CMS results on Higgs boson discovery

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(For the CMS Collaboration)

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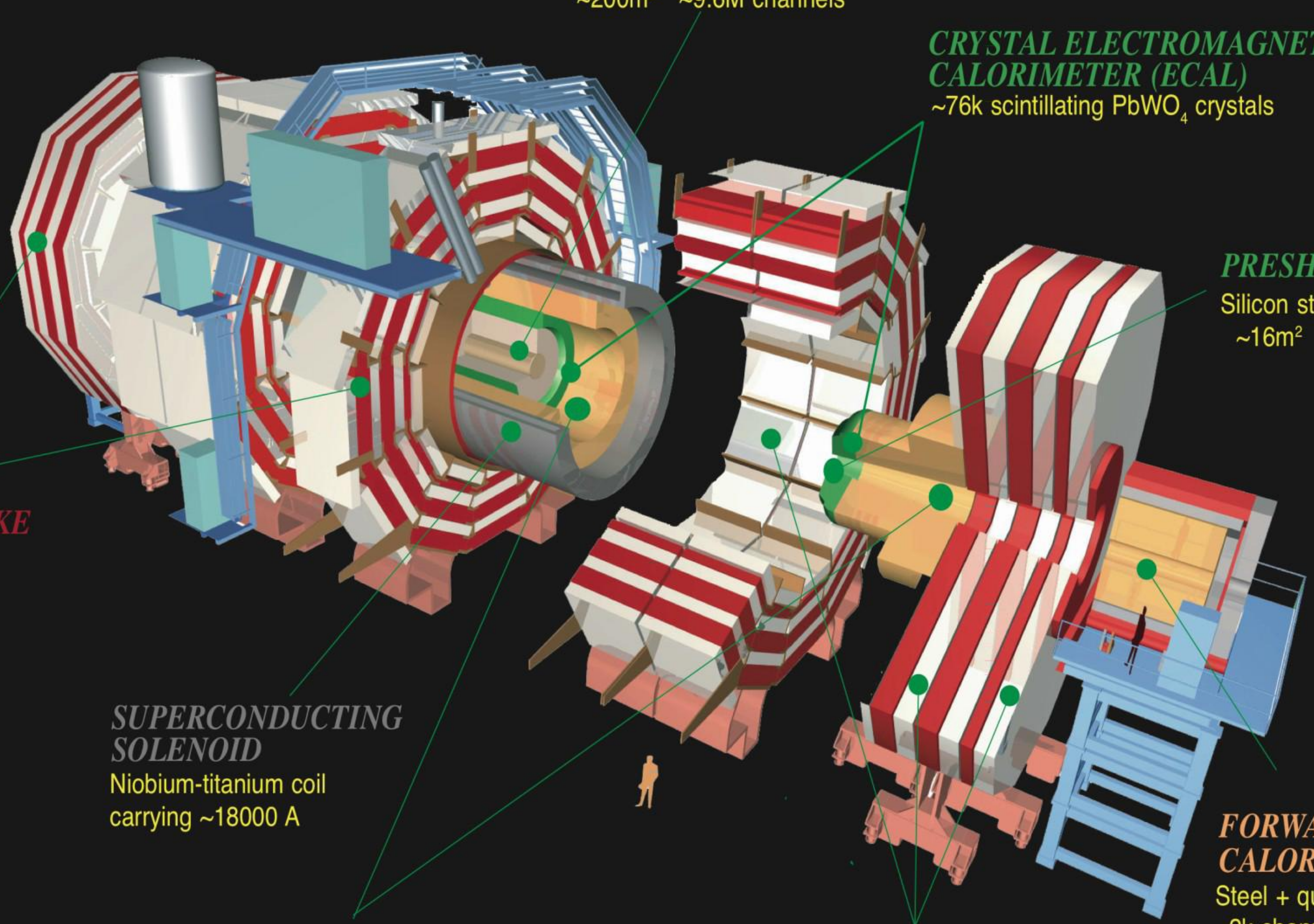
OUTLINE

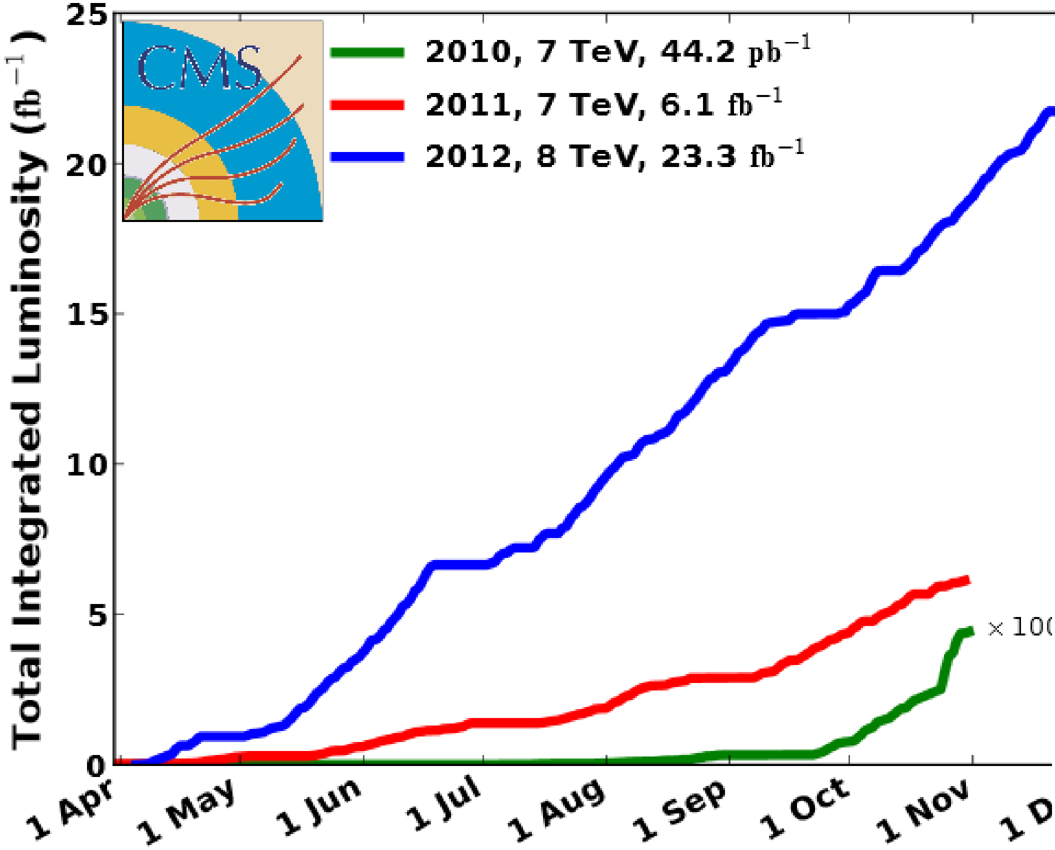
Introduction
Decay modes of new particle
- H-> ZZ
- H->γγ
- H->WW
- H->ττ
- H-bb
Properties of new particle
Conclusions

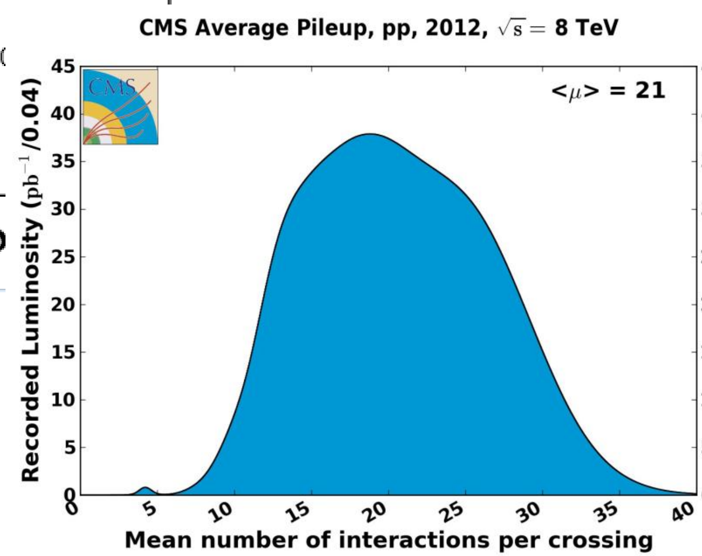
CMS Detector



Total weight	: 14000 tonnes
Overall diameter	: 15.0 m
Overall length	: 28.7 m

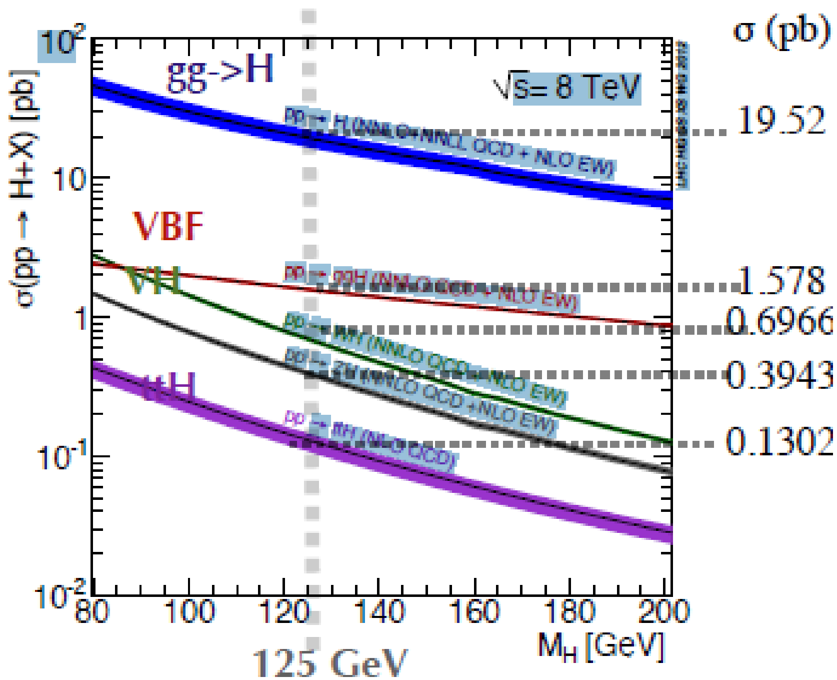
Integral luminosity in pp-interactions CMS

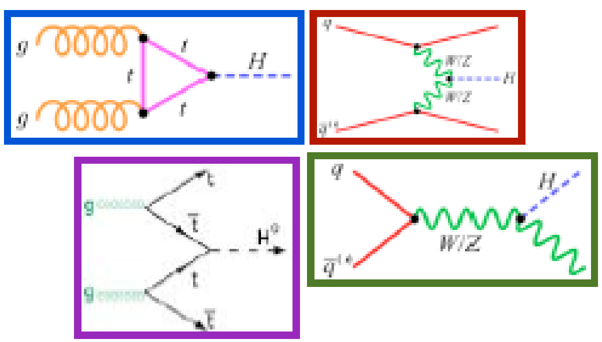




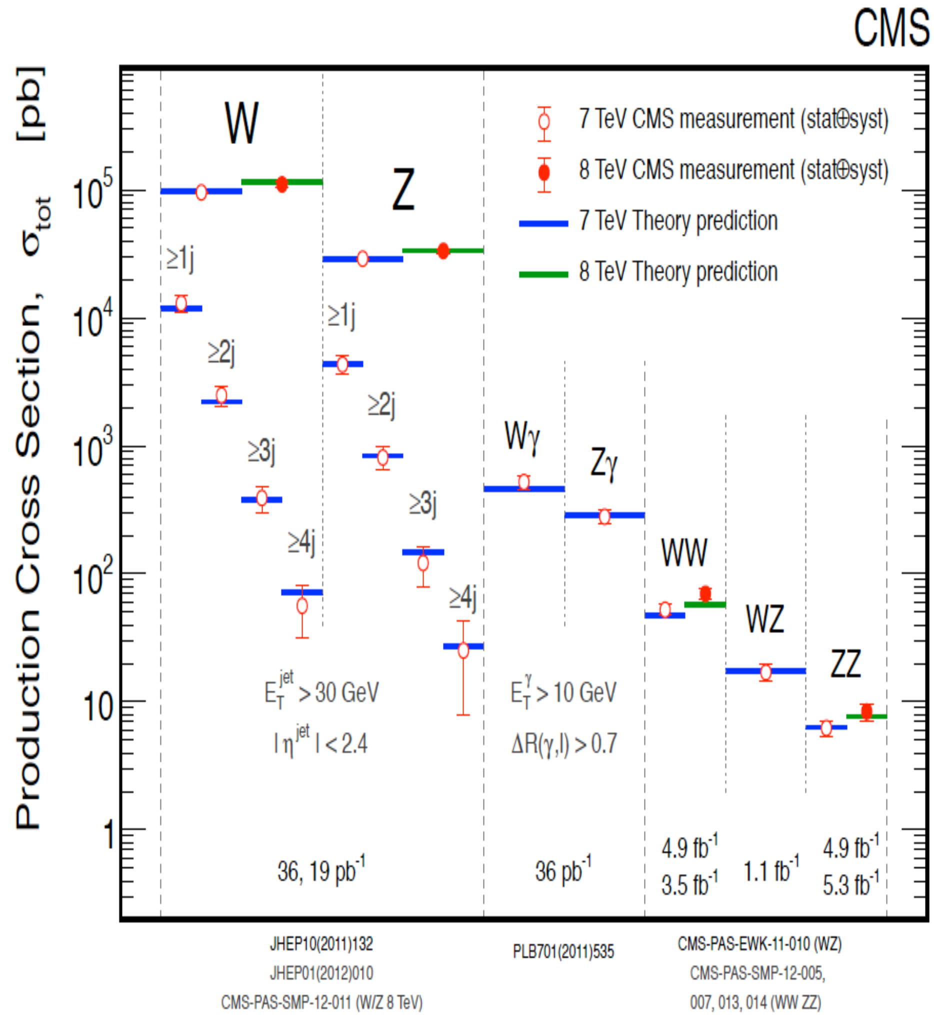
Typical production cross sections

Signal





Background



Decay modes sensitive to study Higgs boson

Channel	Range GeV	Lumi (fb-1) 7 TeV	8 TeV	M_H resolution
H---> γγ	110-150	5.1	19.6	1-2%
H--> ZZ -->4l	110-600	5.1	19.6	1-2%
H-->WW-->ll	110-600	4.9	19.5	20%
H---> ττ	110-145	4.9	19.6	15%
H----> bb	110-135	5.0	12.1	10%

H→ZZ

HIG-13-002

H ---> Z Z ---> 4 l

-- 4 isolated high Pt leptons consistent with Z decay

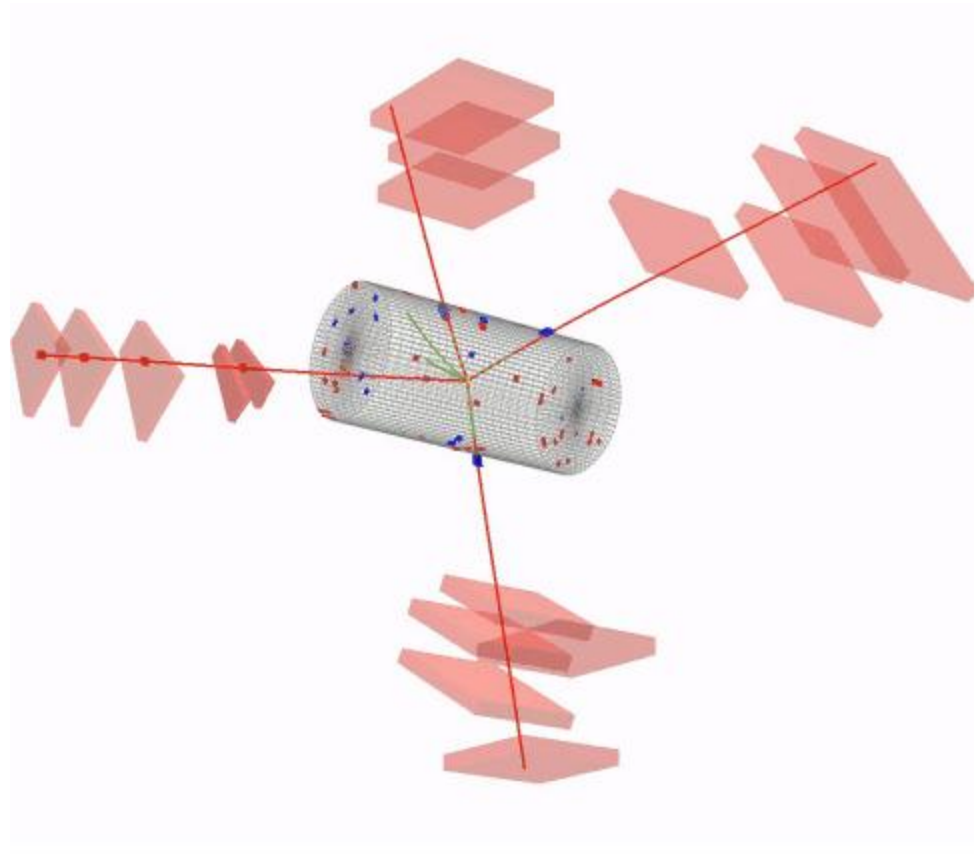
--- Fit 4-lepton peak over a small background

--- 4e, 4μ , 2e2μ were analyzed separately

----- Split into two categories (2 and more jets, less than 2 jets) to increase sensitivity

---Irreducible background from non-resonant ZZ-production (estimated from MC)

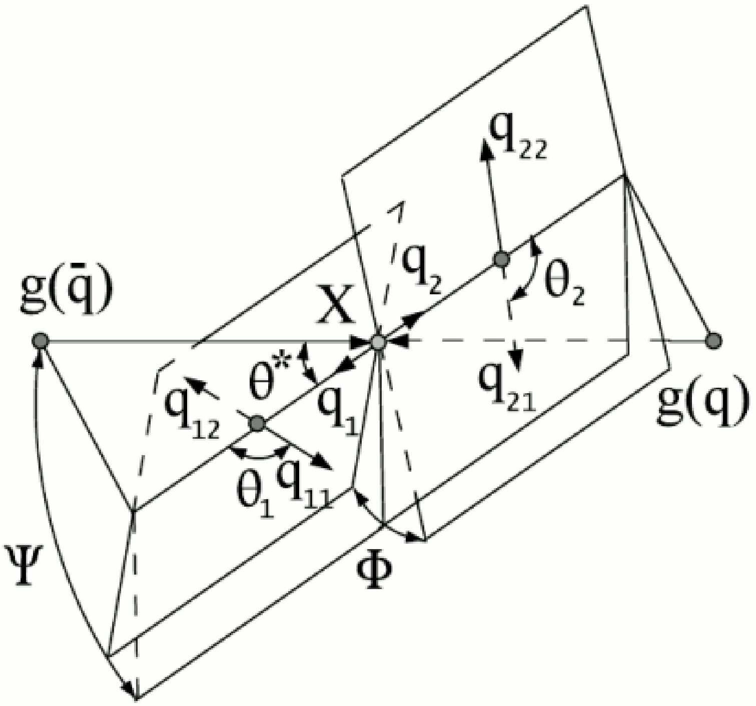
---Reducible background
 Z-> bb,tt, Z+jets (estimated from data)

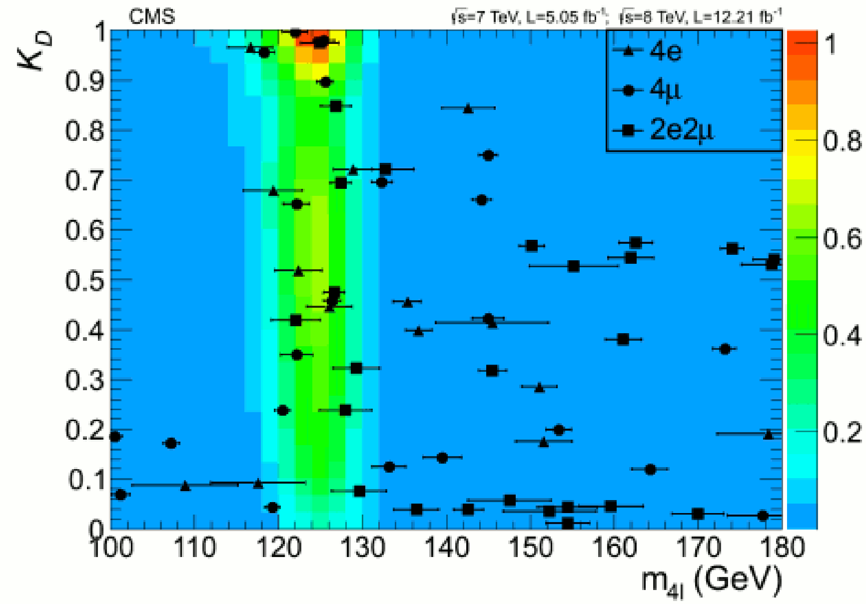


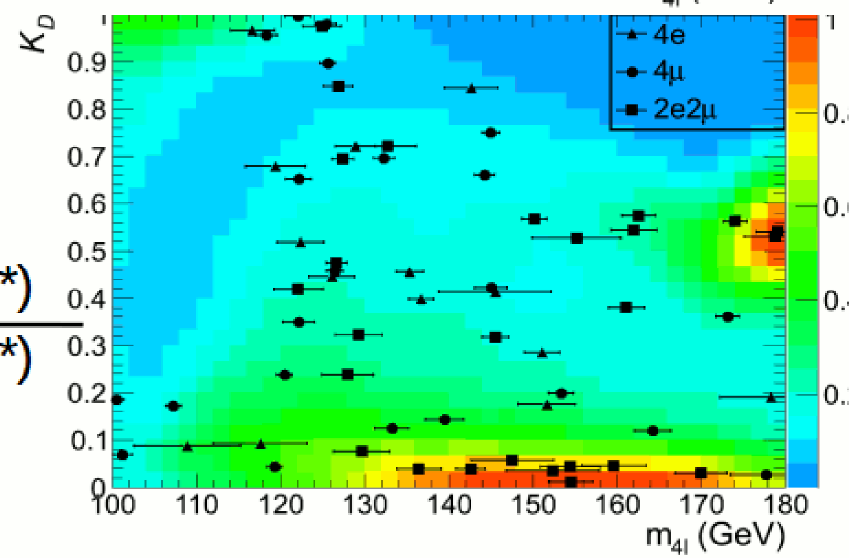
H→ZZ

HIG-13-002

The Golden Mode: $H \rightarrow ZZ \rightarrow 4l$







Angular analysis in CMS

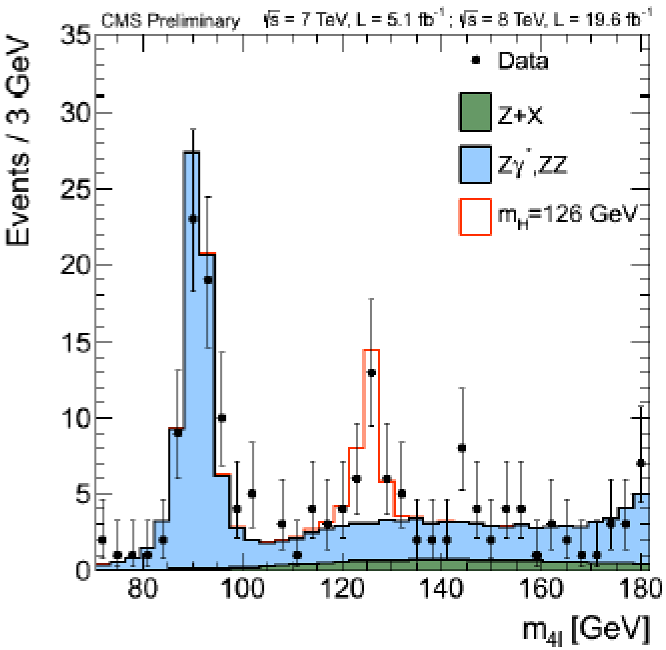
$$1/K_D = 1 + \frac{P_{background}(m_1,m_2,\theta_1,\theta_2,\Phi,\theta^*)}{P_{signal}(m_1,m_2,\theta_1,\theta_2,\Phi,\theta^*)}$$

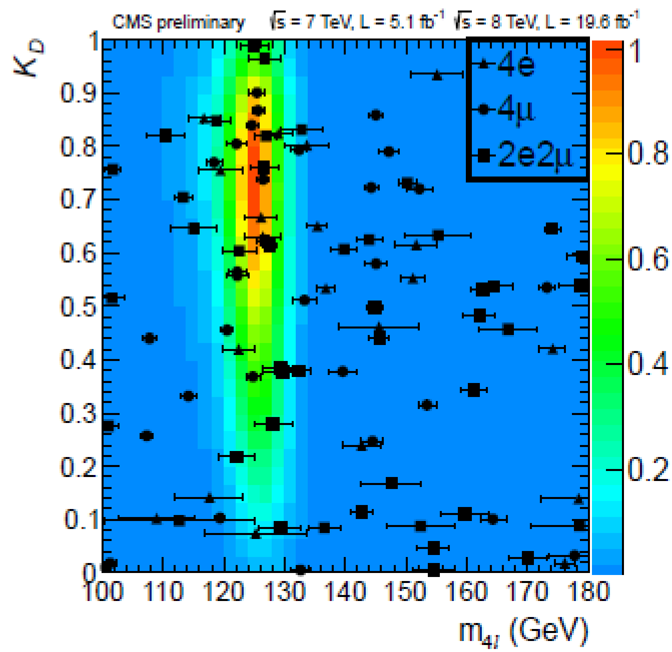
enhances analysis sensitivity

H→ZZ

HIG-13-002

H----> ZZ ----> 4l



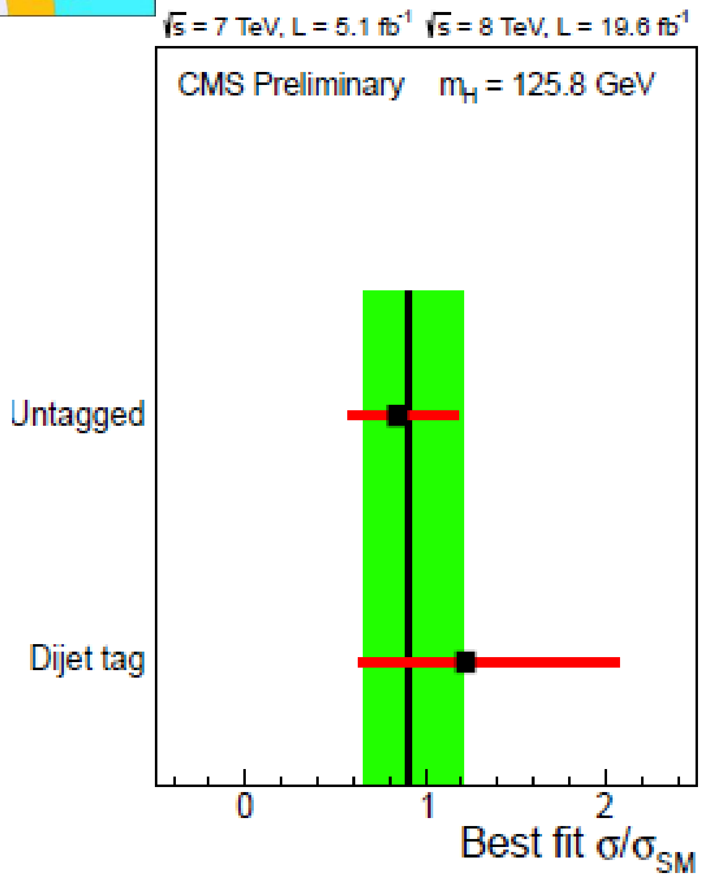


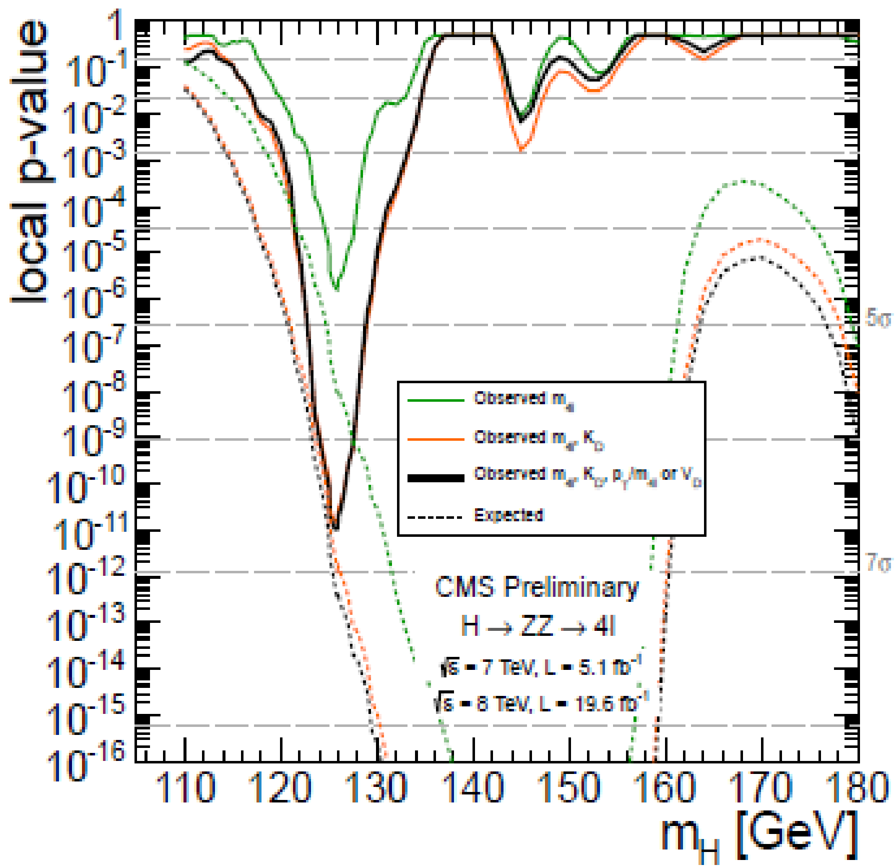
M=125.8 ± 0.5(stat.) ± 0.2(syst.)

H→ZZ

HIG-13-002

H----> ZZ----->4l





$\mu = 0.91(+0.30-0.24)$

Observed 6.7 σ

(Expected 7.1 σ)

H→ZZ

HIG-13-002

H ----> ZZ----->4l

Spin and parity measurement

This channel kinematics is sensitive to spin and parity

$$\mathcal{D}_{J^P} = \frac{\mathcal{P}_{\text{SM}}}{\mathcal{P}_{\text{SM}} + \mathcal{P}_{J^P}} = \left[1 + \frac{\mathcal{P}_{J^P}(m_{Z_1}, m_{Z_2}, \vec{\Omega}|m_{4\ell})}{\mathcal{P}_{\text{SM}}(m_{Z_1}, m_{Z_2}, \vec{\Omega}|m_{4\ell})}\right]^{-1}$$

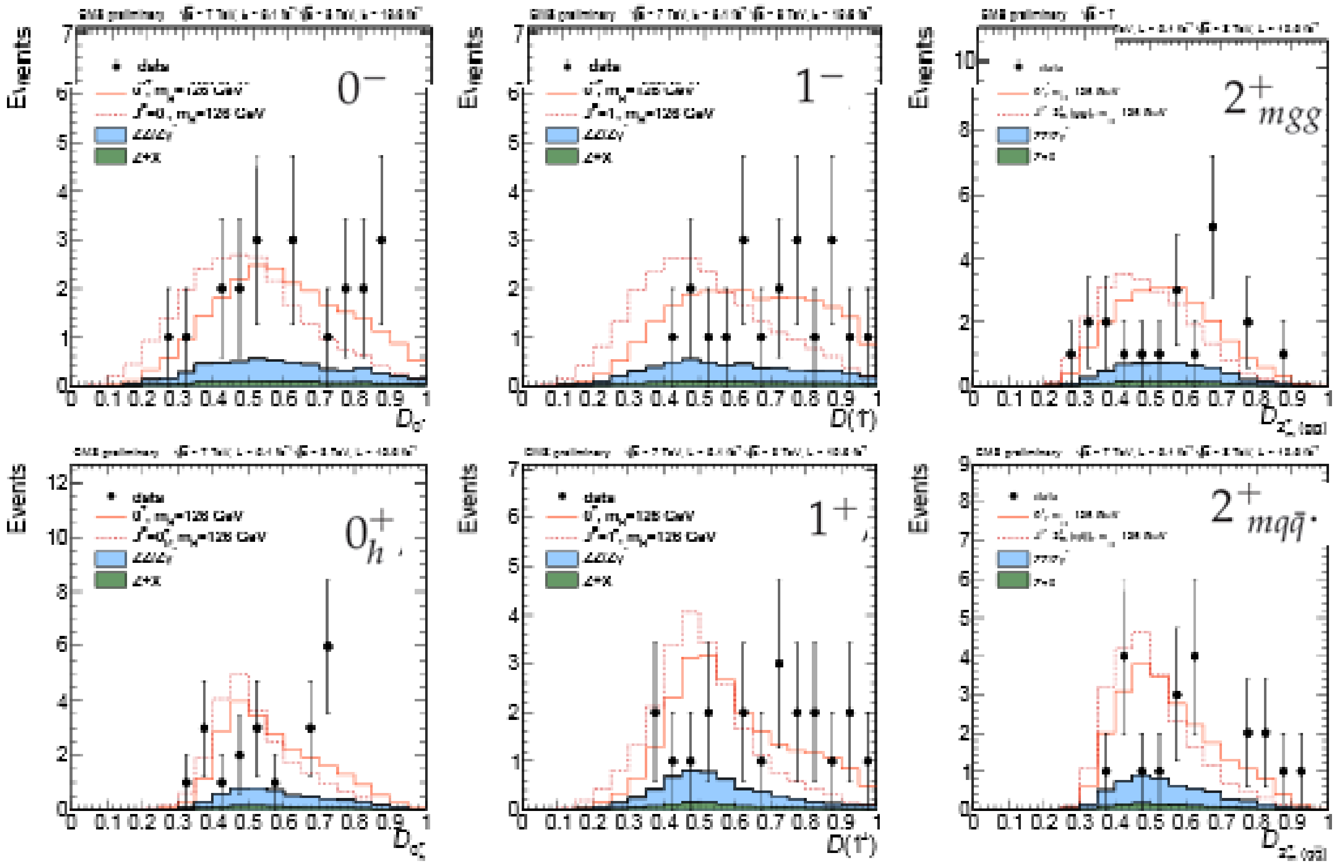
J^P	production	comment
0^-	$gg \to X$	pseudoscalar
0^+_h	$gg \to X$	higher dim operators
2^+_{mgg}	$gg \to X$	minimal couplings
$2^+_{mq\bar{q}}$	$q\bar{q} \to X$	minimal couplings
1^-	$q\bar{q} \to X$	exotic vector
1^+	$q\bar{q} \to X$	exotic pseudovector

H→ZZ

HIG-13-002

H---> ZZ Spin and parity determination

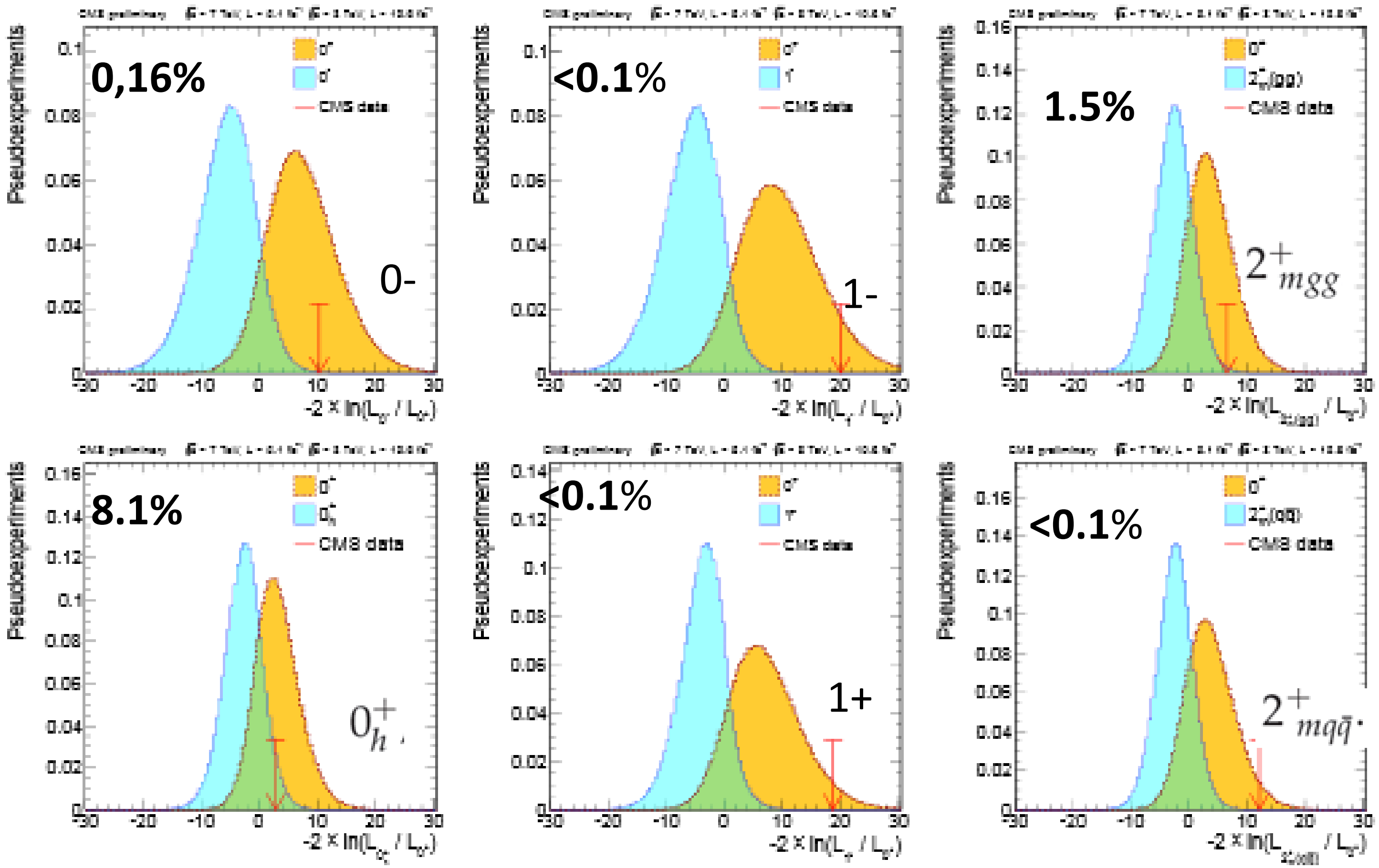
$$J^P = 0^-, 0_h^+, 1^-, 1^+, 2^+_{mgg}, 2^+_{mq\bar{q}}.$$



H→ZZ

HIG-13-002

H----> ZZ---->4l. Determination of spin and parity

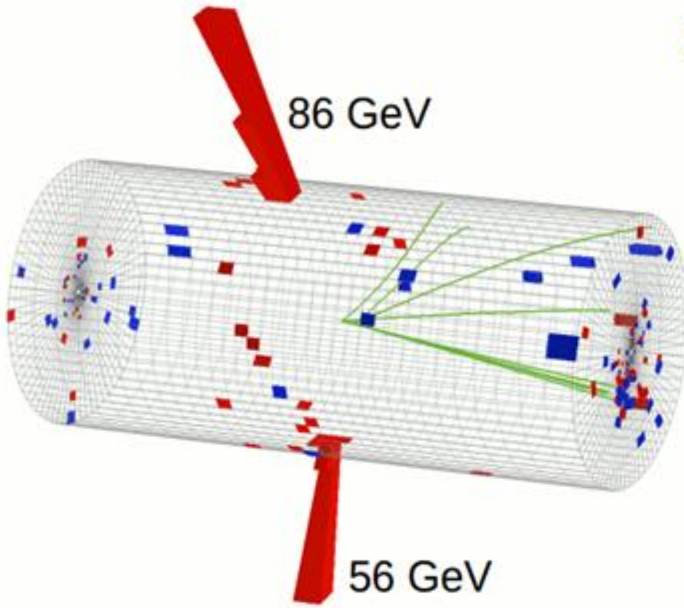


Red arrow – CMS data

At the left corner the ratio of probability of checked hypothesis to probability of 0+ shown

$H \to \gamma\gamma$
HIG-13-001

H-> γγ



Signature and background

- two high momentum photons
- low mass Higgs narrow
- two photon resolution excellent
- looking for narrow peak
- large irreducible background from direct two photons
- smaller fake photon background

Key analysis features

- energy resolution is almost everything: calibrate and optimize
- rejection of fake photons and optimized use of kinematics

MVA –analysis was applied

Cut-based analysis used as a cross-check

MVA increase sensitivity by 15 %

Both analyses were compatible within 2 σ

Diphoton vertex identification

-The mean number of pp-interaction per BX is 9.5(19.9) at 7 TeV(8 TeV)
Their distribution in z-direction has an RMS spread of about 6 cm (5 cm)

-To avoid degradation of mass resolution the distance between choosen vertex and true one should be below 1 cm

-The balance and asymmetry of pT for all tracks and diphoton system for each vertex were studied (BDT)

-With efficiency of 80 % diphoton vertex was located within 1 cm of its true position
Vertex-finding efficiency was measured with Z-> μμ (remove muon tracks to mimic the presence of two photon)

H → γγ
HIG-13-001

To increase sensitivity and better describe background behavior all statistics was divided to 14 classes

Expected signal and estimated background

Event classes		SM Higgs boson expected signal (m_H=125 GeV) Total	ggH	VBF	VH	ttH	σ_{eff} (GeV)	FWHM/2.35 (GeV)	Background $m_{\gamma\gamma}$ = 125 GeV (ev./GeV)
7 TeV 5.1 fb^{-1}	Untagged 0	3.2	61.4%	16.8%	18.7%	3.1%	1.21	1.14	3.3 ± 0.4
	Untagged 1	16.3	87.6%	6.2%	5.6%	0.5%	1.26	1.08	37.5 ± 1.3
	Untagged 2	21.5	91.3%	4.4%	3.9%	0.3%	1.59	1.32	74.8 ± 1.9
	Untagged 3	32.8	91.3%	4.4%	4.1%	0.2%	2.47	2.07	193.6 ± 3.0
	Dijet tag	2.9	26.8%	72.5%	0.6%	–	1.73	1.37	1.7 ± 0.2
8 TeV 19.6 fb^{-1}	Untagged 0	17.0	72.9%	11.6%	12.9%	2.6%	1.36	1.27	22.1 ± 0.5
	Untagged 1	37.8	83.5%	8.4%	7.1%	1.0%	1.50	1.39	94.3 ± 1.0
	Untagged 2	150.2	91.6%	4.5%	3.6%	0.4%	1.77	1.54	570.5 ± 2.6
	Untagged 3	159.9	92.5%	3.9%	3.3%	0.3%	2.61	2.14	1060.9 ± 3.5
	Dijet tight	9.2	20.7%	78.9%	0.3%	0.1%	1.79	1.50	3.4 ± 0.2
	Dijet loose	11.5	47.0%	50.9%	1.7%	0.5%	1.87	1.60	12.4 ± 0.4
	Muon tag	1.4	0.0%	0.2%	79.0%	20.8%	1.85	1.52	0.7 ± 0.1
	Electron tag	0.9	1.1%	0.4%	78.7%	19.8%	1.88	1.54	0.7 ± 0.1
	E_T^{miss} tag	1.7	22.0%	2.6%	63.7%	11.7%	1.79	1.64	1.8 ± 0.1

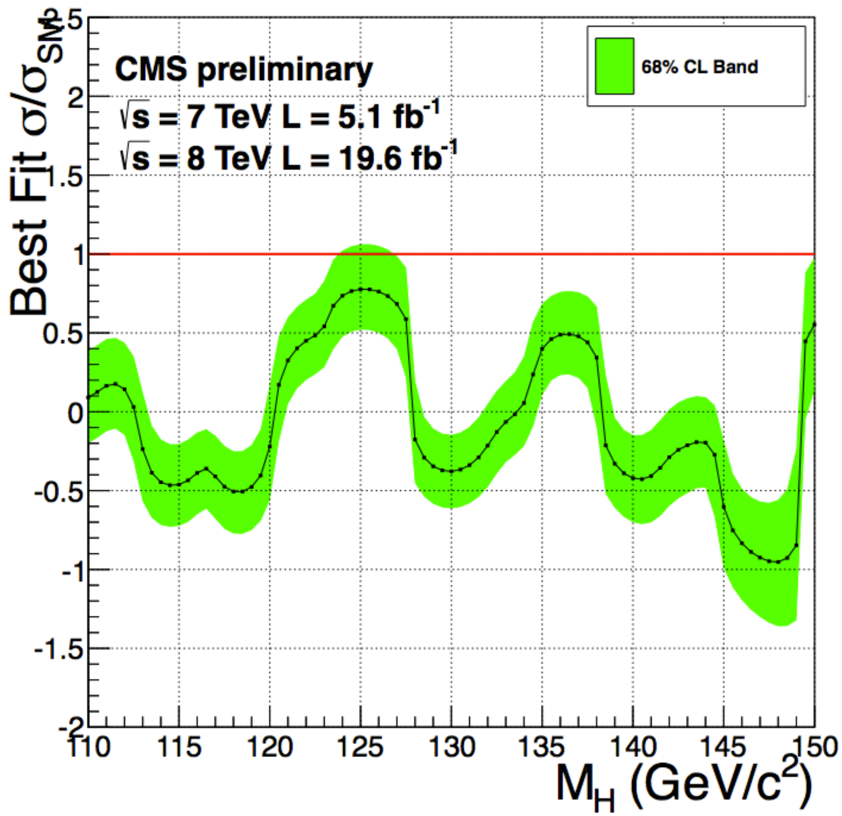
Most of the data (~72 %) irreducible background from two prompt photons
To describe background polinomials from 2th to 5th order were used

H -->γγ

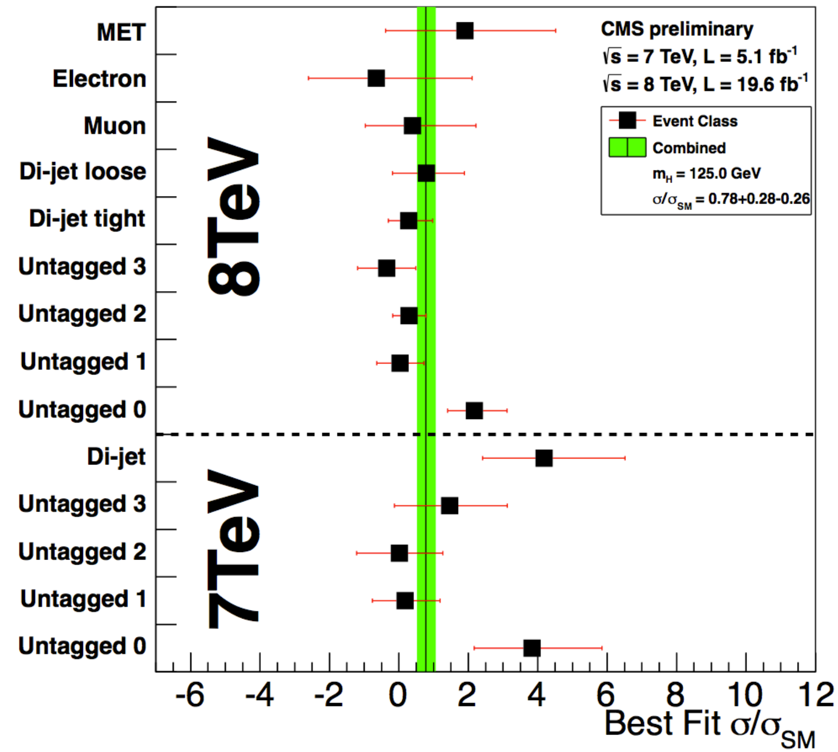
$H \rightarrow \gamma\gamma$

HIG-13-001

Mass fit MVA-analysis



Best fit σ/σ_{SM} distribution vs M_H

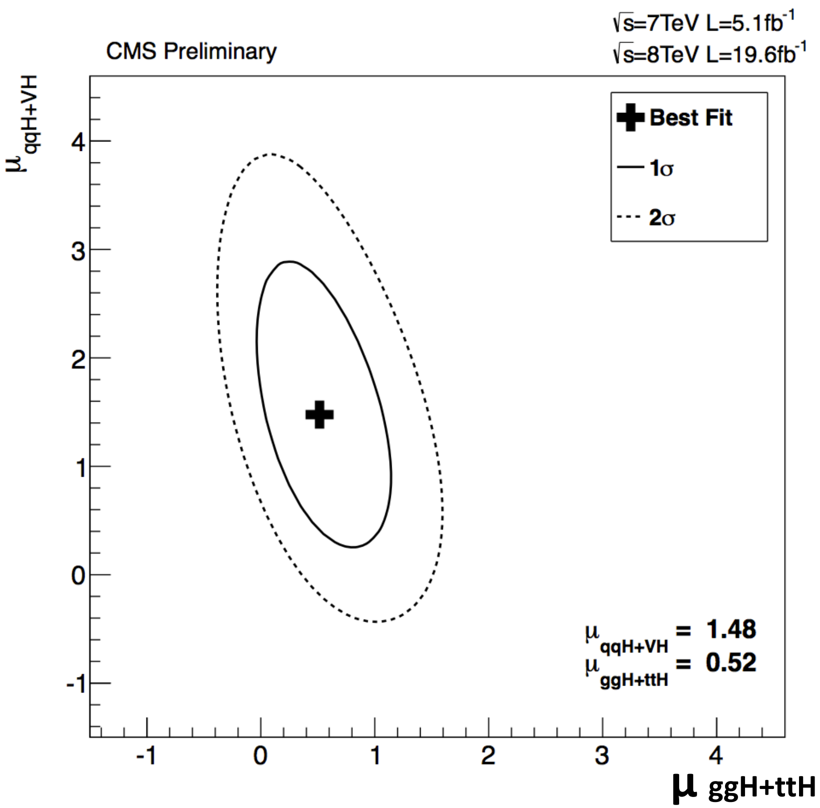


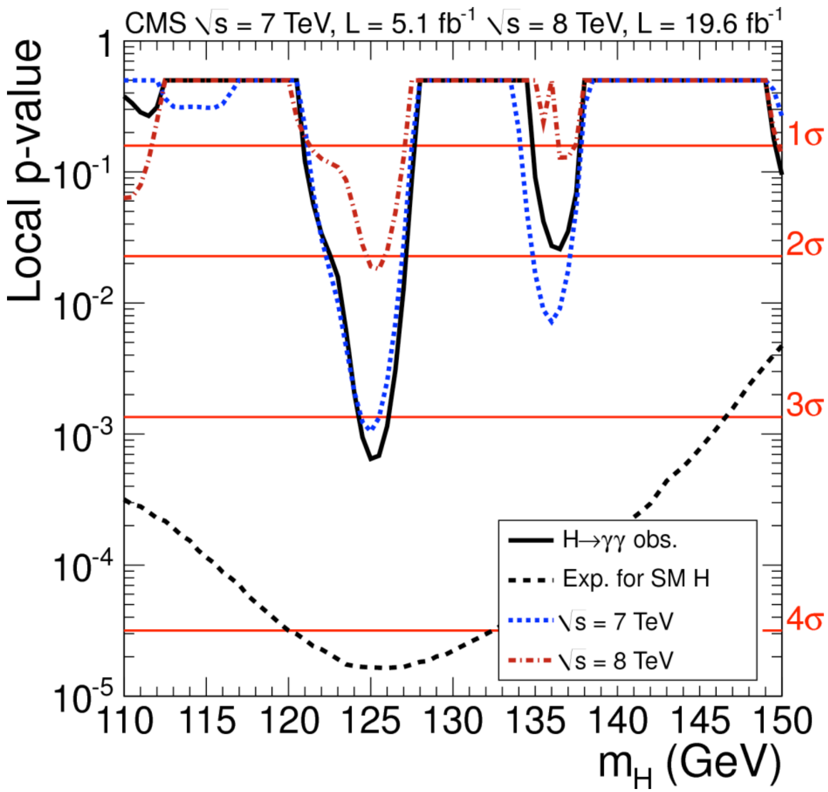
Best fit σ/σ_{SM} = 0.78 +- 0.27

H→γγ

HIG-13-001

H-----> γγ





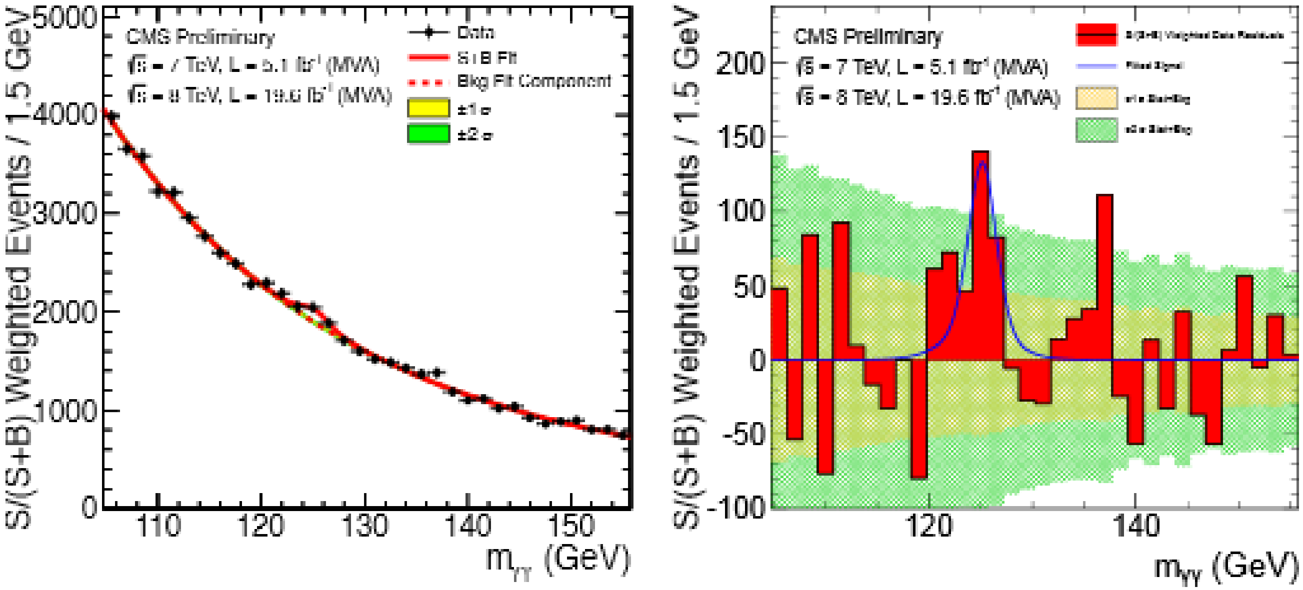
Local significance 3.2 σ (expected 3.7 σ)

H----> γγ

$H \rightarrow \gamma\gamma$

HIG-13-001

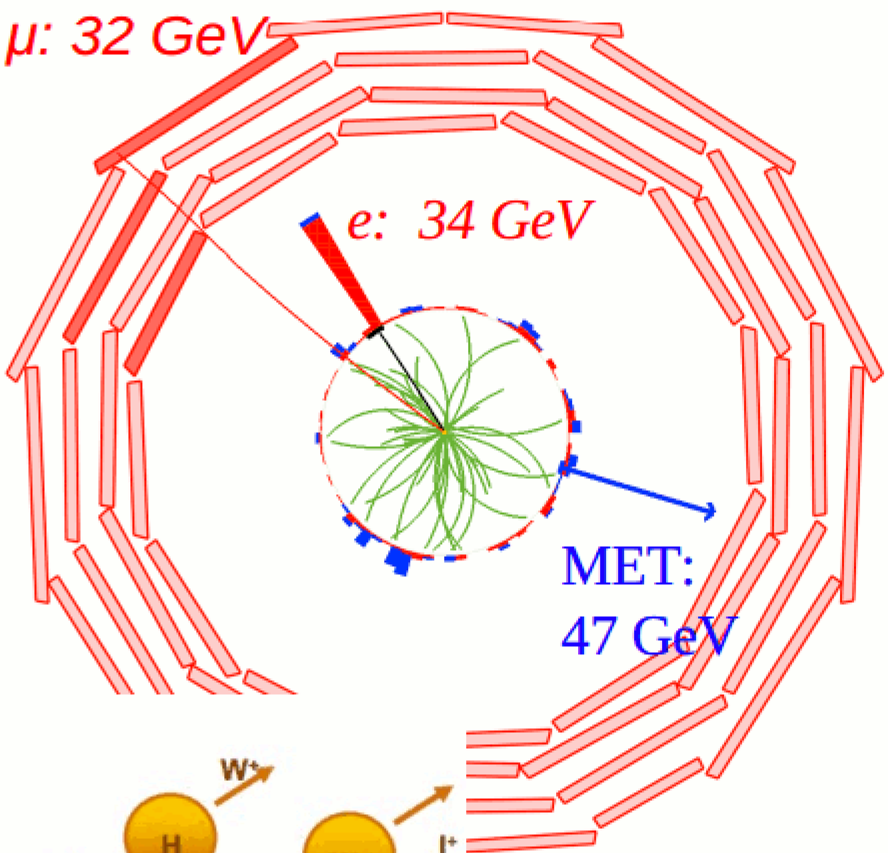
Mass fit MVA-analysis

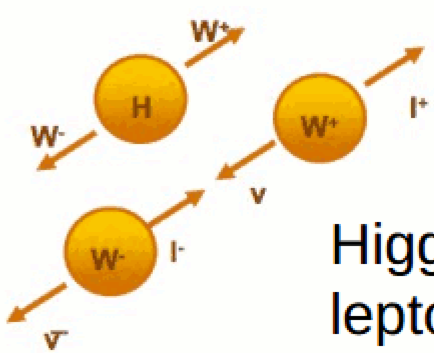


Final two-photon invariant mass presented after weighting signal-background ratio for each event class

M= 125.2±0.5(stat.)±0.6(syst.)

$H \to WW \to 2l\ 2nu$





Higgs is scalar
leptons are close

Signature

- 2 opposite charged leptons (leptons only *e*, *μ*)
- 2 neutrinos == missing transverse energy (MET)
- no Higgs mass peak
- basically a counting analysis

Analysis challenges

- understand backgrounds
- normalize to control regions
- backgrounds: WW, W+jets, top, DY

Shape – 2 Dimensions (m_{ll} - m_T)

H→WW

HIG-13-003

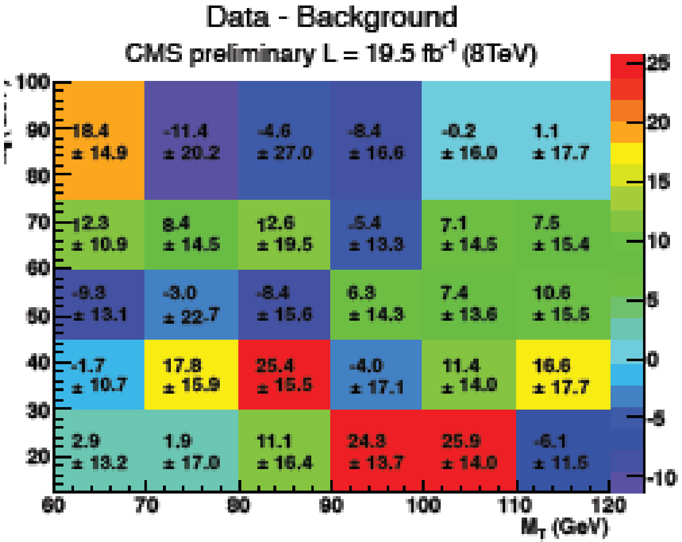
mT = $\sqrt{2 p_T^{\ell\ell} E_T^{miss} (1 - \cos \Delta\phi_{E_T^{miss}\ell\ell})}$

2D-shape analysis allows to separate background in two dimensions

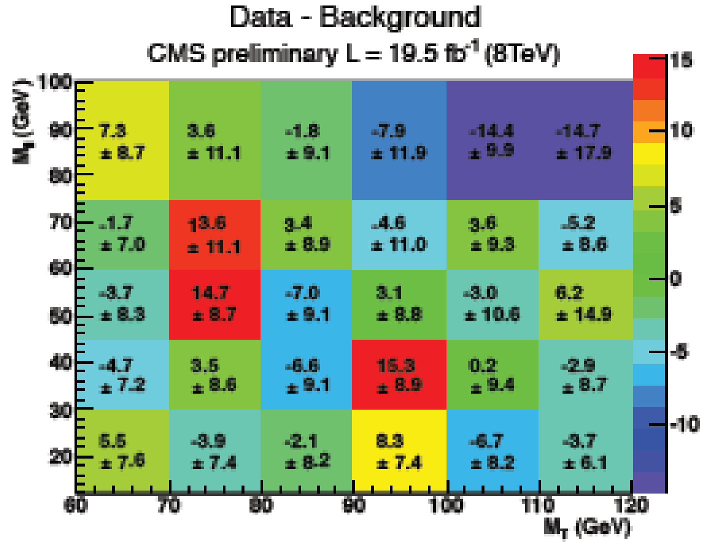
Improve analysis sensitivity

Evaluating systematic uncertainty adjusted (in 2D)

0 Jet-bin



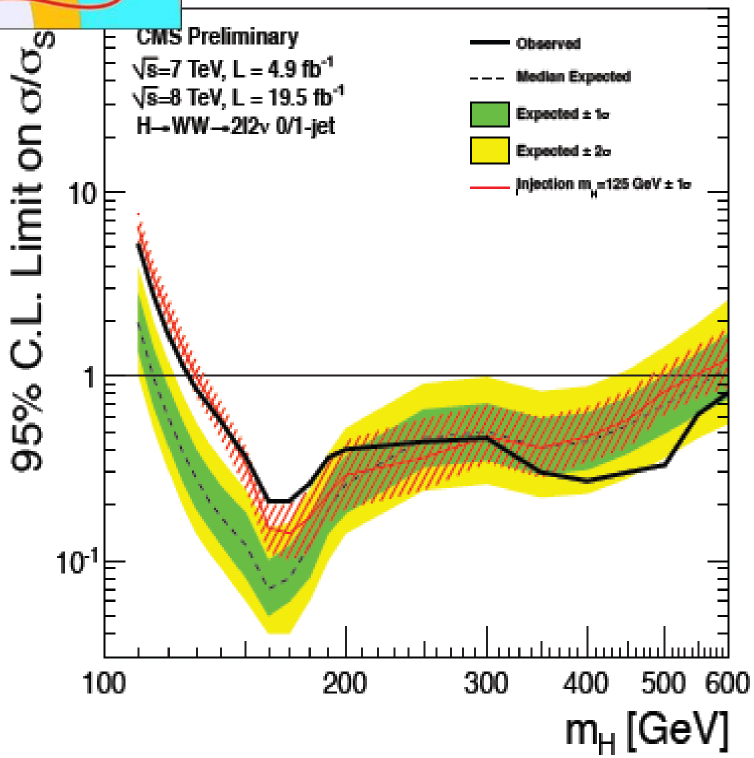
1 Jet-bin

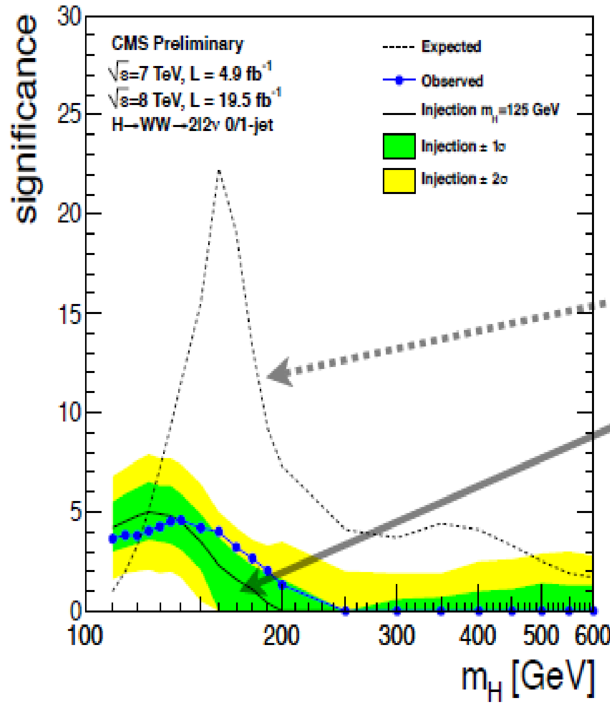


H→WW

HIG-13-003

H-----> WW ----> 2l2nu





expected significance:

- for a Higgs of that mass
- for a Higgs with m_H=125 GeV

Mass range from 128 to 600 GeV is excluded at 95 % CL

Shape-based analysis

Significance 4.0 σ (expected 5.1 σ)

Strength μ= 0.76 ± 0.21

Cut-based analysis

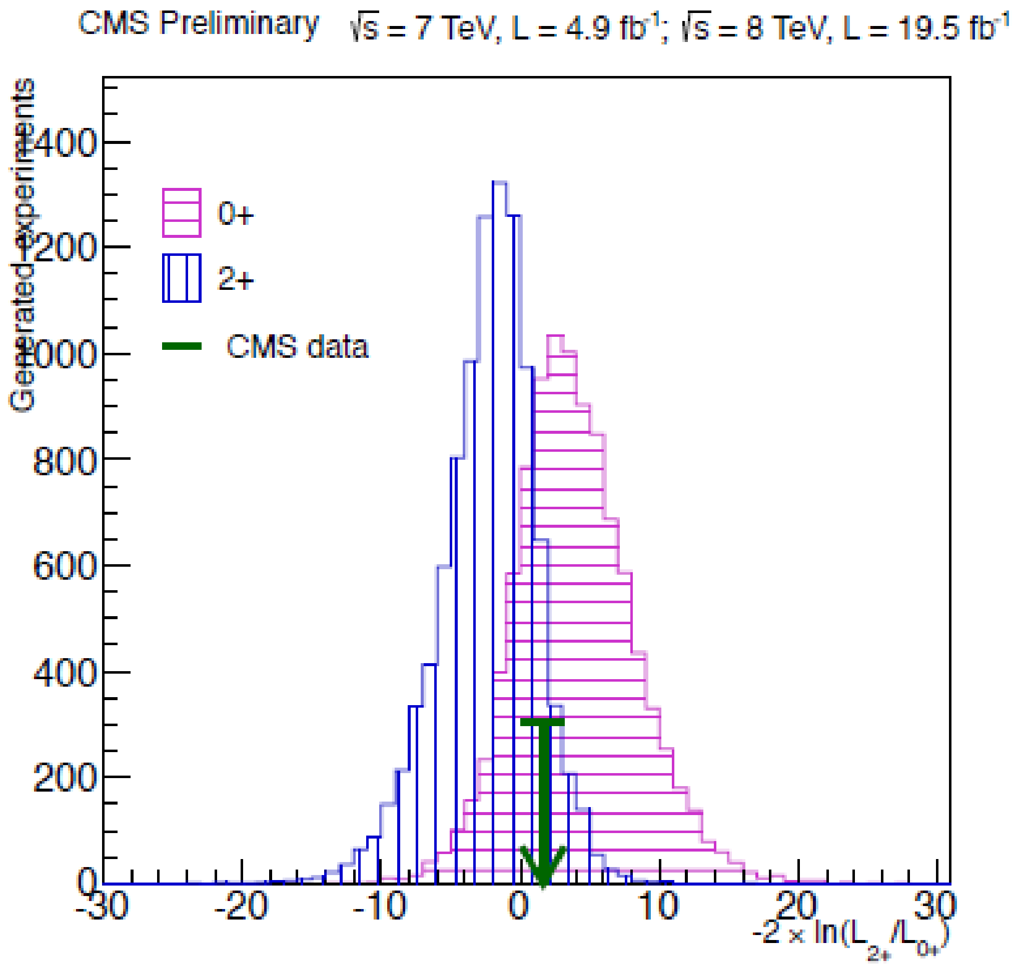
Significance 2.0 σ(expected 2.7 σ)

Strength μ=0.71 ± 0.37

H → WW

HIG-13-003

H----> WW ----> 2l2ν   Spin and parity determination



2+ is disfavored with CLs 14 %

$H \rightarrow \tau\tau$

HIG-13-004

H-----> $\tau\tau$

Final states $e\mu$ $\mu\mu$ $e\tau_h$ $\mu\tau_h$ $\tau_h\tau_h$ (τ_h - hadron decays of lepton)

Two sub-category 1- two backward and forward jets - mostly VBF
2 - at least one high-pt hadronic jet

Zero jet events are used to constrain background normalization, identification efficiency and energy scan

Backgrounds (Z->$\tau\tau$ (irreducible) and reducible(W+jets, multijet productions, Z->ee) are estimated for control data samples

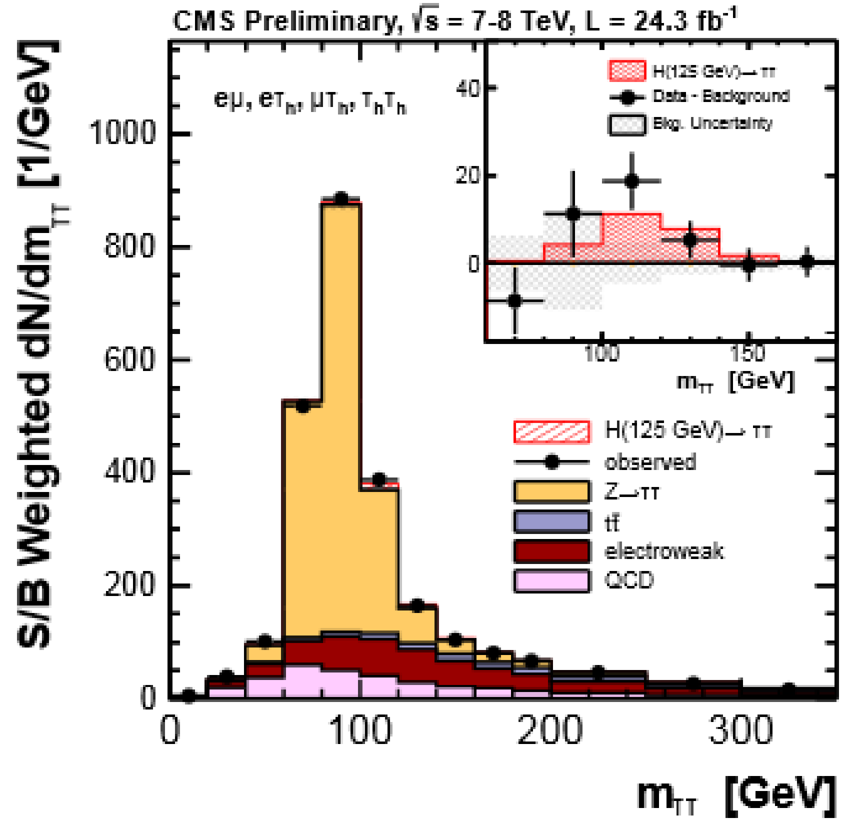
H->$\tau\tau$ in association with W or Z was also studied (the same τ-lepton final states and decays of W and Z to leptons)

$H \rightarrow \tau\tau$

HIG-13-004

Combined Mττ distribution weighted by S/B -ratio

Background contribution mostly were determined from data (EW – shape and ttbar from MC)
Systematics background estimation -~ 10 % (Z-> μμ – 5%)

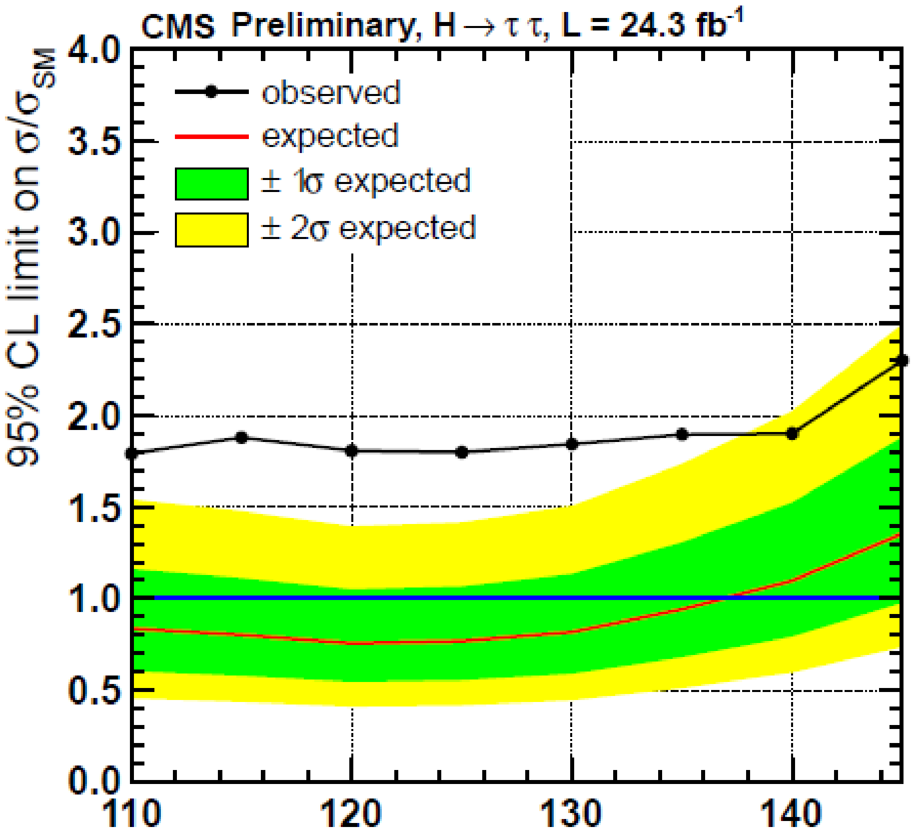


H ⟶ ττ

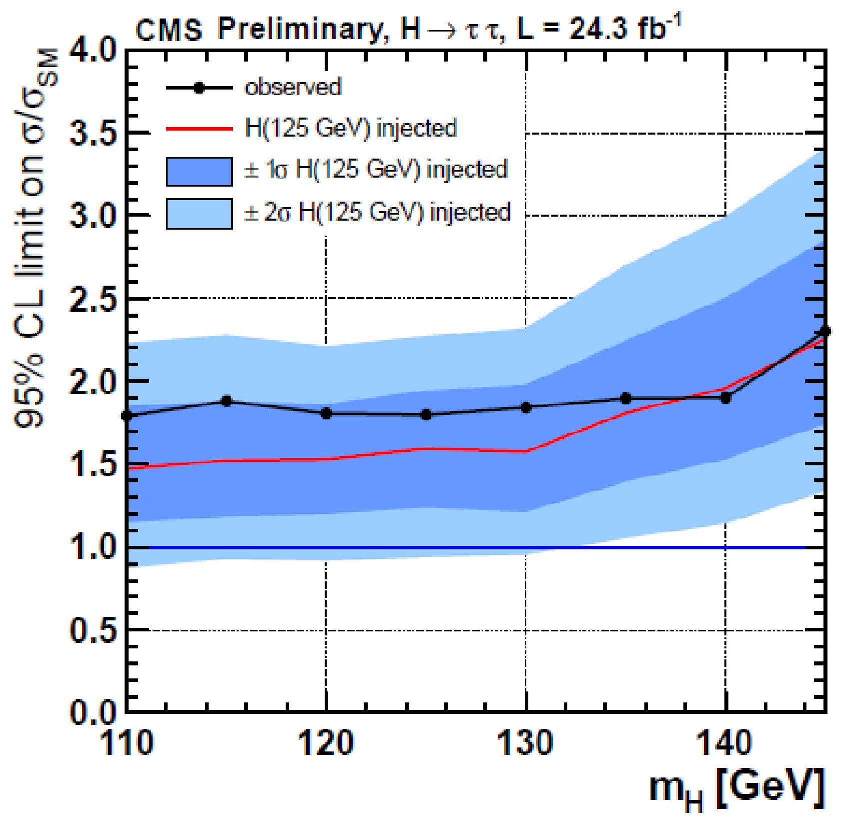
HIG-13-004

H----> ττ

Without Higgs boson contribution



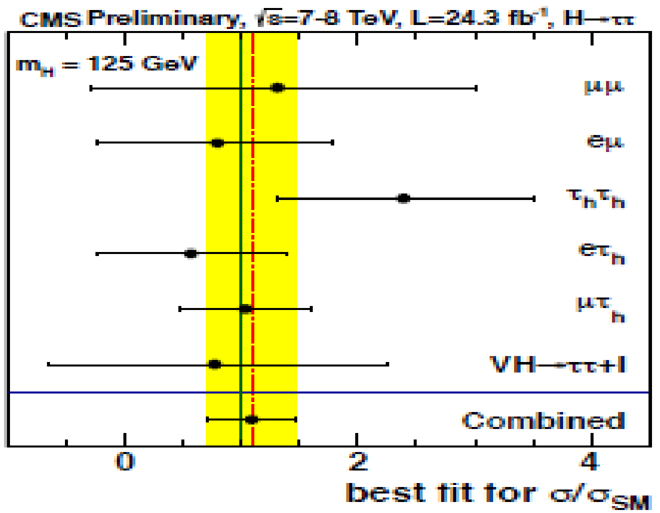
With contribution of Higgs M=125 GeV

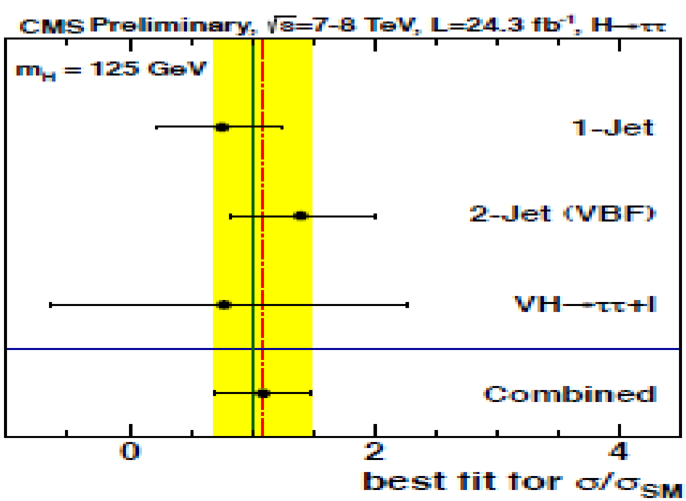


H → ττ
HIG-13-004

H----> tau tau

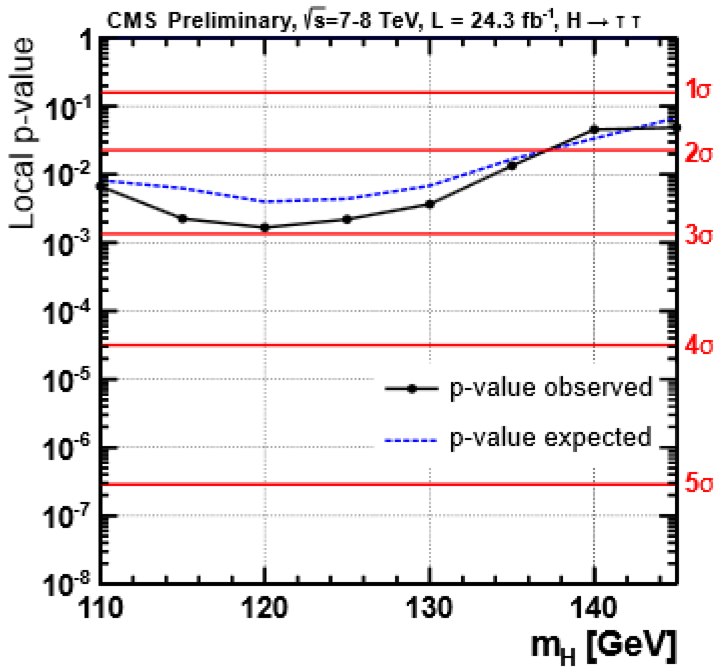
Compatability with SM Higgs





$$\hat{\mu} = 1.1 \pm 0.4$$

Local p-value



Significance 2.8 observed (2.6 expected)

H→bb

HIG-12-044

H-> bb

- Mostly Higgs in association W and Z (W-> eν/μν, Z-> ee/μμ/νν)

- Two b-tagged jets are reconstructed

- MVA is applied

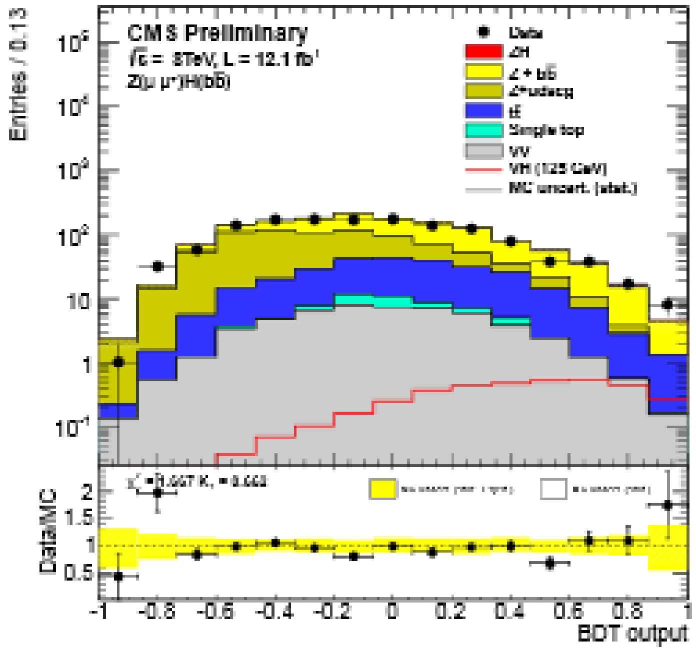
- Background from WZ and ZZ with Z decaying to two b-quark, as well as background from single top-production were estimated from MC

- H-> bb in association with top-quark pair was also studied (less sensitive)

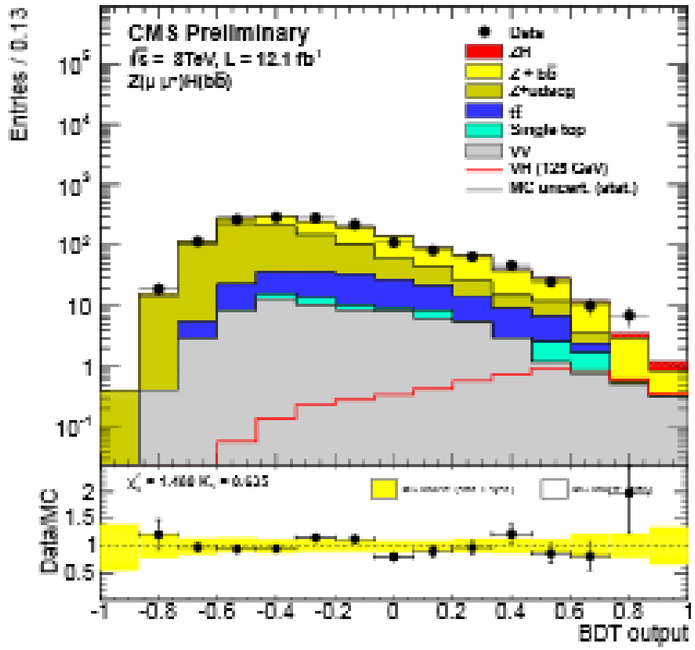
HZ -> bb Z

BDT distribution for HZ (Z->μμ)

Low pt Z-boson



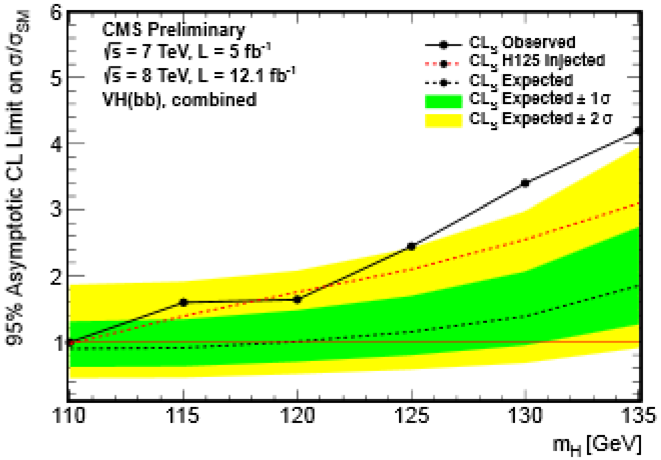
High pt Z-boson



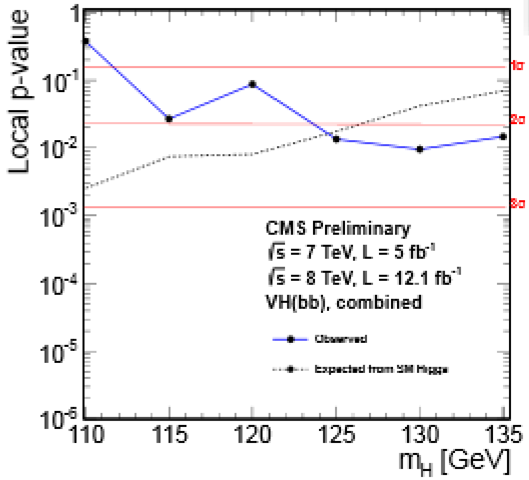
H->bb

H→bb

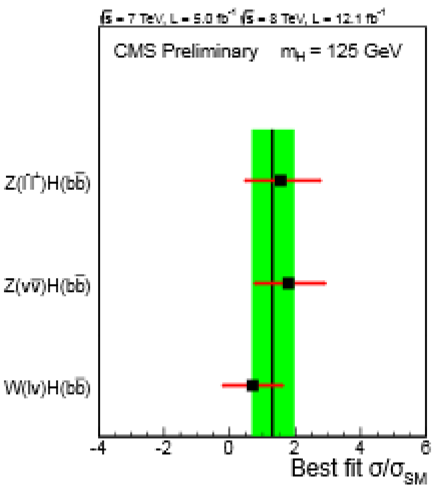
HIG-12-044



m_H(GeV)	110	115	120	125	130	135
Exp.	0.89	0.91	1.00	1.15	1.39	1.85
Obs.	0.99	1.60	1.64	2.45	3.40	4.19



Significance 2.0 σ (expected 2.2 σ)



Best fit σ/σ$_{SM}$

Combination

combination
HIG-13-005

high resolution channels

H decay	Prod. tag	Analyses: Exclusive final states	No. of channels	m_H resolution	Lumi (fb^{-1}) 7 TeV	Lumi (fb^{-1}) 8 TeV
$\gamma\gamma$	untagged	$\gamma\gamma$ (4 diphoton classes)	4 + 4	1-2%	5.1	19.6
	VBF-tag	$\gamma\gamma + (jj)_{VBF}$ (two dijet classes for 8 TeV)	1 + 2	<1.5%	5.1	19.6
	VH-tag	$\gamma\gamma$ + (e, μ, MET)	3	<1.5%		19.6
$ZZ \to 4\ell$	$N_{jet} < 2$	4e, 4μ, 2e2μ	3 + 3	1-2%	5.1	19.6
	$N_{jet} \geq 2$		3 + 3			
$WW \to \ell\nu\ell\nu$	0/1-jets	(DF or SF dileptons) × (0 or 1 jets)	4 + 4	20%	4.9	19.5
	VBF-tag	$\ell\nu\ell\nu + (jj)_{VBF}$ (DF or SF dileptons for 8 TeV)	1 + 2	20%	4.9	12.1
	WH-tag	$3\ell 3\nu$ (same-sign SF and otherwise)	2 + 2		4.9	19.5
$\tau\tau$	0/1-jet	(eτ_h, $\mu\tau_h$, eμ, $\mu\mu$) × (low or high p_T^{τ})	16 + 16	15%	4.9	19.6
	1-jet	$\tau_h\tau_h$	1 + 1			
	VBF-tag	(eτ_h, $\mu\tau_h$, eμ, $\mu\mu$, $\tau_h\tau_h$) + $(jj)_{VBF}$	5 + 5			
	ZH-tag	(ee, $\mu\mu$) × ($\tau_h\tau_h$, eτ_h, $\mu\tau_h$, eμ)	8 + 8		5.0	19.5
	WH-tag	$\tau_h\mu\mu$, τ_heμ, e$\tau_h\tau_h$, $\mu\tau_h\tau_h$	4 + 4			
bb	VH-tag	($\nu\nu$, ee, $\mu\mu$, eν, $\mu\nu$ with 2 b-jets) × (low or high p_T(V) or loose b-tag)	10 + 13	10%	5.0	12.1
	ttH-tag	(ℓ with 4, 5 or ≥6 jets) × (3 or ≥4 b-tags);	6 + 6		5.0	5.1
		(ℓ with 6 jets with 2 b-tags); ($\ell\ell$ with 2 or ≥3 b-tagged jets)	3 + 3			

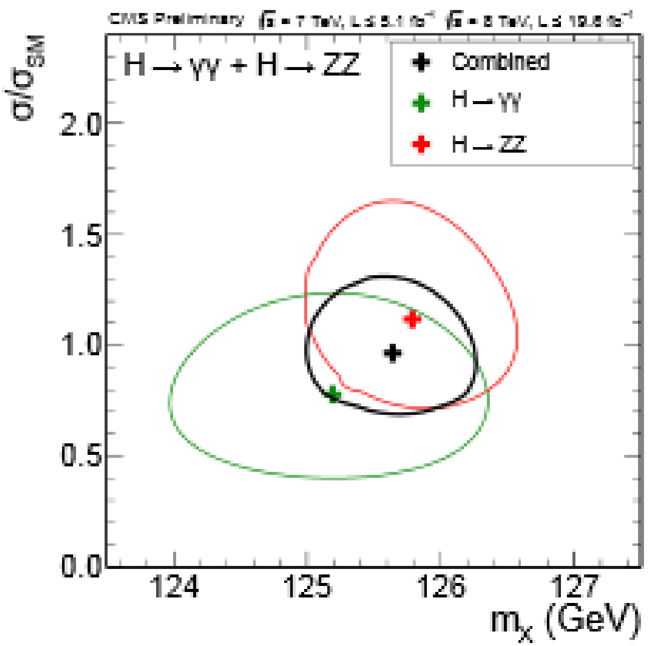
Decay mode	Expected (σ)	Observed (σ)
ZZ	7.1	6.7
$\gamma\gamma$	3.9	3.2
WW	5.3	3.9
bb	2.2	2.0
$\tau\tau$	2.6	2.8

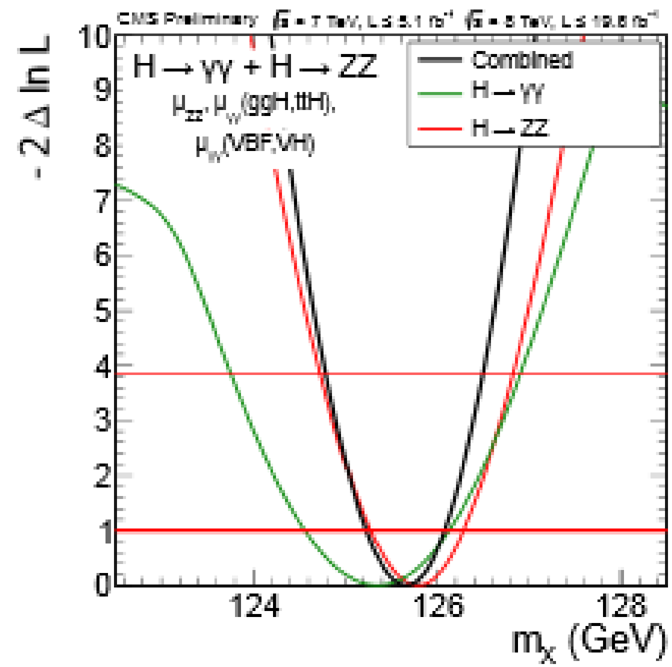
mass measurement and compatibility tests for several properties

combination

HIG-13-005

Combined mass measurement (H->γγ + H-> ZZ)





95 % CL

68 % CL

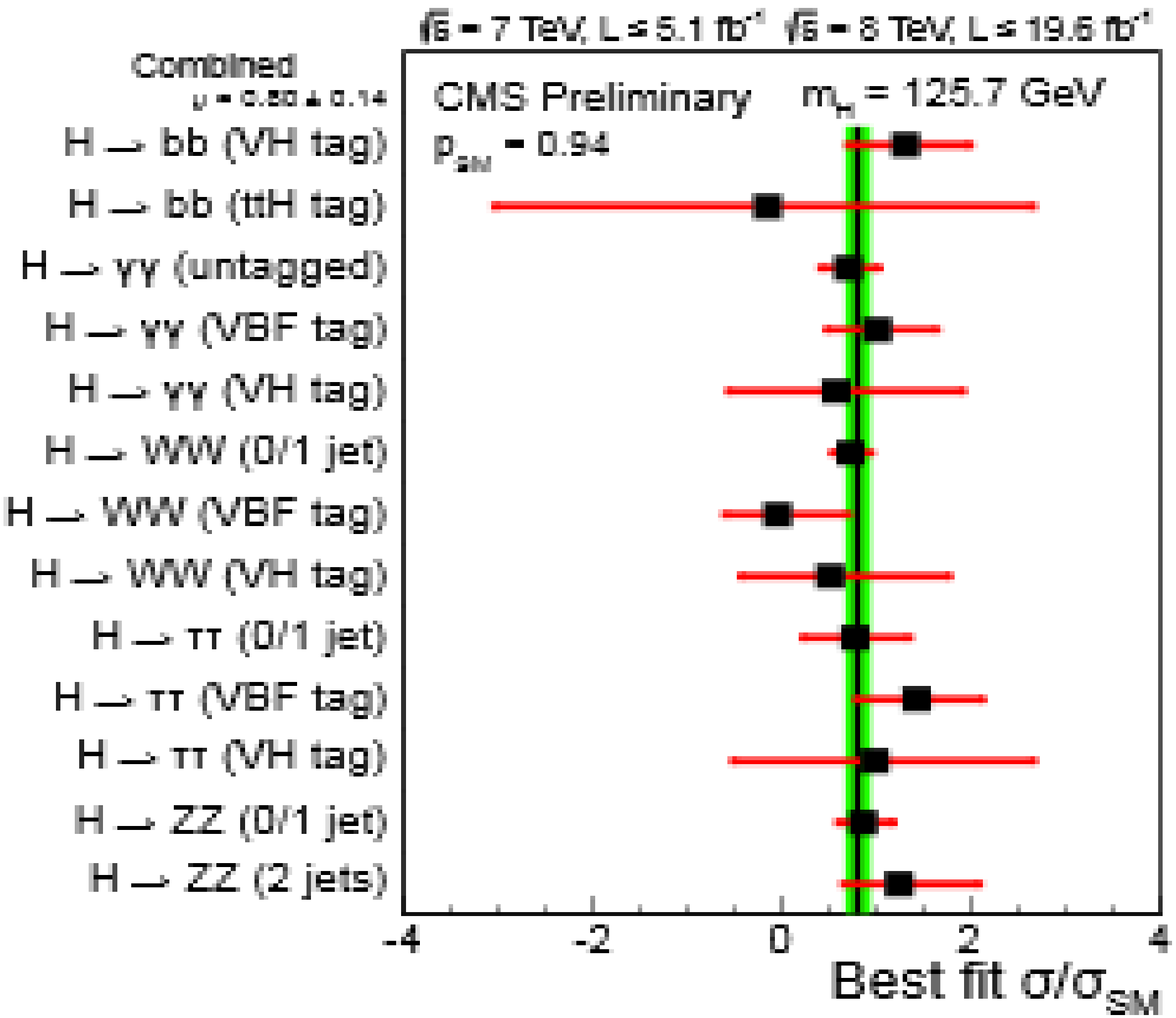
68 % CL contours are shown

M = 125.7 ± 0.3 (stat.) ± 0.3 (syst.)

combination

HIG-13-005

Signal strength



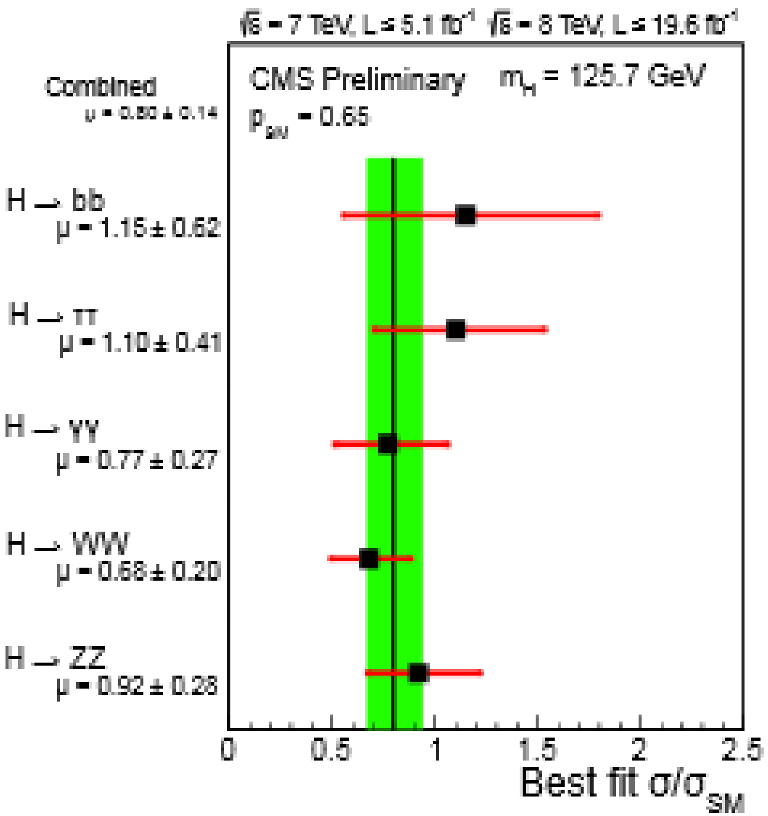
Combined signal strength μ=0.80 ± 0.14

combination

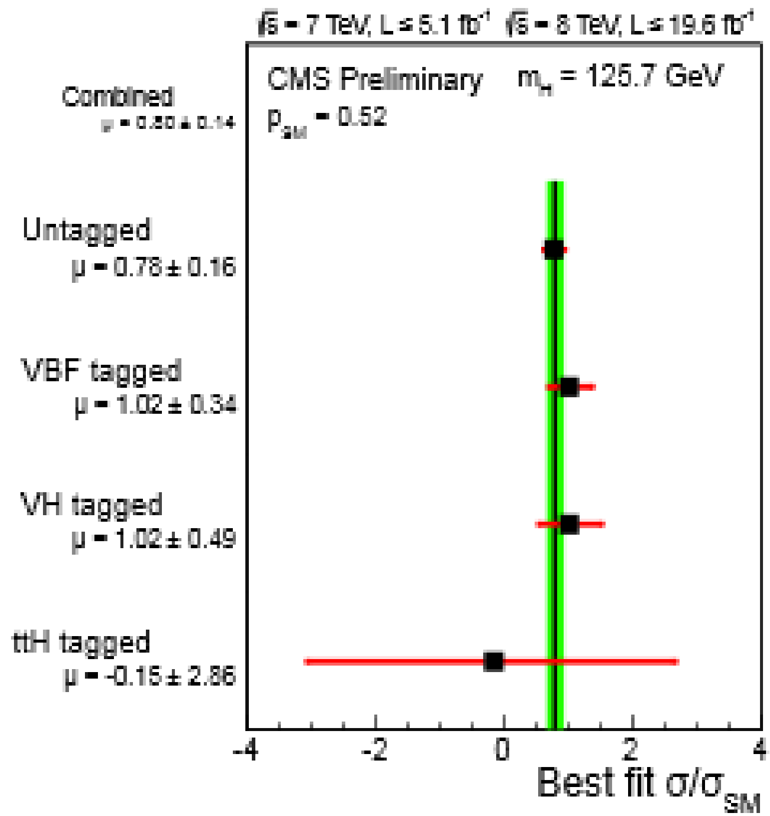
HIG-13-005

Signal strength

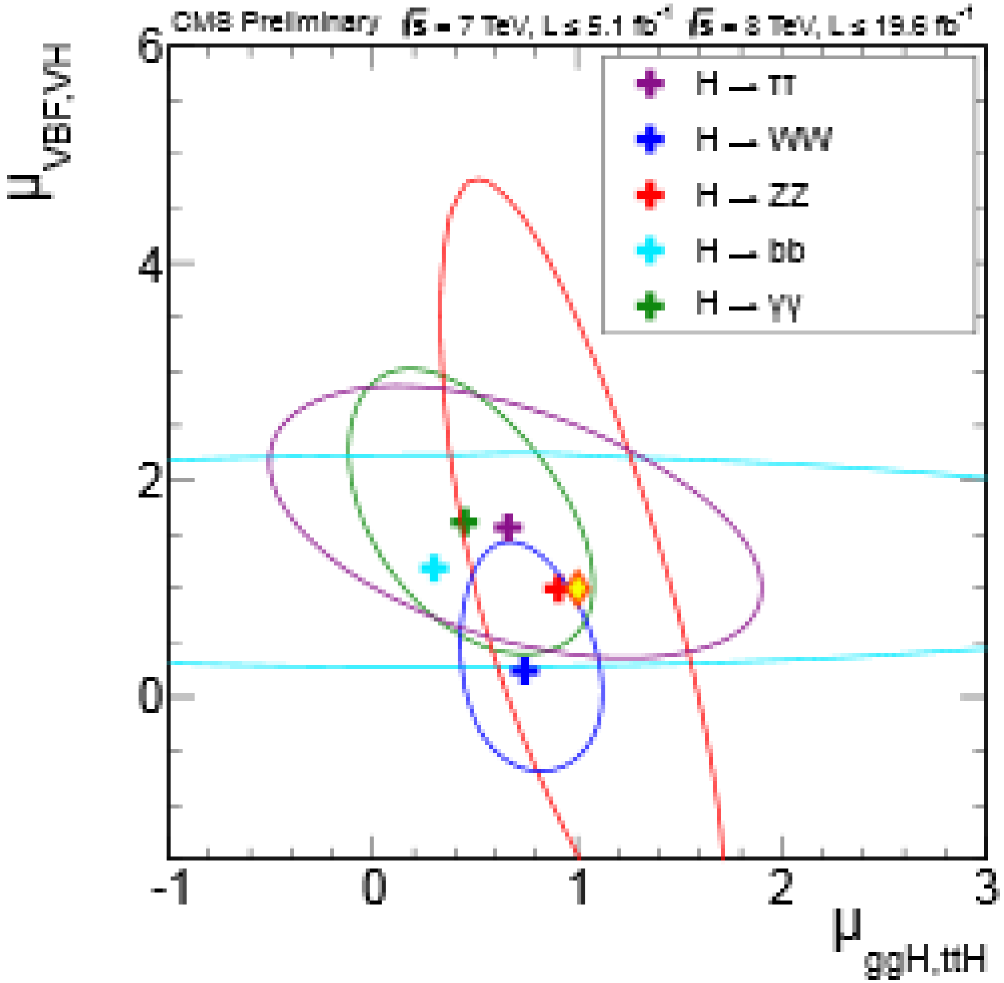
For different decay channels



For different production mechanisms



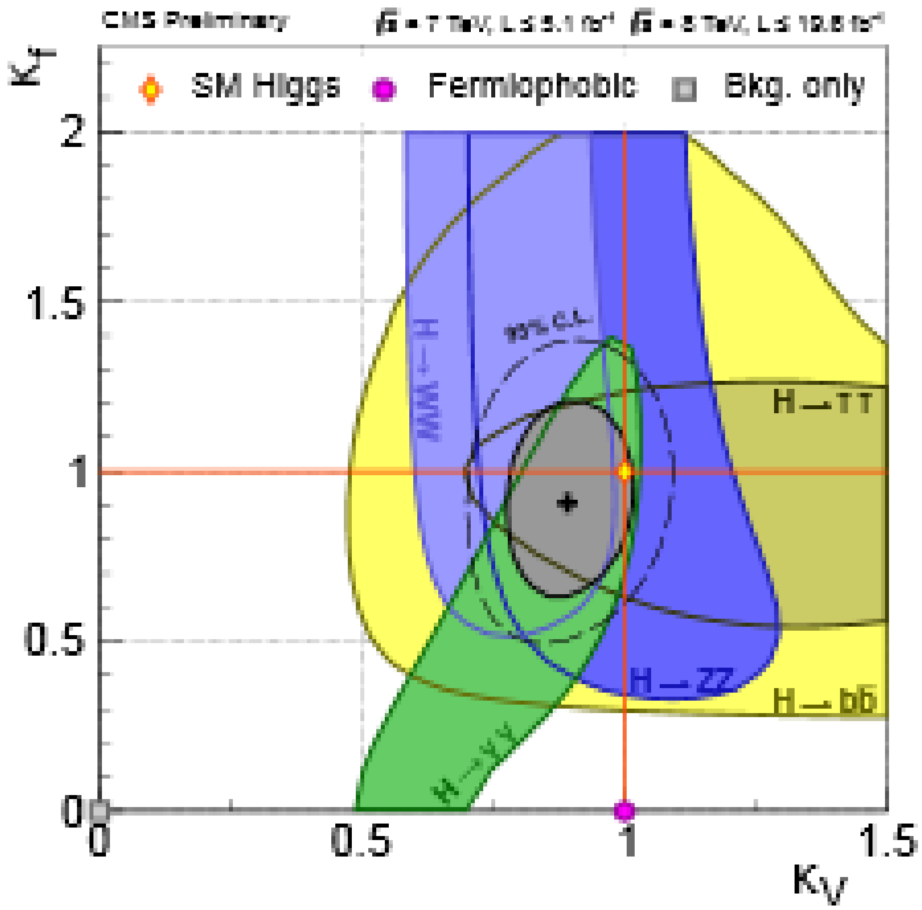
Signal strength for gluon-gluon-fusion-plus- ttH vs VBF-plus-VH production mechanisms



68 % CL contours are shown around the best fit-values

Orange diamond at (1,1)- expected for SM Higgs boson

Coupling to fermions vs coupling to bosons



SM Higgs boson expectations (1,1) are within 68 % contour of combined data

Conclusions

-The new particle with the mass 125.7+-0.3+-0.3 GeV
 was observed
- Total significance more than 9 sigma (6.7 sigma in H->ZZ)
- No discrepancy from SM Higgs observed
- First indication on decay to fermions is obtained
- Further improvements are expecting