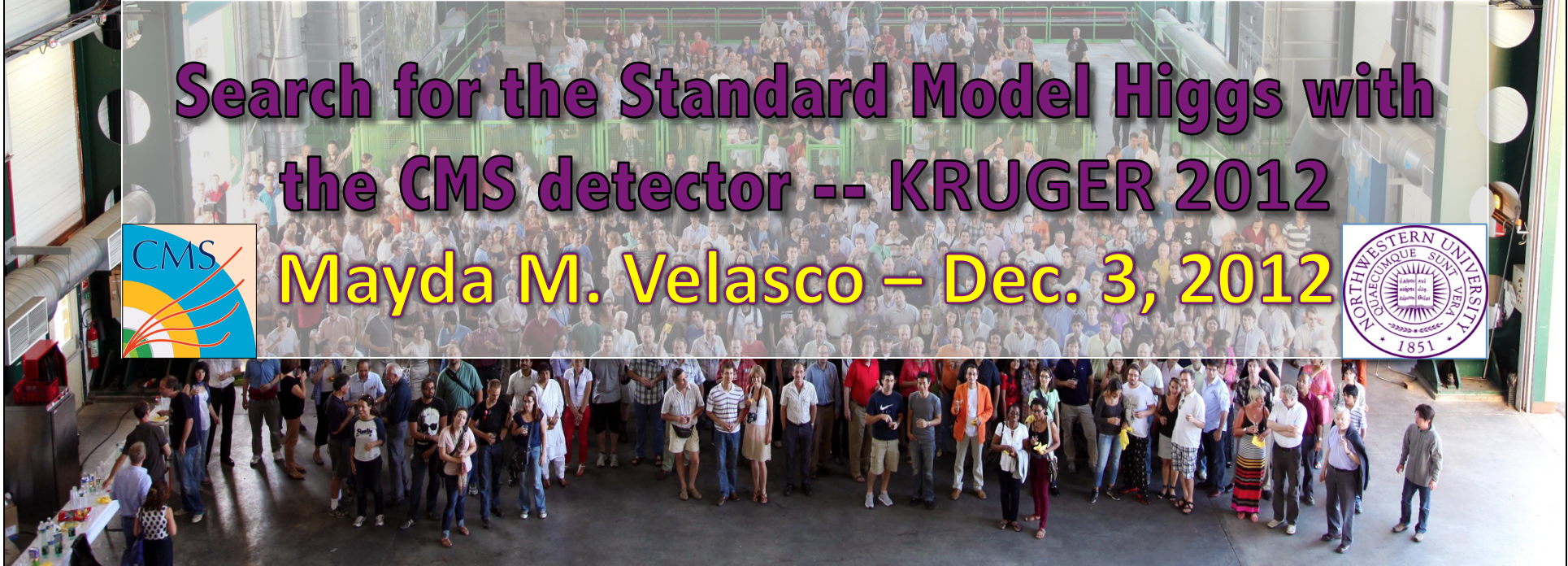
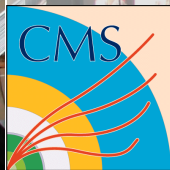


39 countries -- 169 institutes

3170 scientists & engineers

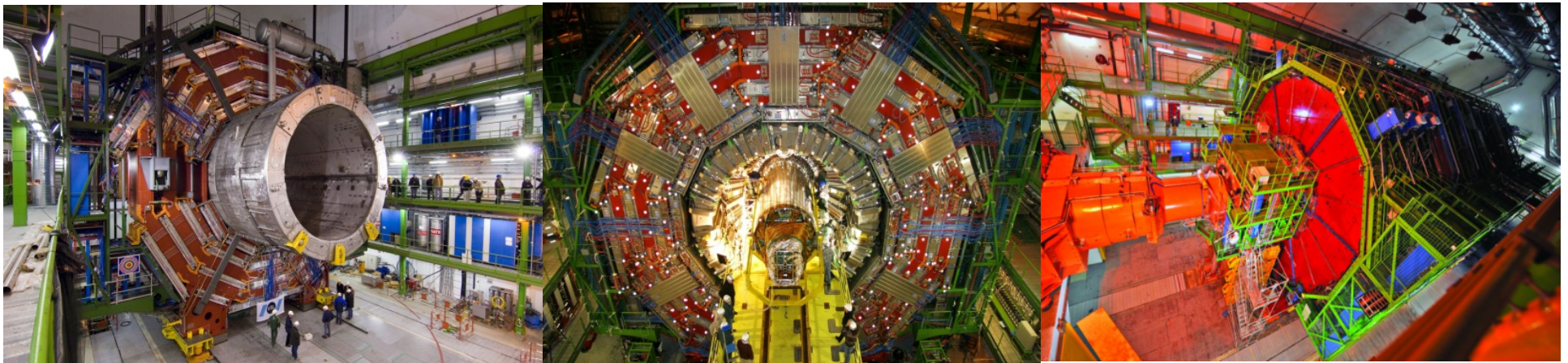
Search for the Standard Model Higgs with the CMS detector -- KRUGER 2012

Mayda M. Velasco – Dec. 3, 2012



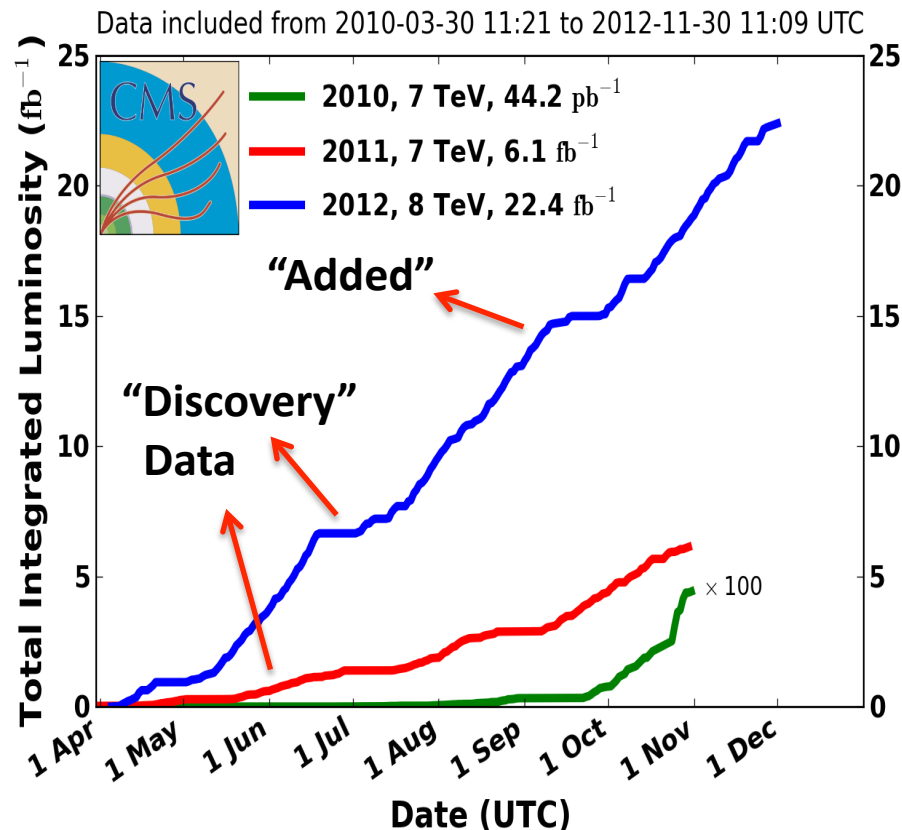
Today's results possible thanks to

- An excellent performance of the:
 - LHC Machine
 - CMS Detector
 - Computing and Software Capabilities (GRID)
 - Strong Analysis Teams
- Careful years of construction ... big payoff

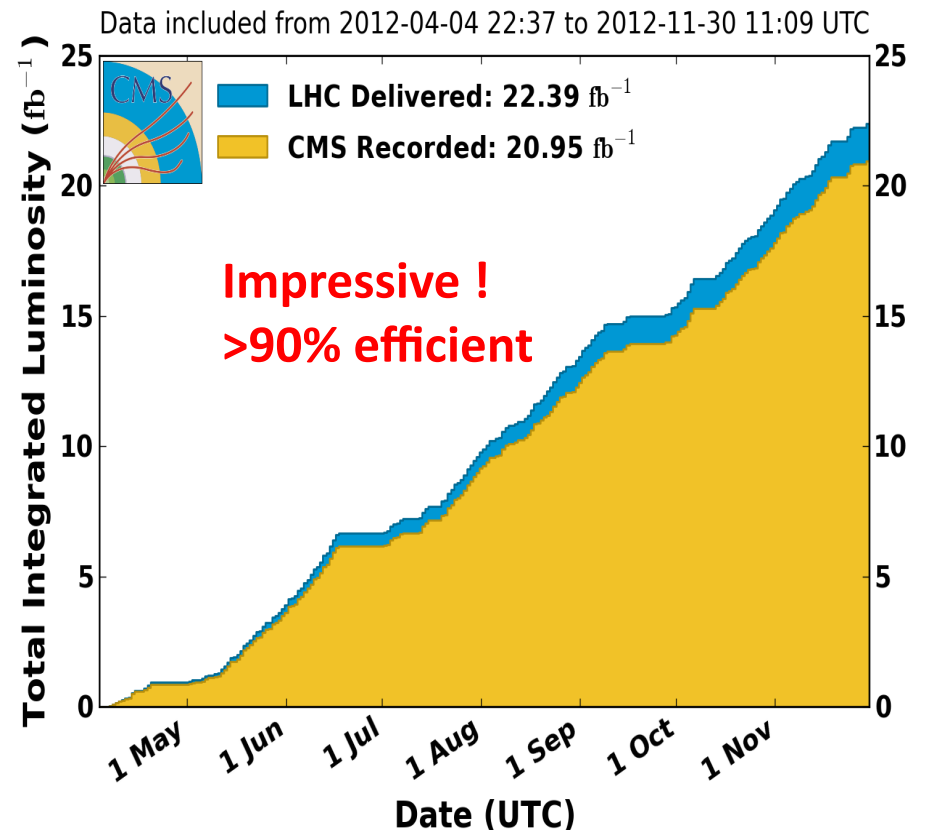


High Luminosity from the LHC

CMS Integrated Luminosity, pp

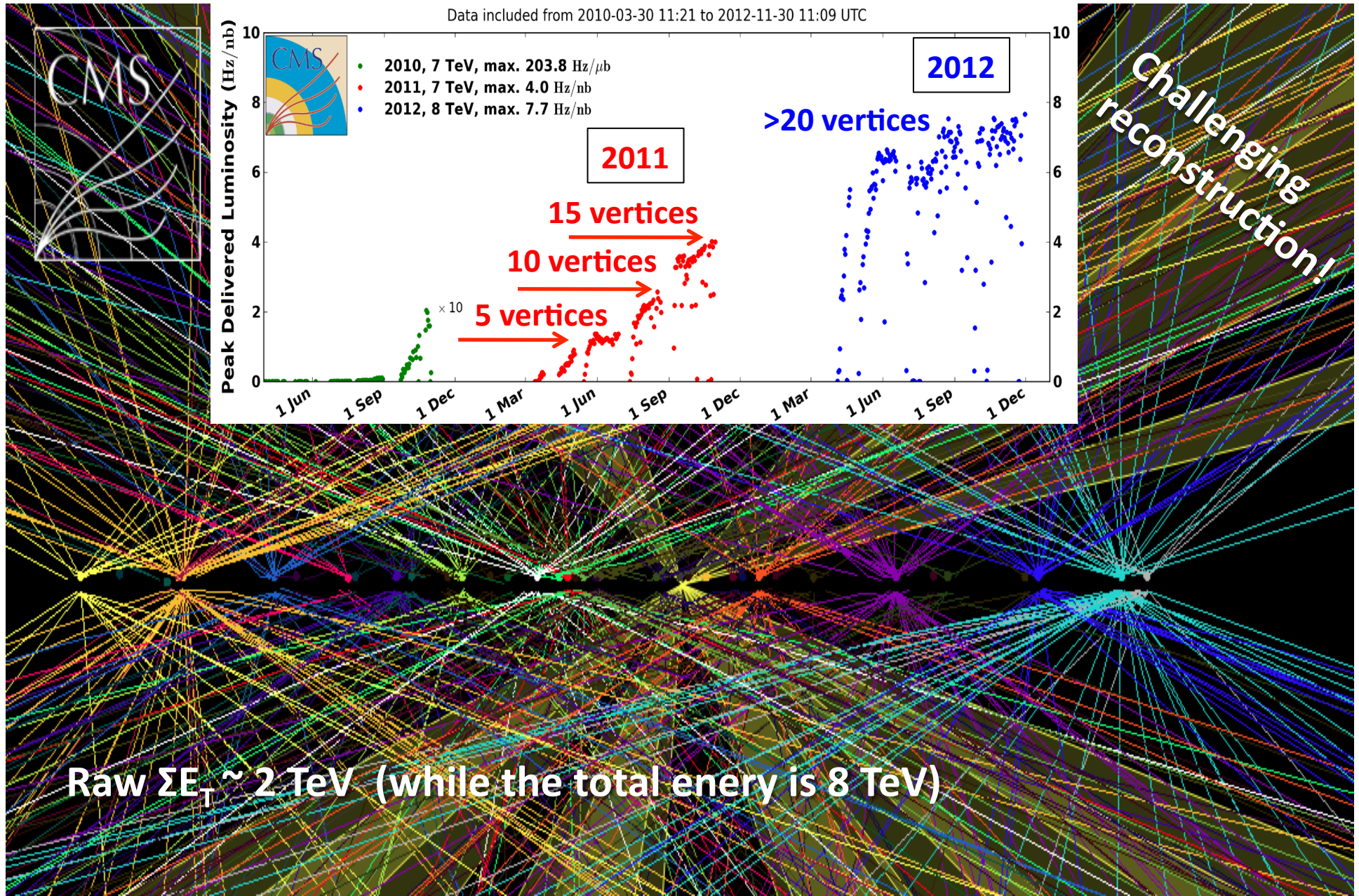


CMS Integrated Luminosity, pp, 2012, $\sqrt{s} = 8$ TeV



Already almost double the 8 TeV data to be used on the analysis to be shown today! On track to for ~ 30 fb⁻¹ at 8 TeV by the end of 2012

High Luminosity multiple proton-proton interactions... No problem 😊



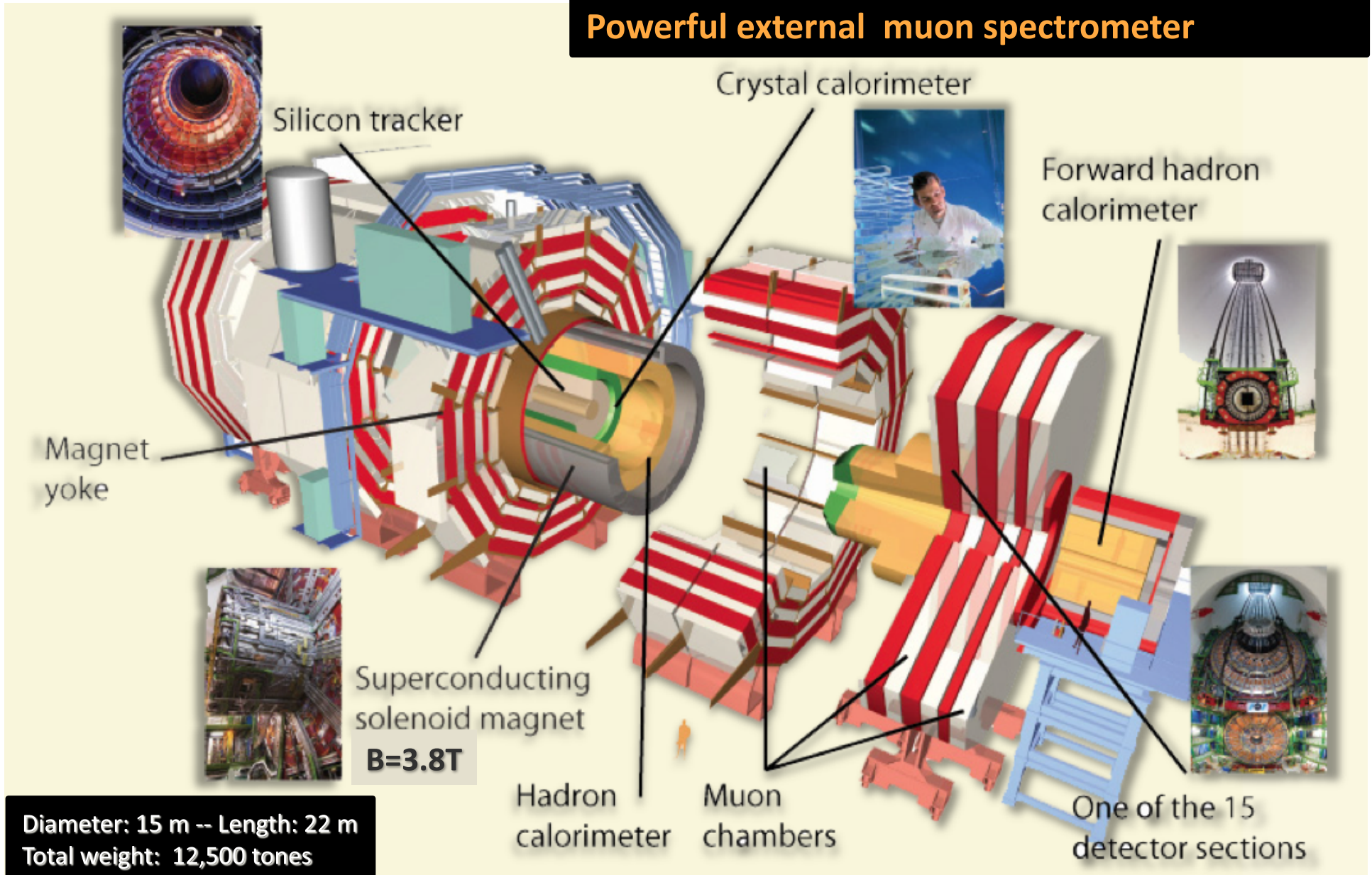
CMS Detector

General purpose LHC experiment

Compact, hermetic, solenoidal design.

All central tracking & calorimetry inside solenoid

Powerful external muon spectrometer



Today's Results

Are for:

- **Standard Model (SM) Higgs searches & characteristics of the observed resonance around a 125 GeV**

More details:

In talks in parallel session to be given based on CMS data on Standard Model Higgs by:

- **Leonardo di Matteo:** *for Higgs to WW*
- **Nicola De Filippis:** *for Higgs to 4 Lepton*
- **Federico de Guio:** *for Higgs to 2 gamma*
- **Jonathan Hays:** *Properties of Higgs-like Boson*

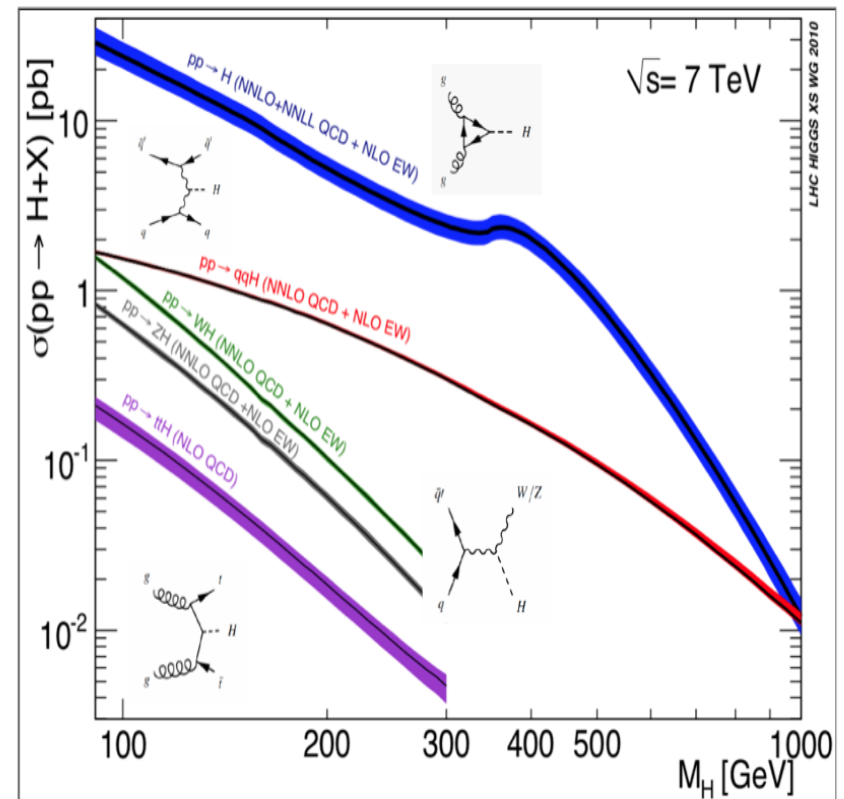
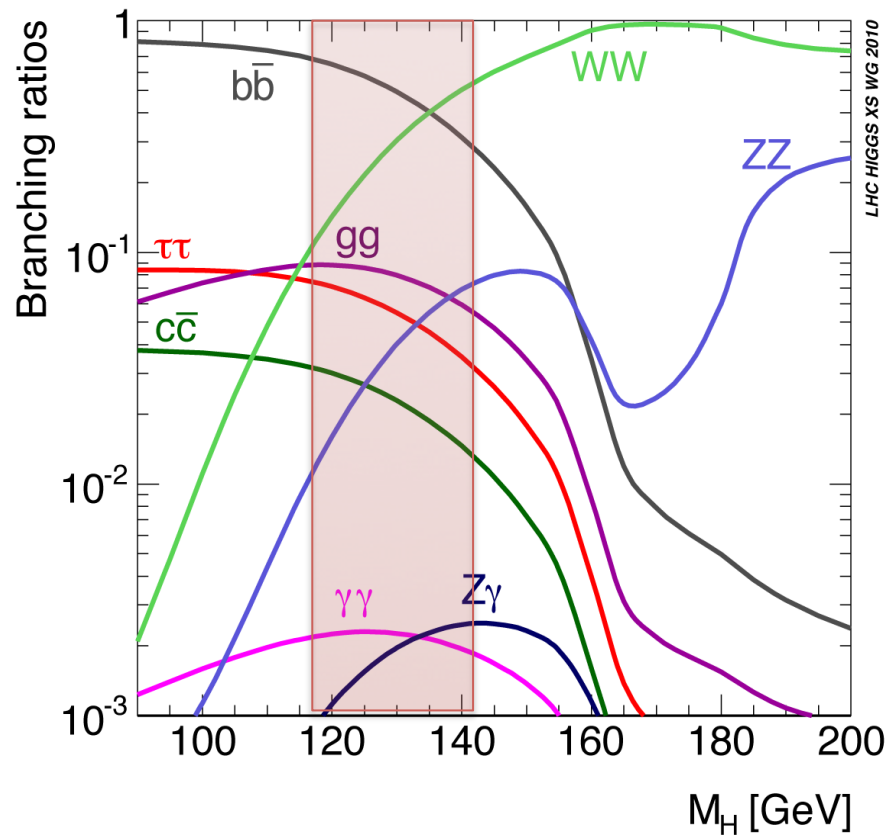
Other Higgs related talks in the parallel sessions by CMS collaborators:

- **Antonio Branca:** *Search for Neutral SUSY Higgs Boson*
- **Vitaliano Ciulli:** *Electroweak results from CMS*

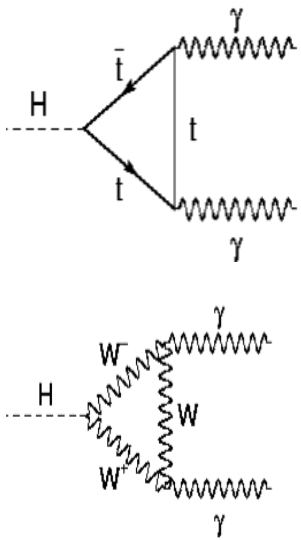
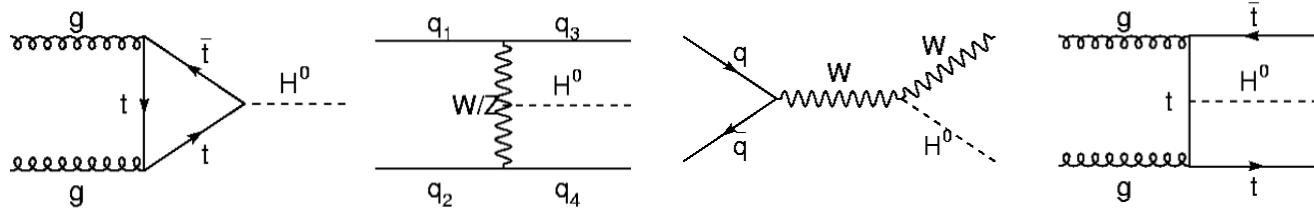
SM Higgs Productions and Branching Fractions @ Low mass

Access to Higgs partial widths to:
 gg , $\gamma\gamma$, ZZ , WW , bb , $\tau\tau$ and $Z\gamma$

$\sqrt{s}=8$ TeV: 25-30% higher signal
 than $\sqrt{s}=7$ TeV at low m_H



Characteristics of Channels



	Untagged	VBF-tag	VH-tag	ttH-tag	S/B	Mass Res.	Today Used For
$H \rightarrow \gamma\gamma$	✓	✓			Low $\mathcal{O}(0.1)$	1-2%	M_h, C_F, C_V
$H \rightarrow bb$			✓	✓	Low $\mathcal{O}(0.1)$	10%	C_F
$H \rightarrow \tau\tau$	✓	✓	✓		Low $\mathcal{O}(0.1)$	15%	C_F
$H \rightarrow WW$	✓	✓	✓		Medium $\mathcal{O}(1)$	20%	C_V
$H \rightarrow ZZ$	✓				High $\mathcal{O}(> 1)$	1-2%	M_h, C_V, J^P

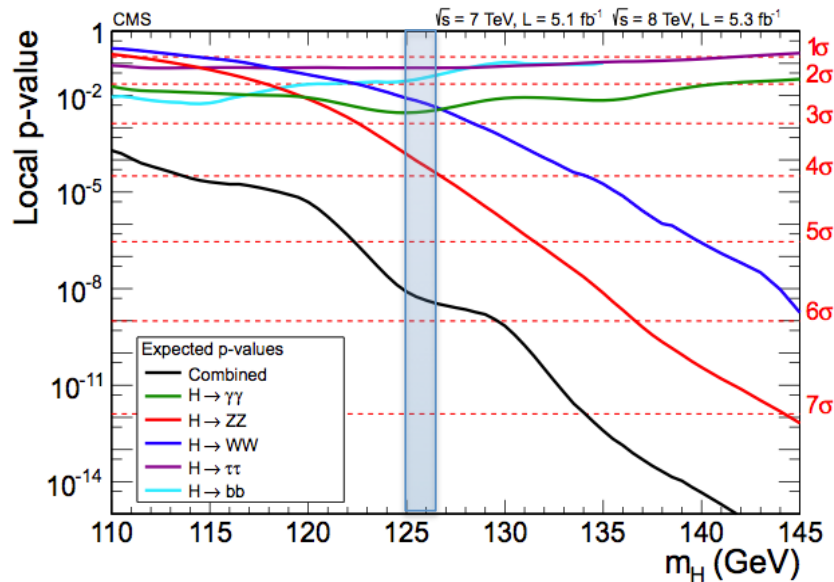
✓ == 5 fb^{-1}

✓ == $5+5 \text{ fb}^{-1}$

✓ == $5+12 \text{ fb}^{-1}$

Improvements in Expected Performance

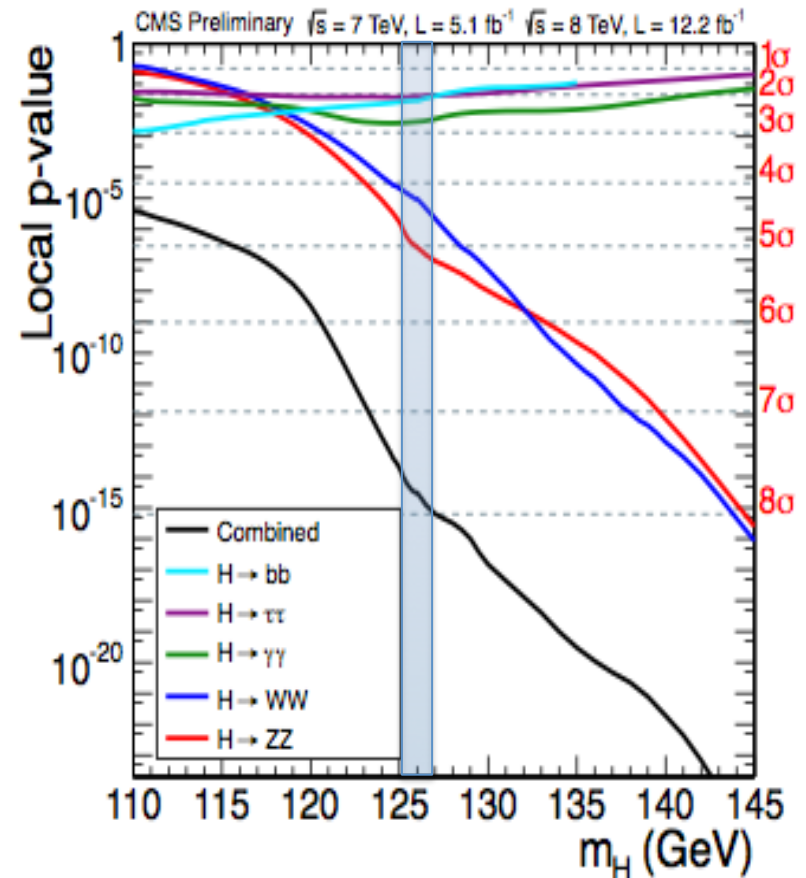
CMS in July...



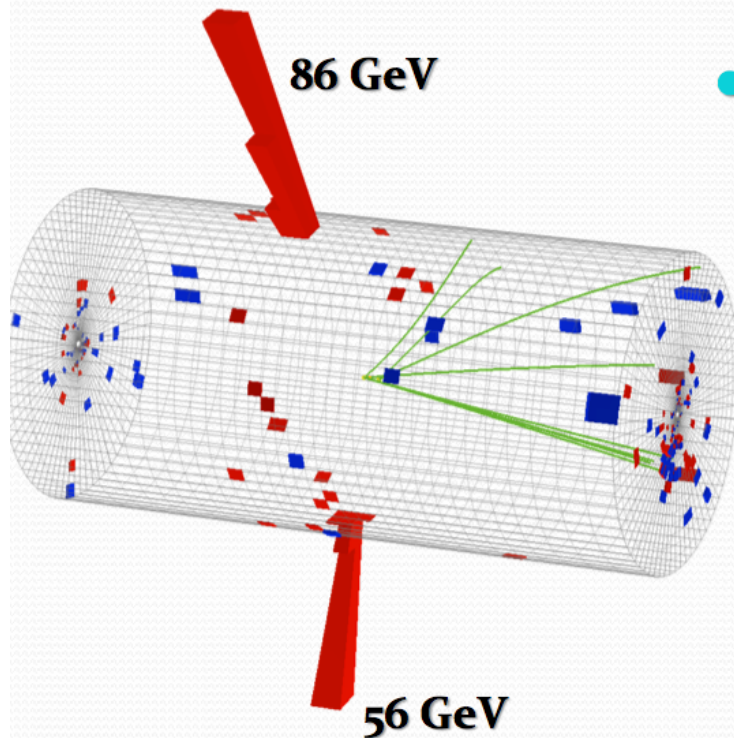
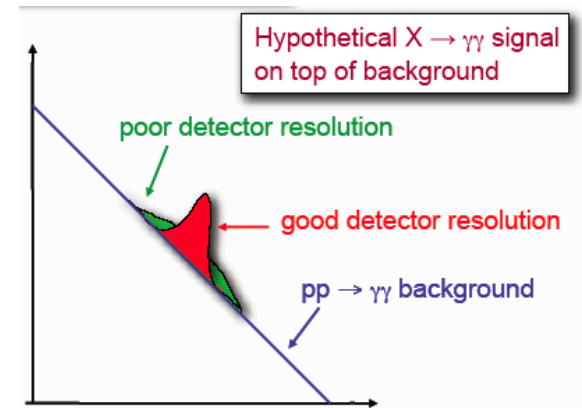
In July already expected $>5\sigma$

Now almost 8σ

And... Now



Search for Higgs to $\gamma\gamma$

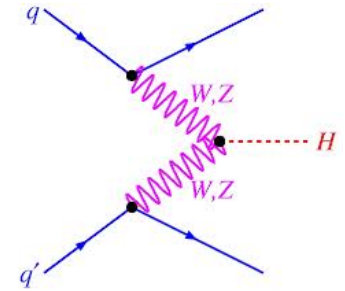


- **Signature and background:**

- Two high momentum photons
- Two photons \rightarrow excellent resolution
- Looking for a narrow peak
- Large irreducible background from direct two photons
- Small fake photo background

Energy resolution is **almost everything**: calibrate and optimize
Rejection of fake photons and optimized use of kinematics

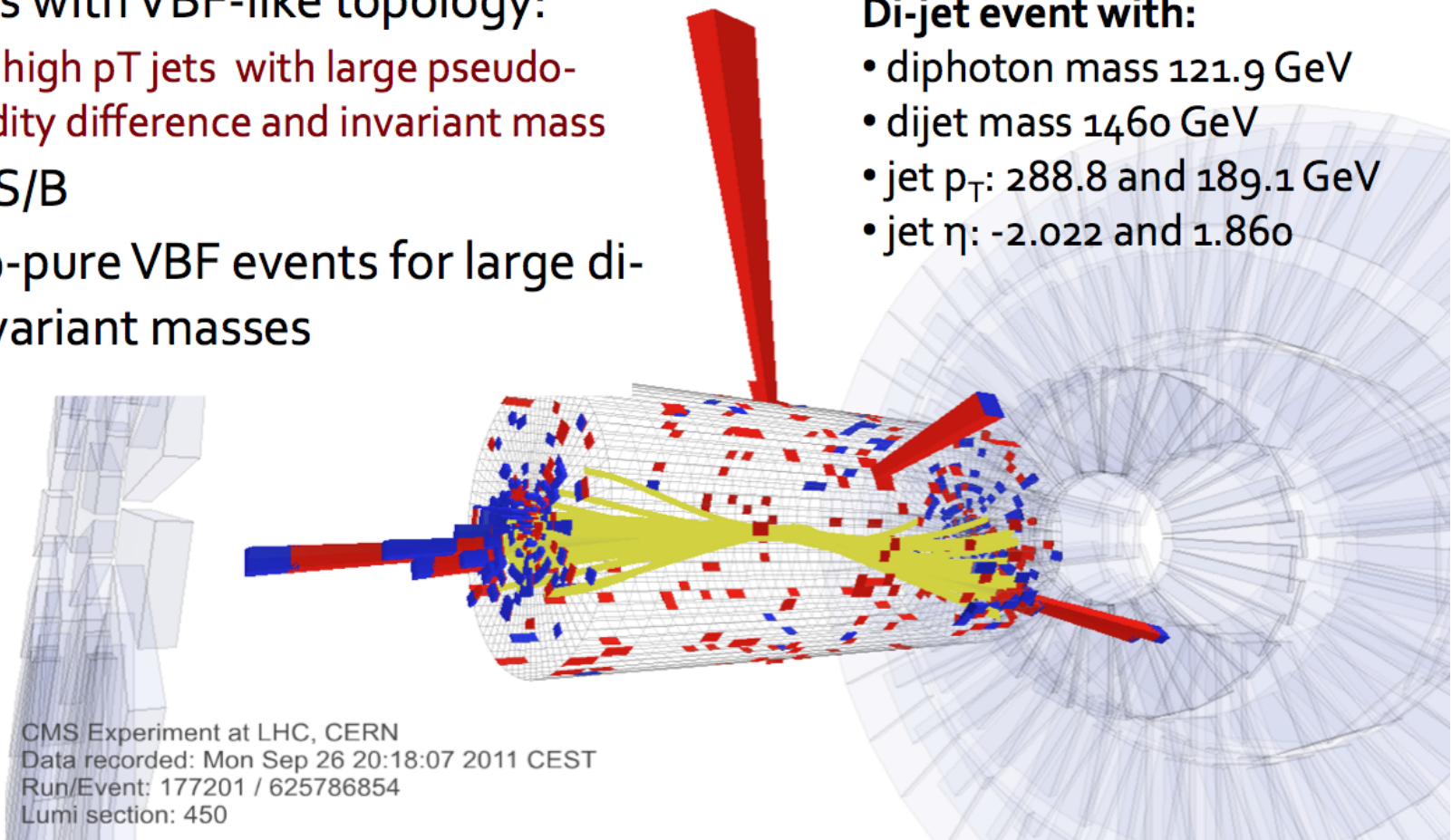
Extra Category Di-Jet Tagged Events



- Exclusive selection of di-photon events with VBF-like topology:
 - Two high p_T jets with large pseudo-rapidity difference and invariant mass
- High S/B
- ~80%-pure VBF events for large di-jet invariant masses

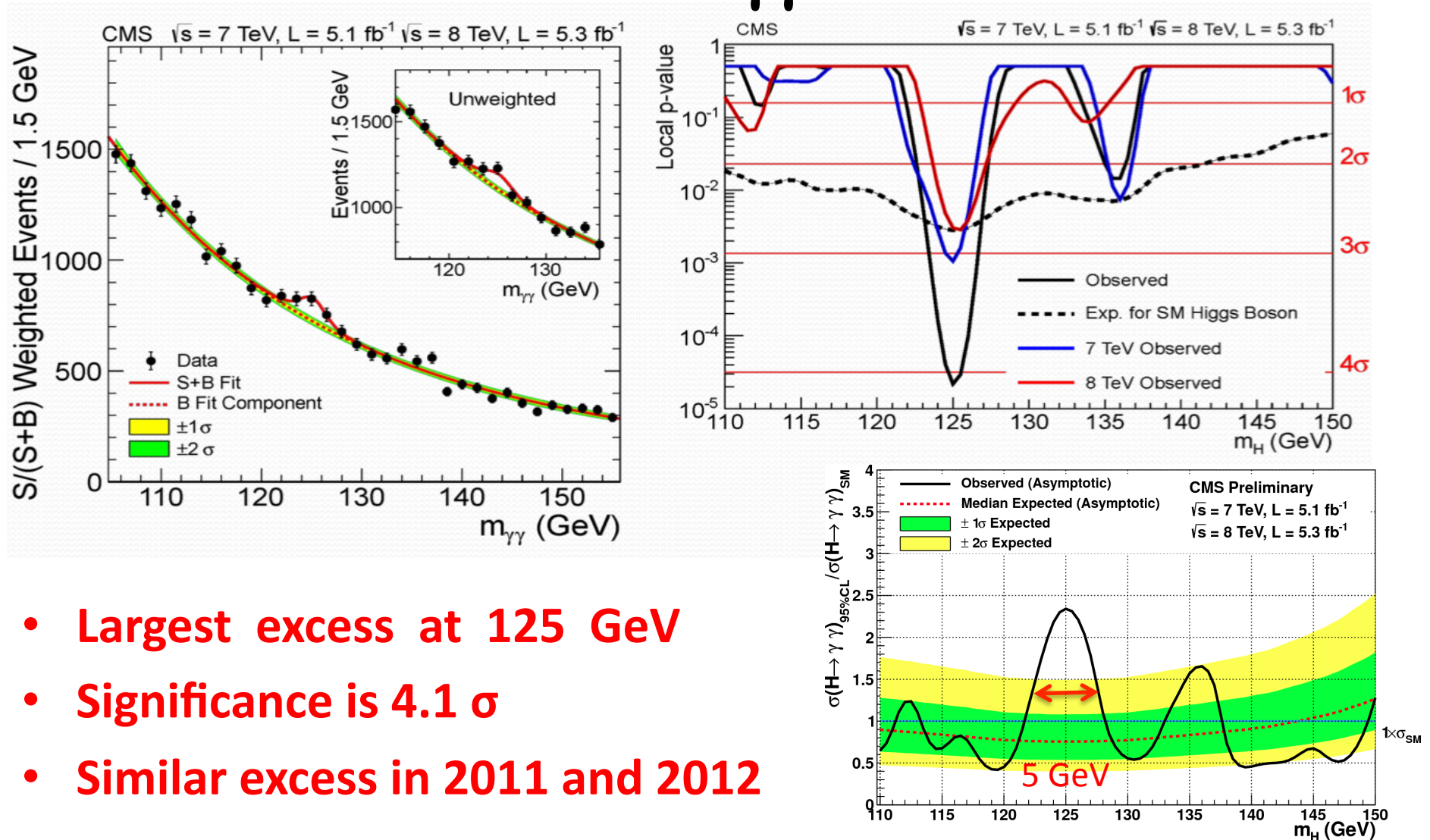
Di-jet event with:

- diphoton mass 121.9 GeV
- dijet mass 1460 GeV
- jet p_T : 288.8 and 189.1 GeV
- jet η : -2.022 and 1.860



CMS Experiment at LHC, CERN
Data recorded: Mon Sep 26 20:18:07 2011 CEST
Run/Event: 177201 / 625786854
Lumi section: 450

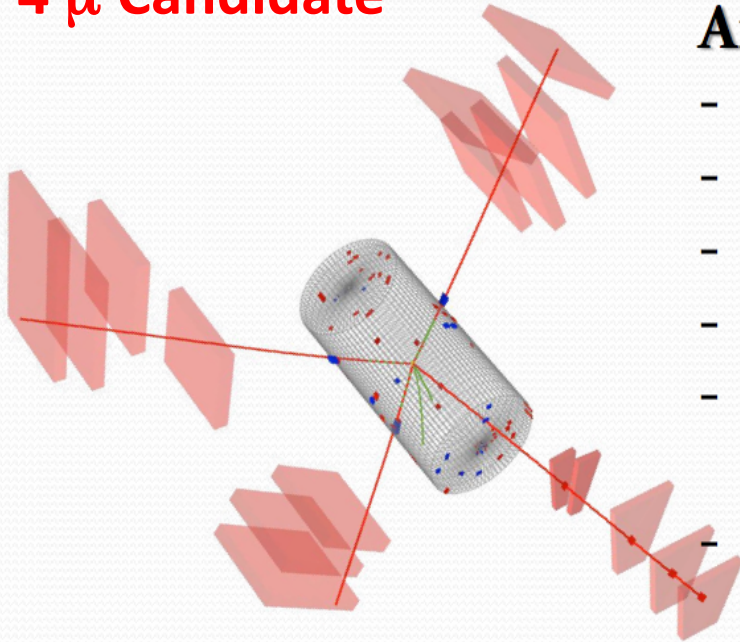
Statistically Significant Signal for H to $\gamma\gamma$



- Largest excess at 125 GeV
- Significance is 4.1σ
- Similar excess in 2011 and 2012

Search for Higgs to ZZ^* to 4L

4 μ Candidate



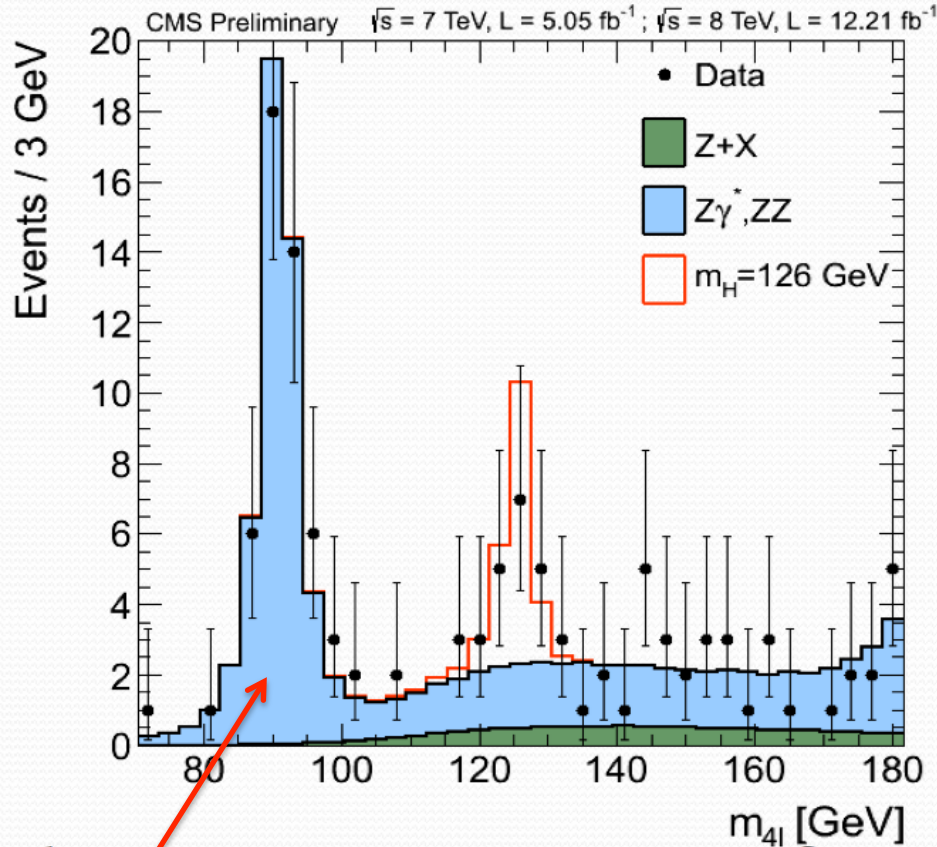
Analysis overview:

- 4 isolated high p_T leptons
- Consistent with Z decays
- From same vertex
- Fit mass peak with resolution 2-4 GeV
- Little background, non resonant ZZ production
- Also Zbb and top ($2l2\nu2b$)

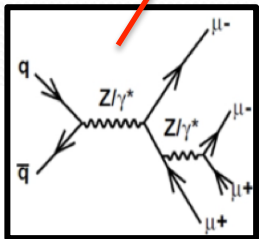
- Background removal:

- Leptons from b-decays are non-isolated and displaced

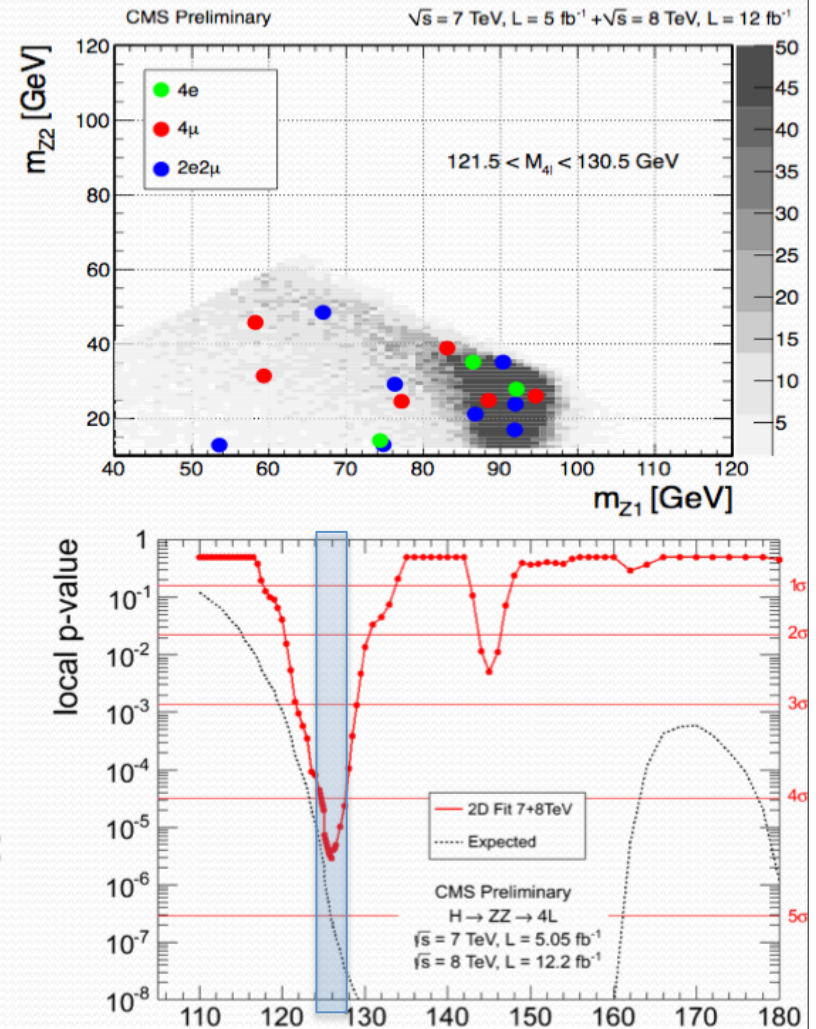
Signal for H to $\gamma\gamma$

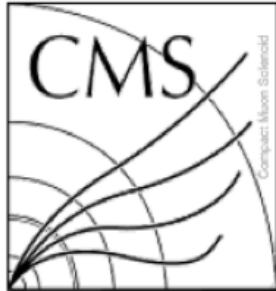


Peak ~ 125 GeV got more significant:
 \rightarrow Significance now 4.6σ



Measured σ (ZZ) = 8.4 ± 1.3 pb
 SM (NLO) σ (ZZ) = 7.7 ± 0.4 pb





**Very clean environment...
More to come from this channel**

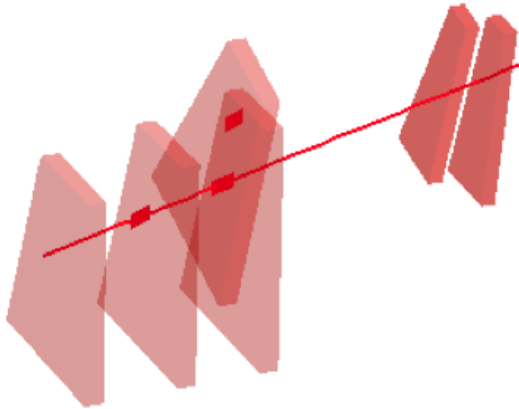


$\mu^+(Z_1) p_T : 43 \text{ GeV}$

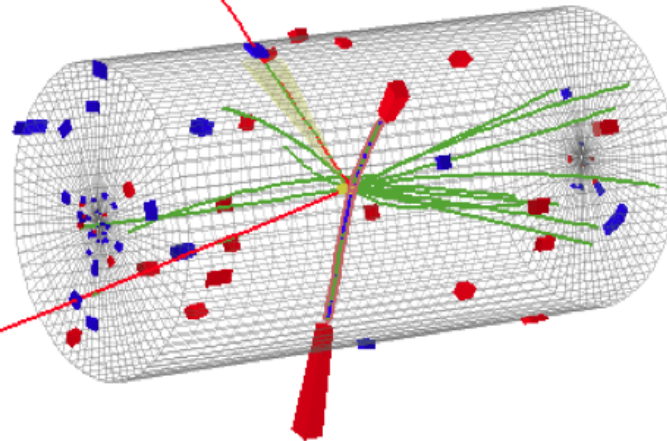
8 TeV DATA

4-lepton Mass : 126.9 GeV

$\mu^-(Z_1) p_T : 24 \text{ GeV}$



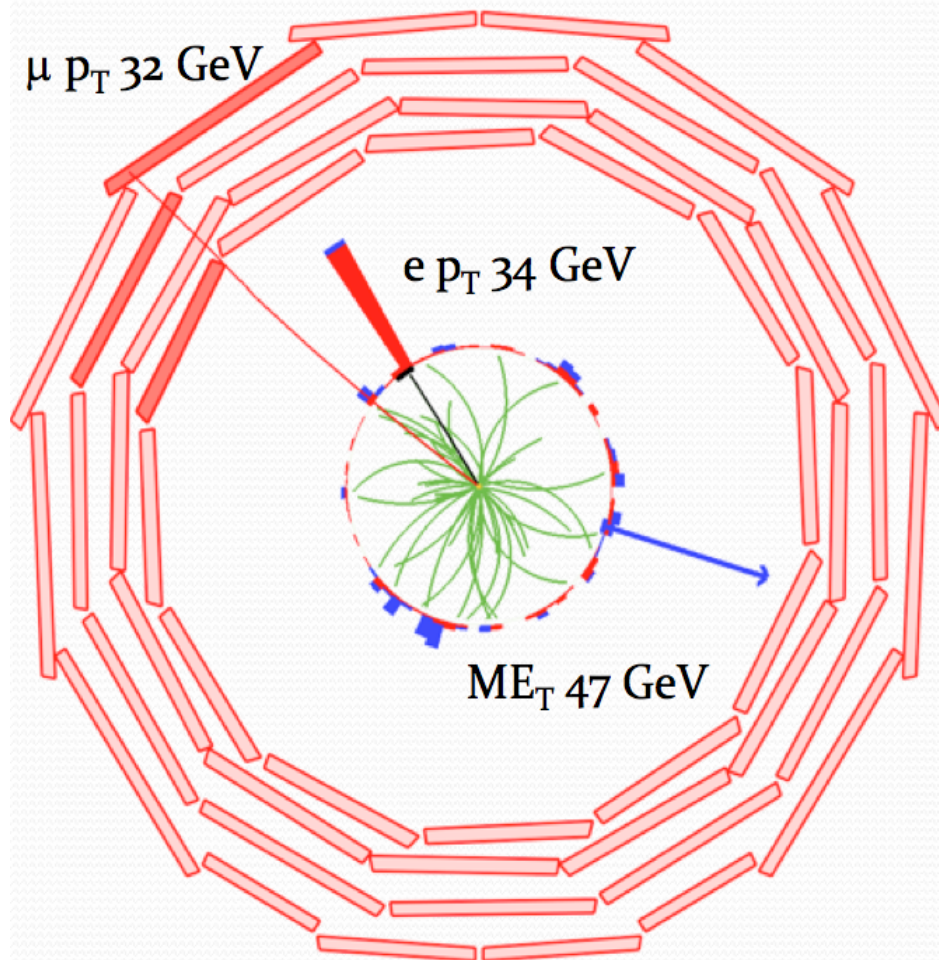
$e^-(Z_2) p_T : 10 \text{ GeV}$



$e^+(Z_2) p_T : 21 \text{ GeV}$

CMS Experiment at LHC, CERN
Data recorded: Mon May 28 01:35:47 2012 CEST
Run/Event: 195099 / 137440354
Lumi section: 115

Searches for Higgs to WW



Signature

- ❖ 2 high p_T leptons (e, μ)
- ❖ Large missing E_T
- ❖ Small $\Delta\phi_{ll}$ and low M_{ll} for low m_H
- ❖ No resonance peak

Backgrounds

- ❖ WW: irreducible background
- ❖ tt/tW: b-jets
- ❖ W+jets: *fake* leptons
- ❖ Z/ γ^* : mis-measured MET
- ❖ WZ/ZZ: V+jj/ $\nu\nu$ or missing lepton

Searches for Higgs to WW

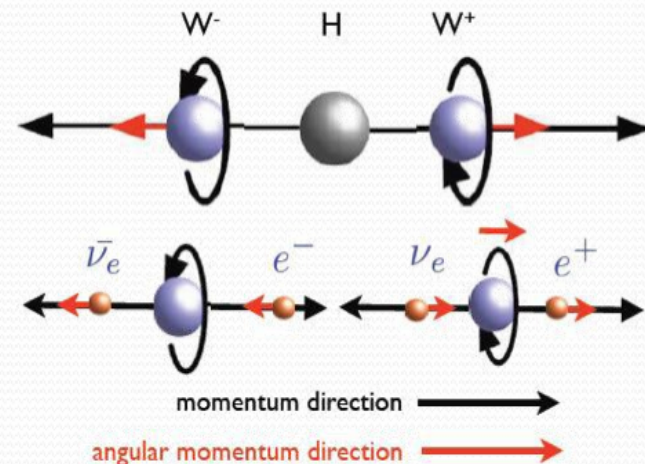
- **Optimisation for different event categories:**
 - Different lepton flavour pairs SF ($ee/\mu\mu$) and DF ($e\mu$)
 - Exclusive jet multiplicity (0,1,2-jets)

Dominant backgrounds

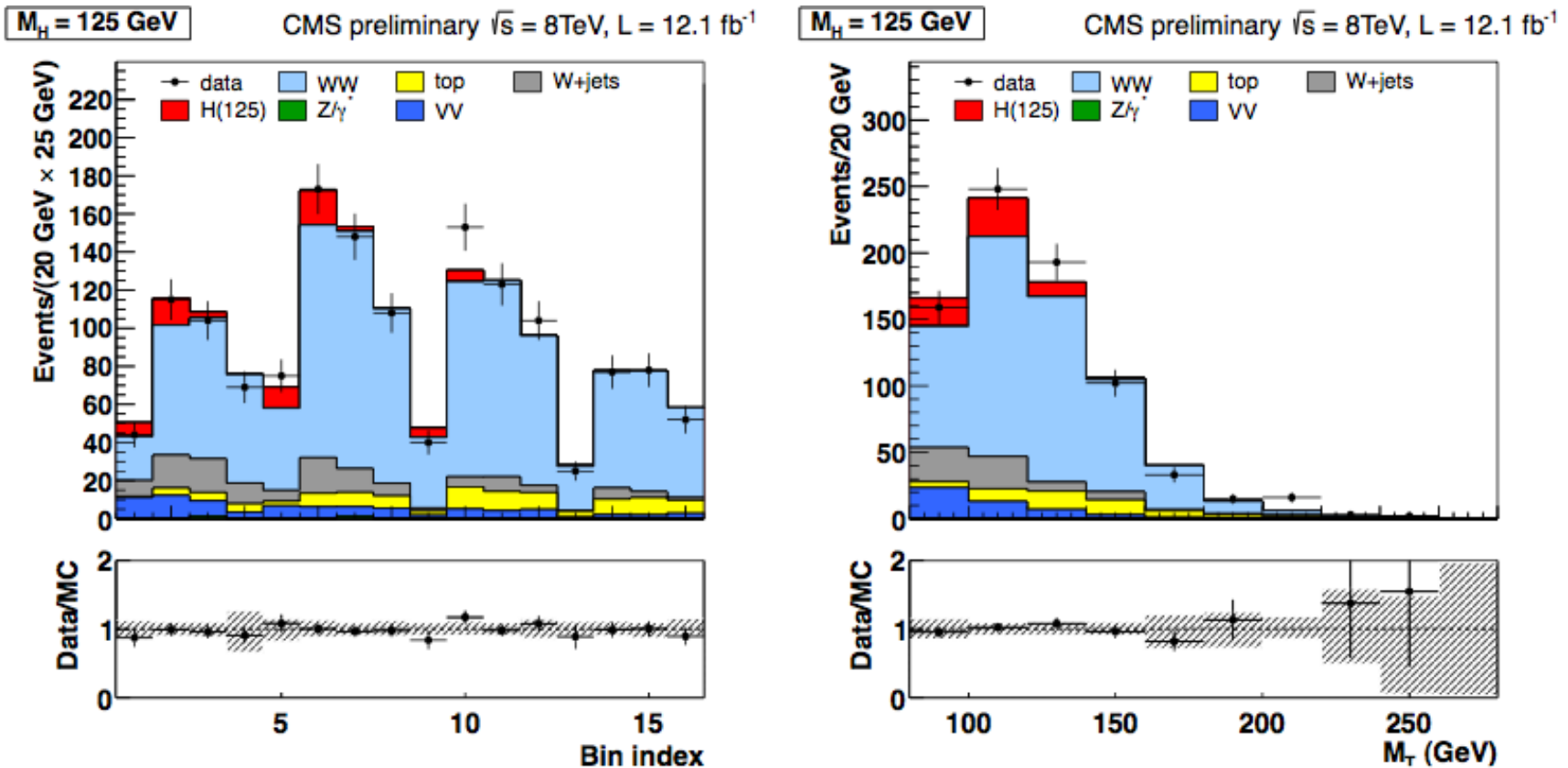
	0-jet	1-jet	2-jets
DF	WW, W+jets, $V+\gamma^*$ (low mH)	WW, Top	WW, Top
SF	WW, Z/γ^* (low mH)	WW, Top	WW, Top, Z/γ^*

- **Two analysis approaches:**
 - Cut-based counting experiment
 - Shape analysis

→ **New 2D M_{ll} versus M_T**

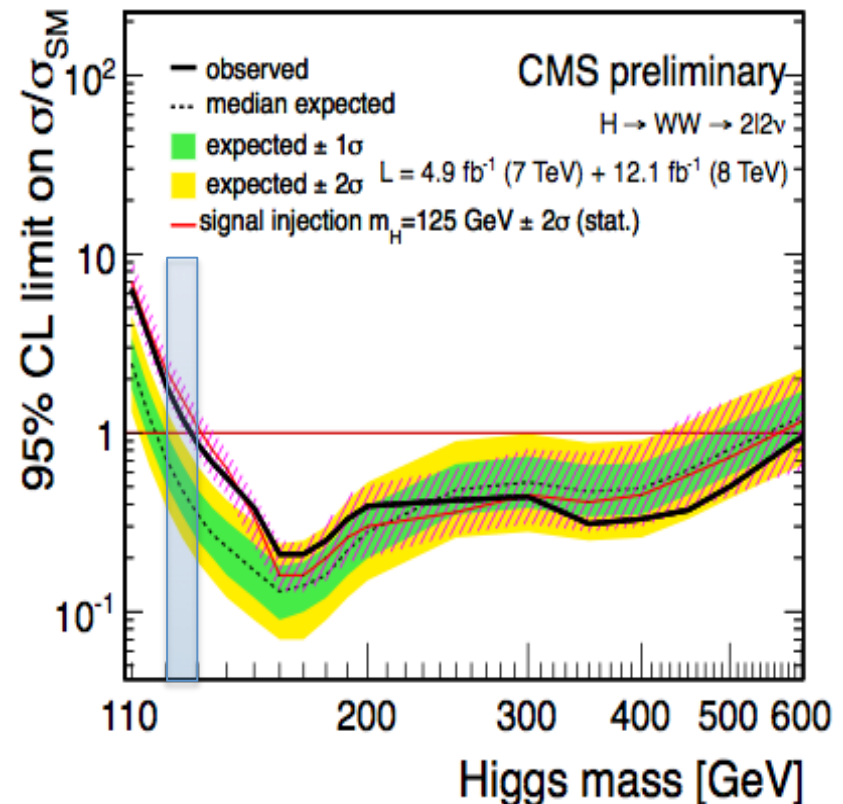
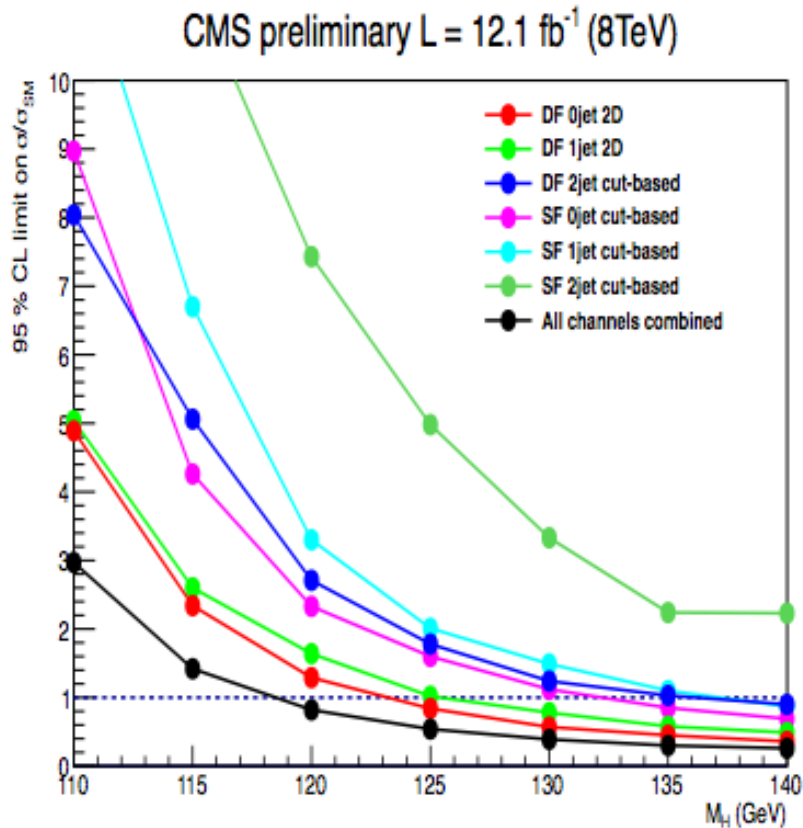


Significant improvement with 2D Shape in M_{II} - M_T plane



→ 0 Jet Case

Significant improvement with 2D Shape in M_h - M_T plane



CMS experiment now sees excess:

- **observed: 3.1 σ** and expected: 4.1 σ
- 7 TeV as published, **8 TeV data with new 2D shape analysis**

Results for Higgs to WW

Significance of observed excess for different m_H hypotheses

- Above 3 in a broad region

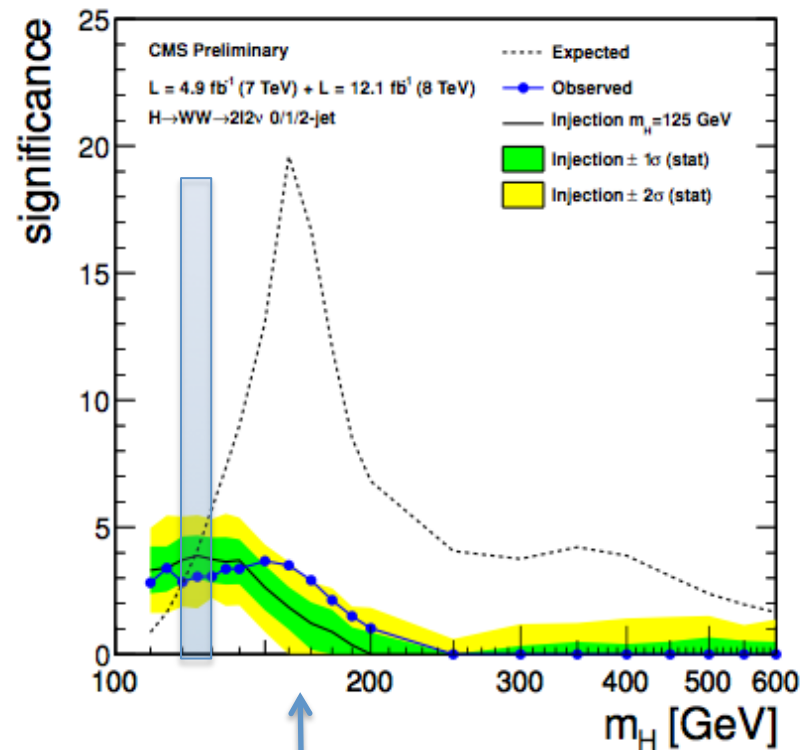
8 TeV results at $m_H=125$ GeV

expected / observed	
Cut-based	2.4 / 1.7
Shape-based	3.7 / 2.9

Combined 7 TeV + 8 TeV significance at $m_H=125$ GeV

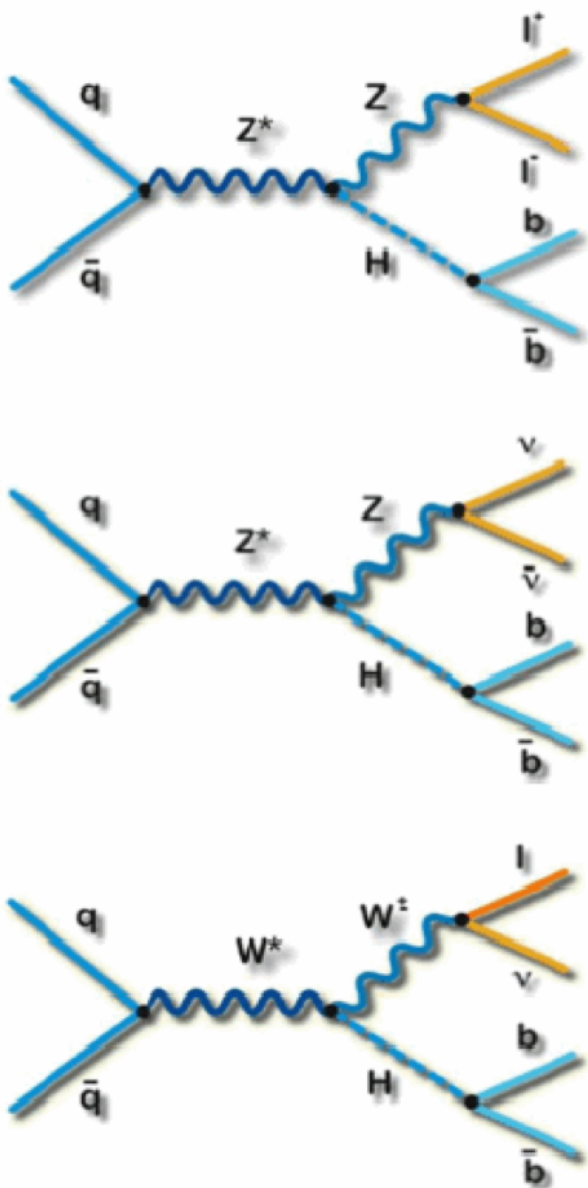
Expected: 4.1

Observed: 3.1



Naively ... likes higher mass?!

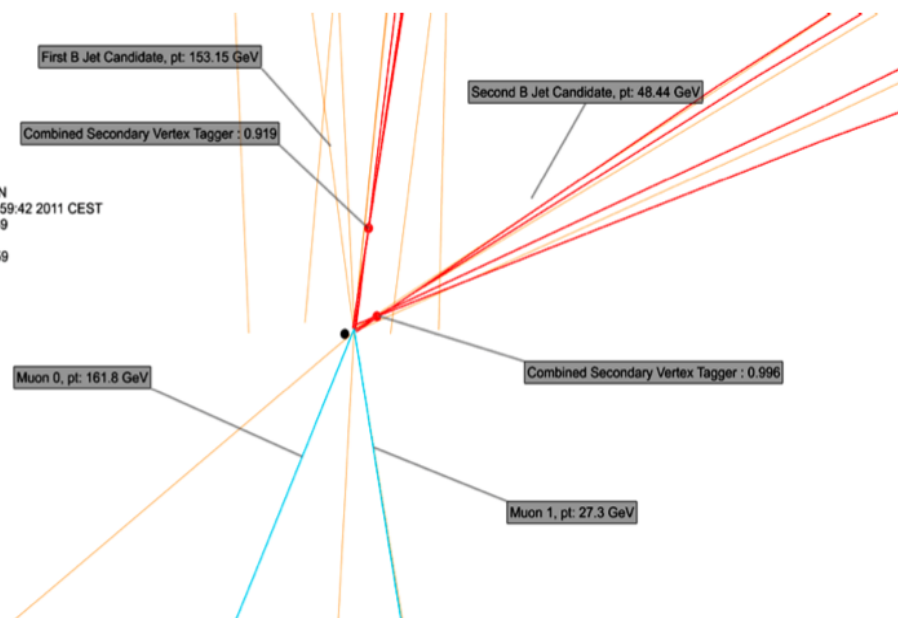
Searches for Higgs to bb



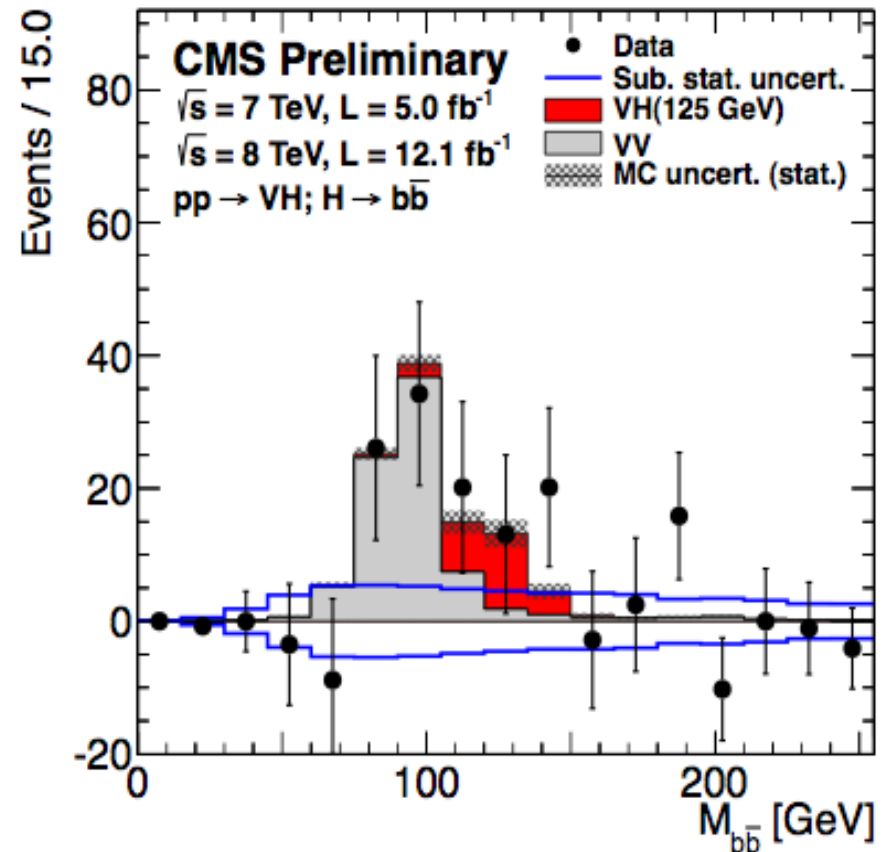
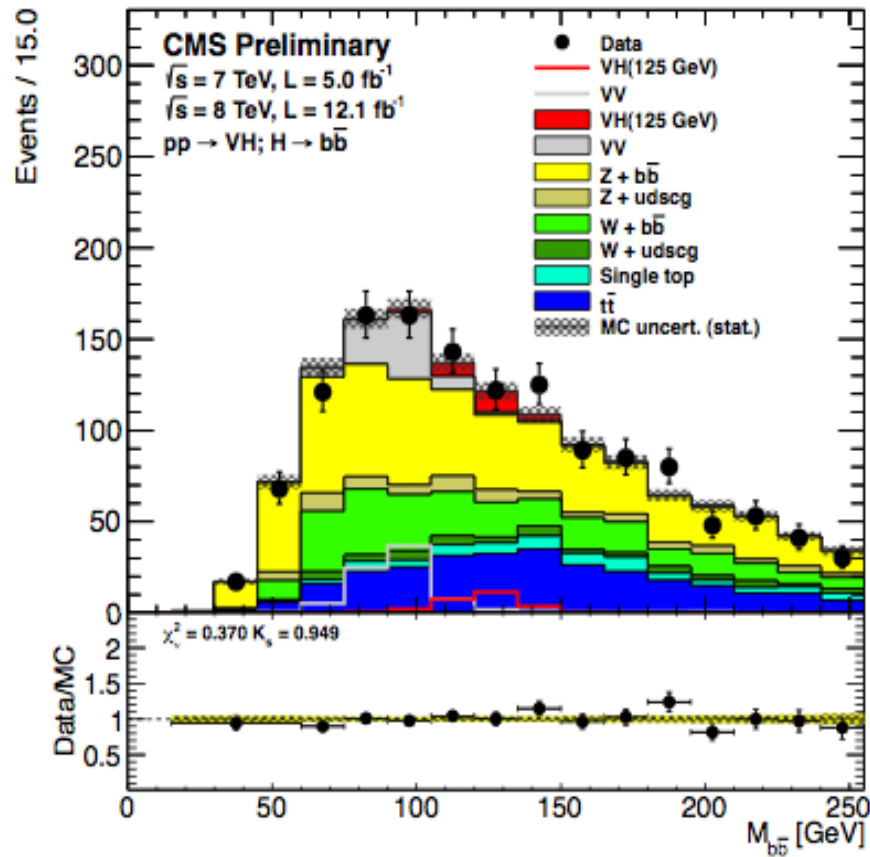
- by far largest number of Higgs decays
- but lots of background (jets)
- trigger based on leptons and missing E_T
- b -jets identified through displaced tracks
- go to high p_T where Higgs is enhanced
- main background **W/Z+jets** and top



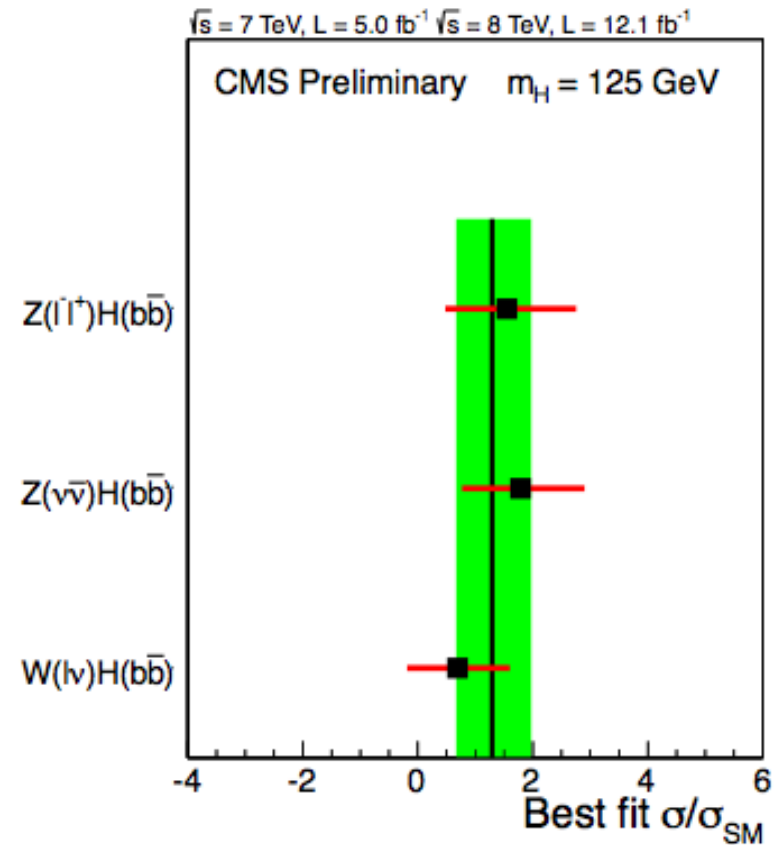
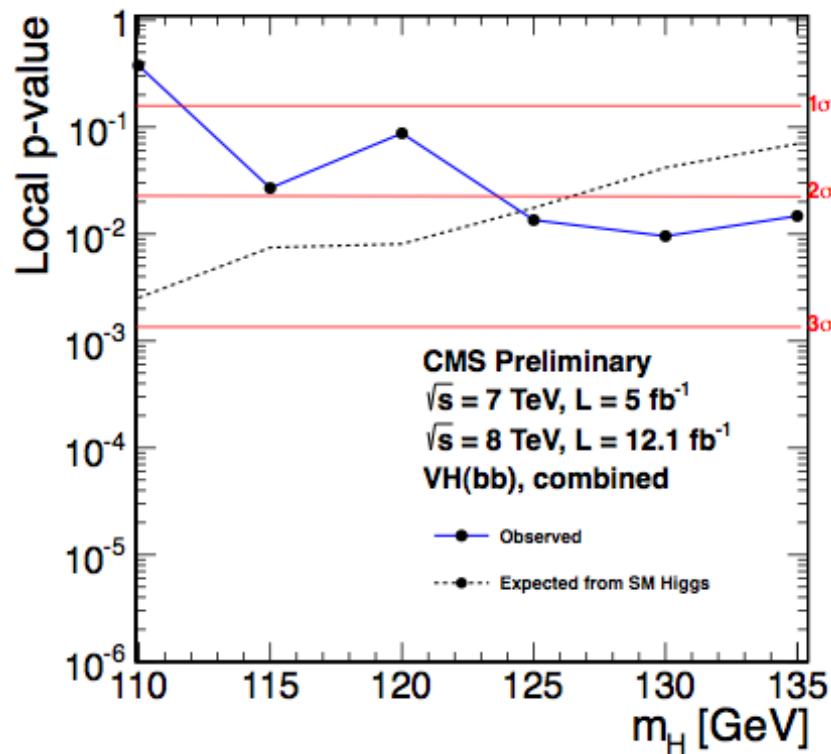
CMS Experiment at LHC, CERN
 Data recorded: Mon Jun 27 02:59:42 2011 CEST
 Run/Event: 167807 / 149404739
 Lumi section: 134
 Orbit/Crossing: 35103256 / 2259



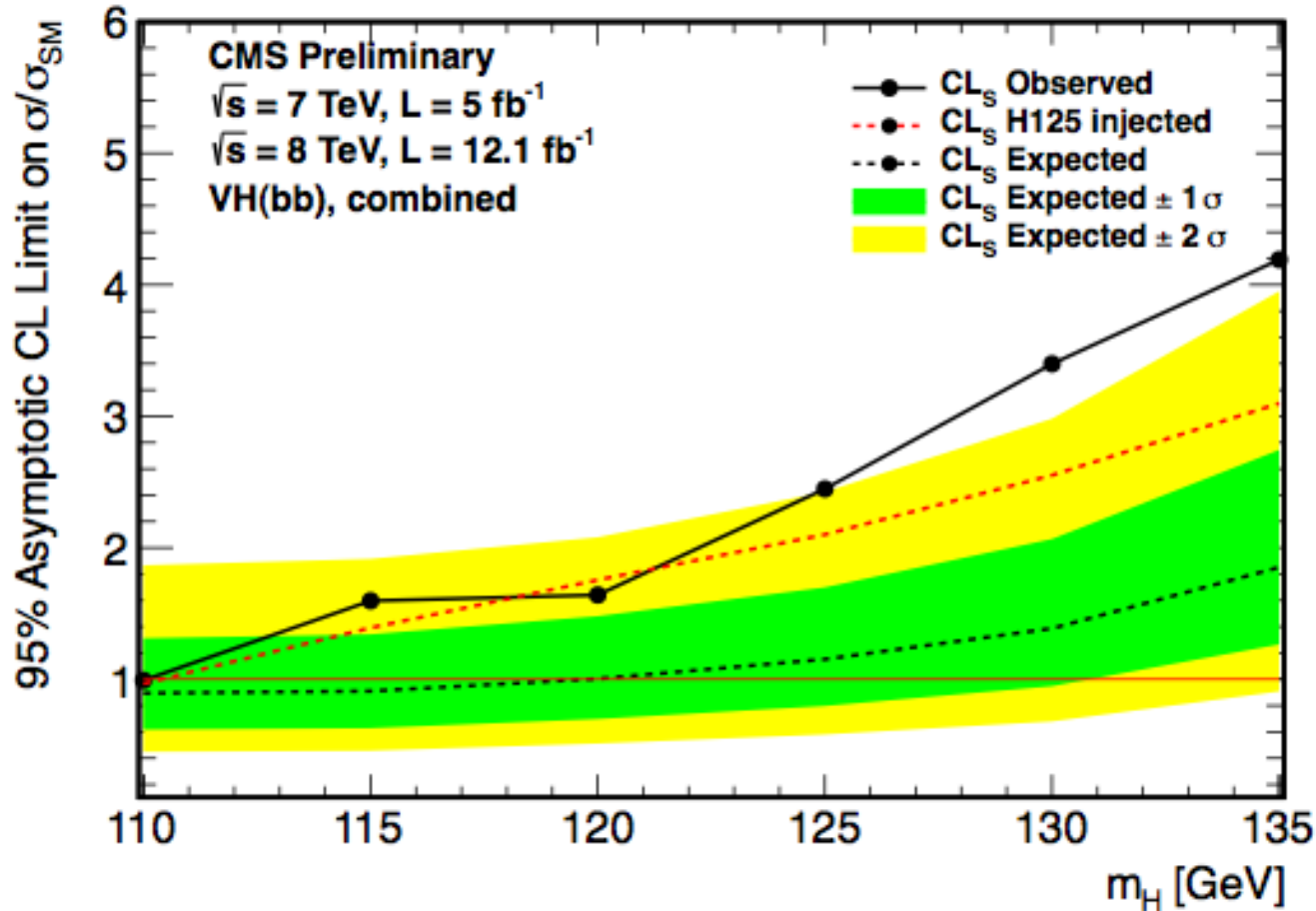
Searches for Higgs to bb in VH



Searches for Higgs to bb



Searches for Higgs to bb



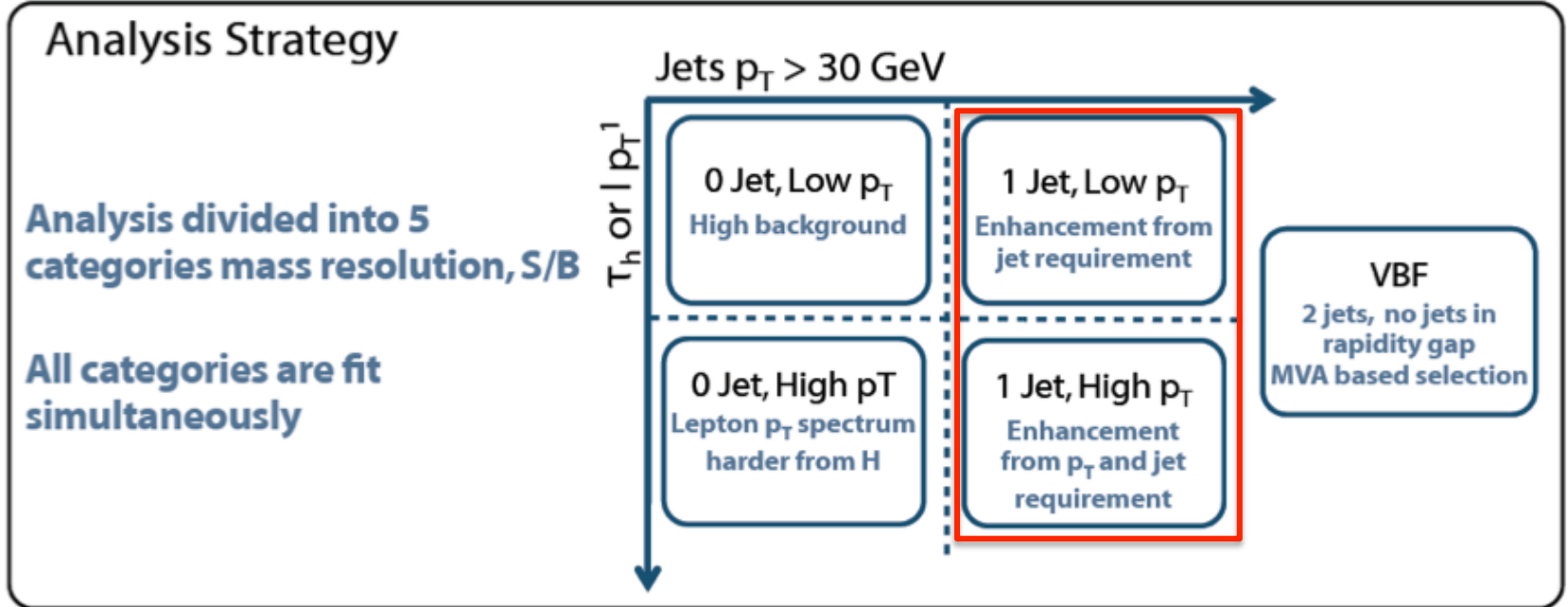
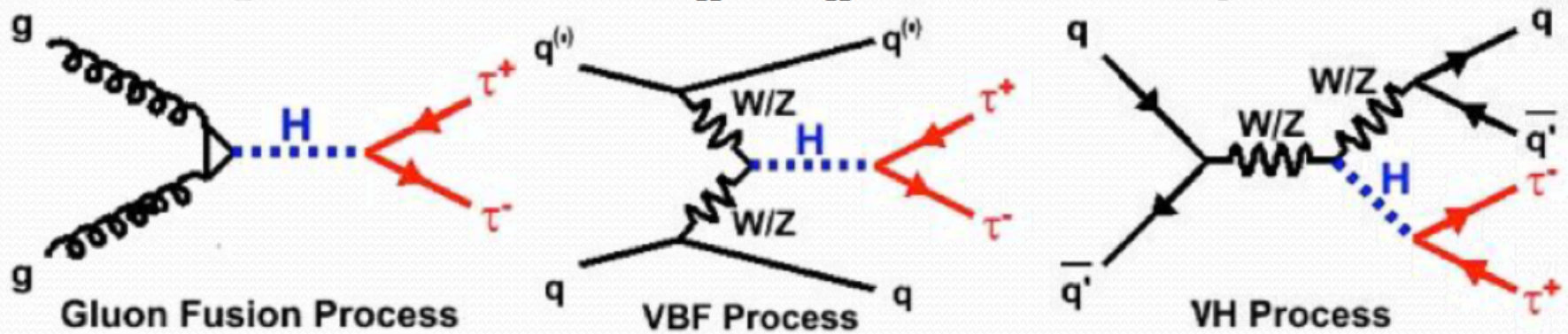
Higher Mass
like in WW?!

Excess compatible with SM starting to appear !?

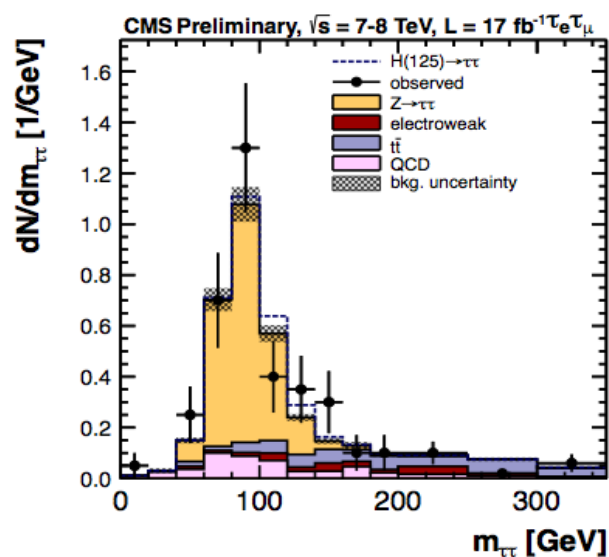
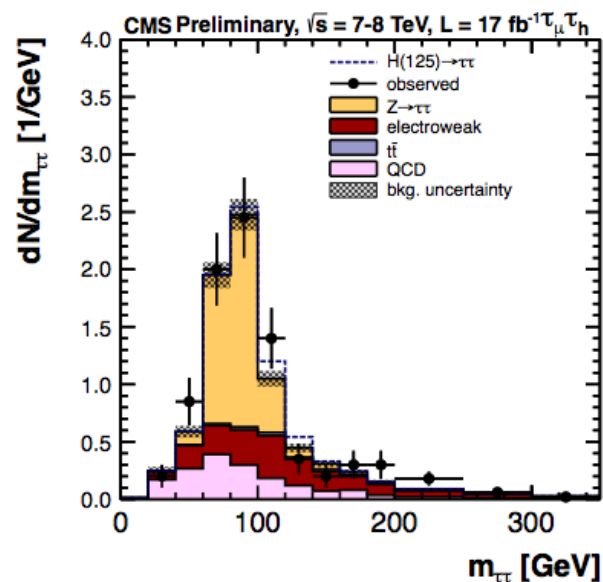
So far a 2.2σ observation

Searches for Higgs to $\tau\tau$

- Combination of three production mechanisms
- Search is performed in $e\tau_h$, $\mu\tau_h$, $e\mu$, $\mu\mu$ decay modes

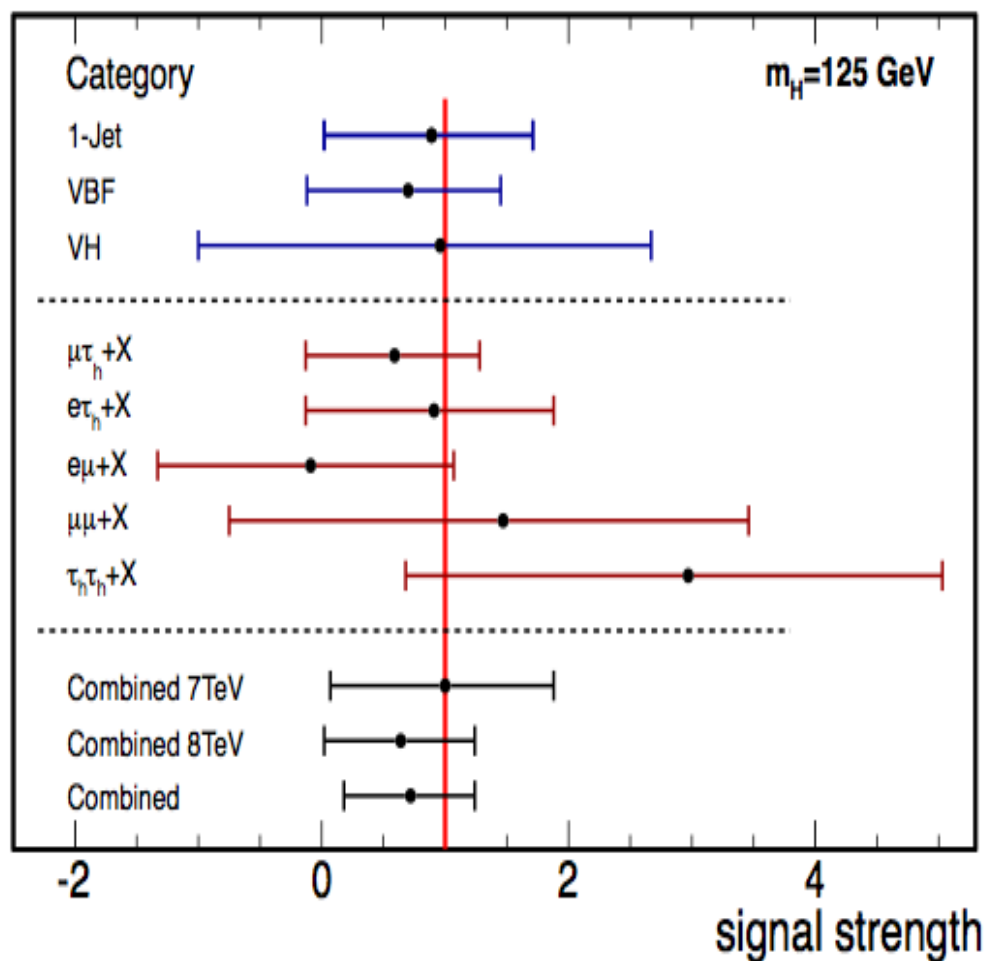


VBF Promising in Higgs to $\tau\tau$



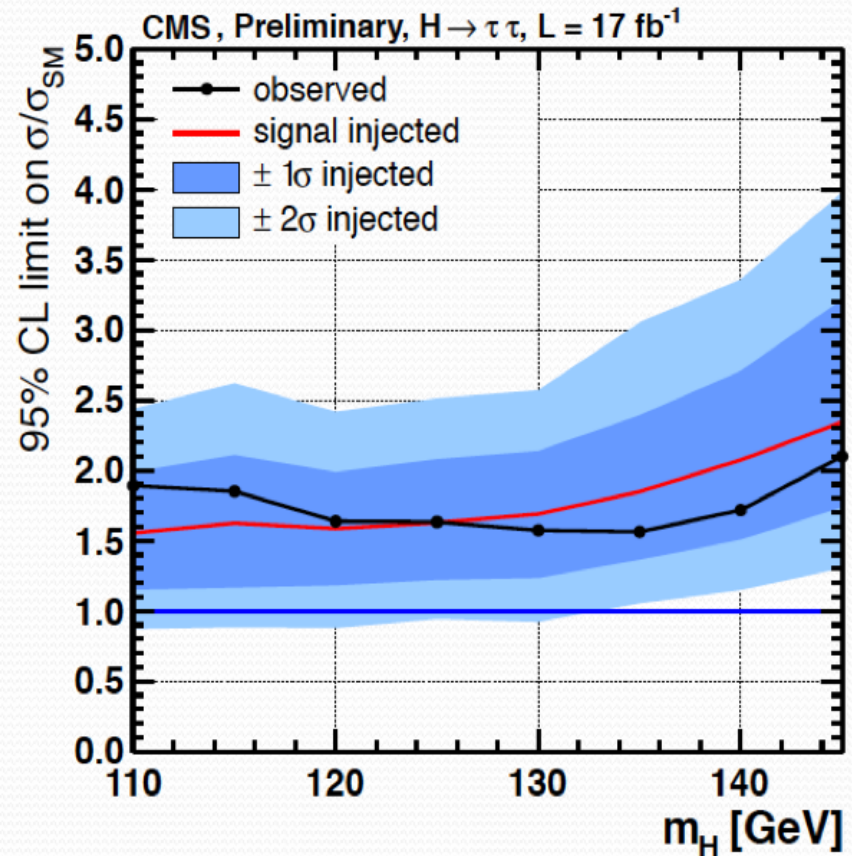
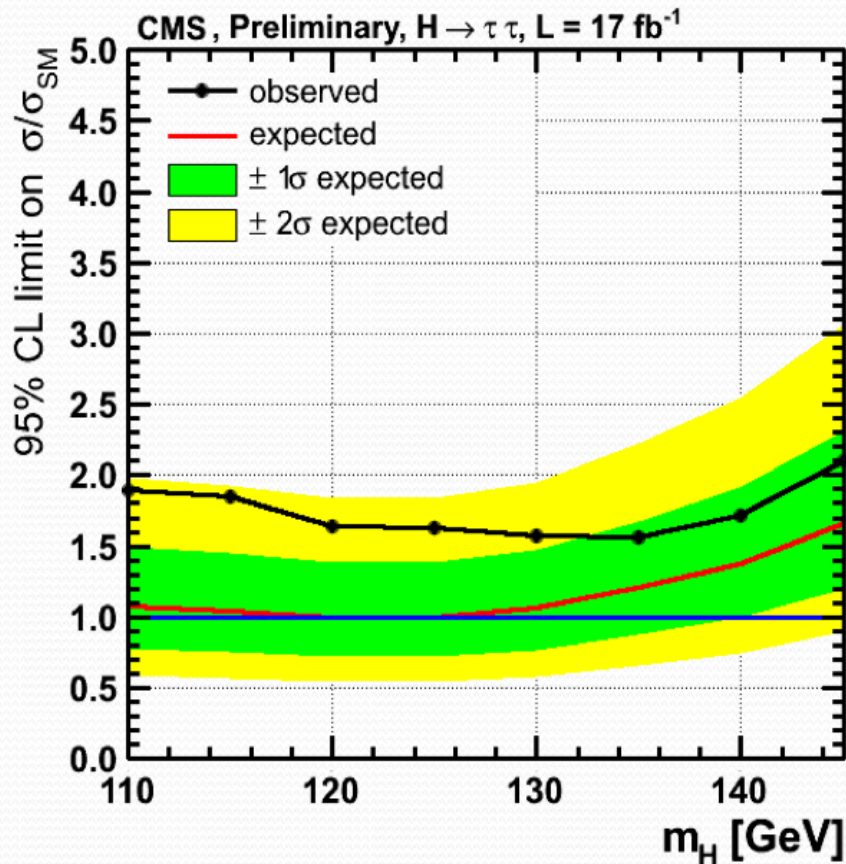
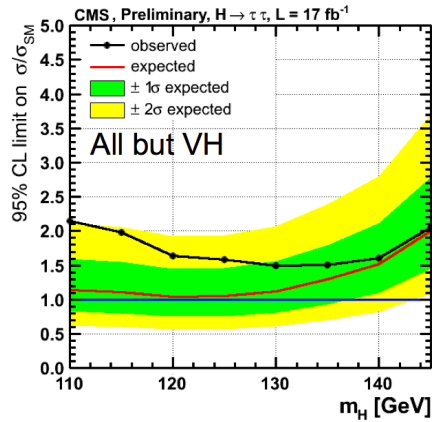
CMS Preliminary

17 fb^{-1} at $\sqrt{s} = 7$ and 8 TeV

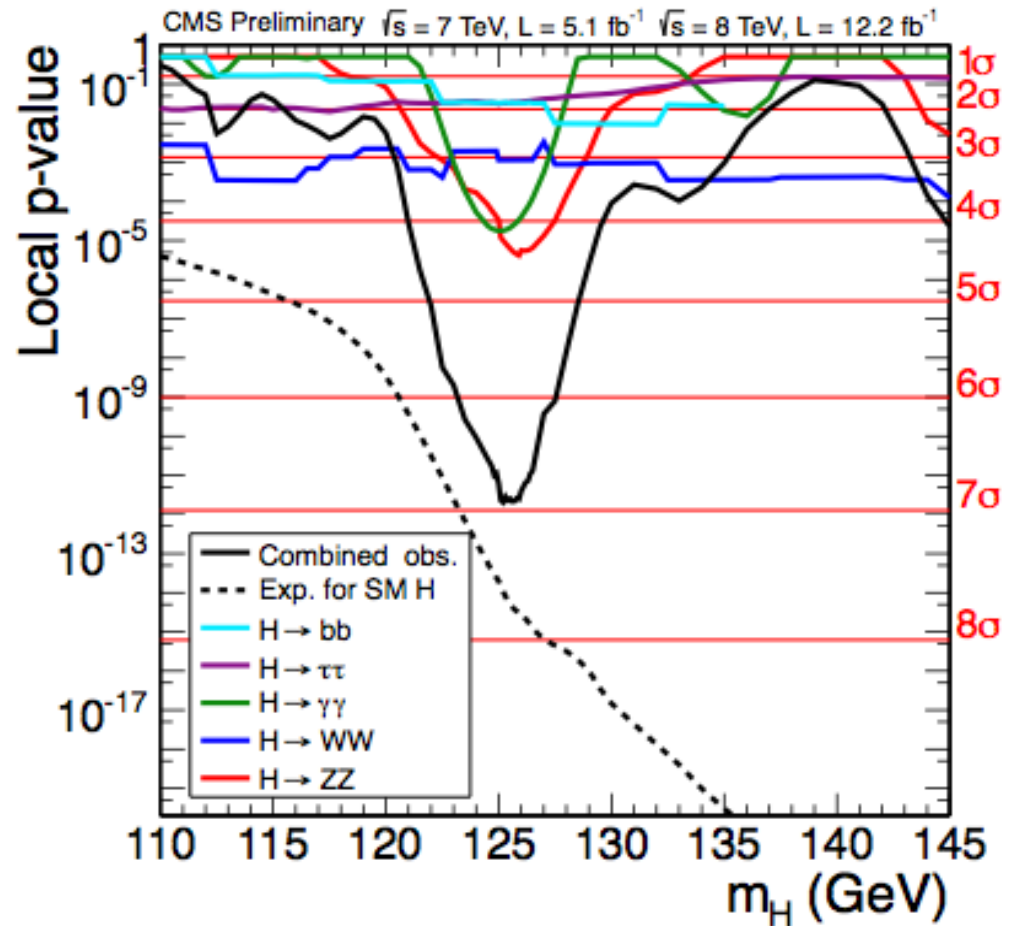
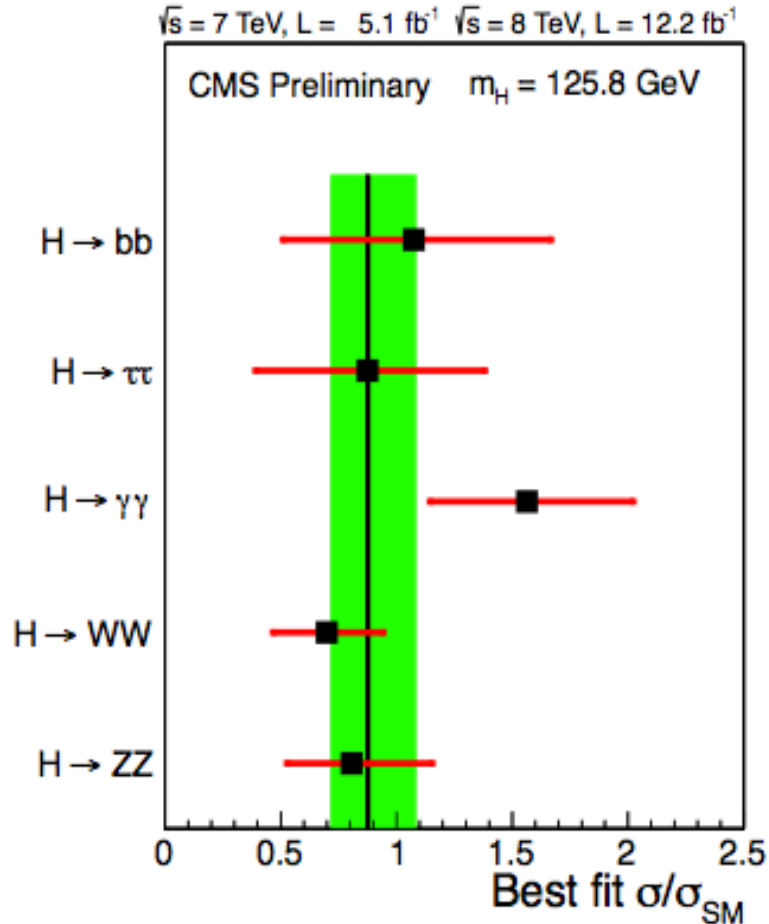


Searches for Higgs to $\tau\tau$

- Analysis significantly improvement
- Sensitivity around 1 times SM



Combined Limit & Global Picture

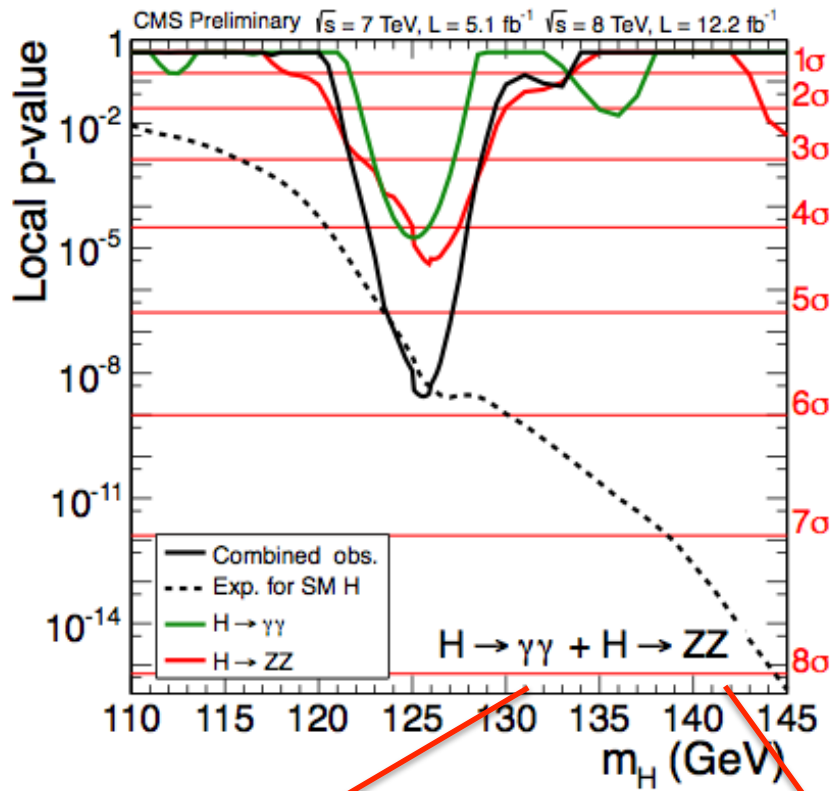


For $M_H = 125.8 \text{ GeV}$

Observed: 6.9; Expected: 7.8 \rightarrow Signal strength: 0.88 ± 0.21

Closer Look...

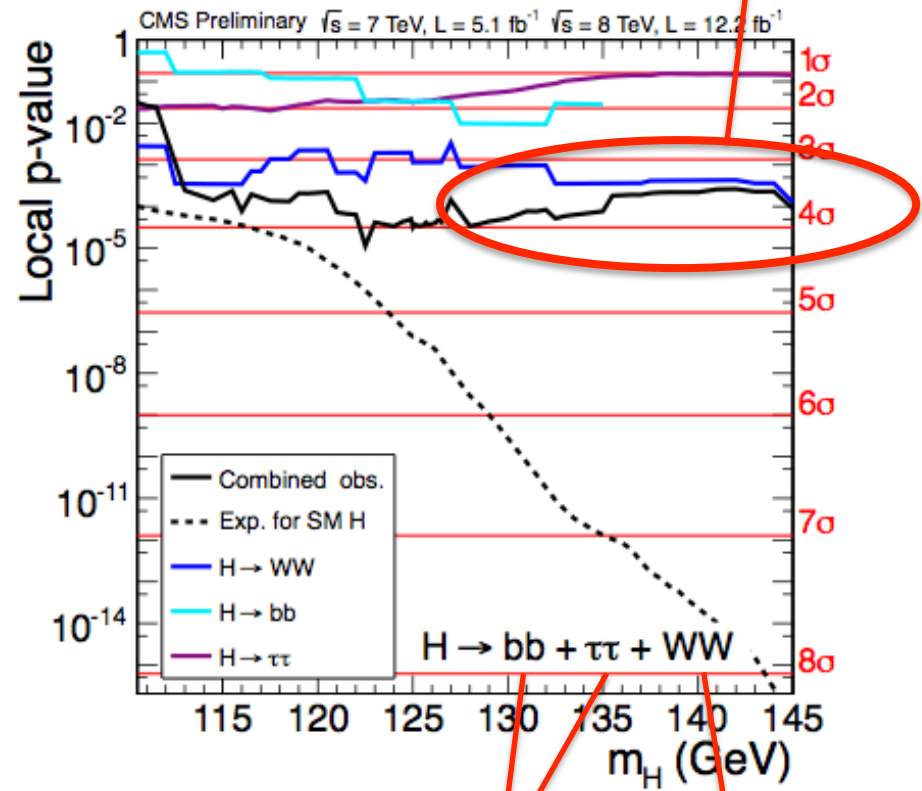
High resolution modes



C_F C_V

C_V

Low resolution modes



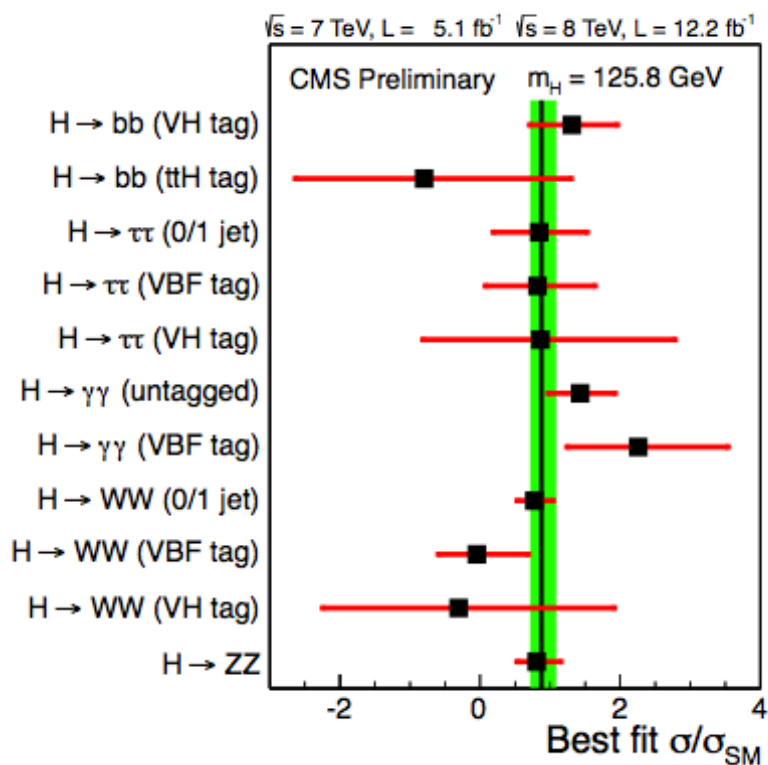
C_F

C_V

Other higher Mass Higgs?

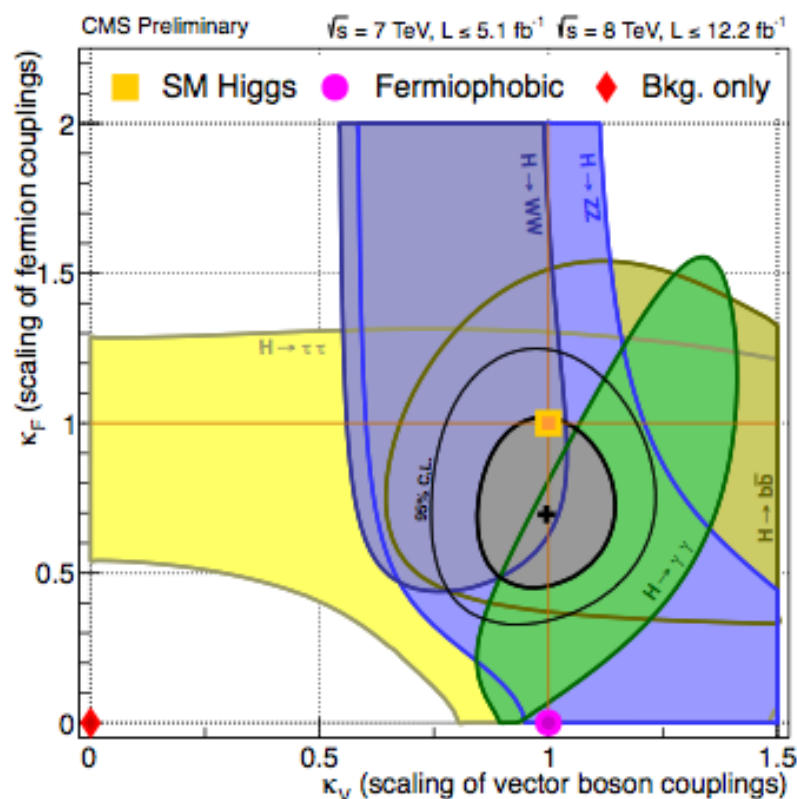
Coupling Measurement

Look at the individual measurements for a given process: ggH , VBF, VH $t\bar{t}H$



Seems of to assume that we are observing a SM Higgs like resonance within current errors

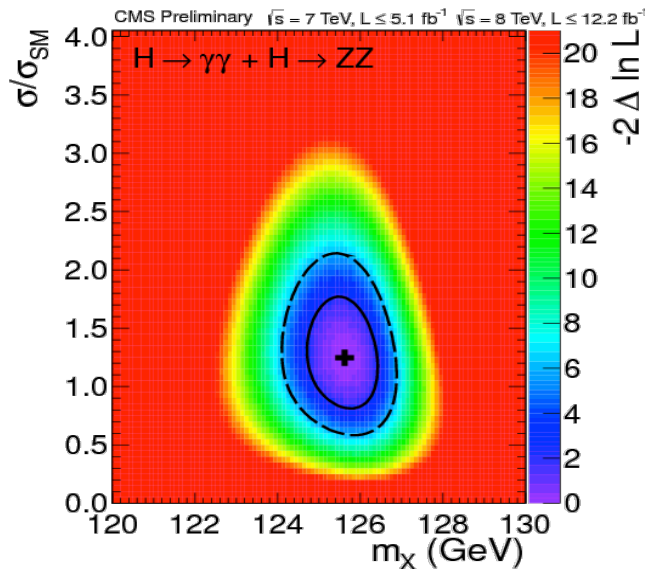
Map vector and fermion couplings C_V & C_F into 2 scale factors, κ_V & κ_F



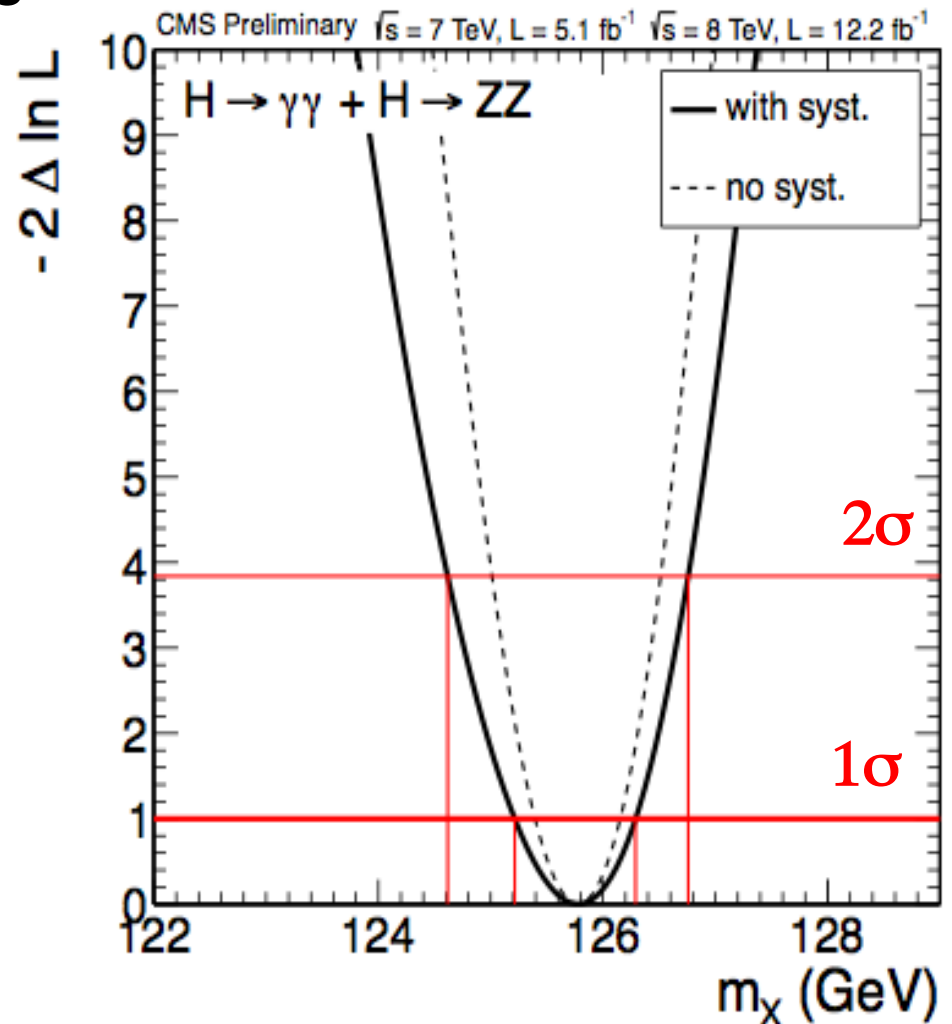
Fermiophobic scenario exclude at $>4\sigma$ level

Mass measurement

Current mass measurements done without making any assumption on individual $\sigma \cdot \text{BR}$

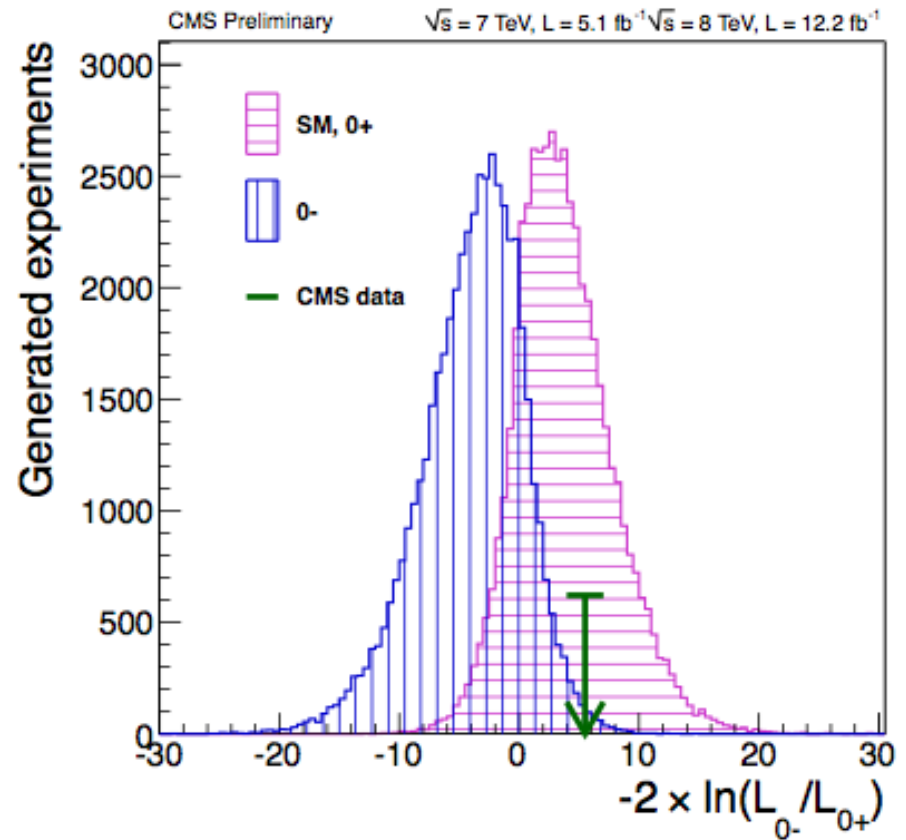


$\rightarrow M = 125.8 \pm 0.4 \text{ (stat)} \pm 0.4 \text{ (syst)}$



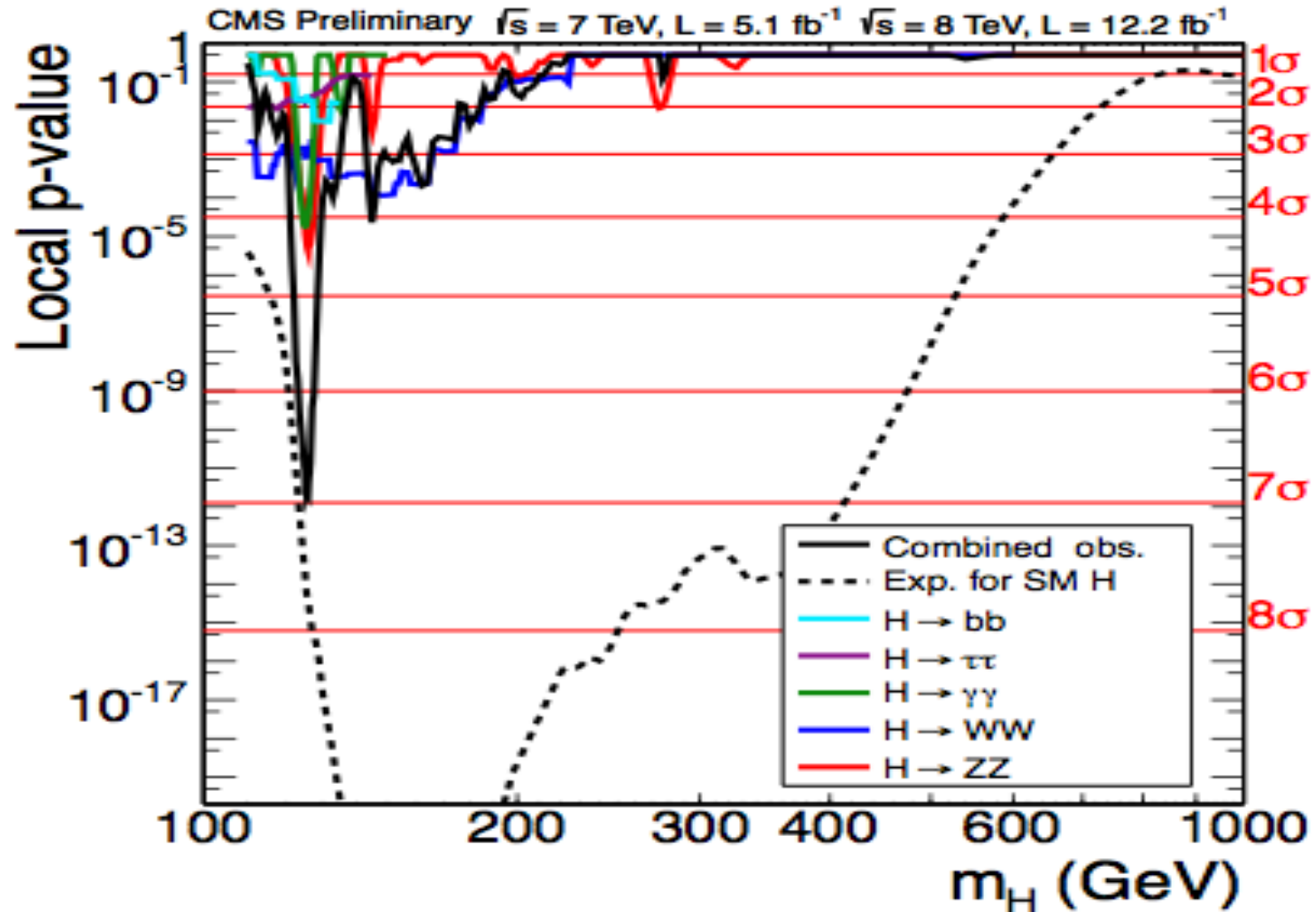
CP measurement

- **J of $\gamma\gamma$ system: spin 0 or spin 2**
- **Leptons kinematics distribution in the $ZZ\rightarrow 4L$ decay used to discriminate $J^{PC} = 0^-$ and 2^+ hypotheses from 0^+ .**
- **No sensitive on spin yet**



**Pseudoscalar hypothesis
excluded at 2.5σ level**

For completeness... Full mass range



Summary of what we know so far and do not

- **Significance and signal strength at 125.8 GeV:**
 - Observed: 6.9σ ;
 - Best fit $\sigma/\sigma_{\text{SM}} = 0.88 \pm 0.21$
- **Mass from $\gamma\gamma$ plus $ZZ \rightarrow 4L$:**
 - $M = 125.8 \pm 0.4$ (stat) ± 0.4 (syst)
- **Parity**
 - 0^+ : Scalar hypothesis consistent at a 0.6σ level
 - 0^- : Pseudo scalar hypothesis excluded at 2.5σ level
- **Spin**
 - No sensitivity yet to separate between Spin 0 & Spin 2
 - ➔ Looking at more ways of doing this...

Summary continue...

- **Couplings**

- Both fermions and vectors measured

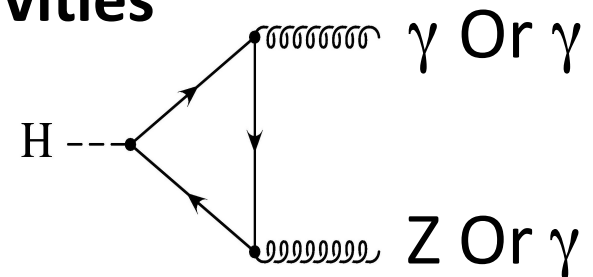
- Overall... good agreement with SM expectation is observed, that is, well within 2σ

- But too early to draw serious conclusions

- More data/precision is required

- See Chris Hill talk for projections on the statistical accuracy with larger data samples

- Add rare llg channel with sensitivities to loop effects in the near future



Conclusions

- Thanks to more statistics and improved analysis, CMS has made a significant test of the new boson near 125.8 GeV
 - 5 decay modes
 - 4 production modes
 - No significant deviations from the SM are seen
- It looks like some kind of Higgs
- From the channels with lower resolution
 - we cannot excluded the existence of additional bosons in the 130-140 GeV range...
- This is just the beginning! STAY TUNED

