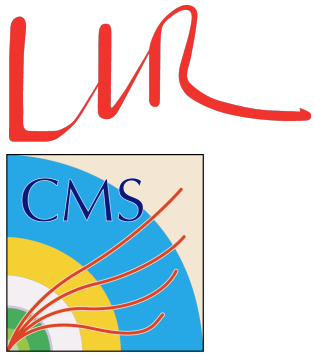
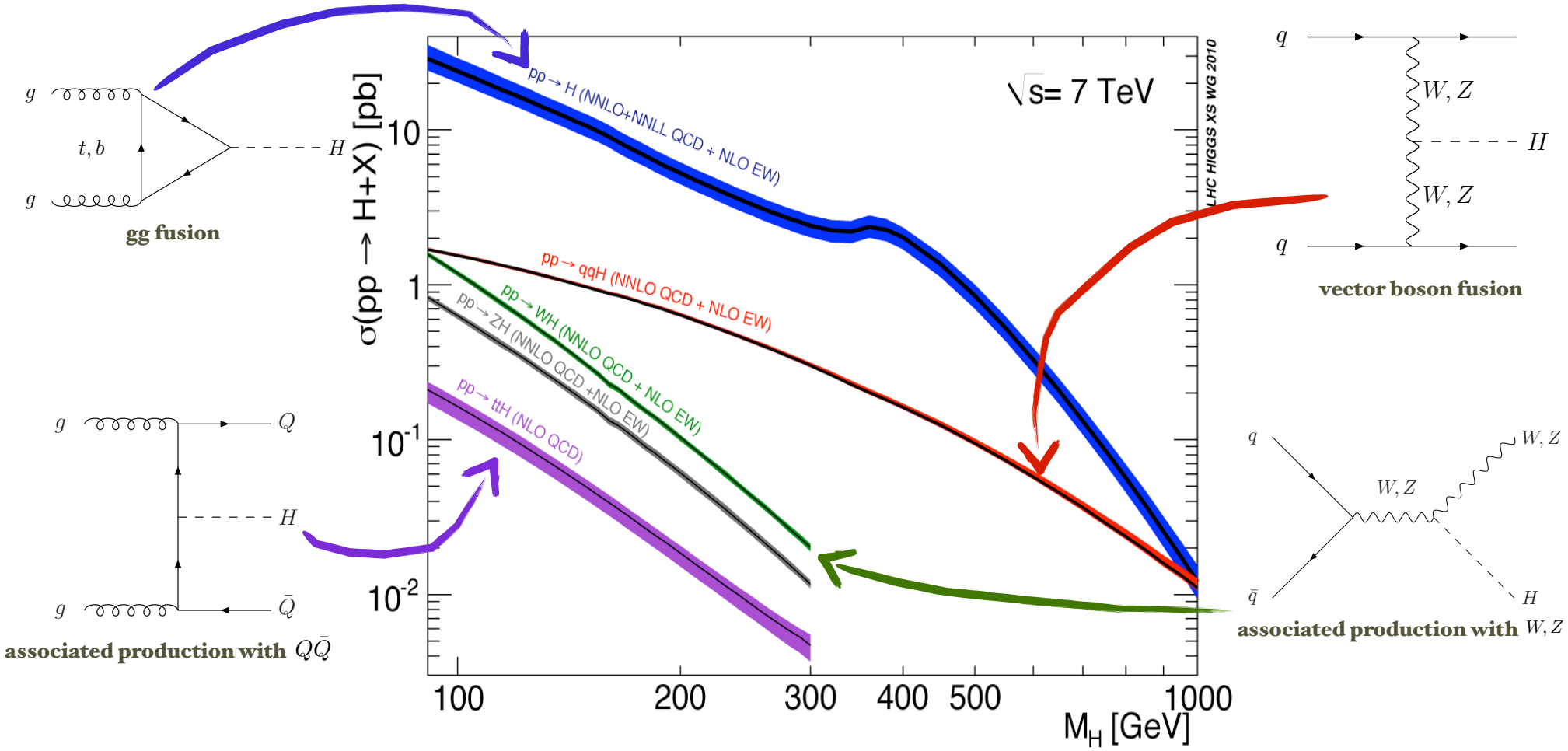


A search for the Higgs boson in $H \rightarrow ZZ^{(*)}$ mode with the CMS detector

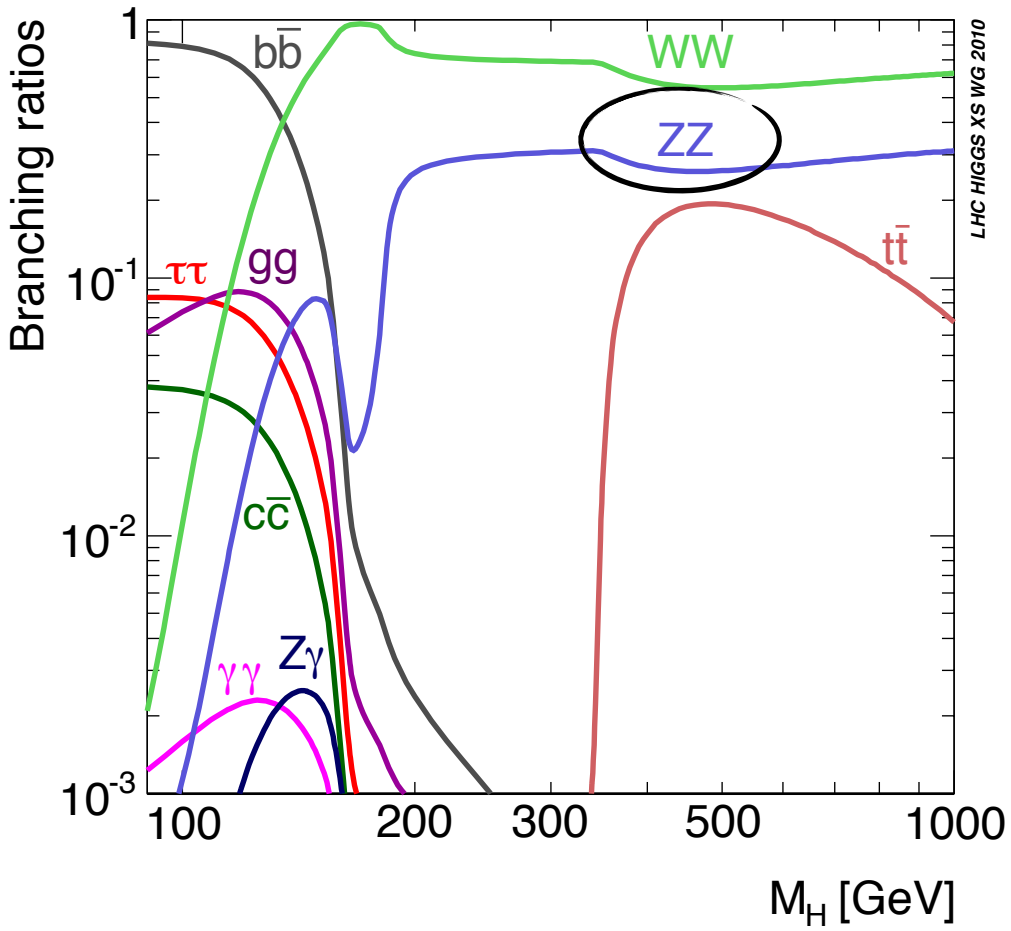
Roberto Salerno[1)]
on behalf of CMS collaboration

[1)] Laboratoire Leprince-Ringuet, Ecole Polytechnique, CNRS/IN2P3

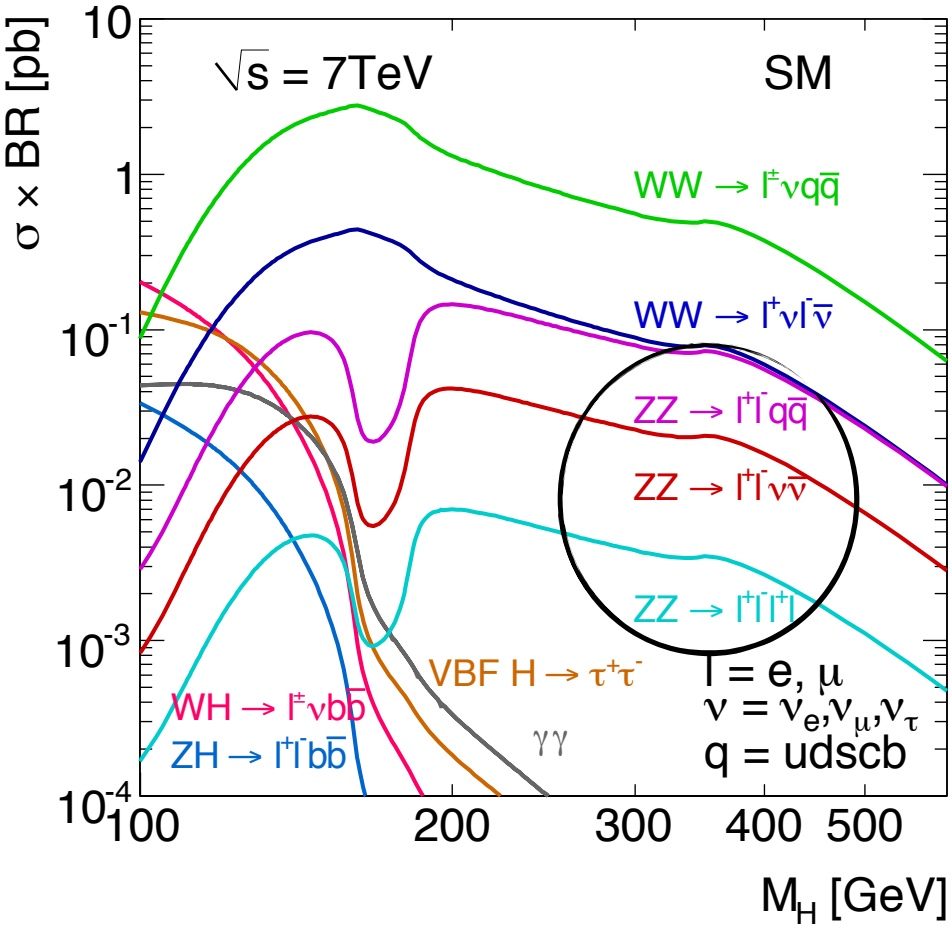
SM Higgs production



SM Higgs decay modes

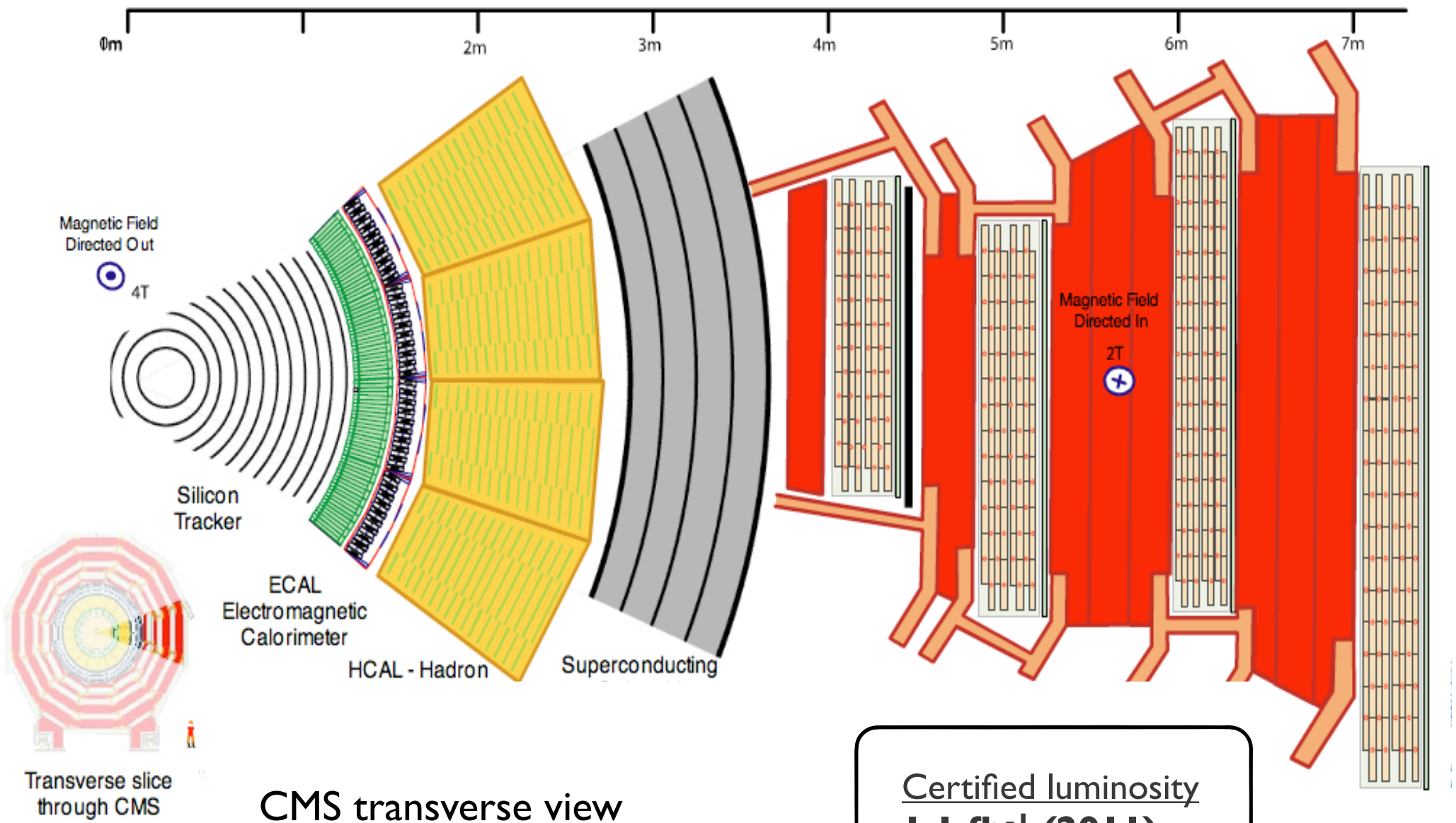


Decay branching ratio



Cross section x branching ratio

CMS detector



CMS transverse view

Certified luminosity
1.1 fb^{-1} (2011)
36 pb^{-1} (2010)

Physical objects

Leptons

$H \rightarrow ZZ \rightarrow llqq/\nu\nu$:
standard leptons selection for Z measurement
$H \rightarrow ZZ^{(*)} \rightarrow llll$:
low p_T leptons with high selection efficiency

	Barrel low p_T-high p_T	Endcap low p_T-high p_T
electron	(95-97)%	(90-95)%
muon	(97-98)%	(98-99)%

reconstruction+identification in $H \rightarrow ZZ^{(*)} \rightarrow llll$

Missing Transverse Energy

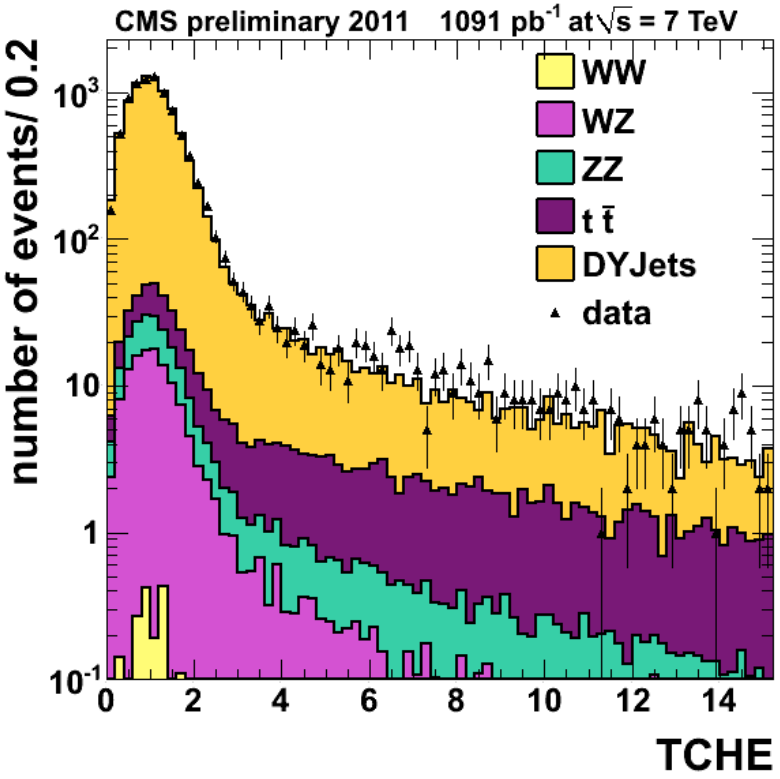
Particle Flow MET

Jets

Particle Flow Jets
anti-k_T algorithm (R = 0.5)

b-tagging

Track Counting High Efficiency algorithm
uses displaced tracks in a jet to compute the discriminator



$H \to ZZ \to l^+l^-q\bar{q}$

REF: CMS-PAS-HIG-11-006

Large Yields

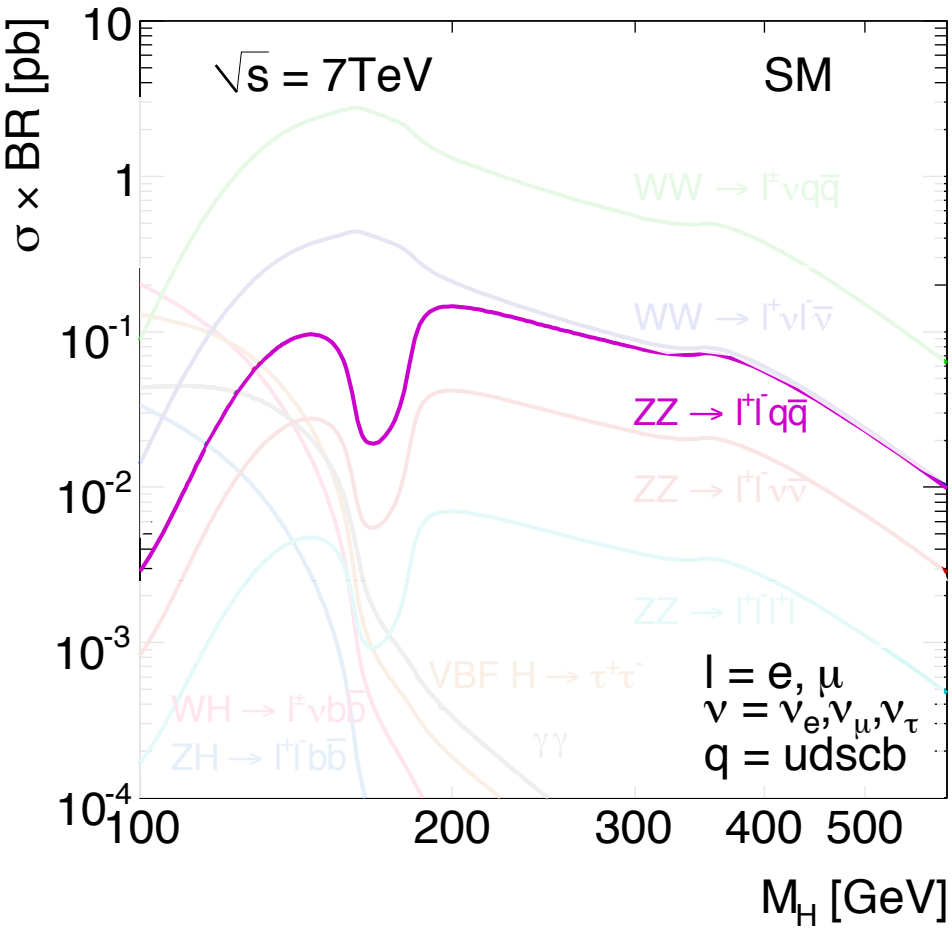
✓ Exploits very large BR(Z→qq) = 70%
✓ Full decay chain reconstructed

Challenge

✓ Large Z+jet background
✓ Limited resolution coming from jets

Background

✓ Resonant: Z+jet
✓ Non-Resonant: ttbar/tW
✓ EWK: ZZ/WZ/WW



Good for exclusion and discovery

Sensitive to high mass Higgs boson: m_H [200-600] GeV/c^2

Selection Procedure

L=1.0 fb^{-1}

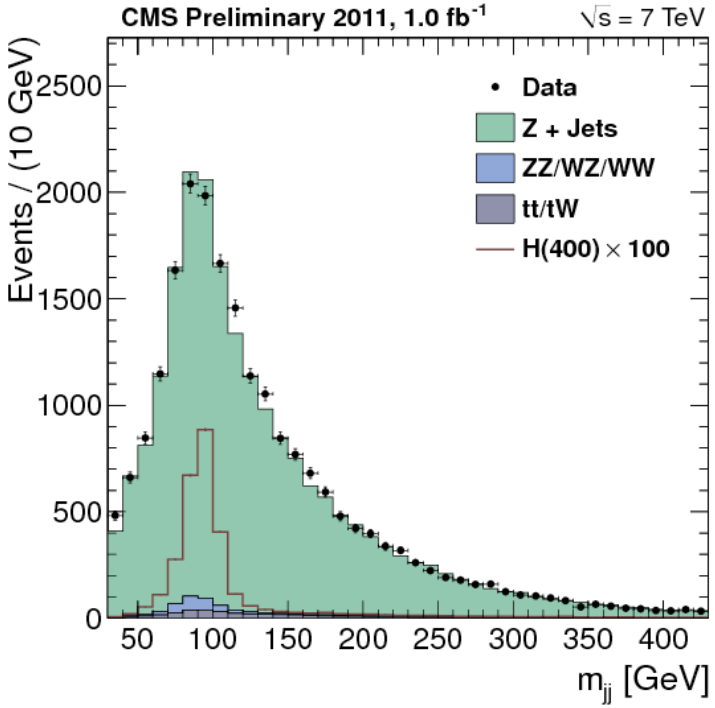
$H \to ZZ \to l^+l^- q\bar{q}$

Two Opposite-Sign Same-Flavor isolated leptons

$p_{T,1/2}$> 40/20 GeV/c & $|\eta_\mu| < 2.4$ $|\eta_e| < 2.5$

At least two jets

$p_{T,1/2} > 30$ GeV/c & $|\eta_j| < 2.4$



Background suppression

$70 < m_{ll} < 110$ GeV/c^2

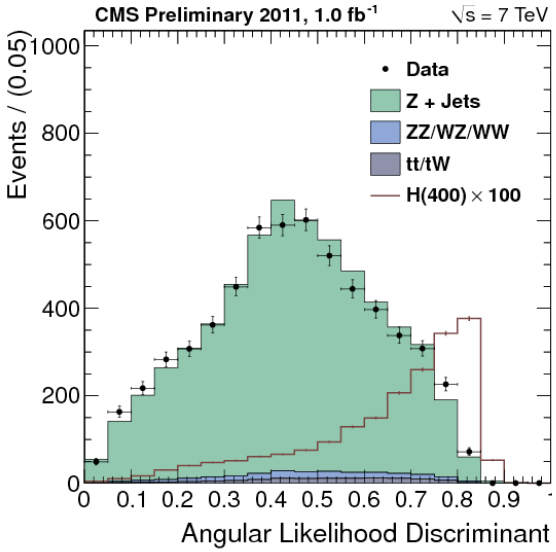
$75 < m_{jj} < 105$ GeV/c^2

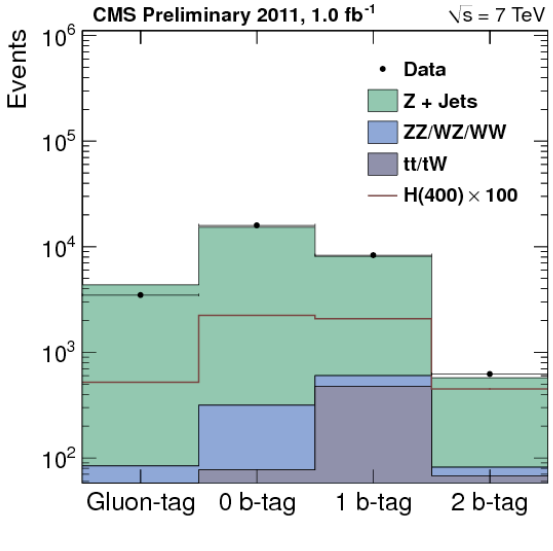
Angular Likelihood Discriminant

Quark-Gluon Likelihood Discriminant

Tagging of b-flavor

Three b-tag categories: *0/1/2 b jet*





Background from DATA

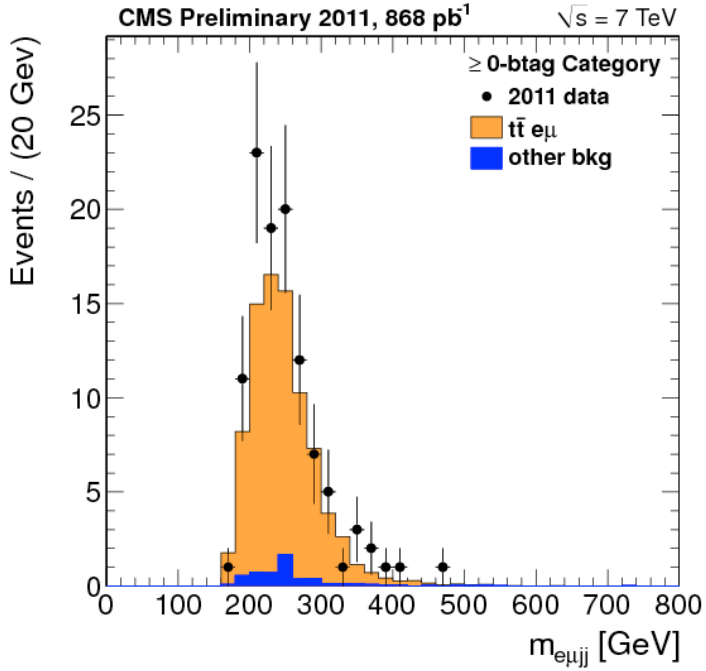
Estimation from the m_{jj} sidebands

$(60 < m_{jj} < 75\ \text{GeV/c}^2) \cup (105 < m_{jj} < 130\ \text{GeV/c}^2)$

$$N_{\text{bkg}}(m_{ZZ}) = N_{\text{sb}}(m_{ZZ}) \times \frac{N_{\text{bkg}}^{\text{sim}}(m_{ZZ})}{N_{\text{sb}}^{\text{sim}}(m_{ZZ})} = N_{\text{sb}}(m_{ZZ}) \times \alpha(m_{ZZ})$$

	0 *b-tag*	1 *b-tag*	2 *b-tag*
μμjj			
Back. from Data	286.4 ± 16.2	334.7± 18.2	20.3 ± 3.1
Observed	**307**	**352**	**30**
eejj			
Back. from Data	345.7 ± 17.8	376.4 ± 19.3	24.3 ± 3.7
Observed	**359**	**396**	**25**

Independently in each b-tag category



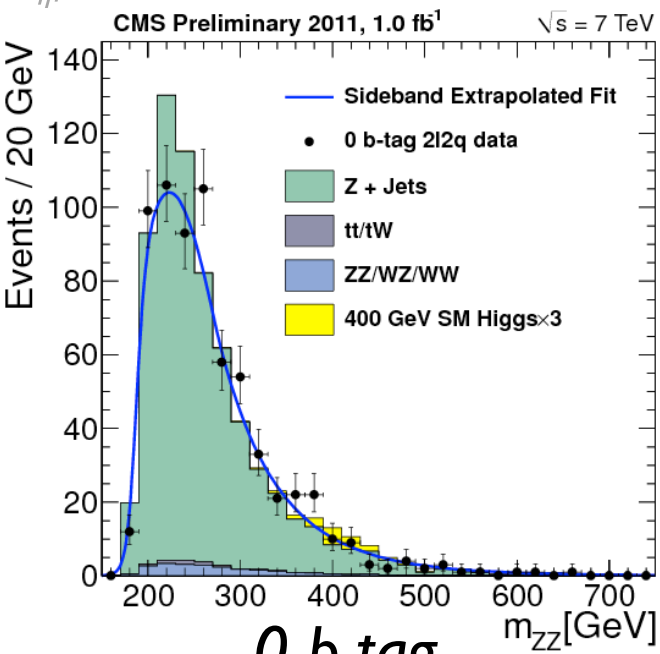
Additional information on ttbar background using the mixed-flavor eμjj sample

Dominant Z+jet background is absent

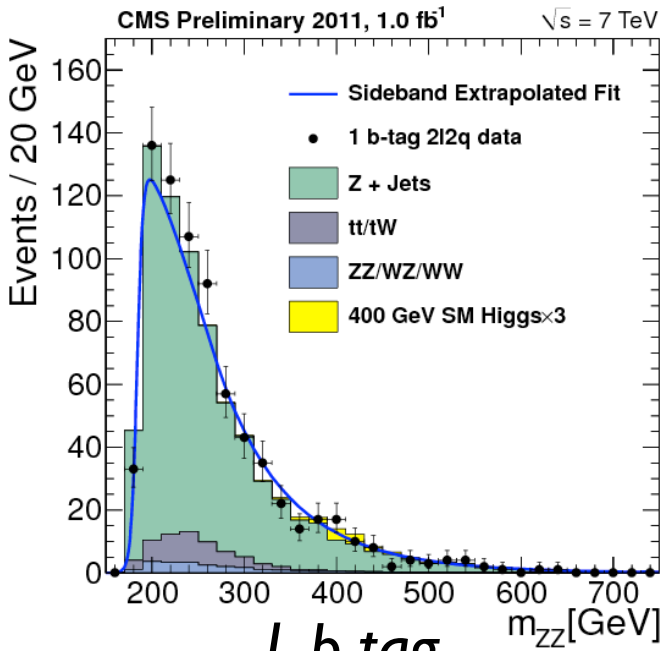
Invariant Mass

$L=1.0\ fb^{-1}$

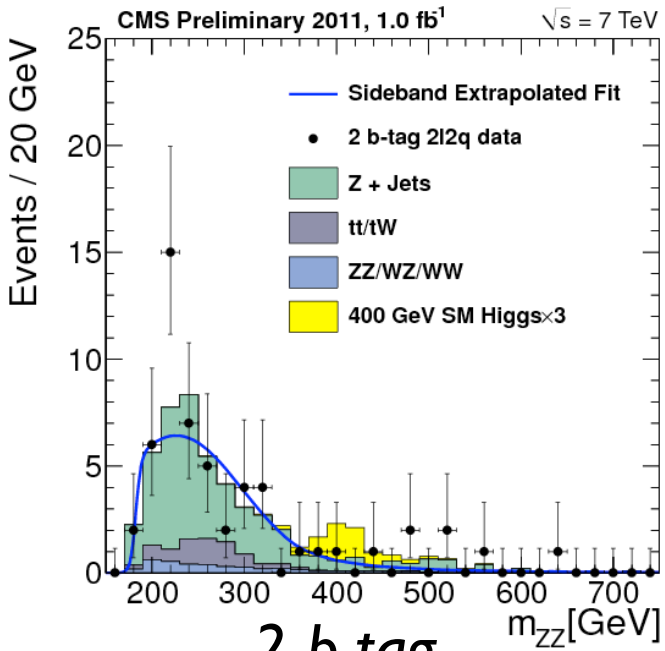
$H \to ZZ \to l^+l^- q\bar{q}$



0 b-tag



1 b-tag



2 b-tag

MC Signal expectation

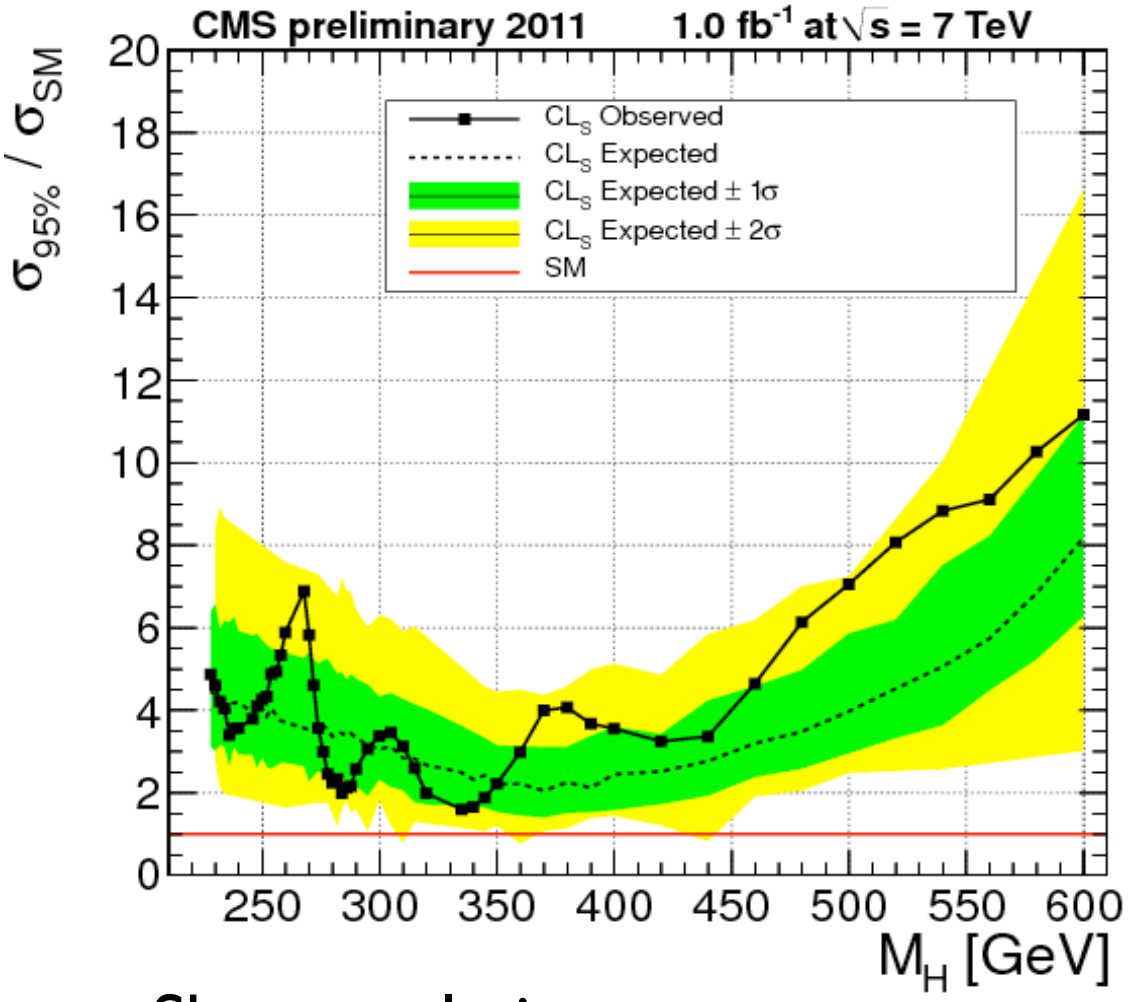
eejj + μμjj

Mass GeV/c^2	0 *b-tag*	1 *b-tag*	2 *b-tag*
200	2.57 ± 0.37	3.43 ± 0.49	0.70 ± 0.19
300	5.84 ± 0.83	4. 97± 0.69	1.75 ± 0.46
400	5.33 ± 0.76	4.83 ± 0.67	1.96 ± 0.50
500	2.21 ± 0.34	2.21 ± 0.32	0.97 ± 0.24
600	0.83 ± 0.21	0.86 ± 0.21	0.39 ± 0.15

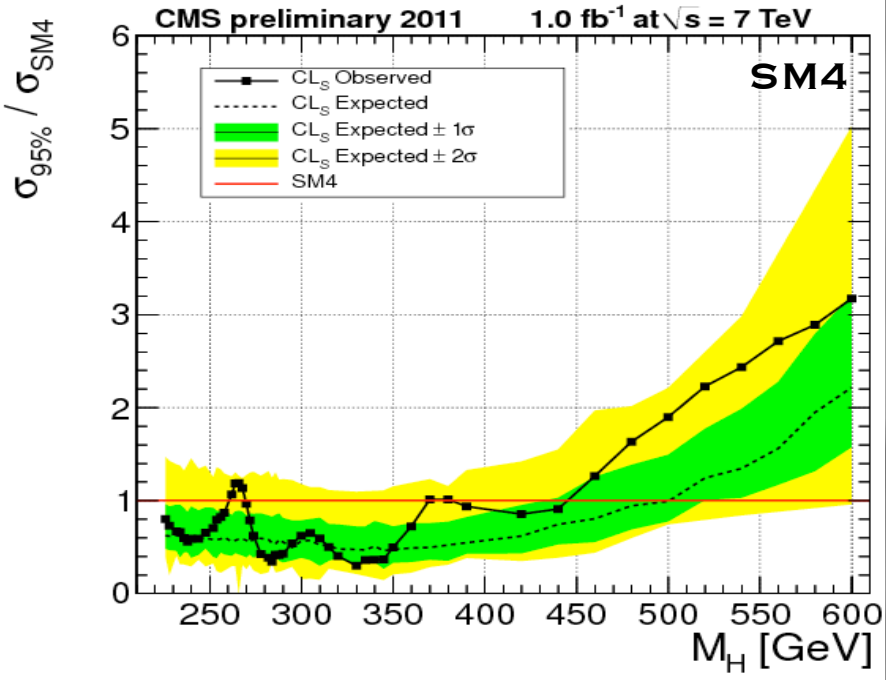
Upper Limits

L=1.0 fb^{-1}

$H \to ZZ \to l^+l^- q\bar{q}$



SM with a 4th fermion family of high mass



Higgs boson with a mass in the **226-445 GeV/c^2** range is excluded at 95% CL but in two windows between 261-270 GeV/c^2 and 370-381 GeV/c^2

Shape analysis:

✓ Signal parametrized with a Breit–Wigner convoluted with a Crystal-Ball

✓ Background parametrized with an empirical probability function normalized from data estimation (m_{jj} sideband)

$H \to ZZ \to l^+l^-\nu\bar{\nu}$

REF: CMS-PAS-HIG-11-005

Large Yields

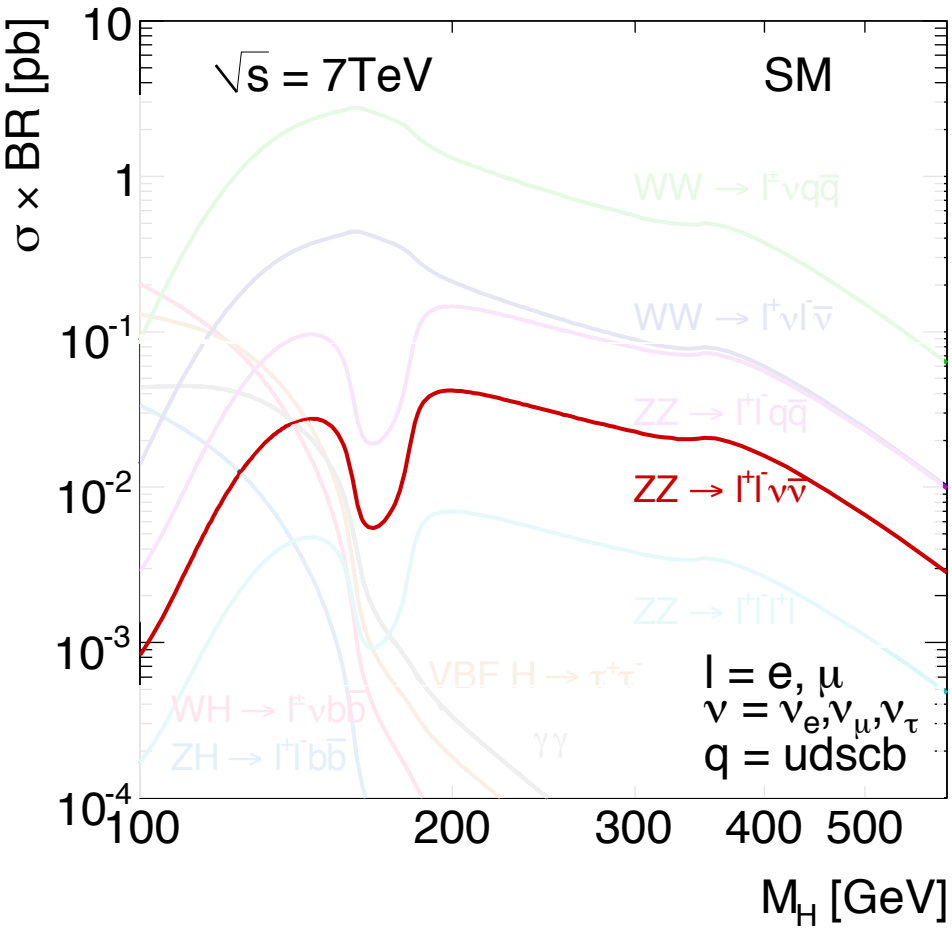
✓ BR($ZZ \to ll\nu\nu$) ~ 6xBR($ZZ \to llll$)

Challenge

✓ Looking for Z+MET signature
✓ Large Z+jet background
✓ No Higgs peak

Background

✓ Resonant: Z+jet
✓ Non-Resonant: ttbar/WW
✓ EWK: WZ/ZZ



Good for exclusion

Sensitive to high mass Higgs boson: m_H [250-600] GeV/c^2

Selection Procedure

L=1.1 fb^{-1}

$H \rightarrow ZZ \rightarrow l^+l^-\nu\bar{\nu}$

Two Opposite-Sign Same-Flavor isolated leptons

$p_{T,1/2} > 20$ GeV/c & $|\eta_\mu| < 2.4$ $|\eta_e| < 2.5$

$|m_{ll} - m_Z| < 15$ GeV/c^2

Background suppression

Mass independent cuts:

Veto events with a b-jet

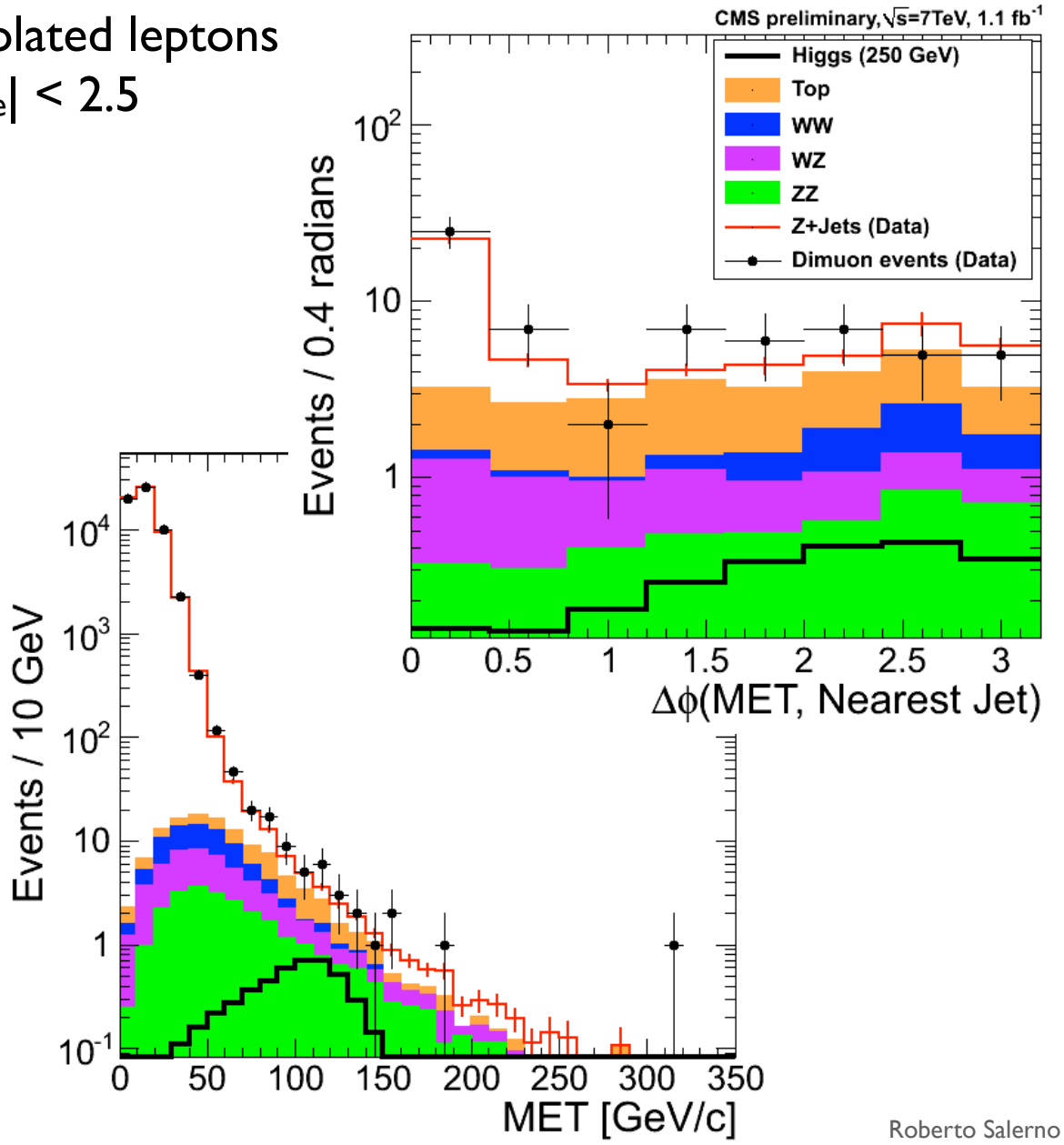
Veto events with a third lepton

Mass dependent cuts:

Missing transverse energy (MET)

MET-jet separation

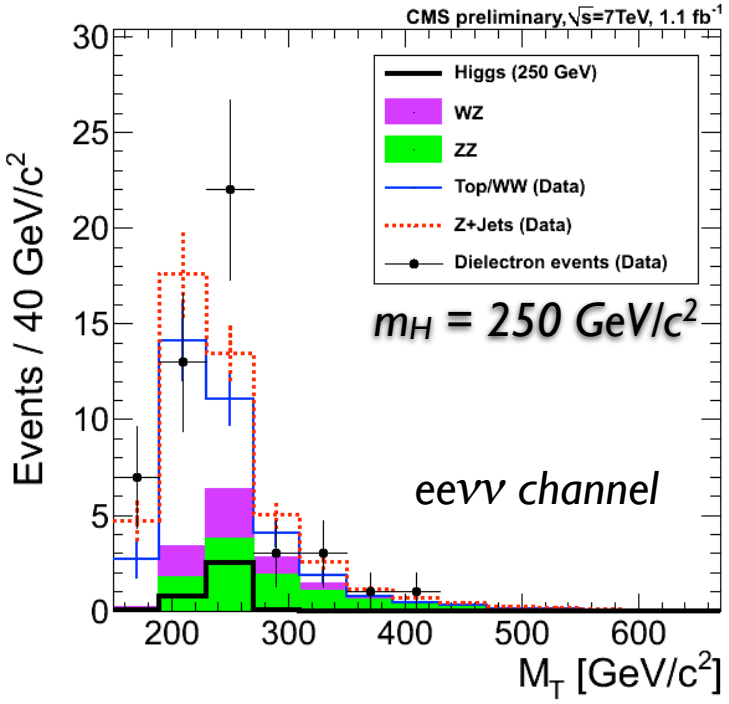
Transverse Mass (M_T)



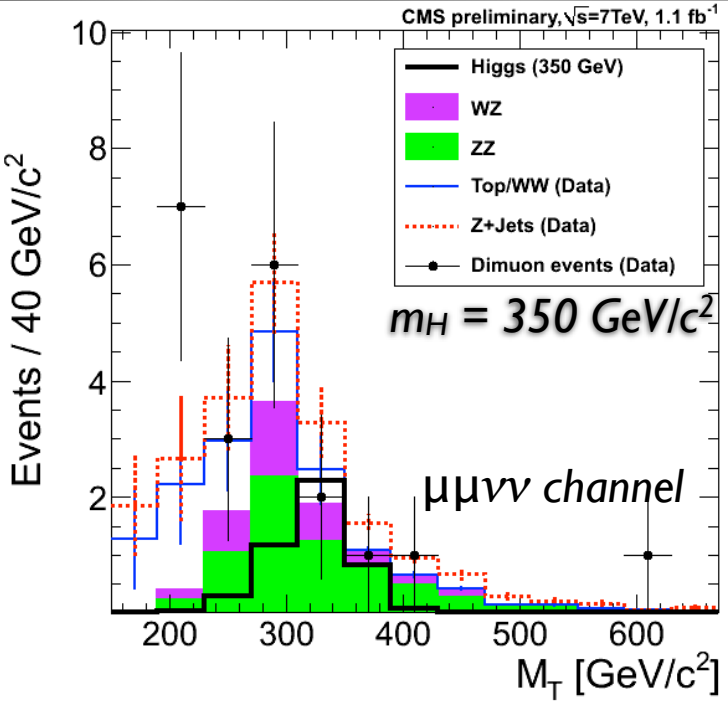
Transverse Mass

L=1.1 fb^{-1}

$H \to ZZ \to l^+l^-\nu\bar{\nu}$



Channel	Total background	m_H 250 GeV/c^2	Observed
ee	22 ± 5	3.1 ± 0.5	29
μμ	30 ± 5	3.9 ± 0.5	28



Channel	Total background	m_H 350 GeV/c^2	Observed
ee	11 ± 2	3.2 ± 0.6	8
μμ	13 ± 2	3.9 ± 0.5	11

Background estimation

Resonant (Z+jet) → gamma+jet

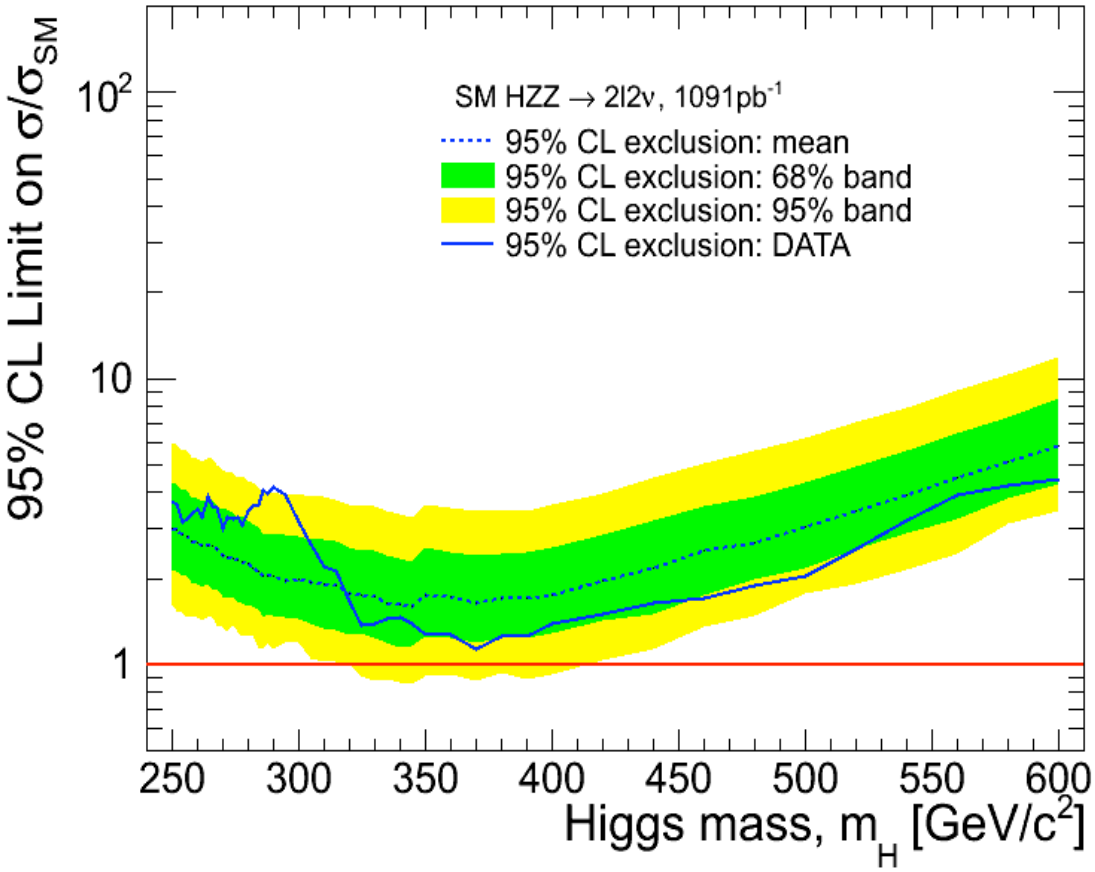
Non-Resonant (ttbar/WW) → eμ final states

Electroweak (WZ/ZZ) → MC

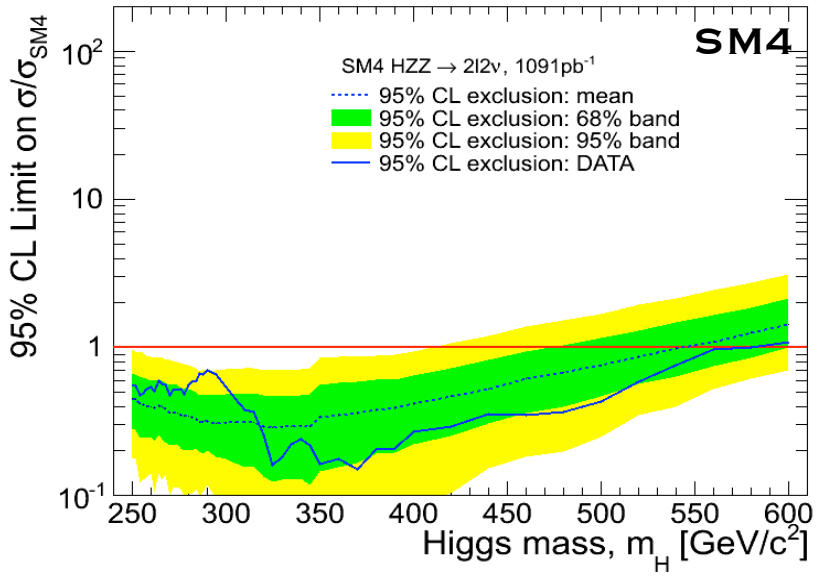
Upper Limits

L=1.1 fb^{-1}

$H \to ZZ \to l^+l^-\nu\bar{\nu}$



SM with a 4th fermion family of high mass



Higgs boson with a mass in the **250-550 GeV/c^2** range is excluded at 95% CL

Cut & Count analysis

final discriminator M_T

Higgs Mass [GeV/c^2]	M_T [GeV/c^2]
250	> 216 AND < 272
350	> 267 AND < 386
450	> 315
550	> 357

$H \rightarrow ZZ^{(*)} \rightarrow l^+l^-l^+l^-$

REF: CMS-PAS-HIG-11-004

Golden channel

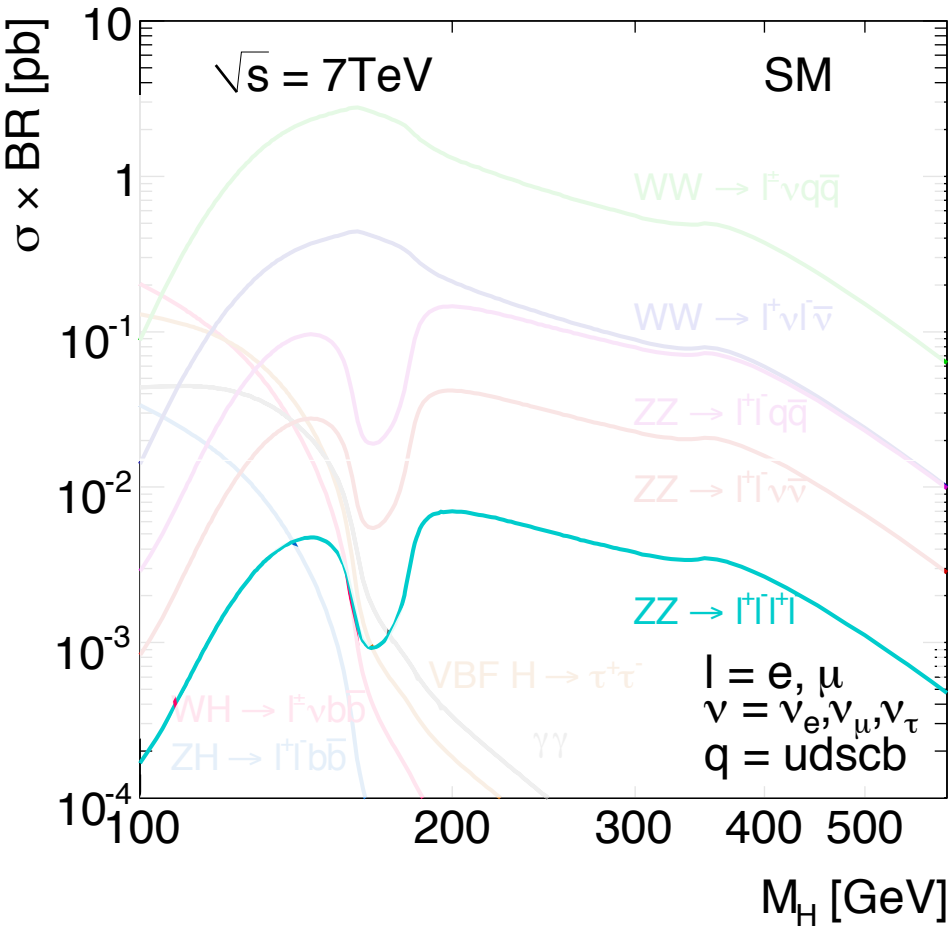
- ✓ Clean experimental signature, four primary and isolated leptons
- ✓ Narrow resonance in 4 leptons invariant mass spectrum

Challenge

- ✓ Small Branching Ratio
- ✓ Low p_T leptons

Background

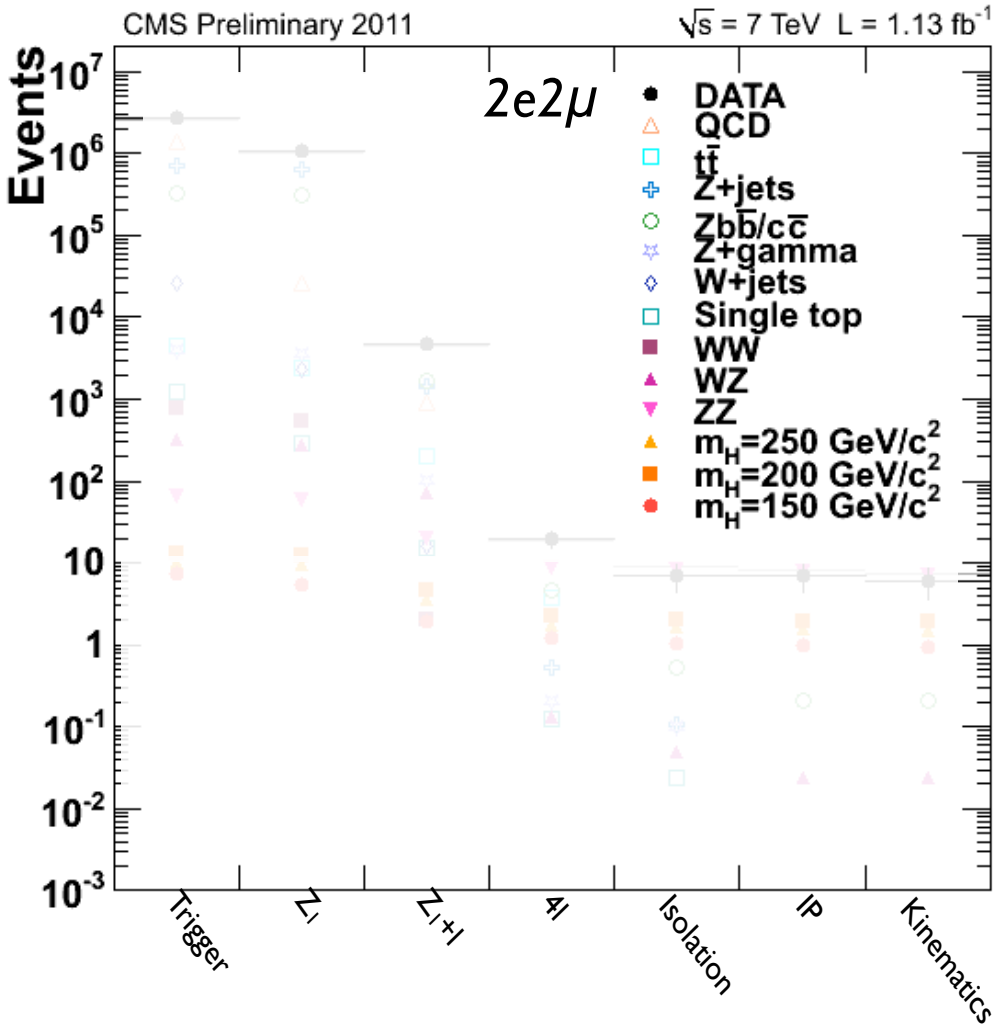
- ✓ Instrumental: Z+fakes
- ✓ Reducible: Zbb/ttbar/WZ
- ✓ Irreducible: $ZZ^{(*)}$



Good for exclusion and discovery

Sensitive to whole mass Higgs boson range: m_H [110-600] GeV/c^2

Selection Procedure



Selection Procedure

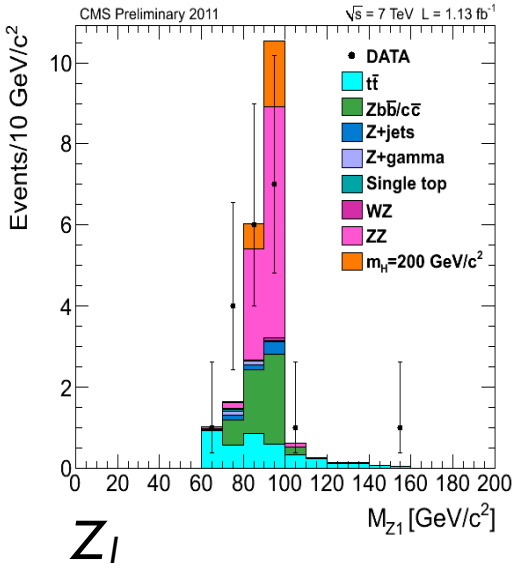
Best 4l candidate choice

✓ Two pair of Opposite-Sign Same-Flavor identified leptons:

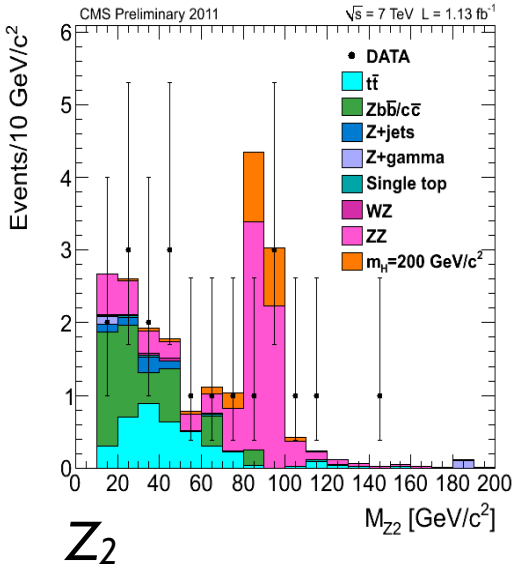
$p_{T,1/2}$ > 20,10 GeV/c $p_{T,3/4}$ > 7(e),5(μ) GeV/c

Z boson candidate

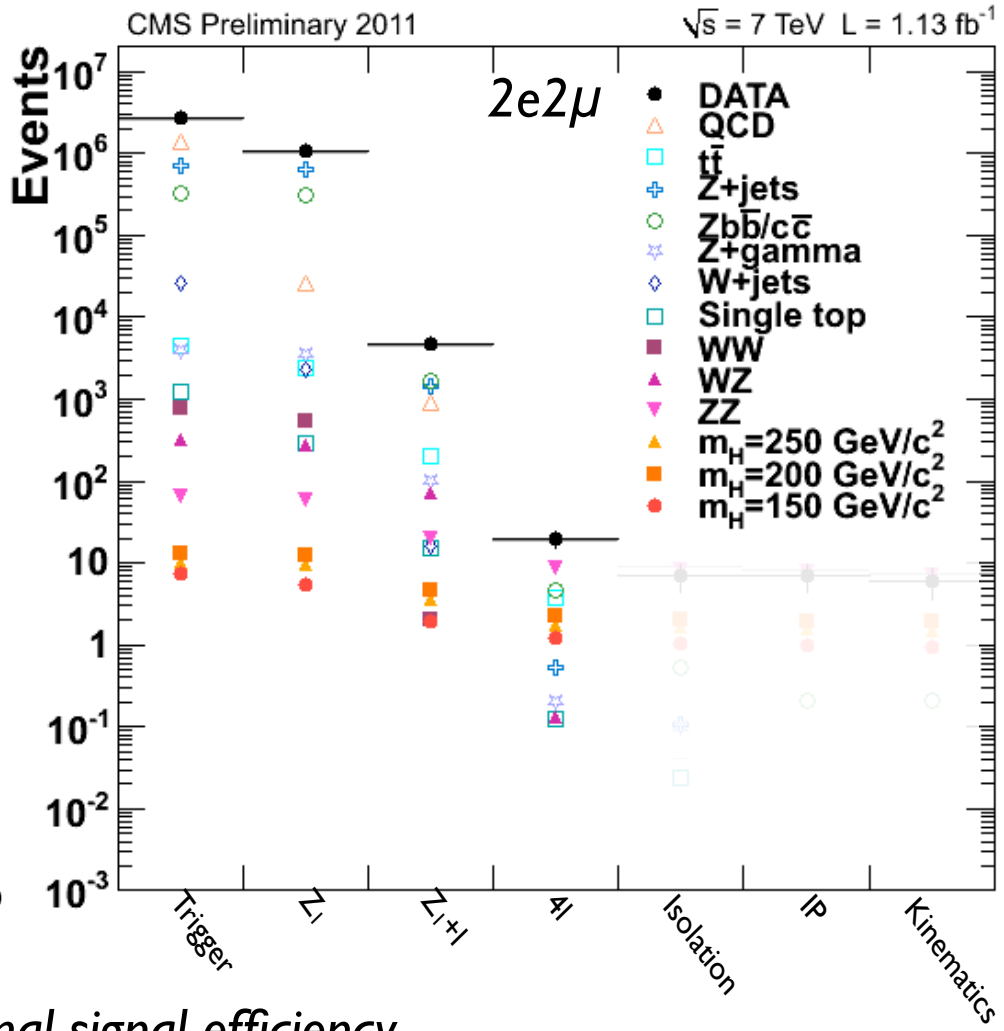
m_{4l}>100 GeV/c^2



Z_1



Z_2

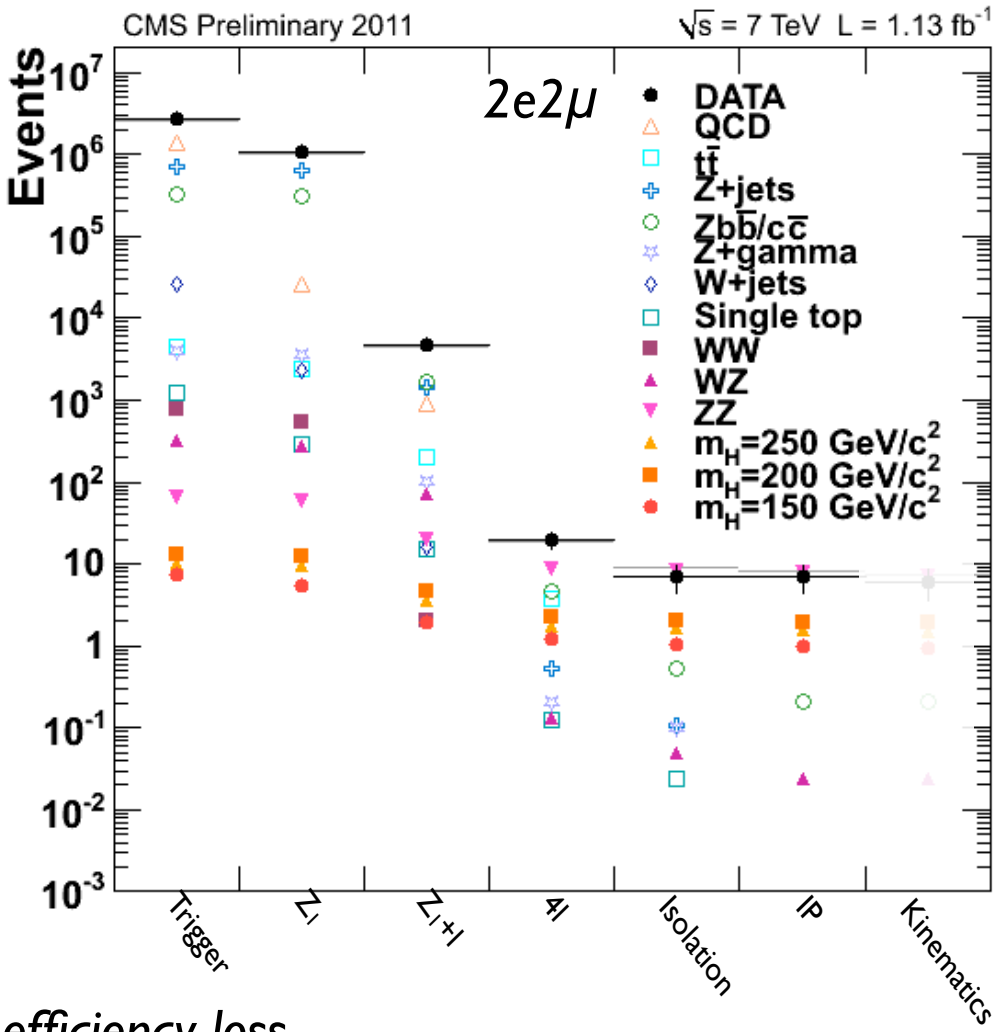


Retaining the maximal signal efficiency
Preserving the phase space for the background control

Selection Procedure

Reducible background suppression

- ✓ Relative isolation on leptons
- ✓ Impact parameter on leptons



Minimal signal efficiency loss
while preserving optimal phase space

Selection Procedure

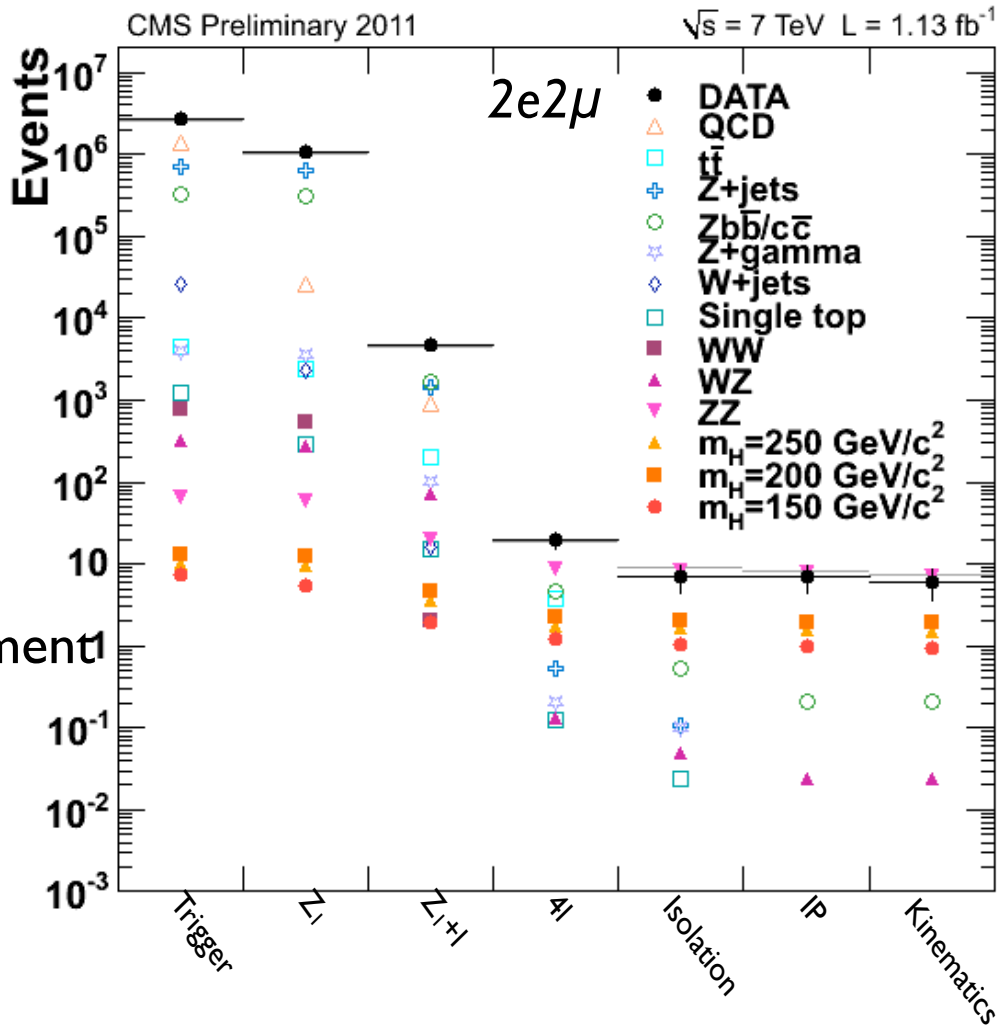
Kinematics (Z and Z*)

Low-mass/Baseline selection

✓ min(m_{Z2}) = 20 GeV/c^2
to search for all Higgs mass hypotheses

High-mass/Two Zs "on-shell"

✓ min(m_{Z2}) = 60 GeV/c^2
to search for high Higgs mass hypotheses
coincides with ZZ cross section measurement



Background from DATA

Control of ZZ continuum

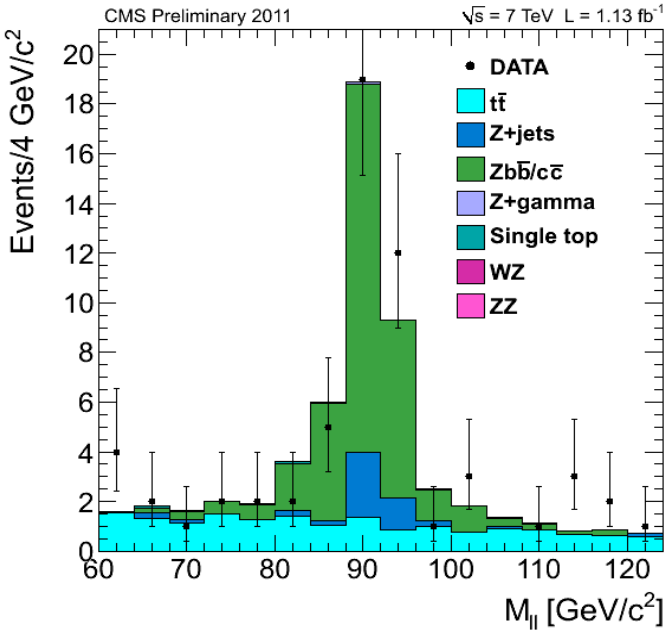
normalization to Z rates in DATA

$$\frac{\sigma_{\mathrm{NLO}}^{q\bar{q}\to \mathrm{ZZ}\to 4\ell} + \sigma_{\mathrm{LO}}^{gg\to \mathrm{ZZ}\to 4\ell}}{\sigma_{\mathrm{NNLO}}^{pp\to \mathrm{Z}\to 2\ell}} \frac{\epsilon_{\mathrm{MC}}^{\mathrm{ZZ}\to 4\ell}}{\epsilon_{\mathrm{MC}}^{\mathrm{Z}\to 2\ell}}$$

Control of reducible backgrounds

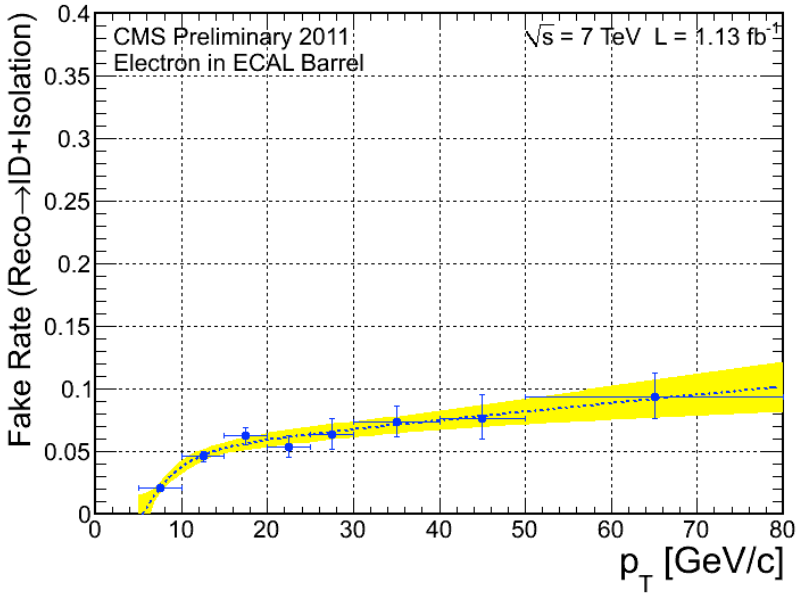
Relax flavor and charge requirements

High impact parameter



Control of instrumental backgrounds

Use fake rate measurements

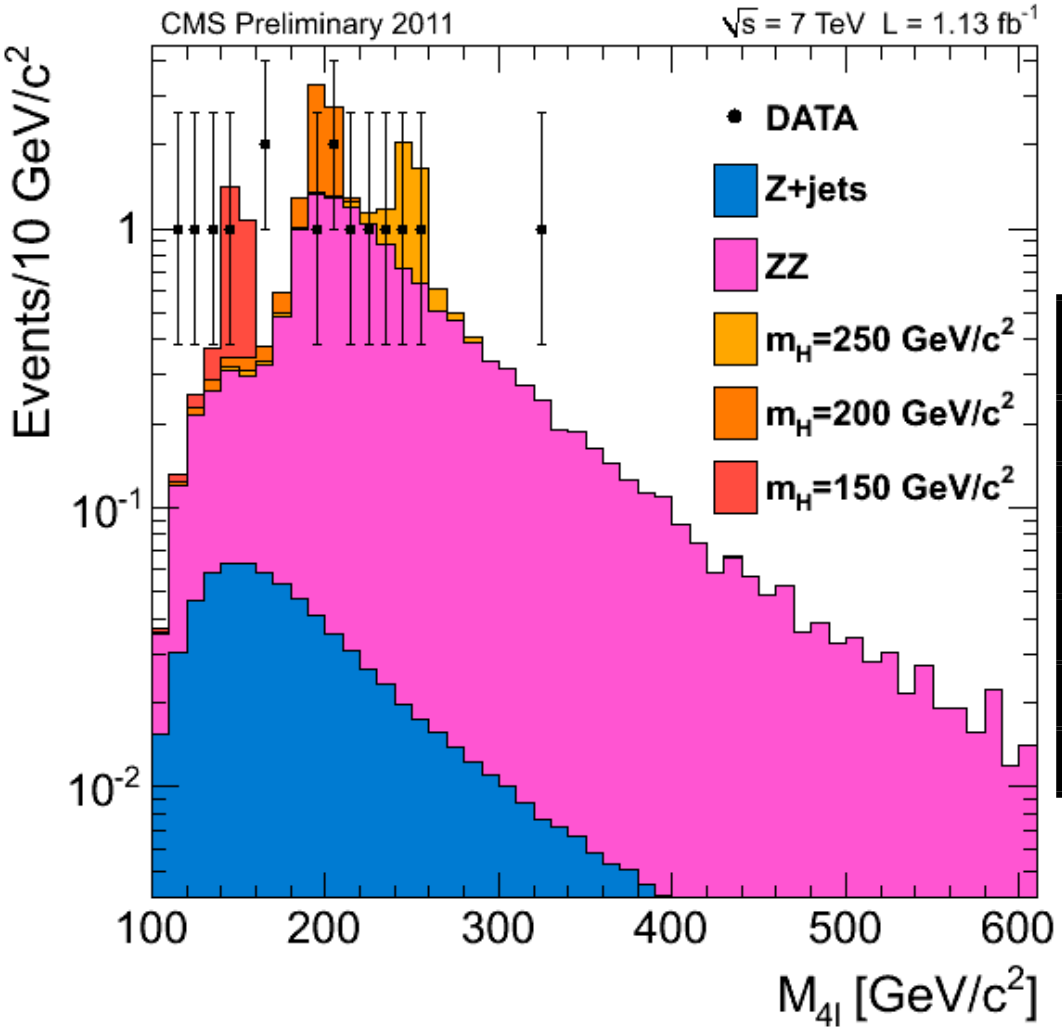


Invariant Mass

L=1.13 fb^{-1}

$H \to ZZ^{(*)} \to l^+l^-l^+l^-$

Low-mass/Baseline selection



$60 < m_{Z1} < 120$ GeV/c^2

$20 < m_{Z2} < 120$ GeV/c^2

	4e	4μ	2e2μ
ZZ	2.76 ± 0.18	4.10 ± 0.27	6.72 ± 0.45
Others back.	0.38 ± 0.07	0.06 ± 0.01	0.41 ± 0.07
Observed	3	6	6
m_H = 150 GeV/c^2	0.368	0.637	0.996
m_H = 200 GeV/c^2	0.816	1.161	1.907
m_H = 250 GeV/c^2	0.656	0.885	1.533

Background estimated with data

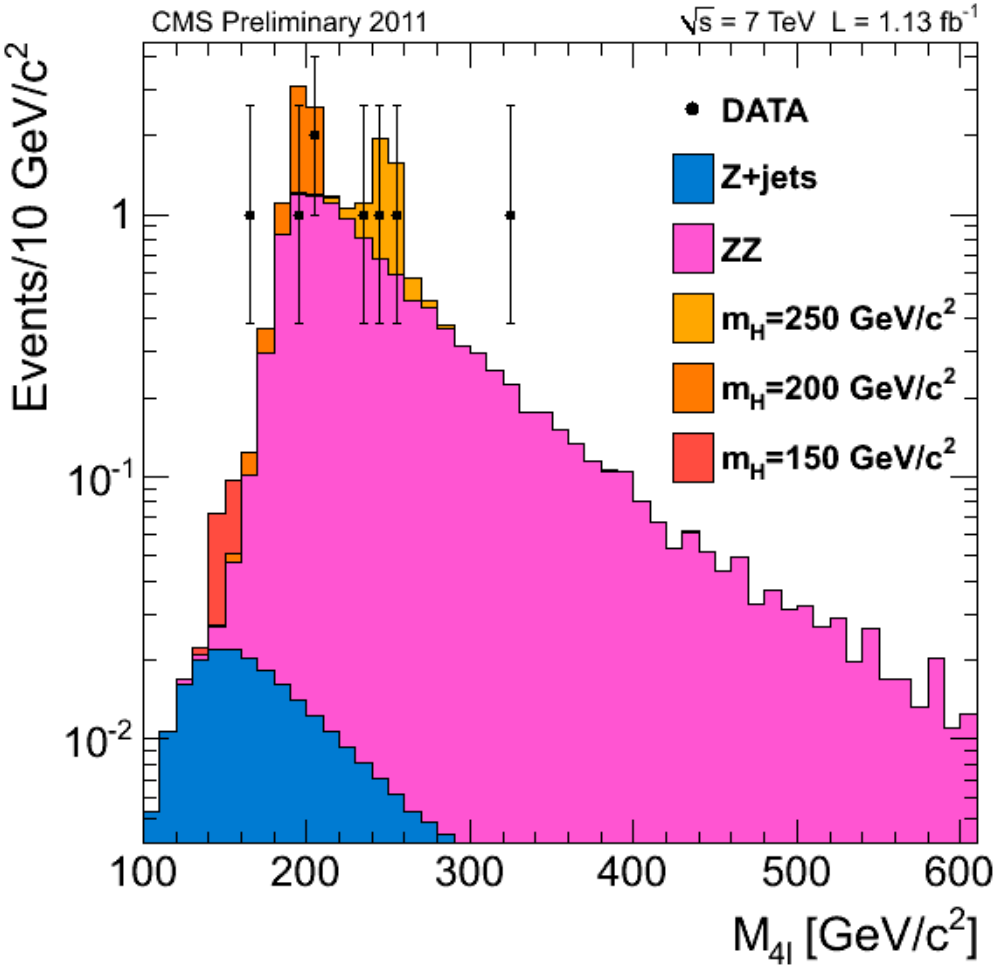
Invariant Mass

High mass/Two Zs "on-shell"

coincides with the selection for ZZ cross section measurement

$60 < m_{Z1} < 120$ GeV/c^2
$60 < m_{Z2} < 120$ GeV/c^2

	4e	4μ	2e2μ
ZZ	2.50 ± 0.17	3.55 ± 0.23	6.10 ± 0.40
Others back.	0.14 ± 0.06	-	0.15 ± 0.06
Observed	0	2	6



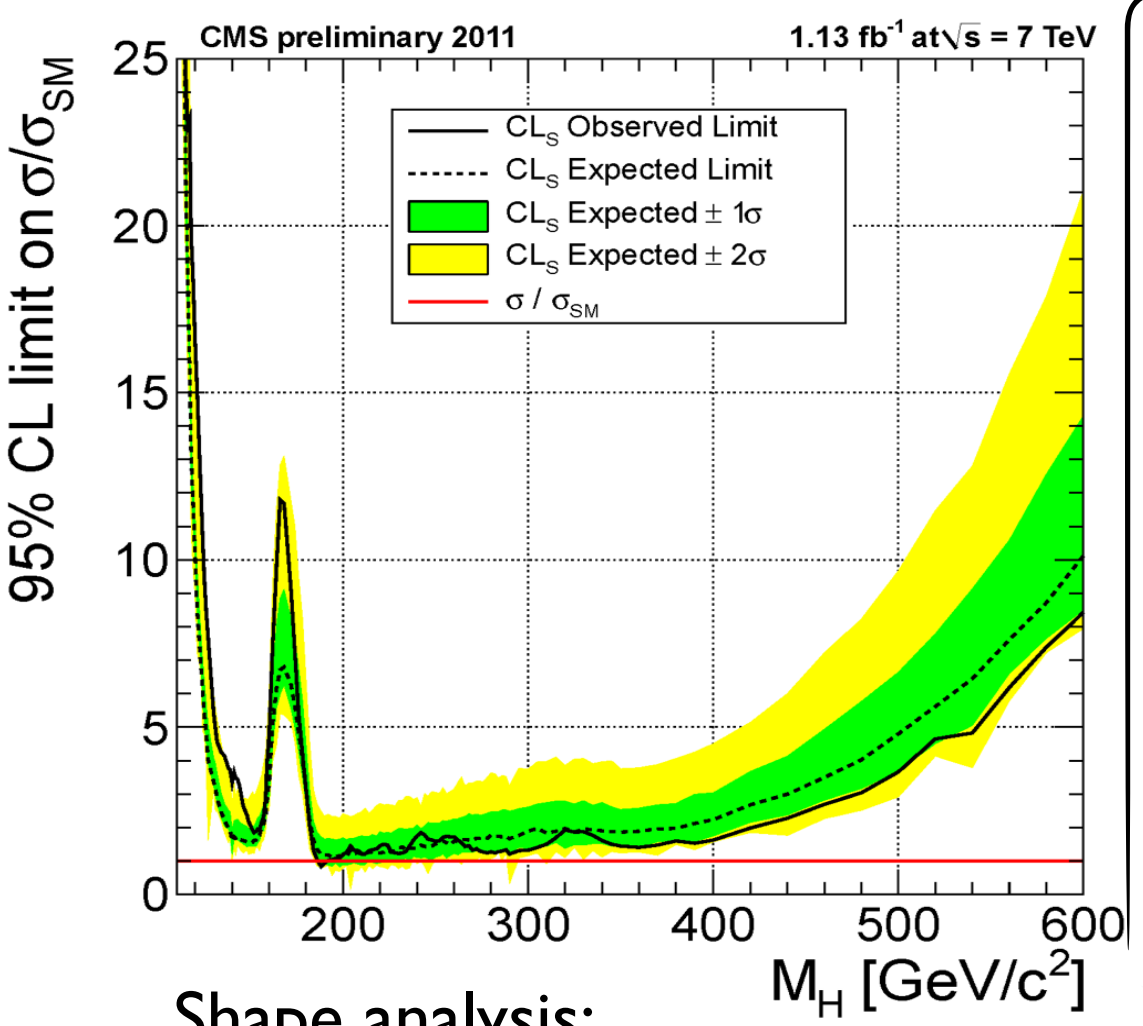
The total cross section for a pair WW/WZ/ZZ bosons has been measured and found to be in agreement with the expectation from the Standard Model

See CMS EWK di-boson talk in this conference for more details

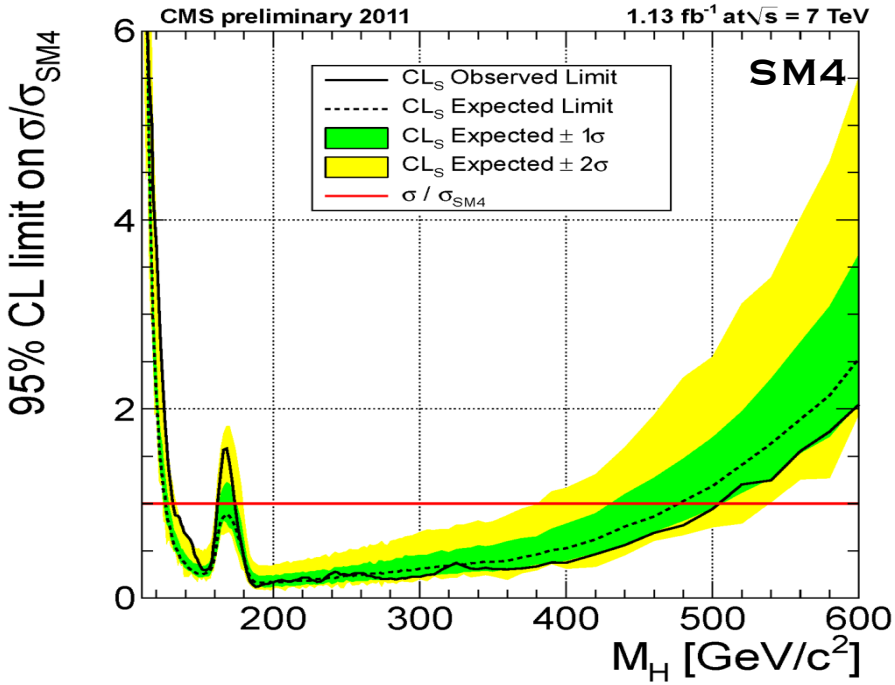
Upper Limits

L=1.13 fb^{-1}

$H \to ZZ^{(*)} \to l^+l^-l^+l^-$



SM with a 4th fermion family of high mass



Higgs boson with a mass in the
138-162 GeV/c^2 and
178-502 GeV/c^2 ranges
is excluded at 95% CL

Shape analysis:

✓ Signal parametrized with a Breit–Wigner convoluted with a Crystal-Ball

✓ ZZ/reducible backgrounds parametrized by an empirical probability function, normalization from data

Conclusion

✓ A search of the H boson in the ZZ mode has been performed for the **first time** in CMS

✓ The ZZ* decays into **llqq, llνν and llll** (**l = e, μ**) have been measured and examined at $\sqrt{s}$ = 7 TeV

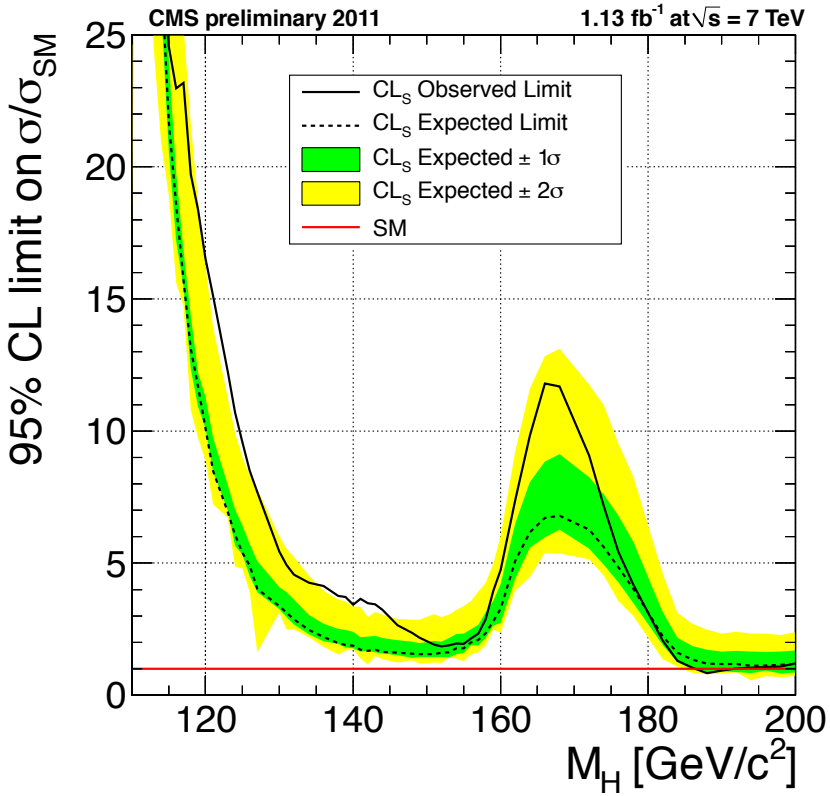
✓ **No evidence** of a SM-like Higgs bosons has been found

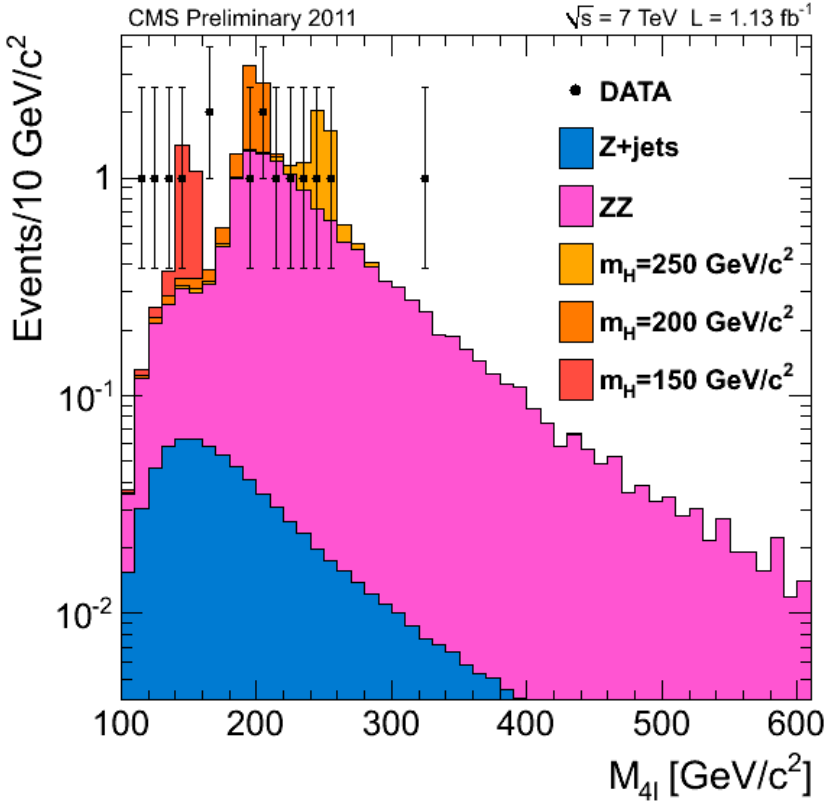
✓ At $m_{4l} > 100$ GeV/c^2 : 15 events observed, 14.4 ± 0.6 events expected
At $m_{4l} < 2 \times m_Z$: 6 events observed, 1.9 ± 0.1 events expected

✓ Upper limits are obtained at 95% CL on the cross section×B.R. for a Higgs boson with SM-like decays for masses in the range
110 < m_H < 600 GeV/c^2

✓ In the context of the Standard Model with a massive fourth fermion family, a Higgs boson with a mass in the ranges **138-162 GeV/c^2** and **178-550 GeV/c^2** is excluded at 95% C.L.

BACKUP


CMS preliminary 2011
1.13 fb-1 at √s = 7 TeV
CLs Observed Limit
CLs Expected Limit
CLs Expected ± 1σ
CLs Expected ± 2σ
SM
95% CL limit on σ/σSM
MH [GeV/c2]


CMS Preliminary 2011
√s = 7 TeV L = 1.13 fb-1
DATA
Z+jets
ZZ
mH=250 GeV/c2
mH=200 GeV/c2
mH=150 GeV/c2
Events/10 GeV/c2
M4l [GeV/c2]