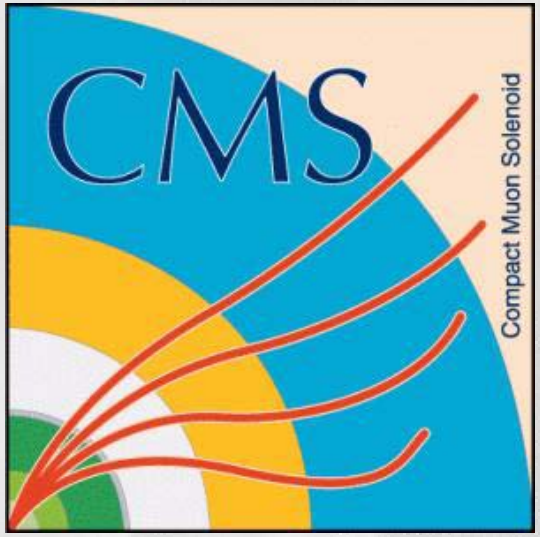


Standard Model Higgs: H→WW and H→ZZ from CMS

G. Codispoti,

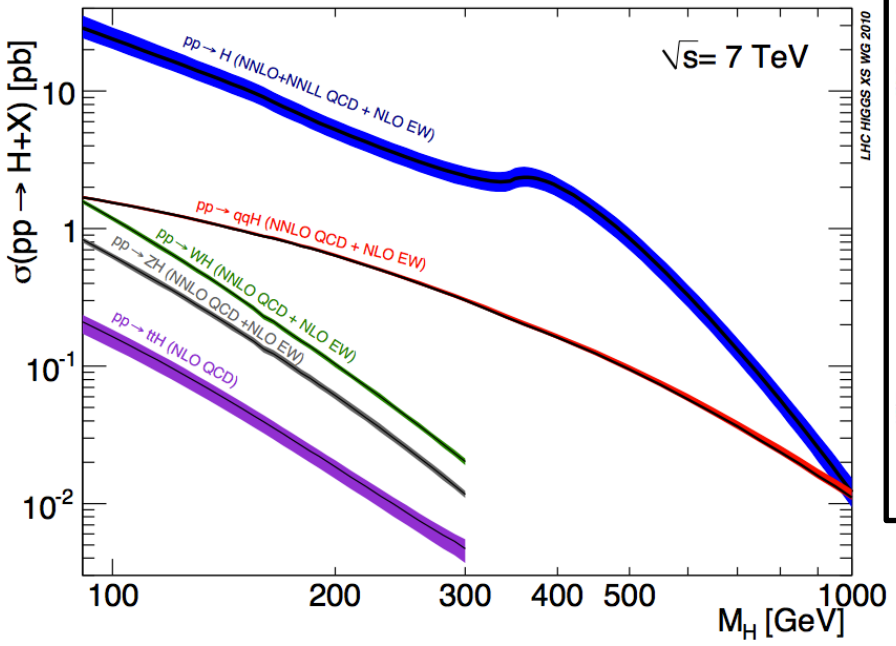
Universidad Autónoma de Madrid

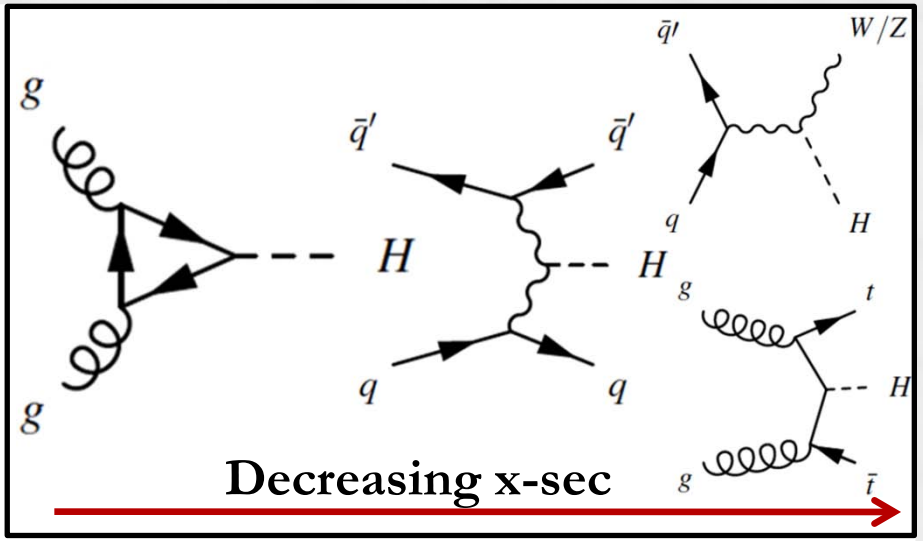
On behalf of the CMS Collaboration

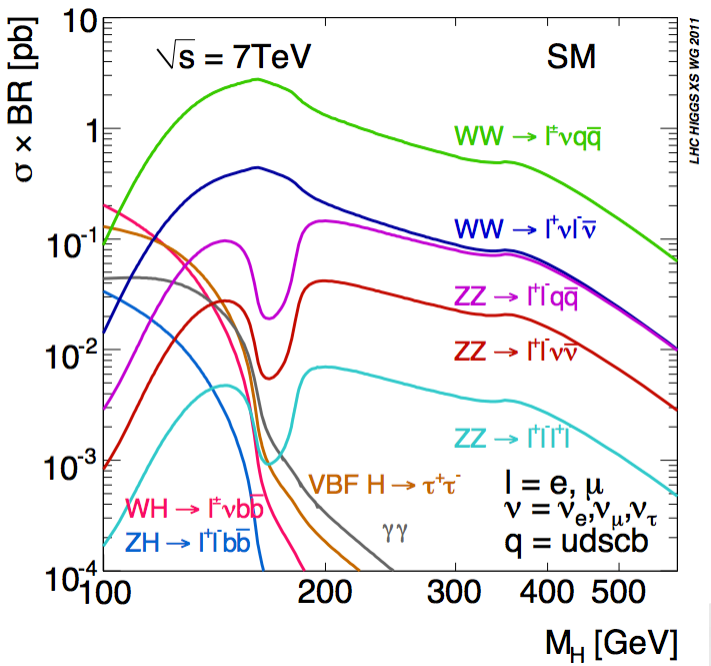
Hadron Collider Physics Symposium 2011

November 14 - 18, 2011
Paris, France

Higgs Production and Decay

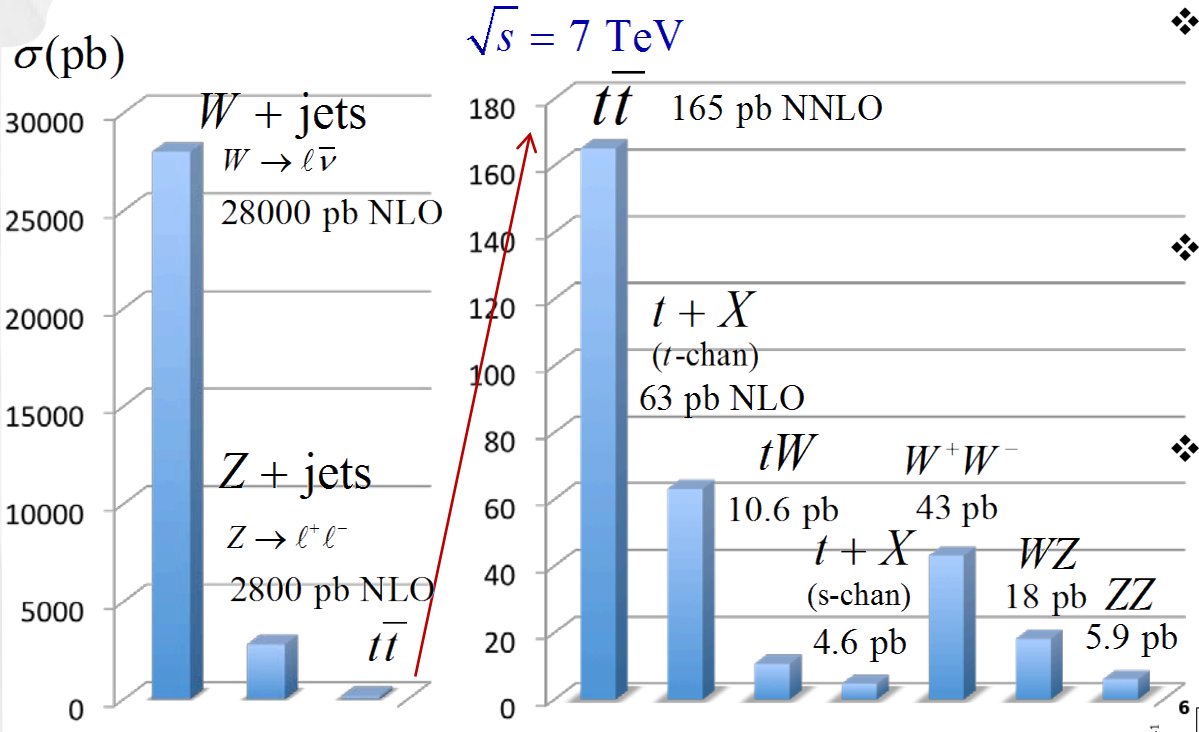






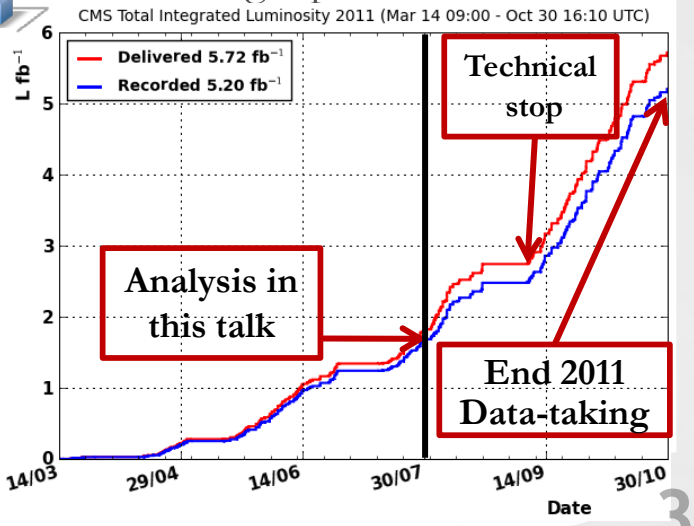
- H→WW and H→ZZ cover a wide mass range:
  - 110-600 GeV/c^2
- I will focus on the following final states (ℓ=e,μ):
  - H → WW → 2ℓ2ν
  - H → ZZ → 4ℓ
  - H → ZZ → 2ℓ2τ
  - H → ZZ → 2ℓ2ν
  - H → ZZ → 2ℓ2jets

Experimental challenges

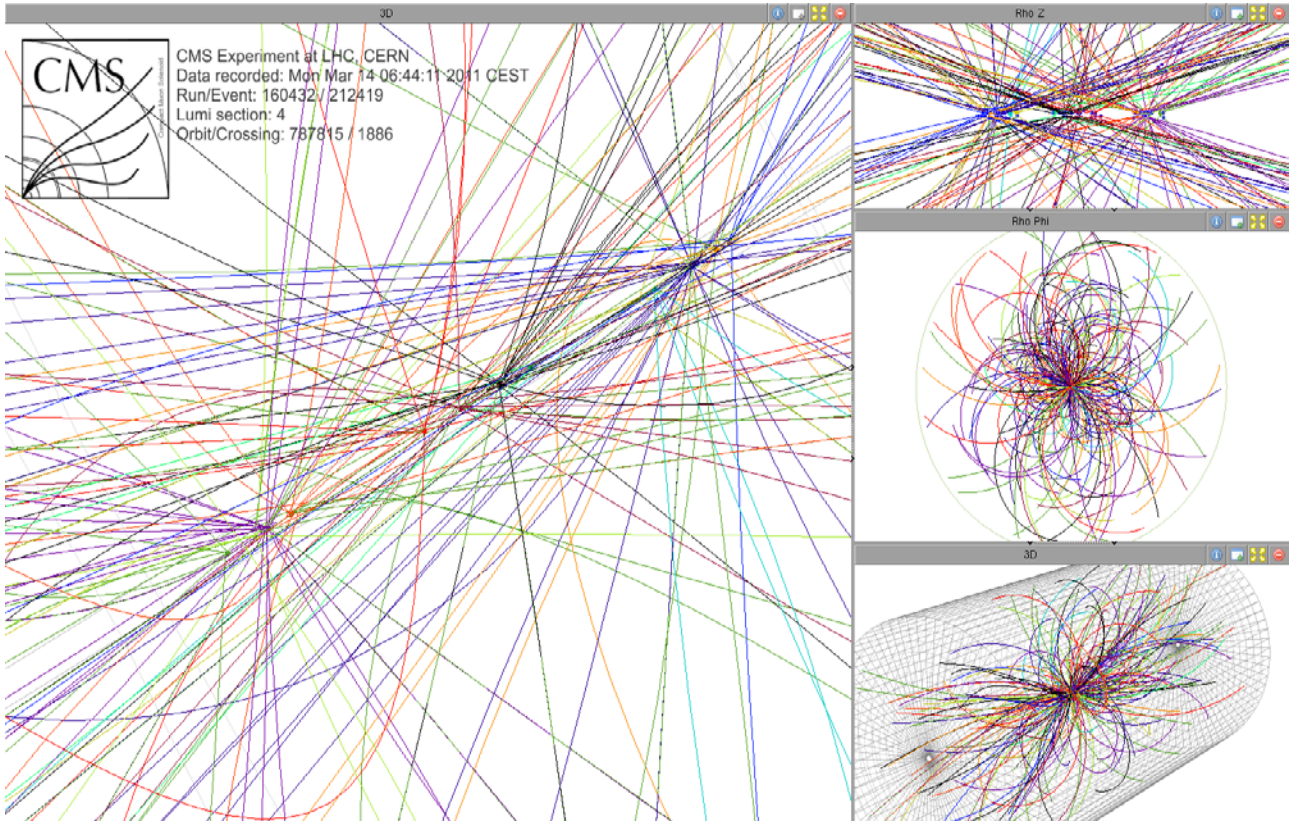


- Backgrounds overwhelm Higgs Signal by several orders of magnitude!
- Irreducible backgrounds:
  - WW/ZZ non resonant
- Reducible backgrounds:
  - V+jets; ttbar; tV; QCD hard scattering with jets faking leptons

- Rapid increase of the instantaneous luminosity in 2011
- Trigger adapting to new conditions
- Increasing pile-up backgrounds



The physics objects and pile-up

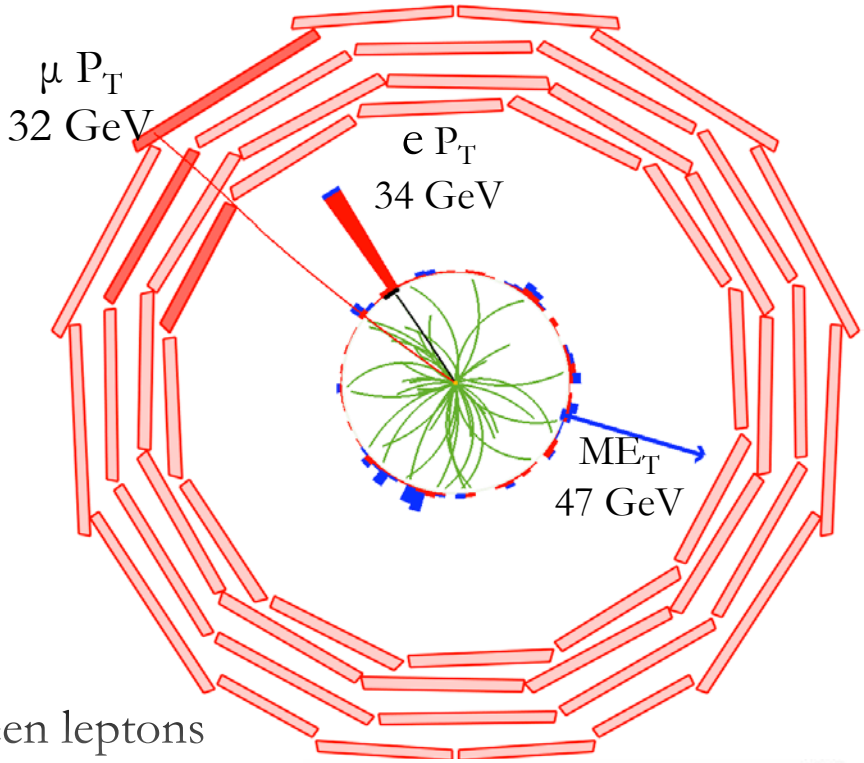


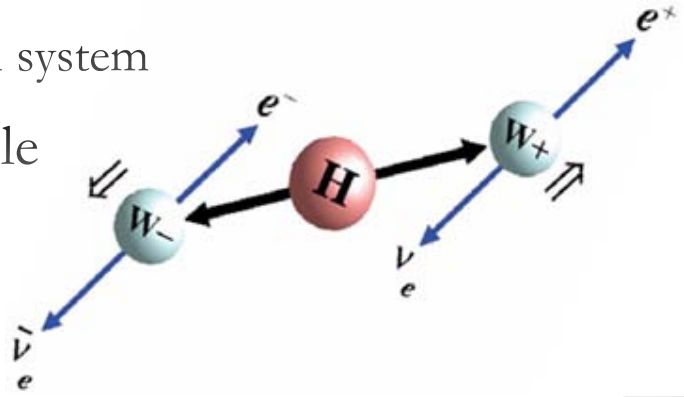
- Improved reconstruction algorithm to distinguish vertices with $\Delta z > 1$ mm
- Correct the jet energy subtracting the event average pile-up contribution
- Use pile-up safe variables for lepton isolation and identification
- Careful estimation of the Missing E_T (ME_T)

$H \rightarrow WW \rightarrow 2\ell 2\nu$

CMS-PAS-HIG-11-014

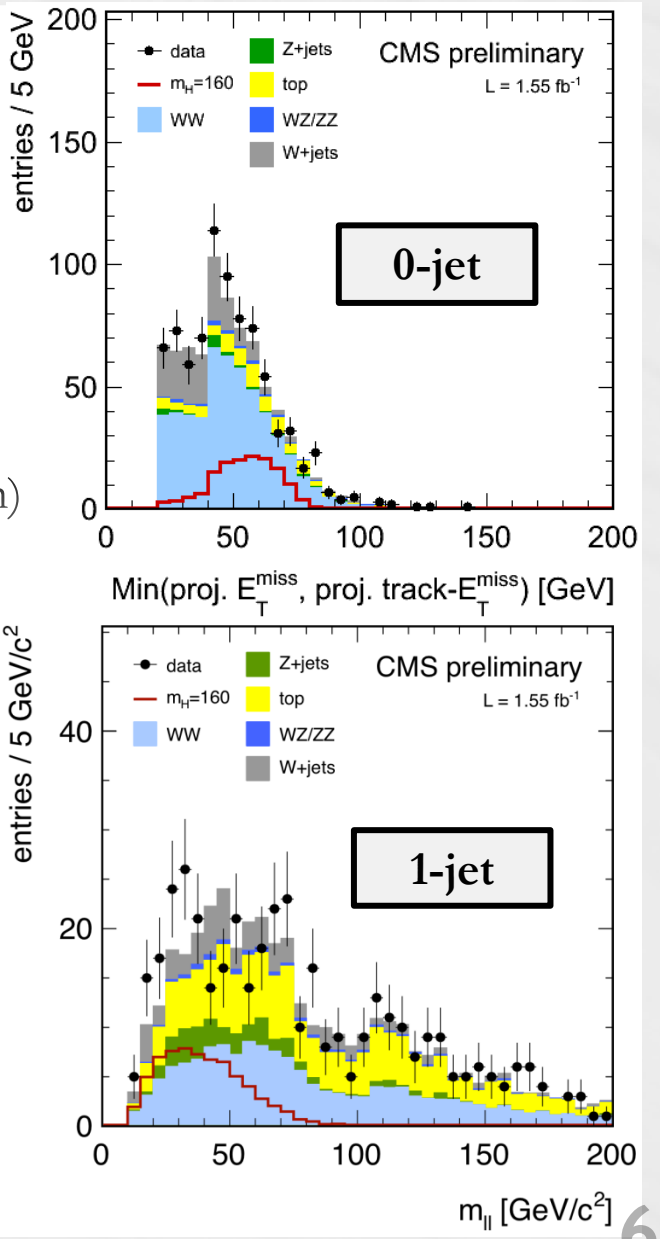
- Signal characterized by:
  - 2ν in the final states
    - Undetected particles: large ME_T
    - No mass peak: counting experiment
  - 2 isolated leptons
    - Selected with p_T>20,10 GeV/c
  - Spin correlation:
    - Moderately small opening angle between leptons
    - Large angle with ME_T direction w.r.t. di-lepton system
  - Reject events with di-lepton pair compatible with Z mass
  - Reject b-tagged events





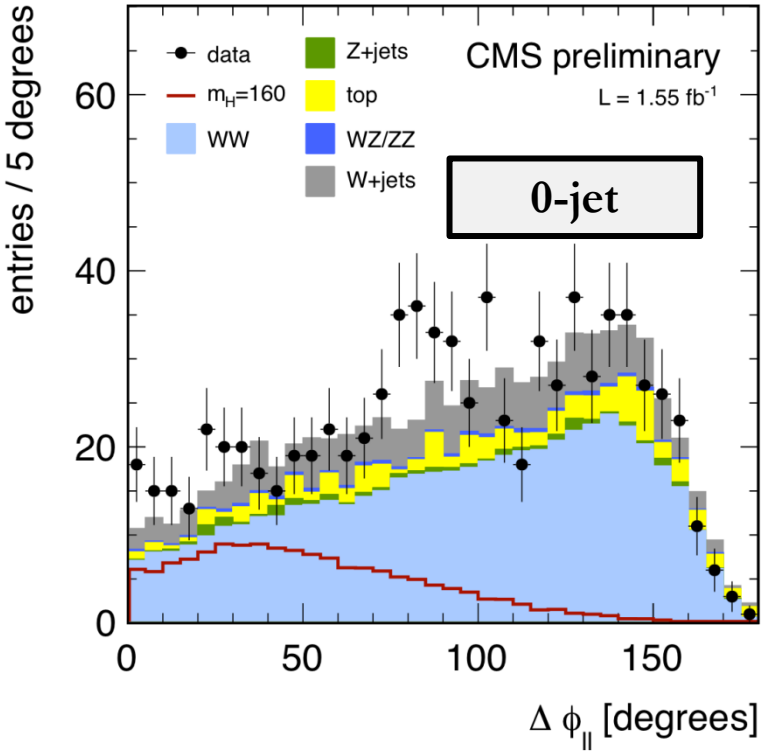
Analysis strategies

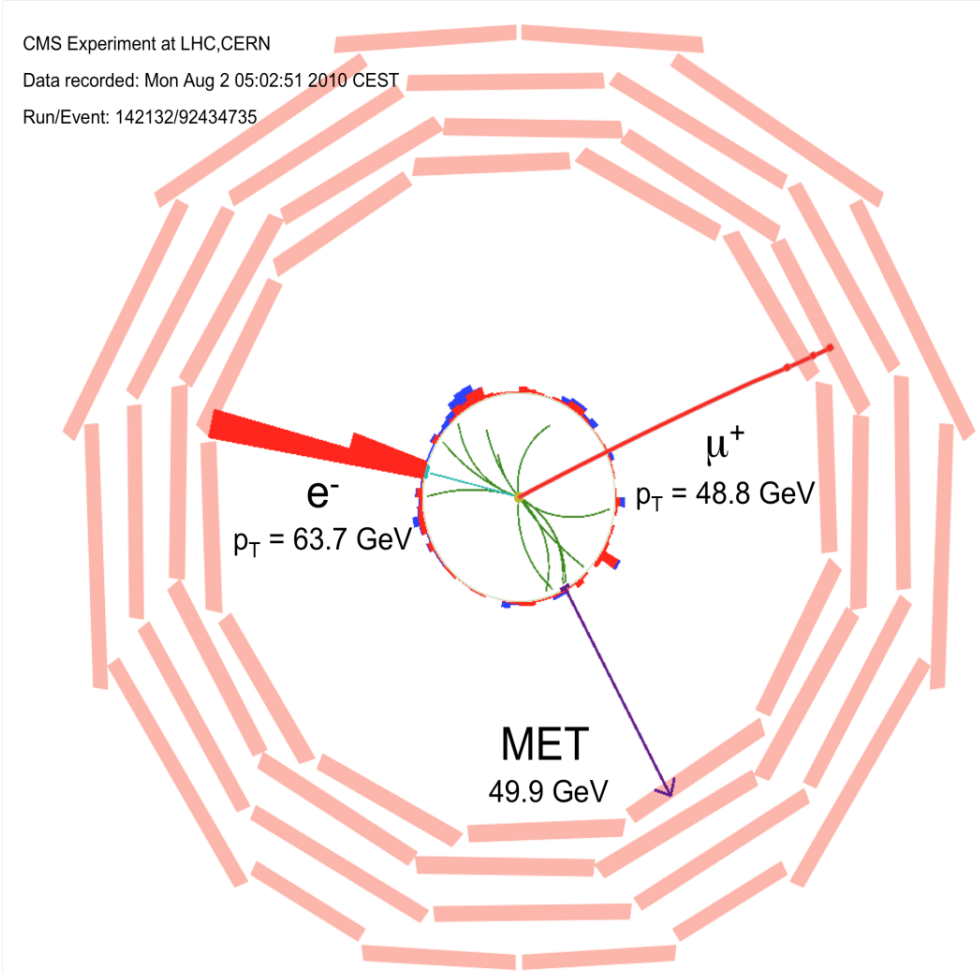
- Selection dependent on Higgs mass hypothesis
- Divided in three categories:
  - 0-jet bin, dominated by WW and W+jets
  - 1-jet bin, dominated by WW and top
  - 2-jet bin, dominated by top (and Higgs VBF production)
- Used min between 2 ME_T estimators to reduce pile-up dependencies
  - Standard ME_T, sensitive to pile-up
  - Track only ME_T, using only tracks compatible with primary vertex
- Projected ME_T in order to reduce Drell-Yan background
  - If angle with closest lepton $\Delta\phi_{min} < \pi/2$ use $ME_T \sin(\Delta\phi_{min})$



W^+W^- background

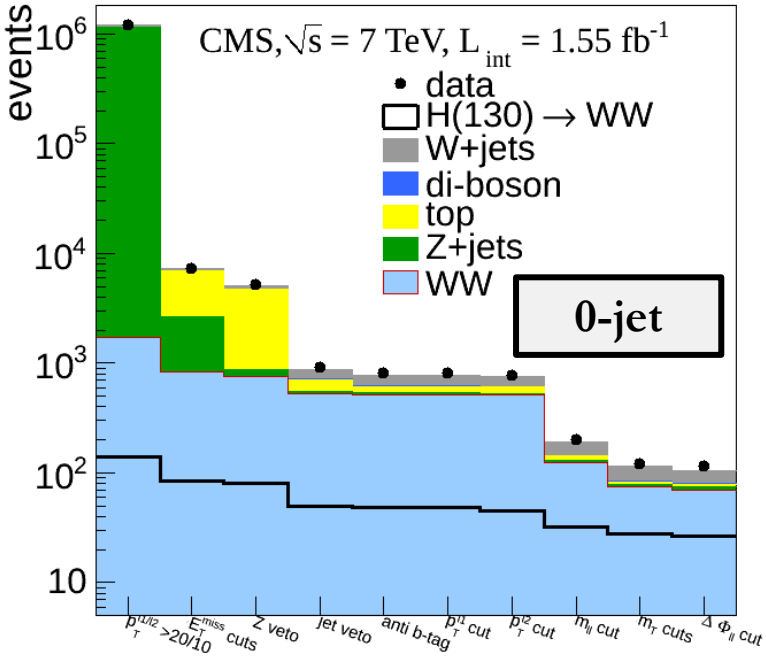
- W^+W^- continuum does not show the same angular correlation as signal
- Large values for $\Delta\phi_{ll}$





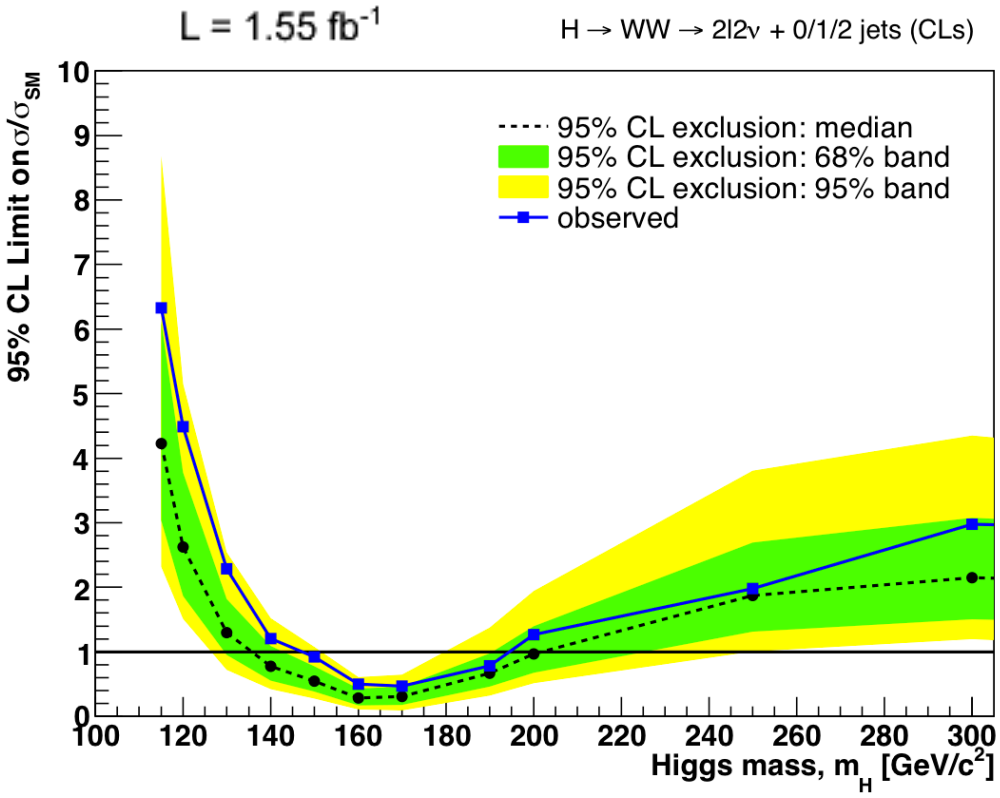
Background Estimation

- W^+W^- non resonant contribution:
  - m_{ll} sidebands extrapolation for $m_H<200 Gev/c^2$
  - MC for high masses
- W+jets and QCD: fake rate method
  - Control sample from loosely identified leptons
  - Extrapolated to the signal region using fake rate



- Residual Z contribution evaluated from data:
  - Extrapolation from Z mass window $\pm 15 GeV/c^2$ rescaled using the ratio of events in/out Z mass window calculated in MC
- ttbar + tW:
  - Extrapolation from top tagged sample

H→WW→2ℓ2ν: results



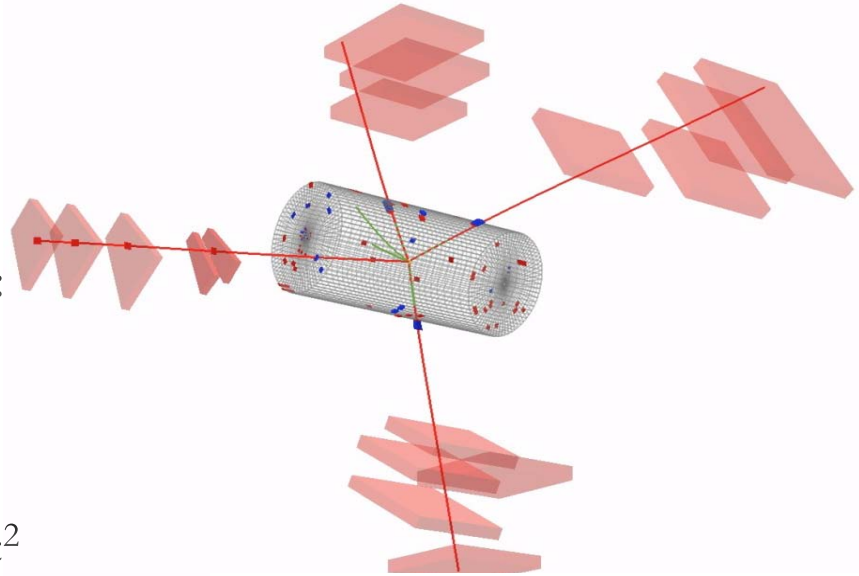
Mass	120	140	160
Higgs	**7.6 ± 1.7**	**18.8 ± 4.2**	**26.6 ± 6.1**
qq → WW	33.7 ± 5.9	31.5 ± 5.5	13.5 ± 2.4
gg → WW	1.3 ± 0.7	1.5 ± 0.8	1.3 ± 0.7
VV*	0.8 ± 0.1	0.8 ± 0.1	0.3 ± 0.1
top*	3.0 ± 1.1	3.1 ± 1.1	1.9 ± 0.9
DY*	0.1 ± 0.0	0.1 ± 0.0	0.0 ± 0.0
W+jets*	19.4 ± 7.3	5.6 ± 2.3	2.0 ± 1.1
Σbkg	**62.3 ± 9.5**	**44.0 ± 6.2**	**19.0 ± 2.9**
Data	**67**	**46**	**18**

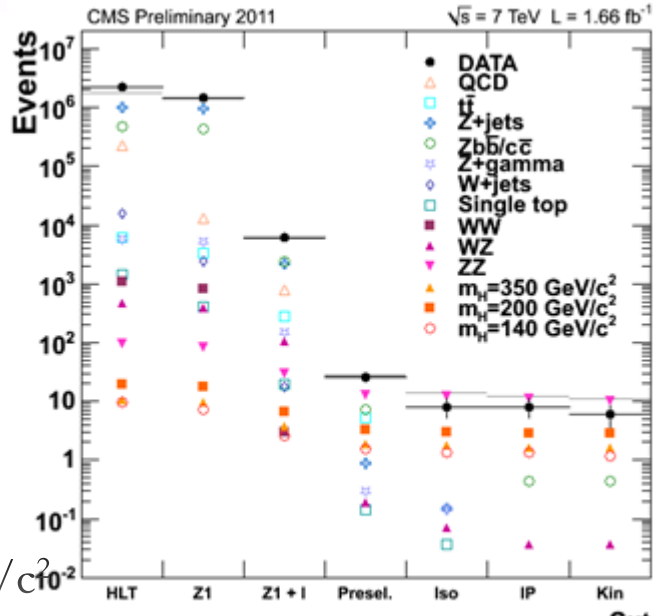
- Higgs excluded in the range 147-194 GeV/c^2 @95%CL
- WW production cross section measured, **see dedicated Di-Bosons talk**:
  - $\sigma(pp \to WW + X) = 55.3 \pm 3.3(\text{stat.}) \pm 6.9(\text{syst.}) \pm 3.3(\text{lumi.})pb$
- Consistent with $\sigma^{\text{th.}}$(NLO) = 43.0±2.0 pb at 1σ level

$H \rightarrow ZZ \rightarrow 4\ell$

CMS-PAS-HIG-11-015

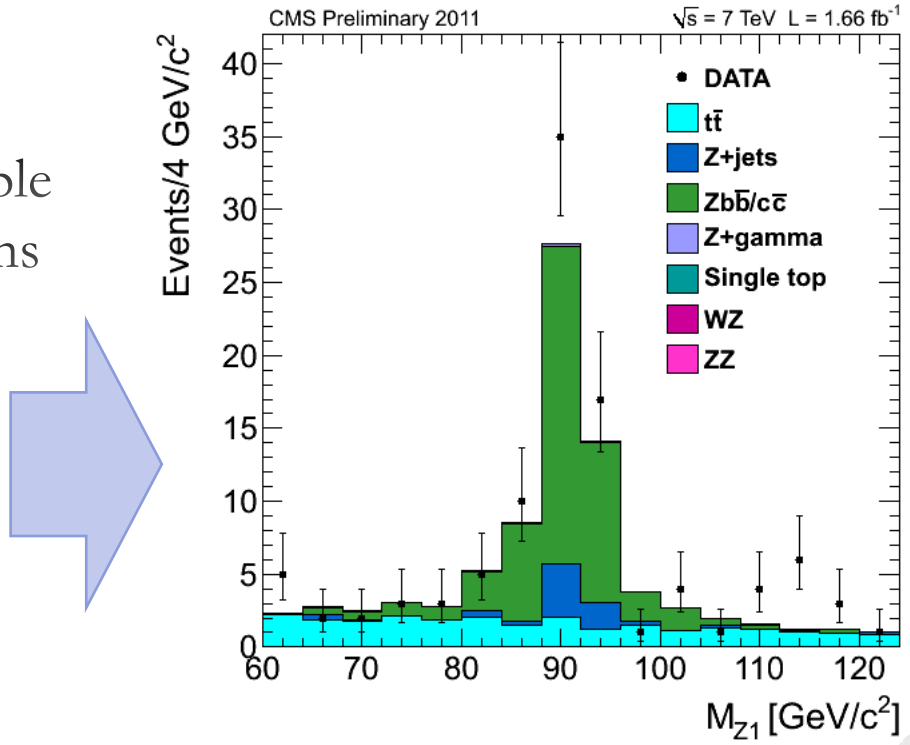
- Signal characterized by:
  - Very clean final state signature
  - 4 isolated lepton from common vertex:
    - 4e; 4μ; 2e2μ
  - Fully reconstructed
  - Expected mass resolution ~2-4 GeV/c^2
  - Small branching ratio: low yield expected
- Analysis tools
  - Using isolation and impact parameter cuts in order to minimize reducible background
  - Lepton pairs constrained to Z nominal mass:
    - Baseline selection 20GeV/c^2< m(Z_2) < 120GeV/c^2
    - High mass selection 60GeV/c^2 < m(Z_2) < 120GeV/c^2





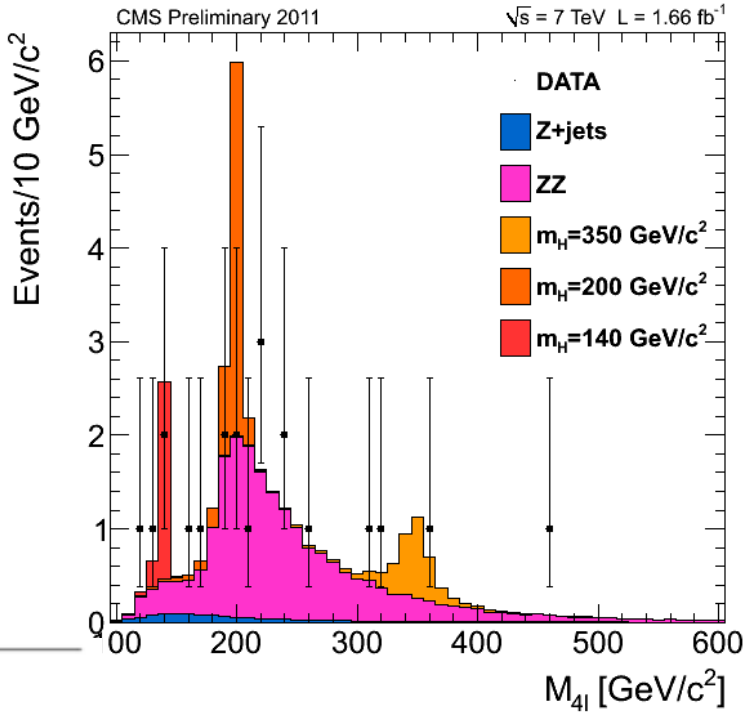
Backgrounds estimation

- ZZ continuum:
  - Shape known at NLO, modeled with MCFM
  - Normalized to $Z \rightarrow \ell^+\ell^-$ events in data, corrected using the theoretical prediction for ratio of ZZ to Z cross sections and acceptance from MC
- Fake-lepton from Z+jets:
  - Estimation from a control sample with Z+loosely identified leptons
- Z→bb, tt:
  - Removing flavour, charge and isolation cuts from Z_2
  - Reverse impact parameter cut



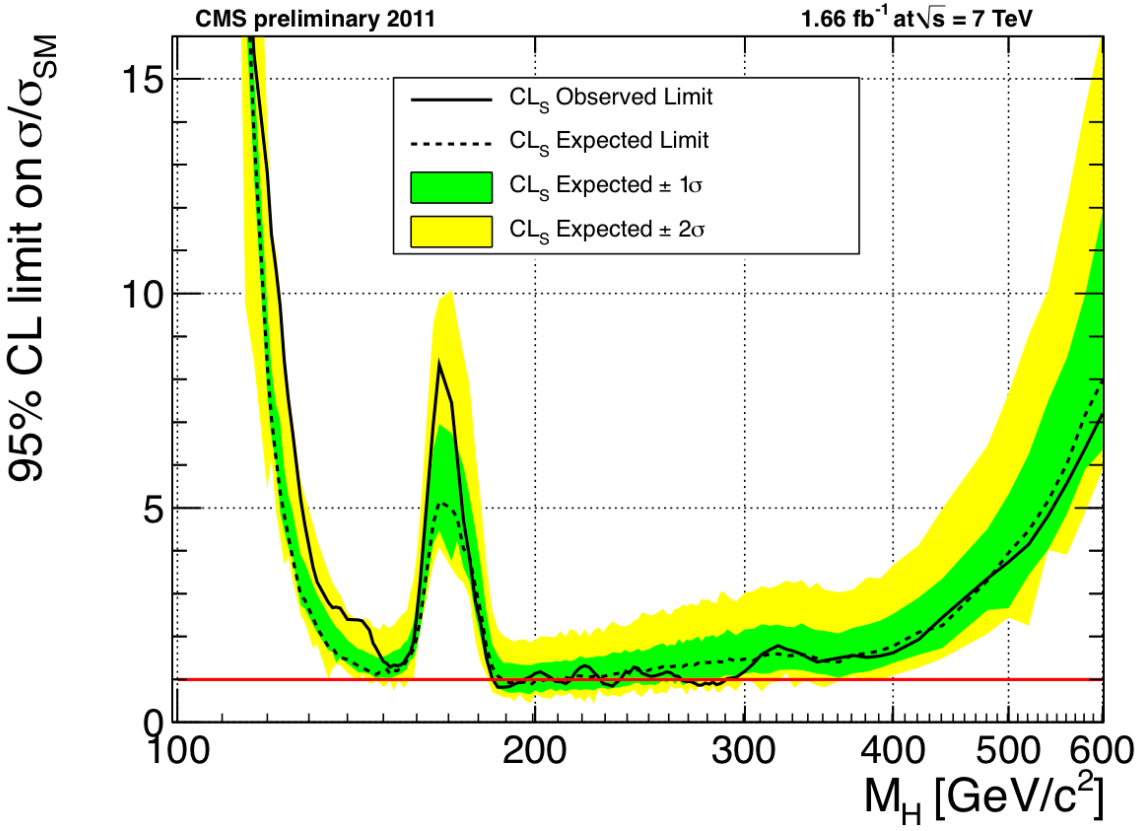
Selection and Yield

- 6 out of 21 events below threshold of 2 on-shell Z's
  - No peak structure
  - Mass paired (122, 142, 165) GeV/c^2
  - 142 GeV/c^2 the most "Higgs-compatible"



	baseline		
	$4e$	4μ	$2e2\mu$
ZZ	4.05 ± 0.26	6.02 ± 0.40	9.87 ± 0.66
Z+jet	0.48 ± 0.08	0.09 ± 0.02	0.61 ± 0.11
$Zb\bar{b}/c\bar{c}, t\bar{t}$	0.01 ± 0.01	0.05 ± 0.01	0.06 ± 0.01
WZ	0.009 ± 0.009	0.009 ± 0.009	0.04 ± 0.02
All background	4.54 ± 0.27	6.12 ± 0.40	10.52 ± 0.67
$m_H = 140\,\mathrm{GeV}/c^2$	0.45	0.82	1.19
$m_H = 200\,\mathrm{GeV}/c^2$	1.20	1.71	2.80
$m_H = 350\,\mathrm{GeV}/c^2$	0.70	0.93	1.63
Observed	5	10	6

H→ZZ→4ℓ: results

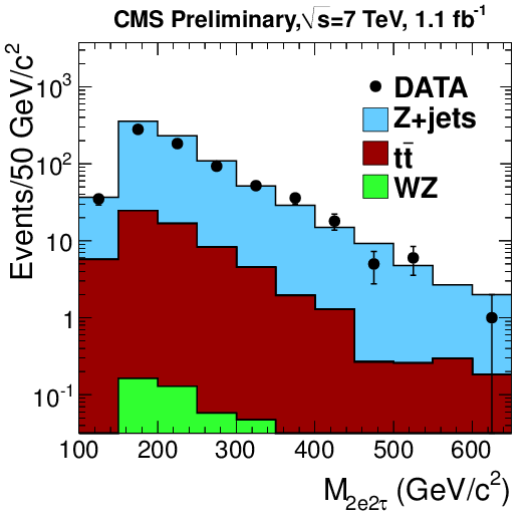


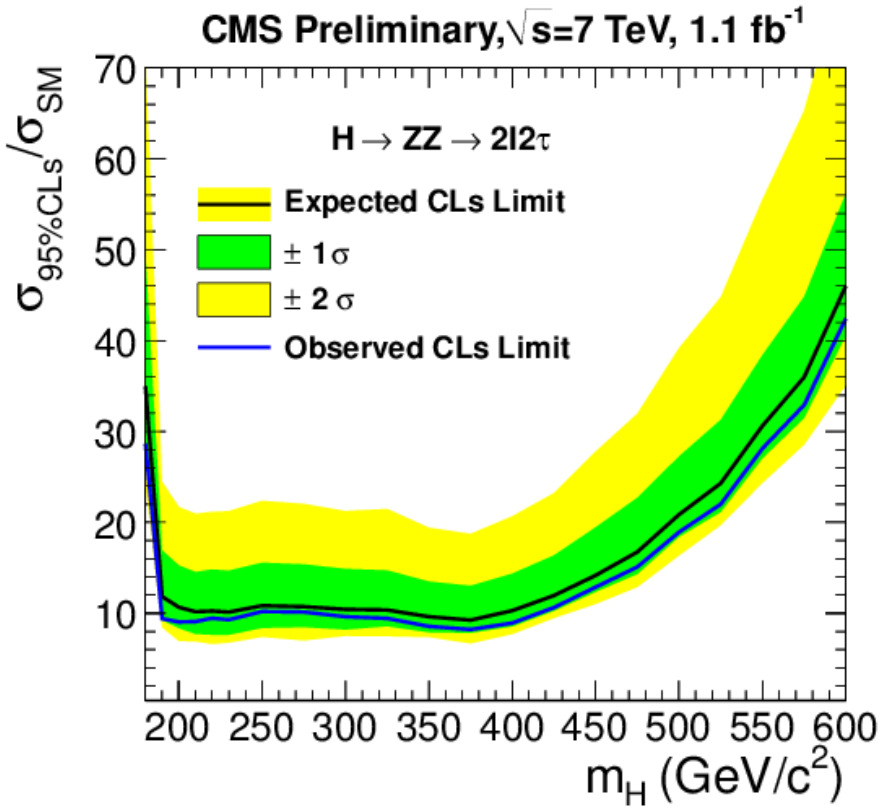
- ZZ production cross section measured, **see dedicated Di-Bosons talk**:
  - $\sigma(pp \to ZZ + X) \times B(ZZ \to 4l) = 20.8^{+6.8}_{-4.0}(stat.) \pm 0.5(syst.) \pm 0.9(lumi)\ fb$
- Consistent with $\sigma^{th.}$(NLO)=28.32 ± 1.95 fb at 1σ level

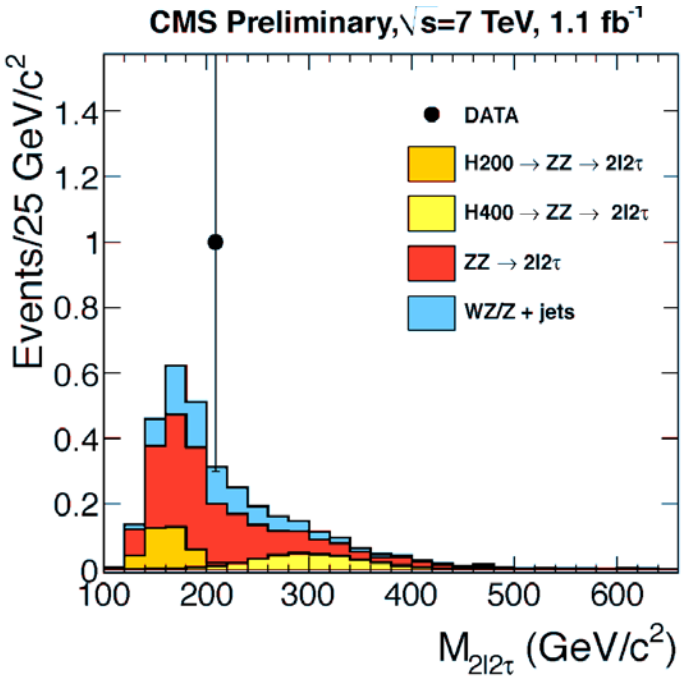
H→ZZ→2ℓ2τ

Hig11013TWiki

- This analysis complements the 4ℓ final states: discard events duplicated in 4ℓ modes
  - Add kinematical constraint for τ reconstruction in Z→ ττ

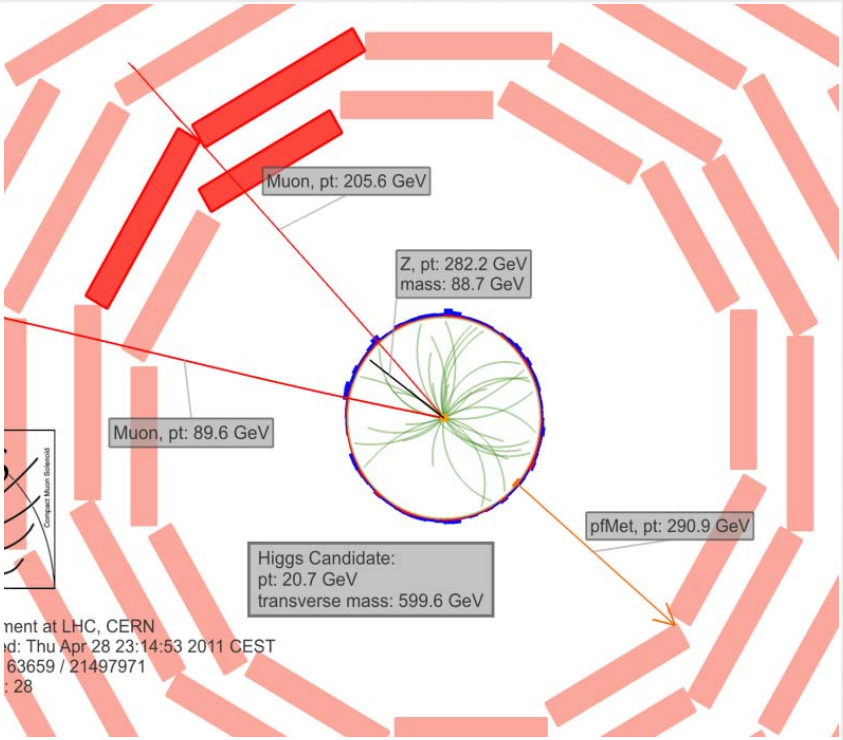






$H \rightarrow ZZ \rightarrow 2\ell 2\nu$

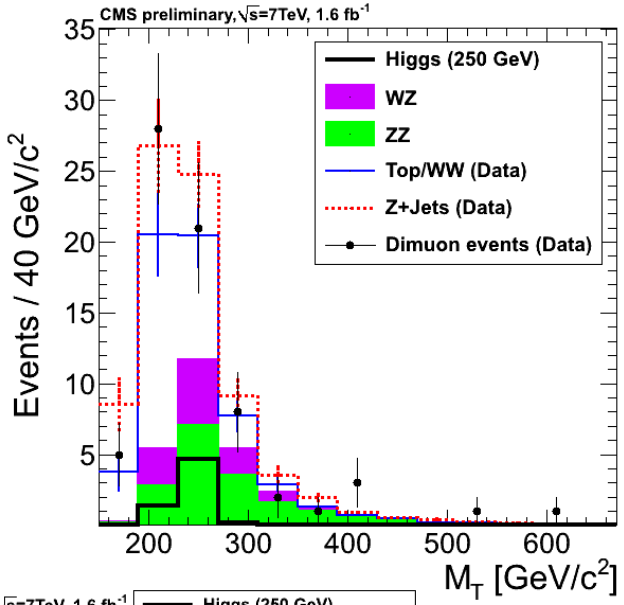
CMS-PAS-HIG-11-016

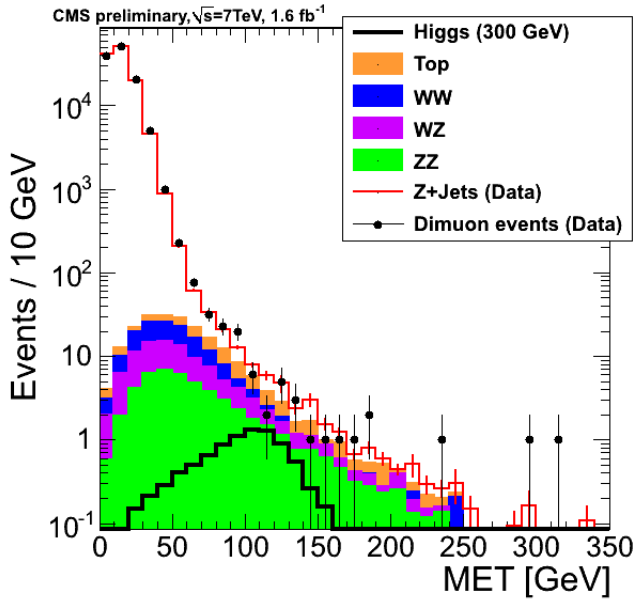


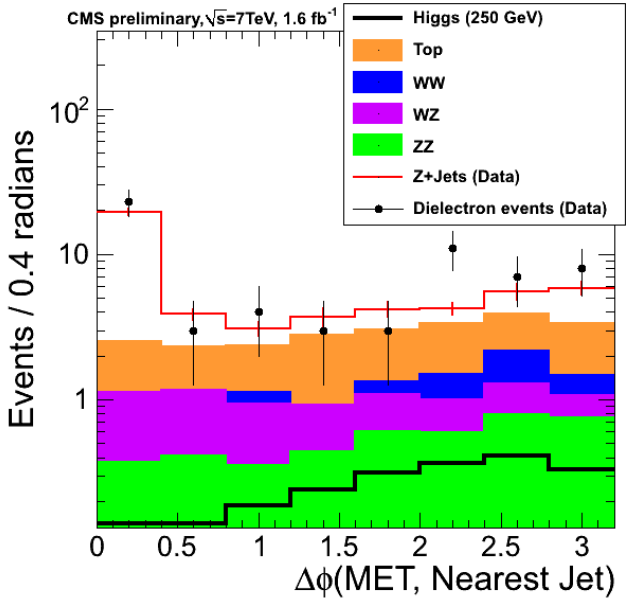
- Signal characterized by:
  - Boosted Z decaying in a $\ell^+\ell^-$ pair, well isolated ($p_{T1,2}$>20GeV/c)
  - Large ME_T from Z decaying in neutrinos
- Background Estimation
  - ttbar suppression through b-tag veto
  - ZZ, WZ background estimated from MC
  - Residual backgrounds estimated from data
    - Z+jets: modeled from γ + jets
    - ttbar and WW: estimated from eμ in data

Discriminating variables

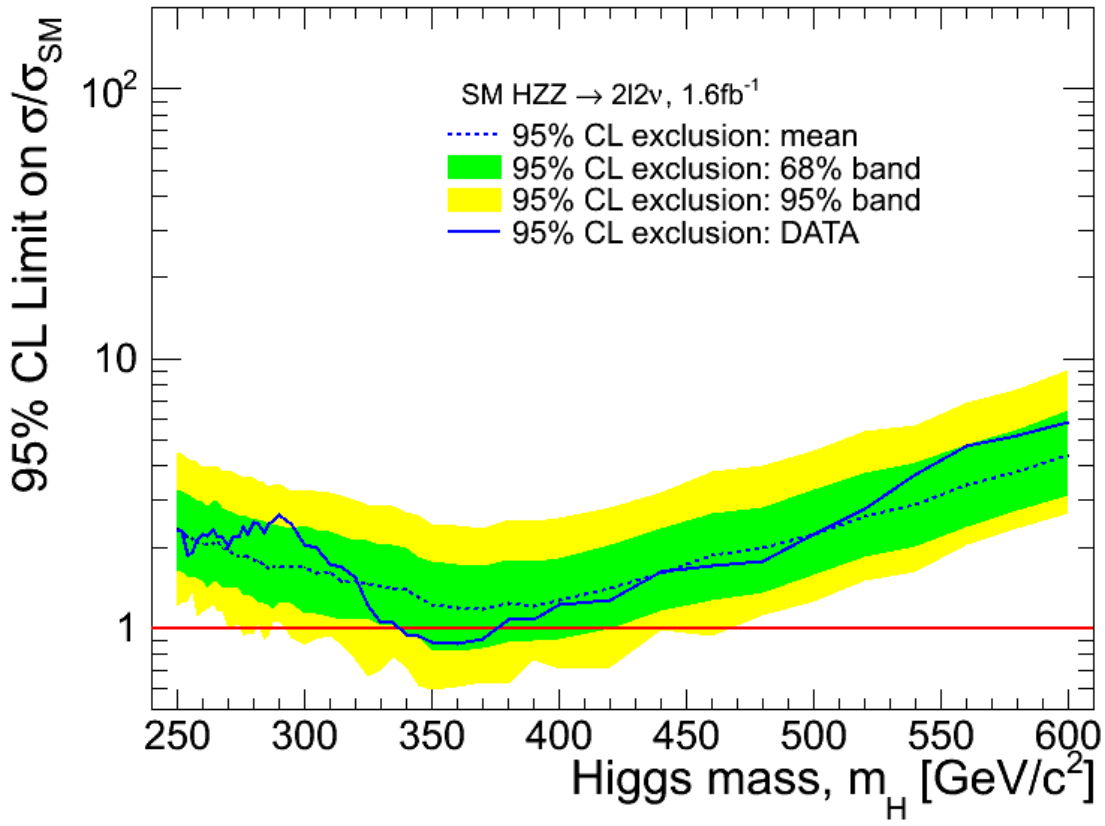
- Cuts optimized by Higgs mass hypothesis
- Di-lepton pair constrained to Z mass
- Large ME_T, not aligned with jets
- Signal events characterized by large M_T, where:
  - $$M_T^2 = \left(\sqrt{P_{TZ}^2 + M_Z^2} + \sqrt{ME_T^2 + M_Z^2}\right)^2 - \left(\vec{P}_{TZ} + \vec{ME}_T\right)^2$$







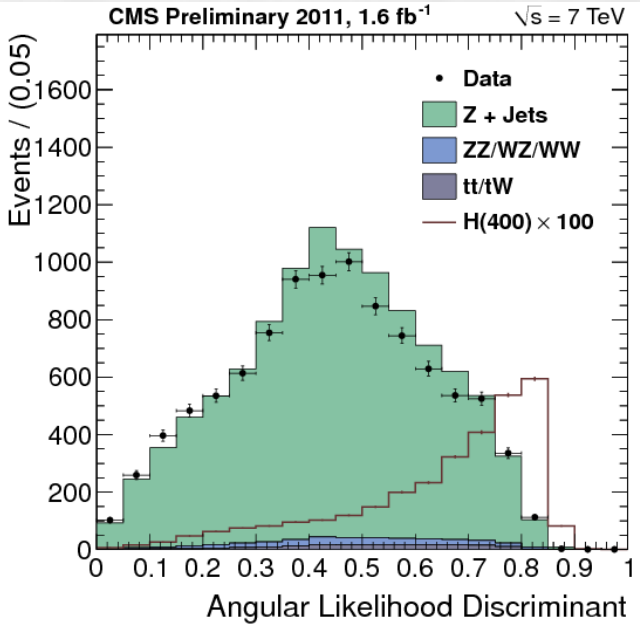
H→ZZ→2ℓ2ν: results



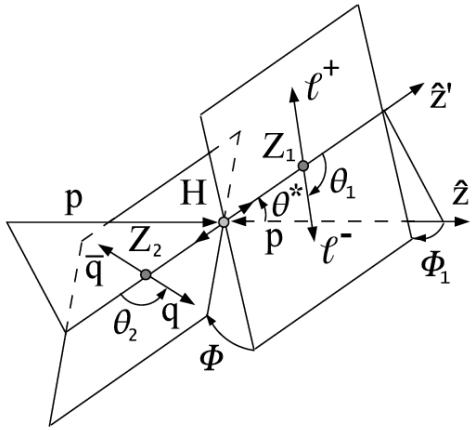
Channel	ZZ	WZ	Top/WW/W+Jets	Z+Jets	Total	mH(300)	Data
$\mu\mu$	$7.3 \pm 0.16 \pm 0.71$	$4.1 \pm 0.21 \pm 0.48$	$5.3 \pm 0.61 \pm 1.8$	$4.4 \pm 0.64 \pm 1.1$	21 ± 2.4	5.4 ± 0.72	18
ee	$5.4 \pm 0.15 \pm 0.58$	$2.8 \pm 0.18 \pm 0.35$	$4 \pm 0.66 \pm 1.3$	$3 \pm 0.42 \pm 0.74$	15 ± 1.9	4.2 ± 0.59	22

$H \rightarrow ZZ \rightarrow 2\ell 2q$

- Signal characterized by: [CMS-PAS-HIG-11-017]
  - Highest rate amongst all $H \rightarrow ZZ$ final states
  - Fully reconstructed final states
    - Well isolated lepton pair (p_T>20,10 GeV/c)
    - Well defined jets (p_T>30GeV/c)
  - Search for a peak (σ~10 GeV/c^2) in $m_{2\ell 2j}$

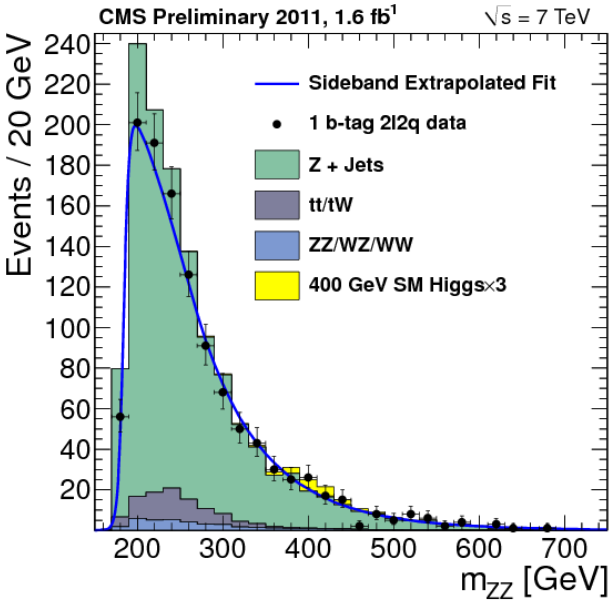


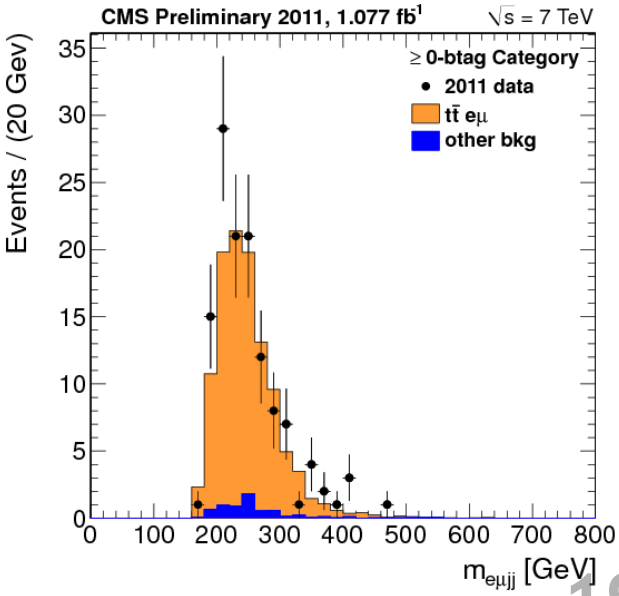
- Analysis tools:
  - Di-lepton and di-jet pairs constrained to Z mass
  - Likelihood selection based on angular variables:
    - Final states angles independent from prod. Mechanism
  - B-tag
  - Quark-gluons discrimination (Z+jets events involve gluon radiations)
    - Gluon jets characterized by high track multiplicity (more intense coupling with strong field)



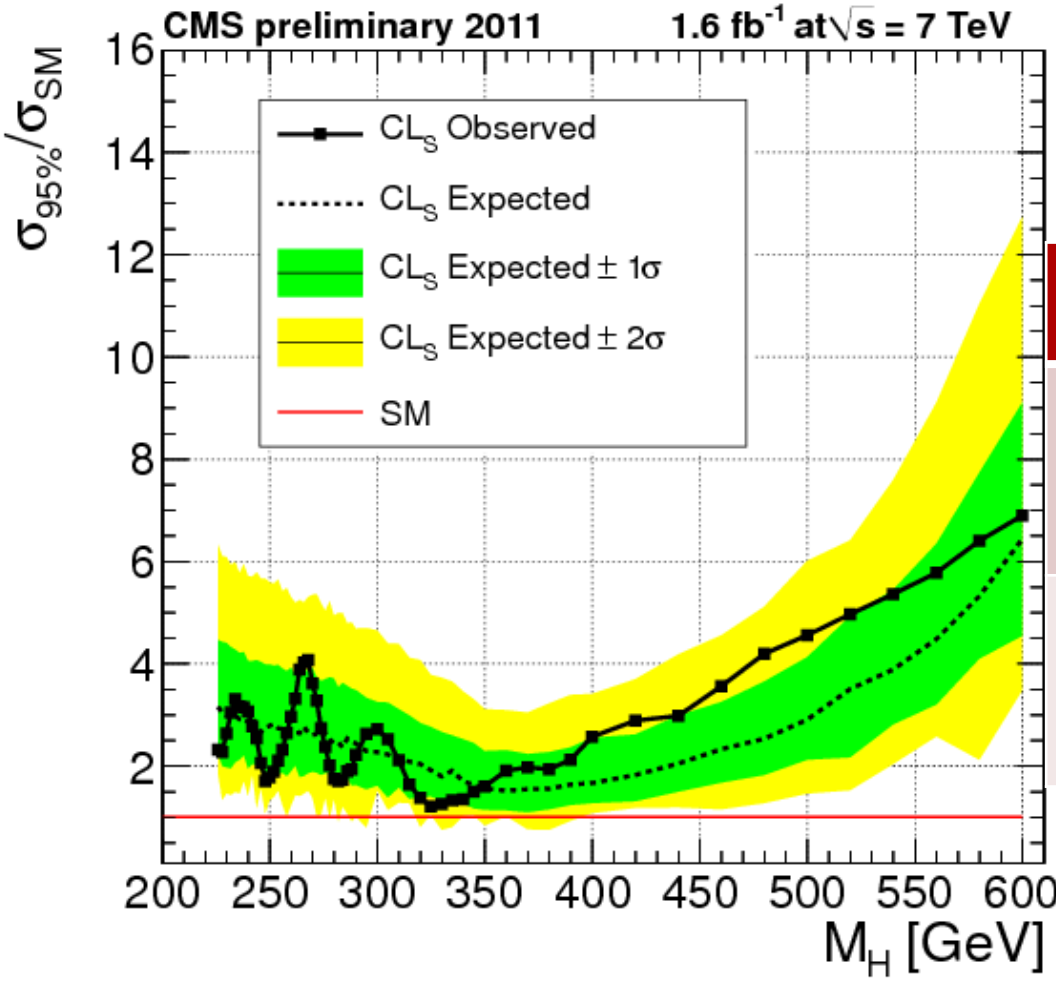
Background Modeling

- Divided in 3 categories
  - 0 btag: no b-tagged jets; Q-G likelihood and gluon-veto
  - 1 btag: only one jet should satisfy the btag algorithm
  - 2 b-tag: the 2 jets in the event should satisfy the btag algorithm
- Sidebands extrapolation:
  - $(60<m_{jj}<75\ GeV/c^2) \cup (105<m_{jj}<130\ GeV/c^2)$
  - Data-driven, better data description than MC
- Reducible background suppression:
  - ttbar suppressed with ME_T cut
  - residual background controlled using eμ events





H→ZZ→2ℓ2q: results



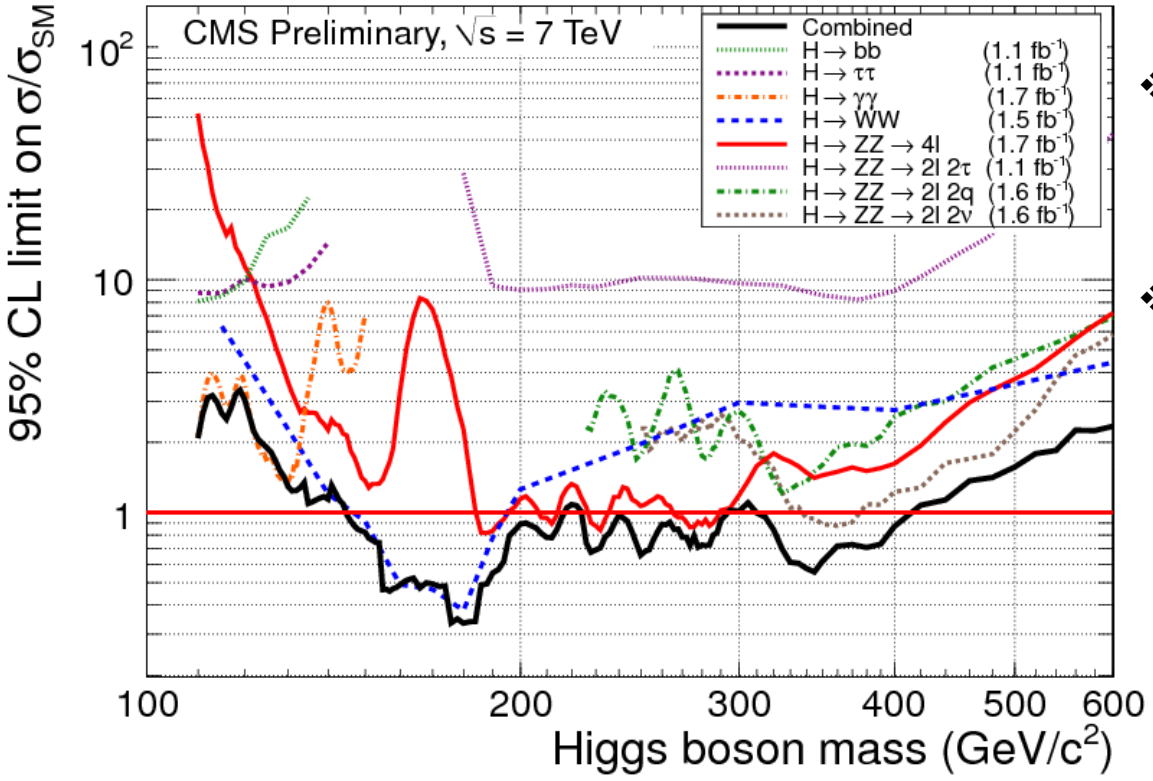
	Yield	Exp. Bkg (data)	Exp. Bkg (MC)
$\mu^-\mu^+jj$	586	575.9±23.1	634.7±10.1
	627	606.8±24.5	681.4±10.7
	48	41.2±4.7	43.1±2.8
e^-e^+jj	492	490.5±21.3	501.4±8.8
	518	526.9±22.8	542.8±9.4
	45	35.4±4.1	37.5±2.6

- Exclusion plot from shape analysis

Combined results

CMS-PAS-HIG-11-022

- **Detailed discussion in the next session**



- Expected exclusion range:
  - 130-440 GeV/c²
- Higgs excluded in ranges:
  - 145-216 GeV/c²
  - 226-288 GeV/c²
  - 310-400 GeV/c²

Conclusions

- Presented the CMS analysis for the Higgs search in ZZ,WW channel
  - Analyzed up to ~1.6 fb^{-1} data
  - Provided a wide exclusion range for the Higgs boson
- In the meanwhile…

  … CMS recorded ~5fb^{-1} data!
- Close to a final word?
  - Stay tuned!
- CMS Higgs Physics Results