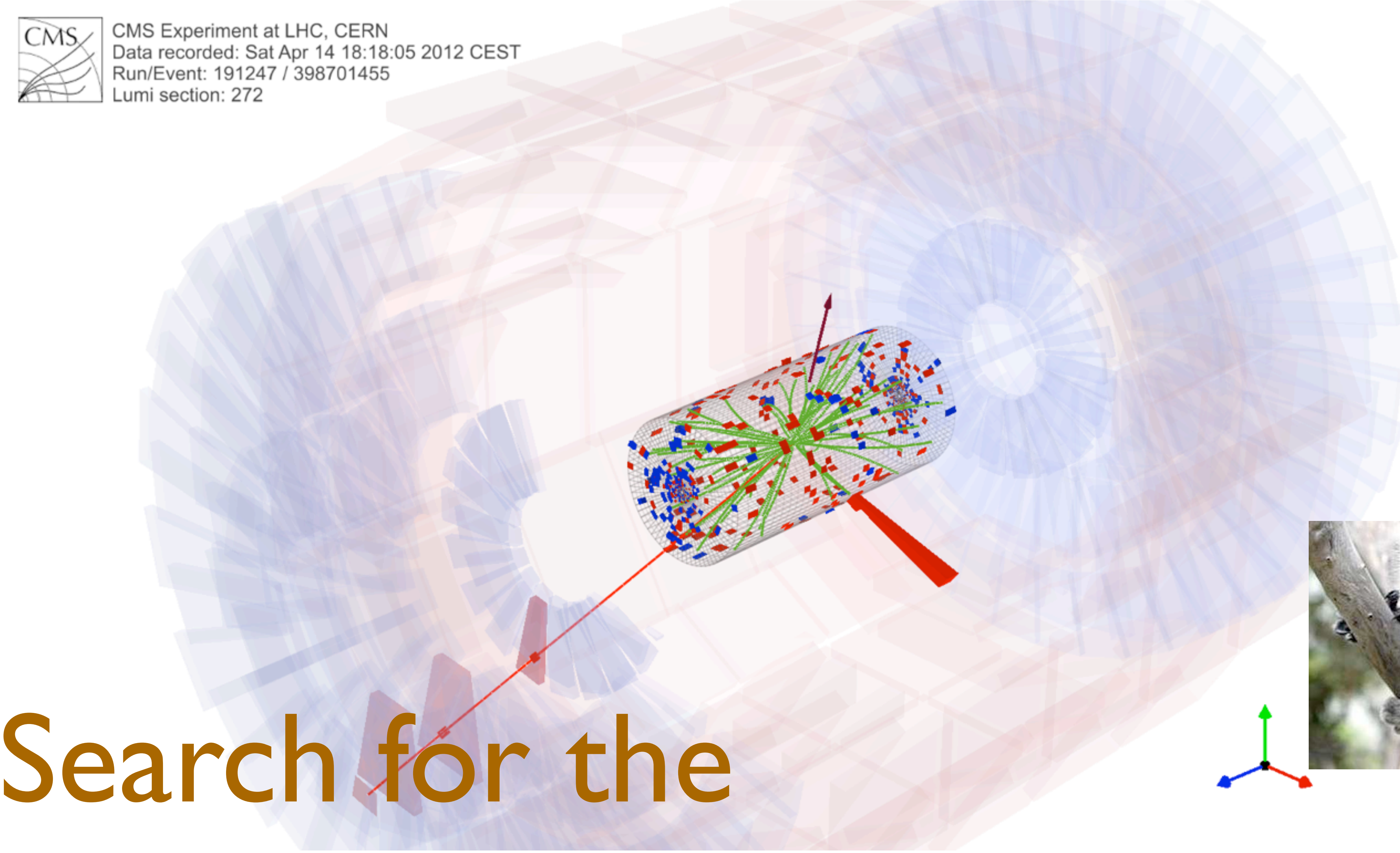
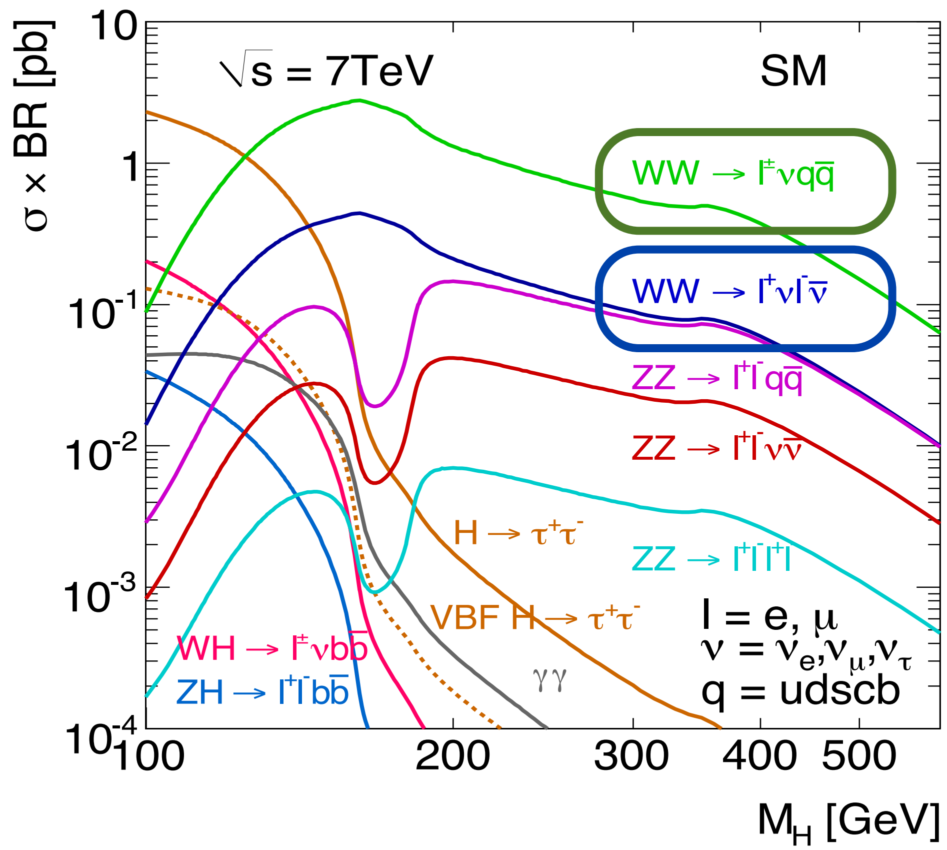


Search for the Higgs boson in H→WW$^{(*)}$

E. Di Marco (Caltech) on behalf of CMS Collaboration

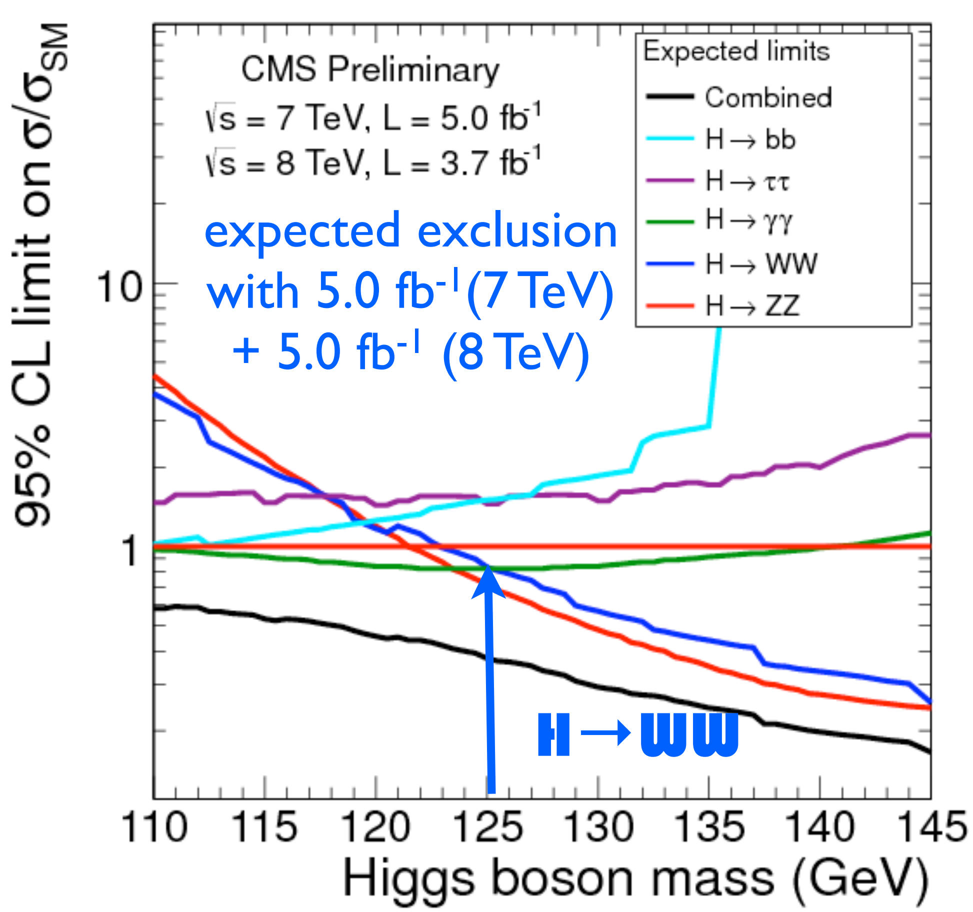
ICHEP, Melbourne, July 7, 2012

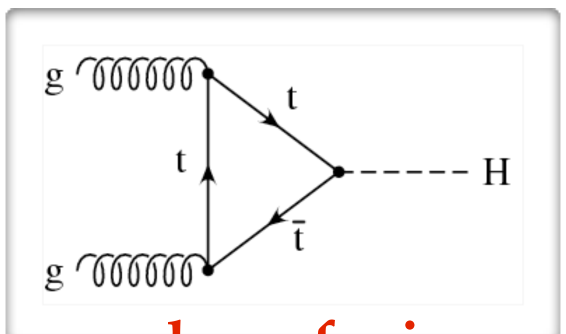
H→WW→2l2ν,lνqq



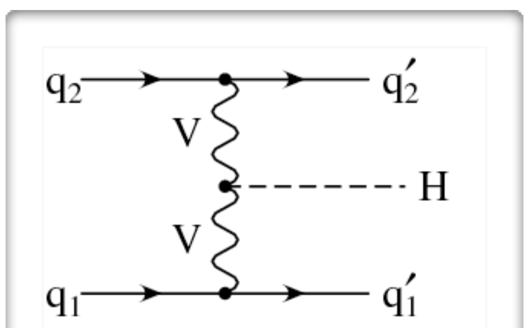
- Final state with the highest rate in most of the m_H mass range:
  - 2l2ν: high BR, clean signature, no mass peak
    region=[125-500] GeV
  - lνqq: highest rate sub-channel, closed kinematics, large background
    region=[300-500] GeV

HWW channel covers by alone m_H=[125-600] GeV



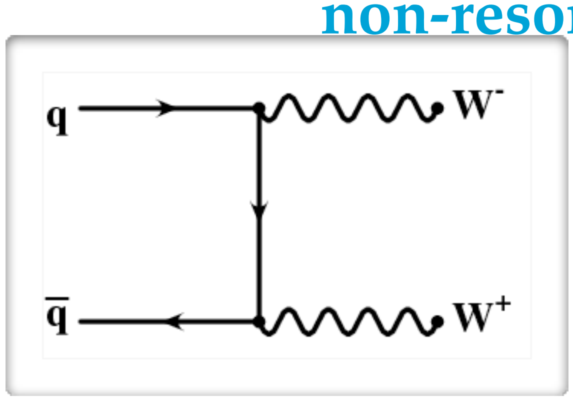


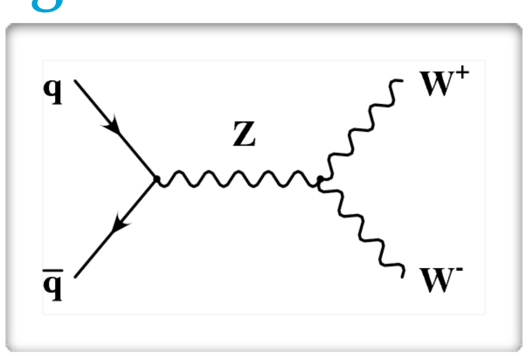
gluon fusion



Vector Boson Fusion

non-resonant background

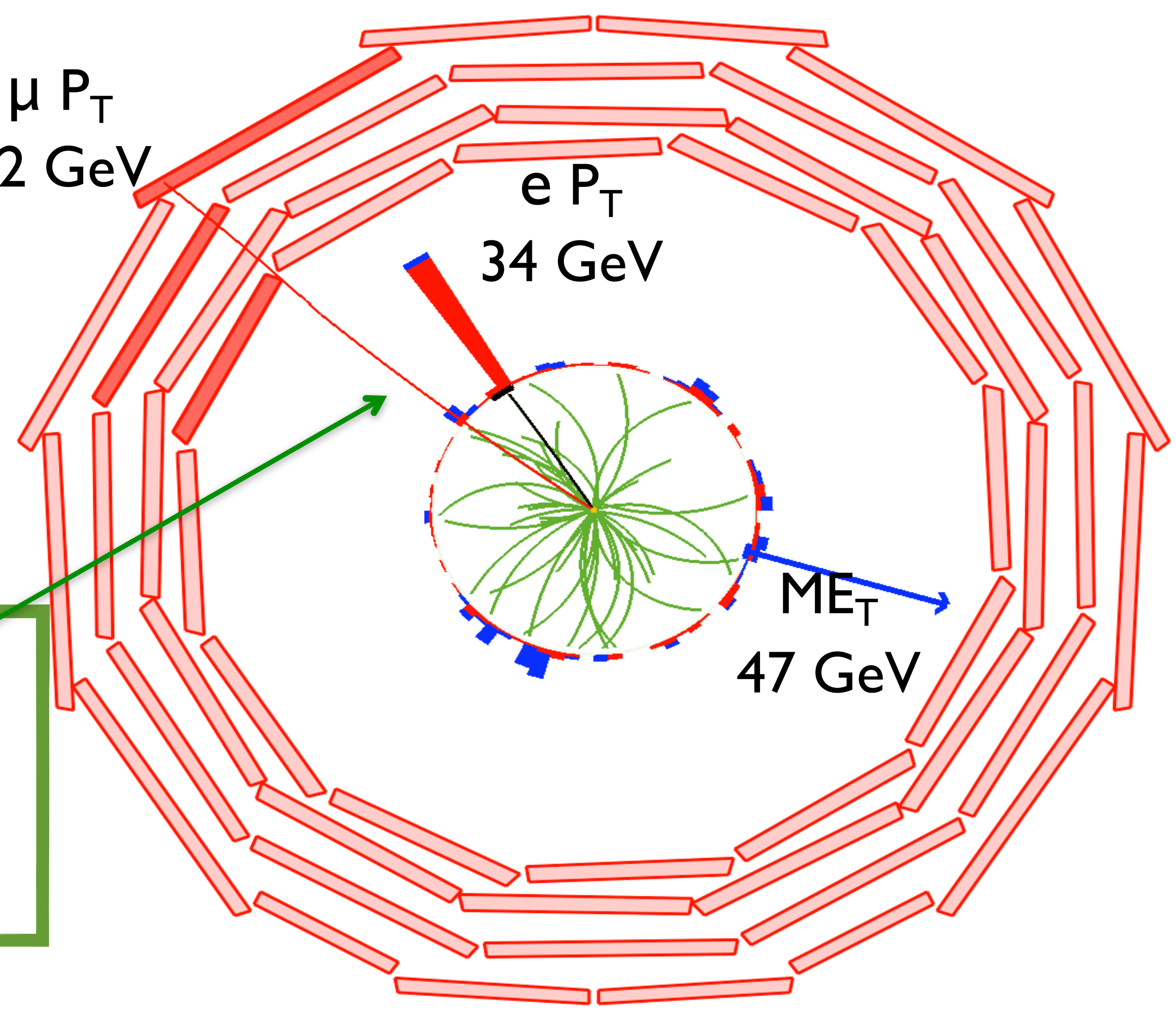


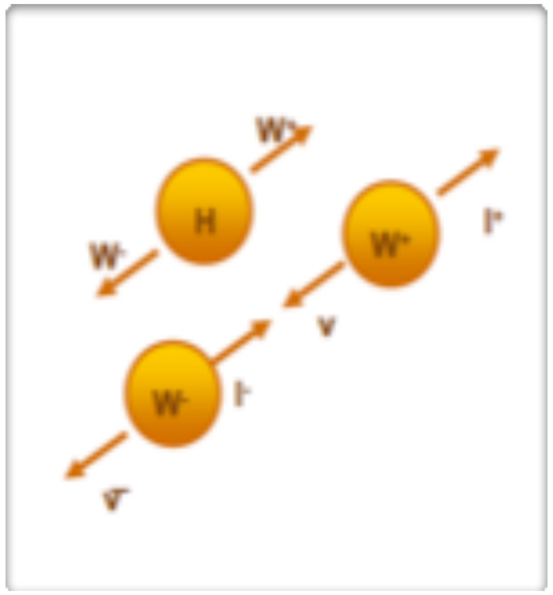


$H \to WW \to 2l2\nu$: strategy

- Most sensitive channel around $2 \times M_W$ ($125 < M_H < 200$ GeV)
- Signature: two high p_T isolated leptons + MET
- **No narrow mass peak**
- Main backgrounds
  - WW (irreducible)
  - Z+jets, WZ, ZZ, tt, W + jets
- BKG estimation crucial
  - Main BG estimated from data

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





Scalar H boson +
V-A structure of W decay
favors small $\Delta\varphi$ between
leptons

$H \rightarrow WW^* \rightarrow 2l2\nu$: backgrounds

decreasing cross section (@ 7 TeV)

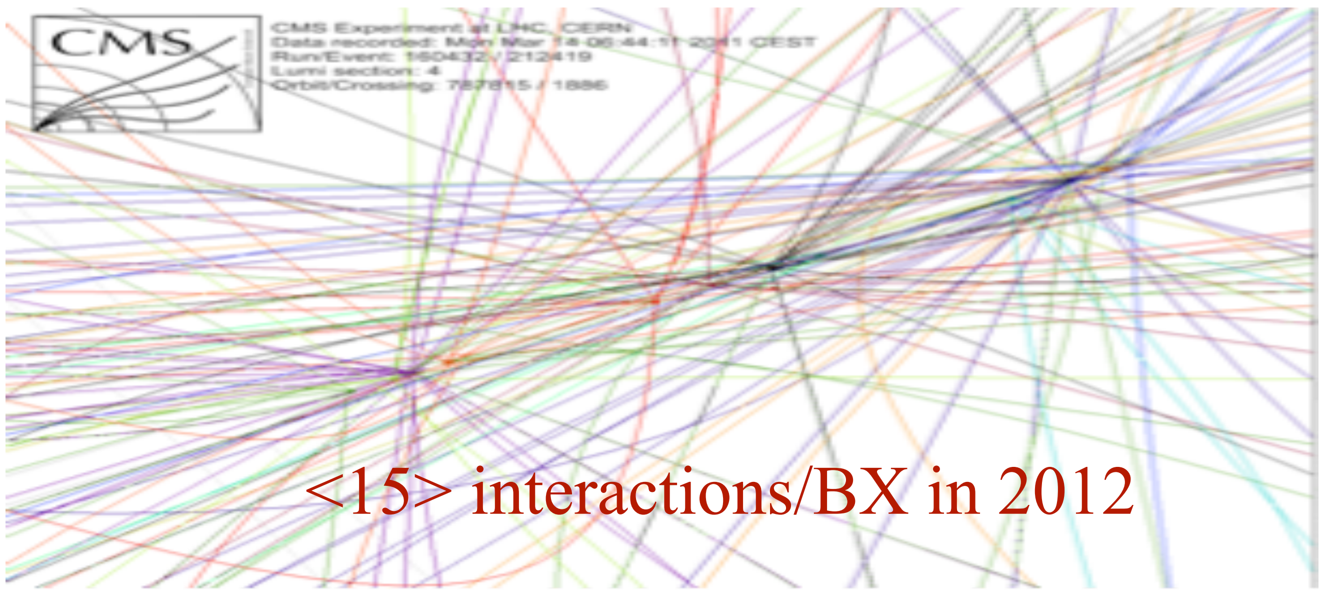
process	characteristic	rejection
W+jets (31000 pb)	lepton + fake lepton	2 well identified and isolated leptons
Z+jets (5000 pb)	Z peak, no real E_T^{miss}	❖ proj $E^T_{miss} > 40$ GeV(ee,μμ), 20 GeV (eμ) ❖ $\lvert m_{ll}-m_Z \rvert<15$ GeV (ee, μμ), $m_{ll}>12$ GeV (eμ)
tt (158 pb), tW (11 pb)	additional (b-)jets	❖ classify events in 0-,1-jet ❖ anti b-tagging
W,Z + γ (165 pb)	electron from γ coversion	❖ conversion veto
WW (43 pb)	non resonant	❖ small $\Delta\varphi_{ll}$
WZ (18 pb), ZZ (6 pb)	Z peak	❖ $\lvert m_{ll}-m_Z \rvert<15$ GeV (ee, μμ), $m_{ll}>12$ GeV (eμ)

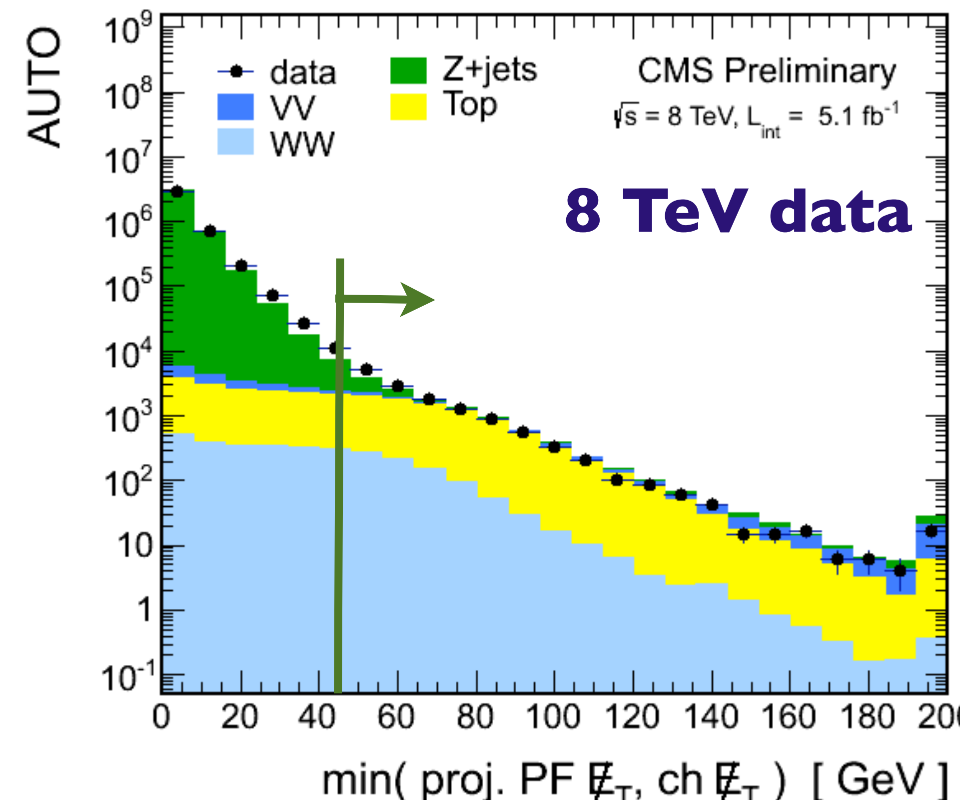
relative importance after selection depends on m_H

H→WW→ 2l2ν: selection

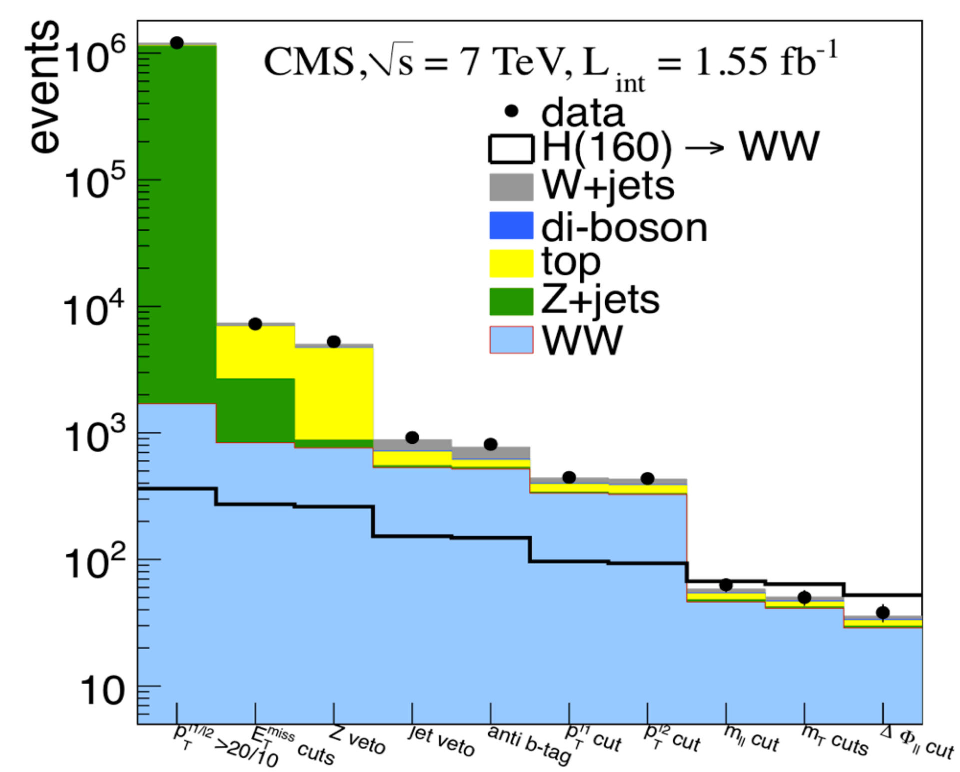
- **DY-dominated sample**, MET selection, Z-veto [crucial the resolution with high pileup]

used a combination of MET / track-based MET / dilepton recoil against MET, etc to reduce Drell Yan for ee/μμ final states



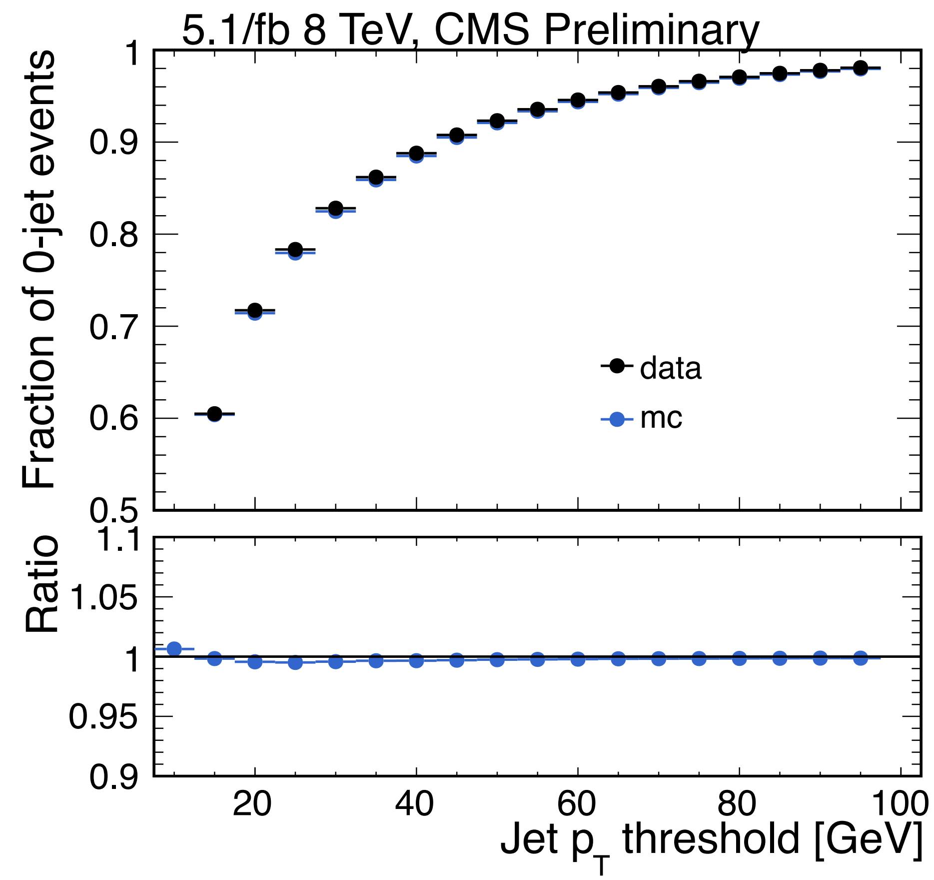


- **top dominated sample**: jet counting (0,1,2) + b-tagging [crucial low mis-tag rate for jelow p_T jets]
- **WW dominated sample [performed measurement of cross section for pp→WW @ 8 TeV]**
- apply m_H dependent cuts: kinematics depending on the Higgs mass (p_T^1,p_T^2,$\Delta\phi_{ll}$,m_{ll},m_T)



Jet categorization

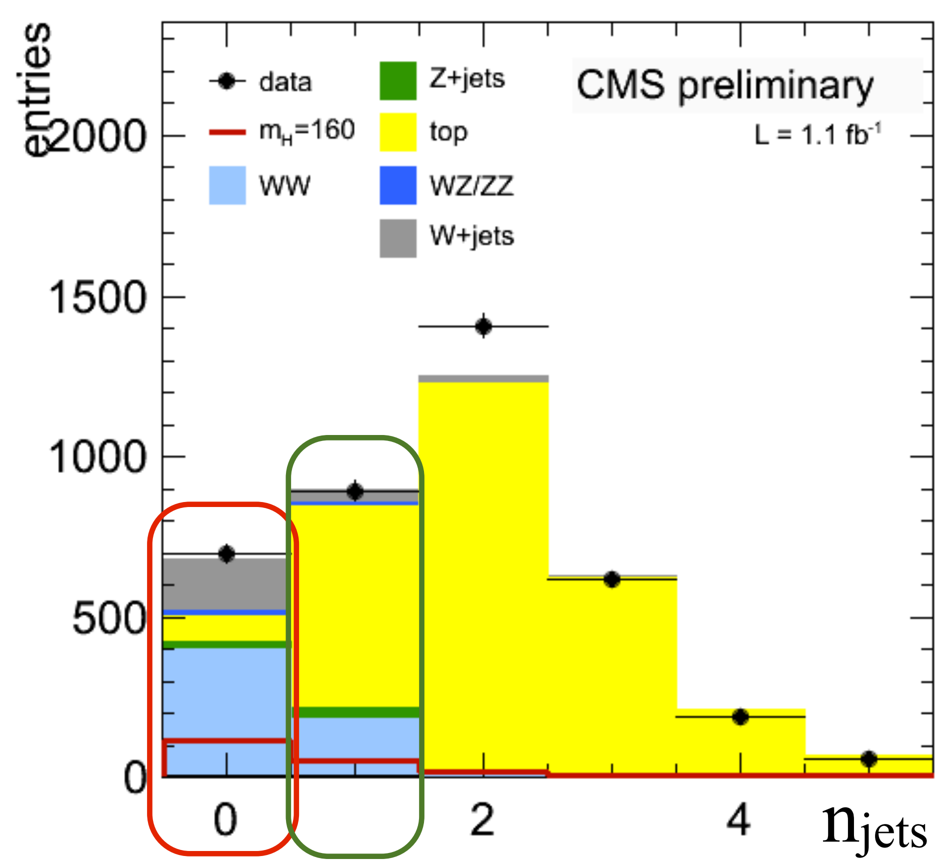
- Categorize events by jet multiplicity (jet p_T>30 GeV, $|\eta|$<4.7)
  - very good description of jet counting, validated with Z→ll events in data
  - jet ID used to reduce pileup effects at high $|\eta|$



- **0-jet**: WW dominated. **Most sensitive category to gg→H**
  - m_H<130 GeV: W+jets, Drell Yan backgrounds
  - **eμ** final state very pure final state

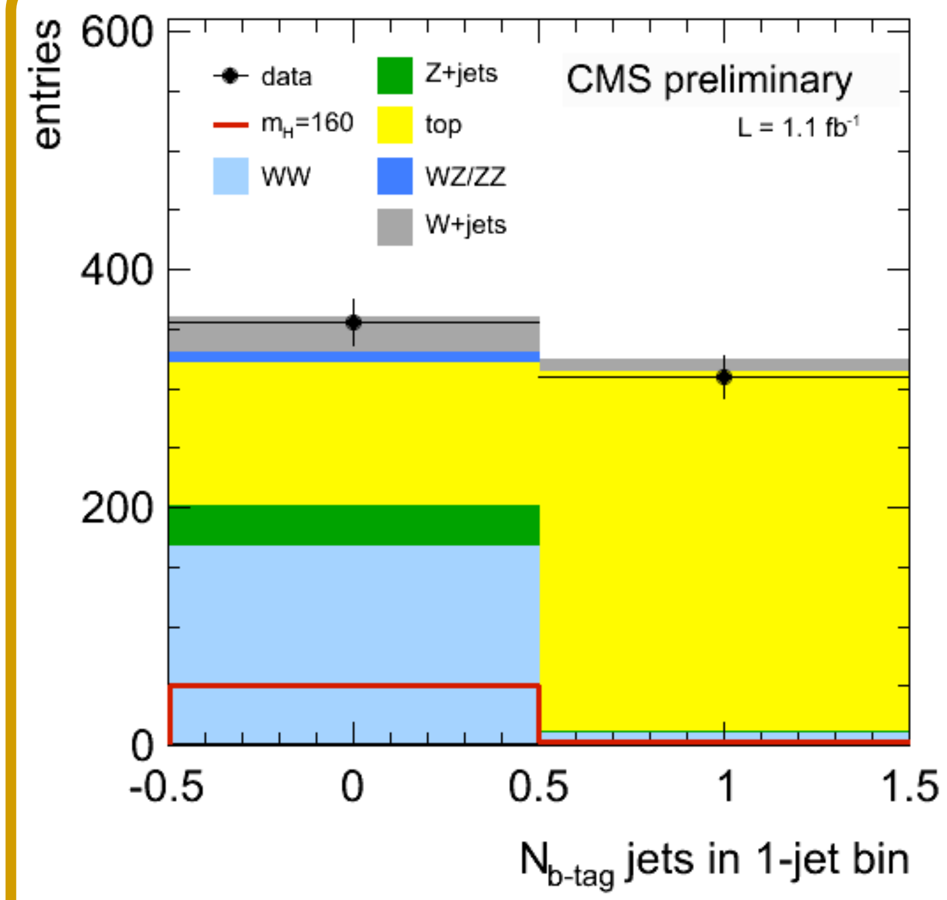
top

- **1-jet**: dominated by tt+tW, apply anti b-tagging on all jets with p_T>10 GeV
  - clean **eμ** from DY→ττ with m_T>80 GeV
- **2-jets**: specific selections to isolate VBF production
  - $\Delta\eta(j_1-j_2)$>3.5, $m_{j1,j2}$>450 GeV



Backgrounds estimation

- Measure **all the backgrounds** from data control samples:
  - **W+jets** from fake-enriched sample, weighted with fake→lepton probability
    - relevant for low p_T leptons (low m_H)
  - **top** from b-tagged events
  - **DY** from Z on-peak data events
  - **WW** from signal free region (m_{ll}>100 GeV for m_H<200 GeV. For high mass H, no signal-free region, taken from simulation)



top control sample from 1 b-tag jet

- Cut & count analysis: dominated by systematics on background normalization:
  - W+jets: ≈40% (do not improve with statistics)
  - Drell-Yan: 60%
  - Top: 25%
  - WW: 15-30%

→ crucial effort in measuring backgrounds from data with the largest precision possible

WW event yields

- With a selection tuned to reduce systematic uncertainties ($p_T^{1,2}$>20/20 GeV), measure the WW cross section at 8 TeV:

$$\sigma_{WW} = 69.9 \pm 2.8(\mathrm{stat}) \pm 5.6(\mathrm{syst}) \pm 3.1(\mathrm{lumi.})\mathrm{pb}$$

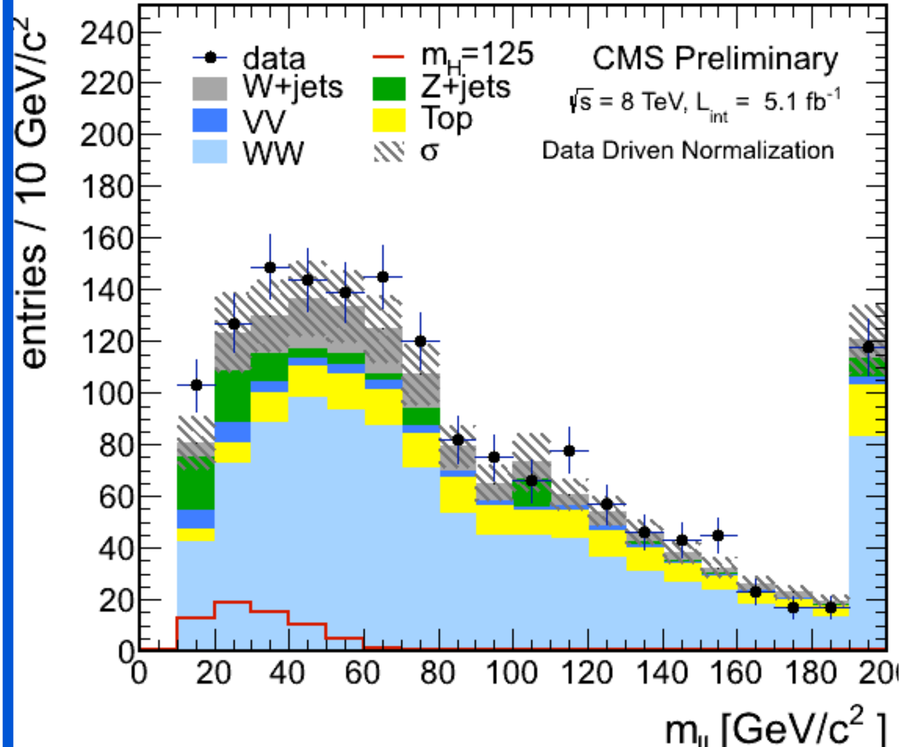
$$\sigma_{WW}^{NLO}(gg \to W^+W^- + qq \to W^+W^-) = 57.25\left(^{+2.35}_{-1.60}\right)\mathrm{pb}$$

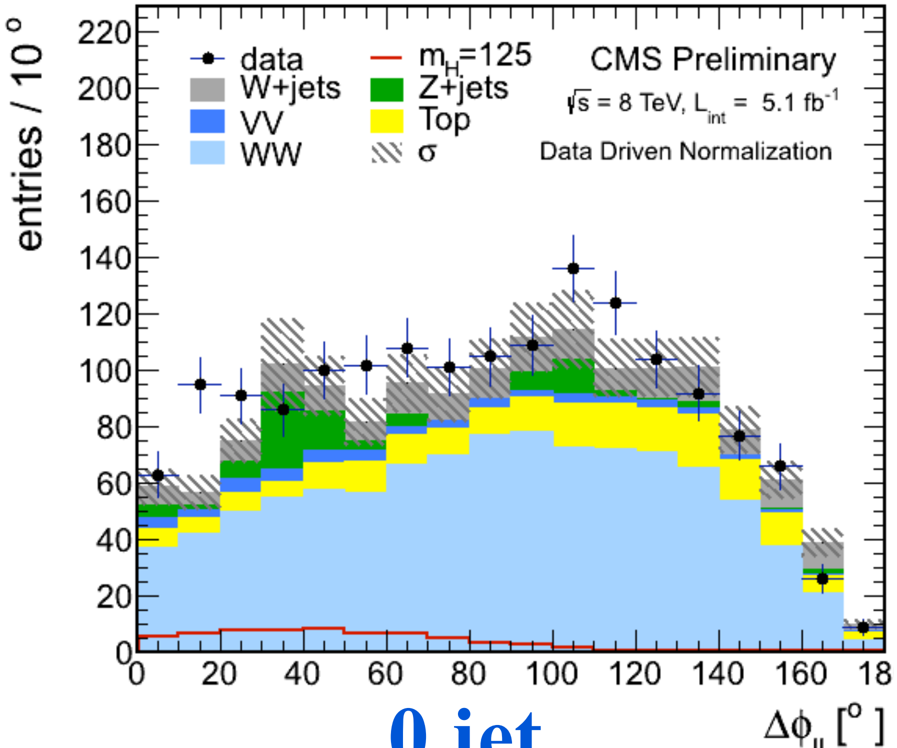
- similar ratio measurement / prediction as in 7 TeV data collected in 2011
- pre-selection relaxed for a low mass Higgs ($p_T^{1,2}$>10/20 GeV):

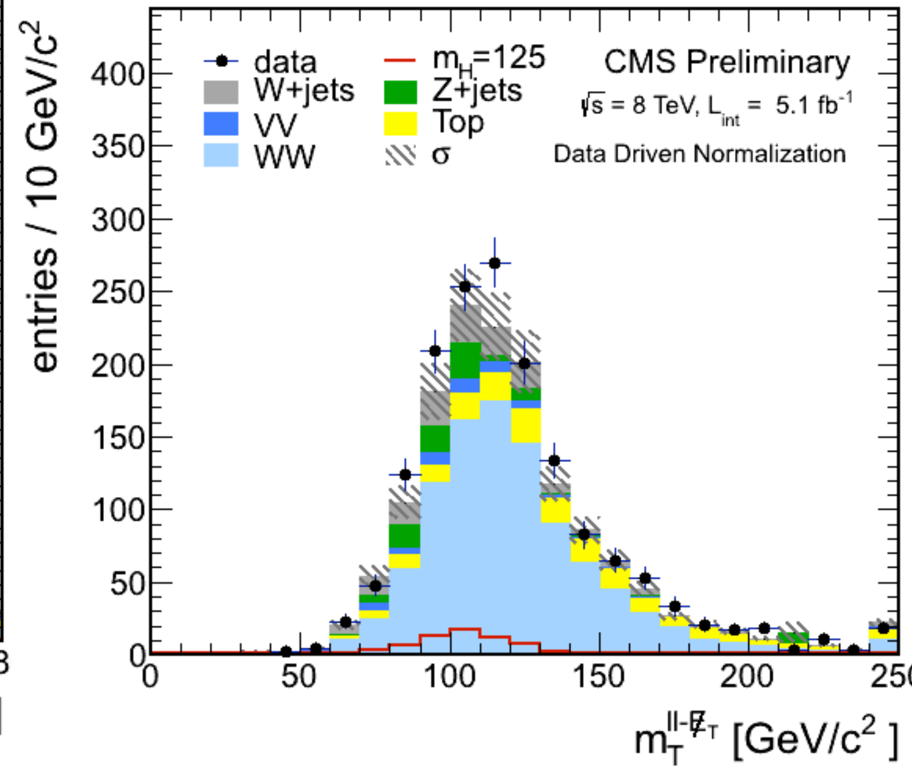
statistical uncertainties only

	data	**tot. bkg.**	WW	tt+tW
0 jet	**1594**	**1501±21**	1046.1±7.2	164.2±5.4
1 jet	**1186**	**1162±27**	381.0±4.0	527.3±8.4
2 jets	**1295**	**1412±24**	177.0±2.8	886.5±11.1
	W+jets	WZ+ZZ	Z/γ*	Wγ
0 jet	158.2±7.1	32.6±0.6	73±17	27.1±3.9
1 jet	122.6±6.7	30.3±0.6	77±24	23.7±5.2
2 jets	94.9±6.4	20.8±0.5	227±20	5.6±2.1

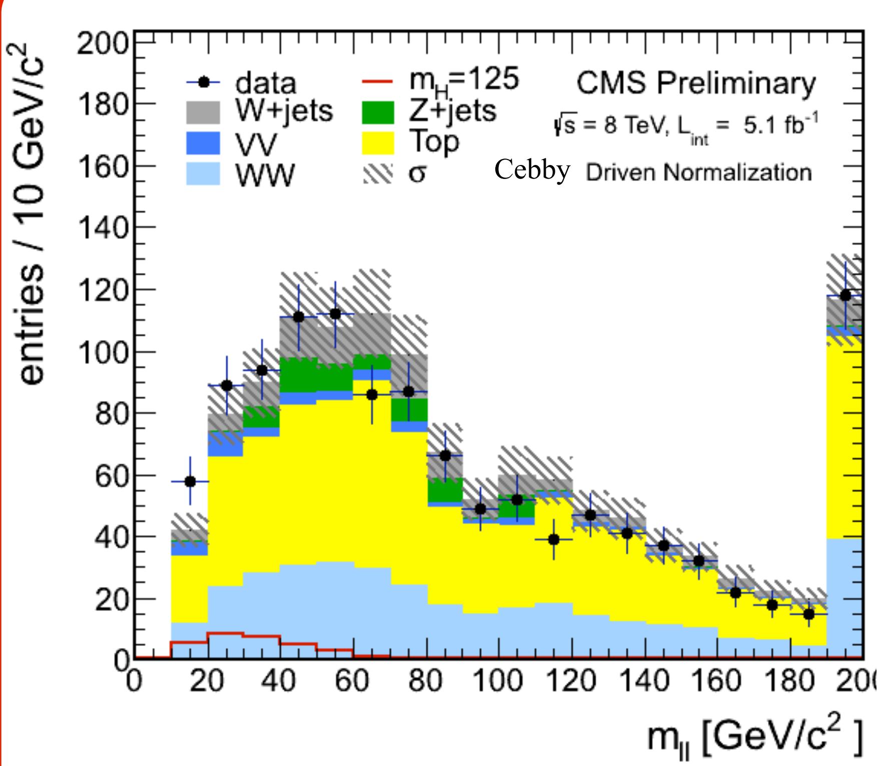
WW→2l2ν event pre-selection

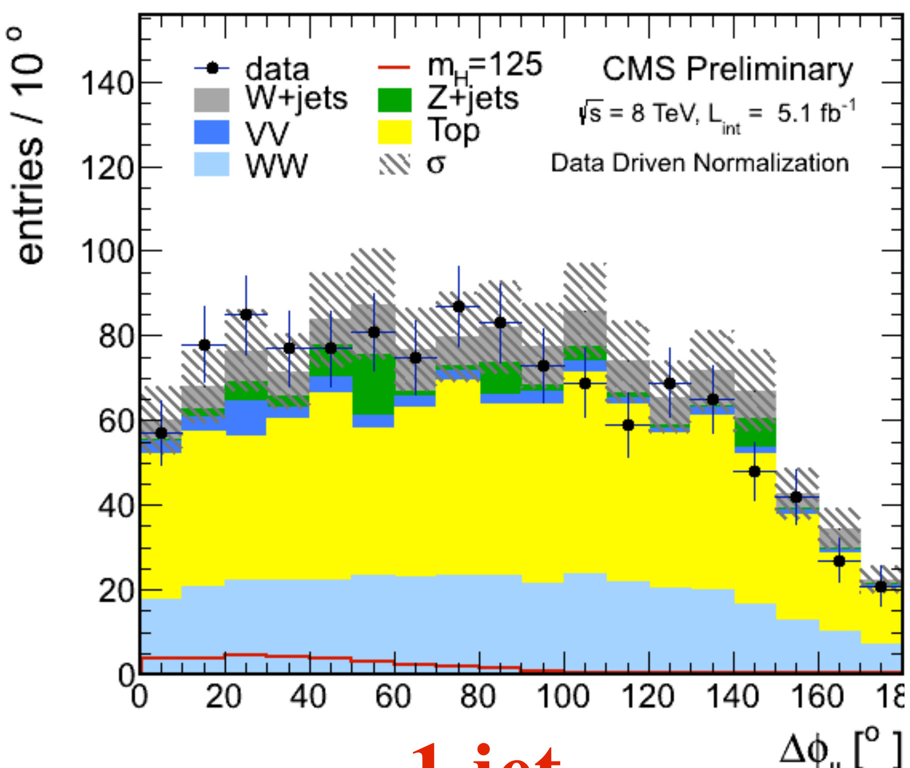


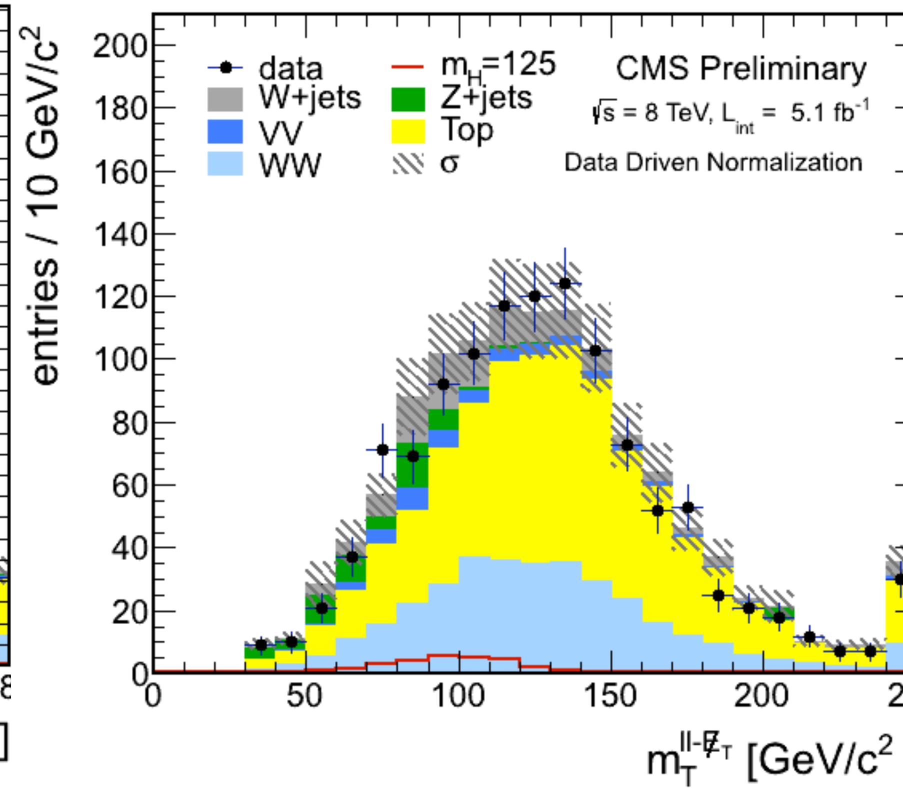




0 jet





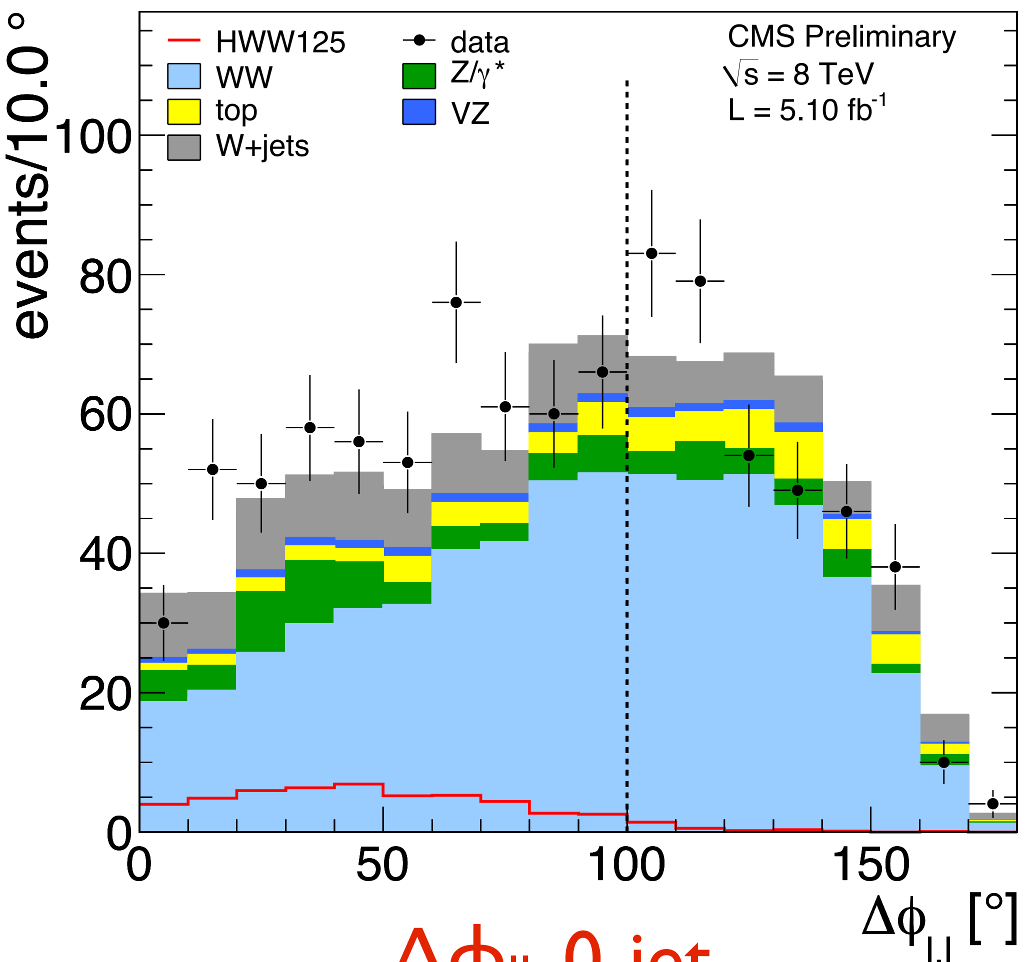


1 jet

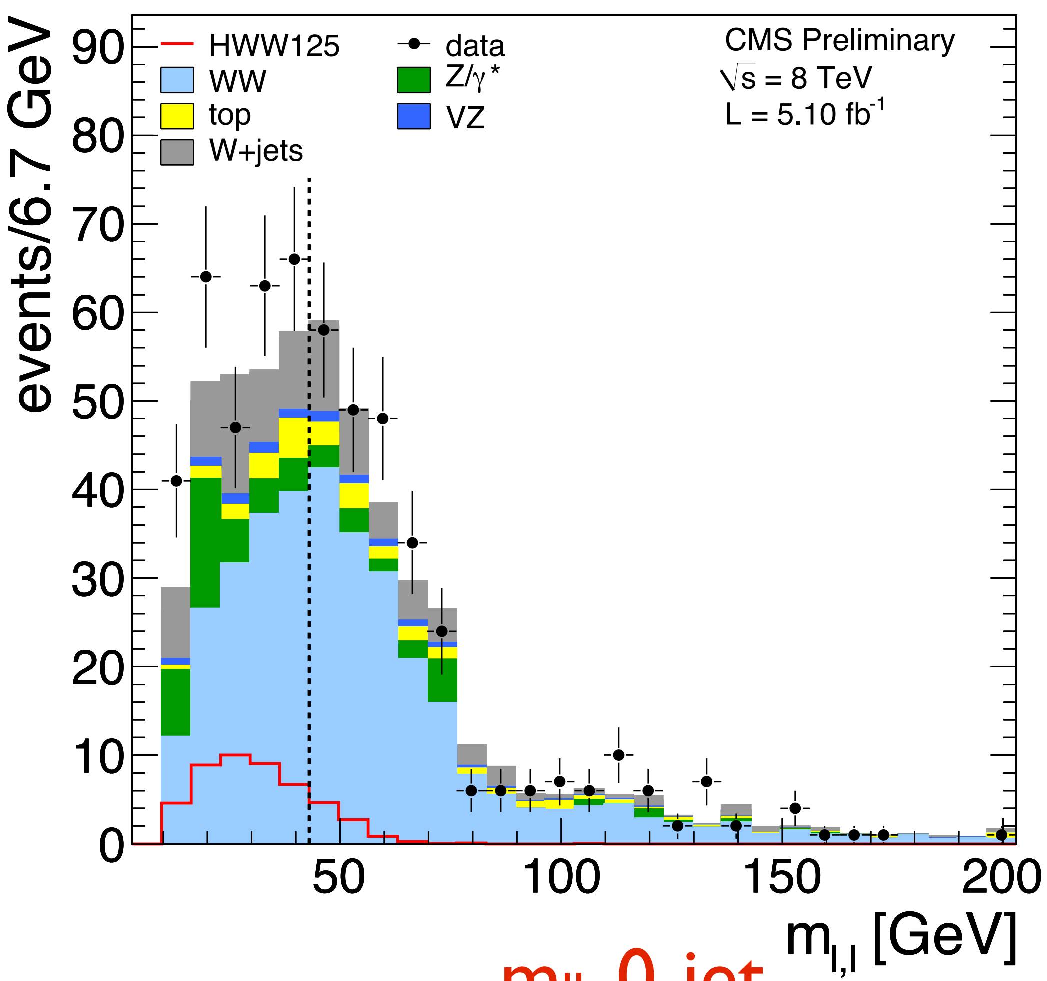
Higgs selection

- Further discrimination with Higgs is provided by kinematic variables: apply optimized cuts:

m_H [GeV]	$p_T^{leading}$ [GeV]	$p_T^{trailing}$ [GeV]	$m_{\ell\ell}$ [GeV]	$\Delta\phi_{\ell\ell}$ [°]	M_T [GeV]
110	> 20	> 10	< 40	< 115	[80 - 110]
115	> 20	> 10	< 40	< 115	[80 - 110]
120	> 20	> 10	< 40	< 115	[80 - 120]
125	> 20	> 10	< 40	< 115	[80 - 120]
130	> 25	> 10	< 45	< 90	[80 - 125]
135	> 25	> 12	< 45	< 90	[80 - 128]



$\Delta\phi_{ll}$, 0-jet

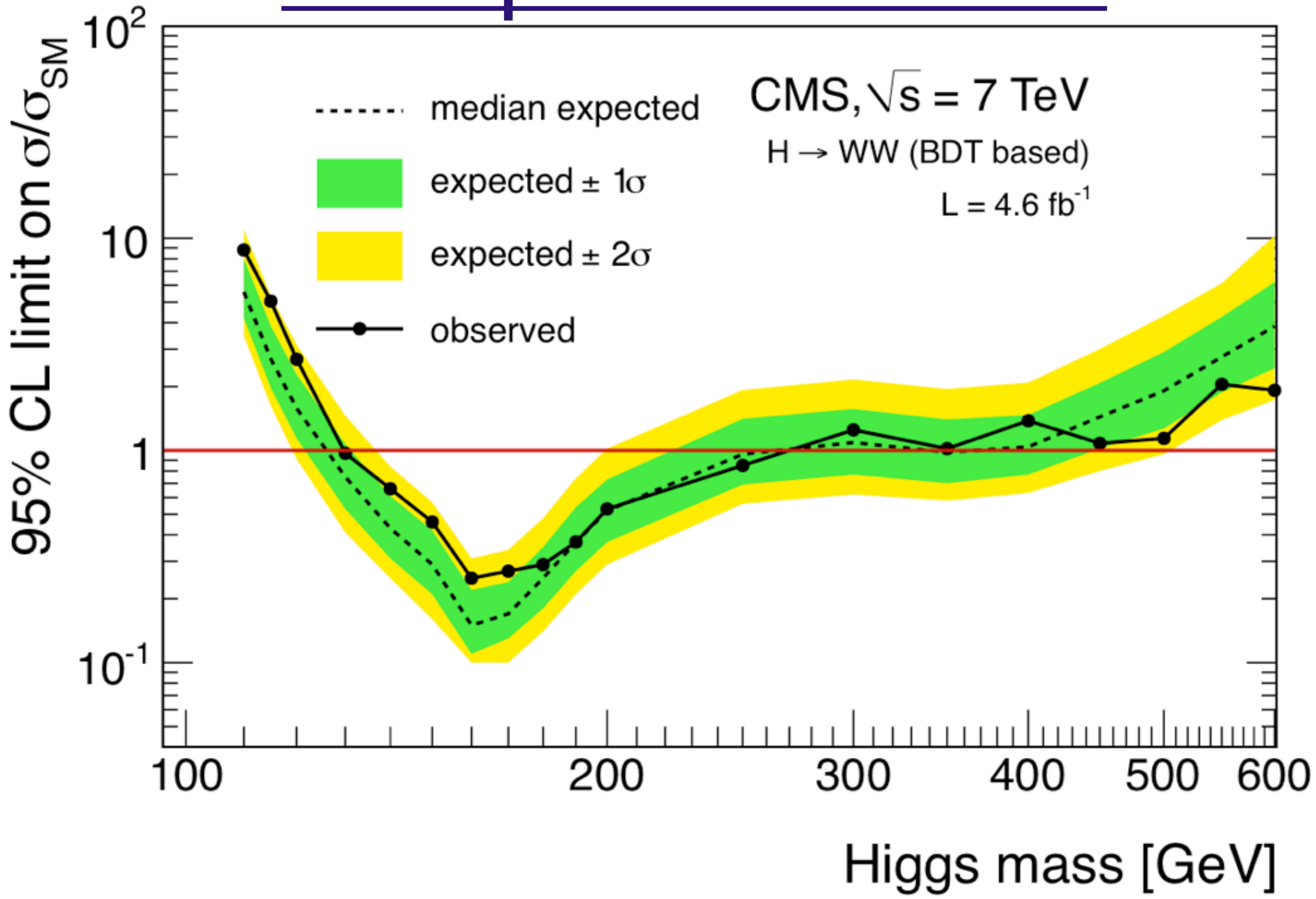


m_{ll}, 0-jet

Results on 2011 and 2012

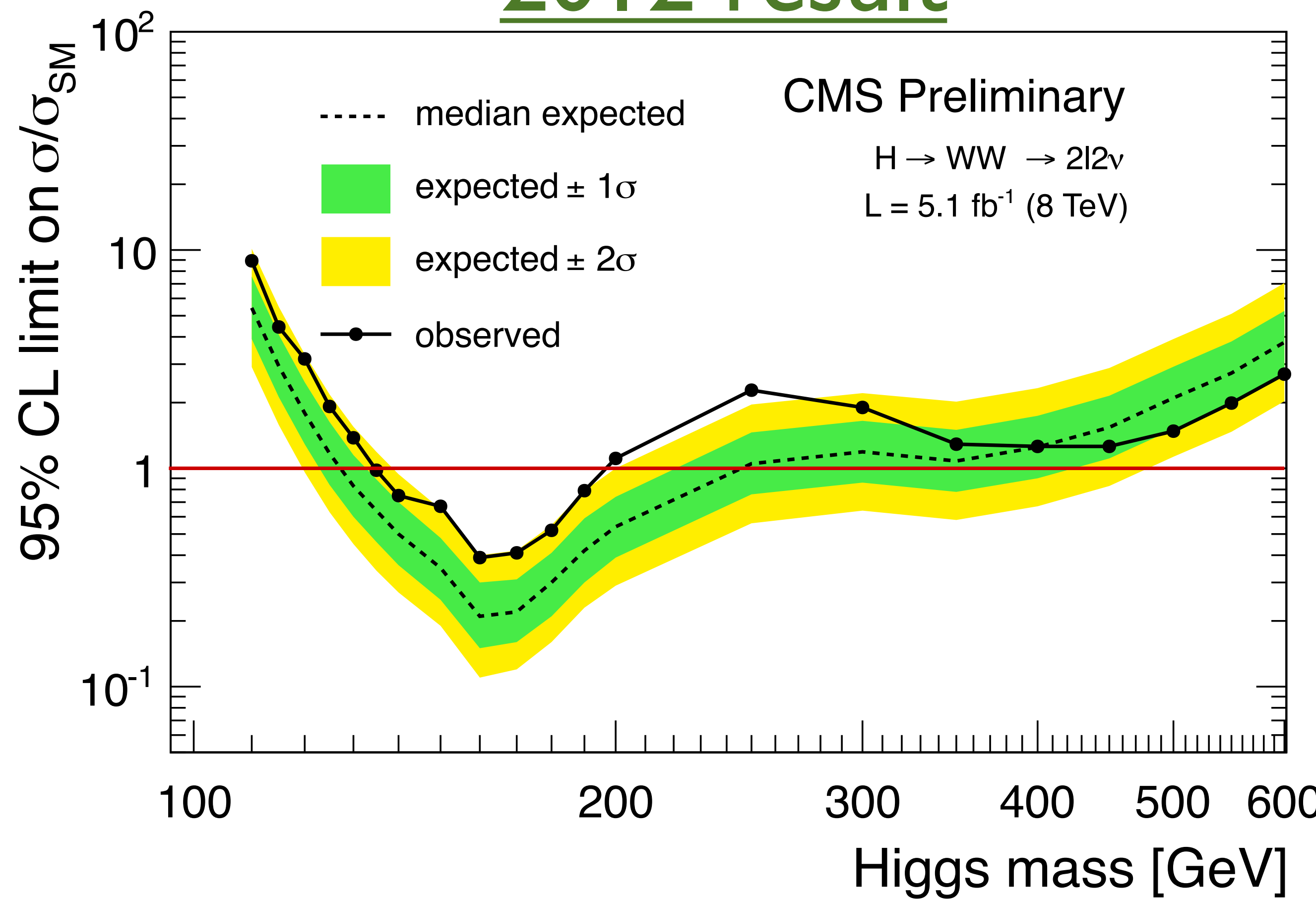
- Result on 8 TeV data: observed exclusion limit: $127 < M_H < 200$ GeV
- 7 TeV data not re-analized: observed exclusion limit: $129 < M_H < 270$ GeV

2011 published result



Expected limit: $127 < M_H < 270$ GeV
Observed limit: $129 < M_H < 270$ GeV

2012 result

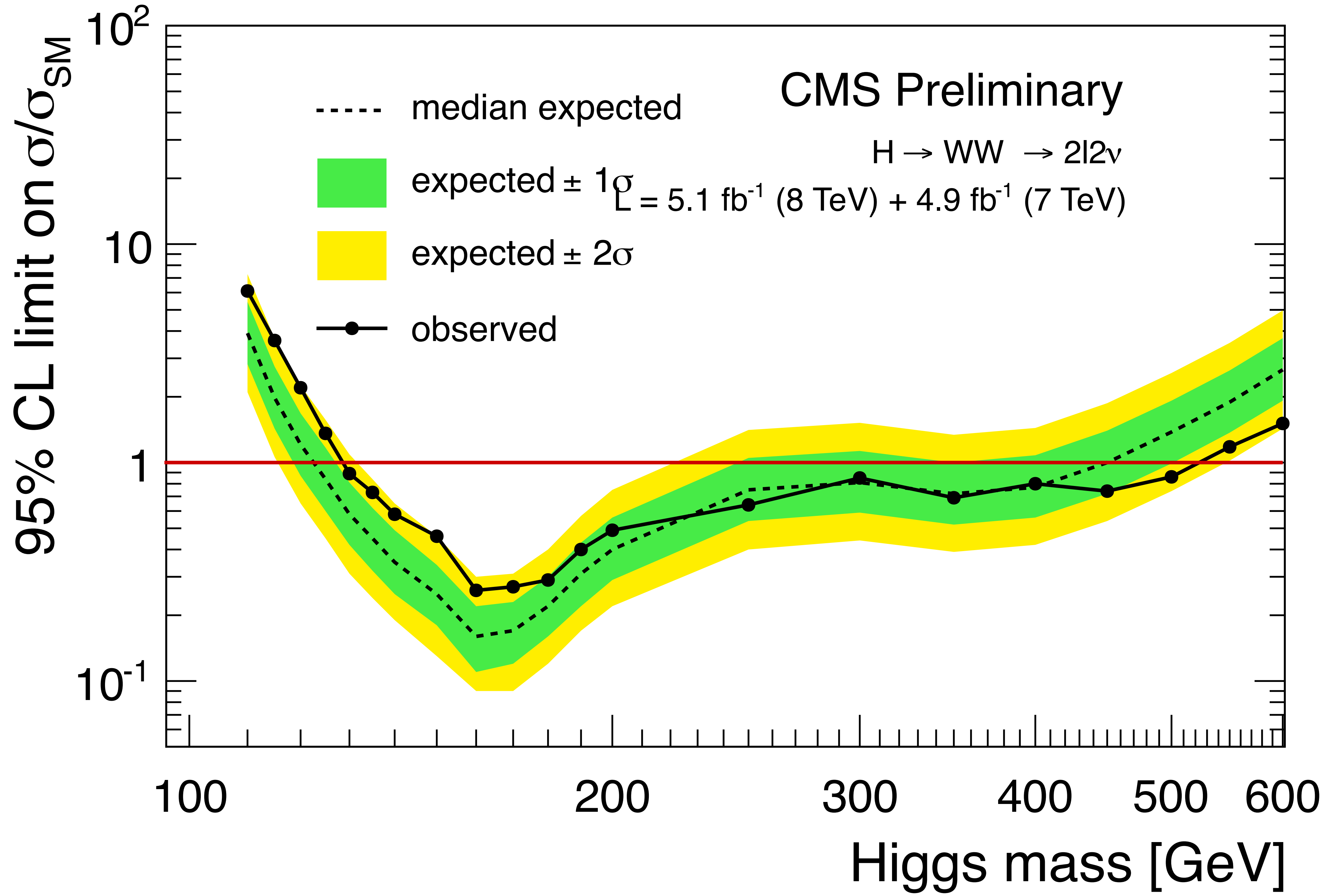


Expected limit: $128 < M_H < 250$ GeV
Observed limit: $135 < M_H < 198$ GeV

this channel is sensitive to m_H=[125-400] GeV with 8 TeV data

Combined result on 10 fb^{-1}

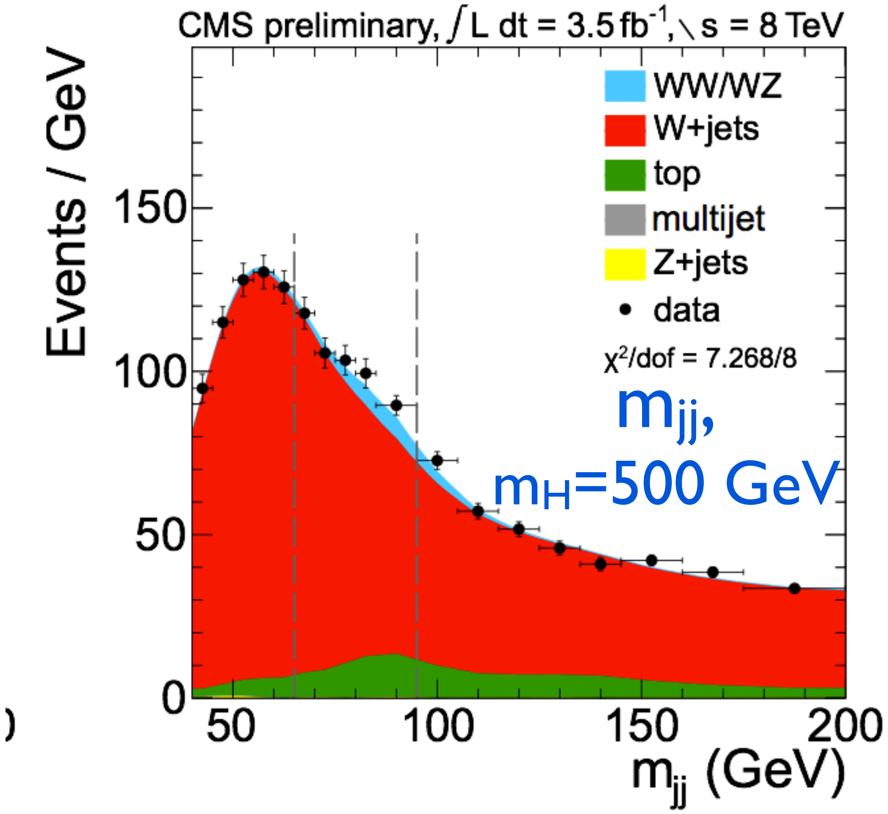
- statistical combination of 8 TeV (5.1 fb^{-1}) and 7 TeV (4.9 fb^{-1}, not reanalized)

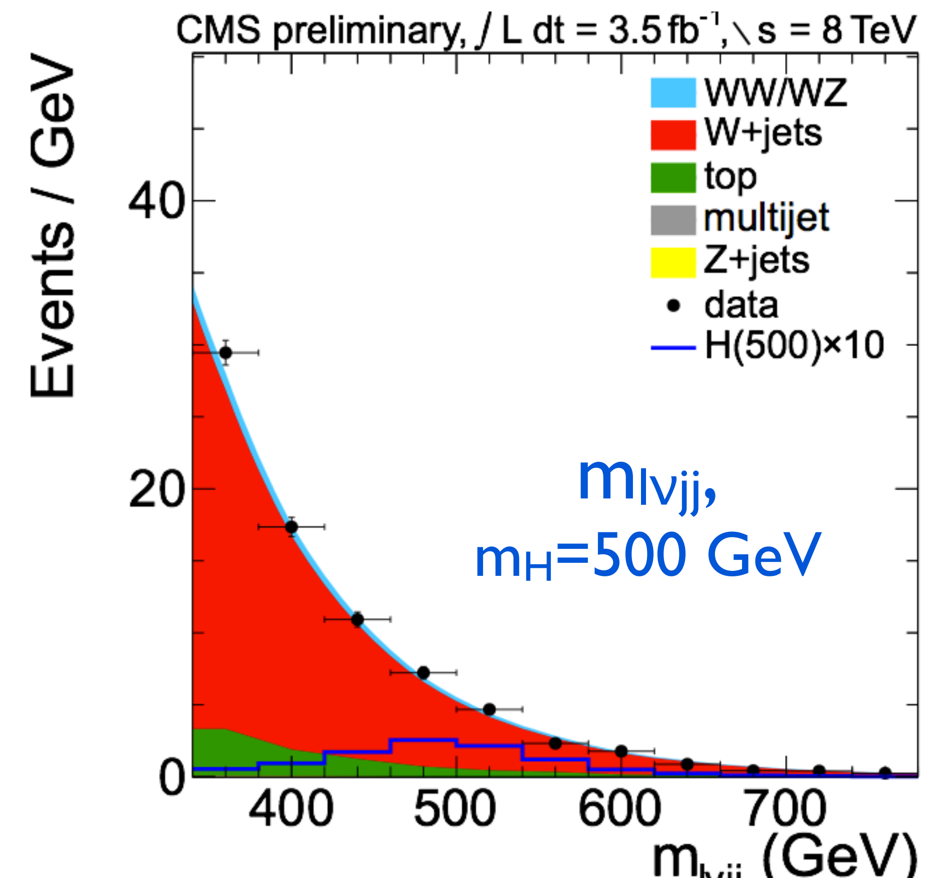


Expected limit: 122 < M_H < 450 GeV
Observed limit: 129 < M_H < 520 GeV

$H \rightarrow WW \rightarrow l\nu qq$

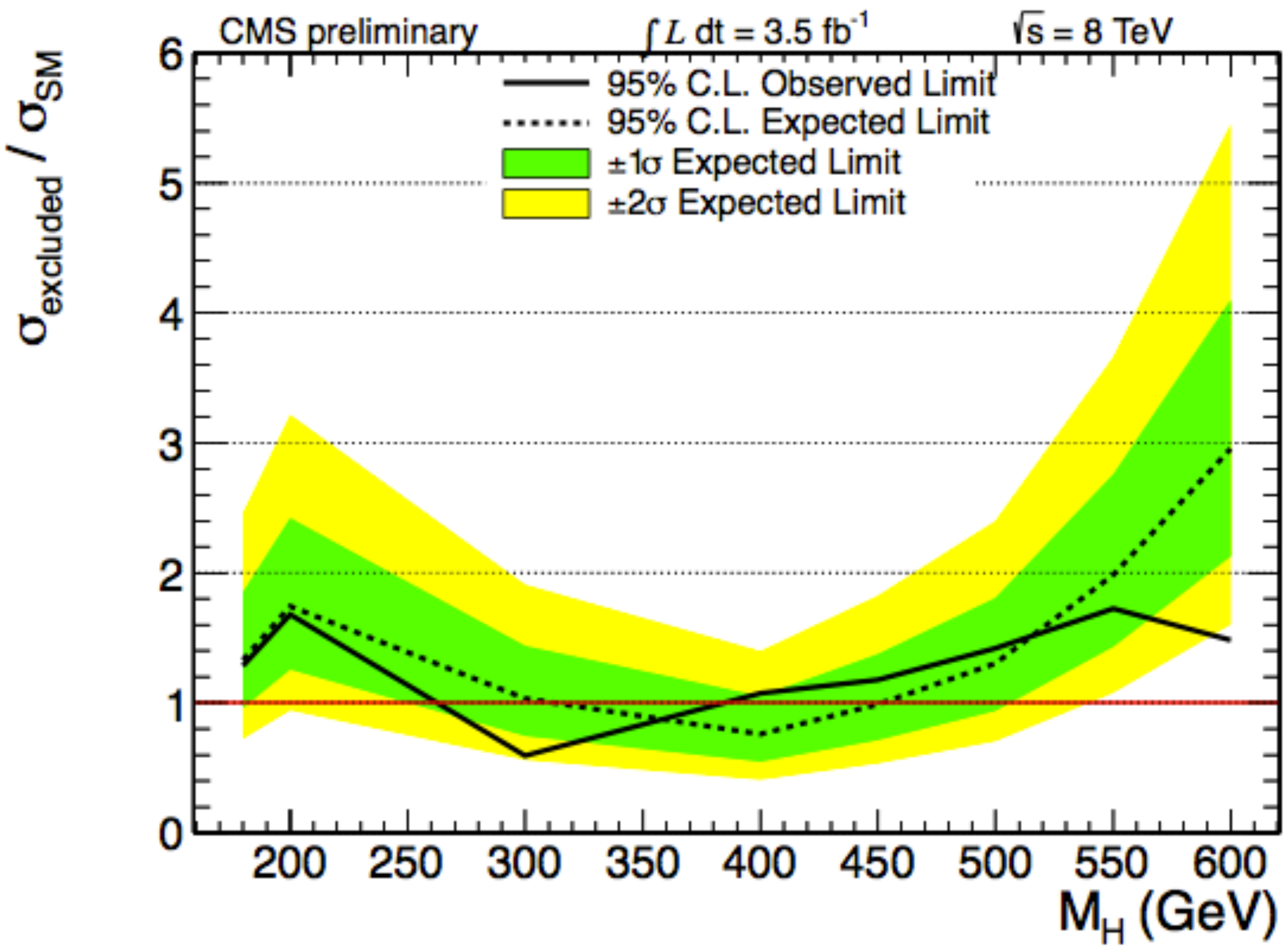
- Sensitive channel for m_H=[300-600] GeV, max sensitivity for m_H=350 GeV
- Event selection: one lepton, E_T^{miss} and 2 or 3 jets:
  - one e(μ) with p_T>35(25) GeV
  - anti kT jets with p_T>30 GeV
  - E_T^{miss} > 25 (30) GeV for e(μ) final state
  - events with di-jet mass 65<m_{j1j2}<95 GeV keep 80% of signal
  - kinematic fit with constraints M(lν)=M_W and M(jj)=M_W allows full reconstruction of Higgs boson mass M(lνjj)
  - use a m_H-dependent angular likelihood discriminant to optimize continuum W+jets rejection
- Search for a peak over a continuum background

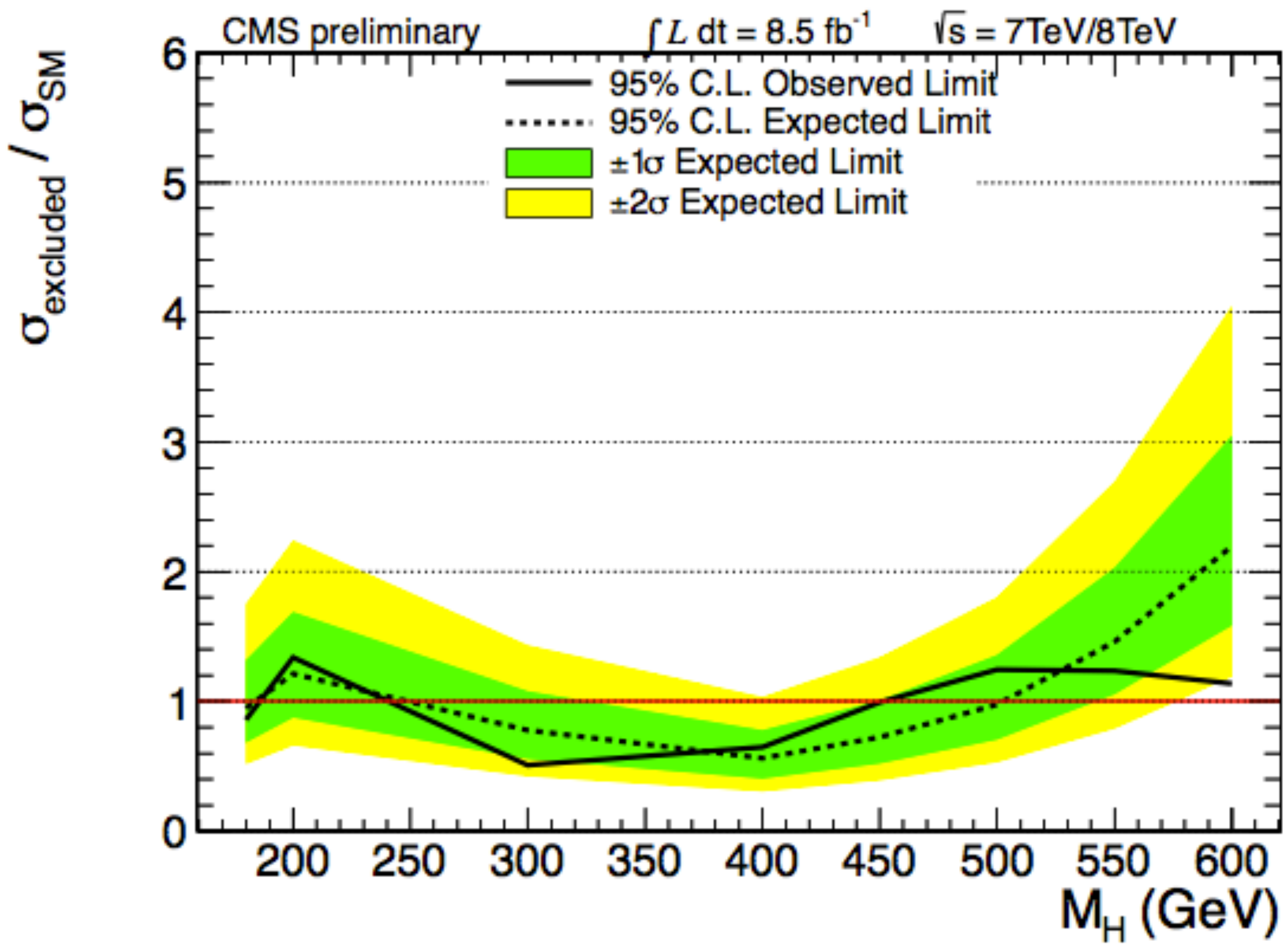




Results with 7,8 TeV data

- Used 4.9 fb^{-1} of 7 TeV data and 3.5 fb^{-1} of 8 TeV data





Observed limit: 260 < M_H < 390 GeV

Observed limit: 240 < M_H < 450 GeV

8 TeV data

7 TeV + 8 TeV data

Conclusions

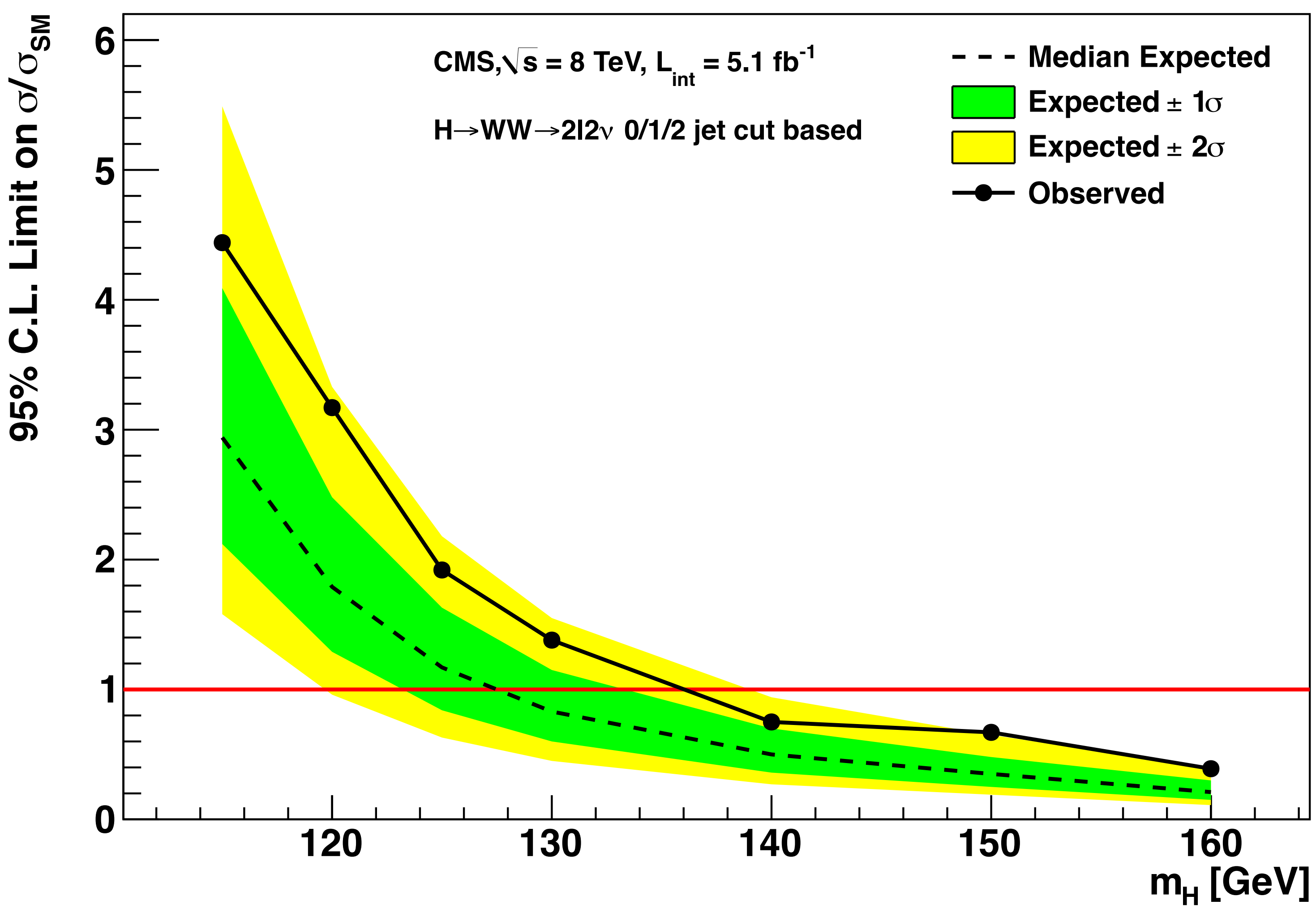
- The **H→WW channel** is one of the **most sensitive** to the SM Higgs in a wide mass range, starting from m_H=125 GeV
- CMS has searched for a Standard Model Higgs boson in WW fully leptonic final state with 4.9 fb^{-1} (7 TeV) and 5.1 fb^{-1} (8 TeV) data
  - observed an exclusion limit of m_H=[129-520] GeV, when expecting m_H=[122-450] GeV exclusion limit
  - for low masses, a broad excess is observed at the level of 2 Standard Deviations
- CMS has extended the search exploring the semi-leptonic final state, excluding the presence of Higgs boson n 240-450 GeV

↓

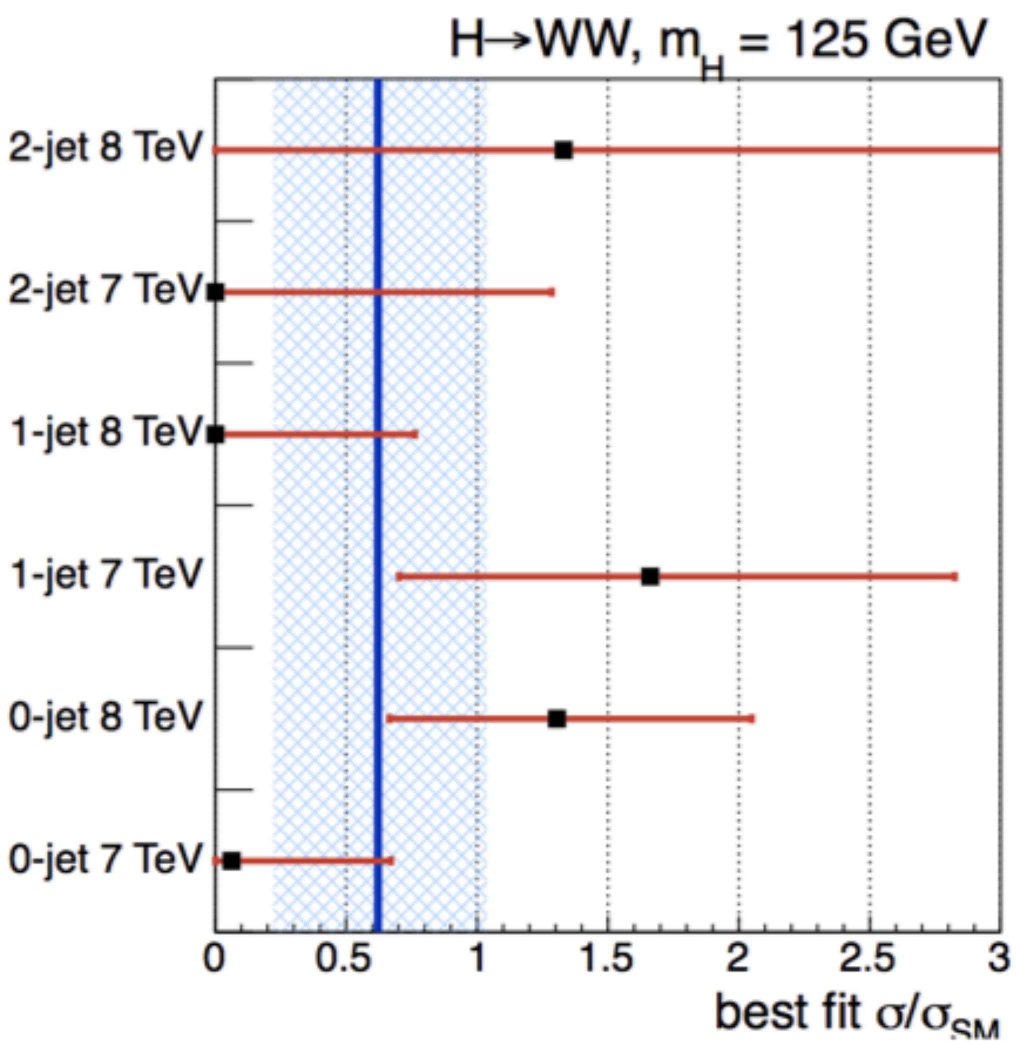
- **the excess at low mass is still both compatible with s Higgs boson with mass mH=125 GeV and with a fluctuation of the backgrounds**

backup

Combination 7 TeV + 8 TeV

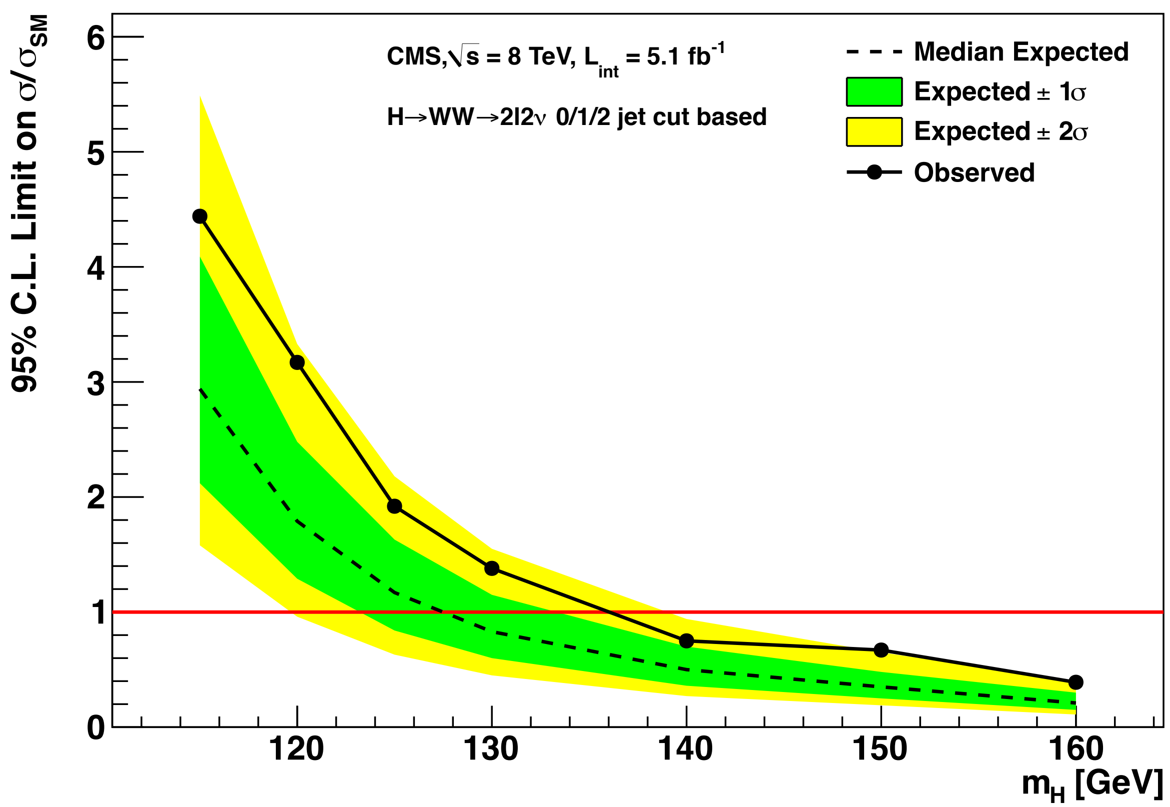


zoom at low m_H
for 7 TeV + 8 TeV

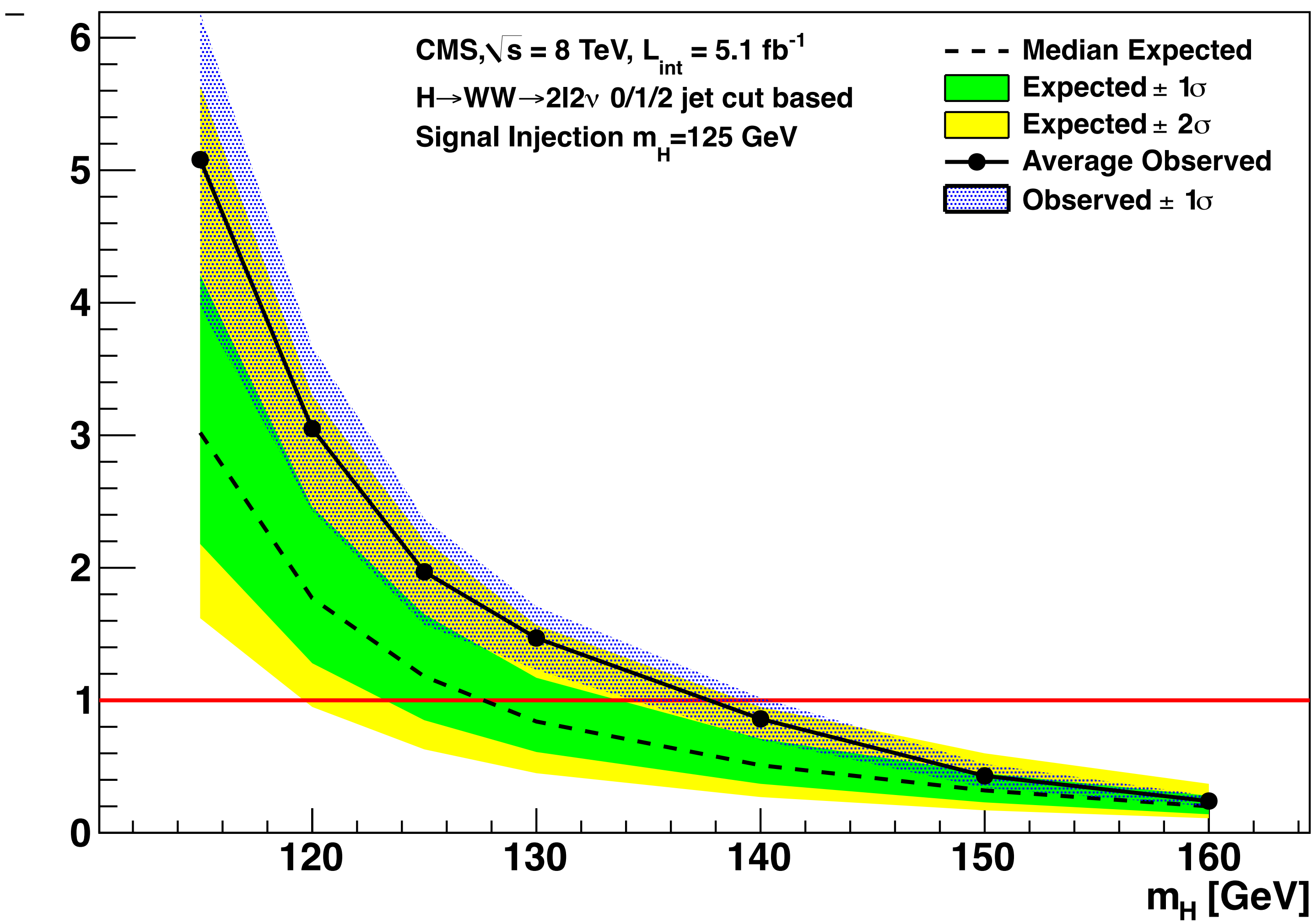


signal strength:
channel
compatibility

signal injection test



7 TeV + 8 TeV data
expected and observed
exclusion limit



expected observed limit and
pseudo-data with background +
$1 \times$ SM Higgs, m_H=125 GeV

Event yields at 8 TeV

m_H	H $\to W^+W^-$	pp $\to W^+W^-$	WZ + ZZ +Z/$\gamma^* \to \ell^+\ell^-$	Top	W + jets	W$\gamma^{(*)}$	all bkg.	data
0-jet category $e\mu$ final state								
125	23.9 ± 5.2	87.6 ± 9.5	2.2 ± 0.2	9.3 ± 2.7	19.1 ± 7.2	6.0 ± 2.3	124.2 ± 12.4	158
130	35.3 ± 7.6	96.8 ± 10.5	2.5 ± 0.3	10.1 ± 2.8	20.7 ± 7.8	6.3 ± 2.4	136.3 ± 13.6	169
160	98.3 ± 21.2	53.6 ± 5.9	1.2 ± 0.1	6.3 ± 1.7	2.5 ± 1.3	0.2 ± 0.1	63.9 ± 6.3	79
400	16.6 ± 4.8	50.5 ± 5.8	1.5 ± 0.2	26.1 ± 5.7	4.5 ± 2.0	0.7 ± 0.5	83.3 ± 8.4	92
0-jet category $ee/\mu\mu$ final state								
125	14.9 ± 3.3	60.4 ± 6.7	37.7 ± 12.5	1.9 ± 0.5	10.8 ± 4.3	4.6 ± 2.5	115.5 ± 15.0	123
130	23.5 ± 5.1	67.4 ± 7.5	41.3 ± 15.9	2.3 ± 0.6	11.0 ± 4.3	4.8 ± 2.5	126.8 ± 18.3	134
160	86.0 ± 18.7	44.5 ± 4.9	11.3 ± 13.4	3.8 ± 0.9	1.3 ± 1.1	0.4 ± 0.3	61.4 ± 14.4	92
400	12.3 ± 3.6	37.1 ± 4.3	5.7 ± 1.3	20.0 ± 4.7	3.4 ± 1.9	13.6 ± 4.8	79.9 ± 8.3	55
1-jet category $e\mu$ final state								
125	10.3 ± 3.0	19.5 ± 3.7	2.4 ± 0.3	22.3 ± 2.0	11.7 ± 4.6	5.9 ± 3.2	61.7 ± 7.0	54
130	15.7 ± 4.7	22.0 ± 4.1	2.6 ± 0.3	25.1 ± 2.2	12.8 ± 5.1	6.0 ± 3.2	68.5 ± 7.6	64
160	52.6 ± 14.9	20.1 ± 4.0	1.6 ± 0.2	21.5 ± 1.8	5.0 ± 2.3	0.9 ± 0.5	49.2 ± 5.0	62
400	11.4 ± 3.3	39.1 ± 6.3	2.1 ± 0.3	56.6 ± 3.7	7.1 ± 3.1	0.6 ± 0.6	105.5 ± 8.0	96
1-jet category $ee/\mu\mu$ final state								
125	4.4 ± 1.3	9.7 ± 1.9	8.7 ± 4.9	9.5 ± 1.1	3.9 ± 1.7	1.3 ± 1.2	33.1 ± 5.7	43
130	7.1 ± 2.2	11.2 ± 2.2	9.1 ± 5.4	10.7 ± 1.2	3.7 ± 1.7	1.3 ± 1.2	36.0 ± 6.3	53
160	37.9 ± 10.9	13.8 ± 2.8	28.4 ± 10.7	16.2 ± 1.6	3.8 ± 2.1	0.0 ± 0.0	62.3 ± 11.4	65
400	7.4 ± 2.2	19.6 ± 3.2	7.9 ± 2.4	33.4 ± 2.4	1.6 ± 1.3	4.4 ± 1.8	66.8 ± 5.1	67
2-jet category $e\mu$ final state								
125	1.5 ± 0.2	0.4 ± 0.1	0.1 ± 0.0	3.4 ± 1.9	0.3 ± 0.3	0.0 ± 0.0	4.1 ± 1.9	6
130	2.5 ± 0.4	0.5 ± 0.2	0.1 ± 0.0	3.0 ± 1.8	0.3 ± 0.3	0.0 ± 0.0	3.9 ± 1.9	6
160	9.9 ± 1.3	0.8 ± 0.2	0.1 ± 0.0	4.2 ± 2.2	0.6 ± 0.4	0.0 ± 0.0	5.6 ± 2.2	11
400	2.3 ± 0.4	1.9 ± 0.8	0.2 ± 0.0	9.1 ± 2.7	0.5 ± 0.4	0.0 ± 0.0	11.7 ± 2.9	22
2-jet category $ee/\mu\mu$ final state								
125	0.8 ± 0.1	0.3 ± 0.1	3.1 ± 1.8	2.0 ± 1.2	0.0 ± 0.0	0.0 ± 0.0	5.4 ± 2.2	7
130	1.3 ± 0.2	0.4 ± 0.2	3.8 ± 2.2	2.0 ± 1.2	0.0 ± 0.0	0.0 ± 0.0	6.2 ± 2.5	7
160	6.0 ± 0.8	0.7 ± 0.3	4.7 ± 2.7	2.4 ± 1.2	0.2 ± 0.4	0.0 ± 0.0	8.0 ± 3.0	9
400	1.6 ± 0.2	1.5 ± 0.7	6.6 ± 2.8	4.9 ± 1.9	0.7 ± 0.7	0.0 ± 0.0	13.8 ± 3.5	15