Higgs search by CMS

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On behalf of CMS
Collaboration
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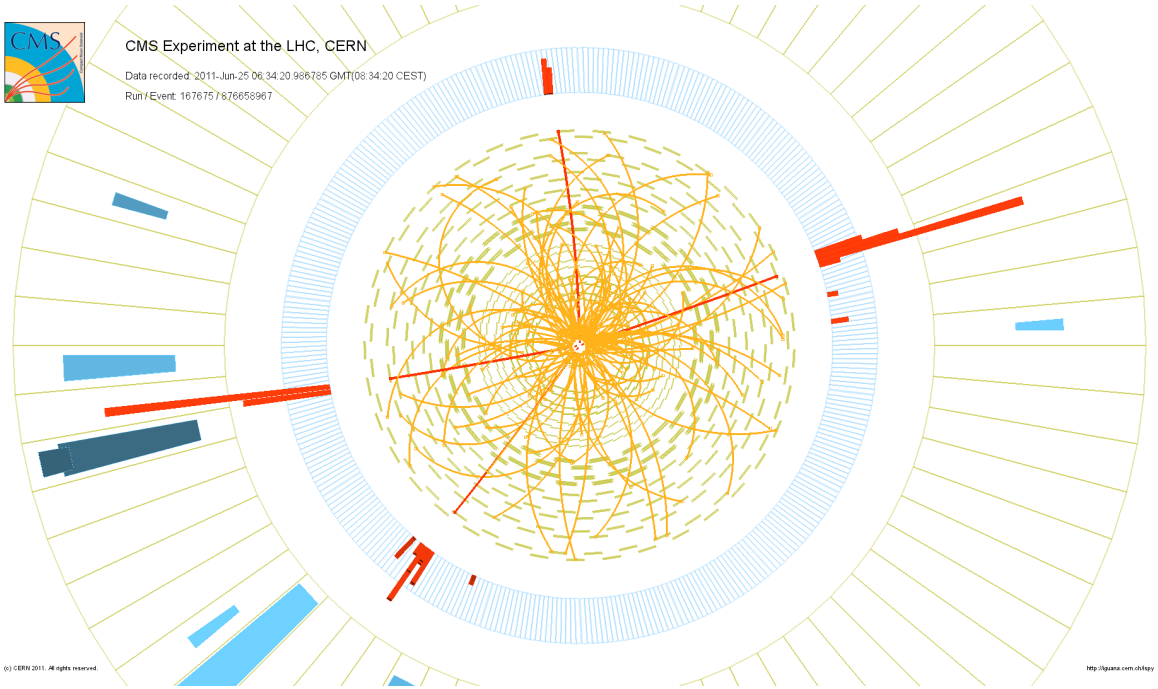
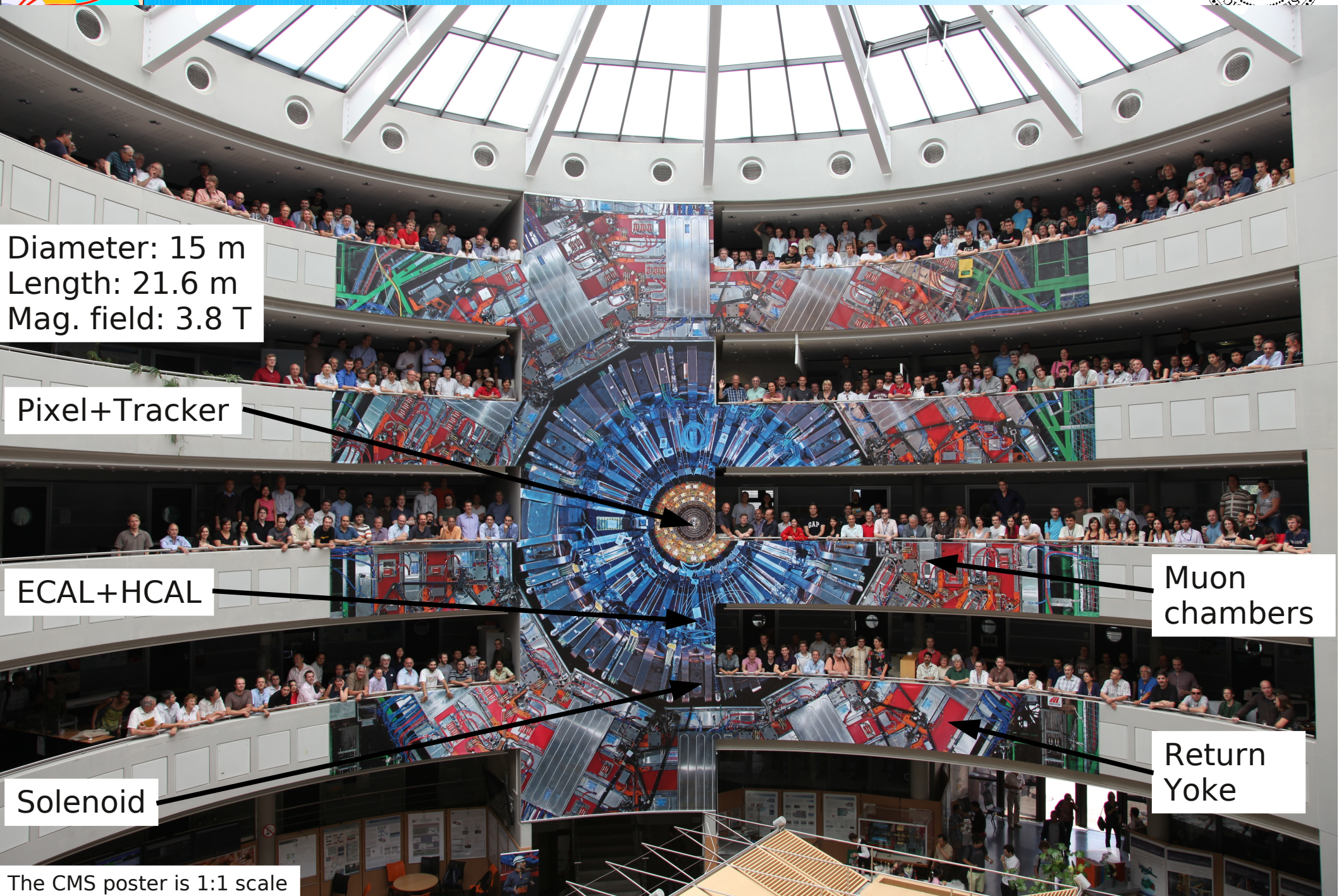
Outline

- Higgs boson production at the LHC
- Search channels at CMS
- Exclusion limits for SM Higgs with up to 1.7 fb^{-1}
- Conclusions

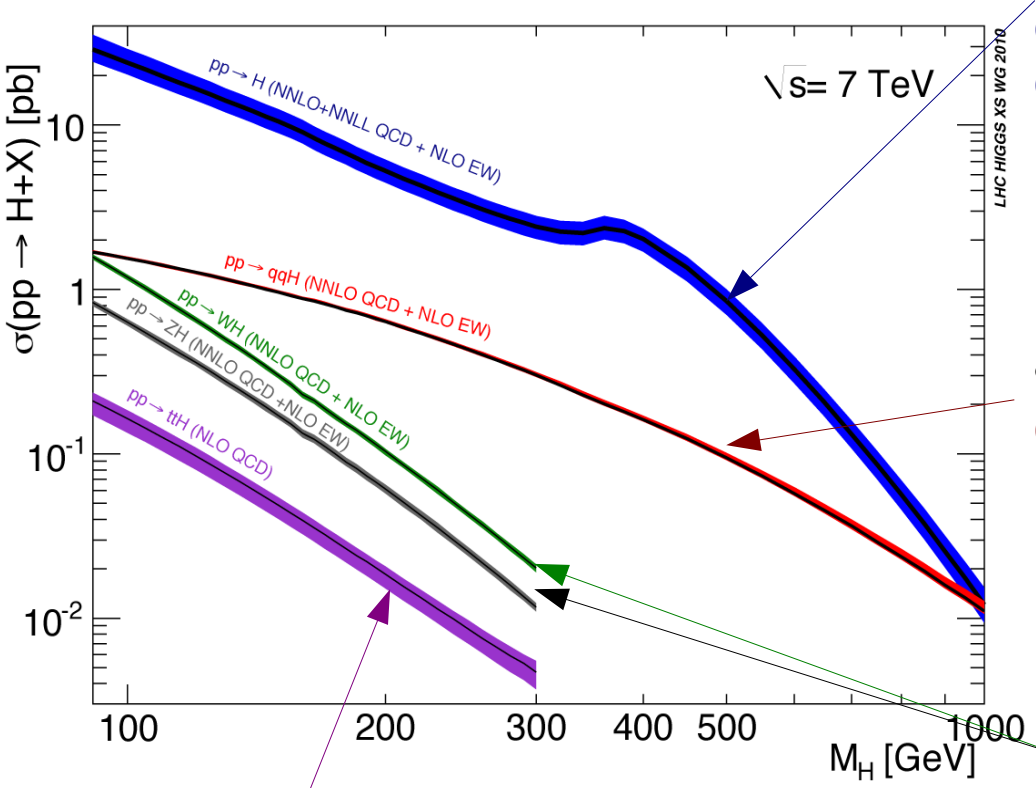


Candidate ZZ→4e event

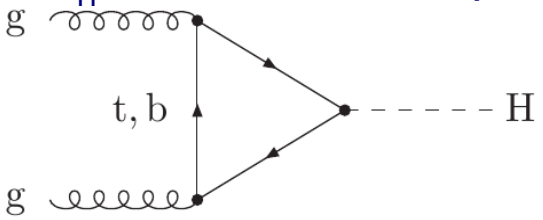
The CMS


Diameter: 15 m
Length: 21.6 m
Mag. field: 3.8 T
Pixel+Tracker
ECAL+HCAL
Solenoid
Muon chambers
Return Yoke
The CMS poster is 1:1 scale

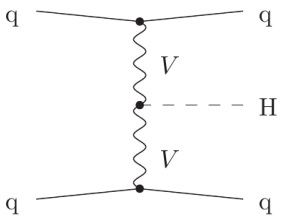
Higgs production modes at LHC



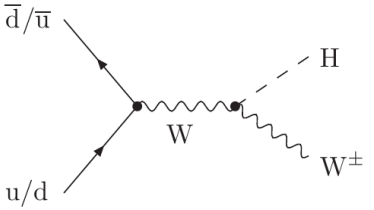
•Dominating production mode in pp collisions @7 TeV is gluon-gluon fusion
gg→H: σ(m_H=120) = 16.63 pb



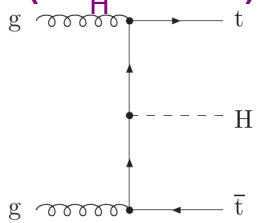
•Next is Vector Boson Fusion (VBF)
qq→qqH: σ(m_H=120) = 1.27 pb



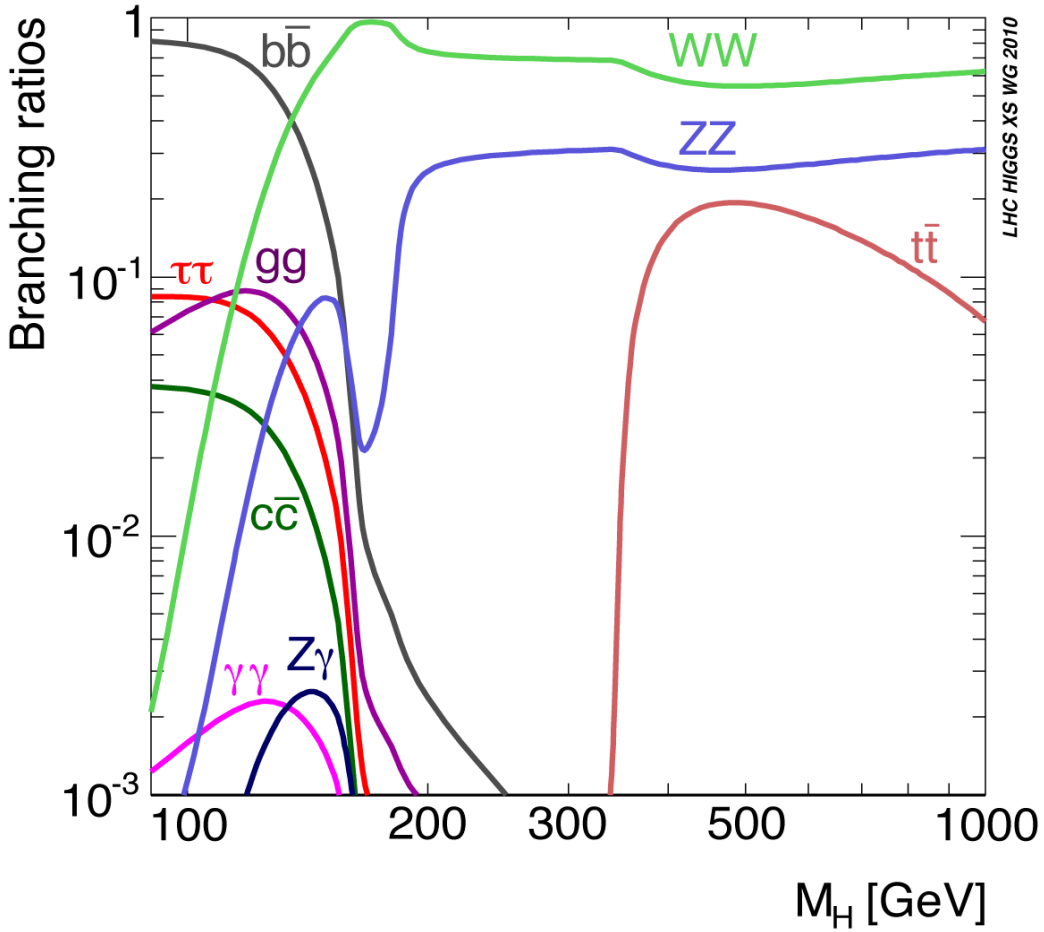
•then is VH associated production:
qq'→WH σ(m_H=120) =0.66 pb and
qq→ZH σ(m_H=120) = 0.36 pb

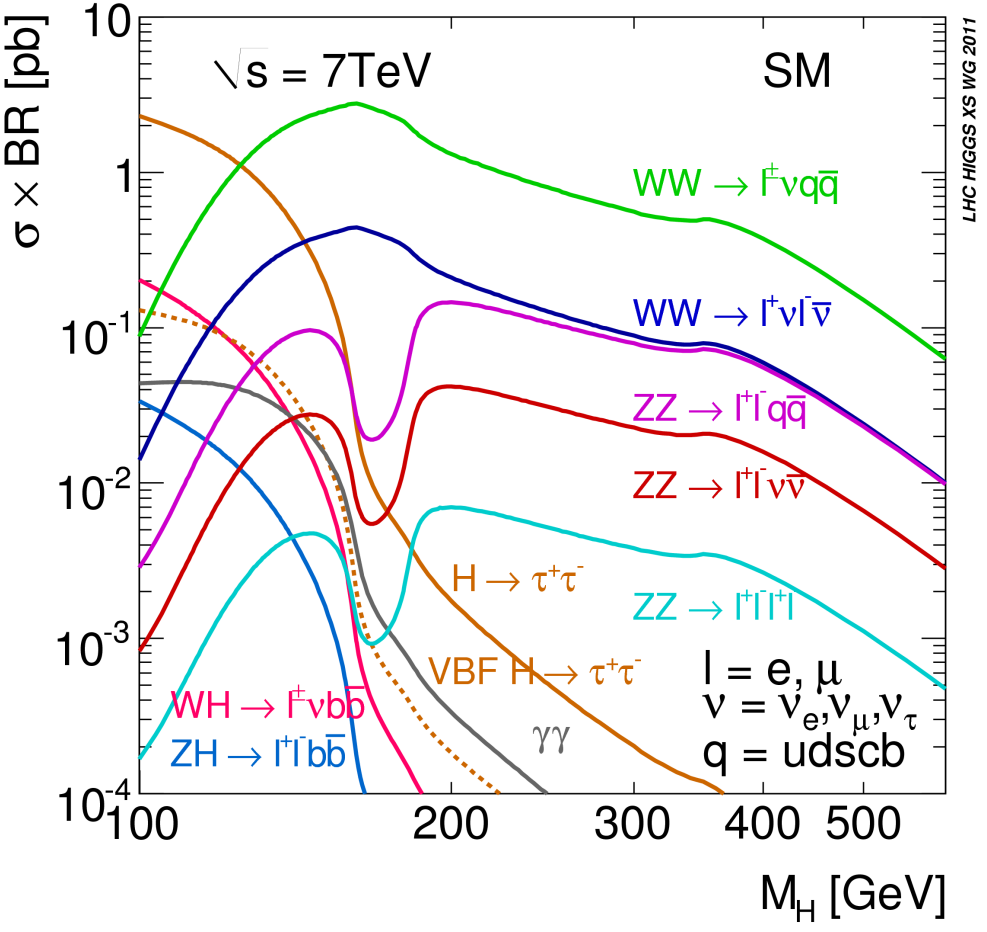


•Finally ttH associated production:
qq→ttH σ(m_H=120) =0.098 pb



Main H decay modes





- channels important for low mass region, m_H<130: H→γγ, H→bb, H→ττ
- channels important for medium and high masses: H→WW, H→ZZ

Channels investigated by CMS

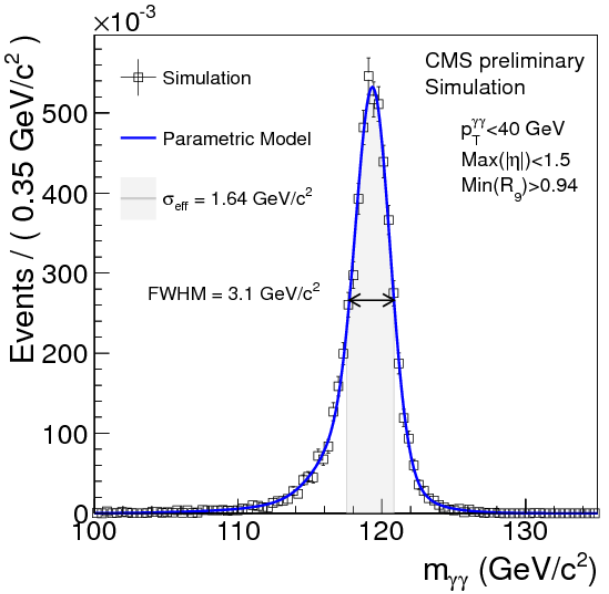
channel	mass range (GeV/c^2)	luminosity (fb^{-1})	number of sub-channels	type of analysis
$H \to \gamma\gamma$	110-150	1.7	8	mass shape (unbinned)
$H \to \tau\tau$	110-140	1.1	6	mass shape (binned)
$H \to bb$	110-135	1.1	5	cut&count
$H \to WW \to 2\ell 2\nu$	110-600	1.5	5	cut&count
$H \to ZZ \to 4\ell$	110-600	1.7	3	mass shape (unbinned)
$H \to ZZ \to 2\ell 2\tau$	180-600	1.1	8	mass shape (unbinned)
$H \to ZZ \to 2\ell 2\nu$	250-600	1.6	2	cut&count
$H \to ZZ \to 2\ell 2q$	226-600	1.6	6	mass shape (unbinned)
TOTAL (8)	110-600	1.1-1.7	27 for low m_H 24 for high m_H	

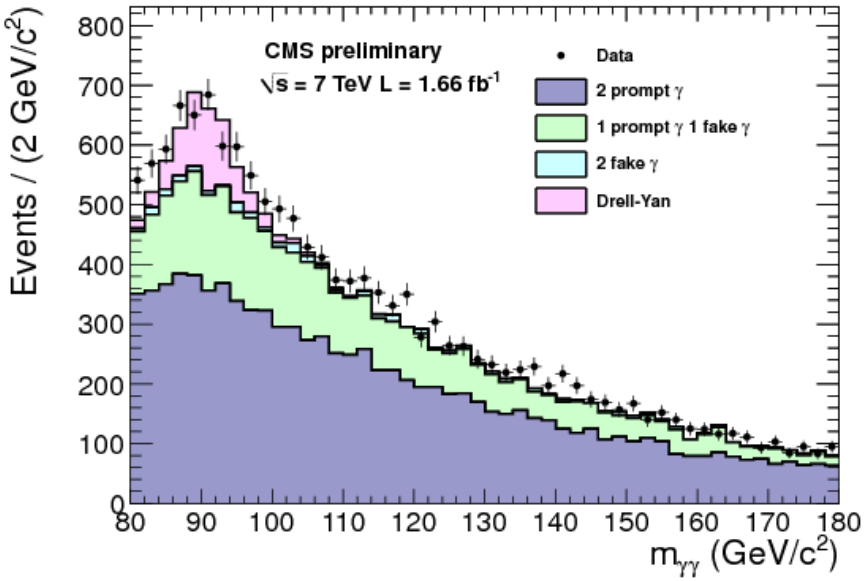
More than 3 fb^{-1} still to be analysed

Large number of sub-channels analysed. CMS working hard to add more

H→γγ analysis

- **Signal signatures:**
  two isolated photons
  excellent mass resolution (FWHM/m_H)
  of order of 2.4% for the best, and
  6.5% for worst category di-photons
- **Main backgrounds:**
  di-photon production
  photon+jet (mis id. as second photon)





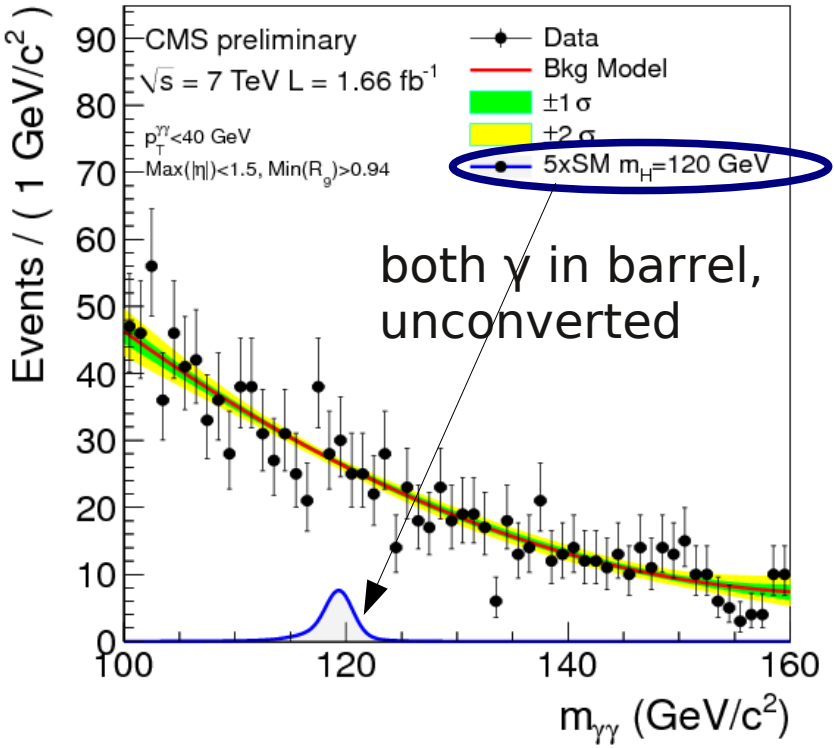
H→γγ analysis

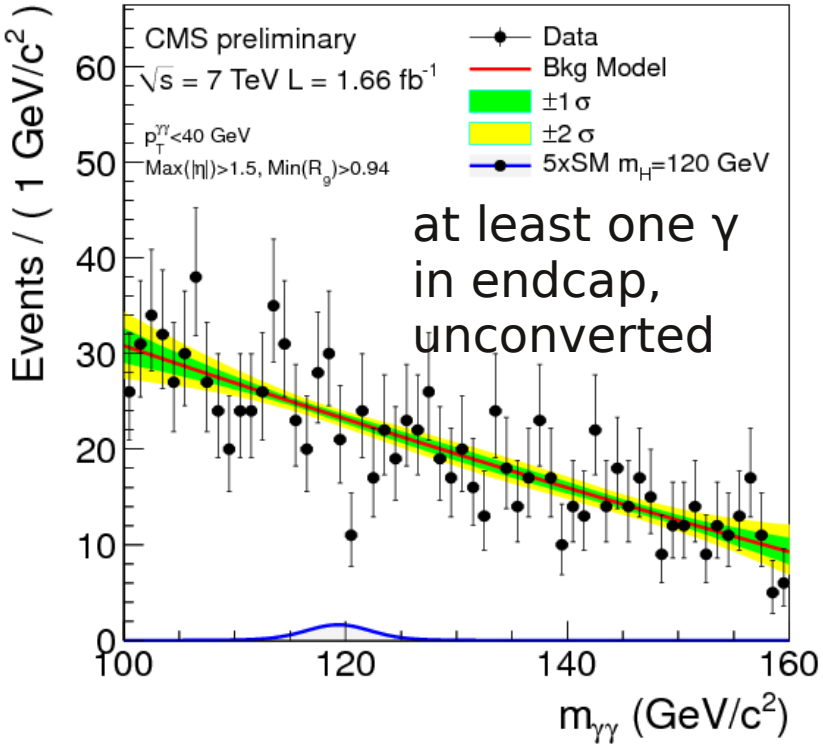
- Data is split into 8 di-photon quality categories based on:

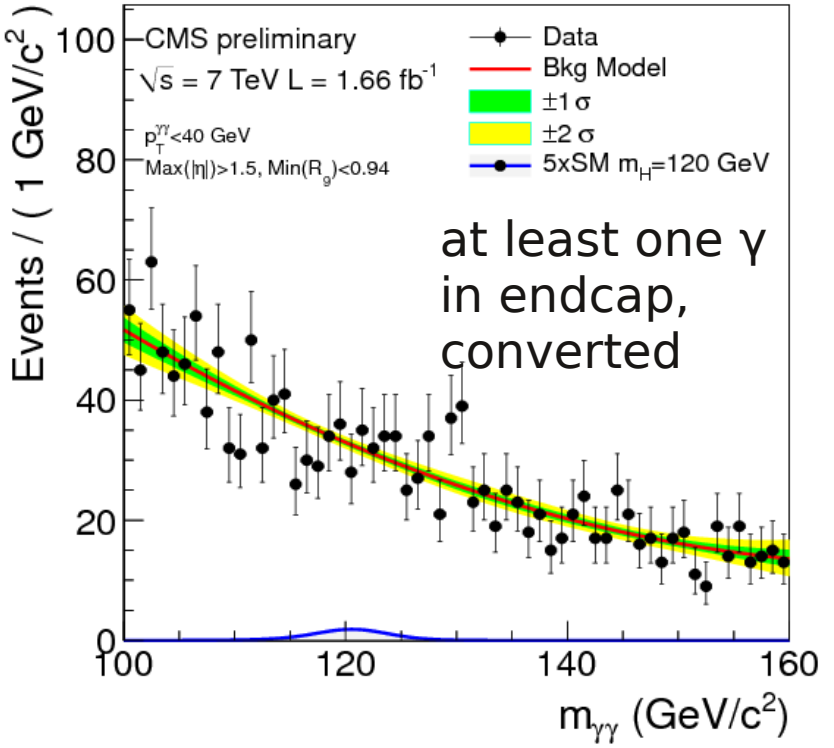
$p_T^{\text{di-photon}}$ > or < 40 GeV,

number of photons in barrel detector,

width of the photon shower in ECAL to reject converted γ



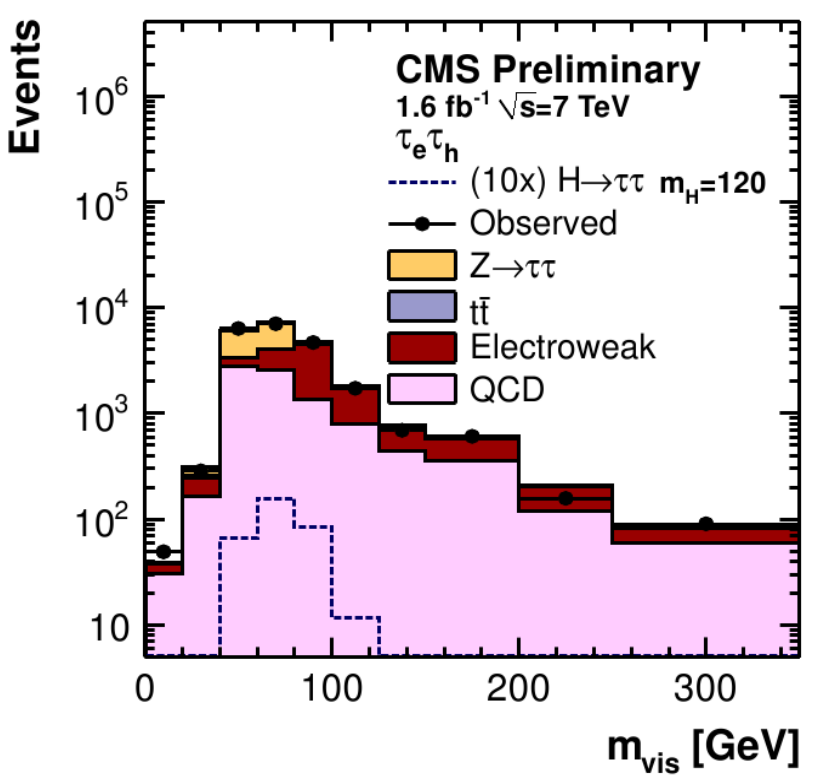


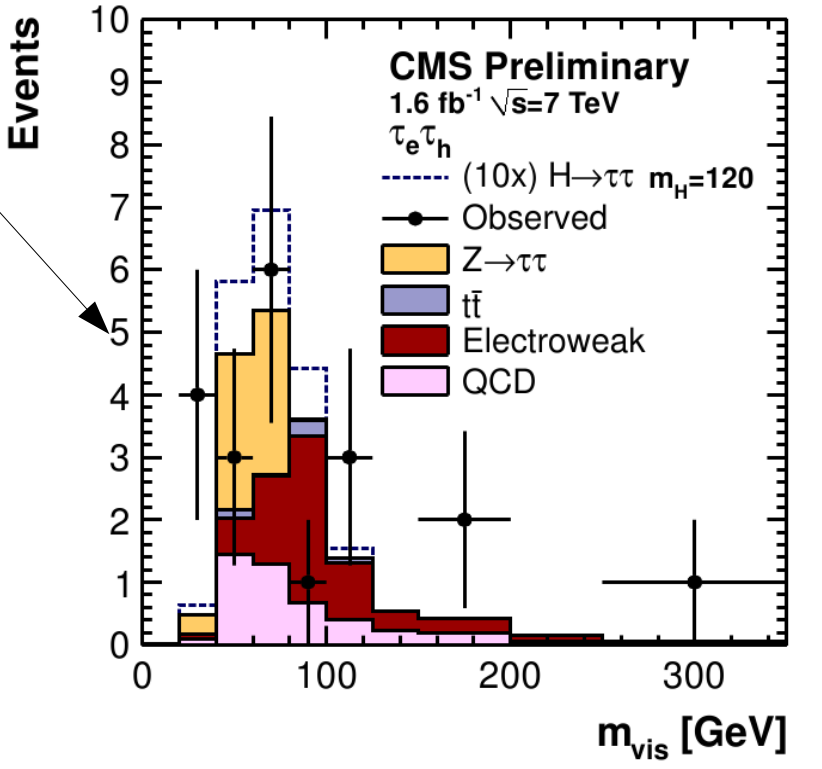


Searches in ττ

- **Signal signatures:**
  CMS analysed e+τ_{had}, μ+τ_{had} and e+μ final states, each divided into categories: without and with VBF-like jets
- **VBF selections:**
  2 additional jets, E_T>30 GeV, m_{jj}>350 GeV, $|\Delta\eta_{jj}|$>3.5, $\eta_1^* \eta_2$<0

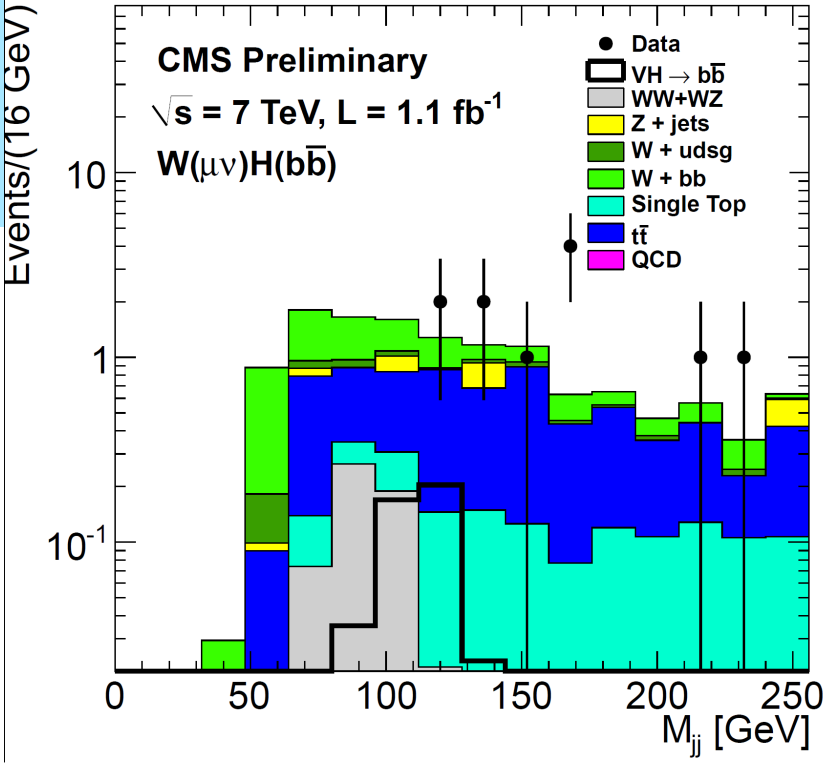
  Very clean signature, but requires high integrated luminosity
- **Neutrinos present in final state:** **invariant mass of visible products used (m_{vis})**
- **Main backgrounds:** **Z→ττ, QCD, tt, W+jets,(Z→ee/μμ)+jets**

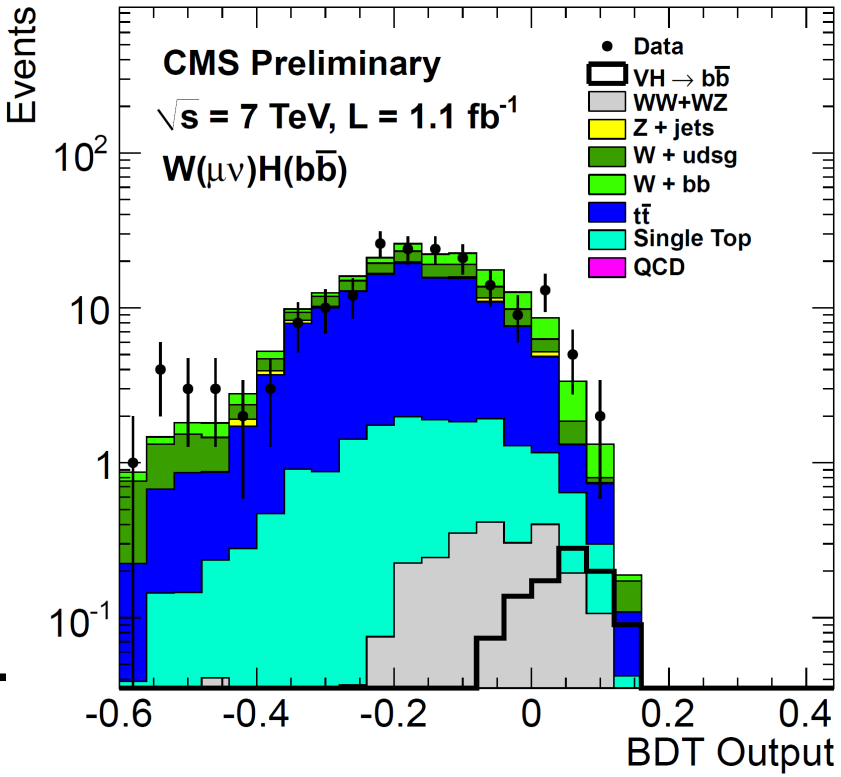




Searches in bb

- **Signal signatures:**
  bb decay is dominant, but requires additional handle to suppress huge QCD background, VH production mode is used with Z→ee/μμ/νν and W→eν/μν
- **Event selections**
  VH azimuthal separation: ΔΦ(V,H)>2.9
  p_T^V>160 (Z→νν)/100 (Z→ll)/150 (W→lν)
  tight b-tag and MET quality
- **Boosted Decision Tree analysis made in parallel**
- **Main backgrounds:**
  V+jets, VV, tt



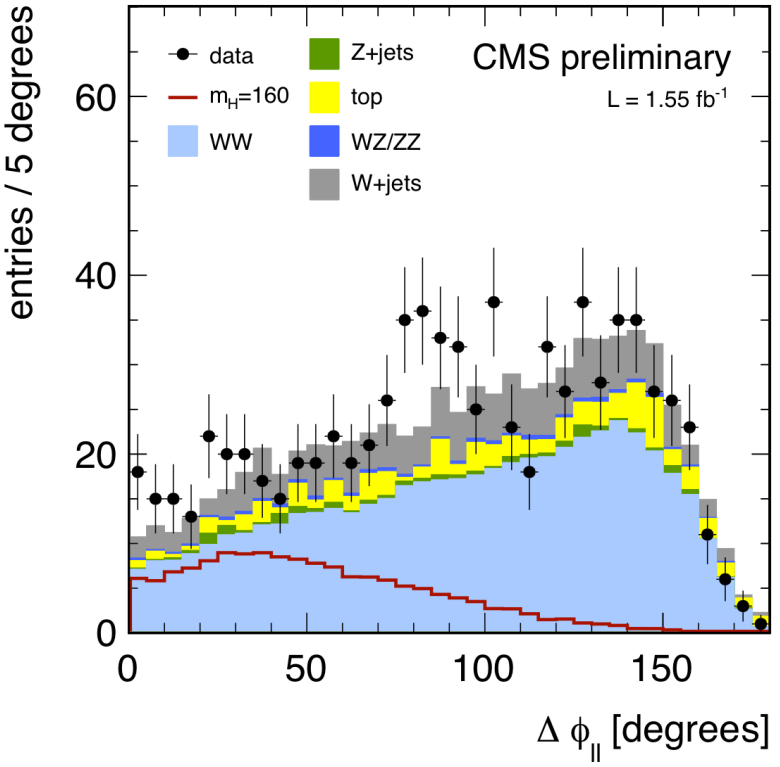


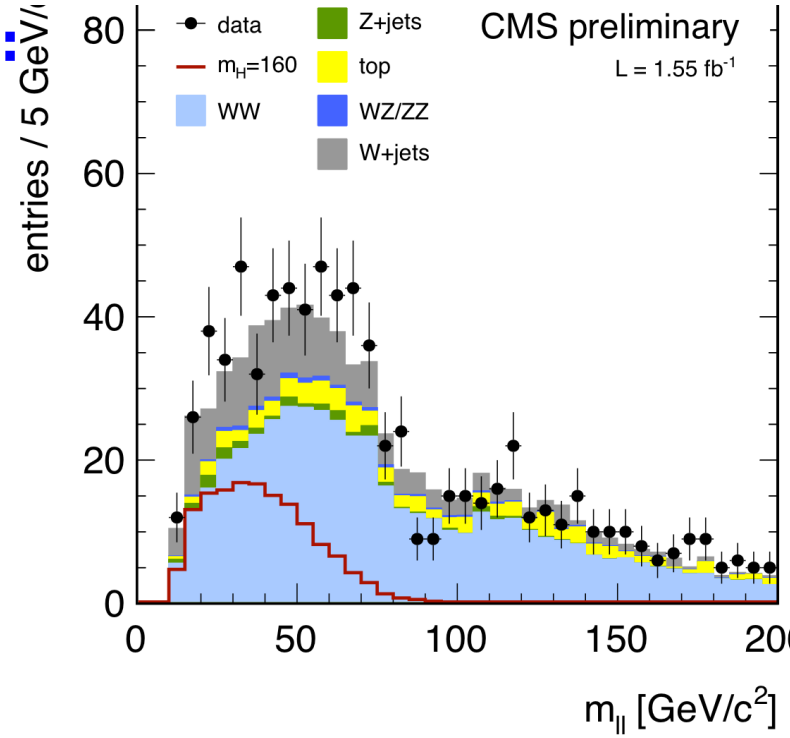
Searches in H→WW→2l2ν

- **Signal signatures:**
  two isolated leptons,
  large missing $E_{T,}$
  lepton azimuthal angle correlations

- **Event selections:**
  lepton p_T>10 GeV, tight ID, isolation,
  veto events with additional soft leptons or with b-tagged jets,
  split events in jet multiplicity categories: 0,1 and 2 jets,
  for 2 jets cat. apply VBF-like selections,
  cut on di-lepton mass,
  cut on di-lepton azimuthal separation,
  cut on transverse mass of (MET,ll) system

- **Main backgrounds:** WW, tt, W+jets,Drell-Yan, WZ, ZZ





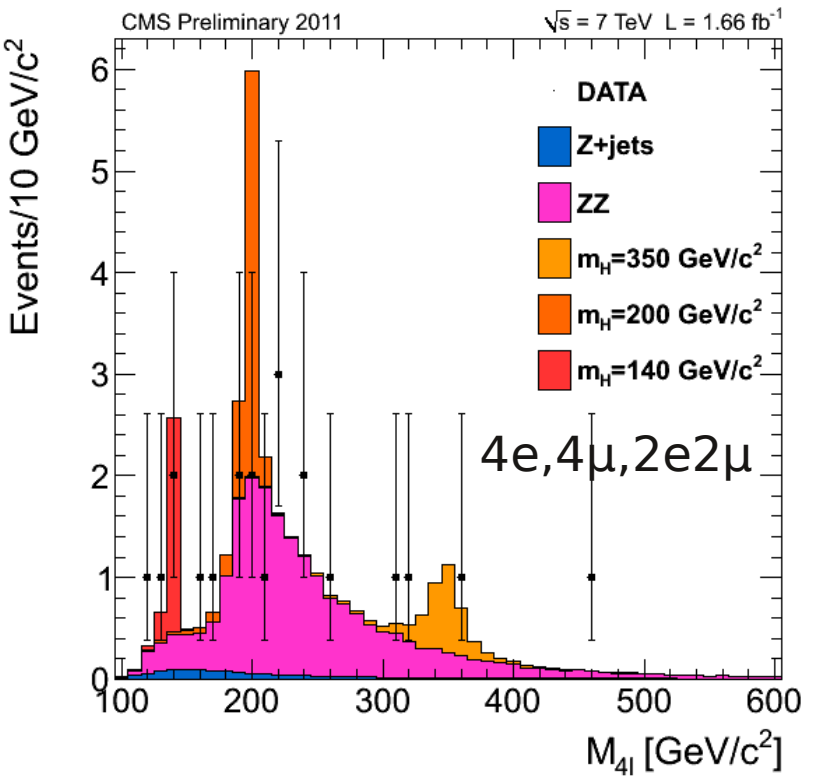
$H \rightarrow ZZ^{(*)} \rightarrow 4l$

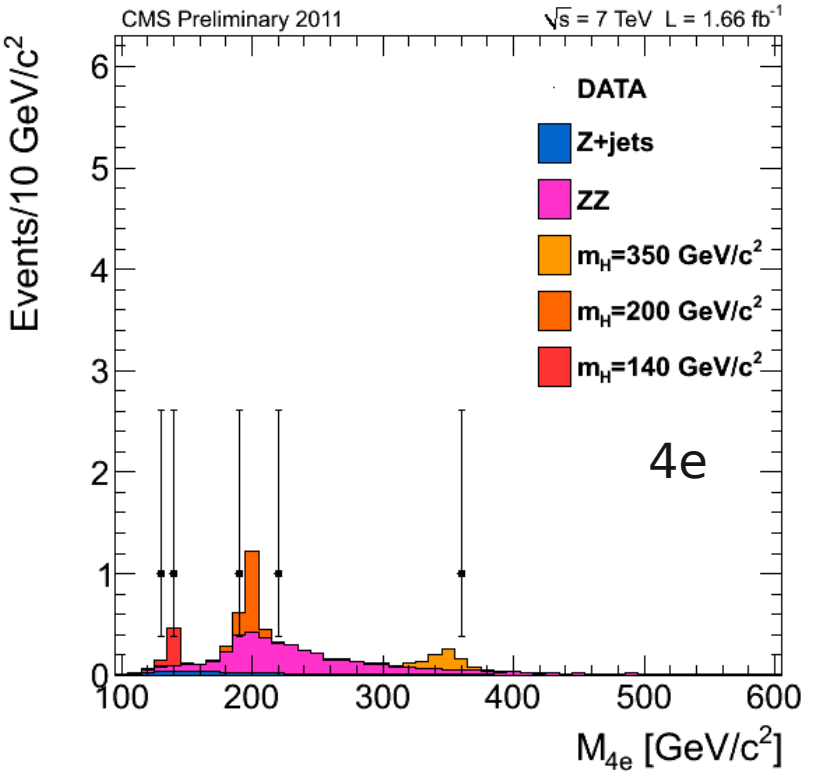
- **Signal signatures:**
  two isolated leptons,
  Z mass constraint for one ll pair,
  full H mass reconstruction with
  2-4 GeV resolution

- **Event Selections:**
  leptons: $p_T^{electron}>7$ GeV, $p_T^{muon}>5$ GeV,
  Z_1: $p_T^{l1}>20$, $p_T^{l2}>10$, $60<m_{ll}<120$,
  Z_2: $20<m_{ll}<120$, $m_{4l}>100$

- **Main backgrounds:**
  ZZ, Zbb, Z+jets, WZ,tt

- **The ZZ continuum estimation:** **normalised with Z yield in data and theoretical prediction of σ(ZZ)/σ(Z)**

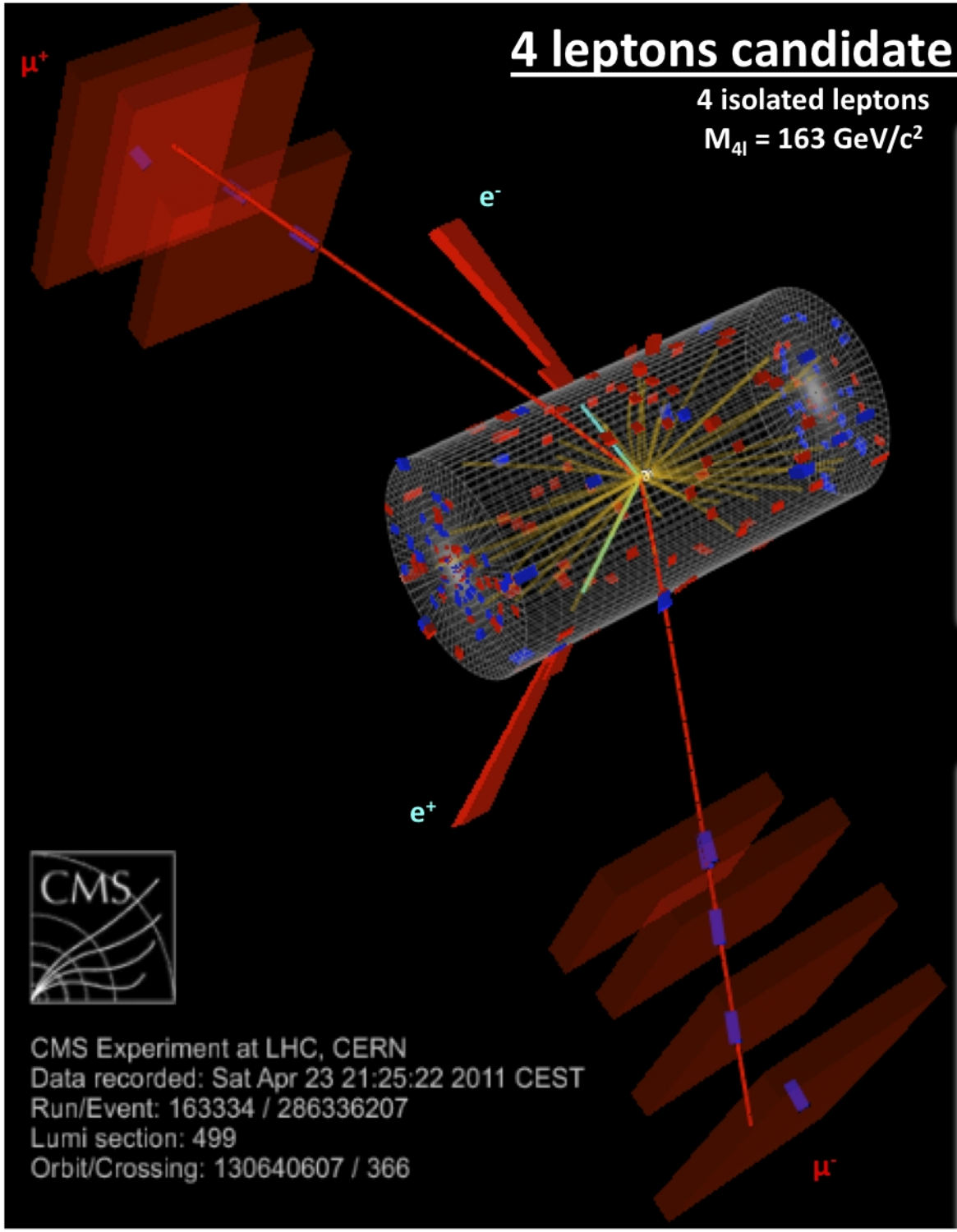


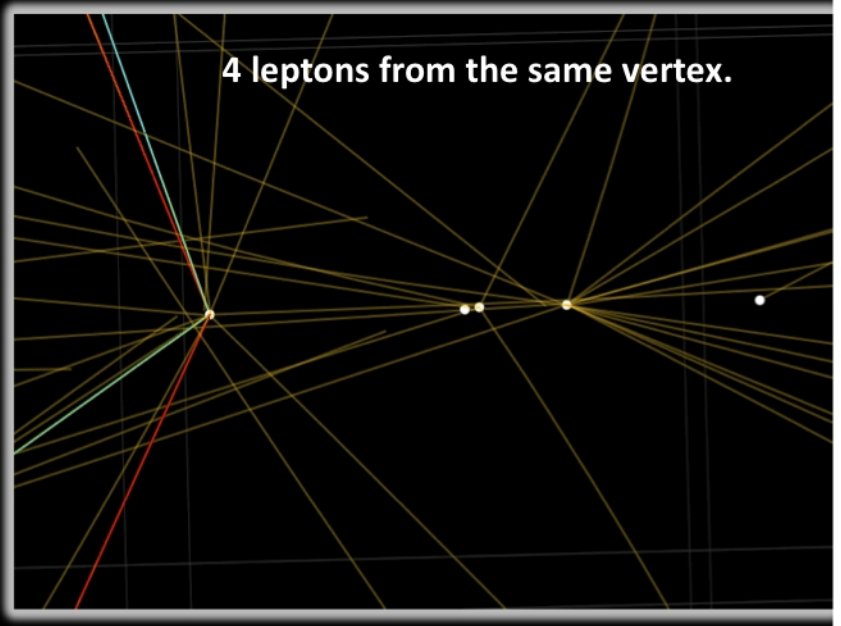


4 leptons candidate : 2e2μ

4 isolated leptons

M_{4l} = 163 GeV/c^2

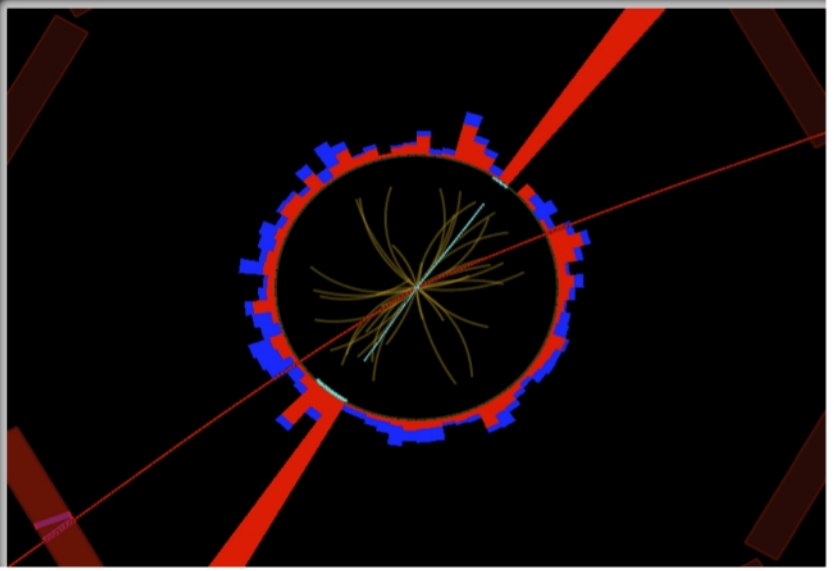




2 leptons pairs

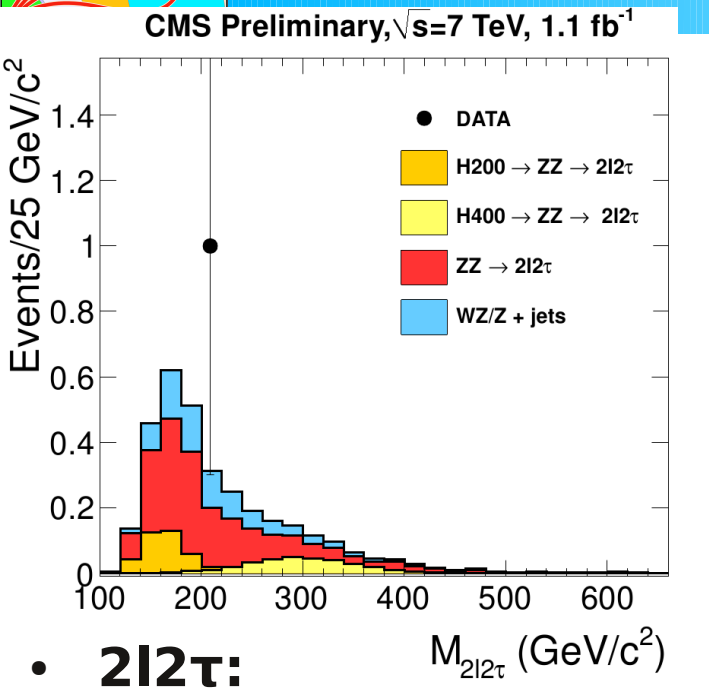
Z (μ+μ-) : m = 94 GeV/c^2

Z*(e+e-) : m = 65 GeV/c^2

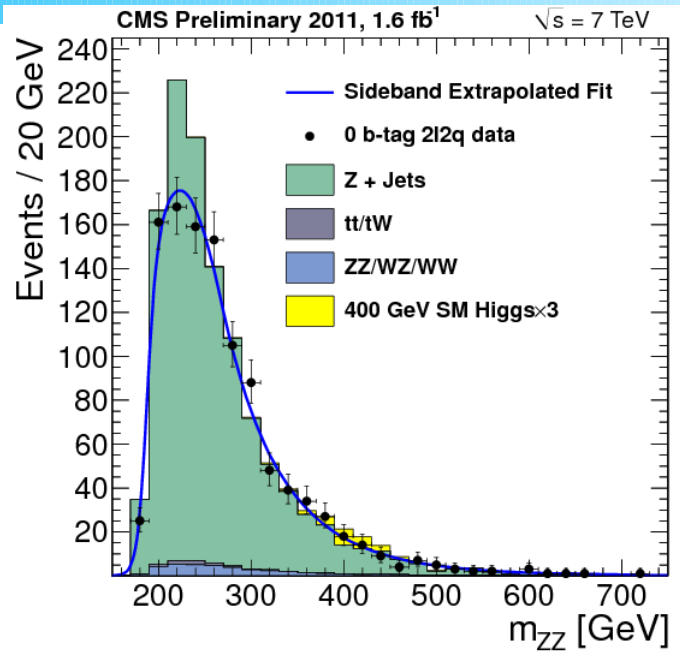


CMS Experiment at LHC, CERN
Data recorded: Sat Apr 23 21:25:22 2011 CEST
Run/Event: 163334 / 286336207
Lumi section: 499
Orbit/Crossing: 130640607 / 366

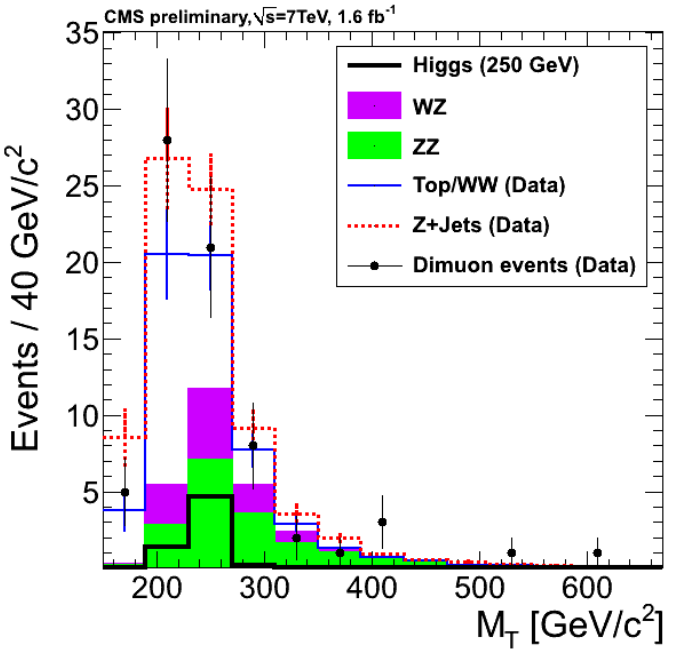
$H \to ZZ^{(*)} \to 2l2\tau/2l2q/2l2\upsilon$



- **2l2τ:**
- **Selection: "leading" Z: 2e/2μ decay, p_T^l>20/10, "subleading" Z: $\mu\tau_{had}$, $e\tau_{had}$, μe, $\tau_{had}\tau_{had}$**
- **Main backgrounds: ZZ,Z+jets, WZ+jets, tt**



- **2l2q: highest rate among ZZ, events categorised by 0,1,2 b-jets,**
- **Selection: $75<m_{jj}<105$, $70<m_{ll}<110$, use lepton angles in likelihood**

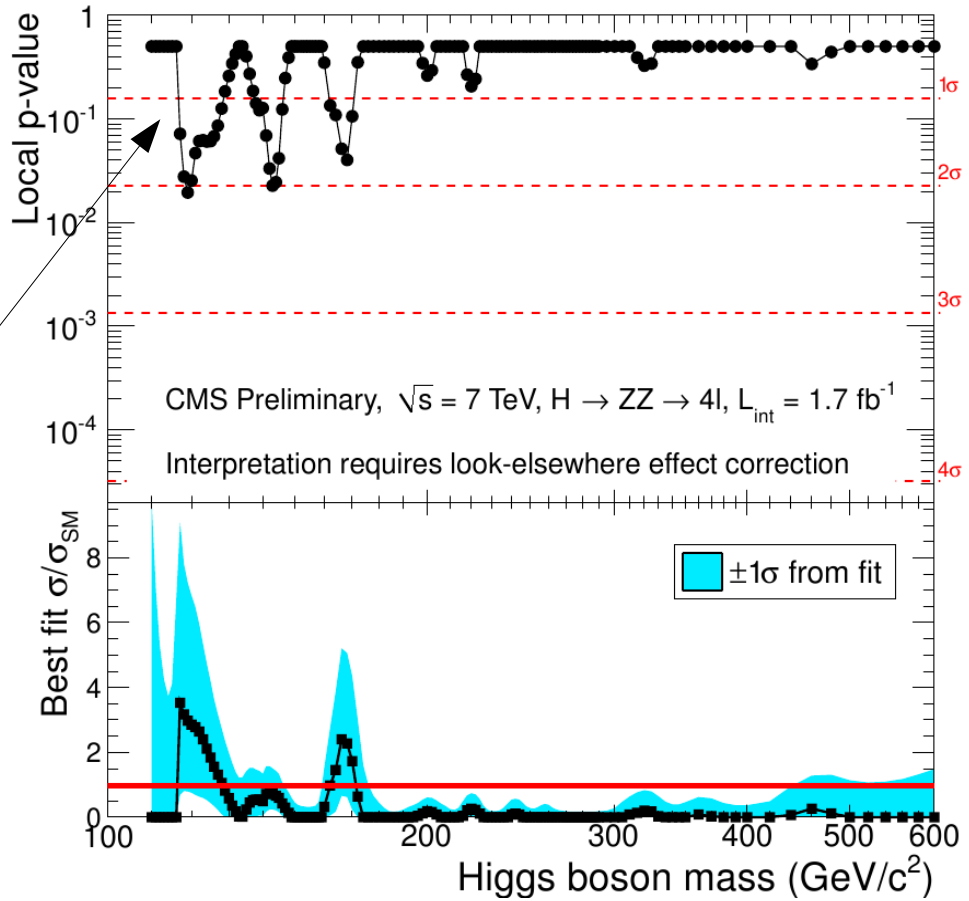


- **2l2υ**
- **Selection: $76<m_{ll}<106$, MET and M_T cut depend on mass hypothesis anti b-tag, M_T**
- **Main backgrounds: ZZ,Z+jets, tt, WZ**

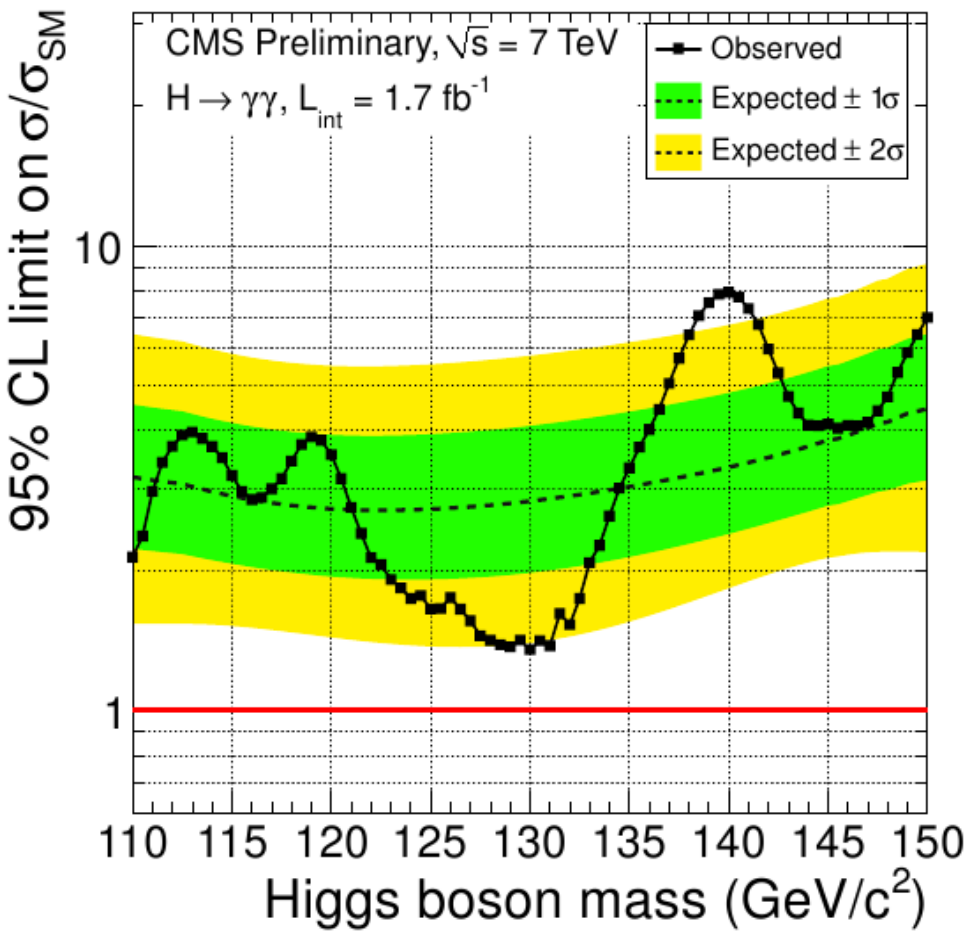
Word of caution: LEE

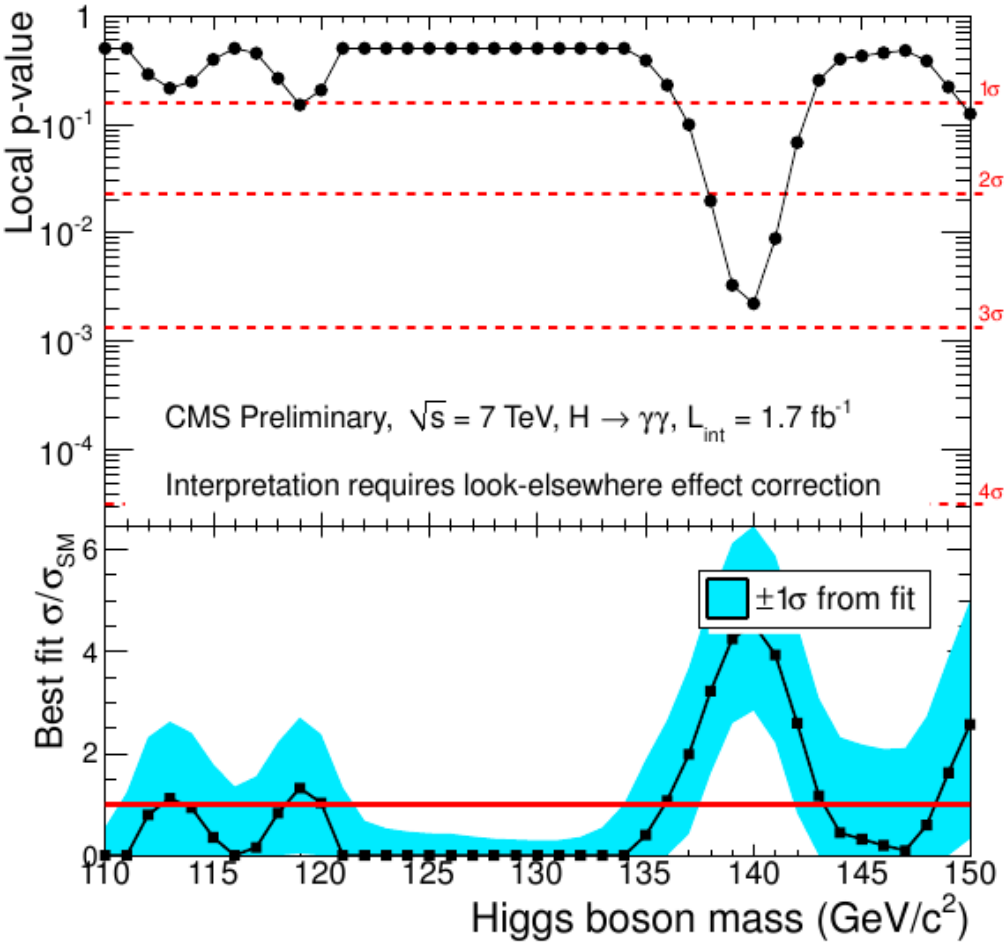
- we are looking at wide mass range divided in many bins
- probability of upward fluctuation in each bin can be small
- **but given many bins, global probability of observing upward fluctuation can be significant**
- the effect is called “look elsewhere effect”, or “trial factor”

- for H→ZZ→4l CMS estimates the trial factor of order of 35
- **local probability for background-only upward fluctuation should be multiplied by a factor of order 35**
- For local p~0.01, Z_{max}~2.3 with LEE we get globally p~0.4, Z_{global}~0.25



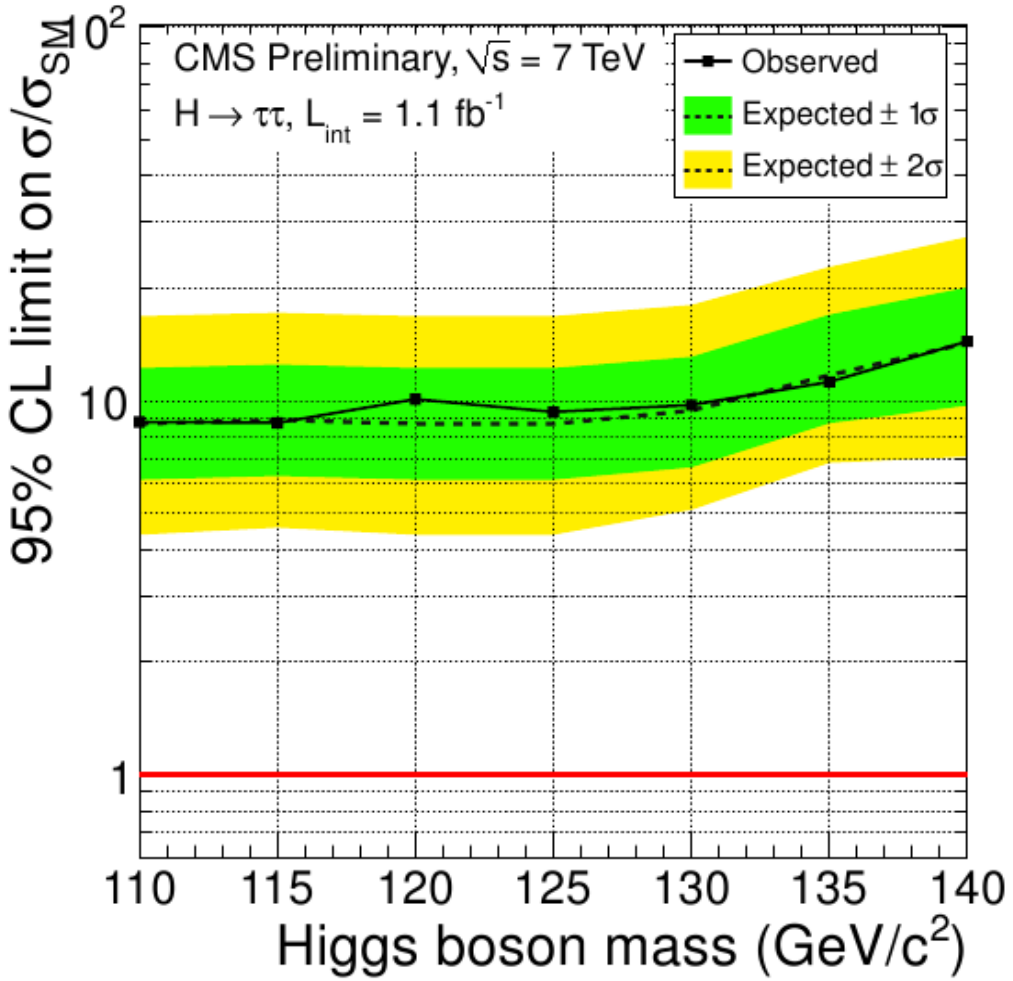
Results in H→γγ

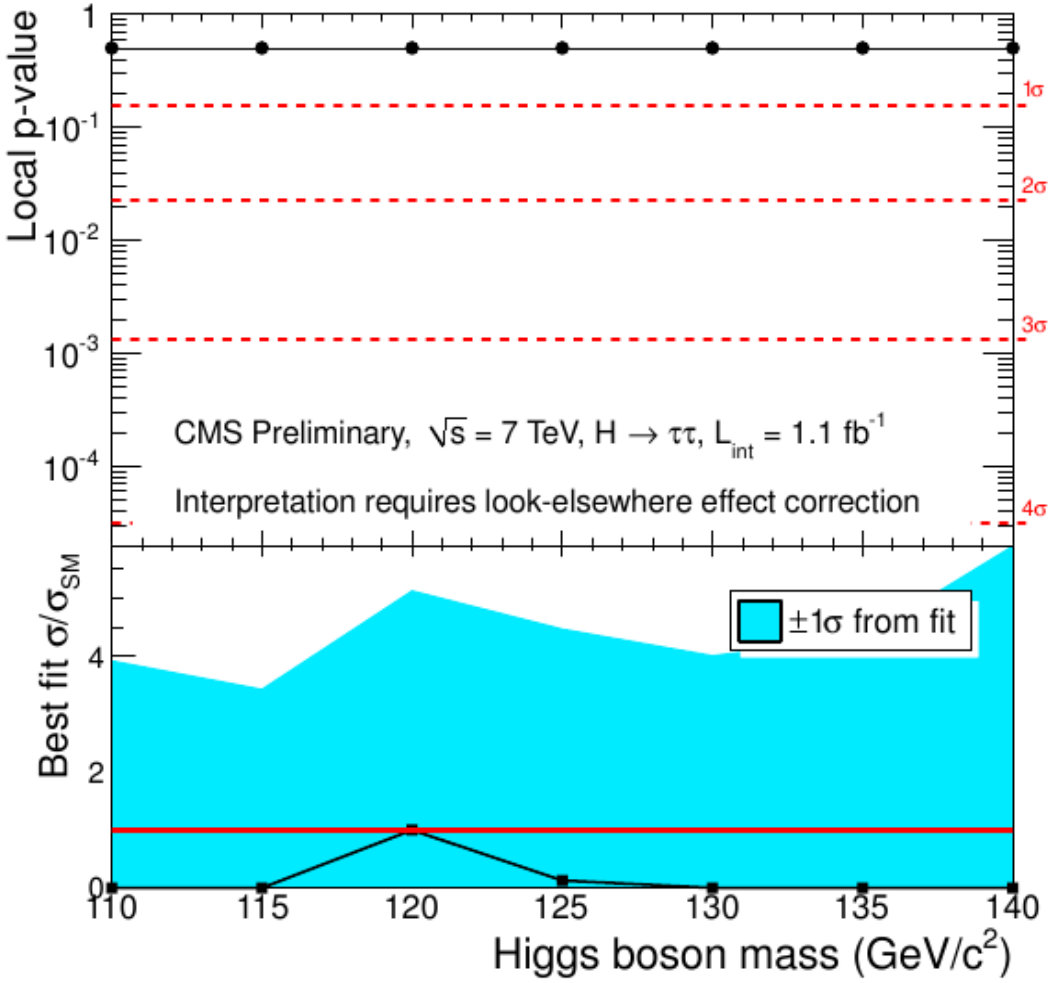




- With 1.7 fb^{-1} exclusion limit in this channel is on the level of 2-5·σ_{SM}
- Local data excess near 140 GeV of 2.8σ is reduced to 1.7σ with LEE correction

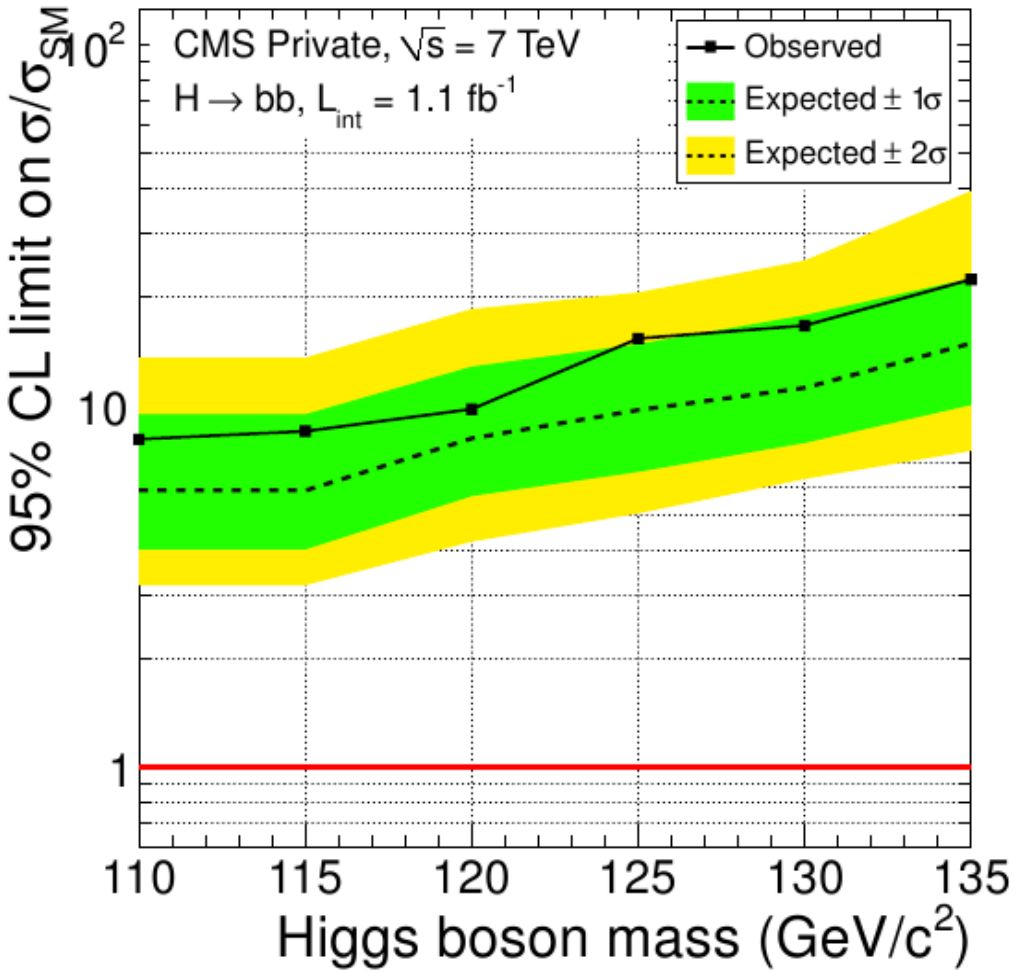
Results in H→ττ

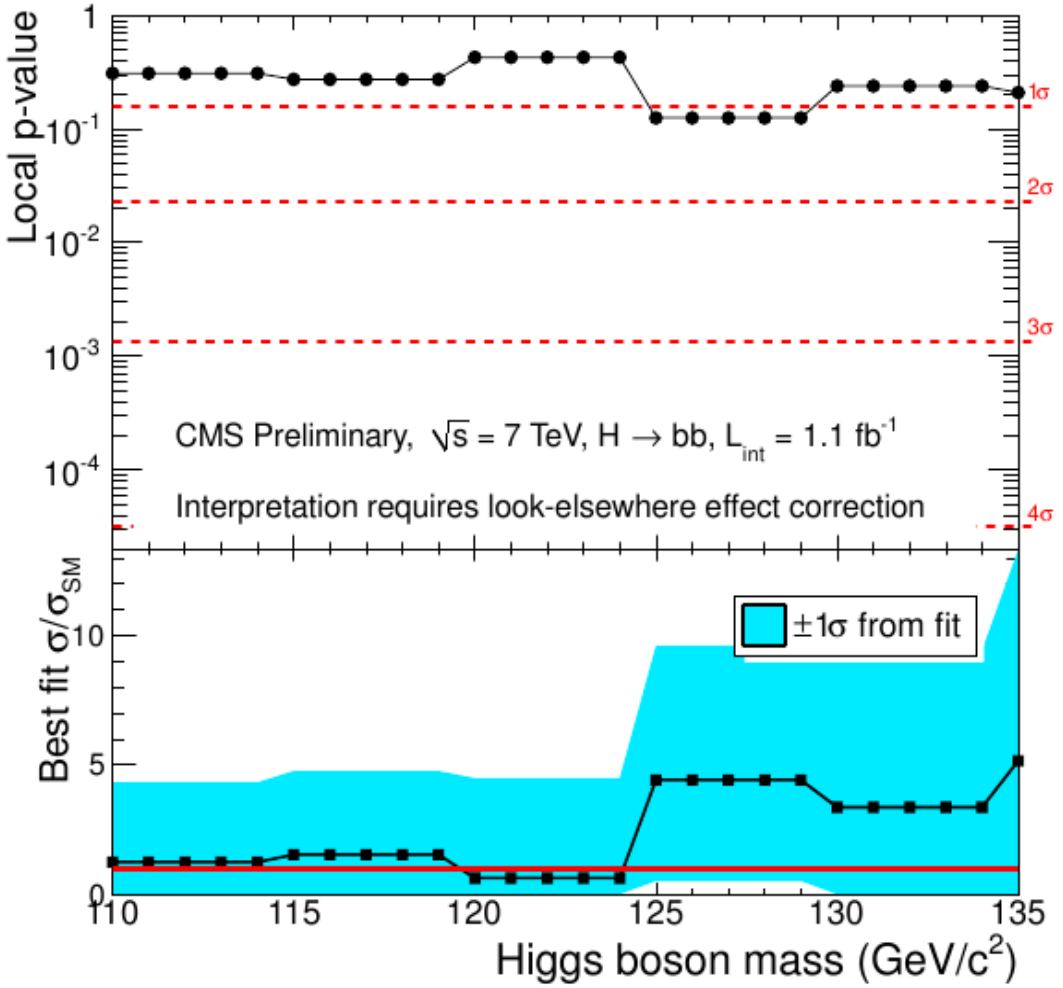




- With 1.1 fb^{-1} exclusion limit in this channel is on the level of $10 \cdot \sigma_{SM}$
- No data excess above expected background is observed

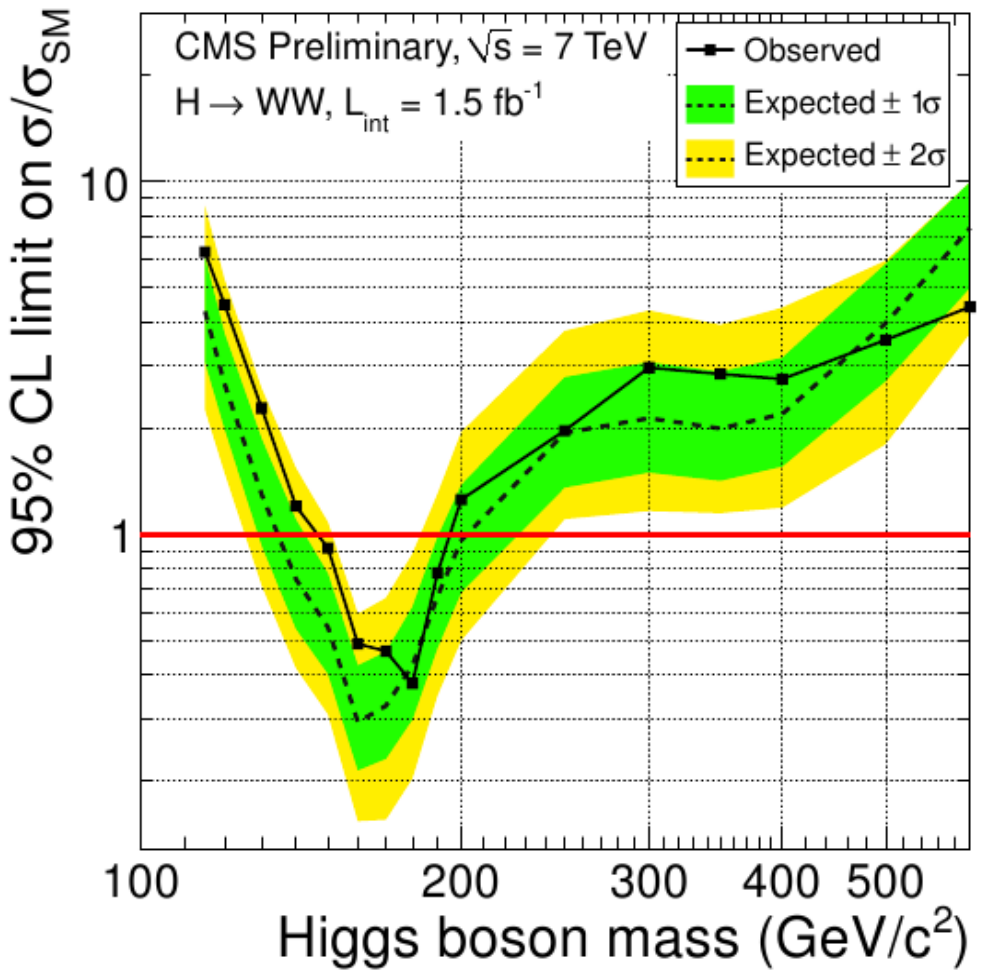
Results in H→bb

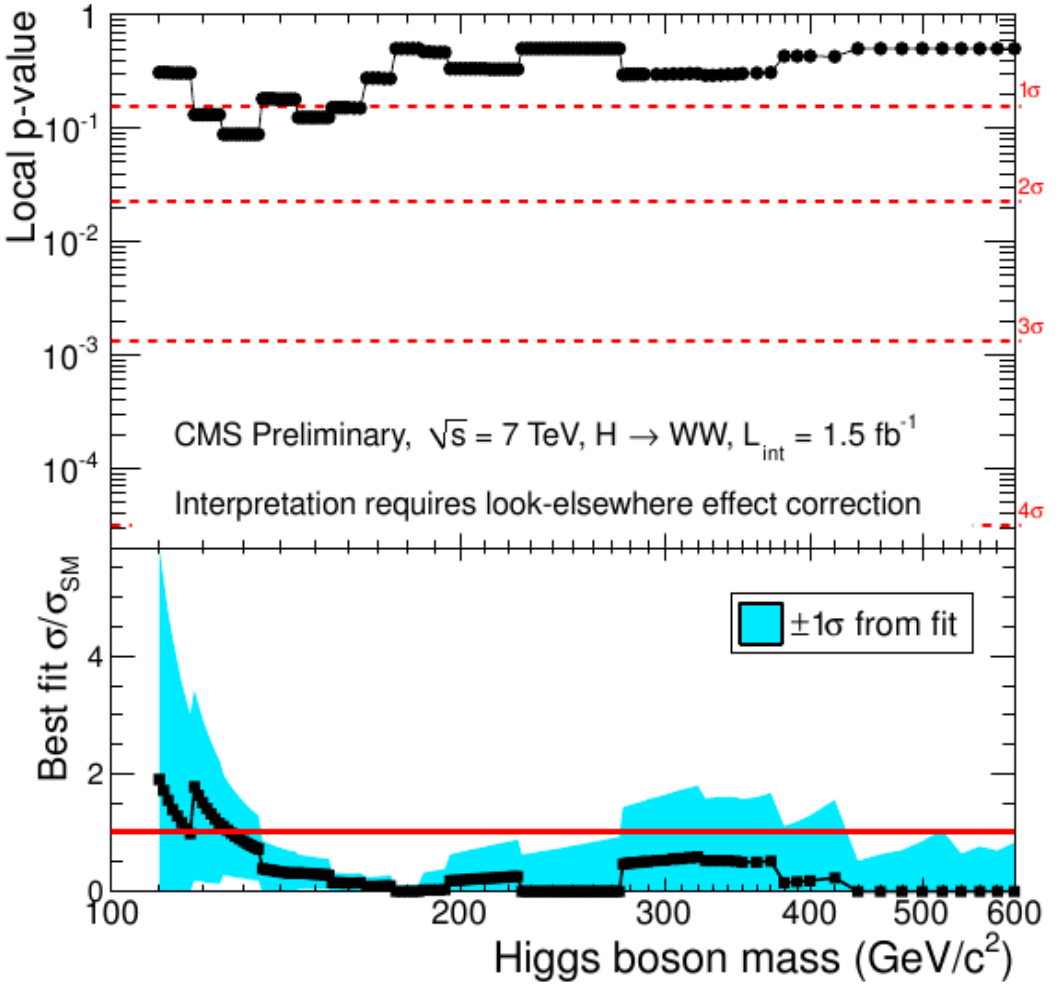




- With 1.1 fb^{-1} exclusion limit in this channel is on the level of 10-20·σ_{SM}
- No significant data excess above expected background is observed

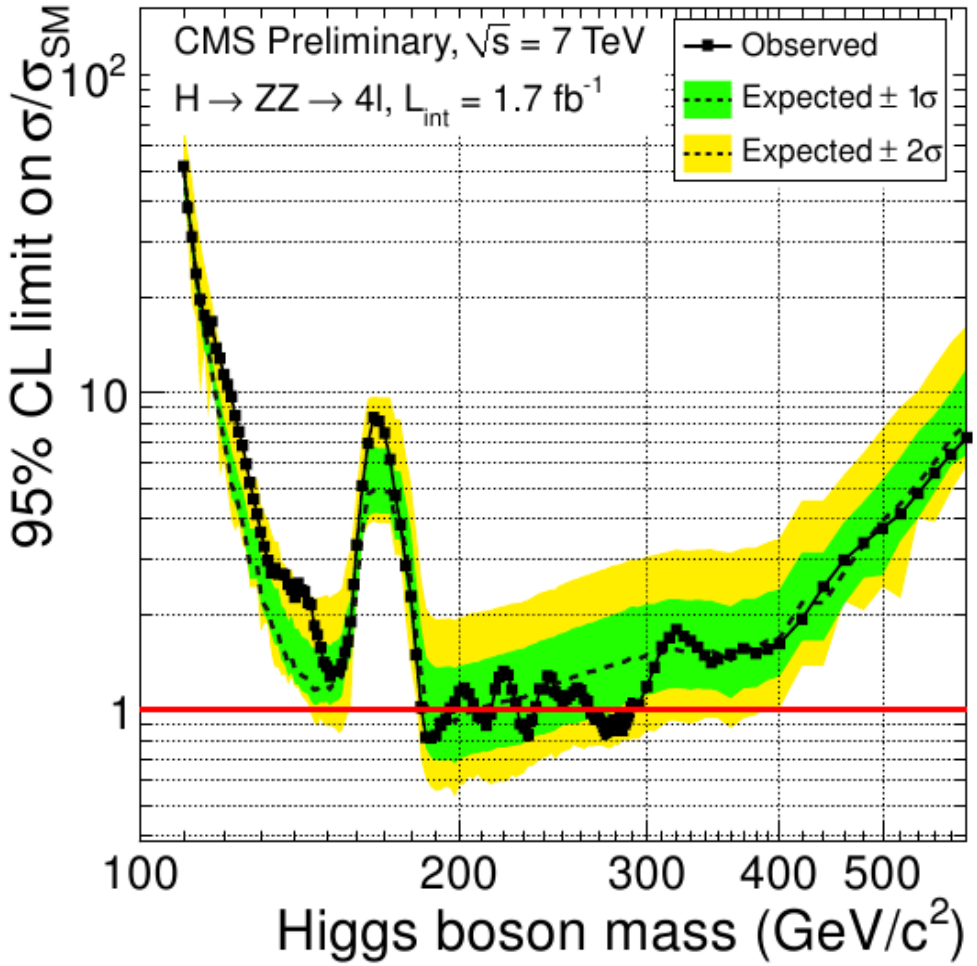
Results in H→WW→2l2ν

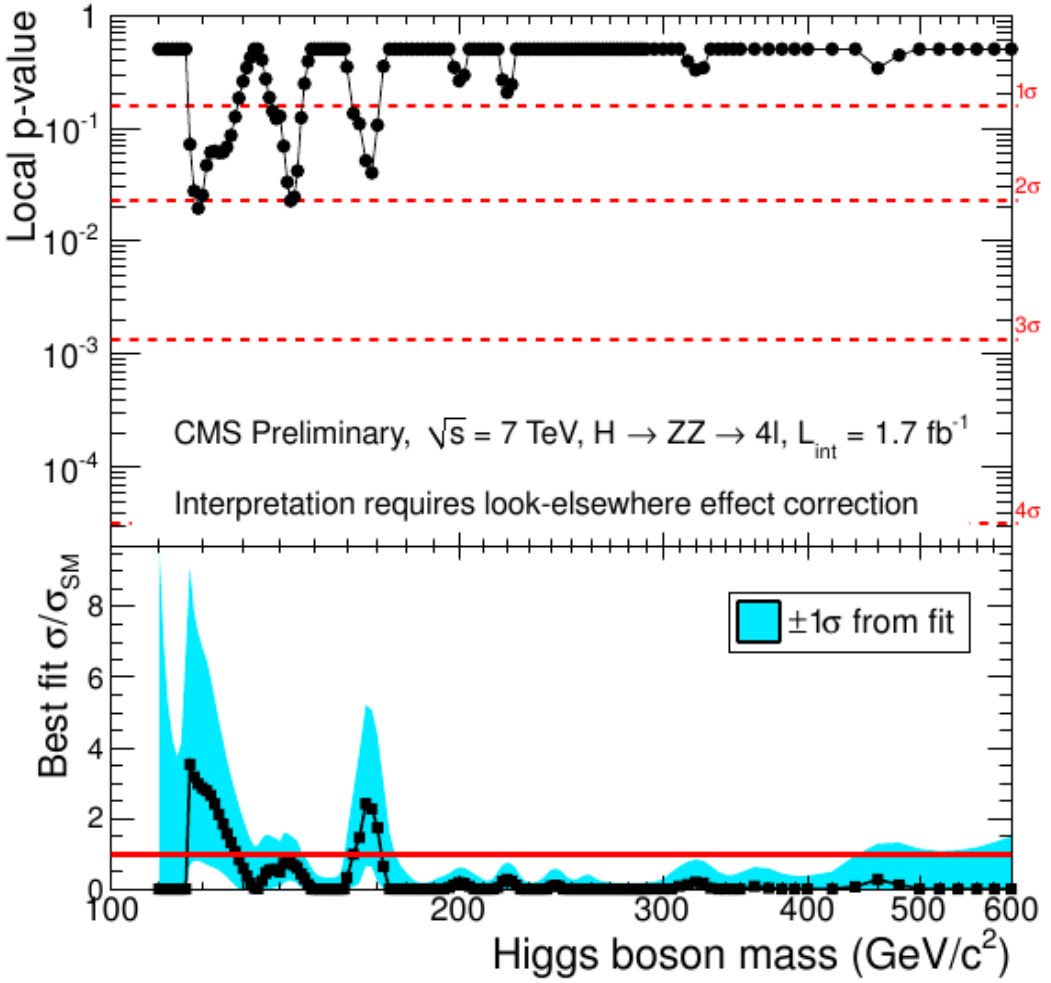




- With 1.5 fb^{-1} exclusion limit in this channel is on the level of 0.4-8·σ_{SM}
- No significant data excess above expected background is observed

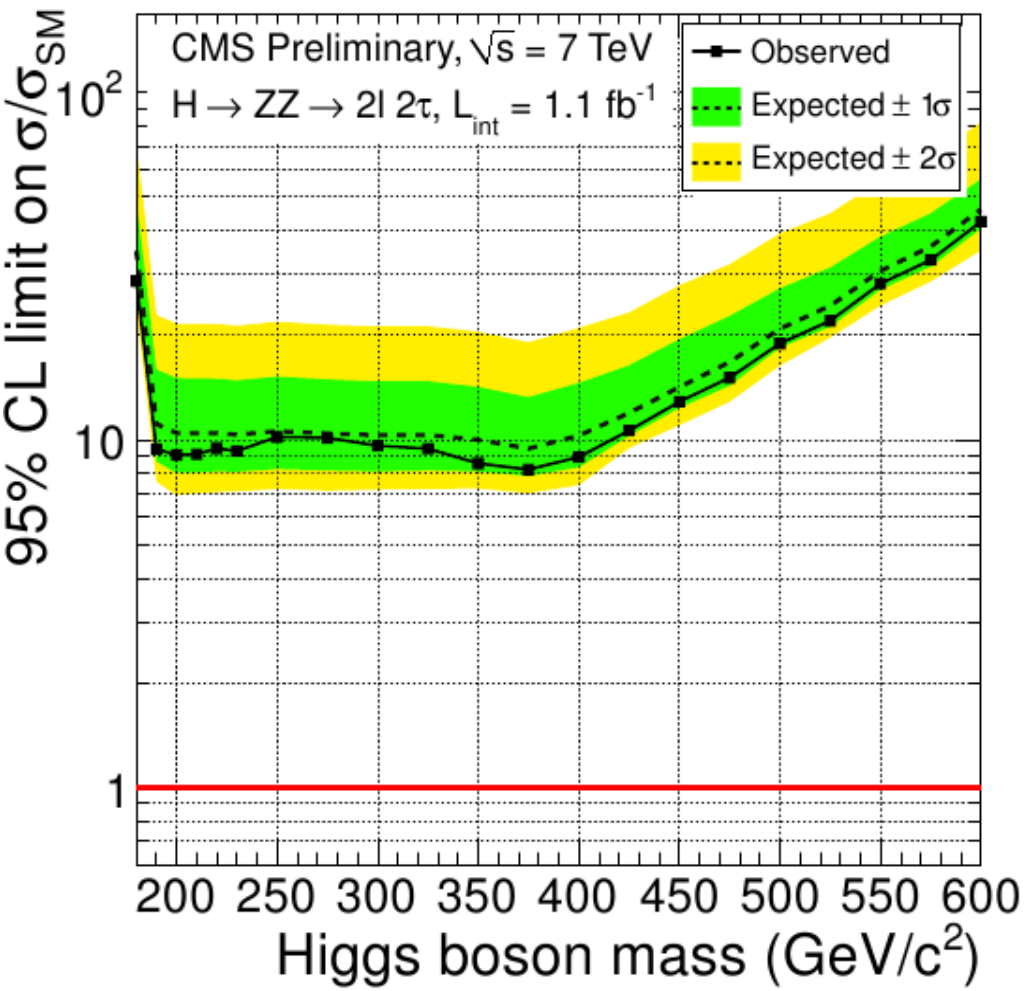
Results in H→ZZ(*)→4l

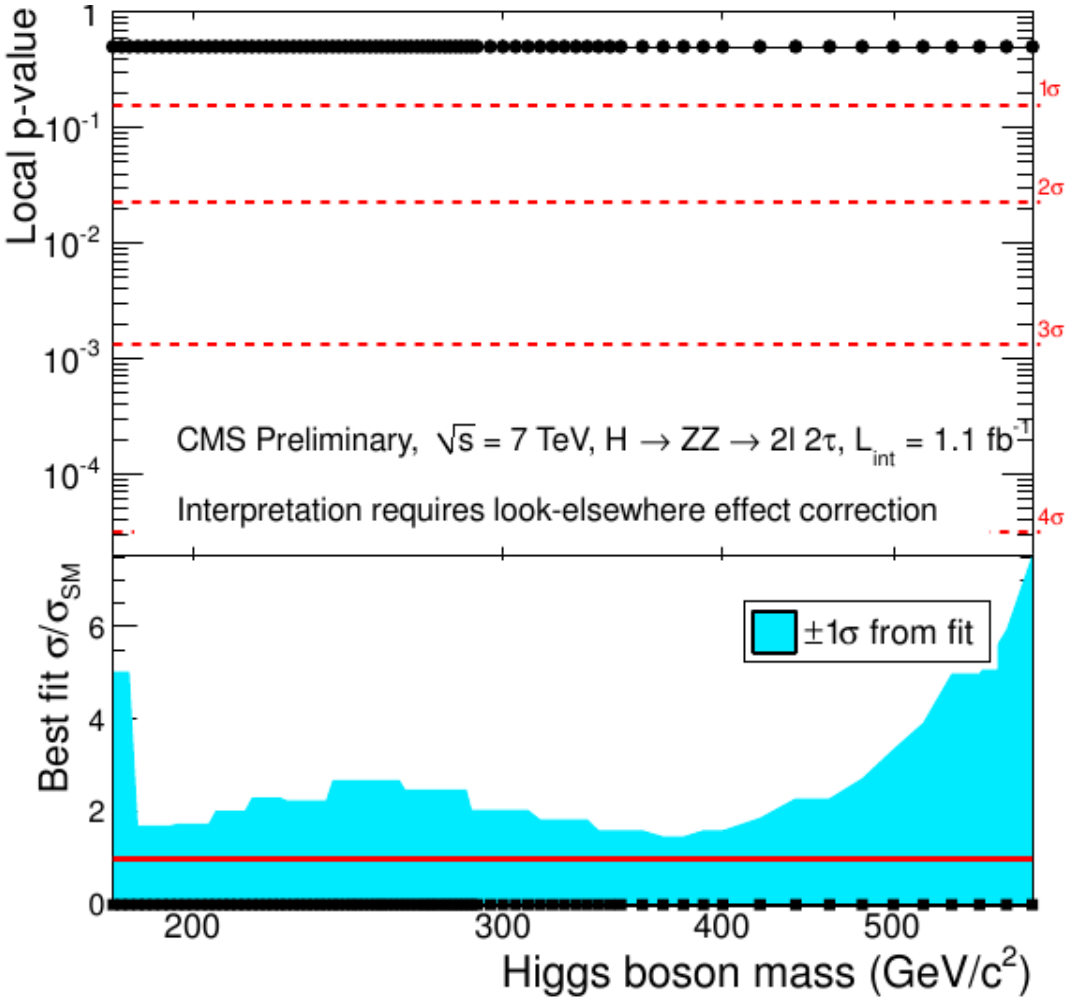




- With 1.7 fb^{-1} exclusion limit in this channel is on the level of 0.8-10·σ_{SM}
- Local data excesses of order ~2σ are reduced to ~0.25σ (p=0.4) with LEE correction

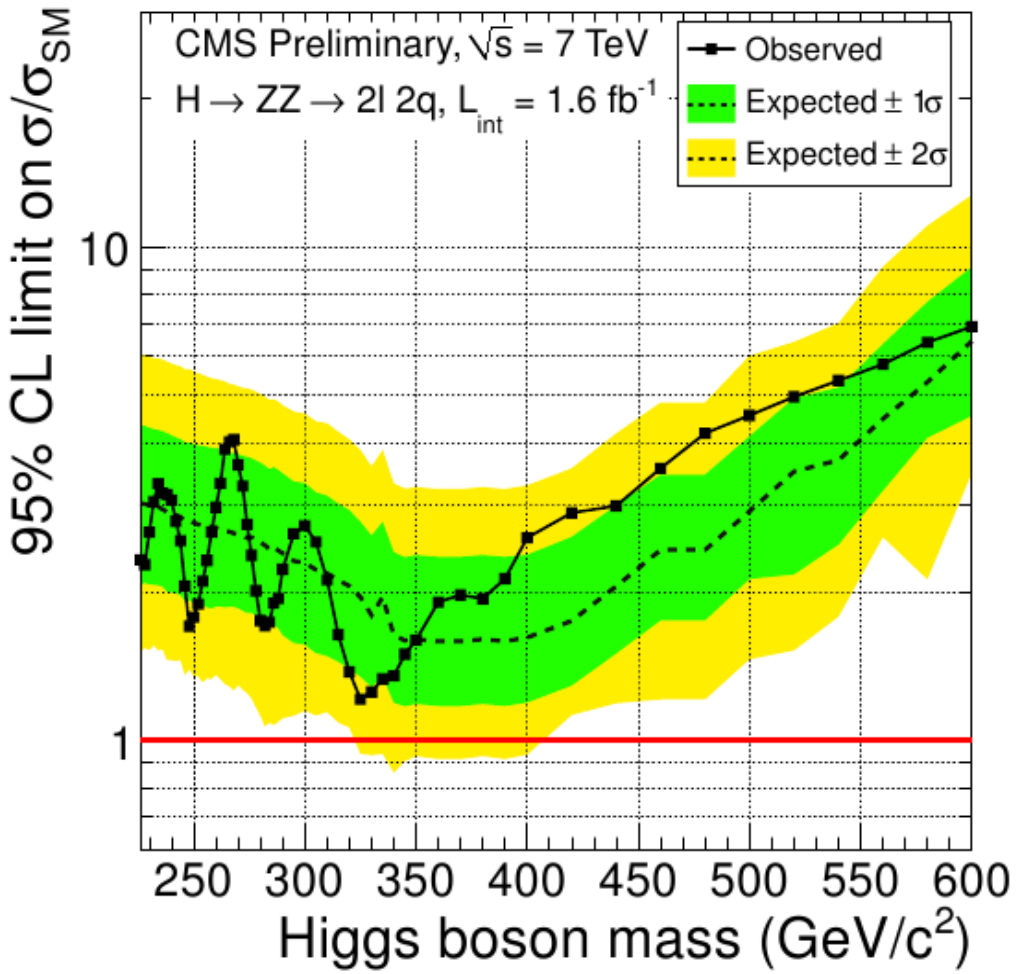
Results in H→ZZ(*)→2l2τ

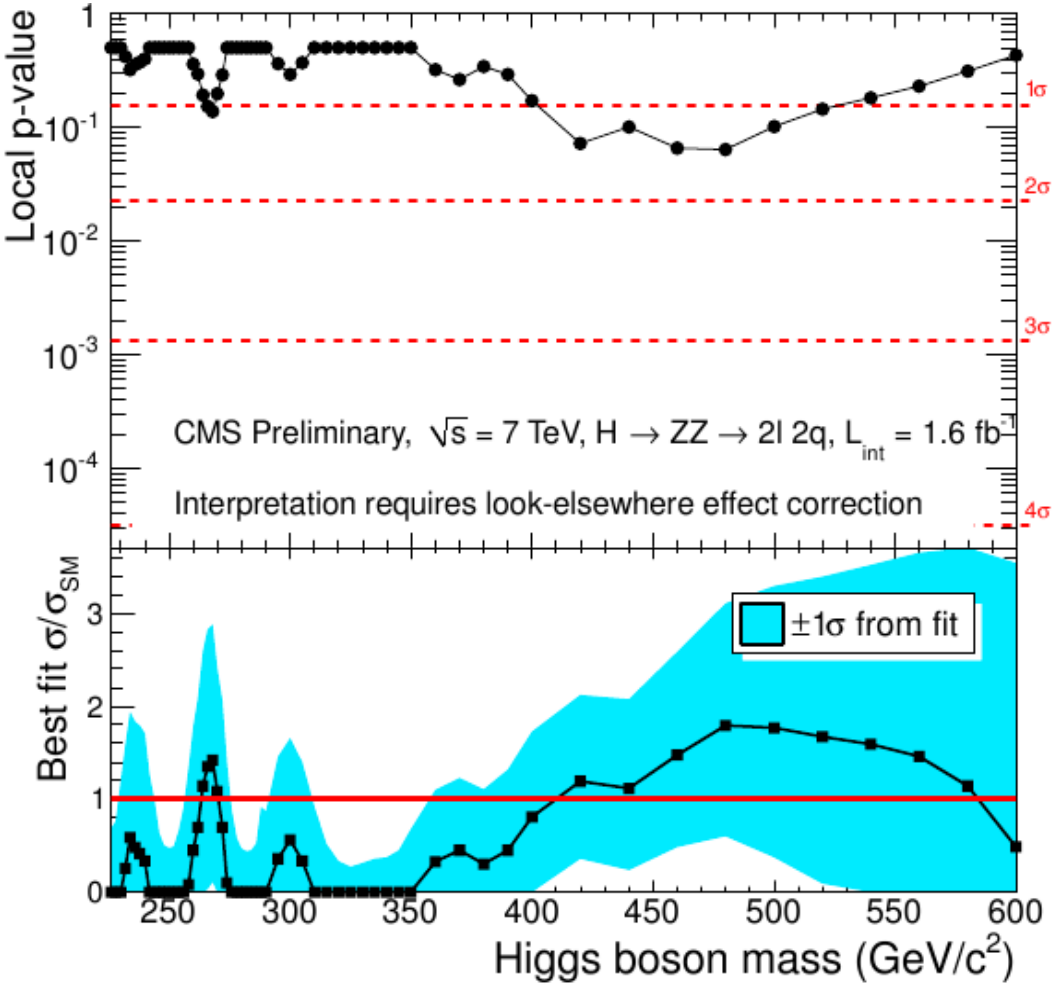




- With 1.1 fb^{-1} exclusion limit in this channel is on the level of 10-40·σ_{SM}
- No data excess above expected background is observed

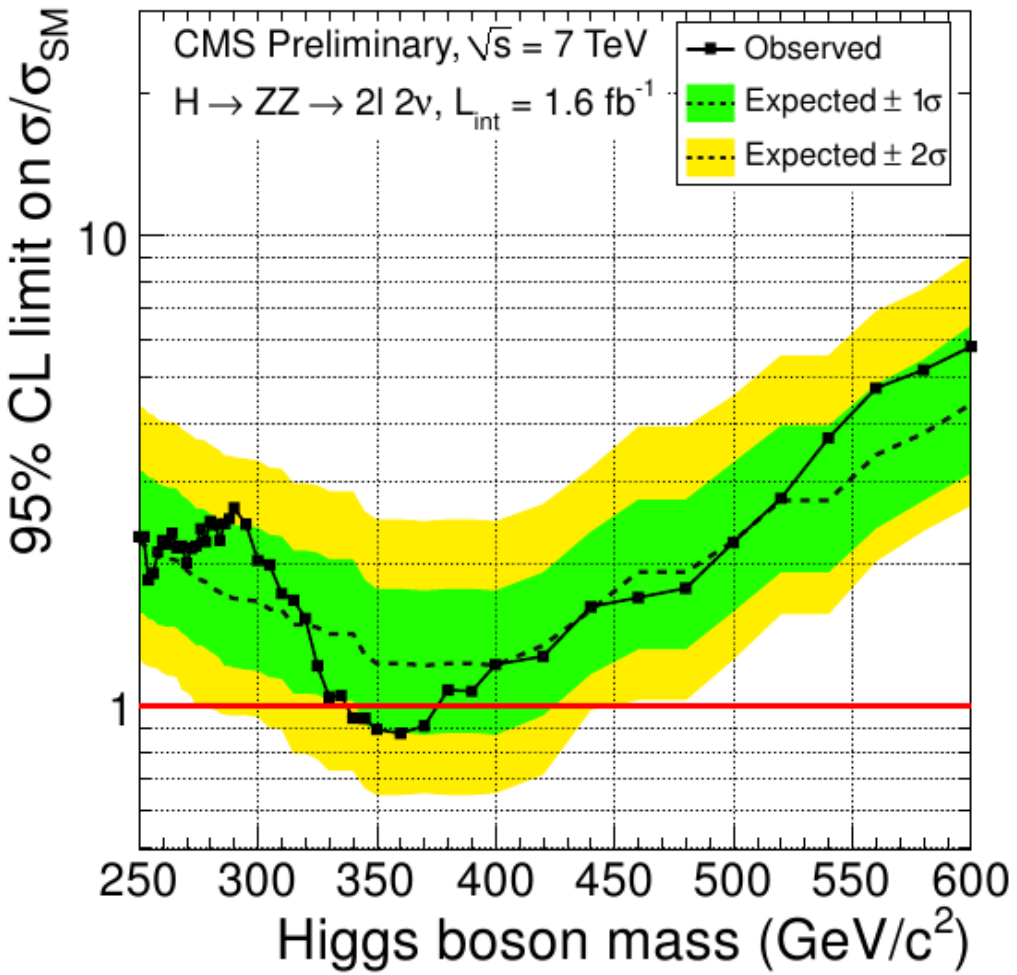
H→ZZ(*)→2l2q

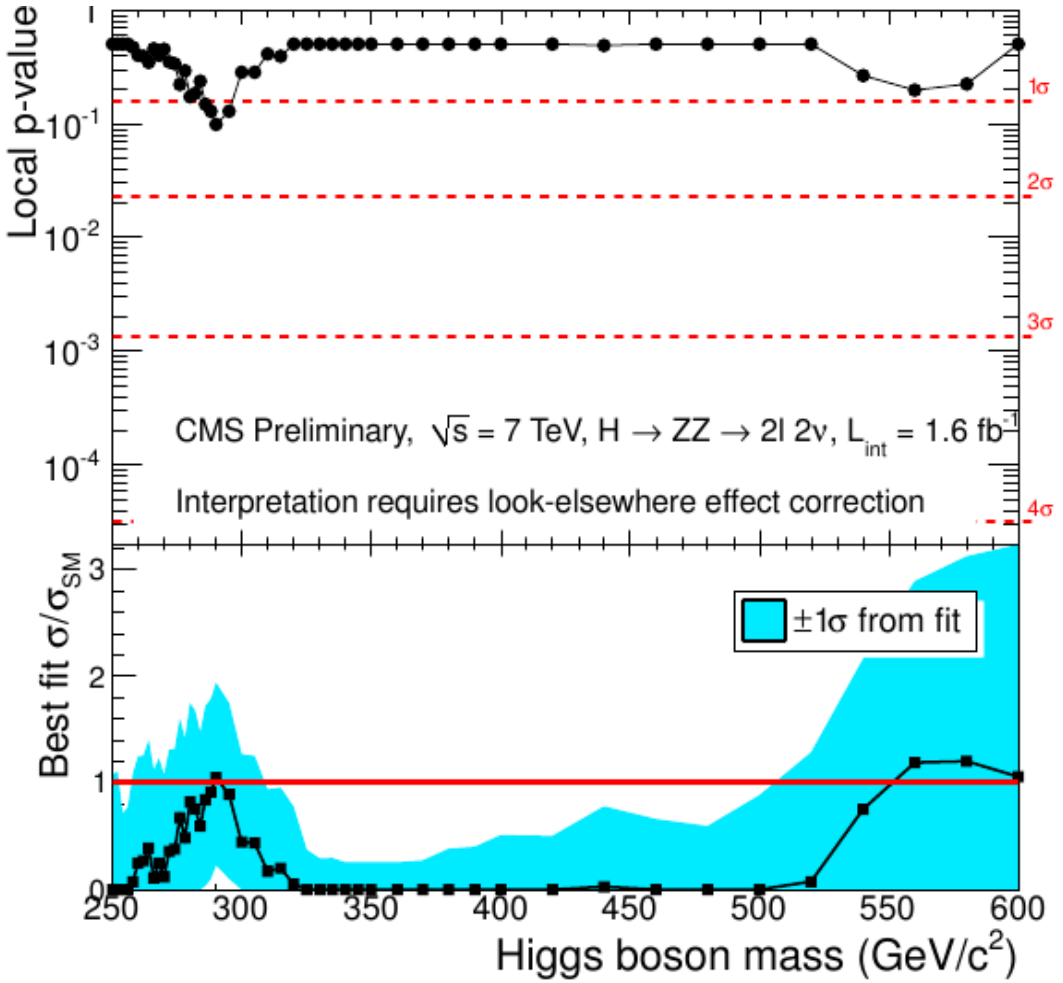




- With 1.6 fb^{-1} exclusion limit in this channel is on the level of 2-7·σ_{SM}
- No significant data excess above expected background is observed

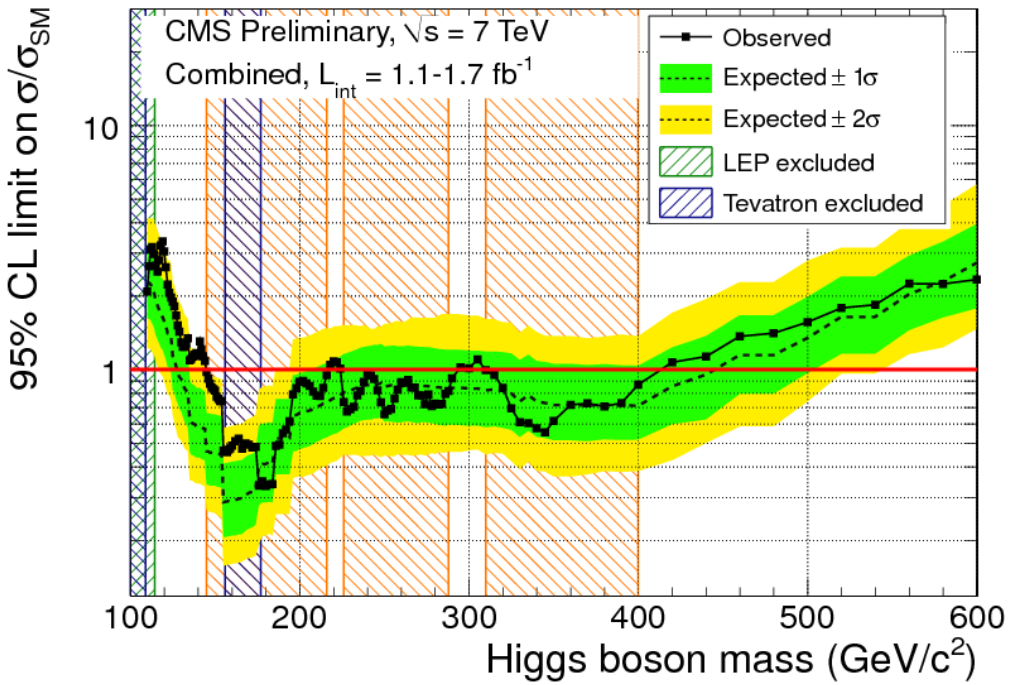
H→ZZ(*)→2l2υ

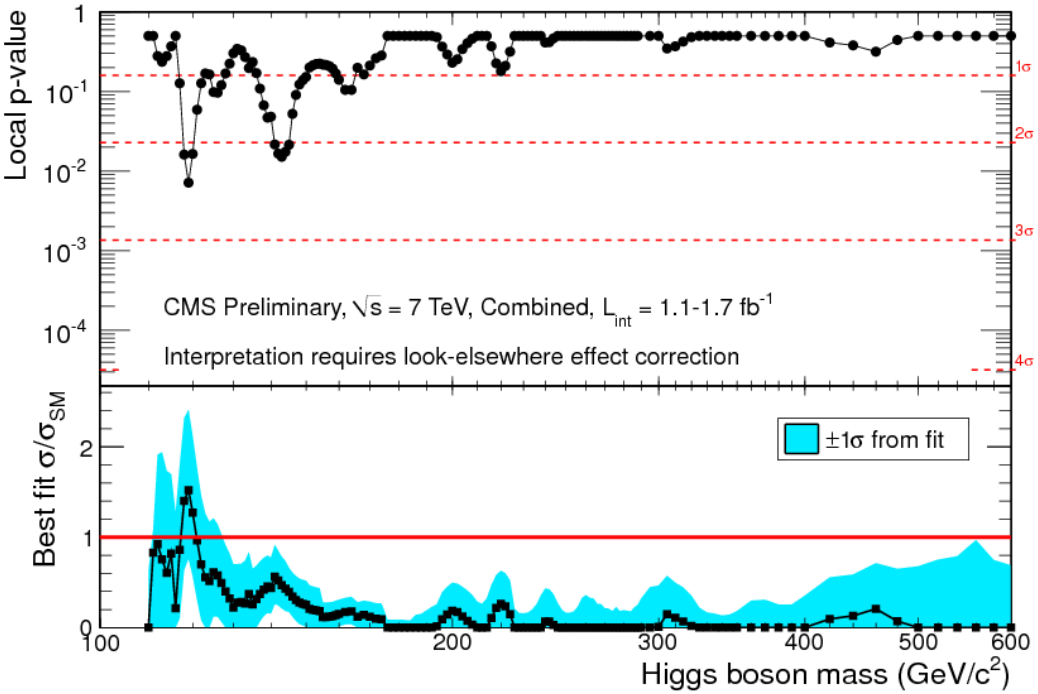




- With 1.6 fb^{-1} exclusion limit in this channel is on the level of 0.9-6·σ_{SM}
- No significant data excess above expected background is observed

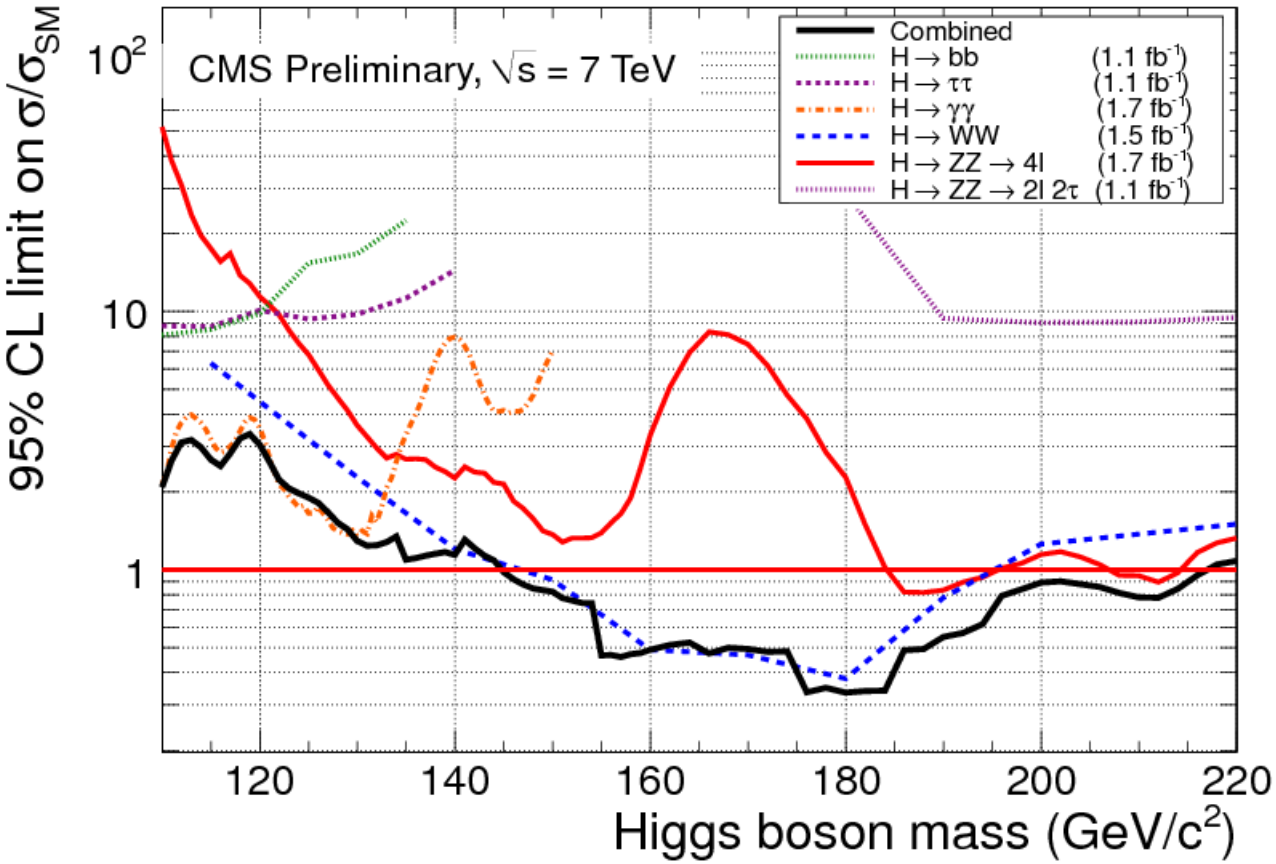
SM Higgs combined results





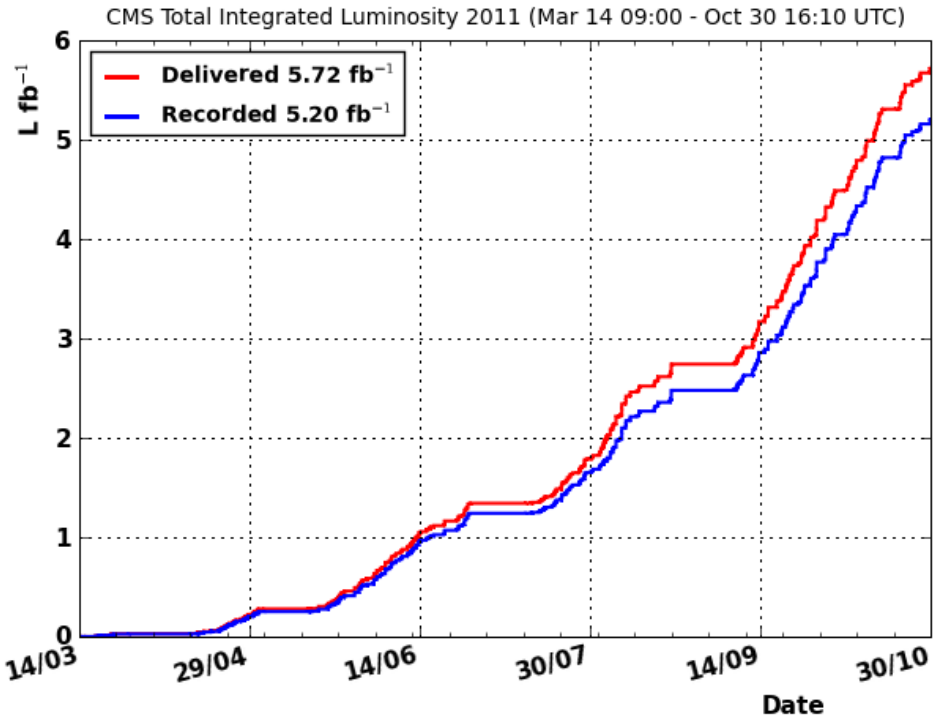
- 95% CL exclusion range: **145 – 216, 226 – 288 and 310 – 400 GeV/c²**
- When looking at p-value plots always remember about the LEE:
  2.3σ visible on the plot is reduced to 0.25σ with LEE
  (trial factor for CMS combination is O(40))
- The CMS observes some “bumps” at low masses, **but those are not statistically significant yet.**

The low mass region



- In low mass region main contribution comes from H→γγ,
- Then H→WW→2l2υ,H→ττ, H→bb,and H→ZZ→4l
- There are many improvements in analyses – at the end of 2011 we can expect better result than what we could get from just more data analysed

Luminosity status



- LHC proton run in 2011 is over now, the machine has delivered over 5 fb^{-1} of data

Conclusions

- **The CMS experiment conducted Higgs boson searches in number of channels with upto 1.7 fb^{-1} of data**
- **No signal was observed in any of those, providing 95% CL exclusion limits in ranges: 145-216, 226-288 and 310-400 GeV**
- **In 2011 LHC has delivered 5 fb^{-1} of data**
- **With 5 fb^{-1}, we could be able to exclude the SM-like Higgs boson in the interesting mass range**

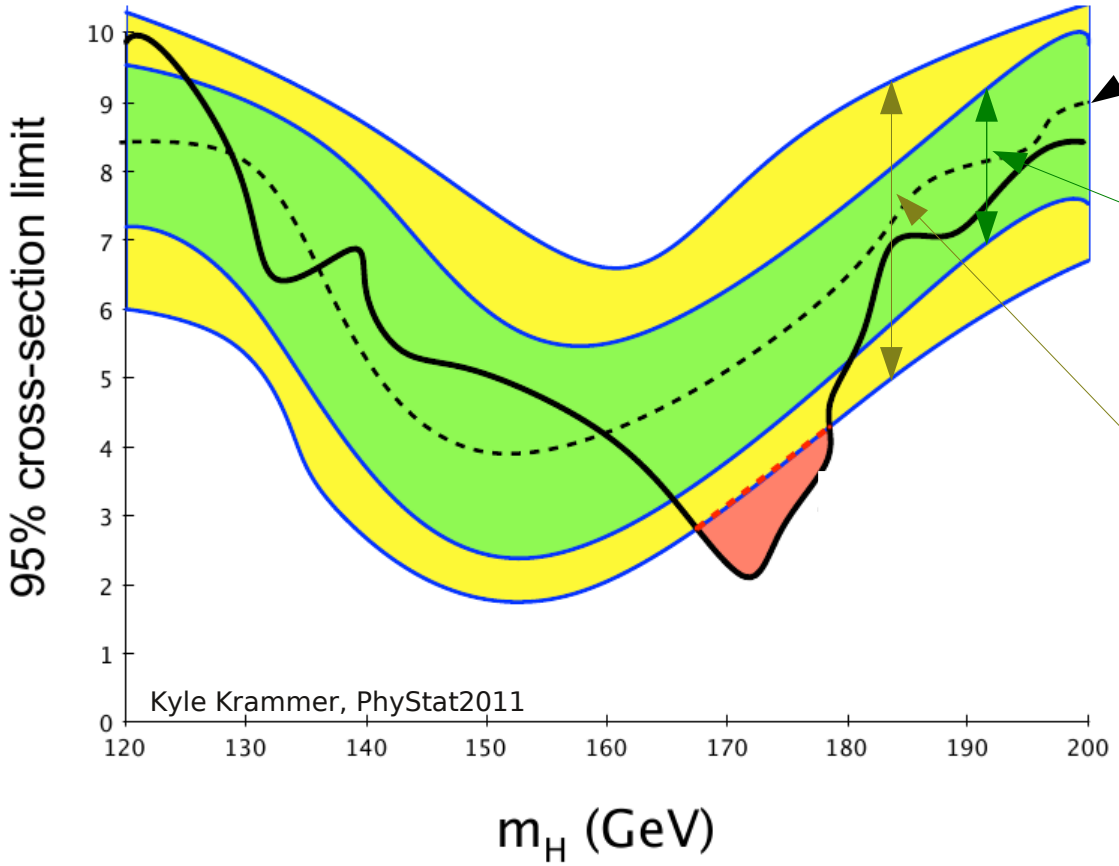
References

- 14 TeV results: CMS Physics Technical Design Report:
  http://cdsweb.cern.ch/record/942733
- 7 TeV Projections: CMS NOTE-2010/008:
  http://cdsweb.cern.ch/record/1264099
- Higgs cross section for LHC:
  LHC Higgs Cross Section Working Group
- CMS Combination of Higgs Searches:
- http://cdsweb.cern.ch/record/1376643?ln=en
- CMS Web page with details on Higgs searches:
- https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsHIG
- CMS detector: JINST 3:S08004,2008
  http://iopscience.iop.org/1748-0221/3/08/S08004

BACKUP SLIDES

The expectation contours

- to compute exclusion expectation for exclusion limits **background only toy Monte Carlo is used**
- ±1σ, ±2σ bands are plotted to show range of **possible statistical fluctuation of the actual result wrt. expectation**



Median, i.e we expect 50% chance that a real experiment will get better (=less background events), or worse (=more background events) exclusion

±1σ – 68% toy MC experiments around median gave result within this range, ie. chance that a real experiment will see result within this band is 68%

±2σ – 95% toy MC experiments around median, ie. chance that a real experiment will see result within this band is 95%

G fitter limits on m_H

Slide from M.Schott, Higgs Hunting 2011 (arXiv:1107.0975v1)

- $\Delta\chi^2$ estimator for the standard and complete fits versus M_H

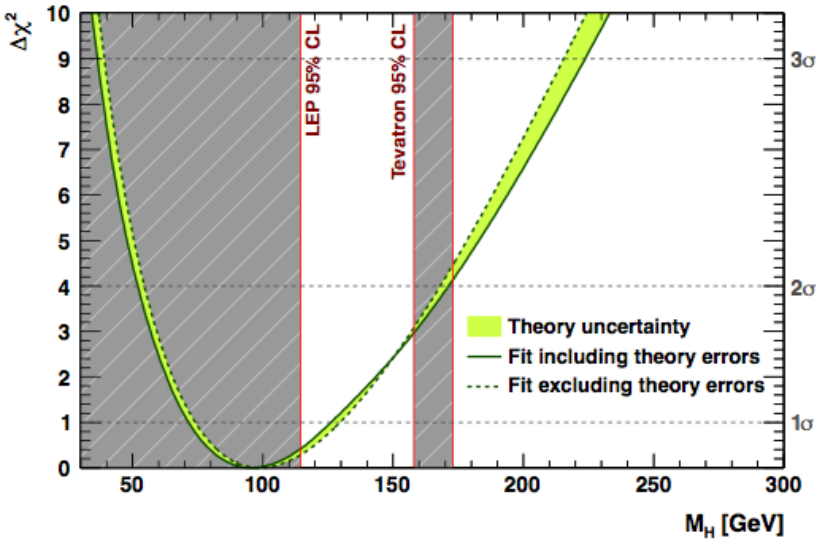
$$M_H = \begin{cases} 96\,^{+31}_{-24}\ \text{GeV} & \text{(standard fit)} \\ 120\,^{+12}_{-5}\ \text{GeV} & \text{(complete fit)} \end{cases}$$

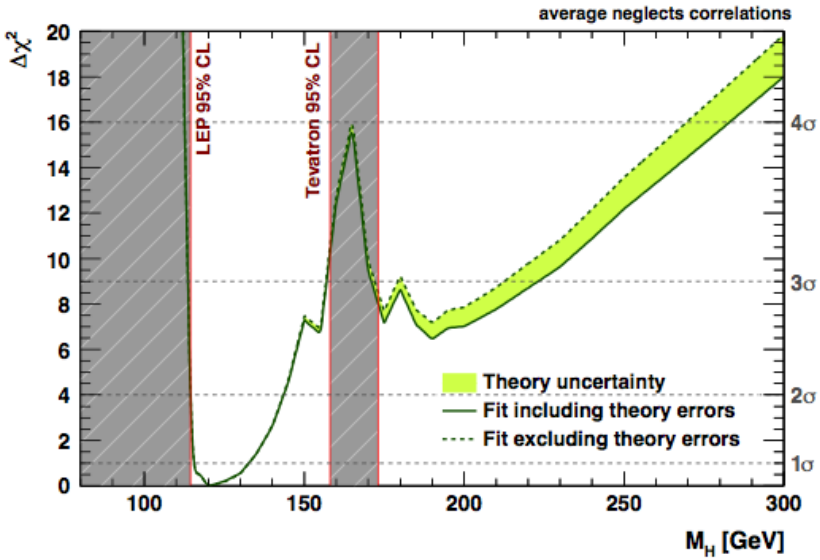
- with the 95% (99%) upper bounds of
  - 169GeV (200 GeV) for the standard fit
  - 143GeV (149 GeV) for the complete fit

- The errors and limits include the various theory uncertainties that taken together amount to approximately 8 GeV on M_H .

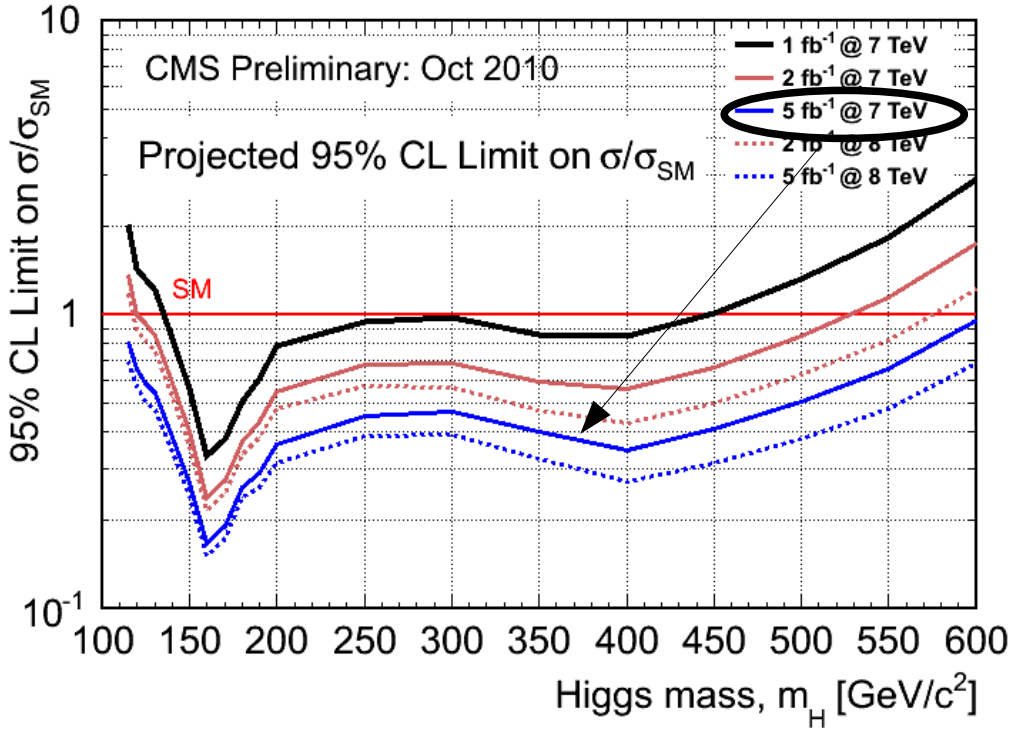
- The standard fit value for MH has moved by +12 GeV as a consequence of the new $\Delta\alpha^{(5)}_{had}(M_Z^2)$
- Using the preliminary result $\Delta\alpha^{(5)}_{had}(M_Z^2)$ of K. Hagiwara, R. Liao, A. D. Martin, D. Nomura and T. Teubner, 1105.3149, we find

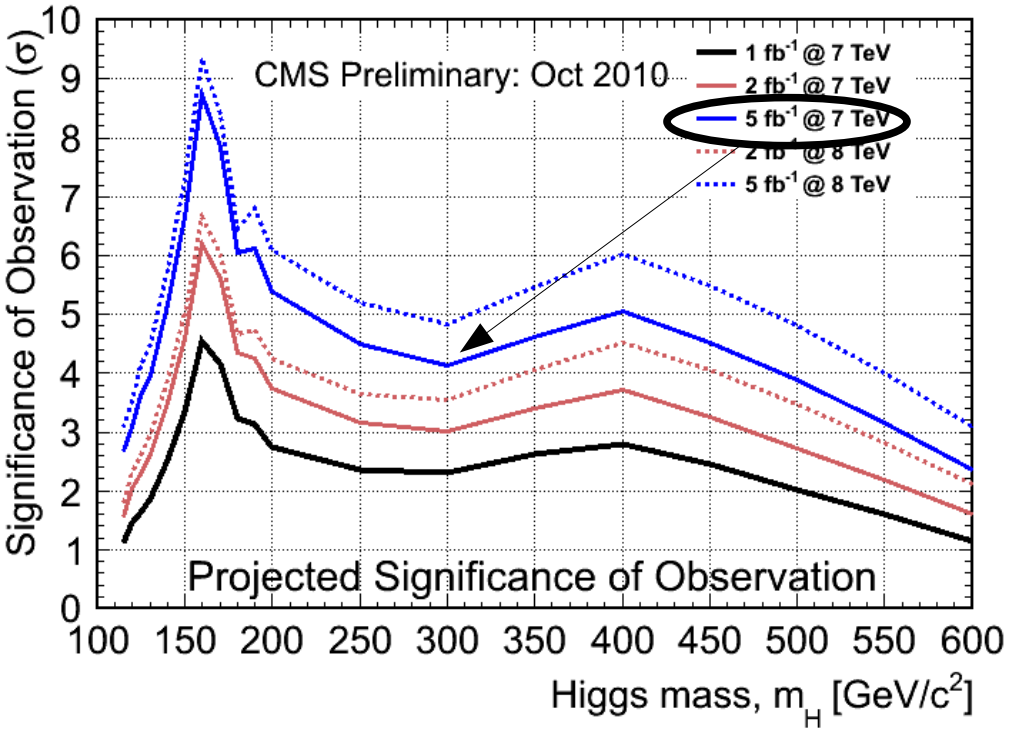
$$M_H = 88\,^{+29}_{-23}\ \text{GeV}$$





Prospects with the whole 2011 data





- In October 2010 CMS produced expectations for exclusion power bases on Monte Carlo studies from 2006
- For 1 fb^{-1} the projected exclusion range was **$145<m_H<300$ GeV/c^2**, with improved analysis methods in 2011, for up to 1.7 fb^{-1} we estimated it to be **$127<m_H<420$ GeV/c^2**