Latest results on the H(125) from the LHC

宇宙史研究センター構成員会議・成果報告会, June 4, 2018

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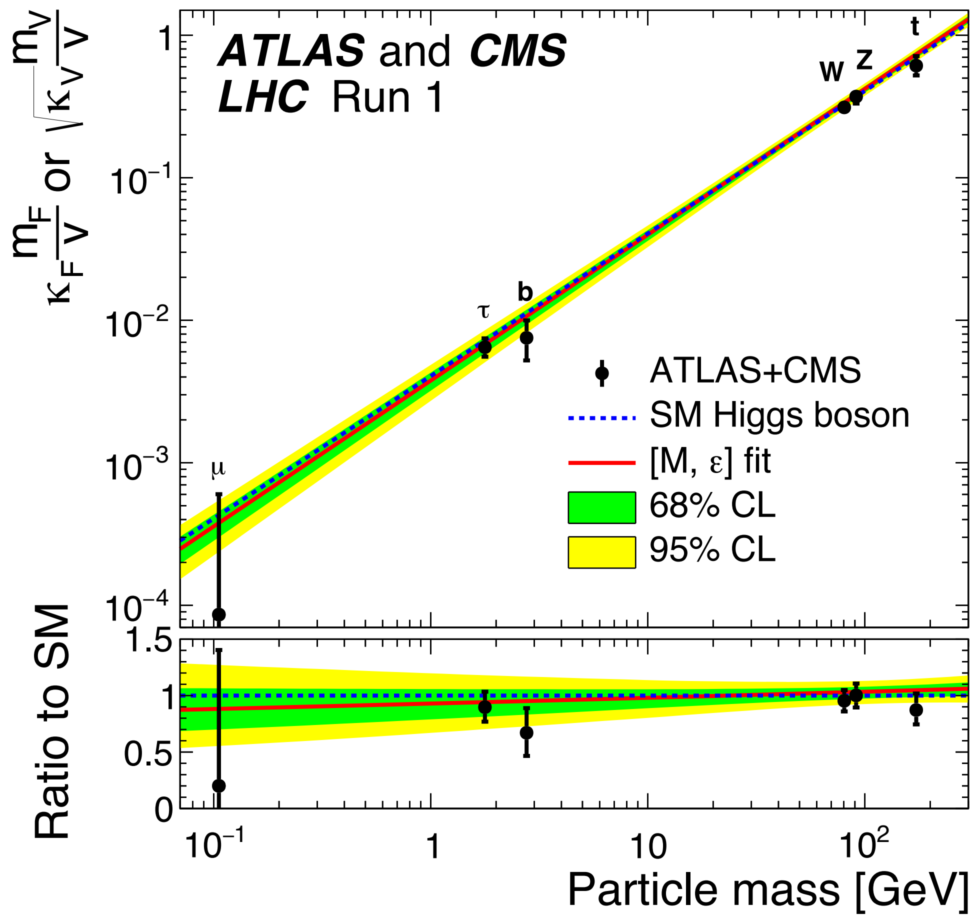
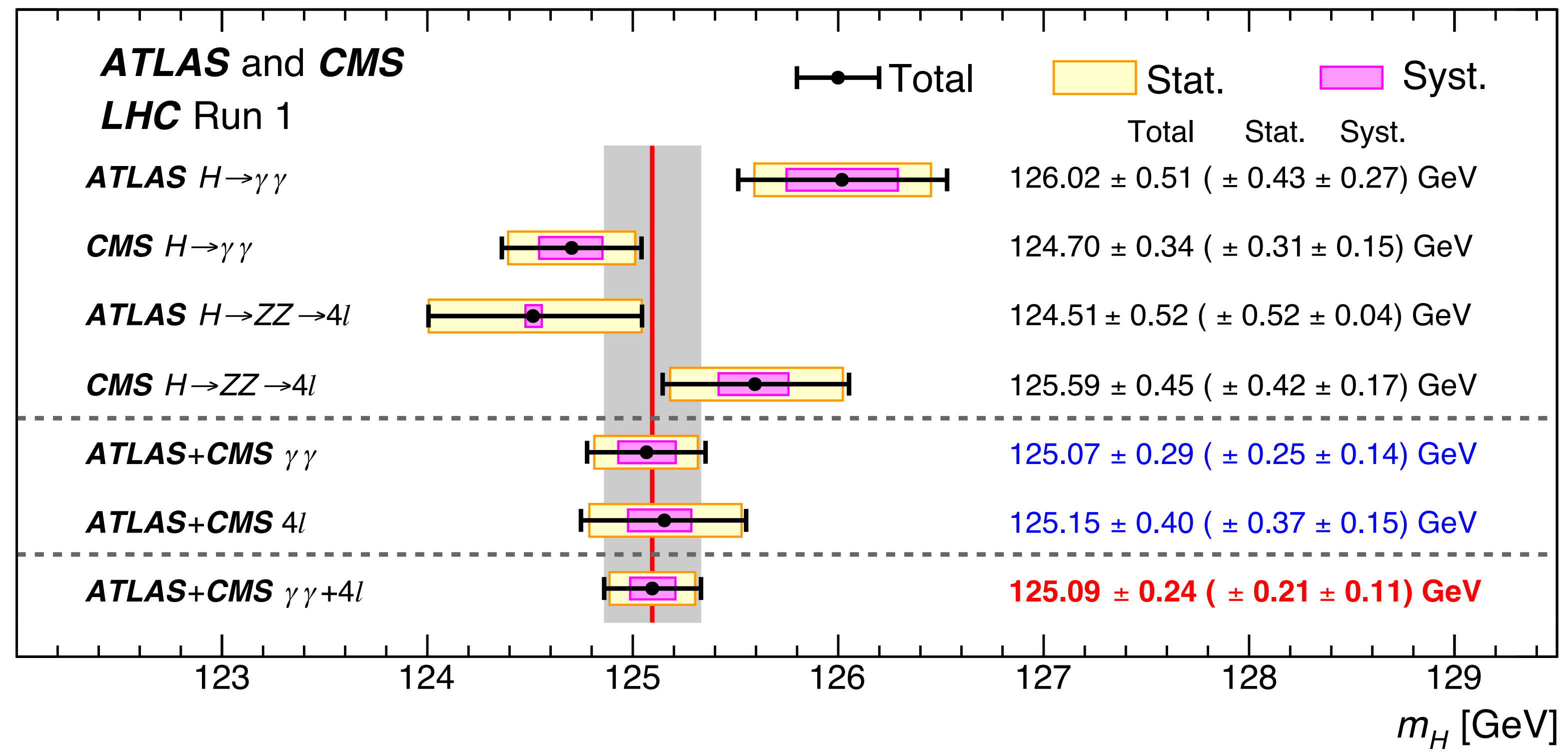
LHC Run 1

JHEP 08 (2016) 045



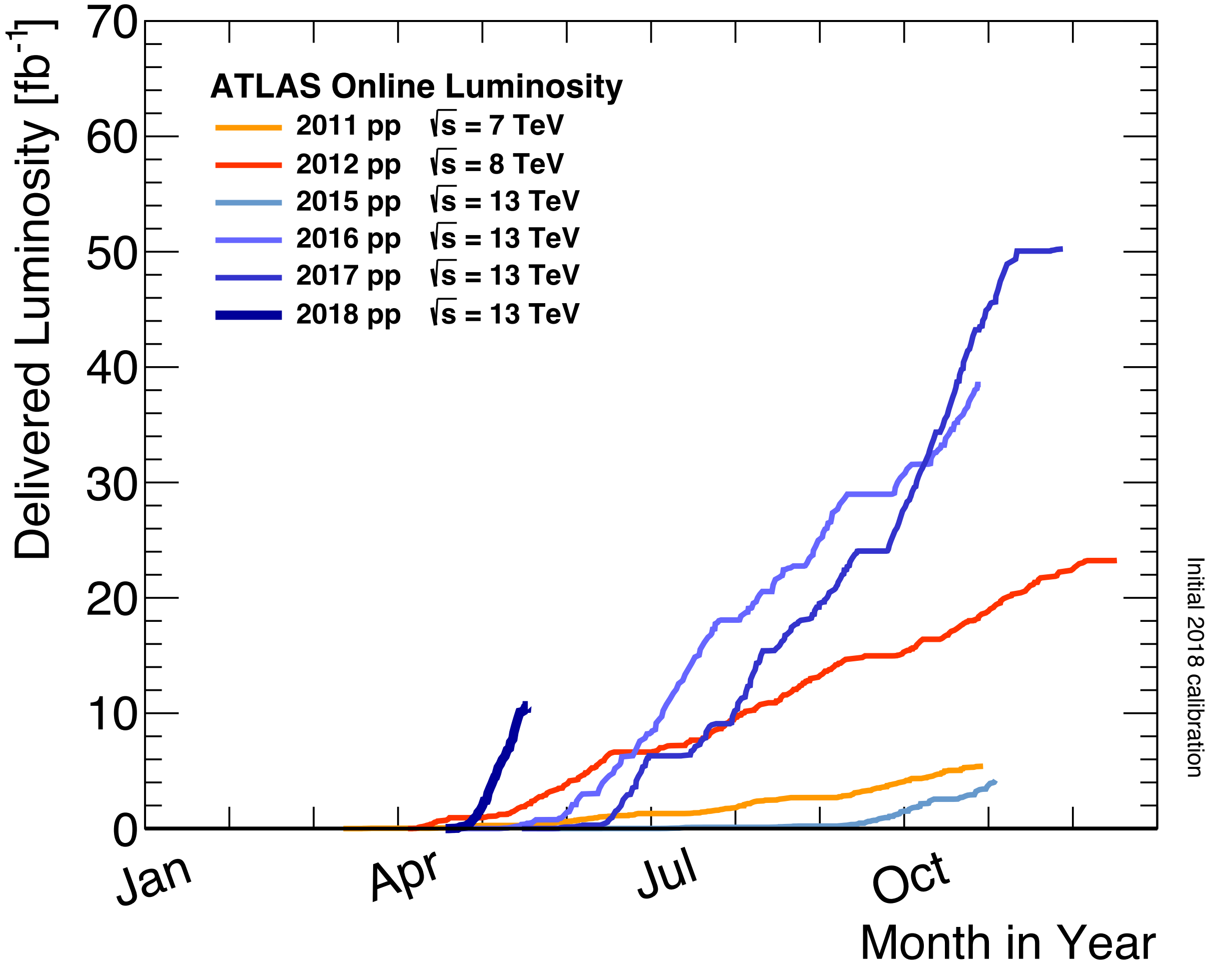
PRL 114 (2015) 191803



- Historical achievements at LHC Run 1:
  - Discovery of a Higgs boson
  - Direct observation of $\gamma\gamma$, ZZ, W^+W^-, $\tau^+\tau^-$
  - Confirmation of Spin/CP properties
  - Precise measurement of its mass

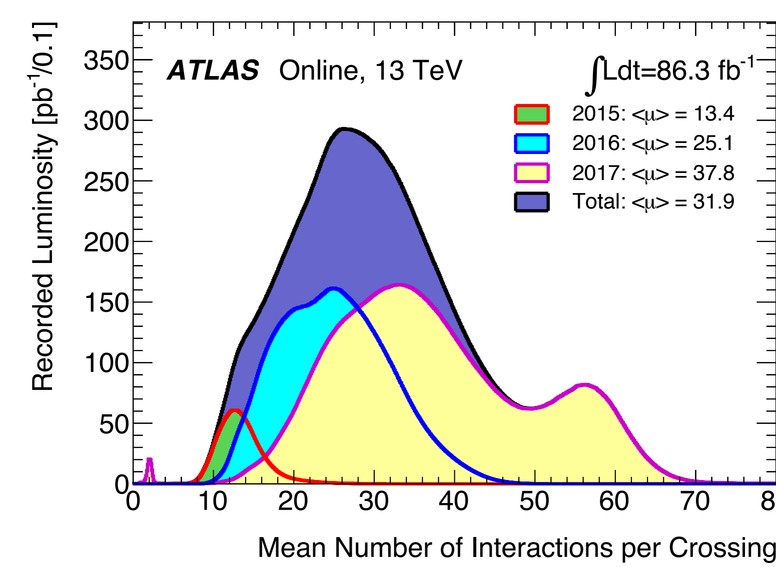
- Yet still missing items:
  - Observation of the largest decay mode ($b\bar{b}$)
  - Direct observation of Top Yukawa coupling
  - Rare decays from new physics?
  - Higgs self-coupling (challenging at LHC)

LHC Run 2

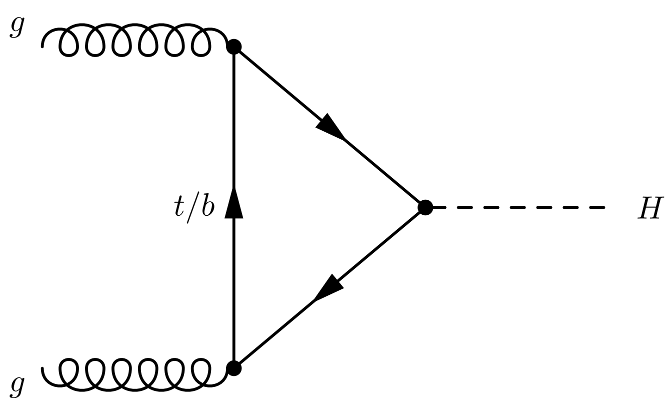


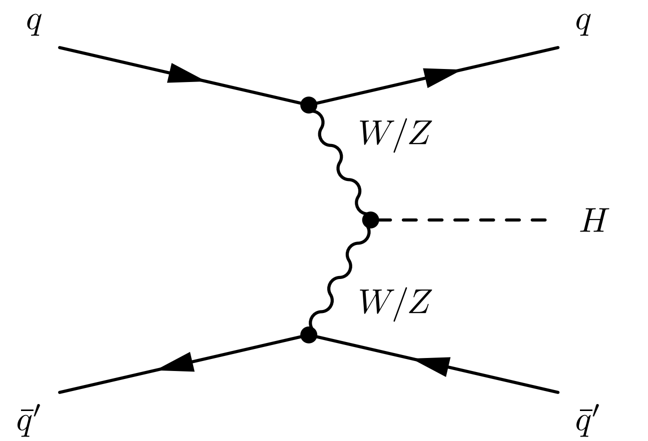
Run 2 (√s = 13 TeV)	Deliv. Lumi.	Peak Lumi. [$cm^{-2}s^{-1}$]
2018 (as of May 17)	**10.4 fb^{-1}**	**2.14×10^{34}**
2017	50.2 fb^{-1}	2.09×10^{34}
2016	38.5 fb^{-1}	1.38×10^{34}
2015	4.2 fb^{-1}	0.50×10^{34}

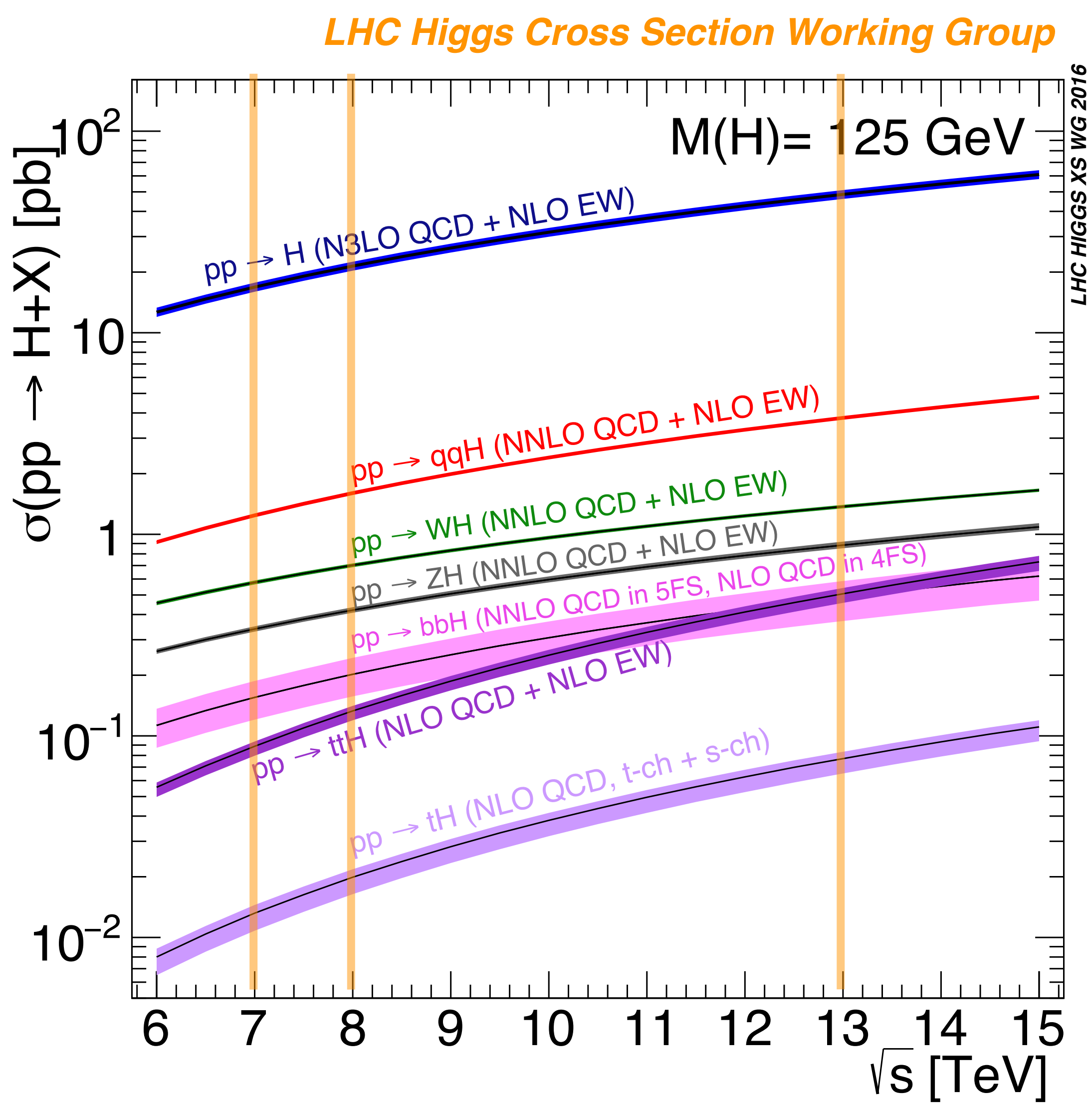
- **Delivered more than 100 fb^{-1} in Run 2 already.** Successful operation of LHC & ATLAS/CMS.
  - **Peak luminosity = 2.14×10^{34} $cm^{-2}s^{-1}$ in 2018 (twice the design luminosity)**, more challenging with pileup
- Results presented here are with **2015+2016 datasets (√s = 13 TeV, 36 fb^{-1})**.

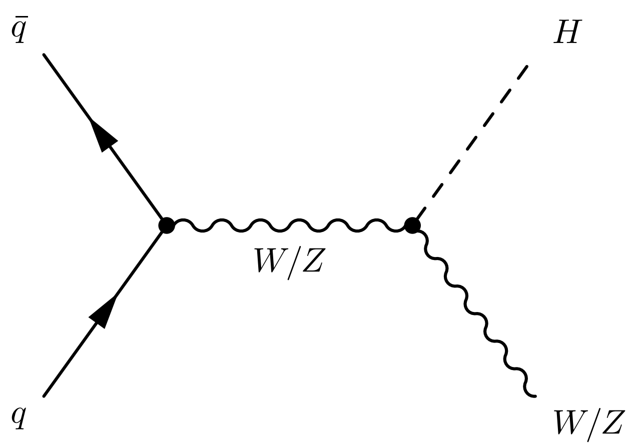


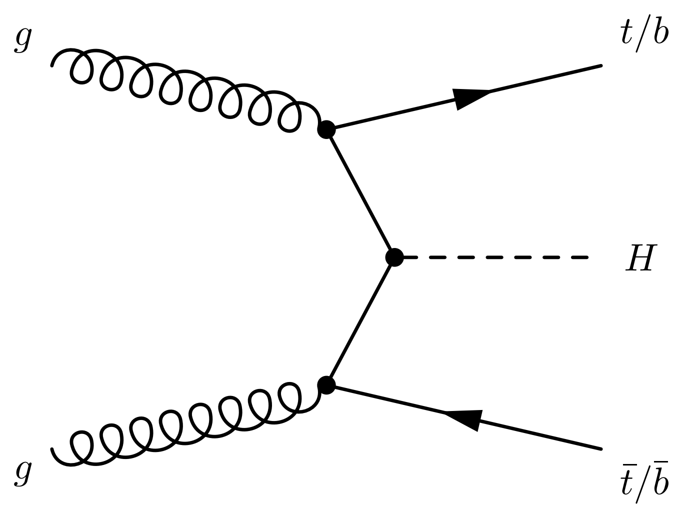
Higgs Production@LHC

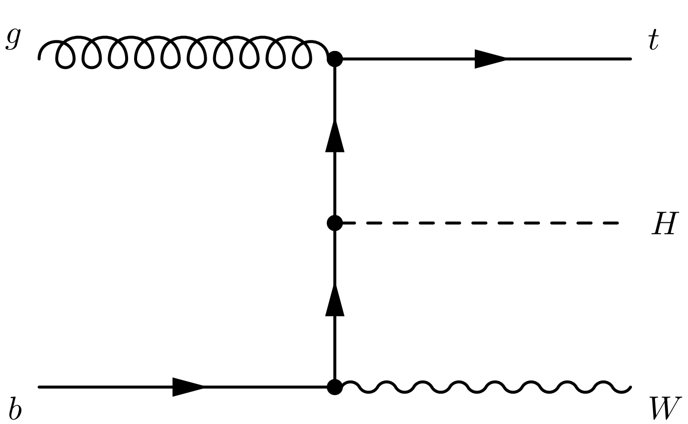






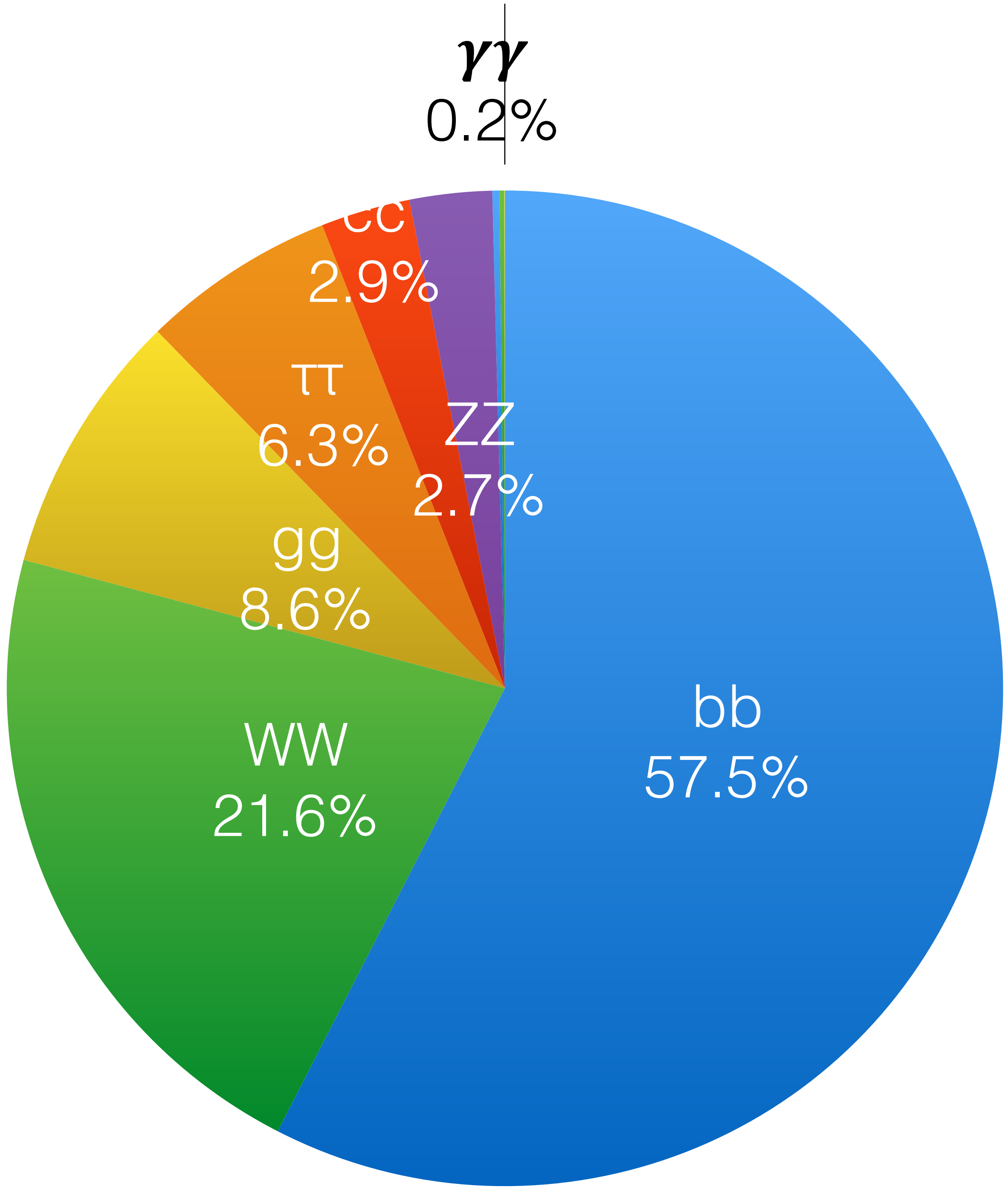






- **Notable increase in the cross section (×2.3 for ggF, ×3.9 for $t\bar{t}H$, ×3.3 for HH) from √s=8→13 TeV.**
- **Run 2 is the dawn of precision measurements for the Higgs boson & discovery phase of the $t\bar{t}H$.**

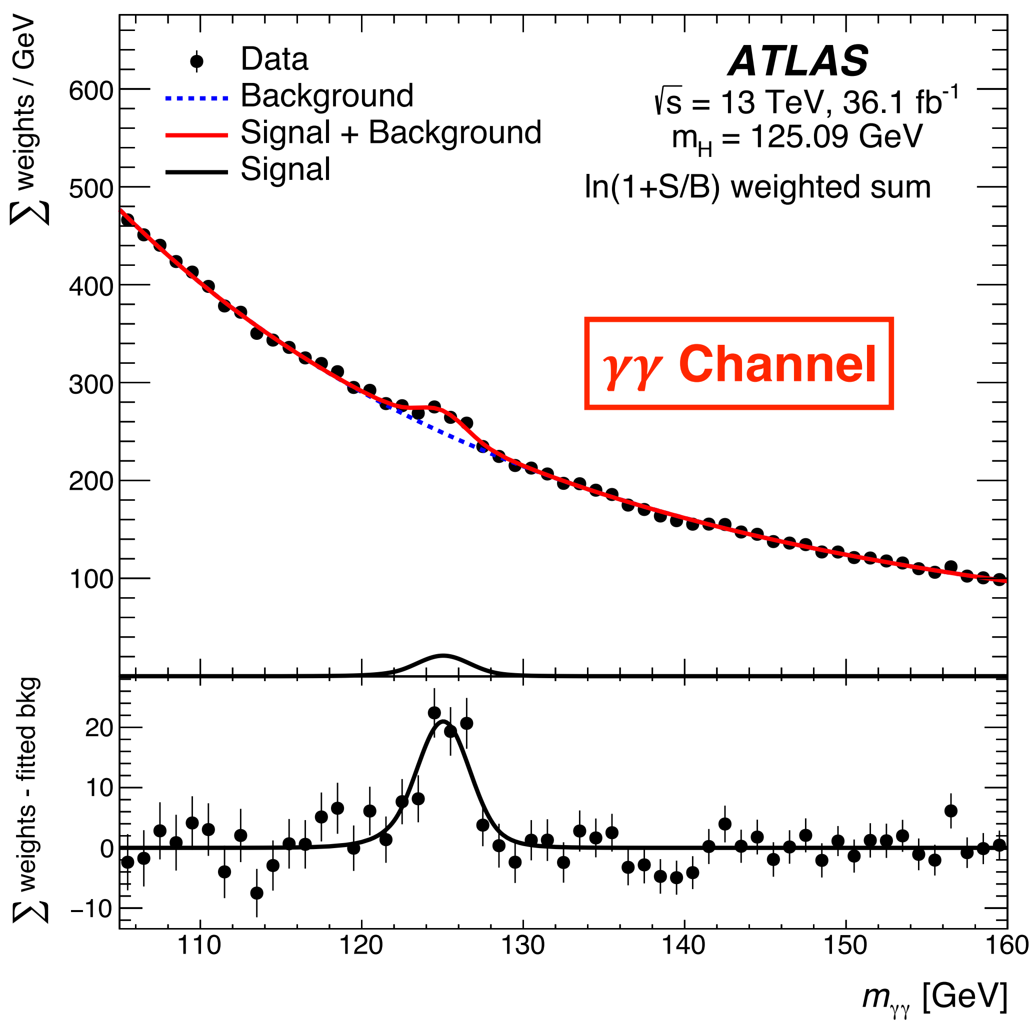
Higgs Decays

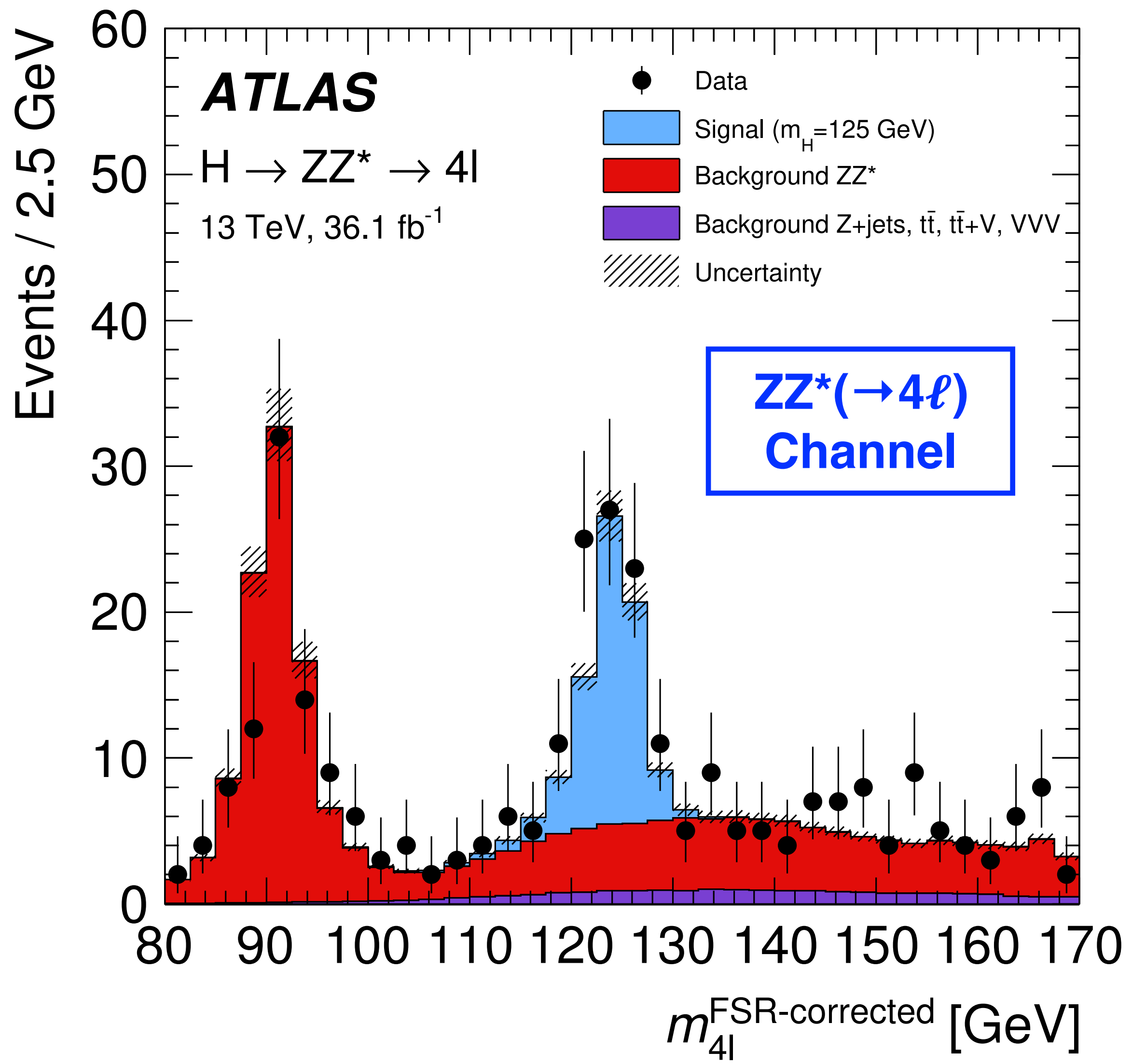


- **$\gamma\gamma$, ZZ(→4ℓ): Discovery channels.** Small branching ratios (BRs), but good mass resolution & clean signatures.
- **W^+W^-($\to l^+\nu l^-\bar{\nu}$): Large BR, good sensitivity to ggF & VBF**, but poor mass resolution due to two neutrinos.
- **$b\bar{b}$: Has the largest BR, but suffers from large BG.** The last major channel to be observed.
- **$\tau^+\tau^-$:** Reasonable mass resolution, good sensitivity to ggF & VBF prod. **Best sensitivity to Higgs-fermion coupling.**
- **gg: Can only be measured at ILC.**
- **$c\bar{c}$: Can only be measured at ILC.**
- **$Z\gamma$, $\mu^+\mu^-$:** Very low BRs. Progressing toward the observation of $\mu^+\mu^-$. $Z\gamma$ should be visible at HL-LHC.

Higgs-boson Couplings

arXiv:1802.04146

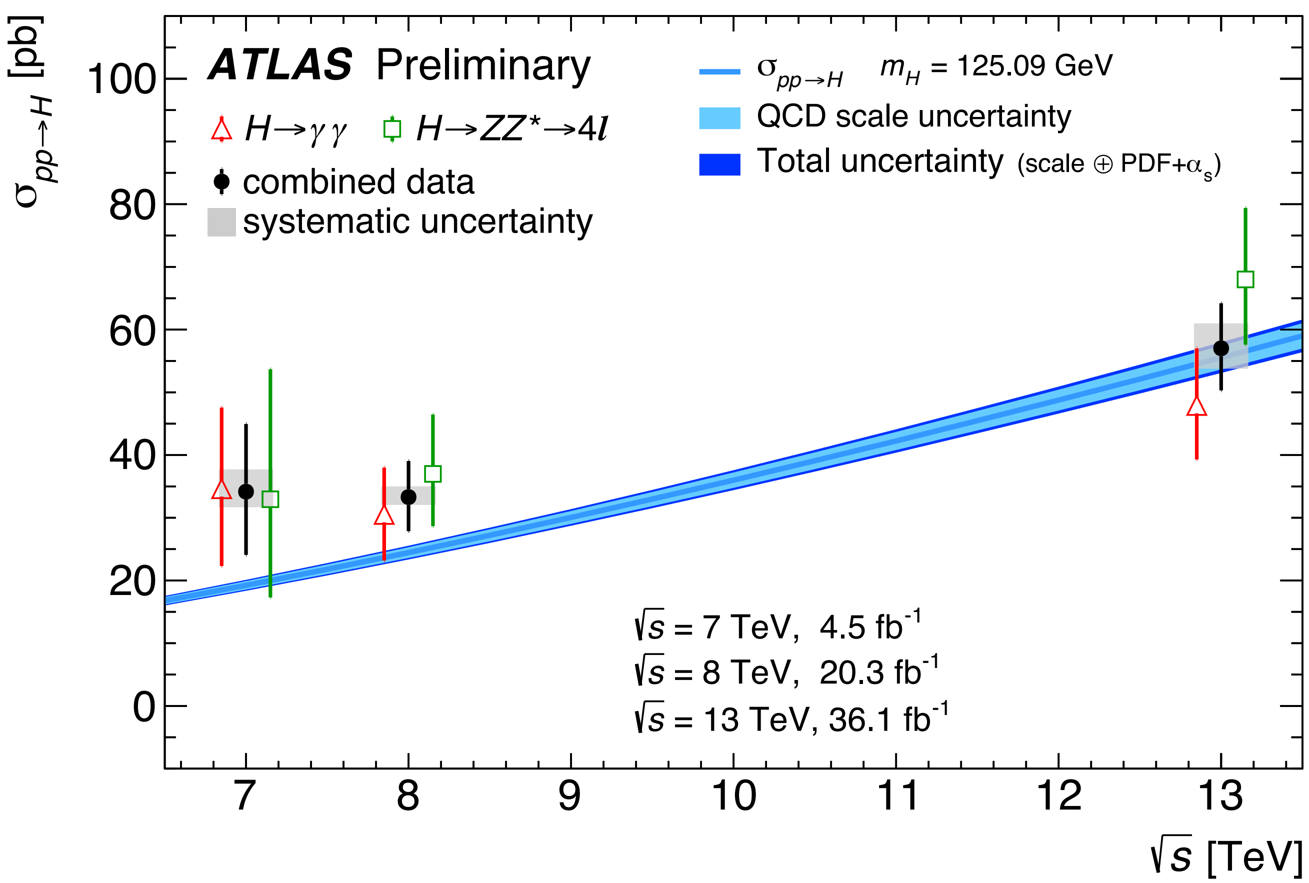


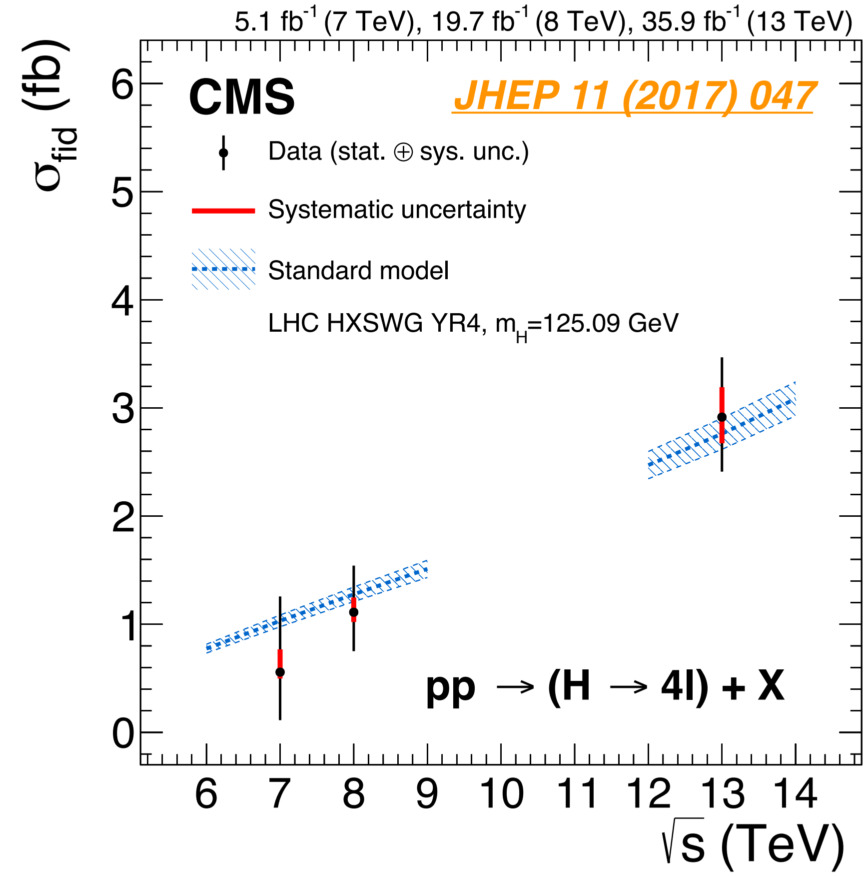


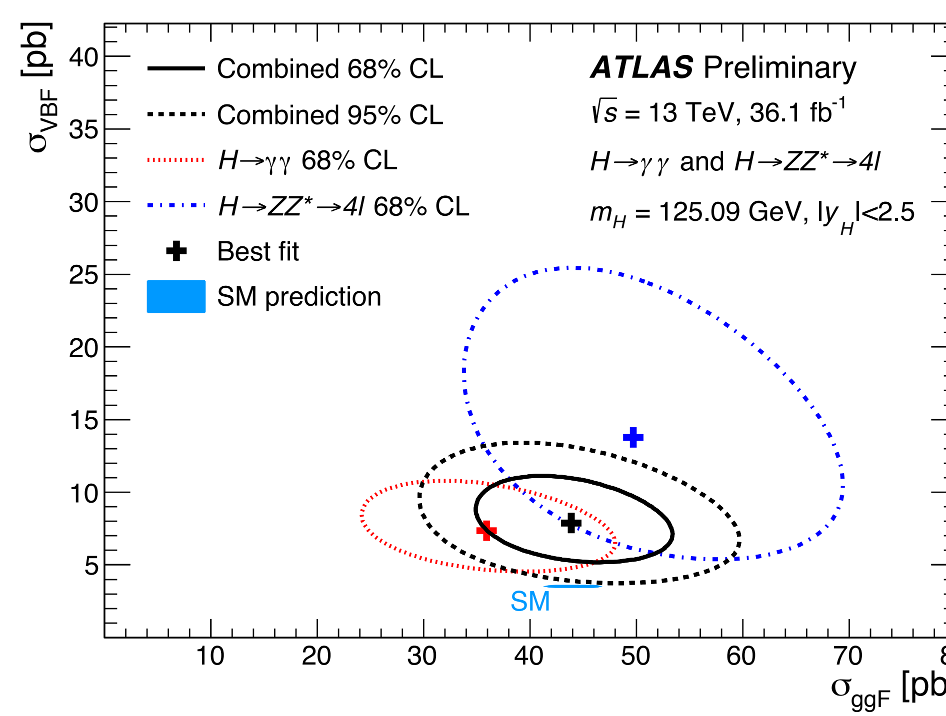
- Higgs boson was discovered by the "Golden" boson-decay channels: $\gamma\gamma$, ZZ*(→4ℓ) at LHC Run 1. **LHC Run 2 is the dawn of the Higgs precision measurements.**
- **The two channels are combined to measure the cross section & mass, as well as the signal strengths of various production modes.**

Higgs Cross Section

ATLAS-CONF-2017-047



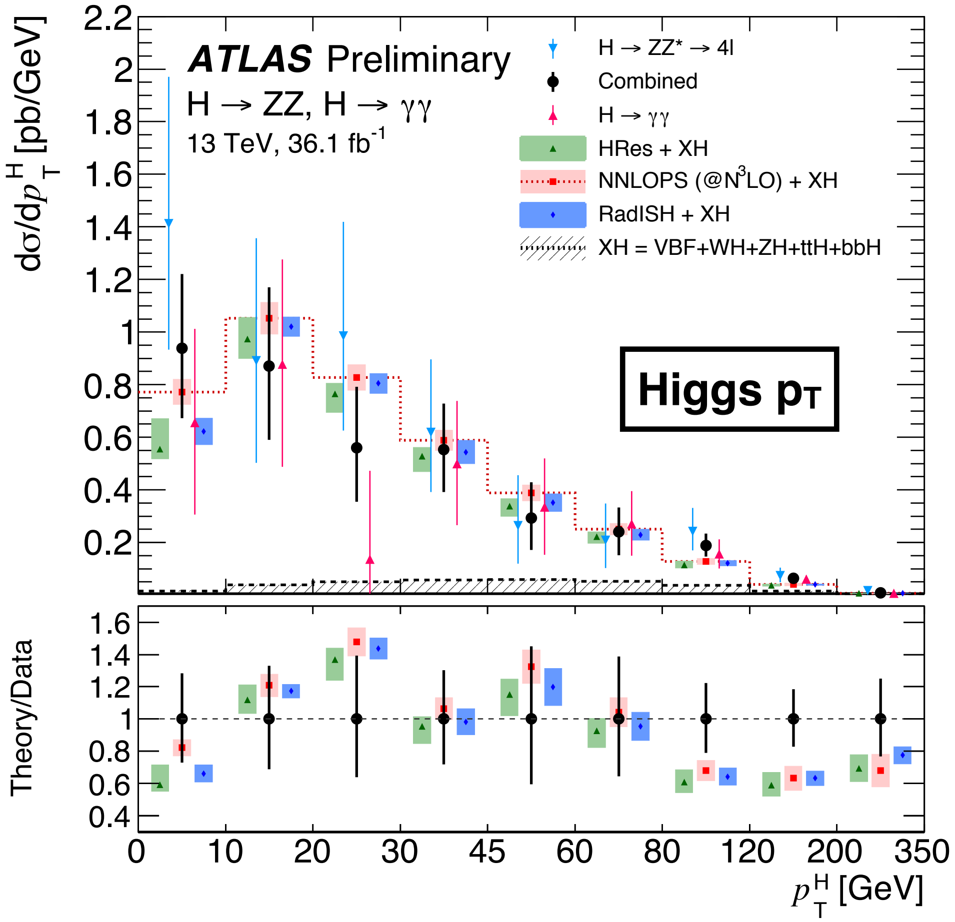


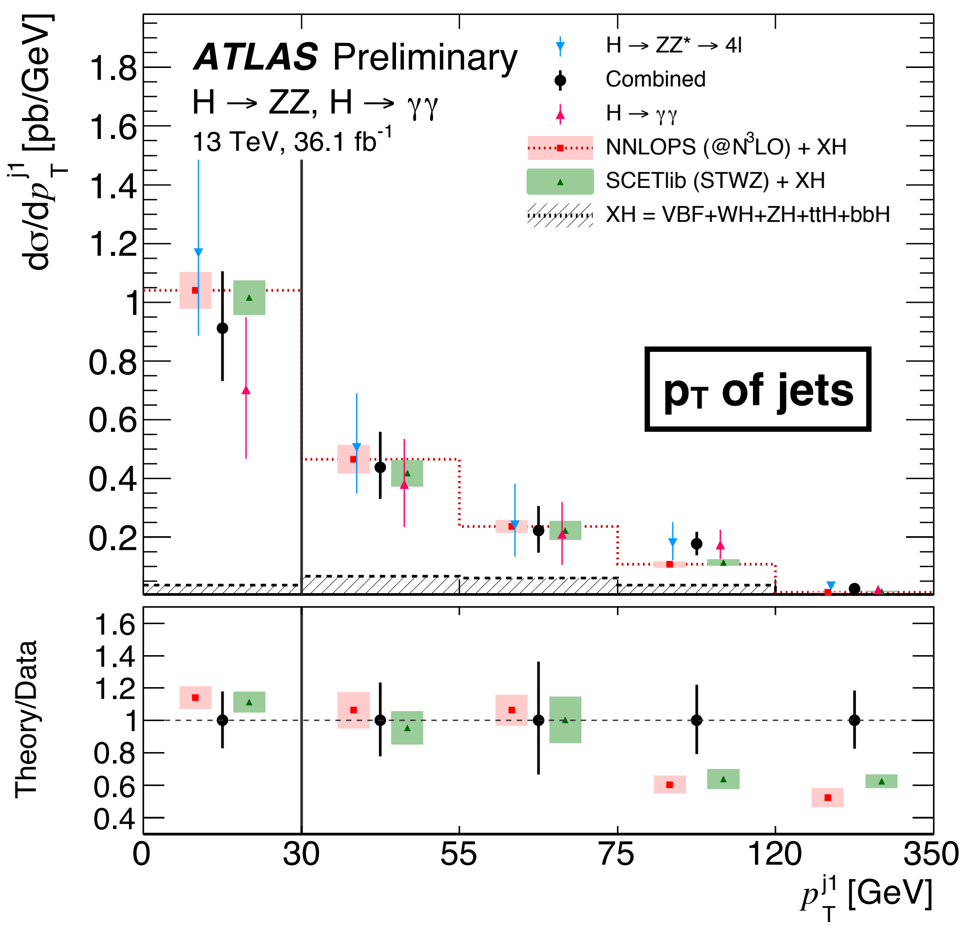


- **Higgs production cross section matches well with the N³LO prediction within the uncertainty in Run 2.**
- VBF cross section is slightly above the SM prediction.

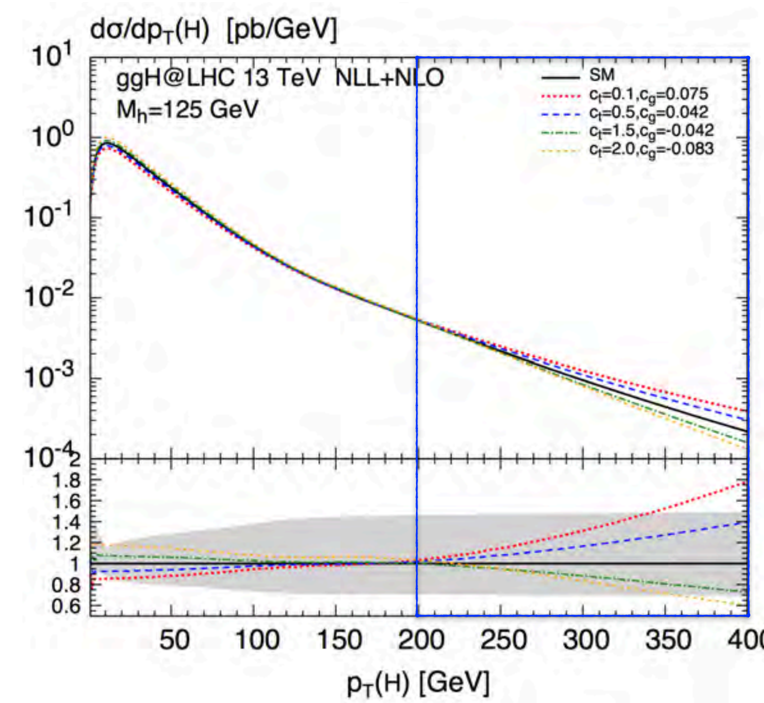
Higgs Diff. Cross Sections

ATLAS-CONF-2018-002





Impact of new physics on Higgs pT

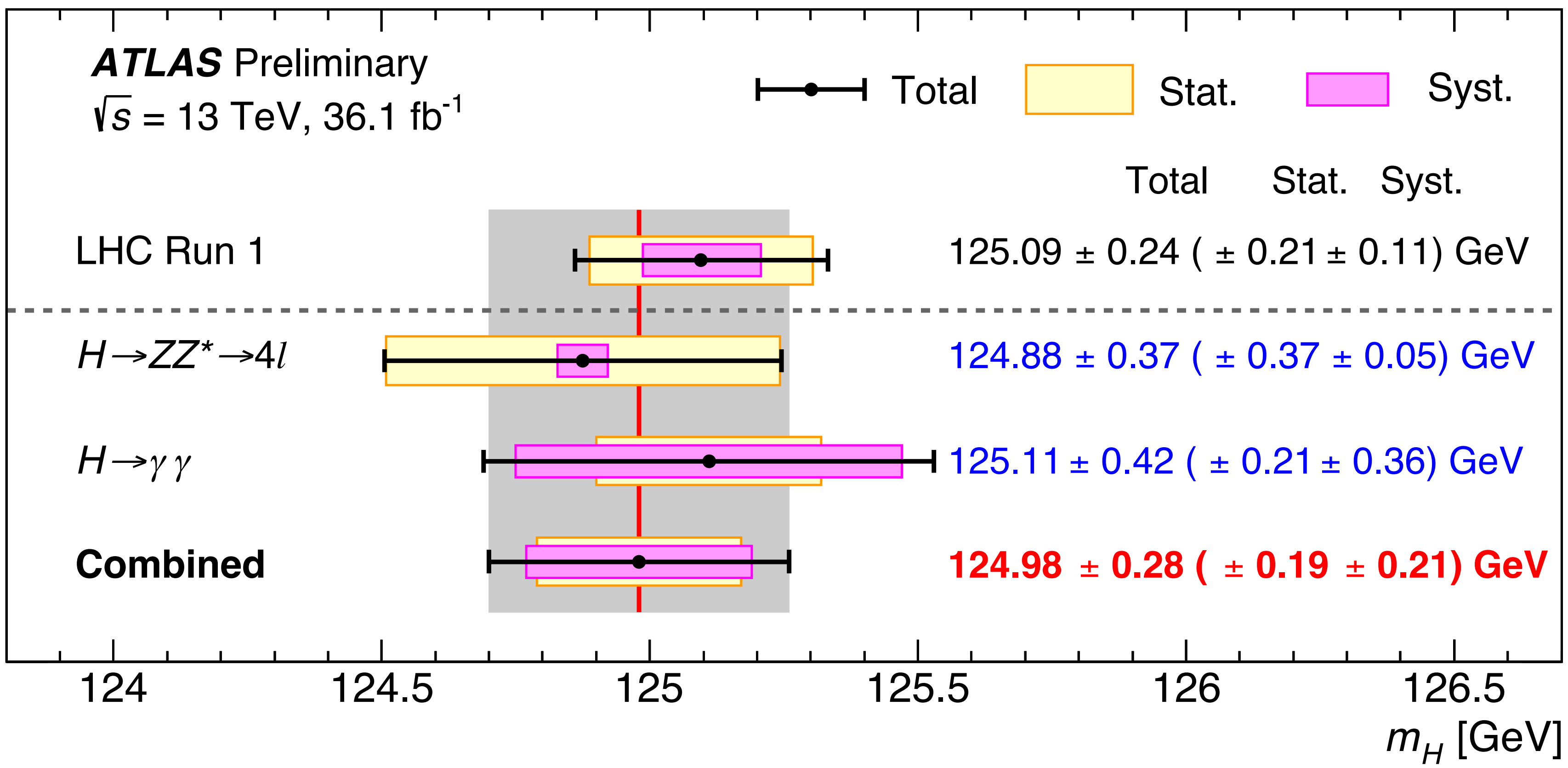


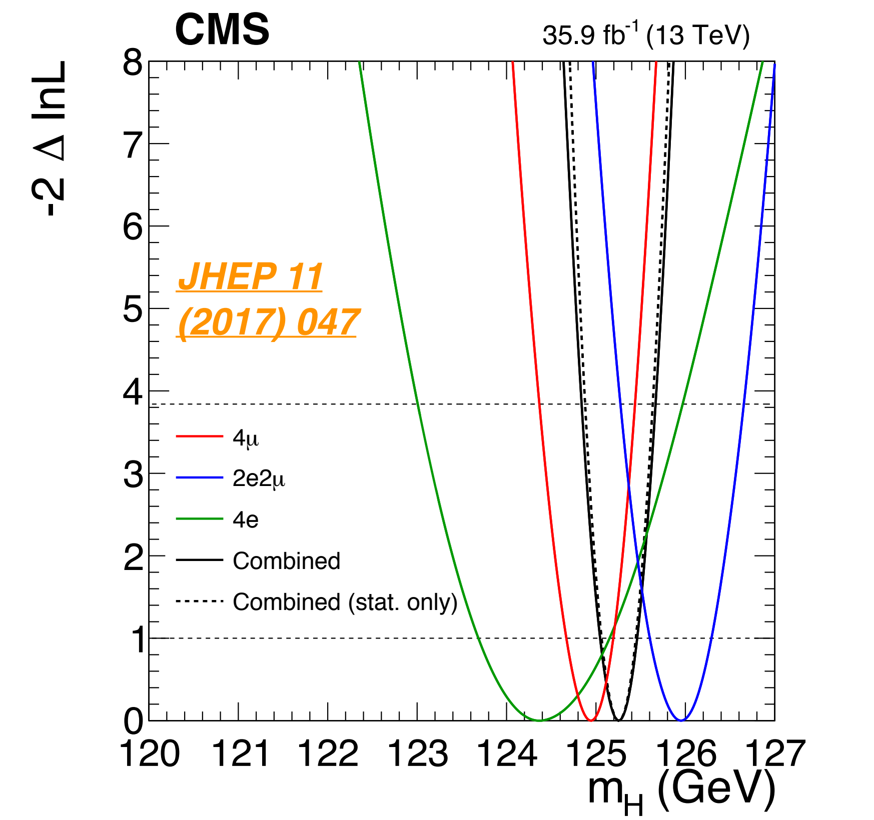
JHEP(2017) 2017:115

- Kinematic distributions (Higgs p_T, y, number of jets & jet p_T) are important probes **to check the validity of the perturbative QCD** and **to understand/ improve the Monte Carlo generators**.
- **Higgs p_T & p_T of jets are also sensitive to physics beyond the Standard Model** & are important to measure them precisely.

Higgs Boson Mass

ATLAS-CONF-2017-046



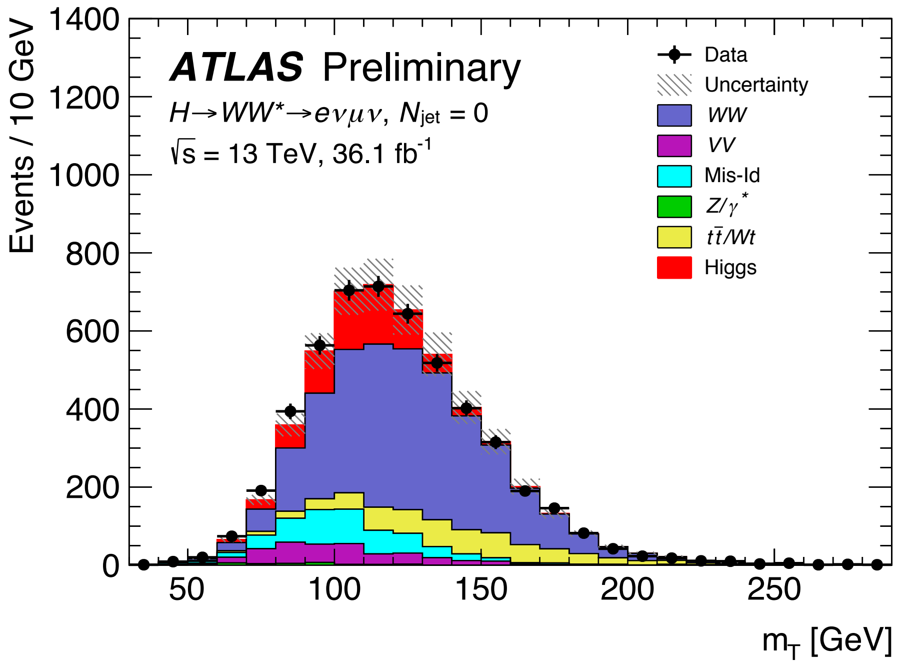


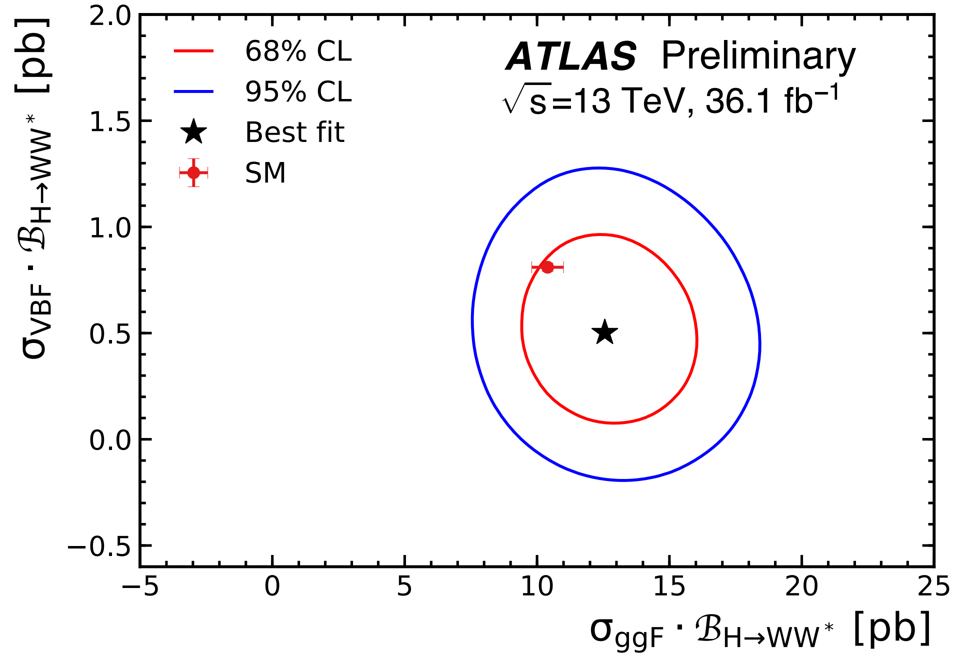
$ZZ^* \to 4\ell$: 125.26 ± 0.20 [Stat.] ± 0.08 [Syst.]

- **Similar precision (~0.2%) as the Run-1 (ATLAS+CMS) measurement with the ATLAS-only Run-2 $\gamma\gamma$+4ℓ combined or CMS-only 4ℓ.**
- $\gamma\gamma$ & $ZZ^*(\to 4\ell)$ channels are currently compatible in precision.
- **$ZZ^*(\to 4\ell)$ channel is still dominated by the statistical uncertainties.**
- **$\gamma\gamma$ channel needs to cope with the systematic uncertainties** (electromagnetic calorimeter response & materials from the inner detectors) to further reduce the uncertainties.

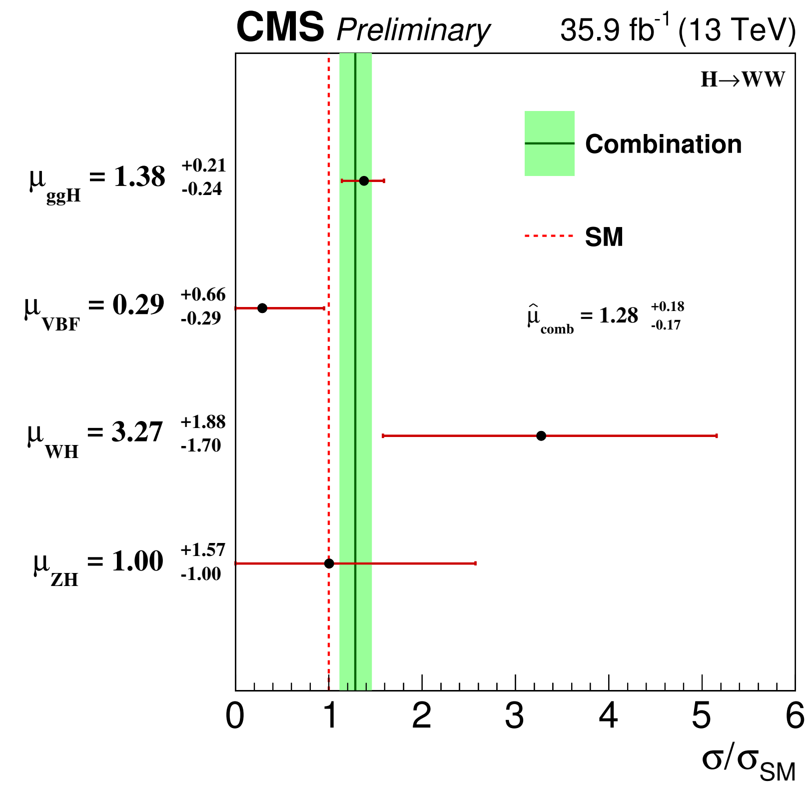
$H \to WW^{(*)} \to \ell\nu\ell\nu$

ATLAS-CONF-2018-004





CMS-PAS-HIG-16-042



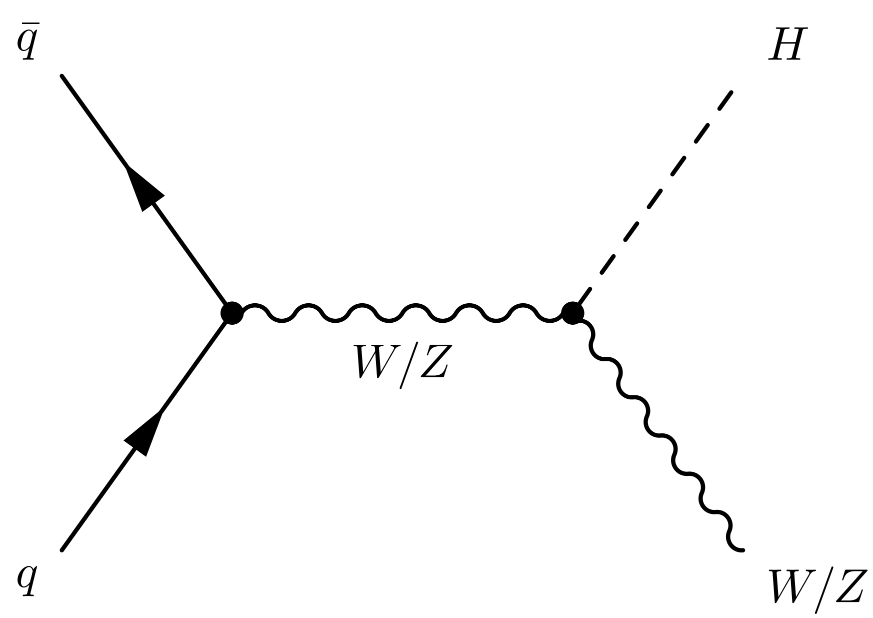
- Large signal statistics available but challenging to cope with the large BG. **Access to all the production modes.**
- ATLAS analyzed the $e\nu\mu\nu$ channel, whereas CMS considered both the different/same lepton flavor channels as well as multilepton channels for WH & ZH production modes.
- **Signal strengths compatible with the SM.**
- **Both ATLAS & CMS observe $H \to WW^{(*)}$ with > 5σ:** 9.1σ (6.3σ) for the observed after combining all (ggF+VBF) channels in CMS (ATLAS).

H($b\bar{b}$) Evidence

- **H($\rightarrow b\bar{b}$) has the largest branching fraction (58%), but is difficult to observe due to the large BG.**

- **WH, ZH production modes have the highest sensitivity.**

- Considered m_{bb} & various kinematic distributions as inputs to multivariate analyses (boosted decision tree; BDT).

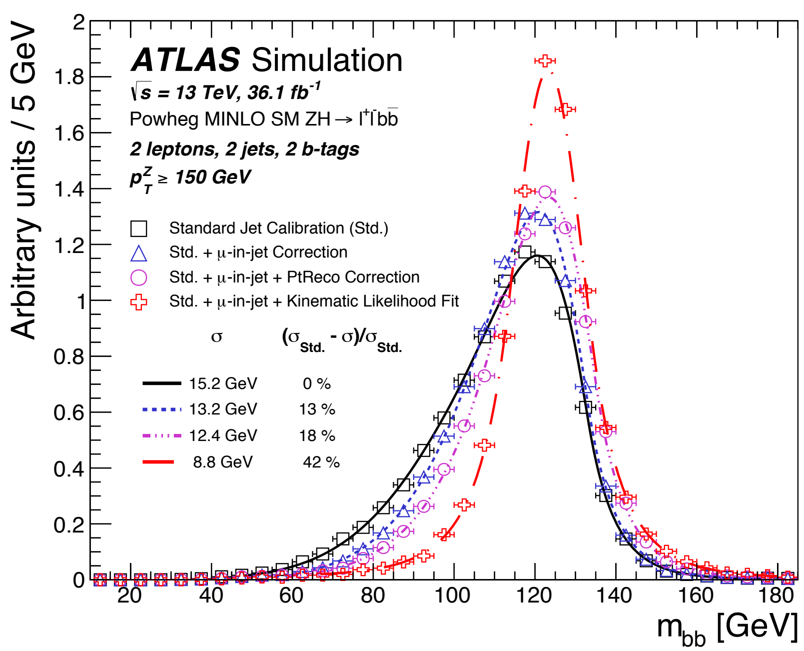


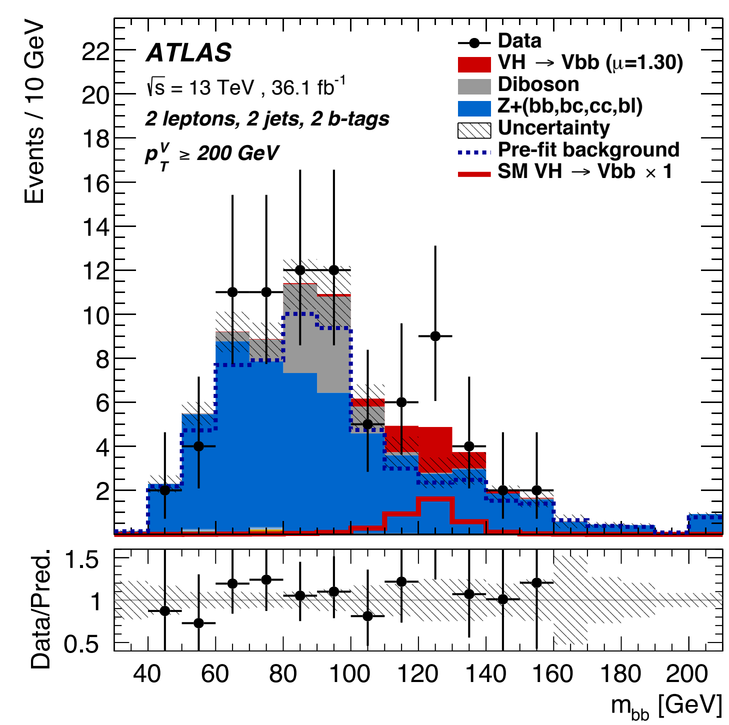
- 0 lepton: $Z(\rightarrow \nu\nu)H(\rightarrow b\bar{b})$
- 1 lepton: $W(\rightarrow \ell\nu)H(\rightarrow b\bar{b})$
- 2 leptons: $Z(\rightarrow \ell\ell)H(\rightarrow b\bar{b})$

- Dedicated b-jet calibration to improve m_{bb} resolution.

- Grouped into various categories by the numbers of leptons (& jets for ATLAS) & W/Z p_T.

JHEP 12 (2017) 024

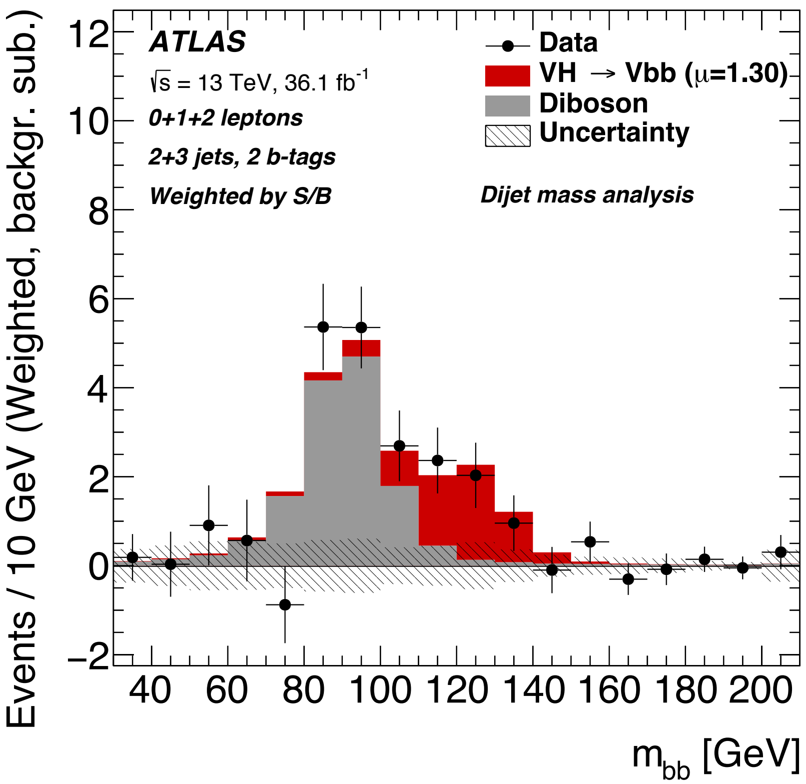


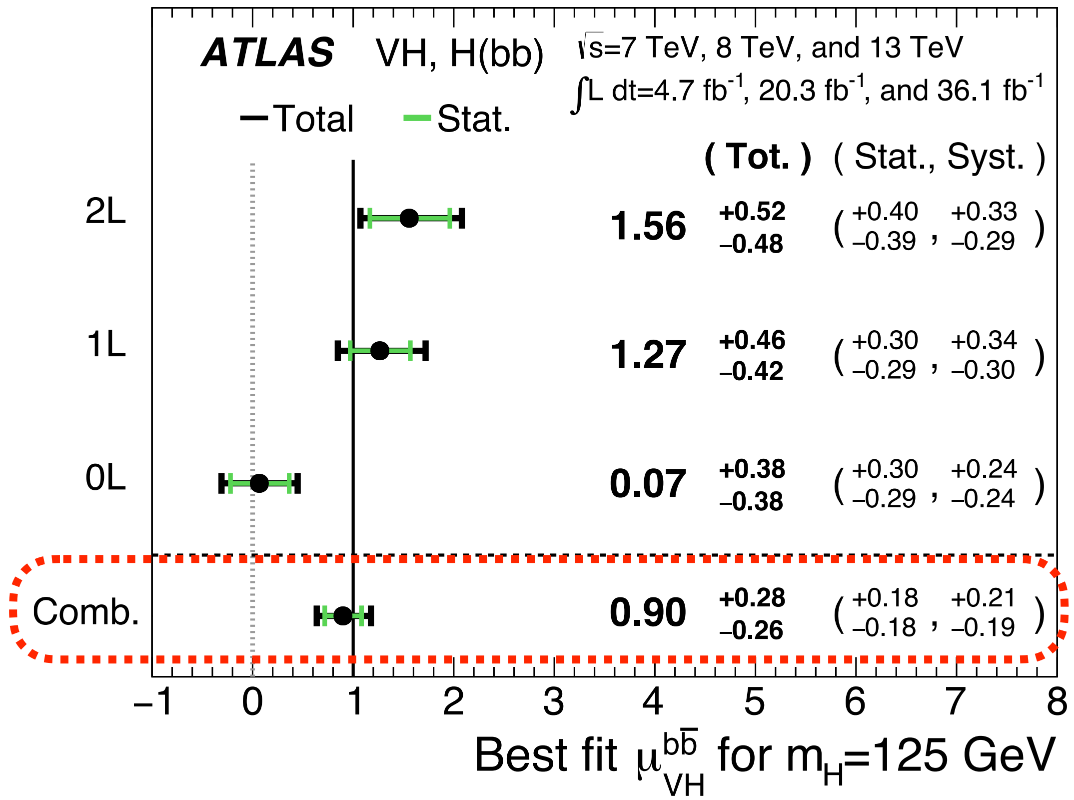


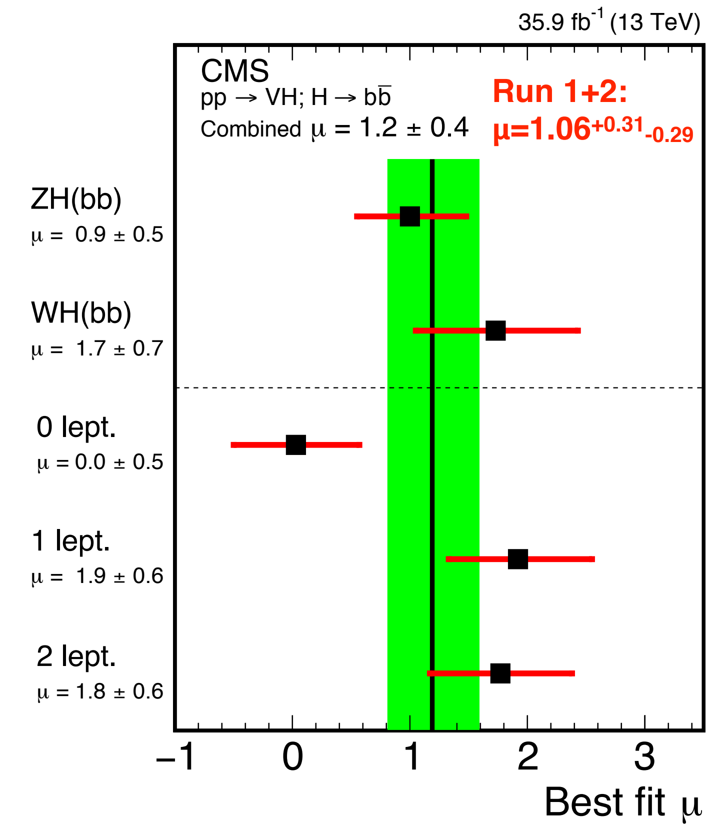
H($b\bar{b}$) Evidence

JHEP 12 (2017) 024

PLB 780 (2018) 501

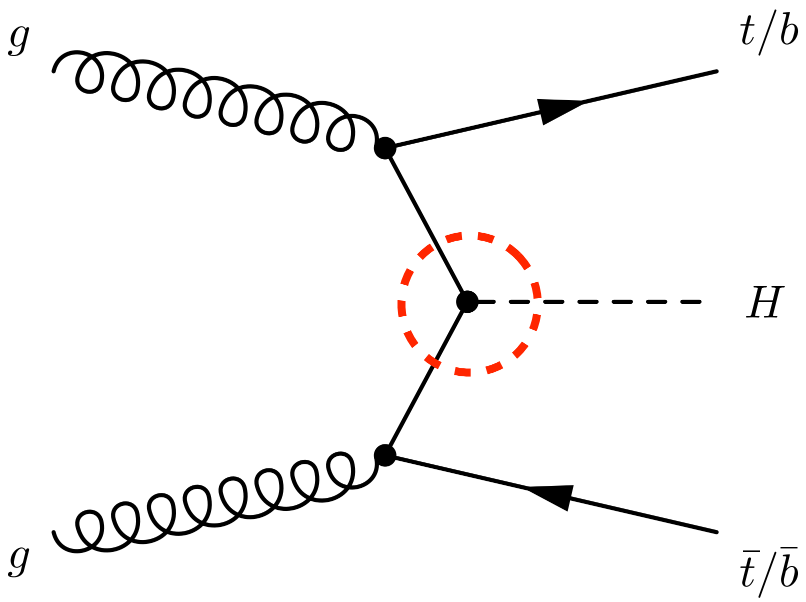






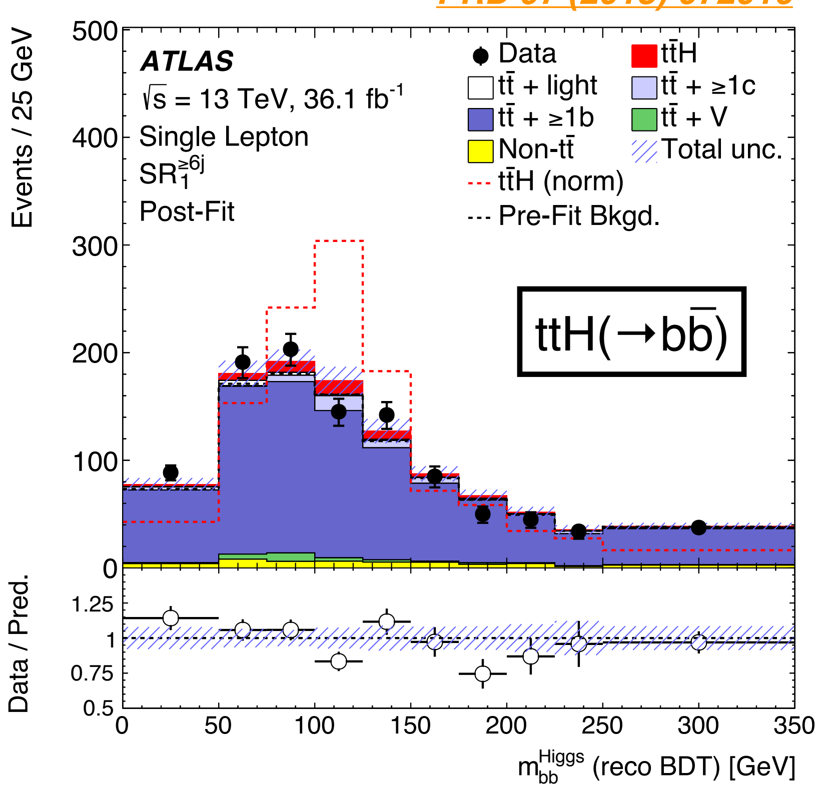
- **Evidence of H($b\bar{b}$) by both experiments!**
  - **ATLAS: 3.6σ (4.0σ) [Run 1+2]** for observed (expected)
  - **CMS: 3.8σ (3.8σ) [Run 1+2]** for observed (expected)
- Consistent results with the cut-based analysis in ATLAS (performed as a cross-check).

tt̄H Measurements



- **The ttH production allows us to directly measure the H-top Yukawa coupling.**
- The following channels are considered in ATLAS & CMS:
  - **ttH(→bb̄):** with 1, 2 leptons (also all had. for CMS)
  - **ttH→multilepton+X:** 2 same-sign, 3, 4 leptons w/ or w/o $\tau_{\rm had}$.
  - **ttH(→$\gamma\gamma$):** several categories with 0/1-lepton & jets/b-jets.

PRD 97 (2018) 072016



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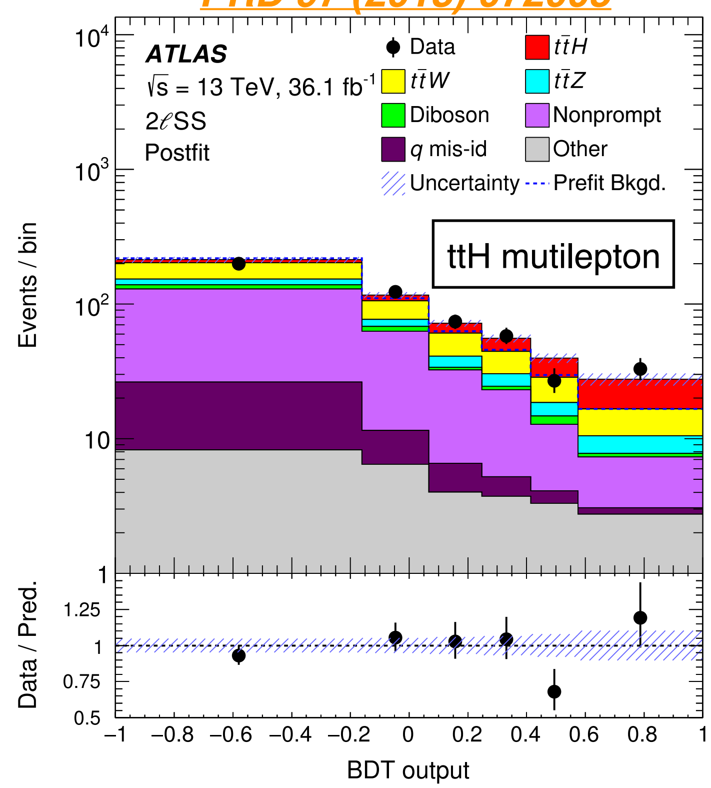
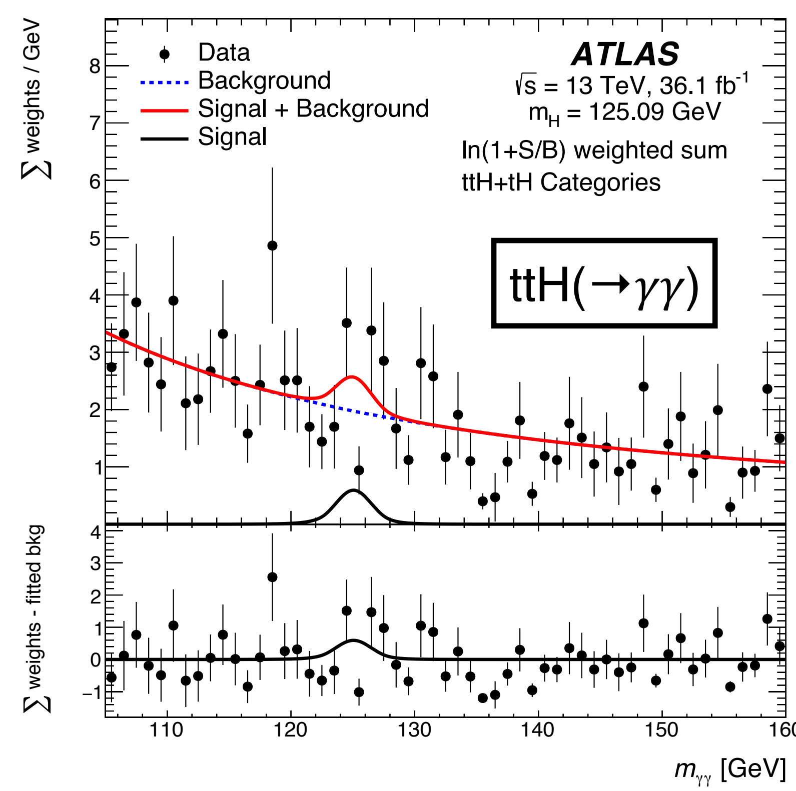
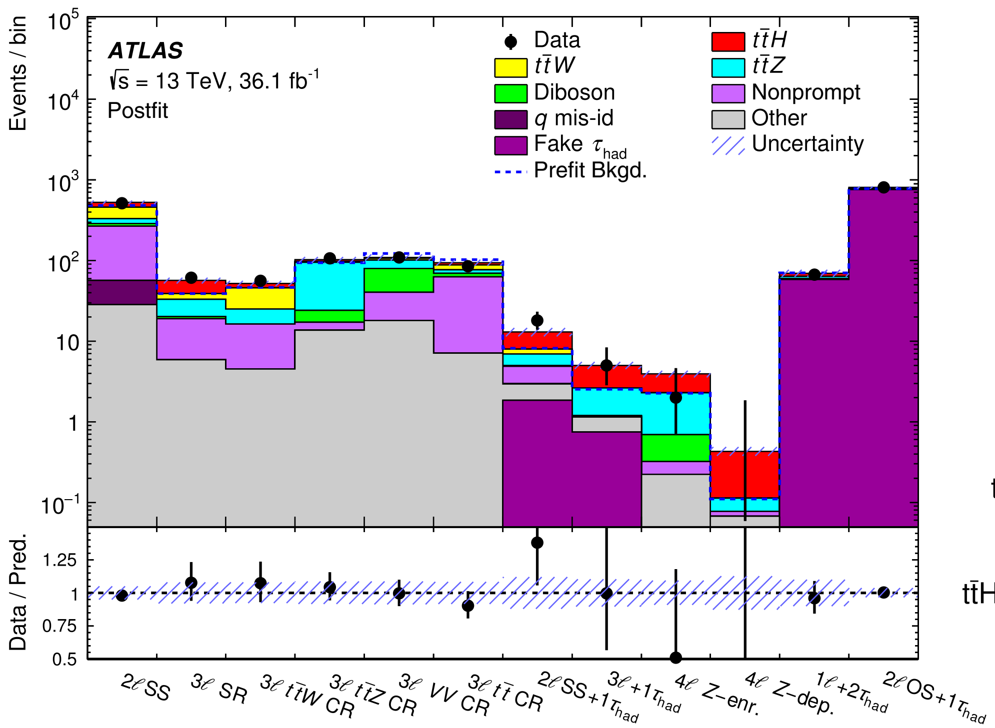


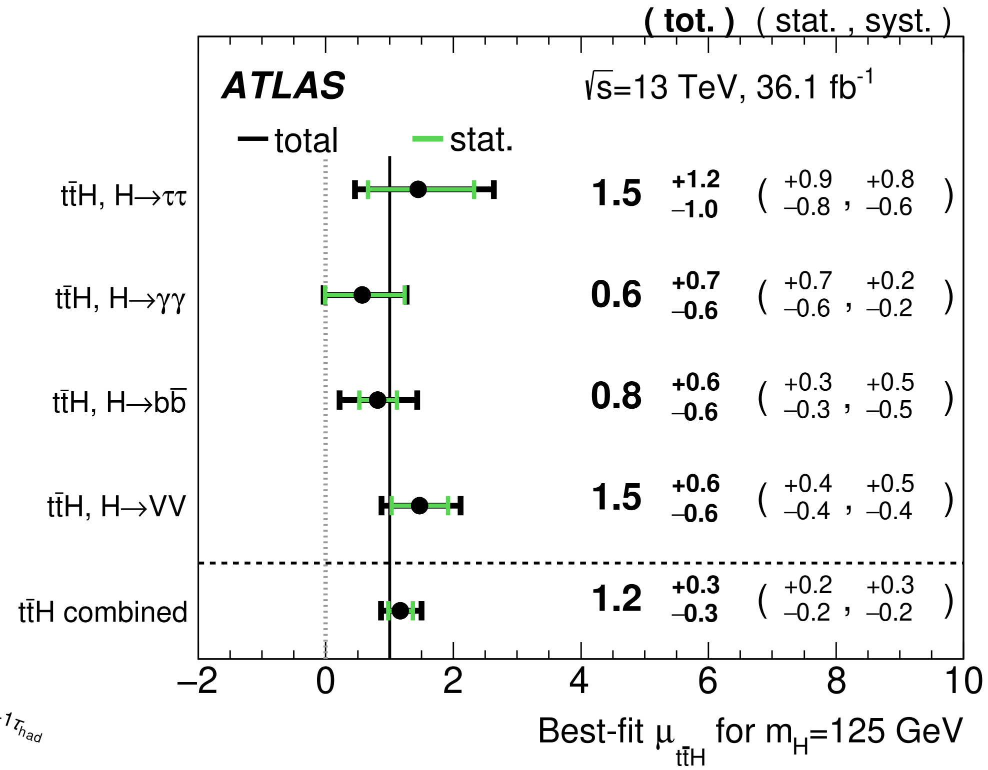
arXiv:1802.04146

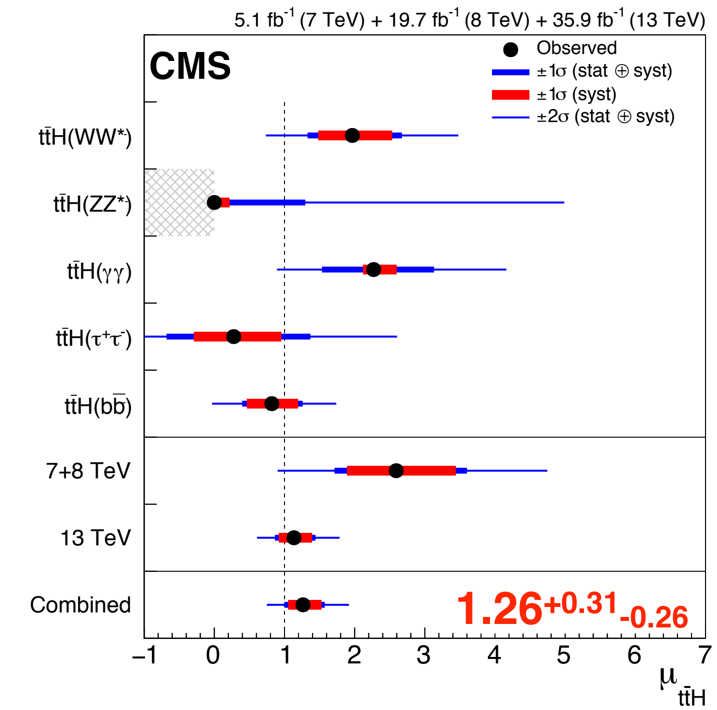


tt̄H Observation

[PRD 97 (2018) 072003](#) [arXiv:1804.02610](#)

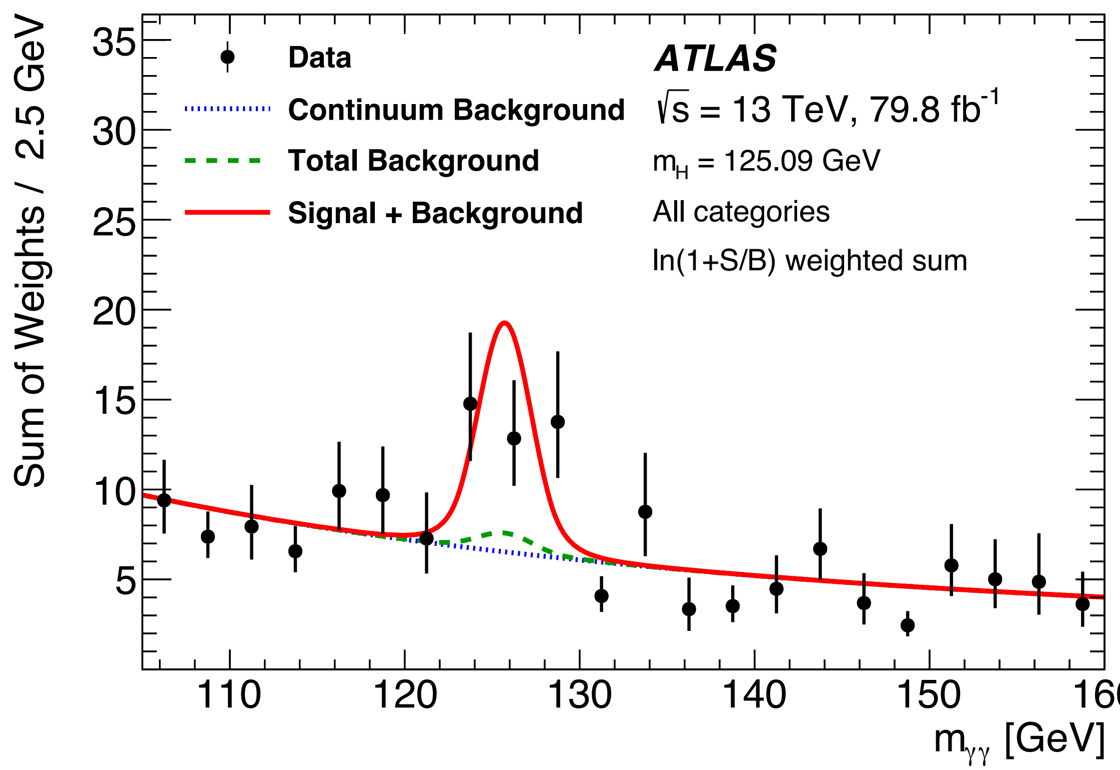


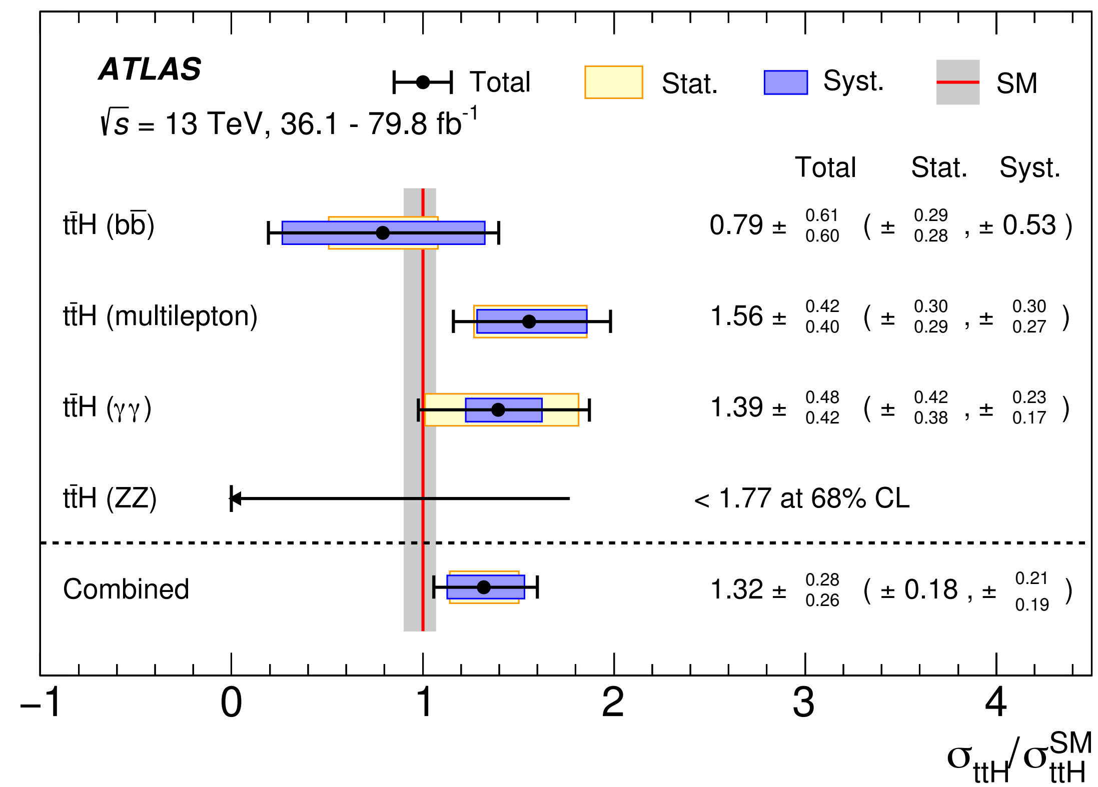




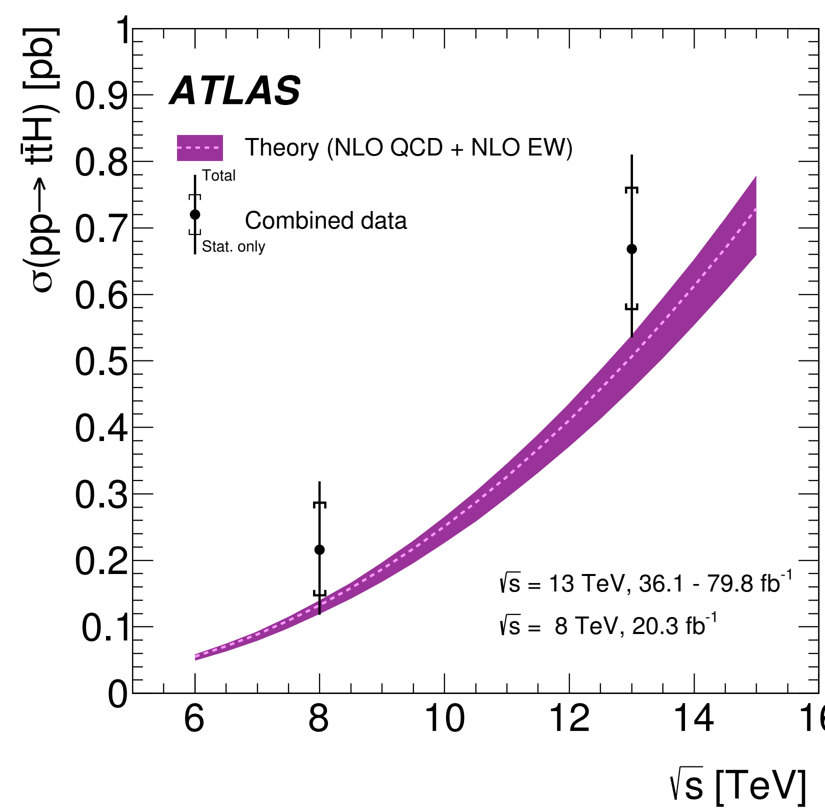
- Both ATLAS & CMS see evidence of ttH production with Run 2 data.
  With Run 1+2 combination by CMS, the production is fully observed:
    - **ATLAS Run 2 : 4.2σ observed (3.8σ expected)**
    - **CMS Run 1+2 : 5.2σ observed (4.2σ expected).**
- **Signal strength of μ_{ttH}=2 is now excluded at 95% CL by both ATLAS and CMS.**

$t\bar{t}H$ Observation NEW





- **With Run 1 & 2017 data (for γγ & $ZZ^{(*)} \to 4\ell$) added, ATLAS also observes the ttH production:**
  - **6.3σ observed (5.1σ expected)**
- Signal strength/cross section consistent with the Standard Model prediction.



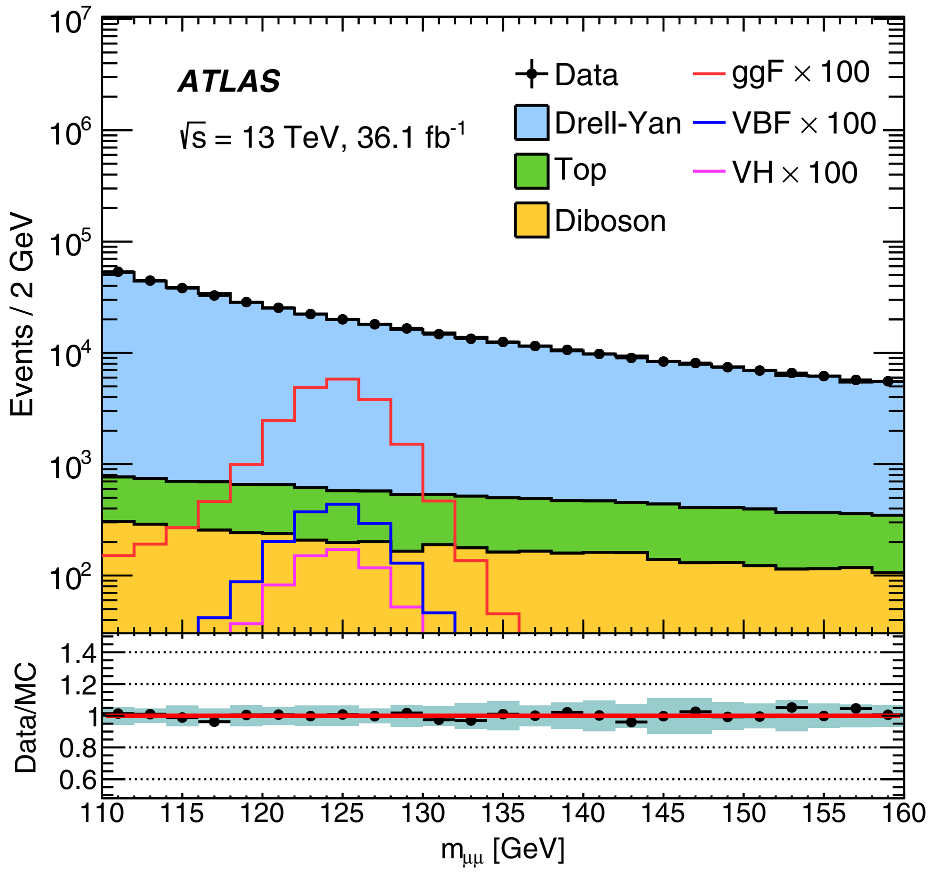
Higgs Rare Decays

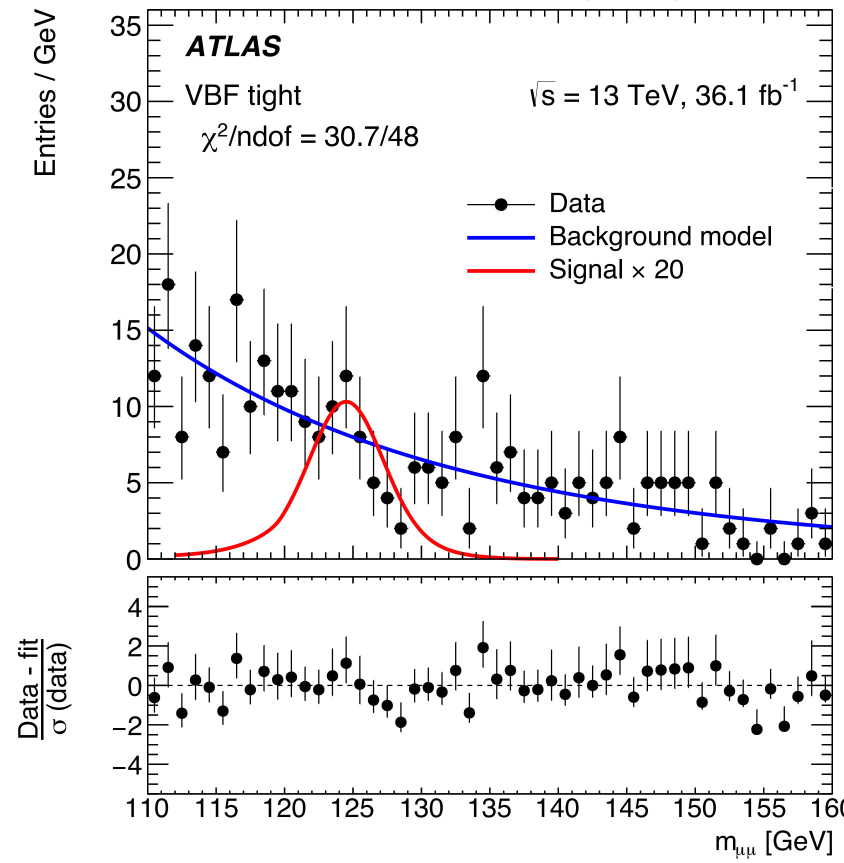
- **Γ_H <~3 Γ_H^{SM} still allows for sizable contributions from BSM decays.**
- **Searches for rare Higgs decays is a probe for new physics,** i.e. in enhancement of expected decays or in new decay modes (invisible, LFV, new bosons, etc.).
- Rare decays searched at the LHC:
  - Loop diagram: H→Zγ
  - 1st generation couplings: H→ργ, H→ee
  - 2nd generation couplings: H→ϕγ, H→J/ψ γ, H→ϒγ, **H→cc, H→μμ**
  - LFV: H→eτ,μτ,eμ; (t→qH)
  - New particles: **H→invisible**, H→aa (a: new (pseudo)scalar), H→ZZ_d,Z_dZ_d→4ℓ (Z_d: new vector boson), H→$f_{d2}f_{d2}$→lepton-jets+X (f_{d2}: hidden fermion)

Will mention in the next slides

$H(\mu^+\mu^-)$

PRL 119 (2017) 051802

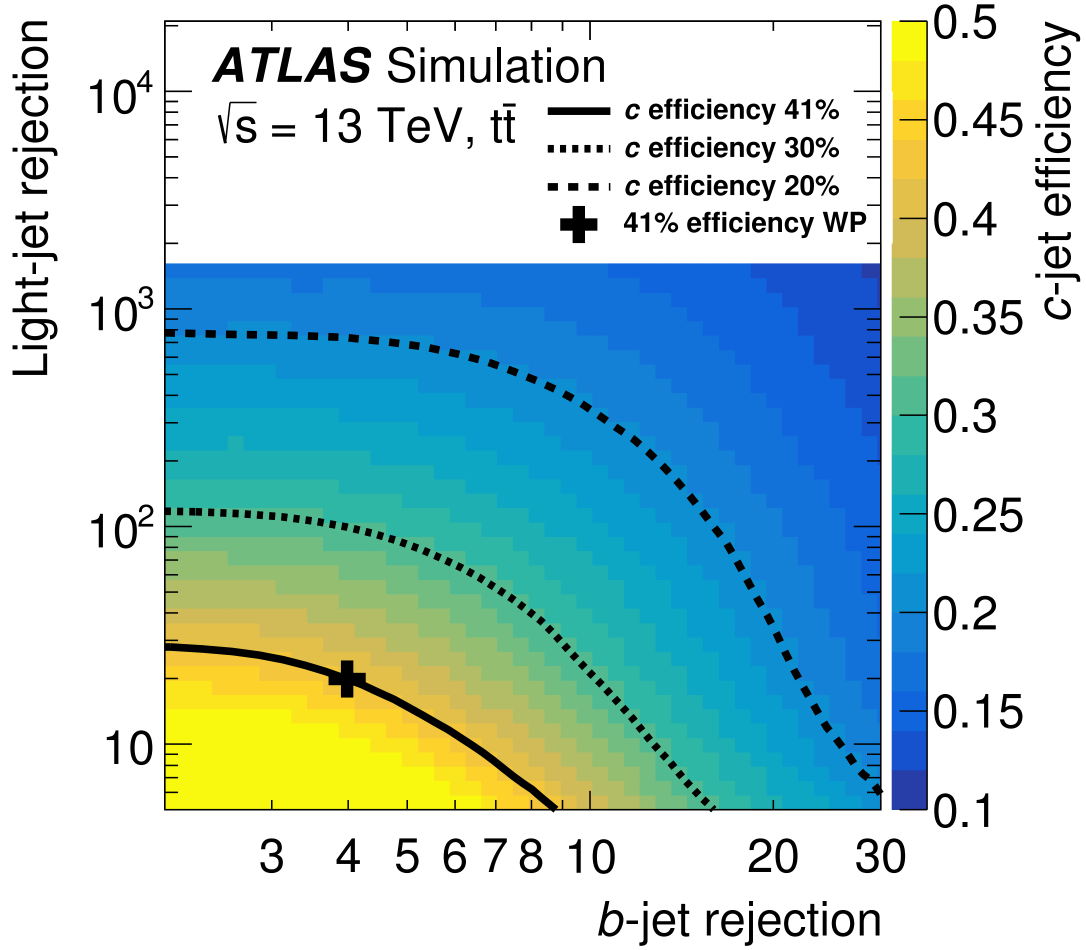


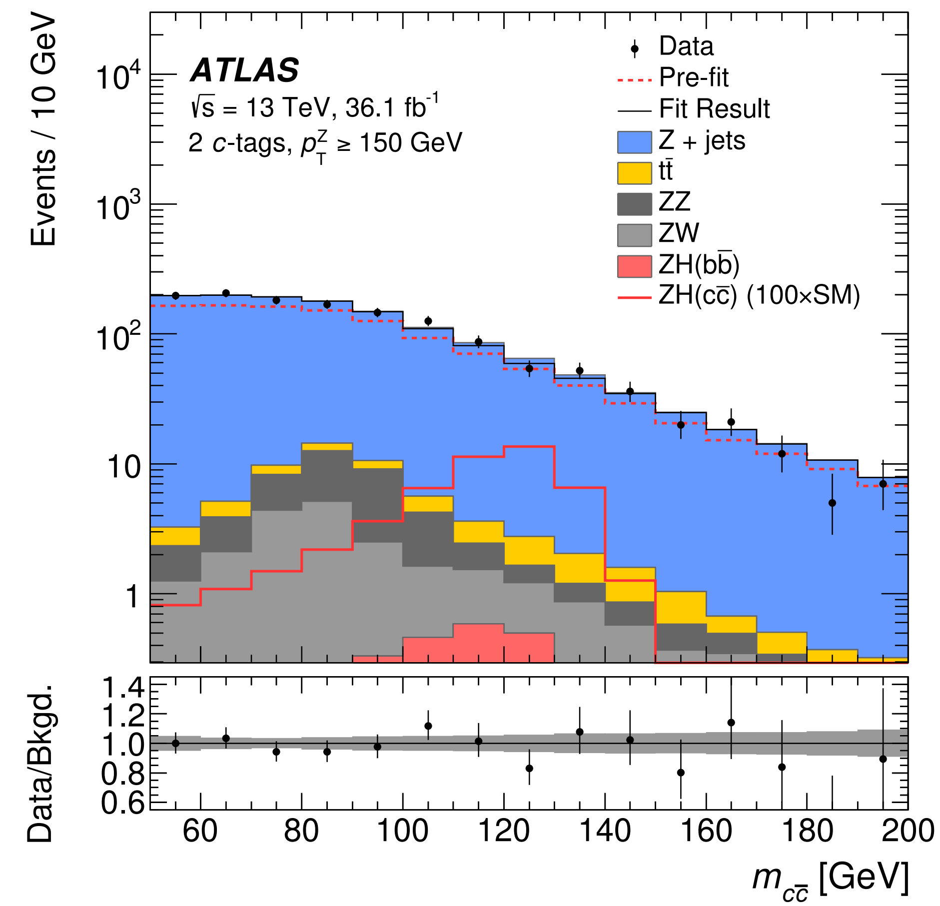


- $BR(H\to\mu^+\mu^-)=2.2\times10^{-4}$ from SM. Best sensitivity to the 2nd generation Yukawa couplings.
- BDT is considered with various muon & jet kinematic variables uncorrelated to $m_{\mu\mu}$. The events are categorized based on the BDT scores & $m_{\mu\mu}$ resolution (i.e. muon directions).
- **$BR(H\to\mu^+\mu^-)/BR_{SM}(H\to\mu^+\mu^-)$ < 2.8 obs (2.9 exp)** for ATLAS & **2.64 obs (1.89 exp)** for CMS @95% CL with Run 1+Run 2 combined dataset.
- **Best fit signal strength: -0.1±1.4 (ATLAS), $0.9^{+1.0}_{-0.9}$ (CMS).** Uncertainty is statistically dominated.

$Z(\ell^+\ell^-)H(c\bar{c})$

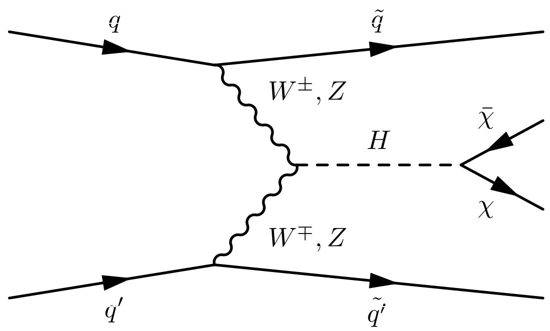
arXiv:1802.04329

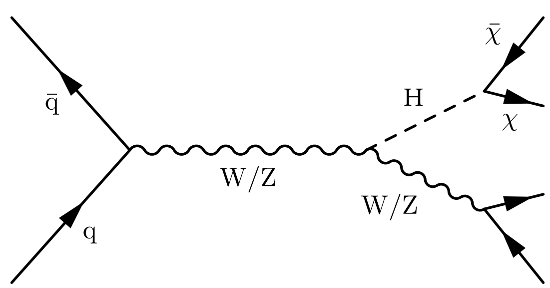


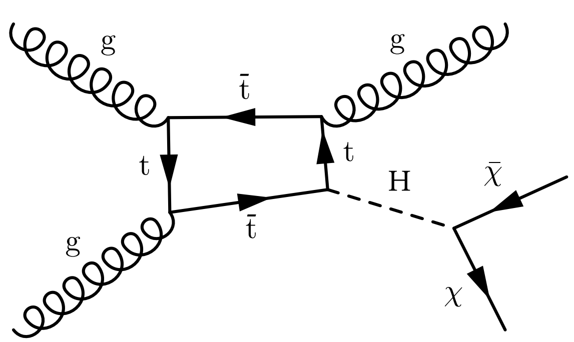


- BR($H\to c\bar{c}$)=2.9% from SM. Charm coupling was previously searched with J/ψ γ channel in Run 1.
- **An approach to search for the coupling with c-tagging has been newly considered by ATLAS in Run 2.**
- $\sigma_{ZH}\times$BR($H\to c\bar{c}$) < 2.7 (3.9) [pb]; 110 (150) times the SM expectation for obs. (exp.)@95% CL.

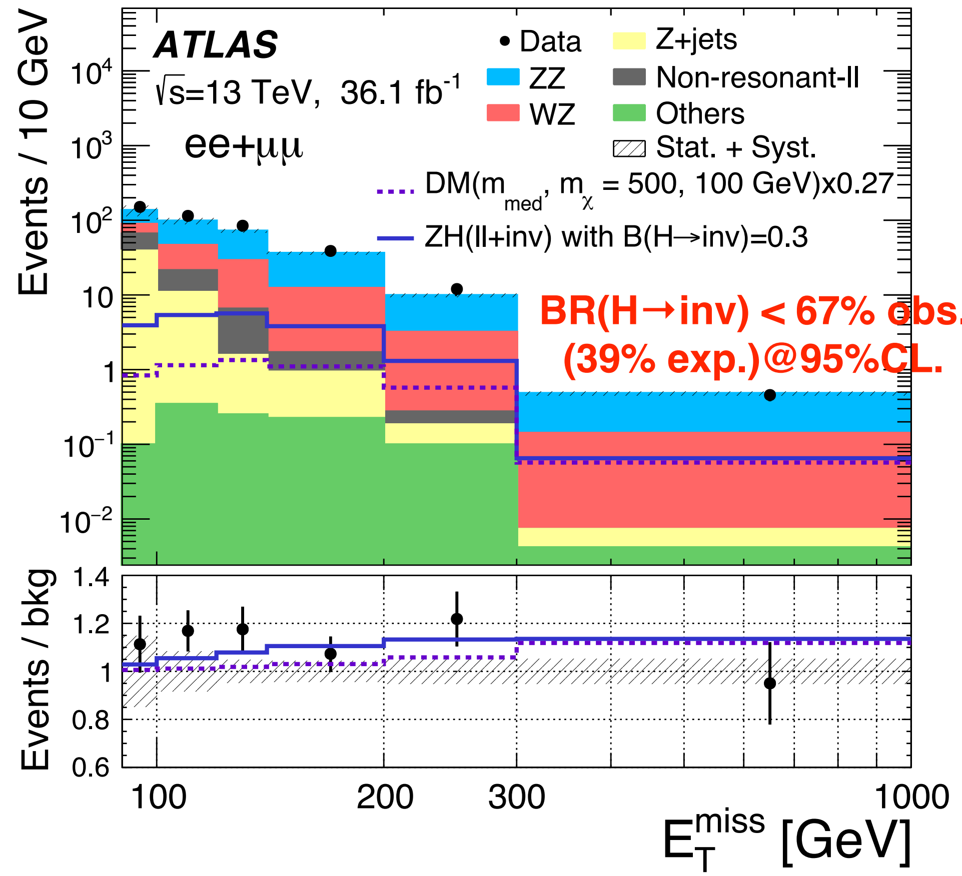
Invisible Higgs Decay



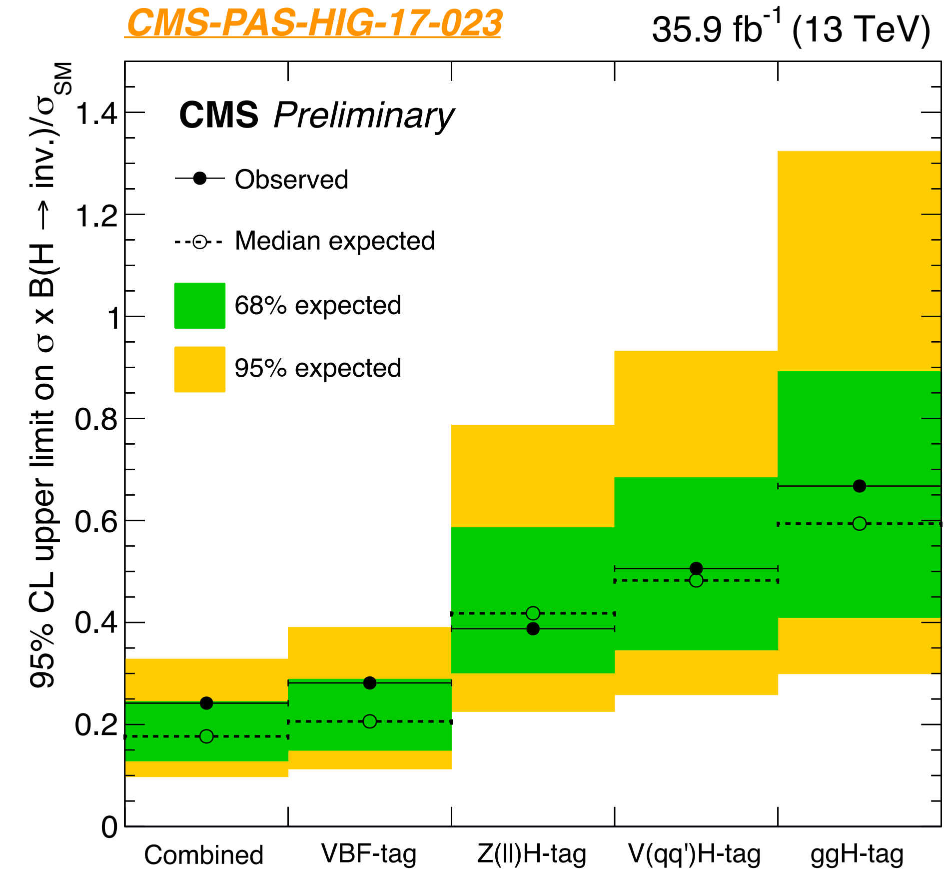




PLB 776 (2017) 318



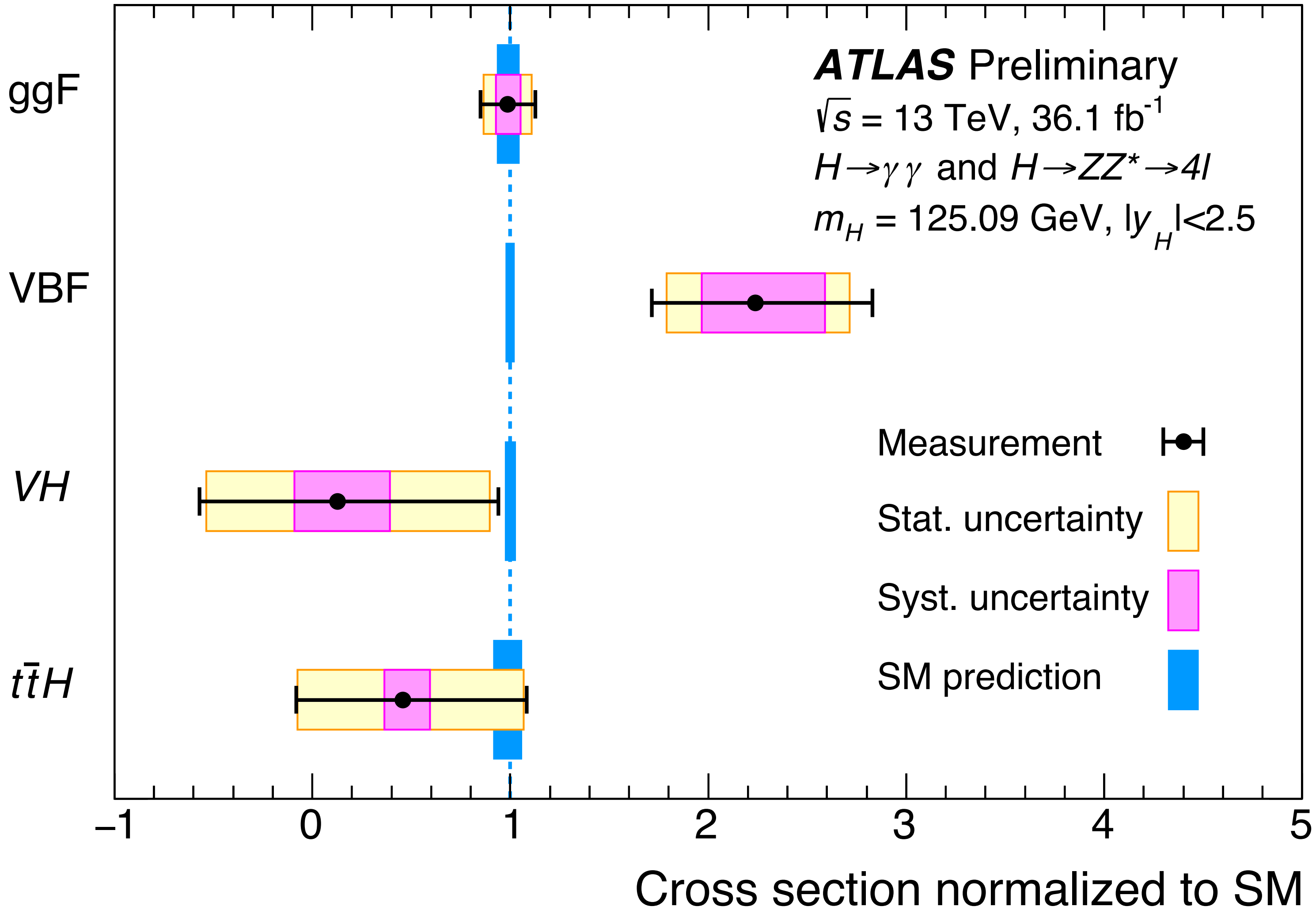
CMS-PAS-HIG-17-023

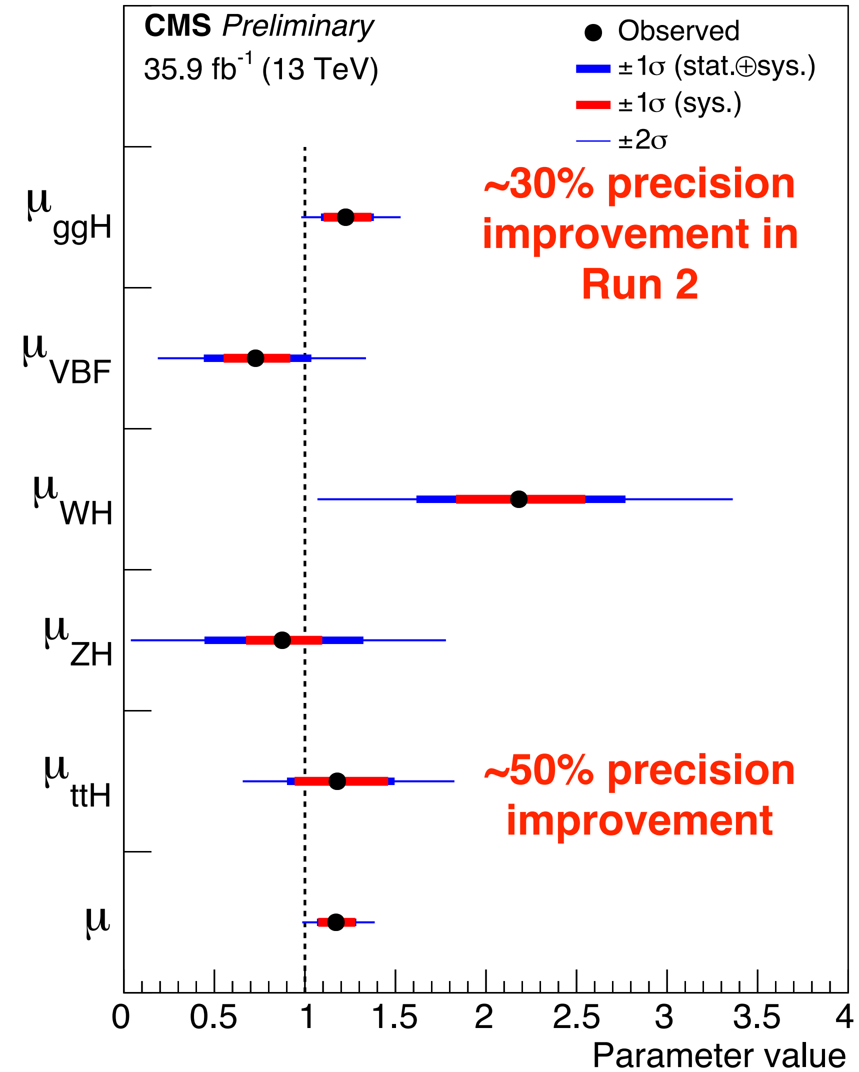


- Invisible decays of the Higgs boson are expected from various BSM models, especially in relation to the dark matter. Searches are pursued with a Higgs recoiling against visible particles.
- For all the channels, the expected sensitivity has surpassed that of Run 1.
- **CMS Combination provides BR(H→inv) < 24% [obs], 18% [exp]@95% CL.**

CMS-PAS-HIG-17-031

Combination





- Visible improvement in sensitivity for ggH & ttH.
- Precision from first 36 fb^{-1} from a single experiment matches Run 1 ATLAS+CMS for various couplings.

Combination - STXS

- Simplified template cross sections (STXS) aimed to balance experimental precision & theory uncertainties. Less model independent than Run 1 approach.
  - Very simple fiducial regions for each production mode & common between ATLAS, CMS, and theory.

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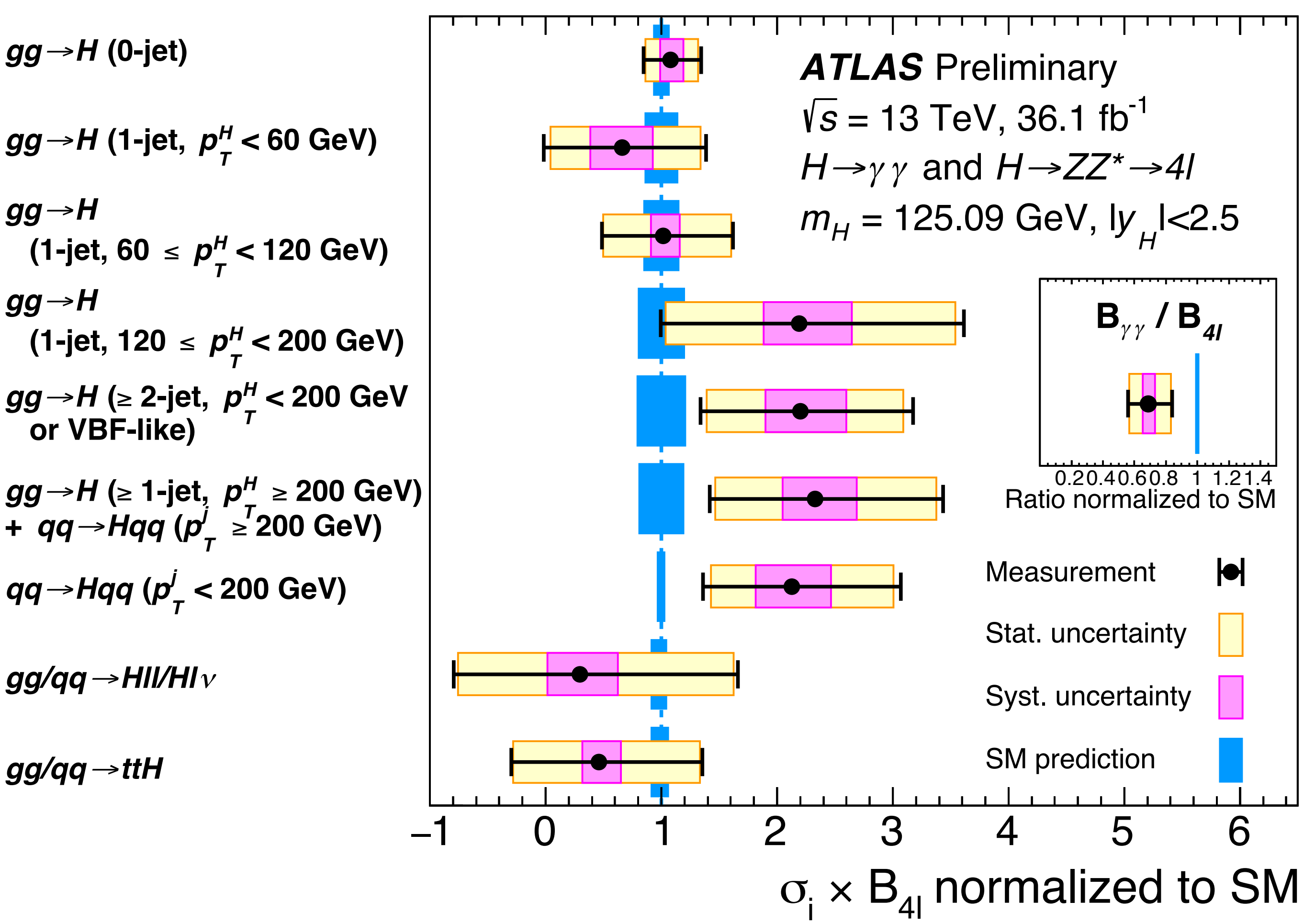
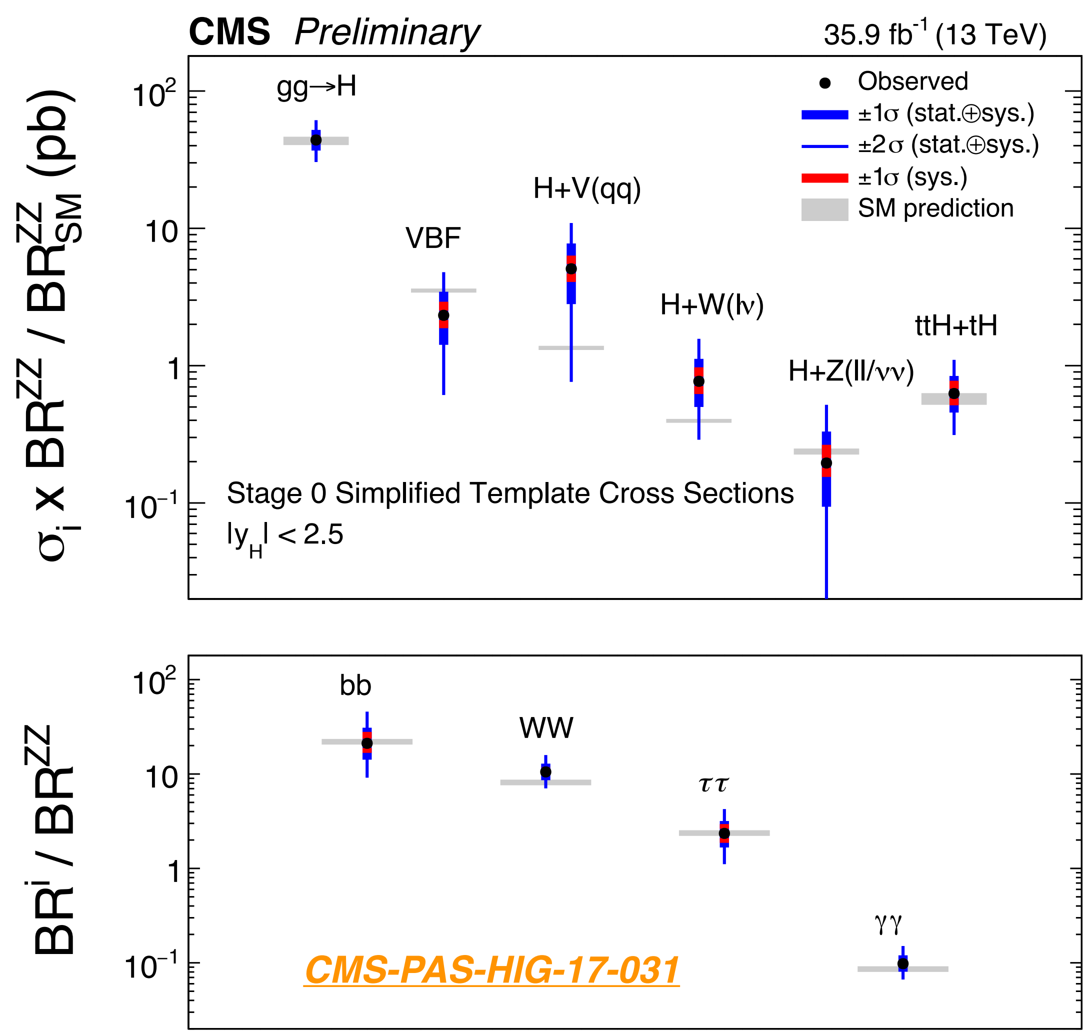
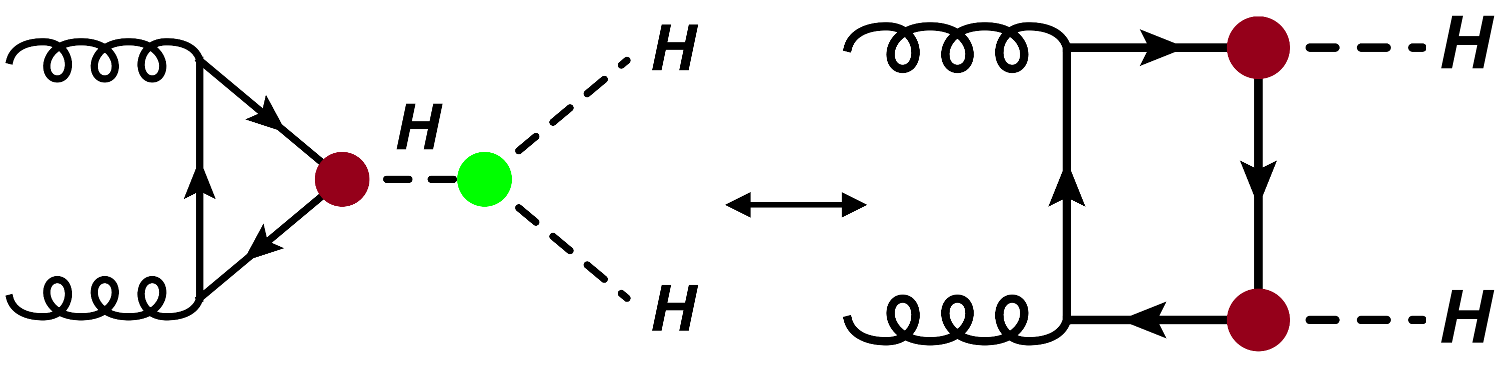




Di-Higgs



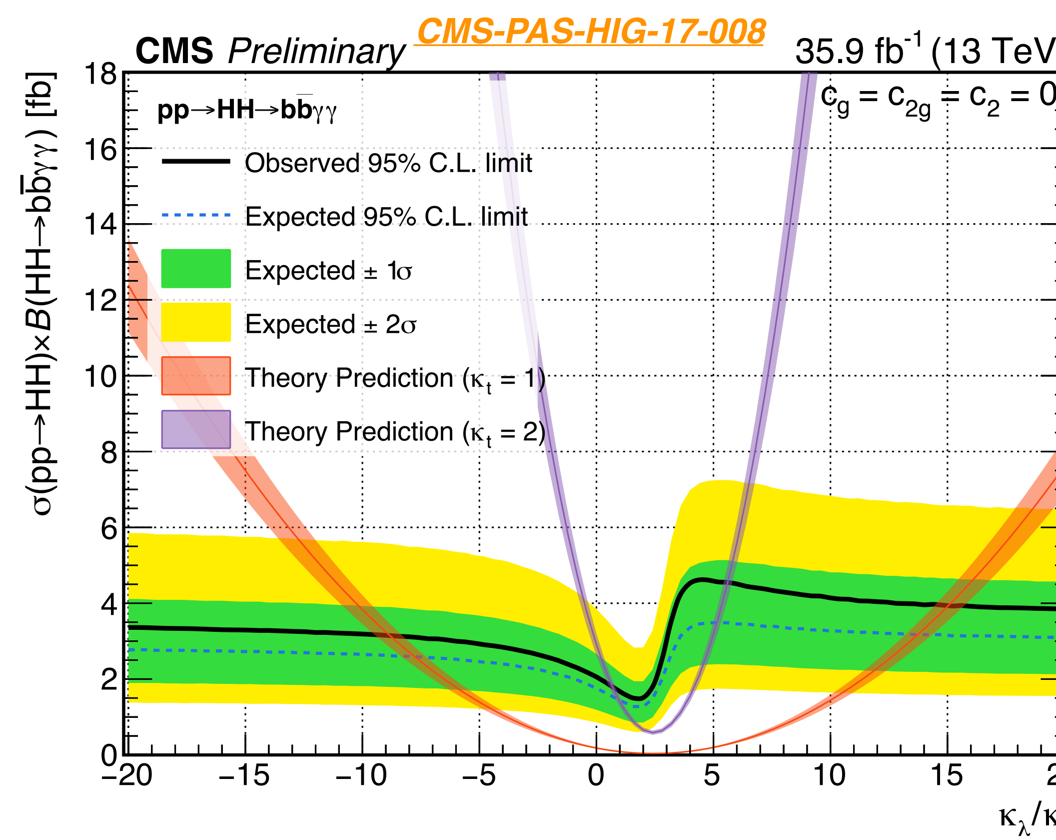
Destructive Interference

- Di-Higgs production searches are pursued at the LHC, mostly in the context of new resonance searches.
- Best constraint on **$\sigma_{HH}/\sigma_{HH}^{SM}$ (<13)** at 95% CL from **HH→4b** (arXiv:1804.06174).

- Best constraint on self-coupling from **HH→bb$\gamma\gamma$** channel: **$-8.82 < \kappa_\lambda < 15.04$** at 95% CL.

Channels	95% CL limits on $\sigma_{HH}/\sigma_{HH}^{SM}$ [obs (exp)]	
	ATLAS	CMS
4b	**< 13 (21)**	< 342 (308)
bbWW	—	< 79 (89)
bb$\tau\tau$	< 160 (130) [Run1]	< 30 (25)
bb$\gamma\gamma$	< 117 (161)	**< 19 (17)**
$\gamma\gamma$WW	< 747 (386)	—

Run-2: 3 fb^{-1}, 13 fb^{-1}, 36 fb^{-1}

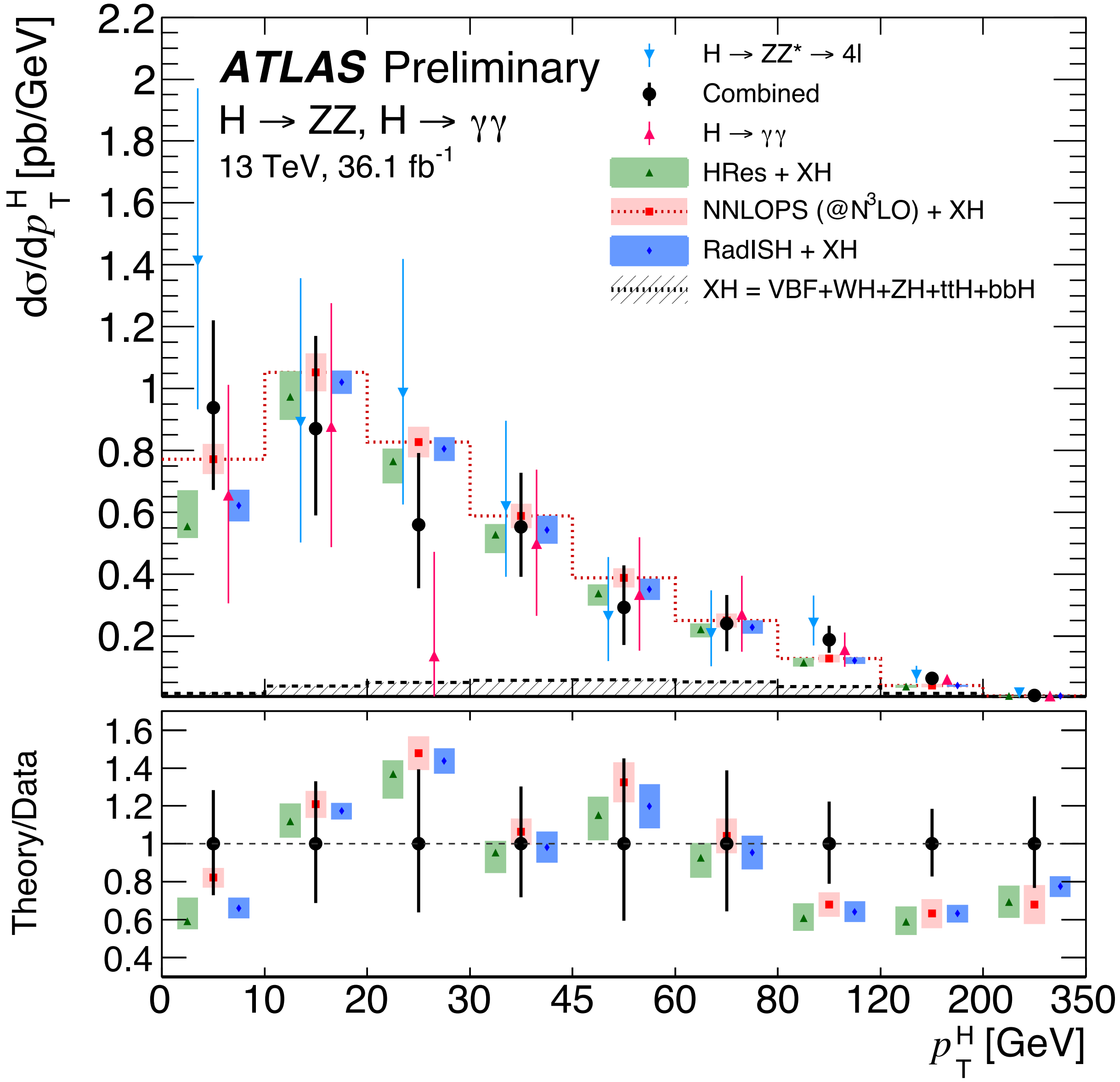


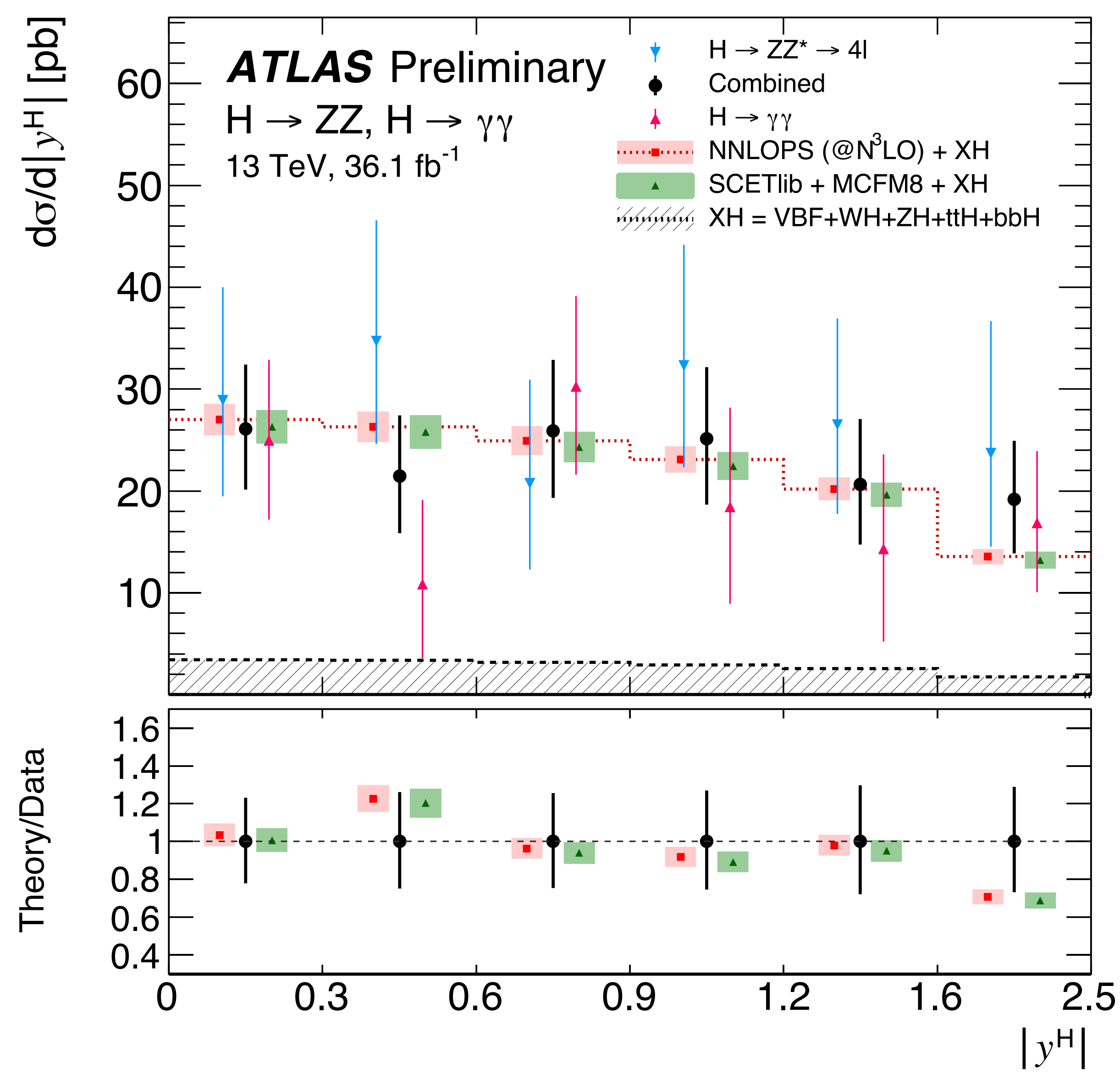
Summary

- Discovery of a Higgs boson is a dawn of a new era, where a totally rich program has opened up to be investigated and to be understood.
- Many achievements in Run 2 beyond the Higgs discovery:
  - More details & improved precision in cross section & coupling measurements
  - Single-experiment observation of $H \to \tau^+\tau^-$.
  - Evidence of $H \to b\bar{b}$
  - Observation of $t\bar{t}H$ production
  - Uncertainty on the signal strength of $H \to \mu^+\mu^-$ is reaching 100%
  - More stringent constraints on various BSM phenomena.
- More to come with the full Run 2 data to be taken until the end of this year.
- Run 3 & HL-LHC will provide various measurements of the Higgs boson w/ even higher precision & sensitivity to various rare processes (both SM & BSM).

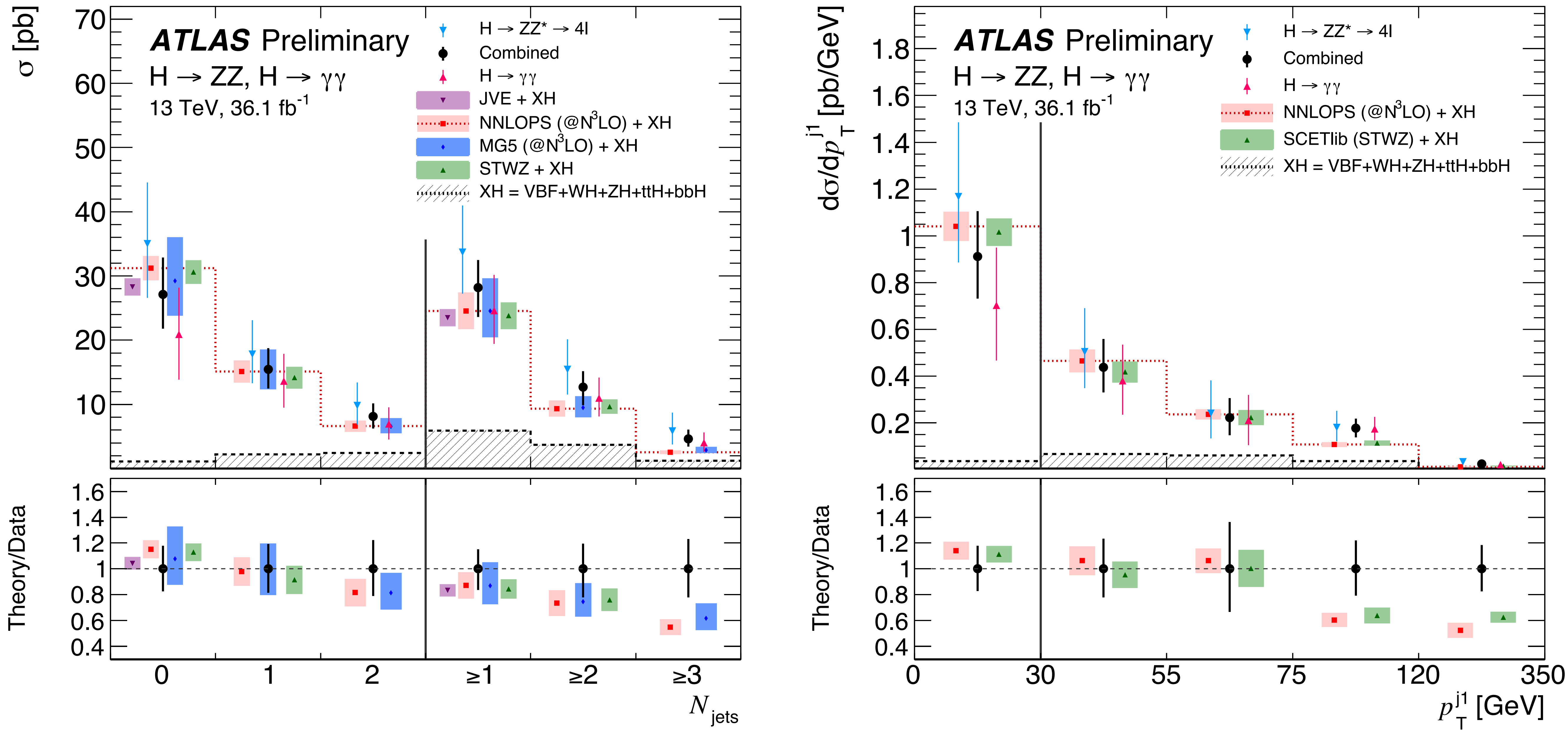
backup

H→γγ & 4ℓ Differential





H→γγ & 4ℓ Differential



Combination

Run 1 (ATLAS+CMS)

Parameter	ATLAS+CMS Measured	ATLAS+CMS Expected uncertainty	ATLAS Measured	CMS Measured
κ_Z	1.00 $[-1.05, -0.86] \cup [0.90, 1.11]$	$[-1.00, -0.88] \cup [0.90, 1.10]$	0.98 $[-1.07, -0.83] \cup [0.84, 1.12]$	1.03 $[-1.11, -0.83] \cup [0.87, 1.19]$
κ_W	$0.91^{+0.10}_{-0.12}$	$^{+0.10}_{-0.11}$	$0.91^{+0.12}_{-0.15}$	$0.92^{+0.14}_{-0.17}$
κ_t	$0.87^{+0.15}_{-0.15}$	$^{+0.15}_{-0.18}$	$0.98^{+0.21}_{-0.20}$	$0.77^{+0.20}_{-0.18}$
$\|\kappa_\tau\|$	$0.90^{+0.14}_{-0.16}$	$^{+0.15}_{-0.14}$	$0.99^{+0.20}_{-0.20}$	$0.83^{+0.20}_{-0.21}$
κ_b	0.67 $[-0.73, -0.47] \cup [0.40, 0.89]$	$[-1.24, -0.76] \cup [0.74, 1.24]$	0.64 $[-0.89, -0.33] \cup [0.30, 0.94]$	0.71 $[-0.91, -0.40] \cup [0.35, 1.04]$
$\|\kappa_\mu\|$	$0.2^{+1.2}$	$^{+0.9}$	$0.0^{+1.4}$	$0.5^{+1.4}$

Run 2 (CMS)

$BR_{inv.} = 0$

Parameter	Best fit	Uncertainty Stat.	Uncertainty Syst.
κ_Z	$0.99^{+0.11}_{-0.11}$ $\left(^{+0.11}_{-0.11}\right)$	$^{+0.09}_{-0.09}$ $\left(^{+0.09}_{-0.09}\right)$	$^{+0.06}_{-0.06}$ $\left(^{+0.06}_{-0.06}\right)$
κ_W	$1.12^{+0.13}_{-0.19}$ $\left(^{+0.12}_{-0.12}\right)$	$^{+0.10}_{-0.18}$ $\left(^{+0.09}_{-0.09}\right)$	$^{+0.08}_{-0.07}$ $\left(^{+0.07}_{-0.07}\right)$
κ_t	$1.09^{+0.14}_{-0.14}$ $\left(^{+0.14}_{-0.15}\right)$	$^{+0.08}_{-0.08}$ $\left(^{+0.08}_{-0.09}\right)$	$^{+0.12}_{-0.12}$ $\left(^{+0.12}_{-0.12}\right)$
κ_τ	$1.01^{+0.17}_{-0.18}$ $\left(^{+0.16}_{-0.15}\right)$	$^{+0.11}_{-0.15}$ $\left(^{+0.11}_{-0.11}\right)$	$^{+0.12}_{-0.09}$ $\left(^{+0.11}_{-0.11}\right)$
κ_b	$1.10^{+0.27}_{-0.33}$ $\left(^{+0.25}_{-0.23}\right)$	$^{+0.19}_{-0.30}$ $\left(^{+0.19}_{-0.17}\right)$	$^{+0.19}_{-0.14}$ $\left(^{+0.17}_{-0.15}\right)$
κ_g	$1.14^{+0.15}_{-0.13}$ $\left(^{+0.14}_{-0.12}\right)$	$^{+0.10}_{-0.09}$ $\left(^{+0.10}_{-0.09}\right)$	$^{+0.11}_{-0.09}$ $\left(^{+0.10}_{-0.09}\right)$
κ_γ	$1.07^{+0.15}_{-0.18}$ $\left(^{+0.12}_{-0.12}\right)$	$^{+0.10}_{-0.17}$ $\left(^{+0.10}_{-0.10}\right)$	$^{+0.11}_{-0.07}$ $\left(^{+0.07}_{-0.07}\right)$

Combination

Run 1 (ATLAS+CMS)

Production process	ATLAS+CMS	ATLAS	CMS
μ_{ggF}	$1.03^{+0.16}_{-0.14}$ $\left(^{+0.16}_{-0.14}\right)$	$1.26^{+0.23}_{-0.20}$ $\left(^{+0.21}_{-0.18}\right)$	$0.84^{+0.18}_{-0.16}$ $\left(^{+0.20}_{-0.17}\right)$
μ_{VBF}	$1.18^{+0.25}_{-0.23}$ $\left(^{+0.24}_{-0.23}\right)$	$1.21^{+0.33}_{-0.30}$ $\left(^{+0.32}_{-0.29}\right)$	$1.14^{+0.37}_{-0.34}$ $\left(^{+0.36}_{-0.34}\right)$
μ_{WH}	$0.89^{+0.40}_{-0.38}$ $\left(^{+0.41}_{-0.39}\right)$	$1.25^{+0.56}_{-0.52}$ $\left(^{+0.56}_{-0.53}\right)$	$0.46^{+0.57}_{-0.53}$ $\left(^{+0.60}_{-0.57}\right)$
μ_{ZH}	$0.79^{+0.38}_{-0.36}$ $\left(^{+0.39}_{-0.36}\right)$	$0.30^{+0.51}_{-0.45}$ $\left(^{+0.55}_{-0.51}\right)$	$1.35^{+0.58}_{-0.54}$ $\left(^{+0.55}_{-0.51}\right)$
μ_{ttH}	$2.3^{+0.7}_{-0.6}$ $\left(^{+0.5}_{-0.5}\right)$	$1.9^{+0.8}_{-0.7}$ $\left(^{+0.7}_{-0.7}\right)$	$2.9^{+1.0}_{-0.9}$ $\left(^{+0.9}_{-0.8}\right)$

Decay channel	ATLAS+CMS	ATLAS	CMS
$\mu^{\gamma\gamma}$	$1.14^{+0.19}_{-0.18}$ $\left(^{+0.18}_{-0.17}\right)$	$1.14^{+0.27}_{-0.25}$ $\left(^{+0.26}_{-0.24}\right)$	$1.11^{+0.25}_{-0.23}$ $\left(^{+0.23}_{-0.21}\right)$
μ^{ZZ}	$1.29^{+0.26}_{-0.23}$ $\left(^{+0.23}_{-0.20}\right)$	$1.52^{+0.40}_{-0.34}$ $\left(^{+0.32}_{-0.27}\right)$	$1.04^{+0.32}_{-0.26}$ $\left(^{+0.30}_{-0.25}\right)$
μ^{WW}	$1.09^{+0.18}_{-0.16}$ $\left(^{+0.16}_{-0.15}\right)$	$1.22^{+0.23}_{-0.21}$ $\left(^{+0.21}_{-0.20}\right)$	$0.90^{+0.23}_{-0.21}$ $\left(^{+0.23}_{-0.20}\right)$
$\mu^{\tau\tau}$	$1.11^{+0.24}_{-0.22}$ $\left(^{+0.24}_{-0.22}\right)$	$1.41^{+0.40}_{-0.36}$ $\left(^{+0.37}_{-0.33}\right)$	$0.88^{+0.30}_{-0.28}$ $\left(^{+0.31}_{-0.29}\right)$
μ^{bb}	$0.70^{+0.29}_{-0.27}$ $\left(^{+0.29}_{-0.28}\right)$	$0.62^{+0.37}_{-0.37}$ $\left(^{+0.39}_{-0.37}\right)$	$0.81^{+0.45}_{-0.43}$ $\left(^{+0.45}_{-0.43}\right)$
$\mu^{\mu\mu}$	$0.1^{+2.5}_{-2.5}$ $\left(^{+2.4}_{-2.3}\right)$	$-0.6^{+3.6}_{-3.6}$ $\left(^{+3.6}_{-3.6}\right)$	$0.9^{+3.6}_{-3.5}$ $\left(^{+3.3}_{-3.2}\right)$

Run 2 (CMS)

Production process														
ggH			VBF			WH			ZH			ttH		
Best fit value	Uncertainty Stat.	Syst.	Best fit value	Uncertainty Stat.	Syst.	Best fit value	Uncertainty Stat.	Syst.	Best fit value	Uncertainty Stat.	Syst.	Best fit value	Uncertainty Stat.	Syst.
$1.23^{+0.14}_{-0.13}$ $\left(^{+0.11}_{-0.11}\right)$	$^{+0.08}_{-0.08}$ $\left(^{+0.07}_{-0.07}\right)$	$^{+0.12}_{-0.10}$ $\left(^{+0.09}_{-0.08}\right)$	$0.73^{+0.30}_{-0.27}$ $\left(^{+0.29}_{-0.27}\right)$	$^{+0.24}_{-0.23}$ $\left(^{+0.24}_{-0.23}\right)$	$^{+0.17}_{-0.15}$ $\left(^{+0.16}_{-0.15}\right)$	$2.18^{+0.58}_{-0.55}$ $\left(^{+0.53}_{-0.51}\right)$	$^{+0.46}_{-0.45}$ $\left(^{+0.43}_{-0.42}\right)$	$^{+0.34}_{-0.32}$ $\left(^{+0.30}_{-0.29}\right)$	$0.87^{+0.44}_{-0.42}$ $\left(^{+0.42}_{-0.40}\right)$	$^{+0.39}_{-0.38}$ $\left(^{+0.38}_{-0.37}\right)$	$^{+0.20}_{-0.18}$ $\left(^{+0.19}_{-0.17}\right)$	$1.18^{+0.31}_{-0.27}$ $\left(^{+0.28}_{-0.25}\right)$	$^{+0.16}_{-0.16}$ $\left(^{+0.16}_{-0.16}\right)$	$^{+0.26}_{-0.21}$ $\left(^{+0.23}_{-0.20}\right)$

Decay mode														
$H \to bb$			$H \to \tau\tau$			$H \to WW$			$H \to ZZ$			$H \to \gamma\gamma$		
Best fit value	Uncertainty Stat.	Syst.	Best fit value	Uncertainty Stat.	Syst.	Best fit value	Uncertainty Stat.	Syst.	Best fit value	Uncertainty Stat.	Syst.	Best fit value	Uncertainty Stat.	Syst.
$1.12^{+0.29}_{-0.28}$ $\left(^{+0.28}_{-0.27}\right)$	$^{+0.19}_{-0.19}$ $\left(^{+0.19}_{-0.18}\right)$	$^{+0.22}_{-0.20}$ $\left(^{+0.21}_{-0.20}\right)$	$1.02^{+0.26}_{-0.24}$ $\left(^{+0.24}_{-0.23}\right)$	$^{+0.15}_{-0.15}$ $\left(^{+0.15}_{-0.14}\right)$	$^{+0.21}_{-0.19}$ $\left(^{+0.19}_{-0.17}\right)$	$1.28^{+0.17}_{-0.16}$ $\left(^{+0.14}_{-0.13}\right)$	$^{+0.09}_{-0.09}$ $\left(^{+0.09}_{-0.09}\right)$	$^{+0.14}_{-0.13}$ $\left(^{+0.11}_{-0.10}\right)$	$1.06^{+0.19}_{-0.17}$ $\left(^{+0.18}_{-0.16}\right)$	$^{+0.16}_{-0.15}$ $\left(^{+0.15}_{-0.14}\right)$	$^{+0.10}_{-0.08}$ $\left(^{+0.10}_{-0.08}\right)$	$1.20^{+0.17}_{-0.14}$ $\left(^{+0.14}_{-0.12}\right)$	$^{+0.12}_{-0.11}$ $\left(^{+0.10}_{-0.10}\right)$	$^{+0.12}_{-0.09}$ $\left(^{+0.09}_{-0.07}\right)$

Higgs Decay Width

- **The decay width of the Higgs boson is 4.1 MeV.** Unable to directly measure at the LHC due to detector resolution (Γ_H < 1.10 GeV@95% CL [CMS]). To be measured at LC.
- However, Higgs off-shell production is sensitive to the Higgs total width & it can be constrained at the LHC using $H^* \rightarrow ZZ \rightarrow 4\ell, \ell\ell\nu\nu$ & $H^* \rightarrow WW \rightarrow \ell\nu\ell\nu$.
- Run 1: **Γ_H < 22.7 (33.0) MeV** [ATLAS], **13 (26) MeV** [CMS]@95% CL for obs (exp).
  model-dependent
- Constraints will improve with statistics.

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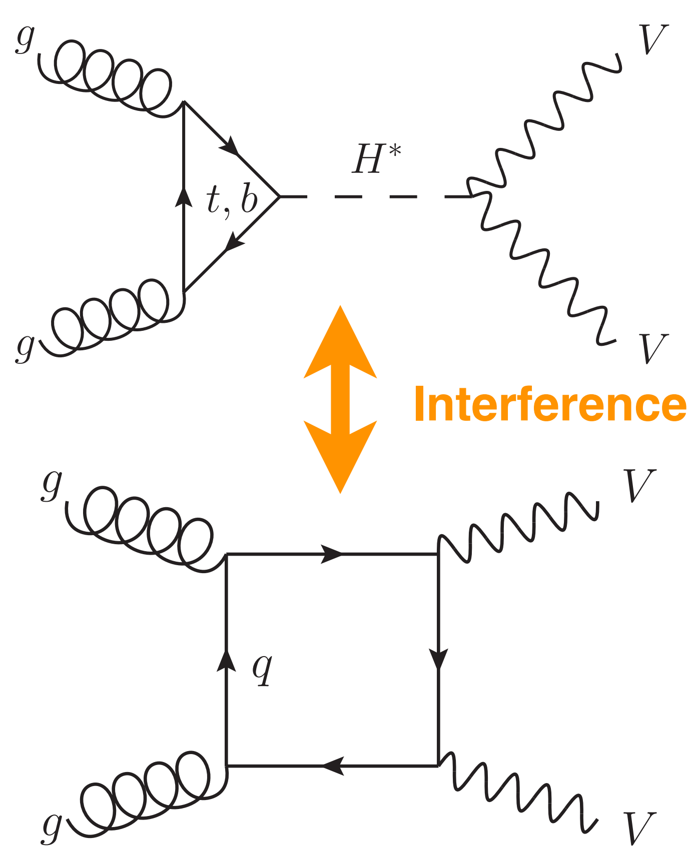
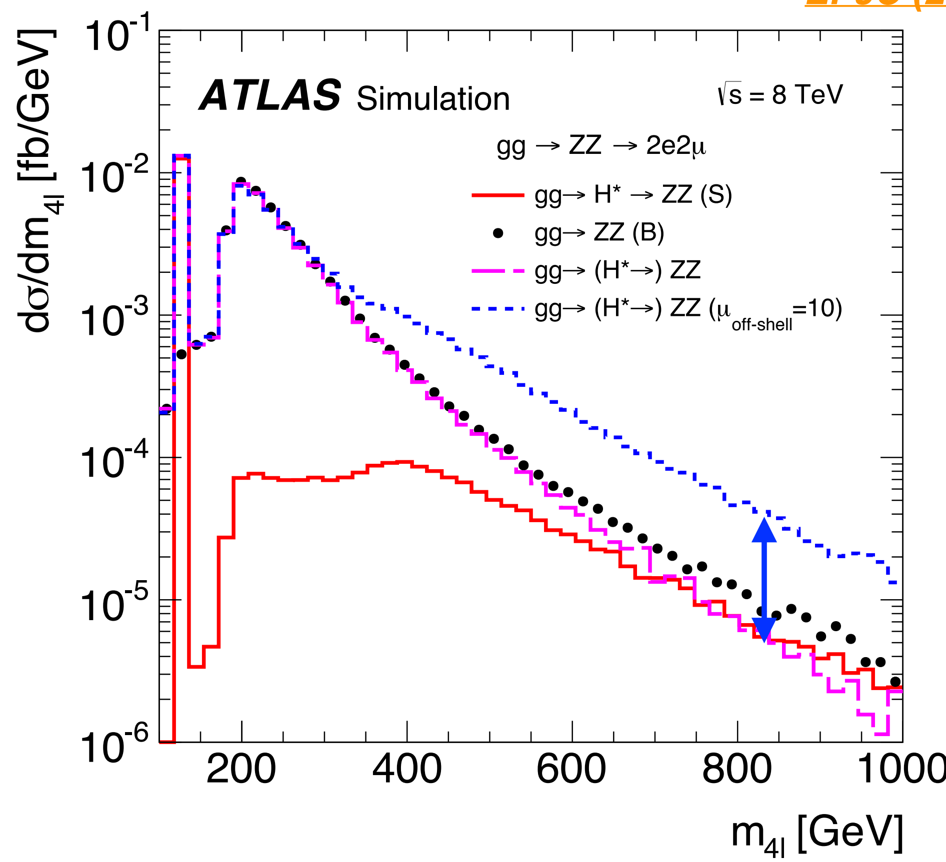
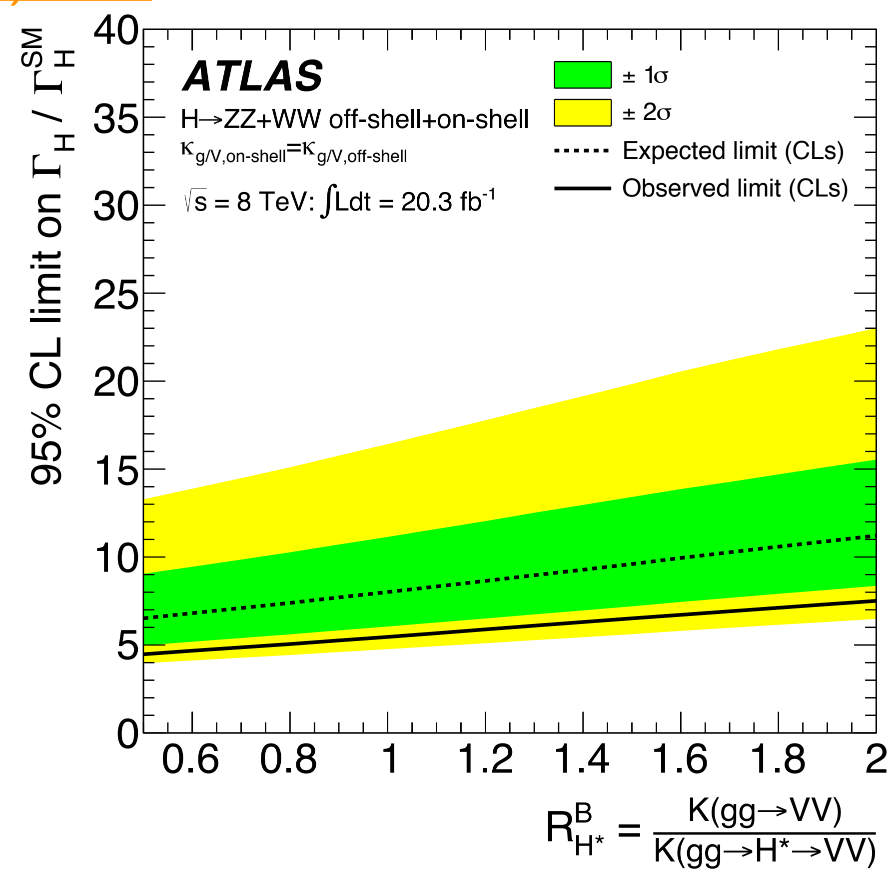
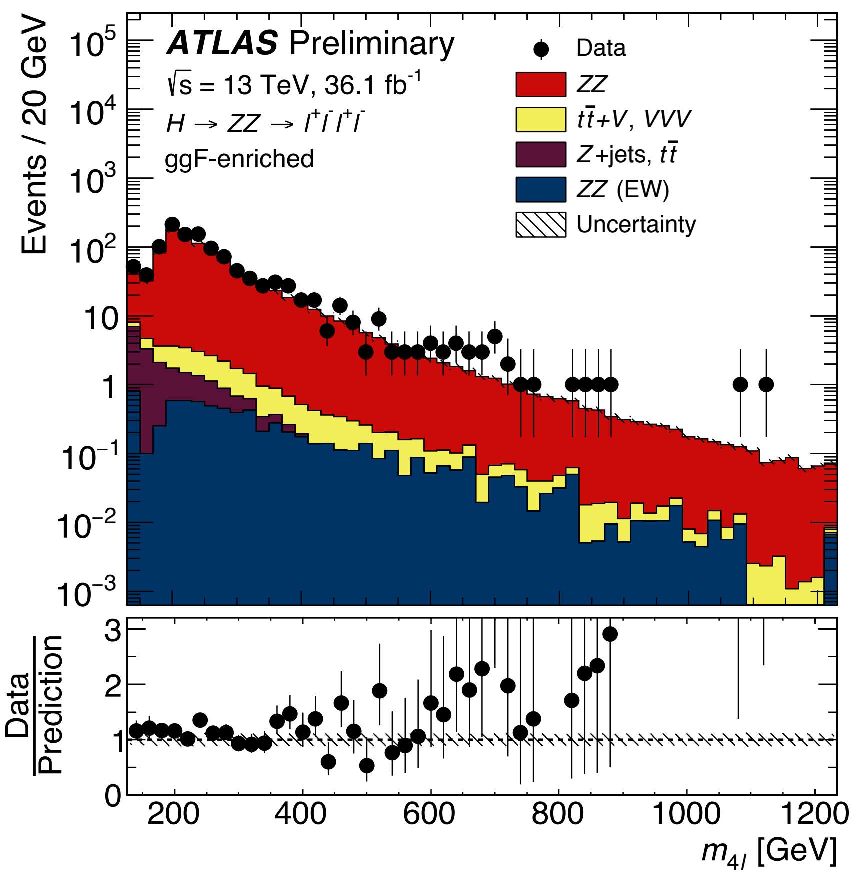




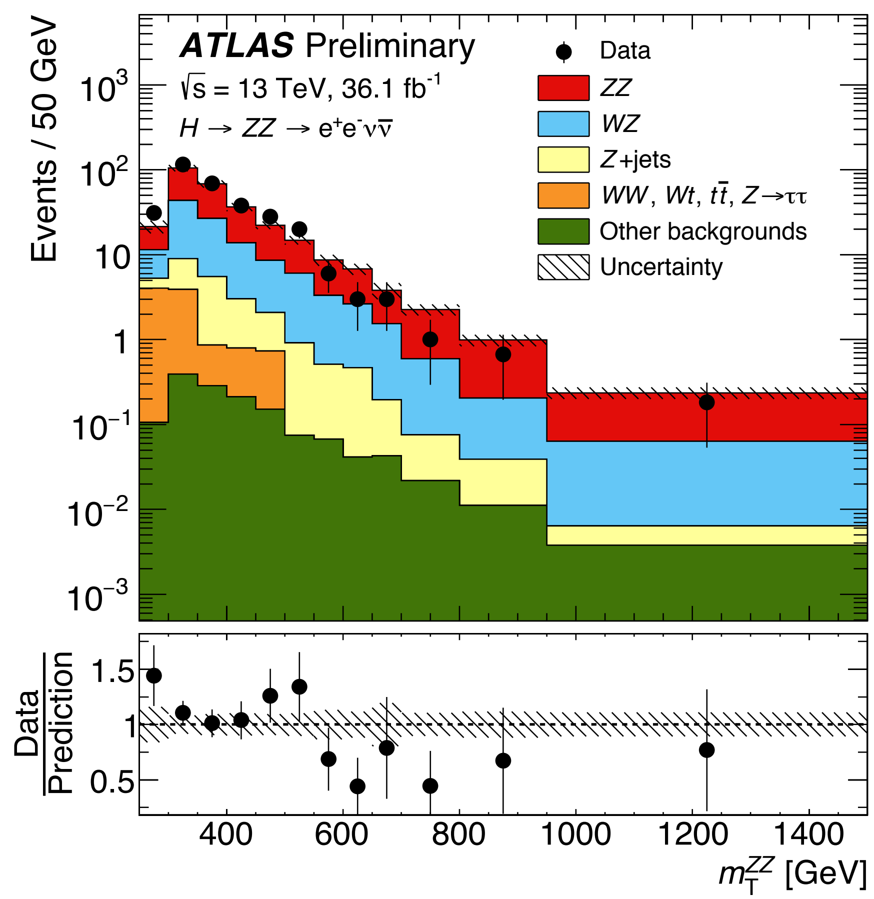


X(→ZZ)

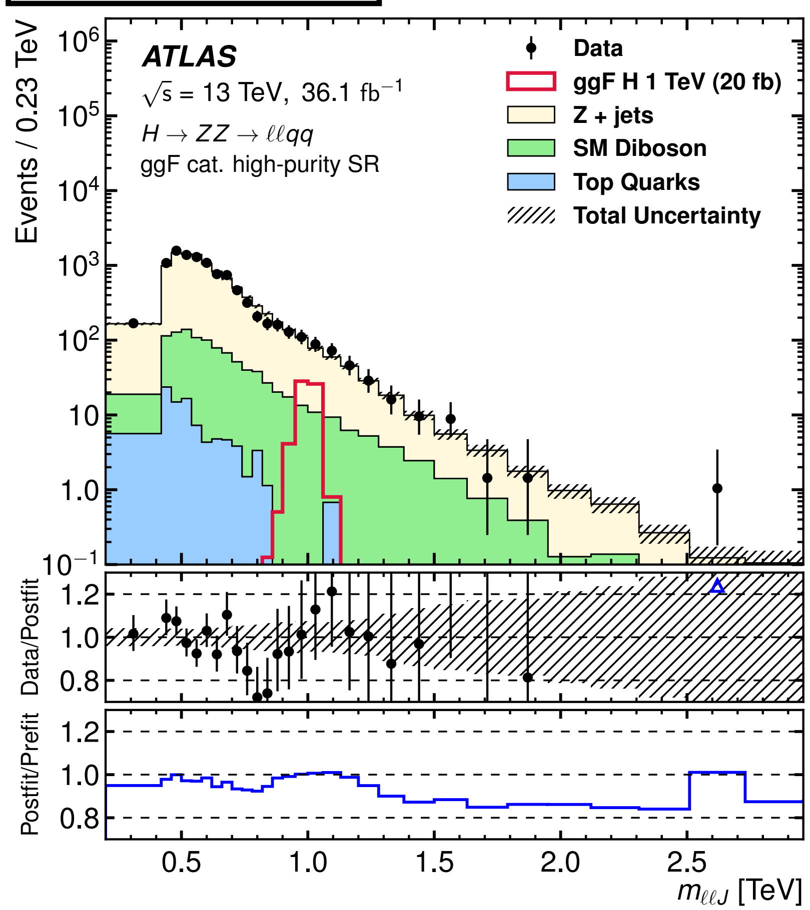
X→ZZ→4ℓ



X→ZZ→ℓℓνν

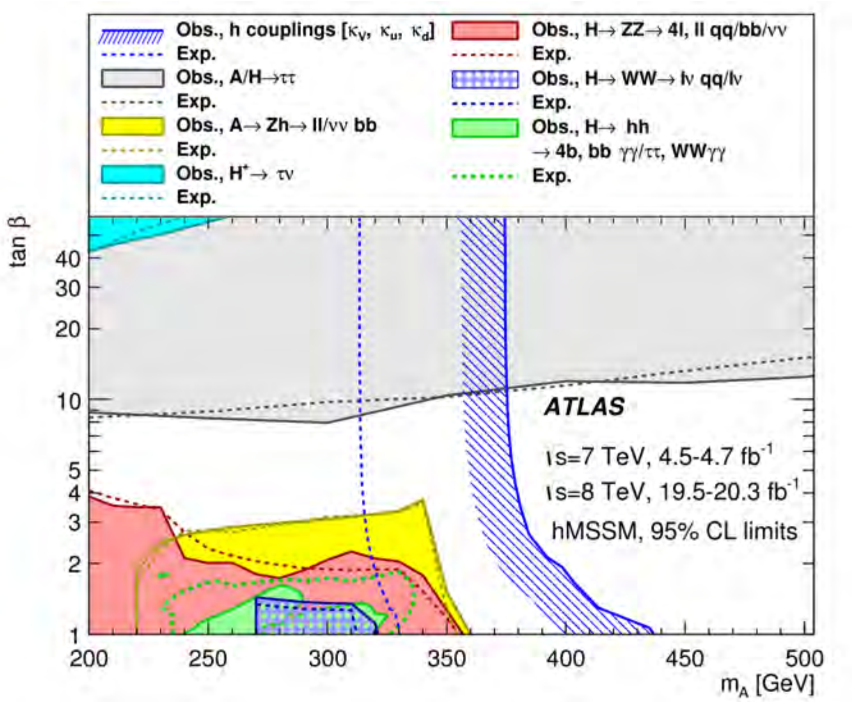


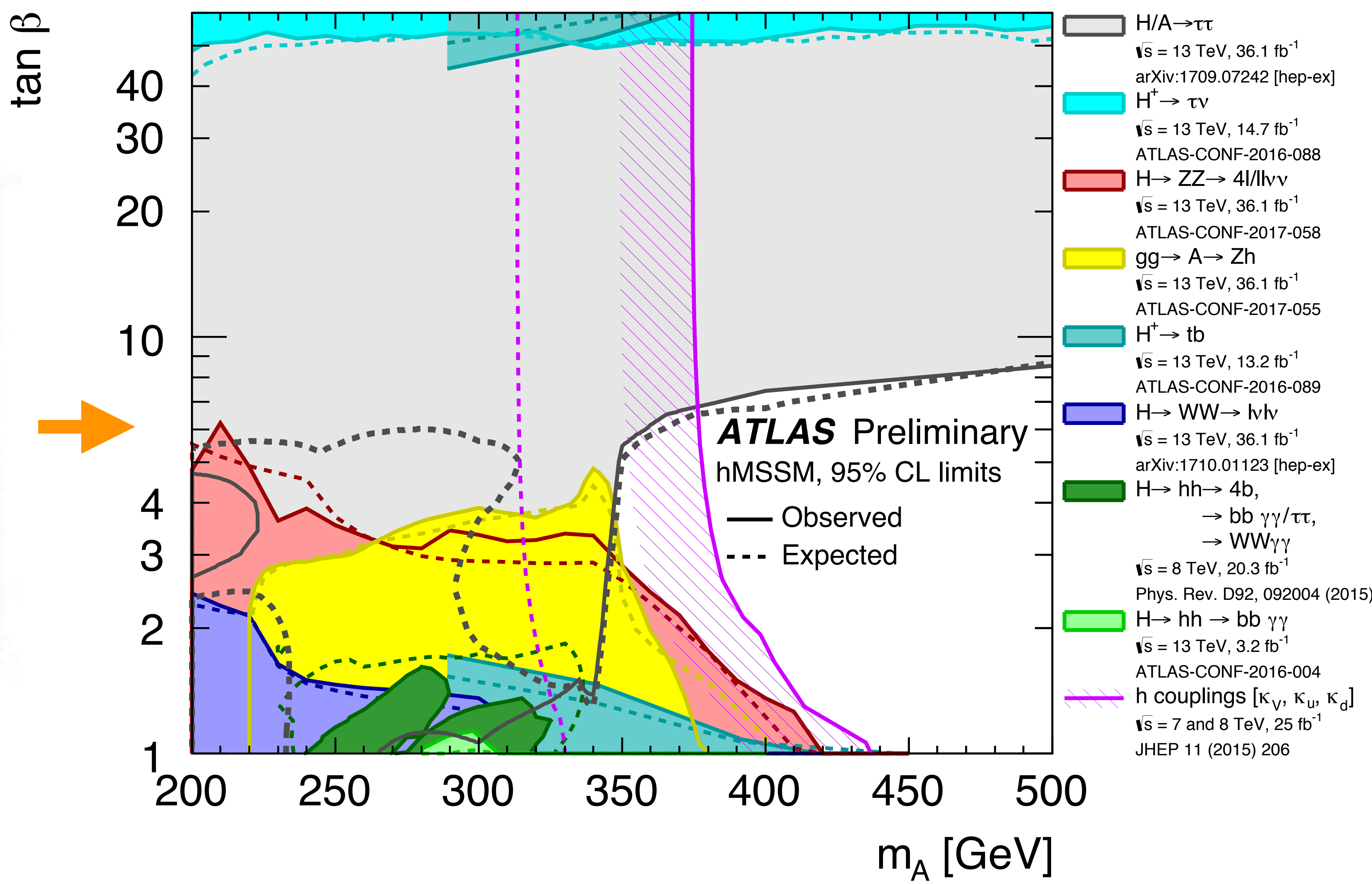
X→ZZ→ℓℓqq



- **Visible excess of 3.6σ** (global 2.2σ) at 240 & 700 GeV. Mainly 4e for 240 GeV.
  - **700 GeV is not expected from the 2HDM.**
- 700 GeV excess not observed in $\ell\ell\nu\nu$, $\ell\ell$qq (deficit in the latter..)
- Need improvement on the ZZ BG estimation for 4ℓと$\ell\ell\nu\nu$ (currently fully relying on MC w/ NNLO QCD & NLO EW precision).

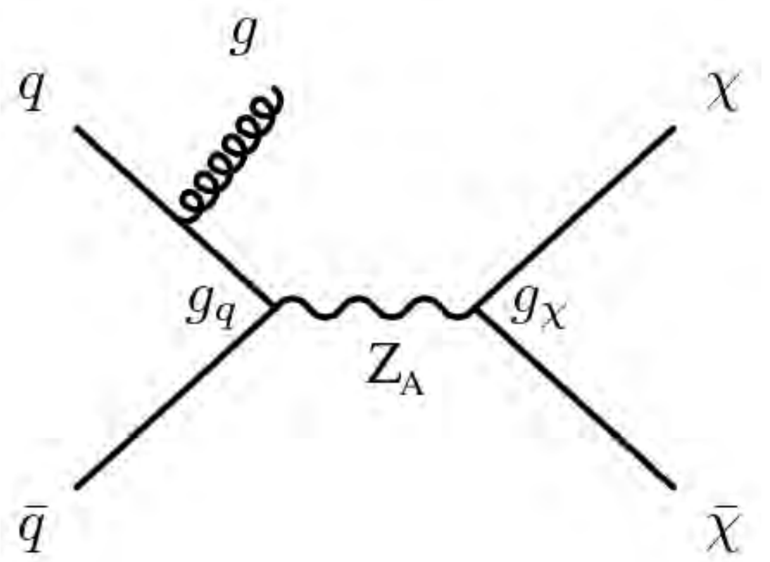
Heavy Higgs Summary

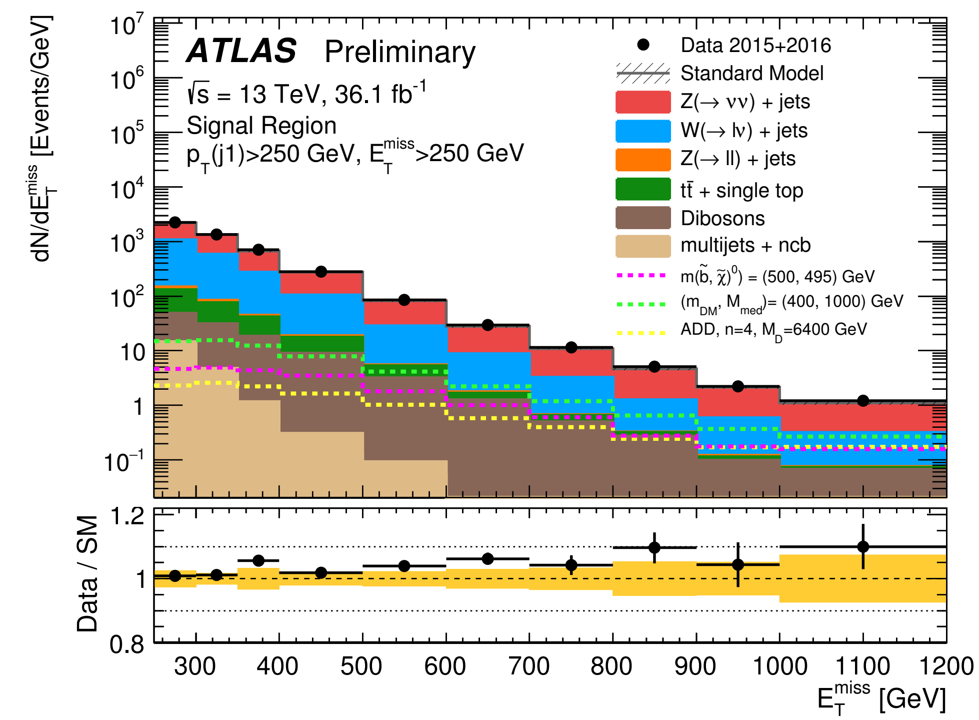


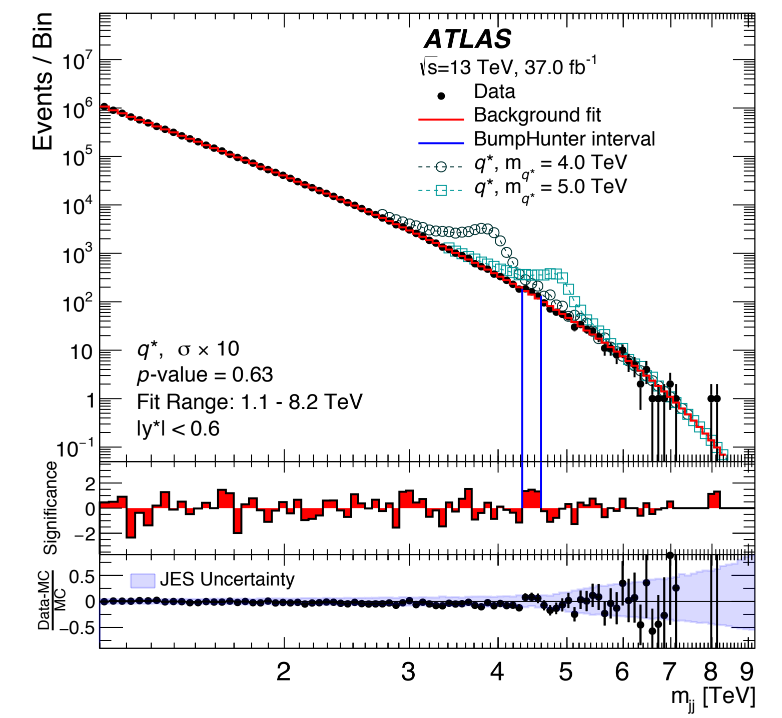


- Exclusions from heavy Higgs searches are summarized in the m_A-tanβ plane for hMSSM.
- Significant improvement in Run-2.

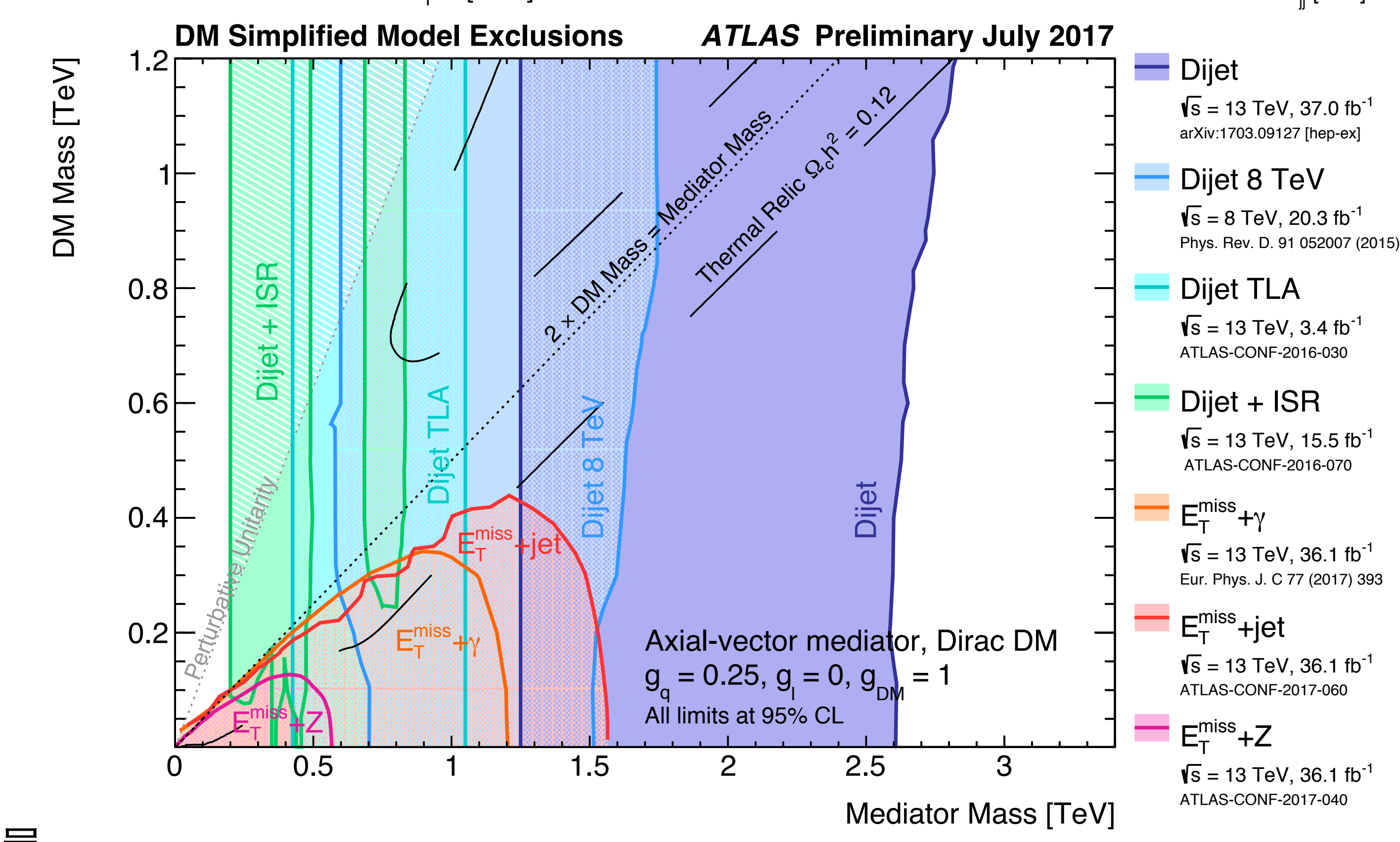
More Generic DM Searches





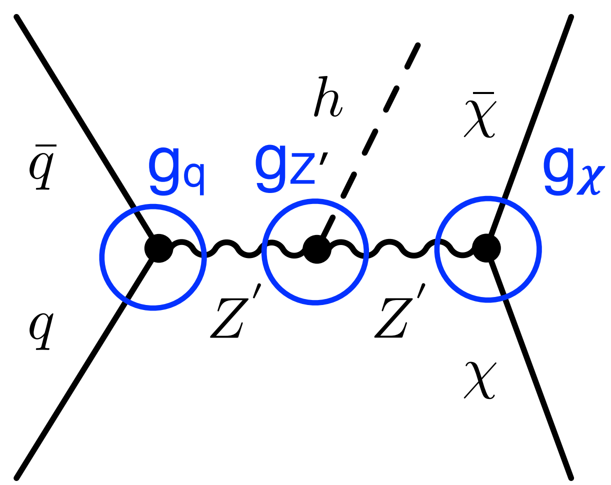


- Direct productions of DM are searched in "E_T^{miss} + ISR (jet,γ, W/Z, etc.)" final states.
- "Monojet" channel (ISR=jet) has the highest sensitivity for generic cases.
- Assuming the simplified model above, the dijet resonance searches can also be interpreted for DM models.

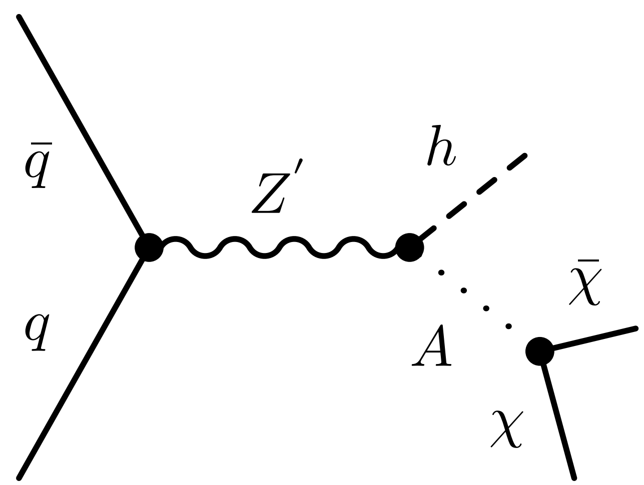


Mono-H DM Searches

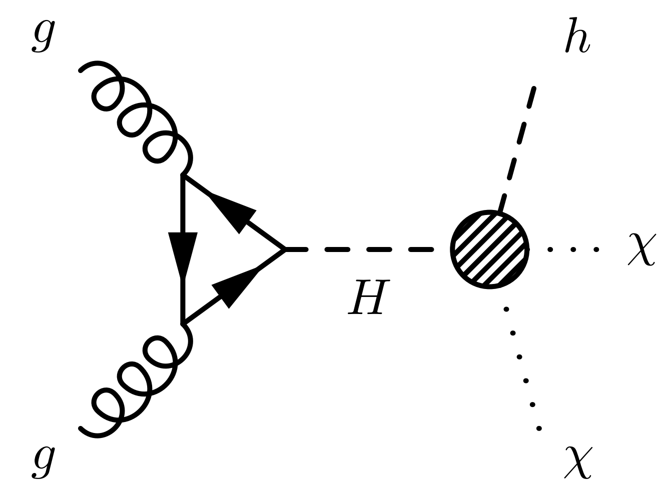
Vector Mediator Model



Z′-2HDM Model



Heavy Scalar Model



- Higgs-strahlung from initial-state partons is suppressed by the Yukawa coupling.
- **Mono-H searches are direct probes for the DM interactions.**