



Riunione nazionale CMS Italia

29/11-01/12 Piacenza

Fisica dell'Higgs: stato e prospettive

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30/11/2017





1. Precision measurements

cross-sections / couplings ($H \rightarrow WW \rightarrow l\nu l\nu$, $H \rightarrow ZZ \rightarrow 4l$, $H \rightarrow \gamma\gamma$)
mass ($H \rightarrow ZZ \rightarrow 4l$, $H \rightarrow \gamma\gamma$)

2. Discovery

direct coupling to fermions ($H \rightarrow \tau\tau$, $H \rightarrow bb$, $t\bar{t}H$)

3. Rare decays and production

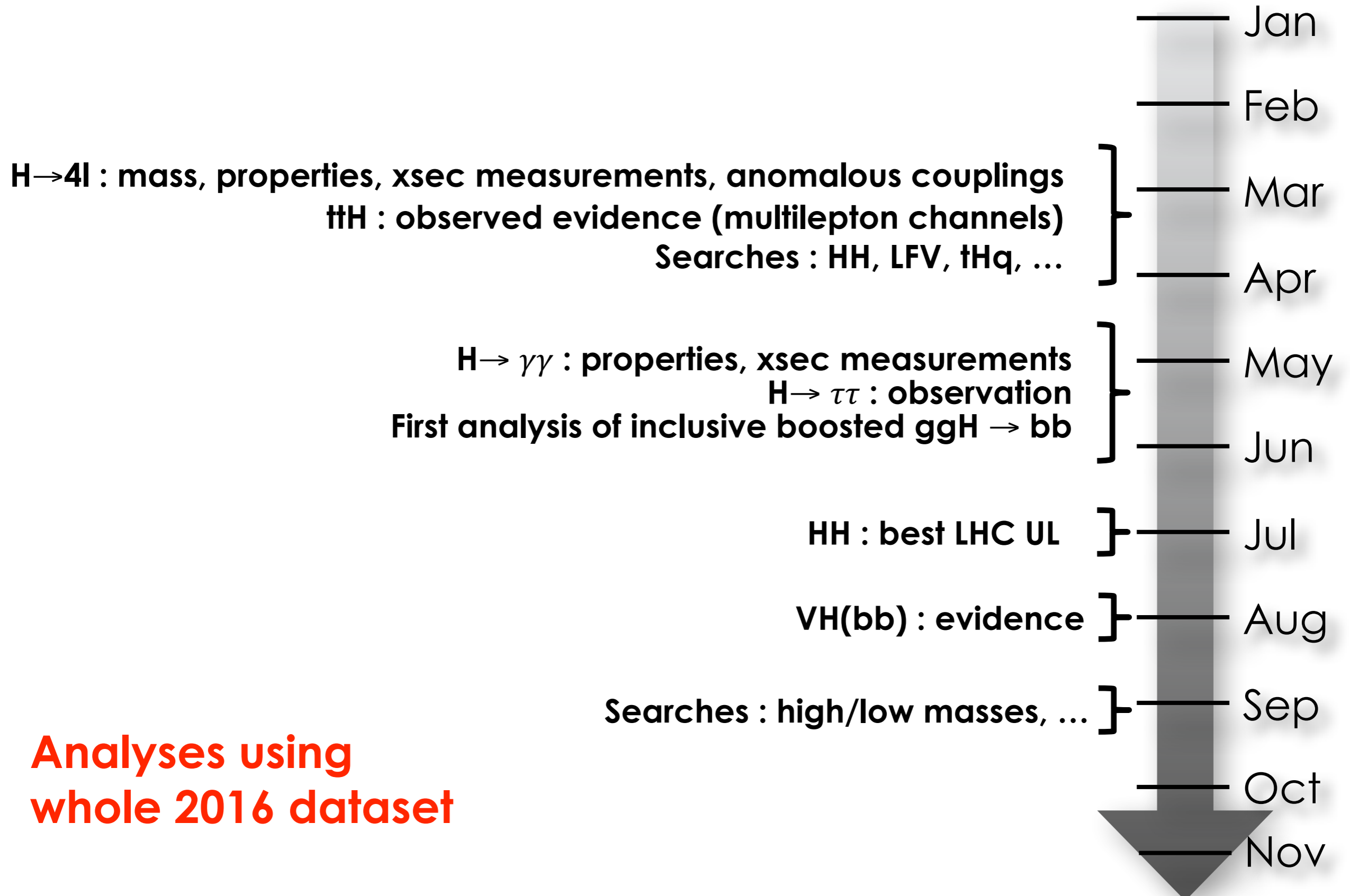
self couplings (HH)
second generation fermion ($H \rightarrow \mu\mu$, $H \rightarrow J/\Psi\gamma$)
probing BSM in loops ($H \rightarrow Z\gamma$, $\gamma\gamma^*$)
invisible decays

4. BSM searches

exotic
anomalous couplings
additional scalars (heavy and light)



HIG IN 2017: TIMELINE



**Analyses using
whole 2016 dataset**

HIG IN 2017: TIMELINE



.. and ATLAS?

H → 4l : mass, properties, xsec measurements, anomalous couplings
tH : observed evidence (multilepton channels)
Searches : HH, LFV, tHq, ...

H → γγ : properties, xsec measurements
H → ττ : observation
First analysis of inclusive boosted ggH → bb

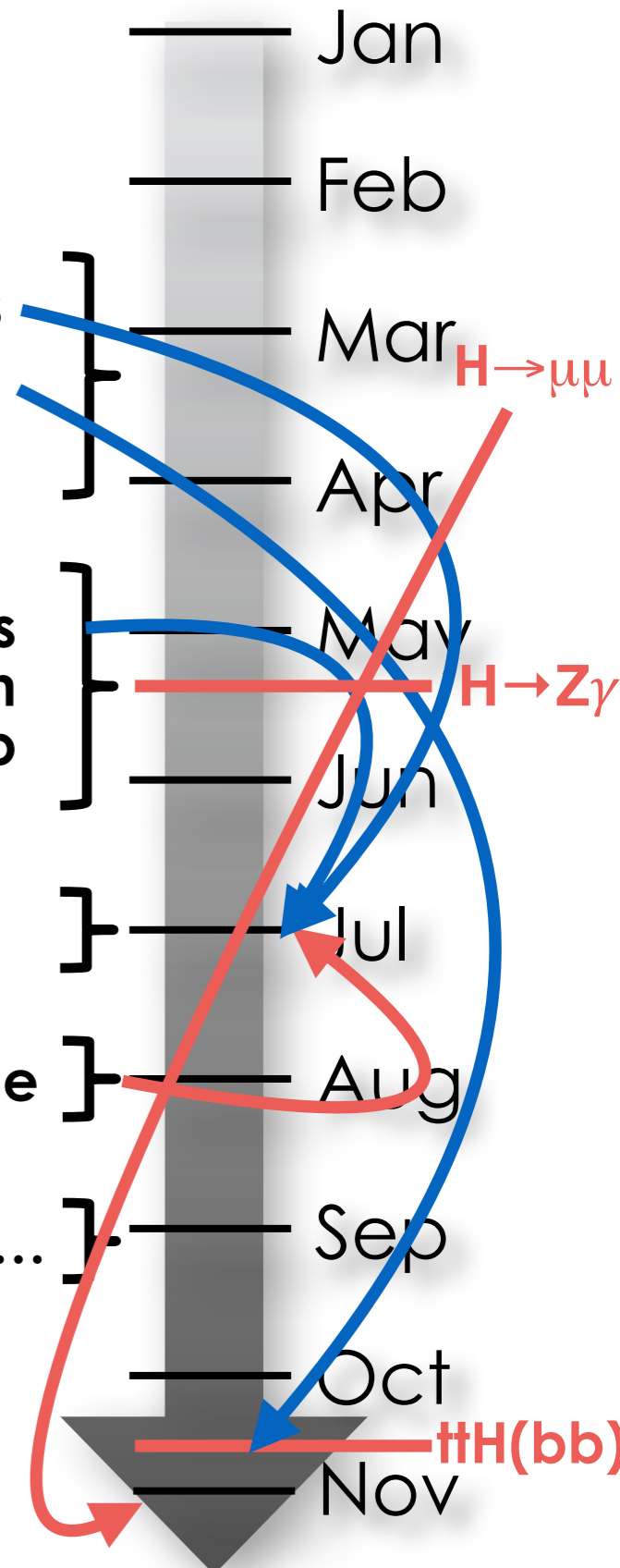
HH : best LHC UL

VH(bb) : evidence

Searches : high/low masses, ...

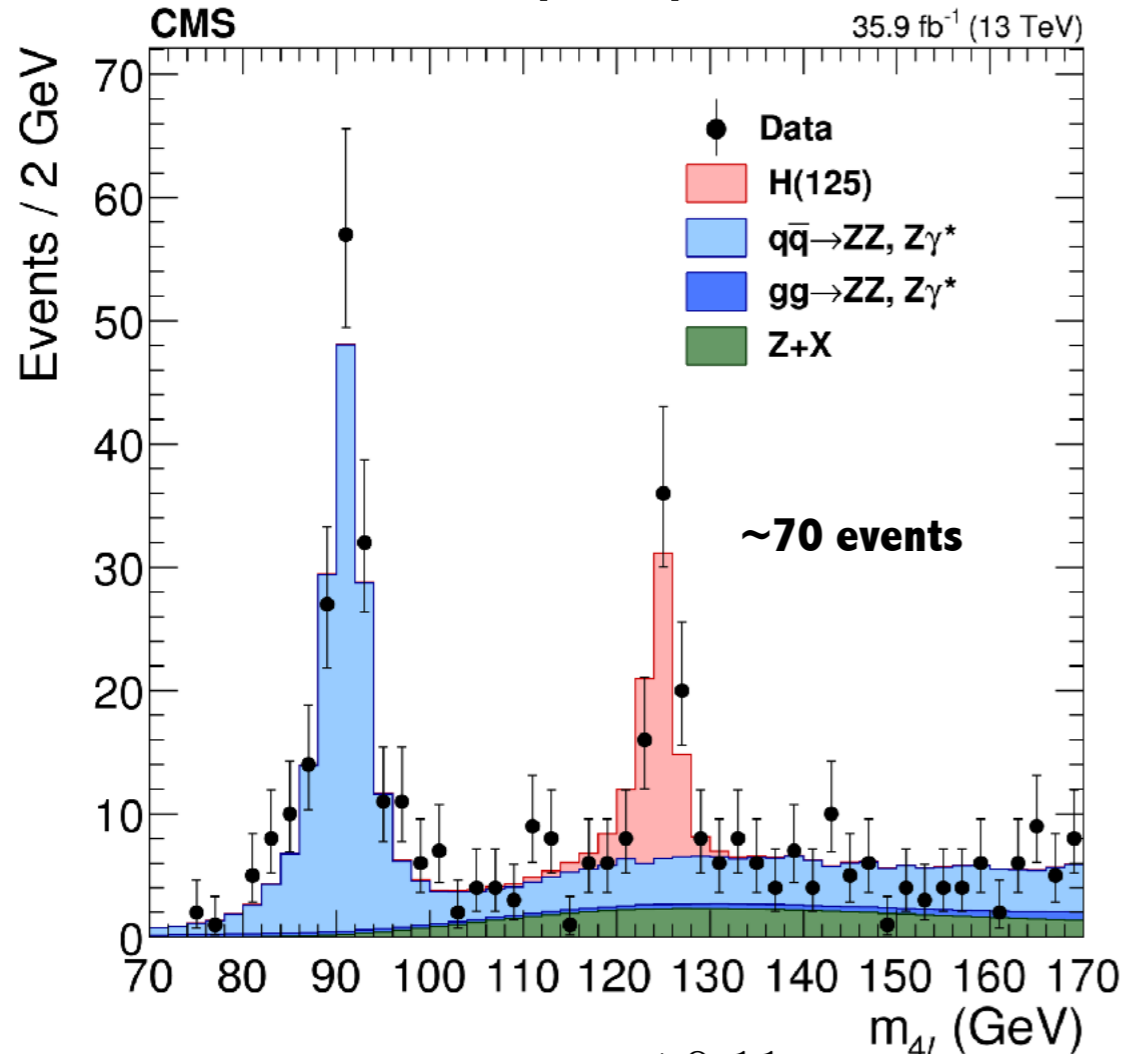
**Analyses using
whole 2016 dataset**

7 CMS first
4 ATLAS first



$H \rightarrow ZZ \rightarrow 4\ell$ & $H \rightarrow \gamma\gamma$

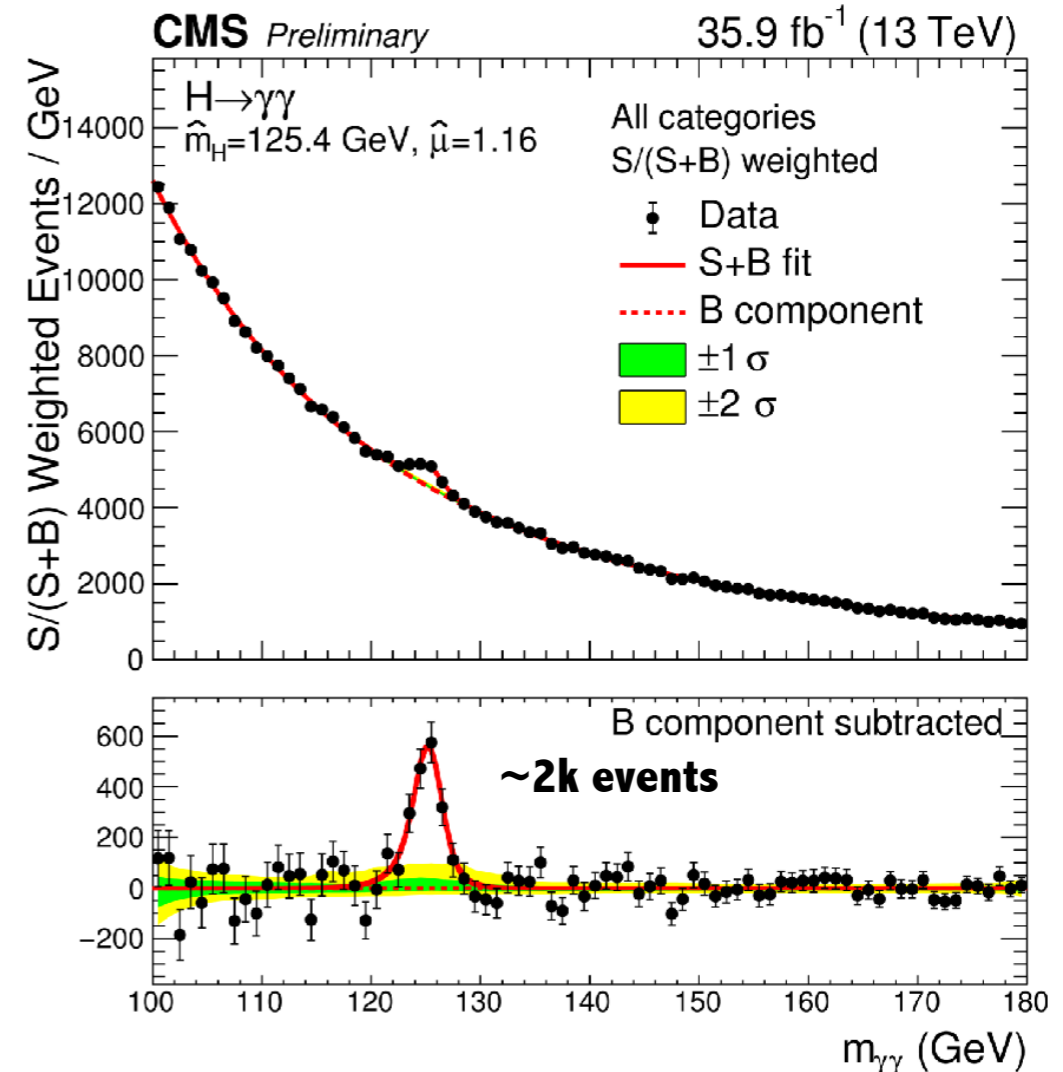
JHEP 11 (2017) 047



$$\mu = 1.05_{-0.14}^{+0.15}(\text{stat})_{-0.09}^{+0.11}(\text{syst})$$

$$m_H = 125.26 \pm 0.20(\text{stat}) \pm 0.08(\text{syst}) \text{ GeV}$$

CMS HIG-16-040



$$\mu = 1.16_{-0.14}^{+0.15} = 1.16_{-0.10}^{+0.11}(\text{stat})_{-0.08}^{+0.09}(\text{exp})_{-0.05}^{+0.06}(\text{theo})$$

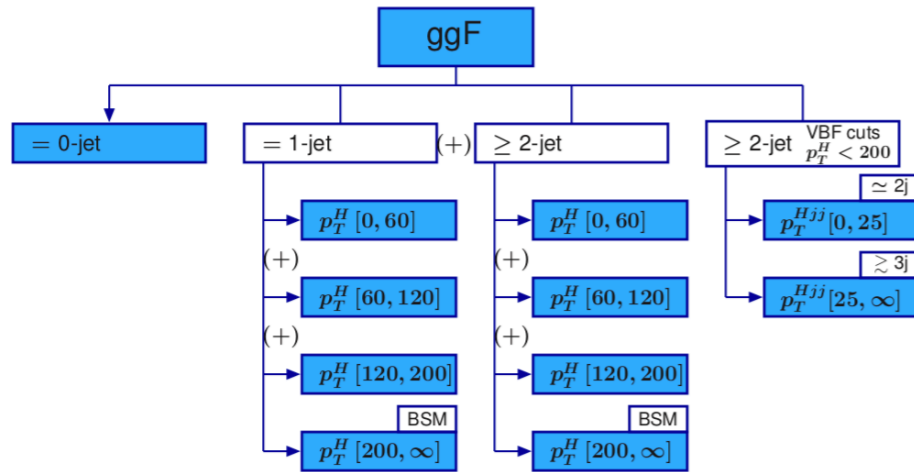
Improvements on overall precision ~ x2 wrt Run1

Overall signal strength: getting closer to theory uncertainty (ggH @ N3LO)

Mass: HZZ alone better than Run1 combination

$H \rightarrow ZZ \rightarrow 4\ell$ & $H \rightarrow \gamma\gamma$

Towards “Simplified template cross-sections”



Event categorisation will evolve for the full Run2 analysis

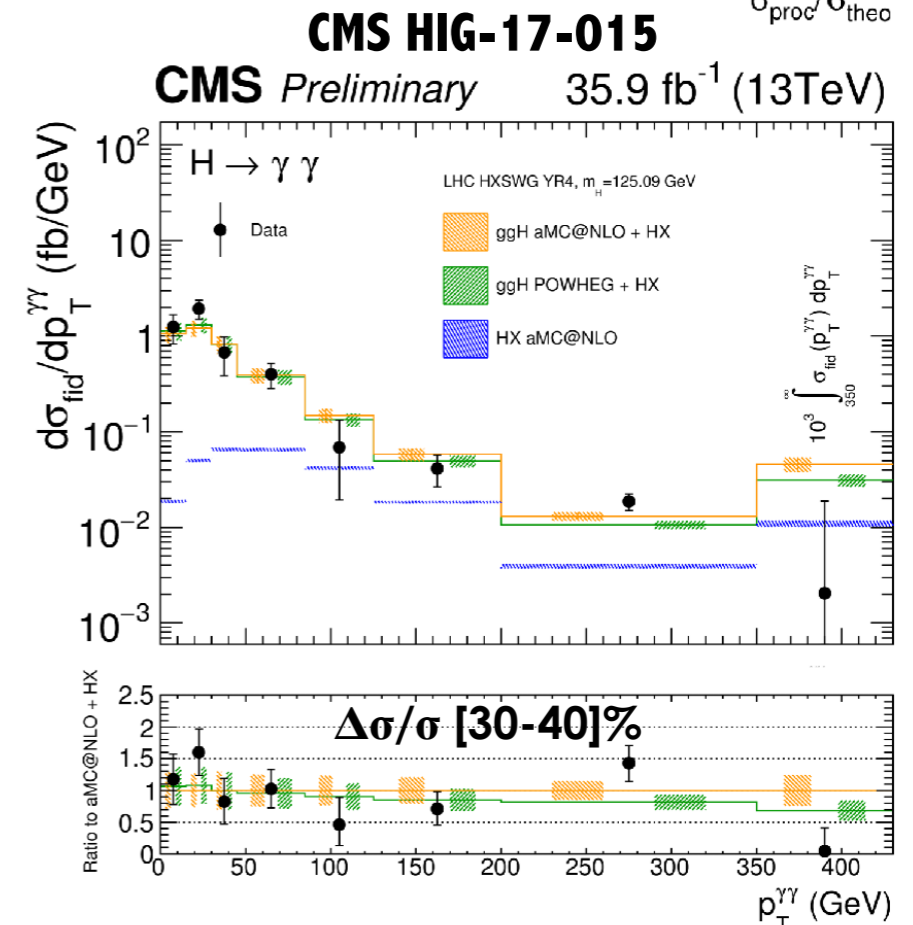
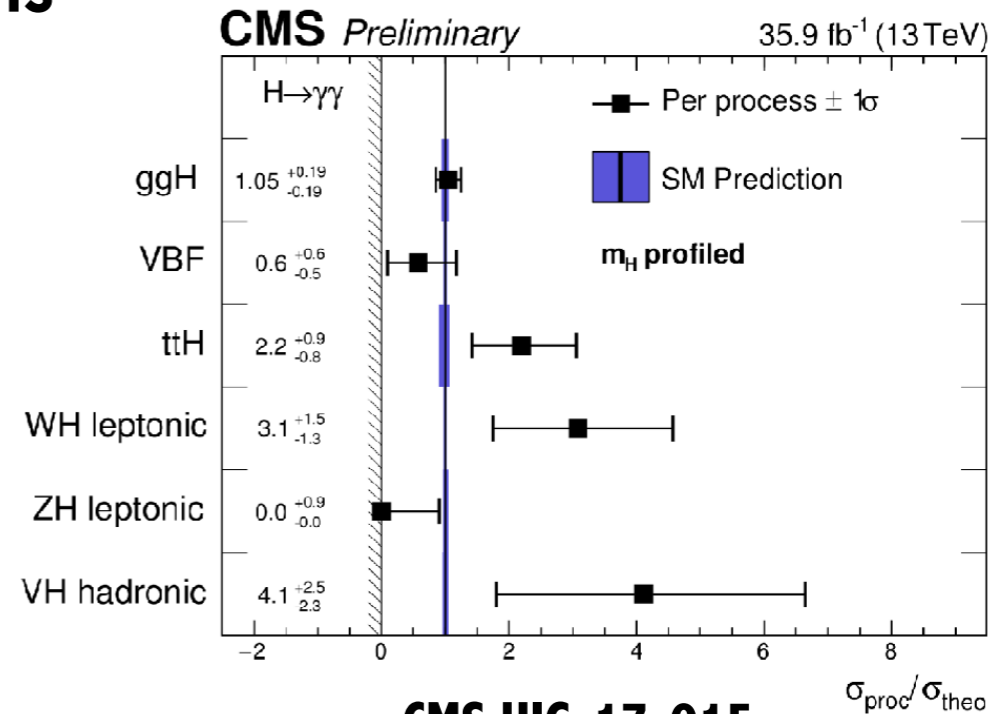
e.g. current ATLAS $H \rightarrow \gamma\gamma$ has 33 categories

Differential distributions: $d\sigma/dp_T$, N_{jets} ...

low p_T region sensitive to b,c anomalous couplings

$p_T > 350$ GeV: anomalous top, new heavy particles

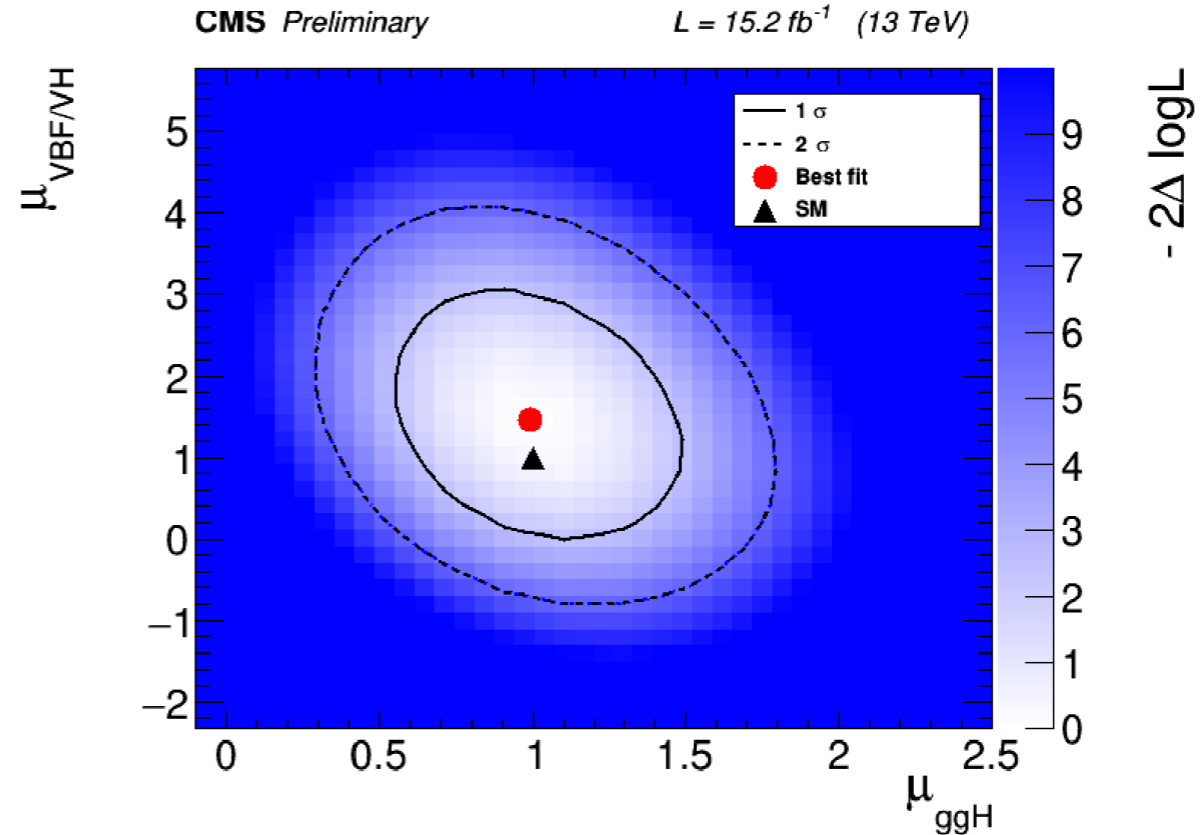
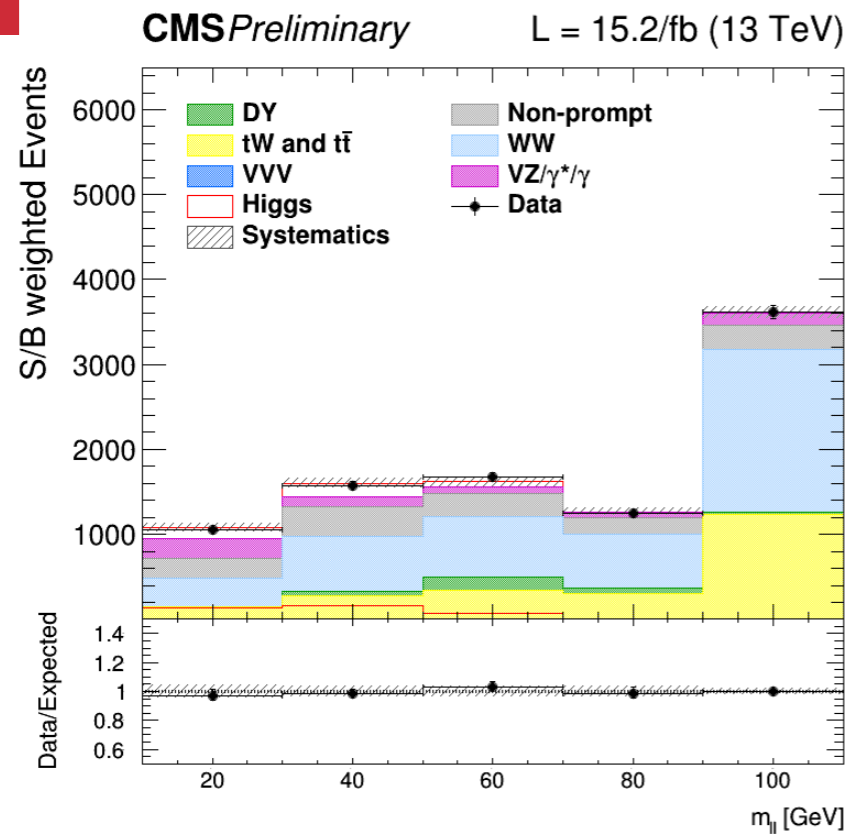
Particularly interesting for full Run2. Significant space for contributions



H → WW



CMS HIG-16-021



Full 2016 analysis currently under review

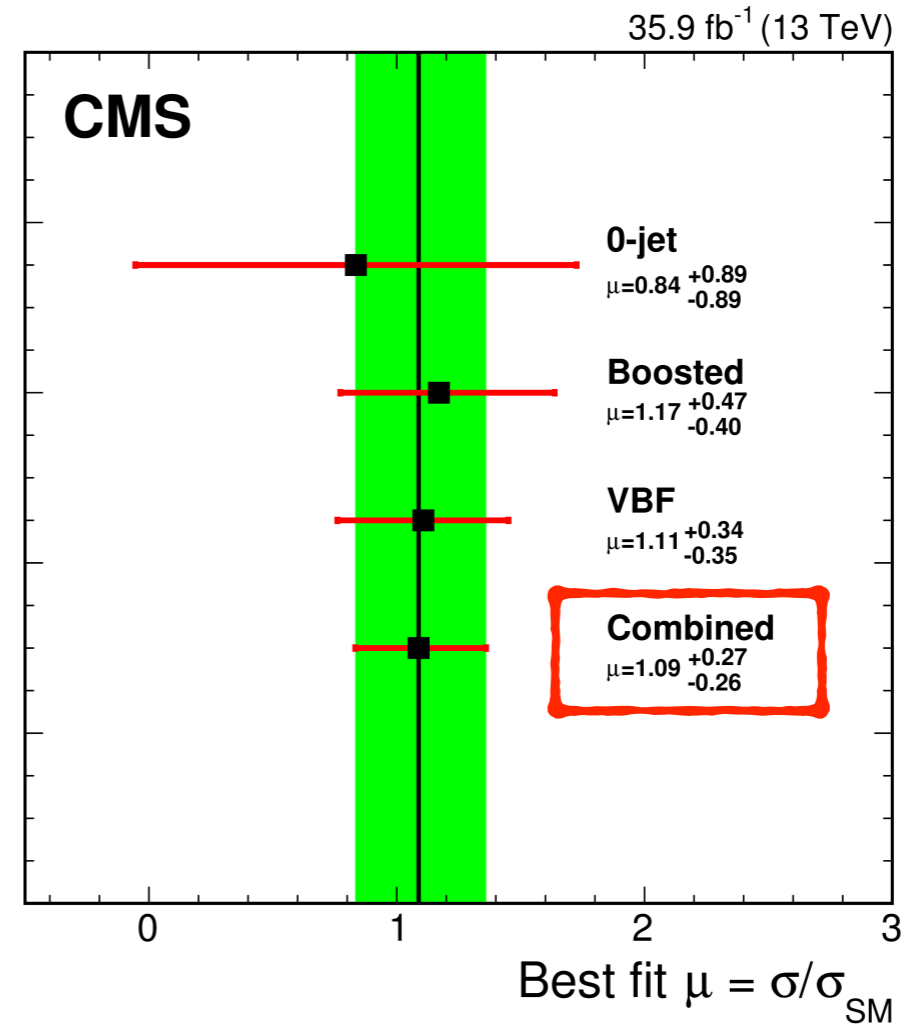
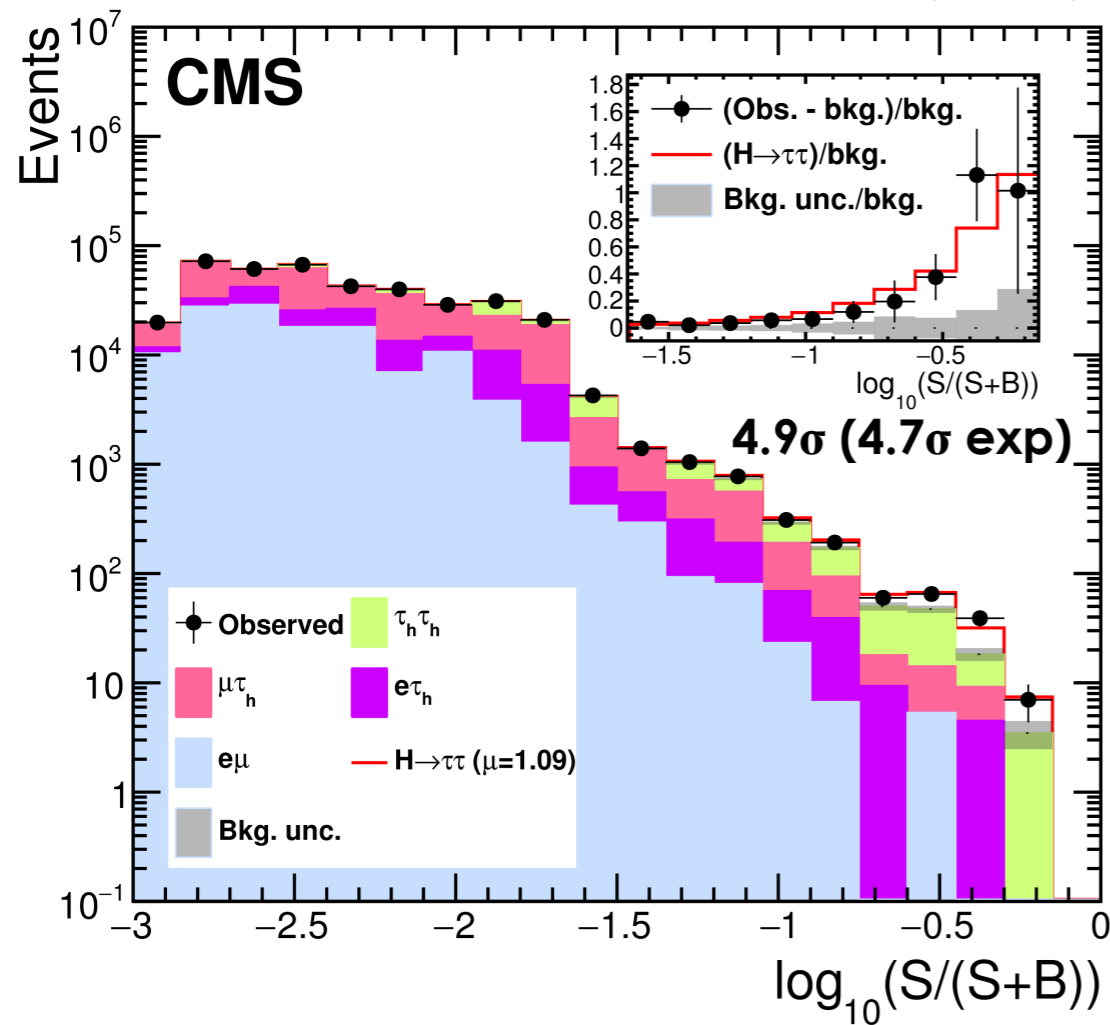
Expected uncertainty on signal strength 16% comparable to $H \rightarrow \gamma\gamma, ZZ$
Event categories: 0j, 1j, 2j (ggH, VBF, VH), 3l (WH), 4l (ZH)

H → WW important for cross-section measurements: will play a crucial role in the coupling combinations

OBSERVATION OF $H \rightarrow \tau\tau$



CMS HIG-16-043: Submitted to PLB
35.9 fb⁻¹ (13 TeV)



sensitivity driven by VBF & boosted category

3 categories (0-jet, boosted, VBF) x 4 $\tau\tau$ channels ($\tau_h\tau_h$, $e\tau_h$, $\mu\tau_h$, $e\mu$)

2D fit signal extraction: $m_{\tau\tau}$ vs (τ decay mode, p_T , di-jet mass)

Observation of $\tau\tau$ decay mode from a single experiment: 4.9 σ (4.7 σ exp), 5.9 σ when combined with CMS Run1

Space to improve analysis in view of full Run2 analysis

EVIDENCE FOR $H \rightarrow bb$

$H \rightarrow bb$: Run1 ATLAS+CMS 2.6σ (3.7 exp)

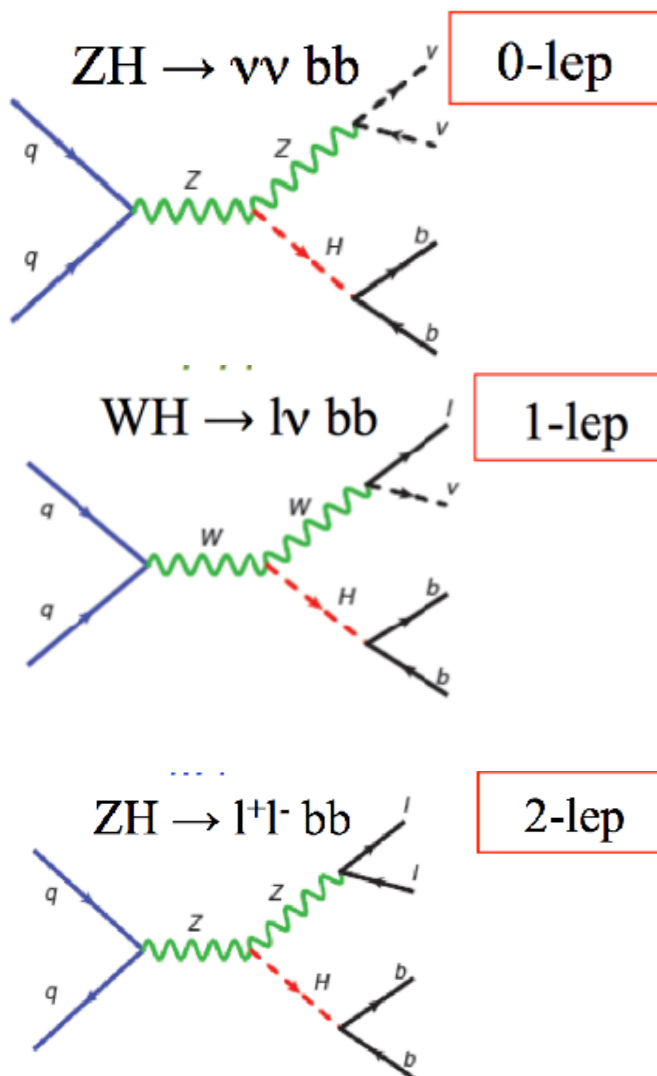
$VH(\rightarrow bb)$: 3 channels 0,1,2 leptons

Backgrounds: W/Z +jets, $t\bar{t}$

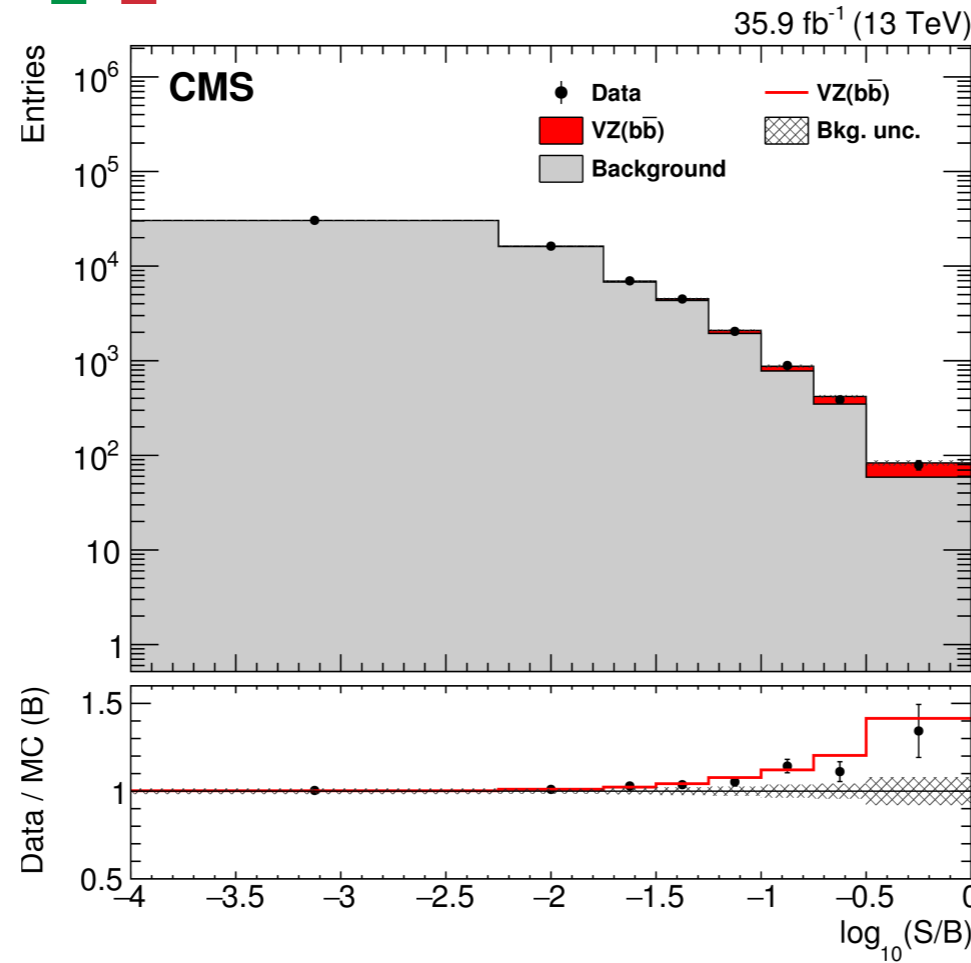
Observable: BDT including m_{bb}

Evidence for $VH(bb)$: 3.8σ when combined with Run1

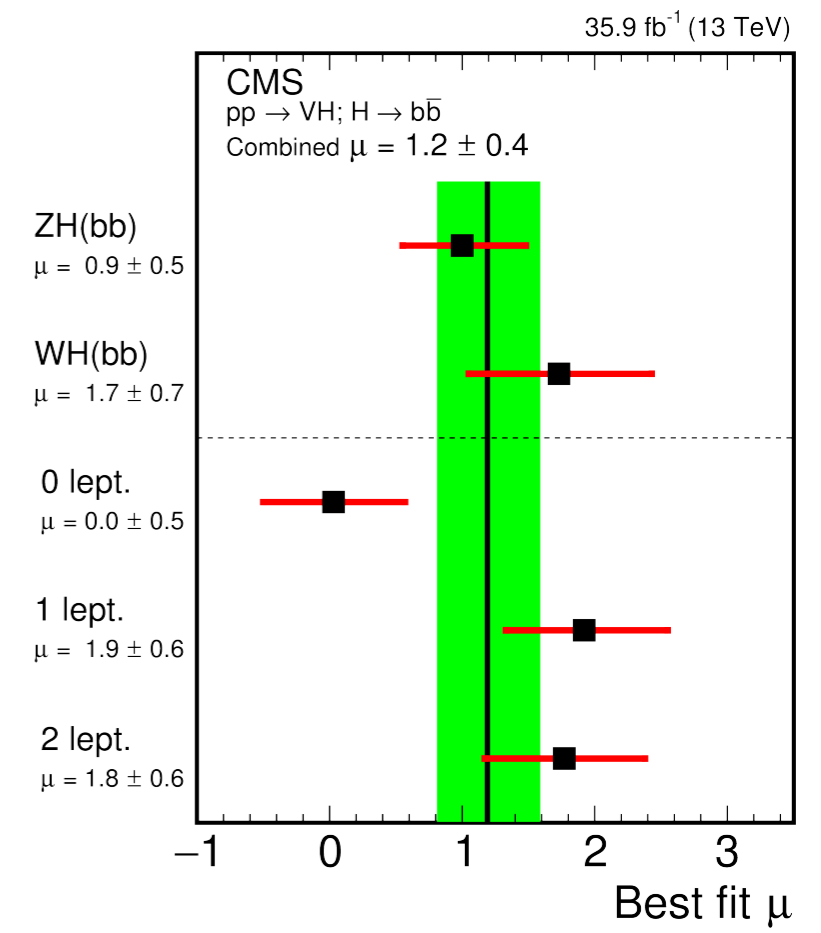
$$\mu = 1.06^{+0.31}_{-0.29}$$



CMS HIG-16-044: Submitted to PLB



3.3σ (2.8 exp)



TOWARDS $H \rightarrow bb$ OBSERVATION

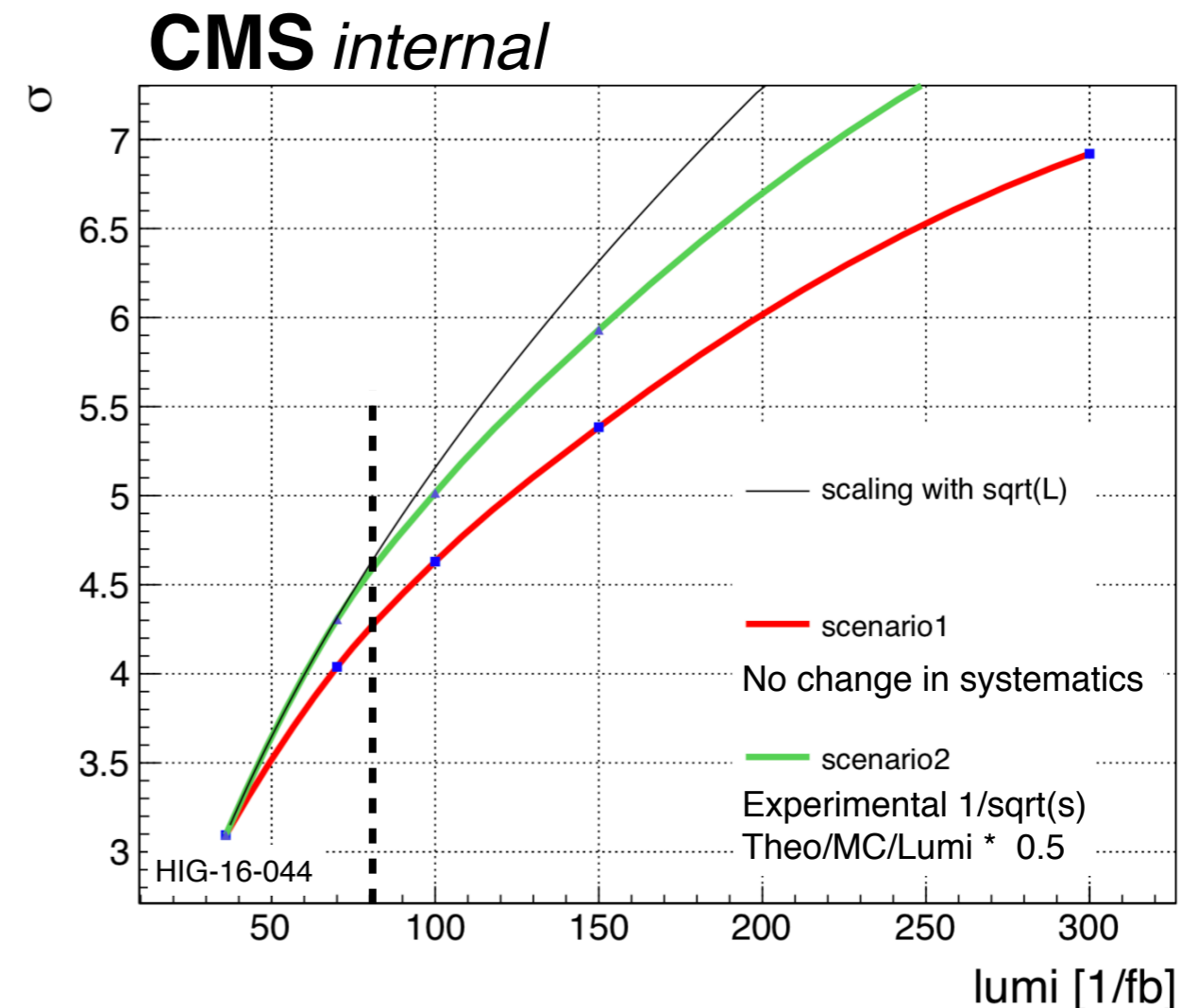


Projections (assuming new data like 2016): **5σ at reach for 2016+2017 (80 fb⁻¹)**

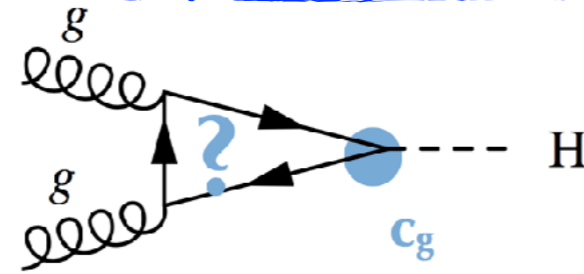
Timescale Summer 2018: critical performance/understanding of b-tagging on 2017 data

Possible improvements: estimation of V+jets background (better NLO MC), DeepCSV, boosted category,.....

	2016+2017 80fb	Run-I + Run-II
Scenario 1	4.3	4.9
Scenario 2	4.7	5.3

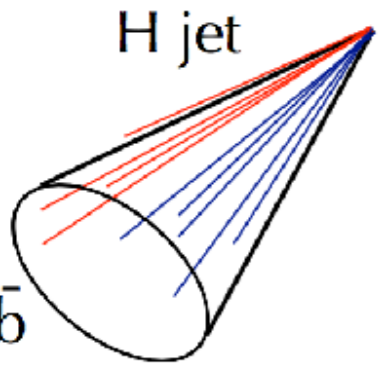


INCLUSIVE $H \rightarrow bb$



Explore a brand new regime
ggF $p_T > 450$ GeV

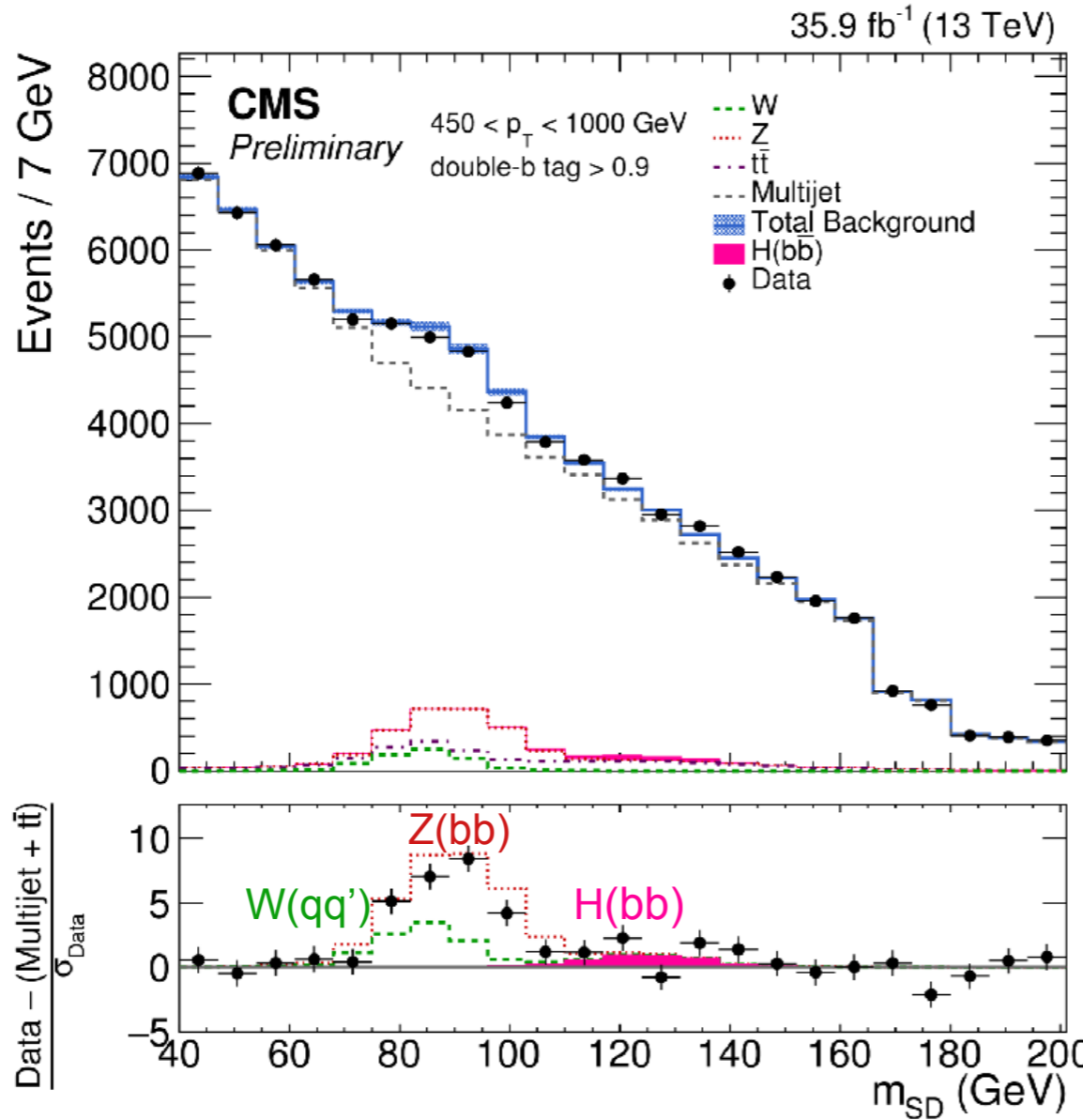
$p_T > 450$ GeV



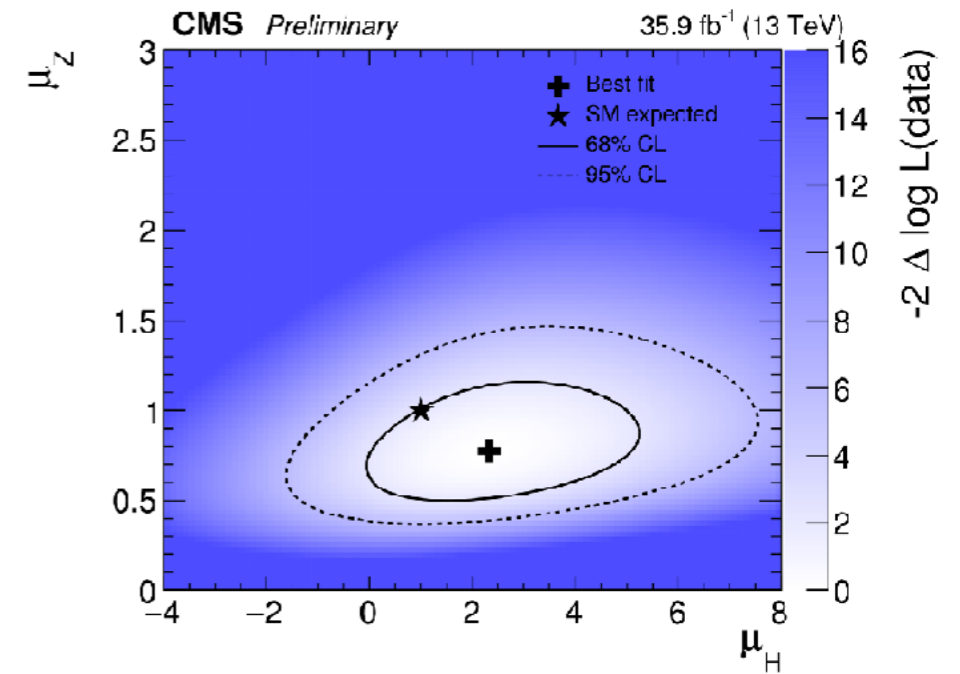
Single large cone
fat jet ($R=0.8$)
 $p_T > 450$ GeV

double b-tagging
on sub-jets

**Observable:
jet mass**



CMS HIG-17-010: Submitted to PRL



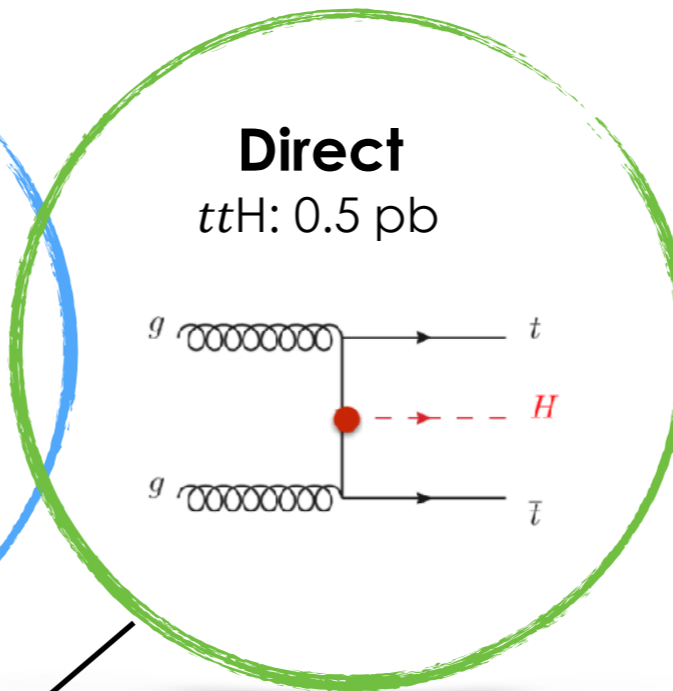
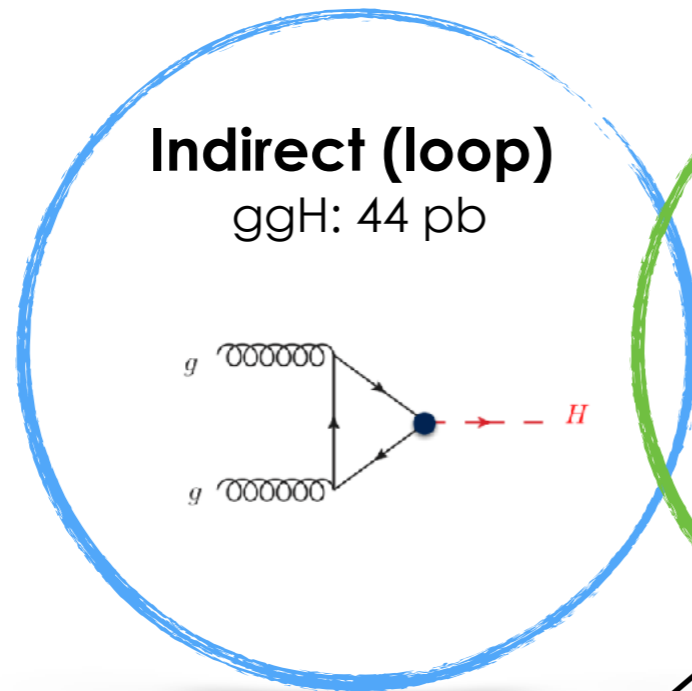
	H	Z
Observed best fit	$\mu_H = 2.3^{+1.8}_{-1.6}$	$\mu_Z = 0.78^{+0.23}_{-0.19}$
Expected significance	0.7σ ($\mu_H = 1$)	5.8σ ($\mu_Z = 1$)
Observed significance	1.5σ	5.1σ

Observation
of boosted
 $Z \rightarrow bb$

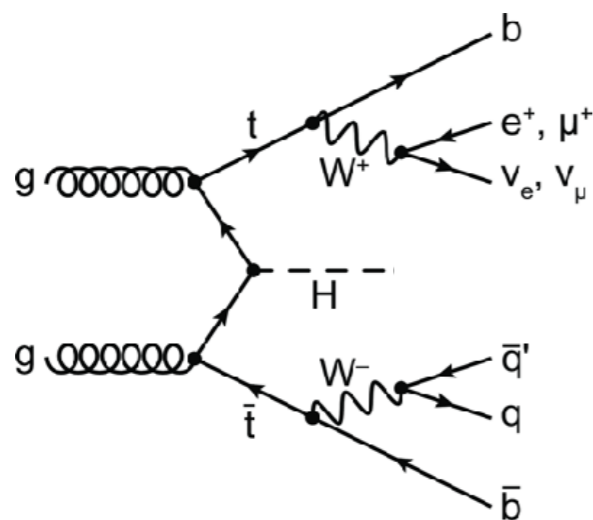
First search for $gg \rightarrow H \rightarrow bb$ in boosted topology

Boosted jet techniques: from searches to measurements

TOWARDS ttH OBSERVATION



Final state with additional leptons, jets, b-jets



$H \rightarrow b\bar{b}$	$H \rightarrow (WW, \tau\tau)$ multileptons	$H \rightarrow (4l, \gamma\gamma)$
High yield	Low yield	Simple background
Low signal/background	High yield	Clear peak
$tt+HF$ background prediction	$tt+V, tt+jets$ background	Clean bump hunt

TOWARDS ttH OBSERVATION



Run1

Run2 13 fb⁻¹ 36 fb⁻¹

$$\mu_{ttH} = \sigma_{ttH} / \sigma_{SM}$$

Run1 comb.		2.3 ^{+0.7} _{-0.6}
bb		-0.2 ± 0.8
multileptons		1.2 ± 0.4
γγ		2.2 ^{+0.9} _{-0.8}
ZZ		0.0 ^(*) +1.2 _{-0.0}

← 4.4σ (2.0σ exp)

36 fb⁻¹ under review:
~2σ exp result (20%
better ATLAS)

← 3.2σ (2.8σ exp)

← 3.3σ (1.5σ exp)

(*): 68% CL interval with $\mu \geq 0$

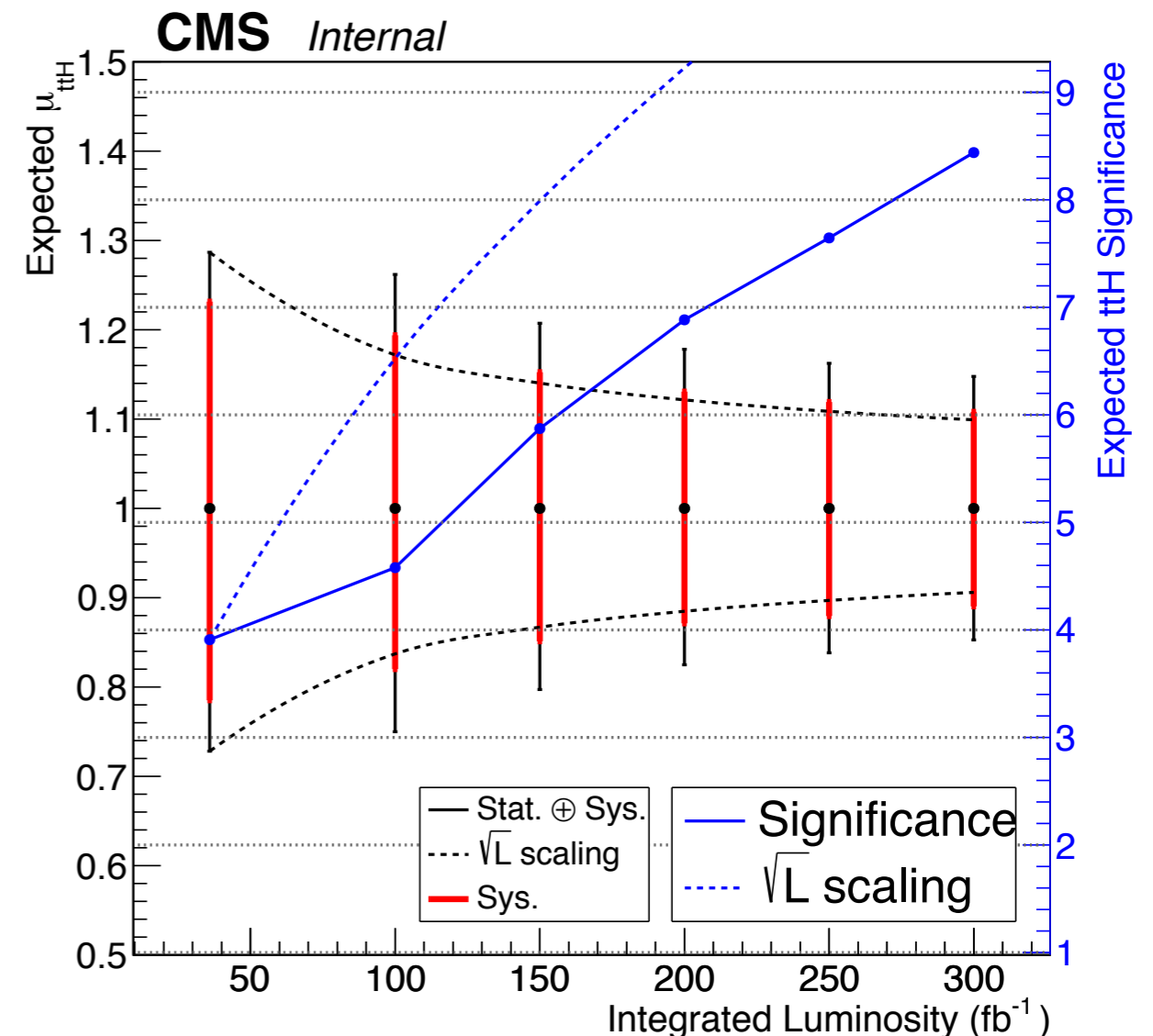
36 fb⁻¹ combination: ~4σ expected (Moriond 2018)

$t\bar{t}H$ COMBINATION

multilepton, $bb, \gamma\gamma$ channels all contributing to 2016+2017 dataset combination

5σ at reach (improvements foreseen for all analyses)

$\geq 150 \text{ fb}^{-1}$: $\gamma\gamma$ starts to dominate the sensitivity



2ND GENERATION COUPLING



$H \rightarrow \mu\mu$: probing 2nd generation Yukawa coupling (BR 2.18E-4)

Run1 + 36fb⁻¹ @ 13 TeV:

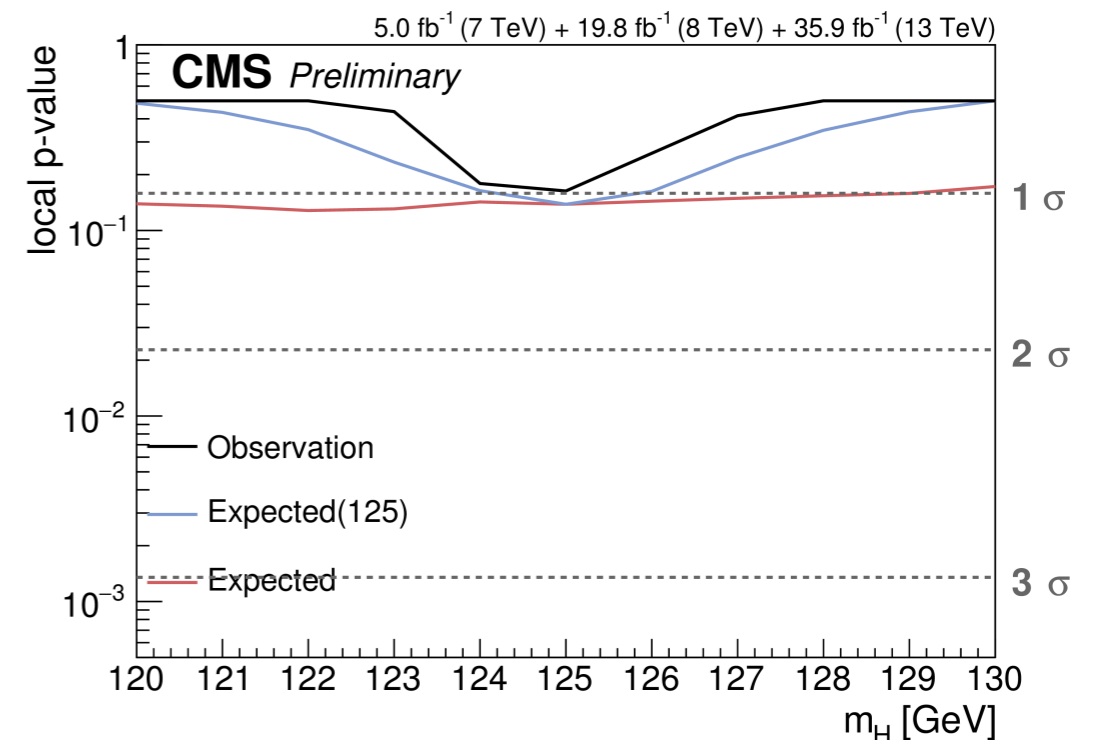
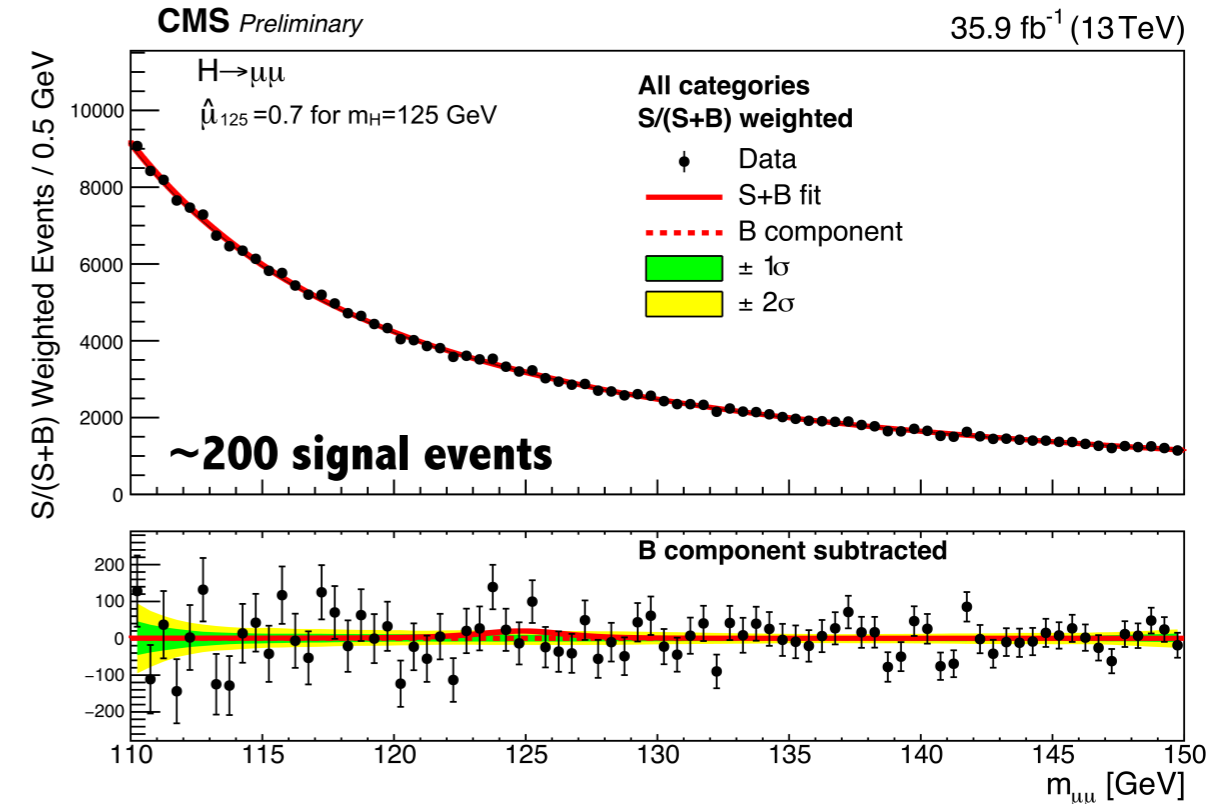
$\sigma/\sigma_{SM} < 2.6$ @ 95%CL (2.1 exp)

$\mu = 0.9^{+1.0}_{-0.9}$ sensitivity at $\sim 1\sigma$

Current analysis: event categorisation based on BDT for kinematics + jets
ideas to improve it for next iteration

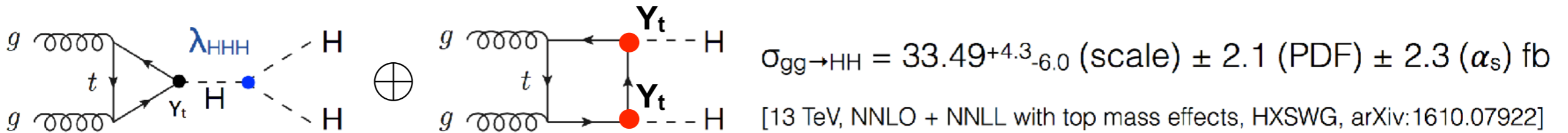
Full Run2 analysis has potential to be at $\geq 2\sigma$

CMS-HIG-17-019

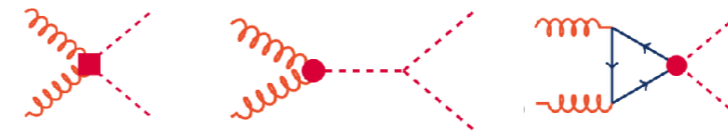


DOUBLE HIGGS PRODUCTION

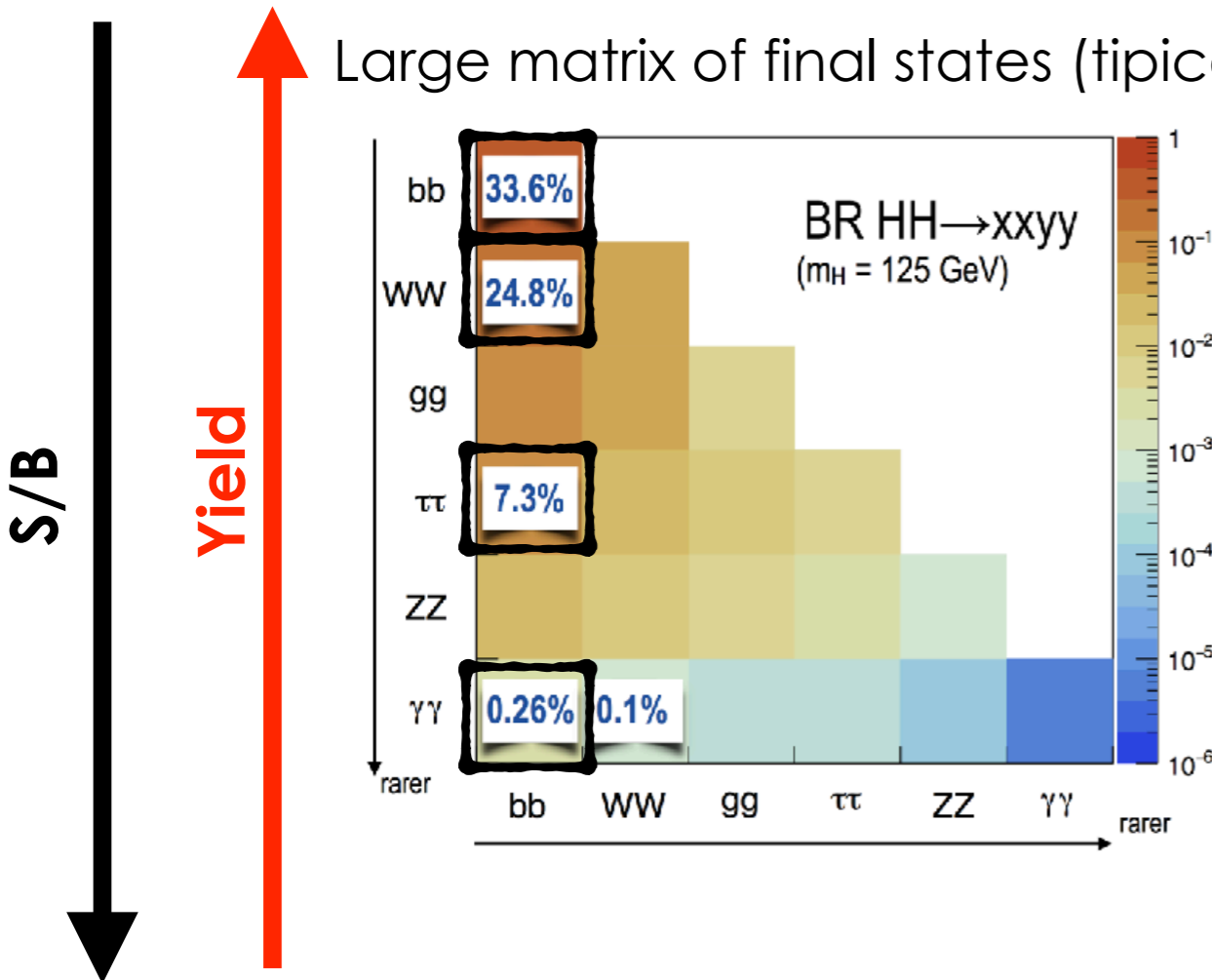
Main probe for trilinear Higgs coupling λ_{HHH} . Diagrams interfere destructively in SM





sensitive to possible BSM contributions



Large matrix of final states (typically ≥ 1 $H \rightarrow bb$)



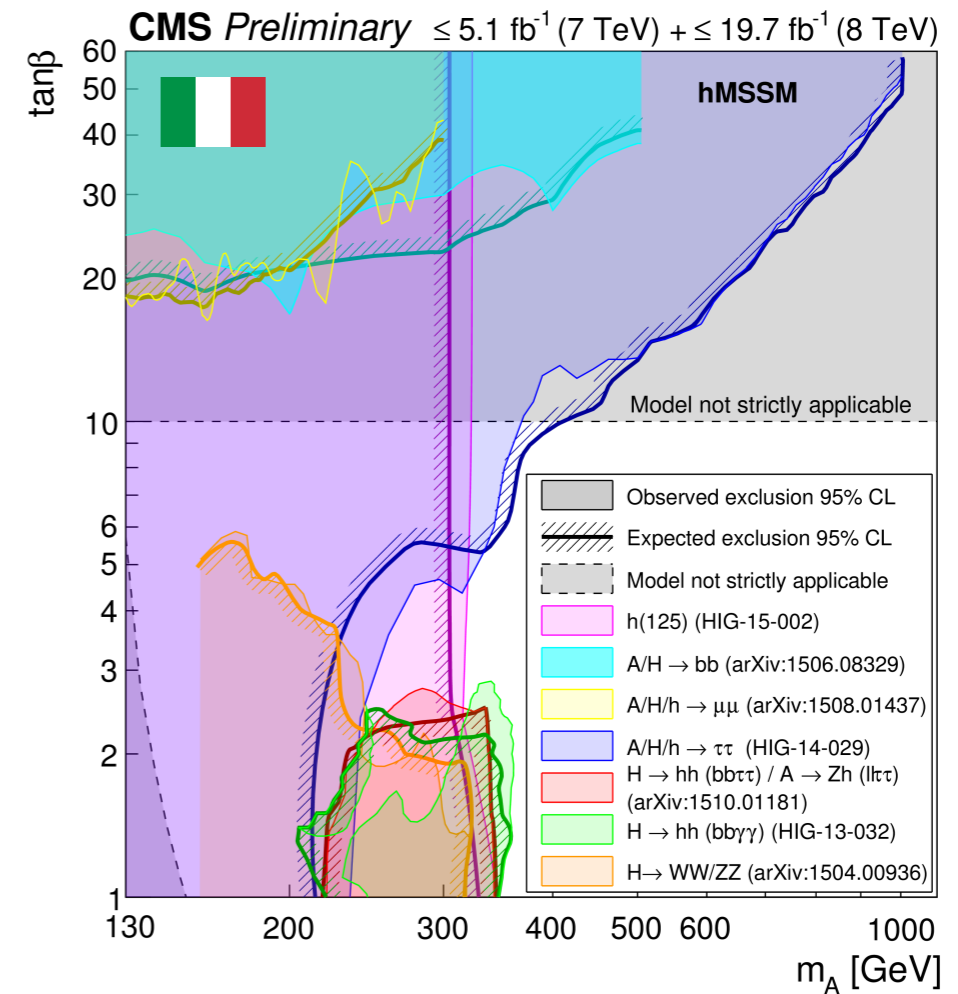
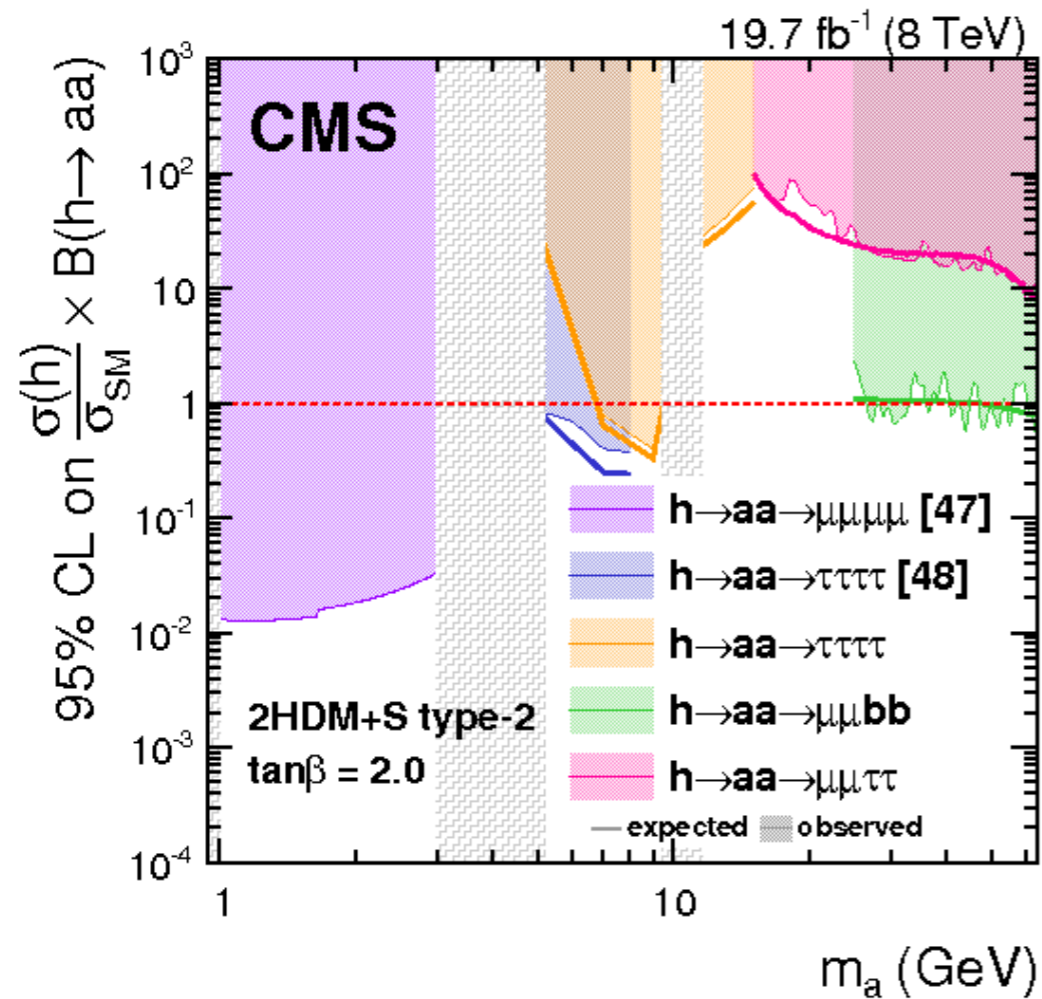
σ/σ_{SM} 95% CL (exp)

 bbbb	<342 (308)
bbWW	<79 (89)
 bb $\tau\tau$	<28 (25)
bb $\gamma\gamma$	<19 (17)

Run2 **3 fb⁻¹** 36 fb⁻¹

HH combination in preparation for Moriond 2018
Full Run2 HH has potential to reach xsec limit $\sim 6-7 \times SM$

OTHER HIGGSES?



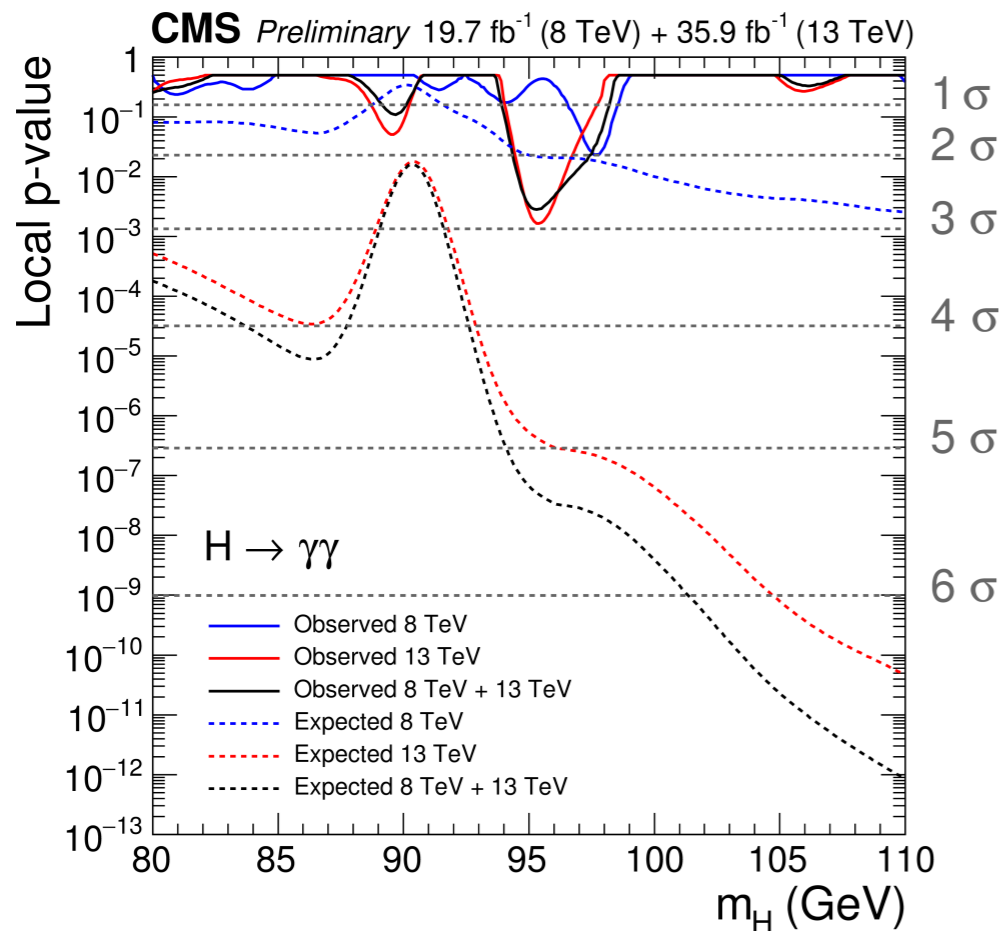
Searches at low mass & high mass for other scalars (pseudo-scalars) neutral or charged

A lot of space to contribute with new analysis and ideas

e.g. $H \rightarrow tt$, $H \rightarrow \chi\chi, \dots$

SOME EXCESSES...

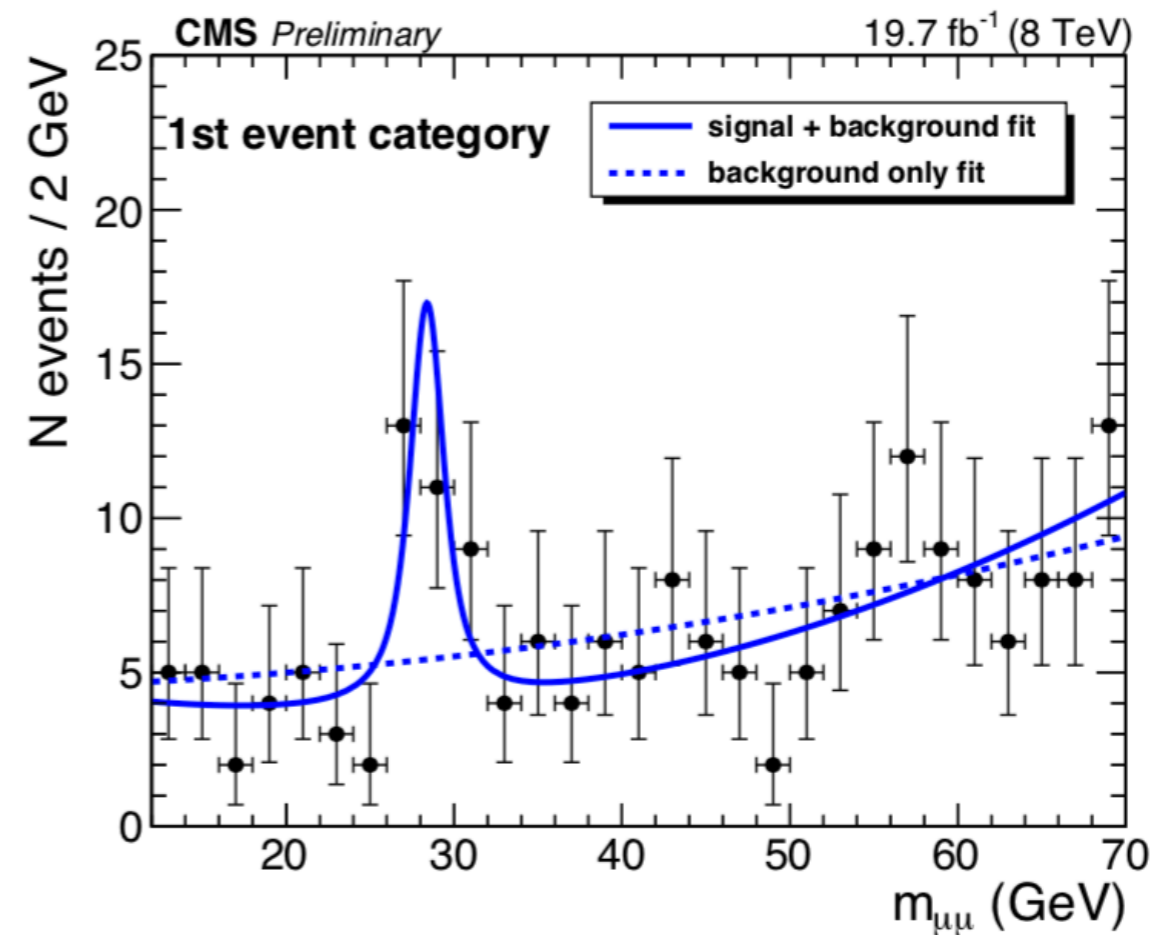
CMS HIG-17-013



Low mass $H \rightarrow \gamma\gamma$:
2.8 σ @ 95.3 GeV (1.3 σ global)

Need to look at 2017 dataset,
also waiting for ATLAS result

CMS HIG-16-017



$\mu\mu$ analysis in 2 categories @ 8 TeV:

1 b-jet and 1 fwd jet
1 b-jet and 1 central jet

4.8 σ (3.5 σ global)
 $m_X = 28.4 \pm 0.4$ GeV
 $\Gamma_X = 1.8 \pm 0.8$ GeV

Soon unblinding of 2016 13 TeV dataset

PLANS FOR 2018



Moriond 2018

“Grand couplings combination”, ttH combination, HH combination, differential cross-section combination

New mass combination ($\gamma\gamma+ZZ$) on 2016 legacy dataset: Spring 2018

2016+2017 dataset: main priority to $H\rightarrow bb$ & ttH observation

Each sub-group will focus at least on 1 analysis

$H\rightarrow\tau\tau$: improved analysis: MVA + embedding + fake factor
CP measurement

$H\rightarrow WW$: ttH multi-leptons
differential cross section measurements

$H\rightarrow ZZ$: STXS measurements
Off-shell width and cross section measurements

$H\rightarrow\gamma\gamma$: ttH, $\gamma\gamma$ low mass search

$H\rightarrow bb$: VH, ttH, ggH boosted

HEXO : $H\rightarrow\mu\mu$ (including MSSM search)

Higgs physics program is full of opportunities

from precise measurements to searches
in several cases measurements start to be limited by systematics: a lot of space to bring new ideas and new experimental techniques

$H \rightarrow bb$ and $t\bar{t}H$ observations are at reach for 2016+2017, main priority for 2018

A full set of new results expected with Run2 dataset ($\geq 150\text{fb}^{-1}$)
perfect timing for a PhD starting now to get involved in a full Run2 analysis

Also several opportunities for future HL-LHC projection studies.
More information in Patrizia's talk