Highlights of the Higgs Boson Measurements at the LHC

XVIII Mexican Summer School of Particles and Fields

20-27 October, Hermosillo, Sonora

by

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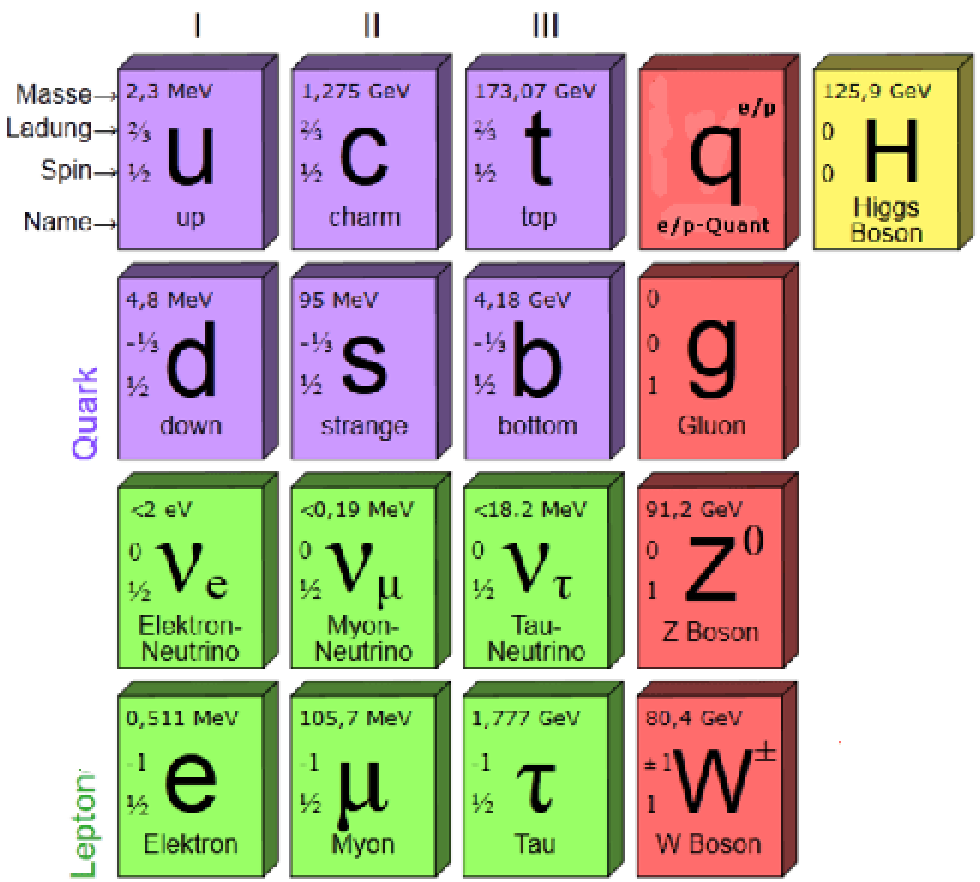


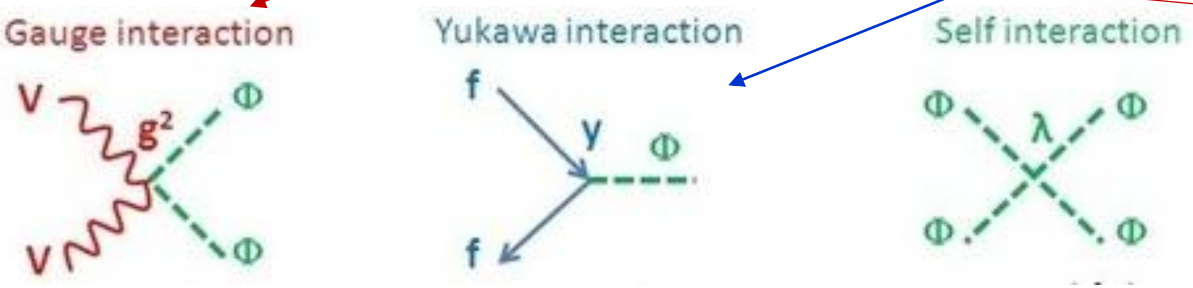
After a very long search, in 2012 particle consistent with Higgs boson discovered at LHC by ATLAS and CMS experiments: at ~125 GeV

(free parameter in SM, but once known all predictions are fixed)

First fundamental Scalar observed:

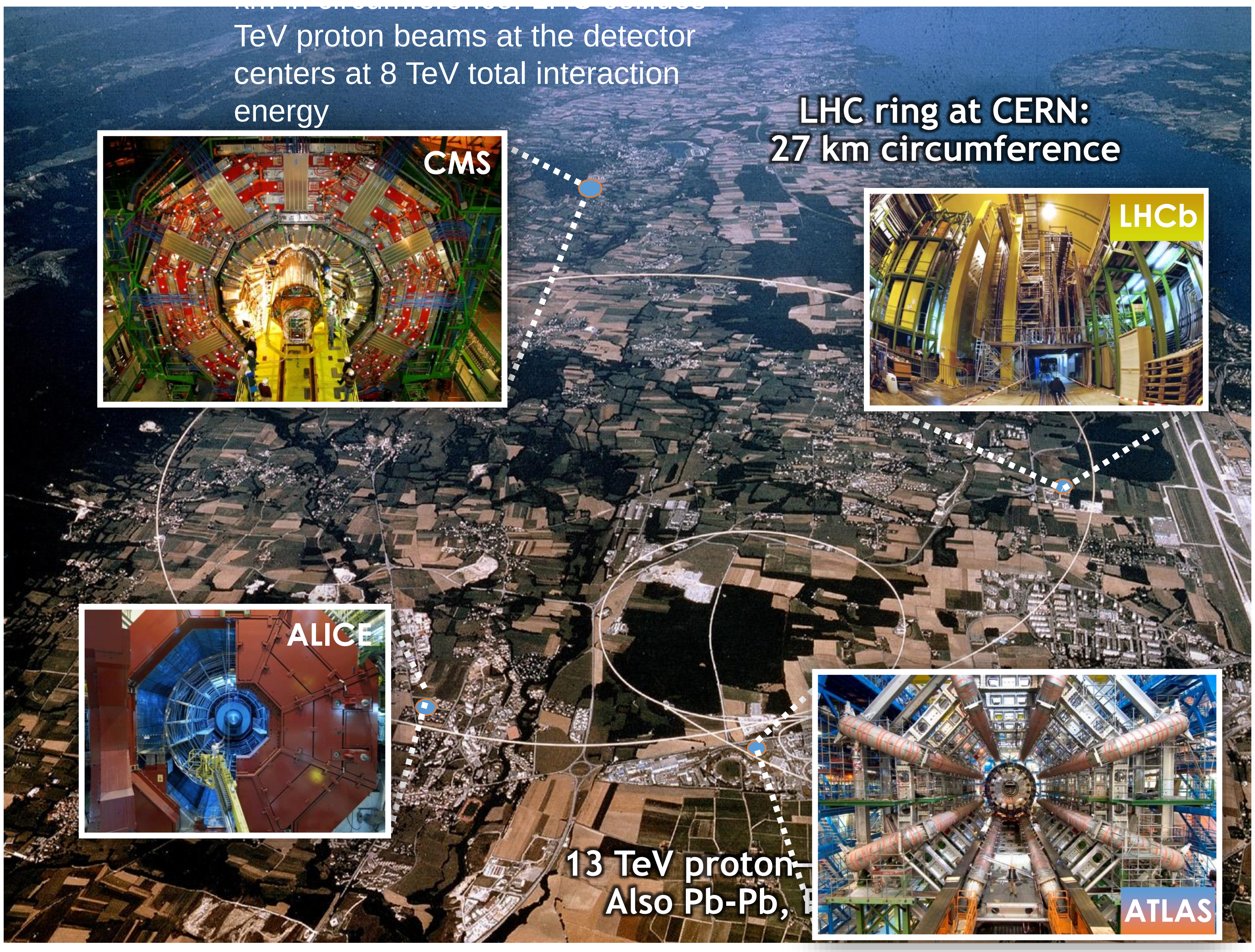
Related to EW symmetry breaking !

$$\mathcal{L} = -\frac{1}{4} F_{\mu\nu} F^{\mu\nu}$$
$$+ i \bar{\Psi} \not{D} \psi + h.c.$$
$$+ \bar{\Psi}_i y_{ij} \psi_j \phi + h.c.$$
$$+ |D_\mu \phi|^2 - V(\phi)$$



$$V(\Phi) = -\mu^2 |\Phi|^2 + \lambda |\Phi|^4$$

The Accelerator : Large Hadron Collider (LHC)



2010-2012 at 7/8 TeV

LS1

2015-2018 at 13 TeV

with some upgrades

LS2

2020-2024 at 14 TeV

LS3

2025- HL-LHC

Depth underground 100-120m

Perimeter ~27 km

25 nsec bunch crossing

~2700 bunches (or less)

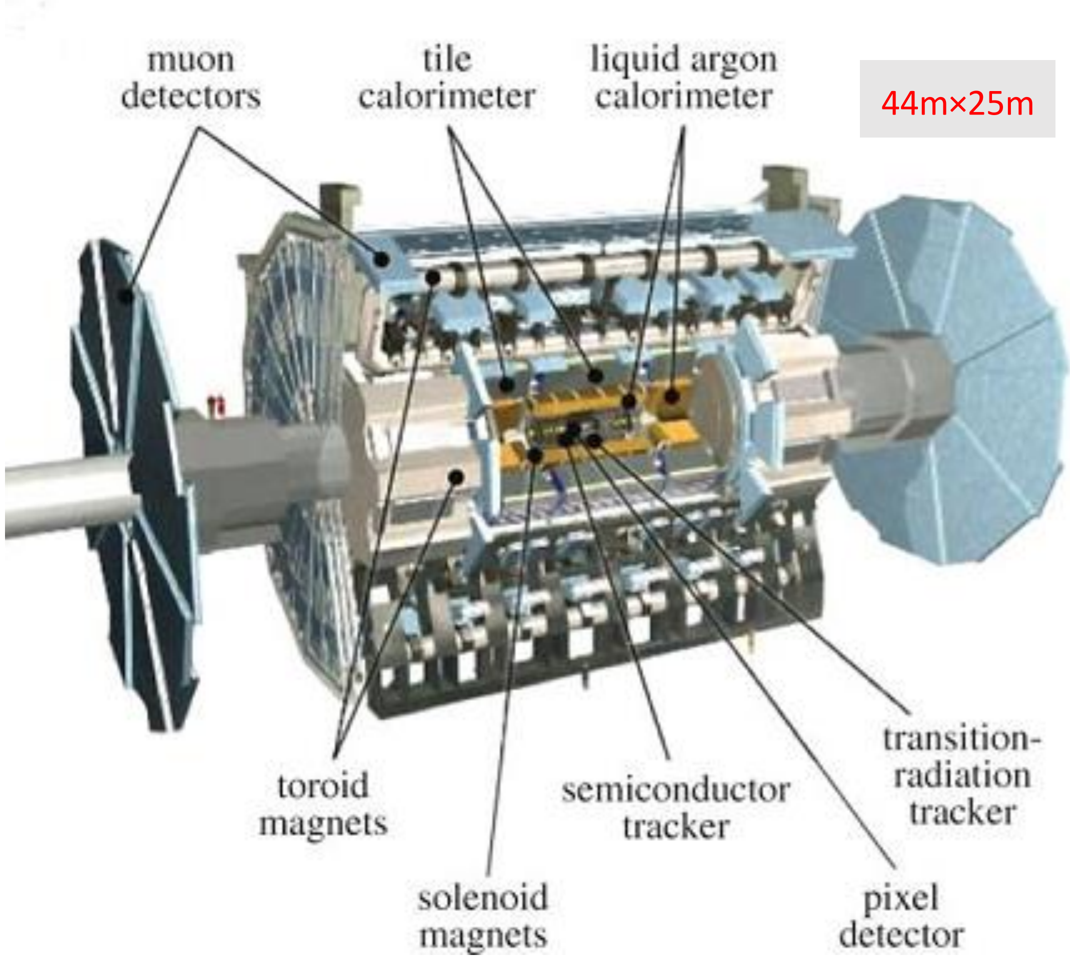
Filled bunches < total

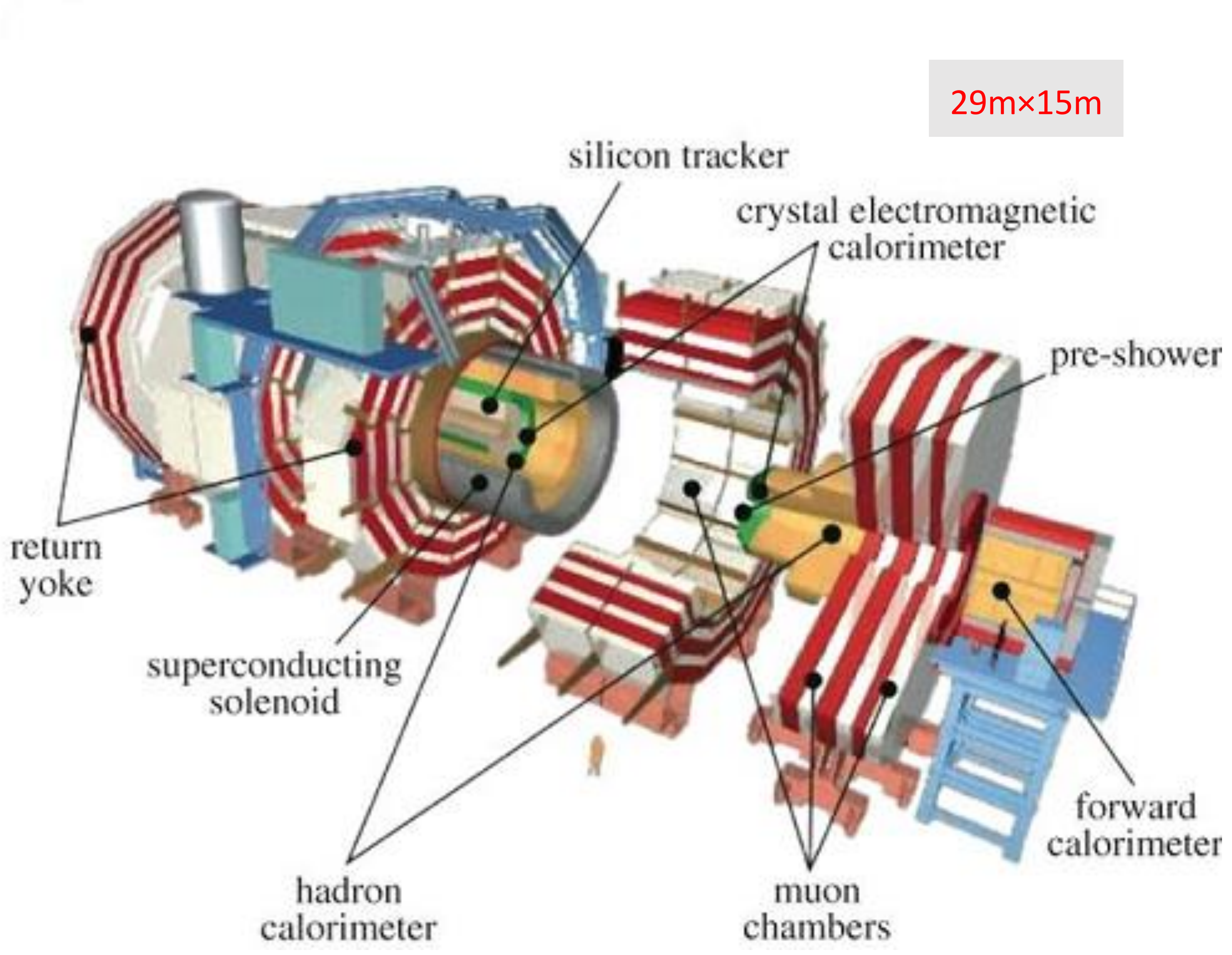
Protons per bunch > 10^{11}

Bunch length ~1-1.2 nsec (4σ)

Beam crossing angle ~170 μrad at collision, slightly different

The detectors : ATLAS (left) and CMS (right)

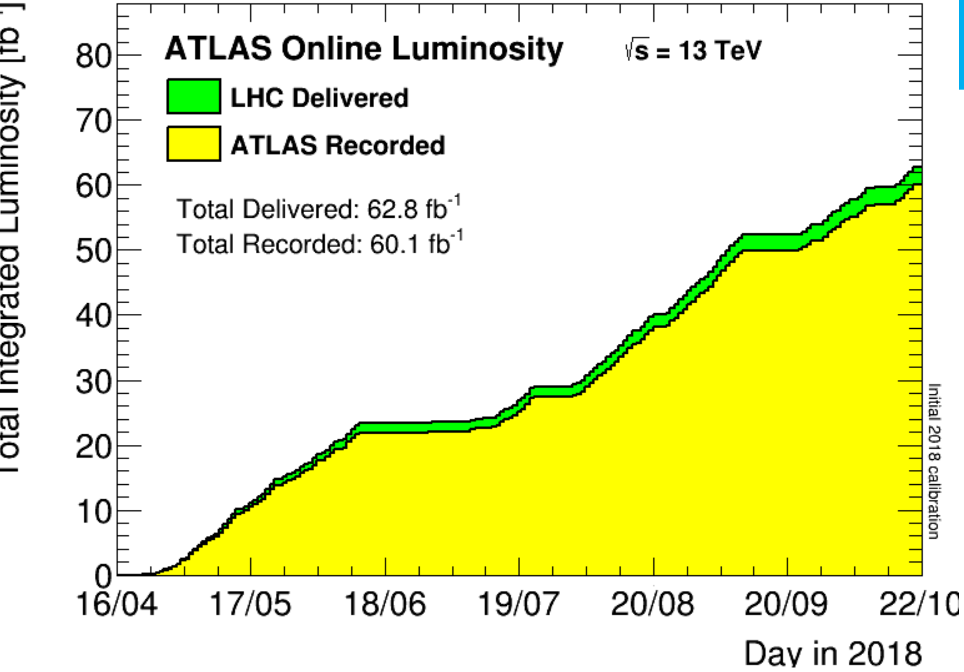


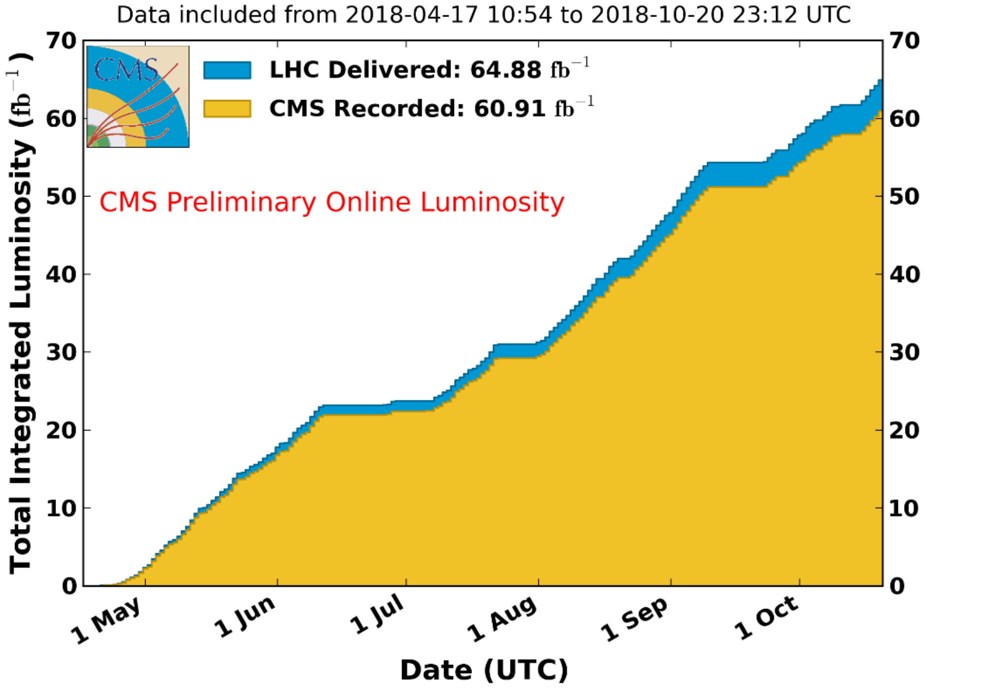


Large general purpose detectors
High resolution tracking, vertexing, calorimetry
Good electron and muon identification

Upgrades for Run2:
New innermost pixel layer (ATLAS, 2015)
Pixel detector replacement (CMS, 2017)
Trigger improvements to cope with ~1GHz pp interaction rate

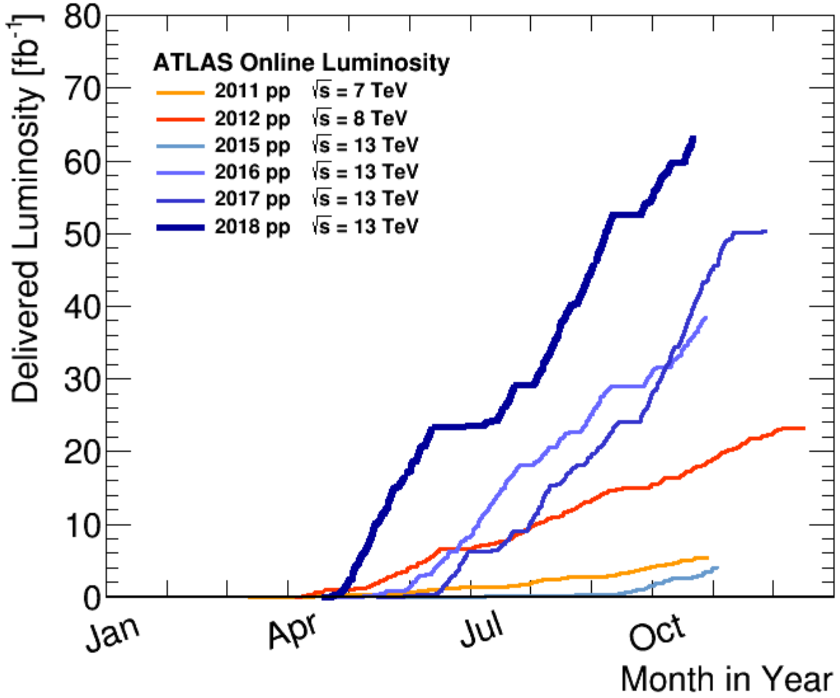
Luminosity

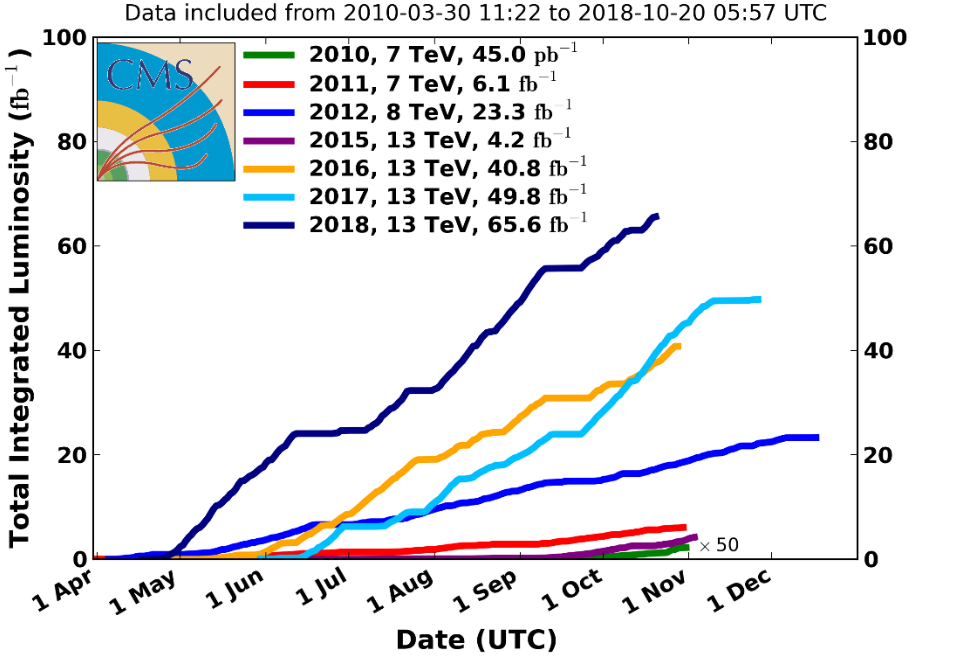




Up to 60 interactions per pp event

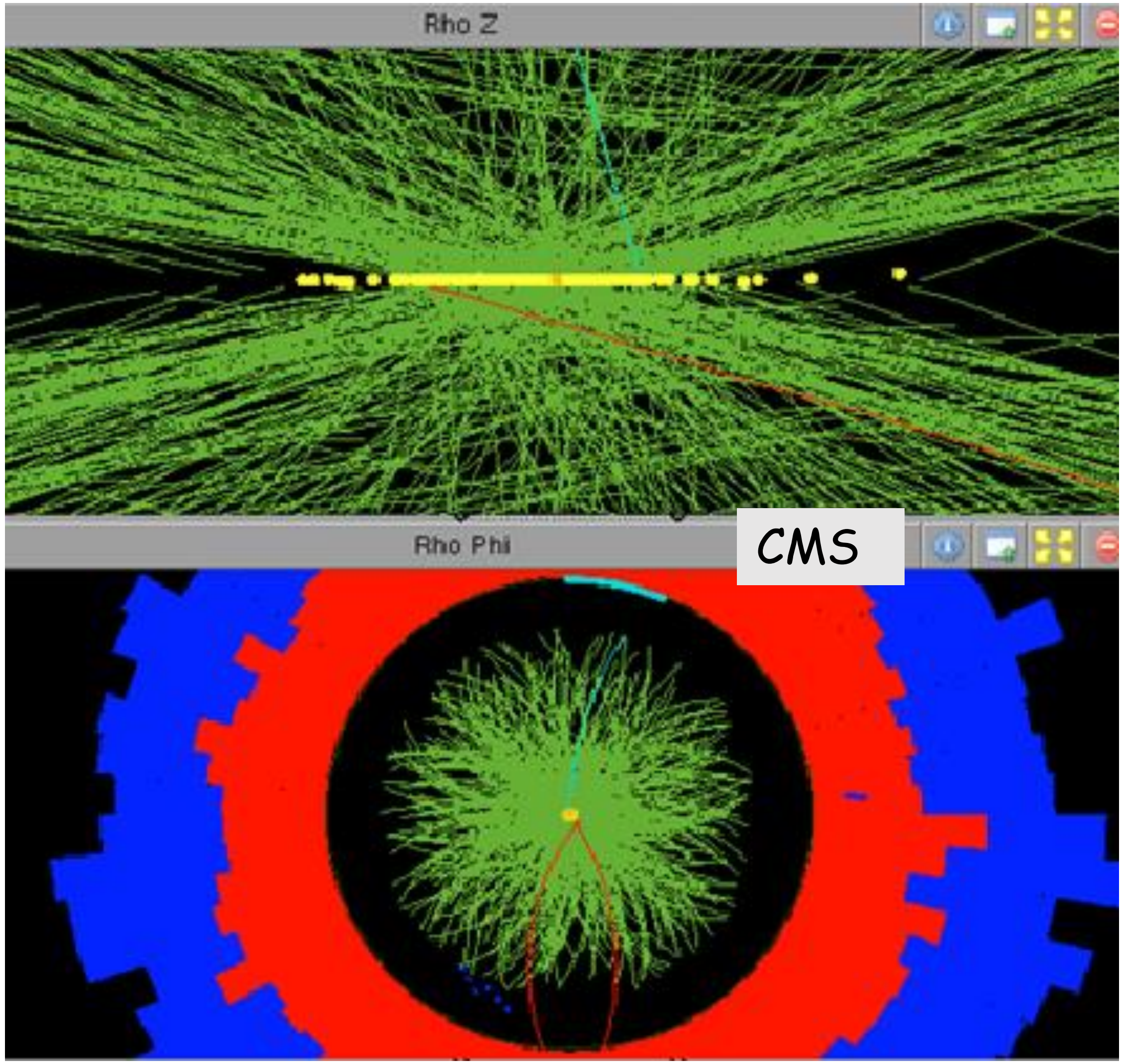
Peak luminosity ~2 × 10^{34} $cm^{-2}s^{-1}$ (twice the design luminosity)

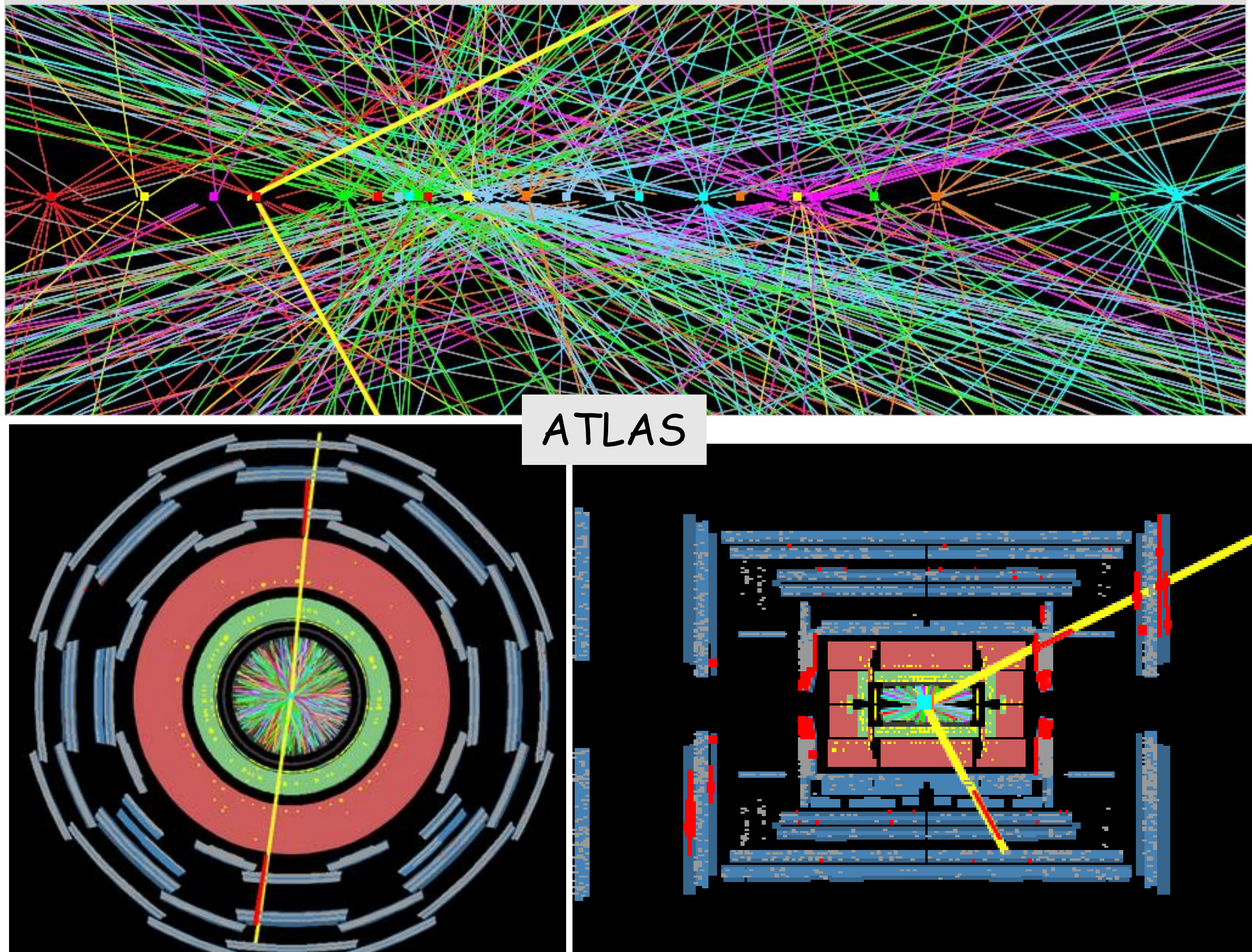




What is pile-up ?

Because so many protons are packed in a single bunch (in order to get very high rate of partonic collisions, when these bunches cross one another, many protons interact. The following **(left)** is an event **with 37 pile-up from CMS** and **from ATLAS (right) with 25 pile-up** after reconstruction. When multiple partons from the same proton interact, they are called multi-parton interaction events.

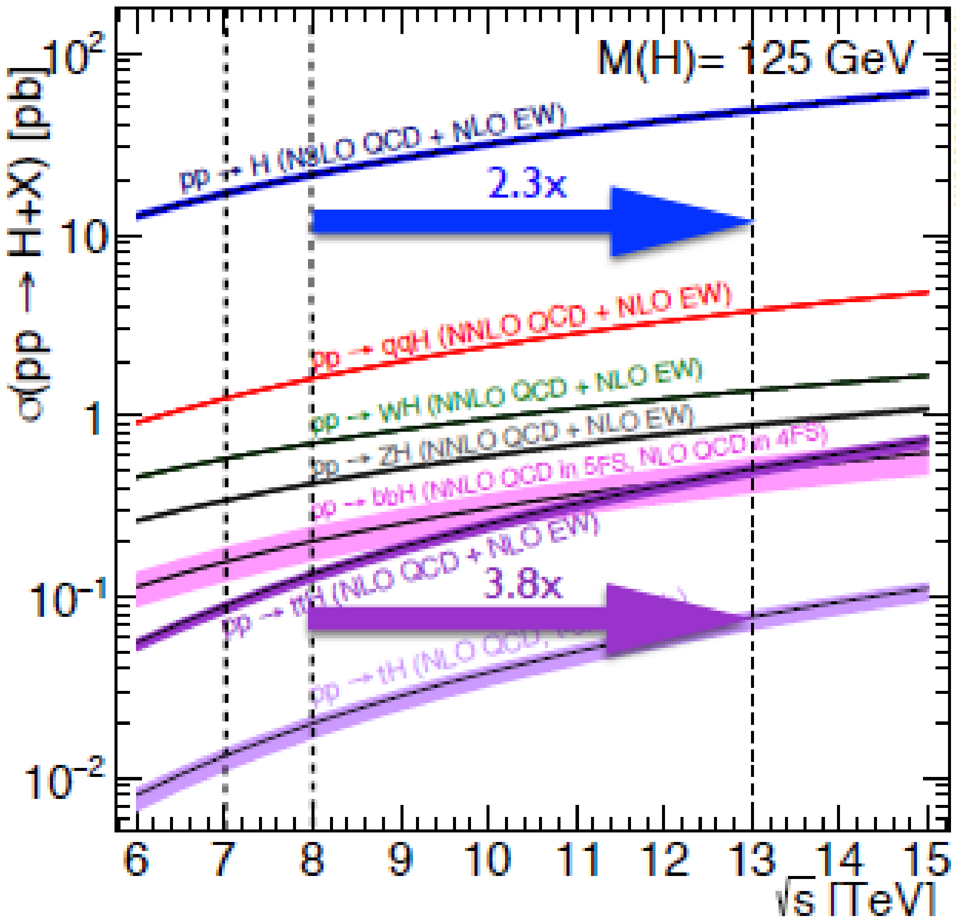


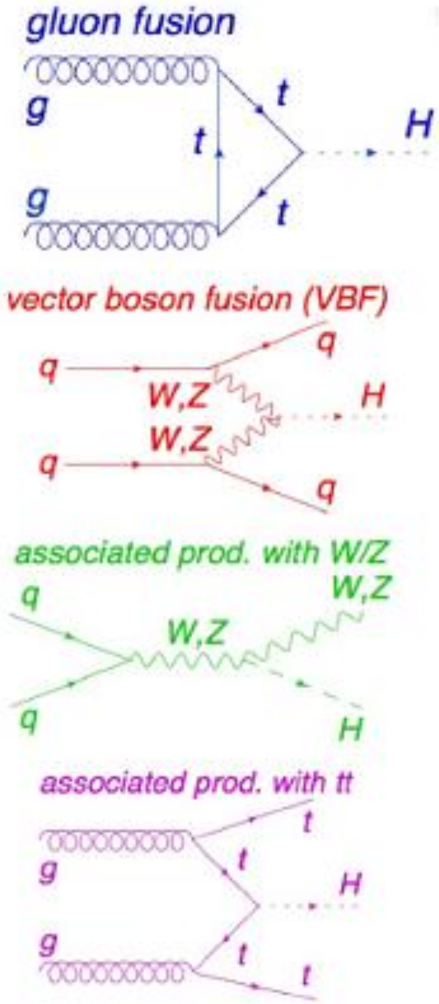


Higgs Boson Discovery and Standard Model calculations

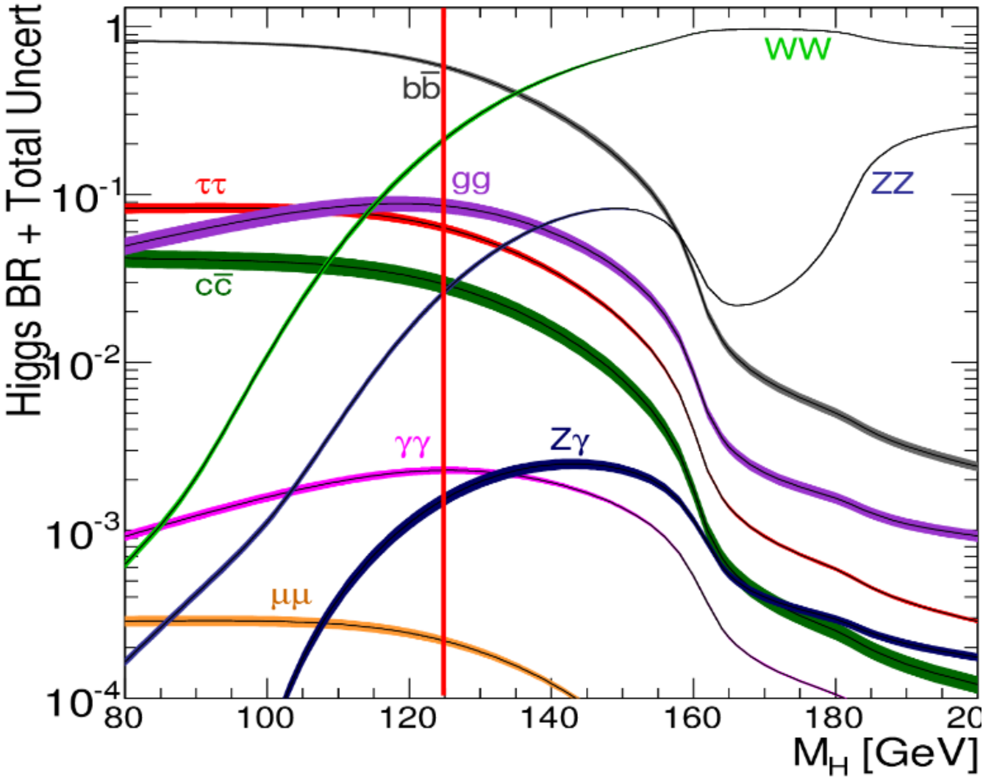
Mass established, Nobel prize to Englert and Higgs (BEH mechanism, Brout, Englert, Higgs, Guralnik, Kibble, Hagen)

Production [LHC Higgs X-sec WG]





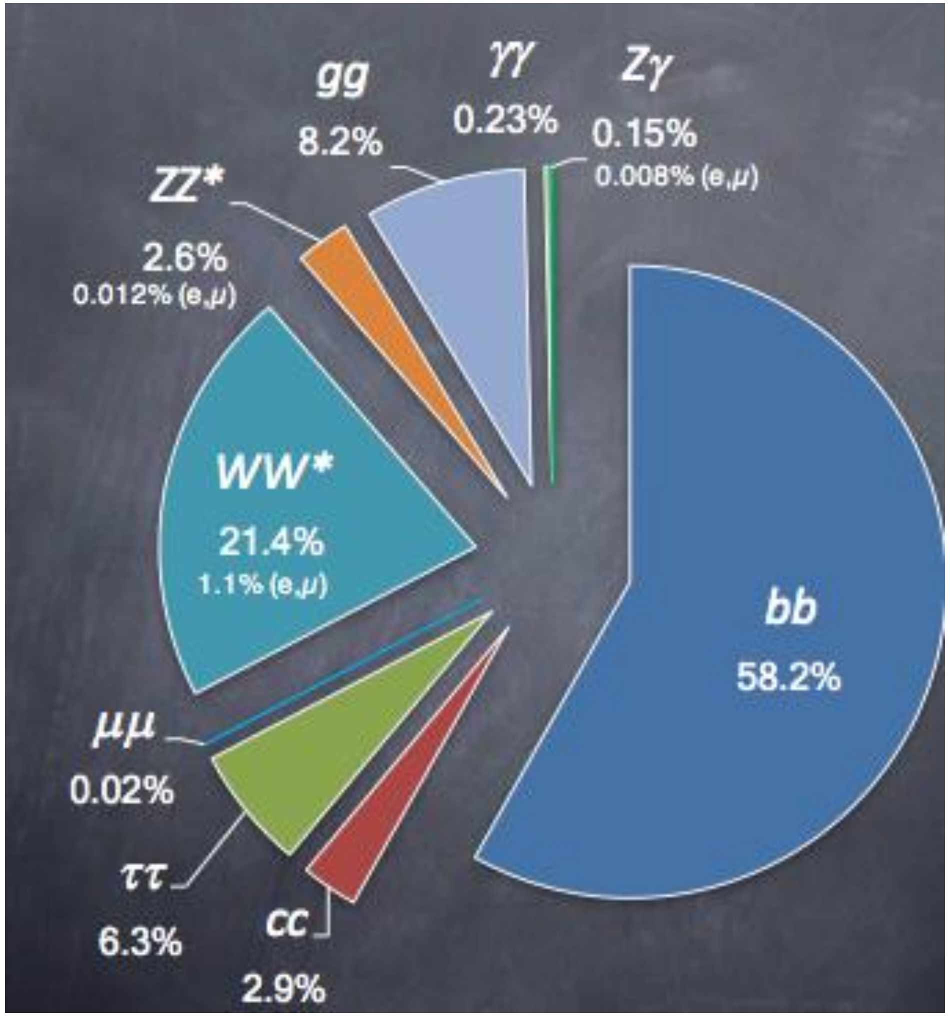
Higgs decay branching ratios (BR)



BR is only part of the story

Increase in production cross-section from 8 to 13 TeV

Various decay modes & possibilities



Decay into a b-pair has highest BR, but S/B is very low….but important to measure the coupling to fermions.

Similar for decays into τ-pairs

WW* (→ lν lν) has a high **Branching Ratio (BR)** but with missing neutrinos, so mass resolution is poor

ZZ* (l^+l^- l^+l^-) decay is ideal, although low BR (discovery channel)

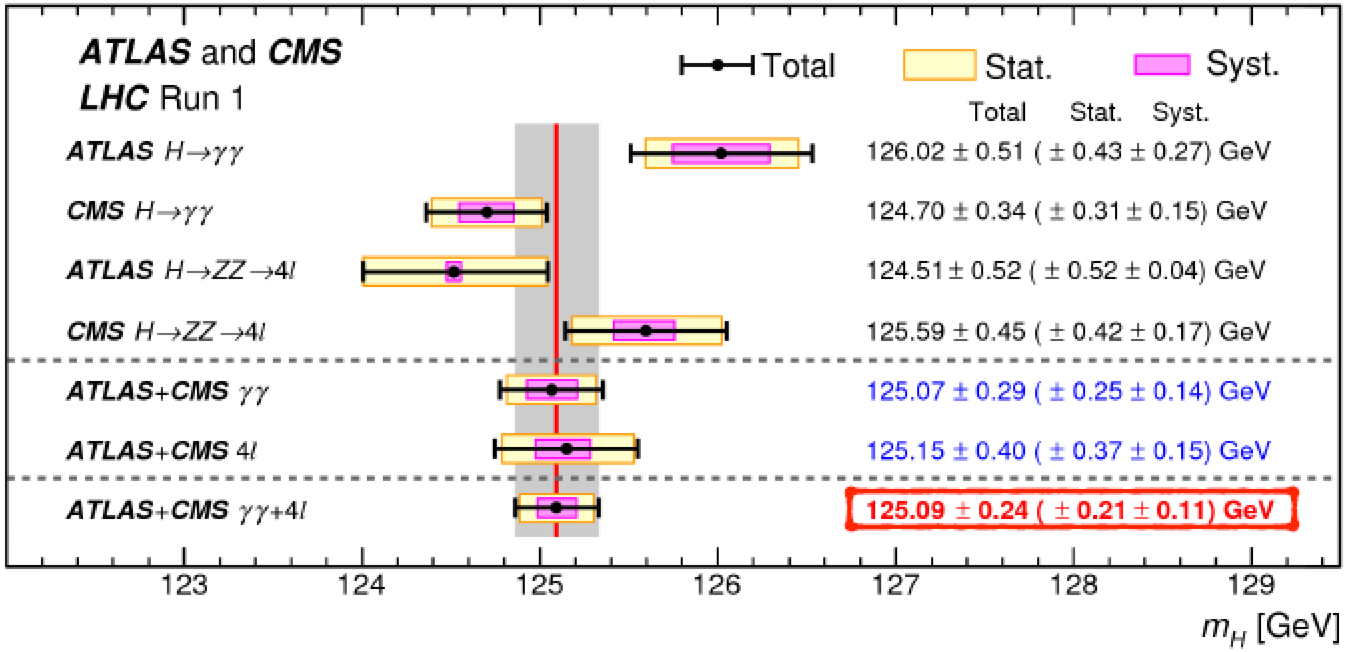
γγ BR is very low, but background is very well modeled, is also ideal (discovery channel)

Discovery channels h→ γγ , ZZ*

Status at the end of Run1 (7 and 8 TeV) data

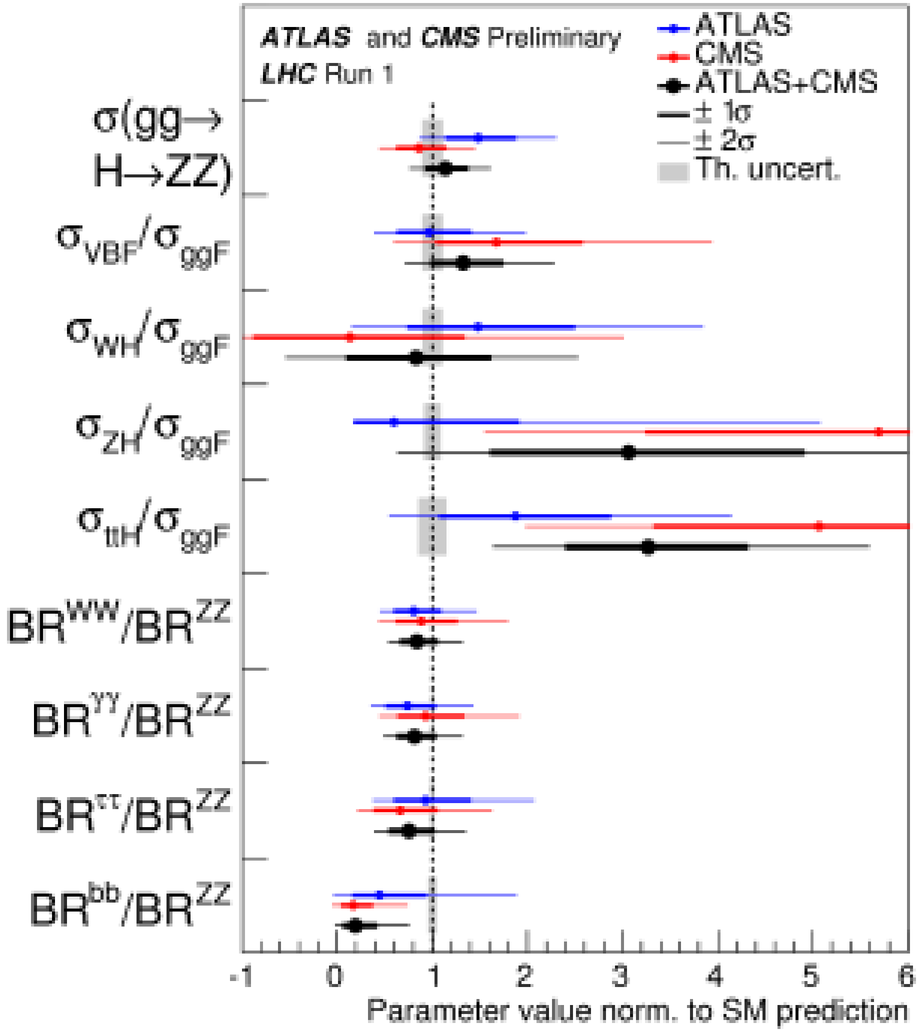
Mass of Higgs boson

ATLAS+CMS PRL 114 (2015) 191803



~0.2% precision (statistically limited)

JHEP 08 (2016) 045



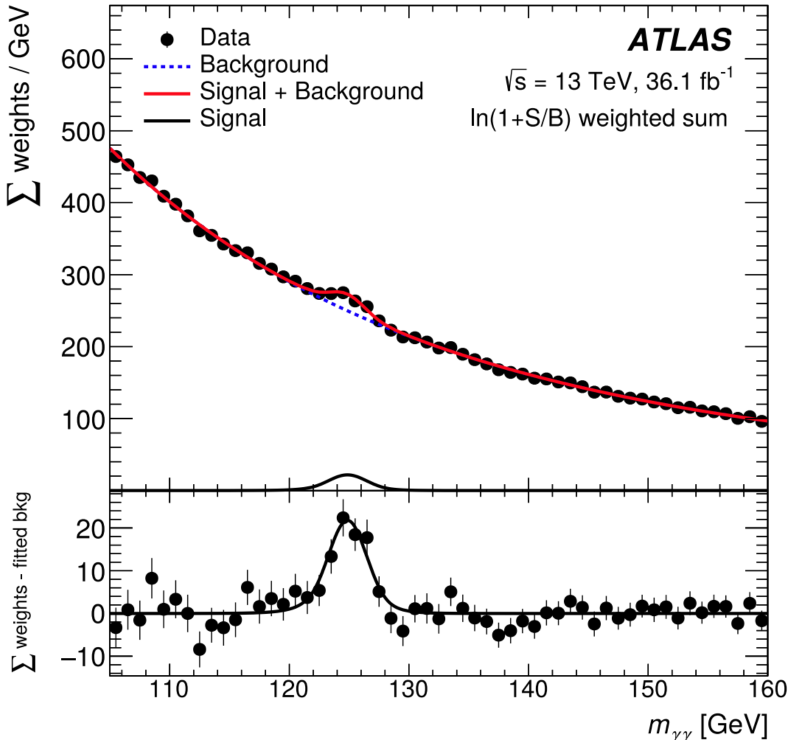
$$\mu = \frac{\sigma \cdot BR}{\sigma \cdot BR_{SM}}$$

Alternatives to spin-parity non 0+ all rejected
~ 10% accuracy in inclusive cross-section measurements
Not quite enough for beyond SM contribution from coupling measurements (10-25%)
Bosonic decays well established, Higgs decays to invisible constrained <25-30%

ATLAS + CMS Run-1: mass of higgs boson M_h = 125.09 ± 0.24 GeV

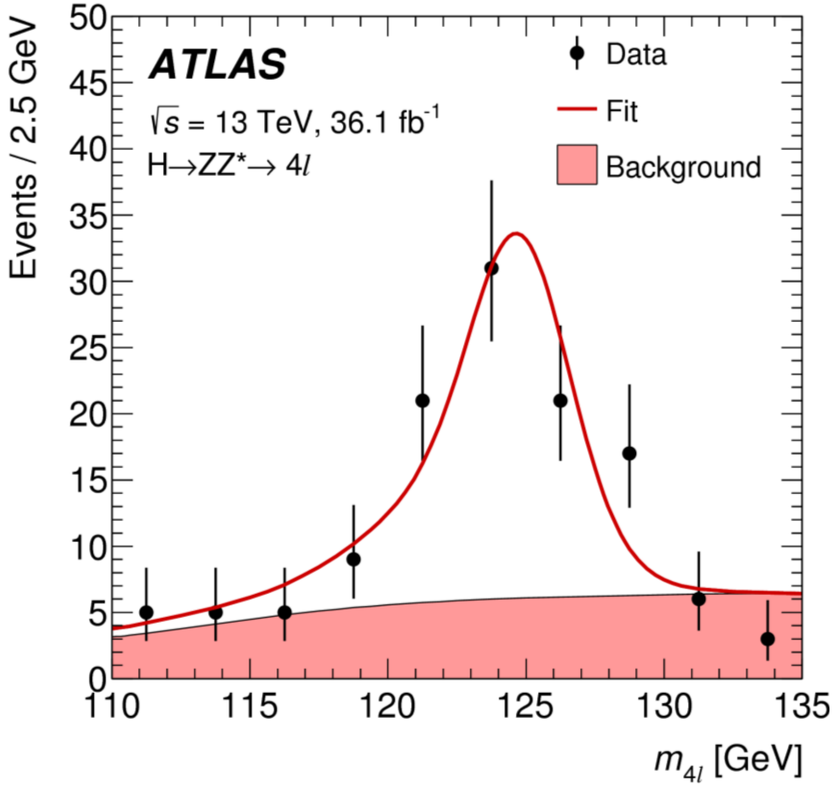
In Run2 much higher statistics and at higher energy 13 TeV

New mass measurements based on **h → γγ** and **h → ZZ* → 4l** final states.



M_h = 124.93± 0.40 GeV

1806.00242



M_h = 124.79± 0.37 GeV

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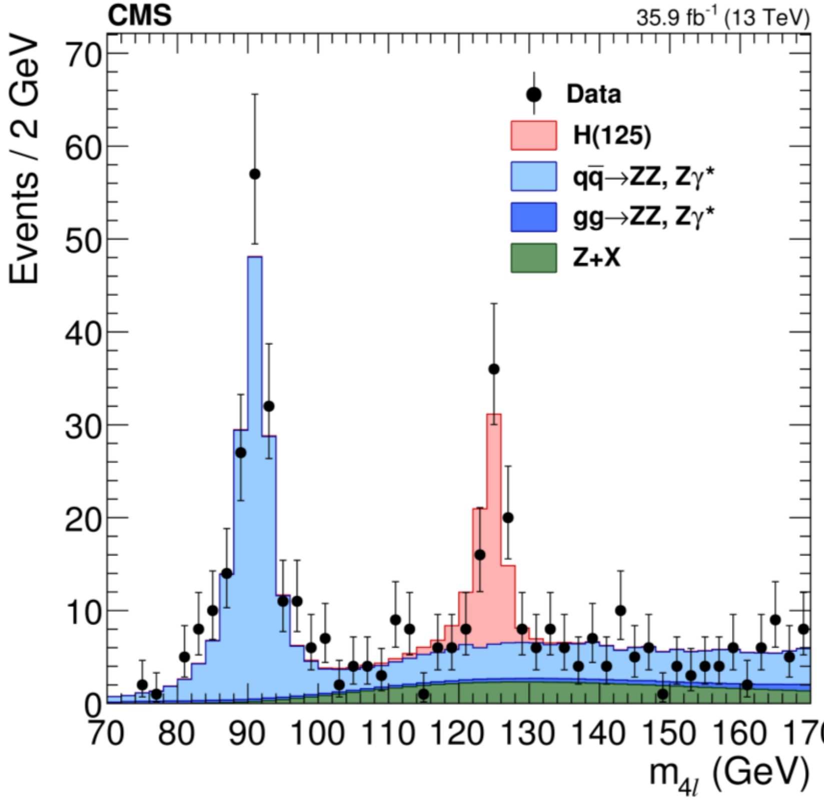
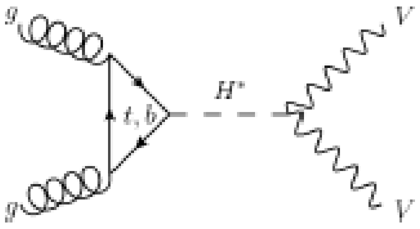


M_h = 125.26± 0.21 GeV

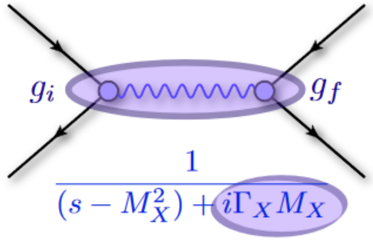
Combined ATLAS Run1 and 2: 124.97 ± 0.24 GeV (± 0.19 stat ± 0.13 syst) mostly from photon energy scale

Width measurement **:** SM width 4 MeV too small to measure directly
[HIGG-2017-06]



CMS direct measurement Γ_h < 1.10 GeV @ 95% CL

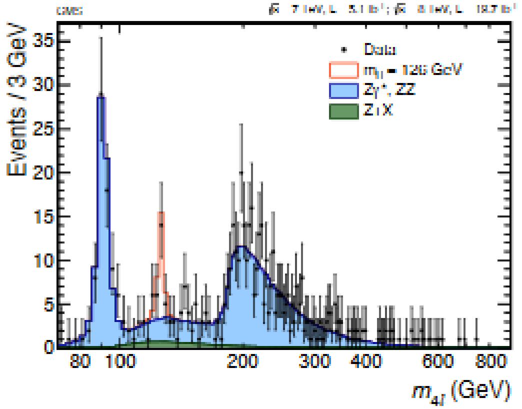
Can measure from comparison of off-shell to on-shell production cross-section also



$\sigma_{off} \propto$ off-shell (prod)• off-shell (decay) **;**
but
$\sigma_{on} \propto$ on-shell (prod)• on-shell (decay)/(Γ_h/ Γ_h^{SM})

ATLAS Run2 new <14.4 MeV (15.2 MeV exp)

Example: on-shell and off-shell production



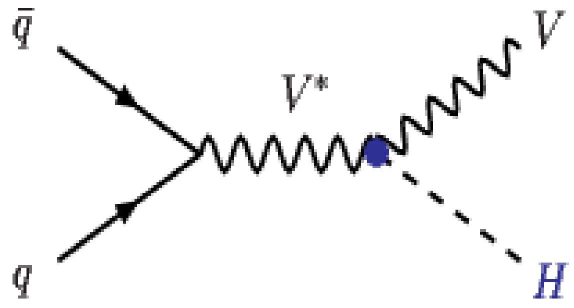
In Run2: *establish Fermionic decays,* precision measurements, search for any deviation from SM (with higher statistics)

Higgs decay into b-quark pair

Highest BR ~59% for h → bb ; but hard to observe; production cross-section low

Most massive SM particles produced decay through single or two b-quarks, e.g.,.
Z → bb, t → bW; also simple QCD b-quark production
Extremely difficult to find b-pairs produced from h-decays

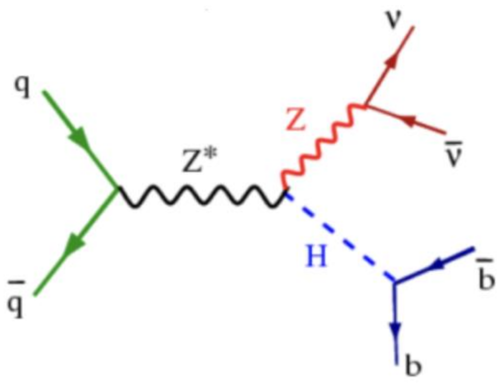
Higgs–strahlung



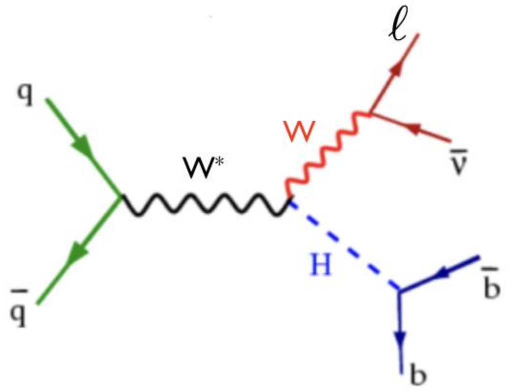
Select associated production of h with a W or a Z as the primary decay channel
Z decay is observed in two oppositely charged leptons
e^+e^- or $\mu^+\mu^-$ (2-leptons) or $\nu\bar{\nu}$ (0-lepton) decays
and W decay is observed in $e/\mu + \nu$ (1-lepton) decays

Leptonic decays allow separation from multi-jet backgrounds

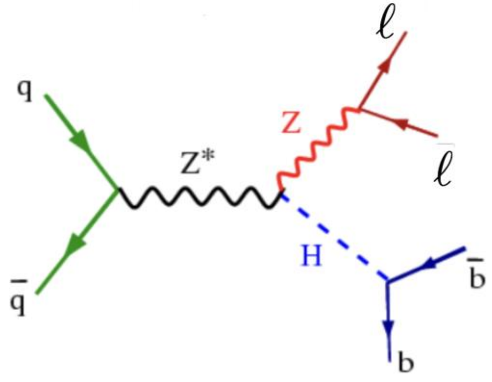
Higgs decay into b-quark pair in Vh, h→bb



0-lepton



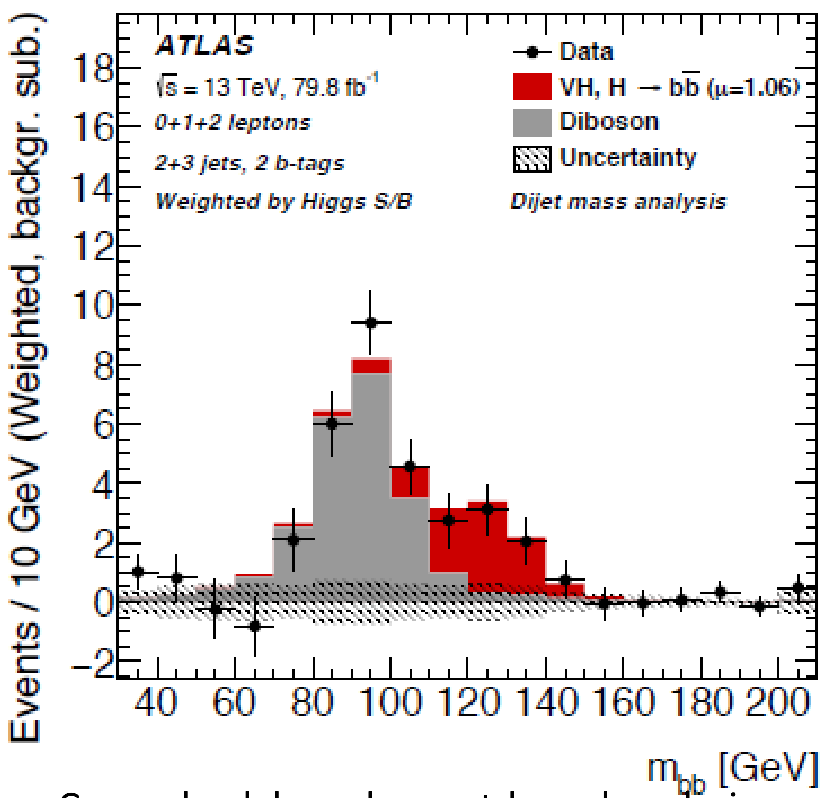
1-lepton

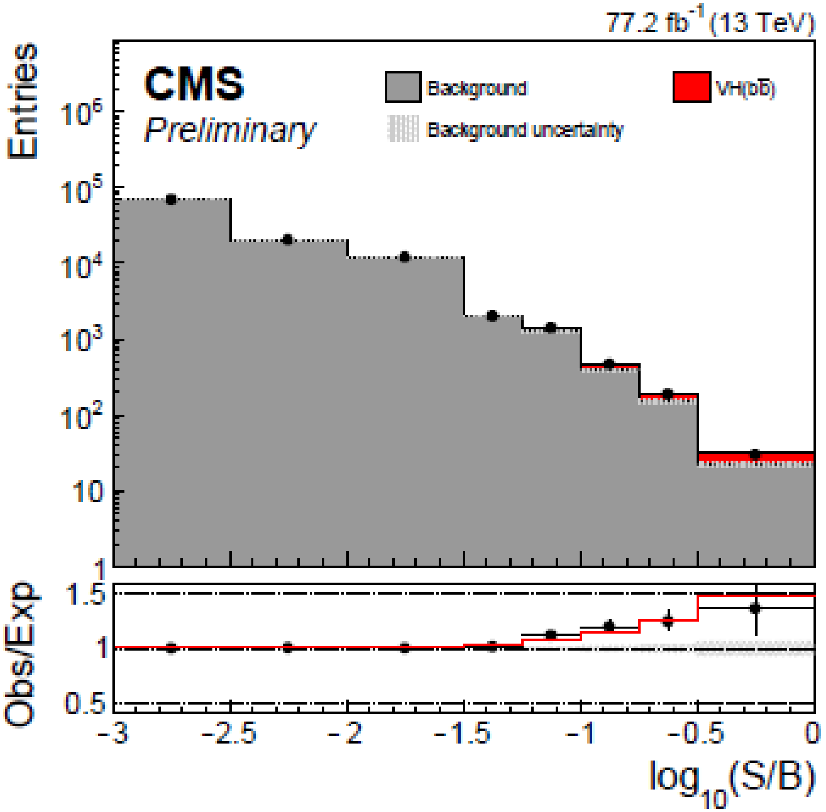


2-lepton

b-identification very important, multi-variate analysis (boosted decision tree), simultaneous fit of signal and backgrounds for constraining normalization (tt-bar, V + jets with heavy flavor, shapes from MC, multijet background from data)

Evidence of decay into b-quark pair in Vh, h→bb





Cross-check based on cut-based analysis

From Run1 + Run2 (~80 fb^{-1}) data

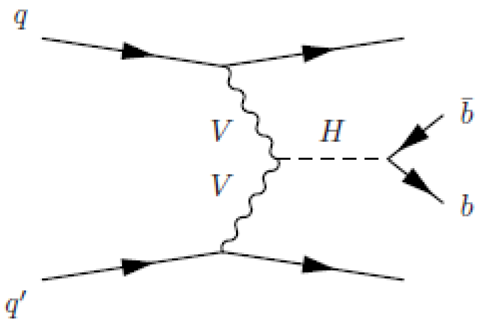
Expected sensitivity

ATLAS 5.1σ, CMS 4.8σ

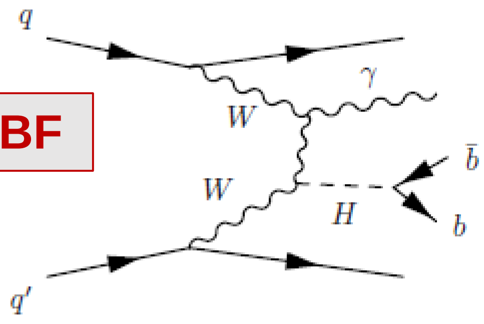
Observed

ATLAS 4.9σ, CMS 4.8σ

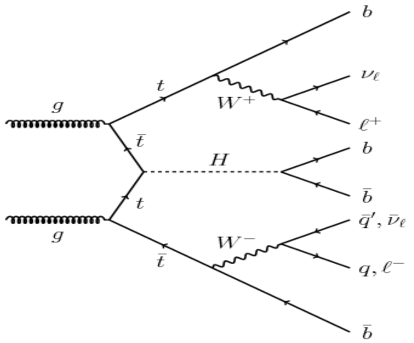
But add other production modes for h→ bb, e.g., VBF (vector boson fusion), and tth (with h→ bb)



VBF



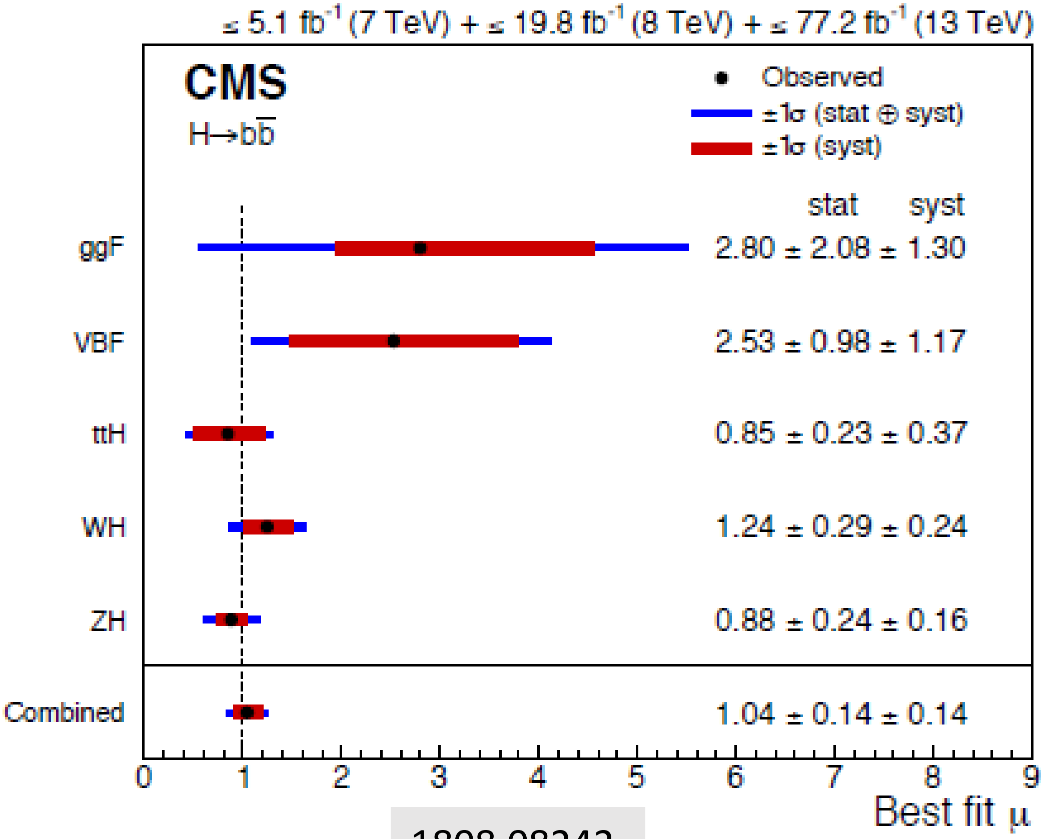
tth, h→bb



Observation of Higgs boson decay into b-pair

Combining the Vh (bb), VBF h(bb) and tth (bb), both ATLAS and CMS observe h → bb decay

From Run1 + Run2 (~80 fb^{-1}) data **Expected** sensitivity **ATLAS 5.4σ, CMS 5.6σ**
Observed ATLAS 5.5σ, CMS 5.6σ (compatible with SM within 20%)



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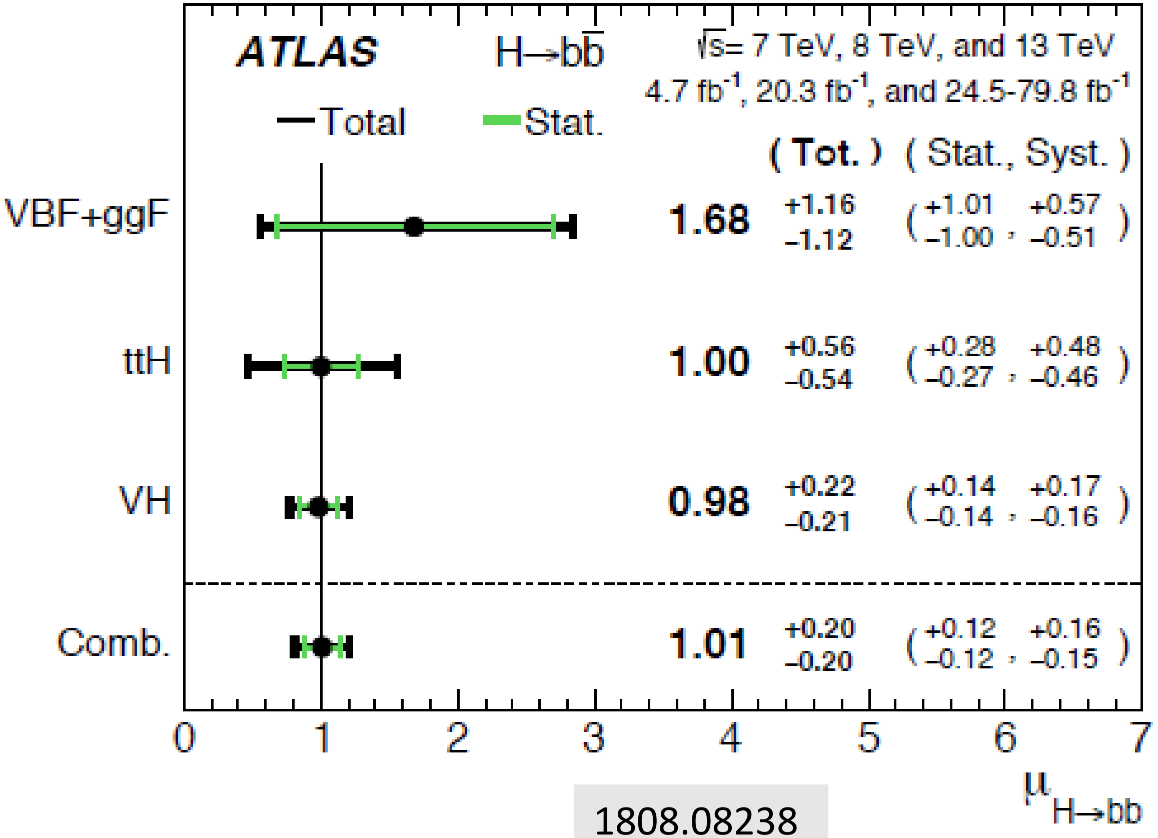
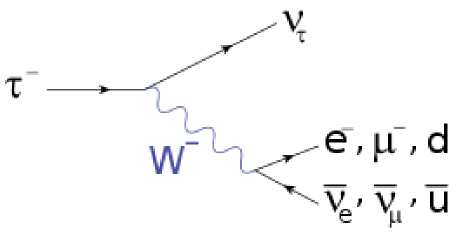
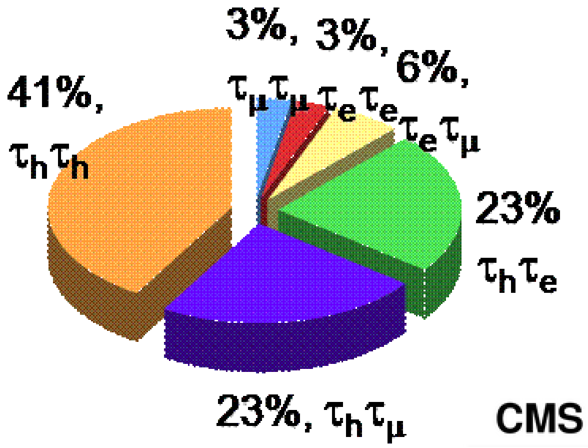
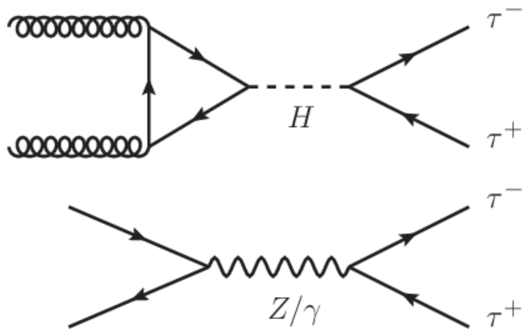


1808.08238
Phys.Lett. B786 (2018) 59-86

Search for Higgs decay into Tau-pair



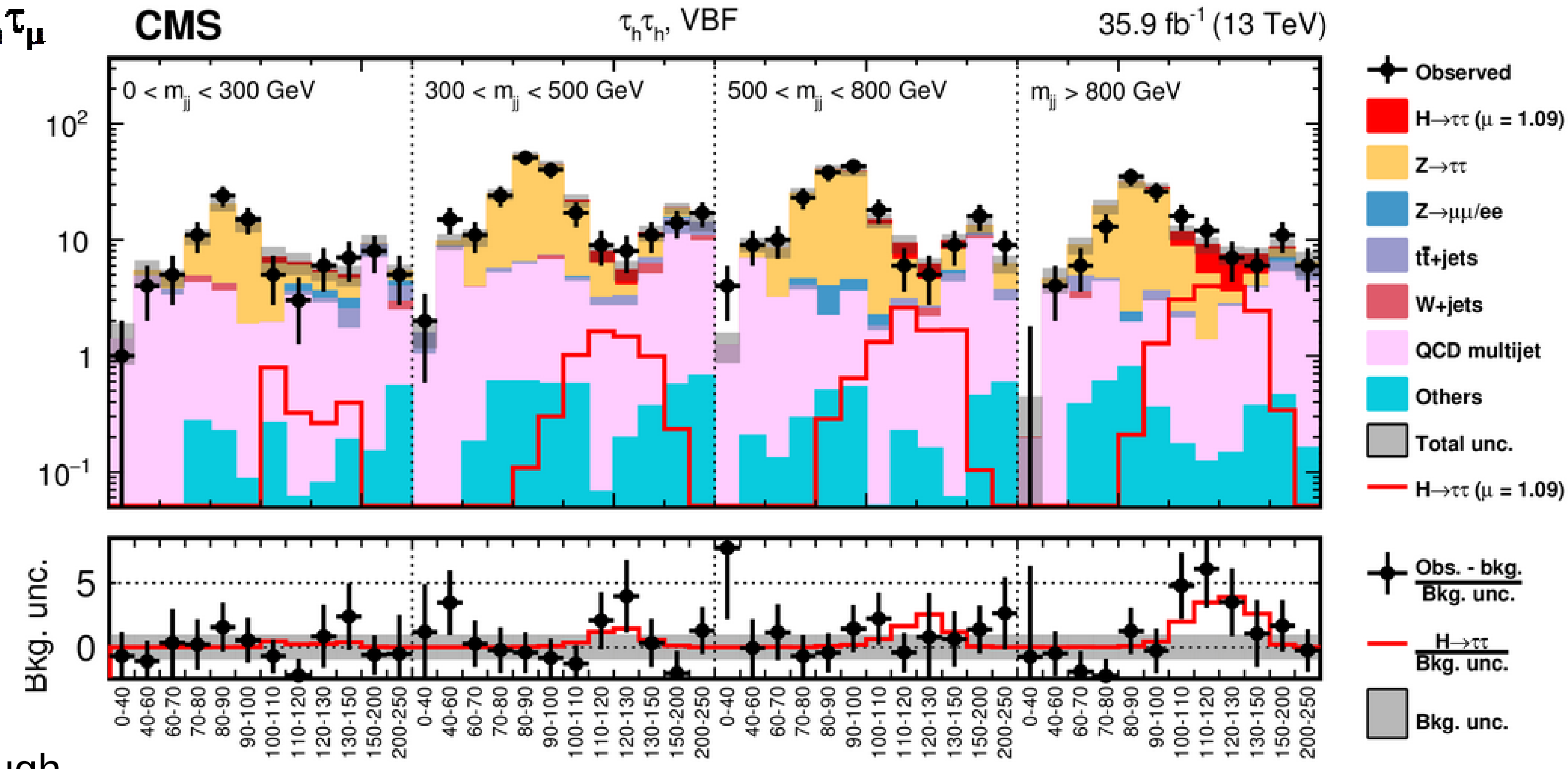




lep-lep, lep-had, had-had Tau-pair decay combinations

categorize according to production mechanism: VBF, gg-fusion

use visible energies from τ's and missing p_T to estimate di-tau mass, then fit mass distribution



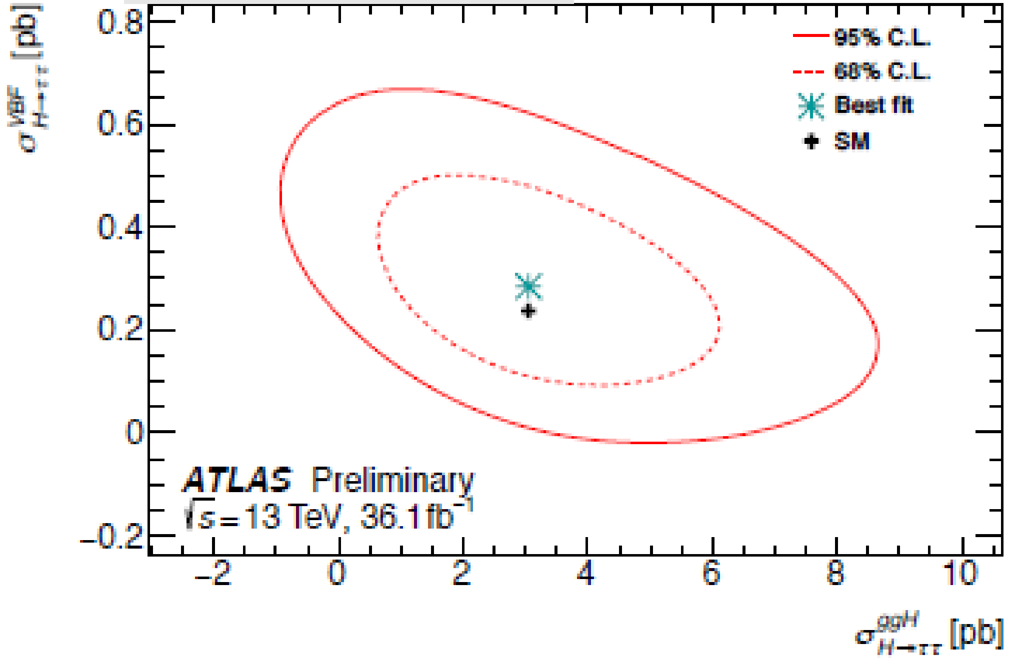
main background from Z → $\tau^+\tau^-$, shape estimated from simulation with normalization determined through data in **control region (CR)** and fake tau's estimated with a data driven technique

Higher m_{jj} in VBF leads to higher purity of signal
In gg-fusion, p_T of higgs candidate used for boosted h

Observation of Higgs decay into Tau-pair

36 fb^{-1} + Run1

ATLAS-CONF-2018-021



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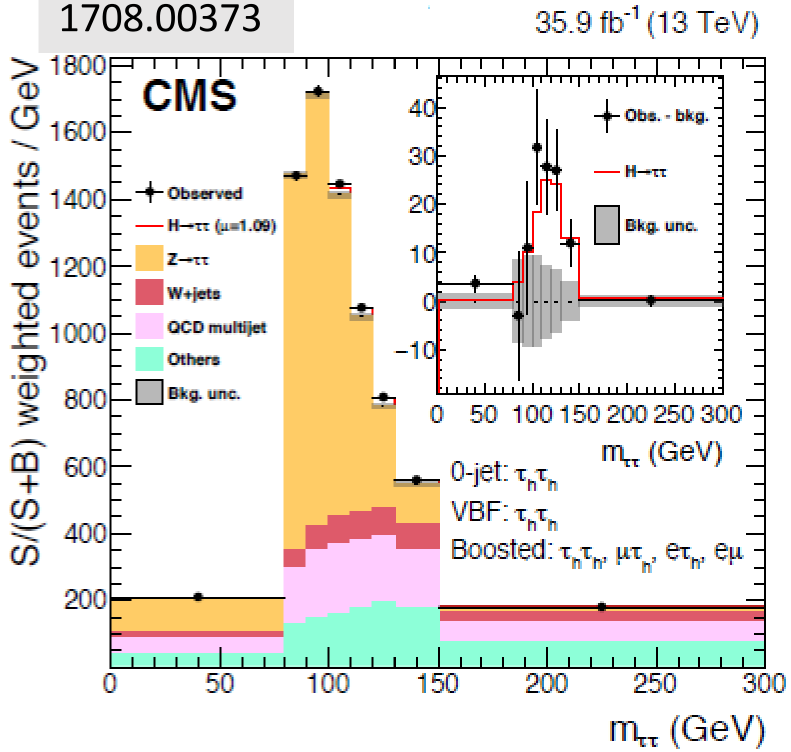


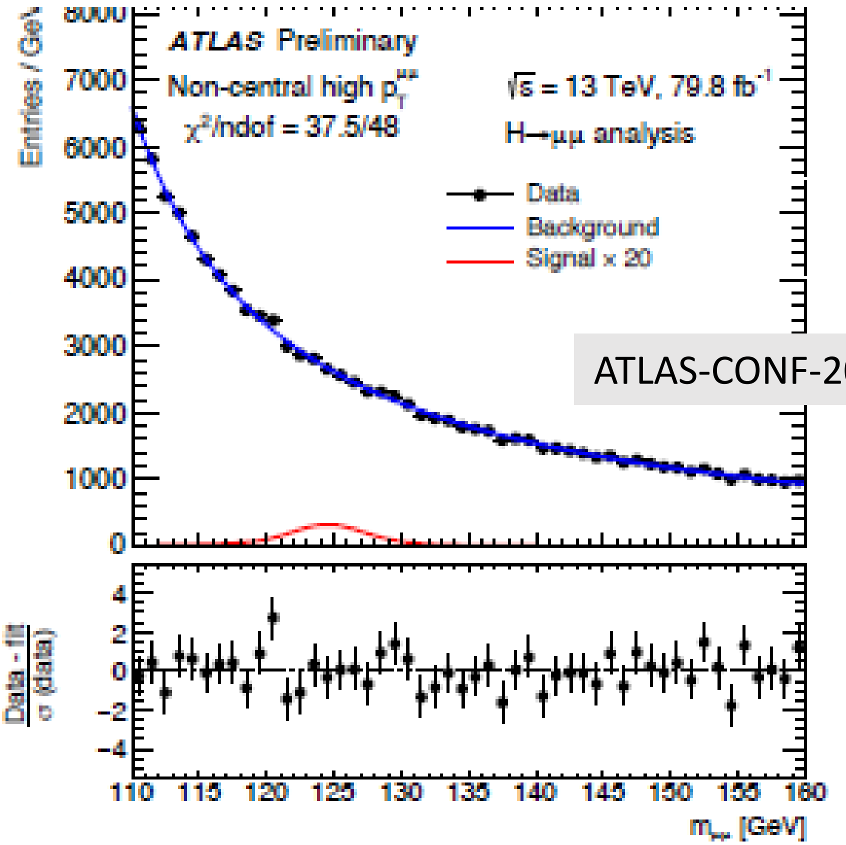
Expected significance : CMS 5.9σ , ATLAS 5.4σ

Observed significance : CMS 5.9σ, ATLAS 6.4σ

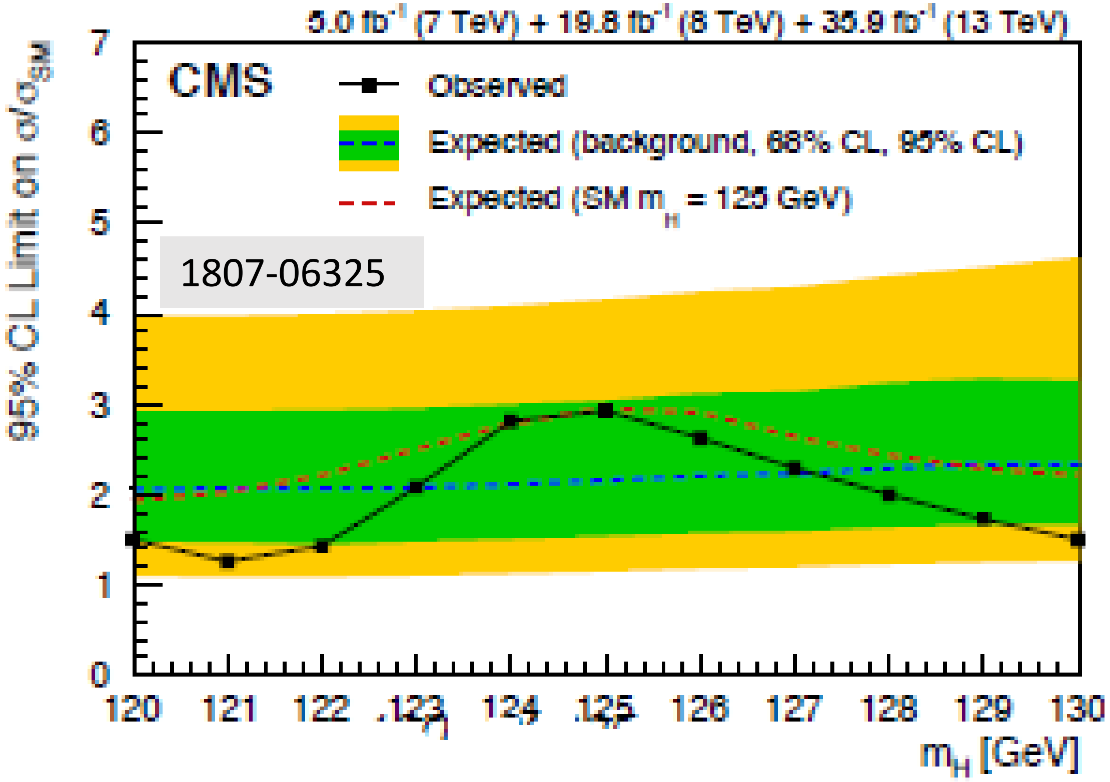
ATLAS $\mu = 1.09\ ^{+0.18}_{-0.17}$ (stat) $^{+0.27}_{-0.22}$ (sys) $^{+0.16}_{-0.11}$ (Th. sys) .; CMS 7&8 TeV data $\mu = 0.98 \pm 0.18$

Search for higgs decay into μ-pair (2nd generation)

Similar production mechanism and main background from Z/γ^* decays into mu-pairs clean signature, but low BR, based on muon centrality (η), [$p_{T\mu\mu}$], and BDT that enhances VBF and g-g fusion contribution, p_T > 25 GeV



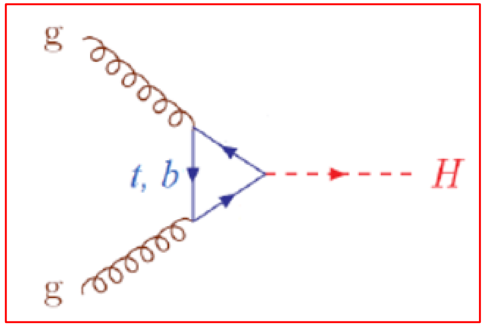
ATLAS-CONF-2018-026



1807-06325

Expected sensitivity no SM signal (ATLAS 2.0, CMS 2.1)*SM
Observed limit ATLAS (2.1, CMS 2.9)* SM

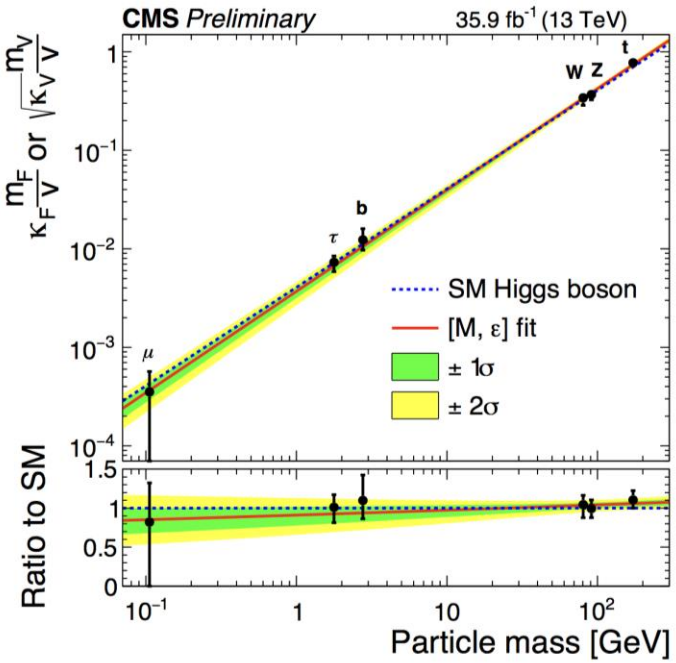
Coupling of h(125) to top quark

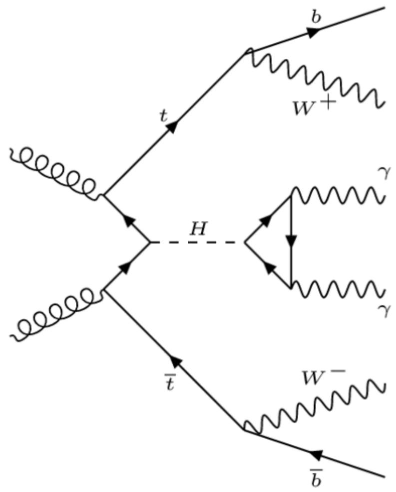


largest coupling to t-quark
Yukawa coupling α mass

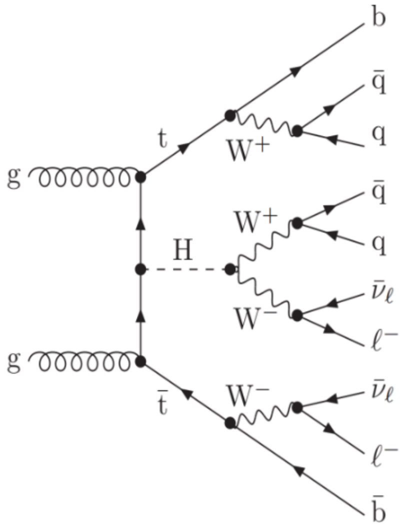
production of Higgs by gluon fusion happens by ***indirect*** coupling of t-quark pair with Higgs boson (highest), but …

Complicated final states with 0-2 leptons, 2-6 jets, 2 b-jets
h decays into $\gamma\gamma$, 4l : clean
WW, $\tau\tau$: no mass peak, need to understand background
bb high BF, but very complex with tt and bb background (combinatorics)
what decay modes could be exploited here ?

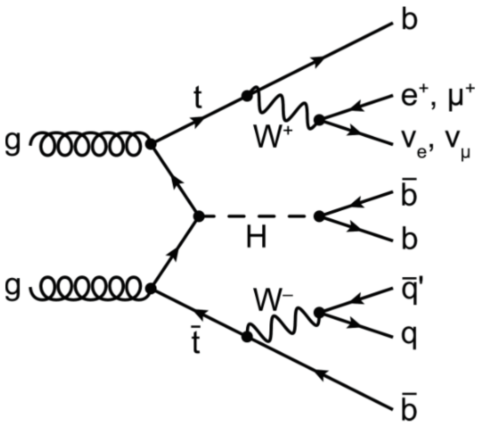




h → γγ, ZZ (4l)*



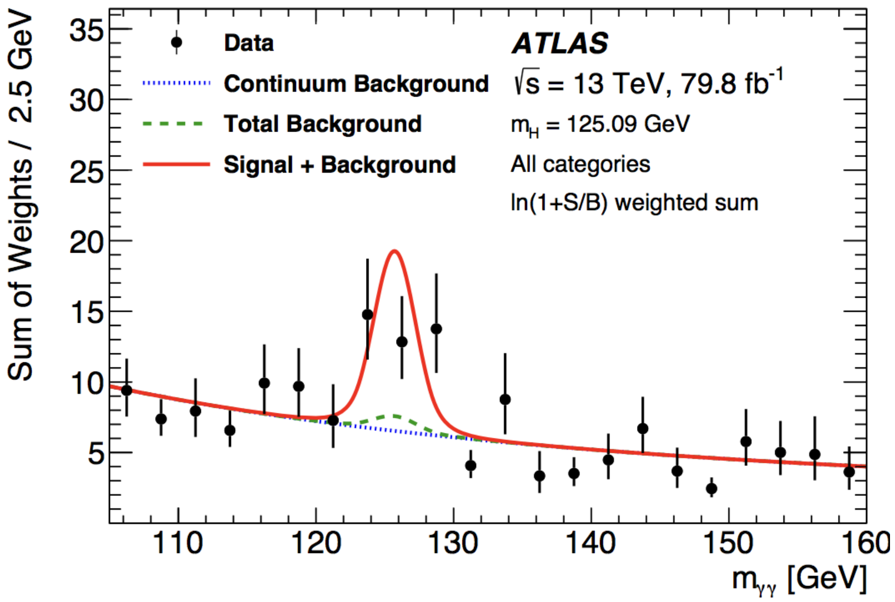
h → WW, ττ*



h → $b\bar{b}$

Higher σ•BF
Higher purity

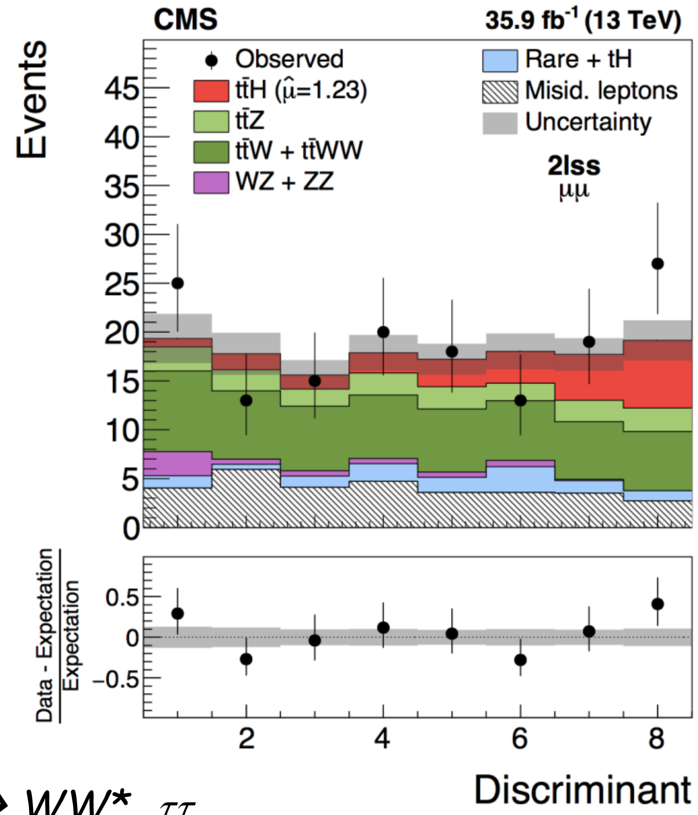
h(125) individual decay channels



h → γγ, ZZ (4l)*

[arXiv:1806.00425]

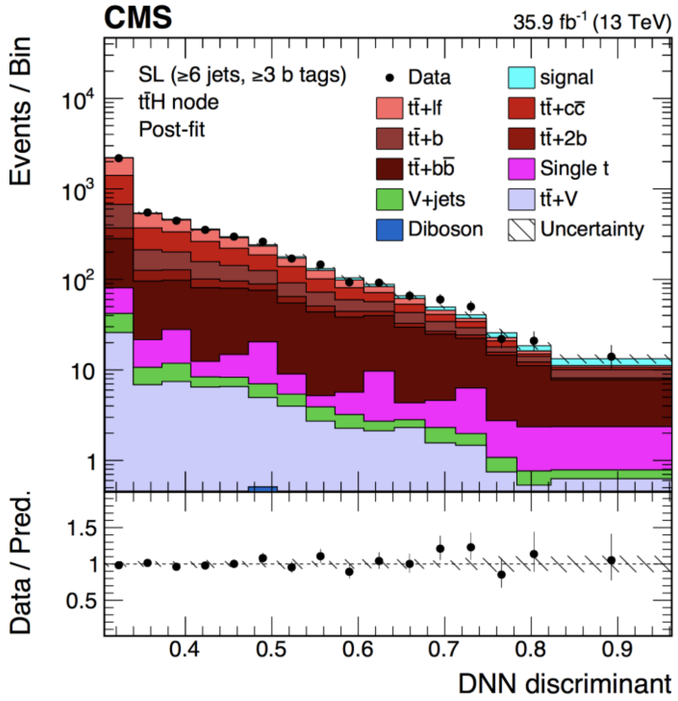
[arXiv:1804.02716]



h → WW, ττ*

[arXiv:1803.05485]

Phys.Rev.D.97(2018)072003



h → $b\bar{b}$

[arXiv:1804.03682]

[Phys. Rev. D 97 (2018) 072016]

Expected ATLAS 3.7σ, CMS 1.5σ
Observed ATLAS 4.1σ, CMS 1.4σ

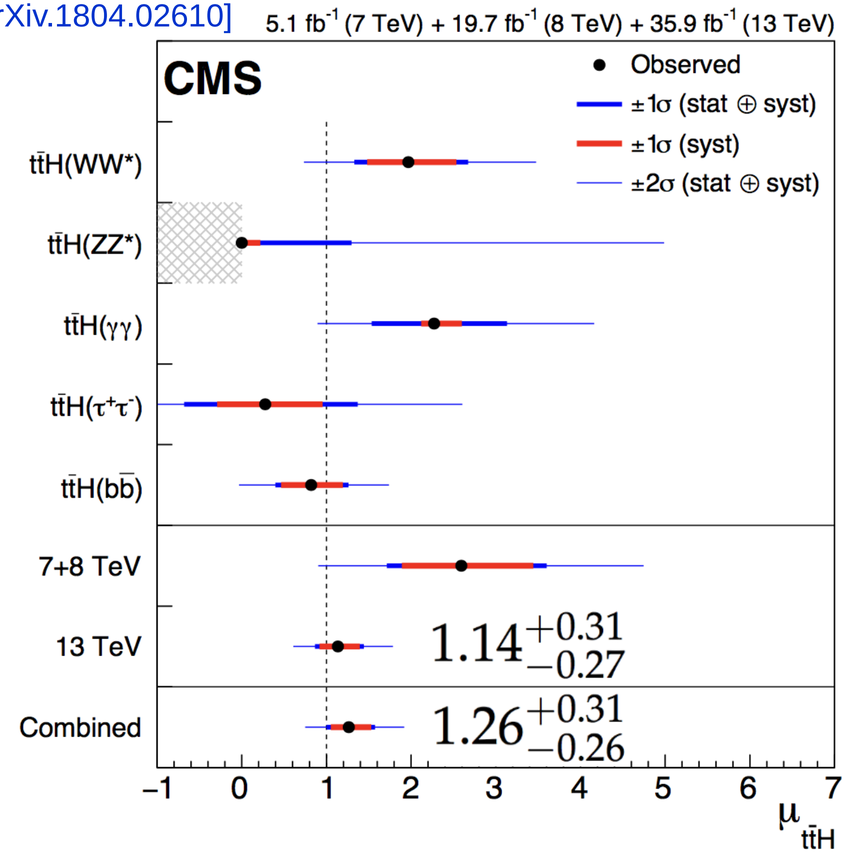
Expected ATLAS 2.8σ, CMS2.8σ
Observed ATLAS 4.1σ, CMS 3.2σ

Expected ATLAS 1.6σ CMS 2.2σ
Observed ATLAS 1.4σ, CMS 1.6σ

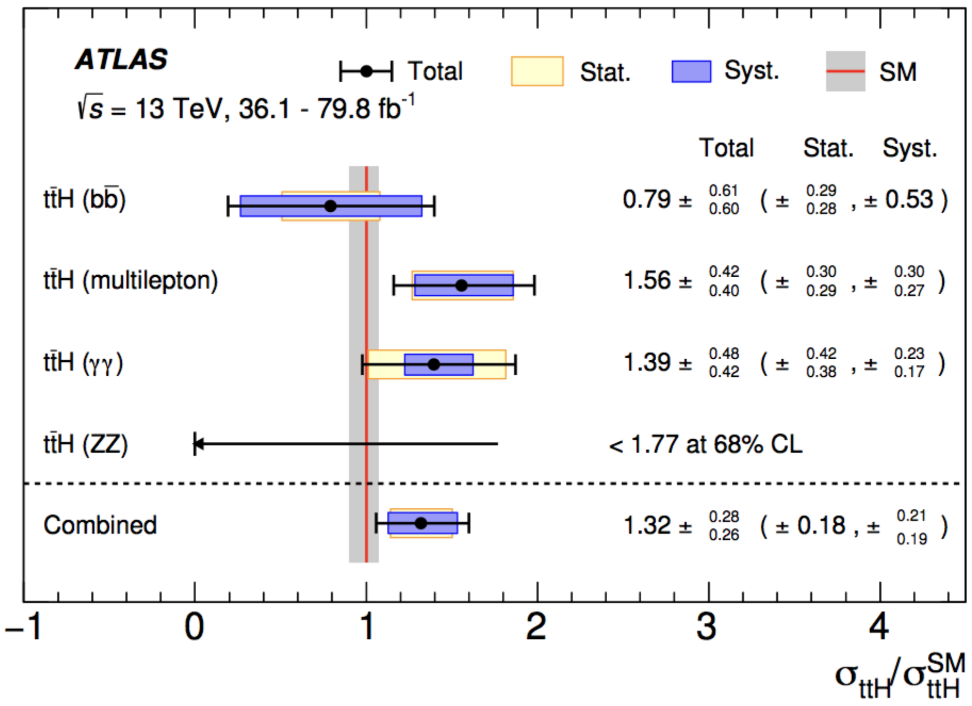
(**CMS**: incl. all-hadronic channel)

Observation of tth production

[arXiv.1804.02610]



[arXiv:1806.00425]



ATLAS used 2017 data for the $\gamma\gamma$ and the four lepton decays mode for tth
V(h→ WW*) in preparation

Expected significance : CMS 4.2σ , ATLAS 5.1σ

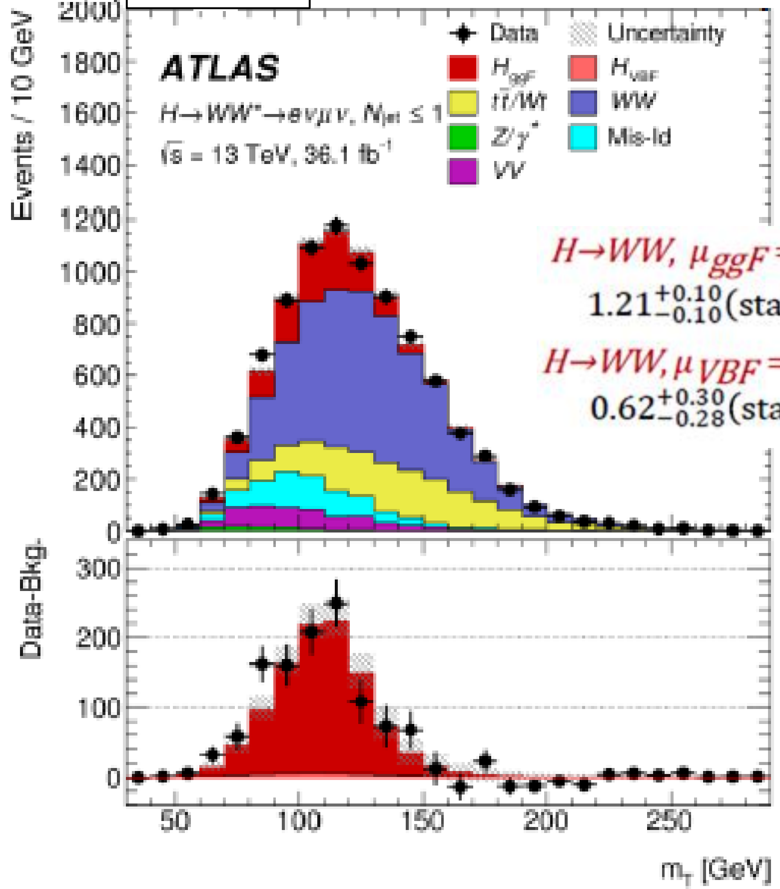
Observed significance : CMS 5.2σ, ATLAS 6.3σ

Measurement of h→WW* decay

Both experiments use gg-fusion and VBF production of higgs; CMS also adds (3+4) leptons from Vh

CERN-EP-2018-212

36.1 fb^{-1}



$H\to WW,\ \mu_{ggF} = 1.21^{+0.22}_{-0.21}$

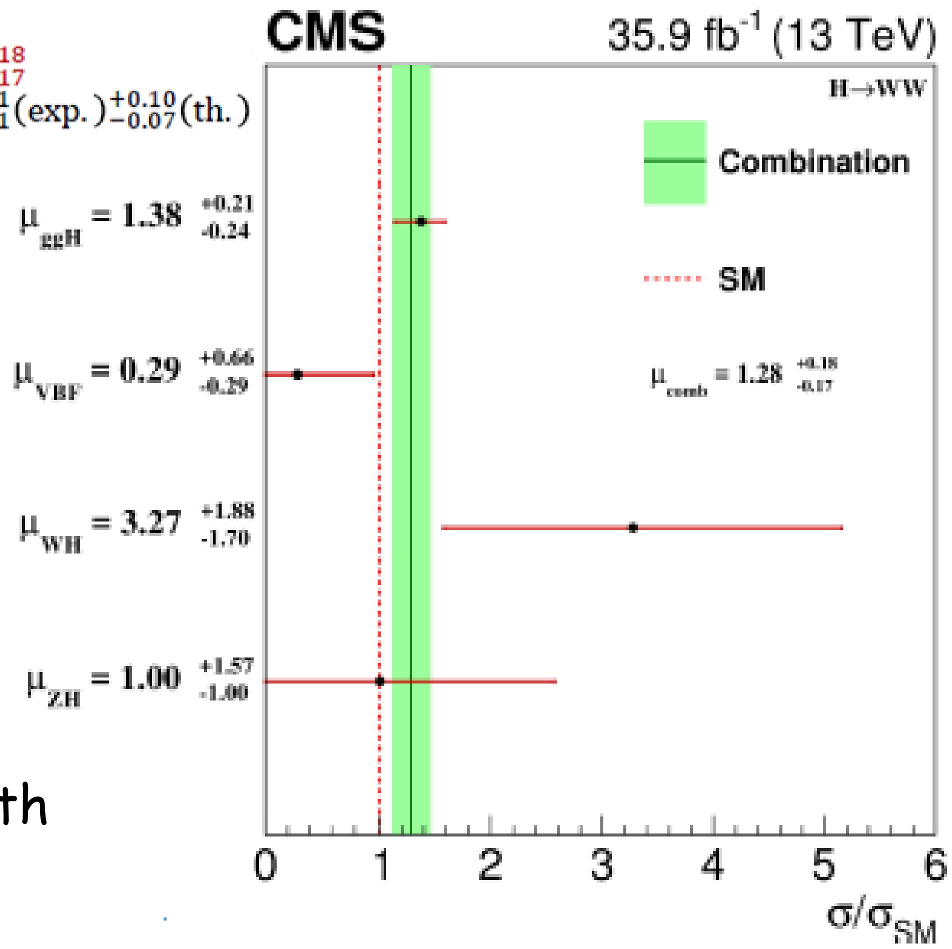
$1.21^{+0.10}_{-0.10}(\text{stat.})^{+0.15}_{-0.15}(\text{exp.})^{+0.13}_{-0.12}(\text{th.})$

$H\to WW,\ \mu_{VBF} = 0.62^{+0.37}_{-0.36}$

$0.62^{+0.30}_{-0.28}(\text{stat.})^{+0.16}_{-0.16}(\text{exp.})^{+0.13}_{-0.13}(\text{th.})$

$H\to WW, \mu = 1.28^{+0.18}_{-0.17}$

$1.28^{+0.10}_{-0.10}(\text{stat.})^{+0.11}_{-0.11}(\text{exp.})^{+0.10}_{-0.07}(\text{th.})$



CERN-EP-2018-141

Good agreement with SM expectations

Expected significance : ATLAS 5.1σ CMS 4.2σ

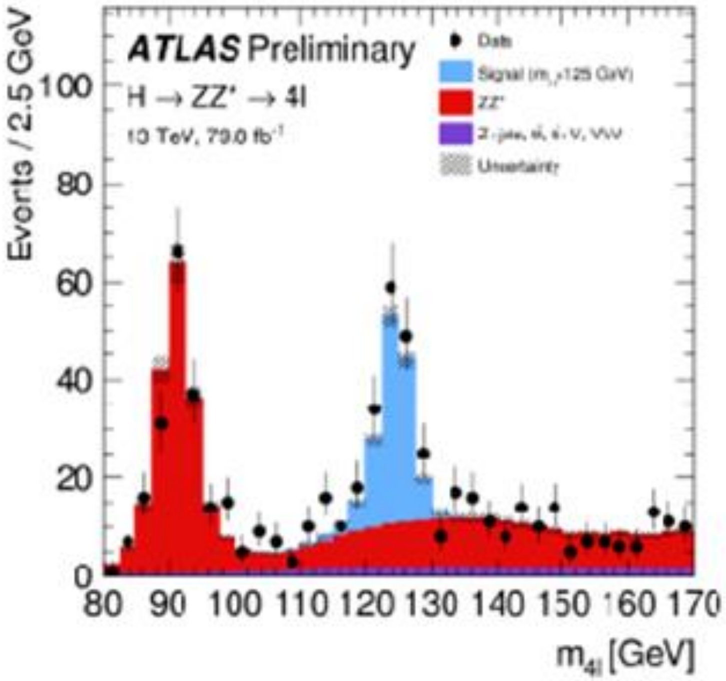
Observed significance : ATLAS 6.3σ CMS 5.2σ

Main backgrounds from WW, top and Wγ production; data driven estimate of `fake' lepton background

The original golden channels: h→ZZ* & γγ

Excellent mass resolutions and clean channels with well-understood backgrounds

ATLAS-CONF-2018-018



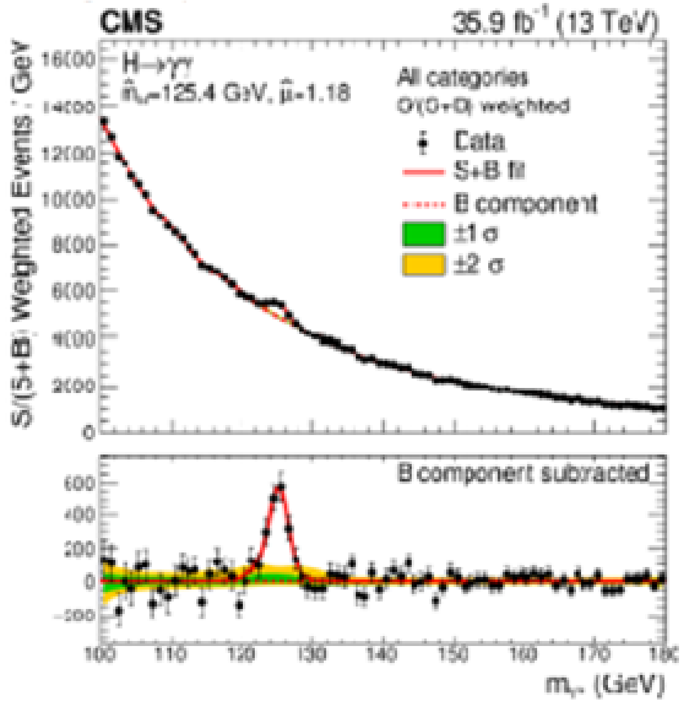
$H\to\gamma\gamma,\ \mu = 1.06^{+0.14}_{-0.12}(80/\text{fb})$

$1.06^{+0.08}_{-0.08}(\text{stat.})^{+0.08}_{-0.07}(\text{exp.})^{+0.07}_{-0.06}(\text{th.})$

$H\to ZZ*\to 4l,\ \mu = 1.19^{+0.16}_{-0.15}(80/\text{fb})$

$1.19^{+0.12}_{-0.12}(\text{stat.})^{+0.06}_{-0.06}(\text{exp.})^{+0.08}_{-0.07}(\text{th.})$

CMS-HIG-16-040



$H\to\gamma\gamma, \mu = 1.18^{+0.17}_{-0.14}(36/\text{fb})$

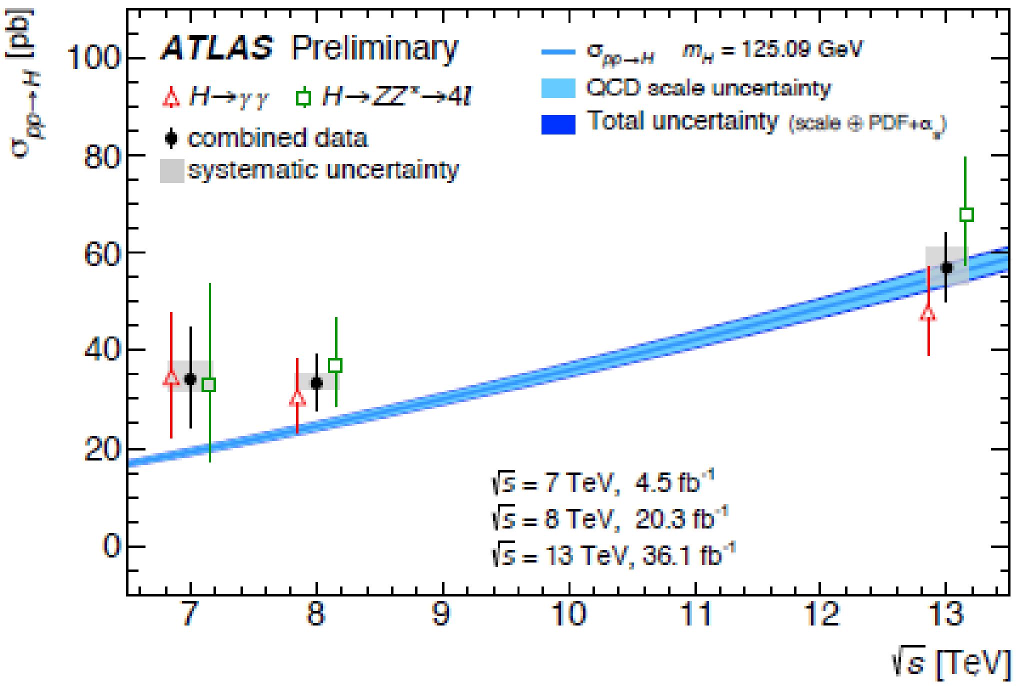
$1.18^{+0.12}_{-0.11}(\text{stat.})^{+0.09}_{-0.07}(\text{exp.})^{+0.07}_{-0.06}(\text{th.})$

$H\to ZZ*\to 4l, \mu = 1.05^{+0.19}_{-0.17}(36/\text{fb})$

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

Very good agreement with SM expectations

Total cross section from h→ZZ*→ 4l & γγ



Similar accuracy in 4l and gamma-gamma channels with little model dependence

~10% accuracy in inclusive cross-section measurements

ATLAS and CMS combination should bring down the experimental uncertainty.

Theory calculation with NNLO and PDF4LHC with improved uncertainties, down to 5%...

A healthy race between theorists and experimentalists

$57^{+6}_{-5.9}\,(stat) \pm {}^{+4.0}_{-3.7}\,(syst)$ pb ATLAS

$61.1 \pm 6.0\,(stat) \pm 3.7\,(syst)$ pb CMS

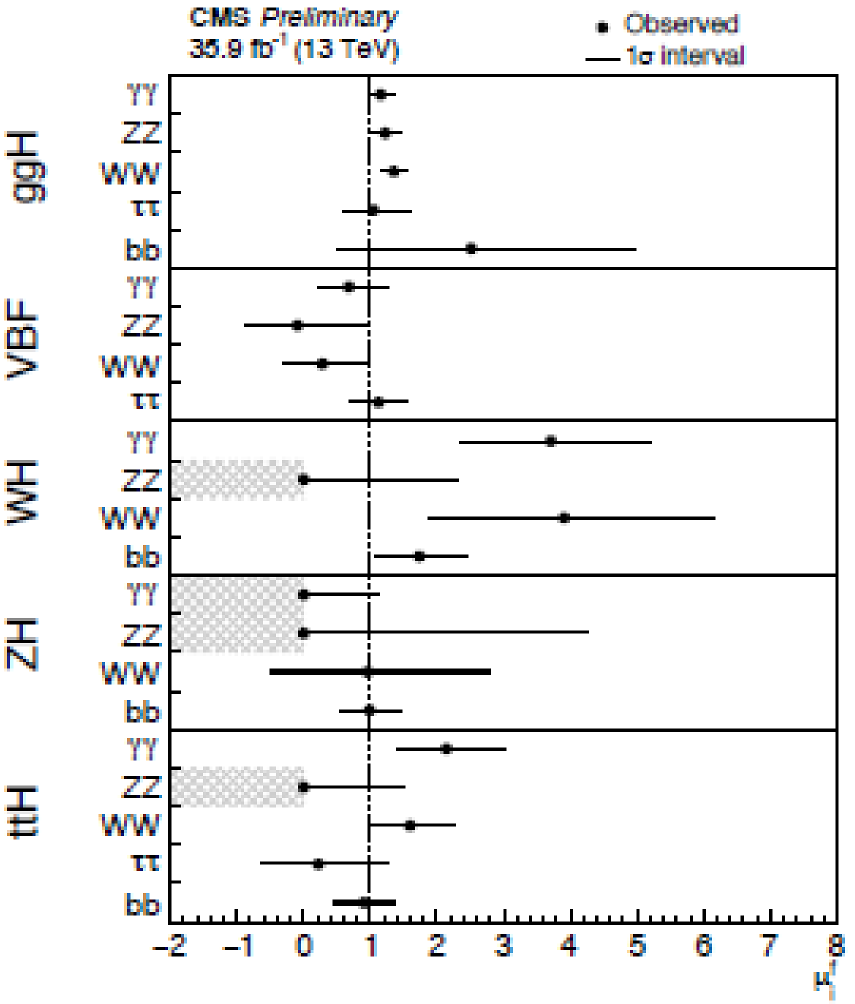
Theoretical prediction 55.6 ± 2.5 pb

arXiV 1805.10197; CMS PAS HIG-17-028

Combination of coupling measurements

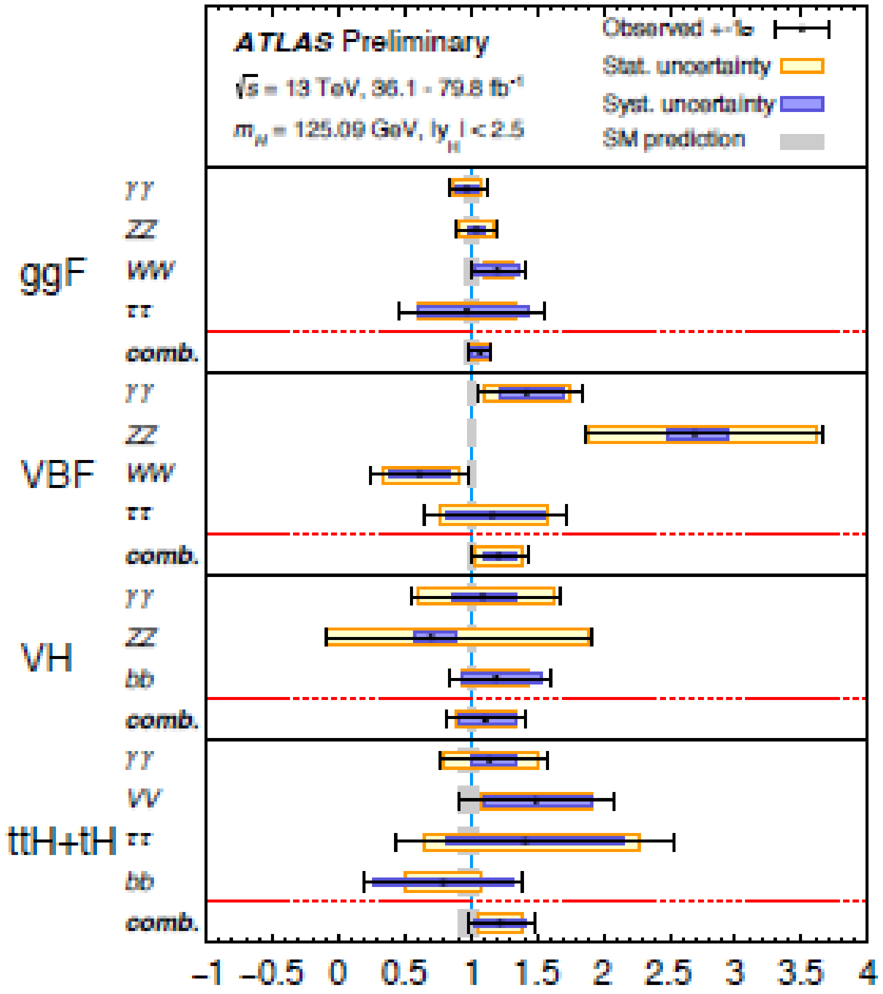
with sigma × BR for each measured channel

CMS-PAS-HIG-17-031



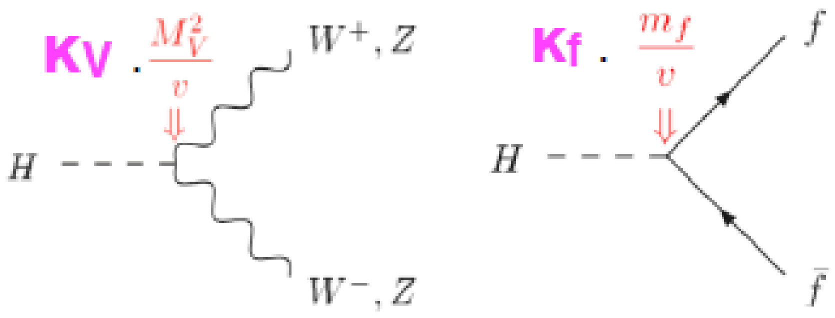
$$\mu = \frac{\sigma \cdot BR}{(\sigma \cdot BR)SM}$$

ATLAS-CONF-2018-031



~36 fb^{-1}data, except ~80 fb^{-1} for $\gamma\gamma$ & 4l

Coupling expressed in kappa (κ)



Assume the same coupling structure as SM
Modify couplings with LO degrees of freedom

$\sigma_i = \kappa_i^2 * \sigma_i(SM)$ $\Gamma_f = \kappa_f^2 * \Gamma_f(SM)$ => $\mu^f_i = \kappa_i^2 . \kappa_f^2 / (\Gamma_H / \Gamma_H(SM))$

Loops (g and γ) : either resolved with SM content, assuming no other particles,
OR
write as effective κ_g or κ_γ

Total width : SM contributions rescaled by appropriate κ's; no BSM contribution even in the width

Primary limitation : same kinematics as SM, no BSM even if true

Coupling parameter framework

Scale the SM production cross sections and partial decay widths with LO motivated scale factors κ_i

Production modes

$$\frac{\sigma_{ggH}}{\sigma_{ggH}^{SM}} = \begin{cases} \kappa_g^2(\kappa_b, \kappa_t, m_H) \\ \kappa_g^2 \end{cases} \quad (5)$$

$$\frac{\sigma_{VBF}}{\sigma_{VBF}^{SM}} = \kappa_{VBF}^2(\kappa_W, \kappa_Z, m_H) \quad (6)$$

$$\frac{\sigma_{WH}}{\sigma_{WH}^{SM}} = \kappa_W^2 \quad (7)$$

$$\frac{\sigma_{ZH}}{\sigma_{ZH}^{SM}} = \kappa_Z^2 \quad (8)$$

$$\frac{\sigma_{t\bar{t}H}}{\sigma_{t\bar{t}H}^{SM}} = \kappa_t^2 \quad (9)$$

Detectable decay modes

$$\frac{\Gamma_{WW^{(*)}}}{\Gamma_{WW^{(*)}}^{SM}} = \kappa_W^2 \quad (10)$$

$$\frac{\Gamma_{ZZ^{(*)}}}{\Gamma_{ZZ^{(*)}}^{SM}} = \kappa_Z^2 \quad (11)$$

$$\frac{\Gamma_{b\bar{b}}}{\Gamma_{b\bar{b}}^{SM}} = \kappa_b^2 \quad (12)$$

$$\frac{\Gamma_{\tau^-\tau^+}}{\Gamma_{\tau^-\tau^+}^{SM}} = \kappa_\tau^2 \quad (13)$$

$$\frac{\Gamma_{\gamma\gamma}}{\Gamma_{\gamma\gamma}^{SM}} = \begin{cases} \kappa_\gamma^2(\kappa_b, \kappa_t, \kappa_\tau, \kappa_W, m_H) \\ \kappa_\gamma^2 \end{cases} \quad (14)$$

Total width

$$\frac{\Gamma_H}{\Gamma_H^{SM}} = \begin{cases} \kappa_H^2(\kappa_i, m_H) \\ \kappa_H^2 \end{cases} \quad (21)$$

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

Coupling results in kappa

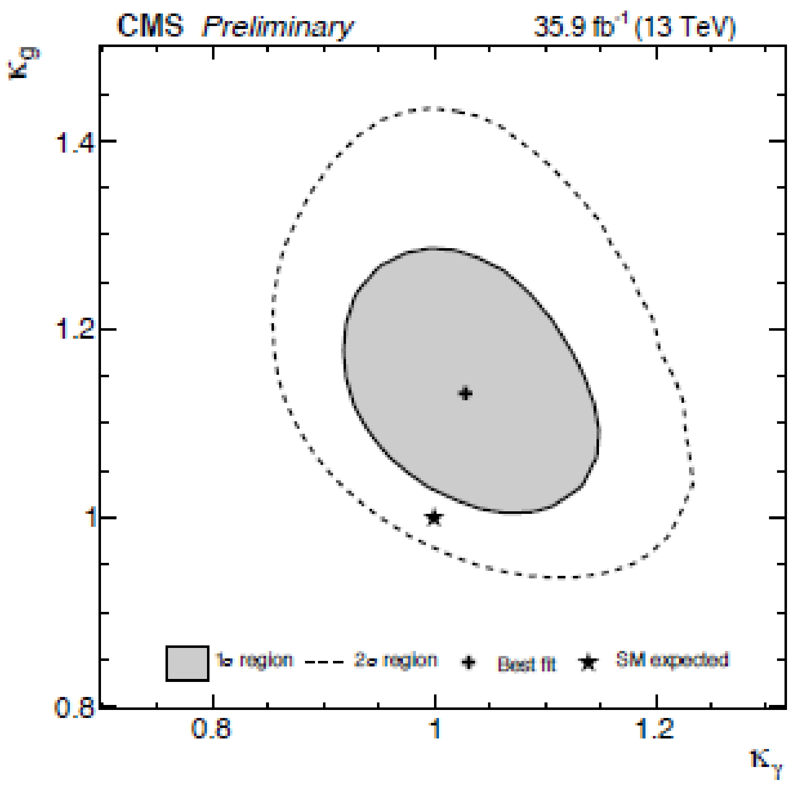
A detailed list of expression (as example shown) exists:
"Handbook of LHC Higgs Cross Sections : 3. Higgs Properties" arXiv 1307.1347

Two different interpretations in κ–coupling framework

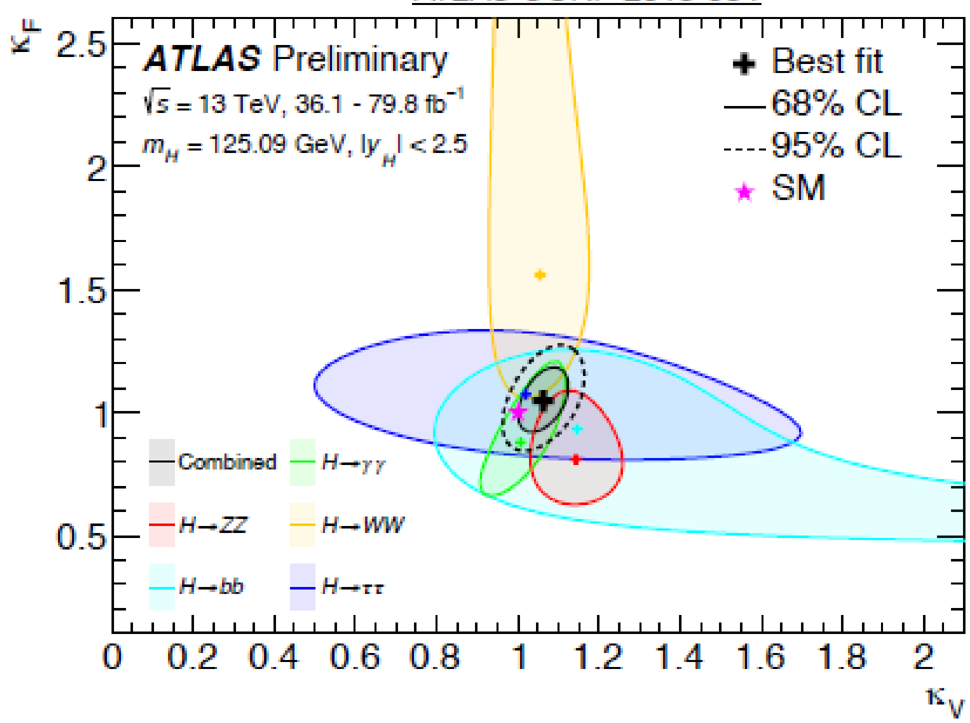
Assume only two coupling modifiers, one for fermion, one for boson; resolve loops assuming SM particle content

Change only effective coupling to gluon and photon (BSM in loop), while other couplings fixed to SM

CMS-PAS-HIG-17-031



ATLAS-CONF-2018-031



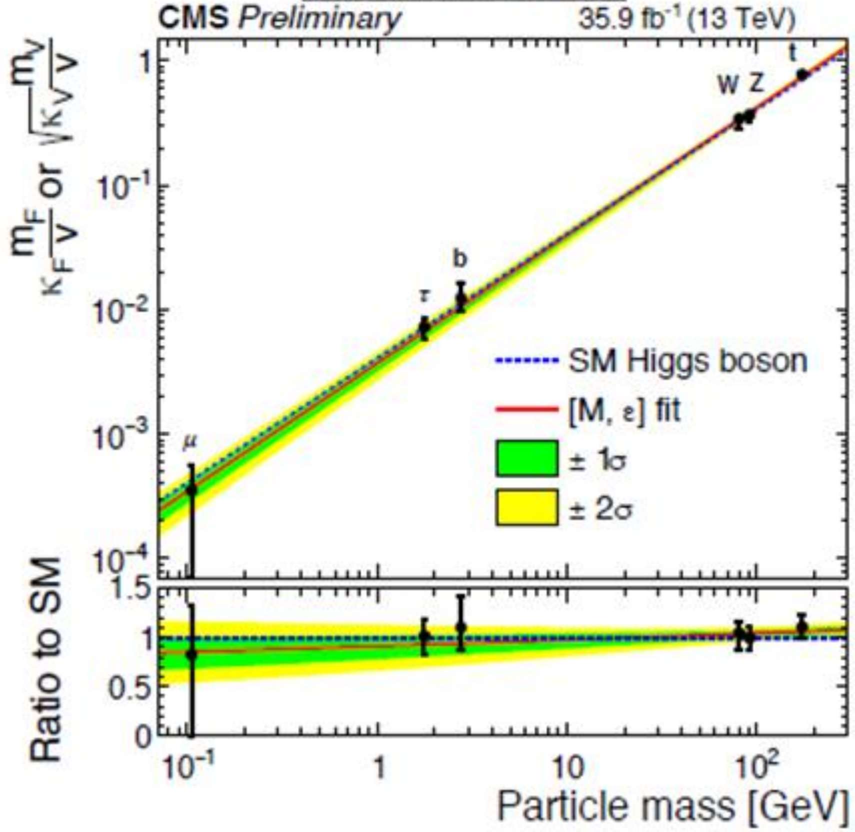
Combination of Higgs coupling measurements

All κ free; effective loop coupling for g, γ
Total width $\Gamma = \Gamma(\kappa)/(1-BF_{BSM})$
Assumption to remove degeneracy between κ and Γ : either
assume $\kappa_V = 0$ if BSM is free or $BF_{BSM} = 0$, $\kappa_{\frac{W}{Z}} \leq 1$

10-20% accuracy on coupling modifiers in each experiment.

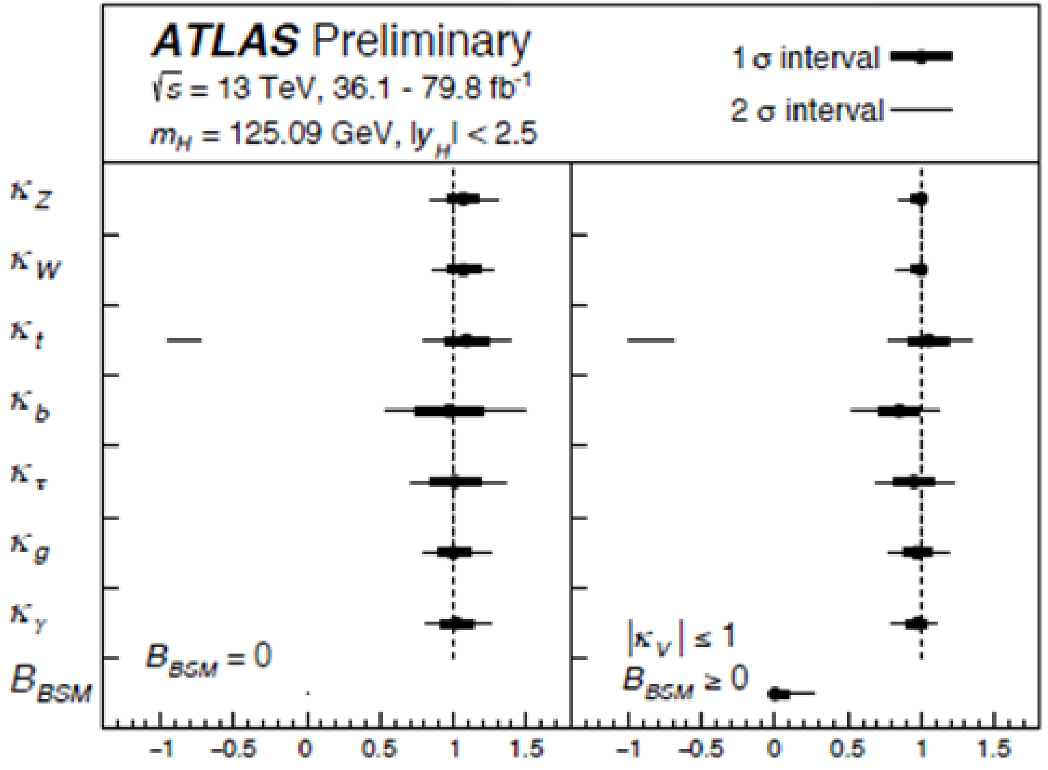
Scaling of coupling vs mass

CMS-PAS-HIG-17-031



(similar results from ATLAS)

ATLAS-CONF-2018-031



(similar results from CMS

Fit with $\kappa_F = V\, m^{\varepsilon}/M^{1+\varepsilon}$ for fermions and $\kappa_V = V\, m^{2\varepsilon}/M^{1+2\varepsilon}$

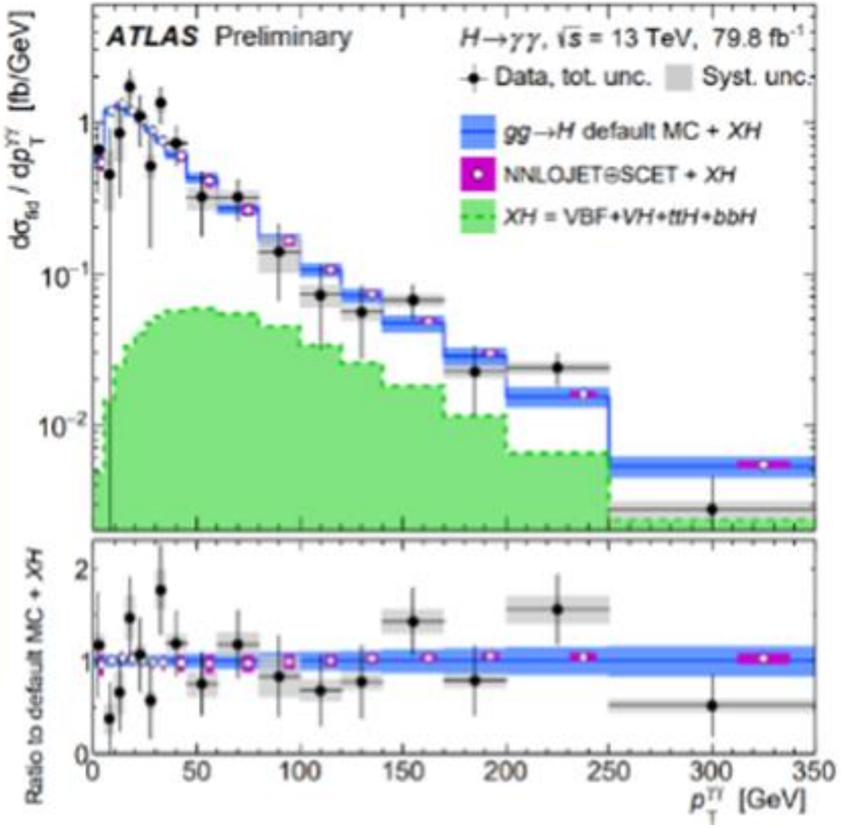
M consistent with V and ε consistent with 0 (SM)

Differential cross section measurements, ATLAS

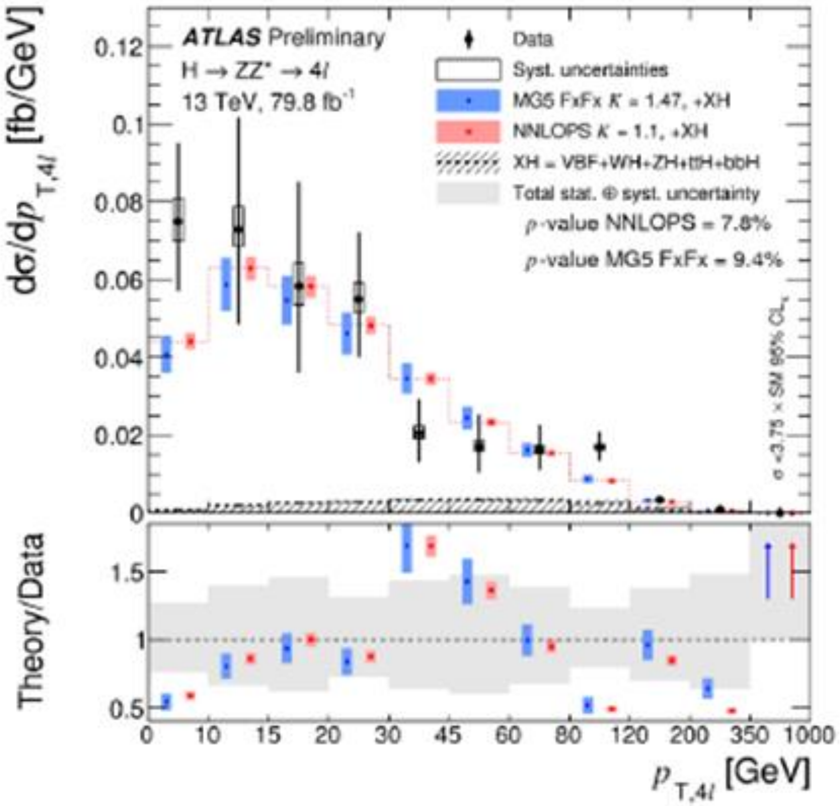
Probes the kinematic properties of Higgs produced, sensitive to new physics

Results reported at the particle level, corrected for detector effects, to have minimal model dependence

ATLAS-CONF-2018-028



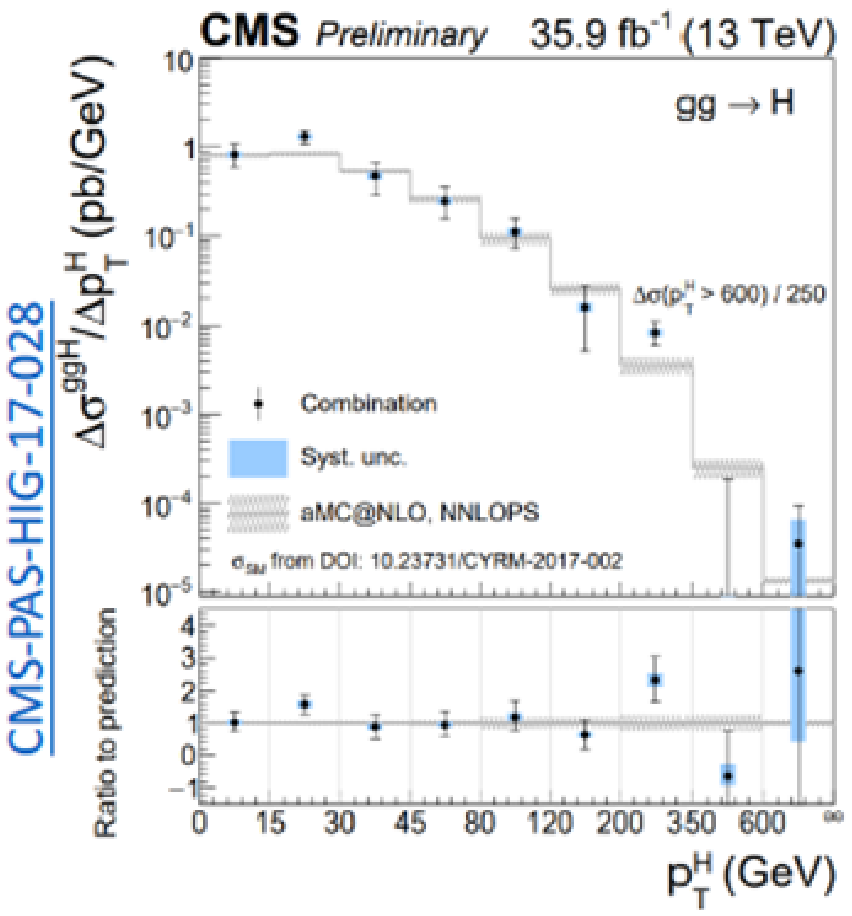
ATLAS-CONF-2018-018

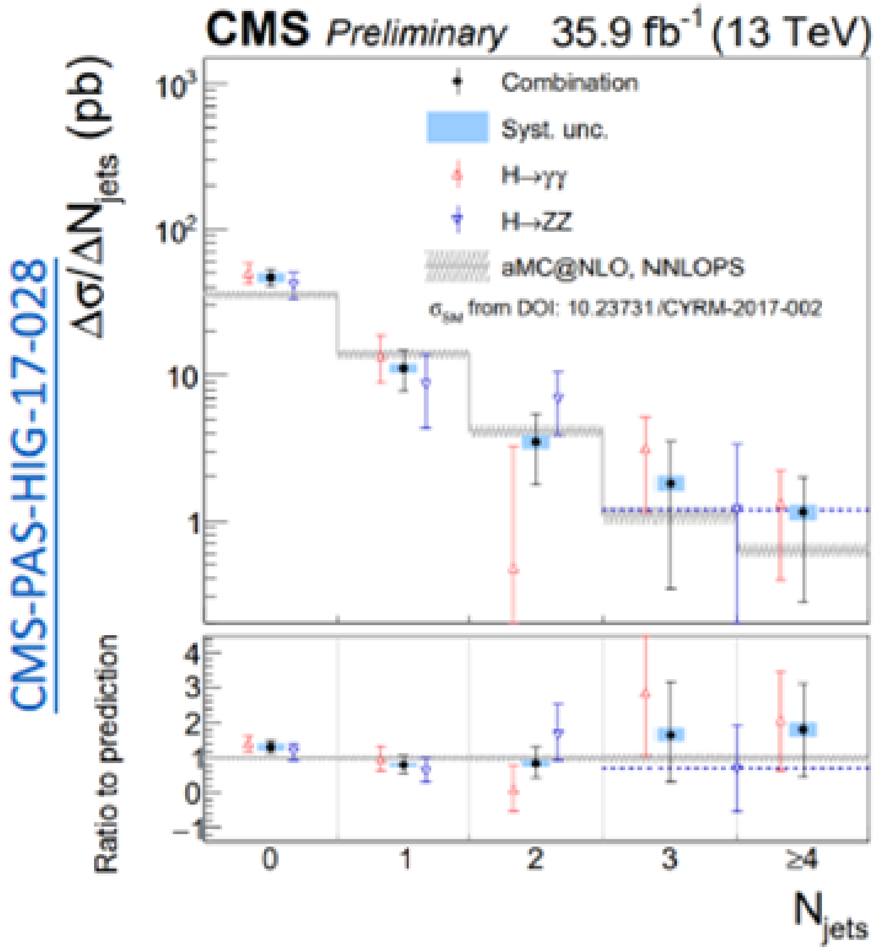


~80 fb^{-1} for $\gamma\gamma$ and ZZ*→ 4l decays

Differential cross section measurements, CMS

~36 fb^{-1} for $\gamma\gamma$ and ZZ*→ 4l, and h → bb decays

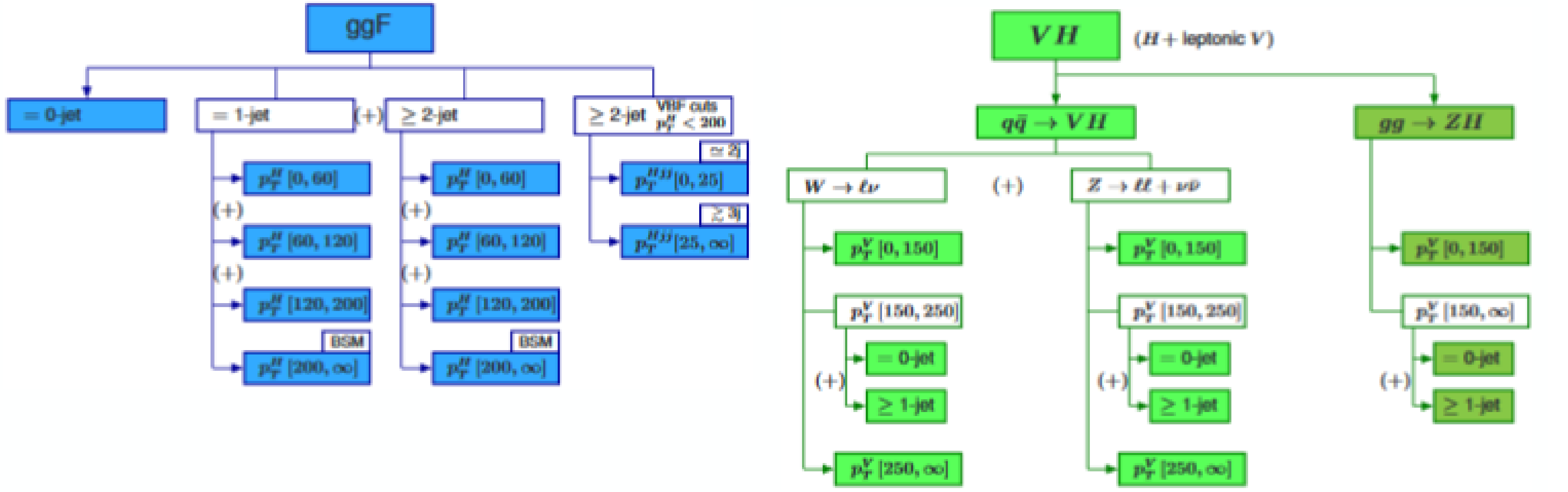


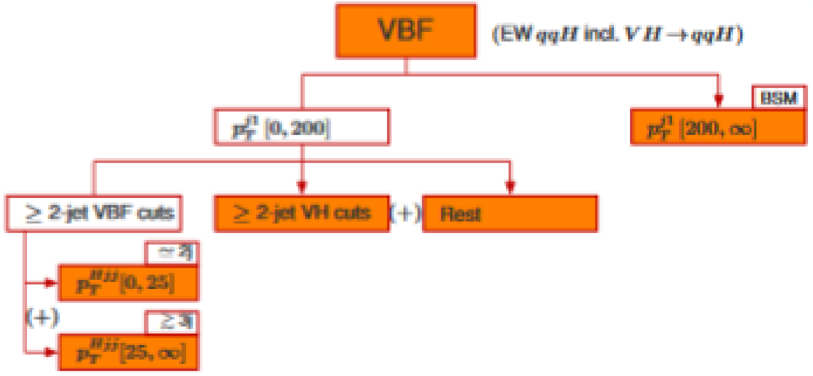


Precise measurements of several differential measurements
All generally compatible with SM predictions

Simplified template cross sections: STXS

Central idea : YR4 section 3.2, to make measurements as little model dependent as possible;
Splits production measurements in *exclusive* kinematic regions;
Try combining of all channels rather than differential (partial) measurements in clean channels only, thus minimizing dependence on theoretical uncertainties



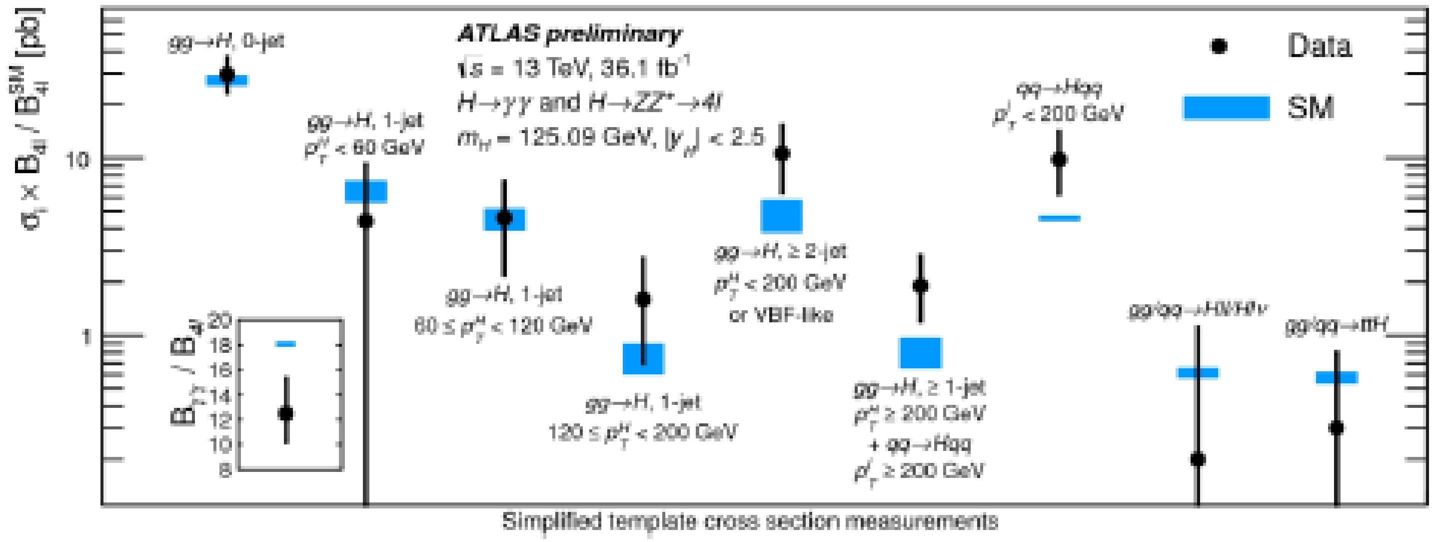


ATLAS Preliminary
Constructed from figures in arXiv:1610.07922

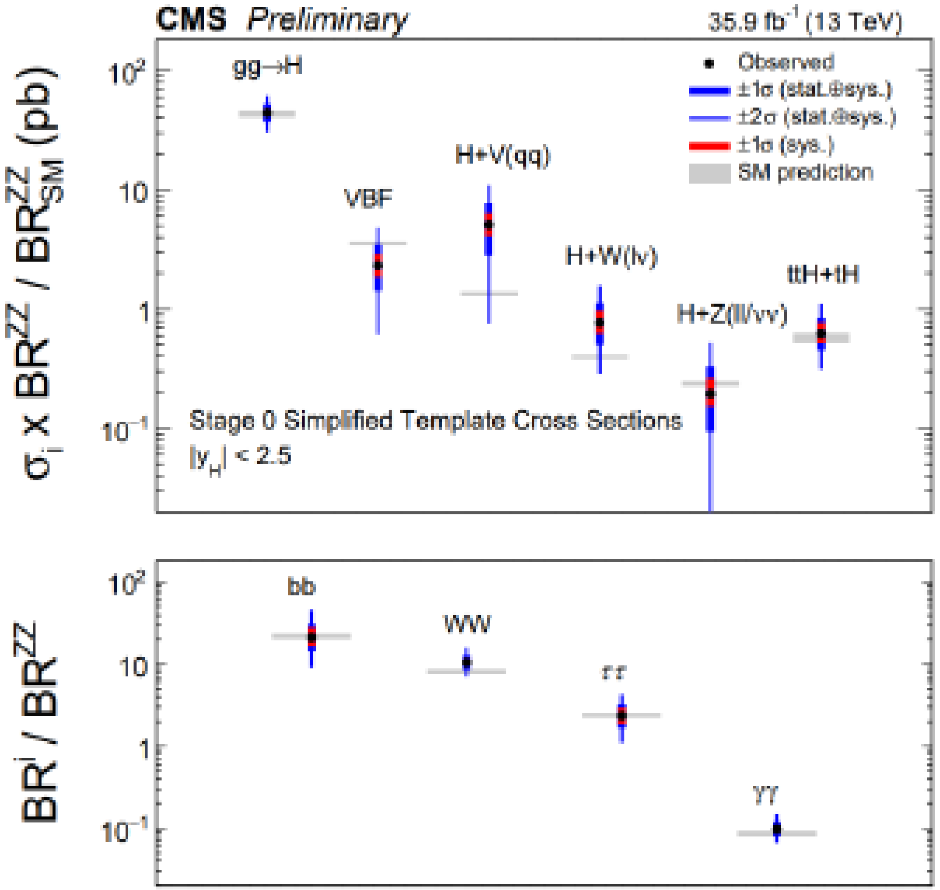
Simplified templet cross sections: STXS

Performed a combination of STXS with a fine granularity of measurements for 36.1 fb^{-1} with h→ γγ and 4l channels. Gluon fusion production of Higgs are in good agreement with SM.
Best ~20% precision achieved.

ATLAS-CONF-2017-047

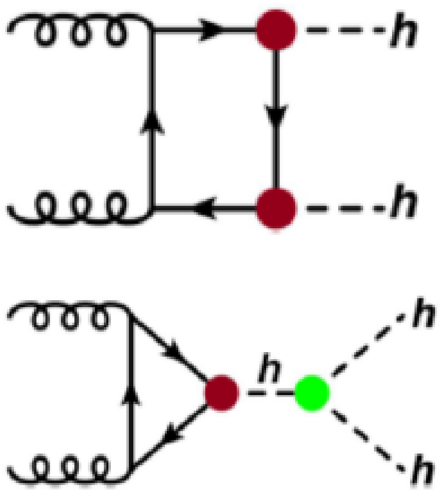


CMS-PAS-HIG-17-031



CMS combined major Higgs decays modes:
γγ, 4l, bb, WW*, ττ for STXS.
Good agreement with SM
Precision close to 20%

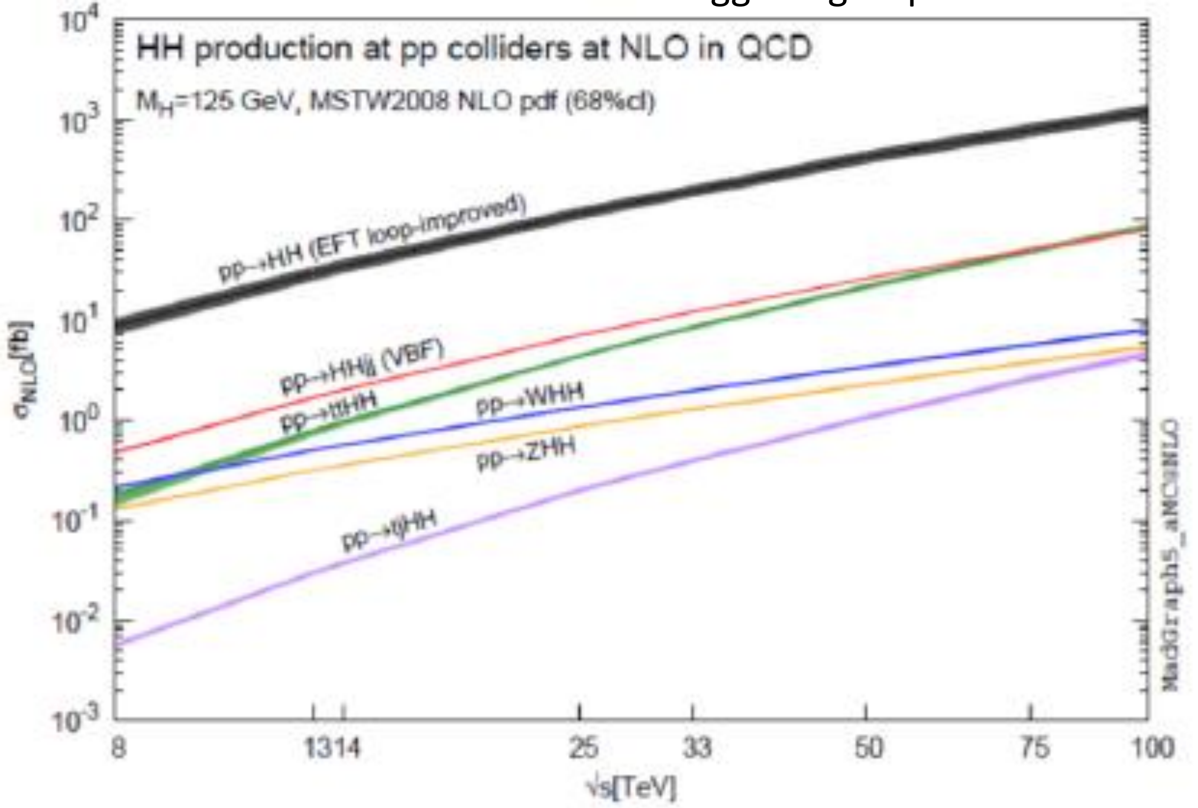
Di-Higgs production



gg-fusion dominates

Self-coupling of the Higgs can be probed by production of di-Higgs measurements at LHC $\lambda \sim m_h^2/2v^2 \sim 0.13$ (SM) [destructive interference makes the measurements challenging]

arXiv : 1401.7340 & Higgs XS group



At $\sqrt{s}$ = 13 TeV, and m_h = 125 GeV

$\sigma^{SM}_{gg\to hh}$ = 33.53 **fb** $[1.0^{+4.3\%}_{-6.0\%}$ (scale) $\pm$ 2.3% (α_s) $\pm$ 2.1% (PDF) $\pm$ 5% (Theory)]

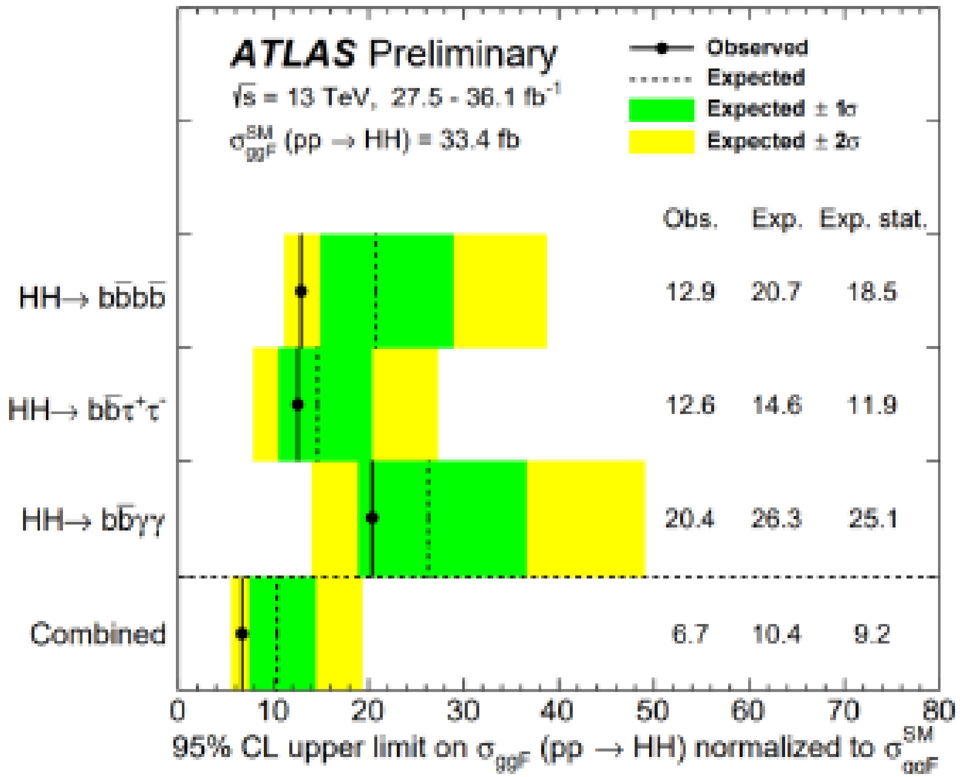
to be compared with (single Higgs)

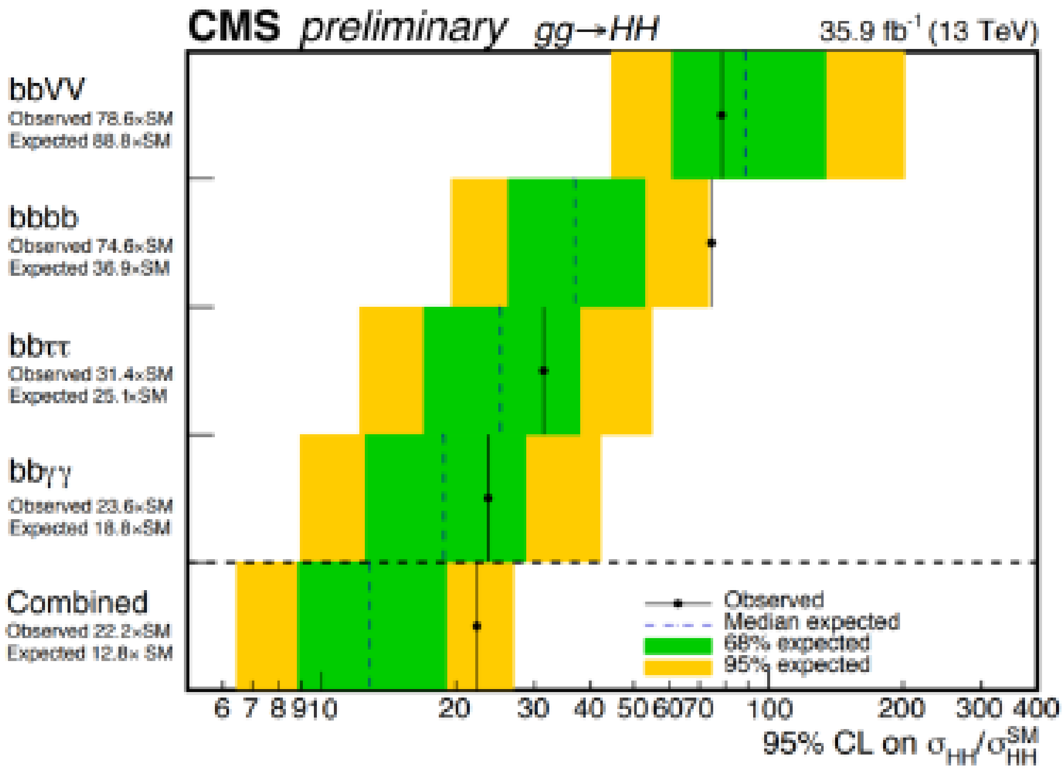
$\sigma^{SM}_{gg\to h}$ = 48.52 **pb** $[1.0^{+7.4\%}_{-7.9\%}$ (scale) $^{+7.1}_{-6.0}(\alpha_s$+ (PDF)]

~1:1500 discrepancy, compromised in signal yields & S/B in analysis mode

Di-Higgs production

CERN-EP-2018-164





CMS-PAS-HIG-17-030

Limit from ATLAS hh combination: μ < **6.7** (**10.4 expected**)

Limit from CMS hh combination: μ < **22** (**13 expected**)

Limit on Higgs self-coupling S.F = $\kappa_\lambda = \frac{\lambda_{hh}}{\lambda_{hh,SM}}$

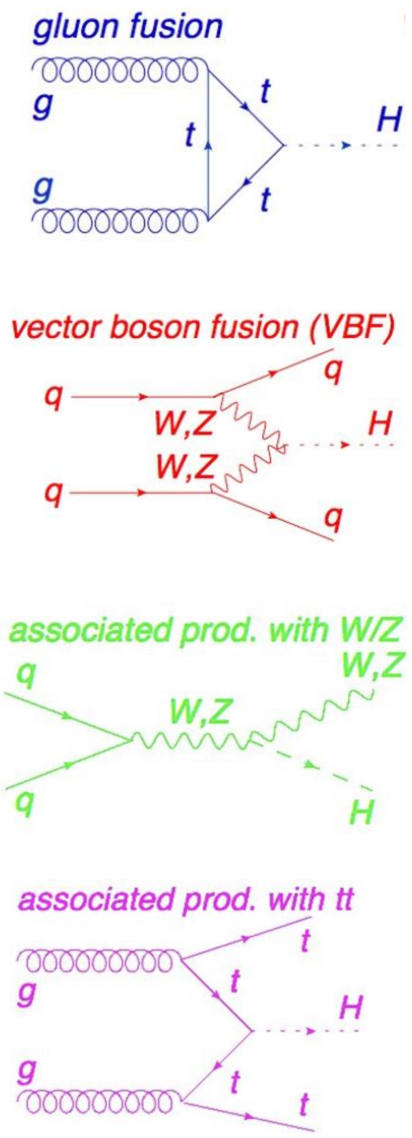
ATLAS : **–5.0 < κ_λ < 12.1** (**–5.8 < κ_λ < 12.0 expected**)

CMS : **–11.8 < κ_λ < 18.8** (**–7.1 < κ_λ < 13.6 expected**)

Both reach 10×SM sensitivity in expected production value SM sensitivity at HL-LHC !

Conclusion

Production



36-80 fb–1 Run2 data,

~ 3 times improvement in boson channels

Observation of all primary production and decay modes, including

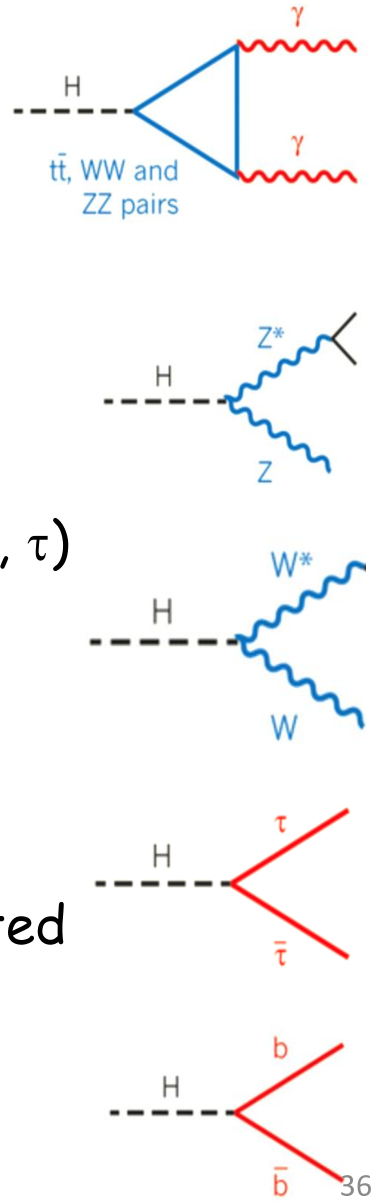
Confirmation of third generation of fermion couplings (t, b, τ)

No deviation from SM so far, but,

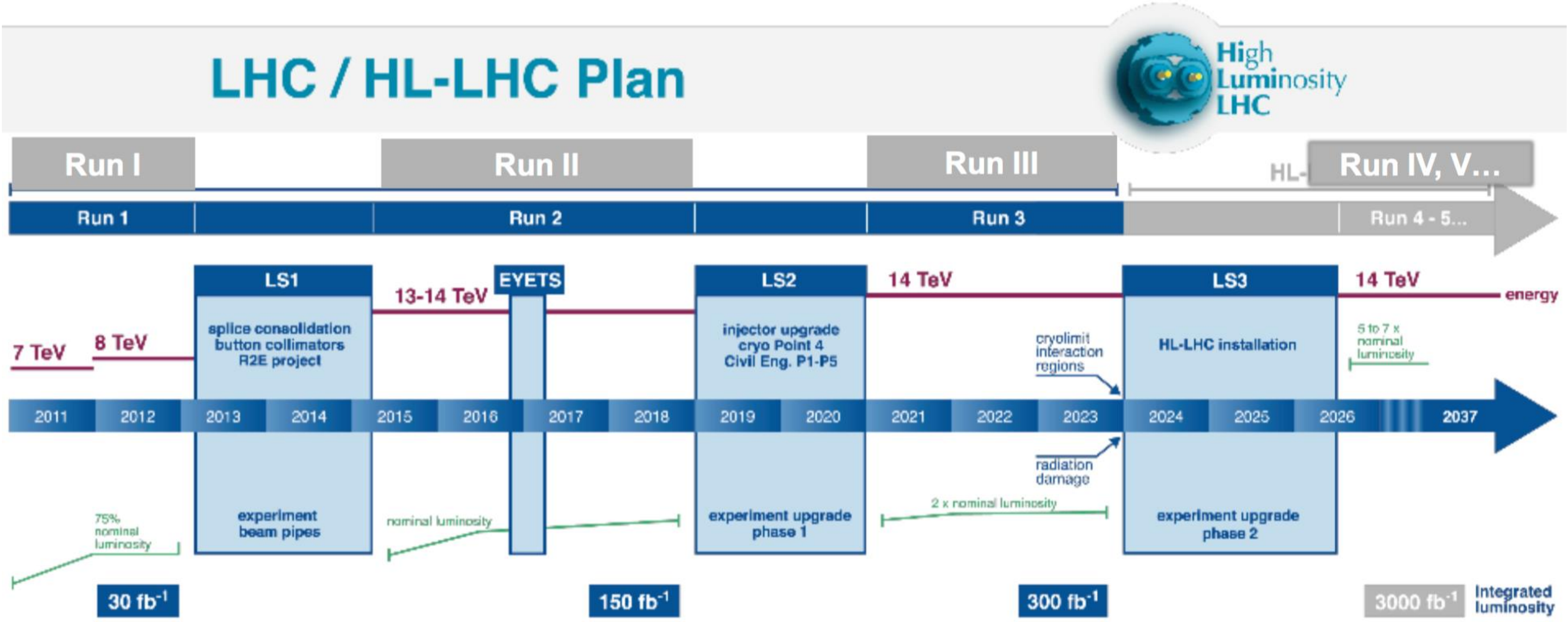
Higgs physics an important indirect probe

Sensitivity to double Higgs production ~10 times SM, started

Decay



Future plans for LHC

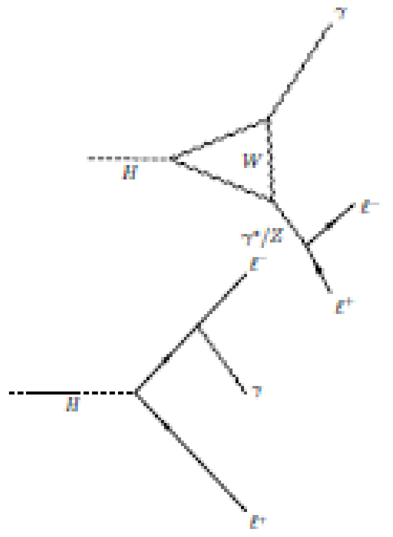


Long journey only begun

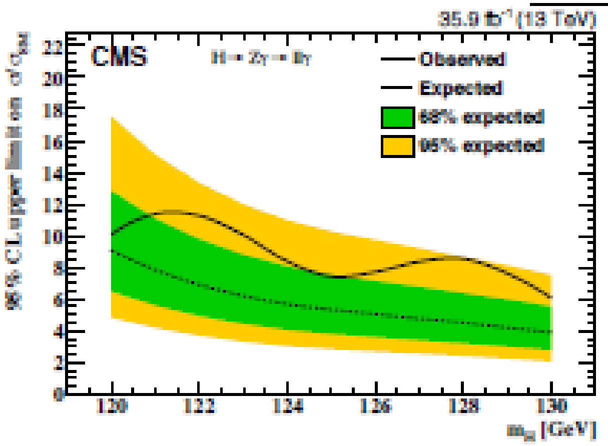
Extra Slides

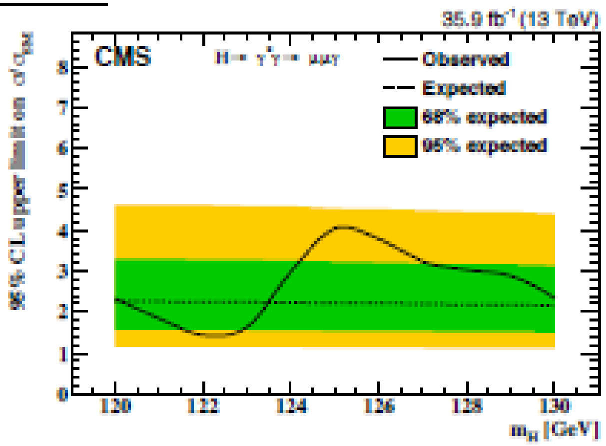
Search for rare Higgs decays

H→ ll gamma



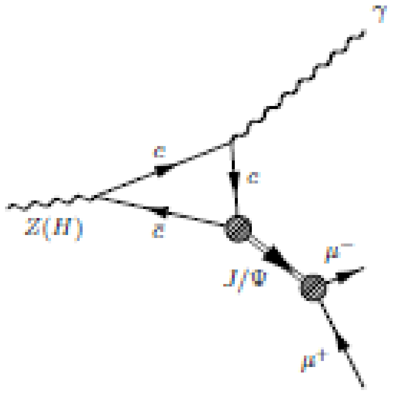
1806.05996

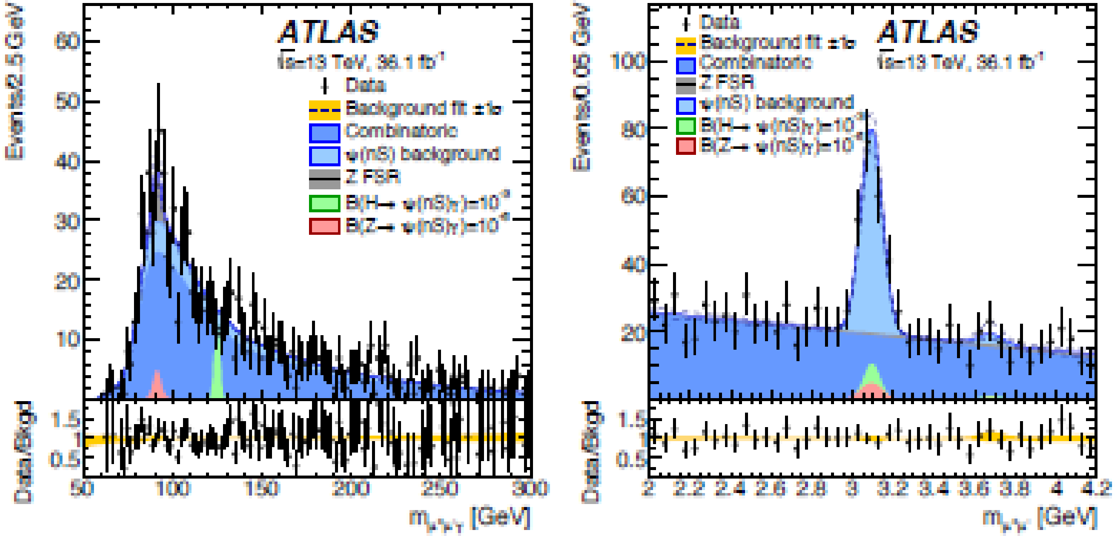




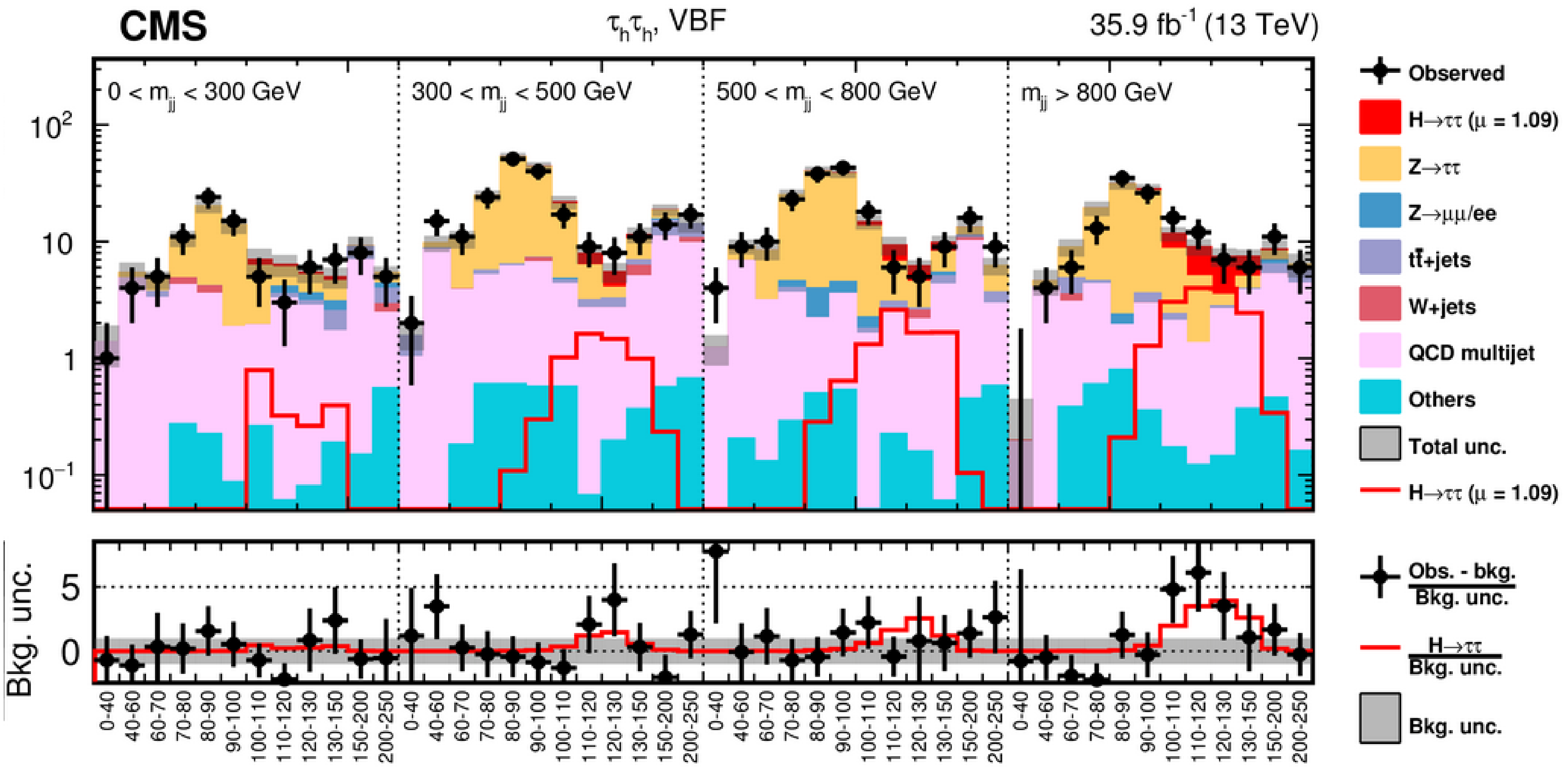
H→ J/psi gamma (→ mu mu gamma)

1807.00802





BR<3.5 10^{-4}
(120xSM)



CMS
$\tau_h\tau_h$, VBF
35.9 fb^{-1} (13 TeV)
0 < m_{jj} < 300 GeV
300 < m_{jj} < 500 GeV
500 < m_{jj} < 800 GeV
m_{jj} > 800 GeV
Observed
H→ττ (μ = 1.09)
Z→ττ
Z→μμ/ee
tt̄+jets
W+jets
QCD multijet
Others
Total unc.
H→ττ (μ = 1.09)
Obs. - bkg. / Bkg. unc.
H→ττ / Bkg. unc.
Bkg. unc.

Coupling parameter framework

Scale the SM production cross sections and partial decay widths with LO motivated scale factors κ_i

Production modes

$$\frac{\sigma_{ggH}}{\sigma_{ggH}^{SM}} = \begin{cases} \kappa_g^2(\kappa_b, \kappa_t, m_H) \\ \kappa_g^2 \end{cases} \quad (5)$$

$$\frac{\sigma_{VBF}}{\sigma_{VBF}^{SM}} = \kappa_{VBF}^2(\kappa_W, \kappa_Z, m_H) \quad (6)$$

$$\frac{\sigma_{WH}}{\sigma_{WH}^{SM}} = \kappa_W^2 \quad (7)$$

$$\frac{\sigma_{ZH}}{\sigma_{ZH}^{SM}} = \kappa_Z^2 \quad (8)$$

$$\frac{\sigma_{t\bar{t}H}}{\sigma_{t\bar{t}H}^{SM}} = \kappa_t^2 \quad (9)$$

Detectable decay modes

$$\frac{\Gamma_{WW^{(*)}}}{\Gamma_{WW^{(*)}}^{SM}} = \kappa_W^2 \quad (10)$$

$$\frac{\Gamma_{ZZ^{(*)}}}{\Gamma_{ZZ^{(*)}}^{SM}} = \kappa_Z^2 \quad (11)$$

$$\frac{\Gamma_{b\bar{b}}}{\Gamma_{b\bar{b}}^{SM}} = \kappa_b^2 \quad (12)$$

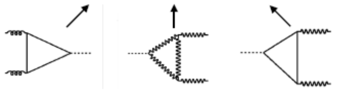
$$\frac{\Gamma_{\tau^-\tau^+}}{\Gamma_{\tau^-\tau^+}^{SM}} = \kappa_\tau^2 \quad (13)$$

$$\frac{\Gamma_{\gamma\gamma}}{\Gamma_{\gamma\gamma}^{SM}} = \begin{cases} \kappa_\gamma^2(\kappa_b, \kappa_t, \kappa_\tau, \kappa_W, m_H) \\ \kappa_\gamma^2 \end{cases} \quad (14)$$

Total width

$$\frac{\Gamma_H}{\Gamma_H^{SM}} = \begin{cases} \kappa_H^2(\kappa_i, m_H) \\ \kappa_H^2 \end{cases} \quad (21)$$

Rate (gg→H→γγ) ~ κ_F^2 * (1.6 κ_V^2+0.07 κ_F^2-0.66 κ_F κ_V) / (0.75* κ_F^2+0.25* κ_V^2)



Γ(H)

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