



Study of Higgs boson production in the WW decay channel at the LHC

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on behalf of the ATLAS and CMS collaborations



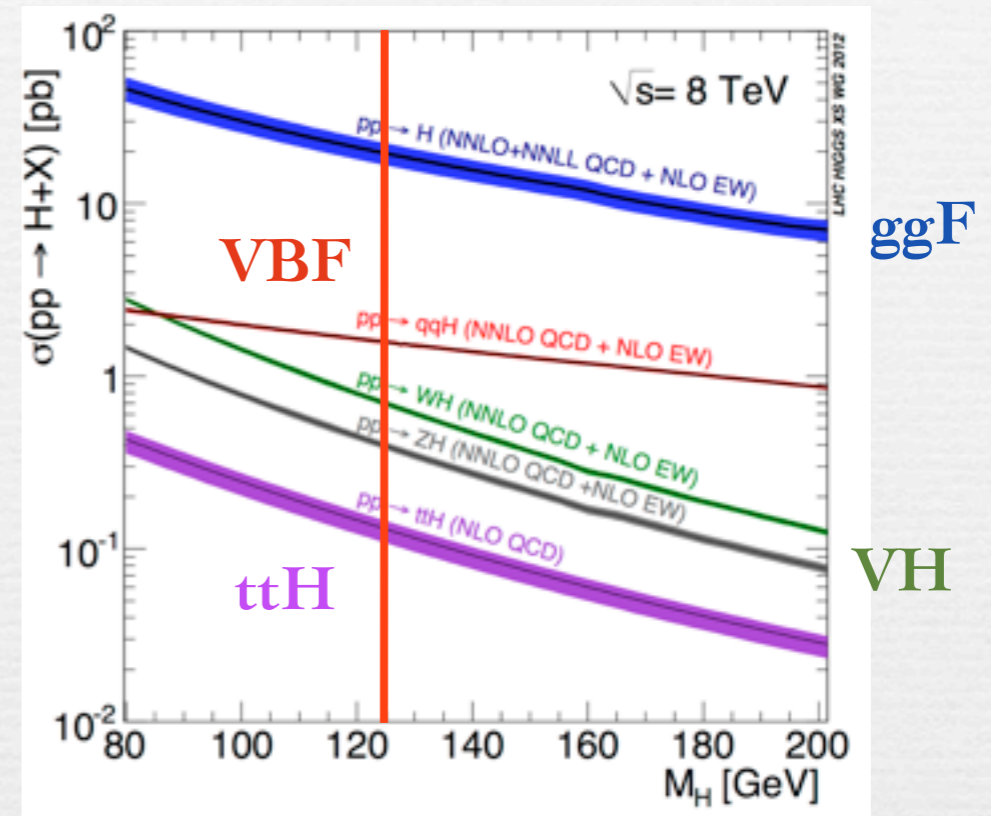
14.08.2013

Rencontres du Vietnam

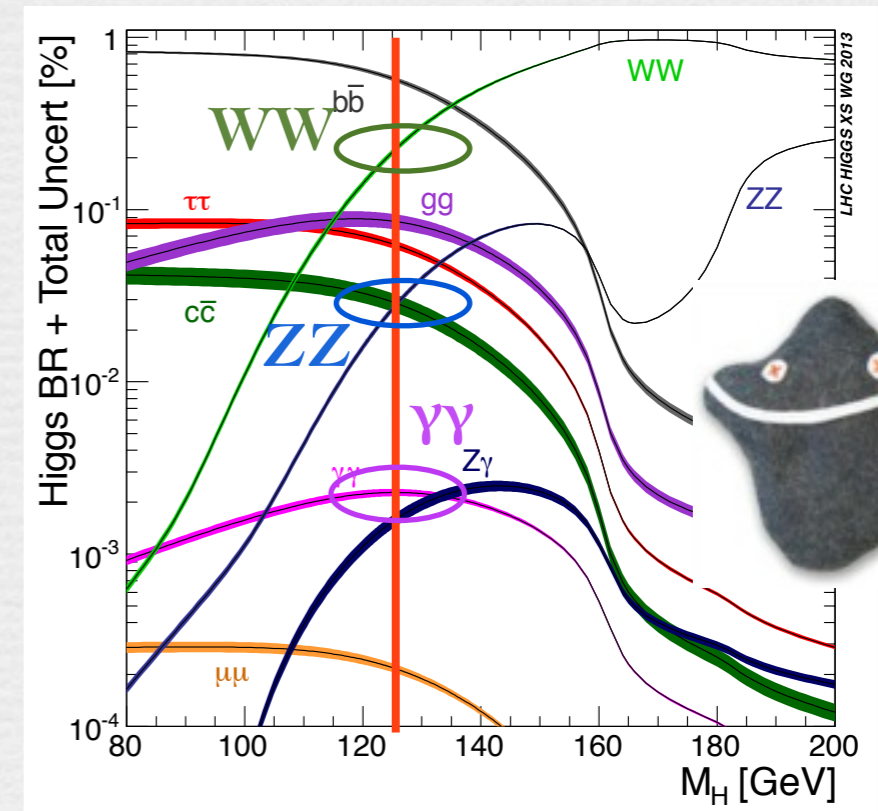


Introduction

- 4th July 2012 - the discovery of a new particle
- ATLAS and CMS today:
 - ~2.5x larger data set
 - reduced experimental uncertainties
 - new exclusive analyses - event categories targeting specific production modes
- WW channel:
 - large branching ratio
 - clear signature
 - but no mass peak

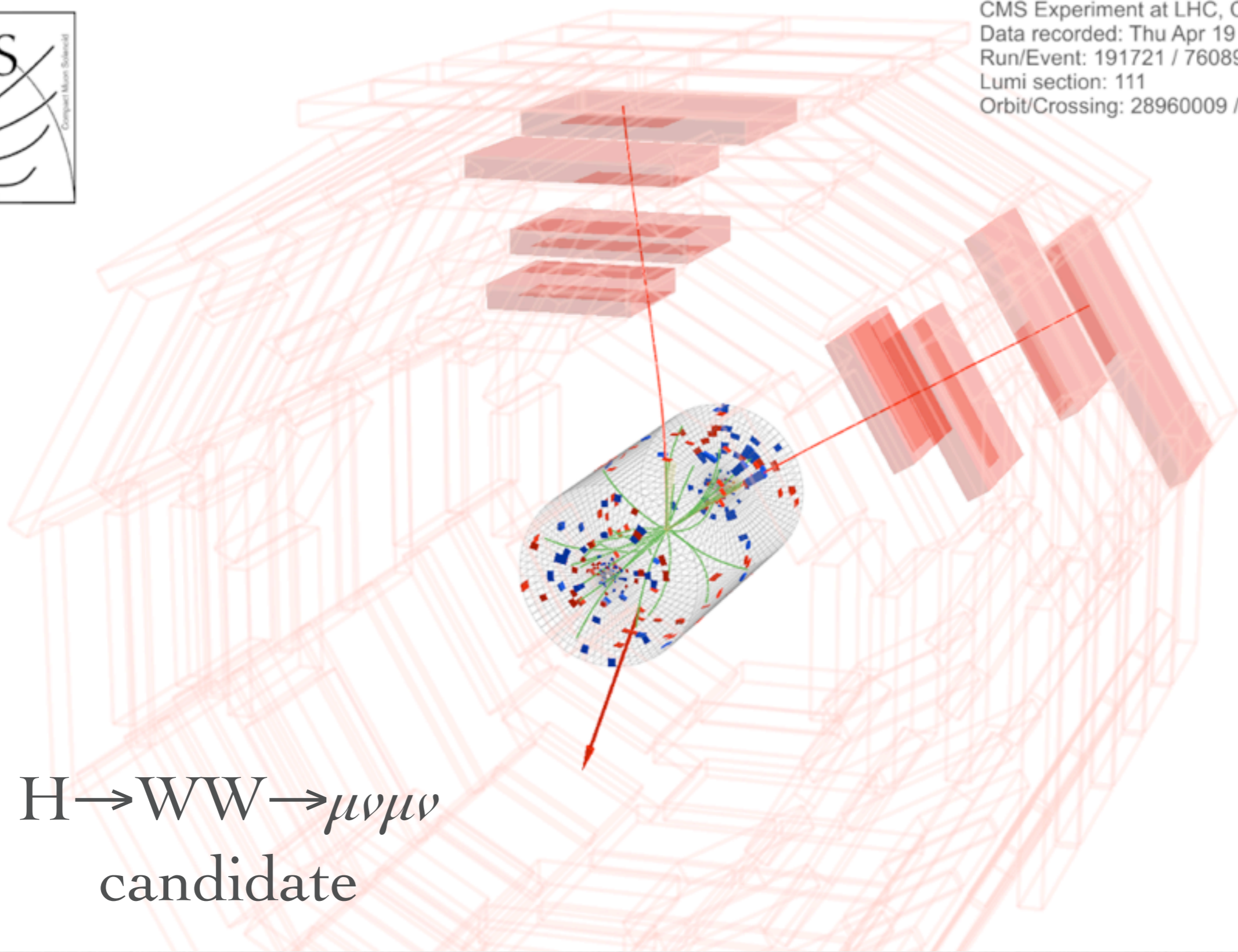


	Production	mass range	luminosity
$WW \rightarrow l\bar{l}l\nu$ CMS	ggF	110-600	4.9/19.6
	VBF	110-600	4.9/12.1
	WH, $W \rightarrow l\nu$	110-200	4.9/19.6
	<i>new</i> VH, $V \rightarrow jj$	110-300	4.9/19.6
$WW \rightarrow l\bar{l}l\nu$ ATLAS	ggF	110-200	4.9/20.7
	VBF	110-200	4.9/20.7
	<i>new</i> VH, 3l or 4l	110-200	4.9/20.7
	<i>new</i> high mass	260-1000	20.7





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



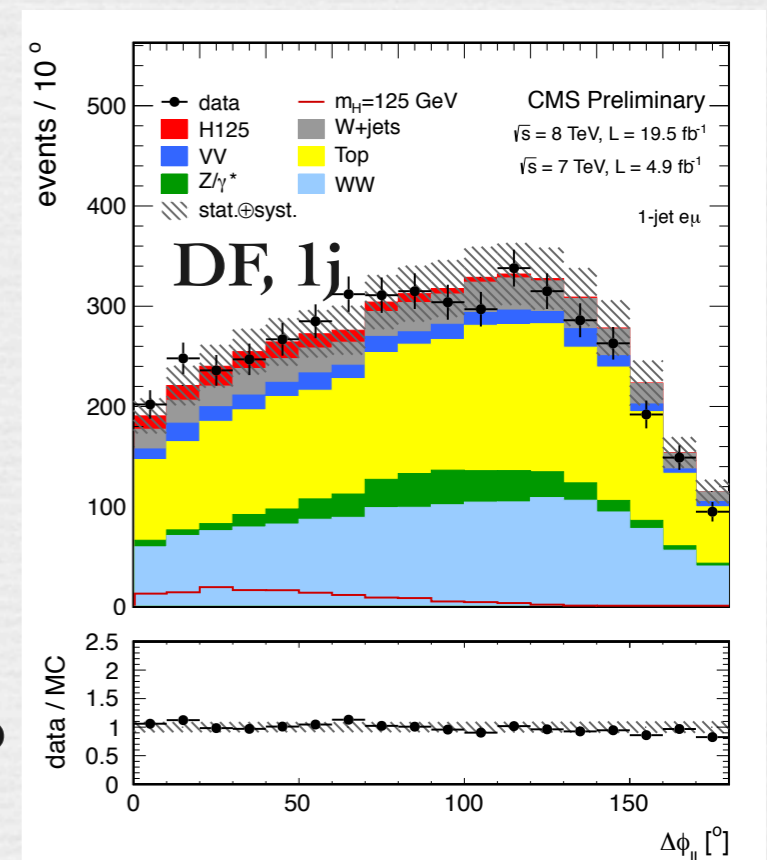
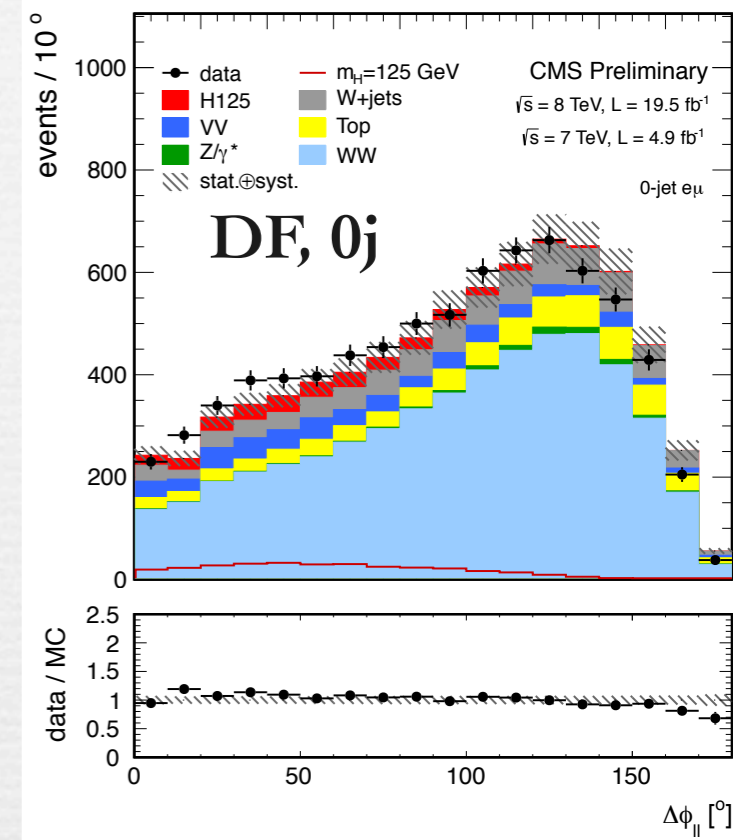
$H \rightarrow WW \rightarrow \mu\nu\mu\nu$
candidate

Higgs to $WW \rightarrow l\nu l\nu$ CMS

CMS-PAS-HIG-13-003

VBF: CMS-PAS-HIG-12-041

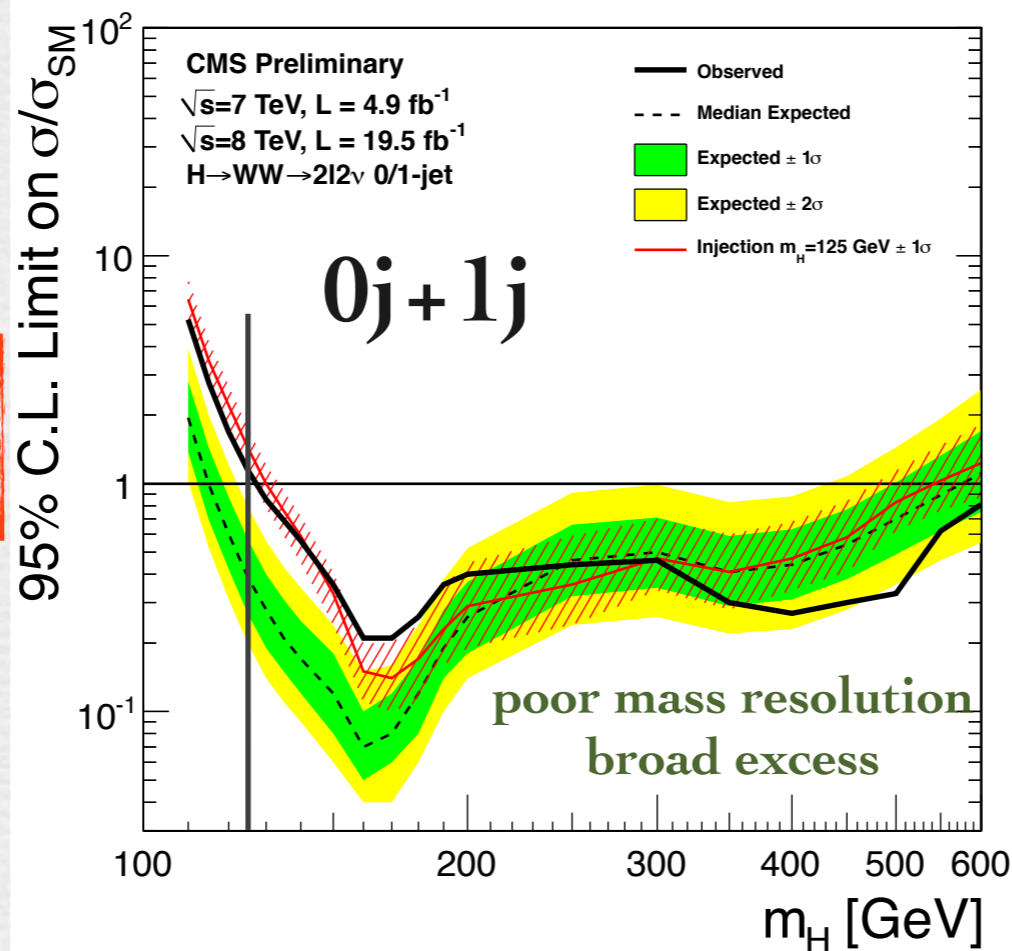
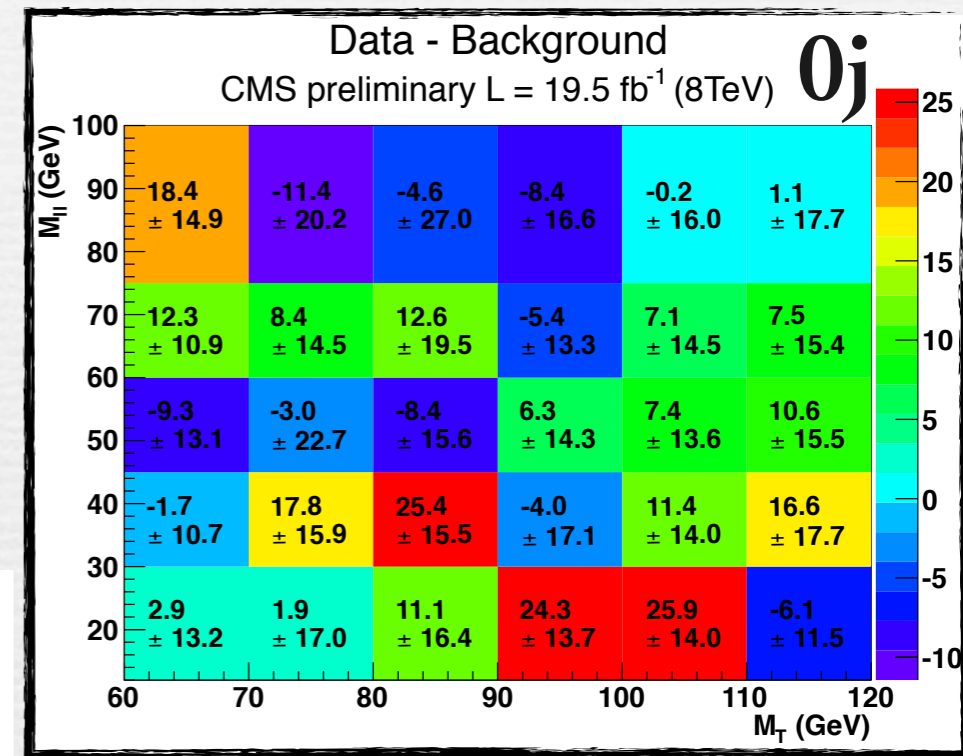
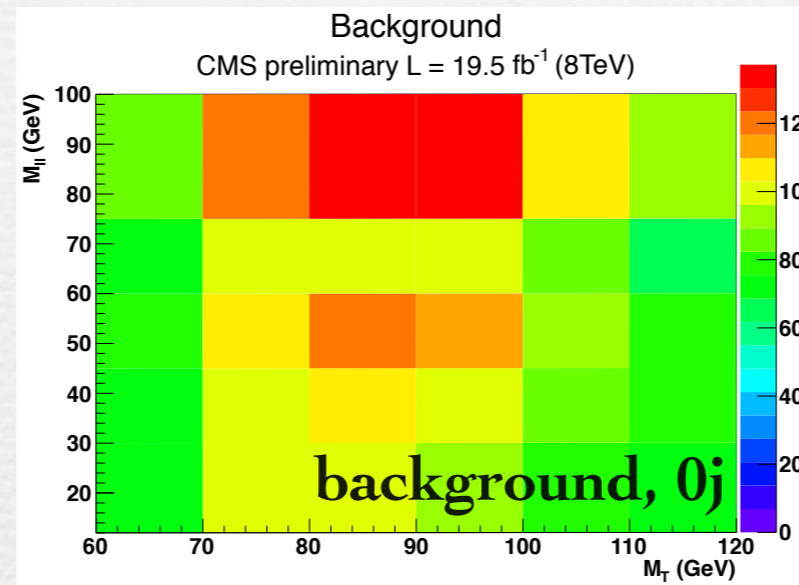
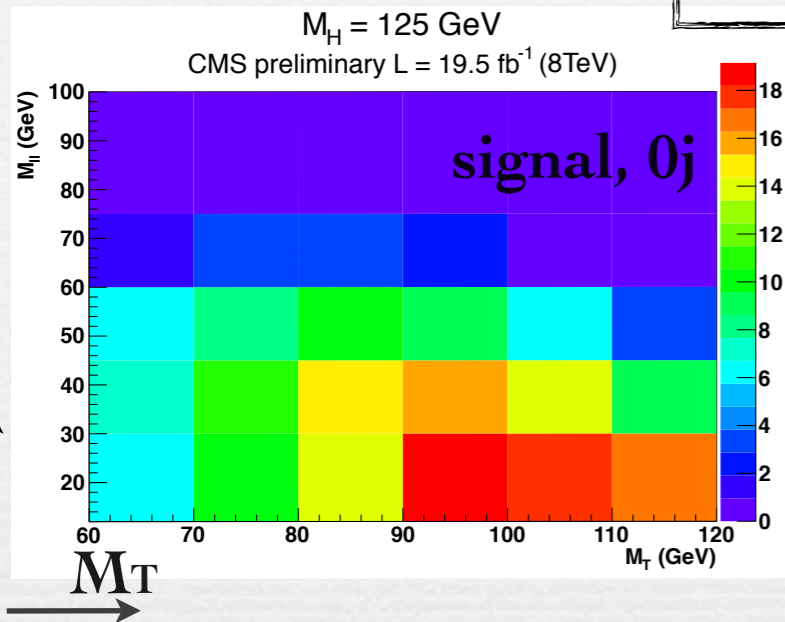
- exactly two opposite sign iso. leptons (e, μ) and large MET
- cuts on m_{ll} , $p_T(l_l)$, Z-peak veto, b-jet veto, Z/γ^* rejection using MVA
- split in categories:
 - jet multiplicity: 0j, 1j, 2j
 - separated in same (SF) and opposite (DF) flavour
- challenging backgrounds:
 - data-driven methods for reducible bkg: tt/tW , $W+jets$, $Z \rightarrow ll$, $Z \rightarrow \tau\tau$
 - WZ/ZZ , $V+\gamma^*$ from MC
 - WW fit to data in sidebands
- analysis categories:
 - **0j, 1j DF category:** 2D shape analysis
 - **0j, 1j SF category:** m_H dependent cuts on $\Delta\phi(l_l)$, $p_T(l_{max})$, $p_T(l_{min})$, m_{ll} , m_T
 - **VBF category:** 2 or 3 jets (2 jets with $p_T > 30$ GeV), no jets in the gap $|\Delta\eta(jj)| > 3.5$ and $m_{jj} > 500$ GeV



Higgs to $WW \rightarrow l\nu l\nu$ CMS

0j, 1j DF category: 2D shape analysis

CMS-PAS-HIG-13-003



4.0 (5.1) obs. (exp.)
significance at 125 GeV

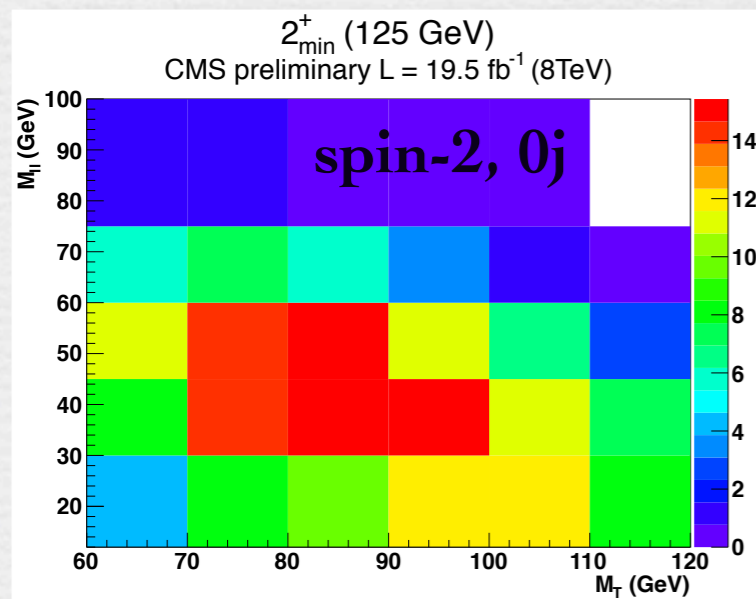
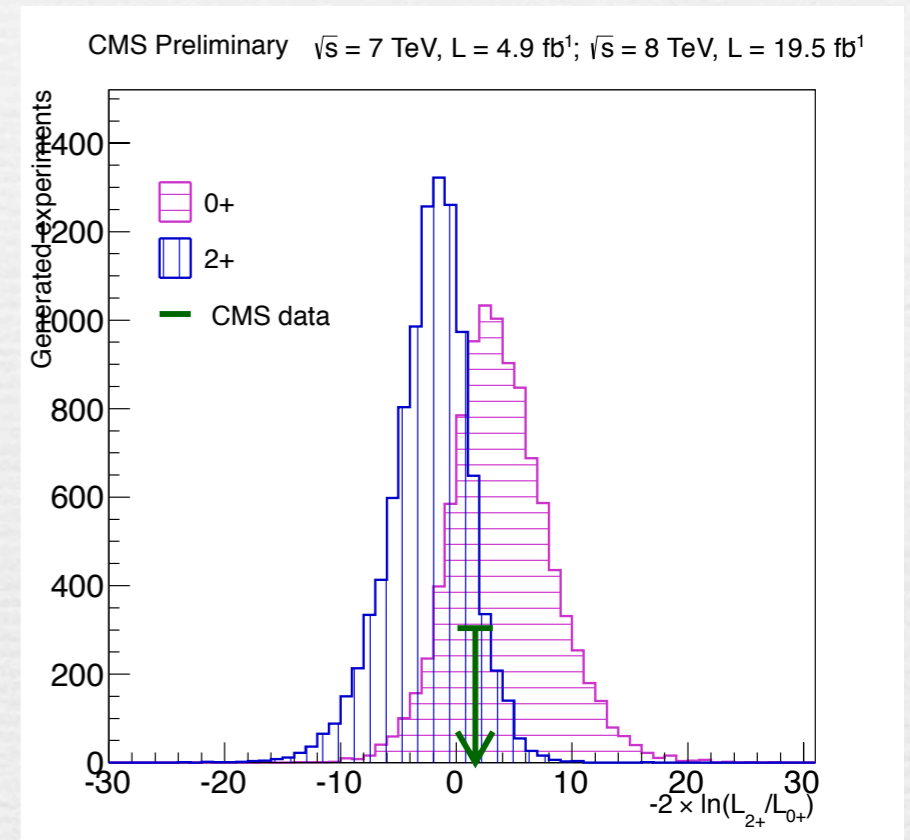
additional SM Higgs-like boson
excluded in the mass range
128 - 600 GeV at 95% CL.

Higgs to WW Spin CMS

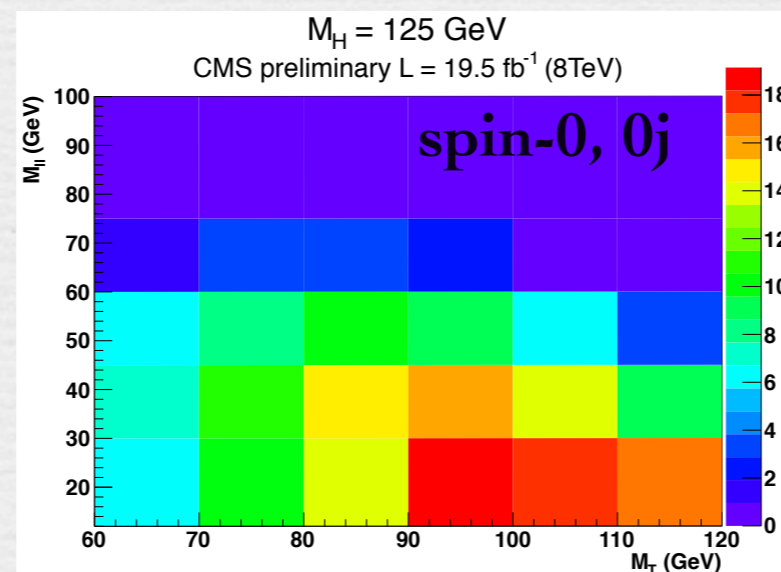
CMS-PAS-HIG-13-003

- test spin-2 resonance which couples to WW through minimal couplings (100% gg production)
- WW final state can't be fully reconstructed but use other spin-sensitive variables:
 - $\Delta\phi(\ell\ell)$, $M_{\ell\ell}$, m_T
- DF only, all jet bins
- build a maximum likelihood fit like in the standard analysis but for both models - SM and spin-2 model
- use test statistic q to quantify the consistency of data to the two models

spin-2: 100% gg



$$q = -2 \ln(L_{2_{\min}^+} / L_{0^+})$$



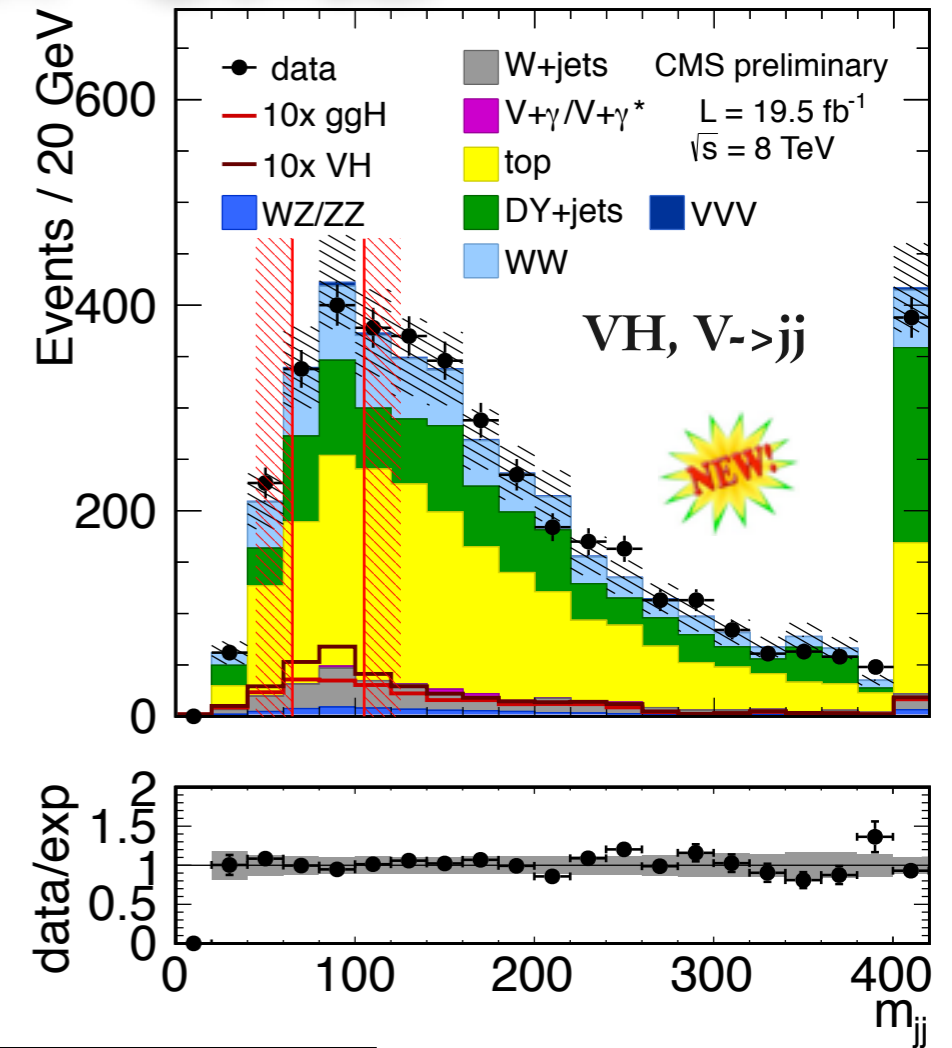
exclusion of the
spin-2 hypothesis
at 86% CL
in favour of SM

VH, Higgs to WW CMS

CMS-PAS-HIG-13-017

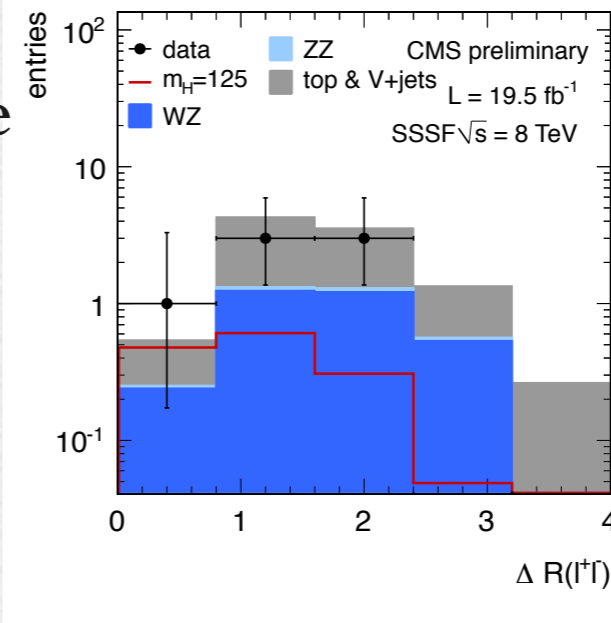
VH, $H \rightarrow WW \rightarrow 2l2\nu$ and $V \rightarrow jj$

- same event preselection as 0/1 jet analysis plus:
 - two central jets with $p_T > 30$ GeV and $|\eta| < 2.5$, $\Delta\phi(l, jj) < 165^\circ$, $65 < m(jj) < 105$ GeV
 - 30% VH, 60% ggH and 10% VBF at 125 GeV
- mH dependent cuts on $\Delta R(l, l)$, m_{ll} , m_T
- 95% CL on σ/σ_{SM} at 125 GeV: 5.0(4.2) obs(exp)

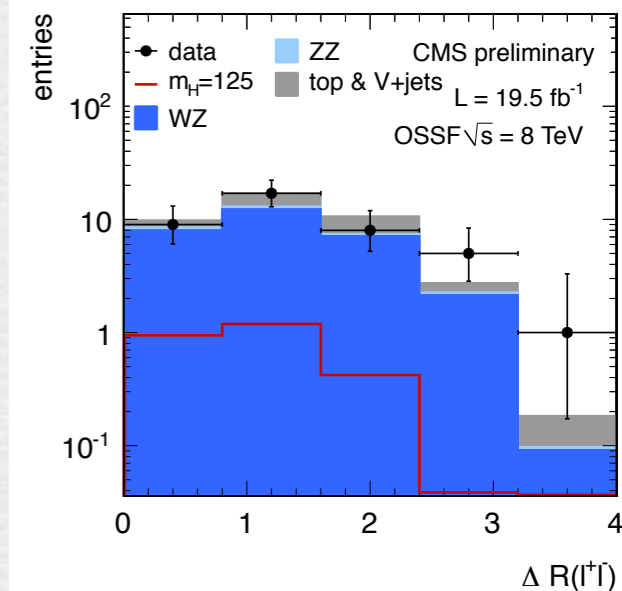


WH, $H \rightarrow WW \rightarrow 2l2\nu$ and $W \rightarrow l\nu$

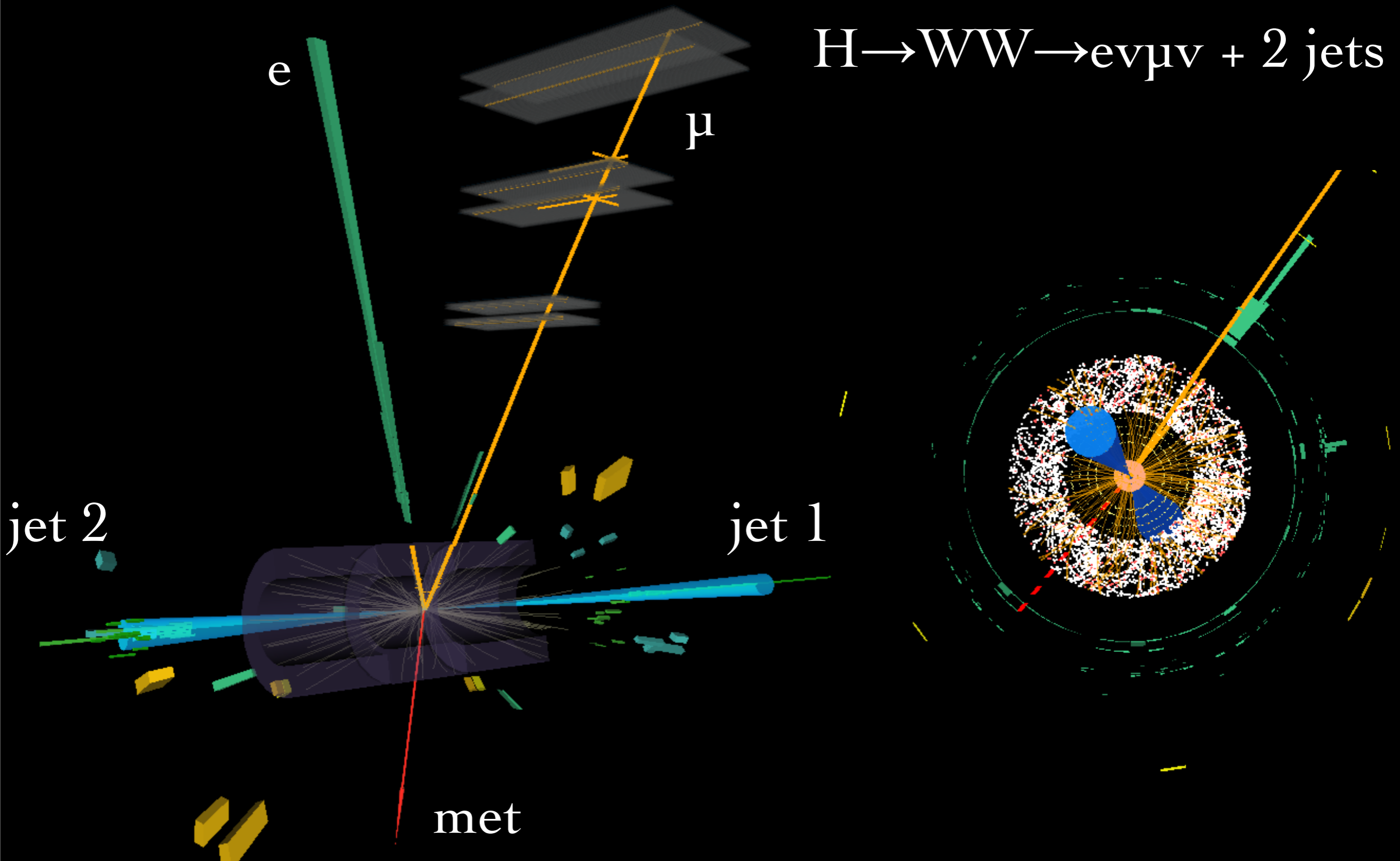
- look for 3 isolated leptons (e, μ) and large trans. miss. energy
- two categories according to the presence of an OSSF pair or not
- shape based approach based on $\Delta R(l^+l^-)$
- 95% CL on σ/σ_{SM} at 125 GeV: 3.3(3.0) obs(exp)



CMS-PAS-HIG-13-009



$H \rightarrow WW \rightarrow e\nu\mu\nu + 2 \text{ jets}$



Higgs to $WW \rightarrow l\nu l\nu$ ATLAS

<http://arxiv.org/abs/1307.1427>

• single e, μ triggers

• lepton $p_t > 25, 15$ GeV

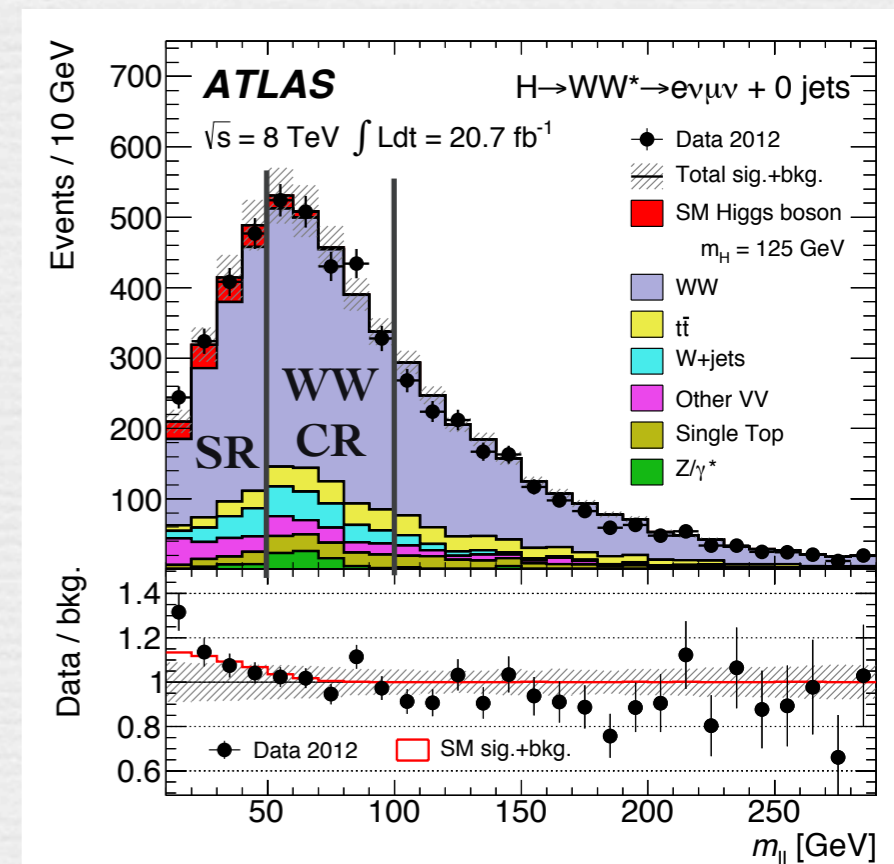
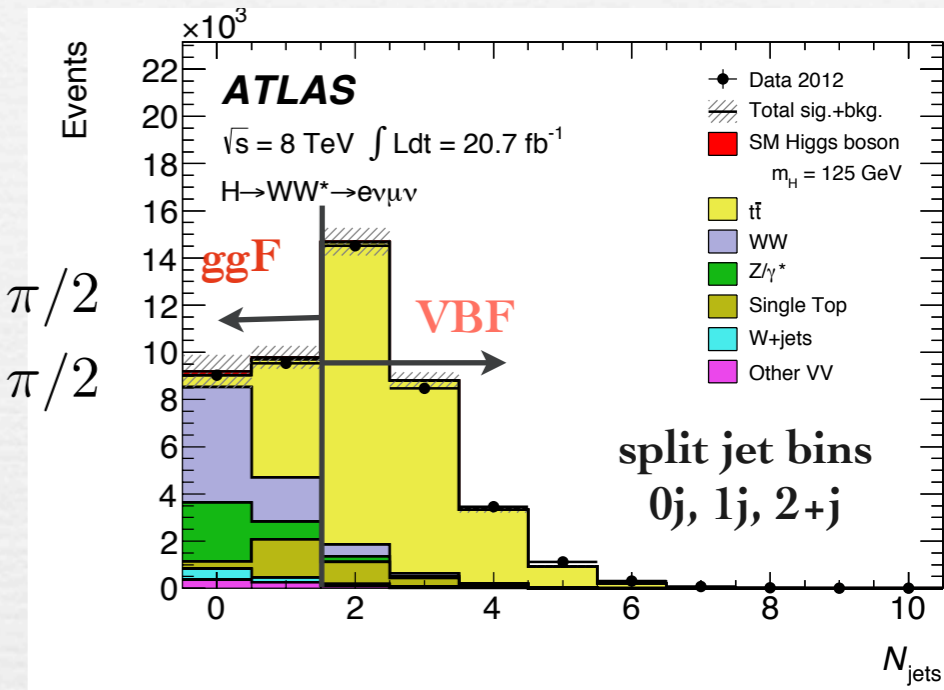
• jet $p_t > 25$ GeV, 30 GeV for $|\eta| > 2.5$

• rel. MET > 25 GeV $E_T^{miss} = \begin{cases} E_T^{miss} & \text{if } \Delta\phi \geq \pi/2 \\ E_T^{miss} \times \sin \Delta\phi & \text{if } \Delta\phi < \pi/2 \end{cases}$

WW- $\rightarrow l\nu l\nu$	irreducible	norm. to data
W+jets	jet fakes lepton	data driven
$V\gamma^*$	photon conversion	MC
tt	not identified 2 b-jets	norm. to data
Wt	not identified b-jet	norm. to data
Z- $\rightarrow \tau\tau$	real missing energy	norm. to data
ZZ- $\rightarrow ll\nu\nu$	irreducible	MC
WZ	lose lepton	MC

• ggF category (0j+1j): Higgs spin-0 and V-A decays \Rightarrow collinear leptons

• DPhll < 1.8 , $P_{tll} > 30$ GeV, $M_{ll} < 50$ GeV



Higgs to $WW \rightarrow l\nu l\nu$ ATLAS

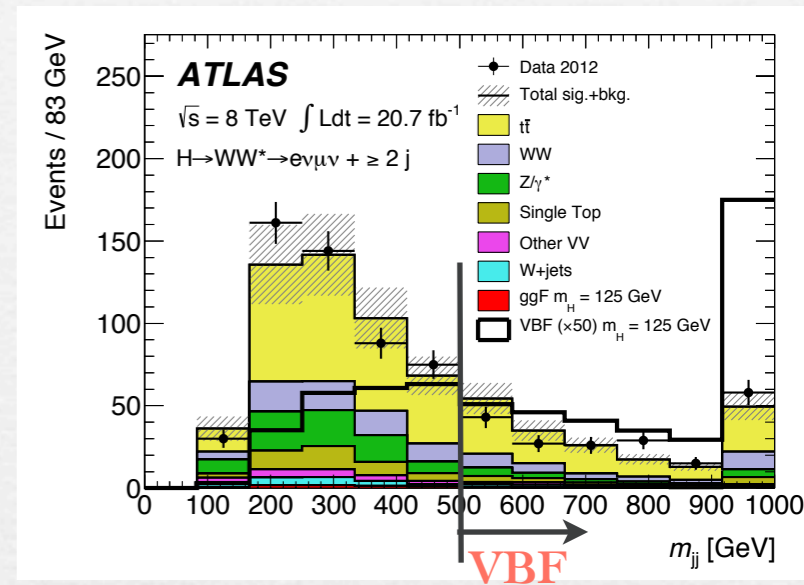
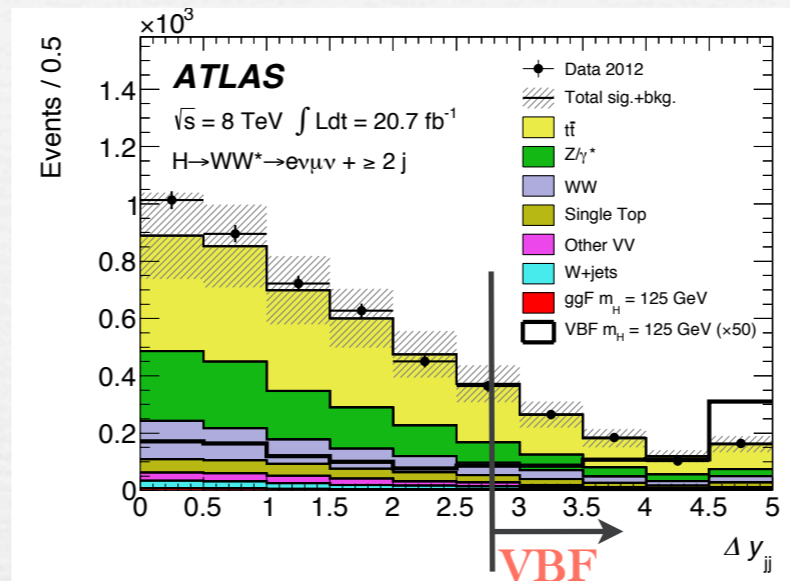
<http://arxiv.org/abs/1307.1427>

• VBF category(2+j):

• require b-veto and two forward jets

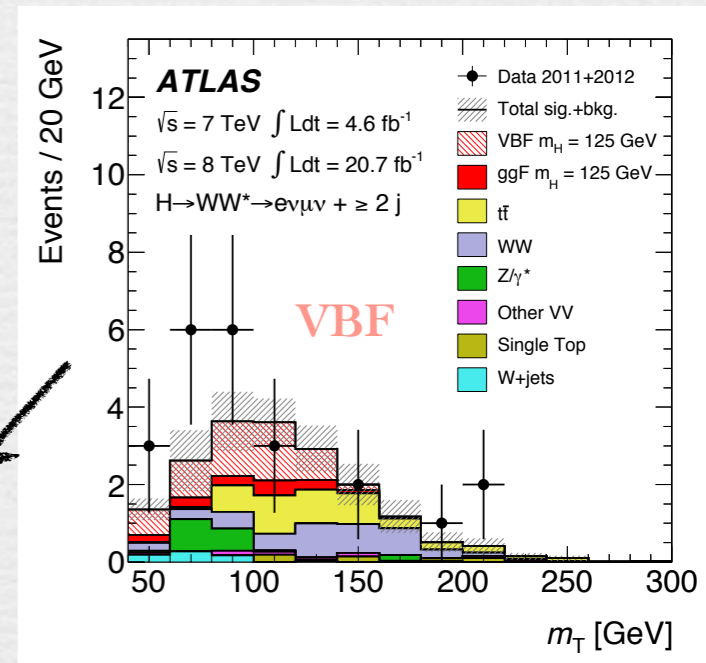
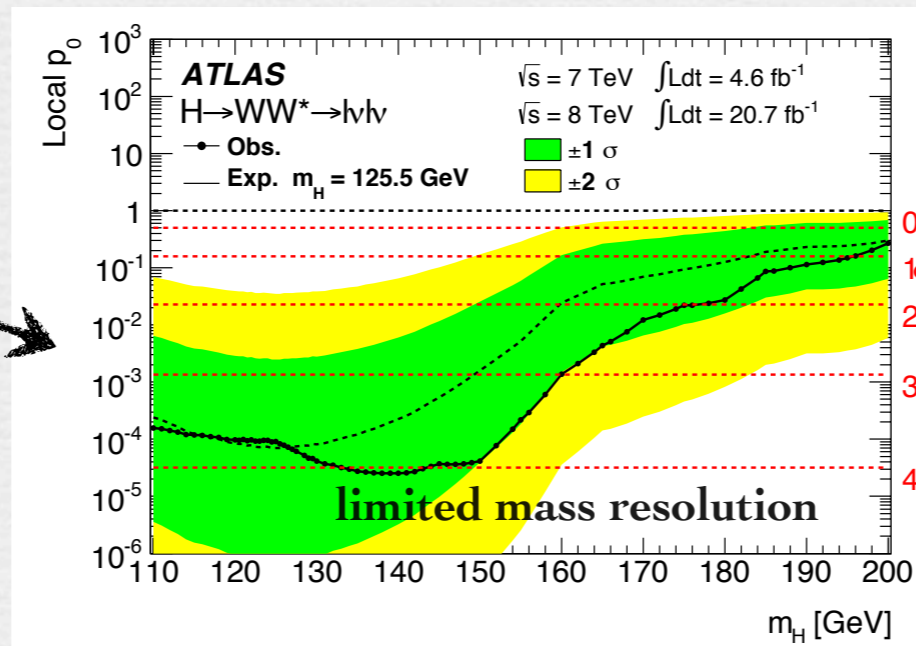
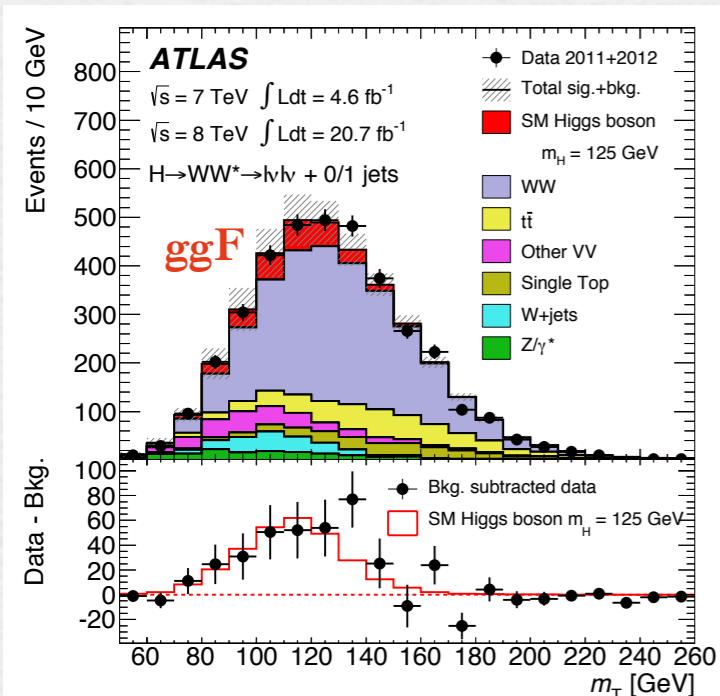
• $\Delta Y_{jj} > 2.8, M_{jj} > 500 \text{ GeV}$

split in $ee, \mu\mu, e\mu$ and μe
0jet, 1jets and ≥ 2 jets
channels



binned likelihood fit of

$$m_T = \sqrt{(E_T^{\ell\ell} + E_T^{\text{miss}})^2 - |\mathbf{p}_T^{\ell\ell} + \mathbf{E}_T^{\text{miss}}|^2}$$



0j+1j $e\mu$ fit in 2 bins of M_{ll}

Higgs to $WW \rightarrow l\bar{l}l\nu$ ATLAS



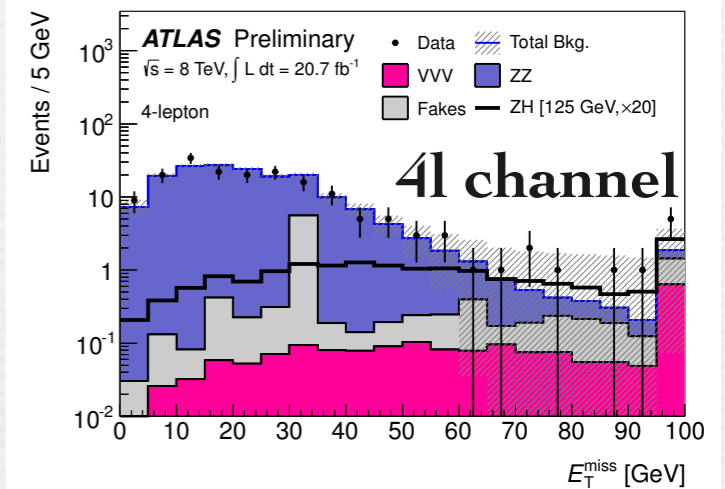
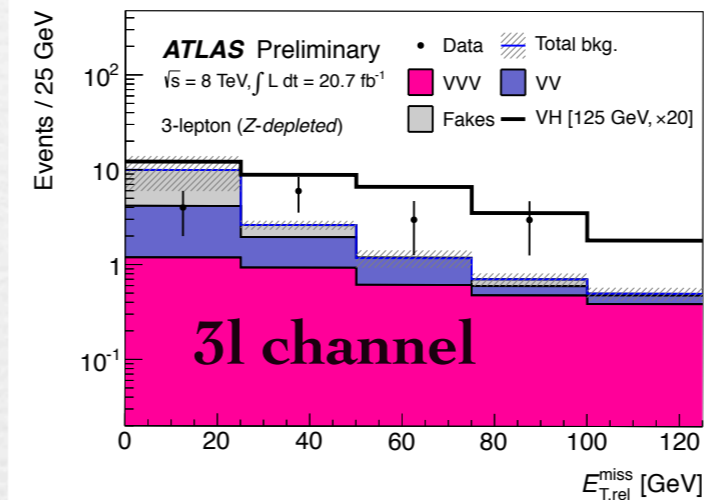
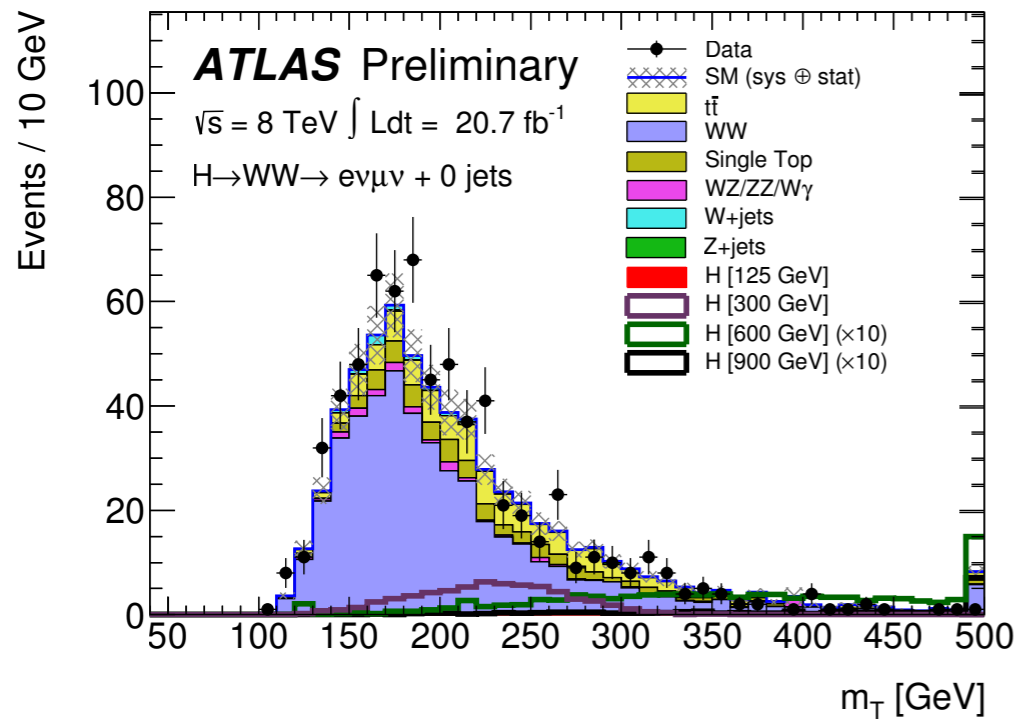
high mass search:

- based on the previous analysis but:
 - lepton $p_T > 40$ GeV
 - only DF, all jet bins

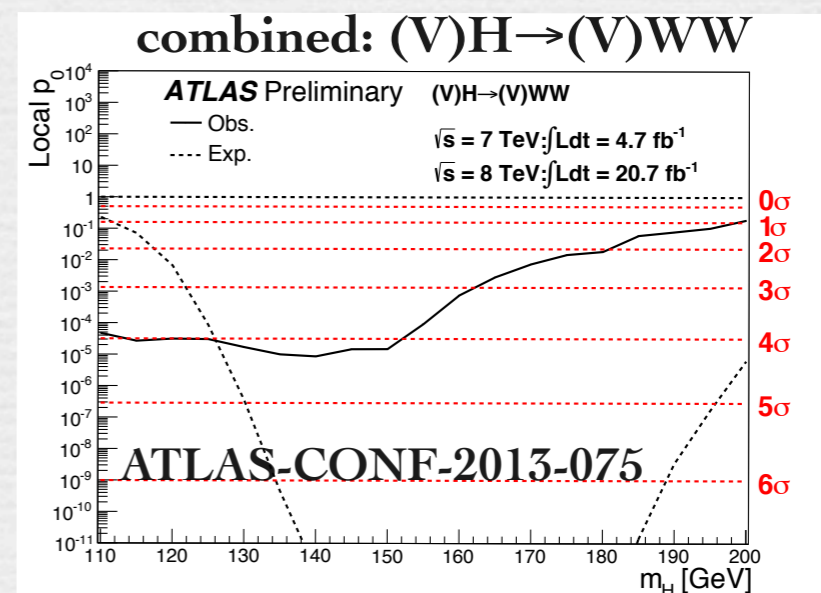
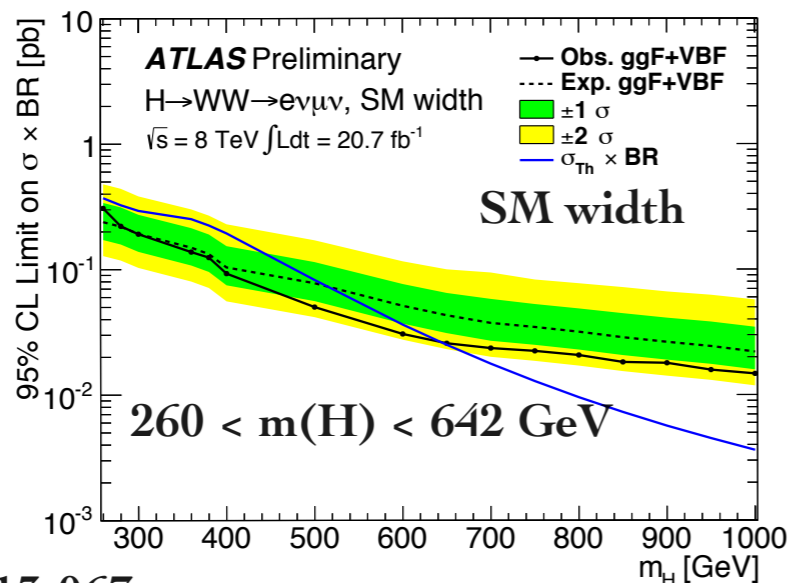


VH channel:

- WH, ZH production in $3l, 4l$ channels
- 95% CL on σ/σ_{SM} is 7.2(3.6) obs(exp)



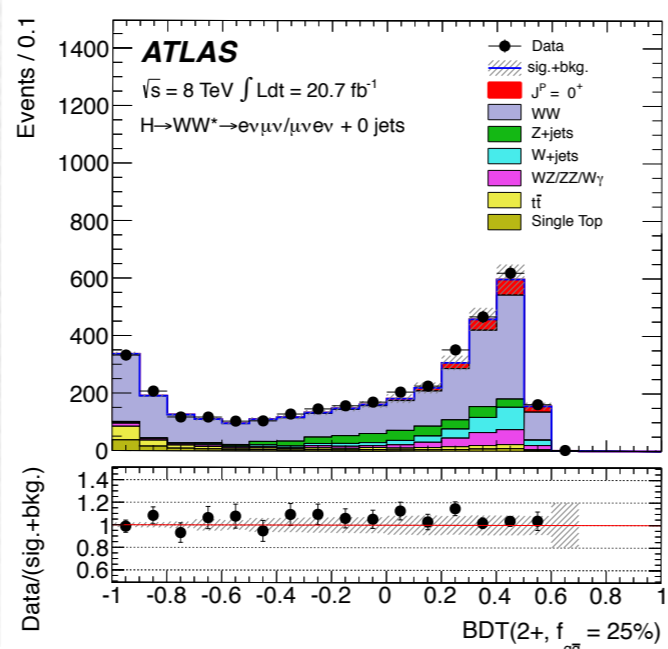
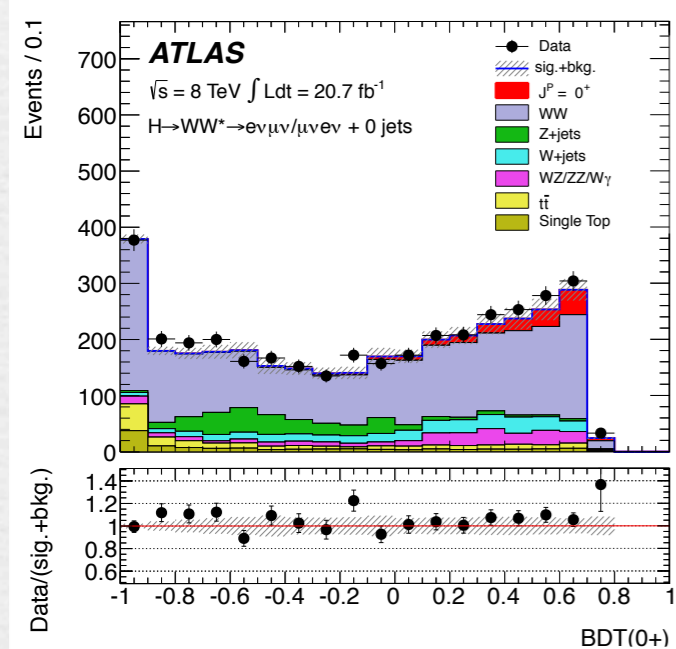
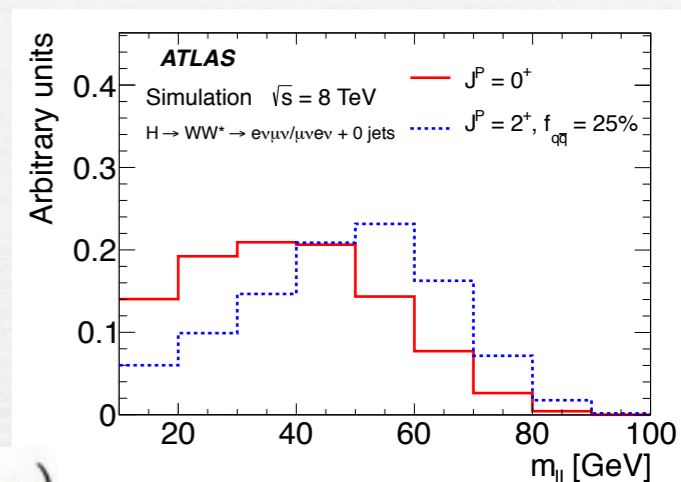
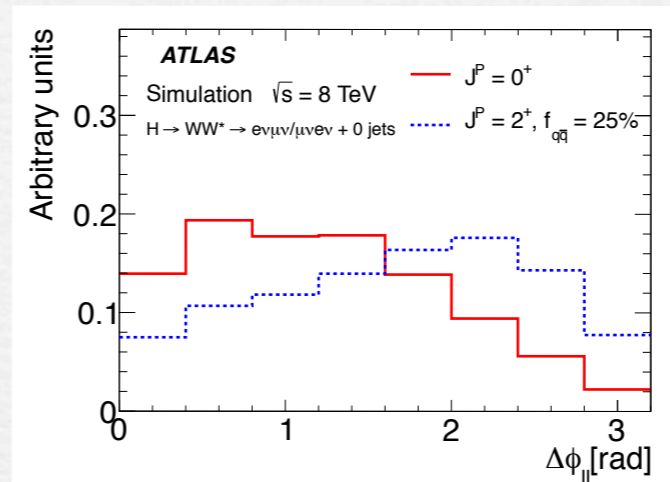
significance (σ)	VH	$H \rightarrow WW^{(*)}$ [6]	Combined
expected	0.7	3.7	3.8
observed	2.0	3.8	4.0



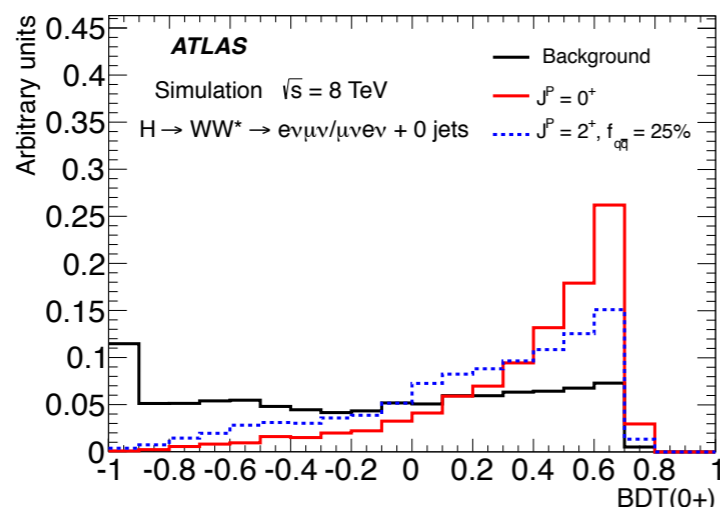
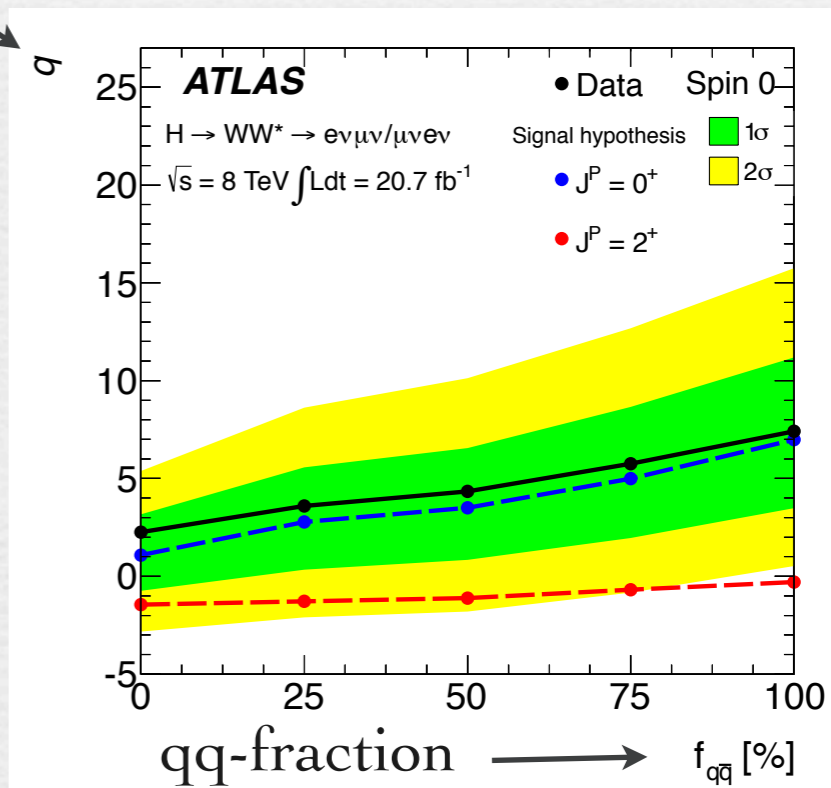
Higgs to WW Spin ATLAS

- same preselection like in the $H \rightarrow WW$ rate analysis but 0 jet, $e\mu$ -channel only
- looser cuts on metrel, $p_T(\ell)$, $M(\ell)$, $\Delta\phi(\ell)$
- train separate BDTs on 4 variables: $p_T(\ell)$, $M(\ell)$, $\Delta\phi(\ell)$ and m_T
 - $J=0+, 1-, 1+$ and $2+$ vs all backgrounds
- study test statistic of $J=0+$ vs others

<http://arxiv.org/abs/1307.1432>



$$q = -2 \ln(L_{2+_{\min}} / L_{0+})$$



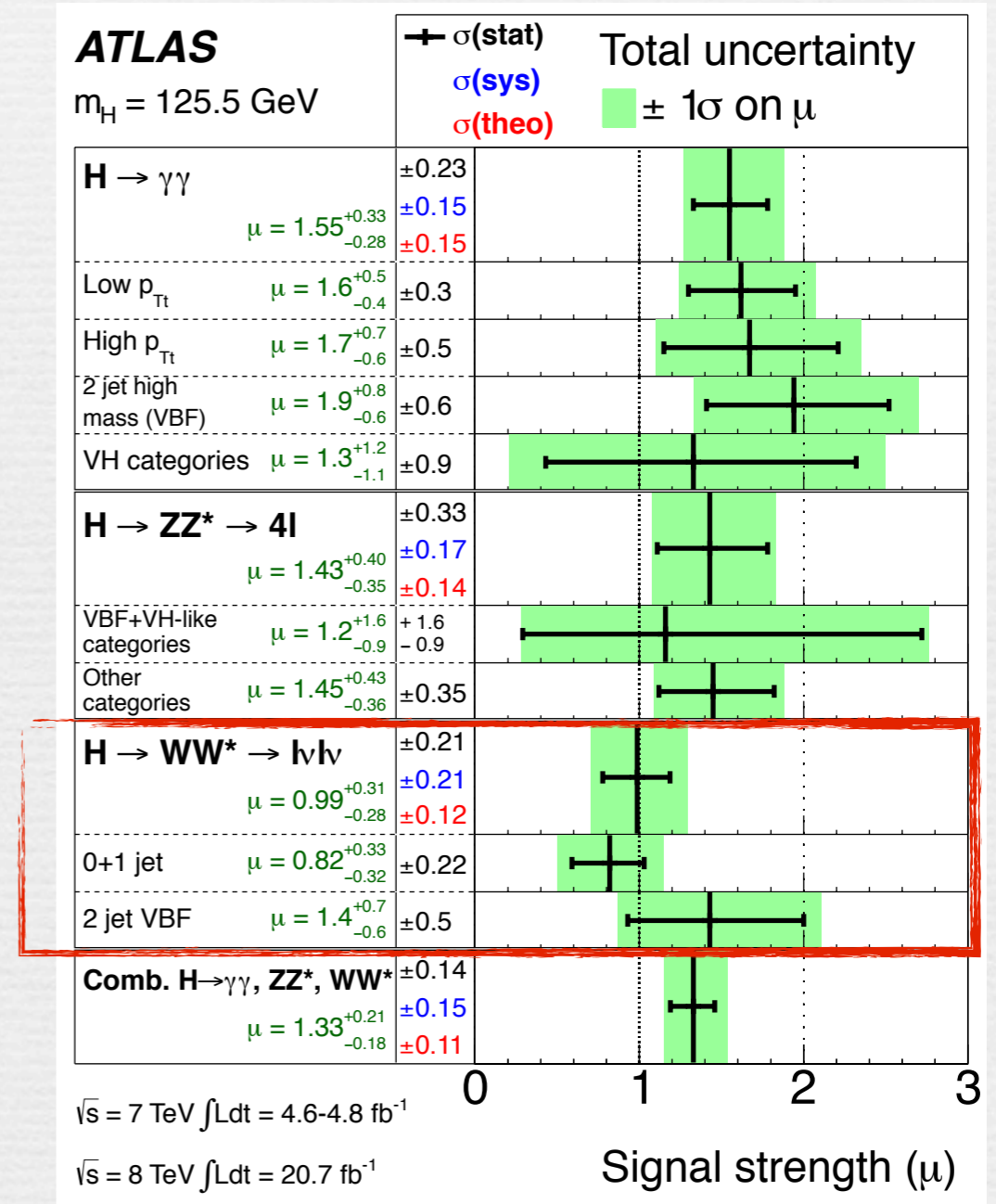
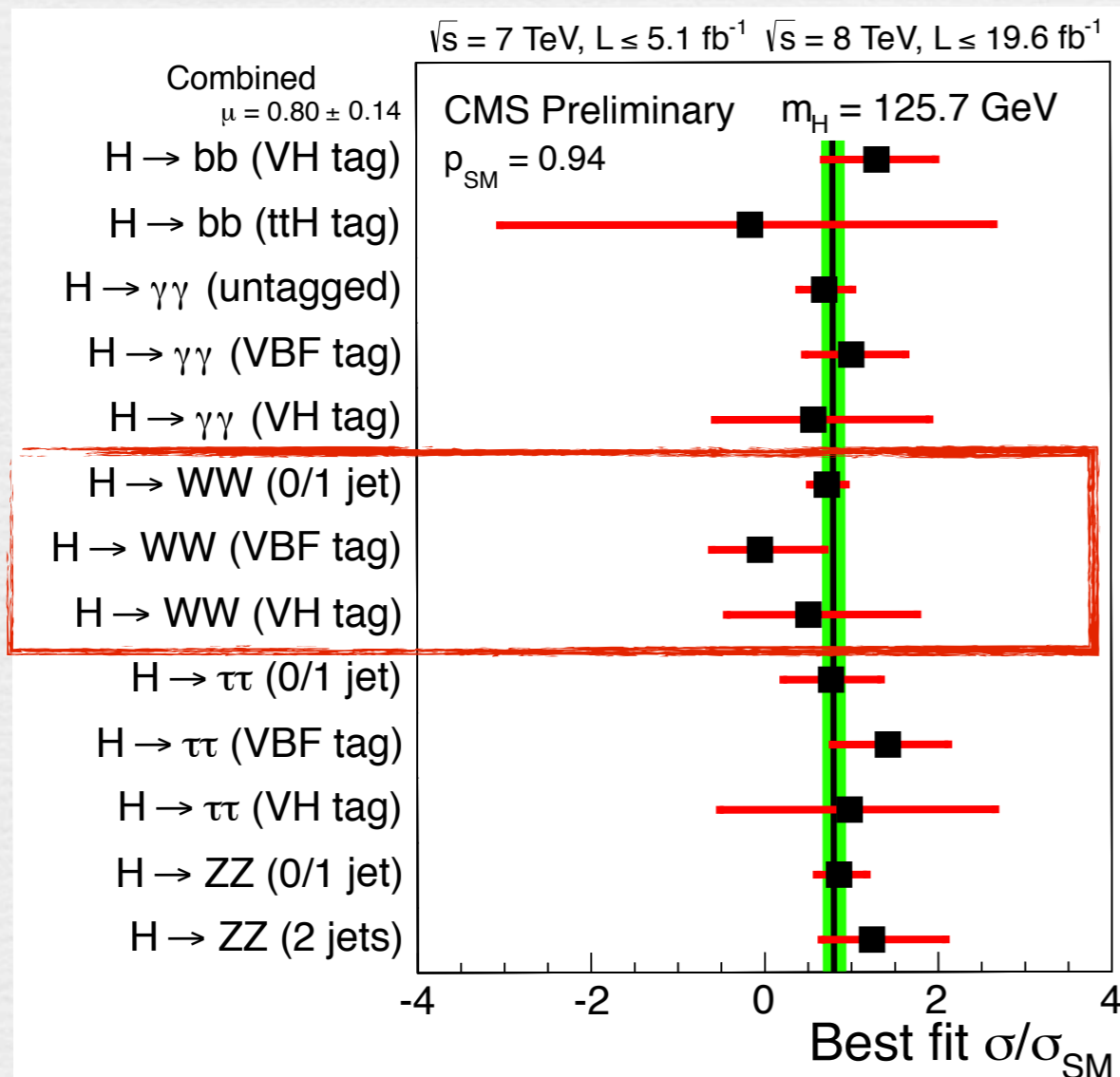
spin-2+ excluded at at least 95%CL
 spin-1+ at 92% CL
 spin-1- at 98% CL

Summary

- a Higgs boson seen beyond any doubts in all three bosonic channels
- evidence in the WW channel
- looks more and more like a SM Higgs boson
- no evidence for additional Higgs bosons at higher or lower mass

<http://arxiv.org/abs/1307.1427>

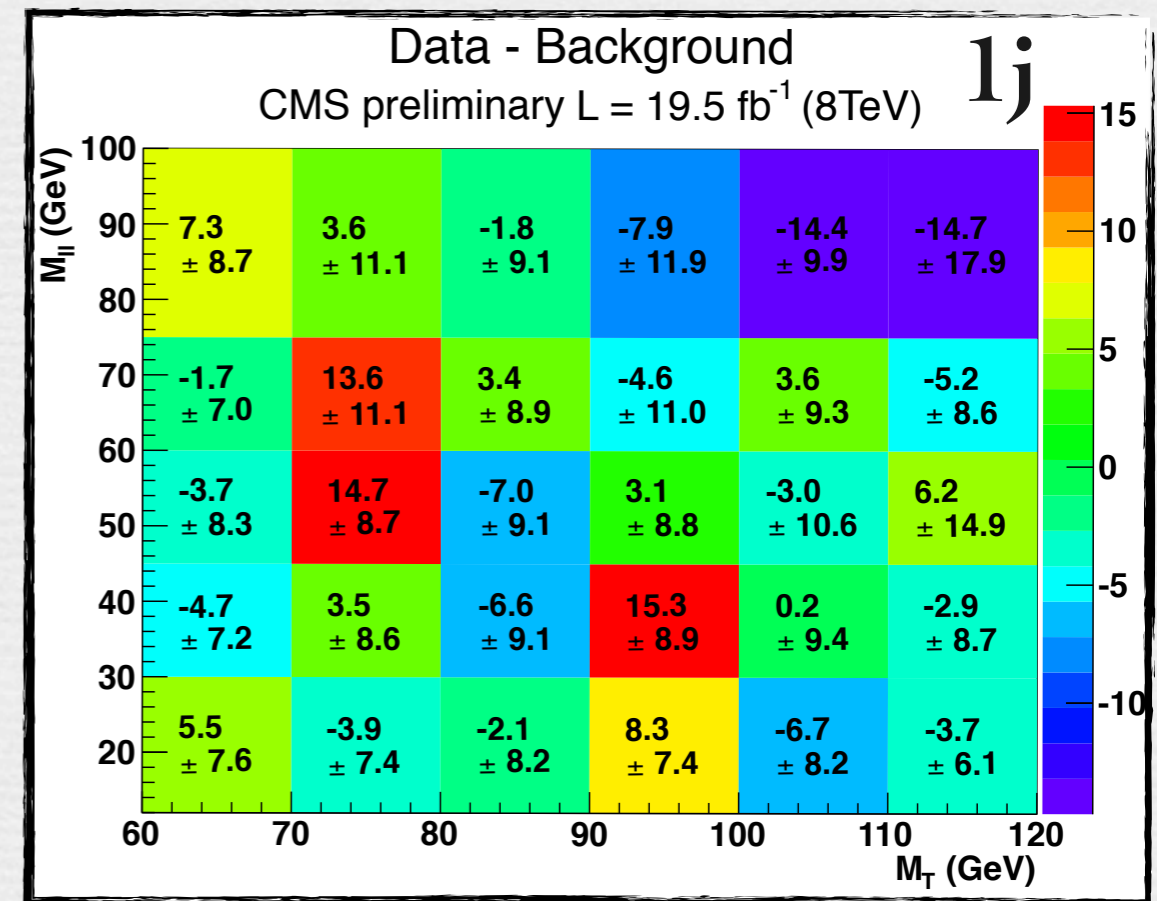
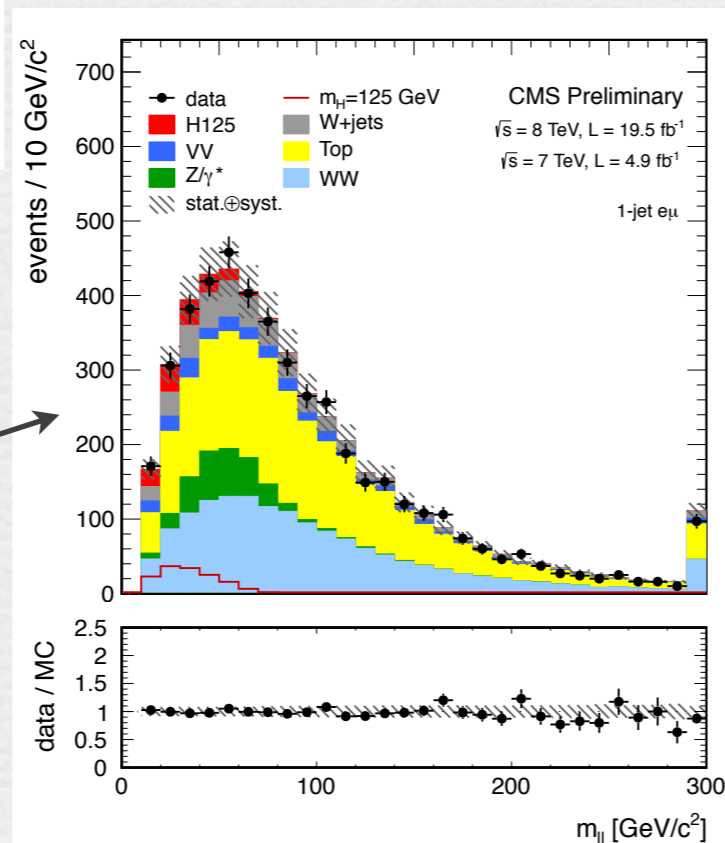
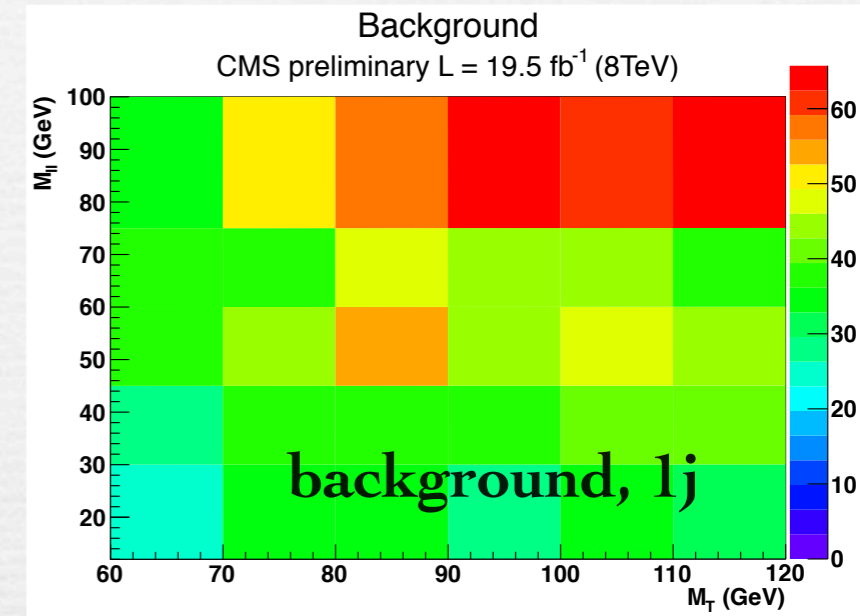
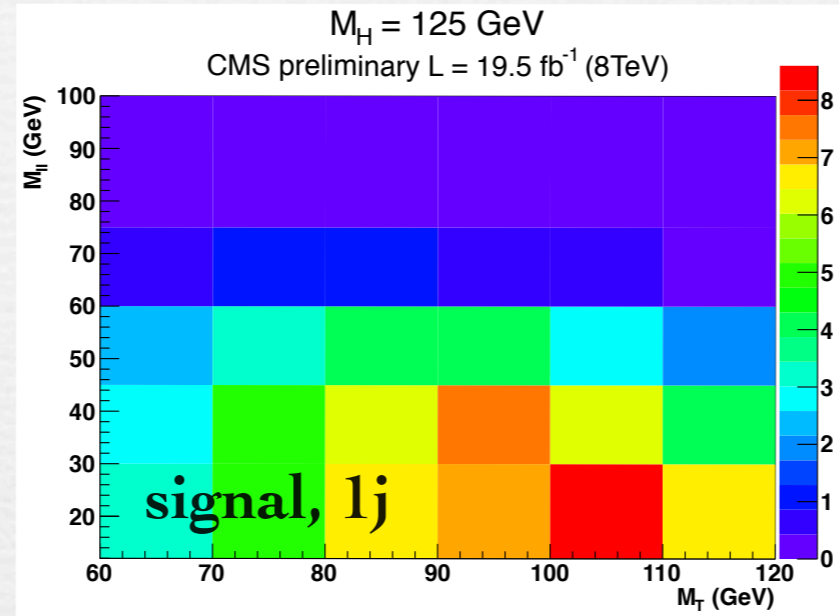
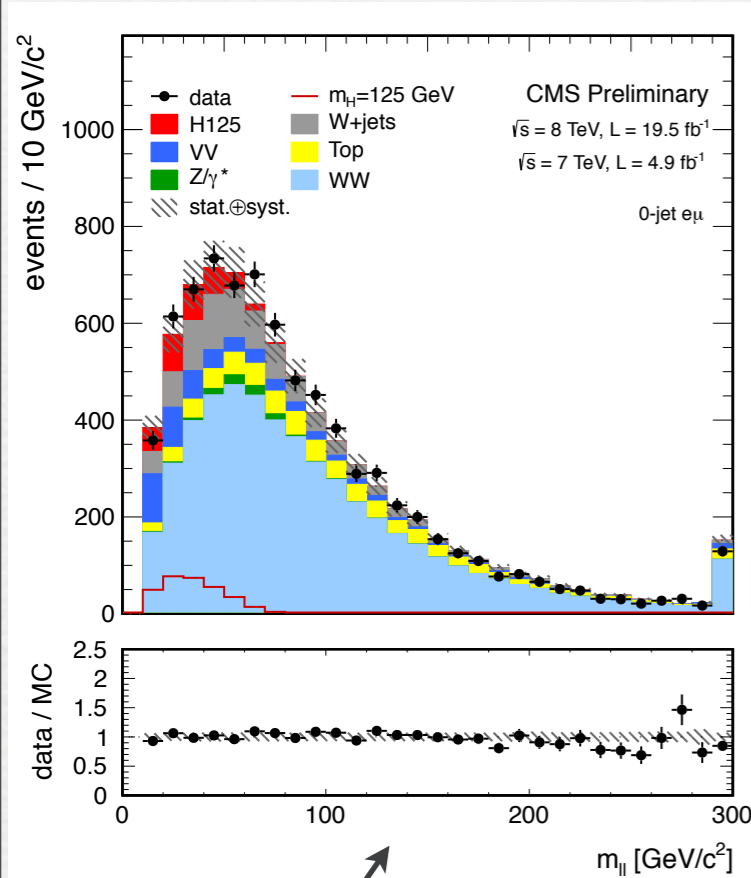
CMS-PAS-HIG-13-005



BACKUP

Higgs to $WW \rightarrow l\nu l\nu$ CMS

CMS-PAS-HIG-13-003

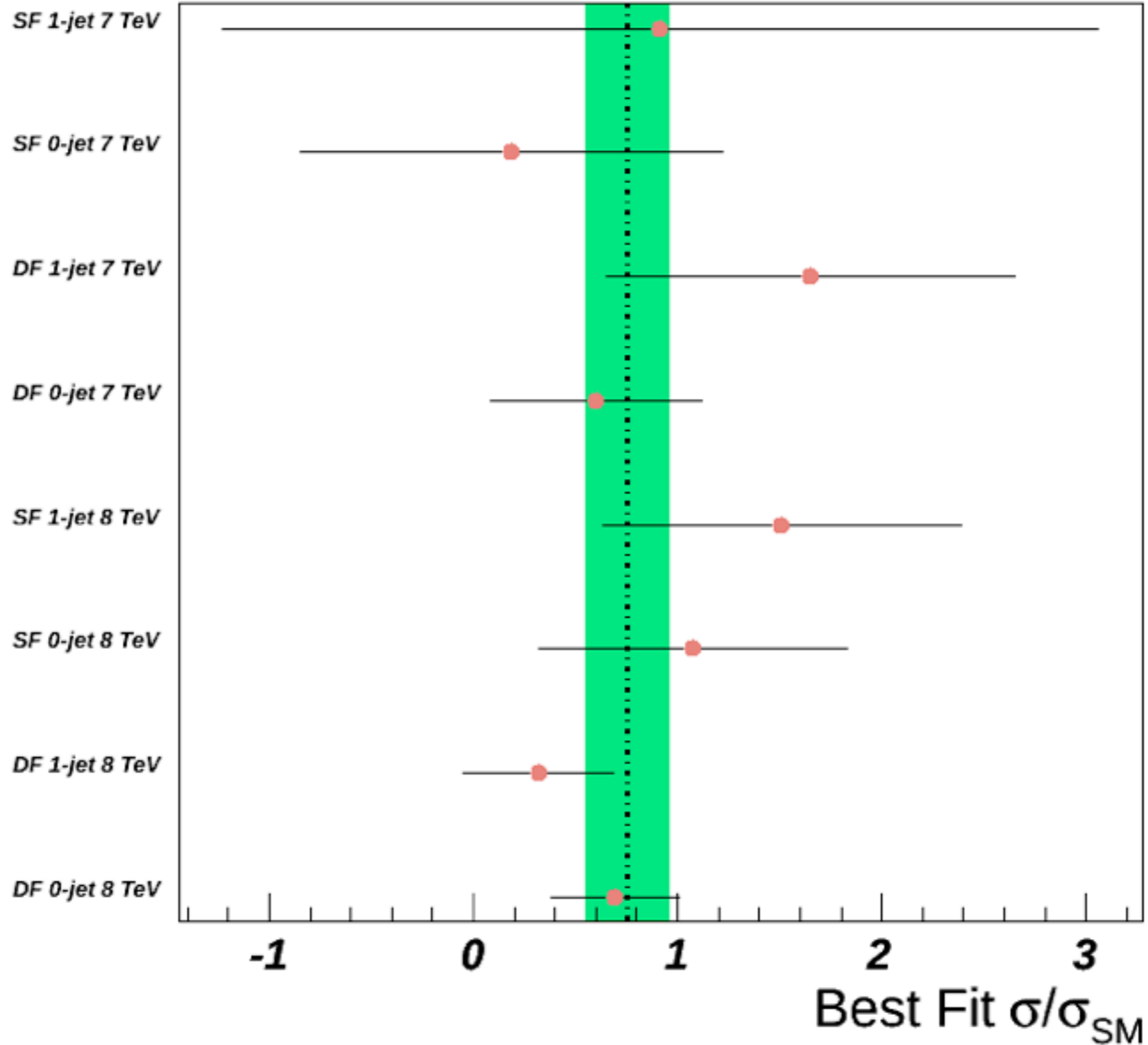


standard selection for 2D fit

Higgs to $WW \rightarrow l\nu l\nu$ CMS

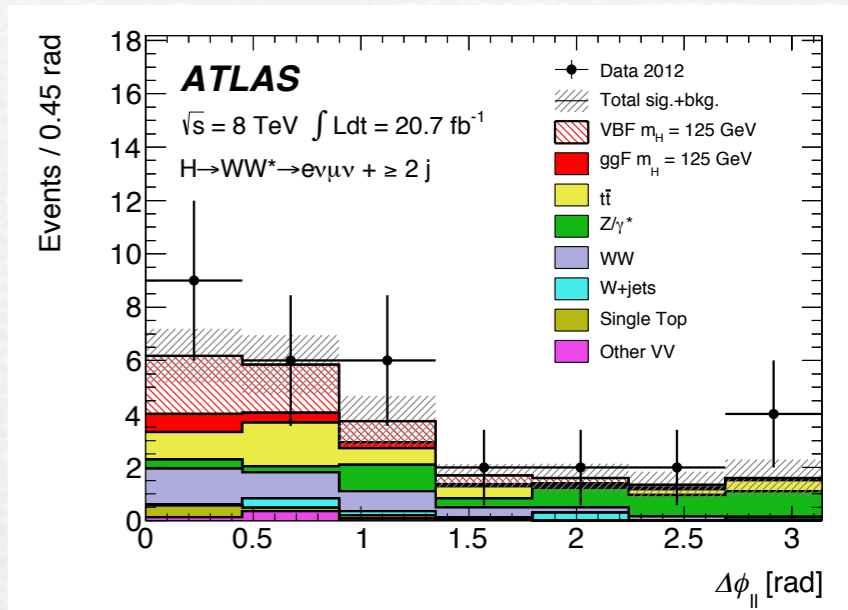
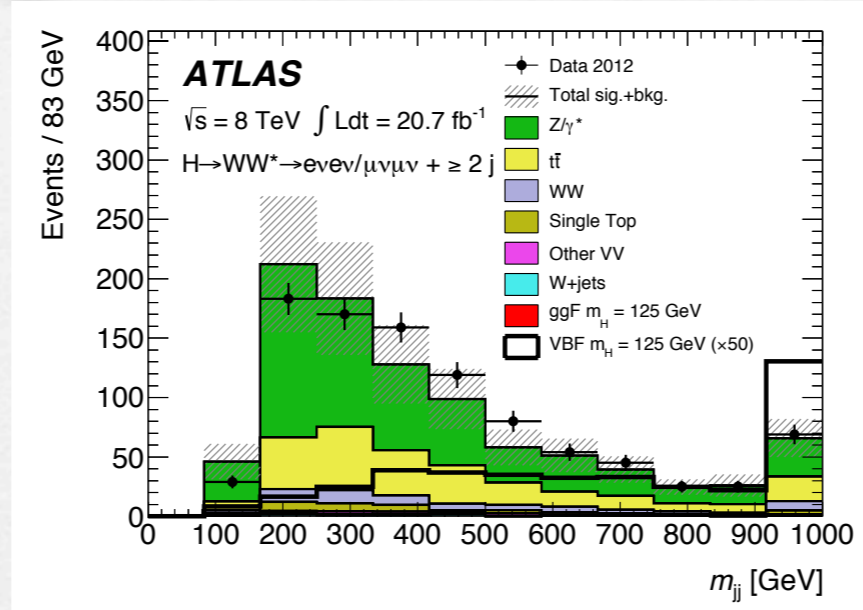
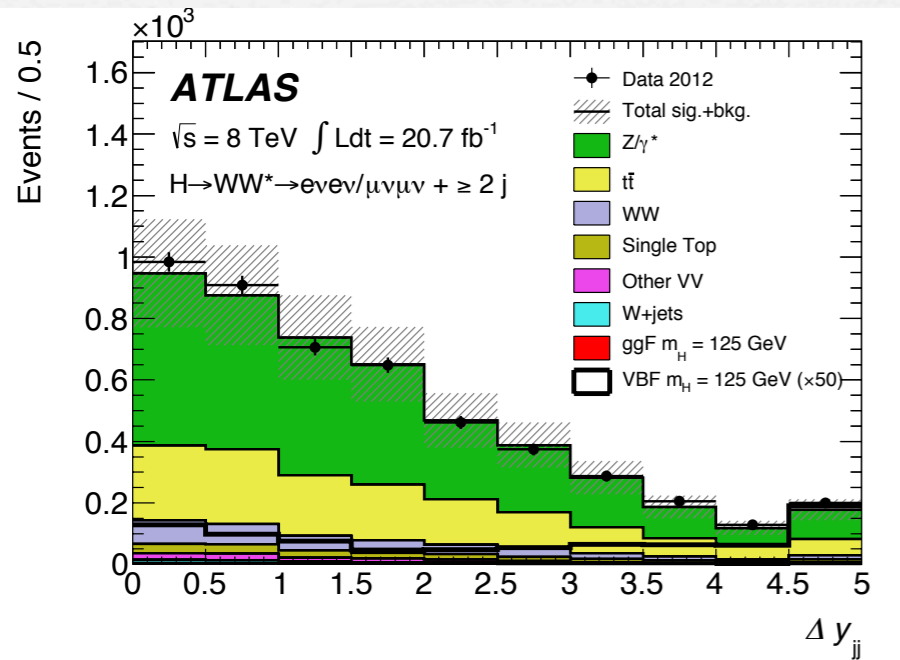
signal strength, CMS preliminary, $L = 24.4 \text{ fb}^{-1}$

CMS-PAS-HIG-13-003



Higgs to WW ATLAS

<http://arxiv.org/abs/1307.1427>



VBF SF and DF

