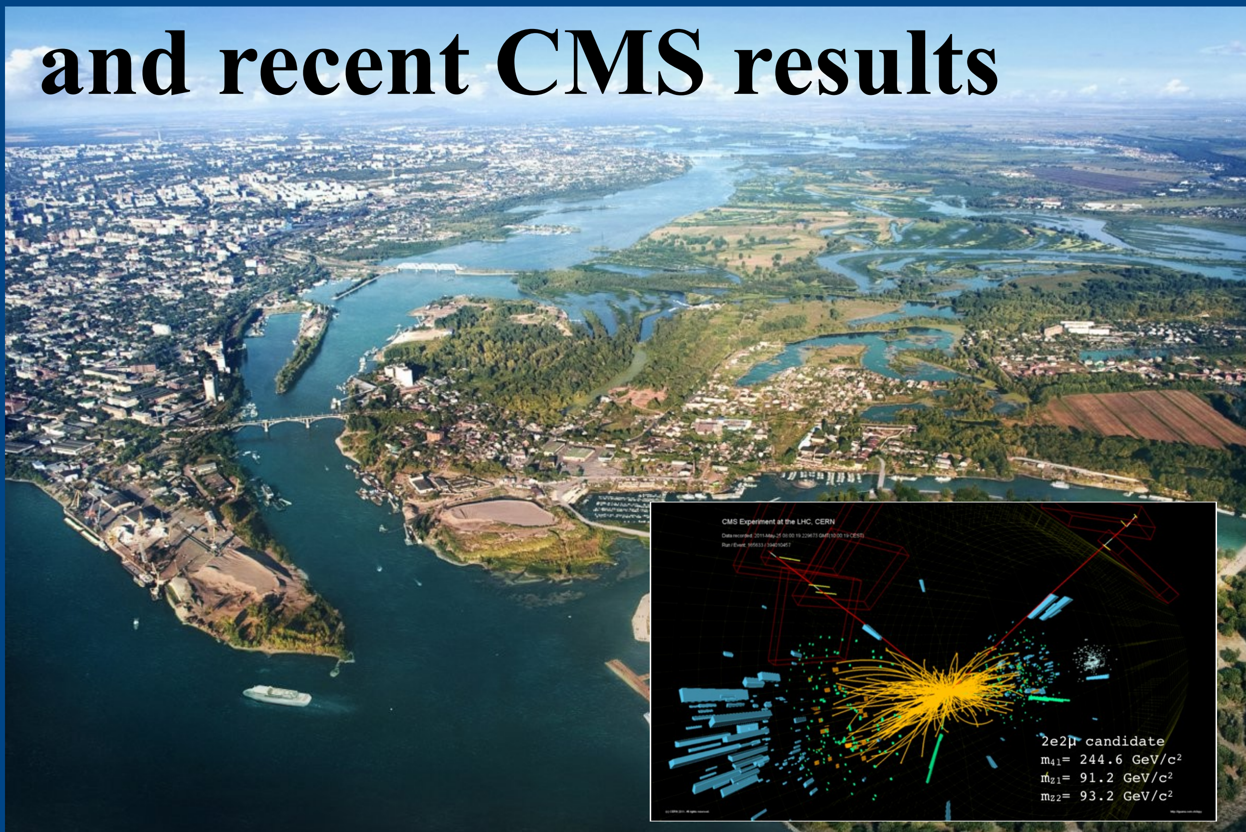
Higgs boson discovery and recent CMS results



Martin Flechl (HEPHY Vienna)

QFTHEP 2015, 2015/06/25

HEPHY Institut für Hochenergiephysik

CERN

CMS

ÖSTERREICHISCHE AKADEMIE DER WISSENSCHAFTEN MDCCCXLVII

Outline

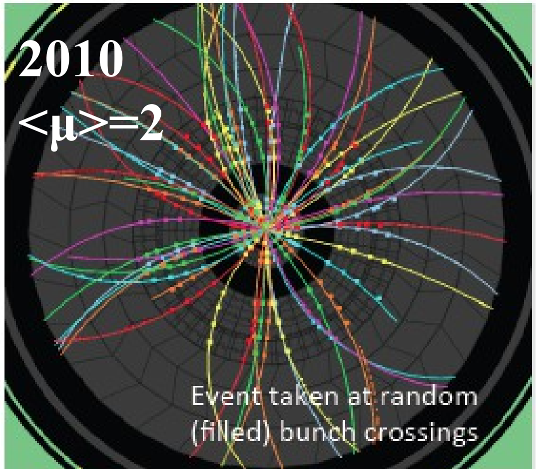
- The Higgs boson discovery
- Overview of SM Higgs boson searches

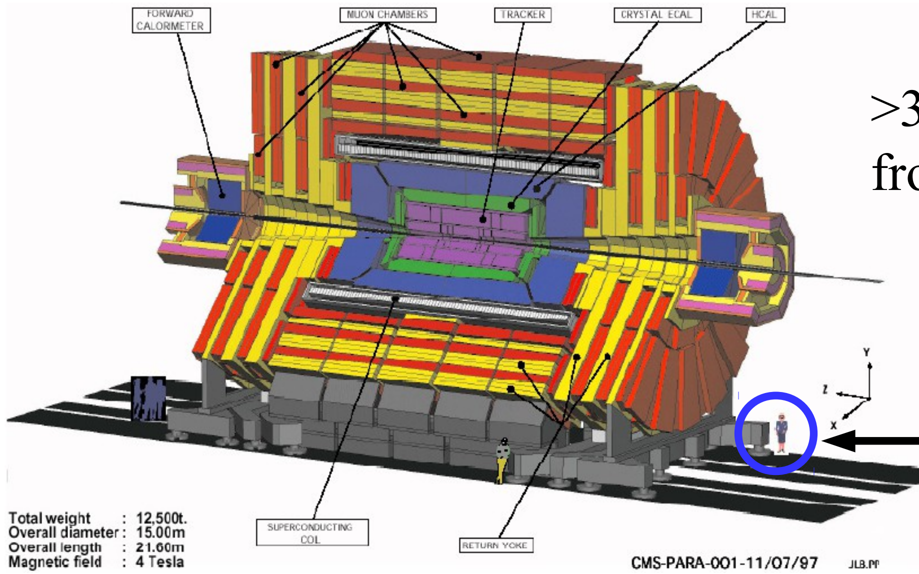
- Recent results (SM Higgs properties)
  - signal strength / couplings
  - mass / width
  - CP properties

- Rare decays
- BSM Higgs boson searches

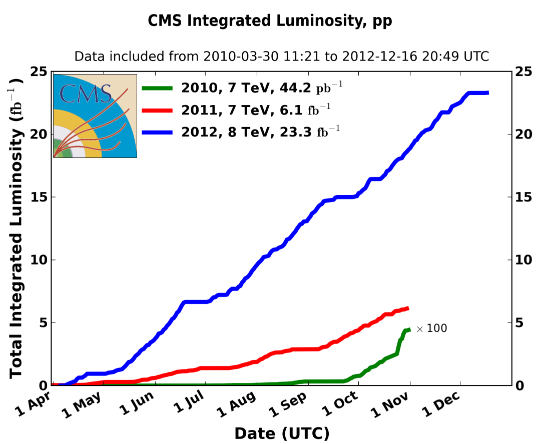
- Prospects for 2015-2035

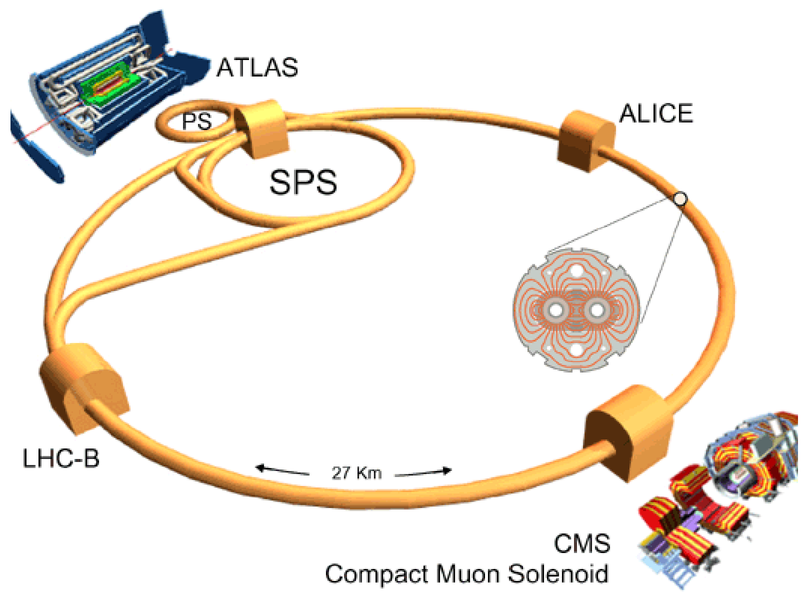
CMS & LHC





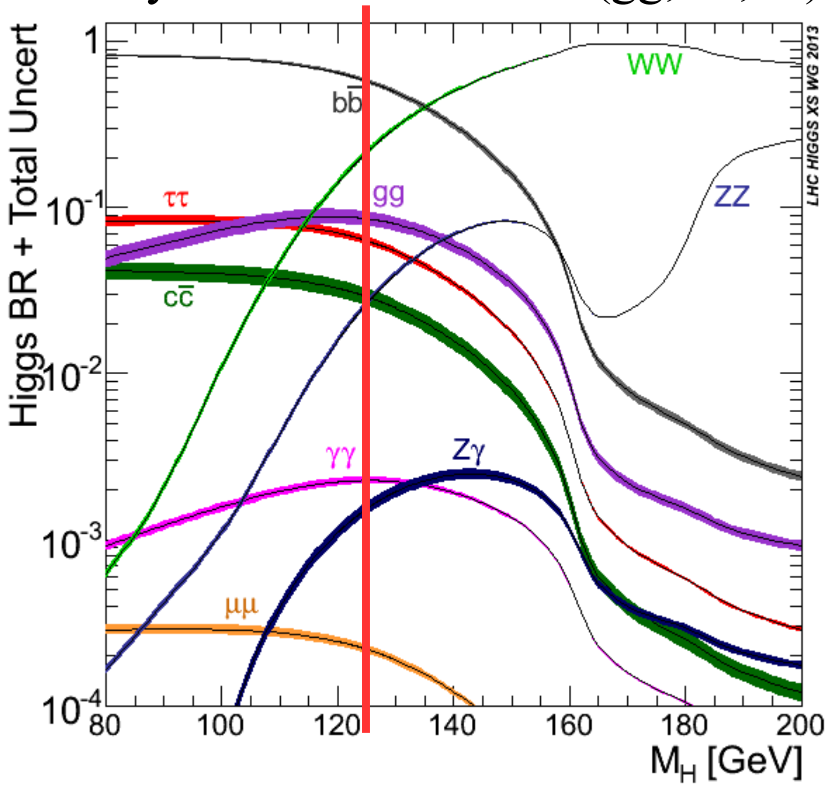
>3000 physicists
from ≈40 countries





Higgs boson production / decay

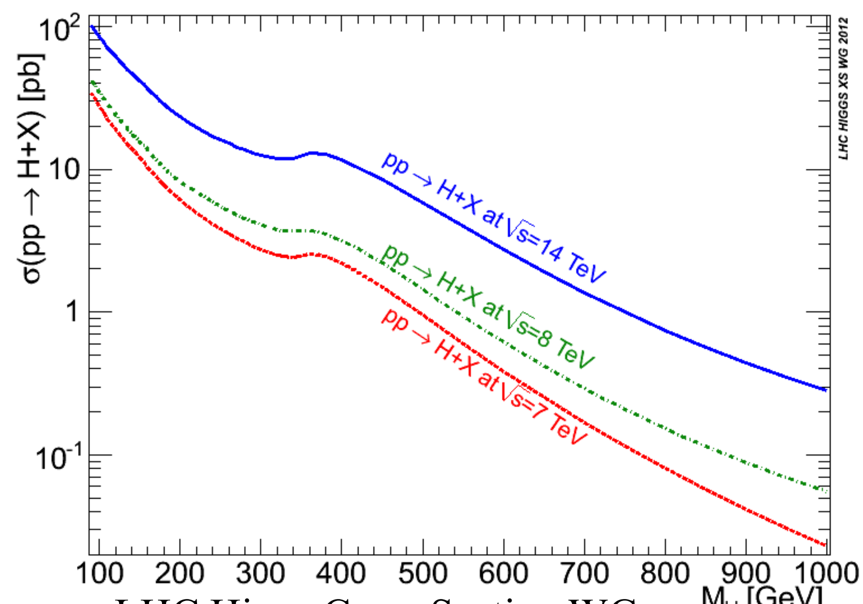
- SM: **≈1M Higgs bosons produced at the LHC (2011-2012)**
- Spectacular mass: 125 GeV – many decay channels open
  - only 11% unobservable (gg, cc, ...)



2015: Cross section increase by factor 2.5; almost 5 for ttH!

Production cross section, mh=125 GeV, sqrt(s)=8 [14] GeV:

ggF:	19.3 pb	[49.9]
VBF:	1.58 pb	[4.2]
WH:	0.70 pb	[1.5]
ZH:	0.42 pb	[0.88]
ttH:	0.13 pb	[0.61]



LHC Higgs Cross Section WG

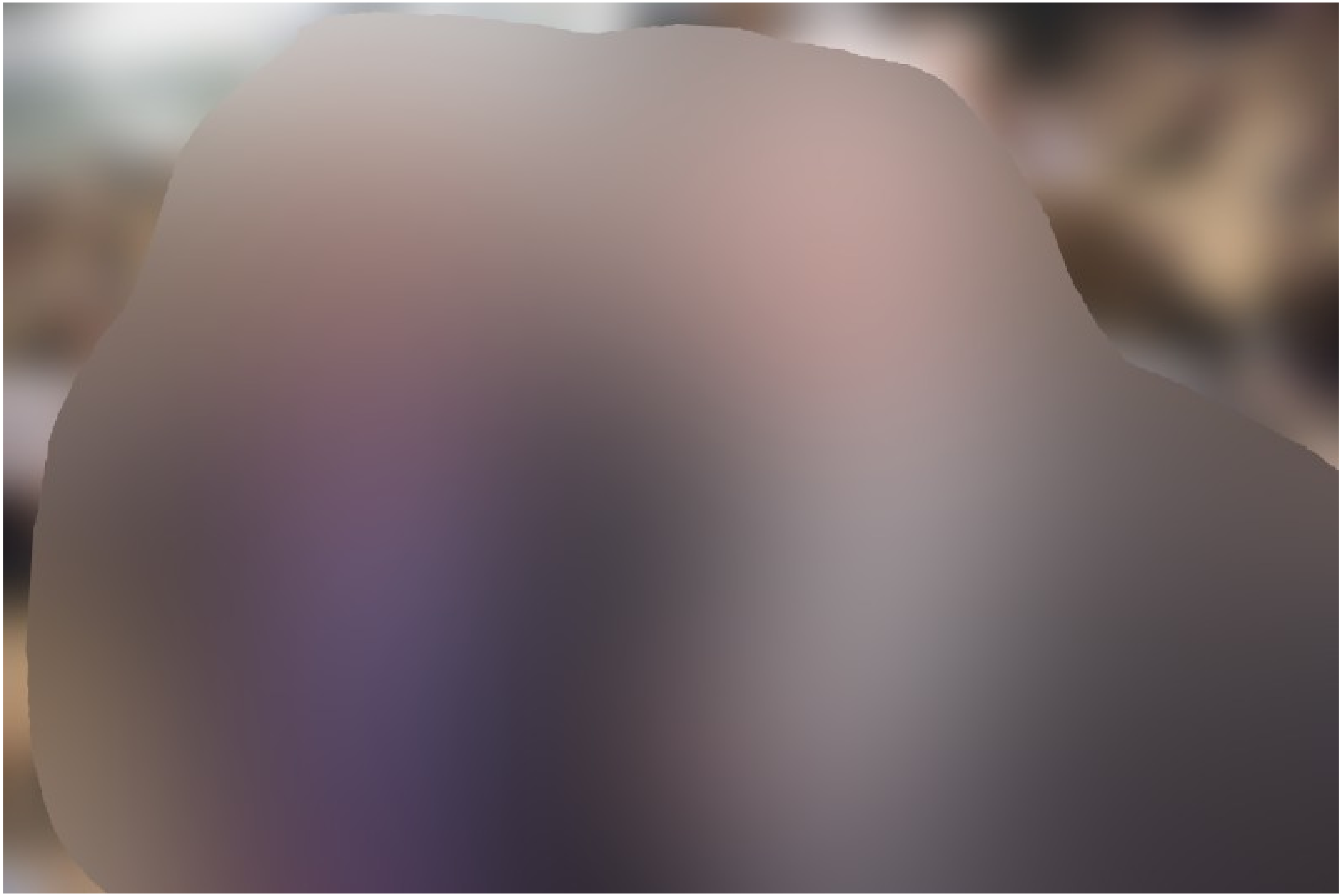
Higgs boson discovery

More than CMS and ATLAS

- I will not say much about the great efforts of both the theoretical and experimental HEP Higgs community before the LHC
  - The discovery would have taken much longer without
    - precise predictions from the **theory community** (early days to LHCHXSWG)
    - excellent tools due to **previous experiments** (e.g. PDFs from HERA)
    - restrictions on the m_H phase space (LEP, Tevatron)
  - and would have been impossible without
    - the **excellent operation of the LHC** by the accelerator team
    - the excellent performance of the **world-wide LHC Computing Grid**

- We are deeply grateful...
  - ...but this talk is about
    - the **Higgs boson discovery** at the LHC
    - the **current status of Higgs boson searches**

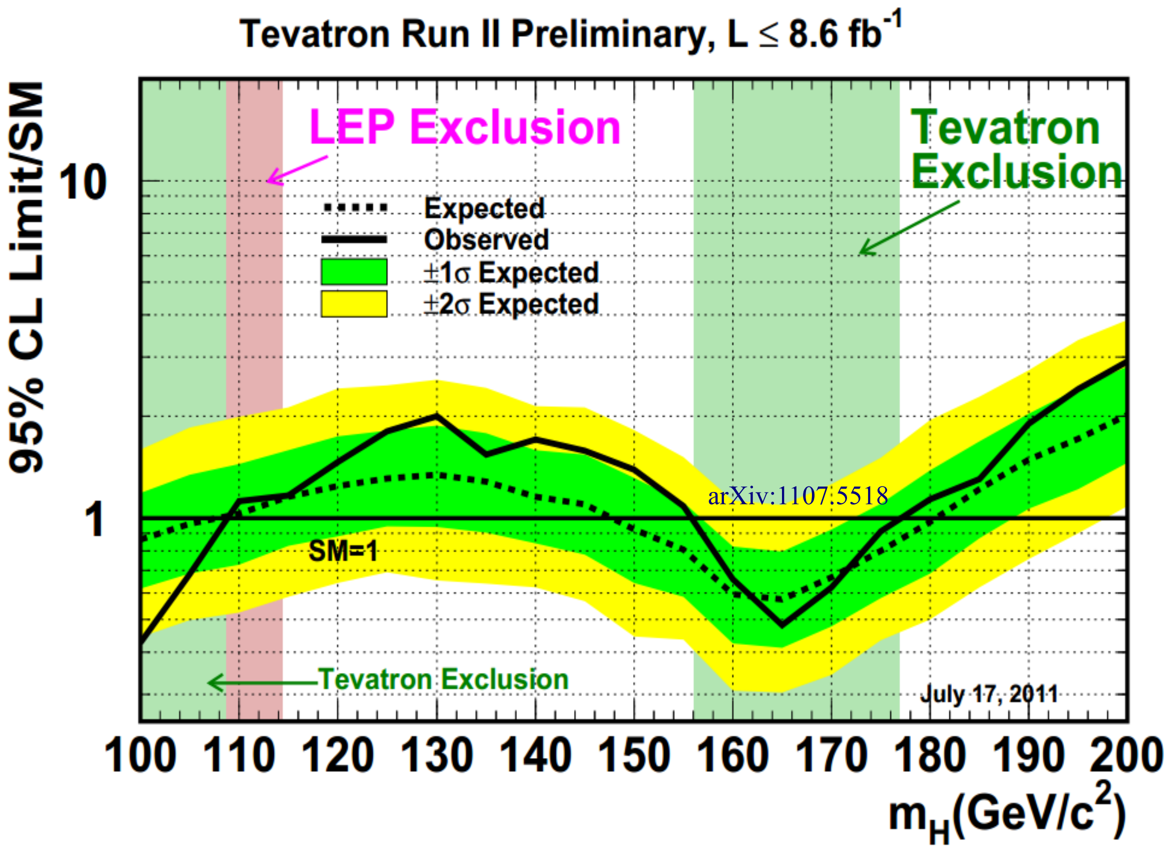
Before the LHC



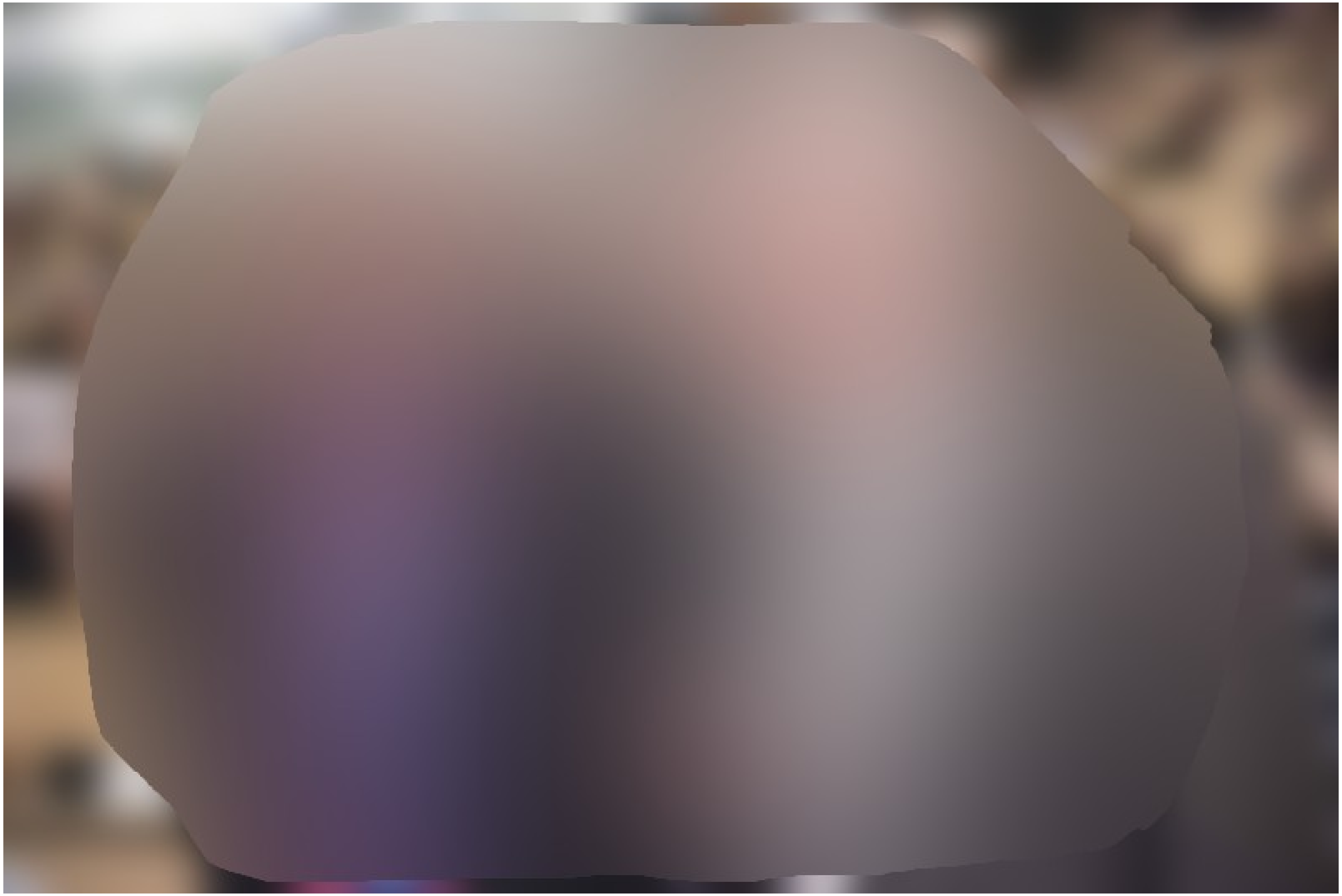
A little hazy, with structure in some regions of phase space.

Before the LHC

- **SM Higgs boson constraints**
  - m_H>15 MeV (NA31, 1989)
  - m_H>114.4 GeV (LEP, 2000)
  - m_H<156 GeV OR m_H>177 GeV (Tevatron, 2011)



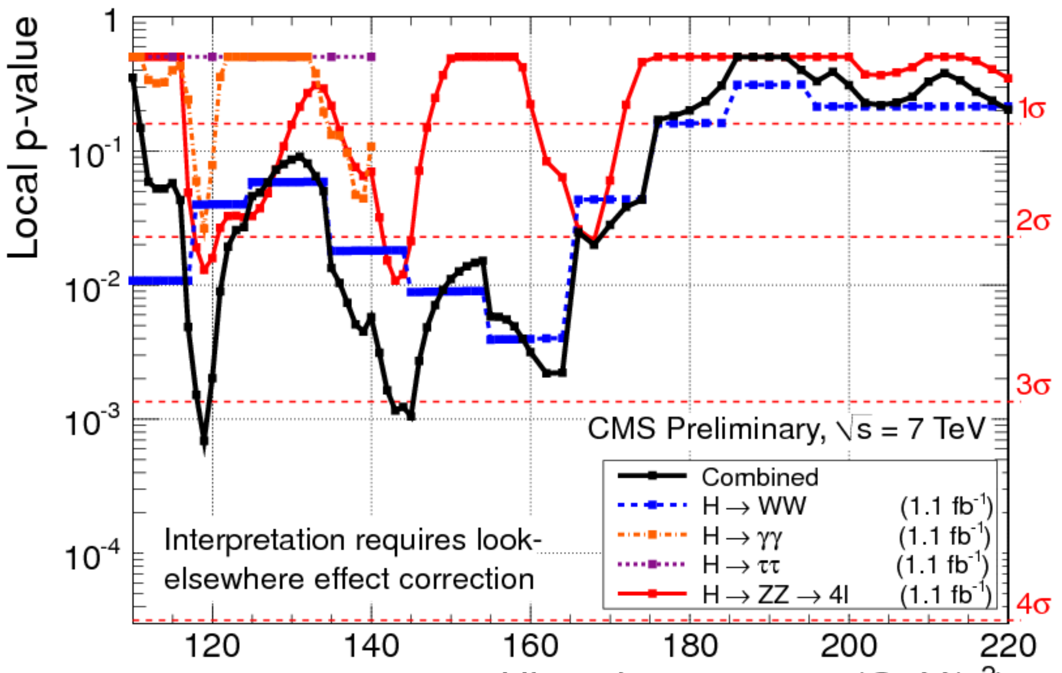
EPS, July 2011



The situation is mostly unchanged. The disfavored region becomes somewhat clearer.

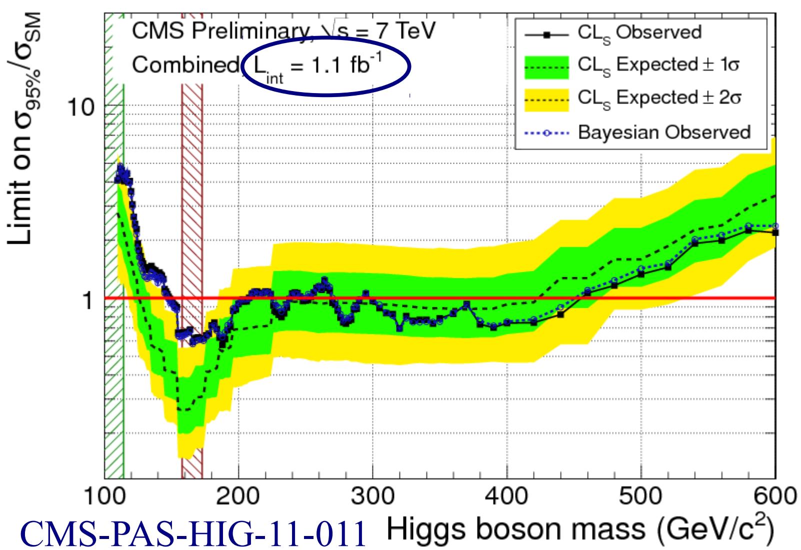
EPS, July 2011

- 3 significant* excesses ($\approx 3\sigma_{local}$)
  - m_H=118 GeV
  - m_H=144 GeV
  - m_H=162 GeV



CMS-PAS-HIG-11-011

- **First LHC exclusion of m_H values in the SM**
  - 145-216 / 226-288 / 310-400 GeV



CMS-PAS-HIG-11-011

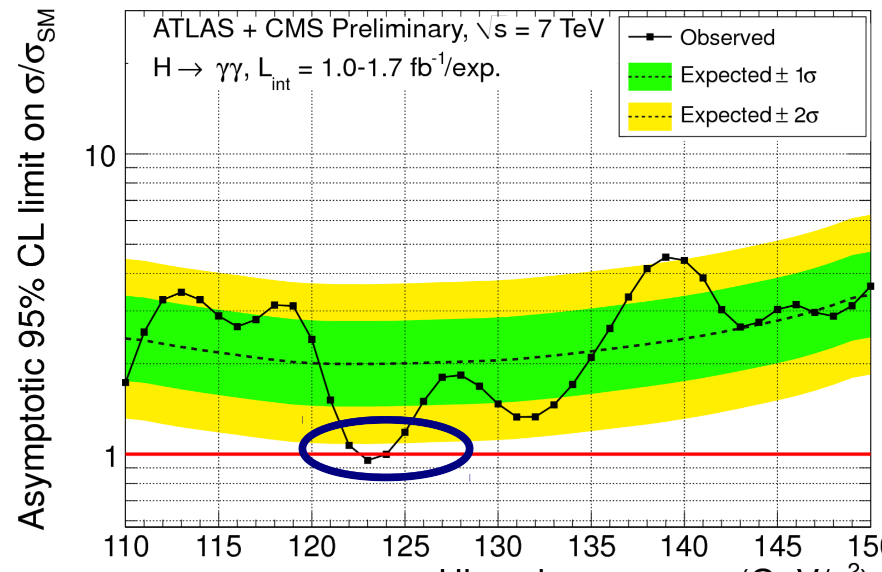
*locally (!) significant

HCP, November 2011

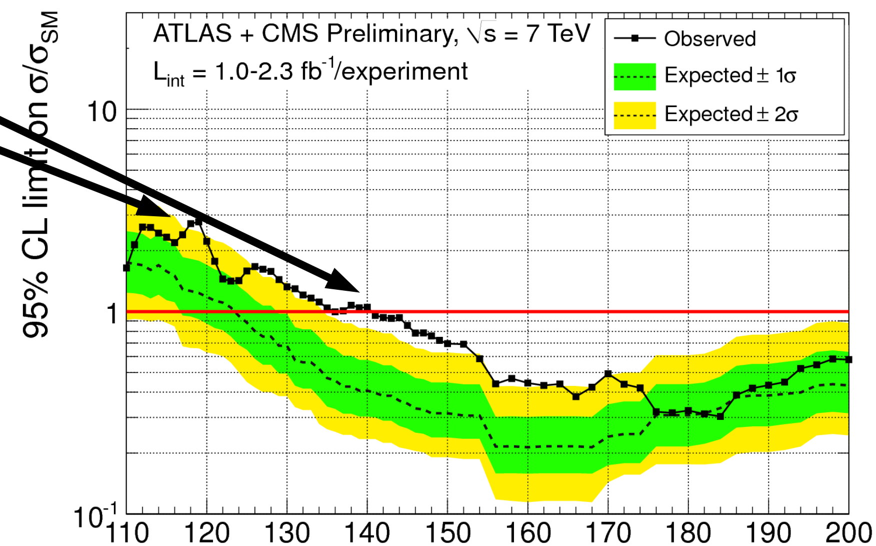
It is getting clearer where the Higgs is not and we can clearly see the background.

HCP, November 2011

- **First ATLAS+CMS combination**
  - m_H=125 GeV almost excluded!
    - remember, 95% C.L.
    - only one of the channels
- Most significant* excesses (≈$3\sigma_{local}$)
  - m_H=145 GeV
  - m_H=119 GeV
- **Exclusion (95% CL): m_H=141-476 GeV**



CMS-PAS-HIG-11-023



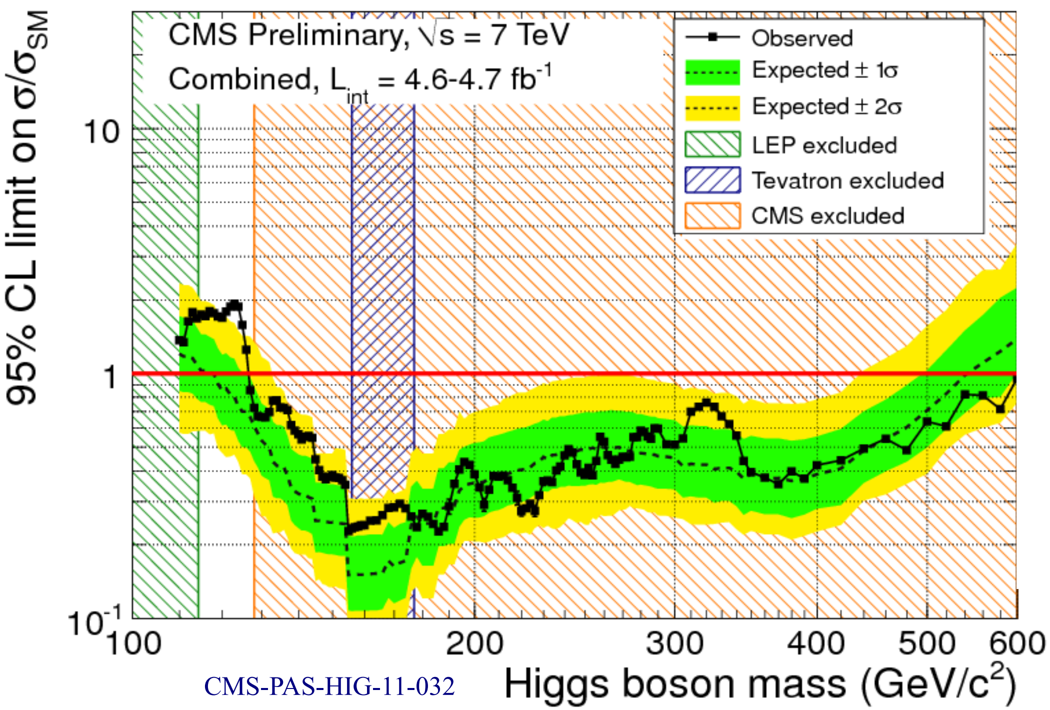
CMS-PAS-HIG-11-023

*globally, this corresponds to only 1.6σ

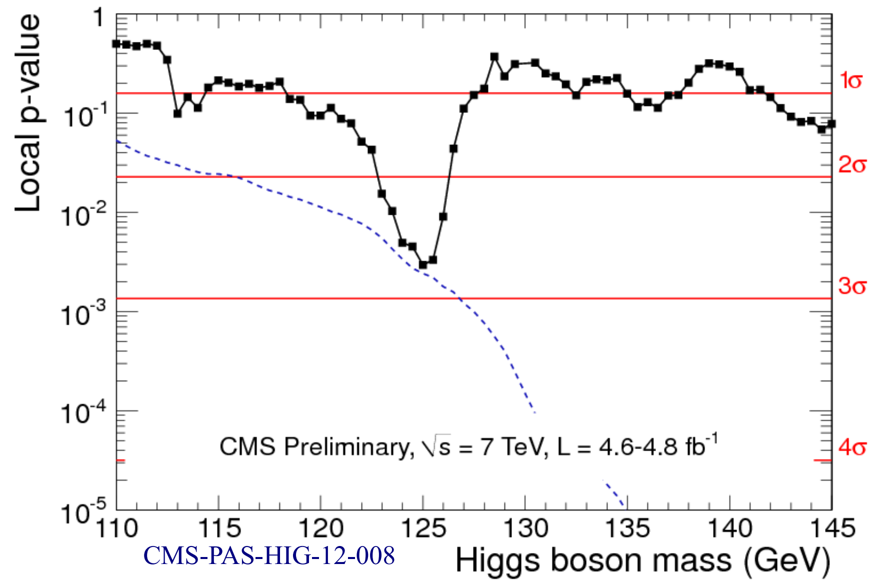
Dec 2011, CERN + Moriond 2012

The Higgs is pretty much cornered. Something seems to be there – but what is it?

Dec 2011, CERN + Moriond 2012



CMS-PAS-HIG-11-032

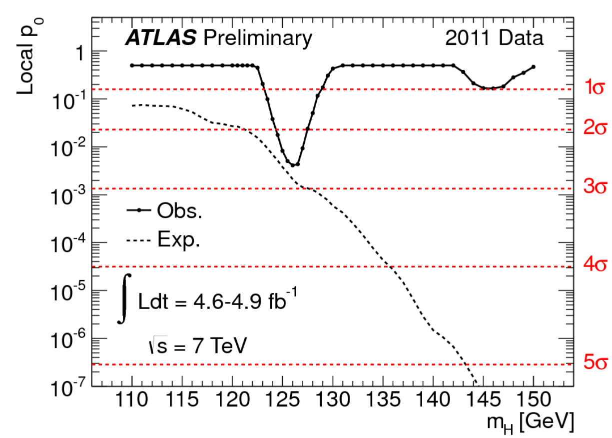


CMS-PAS-HIG-12-008

Excluded: m_H=(127-600) GeV

2.8 σ local significance at mH=125 GeV (=0.8 σ global significance)

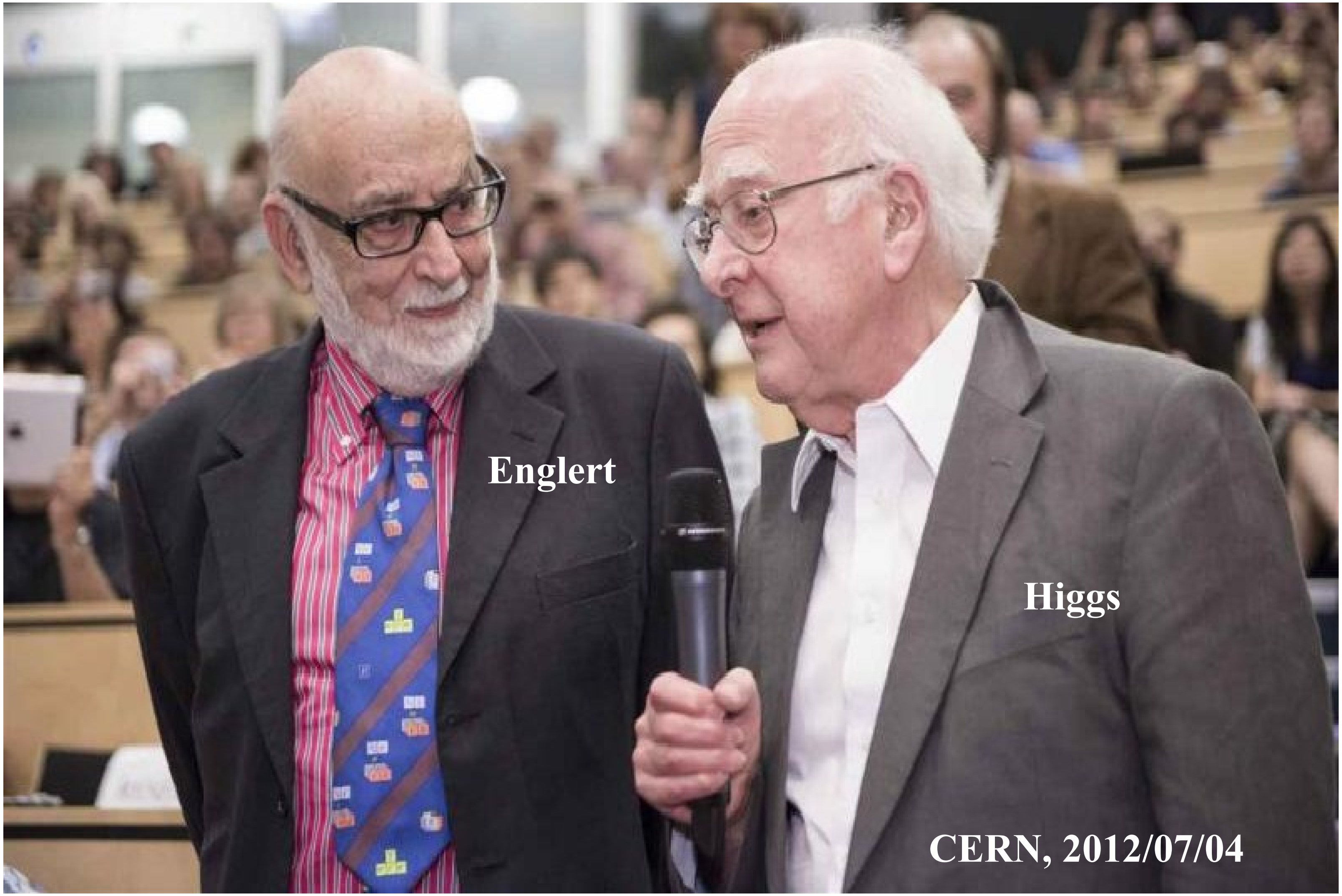
Similar observation by ATLAS



ATLAS-CONF-2012-019

The Higgs boson, if it exists and is SM-like, very likely is at mH≈125 GeV

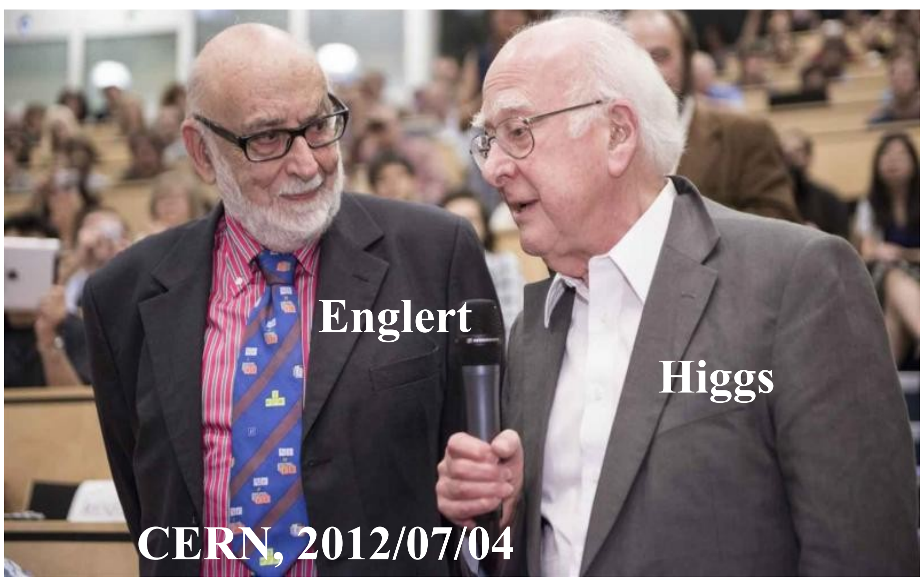
CERN, July 2012

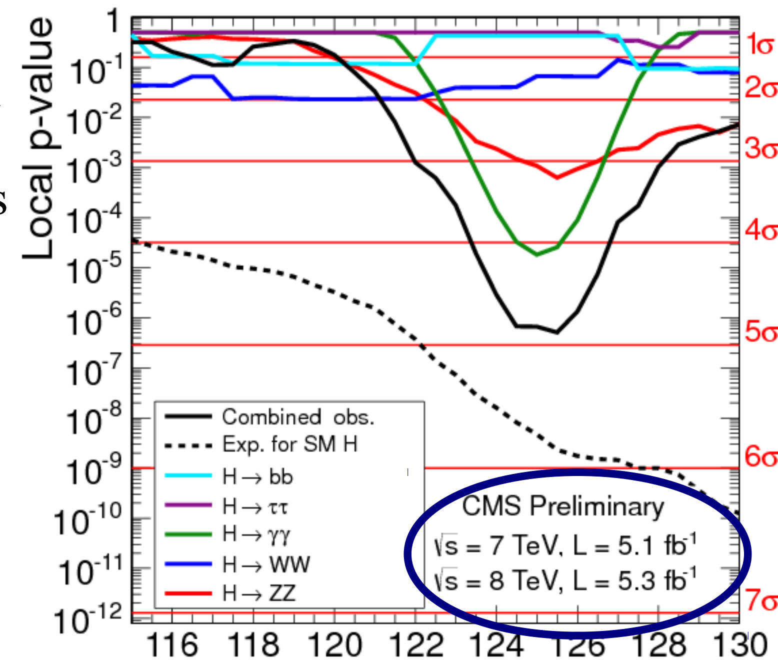


Suddenly things become a lot clearer. There is a Higgs!

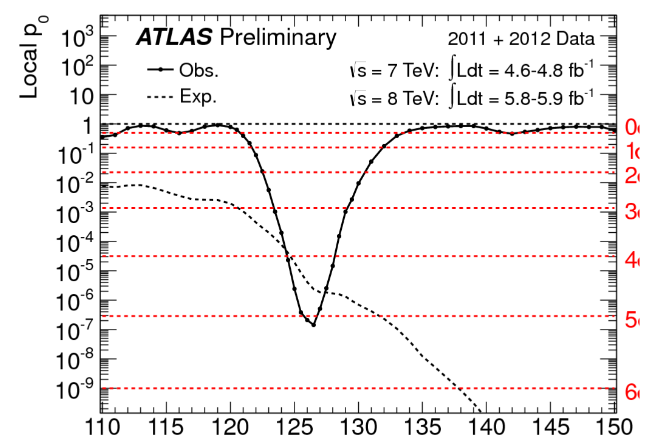
CERN, July 2012

- CERN seminar on July 4th, 2012
  - ≈5σ each for both experiments, mH≈125 GeV
    - Combining γγ, ZZ, WW, bb, ττ decay channels
- *Observation of a new boson, compatible with SM Higgs boson predictions*
  - The end of a 50-year-hunt!





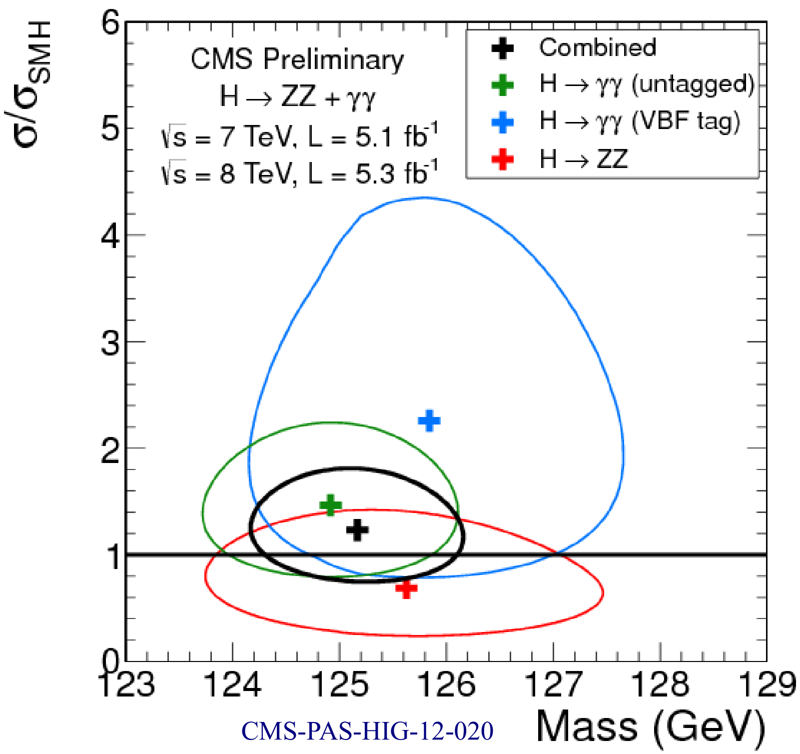
CMS-PAS-HIG-12-020

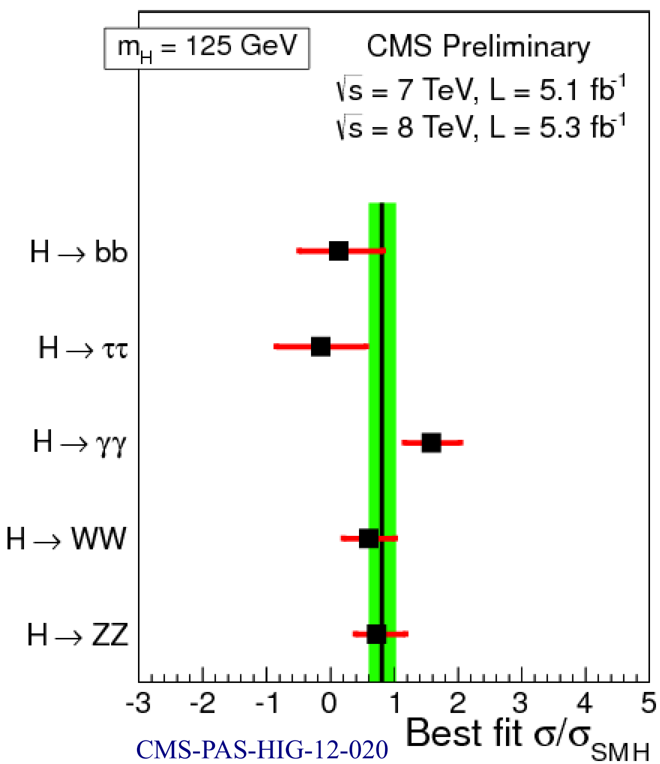


ATLAS-CONF-2012-093

CERN, July 2012

- This also marks the transition
  - **Higgs boson search period => Higgs boson measurement period**





Mass precision below 1%

Signal strength compatible with SM (...but also with many BSM models)

Recent CMS Higgs results

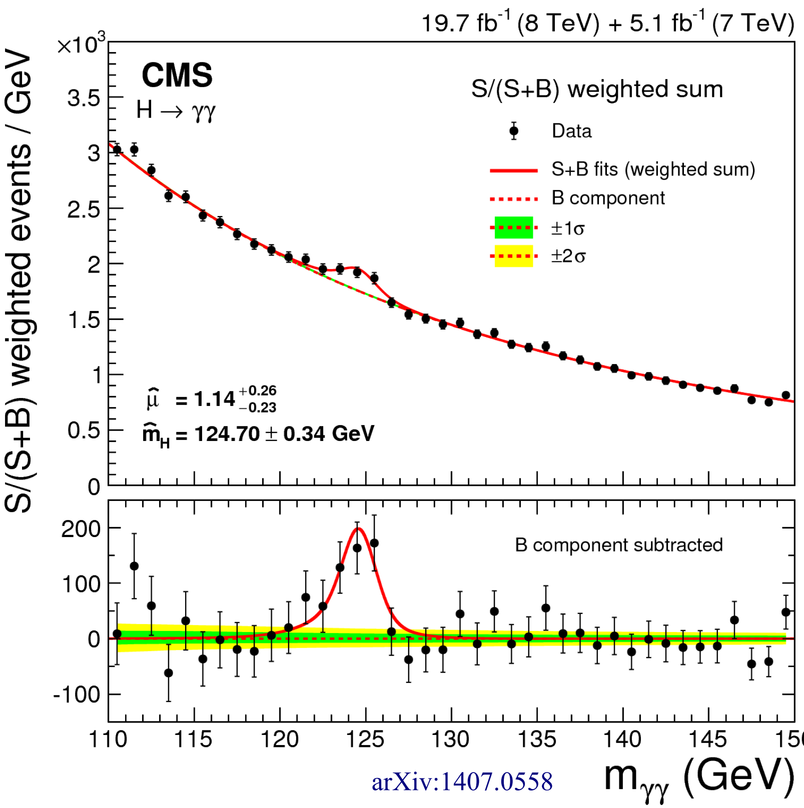
	Updated:
Big five: results	
• γγ	Aug 2014
• 4 leptons	Aug 2014
• WW	Oct 2014
• ττ	Oct 2014
• bb	**June 2015**
+ ttH combination	Aug 2014
Properties	
• Mass, Width	**Mar 2015**
• Coupling strength	Dec 2014
• Tensor coupling structure	Nov 2014
Rare processes (ee, μμ, μτ; Zγ, tHq)	**Feb 2015**
Direct BSM Higgs searches	**May 2015**
Prospects	**June 2015**

The „big five“ channels

- γγ
- 4 leptons
- WW
- ττ
- bb

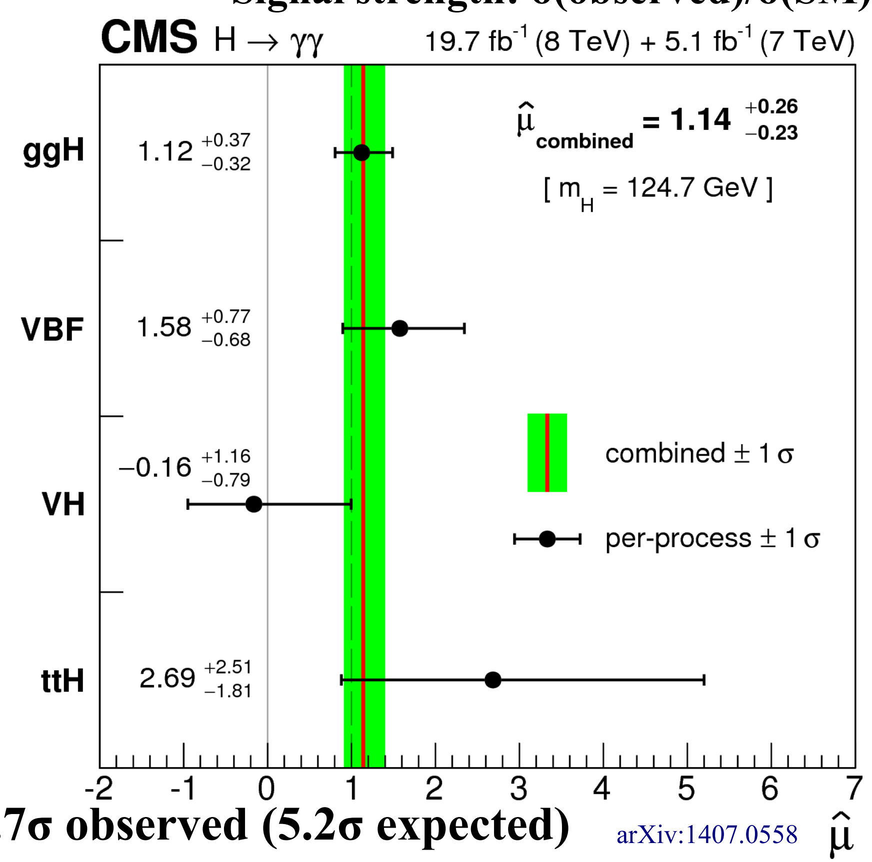
$H\to\gamma\gamma$: Analysis

- High statistics, **low S/B, high mass resolution**
- Select 2 photons in various categories (including VBF, VH, ttH)
- Estimate background by **fitting the m(γγ) distribution** (sidebands)
  - By now, mass peak visible with naked eye!



arXiv:1407.0558

Signal strength: σ(observed)/σ(SM)

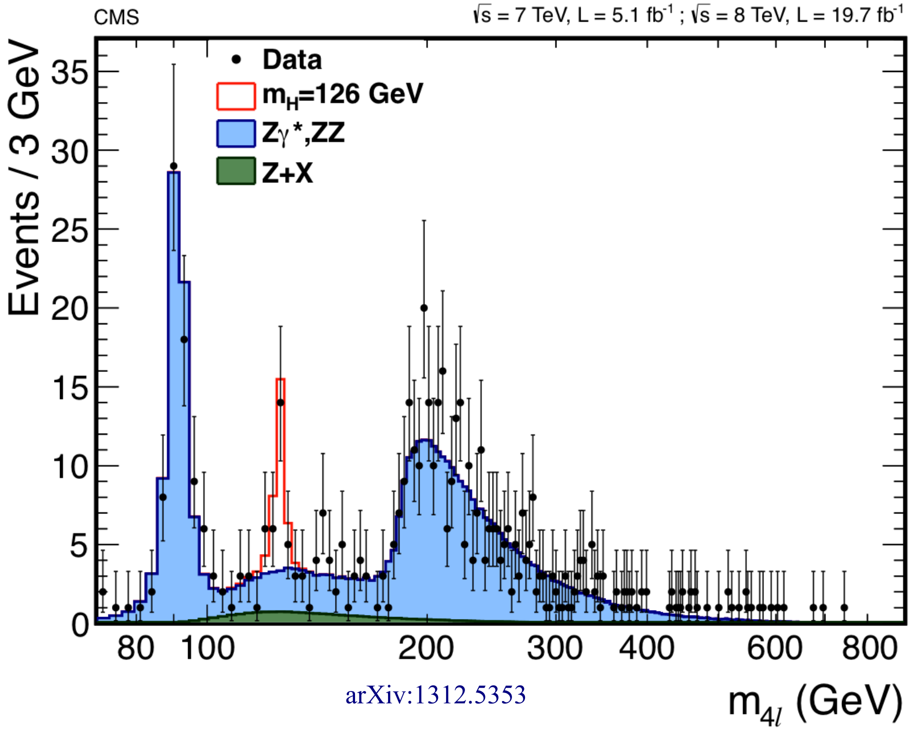


5.7σ observed (5.2σ expected)

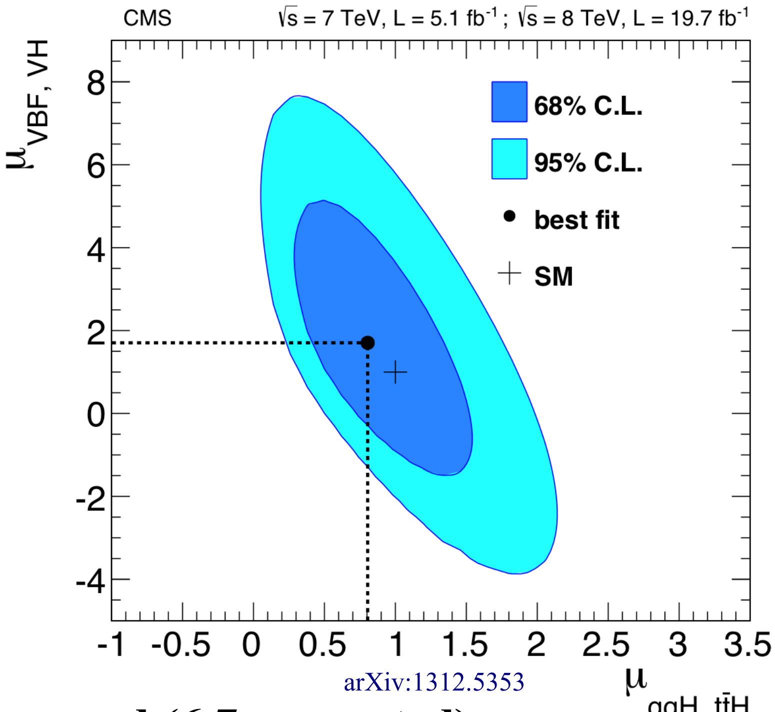
arXiv:1407.0558

H→4l: Analysis

- **Low statistics, excellent S/B, high mass resolution**
- Select 4 leptons in the channels 4e, 2e2μ, 4μ
  - Categories for VH, VBF, ttH – but main sensitivity in 0/1 jet
- Main background: **non-resonant ZZ***
  - Estimated from simulation, validated in control regions



arXiv:1312.5353



arXiv:1312.5353

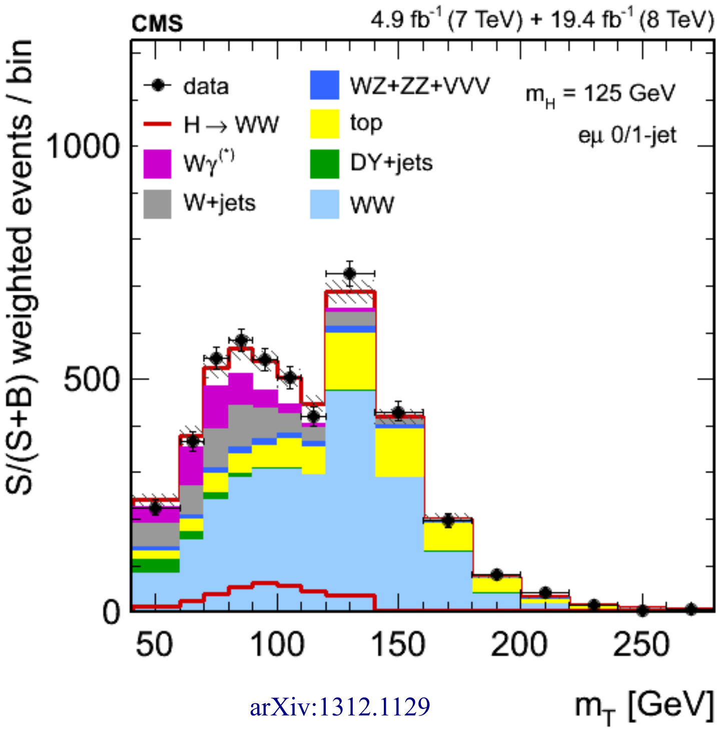
6.8σ observed (6.7σ expected)

H→WW: Analysis

- **High statistics, Low mass resolution**
- Main background: continuum WW

- Categories aiming at ggF, VBF, VH, ttH
  - Main sensitivity in eνμν + 0/1 jet

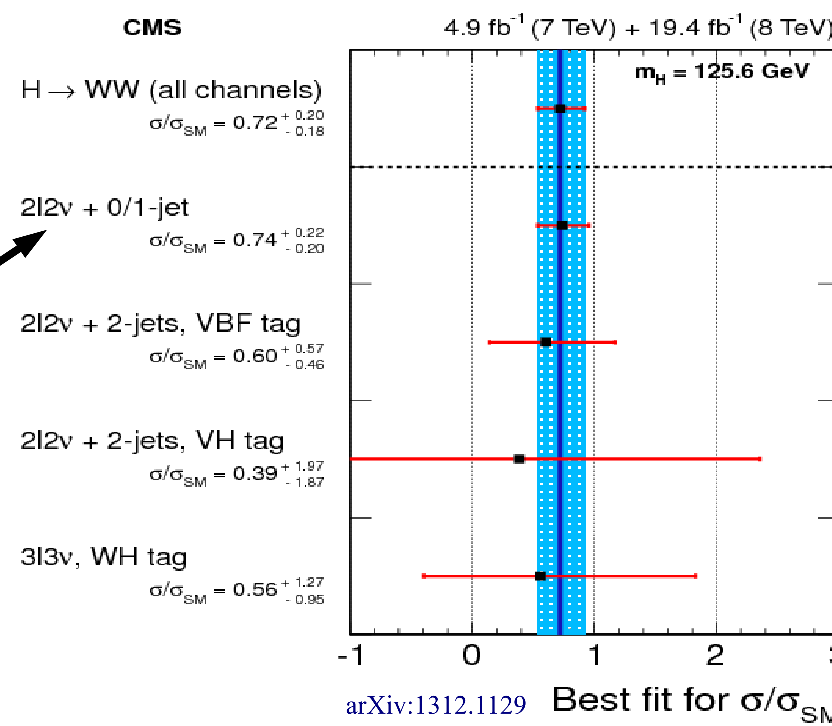
4.3σ observed (5.8σ expected)



arXiv:1312.1129

Weighted sum of channels

Most sensitive category



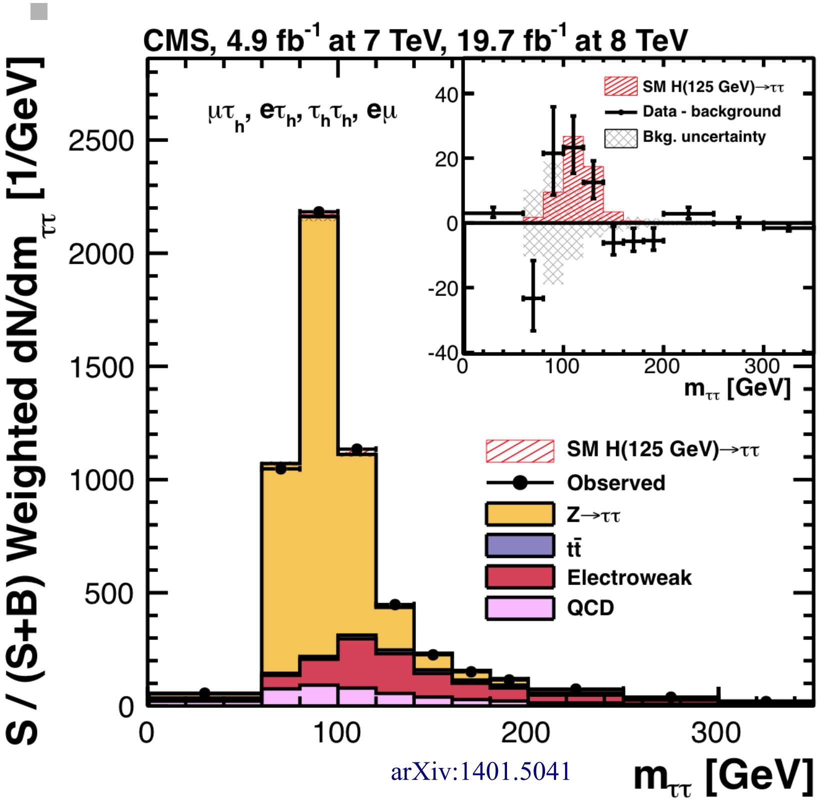
arXiv:1312.1129

H→ττ: Analysis

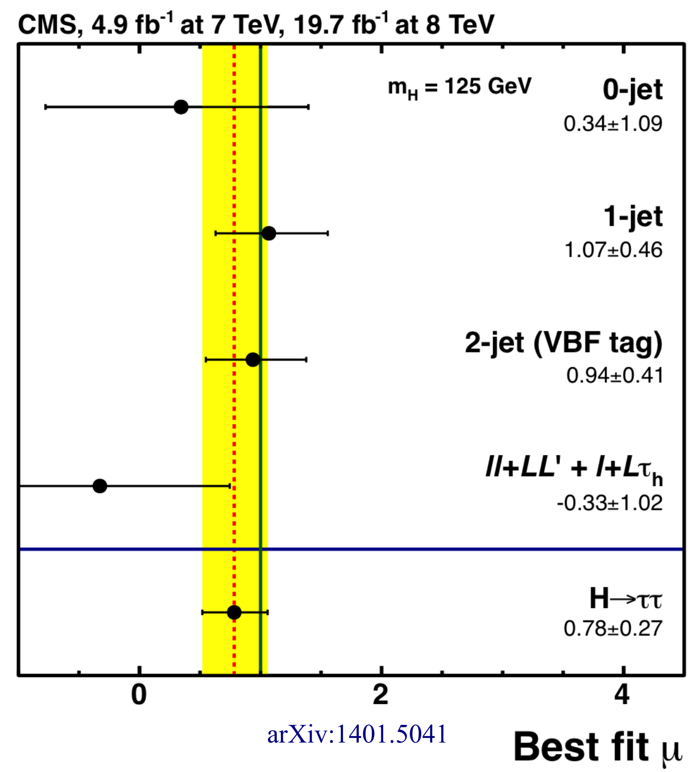
- Channels depending on tau decays (ee, eμ, μμ, eτ, μτ, ττ)
- Categories motivated by production: 0/1 jet, boosted, VBF, VH
  - **Sensitivity driven by VBF**
- Main background: ***Z/γ* → ττ***

Evidence of Higgs decays to fermions

3.2σ observed (3.7σ expected)



arXiv:1401.5041



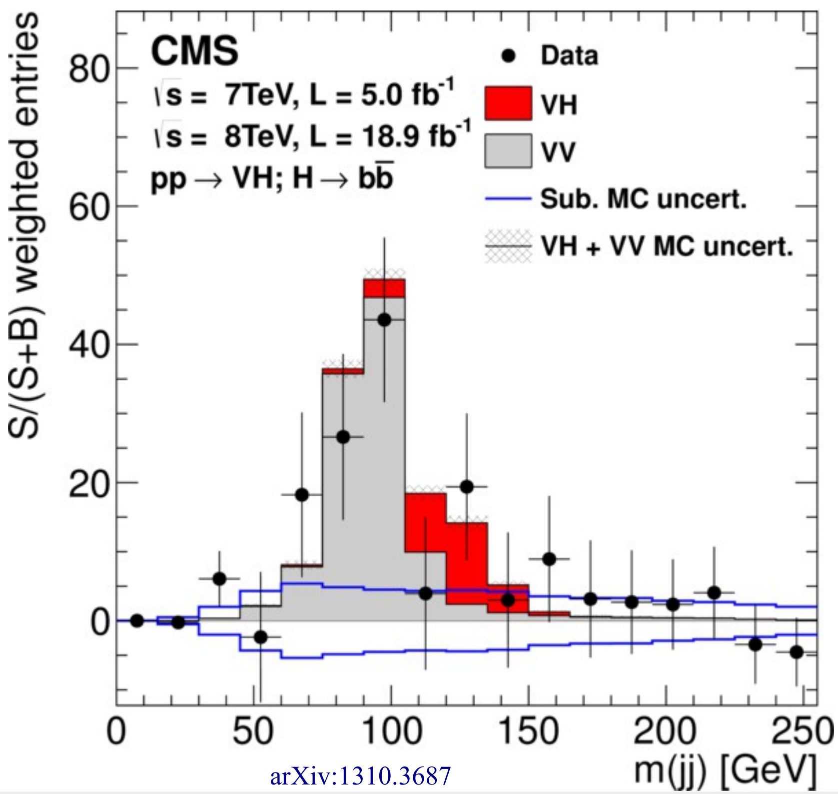
arXiv:1401.5041

H→bb: Analysis

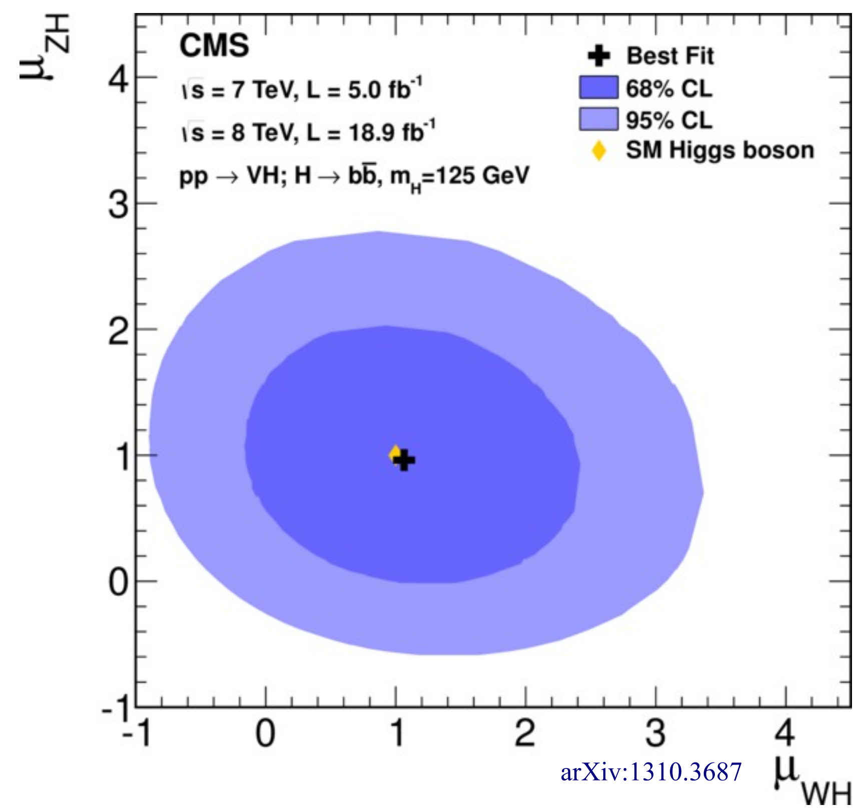
- Very challenging at a hadron collider, despite high BR
  - **WH/ZH (and ttH)**: use a lepton trigger
    - very recently, added **VBF** H→bb: use a dedicated trigger (+generic VBF trigger)

arXiv:1506.01010

  - **BDT-based analysis**
  - Backgrounds: VV, V+bb, tt



arXiv:1310.3687



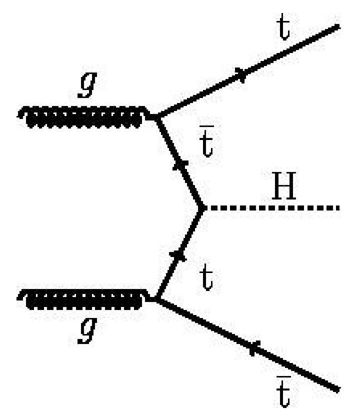
arXiv:1310.3687

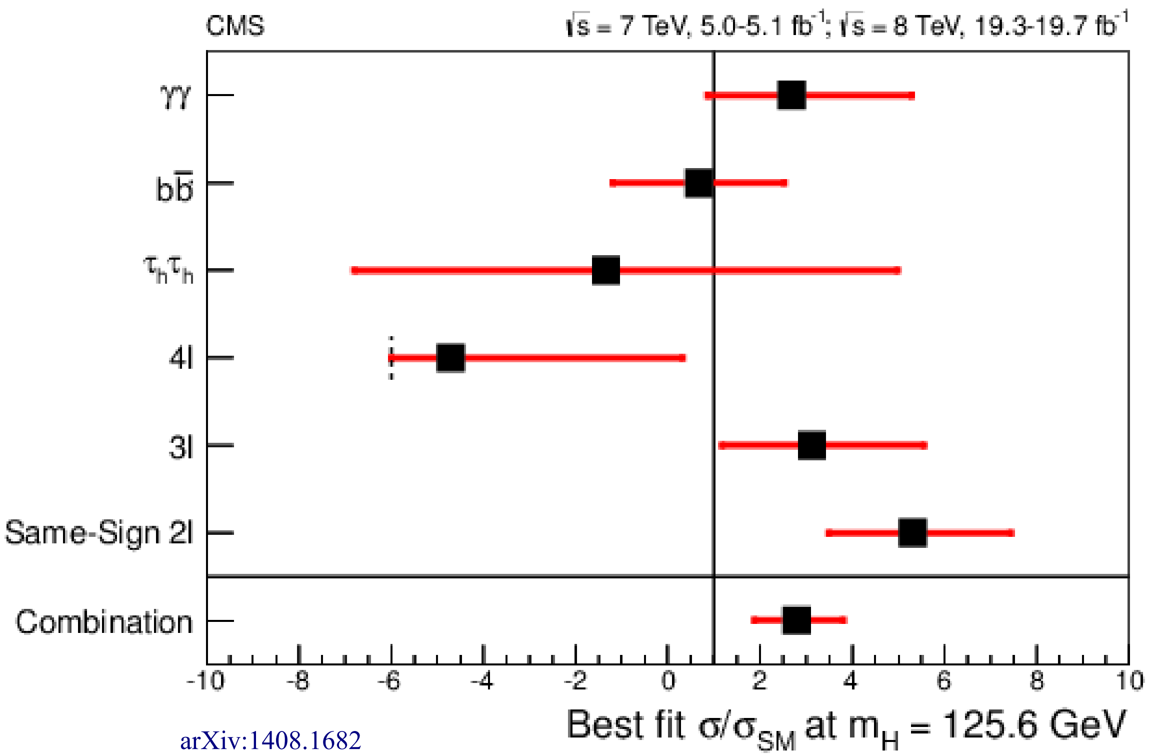
Combined VH+ttH+VBF:

μ=1.0±0.4, 2.6σ observed (2.7σ expected)

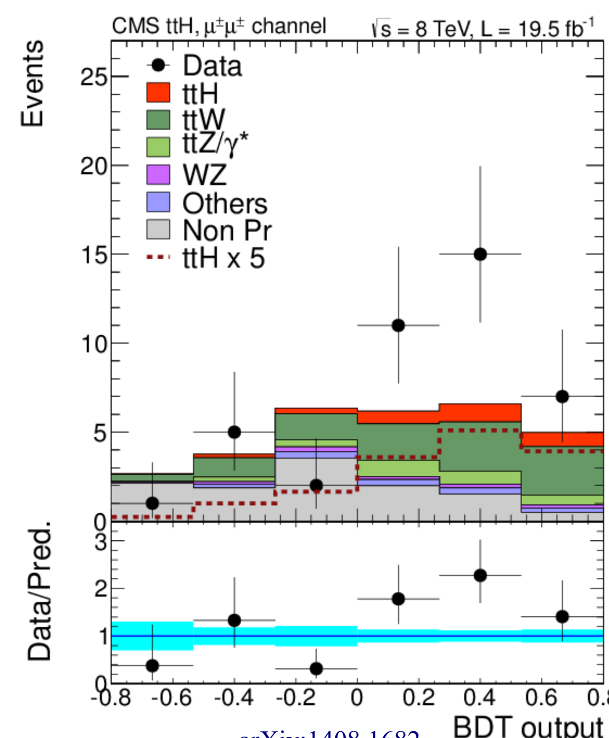
ttH

- CMS: combined signal strength: **μ=2.8 +/- 1.0**
  - About 2σ from SM, mostly driven by same-sign two-lepton analysis
- Almost **factor 5 increase in cross section** in LHC Run 2 expected (SM)





arXiv:1408.1682



arXiv:1408.1682

Higgs property measurements

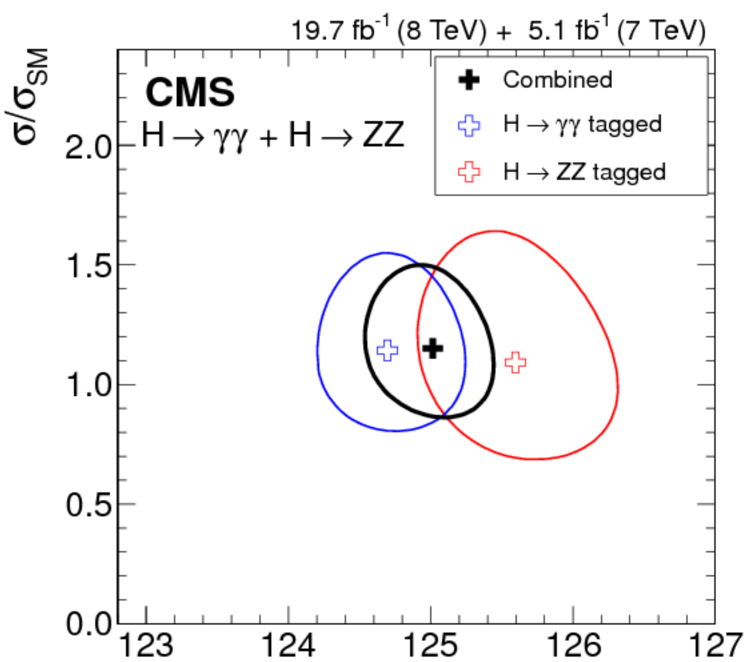
(maximum) input used for combined property measurements:

Decay/Production tag	GGF	VBF	VH	ttH
$H \rightarrow \gamma\gamma$	X	X	X	X
$H \rightarrow 4l$	X	X	X	X
$H \rightarrow WW$	X	X	X	X
$H \rightarrow \tau\tau$	X	X	X	X
$H \rightarrow bb$		*	X	X
$H \rightarrow inv$		X	X	
$H \rightarrow \mu\mu$	X	X		

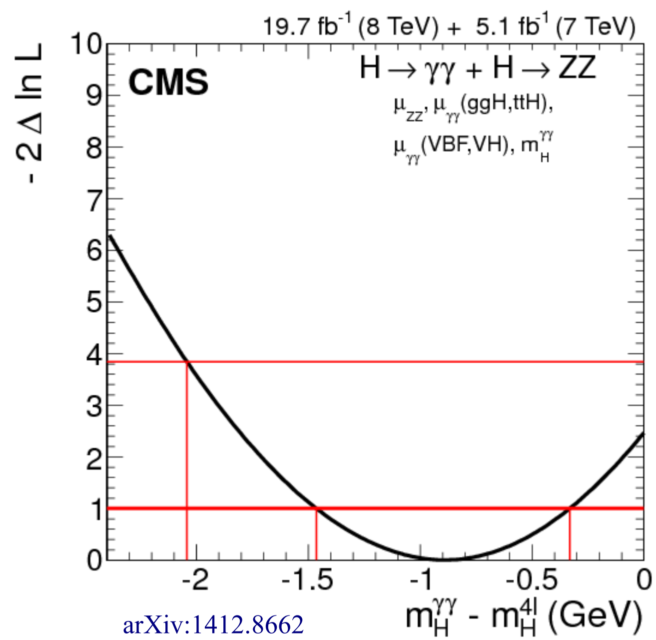
* available but not included in the combination

Mass

- Measured in **γγ** and **4l** (high-resolution channels)
  - **Precision of about 0.2%**!
- CMS: $m_{\mathrm{H}} = 125.02\,^{+0.26}_{-0.27}\,(\mathrm{stat})\,^{+0.14}_{-0.15}\,(\mathrm{syst})\,\mathrm{GeV}$ arXiv:1412.8662
- ATLAS+CMS: $m_H = 125.09 \pm 0.21\,(\mathrm{stat.}) \pm 0.11\,(\mathrm{syst.})\,\mathrm{GeV}$ arXiv:1503.07589
  - Statistical uncertainties still dominate



arXiv:1412.8662



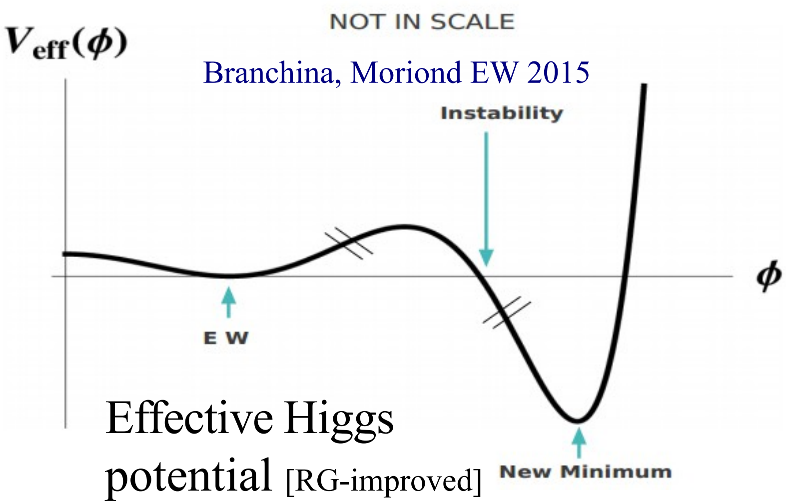
arXiv:1412.8662

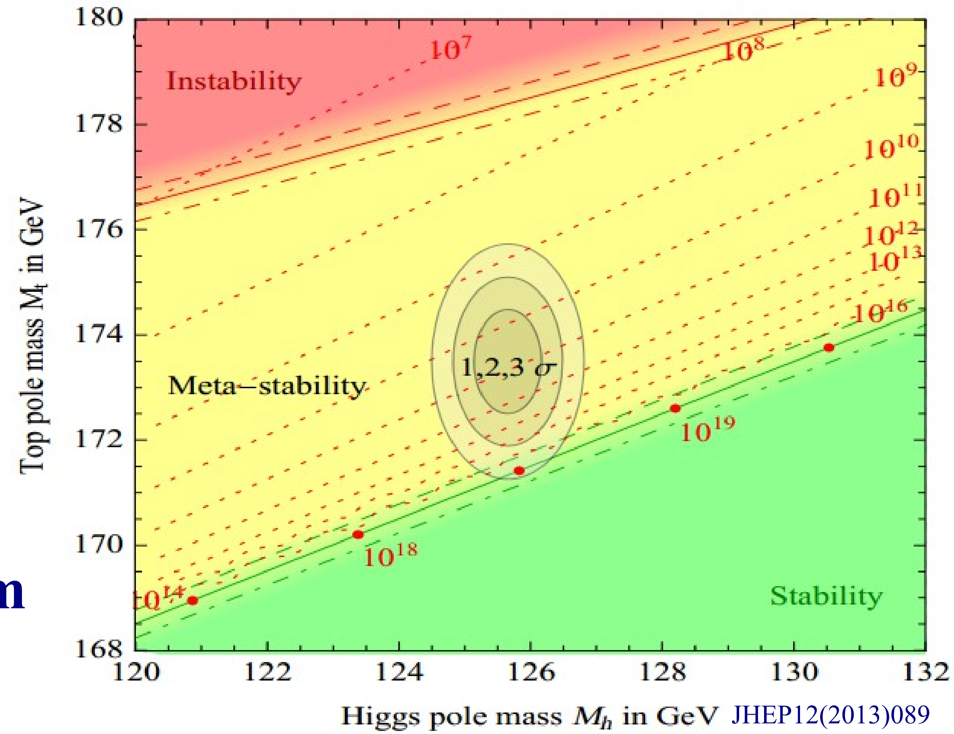
γγ and 4l compatible within 1.4σ

WW: $m_{\mathrm{H}} = 128^{+7}_{-5}\,\mathrm{GeV}$

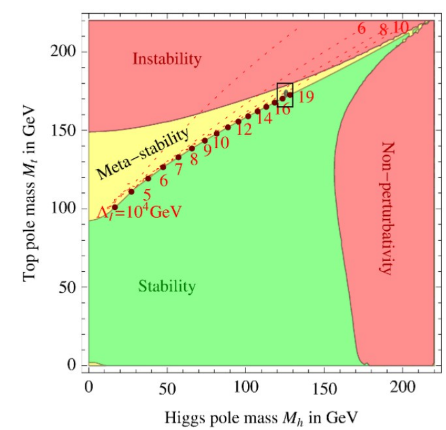
ττ: $m_{\mathrm{H}} = 122 \pm 7\,\mathrm{GeV}$

„The fate of the universe“





- Top-loop corrections: **2nd minimum in the Higgs potential**, either
  - above EW minimum => **stable vacuum**
  - below => **unstable** [meta-stable if life time >> life time of universe]



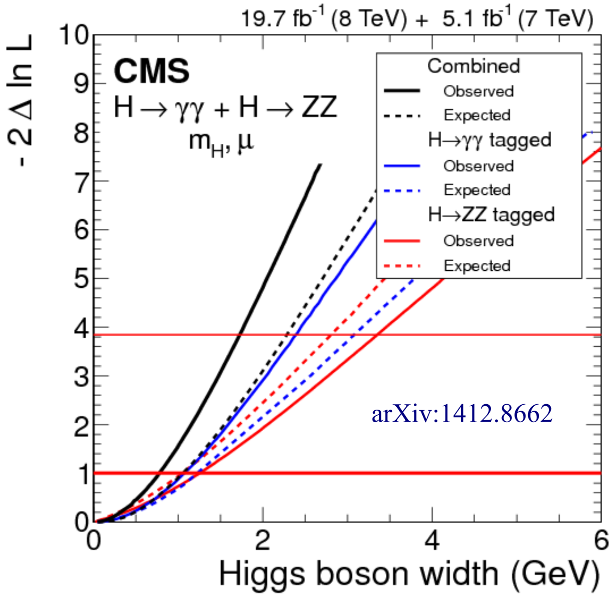
- Vacuum stability depends strongly on mH and mtop
- However, stability diagram depends on physics at m_{Planck}

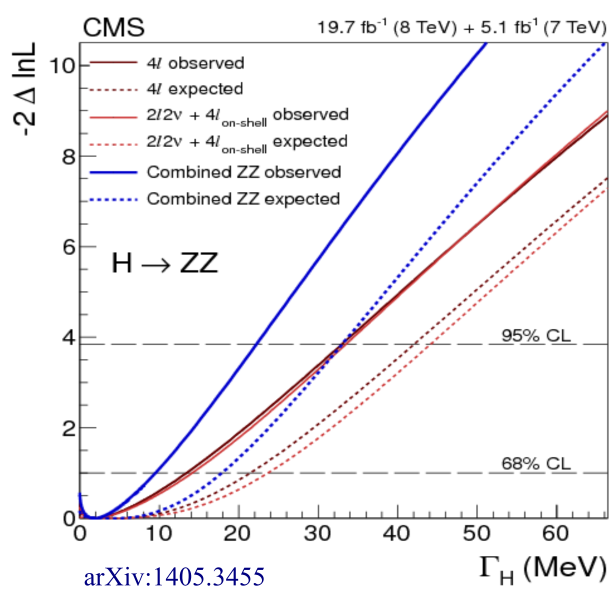
Branchina, Moriond EW 2015

  - even perfect mH/mtop resolution might not tell us about stability

Higgs width limits

- SM expectation: 4 MeV
- **Direct**: Limits on Higgs width from
  - H→γγ: Γ < 2.4 GeV arXiv:1407.0558
  - H→ZZ: Γ < 3.4 GeV arXiv:1312.5353
  - Combined: Γ < **1.7 GeV** arXiv:1412.8662
- **Indirect**: Coupling fits and Higgs-to-invisible searches
- **Indirect: From comparison of on- and off-shell H→4l signal strength** arXiv:1405.3455
  - Model-dependent!
  - **Γ < 22 (33) MeV**
    < 5.4 (8.0) times SM expectation



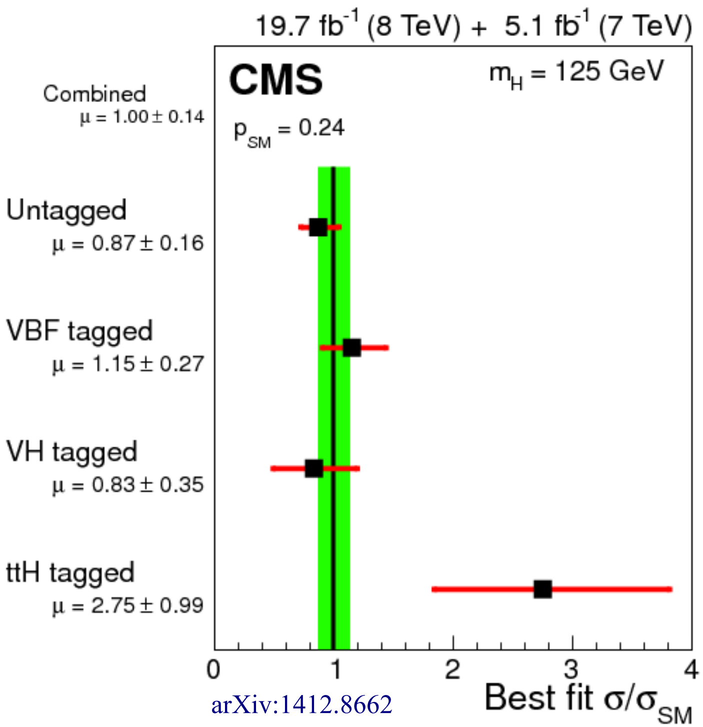


arXiv:1405.3455

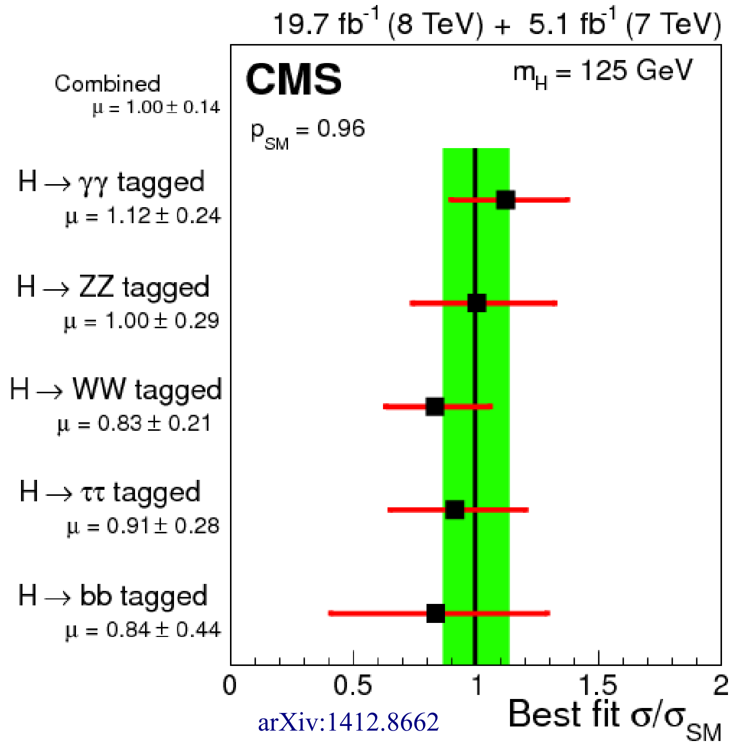
Signal strength

- $\mu = \sigma_{obs}/\sigma_{SM}$
- Combination: **μ=1.00 ± 0.13**

Production



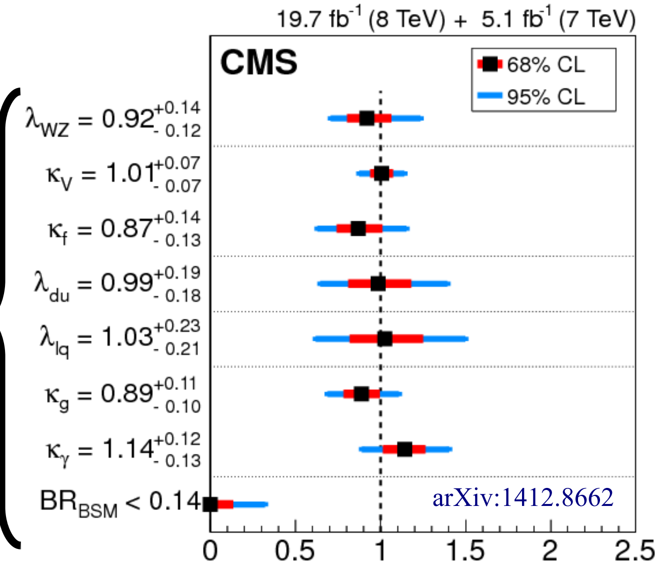
Decay



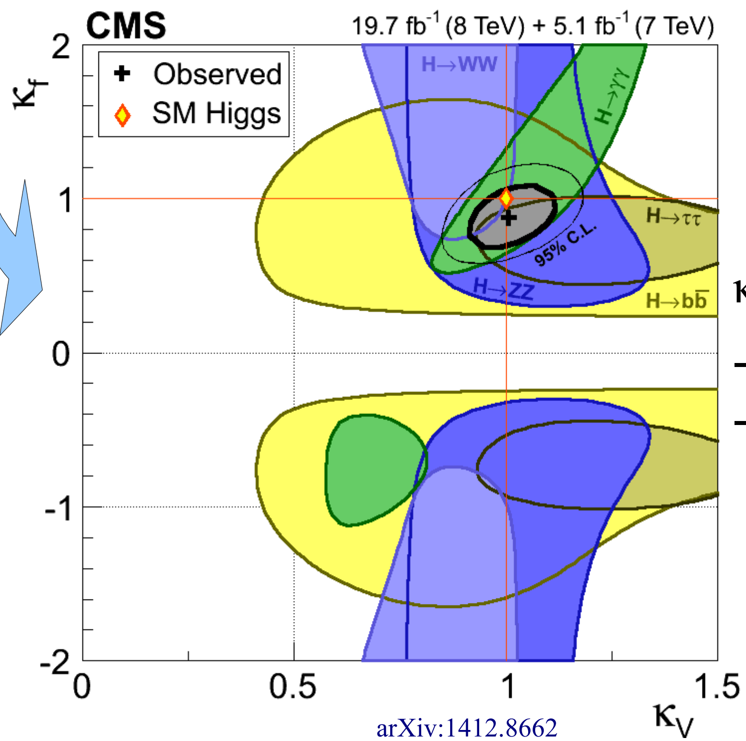
- Only deviation from SM beyond 1σ: ttH
- **High compatibility with SM** (p=0.24 / p=0.96)

Coupling strength

- Processes involve several couplings
- Requires assumptions (Γ_H, universality..)
- Typical tests:
  - **Fermions vs bosons**
  - **Custodial symmetry** (W vs Z)
  - **Loop contributions** (effective gg, γγ)

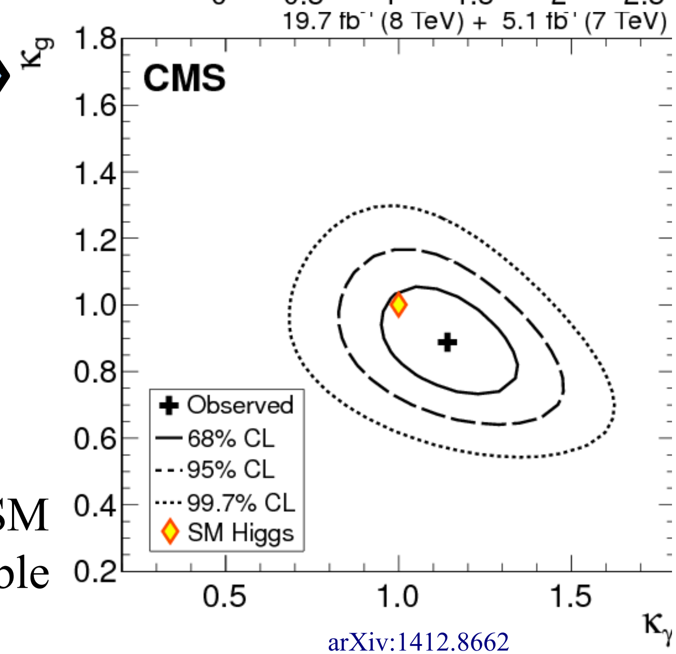


agrees with SM



κ_V and κ_F

- agreement with SM
- γγ removes sign ambiguity



no significant BSM loop effects visible

Tensor coupling structure

J^P Model	J^P Prod.	Expected $X \to ZZ$	Expected $X \to WW$	Expected (μ=1)	Obs. 0^+	Obs. J^P	CL_s
1^-	$q\bar{q}$	2.9σ	2.2σ	3.6σ (4.6σ)	-1.2σ	$+4.9\sigma$	<0.001%
1^+	$q\bar{q}$	2.4σ	1.8σ	3.0σ (3.8σ)	-0.8σ	$+4.3\sigma$	0.004%
2^+_m	gg	1.9σ	1.8σ	2.4σ (3.4σ)	-0.4σ	$+2.9\sigma$	0.53%
2^+_{h2}	gg	2.0σ	1.7σ	2.5σ (3.3σ)	-0.2σ	$+2.8\sigma$	0.52%
2^+_{h3}	gg	3.2σ	1.6σ	3.7σ (4.3σ)	$+0.4\sigma$	$+3.5\sigma$	0.031%
2^+_h	gg	3.8σ	0.7σ	3.8σ (4.2σ)	$+1.7\sigma$	$+2.1\sigma$	1.9%
2^+_b	gg	1.6σ	1.8σ	2.4σ (3.2σ)	-0.9σ	$+3.4\sigma$	0.16%
2^+_{h6}	gg	3.4σ	2.5σ	4.2σ (4.9σ)	-0.5σ	$>5\sigma$	<0.001%
2^+_{h7}	gg	3.8σ	1.8σ	4.2σ (5.0σ)	-0.1σ	$+4.7\sigma$	<0.001%
2^-_h	gg	4.2σ	1.2σ	4.3σ (5.0σ)	$+1.0\sigma$	$+3.4\sigma$	0.039%
2^-_{h9}	gg	2.5σ	1.4σ	2.8σ (3.5σ)	-1.0σ	$+4.2\sigma$	0.009%
2^-_{h10}	gg	4.2σ	2.0σ	4.6σ (5.3σ)	$+0.1\sigma$	$+4.9\sigma$	<0.001%
2^+_m	$q\bar{q}$	1.7σ	2.7σ	3.1σ (4.3σ)	-1.0σ	$+4.5\sigma$	0.002%
2^+_{h2}	$q\bar{q}$	2.2σ	2.6σ	3.3σ (4.3σ)	-0.8σ	$+4.4\sigma$	0.002%
2^+_{h3}	$q\bar{q}$	3.1σ	2.6σ	3.8σ (4.5σ)	0.0σ	$+4.1\sigma$	0.005%
2^+_h	$q\bar{q}$	4.0σ	1.6σ	4.3σ (4.5σ)	$+0.2\sigma$	$+4.3\sigma$	0.002%
2^+_b	$q\bar{q}$	1.7σ	2.8σ	3.1σ (4.2σ)	-1.3σ	$+4.8\sigma$	<0.001%
2^+_{h6}	$q\bar{q}$	3.4σ	2.8σ	4.3σ (5.0σ)	-0.1σ	$+4.8\sigma$	<0.001%
2^+_{h7}	$q\bar{q}$	4.1σ	2.2σ	4.6σ (5.0σ)	$+0.3\sigma$	$+4.5\sigma$	<0.001%
2^-_h	$q\bar{q}$	4.3σ	2.0σ	4.7σ (5.2σ)	$+0.1\sigma$	$+5.0\sigma$	<0.001%
2^-_{h9}	$q\bar{q}$	2.4σ	2.0σ	3.1σ (3.8σ)	$+0.5\sigma$	$+2.7\sigma$	0.55%
2^-_{h10}	$q\bar{q}$	4.0σ	2.6σ	4.7σ (5.3σ)	$+0.5\sigma$	$+4.6\sigma$	<0.001%

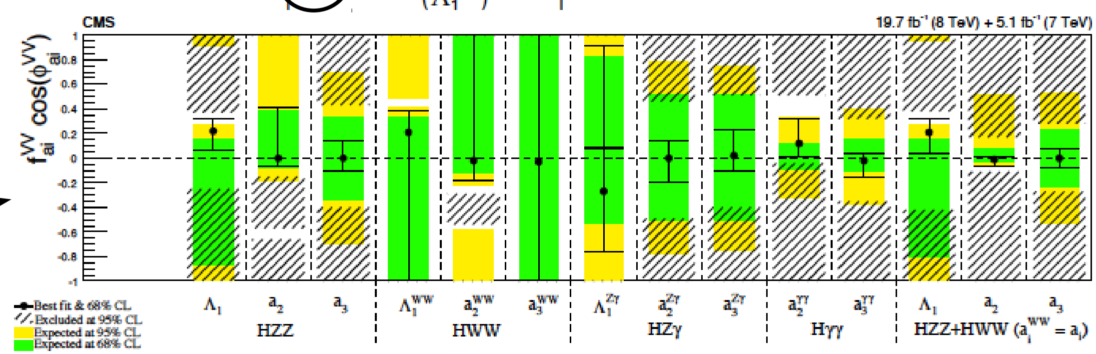
arXiv:1411.3441

- Using input from ZZ, WW; and γγ (spin only)
- From observed decay modes:
  - Particle is a boson
  - Not spin 1 due to H→γγ [Landau-Yang theorem]
    - Unless: e.g. via H→a1a1→γγγγ
  - **Remaining options**:
    - **0+(SM), 0+(anom), 0-** [or mixture of these]
    - Continuum of **2+/2-** states [non-renormalisable]

- **Spin 1, 2 disfavored**; all tested options excluded at high confidence level
- **0- disfavored, but more weakly** than spin 1, 2
- **Significant CP-odd admixture** to SM Higgs is still **possible**

SM tree-level amplitude

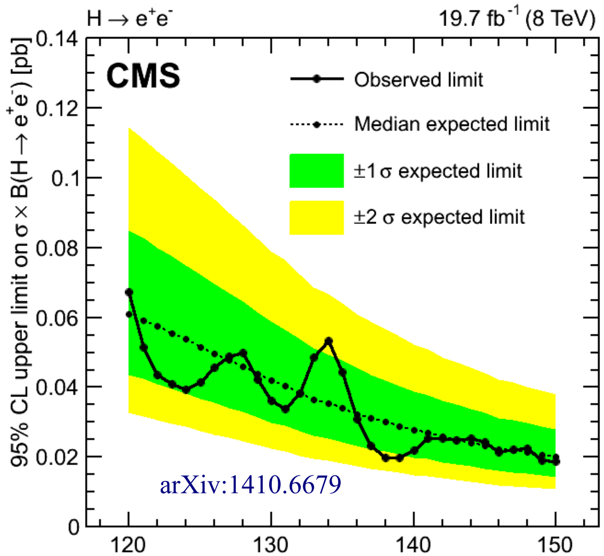
$$A(\mathrm{HVV}) \sim \left[a_1^{\mathrm{VV}} - \frac{\kappa_1^{\mathrm{VV}} q_{\mathrm{V1}}^2 + \kappa_2^{\mathrm{VV}} q_{\mathrm{V2}}^2}{\left(\Lambda_1^{\mathrm{VV}}\right)^2} \right] m_{\mathrm{V1}}^2 \epsilon_{\mathrm{V1}}^* \epsilon_{\mathrm{V2}}^* + a_2^{\mathrm{VV}} f_{\mu\nu}^{*(1)} f^{*(2),\mu\nu} + a_3^{\mathrm{VV}} f_{\mu\nu}^{*(1)} \tilde{f}^{*(2),\mu\nu}$$

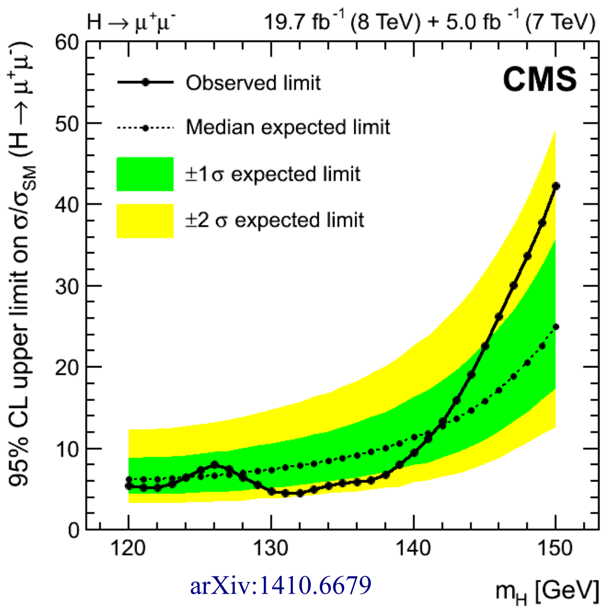


arXiv:1411.3441

Rare Higgs processes and BSM Higgs searches

Leptonic Higgs decays





Numerical limits: for m_H=125 GeV

H→ee

$$\sigma/\sigma_{\mathrm{SM}} < 3.7 \cdot 10^5$$

H→τμ

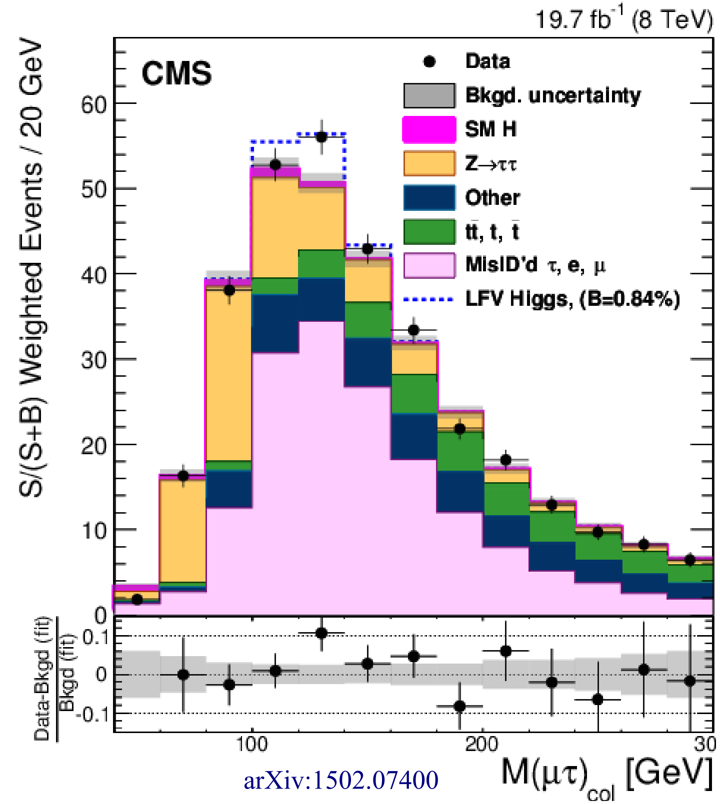
2.5σ excess, compatible with B(H→τμ)=0.8%

H→μμ

$$\sigma/\sigma_{\mathrm{SM}} < 7.4 \; (6.5^{+2.8}_{-1.9})$$

observed expected

Exclusion of universal leptonic couplings

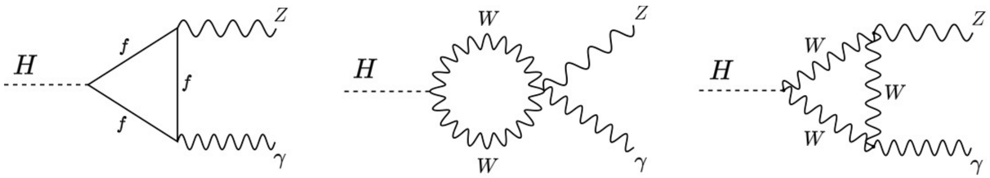


$$\begin{pmatrix} y_{ee} & y_{e\mu} & y_{e\tau} \\ & y_{\mu\mu} & y_{\mu\tau} \\ & & y_{\tau\tau} \end{pmatrix}$$

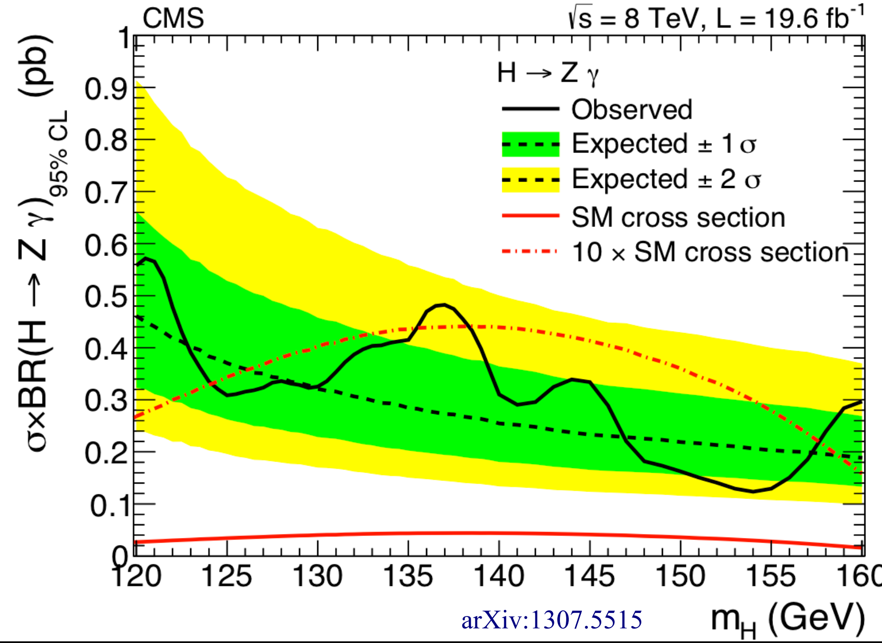
SM Higgs: flavor diagonal

Zγ and tHq

H→Zγ



- SM: Via loops, BR=0.15%
  - BSM sensitivity

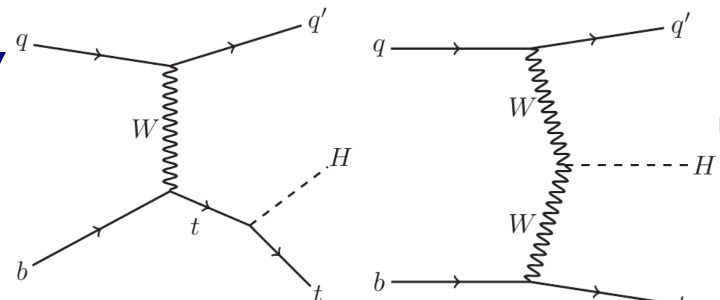


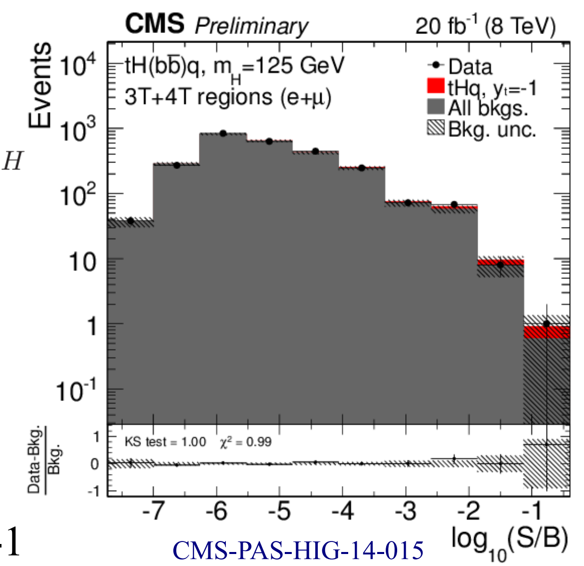
arXiv:1307.5515

- **Exclusion of about 10xσ_{SM}** [125 GeV]

tHq, H→bb/WW/ττ/γγ

SM: nearly total destructive interference of these two diagrams





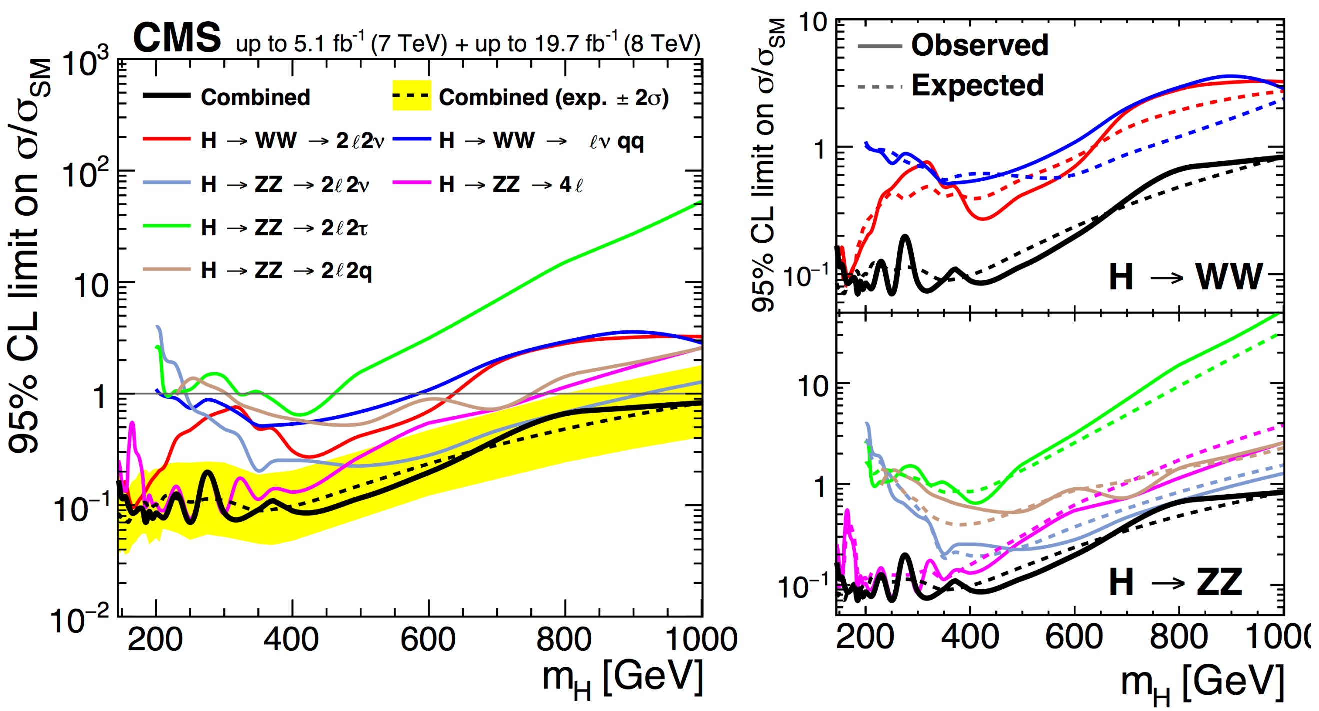
CMS-PAS-HIG-14-015

- Sensitive to relative sign of couplings to fermions/bosons
  - No excess observed
  - **Excludes** 4.1x SM (γγ) / 7.6x SM (bb) / 6.7x SM (WW/ττ) cross section with yt=-1

CMS-PAS-HIG-14-001 CMS-PAS-HIG-14-015 CMS-PAS-HIG-14-026

Heavy SM-like Higgs bosons

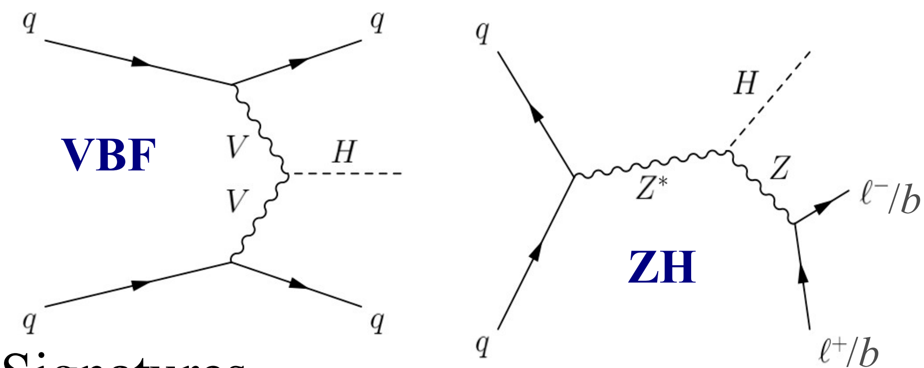
- Search for additional SM-like heavy Higgs bosons
  - Motivation: e.g. **Higgs singlet** (in addition to doublet), **2HDM**
- Most sensitive channels:
  - intermediate mass: H→WW→2l2ν, H→ZZ→2l2l'
  - high mass: H→ZZ→2l2ν
- **Limit on $\sigma/\sigma_{SM} < 1$ up to 1 TeV!**



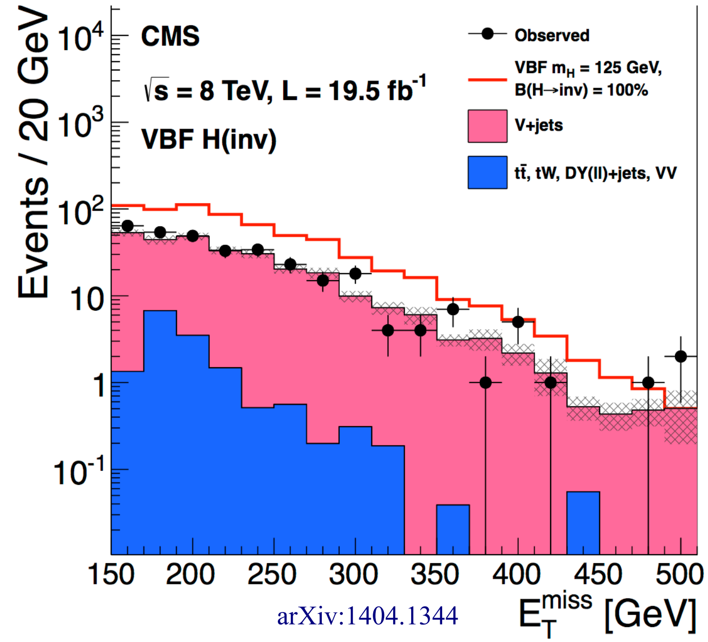
arXiv:1504.00936

Invisible Higgs decays

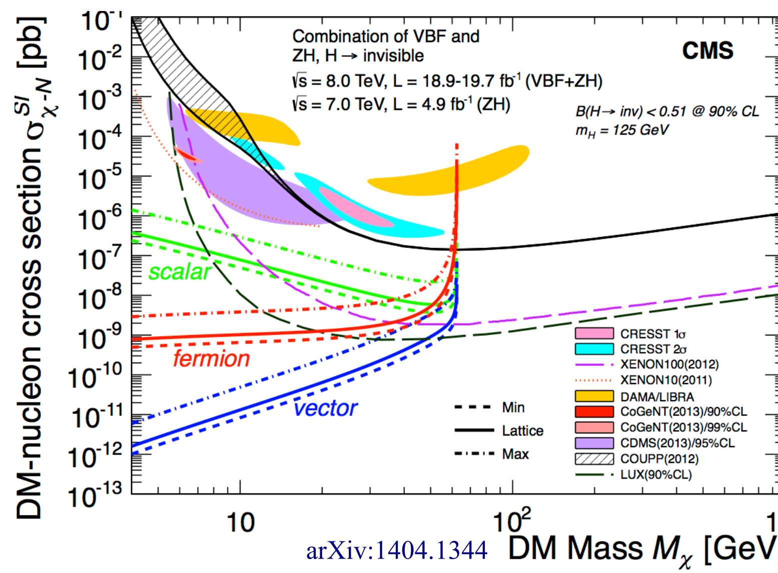
- Motivation: **Non-SM decays to stable or long-lived particles**
  - e.g. SUSY, Extra dimensions, Higgs portal



- Signatures
  - CMS-PAS-HIG-14-038
  - **VBF**: 2 jets (large $\Delta\eta$, high m_{jj}) + MET
  - **ZH**: 2 leptons / 2 b quarks (m_Z) + MET
  - arXiv:1404.1344
- **Limit on BR(H→inv)**:
  - VBF: 57% obs (40%)
  - Combination: 58% (44%) [previous VBF results]
- Translated to DM-nucleon cross-section
  - for $m_{DM}<m_H$; model-dependent [H-nucleon xsec]



arXiv:1404.1344

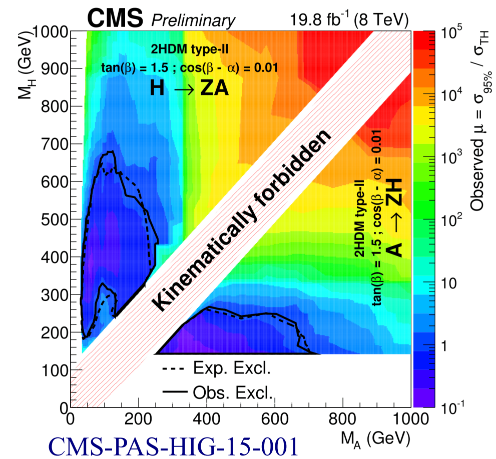


arXiv:1404.1344

X→hh, H→Zh

- **H→hh, H→Zh** in multi-lepton final states arXiv:1410.2751
- **H→ZA, A→ZH**, H→bb/ττ CMS-PAS-HIG-15-001

constrain 2HDM

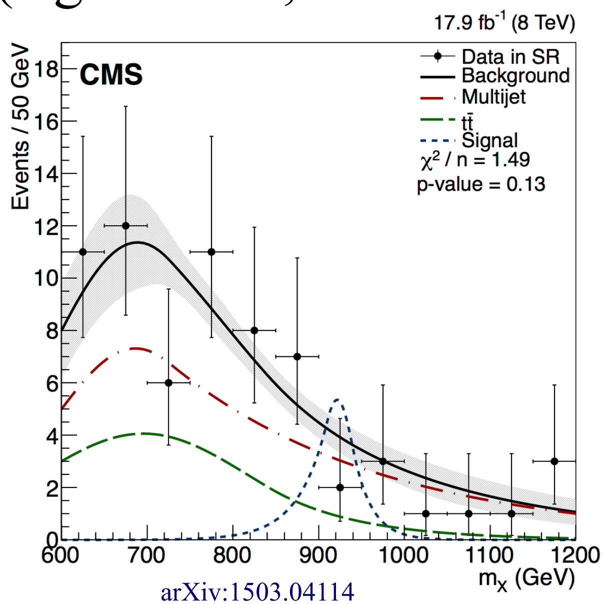


CMS-PAS-HIG-15-001

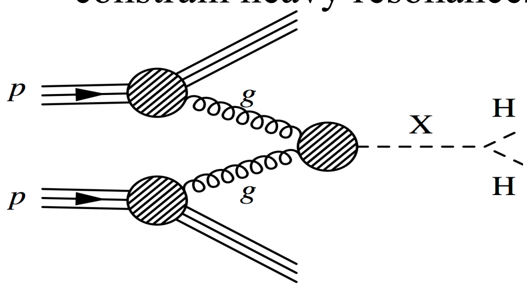
- **X→HH→4b**

(e.g. Radion, KK-Graviton)

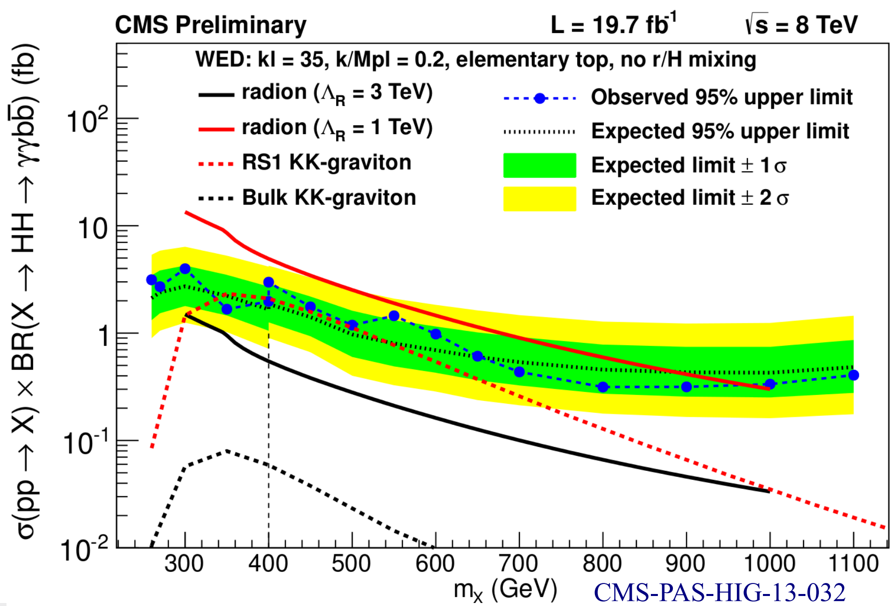
constrain heavy resonances



arXiv:1503.04114



- **X→HH→γγbb**

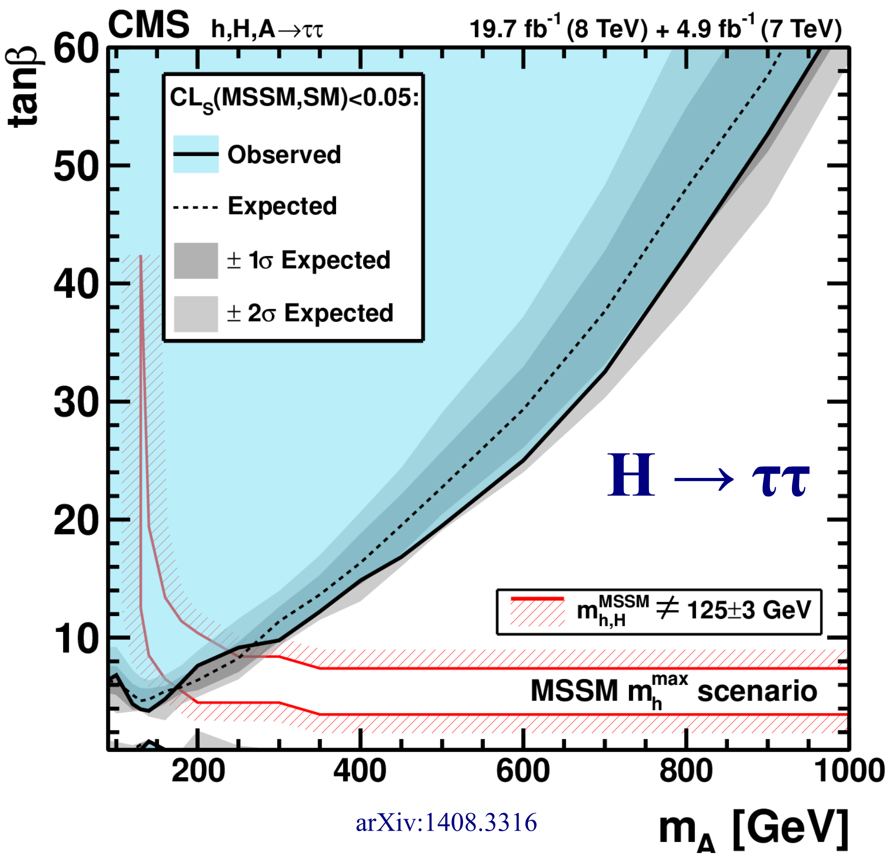


CMS-PAS-HIG-13-032

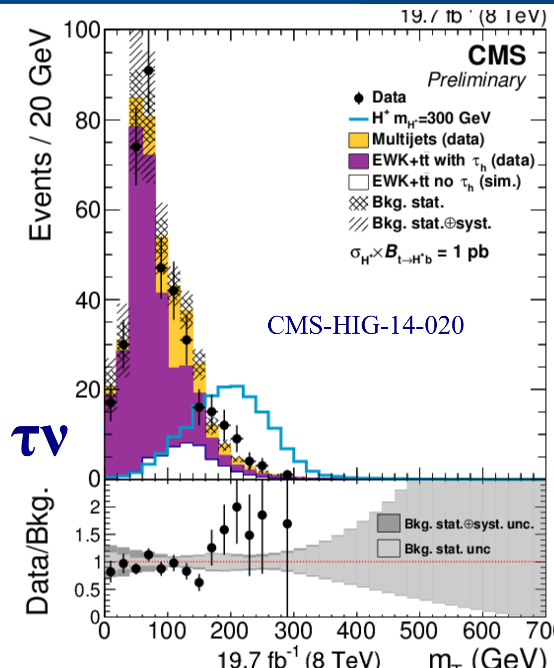
No excesses observed. Phase space for spin-0/-2 resonances constrained.

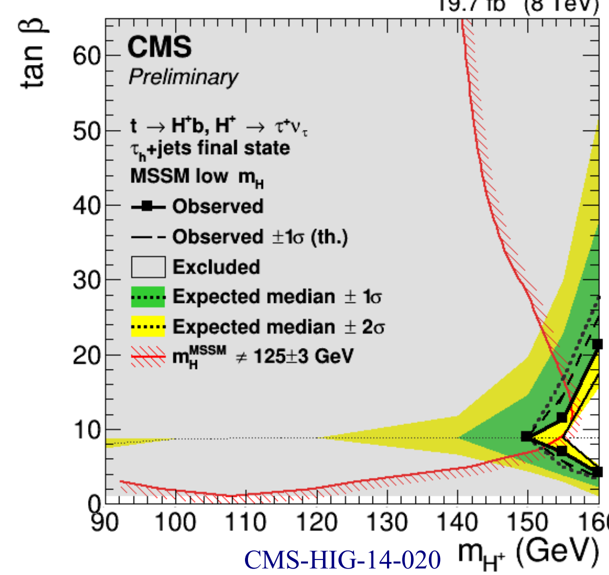
MSSM Higgs boson searches

- **H/A → ττ**: exclude mA up to 1000 GeV, depending on tan β
- **H+ → τν**: almost excludes possibility that h_{125} is the heavy neutral scalar H_0



heavy H+ → τν





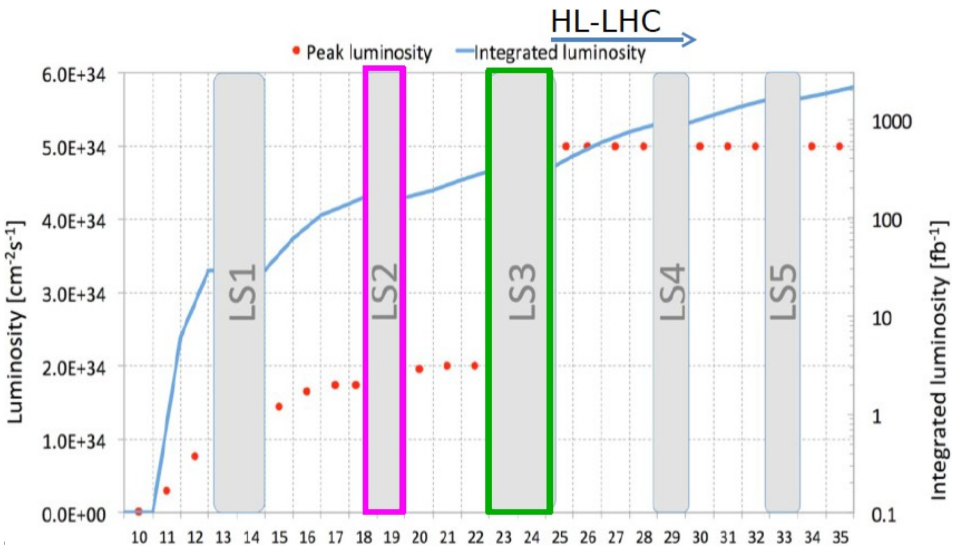
light H+ → τν

Plethora of BSM Higgs searches

- MSSM-/NMSSM-inspired searches
  - H+ → csbar
  - H+ → τν
  - H+ → tb
  - H → ττ/μμ
  - H → WW
  - H → bb
  - a1 → γγ / bb
- Generic / exotic Higgs searches
  - Heavy Higgs → WW/ZZ/γγ
  - Invisible Higgs
  - Doubly charged Higgs
  - Lepton flavor violation: H→τμ
  - t → cH
  - Fermiophobic Higgs
  - 4^{th} generation
- Indirect search for BSM physics via Higgs property measurements

No significant deviation from SM expectation found
=> heavily constrained the phase space for BSM Higgs bosons

- Higgs-to-Higgs, Higgs pairs
  - X → HH
  - A → ZH, H → ZA
  - H → H+W, H+ → Wh
- Even more exotic searches
  - Higgs portal models
  - Higgs to long-lived particles
  - Higgs to electron jets
  - Higgs to displaced muon jets
  - a1 → μμ
- …



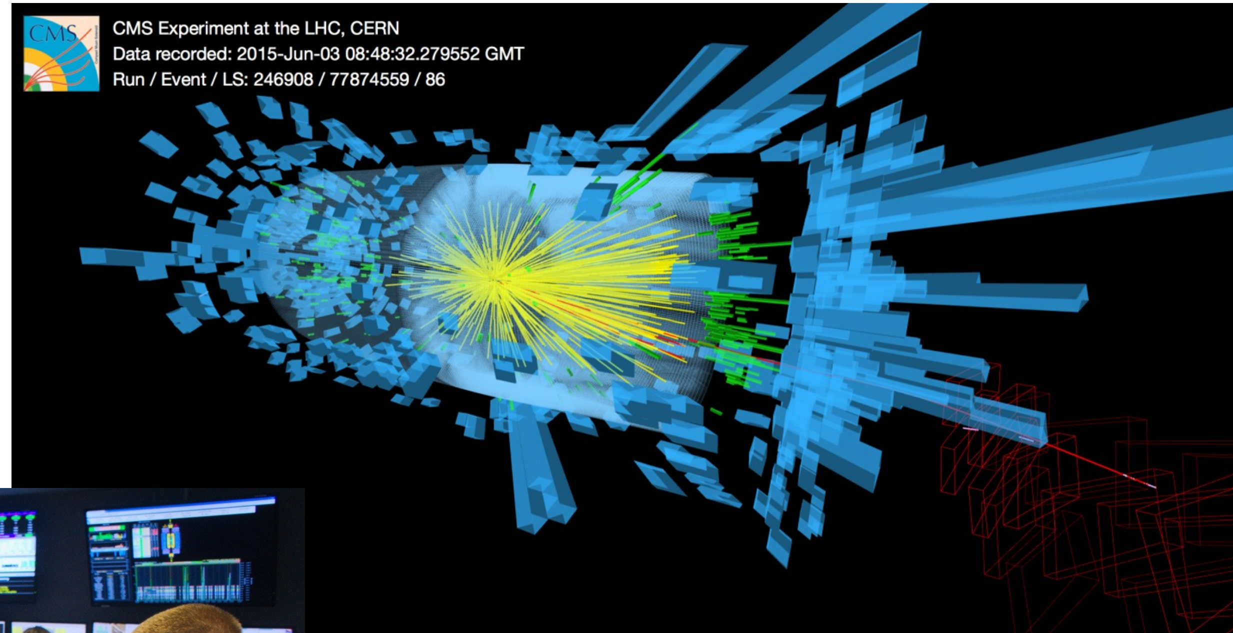
Prospects

"Data! Data! Data!"
he cried impatiently.
"I can't make bricks without clay."

Sherlock Holmes, in: Arthur Conan Doyle,
The Adventure of the Copper Beeches

LHC Run 2 has started!

CMS-PHO-EVENTS-2015-004



First 13 TeV collision events!

CMS control room

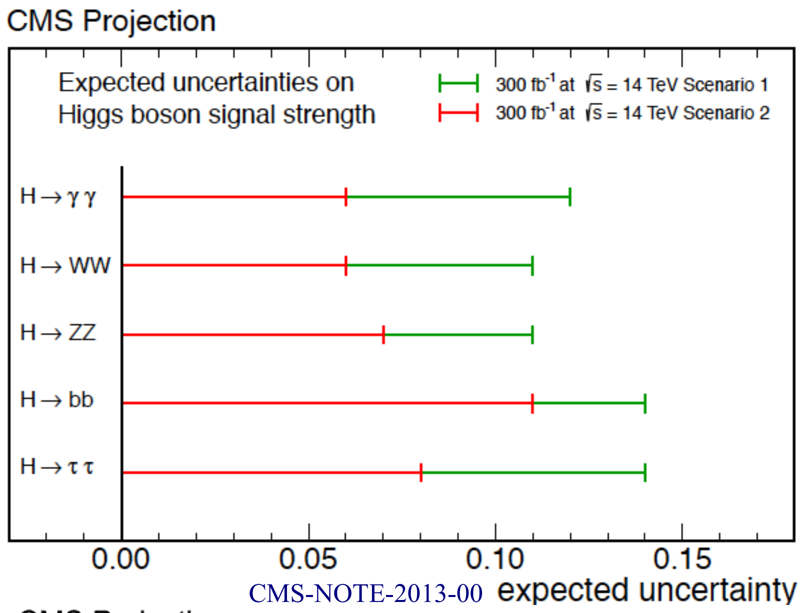
CERN-PHOTO-201506-130

Signal strength projections

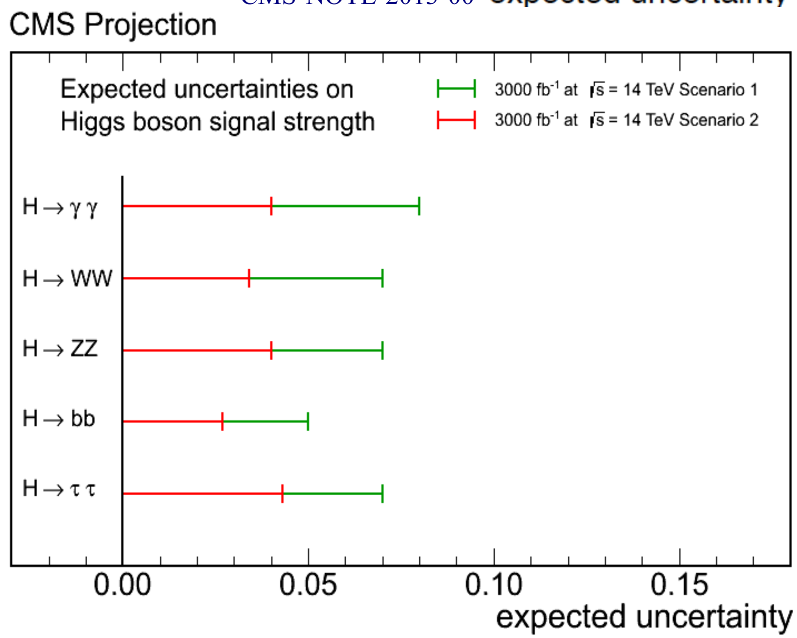
- **For 300 fb^{-1} [≈2022], 3000 fb^{-1} [≈2035]**
- Big five (**γγ, ZZ, WW, ττ, bb**)
  - Run 1: Precision (20-50)%
  - 300 fb^{-1}: Precision about **10%**
  - 3000 fb^{-1}: Precision about **5%**
- Rare channels, 300 fb^{-1} (3000 fb^{-1})
  - **Zγ**: 60% (**20%**)
  - **μμ:** 40% (**20%**)
  - **invisible:** 20% (**10%**)

3000 fb^{-1}: strong improvement bb, ττ, Zγ, μμ

Note: Numbers depend on scenarios for systematic uncertainties. Here, very rough rounded averages are given.

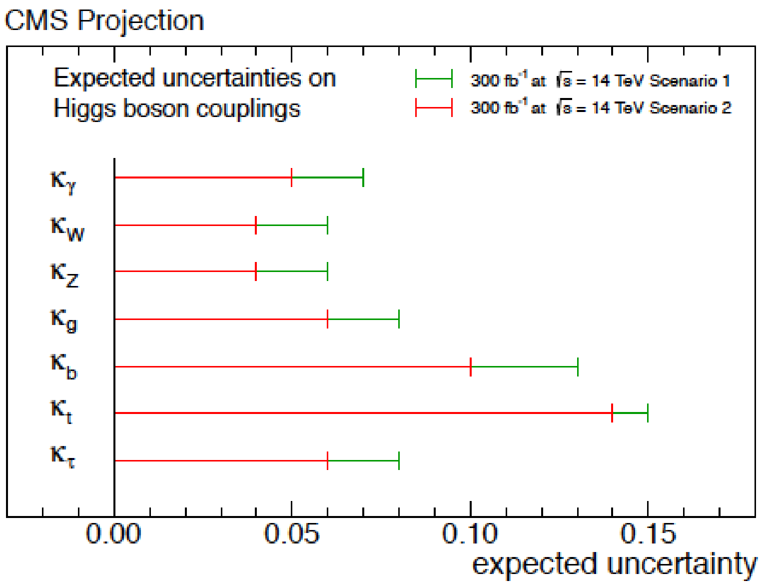


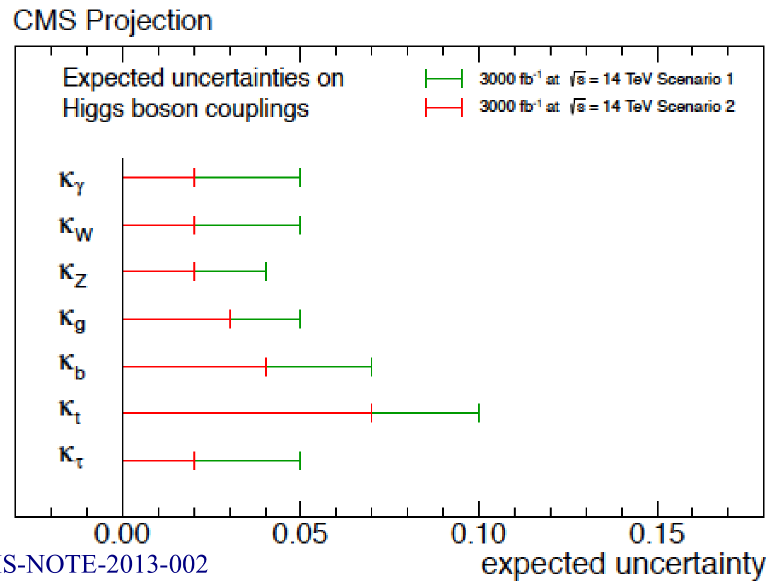
CMS-NOTE-2013-00



Couplings projection

- Precision, **300 fb^{-1}**:
  - **≈5% : bosons** (today: 20-30%)
  - **≈10%: fermions** (better: τ, today 30%)
- Substantial improvement with **3000 fb^{-1}**
  - Uncertainties can be almost **halved**
  - **≈10%: Zγ, μμ**
- 5-20% are needed to probe composite Higgs, MSSM, additional H singlet

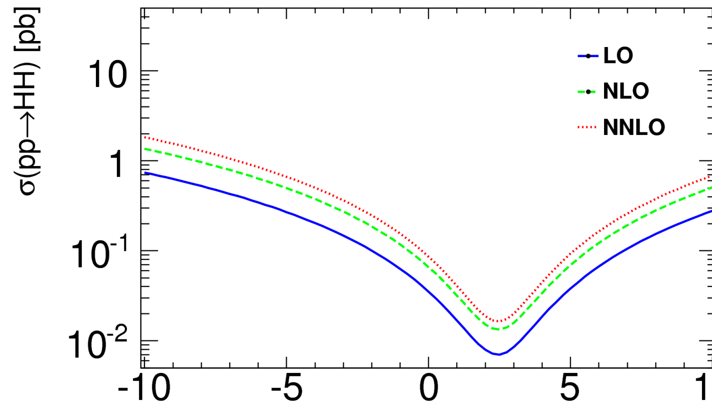




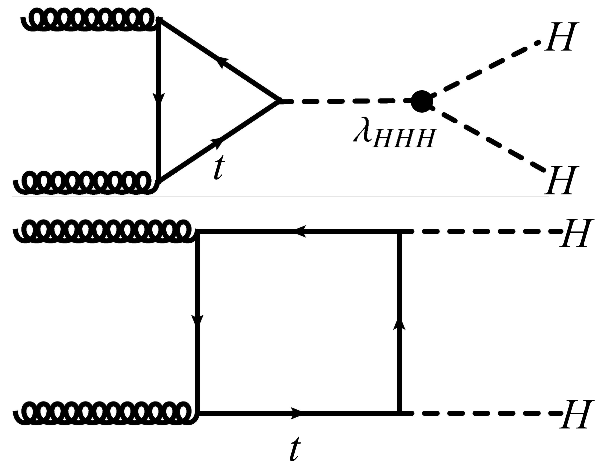
CMS-NOTE-2013-002

Self coupling, HH production

Negative interference
between HH production
a) with and
b) without HHH vertex

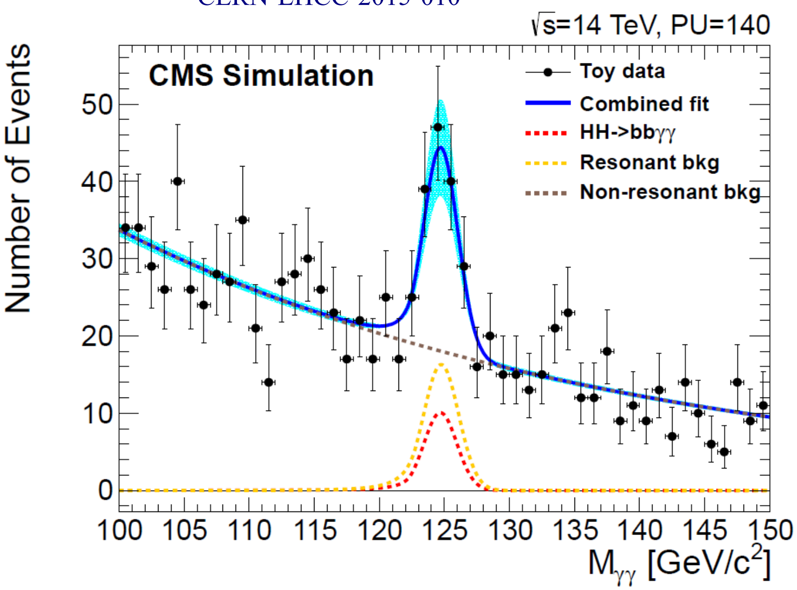


HH cross section vs λ



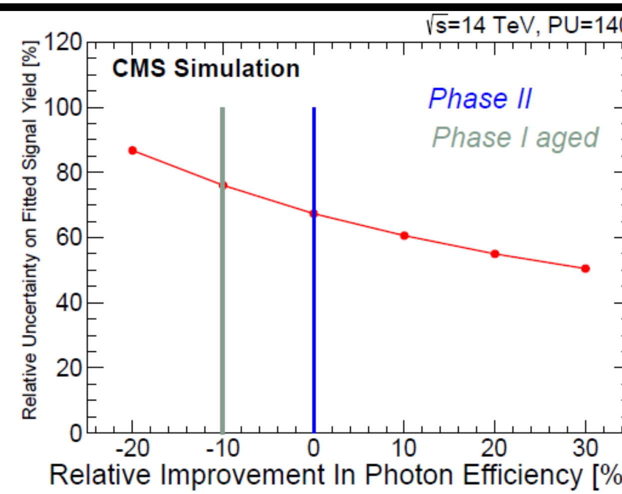
HH→bbγγ

CERN-LHCC-2015-010



3000 fb^{-1}: relative unc. on HH cross section: 67%

≈10 signal events
=> potential for self-coupling measurement unclear (despite theorist claims)



CERN-LHCC-2015-010

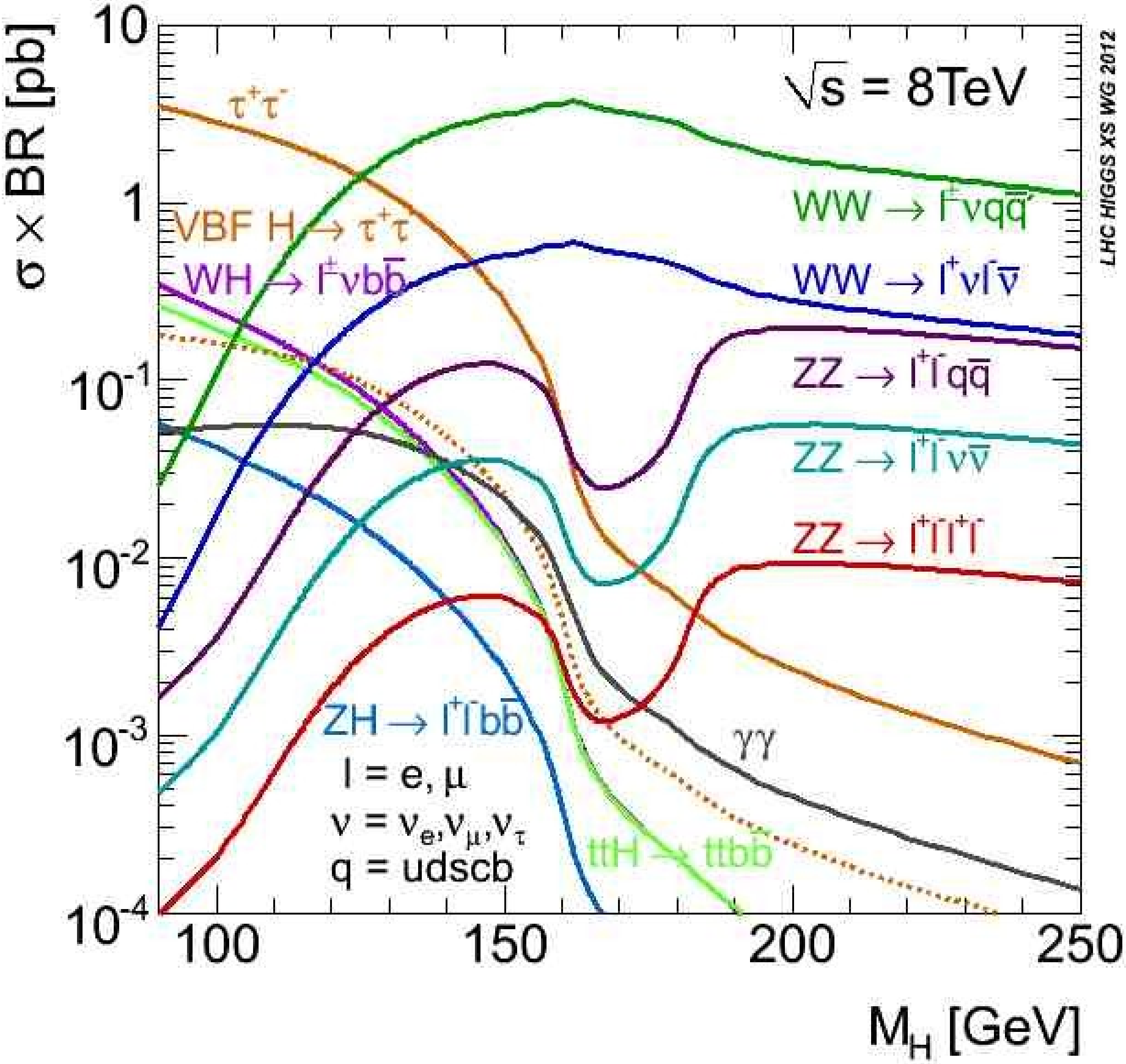
Conclusions and outlook

- Excellent performance of LHC & CMS detector
- Reconstruction performs beyond design specifications

- Plethora of Higgs boson measurements
  - All in agreement with SM :-(
  - ...but still a lot of room for more interesting theories!

- Prospects for 2015-2035
  - Substantial improvements in Higgs couplings determination
    - Needed to probe BSM Higgs
  - Rare channels: H→Zγ, H→μμ, HH→...

Backup slides


σ × BR [pb]
10
1
10^{-1}
10^{-2}
10^{-3}
10^{-4}
100
150
200
250
M_H [GeV]
√s = 8TeV
LHC HIGGS XS WG 2012
$\tau^+\tau^-$
VBF H → $\tau^+\tau^-$
WH → $l^+\nu b\bar{b}$
WW → $l^+\nu q\bar{q}'$
WW → $l^+\nu l^-\bar{\nu}$
ZZ → $l^+l^-q\bar{q}$
ZZ → $l^+l^-\nu\bar{\nu}$
ZZ → $l^+l^-l^+l^-$
ZH → $l^+l^-b\bar{b}$
γγ
l = e, μ
$\nu = \nu_e, \nu_\mu, \nu_\tau$
q = udscb
ttH → ttbb̄

Kappa framework

Production modes

$$\frac{\sigma_{ggH}}{\sigma^{SM}_{ggH}} = \begin{cases} \kappa_g^2(\kappa_b, \kappa_t, m_H) \\ \kappa_g^2 \end{cases}$$

$$\frac{\sigma_{VBF}}{\sigma^{SM}_{VBF}} = \kappa^2_{VBF}(\kappa_W, \kappa_Z, m_H)$$

$$\frac{\sigma_{WH}}{\sigma^{SM}_{WH}} = \kappa_W^2$$

$$\frac{\sigma_{ZH}}{\sigma^{SM}_{ZH}} = \kappa_Z^2$$

$$\frac{\sigma_{t\bar{t}H}}{\sigma^{SM}_{t\bar{t}H}} = \kappa_t^2$$

Total width

$$\frac{\Gamma_H}{\Gamma^{SM}_H} = \begin{cases} \kappa_H^2(\kappa_i, m_H) \\ \kappa_H^2 \end{cases}$$

Detectable decay modes

$$\frac{\Gamma_{WW^{(*)}}}{\Gamma^{SM}_{WW^{(*)}}} = \kappa_W^2$$

$$\frac{\Gamma_{ZZ^{(*)}}}{\Gamma^{SM}_{ZZ^{(*)}}} = \kappa_Z^2$$

$$\frac{\Gamma_{b\bar{b}}}{\Gamma^{SM}_{b\bar{b}}} = \kappa_b^2$$

$$\frac{\Gamma_{\tau^-\tau^+}}{\Gamma^{SM}_{\tau^-\tau^+}} = \kappa_\tau^2$$

$$\frac{\Gamma_{\gamma\gamma}}{\Gamma^{SM}_{\gamma\gamma}} = \begin{cases} \kappa_\gamma^2(\kappa_b, \kappa_t, \kappa_\tau, \kappa_W, m_H) \\ \kappa_\gamma^2 \end{cases}$$

$$\frac{\Gamma_{Z\gamma}}{\Gamma^{SM}_{Z\gamma}} = \begin{cases} \kappa_{(Z\gamma)}^2(\kappa_b, \kappa_t, \kappa_\tau, \kappa_W, m_H) \\ \kappa_{(Z\gamma)}^2 \end{cases}$$

Currently undetectable decay modes

$$\frac{\Gamma_{t\bar{t}}}{\Gamma^{SM}_{t\bar{t}}} = \kappa_t^2$$

$$\frac{\Gamma_{gg}}{\Gamma^{SM}_{gg}} : \text{see Section 3.1.2}$$

$$\frac{\Gamma_{c\bar{c}}}{\Gamma^{SM}_{c\bar{c}}} = \kappa_t^2$$

$$\frac{\Gamma_{s\bar{s}}}{\Gamma^{SM}_{s\bar{s}}} = \kappa_b^2$$

$$\frac{\Gamma_{\mu^-\mu^+}}{\Gamma^{SM}_{\mu^-\mu^+}} = \kappa_\tau^2$$

arXiv:1307.1347

nn 1
nn 2
nn 3

Modified couplings, parameterized in terms of scale factors κ

- single-resonance assumption
- narrow width assumption
- no change of tensor structure in fields and couplings

Example : diphoton
from gluon fusion

$$(\sigma \cdot BR)(gg \to H \to \gamma\gamma) = \sigma_{SM}(gg \to H) \cdot BR_{SM}(H \to \gamma\gamma) \cdot \frac{\kappa_g^2 \cdot \kappa_\gamma^2}{\kappa_H^2}$$

- Prospects strategy

Rescaling of run 1 signal and background yields for 14 TeV cms energy
with the assumption that current detector performance kept after upgrades.
Complemented by parametrized detector simulation (e.g. for 2HDM studies).

Scenario 1: Systematics as in Run 1
Scenario 2: Theory systematics halved; Experimental systematics scale with 1/sqrt(lumi)