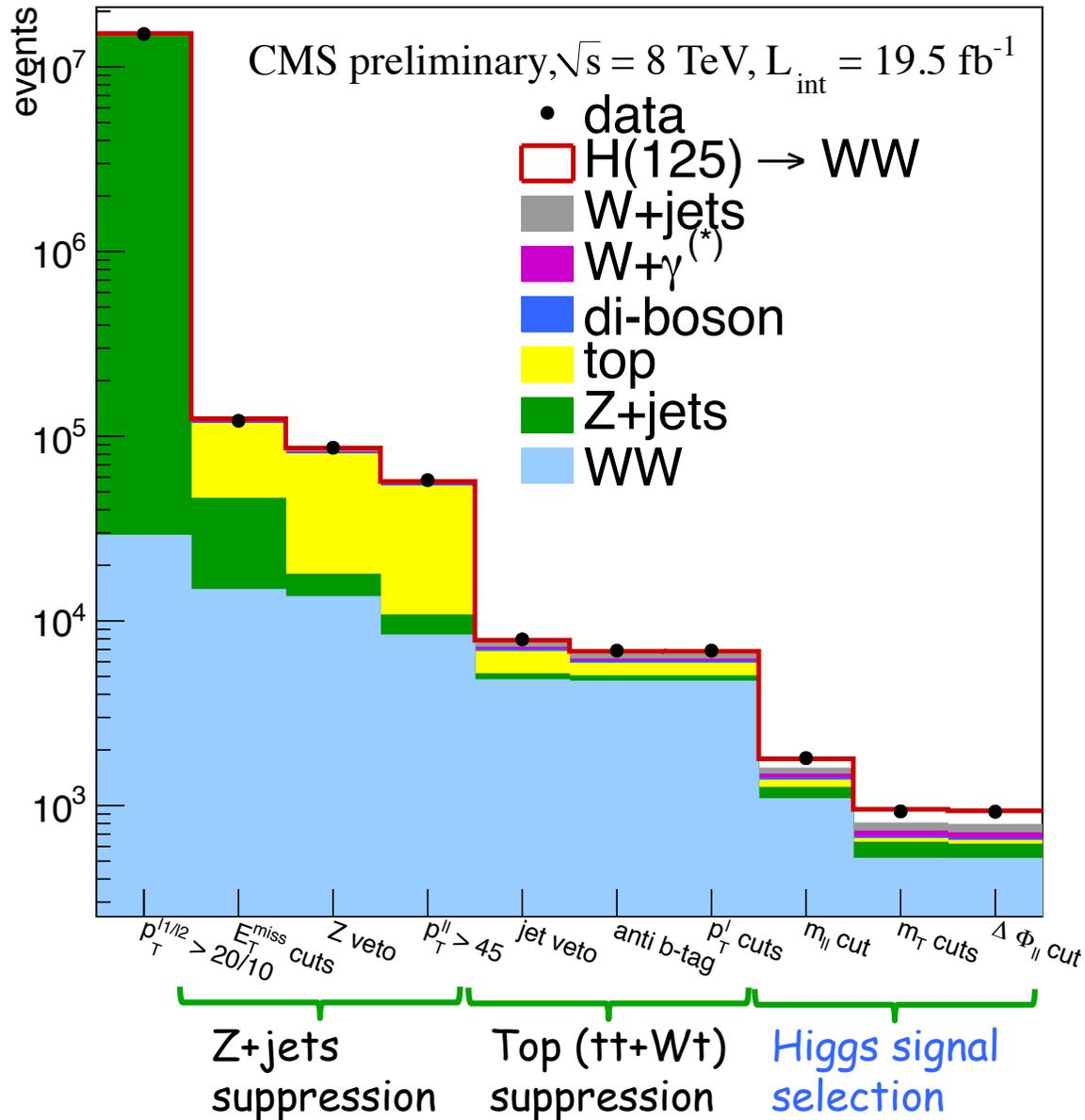
Based mainly on

Two ATLAS CONF notes: ATLAS-CONF-2013-030 (rate and couplings)

ATLAS-CONF-2013-031 (Spin property)

One CMS CONF note: CMS-HIG-13-003-PAS

Object and Event Selections



Signal/background drastically improved toward the end of the selection

Similar selections in ATLAS, CMS analyses with some differences in object definition and cut values

e.g. at 125 GeV

$p_T^{1/2} > 23/10 \text{ GeV}$ (CMS)

$> 25/15 \text{ GeV}$ (ATLAS)

In the shape analysis, some of cuts (M_T and/or m_{\parallel}) not applied

Overview of Background Determination

General idea: use data whenever possible

W+jets: fully data driven

WW, top, Z+jets, $W\gamma^*$: use control regions to fix the normalization

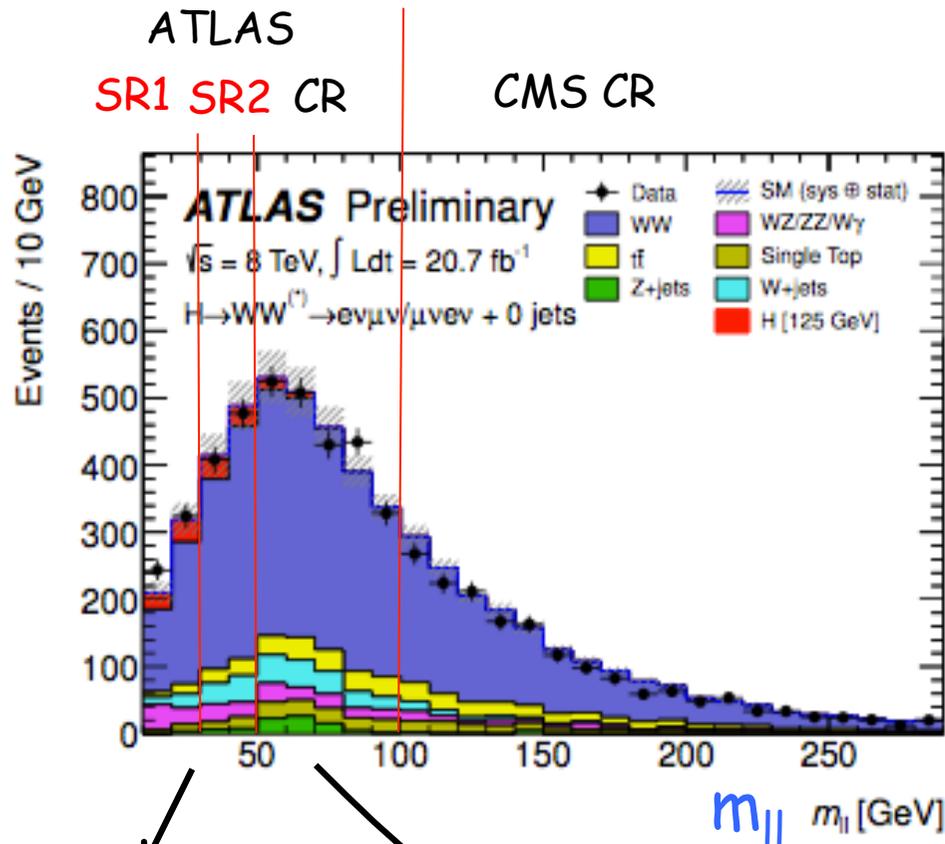
WZ/ZZ: small contribution, MC based

SR: Signal Region (signal largely excluded in **blinded analysis**)

CR: Control Region (with negligible signal contribution)

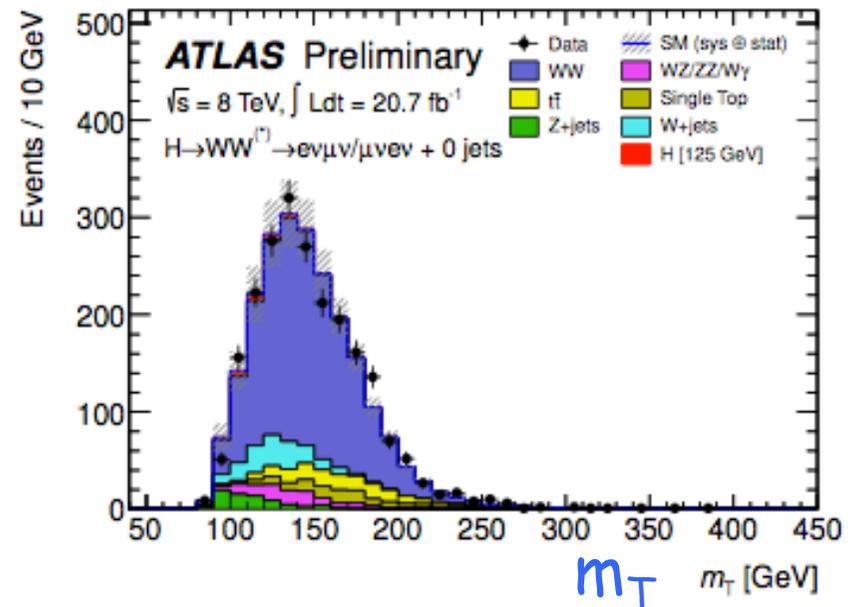
VR: Validation Region to check the normalization

WW Background (CR)



Signal at low $m_{||}$
 or small $\Delta\phi_{||}$
 due to spin
 correlation of
 WW^* from O^+

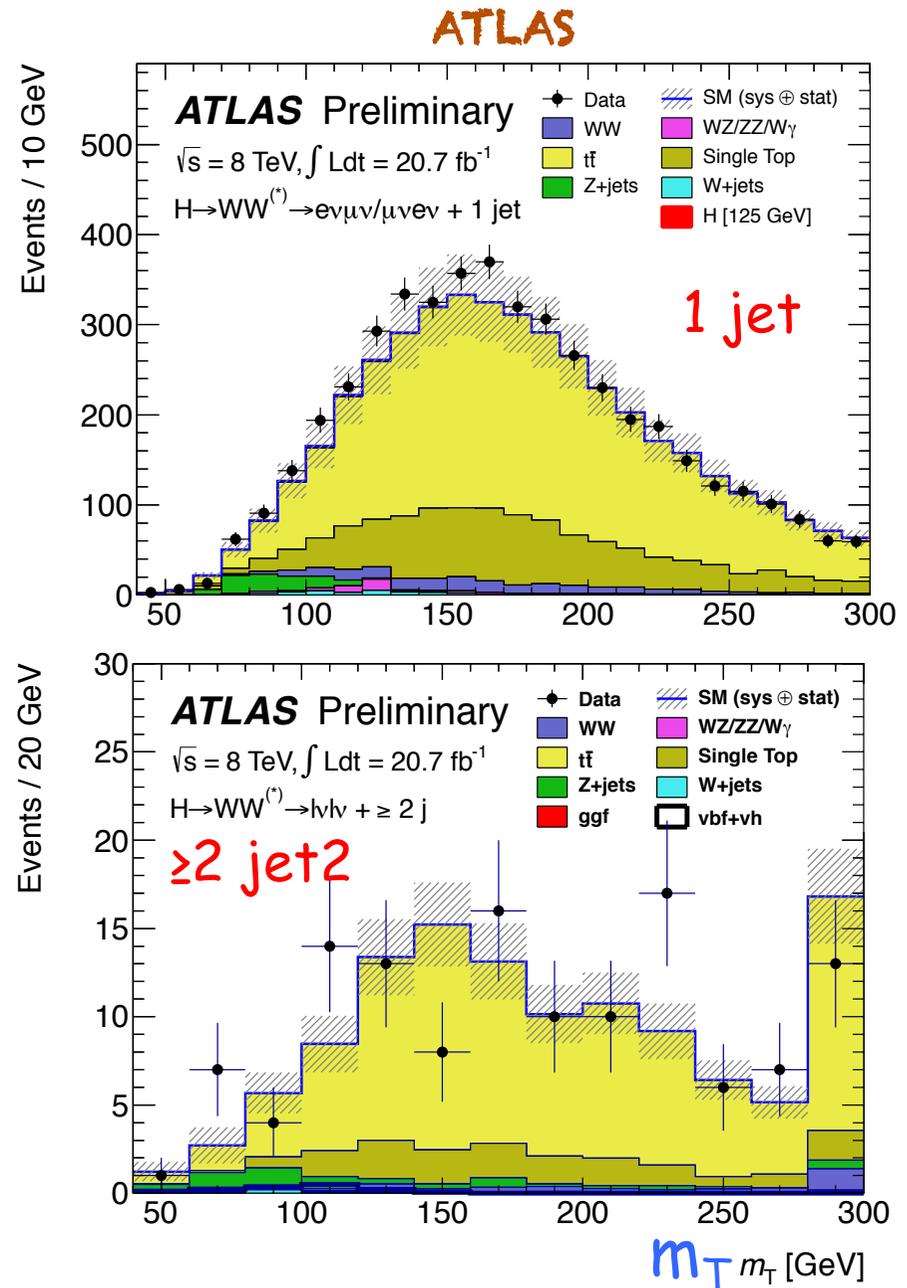
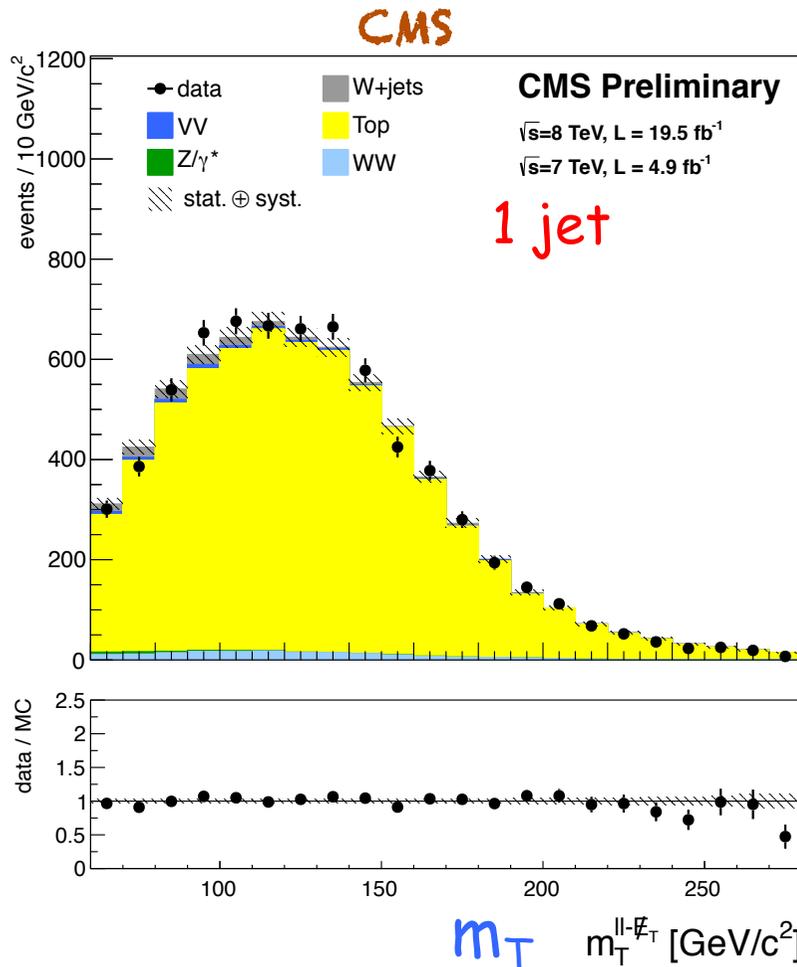
ATLAS m_T distribution
 in WW CR



ATLAS new WW CR (0 jet)
 is closer to SRs to reduce
 extrapolation uncertainty

Top Background (CR)

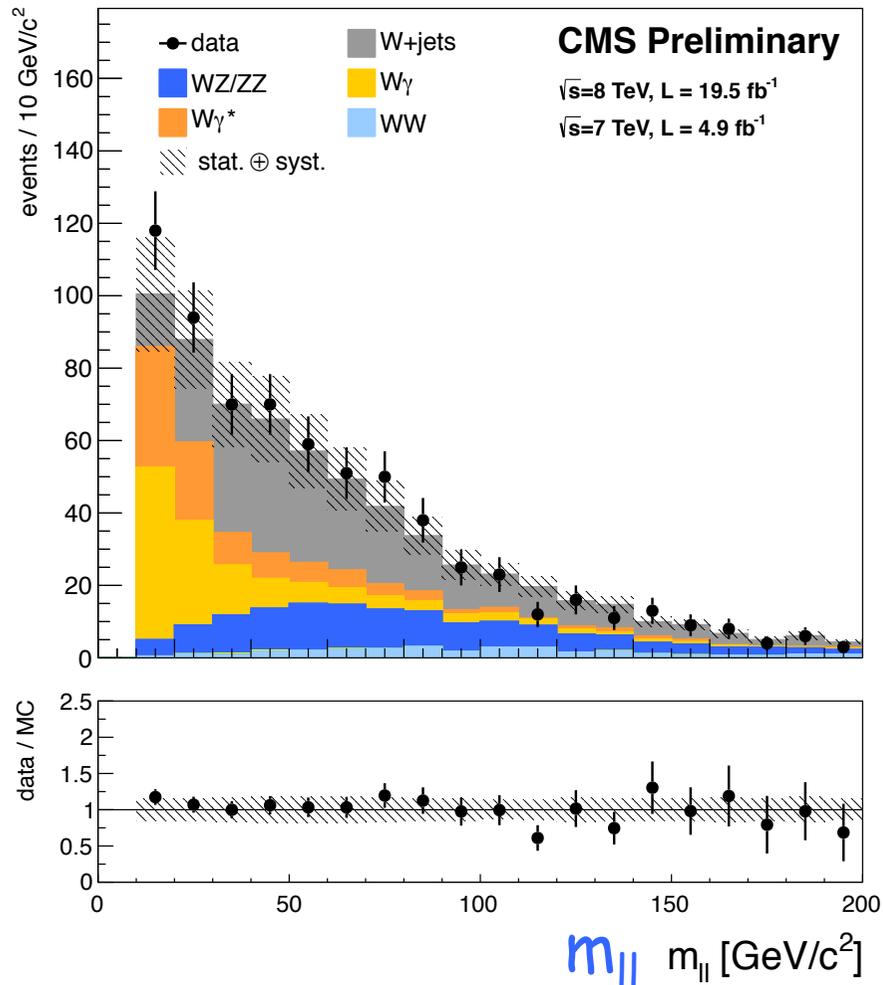
ATLAS, CMS both use b-tagged jets for veto or defining CR though with different sophistications
 Ojet: more involved, cf PRD84 (2011) 096005, see also Yichen Li's poster



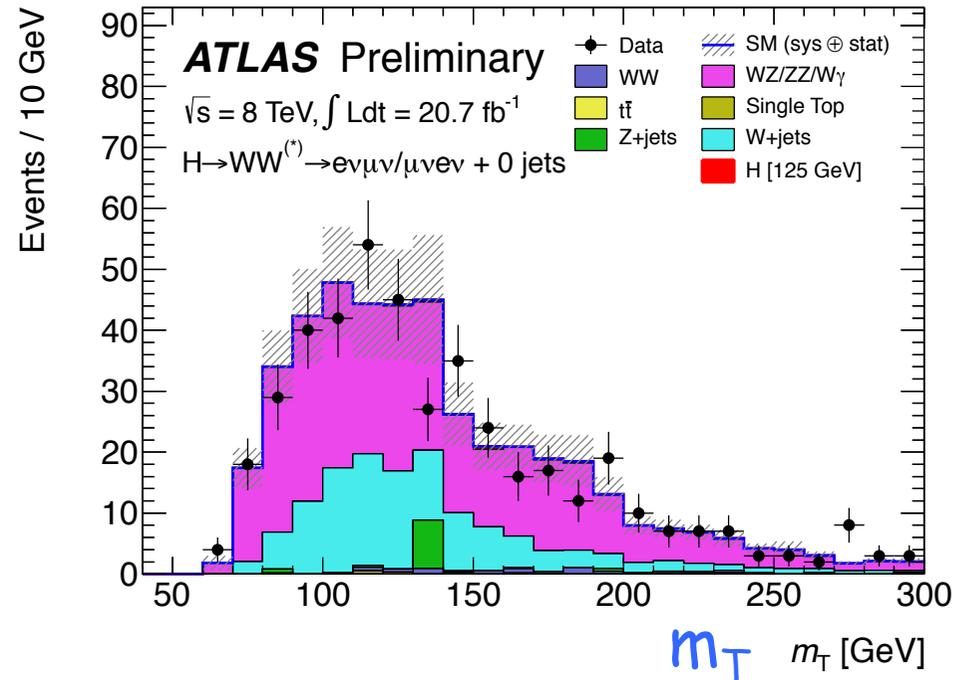
Other Backgrounds (VR)

Use same sign charged lepton sample to validate the W +jets and $WZ/ZZ/W\gamma^{(*)}$

CMS

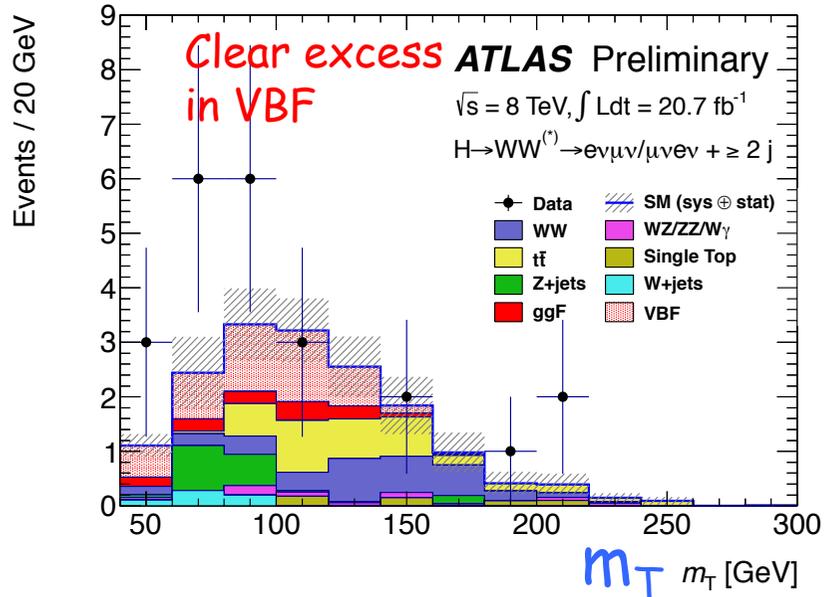
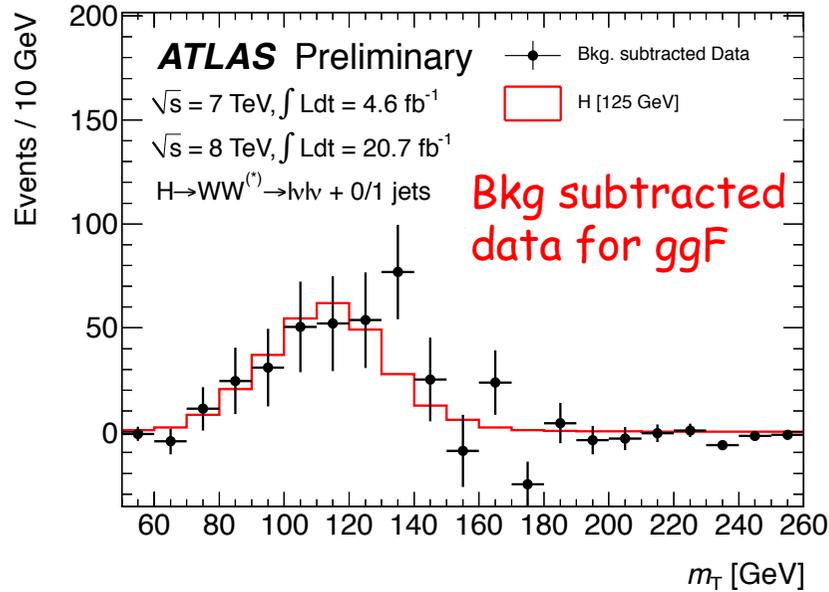


ATLAS

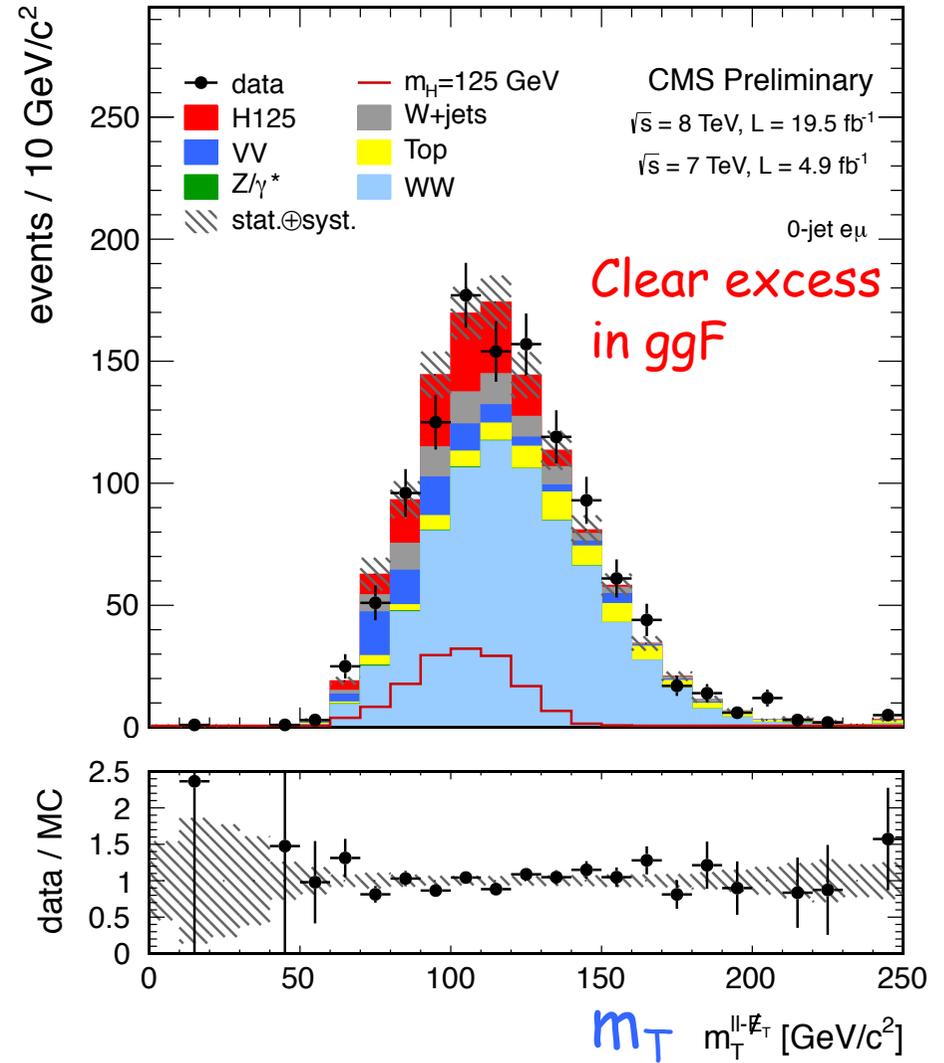


m_T Distributions in Signal Region

ATLAS

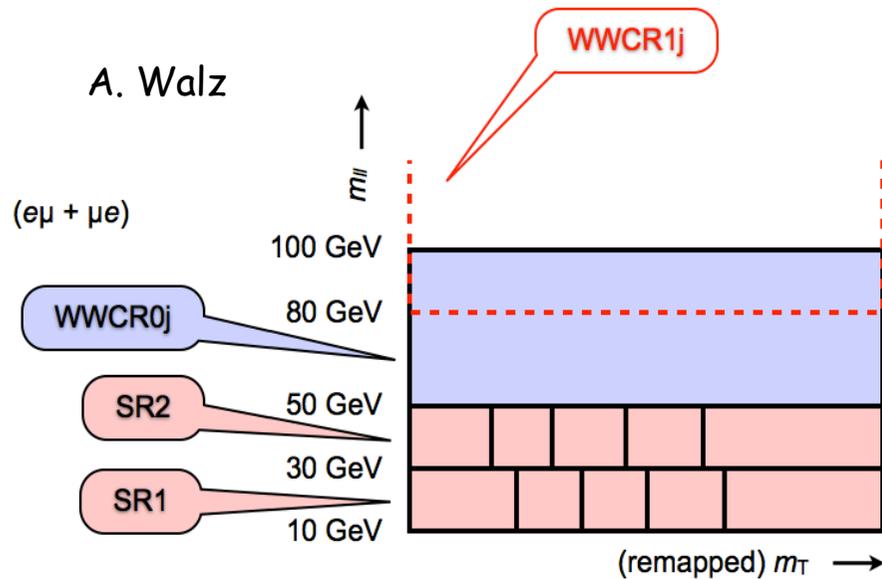


CMS

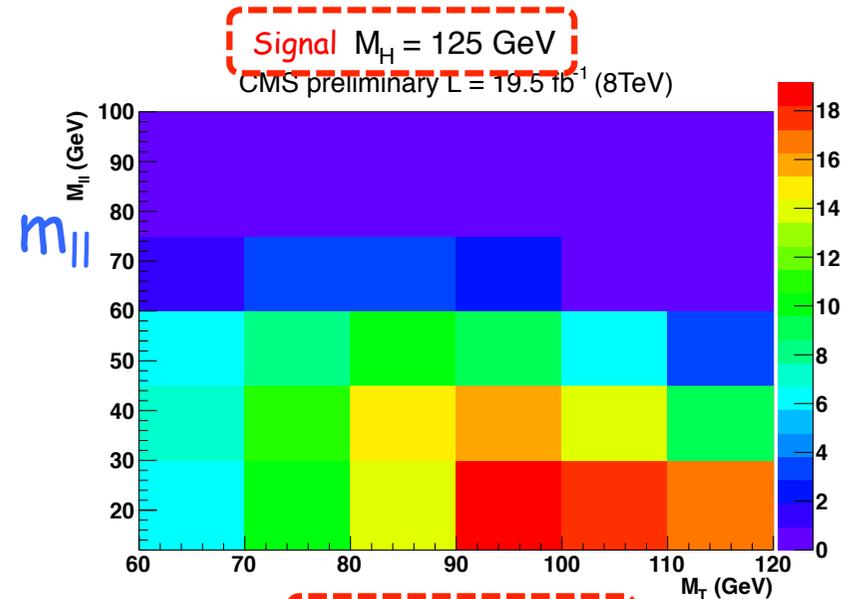


Signal Extraction

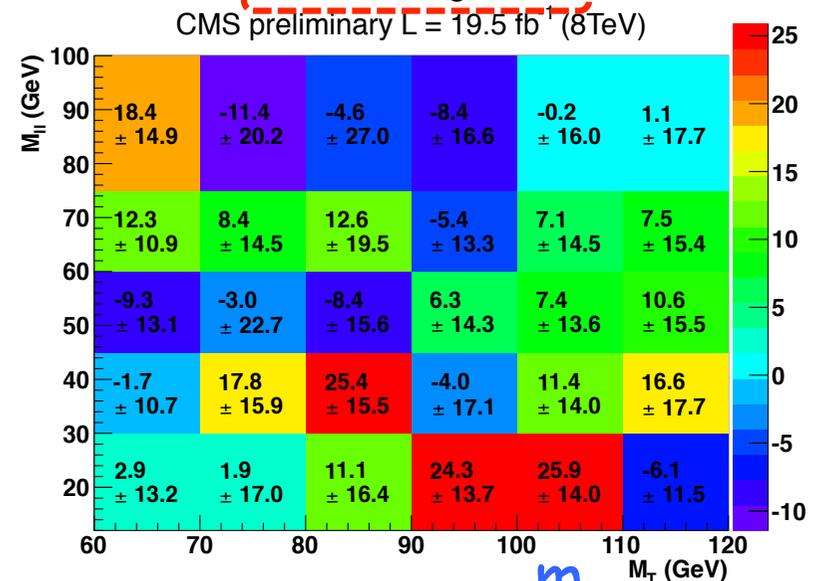
ATLAS: Cuts + m_T shape (for 0/1 jet)



CMS: 2d shape (for DF)



Data - Background



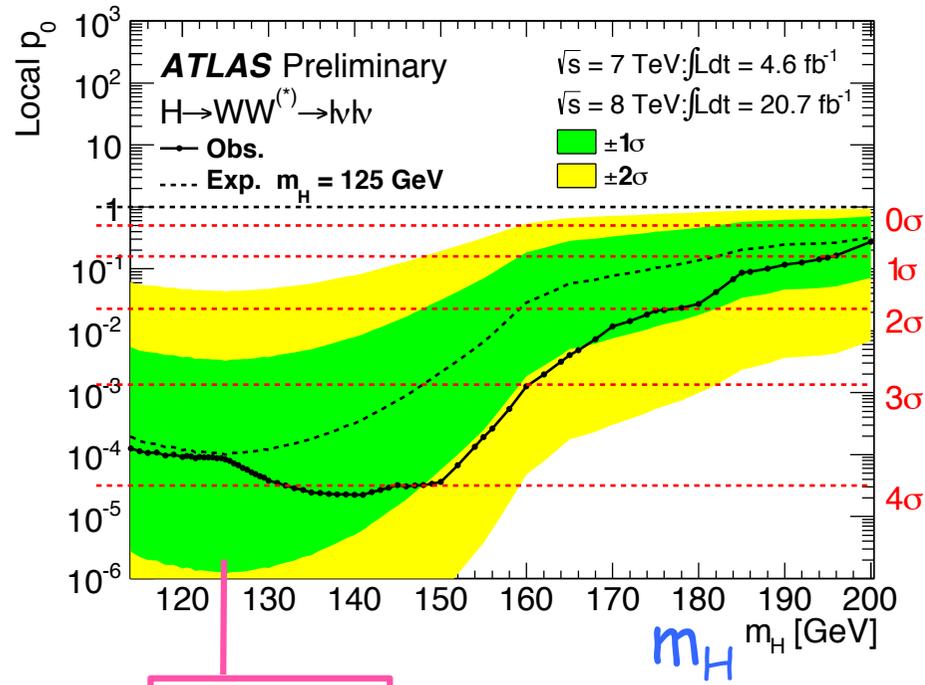
ATLAS sees less gain than CMS

- from 1d to 2d
- from cut-based to shape-based

→ Difference being understood

Signal Significance

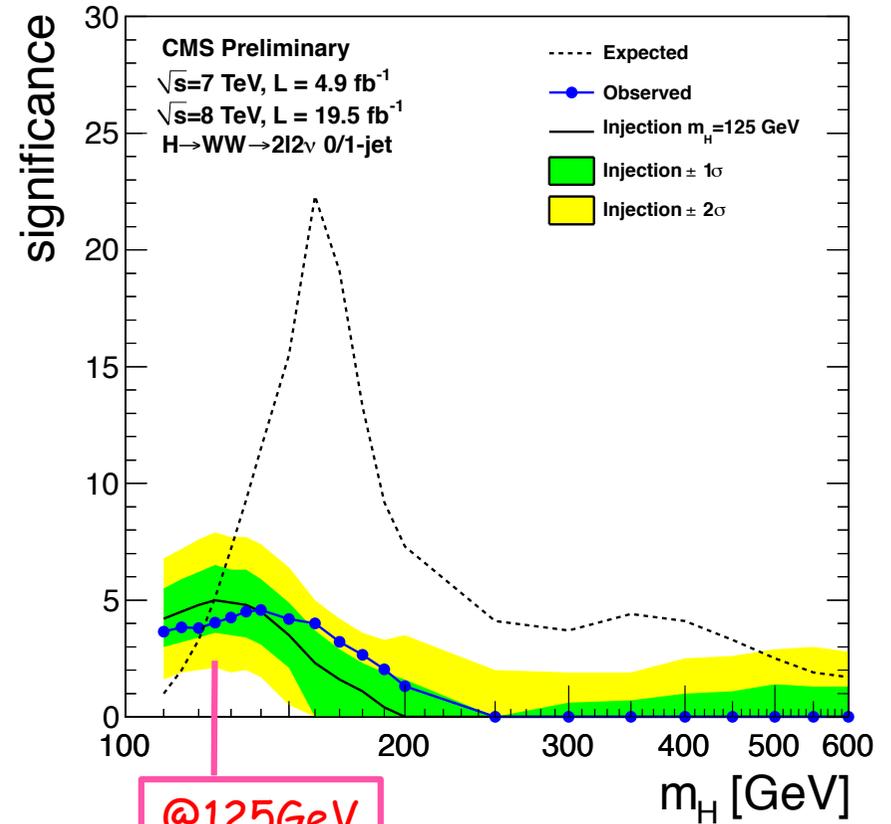
ATLAS



@125GeV

0+1+2jets	Observed	Expected
7TeV	0	1.8
8TeV	4.3	3.5
7+8TeV	3.8	3.7

CMS

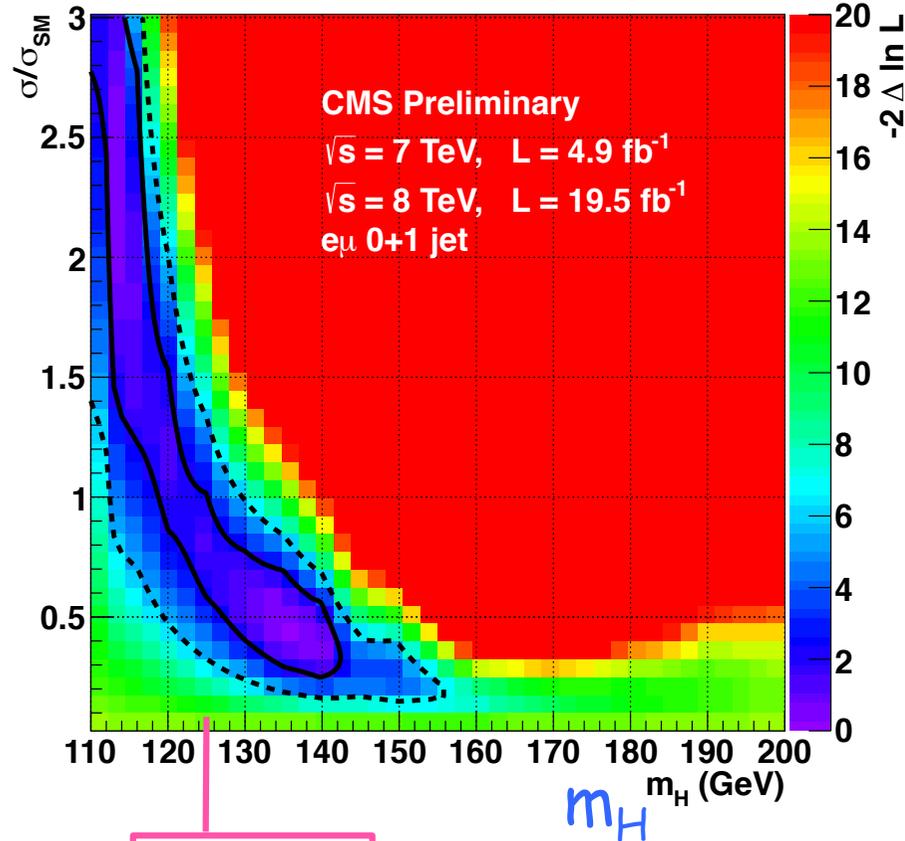


@125GeV

7+8TeV	Observed	Expected
Cut based (DF+SF)	2.0	2.7
Shape(DF)+cut(SF)	4.0	5.1

Signal Strength ($\mu = \sigma/\sigma_{SM}$)

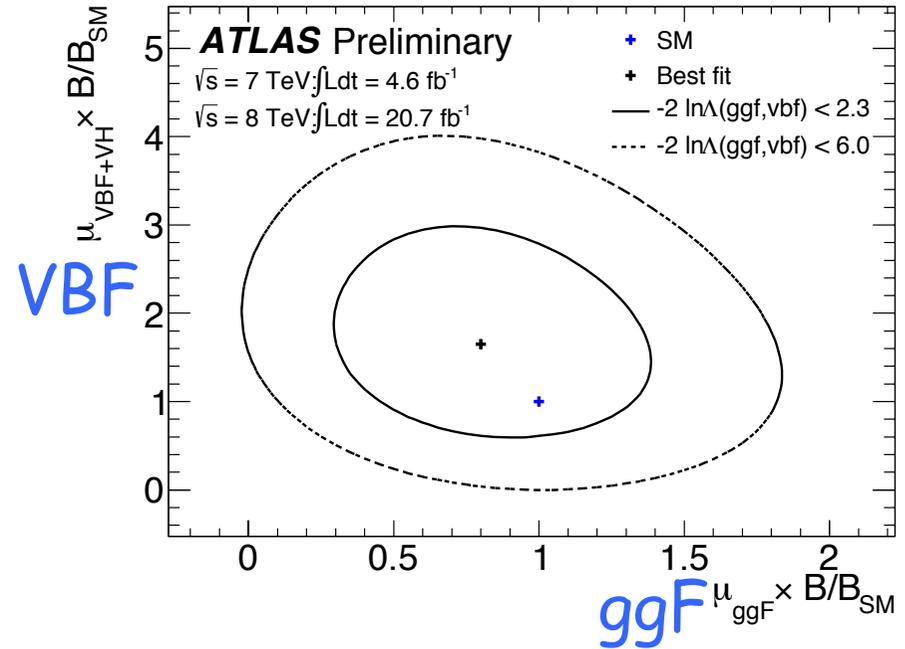
CMS



@125GeV

7+8TeV	Observed
Cut based (DF+SF)	0.71±0.37
Shape(DF)+cut(SF)	0.76±0.21

ATLAS



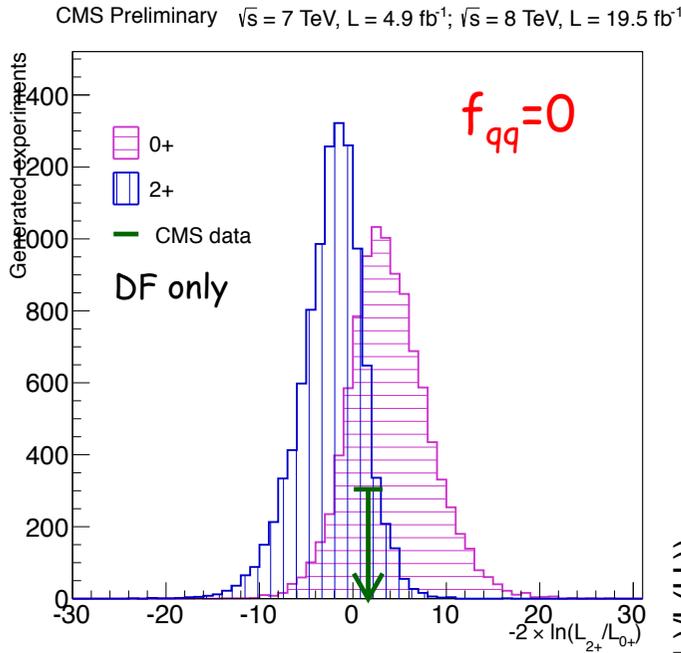
@125GeV

7+8TeV	Observed
ggF	0.82±0.36
VBF	1.66±0.79
ggF+VBF	1.01±0.31

Spin & Parity Results (0^+ vs. 2^+_{\min})

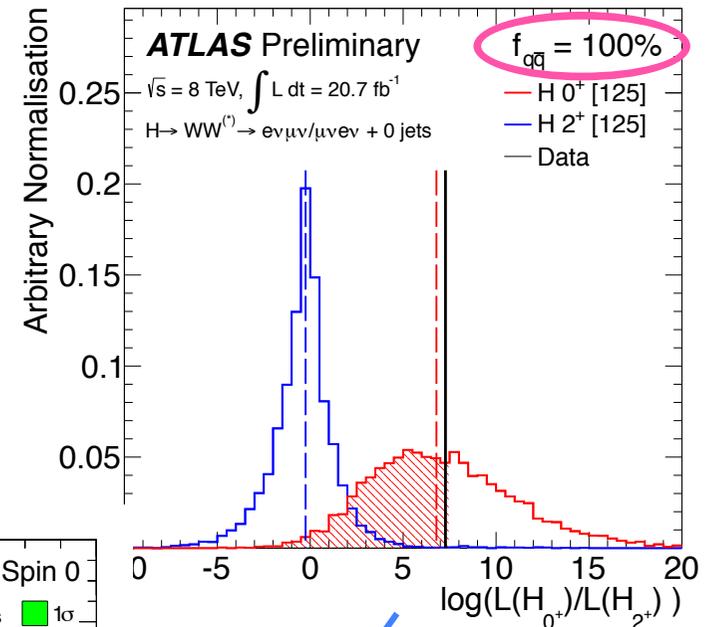
CMS

ATLAS



CMS only considered $gg \rightarrow X$ production with 2^+_{\min} coupling

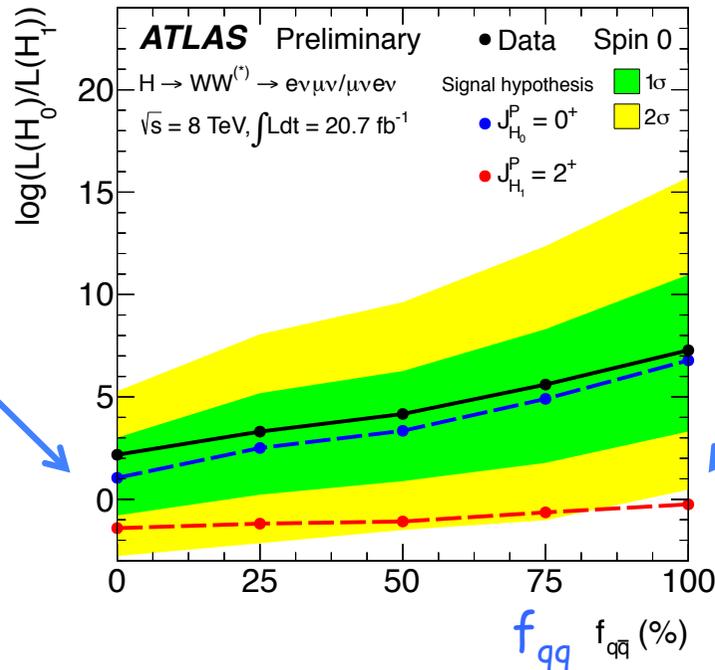
ATLAS looked at a mixture of gg and qq with 5 working points



Use signal strengths from fit to data ($\sigma/\sigma_{SM} \sim 0.8$)

CMS slightly in favor of SM 0^+

2^+_{\min} is a graviton-like state with 2 non-zero couplings over 10



ATLAS also in favor of SM 0^+ with 2^+_{\min} excluded at 99% (95%) CL for $f_{qq}=100\%$ (0%)

Summary

- $H \rightarrow WW^* \rightarrow l\nu l\nu$ channel was one of the three discovery channels in July 2012
- Clear evidence now established with this channel alone with full data sample, both for ggF and VBF processes
- All measurements (rate, coupling, spin, parity) so far in agreement with a SM Higgs boson

Backup: Comparison of Event Yield

8 TeV, 125 GeV

Jianming Qian

Final states	S	B	S/B	WW	Top	W+jets	VV	Z+jets	$W\gamma^*$
ATLAS									
$e\mu$ 0j	40.5	252.6	0.16	202.9	15.9	11.3	18.6	3.9	
$e\mu$ 1j	16.8	100.2	0.17	42.7	38.6	5.6	11.7	1.7	
$ee + \mu\mu$ 0j	25.5	218.7	0.12	166.1	7.5	8.7	10.8	25.6	
$ee + \mu\mu$ 1j	9.2	67.1	0.14	29.0	21.5	1.7	5.9	9.1	
CMS									
$e\mu$ 0j	90	429	0.21	310	20	48	11.4		40
$e\mu$ 1j	42	209	0.20	80	78.9	25.8	12.9		11.2
$ee + \mu\mu$ 0j	56	360	0.16	207	9.3	28.7	106		9.3
$ee + \mu\mu$ 1j	18	111.3	0.16	39.8	40.4	6.6	21.2		3.3
ATLAS/CMS									
$e\mu$ 0j	0.45	0.59	0.76	0.65	0.79	0.23		0.44	
$e\mu$ 1j	0.40	0.48	0.83	0.53	0.49	0.22		0.55	
$ee + \mu\mu$ 0j	0.46	0.61	0.75	0.80	0.80	0.30		0.32	
$ee + \mu\mu$ 1j	0.51	0.60	0.85	0.73	0.53	0.25		0.61	

CMS has larger signal acceptance (lower lepton P_T threshold, use of MVA, ...)
 ATLAS is doing well for W+jets background rejection

Backup: Comparison of Relative Uncertainties

8 TeV, 125 GeV

Jianming Qian

Final states	Signal	Tot. bkg	WW	Top	W+jets	VV + Z+jes + $W\gamma^*$
ATLAS						
$e\mu + ee + \mu\mu$ 0j	21%	5.3%	7.3%	9.2%	33%	16%
$e\mu + ee + \mu\mu$ 1j	33%	11%	36%	22%	25%	22%
CMS						
$e\mu$ 0j	21%	7.9%	9.4%	22%	27%	25%
$ee + \mu\mu$ 0j	21%	11%	9.2%	24%	27%	27%
$e\mu$ 1j	29%	6.7%	14%	5.7%	27%	20%
$ee + \mu\mu$ 1j	29%	7.7%	14%	7.7%	30%	23%

ATLAS has smaller uncertainty for 0 jet
CMS is better for 1 jet

Spin Analysis

The most general $J^{CP}=2^+$ amplitude:

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

Assume graviton-like state 2^+ with minimum couplings:

$$g_1 = g_5 = 1$$

$$\text{Production: } N = f_{qq} \times N(qq \rightarrow X) + (1 - f_{qq}) \times N(gg \rightarrow X)$$

Arbitrary f_{qq} with 25% (default)

Event yield fixed to be SM (0^+)