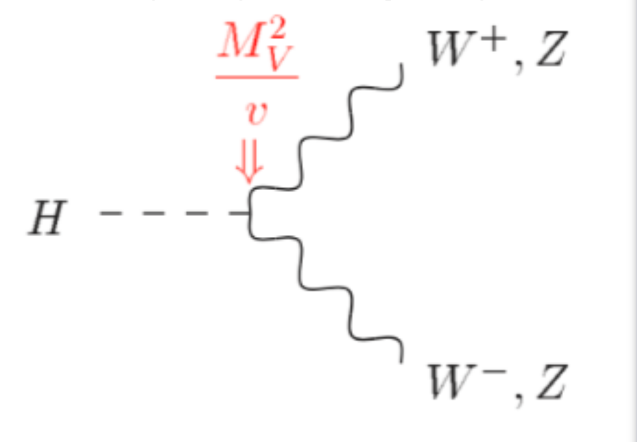
Higgs boson measurements at the LHC

PIC 2018 conference
12/09/2018

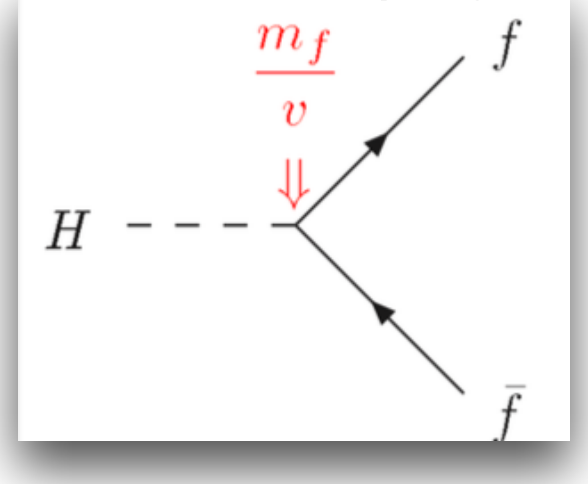
G.Unal (CERN)
on behalf of the ATLAS and CMS collaborations

- Particle consistent with SM Higgs boson discovered in 2012 at the LHC with a mass ~125 GeV
- First fundamental scalar particle observed
- Related to the EW symmetry breaking
- Several open questions:
  - Only one Higgs boson or more ?
  - Stability of the Higgs boson mass ?
- Probe properties of the H(125) boson and search deviations from Standard Model predictions
  - Want to probe all possible couplings of the Higgs boson, including to both gauge bosons and fermions

gauge coupling



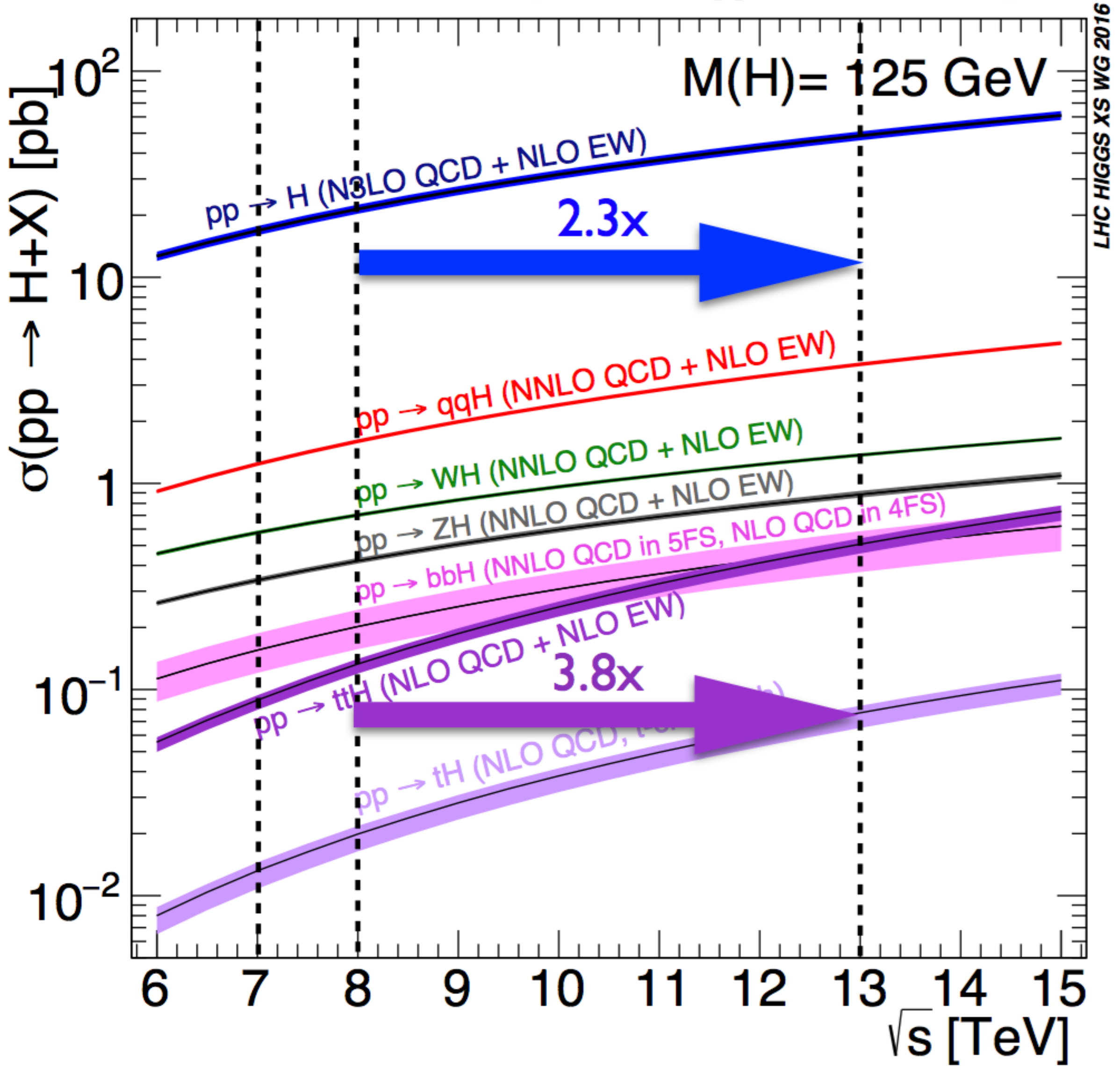
Yukawa coupling



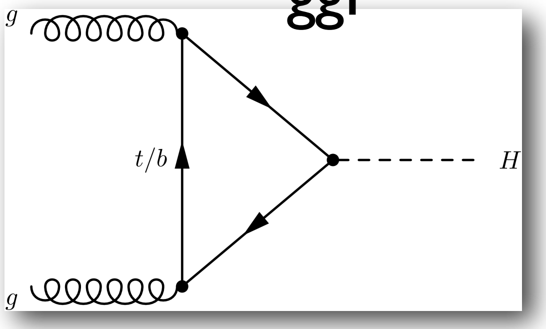
Production and decay in the SM

https://twiki.cern.ch/twiki/bin/view/LHCPhysics/CrossSections

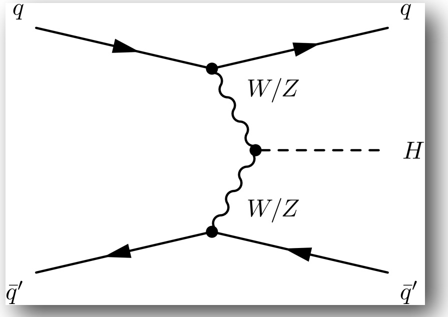
[LHC Higgs X-sec WG]



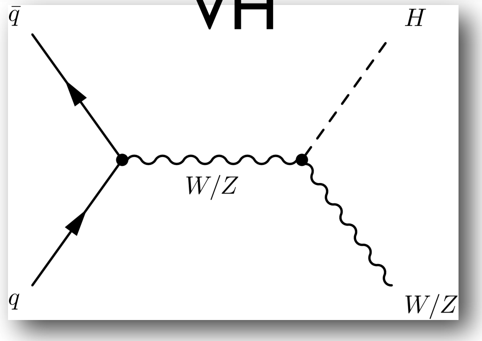
ggF



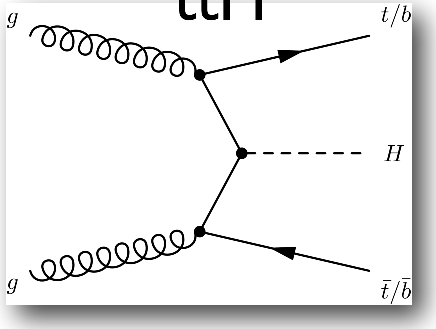
VBF



VH



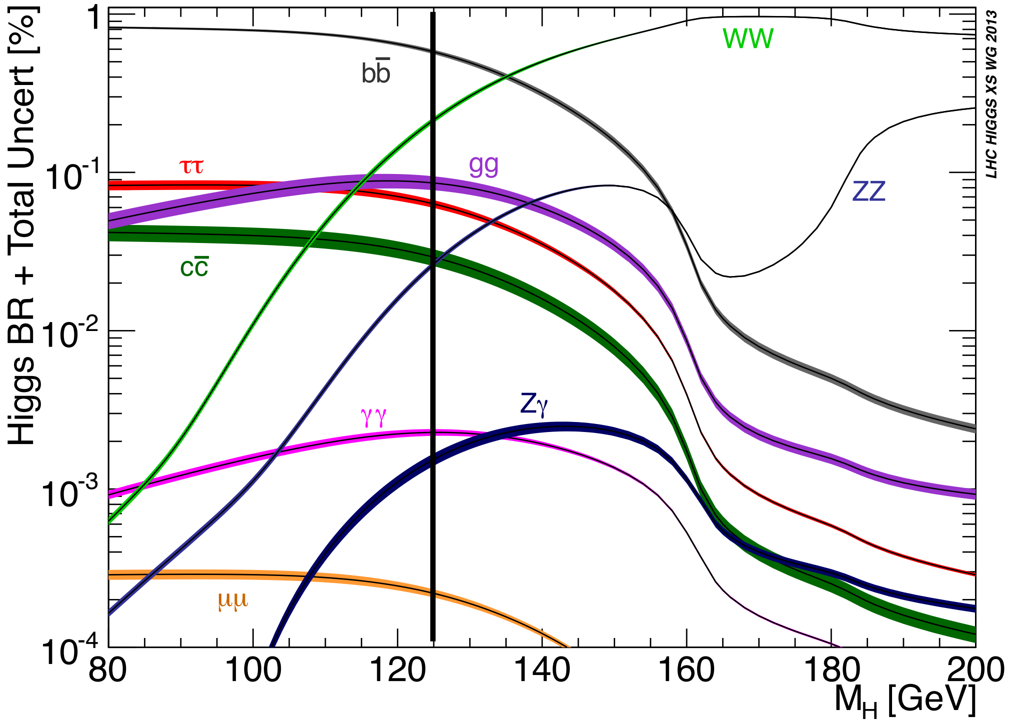
ttH



Gluon fusion cross-section computed at NNNLO accuracy

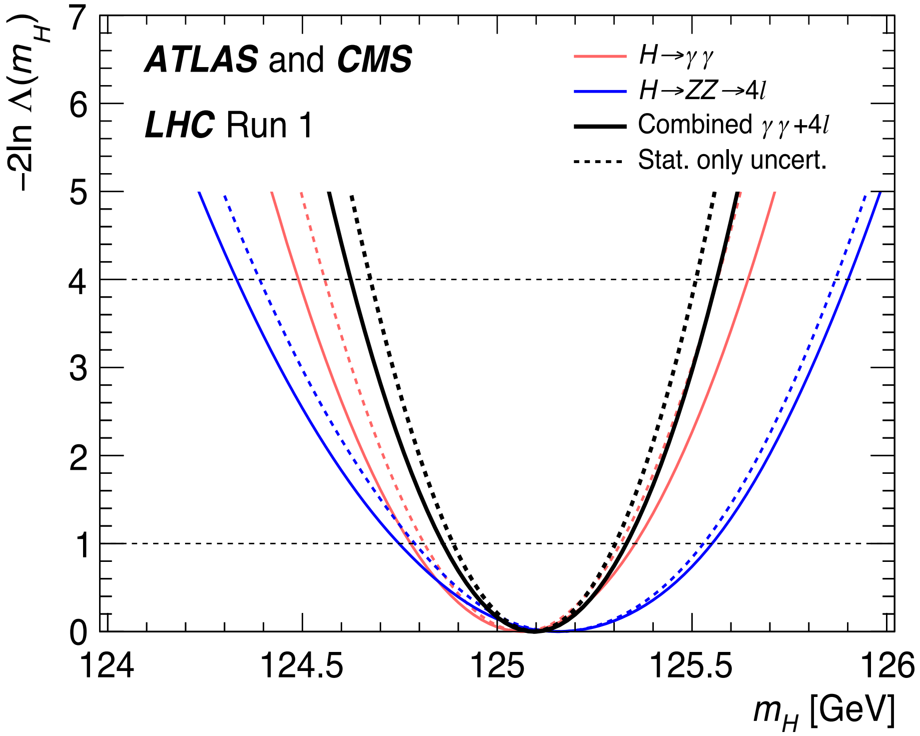
Uncertainty on theory prediction now at O(5%) level

About 8 Million Higgs events produced per experiment since LHC start

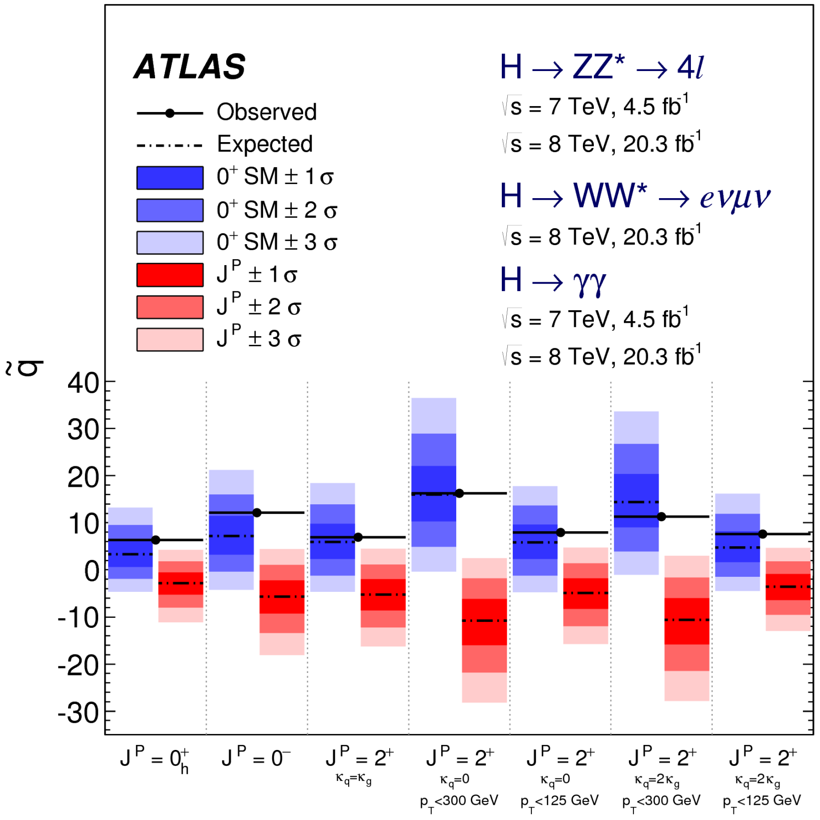


Lessons from LHC run 1

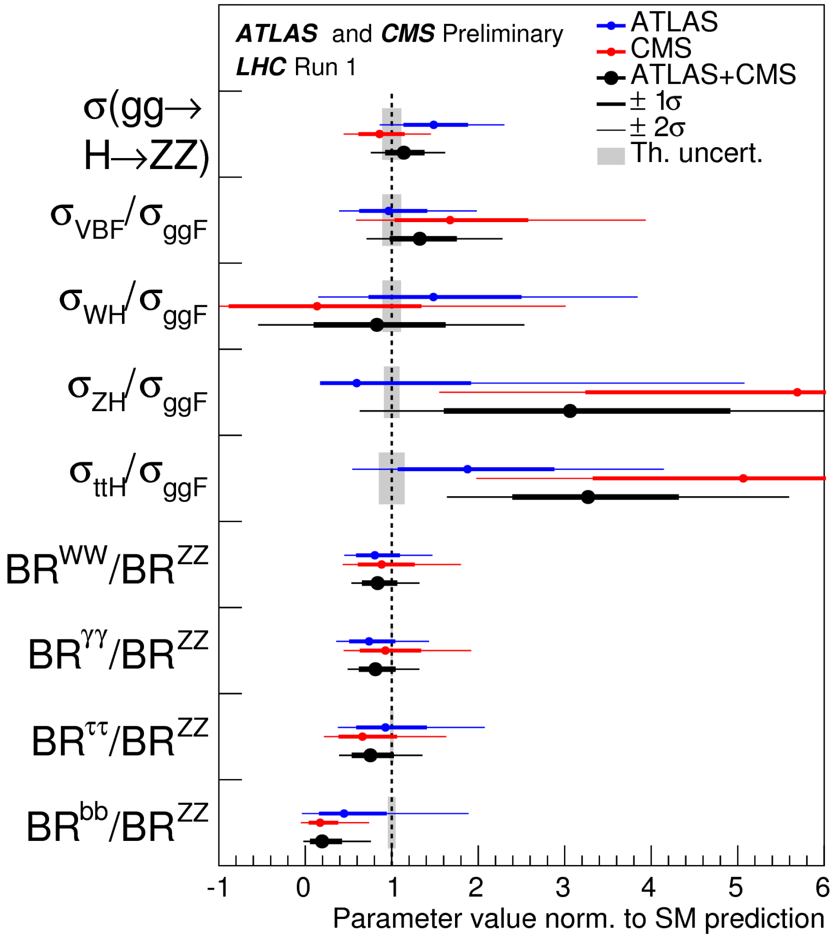
Phys. Rev. Lett. 114 (2015) 191803



ATLAS EPJC75(2015)476



JHEP 08 (2016) 045



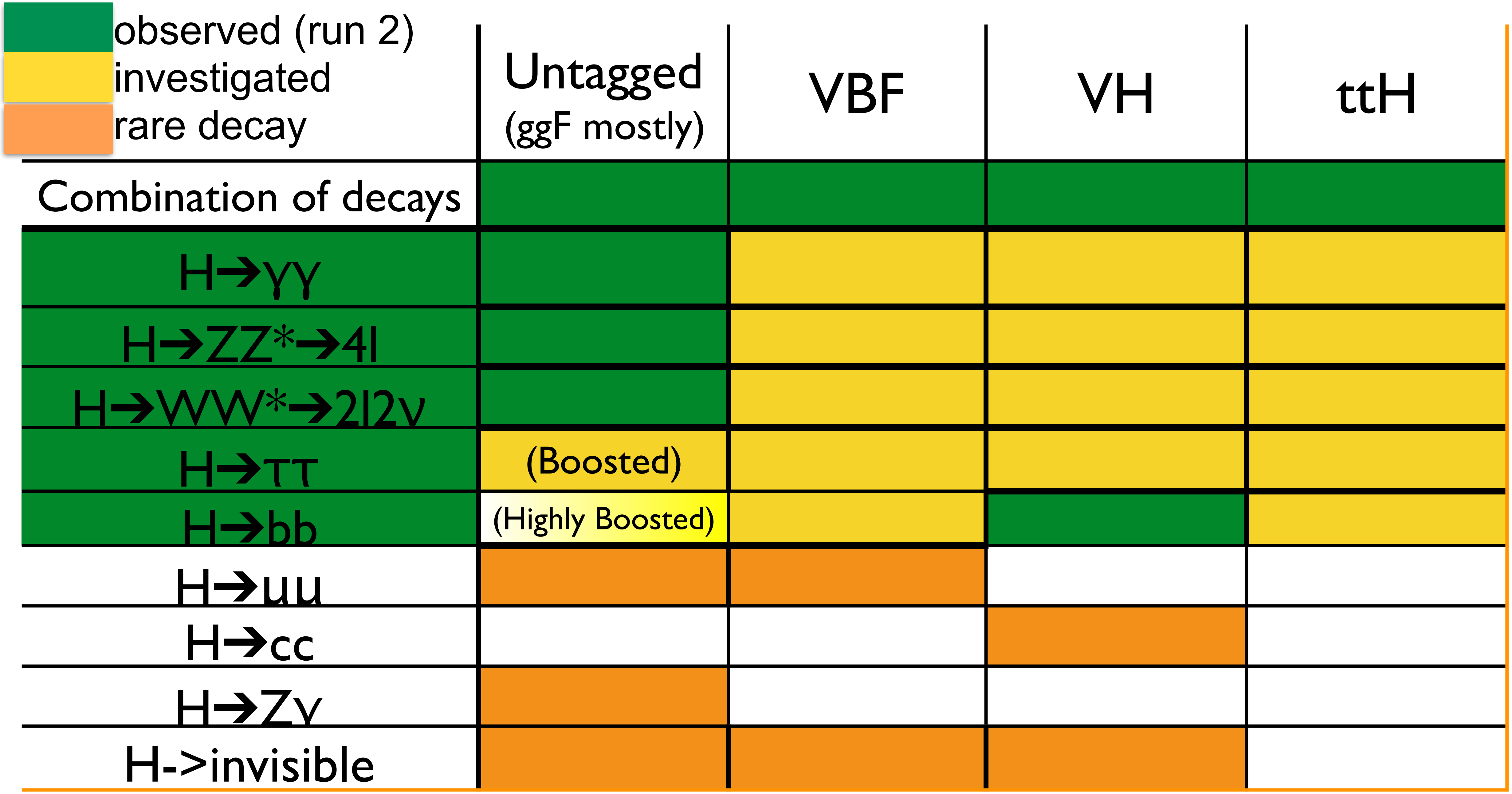
- ~ 0.2% mass measurement accuracy
- All tested alternatives to 0+ spin-parity (SM) rejected
- ~ 10% accuracy for inclusive cross-section measurement
  >= O(10%) accuracy on coupling studies. **Need better accuracy to probe BSM physics**

Decays to bosons well established

Decays to fermions observed at ~5 sigma level only for tau-tau when combining ATLAS and CMS

Lack direct observation of coupling to b and top quarks (indirect observation of top coupling via gluon fusion loop process)

Production modes and decays studied



🟩 observed (run 2)
🟨 investigated
🟧 rare decay

	Untagged (ggF mostly)	VBF	VH	ttH
Combination of decays	🟩	🟩	🟩	🟩
🟩 H→γγ	🟩	🟨	🟨	🟨
🟩 H→ZZ*→4l	🟩	🟨	🟨	🟨
🟩 H→WW*→2l2ν	🟩	🟨	🟨	🟨
🟩 H→ττ	🟨 (Boosted)	🟨	🟨	🟨
🟩 H→bb	🟨 (Highly Boosted)	🟨	🟩	🟨
H→μμ	🟧	🟧		
H→cc			🟧	
H→Zγ	🟧			
H->invisible	🟧	🟧	🟧	

Each decay*Production mode combination involves usually several analysis categories to improve sensitivity

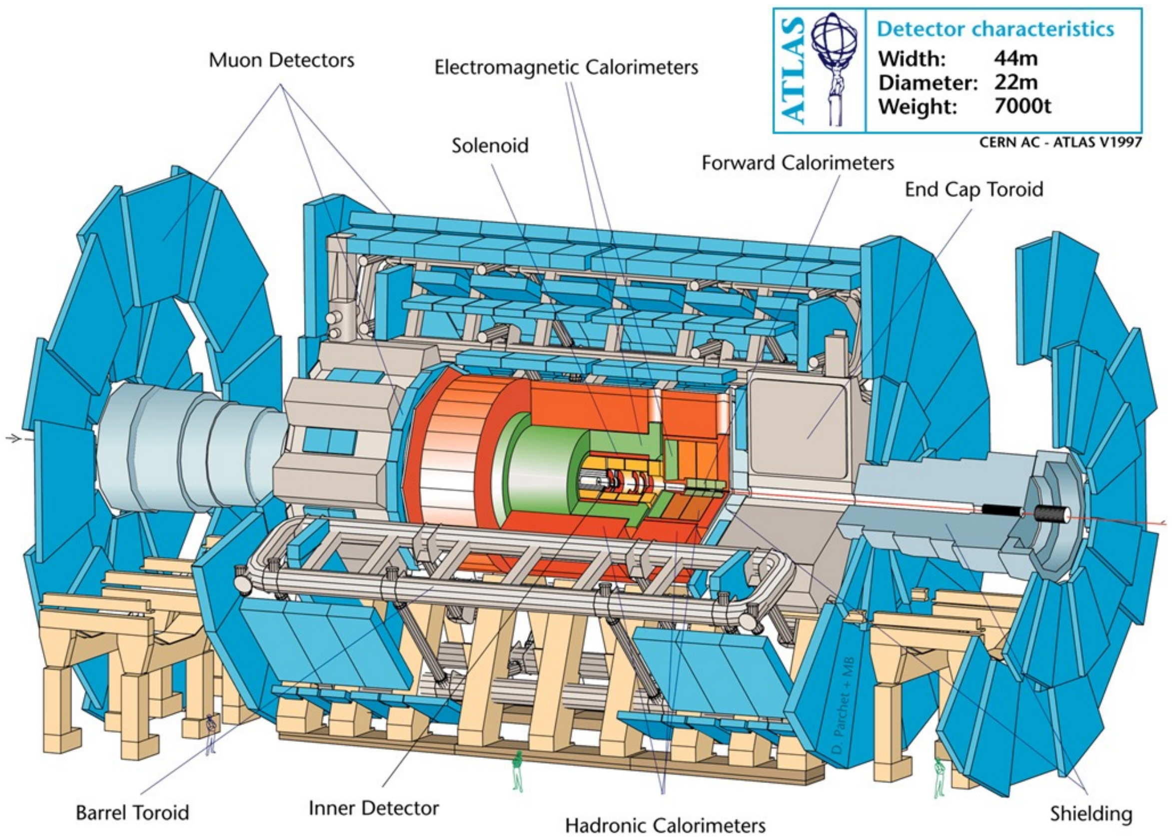
Main backgrounds usually derived or checked with data control regions

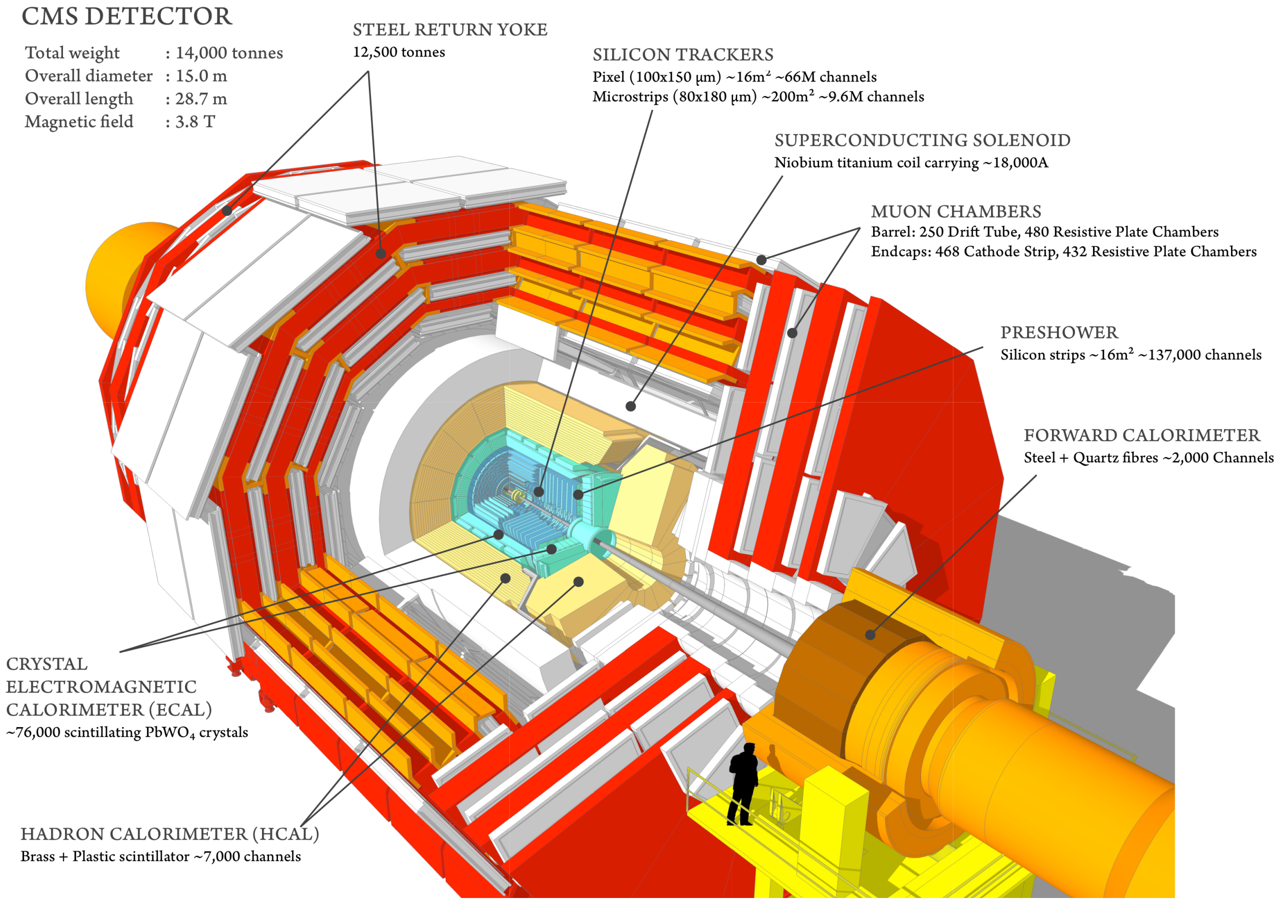
ATLAS and CMS

Large general purposes detectors

Upgrades for run 2 (starting 2015)

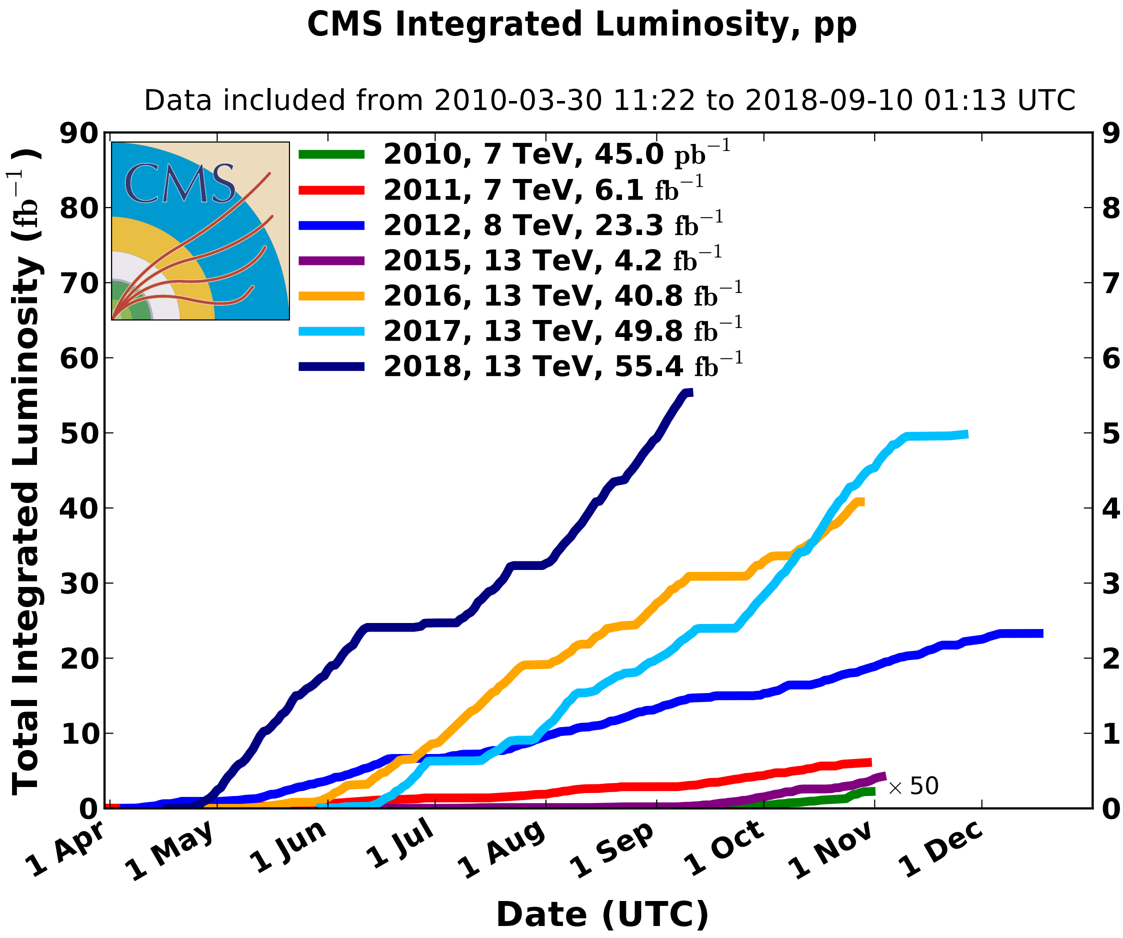
- new innermost pixel layer (ATLAS)
- pixel detector replacement in 2017 (CMS)
- trigger improvements to cope with ~1 GHz pp interaction rate

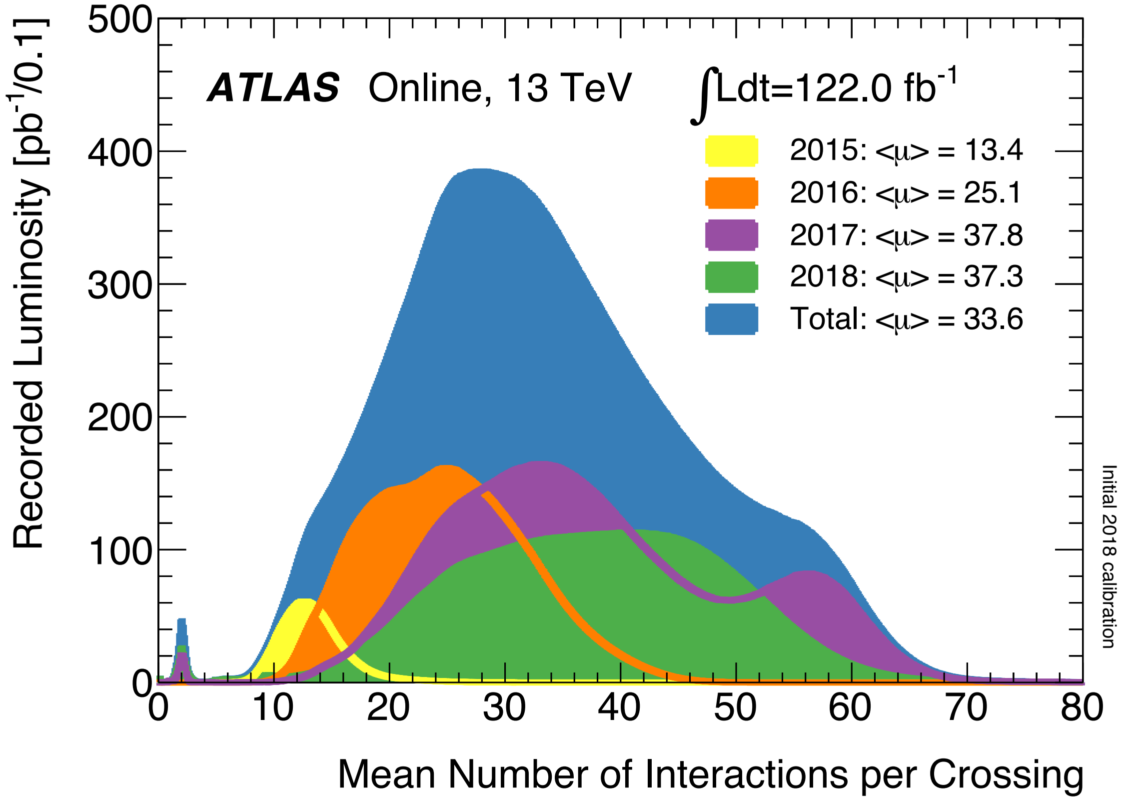




Run 2 dataset

- Run 2 √s =13 TeV, 25 ns bunch spacing
- Peak luminosity ~2.10^{34} cm^{-2}s^{-1} (twice design)
  - Up to ~60 pp interactions per bunch crossing
- Results shown here based either on
  - 2015+2016 dataset ~ 35 fb^{-1} of "good" data
  - 2015+2016+2017 ~80 fb^{-1} of "good" data





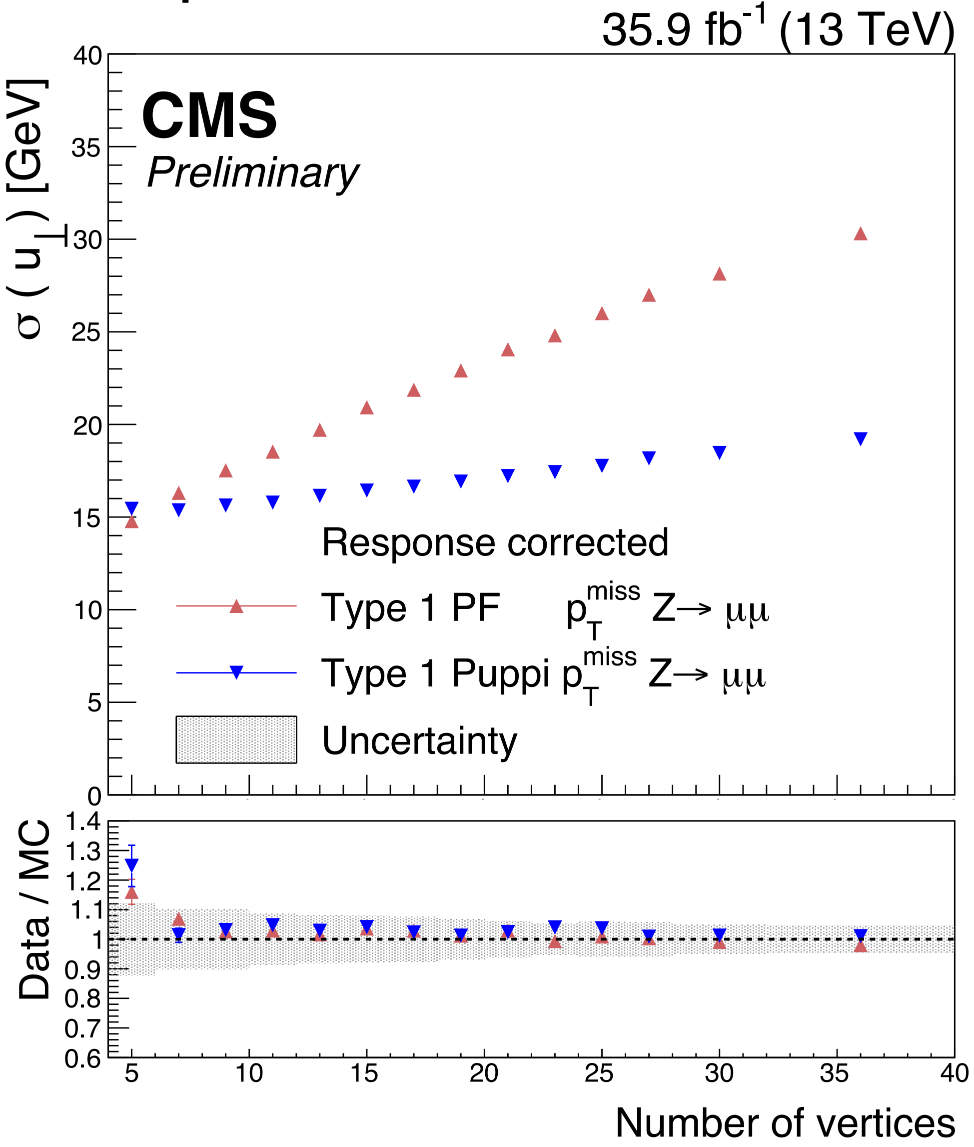
Dealing with high luminosity and pileup

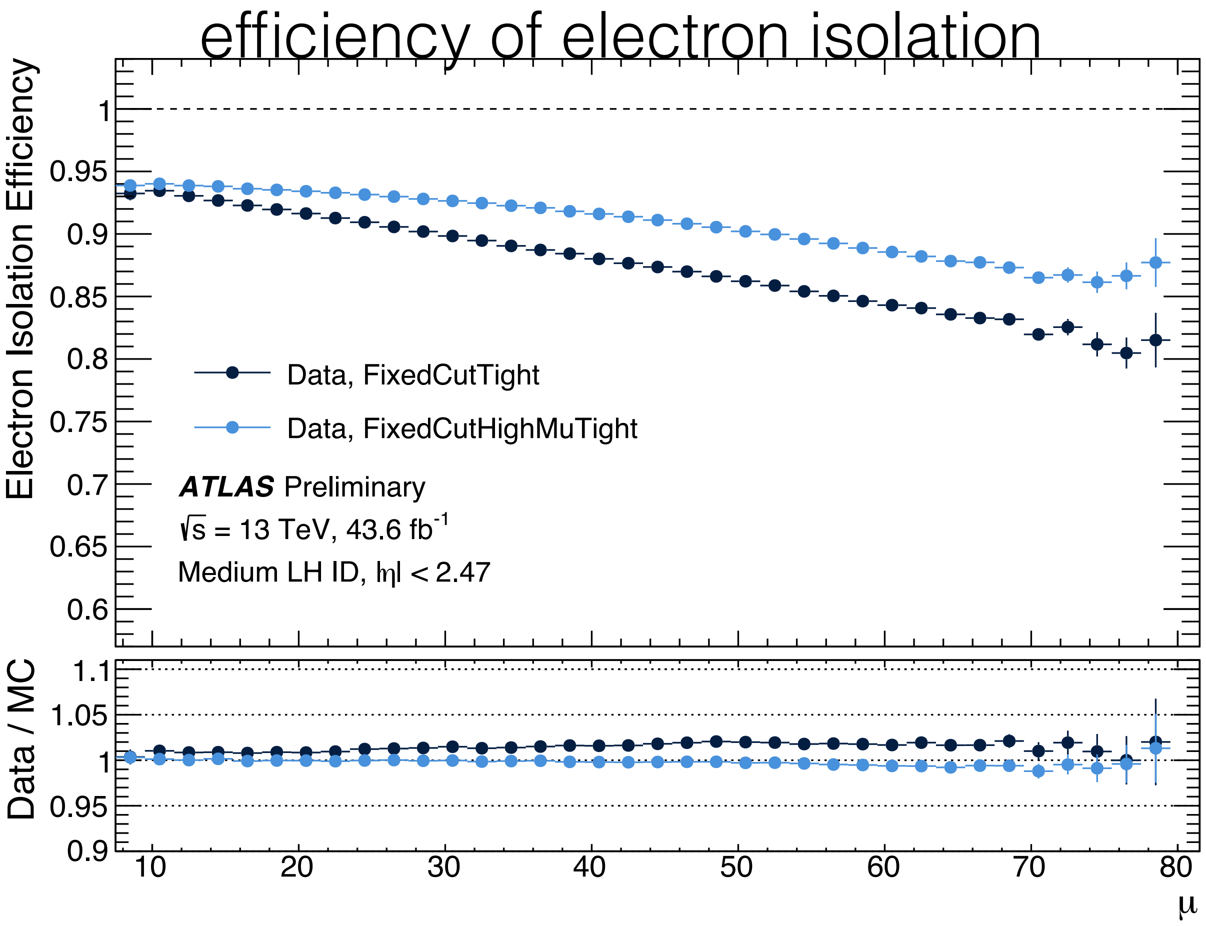
Develop techniques to mitigate pileup (=simultaneous pp interactions within detector sensitive time)

- Detailed use of tracking detector information (resolve each interaction vertex)

- Event-by-event (particle per particle) identification of pileup energy deposit and subtraction of pileup

Most sensitive variables to pileup are missing transverse momentum resolution and lepton isolation variables





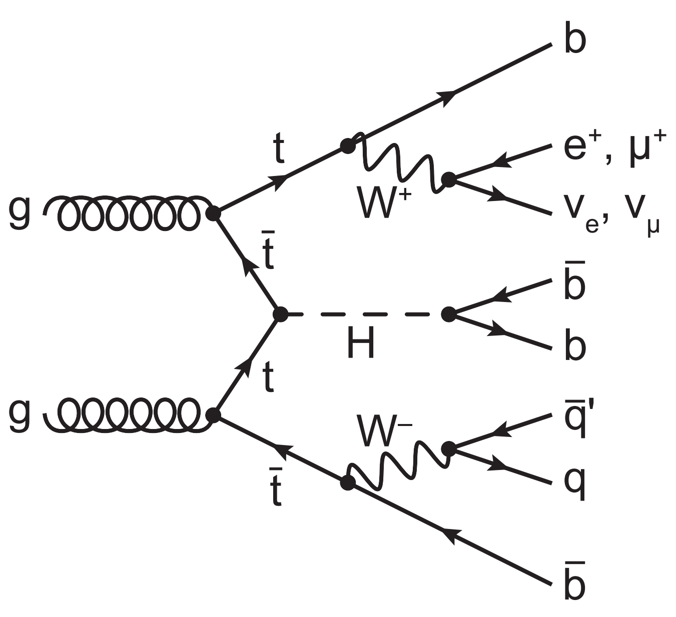
Measurements reviewed in this talk

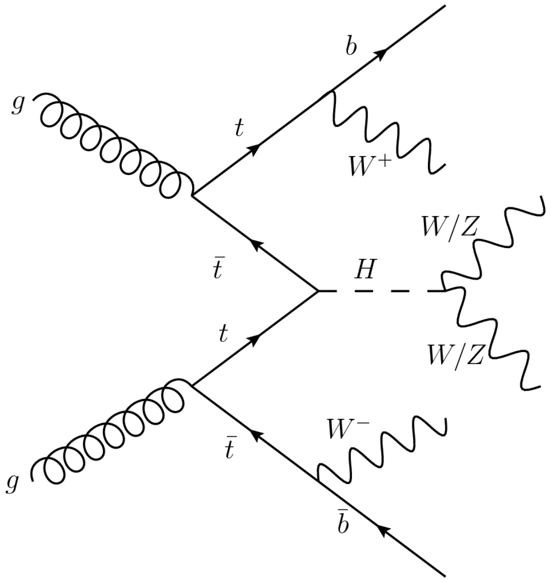
- Couplings to fermions: Observation with run 2 data
    - ttH observation with run 2 data (one of the key goal of run 2)
    - H→bb observation with run 2 data
    - H→ττ observation and H→μμ search
- Decays to bosons: Towards higher precision
    - H→WW, ZZ and γγ
    - (Differential) cross-section measurements
- Combination of all channels
- Rare decay searches
- Run 2 Higgs boson mass and width measurements

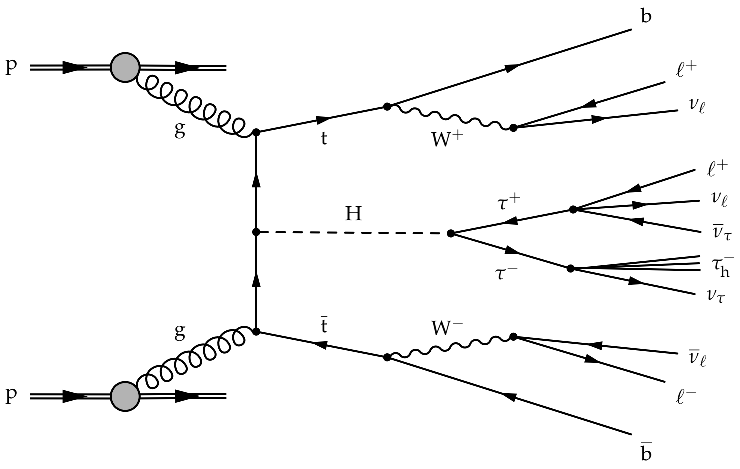
How to look for ttH production ?

- Sensitive at tree level to top-Higgs coupling
  - gluon fusion sensitive to top-Higgs couplings in loop (more sensitive to BSM)
  - Top yukawa coupling close to 1 in the SM
  - Rare production process (cross-section ~0.5 pb)

- Complicated final states
  - ttbar → (0,1 or 2 leptons)+(2-6 jets) among 2 from b-jets
  - Higgs decay products
    - H→bb larger BR, but complicated tt+bb background (+combinatorics bkg)
    - H→WW, tau tau : signature with multi leptons, no mass peak, need to understand background yields
    - H→gamma gamma: "clean" mass peak but very low stat (BR ~ 0.2%)
    - H→4l: "even cleaner" but ~little sensitivity given current stat. (not discussed here)







ttH   H→bb searches

Look at 1 or 2 lepton + jet events   (0 lepton analysis also done by CMS in 1803.06986)

Classify as function of Njet and jet b-tagging properties (up to 6 jets and 4 b-tagged jets)

Main background is tt + heavy flavor production (ttbb, ttcc)

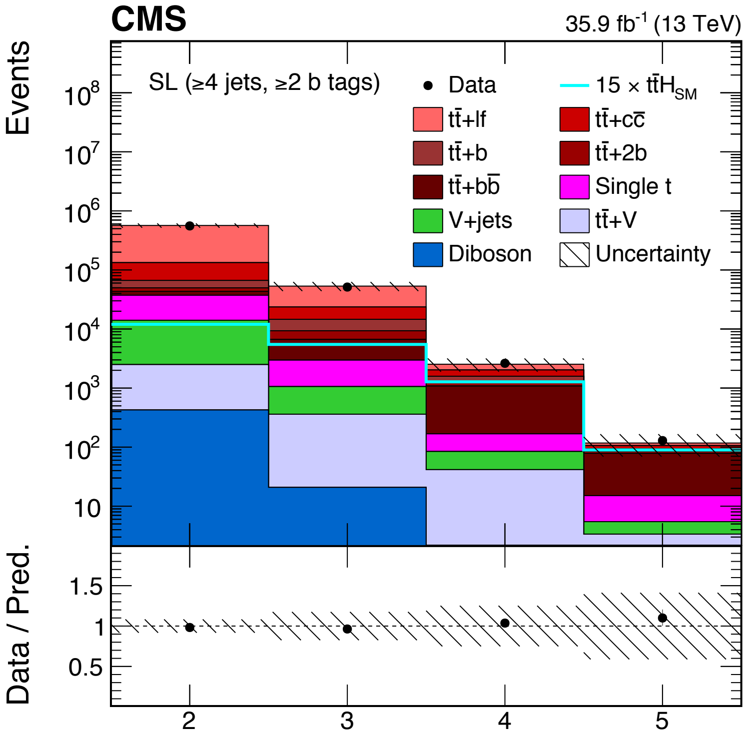
Define multivariate discriminant based on kinematic variables to separate signal and background in signal regions

Overall fit with free normalization of ttbb and ttcc backgrounds

(still rely on MC for shape of these backgrounds=> systematics)

Expected sensitivity to SM ttH: 1.6 (ATLAS) ,2.2 (CMS) sigma

Observed: 1.4 (ATLAS),1.6 (CMS)



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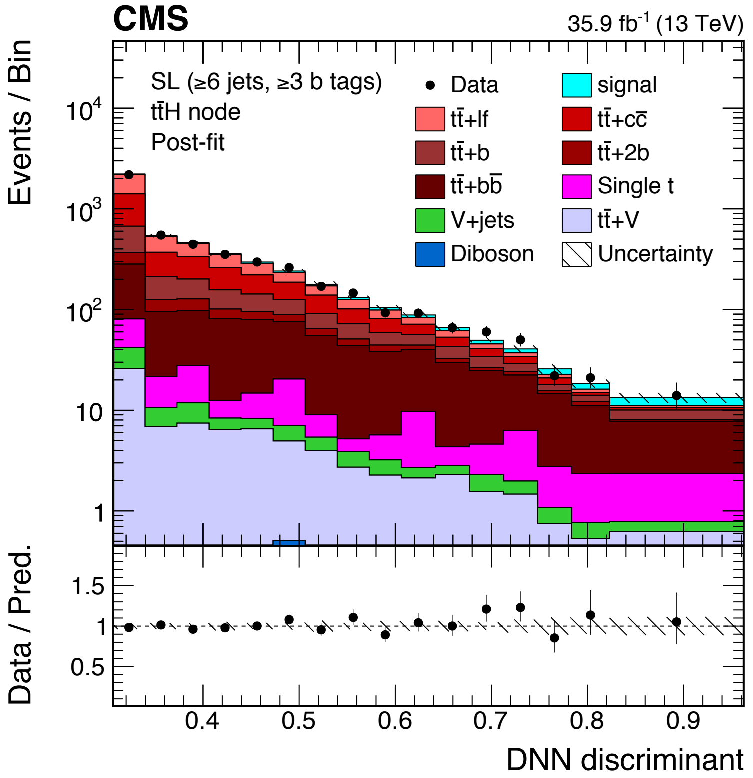

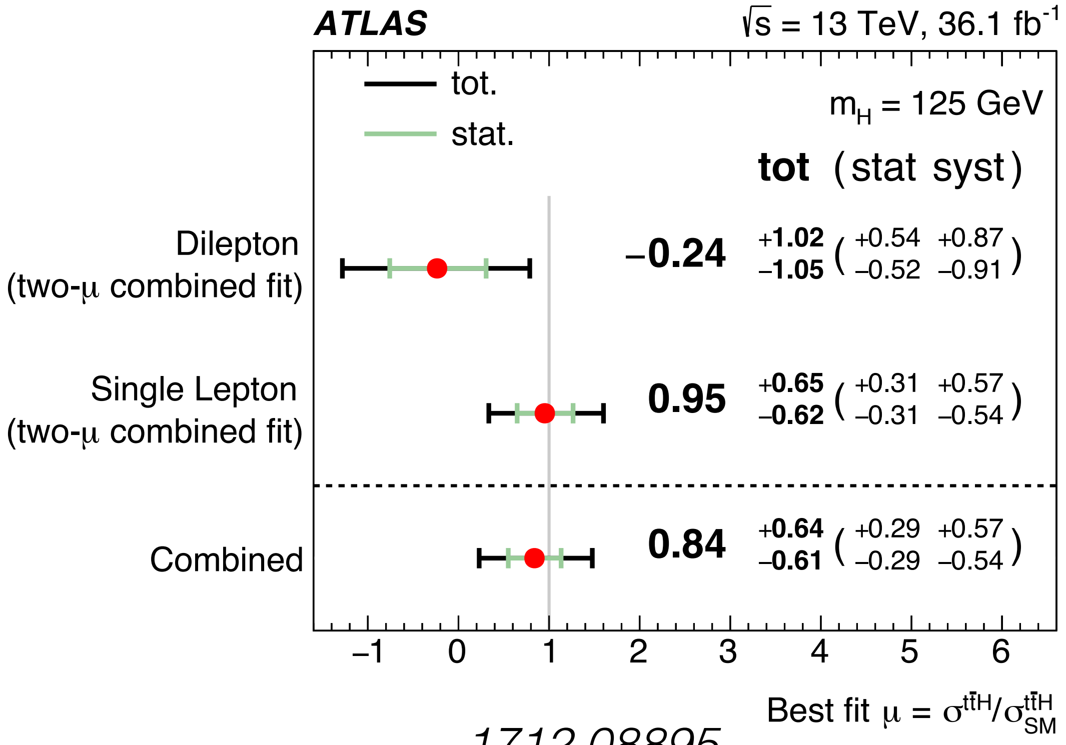

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ttH → multilepton searches

Use two same sign lepton (l=e,mu), 3 leptons (3l, 2l+1 tau) and 4 leptons to avoid ttbar -> dilepton background

Define categories according to lepton multiplicity
Main backgrounds are ttV, VV and background with non-prompt lepton or charge misidentification from ttbar

Multivariate discriminants trained in each category to separate S and B

Global fit with background estimates checked/refined in Control regions

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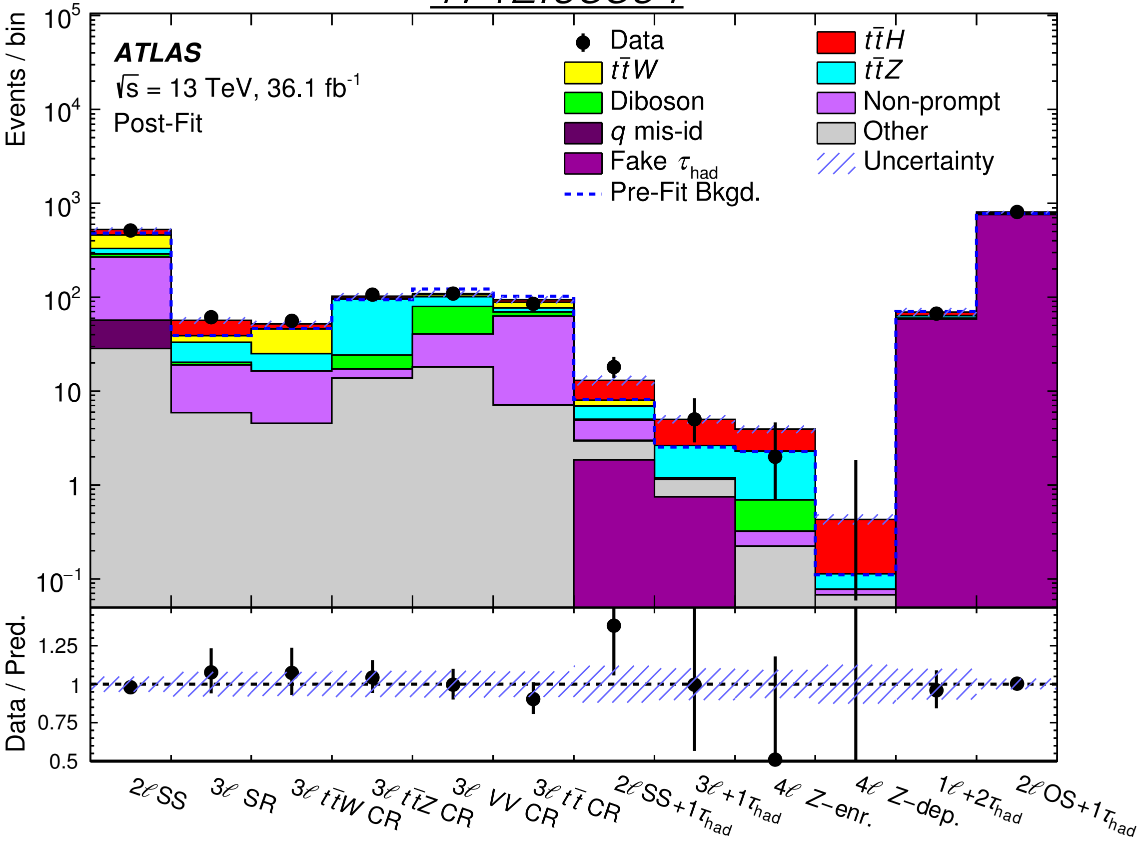

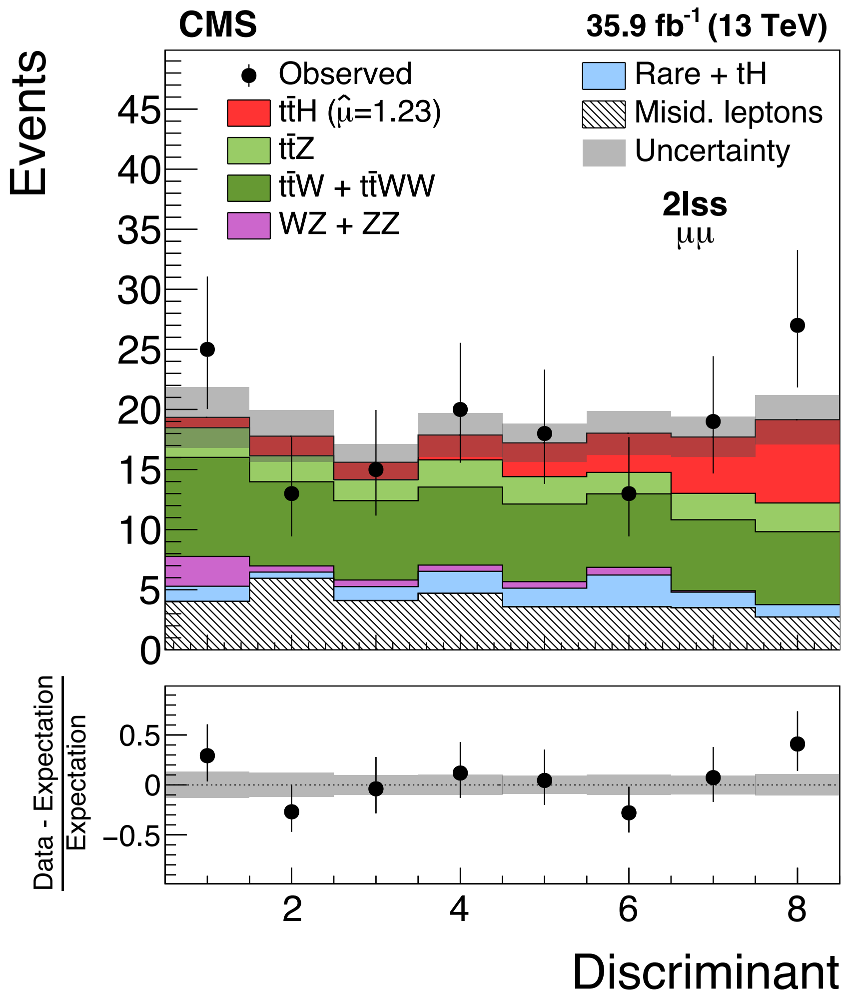

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ttH → multilepton searches

Expected significance for SM ttH: ~2.8 (both ATLAS and CMS) standard deviations

Observed significance: ~4.1 (ATLAS), 3.8 (CMS)

Main systematics from ttV background modeling and non-prompt lepton background. Total systematic uncertainty ~ similar to stat. uncertainty

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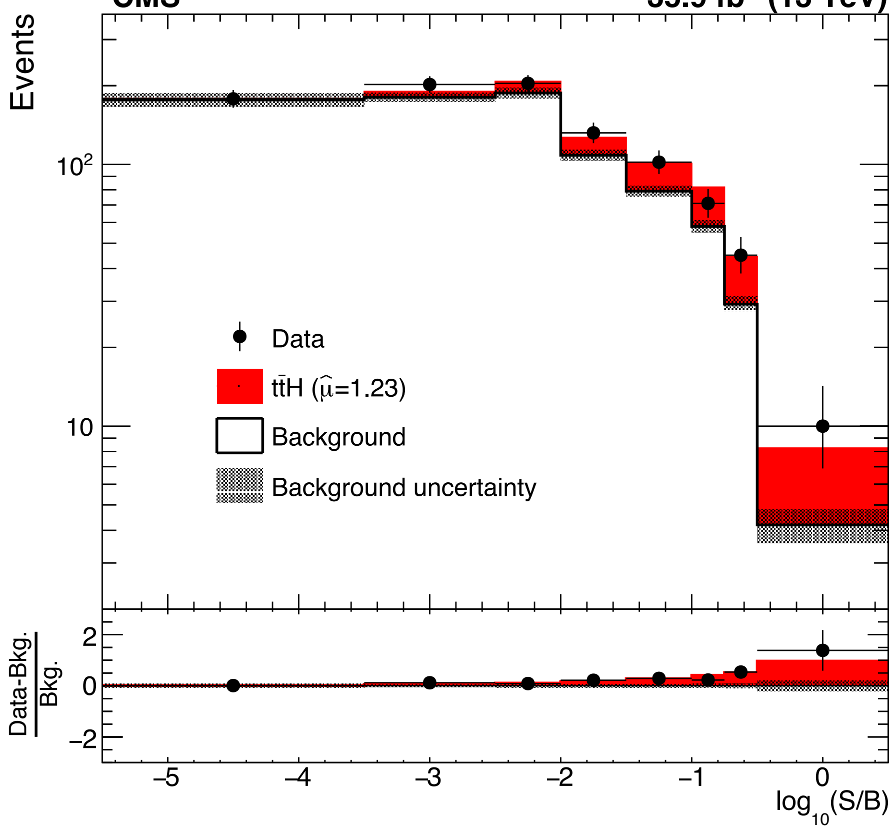

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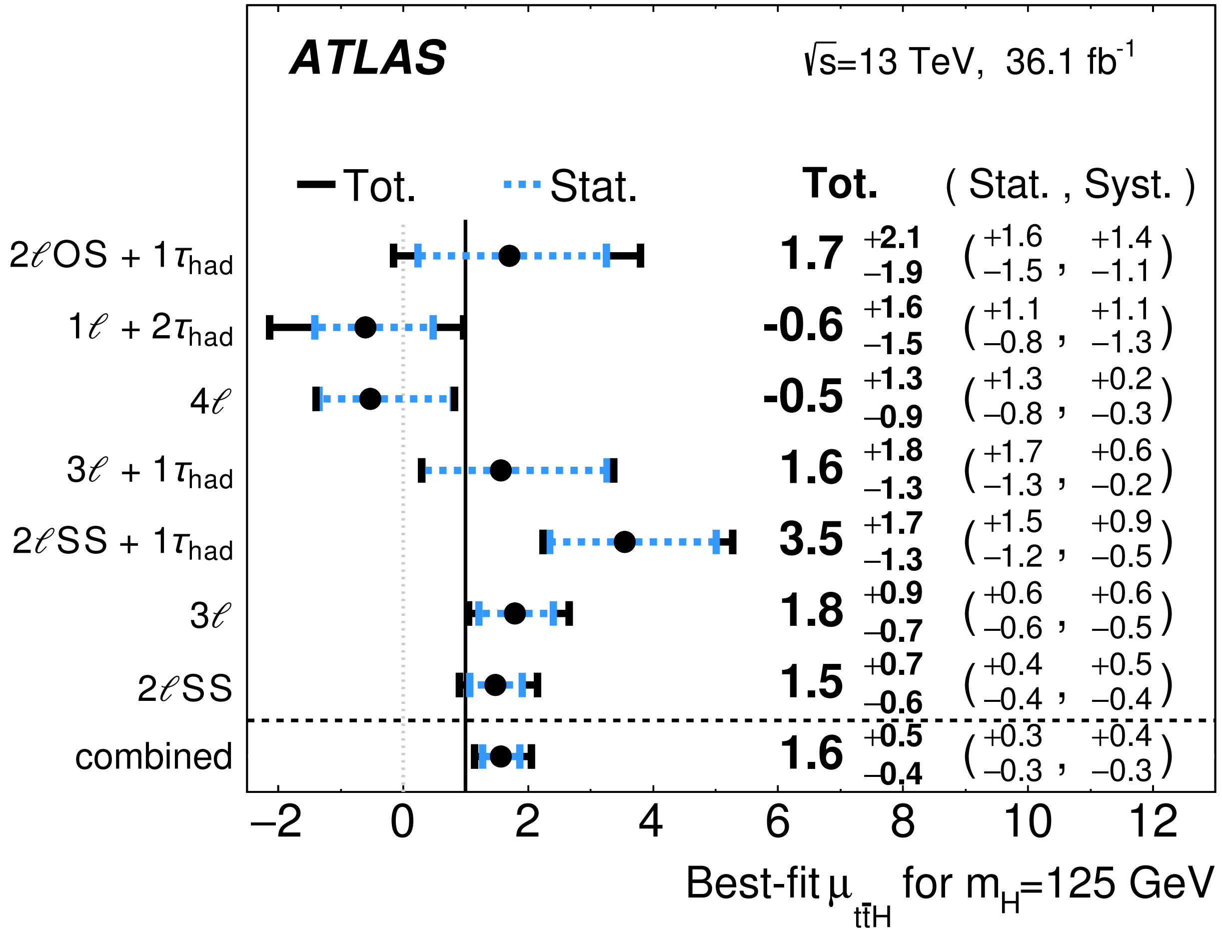

ttH H→gamma gamma searches

2 selections: lepton+jets and all hadronic

Main background: non resonant production (tt +gammagamma, etc..) and also non-ttH H production modes

ATLAS (80 fb^{-1}): Deep neural networks trained using mixture of data and simulation to define data categories

S+B fit of M(gamma-gamma) in each category

B constrained by mass sidebands

observed (expected) significance: 4.1 (3.7)

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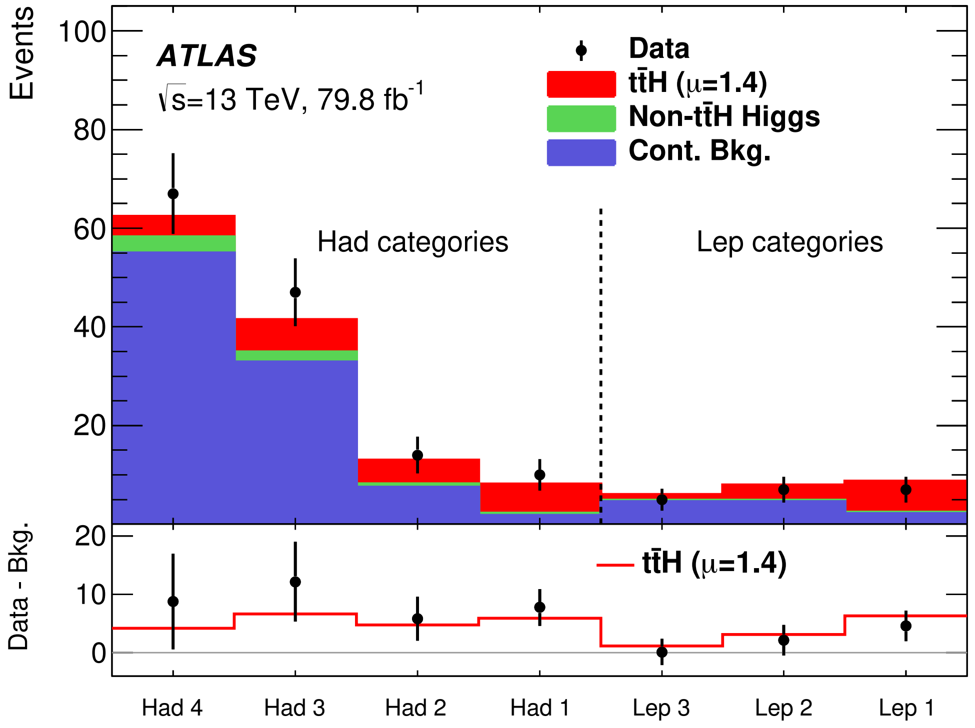

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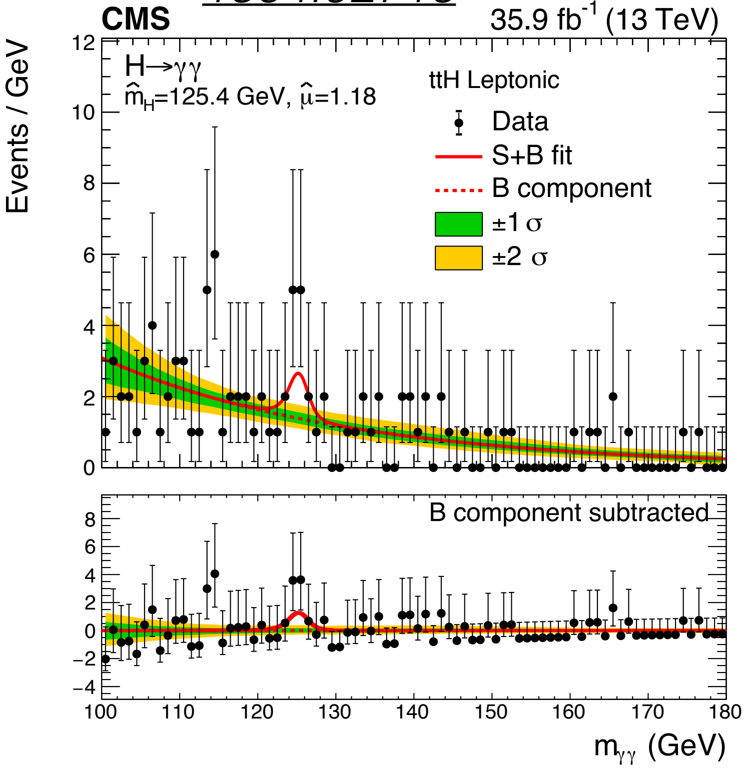
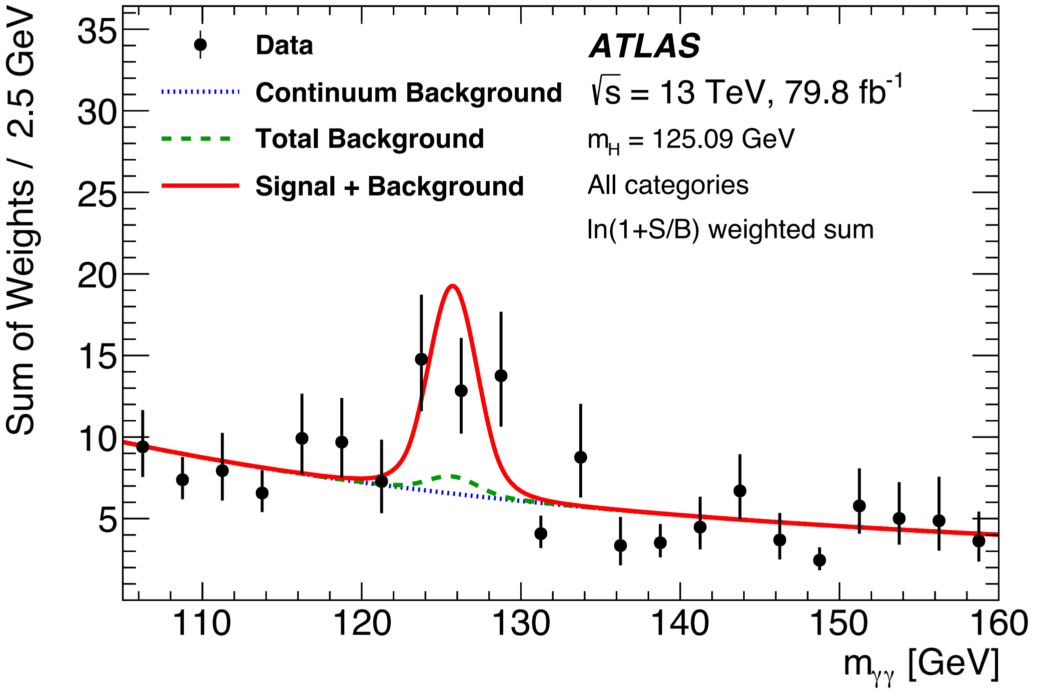
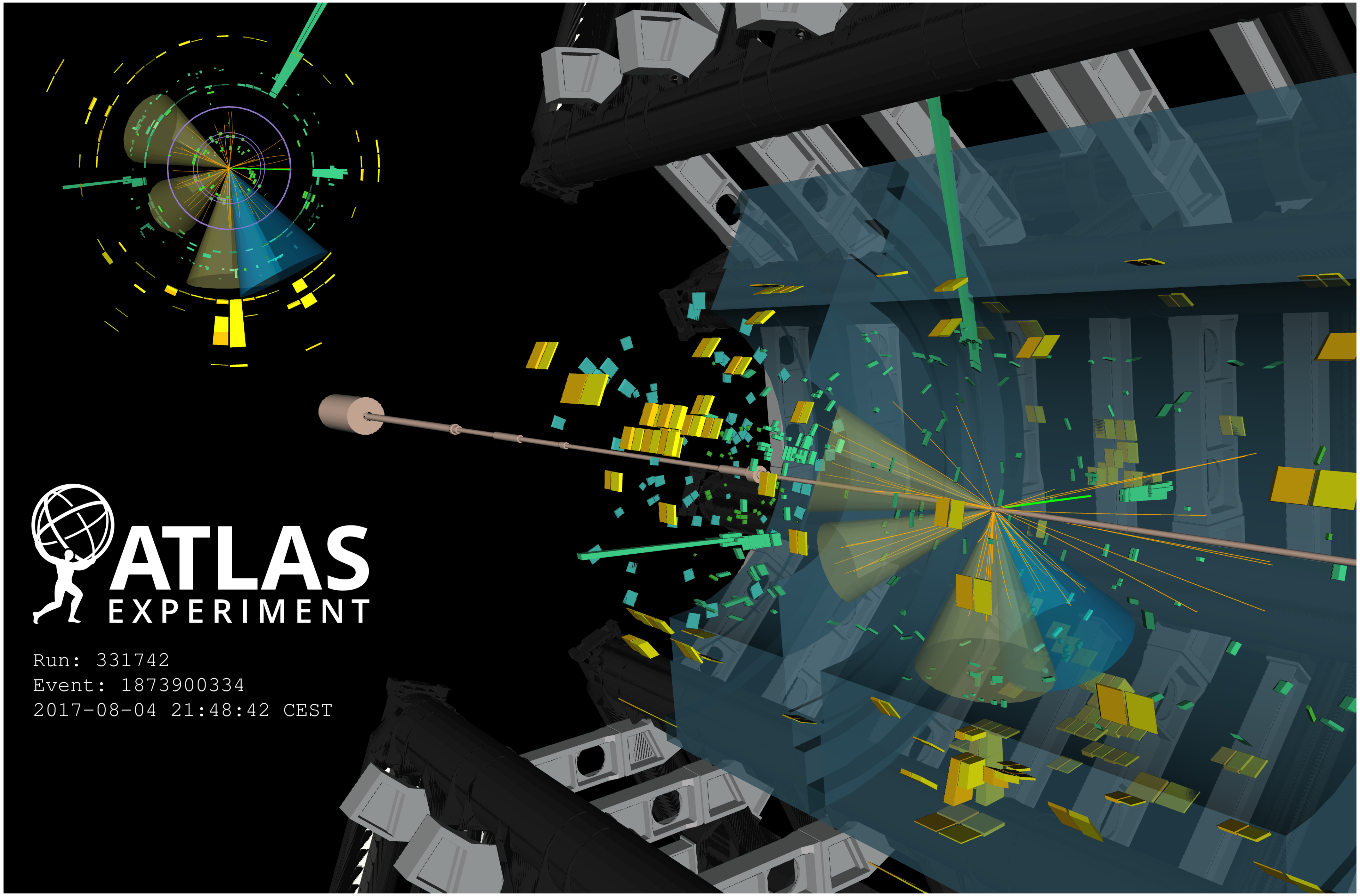


CMS (36 fb^{-1})

Data/Prediction yield for ttH(H->gamma gamma) = 2.3 +-0.8



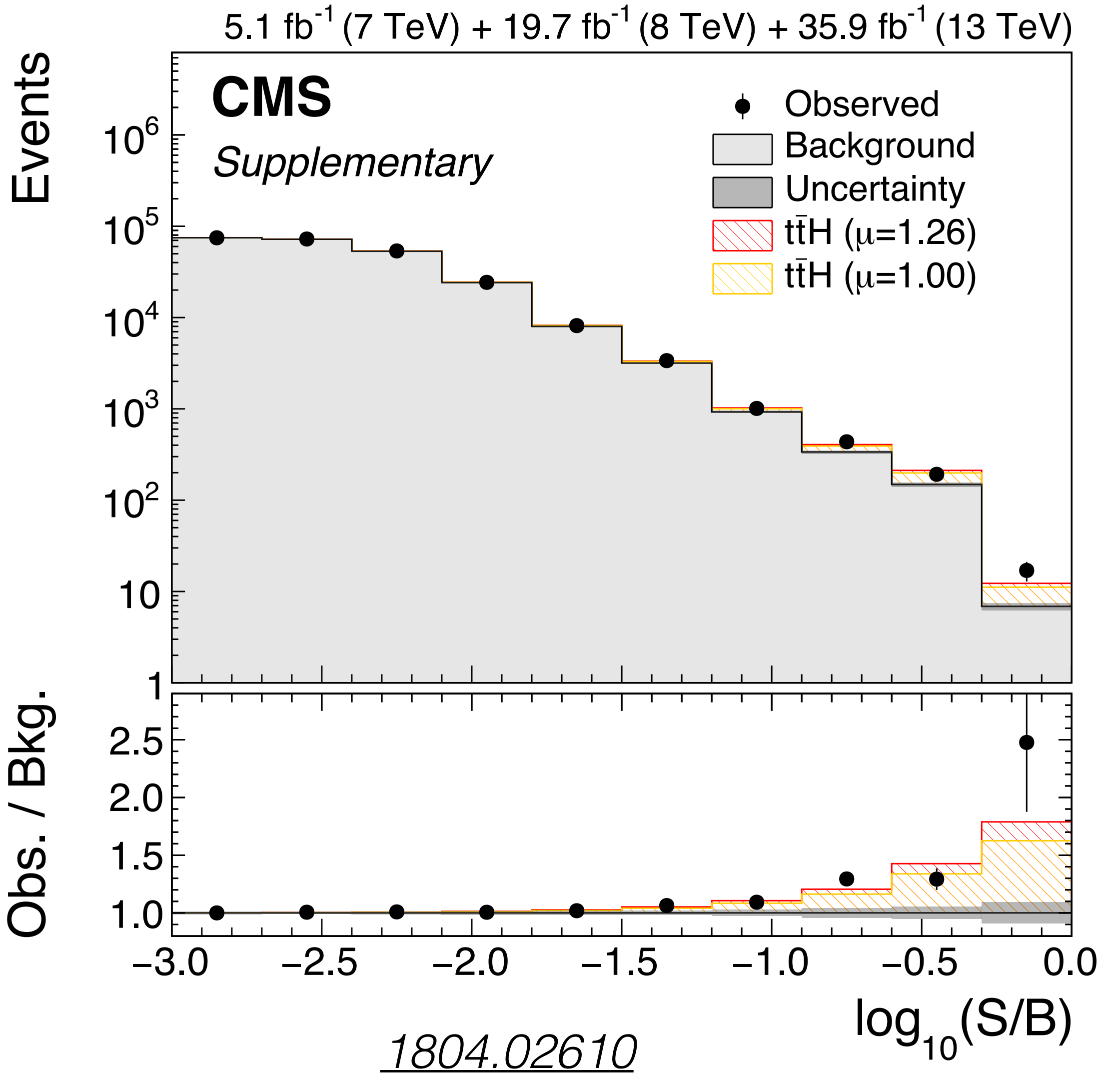
Example candidate for ttH, H->gamma gamma in lepton+jet final state



ttH observation

Combine different decay modes assuming SM for the decay BR
Combine also with run 1 data (lower sensitivity, 20 (5) fb^{-1} @ 8(7) TeV)

Expected significance 4.2 (CMS), 5.1 (ATLAS)
Observed significance 5.2 (CMS), 6.3 (ATLAS)
(note that ATLAS uses 2017 data for ttH,H->gamma gamma and 4l)



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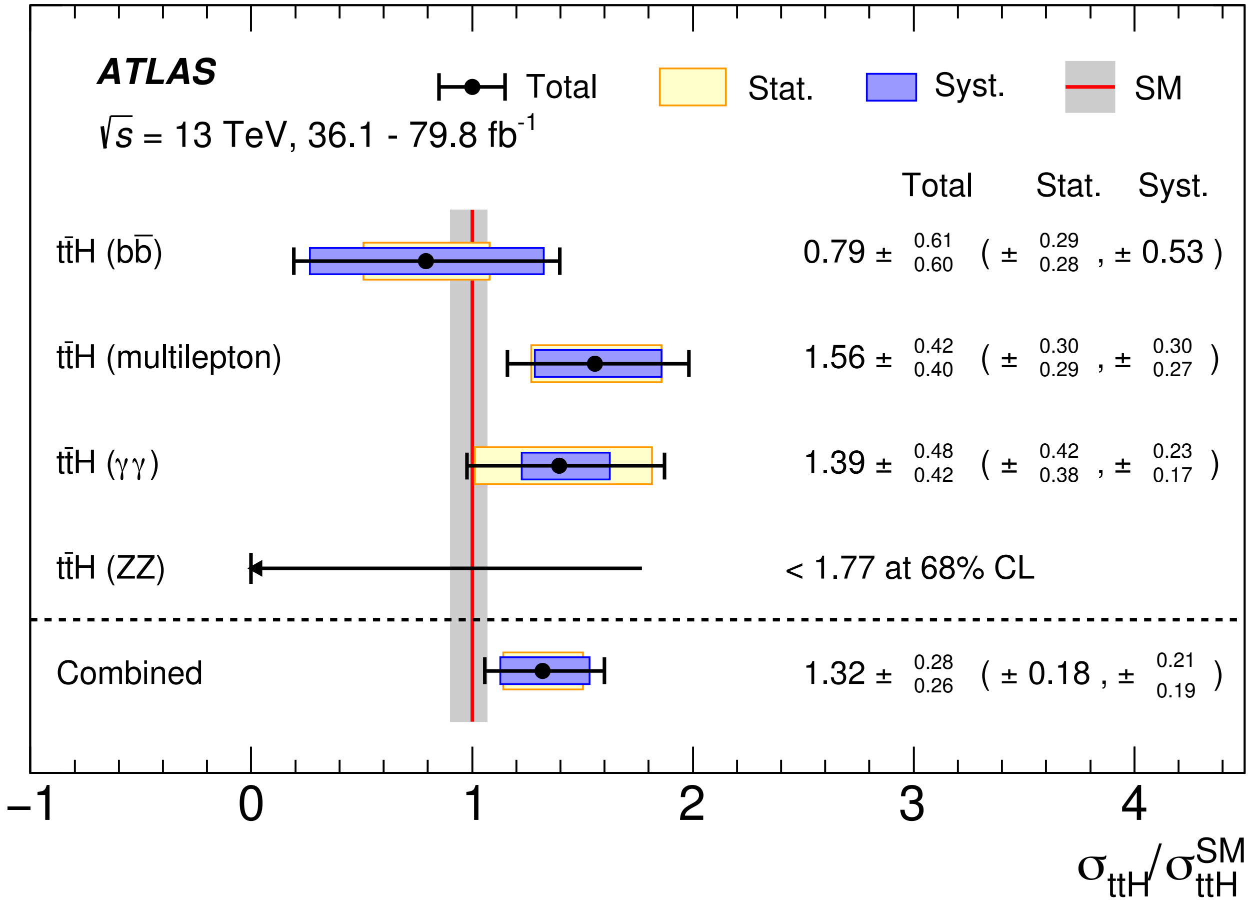

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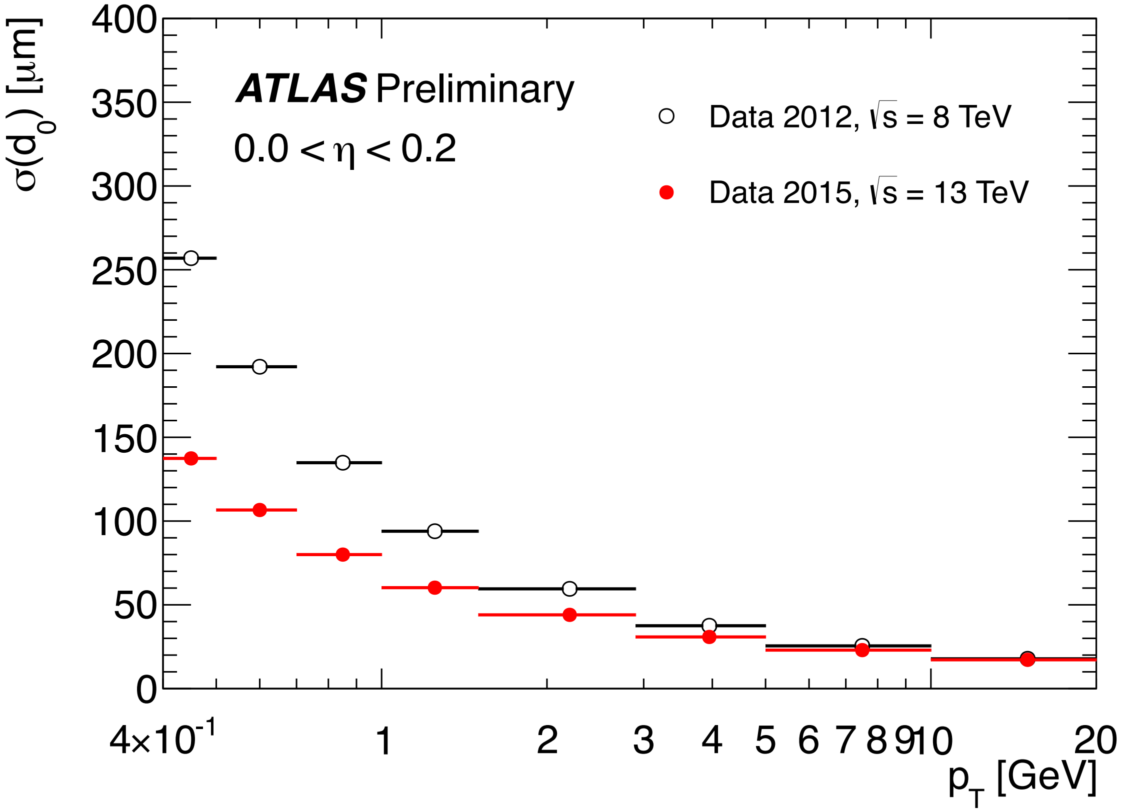
How to look for H→bb decays ?

A long journey to observe H→bb decays even if it is the dominant H decay mode (BR~58 %). This was the main decay search at LEP and Tevatron (2.8 sigma evidence in Tevatron legacy result)

- Inclusive production very challenging given large cross-section for bbbar production at LHC
- Associated production with vector boson (V=W,Z) is the most sensitive channel
  - W,Z decay provide ways to trigger the event
  - But still have to deal with large backgrounds from V+jets, Vbbbar and ttbar production
  - Was considered ~ hopeless 20 years ago...
- Can also use ttH production (see previous slides) and VBF production

b-tagging performances are a key ingredient for this search in addition to the ability to reconstruct the bb invariant mass (but needs to use also many other variables, usually combined in a multivariate discriminant)

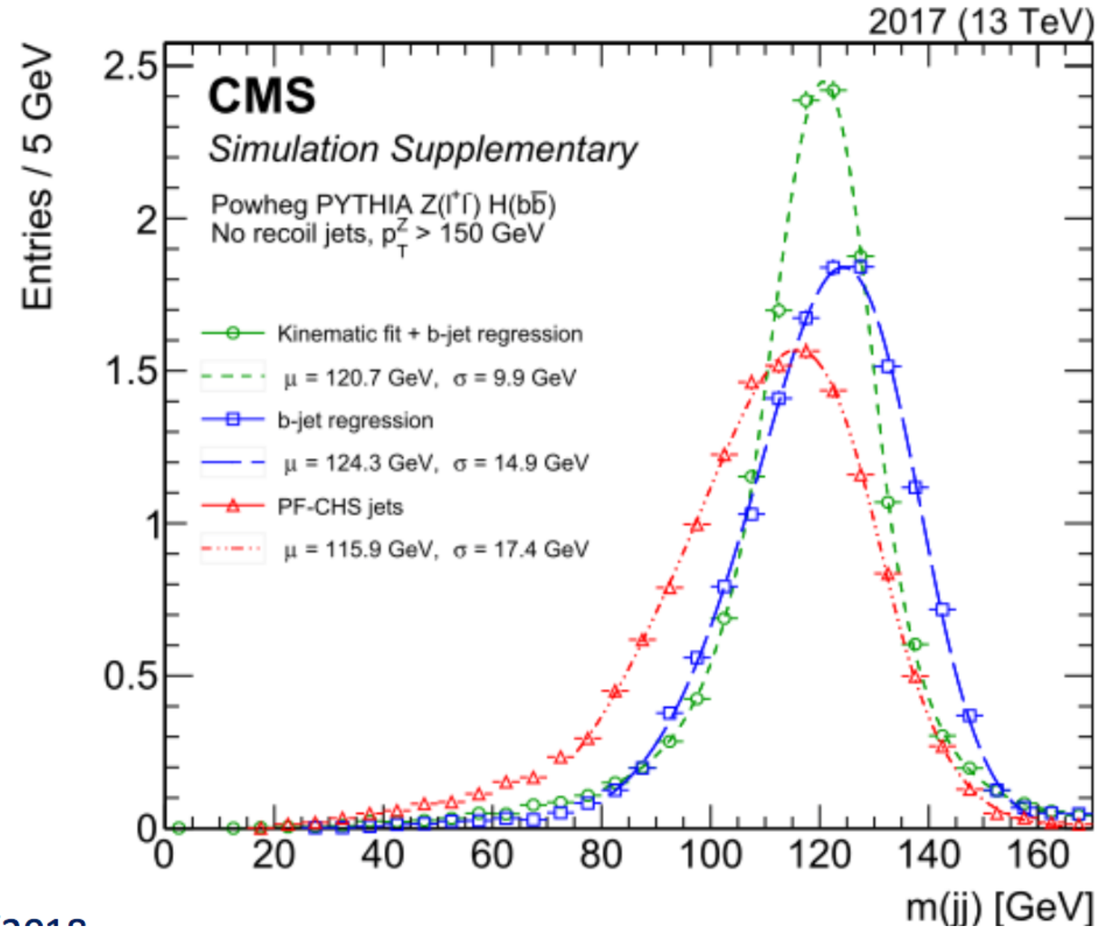


Searches for VH, H→bb

0,1,2 lepton selections to target Z→nunu, W→l nu or Z→ll

2 b-tagged jets, optimize invariant mass resolution (dedicated corrections) Multivariate analysis based on kinematic variables (including Mbb) for different signal regions (use also Pt(V) in signal region definition).

Simultaneous fit of signal distribution and of control regions for constraining normalization for V+jets (including V+heavy flavor) and ttbar background (background shapes from MC simulation). Multijet backgrounds from data



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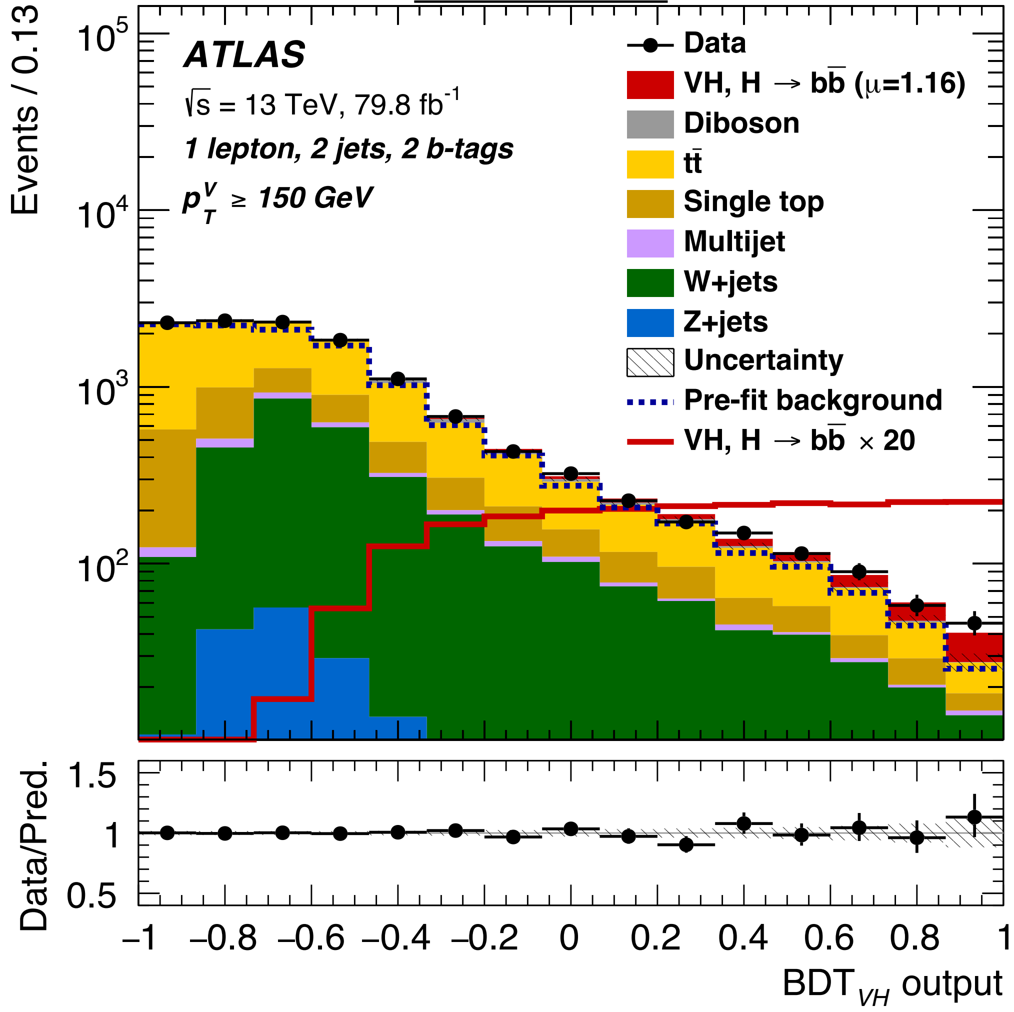


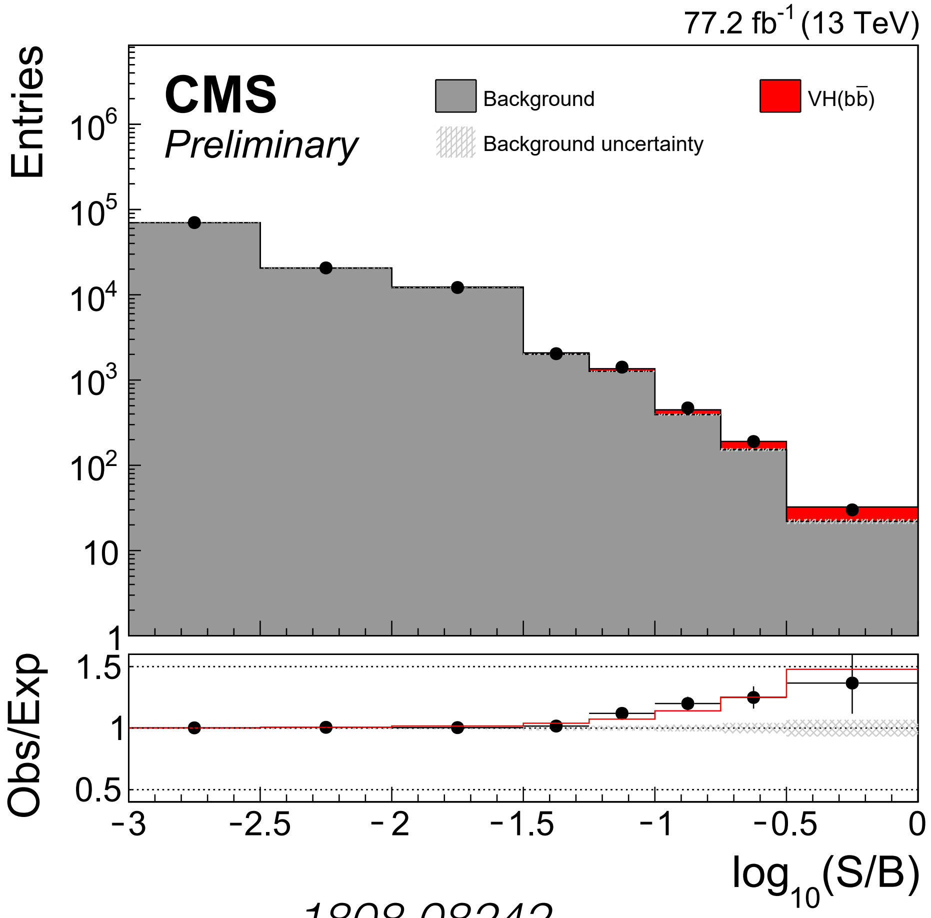
Searches for VH, H→bb

Validation: VZ with Z→bb seen as expected from SM predictions (with ~ 20% accuracy)

Main uncertainties: stat., background modeling, b-tagging performance, jet energy scale

Expected sensitivity to VH,H->bb (run1 + 80 fb-1 run 2): 5.1 (ATLAS) 4.8 (CMS)
Observed : 4.9 (ATLAS) 4.8 (CMS)

Cross-check cut-based analysis
(mbb used only as final variable)



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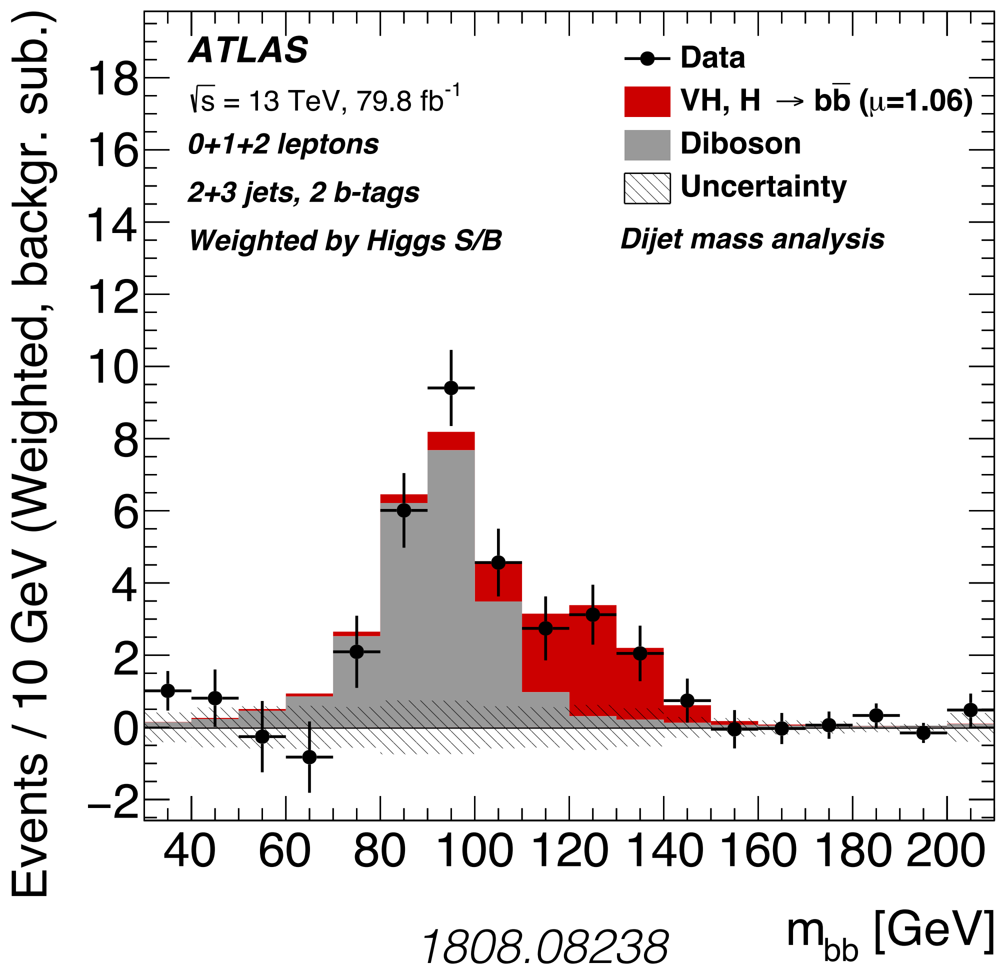

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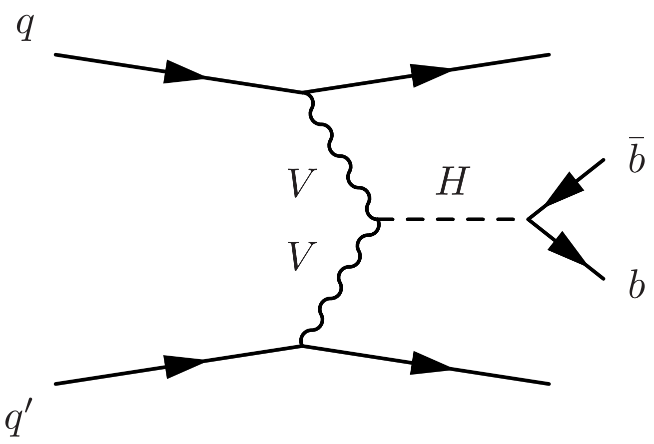
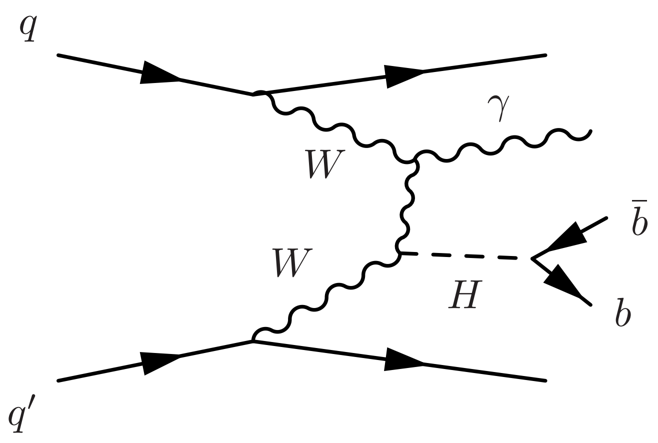
Other searches for H→bb:VBF production





VBF specific kinematic give handle to reject background

Use also VBF+photon events (easier to trigger, better S/B, reject bbjj background)

Divide events in different signal regions according to S/B (multivariate BDT)
m_bb (2 b-tagged jets) as final discriminant

Fitted Yield /SM prediction=2.4+1.4-1.3
(driven by stat. uncertainties)

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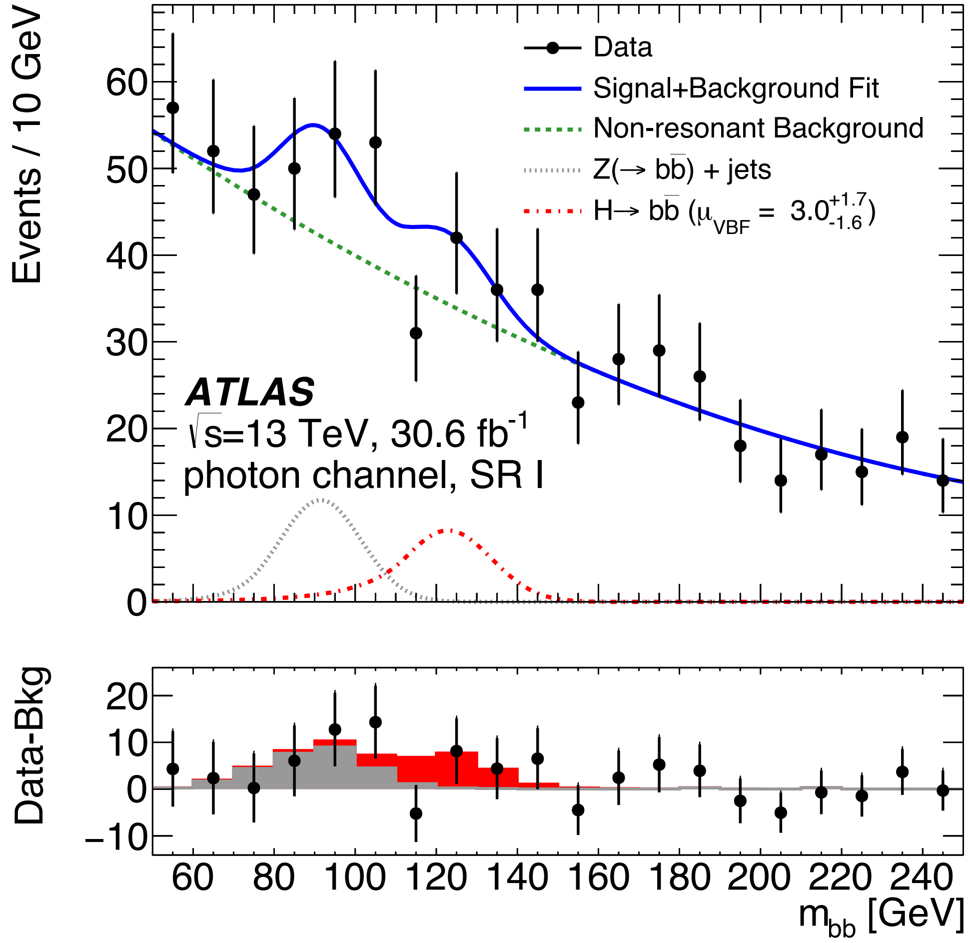


Other searches for H→bb: gluon fusion

gg→H+X with high Pt(H) has better S/B ratio

H decay products merged in a "fat" jet (m/Pt~0.25)

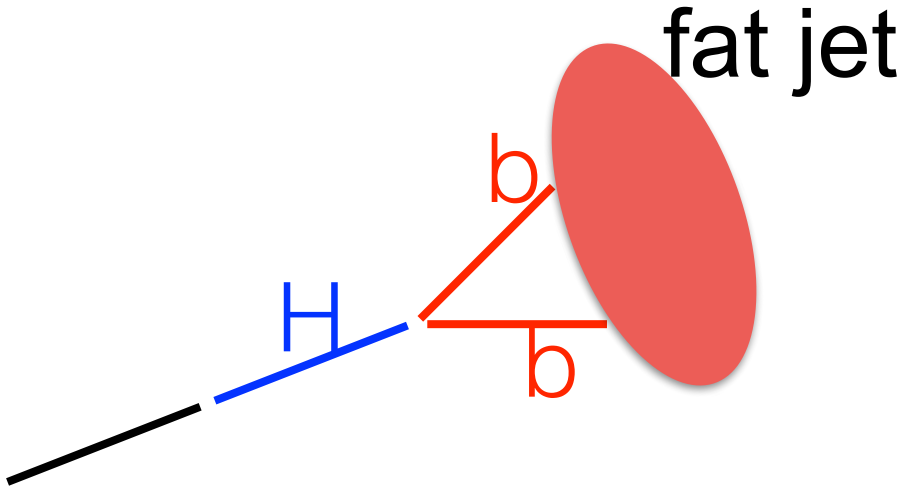
Ask for double b-tagging and look at mass of jet

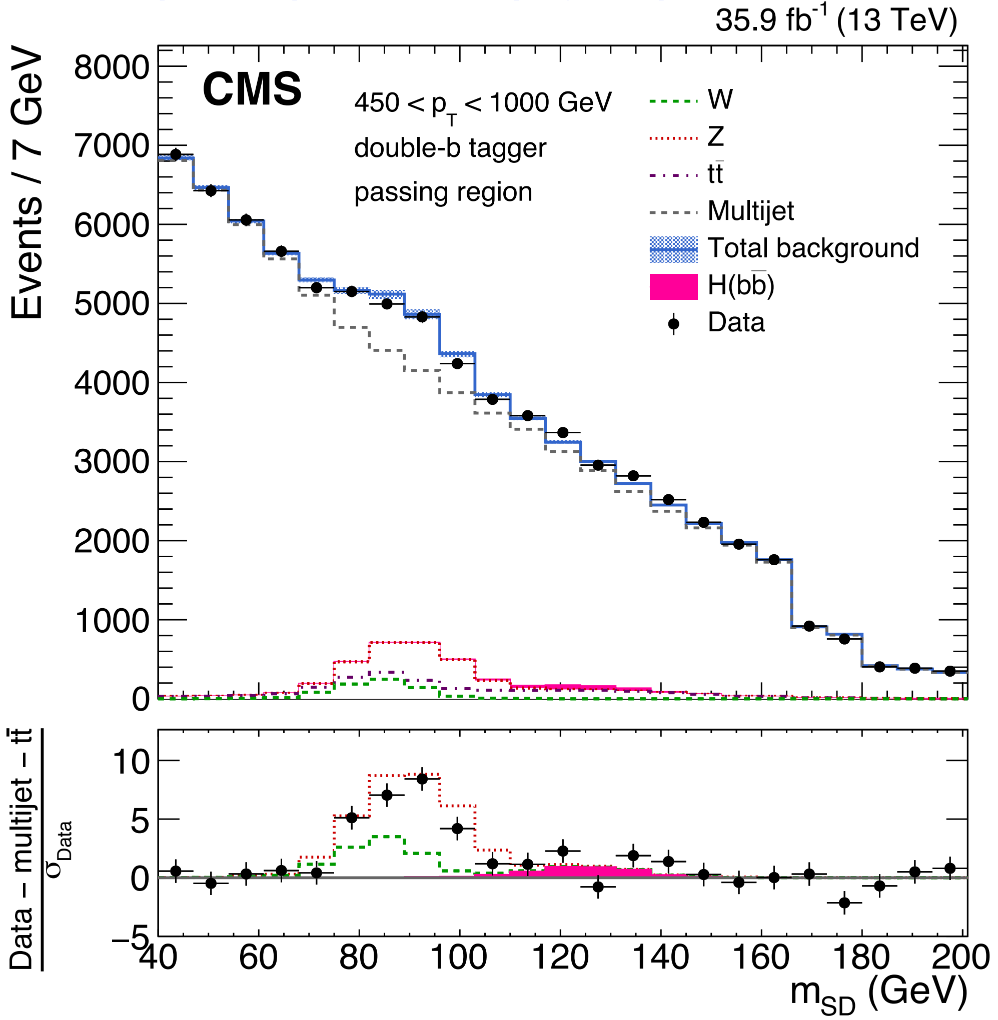
QCD bkg shape from data control region (failing double b-tagging)

Z→bb signal clearly observed as expected

~0.7 sigma expected significance for H, 1.5 sigma observed

σ(pt(H)>450 GeV) /SM prediction=2.3 ± 1.5 (stat)$^{+1.0}_{-0.4}$(syst)





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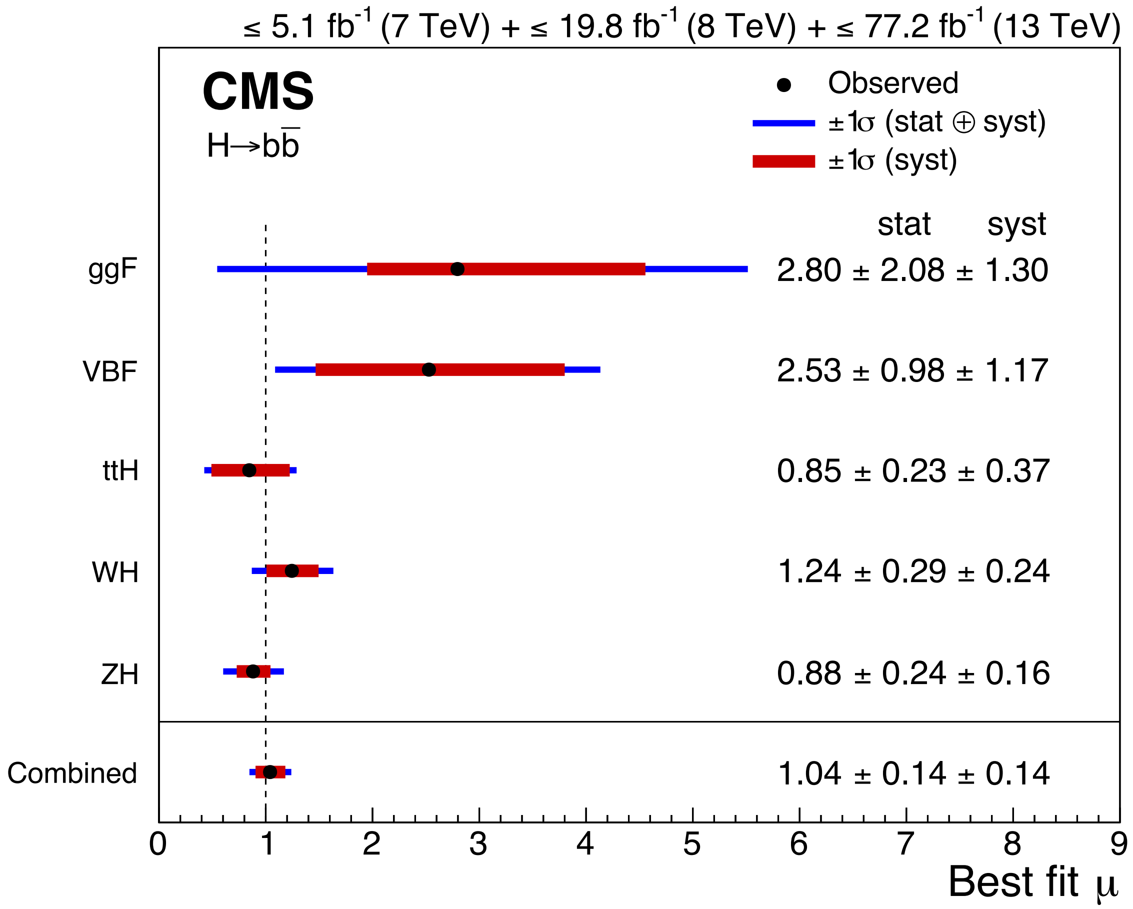
H→bb observation

Combine searches in all channels with bb decay
(including also ttH production mode)
Assume common signal strength
Also combine with run-1 data

Significance of observation : 5.4 sigmas (ATLAS), 5.6 sigmas (CMS)
Observed yield well consistent with SM predictions



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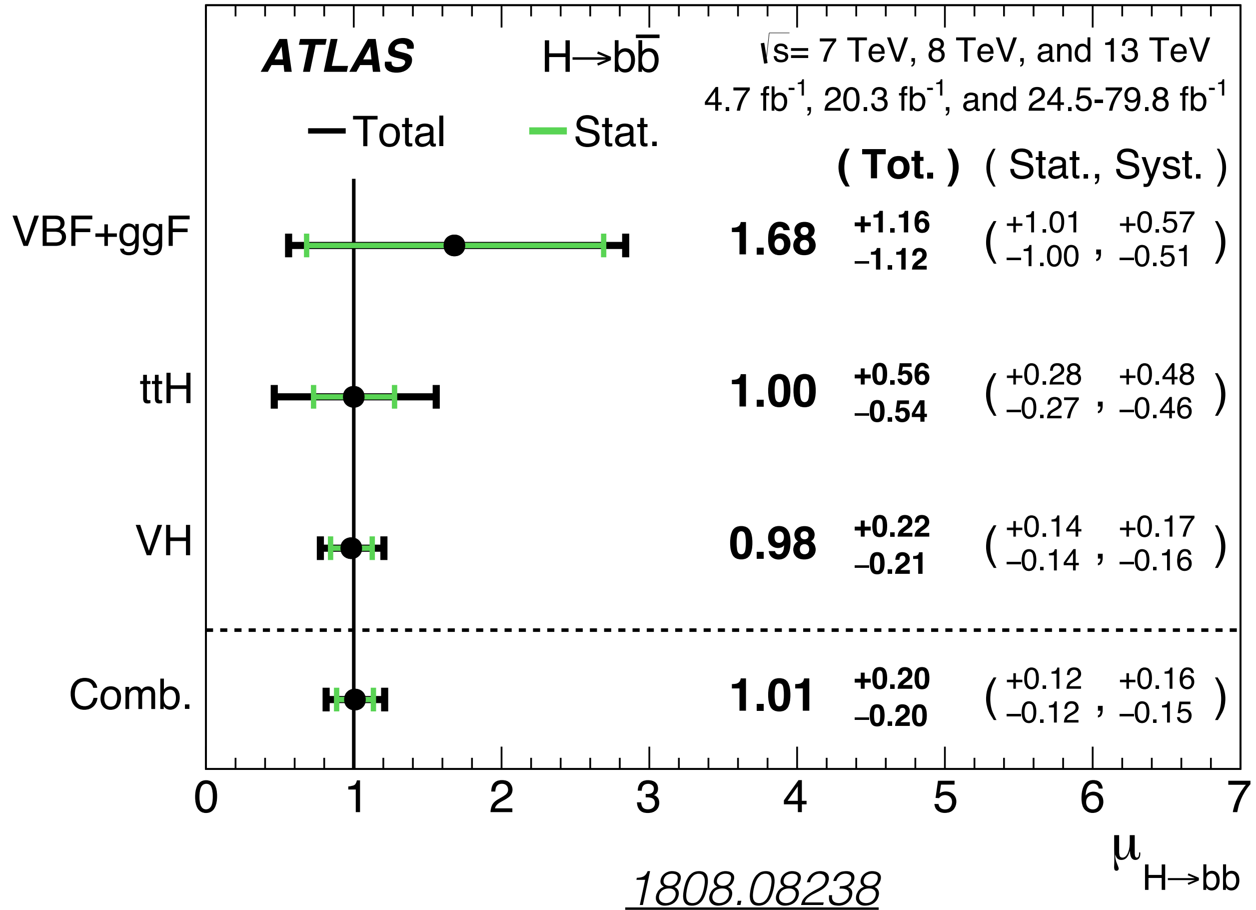

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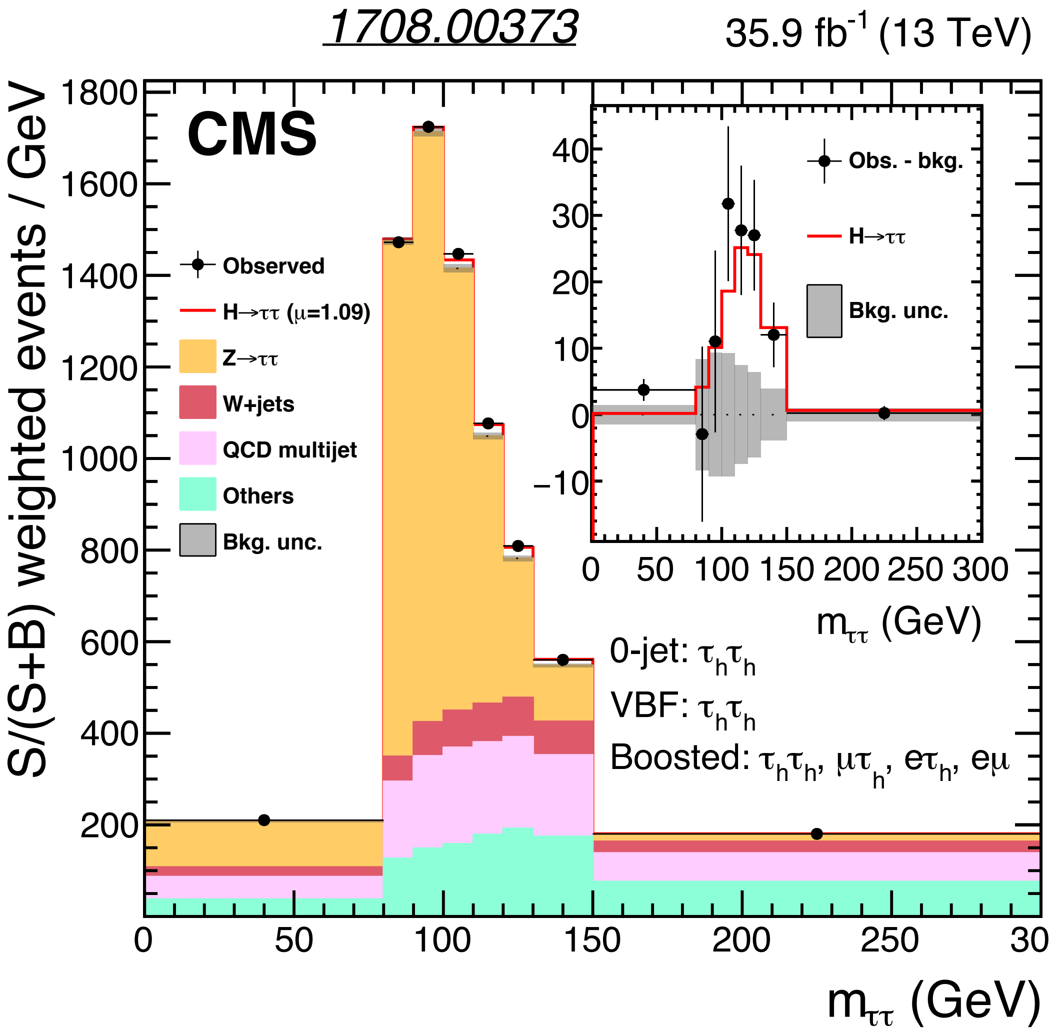
H→tau tau observation

- Different tau decay modes: lep-lep, lep-had, had-had
- Categories according to production: VBF, boosted gg->H
- di-tau mass estimate using visible tau energies and pt(miss)
- Main background is from Z->tau tau (simulation with CR normalization) and fake tau (data driven)
- Fit di-tau mass distribution



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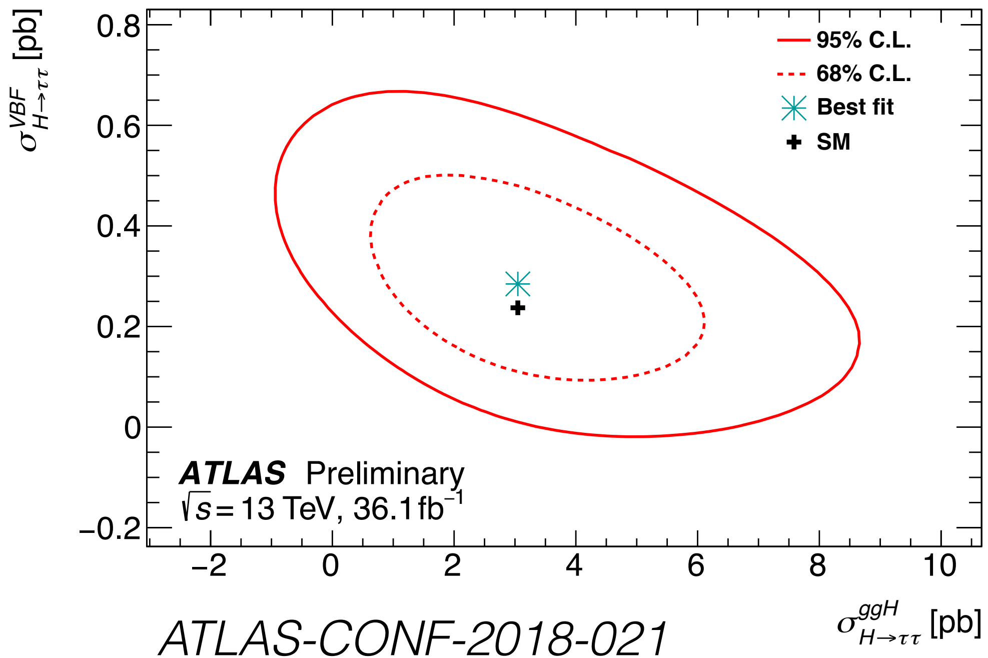


ATLAS-CONF-2018-021

36 fb^{-1} run 2 results + run 1:

Exp. significance: 5.4 (ATLAS) 5.9 (CMS)

Obs significance:6.4 (ATLAS) 5.9(CMS)

Coupling to 2nd generation: H→mu mu

Very low S/B

Main background from continuum Z/γ*→mu mu

Categories targeting gluon fusion and VBF production

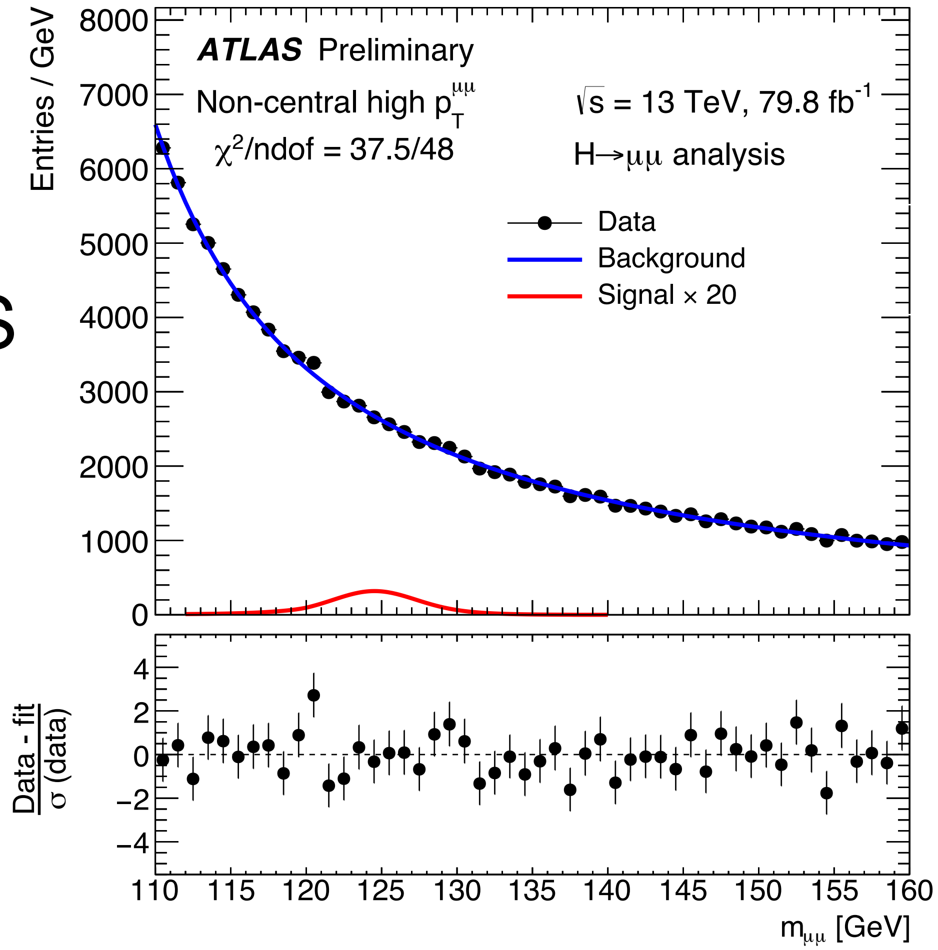
Background parameterized by empirical function

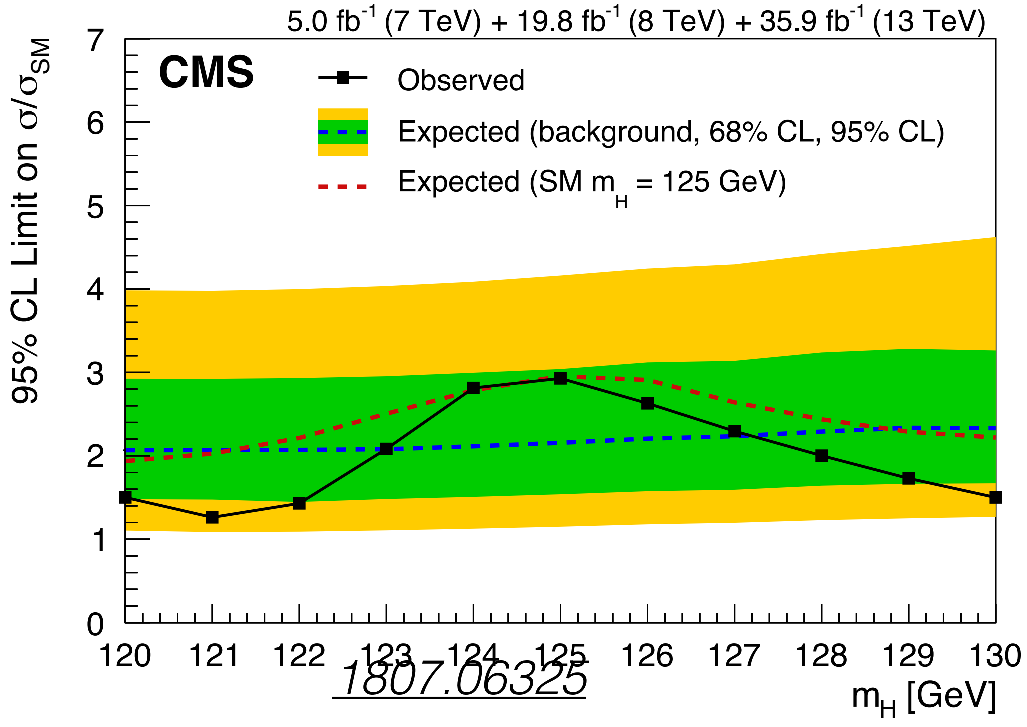
1.2 GeV mass resolution for best category in CMS

~1 standard deviation exp. sensitivity for SM rate

With naive sqrt(L) scaling would need ~ 1000 fb^{-1} for 5 sigma significance

ATLAS-CONF-2018-026





1807.06325

Observed limit: 2.1xSM (ATLAS 80fb^{-1})

2.9xSM (CMS 36fb^{-1} + run 1)

Expected (no SM signal): 2.0 (ATLAS) 2.1 (CMS)

- Couplings to fermions: Observation with run 2 data
    - ttH observation with run 2 data (one of the key goal of run 2)
    - H→bb observation with run 2 data
    - H→ττ observation and H→μμ search
- Decays to bosons: Towards higher precision
    - H→WW, ZZ and γγ
    - (Differential) cross-section measurements
- Combination of all channels
- Rare decay searches
- Run 2 Higgs boson mass and width measurements

Measurements of H→WW

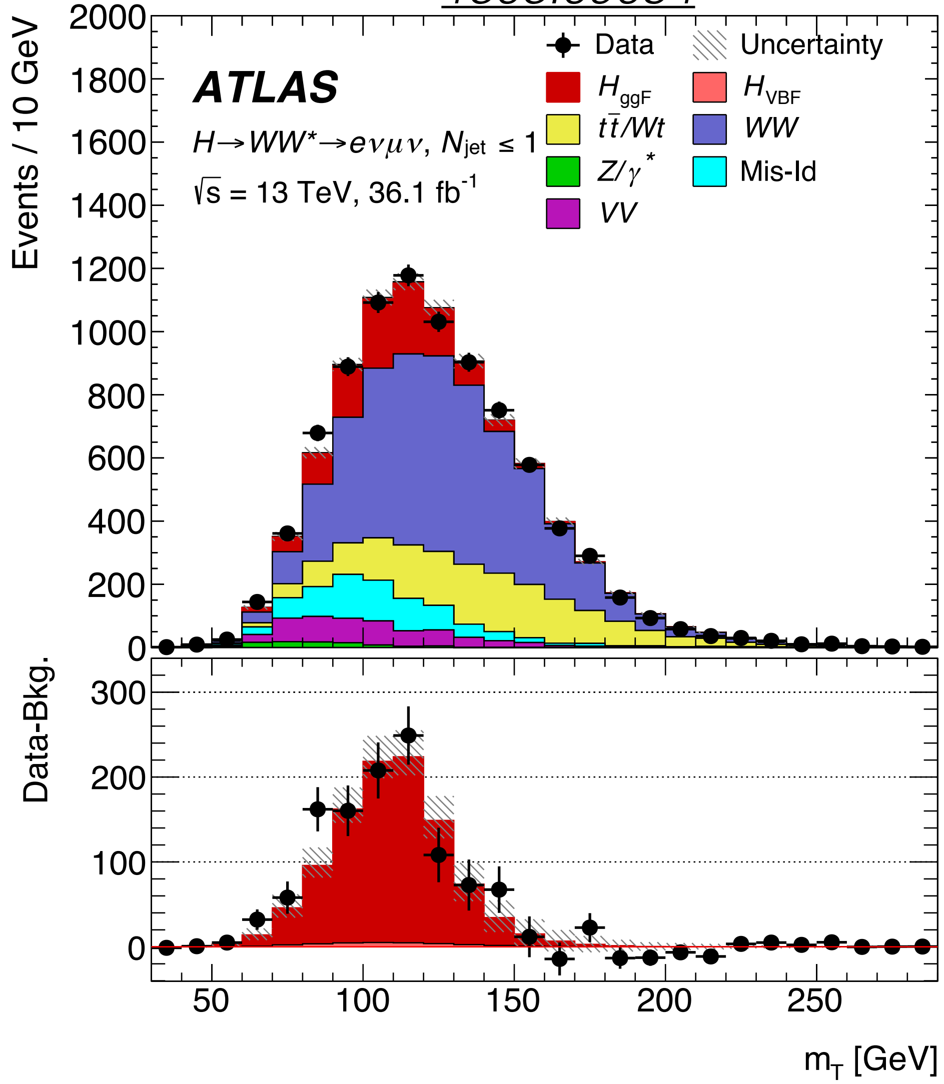
Look at H→WW→l nu l nu (e-mu channel most sensitive)

Mass reconstruction not possible => "counting" experiment

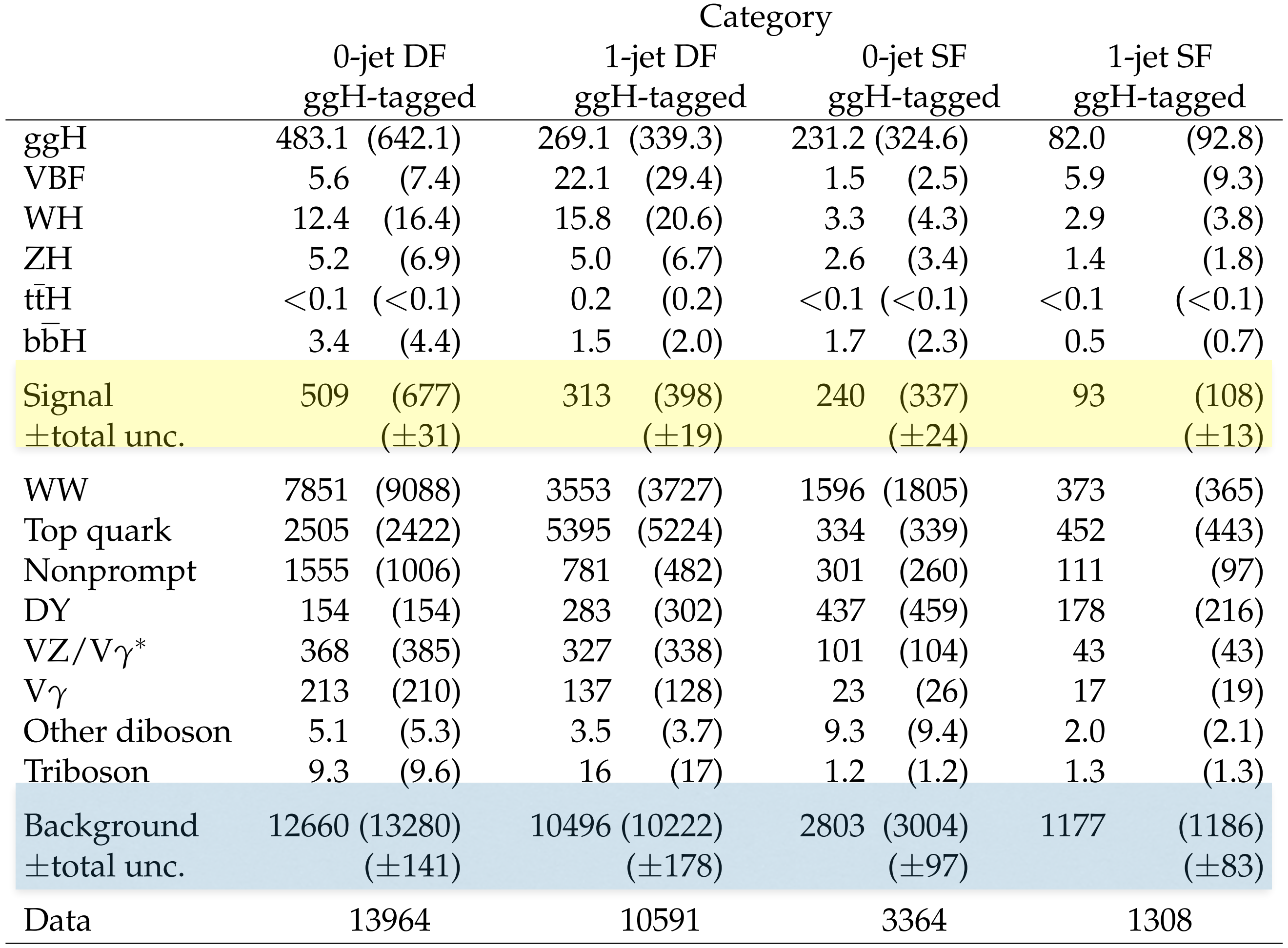
"Large" signal rate but need careful background estimate (S/B<1)

Main backgrounds from WW, top and Wgamma production normalized in control region. Data driven estimate of "fake" lepton backgrounds

1808.09054



example of S and B yield in some categories used by CMS



	Category			
	0-jet DF ggH-tagged	1-jet DF ggH-tagged	0-jet SF ggH-tagged	1-jet SF ggH-tagged
ggH	483.1 (642.1)	269.1 (339.3)	231.2 (324.6)	82.0 (92.8)
VBF	5.6 (7.4)	22.1 (29.4)	1.5 (2.5)	5.9 (9.3)
WH	12.4 (16.4)	15.8 (20.6)	3.3 (4.3)	2.9 (3.8)
ZH	5.2 (6.9)	5.0 (6.7)	2.6 (3.4)	1.4 (1.8)
$t\bar{t}$H	<0.1 (<0.1)	0.2 (0.2)	<0.1 (<0.1)	<0.1 (<0.1)
$b\bar{b}$H	3.4 (4.4)	1.5 (2.0)	1.7 (2.3)	0.5 (0.7)
Signal	509 (677)	313 (398)	240 (337)	93 (108)
±total unc.	(±31)	(±19)	(±24)	(±13)
WW	7851 (9088)	3553 (3727)	1596 (1805)	373 (365)
Top quark	2505 (2422)	5395 (5224)	334 (339)	452 (443)
Nonprompt	1555 (1006)	781 (482)	301 (260)	111 (97)
DY	154 (154)	283 (302)	437 (459)	178 (216)
VZ/Vγ^*	368 (385)	327 (338)	101 (104)	43 (43)
Vγ	213 (210)	137 (128)	23 (26)	17 (19)
Other diboson	5.1 (5.3)	3.5 (3.7)	9.3 (9.4)	2.0 (2.1)
Triboson	9.3 (9.6)	16 (17)	1.2 (1.2)	1.3 (1.3)
Background	12660 (13280)	10496 (10222)	2803 (3004)	1177 (1186)
±total unc.	(±141)	(±178)	(±97)	(±83)
Data	13964	10591	3364	1308

Measurements of H→WW

Measure separately cross-sections for gluon fusion and VBF production

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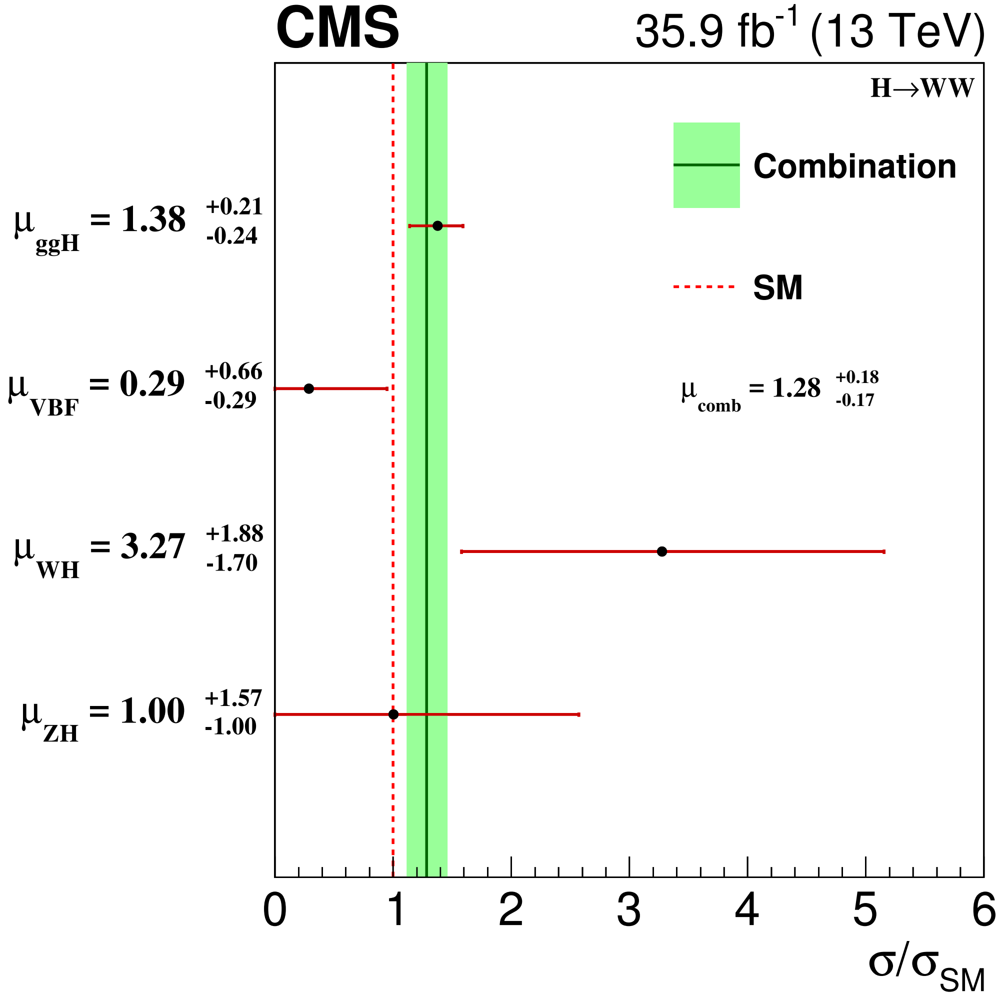

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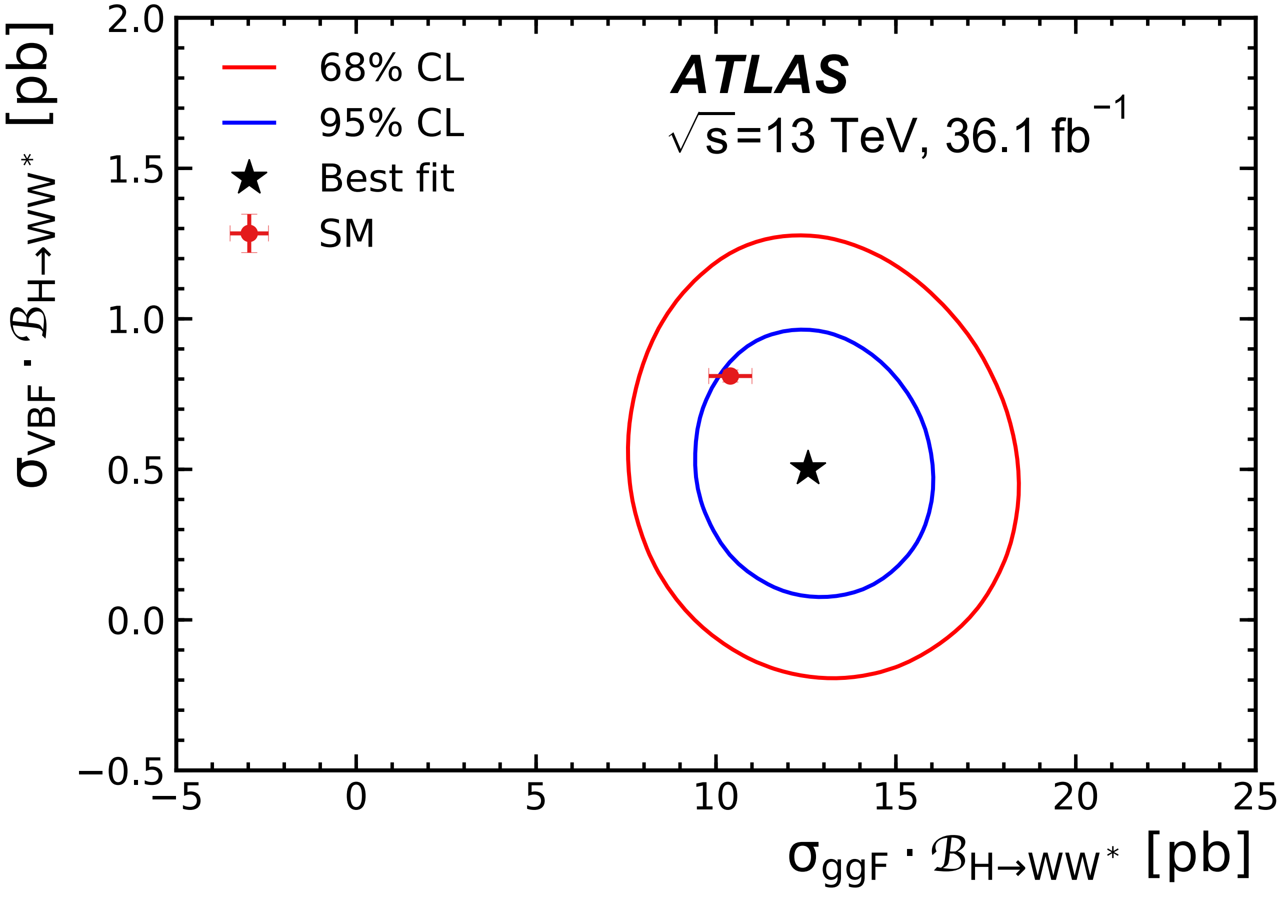


$\mu_{ggF}=1.21\ ^{+0.22}_{-0.21}$

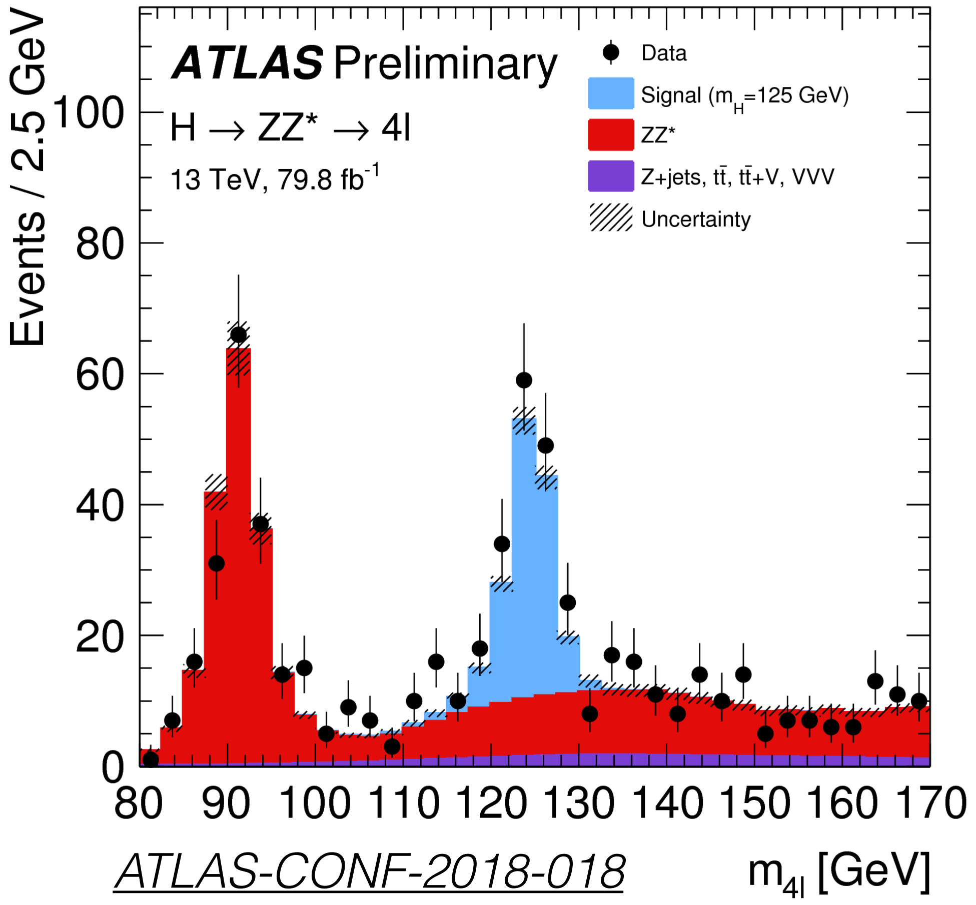
$\mu_{VBF}=0.62\ ^{+0.37}_{-0.36}$

Measurements in H→ZZ→4l channel

Very clean channel
but low rate (BR ~0.009%) and low energy leptons
=> great care to optimize reconstruction and identification of lepton, especially electrons, down to ~5-7 GeV

Background mostly irreducible ZZ* production (from simulation), followed by ttbar and Z+bbbar with non-prompt leptons (from data)

Divide data into categories sensitive to different production modes



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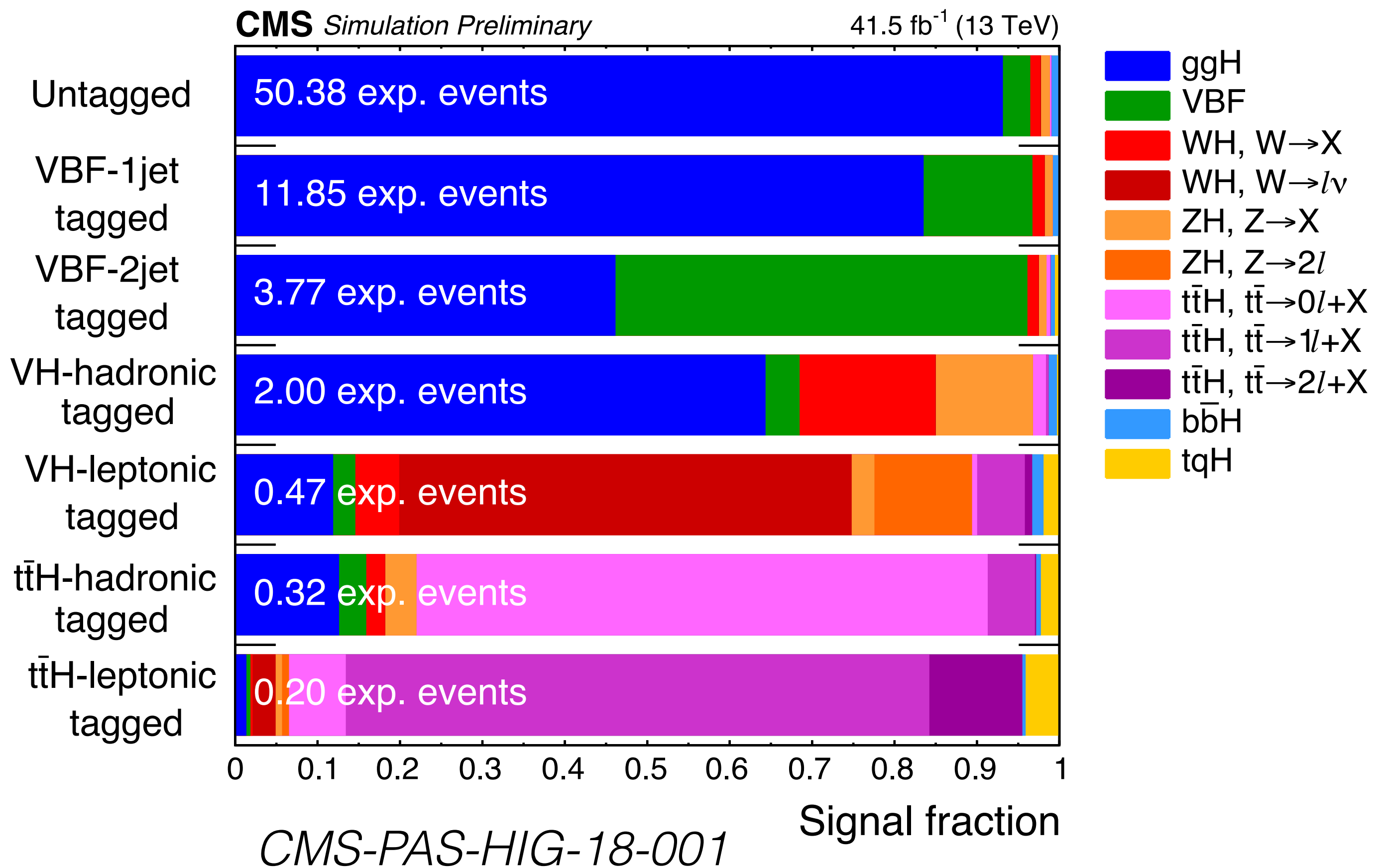


CMS-PAS-HIG-18-001

Measurements in H→gamma gamma

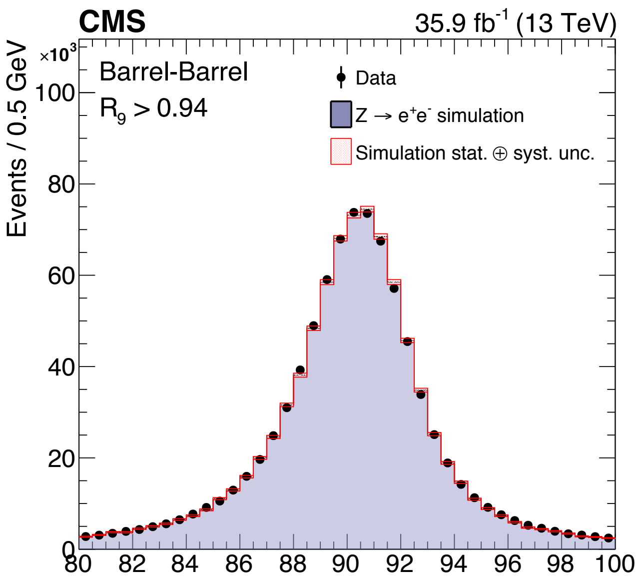
Clear signature with narrow mass peak

BR ~ 0.2%

Large background from (mostly) diphoton production (S/B ~few %)

=> optimize and study mass resolution starting from Z->ee events

=> Categorize events according to S/B and mass resolutions (and production mode) to increase sensitivity



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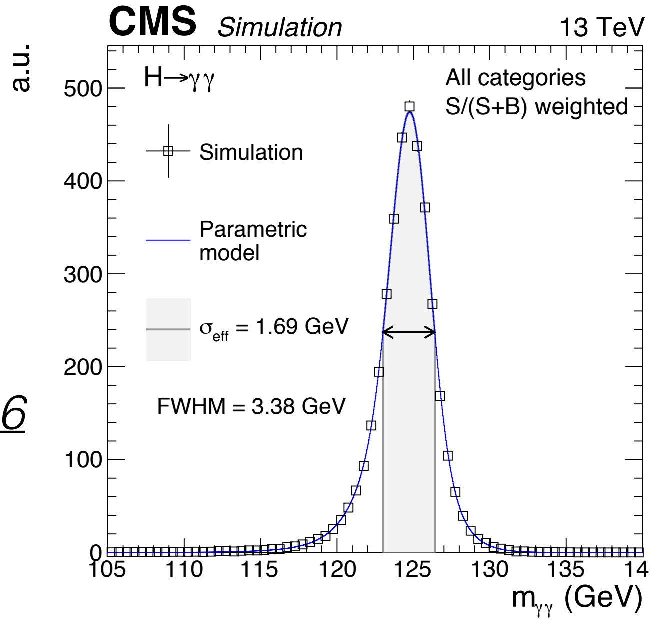
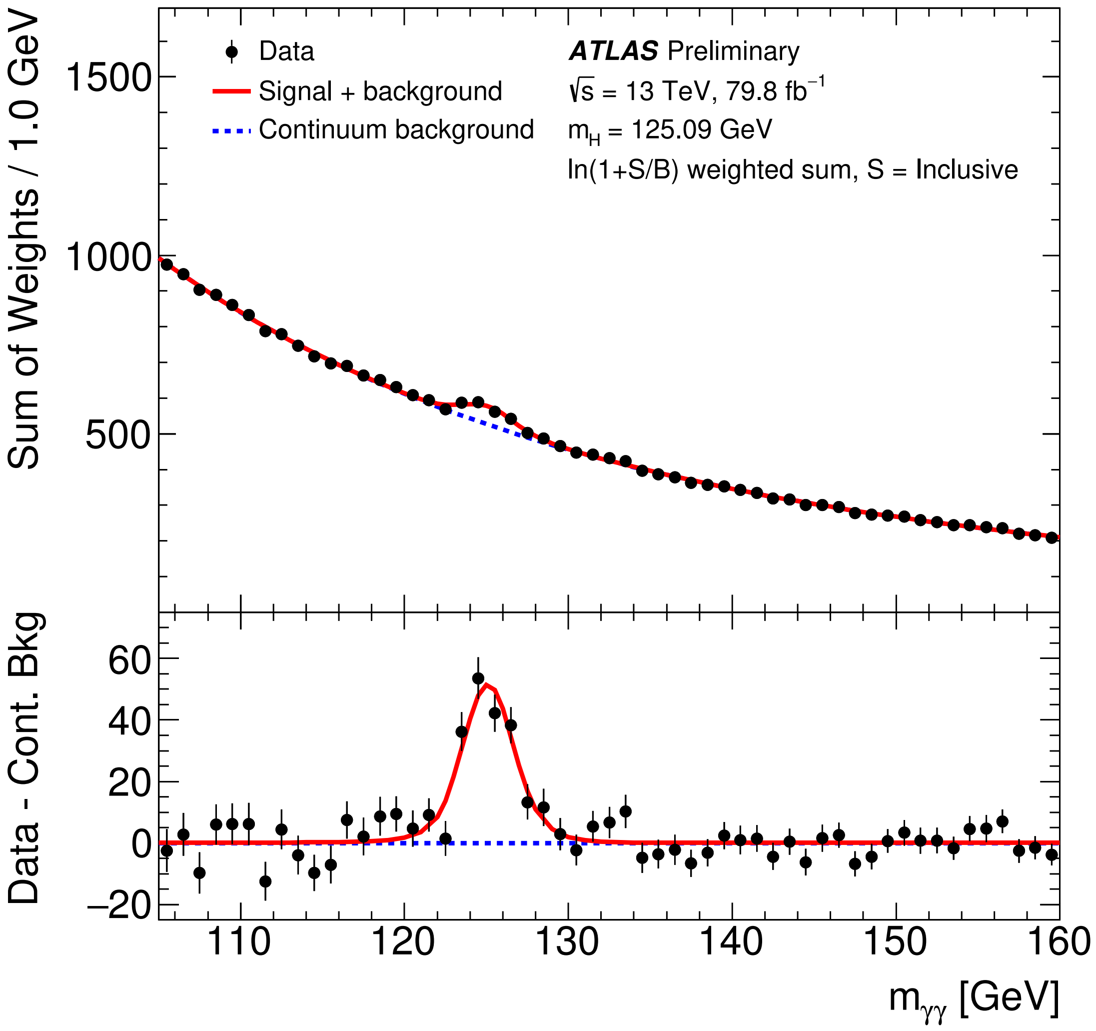
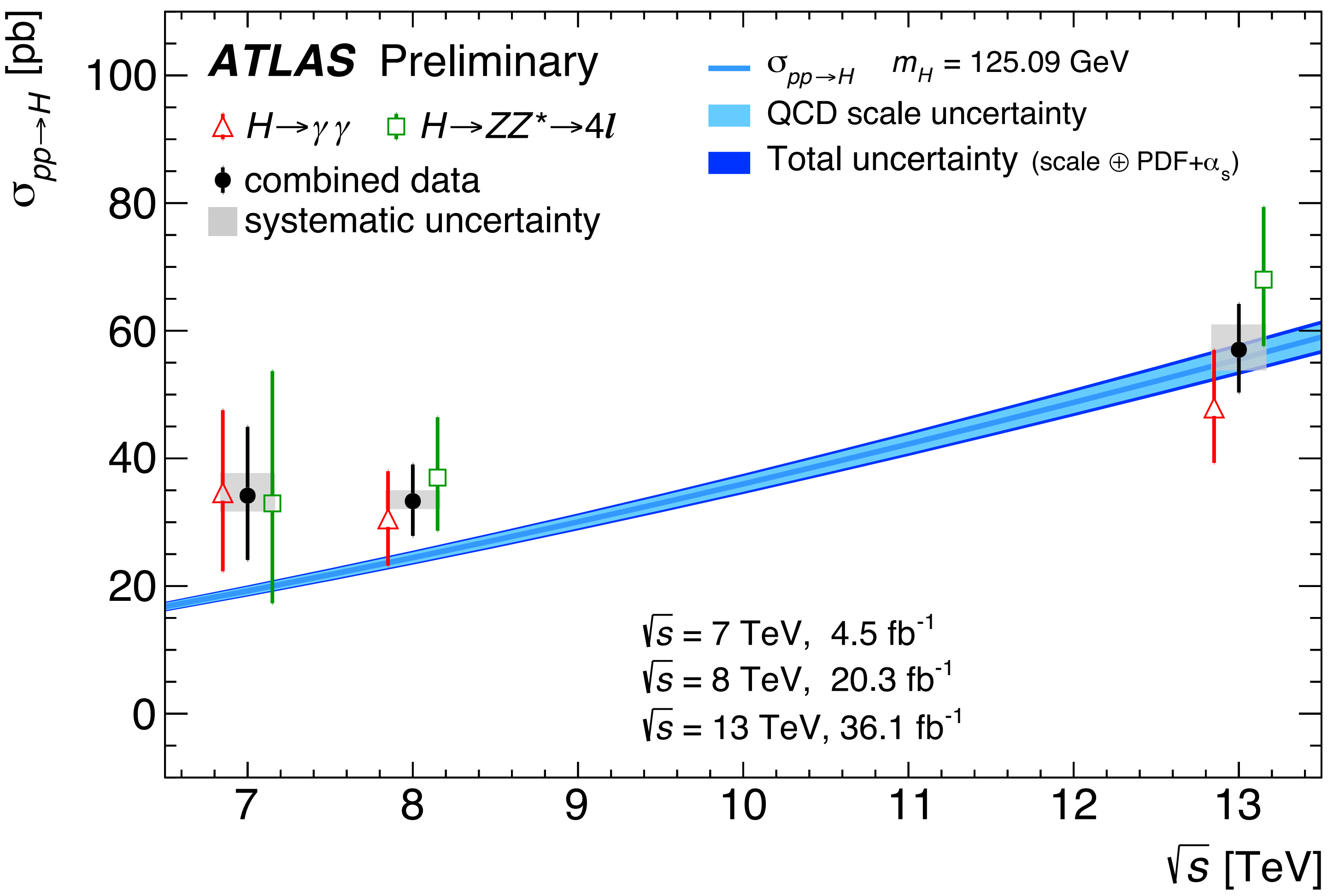


ATLAS-CONF-2018-028



Total cross-section from H→4l and H→gamma gamma



similar accuracy in 4l and gamma-gamma channels

Little model dependance

About 10% accuracy in inclusive cross-section:

57 $^{+6}_{-5.9\ \text{stat}}$ $^{+4}_{-3.3\ \text{syst}}$ pb (ATLAS) 1805.10197

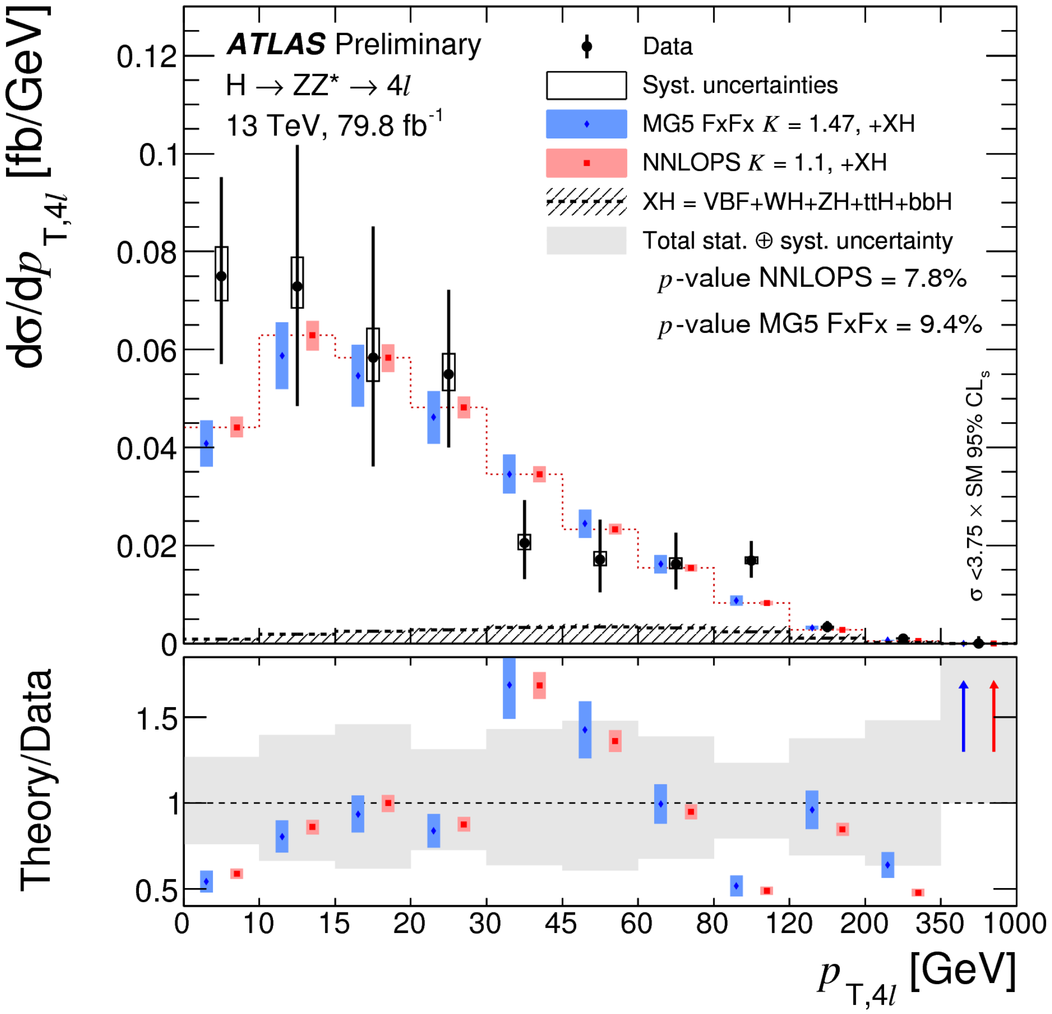
61.1 ±6.0 $_{\text{stat}}$ ± 3.7 $_{\text{syst}}$ pb (CMS) CMS-PAS-HIG-17-028

Theory prediction: 55.6 +- 2.5 pb

Differential cross-section with H→gamma gamma and H→4l

Pt(H) boson

ATLAS-CONF-2018-018



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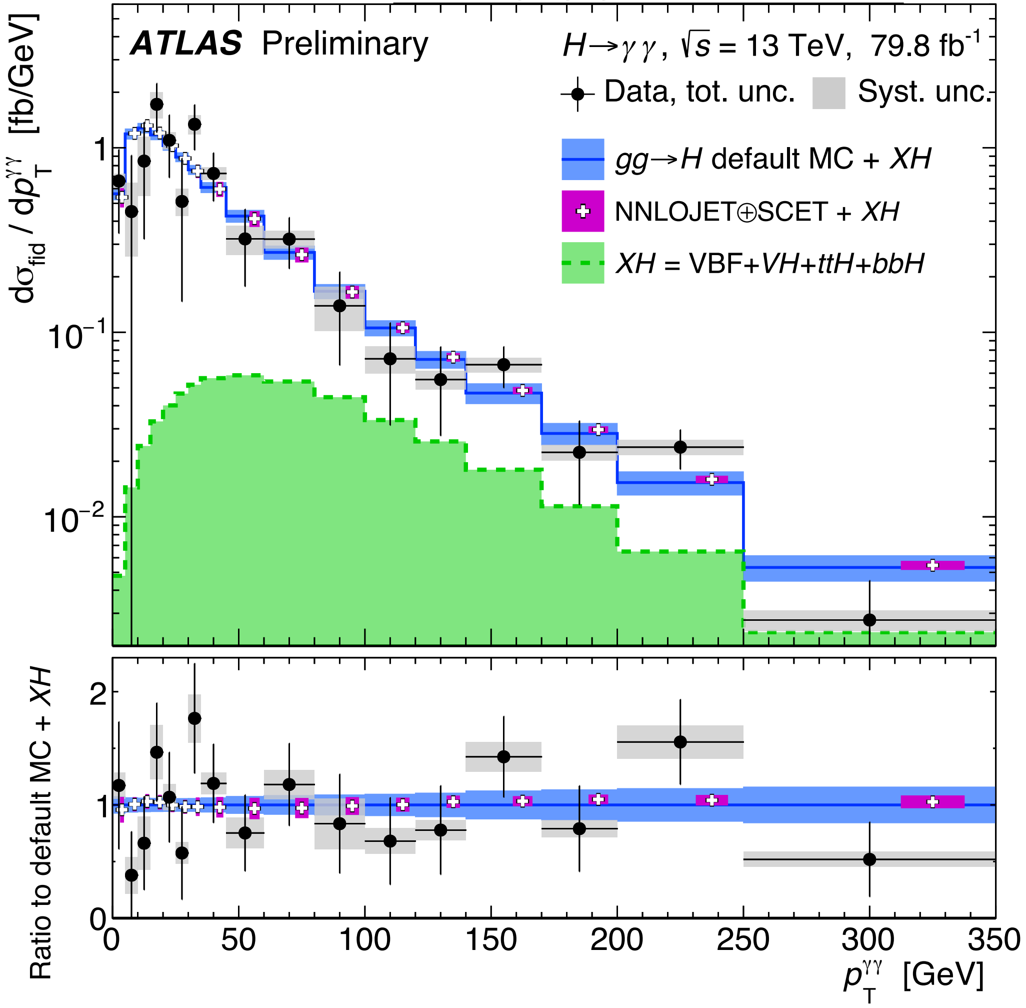
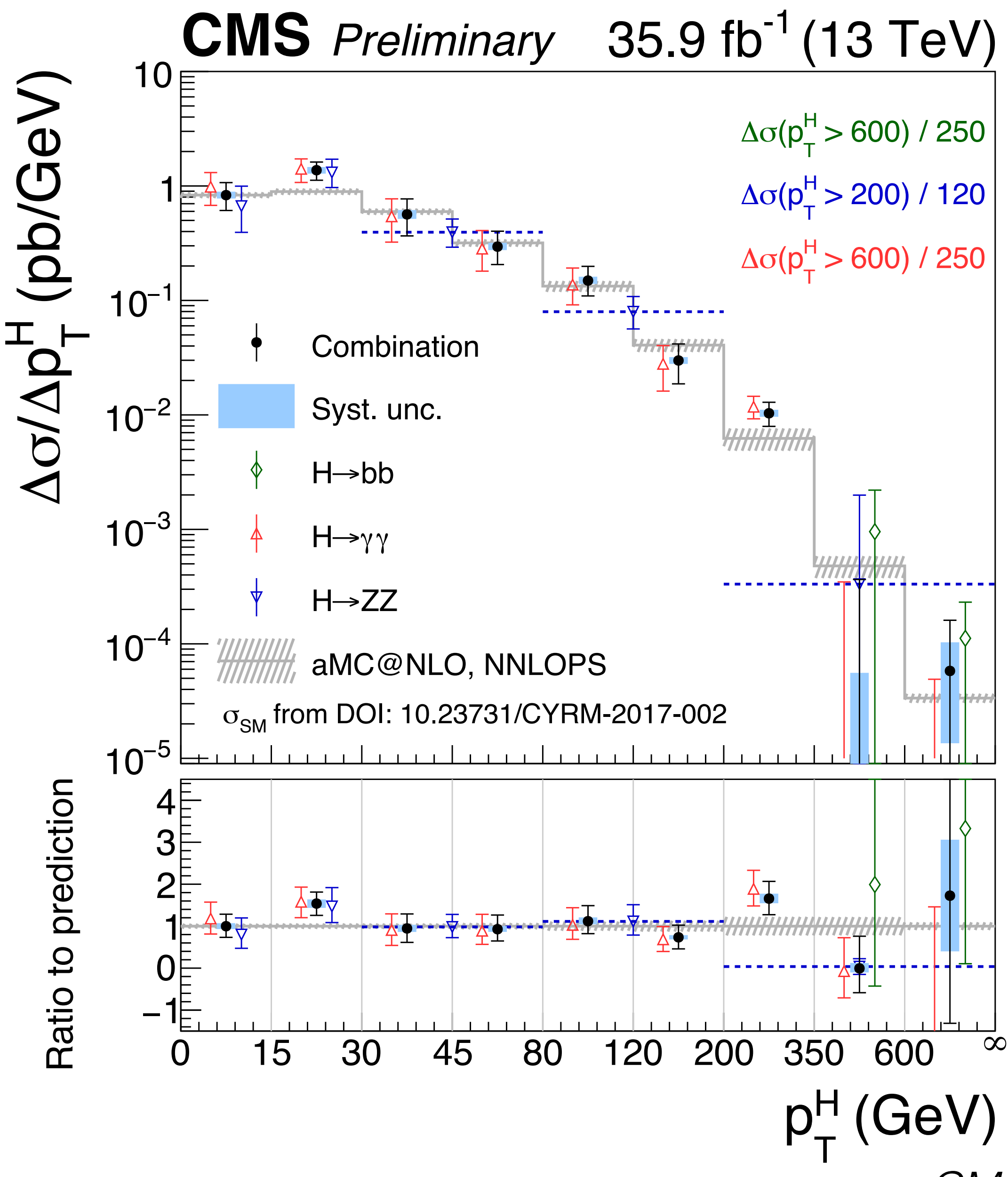
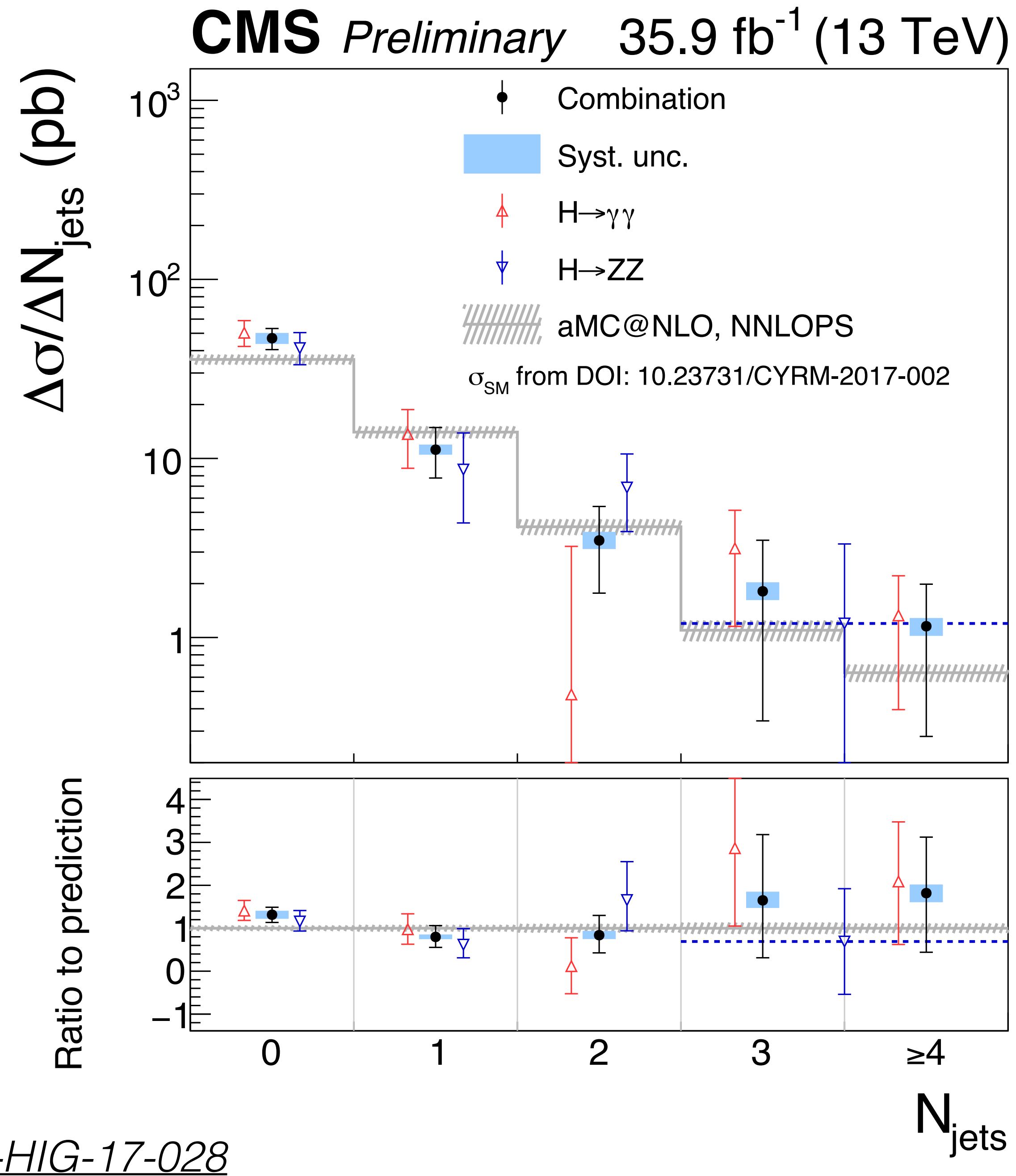


~similar accuracy in gamma-gamma and 4l channels
little model dependance
consistent with SM expectations within uncertainties
Significant reduction of measurement uncertainties compared to run 1

Combination of differential cross-section measurements

Add also boosted gg→H→bb search in high Pt(H) bin
Pt(H) distribution also sensitive to b and c couplings (with some assumption)





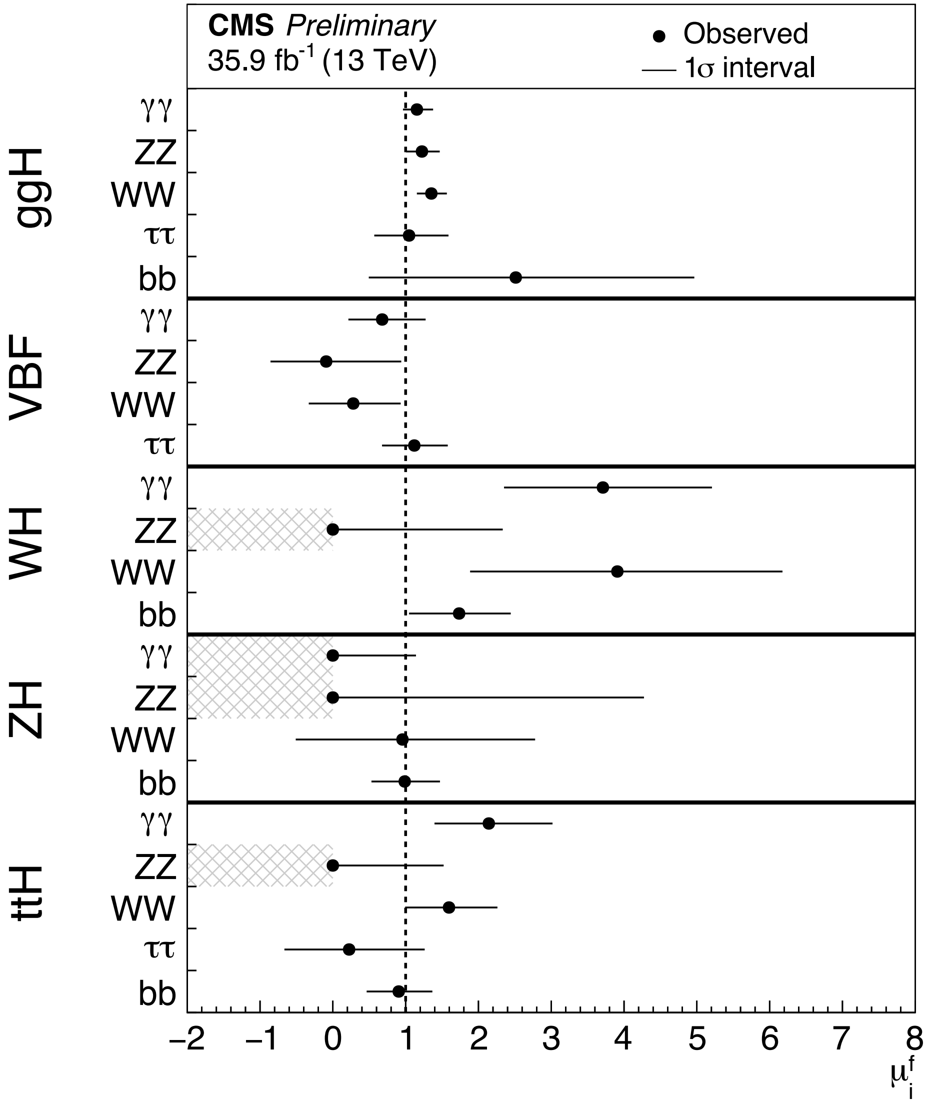
CMS-PAS-HIG-17-028

Combination of Higgs coupling measurements

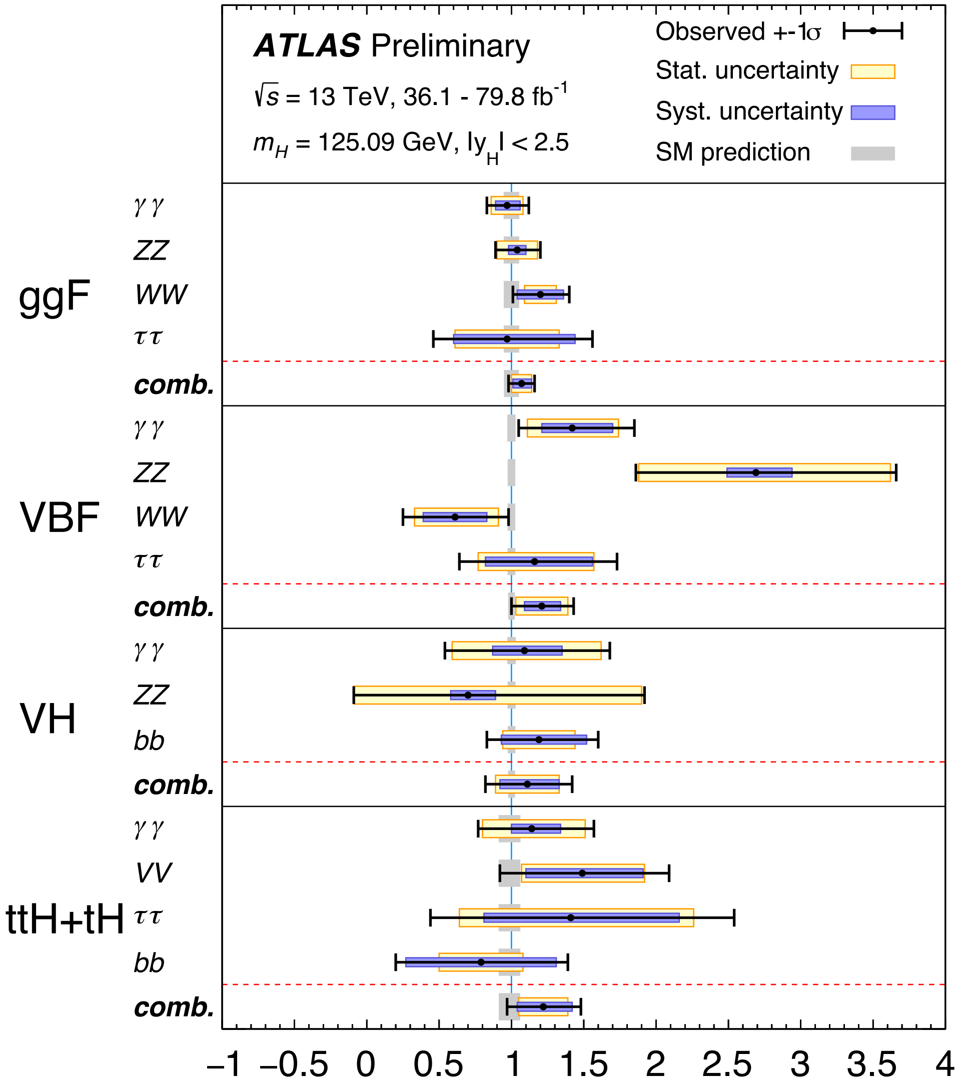
Start from measured sigma*BR in each investigated production mode * decay channel

CMS: 36 fb^{-1} dataset
ATLAS: 36 fb^{-1} dataset , 80 fb^{-1} for gamma-gamma and 4l

CMS-PAS-HIG-17-031



ATLAS-CONF-2018-031

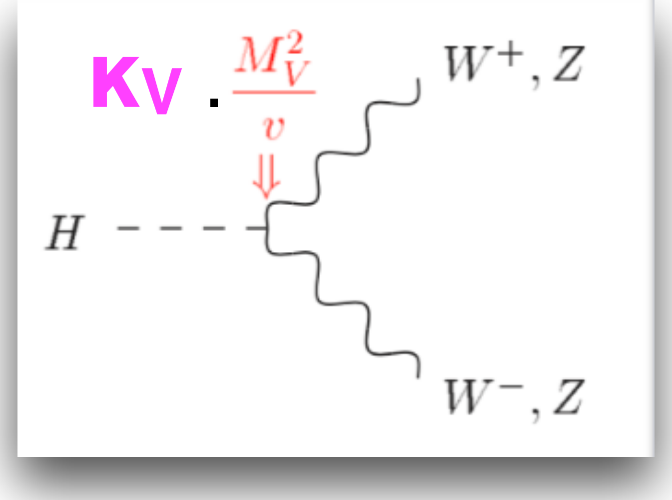


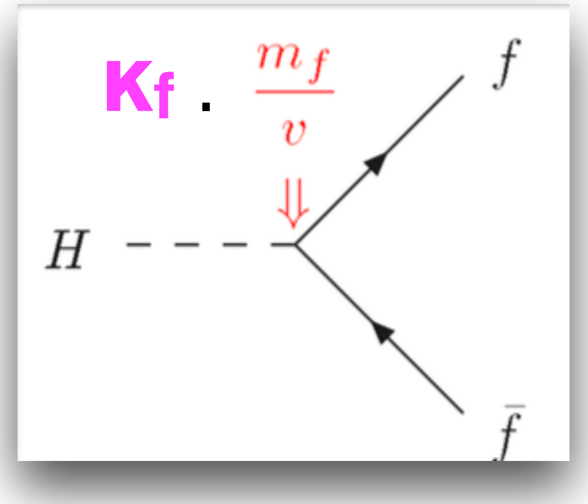
μ = σ × B normalized to SM value

The "kappa" framework

Assume exactly same coupling structure as SM

Modify couplings with LO degrees of freedom





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

Loops (g and γ): either resolved with SM content (assuming no other particles) or write as effective κg,$\kappa\gamma$

Total width: SM contributions rescaled by appropriate **κ**'s. Assume no BSM contribution or allow additional BSM contribution to the width

Main limitation: same kinematics as in Standard Model, not necessarily true if BSM physics

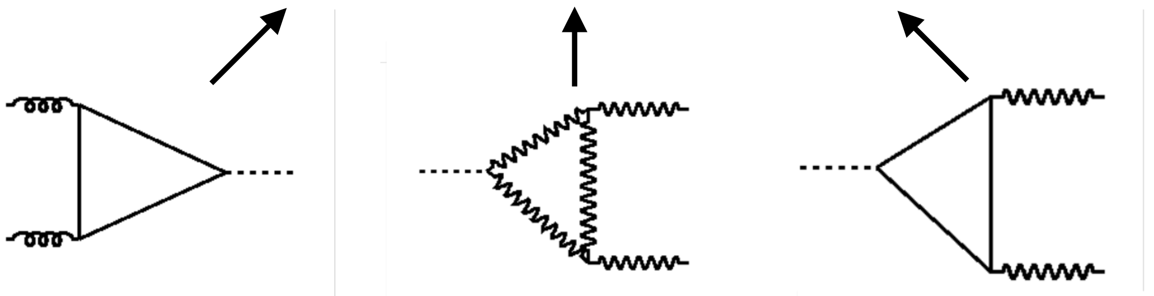
κ dictionary

Production	Loops	Interference	Multiplicative factor
$\sigma(gg\mathrm{F})$	✓	$b-t$	$\kappa_g^2 \sim 1.06 \cdot \kappa_t^2 + 0.01 \cdot \kappa_b^2 - 0.07 \cdot \kappa_t \kappa_b$
$\sigma(V\mathrm{BF})$	–	–	$\sim 0.74 \cdot \kappa_W^2 + 0.26 \cdot \kappa_Z^2$
$\sigma(WH)$	–	–	$\sim \kappa_W^2$
$\sigma(qq/qg \to ZH)$	–	–	$\sim \kappa_Z^2$
$\sigma(gg \to ZH)$	✓	$Z-t$	$\sim 2.27 \cdot \kappa_Z^2 + 0.37 \cdot \kappa_t^2 - 1.64 \cdot \kappa_Z \kappa_t$
$\sigma(ttH)$	–	–	$\sim \kappa_t^2$
$\sigma(gb \to WtH)$	–	$W-t$	$\sim 1.84 \cdot \kappa_t^2 + 1.57 \cdot \kappa_W^2 - 2.41 \cdot \kappa_t \kappa_W$
$\sigma(qb \to tHq)$	–	$W-t$	$\sim 3.4 \cdot \kappa_t^2 + 3.56 \cdot \kappa_W^2 - 5.96 \cdot \kappa_t \kappa_W$
$\sigma(bbH)$	–	–	$\sim \kappa_b^2$
Partial decay width			
Γ^{ZZ}	–	–	$\sim \kappa_Z^2$
Γ^{WW}	–	–	$\sim \kappa_W^2$
$\Gamma^{\gamma\gamma}$	✓	$W-t$	$\kappa^2 \sim 1.59 \cdot \kappa_W^2 + 0.07 \cdot \kappa_t^2 - 0.66 \cdot \kappa_W \kappa_t$
$\Gamma^{\tau\tau}$	–	–	$\sim \kappa_\tau^2$
Γ^{bb}	–	–	$\sim \kappa_b^2$
$\Gamma^{\mu\mu}$	–	–	$\sim \kappa_\mu^2$
Total width for $\mathrm{BR}_{\mathrm{BSM}} = 0$			
Γ_H	✓	–	$\kappa_H^2 \sim 0.57 \cdot \kappa_b^2 + 0.22 \cdot \kappa_W^2 + 0.09 \cdot \kappa_g^2 +$ $+ 0.06 \cdot \kappa^2 + 0.03 \cdot \kappa_Z^2 + 0.03 \cdot \kappa_c^2 +$ $+ 0.0023 \cdot \kappa^2 + 0.0016 \cdot \kappa_Z^2 +$ $+ 0.0001 \cdot \kappa_s^2 + 0.00022 \cdot \kappa^2$

Handbook of LHC Higgs Cross Sections: 3. Higgs Properties" (arXiv:1307.1347)

Example resolving loops

$$\boxed{\text{Rate }(gg\to H\to\gamma\gamma) \sim \kappa_F^2 * (1.6\ \kappa_V^2+0.07\ \kappa_F^2-0.66\ \kappa_F\ \kappa_V)\ /\ (0.75^*\ \kappa_F^2+0.25^*\ \kappa_V^2)}$$



Γ(H)

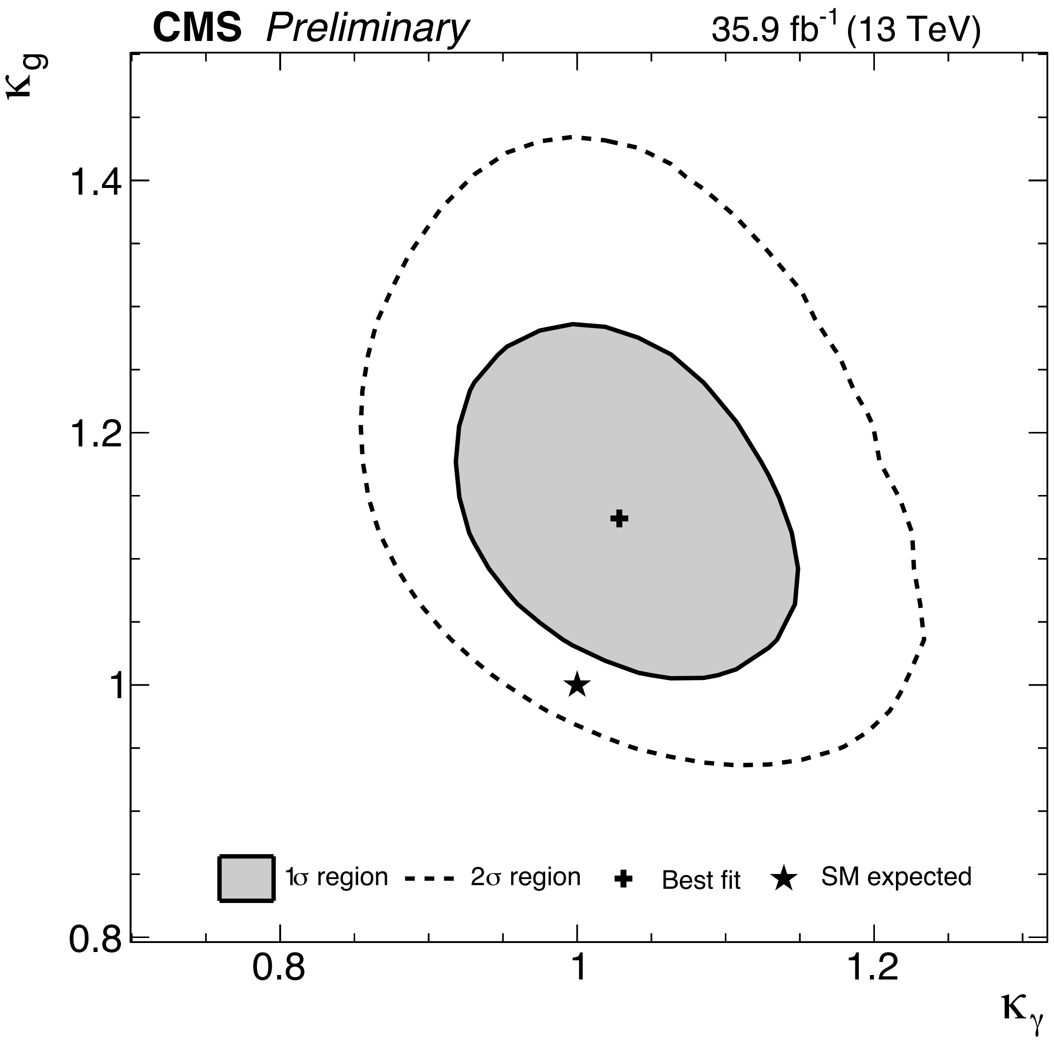
Combination of Higgs coupling measurements

2 different interpretations in "kappa" coupling framework

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

Assuming only two coupling modifiers, one for fermion one for boson. Resolve loops assuming SM particle content

CMS-PAS-HIG-17-031



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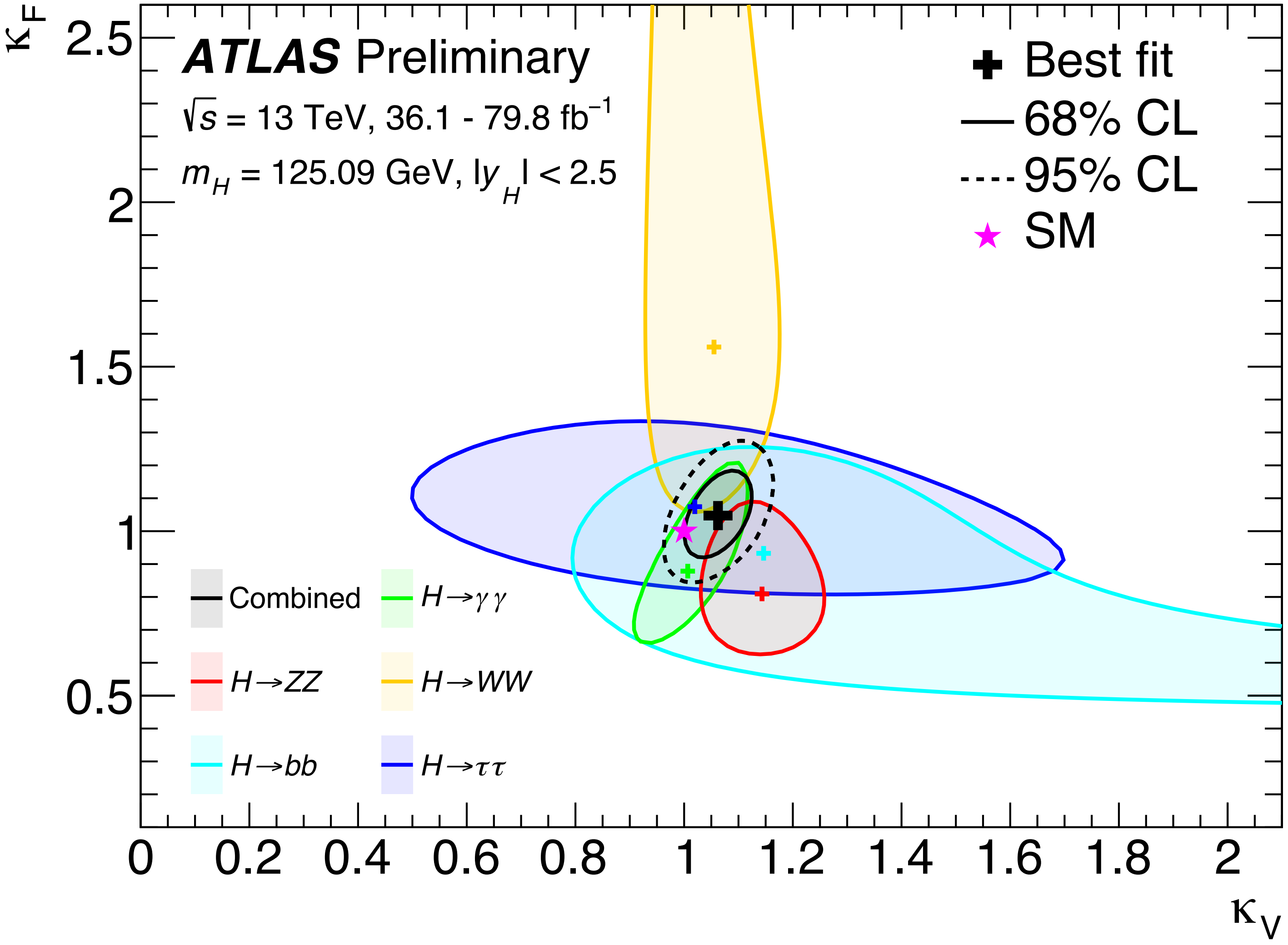


Combination of Higgs coupling measurements

All κ free

Effective loop couplings for g and γ

Total width $\Gamma = \Gamma(\boldsymbol{\kappa})/(1\text{-}BR_{BSM})$

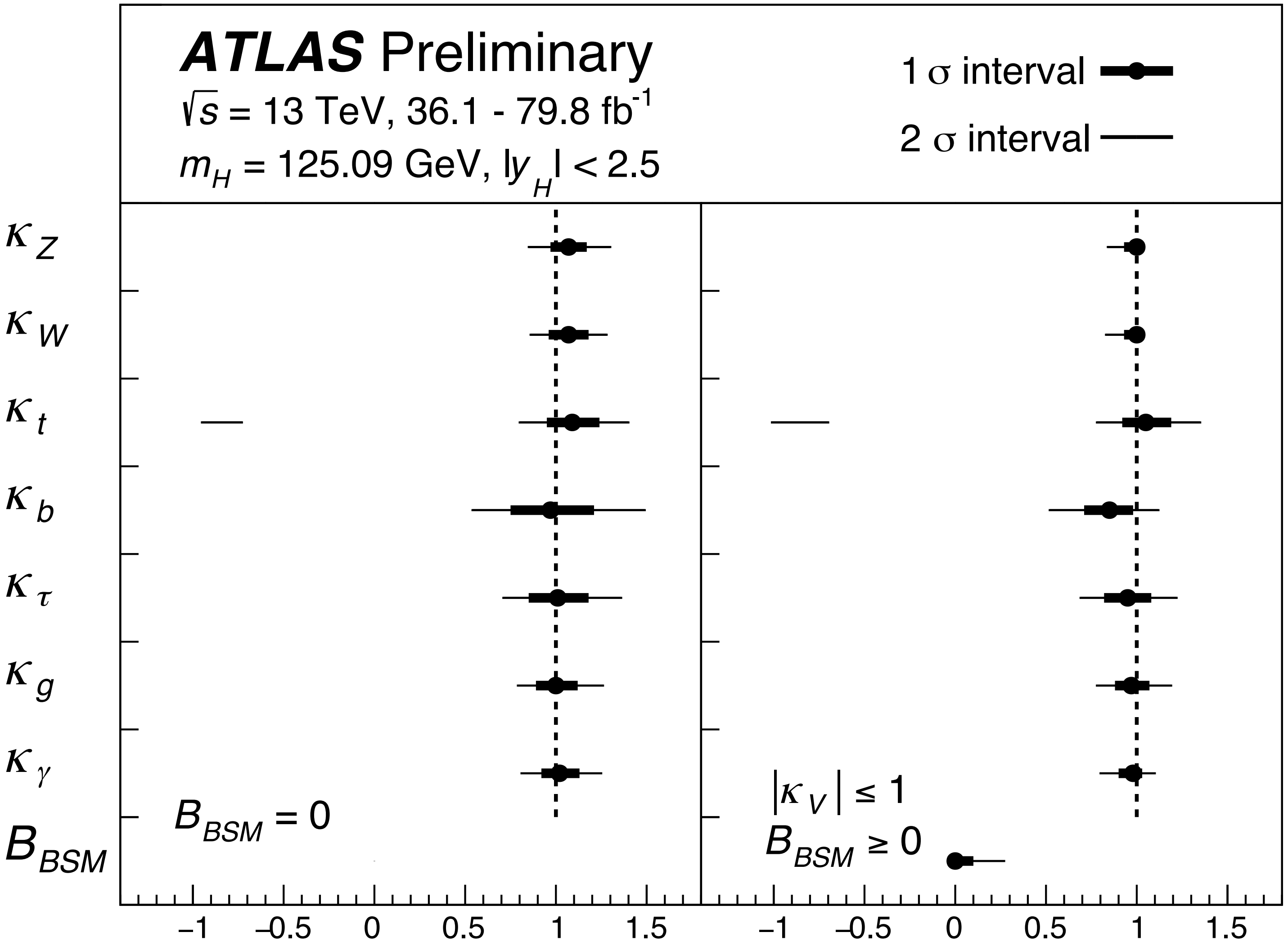
Need some assumption to remove degeneracy between κ and Γ : Either assume $\kappa_V \leq 1$ if BR_{BSM} is free or $BR_{BSM}=0$

ttH measurement crucial to constraint κ_t in this scenario

H→bb important to constrain κ_b (main contribution to total width)

10-20% accuracy on coupling modifiers by single experiment, getting better than combined run 1 ATLAS+CMS

ATLAS-CONF-2018-031



(similar results from CMS)

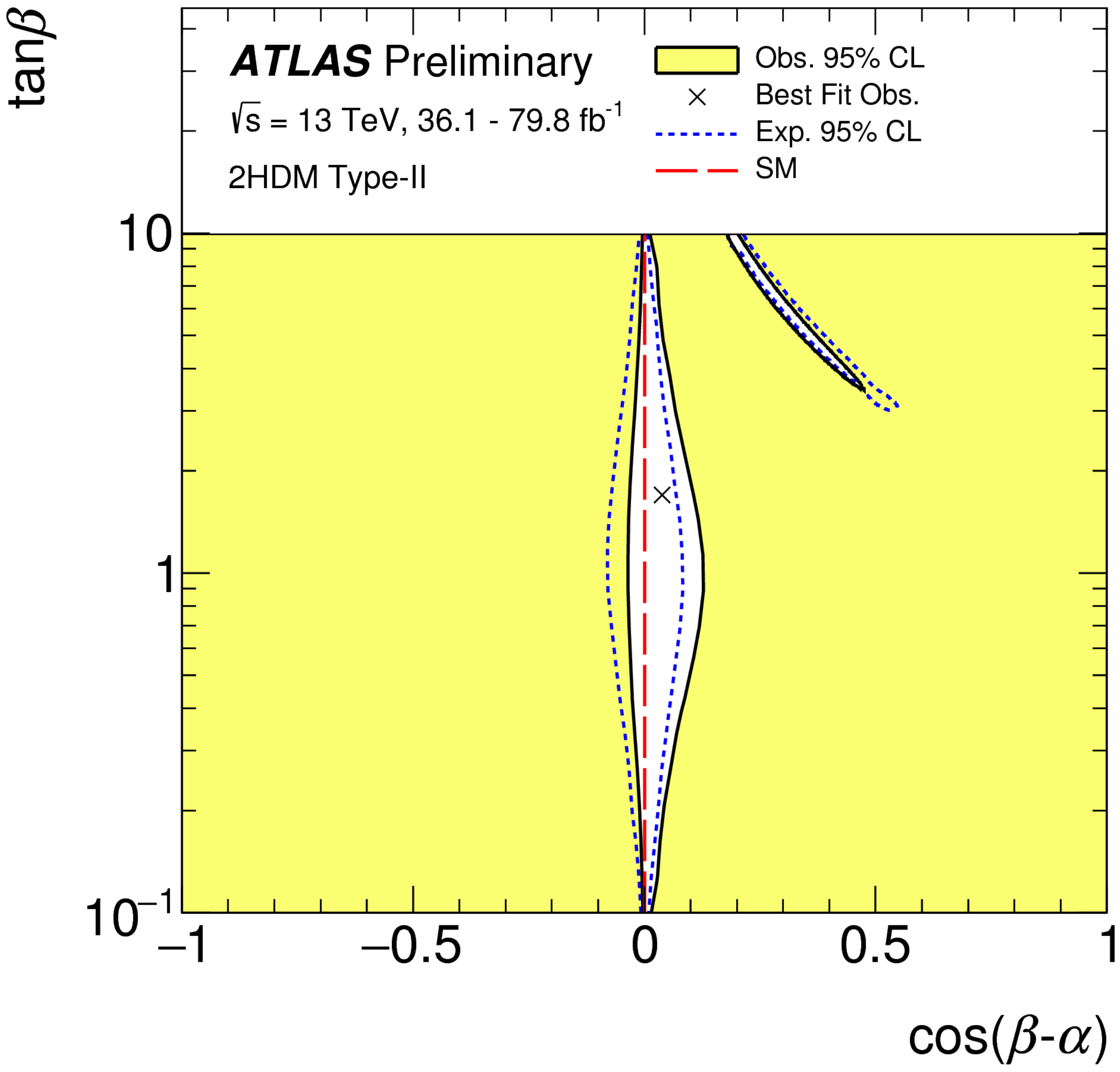
Not discussed here: H selfcoupling (from HH production) still far from SM sensitivity (see next talk)

Example of implications in 2 Higgs doublet Model ("type-II" shown here)

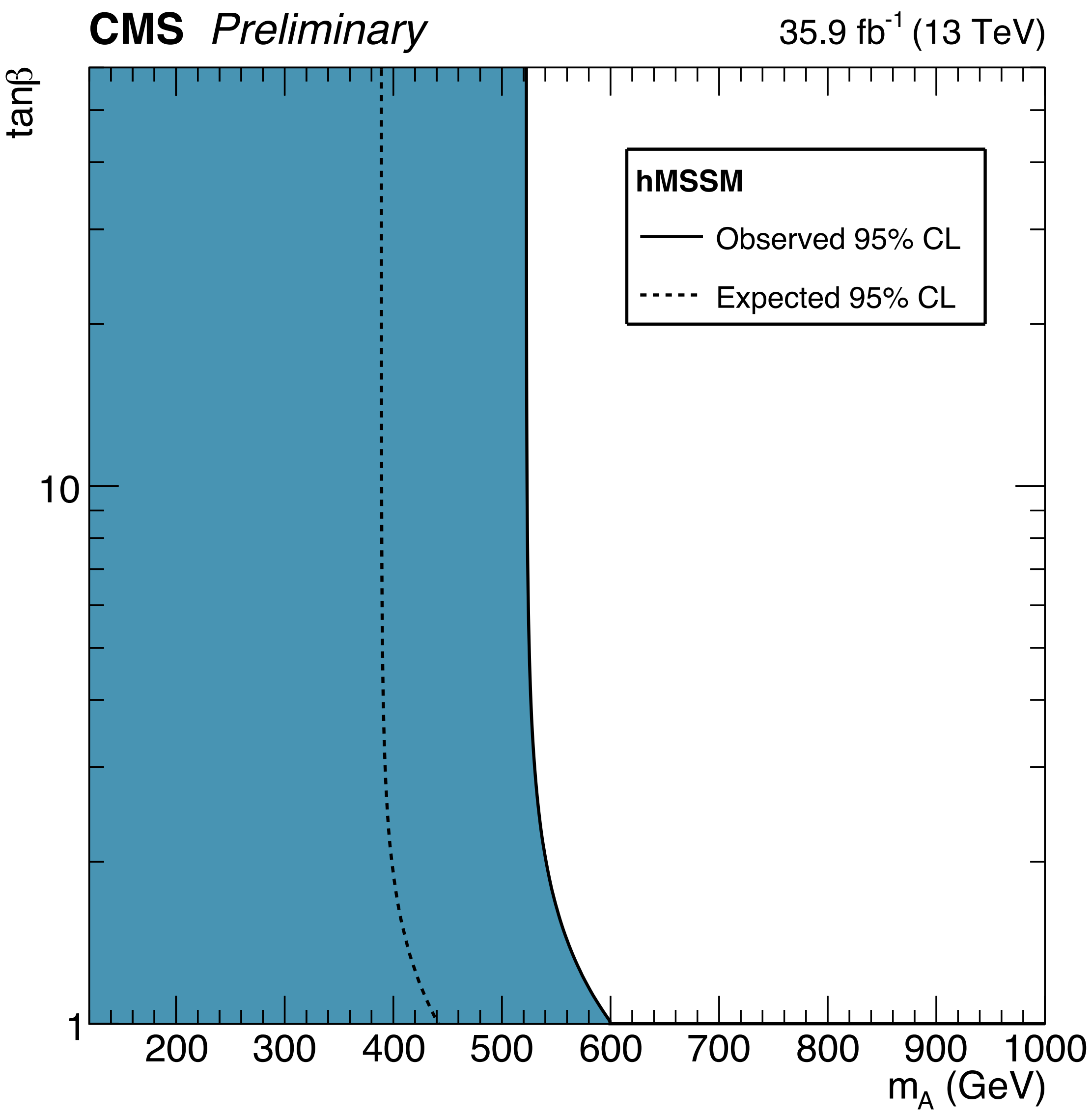
Coupling of heavier scalar Higgs to vector boson scales as
cos(β-α) => the 125 GeV one takes "all" coupling to W and Z
and little left for the heavy scalar

Translating H(125) coupling measurement on limits in (MA,tan(β)) parameters
of a specific hMSSM model

ATLAS-CONF-2018-031



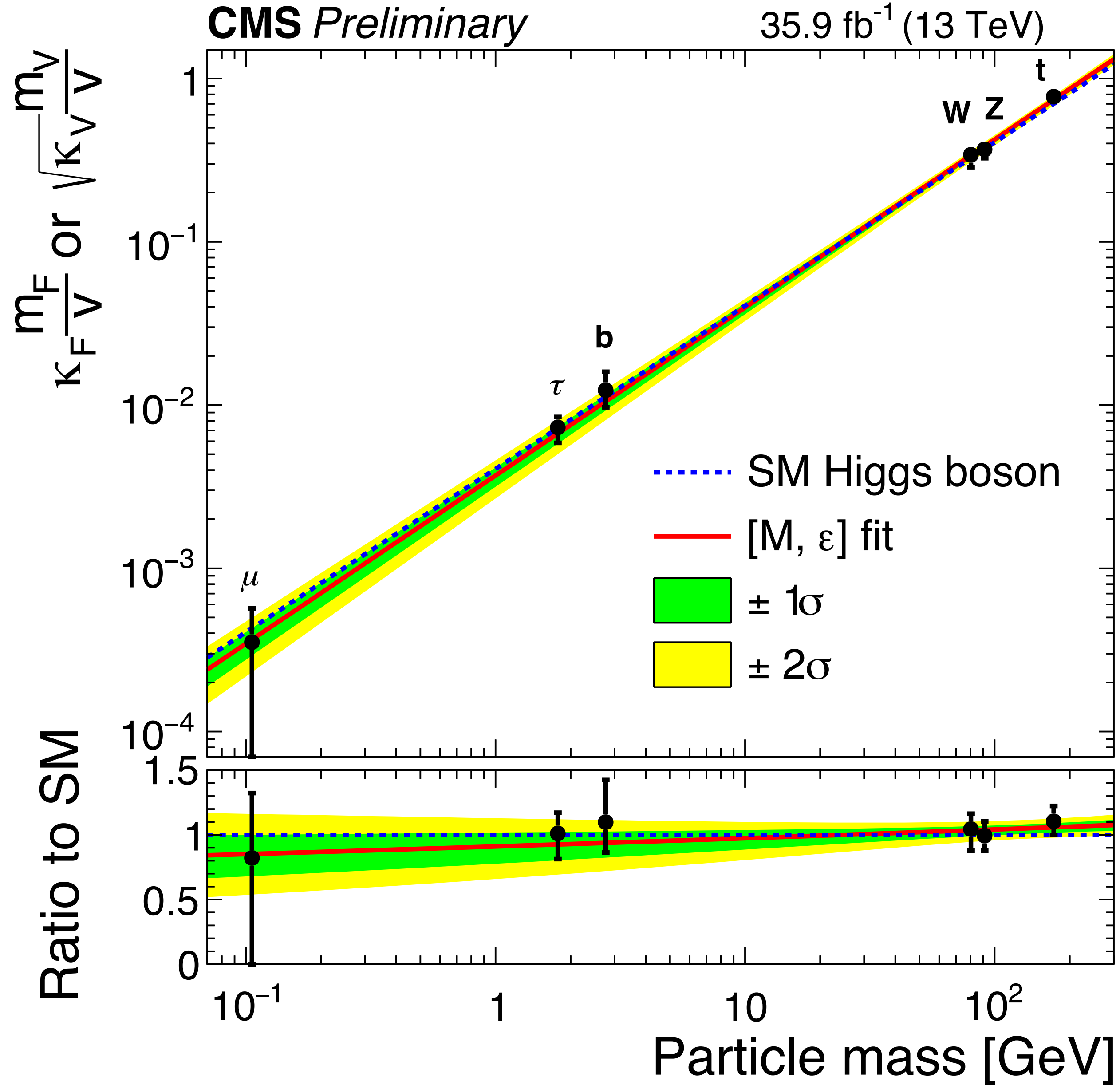
CMS-PAS-HIG-17-031



Combination of Higgs coupling measurements

Scaling of coupling vs particle mass

CMS-PAS-HIG-17-031



(similar results from ATLAS)

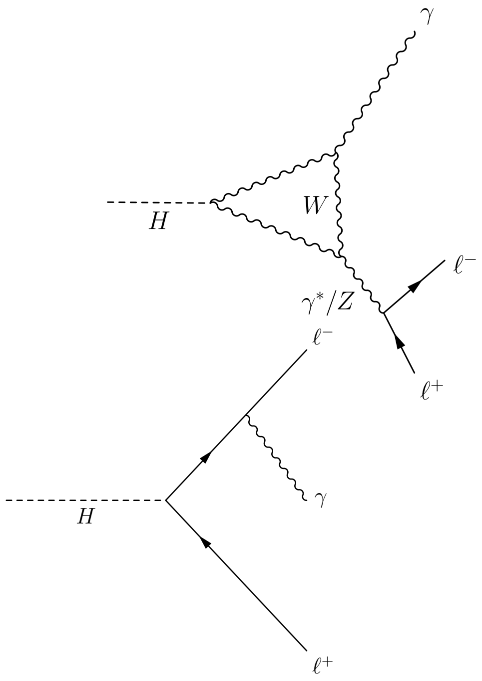
Fit with $\kappa_F = v\ m^{\varepsilon}/M^{1+\varepsilon}$ for fermions and $\kappa_V = v\ m^{2\varepsilon}/M^{1+2\varepsilon}$

M consistent with v and ε consistent with 0 (SM prediction)

Searching for rare H decays

(examples)

H→ ll gamma



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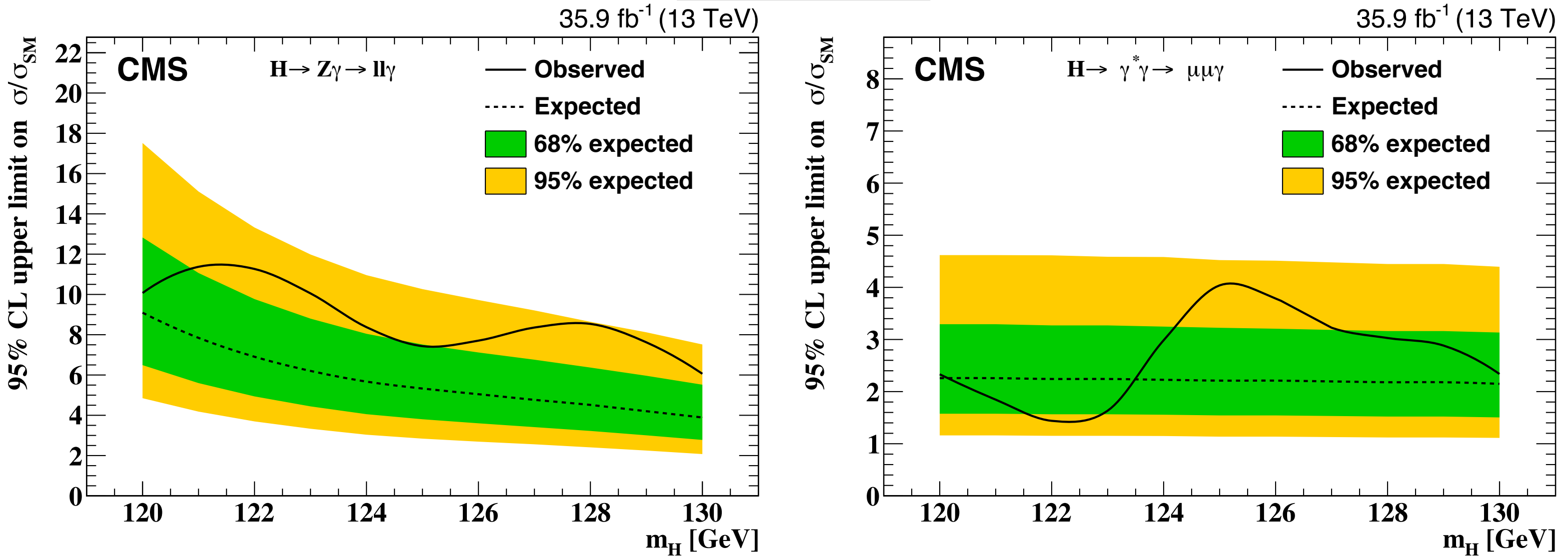

H→ J/psi gamma (→ mu mu gamma)

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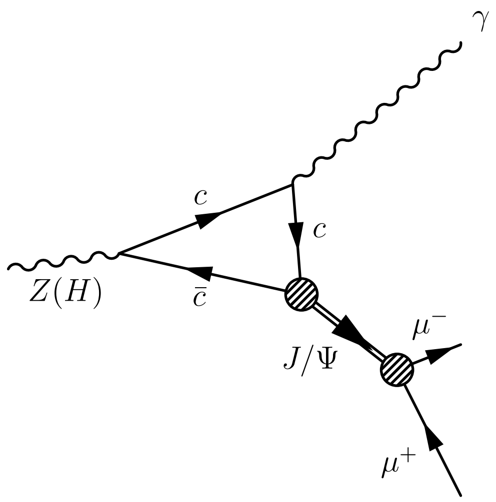

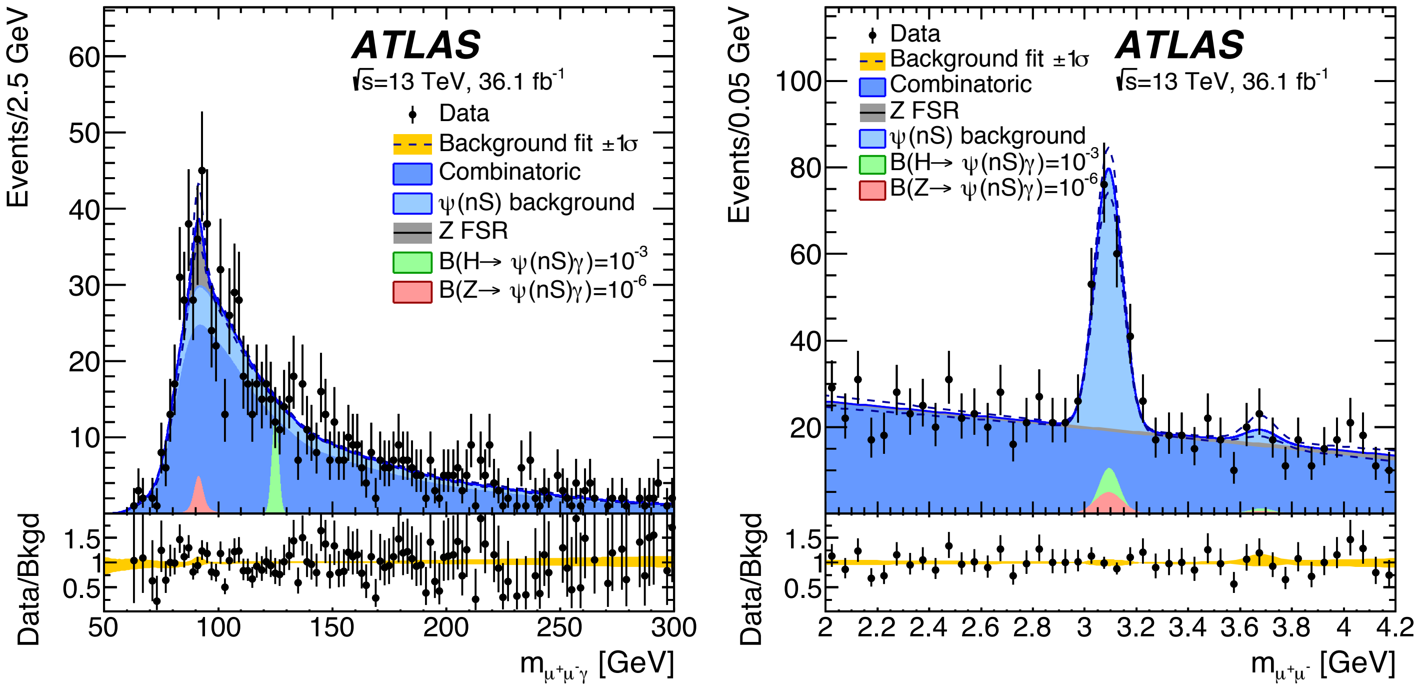

BR<3.5 10^{-4}
(120xSM)

See next talk for H→ new particles and lepton flavor violation decay

Run-2 Higgs boson mass measurements

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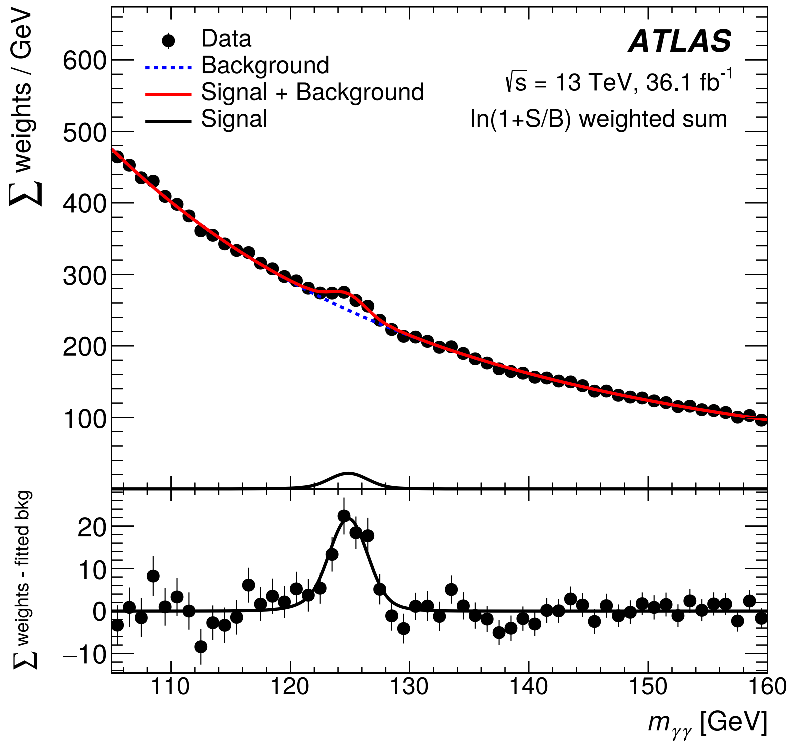
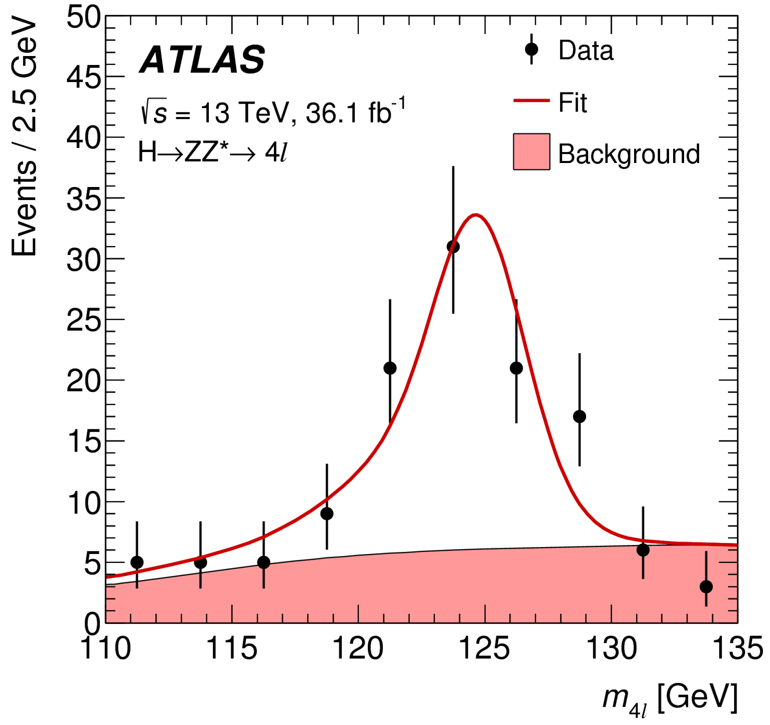
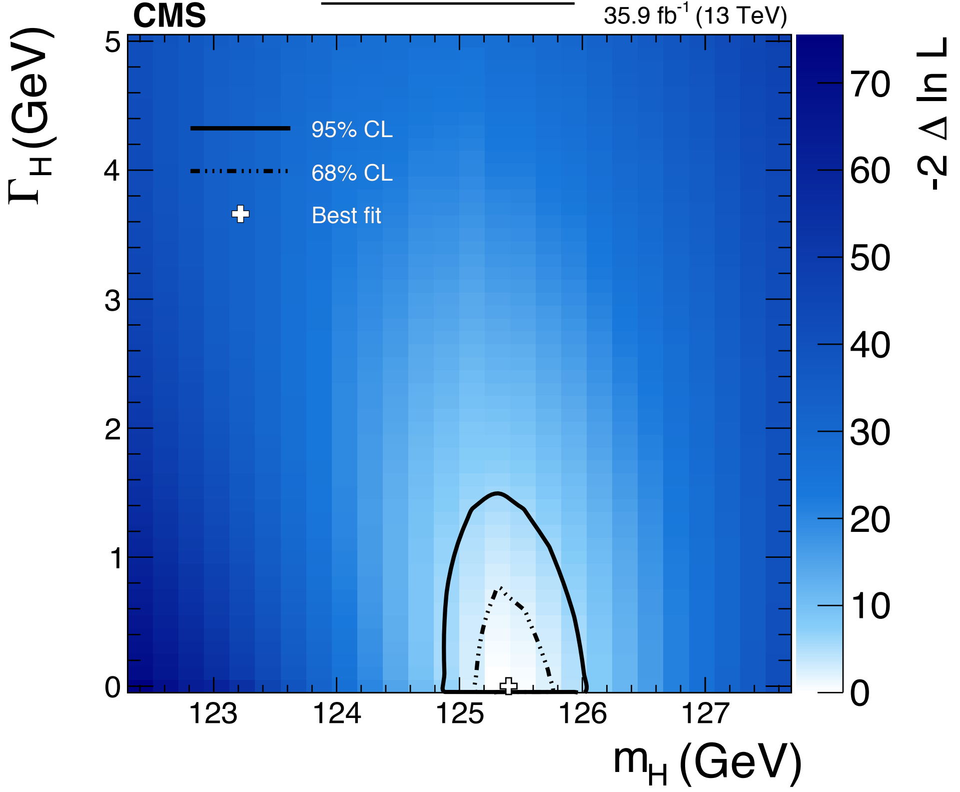


ATLAS γγ channel
same categories as
for coupling
124.93±0.40 GeV



ATLAS 4l channel
event-by event resolution
+S/B discriminant
124.79±0.37 GeV

1706.09936



CMS 4l channel
event-by event resolution
+S/B discriminant
(3D fit)
125.26 ± 0.21 GeV
Γ_H<1.1 GeV (95%CL)

combined ATLAS run1+run2
124.97±0.24 GeV (±0.19$_{stat}$ ±0.13$_{syst}$)
Syst. uncertainties mainly from photon energy scale

Conclusion and Outlook

- All main 5 decay modes and 4 production modes now observed thanks to run 2 data (up to 80 fb^{-1} of data, 36 fb^{-1} for many channels)
    - All studied production mode*decay channel consistent with SM
- Global yield of Higgs production measured to <10% accuracy in both ATLAS and CMS separately (with similar stat. , exp. syst. and theory uncertainties)
- Measurement of differential cross-sections performed in gamma-gamma and 4l decay channel, in agreement with SM Higgs production expectations
- Coupling measured to ~10-20% accuracy in each experiment, improving over run 1 measurements. No deviation from SM observed
- Full run 2 (2015-2018) sample will be O(150 fb^{-1}) per experiment
- In the future:
    - run 3 (2021-2023) O(300 fb^{-1})
    - HL-LHC O(3000 fb^{-1})

backup

Observables to measure

N (i->H->j with selection k) = Luminosity* σ_i* Γ_j/Γ_H * Acceptance_{ijk}*ε_{ijk} + background_{ijk}

Γ_H not directly measurable (~4 MeV in the SM)

Different measurement strategies and way to report results:

i) measure total cross-section in each i->j channel and compare to SM ("signal strength" μ). Can also assume only one "global" signal strength

ii) extract ratio of cross-section and BR, independent on total width assumption

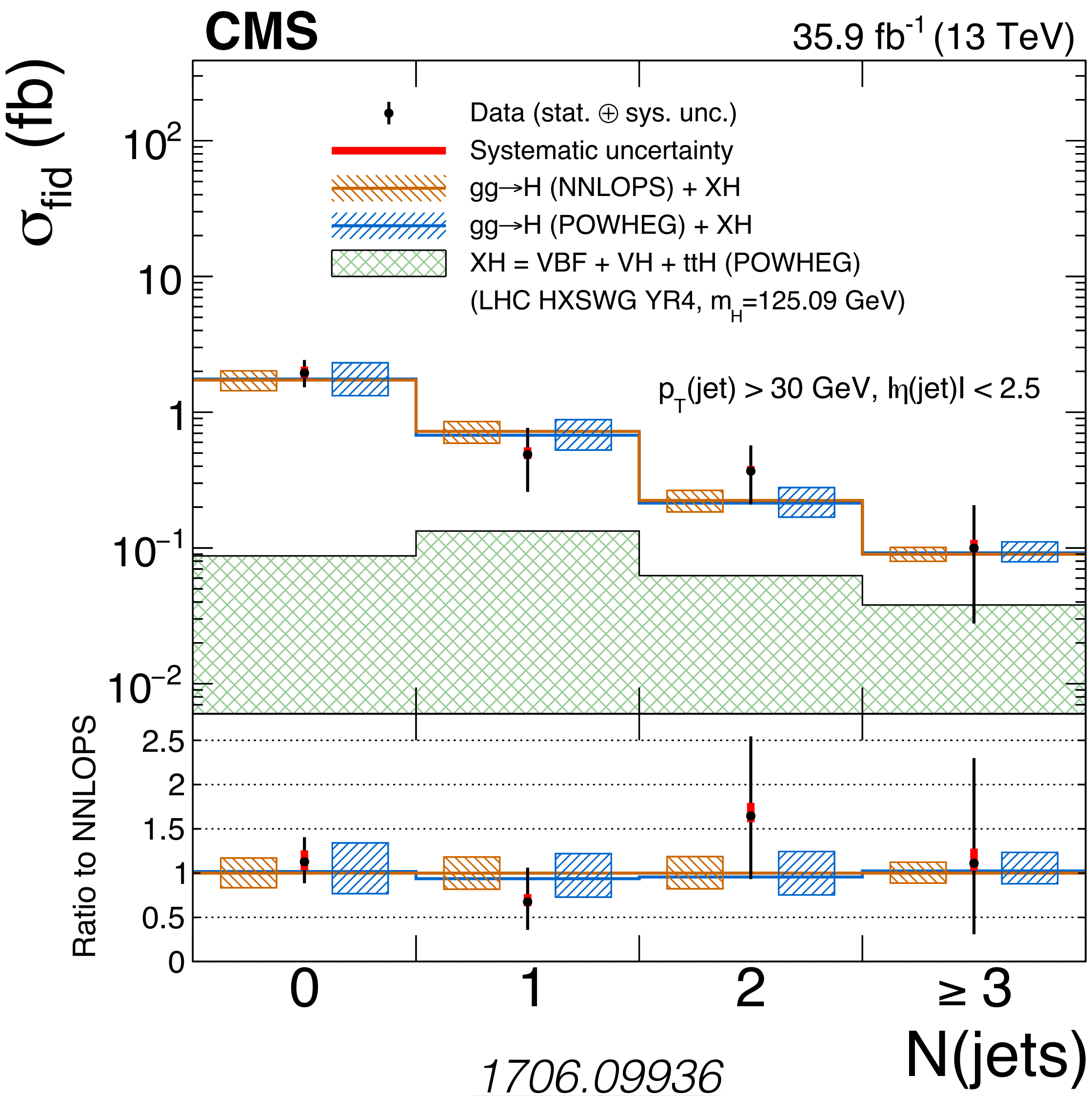
iii) assume couplings for H to given particle scales with κ_n and constraint these coupling modifiers from yield measurements ("κ framework")
  - assume same kinematics as SM, not necessarily true if BSM
  - Need some hypothesis on total width

iv) Split measured cross-section per production mode in wide kinematical region to increase sensitivity to BSM physics ("simplified template cross-sections")
  - still a bit of model dependence, doable for most i->j processes

v) Extract fiducial (acceptance applied at particle level) and differential (vs Higgs Pt, etc.) cross-sections
  - less model dependent
  - can be used as input for effective field theory BSM parameterization
  - not easily doable in signal with poor S/B or worse resolution

Differential cross-section with H→gamma gamma and H→4l

Njet produced in association with H



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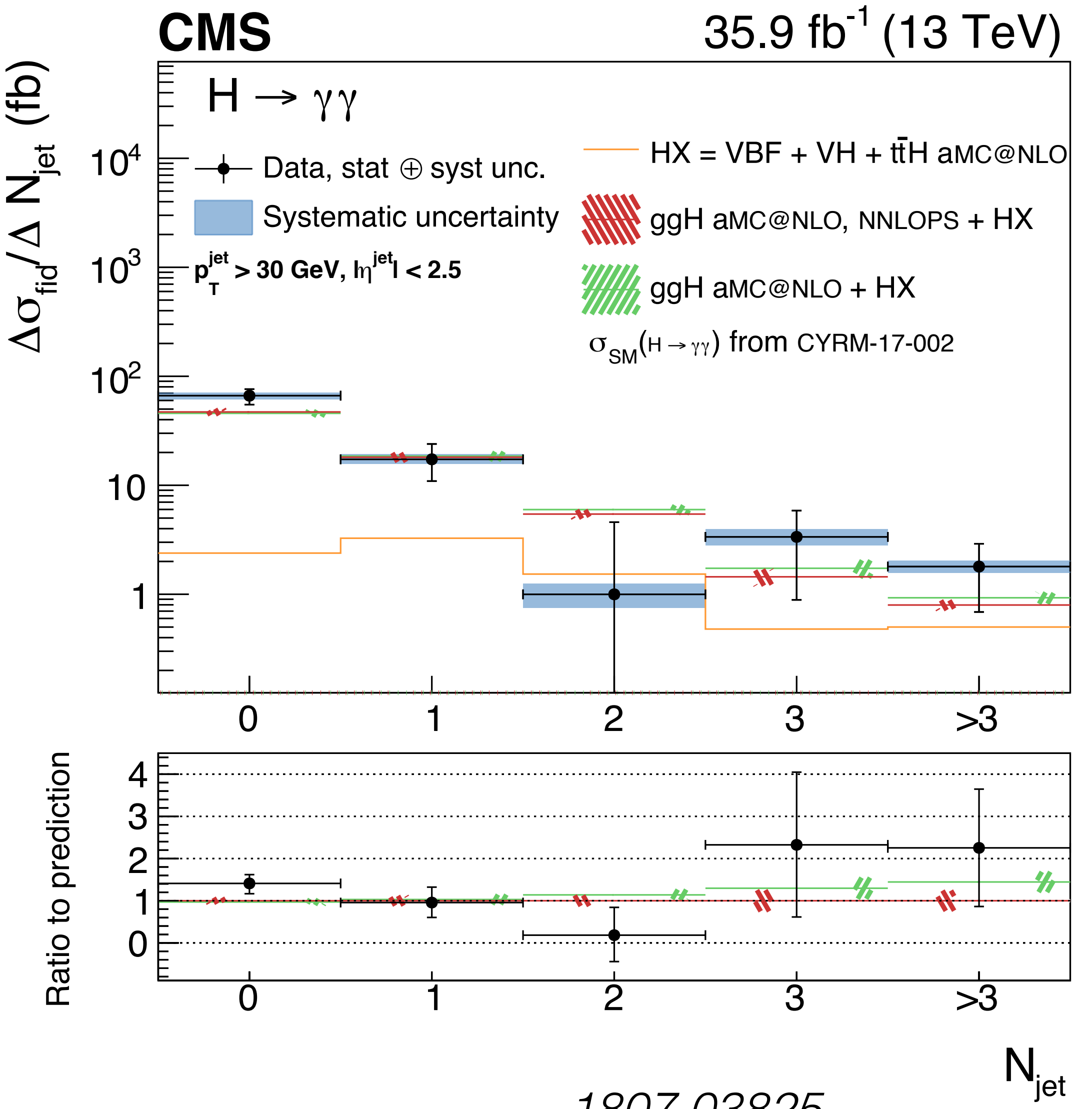

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STX cross-section in H→ZZ and H→gamma gamma

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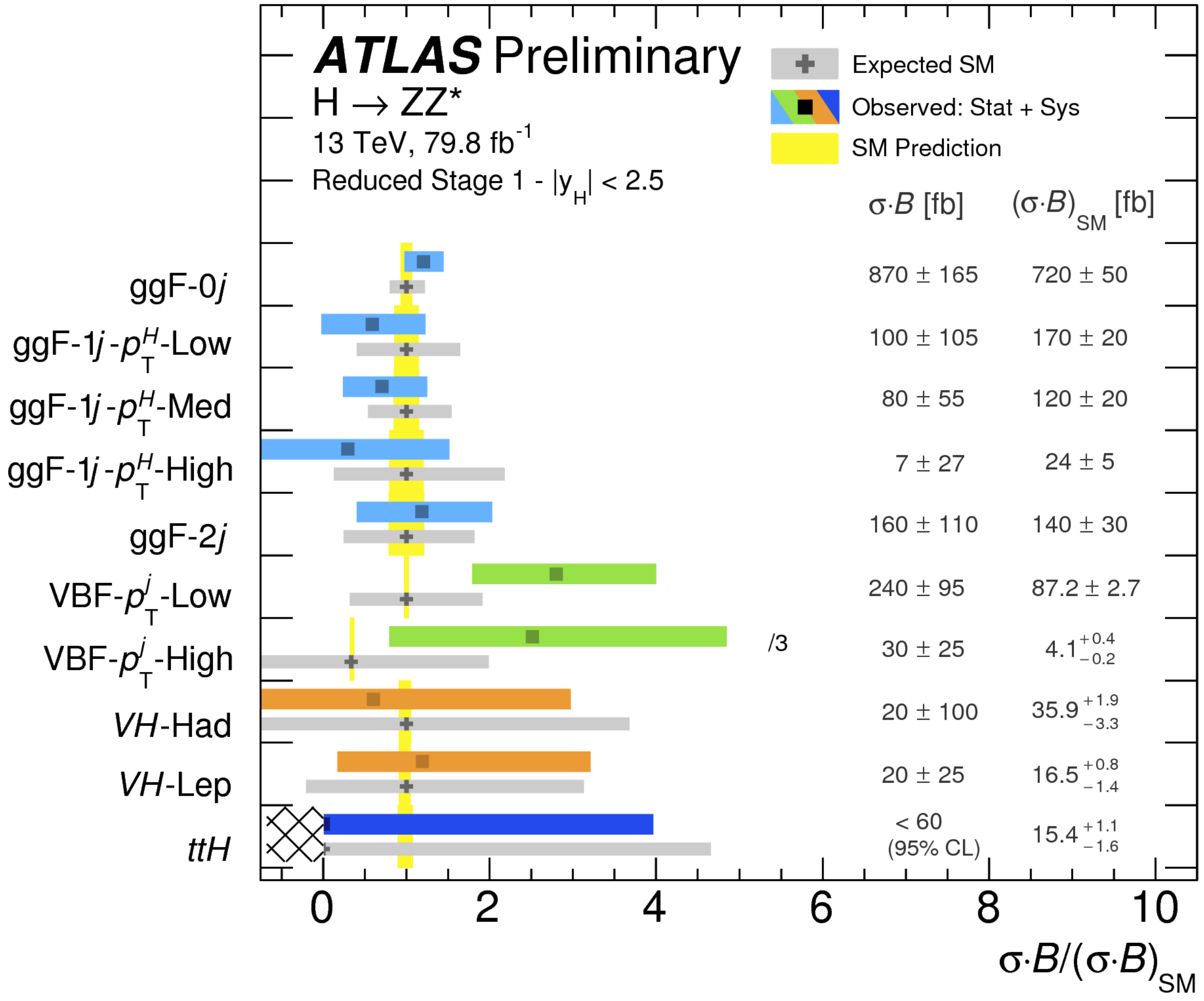

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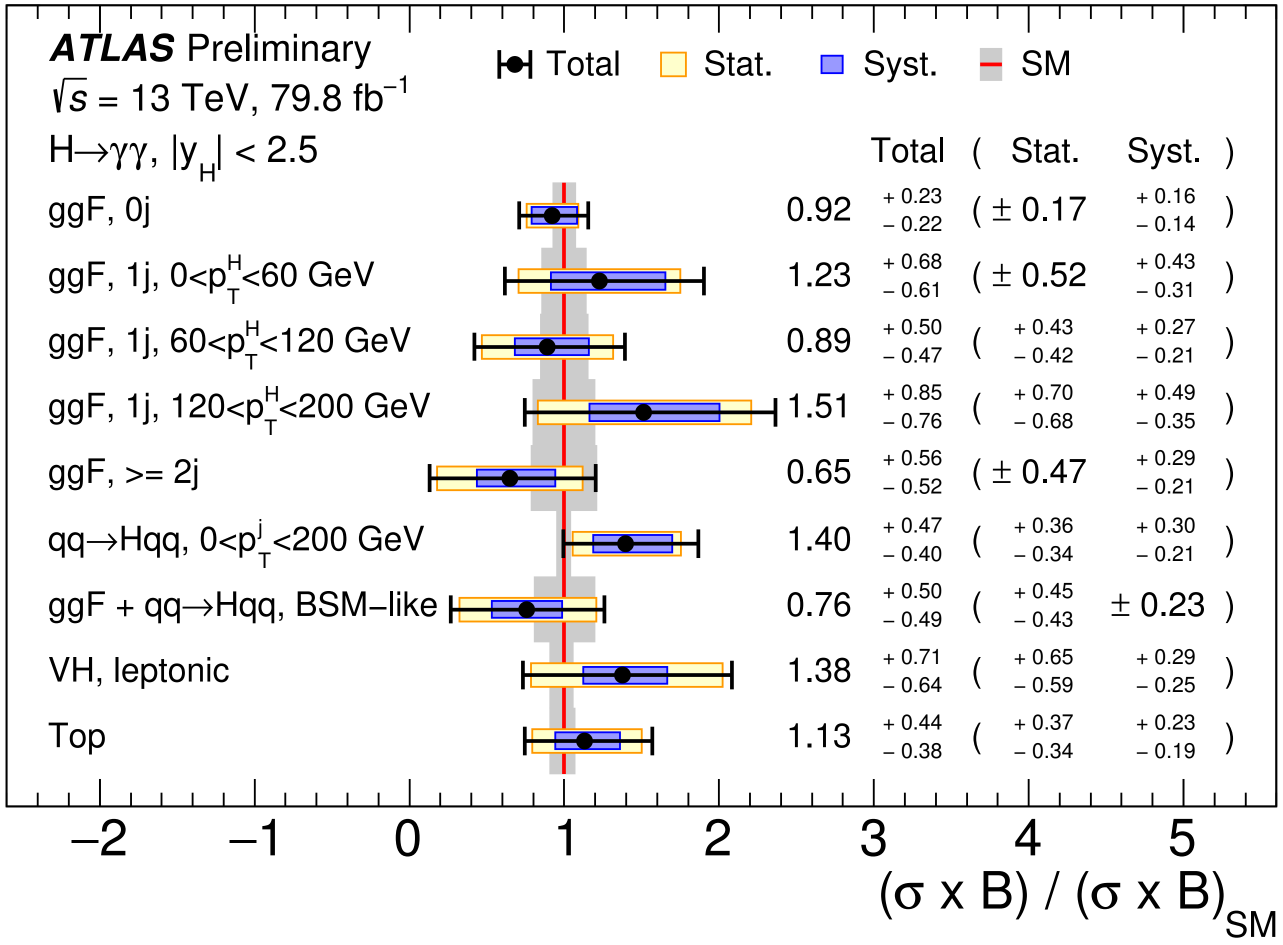
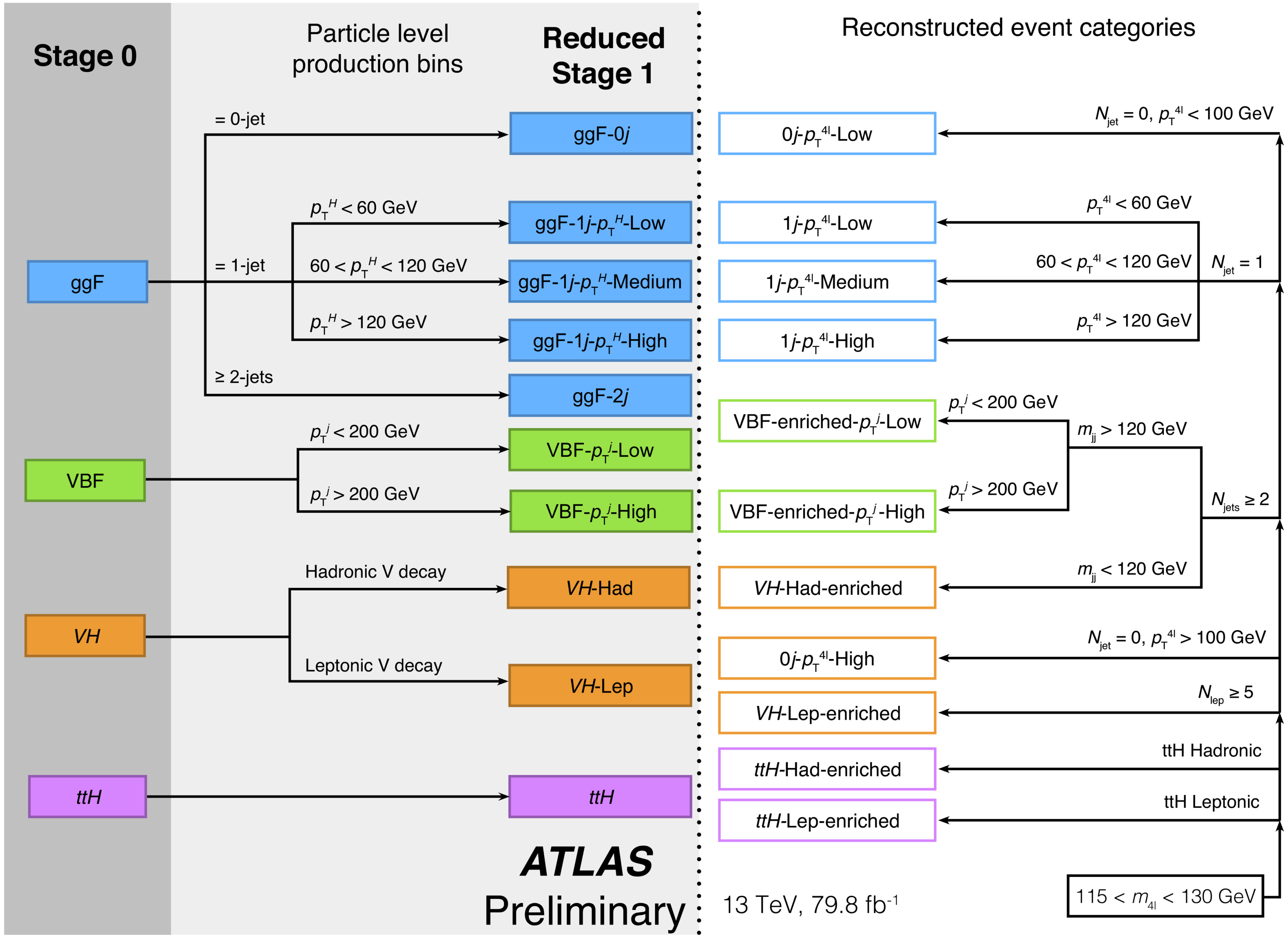


no significant deviations from SM predictions
Uncertainties still dominated by stat. (but syst not negligible)
accuracy from 20% to ~ 100%

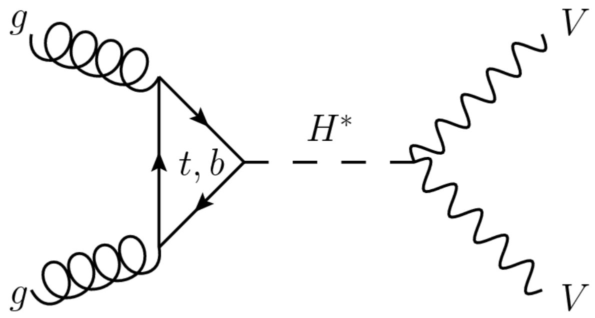
STX cross-sections in H→ZZ and H→gamma gamma

split gluon fusion cross-section depending on Njet and jet pt
(define "Simplified Template Cross-Section")



Off shell Higgs production and Higgs width

Γ(SM) ~4 MeV



q ~M_H (on shell) σ~1/Γ_H *(couplings)
q>>M_H (off shell) σ~(couplings) ⇒Ratio ~Γ_H

Interference with gg->ZZ taken into account
Γ<14.4 MeV assuming no change in coupling and no new physics at high VV mass

Can also be used to probe off-shell Higgs boson couplings

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