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Higgs differential cross section and STXS measurements at CMS

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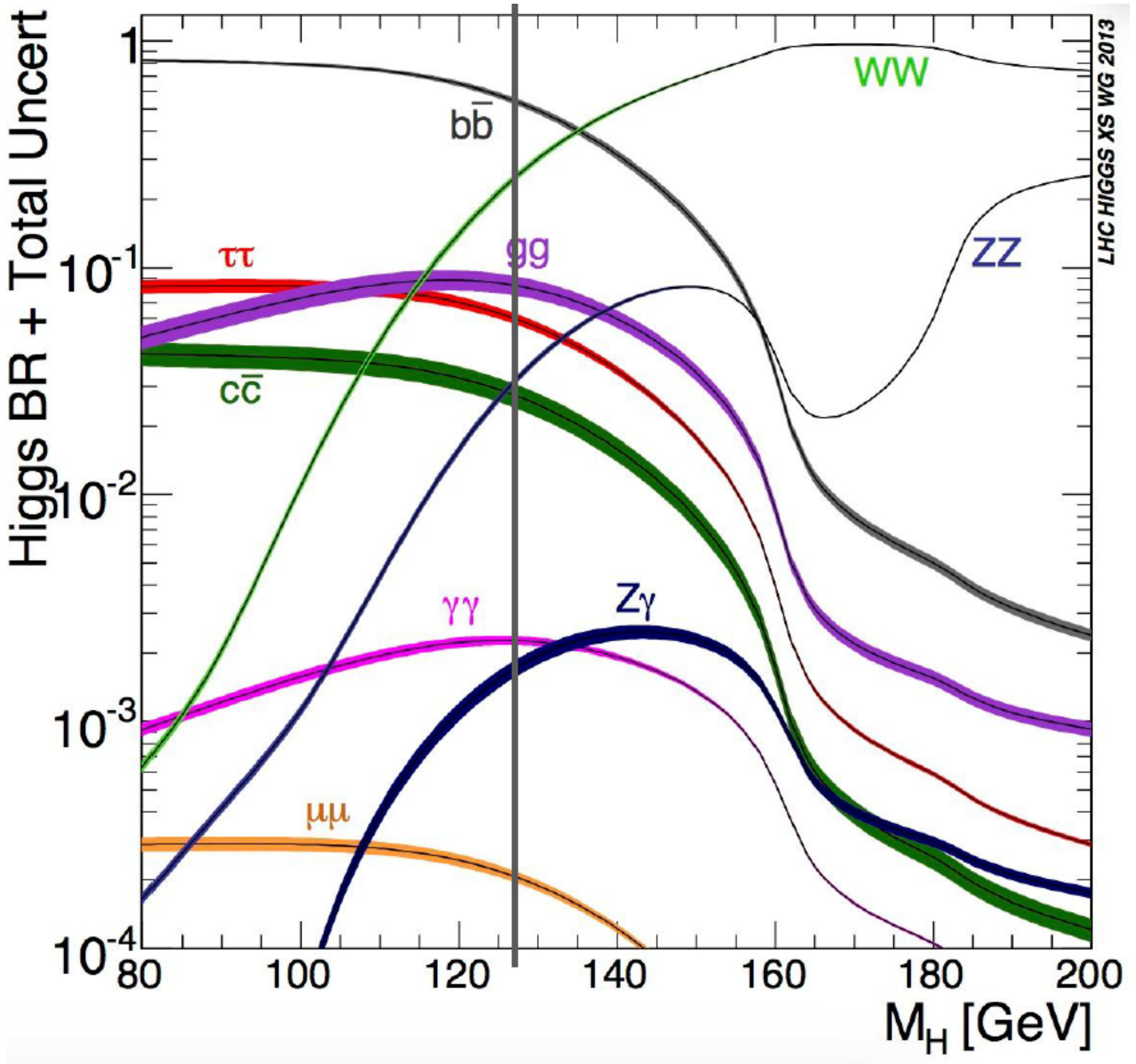
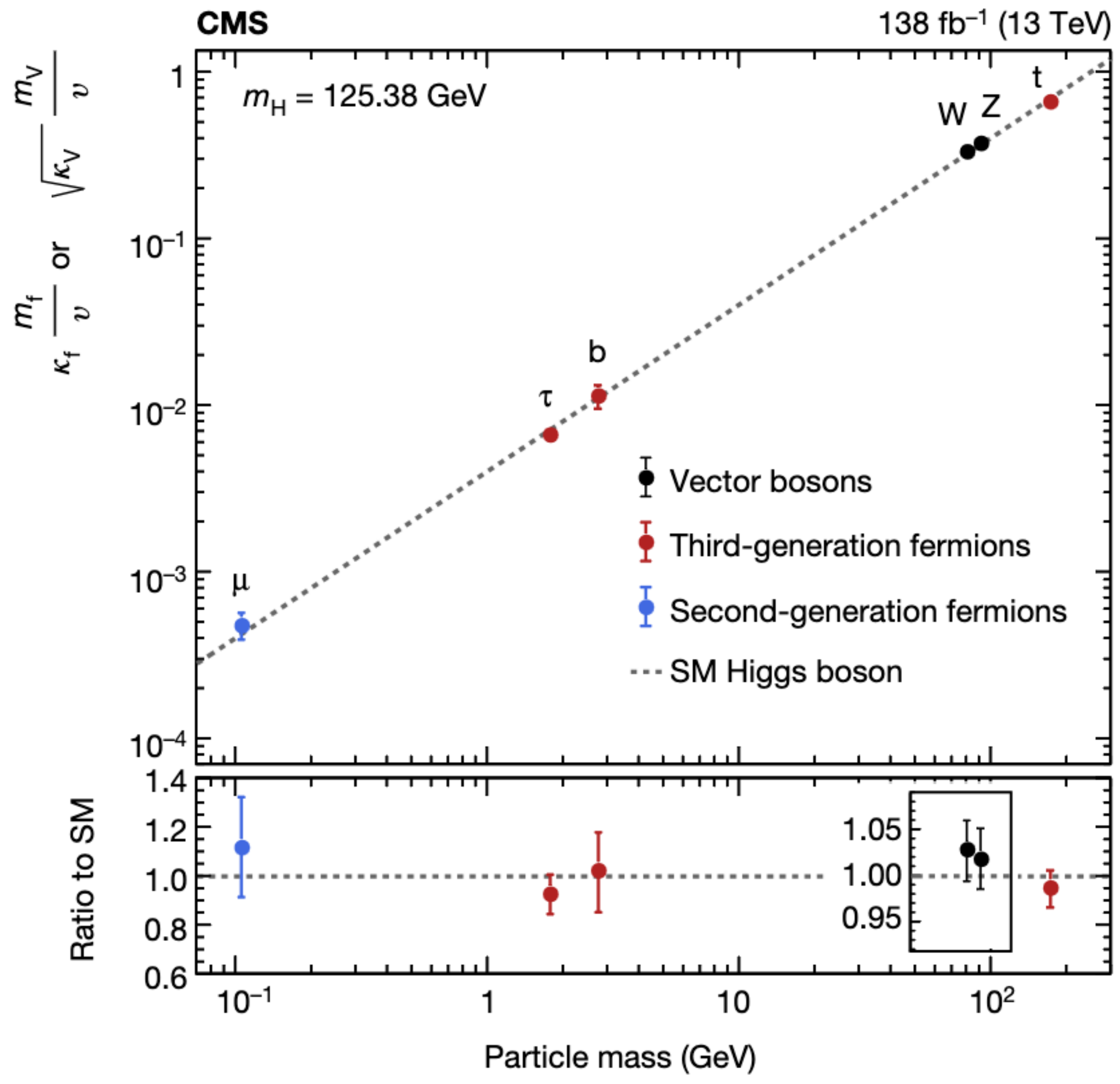
On behalf of the **CMS collaboration**

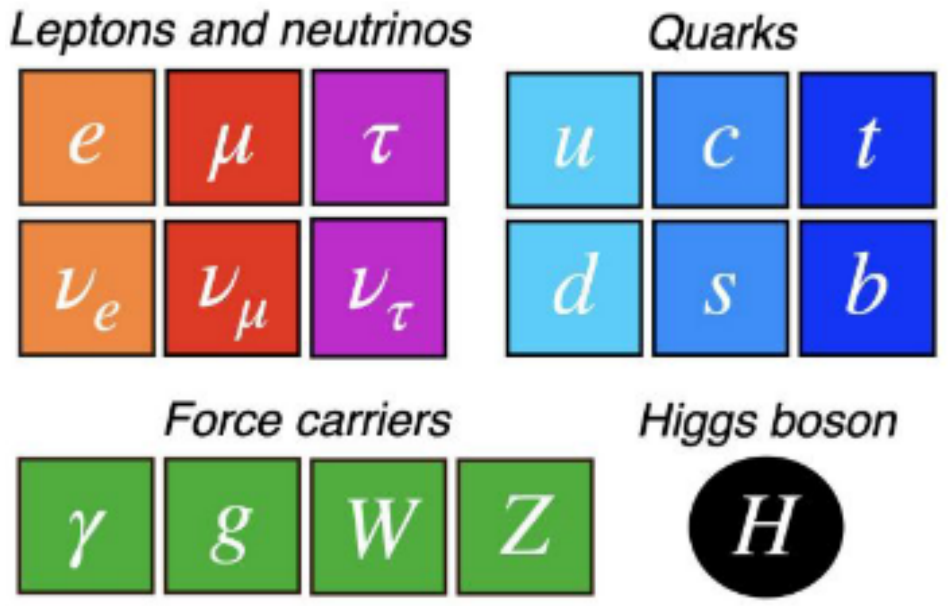
Overview

- ✳ Higgs boson discovered in 2012 at CERN
- ✳ Its properties have been measured with evolving precision since the discovery
  - Couplings, cross-section and etc.
- ✳ Several decay modes studied so far.



https://doi.org/10.1038/s41586-022-04892-x





Recent results from CMS on the topic

★ = *Not covered in talk*

Decay Channel		CMS data	Results	URL(s)	
Bosonic	$H \to \gamma\gamma$	Early Run3 (2022)	Inclusive, diffferential (1D)	CMS-PAS-HIG-23-014	
	$H \to ZZ$	Early Run3 (2022)	Inclusive, diffferential (1D)	CMS-PAS-HIG-24-013	
	$H \to WW$	Full Run2	STXS	Eur. Phys. J. C 83 (2023) 667	★
Fermionic	$H \to bb$	Full Run2	STXS	CMS-PAS-HIG-21-020 CMS-PAS-HIG-19-011 10.1007/JHEP01(2024)173 10.1103/PhysRevD.109.092011 10.1140/epjc/s10052-024-13021-z	★ (10.1007/JHEP01(2024)173) ★ (10.1140/epjc/s10052-024-13021-z)
	$H \to \tau\tau$	Full Run2	Inclusive, differential (1D), STXS	10.1140/epjc/s10052-023-11452-8 10.1103/PhysRevLett.128.081805 10.1016/j.physletb.2024.138964	
Combination	$H \to \gamma\gamma$, $H \to ZZ$, $H \to WW$, $H \to \tau\tau$, $H \to \tau\tau$ $(boosted)$	Full Run2	Differential, Interpretations	CMS-PAS-HIG-23-013	

$H \to \gamma\gamma$ measurement (early Run3 CMS data)

CMS-PAS-HIG-23-014

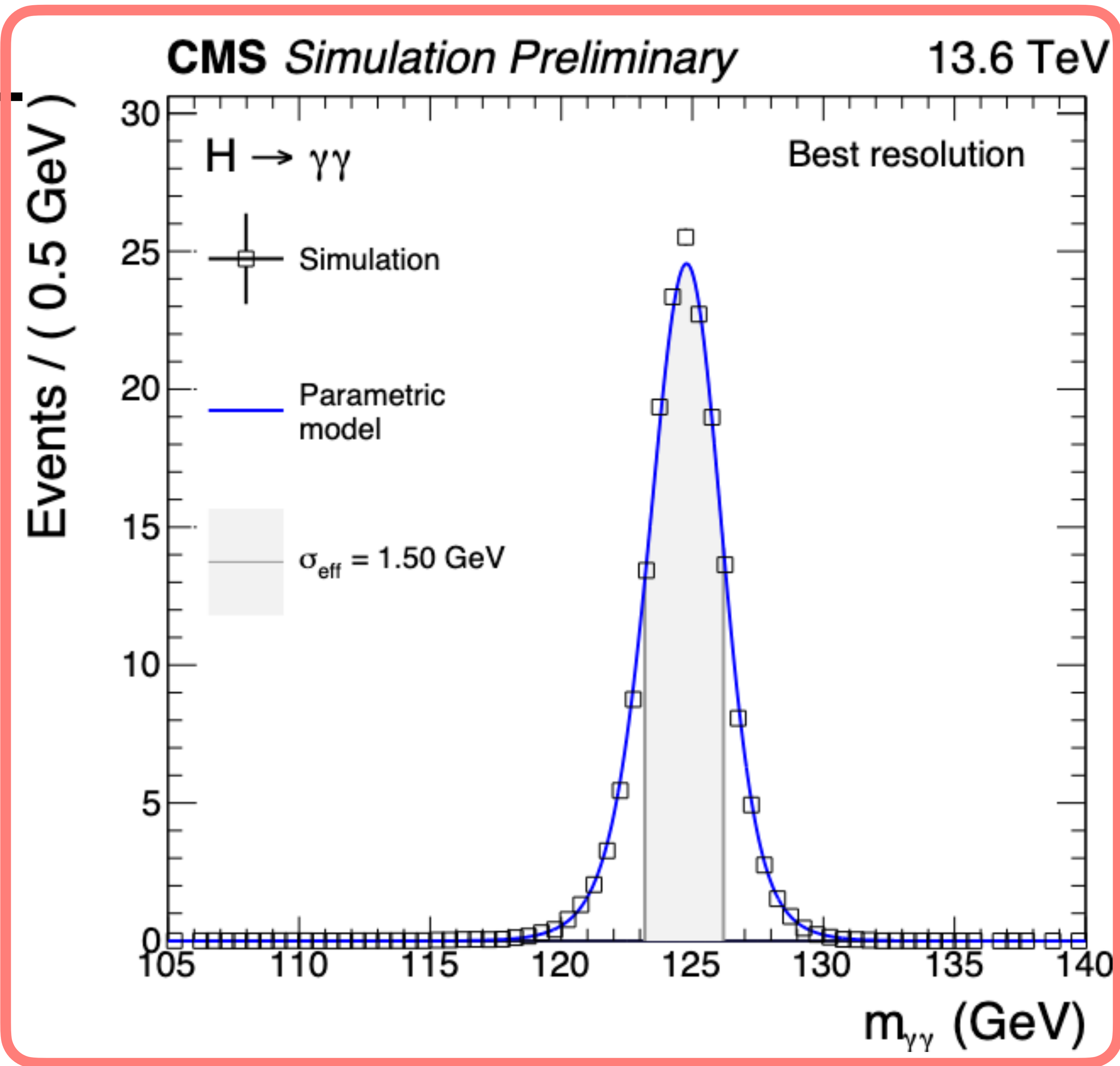
✳Overall, similar strategy in Run 2 and Run3

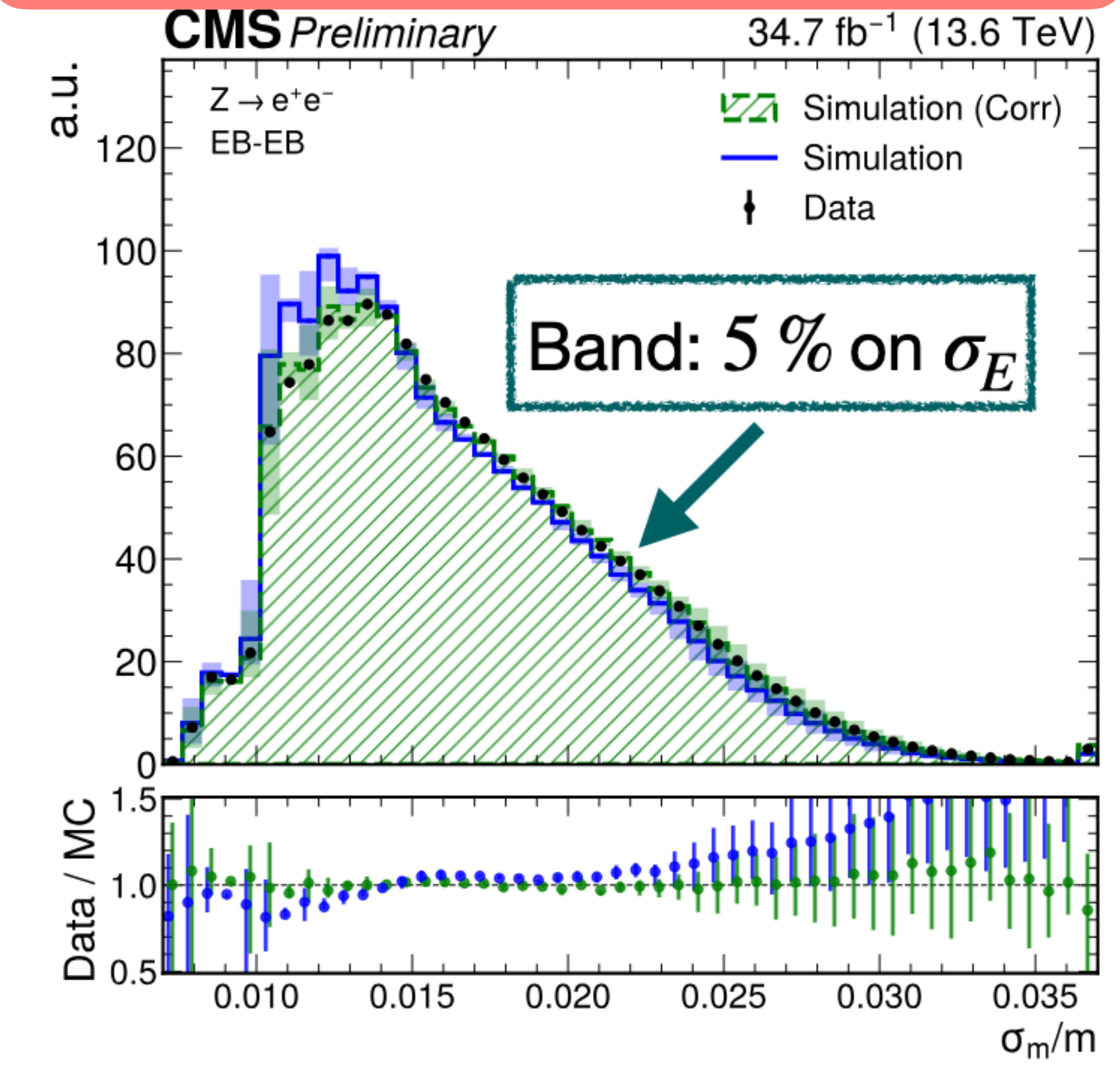
- Requirements on p_T^γ, η_{SC}, photon ID, and shower shape and isolation observables to match the HLT requirements
- Suppression of non-prompt photons with BDT (correction for disagreement in input variables for photon ID BDT applied)
  - single normalising flow (2403.18582) conditioned on kinematics **(new approach in Run3)**
- In contrast to $H \to ZZ \to 4\ell$, lower S/B ratio
- However, excellent data-driven background estimation under the peak

✳Categorisation based on **mass resolution** (**best**, medium, worst)

$$\frac{\sigma_m}{m} = \frac{1}{2}\sqrt{\left(\frac{\sigma_{E_1}}{E_1}\right)^2 + \left(\frac{\sigma_{E_2}}{E_2}\right)^2}$$

✳Inclusive and differential measurement





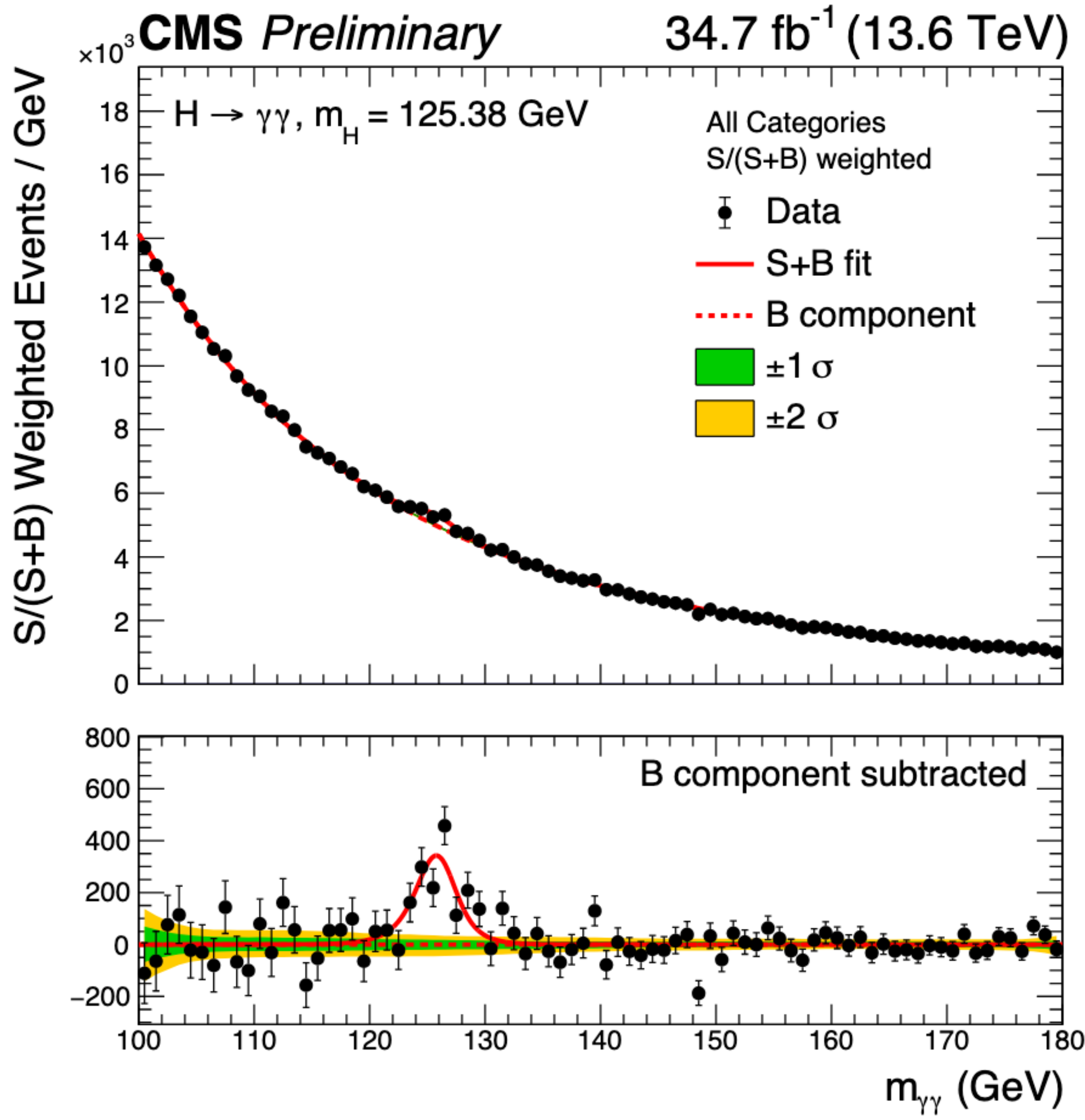
$H \to \gamma\gamma$: Inclusive Cross Section

CMS-PAS-HIG-23-014

✳ Apply fiducial requirement on geometric mean: $\frac{\sqrt{p_T^{\gamma_1}\ p_T^{\gamma_2}}}{m_{\gamma\gamma}} > \frac{1}{3}$

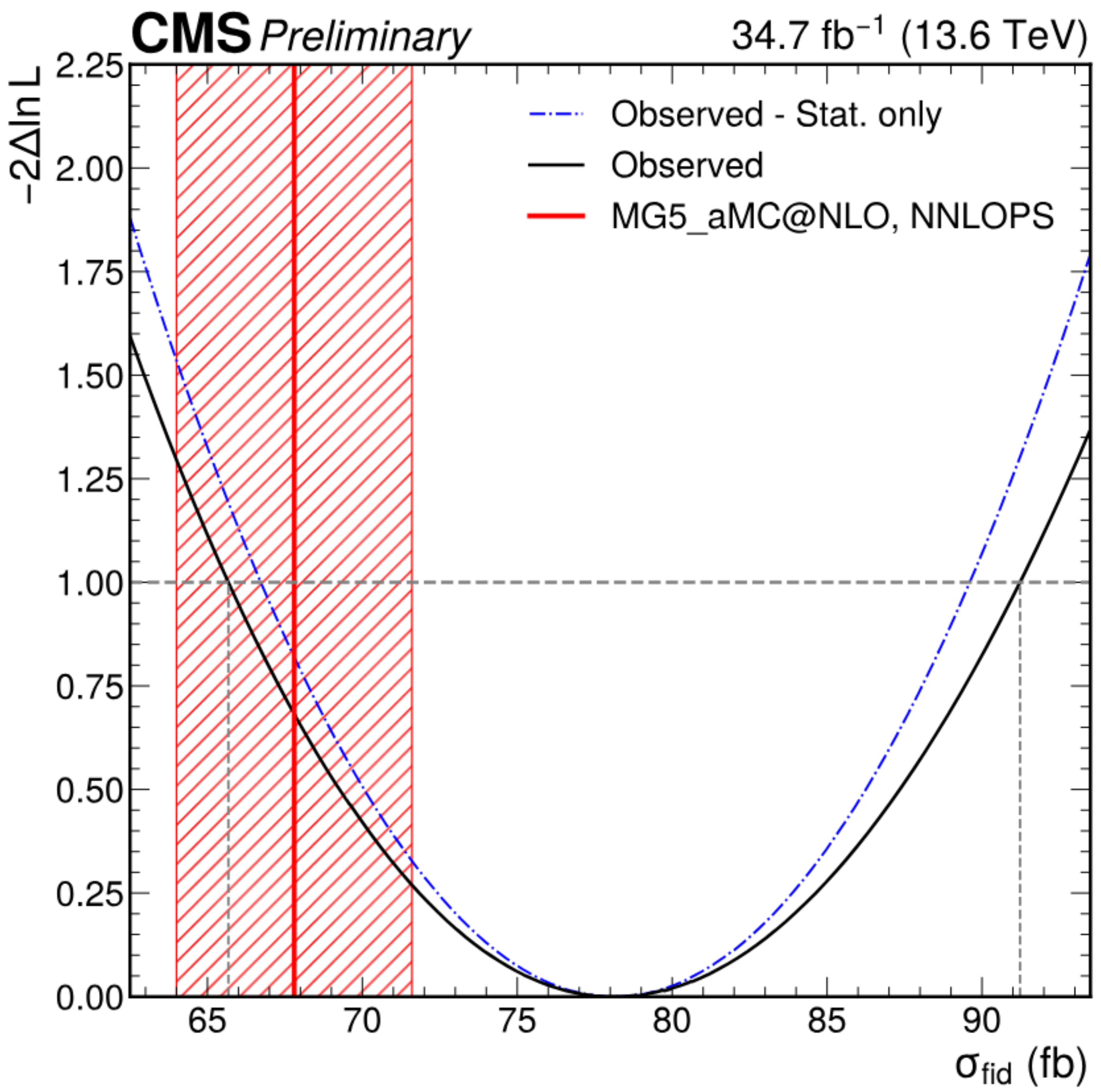
- "OutsideAcceptance" events fixed to SM and treated as **signal**
- Improved perturbative convergence in phase space (2106.08329)

$$\sigma_{\text{fid}} = 78 \pm 11\ (\text{stat.})^{+6}_{-5}\ (\text{syst.})\,\text{fb} = 78^{+13}_{-12}\,\text{fb}$$



✳ Systematics dominated by photon scale/resolution

Systematic uncertainty	Magnitude
Photon energy scale and resolution group	+5.8%/ − 4.9%
Category migration from energy resolution	+3.5%/ − 3.9%
Integrated luminosity	±1.4%
Photon preselection efficiency	±1.4%
Non-linearity	+0.8%/ − 1.6%
Photon identification efficiency	±1.0%
Pileup reweighting	±0.8%

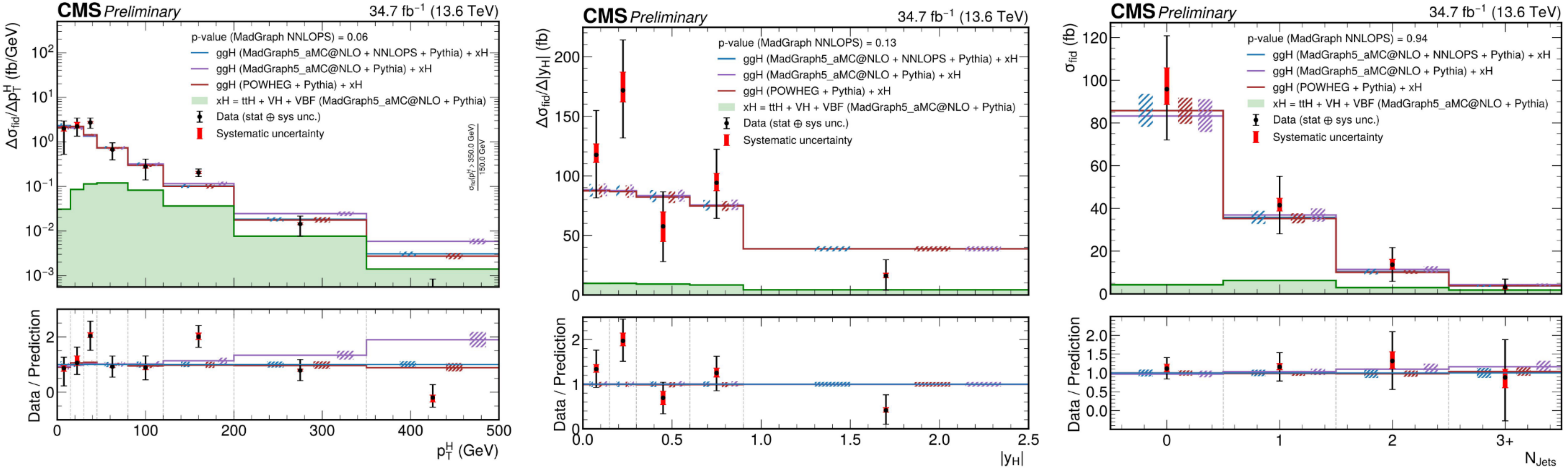


$H \rightarrow \gamma\gamma$: Differential Cross Section

CMS-PAS-HIG-23-014

✴3 variables studied: p_T^H , $|y^H|$ and N_{jets}

- In agreement with SM
- Systematics dominated by photon scale/resolution



$H \to ZZ \to 4\ell$ ($\ell = e, \mu$) **measurement** (early Run3 CMS data)

CMS-PAS-HIG-24-013

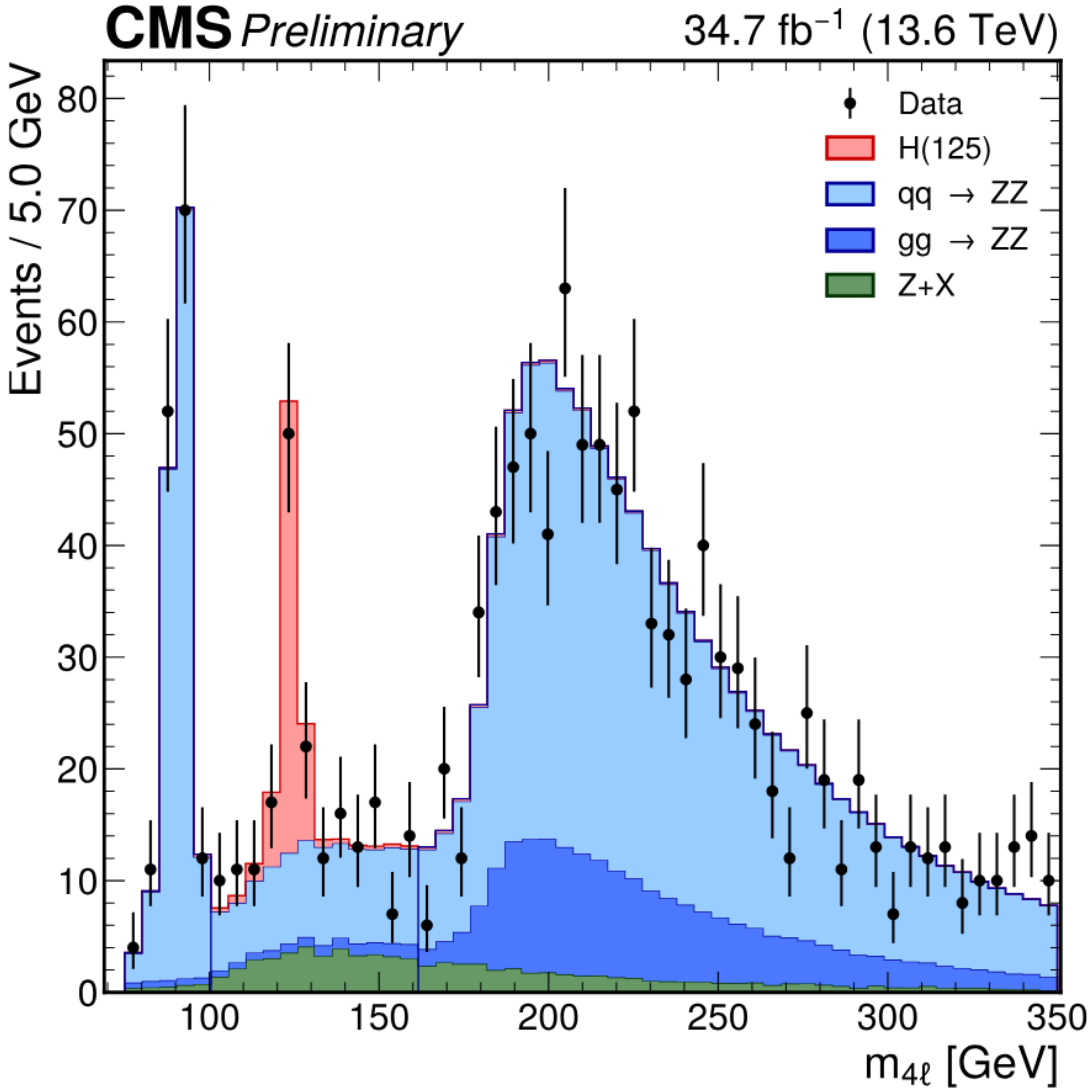
✳ Well-suited for measurement with a clean signal

✳ Overall, similar strategy in Run 2 and Run 3

- Requirements on lepton kinematics (p_T , η , ID), and isolation to match the HLT requirements
  - Dedicated BDT for electron identification
- Reducible (data-driven), Irreducible (simulation)
- Unbinned maximum-likelihood fit

✳ Excellent validation of muon and electron performance of CMS

✳ Most relevant systematic: Electron efficiency



$H \to ZZ \to 4\ell$ ($\ell = e, \mu$) : Inclusive Cross Section

- ✳Well-suited for measurement with a clean signal
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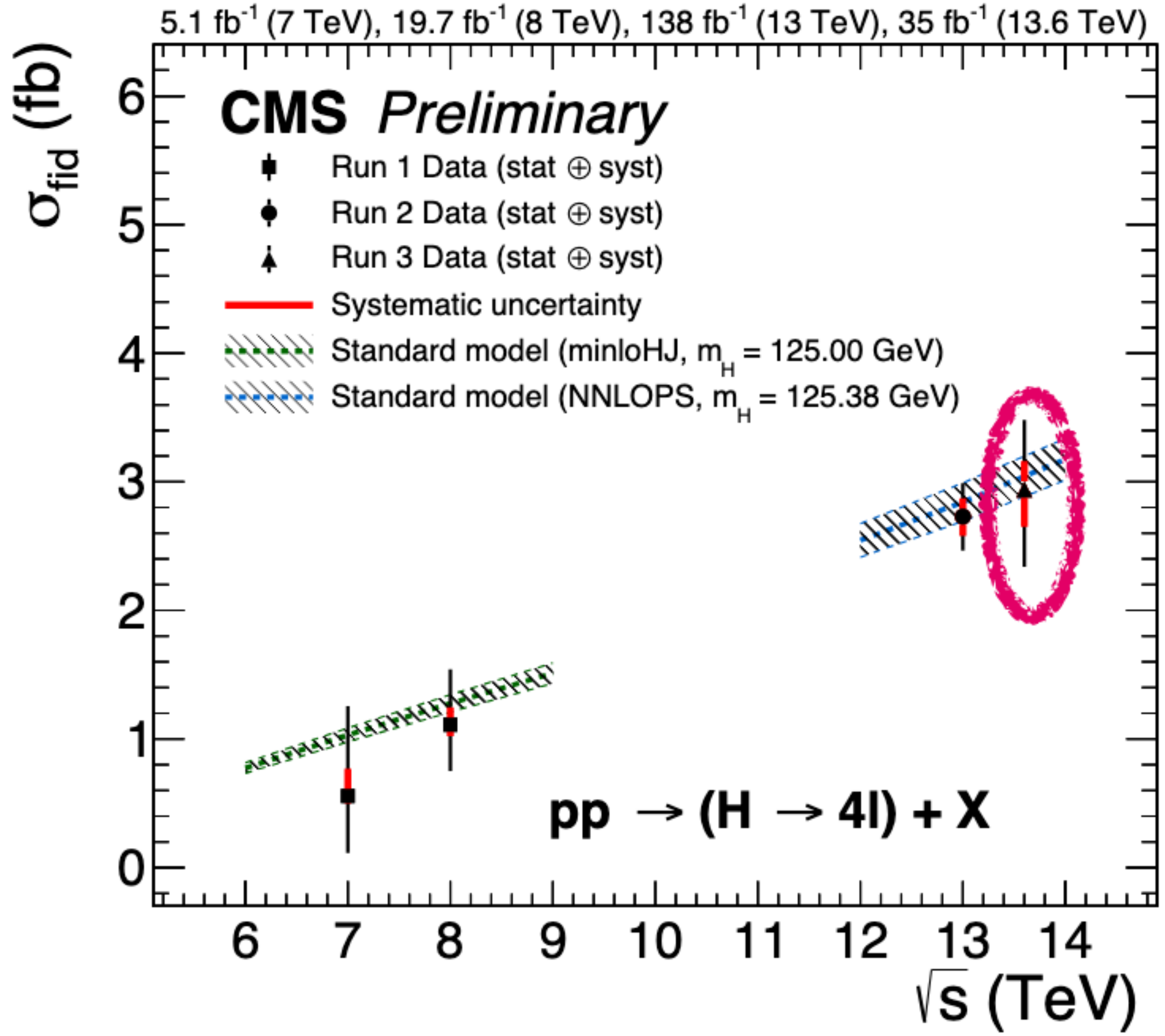
  - Reducible (data-driven), Irreducible (simulation)
  - Unbinned maximum-likelihood fit
- ✳Excellent validation of muon and electron performance of CMS
- ✳Most relevant systematic: Electron efficiency
- ✳Measured inclusive cross section

$$\sigma_{\text{fid}} = 2.94^{+0.53}_{-0.49}\ (\text{stat.})^{+0.29}_{-0.22}\ (\text{syst.})\ \text{fb}$$



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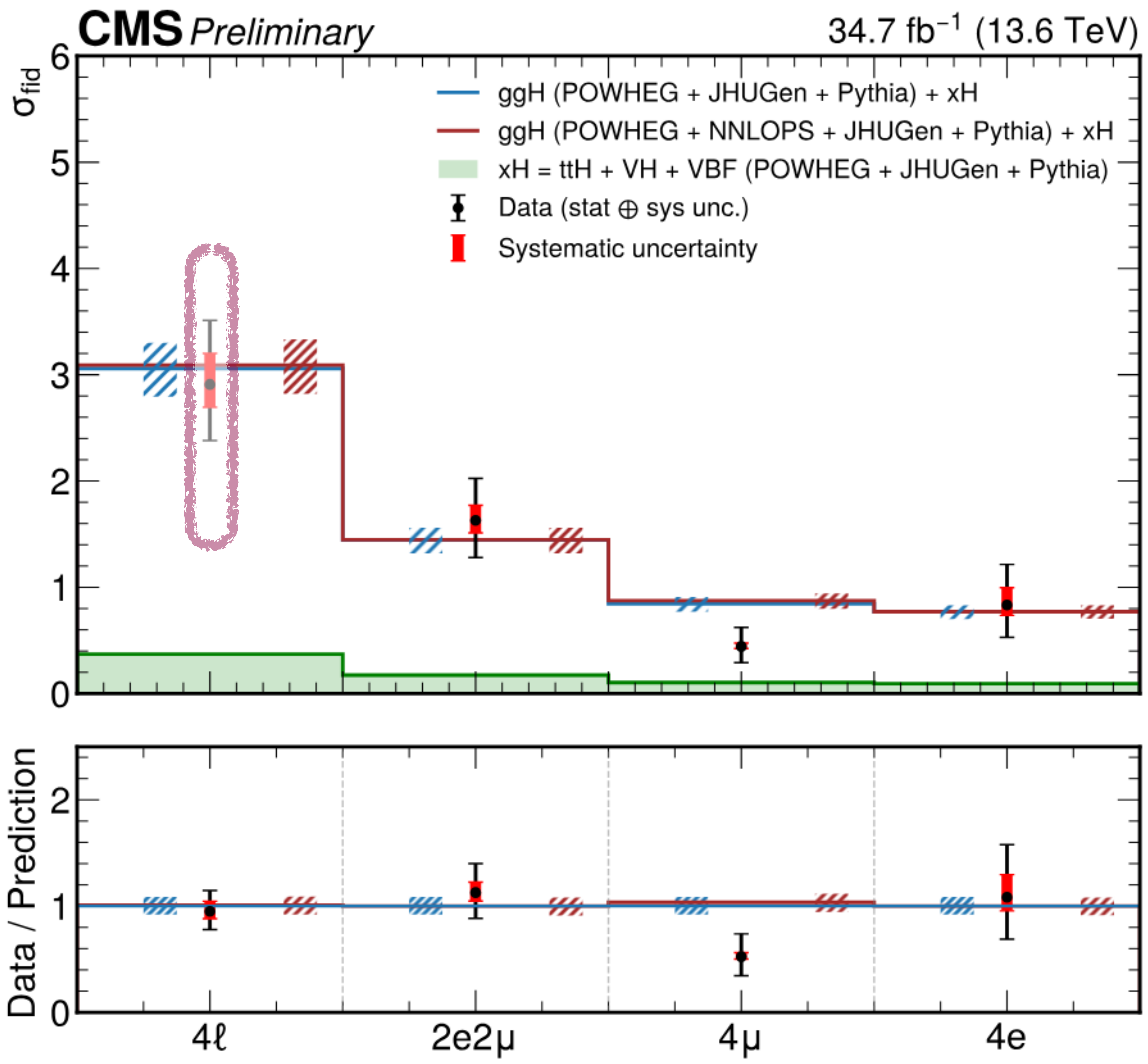
✳ Measurements per lepton category consistent with each other



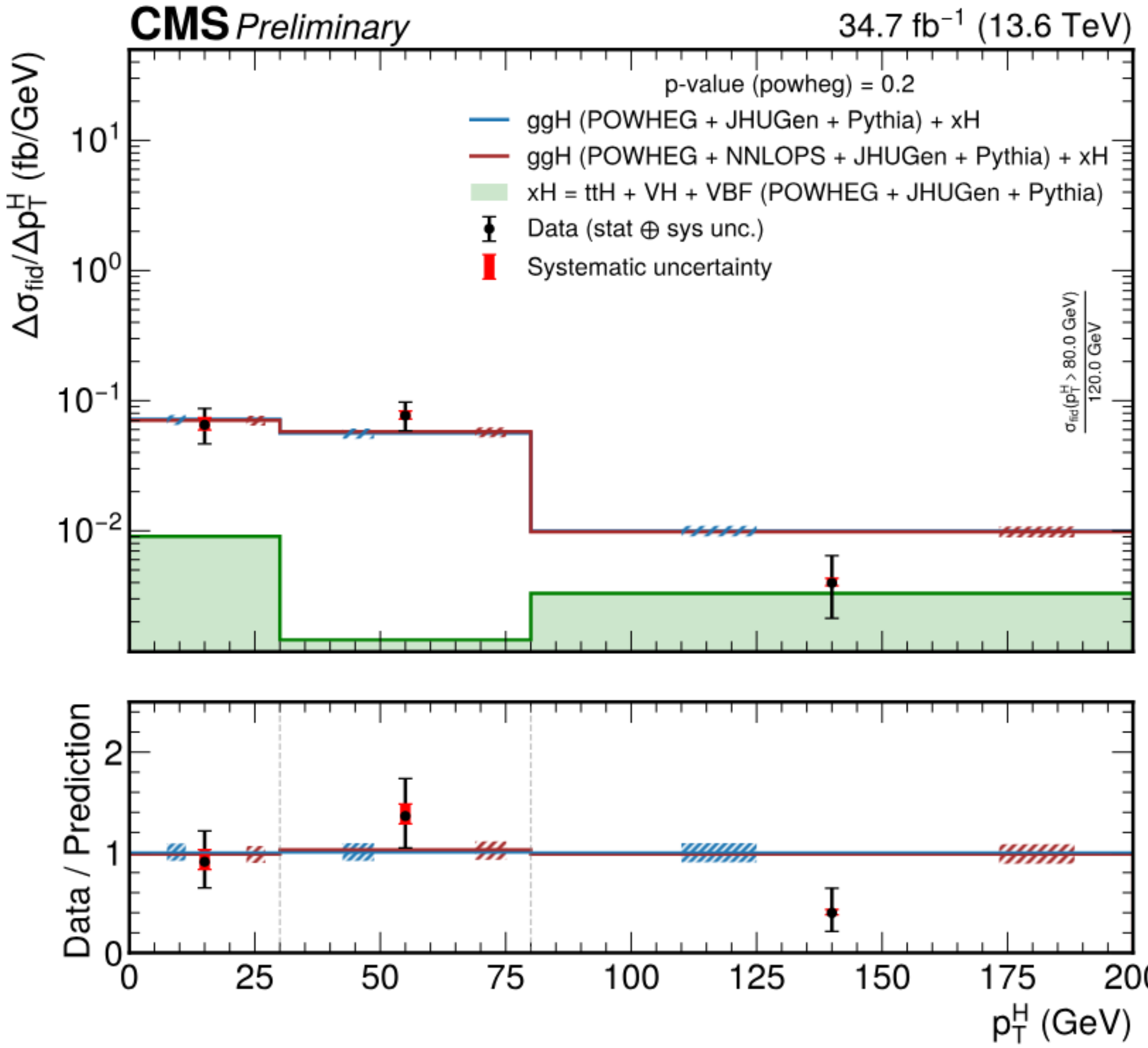
$H \to ZZ \to 4\ell\ (\ell = e, \mu)$: Differential Cross Section

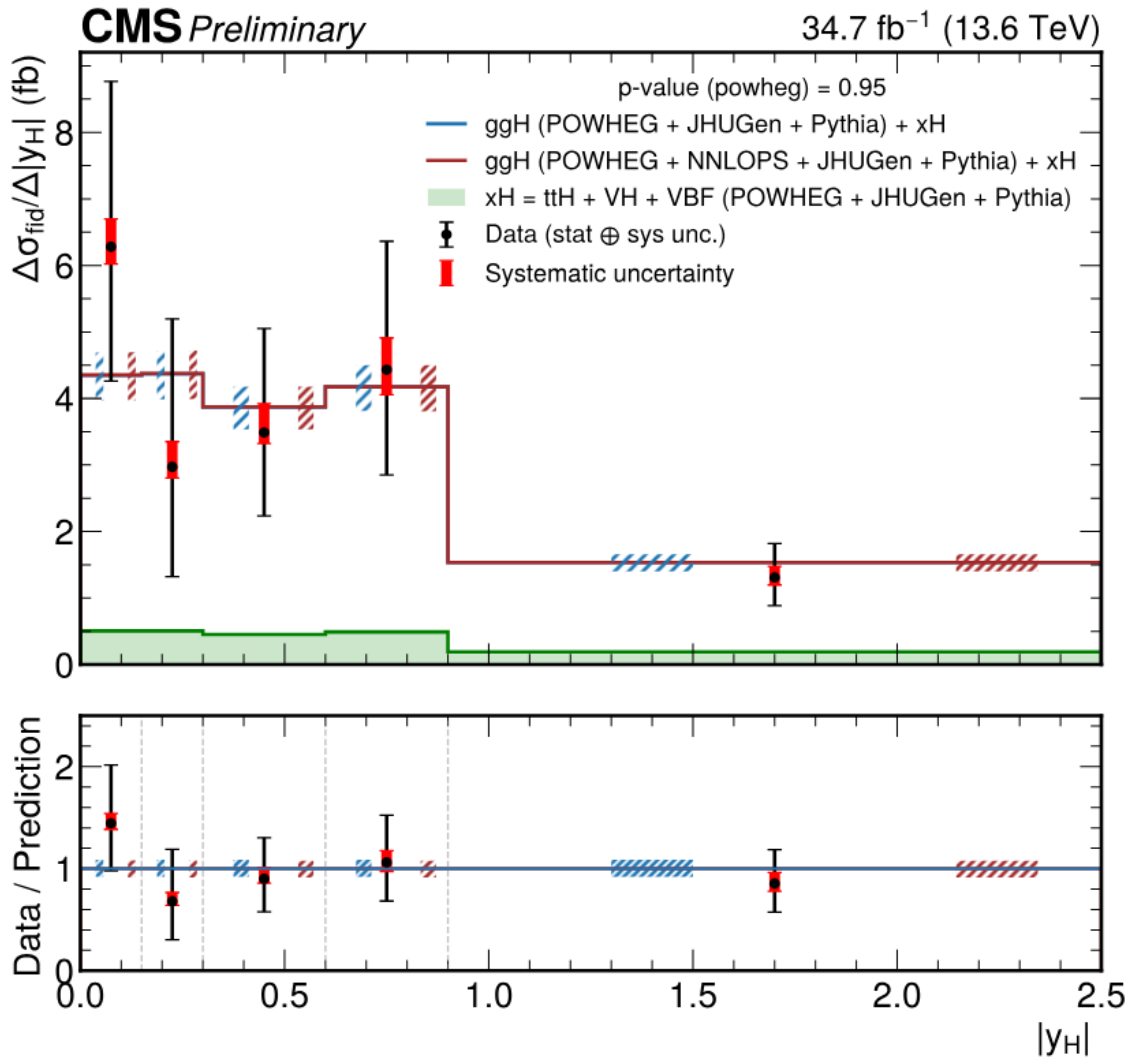
CMS-PAS-HIG-24-013

✳Two variables studied: p_T^H , $|y^H|$ (coarse binning w.r.t. Run2)

- In agreement with SM
- Systematics dominated by Electron efficiency

✳Full Run3(+Run2) dataset → more granular binning expected

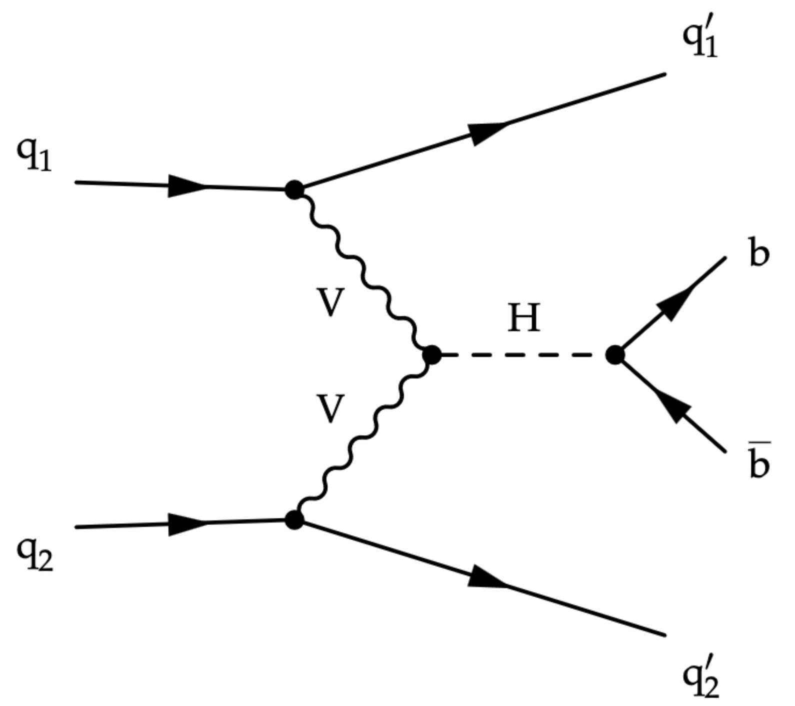




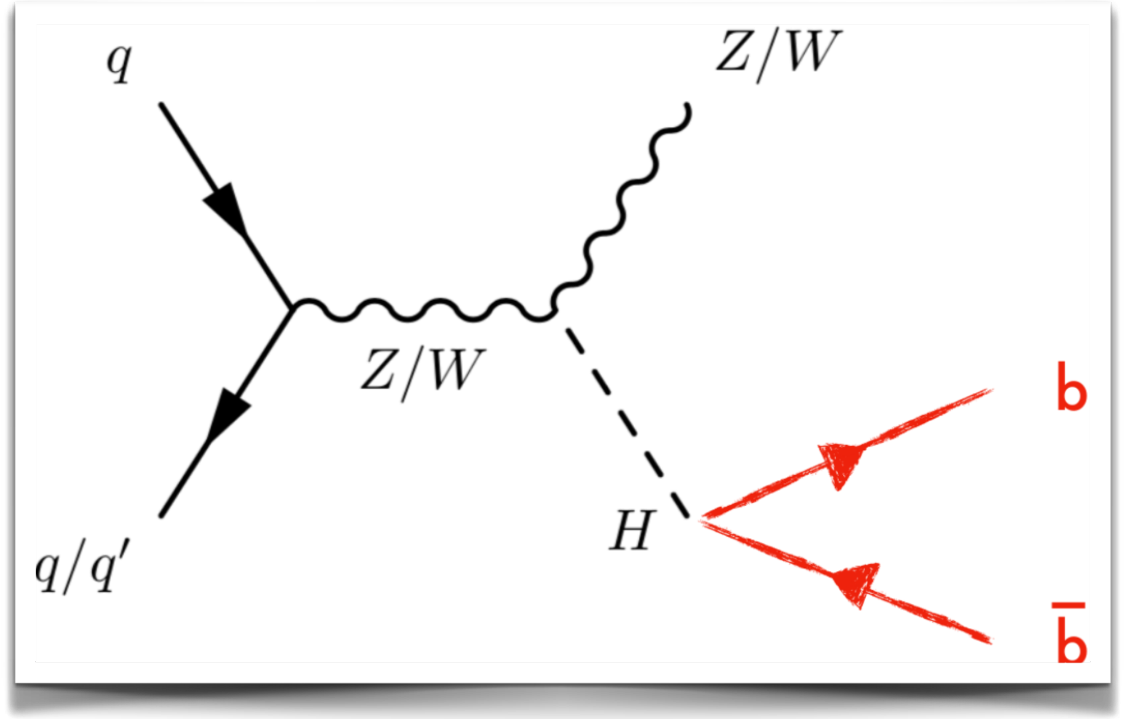
Higgs production in bb final state

- $\ast\, H \rightarrow bb$
  - Signal Strengths, STXS

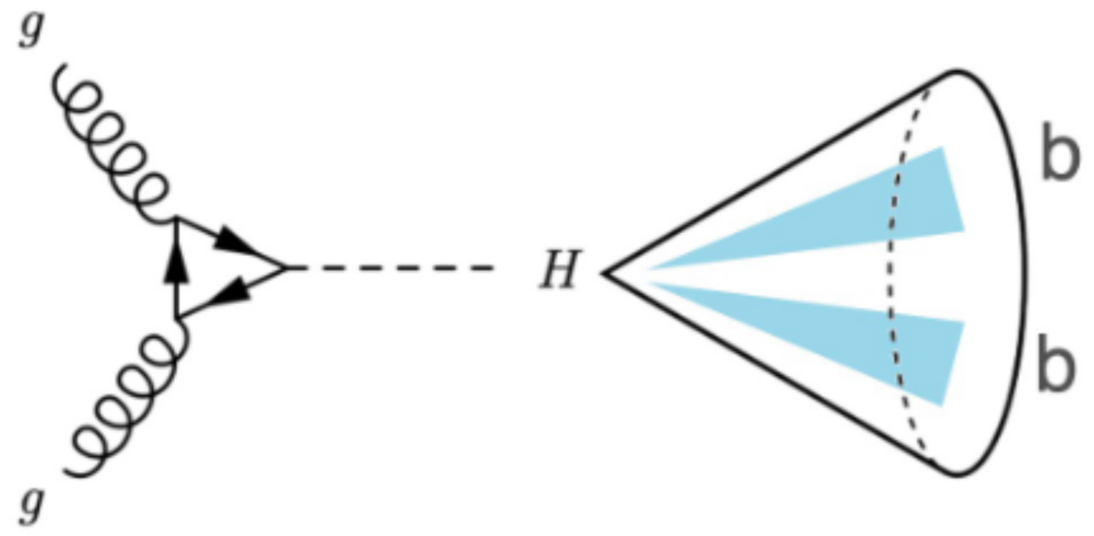
VBF

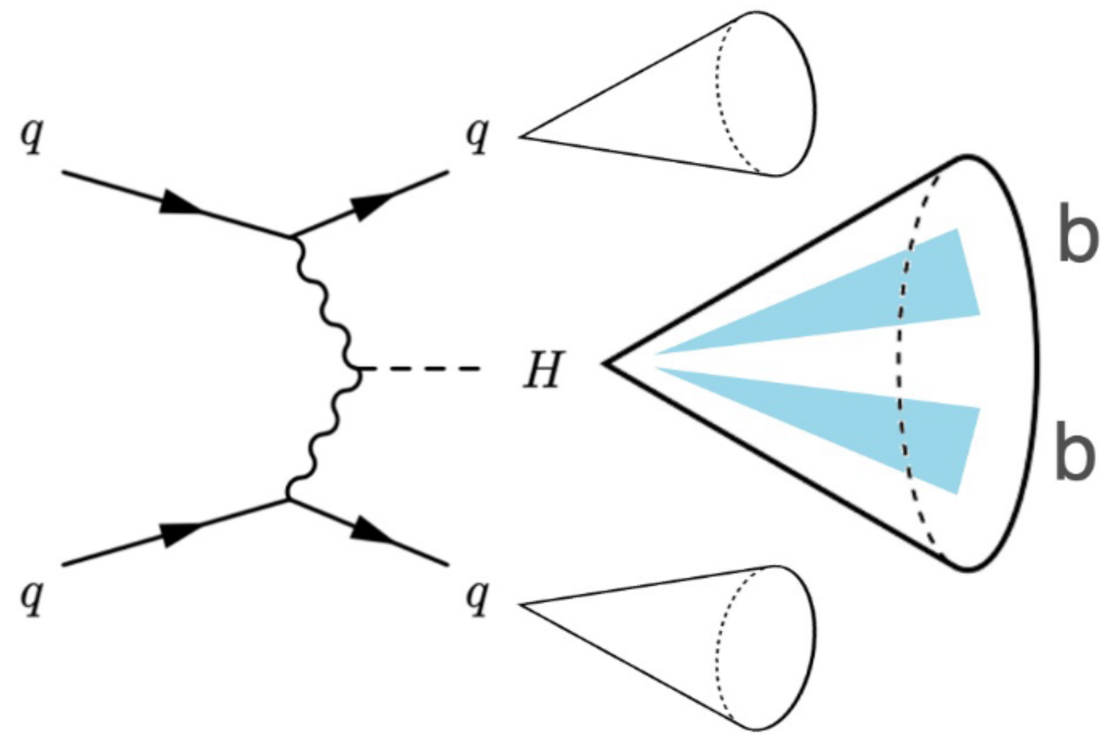


VH

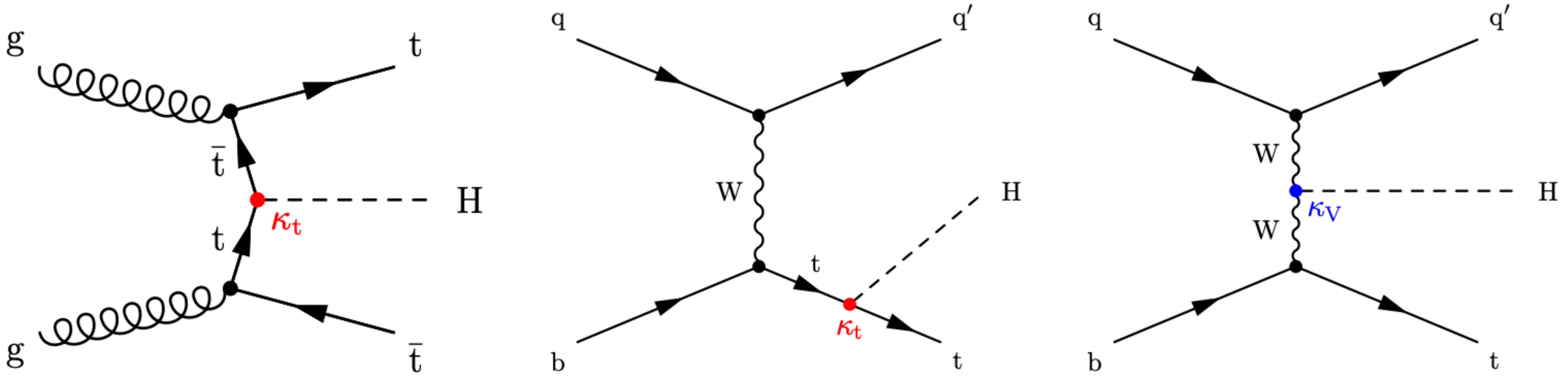


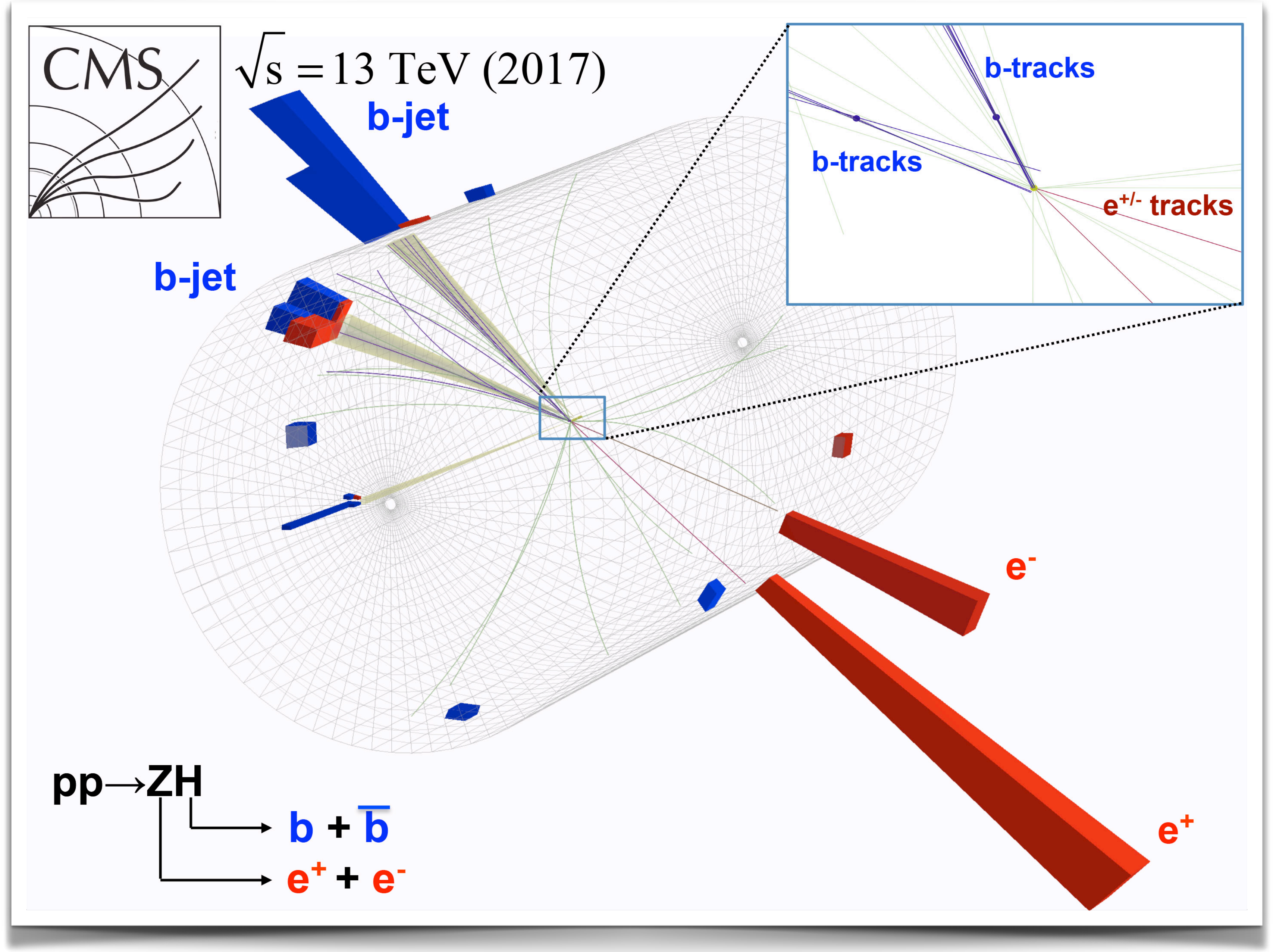
Boosted ggH/VBF





tH/ttH



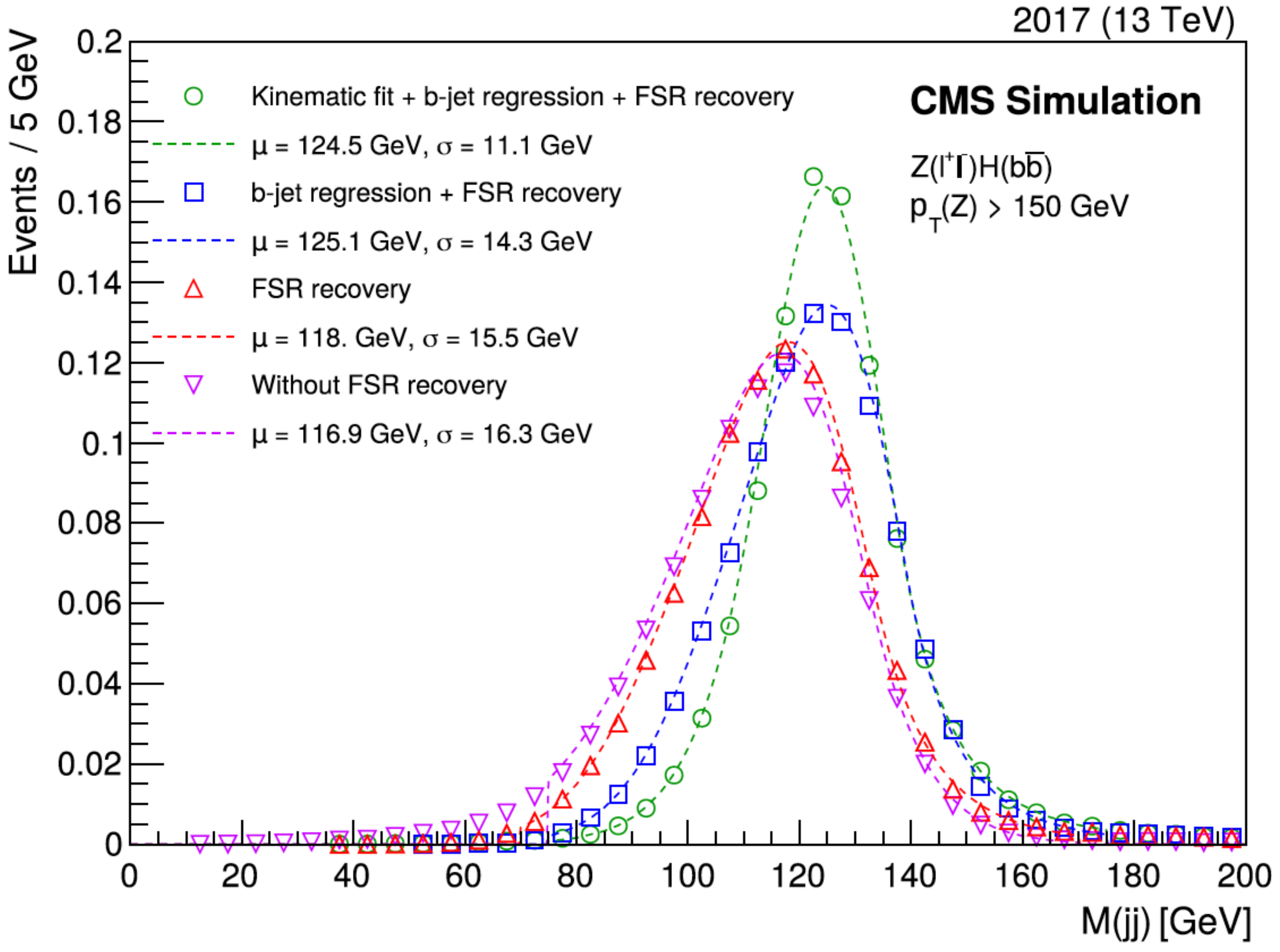


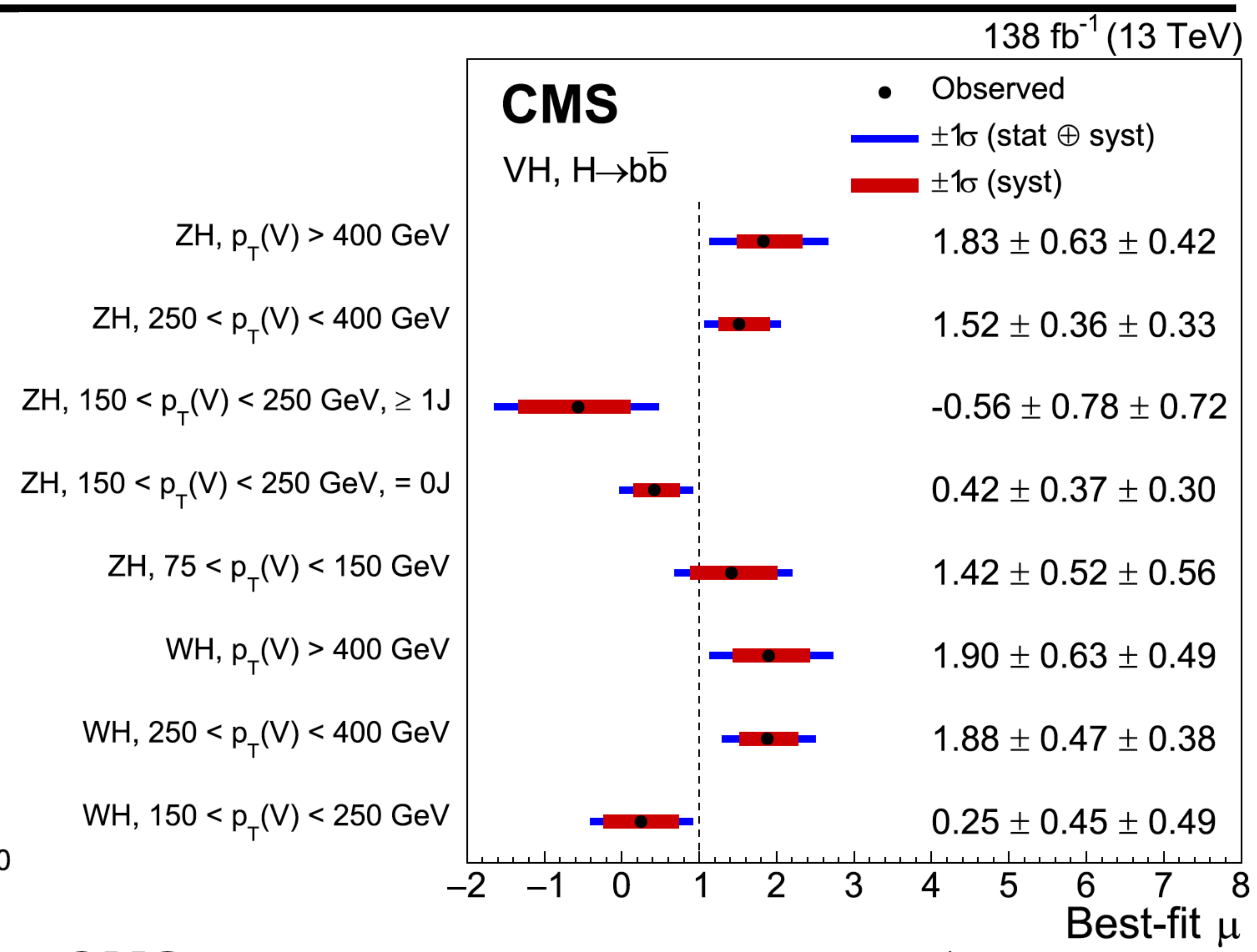
CMS-PAS-HIG-21-020
CMS-PAS-HIG-19-011
10.1007/JHEP01(2024)173
10.1103/PhysRevD.109.092011
10.1140/epjc/s10052-024-13021-z

$V(W/Z \to leptons)\ H \to bb$

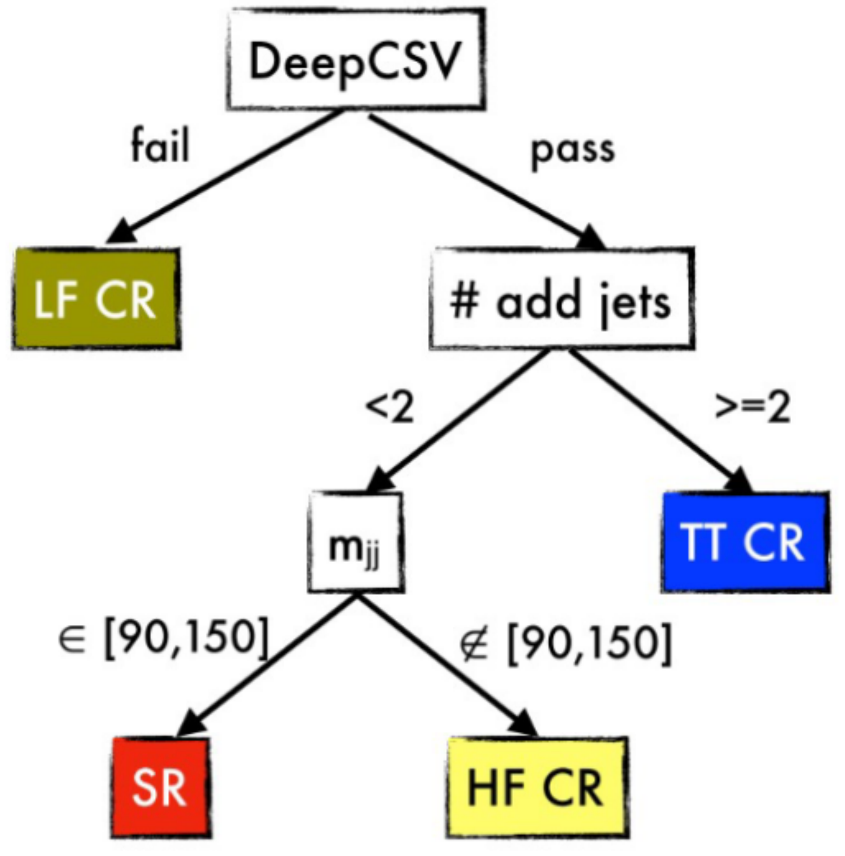
10.1103/PhysRevD.109.092011

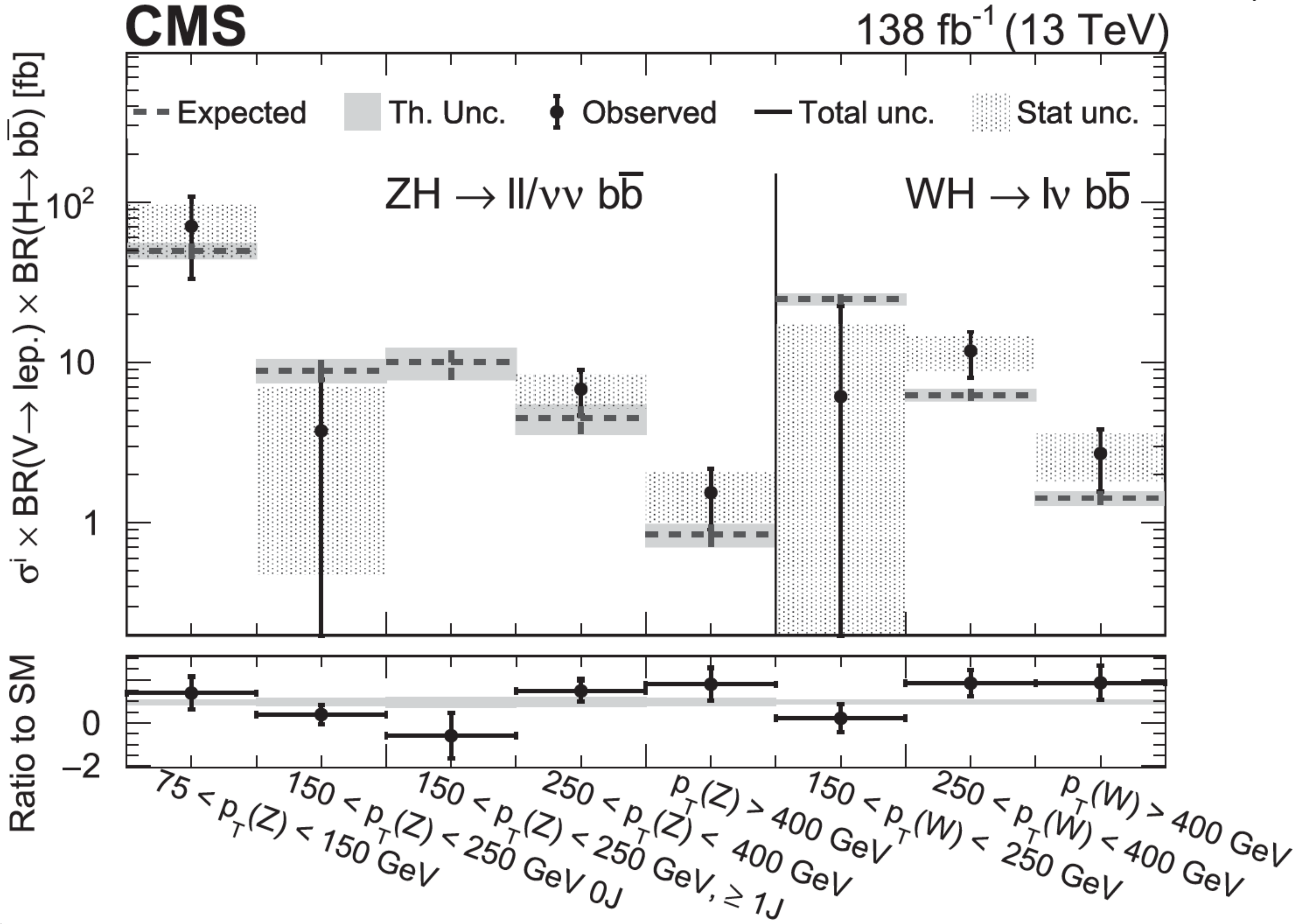
- ✳ 3 channels are considered for V:
  - 0-lepton ($Z \to \nu\nu$)
  - 1-lepton ($W \to \ell\nu$)
  - 2-lepton ($Z \to \ell\ell$); kinematic fit applied
- ✳ Fit to SR and orthogonal control regions (CRs):
  - tt
  - V+HF(heavy flavor)
  - V+LF (light flavors)
- ✳ Multi-category DNN in V+HF CR
- ✳ **DNN** for signal classification and extraction
  - 8 VH categories (pT and jet multiplicity; 5 ZH & 3 WH)
- ✳ Sim. Modeling, b-tagging, JER being leading systematic sources





1-lepton example





(Boosted VBF/ggH) $H \rightarrow bb$

[CMS-PAS-HIG-21-020]

✳ Higgs at large pT (>450 GeV considered)

- To probe BSM effects in scalar sector, test higher-order EW radiative corrections in H production

✳ Updated multivariate Deep Double B-Tagger (DDB)

- Signal significance increased by **twice**

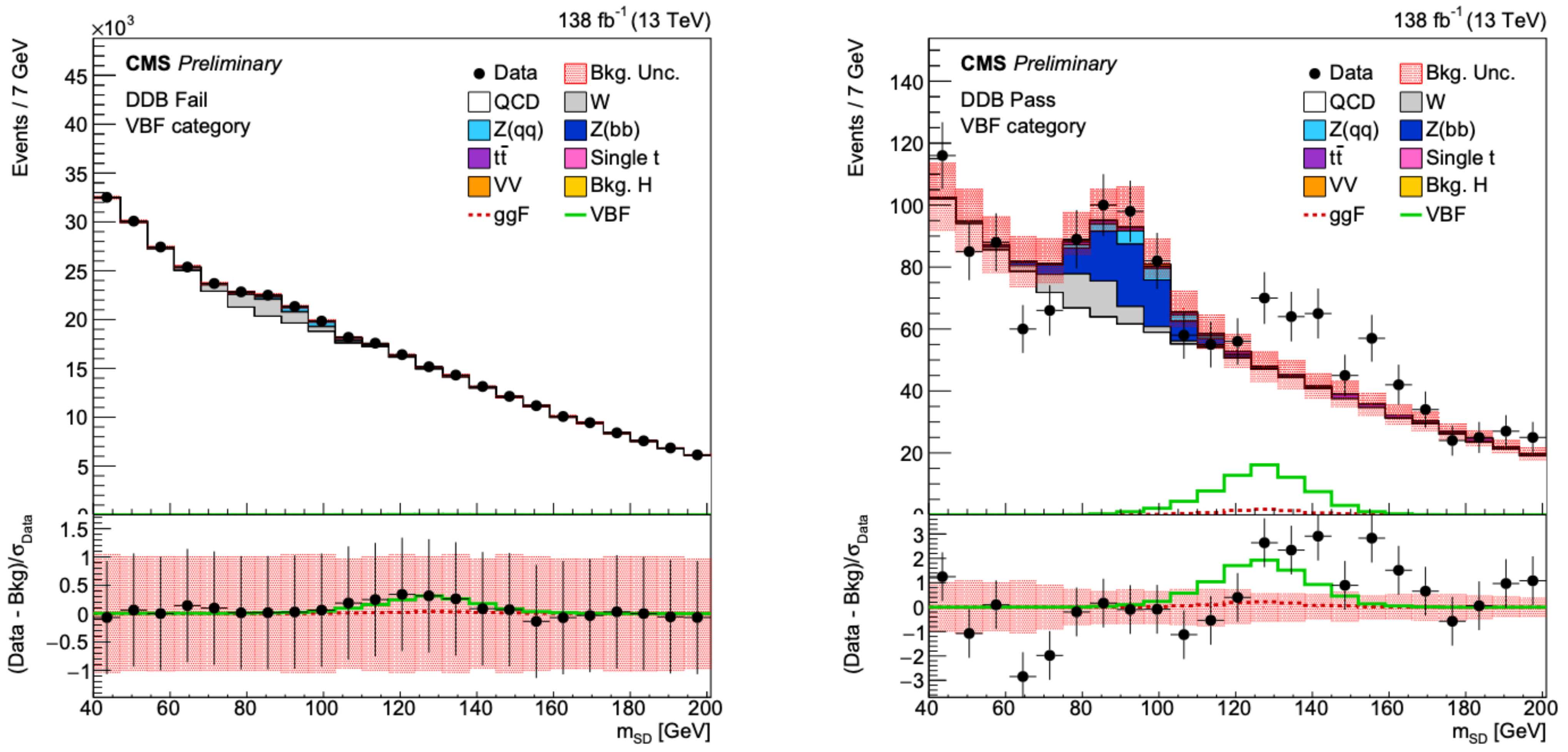
✳ Generalized energy correlation functions for 2-prong (W/Z/**H**) tagging [JHEP 1612 (2016) 53] (to reduce tt bkg)

- Mass-decorrelated version; using the Designed Decorrelated Tagger method [JHEP 1605 (2016) 156]

✳ Jet substructure and novel b-tagging (DDB fail region) to reject QCD background

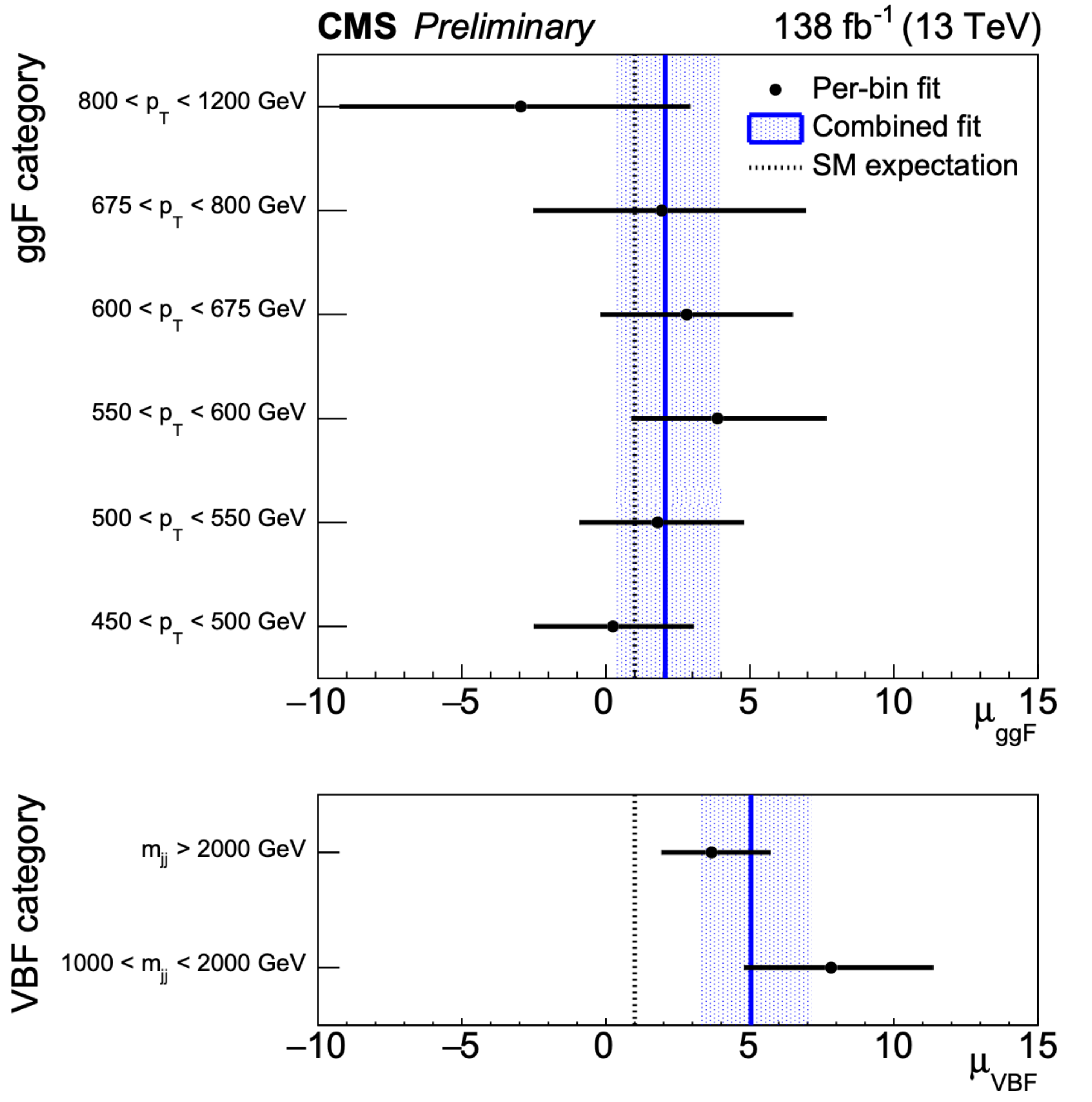
✳ ML fit to the observed m_{SD} distributions for ggH and VBF

✳ W and Z boson resonances used to constraint syst. unc.



Observed differential Signal strengths:

- In p_T bins for ggF
- Inv. mass of forward jets for VBF



$t\bar{t}H/tH$, with $H \to bb$: Analysis Strategy

[CMS-PAS-HIG-19-011]

✳ **3 channels** are considered:

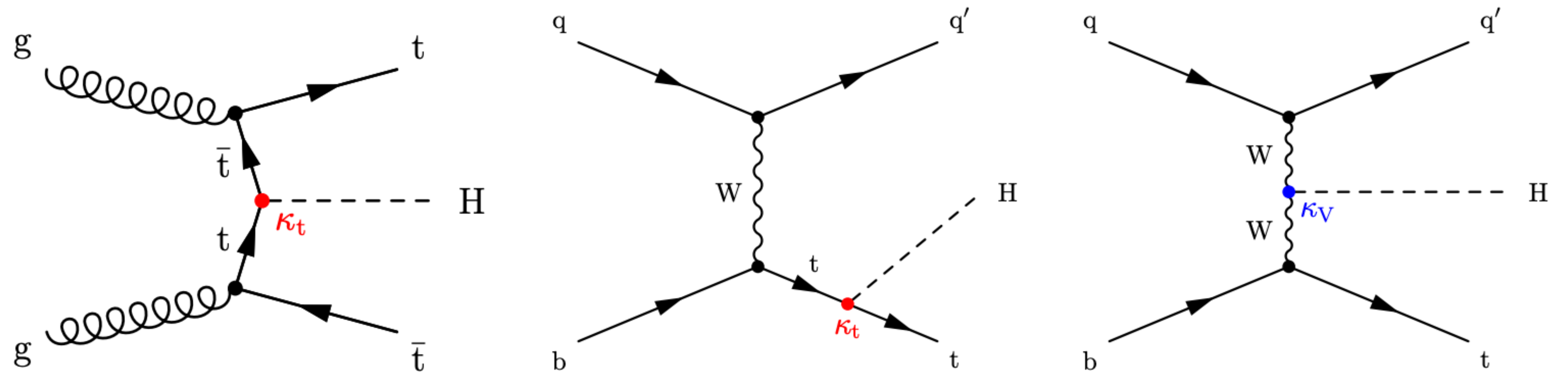
- Fully Hadronic (FH): 0-leptons (2 x$W \to q\bar{q}$)
- Semi leptonic (SL): 1-lepton (1 x$W \to \ell\nu$)
- Dileptonic (DL): 2-leptons (2 x $W \to \ell\nu$)

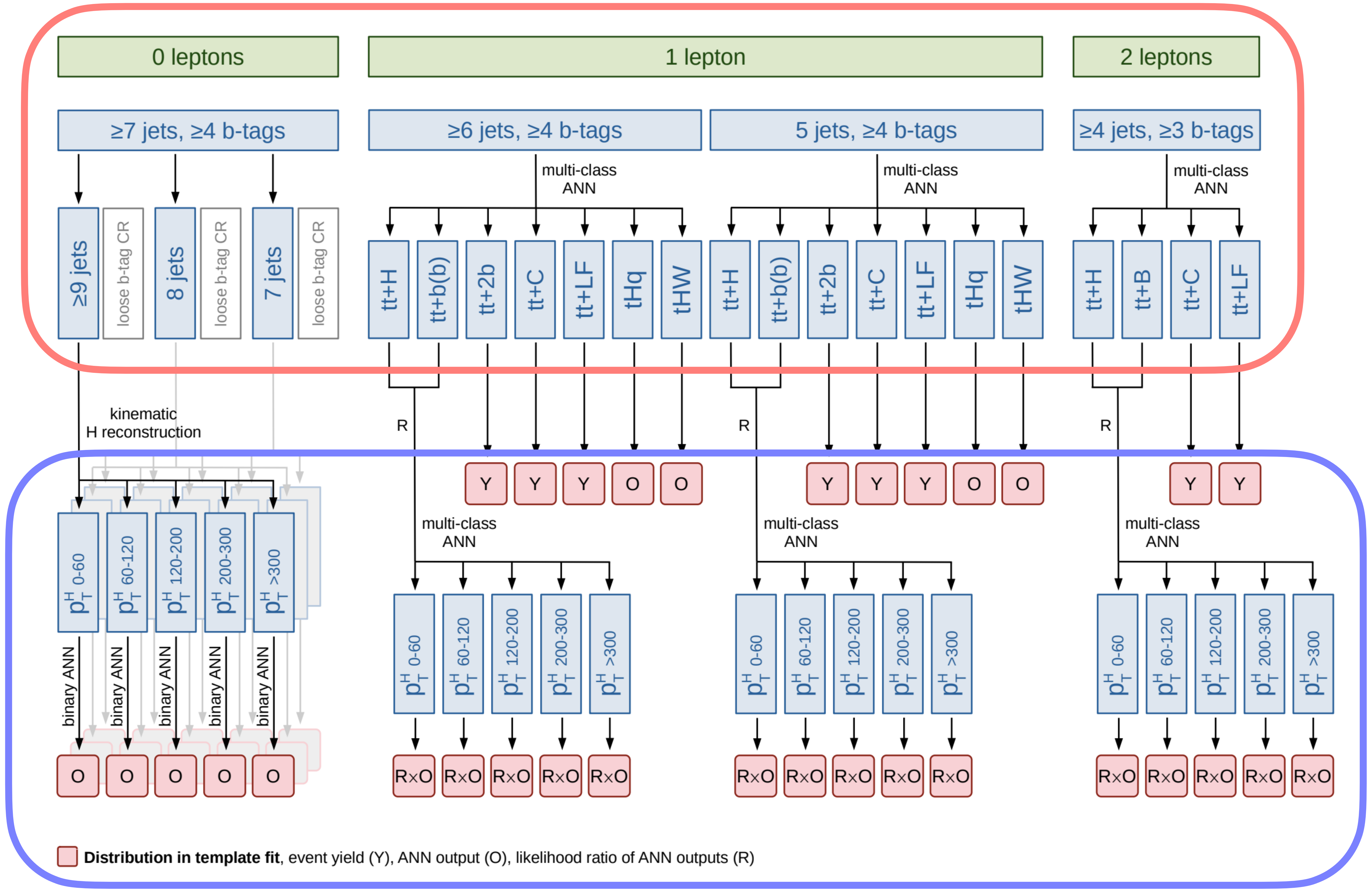
✳ categorization done with *jet* and b-tag multiplicity (**inclusive, STXS**).

✳ **ANNs** trained for sig./bkg. separation, further categorization, and building **discriminants**

✳ Improvements w.r.t. (CMS-PAS-HIG-18-030):

- dominant QCD bkg. estimation (FH); data-driven
- (Refined) neural network classifiers
- DeepJet b tagging algorithm





$t\bar{t}H/tH$, with $H \to bb$: Results on Signal Strength Modifier

[CMS-PAS-HIG-19-011]

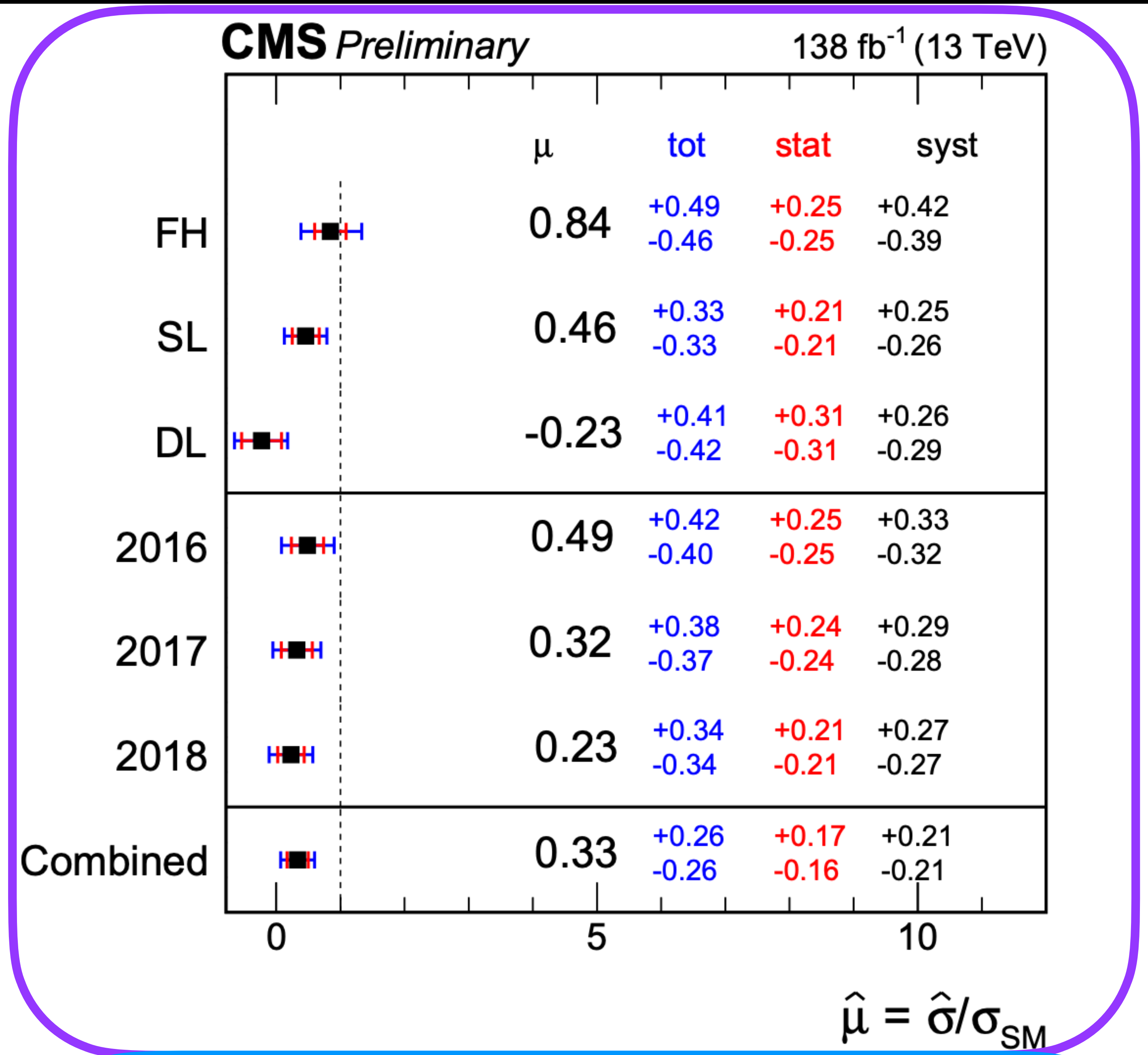
✳ $t\bar{t}H$:

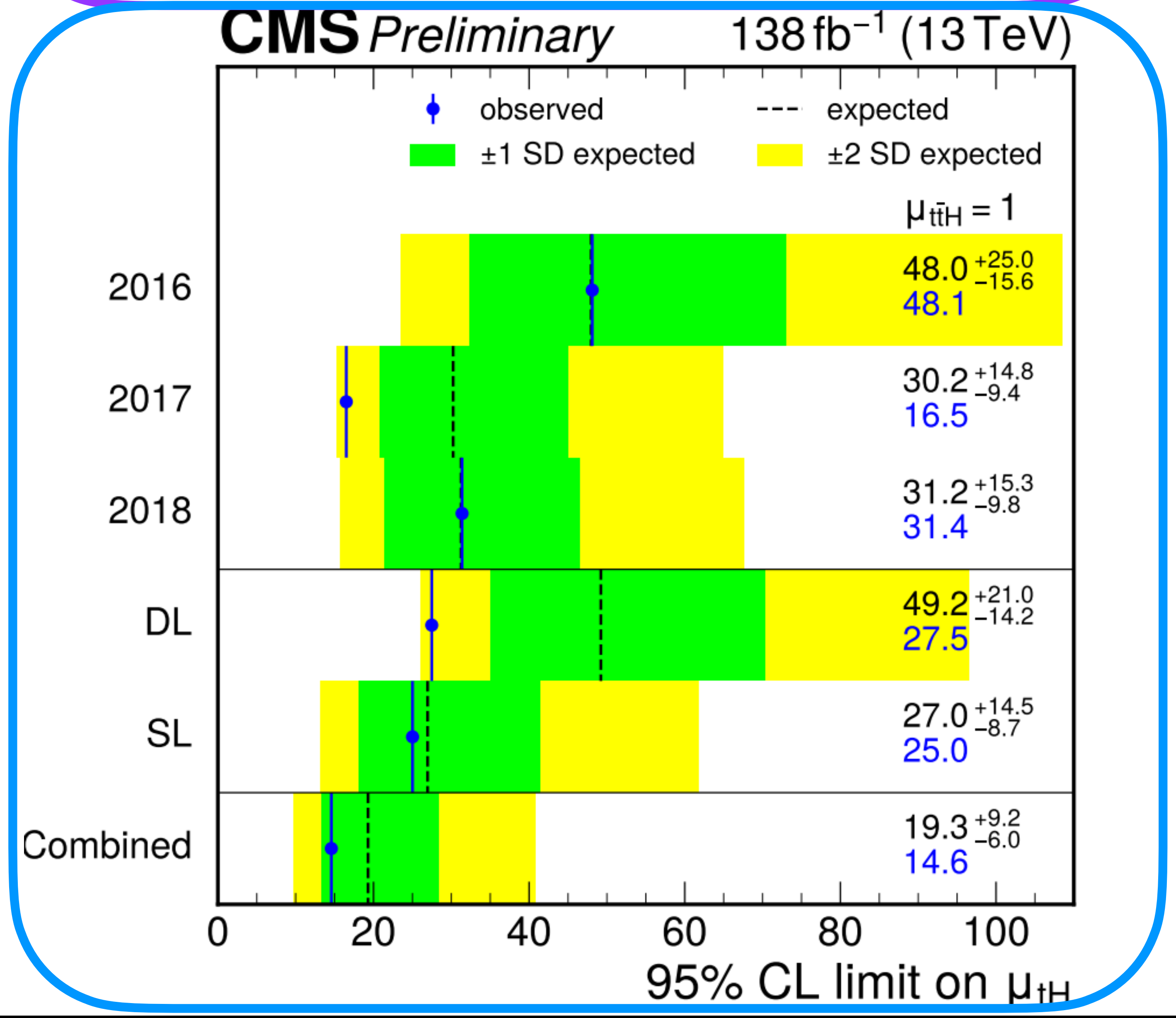
- inclusive
  - $\mu_{t\bar{t}H} = 0.33 \pm 0.26$

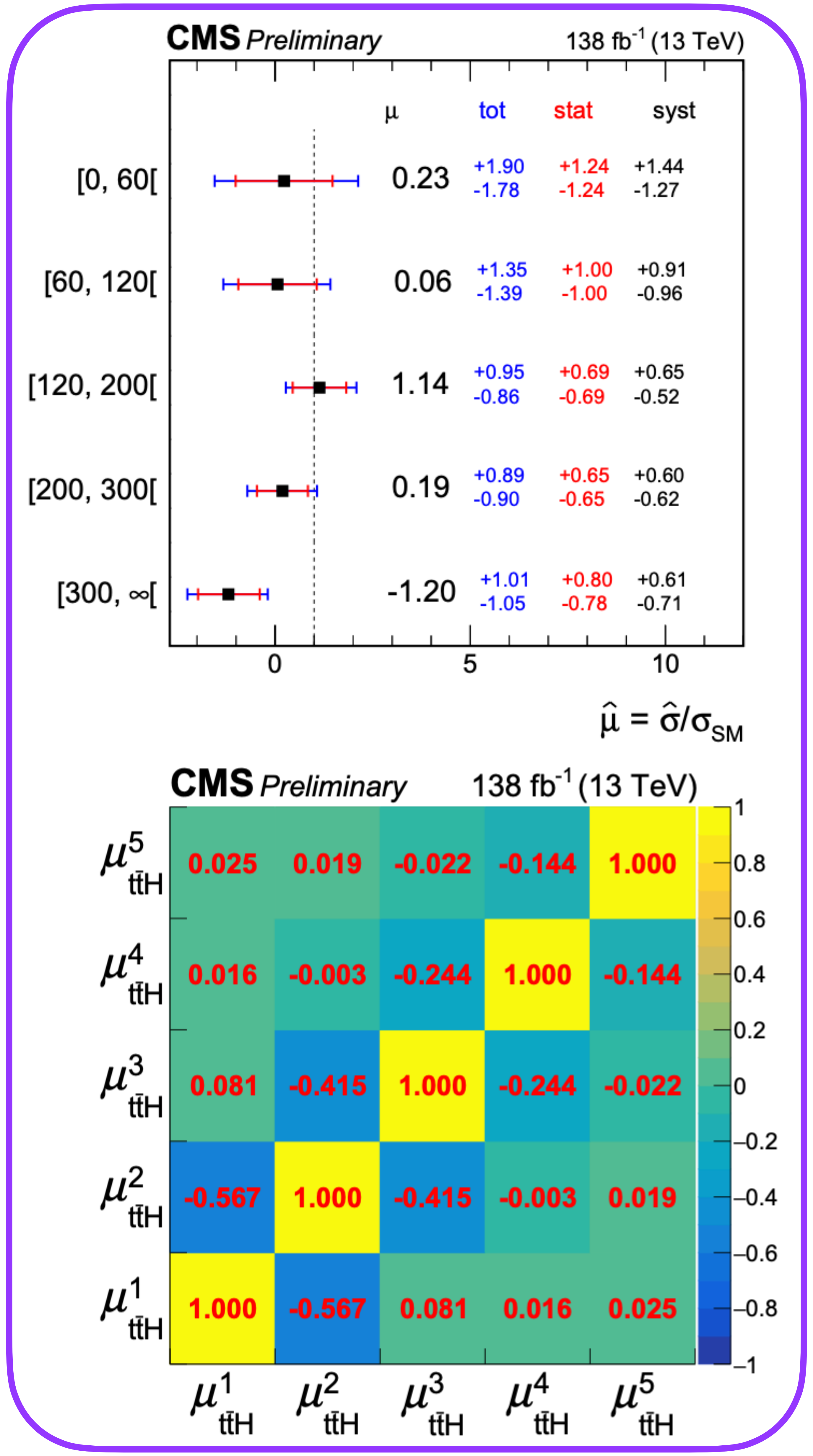
    significance: obs.(exp.) 1.3σ (4.1σ)
  - Background normalization ($t\bar{t}B, t\bar{t}C$) (backup)
- exclusive in p_T bins

✳ tH (inclusive):

- Expected and observed 95% CL upper limits
- Simultaneous with $t\bar{t}H$ (backup)



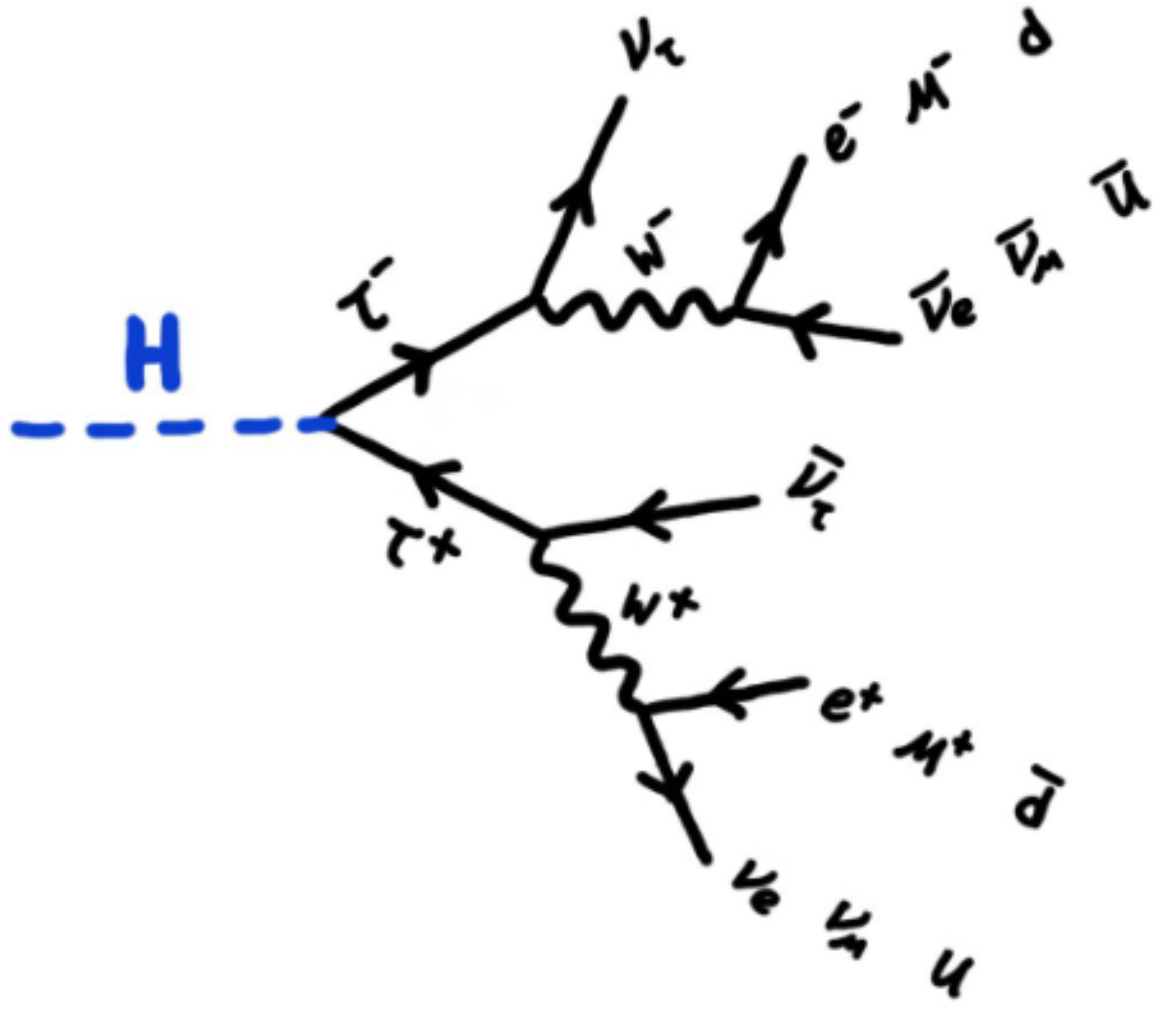


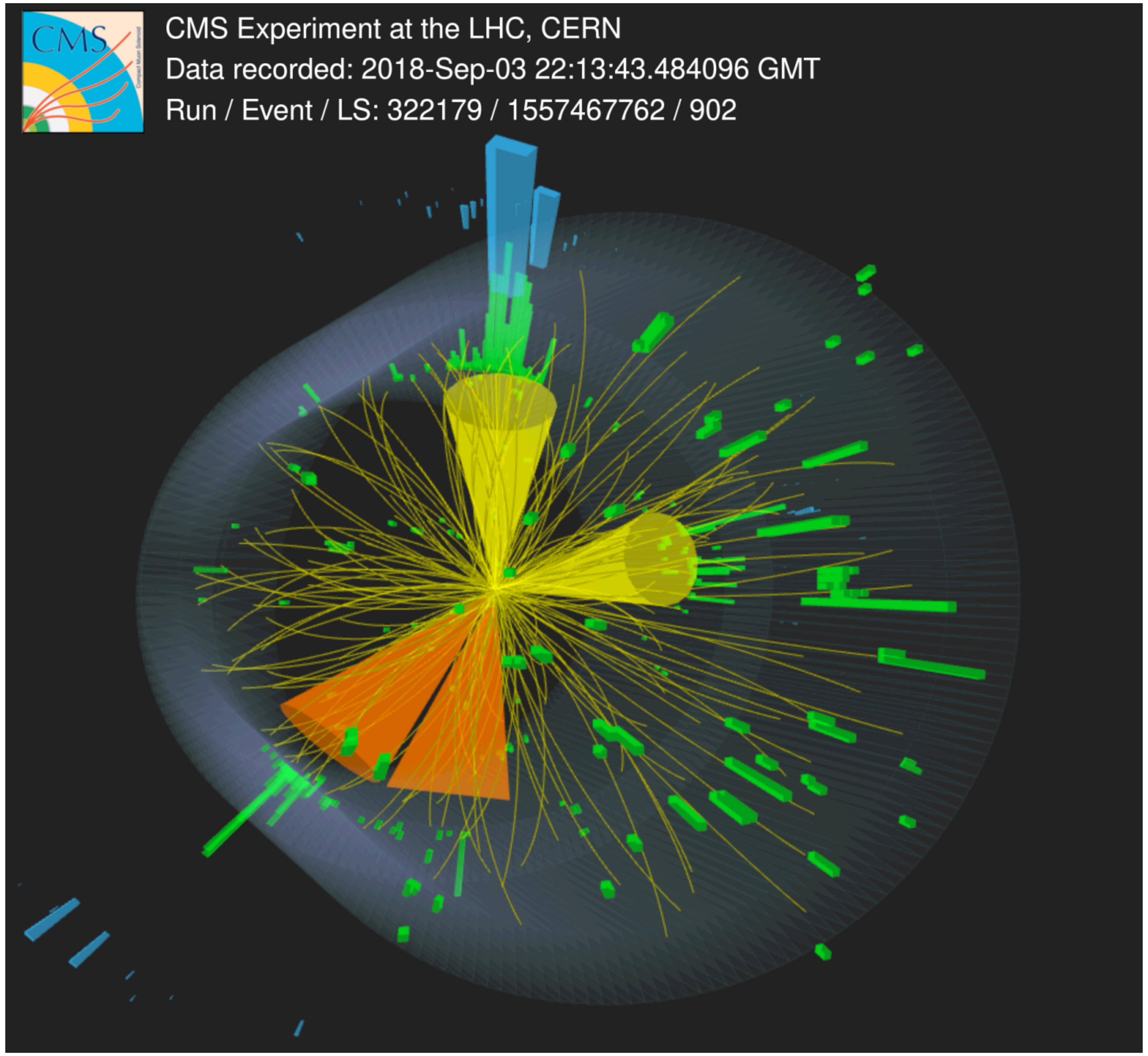


Higss production in $\tau\tau$ final state

✴$H \to \tau\tau$

- Signal Strengths, STXS, inclusive and differential (resolved and boosted)





10.1140/epjc/s10052-023-11452-8
10.1103/PhysRevLett.128.081805
CMS-PAS-HIG-21-017

$H \to \tau\tau$: STXS

10.1140/epjc/s10052-023-11452-8
10.1103/PhysRevLett.128.081805
10.1016/j.physletb.2024.138964

✳ Categories of Higgs Production:

- **ggH** : $(ggF + gg \to Z(qq)H)$
- **qqH** : $(VBF + qq \to V(qq)H)$
- **VH** : $(W/Z)H$

✳ 4 channels considered:

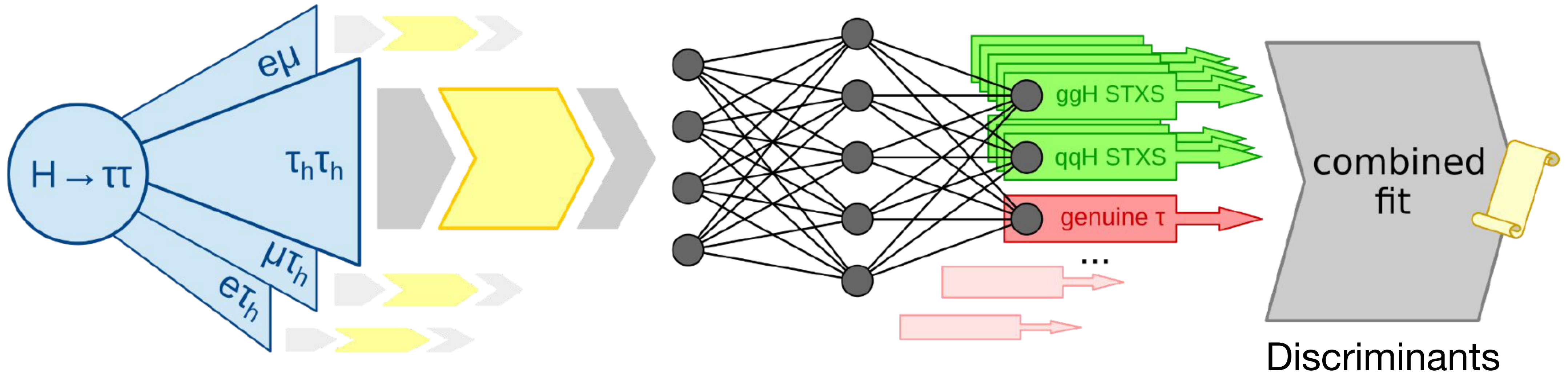
- $\tau_h\tau_h, \mu\tau_h, e\tau_h, e\mu$

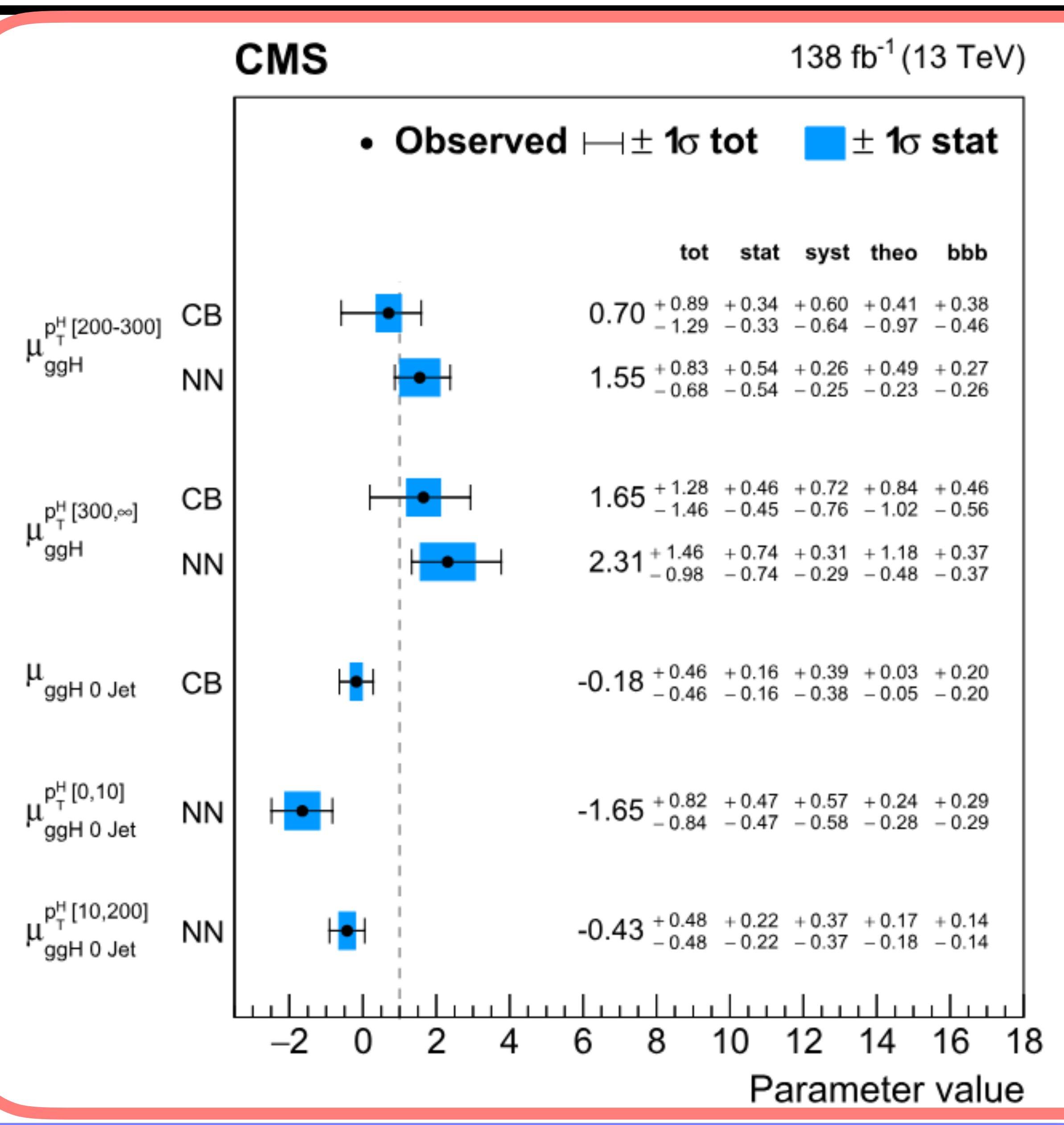
✳ Two analyses:

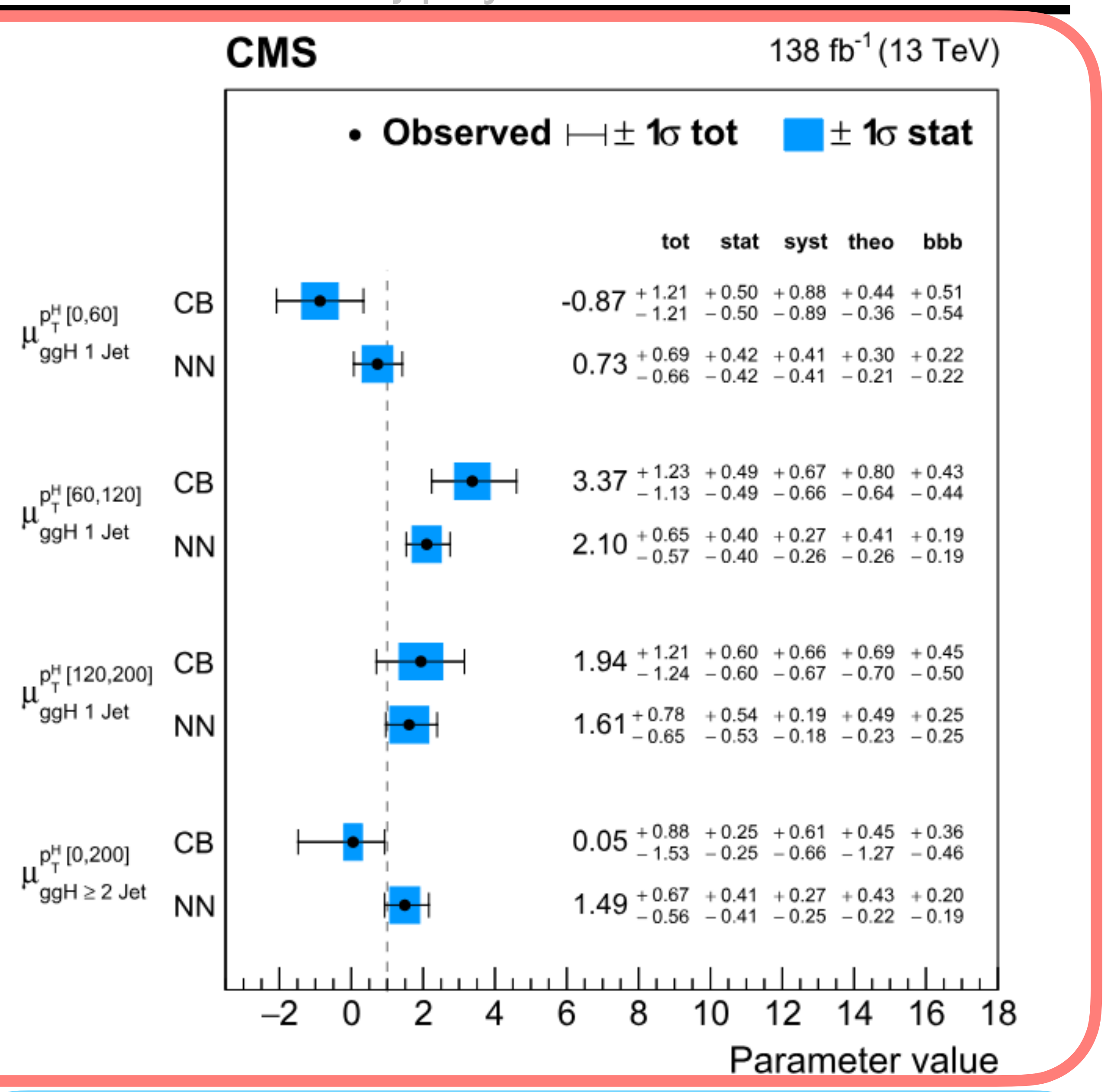
- Cut-based (S/B for event categorization)
- Neural Network (exploits **NN** event multiclassification)

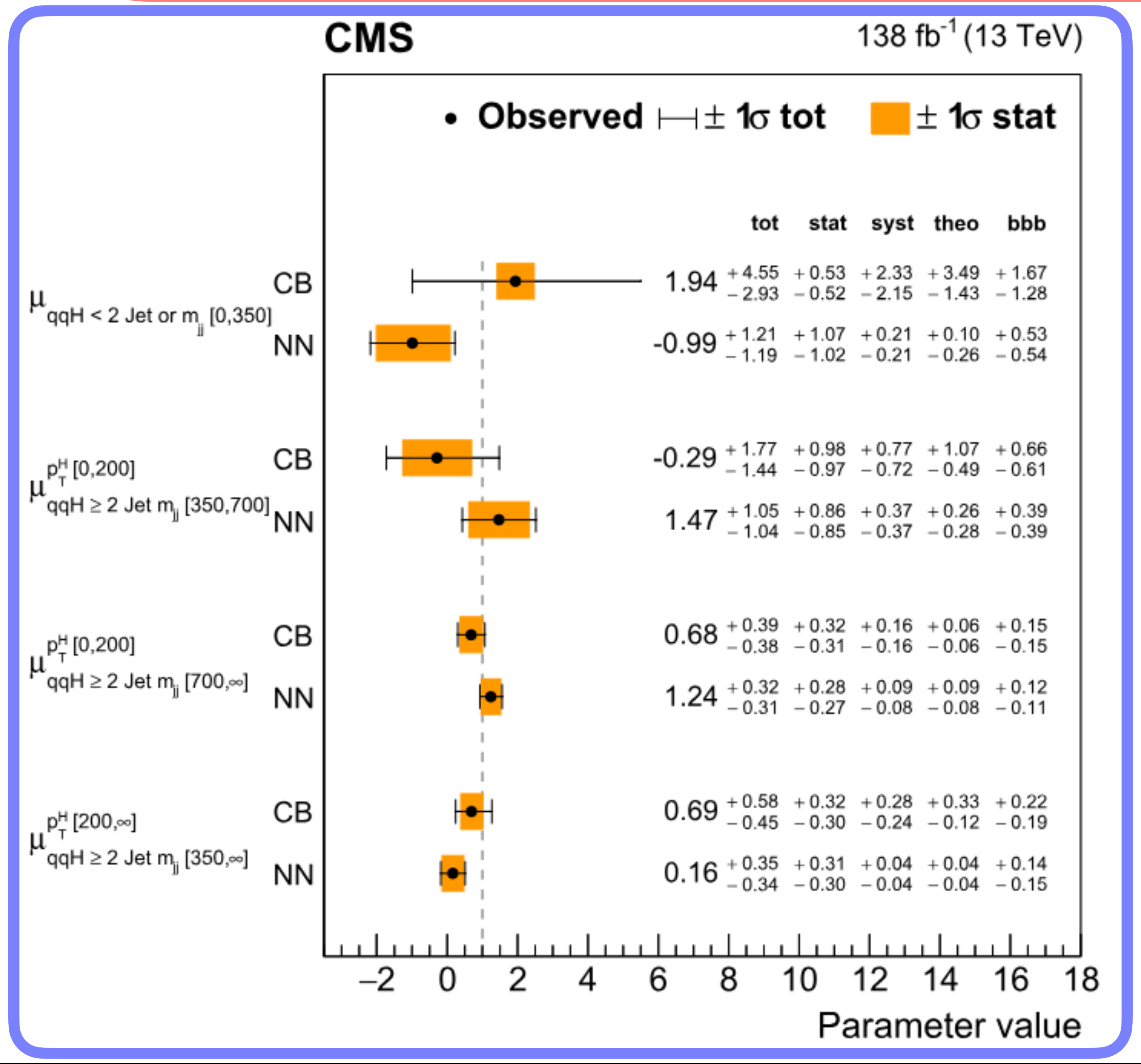
✳ Majority of background estimated from data

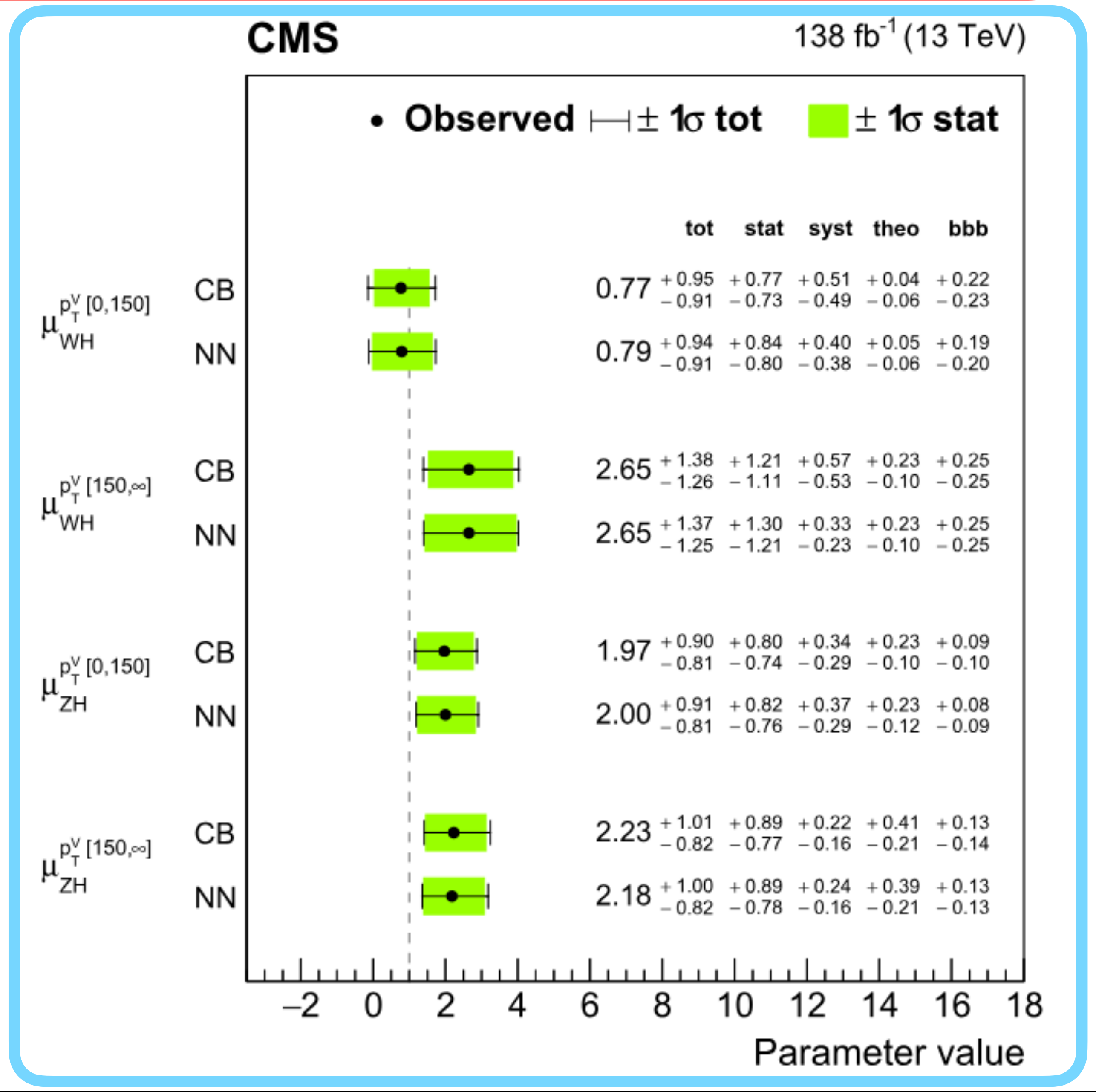
- Genuine $\tau\tau$ events: estimated using Tau Embedding
- Jet misidentified as τ_h: Fake factor (F_F) Method







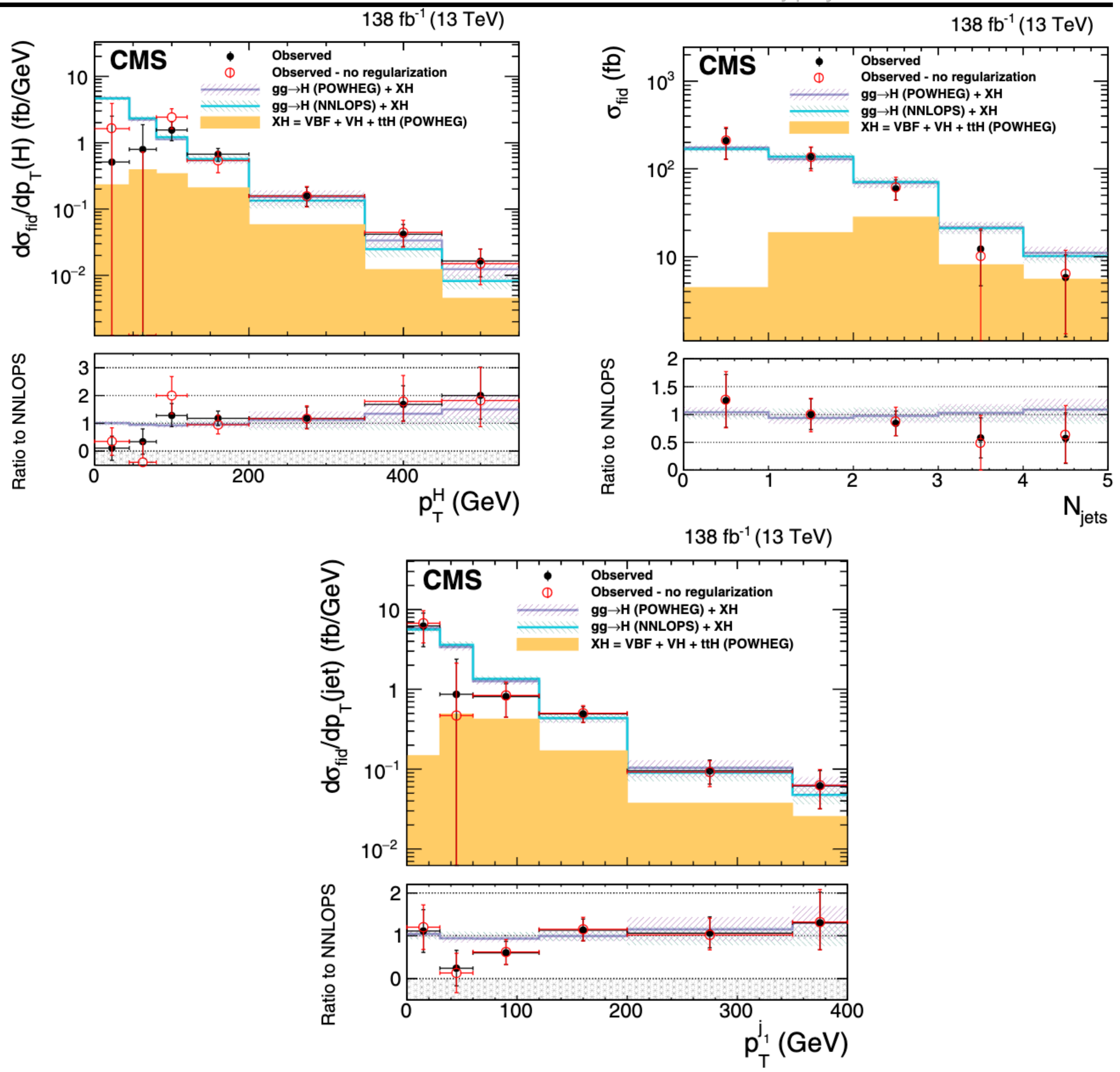




$H \rightarrow \tau\tau$: differential (resolved)

10.1140/epjc/s10052-023-11452-8
10.1103/PhysRevLett.128.081805
10.1016/j.physletb.2024.138964

- ✳ Measured in fiducial region defined to match the offline selection for each decay channel
  - "OutsideAcceptance" events fixed to SM and treated as background
- ✳ Reported Differential measurements
  - Observables (resolved) : p_T^H, N_{jets} and p_T^{j1}
  - Observables (boosted): p_T^H, $p_T^{j_1}$
    - Final observable is NN output
  - In agreement with SM



$H \to \tau\tau$: differential (boosted)

10.1140/epjc/s10052-023-11452-8
10.1103/PhysRevLett.128.081805
10.1016/j.physletb.2024.138964

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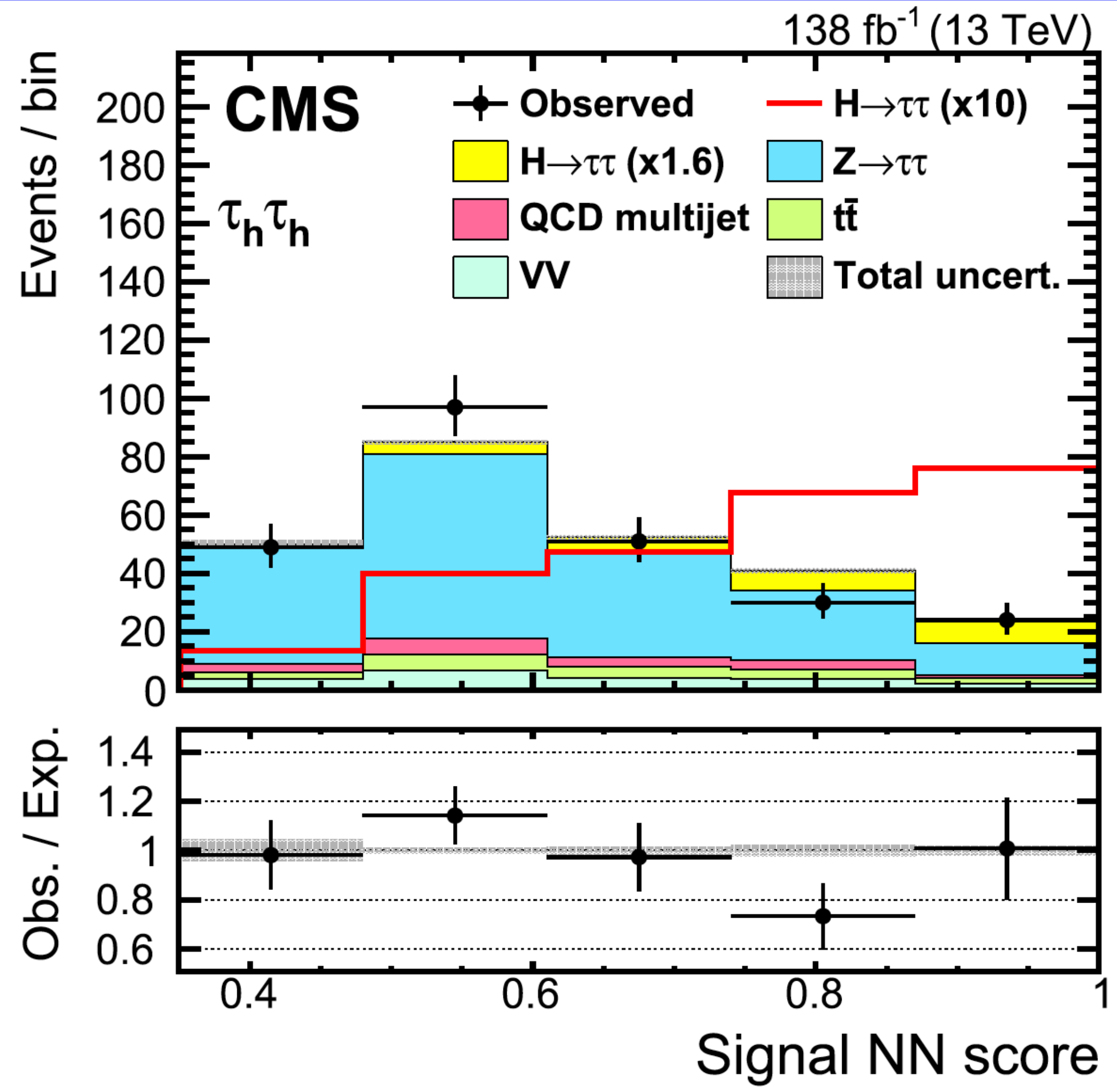
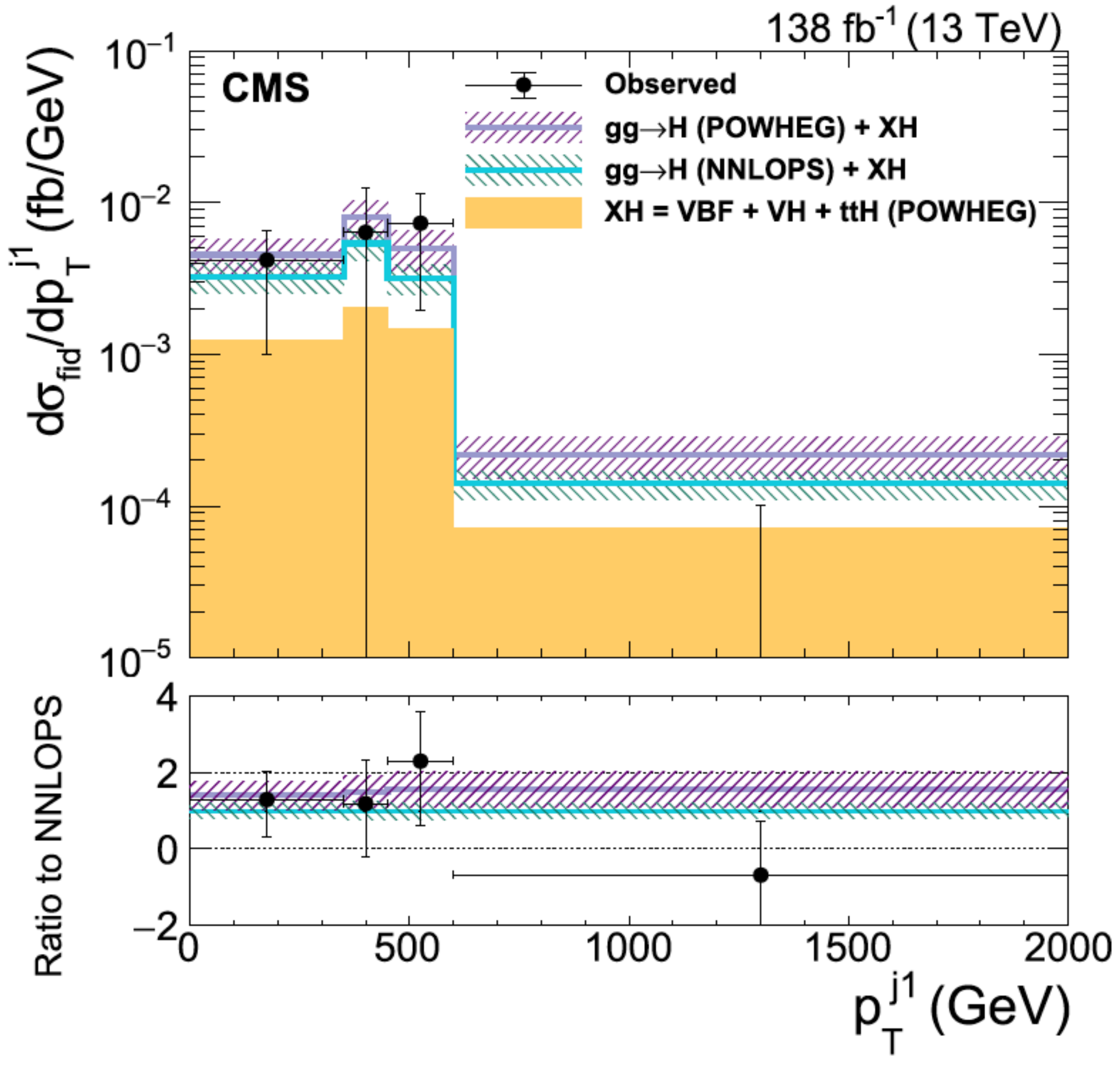
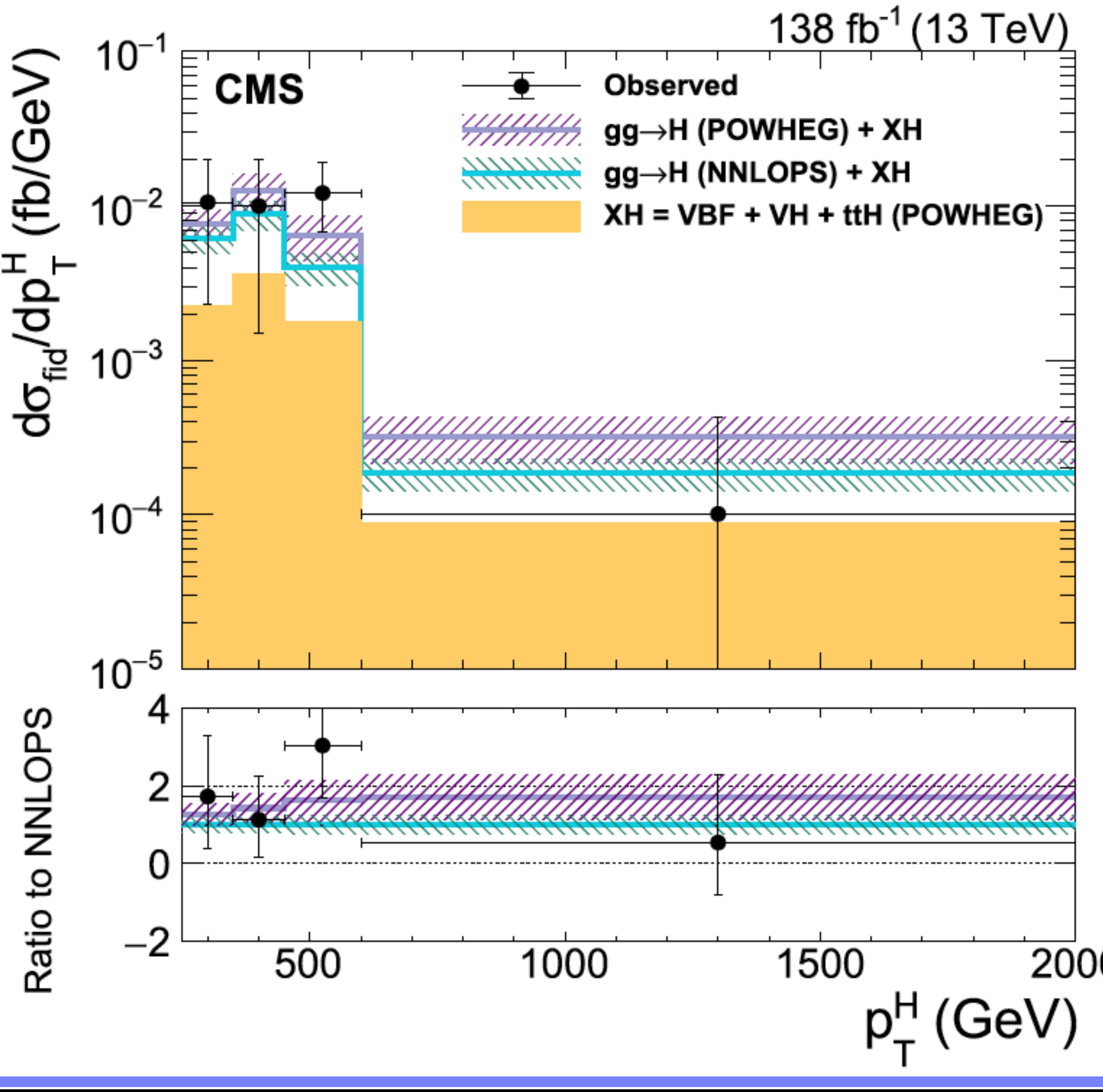






Combined measurements in $H \to X$ decays

CMS-PAS-HIG-23-013

✳ Combination of differential spectra in the analyses:

- $H \to \gamma\gamma$ (JHEP07(2023) 091), $H \to ZZ$ (JHEP08(2023) 040), $H \to WW$ (JHEP03(2021) 003), $H \to \tau\tau$ (Phys. Rev. Lett. 128, 081805), $H \to \tau\tau\ (boosted)$ arXiv:2403.20201

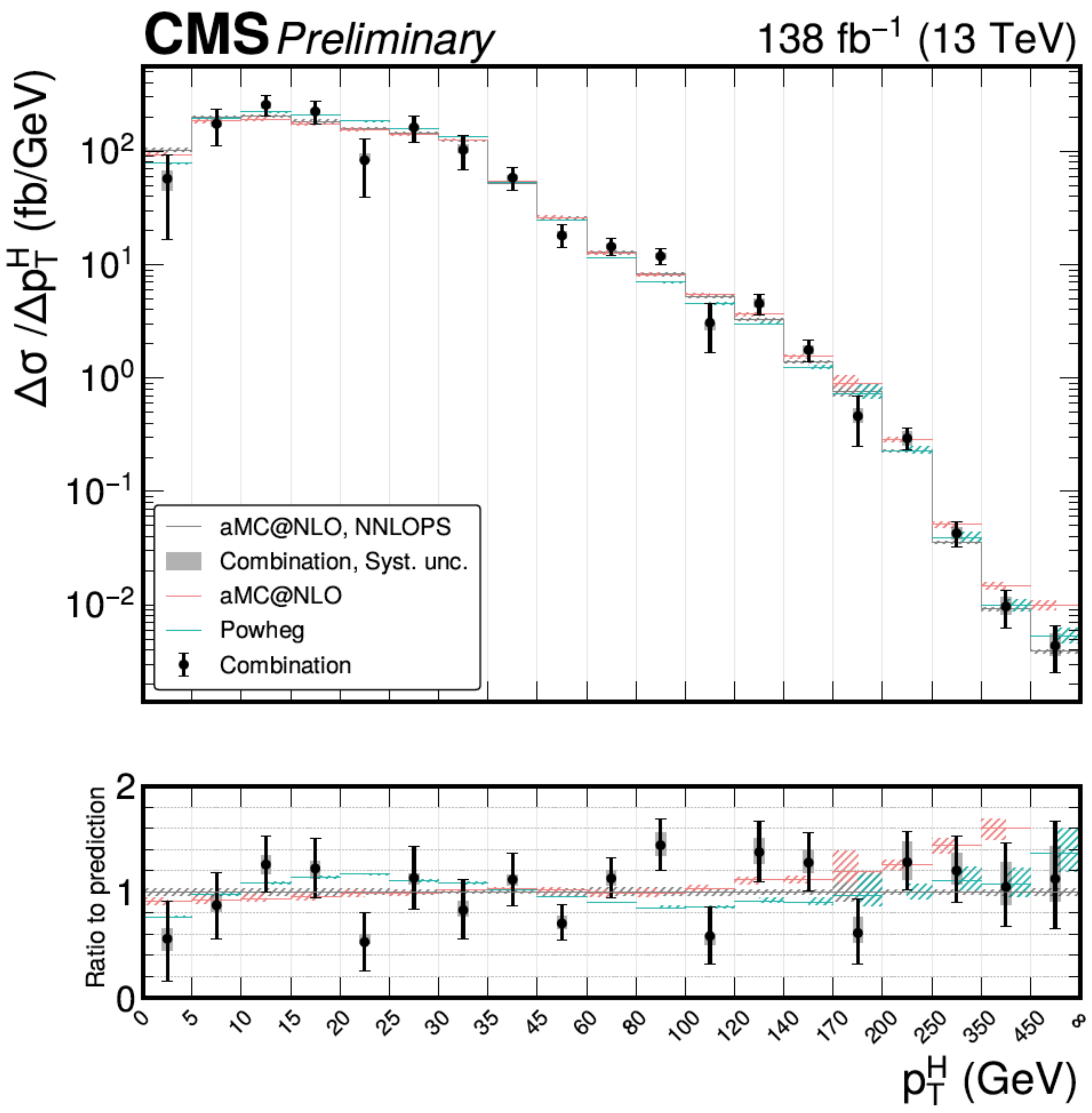
✳ Differential XS

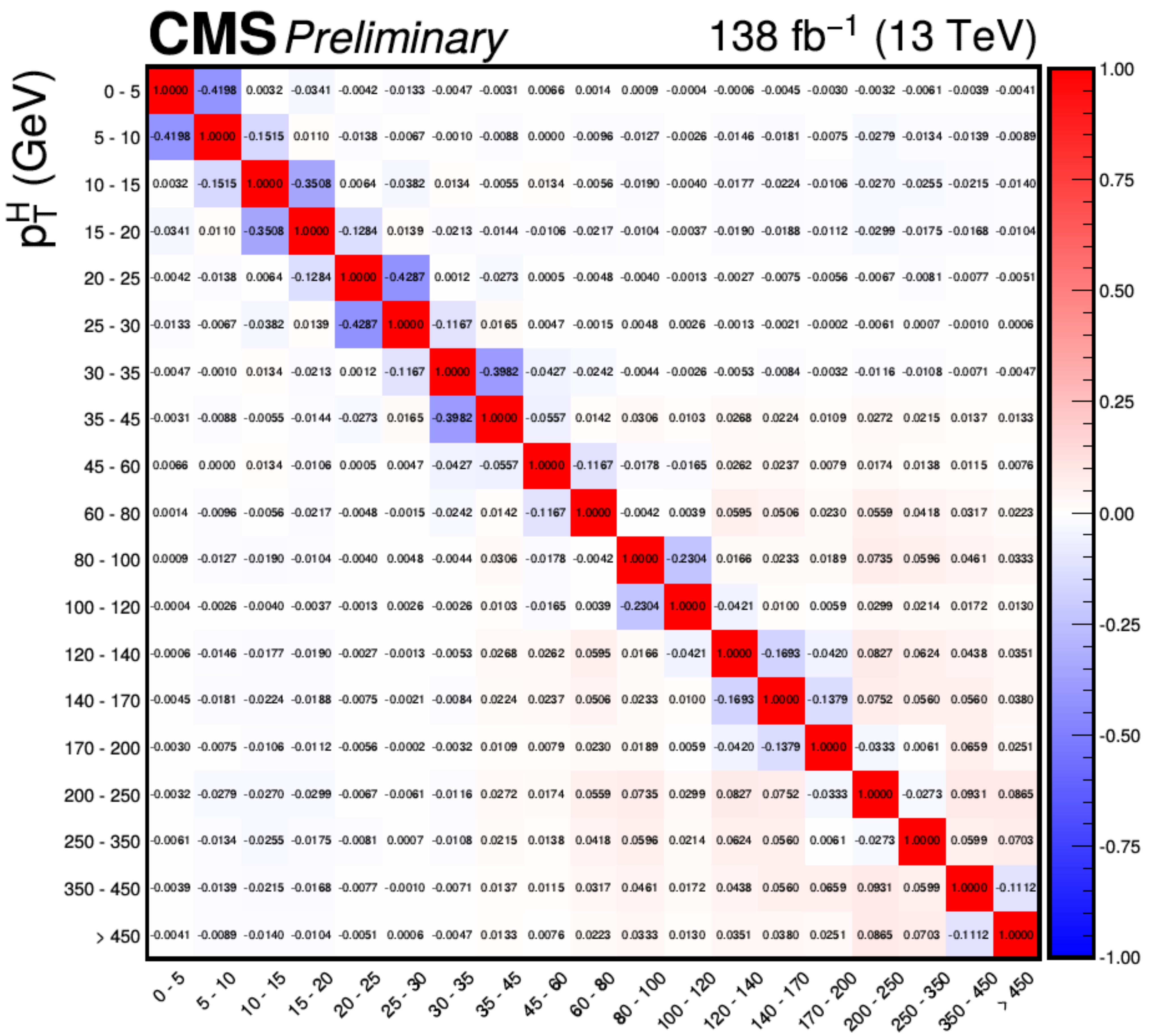
- Fit Strategy:
  - Measurements in input analyses performed in *different fiducial phase spaces*
    - μ is used across the *channels* (inclusive phase space)
- *Signal* models with differrent bin boundaries combined with a procedure
- Systematics:
  - Lumi, efficiencies, energy scale & resolution *correlated* among channels except:
    - τ energy scale and lepton efficiencies in $H \to \tau\tau$, $H \to \tau\tau(boosted)$, $H \to ZZ$

✳ Interpretation of differential distribution (p_T^H) observable

- SMEFT: SM with series of higher dimensional operators which are invariant under SU(3) x SU(2) x U(1) symmetry

$$\mathcal{L}_{\mathrm{SMEFT}} = \mathcal{L}_{\mathrm{SM}} + \sum_{j=0}^{2499} \frac{c_j^{(6)}}{\Lambda^2} O_j^{(6)}$$



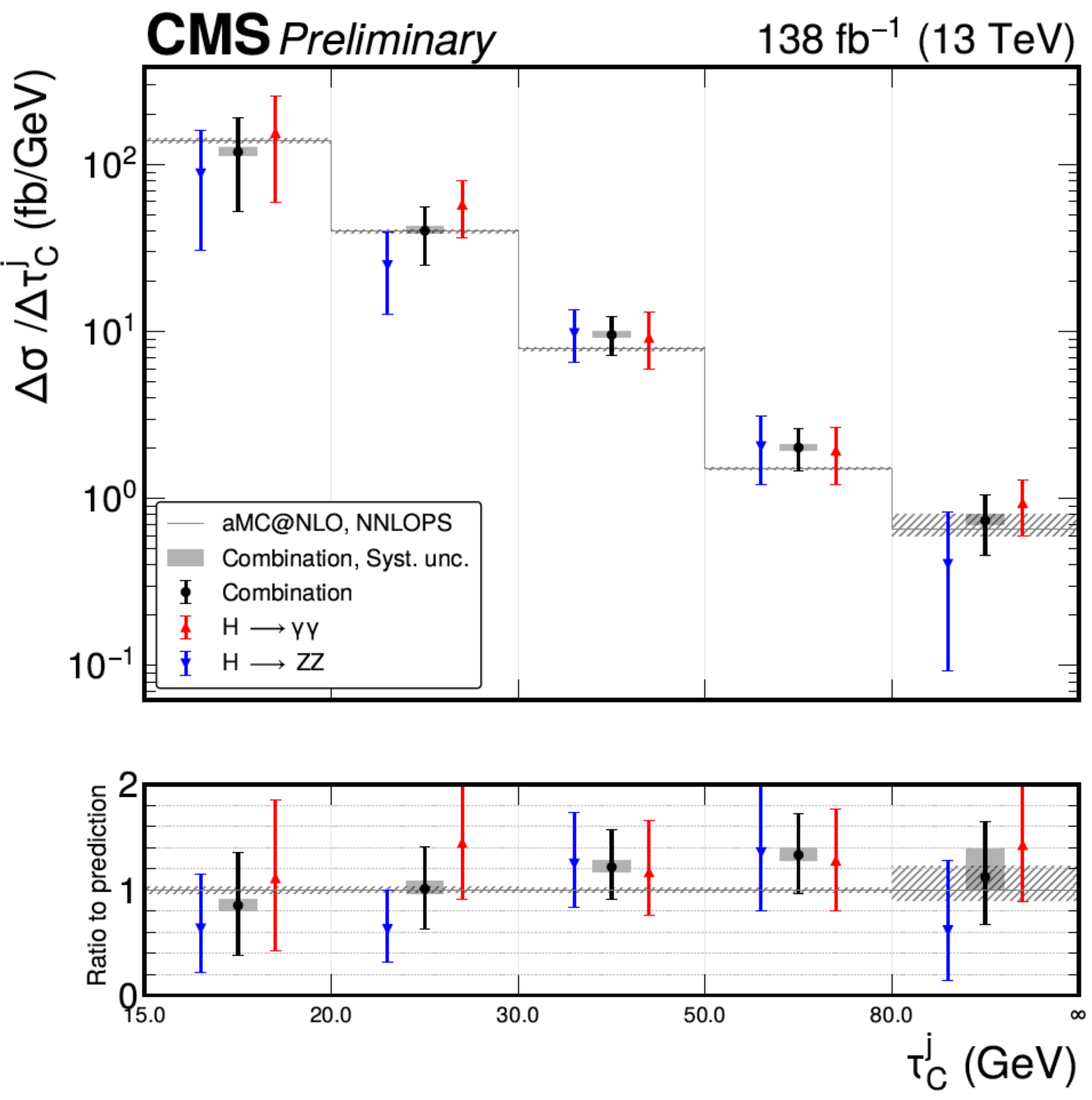


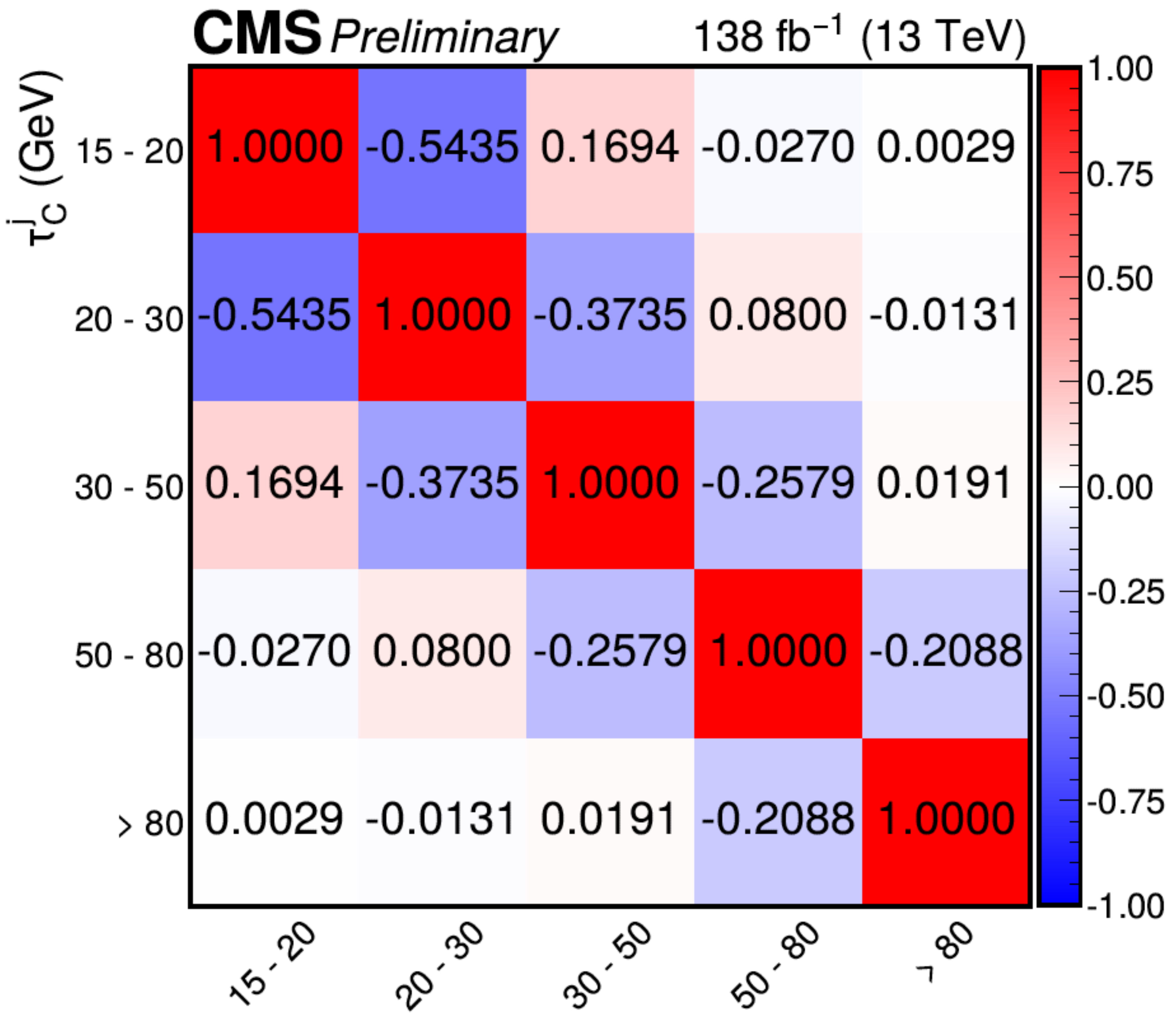
✳ Reported Differential measurements

- Observables: $p_T^H, N_{jets}, |y^H|, p_T^{j1}, m_{jj}, |\Delta\eta_{jj}|$ and τ_C^j

Combined measurements in $H \to X$ decays: Differential XS

CMS-PAS-HIG-23-013





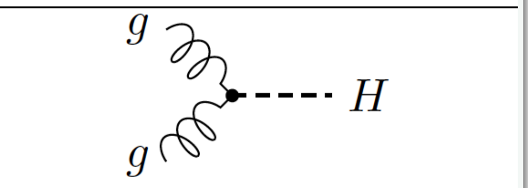
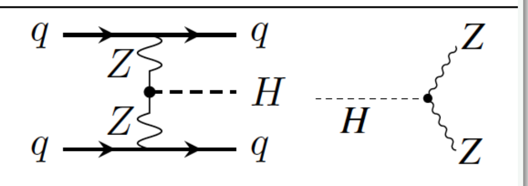
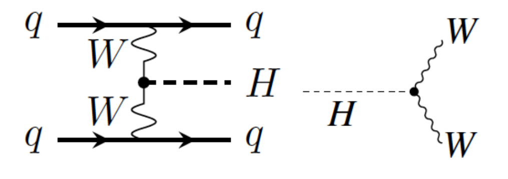
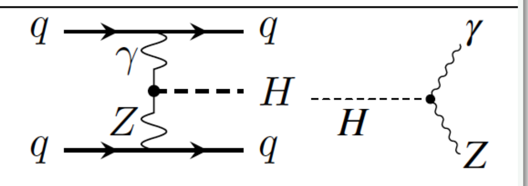
✴ Reported Differential measurements

- Observables: $p_T^H, N_{jets}, |y^H|, p_T^{j1}, m_{jj}, |\Delta\eta_{jj}|$ and τ_C^j *(see* backup slides *for other distributions)*

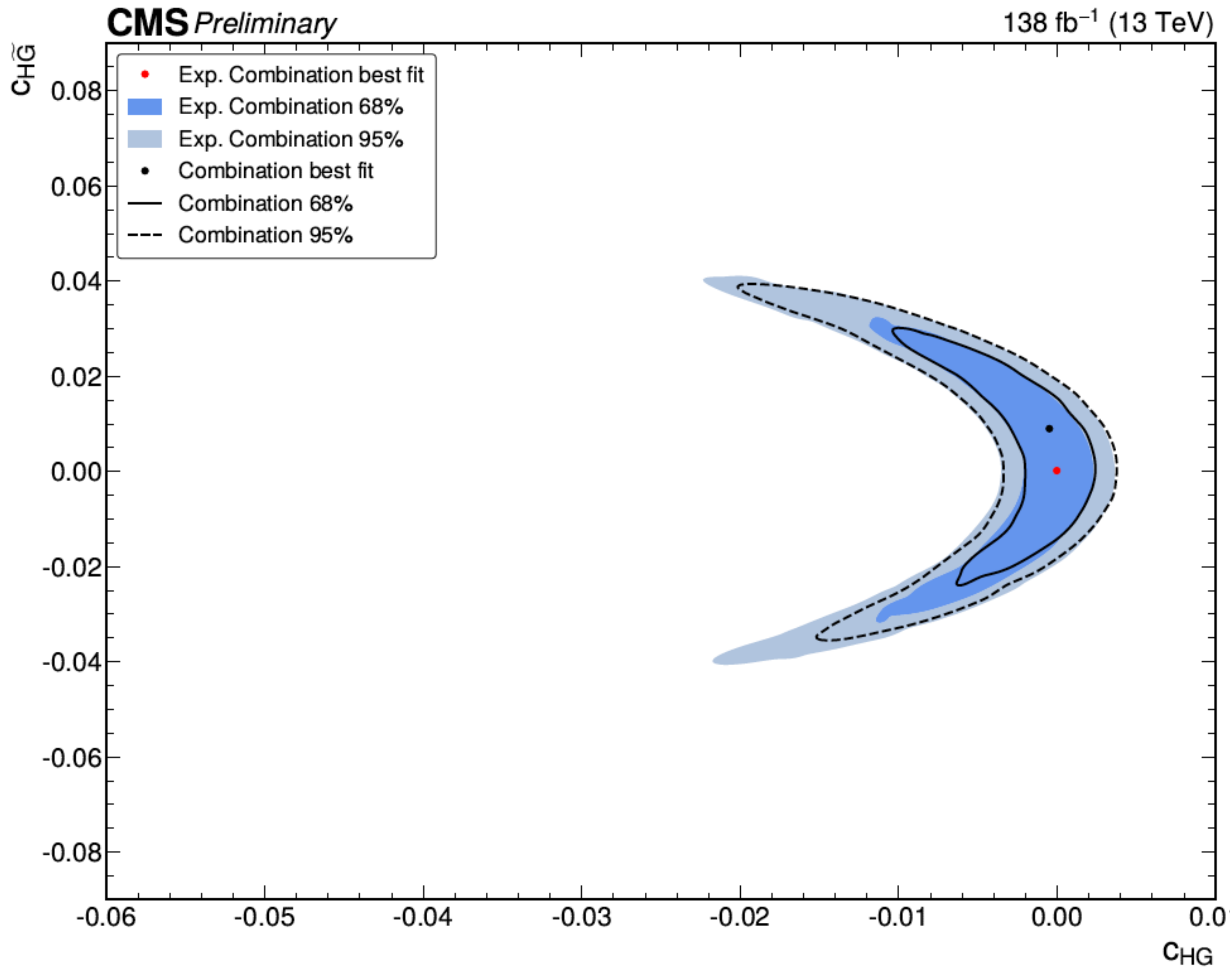
Combined measurements in $H \to X$ decays: Interpretation

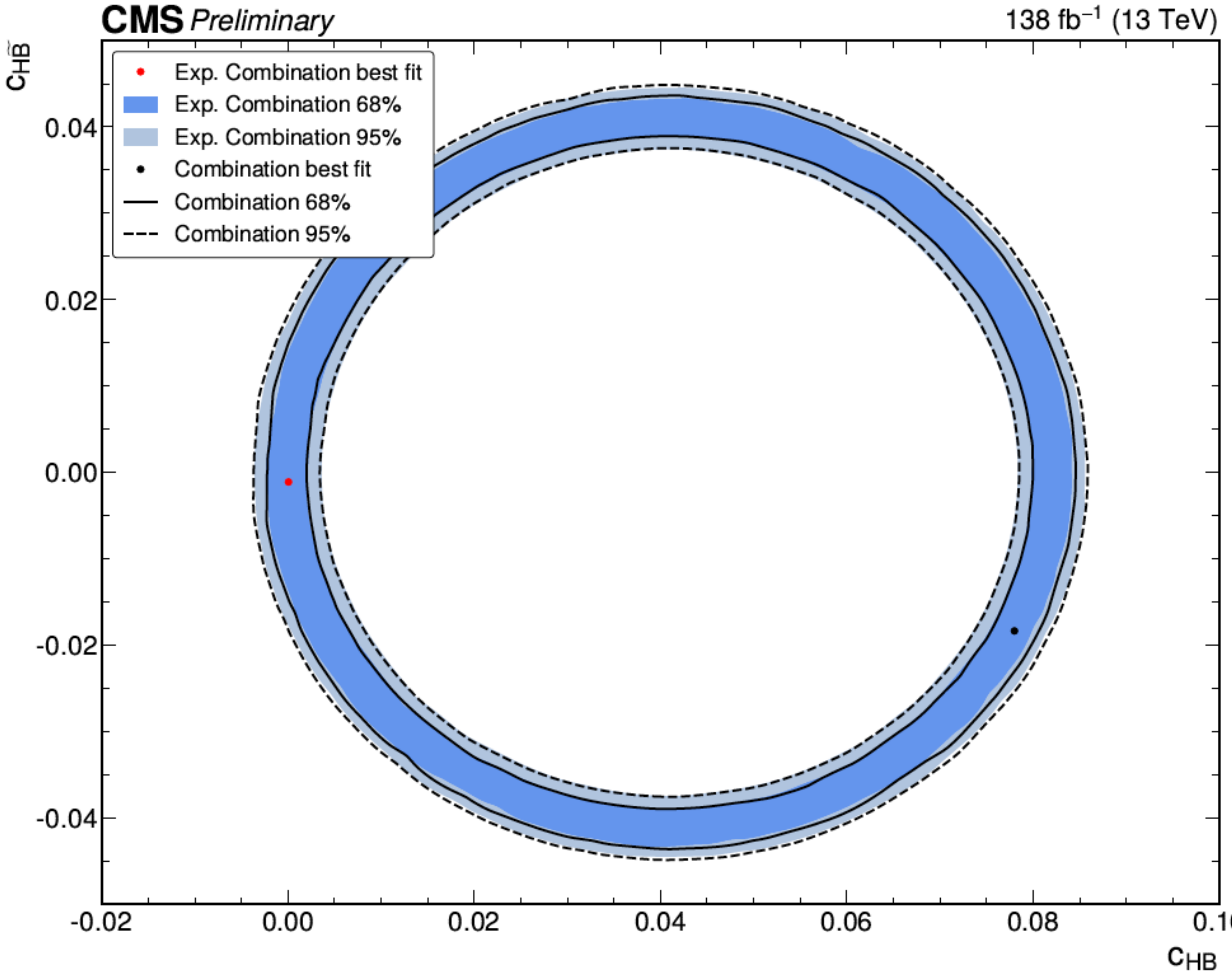
CMS-PAS-HIG-23-013

- ✳Observable being p_T^H (see slide 21)
- ✳Fit pairs of CP-even, CP-odd WCs while setting all other WC = 0 (SM)

Class	Operator	Wilson coefficient	Example process
$\mathcal{L}_6^{(4)} - X^2H^2$	$H^\dagger H G^a_{\mu\nu} G^{a\mu\nu}$	c_{HG}	
	$H^\dagger H \tilde{G}^a_{\mu\nu} G^{a\mu\nu}$	$\tilde{c}_{HG}$	
	$H^\dagger H B_{\mu\nu} B^{\mu\nu}$	c_{HB}	
	$H^\dagger H \tilde{B}_{\mu\nu} B^{\mu\nu}$	$\tilde{c}_{HB}$	
	$H^\dagger H W^i_{\mu\nu} W^{i\mu\nu}$	c_{HW}	
	$H^\dagger H \tilde{W}^i_{\mu\nu} W^{i\mu\nu}$	$\tilde{c}_{HW}$	
	$H^\dagger \sigma^i H W^i_{\mu\nu} B^{i\mu\nu}$	c_{HWB}	
	$H^\dagger \sigma^i H \tilde{W}^i_{\mu\nu} B^{i\mu\nu}$	$\tilde{c}_{HWB}$	

2D scans of Wilson Coefficients

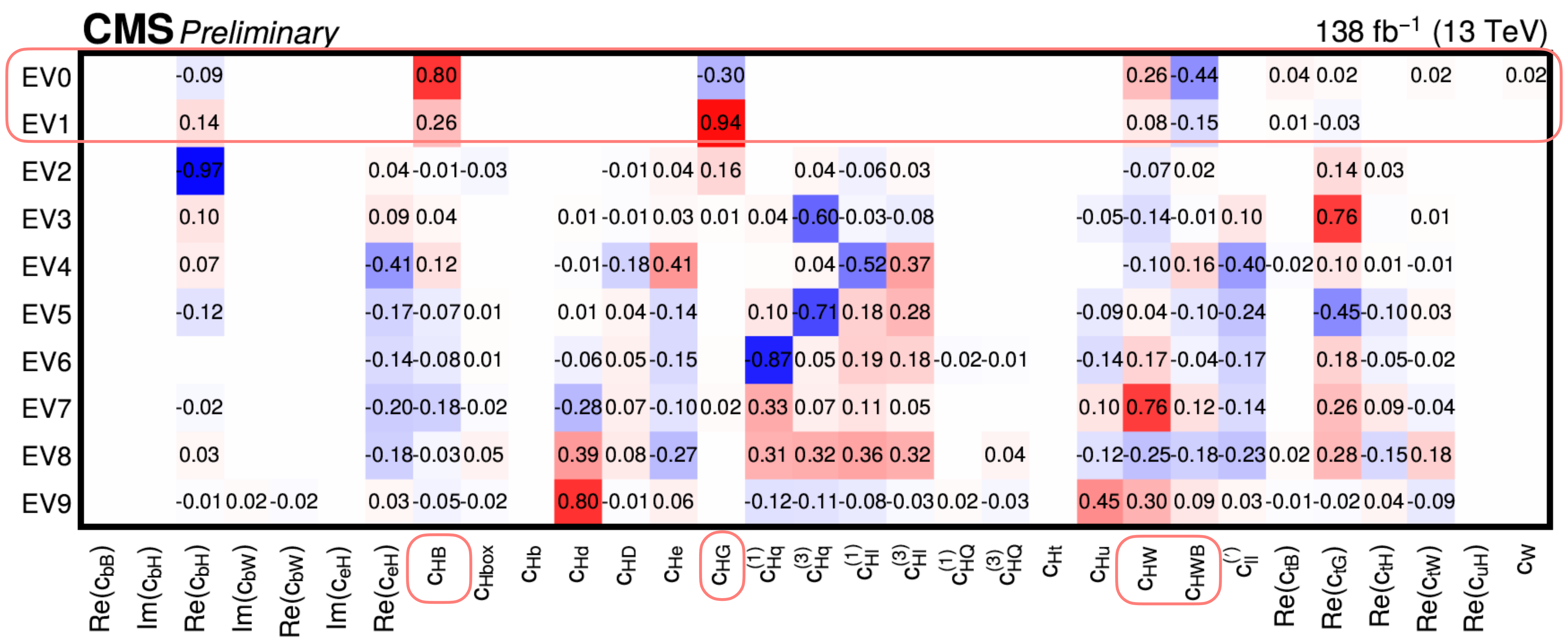


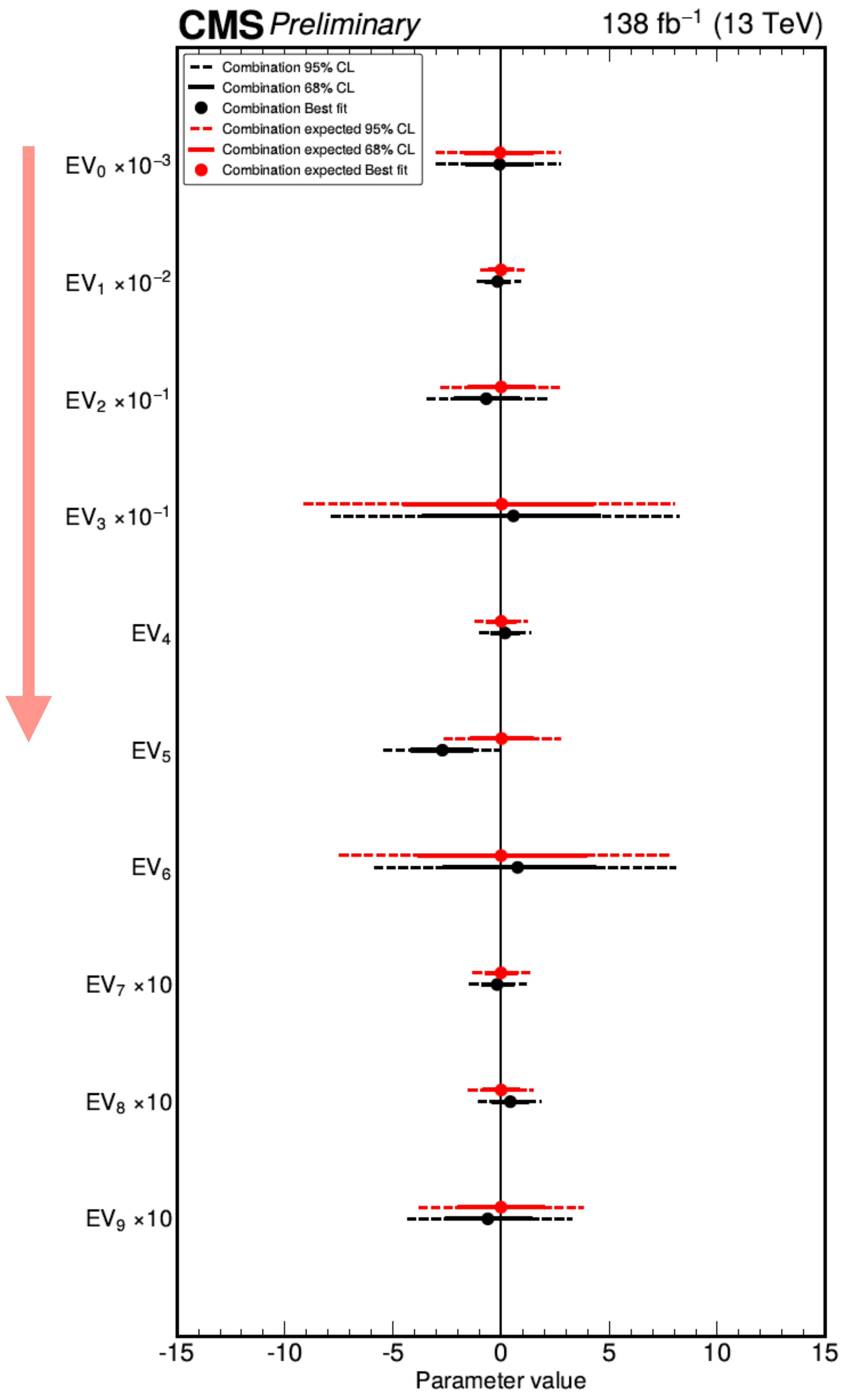


See also Hannah's talk

✳Constraints on linear combination of Wilson Coeficients:

- Define linear combinations of WCs to simultaneously constrain 10 directions in the parameter space





Absolute value signifies importance of WC in linear combination

Summary

✳Presented the recent Higgs cross sections measured in bosonic and fermionic final states

- Run Run3/2 CMS data
- Several fronts explored:
  - $STXS$, differential (compared with theory predictions) results
  - Differential Combination from several channels and the interpretation

✳Full Run 3 (+Run2) data would provide us the opportunity to explore more fine granularity to see the BSM effects (if any) in this regime


Thank
you

BACKUP SLIDES

$H \rightarrow \gamma\gamma$ measurement (early Run3 CMS data)

CMS-PAS-HIG-23-014

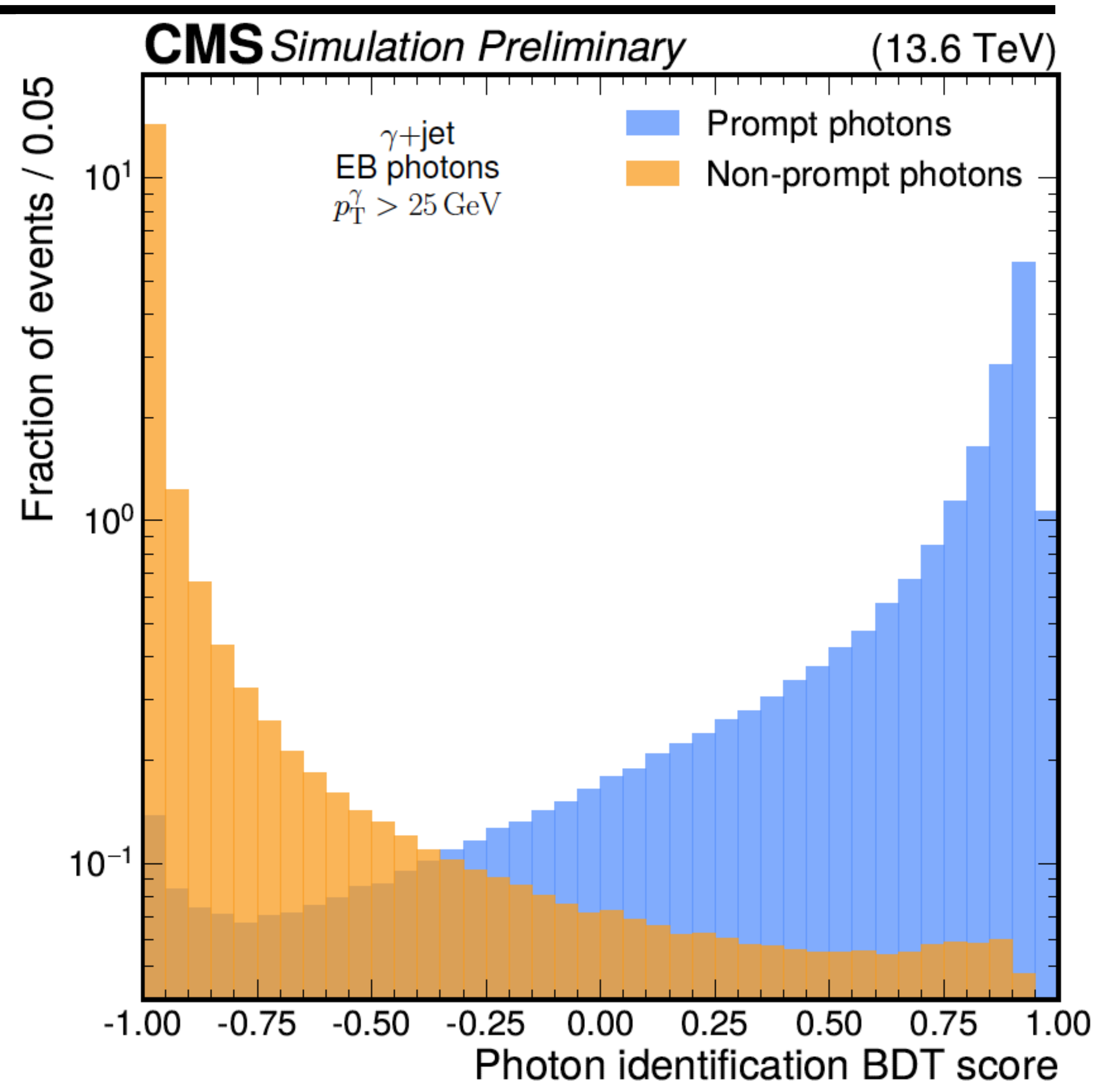
✳Overall, similar strategy in Run 2 and Run3

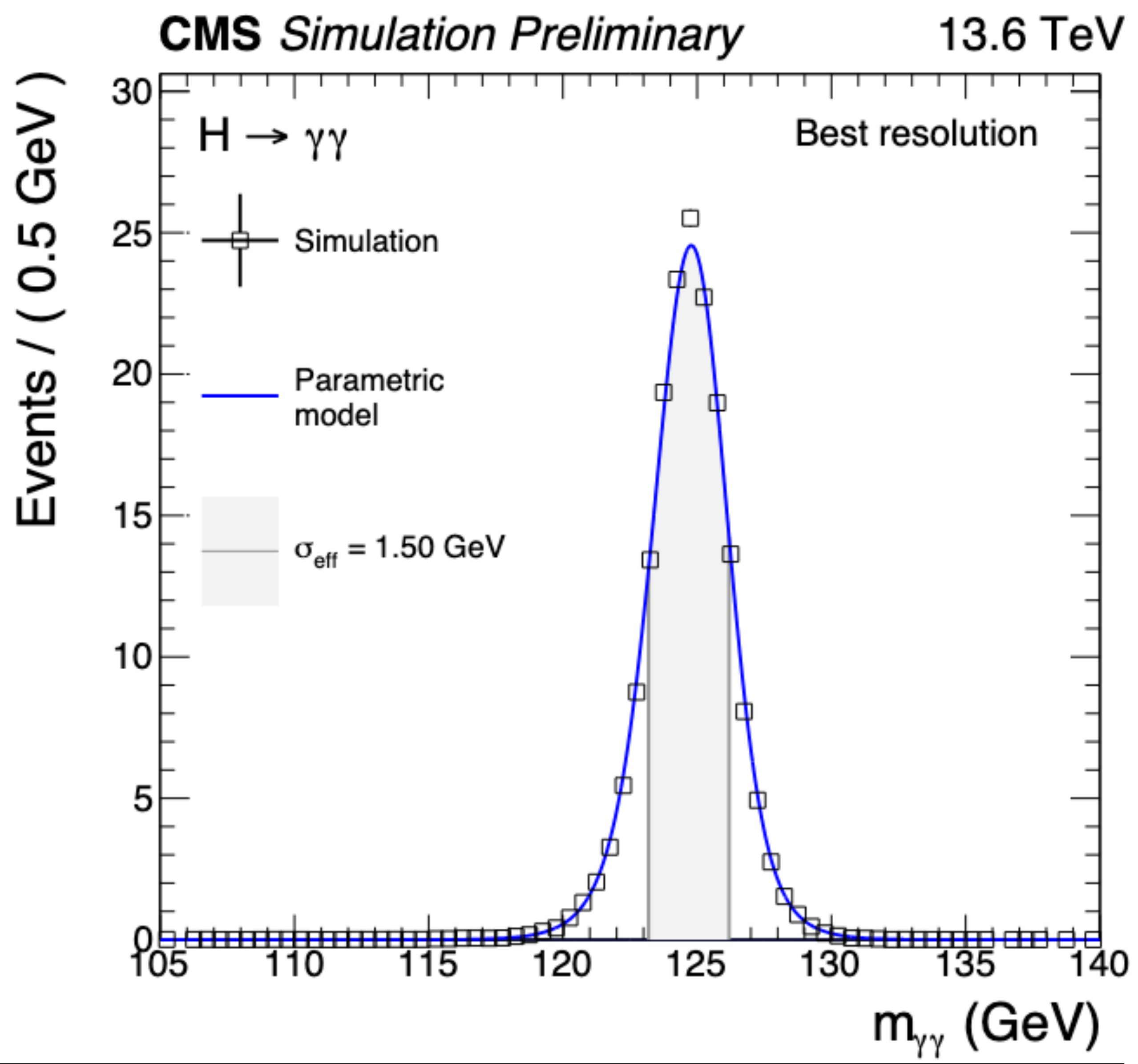
- Requirements on p_T^{γ}, η_{SC}, photon ID, and shower shape and isolation observables to match the HLT requirements
- Suppression of non-prompt photons with BDT
- In contrast to $H \rightarrow ZZ \rightarrow 4\ell$, lower S/B ratio
- However, excellent data-driven background estimation under the peak

✳Categorisation based on **mass resolution**

$$\frac{\sigma_m}{m} = \frac{1}{2}\sqrt{\left(\frac{\sigma_{E_1}}{E_1}\right)^2 + \left(\frac{\sigma_{E_2}}{E_2}\right)^2}$$

✳Inclusive and differential measurement





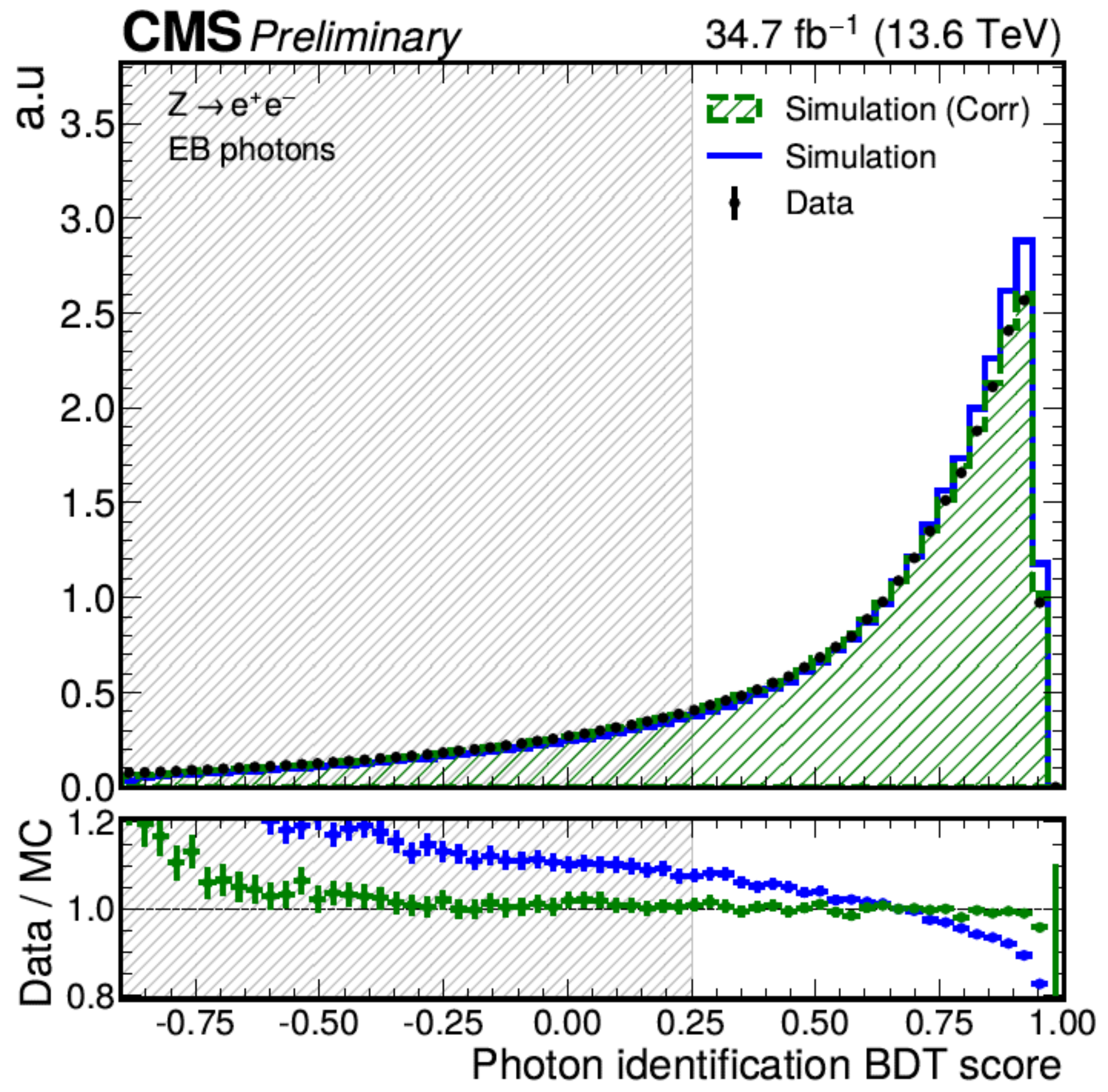
$H \to \gamma\gamma$: Corrections to Simulation

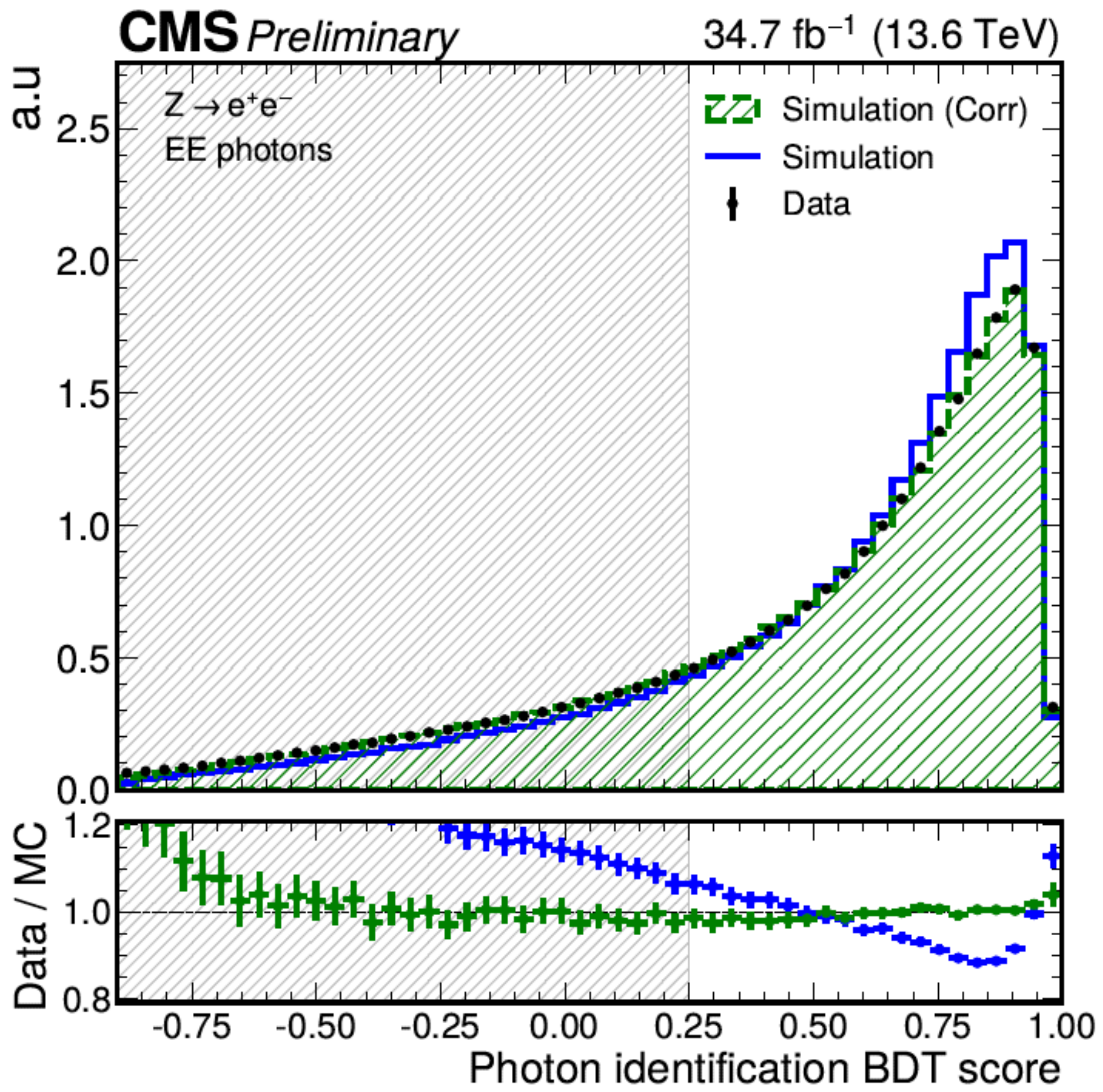
CMS-PAS-HIG-23-014

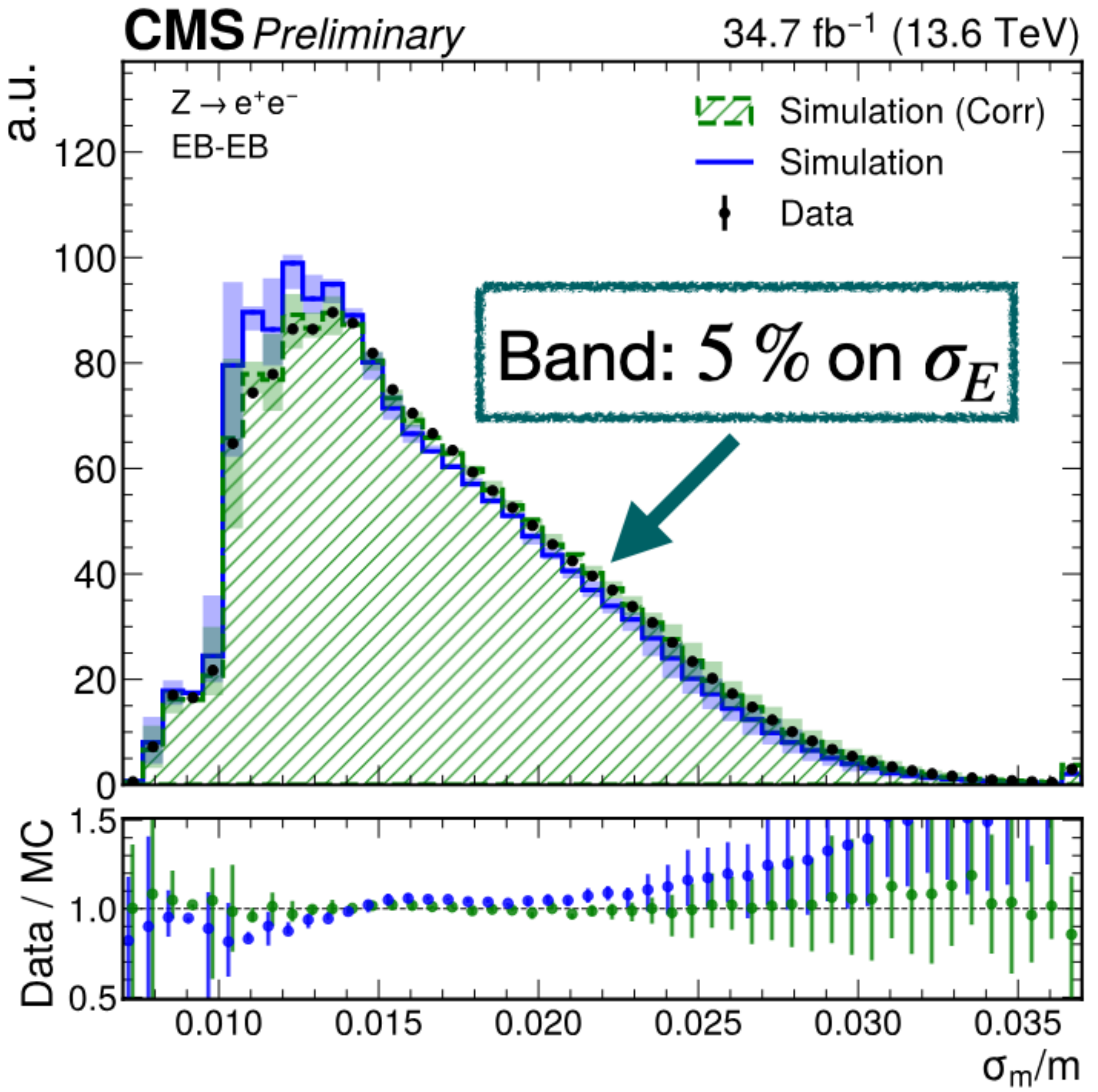
✳Disagreement in input variables for photon ID BDT propagates to output score

✳Corrected with single normalising flow (2403.18582) conditioned on kinematics **(new approach in Run3)**

- Trained using $Z \to ee$ probes, simplified compared to Run 2 BDT approach
- Excellent agreement after correction in ID score and also mass resolution







(Boosted VBF/ggH) $H \rightarrow bb$: Analysis Strategy

[CMS-PAS-HIG-21-020]

✳ Higgs at large pT (>450 GeV considered)

- To probe BSM effects in scalar sector, test higher-order EW radiative corrections in H production

✳ Generalized energy correlation functions for 2-prong (W/Z/H) tagging [JHEP 1612 (2016) 53]

- Mass-decorrelated version; using the Designed Decorrelated Tagger method [JHEP 1605 (2016) 156]

✳ Updated multivariate Deep Double B-Tagger (DDB)

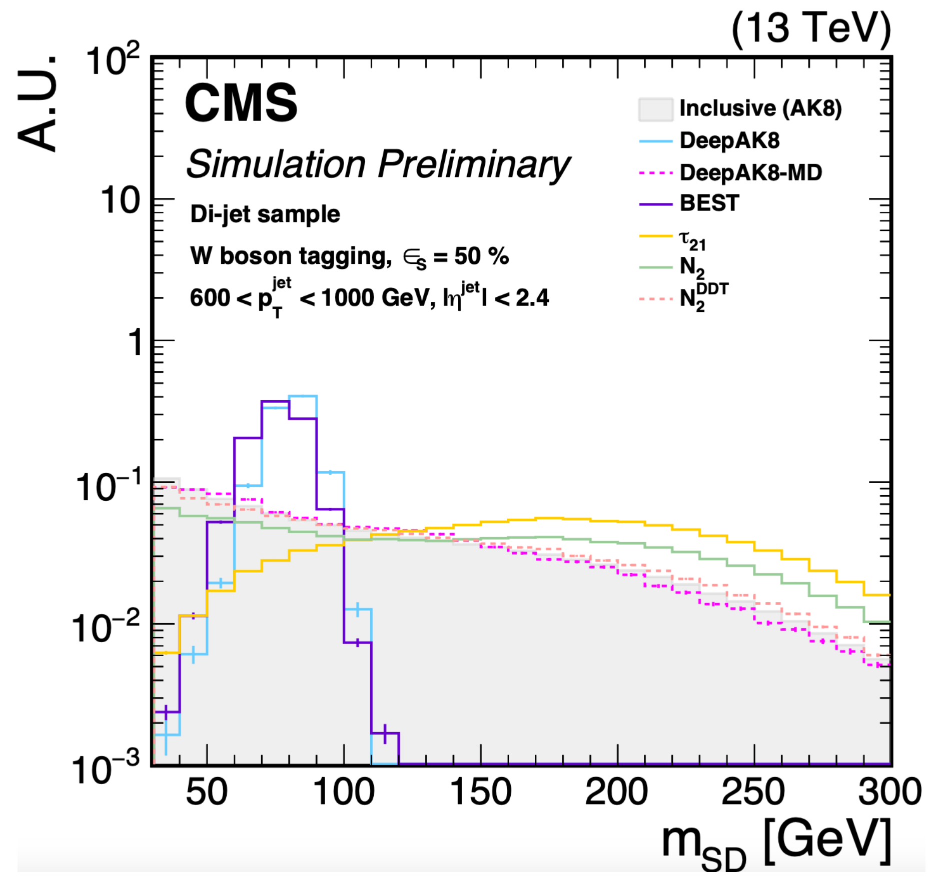
- Signal significance increased by twice

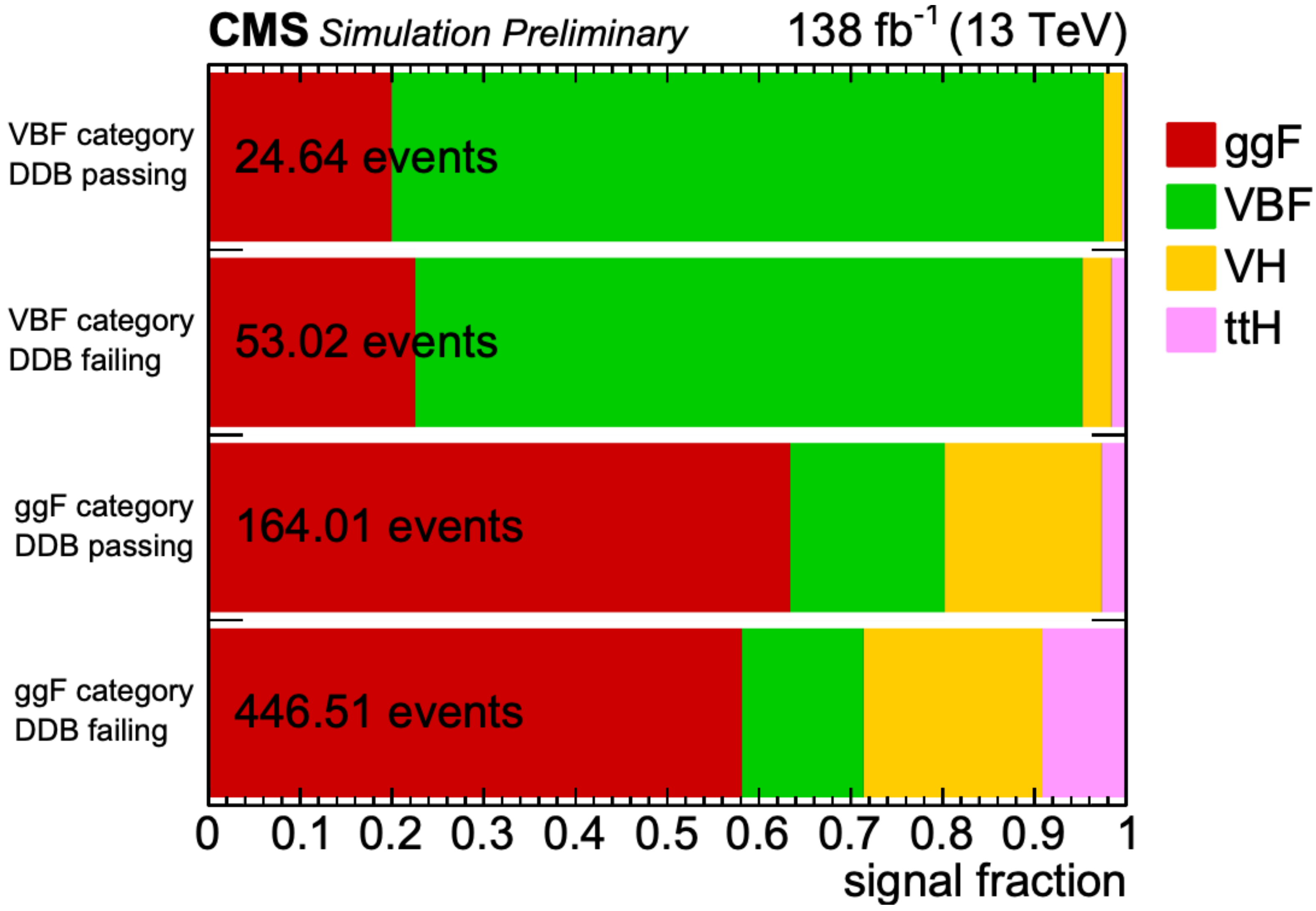
✳ Jet substructure and novel b-tagging (DDB fail region) to reject QCD

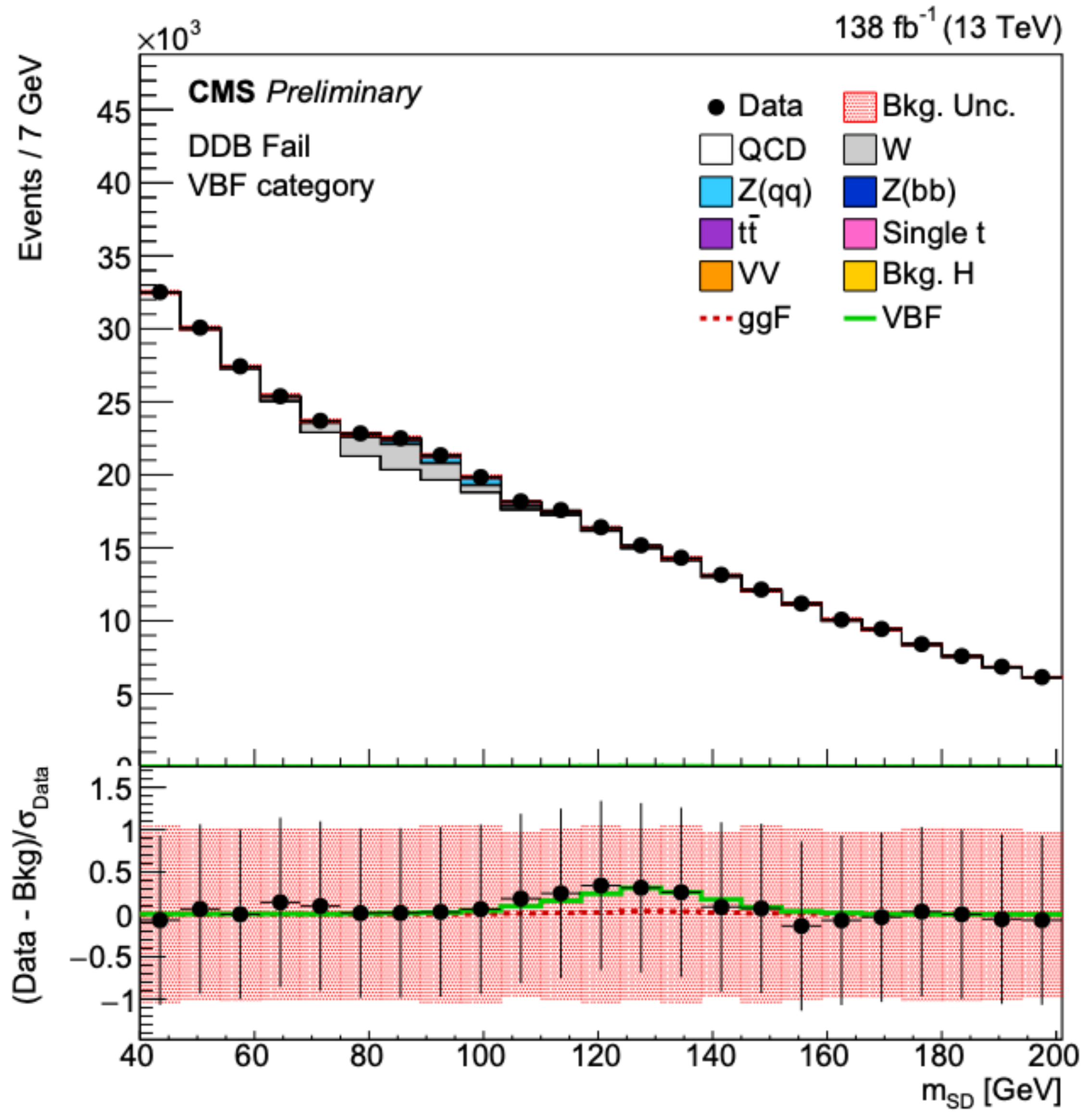
✳ ML fit to the observed m_{SD} distributions for ggH and VBF

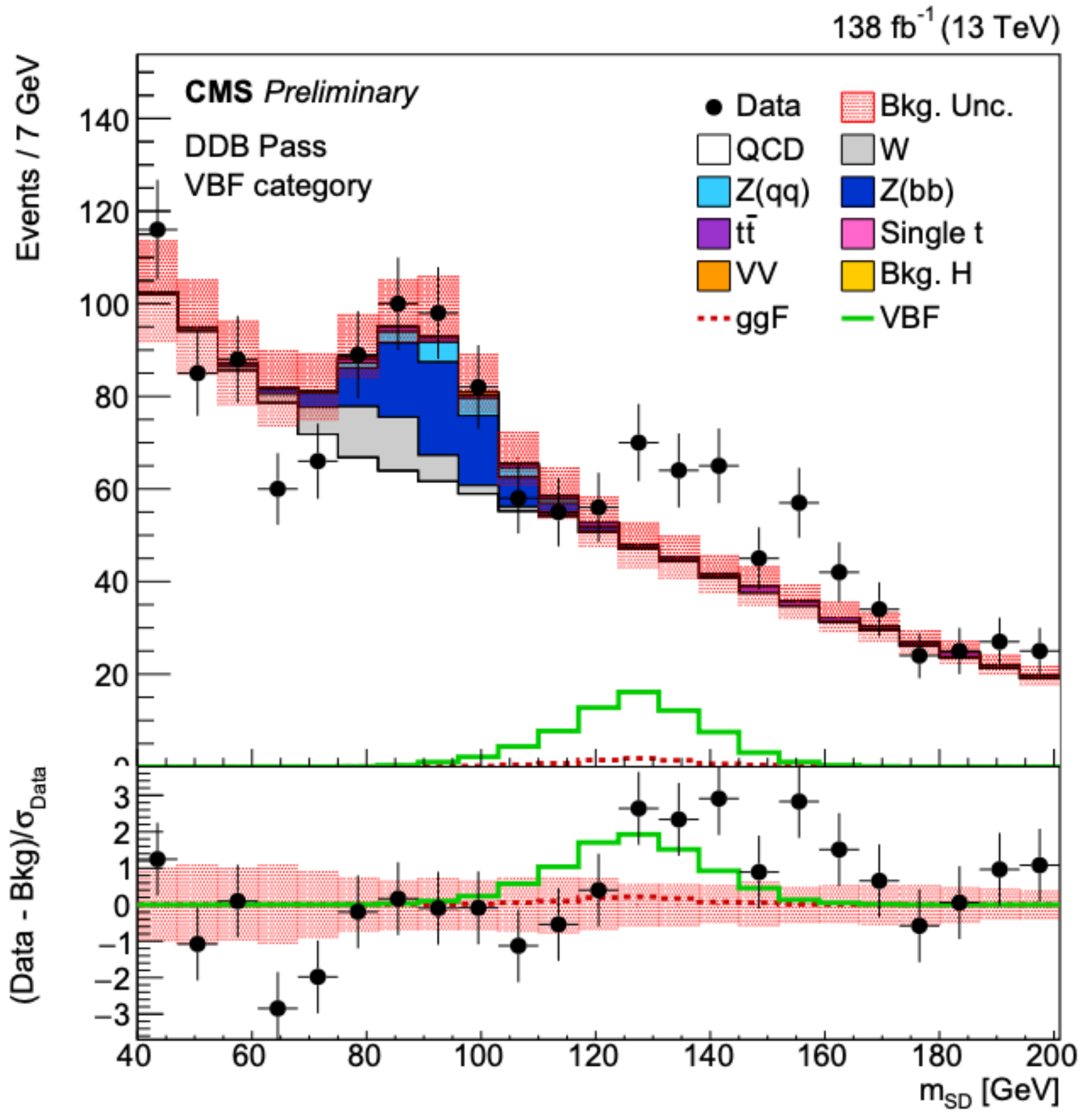
✳ W and Z boson resonances used to constraint syst. unc.

CMS-PAS-JME-18-002







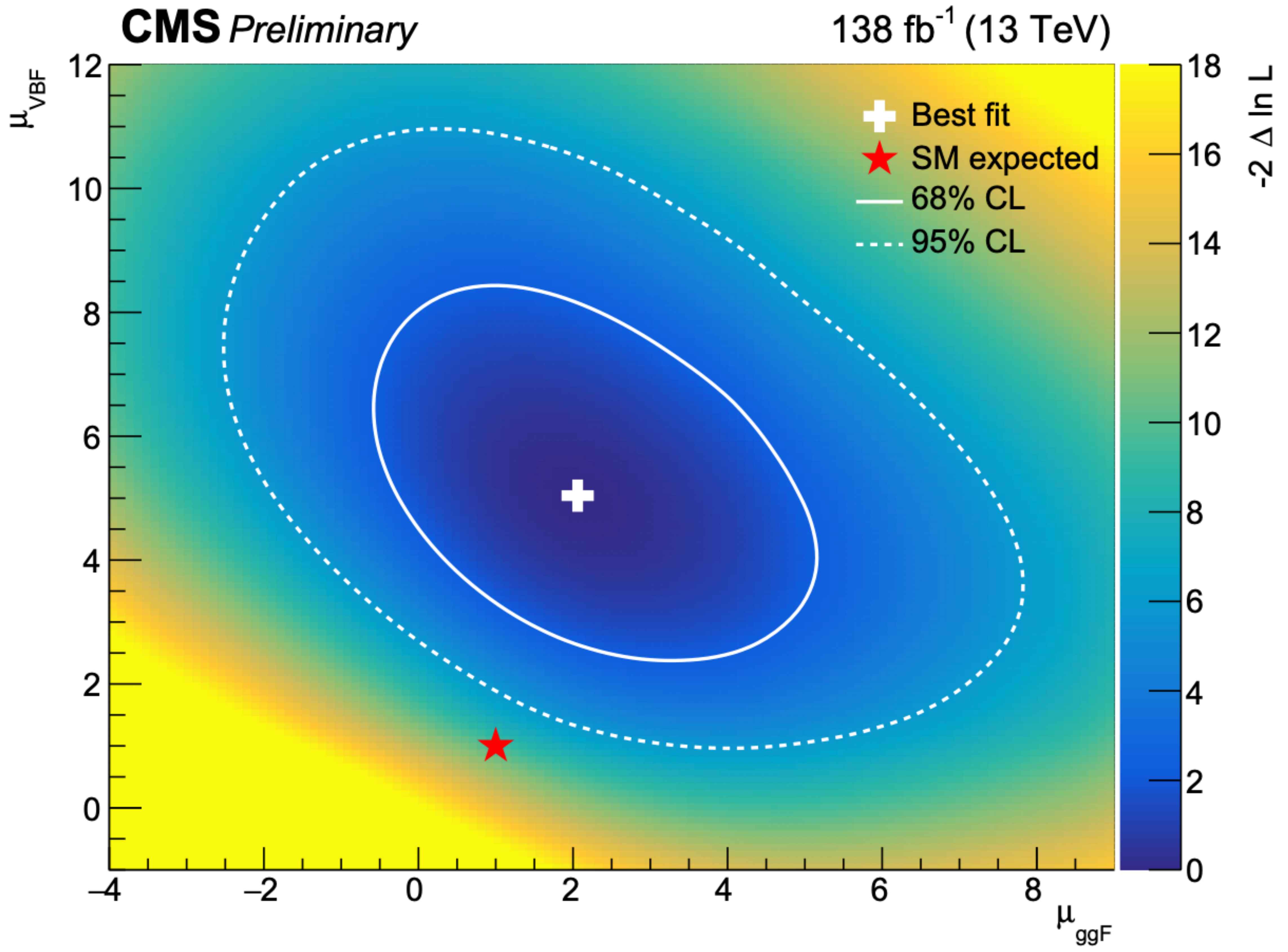


(Boosted VBF/ggH) $H \rightarrow bb$: Results

[CMS-PAS-HIG-21-020]

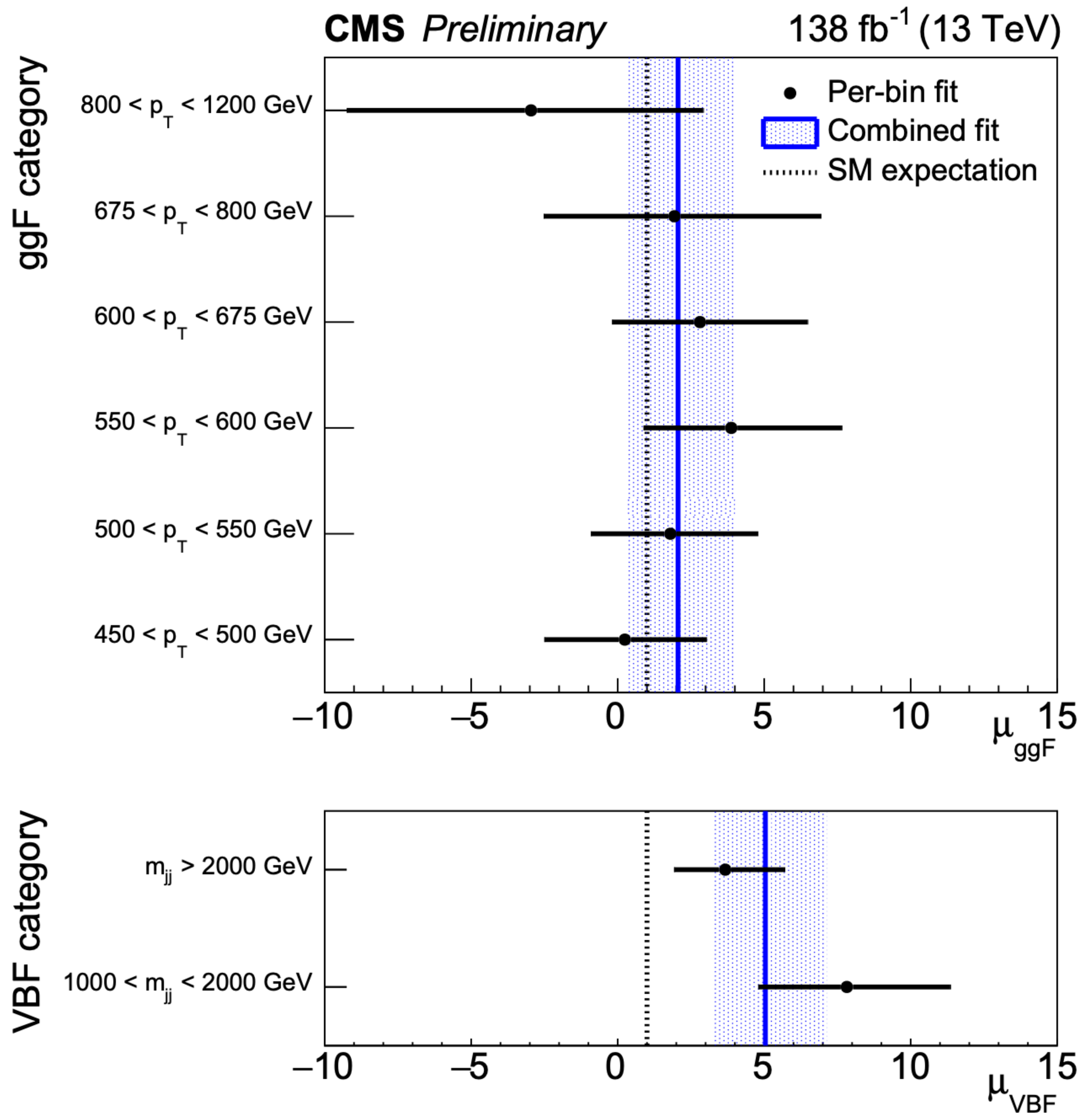
✳Observed inclusive Signal Strengths:

- VBF process: $5.0^{+2.1}_{-1.8}$ [obs(exp.) → 3.0σ (0.9σ)]
- ggF process: $2.1^{+1.9}_{-1.7}$ [obs(exp.) → 1.2σ (0.9σ)]



✳Observed differential Signal strengths:

- In p_T bins for ggF
- Inv. mass of forward jets for VBF



$H \to \tau\tau$: Results (differential)

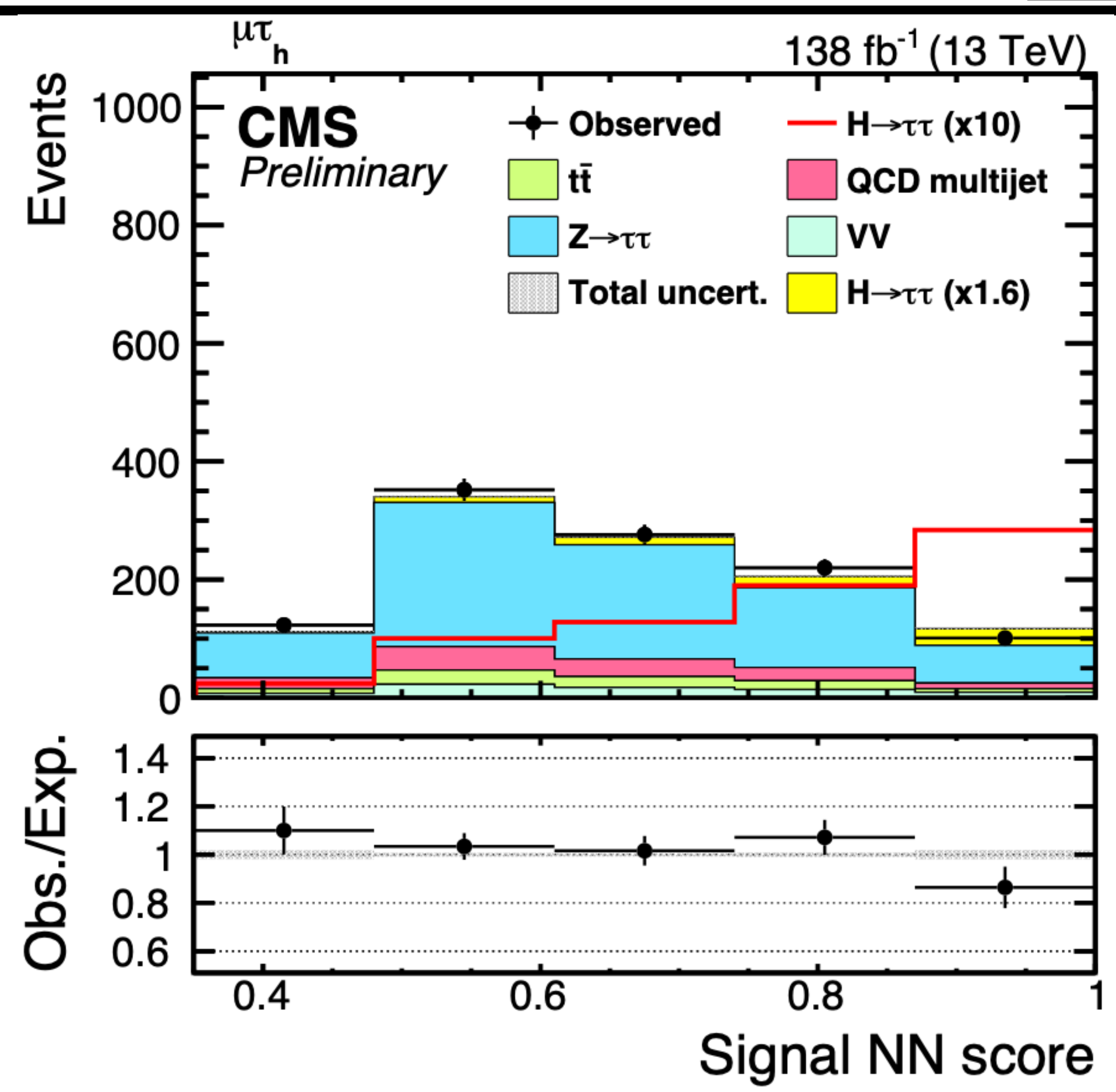
10.1140/epjc/s10052-023-11452-8
10.1103/PhysRevLett.128.081805
CMS-PAS-HIG-21-017

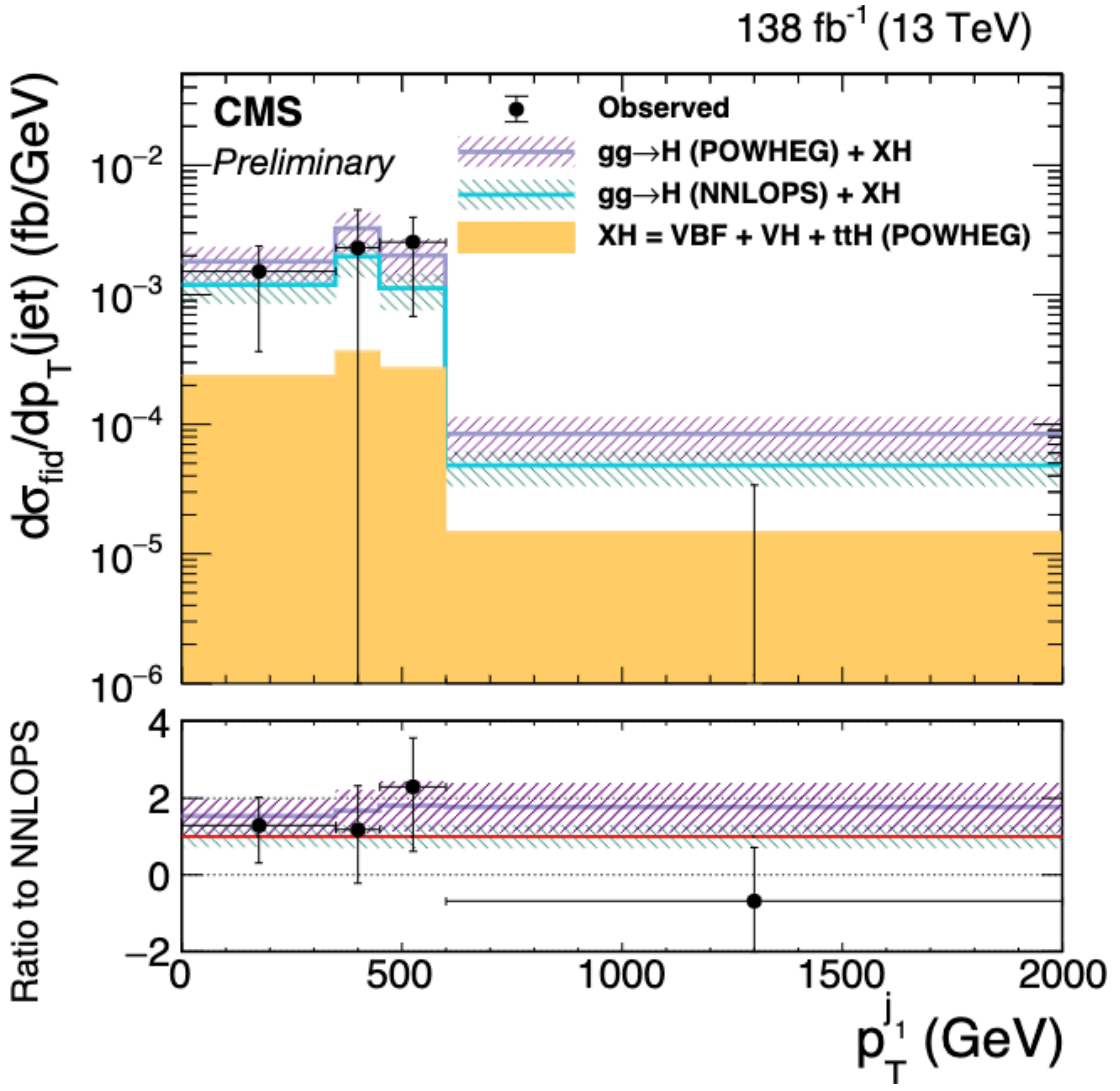
✳ Measured in fiducial region defined to match the offline selection for each decay channel

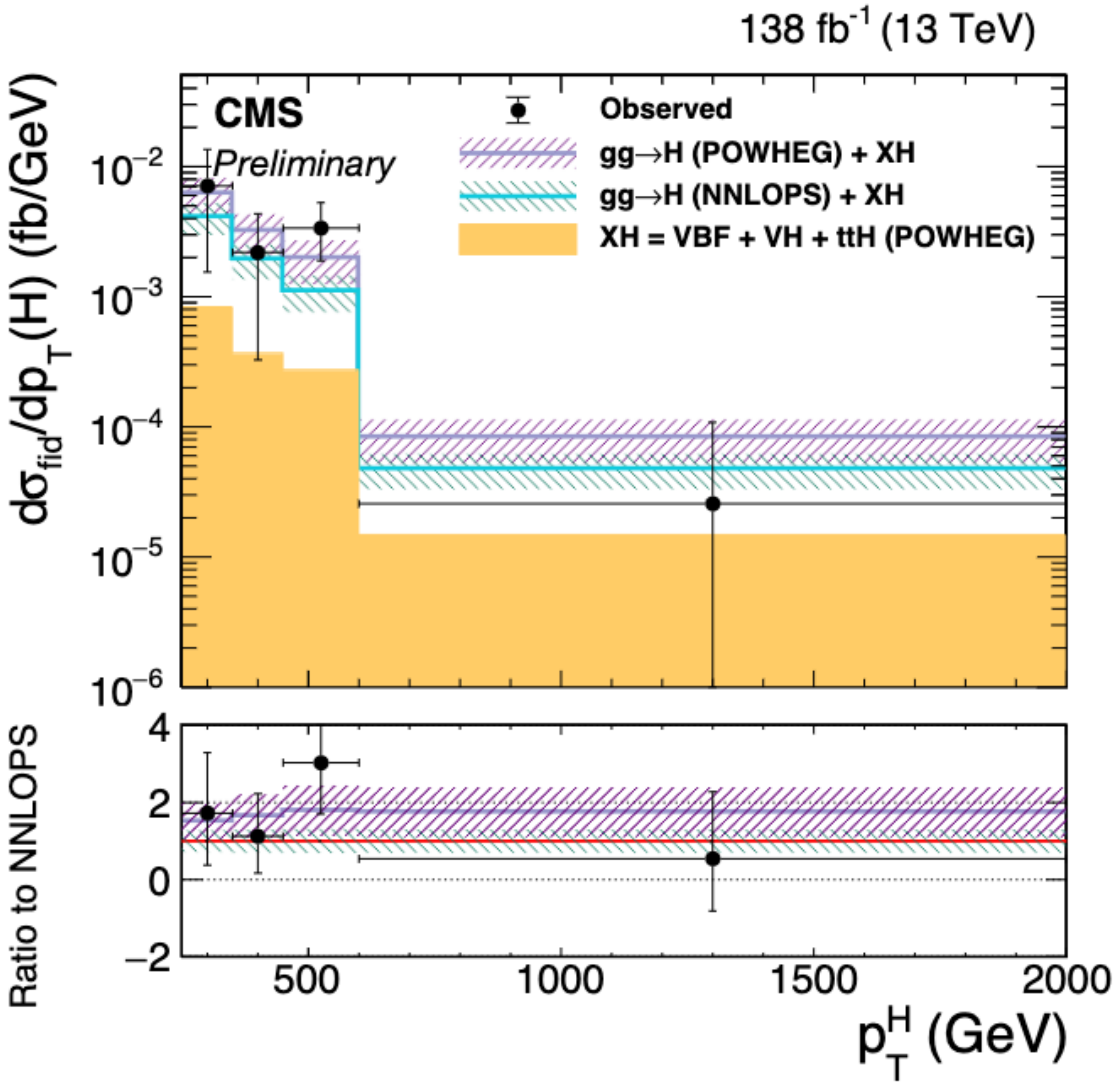
- "OutsideAcceptance" events fixed to SM and treated as background

✳ Reported Differential measurements

- Observables (resolved) : p_T^H, N_{jets} and p_T^{j1}
- Observables (boosted): p_T^H, $p_T^{j_1}$
  - Final observable is NN output
- In agreement with SM







VBF

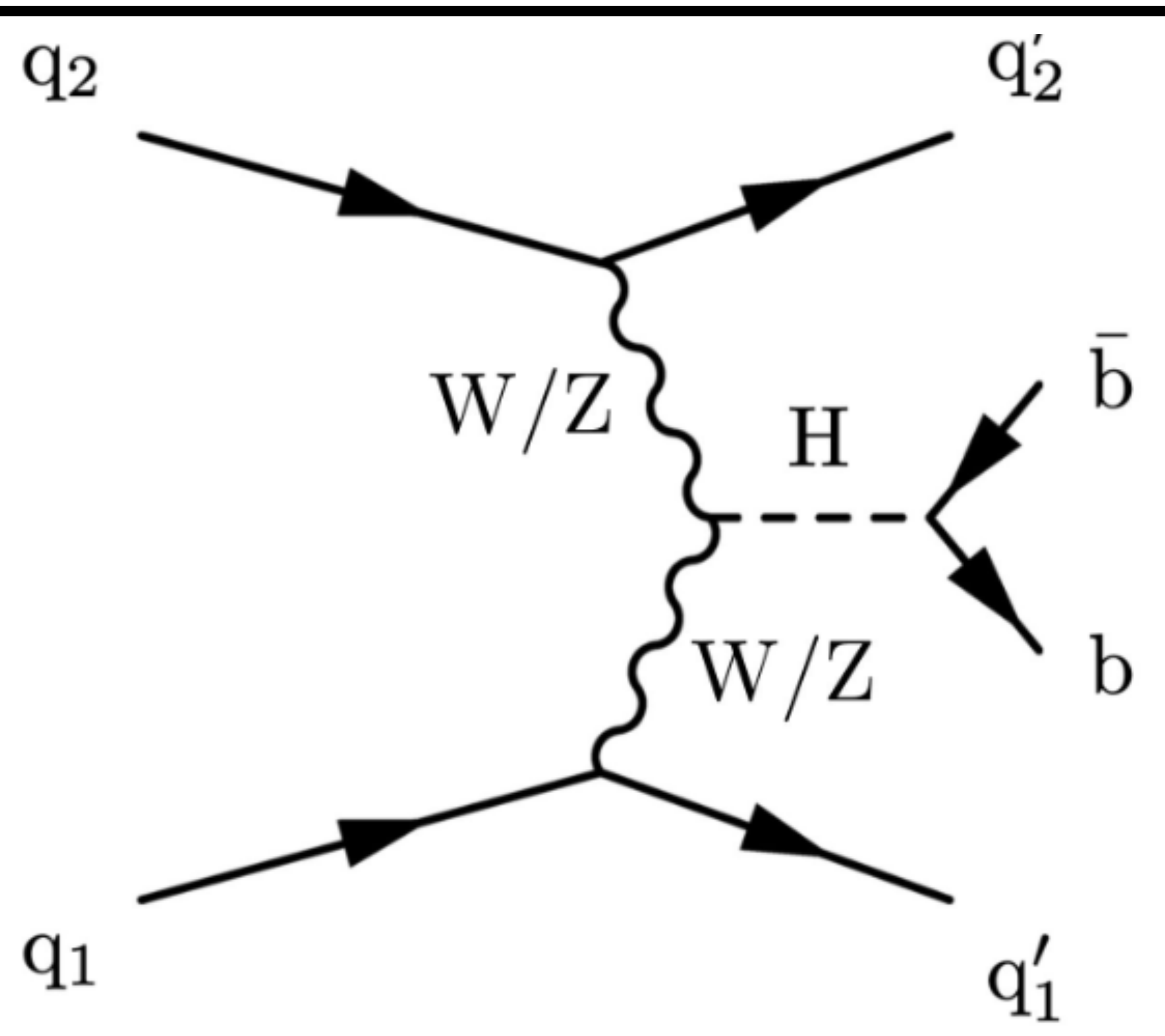
Vector Boson Fusion (VBF) process: second most dominant Higgs production @LHC

cross section ~ 3.78 pb @ $\sqrt{s}$ = 13 TeV with N^{2}LO QCD & NLO EWK accuracy.

→ Br(H→ bb) : largest, ~ 58%

→ VBFHbb process at tree level probes C_V **(HVV) coupling at the production**

and y_b **(Hbb) coupling at the decay**.



Hbb coupling established already via VH process→ allowed strength varies over considerably large range.

Experimental challenges

→ Overwhelming QCD multijet background

→ Large resonant Z→ bb background (overlapping with the signal in the higher tail of the Z peak)

→ Triggering VBFHbb events with high efficiency at reasonable rate

Signatures of VBF process:

→ **Two forward-backward** jets from the outgoing scattered partons

→ Mostly with moderate p_T => positioned at the higher |η| region, reasonably large rapidity gap ($\Delta\eta_{jj}$)

→ High dijet invariant mass (m_{jj})

→ jet pair termed as **VBF jets**

Strategy (Resolved analysis dealing with AK4 jets : 2 b-jets from Higgs decay + 2 VBF jets)

→ **Dedicated HLT Triggers** based on the **VBF & b-tag requirements**

→ **Multivariate analysis techniques (MVA)** to discriminate signal against major backgrounds

→ Reconstructed Higgs candidate mass **(invariant mass of two b jets, m_{bb})** distribution is used to extract signal.

$t\bar{t}H/tH$, with $H \to bb$: Results

[CMS-PAS-HIG-19-011]

✳ $t\bar{t}H$:

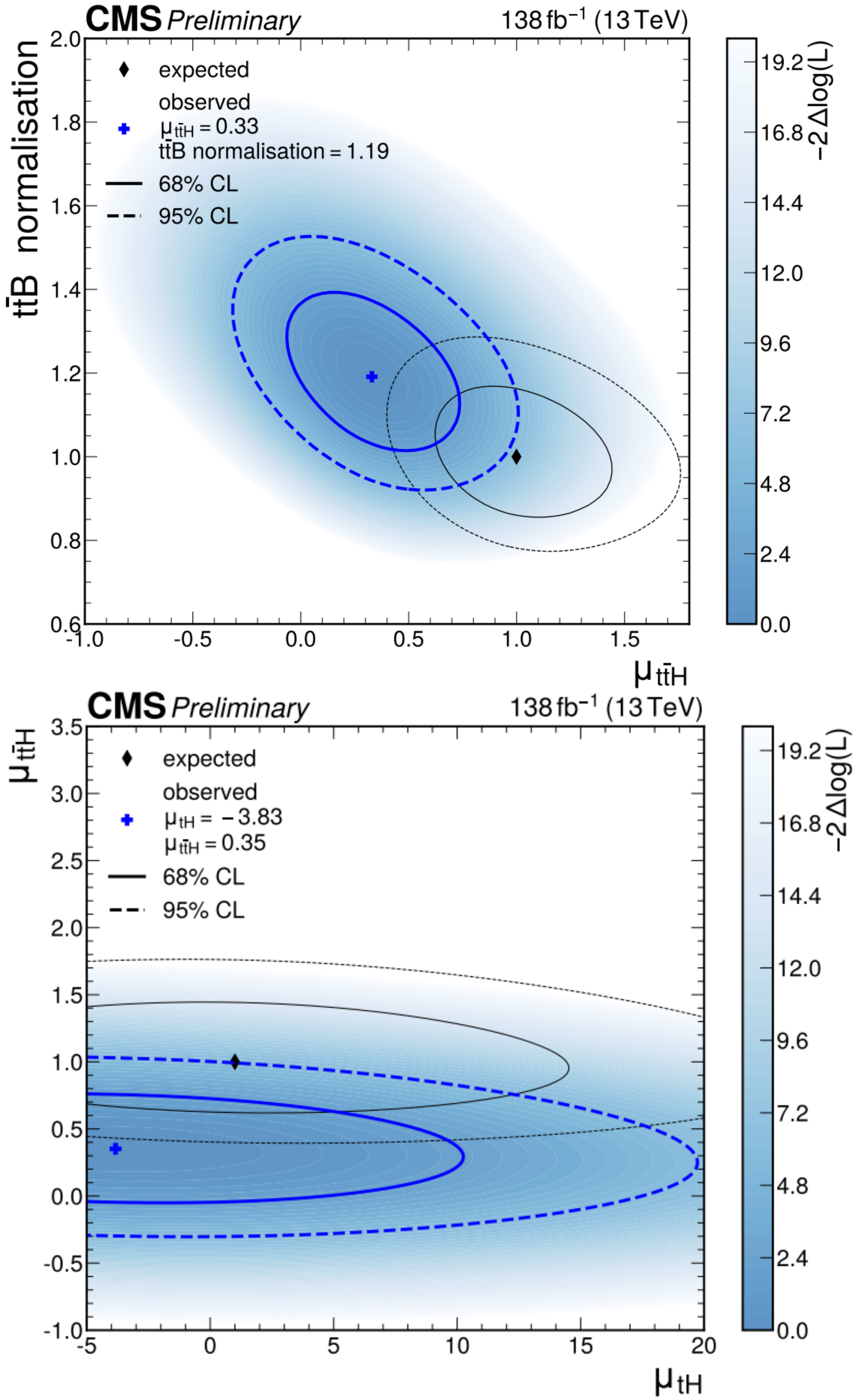
- inclusive
  - $\mu_{t\bar{t}H} = 0.33 \pm 0.26$

    significance: obs.(exp.) 1.3σ (4.1σ)
  - Background normalization ($t\bar{t}B, t\bar{t}C$)

    (backup)
- exclusive in p_T bins

✳ tH (inclusive):

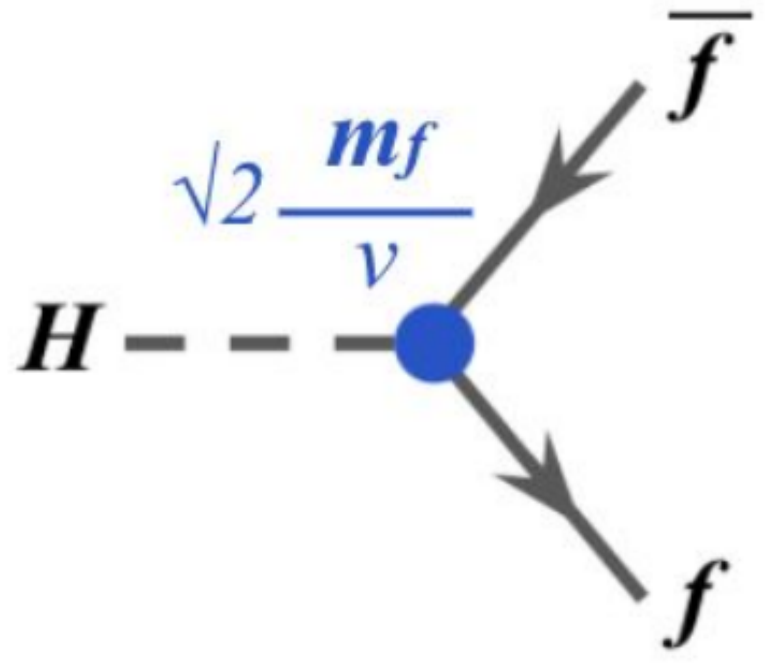
- Expected and observed 95% CL upper limits
- Simultaneous with $t\bar{t}H$ (backup)



$H \to \tau\tau$

Why are we interested in Higgs couplings to fermions?

- In the **SM**, fermions interact with Higgs boson via Yukawa couplings
- In the many **BSM** theories, deviations of the couplings of the observed Higgs boson to down-type fermions is implied



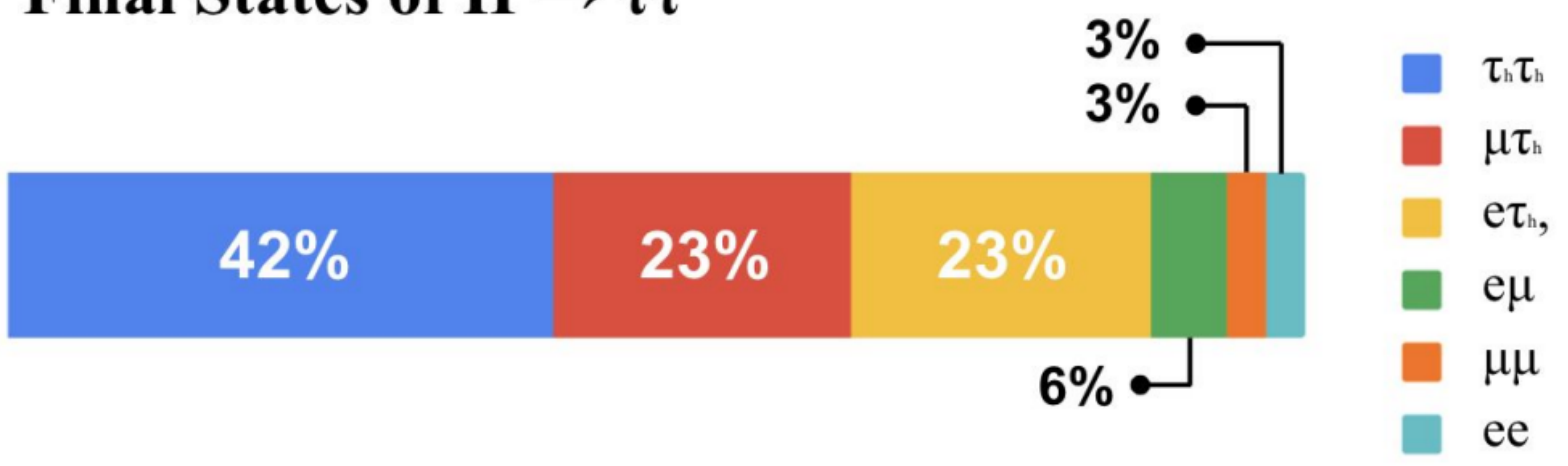
Why do we use H→ττ?

- The H→ττ decay allows to demonstrate direct coupling of the H boson to fundamental fermions
- Particularly sensitive to the Higgs boson production at high p_T^{Higgs} and with jets

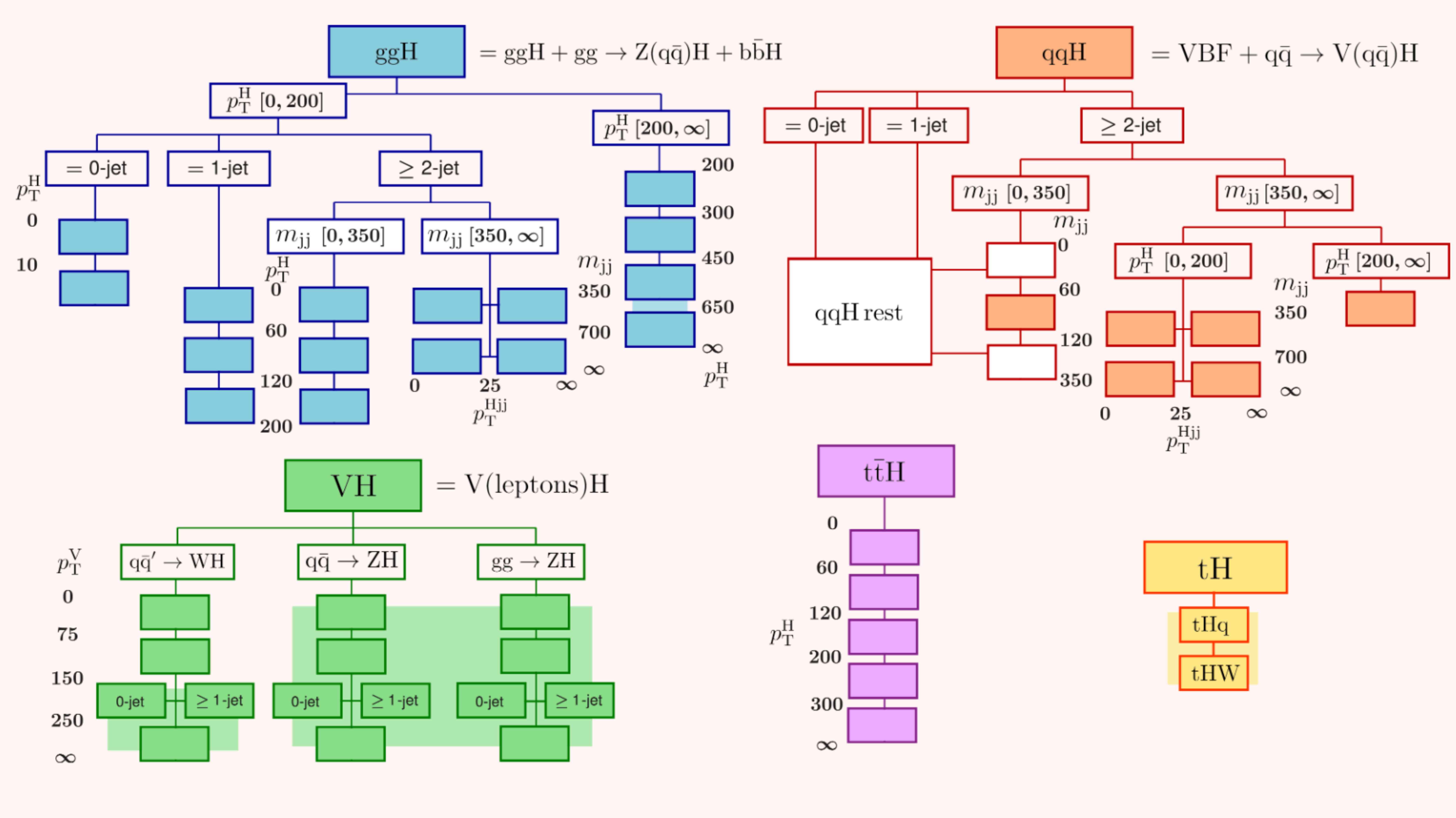
Analysis targets

- **ggF** and **VBF** productions using $H \to \tau_h\tau_h$, $\mu\tau_h$, $e\tau_h$, $e\mu$ final states to measure $\boldsymbol{\mu}$ and $\boldsymbol{\sigma}$**×BR**(H→ττ)

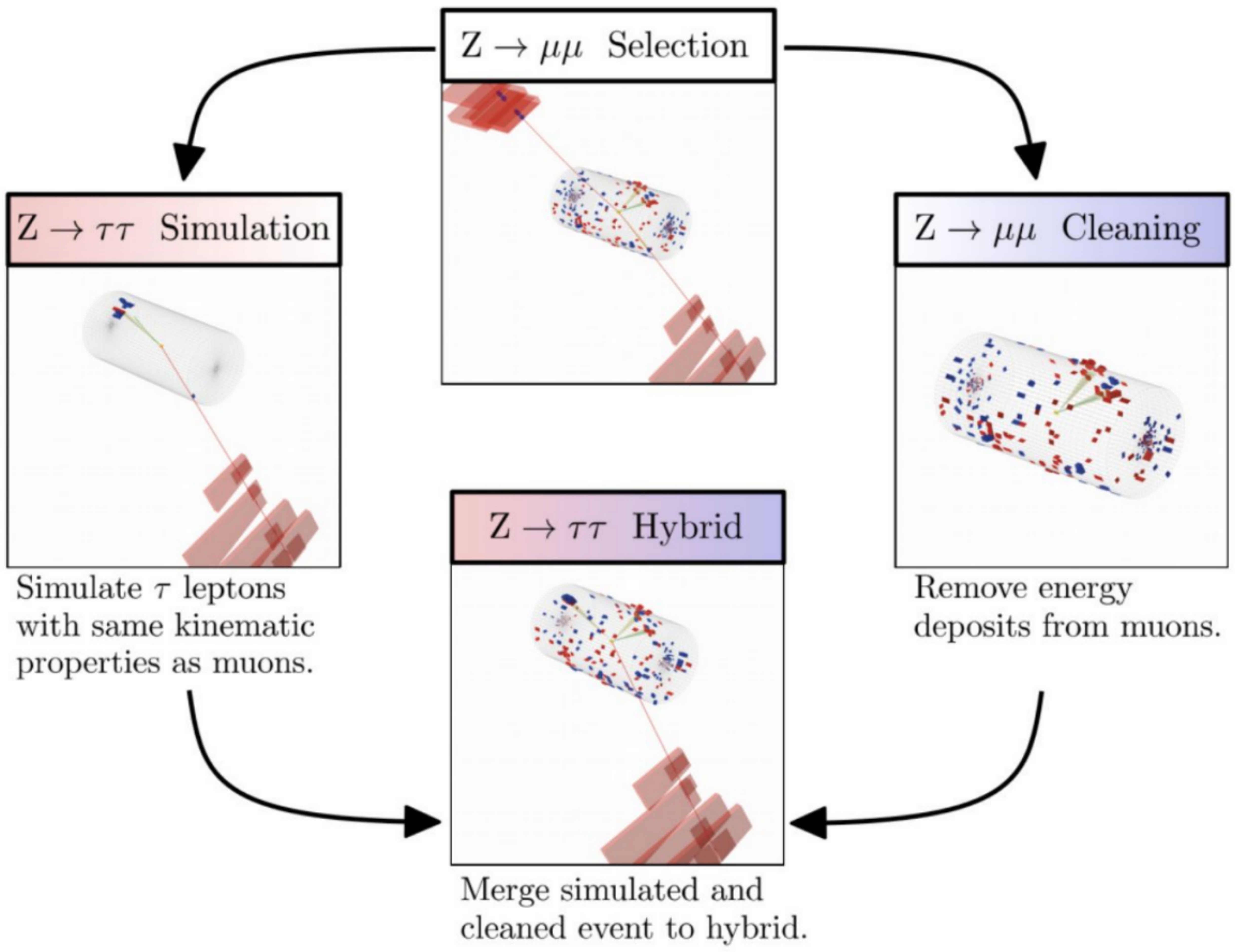
Final States of H → ττ



STXS



- Higgs kinematics can be sensitively modified by BSM physics
- "Simplified Template Cross Sections" approach: Measure cross sections separated into production modes, inclusively over the Higgs decays, in specific regions of phase-space ("bins"), defined in terms of specific kinematic variables (p_T^H, m_{jj}, p_T^{Hjj}, p_T^V)
- STXS provide a largely model-independent way to test for BSM deviations in kinematic distributions.
- Specific bins defined in coordination with the theoretical community

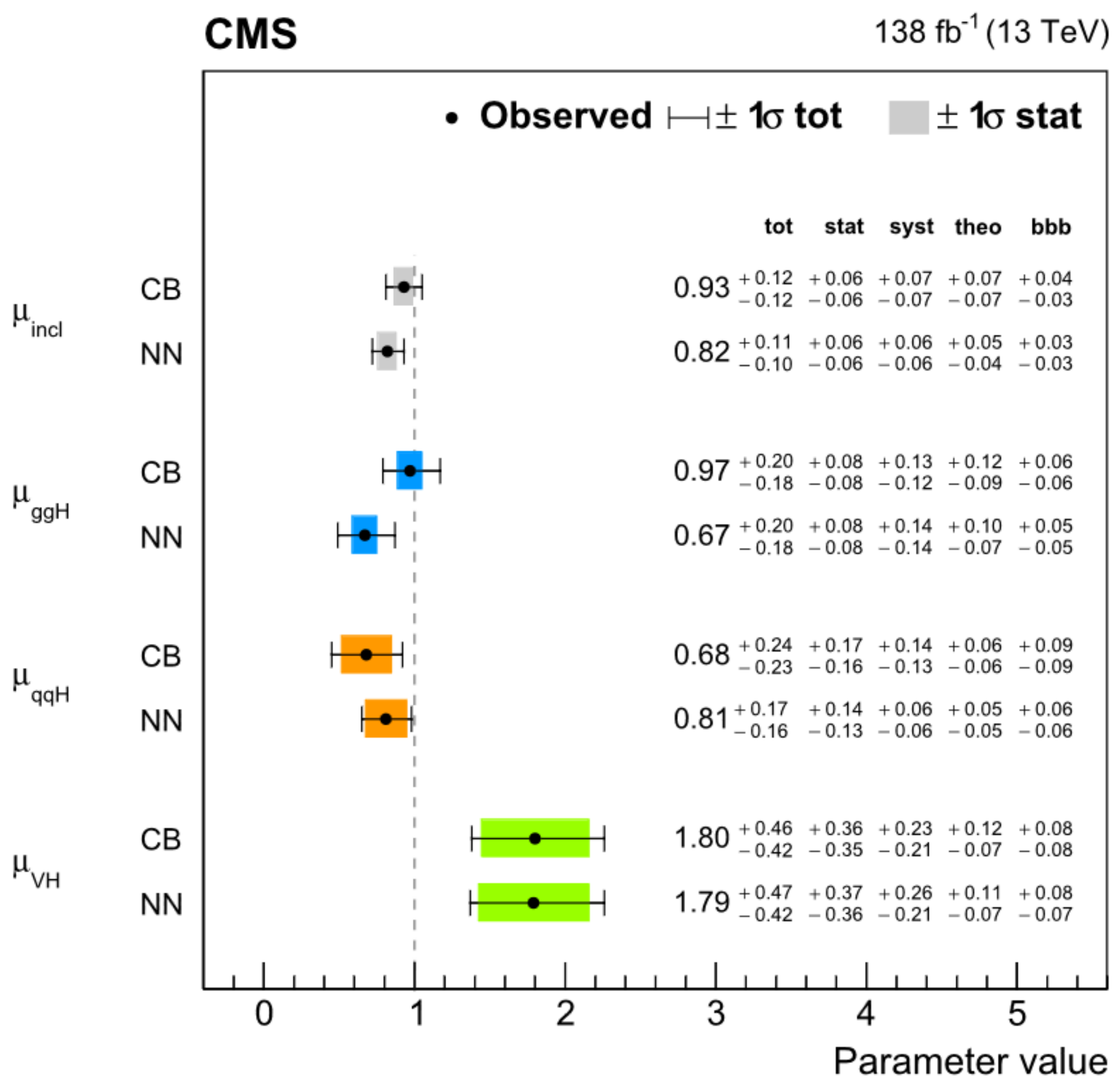


- Estimate all **backgrounds with two real τ**
- Select di-muon events from data, remove muon hits
- Muons are replaced by simulated taus with the same kinematics
- Advantages
  - Decent description of jet and underlying event
  - Less systematic uncertainties
- Used in HIG-18-032

Note:
MET covariance matrix issue does not effect on this analysis

Table 9 Tabulated values of the STXS stage-0 and -1.2 signal strengths for the combination of the (CB) CB-, resp. (NN) NN-analysis with the VH-analysis. The upper four lines refer to the inclusive and STXS stage-0 measurements. The values in braces correspond to the expected 68% confidence intervals for an assumed SM signal. The products of cross sections and branching fraction to τ leptons as expected from the SM with the uncertainties as discussed in Sect. 10.4 are also given

				SM (fb)	μ_s (CB)	μ_s (NN)
Inclusive				3422.28 ± 0.05	$0.93 \pm^{0.12}_{0.12}$ $(^{0.13}_{0.13})$	$0.82 \pm^{0.11}_{0.10}$ $(^{0.12}_{0.11})$
ggH				3051.34 ± 0.05	$0.97 \pm^{0.20}_{0.18}$ $(^{0.24}_{0.22})$	$0.67 \pm^{0.20}_{0.18}$ $(^{0.27}_{0.23})$
qqH				328.68 ± 0.03	$0.68 \pm^{0.24}_{0.23}$ $(^{0.24}_{0.23})$	$0.81 \pm^{0.17}_{0.16}$ $(^{0.17}_{0.17})$
VH				44.19 ± 0.03	$1.80 \pm^{0.46}_{0.42}$ $(^{0.41}_{0.37})$	$1.79 \pm^{0.47}_{0.42}$ $(^{0.41}_{0.37})$
	N_{jet}	p_T^H (GeV)				
ggH	$= 0$	0–10		423.58 ± 0.13	$-0.18 \pm^{0.46}_{0.46}$ $(^{0.45}_{0.44})$	$-1.65 \pm^{0.82}_{0.84}$ $(^{0.84}_{0.83})$
		10–200		1329.36 ± 0.07		$-0.43 \pm^{0.48}_{0.48}$ $(^{0.49}_{0.48})$
		0–60		451.09 ± 0.14	$-0.87 \pm^{1.21}_{1.21}$ $(^{1.06}_{0.99})$	$0.73 \pm^{0.69}_{0.66}$ $(^{0.68}_{0.64})$
	$= 1$	60–120		287.68 ± 0.14	$3.37 \pm^{1.23}_{1.13}$ $(^{0.90}_{0.83})$	$2.10 \pm^{0.65}_{0.57}$ $(^{0.54}_{0.50})$
		120–200		50.04 ± 0.19	$1.94 \pm^{1.21}_{1.24}$ $(^{1.04}_{0.90})$	$1.61 \pm^{0.78}_{0.65}$ $(^{0.68}_{0.60})$
	≥ 2	0–200		306.26 ± 0.23	$0.05 \pm^{0.88}_{1.53}$ $(^{0.83}_{0.71})$	$1.49 \pm^{0.67}_{0.56}$ $(^{0.66}_{0.56})$
		200–300		27.51 ± 0.42	$0.70 \pm^{0.89}_{1.29}$ $(^{0.91}_{0.77})$	$1.55 \pm^{0.83}_{0.68}$ $(^{0.76}_{0.65})$
		300–∞		7.19 ± 0.47	$1.65 \pm^{1.28}_{1.46}$ $(^{1.20}_{0.96})$	$2.31 \pm^{1.46}_{0.98}$ $(^{1.10}_{0.86})$
	N_{jet}	p_T^H (GeV)	m_{jj} (GeV)			
qqH		0–200	350–700	34.43 ± 0.04	$-0.29 \pm^{1.77}_{1.44}$ $(^{1.31}_{1.32})$	$1.47 \pm^{1.05}_{1.04}$ $(^{1.03}_{1.03})$
	≥ 2	0–200	700–∞	47.48 ± 0.04	$0.68 \pm^{0.39}_{0.38}$ $(^{0.39}_{0.38})$	$1.24 \pm^{0.32}_{0.31}$ $(^{0.31}_{0.30})$
		200–∞	350–∞	9.90 ± 0.03	$0.69 \pm^{0.58}_{0.45}$ $(^{0.45}_{0.43})$	$0.16 \pm^{0.35}_{0.34}$ $(^{0.37}_{0.35})$
	$N_{jet} < 2$ or m_{jj} [0, 350] GeV			209.46 ± 0.03	$1.94 \pm^{4.55}_{2.93}$ $(^{2.15}_{2.16})$	$-0.99 \pm^{1.21}_{1.19}$ $(^{1.23}_{1.18})$
		p_T^V (GeV)				
WH		0–150		20.57 ± 0.03	$0.77 \pm^{0.95}_{0.91}$ $(^{0.90}_{0.85})$	$0.79 \pm^{0.94}_{0.91}$ $(^{0.90}_{0.85})$
		150–∞		3.30 ± 0.05	$2.65 \pm^{1.38}_{1.26}$ $(^{1.26}_{1.15})$	$2.65 \pm^{1.37}_{1.25}$ $(^{1.26}_{1.15})$
ZH		0–150		11.99 ± 0.06	$1.97 \pm^{0.90}_{0.81}$ $(^{0.79}_{0.71})$	$2.00 \pm^{0.91}_{0.81}$ $(^{0.79}_{0.71})$
		150–∞		2.55 ± 0.10	$2.23 \pm^{1.01}_{0.82}$ $(^{0.78}_{0.61})$	$2.18 \pm^{1.00}_{0.82}$ $(^{0.78}_{0.61})$

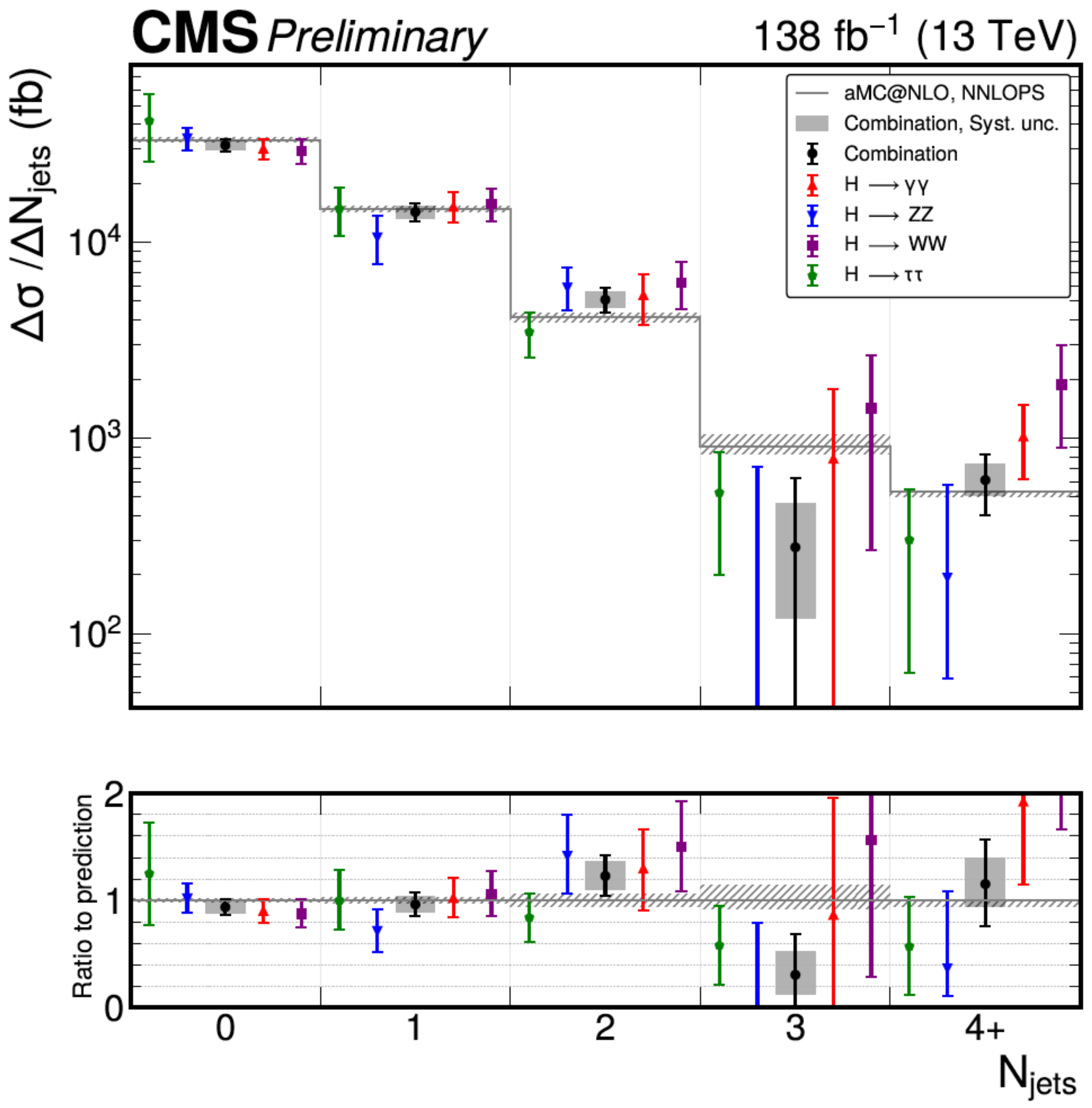


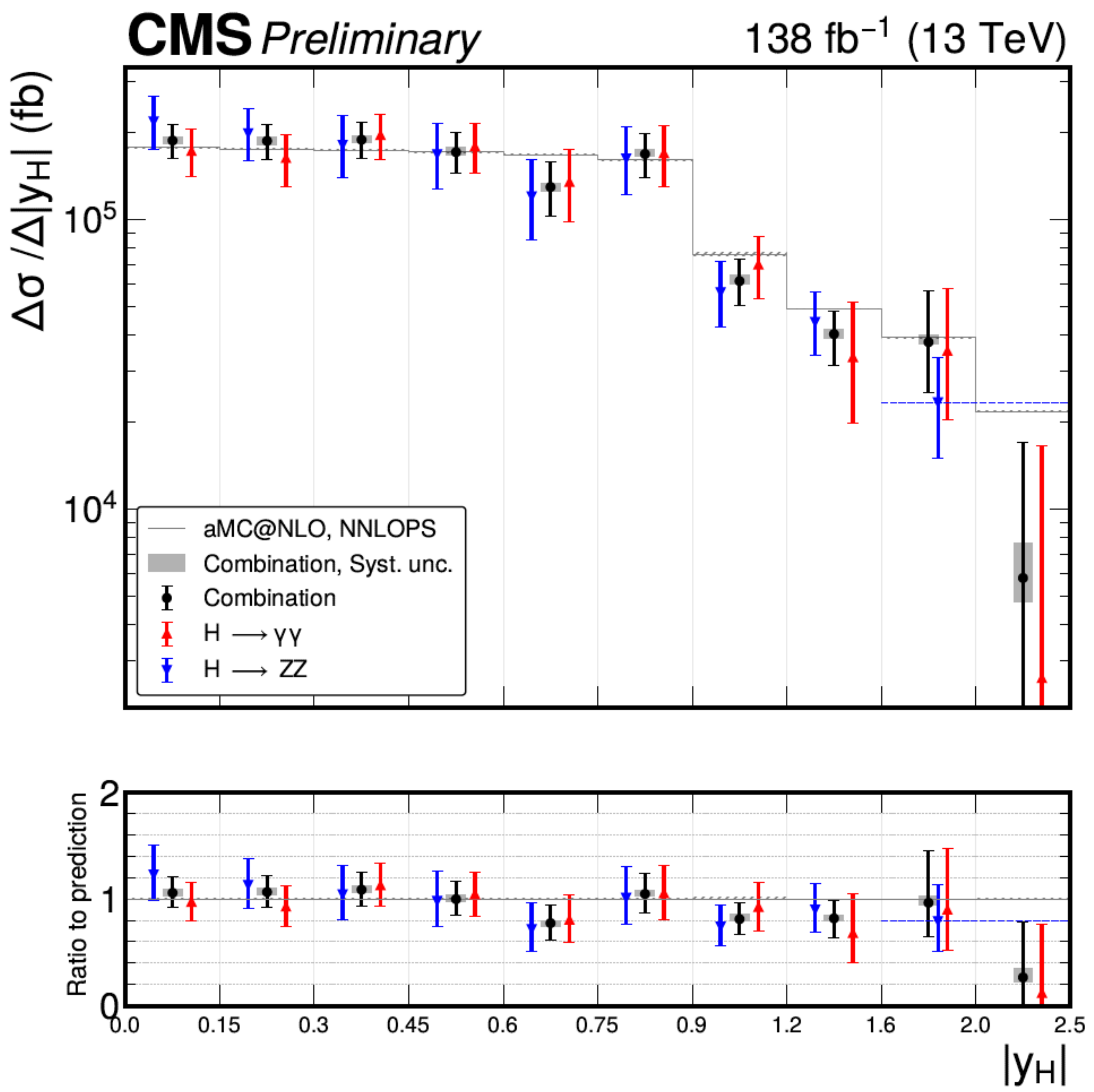
✳ Inclusive signal strength

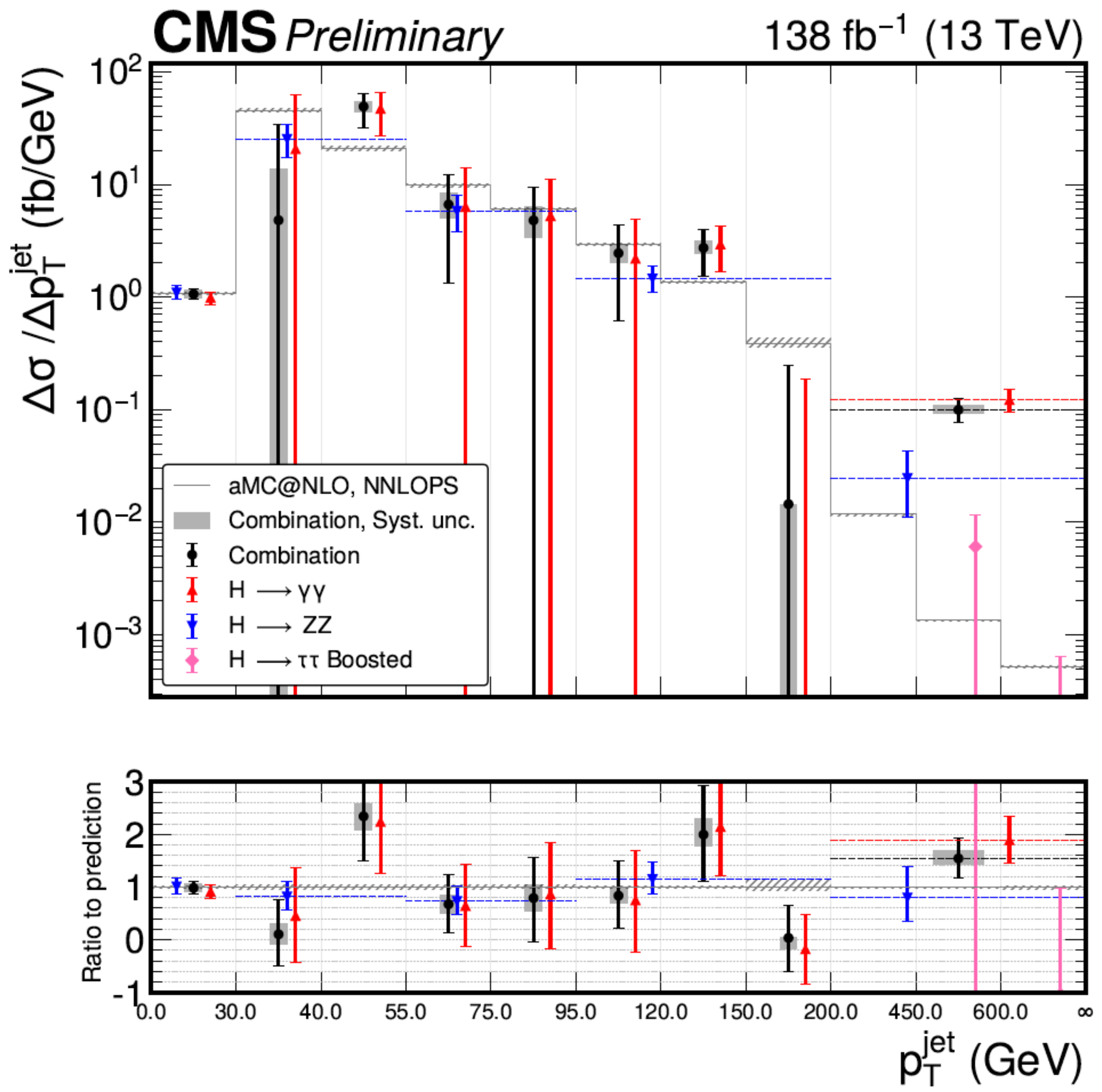
- $\mu_{incl} = 0.82 \pm 0.11$
  - p-value for compatibility of incl. with SM: 0.10
  - Correlation b/w μ_{ggH} and μ_{qqH} : -0.35

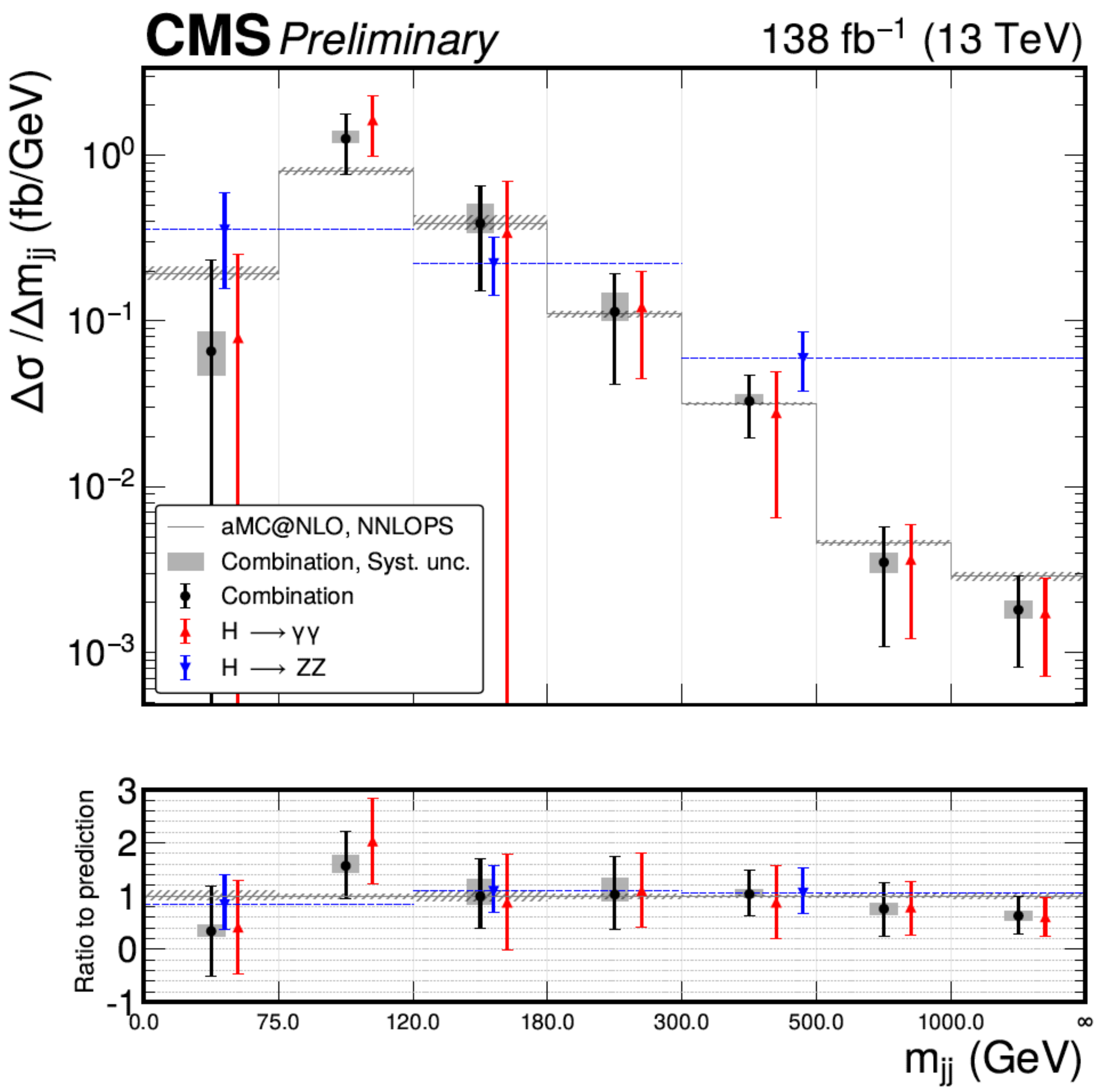
Combined measurements in $H \rightarrow X$ decays: Differential XS

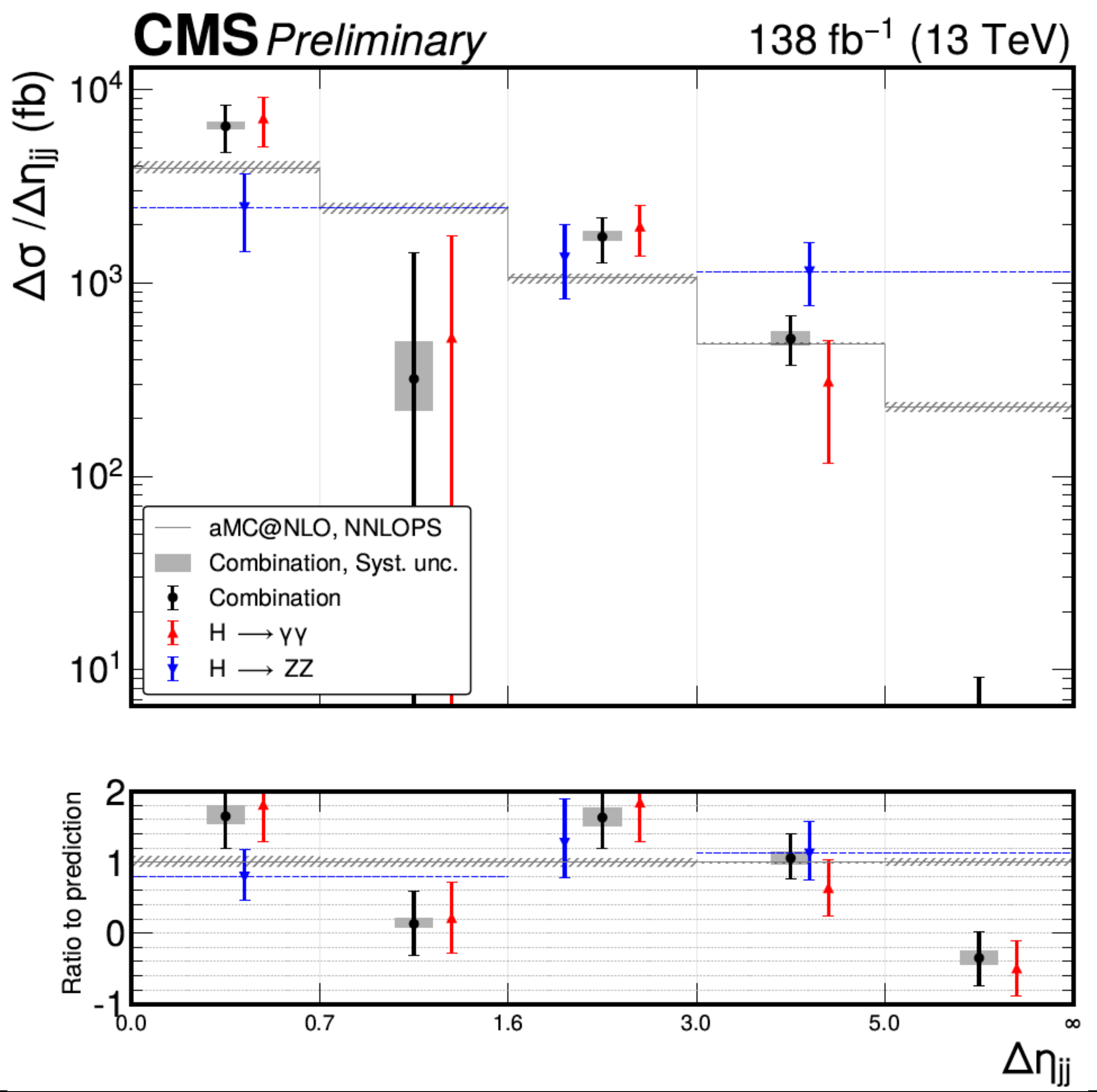
CMS-PAS-HIG-23-013











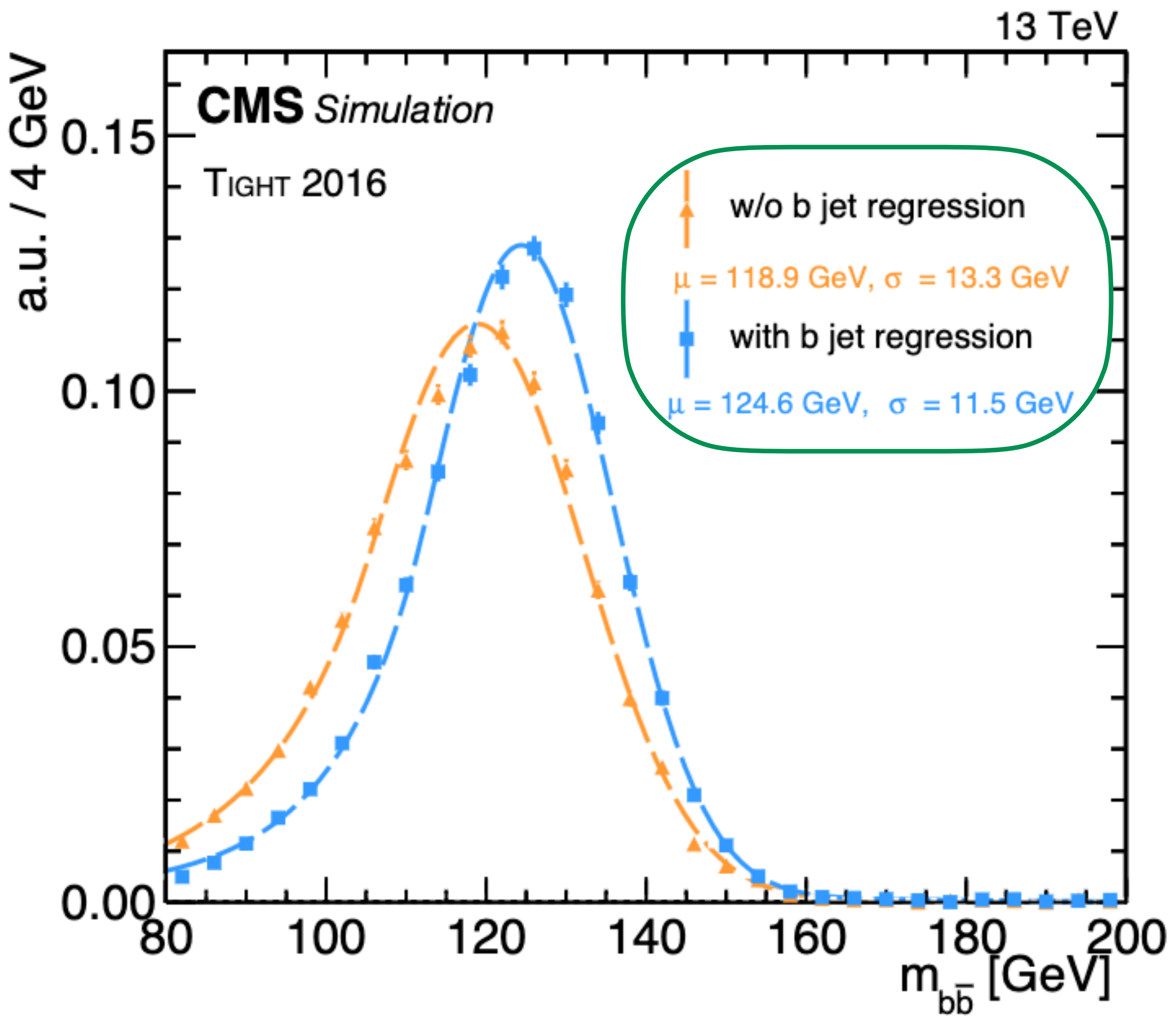
✴ Reported Differential measurements

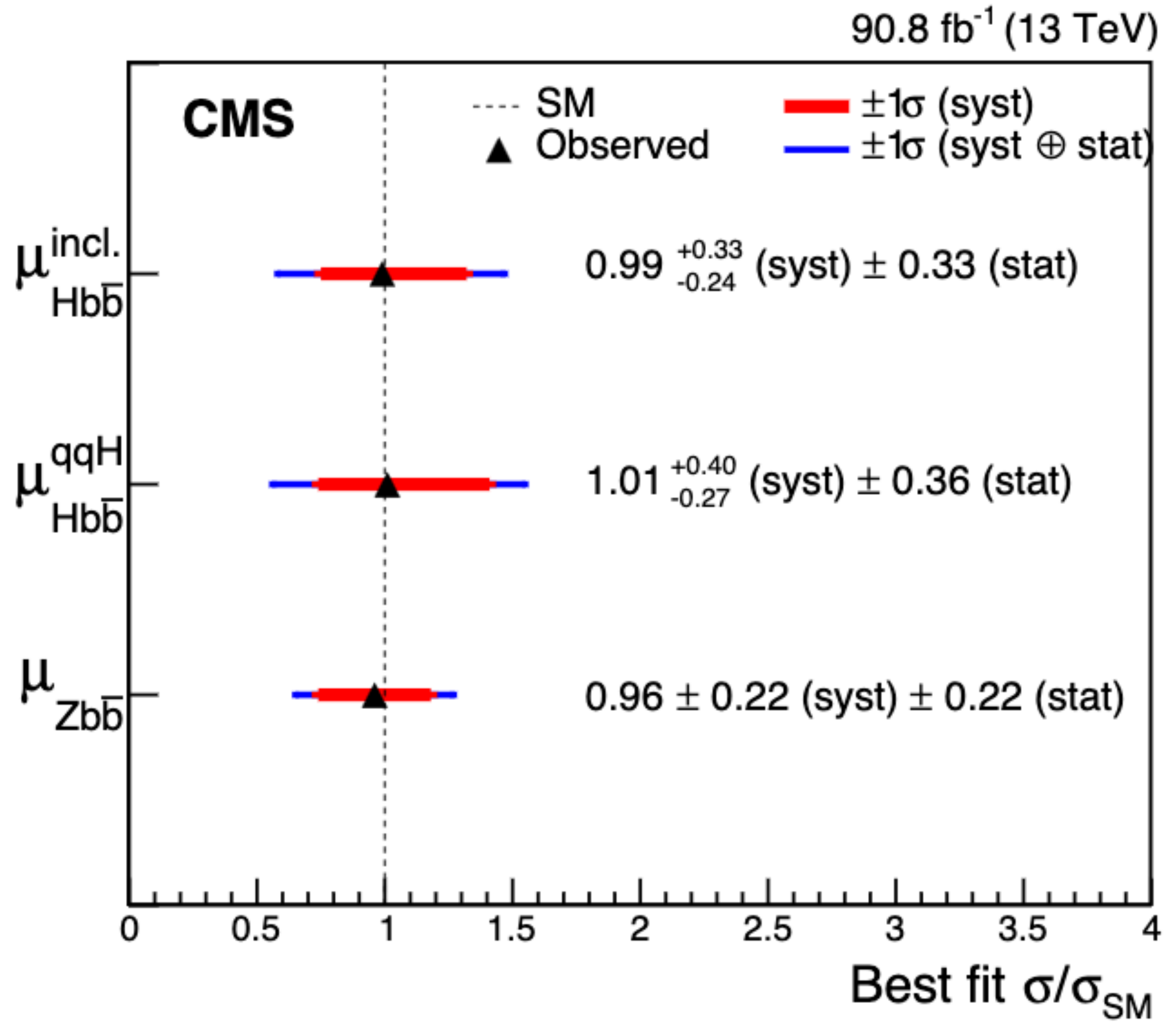
- Observables: p_T^H, N_{jets}, $|y^H|$, p_T^{j1}, m_{jj}, $|\Delta\eta_{jj}|$ and τ_C^j

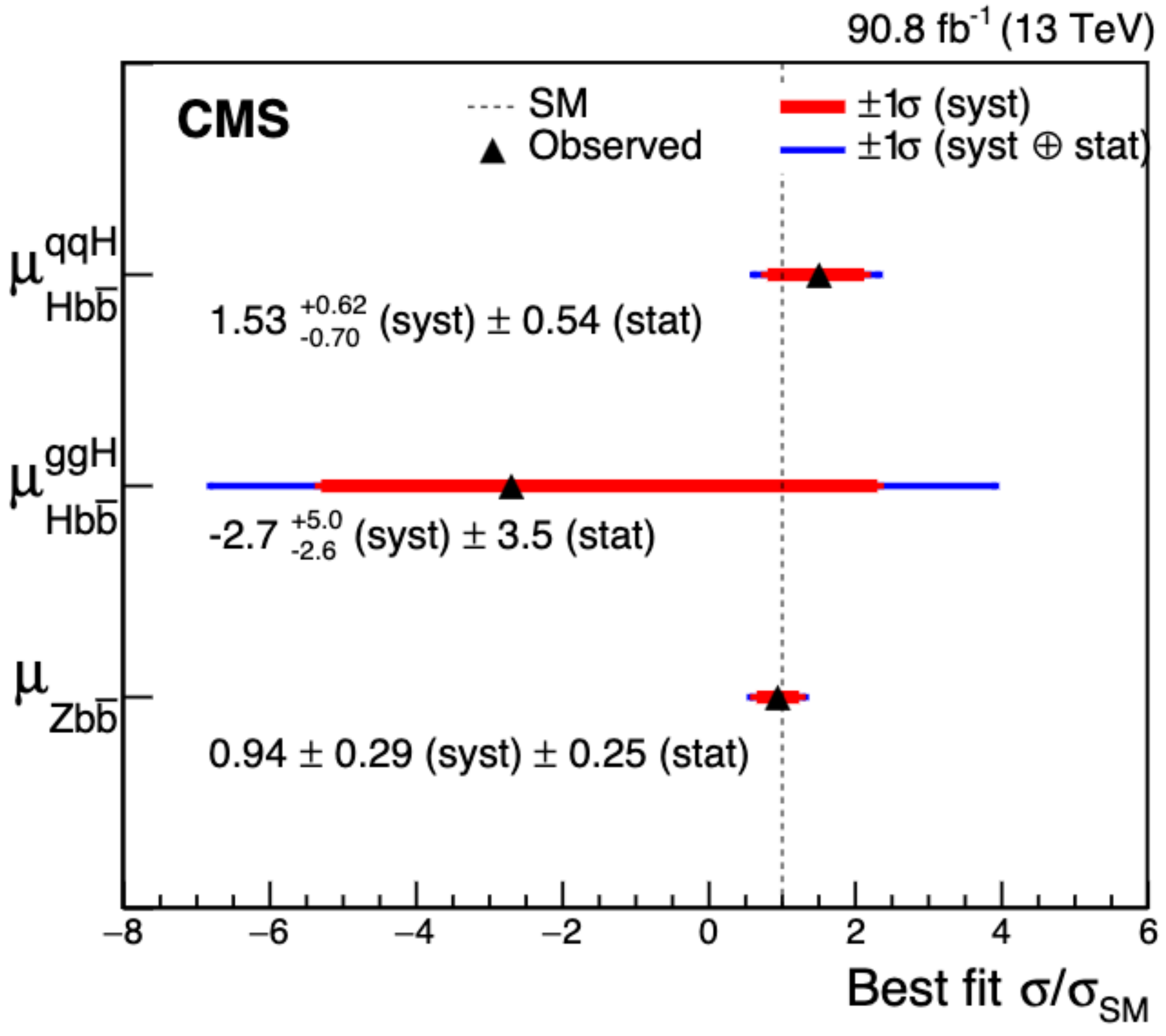
$(VBF)\ H \rightarrow bb$

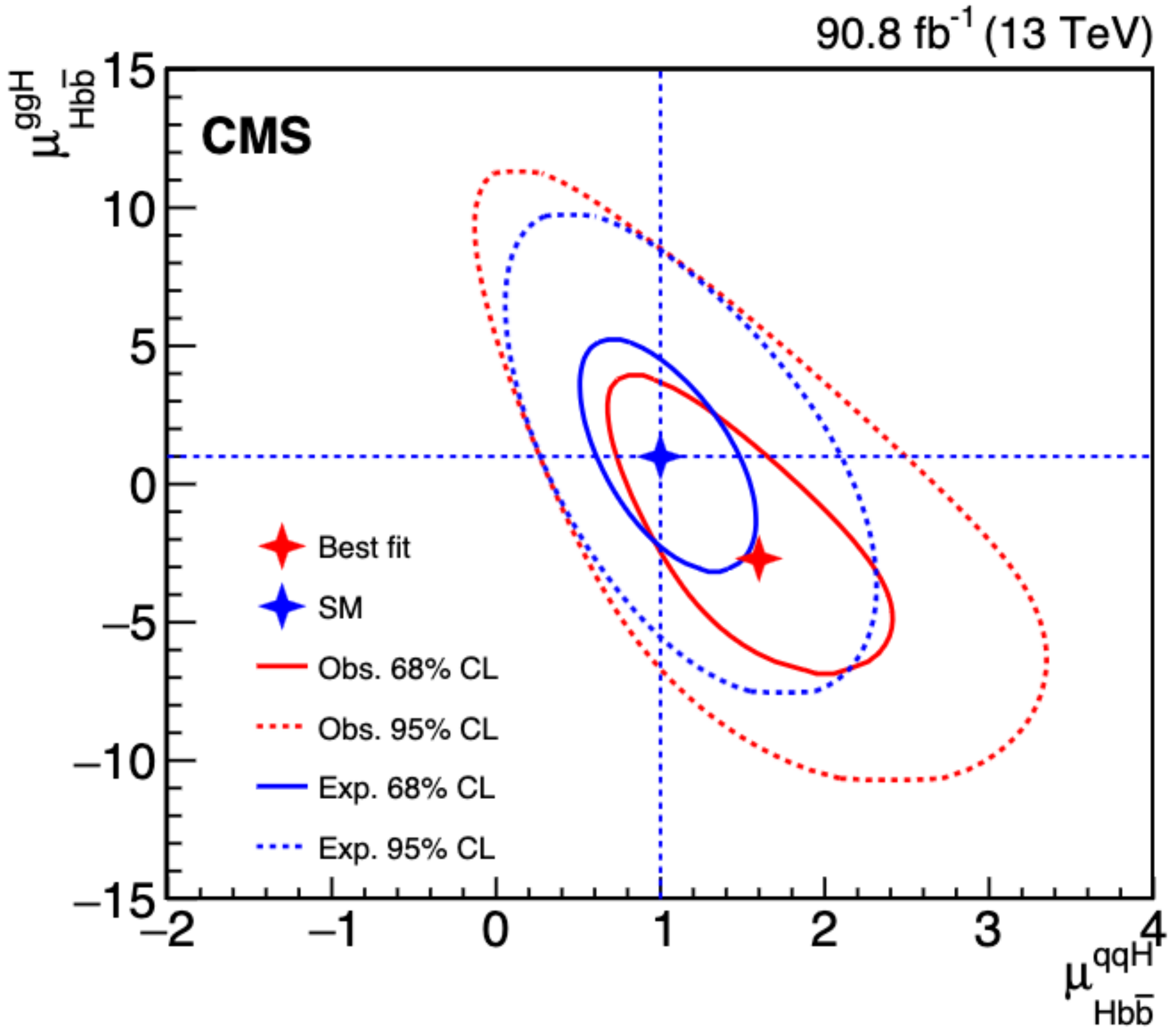
https://arxiv.org/abs/2308.01253

- ✳ Events categorization in Loose and Tight VBF with BDT Classifier
- ✳ Scale and Smearing corrections applied to DeepNN-based regressed b-jets
- ✳ Background estimation:
  - Resonant Z(bb) + jets [DY & EWK] (simulation)
  - Continuum QCD multijet production (fit to data) [80, 104] & [146, 200] GeV
- ✳ VBF Parton shower and JES being leading systematic sources
- ✳ Simultaneous fit to $m_{b\bar{b}}$ extract signal









$ZZ/ZH \to 4b$

10.1140/epjc/s10052-024-13021-z

✳ A search for ZZ and ZH production in the $b\bar{b}b\bar{b}$ final state

- larger XS than HH

✳ Multi-class multivariate classifier (4b)

- Extract the signal and background model

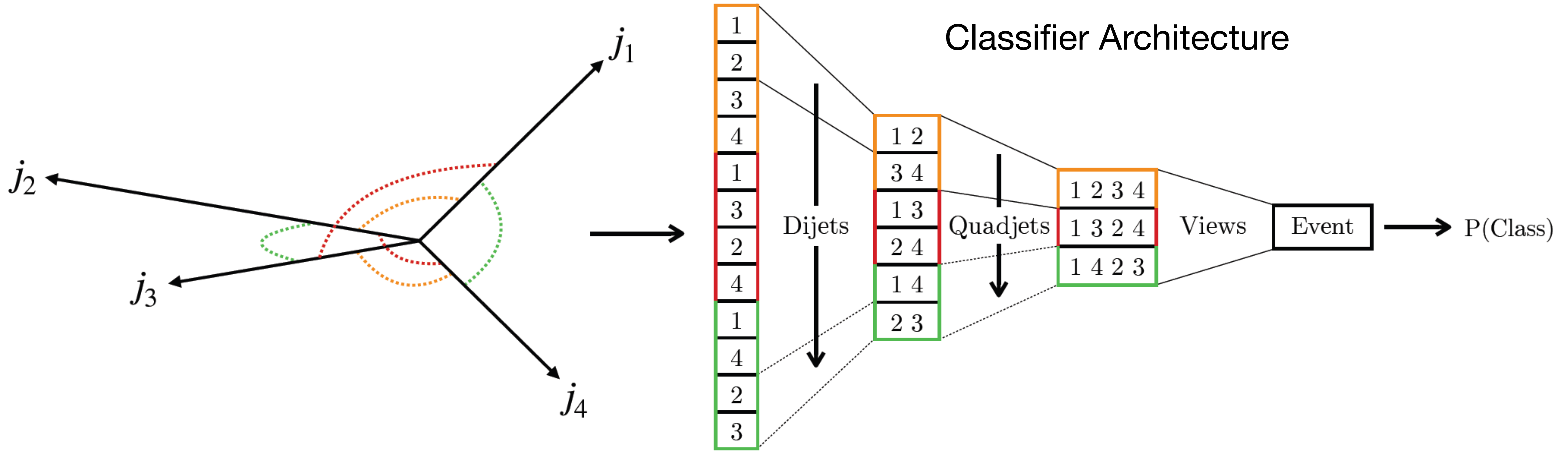
✳ Major (multi-jet) background estimated from data

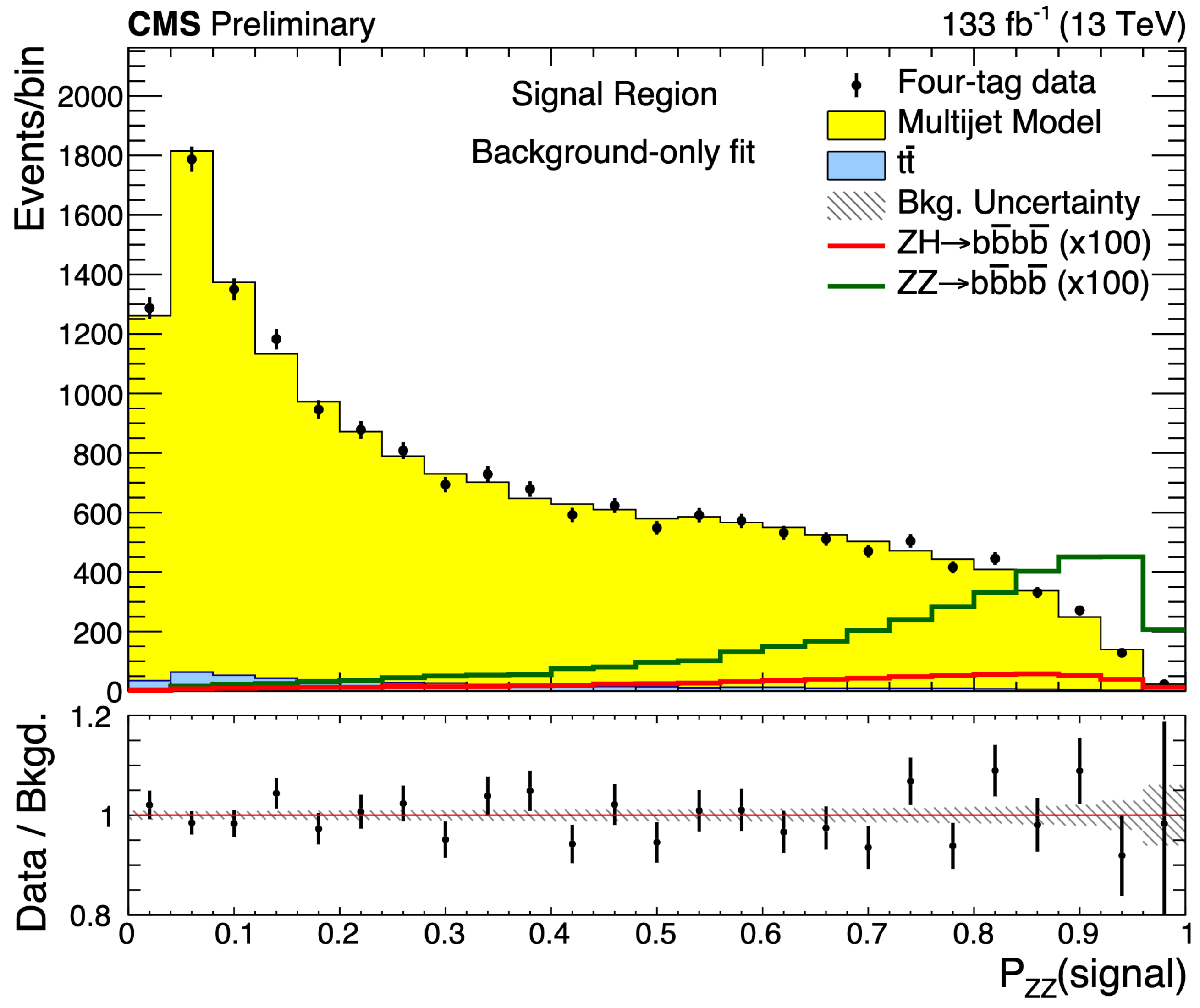
✳ Novel approach to validate the background model

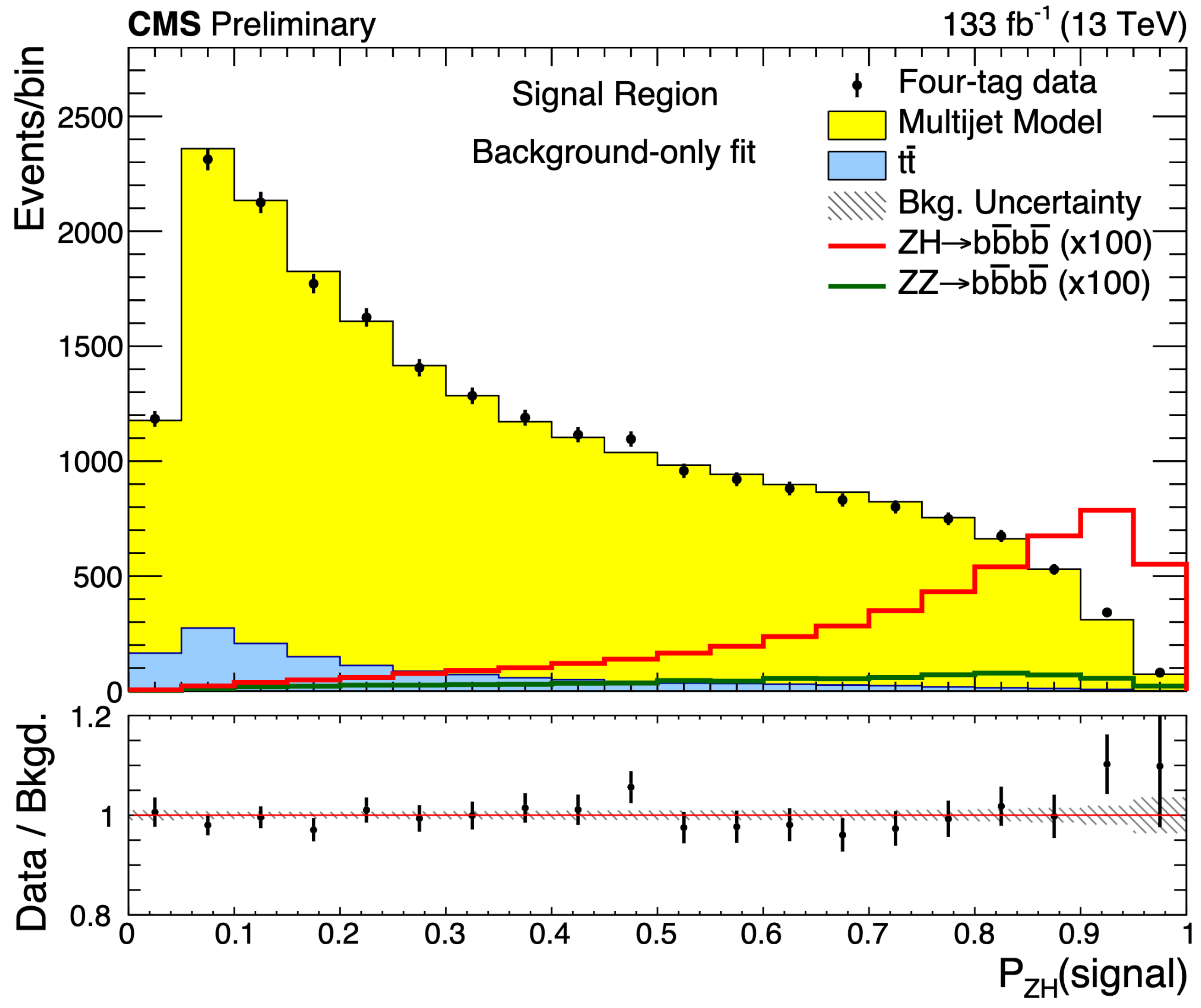
- Using synthetic data

✳ Signal vs Background **probabilities**

- Combined fit in ZZ and ZH regions







	ZZ	ZH
Signal strength expected (stat-only)	$1^{+1.9}_{-1.7}$ $(1^{+1.4}_{-1.3})$	$1^{+1.5}_{-1.4}$ $(1^{+1.1}_{-1.1})$
Signal strength observed	$0.0^{+2.0}_{-1.7}$	$2.2^{+0.9}_{-0.8}$
Expected Limit at 95% CL (stat-only)	3.8 (2.8)	2.9 (2.3)
Observed Limit at 95% CL	3.8	5.0

$H \to \tau\tau$: Analysis Strategy

10.1140/epjc/s10052-023-11452-8
10.1103/PhysRevLett.128.081805
CMS-PAS-HIG-21-017

✴SS, STXS and differential cross-sections

✴4 channels considered in ggF and VBF productions:

- $\tau_h\tau_h, \mu\tau_h, e\tau_h, e\mu$

✴Events categorized according to jets' p_T and the multiplicity (**NN** multiclassification for signal and background)

✴Majority of background estimated from data

- Genuine $\tau\tau$ events: estimated using Tau Embedding
- Jet misidentified as τ_h: Fake factor (F_F) Method