Higgs searches at CMS

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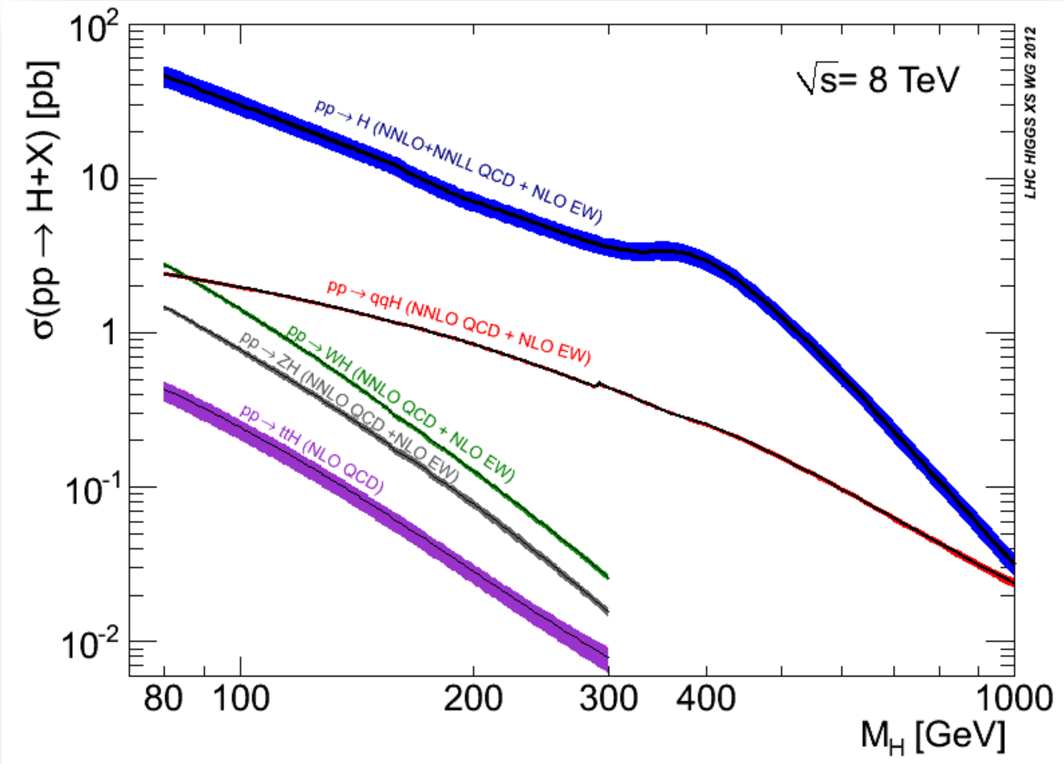
Outline

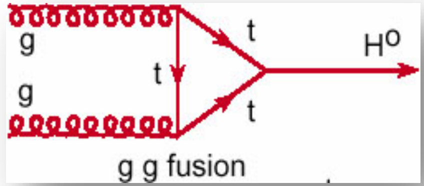
- Presentation of the very last HOT results about the Higgs searches at the Compact Muon Solenoid (CMS)
  - quick scan of the main analyses
  - focus on the results
- A deeper look at the H→ZZ→2l2q analysis
  - the CMS Naples group is involved in this search

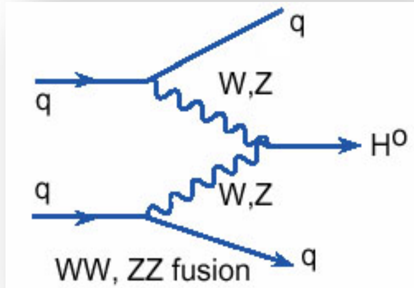
Introduction -

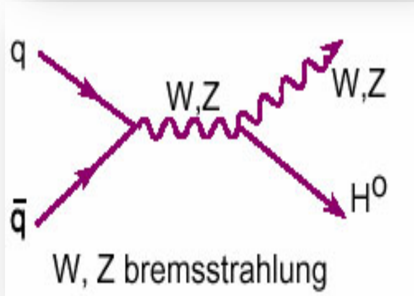
- First results with data collected by the CMS Experiment were presented on the 4th of July
  - It was a great day for all (physicists and not ☺)
  - Results were based on the analysis of and integrated luminosity of
    - ~5 fb^{-1} data collected in 2012, $\sqrt{s}$ = 8 TeV
    - ~5 fb^{-1} data collected in 2011, $\sqrt{s}$ = 7 TeV
  - Combination of results from searches in different channels for 7 and 8 TeV periods

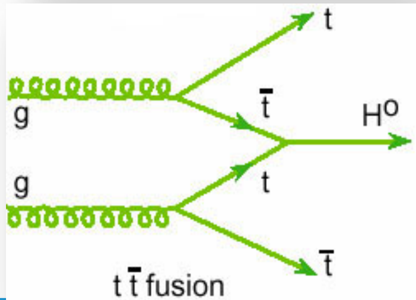
The SM Higgs boson production







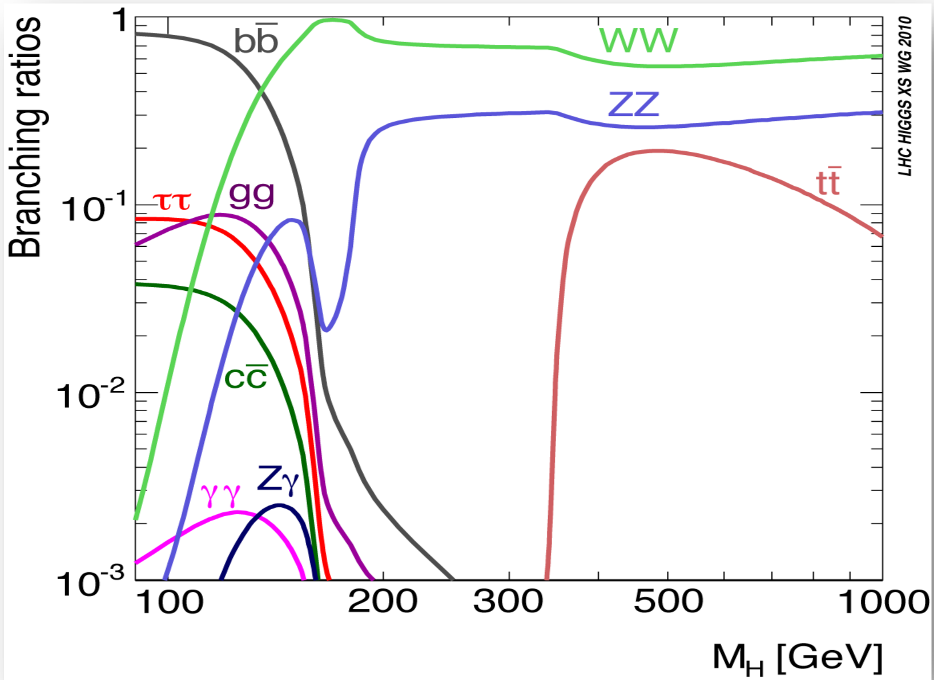




- √s=8 TeV: 25-30% higher σ than √s=7 TeV at low m_H
- All production modes to be exploited
  - gg VBF VH ttH
  - Latter 3 have smaller cross sections but better S/B in many cases

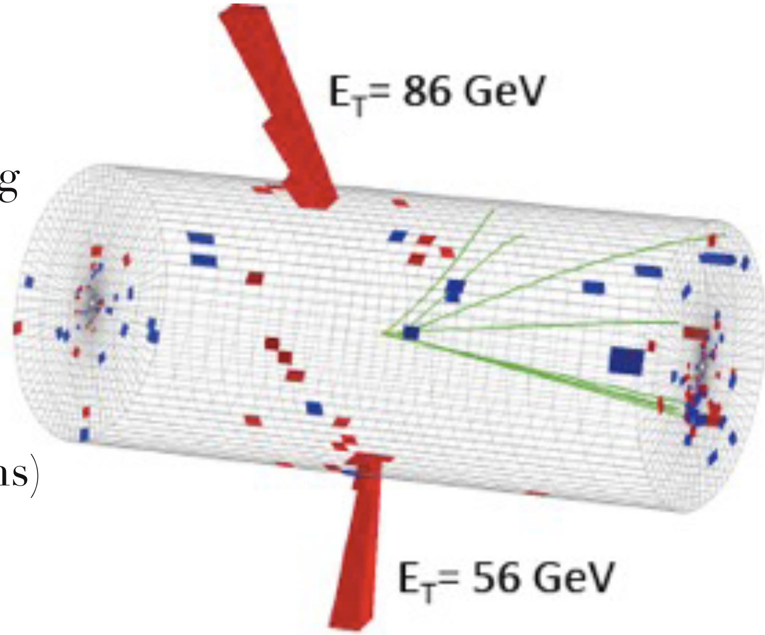
The SM Higgs boson decays

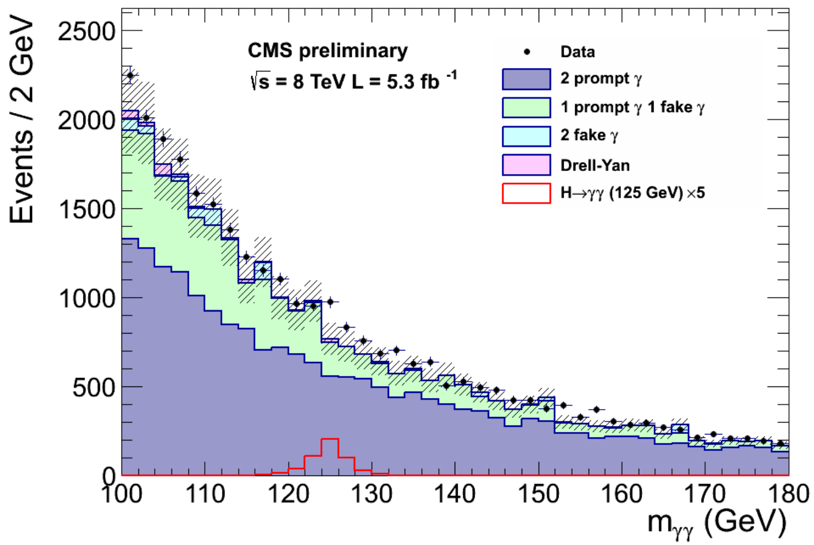
- The main decay modes exploited in CMS are:
    - bb, $\tau\ \tau$, WW, ZZ, $\gamma\ \gamma$
- In the low mass region:
    - bb and ττ has larger BR, but more affected by backgrounds
    - H→ZZ→4l and H→ΥΥ very good resolution
- At high mass:
    - WW higher yields but worse resolution
    - ZZ channels good for discovery at high mass



H→γγ

- **Clear signature:**
  - two isolated, high ET gamma;
  - narrow peak (~1% resolution) in mγγ over decreasing background
  - 2 additional jets for the VBF channel
- **Main backgrounds:**
  - Reducible: fake photons (γ+jet, Drell-Yan to electrons)
  - Irreducible: γγ QCD production



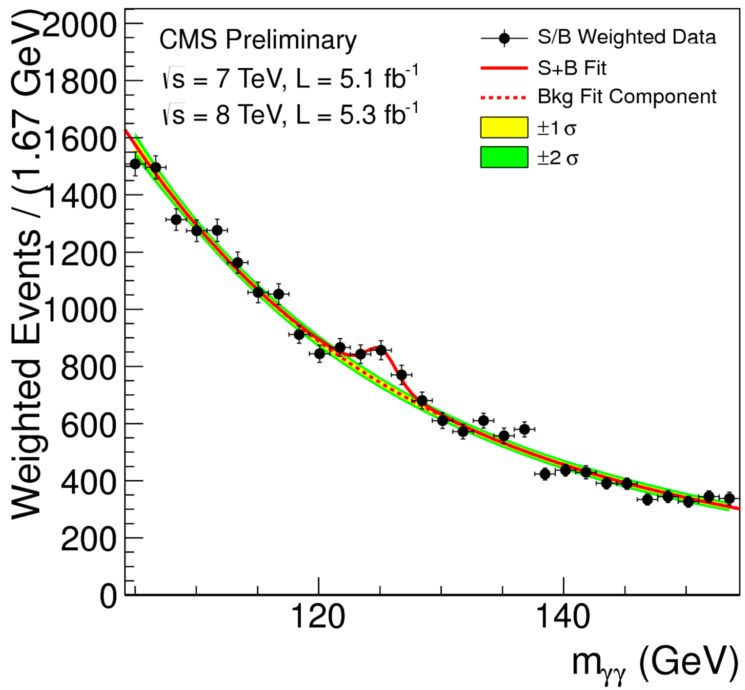


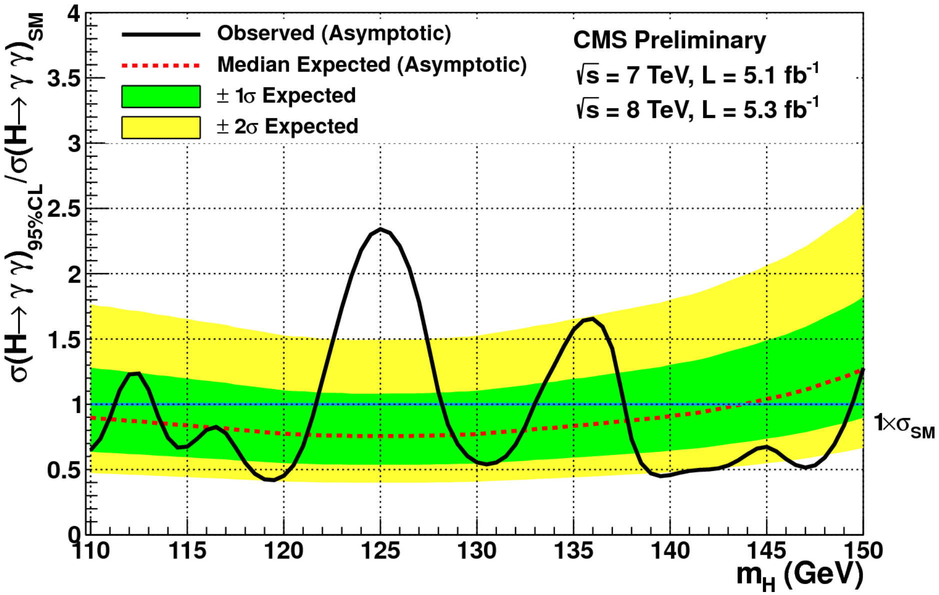
Main analysis is a Multi-Variate-Analysis (MVA)

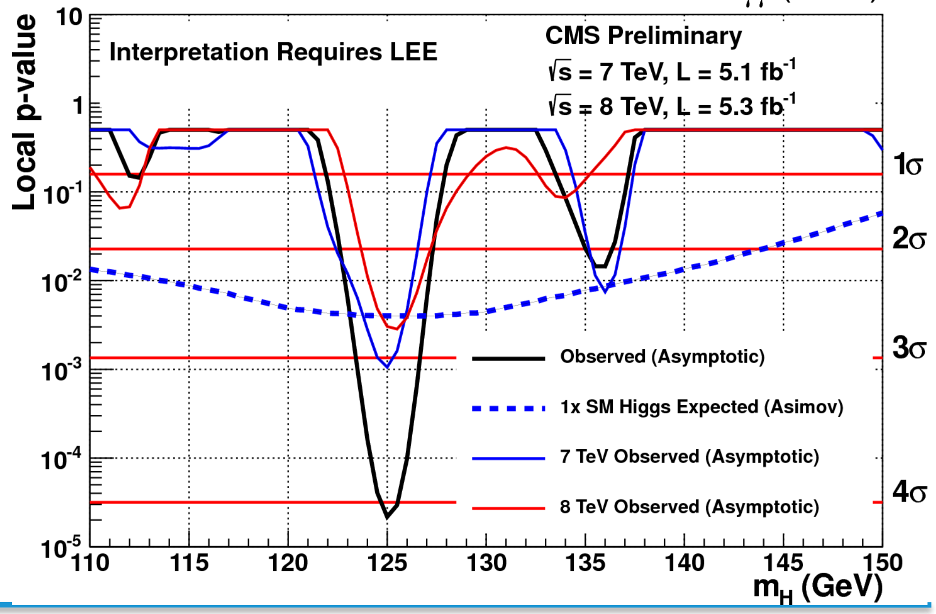
- MVAs for photon ID and event classification
- Fit mass distribution in 4 event classes based on a diphoton MVA output + 2 di-jet categories

H→γγ

- Expected 95% CL exclusion 0.76 times SM at 125 GeV
- Largest excess at 125 GeV
- Minimum local p-value at **125 GeV** with a local significance of **4.1σ**
- Similar excess in 2011 and 2012

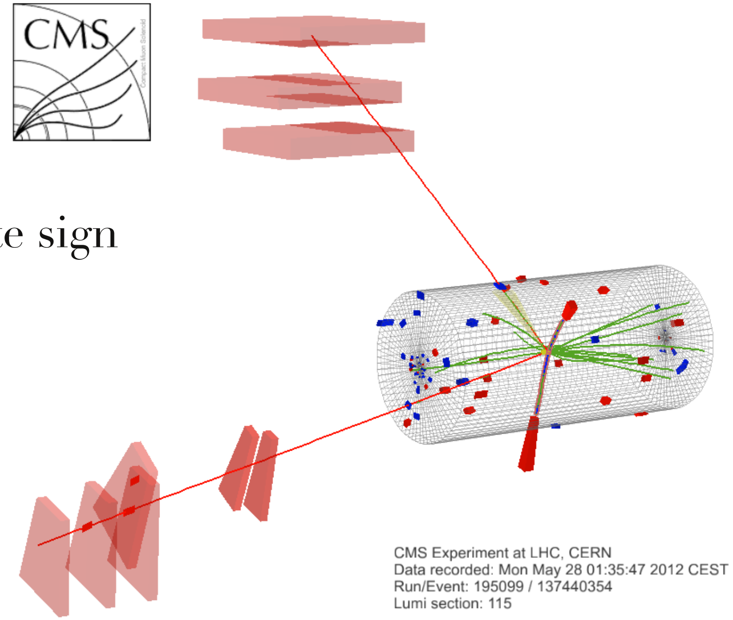


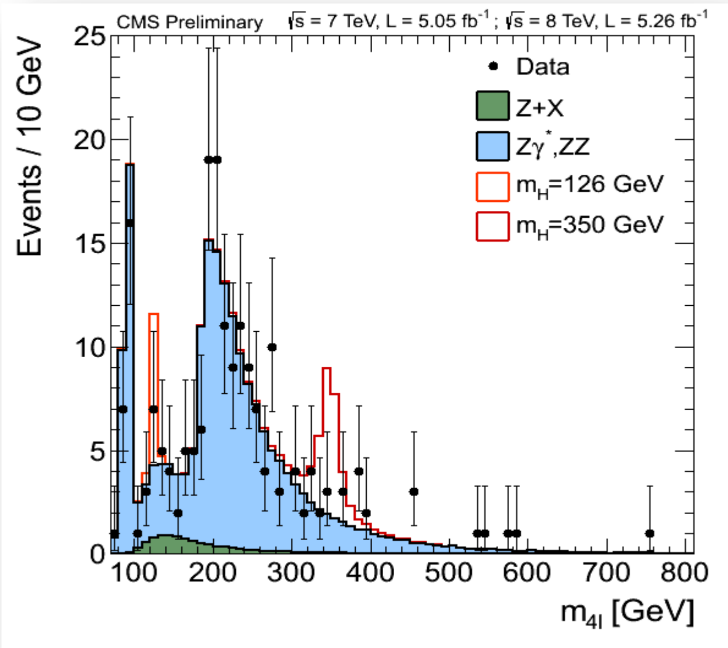




H→ZZ→4l

- **Clear signature:**
  - 2 pairs of isolated, hoght pT leptons of opposite sign
  - one Z boson can be off-mass shell
  - narrow peak, low background
- **Main backgrounds:**
  - Reducible: Z+jets, ttbar, WZ
  - Irreducible: $ZZ^{(*)}$



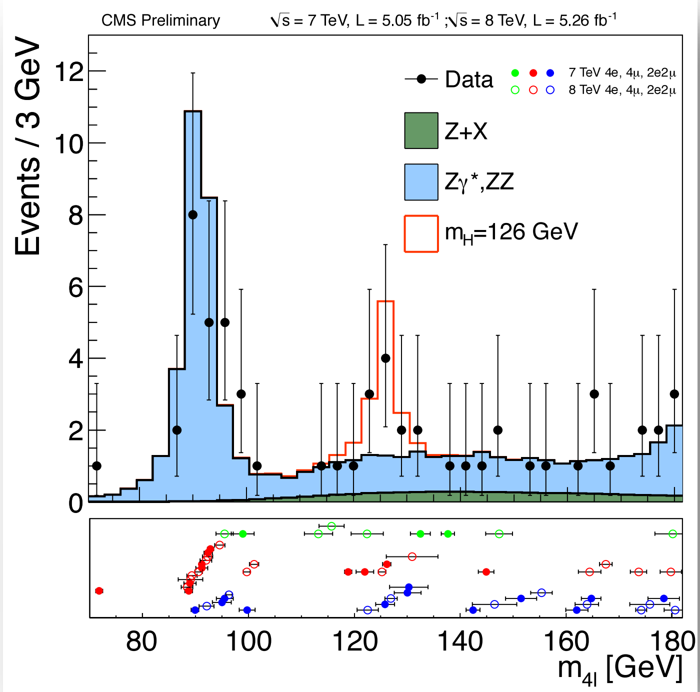


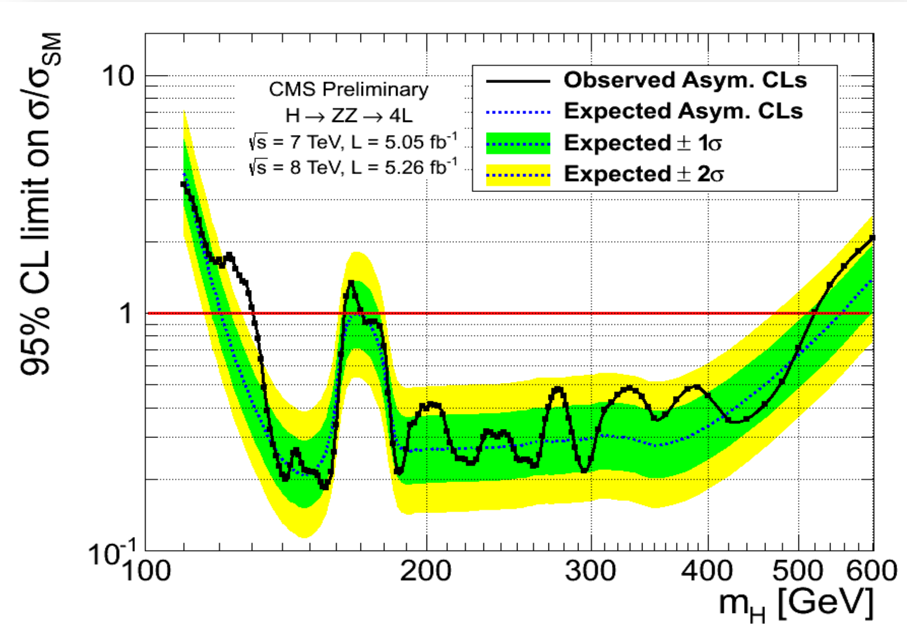
Analysis strategy:

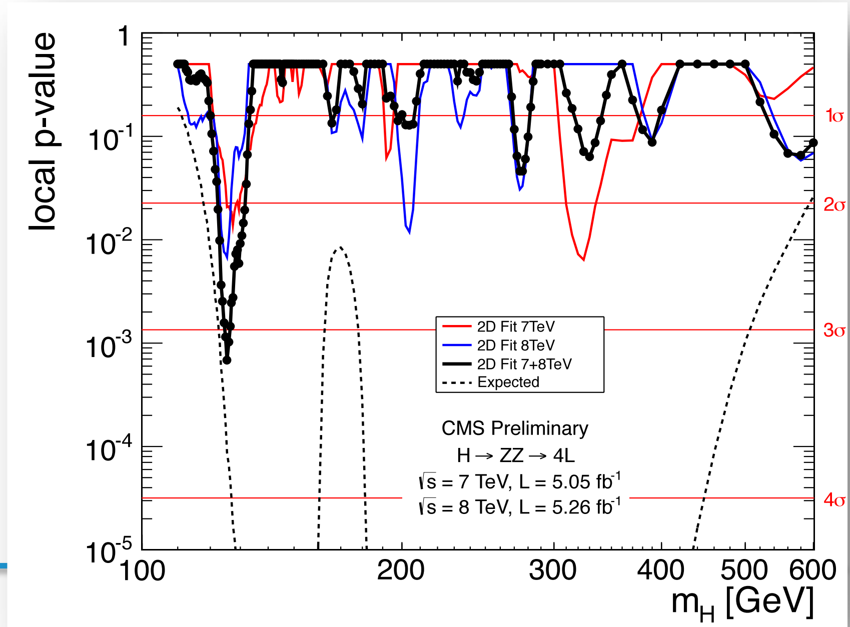
- 2D analysis performed on m_{4l} and the output of a kinematic discriminator build on angular variabl distributions.

H→ZZ→4l

- Expected 95% CL exclusion in the range 121-550 GeV
- Excess at 125.5 GeV
- Minimum local p-value at **125.5 GeV** with a local significance of **3.2σ**
- Similar excess in 2011 and 2012

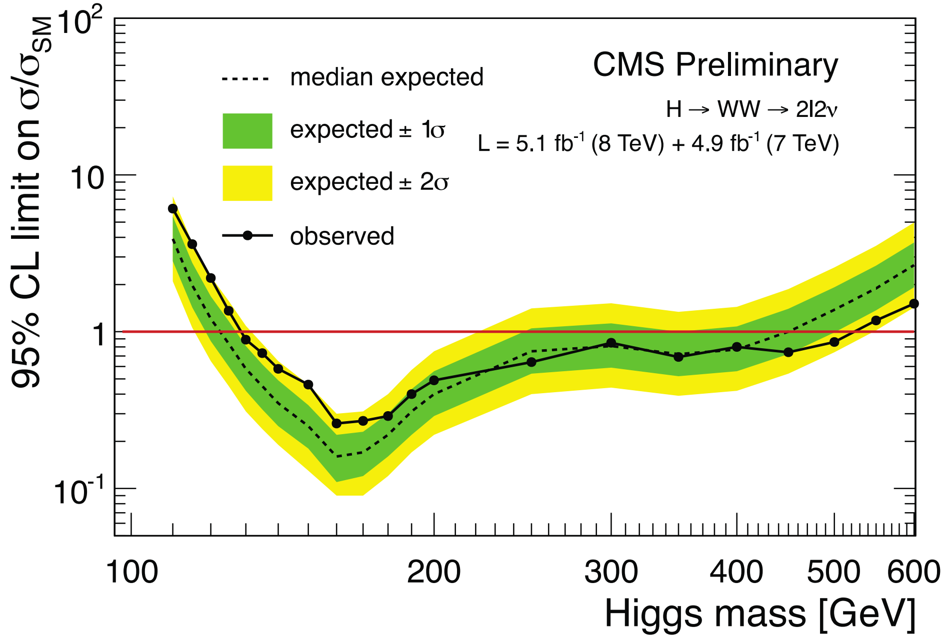






H→WW→2l2ν

- **Clear signature:**
  - 2 hight p_T leptons and large missing E_T
- **Main backgrounds:**
  - WW, ttbar. Others: W+jets, dibosons

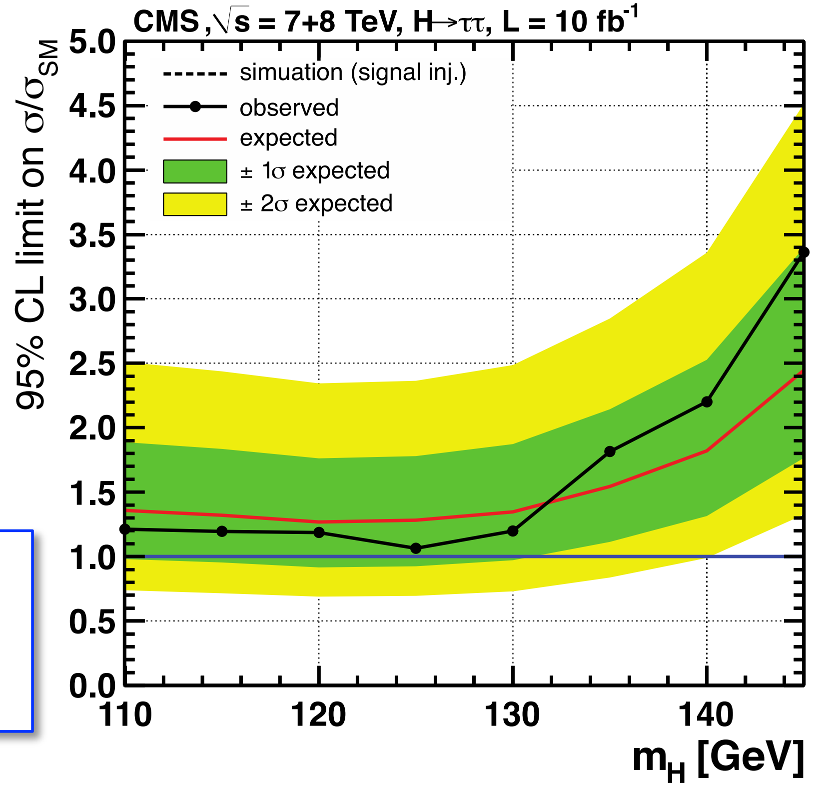


Analysis strategy:
- Data-driven background estimation
- Split in categories, 0/1jet + VBF, and final state lepton flavors
- Cut based approach for the first 2012 result
- MVA analysis for 2011 data analysis

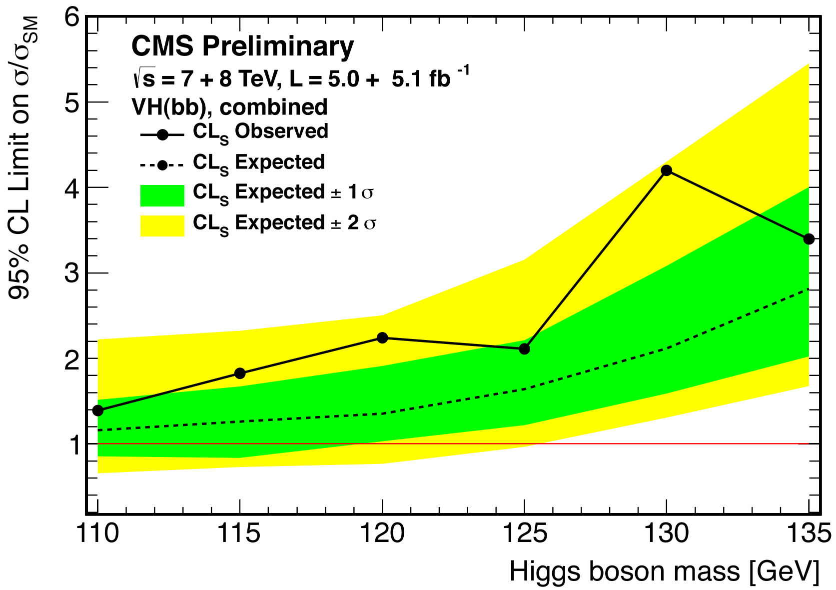
Combined limits from 2011 and 2012
- 7 TeV result using a multivariate discriminant and updated with the final luminosity measurement
- 8 TeV cut-based analysis, shape in preparation

H→ττ && H→bb

- High σBR at low mass
- Sensitive to all production modes
- Probe couplings to leptons
- Challenging large background



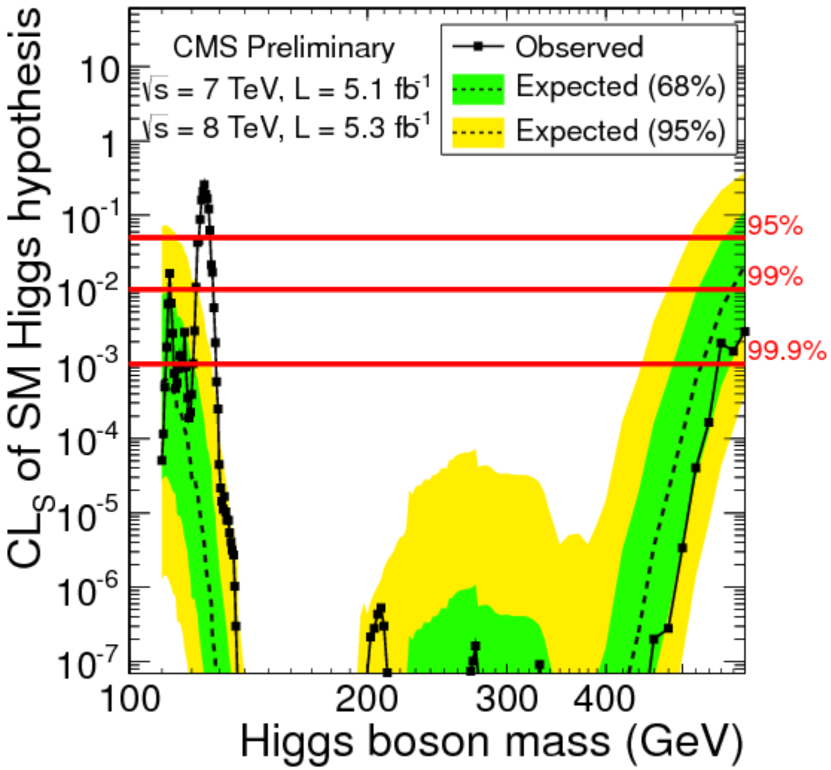
Analysis strategy:
- Analysis divided into 5 categories (# of jets + p_T)
- All categories are fit simultaneously

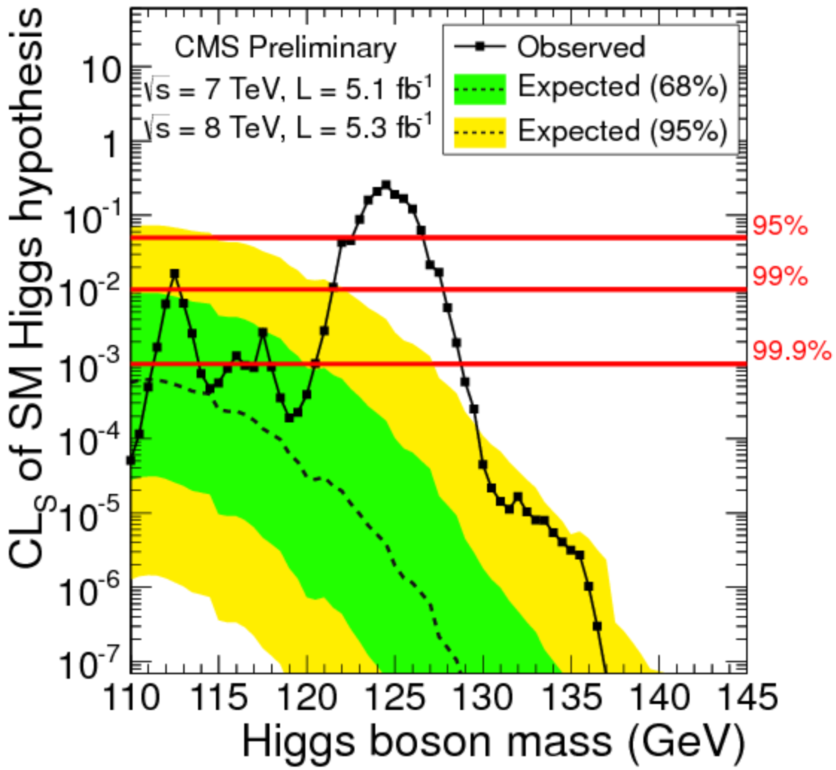


- Largest BR for mH <130 GeV
- Test specific production & decay couplings
- Large backgrounds

Analysis strategy:
- Fit the shape of the MVA output distribution

Combination of results





Observed exclusion 110 – 122.5 and 127 – 600 GeV at 95% CL

110 – 112 .. 113 – 121.5 and 128 – 600 GeV at 99% CL

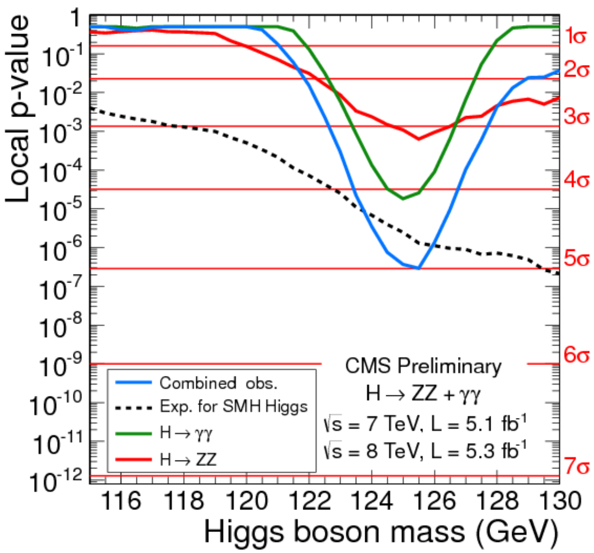
Expected in absence of SM Higgs boson: 110 – 600 GeV at 95% CL

110 – 580 GeV at 99% CL

110 – 520 GeV at 99.9% CL

Combination of results - pvalue

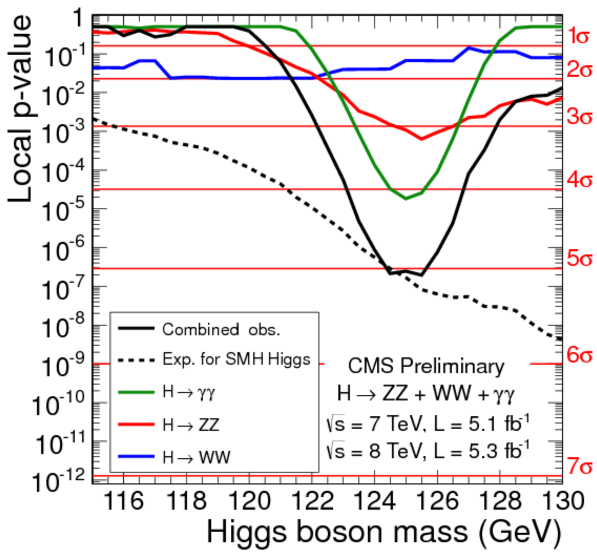
The pvalue is the probability that background fluctuates to give an excess as large as the (average) signal size expected for a SM Higgs.



γγ+4l

combined significance:

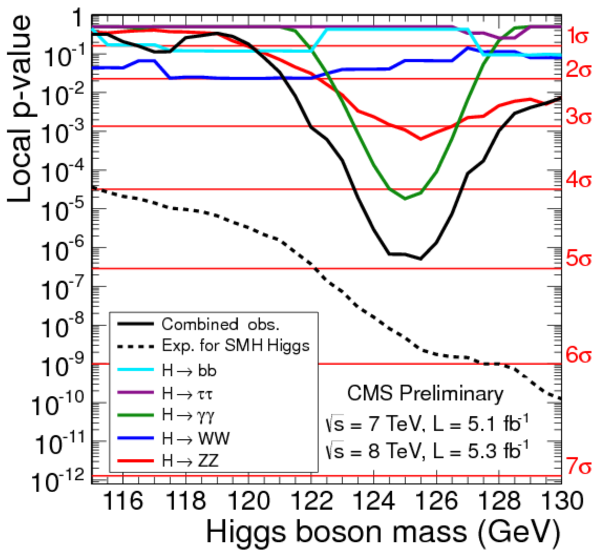
5.0 σ



γγ+4l +WW

combined significance:

5.1 σ



γγ+4l+WW+bb+ττ

combined significance:

4.9 σ

Conclusion – Part I

This is the first observation of a new boson with a mass of

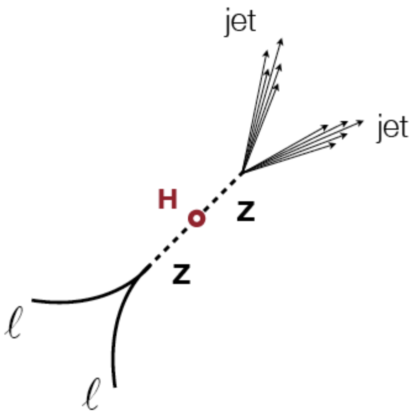
125.3 ± 0.6 GeV

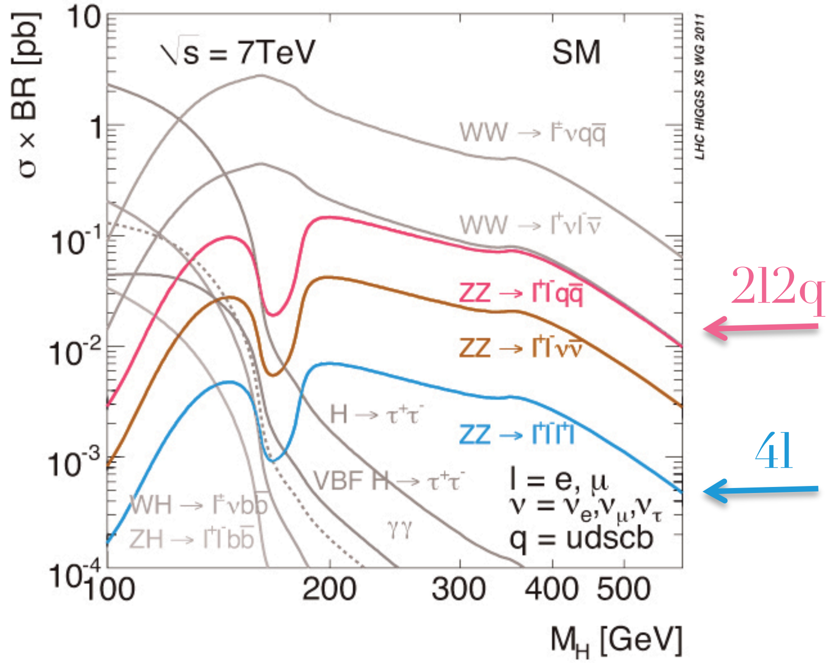
At 4.9 σ significance

Now…we need to investigate more to understand if it is really the Higgs boson we are looking for ☺

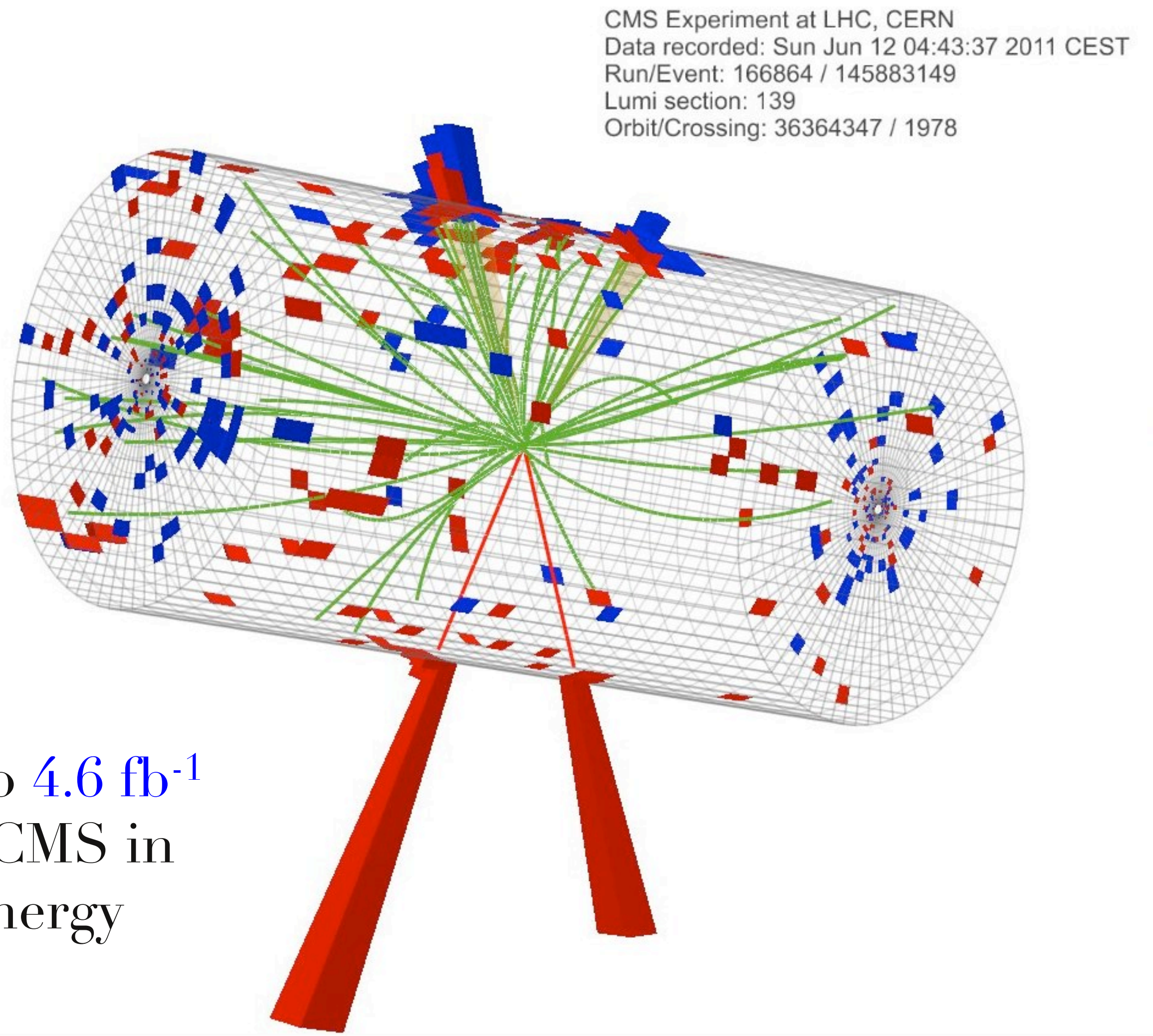
H→ZZ→2l2q analysis

- Main features:
  - Large signal yield (BR ~20 times the “golden channel” BR, H→ZZ→4l BR)
  - Large background (mainly Z+Jets, TTbar and diboson events
  - Worse resolution (due to jets)
  - Fully reconstructed final state:
    - 2 isolated leptons and 2 jets
    - lepton and jet pairs peaking at Z mass
- Analysis more sensitive at high mass





H→ZZ→2l2q



The results presented refer to 4.6 fb^{-1} of collision data recorded at CMS in 2011 with a centre-of-mass energy $\sqrt{s}=7TeV$

Fighting backgrounds: Low mass

Analysis strategy – 2011:

- Reconstruction of Higgs candidates starting from **2 leptons and 2 jets**:
  - 2 leptons **isolated** from other activities in the calorimeters and in the tracker
  - high quality leptons and with high transverse momentum, p_T:
    - $p_T^{(1)}>40$ **GeV** and $p_T^{(2)}>20$ **GeV**
  - 2 jets with $p_T > 30$ **GeV**
    - Resolution improved using a kinematic fit
  - Constraint on dilepton and dijet mass:
    - $70 < m_{ll} < 110$ **GeV** and $75 < m_{jj} < 115$ **GeV**
- in Z+jets events, jets come from quarks and gluons (signal jets come only from q)
  - quarks and gluons hadronize differently:
    - build a **quark-gluon discriminator**
- Classify events in 3 categories according to the number of b-jets
- Powerful signal-background discrimination provided by different distribution of Higgs production and **decay angular variables**

Btag categories

Events are classified in 3 exclusive categories according to the number of b-jets identified in the final state

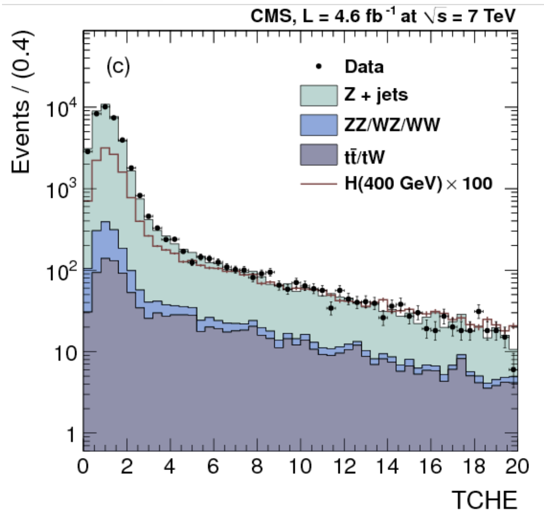
H→ZZ→2l2q

0 b-tags:
- no jet b-tagged
- Highest signal yield
- Large background

1 b-tags:
- one jet b-tagged
- Worst category
- Large background

2 b-tags:
- two jet b-tagged
- Purest category
- Lowest signal yield

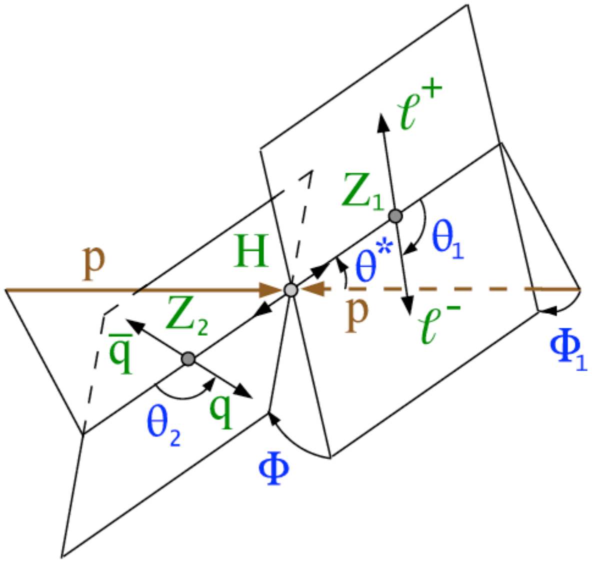
B-jets are identified using an algorithm called **Track Counting High Efficiency, TCHE**. It exploits the long lifetime of B hadrons and is based on the computation of the impact parameters significance of good tracks

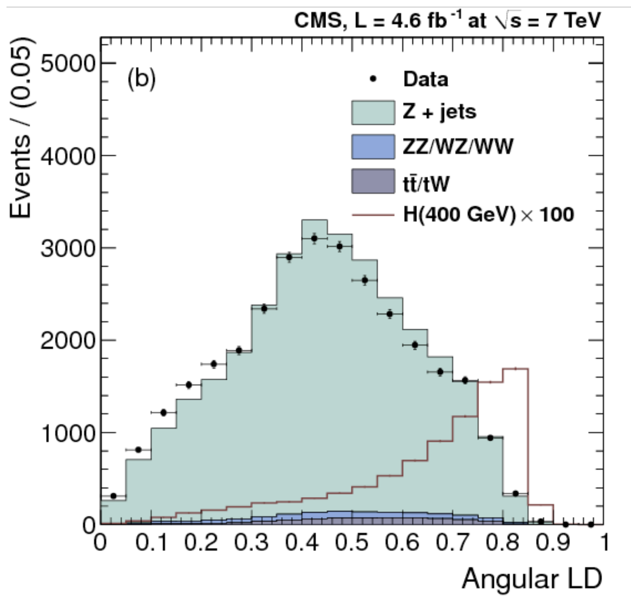


Angular variables

Kinematics of the event described by 5 production and decay angles:

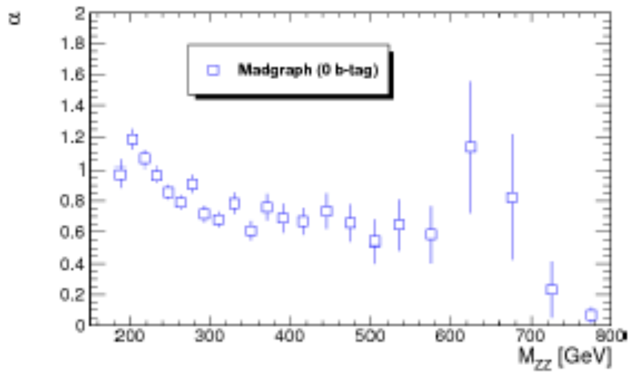
- A likelihood discriminant is built:
  - based on the probability ratio of the signal and background hypotheses
  - Probability parametrized as function of m_{ZZ}
- Selection on LD optimized per category

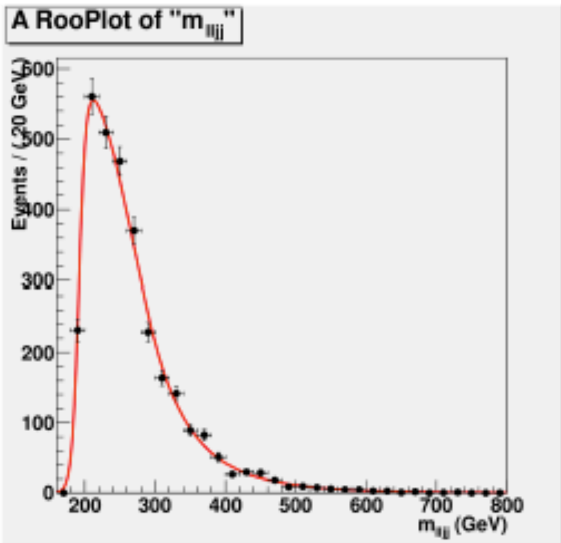


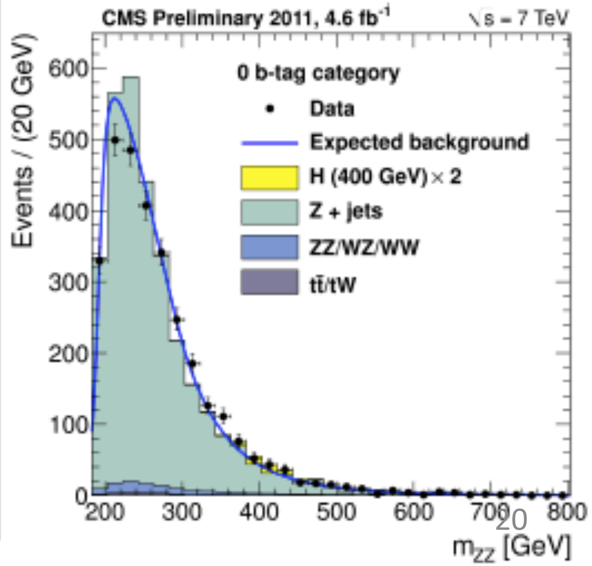


Background estimation

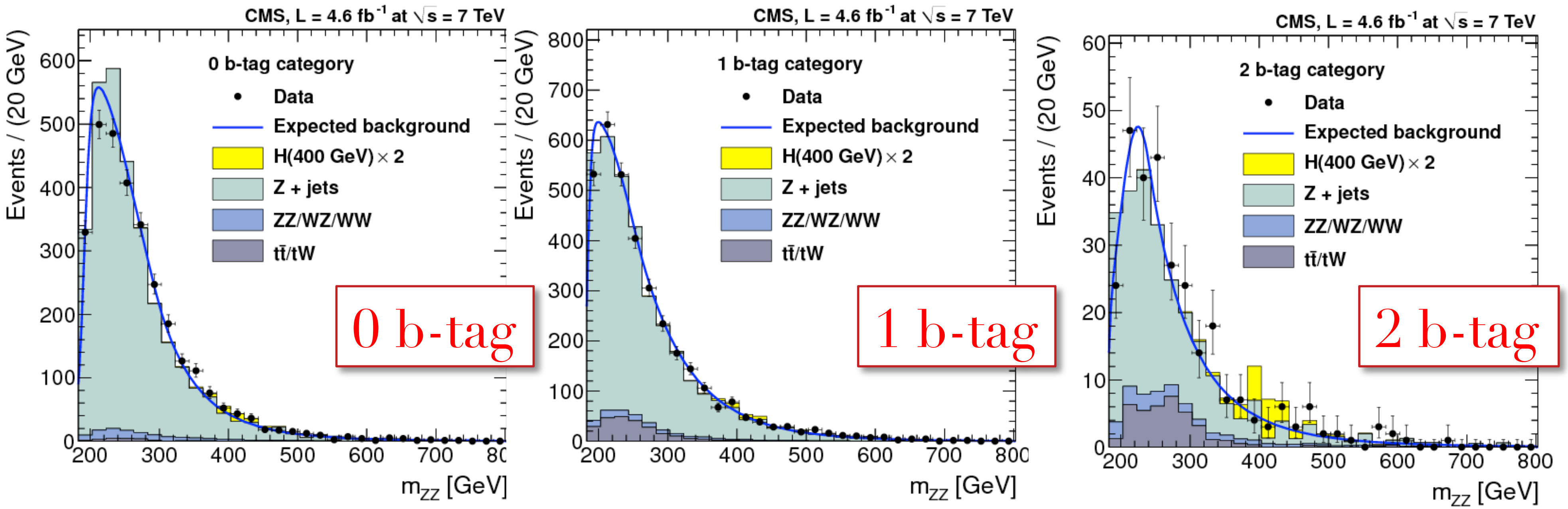
- Strategy: **definition of m_{jj} sidebands for a data-driven estimation of the background:**
  - Number of background events in signal region extrapolated by control region using factor α(mZZ) taken by MC:
    - $N_{bkg}(m_{ZZ}) = N_{sb}(m_{ZZ}) \times \alpha(m_{ZZ})$
    - $\alpha(m_{ZZ}) = N^{sim}_{bkg}(m_{ZZ})/N^{sim}_{sb}(m_{ZZ})$
- Fit to extrapolated background with empirical function, able to model the core and the long tail at high masses





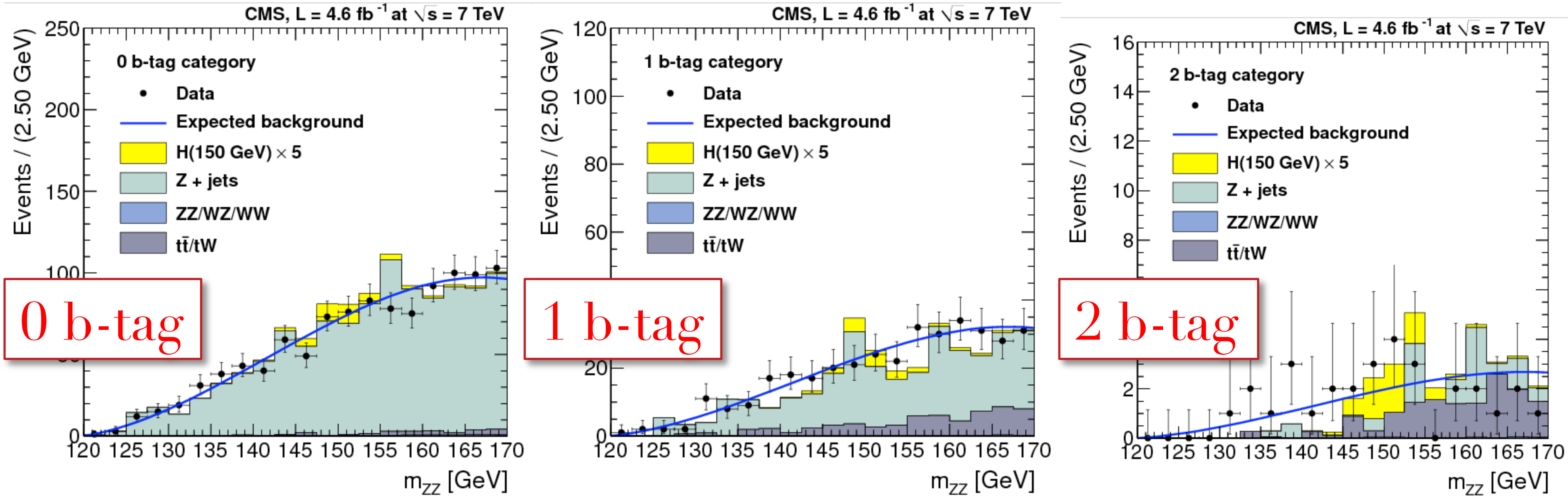


M_{ZZ} spectra: high mass



- Analysis performed on diboson reconstructed mass, m_{ZZ}
- Background estimated from data
- Blue line is the shape extrapolated from sidebands

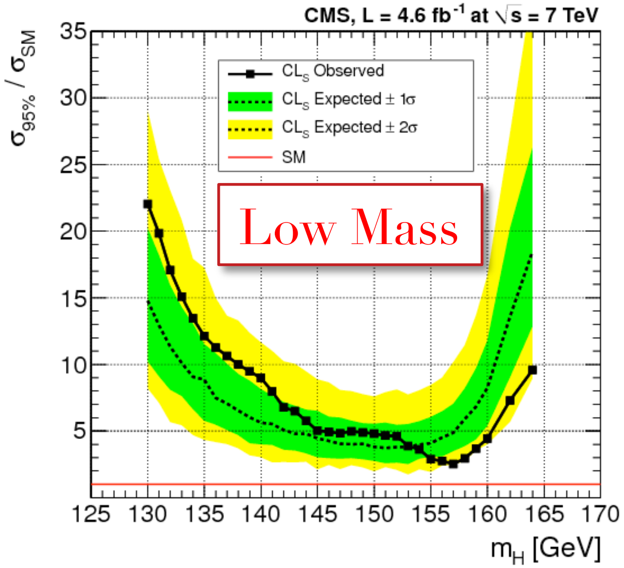
M_{ZZ}spectra: Low mass

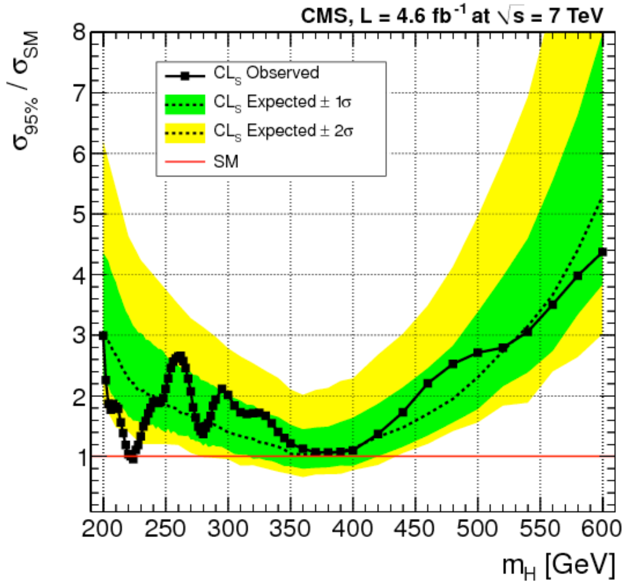


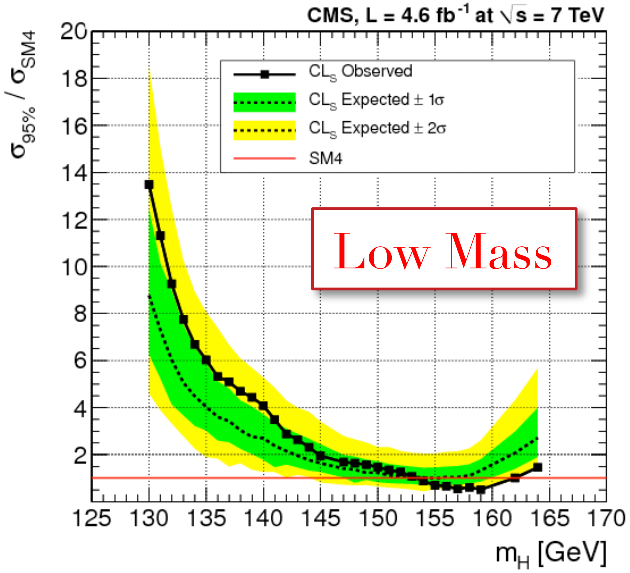
- For the low mass analysis cut on lepton p_T are released:
  - $p_T^{(1)} > 20$ GeV and $p_T^{(1)} > 10$ GeV
- Background estimated from m_{jj} sidebands:
  - Normalization taken from mZZ sidebands
  - unique shape for the 3 categories

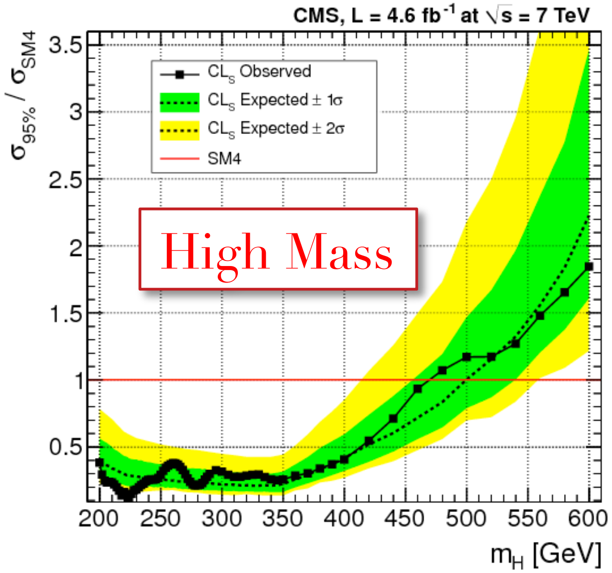
Finaly the results

- Reached 3xSM around 155 GeV
- Close to exclusion at high mass: 1xSM in 370÷400 GeV









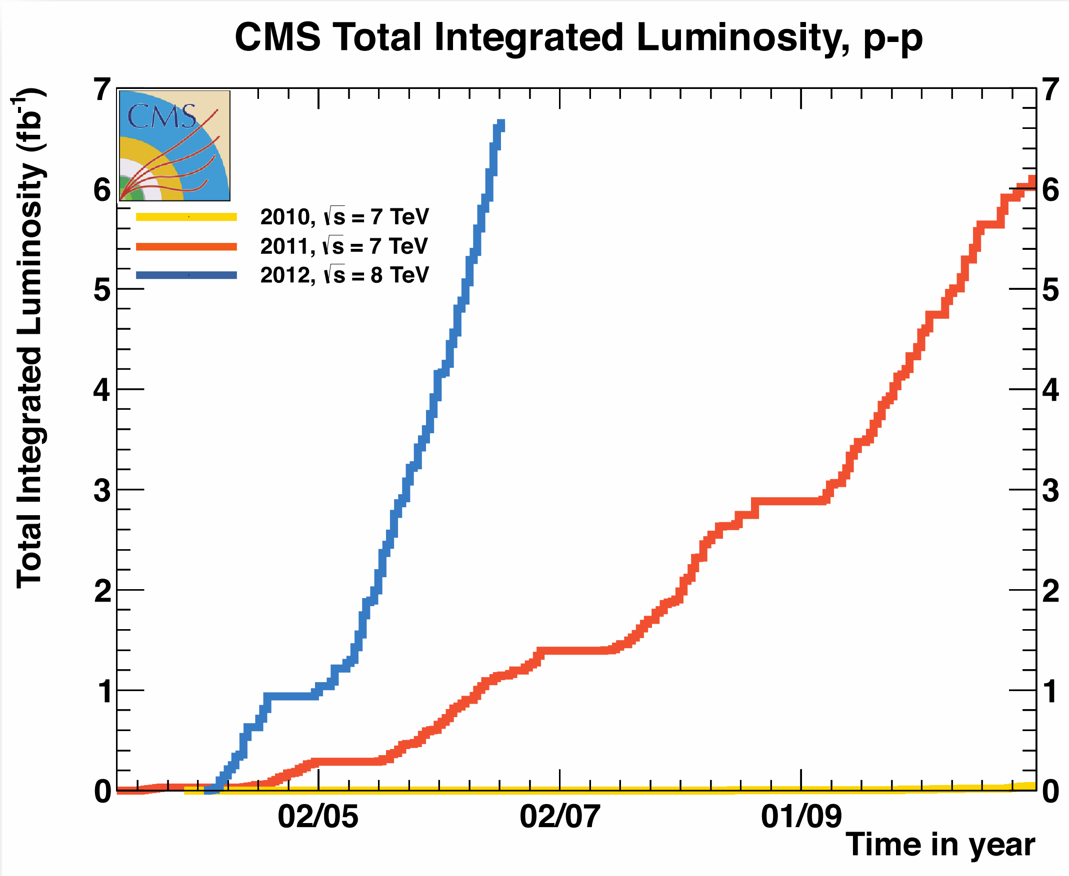
- A Higgs boson is excluded in the 4th fermion standard model in the ranges 153÷162 GeV and 200÷470 GeV

Conclusion – Part II

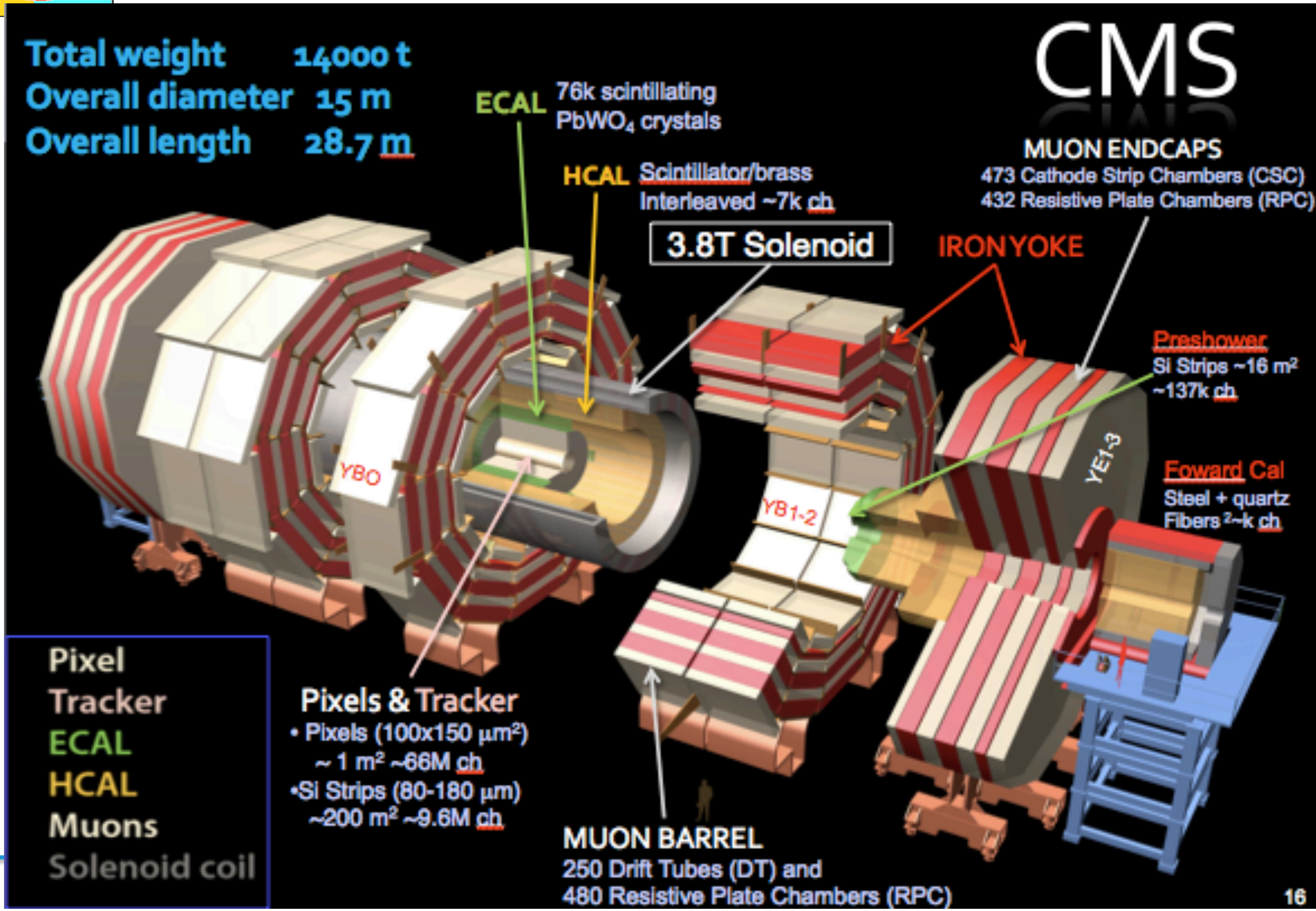
- The results presented refer to 4.6 fb^{-1} of collision data recorded at CMS in 2011 with a centre-of-mass energy $\sqrt{s}$=7TeV
- Results have been published at the begin of 2012 on the Journal Of High Energy Physics, JHEP:
  - arXiv:1202.1416v1
- Analysis on 2012 data are ongoing, not yet public

Backup

LHC performance

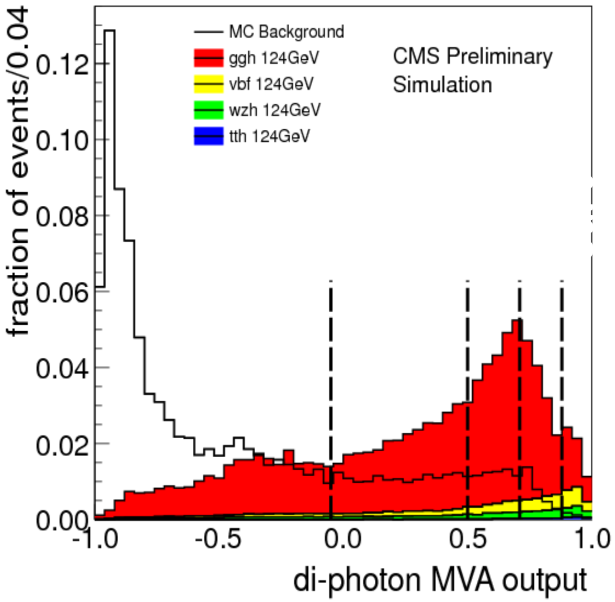


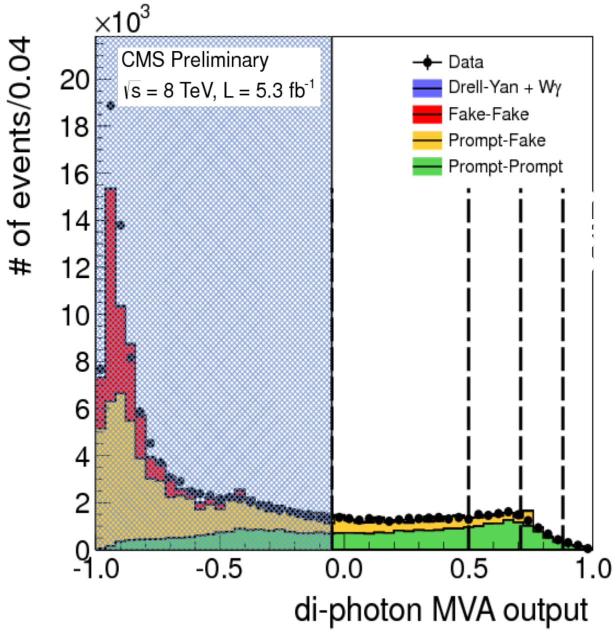
CMS detector



Diphoton MVA

- Diphoton MVA trained on signal and background MC with input variables largely independent of $m_{\gamma\gamma}$
  - Kinematics: p_T and η of each photon, and $\cos\Delta\phi$ between the 2 photons
  - Photon ID MVA output for each photon
  - per-event mass resolution and vertex probability
- Encode all relevant information on signal vs background discrimination (aside from $m_{\gamma\gamma}$ itself) into a single di-photon MVA output to first order independent of $m_{\gamma\gamma}$





- For BG only make analysis sub-optimal
- For signal would cause some category migration included in the systematic errors