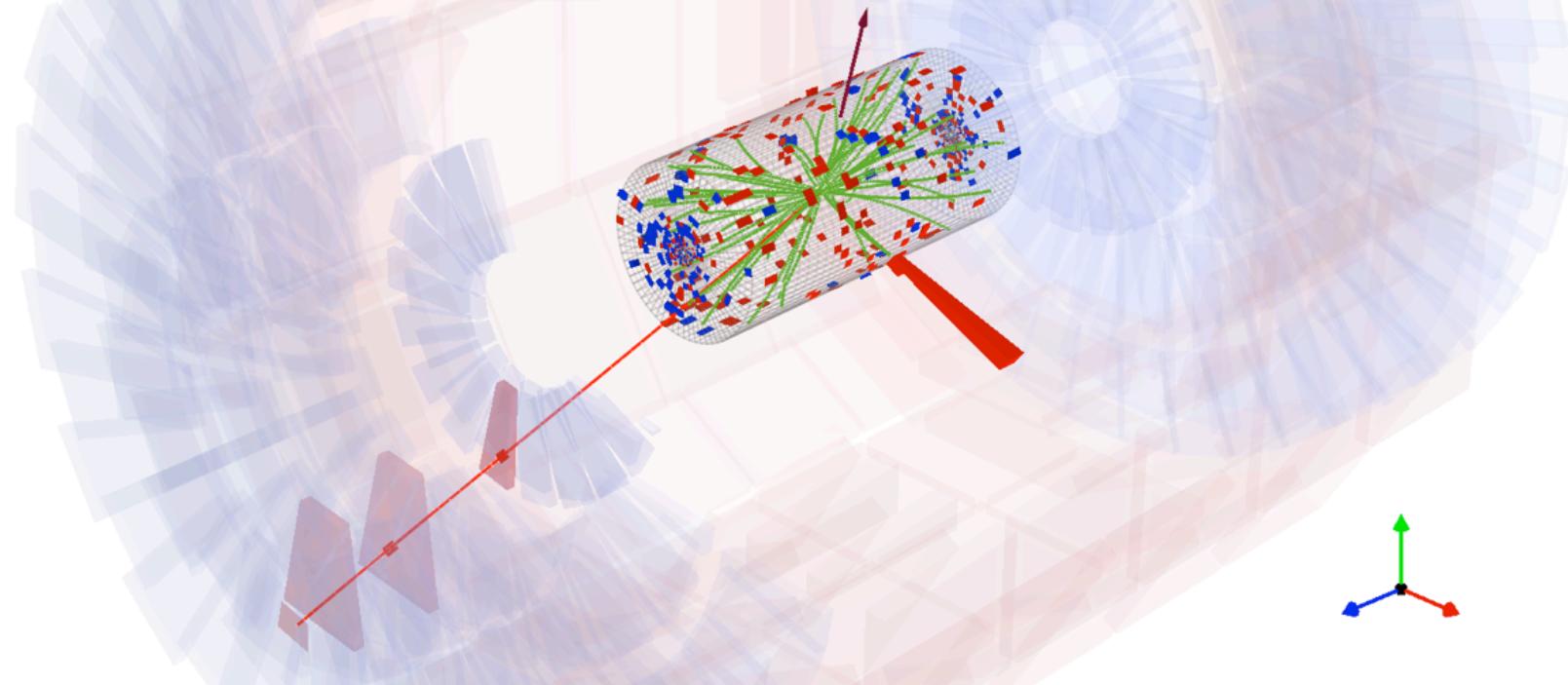




CMS Experiment at LHC, CERN
Data recorded: Sat Apr 14 18:18:05 2012 CEST
Run/Event: 191247 / 398701455
Lumi section: 272

CMS Search for Higgs in WW^*



Sergo Jindariani (Fermilab)
on behalf of CMS collaboration

$ZZ/\gamma\gamma$ -peak



WW -no peak



$ZZ/\gamma\gamma$ -peak

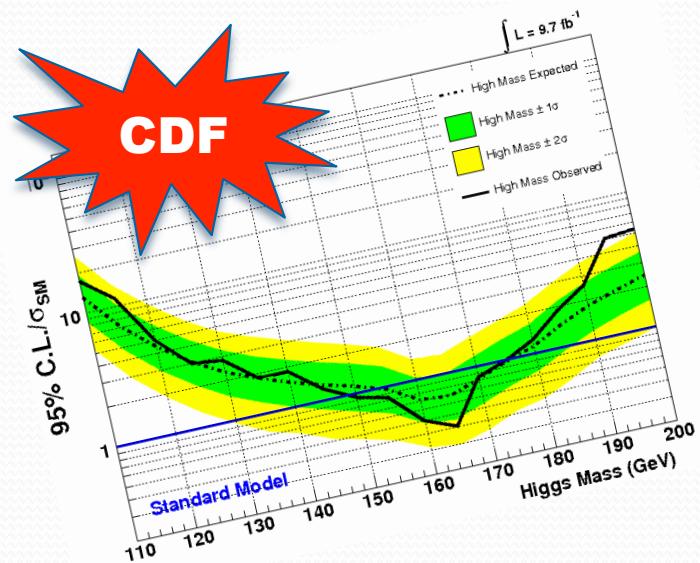


WW -no peak

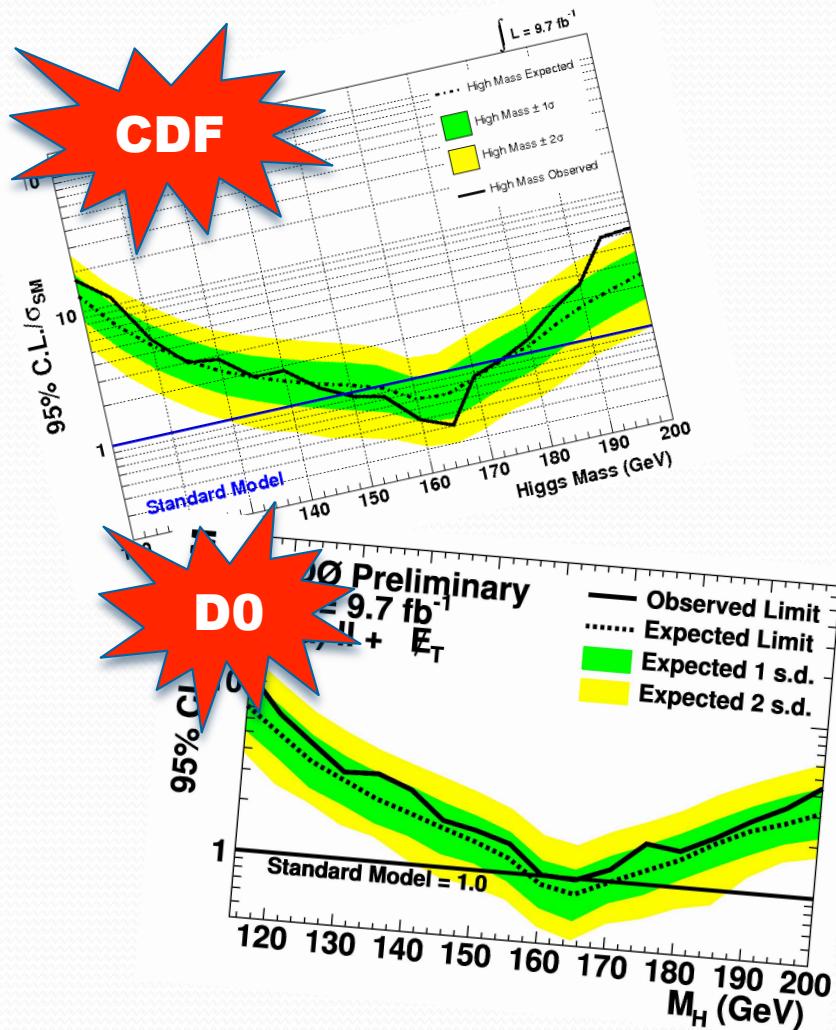


Where WW world stands?

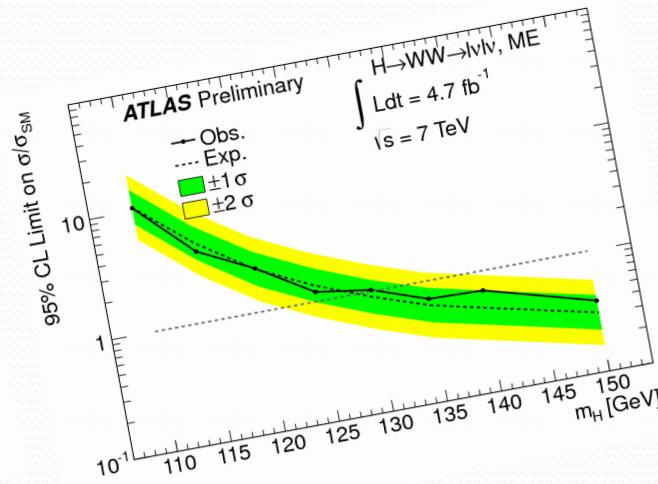
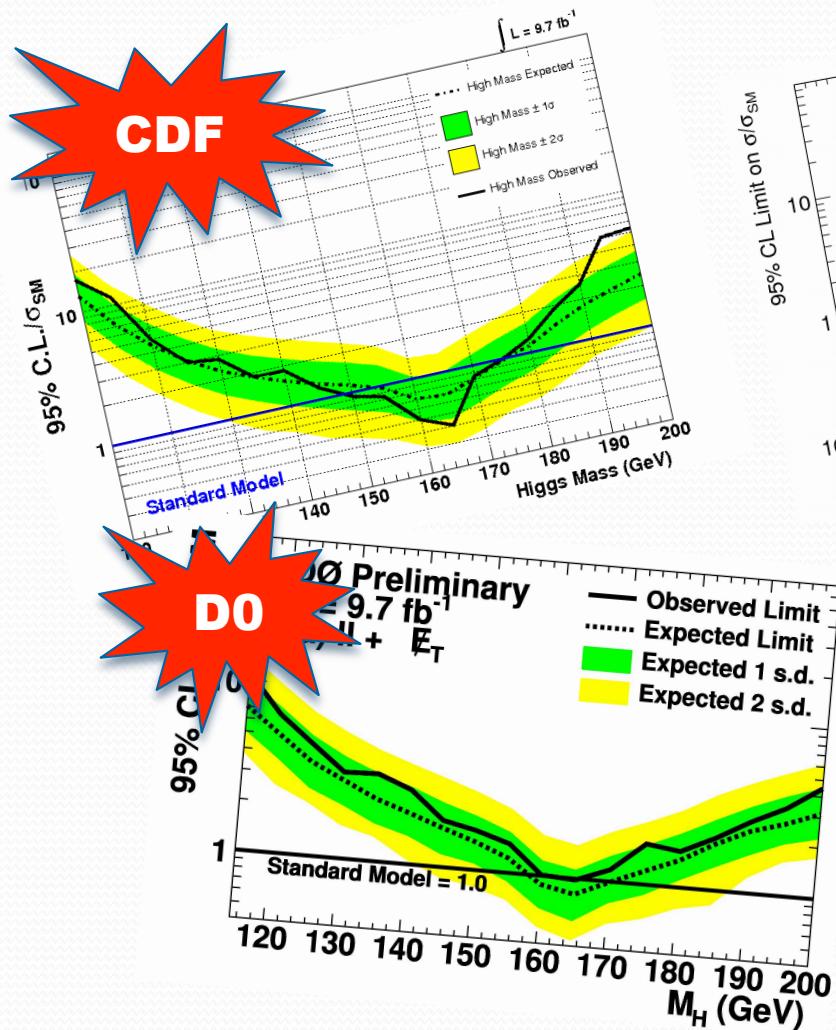
Where WW world stands?



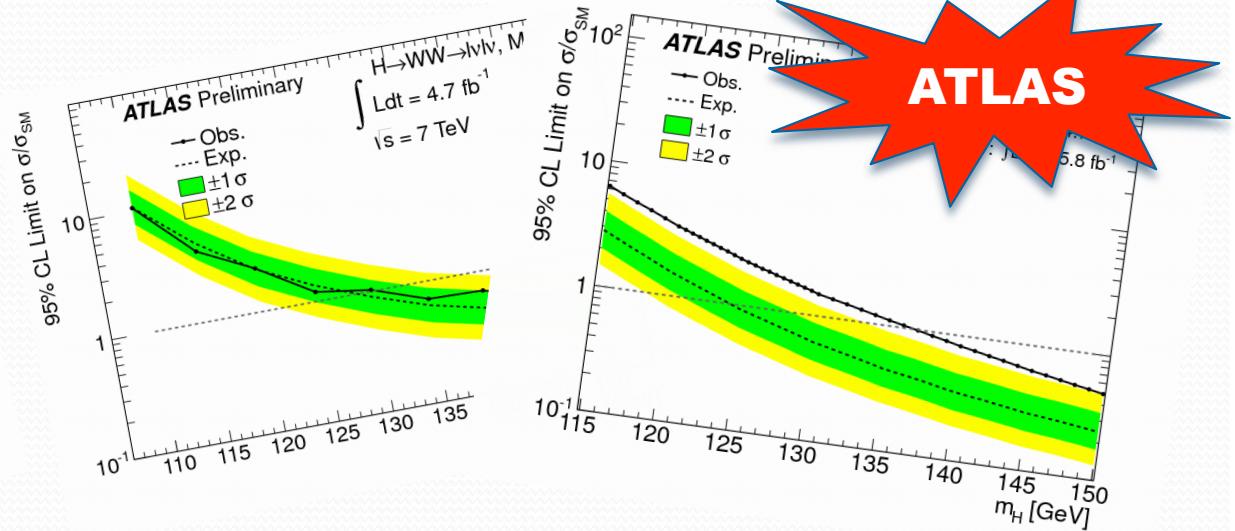
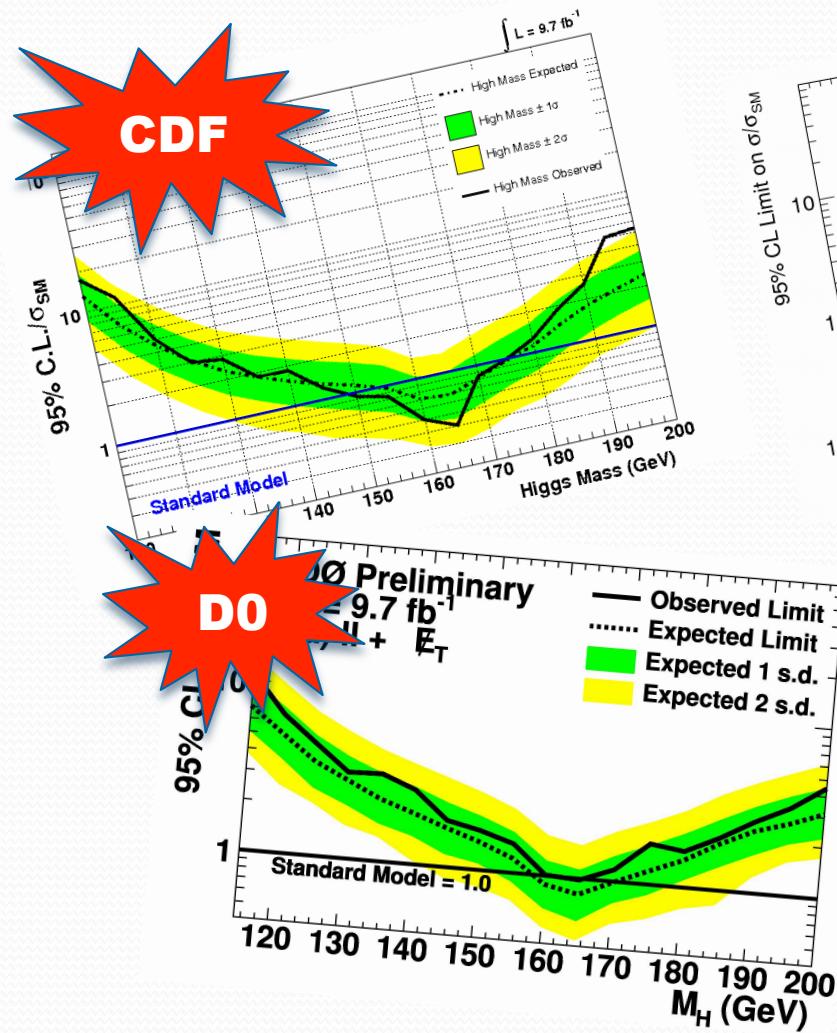
Where WW world stands?



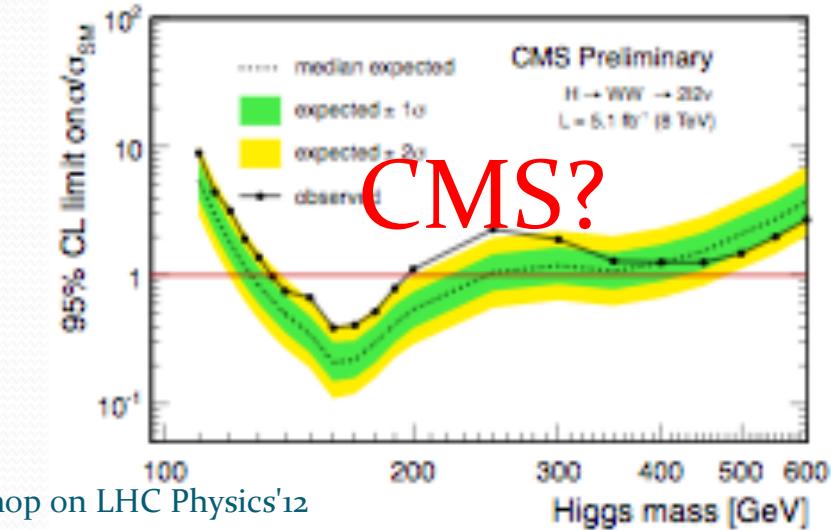
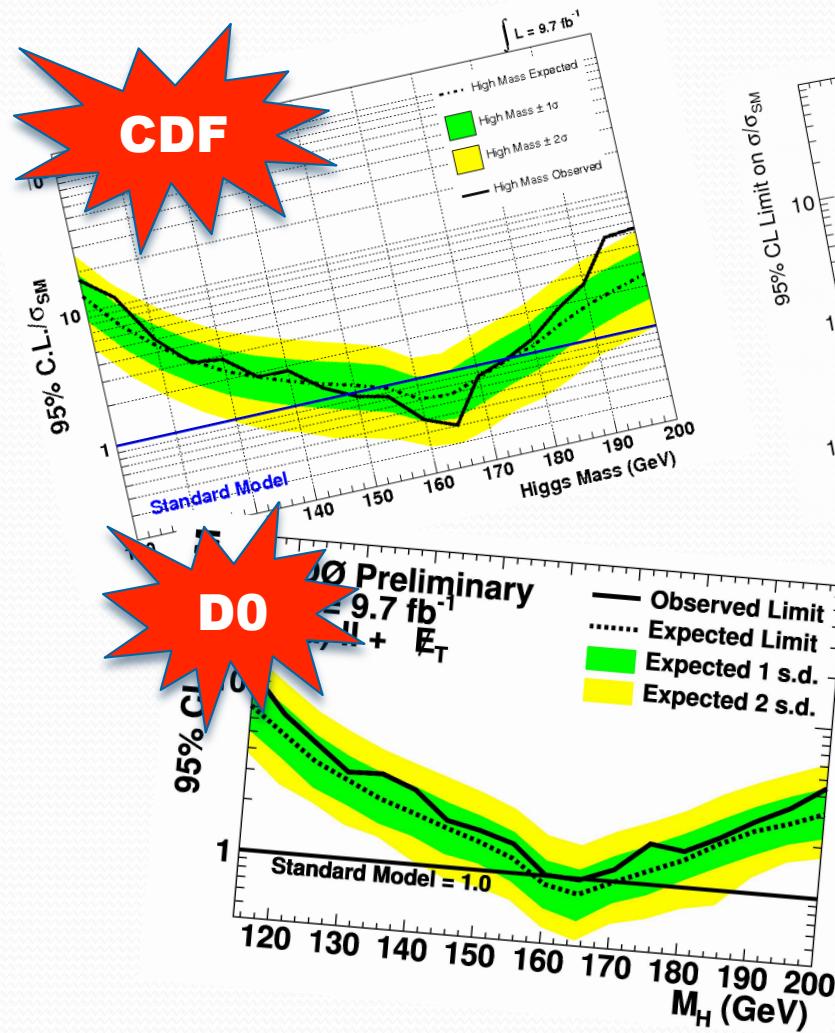
Where WW world stands?



Where WW world stands?

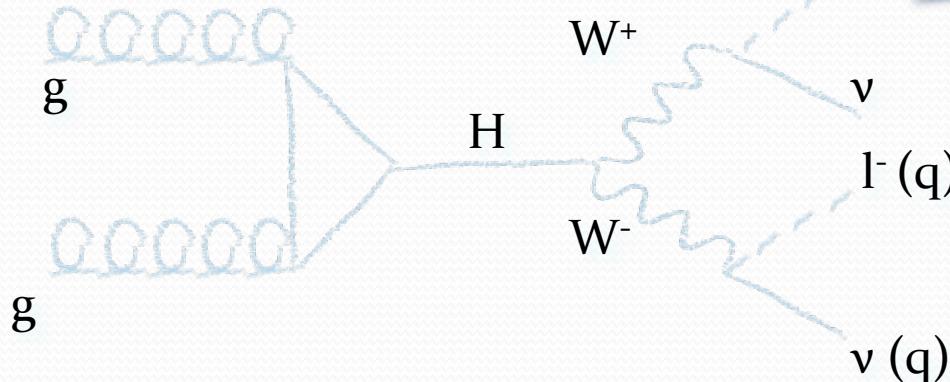


Where WW world stands?

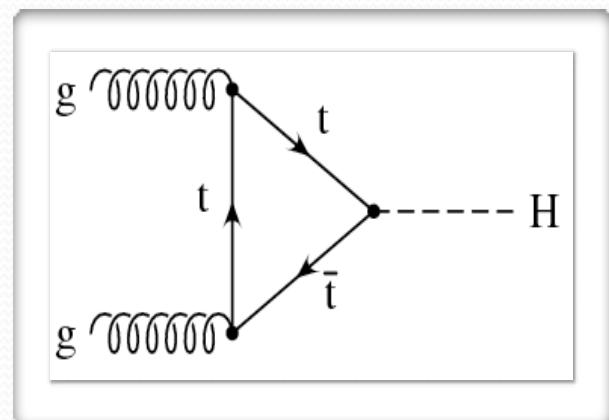


Overview:

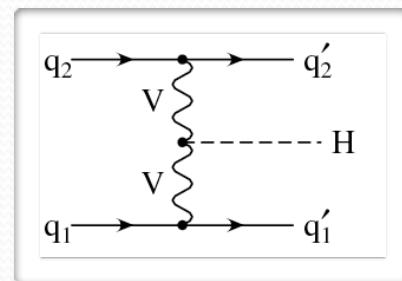
Main Diagram:



12 fb^{-1} at
8 TeV



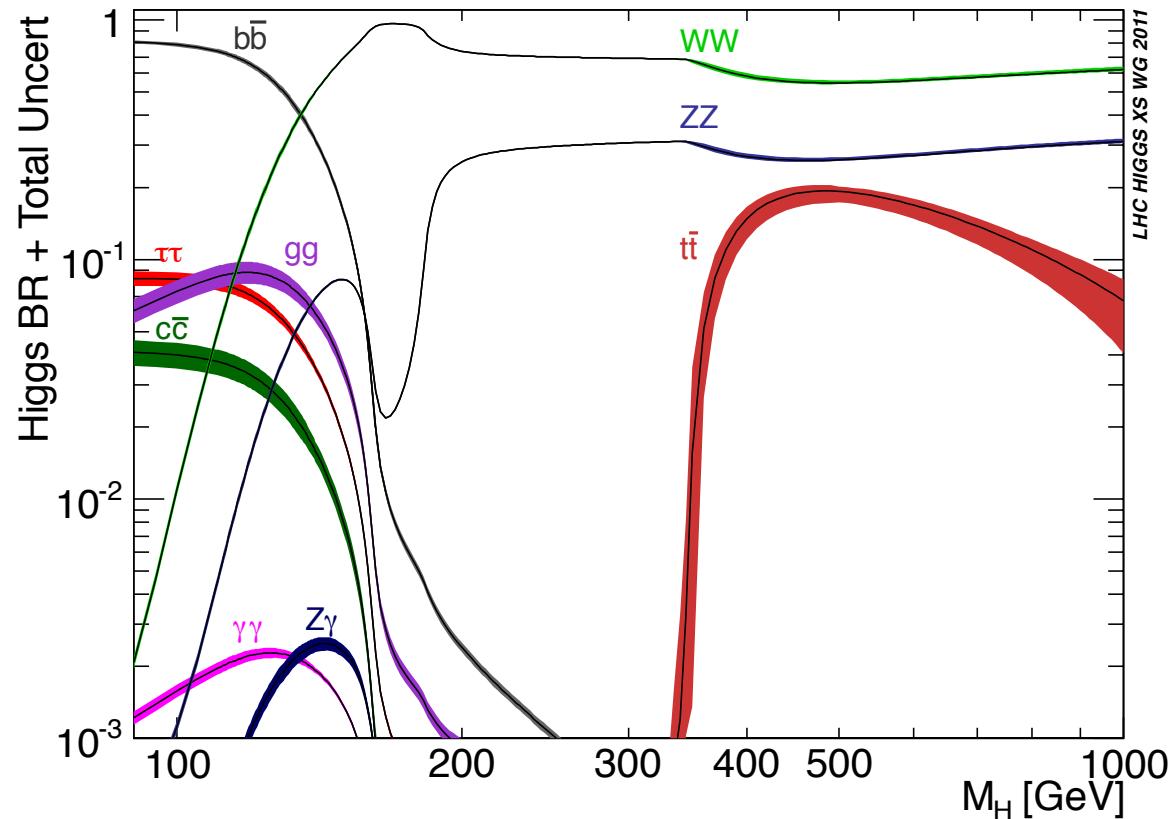
Gluon fusion



Vector Boson fusion

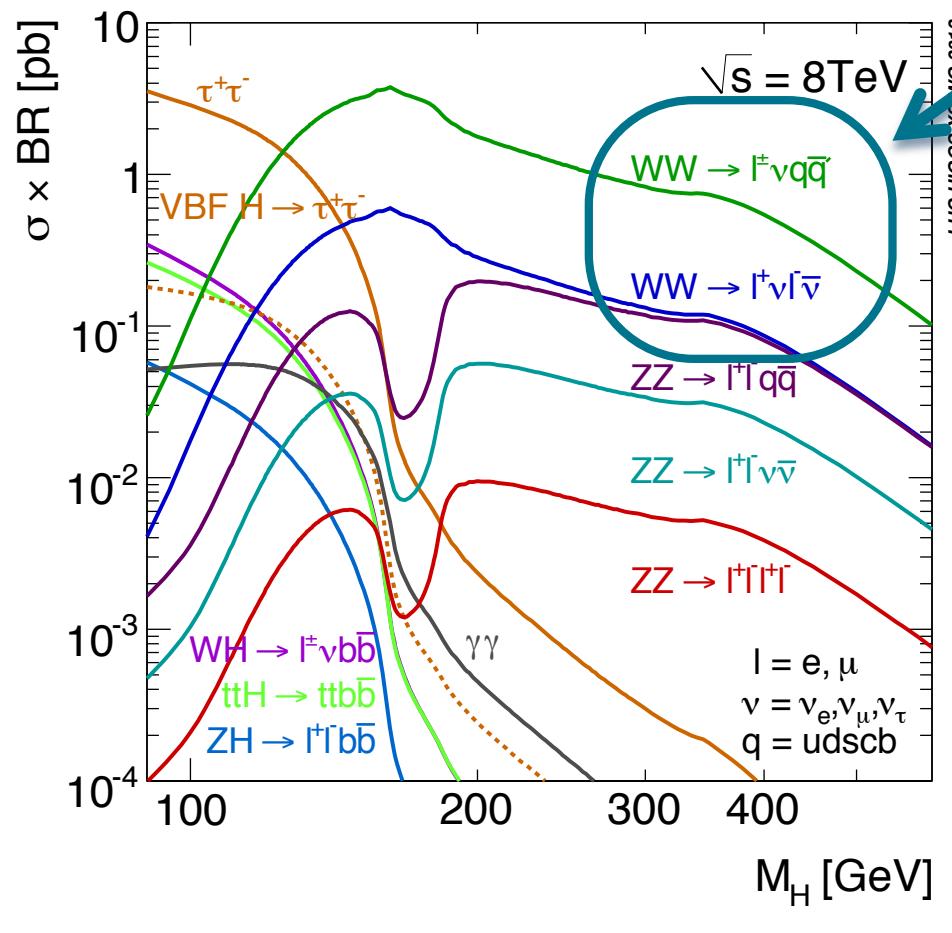
*Not covering $WH \rightarrow WWW$ in this talk
Please see CMS twiki for details

Overview:



- Largest BR for $M_H > 140$ GeV
- Contributes significantly down to 125 GeV
- Workhorse channel at the Tevatron and at the LHC

Comparing sub-channels:



Highest signal yield in most of the Higgs mass range

WW → $2l 2\nu$

WW → $qq l \nu$

Clean signature

Highest signal yield

No mass-peak

Closed Kinematics

Very large W+jets BG

125-500 GeV

200 - 600 GeV

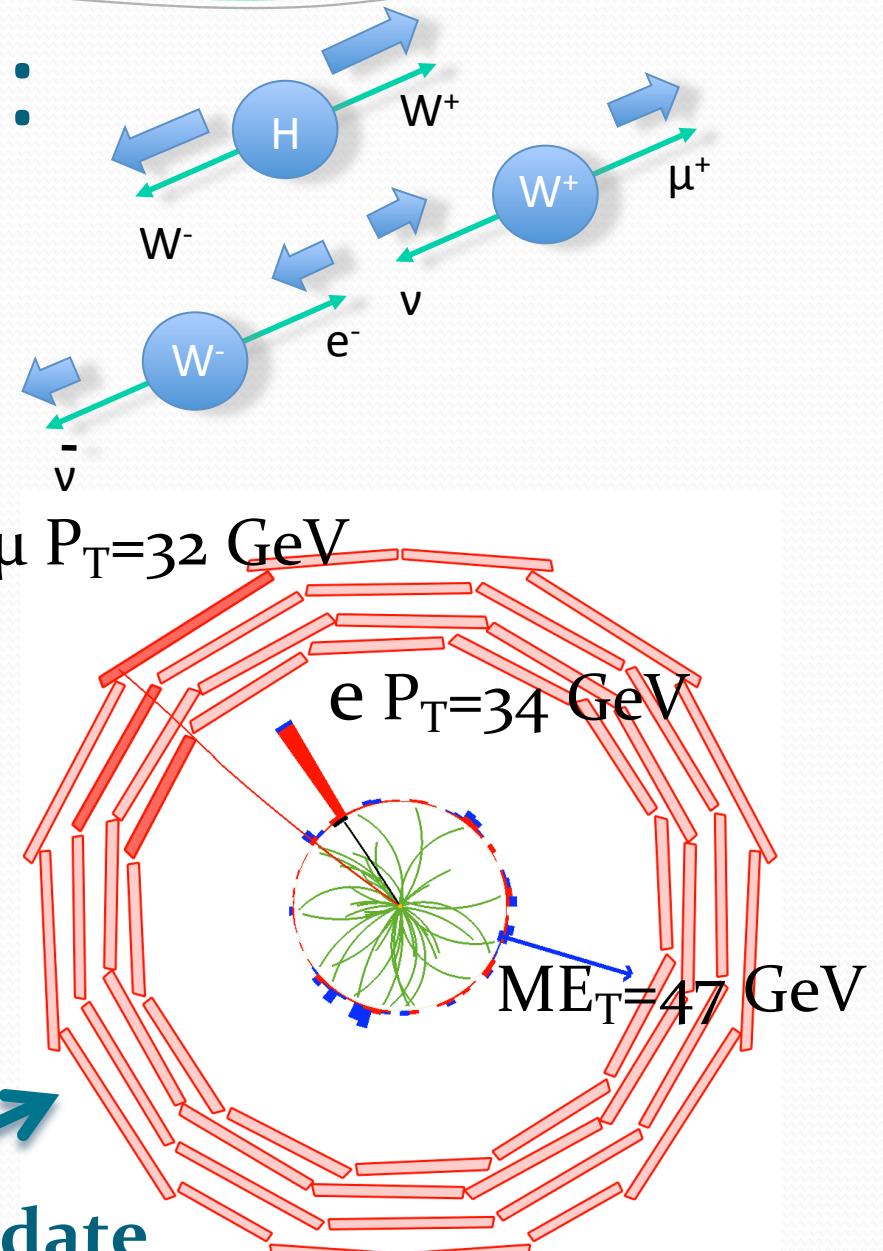
VERY LARGE SPAN!

Di-lepton channel:

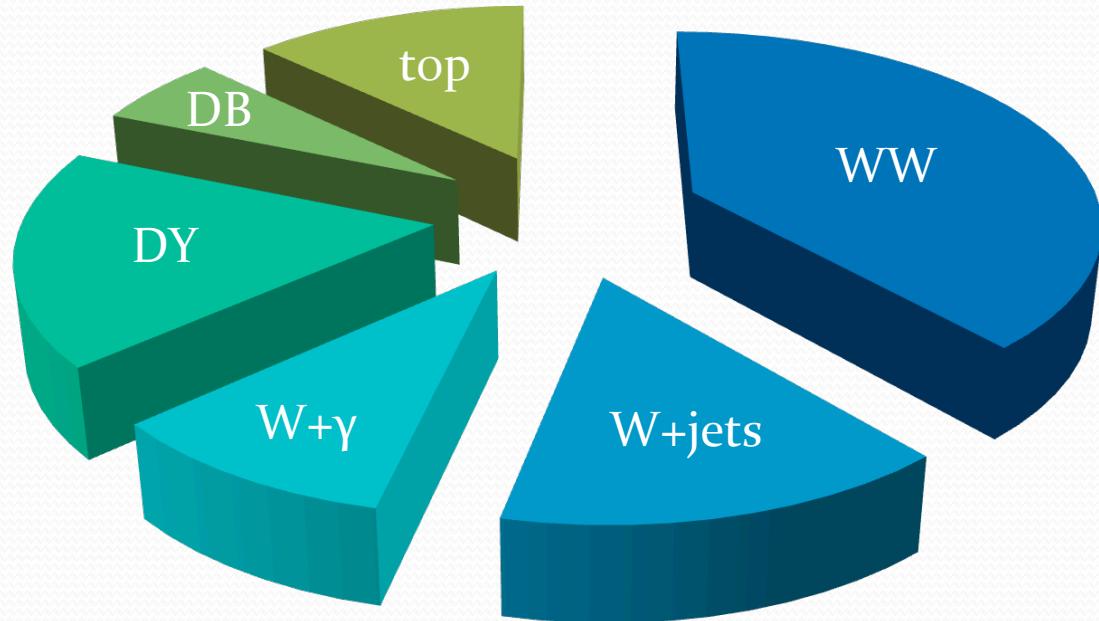
- **Signature:**
 - Two -high p_T leptons and large MET
 - No reconstructed mass-peak
- **No peak:**
 - Count events with signal-like kinematics
 - Need to know how many of them are not signal
 - Its all about backgrounds

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

Jindariani, Chicago Workshop on LH

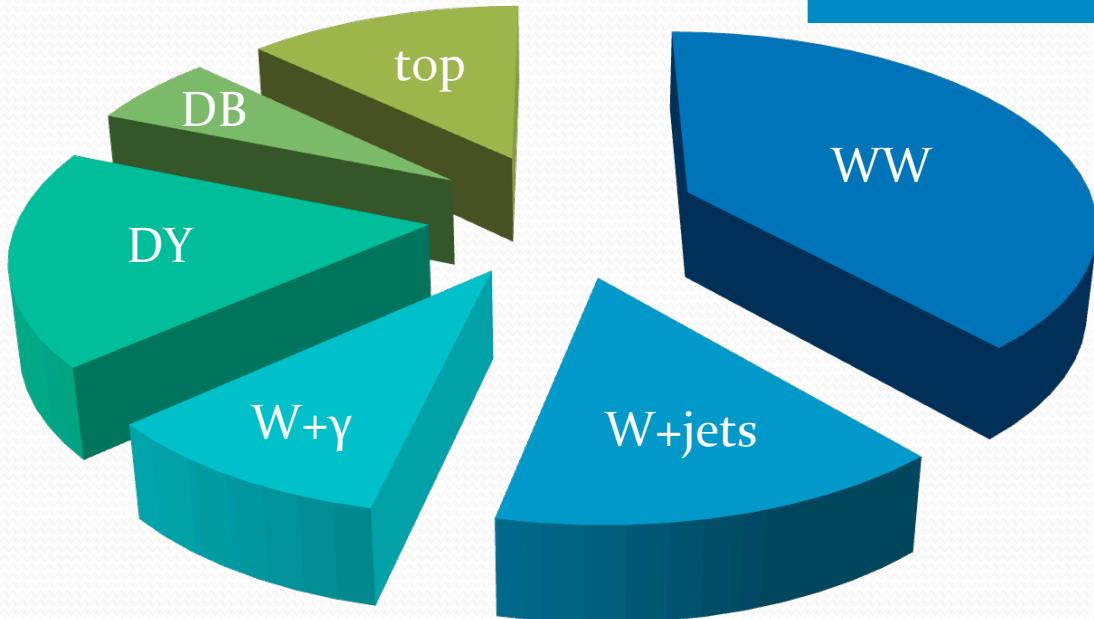


Backgrounds*



*Relative importance depends on M_H
Jindariani, Chicago Workshop on LHC Physics'12

Backgrounds*

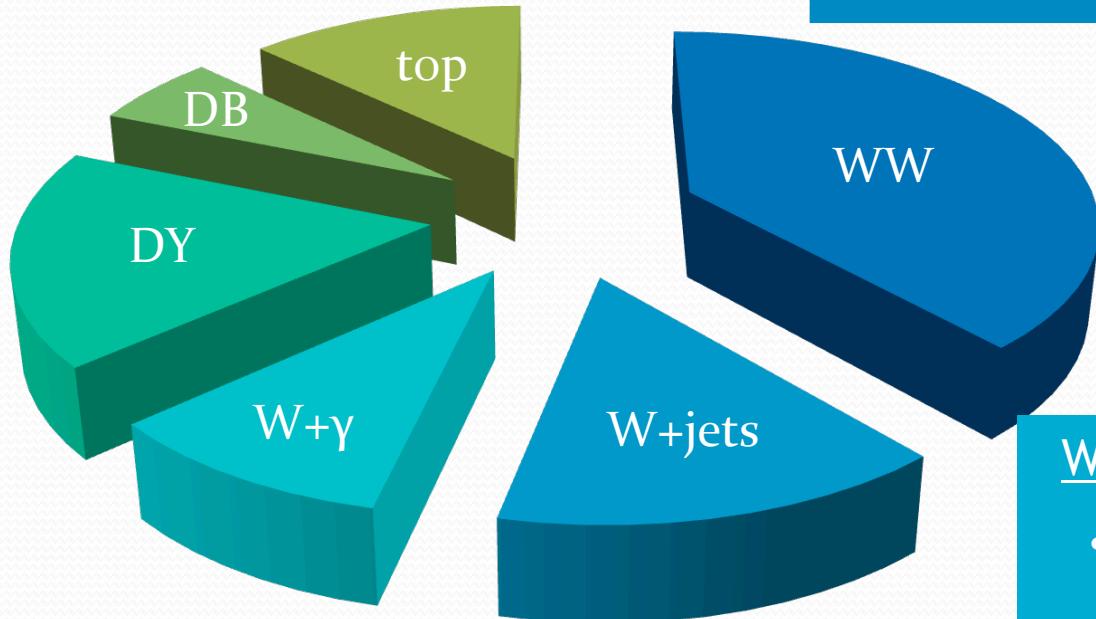


Non-resonant WW is the most important PHYSICS BG

- Looks a lot like signal
- But produced at 10x larger rate
- Reduced by requiring small $d\phi_{ll}$

*Relative importance depends on M_H
Jindariani, Chicago Workshop on LHC Physics'12

Backgrounds*



Non-resonant WW is the most important PHYSICS BG

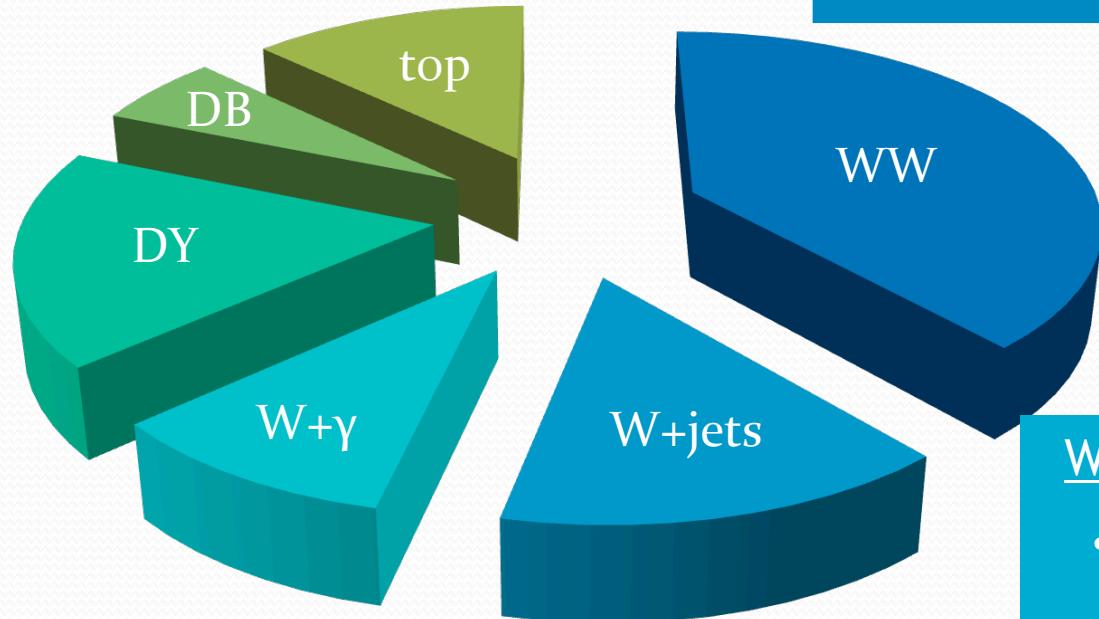
- Looks a lot like signal
- But produced at 10x larger rate
- Reduced by requiring small $d\phi_{ll}$

W+jets:

- Most important INSTRUMENTAL BG
- Jet is wrongly identified as an electron or muon
- Require 2 well identified and isolated leptons

*Relative importance depends on M_H

Backgrounds*



W+gamma

- Electron from photon conversion
- Rejected using conversion veto

Non-resonant WW is the most important PHYSICS BG

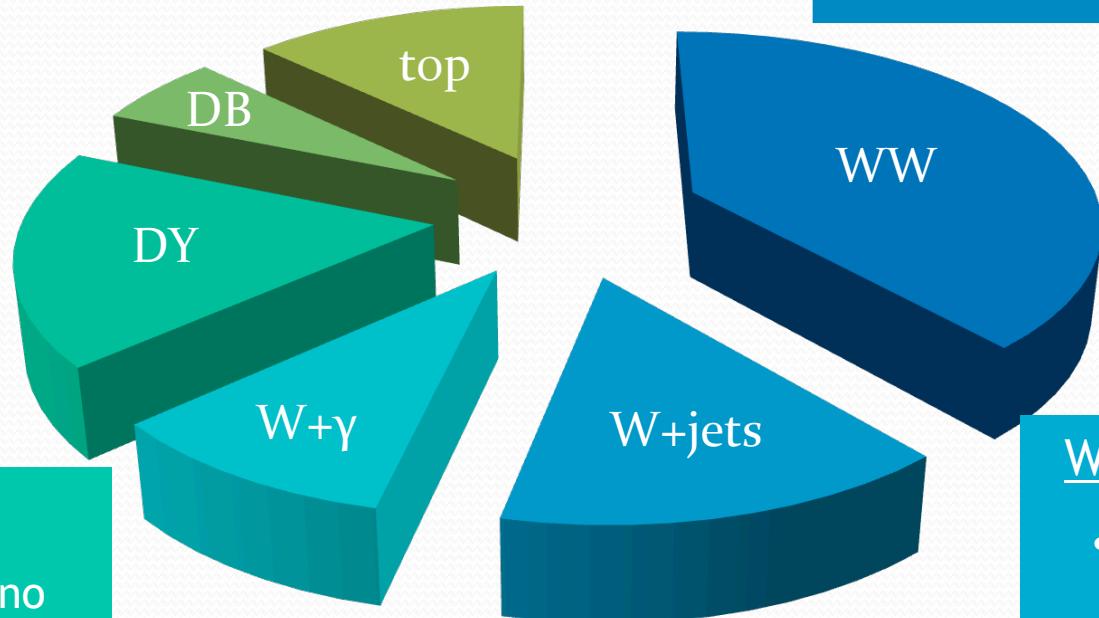
- Looks a lot like signal
- But produced at 10x larger rate
- Reduced by requiring small $d\phi_{ll}$

W+jets:

- Most important INSTRUMENTAL BG
- Jet is wrongly identified as an electron or muon
- Require 2 well identified and isolated leptons

*Relative importance depends on M_H

Backgrounds*



Drell-Yan:

- Z-peak and no real MET
- Rejected using Z-peak veto and projected-MET

W+gamma

- Electron from photon conversion
- Rejected using conversion veto

Non-resonant WW is the most important PHYSICS BG

- Looks a lot like signal
- But produced at 10x larger rate
- Reduced by requiring small $d\phi_{ll}$

W+jets:

- Most important INSTRUMENTAL BG
- Jet is wrongly identified as an electron or muon
- Require 2 well identified and isolated leptons

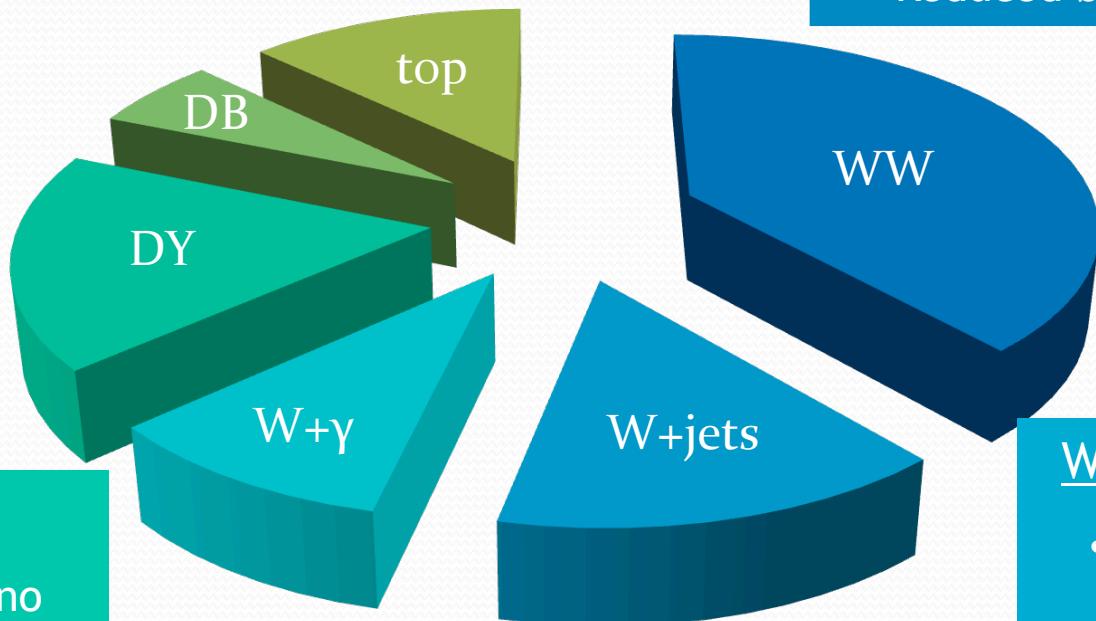
*Relative importance depends on M_H

Jindariani, Chicago Workshop on LHC Physics'12

Dibosons (WZ+ZZ):

- Z-peak veto

Backgrounds*



Drell-Yan:

- Z-peak and no real MET
- Rejected using Z-peak veto and projected-MET

W+gamma

- Electron from photon conversion
- Rejected using conversion veto

Non-resonant WW is the most important PHYSICS BG

- Looks a lot like signal
- But produced at 10x larger rate
- Reduced by requiring small $d\phi_{ll}$

W+jets:

- Most important INSTRUMENTAL BG
- Jet is wrongly identified as an electron or muon
- Require 2 well identified and isolated leptons

*Relative importance depends on M_H

Jindariani, Chicago Workshop on LHC Physics'12

Dibosons (WZ+ZZ):

- Z-peak veto

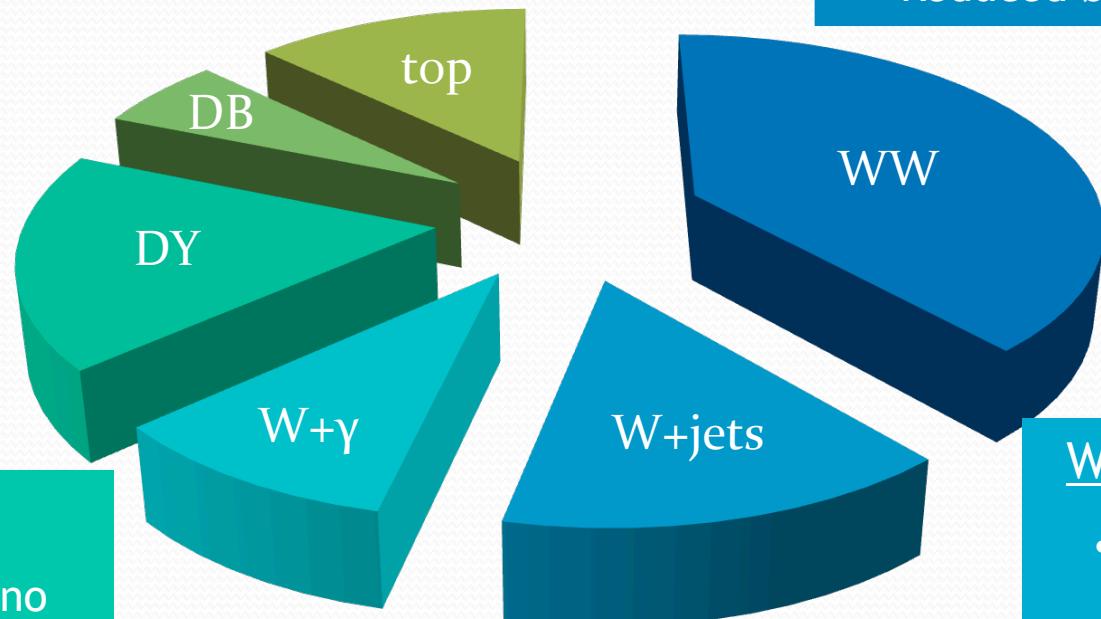
Backgrounds*

Top:

- 2 jets from b-quarks
- classify events in N_{jets}
- anti b-tagging

Non-resonant WW is the most important PHYSICS BG

- Looks a lot like signal
- But produced at 10x larger rate
- Reduced by requiring small $d\phi_{ll}$



Drell-Yan:

- Z-peak and no real MET
- Rejected using Z-peak veto and projected-MET

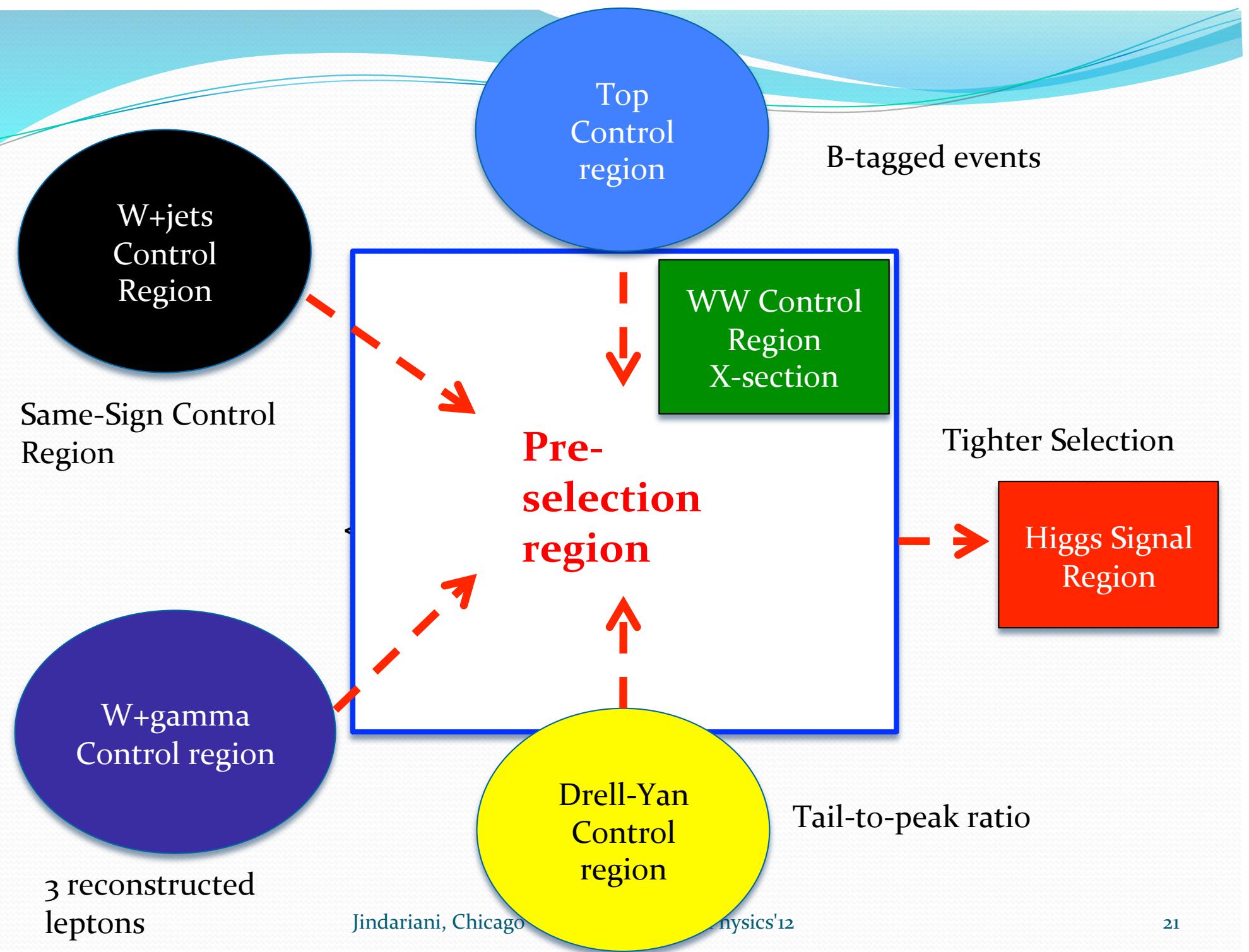
W+gamma

- Electron from photon conversion
- Rejected using conversion veto

W+jets:

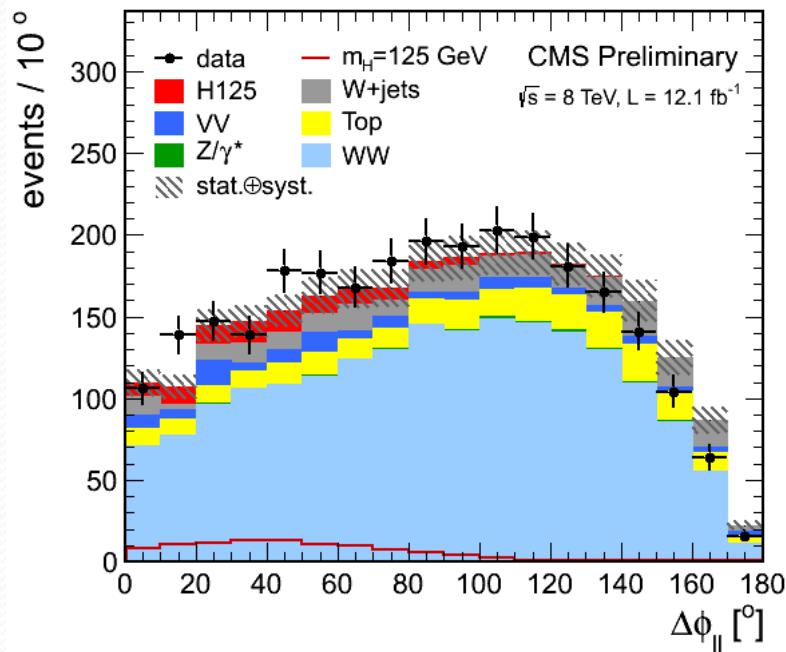
- Most important INSTRUMENTAL BG
- Jet is wrongly identified as an electron or muon
- Require 2 well identified and isolated leptons

*Relative importance depends on M_H



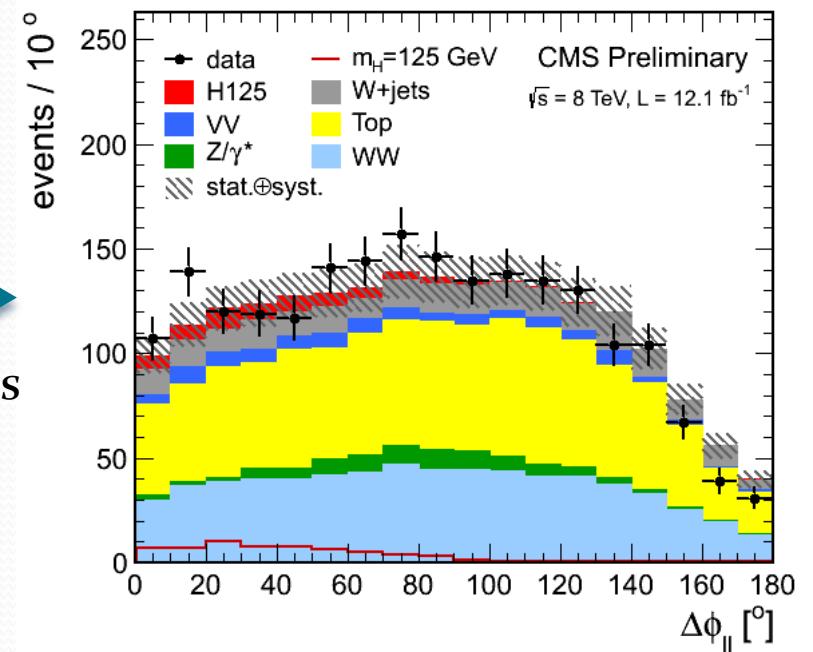
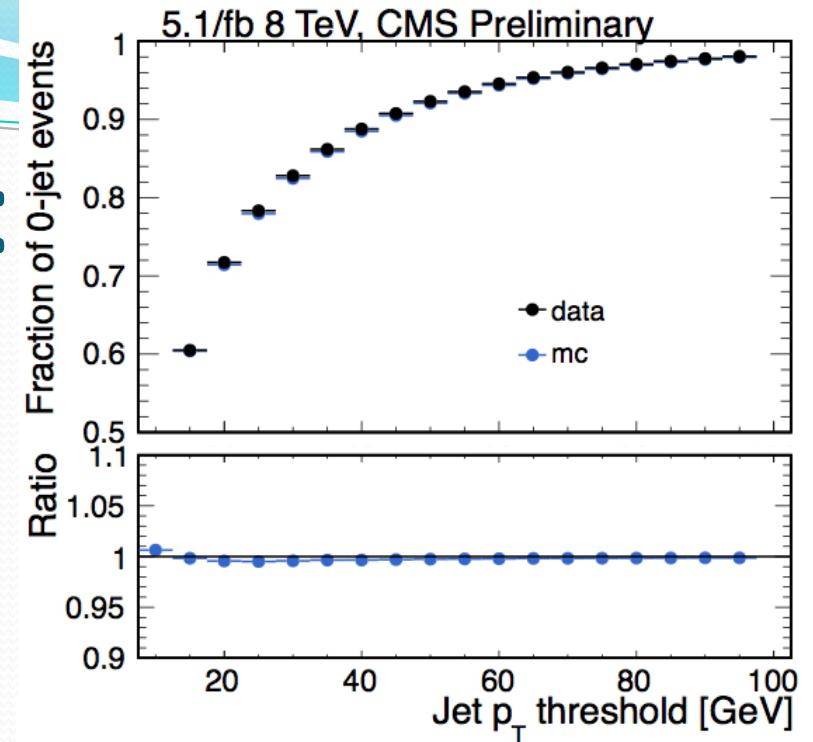
Divide and conquer:

- Categorize events based on number of jets in the final state:
 - Reduce top, isolate VBF (2j)
- Categorize events based on di-lepton flavor
 - Isolate DY



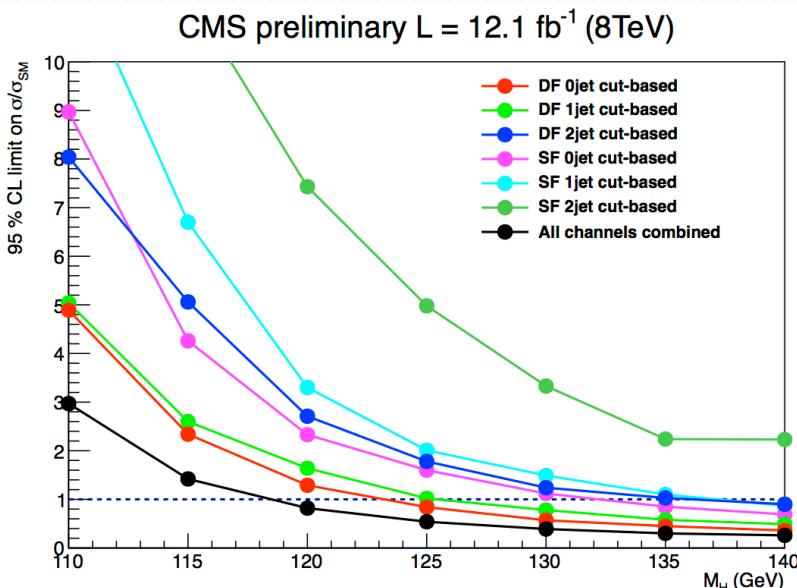
From no-jets
to one jet

Workshop on LHC Phy



Signal Extraction:

- Opposite flavor channels have higher sensitivity – take advantage of shape information
- Same-flavor states – large fake MET in high PU
 - Suffers from large systematic uncertainties
 - Cut and count there



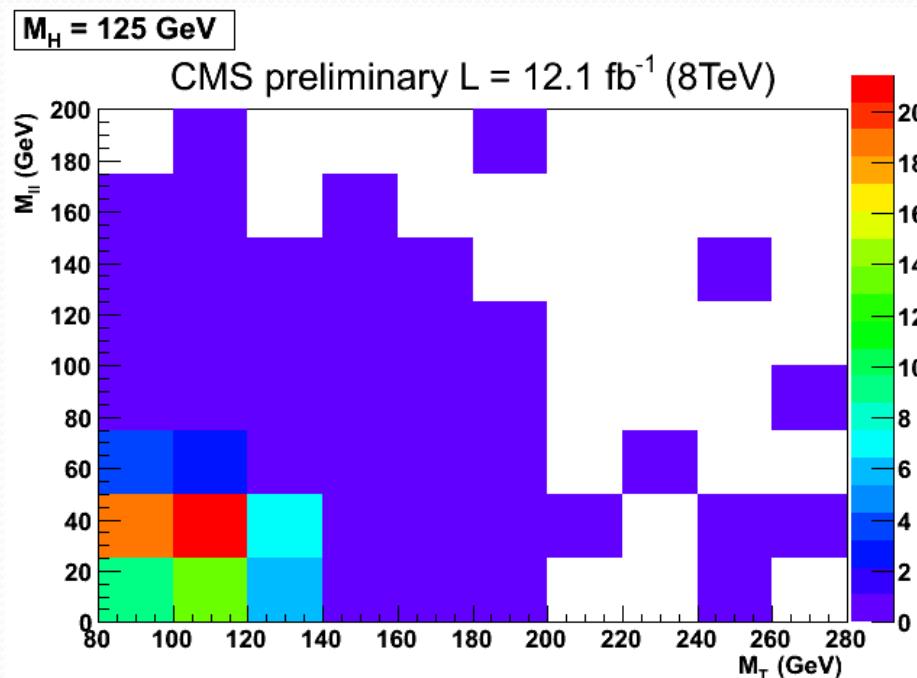
	0-Jets	1-Jets	2-Jets
Different Flavor	2D-shape	2D-shape	cut- and count
Same Flavor	cut- and count	cut- and count	cut- and count

Cut and count analysis:

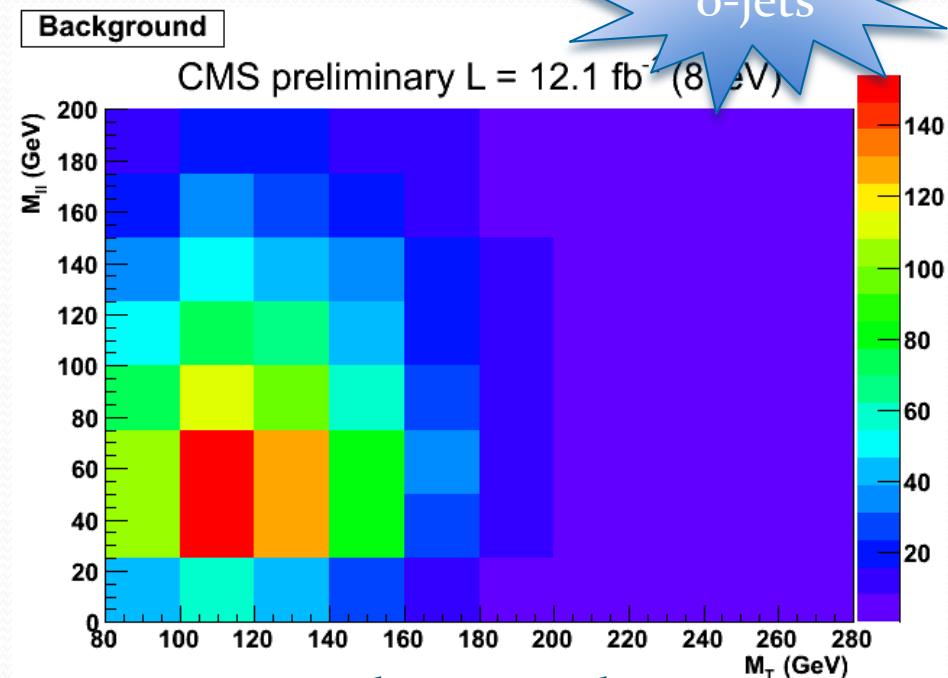
m_H	$H \rightarrow W^+W^-$	$p p \rightarrow W^+W^-$	$WZ + ZZ$ $+ Z/\gamma^* \rightarrow \ell^+\ell^-$	Top	$W + \text{jets}$	$W\gamma^{(*)}$	all bkg.	data
0-jet category $e\mu$ final state								
120	34.0 ± 7.3	162 ± 16	5.3 ± 0.5	8.6 ± 2.0	38 ± 14	23.1 ± 8.8	237 ± 23	285
125	58 ± 12	203 ± 19	6.6 ± 0.6	11.0 ± 2.5	44 ± 16	25.6 ± 9.5	291 ± 27	349
130	86 ± 18	226 ± 21	7.1 ± 0.7	12.2 ± 2.8	47 ± 17	27 ± 10	319 ± 29	388
160	238 ± 51	125 ± 12	3.7 ± 0.4	13.1 ± 3.1	5.9 ± 2.7	2.6 ± 1.5	160 ± 13	197
200	95 ± 21	204 ± 19	6.3 ± 0.6	28.9 ± 6.4	7.7 ± 3.5	1.3 ± 0.9	278 ± 21	309
400	40 ± 11	133 ± 15	6.2 ± 0.7	50 ± 11	7.6 ± 3.3	3.5 ± 2.1	200 ± 19	198
600	6.6 ± 2.3	42.2 ± 4.8	2.5 ± 0.3	16.5 ± 3.8	4.4 ± 2.0	2.4 ± 1.8	67.9 ± 6.7	64
0-jet category $ee/\mu\mu$ final state								
120	20.8 ± 4.5	108 ± 10	4.8 ± 1.4	3.9 ± 1.1	24.5 ± 9.3	5.8 ± 2.5	191 ± 20	209
125	37.0 ± 8.0	140 ± 13	5.9 ± 1.8	5.2 ± 1.3	30 ± 11	6.7 ± 2.8	241 ± 25	266
130	57 ± 12	162 ± 15	6.7 ± 2.0	6.2 ± 1.5	30 ± 11	7.7 ± 3.1	273 ± 28	295
160	209 ± 45	107 ± 10	17.6 ± 7.4	7.0 ± 1.7	5.2 ± 2.7	1.2 ± 0.7	138 ± 13	161
200	77 ± 17	177 ± 16	19.6 ± 4.2	21.9 ± 4.9	9.0 ± 4.1	1.8 ± 0.9	230 ± 18	249
400	34.0 ± 9.2	117 ± 13	34 ± 16	40.1 ± 8.7	4.4 ± 2.4	34 ± 11	230 ± 25	180
600	5.7 ± 2.0	38.2 ± 4.4	4.8 ± 0.4	11.6 ± 2.7	1.8 ± 1.3	5.0 ± 2.1	61.3 ± 5.7	61

Shape analysis:

- 2D [M_T , M_{ll}]
 - Allows good discriminations against WW and W+jets



Signal

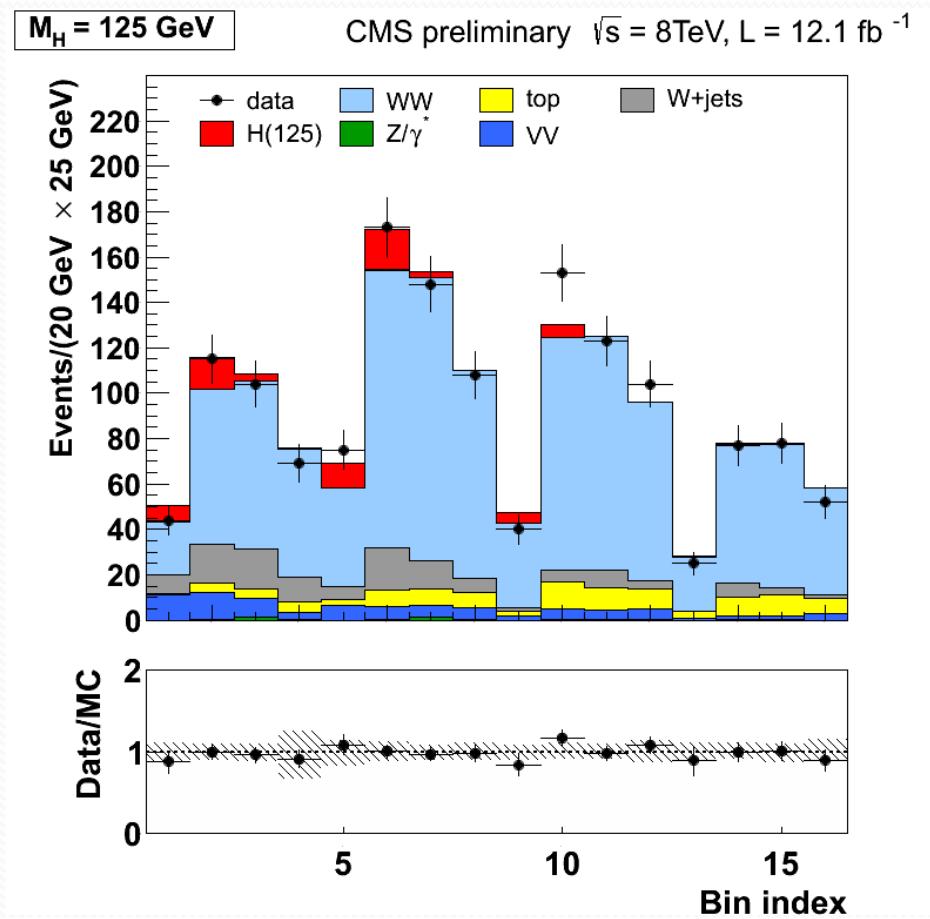
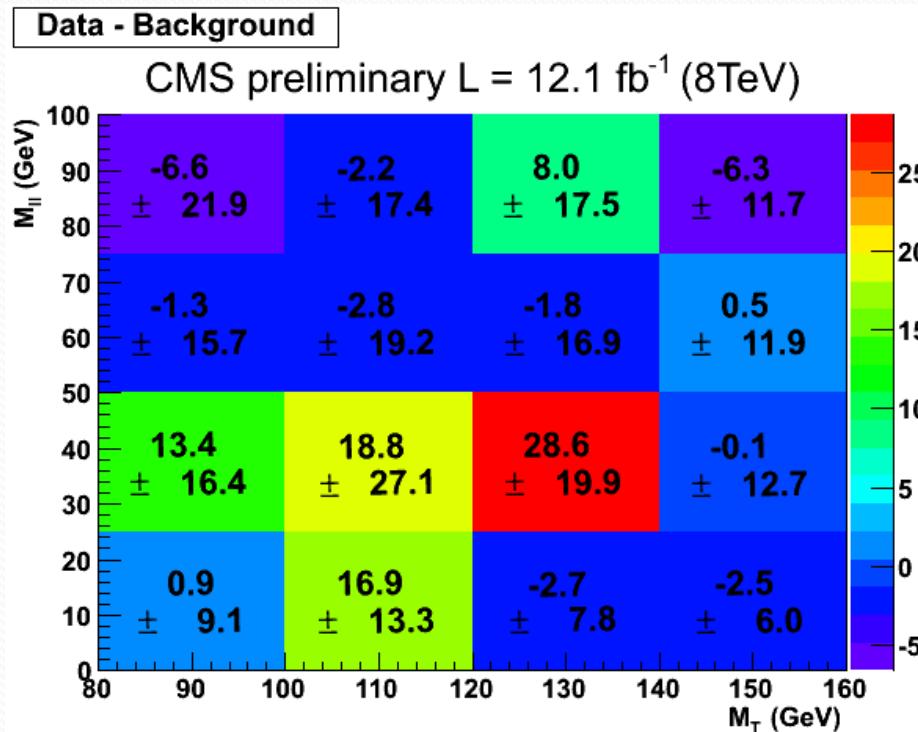


Background

Shape analysis (0-jets):



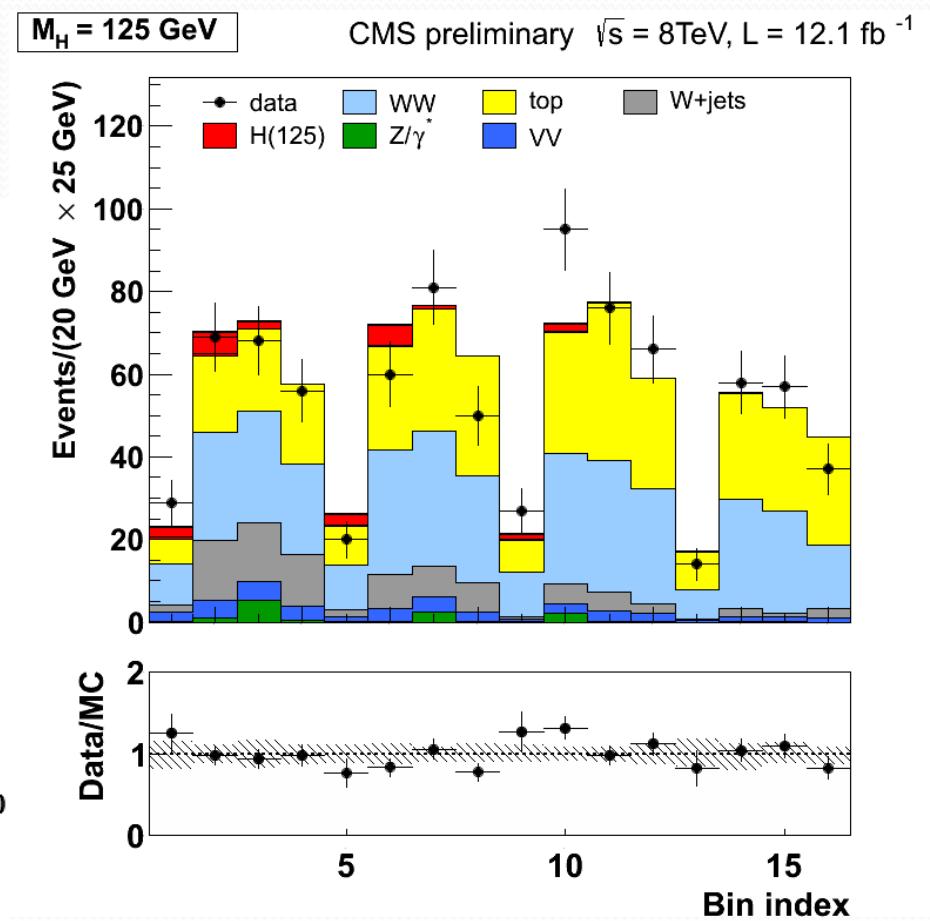
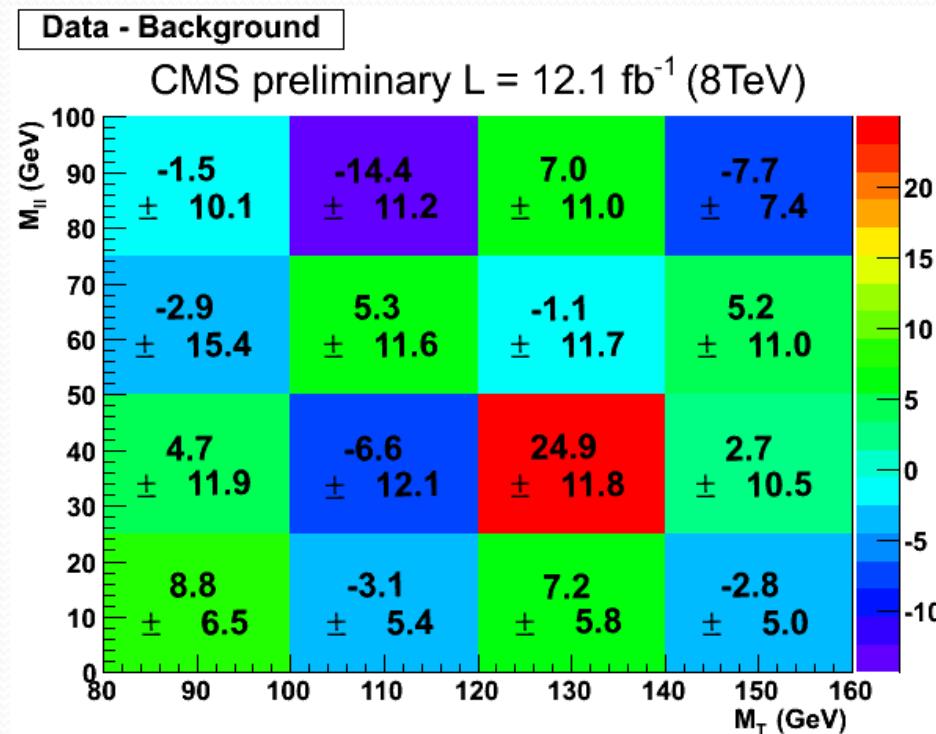
- Plot (data-Background) in 2D
- Can also unroll into a 1D distribution



Shape analysis (1-jet):



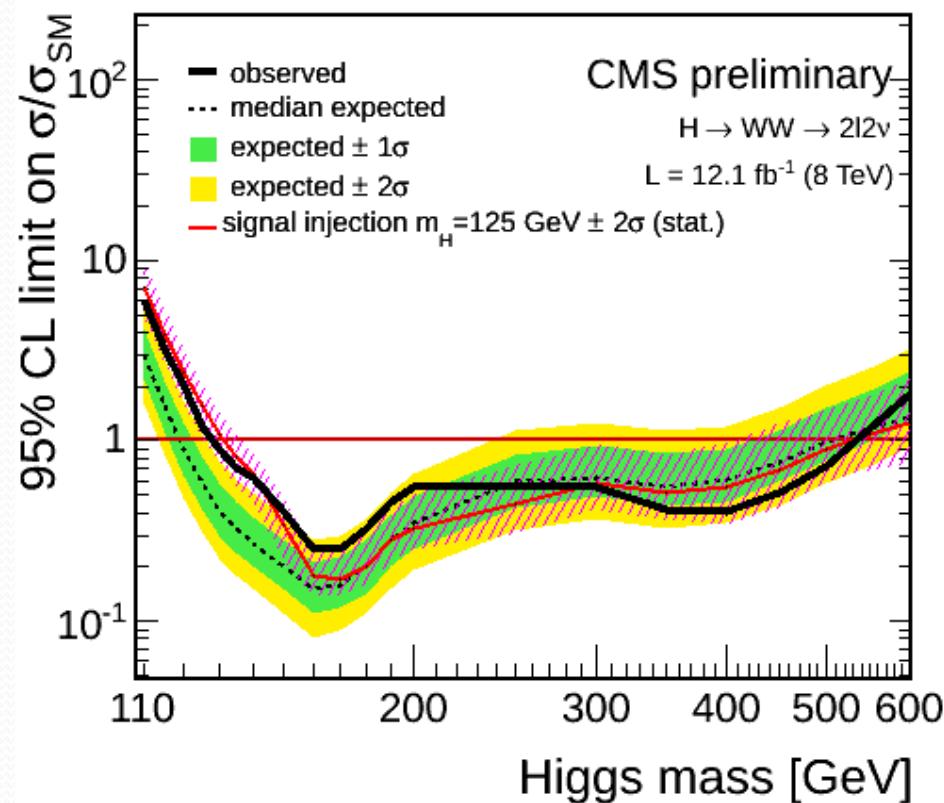
- Same plots but for events with 1 jet



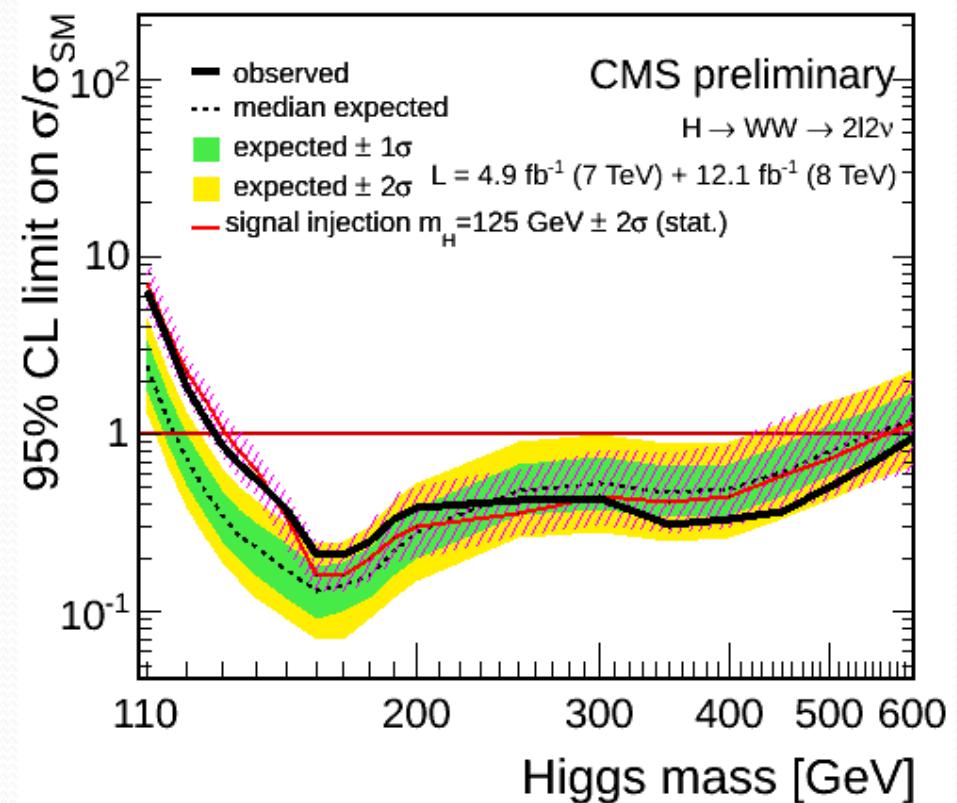
Putting everything together:

Putting everything together:

8 TeV only



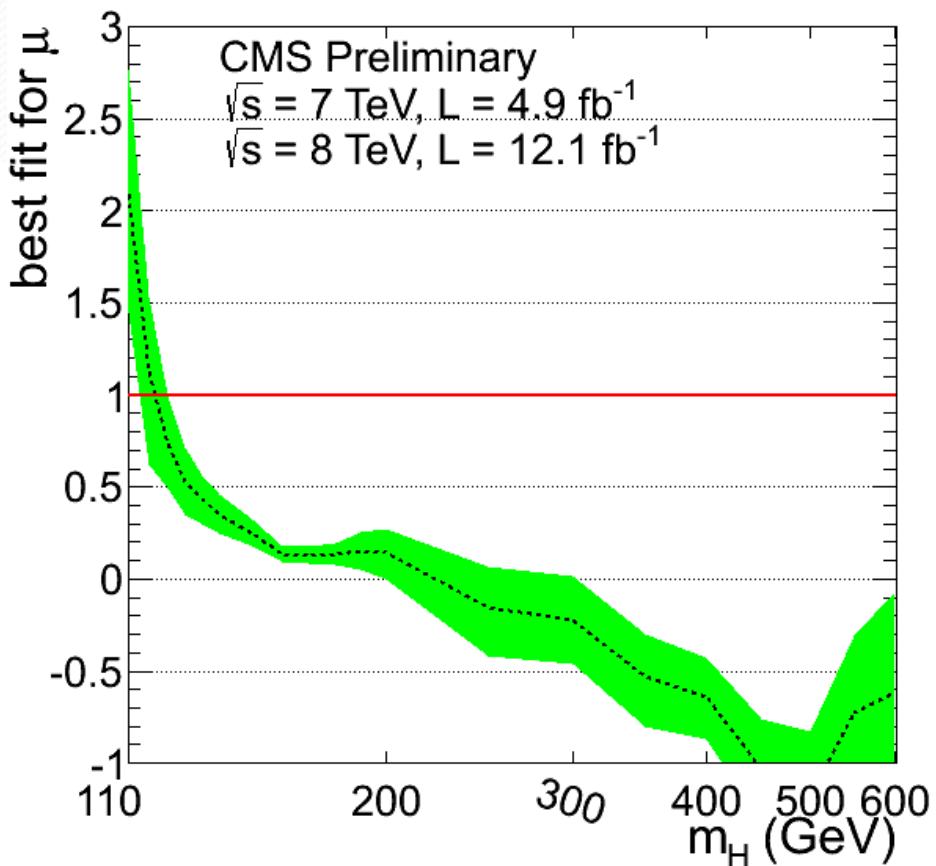
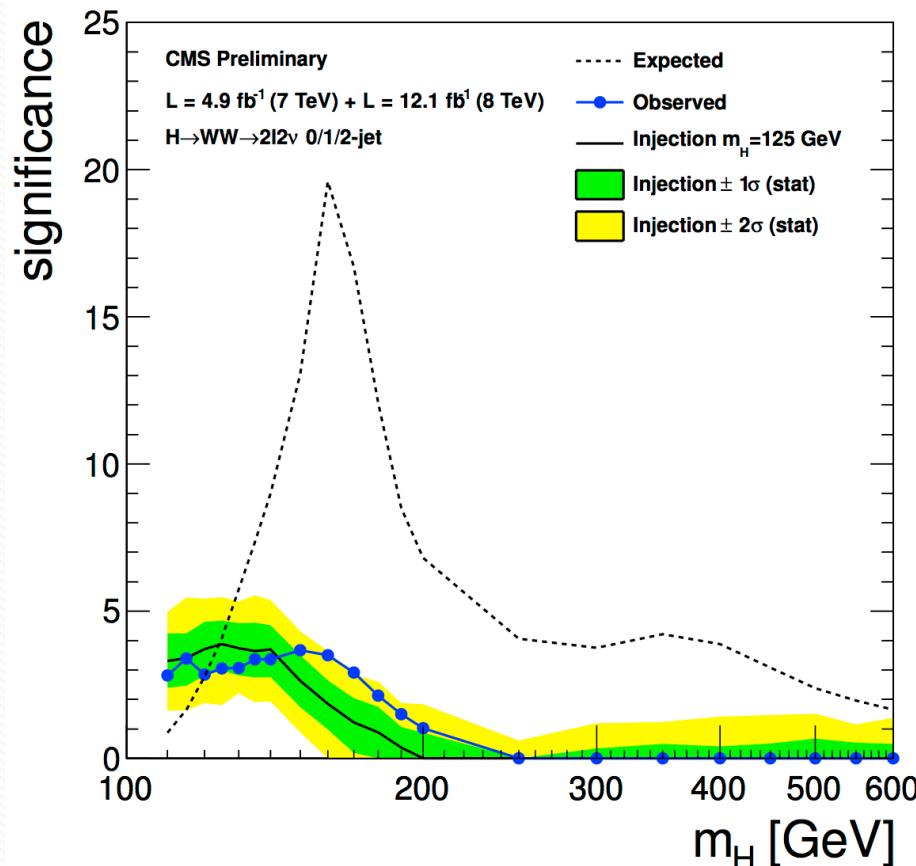
7+8 TeV



Sizable excess can be seen in both plots

Anatomy of the excess:

Expected/Observed
significance 4.1 (3.1) sigma

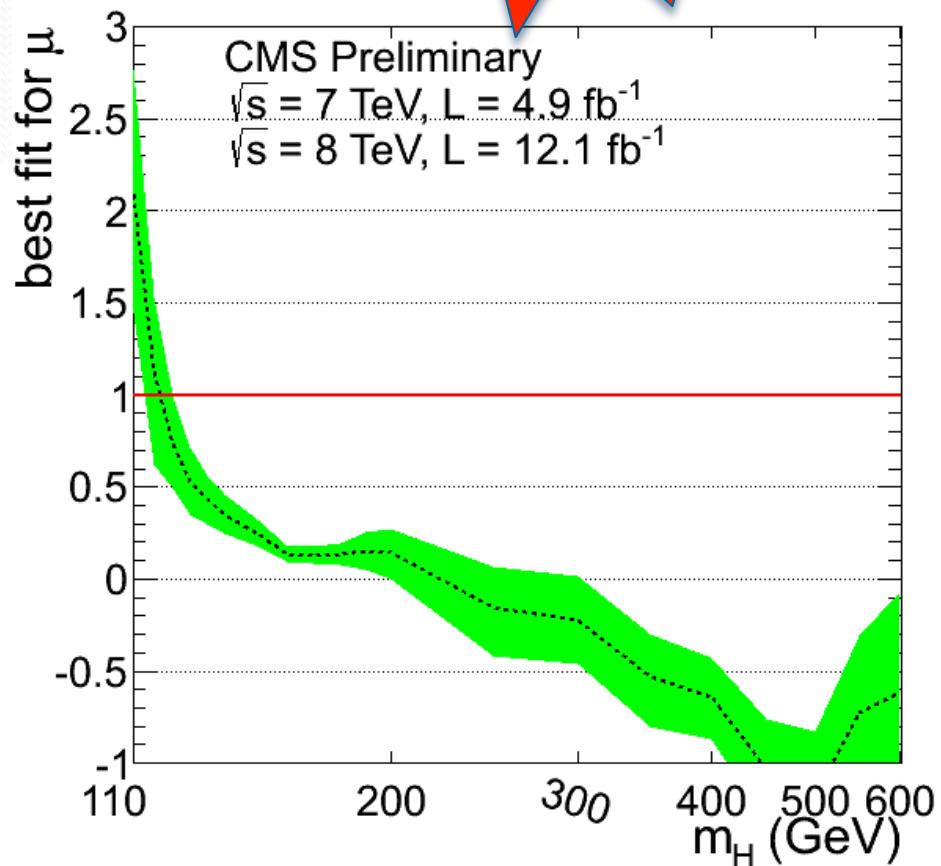
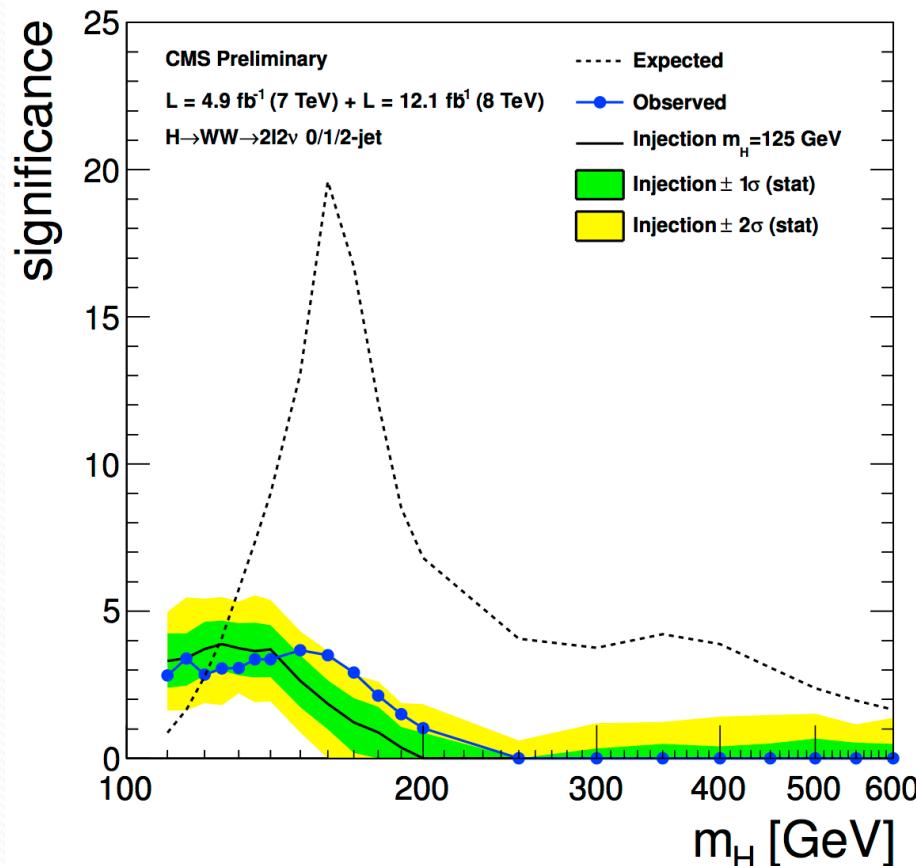


Best fit value for signal
strength $0.74^{+0.25}$

Anatomy of the excess.

Observation in
WW!

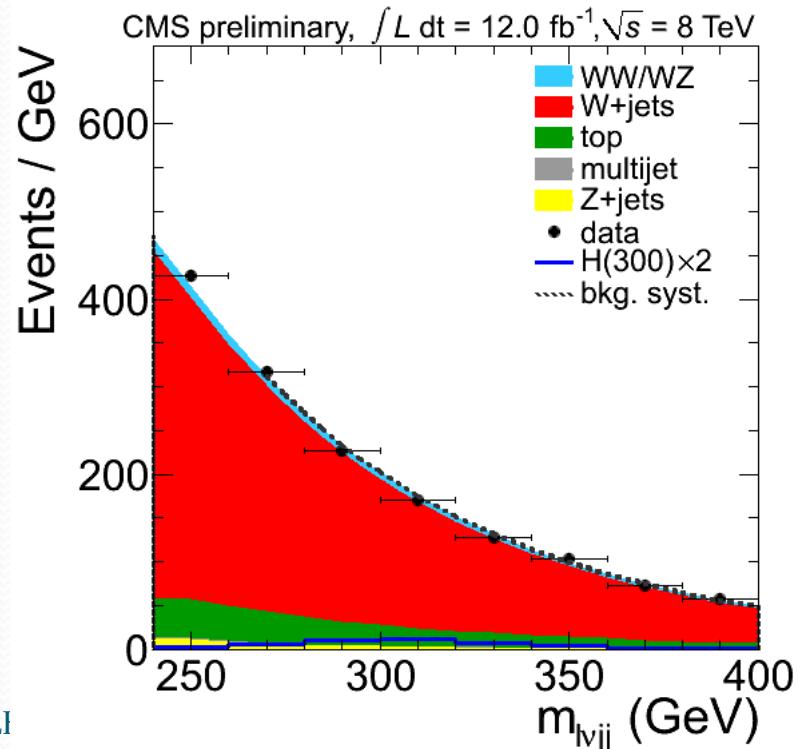
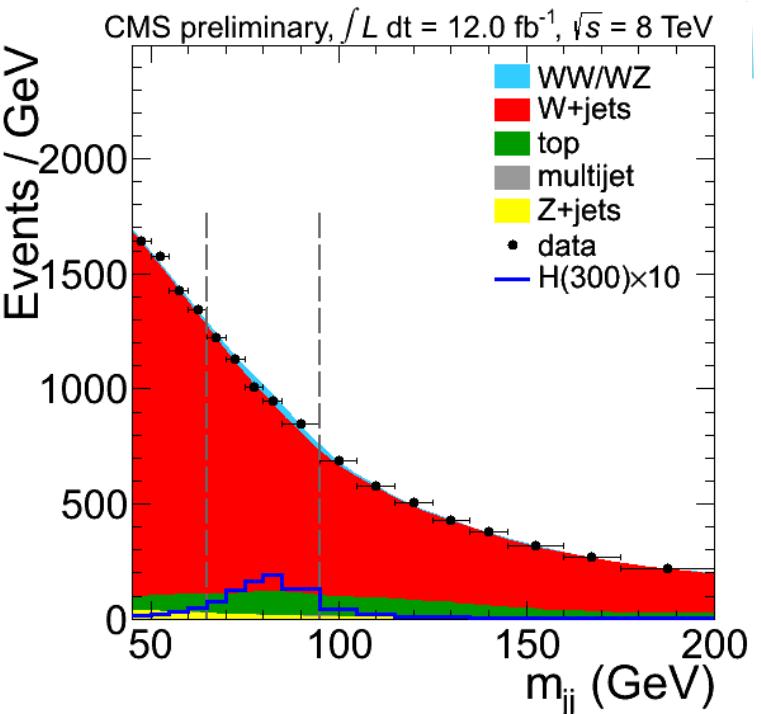
Expected/Observed
significance 4.1 (3.1) sigma



Best fit value for signal
strength $0.74^{+0.25}_{-0.25}$

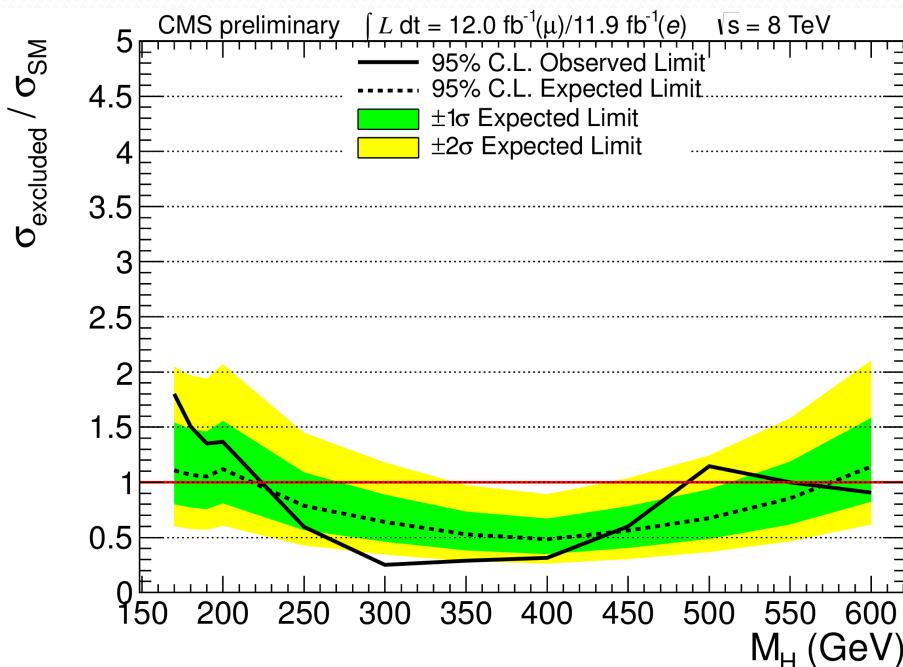
Single-lepton :

- Sensitive in the region $m_H = [200, 600]$ GeV
- Event selection – single lepton and 2 or 3 jets
 - Kinematic fit with constraints
 - $M(l\nu) = M_W$
 - $M(jj) = M_W$
 - Allows for reconstruction of Higgs mass
- m_H -dependent angular likelihood discriminant to optimize $W+jets$ rejection

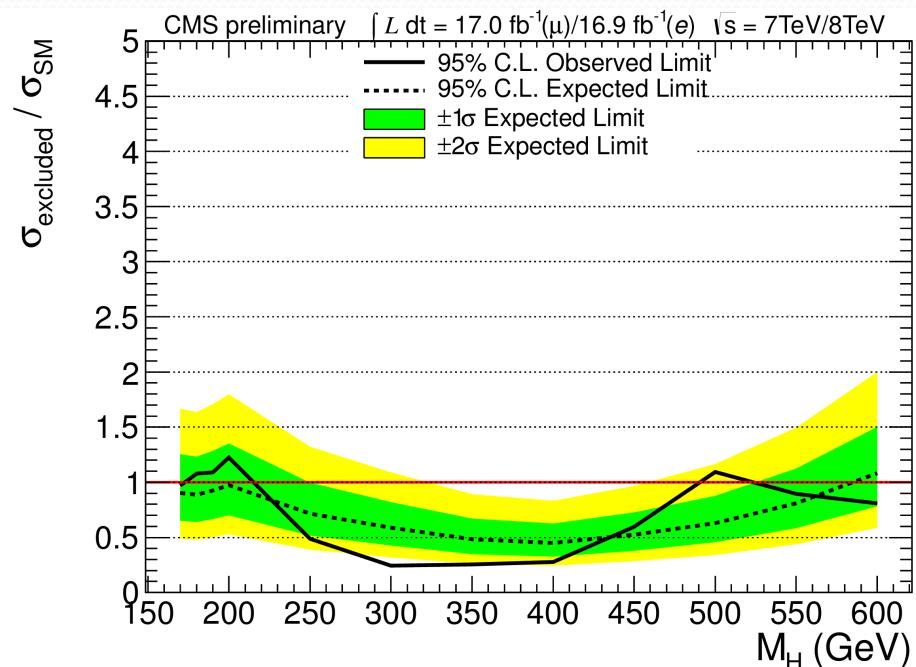


Single-lepton :

8 TeV only



7+8 TeV



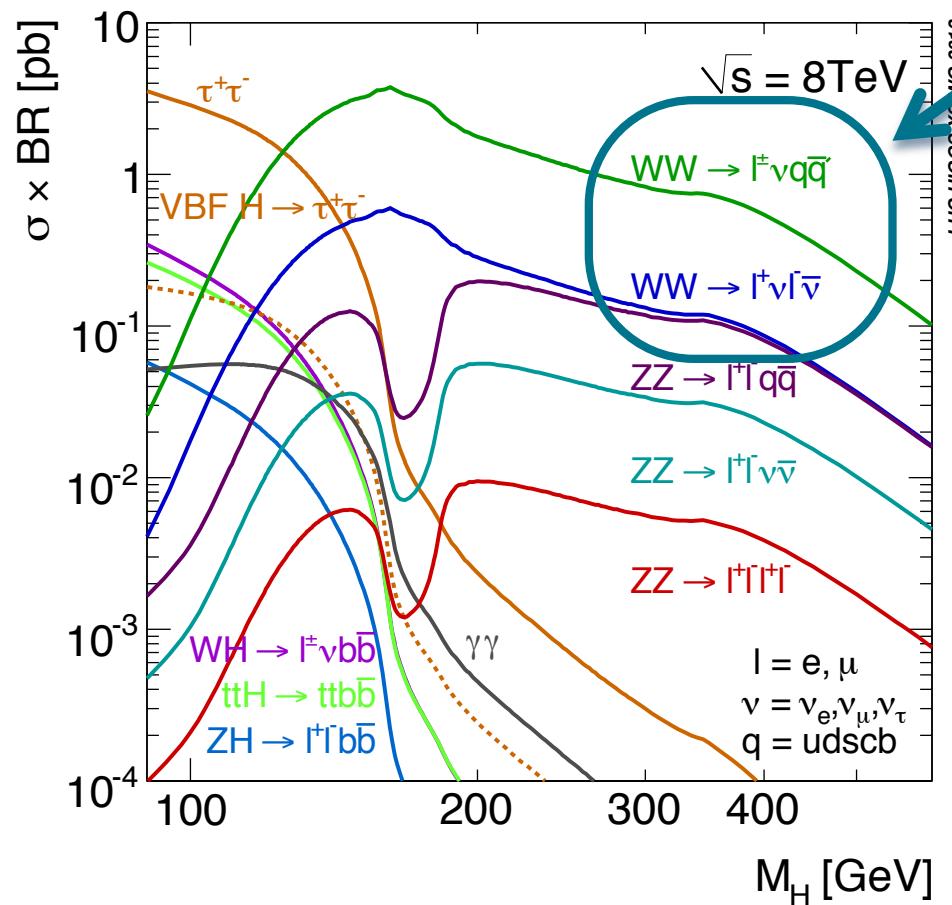
Exclusion range: 215-490 and 525-600 GeV at 95% confidence level.

Conclusions:

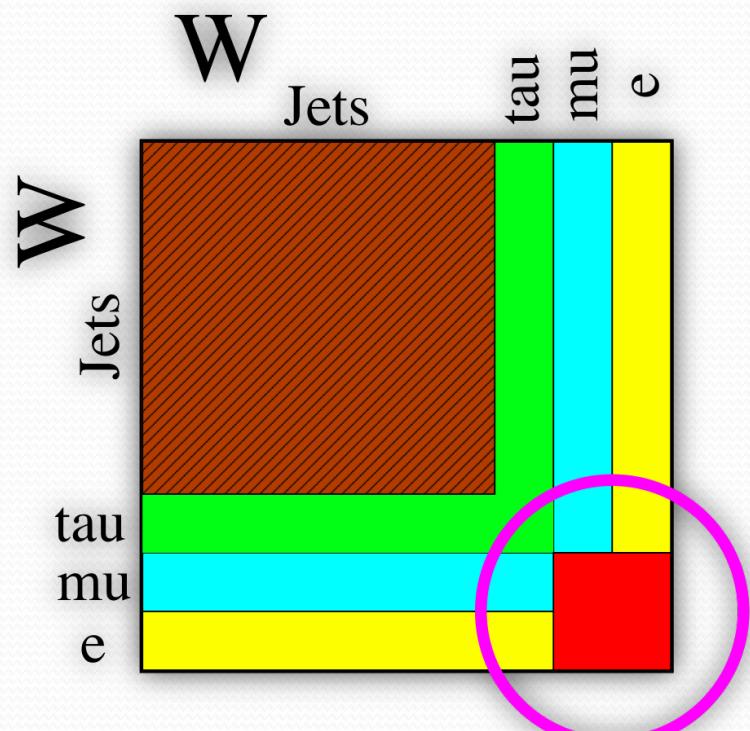
- $H \rightarrow WW$ is a very important part of CMS's Higgs program
 - Large signal yield (though no mass resolution)
 - can contribute to spin/parity measurement
- CMS has updated both single-lepton and di-lepton channels with 12 fb^{-1} of 8 TeV luminosity
 - large masses are excluded at 95% C.L.
 - **3.1σ excess** at small masses (with 4.1σ expected)
- **First observation of Higgs-like boson in WW mode at CMS**
 - Signal strength consistent with the predictions
 - Another round goes to the Standard Model

Backup:

Comparing sub-channels:

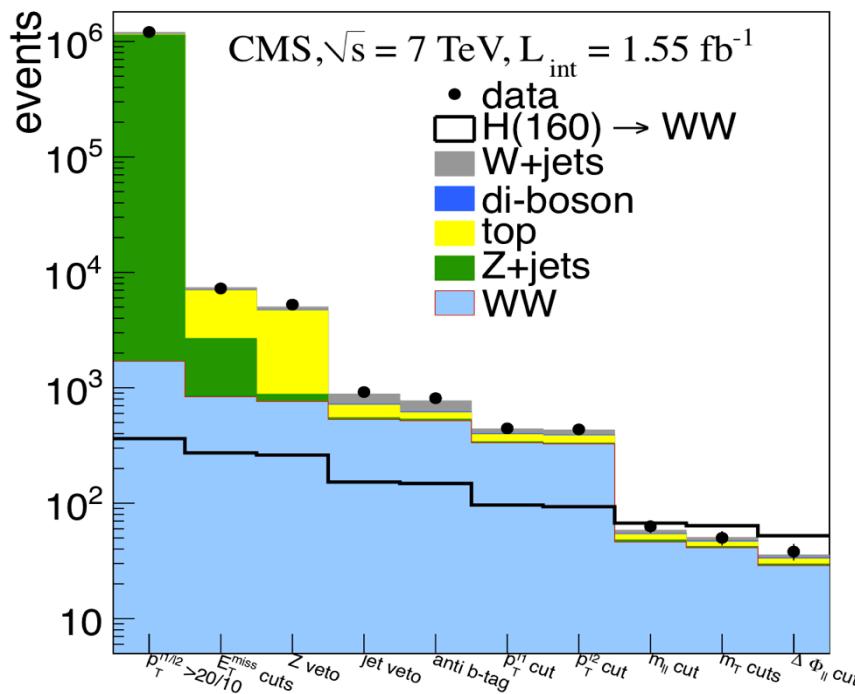
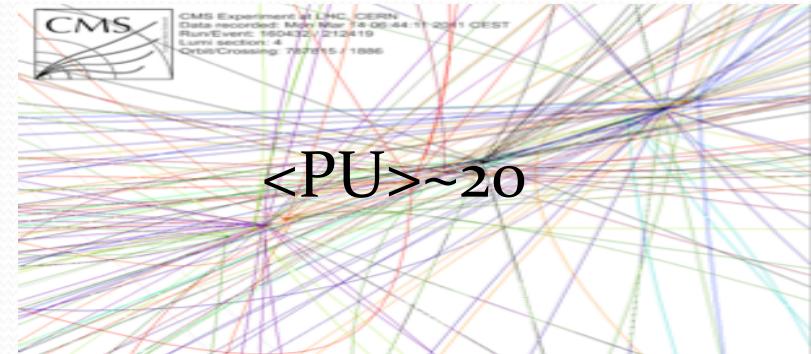


Highest signal yield in most of the Higgs mass range



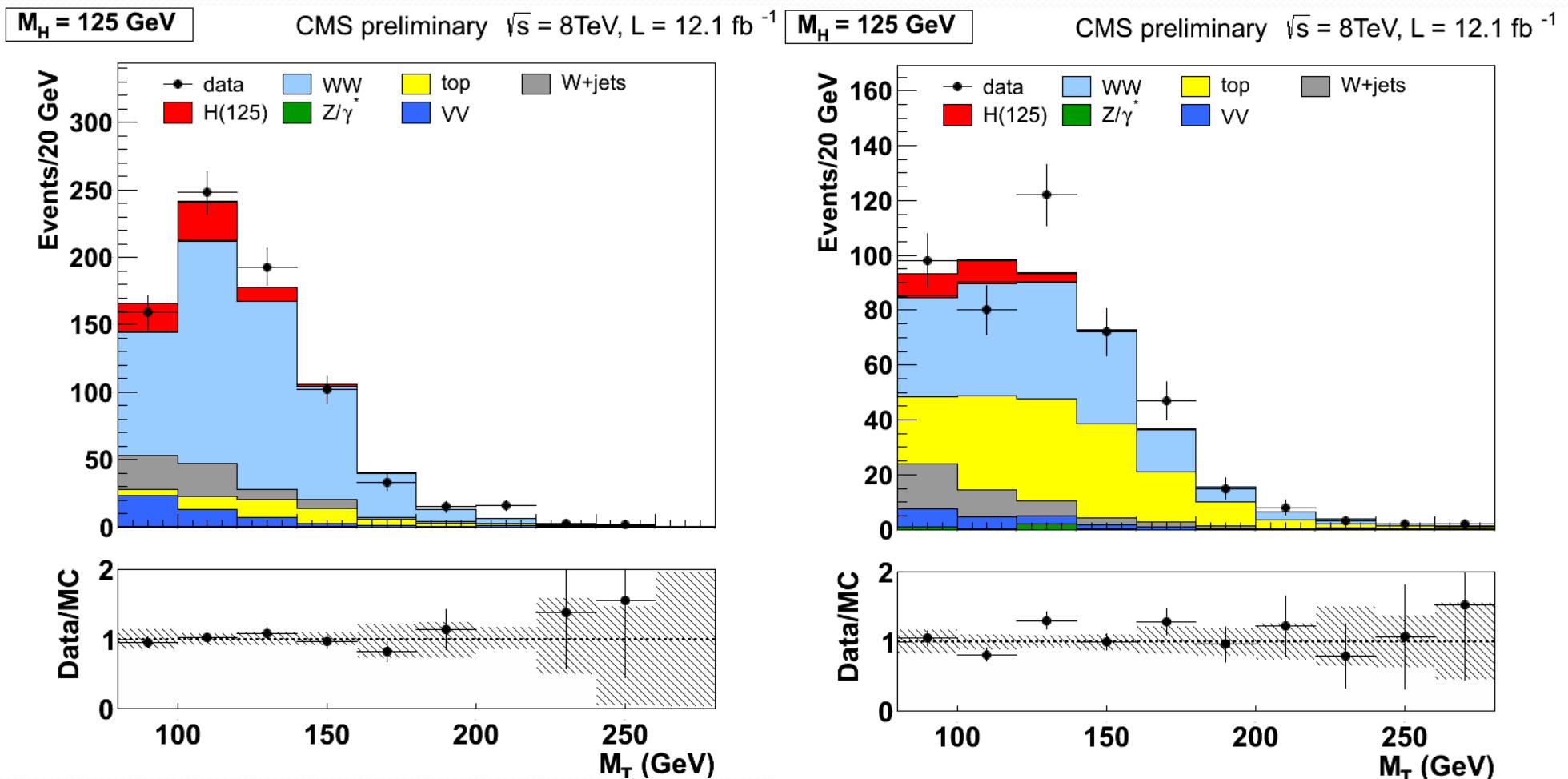
Di-lepton channel:

- DY dominated sample – Z-veto and MET are crucial [resolution at high PU!!!]
 - use combination of MET, tracker-MET, dilepton recoil to distinguish signal from DY with fake MET



- Top dominated sample:
 - Jet counting + b-tagging [low mistag rate is crucial]
 - Verify modeling in events with at least one b-tag
- WW dominated sample:
 - Kinematic cuts to explore scalar feature of Higgs
 - Measure WW x-section

M_T for event with $M_{||} < 50$



WW selection yields:

	data	tot bkg.	WW	ttbar+tw
0-jet bin	4450	4233 ± 220	3146 ± 192	417 ± 45
1-jet bin	3053	2899 ± 152	976 ± 111	1369 ± 56
2-jet bin	3148	3229 ± 137	473 ± 21	1865 ± 100
	Wjets	WZ+ZZ	dYLL	WZ+gamma*
0-jet bin	334 ± 91	118.1 ± 7.1	128 ± 21	89 ± 22
1-jet bin	288 ± 83	88.6 ± 5.3	131 ± 28	46 ± 12
2-jet bin	220 ± 58	51.2 ± 3.5	579 ± 70	41.3 ± 3.9

Selection cuts:

Selection [units]	ee,μμ	eμ
pT ^{max} [GeV/c]	20	20
pT ^{min} [GeV/c]	10	10
third lepton veto	applied	applied
opposite-sign requirement	applied	applied
mll [GeV/c ²]	12	12
projected MET [GeV] (**)	45 (*)	20
Z mass veto	applied	---
Δφ(l ^l -jet ^{max}) [dg.]	165 (*)	---
top veto	applied	applied
pT ^{ll} [GeV/c]	45	45

mH [GeV/c ²]	pT ^{max} [GeV/c]	pT ^{min} [GeV/c]	mll [GeV/c ²]	Δφll	mT [GeV/c ²]
120	20	10	40	115	[80,120]
125	23	10	43	100	[80,213]
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]

HWW Yields:

m_H	$H \rightarrow W^+W^-$	$p p \rightarrow W^+W^-$	$WZ + ZZ$ $+ Z/\gamma^* \rightarrow \ell^+\ell^-$	Top	$W + \text{jets}$	$W\gamma^{(*)}$	all bkg.	data
0-jet category $e\mu$ final state								
120	34.0 ± 7.3	162 ± 16	5.3 ± 0.5	8.6 ± 2.0	38 ± 14	23.1 ± 8.8	237 ± 23	285
125	58 ± 12	203 ± 19	6.6 ± 0.6	11.0 ± 2.5	44 ± 16	25.6 ± 9.5	291 ± 27	349
130	86 ± 18	226 ± 21	7.1 ± 0.7	12.2 ± 2.8	47 ± 17	27 ± 10	319 ± 29	388
160	238 ± 51	125 ± 12	3.7 ± 0.4	13.1 ± 3.1	5.9 ± 2.7	2.6 ± 1.5	160 ± 13	197
200	95 ± 21	204 ± 19	6.3 ± 0.6	28.9 ± 6.4	7.7 ± 3.5	1.3 ± 0.9	278 ± 21	309
400	40 ± 11	133 ± 15	6.2 ± 0.7	50 ± 11	7.6 ± 3.3	3.5 ± 2.1	200 ± 19	198
600	6.6 ± 2.3	42.2 ± 4.8	2.5 ± 0.3	16.5 ± 3.8	4.4 ± 2.0	2.4 ± 1.8	67.9 ± 6.7	64
0-jet category $ee/\mu\mu$ final state								
120	20.8 ± 4.5	108 ± 10	48 ± 14	3.9 ± 1.1	24.5 ± 9.3	5.8 ± 2.5	191 ± 20	209
125	37.0 ± 8.0	140 ± 13	59 ± 18	5.2 ± 1.3	30 ± 11	6.7 ± 2.8	241 ± 25	266
130	57 ± 12	162 ± 15	67 ± 20	6.2 ± 1.5	30 ± 11	7.7 ± 3.1	273 ± 28	295
160	209 ± 45	107 ± 10	17.6 ± 7.4	7.0 ± 1.7	5.2 ± 2.7	1.2 ± 0.7	138 ± 13	161
200	77 ± 17	177 ± 16	19.6 ± 4.2	21.9 ± 4.9	9.0 ± 4.1	1.8 ± 0.9	230 ± 18	249
400	34.0 ± 9.2	117 ± 13	34 ± 16	40.1 ± 8.7	4.4 ± 2.4	34 ± 11	230 ± 25	180
600	5.7 ± 2.0	38.2 ± 4.4	4.8 ± 0.4	11.6 ± 2.7	1.8 ± 1.3	5.0 ± 2.1	61.3 ± 5.7	61

HWW Yields:

1-jet category $e\mu$ final state								
120	14.9 ± 4.3	38.9 ± 6.4	5.3 ± 0.6	40.3 ± 3.0	19.1 ± 7.4	7.1 ± 3.4	111 ± 11	123
125	27.3 ± 8.0	47.9 ± 7.8	6.5 ± 0.7	49.5 ± 3.3	22.4 ± 8.6	7.1 ± 3.4	134 ± 13	160
130	40 ± 12	53.9 ± 8.8	7.3 ± 0.8	55.2 ± 3.6	24.5 ± 9.4	7.1 ± 3.4	148 ± 14	182
160	131 ± 37	44.4 ± 7.0	5.3 ± 0.7	51.8 ± 3.5	9.0 ± 3.9	0.6 ± 0.4	111.1 ± 8.8	145
200	58 ± 15	80 ± 13	6.8 ± 0.8	114.6 ± 6.5	16.1 ± 6.5	0.4 ± 0.3	238 ± 16	276
400	29.4 ± 8.1	81 ± 13	7.9 ± 1.2	129.0 ± 7.1	16.8 ± 6.6	0.6 ± 0.5	235 ± 16	226
600	6.9 ± 1.8	30.0 ± 4.8	3.1 ± 0.4	40.3 ± 3.0	8.4 ± 3.5	0.0 ± 0.0	81.8 ± 6.6	74
1-jet category $ee/\mu\mu$ final state								
120	6.5 ± 1.9	19.2 ± 3.2	11.5 ± 3.0	20.6 ± 2.0	6.1 ± 2.6	2.0 ± 1.2	59.5 ± 5.6	77
125	11.8 ± 3.4	24.8 ± 4.1	13.1 ± 3.5	26.7 ± 2.3	6.5 ± 2.8	2.0 ± 1.2	73.0 ± 6.6	92
130	18.2 ± 5.4	28.0 ± 4.6	15.6 ± 4.2	30.0 ± 2.5	7.8 ± 3.3	1.7 ± 1.1	83.1 ± 7.6	115
160	76 ± 22	28.9 ± 4.6	9.3 ± 2.8	31.0 ± 2.4	7.7 ± 3.6	0.3 ± 0.4	77.2 ± 6.9	89
200	35.4 ± 9.4	52.9 ± 8.4	16.8 ± 3.7	74.5 ± 4.6	8.0 ± 3.8	0.0 ± 0.0	152 ± 11	166
400	21.0 ± 5.8	45.0 ± 7.1	18.0 ± 8.4	77.5 ± 4.7	9.5 ± 4.3	14.5 ± 5.2	165 ± 14	128
600	4.4 ± 1.2	15.7 ± 2.5	2.8 ± 0.3	19.3 ± 1.6	1.8 ± 1.2	3.5 ± 1.6	43.0 ± 3.6	41

HWW Yields:

2-jet category $e\mu$ final state								
	120	125	130	160	200	400	600	
	1.7 ± 0.2	0.8 ± 0.5	0.1 ± 0.0	0.9 ± 0.3	0.3 ± 0.2	0.1 ± 0.1	2.2 ± 0.6	2
	2.8 ± 0.4	0.9 ± 0.5	0.1 ± 0.0	1.5 ± 0.5	0.3 ± 0.2	0.1 ± 0.1	2.9 ± 0.8	2
	4.4 ± 0.6	1.3 ± 0.7	0.1 ± 0.0	1.6 ± 0.5	0.3 ± 0.2	0.1 ± 0.1	3.4 ± 0.9	4
	11.7 ± 1.5	1.2 ± 0.6	0.0 ± 0.0	1.5 ± 0.5	0.0 ± 0.0	0.1 ± 0.1	2.9 ± 0.8	4
	9.3 ± 1.2	2.5 ± 1.2	1.7 ± 1.6	4.6 ± 1.3	0.3 ± 0.4	0.0 ± 0.0	9.1 ± 2.4	8
	3.9 ± 0.5	3.5 ± 2.2	1.7 ± 1.6	4.6 ± 1.3	0.0 ± 0.0	0.0 ± 0.0	9.8 ± 3.0	7
	1.4 ± 0.2	1.6 ± 1.0	0.0 ± 0.0	1.9 ± 0.8	0.3 ± 0.2	0.0 ± 0.0	3.7 ± 1.3	3
2-jet category $ee/\mu\mu$ final state								
	120	125	130	160	200	400	600	
	1.0 ± 0.1	0.5 ± 0.3	3.2 ± 1.5	0.7 ± 0.2	0.8 ± 0.5	0.1 ± 0.1	5.2 ± 1.7	9
	1.5 ± 0.2	0.5 ± 0.3	4.4 ± 1.3	0.7 ± 0.2	0.8 ± 0.5	0.1 ± 0.1	6.5 ± 1.5	11
	2.3 ± 0.3	0.5 ± 0.3	4.8 ± 1.6	0.8 ± 0.2	0.8 ± 0.5	0.1 ± 0.1	7.0 ± 1.7	11
	7.4 ± 1.0	0.5 ± 0.3	3.8 ± 3.8	0.9 ± 0.3	0.1 ± 0.1	0.0 ± 0.0	5.2 ± 3.8	5
	4.9 ± 0.6	1.5 ± 0.7	4.4 ± 3.0	2.0 ± 0.5	0.5 ± 0.4	0.0 ± 0.0	8.3 ± 3.2	9
	2.7 ± 0.4	1.4 ± 0.9	0.1 ± 0.0	3.6 ± 1.1	0.2 ± 0.4	0.0 ± 0.0	5.3 ± 1.4	8
	1.1 ± 0.1	0.5 ± 0.4	0.0 ± 0.0	1.4 ± 0.6	0.1 ± 0.1	0.0 ± 0.0	2.0 ± 0.7	2

SM consistency:

