

# Search for the Standard Model Higgs boson with the CMS detector at LHC

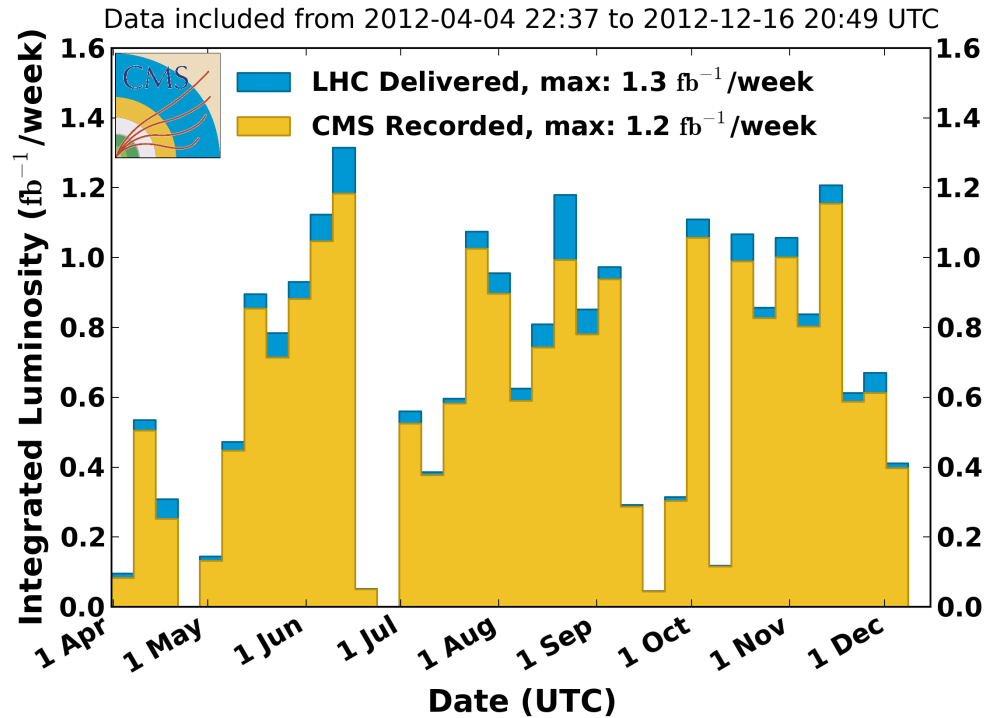
Tomasz Früboes  
National Centre for Nuclear Research  
On behalf of CMS collaboration



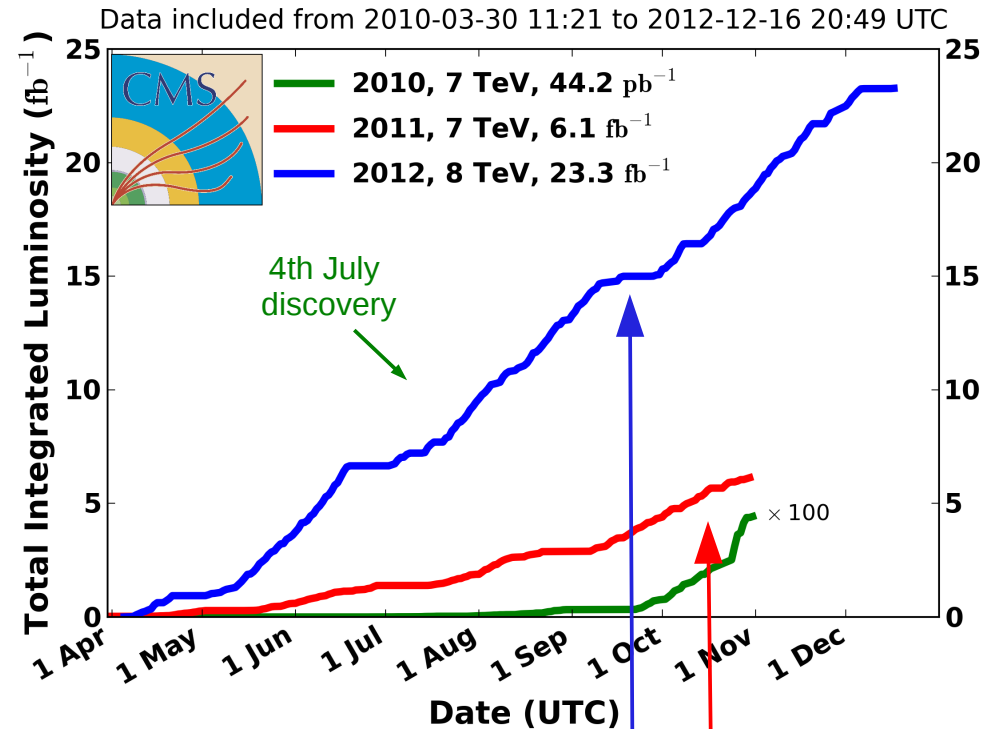
# LHC performance



CMS Integrated Luminosity Per Week, pp, 2012,  $\sqrt{s} = 8$  TeV



CMS Integrated Luminosity, pp

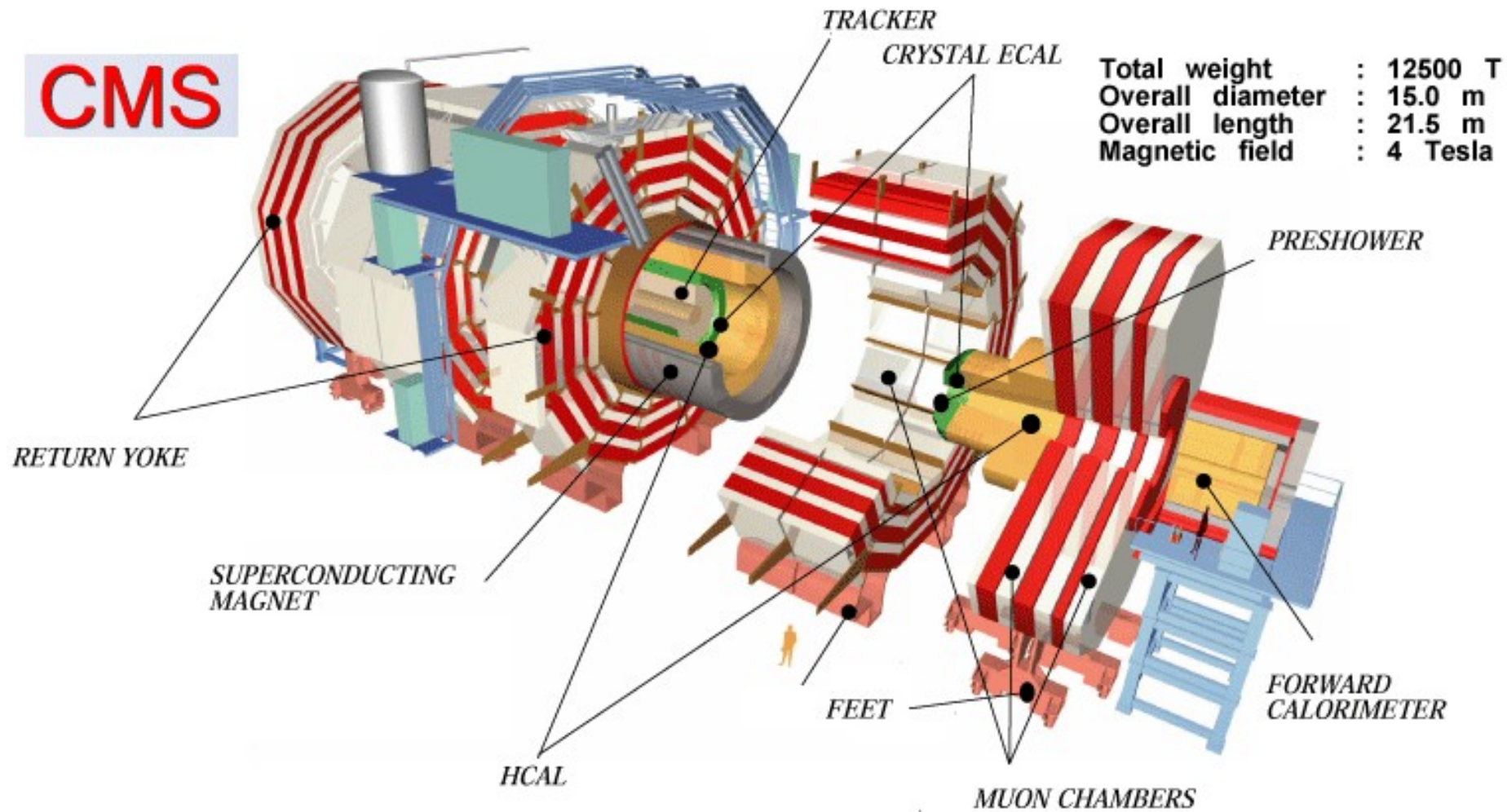


- Impressive year for the LHC operation
  - Often more than  $1/\text{fb}$  delivered per week!
- For presented analyses:
  - $\sim 12/\text{fb}$  @ 8TeV
  - $\sim 5/\text{fb}$  @ 7TeV

# CMS detector



**CMS**



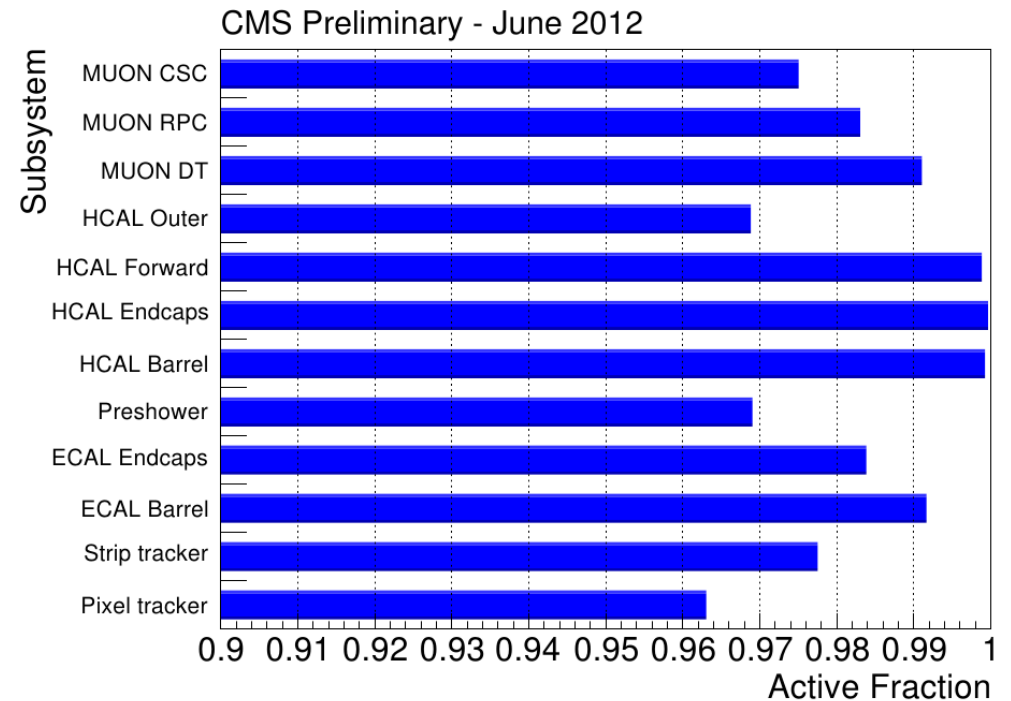
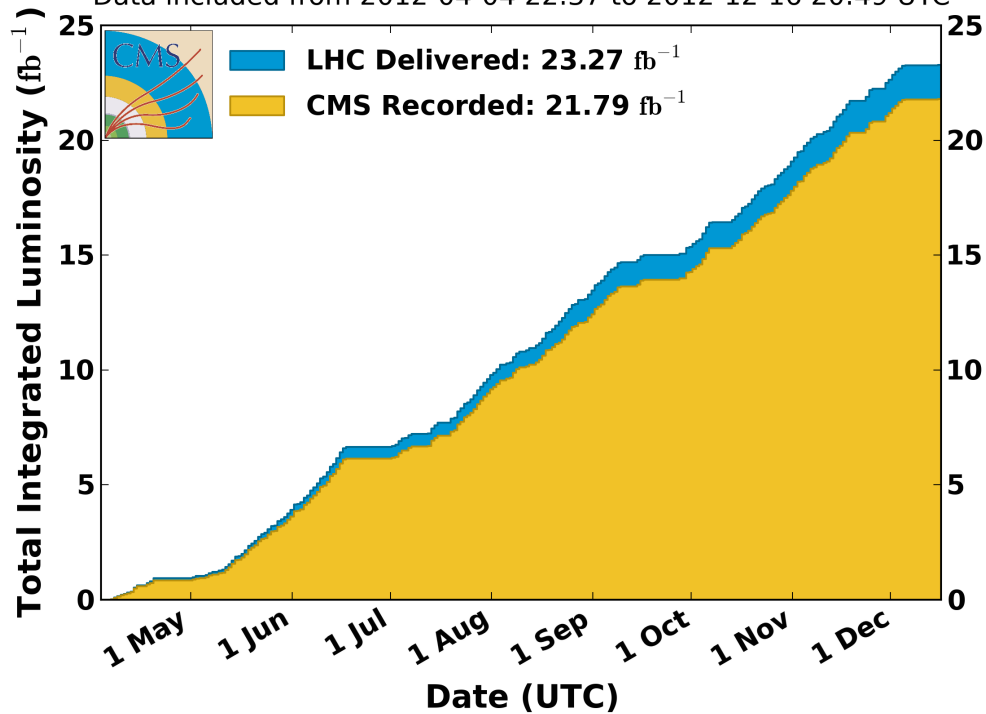


# CMS performance



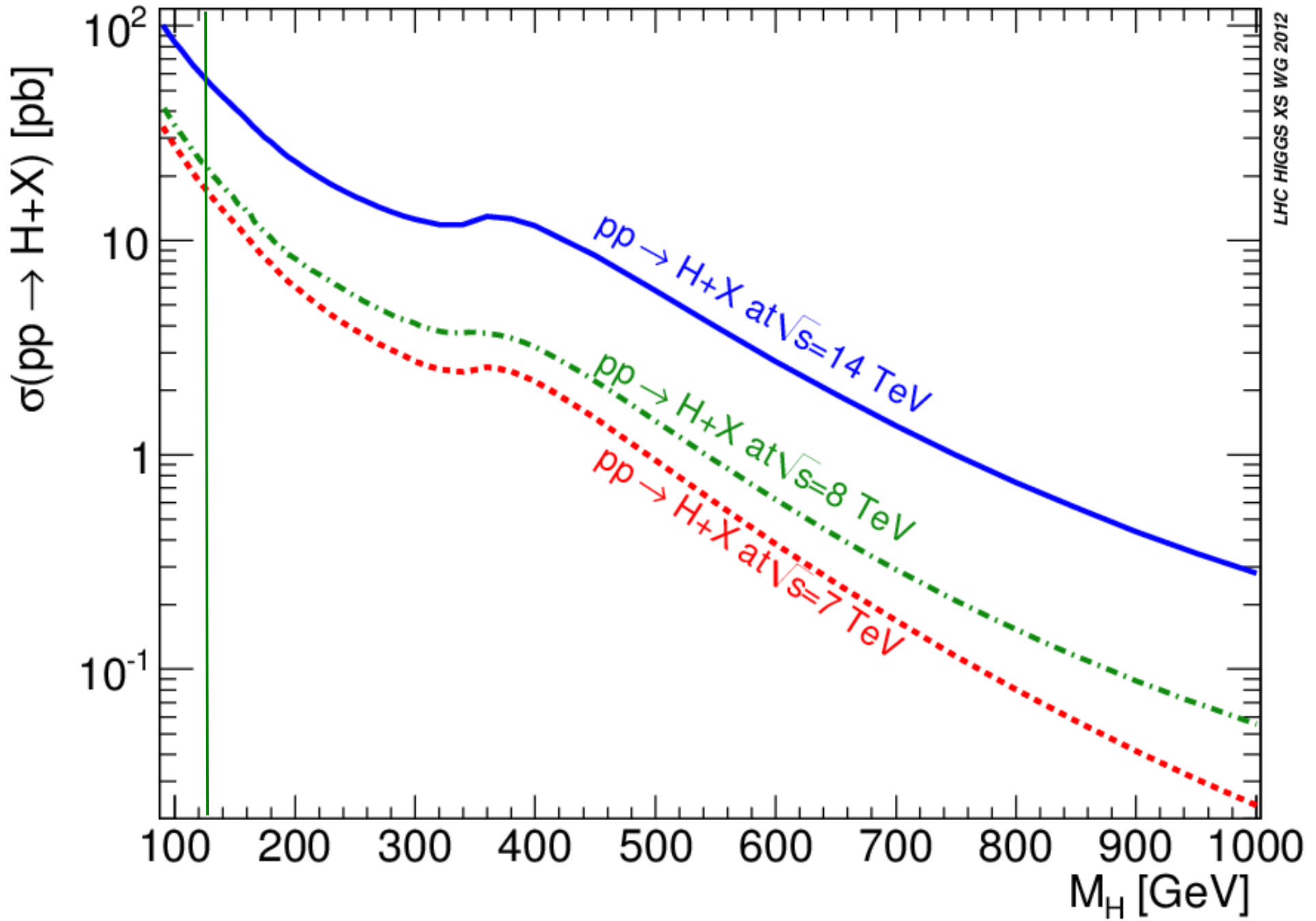
## CMS Integrated Luminosity, pp, 2012, $\sqrt{s} = 8$ TeV

Data included from 2012-04-04 22:37 to 2012-12-16 20:49 UTC

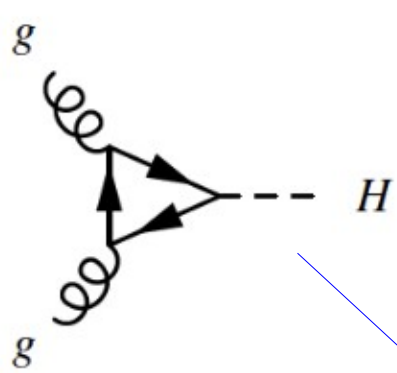


Very good detector performance, excellent data taking efficiency

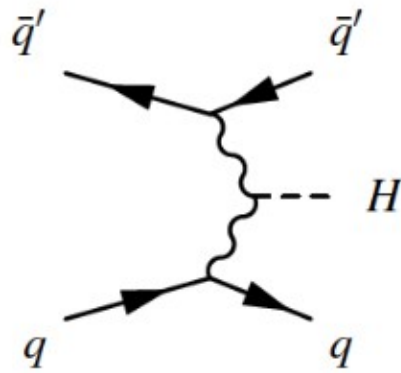
# Higgs XS – 7, 8, 14 TeV



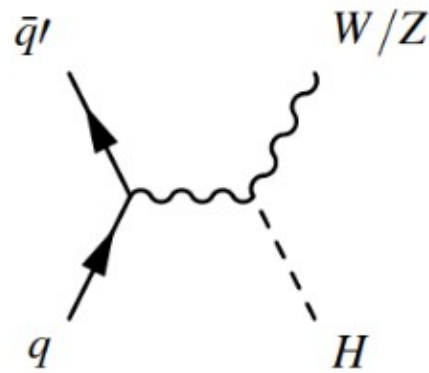
# Higgs at LHC



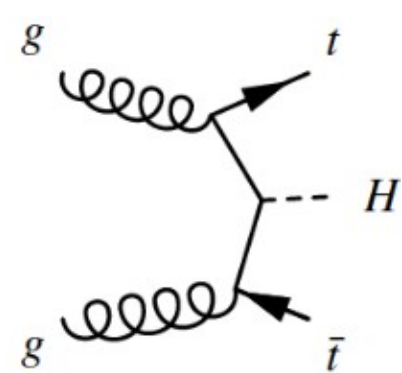
(a)  $gg \rightarrow H$



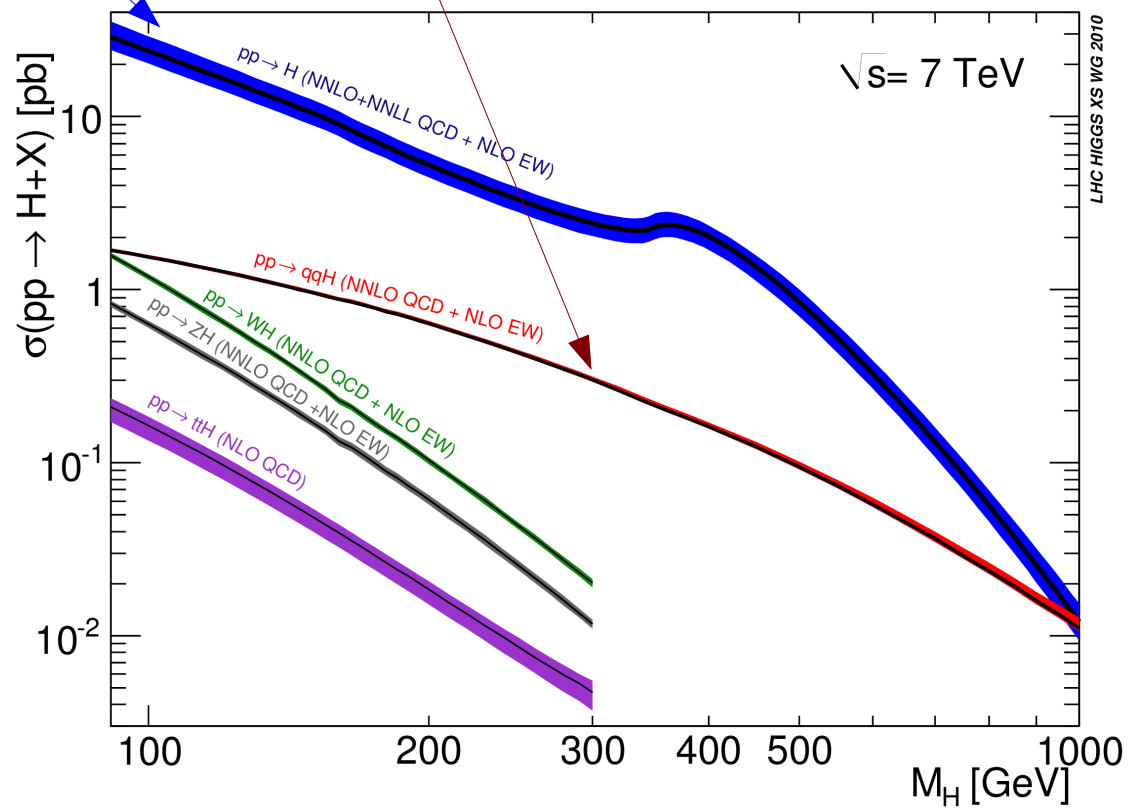
(b) VBF



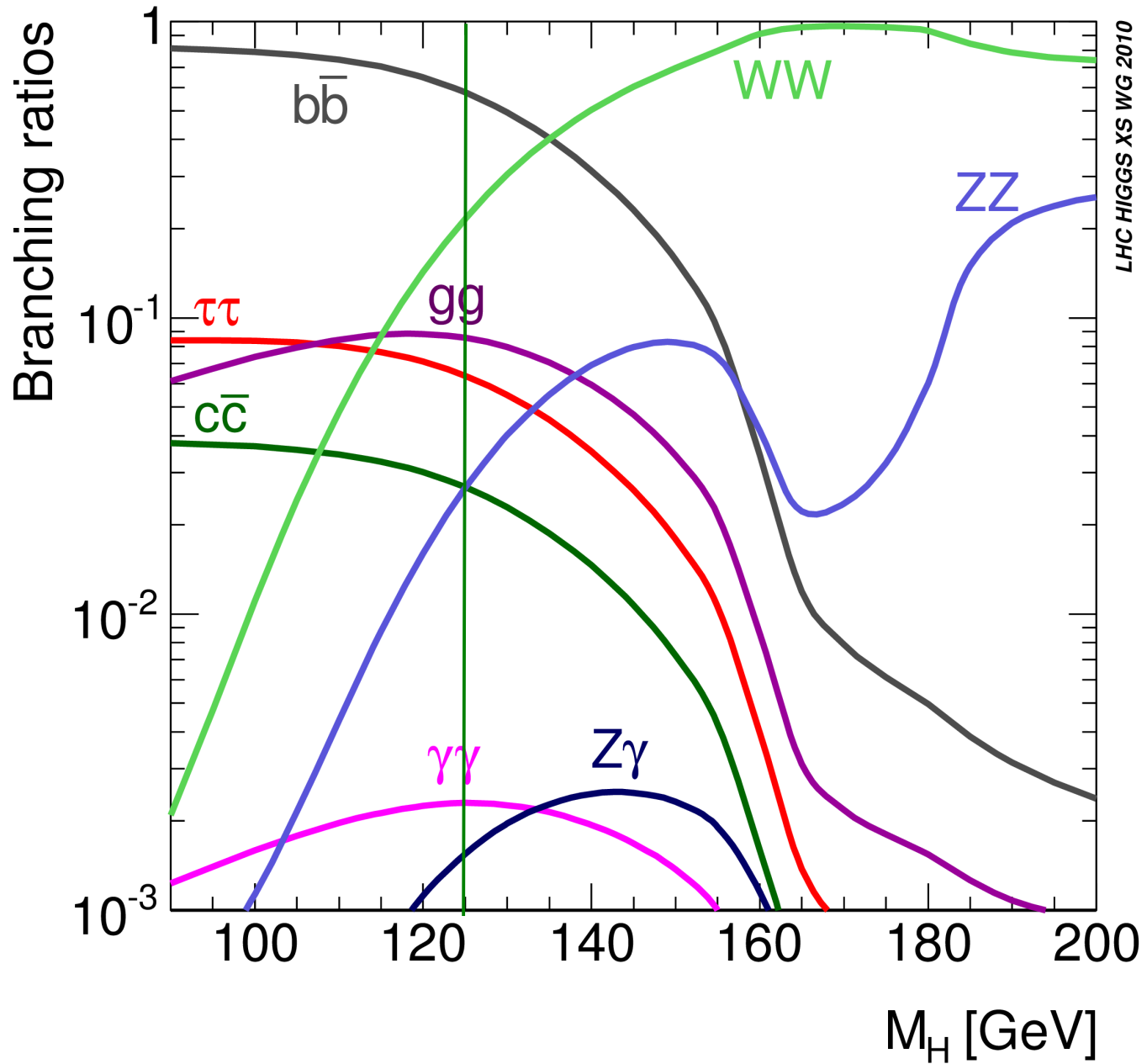
(c) VH



(d)  $t\bar{t}H$



# Higgs BR



LHC HIGGS XS WG 2010

# In this talk...



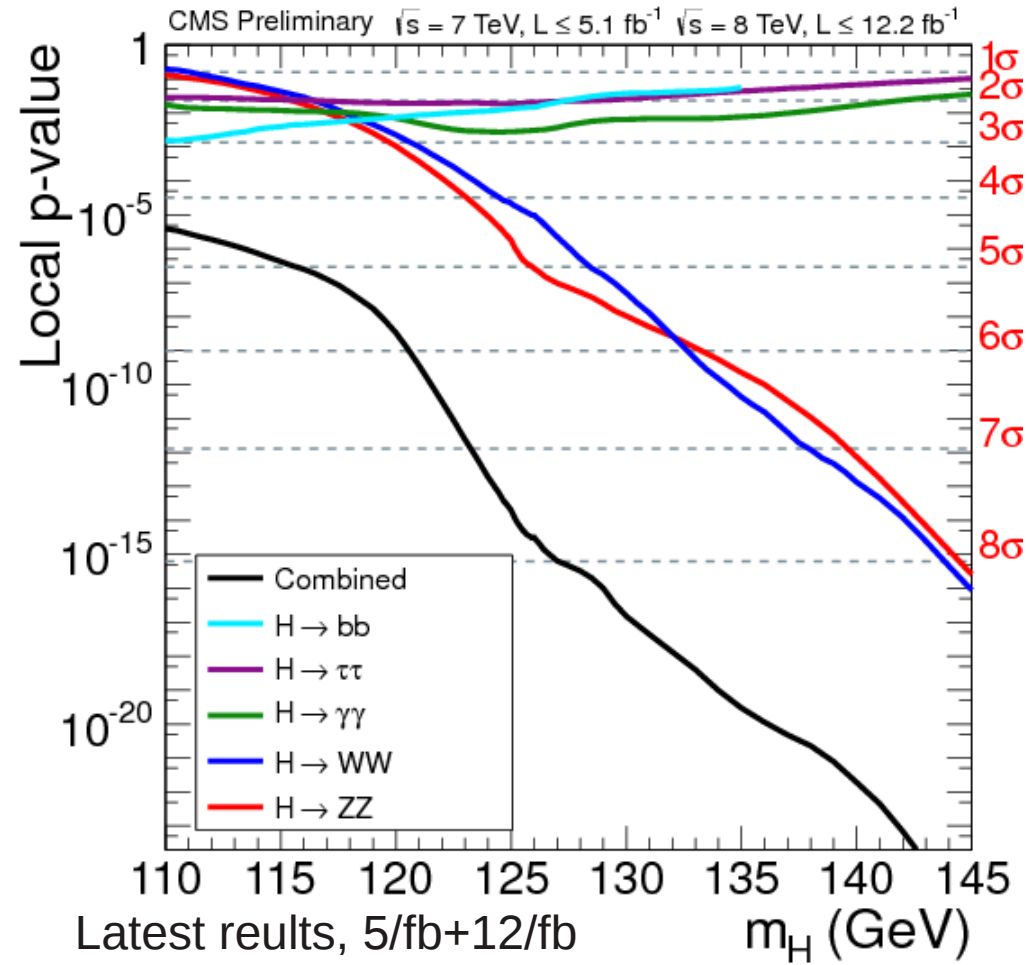
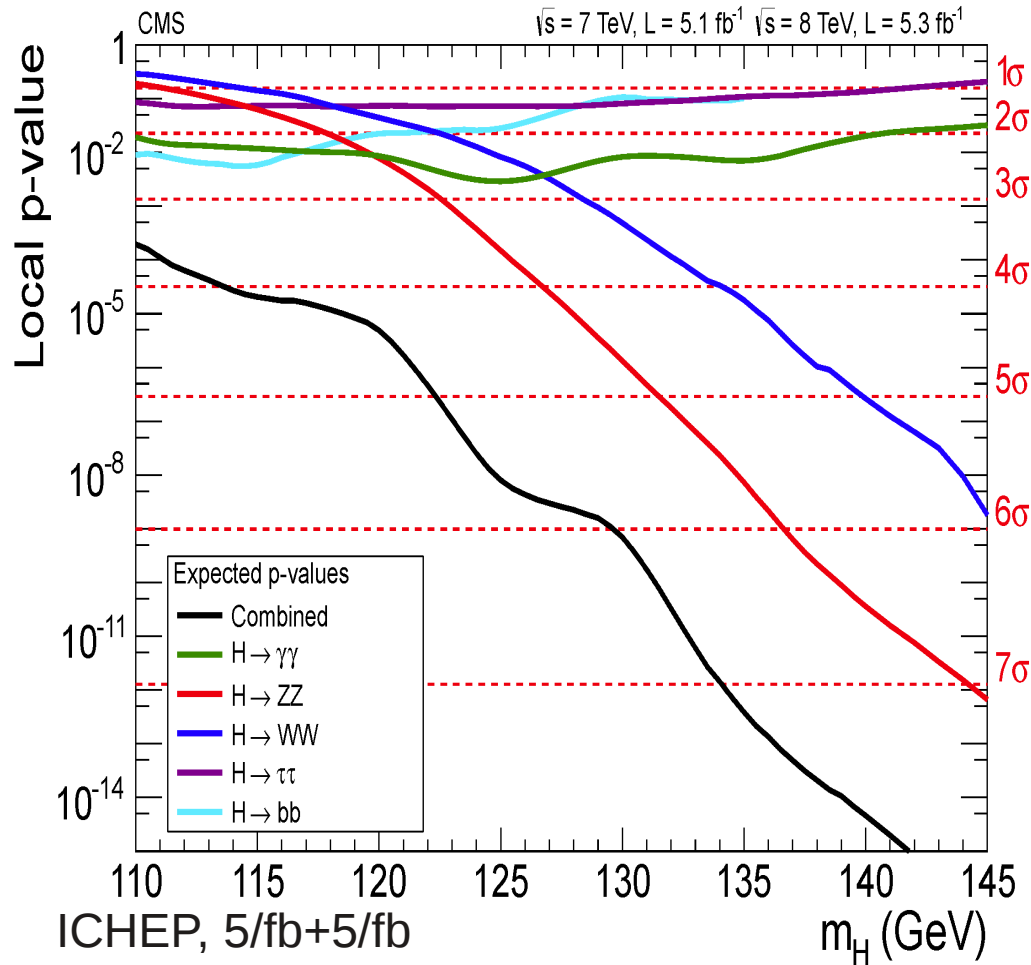
- **$H \rightarrow WW$  - 5/fb + 12/fb**
  - Good sensitivity, no mass peak
  - CMS-PAS-HIG-12-042
- **$H \rightarrow ZZ$  - 5/fb + 12/fb**
  - Clear signature, narrow mass peak
  - CMS-PAS-HIG-12-041
- **$H \rightarrow bb$  - 5/fb + 12/fb**
  - High BR but high background
  - CMS-PAS-HIG-12-044
- **$H \rightarrow \tau\tau$  - 5/fb + 12/fb**
  - High BR but high background
  - CMS-PAS-HIG-12-043
- **$H \rightarrow \gamma\gamma$  - 5/fb + 5/fb**
  - Clear signature, narrow mass peak
  - CMS-PAS-HIG-12-015
  - No update since ICHEP (5/fb+5/fb)

Whole mass range

$110 < m_H < 145$  GeV



# CMS expected sensitivity



- Big improvement since ICHEP, 5.8  $\rightarrow$  7.8 @ 125 GeV
- More data, better analyses



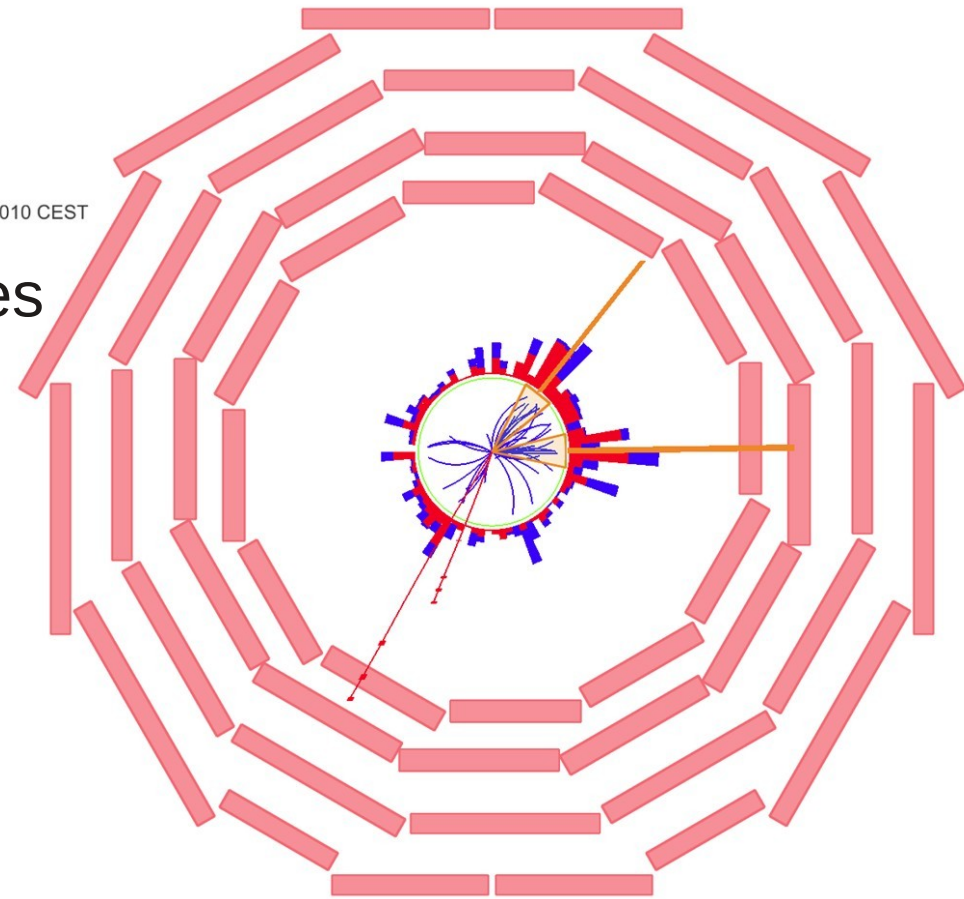
Higgs  $\rightarrow$  WW

# H $\rightarrow$ WW - basic analysis strategy



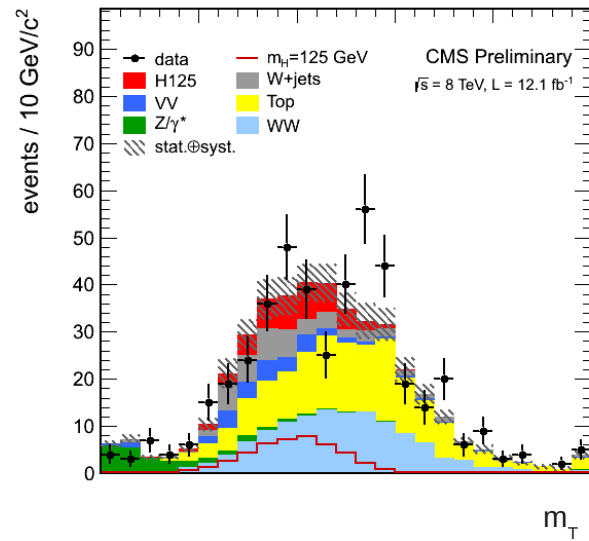
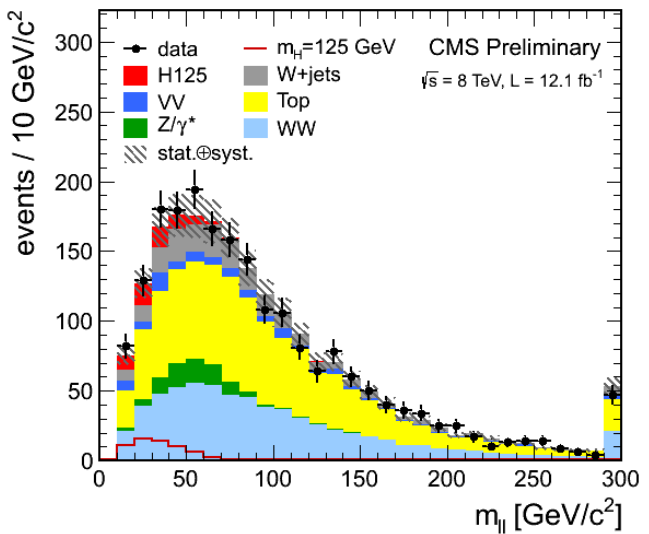
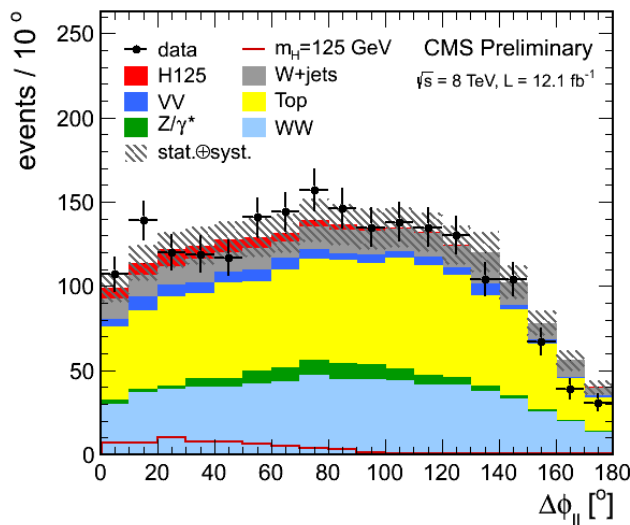
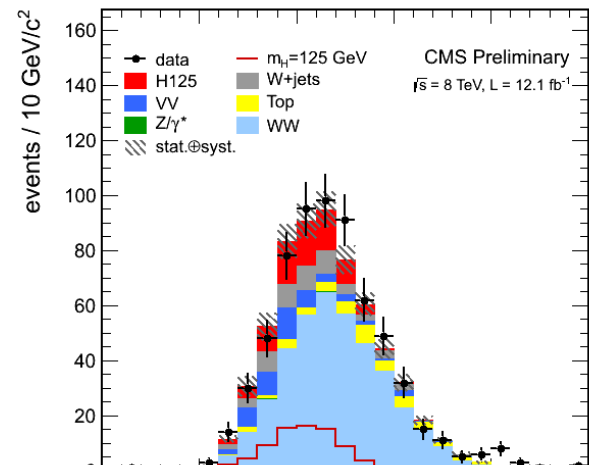
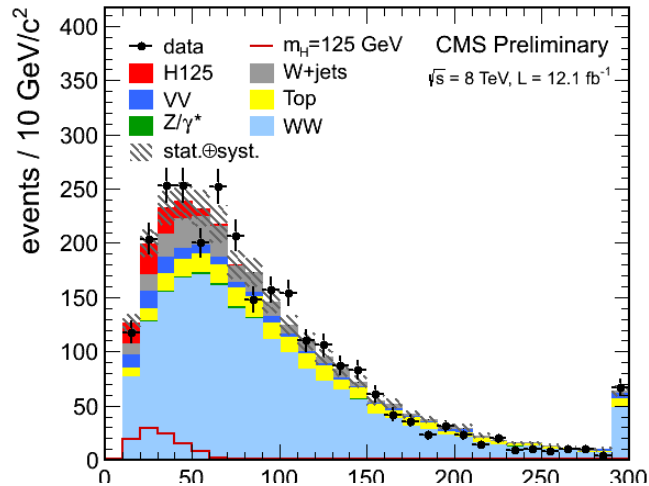
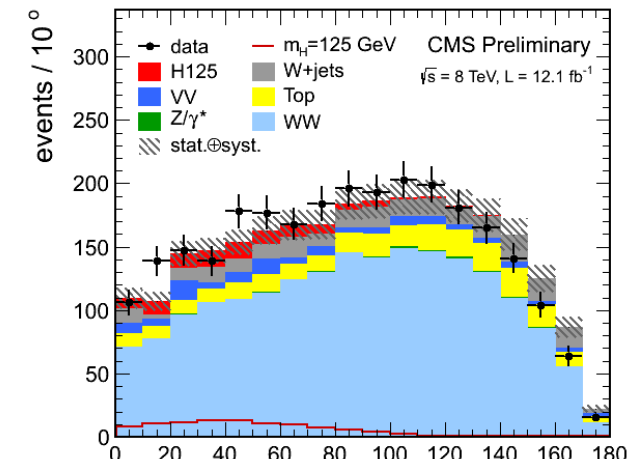
- Two isolated leptons (e or  $\mu$ ) with opposite charge
- No mass peak due to MET
- Analysis split into two main categories – different flavour (e+ $\mu$ ) and same flavour (ee, $\mu\mu$ )
  - Subcategories depending on number of jets (0-2)
- For most sensitive categories - analysis using 2D shapes ( $m_{||}$ - $m_{\perp}$ )
- Remaining - cut & count

2 2010 CEST



e+ $\mu$ :	0 jets, shape analysis	1 jet, shape analysis	VBF (2 jets)
e+e, $\mu$ + $\mu$ :	0 jets	1 jet	VBF (2 jets)

# H → WW – data vs expected

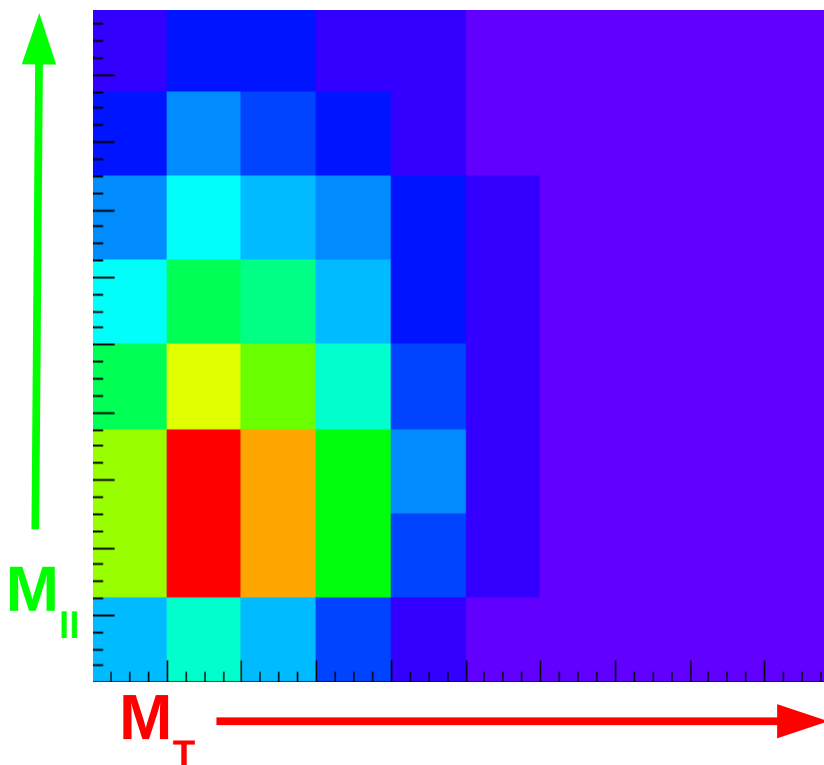
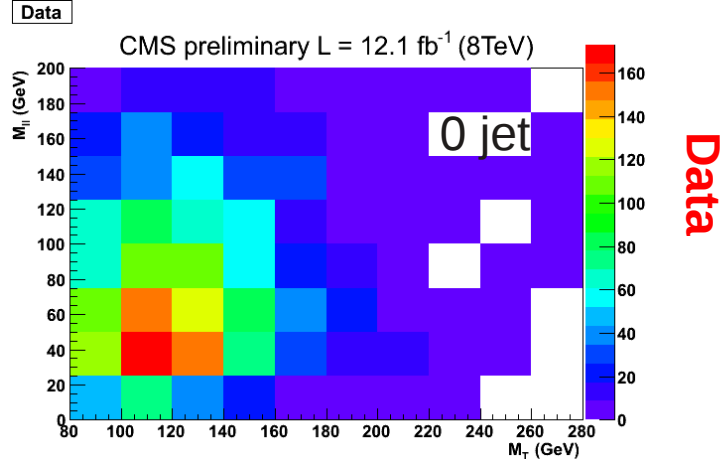
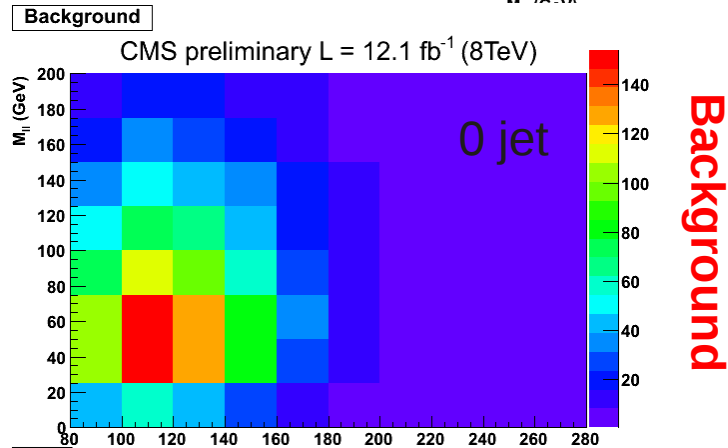
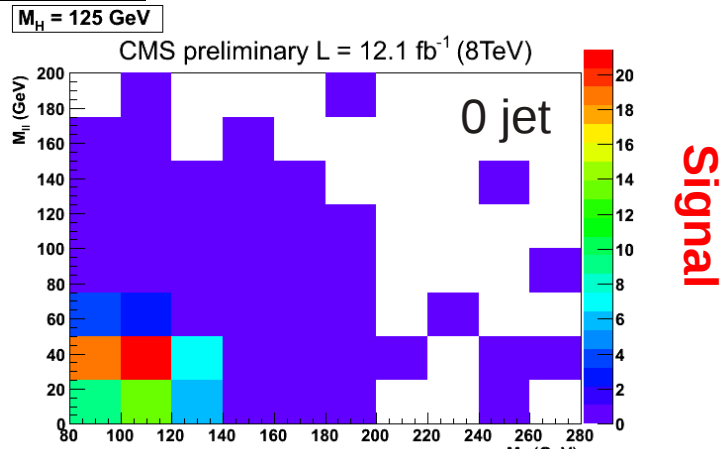


- Comparison of main variables ( $\Delta\Phi_{||}$ ,  $m_{||}$ ,  $m_T$ ) for different flavour, 0 (top) and 1 (bottom) jet categories

# H → WW – 2D shape analysis

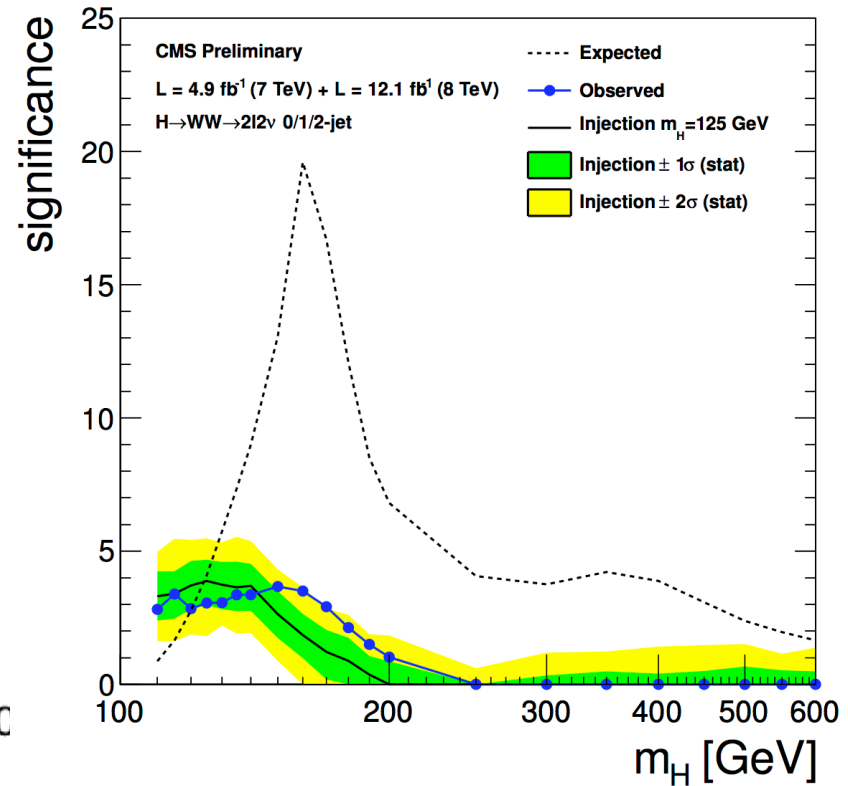
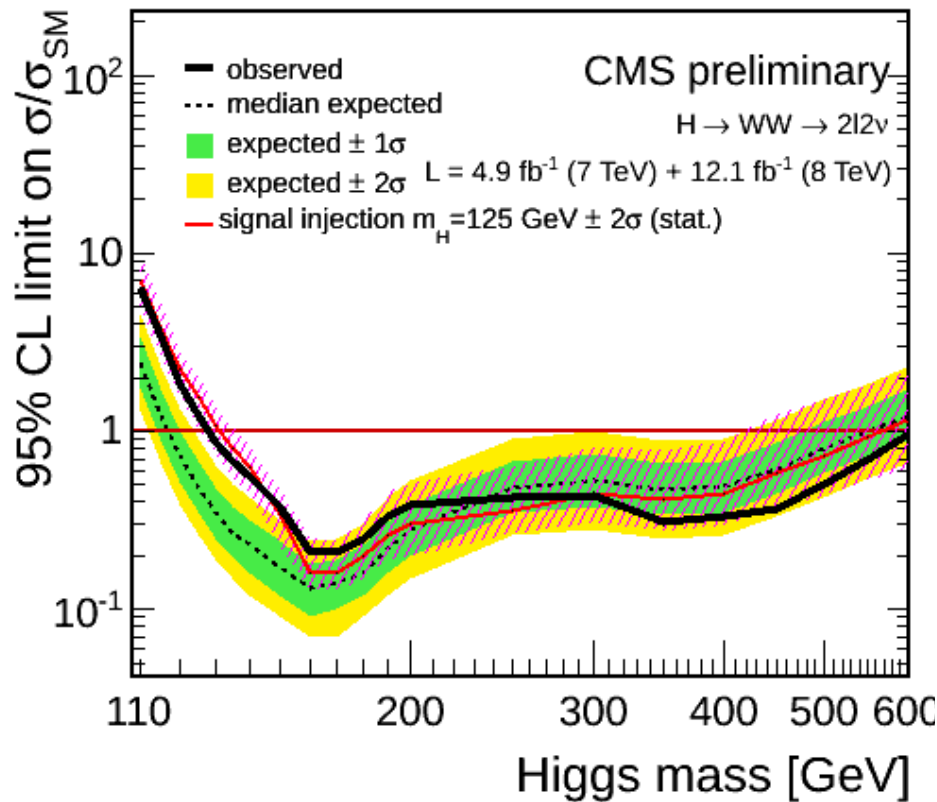


- Signal-background separation thanks to 2D shape analysis:



- Different 2D shapes of W+jets and WW background ease background normalization (not shown on the plot)

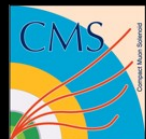
# H → WW - results



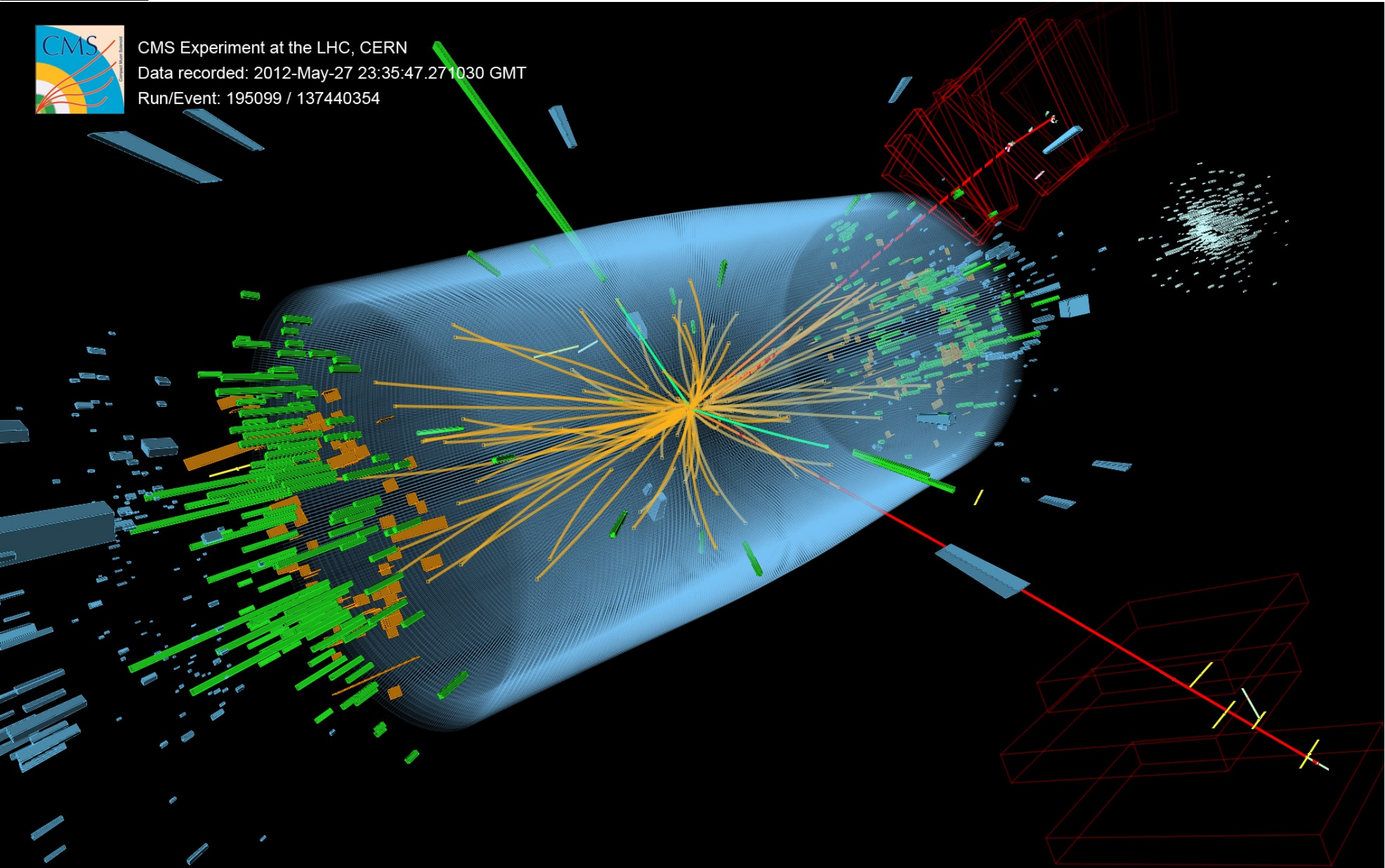
- 7 TeV analysis unchanged, improved 8 TeV analysis (including 2D shape analysis)
- 3.1 sigma excess seen (4.1 expected)
- Very wide excess due to low mass resolution



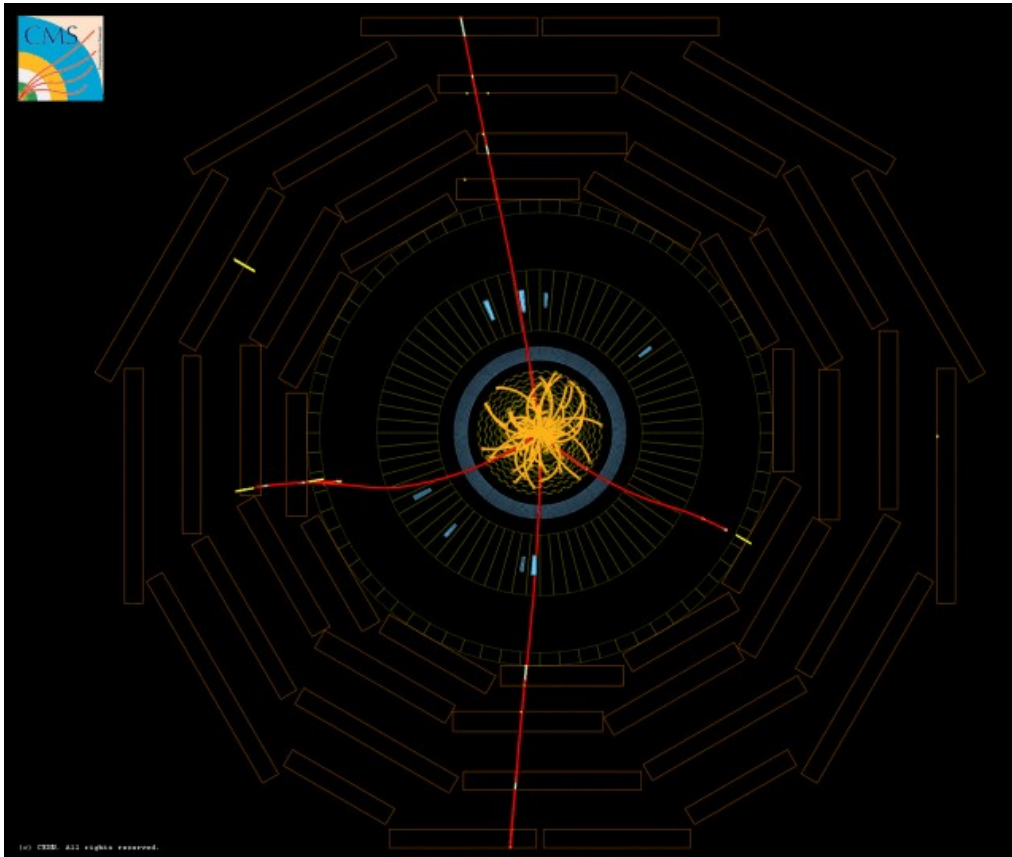
$$H \rightarrow ZZ$$



CMS Experiment at the LHC, CERN  
Data recorded: 2012-May-27 23:35:47.271030 GMT  
Run/Event: 195099 / 137440354



$$H \rightarrow ZZ$$



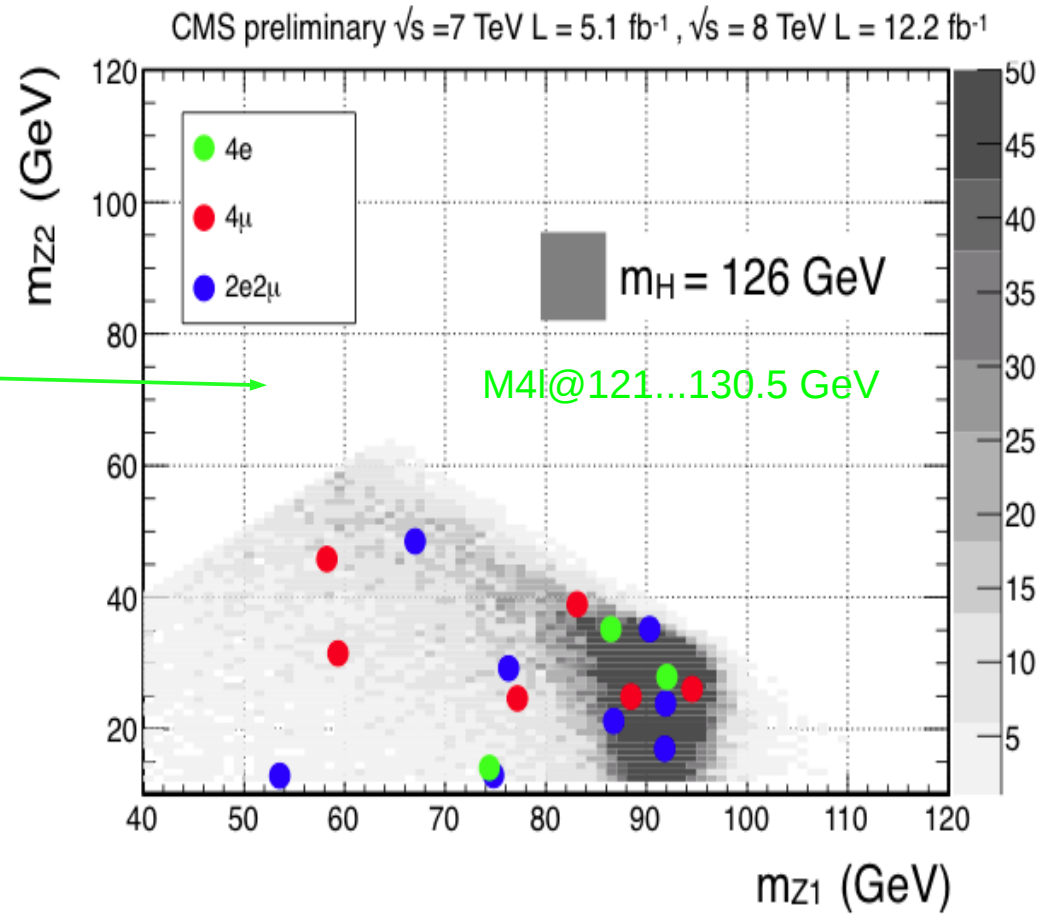
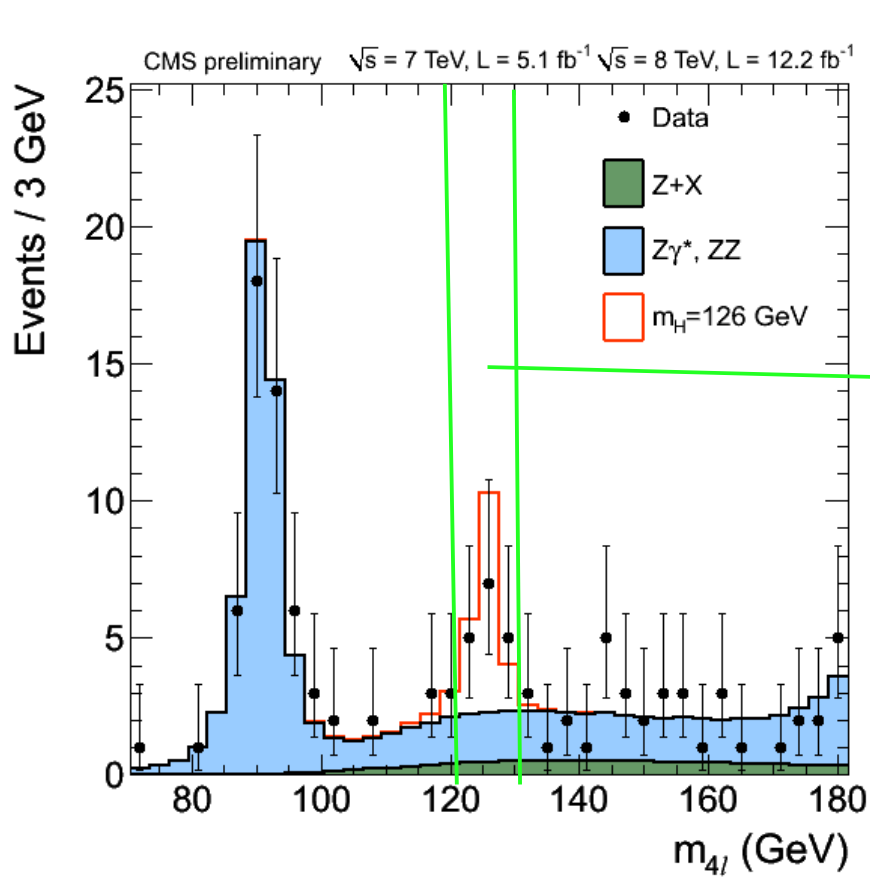
Analysis strategy:

- Require 4 high  $p_T$  leptons...
- ...isolated...
- ...same vertex
- One lepton pair should be consistent with Z boson decay

- Golden channel with very low background (direct ZZ production, also Zbb and top)

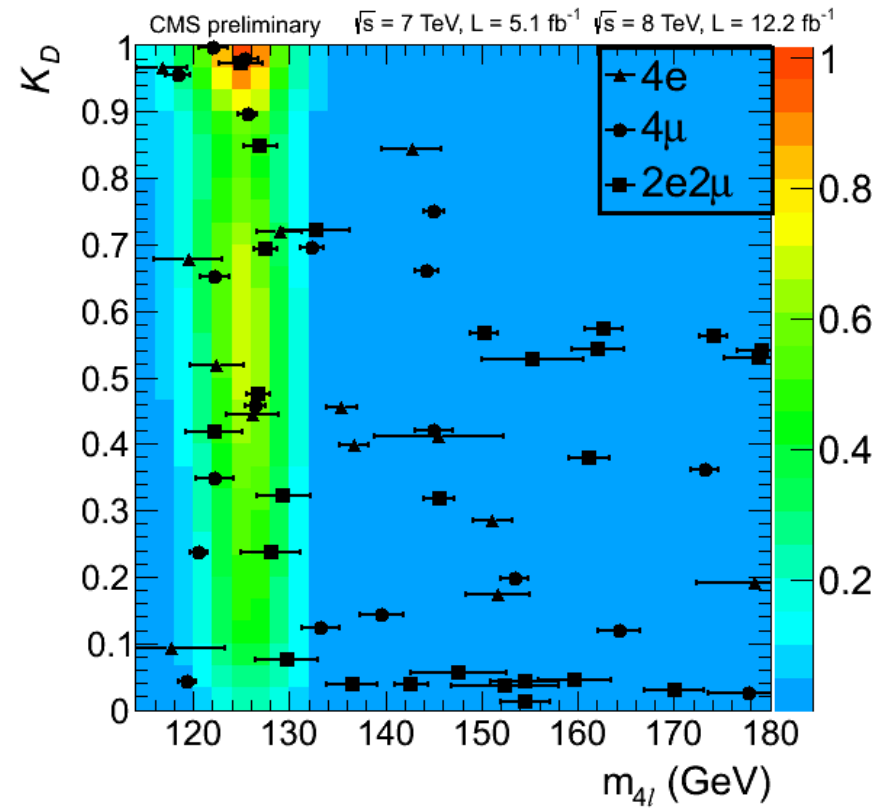
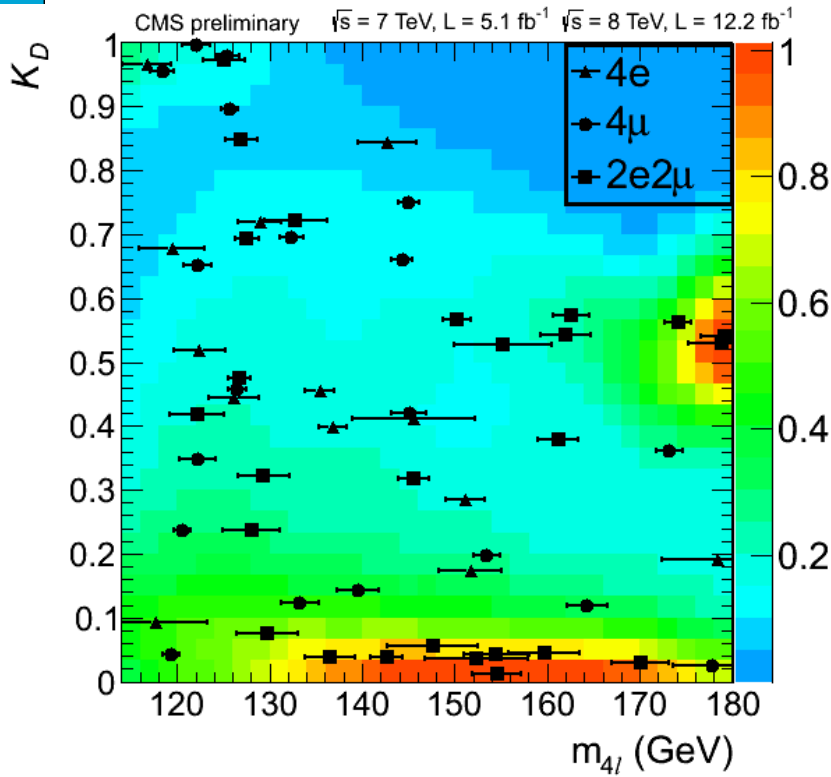


# H $\rightarrow$ ZZ



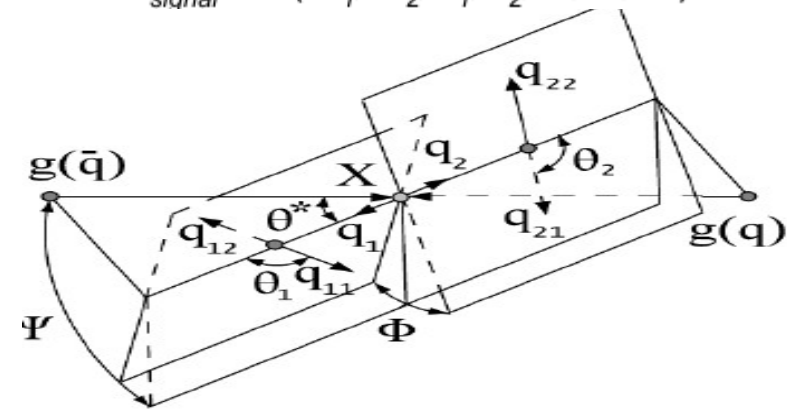
- Significant peak visible around 125 GeV
- Distribution  $m(Z1)$  vs  $m(Z2)$  around the peak as expected

# H → ZZ

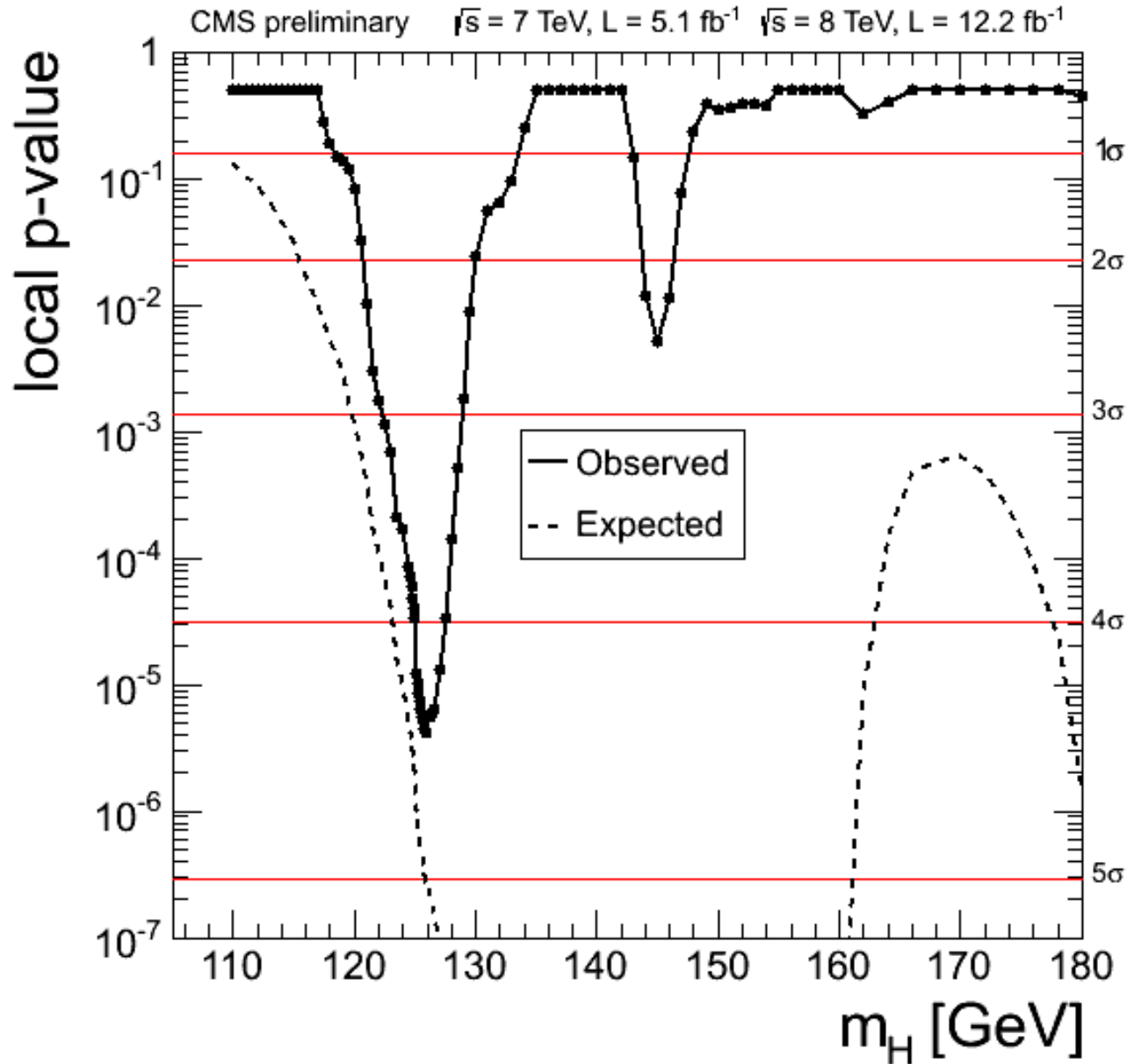


- Analysis sensitivity further enhanced by exploiting the event kinematics (invariant masses + angles between leptons)

$$1/K_D = 1 + \frac{P_{\text{background}}(m_1, m_2, \theta_1, \theta_2, \Psi, \Phi, \theta^*)}{P_{\text{signal}}(m_1, m_2, \theta_1, \theta_2, \Psi, \Phi, \theta^*)}$$



# H → ZZ - results



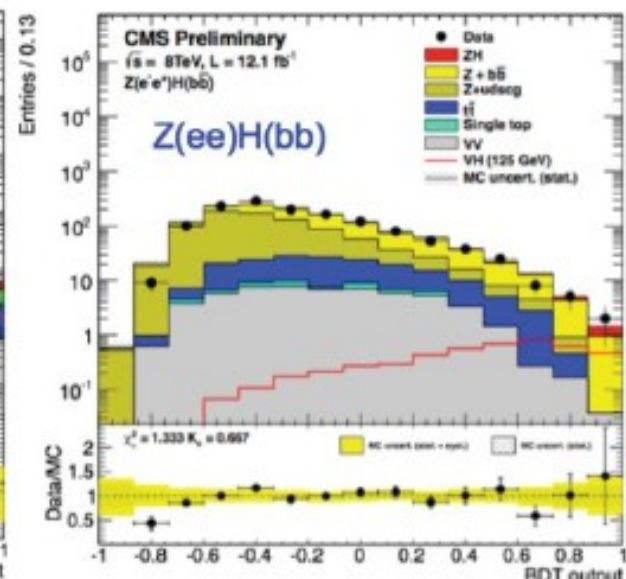
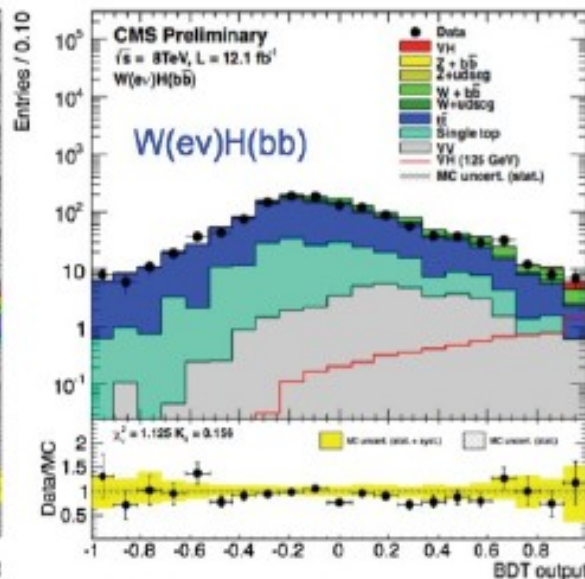
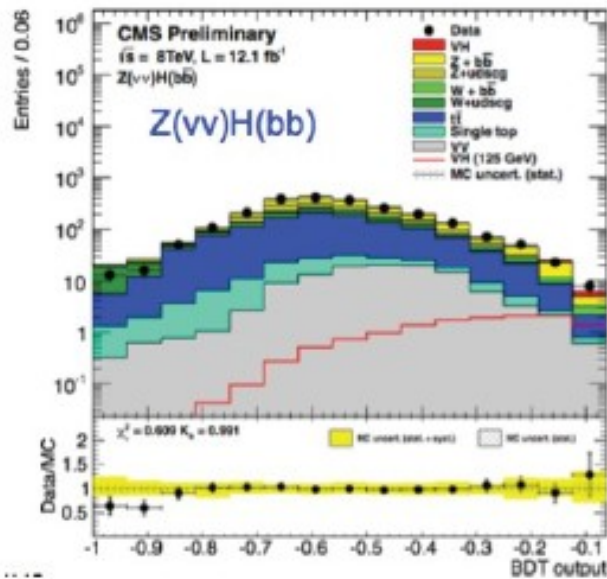
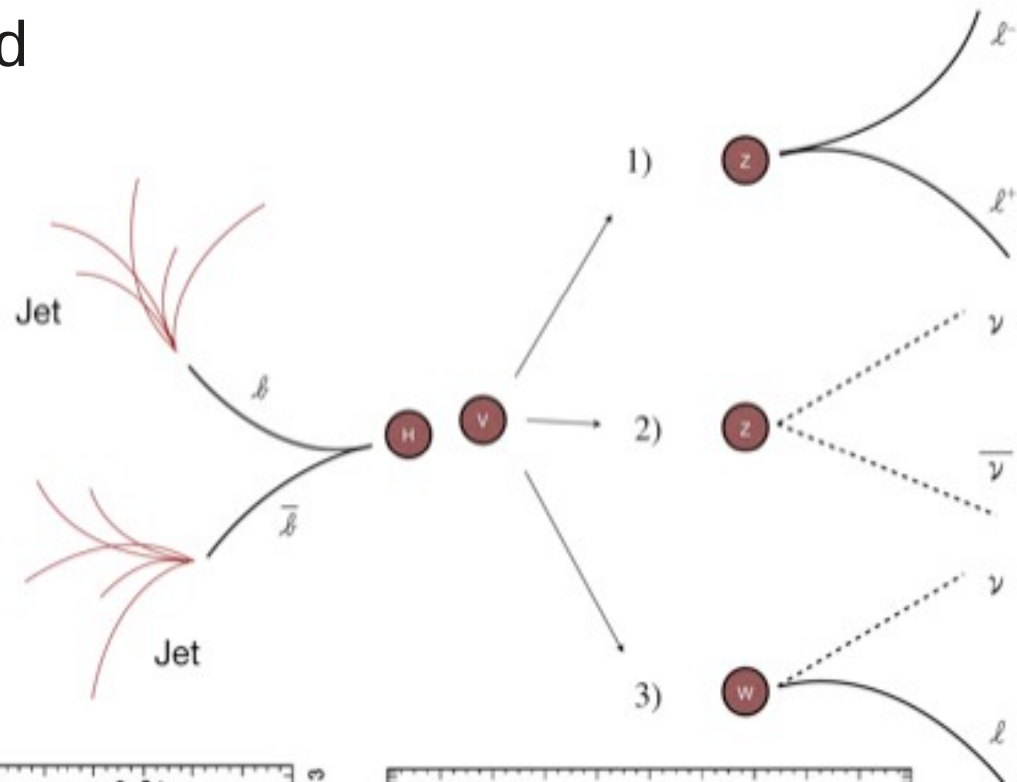
- Observed significance – 4.6 sigma

Higgs  $\rightarrow$  bb

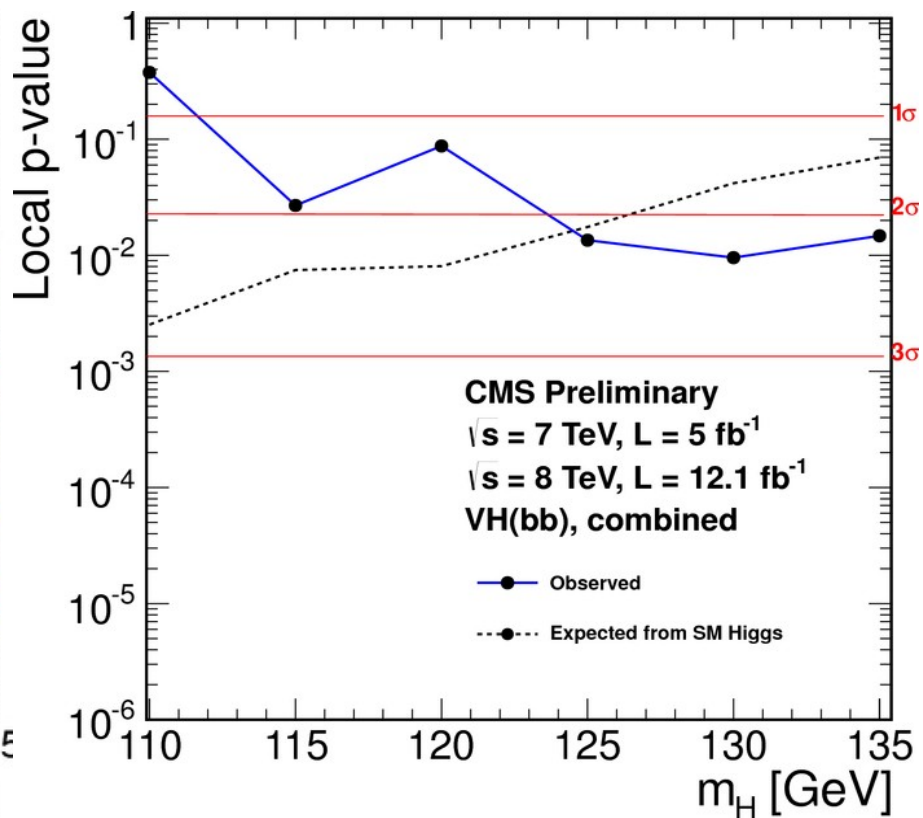
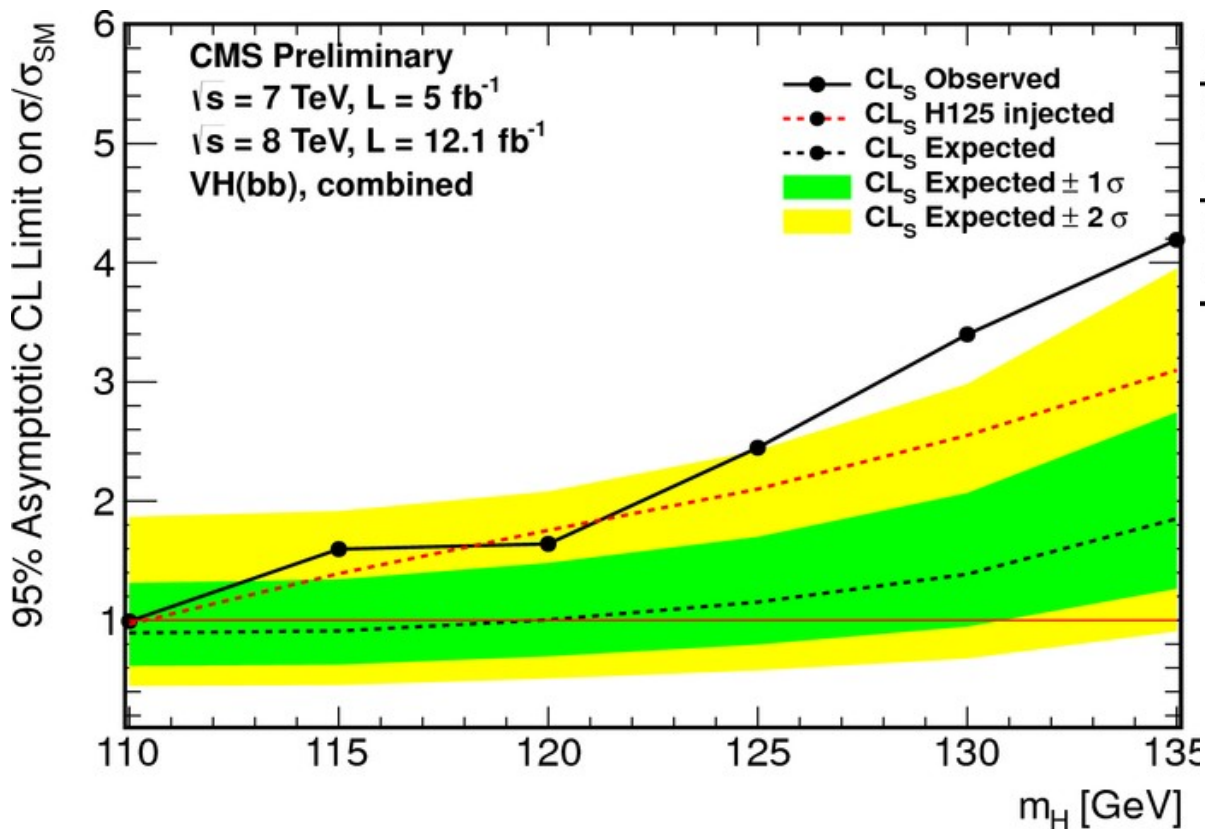
# H → bb



- Largest BR, but large background from QCD jets
  - Exploit the associated production mode to gain more discriminating power
- 5 categories (depending on W/Z final state)
  - Zνν, Zμμ, Zee, Wμν, Weν
- MVA used to enhance sensitivity



# H → bb

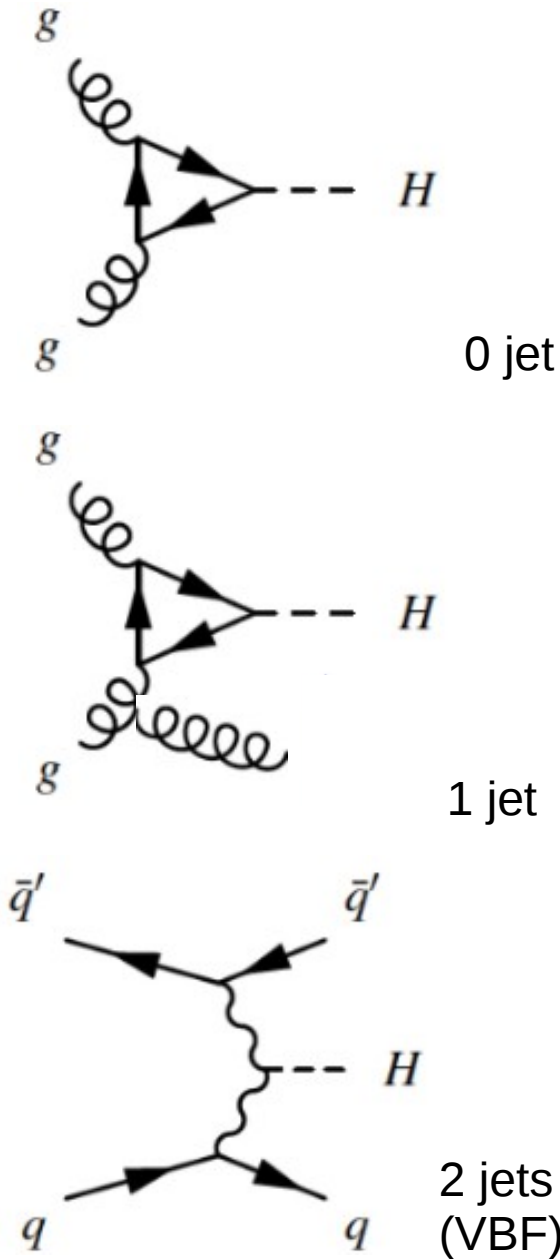


2.2 $\sigma$  excess visible for 125 GeV Higgs boson mass

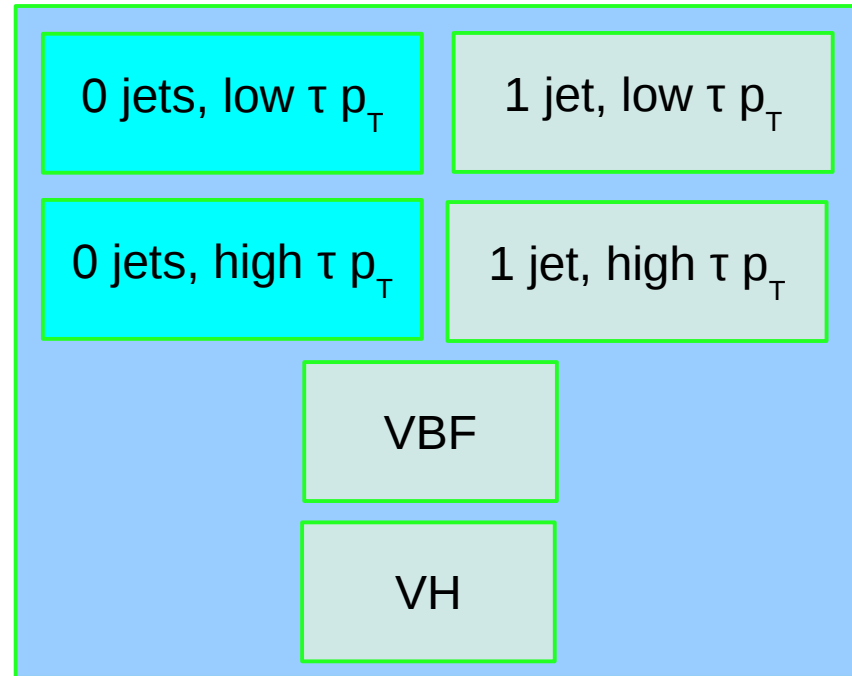


$$H \rightarrow \tau\tau$$

# $H \rightarrow \tau\tau$



- Analysis in 6 categories:



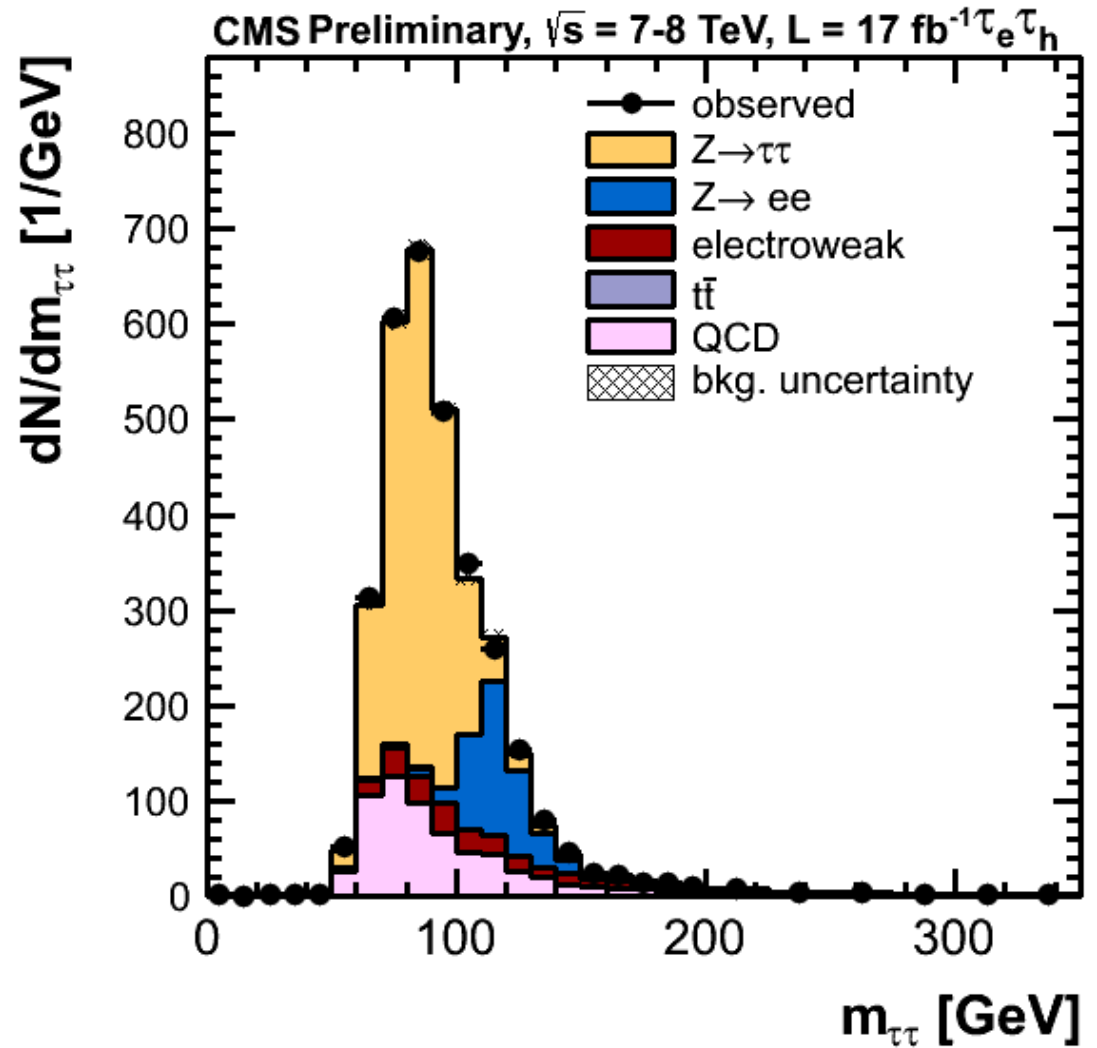
- Inclusive category used only for background constraint (no signal fitted)
- All tau final states considered



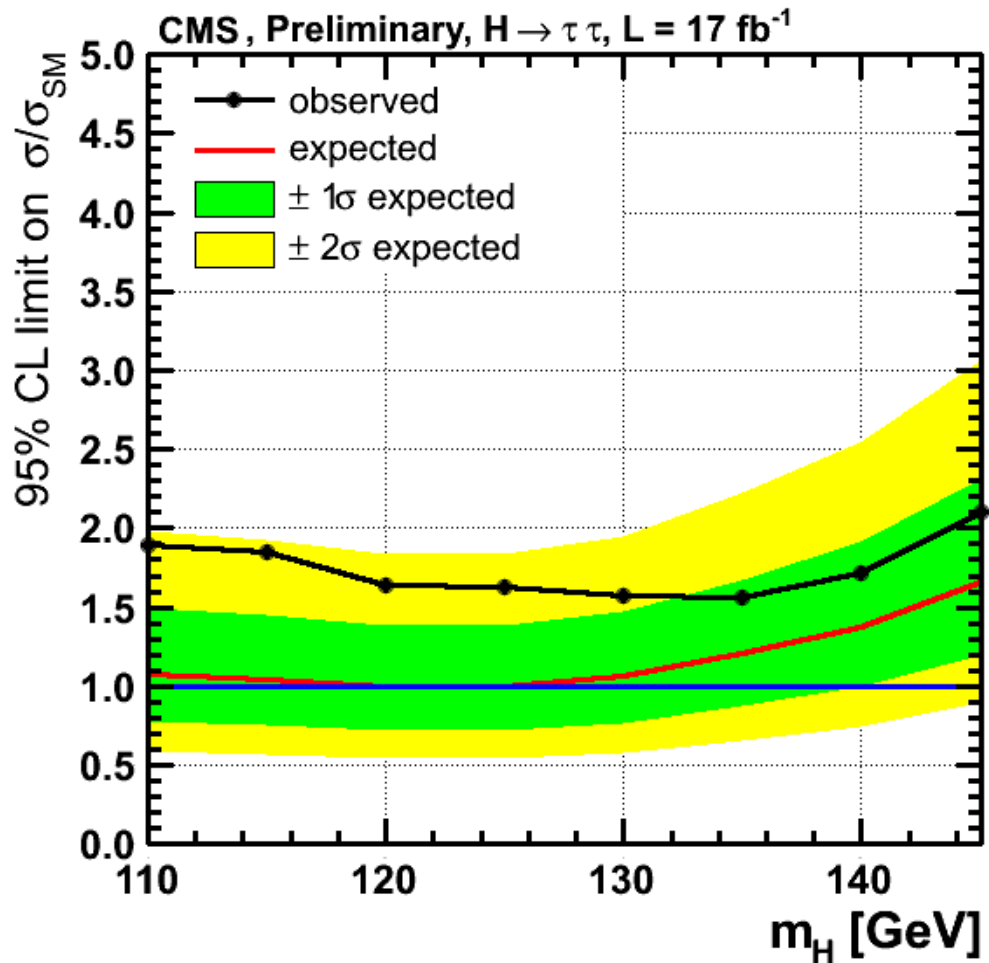
# $H \rightarrow \tau\tau$



- A challenging analysis – hadronic tau decay reconstruction, MET, plenty of background sources to control
- $DY\tau\tau$  estimated from embedding technique:
  - Use  $DY\mu\mu$ , replace muons with simulated tau decays
  - Gives shape and normalization
- QCD – SS/OS ratio
- Remaining sources estimated from control regions (W, tt) or from simulation



# H → ττ - results



- Various significant improvements in the analysis since ICHEP – fully hadronic mode added, MVA MET, others
- Signal over background excess starts to be visible

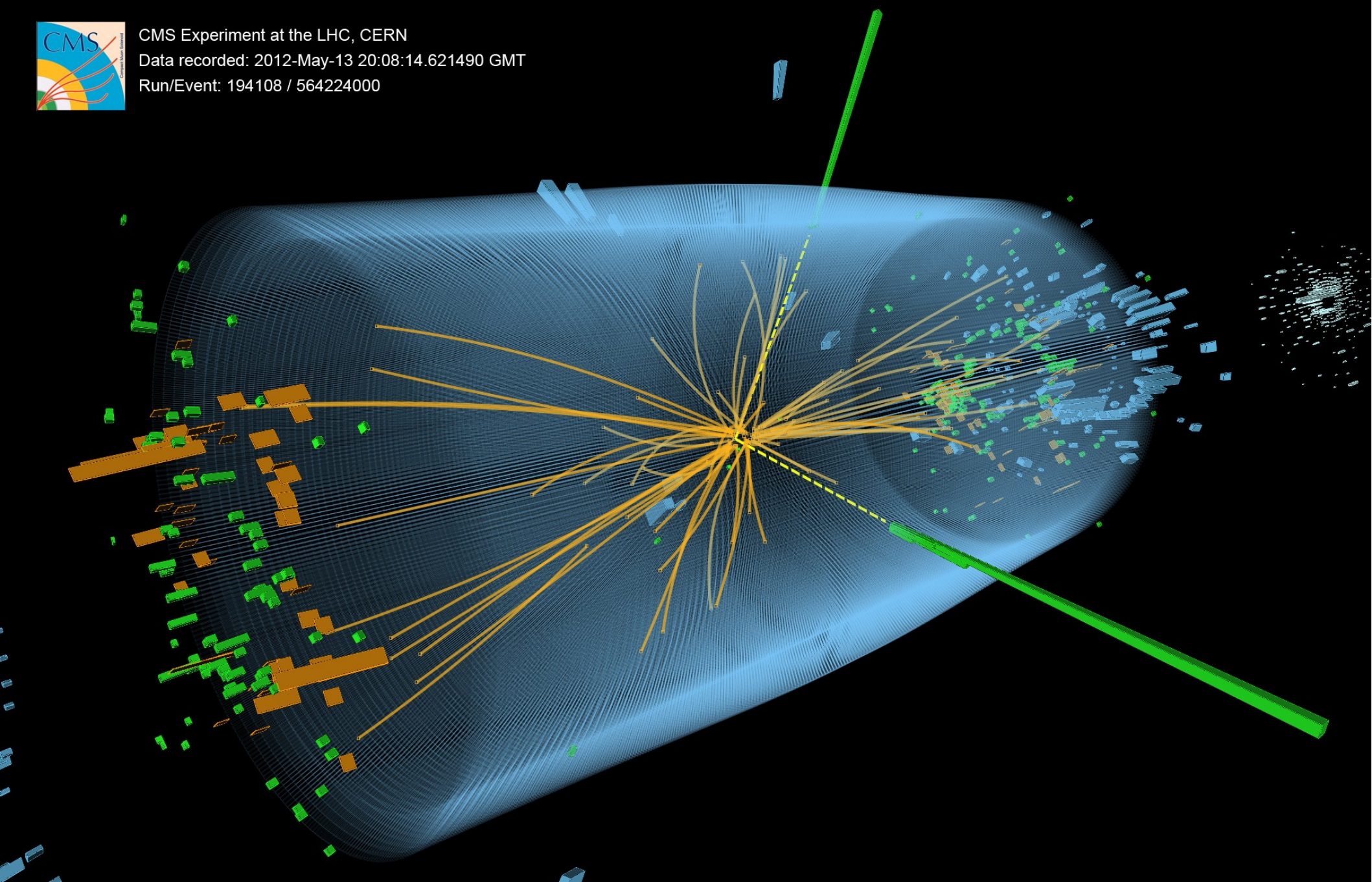
$$H \rightarrow \gamma\gamma$$



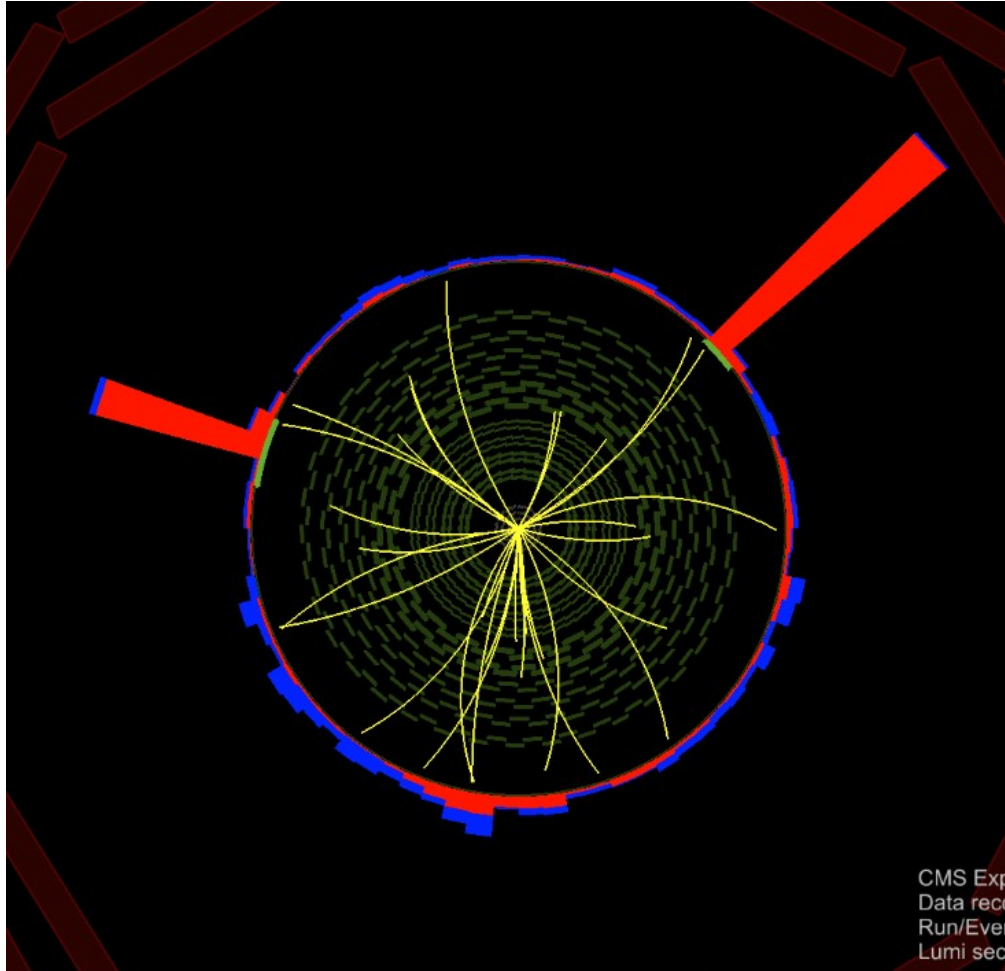
$$H \rightarrow \gamma\gamma$$



CMS Experiment at the LHC, CERN  
Data recorded: 2012-May-13 20:08:14.621490 GMT  
Run/Event: 194108 / 564224000



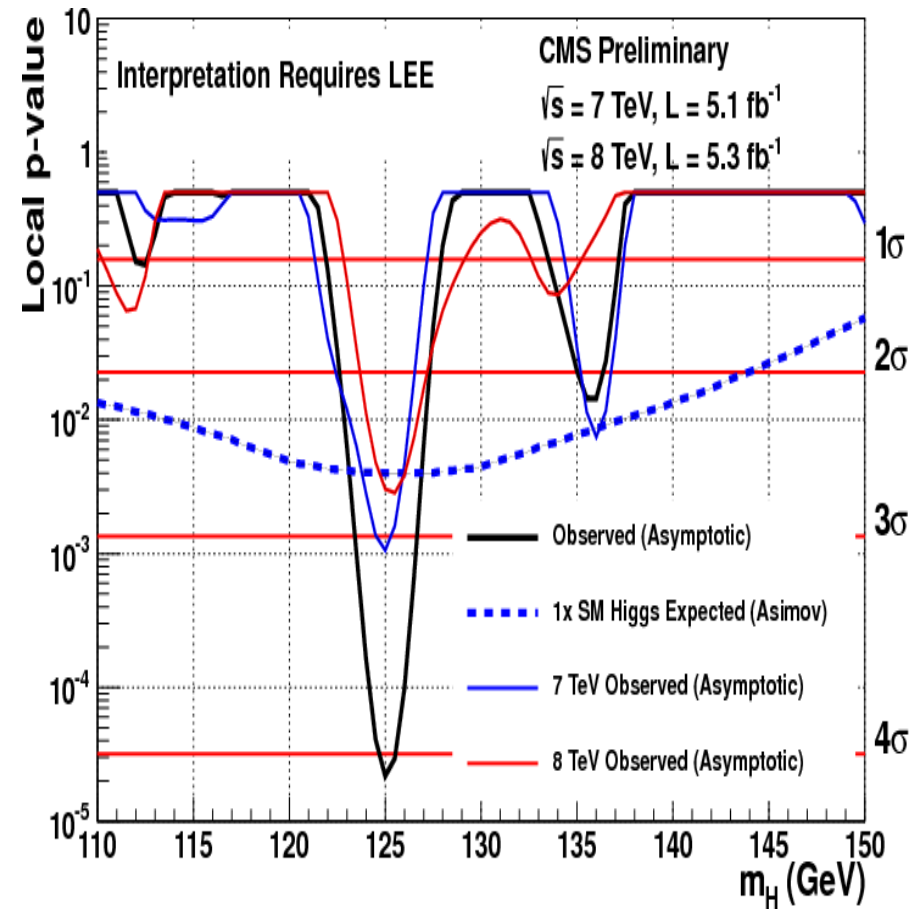
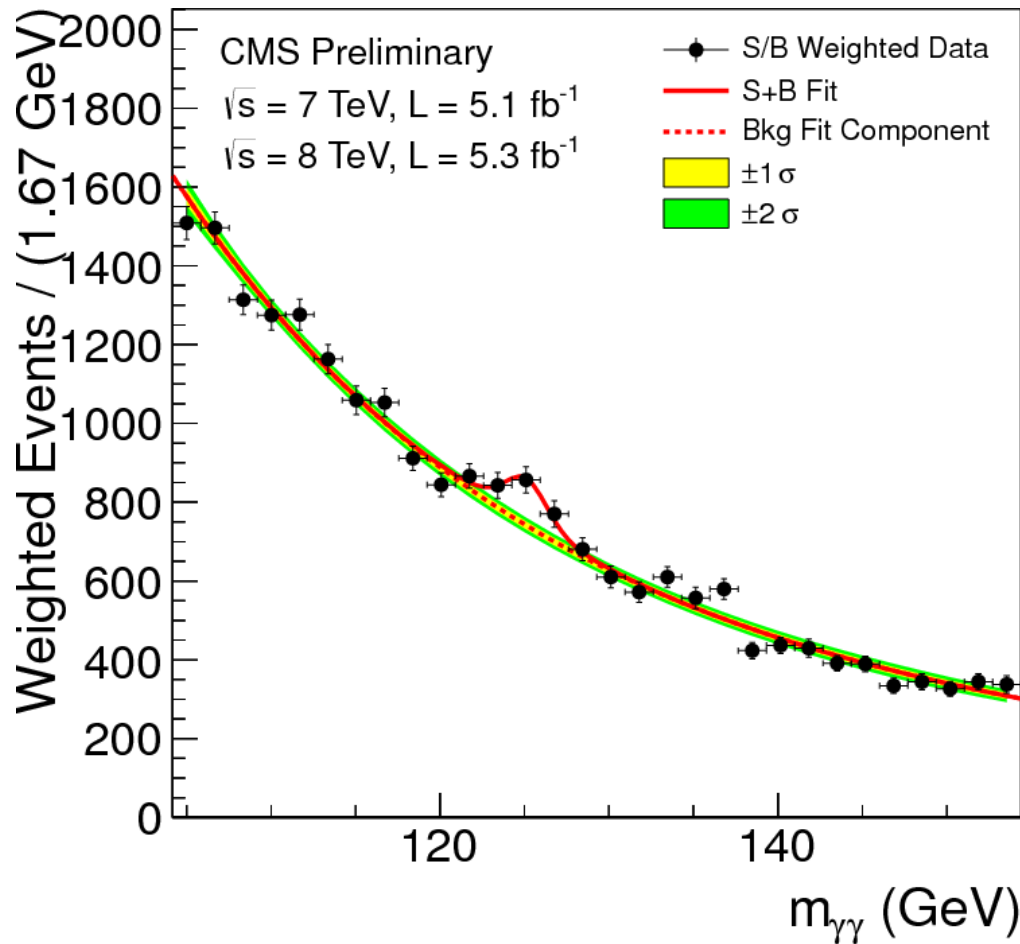
$$H \rightarrow \gamma\gamma$$



- Require two photons with high momenta
- Huge two photon background
- Very good mass resolution – expect a narrow peak
- Important aspects:
  - ECAL calibration
  - Vertex assignment
  - Photon identification

– **No update since ICHEP (analysis on 5/fb@7TeV+5/fb@8TeV)**

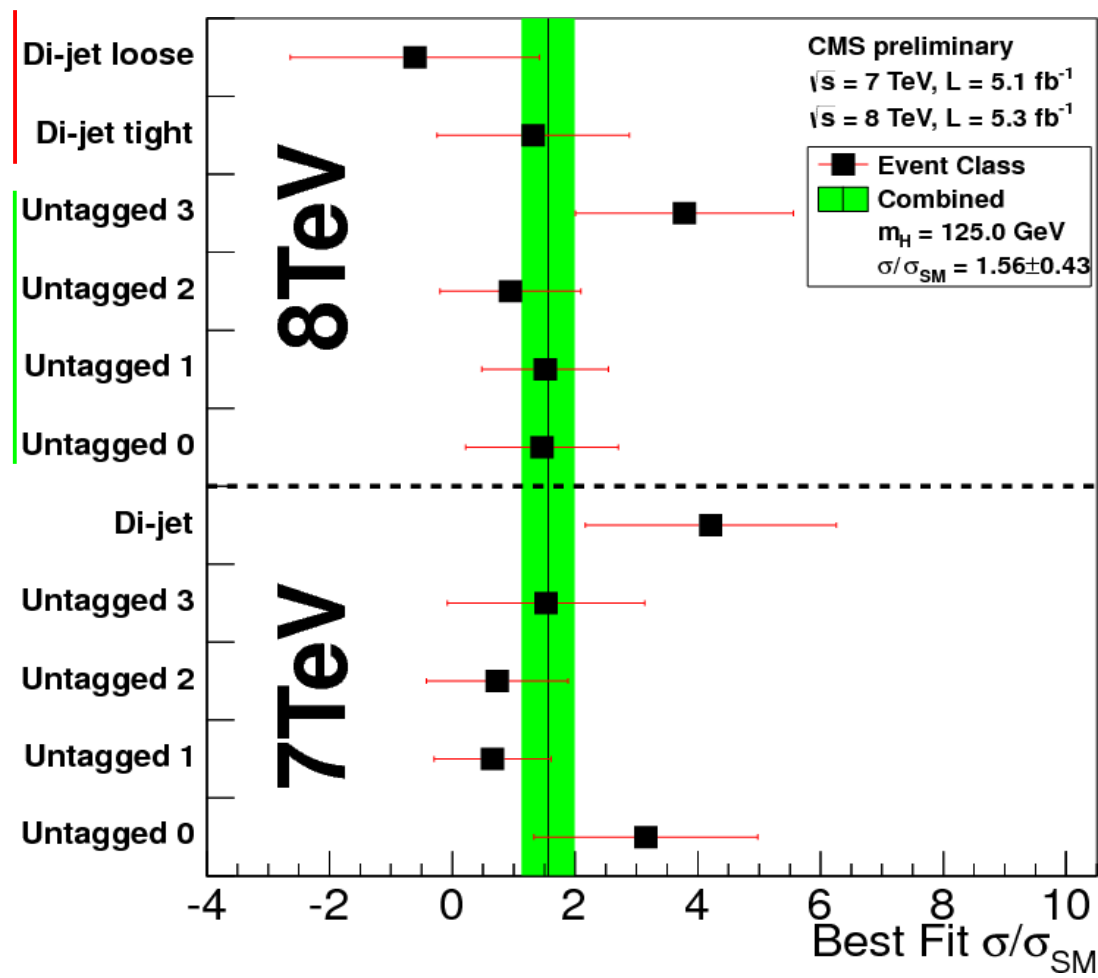
# H $\rightarrow$ $\gamma\gamma$ - results



- Background extracted from sidebands
- Over 4 $\sigma$  excess

# H → γγ - results by category

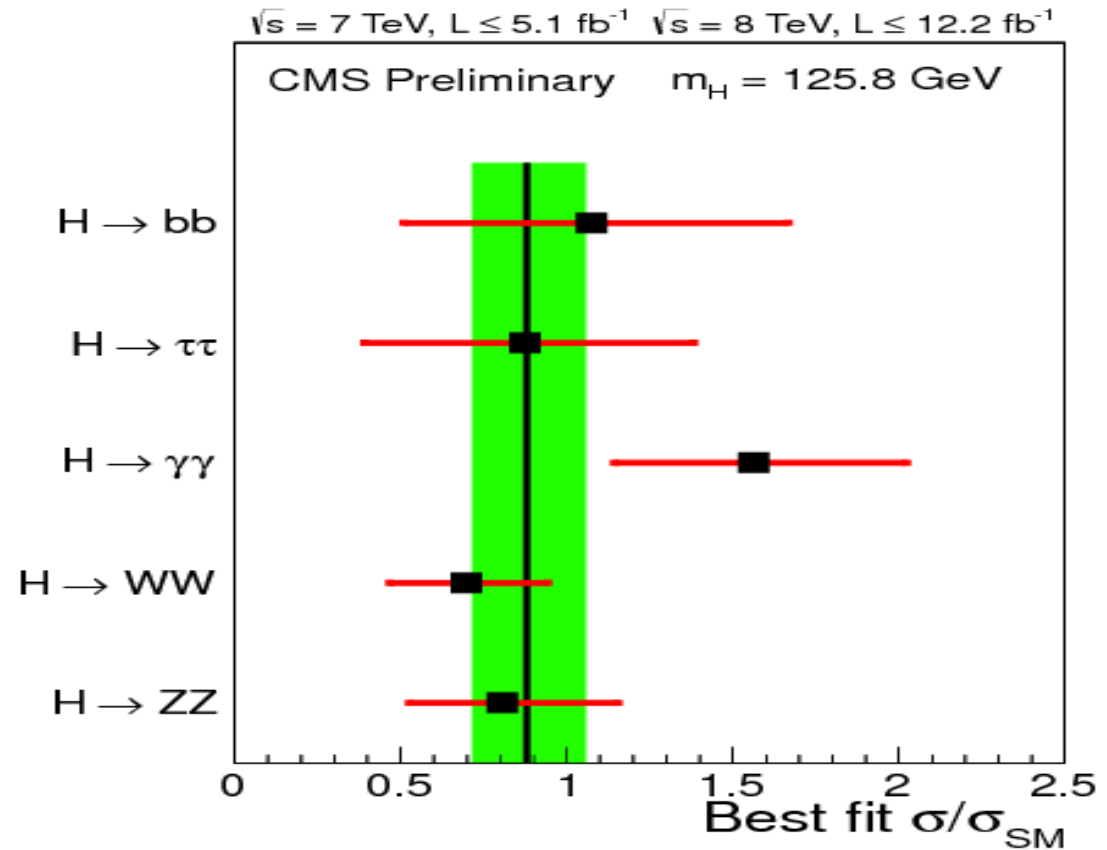
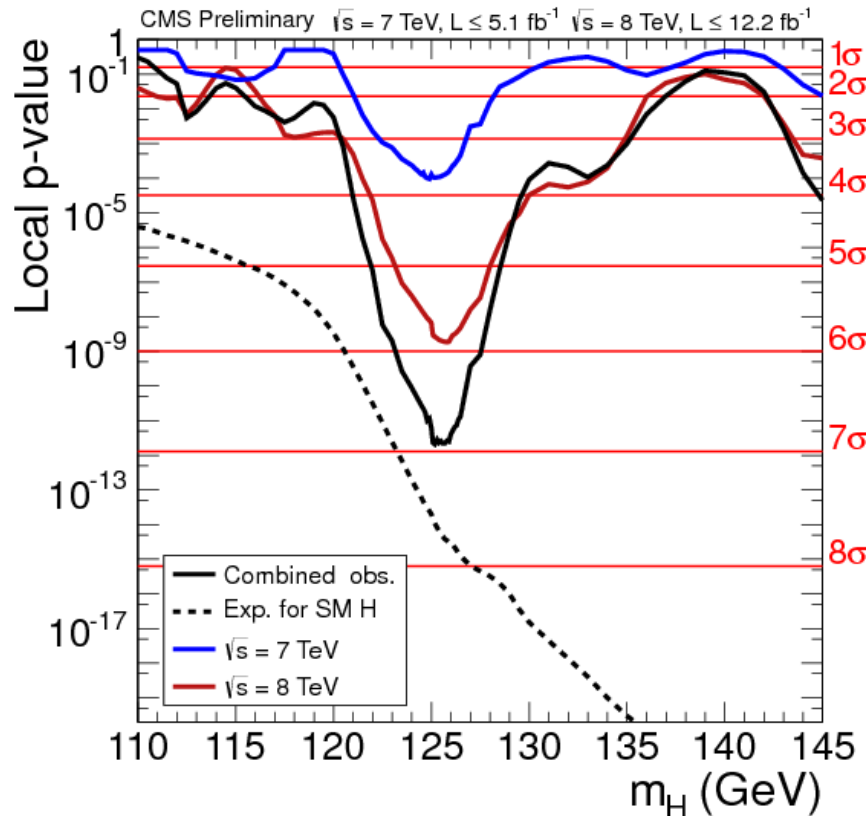
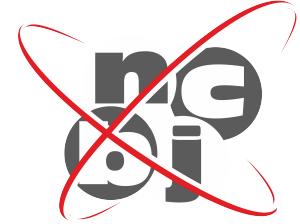
- Two VBF event categories
- Event categories depending on diphoton MVA output built from:
  - Diphoton mass resolution
  - Photon quality
  - Signal like kinematics
- **MVA does not depend on diphoton mass**
- $\sigma_{\text{obs}} / \sigma_{\text{SM}} = 1.56 \pm 0.43$



# Combination

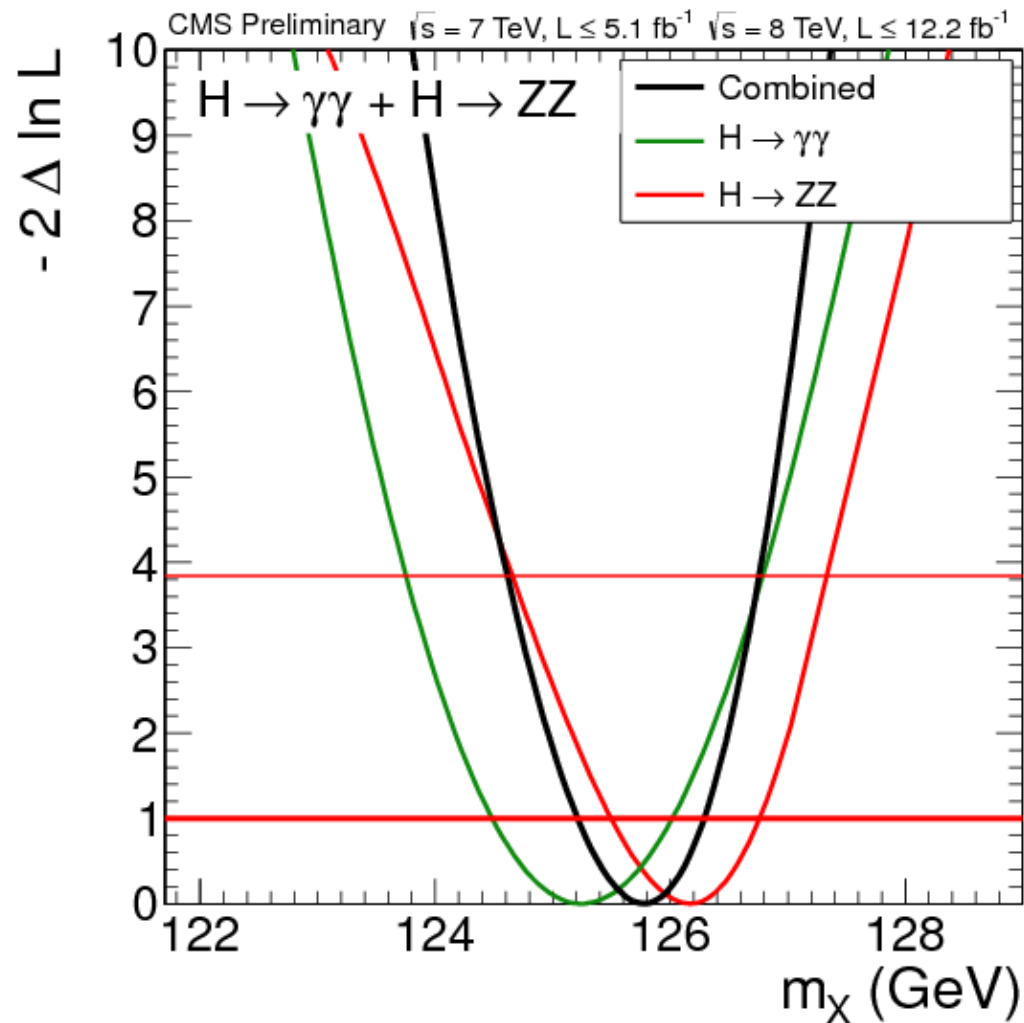
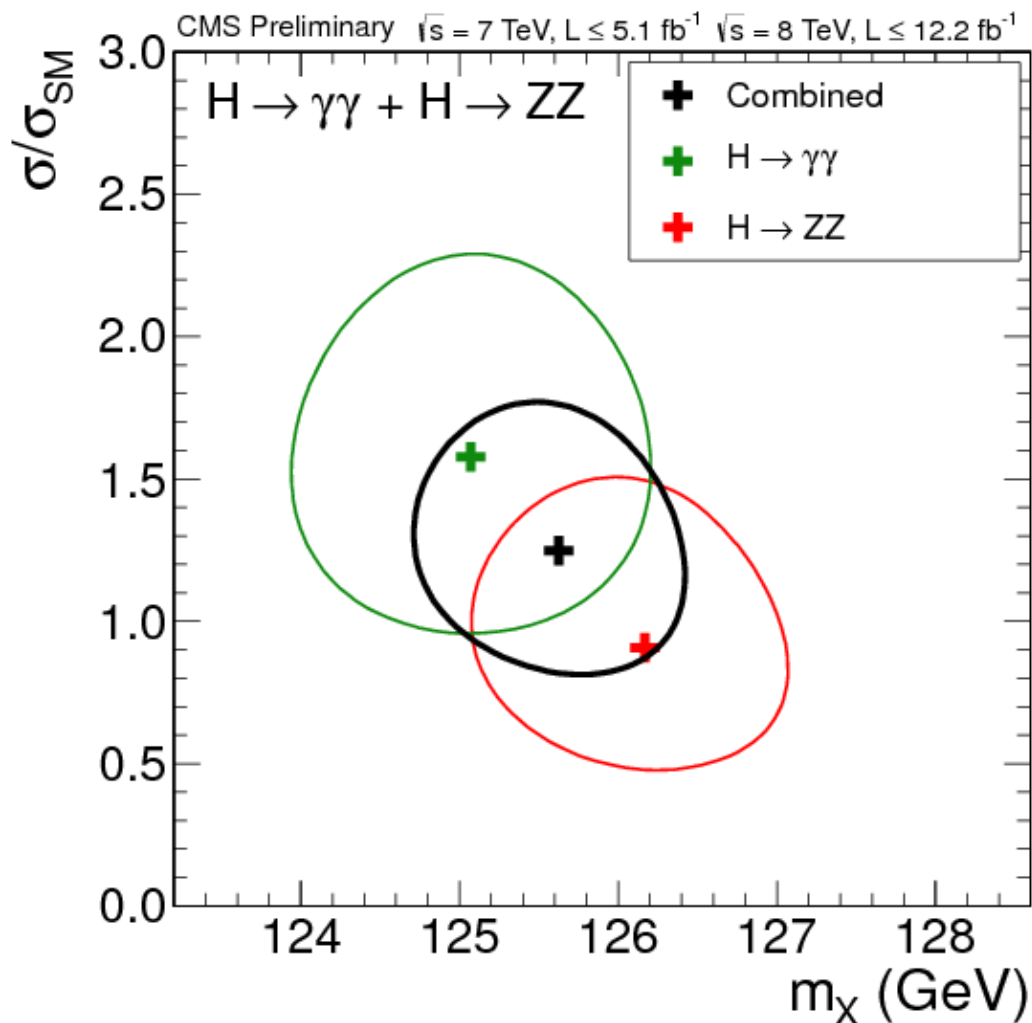


# Higgs searches combination



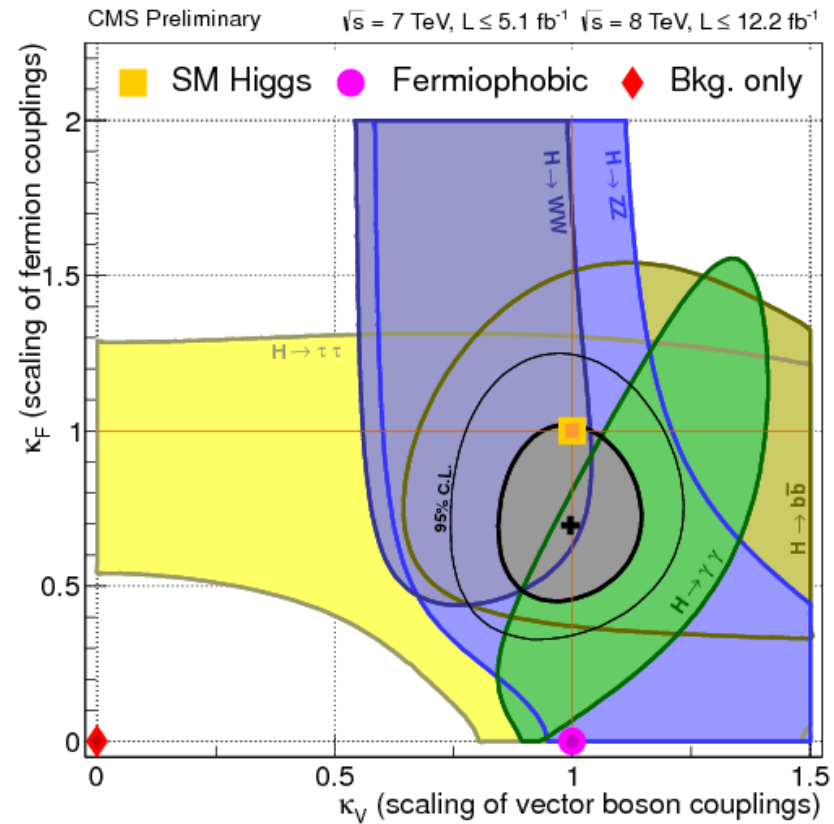
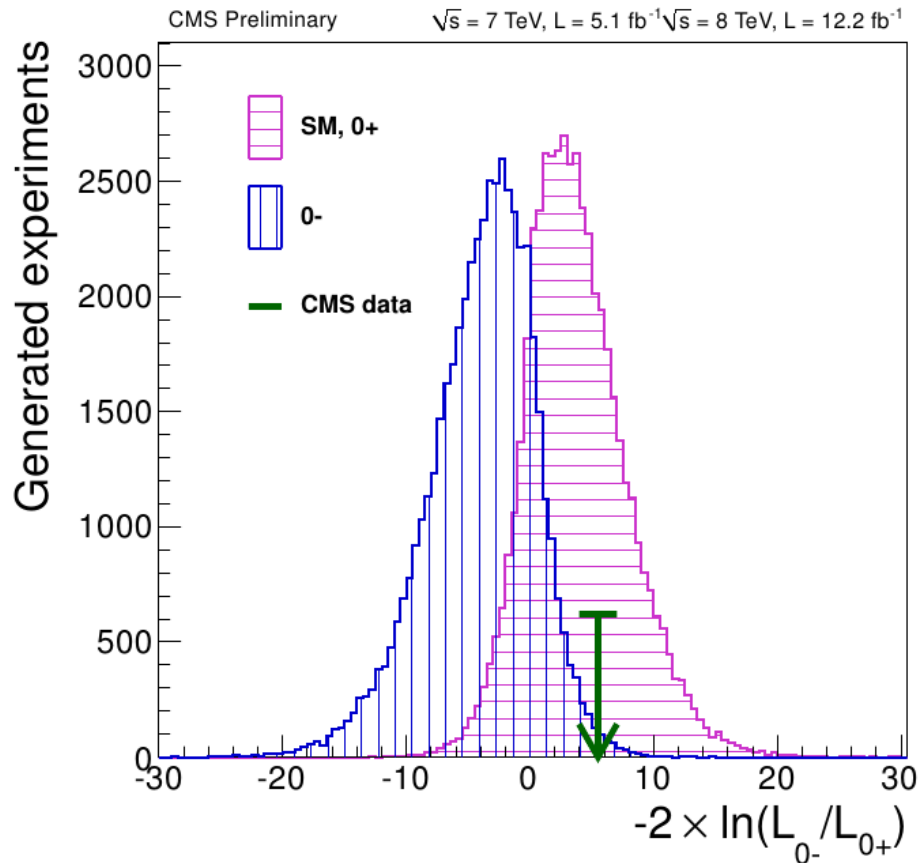
- All presented channels enter the combination
- Since ICHEP no update in  $H \rightarrow \gamma\gamma$
- Signal strength is  $0.88 \pm 0.21$  ( $\sigma_{obs} = 6.9$ ,  $\sigma_{exp} = 7.8$ ), consistent with SM

# Higgs mass



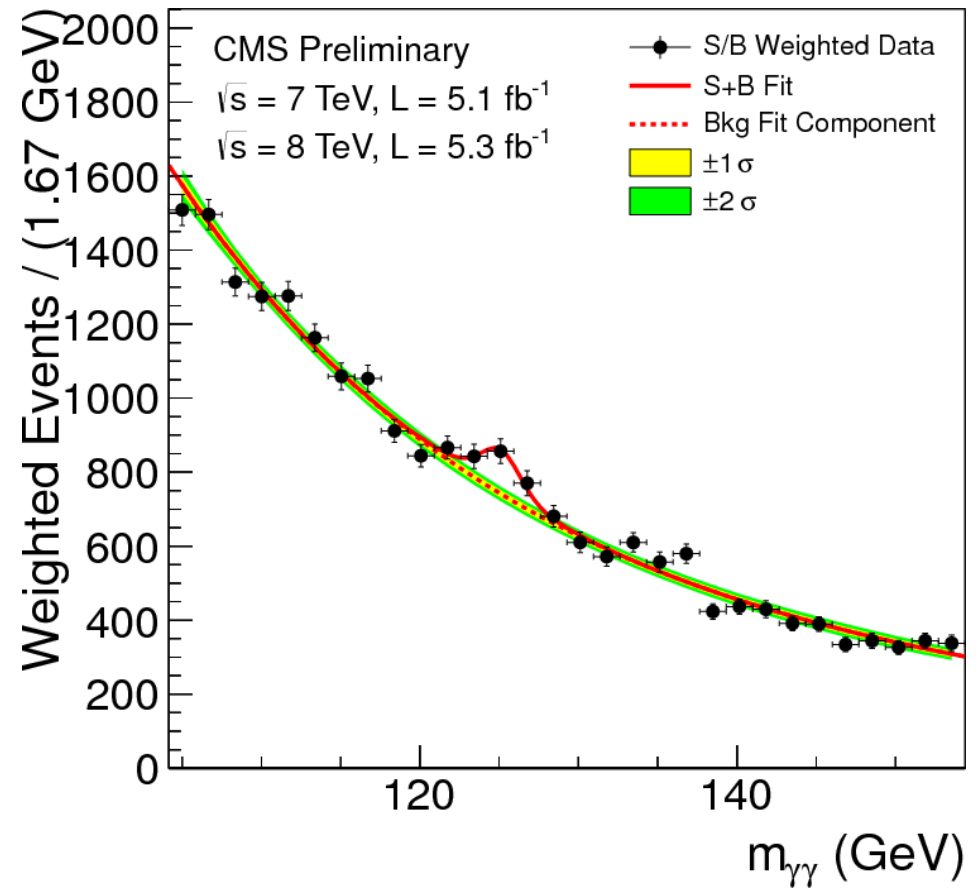
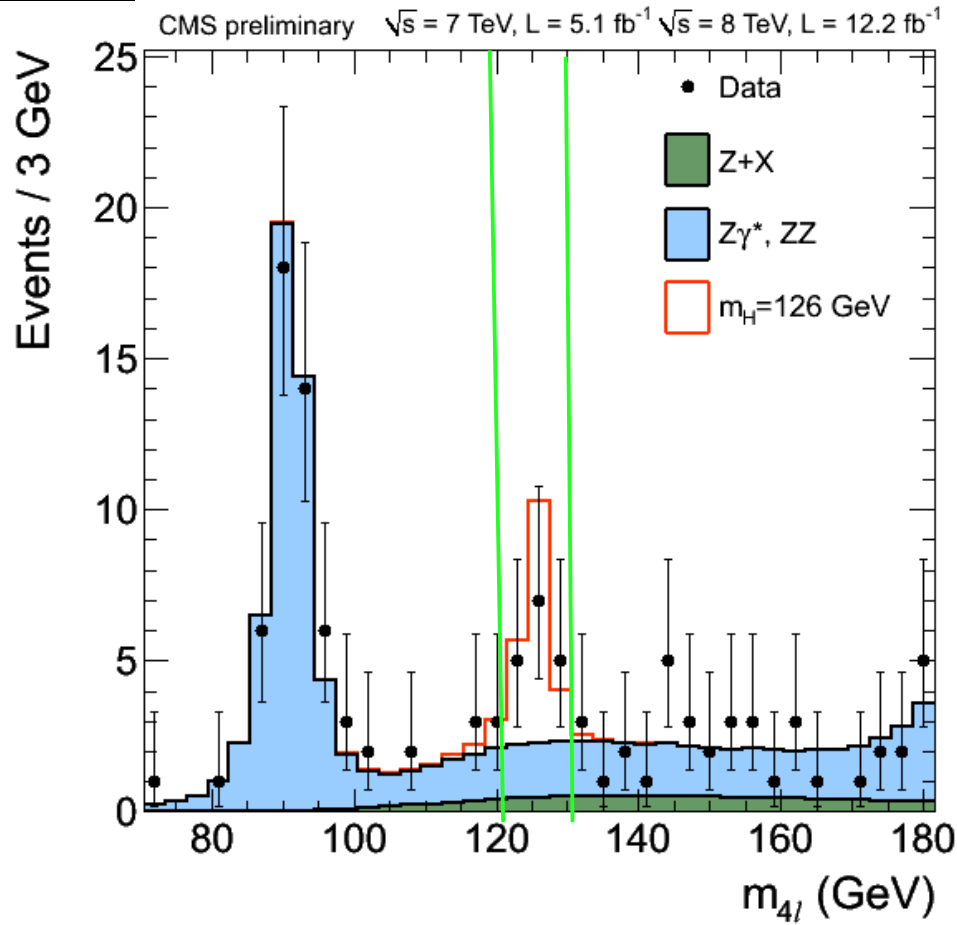
- For mass measurement modes with good resolution used ( $ZZ$  and  $\gamma\gamma$ )
- Both channels give consistent results
- Measured mass is  $125.8 \pm 0.4(\text{stat}) \pm 0.4(\text{sys}) \text{ GeV}$

# Higgs parity and couplings



- Parity measured by exploiting lepton kinematic correlations in ZZ channel
  - pseudo-scalar hypothesis disfavoured at 2.4%  $CL_s$
- Other properties of the new particle tested (here fermion and vector boson couplings shown, consistent with SM Higgs). For more details and other tests see CMS-PAS-HIG-12-045

# Summary



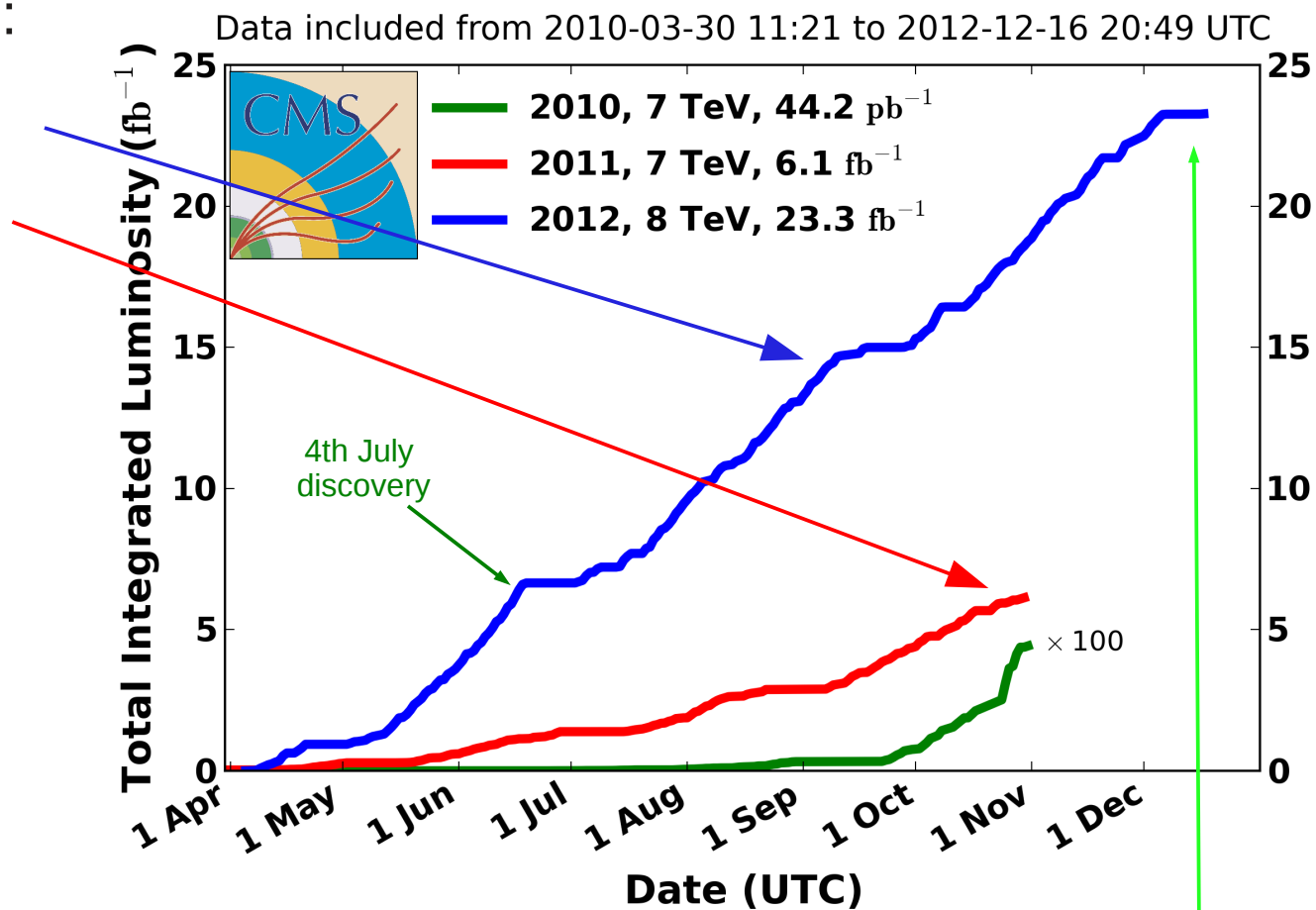
- New particle observed - so far consistent with SM Higgs boson:
  - 6.8  $\sigma$  excess
  - $M = 125.8 \pm 0.4(\text{stat}) \pm 0.4(\text{sys}) \text{ GeV}$

# Summary (2)

- For this presentation:

- ~12/fb @ 8TeV
- ~5/fb @ 7TeV

## CMS Integrated Luminosity, pp



Plenty new results to come!

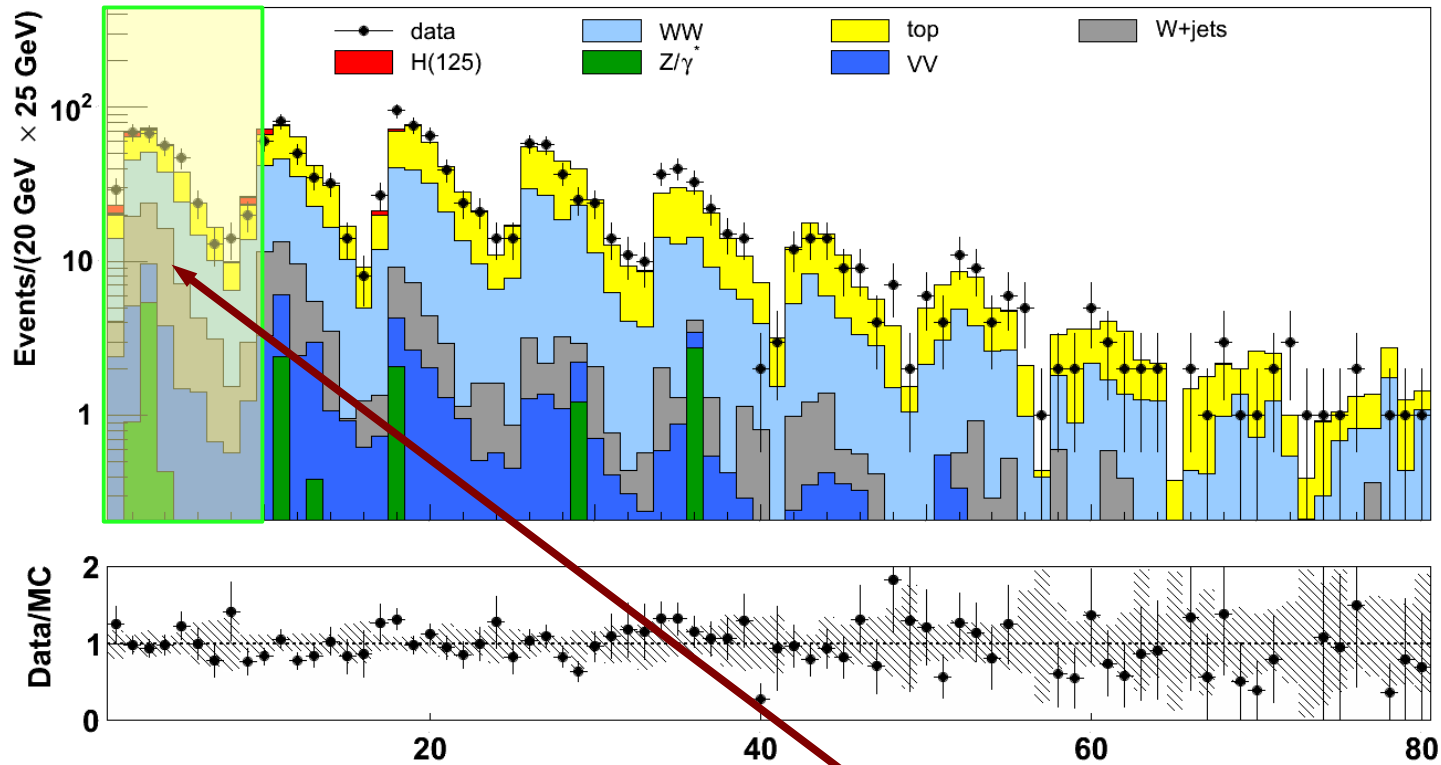


# Backup

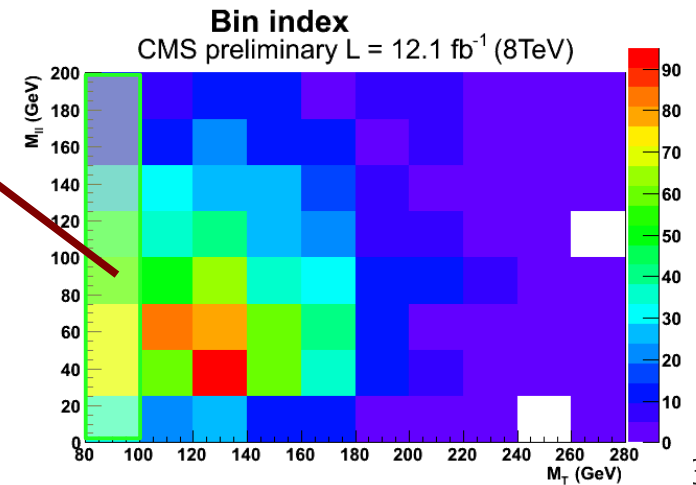
# Higgs $\rightarrow$ WW – 2D analysis

$M_H = 125$  GeV

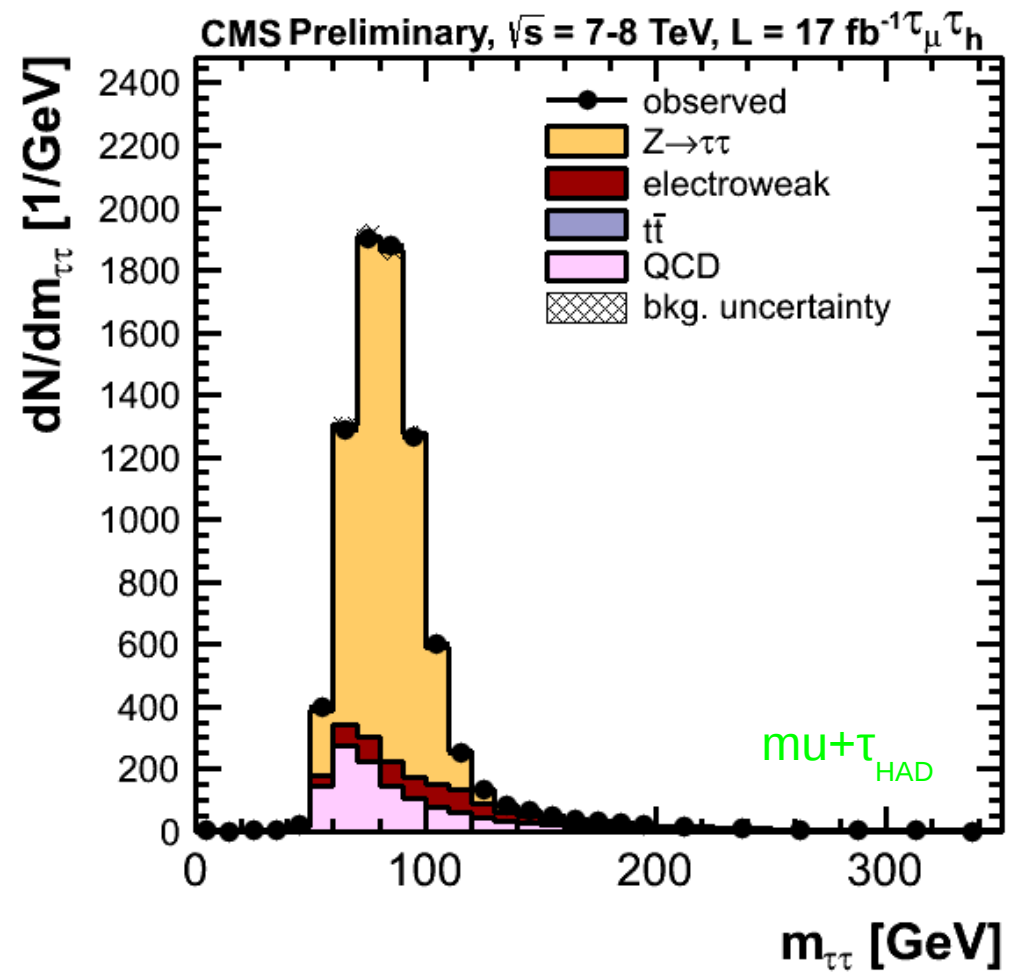
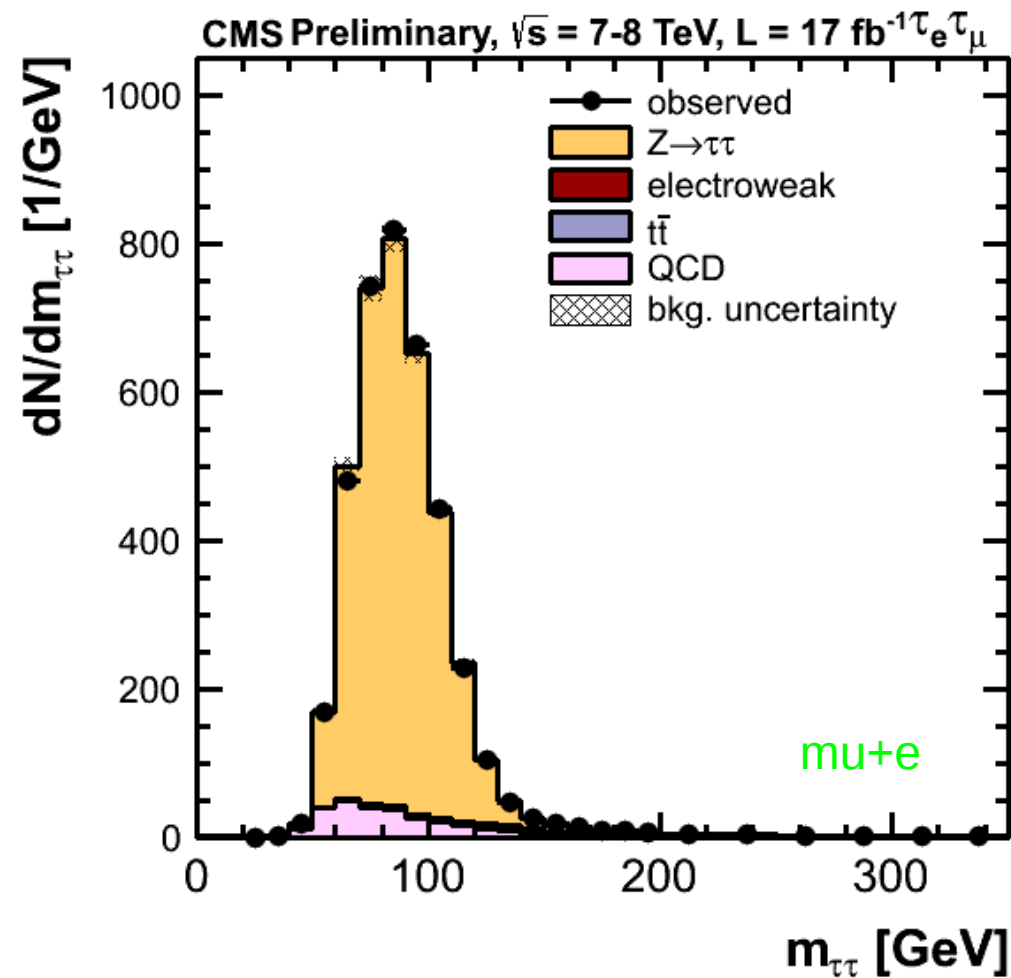
CMS preliminary  $\sqrt{s} = 8\text{TeV}$ ,  $L = 12.1 \text{ fb}^{-1}$



- Unrolling of 2D distribution - column by column comparison



# H → ττ – 0 jets category



- 0 jets category provides constrains on background in other categories
  - Conservative approach - no signal fitted in this category



# H → ττ - VBF category

