CMS Higgs searches

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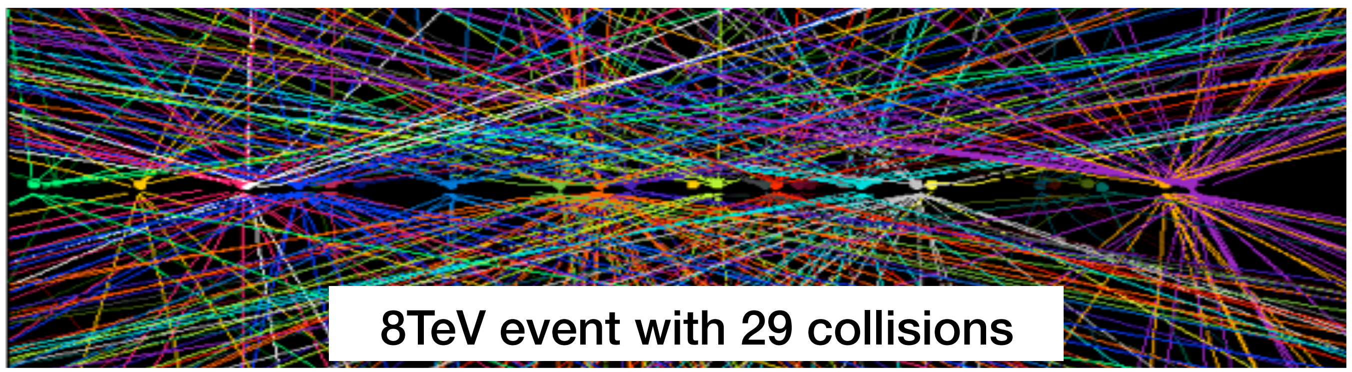
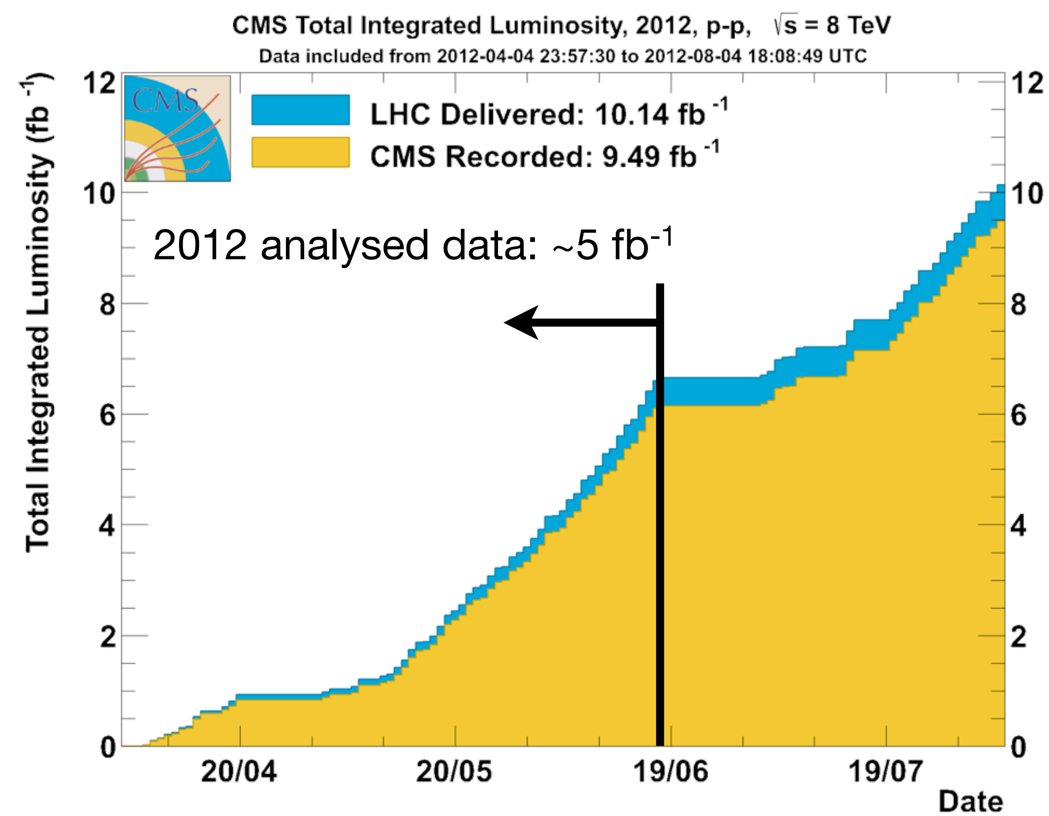
DESY

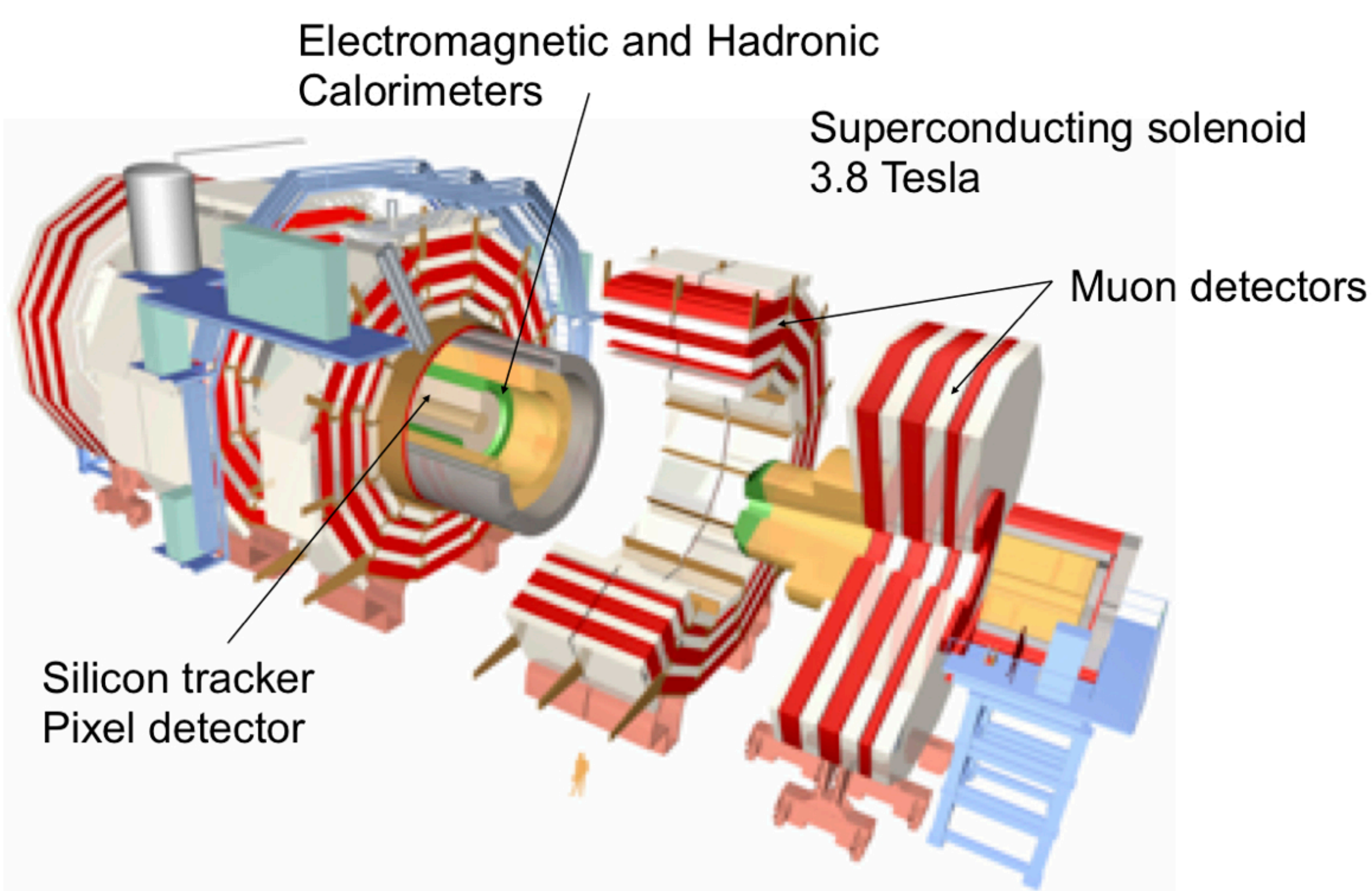
LHC Physics Discussions
06.08.2012 DESY

Introduction

- LHC good performance at 8 TeV.
- High luminosity → high pile-up
- Analysed data: ~5 fb^{-1} (2012) + ~5 fb^{-1} (2011)





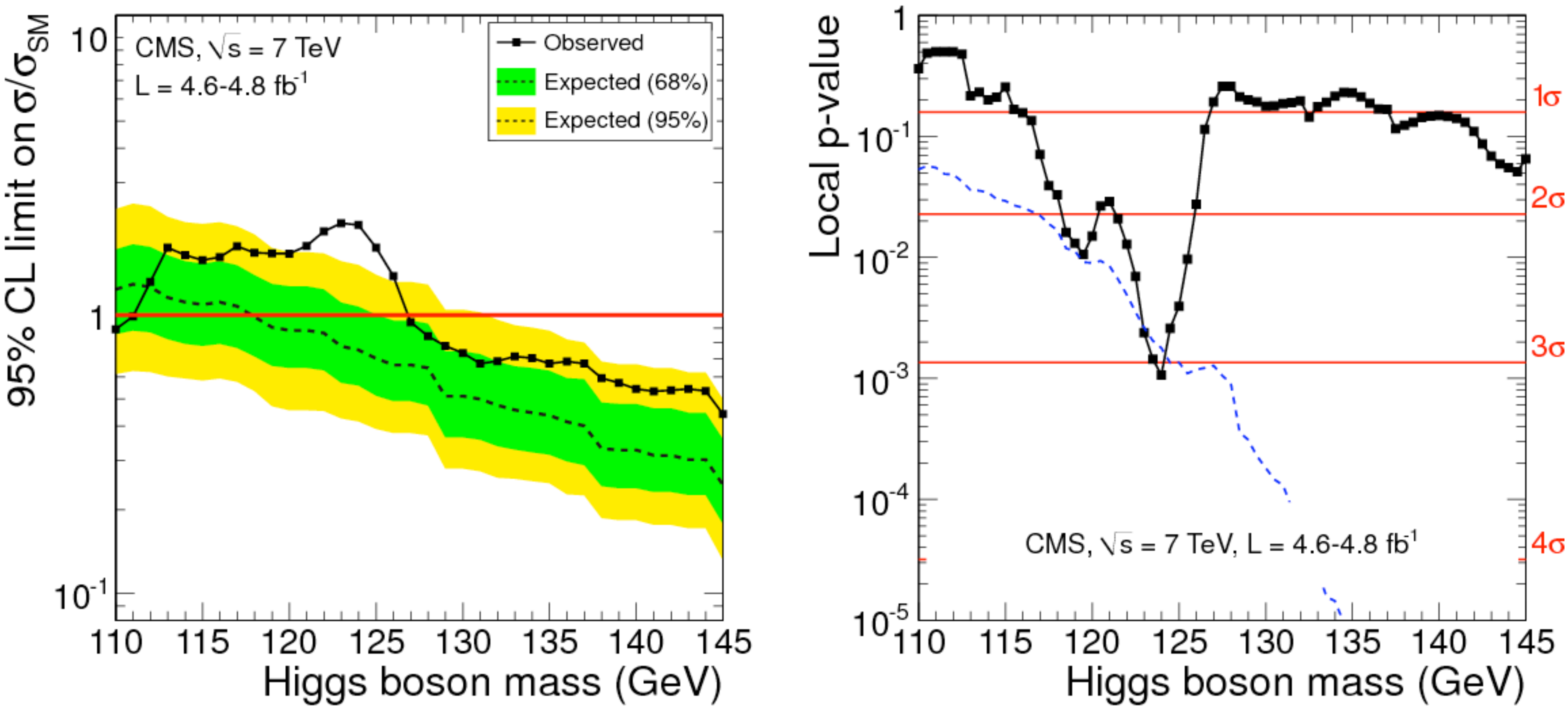


- Excellent performance of the CMS detector in data taking and reconstruction of physics objects used in Higgs searches:
  - photons;
  - electrons and muons;
  - tau leptons
  - b-tagging
  - jets and missing E_T

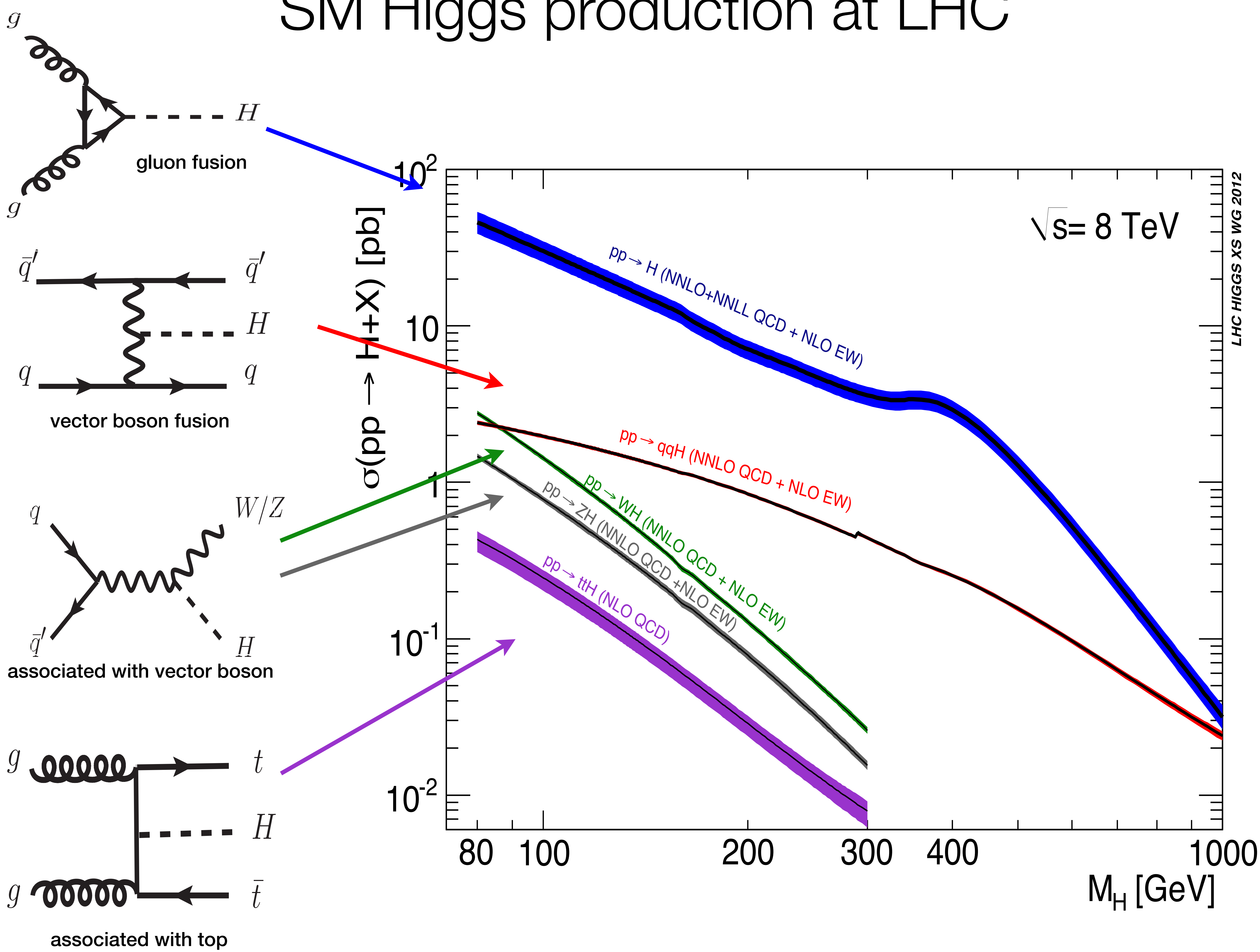
CMS Higgs results from 2011 – reminder

Phys. Lett. B 710 (2012) 26

- SM Higgs boson excluded in the mass range 127–600 GeV/c^2 at 95% CL.
- Observed excess of 3.1σ for a mass of 124 GeV/c^2.

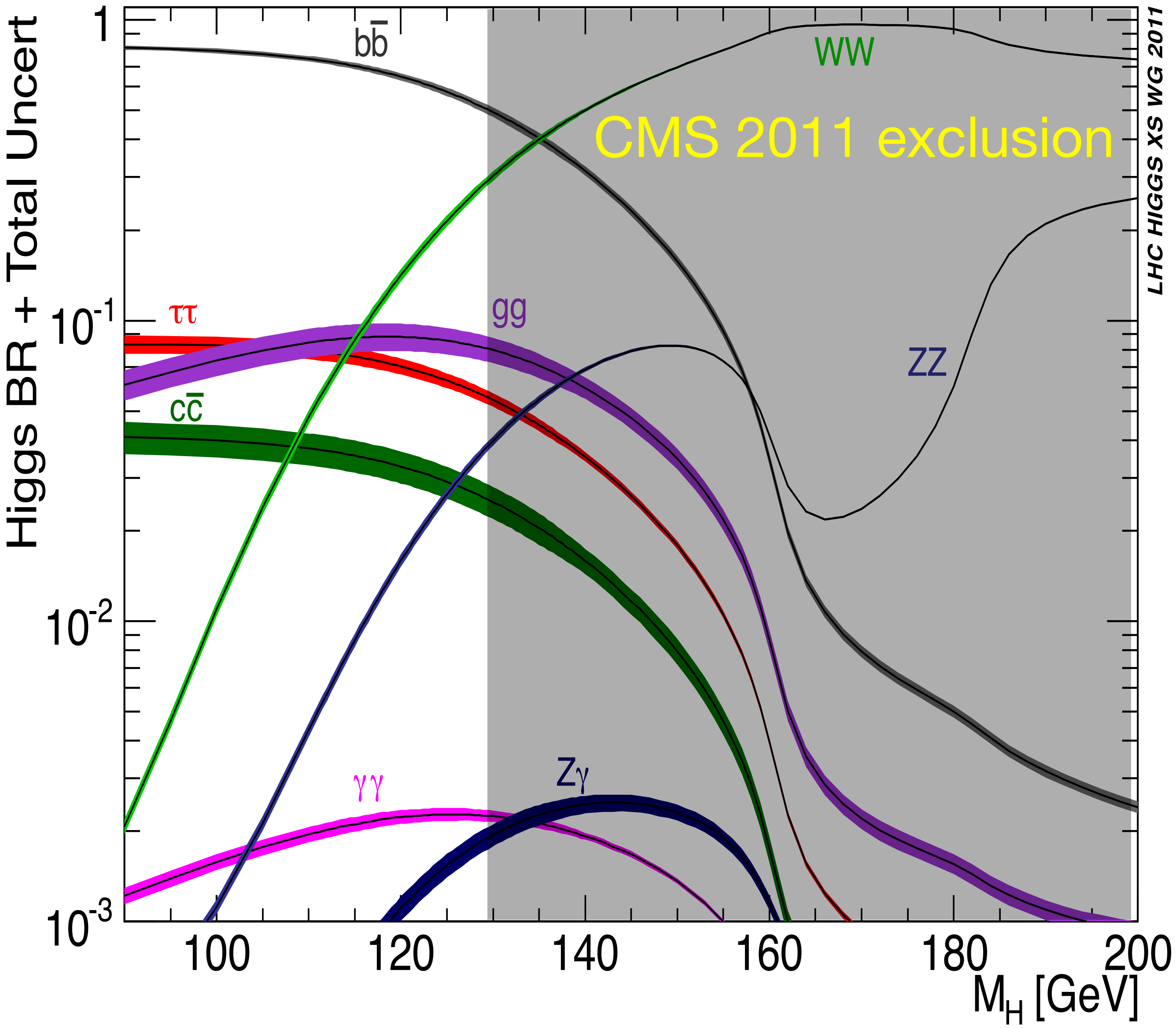


SM Higgs production at LHC



SM Higgs decay modes

- Low masses:
  - Decay into b quarks is dominant.
  - Most significant at the LHC: γγ and ZZ
- High masses (excluded):
  - Dominated by WW and ZZ.
- Searches: explore all possible channels.
- Use as many channels as possible to establish the Higgs mechanism



SM Higgs searches in CMS (2011+2012)

Decay channels

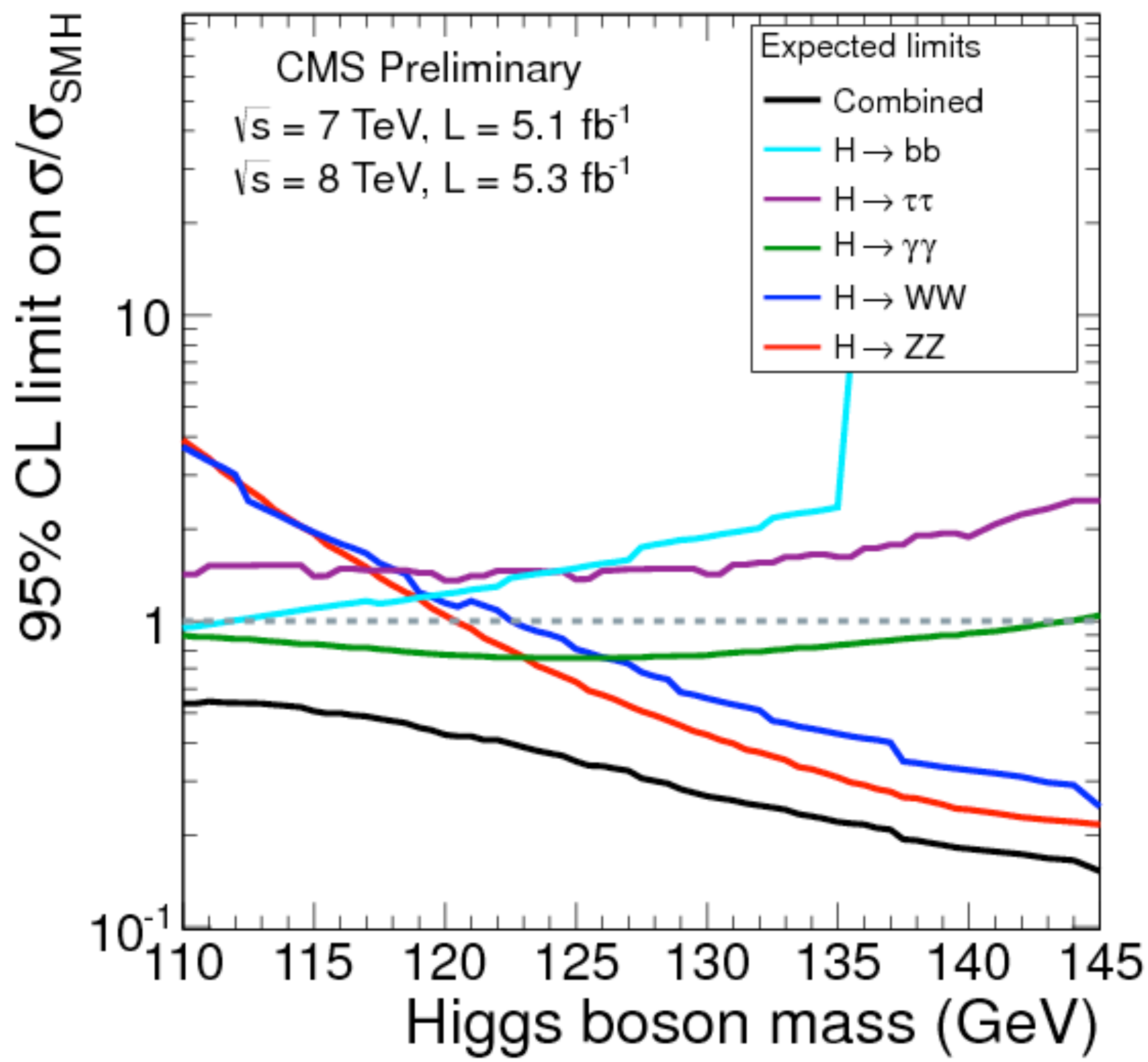
- H → ZZ
  - ZZ → 4l
  - ZZ → 2l2ν
  - ZZ → 2l2q
  - ZZ → 2l2q
- H → γγ
- H → WW
  - WW → lνlν
  - WW → lνqq
- H → ττ
  - ττ → $\mu\tau_h$
  - ττ → $e\tau_h$
  - ττ → eμ
  - ττ → μμ
- H → bb

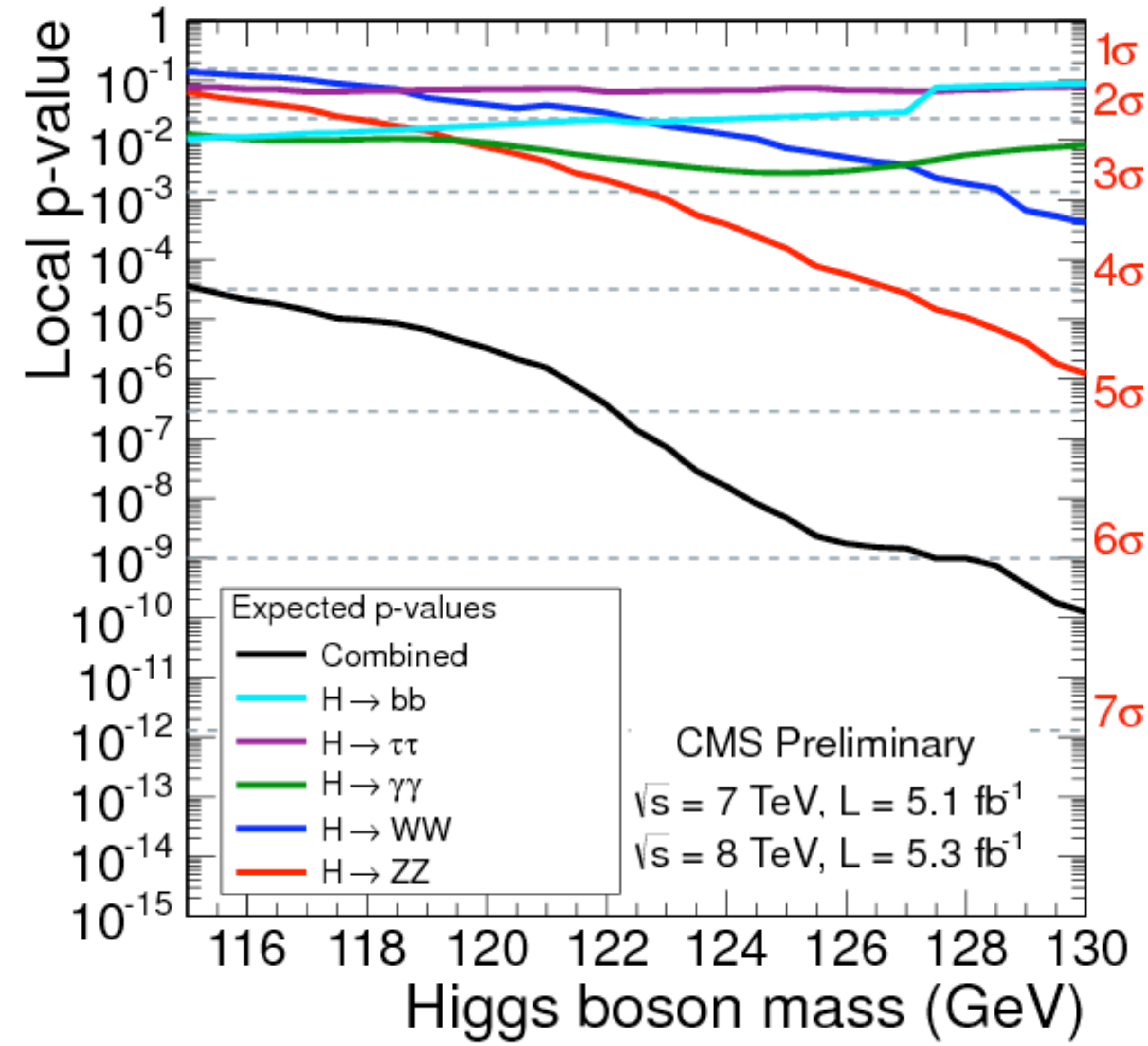
Production mechanisms

	untagged	VBF-tag	VH-tag	ttH-tag
$\mathrm{H} \to \gamma\gamma$	✓	✓		
$\mathrm{H} \to bb$			✓	✓
$\mathrm{H} \to \tau\tau$	✓	✓	✓	
$\mathrm{H} \to WW$	✓	✓	✓	
$\mathrm{H} \to ZZ$	✓			

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

CMS sensitivity at low M_H



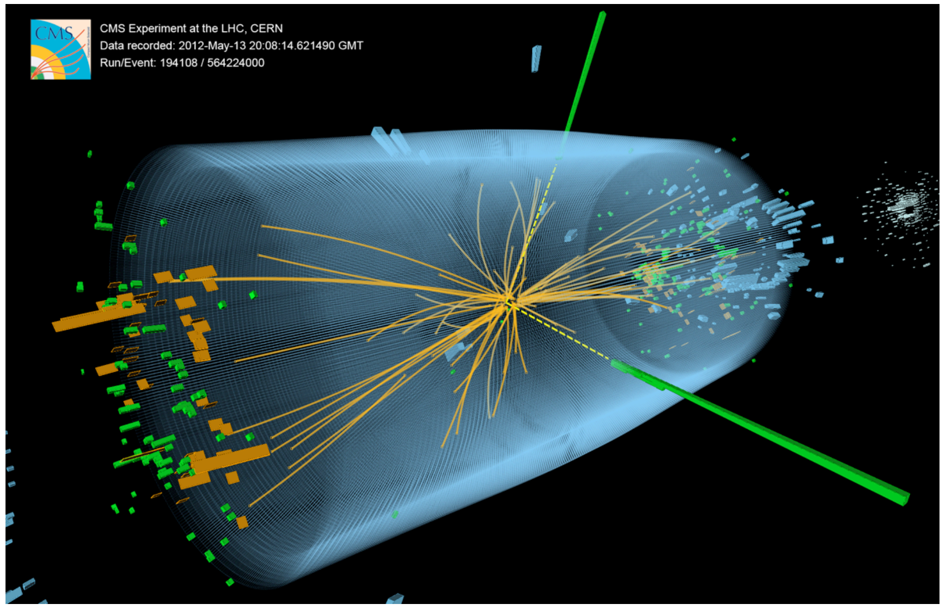


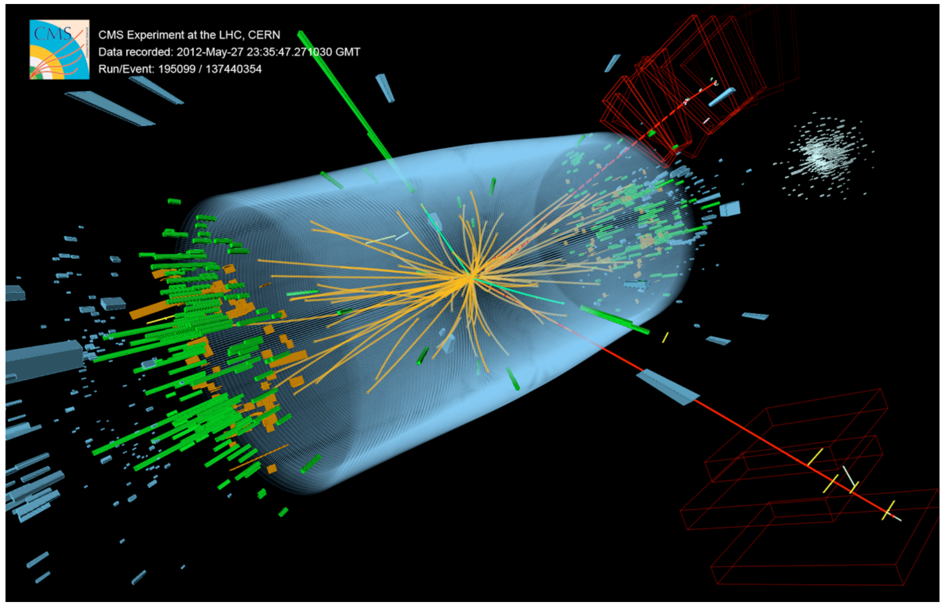
- In case no signal is observed, the SM Higgs can be excluded at 95% C.L.
- In the case of presence of an excess of events, a significance larger than 5σ is obtained in the mass range 122–130 GeV/c^2.

Then came the 4th of July

"We have a discovery - we have observed a new particle consistent with a Higgs boson. But which one? That remains open."

Rolf Heuer, 4th of July 2012

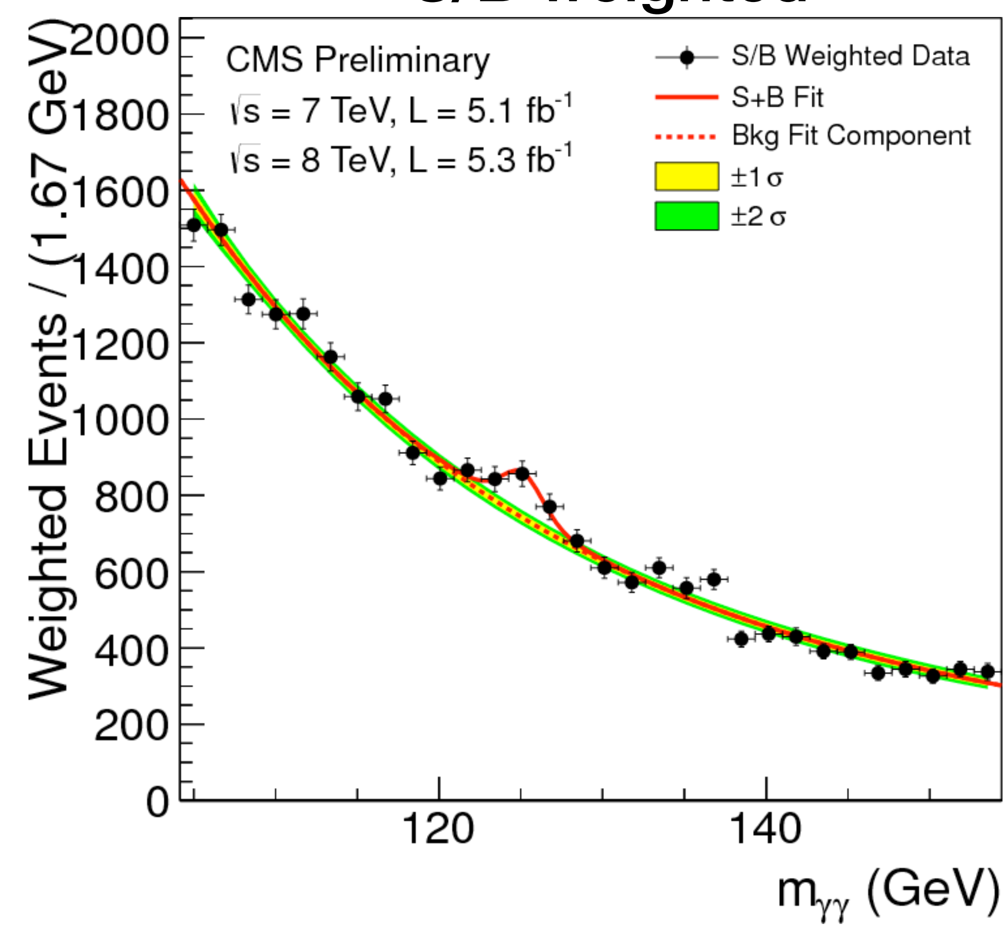


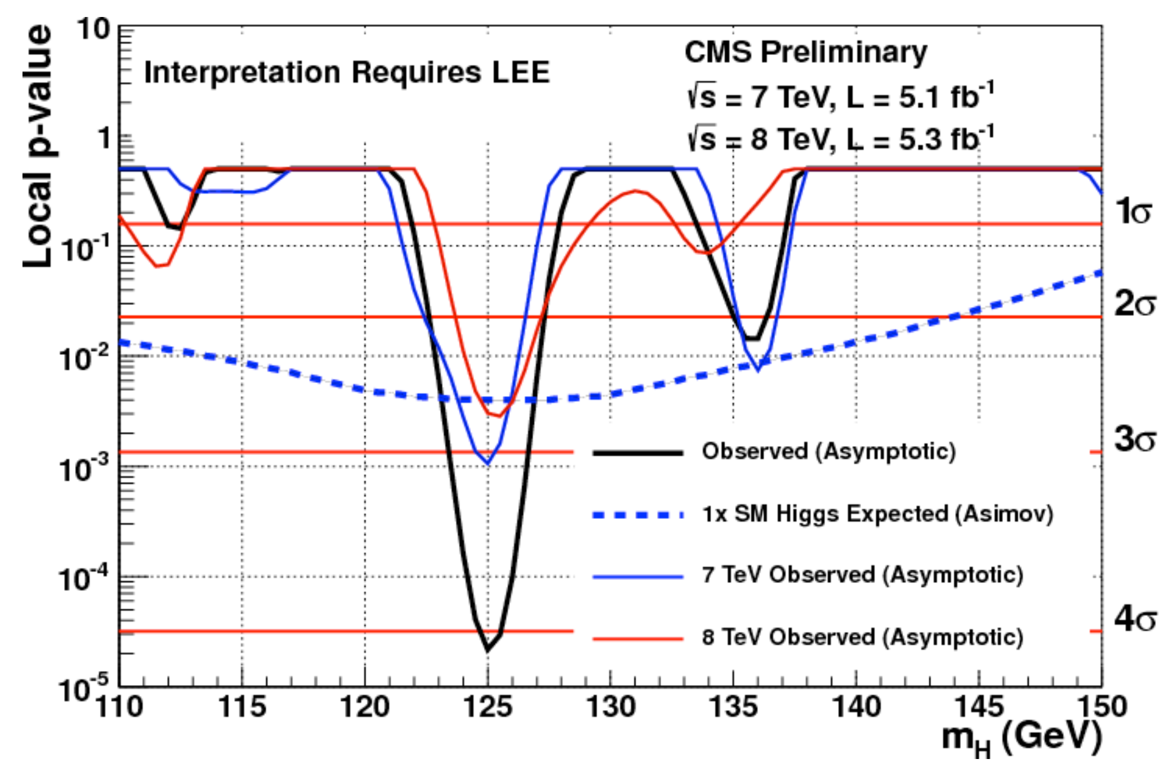


Summary of H → γγ search

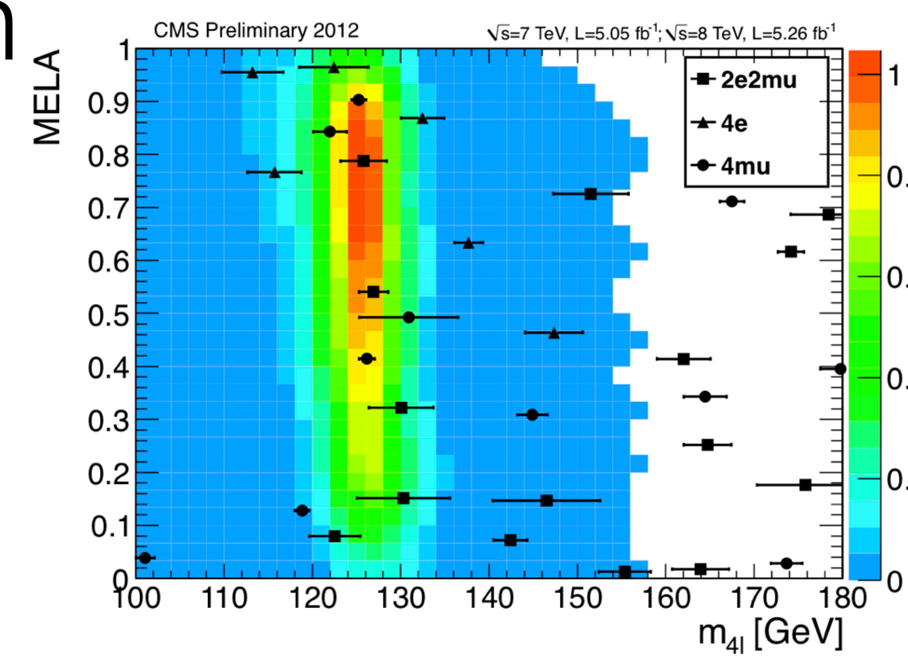
- Sample split into two sets: untagged and VBF-tag.
  - Further categorisation of each set is applied.
- Background shape and normalisation obtained a posteriori from fits of the mass distributions with a smooth function.
- Excess of events observed for a Higgs with mass 125 GeV/c^2.
  - Local significance 4.1σ
  - Global significance 3.2σ

S/B weighted

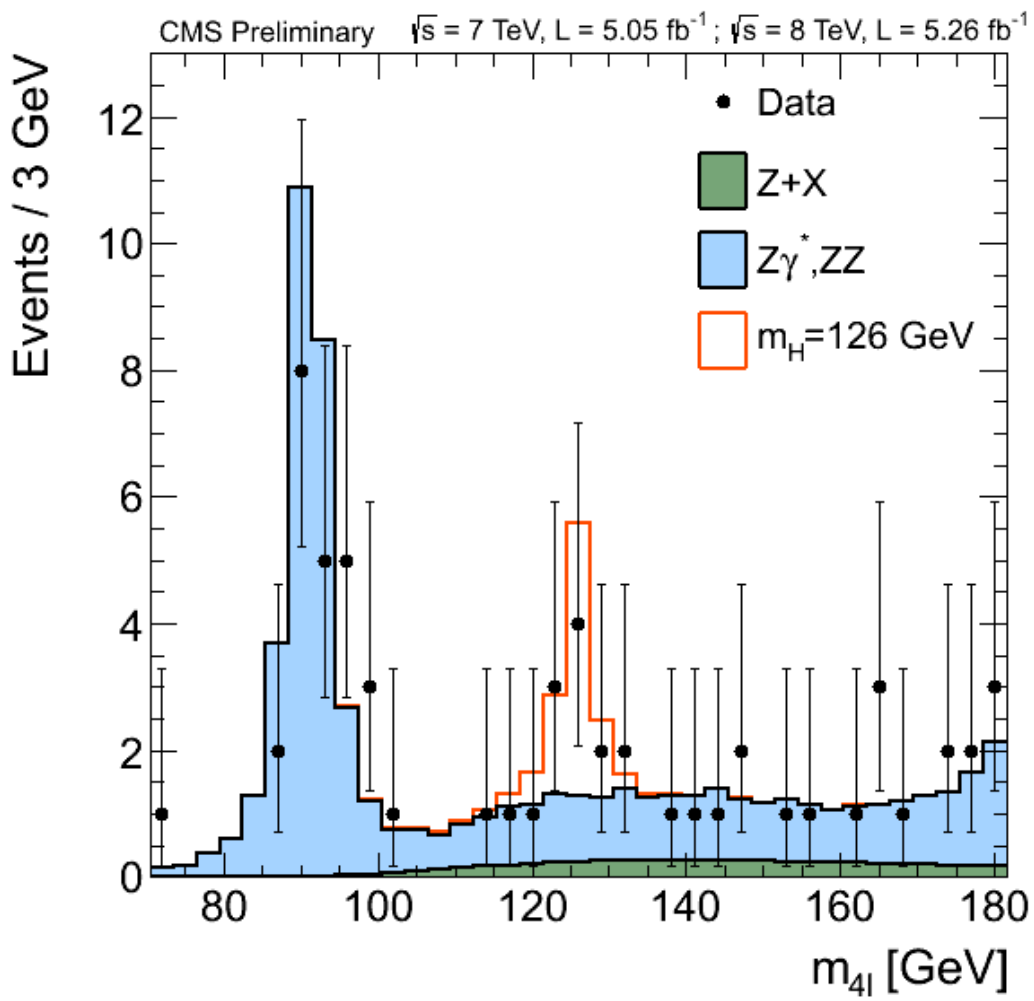


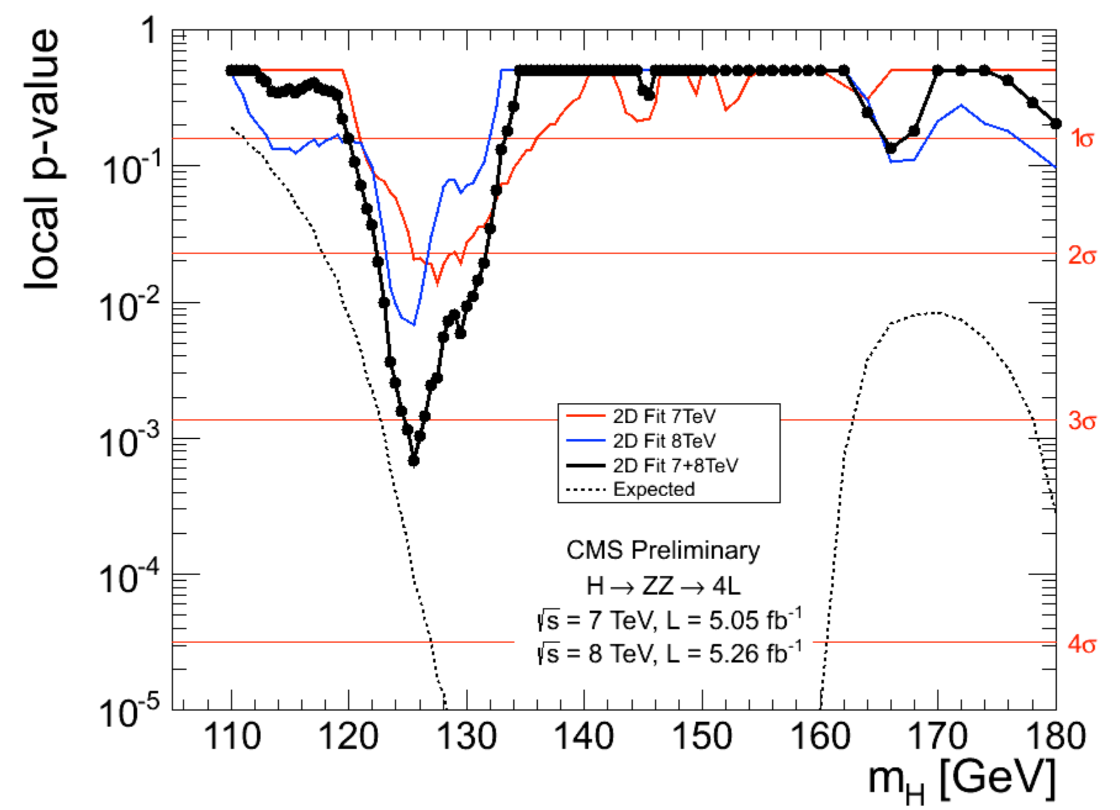


Summary of H → ZZ → 4l search



- Two-dimensional analysis [M_{4l}, MELA].
  - MELA: matrix element likelihood analysis
    - inputs: masses of di-leptons and the five angles defining the four-lepton configuration



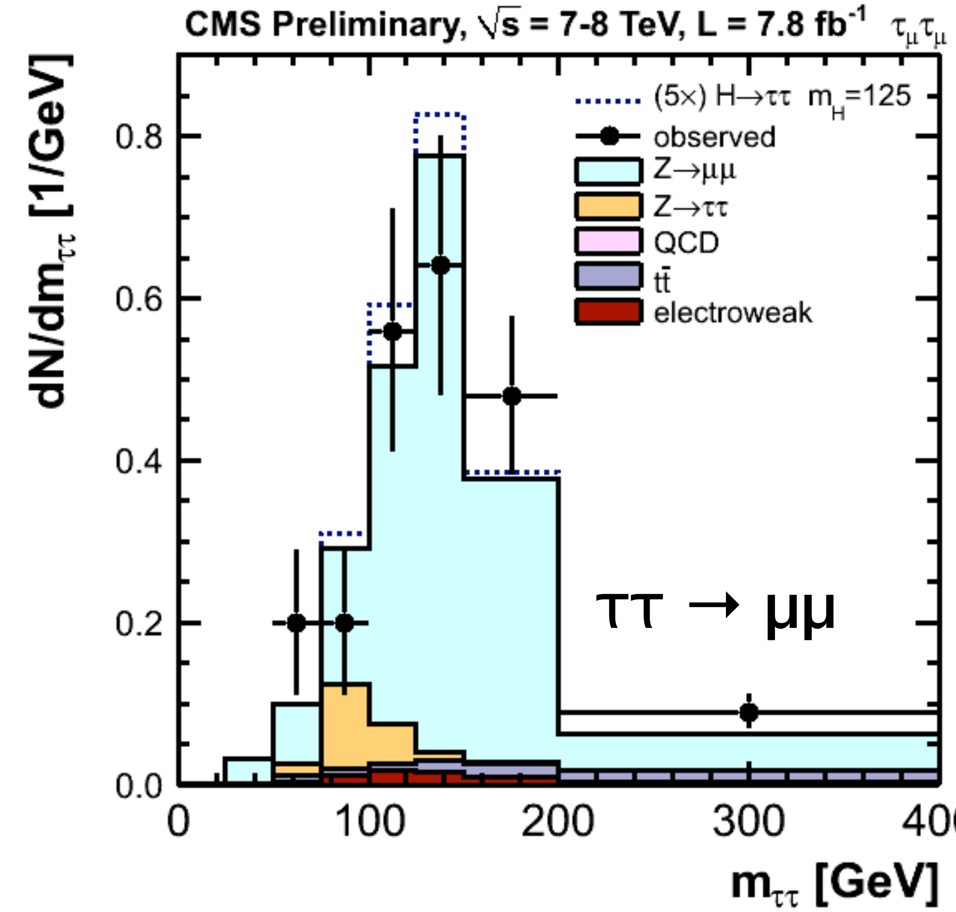


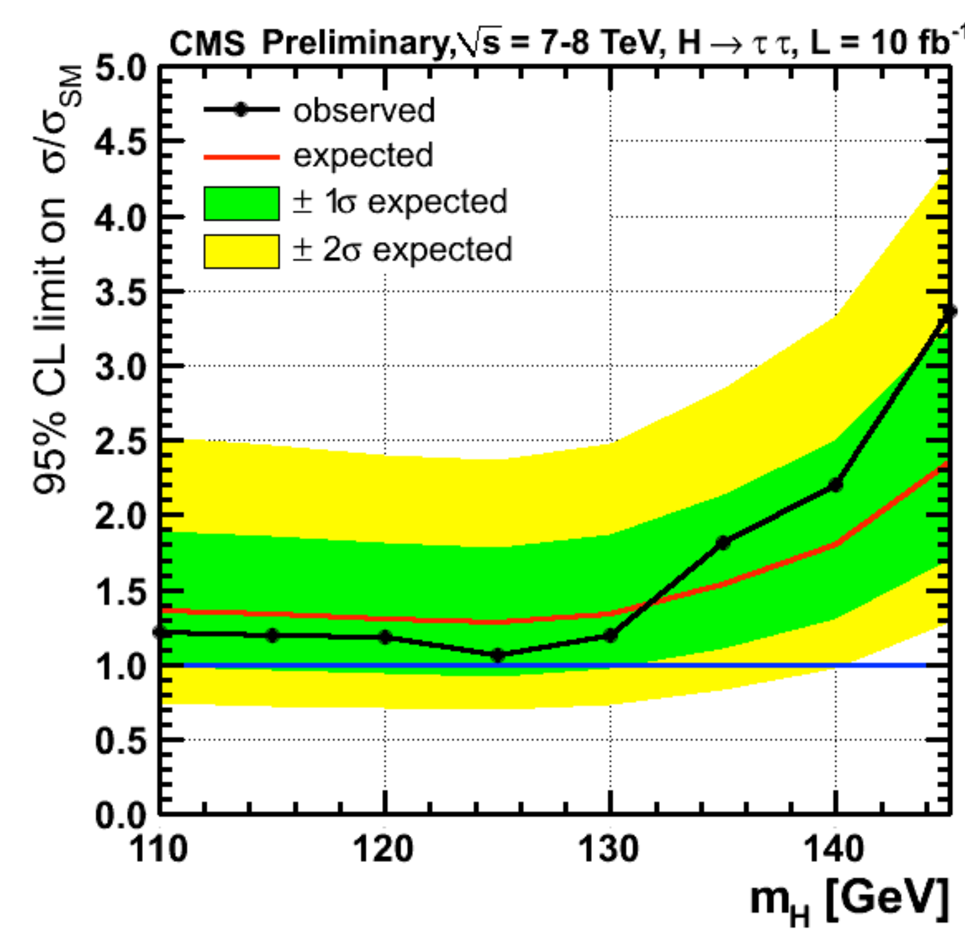
- Excess of events observed for a Higgs with mass 125 GeV/c^2.
  - Local significance 3.2σ

Summary of H → ττ search

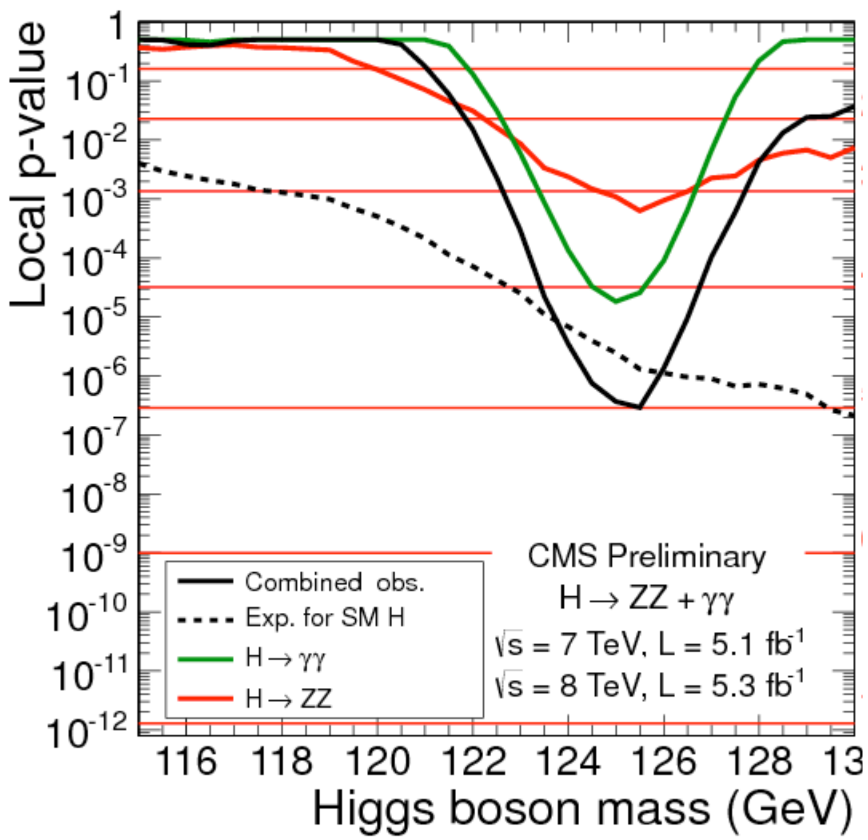
- ττ → μτ_h, eτ_h, eμ, μμ
- Three categories: 0-jet, boost and VBF
- In μτ_h, eτ_h and eμ channels, inference in $m_{\tau\tau}$ distribution.
- In μμ channel, inference in 2D [$m_{\tau\tau}$, $m_{\mu\mu}$] distribution.
- Main irreducible background Z → ττ evaluated in a data-driven way using tau embedding technique.
- No excess of events observed with respect to expected SM background
  - Observed exclusion : 1.06 × σ_{SM} for m_H = 125 GeV/c^2

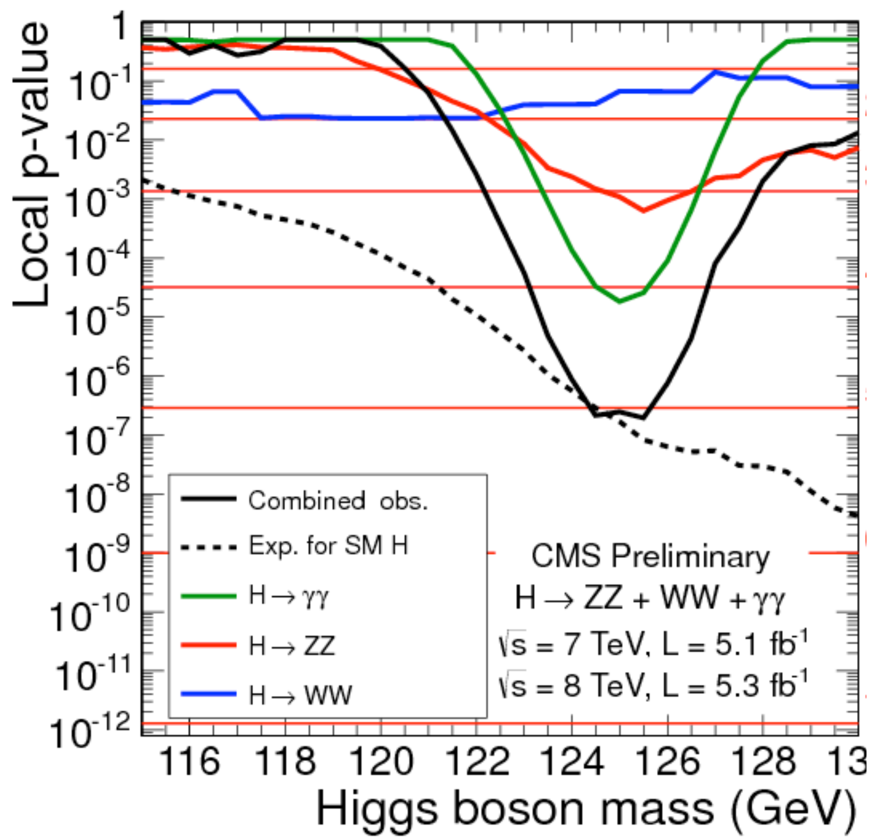
VBF category

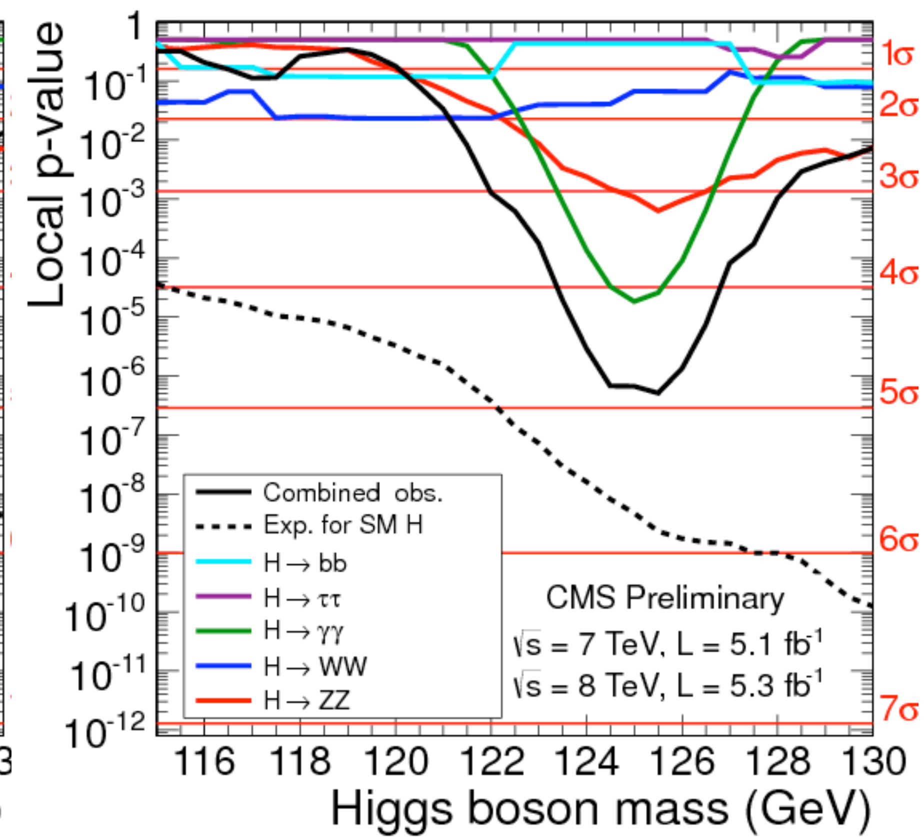




Significance – all channels







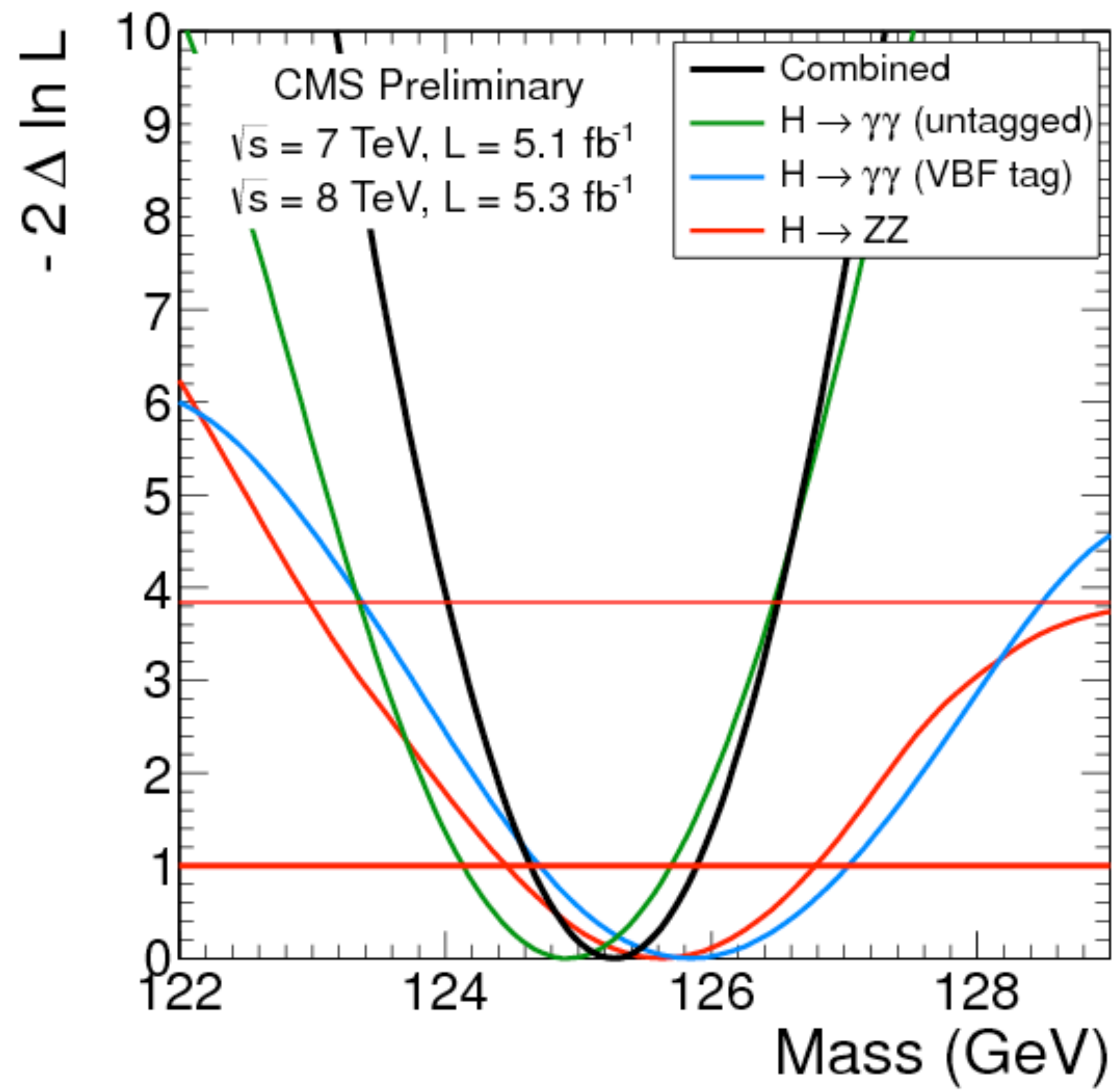
- The high mass resolution channels γγ and ZZ
- combined significance at 125 GeV: 5.0σ

- Adding the high sensitive but low mass resolution channel WW
- combined significance at 125 GeV: 5.1σ

- Full combination, adding ττ and bb
- combined significance at 125 GeV: 4.9σ

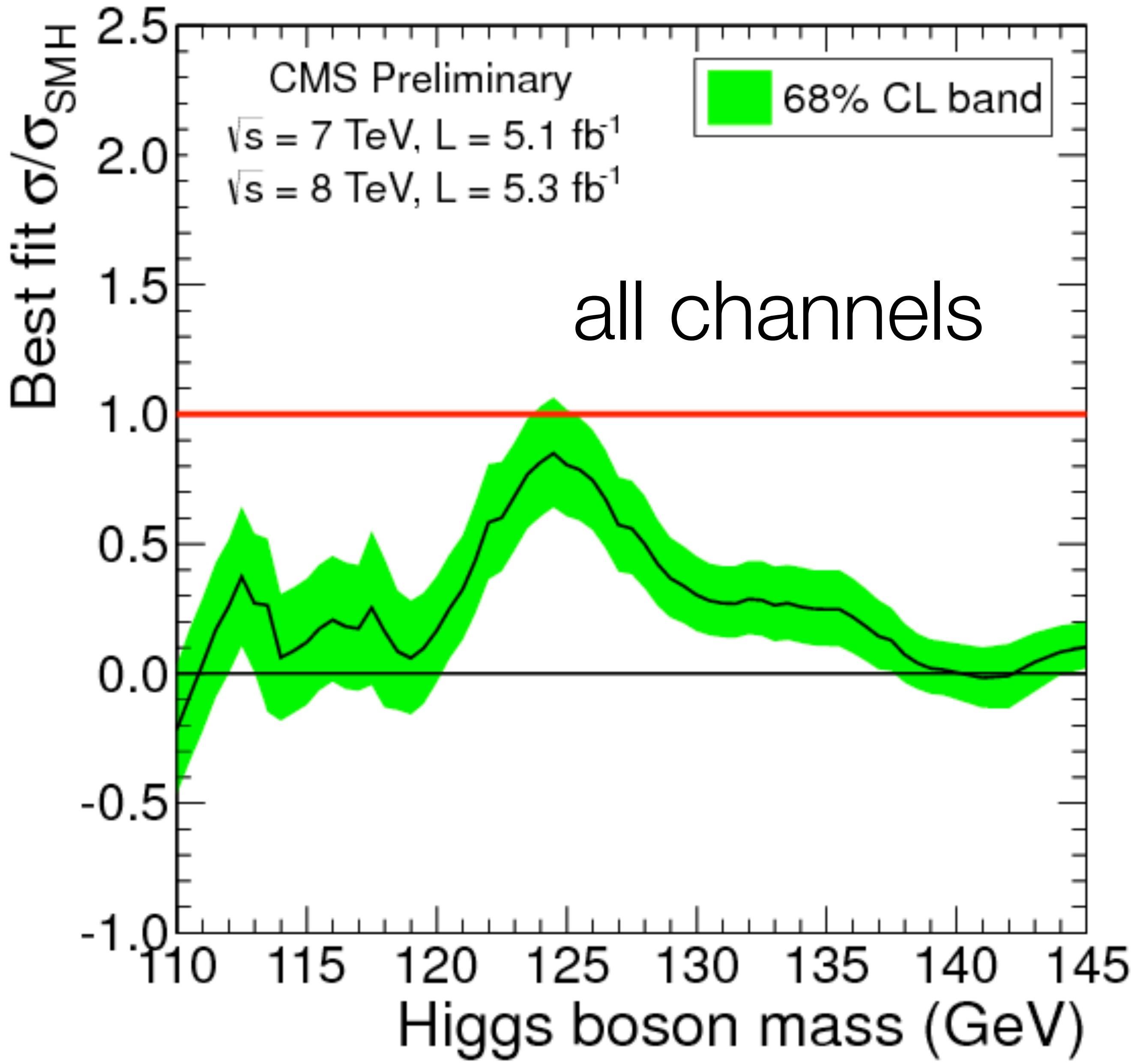
Mass of the observed state

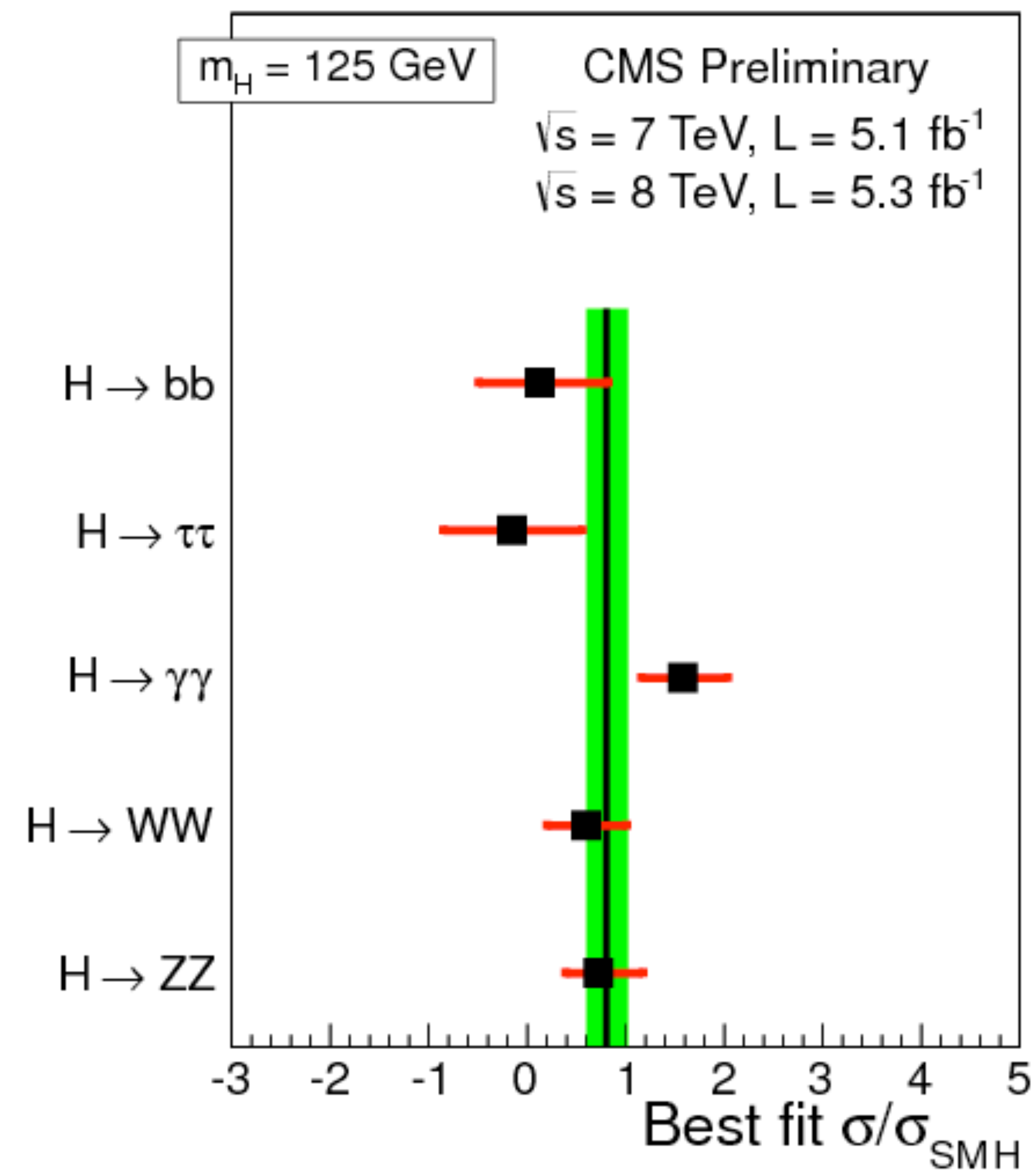
- Combined only
  γγ and ZZ → 4l channels
  - Excellent mass resolution
  - High significance



combined best-fit mass
$m_X = 125.3 \pm 0.4\ (\mathrm{stat}) \pm 0.5\ (\mathrm{syst})$ GeV

Compatibility of the observed state with the SM Higgs boson (I)





combined best-fit in signal strength around 125 GeV/c^2

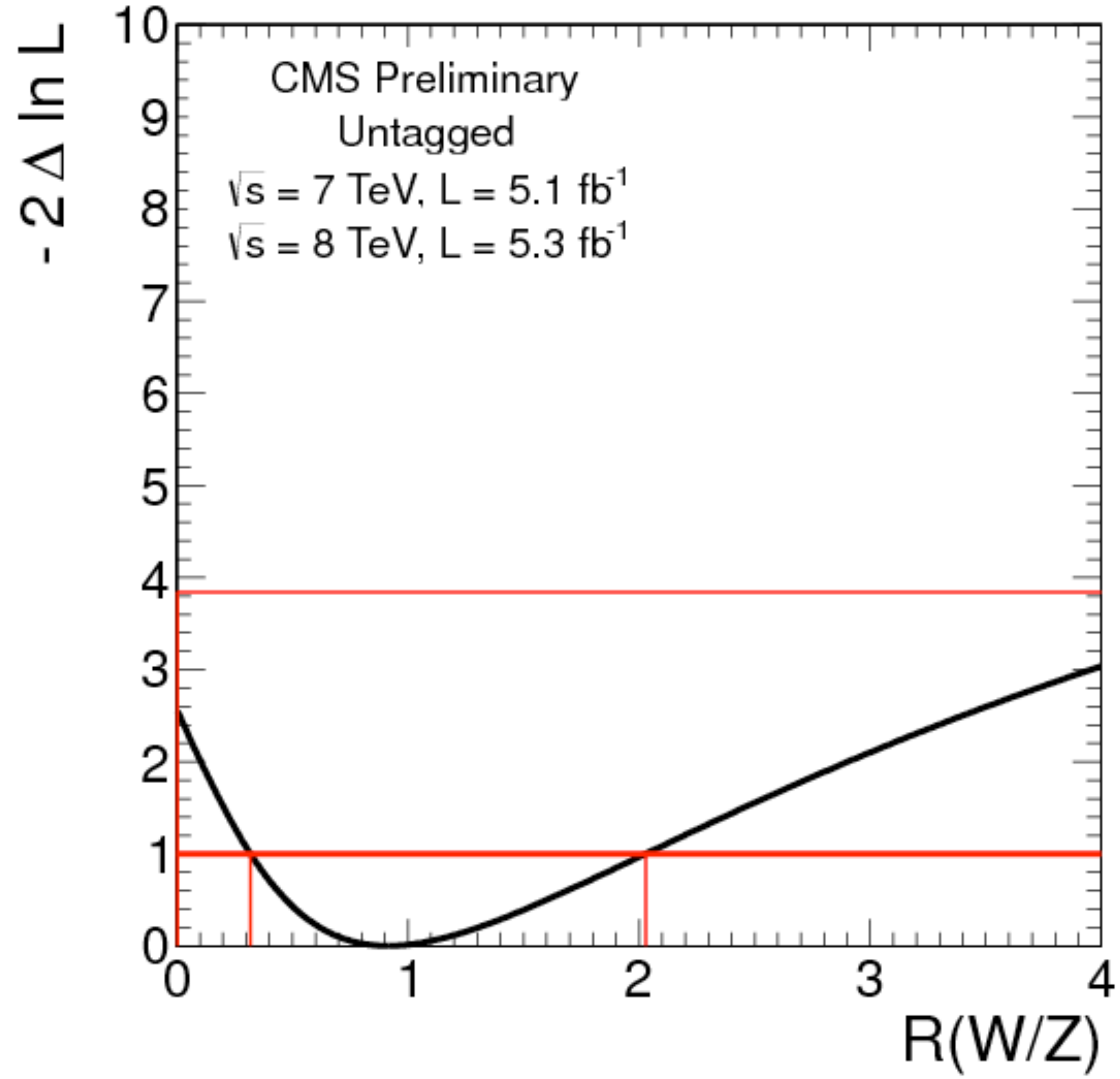
$\sigma/\sigma_{SMH} = 0.80 \pm 0.22$

Compatibility of the observed state with the SM Higgs boson (II)

- Ratio of WW and ZZ yields driven by the ratio g_{HWW}/g_{HZZ}, well defined by the SM.
- Combination of untagged WW and ZZ and fitting for the difference with respect to the expectation.

$$R_{WZ} = 0.9^{+1.1}_{-0.6}$$

- Consistent with the SM prediction within uncertainty.



Compatibility of the observed state with the SM Higgs boson (III)

- At LO the parameters $c_V(c_F)$ scales the SM Higgs boson couplings to vector bosons (fermions)
- Partial widths scales as c_V^2 or c_F^2
- $\Gamma_{\gamma\gamma}$ scales as $|\alpha c_V + \beta c_F|^2$
  - α and β are taken from theory
- Results in agreement with the SM prediction at 95% CL

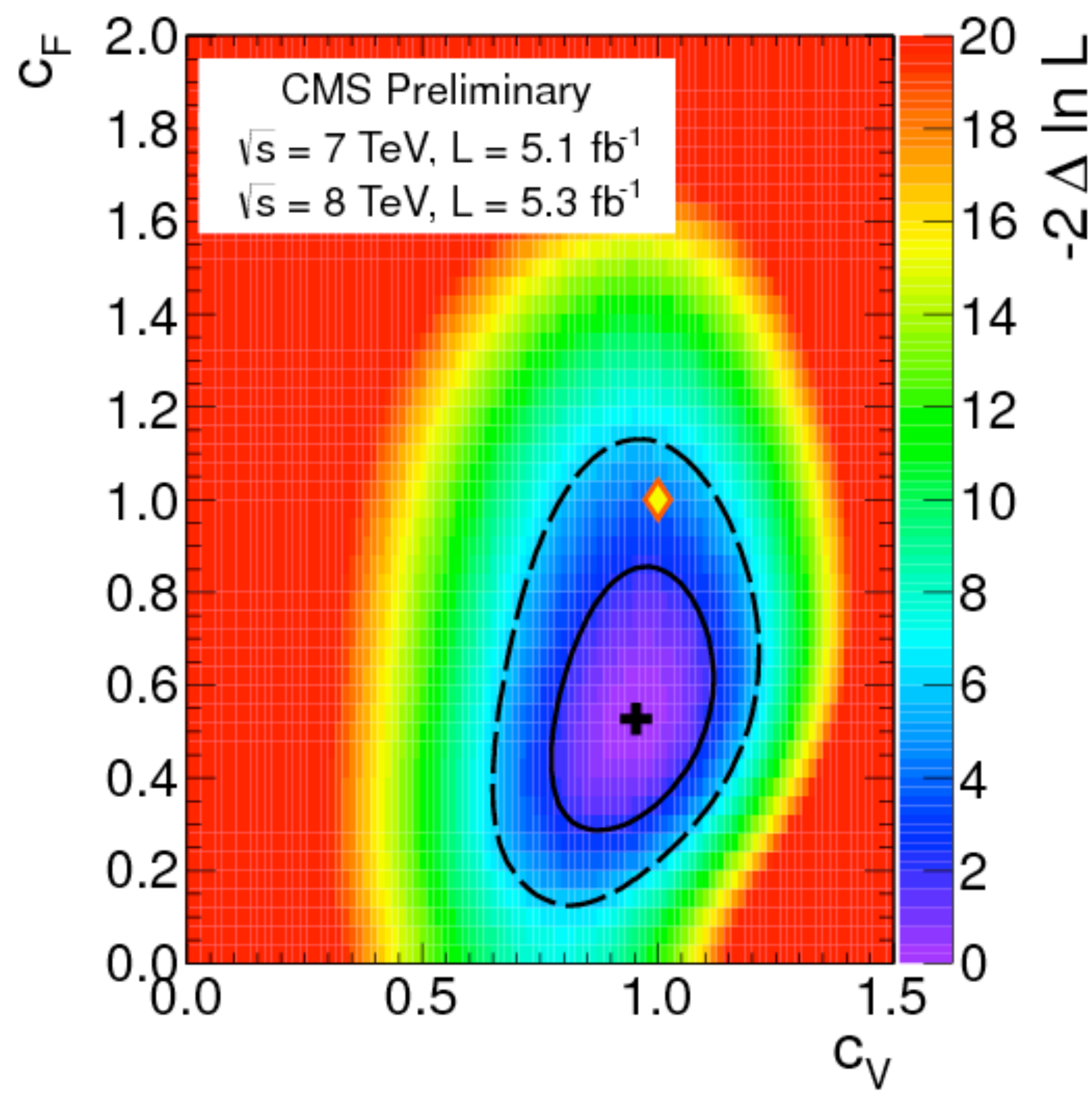
best-fit (M=125 GeV/c^2)

$(c_V, c_F) = (1.0, 0.5)$

1D 95% CL (M=125 GeV/c^2)

$c_V = [0.7;1.2]$

$c_F = [0.3;1.0]$



Is the observed state the SM Higgs boson?

- To prove that the new observed state is the Higgs boson it requires various measurements (not all possible at the LHC), such as:
  - Measurement of its couplings to standard model particles.
  - Measurement of self-coupling.
  - Measurement of quantum numbers.
  - Spin must be 0:
    - observation of $H \rightarrow \gamma\gamma$ rules out J=1
    - observation of $H \rightarrow WW$, $WW \rightarrow 2l2\nu$ with trend to small $\Delta\phi(l,l)$ rules out J=2
  - Angular and m_{Z^*} spectra in $H \rightarrow ZZ^*$ distinguish 0+/0– state → separation at 3σ level expected until shutdown
  - Investigation of the structure of the Higgs sector.
    - If the observed state is a Higgs boson, is it the SM one or one of the states predicted in BSM theories?

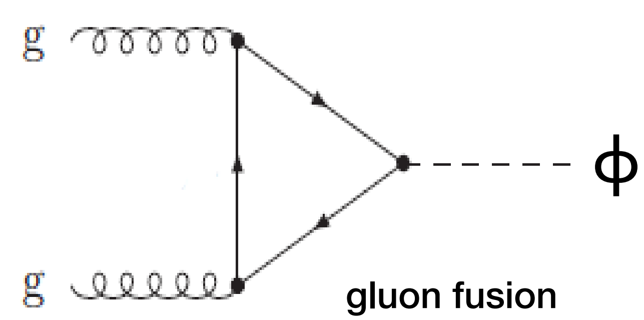
MSSM neutral Higgs production at LHC

Three neutral Higgs: ϕ=h, H, A

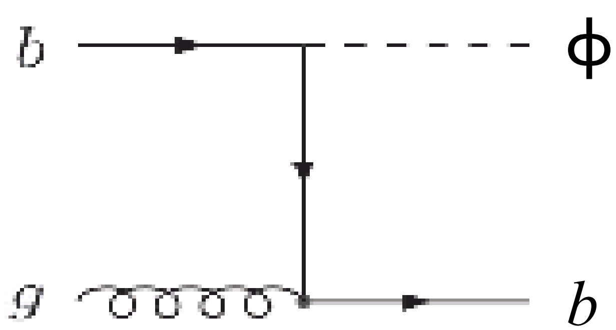
Parameters: tanβ and M_A

BR(ϕ→bb) ≃ 85%–90%
BR(ϕ→ττ) ≃ 10%–15%

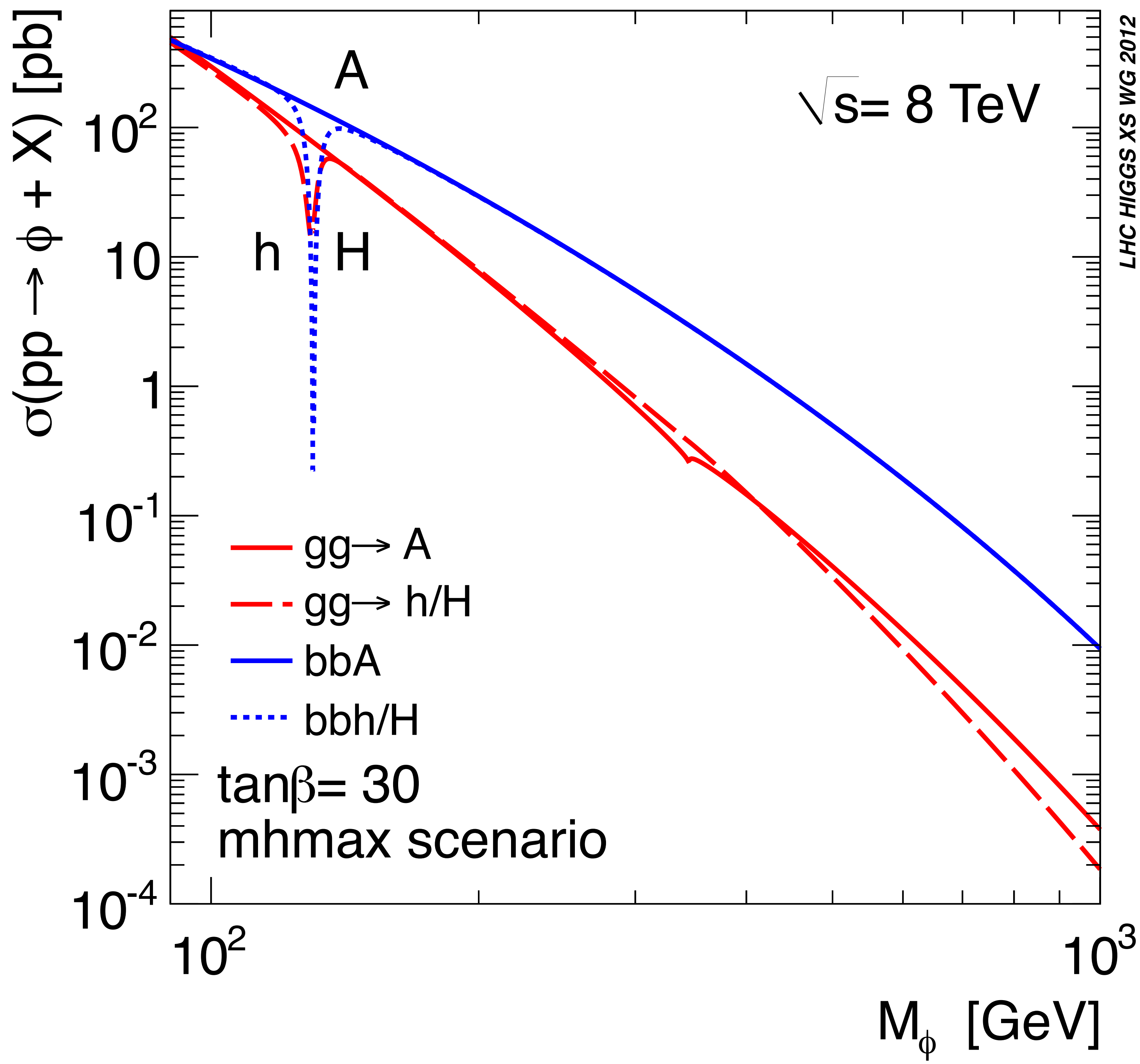
Production mechanisms:



gluon fusion

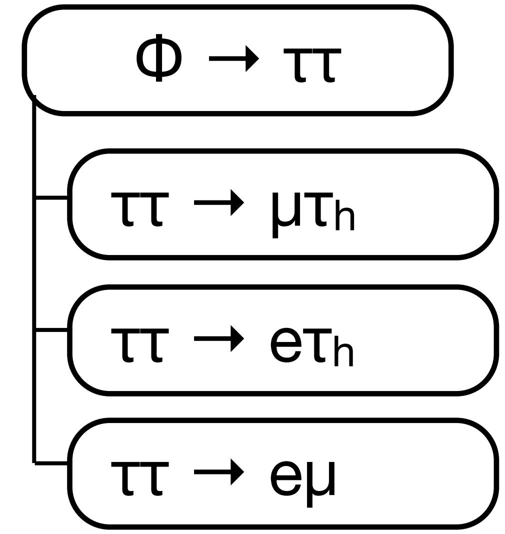


associated with b quarks



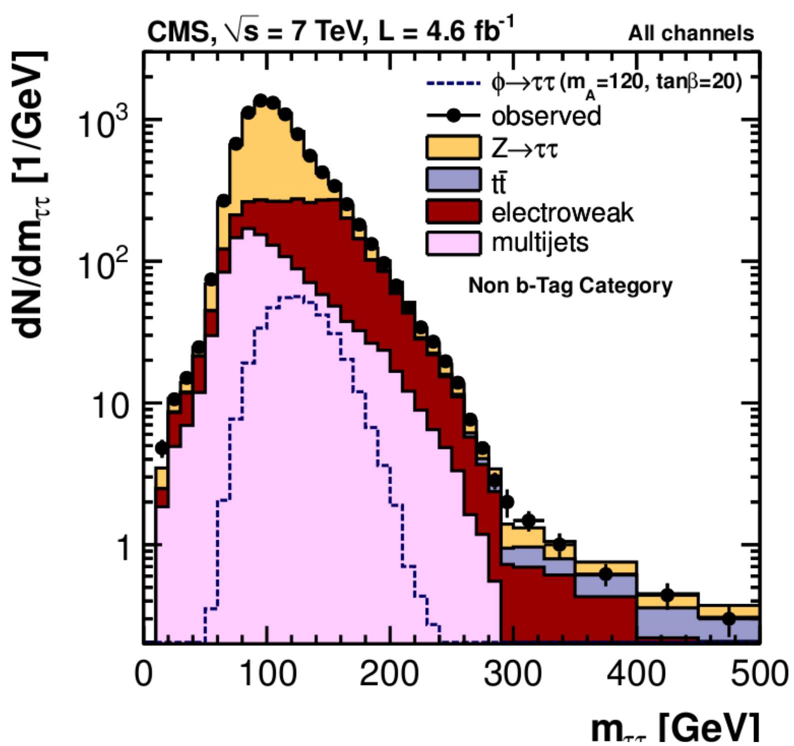
Monday, 6 August 12

MSSM $\Phi \rightarrow \tau\tau$ (I)

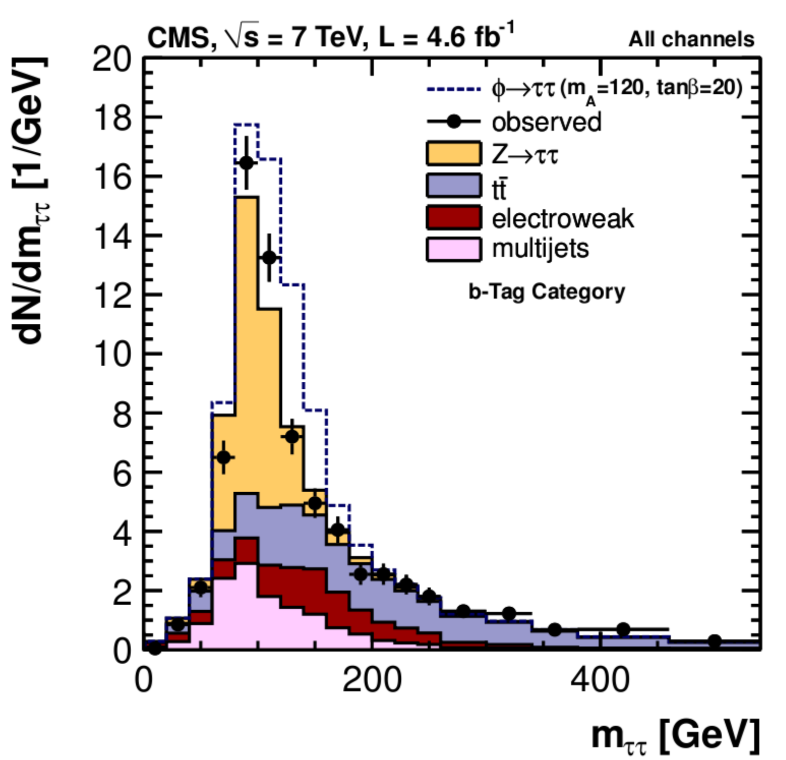


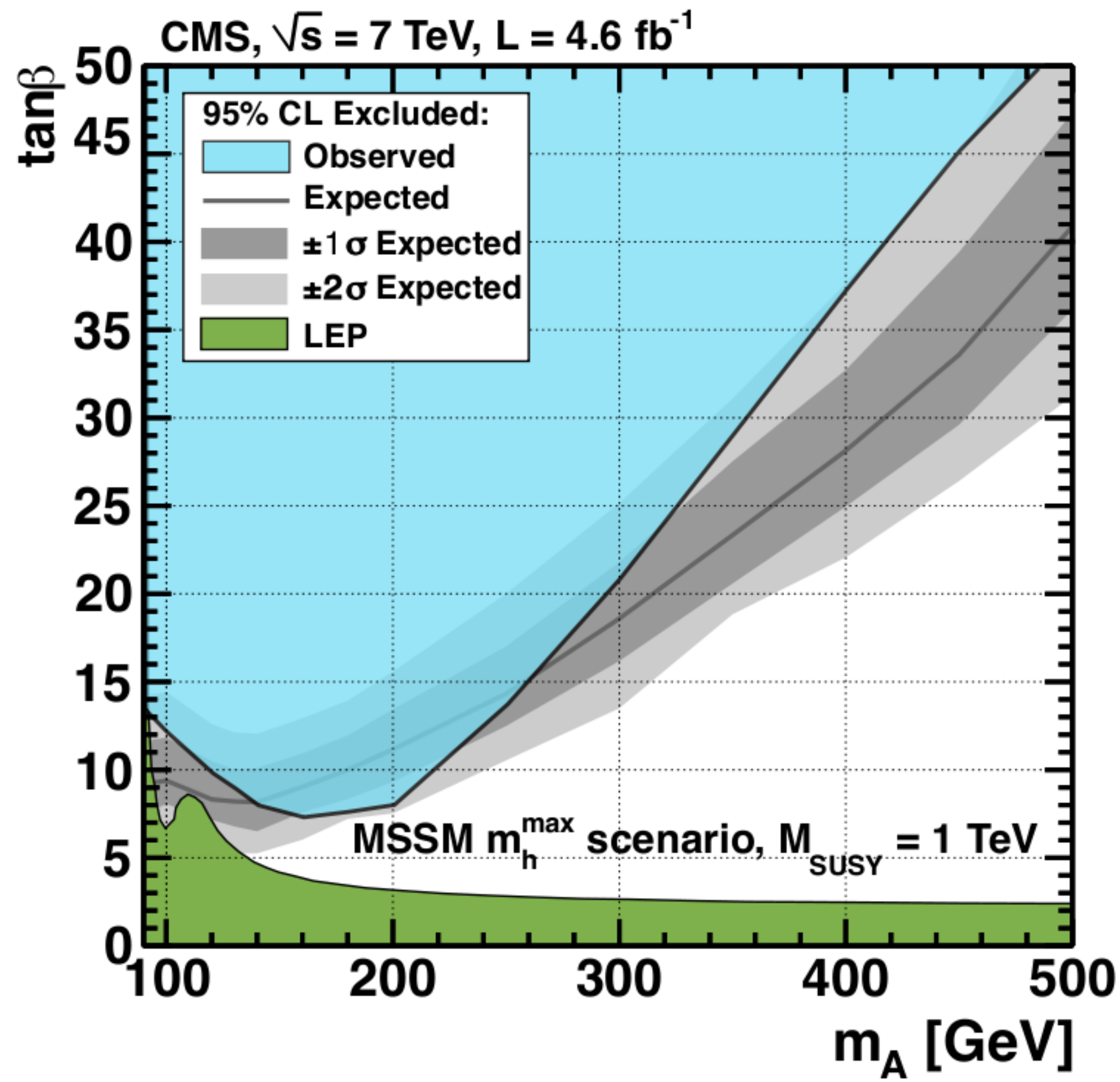
- Event categories

no b-jets



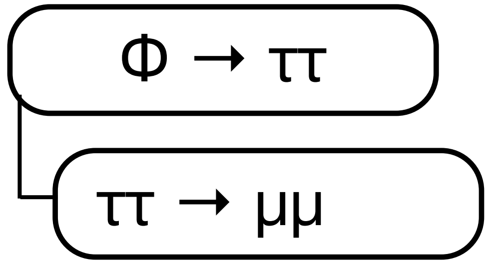
at least one b-jet

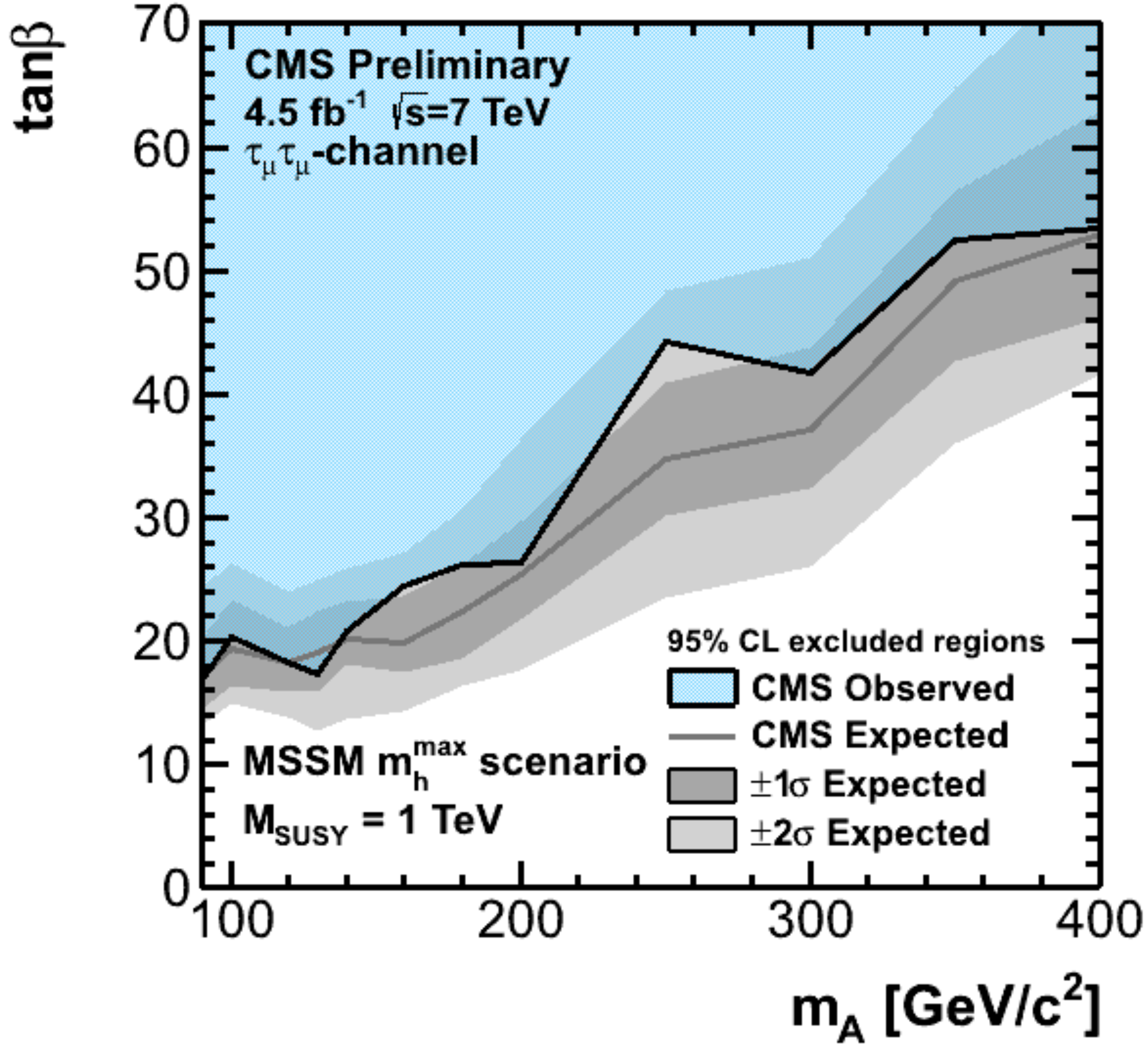


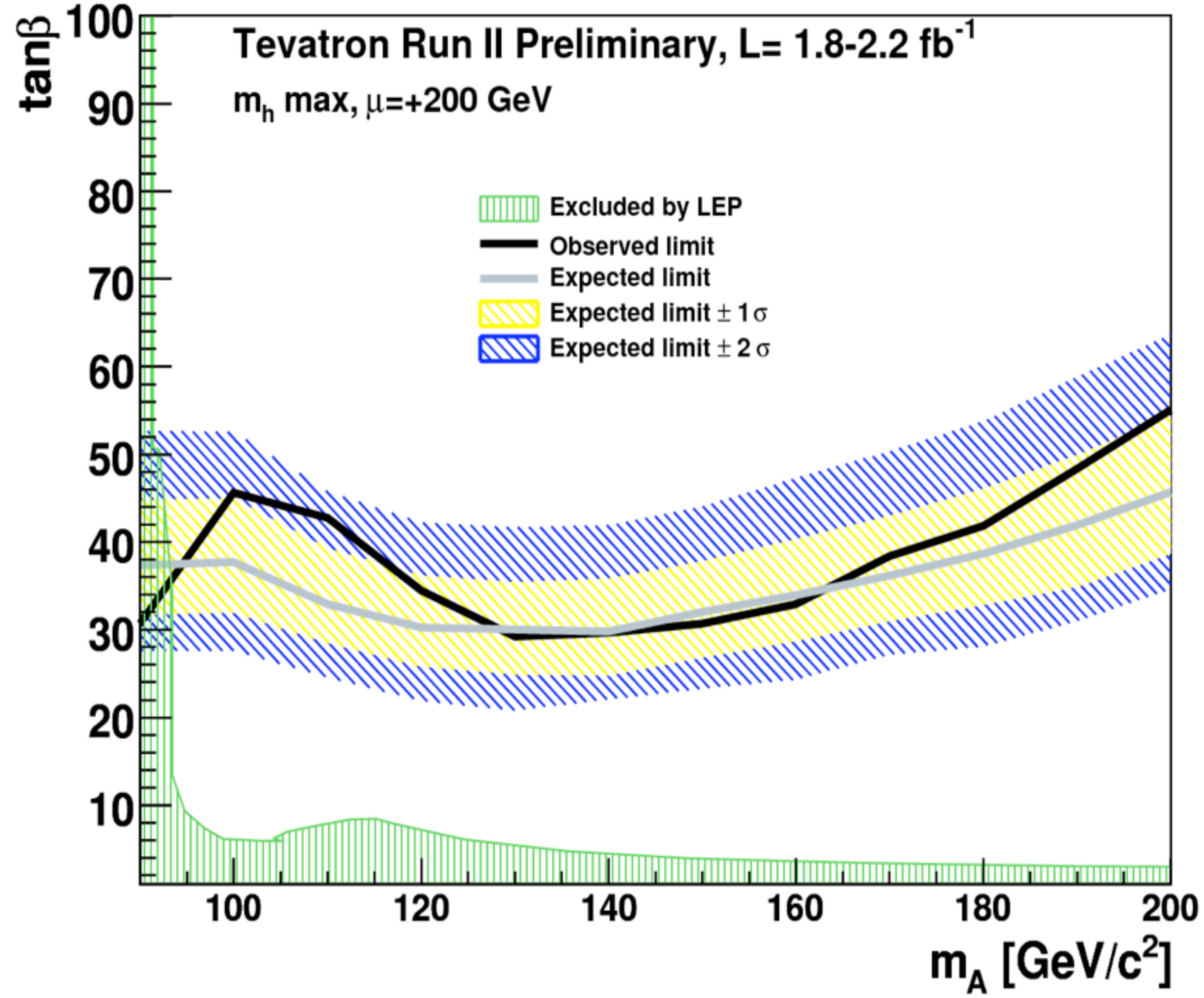


MSSM Φ→ττ (II)

- Additional channel





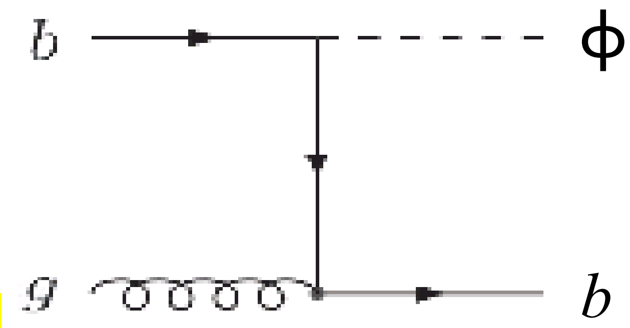


This channel alone is competitive with the Tevatron

MSSM bΦ→bbb (I)

CMS PAS HIG-12-026

- A search for an MSSM Higgs boson decaying into b quarks has been performed in the process



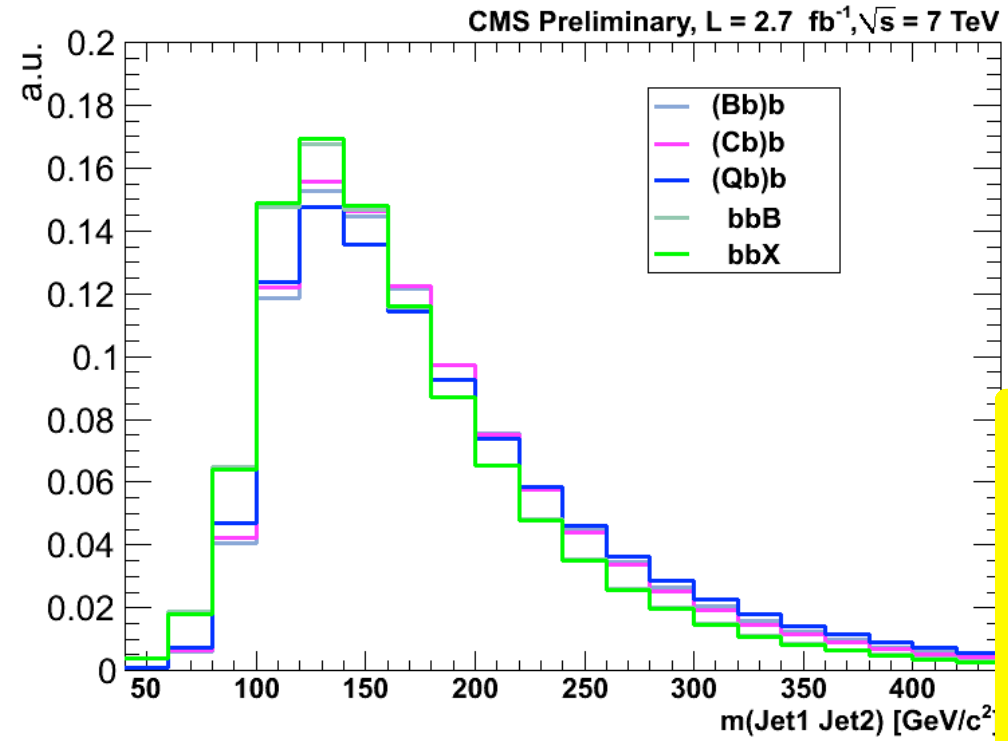
associated with b quarks

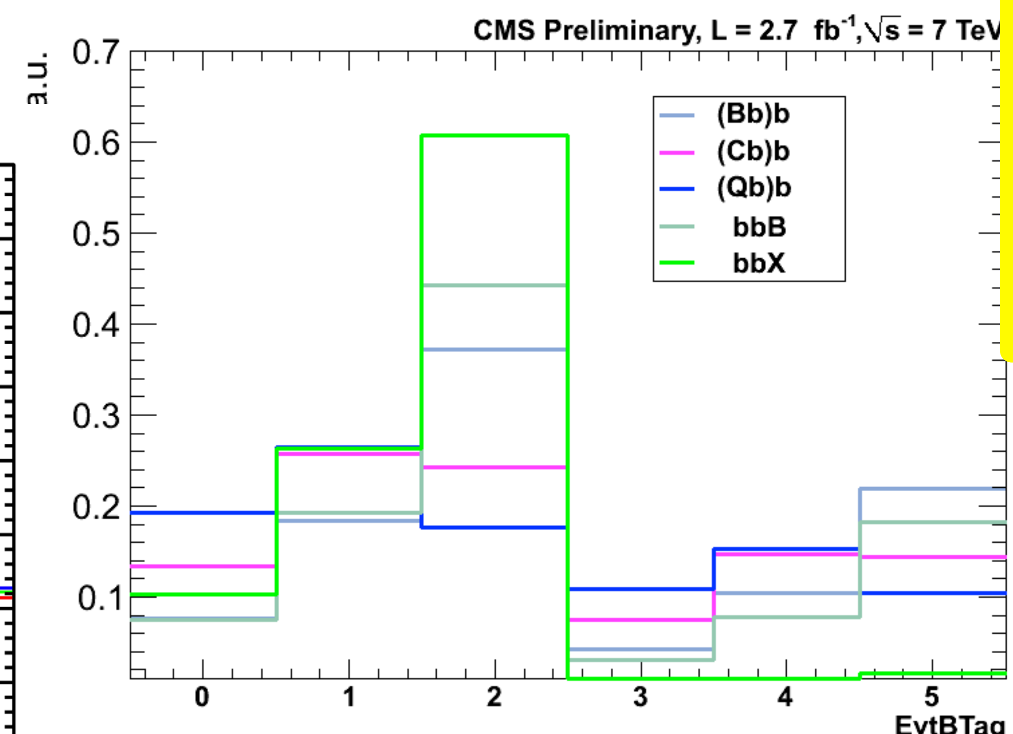
"Challenging final state, not accessible at LHC"
Marco Verzocchi at Mumbai Lepton-Photon 2011

- Large backgrounds, mainly from multi-jet QCD.
- Jets p_T spectra very soft for low masses.
- Dedicated fully hadronic triggers developed:
  - At least two or three jets; at least two online b-tagged jets
- Data-driven background estimation:
  - Background templates for the different flavour compositions derived from double b-tagged sample,
  - Flavour of untagged jet modelled by weighting the event to b-tag probabilities of the assumed flavour.

MSSM bΦ→bbb (II)

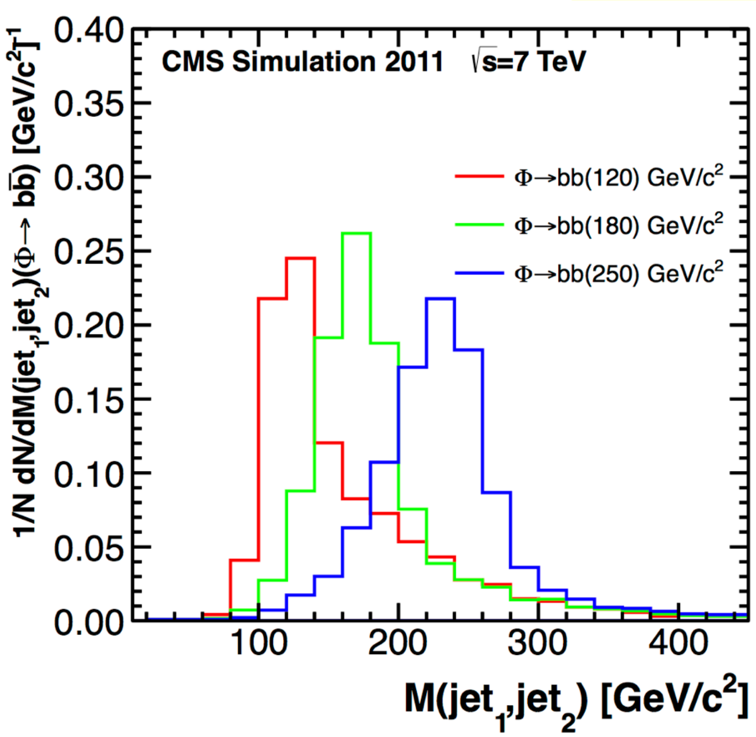
- Statistical inference with a two-dimensional distribution: [Mjj, EventBTag]
  - EventBTag is a discrete based on secondary vertex information providing additional flavour separation power.
- Signal yields from fits of the data with linear combination of signal and background templates

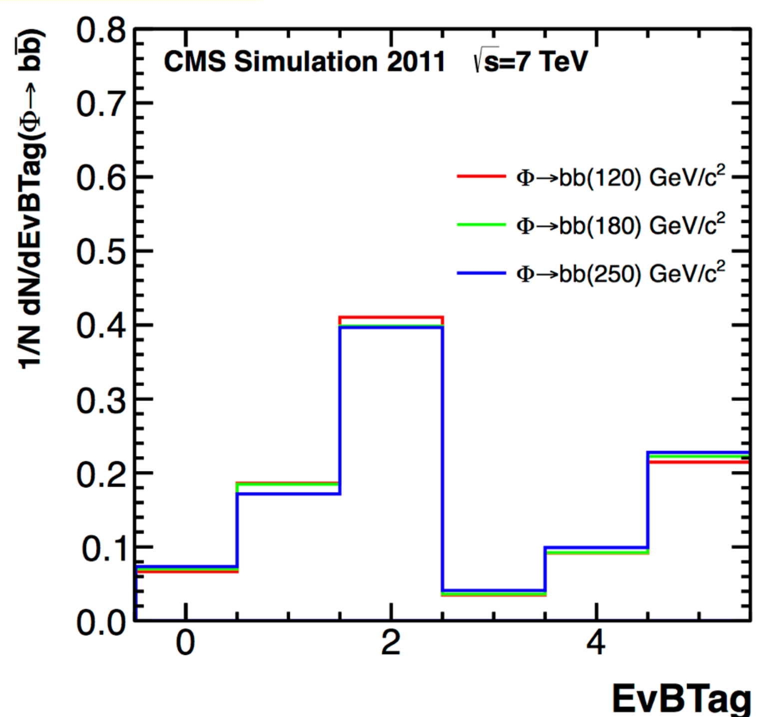




background templates

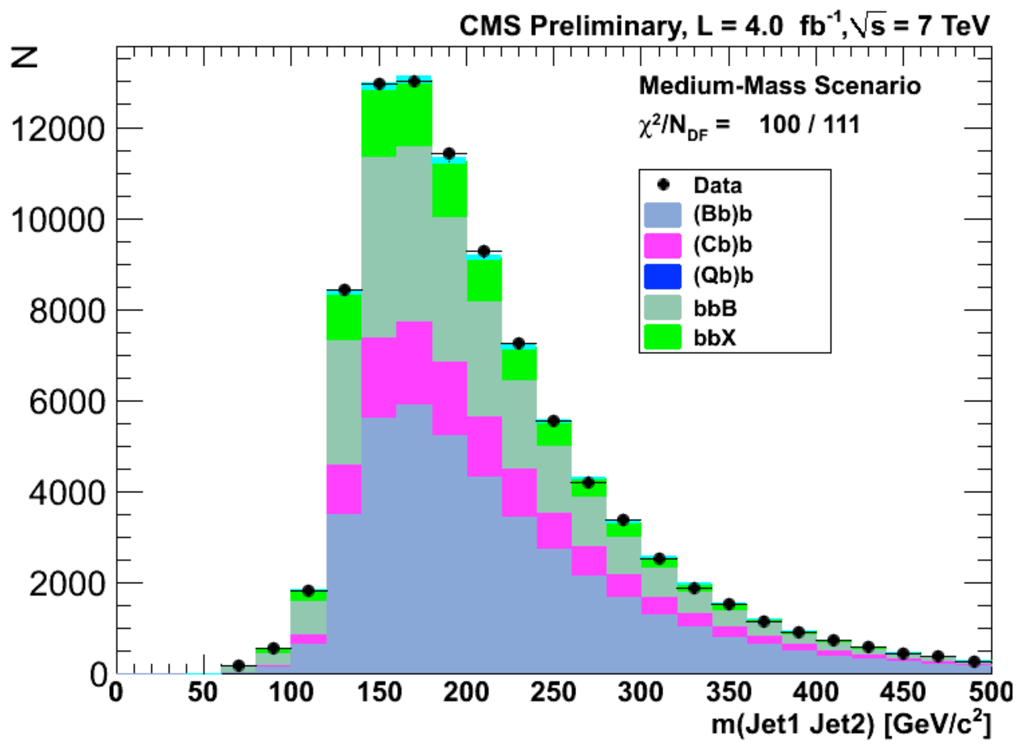
signal templates

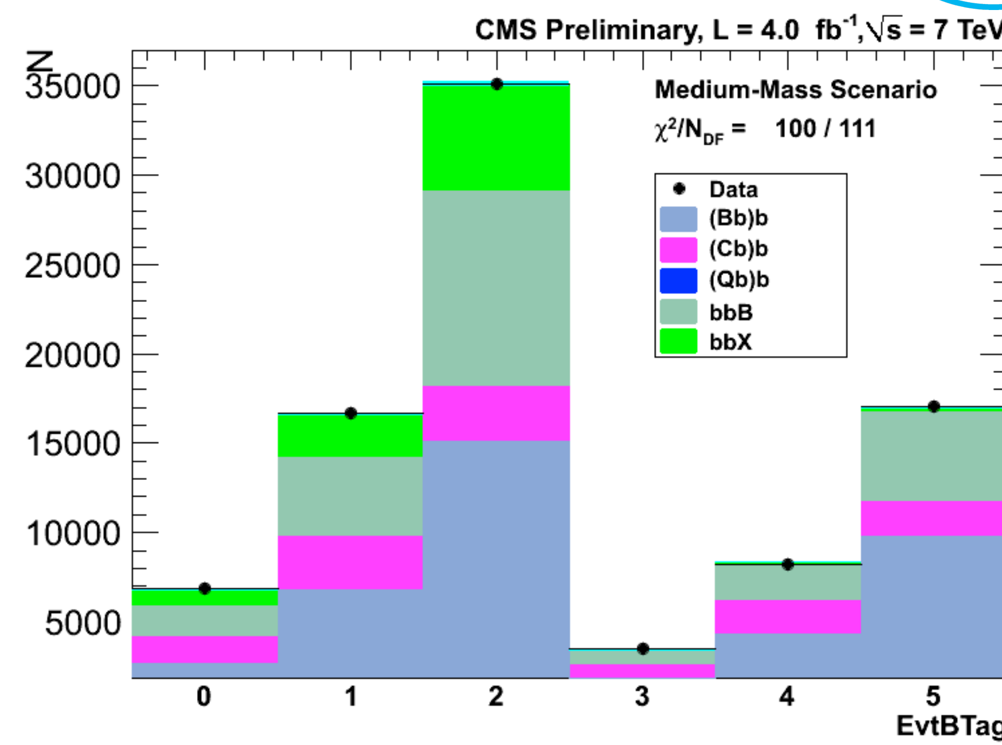




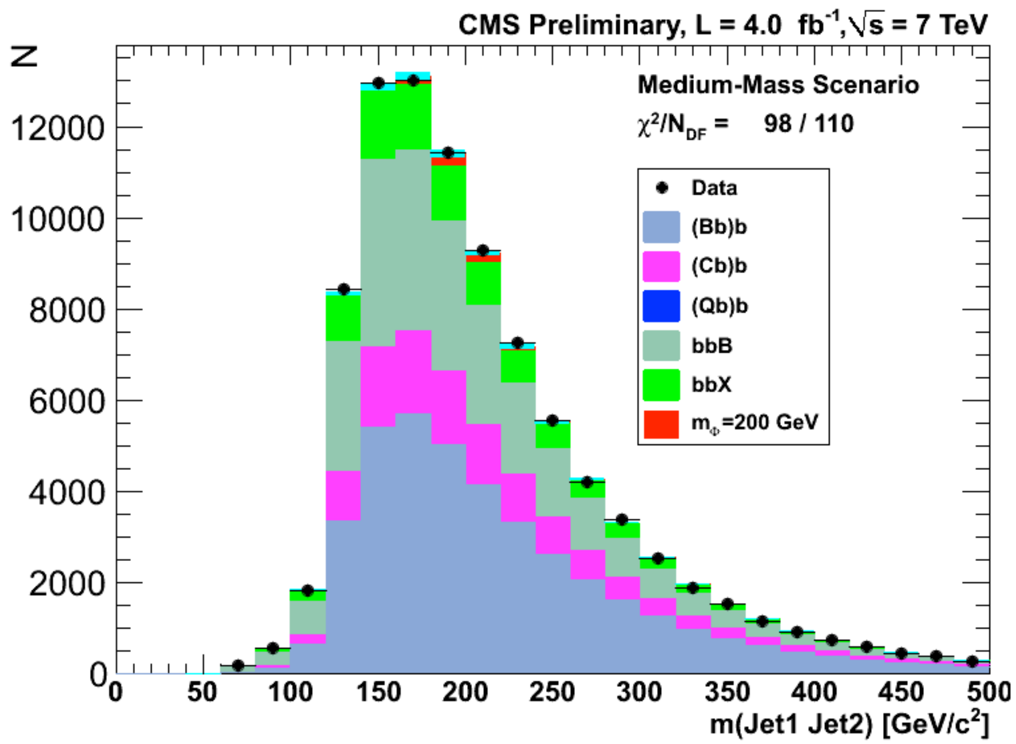
MSSM bΦ→bbb (III)

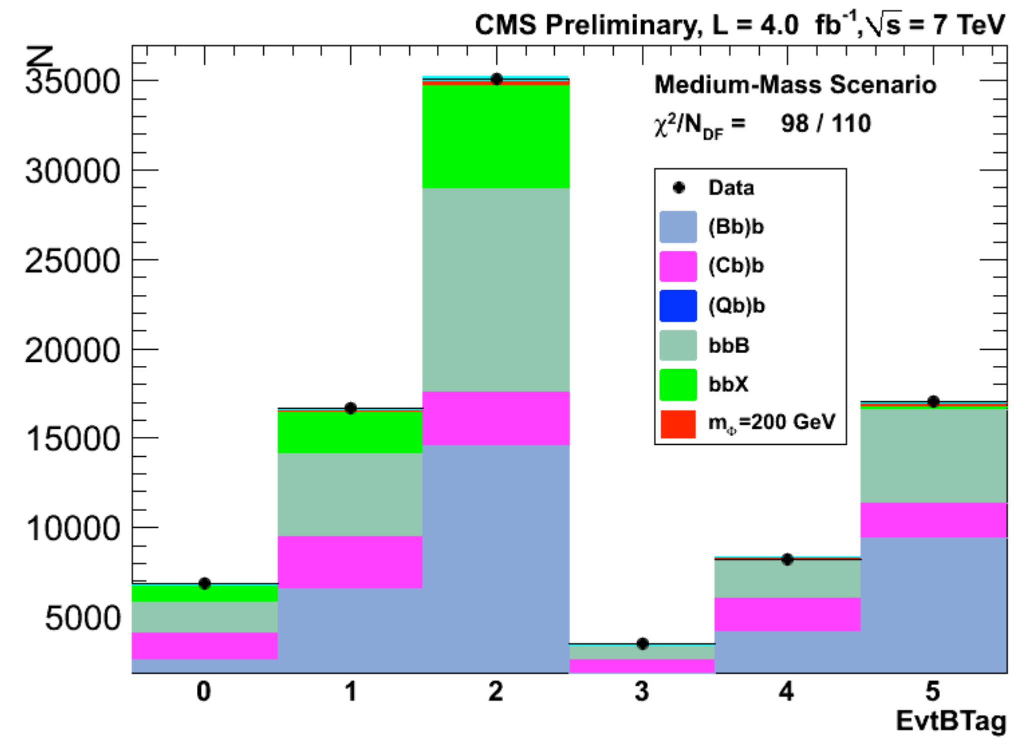
- Background-only fit





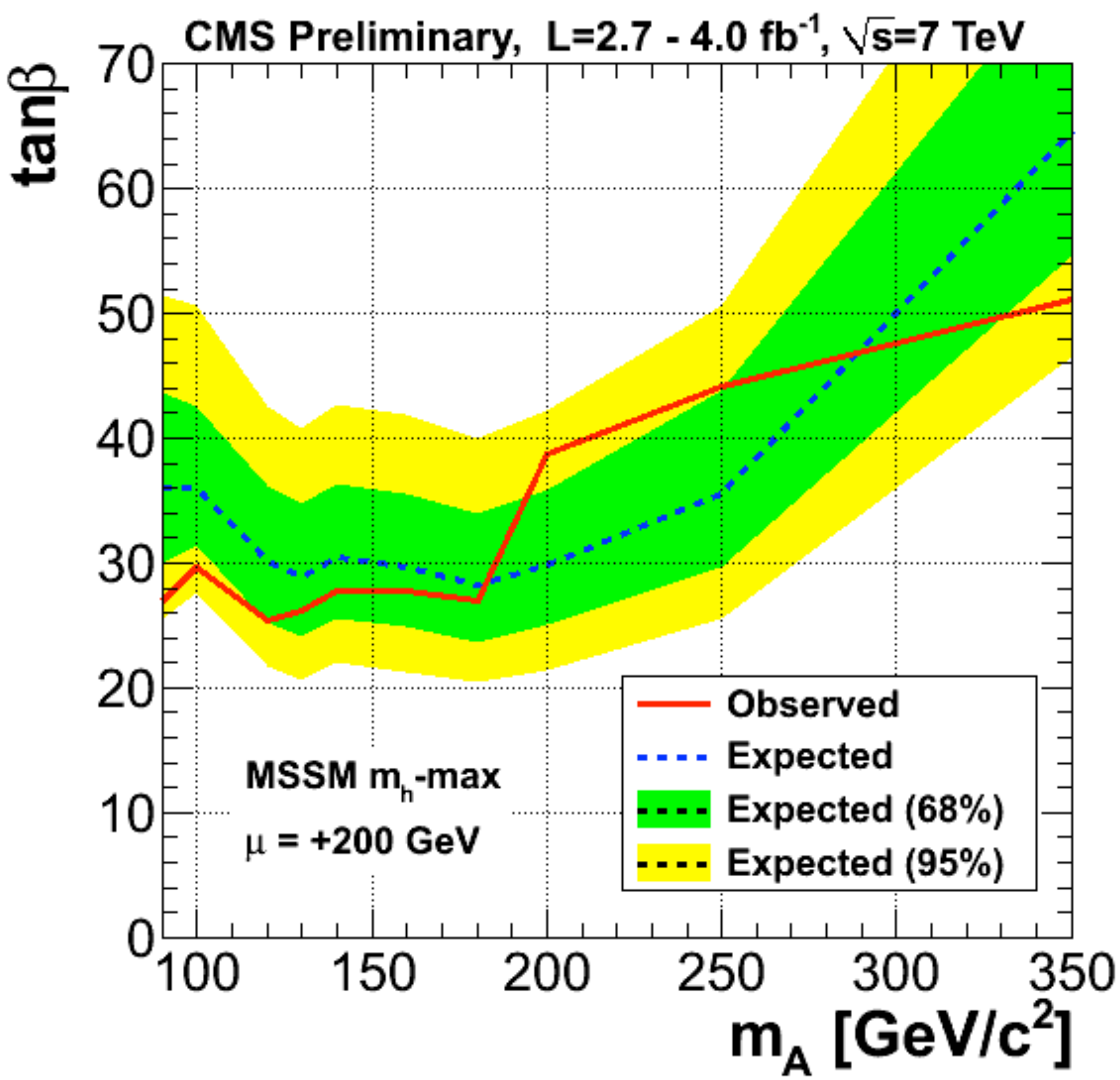
- Signal (M=200 GeV/c^2)+background fit

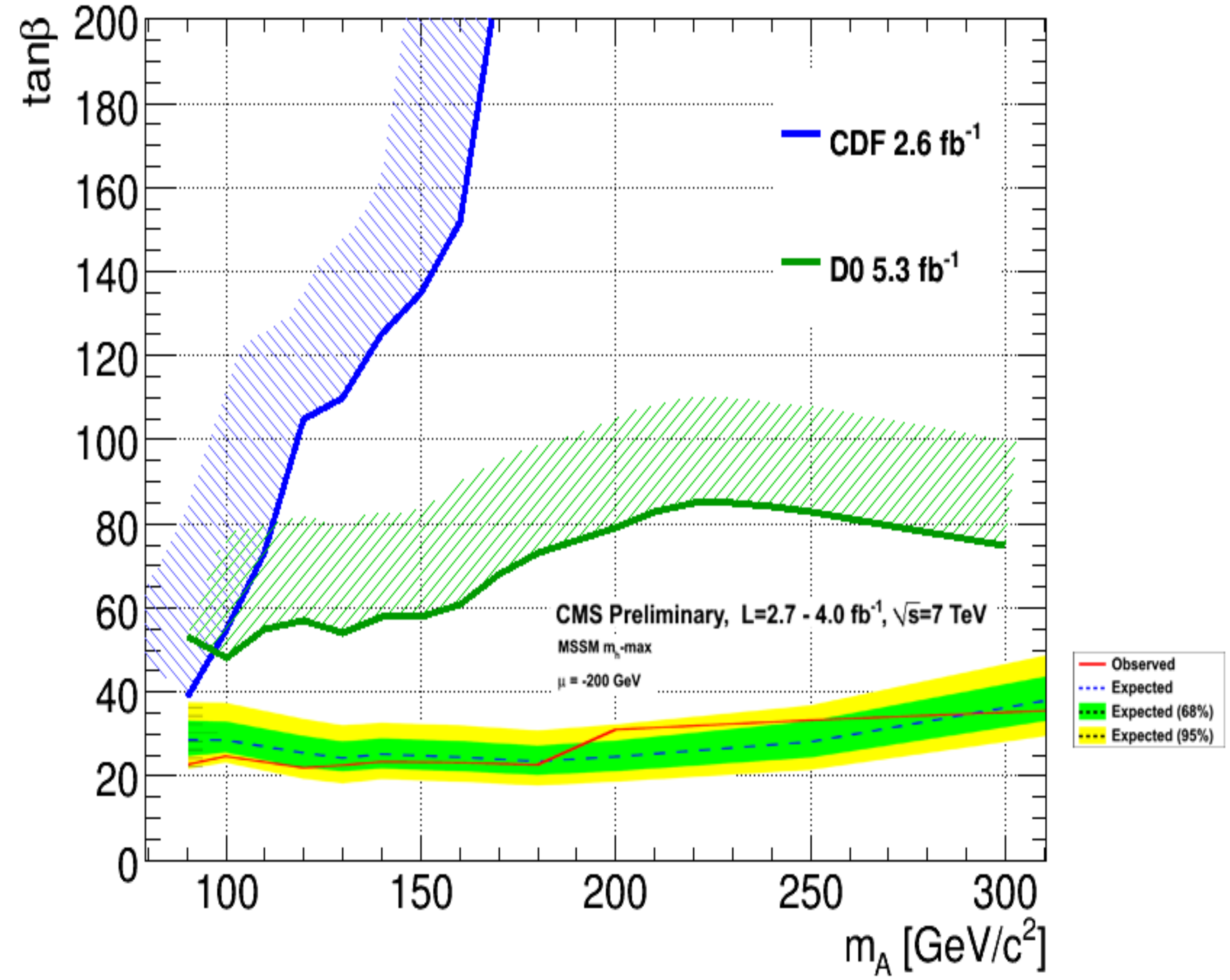




MSSM bΦ→bbb (IV)

- No evidence of a signal in the mass range 90 – 350 GeV/c^2.
- Limits on MSSM parameters tan β, M_A. Competitive with Tevatron.



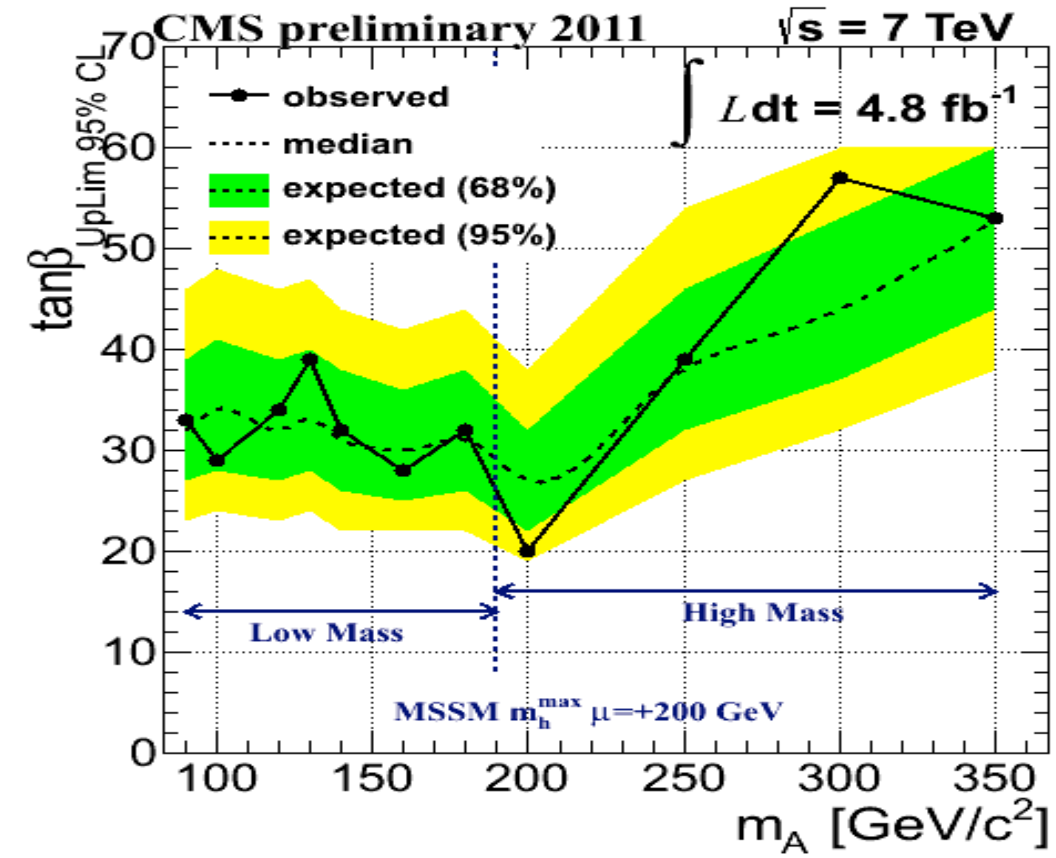


MSSM bΦ→bbb with lepton tag

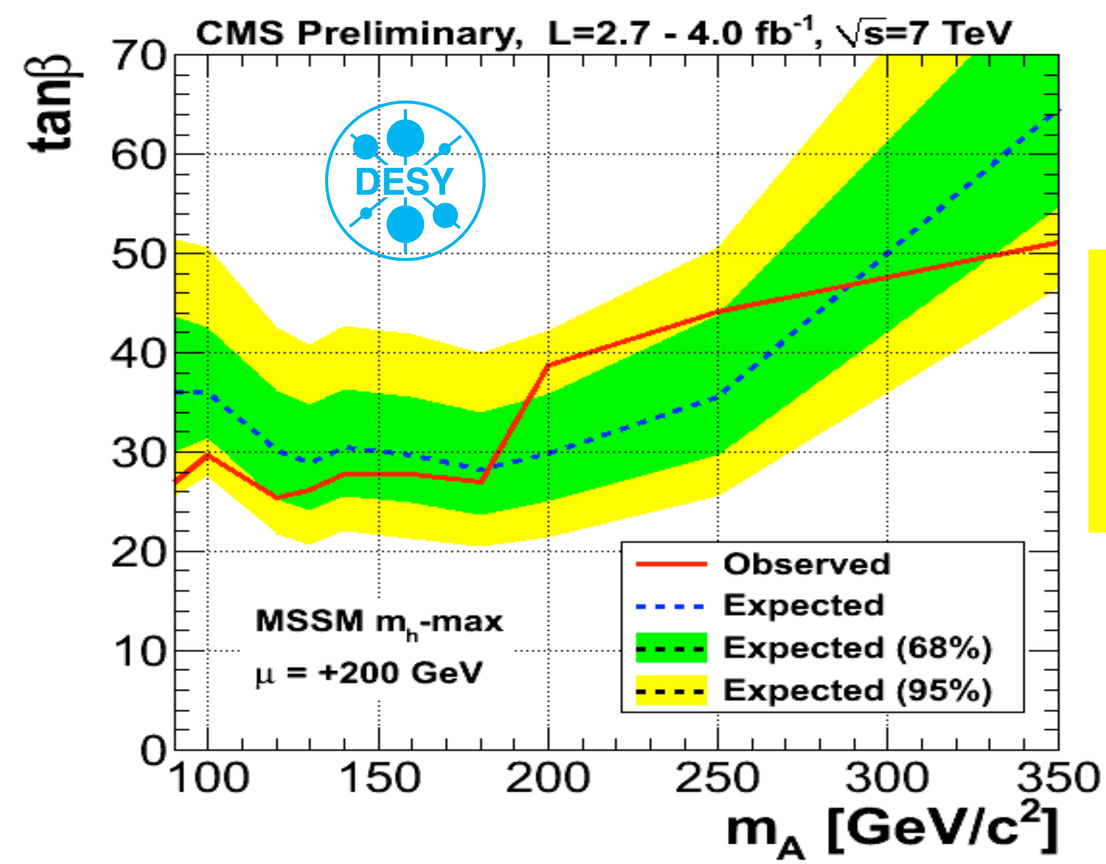
CMS PAS HIG-12-027

- Signature: 3 b-tagged jets + 1 non-isolated muon ('semi-leptonic' channel)

Trigger	Muon+1/2 Jets ≥ 1/2 b-tagged
Jets	≥ 2 Jets of P_T > 30 GeV + 3rd Jet of P_T > 20 GeV all 3 b-tagged
Muon	P_T > 15 GeV (no Isolation applied)



semi-leptonic



hadronic

Summary

- A new boson state compatible with the SM Higgs boson has been observed with a mass near 125 GeV/c^2.
  - Local significance: 4.9σ (global: 4.0σ)
- Two dominant channels (high resolution, high sensitivity)
  - γγ with 4.1σ
  - $ZZ \rightarrow 4l$ with 3.2σ
  - excesses at the same mass value
  - measured mass = 125.3 ± 0.4 (stat) ± 0.5 (sys) GeV/c^2.
- Results consistent with the expectations for a SM Higgs boson.
- Searches for Higgs bosons within MSSM
  - Channels: $\Phi \rightarrow \tau\tau$, $\Phi \rightarrow bb$ (competitive with the Tevatron).
  - No evidence of a signal → limits on tan β and M_A.
- All CMS public results on Higgs searches can be found in https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsHIG

back up slides

channels and production mechanisms

Table 1: Summary information on the analyses included in this combination. All final states are exclusive. Notations used are: $(jj)_{VBF}$ stands for a dijet pair consistent with the VBF topology (VBF-tag); $(jj)_V$ – dijet pair with an invariant mass consistent with coming from a W or Z dijet decay; V – W and Z bosons; SF dileptons – ee or $\mu\mu$ pairs (same flavour); DF dileptons – $e\mu$ pairs (different flavour). The column "H prod" indicates which production mechanism is targeted by an analysis; it does not imply 100% purity (e.g. analyses targeting VBF are expected to have 30%-50% of their signal events coming from gluon-gluon fusion). The main contribution in the untagged and inclusive categories is always gluon-gluon fusion. When two references are given, they refer to the 7 TeV and 8 TeV analyses, respectively. When one reference is given for an analysis using both 7 TeV and 8 TeV data, the 7 TeV data have been re-analysed with improved analysis strategies and the new results may differ from the previously published results.

Analyses: H decay	H prod	Exclusive final states	No. of channels	m_H range (GeV)	m_H resolution	Lumi (fb^{-1}) 7 TeV	8 TeV	Ref
$\gamma\gamma$	untagged	$\gamma\gamma$ (4 diphoton classes)	4	110–150	1-2%	5.1	5.3	[73]
	VBF-tag	$\gamma\gamma + (jj)_{VBF}$ (low or high m_{jj} for 8 TeV)	1 or 2	110–150	1-2%	5.1	5.3	[73]
bb	VH-tag	($\nu\nu$, ee, $\mu\mu$, $e\nu$, $\mu\nu$ with 2 b-jets)$\otimes$ (low or high p_T^V)	10	110–135	10%	5.0	5.1	[74]
	ttH-tag	(ℓ with 4,5,$\geq$6 jets) $\otimes$ (3,$\geq$4 b-tags); (ℓ with 6 jets with 2 b-tags); ($\ell\ell$ with 2 or $\geq$3 b-tagged jets)	9	110–140		5.0	-	[75]
$H \to \tau\tau$	0/1-jets	($e\tau_h$, $\mu\tau_h$, $e\mu$, $\mu\mu$)$\times$ (low or high $p_T^{\tau\tau}$) $\times$ (0 or 1 jets)	16	110–145	20%	4.9	5.1	[76]
	VBF-tag	($e\tau_h$, $\mu\tau_h$, $e\mu$, $\mu\mu$) + $(jj)_{VBF}$	4	110–145	20%	4.9	5.1	[76]
	ZH-tag	(ee, $\mu\mu$) $\times$ ($\tau_h\tau_h$, $e\tau_h$, $\mu\tau_h$, $e\mu$)	8	110–160		5.0	-	[77]
	WH-tag	$\tau_h ee$, $\tau_h\mu\mu$, $\tau_h e\mu$	3	110–140		4.9	-	[78]
WW $\to \ell\nu qq$	untagged	($e\nu$, $\mu\nu$)$\otimes$($(jj)_W$ with 0 or 1 jets)	4	170–600		5.0	5.1	[79, 80]
WW $\to \ell\nu\ell\nu$	0/1-jets	(DF or SF dileptons) $\otimes$ (0 or 1 jets)	4	110–600	20%	4.9	5.1	[81, 82]
WW $\to \ell\nu\ell\nu$	VBF-tag	$\ell\nu\ell\nu + (jj)_{VBF}$ (DF or SF dileptons for 8 TeV)	1 or 2	110–600	20%	4.9	5.1	[81, 82]
WW $\to \ell\nu\ell\nu$	WH-tag	$3\ell 3\nu$	1	110–200		4.9	-	[83]
WW $\to \ell\nu\ell\nu$	VH-tag	$\ell\nu\ell\nu + (jj)_V$ (DF or SF dileptons)	2	118–190		4.9	-	[84]
ZZ $\to 4\ell$	inclusive	$4e$, 4μ, $2e2\mu$	3	110–600	1-2%	5.0	5.3	[85]
ZZ $\to 2\ell 2\tau$	inclusive	(ee, $\mu\mu$) $\times$ ($\tau_h\tau_h$, $e\tau_h$, $\mu\tau_h$, $e\mu$)	8	200–600	10-15%	5.0	5.3	[85]
ZZ $\to 2\ell 2q$	inclusive	(ee, $\mu\mu$)$\times$($(jj)_Z$ with 0, 1, 2 b-tags)	6	130–164; 200–600	3%	4.9	-	[86]
ZZ $\to 2\ell 2\nu$	untagged	((ee, $\mu\mu$) with MET) $\otimes$ (0 or 1 or 2 non-VBF jets)	6	200–600	7%	4.9	5.1	[87]
ZZ $\to 2\ell 2\nu$	VBF-tag	(ee, $\mu\mu$) with MET and $(jj)_{VBF}$	2	200–600	7%	4.9	5.1	[87]