Differential Higgs Cross Section Measurement

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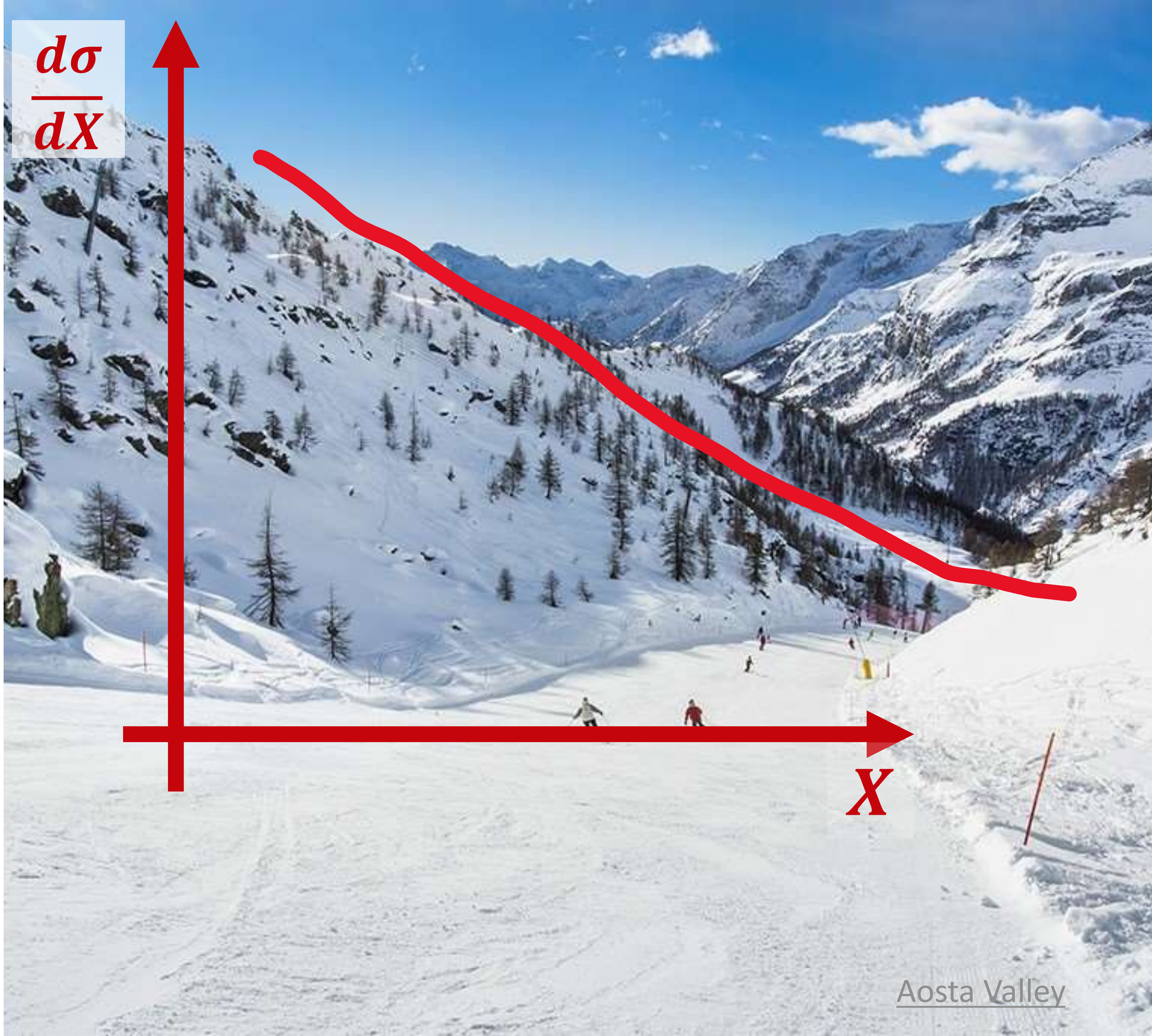
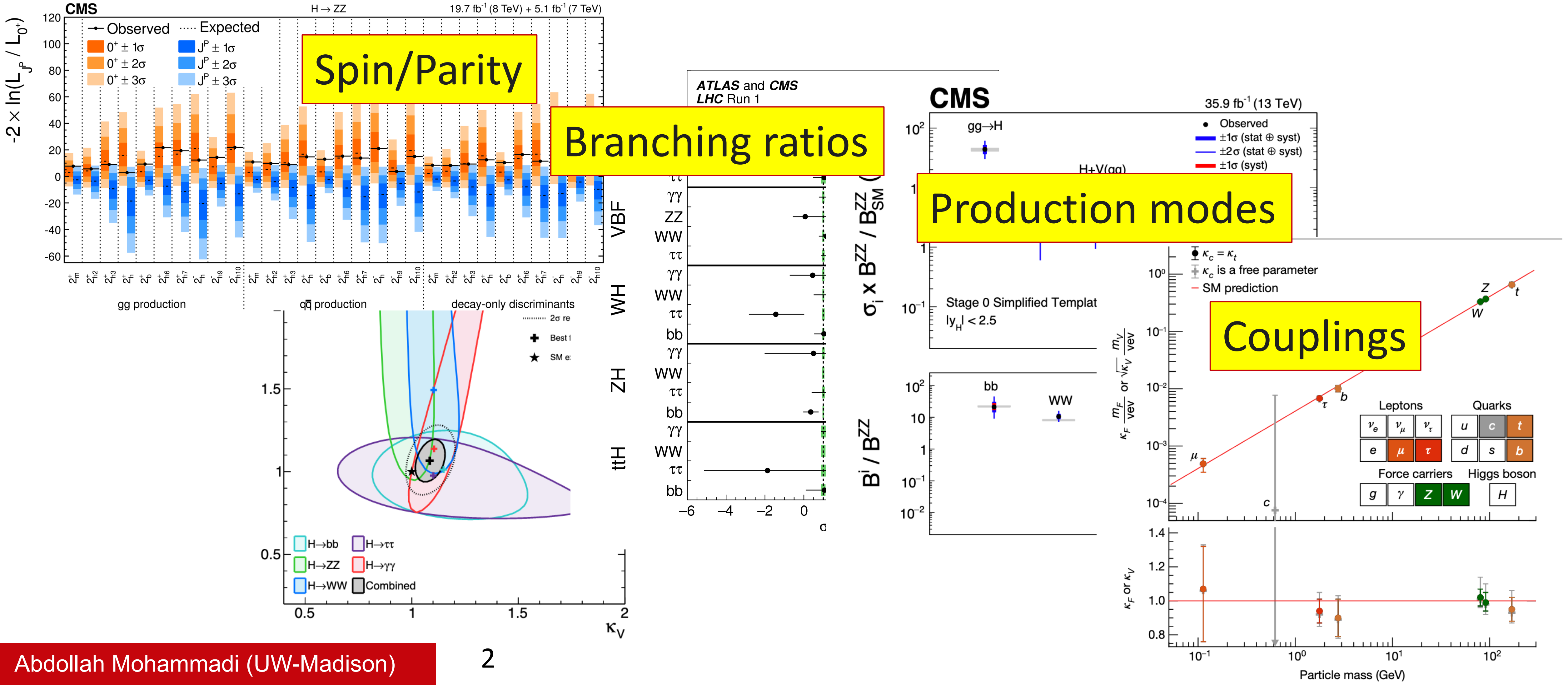
On behalf of the ATLAS & CMS Collaborations

Rencontres de Moriond

March 25th, 2024

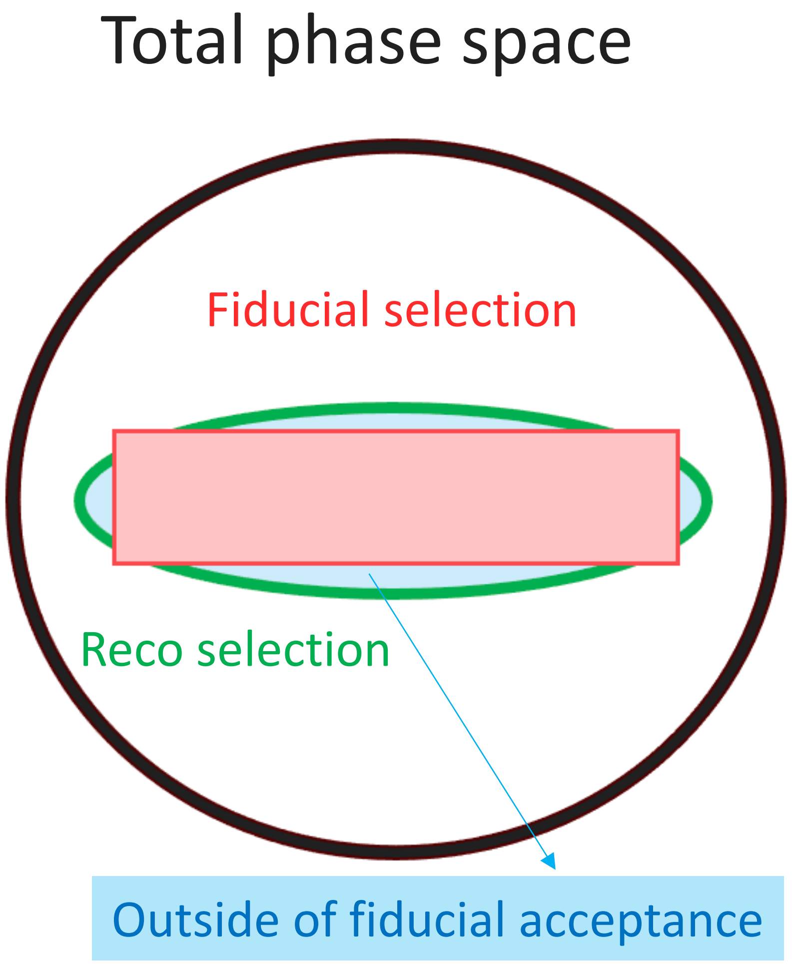


First question after observation of 125-GeV boson: Is it "the" SM Higgs boson?



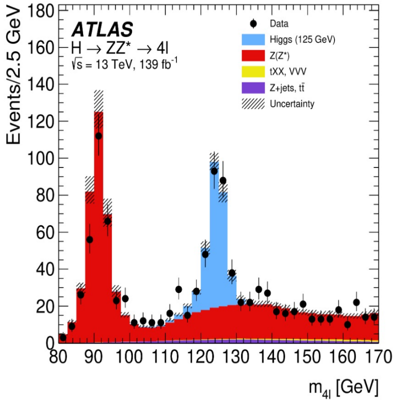
Fiducial Differential Cross Section

- Fiducial differential measurements represent the most ***model-independent*** way to measure H boson production cross section
  - When coupling is varied, the diff. XS distribution, i.e. p_T^H, distorts
  - It could be sensitive to the existence of the BSM effects
- Fiducial : region of interest is aligned with detector configuration; thus minimizes the assumption for extrapolation to full phase-space
  - Reco-level selection and truth-level selection do not align perfectly → Misalignment effects have to be taken into account in analysis.
- Differential : Measurement is presented in as a function of variables in various bins
  - Offers more information than inclusive XS measurement



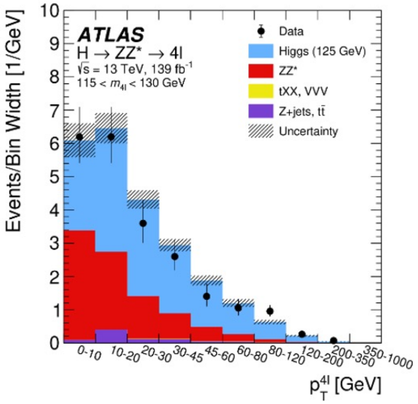
Analysis Flow

Reconstructing an Observable



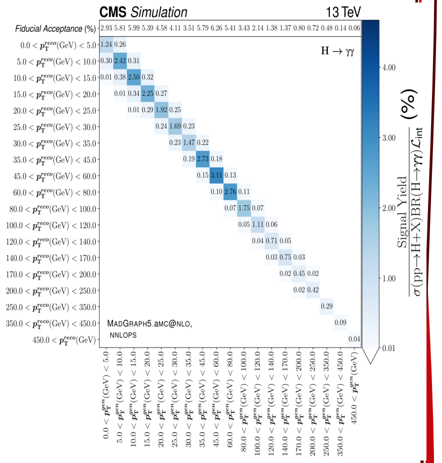
m_{ZZ}, $m_{\gamma\gamma}$, m_T, NN, counting, …

Variable definition



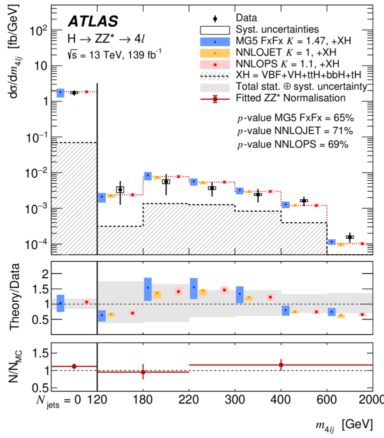
1D, 2D, Number of bins, S/B, …

Unfolding method



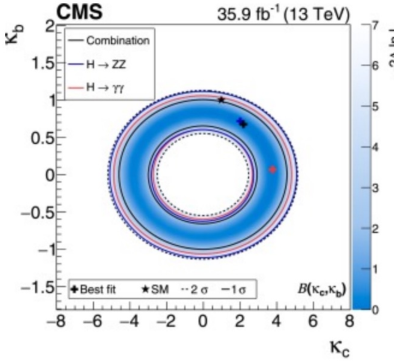
Bin-by-bin migration, Matrix inversion,fit, …

Unfolded results



Diff XS v.s. variable, …

Interpretation



In SMEFT, κ-framework, …

Current results

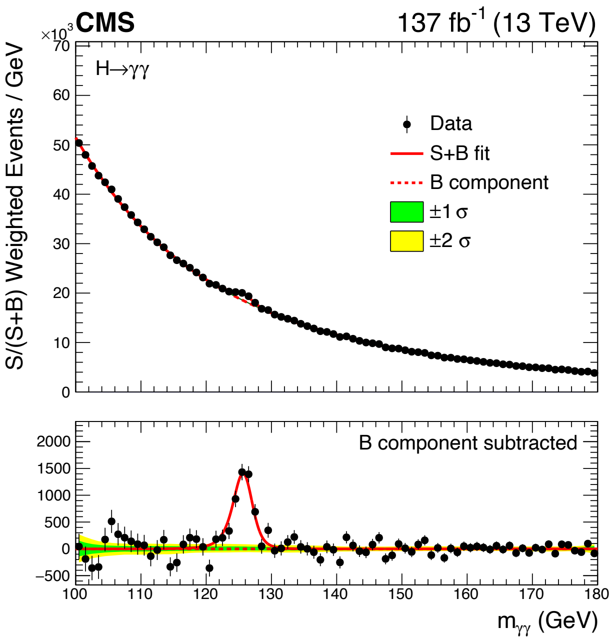
- ❑ Most results are based on the full Run II analysis
- ❑ Combination of the results are ongoing

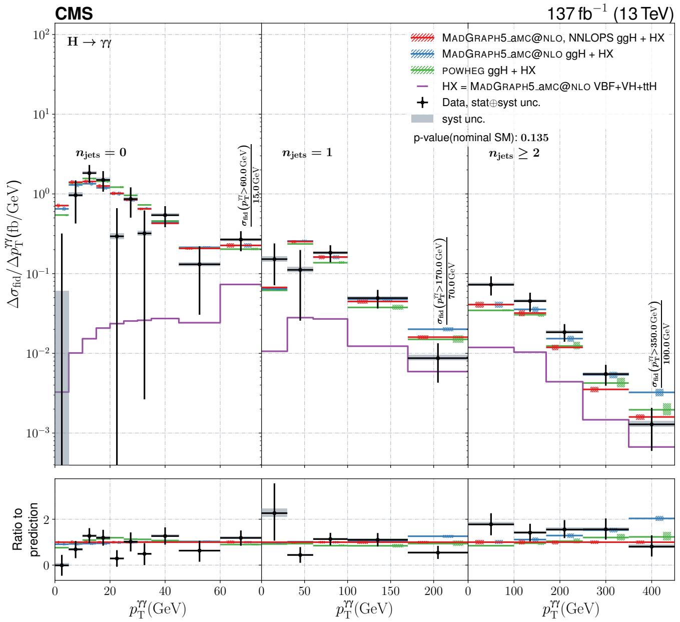
New
Since Moriond23

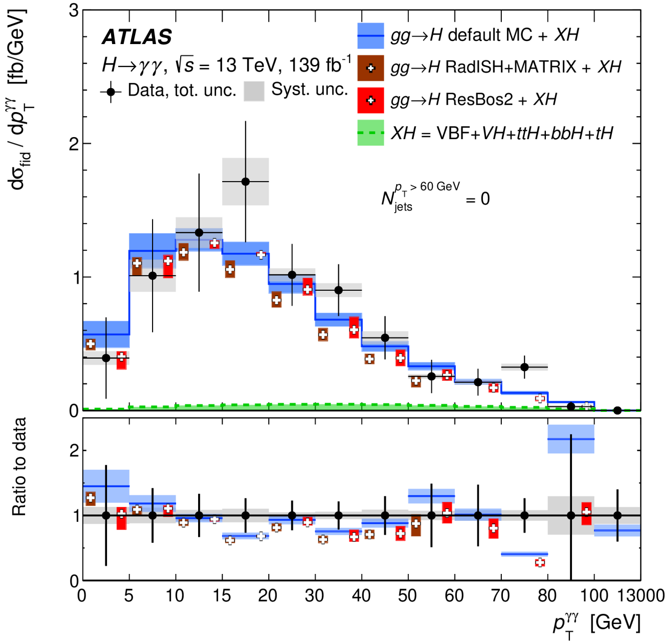
	ATLAS	CMS
$H \rightarrow \gamma\gamma$	JHEP08(2022)027	JHEP 07 (2023) 091
$H \rightarrow ZZ$	Eur. Phys. J. C 80 (2020) 942	JHEP 08 (2023) 040
$H \rightarrow WW$ VBF $H \rightarrow WW$	Eur. Phys. J. C 83 (2023) 774 Phys. Rev. D 108 (2023) 072003	JHEP 03 (2021) 003
$H \rightarrow bb$	Phys. Rev. D 105 (2022) 092003 2312.07605	HIG-21-020
$H \rightarrow \tau\tau$ Boosted $H \rightarrow \tau\tau$	- -	Phys. Rev. Lett. 128 (2022) 081805 HIG-21-017
Combination & Interpretation	JHEP 05 (2023) 028 2402.05742	PLB 792 (2019) 369 (2016) Full Run II in process

H→γγ

[JHEP 07 (2023) 091] [JHEP08(2022)027]





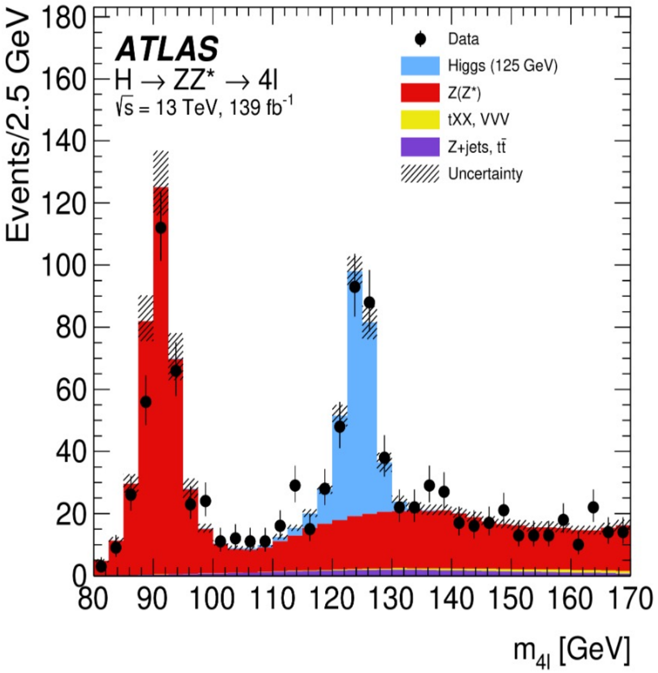


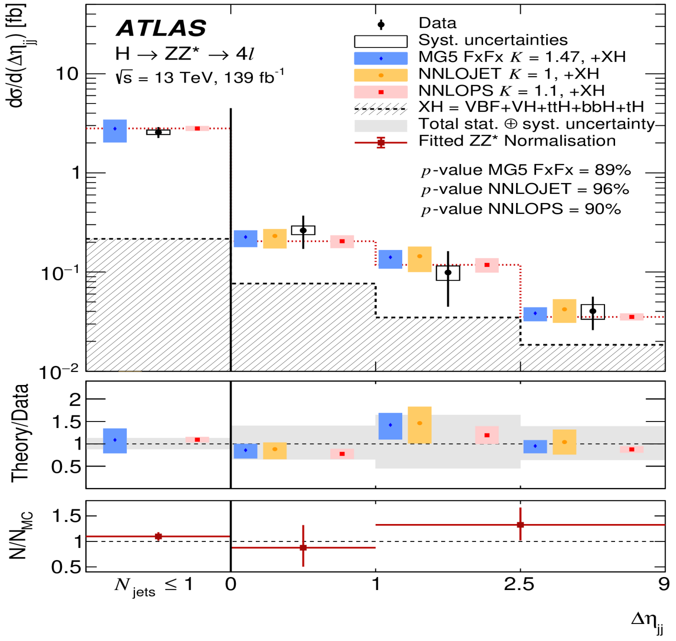
- ❑ Excellent mass resolution; narrow peak over a smoothly falling bkg. Large yields allow double differential
- ❑ Results are presented as a function di-photon system, (sub) leading jet, di-jet system, event level observables, …
- ❑ Parametrization v.s. Hp_T probes the perturbative QCD modelling of ggH production mode
  - ❑ low p_T region is sensitive to the Yukawa coupling of the b and charm quark and QCD resummation
  - ❑ High p_T region is sensitive to the top quark coupling and BSM scenarios
- ❑ XS v.s. n jet is sensitive to the production mode composition and gluon emission

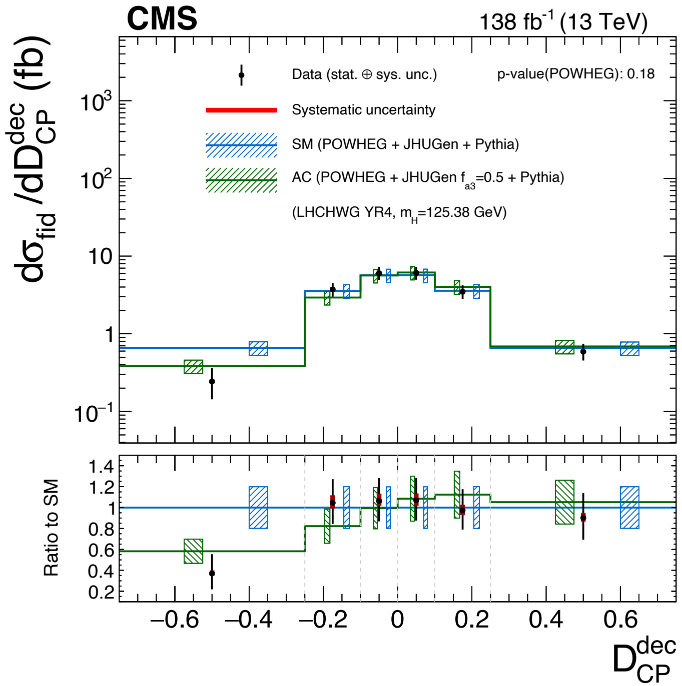
H→ZZ

Eur. Phys. J. C 80 (2020) 942

JHEP 08 (2023) 040







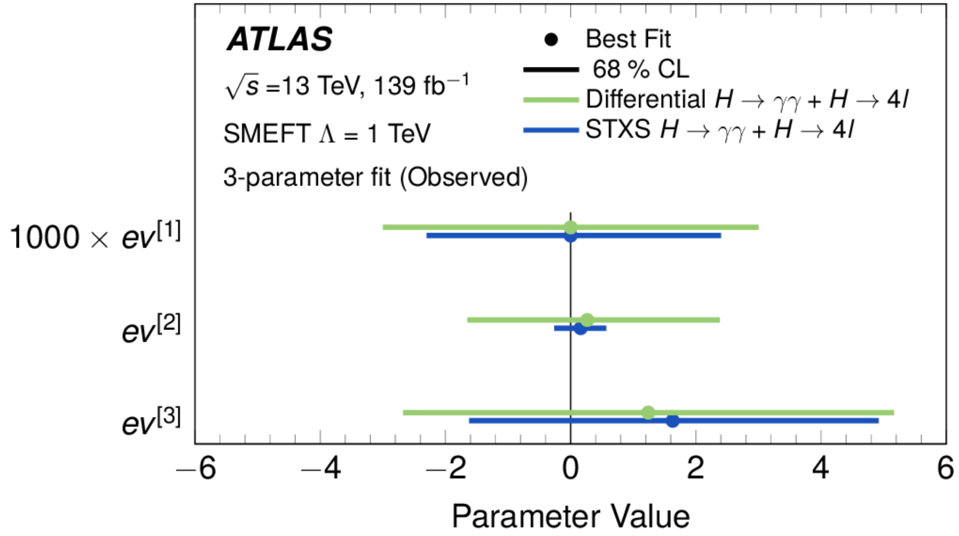
- ❑ The cleanest channel with excellent mass resolution and large S/B
- ❑ Results are presented as a function of production and decay variables, jet related variables, Matrix Element (MELA) variables, …
  - ❑ $\Delta\eta_{jj}$ is sensitive to the VBF production mode
  - ❑ Diff XS v.s. MELA variables are sensitive to the spin and charge conjugation and parity properties of the Higgs
    - ❑ D_{CP}^{dec} is sensitive to CP-mixing. Build under two hypotheses: SM prediction & anomalous coupling prediction

Interpretation based on SMEFT

arXiv:2402.05742

$$\mathcal{L}_{\text{SMEFT}} = \mathcal{L}_{\text{SM}} + \sum_i^{N_{d=6}} \frac{c_i}{\Lambda^2} O_i^{(6)} + \sum_j^{N_{d=8}} \frac{b_j}{\Lambda^4} O_j^{(8)} + \ldots,$$

$$ev^{[1]} = 0.999 c_{HG} - 0.035 c_{tG} - 0.003 c_{tH},$$
$$ev^{[2]} = 0.035 c_{HG} + 0.978 c_{tG} + 0.205 c_{tH},$$
$$ev^{[3]} = -0.005 c_{HG} - 0.205 c_{tG} + 0.979 c_{tH}.$$

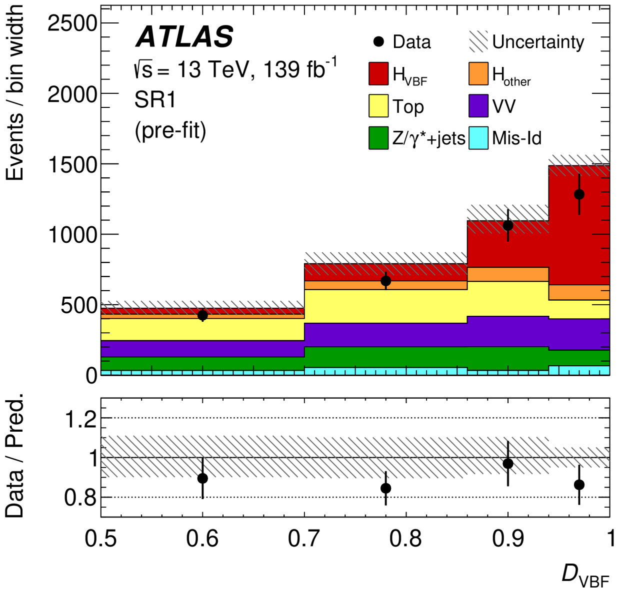


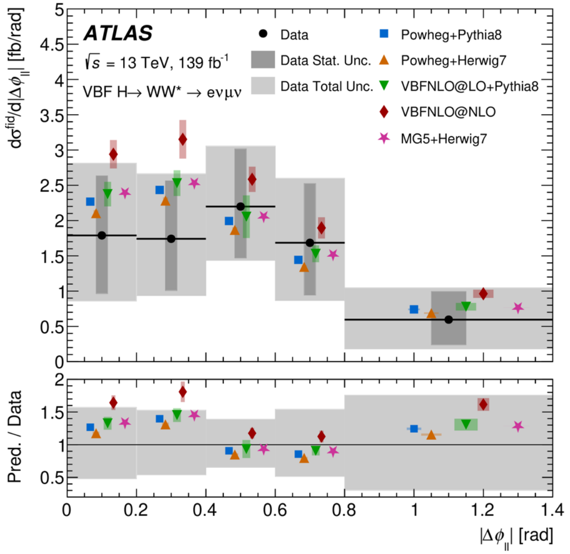
- Fiducial diff. XS distributions as p_T^H in $H \to ZZ/H \to \gamma\gamma$ used to constrain the Wilson coefficient of SMEFT operators
- The three relevant operators are:
  - O_{HG} : modifies the value and p_T-dependence of the ggF & $H \to \gamma\gamma$ partial decay width,
  - O_{tG} : introduces a $ttH\gamma$ vertex & leads to additional contributions to the amplitude for ggF or ttH Higgs boson production, as well as for $H \to \gamma\gamma$ decay
  - O_{tH} : modifies the ttH vertex & affects Higgs boson production through top-quark-loop mediated gg fusion and top-quark-loop amplitude
- Limit is set on 3 eigenvectors, ev^1, ev^2, and ev^3, that are a linear combination of the WCs.
- Less constraining power than the STXS which separates the production modes.

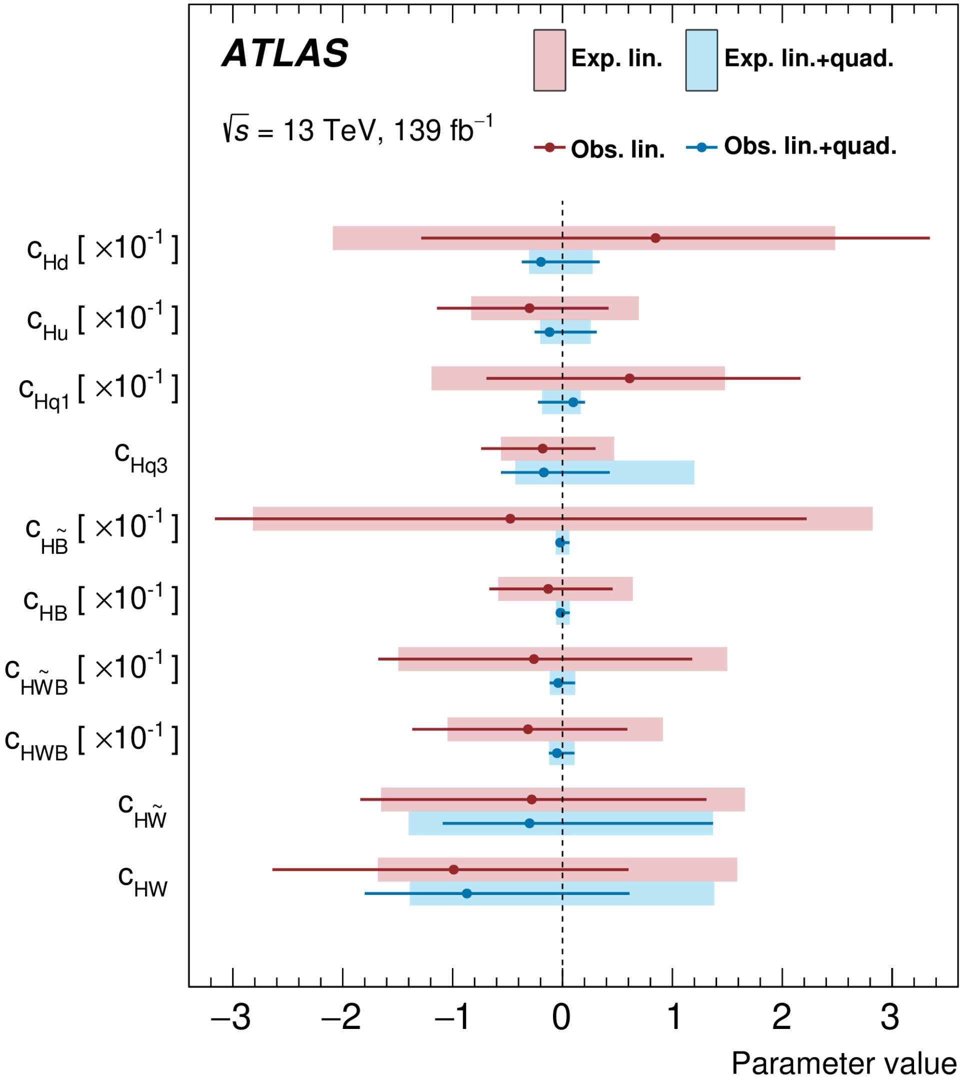
VBF H→WW

VBF $H \to WW^* \to e\nu\mu\nu$

[Phys. Rev. D 108 (2023) 072003](https://doi.org/10.1103/PhysRevD.108.072003)





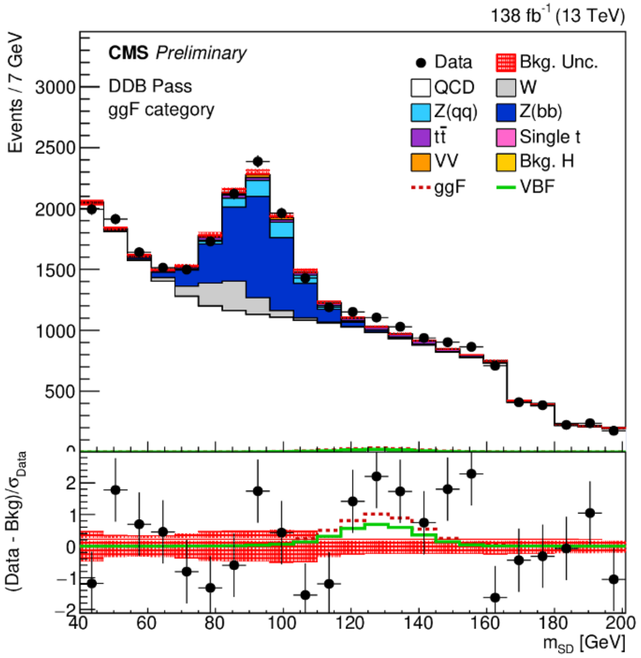


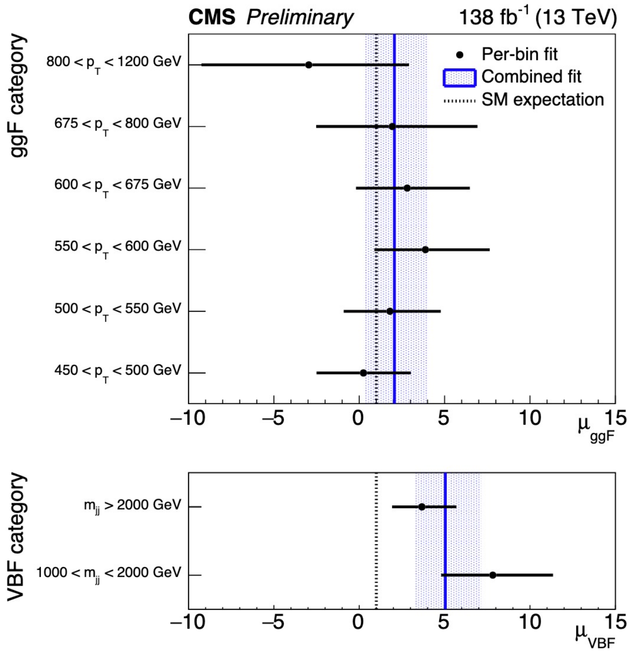
- ❑ Large branching ratio, but poor mass resolution due to the presence of neutrinos. BDT is used as the observable.
- ❑ The results are interpreted in SMEFT
- ❑ One Wilson coefficient left floating at a time in the fit to data while all others are set to zero

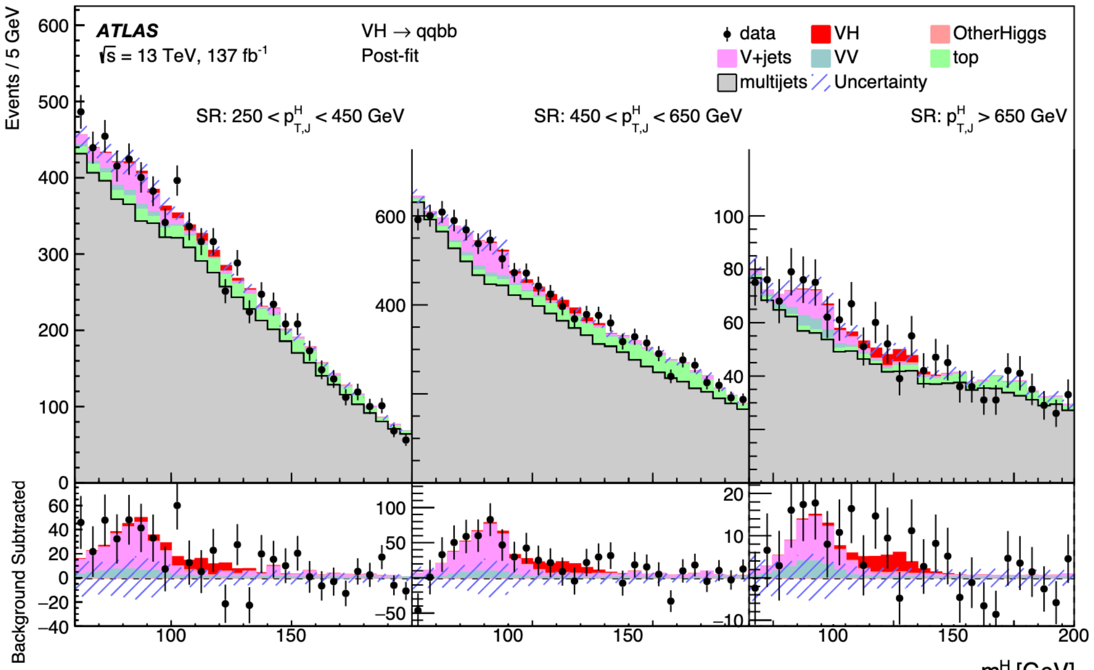
H→bb

HIG-21-020

arXiv:2312.07605







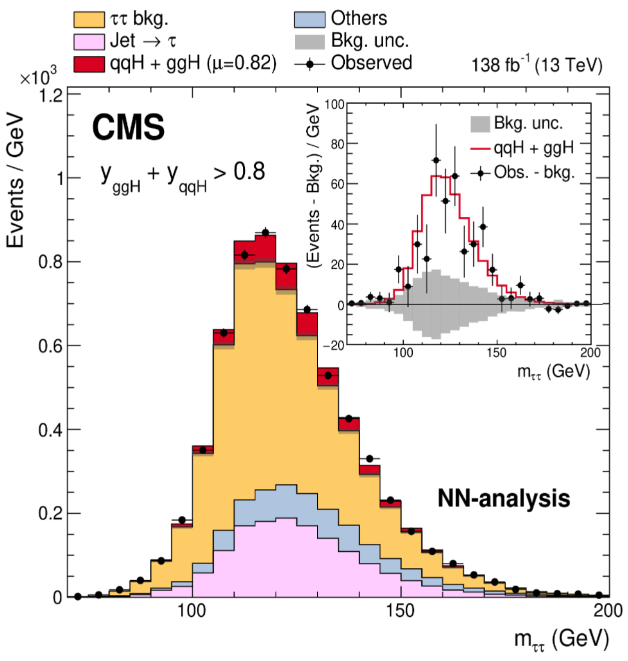
Kinematic region	Observed μ	Observed σ [fb]	Expected σ [fb]
$250 \le p_T^H < 450$ GeV, $\lvert y_H \rvert < 2$	$0.8^{+2.2}_{-1.9}$	47^{+125}_{-109}	57.0
$450 \le p_T^H < 650$ GeV, $\lvert y_H \rvert < 2$	$0.4^{+1.7}_{-1.5}$	2^{+10}_{-9}	5.9
$p_T^H \ge 650$ GeV, $\lvert y_H \rvert < 2$	$5.3^{+11.3}_{-3.2}$	6^{+13}_{-4} (<43)	1.2

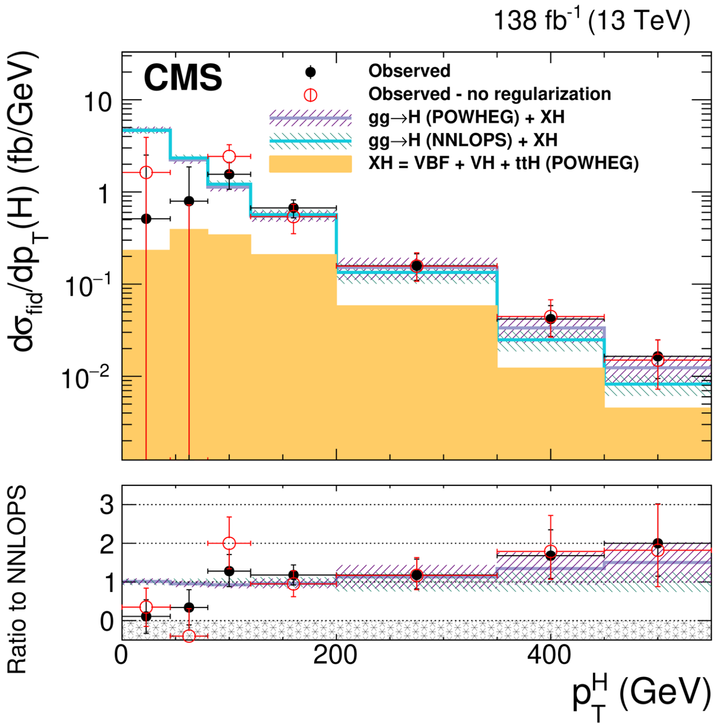
- Large BR, but small S/B
- Events are split into a signal and BG control regions based on the value of ***DeepDoubleB*** tagger.
- Two analyses primarily targeting ggH and VBF production modes
  - ggH analysis: QCD background is modelled from sideband region in data
  - VBF analysis: QCD background is estimated using transfer factor method from failing Hbb tagger to passing Hbb tagger regions

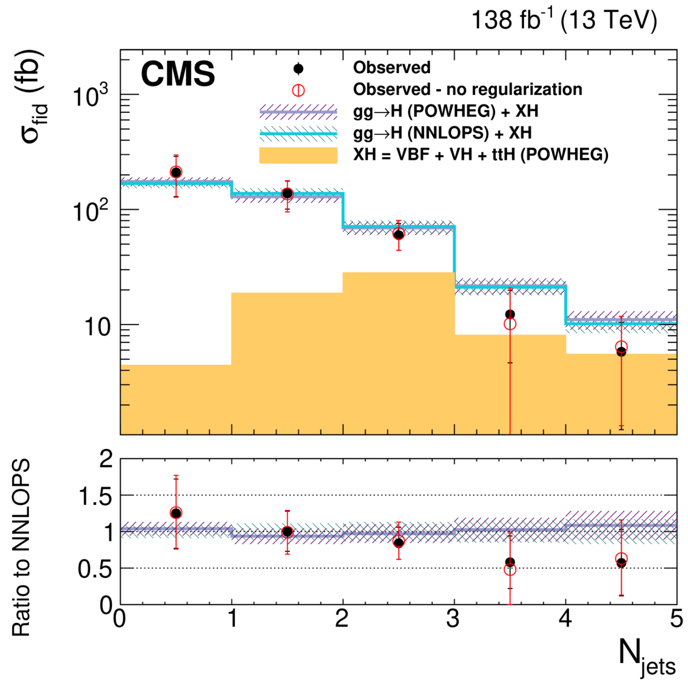
H→ ττ

Phys. Rev. Lett. 128 (2022) 081805

- A channel with large branching fraction, but poor ττ mass resolution
- A simplified likelihood algorithm employed to reconstruct the invariant mass
- NN developed to better separate signal from irreducible Z+jet (estimated from embedding sample) and fake backgrounds (estimated from data)
- The low measured cross sections (< 80 GeV) are attributed to statistical fluctuations.



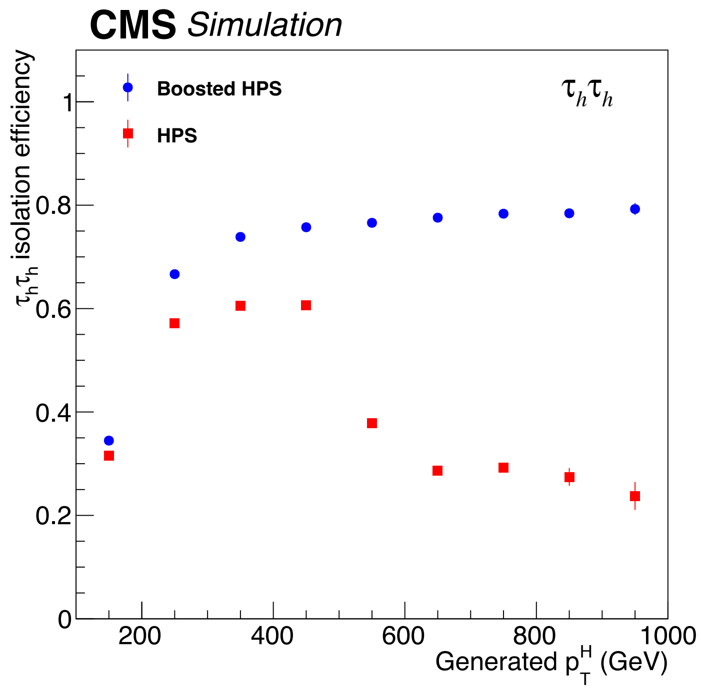


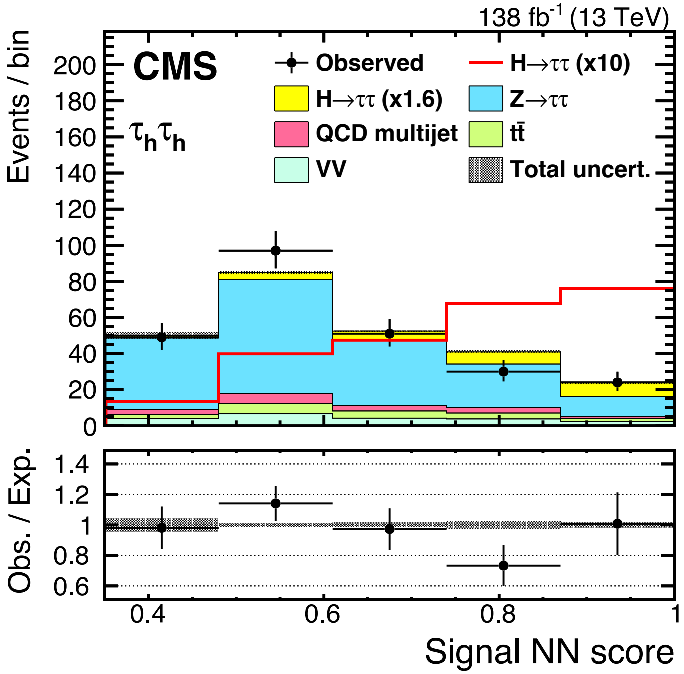


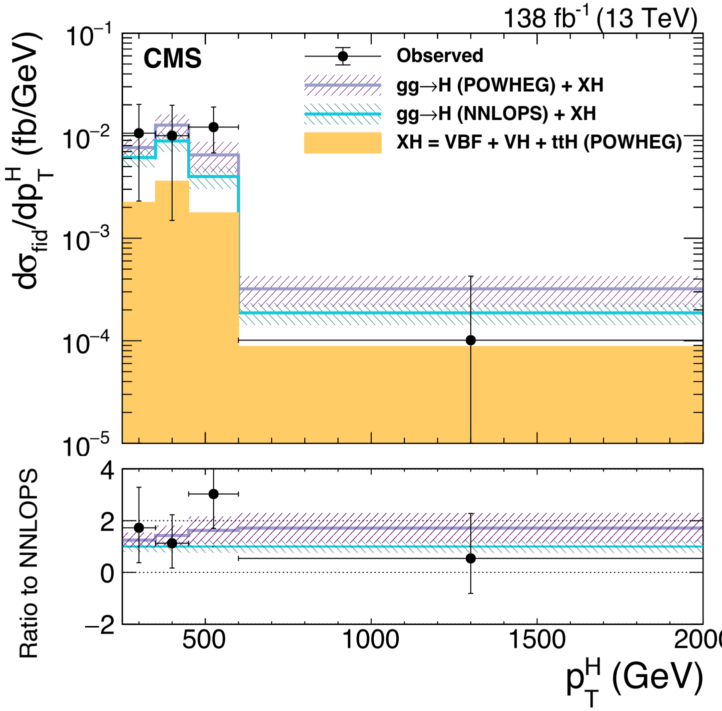
Boosted H→ ττ

[HIG-21-017](HIG-21-017)

arXiv:2403.XXXXX (will appear soon!)





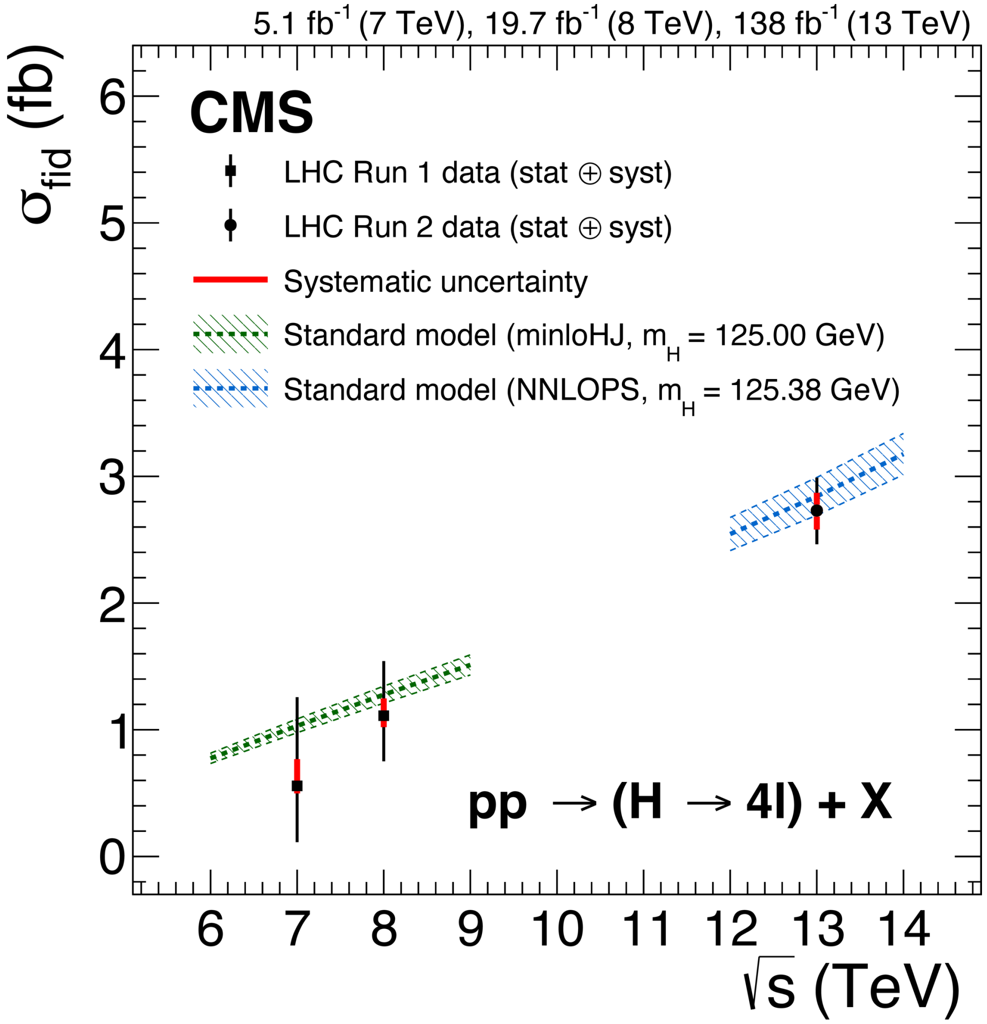


- ❑ Two tau leptons are required to be spatially close: $\Delta R < 0.8$.
- ❑ A dedicated algorithm is developed to reconstruct tau lepton in boosted topologies.
- ❑ A multiclass NN method is deployed to separate signal from major backgrounds in each final state
- ❑ The analysis is mostly sensitive in the tail of the Higgs/leading jet p_T distributions
  - ❑ Sensitive to the coupling to BSM!

Summary

JHEP 08 (2023) 040

- ❑Data collected during LHC Run II makes it feasible to conduct an extensive set of measurements of Higgs fiducial differential cross section.
- ❑So far, all measurements, within their uncertainties, are consistent with the expectations for the Standard Model. Convincing us that the 125-GeV boson looks very like “the” SM Higgs boson!
- ❑Data from Run III with slightly higher energy is ready to be analyzed. So more results, most likely with more granular binning, and more intrepretations will show up soon.

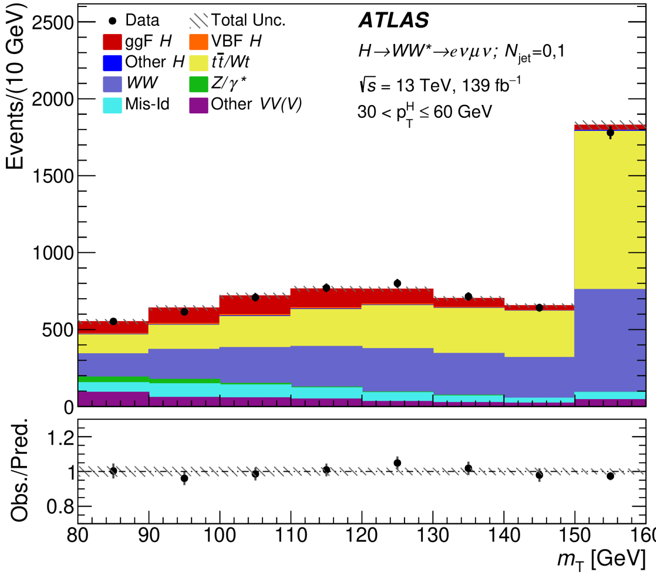


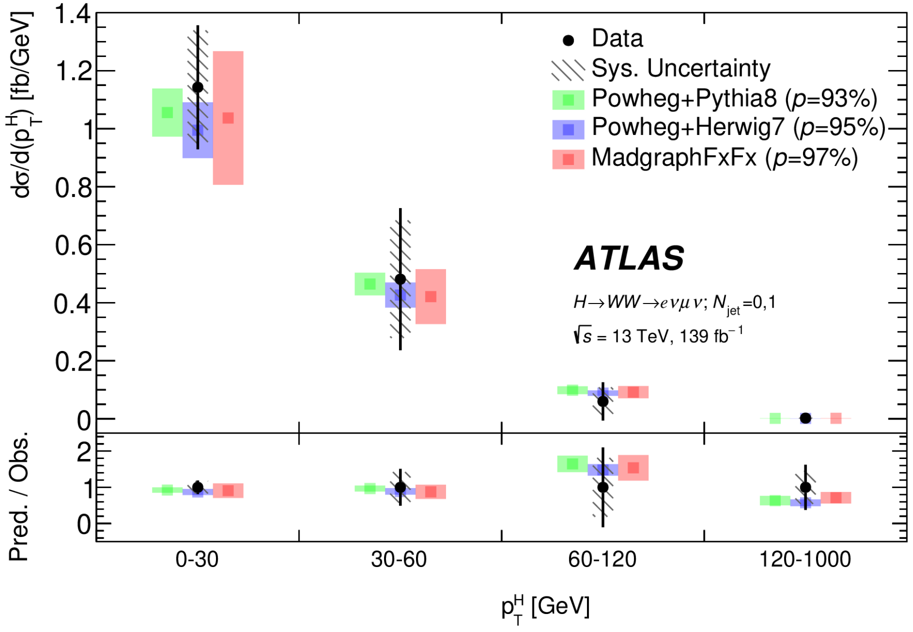
Back up

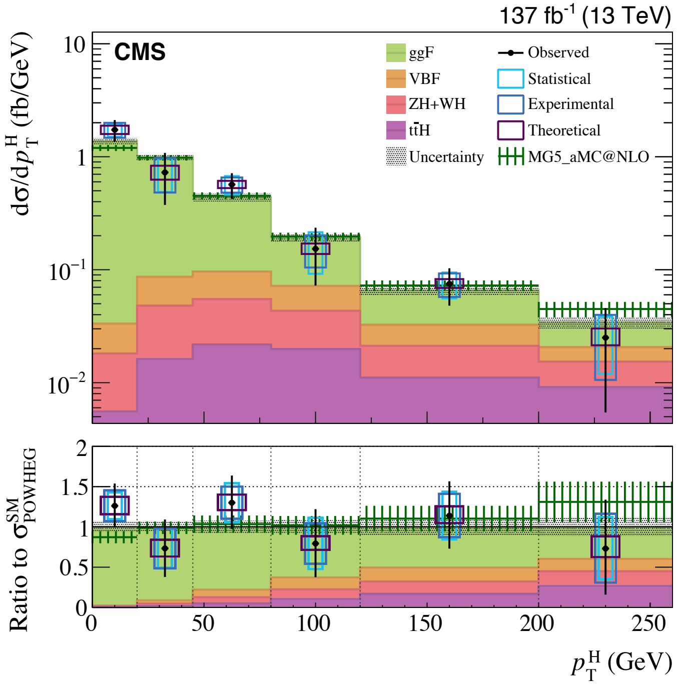
H→WW

[Eur. Phys. J. C 83 (2023) 774]

[JHEP 03 (2021) 003]





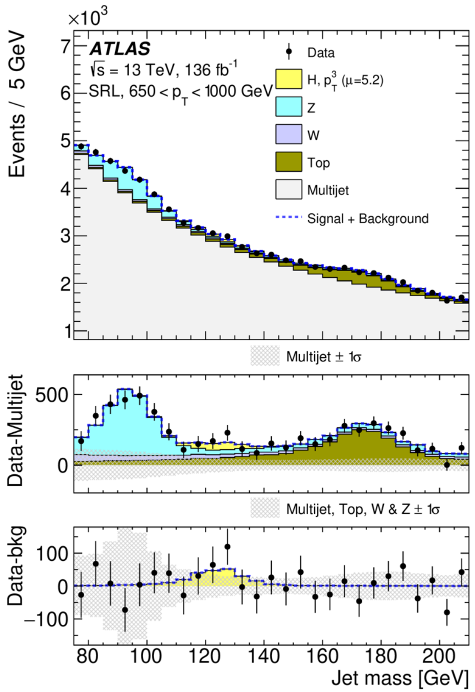


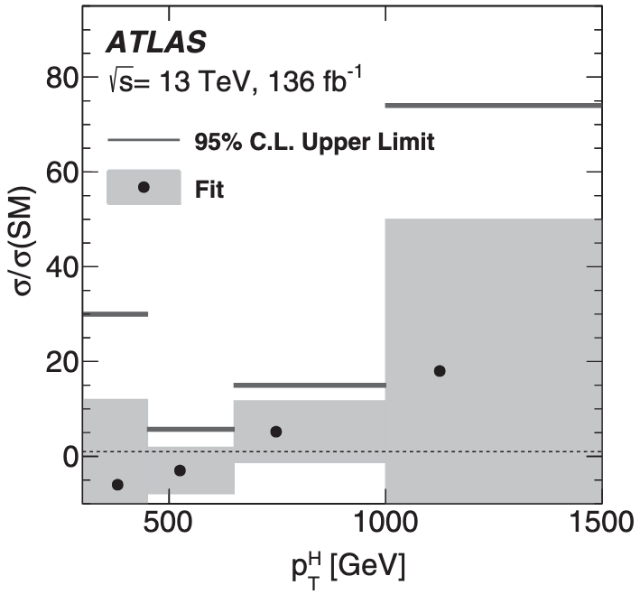
- ❑ Large branching ratio, but poor mass resolution due to the presence of neutrinos
- ❑ Cross section extracted by fitting m_{ll} and m_T distribution in each bin, with control regions for background estimation
- ❑ Sensitivity improved by using BDTs to separate the processes in different regions
- ❑ ggH contribution in diff XS production decreases at high Higgs boson p_T.

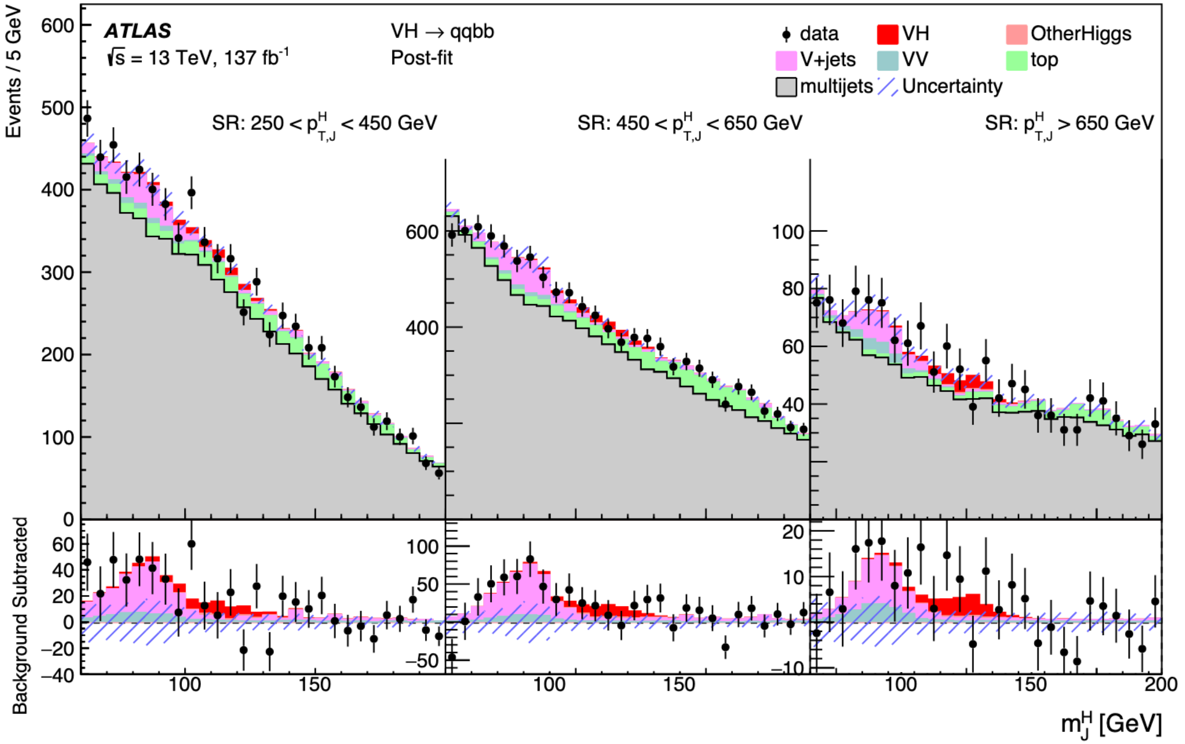
H→bb

[Phys. Rev. D 105 (2022) 092003]

[arXiv:2312.07605]







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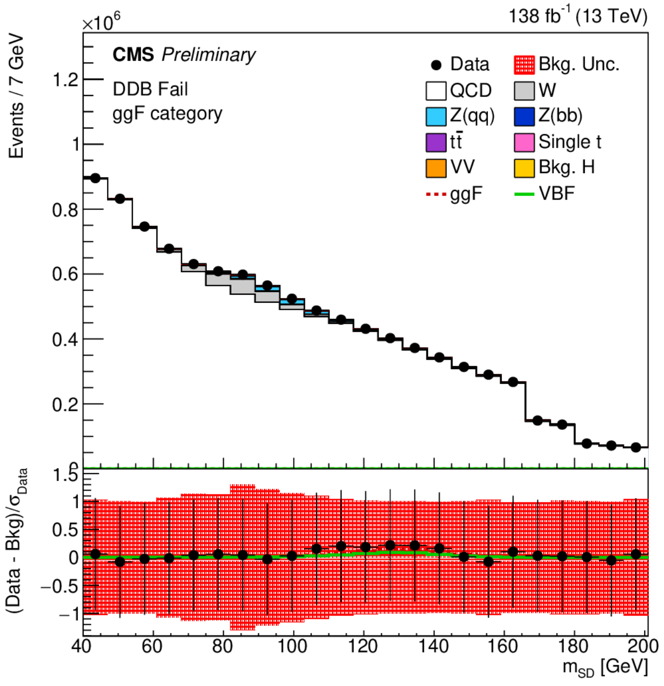
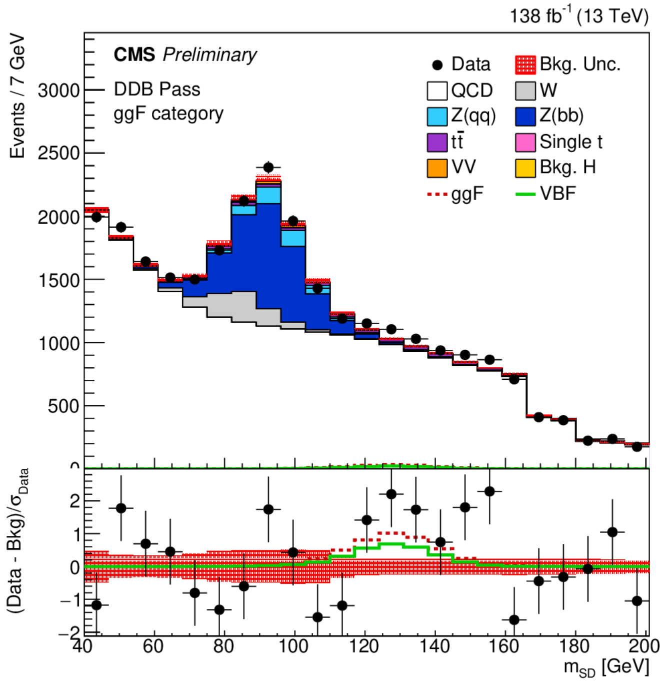
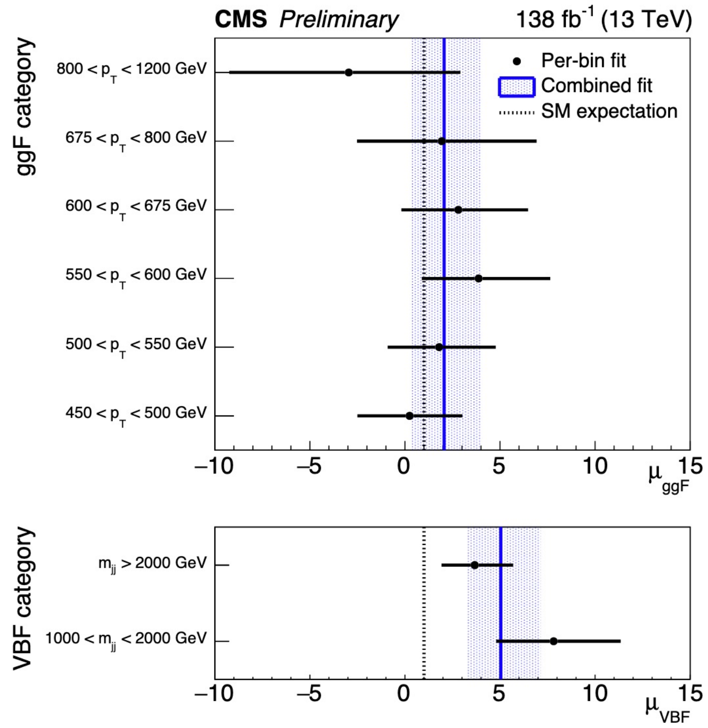
H→bb

[HIG-21-020](HIG-21-020)







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- ❑ Events are split into a signal and BG control regions based on the value of ***DeepDoubleB*** tagger.
- ❑ Deployed boosted Higgs and VH production modes