H→WW and Higgs combination

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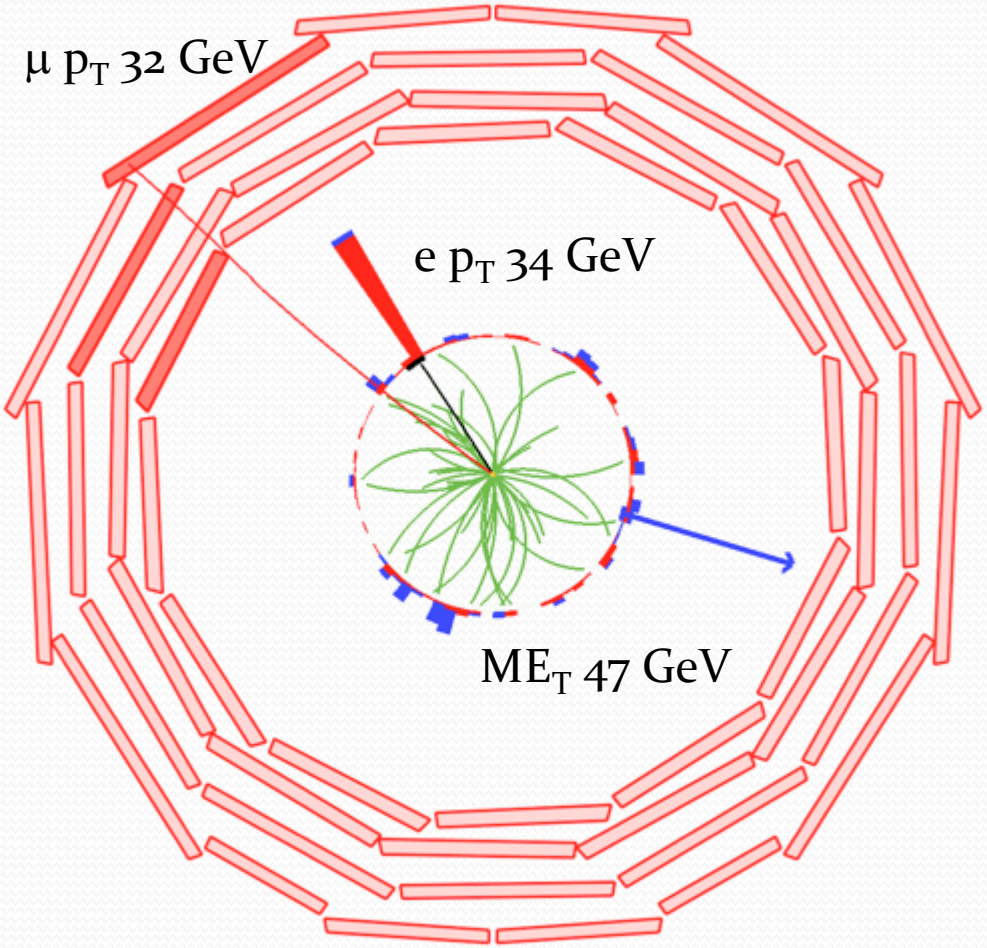
Index

- H→ WW analysis
  - H→WW in a nutshell
  - Analysis selection
  - Background estimation
  - Systematics
  - Results
- Higgs combination
- Summary

H→WW in a nutshell



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/νν or missing lepton

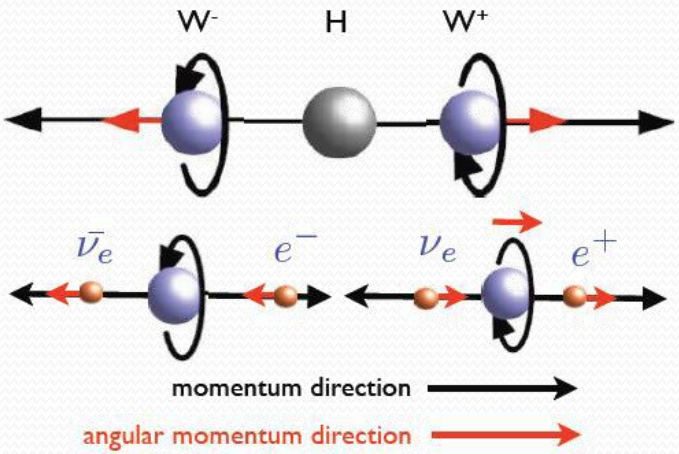
H→WW in a nutshell

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

Dominant backgrounds

	0-jet	1-jet	2-jets
DF	WW, W+jets, V+γ^* (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



Analysis strategy

WW analysis

Mass independent

2D shape

	0 jets	1 jet	2 jets
DF	2D	2D	cut
SF	cut	cut	cut

Cut based

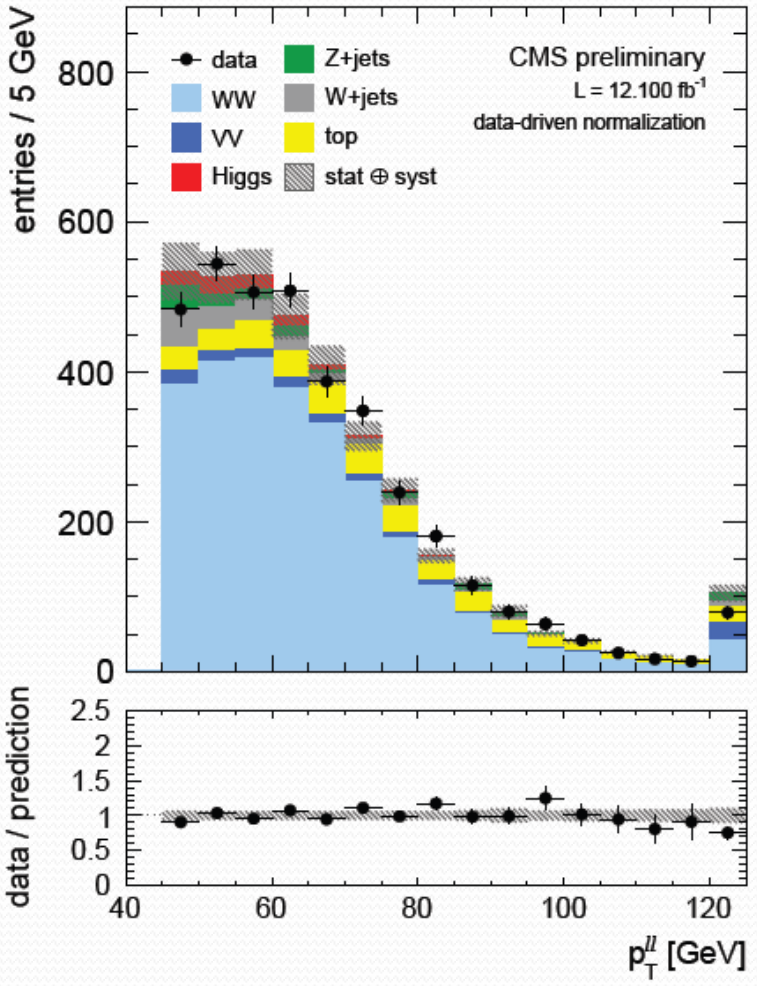
	0 jets	1 jet	2 jets
DF	cut	cut	cut
SF	cut	cut	cut

- **Baseline:** 2D [m_T^*, m_{ll}] shape analysis in DF 0 and 1 jet bins
  - Exploits the correlation of two kinematic variables
  - Easier interpretation than multivariate discriminants
- **Cross-check:** Cut-based analysis

* $m_T = \sqrt{2p_T^{\ell\ell} E_T^{\text{miss}} \left(1 - \cos \Delta\phi_{E_T^{\text{miss}}\ell\ell}\right)}$

Analysis selection

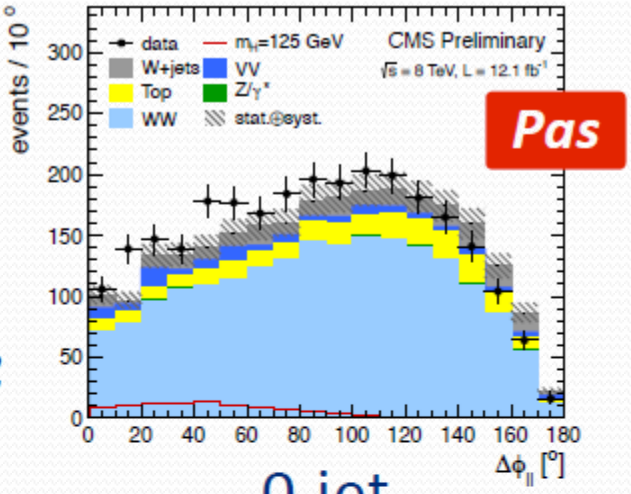
- **Lepton selection**
  - 2 opposite sign leptons ($|\eta| < 2.5$ for e, $|\eta| < 2.4$ for μ)
  - $p_T^{lead} > 20$ GeV/c and $p_T^{trail} > 10$ GeV/c
- **WW selection level**
  - Low mass resonances: $m_{ll} > 12$ GeV/c²
  - Z-peak veto: $|m_{ll} - m_z| < 15$ GeV/c² for ee/$\mu\mu$ events
  - Soft projected E_T^{miss} preselection
  - Extra lepton veto: 2 leptons only
  - Kinematical cut: $p_T^{ll} > 45$ GeV/c
  - b-veto: no b-tagged jets nor softmuons
  - Z/γ^* rejection: E_T^{miss} cut



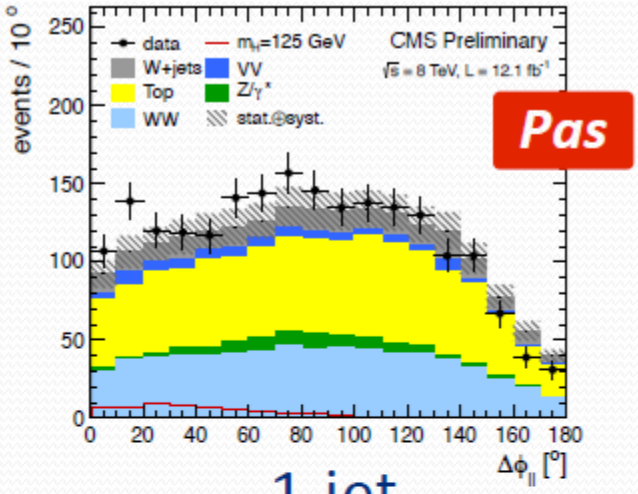
WW level

Data driven estimates applied

$\Delta\phi_{ee}$

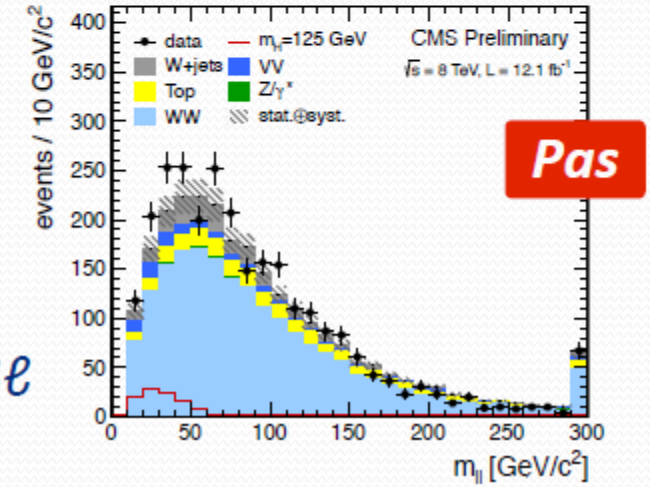


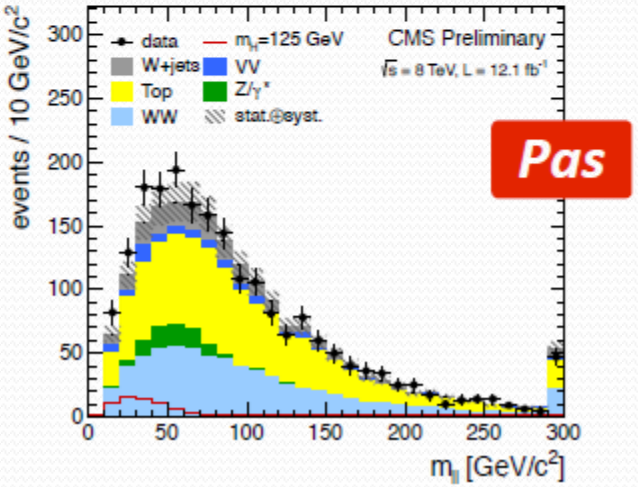
0-jet



1-jet

m_{ee}

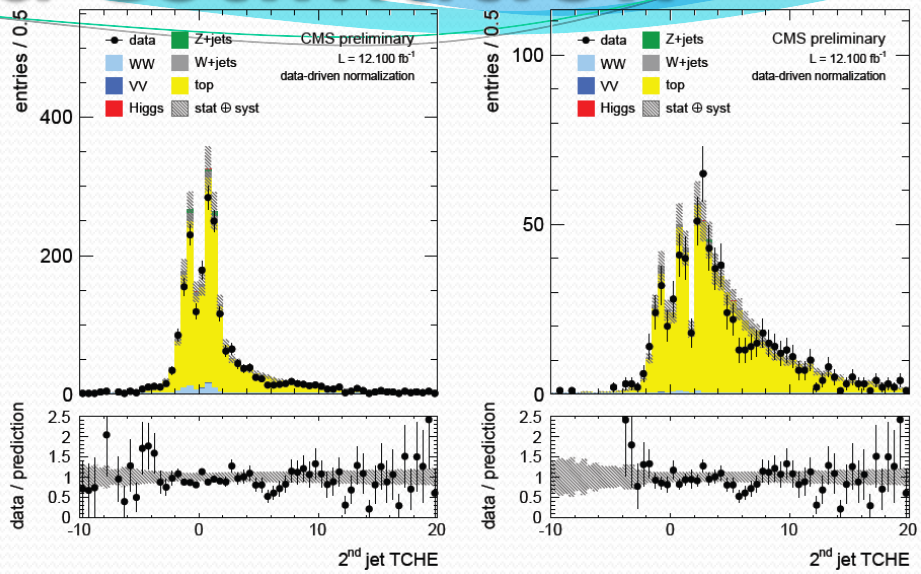


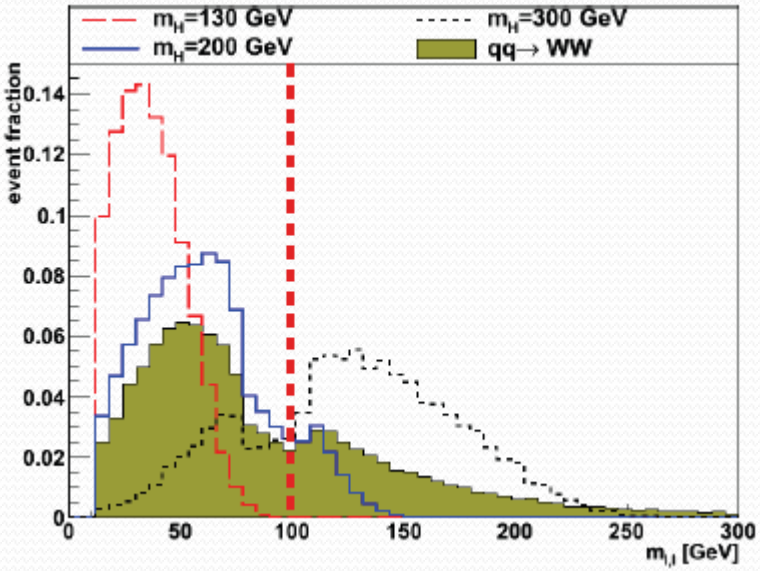


Background estimation

Top background

- **Normalization procedure relies on the measurement on data of the "top-tagging" efficiency**
  - Efficiency is measured in a top-enriched sample
  - Extrapolation to the signal region from the data yields obtained by inverting the top tag veto.





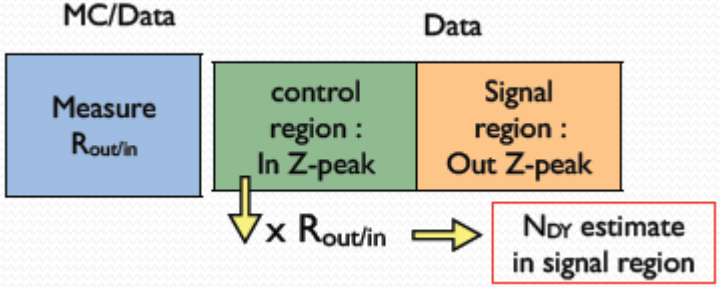
WW background

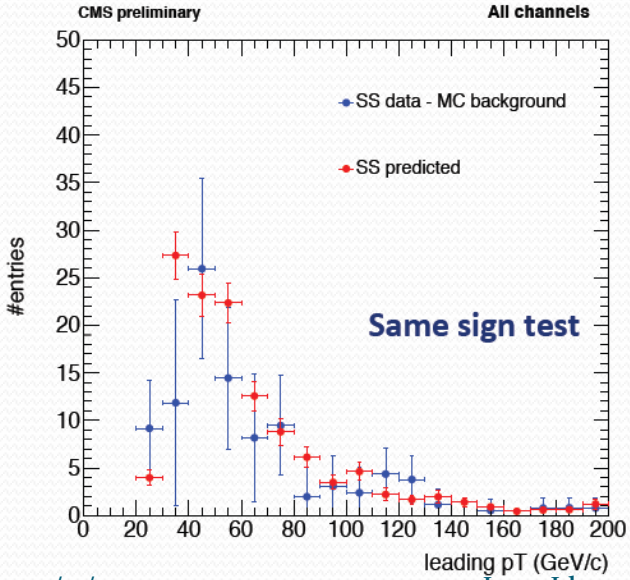
- **For mH < 200 GeV, 0/1 jet bins:**
  - WW yields computed in data from a side band defined as:
    - Mll > 100 GeV
    - mH dependent cuts on lepton pT
  - Substract all other backgrounds according to their data driven estimates
  - WW data driven yields propagated by MC to the final level selection.
- **For mH > 200 GEV and 2 jets bin:**
  - Using MC prediction.

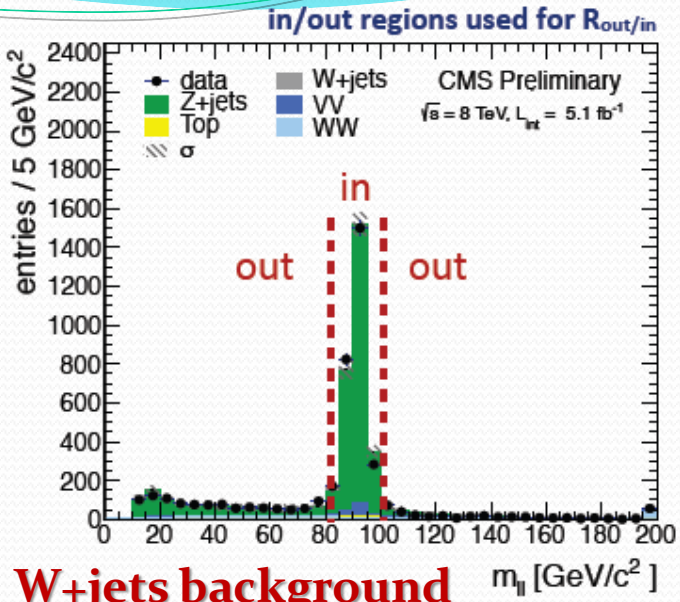
Background estimation

DY background

- **Esssential to estimate the contribution in the SF states from data**
  - Reduced with Z-peak window veto + MET cuts
  - Using the $R_{OUT/IN}$ method to extrapolate from the control region to the signal region.

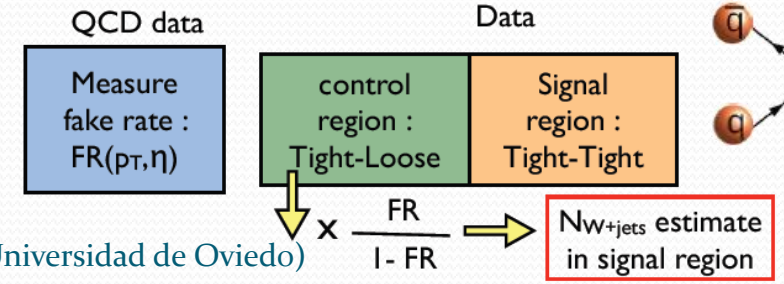


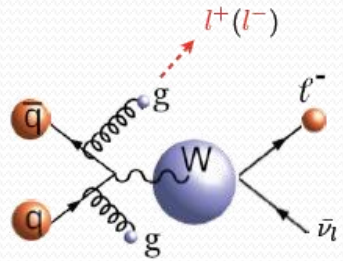




W+jets background

- **Critical background in the low mass region**
  - Measure the ratio of tight-to-loose quality leptons using QCD dominated data
  - Apply "fake rate" to selected dilepton control region to estimate the fake contribution to the analysis sample





Final HWW level

0/1 jet Cut Based Selection:

Cut-and-count approach with mass-dependent selection optimised at each mass-point:

- $p_T(l_{max})$, $p_T(l_{min})$
- m_{ll}
- $\Delta\phi_{ll}$
- m_T

m_H	$p_T^{\ell,max}$	$p_T^{\ell,min}$	$m_{\ell\ell}$	$\Delta\phi_{\ell\ell}$	m_T
[GeV]	[GeV]	[GeV]	[GeV]	[°]	[GeV]
	>	>	<	<	[,]
120	20	10	40	115	[80,120]
125	23	10	43	100	[80,123]
130	25	10	45	90	[80,125]
160	30	25	50	60	[90,160]
200	40	25	90	100	[120,200]
250	55	25	150	140	[120,250]
300	70	25	200	175	[120,300]
400	90	25	300	175	[120,400]

cut-based mass dependent selection

VBF (2-jets) Cut Based Selection:

- 2 jets with $p_T > 30$ GeV
- No jet above 30 GeV in the η region between the two leading jets
- $\Delta\eta\ (j_1 - j_2) > 3.5$
- $m_{j1j2} > 500$ GeV/c2
- Additional mass-dependent cuts on lepton pT, Dpll, mll

(as in the 0/1 jet bin except for mT > 30 GeV at all masses)

Systematic Uncertainties

Sources of uncertainties

- Theoretical uncertainties on PDF and QCD scale and generator uncertainties: 10-50%
- Data-driven background estimation:
  - WW and Top : 10-30%
  - W+jets ~40-70%
  - $Z/\gamma^* \rightarrow ll$: 20% to > 100%
  - $W+\gamma(*)$, $Z/\gamma^* \rightarrow \tau\tau$ ~30%
- MC description of experimental (energy scale and resolution, efficiency): 2-10%
- Luminosity: 4.4%

Uncertainty variation in shape templates

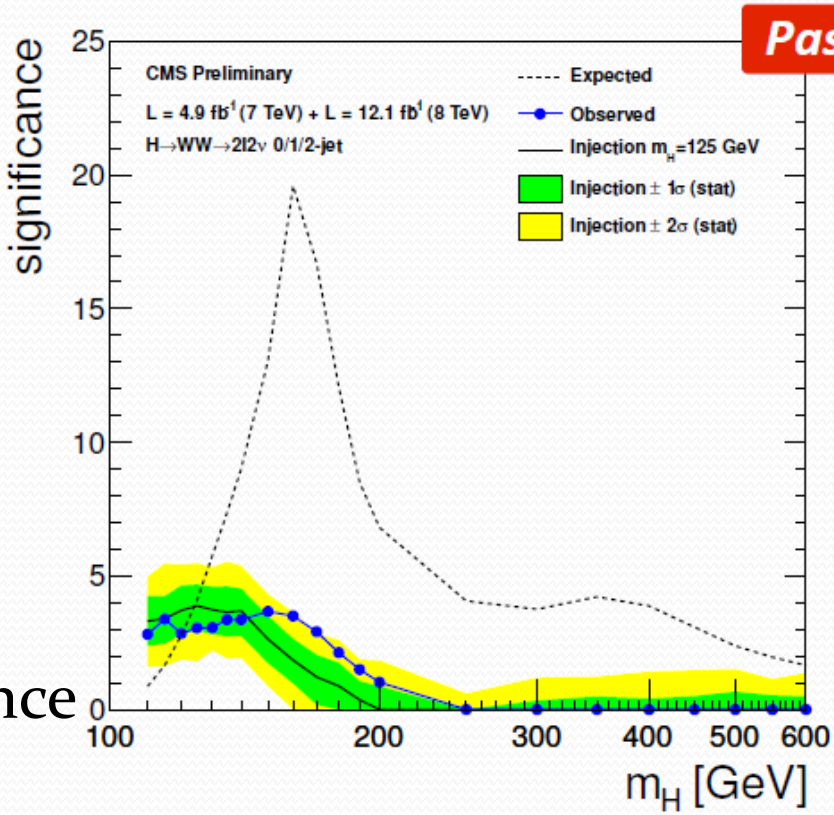
- QCD scale variation and generator modelling (WW, Top)
- Data-driven template uncertainties (W+jets)
- Experimental measurements and selection efficiency bias
- Sample statistics

Results

- **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

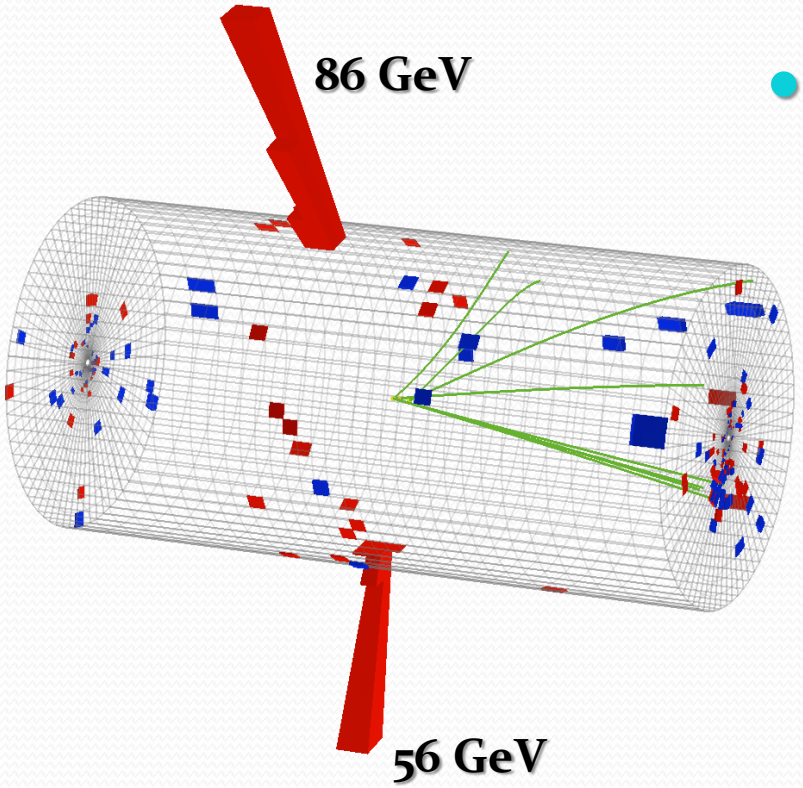
Expected:4.1

Observed: 3.1

Combination overview

Channel	m_H range [GeV/c^2]	Dataset [fb^{-1}]	Data used	m_H resolution
H→γγ	110-150	5+5	2011 + 2012	1-2%
H→ττ	110-145	5+12	2011 + 2012	15%
H→bb	110-135	5+12	2011 + 2012	10%
H→WW→lνlν	110-600	5+12	2011 + 2012	20%
H→ZZ→4l	110-1000	5+12	2011 + 2012	1-2%

$H \rightarrow \gamma\gamma$

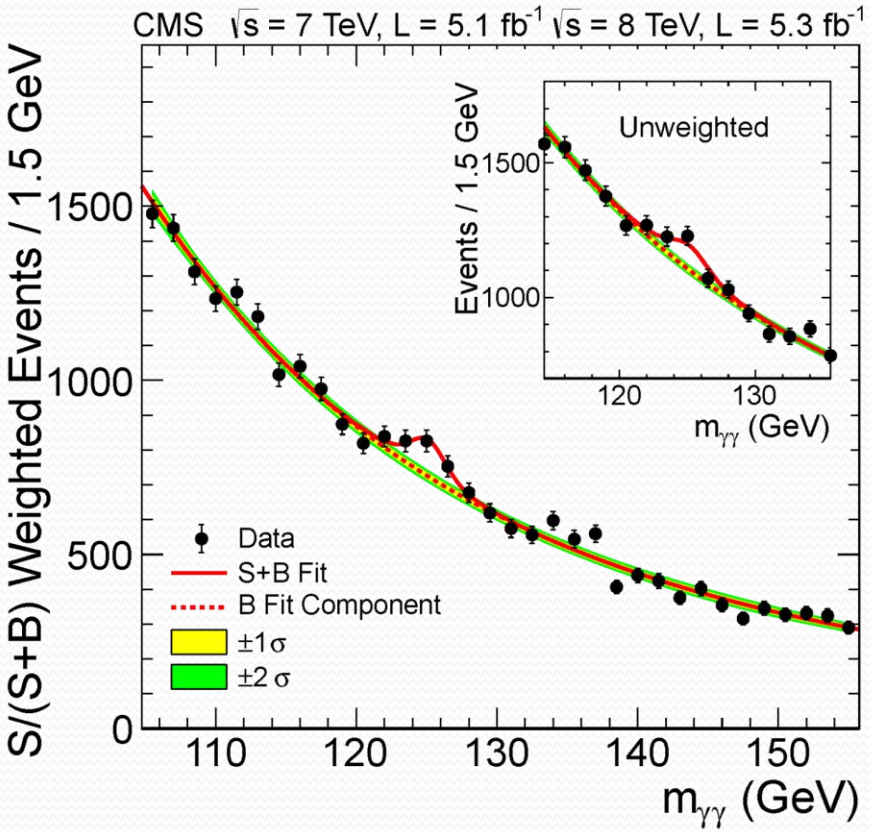


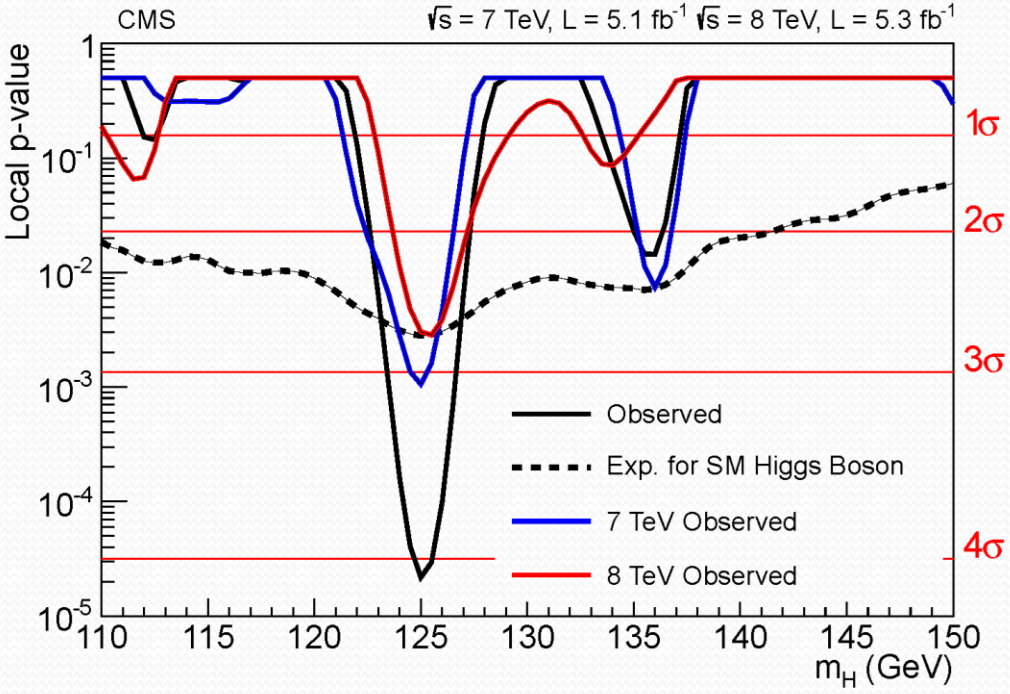
- **Signature and background:**
  - Two high momentum photons
  - Two photons → excelent resolution
  - Looking for a narrow peak
  - Large irreducible background from direct two photons
  - Small fake photon backgound

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

NO UPDATE SINCE ICHEP

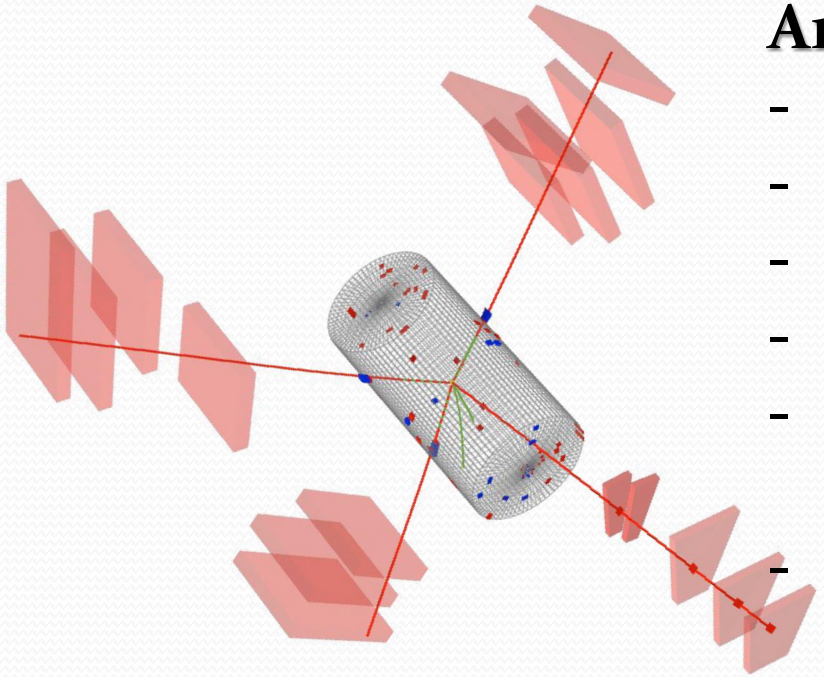
H→ γγ





Over 4 standard deviations

H→ZZ→4l

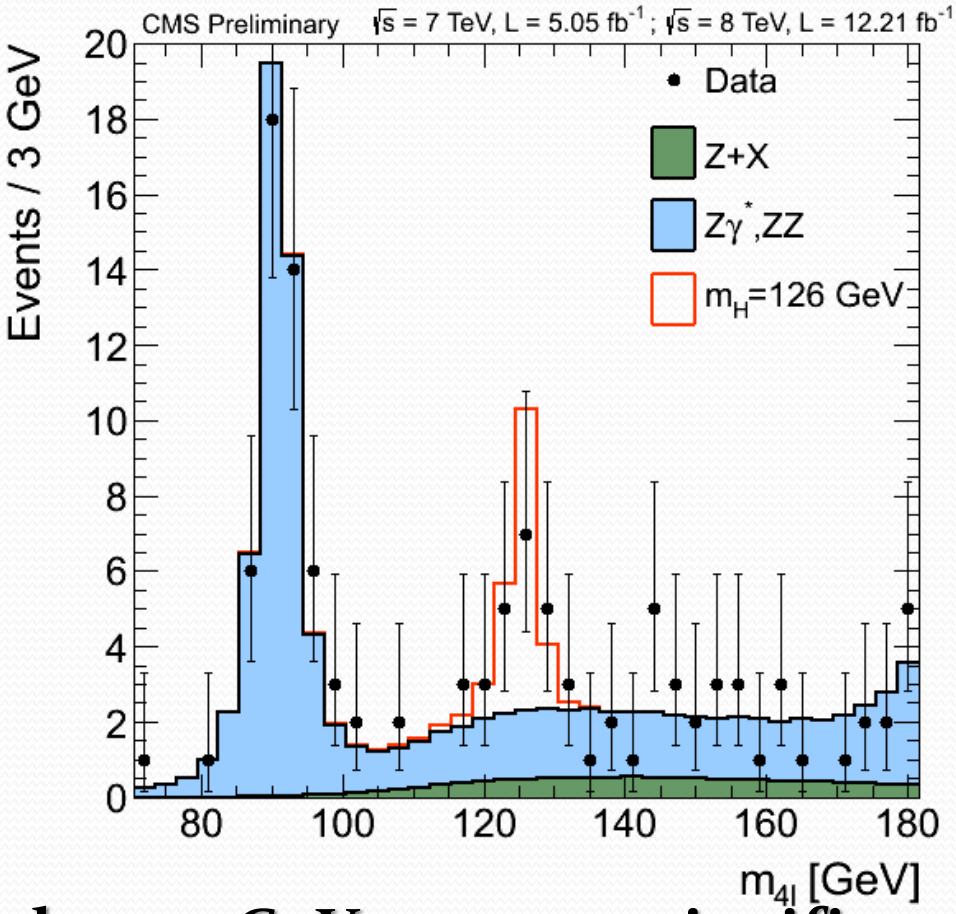


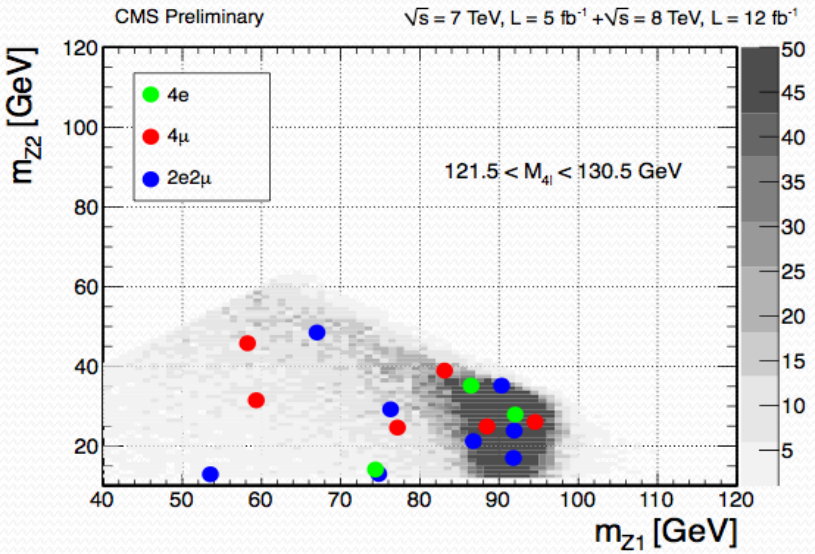
Analysis overview:

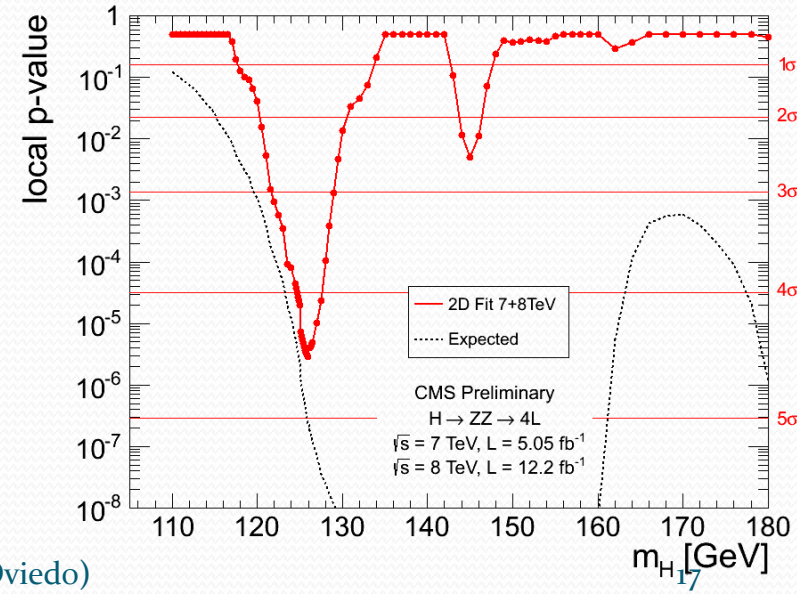
- 4 isolated high p_T leptons
- Consistent with Z decays
- From same vertex
- Fit mass peak with resolution.2-4 GeV
- Little background, non resonant ZZ production
- Also Zbb and top (2l2ν2b)

- **Background removal:**
  - Leptons from b-decays are non-isolated and displaced
  - Analysis with only minor modifications since ICHEP

H→ZZ→4l





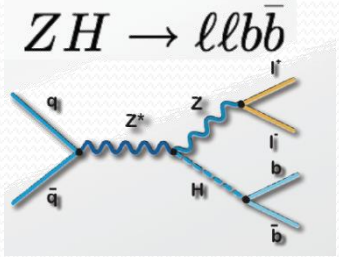


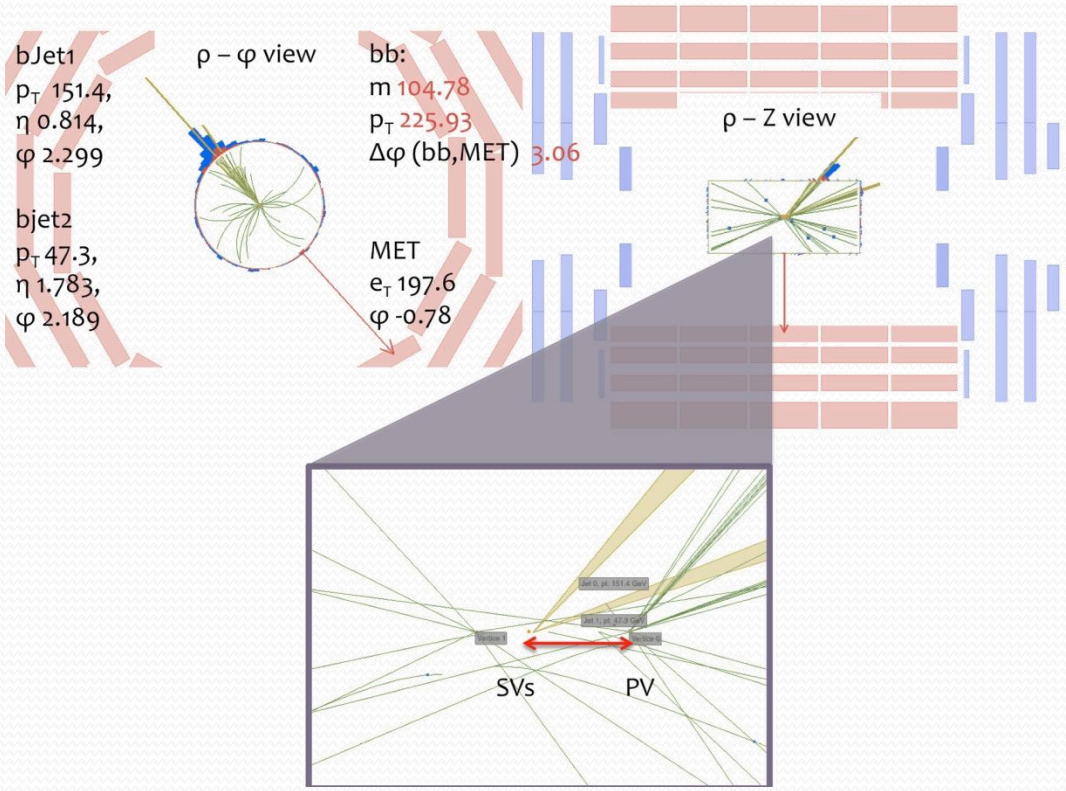
Peak ~ 125 GeV got more significant:

→ **Significance now 4.6 σ**

H→ bb

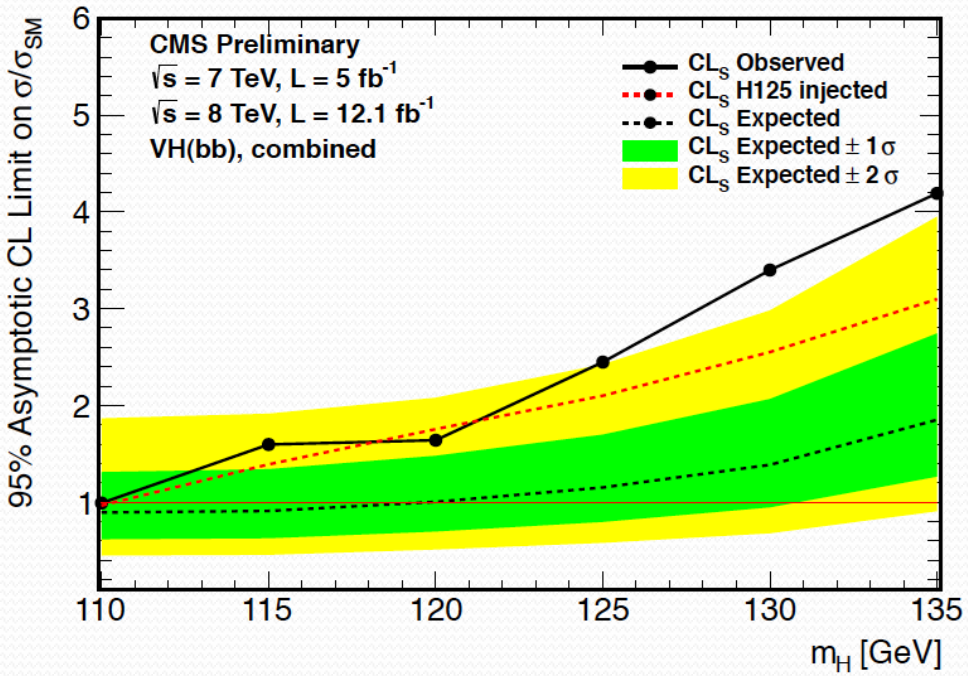
- **gg → H → bb and VBF are dominant production modes but overwhelmed by enormous QCD di-jet background**
- Best option: qq → VH; H→bb
  - Major backgrounds are V+jets, VV, ttbar
- **Use:**
  - VH topology: $\delta\phi(V,H) > 3$
  - p_T (V) > 100-160 GeV (boosted W/Z)
  - Tight b-tagging & MET quality
  - Backgrounds estimated from control data

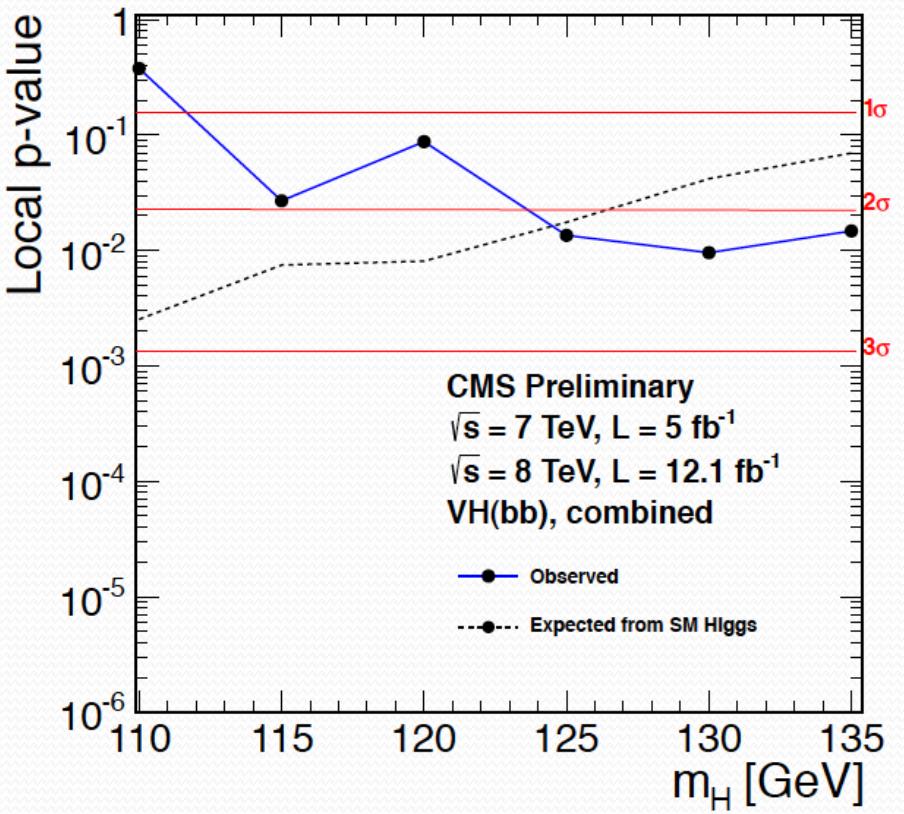




5 sub channels:
- Z(→ll); H→bb, l=μ,e
- W(→lν); H→bb;l=μ,e
- Z(→νν); H→bb

H→ bb

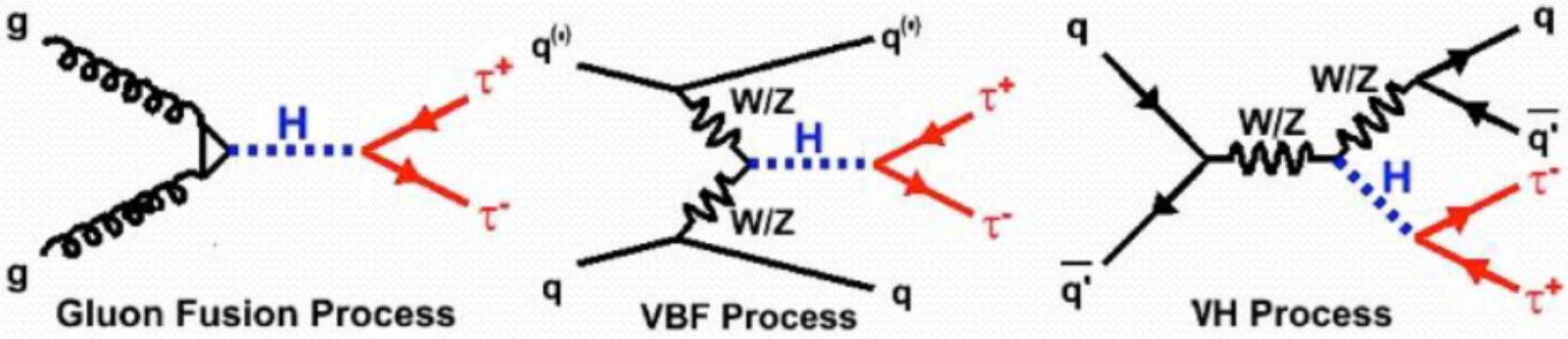




Excess compatible with SM starts to build up: 2.2 sigma

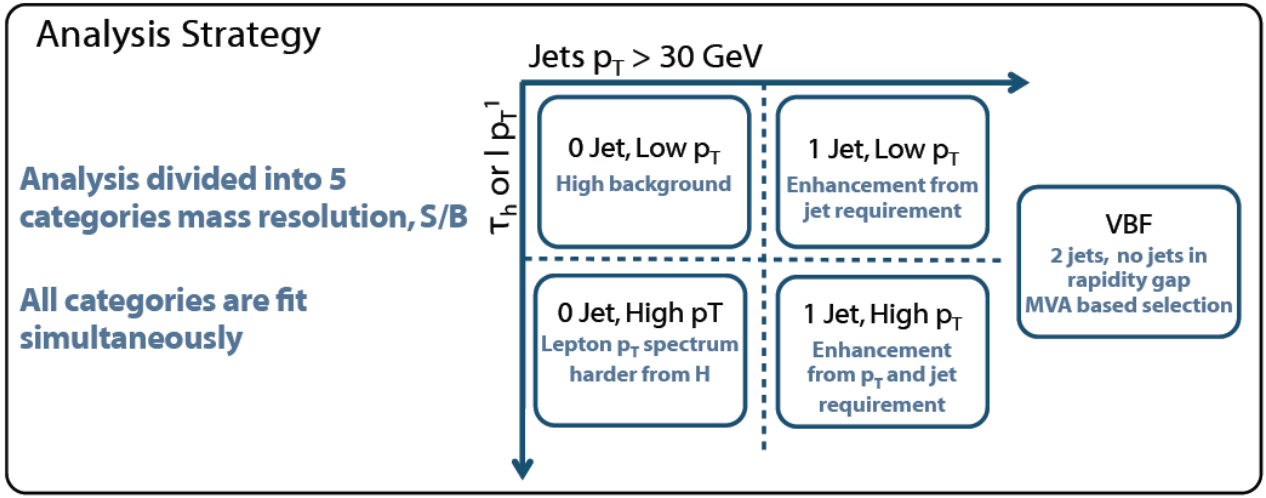
H→ττ

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

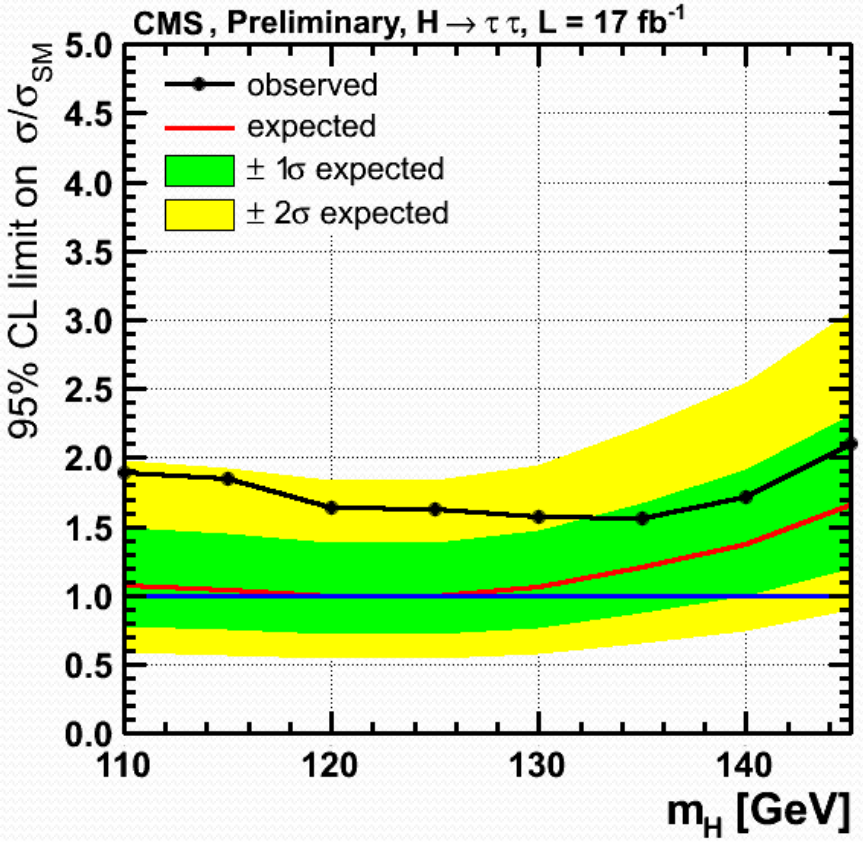


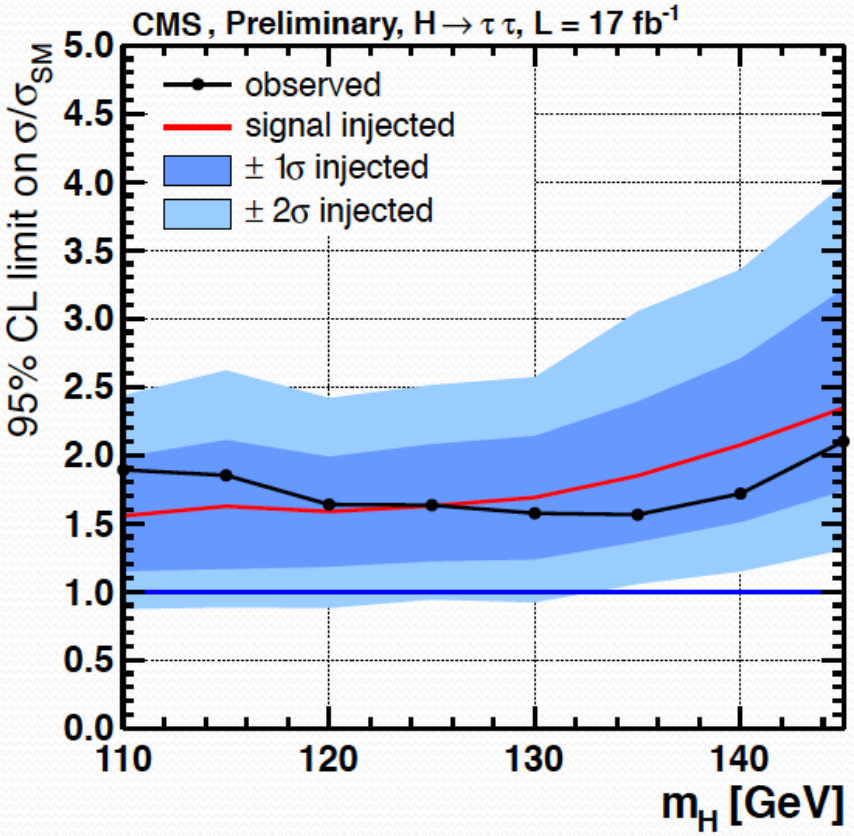
Characteristics:

- High σxBR at low mass
- Sensitive to all production modes
- Probes coupling to leptons
- Challenging large backgrounds:
  - DY→ ττ, W+Jets, QCD



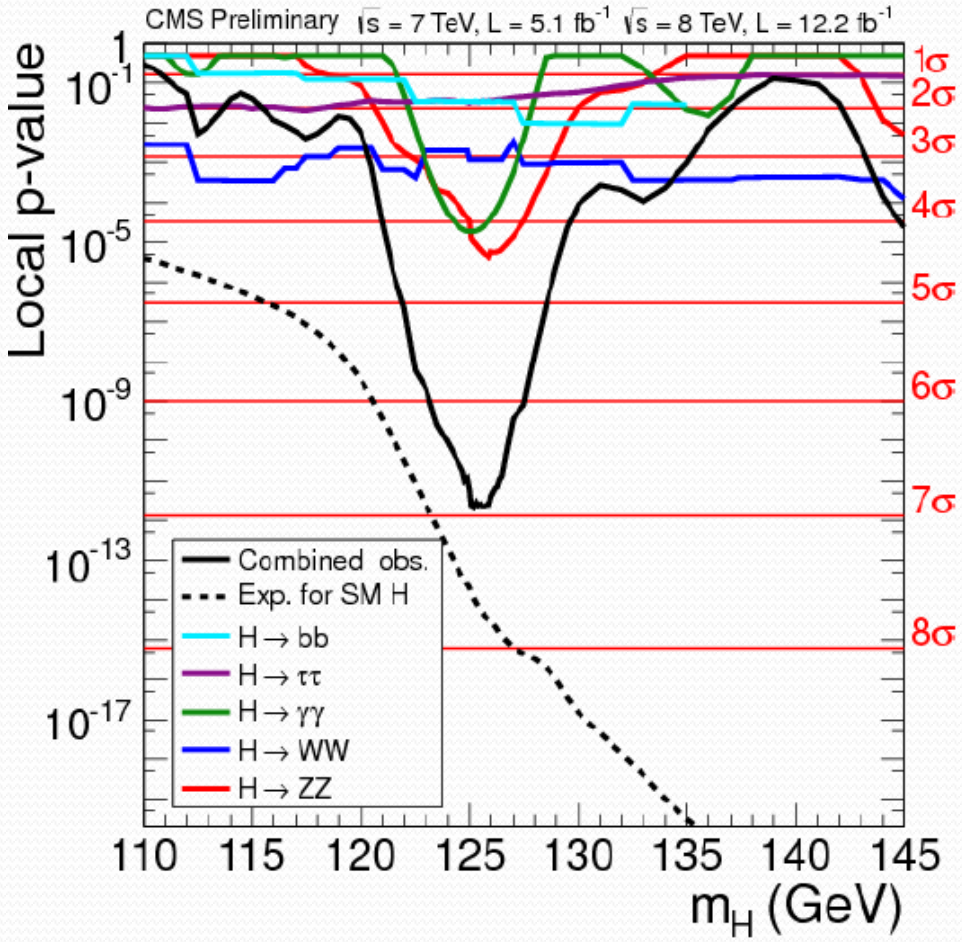
H→ττ





Sensitivity ~1 times SM → very mild excess is building at 1.3 σ

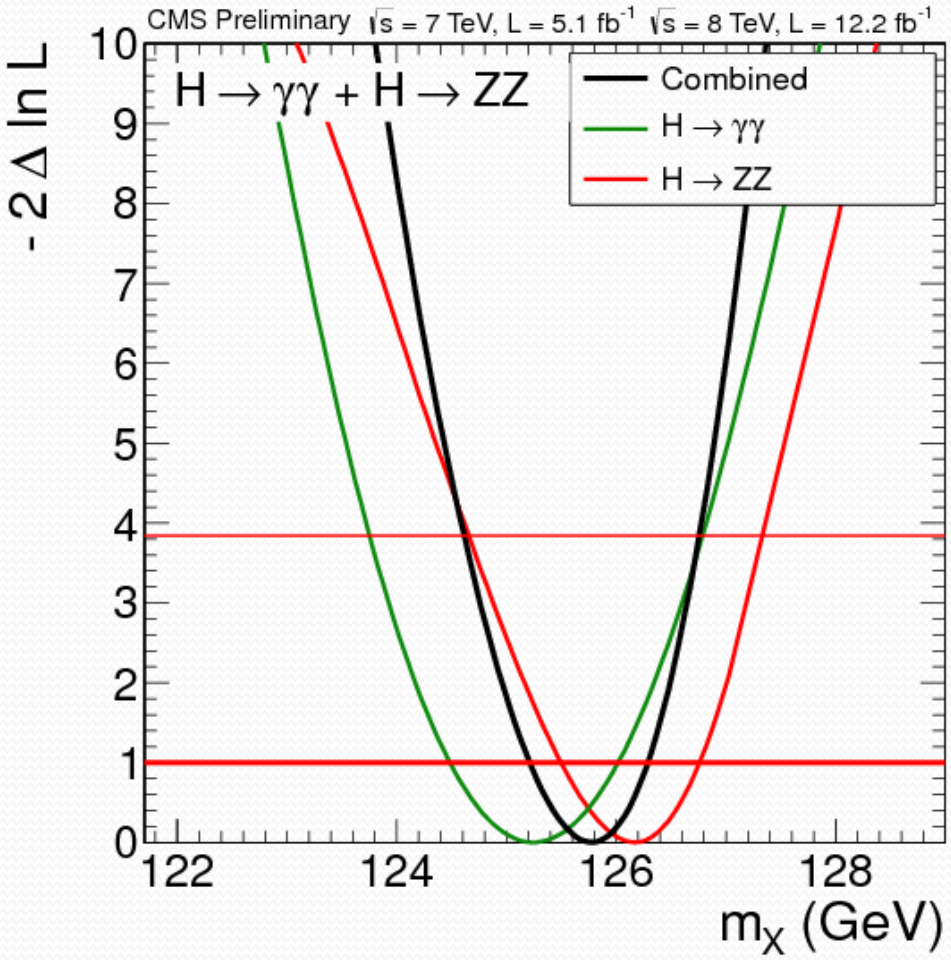
Combination



- Observed: 6.9; Expected: 7.8 [signal strength: 0.88 +/- 0.21]

Combination

→ **Mass measurement:**
M_H = 125.8 ± 0.4 (stat) ± 0.4 (syst)



Conclusions

- **New results consistent with publications**

– Significance of the signal now at 6.8 standard deviations

– Mass of the particle: $\mathbf{M_H = 125.8 \pm 0.4\ (stat) \pm 0.4\ (syst)}$

- **Particle behaves even more like Higgs compared to ICHEP**

- **More data for the winter conferences.**

BACKUP

Combination