Higgs Searches at the LHC with CMS

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LC - Forum
DESY, Feb 7th 2012

Summary

- Tremendous progress in the hunt for the Higgs boson

- SM Higgs boson masses excluded by CMS

  at 95% CL: expected 117-543 GeV, observed 127-600 GeV

  at 99% CL: expected 129-500 GeV, observed 128-525 GeV

- Remaining small mass window for SM Higgs boson

  114.4-127 GeV

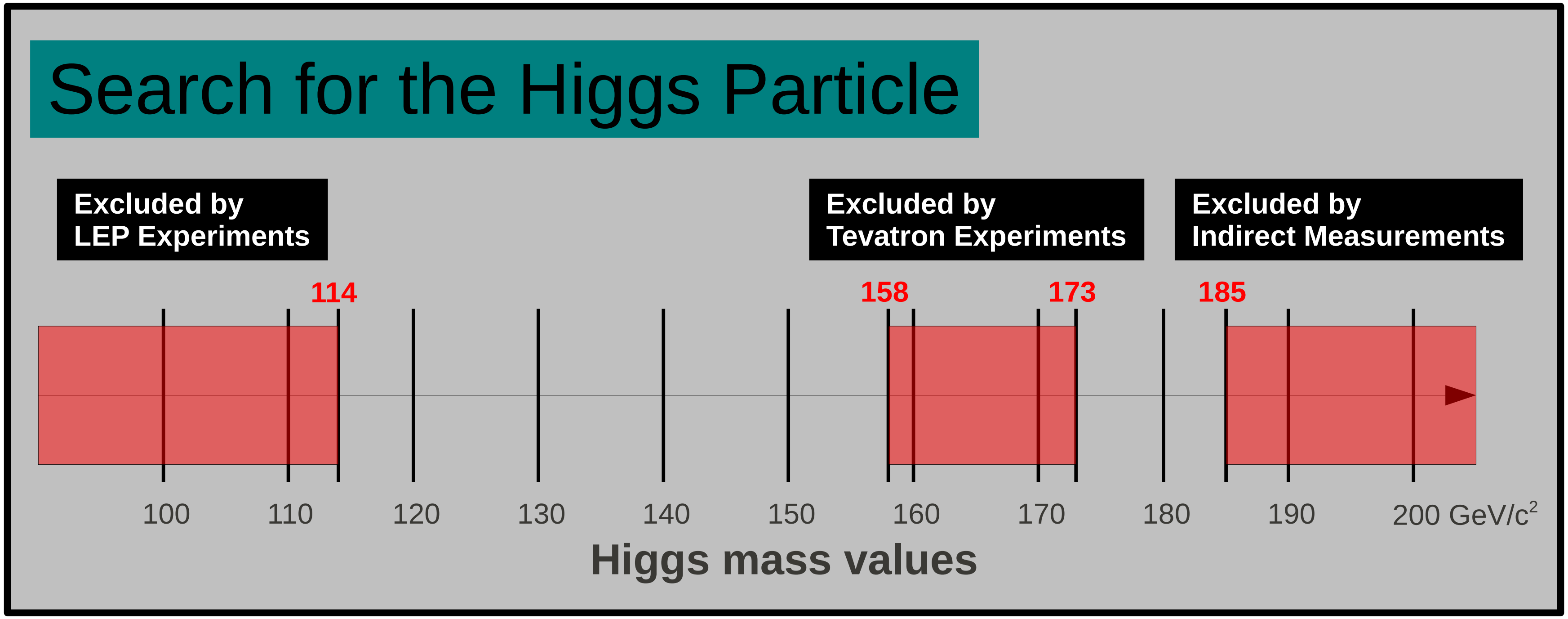
- Low mass excess

  inconclusive with the current amount of data

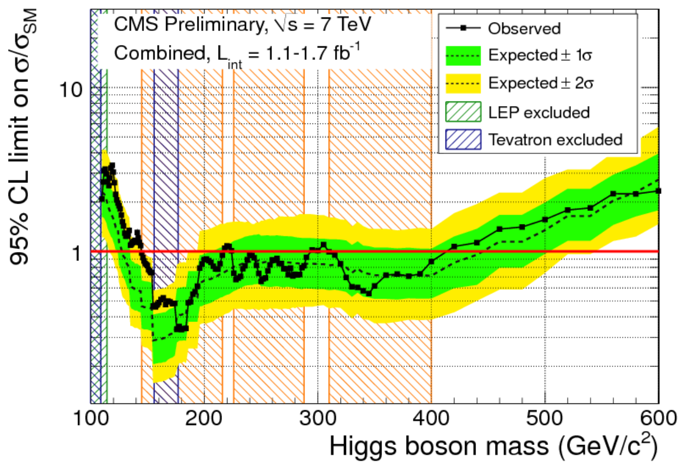
What I will not cover

- CMS detector and its performance
- The Higgs Mechanism
- Exotic Higgs results
- ATLAS results

Standard Model Higgs Landscape before LHC Era



Standard Model Higgs Landscape with 1.0-2.3 fb^{-1} of LHC data



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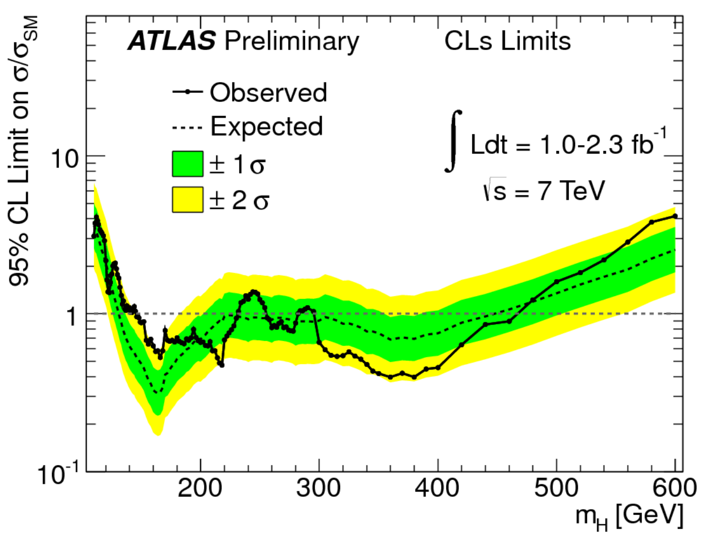

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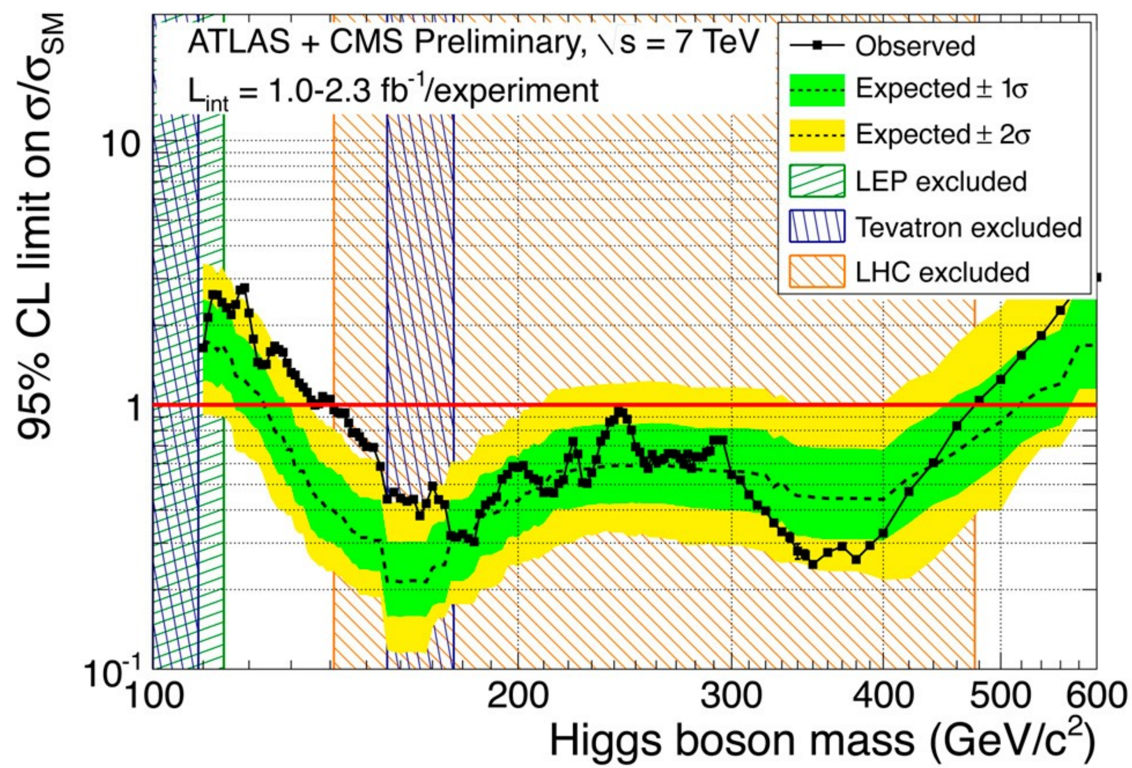
No significant excess

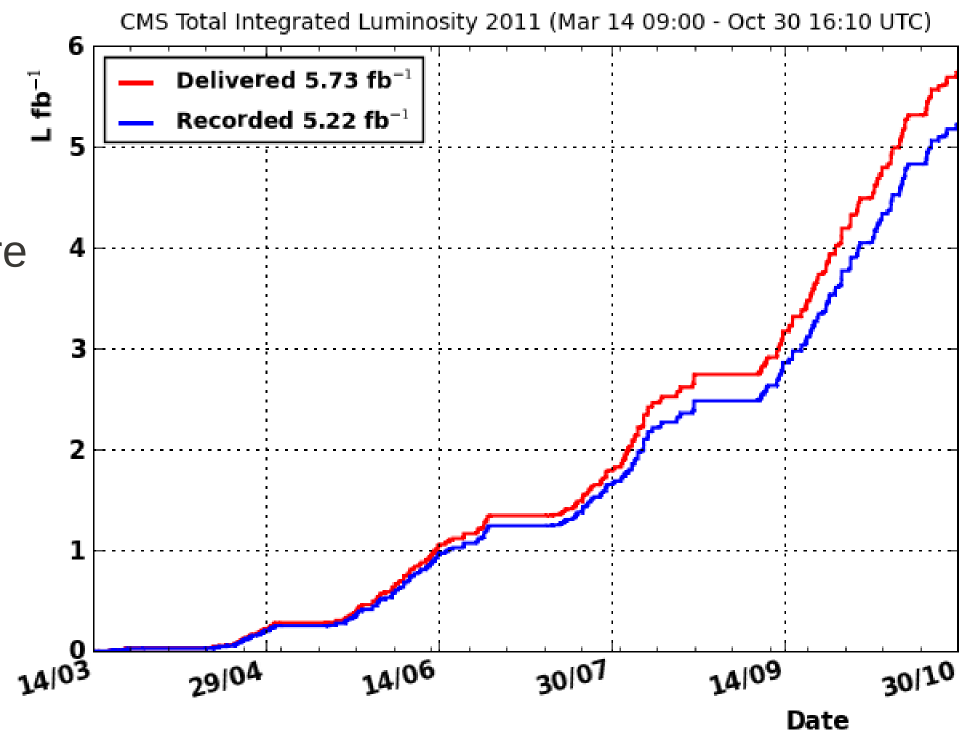


Range: 141-476 GeV excluded
124-520 GeV expected

LHC Performance

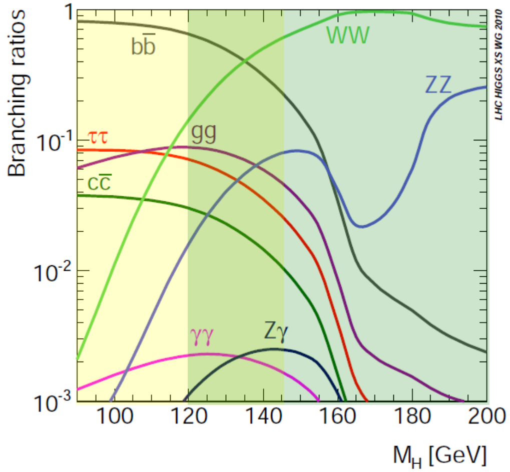
- 2010 pp: 47pb^{-1} delivered, L = 2x10^{32} cm^{-2}s^{-1} @ 7 TeV
- 2010 PbPb: 10μb^{-1} delivered
- 2011 pp: 5.7 fb^{-1} delivered, 550 pb^{-1} / week
- 2011 PbPb: 140 μb^{-1} delivered (1PB / month)
- 2012 pp: 10-15 fb^{-1} @ 8 TeV
- 2012 pPb

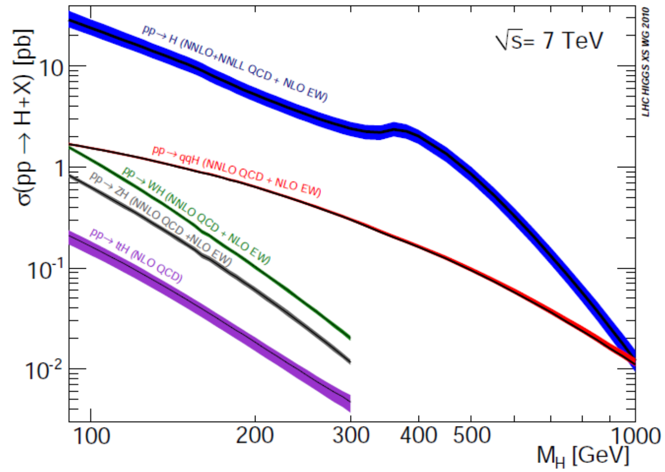
- Long shutdown in 2013 and 2014 to prepare the machine for higher energies



At L = 3.7x10^{33} cm^{-2}s^{-1}, produce 280 (160) Higgs bosons of 115 (150) GeV mass in CMS per hour

SM Higgs Overview Table





Channel	Physics Analysis Summary	m_H range (GeV/c^2)	Luminosity (fb^{-1})	sub-channel	m_H resolution
$H \to \gamma\gamma$	HIG-11-030	110-150	4.7	4	1-3%
$H \to \tau\tau$	HIG-11-029	110-145	4.6	9	15%
$H \to bb$	HIG-11-031	110-135	4.7	5	10%
$H \to WW \to l\nu l\nu$	HIG-11-024	110-600	4.6	5	20%
$H \to ZZ \to 4l$	HIG-11-025	110-600	4.7	3	1-2%
$H \to ZZ \to 2l2\tau$	HIG-11-028	190-600	4.7	8	10-15%
$H \to ZZ \to 2l2\nu$	HIG-11-026	250-600	4.6	2	7%
$H \to ZZ \to 2l2q$	HIG-11-027	130-165, 200-600	4.6	6	3%
Combination	HIG-11-032				

https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResults

Statistical Interpretation

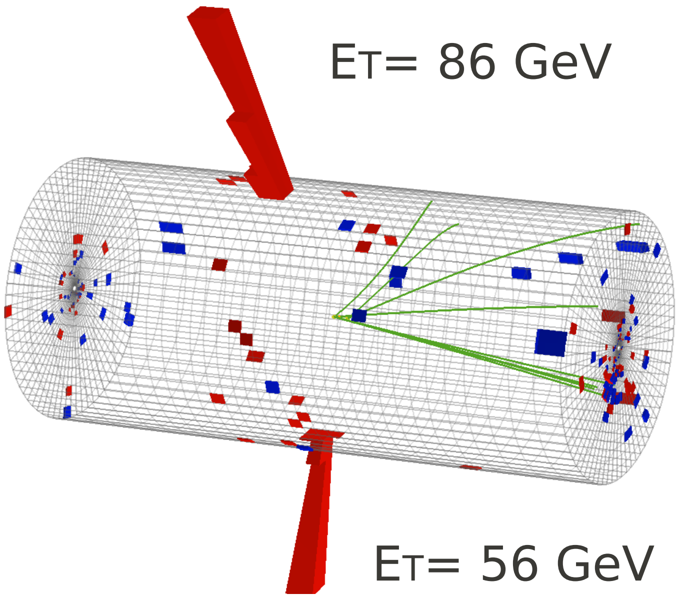
Main parameter of interest

- 95% CL limits on μ: cross section factor needed to exclude Higgs at 95% CL
- Local p-value: probability for background to produce excess as high as observed
- Global p-value: look elsewhere (LEE) corrected for largest excess
- Significance: p-value are converted into significance
- μ-hat: cross section scale factor best describing data

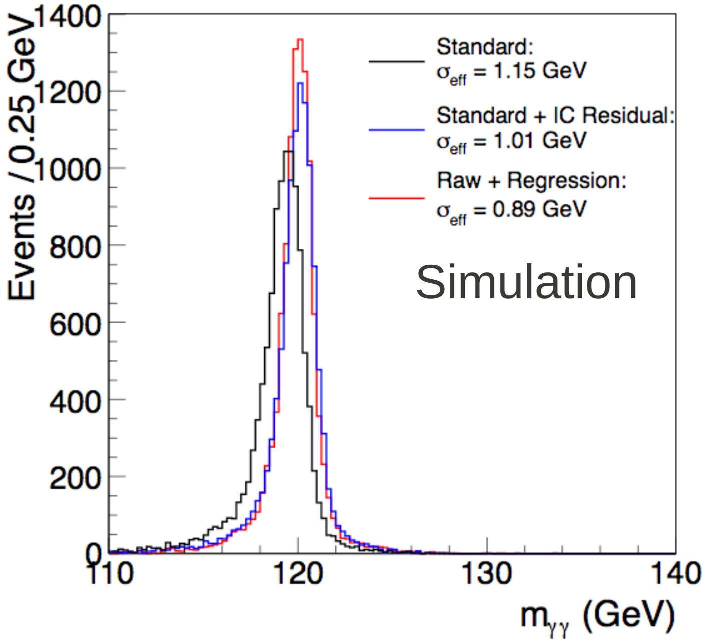
Methods consistently used by CMS and ATLAS for individual analysis and their combination

$H \rightarrow \gamma\gamma$

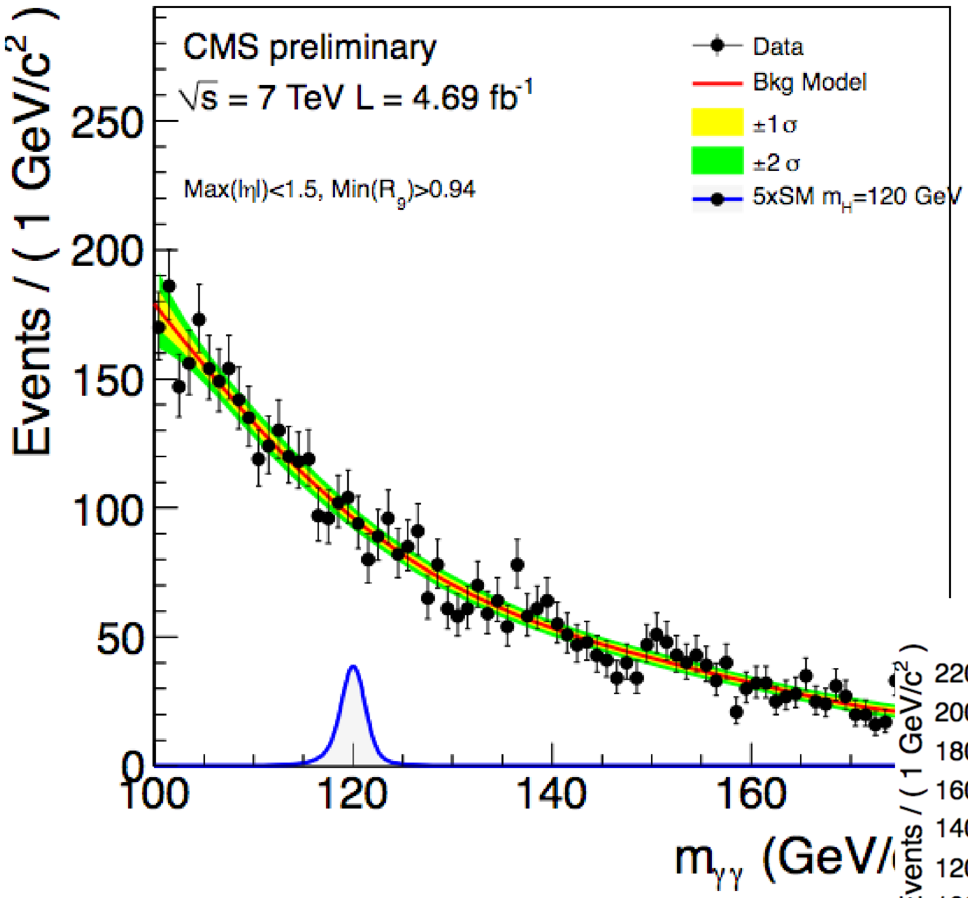
- 2 isolated photons with $p_T/m_{\gamma\gamma} > 1/3$ (¼)
- Efficiencies, scale and resolution measured from $Z \rightarrow ee$ and $Z \rightarrow \mu\mu\gamma$
- Regression techniques used to correct raw energies
- Divide data in 4 categories
- Background shape fitted in each category with 5th order polynomial

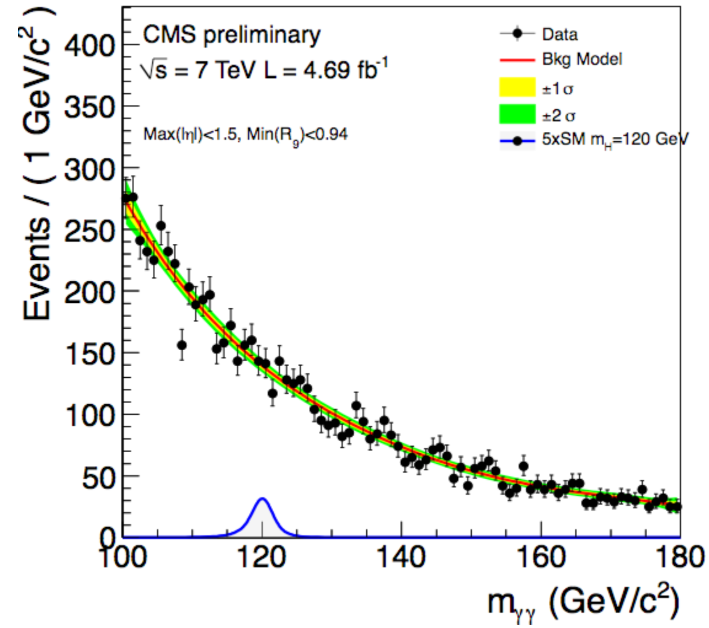


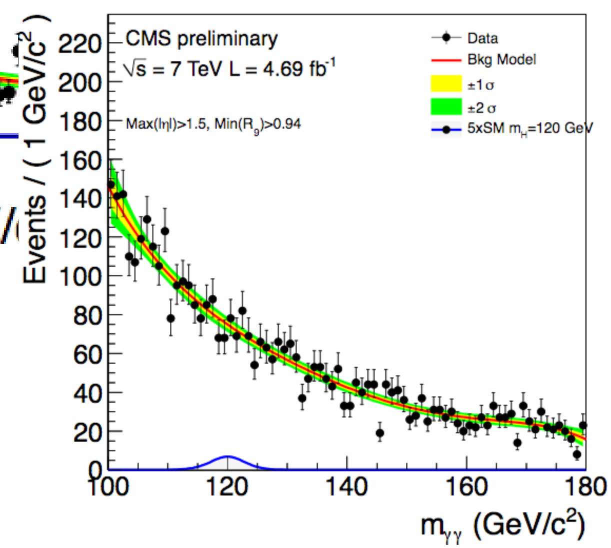
	Both photons in barrel		One or more in endcap	
	$min(R_9) > 0.94$	$min(R_9) < 0.94$	$min(R_9) > 0.94$	$min(R_9) < 0.94$
Signal	31.1%	40.3%	12.2%	16.4%
Data	23.0%	33.8%	17.8%	25.4%
σ_{eff} (GeV/c^2)	1.38	1.84	2.80	3.20
(FWHM/2.35)/m_H	0.99%	1.32%	2.18%	2.55%

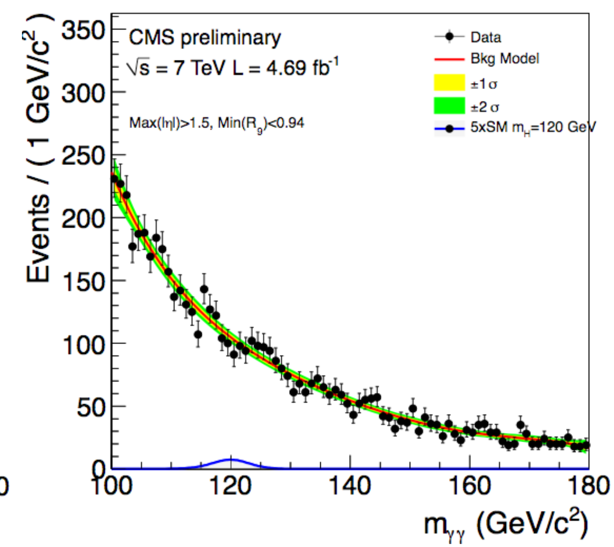


$H \rightarrow \gamma\gamma$

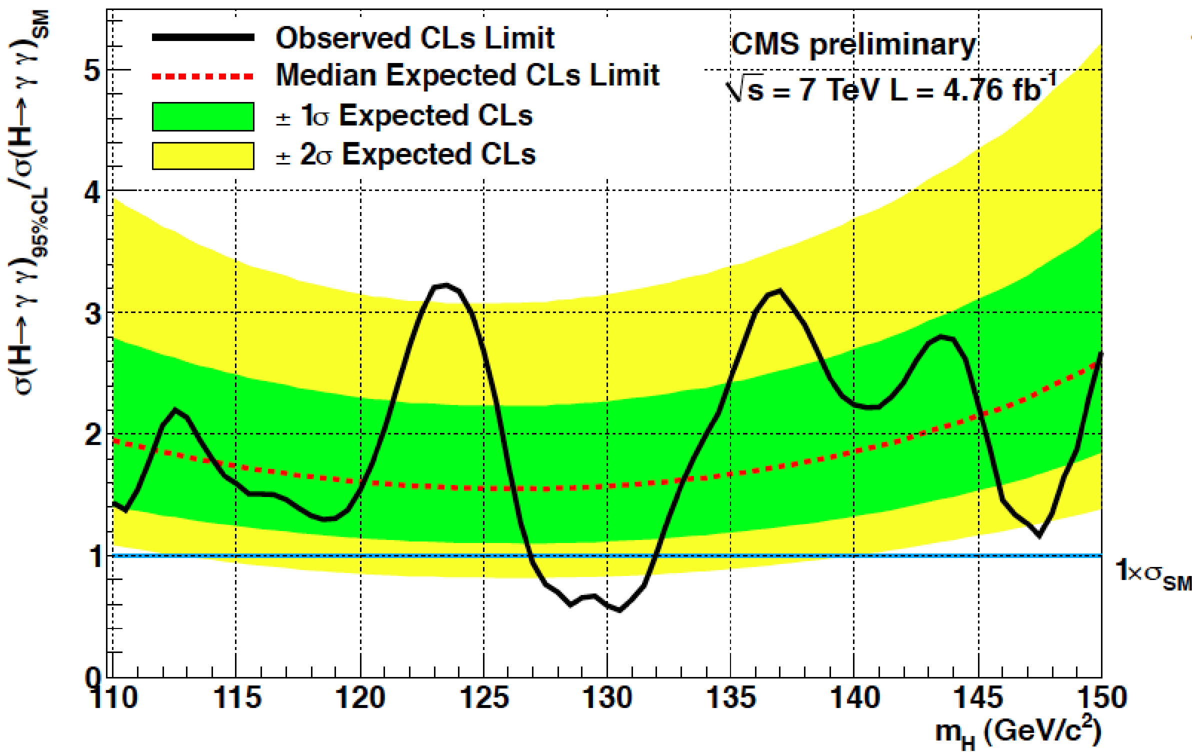


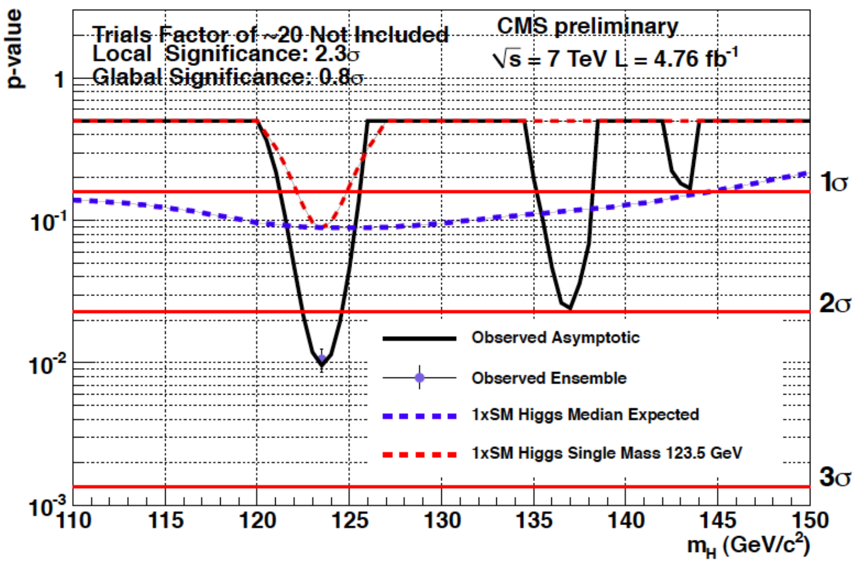






H → γγ



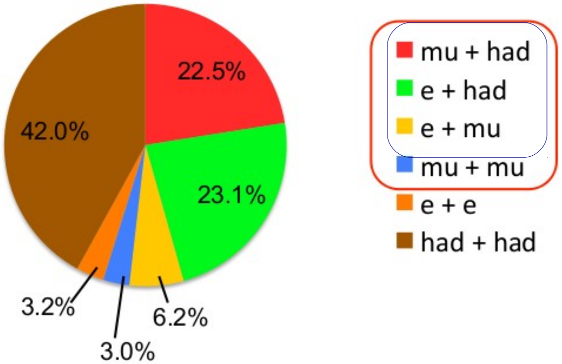


Excluded SM Higgs boson at 95% CL
in mass range 127-131 GeV

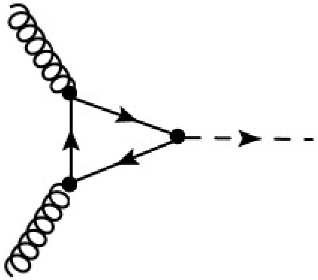
Excess at 123.5 GeV:
Local significance 2.3σ
Global significance 0.8σ
Signal strength 1.7 ± 0.8 times SM

$\phi \rightarrow \tau\tau$

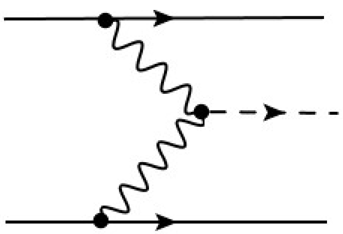
- Di-Tau selection: μ-τ, e-τ, e-μ



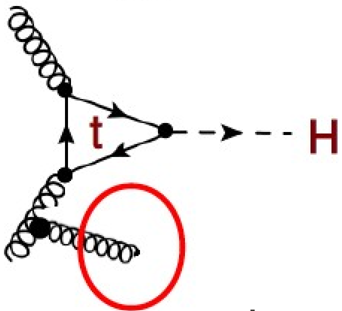
- Standard Model (110-145 GeV): 3 channels



Inclusive



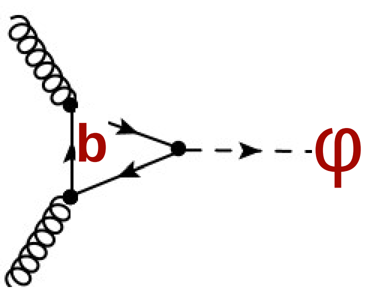
VBF



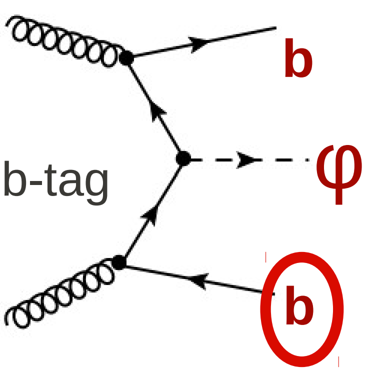
Boosted

- MSSM (90-1000 GeV): 2 channels

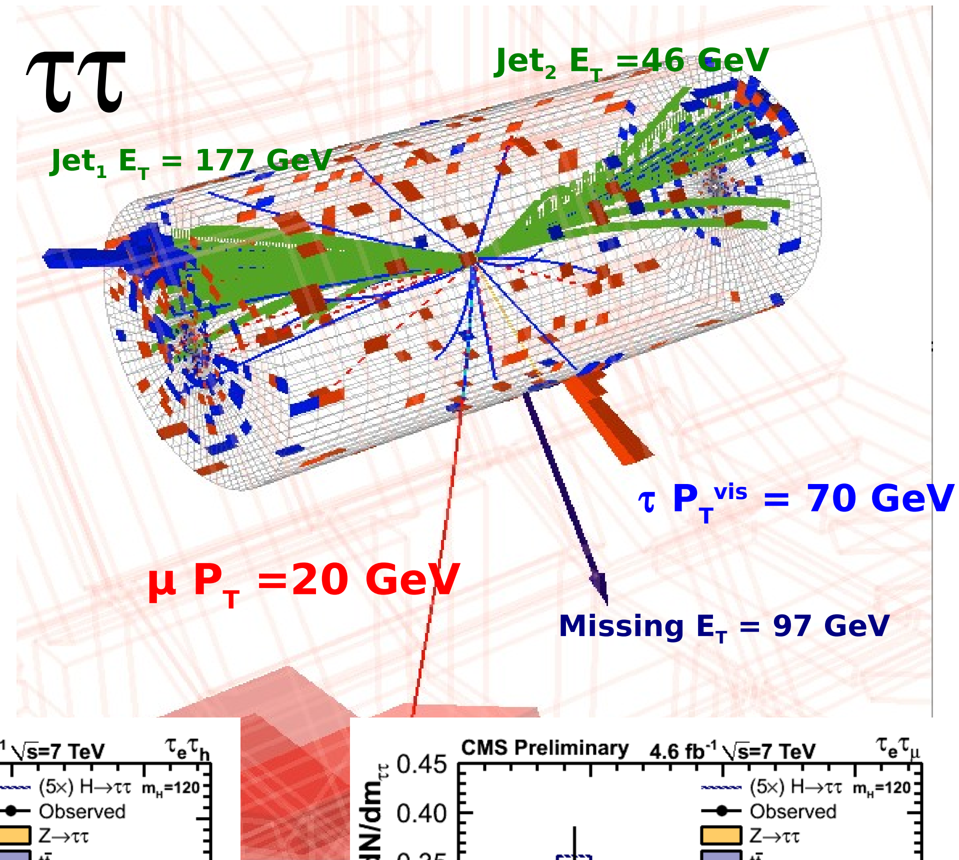
w/o b-tag



w/ b-tag

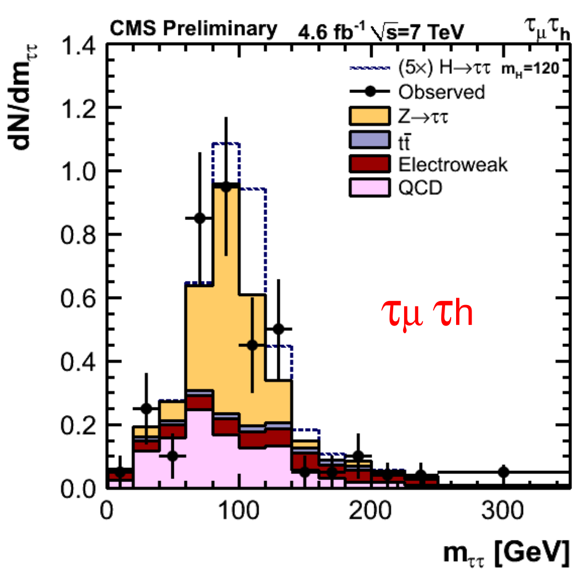


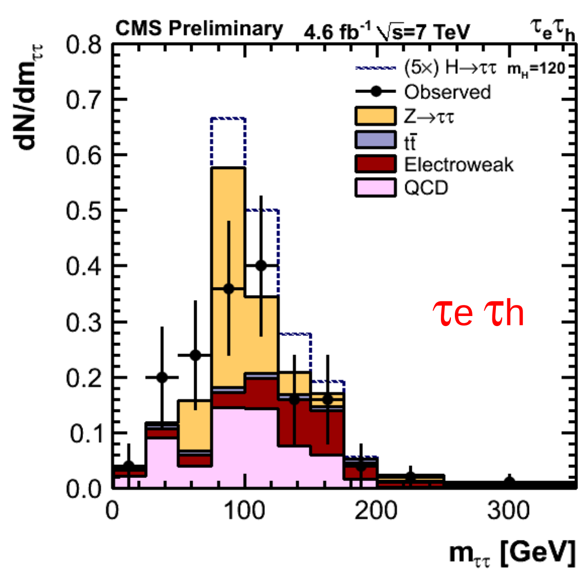
$H \to \tau\tau$

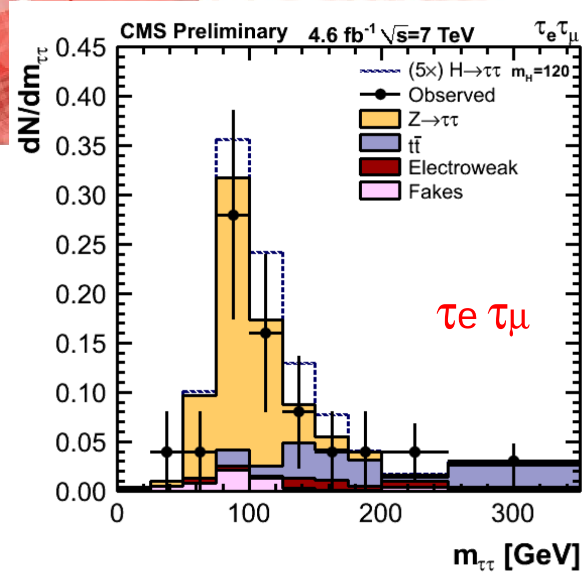


- Look for excess observed in di-τ mass spectrum
- Use inclusive sample to calibrate
- Z boson production irreducible background
- Limits on cross section and MSSM [tanβ,mA] exclusion
- Improvements wrt summer: full mass reconstruction, boosted category, improved VBF selection

di-τ mass spectrum in VBF selection

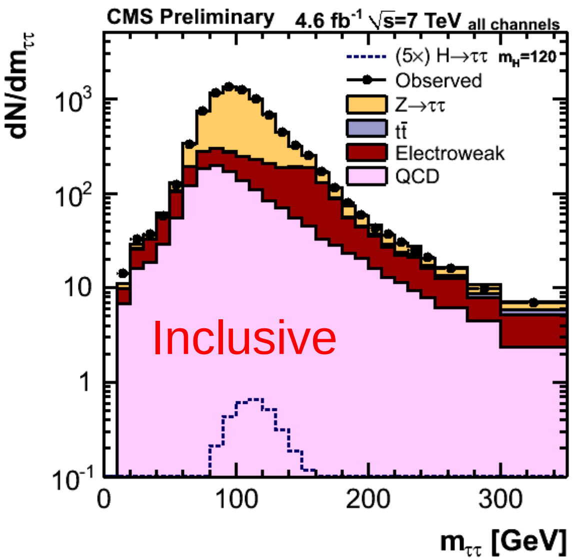


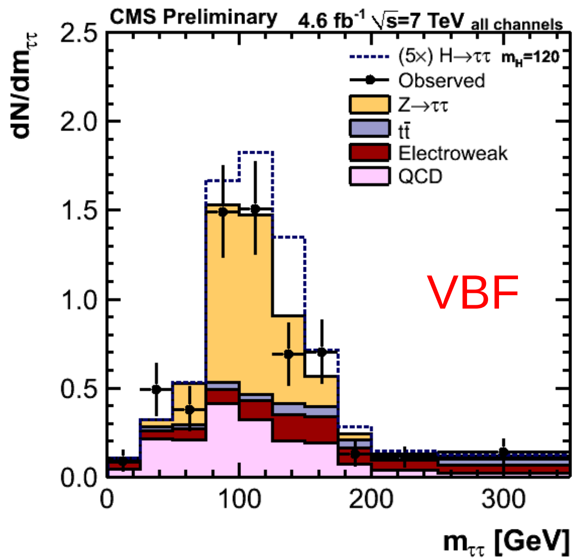


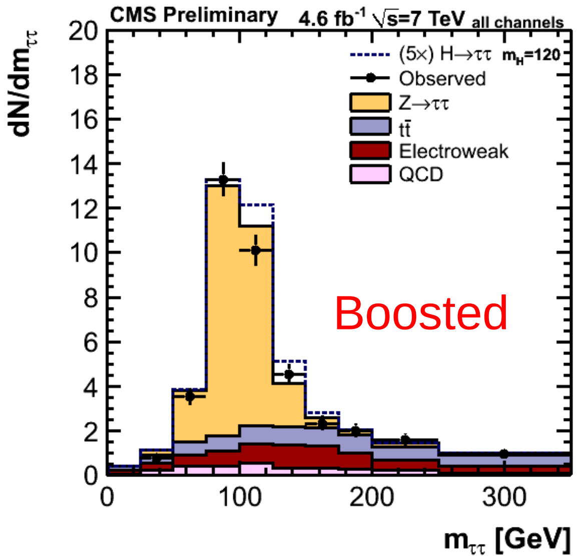


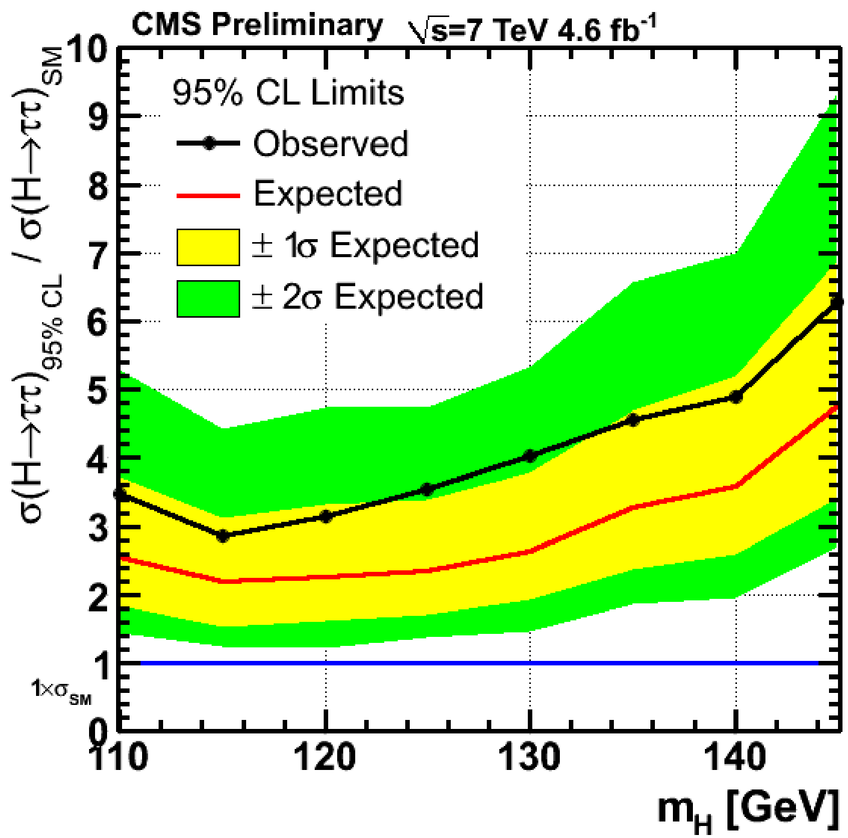
H → ττ

di-τ mass spectrum by category

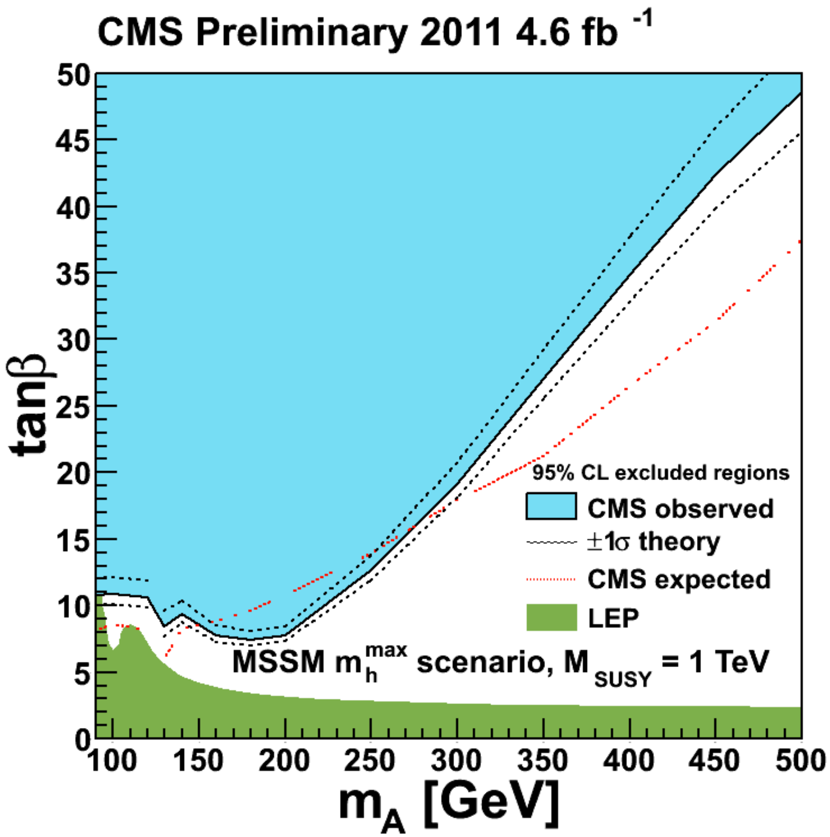


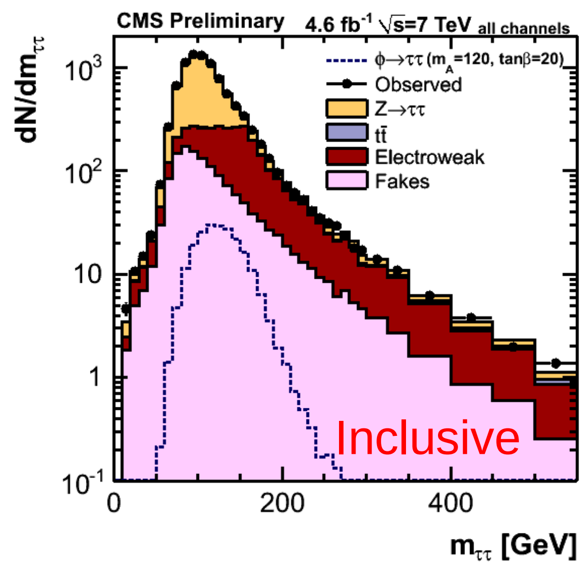


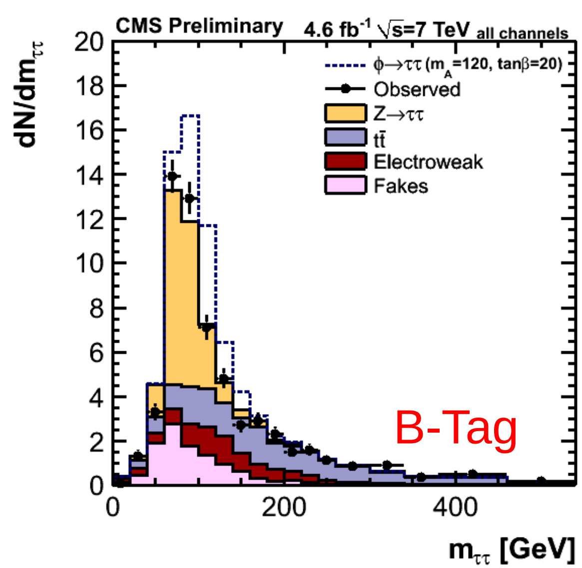


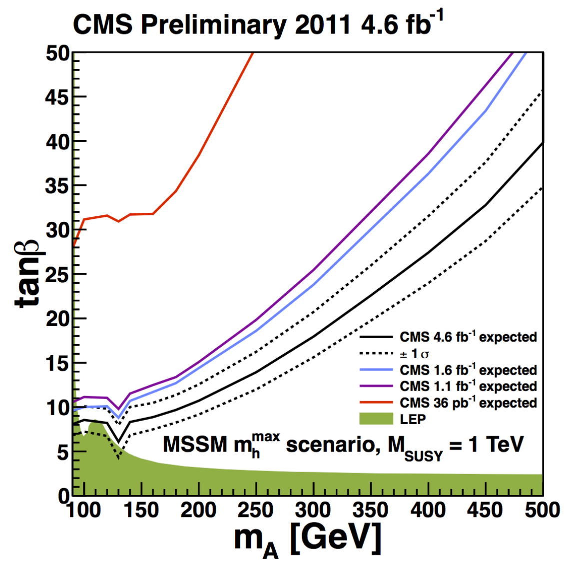


MSSM $\phi \to \tau\tau$



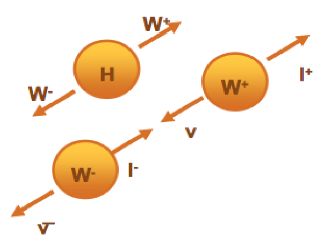


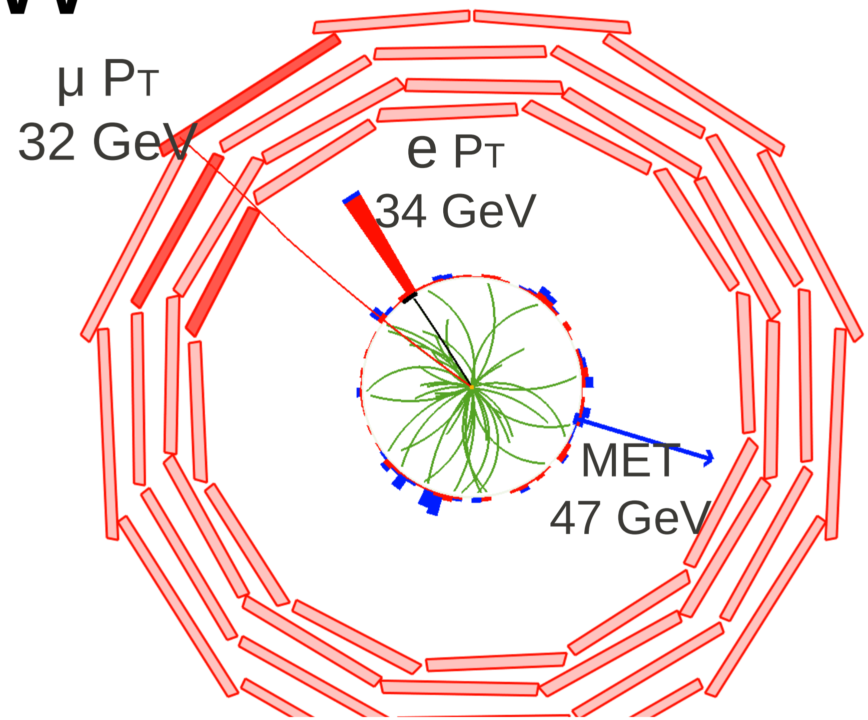


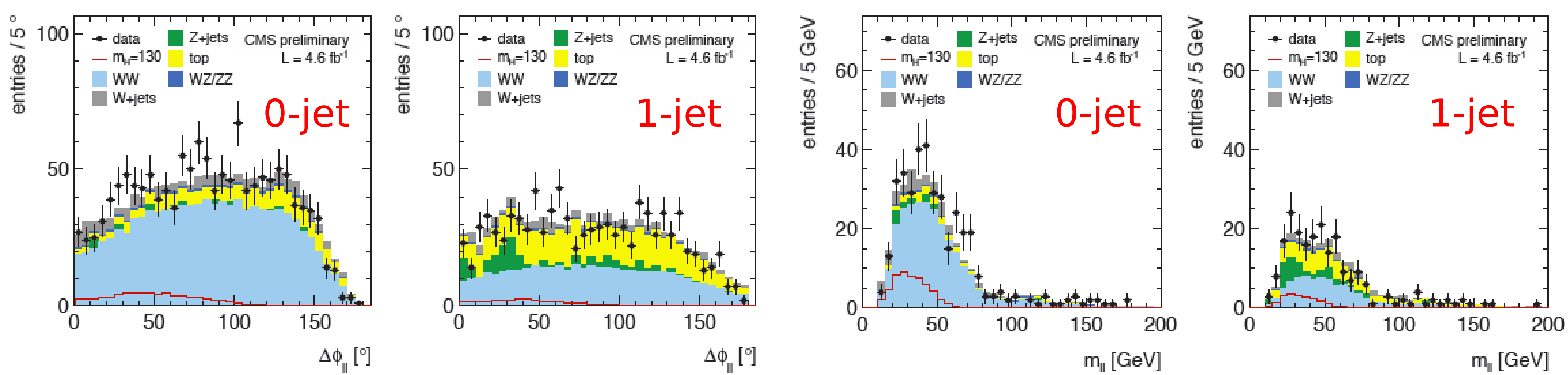


H → WW

- Signal: 2 leptons (e^+e^-, $\mu^+\mu^-$, $e^\pm\mu^\mp$), missing E_T
- Background: W+jets, Drell-Yan, Top, WW
- No signal peak
- Use event kinematic to suppress WW background

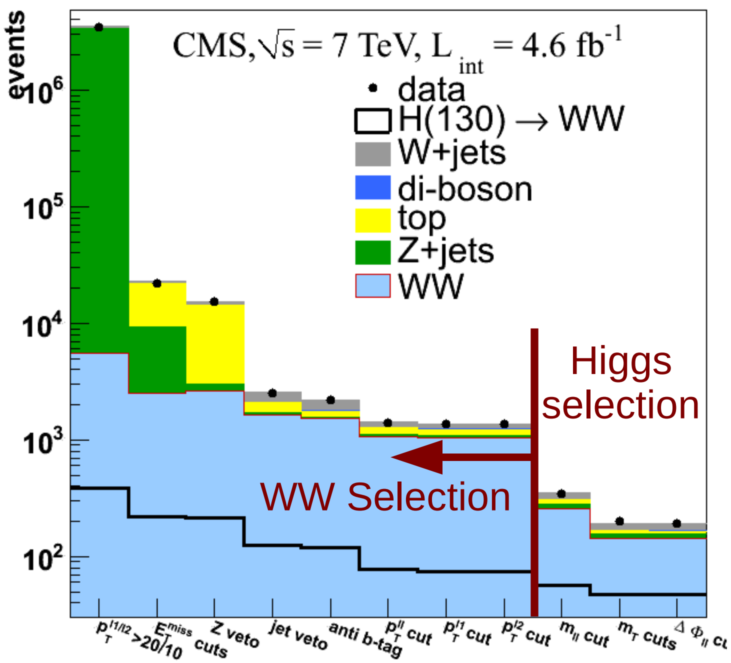


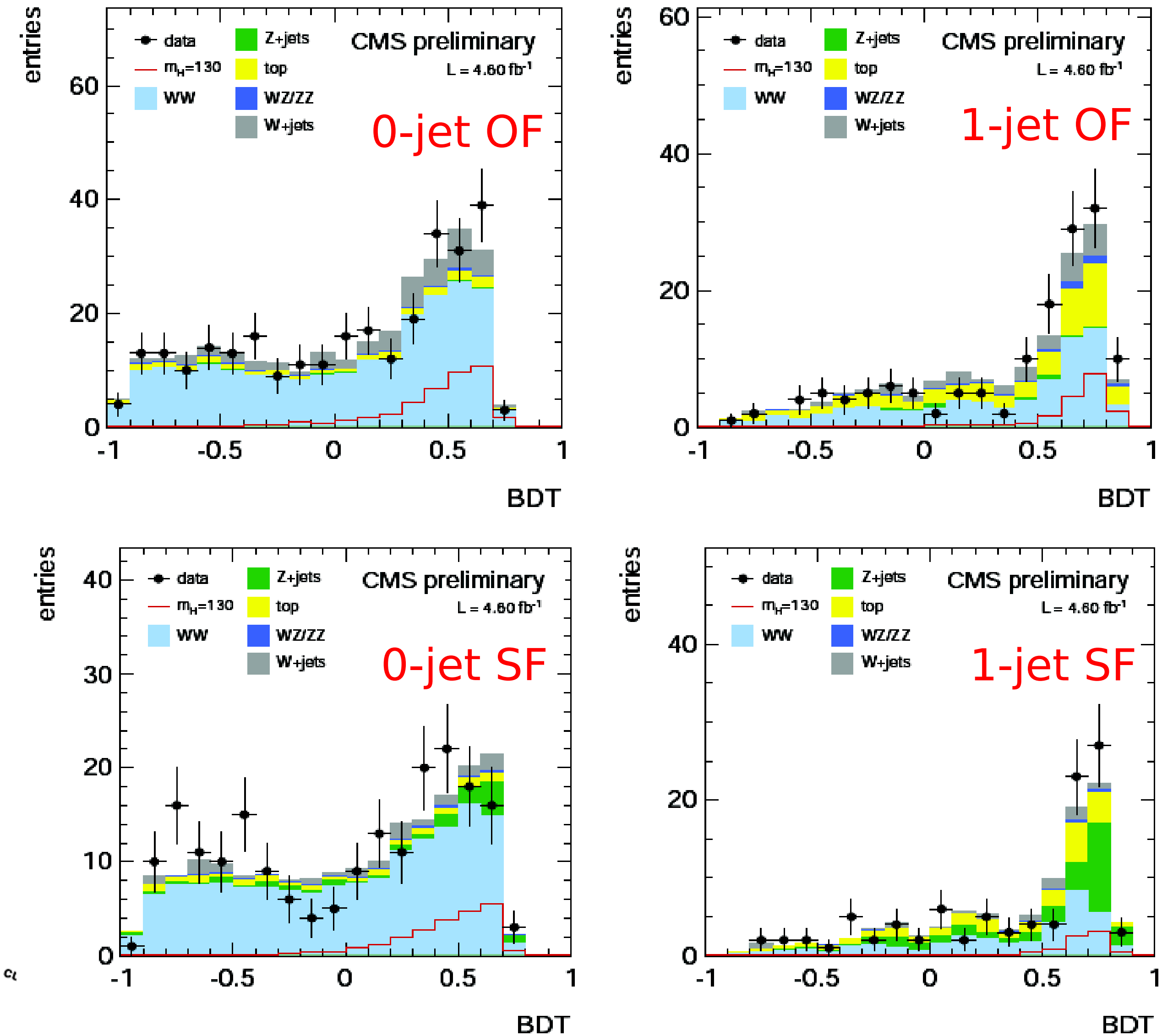




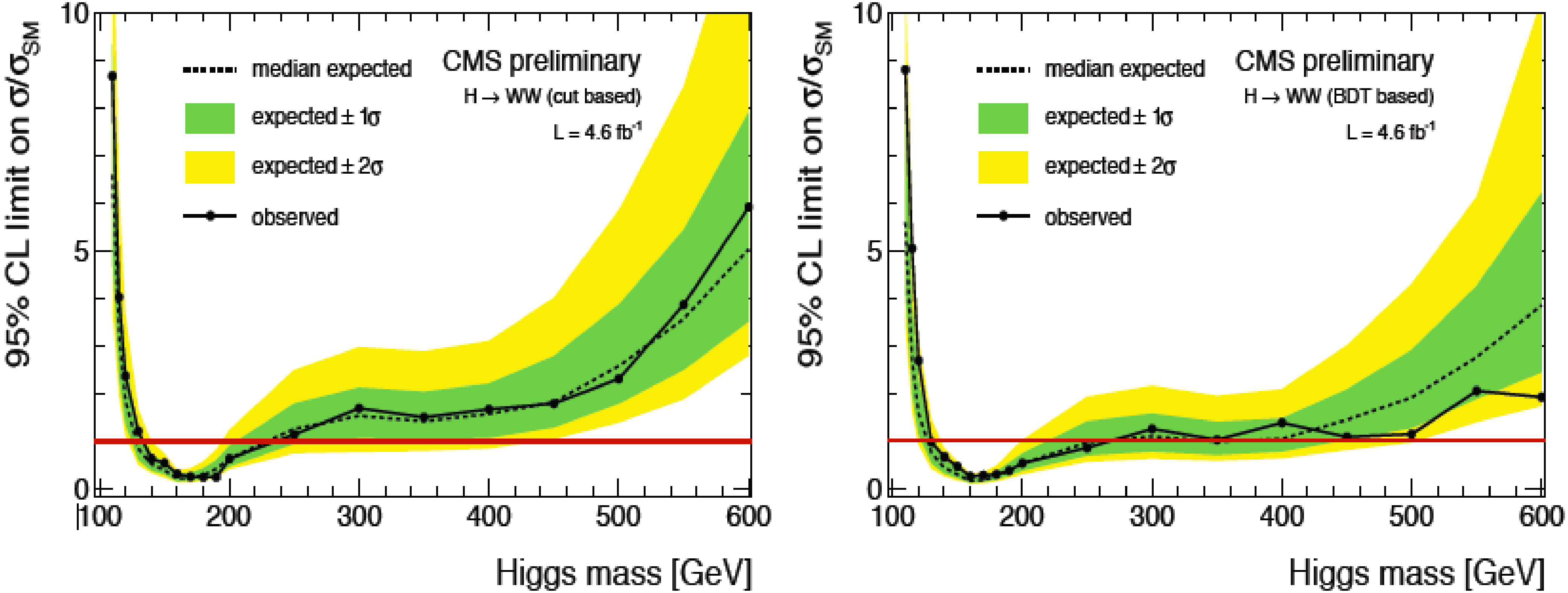
H → WW

- Cut-based analysis, optimized per mass hypothesis
- BTD explores event kinematic
- Classification by # of jets and lepton flavor





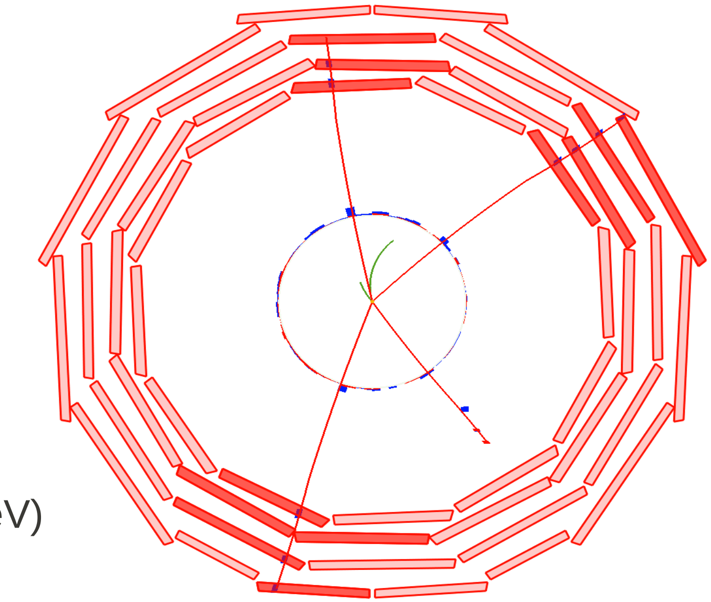
H → WW



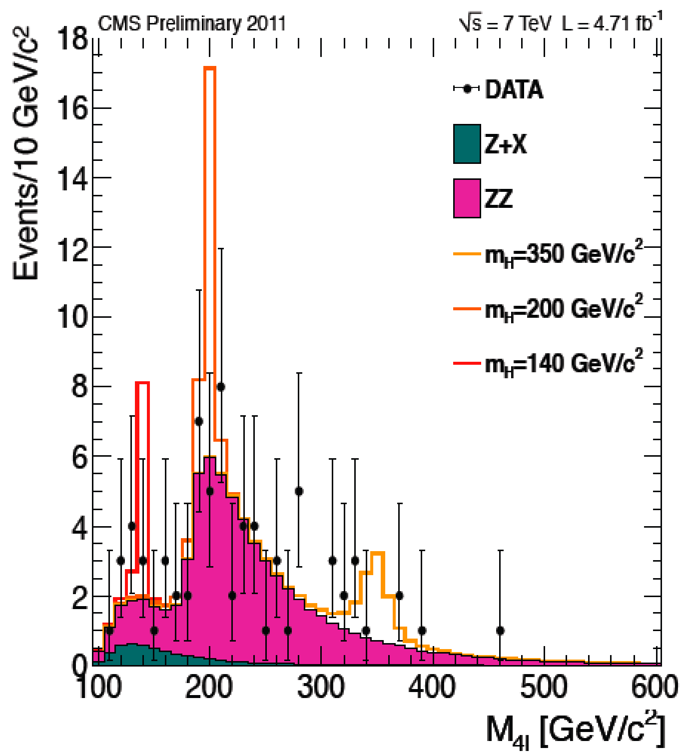
Cut based:
Expected range: **129 < MH < 236 GeV**
Observed range: **132 < MH < 238 GeV**

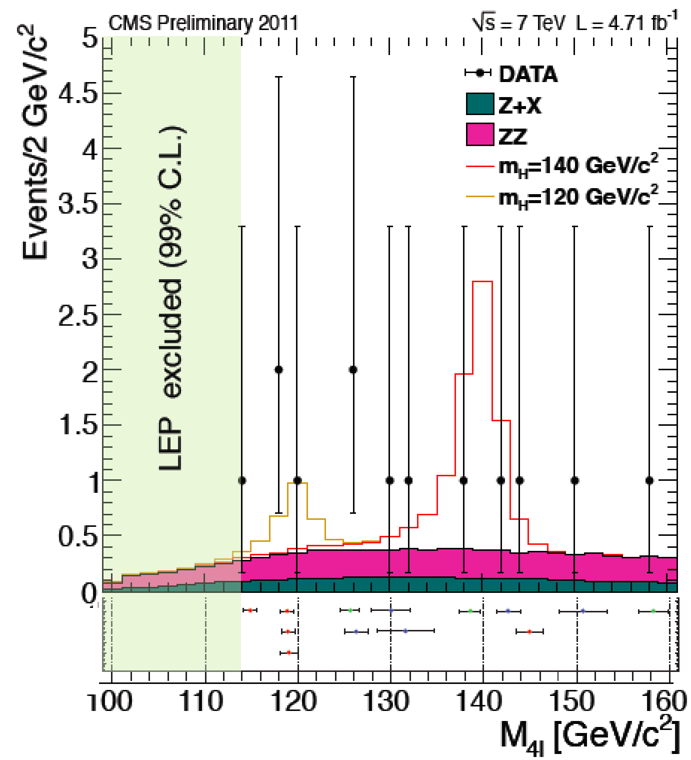
BDT:
Expected range: **127 < MH < 270 GeV**
Observed range: **129 < MH < 270 GeV**

H → ZZ



- Clean signature with 4 lepton and narrow mass peak
- Main background from continuous ZZ production
- data: 72, expected bkgr: 67.1 ± 5.5 (m_{4l} > 100 GeV)
- data: 13, expected bkgr: 9.8 ± 0.8 (m_{4l} > 100 GeV && < 160 GeV)
- Improvements: kinematic selection optimized for low mass search

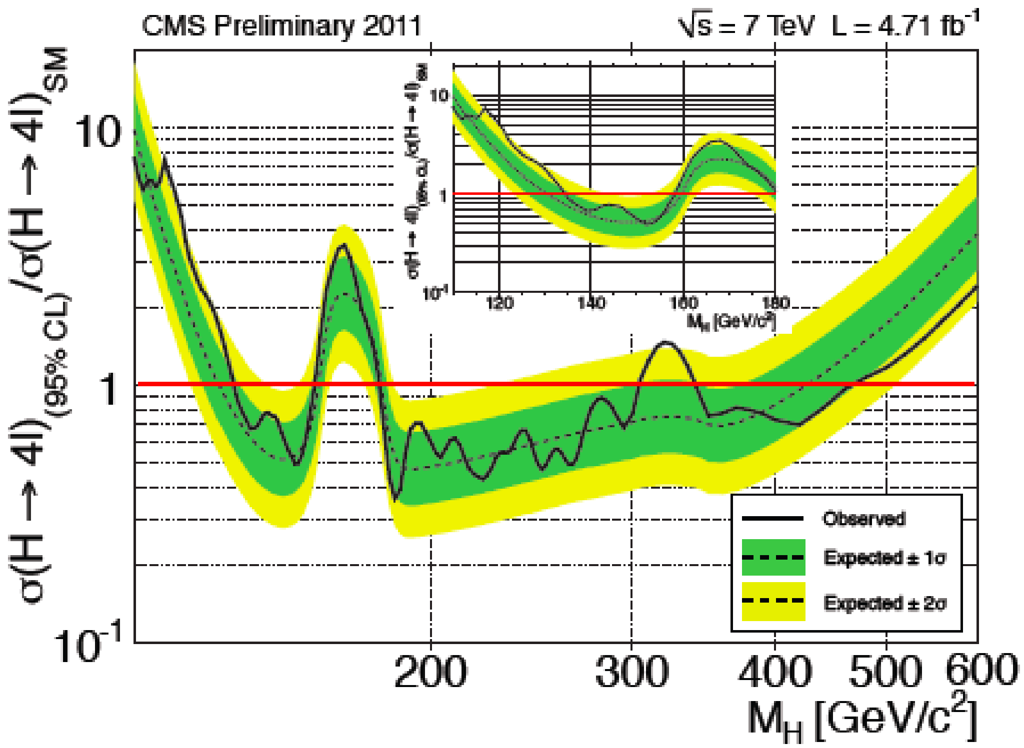


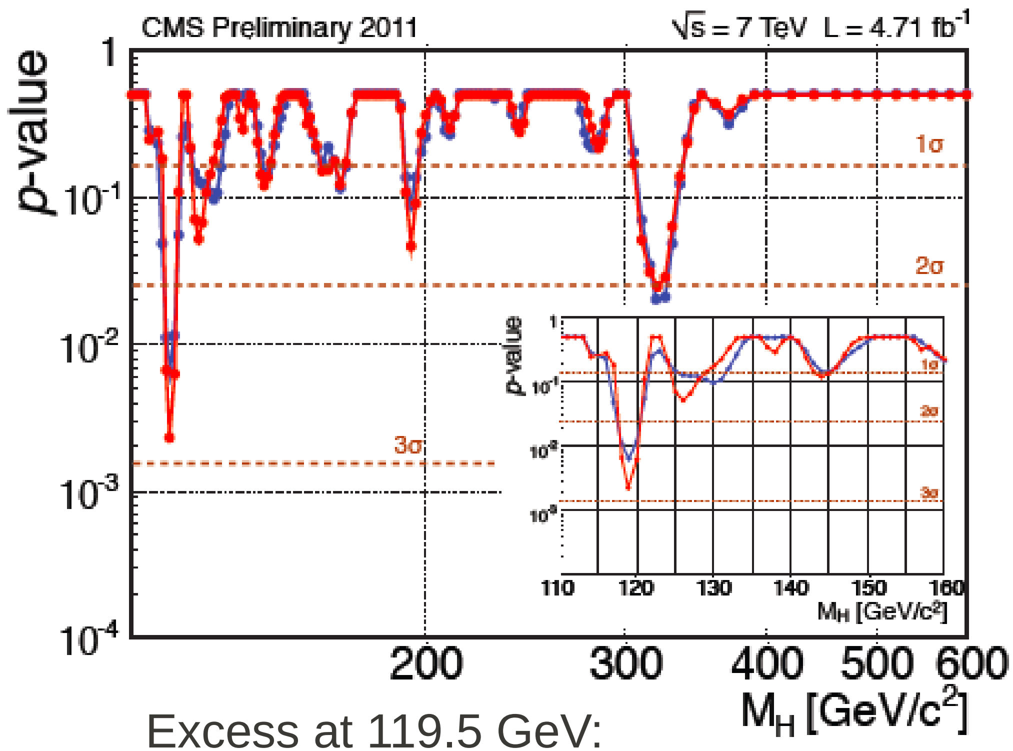


Expect 1.2 Higgs events at 120 GeV

Event-by-event mass resolution

$H \rightarrow ZZ$





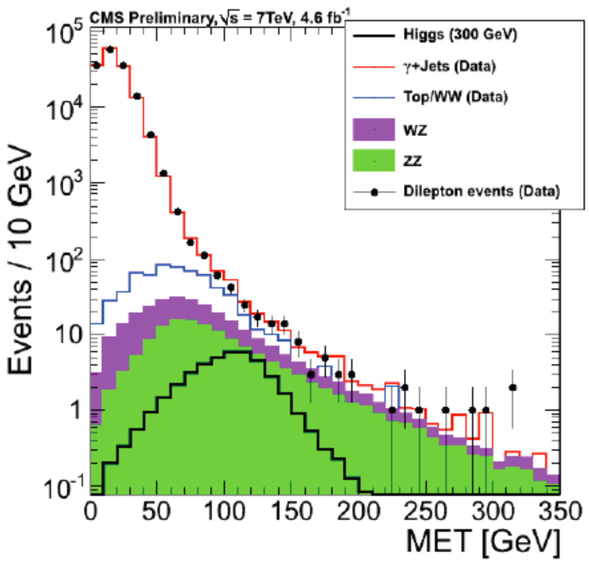
Excess at 119.5 GeV:

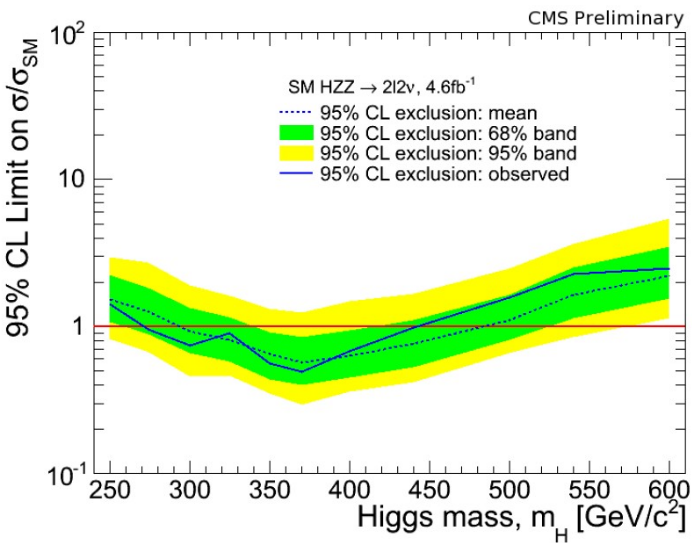
Local significance	2.5 (2.9)σ
Global significance	1.1 (1.3)σ
Signal strength	2 ± 1 times SM

Expected range: **130 < M_H < 160 GeV; 182 < M_H < 420 GeV**

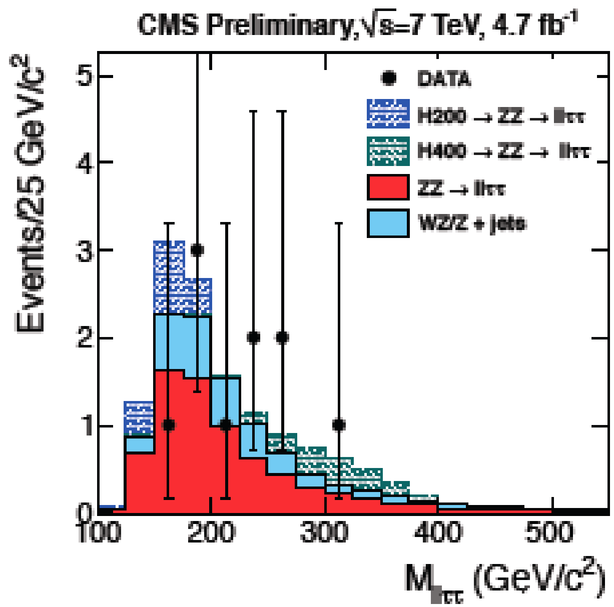
Observed range: **134 < M_H < 158 GeV; 180 < M_H < 305 GeV; 340 < M_H < 465 GeV**

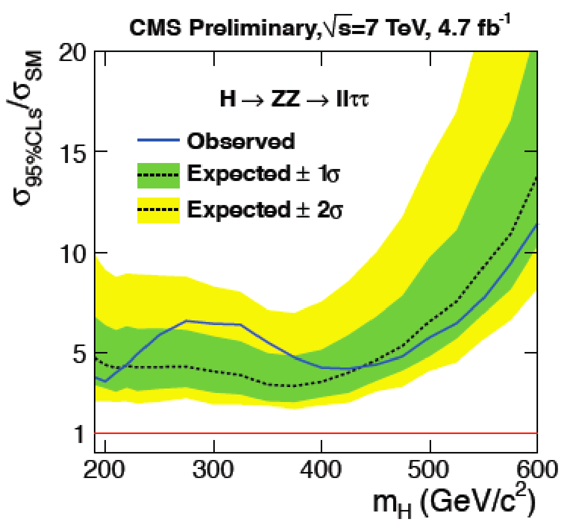
$H \to ZZ \to ll\,\nu\nu$



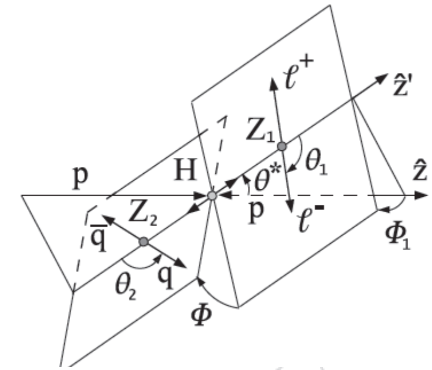


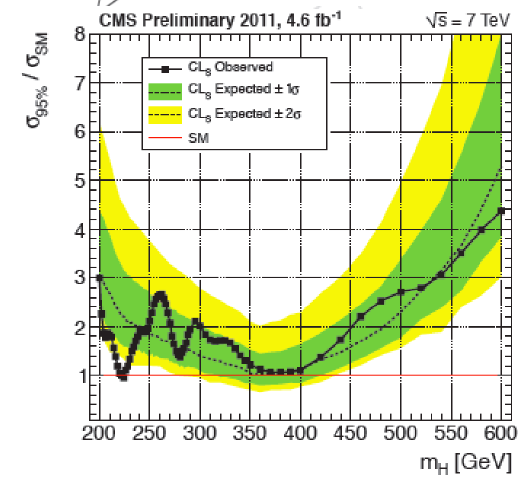
$H \to ZZ \to ll\,\tau\tau$

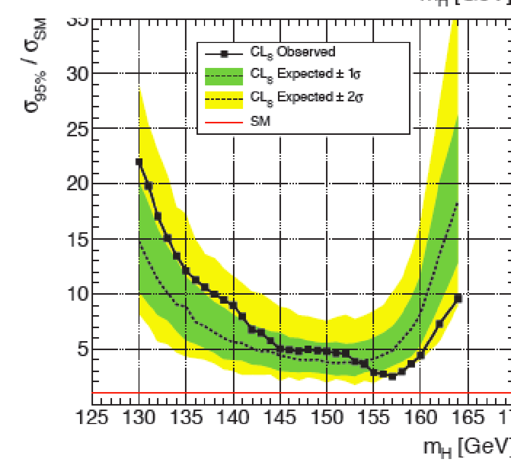




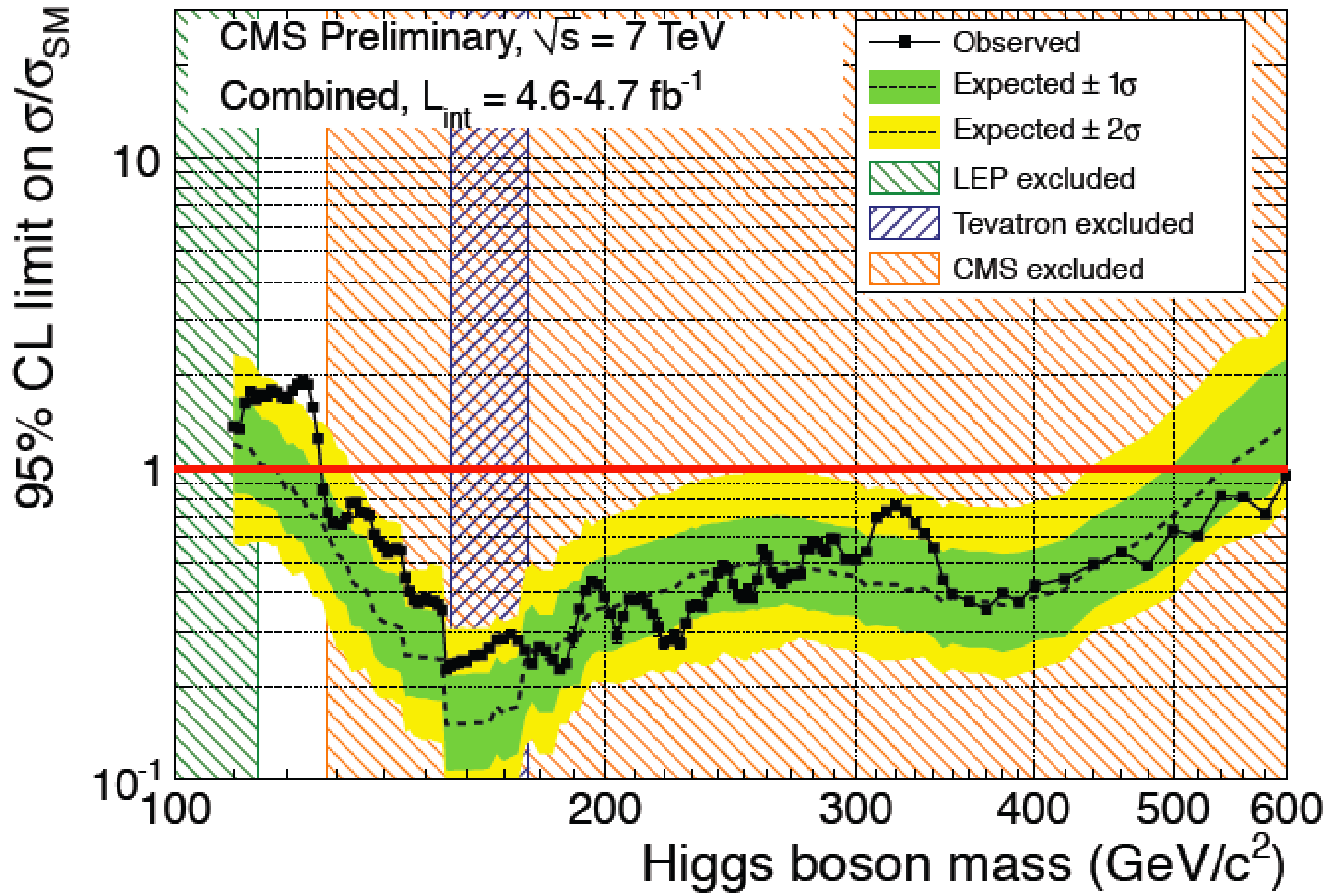
$H \to ZZ \to ll\,qq$





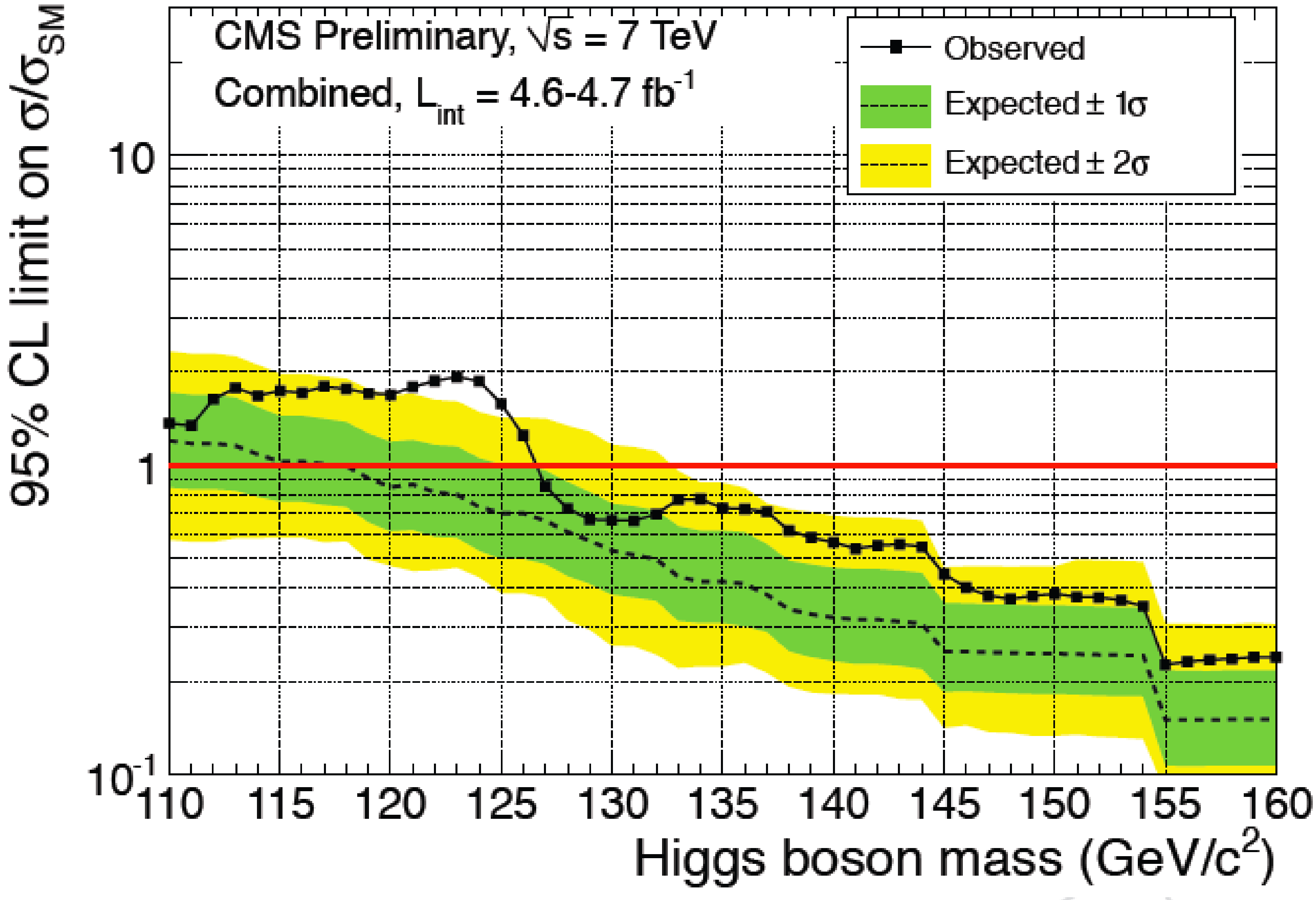


Grand SM Combination

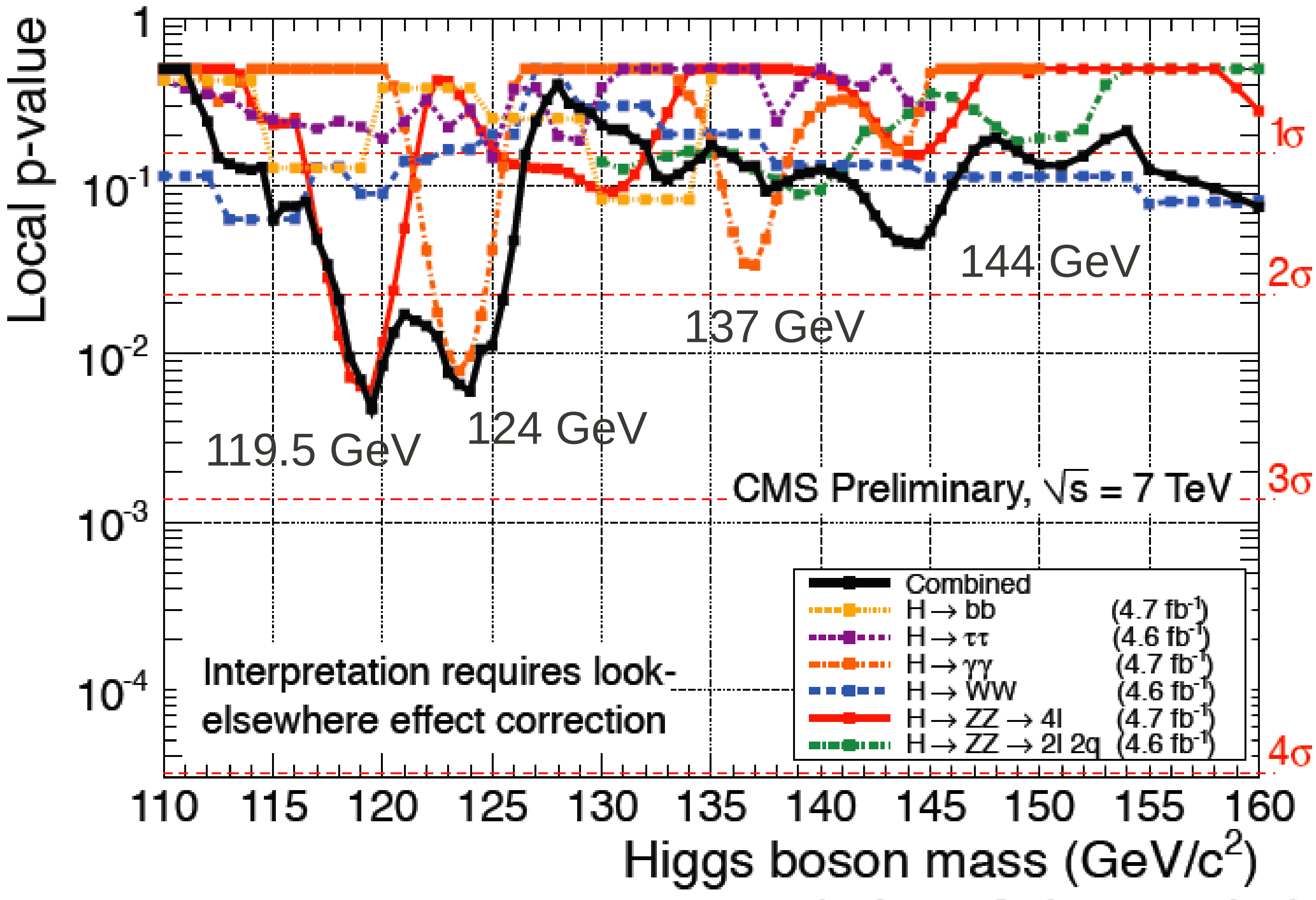


at 95% CL: expected 117-543, observed 127-600
at 99% CL: expected 129-500, observed 128-525

CMS Grand SM Combination



P-value at Low Mass



Summary

- Tremendous progress in the hunt for the Higgs boson
- Excluded SM Higgs boson masses

  at 95% CL: expected 117-543 GeV, observed 127-600 GeV

  at 99% CL: expected 129-500 GeV, observed 128-525 GeV
- Remaining small mass window

  114.4-127 GeV
- Low mass excess

  inconclusive with the current amount of data
- Preparing updated SM results and new BSM results for Winter conferences

Possible Scenarios for 2012

- SM-like Higgs boson is discovered. No evidence for BSM physics.
- SM-like Higgs boson is discovered. And evidence for BSM physics emerges.
- Light Higgs-like particle is discovered, with properties different from the SM.
- A heavy scalar state is discovered.
- No Higgs boson candidate is discovered and the entire mass range for SM-like Higgs boson is excluded

- Probe the Higgs mass region, 114 GeV < mH < 127 GeV where the SM Higgs (if it exists) is likely to be found.
- Continue to scan the entire mass range and final states beyond the SM
- Chance for evidence and discovery Fall 2012
- If discovered, we must measure its properties
  - Mass, cross section, branching ratios and couplings

P-value and best fit for σ/σ_{SM}

Maximum local significance

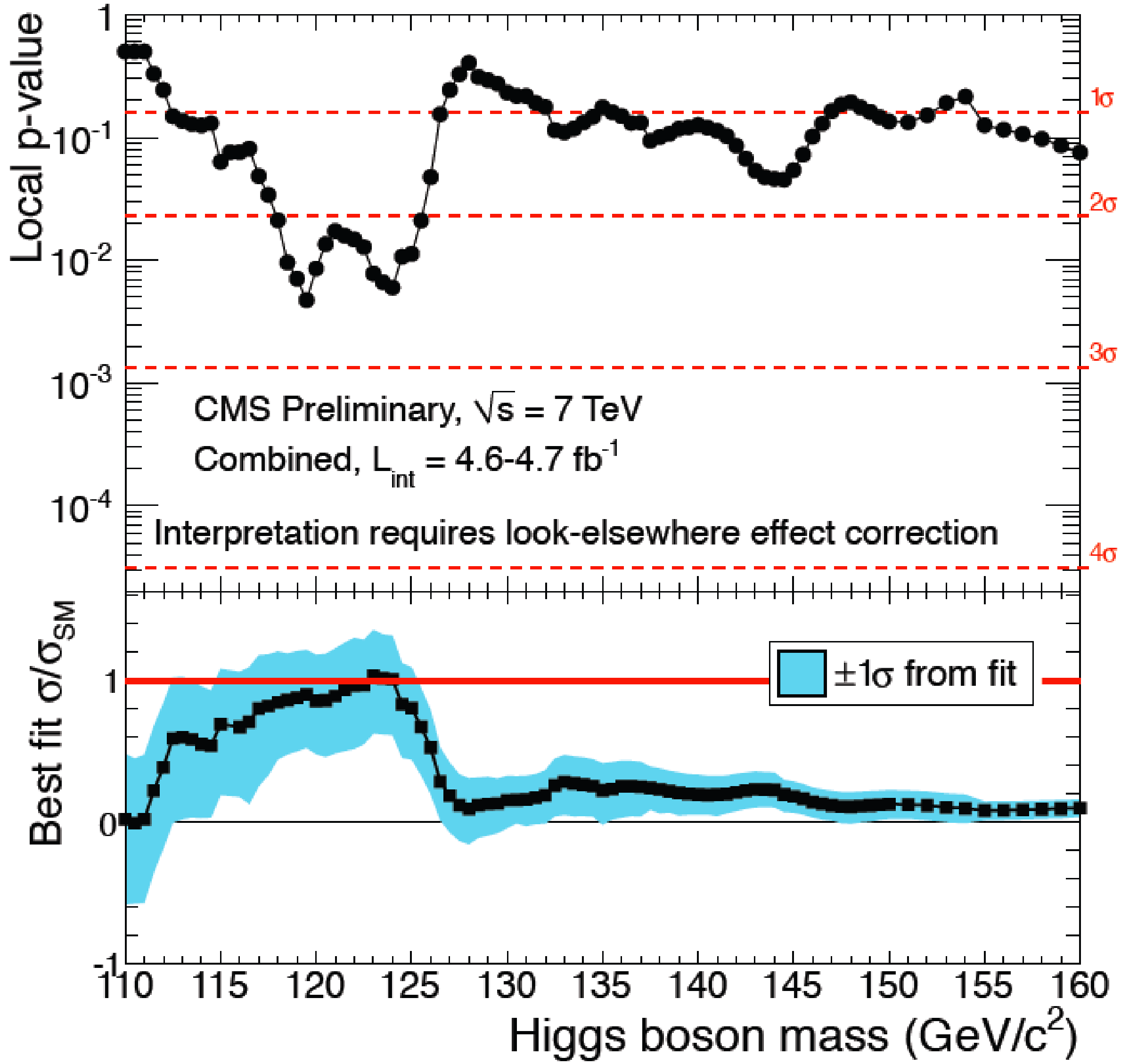
2.6σ

Global significance 110-600 GeV

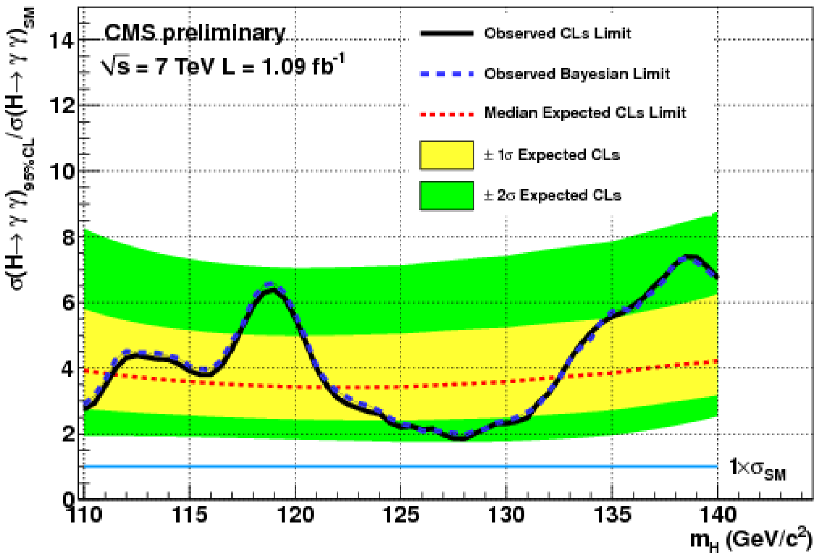
0.6σ

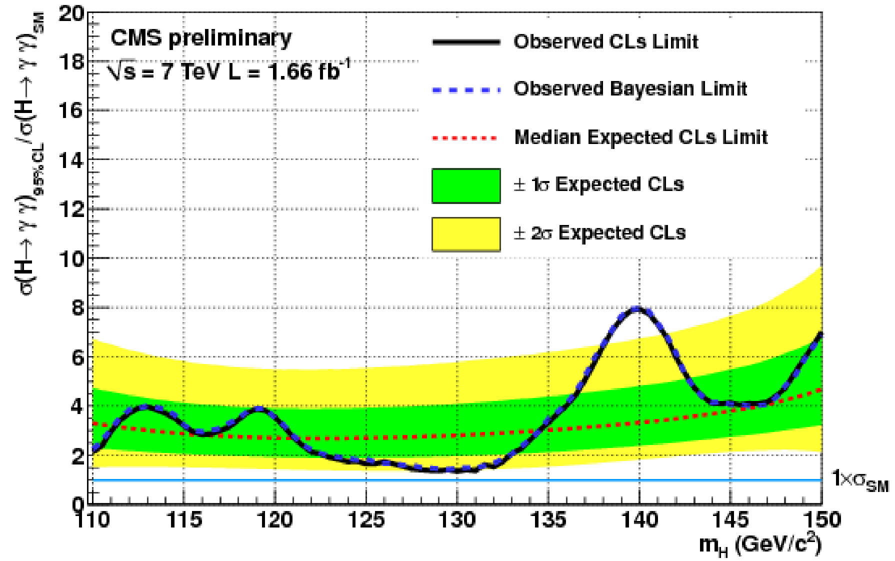
Restrict to 110-145 GeV

1.9σ

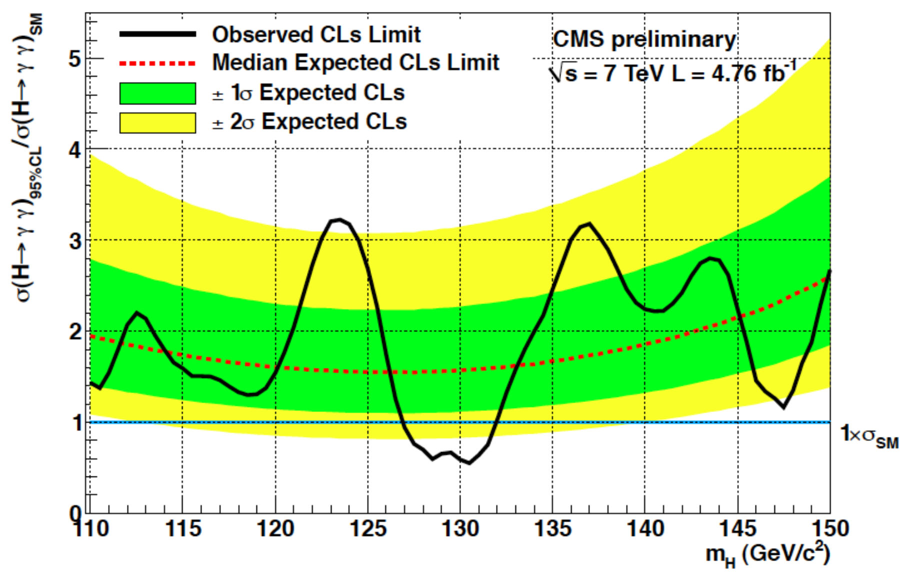


$H \to \gamma\gamma$



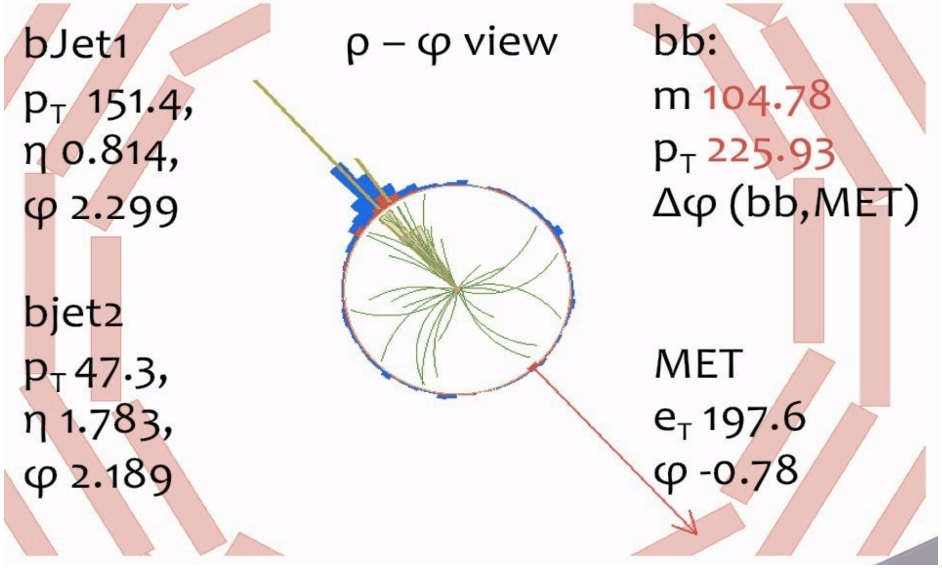


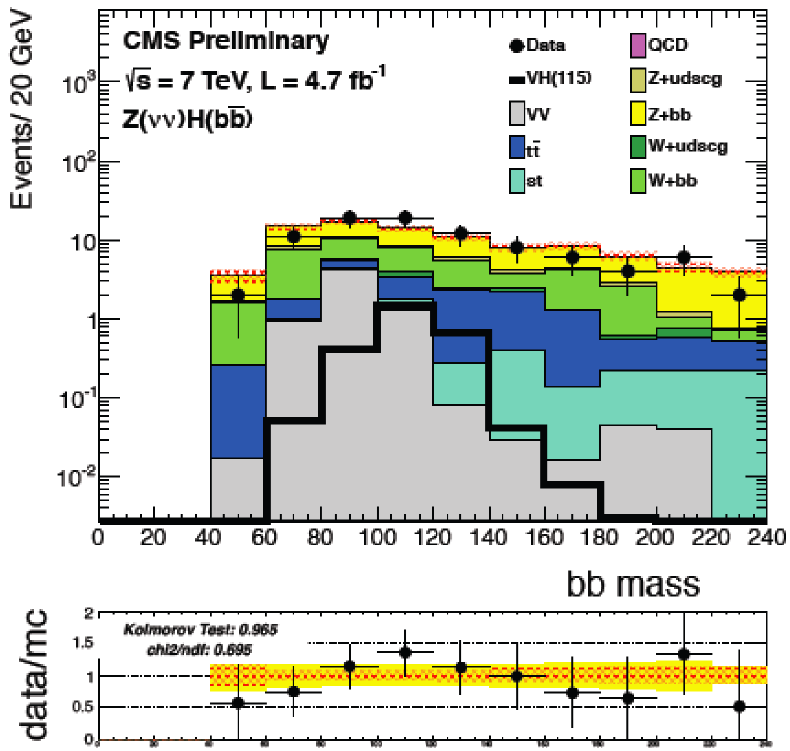
Evolution of CMS $H \to \gamma\gamma$ search in 2011



H → bb

- gg→H→bb and VBF dominant production modes overwhelmed by large backgrounds
- Strategy: VH→Vbb with large boost (100-160 GeV)
- m_H resolution ~10%
- 5 sub-channels (l = e,μ)
    - ZH → llbb
    - WH → lνbb
    - ZH → ννbb

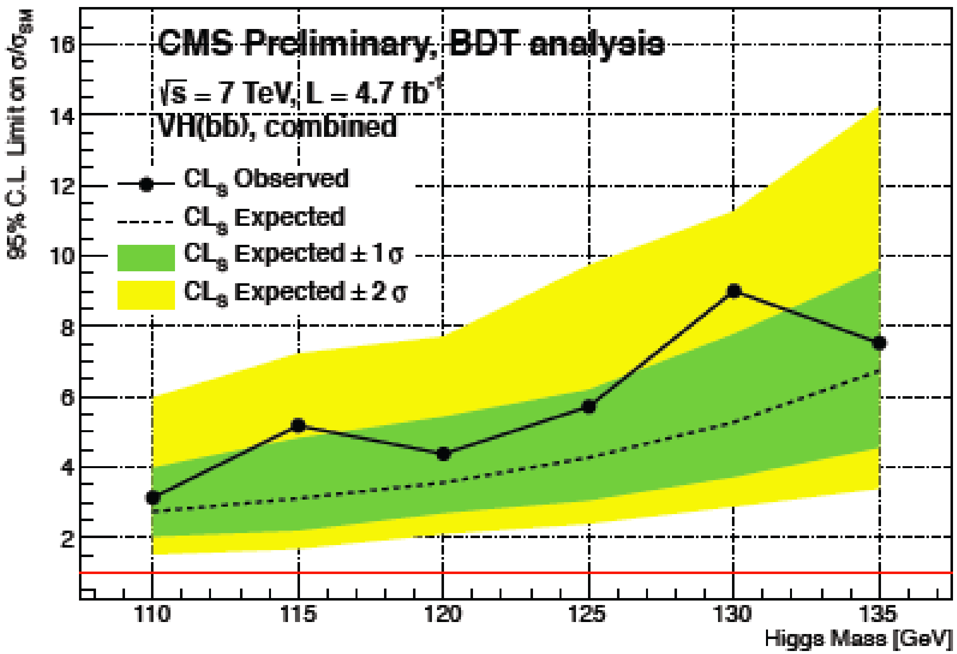


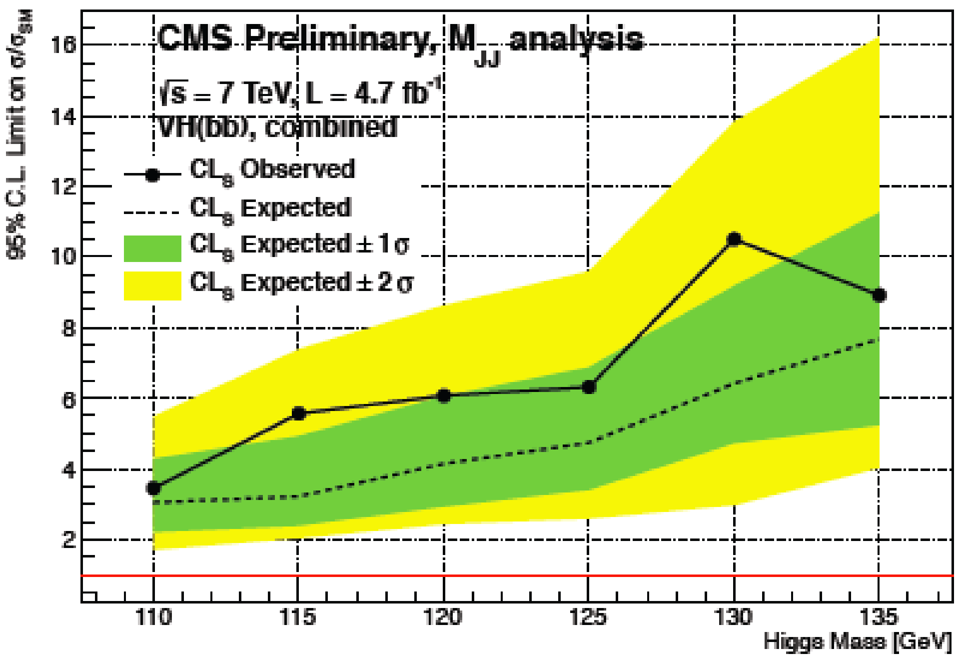


$H \rightarrow bb$

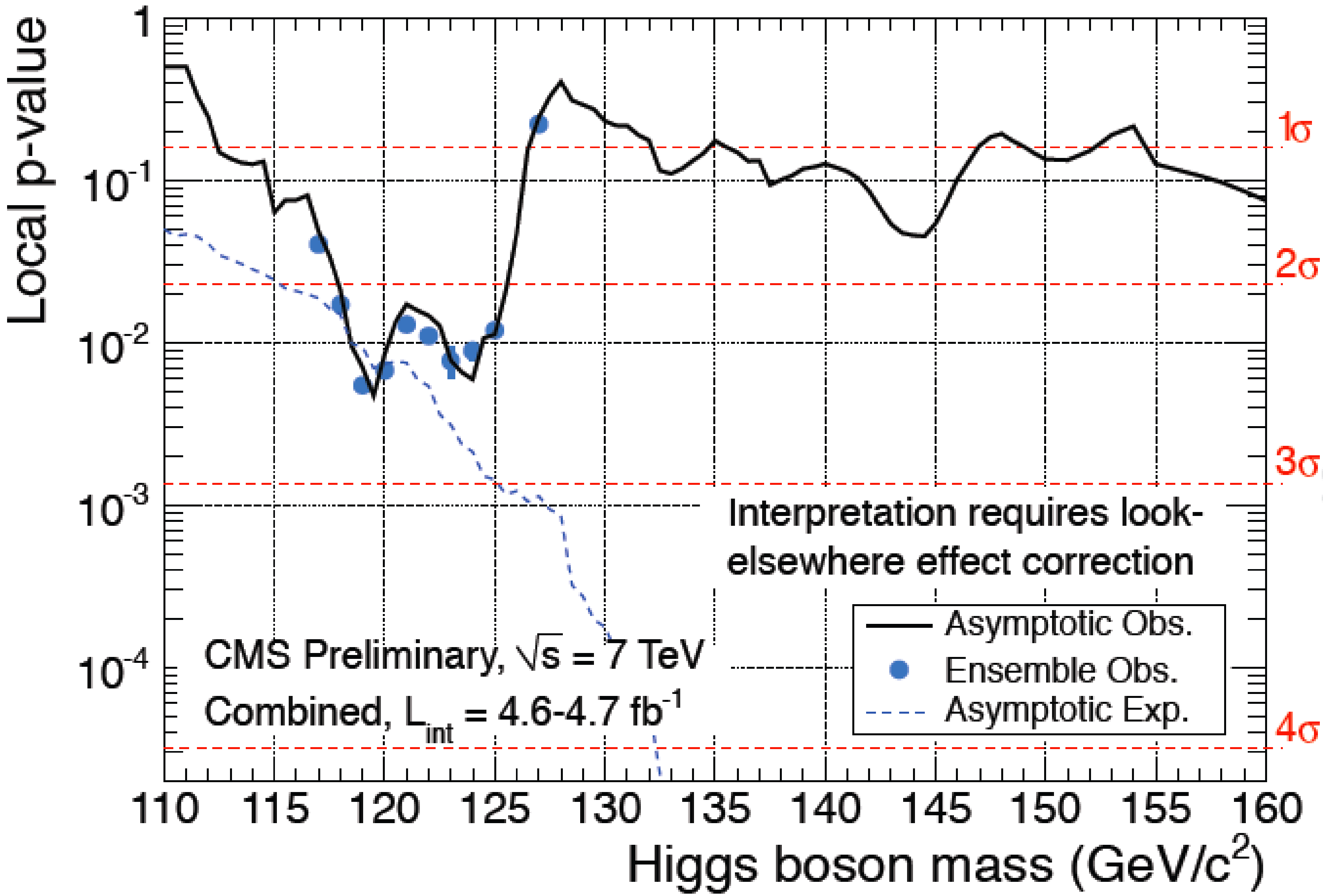
- Two independent analysis strategies
- M_{JJ}: sliding mass window around m_H
- BDT: includes m(jj), p_T (jj), p_T (V), b-tag, $\Delta\phi$(V,H), $\Delta\eta(j_1,j_2)$

  ~10% improvement wrt M_{JJ} analysis

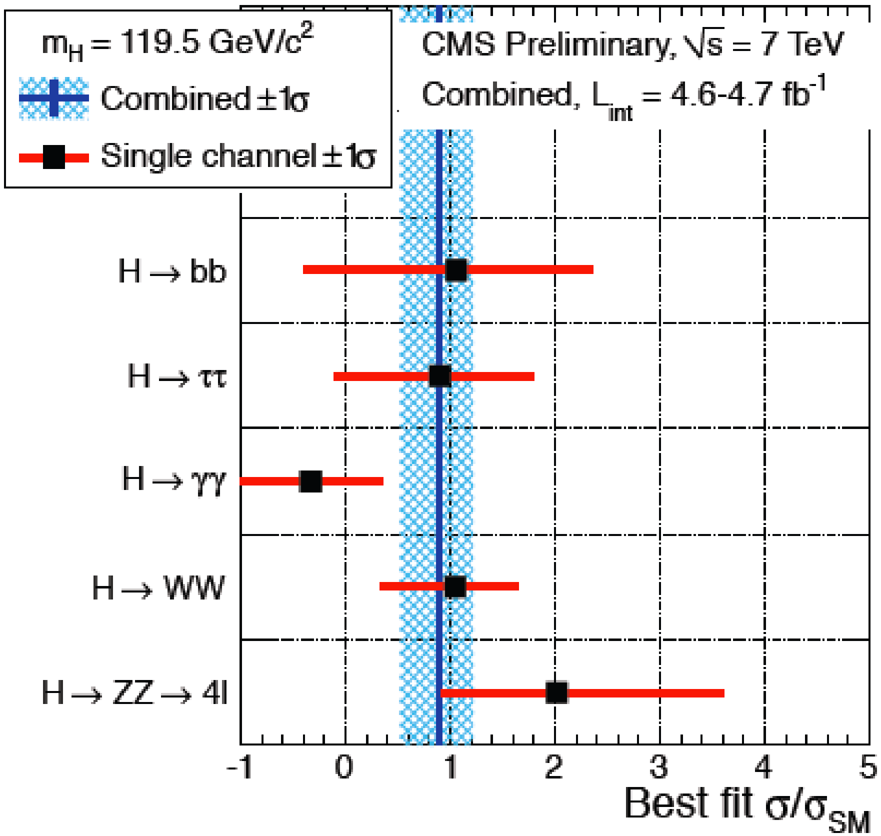




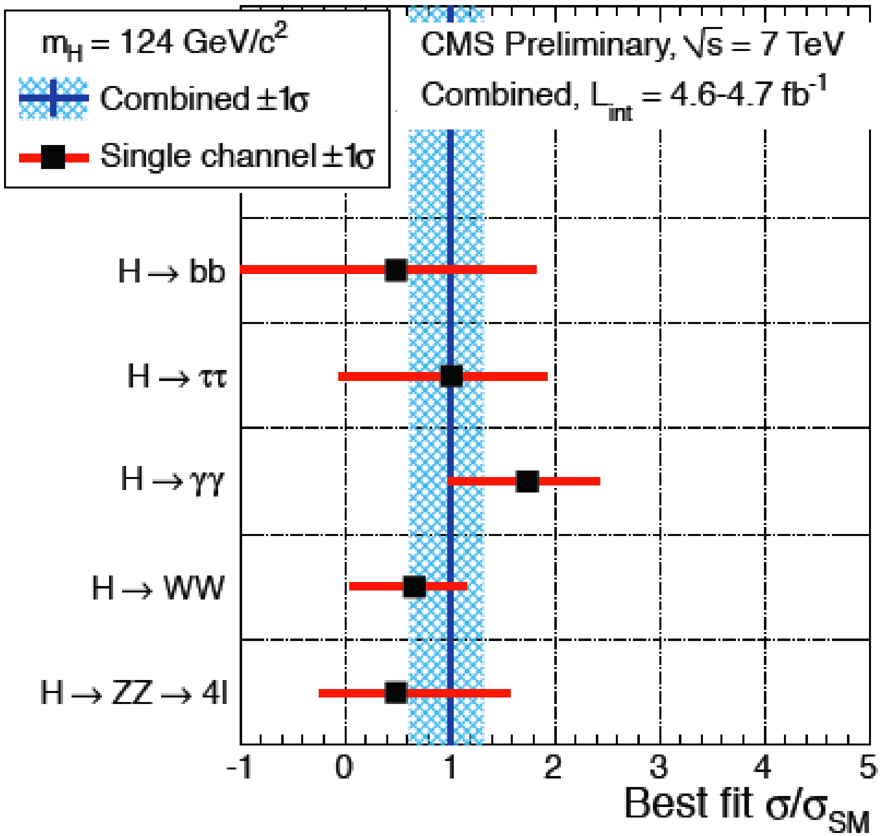
P-value with Toys



Channel by Channel Comparison



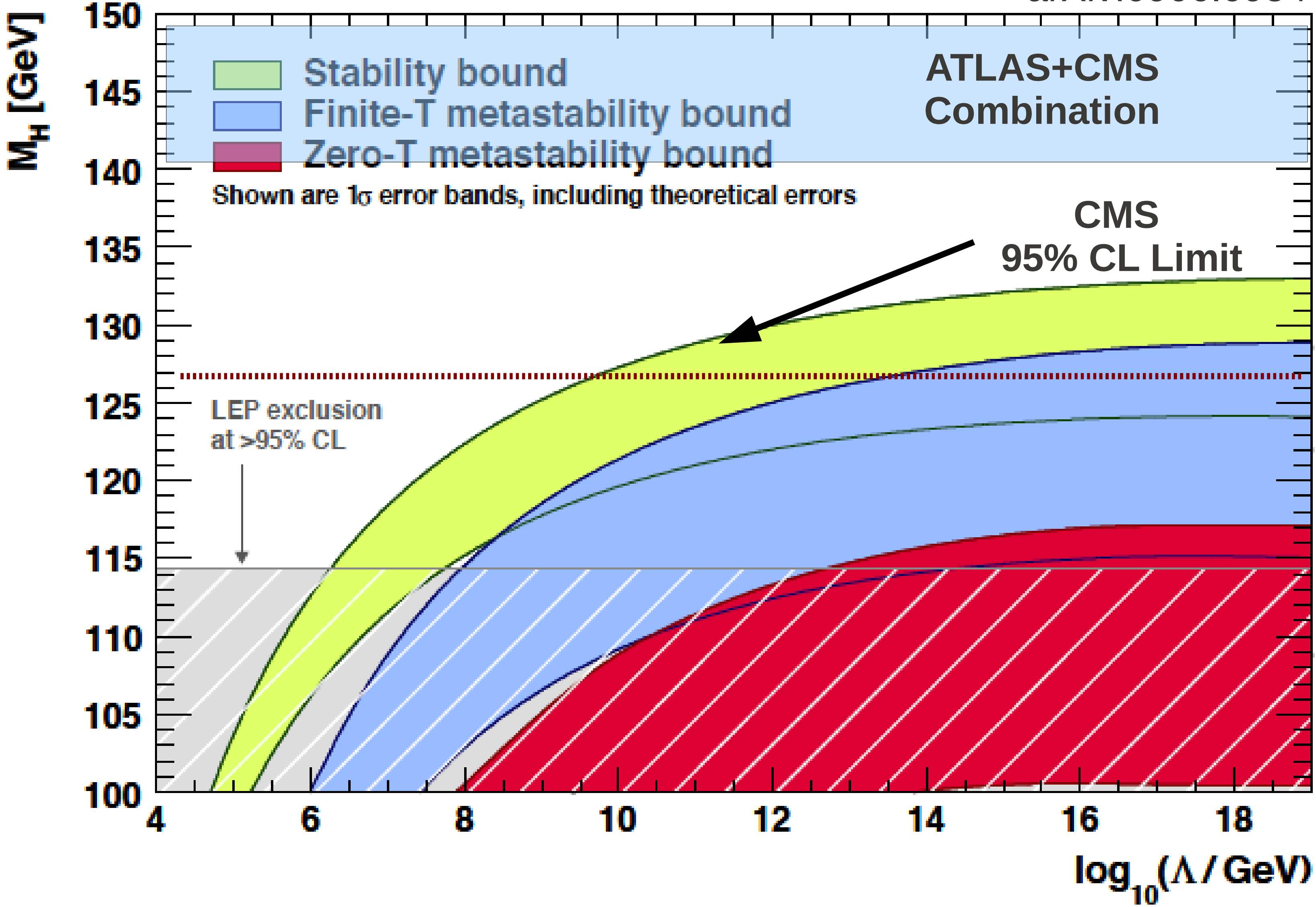
Driven by H → ZZ



Driven by H → γγ

Fate of the Standard Model

arXiv:0906.0954

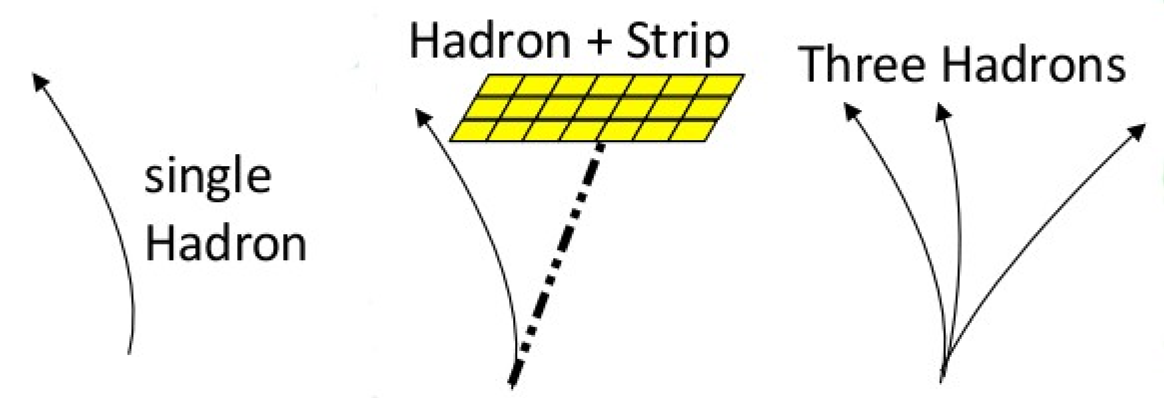


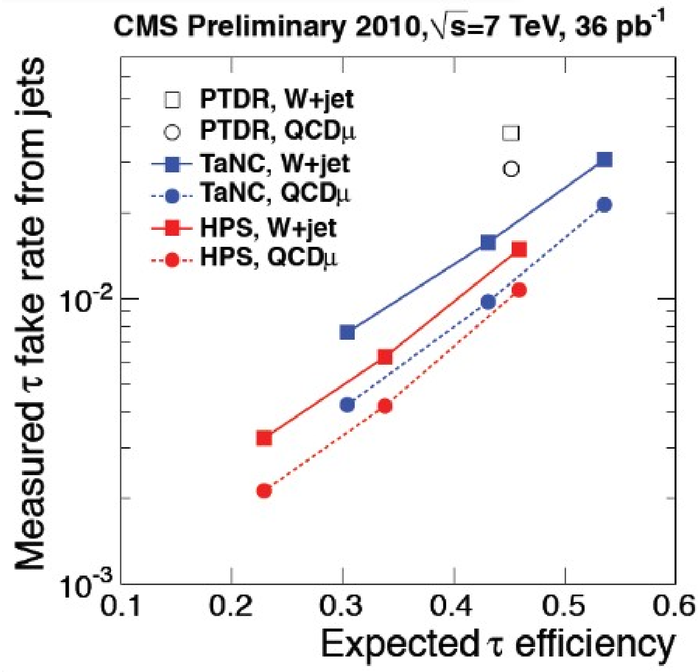
Dear colleagues,
I would like to invite you to a seminar in the main auditorium on 13 December at 14:00, at which the ATLAS and CMS experiments will present the status of their searches for the Standard Model Higgs boson. These results will be based on the analysis of considerably more data than those presented at the Summer conferences, sufficient to make significant progress in the search for the Higgs boson, but not enough to make any conclusive statement on the existence or non-existence of the Higgs. The seminar will also be webcast.
Rolf Heuer

"not enough to make any conclusive statement on the existence or non-existence of the Higgs"

Tau Leptons in CMS

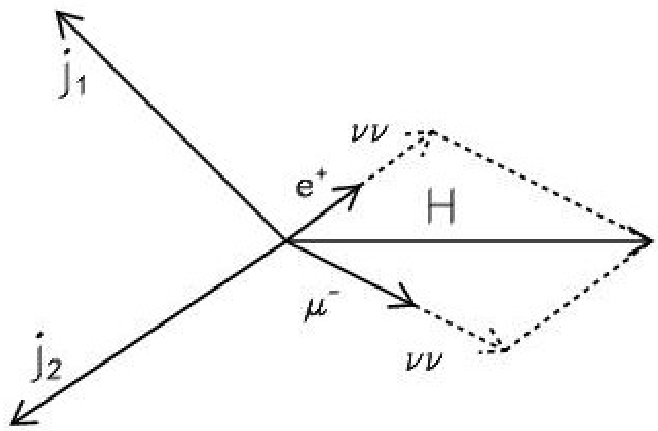
- τ_h reconstruction
  - based on particle flow candidates
  - builds individual decay modes
  - energy measured from τ constituents (in contrast to a cone algorithm)
- add particle flow isolation





Di-Tau Mass Reconstruction

- **Visible mass**
  - reconstruct mass from visible tau decay products
  - ~20% mass resolutions
  - all events can be considered
- **Likelihood technique**
  - using MET to reconstruct original tau momenta
  - moderate improvement compared to m_{vis}
  - called svfit in CMS (which is a little misleading)
  - all events can be considered
- **Collinear approximation**
  - works well for boosted Higgs
  - expect 10% mass resolution for VBF Higgs
  - loss in efficiency



$p(l) = x * p(\tau)$, collinear approximation

$p_T(H) = p_T(\tau 1) + p_T(\tau 2) = p_T(e) + p_T(\mu) + \not{p}_T$

$m^2_{\tau\tau} = m^2_{e\mu} / (x_{\tau e} * x_{\tau\mu})$