Higgs Physics at CMS

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On behalf of the CMS Collaboration

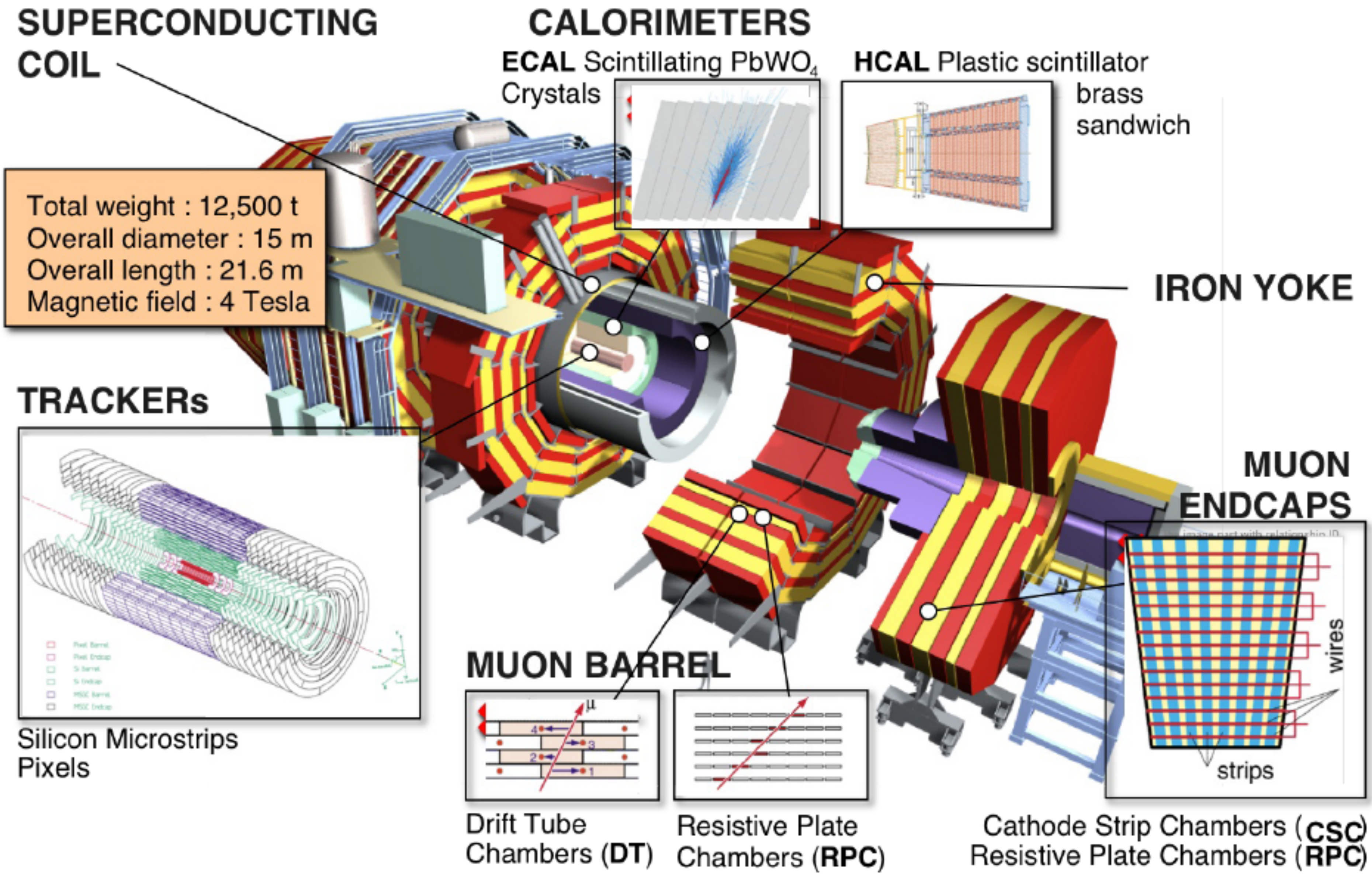
Workshop on Multi-Higgs Models
2-5 September 2014
Lisbon, Portugal

Outline

- Introduction
- SM Higgs Studies (H125)
  - Analysis in the high mass resolution channels (γγ and ZZ)
  - Analysis in the low mass resolution channels (WW, ττ and bb)
  - Measurement of the H125 Higgs boson properties
- BSM Higgs Searches
  - Only some selected, more recent results
- Summary and Outlook

For all CMS public results on Higgs searches see:
https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsHIG

CMS Detector

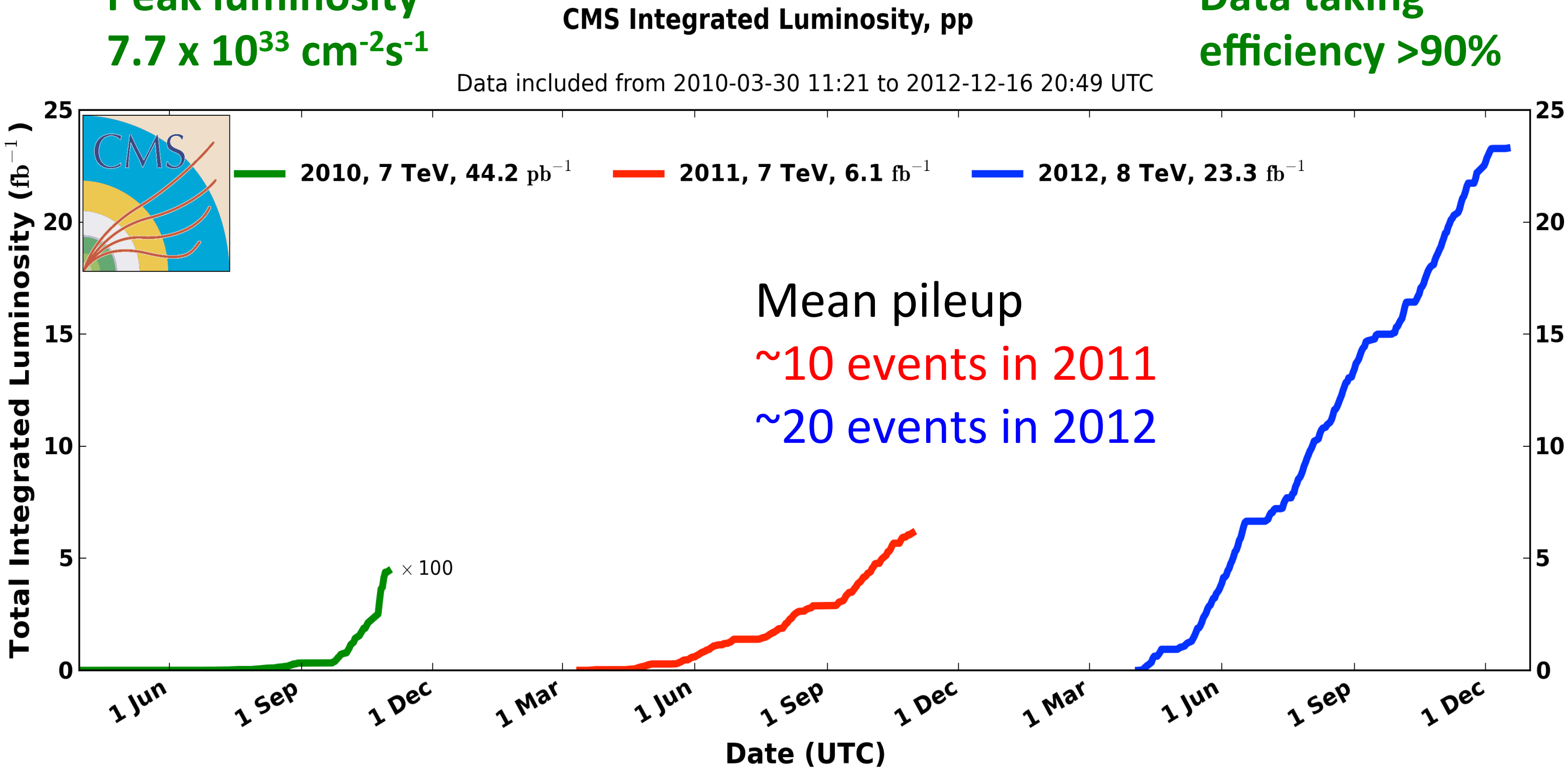


Data: pp collision at 7 and 8 TeV

- Excellent performance of LHC and CMS in 2011 and 2012
- 25 fb^{-1} IntL good pp collisions data collected until now at 7 and 8 TeV CM energy:
  - 5 fb^{-1} IntL at 7 TeV
  - 20 fb^{-1} IntL at 8 TeV

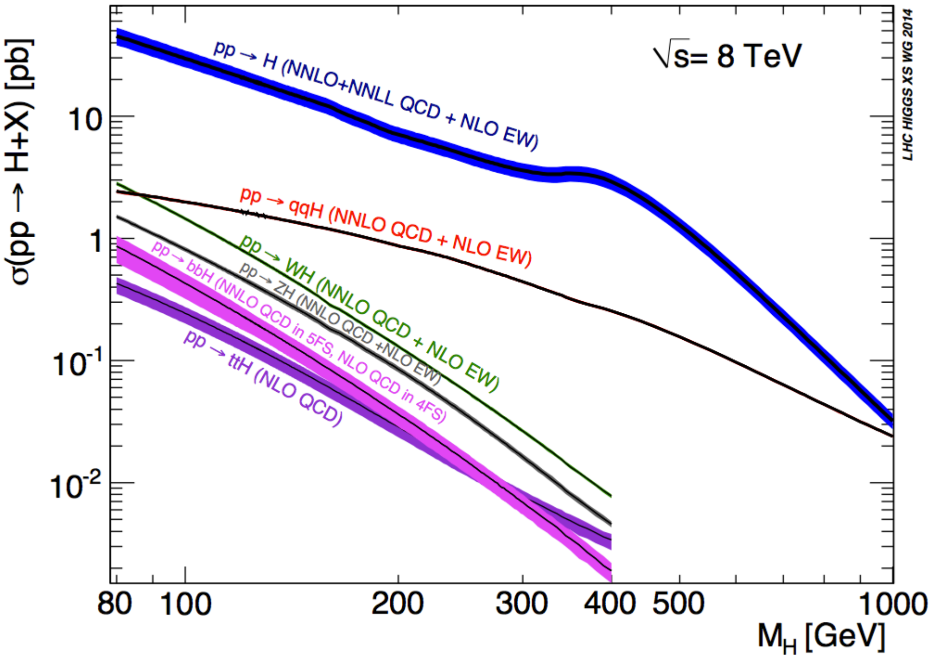
Peak luminosity 7.7 x 10^{33} $cm^{-2}s^{-1}$

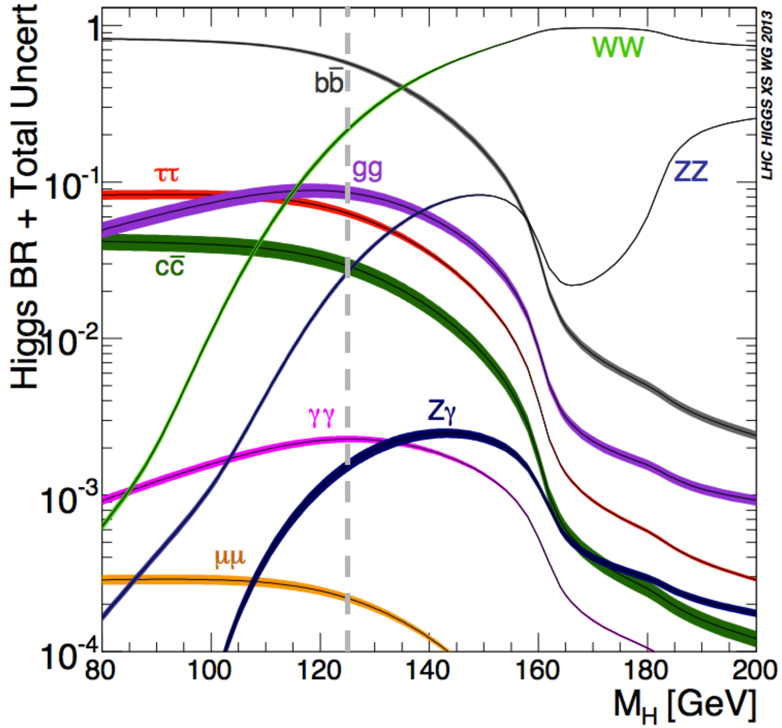
Data taking efficiency >90%

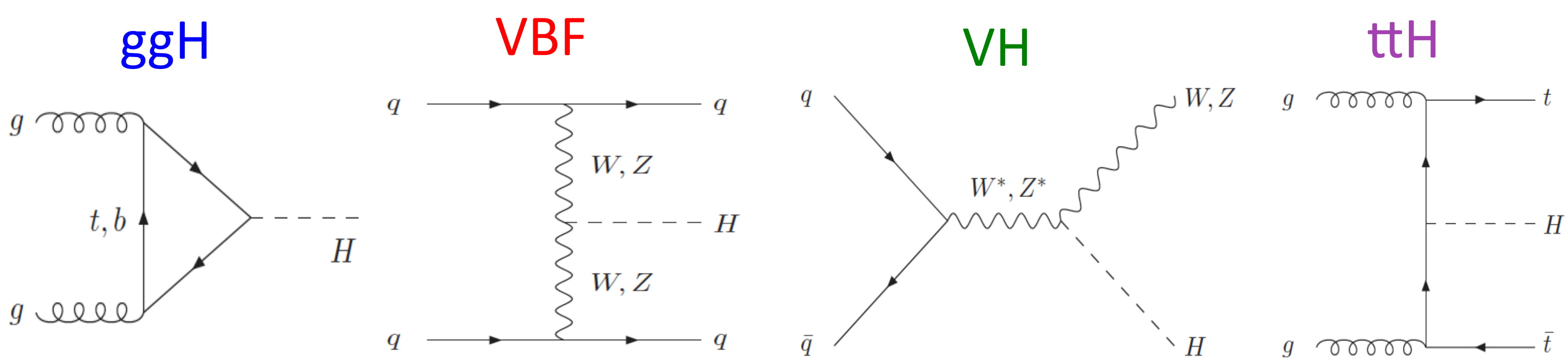


Mean pileup
~10 events in 2011
~20 events in 2012

SM Higgs production and decay

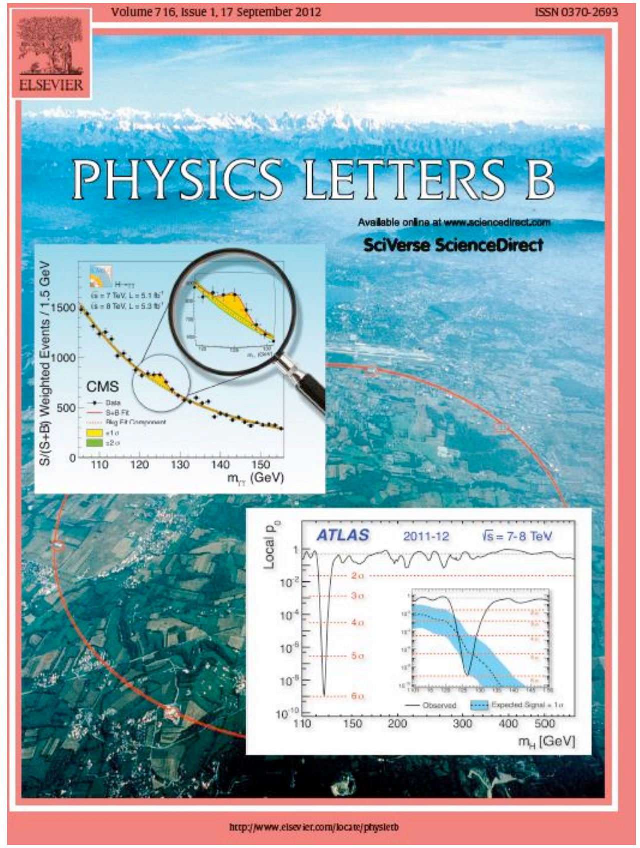






Exploit all four production modes

A Higgs boson discovered



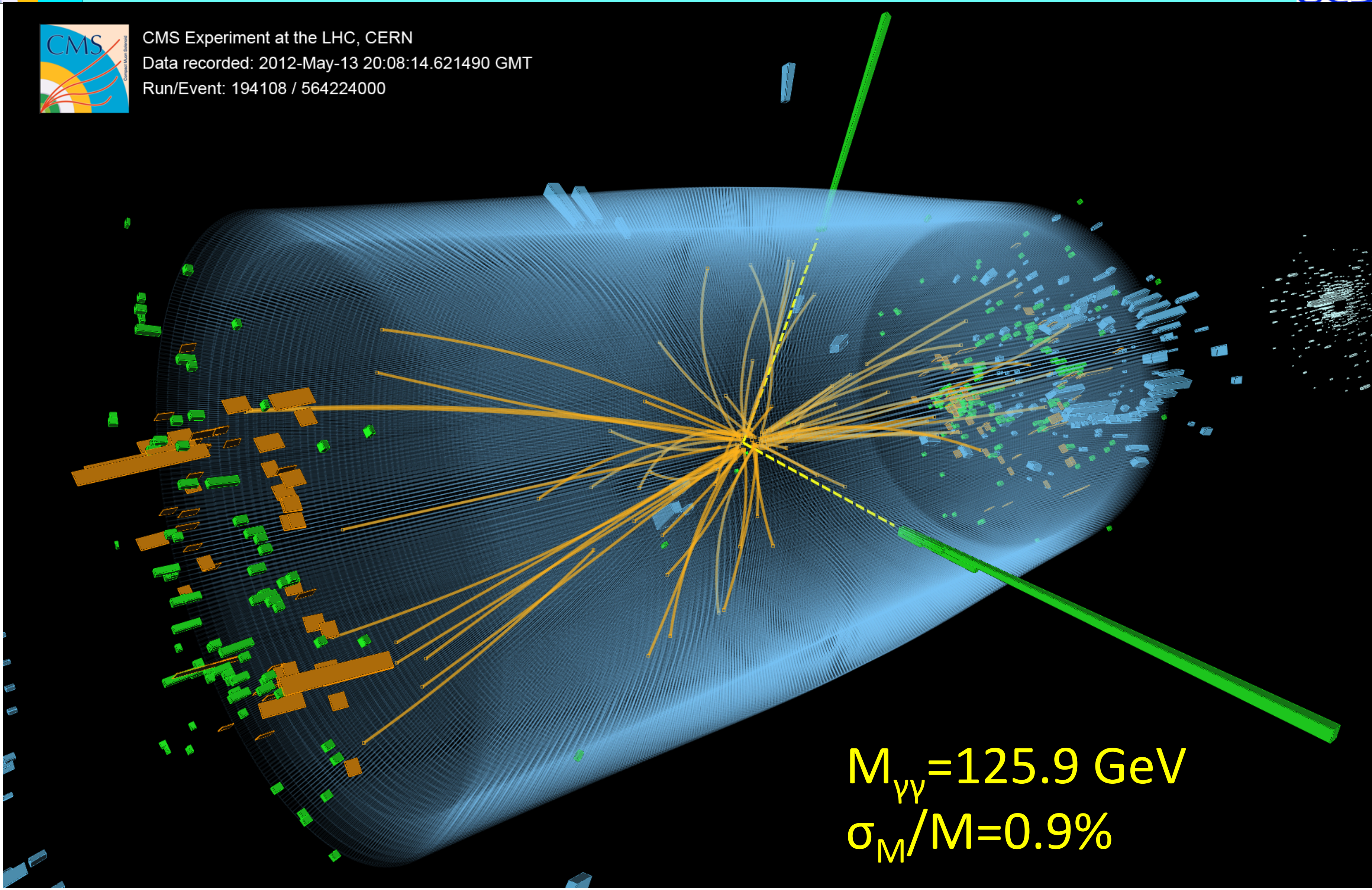
ATLAS:
Phys.Lett. B716 (2012) 1-29
CMS
Phys.Lett. B716 (2012) 30-61

- On July 4th 2012 the discovery was announced by ATLAS and CMS
- In 2013 it was confirmed that the new boson was a Higgs boson and the precise measurements started

High mass resolution decay channels

- 2 channels with excellent mass resolution (1-2%)
  - H→γγ
  - H→ZZ
  - Search for mass peak over the BG (large yield and BG for γγ and small yield and BG for ZZ)

H→γγ


CMS Experiment at the LHC, CERN
Data recorded: 2012-May-13 20:08:14.621490 GMT
Run/Event: 194108 / 564224000
$M_{\gamma\gamma}$=125.9 GeV
σ_M/M=0.9%

H→γγ analysis strategy

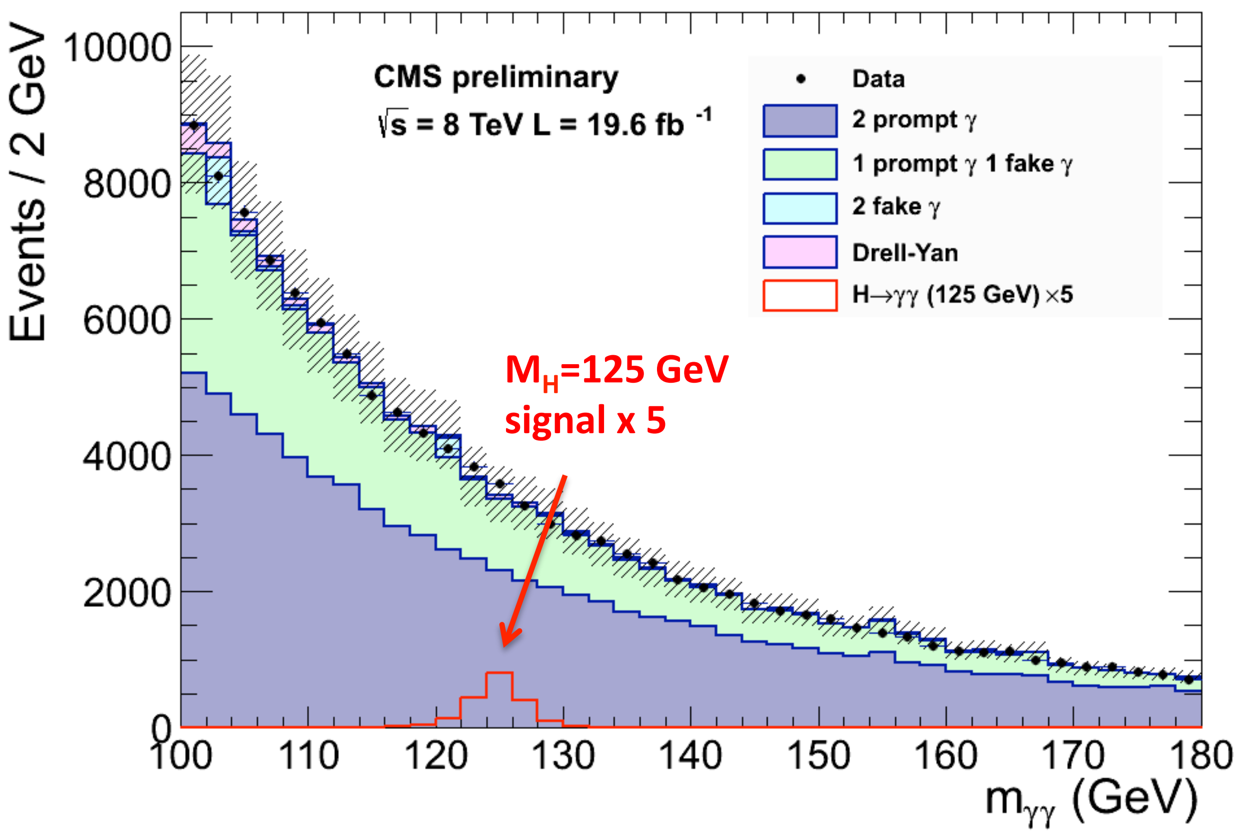
- Search for a small mass peak over large and smooth background
  - Irreducible: 2γ QCD production
  - Reducible: γ+jet with 1 additional fake photon, QCD with 2 fake photons, DY with electrons faking photons

Small BR: ~2x10^{-3}

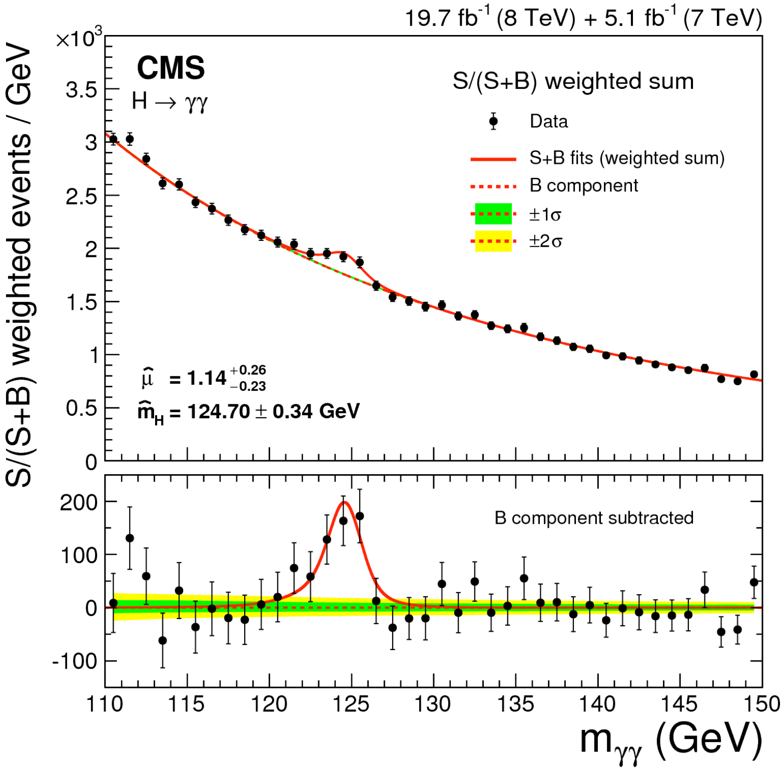
Two isolated high E_t photons

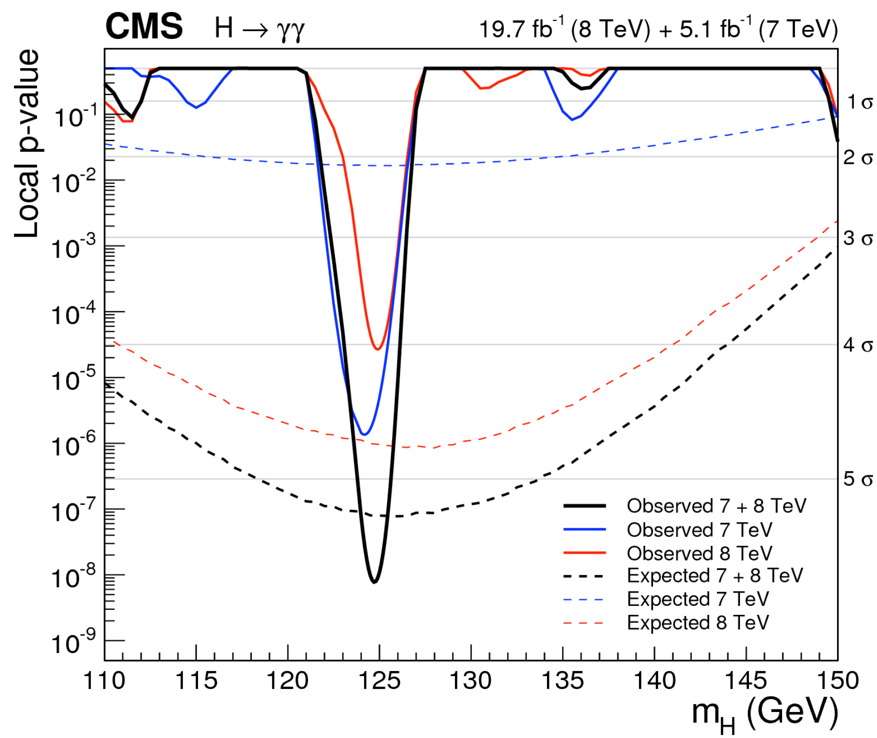
- **Narrow mass peak**
  - resolution 1-2%
- Studied mass range: 110-150 GeV

MC BG not used for deriving results, only for selection optimization



H→γγ results





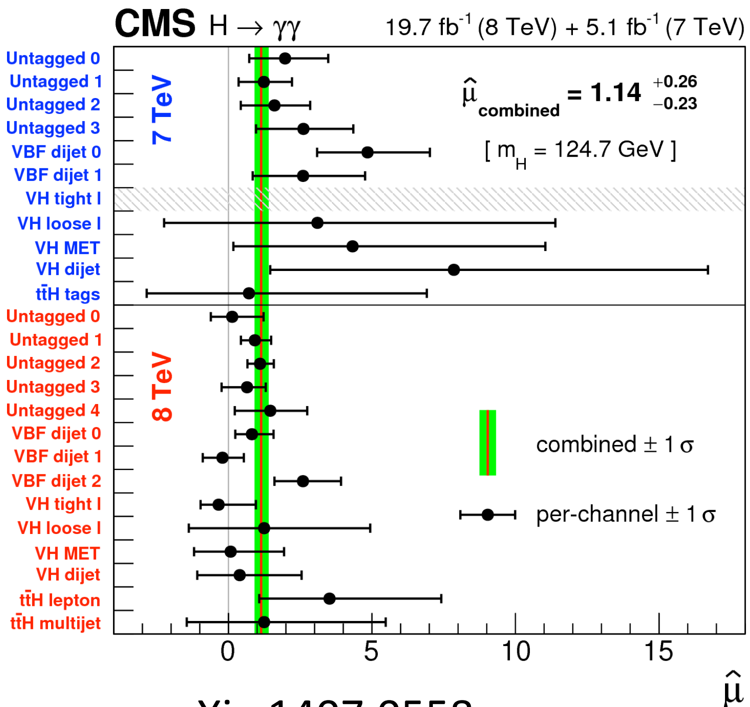
- Largest signal observed around 125 GeV (standalone discovery)
  - Local significance 5.7 σ
  - Expected significance 5.2 σ
  - Fitted $\mu = \sigma/\sigma_{SM}$ at 125 GeV $1.14^{+0.26}_{-0.23}$

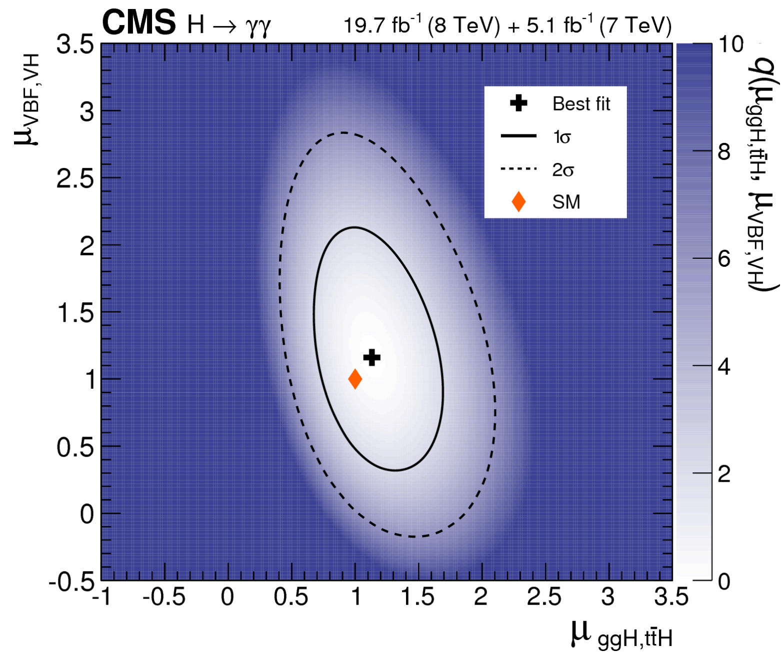
Final Run 1 results submitted for publication

arXiv:1407.0558
Submitted to EPJC

Measurement of different production processes

- Many exclusive channels addressing all production modes
- Untagged mode split into categories with decreasing s/b with MVA





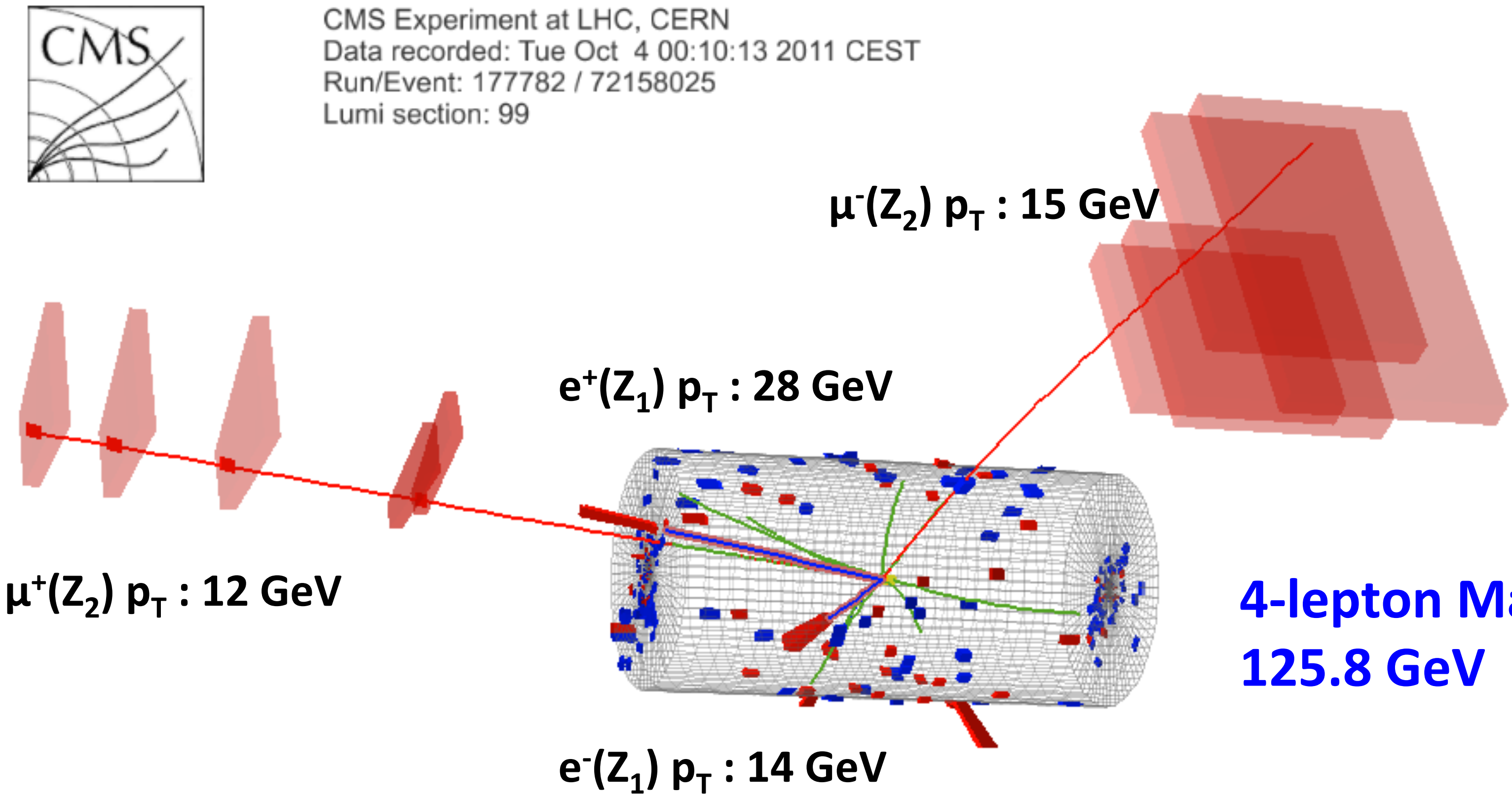
arXiv:1407.0558
Submitted to EPJC

- Results of the fit for individual production modes:

Process	$\hat{\mu}$	Uncertainty total	stat	systematic theo	systematic exp
ggH	$1.12^{+0.37}_{-0.32}$	0.34	0.30	0.13	0.09
VBF	$1.58^{+0.77}_{-0.68}$	0.73	0.69	0.20	0.15
VH	$-0.16^{+1.16}_{-0.79}$	0.97	0.97	0.08	
$t\bar{t}$H	$2.69^{+2.51}_{-1.81}$	2.2	2.1	0.4	

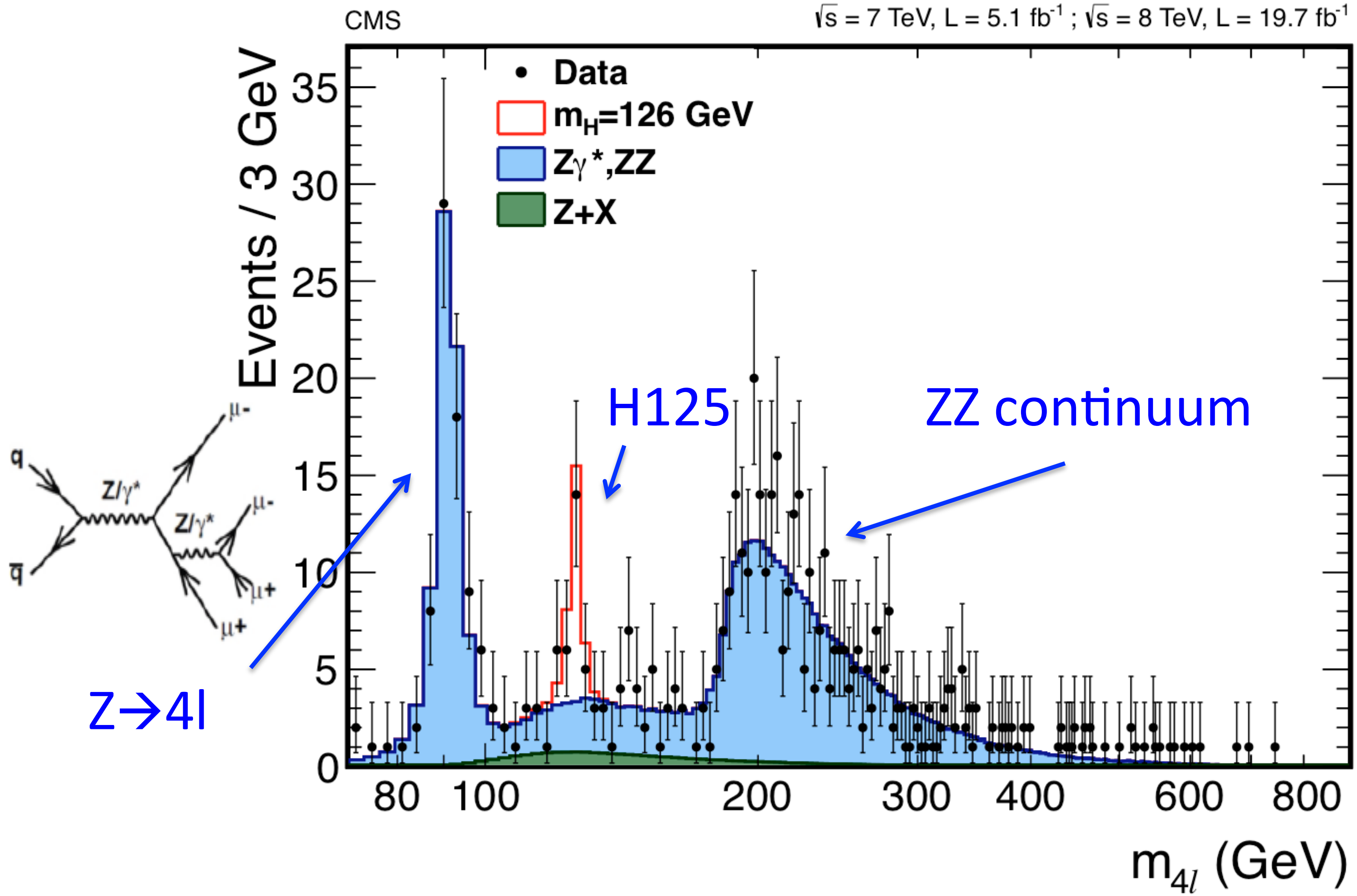
H → ZZ → 4l (4μ, 4e, 2e2μ)

- Clean channel: 2 high mass pairs of opposite sign isolated electrons or muons coming from PV
- **Narrow mass peak**
  - Very good mass resolution 1-2 %
- Very small BR ~10^{-4} at 125 GeV
- Background
  - irreducible: ZZ
  - reducible: Z+jets, Zbb, tt, WZ

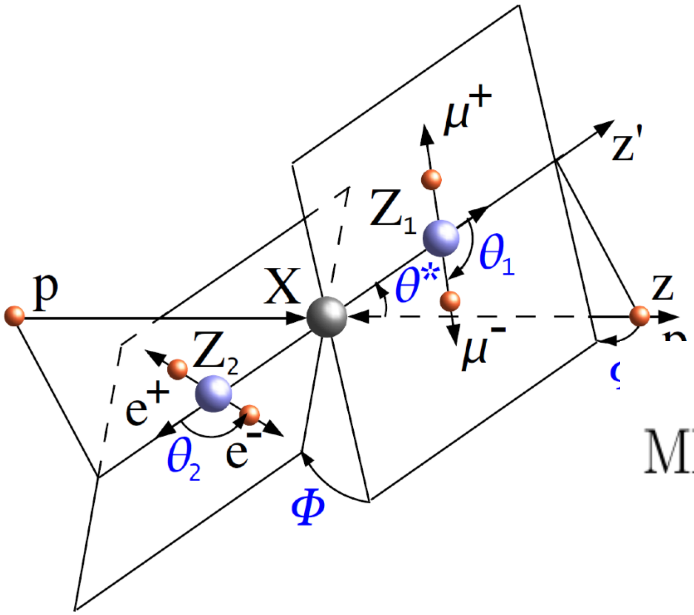


4-lepton Mass : 125.8 GeV

H → ZZ → 4l: candidates



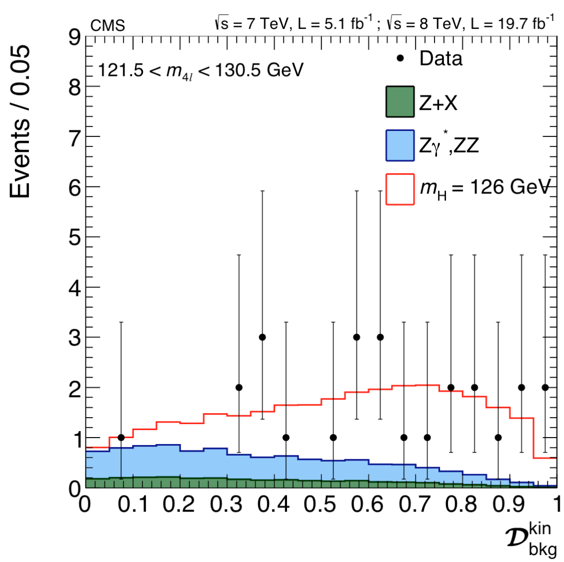
Use other kinematical variables: K_D



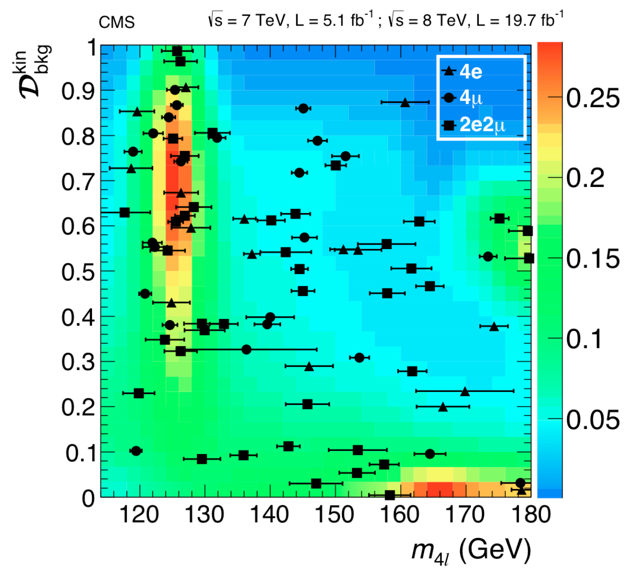
MELA: Matrix Element Likelihood Analysis:
uses kinematic inputs for
signal to ZZ background discrimination
$\{m_1, m_2, \theta_1, \theta_2, \theta^*, \Phi, \Phi_1\}$

$$\mathrm{MELA} = \left[1 + \frac{\mathcal{P}_{\mathrm{bkg}}(m_1, m_2, \theta_1, \theta_2, \Phi, \theta^*, \Phi_1 | m_{4\ell})}{\mathcal{P}_{\mathrm{sig}}(m_1, m_2, \theta_1, \theta_2, \Phi, \theta^*, \Phi_1 | m_{4\ell})}\right]^{-1}$$

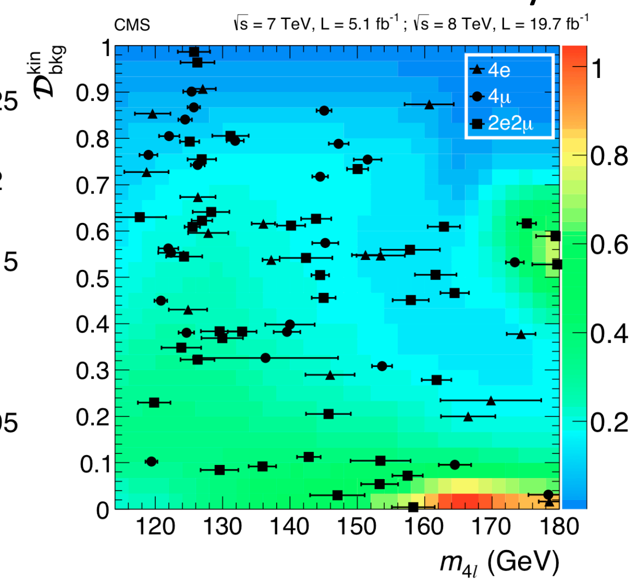
M_{4l} = 121.5 – 130.5 GeV



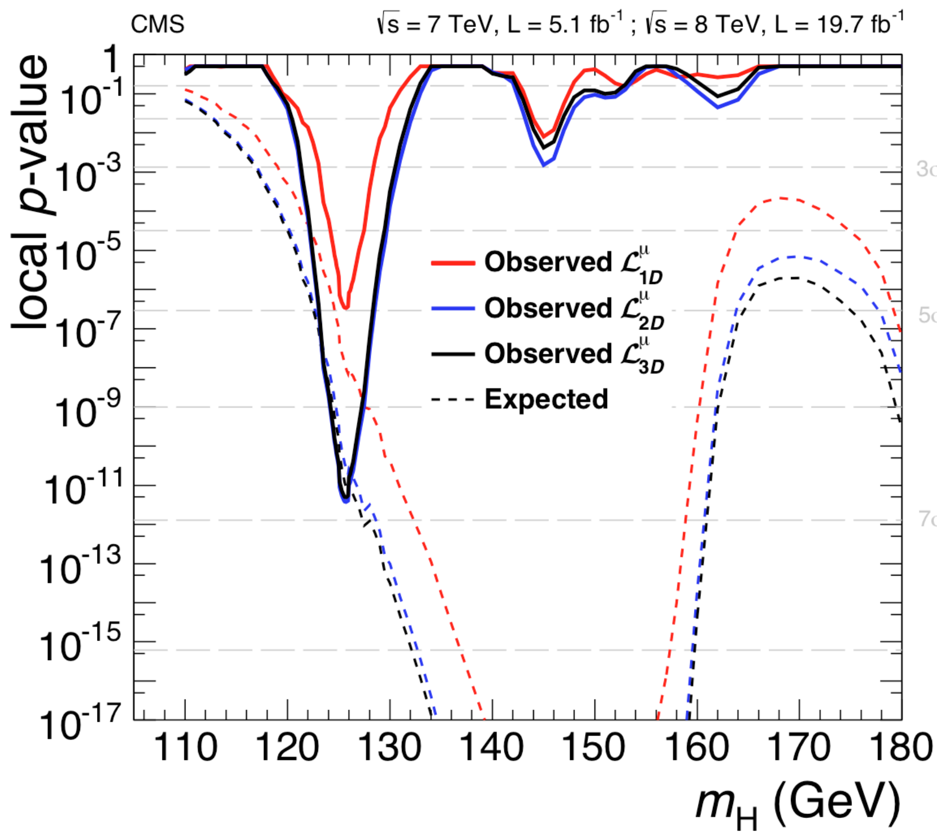
Colours are signal + BG



Colours are BG only



H → ZZ → 4l: results

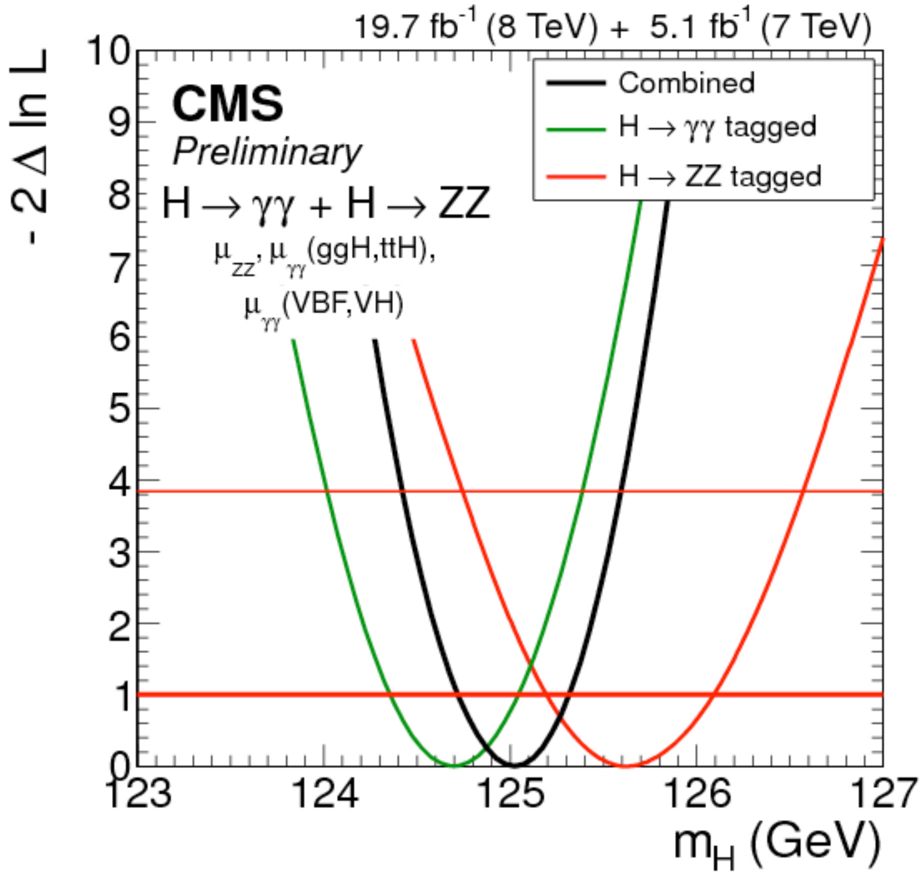


Phys.Rev. D89 (2014) 092007

- Largest signal observed around 125 GeV (standalone discovery)
  - Local significance 6.8 σ
  - Expected significance 6.7 σ
  - Fitted $\mu = \sigma/\sigma_{SM}$ at 125 GeV $0.93^{+0.26}_{-0.23}$ (stat.) $^{+0.13}_{-0.09}$ (syst.)

Higgs mass measurement

- From H→γγ and H→ZZ→4l we can precisely measure the mass



CMS PAS HIG-14-009

The two measurements are consistent within 1.6 sigma

H→γγ M_H = 124.7 ± 0.34 GeV (± 0.31 GeV stat. ± 0.15 GeV syst.)

H→ZZ→4l M_H = 125.6 ± 0.4 (stat.) ± 0.2 (syst.) GeV

Combined $M_H = 125.03^{+0.29}_{-0.31}$ GeV $\left(^{+0.26}_{-0.27} (\text{stat.}) \; ^{+0.13}_{-0.15} (\text{syst.}) \; \text{GeV} \right)$

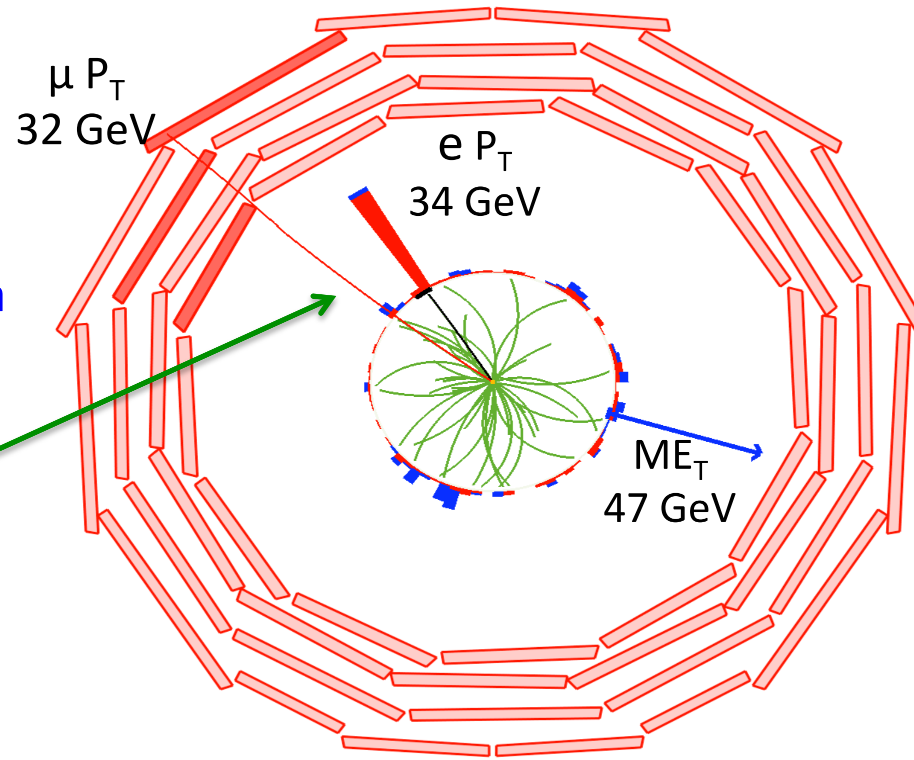
Low mass resolution channels

- 3 channels with lower mass resolution (10-20%)
  - $H \rightarrow WW$
  - $H \rightarrow \tau\tau$
  - $H \rightarrow bb$
  - Search for wide excess over the predicted BG

H→WW→lνlν

- Most sensitive channel around $2xM_W$
  - Also at 125 GeV it gives the smallest error on μ
- **No narrow mass peak (mass resolution ~20%)**
- Two high p_T isolated leptons **+ MET**
- Main backgrounds
  - WW (irreducible)
  - Z+jets, WZ, ZZ, tt, W + jets
- BG estimation is crucial
  - Main BG estimated from data

H→WW→eμνν candidate



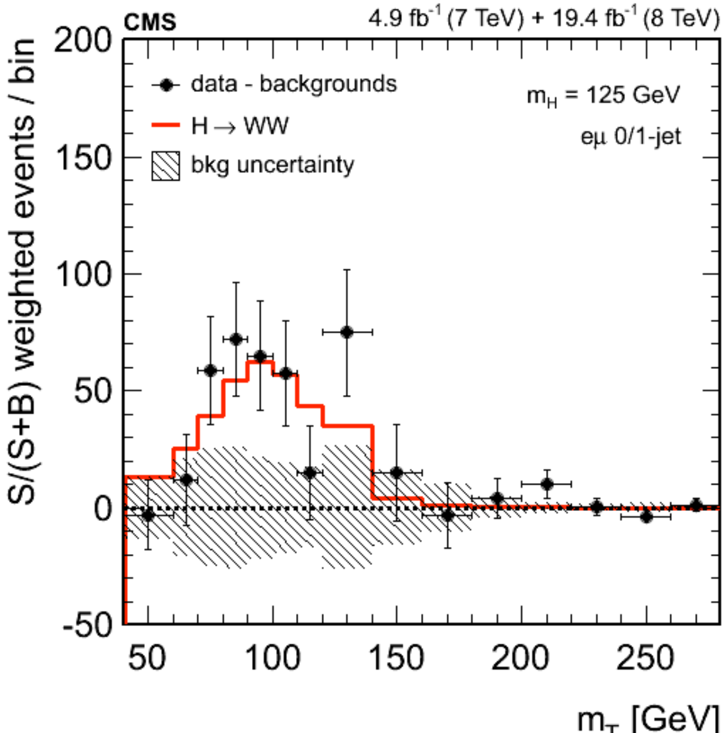
Scalar Higgs boson +
V-A structure of W decay
favors small opening angle
between the 2 charged
leptons
(tend to have small Δϕ)

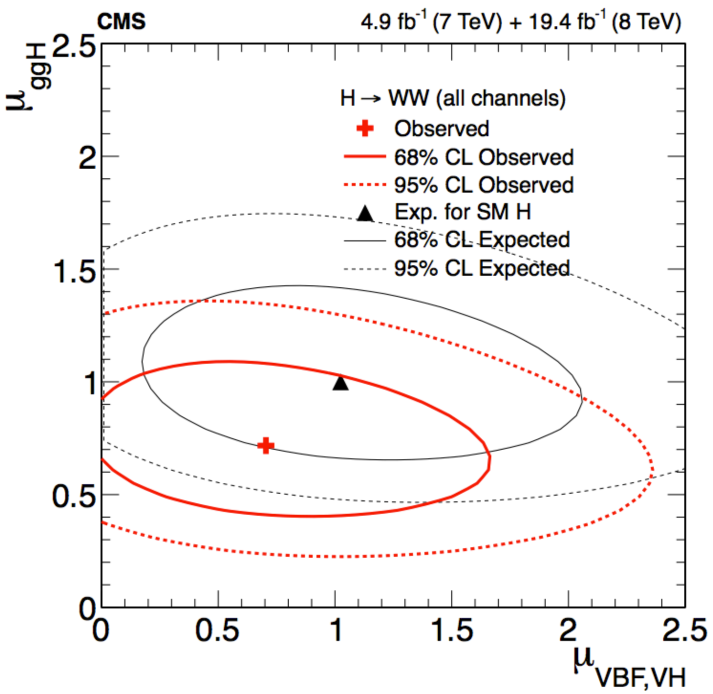
H→WW→lνlν: results

- Broad evidence of signal around 125 GeV
  - expected significance: 5.8 σ
  - observed significance: 4.3 σ
  - Fitted $\sigma/\sigma_{SM} = 0.72^{+0.20}_{-0.18}$

JHEP 01 (2014) 096

Several channels are used: 0jet, 1 jet, VBF, VH





H→ττ analysis

- Complicated analysis, many different sub-channels

Decay

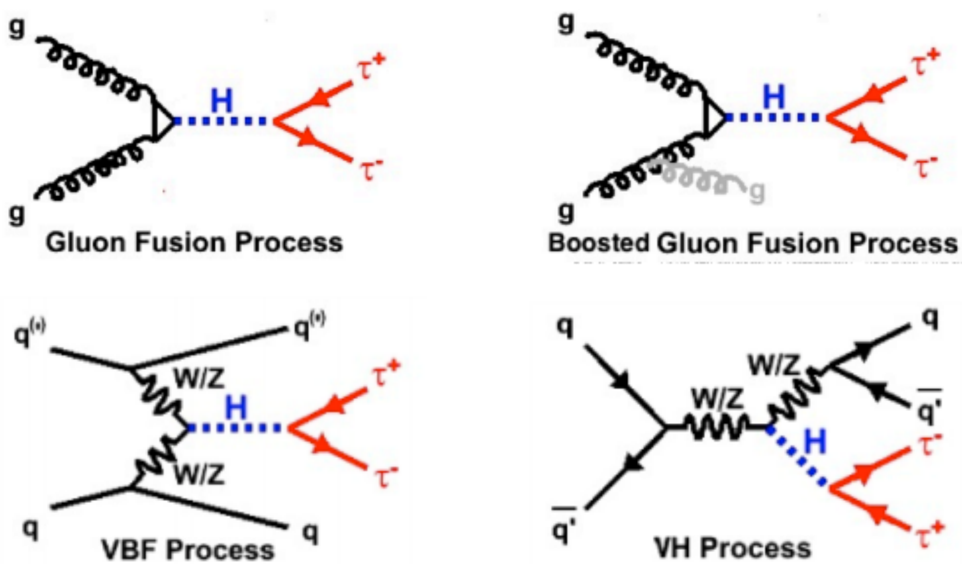
$$H \to \tau\tau \to \ell\ell + 4\nu \ (12\%)$$
$$H \to \tau\tau \to \ell\tau_h + 3\nu \ (46\%)$$
$$H \to \tau\tau \to \tau_h\tau_h + 2\nu \ (42\%)$$

$\otimes$

Production/signature

0-jet
1-jet boosted
2-jet VBF
VH (use leptonic decays of V)

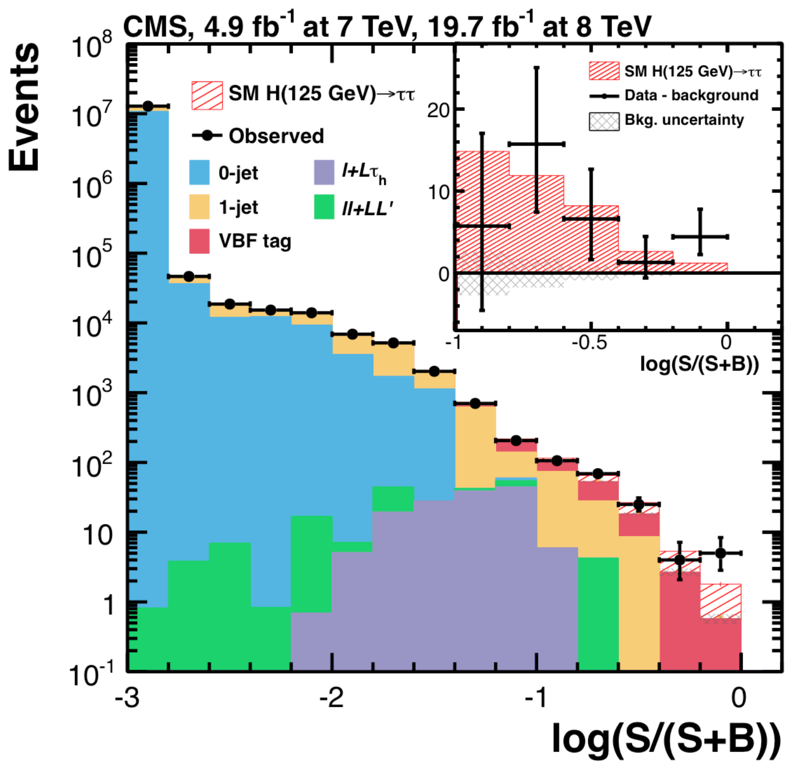
Also split e and μ in the analysis

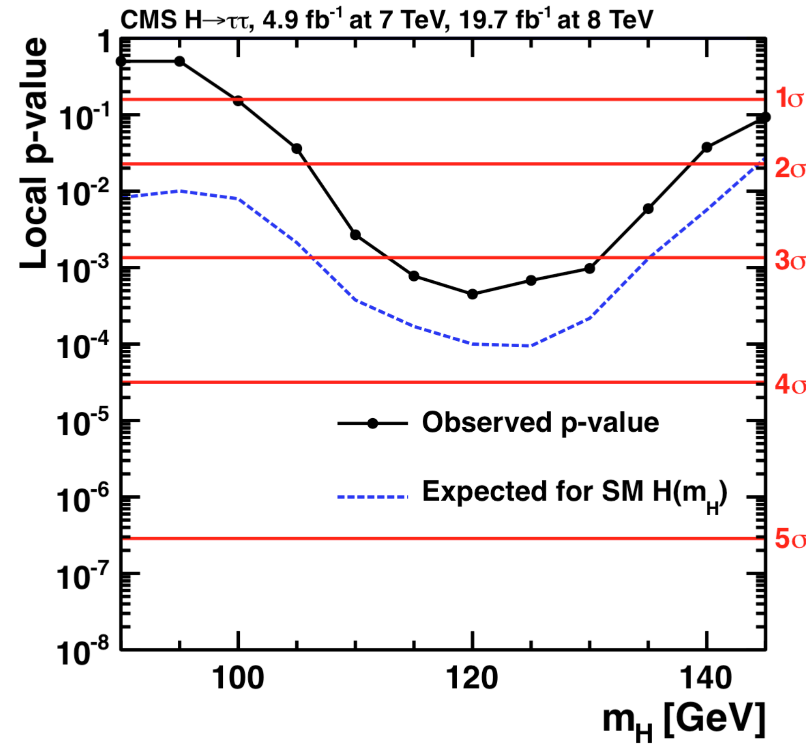


- Z→ττ main BG (also W+jets, tt and QCD)
- 0-jet category not very senstive but mainly useful to fit BG normalization and other nuisances

- Also important for MSSM

H→ττ: results



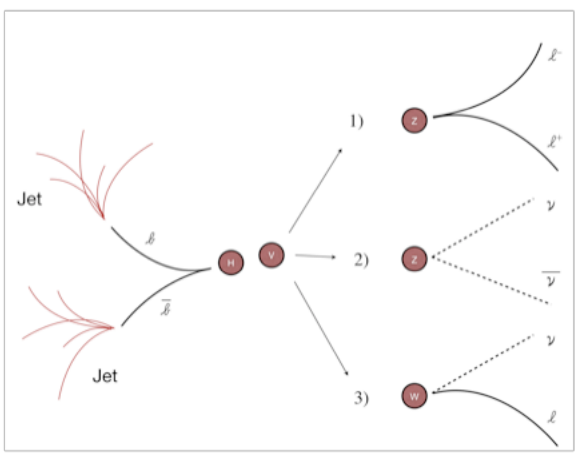


- Broad evidence of signal near 125 GeV
  - observed significance: 3.2 σ
  - expected significance: 3.7 σ
  - Fitted $\sigma/\sigma_{SM} = 0.78 \pm 0.27$
- Evidence of Higgs coupling to τ leptons

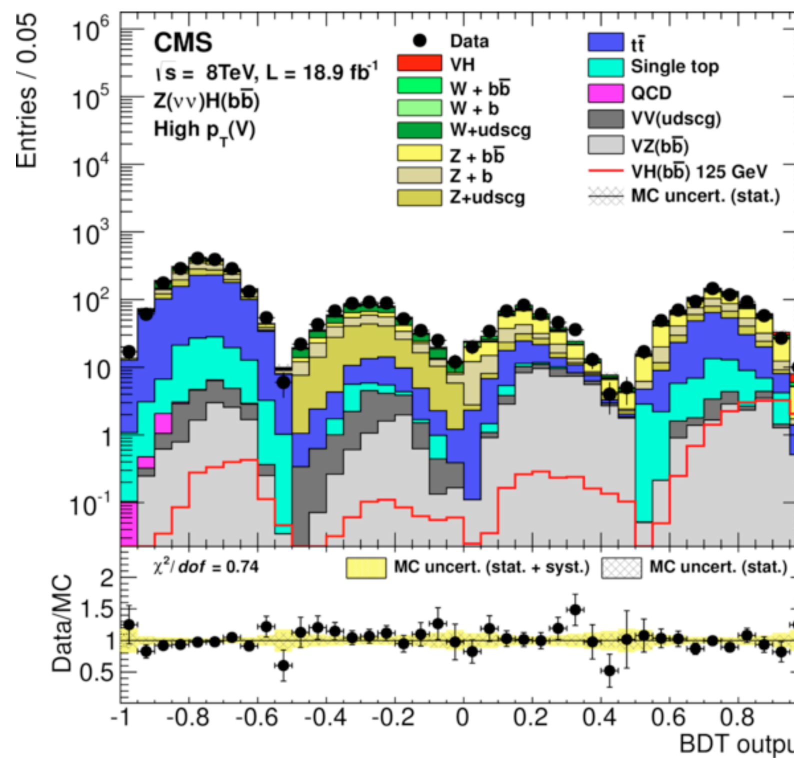
JHEP 1405 (2014) 104

H→bb channel

- QCD BG too large for gg fusion, needs additional tag
- Most sensitive is VH (but also use VBF and ttH)
- Common features:
  - B-tagging
  - bb mass reconstruction, use BDT regression (σ_M/M = 8-9%)
  - MVA based analyses to enhance the sensitivity

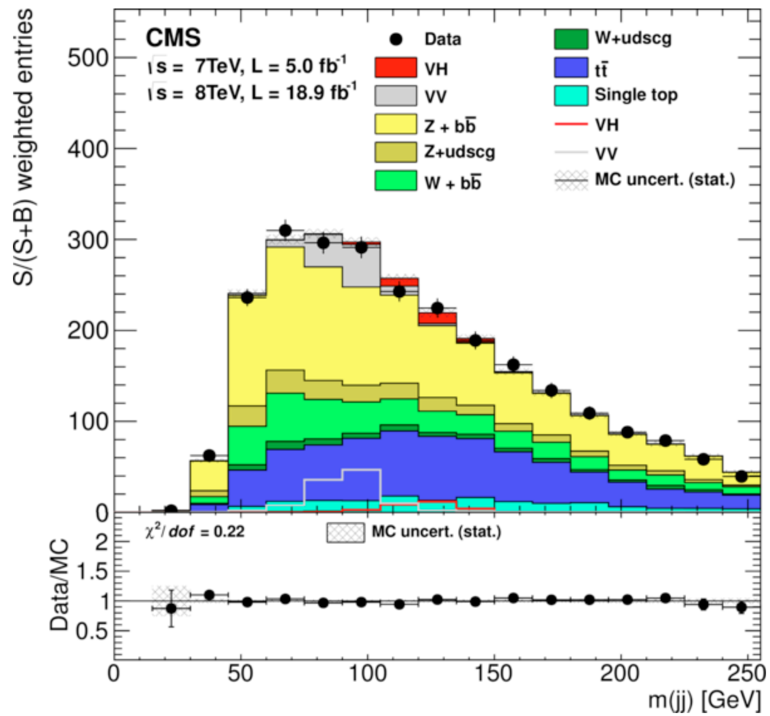


W→e,μ, Z→ee,μμ,νν

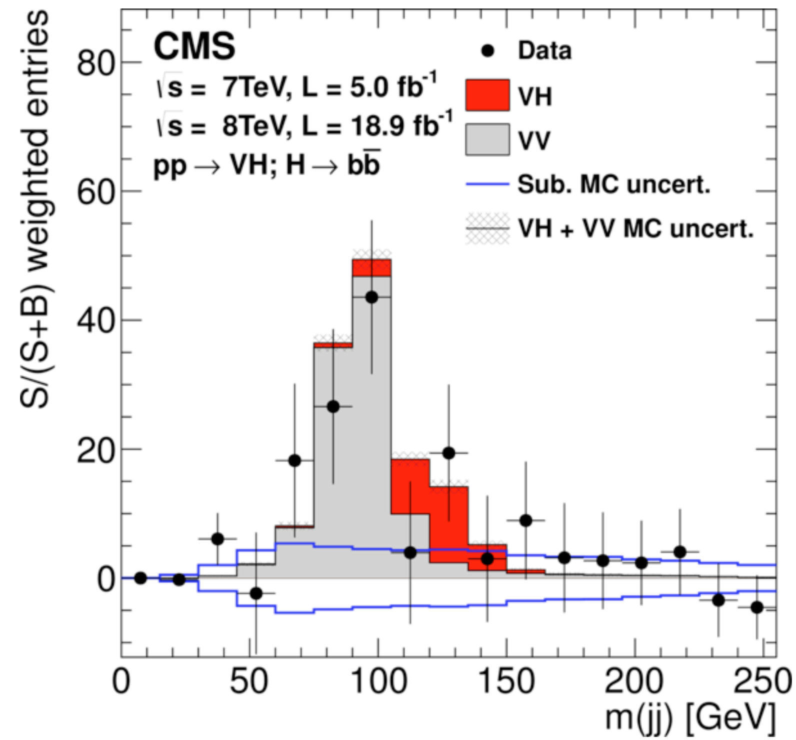


VH, H→bb: combined plots

s/b weighted mass distribution



BG subtracted (except VV)



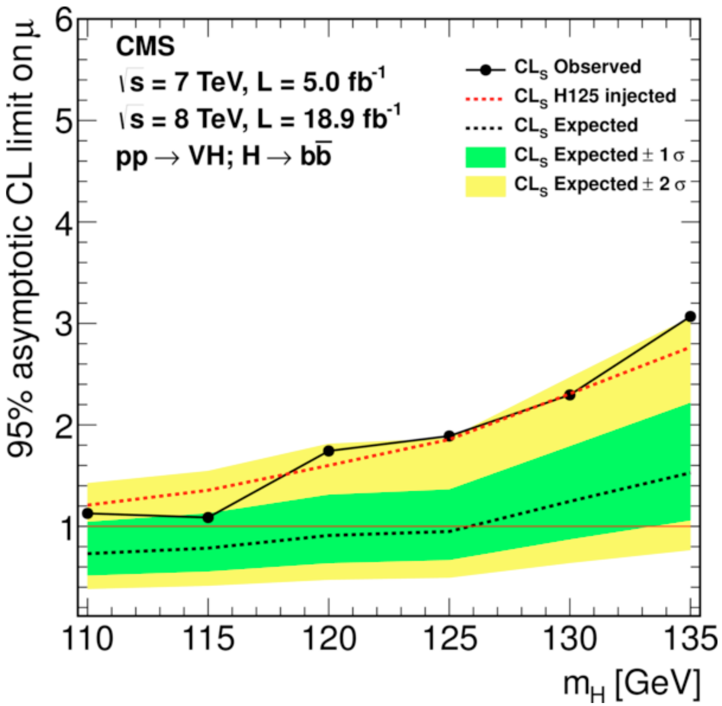
Dibosons, mainly ZZ and WZ with Z→bb

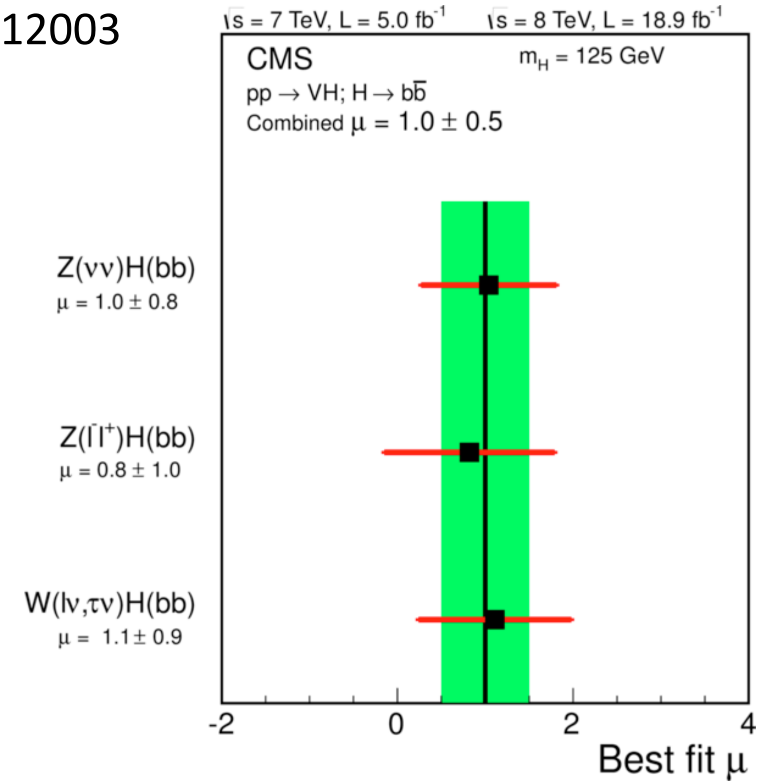
Higgs signal

Phys. Rev. D 89, 012003

VH with H→bb: results

Phys. Rev. D 89, 012003





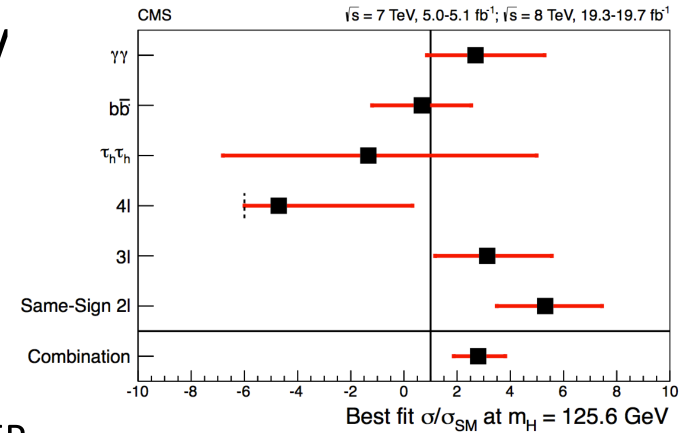
- Excess of events near 125 GeV
  - expected significance: 2.1 σ
  - observed significance: 2.1 σ
  - Fitted $\sigma/\sigma_{SM} = 1.0 \pm 0.5$

Combined with H→ττ gives 3.8 σ significance: evidence of Higgs coupling to down type fermions

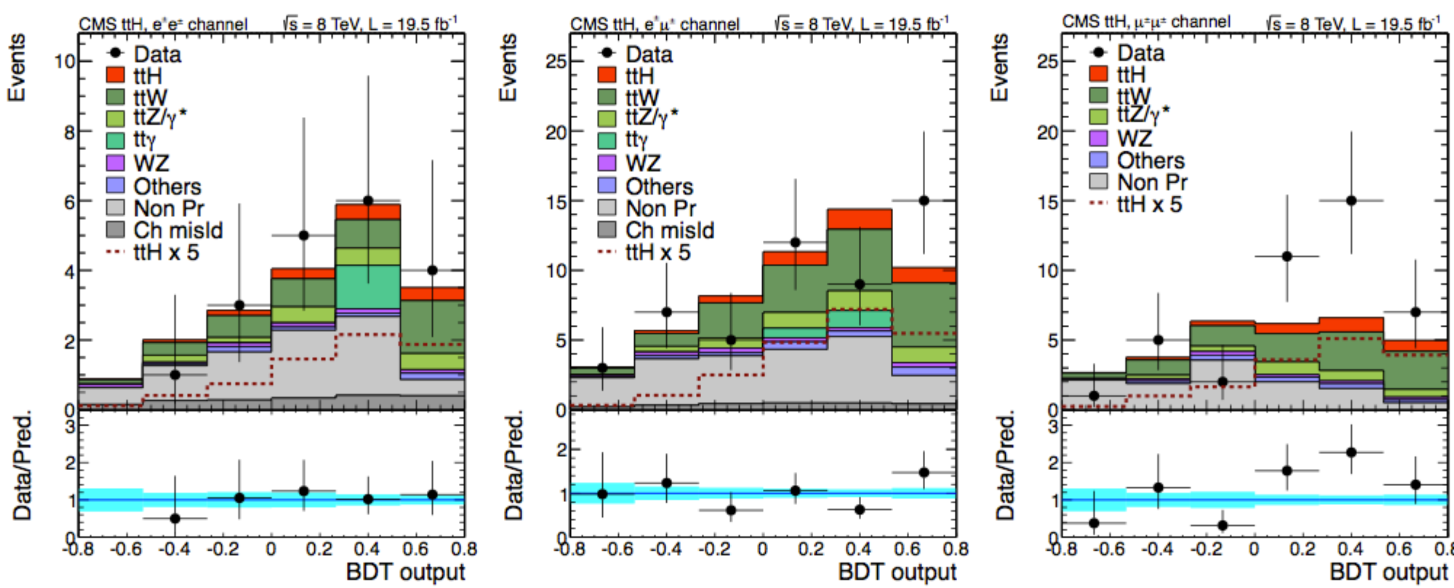
Nature Phys. 10 (2014)

ttH production

- Search for ttH production in H→bb, γγ, multileptons
- Some excess of events near 125 GeV (~2σ above SM expectation)
  - expected significance: 1.1 σ
  - observed significance: 3.4 σ
  - Fitted σ/σ_{SM} = 2.8 ± 1.0



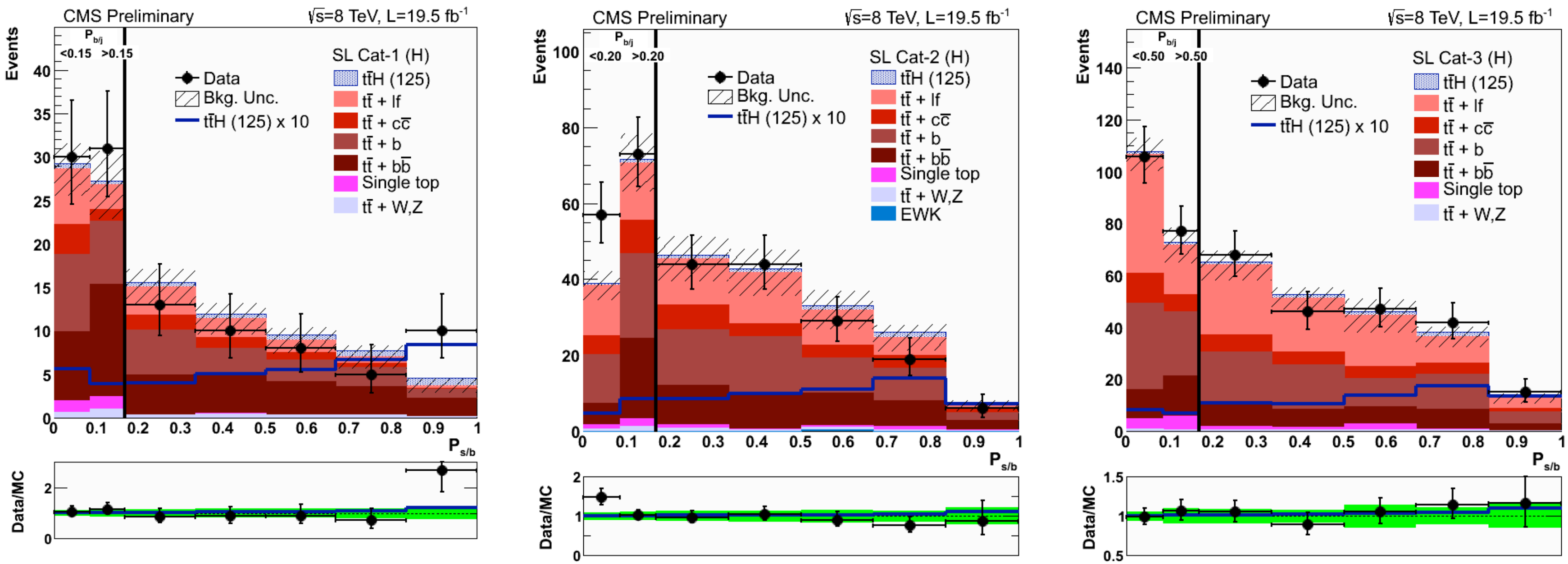
arXiv:1408.1682
Accepted by JHEP



Excess driven by the same sign di-lepton search

ME approach for ttH, H→bb

- New preliminary analysis using the Matrix Element Method (MEM)
- Assigns a differential probability density to each event based on the LO matrix element for signal and ttbb BG



- 95% upper limit on μ: 2.9 (3.3 expected) - Large improvement compared to published analysis
- Best fit $\mu = 0.67^{+1.35}_{-1.33}$

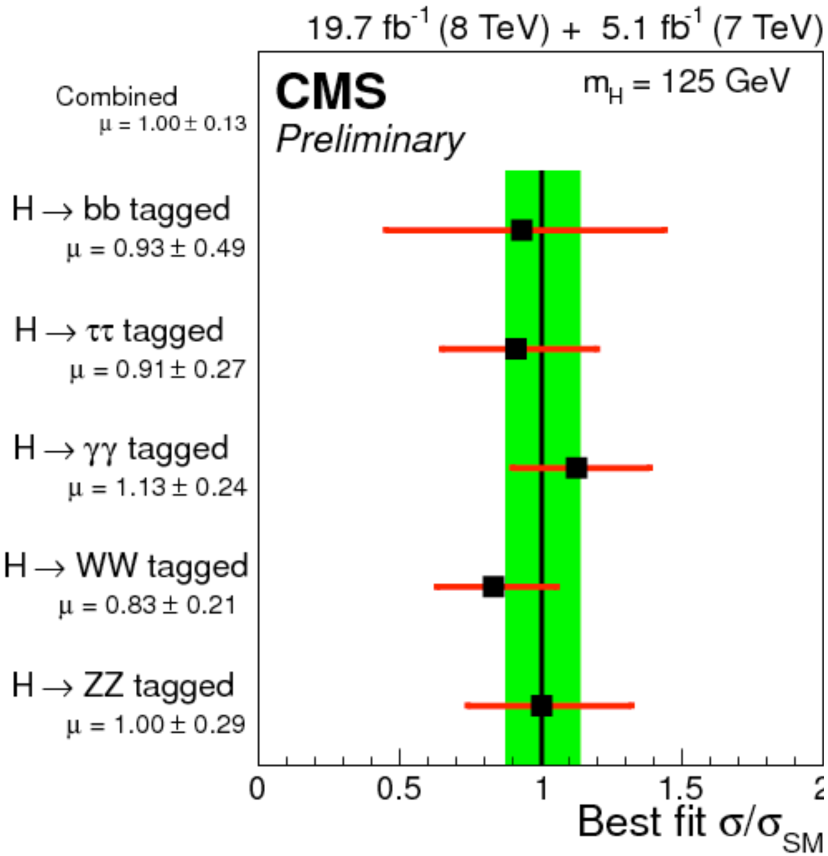
CMS PAS HIG-14-010

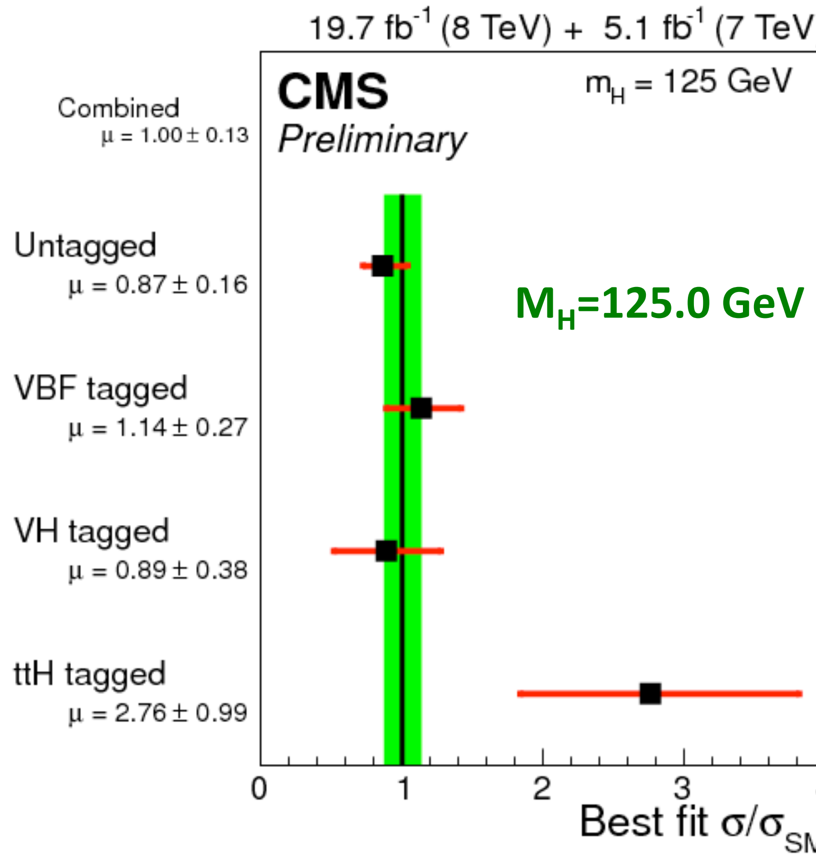
H125 Higgs boson properties

- All channels are combined
- Profile likelihood fits are carried out with all nuisances profiled
- Again, cross sections, BR and recommendations taken from the LHC cross section WG:
  - https://twiki.cern.ch/twiki/bin/view/LHCPhysics/CrossSections

Measured signal strengths

CMS PAS HIG-14-009



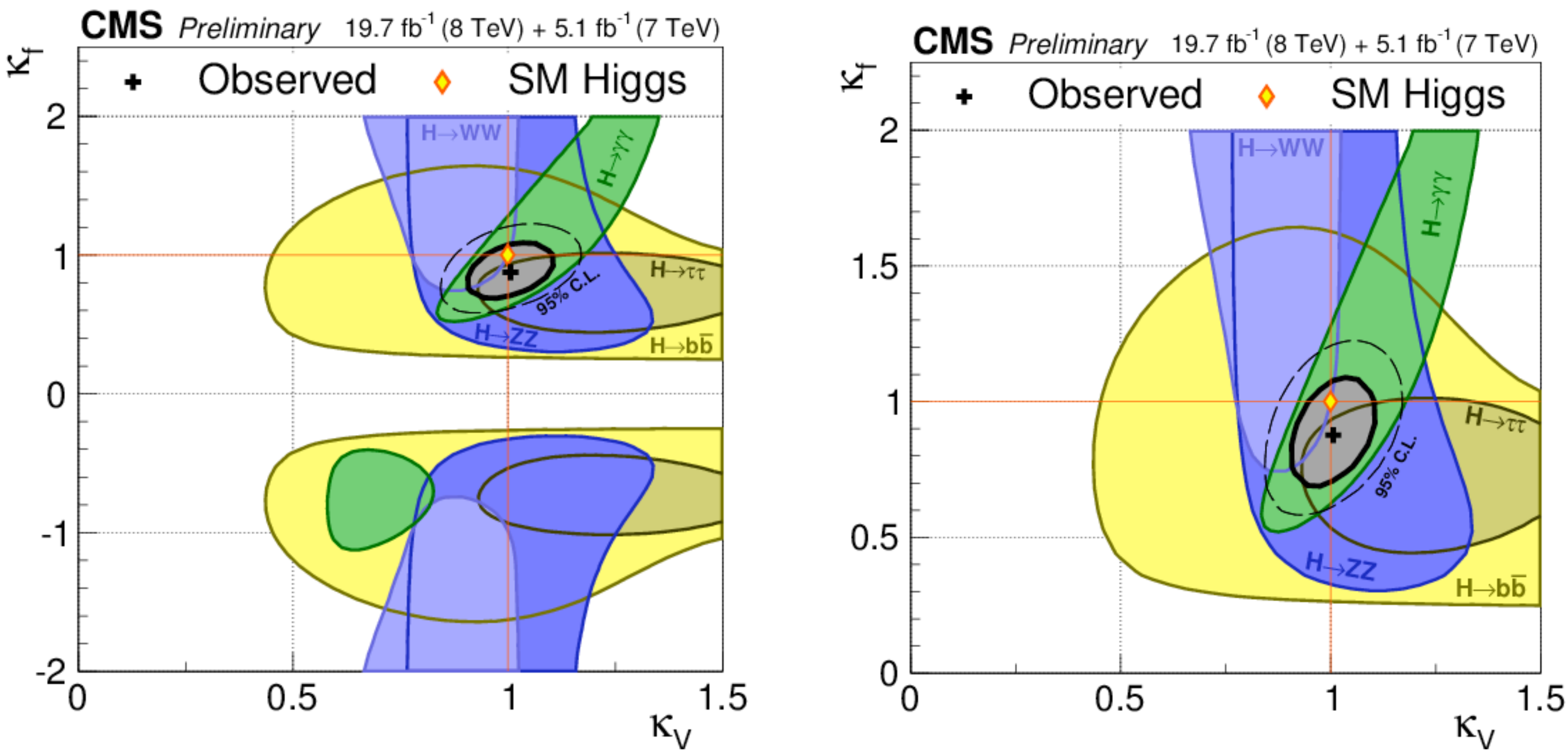


- The fitted μ of the 125 GeV Higgs signal is:
  - $\sigma/\sigma_{SM} = 1.00 \pm 0.13$
- Signal strengths in different channels are consistent with the SM
- Common cross section theoretical errors contribute to all measurements
  - dominated by 15% error on gg-fusion where applicable

CMS: κ_V, κ_f contours

- Vector and fermion couplings are scaled by two scale factors , κ_V and κ_F
- Agree with SM within ~1 σ

CMS PAS HIG-14-009



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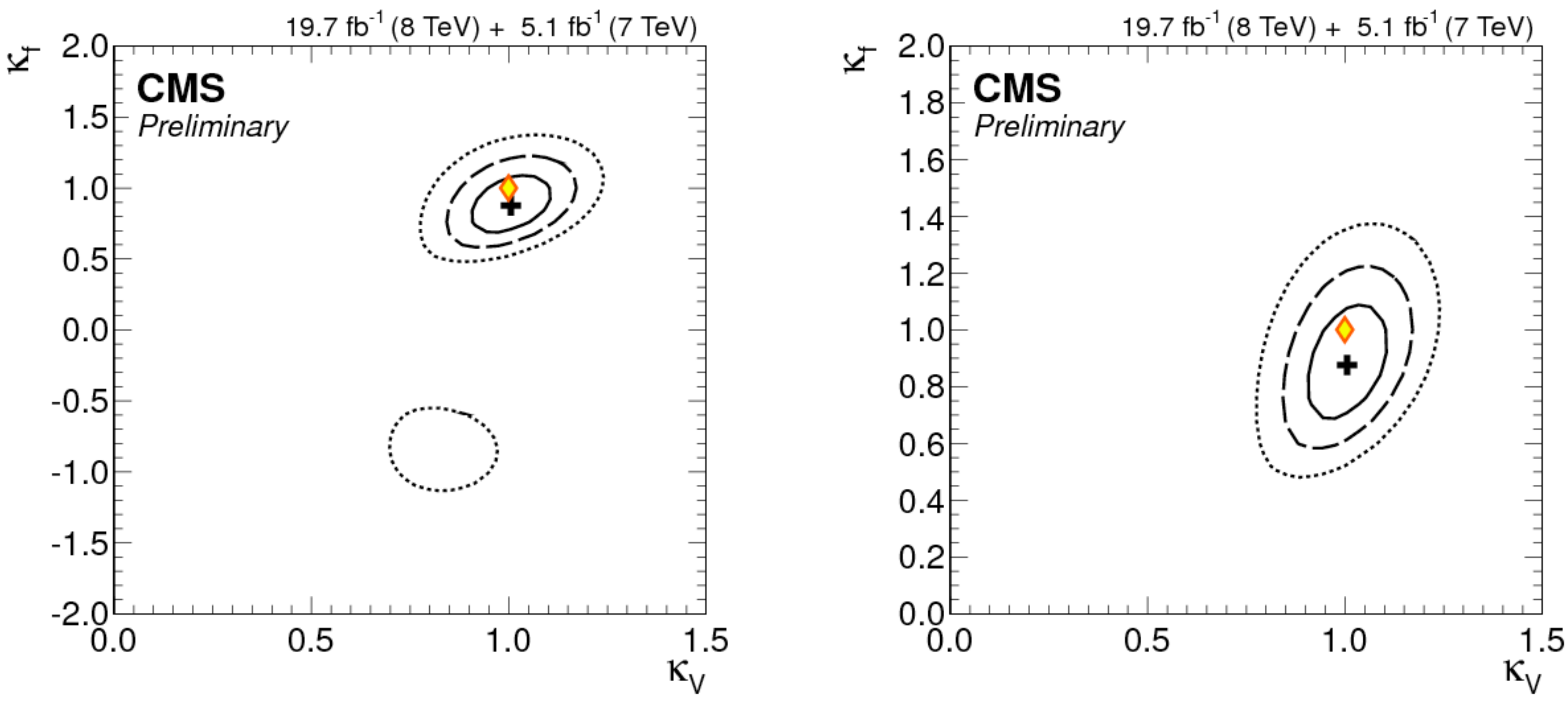
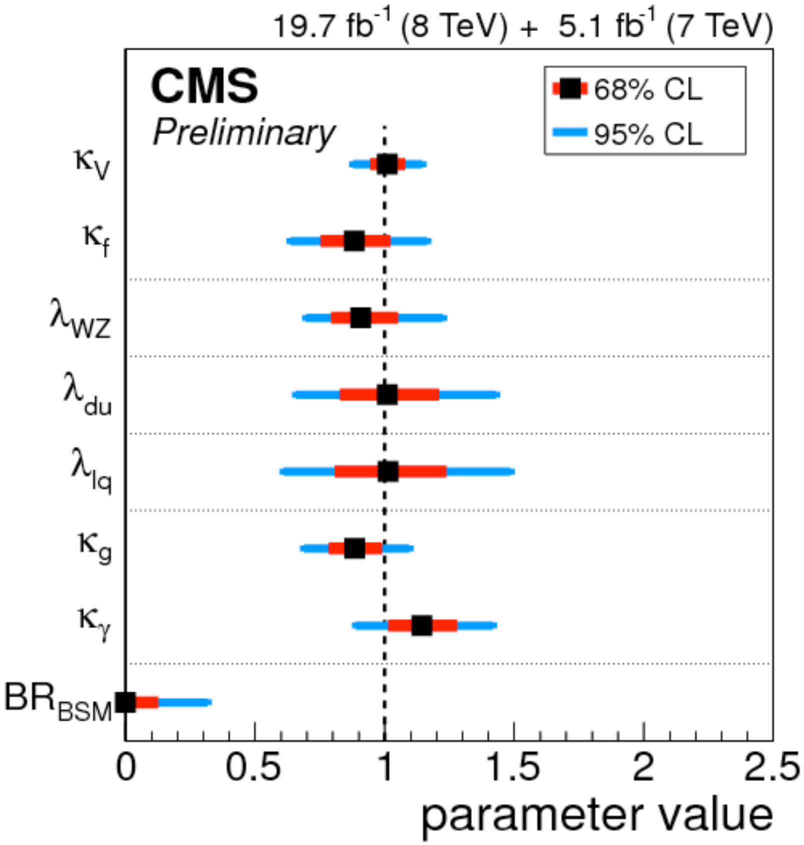
CMS PAS HIG-14-009

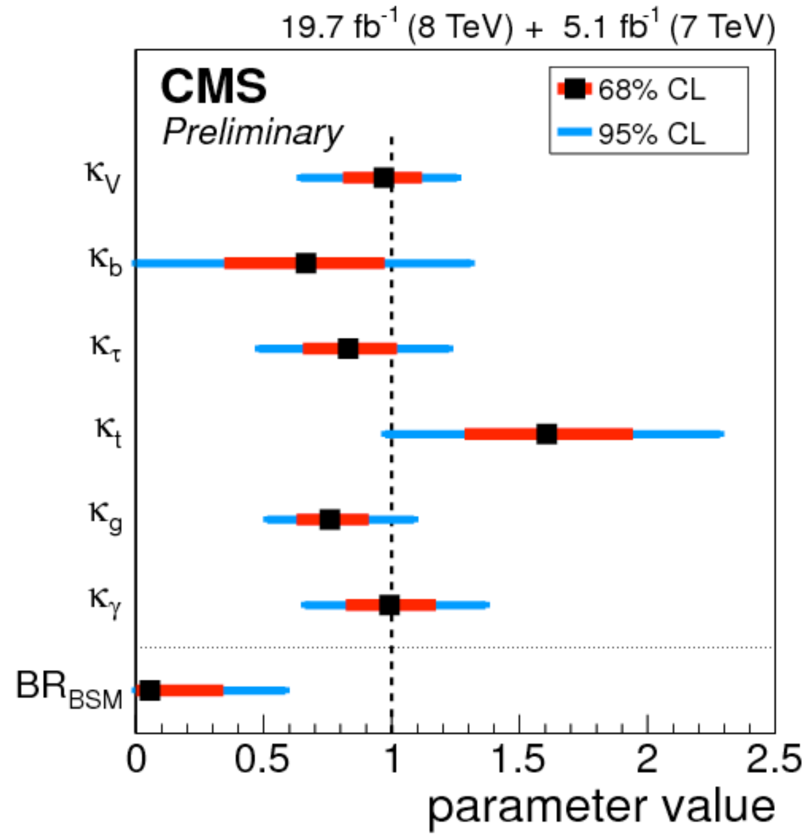


Other couplings fits

For each fit the most relevant model Parameters are profiled and others are fixed to the SM

six-parameter model including effective loop couplings



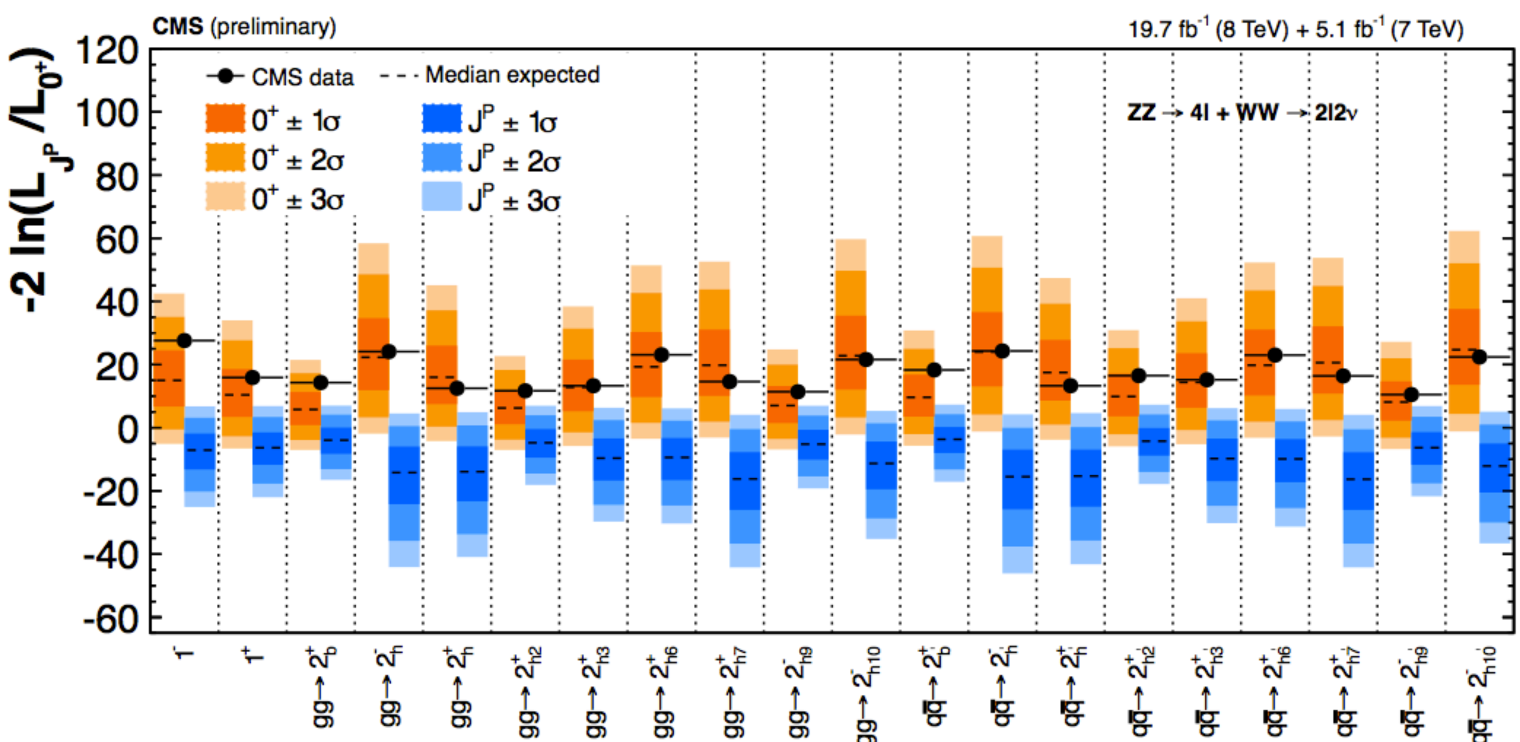


- $BR_{BSM} < 0.58$ at 95% C.L. (with $\kappa_V \leq 1$)

CMS PAS HIG-14-009

Spin-parity hypothesis testing

- Spin and parity can be probed using angular distributions
- Mainly use H→ZZ and H→WW
  - Using discriminators similar to K_D we can distinguish between scalar and pseudo-scalar and different spin hypotheses
  - **Tested models for 0^-, spin 1 and spin 2 excluded at C.L > 99%**

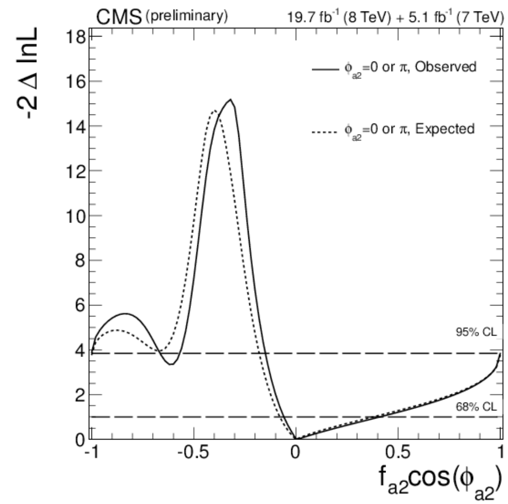


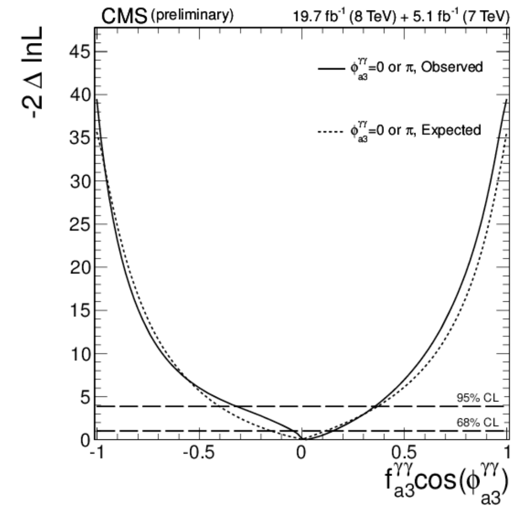
HIG-14-012, HIG-14-014

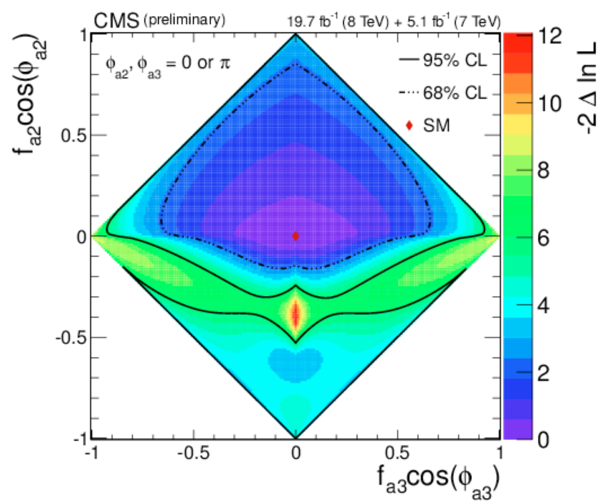
Constraints on anomalous HVV interactions

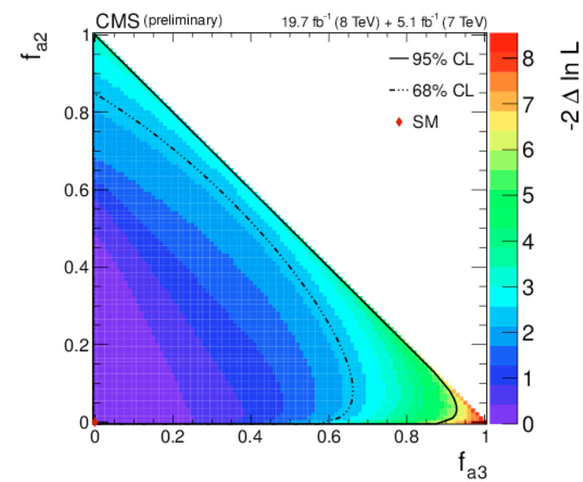
HIG-14-012, HIG-14-014

- Using H→ZZ, γ*Z, γ*γ* and H→WW set limits on the fraction of anomalous contributions
- We have already published a limit on f_{a3} (fraction of pseudo-scalar component) $f_{a3}=0.00^{+0.15}_{-0.00}$
- We now probe more anomalous couplings including Higgs interactions with γ*Z, γ*γ*





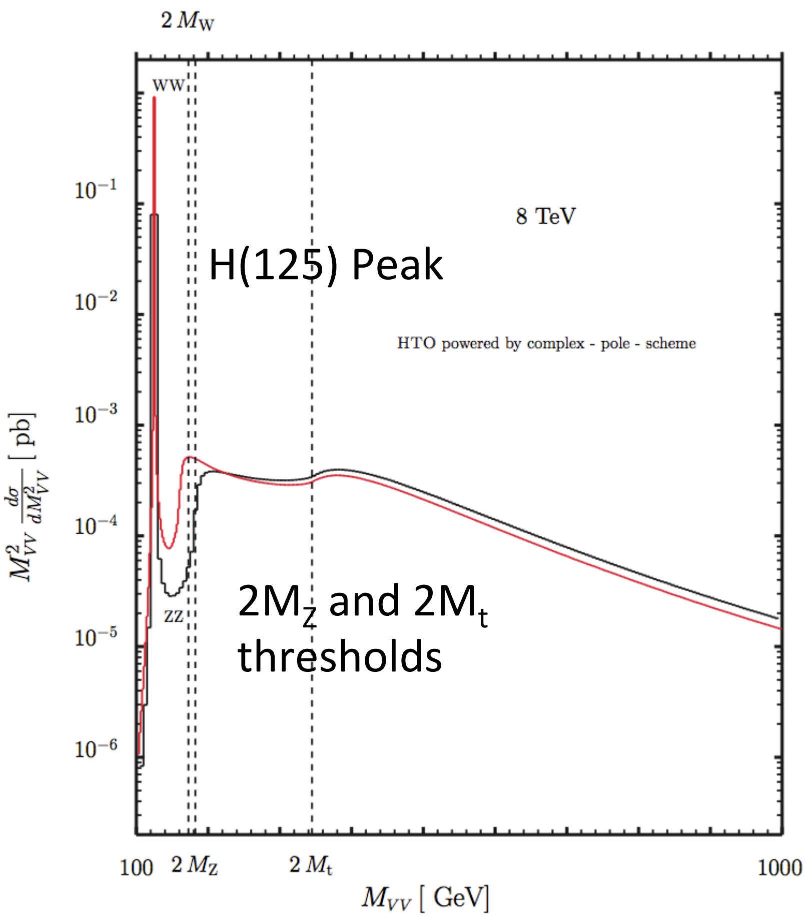




All results are found consistent with the SM

Width from off-shell ZZ production

Narrow width approximation not adequate for Higgs to VV



N. Kauer and G. Passarino, JHEP 08 (2012) 116

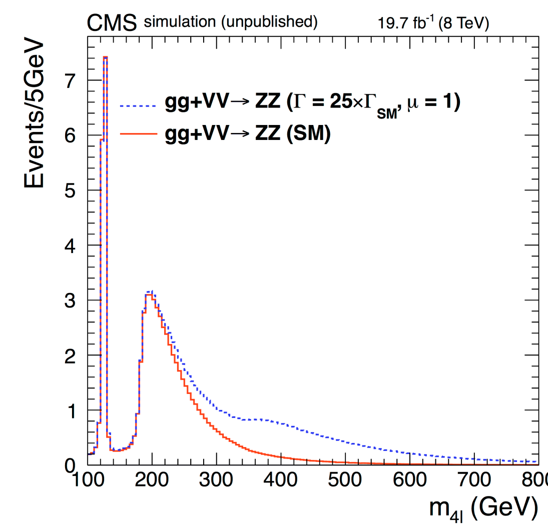
$$\frac{d\sigma_{gg\to H\to ZZ}}{dm^2_{ZZ}} \sim \frac{g^2_{ggH}g^2_{HZZ}}{(m^2_{ZZ}-m^2_H)^2+m^2_H\Gamma^2_H}$$

Off-shell   On-shell

$$\sigma^{\text{off-shell}}_{gg\to H^*\to ZZ} \sim \frac{g^2_{ggH}g^2_{HZZ}}{(2m_Z)^2} \qquad \sigma^{\text{on-shell}}_{gg\to H\to ZZ^*} \sim \frac{g^2_{ggH}g^2_{HZZ}}{m_H\Gamma_H}$$

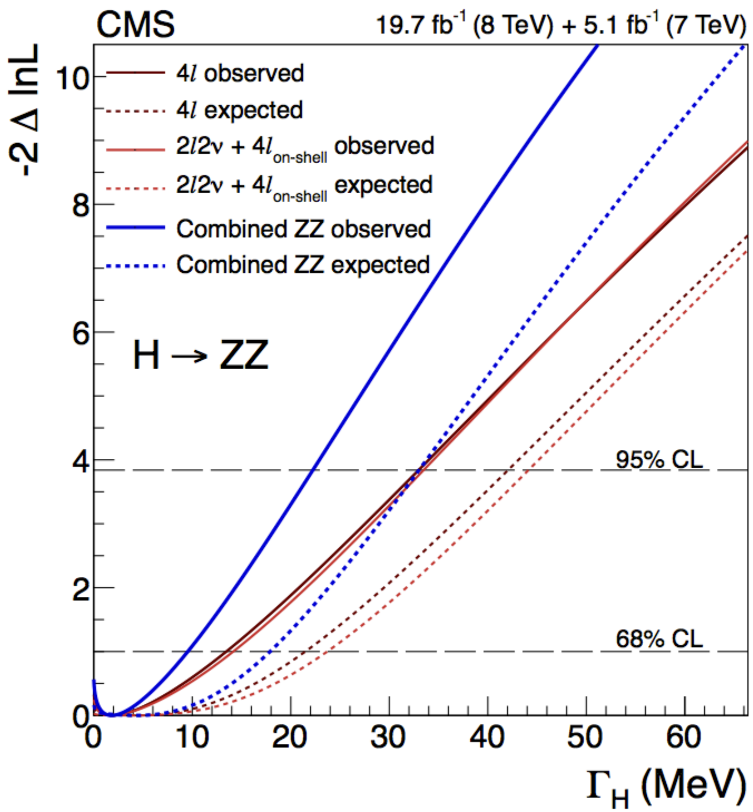
Off-shell contribution sizeable: O10%)

In the assumption the the couplings are unchanged
Between on-shell and off-shell, from the ratio we can derive information on the width



Analysis and results

- Use MELA gg→ZZ discriminator vs mass for H→4l (on-shell and off-shell)
- Transverse mass for H→2l2nu (off-shell only)



Phys. Lett. B 736 (2014) 64

Results:

95% Exclusion observed (expected):

Γ_H/Γ_{HSM}<8.1 (10.6)

Γ_H<33 (44) MeV (SM width 4.15 MeV)

Best fit value:

$1.8^{+12.4}_{-1.8}$ MeV

Direct 95% C.L. upper limit from ZZ and γγ much worse, O(1 GeV)

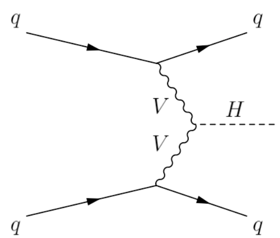
Other H decay channels

- H→invisible
- H→μτ (Lepton Flavour Violation)

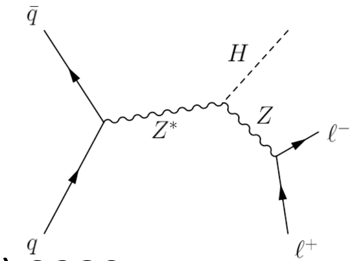
Higgs to invisible

- The Higgs boson could decay to invisible particles, such as dark matter candidates
- Exploit VBF qqH and ZH with Z→ll(bb) production modes

VBF

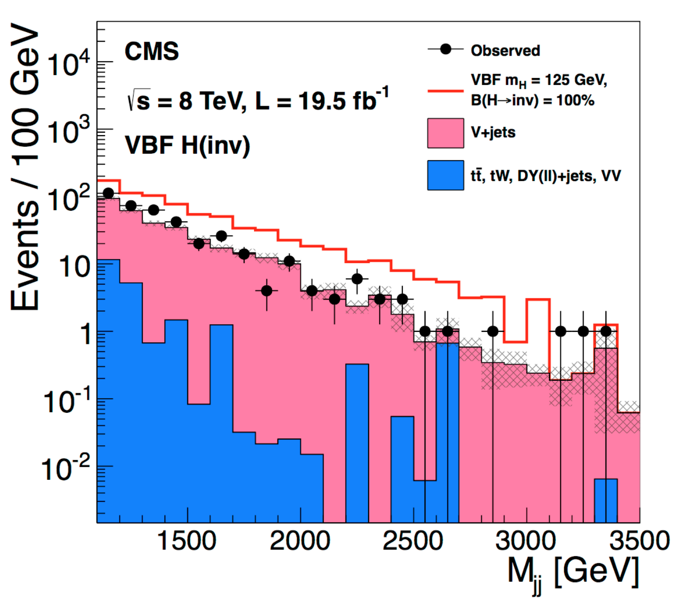


ZH

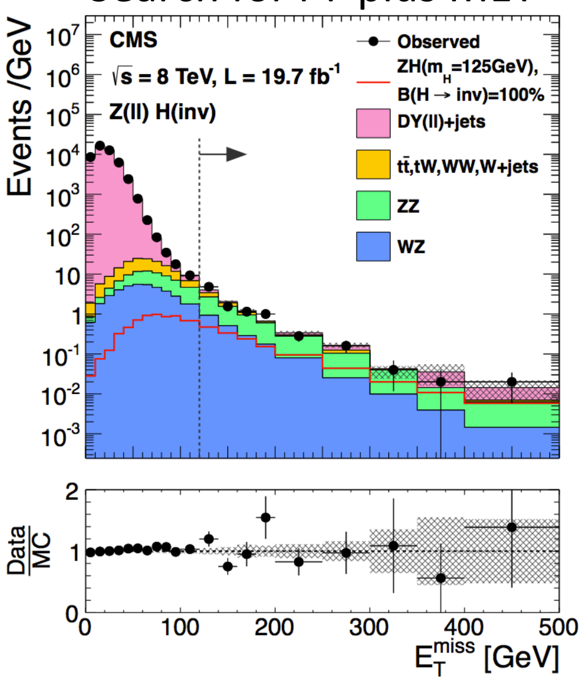


Eur. Phys. J. C 74 (2014) 2980

Search for VBF jets plus MET



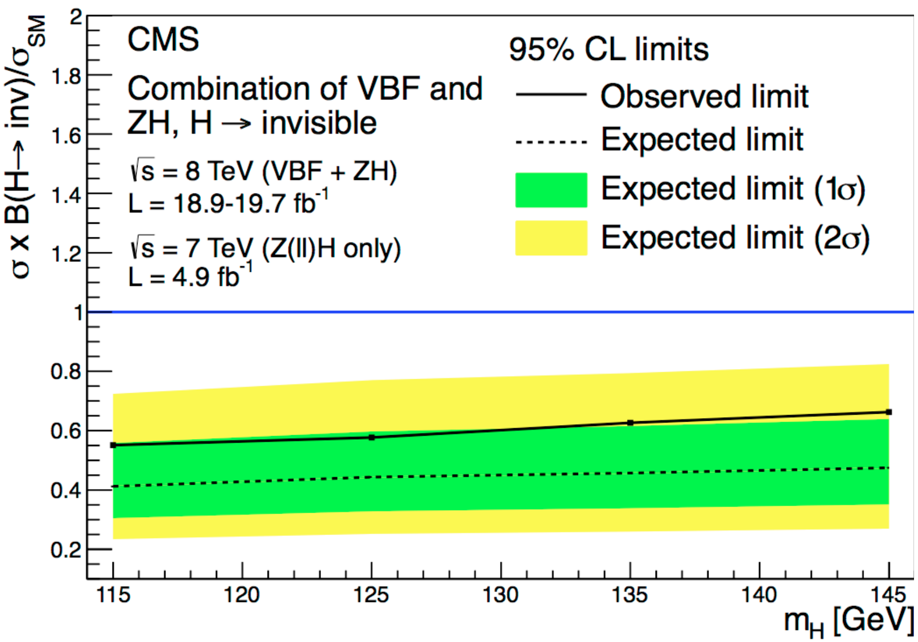
Search for l^+l^- plus MET

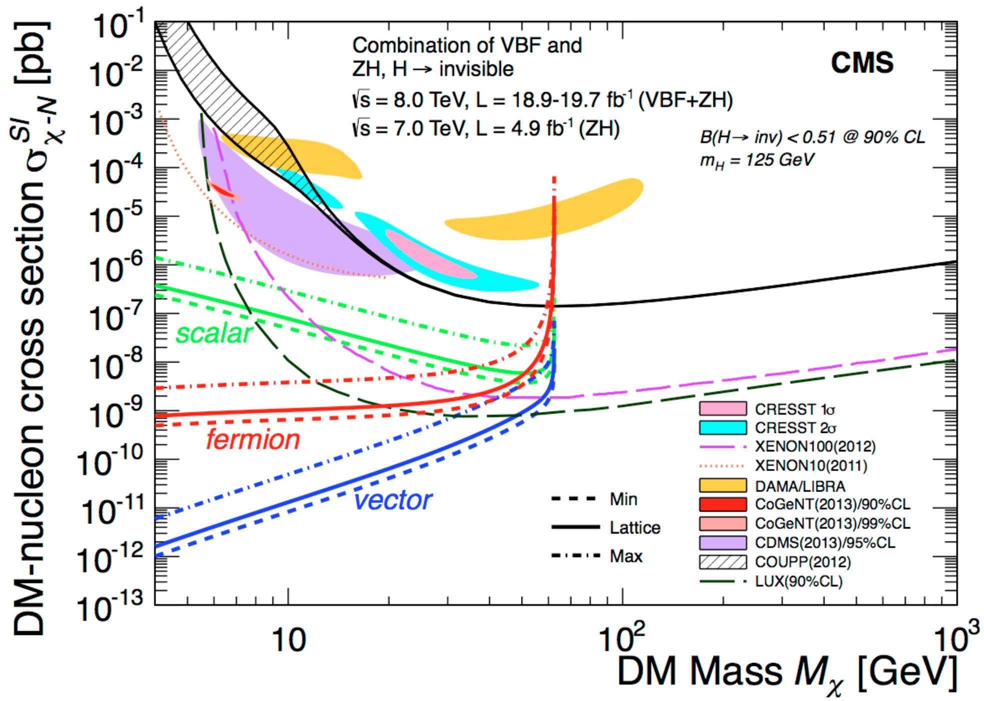


Combined exclusion and DM interpretation

No signal observed and limits are derived

Eur. Phys. J. C 74 (2014) 2980





Combined limit:
BR(H→inv) < 0.58 at 95% CL (exp. 0.44)

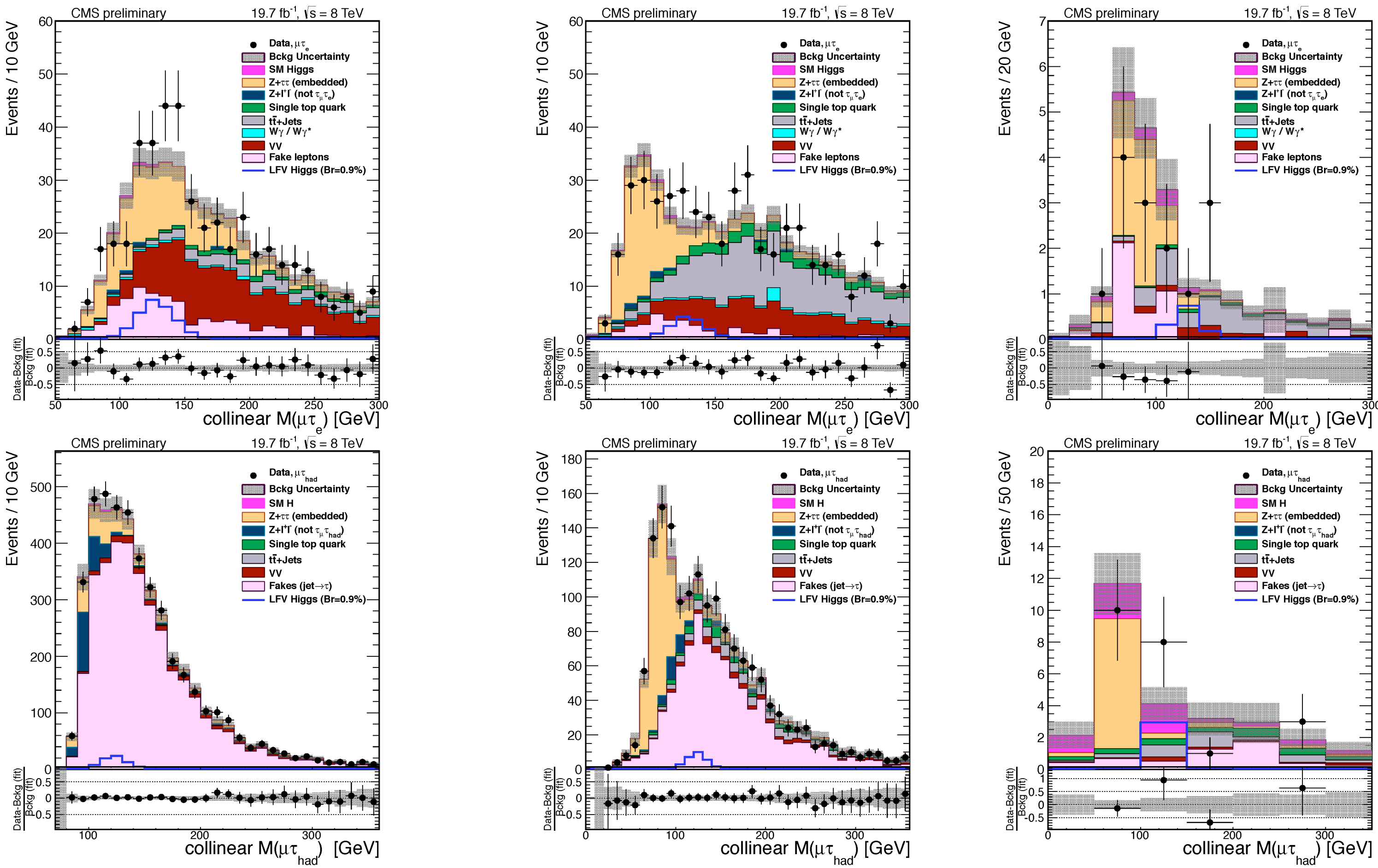
These limits can be interpreted in a Higgs portal model in which the DM couples to the Higgs

LFV H→τμ

- Use 19.7 fb^{-1} of 8 TeV data
- Search for $\mu\tau_e$ and $\mu\tau_{had}$

CMS PAS HIG-14-005

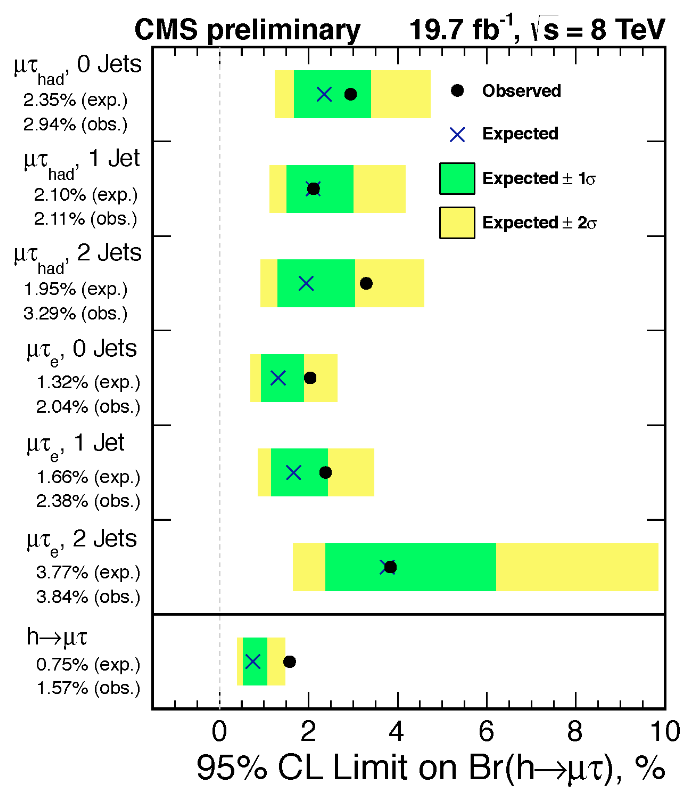
- Split the search in jet-mutiplicity bins (0, 1, 2)

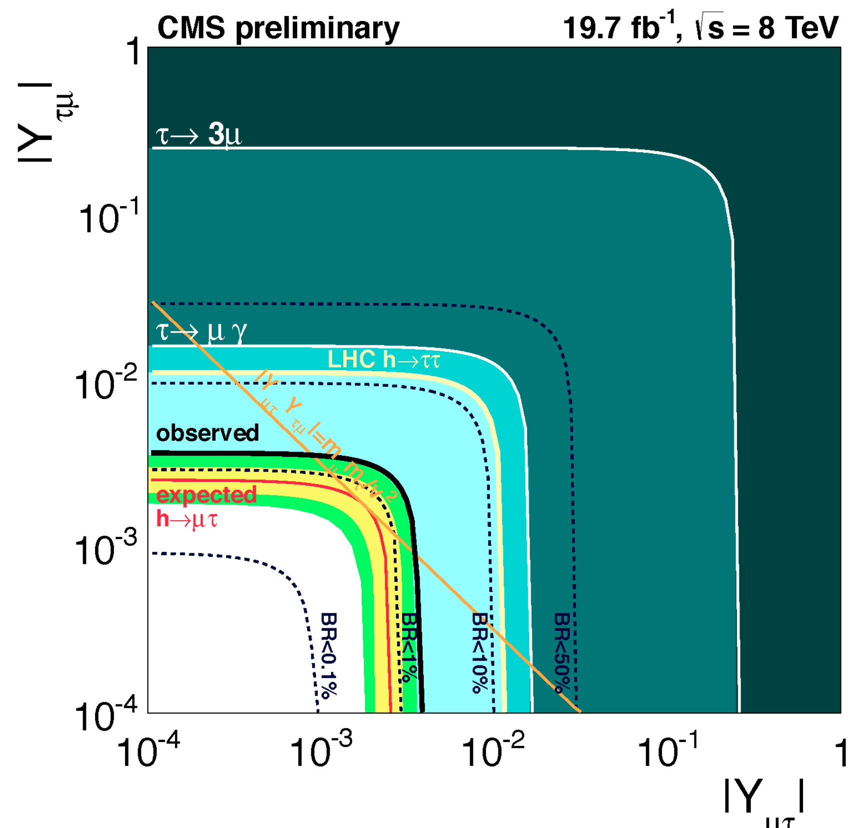


LFV H→τμ results

- BR(H→μτ) < 1.57% at 96% C.L. improved x10 compared to indirect limits
- Slight excess observed in the data (2.5 σ)
- Best fit BR = 0.89 $^{+0.40}_{-0.37}$ %

CMS PAS HIG-14-005





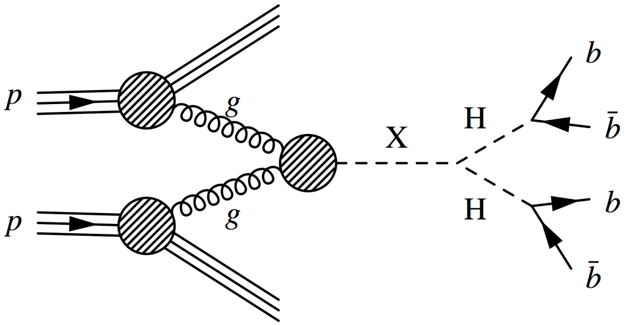
Other BSM Higgs studies

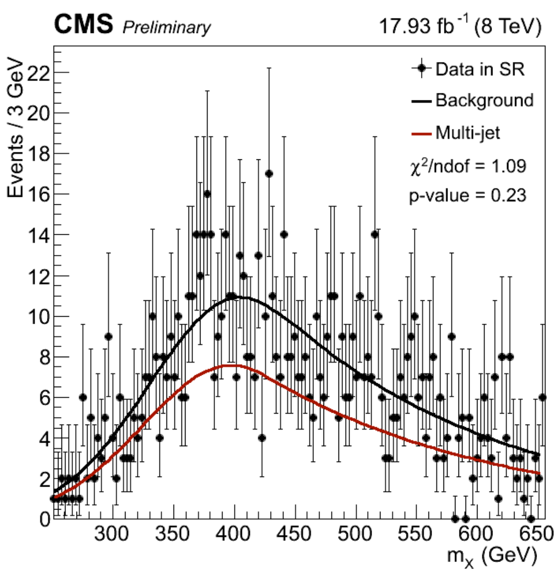
- Resonant di-Higgs production
- MSSM $\phi \rightarrow \tau\tau$ searches

X→HH→4b, bbγγ

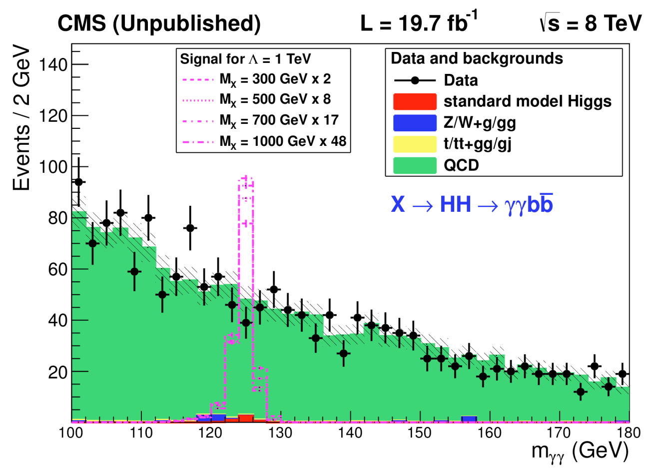
- Search for the resonant production of 2 Higgs bosons: i.e. radion or graviton

HH→bbbb HIG-14-013

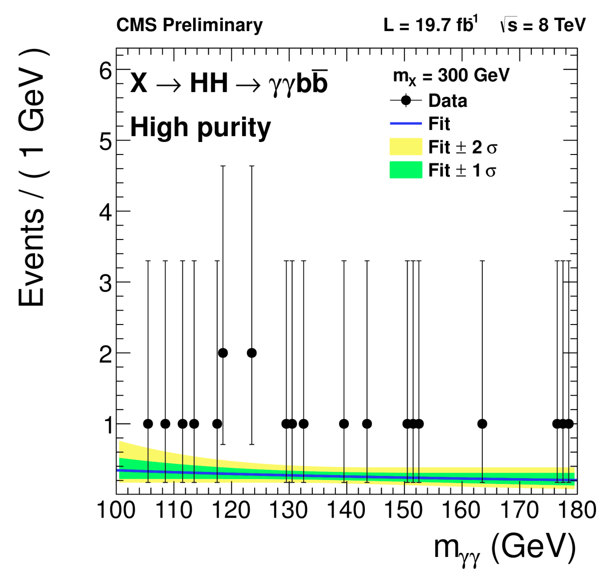




HH→bbγγ HIG-13-032



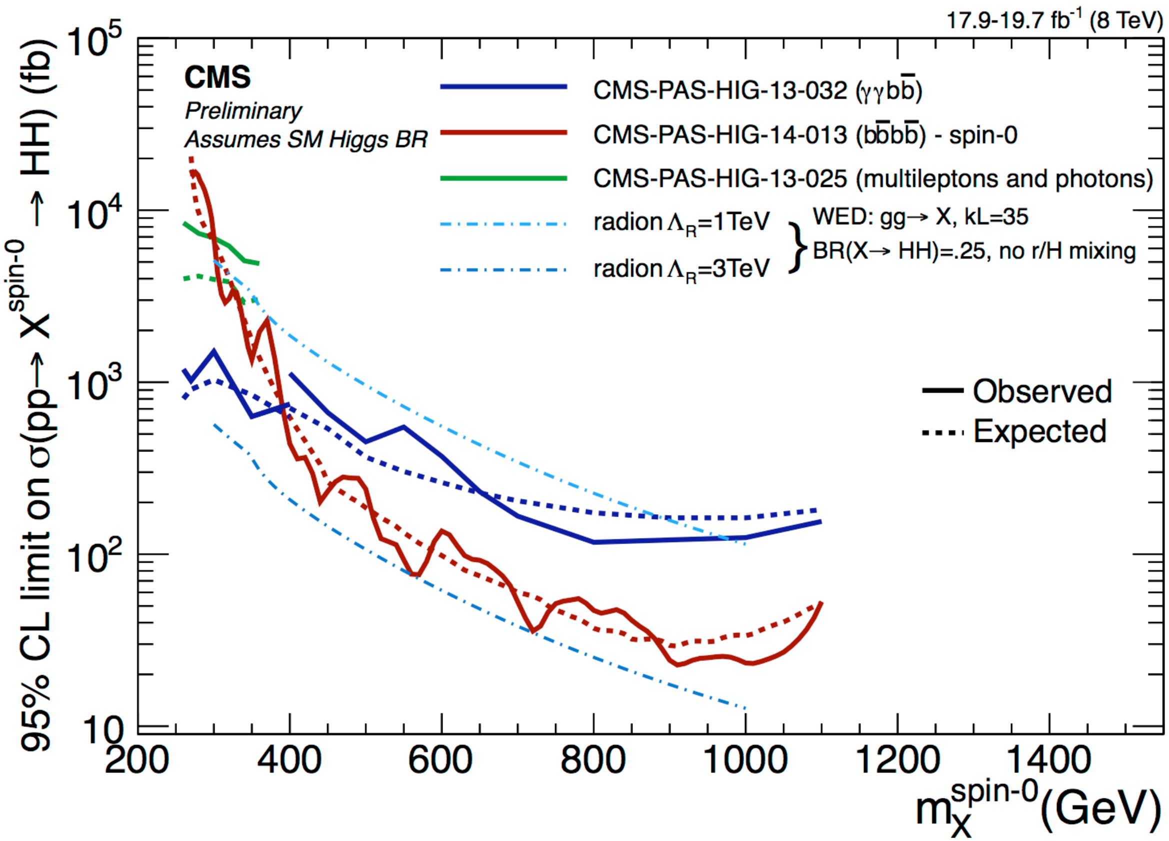
Loose selection



Final selection M_X = 300 GeV=

HH→4b, bbγγ results

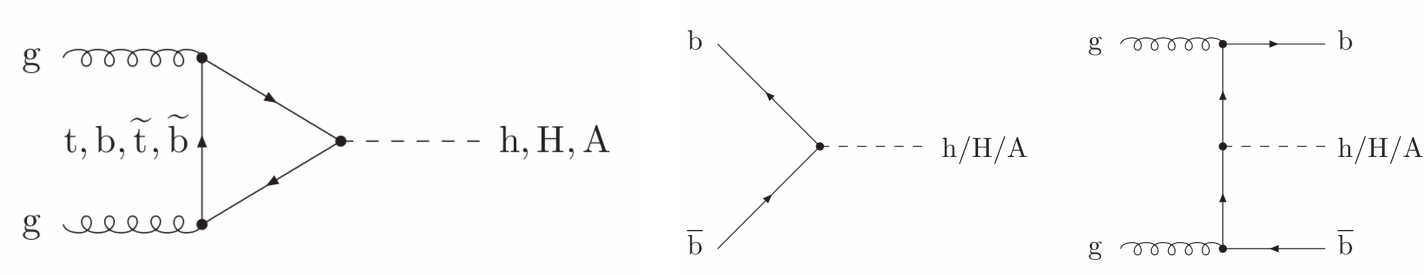
- No signal observed, derive limits on σxBR (assume BR X→HH = 25% for this plot)



- Complementary: bbγγ more sensitive at lower masses, 4b at higher masses

MSSM Higgs bosons: Φ (h,H,A), Φ→ττ,bb,μμ

- In MSSM Φ can be produced by gg fusion or bb annihilation

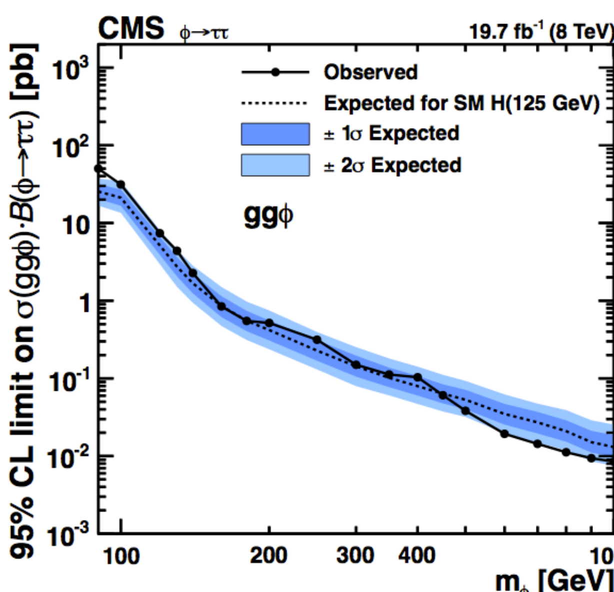


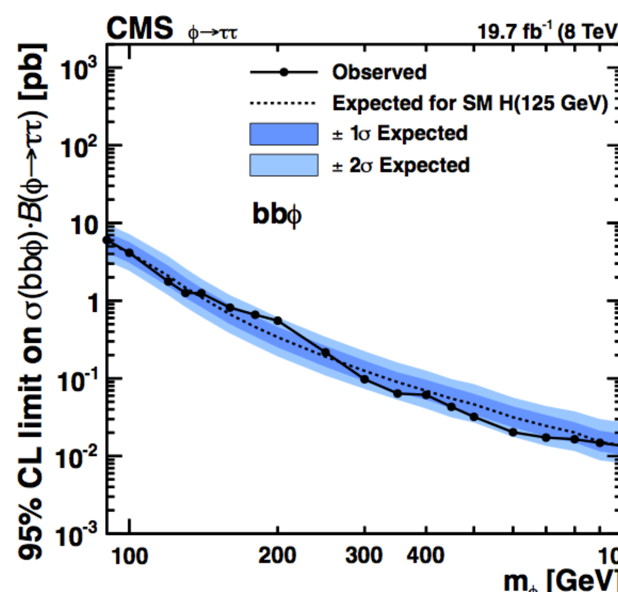
Often at least one b jet produced in the central detector

- **Φ→ττ is the most sensitive**
- **No significant excess observed**

Model independent limits for one single Higgs boson ϕ

ggϕ **bbϕ**

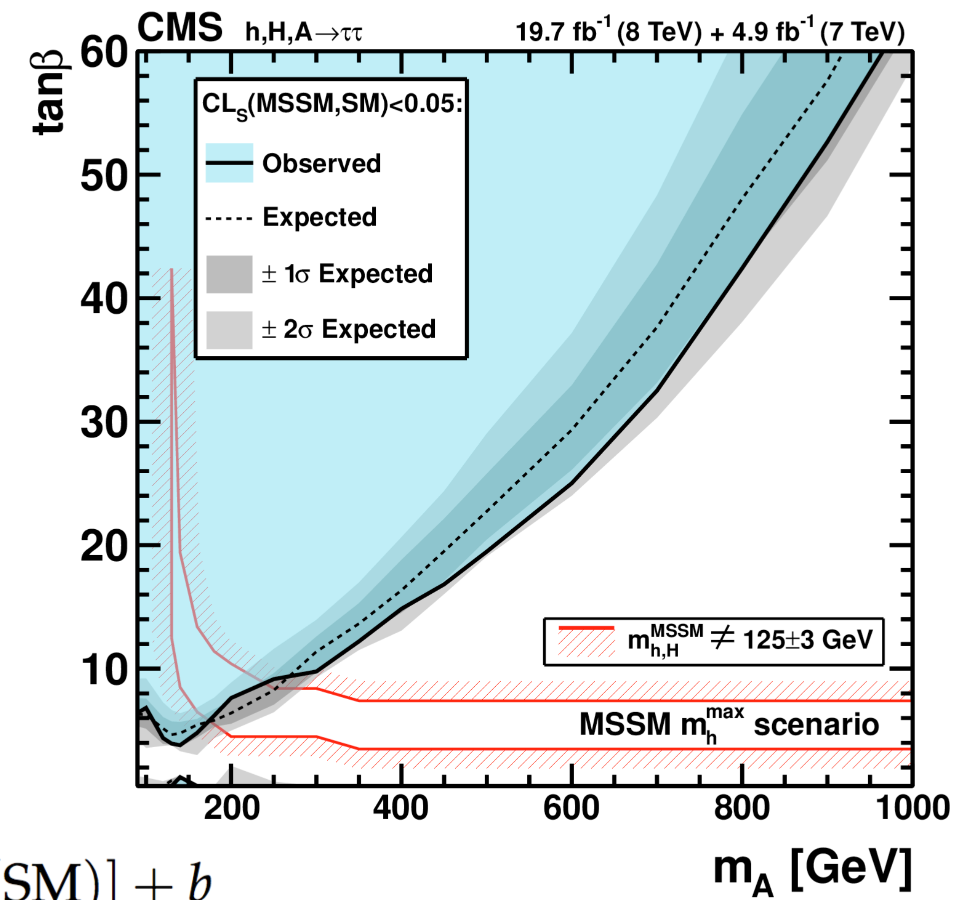




arXiv:1408.3316
Submitted to JHEP

MSSM limits

- In addition to the method used in the past of comparing with BG only (no Higgs), we carry out Hypothesis testing MSSM vs SM(125 GeV)



arXiv:1408.3316
Submitted to JHEP

$$M(\mu) = [\mu \cdot s(\mathrm{MSSM}) + (1-\mu) \cdot s(\mathrm{SM})] + b$$

$$q_{\mathrm{MSSM/SM}} = -2 \ln \frac{L\left(N_{\mathrm{obs}} | M(1), \hat{\theta}_1\right)}{L\left(N_{\mathrm{obs}} | M(0), \hat{\theta}_0\right)}$$

New benchmark scenarios, more consistent with the observed H125 from: M.S. Carena et al. Eur. Phys. J. **C73** (2013) 2552

Summary

- LHC performed extremely well from 2010 until 2012 and the full data set has been analyzed
- After the discovery of the H125 Higgs boson we started to measure its properties
  - All are found to be in agreement with the SM
- No evidence of BSM Higgs bosons, improved limits are obtained in different scenarios
- After two years of LHC shutdown to prepare the higher energy data taking will resume in 2015 at 13/14 TeV:
  - Improve Higgs coupling measurements
  - Search for new Higgs bosons or unexpected decays

Backup

Direct width measurements

- From the mass peaks in $H \to \gamma\gamma$ and $H \to ZZ \to 4l$ it is also possible to directly measure the Higgs width
- We derive upper limits, observed (expected) at 95% CL:
  - $\Gamma_H < 2.4$ (3.1) GeV from $H \to \gamma\gamma$
  - $\Gamma_H < 3.4$ (2.8) GeV from $H \to ZZ \to 4l$
- Three order of magnitude more that the SM prediction of 4.15 MeV

Tensor structure

- HZZ
- HWW

Parametrization of the decay amplitude

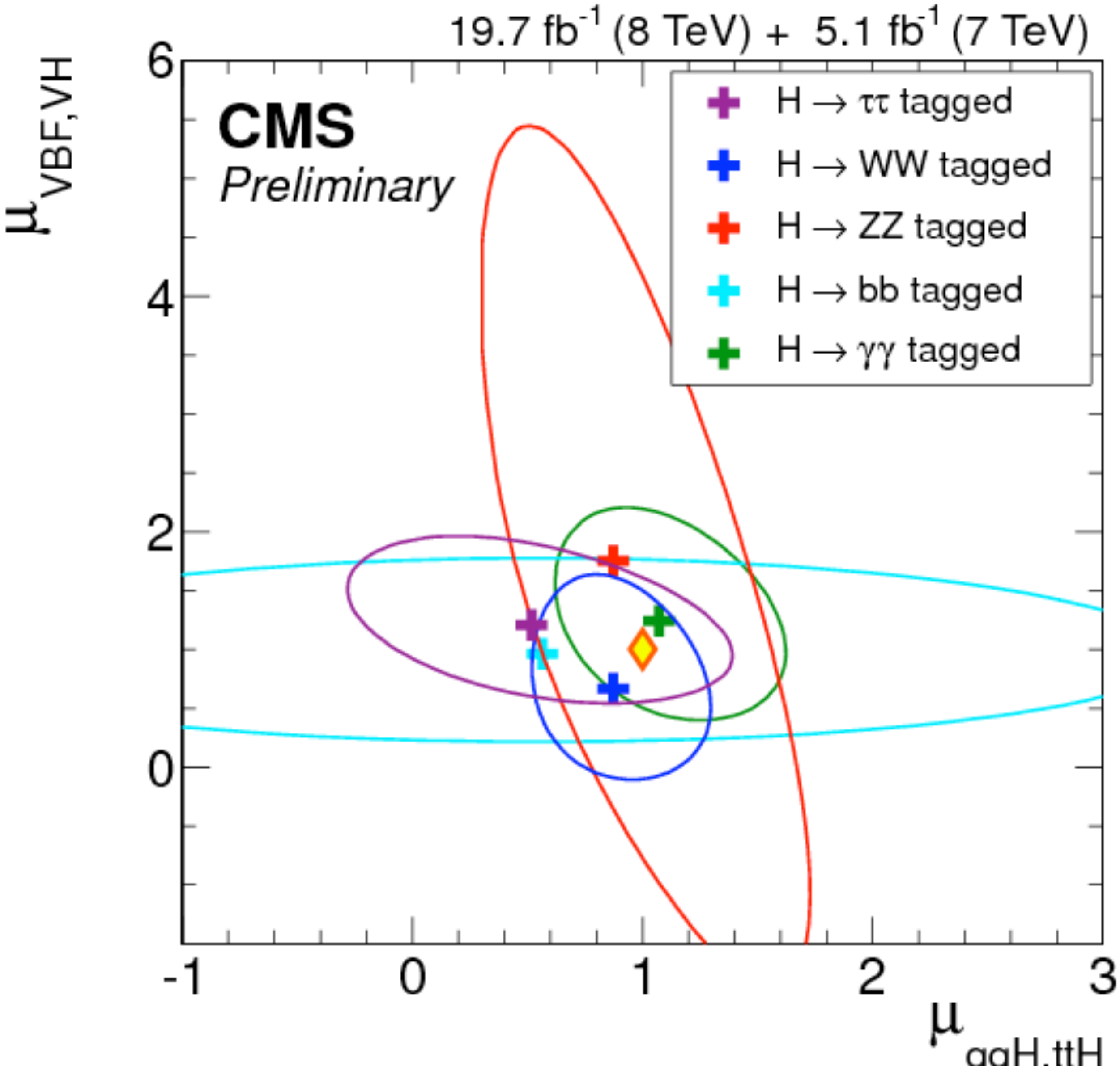
$$
\begin{aligned}
A(X_{J=0} \to V_1V_2) \quad \sim \quad & v^{-1} \left(\left[a_1 - e^{i\phi_{\Lambda_1}} \frac{q_{Z_1}^2 + q_{Z_2}^2}{(\Lambda_1)^2} \right] m_Z^2 \epsilon_{Z_1}^* \epsilon_{Z_2}^* \right. \\
+ \quad & a_2 f_{\mu\nu}^{*(Z_1)} f^{*(Z_2),\mu\nu} + a_3 f_{\mu\nu}^{*(Z_1)} \tilde{f}^{*(Z_2),\mu\nu} \\
+ \quad & a_2^{Z\gamma} f_{\mu\nu}^{*(Z)} f^{*(\gamma),\mu\nu} + a_3^{Z\gamma} f_{\mu\nu}^{*(Z)} \tilde{f}^{*(\gamma),\mu\nu} \\
+ \quad & \left. a_2^{\gamma\gamma} f_{\mu\nu}^{*(\gamma_1)} f^{*(\gamma_2),\mu\nu} + a_3^{\gamma\gamma} f_{\mu\nu}^{*(\gamma_1)} \tilde{f}^{*(\gamma_2),\mu\nu} \right)
\end{aligned}
$$

- In the SM a_1 non zero and all others vanishing or very small
- Use fractions:

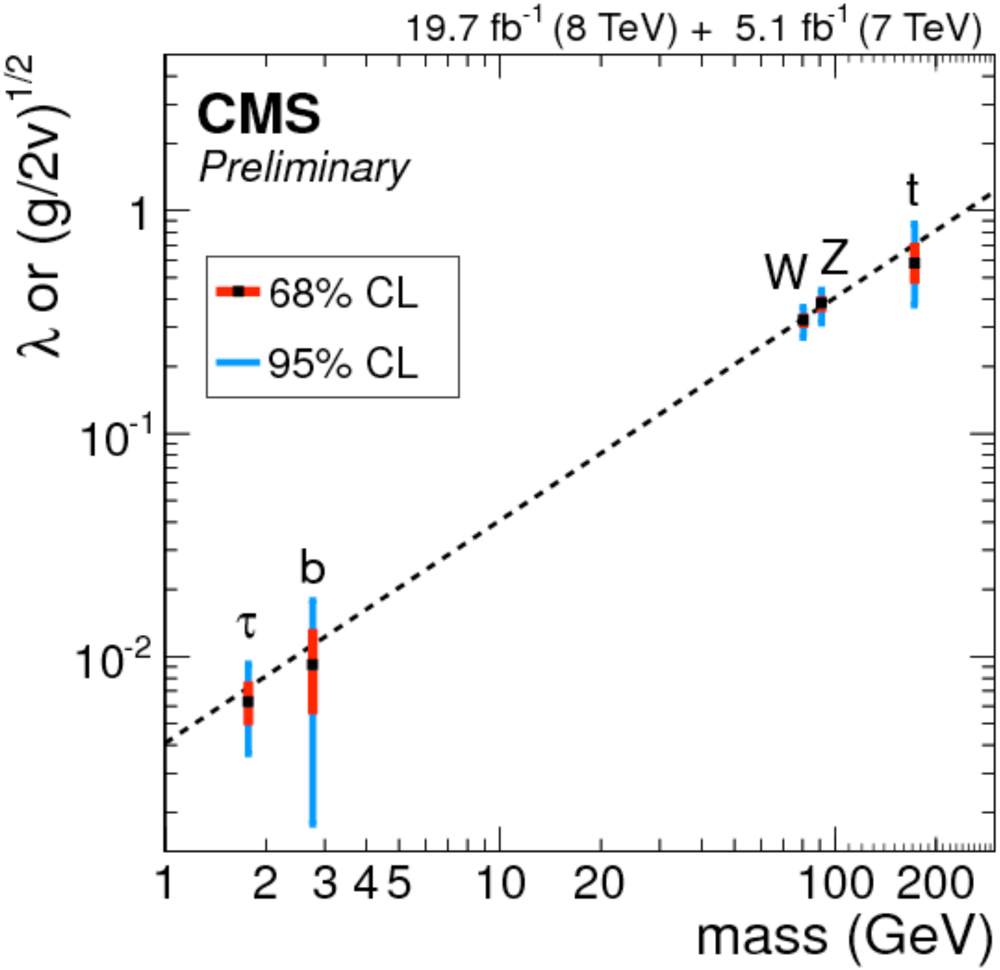
$$
\begin{aligned}
f_{a3} &= \frac{|a_3|^2\sigma_3}{|a_1|^2\sigma_1 + |a_2|^2\sigma_2 + |a_3|^2\sigma_3 + \tilde{\sigma}_{\Lambda_1} / (\Lambda_1)^4} & \phi_{a3} = \arg\left(\frac{a_3}{a_1}\right) \\
f_{a2} &= \frac{|a_2|^2\sigma_2}{|a_1|^2\sigma_1 + |a_2|^2\sigma_2 + |a_3|^2\sigma_3 + \tilde{\sigma}_{\Lambda_1} / (\Lambda_1)^4} & \phi_{a2} = \arg\left(\frac{a_2}{a_1}\right) \\
f_{\Lambda 1} &= \frac{\tilde{\sigma}_{\Lambda_1} / (\Lambda_1)^4}{|a_1|^2\sigma_1 + |a_2|^2\sigma_2 + |a_3|^2\sigma_3 + \tilde{\sigma}_{\Lambda_1} / (\Lambda_1)^4} & \phi_{\Lambda 1},
\end{aligned}
$$

HZZ, HZγ*, Hγγ anomalous couplings

Allowed 95% CL intervals (real couplings)				
Kinematic discriminants method				
Parameter ($\phi_{ai} = 0$ or π)	Observed		Expected	
$f_{\Lambda 1}\cos(\phi_{\Lambda 1})$	$[-0.25, 0.37]$		$[-1.00, 0.27] \cup [0.92, 1.00]$	
$f_{a2}\cos(\phi_{a2})$	$[-0.66, -0.57] \cup [-0.15, 1.00]$		$[-0.18, 1.00]$	
$f_{a3}\cos(\phi_{a3})$	$[-0.40, 0.43]$		$[-0.70, 0.70]$	
$f_{a2}^{Z\gamma}\cos(\phi_{a2}^{Z\gamma})$	$[-0.49, 0.46]$		$[-0.78, 0.79]$	
$f_{a3}^{Z\gamma}\cos(\phi_{a3}^{Z\gamma})$	$[-0.40, 0.51]$		$[-0.75, 0.75]$	
$f_{a2}^{\gamma\gamma}\cos(\phi_{a2}^{\gamma\gamma})$	$[-0.51, 0.04]$		$[-0.34, 0.32]$	
$f_{a3}^{\gamma\gamma}\cos(\phi_{a3}^{\gamma\gamma})$	$[-0.32, 0.35]$		$[-0.40, 0.37]$	
	Observed		Expected	
Parameter	$\phi_{ai} = 0$	$\phi_{ai} = \pi$	$\phi_{ai} = 0$	$\phi_{ai} = \pi$
$f_{\Lambda 1}$	$[0.00, 0.37]$	$[0.00, 0.82]$	$[0.00, 0.27] \cup [0.92, 1.00]$	–
$f_{a2}^{\gamma\gamma}$	$[0.00, 0.10]$	$[0.00, 0.51]$	$[0.00, 0.32]$	$[0.00, 0.34]$
Multidimensional distributions method				
Parameter ($\phi_{ai} = 0$ or π)	Observed		Expected	
$f_{a2}\cos(\phi_{a2})$	$[-0.14, 1.00]$		$[-0.18, 0.97]$	
$f_{a3}\cos(\phi_{a3})$	$[-0.44, 0.40]$		$[-0.67, 0.67]$	


19.7 fb^{-1} (8 TeV) + 5.1 fb^{-1} (7 TeV)
CMS
Preliminary
H → ττ tagged
H → WW tagged
H → ZZ tagged
H → bb tagged
H → γγ tagged
$\mu_{VBF,VH}$
$\mu_{ggH,ttH}$
6
4
2
0
-1
0
1
2
3

- The Higgs boson couples to mass as expected in the SM



H→Zγ

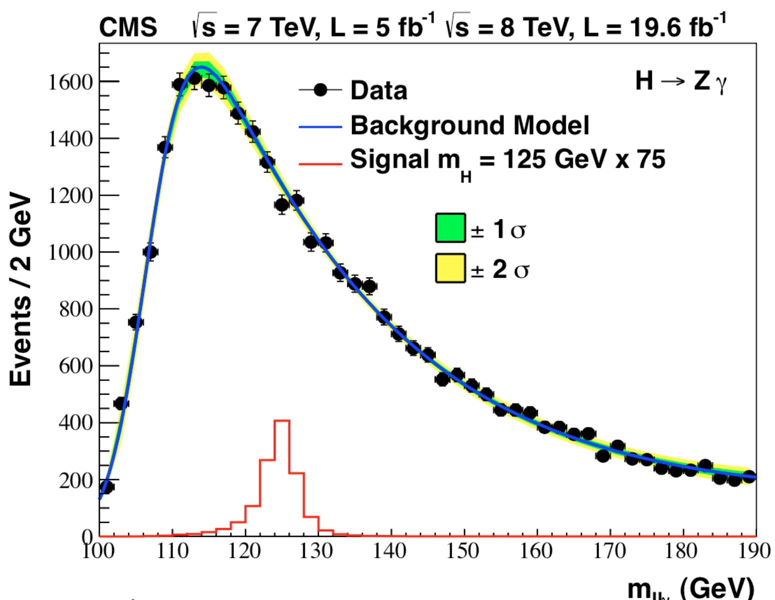
- Cross section similar to γγ
- Use Z→ee and Z→μμ (reduce cross section)
- Large BG from Drell Yan with ISR

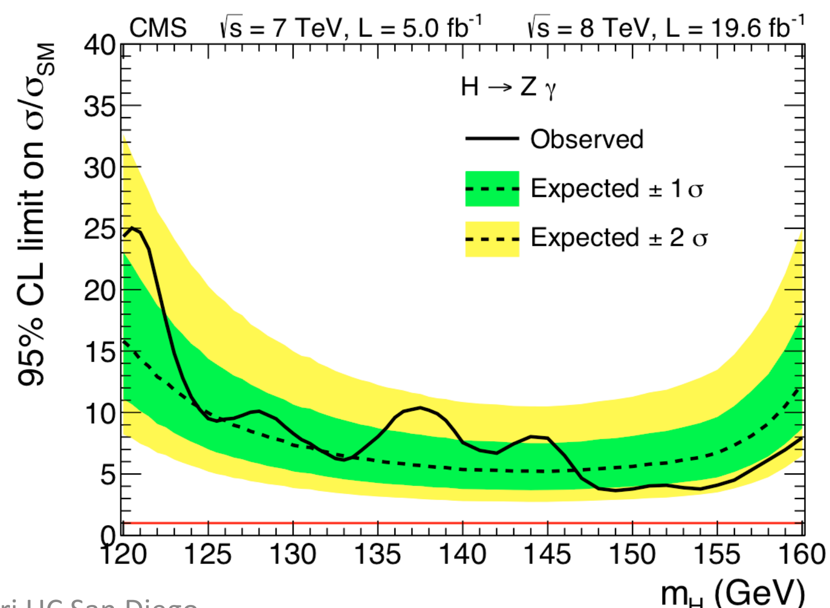
Models exist with BR(Zγ) >100 x SM while BR(γγ) is SM-like

Table 1: Observed and expected event yields for a 125 GeV SM Higgs boson.

Sample	Integrated luminosity (fb^{-1})	Observed event yield for $100 < m_{\ell\ell\gamma} < 190$ GeV	Expected number of signal events for $m_H = 125$ GeV
2011 ee	5.0	2353	1.2
2011 $\mu\mu$	5.1	2848	1.4
2012 ee	19.6	12899	6.3
2012 $\mu\mu$	19.6	13860	7.0

Phys. Lett. B 726 (2013) 587

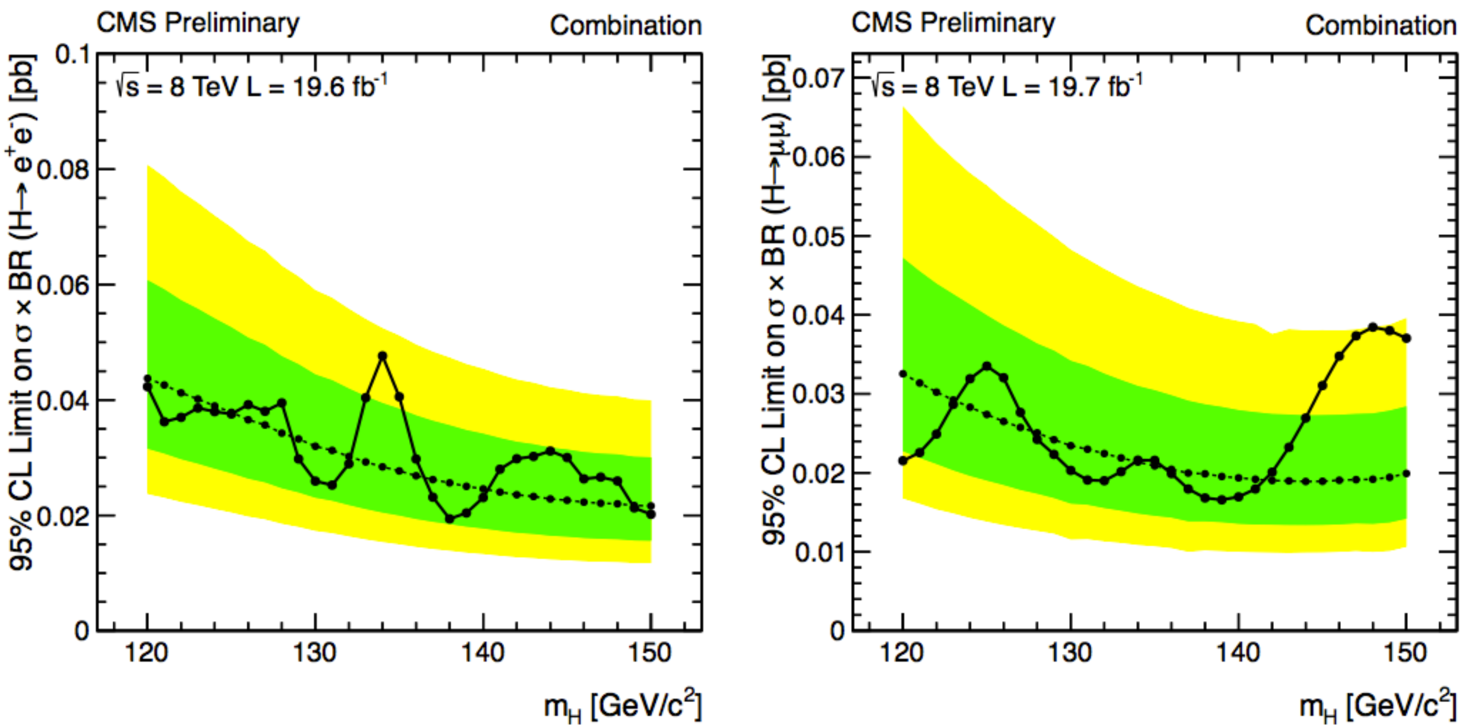




H→μμ, ee

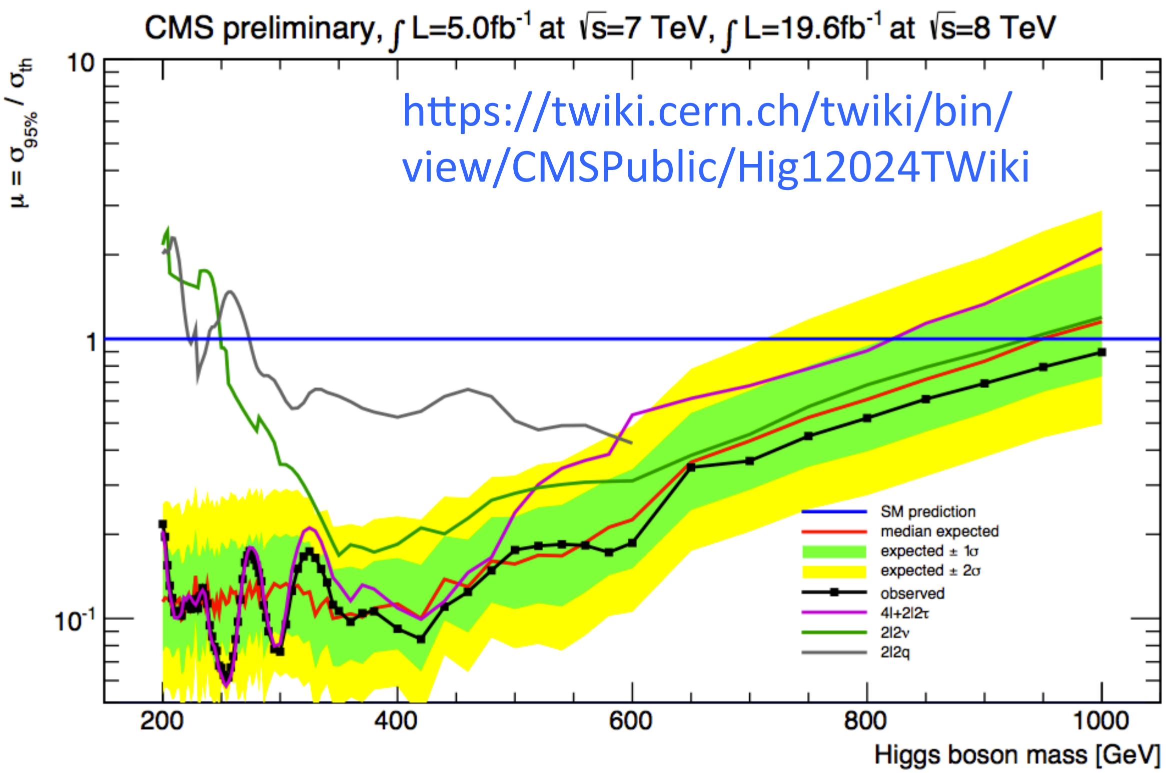
- In the SM the H→μμ BR is much smaller than H→ττ and ee is totally negligible
- BR limits

CMS PAS HIG-13-007



High mass searches and EW singlet model

- High mass: WW and ZZ decays
  - add WW→lvqq, ZZ→2l2v, ZZ→2l2q, ...

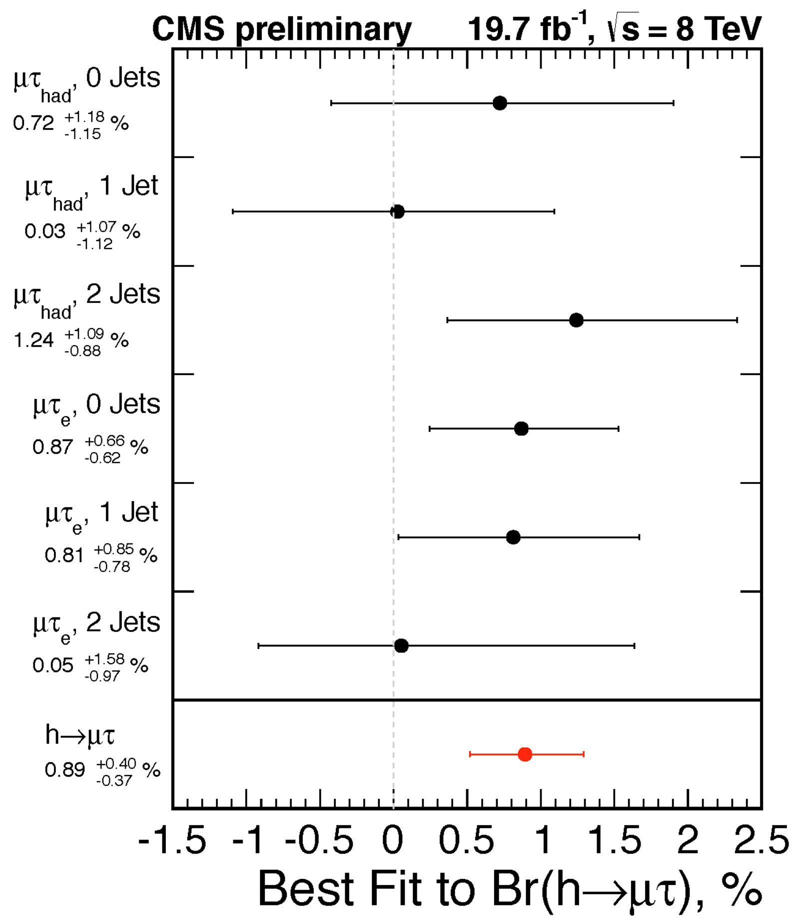


https://twiki.cern.ch/twiki/bin/view/CMSPublic/Hig12024TWiki

ZZ combination of latest results excludes at 95% CL SM like Higgs up to 1 TeV

LFV selection and results

Variable	$H \to \mu\tau_e$			$H \to \mu\tau_{had}$		
	0-jet	1-jet	2-jet	0-jet	1-jet	2-jet
$p_T^{\mu} >$ [GeV]	50	45	25	40	35	30
$p_T^{e} >$ [GeV]	10	10	10	-	-	-
$p_T^{\tau} >$ [GeV]	-	-	-	35	40	40
$\Delta\phi_{\vec{\mu}-\vec{\tau}_{had}} >$	-	-	-	2.7	-	-
$\Delta\phi_{\vec{e}-\vec{E}_T^{miss}} <$	0.5	0.5	0.3	-	-	-
$\Delta\phi_{\vec{e}-\vec{\mu}} >$	2.7	1.0	-	-	-	-
$M_T(e) <$ [GeV]	65	65	25	-	-	-
$M_T(\mu) >$ [GeV]	50	40	15	-	-	-
$M_T(\tau) <$ [GeV]	-	-	-	50	35	35



New MSSM benchmark scenarios

Proposed in: M.S. Carena et al. Eur. Phys. J. **C73** (2013) 2552

Parameter	m_h^{max}	m_h^{mod+}	m_h^{mod-}
m_A	90–1000 GeV	90–1000 GeV	90–1000 GeV
$\tan\beta$	0.5–60	0.5–60	0.5–60
M_{SUSY}	1000 GeV	1000 GeV	1000 GeV
μ	200 GeV	200 GeV	200 GeV
M_1	$(5/3)\ M_2 \tan^2\theta_W$	$(5/3)\ M_2 \tan^2\theta_W$	$(5/3)\ M_2 \tan^2\theta_W$
M_2	200 GeV	200 GeV	200 GeV
X_t	$2\ M_{SUSY}$	$1.5\ M_{SUSY}$	$-1.9\ M_{SUSY}$
A_b, A_t, A_τ	$A_b = A_t = A_\tau$	$A_b = A_t = A_\tau$	$A_b = A_t = A_\tau$
$m_{\tilde{g}}$	1500 GeV	1500 GeV	1500 GeV
$m_{\tilde{l}_3}$	1000 GeV	1000 GeV	1000 GeV

Parameter	light-stop	light-stau	τ-phobic	low-m_H
m_A	90–600 GeV	90–1000 GeV	90–1000 GeV	110 GeV
$\tan\beta$	0.7–60	0.5–60	0.9–50	1.5–9.5
M_{SUSY}	500 GeV	1000 GeV	1500 GeV	1500 GeV
μ	400 GeV	500 GeV	2000 GeV	300-3100 GeV
M_1	340 GeV	$(5/3)\ M_2 \tan^2\theta_W$	$(5/3)\ M_2 \tan^2\theta_W$	$(5/3)\ M_2 \tan^2\theta_W$
M_2	400 GeV	200 GeV	200 GeV	200 GeV
X_t	$2\ M_{SUSY}$	$1.6\ M_{SUSY}$	$2.45\ M_{SUSY}$	$2.45\ M_{SUSY}$
A_b, A_t, A_τ	$A_b = A_t = A_\tau$	$A_b = A_t, A_\tau = 0$	$A_b = A_t = A_\tau$	$A_b = A_t = A_\tau$
$m_{\tilde{g}}$	1500 GeV	1500 GeV	1500 GeV	1500 GeV
$m_{\tilde{l}_3}$	1000 GeV	245 GeV	1000 GeV	1000 GeV

Charged Higgs to cs

- Search for Charged Higgs in tt decays in the mass range 90-160 GeV in 8 TeV data

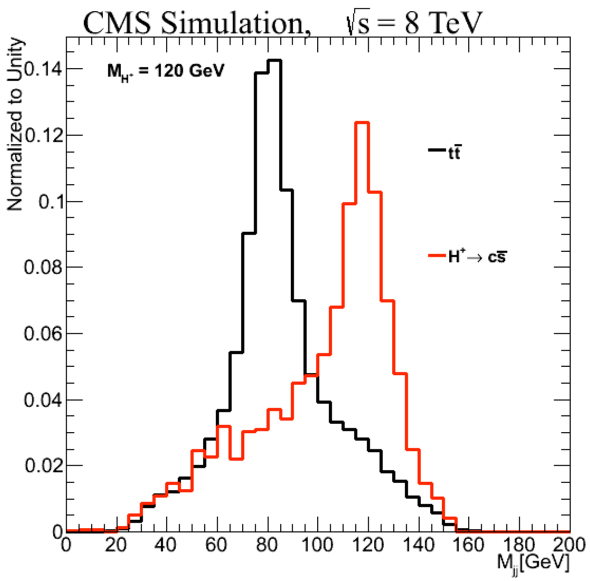
CMS PAS HIG-13-035

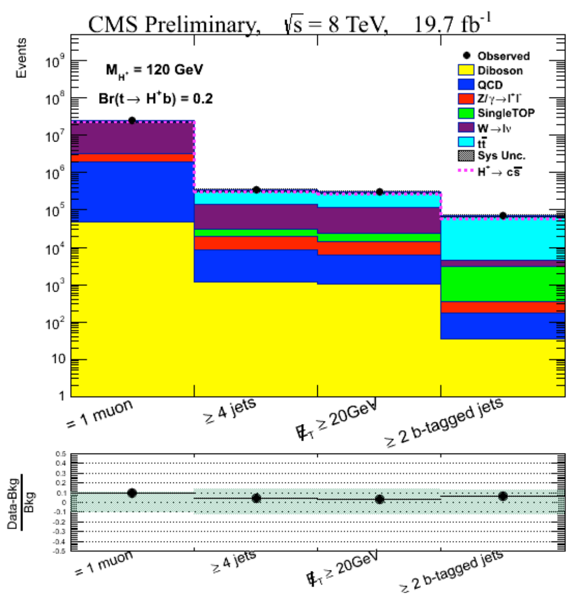
- W from other top is required to decay into μν

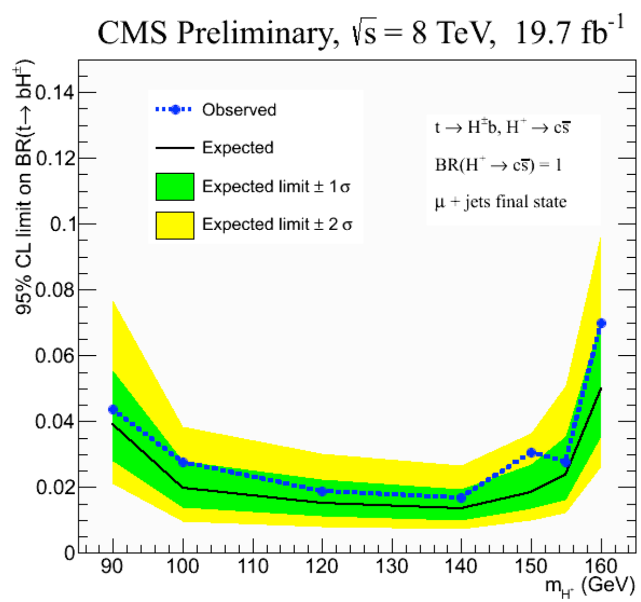
Use kin fit for mass reconstruction constraining the top masses

Event selection

No excess observed, BR(t→bH±) limits are derived assuming BR(bH±→cs = 100%







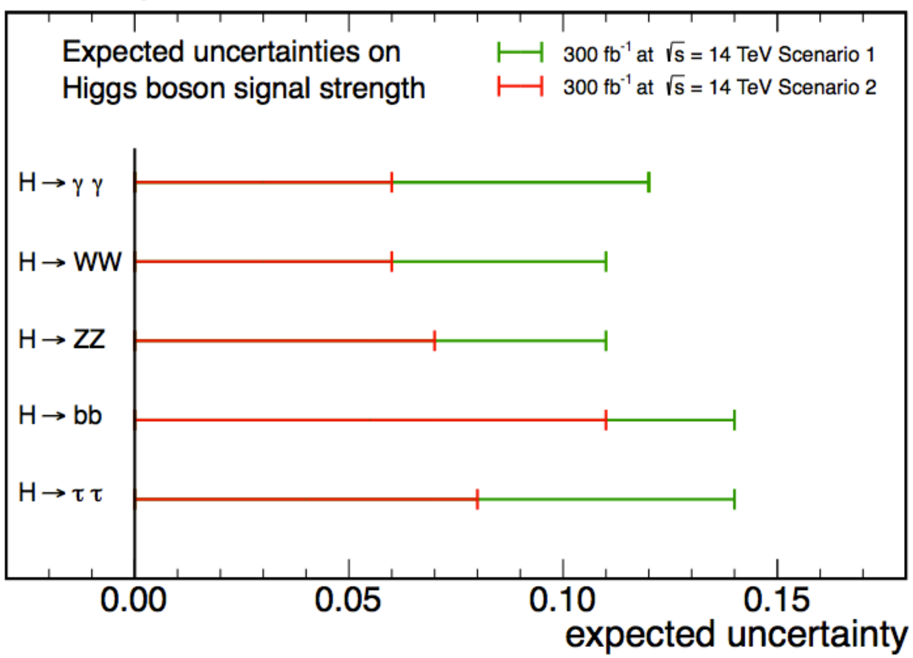
Future: projections at 14 TeV

Scenario 1 – Systematic and theory errors as they are now

Scenario 2 – Theory errors reduced by a factor 1/√2, systematic errors reduced by 1/√(IntL)

CMS-NOTE-2013-002

CMS Projection **IntL = 300 fb^{-1}, end of Phase I**



CMS Projection **IntL = 3000 fb^{-1}, end of Phase 2**