Recent Highlights in Differential/ STXS Results for Higgs

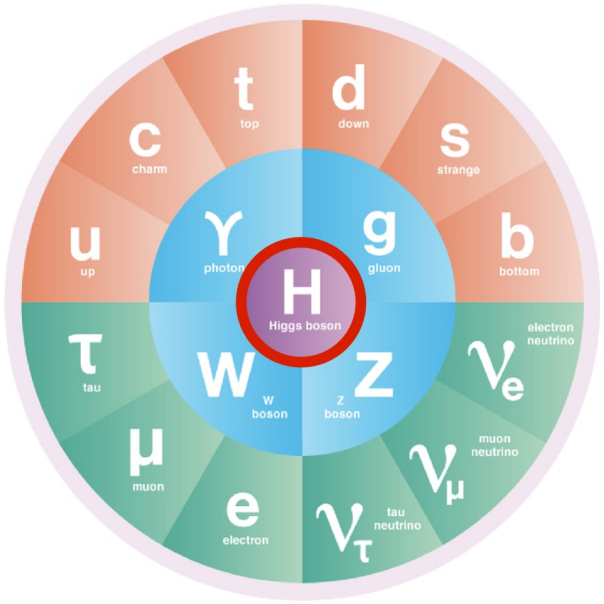
George Uttley

On behalf of the ATLAS and CMS collaborations

SM@LHC2025

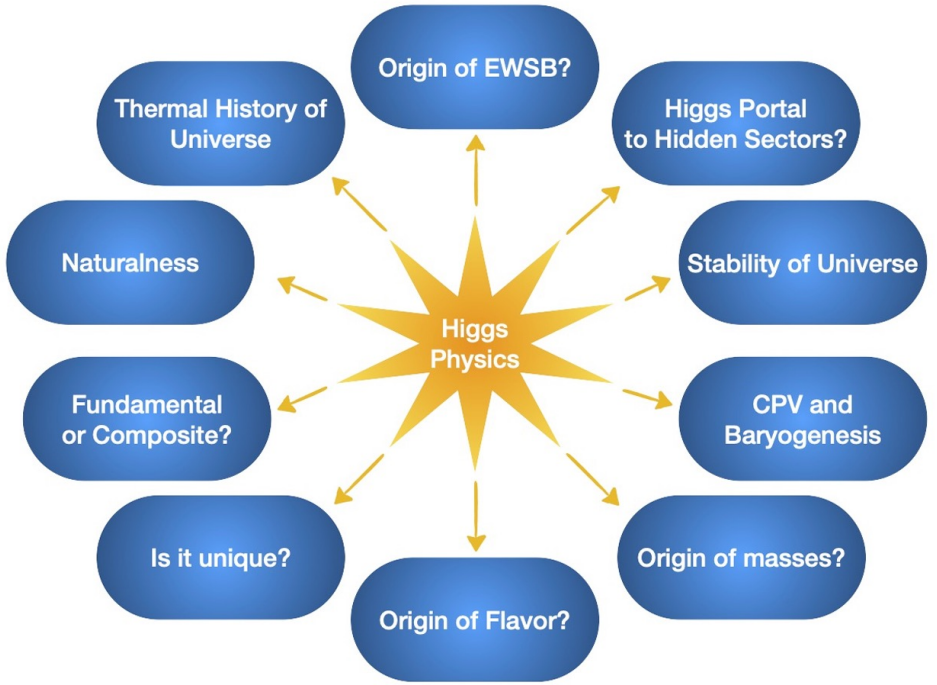
9th April 2025

Motivation



but we have been lucky in discovering a 125 GeV Higgs boson

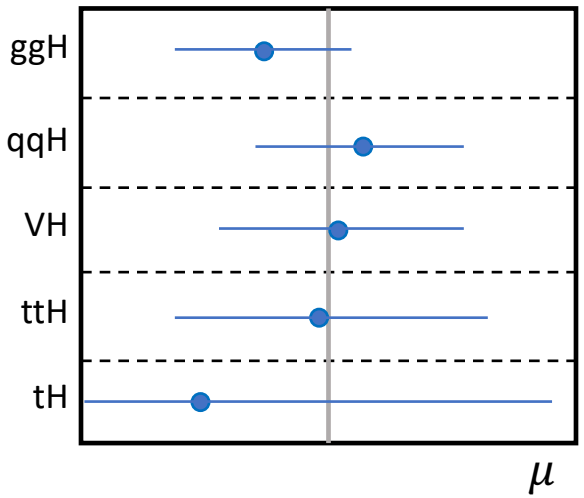
it opens a door to the most mysterious part of the Standard Model



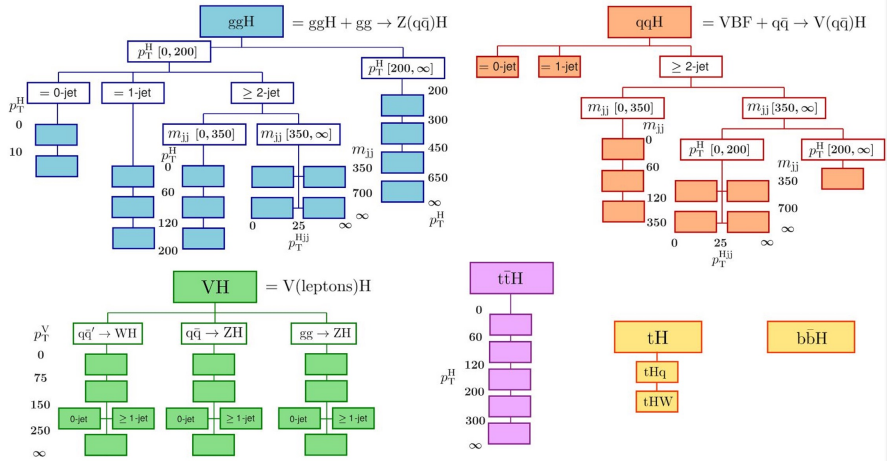
Gavin Salam – FCC Week 2023
https://indico.cern.ch/event/1202105/contributions/5423455/attachments/2659121/4607170/fcc-london.pdf

Motivation

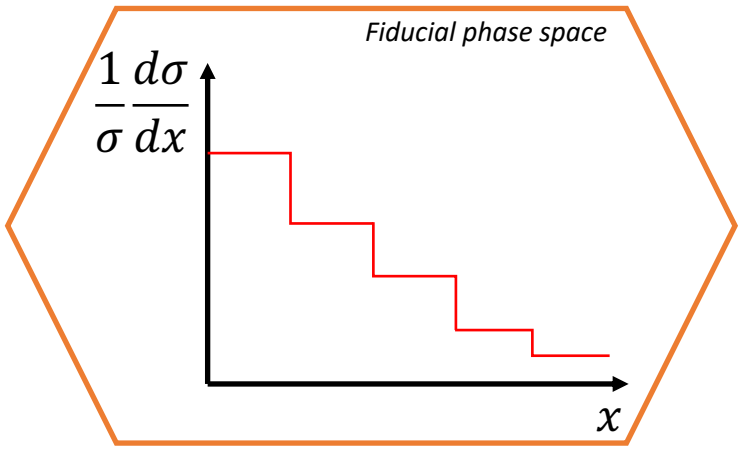
Signal strength modifiers



Simplified Template Cross Sections (STXS)



Fiducial differential cross sections



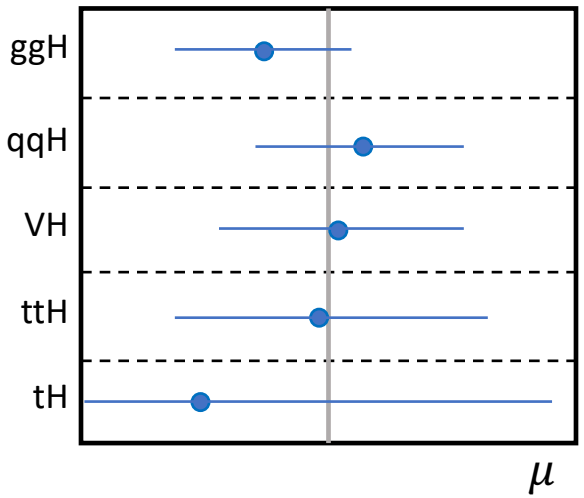
Model independence

Experimental sensitivity

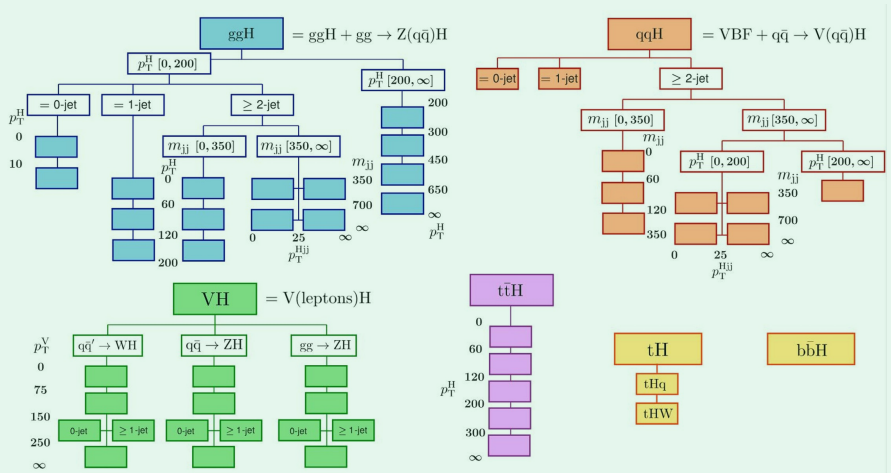
Motivation

Topic of this talk!

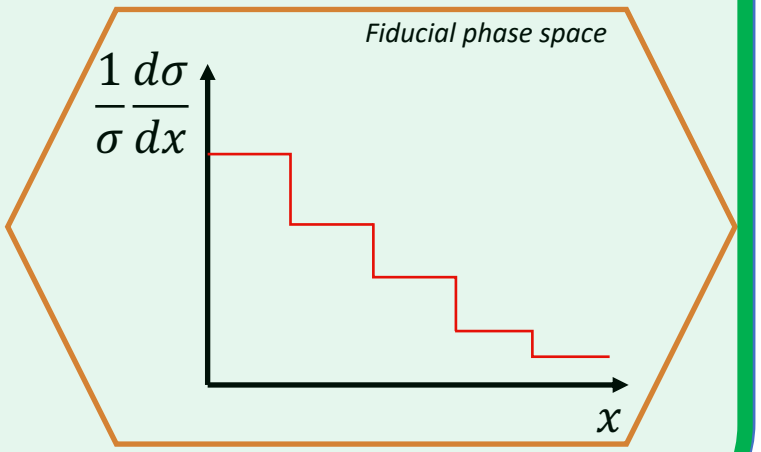
Signal strength modifiers



Simplified Template Cross Sections (STXS)



Fiducial differential cross sections



Model independence

Experimental sensitivity

Overview

New *New for Moriond*

Run 2 Analyses

ATLAS EXPERIMENT — ggH + VBF, H→WW*→lνlν (New)
ATL-HIGP-2024-07 (not live)

ATLAS EXPERIMENT — VH, H→WW*→lνlν, lνjj (New)
ATL-HIGG-2023-09

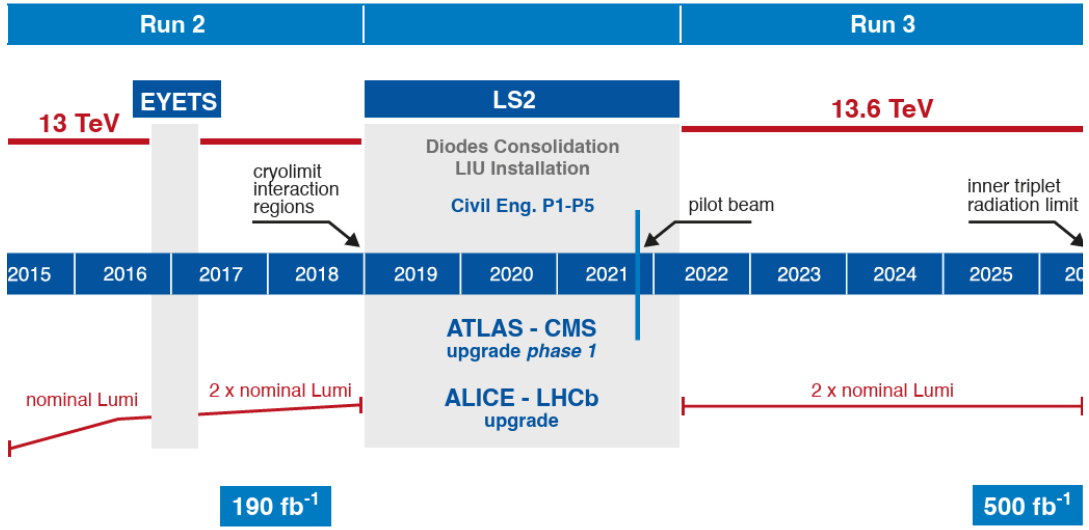
CMS — H + 2-jets, H →WW*→eνμν (New)
CMS-PAS-HIG-24-004

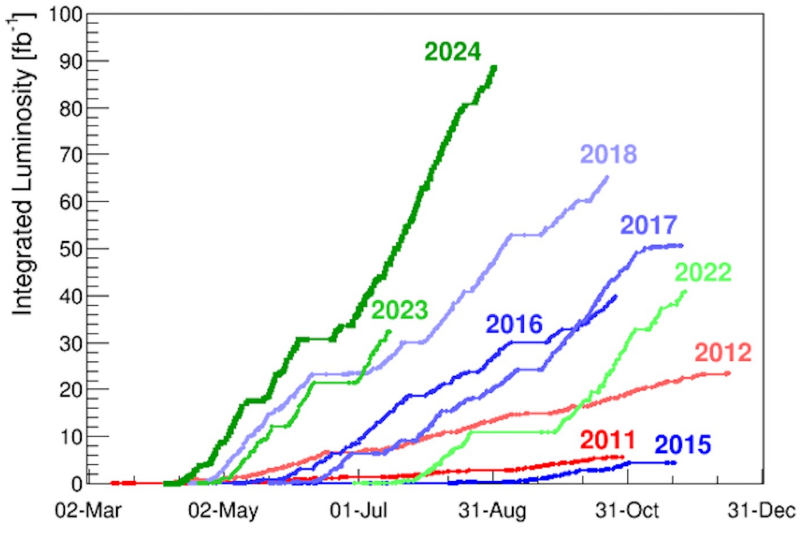
Run 2 Combination

CMS — Legacy Run 2 STXS Combination (New)
CMS-PAS-HIG-21-018 (not live)

Run 3 Analysis

ATLAS EXPERIMENT — H→ZZ*→4l (New)
ATLAS-CONF-2025-002



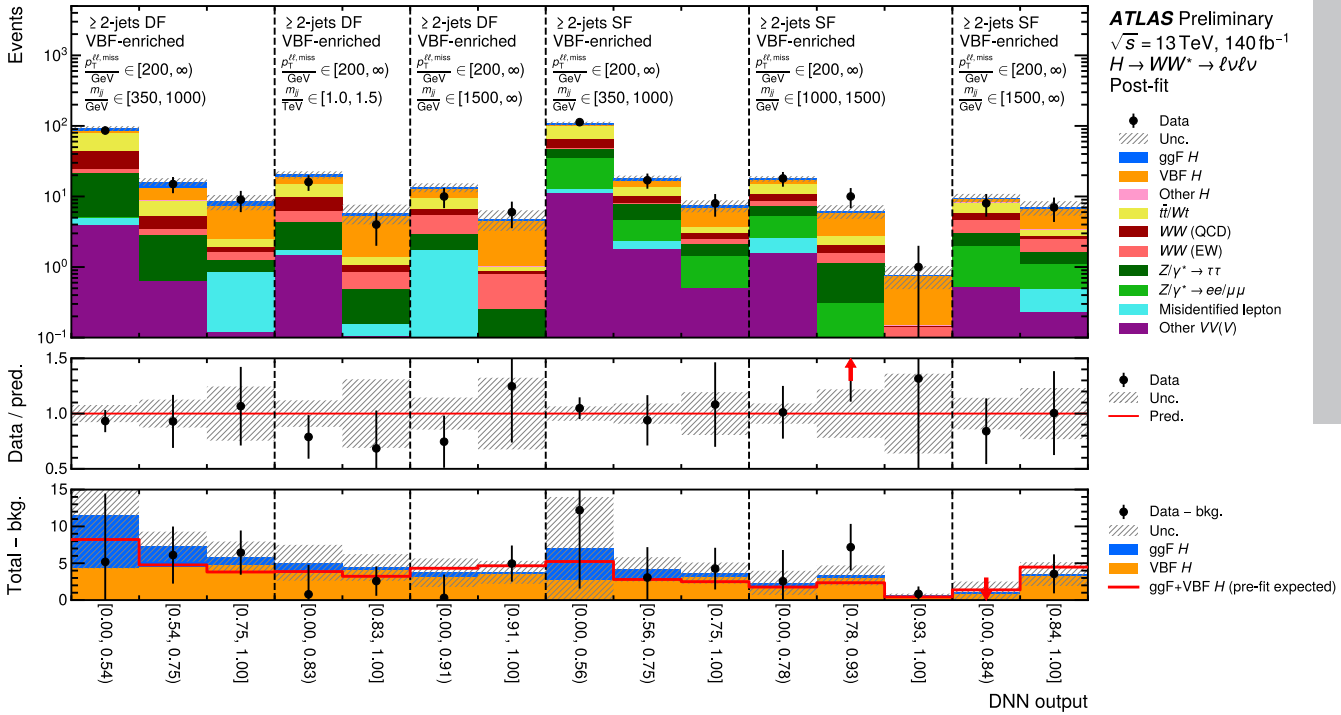


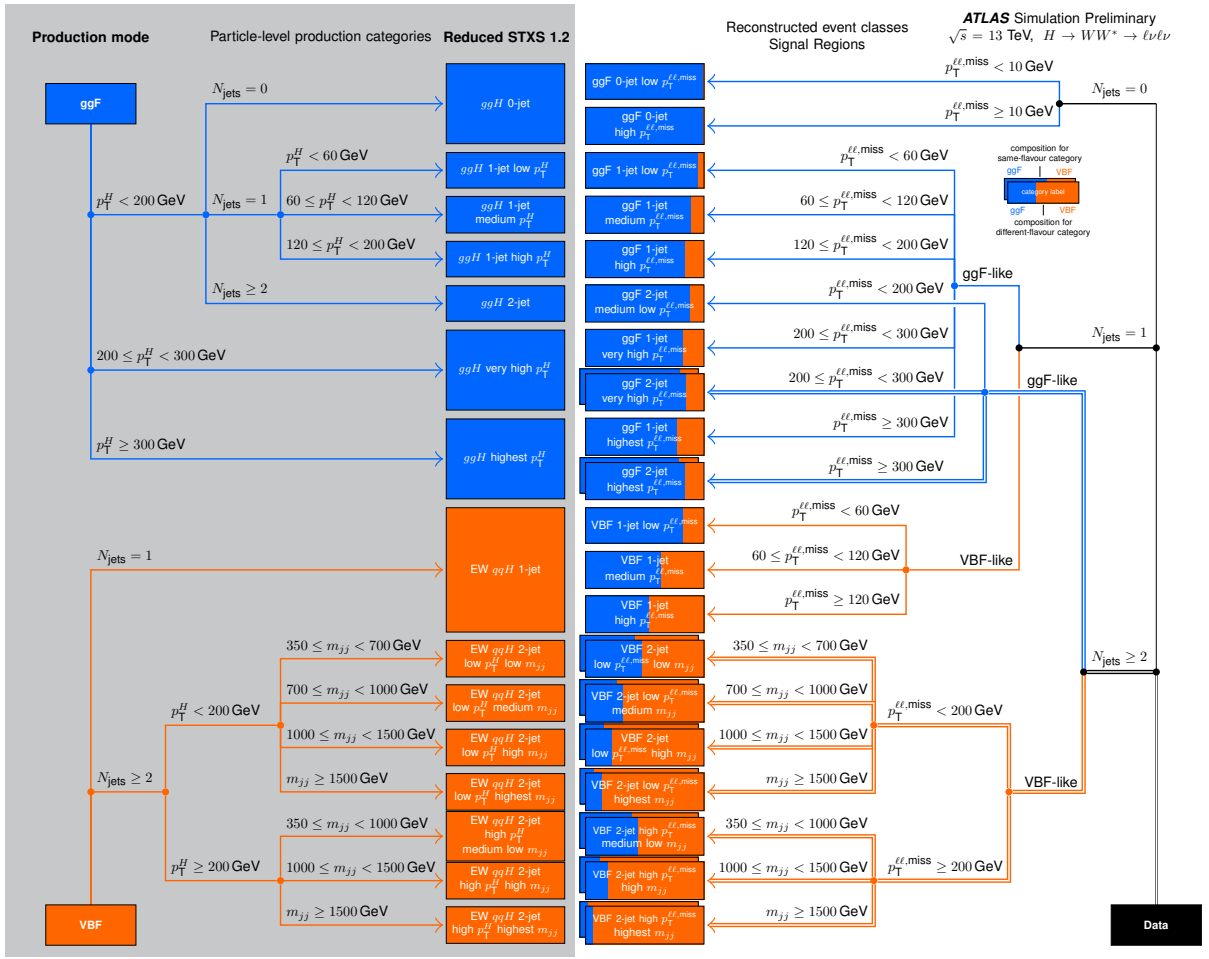
ggH + VBF, H→WW*→lνlν

ATL-HIGP-2024-07

ggH + VBF, H→WW*→lνlν

- Update on Phys. Rev. D 108 (2023) 032005.
- Added same-flavor lepton final states.
- Utilizes a Deep Neural Network (DNN) for signal vs background classification in all categories.



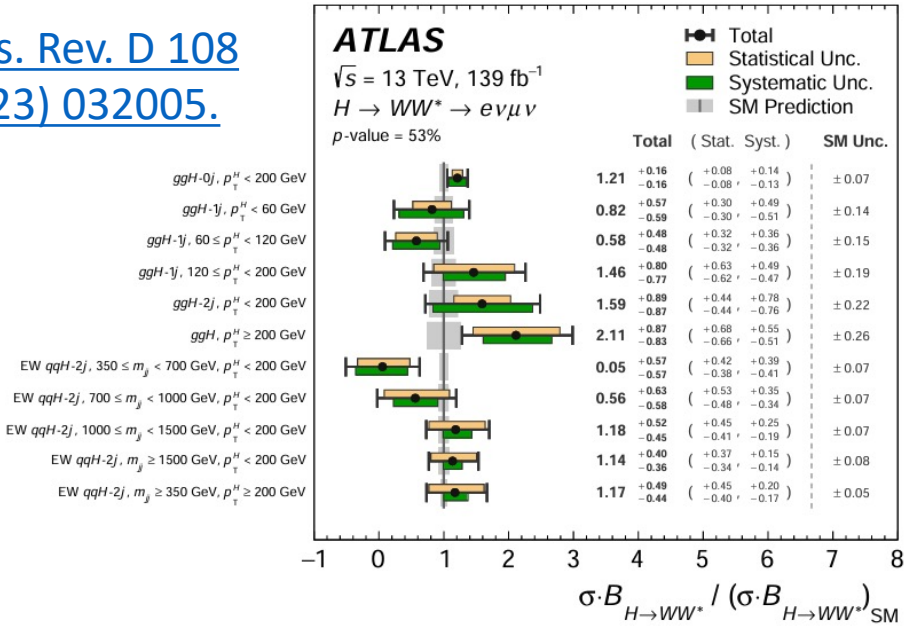


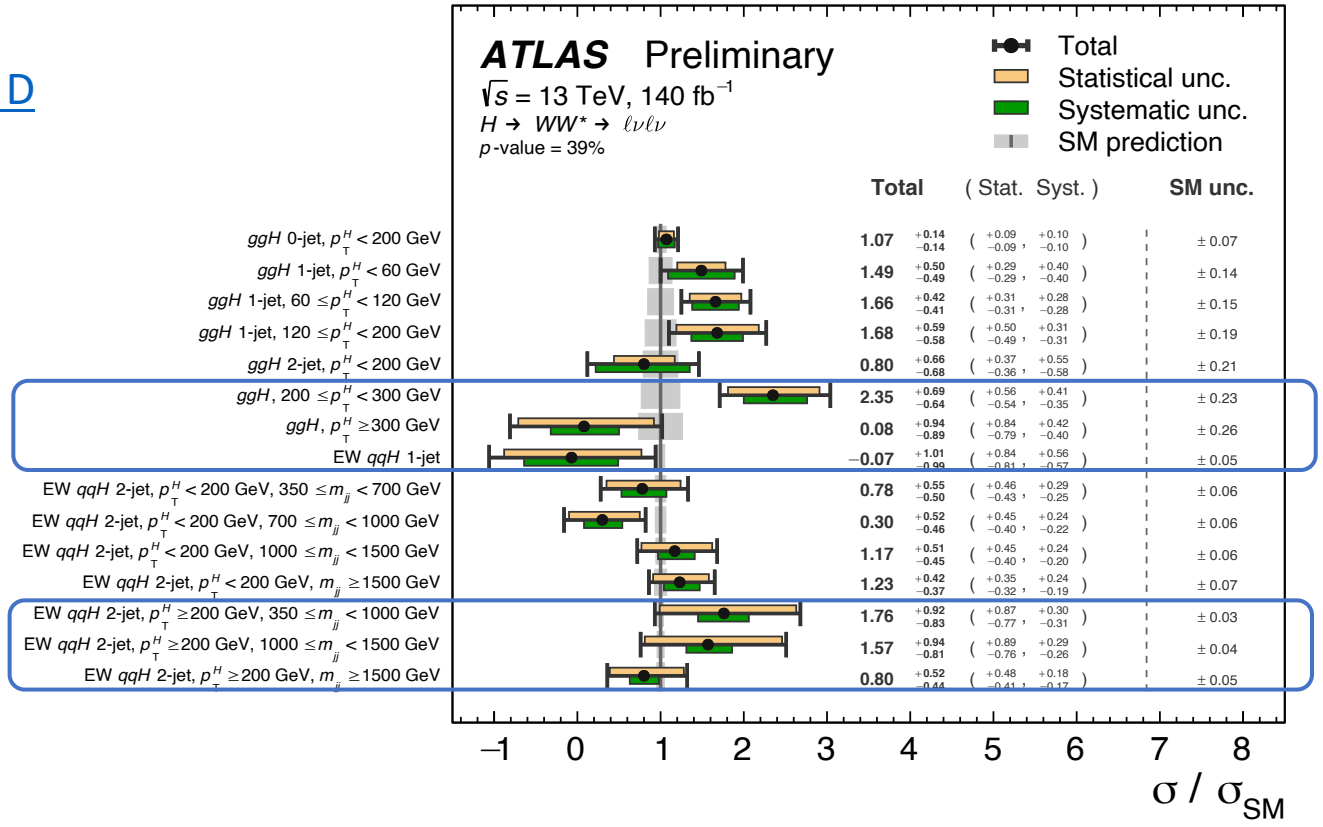
ggH + VBF, H→WW*→lνlν

ATL-HIGP-2024-07

- Use more granular bins in m_{jj} at high p_T^H for qqH 2-jet and another bin at higher p_T^H for ggH than in Phys. Rev. D 108 (2023) 032005.
- New region - qqH 1-jet.
- Significant improvement in the precision of measured STXS bins.

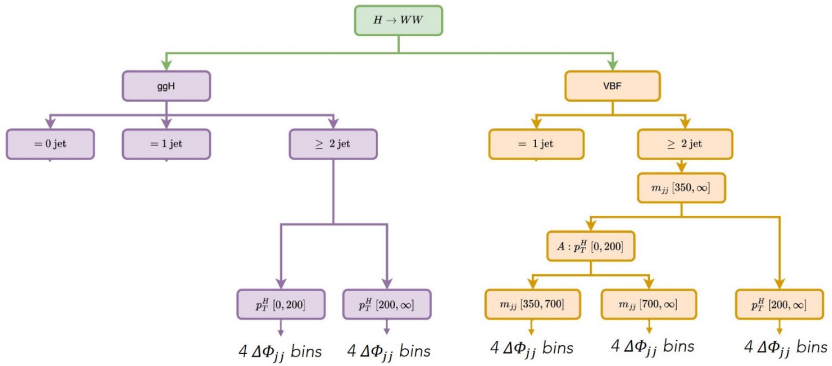
Phys. Rev. D 108 (2023) 032005.

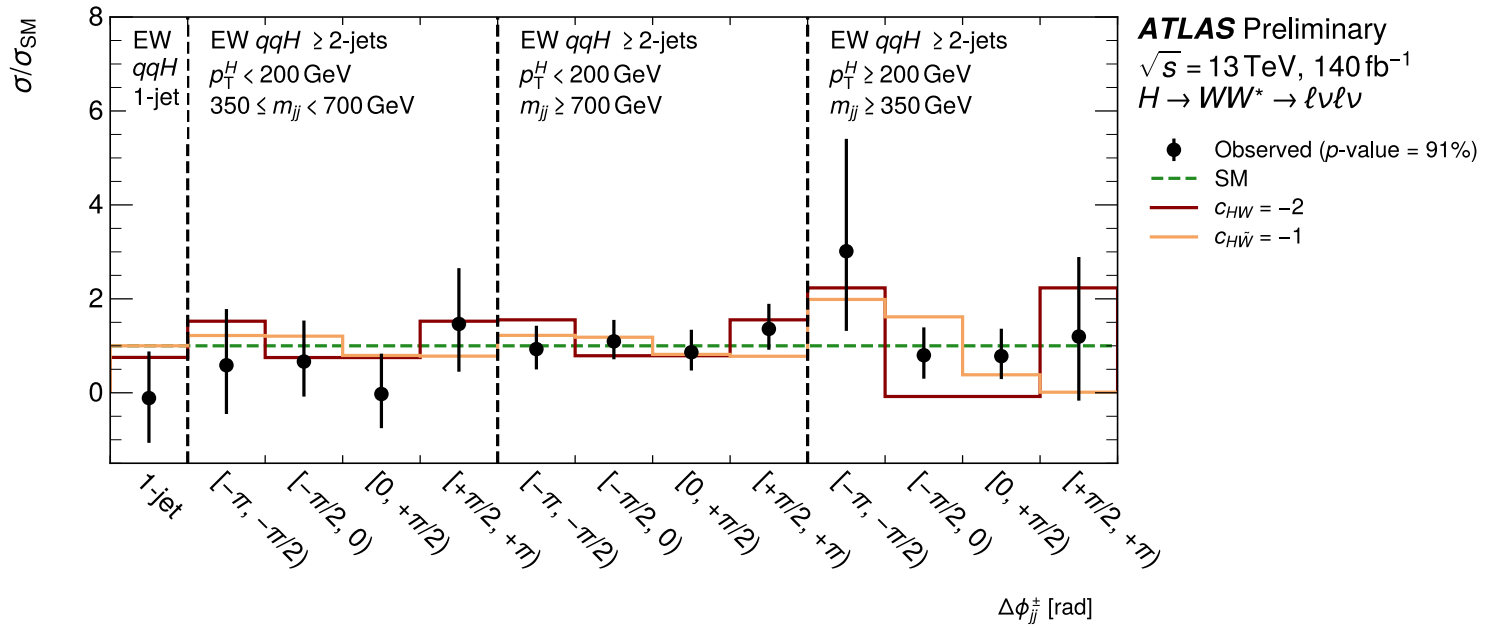


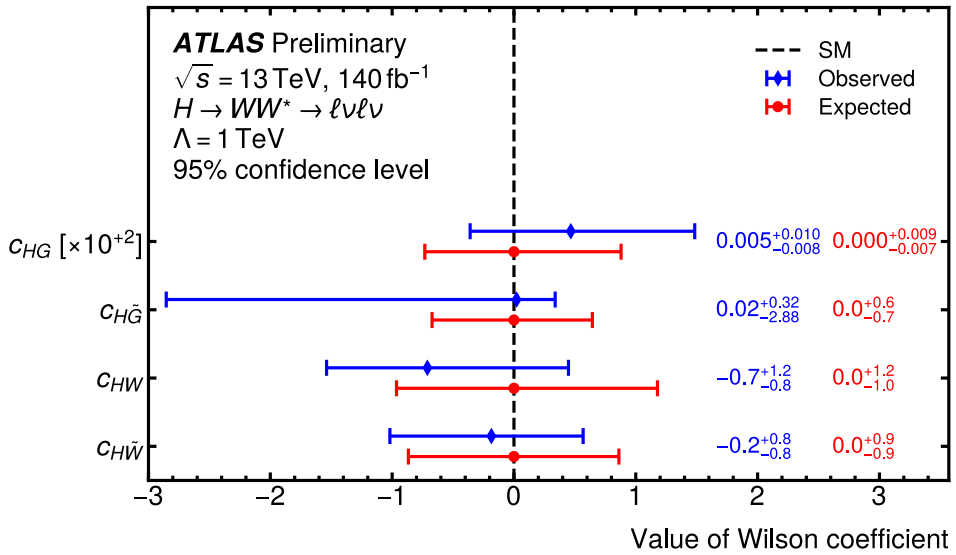


ggH + VBF, H→WW*→lνlν

- Additional binning of STXS in CP sensitive variable $\Delta\phi_{jj}^{\pm}$, azimuthal angular difference between the rapidity-ordered leading jets.
- **Very first STXS$_{CP}$ measurement!**
- Results are interpreted in the context of an EFT with CP-violating modifications to HVV/Hgg couplings and good agreement is seen with the SM Higgs boson.





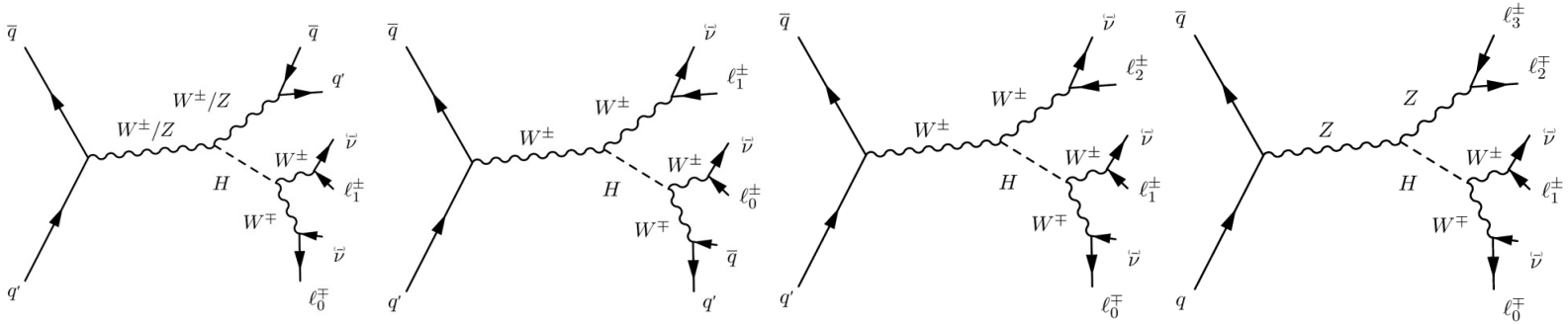


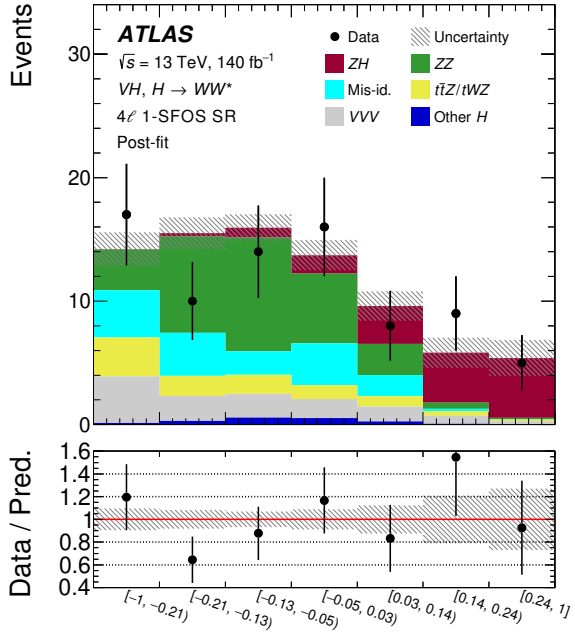
VH, H→WW*→lνlν, lνjj

ATL-HIGG-2023-09

VH, H→WW*→lνlν, lνjj

ATL-HIGG-2023-09

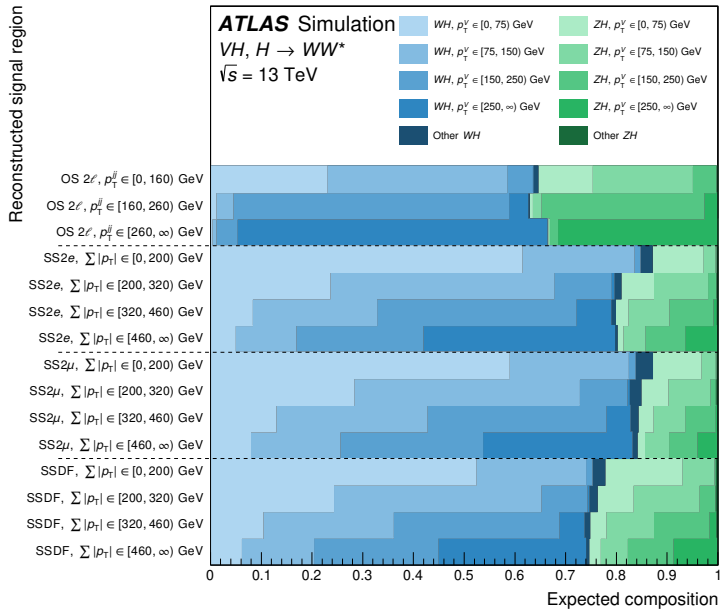


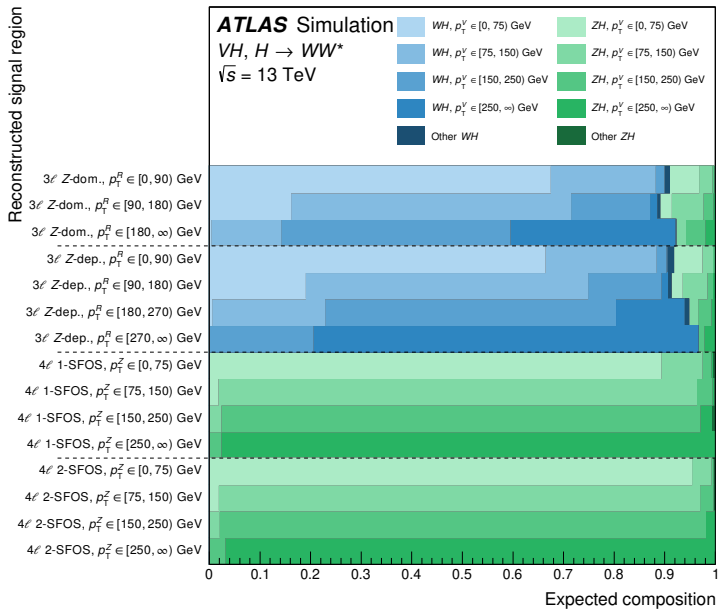


- Update on Phys. Lett. B 798 (2019) 134949.

- Now have 2, 3 and 4-lepton channels and utilize MVA signal discriminators.
  - DNNs for 2l & 3l channels,
  - BDTs for 4l.

- Define many categories targeting both STXS and differential bins



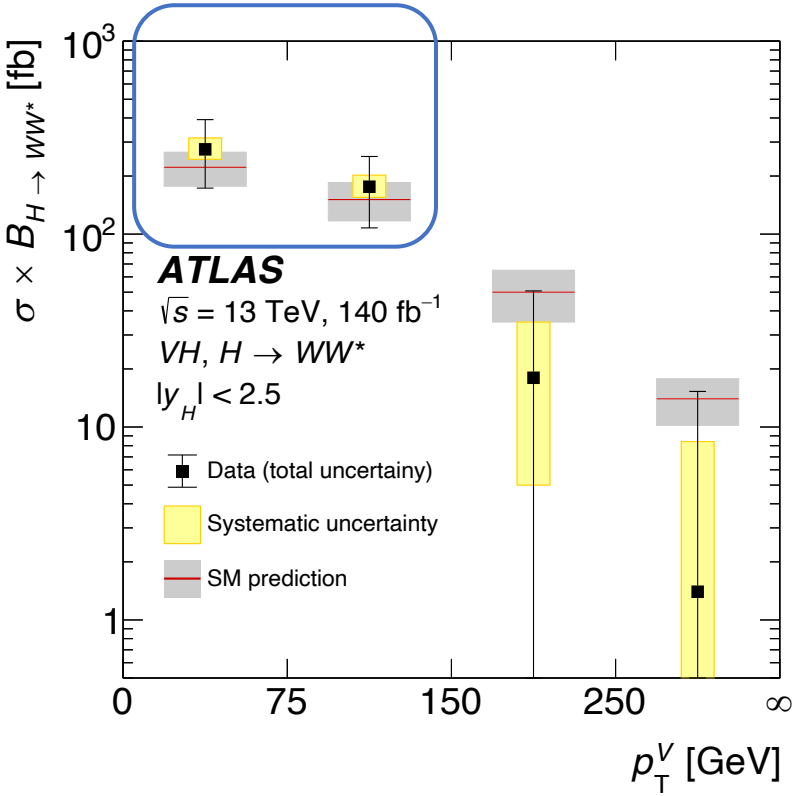


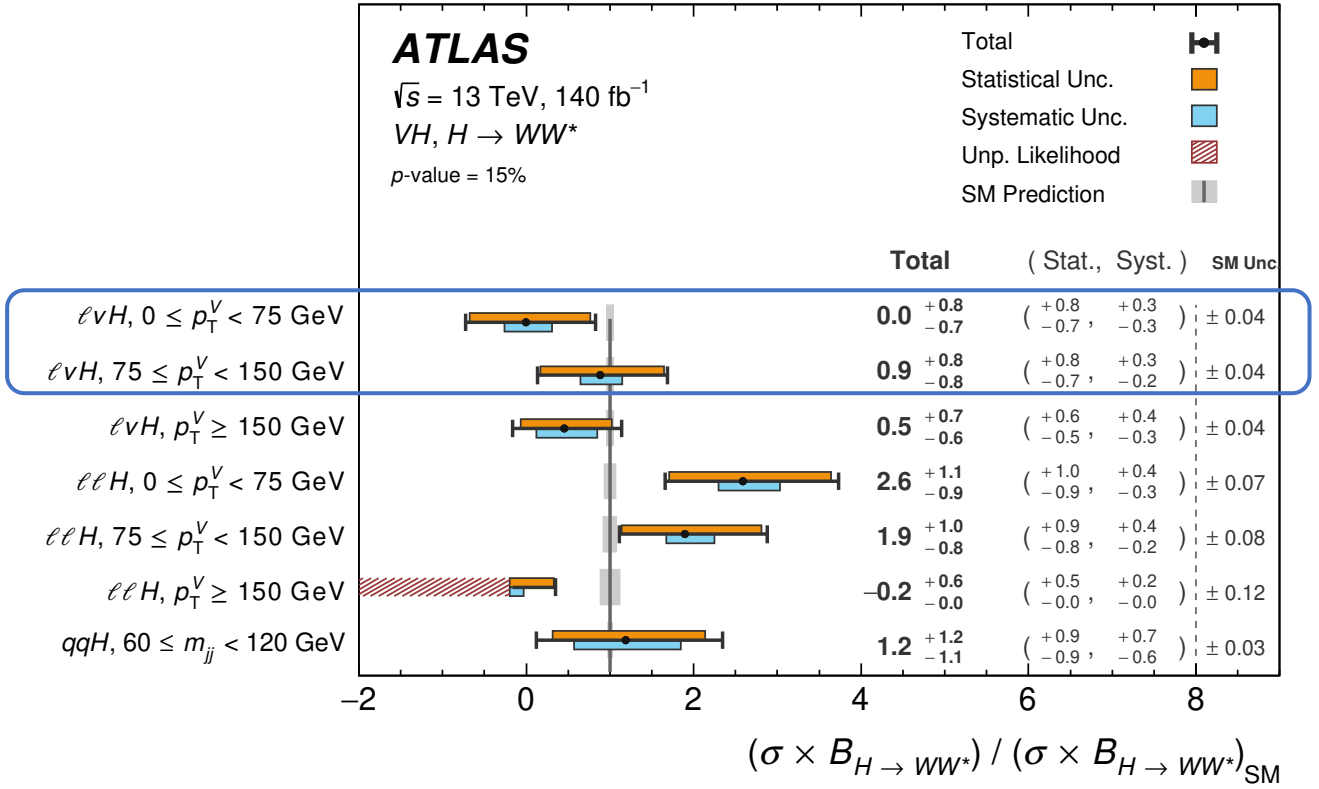
VH, H→WW*→lνlν, lνjj

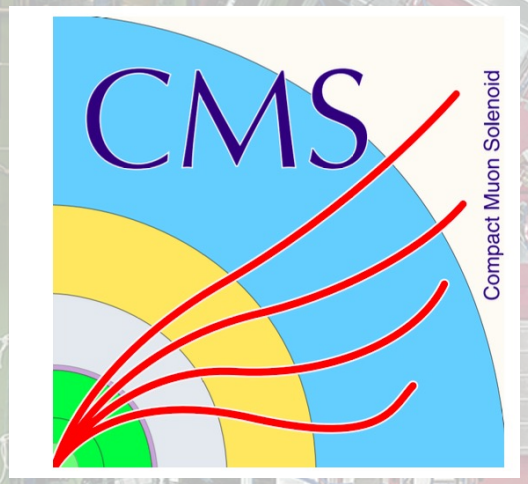
ATL-HIGG-2023-09

- Both differential results in p_T^V and in the STXS binning.
- Improved techniques help low p_T^V differential and STXS bins.
- All results consistent with the SM Higgs boson.

p_{T}^V scheme	STXS scheme
VH, $0 \le p_{\mathrm{T}}^V < 75$ GeV	$\ell\nu H$ and $\ell\ell H$, $0 \le p_{\mathrm{T}}^V < 75$ GeV
VH, $75 \le p_{\mathrm{T}}^V < 150$ GeV	$\ell\nu H$ and $\ell\ell H$, $75 \le p_{\mathrm{T}}^V < 150$ GeV
VH, $150 \le p_{\mathrm{T}}^V < 250$ GeV	$\ell\nu H$ and $\ell\ell H$, $p_{\mathrm{T}}^V \ge 150$ GeV
VH, $p_{\mathrm{T}}^V \ge 250$ GeV	EW qqH, $60 \le m_{jj} < 120$ GeV





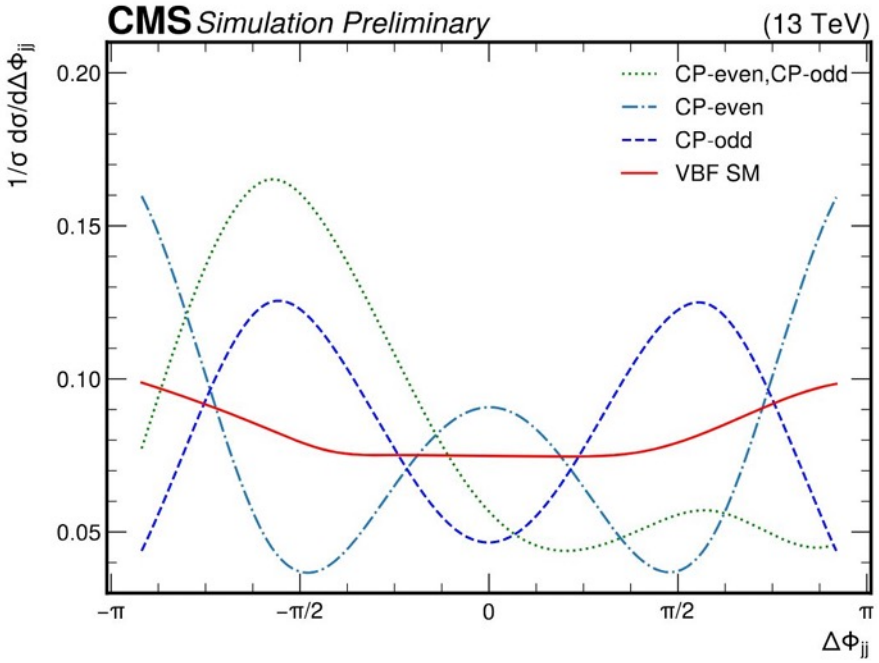


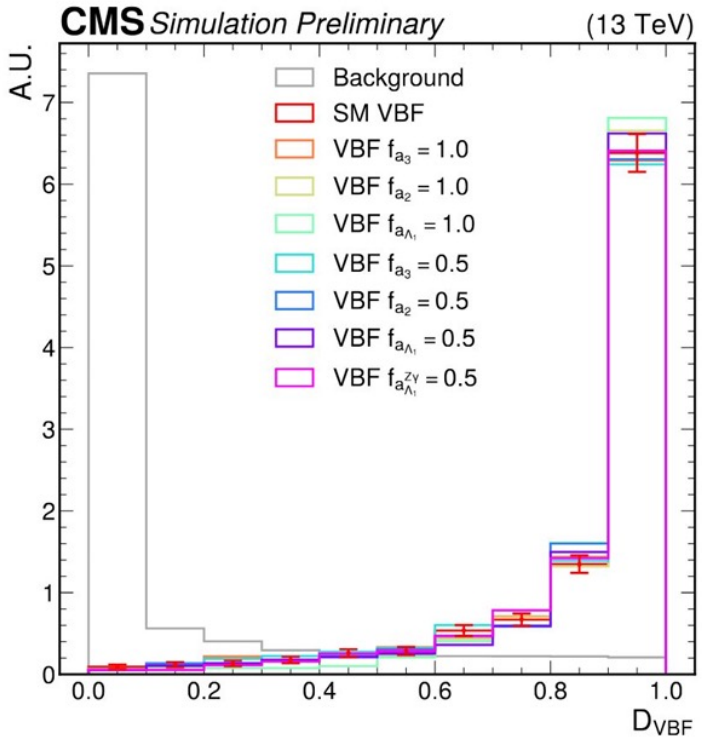
H + 2-jets, H →WW*→eνμν

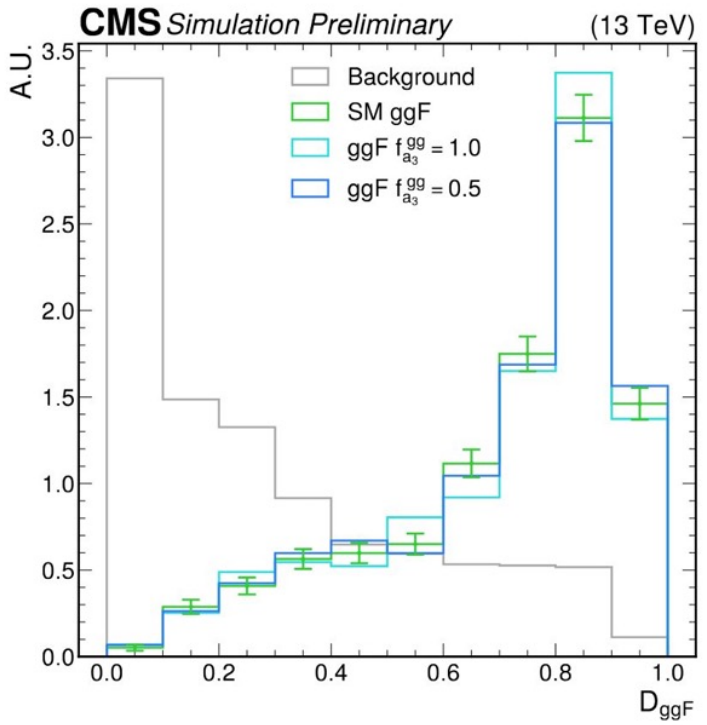
CMS-PAS-HIG-24-004

H + 2-jets, H →WW*→eνμν

- Search for anomalous couplings (AC) in the HVV vertex.
- Differential cross section measurement in the CP AC sensitivity variable $\Delta\phi_{jj}$.
- Train an Adversarial Deep Neural Network (ADNN), to maintain model independence and provide excellent all-round sensitivity.



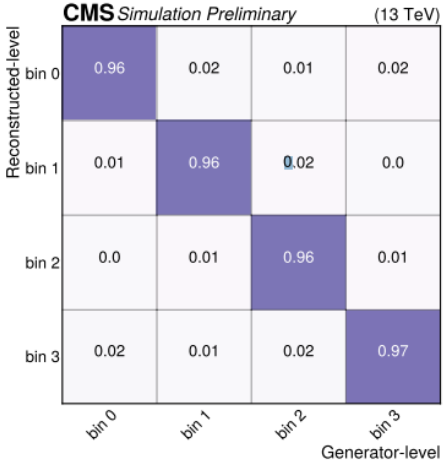




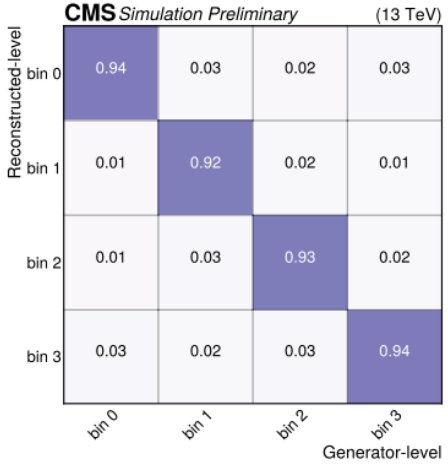
H + 2-jets, H →WW*→eνμν

- Perform likelihood-based unfolding to extract the differential cross section.

VBF

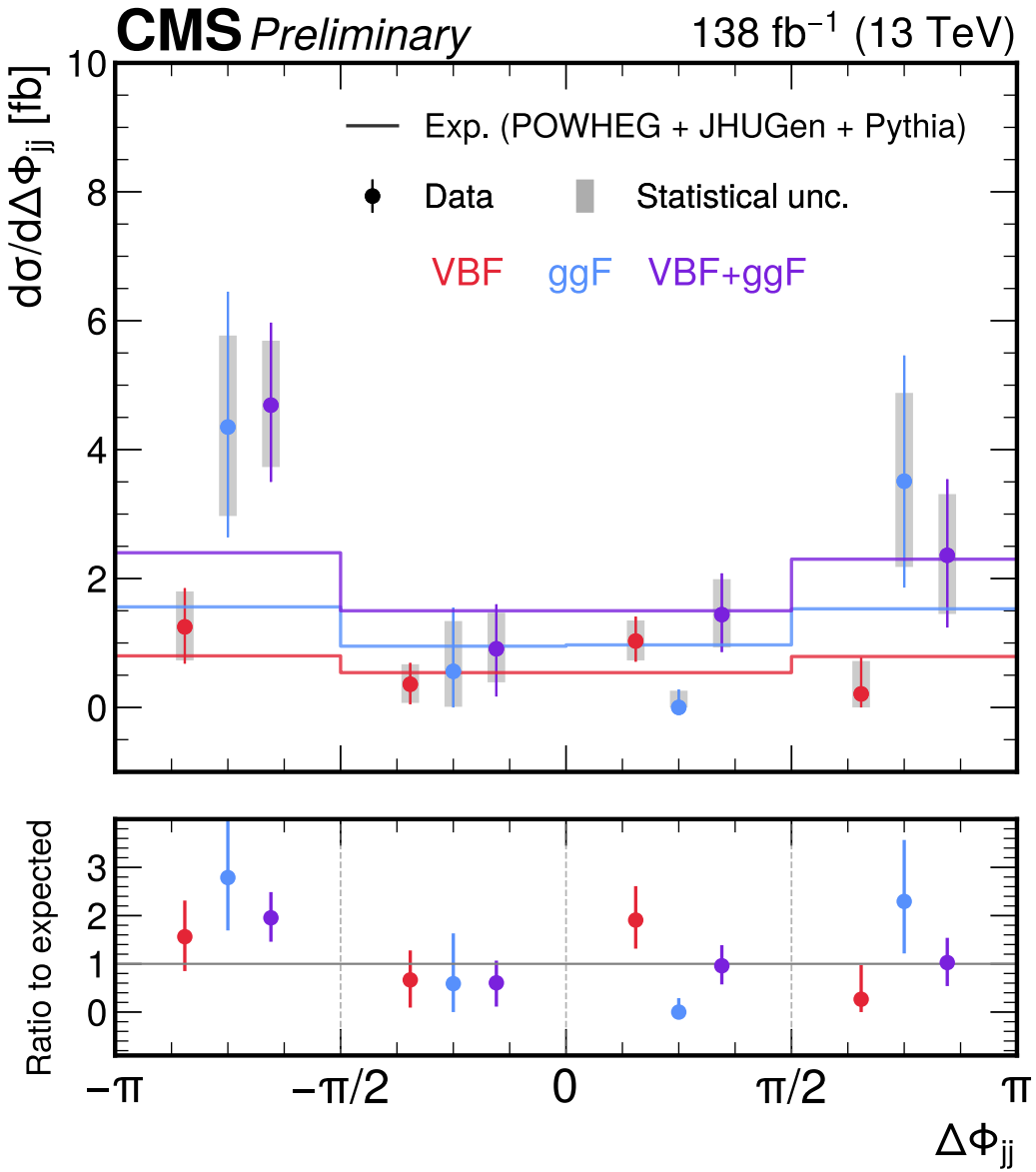


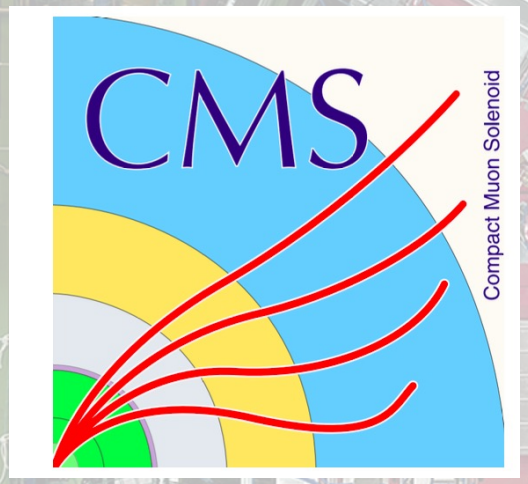
ggF



- No significant deviations from the standard model were found.

- Differential cross sections were used to constrain Wilson coefficients.





Legacy Run 2 STXS Combination

CMS-PAS-HIG-21-018

Legacy Run 2 STXS Combination

CMS-PAS-HIG-21-018

- **Update on the Nature combination Nature volume 607, 60–68 (2022), with new channels and many more interpretations.**

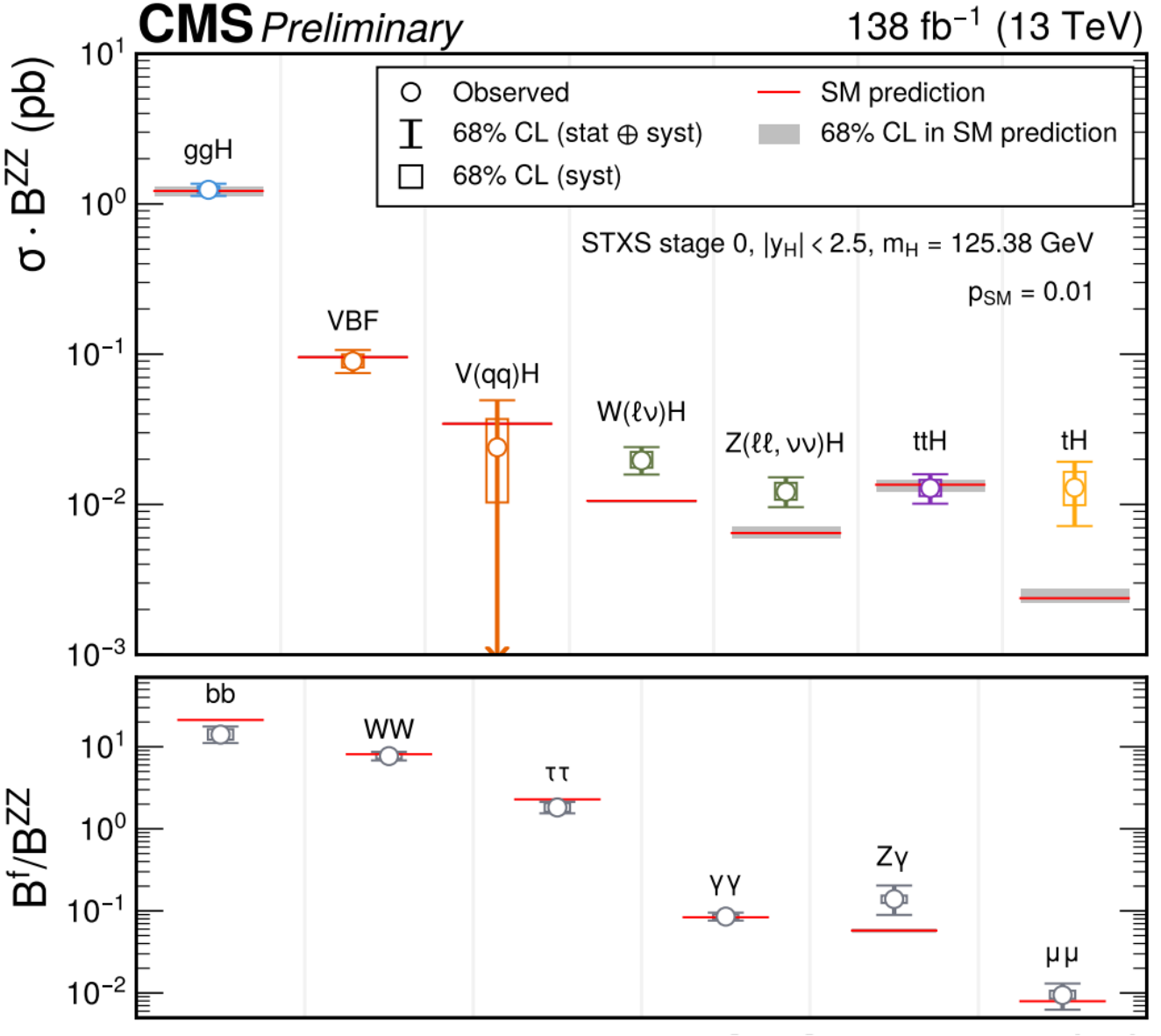
- Channels include H→$\gamma\gamma$, H→ZZ*→4l, H→WW*→lνlν, H→$\tau\tau$, H→bb, H→μμ, H→Zγ.

- Includes interpretations in:
  - Signal strength modifiers
  - **STXS**
  - Kappas
  - Higgs self coupling
  - EFT

Analysis categories ~1K

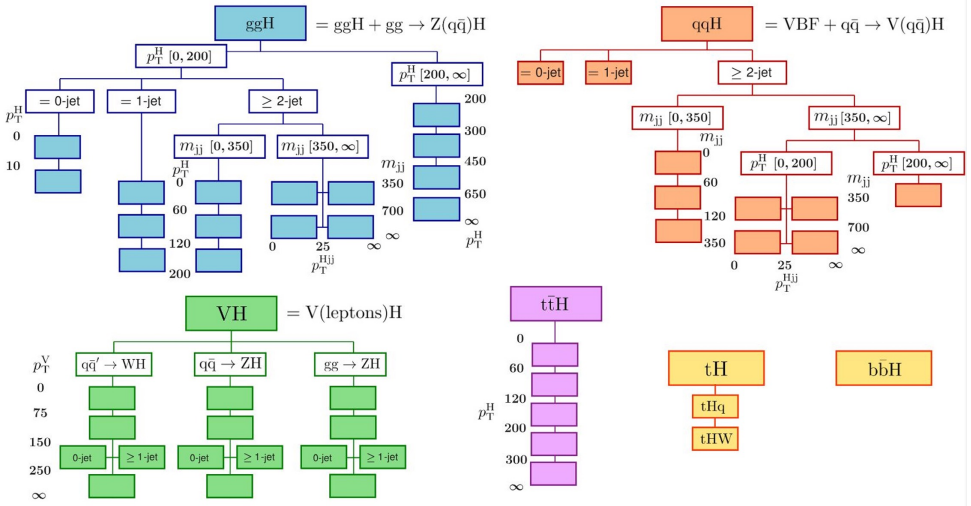
Nuisance parameters ~10K

$$L(\vec{x};\vec{\alpha},\vec{\theta}) = \prod_r L_r(\vec{x};\vec{\alpha},\vec{\theta}) \prod_l p_l(y_l;\theta_l)$$

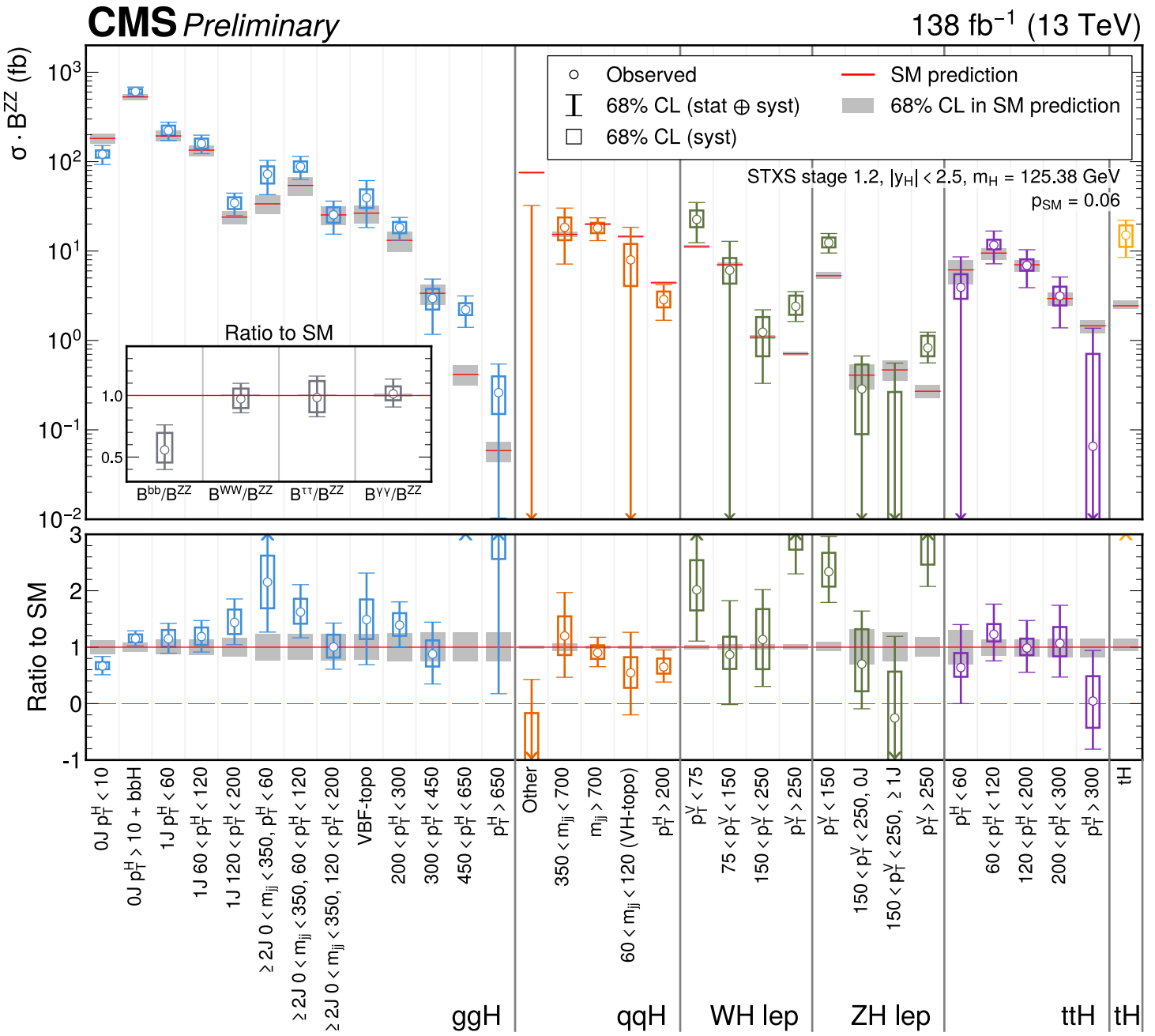


STXS Stage 1.2

CMS-PAS-HIG-21-018

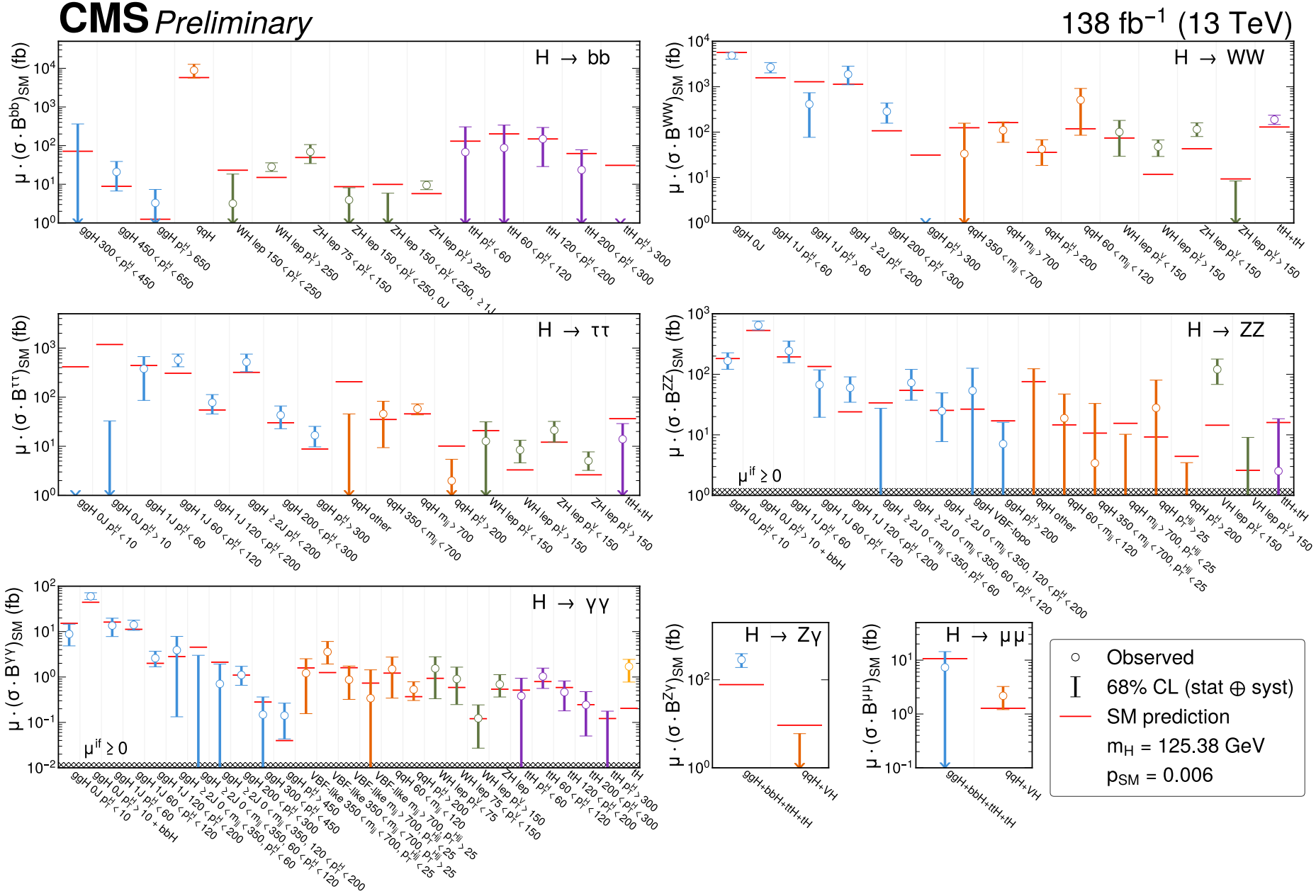


- **First CMS run 2 STXS combination!**
- Reasonable agreement with the SM.
- Deviations in the high p_T^V WH/ZH leptonic regions + tH production



STXS Stage 1.2 split by decay channel

- Another fit with separate parameter per cross section times branching fraction.
- Most granular fit performed by CMS in the Higgs sector
- **97 parameters of interest!**
- Provide tabular version of results and covariance matrix to use for BSM interpretations.



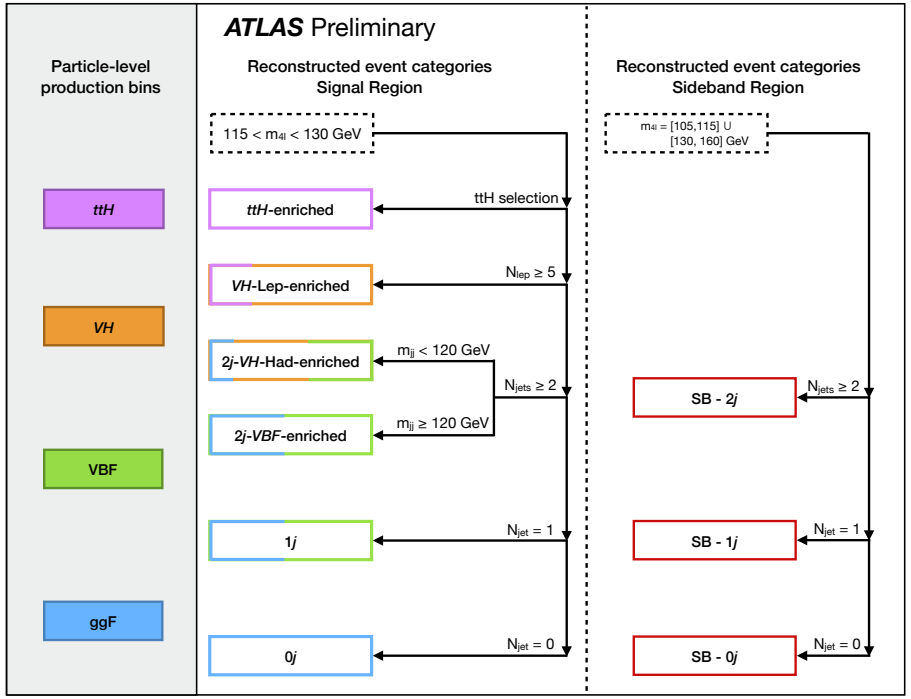
$H \to ZZ^* \to 4l$

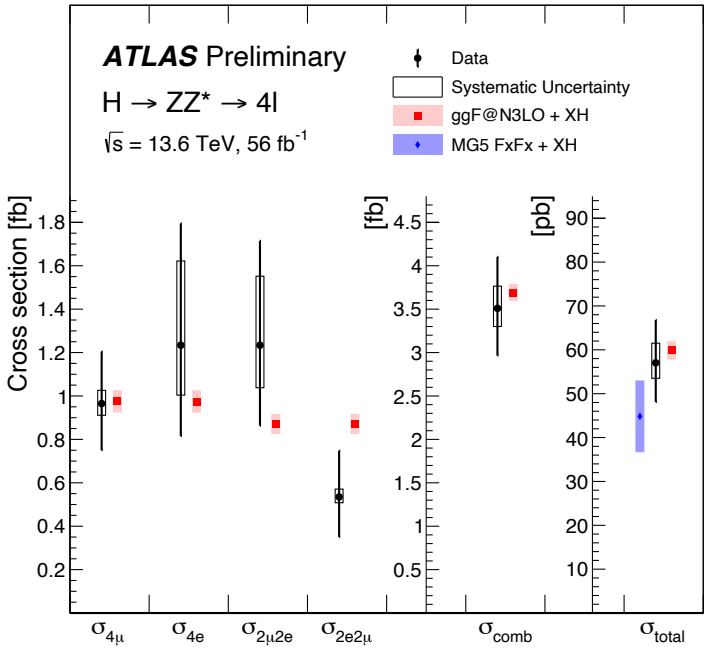
ATLAS-CONF-2025-002

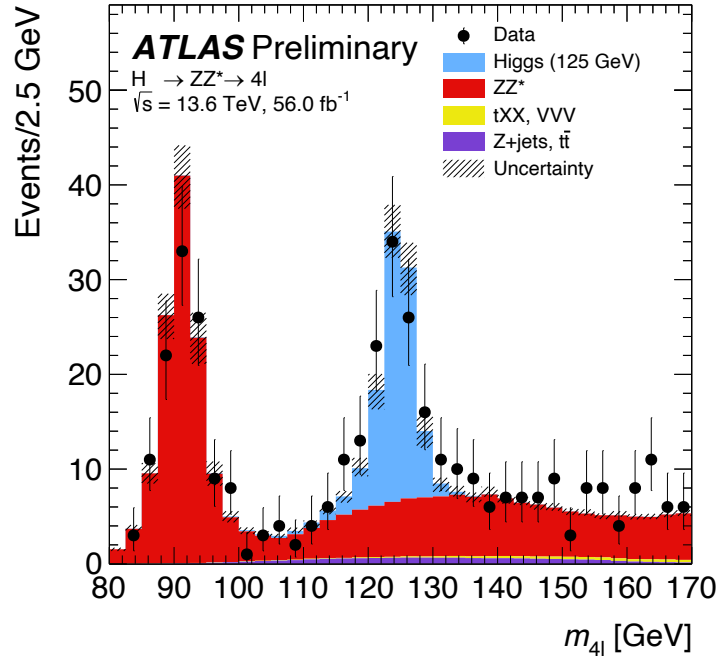
H→ZZ*→4l

ATLAS-CONF-2025-002

- “Golden” decay channels (4μ, 4e, 2μ2e, 2e2μ).
- Uses 56 fb^{-1} of $\sqrt{s}$ = 13.6 TeV collected collected in 2022 and 2023.
- Measure both inclusive and differential production cross sections within a defined fiducial phase space.







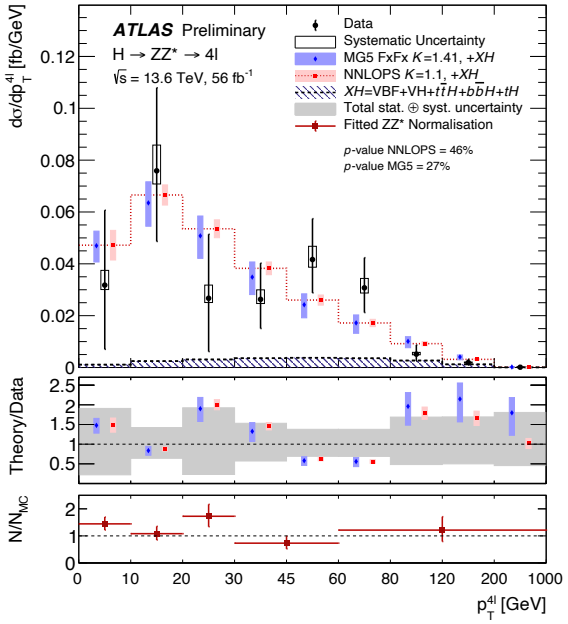
H→ZZ*→4l

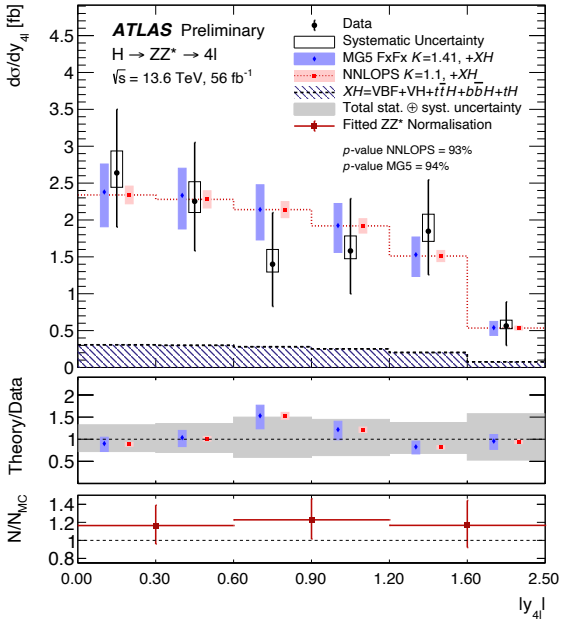
[ATLAS-CONF-2025-002]

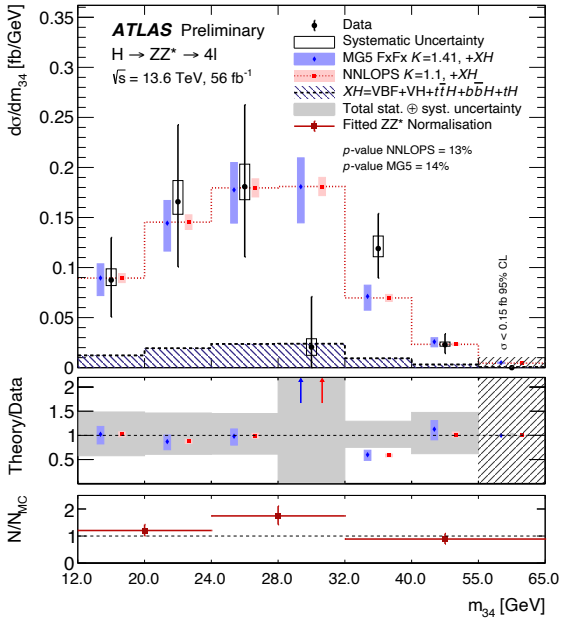
Measure the Higgs cross section differentially across 4 variables of interest.

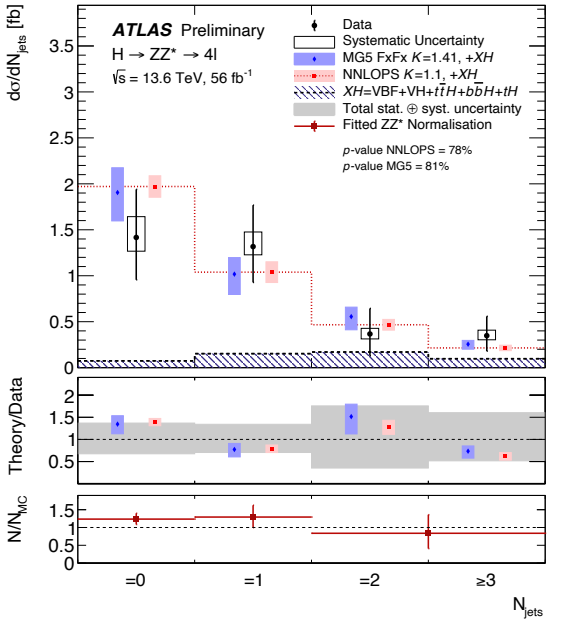
- p_T^{4l}: Useful for QCD radiation and potential BSM effects at high momenta
- $|y_{4l}|$: Test PDF parameterizations
- m_{34}: Sensitive to spin and CP properties
- N_{jets}: Separate Higgs production modes.

Excellent agreement with the SM Higgs boson.



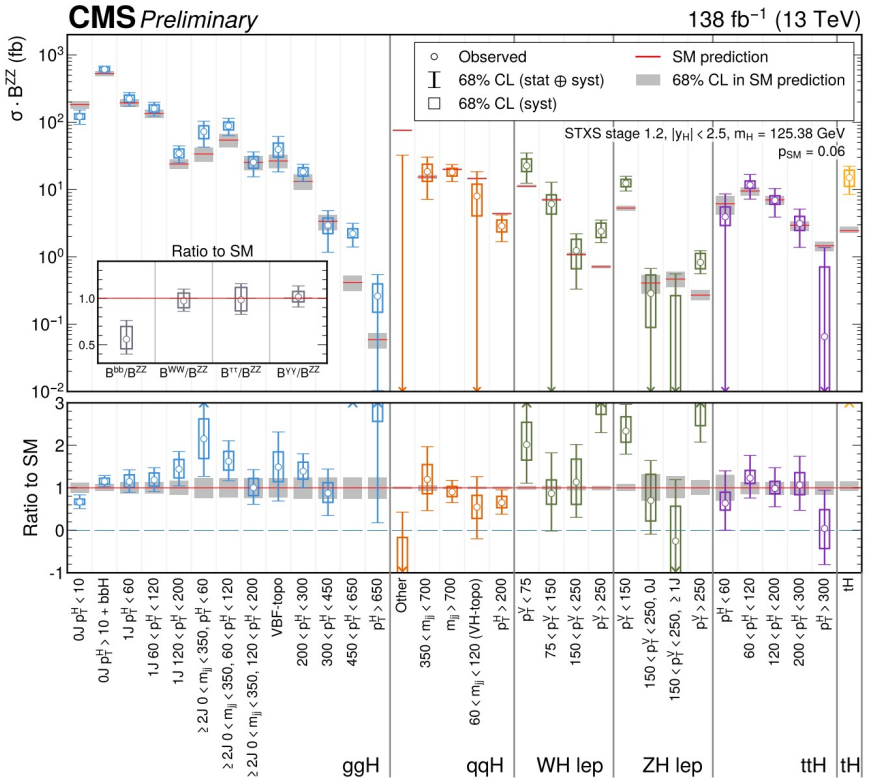


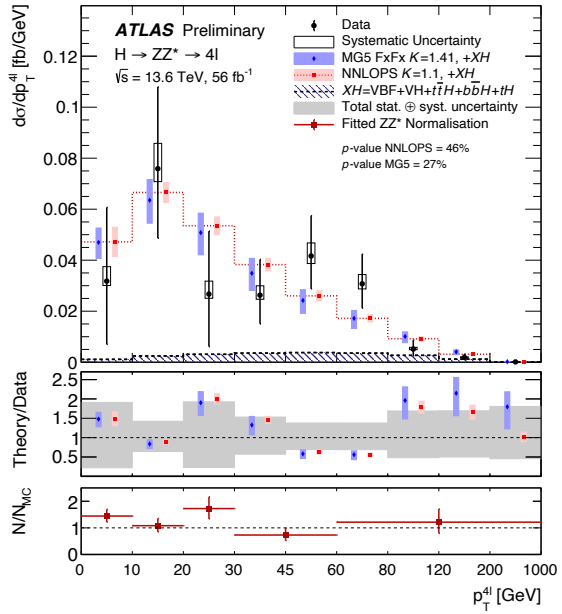




Summary

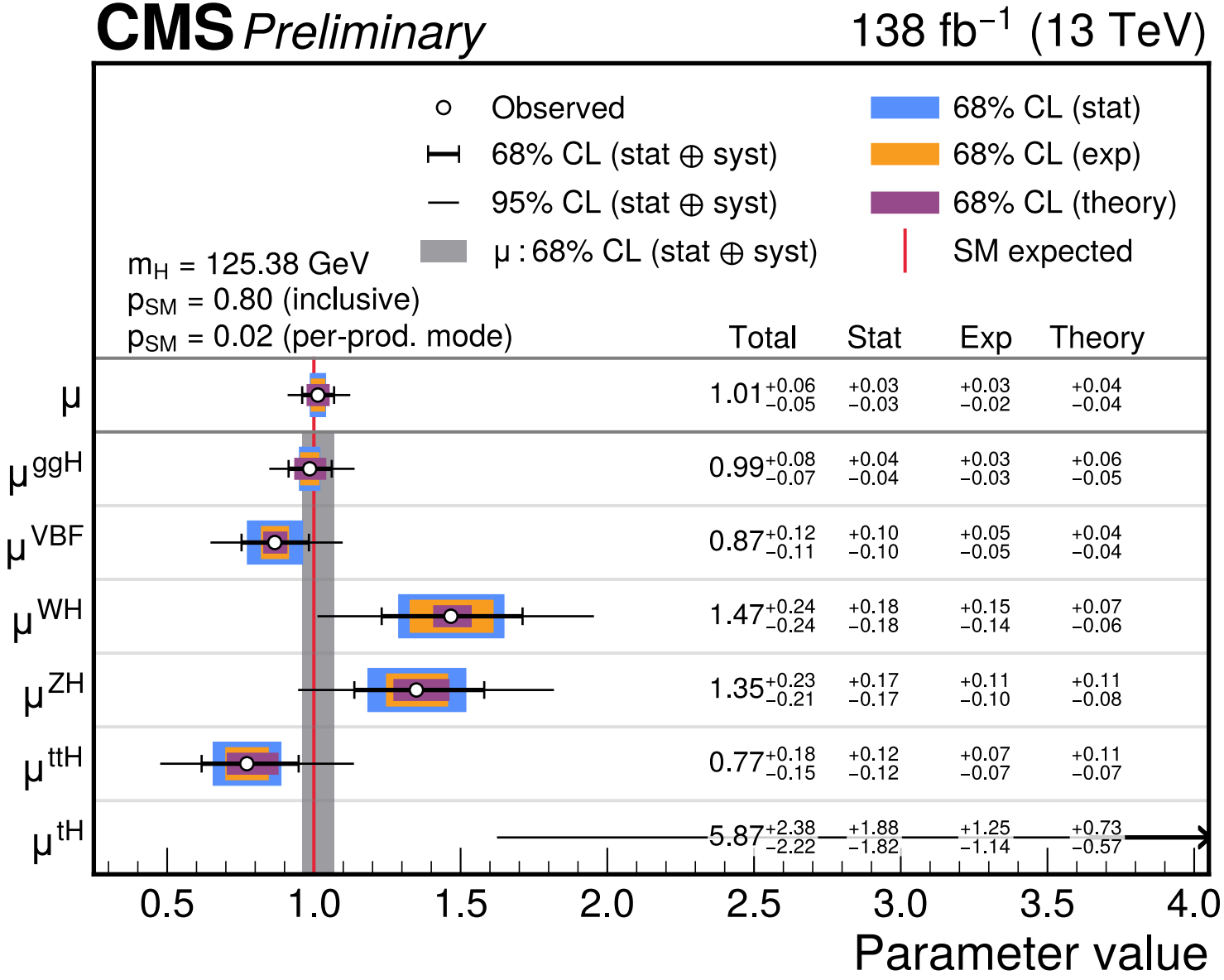
- Many new results from Higgs STXS/differential measurements.
- Wealth of new “model independent” Higgs measurements ready to be utilized.
- Updates on Run 2 measurements utilizing new techniques are bringing improvements on the precisions and on the granularity.
- Reaching the end of Run 2 single Higgs measurements.
  - Includes a CMS Run 2 legacy combination.
- Beginning to see more Run 3 Higgs measurements.
- **Run 3 is an exciting time as we can look more differentially/granularly at the Higgs boson's properties and potentially reveal BSM effects.**



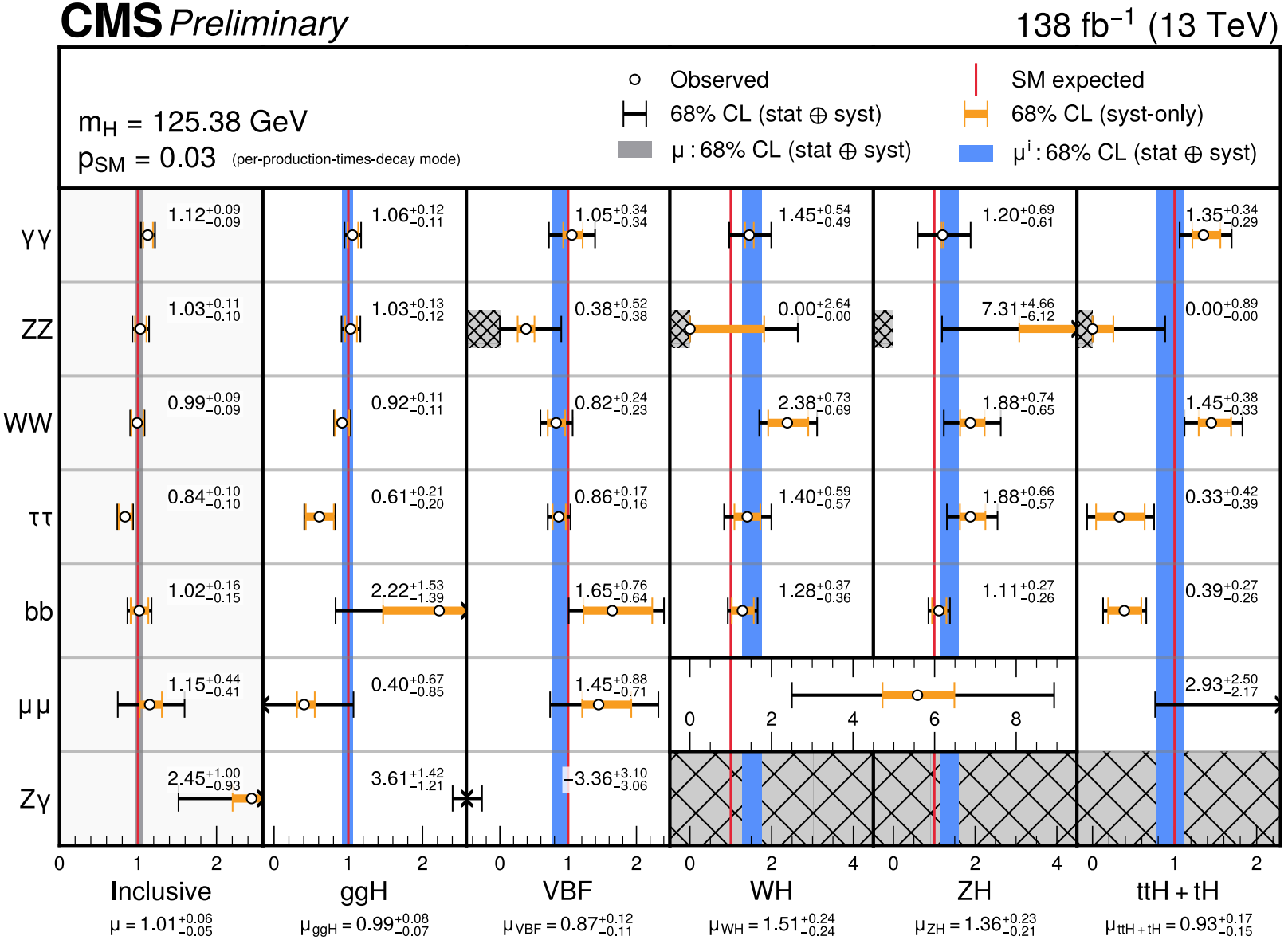


Backup

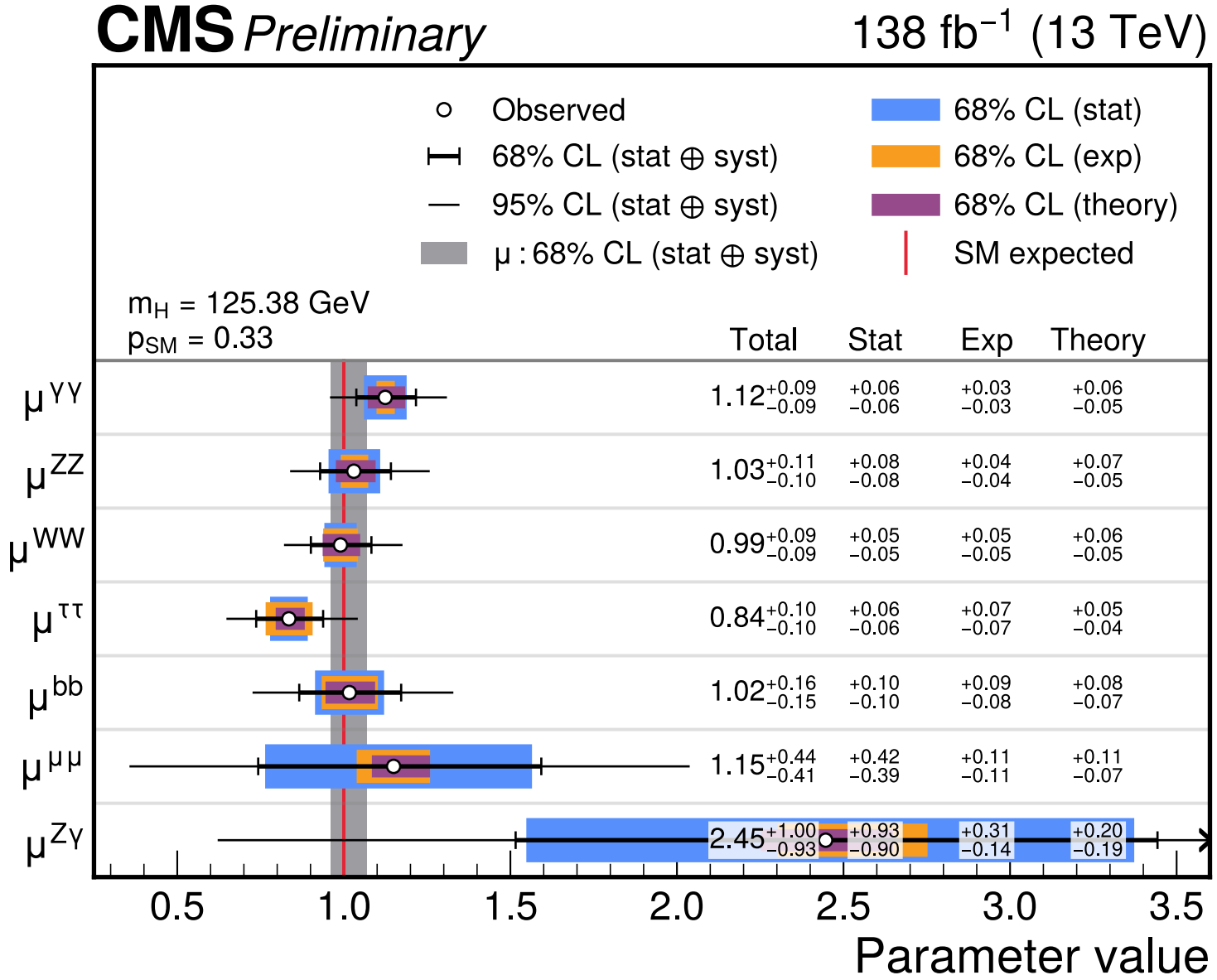
Legacy Run 2 STXS Combination



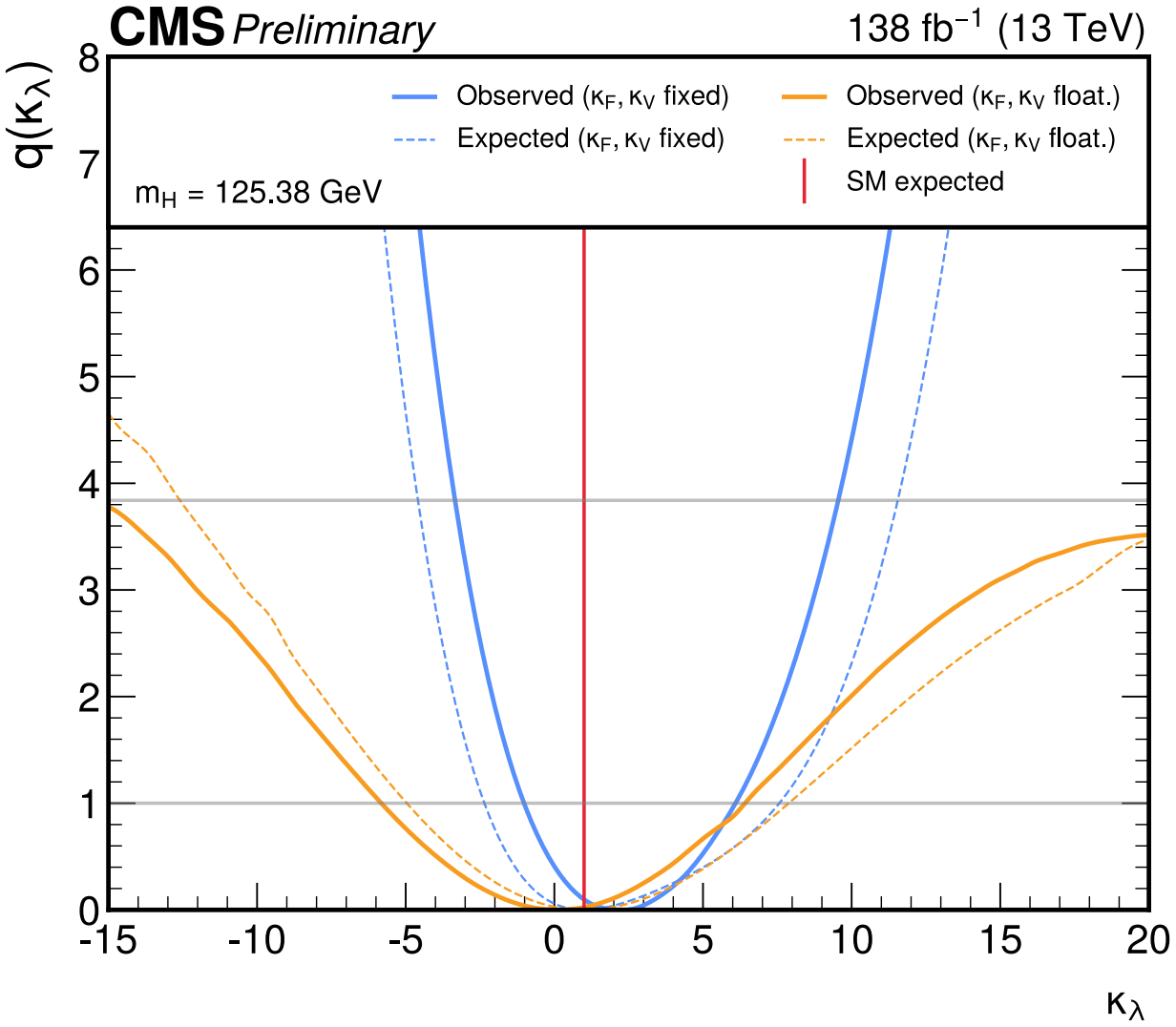
Legacy Run 2 STXS Combination



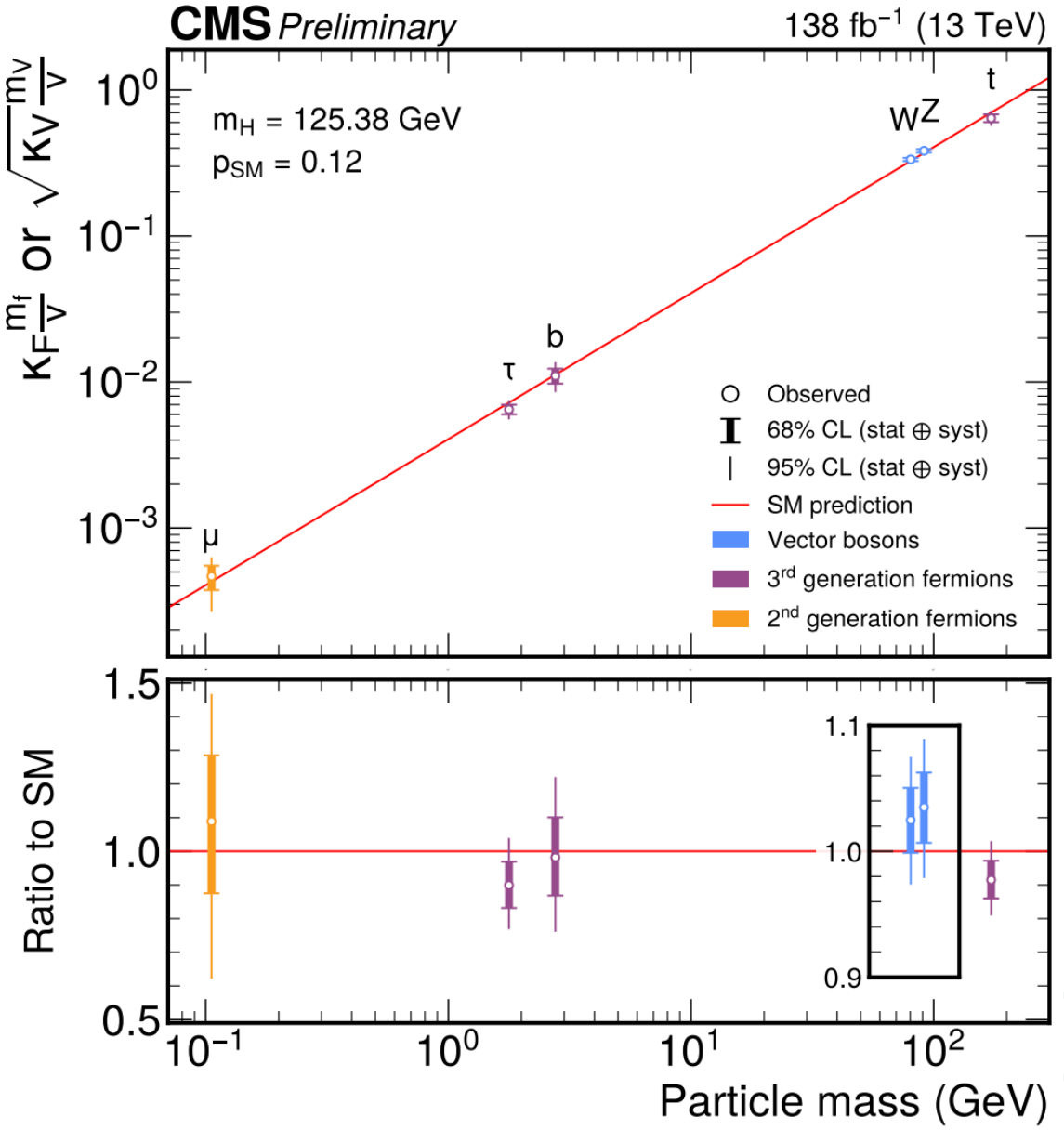
Legacy Run 2 STXS Combination



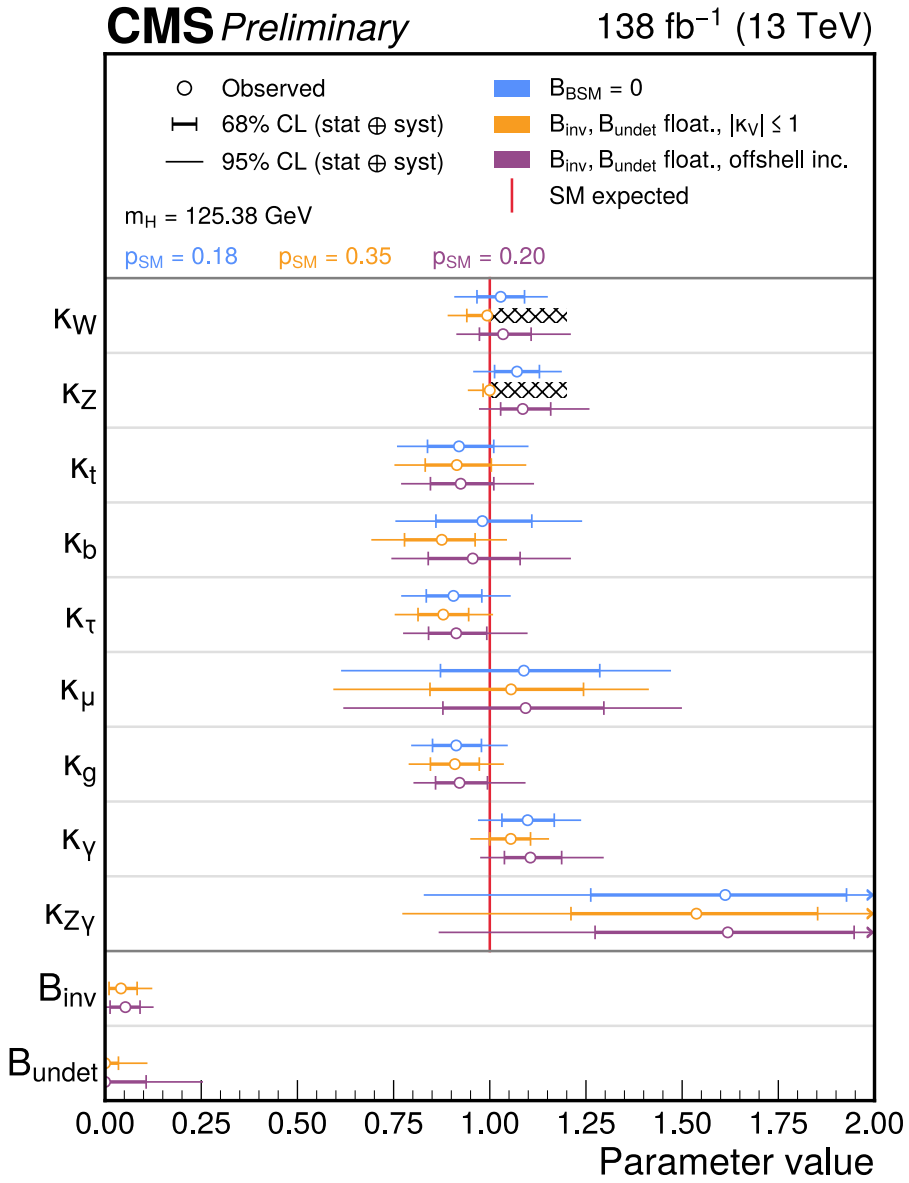
Legacy Run 2 STXS Combination



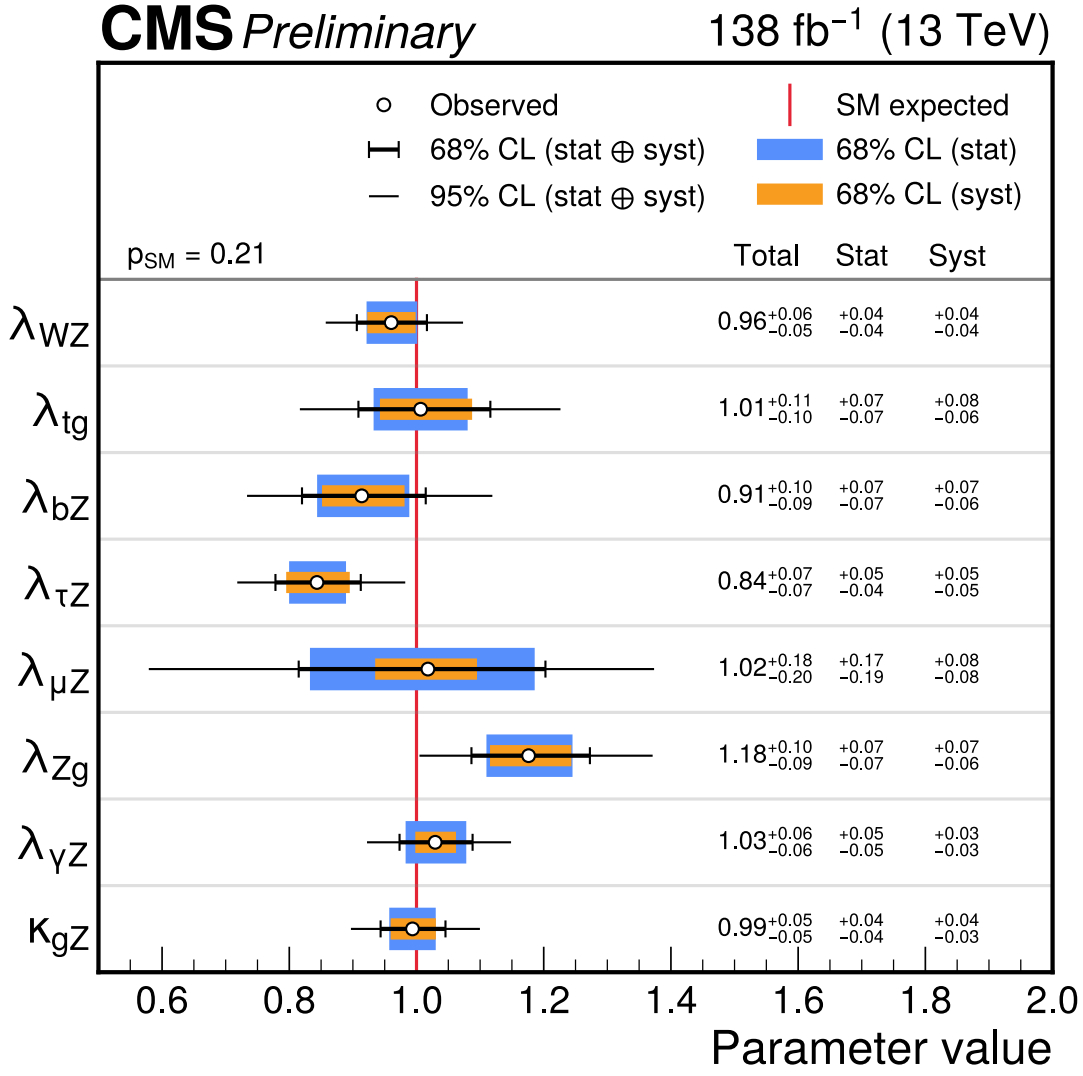
Legacy Run 2 STXS Combination



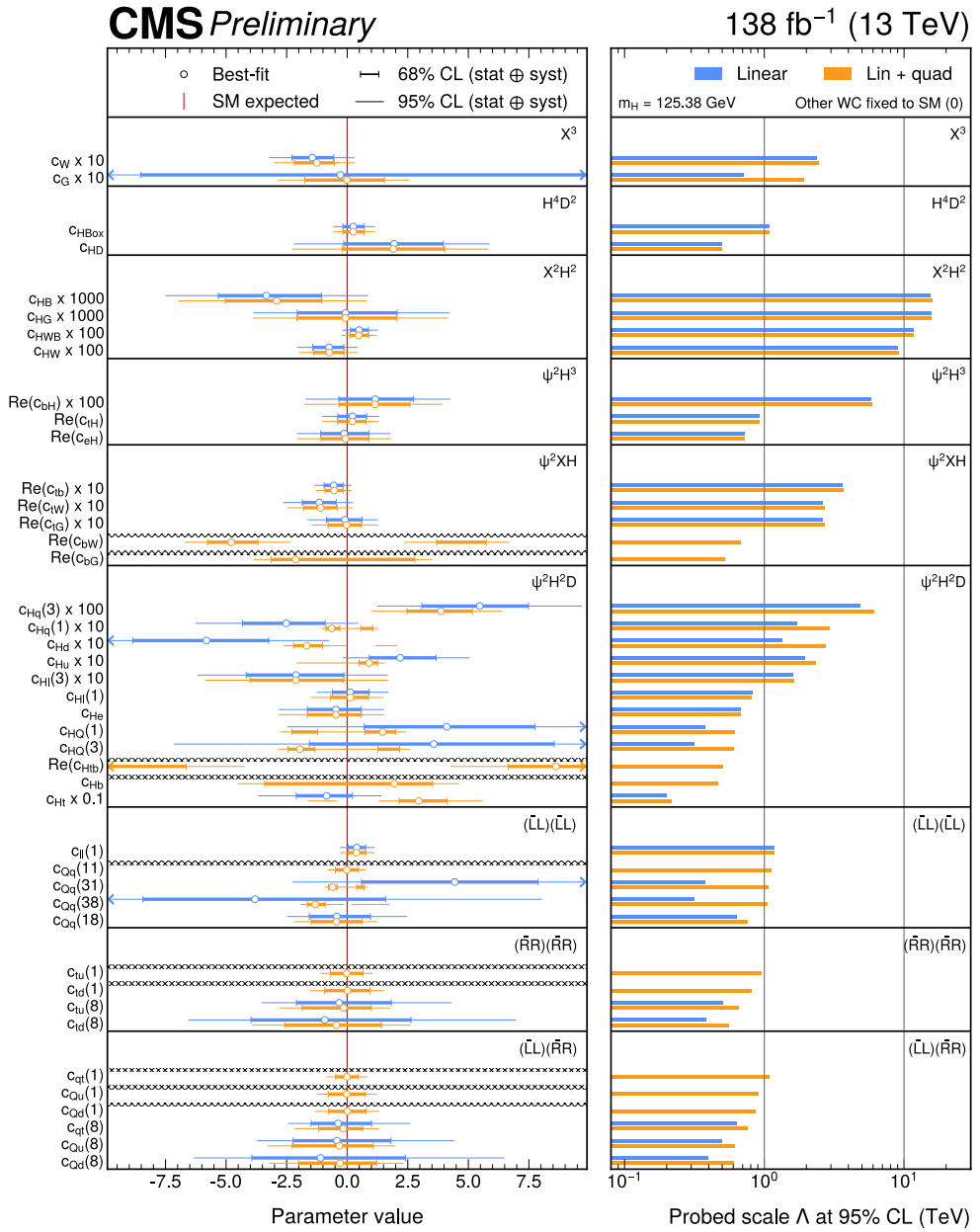
Legacy Run 2 STXS Combination



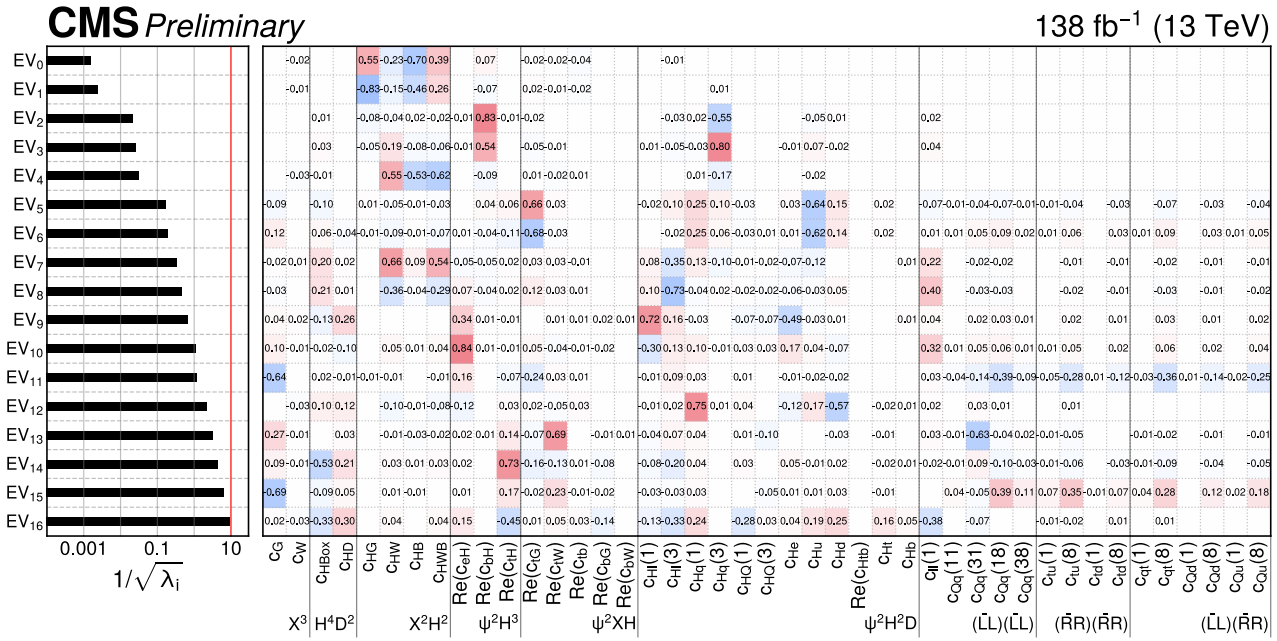
Legacy Run 2 STXS Combination

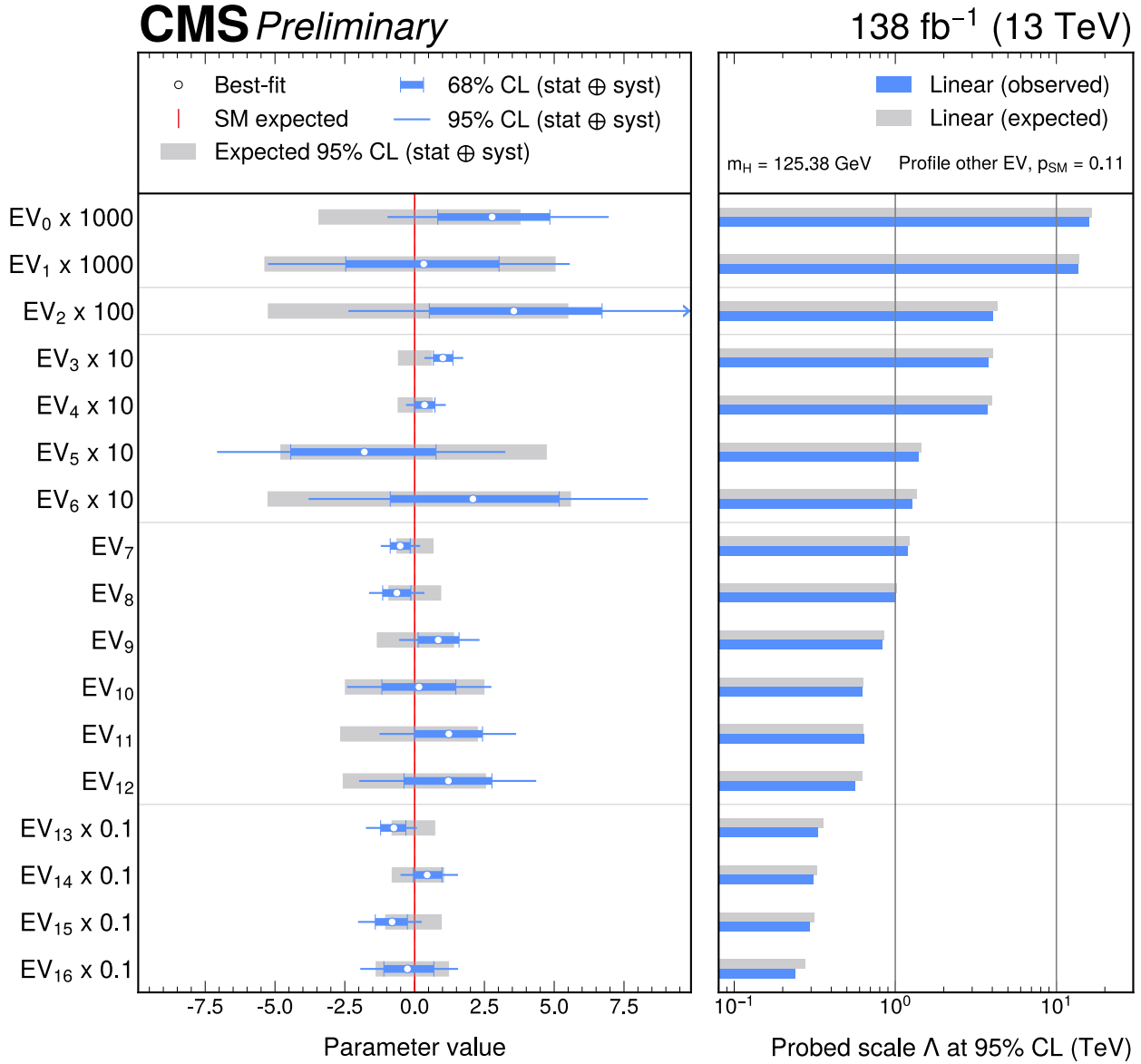


Legacy Run 2 STXS Combination

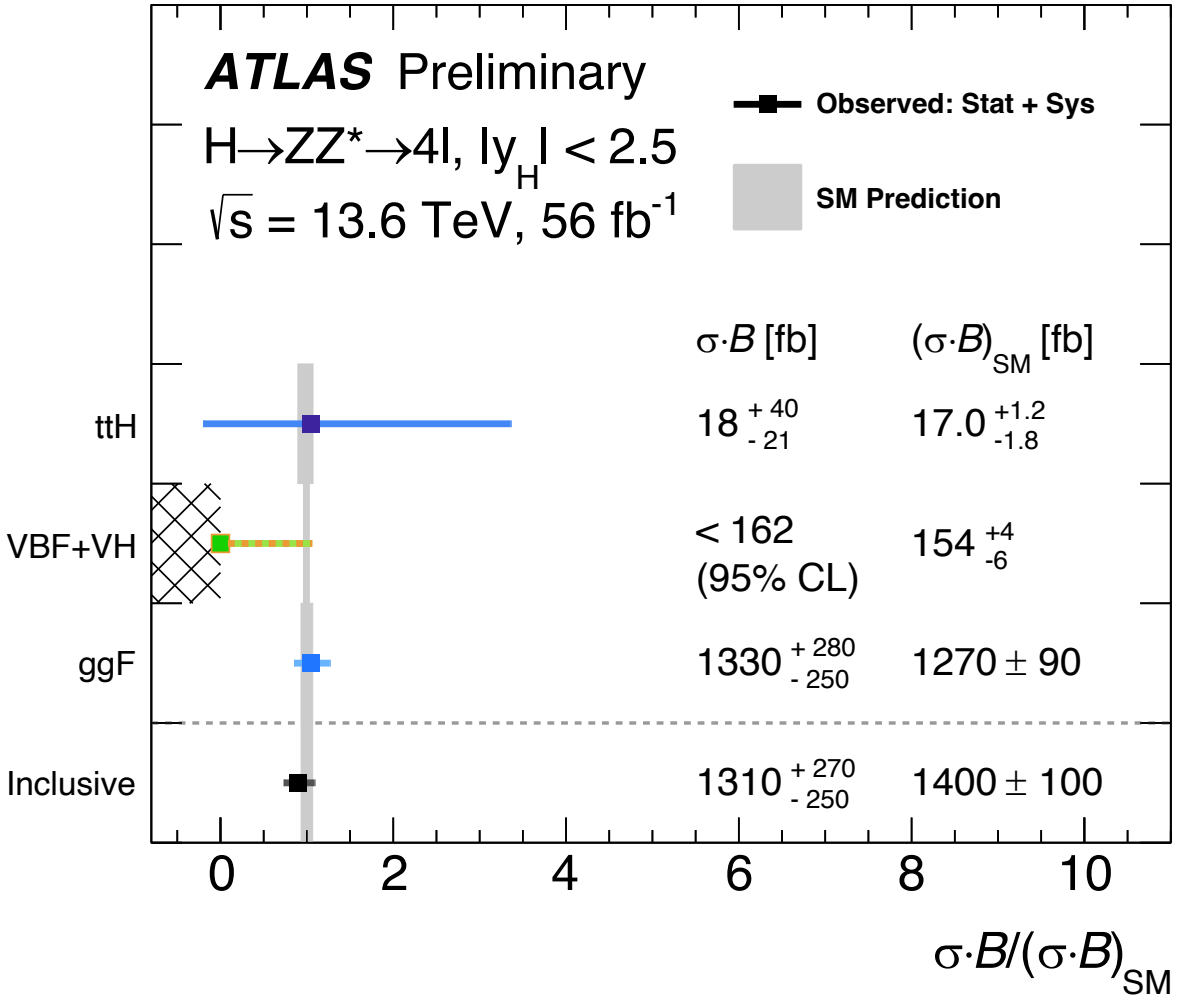


Legacy Run 2 STXS Combination





H→ZZ*→4l


ATLAS Preliminary
H→ZZ*→4l, |y_H| < 2.5
√s = 13.6 TeV, 56 fb-1
Observed: Stat + Sys
SM Prediction
σ·B [fb]
(σ·B)SM [fb]
ttH
18 +40 -21
17.0 +1.2 -1.8
VBF+VH
< 162 (95% CL)
154 +4 -6
ggF
1330 +280 -250
1270 ± 90
Inclusive
1310 +270 -250
1400 ± 100
0
2
4
6
8
10
σ·B/(σ·B)SM