Higgs Physics at CMS

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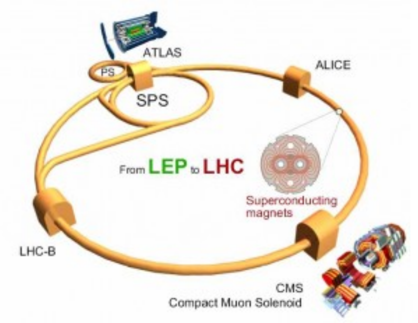
Outline

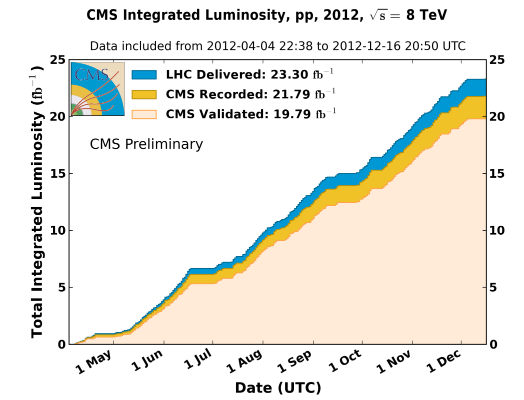
- **Introduction:**
  - LHC
  - CMS
- **Higgs Physics:**
  - SM Higgs @ 125 GeV
    - Higgs properties
  - More Higgs Searches
- **Conclusions**

The LHC

High luminosity pp collisions

- 2011: $6.1 fb^{-1}$ at 7 TeV
- 2012: $23.3 fb^{-1}$ at 8 TeV



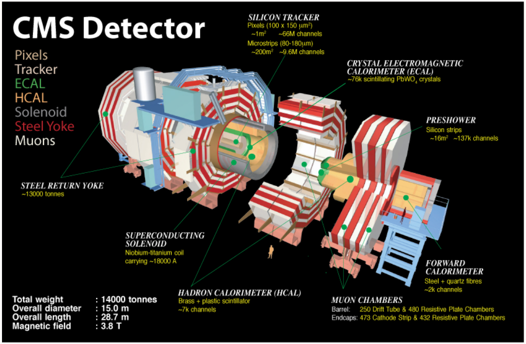


Congratulations to the accelerator teams for the excellent performance !!

The CMS detector

CMS is a fast-electronics detector, embedded in a 3.8 T solenoid, providing a precise 3D event reconstruction.

- Inner Tracker (silicon pixel and strip detectors)
- ECAL ($PbWO_4$ crystals)
- HCAL (brass/scintillator samplers)
- Muon Chambers: Drift Tubes, Cathode Strips, and Resistive Plate Chambers

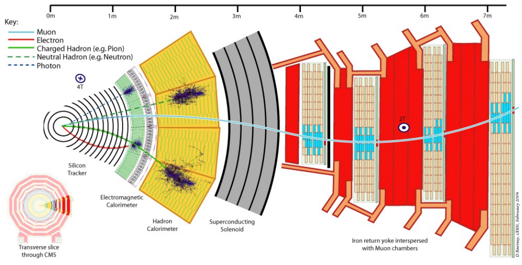


Taking data during 3 years with an efficiency above 96% in all subdetectors !!!!

Object Reconstruction

The Particle Flow algorithm attempts to reconstruct all the individual particles in the event: photons, charged and neutral hadrons, electrons, and muons.

- Muon: Matching tracks in inner tracker and muon chambers
- Electron: EM cluster with an associated track
- Photon: EM cluster without an associated track
- Jet: Cluster in EM and hadronic calorimeters (and inner tracker)



- Tau lepton : Narrow jet with matching track(s)
- MET: p_T required to balance all of these

Higgs Discovery

More than one year ago!!

A lot of work was done during last year (summarised in this talk). But it is not over, more to come.

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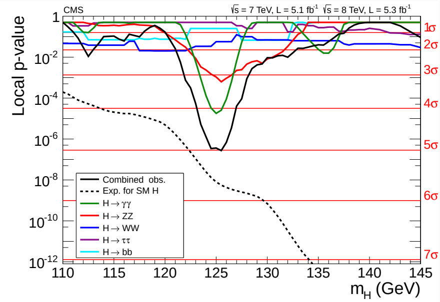
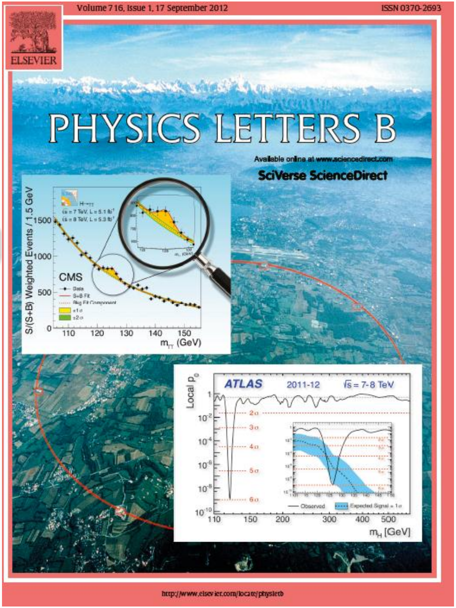
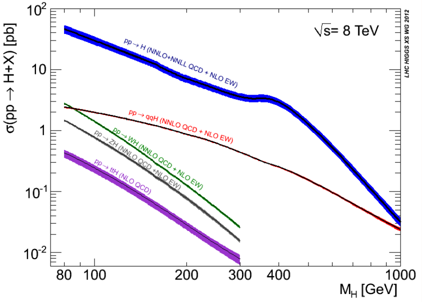




Standard Model Higgs @ 125 GeV

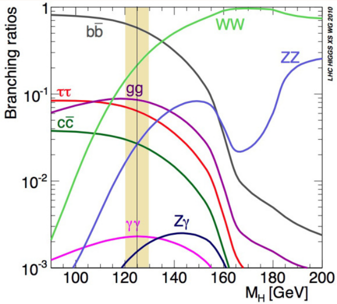
SM Higgs Production and Decays

The highest cross section times branching ratio scenario, not allways tells you the best spot to perform a search



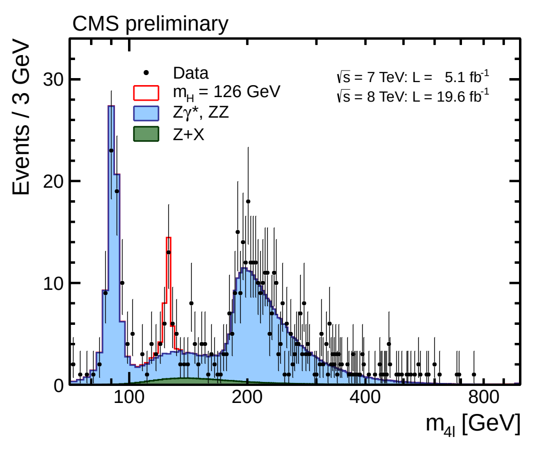
The study of all these scenarios is crucial to understand the nature of the new particle:

- mass
- couplings
- spin-parity



$H \rightarrow ZZ \rightarrow 4l$

- Four high p_T isolated leptons from the primary vertex
- Search for a narrow resonance in the 4l mass spectrum
- Very clean final state but low branching ratio
- Crucial to keep the lepton efficiency as high as possible

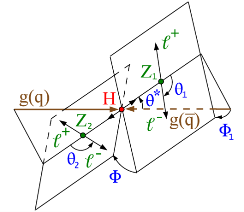


Events categorized in two regions:
untagged (0/1 jet) and dijet tagged ($\geq$ 2 jets - VBF like)

$H \to ZZ \to 4l$

J^P-dependent Kinematic Discriminant (K_D)

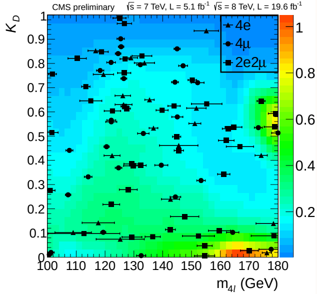
$$K_D = P_{sig}/(P_{sig} + P_{back}),$$

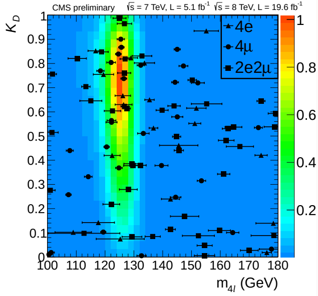


where

$$P_{sig,back} = f(m_1, m_2, \theta_1, \theta_2, \phi_1, \theta^*, \phi^* | m_{4l})$$

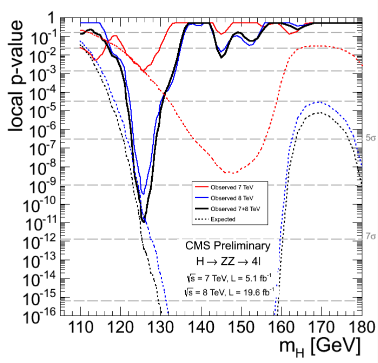
Calculated from the production and decay kinematics to distinguish the **Higgs** boson from **ZZ** background





$H \rightarrow ZZ \rightarrow 4l$

Significance of the local excess based on a 3D fit to: K_D, m_{4l}, and kinematic variables.



Some properties:

- $\sigma/\sigma_{SM} = 0.91^{+0.30}_{-0.24}$

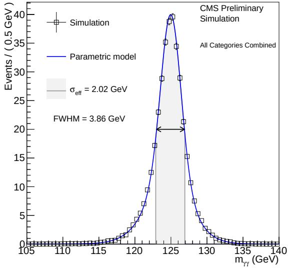
$$m_H = 125.8 \pm 0.5(stat.) \pm 0.2(sys.)GeV$$

- Spin-parity test constructing K_D for different J^P Higgs-like states

More details in the talk by Giacomo Ortona

$H \to \gamma\gamma$

- Two isolated high p_T photons
- Search for a narrow mass peak, $m_{\gamma\gamma}$, in a steeply falling background distribution
- Small branching fraction

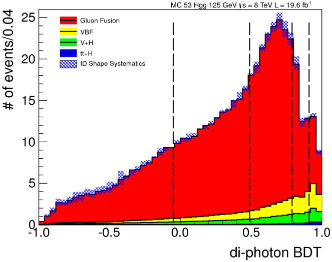


Two incusive analyses:

- MVA-based selection: MVA for γ shower shape and isolation, kinematics and $m_{\gamma\gamma}$ resolution
- Cut-based selection (cross check)

Exclusive analyses:

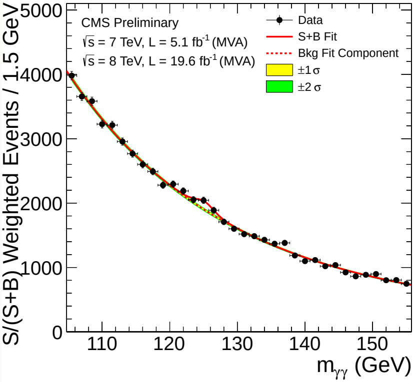
- VH: e, μ, and MET
- VBF: 2 dijet categories



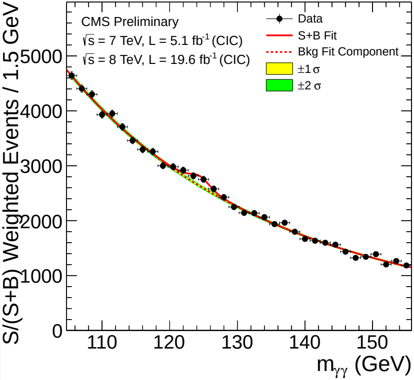
$H \to \gamma\gamma$

Weighted mass distributions (for visualisation only).

Events weighted by the S/(S+B) of its category.

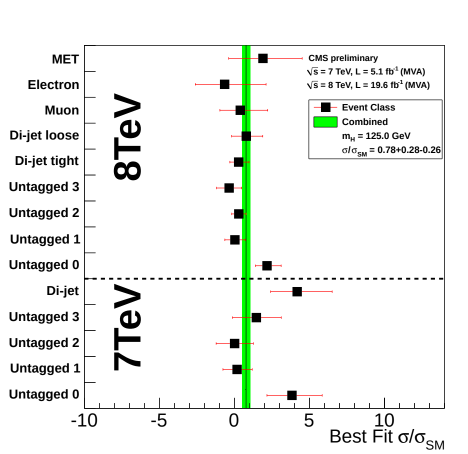


MVA analysis



Cut-based analysis

$$m_H = 125.4 \pm 0.5(stat.) \pm 0.6(sys.) GeV$$



Signal strenght (MVA analysis)

$$\sigma/\sigma_{SM} = 0.78^{+0.28}_{-0.27}$$

Significances for m_H=125 GeV:

- MVA: observed 3.2 σ, expected 4.2 σ
- Cut-based: observed 3.9 σ, expected 3.5 σ

More details in the talk by Rishi Gautam Patel

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

- Two high p_T OS isolated leptons, large $\not{E}_T$, mass not reconstructed (m_T)
- Large branching ratio
- No mass peak

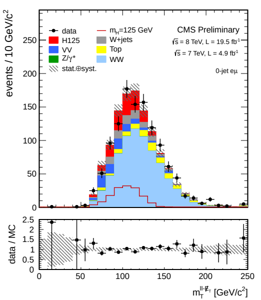
3 jet categories: 0,1 and 2 jets (**VBF**)

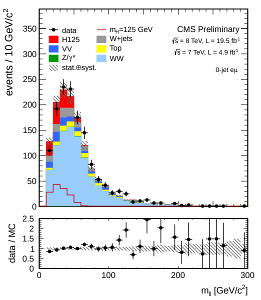
Two analyses in the 0 and 1 jet category:

- Same Flavour: Cut-based ($\Delta\phi_{ll}, p_T^{lmax}, p_T^{lmin} m_{ll}, m_T$)
- Different Flavour: 2D shape m_T and m_{ll}

Two analyses in the VBF category:

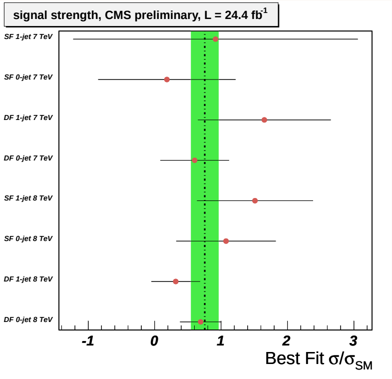
- Same Flavour: Cut-based
- Different Flavour: Shape analysis m_{ll}

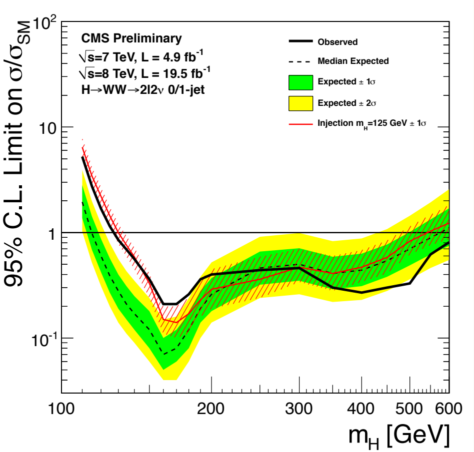




Broad excess compatible with a Higgs signal at low mass

Significances for m_H=125 GeV:
observed 4σ, expected 5.1σ





Signal strenght:
$\sigma/\sigma_{SM} = 0.76 \pm 0.21$

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

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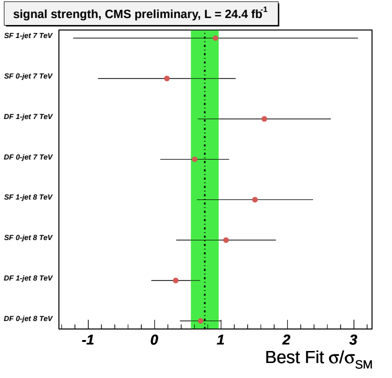
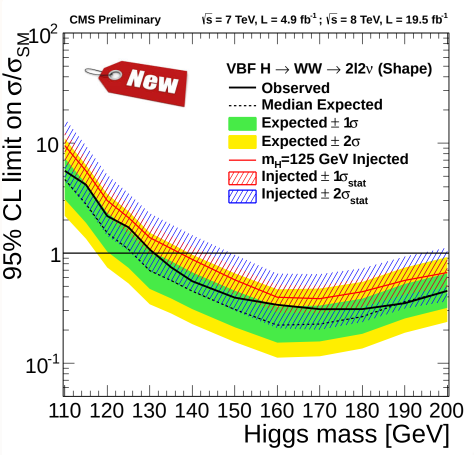




Signal strenght:

$$\sigma/\sigma_{SM} = 0.76 \pm 0.21$$

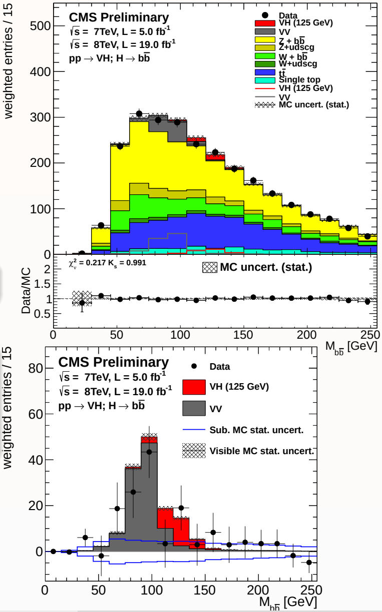
VH($b\bar{b}$)

- Final state with 2 central b-jets plus the decay products of the associated V (leptons and/or ν's)
- Main backgrounds: V+jets, VV, top.

Important to test coupling to fermions

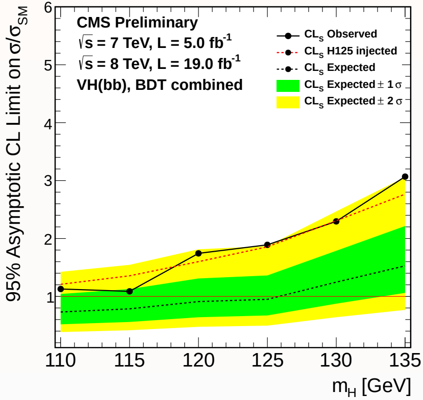
Signal optimization: BDT shape analysis based on jet and V kinematics, and b tagging.

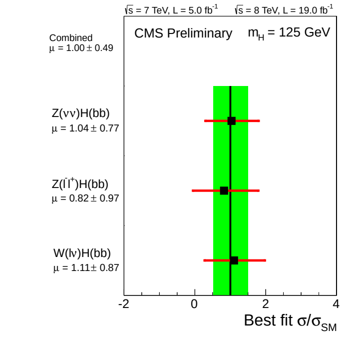
Dijet ($b\bar{b}$) mass distribution for all the channels combined, weighted according to its S/(S+B)



VH($b\bar{b}$)

Broad excess compatible with a Higgs signal at low mass.





Significances for m_H=125 GeV:
observed 2.1σ, expected 2.1σ

Signal strenght:
$\sigma/\sigma_{SM} = 1.0 \pm 0.5$

H $\rightarrow \tau\tau$

Final states:

$\mu\tau_h, e\tau_h, \tau_h\tau_h, \mu\mu, e\mu, VH(\tau\tau)$

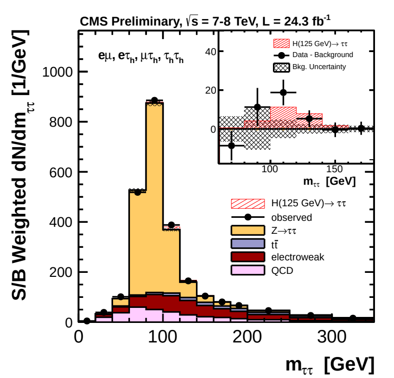
Divided in jet categories: 0 jet (control), 1 jet, and 2 jets (VBF)

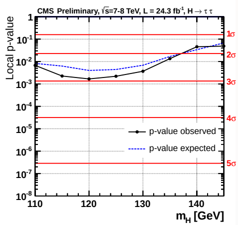
Broad excess compatible with a Higgs signal at low mass.

Significances for m$_H$=125 GeV:
observed 2.9σ, expected 2.6σ

Signal strenght: $\sigma/\sigma_{SM} = 1.1 \pm 0.4$

Combined with VH($b\bar{b}$): 3.4σ evidence for H to fermions coupling





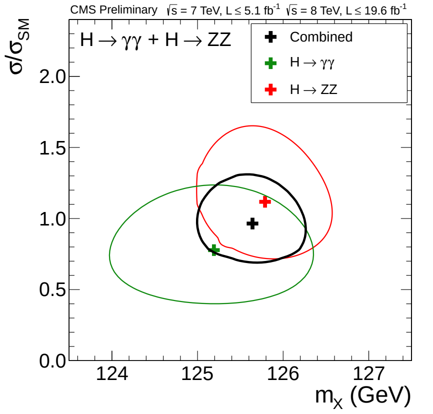
Higgs Properties: Mass, Couplings

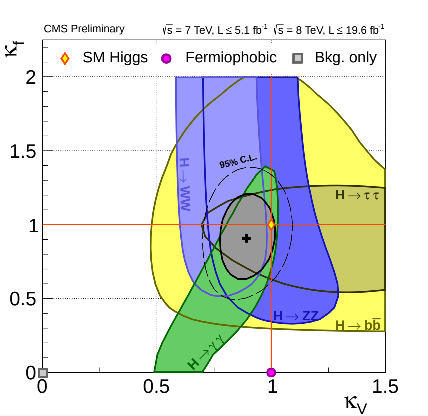
Mass of the observed state

m_x= 125.7 $\pm$ 0.3 (stat.) $\pm$ 0.3 (sys.) GeV = **125.7 $\pm$ 0.4 GeV**

$\sigma \times BR(x \rightarrow H \rightarrow ff) = \frac{\sigma_x \cdot \Gamma_{ff}}{\Gamma_{total}}$

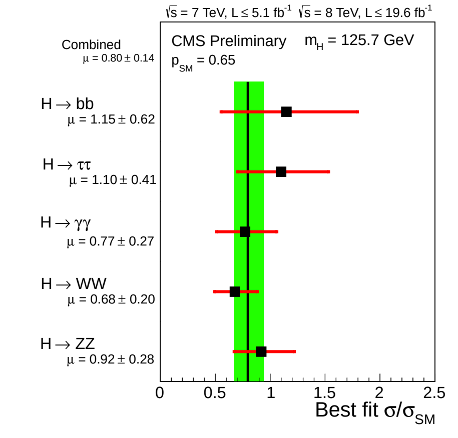
Γ_{ff} proportional to the effective H couplings (g_i):
Scale factors $\kappa_i = g_i / g_i^{SM}$





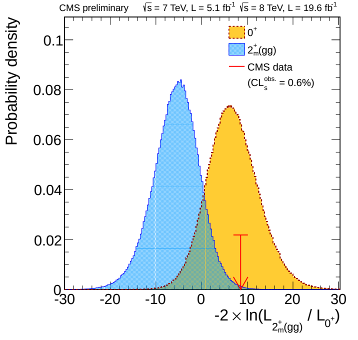
Higgs Properties: Test of Production Modes, Spin-Parity

Best $\sigma/\sigma_{SM} = 0.8 \pm 0.14$



Several alternative models: 0^-, 1^+, 1^-, 2^+ tested against the SM Higgs 0^+ hypothesis

Example 0^+ vs 2^+ (WW + ZZ)



More Higgs Searches

ttH($b\bar{b} + \tau\tau$)

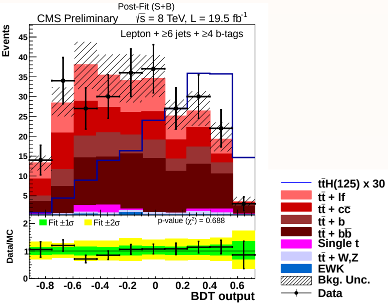
- H$\rightarrow$ $b\bar{b}$: 2 or more b jets; tt in the dilepton and lepton+jets channels
- H$\rightarrow$ $\tau\tau$: $\tau_h\tau_h$; tt into lepton+jets (with 1 or 2 b-tagged jets)

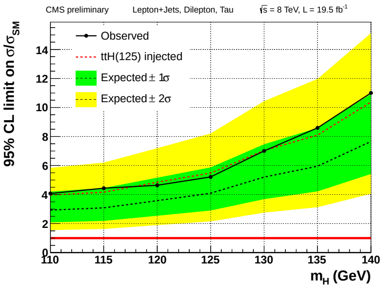
Analysis performed in several categories divided in jet and b-jet multiplicity

Signal optimization via BDT's based mainly in kinematics and b-tag information.

Limits @125 GeV:

- Observed: 5.2 $\times\sigma_{SM}$ @ 95% CL
- Expected: 4.1 $\times\sigma_{SM}$ @ 95% CL

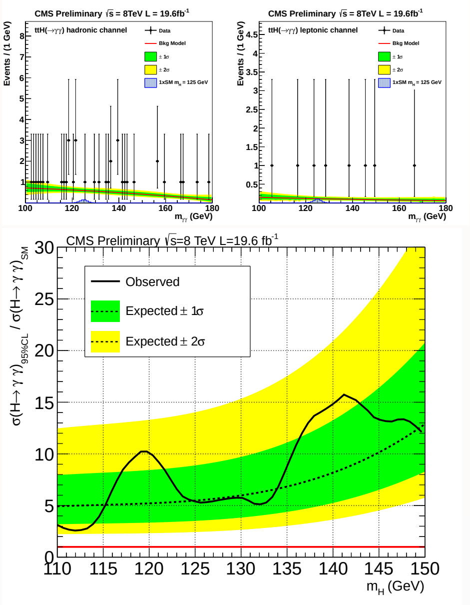




ttH($\gamma\gamma$)

Two different analyses to maximize the sensitivity:

- Leptonic $t\bar{t}$ decays
- Hadronic $t\bar{t}$ decays



Search for a narrow peak in the diphoton mass distribution

Limits @125 GeV:

- Observed: 5.4 $\times\sigma_{SM}$, 95% CL
- Expected: 5.3 $\times\sigma_{SM}$, 95% CL

More details in the talk by Francesco Micheli

ttH($\gamma\gamma$)

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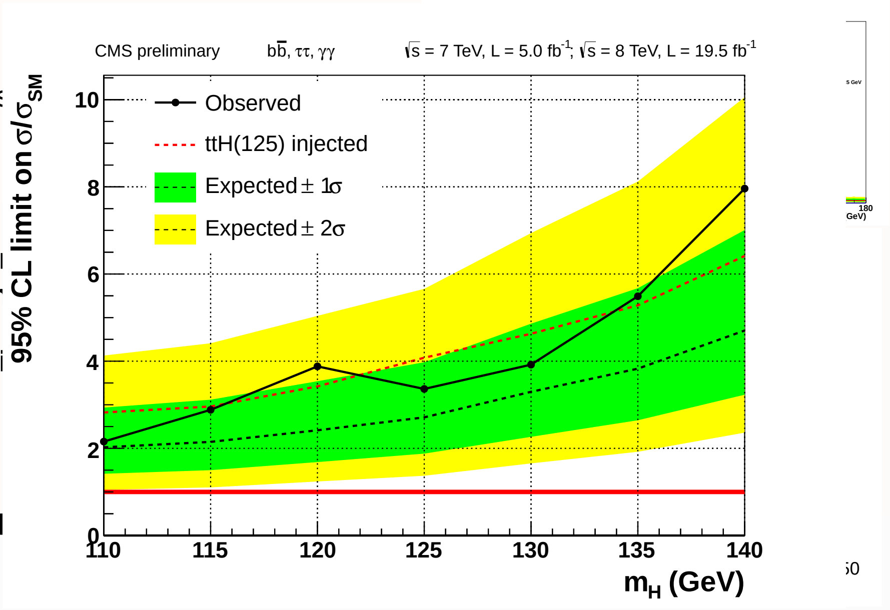
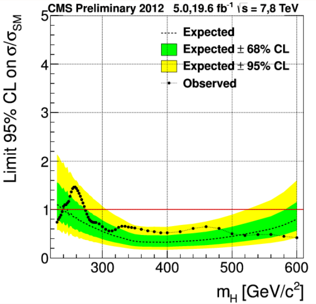


H → ZZ - High mass

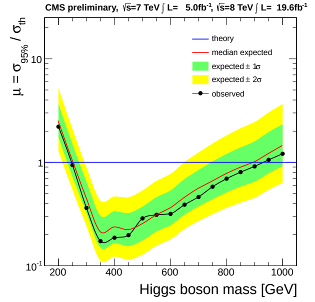
H → ZZ → 2l2q

- 3 categories (0, 1, and 2 bjets)
- Signal optimization based on decay angles



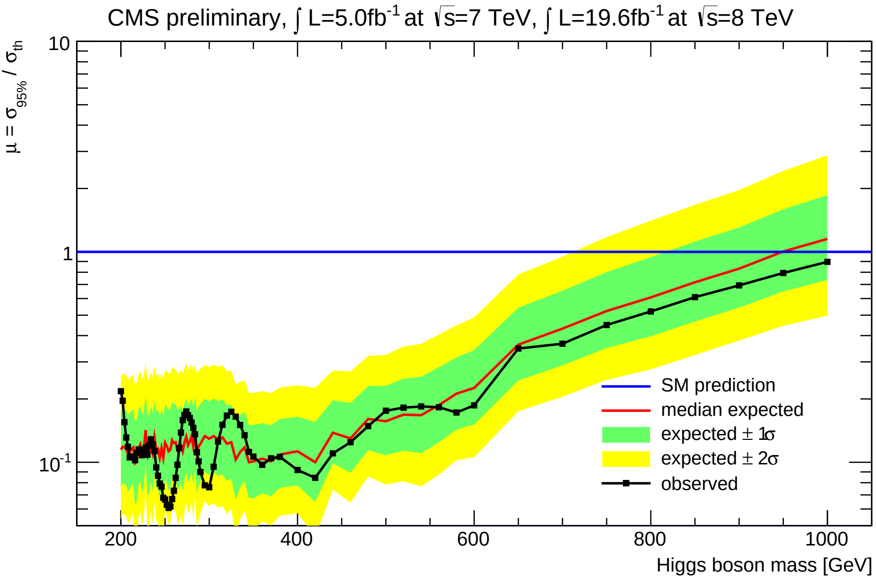
H → ZZ → 2l2ν

- Two leptons + $\not{E}_T$ from the ν's
- Optimized for gluon fusion and VBF



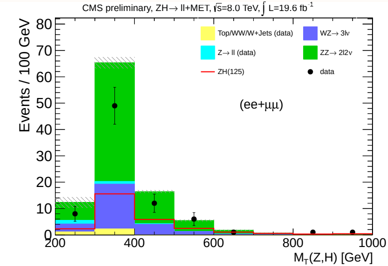
Both analysis combined with $H \to ZZ \to 4l$ from 200 GeV to 1 TeV

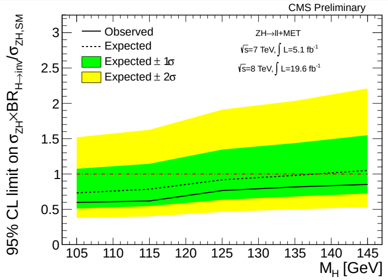
H → ZZ - High mass



Higgs to invisible

- Higgs decaying into invisible particles i.e. non-SM decays
- You can always find a model that predicts such a decay, and anything you want :-)
- Search for associated production with a Z boson
- Z boson decaying into leptons (ee, $\mu\mu$)





For m_H = 125 GeV:
BR(H $\rightarrow \chi\chi$) $<$ 75% ($<$ 91% expected) @ 95% CL

Conclusions

Impressive performance of LHC and CMS detector

- The CMS collaboration successfully covered a large Higgs program in the last years
- The observation of the new boson was confirmed by the latest data. Most of the analyses updated to the full data set.
- Everything points to a **SM-like Higgs**
- **Waiting for new data!!** 2015 will be the starting point of a new era: precision measurements of the properties, new channels, BSM searches ...

More details in the CMS official web page:
`http://cms.web.cern.ch/org/cms-higgs-results`