Measurements of Higgs boson production and decay rates and their interpretation with the ATLAS experiment

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On behalf of the ATLAS Collaboration

SUSY 2023 - 18.07.2023

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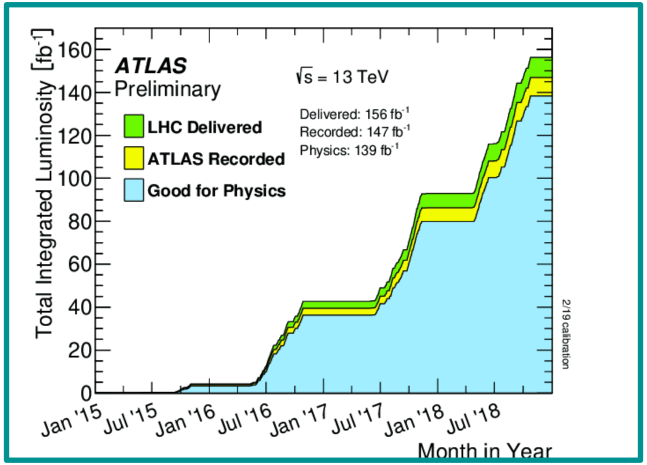
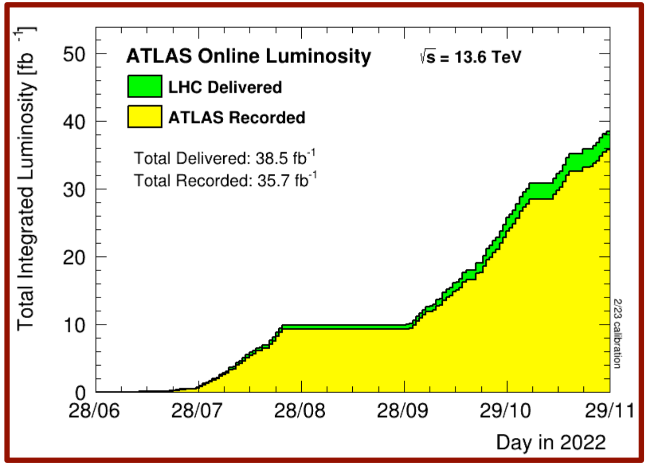
Introduction

- After the Higgs discovery the overall goal is precision measurements to search for deviations from the SM predictions.
- ATLAS recorded **~140 fb^{-1} of good pp collision data at 13 TeV with LHC Run 2** during 2015-2018.
- LHC started **Run 3 collisions at 13.6 TeV: ~36 fb^{-1} of data was recorded last year.**





This talk mainly summarises the latest publications of Higgs boson production and decay rates with ATLAS full Run 2 and Run 3 dataset.

Overview

H→γγ and H→ZZ→4l

2023/06/20: H→γγ and H→ZZ→4l xsec Run 3: CERN-EP-2023-114

2022/07/18: H→γγ and H→ZZ→4l total and diff xsec: JHEP 05 (2023) 028

H→WW: ggF+VBF, VH

2023/01/17: H→WW ggf differential xsec: CERN-EP-2022-228
2022/07/01: H→WW ggf+VBF STXS/couplings: CERN-EP-2022-078
2022/11/07: H→WW VH: ATLAS-CONF-2022-067

ATLAS+CMS H→Zγ

2023/05/24: ATLAS+CMS H→Zγ: ATLAS-CONF-2023-025

Higgs Run 2 combination

2022/07/04: **Comb Higgs coupling: Nature 607, pages 52-59 (2022)**

BSM Higgs searches

2023/01/25 H→inv, comb: Phy. Lett. B 842 (2023) 137963
2023/01/24 Higgs+X, H→γγ: CERN-EP-2022-232

H→γγ & H→ZZ→4l: Run 3 with ~30fb^{-1}

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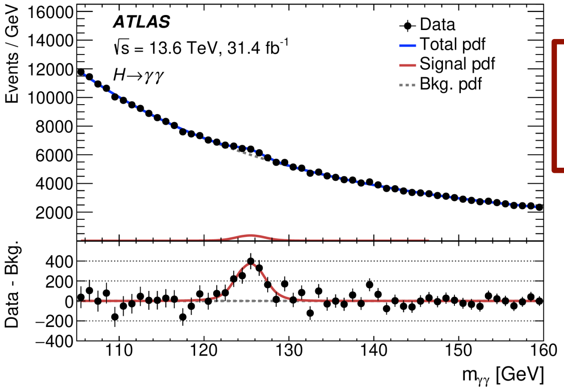
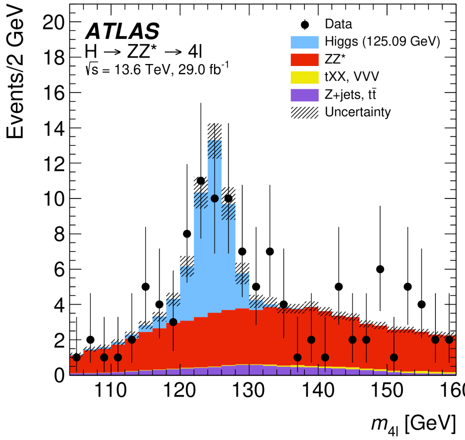


NEW! ATLAS Higgs result with Run 3 data

Higgs production cross-section (xsec) from H→**γγ** and H→ZZ→4l @13.6TeV

Measured xsec in agreement with the SM predictions



Fiducial xsecs @13.6TeV

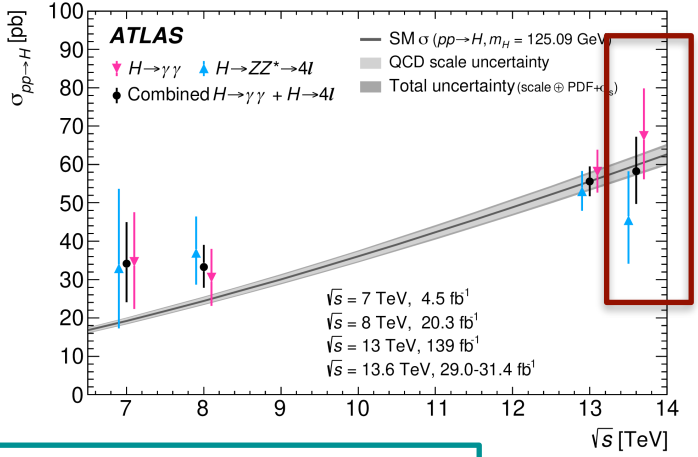
H→**γγ**: 76^{+14}_{-13} (67.6 ± 3.7)fb

H→ZZ→4l: 2.80 ± 0.74fb (3.67 ± 0.19)fb

Total xsec: pp→H @13.6TeV

H→**γγ**: 67^{+12}_{-11} pb

H→ZZ→4l: 46 ± 12 pb



CERN-EP-2023-114

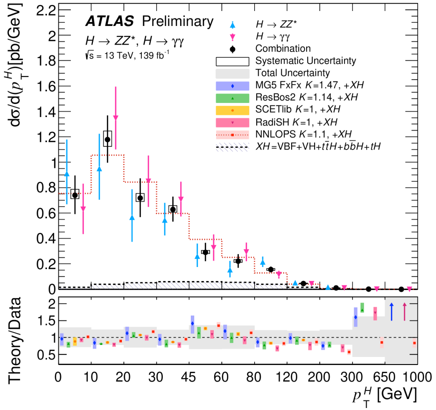
Combination: 58.2 ± 8.7 pb
SM expectation: 59.9 ± 2.6 pb

H→γγ + H→ZZ and H→WW: differential cross-sections

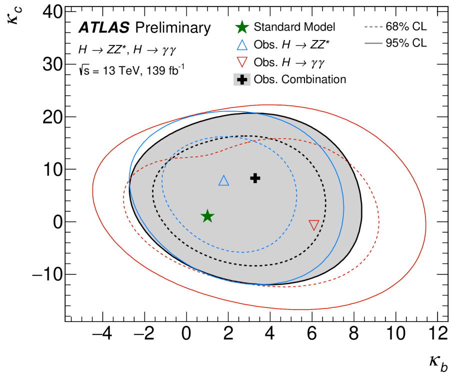
JHEP 05 (2023) 028

H→γγ + H→ZZ Run 2 combination!

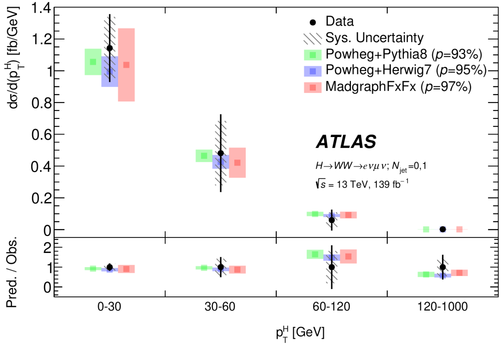
Total Higgs boson production **cross-section in agreement with the SM:**
$55.5^{+4.0}_{-3.8}$ pb
(55.6 ± 2.8) pb

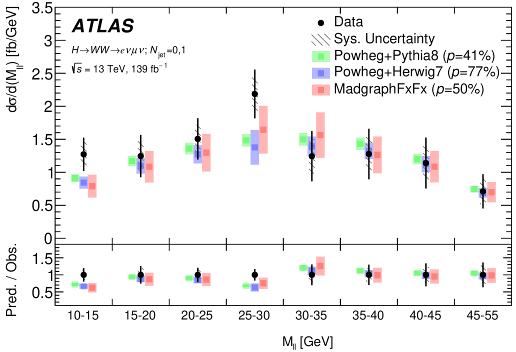


p_T^H used to probe the Yukawa coupling of the Higgs to bottom and charm quarks.



CERN-EP-2022-228





H→WW full Run 2

> Events with at most one jet.

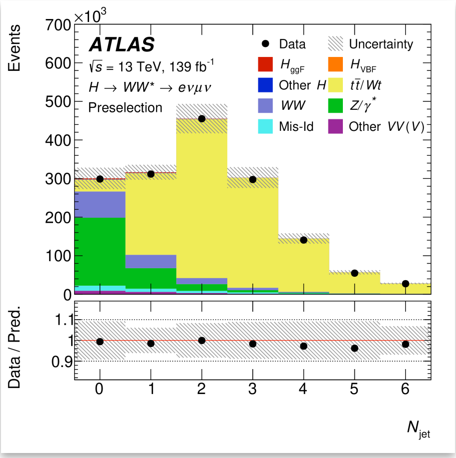
Differential fiducial cross-section: results are consistent with SM expectations

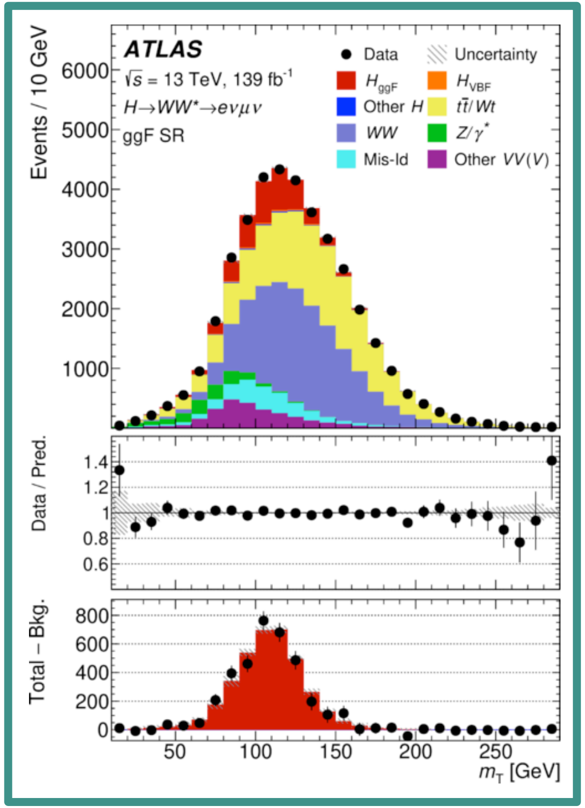
H→WW*: ggF+VBF STXS/couplings

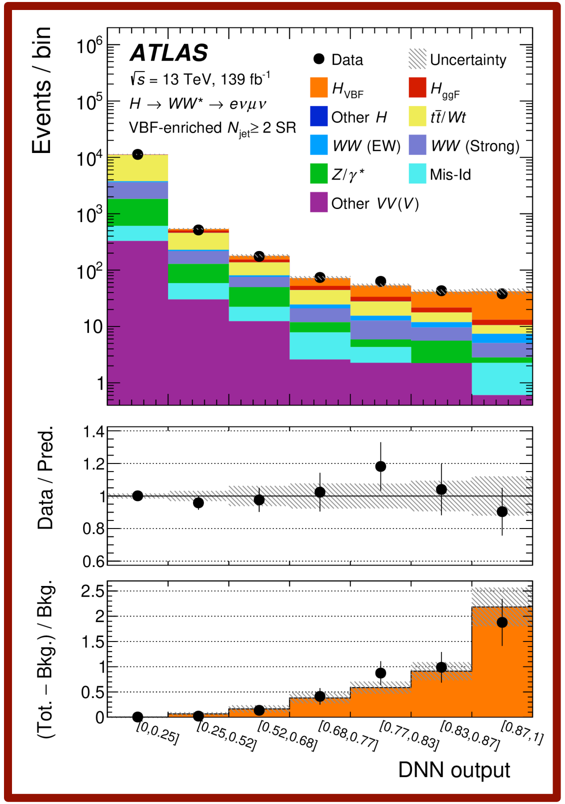
CERN-EP-2022-078

Event selection

Consider eμ events and split in Njets







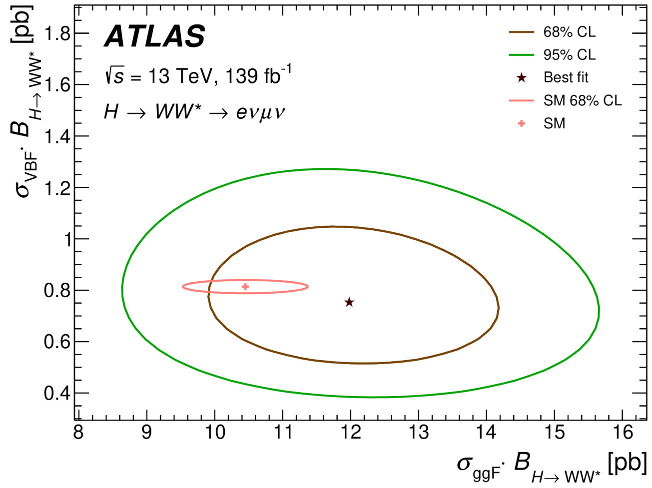
Discriminants:

ggF: 0,1,>=2jets → **mT**

VBF: >=2 jets → **DNN**

H→WW*: ggF+VBF STXS/couplings

CERN-EP-2022-078

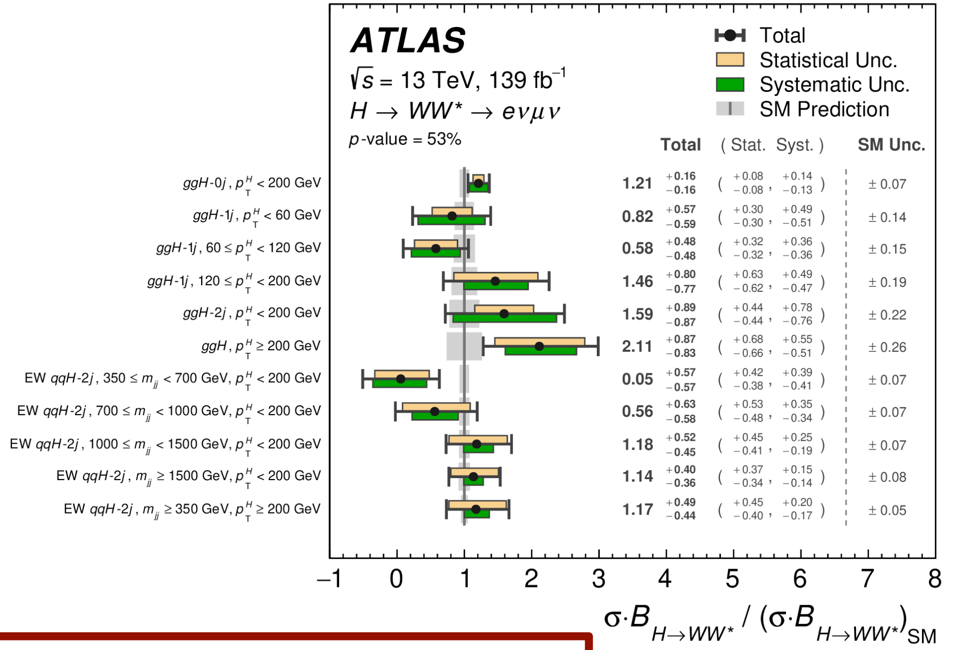


ggF: 12.0±1.4 (10.4±0.6) pb

VBF: $0.75^{+0.19}_{-0.16}$ (0.81±0.02) pb

Simplified Template Cross-Section results:

11 kinematical fiducial regions in Njet, p_T^H and m_{jj}



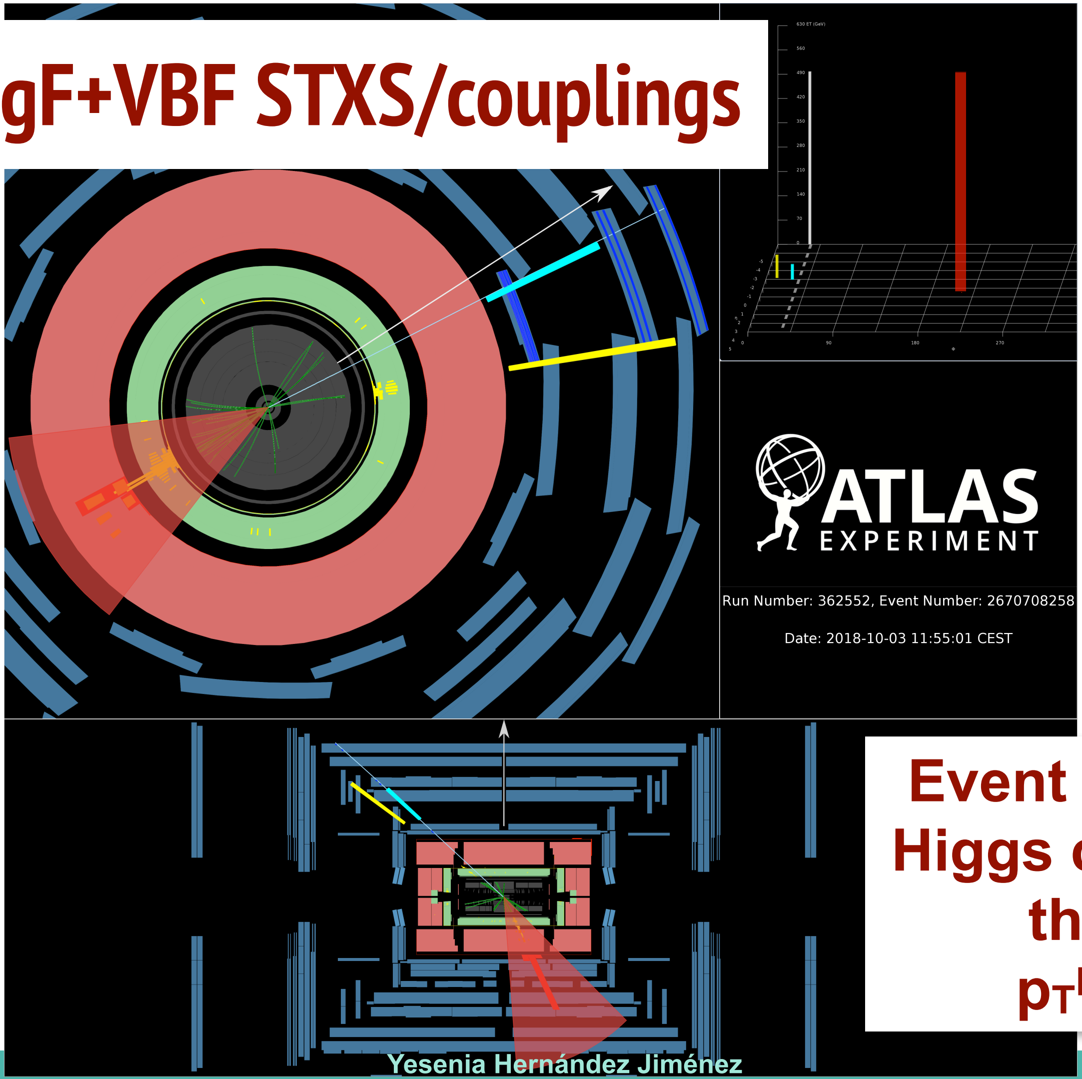
xsec x BR(H→WW) and STXS results in agreement with SM

H→WW*: ggF+VBF STXS/couplings

CERN-EP-2022-078

Higgs candidate event in ggF+1jet

(p_T^{jet}=670GeV)



Event display of the Higgs candidate with the highest p_T^H=625GeV

H→WW*: VH

ATLAS-CONF-2022-067

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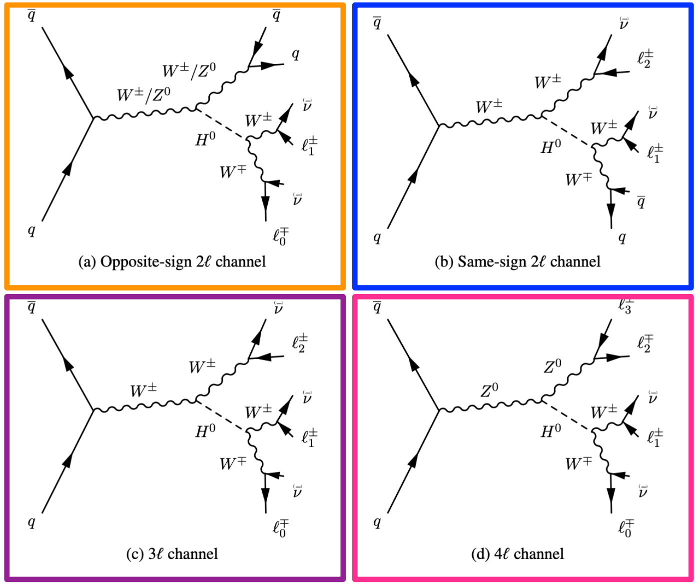
Targeting WH and ZH productions: 2, 3 and 4 leptons in the final state

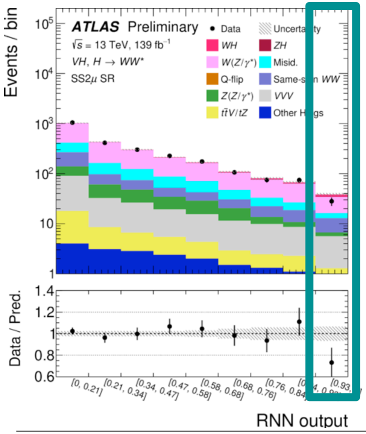
- **8 SRs according to the number, flavour and charges of the leptons**

  Opposite-sign 2l (VH, V→qq)
  Same-sign 2l (WH): ee, mm, emu
  3l (WH): Z-depleted/enriched
  4l (ZH): Same-flavour opposite sign (SFOS)
  - 3e1m + 1m3e: **1-SFOS→ highest sensitivity**
  - 4e, 4m, 2e2m: 2-SFOS

- **Use of MVA techniques to separate Higgs signal from main SM backgrounds for all channels**



H→WW*: VH

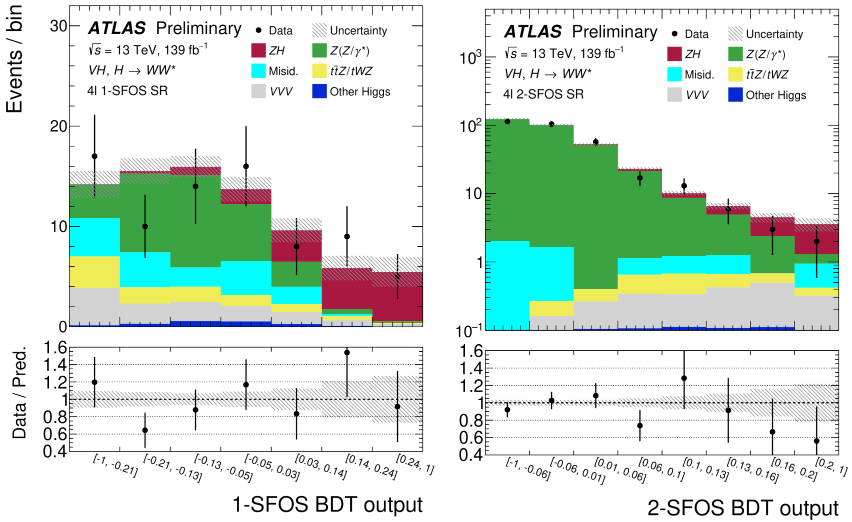


→ Statistical **down fluctuation in** the most sensitive bin for **SS 2μ channel** results in WH **signal strength~0**

Channel	POI / Z_0	Expected	Observed
Opposite-sign 2ℓ	μ_{VH}	$1.00^{+1.02}_{-0.98}$	$1.94^{+1.07}_{-1.02}$
	Z_0	1.0	1.9
Same-sign 2ℓ	μ_{WH}	$1.00^{+0.61}_{-0.60}$	-0.08 ± 0.58
	Z_0	1.6	0.0
3ℓ	μ_{WH}	$1.00^{+0.44}_{-0.40}$	$0.64^{+0.42}_{-0.37}$
	Z_0	2.8	1.8
4ℓ	μ_{ZH}	$1.00^{+0.47}_{-0.39}$	$1.59^{+0.54}_{-0.47}$
	Z_0	3.1	4.5
Combined 1-POI	μ_{VH}	$1.00^{+0.27}_{-0.25}$	$0.92^{+0.25}_{-0.23}$
	Z_0	4.7	4.6
Combined 2-POI	μ_{WH}	$1.00^{+0.35}_{-0.33}$	$0.45^{+0.32}_{-0.30}$
	μ_{ZH}	$1.00^{+0.47}_{-0.39}$	$1.64^{+0.55}_{-0.47}$
	Z_0^{WH}	3.3	1.5
	Z_0^{ZH}	3.1	4.6

4l is the most sensitive

Strong evidence (almost observation) **of ZH(→WW): Z_0=4.6σ**



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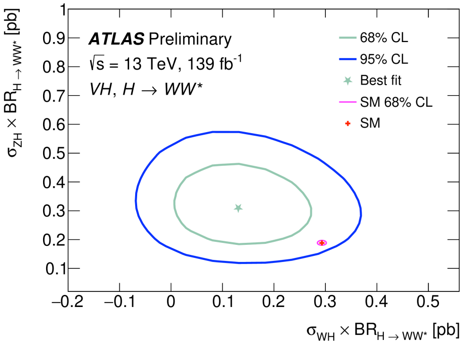

Results in agreement with SM within 1.8σ

Most sensitive channels limited by statistics → will highly benefit from new Run 3 data

ATLAS + CMS: H→Zγ

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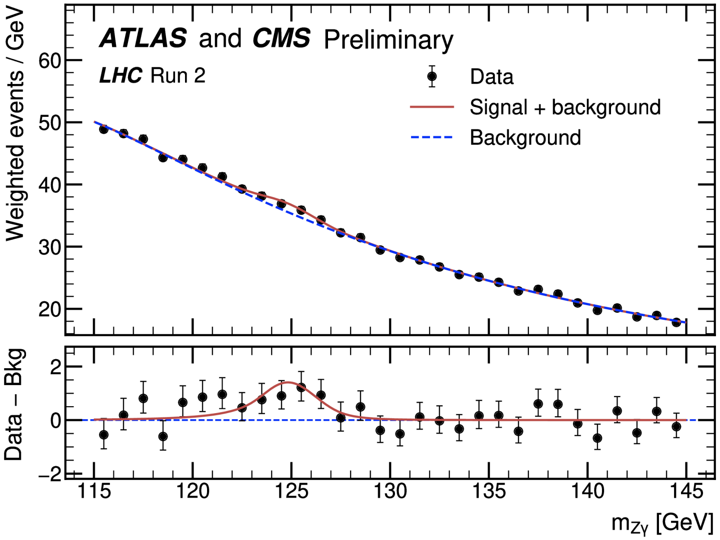
ATLAS+CMS Run 2 combination!

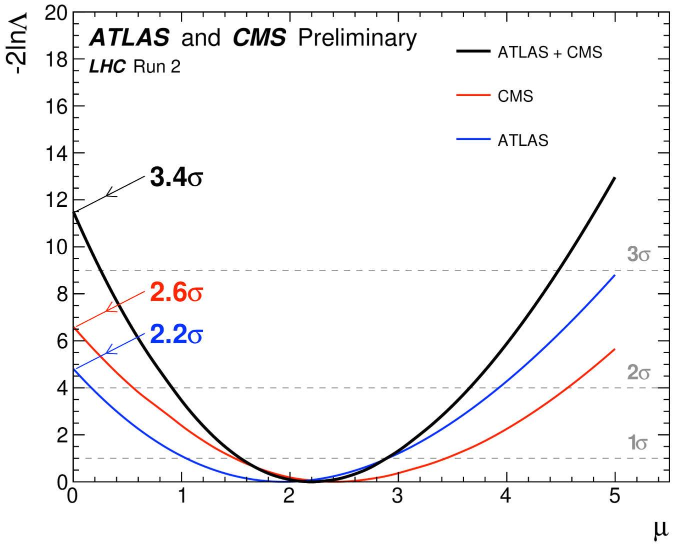
ATLAS-CONF-2023-025

Similar strategies in both analyses:

ATLAS: 6 categories (1 BDT for VBF + 5 with different lepton flavour & Zγ kinematics for ggF)

CMS: 8 categories (1 for VH and ttH + 7 BDT)





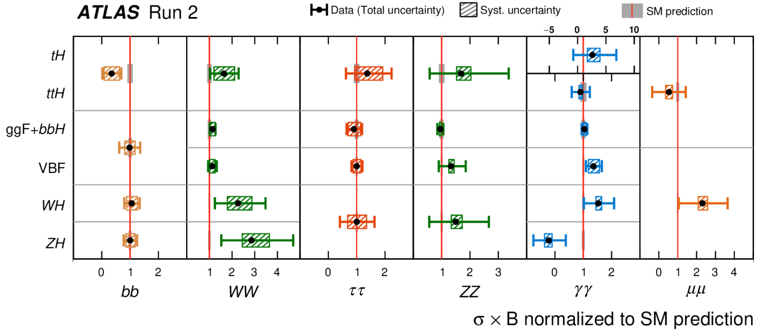
First evidence for H→Zγ with 3.4σ significance

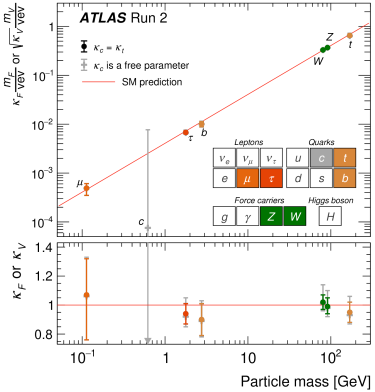
Signal strength 2.2 ± 0.7: agrees with SM within 1.9 s.d

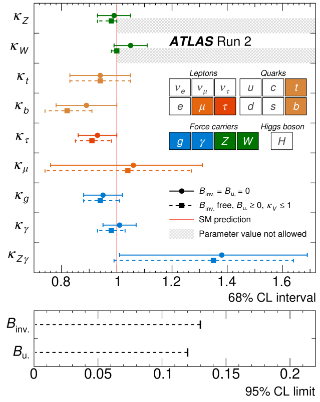
ATLAS combination: xsec and couplings

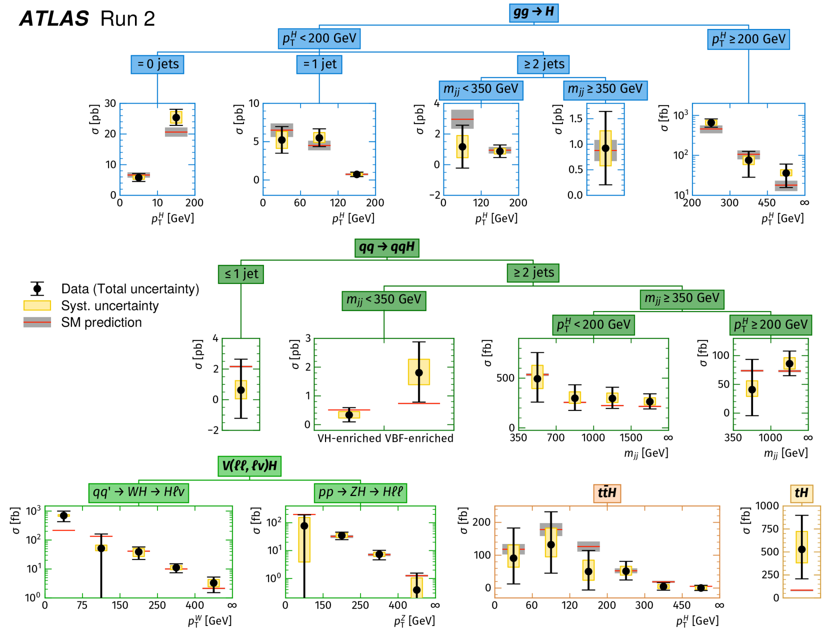
Nature 607, pages 52-59 (2022)

Unprecedented ATLAS combination of production modes and decay processes of the Higgs boson









- Higgs boson couplings strength modifiers **following SM prediction at high accuracy.**
- Higgs boson production cross section in many kinematic regions **compatible with SM expectations.**

H→invisible

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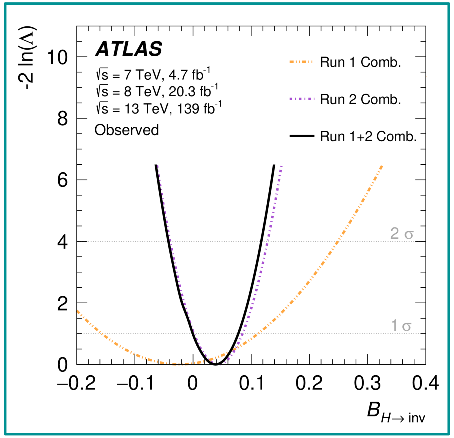
[Phy. Lett. B 842 (2023) 137963]

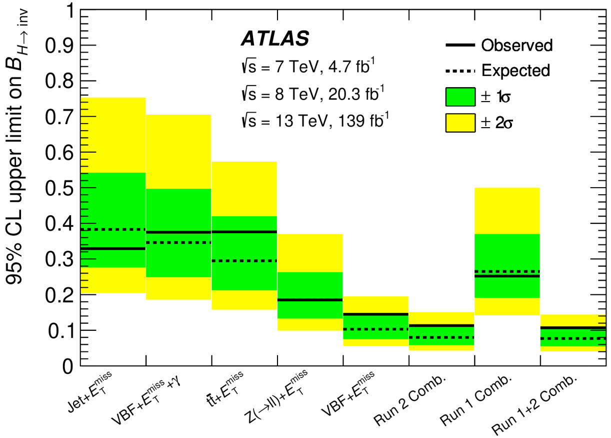
Light dark matter particles may be produced in decays of the Higgs boson that would appear invisible to the detector → E_T^{miss}

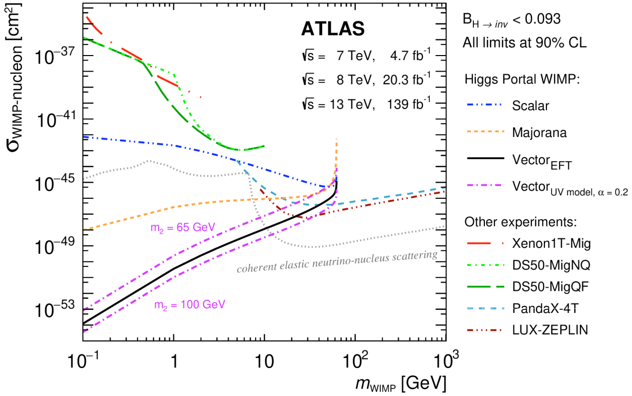
Run 1 + Run 2 combination!

Many Higgs production modes: ggF, VBF, VH and ttH and final states

Upper limit on BR(H→invisible)=0.107 obs (0.077 exp) @95%CL







Results also interpreted in models where the Higgs boson acts as a portal to dark matter

Higgs+X, H→γγ

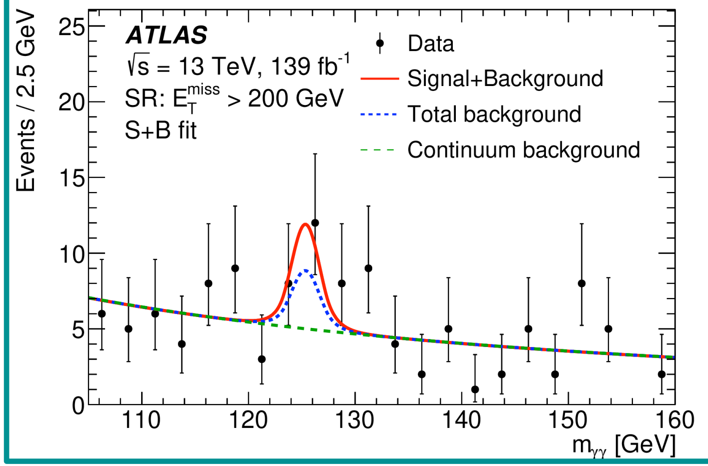
CERN-EP-2022-232

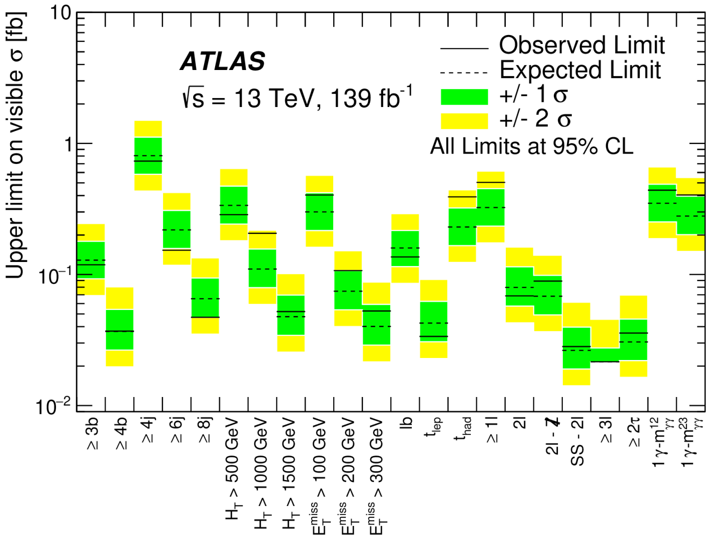
Model independent search with H→γγ + X

22 final states depending of the particles associated to the Higgs boson:

→ **e, μ, τ, γ, (b-tagged) jets and E_T^{miss}.**

Diphoton mass as discriminant



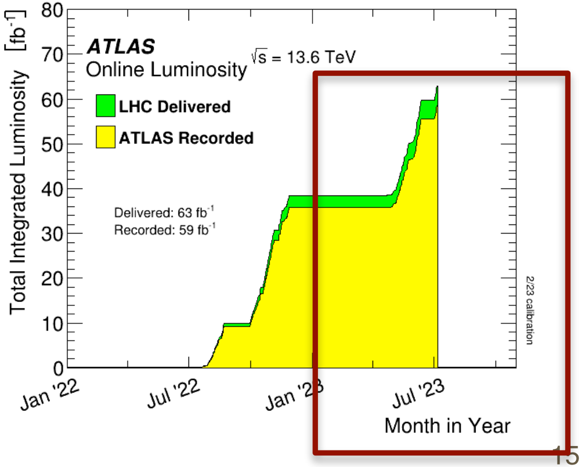


No significant excess above the SM observed

Conclusions

- Full Run 2 dataset allows measurements of many Higgs production / decay modes.
- The analyses with the full Run 2 ATLAS data are well established:
  - Discovery channels start to enter precision regime: <10% uncertainty.
  - Differential measurements and small branching ratio channels still have significant statistical uncertainties.
  - All measurements are compatible with SM predictions.
- First Run 3 Higgs result using 13.6TeV data combining $H \rightarrow \gamma\gamma$ and $H \rightarrow ZZ \rightarrow 4l$.

Looking forward to more Run 3 results to come!



Backup Slides

H→γγ & H→ZZ→4l: Run 3 with ~30fb^{-1}

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Source	Uncertainty [%]
Statistical uncertainty	14.0
Systematic uncertainty	10.3
Background modelling (spurious signal)	6.0
Photon trigger and selection efficiency	5.8
Photon energy scale & resolution	5.5
Luminosity	2.2
Pile-up modelling	1.2
Higgs boson mass	0.1
Theoretical (signal) modelling	<0.1
Total	17.4

Source	Uncertainty [%]
Statistical uncertainty	25.1
Systematic uncertainty	7.9
Electron uncertainties	6.3
Muon uncertainties	3.8
Luminosity	2.2
ZZ^* theoretical uncertainties	0.7
Reducible background estimation	0.6
Other uncertainties	<1.0
Total	26.4

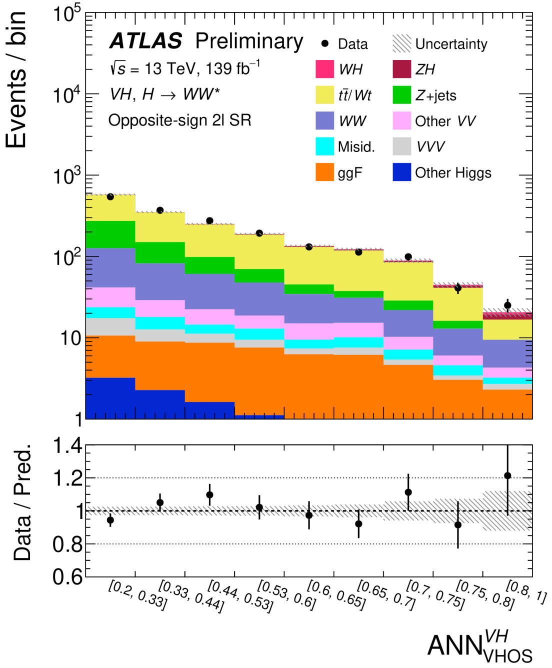
H→WW: differential cross-sections

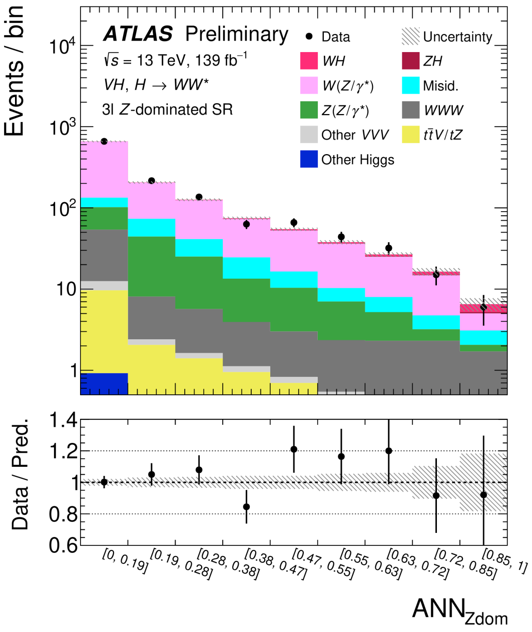
Contribution	$\frac{\Delta\sigma_{p_T^H<30GeV}}{\sigma_{p_T^H<30GeV}}$[%]	$\frac{\Delta\sigma_{30GeV<p_T^H<60GeV}}{\sigma_{30GeV<p_T^H<60GeV}}$[%]	$\frac{\Delta\sigma_{60GeV<p_T^H<120GeV}}{\sigma_{60GeV<p_T^H<120GeV}}$[%]	$\frac{\Delta\sigma_{120GeV<p_T^H}}{\sigma_{120GeV<p_T^H}}$[%]
Total relative uncertainty	19	51	108	62
Total systematic uncertainty	17	41	81	45
Statistical uncertainties from data	8.5	29	72	43
Statistical uncertainties from Monte Carlo simulation	6.2	15	17	18
Experimental systematic uncertainty	10	24	58	31
Flavour tagging	4.9	6.1	13	18
Jet Energy Scale	4.9	17	30	21
Jet Energy Resolution	4.8	8.4	12	10
Missing transverse energy	4.6	8.2	11	8.2
Muons	4.6	4.2	4.8	2.3
Electrons	3.2	2.2	2.5	1.1
Misidentified objects	3.9	10	3.3	1.3
Pile-up	3.8	1.2	6.9	4.4
Luminosity	2.7	4.5	3.5	2.8
Systematic uncertainty from theory	11	27	23	25
on gluon-fusion production	6.1	7.1	4.7	5.2
on Vector Boson Fusion production	2.4	1.8	2.7	3.2
on top quark production	4.3	20	18	21
on decays of $Z \to \tau\tau$	4.2	5.9	2.2	3.9
on the WW background	7.3	10	12	6.0
on other diboson processes	5.9	14	7.8	8.8
Background normalization factors	2.3	0.7	0.9	0.6

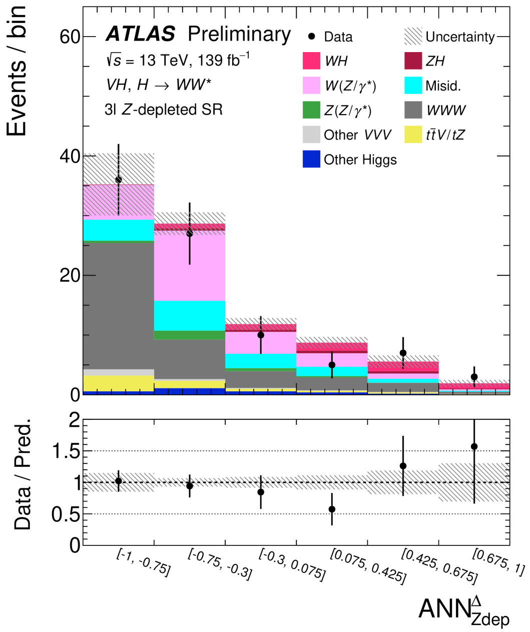
CERN-EP-2022-228

H→WW*: VH (2lOS and 3l)

ATLAS-CONF-2022-067







H→WW*: VH (2SSl ee and eμ)

ATLAS-CONF-2022-067