

Higgs boson cross section measurements at CMS

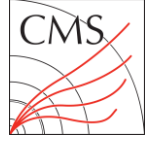
Nico Härringer

On behalf of the CMS collaboration

28.09.2026, QCD@LHC2026

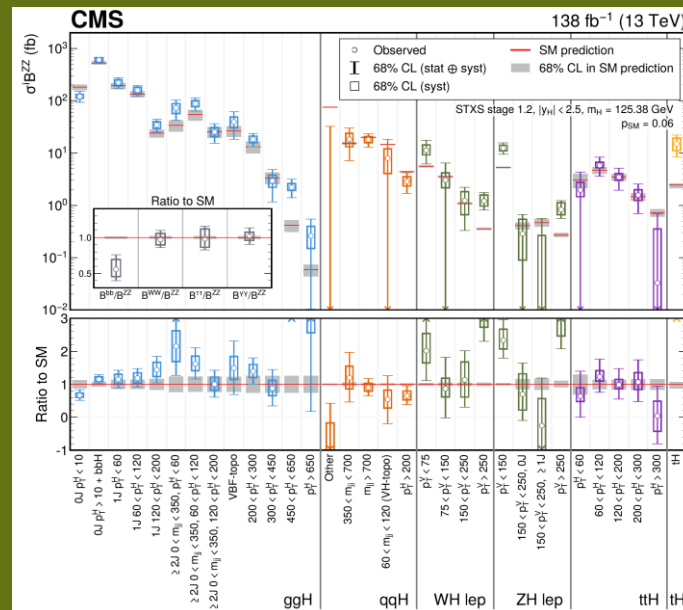


Analysis overview



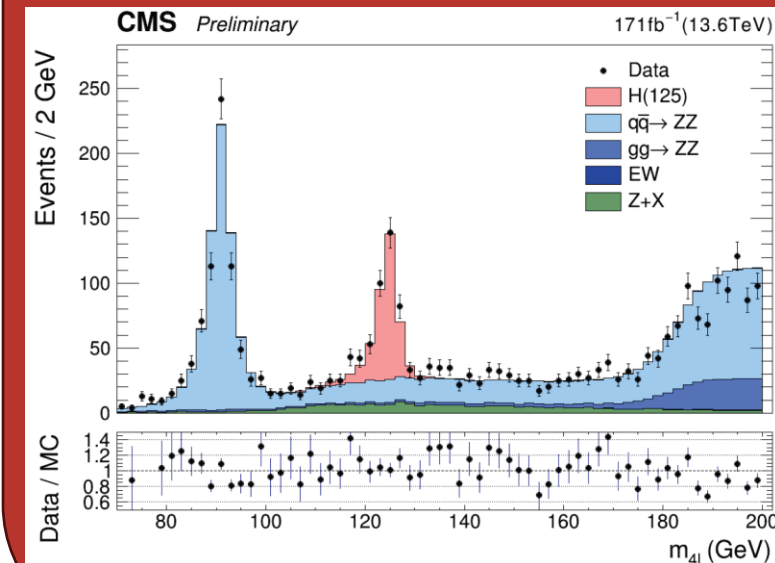
Run 2 combinations

- Combine multiple Higgs boson decay channels
- Interpret results in different frameworks



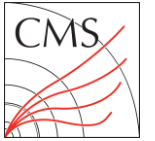
$H \rightarrow ZZ^* \rightarrow 4l$

- Rare decay (BR ~ 0.013%)
- Narrow peak over a flat background
- Three final states: $4e$, 4μ , $2e2\mu$



Run 2 combinations

Run 2 combinations: Measurements



- Idea: Combine measurements to get ultimate precision
 - Full Run 2 data (138 fb^{-1} @ 13 TeV)
- Two important legacy Run 2 cross section combinations
 - Differential Higgs boson combination ([CMS-HIG-23-013](#))
 - Higgs boson combination ([CMS-HIG-21-018](#))

Run 2 combinations: Measurements



Model independence

Experimental sensitivity

Signal Strength Modifiers

- Check agreement between Data and MC
- Maximal model dependence by construction
- Measurement of the signal strength

$$N = \mu \cdot \sum_i [(\epsilon \cdot A^{\text{SM}})_i \cdot \sigma_i^{\text{SM}} \cdot \text{BR}^{\text{SM}} \cdot \mathcal{L}] + \text{bkg}$$

Simplified Template Cross Sections (STXS)

- Usage of mutually exclusive STXS bins
- Minimize model dependence
- Measurement of the cross section

$$N = \sum_{\text{bin}} [\mu_{\text{bin}} \cdot \sigma_{\text{bin}}^{\text{SM}} \cdot (\epsilon \cdot A^{\text{SM}})_{\text{bin}} \cdot \text{BR}^{\text{SM}} \cdot \mathcal{L}] + \text{bkg}$$

Fiducial Cross Sections

- Remove detector effects by unfolding to the fiducial phase space
- Minimal model dependence

$$N_j = \sum_i [\sigma_i^{\text{fid}} \cdot R_{ij} \cdot \mathcal{L}] + \text{bkg}_j$$

[CMS-HIG-21-018](#)

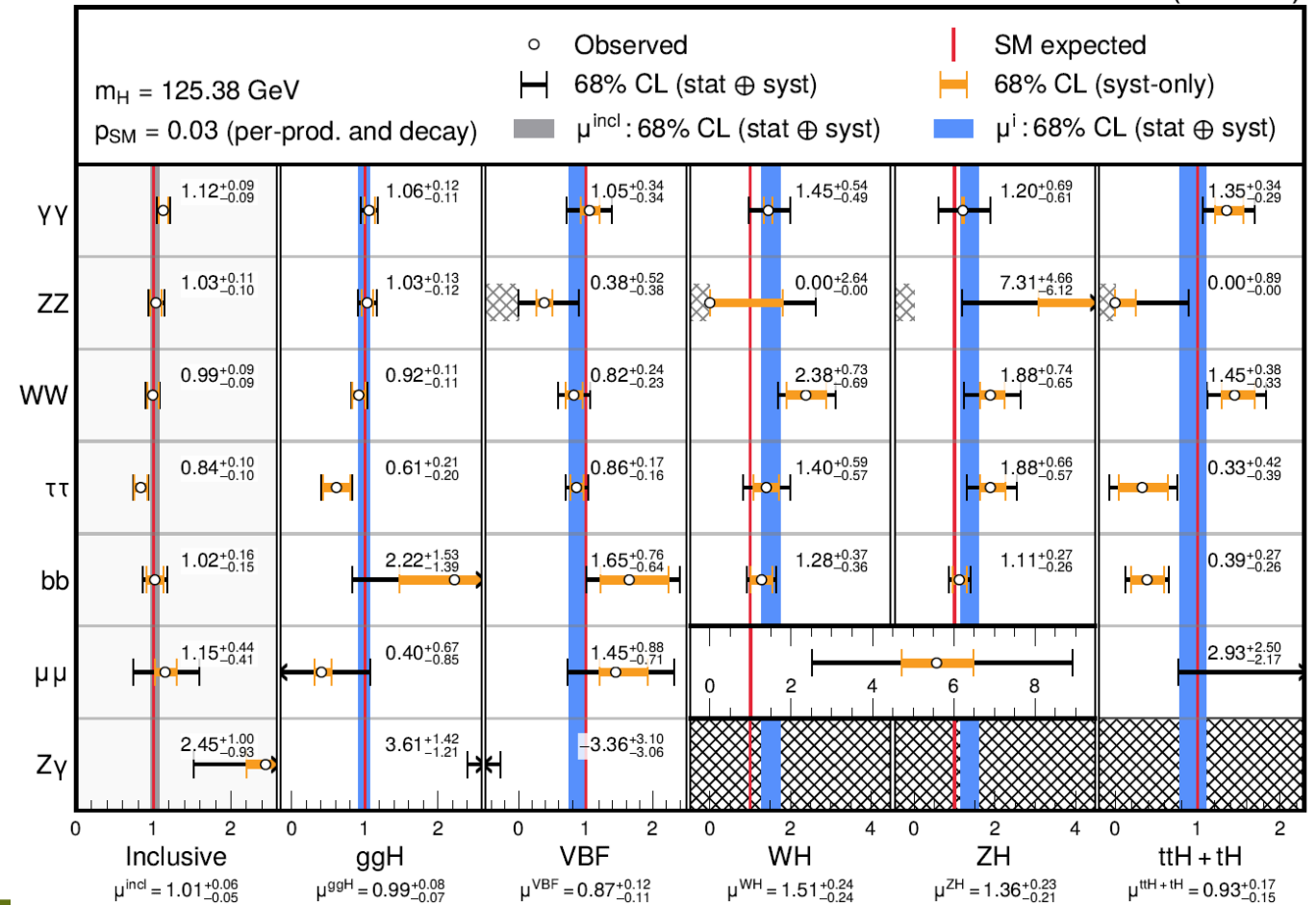
[CMS-HIG-23-013](#)

- Signal Strength Modifiers

CMS

Rep. Prog. Phys. 89 (2026) 087801

138 fb⁻¹ (13 TeV)



Run 2 combinations: Measurements

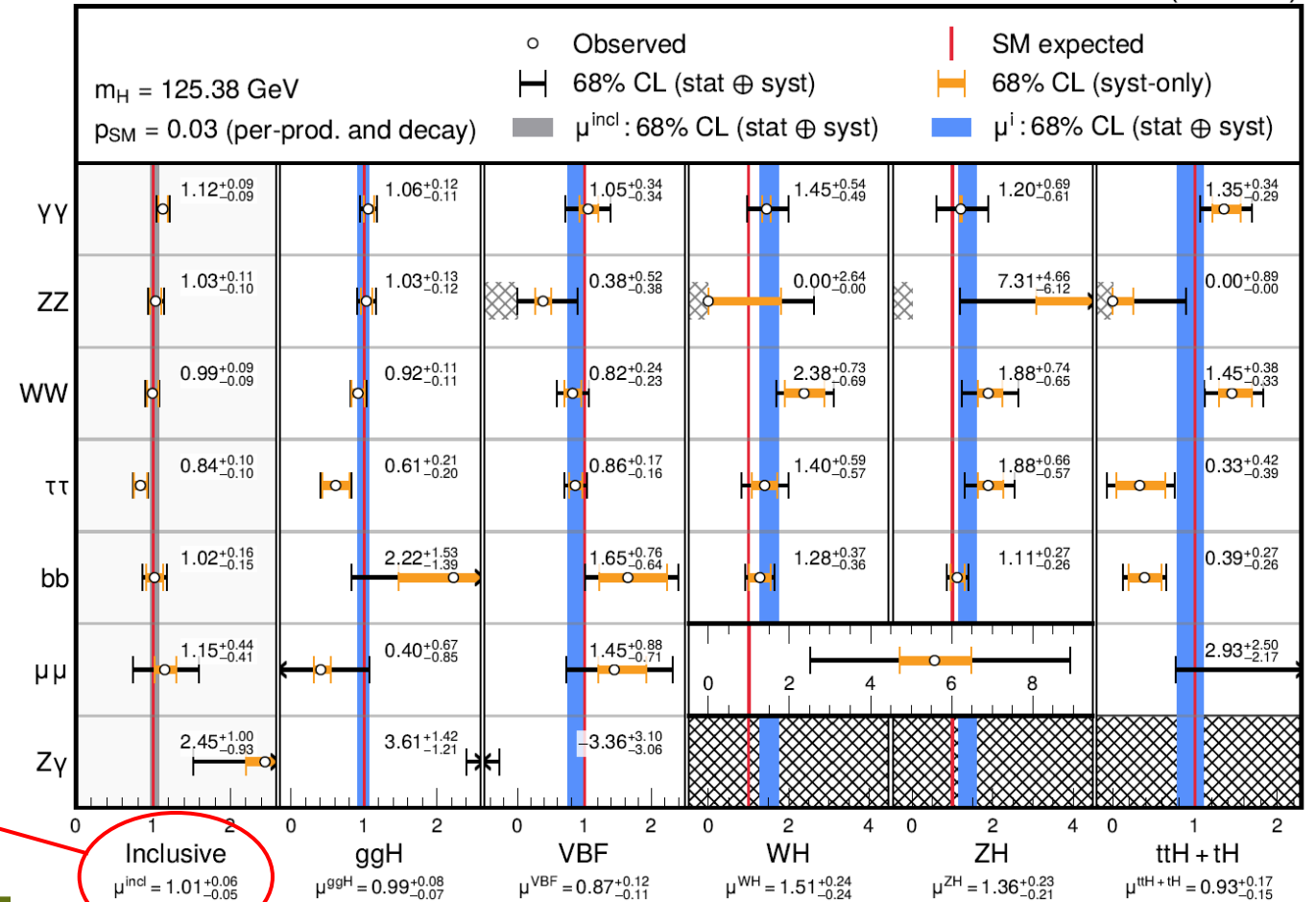


- Signal Strength Modifiers
 - Fully in agreement with SM
 - Theory: Limiting uncertainty

CMS

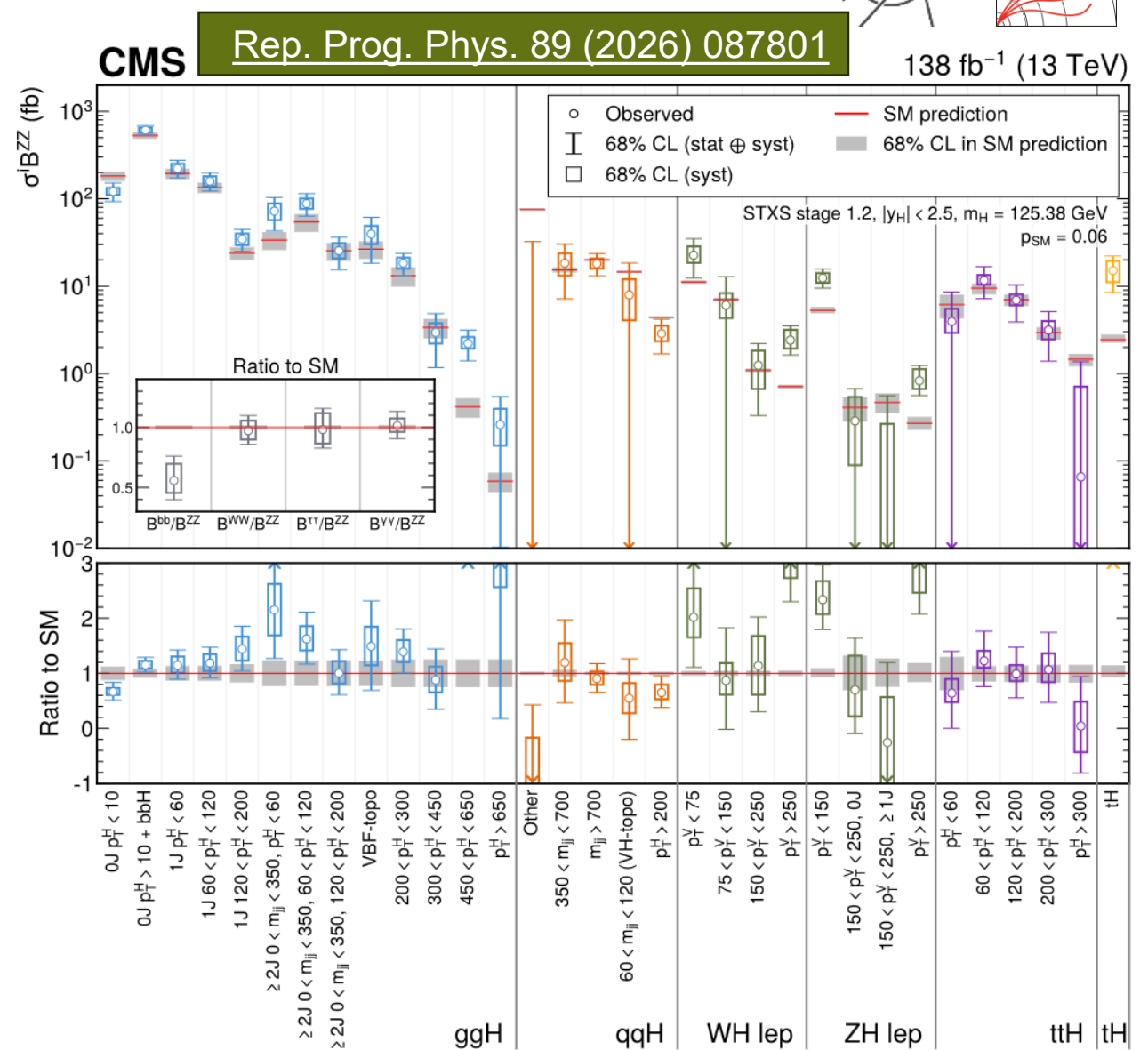
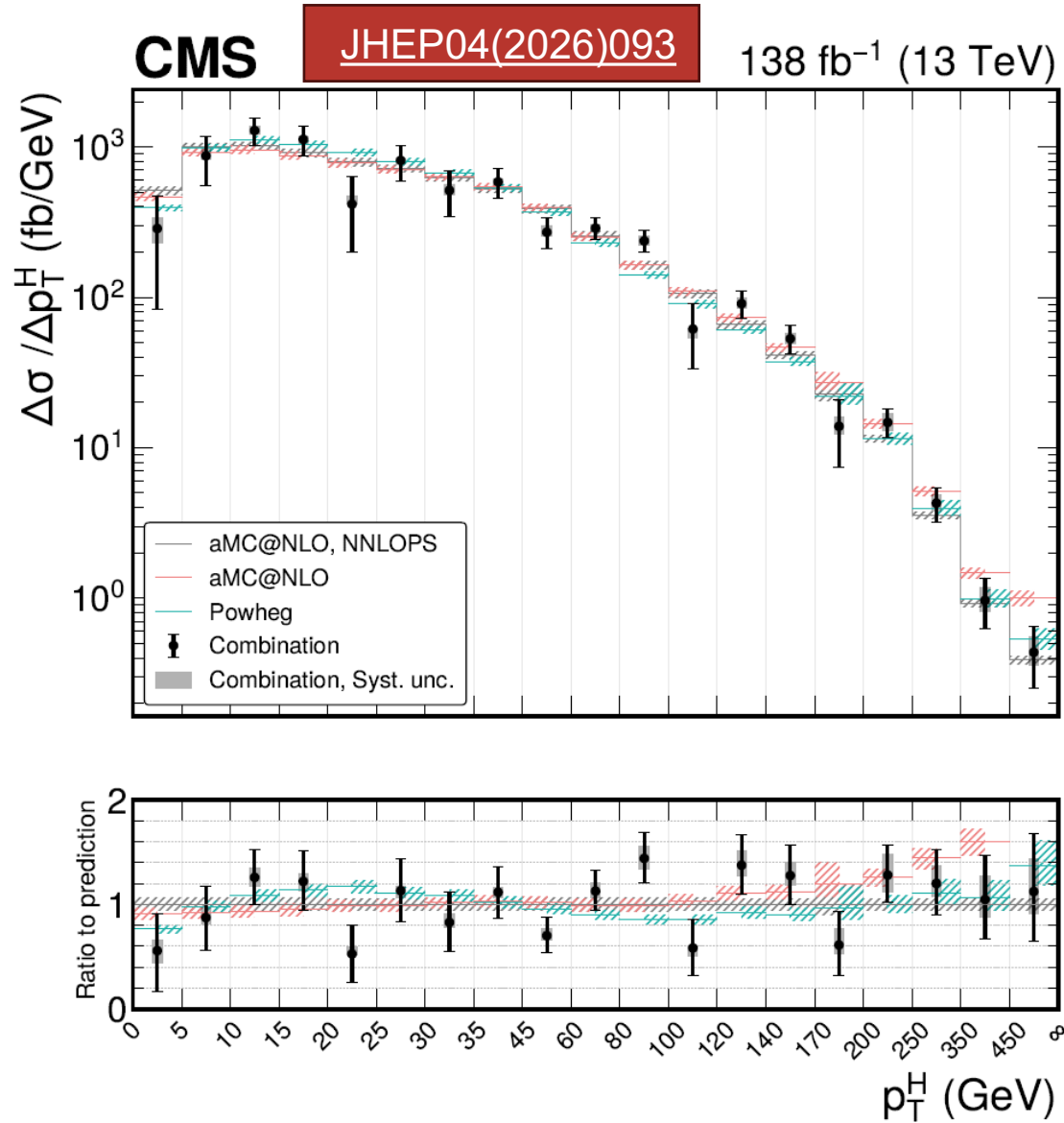
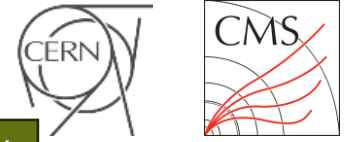
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138 fb⁻¹ (13 TeV)



Total	Stat	Exp	Theo
$1.01^{+0.06}_{-0.05}$	$+0.03_{-0.03}$	$+0.03_{-0.02}$	$+0.04_{-0.04}$

Run 2 combinations: Measurements

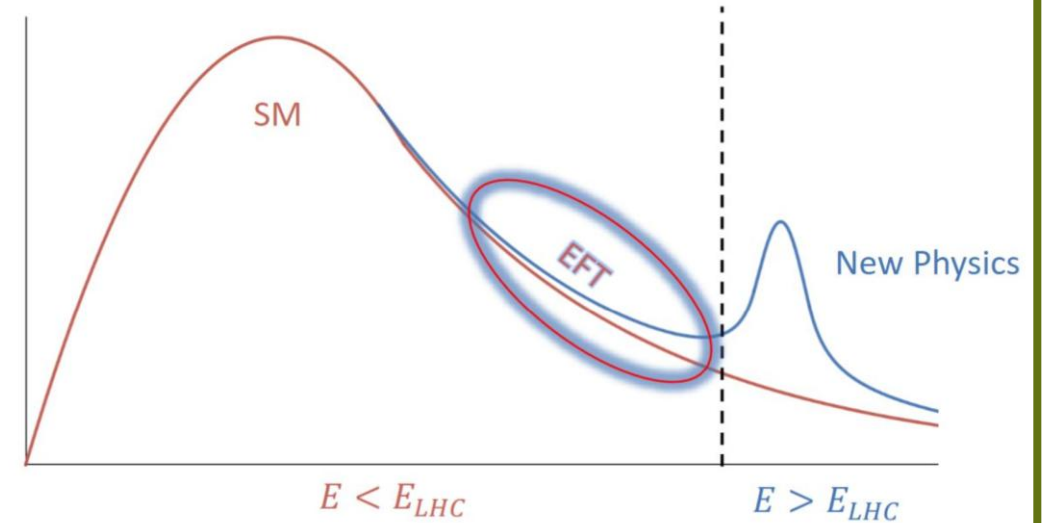
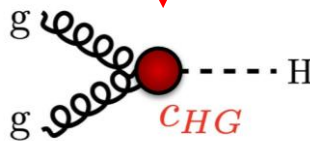


- Interpret results using Effective Field Theories (EFT)

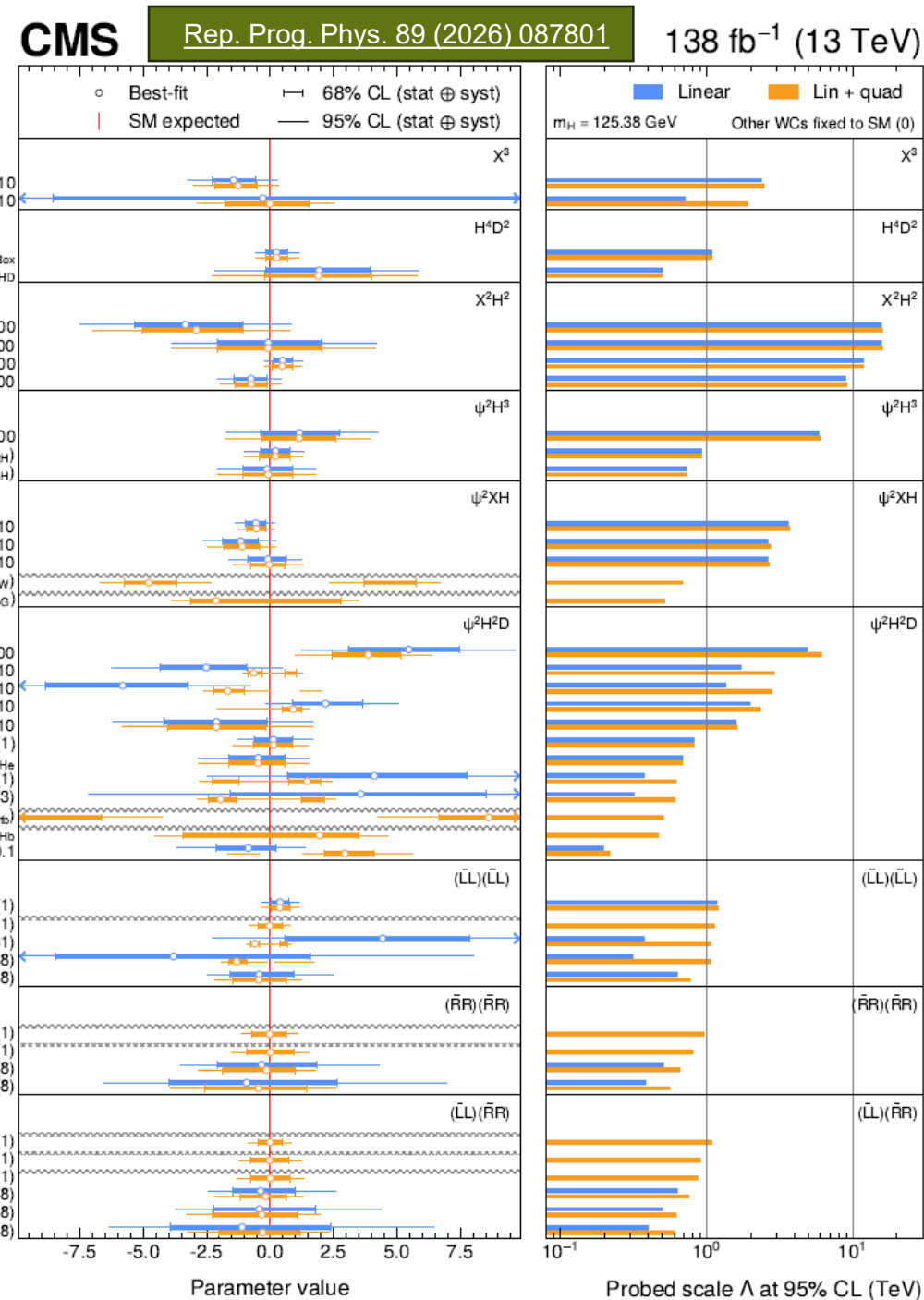
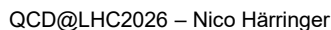
- Assuming new physics exists at $E > E_{LHC}$
- Effects propagate down to lower energy scales using effective interactions
- Consider CP conserving operators $\mathcal{O}_j$ of mass dimension $d = 6$

$$\mathcal{L}_{\text{SMEFT}} = \mathcal{L}_{\text{SM}} + \sum_d \sum_{j \in \mathcal{O}^{(d)}} \frac{c_j^{(d)}}{\Lambda^{d-4}} \mathcal{O}_j^{(d)}$$

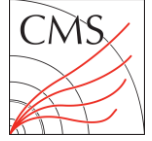
Wilson coefficient (WC)



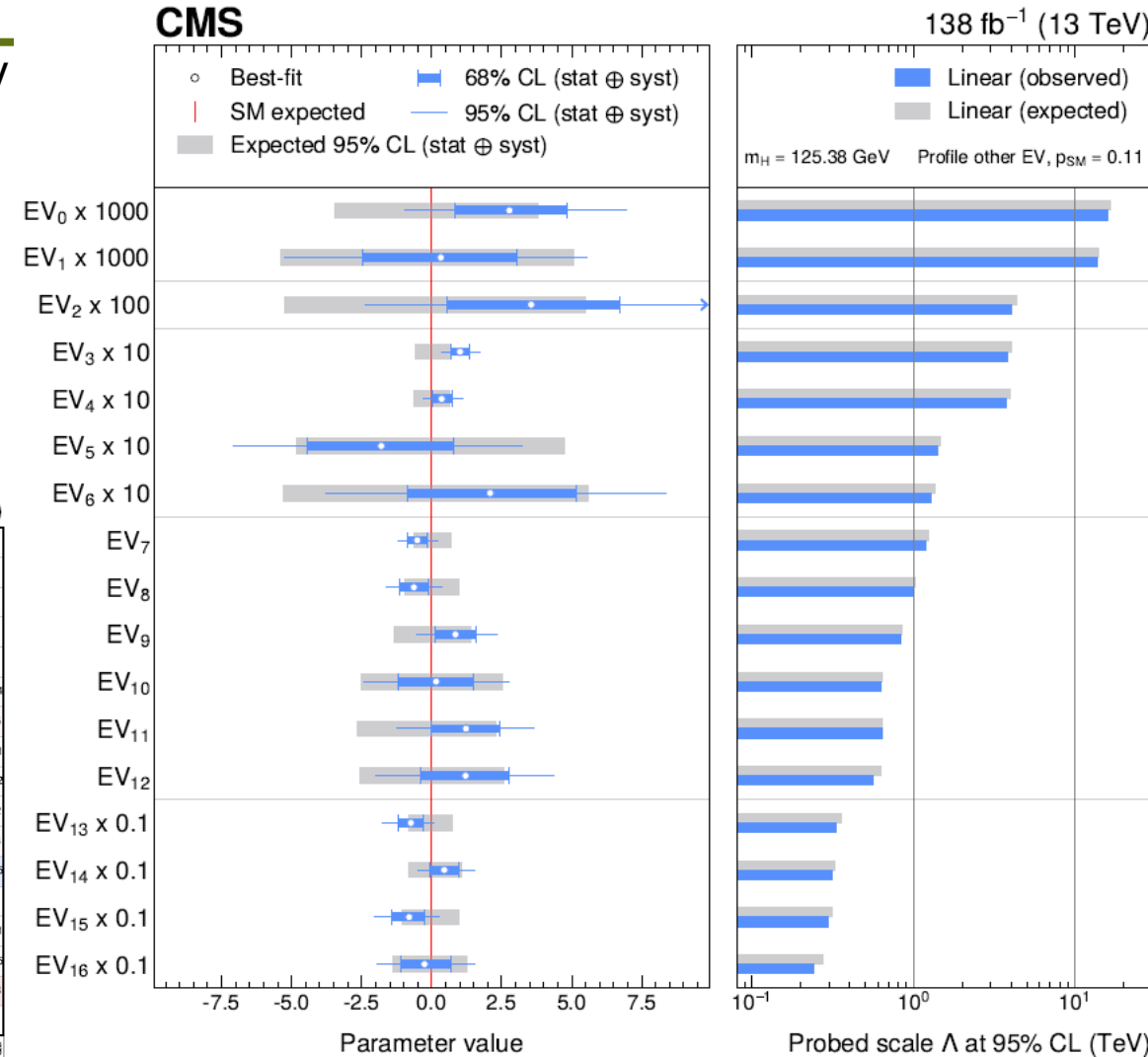
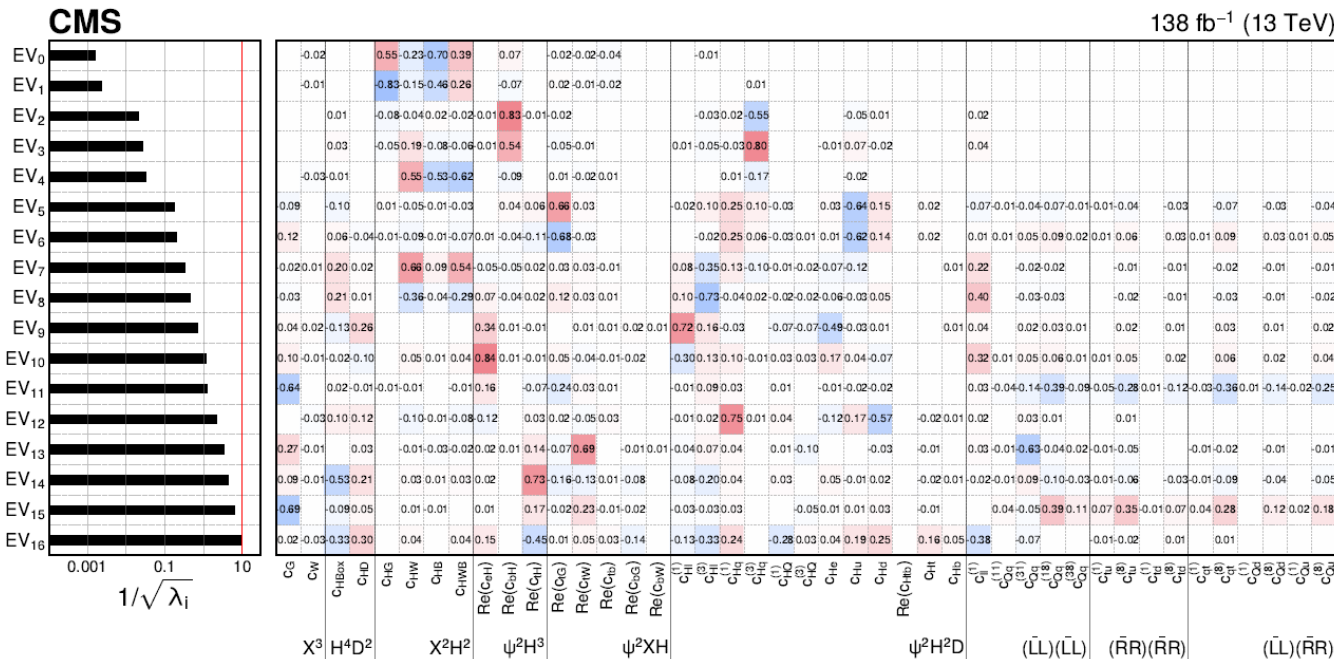
ETH zürich



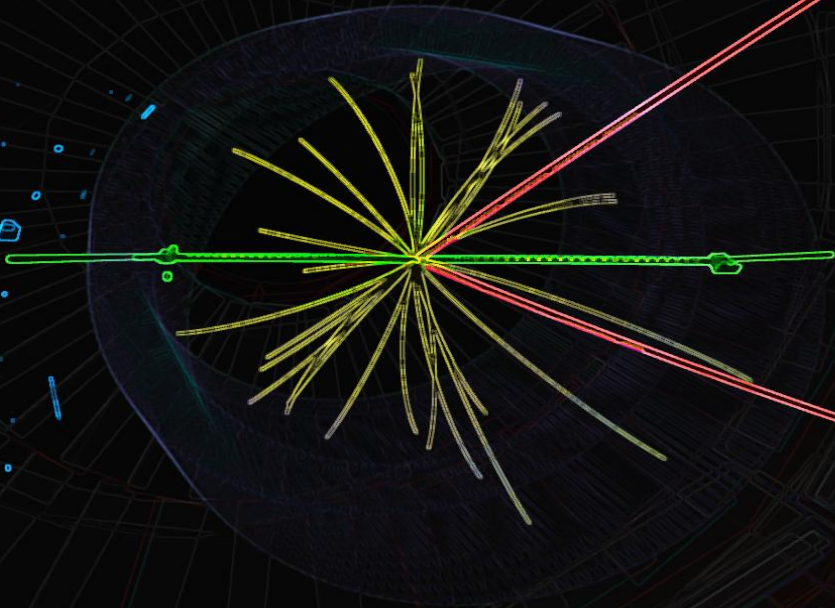
Run 2 combinations: EFT interpretation



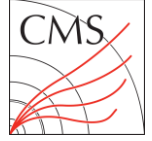
- New physics might modify multiple WCs simultaneously
- Large degeneracies between WCs
 - Flat likelihood surfaces, difficult fit
- Principal Component Analysis (PCA) identifies sensitive directions
- Simultaneous fit to 17 linear combinations of WCs



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

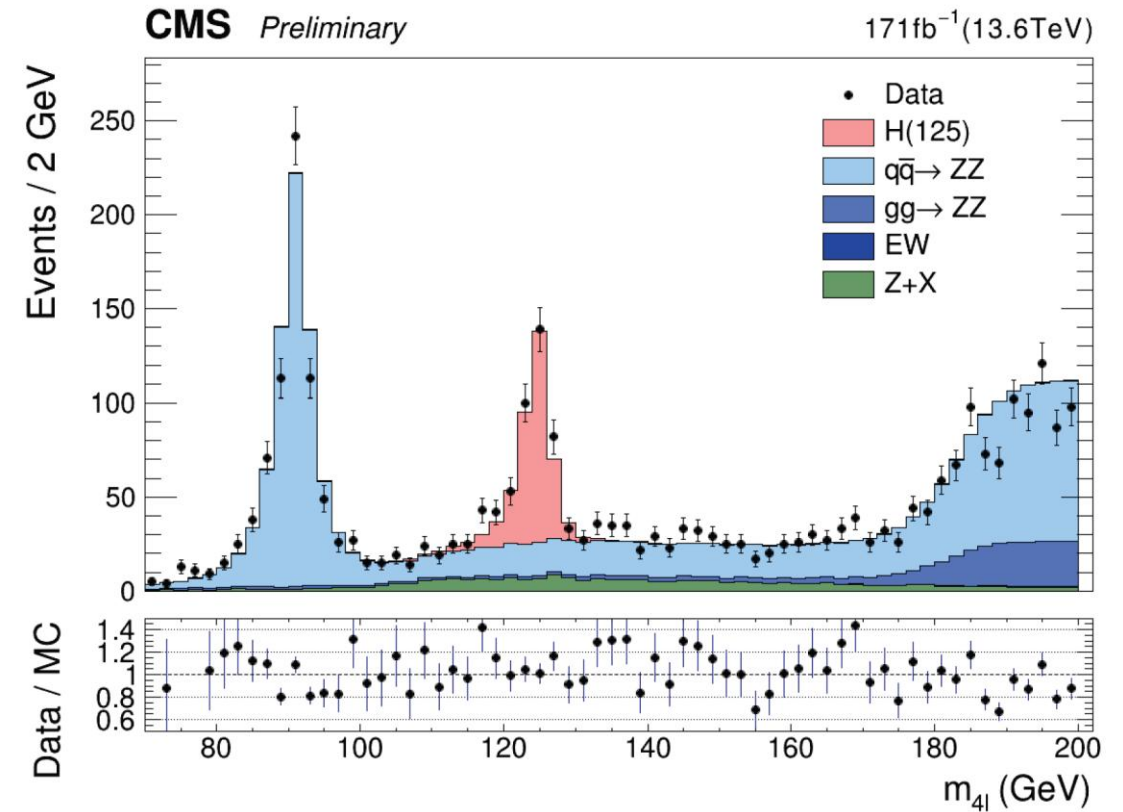


$H \rightarrow ZZ^* \rightarrow 4l$: Description

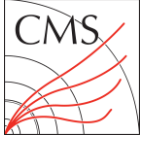


CMS HIG-25-015

- 171 fb⁻¹ @ 13.6 TeV (2022-2024)

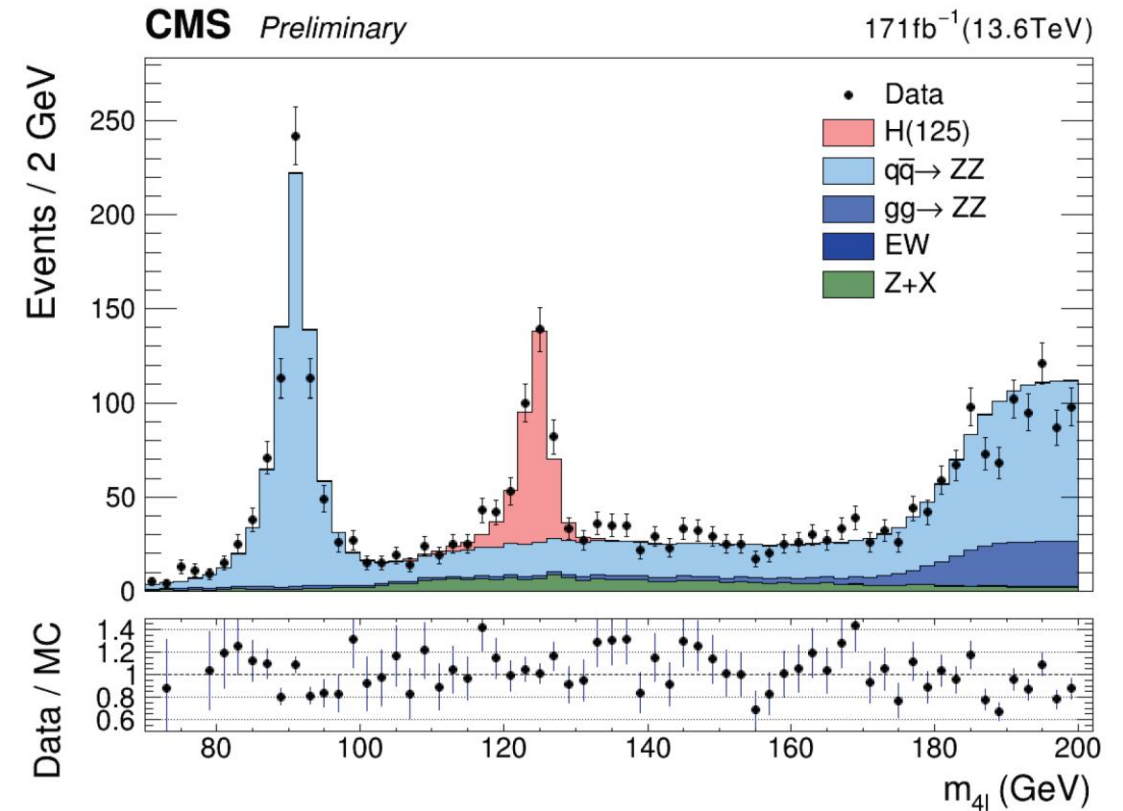


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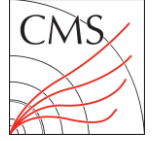


[CMS HIG-25-015](#)

- 171 fb^{-1} @ 13.6 TeV (2022-2024)
- Same strategy as in the 2022 iteration ([JHEP05\(2025\)079](#))

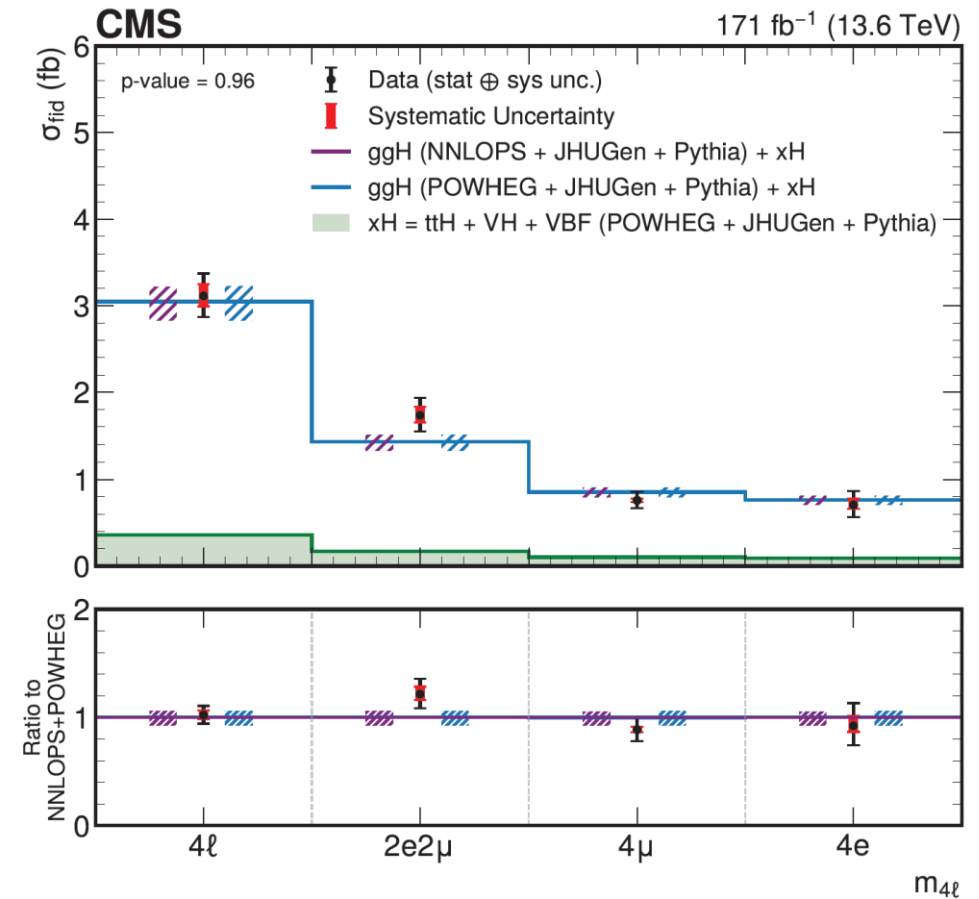


$H \rightarrow ZZ^* \rightarrow 4l$: Inclusive fiducial cross section

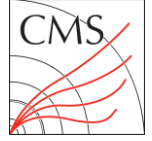


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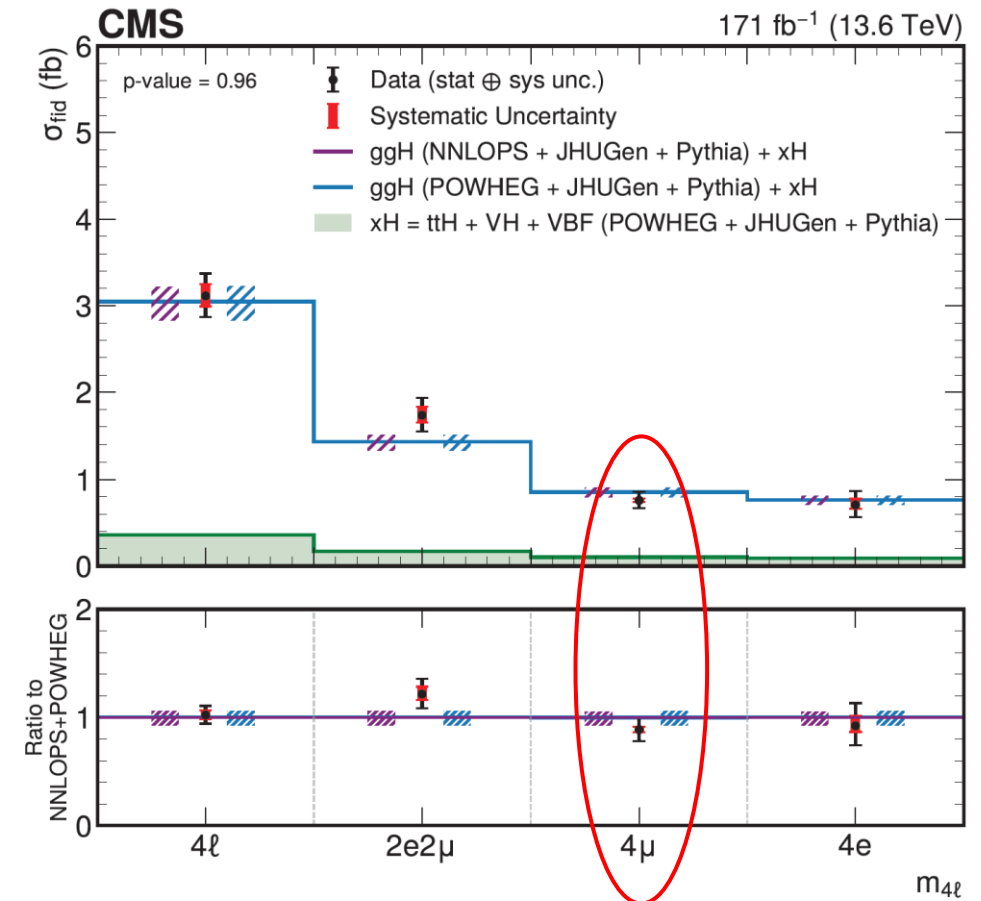


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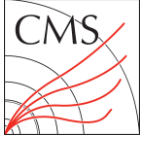


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 - Smallest systematic uncertainty for 4μ

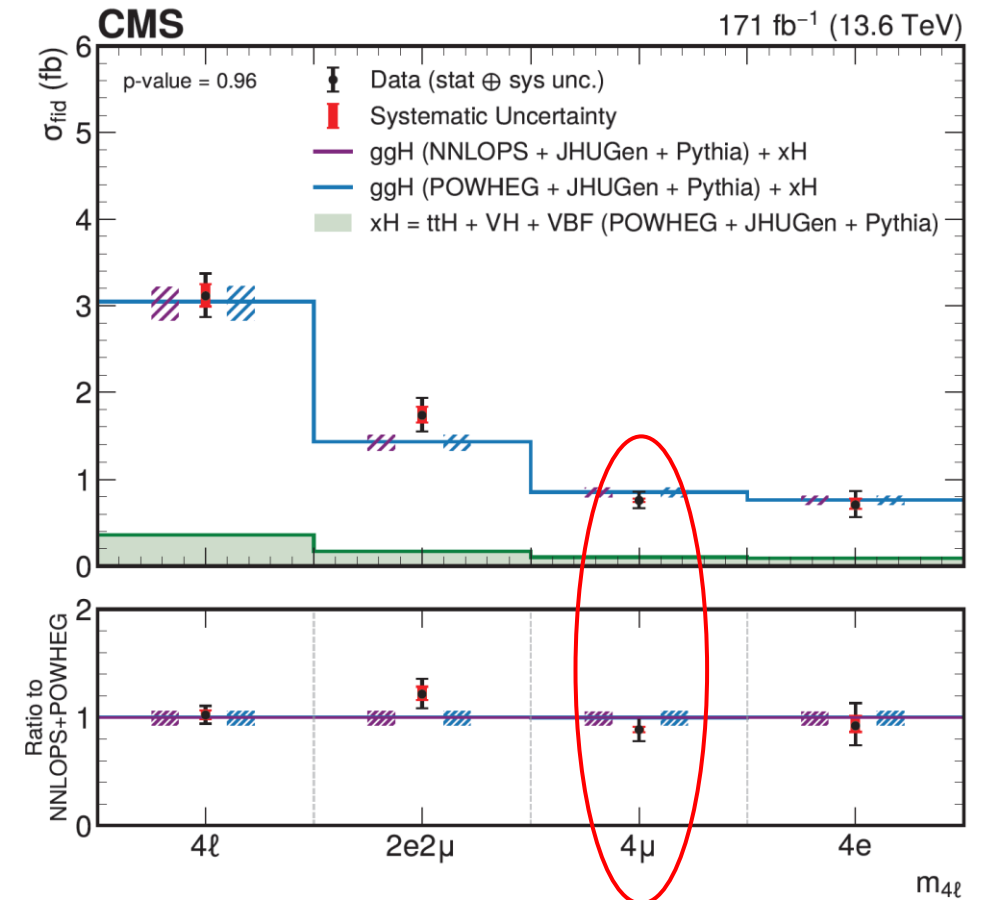


$H \rightarrow ZZ^* \rightarrow 4l$: Inclusive fiducial cross section



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 - Use J/Ψ resonance for low $p_T \mu$ in TnP instead of Z

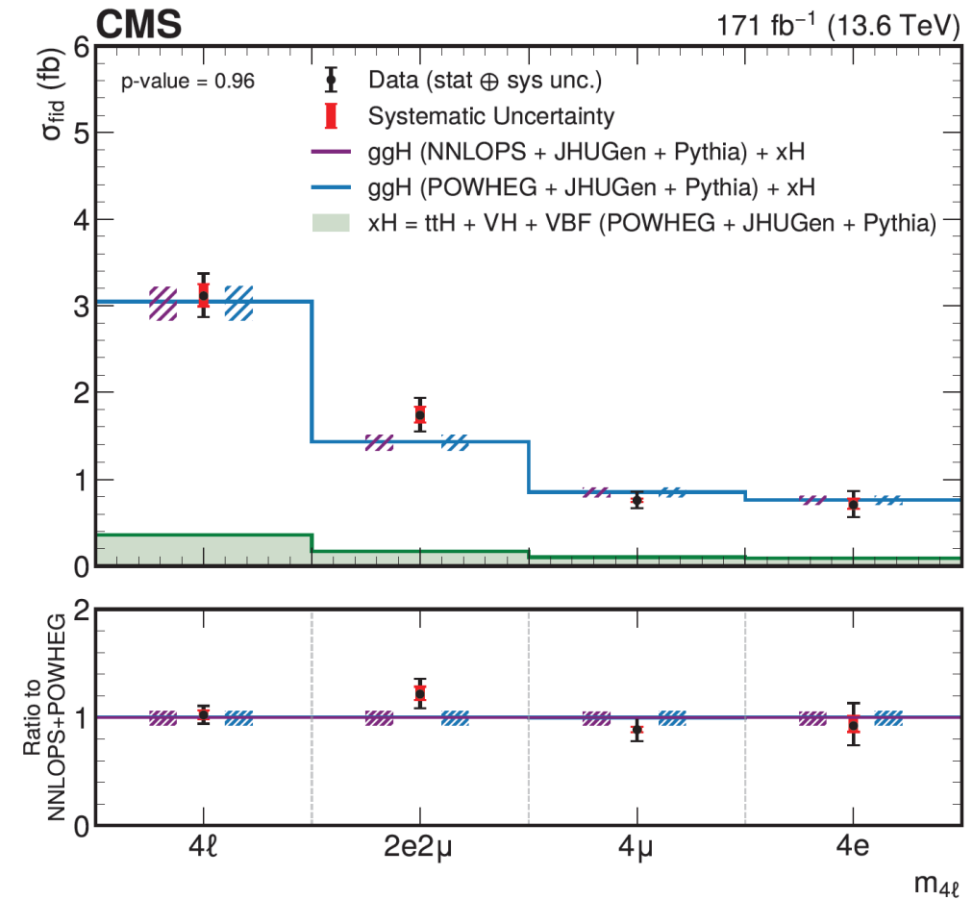


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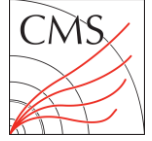


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 - SM expectation: $3.05^{+0.17}_{-0.22}$ fb



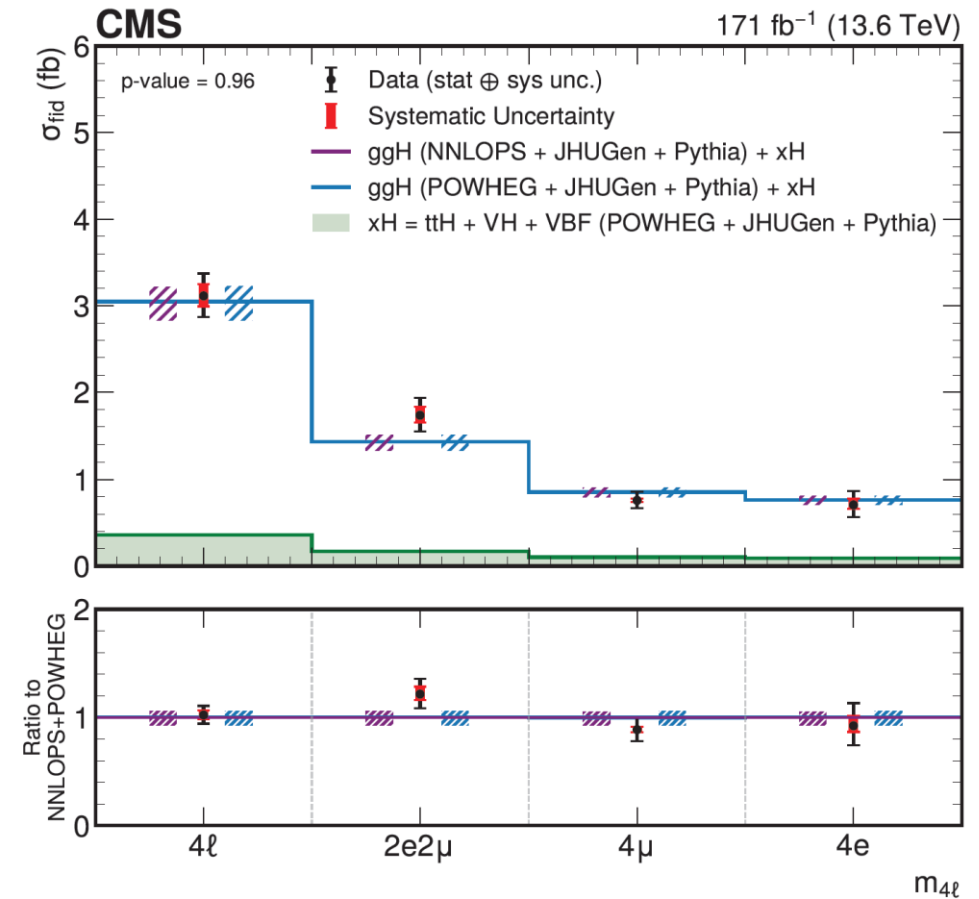
$H \rightarrow ZZ^* \rightarrow 4l$: Inclusive fiducial cross section



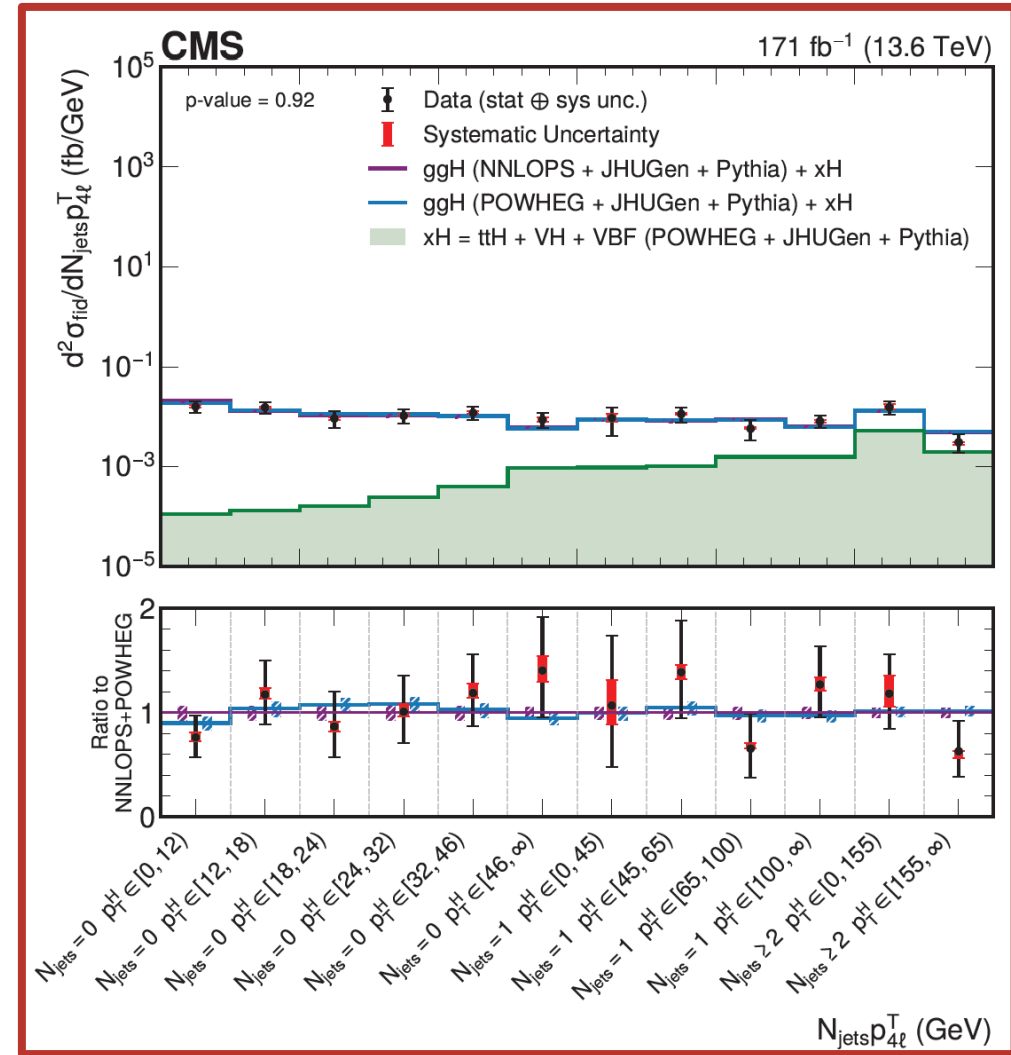
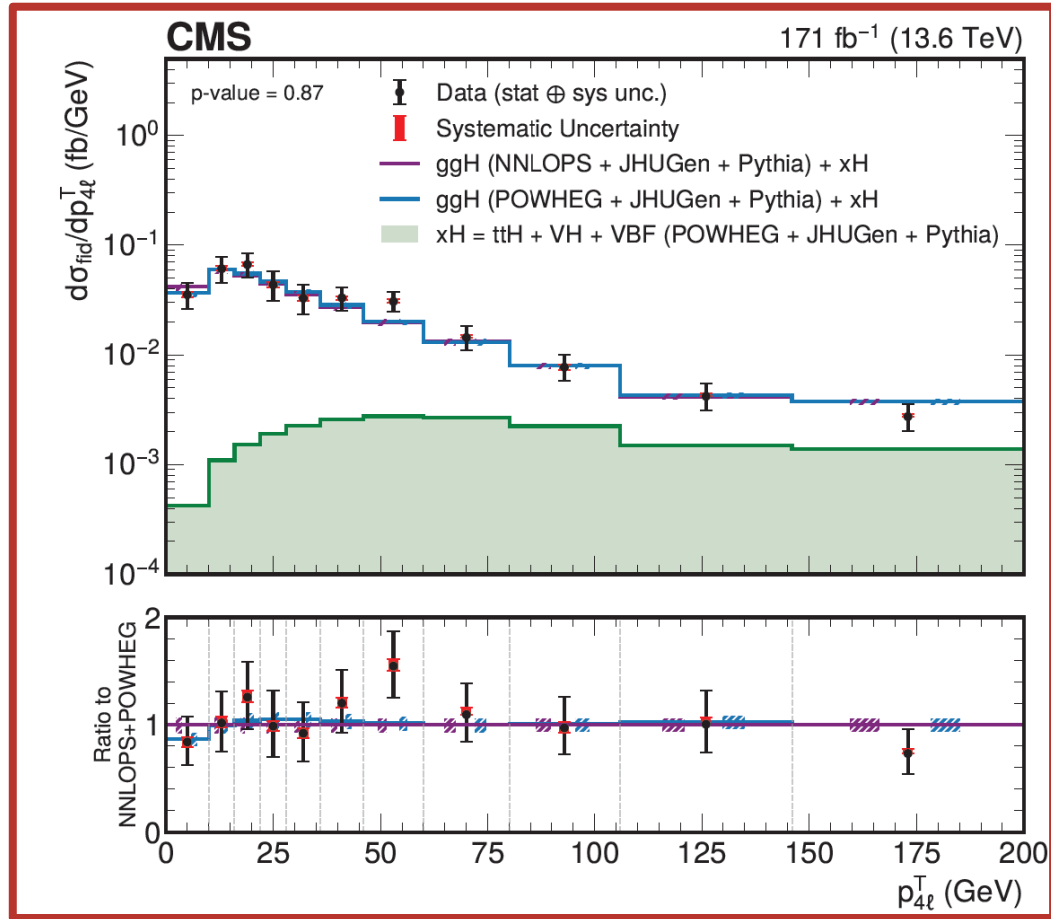
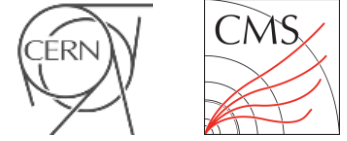
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$$\sigma_{fid}^{4l} = 3.11^{+0.22}_{-0.21} \text{ (stat.) } ^{+0.14}_{-0.12} \text{ (syst.) fb}$$



$H \rightarrow ZZ^* \rightarrow 4l$: Differential fiducial cross section



Conclusion

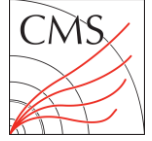
- Run 2 combinations:
 - First combined legacy Higgs boson measurement by CMS
 - EFT interpretations
 -  In agreement with the predictions
- $H \rightarrow ZZ^* \rightarrow 4l$:
 - Inclusive & differential cross sections
 -  In agreement with prediction
 - New 2D differential measurements (e.g. N_{jets} vs p_{4l}^T)

An aerial, high-angle view of a city, likely Zurich, featuring a large, prominent cathedral with multiple spires and a complex roofline. The city is densely packed with buildings, and the overall scene is rendered in a dark, muted color palette. The text "Thank you for listening!" is overlaid in white, sans-serif font in the upper left quadrant.

Thank you for listening!

Backup

The Higgs Boson



Almost every problem of the Standard Model originates from Higgs interactions

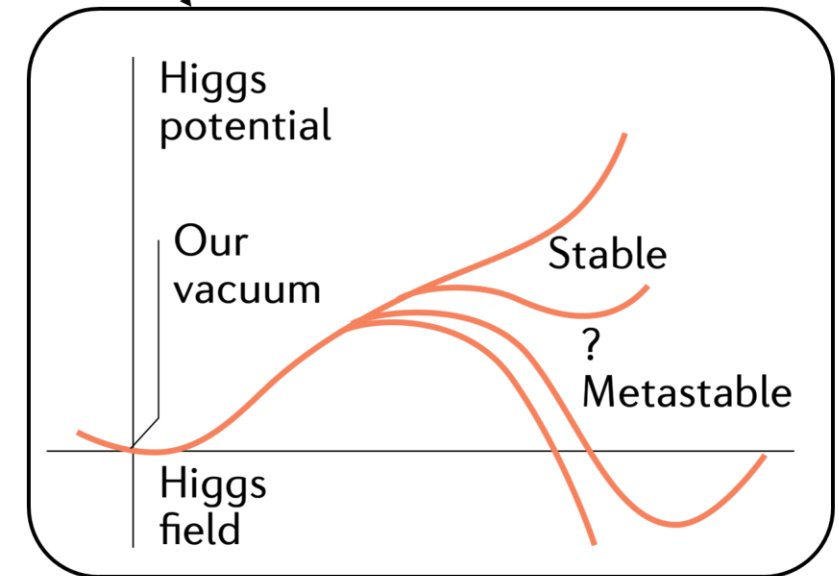
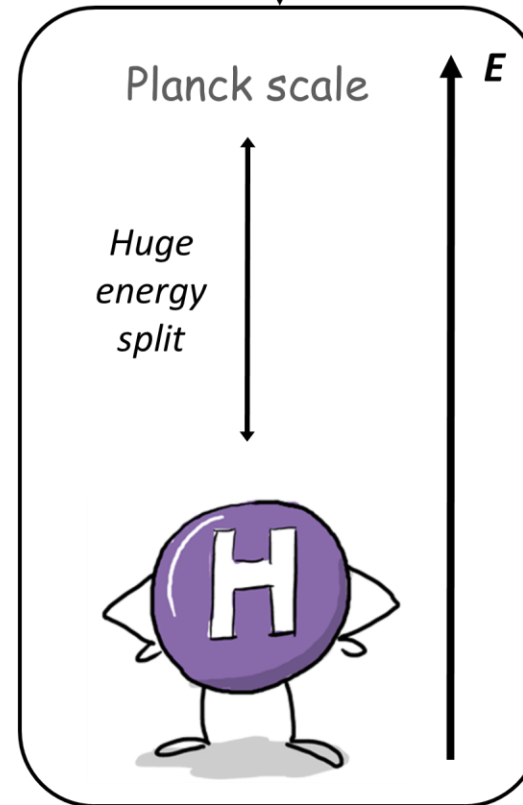
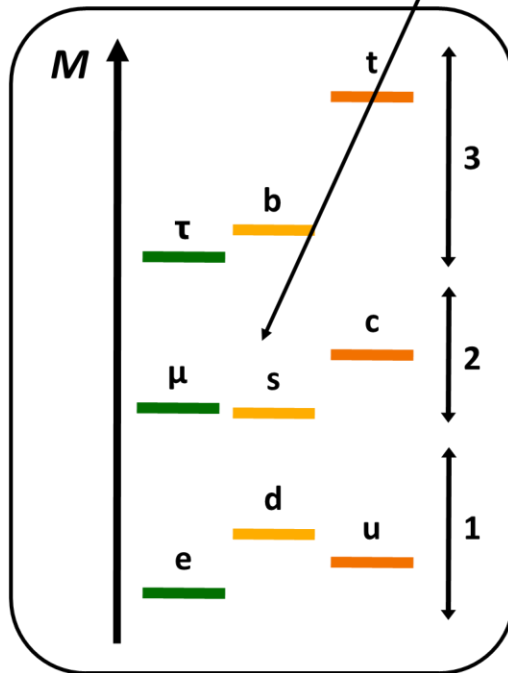
$$\mathcal{L} = \underline{yH\psi\bar{\psi}} + \underline{\mu^2|H|^2} - \underline{\lambda|H|^4} - \underline{V_0}$$

Flavour

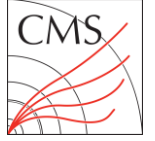
Naturalness

Stability

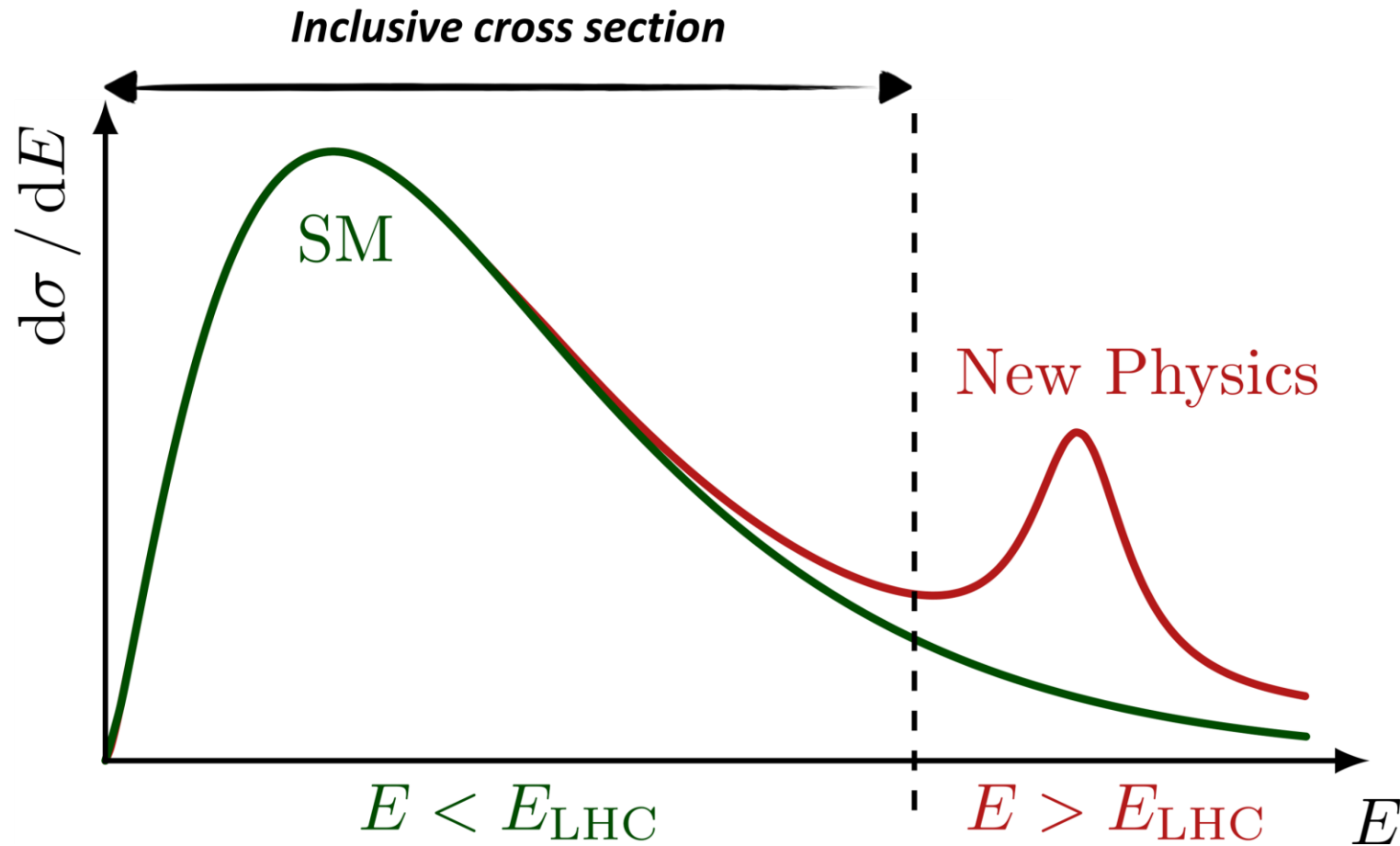
Cosmological
constant?



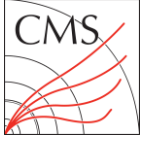
How to study the Higgs Boson?



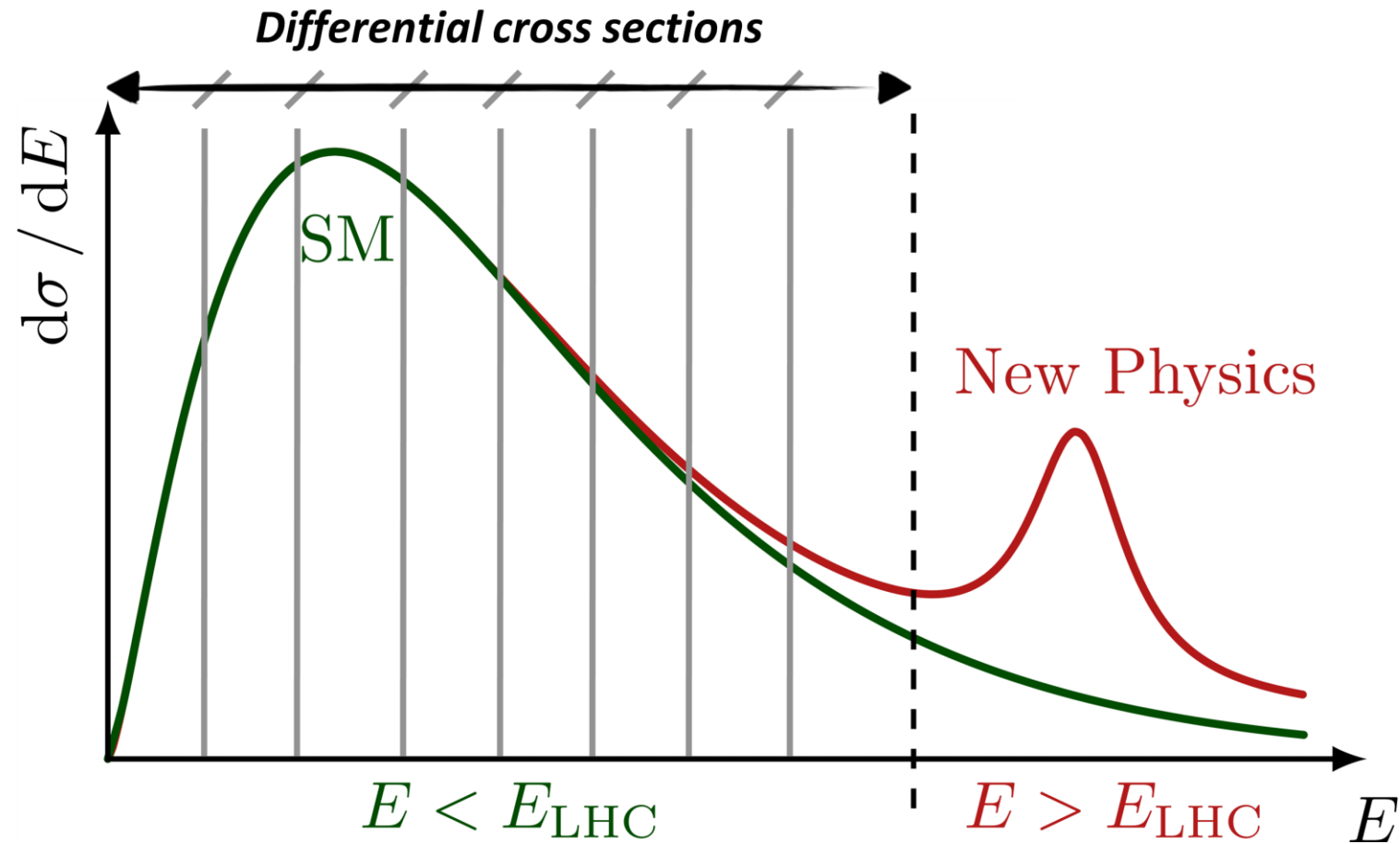
Measuring cross sections is a portal to unveiling the fundamental aspects of how Nature works



How to study the Higgs Boson?



Measuring cross sections is a portal to unveiling the fundamental aspects of how Nature works



Run 2 combination: Backup

Run 2 combination: Results

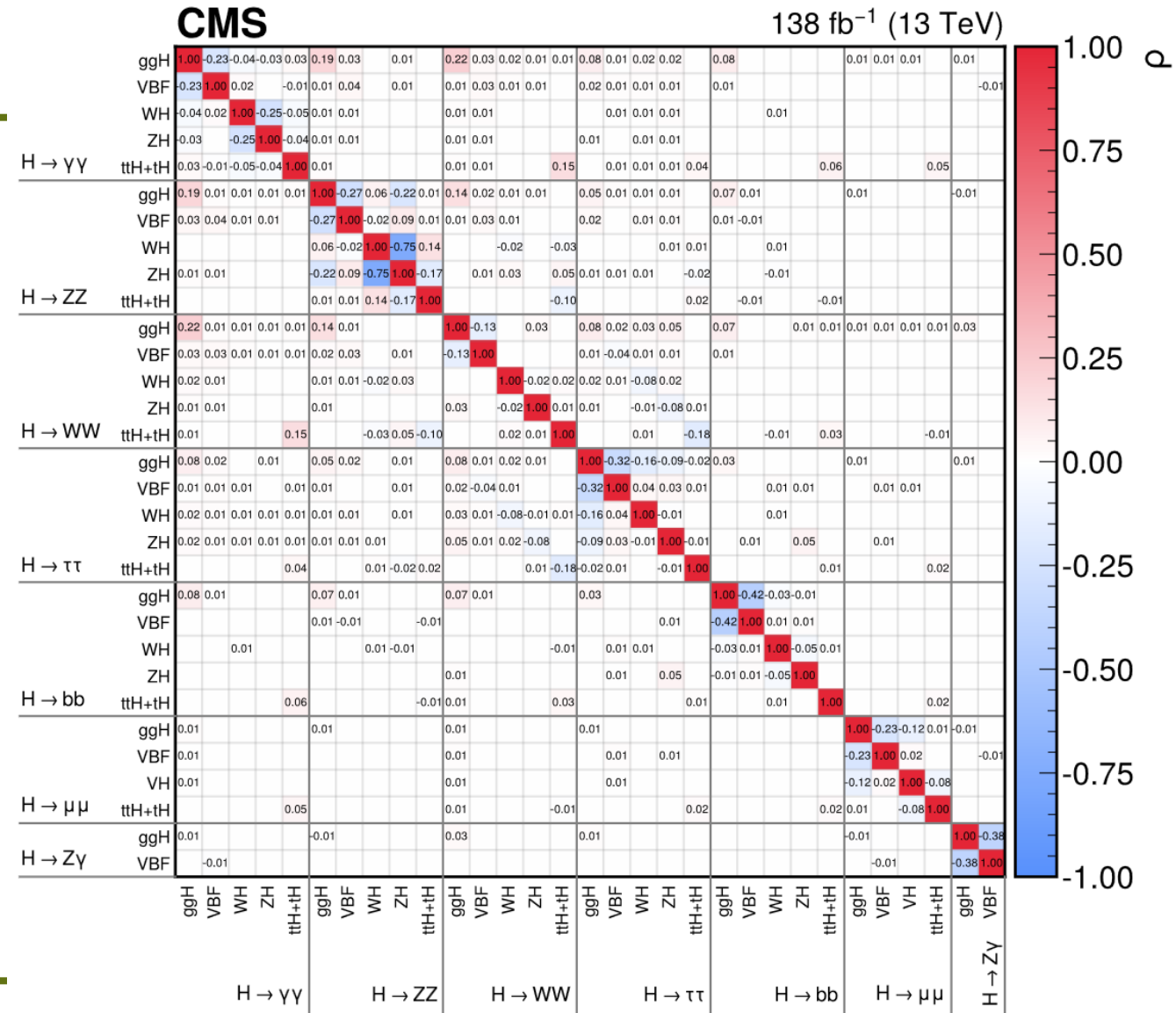
[Rep. Prog. Phys. 89 \(2026\) 087801](#)



138 fb⁻¹ (13 TeV)

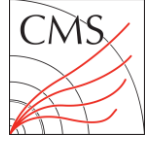
- Measure Signal Strength modifiers across analysis regions

- Inclusively μ^{incl}
- Per process μ^i
- Per decay μ^f
- Per process and decay μ^{if}

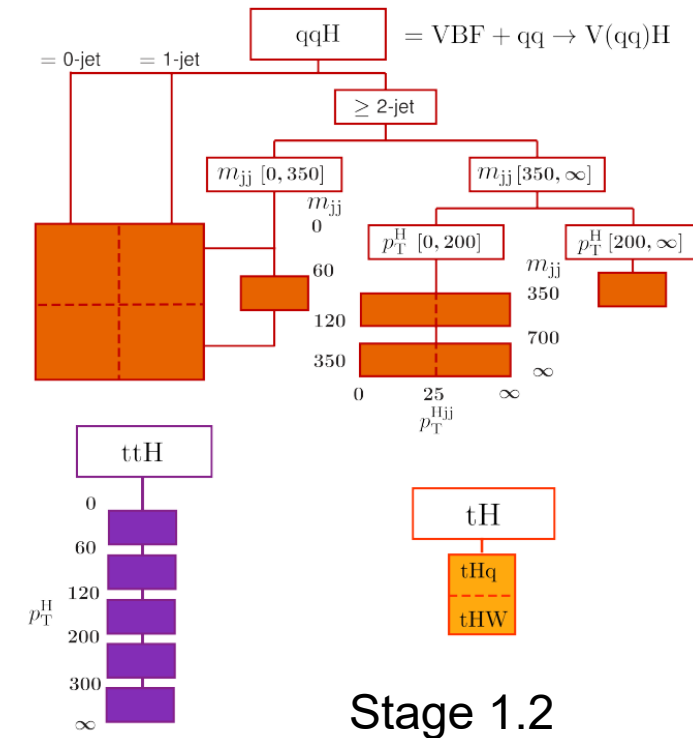
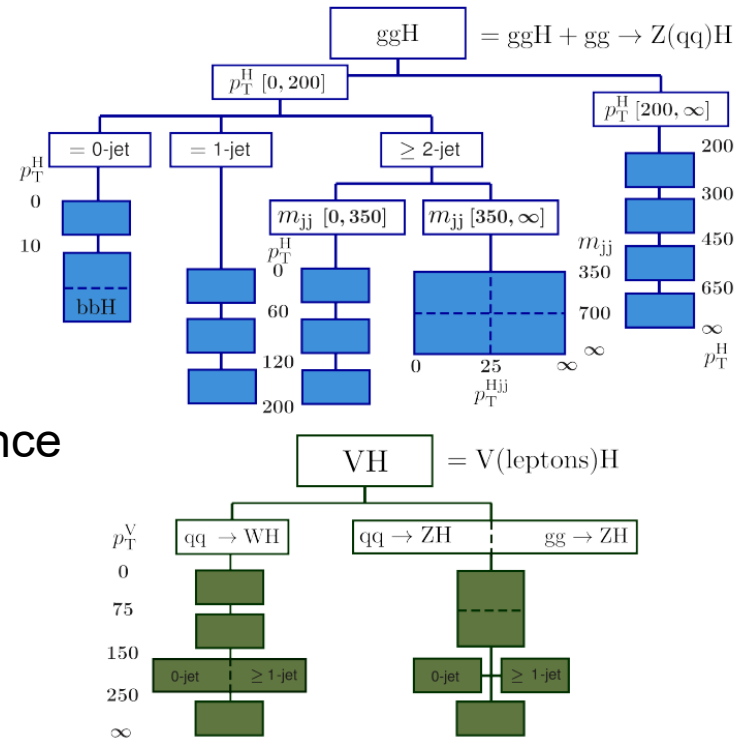


Run 2 combination: STXS

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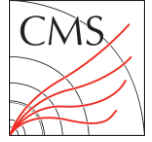
- Simplified Template Cross Sections (STXS)
 - Maximize sensitivity to isolate BSM effects while reducing theory dependence
- Merged some bins to avoid large uncertainties or large correlations
 - At the cost of model-independence



Stage 1.2

Run 2 combination: EFT interpretation

[Rep. Prog. Phys. 89 \(2026\) 087801](#) and [JHEP04\(2026\)093](#)



Run 2 fiducial
differential combination

- Interpret results using Effective Field Theories (EFT)

- Assuming new physics exists at $E > E_{LHC}$
- Effects propagate down to lower energy scales using effective interactions
- Consider CP conserving operators $\mathcal{O}_j$ of mass dimension $d = 6$

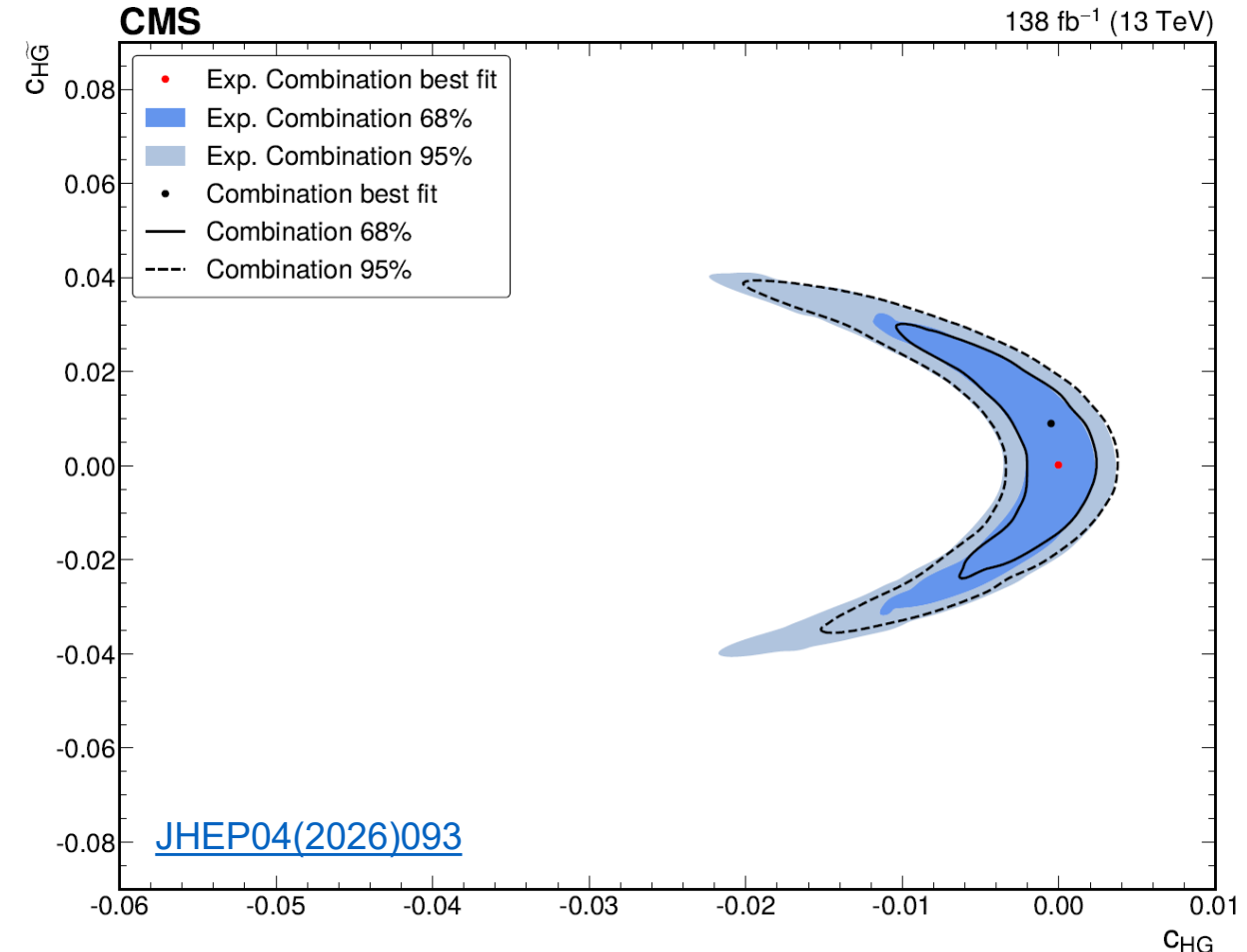
- Parametrize signal strength as a function of Wilson coefficients (WCs)

$$\mu = 1 + \sum_j A_j c_j + \sum_{jk} B_{jk} c_j c_k$$

linear quadratic

- Individual constraints of WCs

- Rest set to SM expectation ($c_i = 0$)



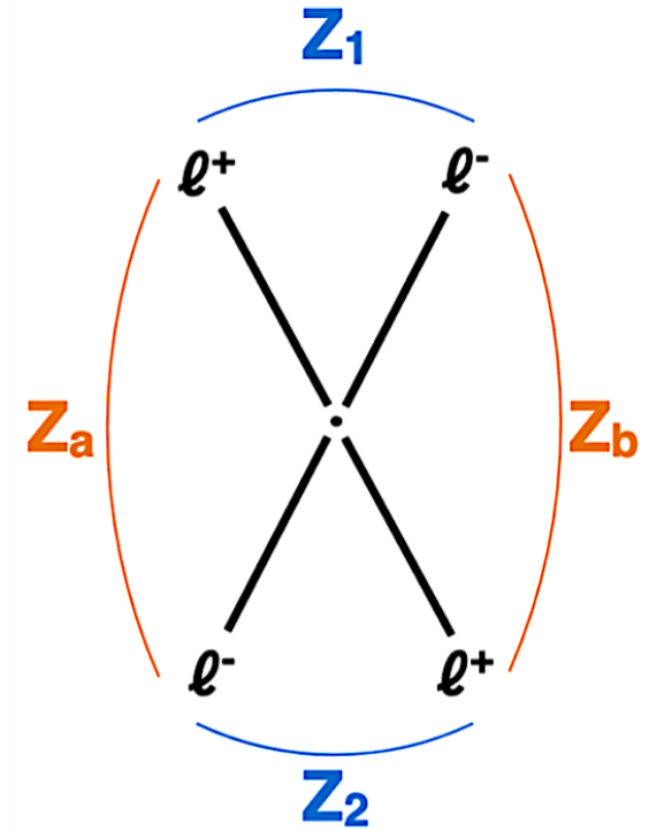
$H \rightarrow ZZ^* \rightarrow 4l$: Backup

Events selections

Z Candidates: any OS-SF pair that satisfies $12 < m_{ll}(\gamma) < 120 \text{ GeV}/c^2$

ZZ Candidates: all possible ZZs are built, defining Z_1 the candidate with $m_{ll}(\gamma)$ closest to the nominal Z mass

- $m_{Z_1} > 40 \text{ GeV}/c^2$
- $p_{T(l_1)} > 20 \text{ GeV}/c^2, p_{T(l_2)} > 10 \text{ GeV}/c^2$
- $\Delta R(\eta, \Phi) > 0.02$ between each of the four leptons
- $m_{ll} > 4 \text{ GeV}$ for OS pair
- Reject 4μ and $4e$ candidates where the alternative pairing $Z_a Z_b$ satisfies $|m(Z_a) - m_Z| < |m_{Z_1} - m_Z|$ AND $m_{Z_b} < 12 \text{ GeV}/c^2$
- $m_{4l} > 70 \text{ GeV}$

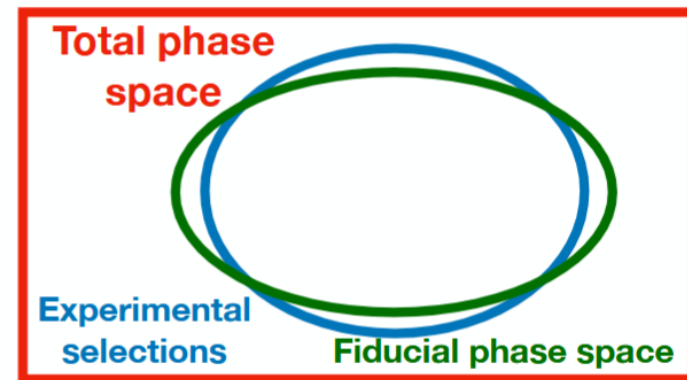


Z1: candidate with invariant mass closest to the PDG Z

If multiple Z2s are present, the one with the largest pT sum of the leptons is retained

Fiducial phase space

- Cross section is measured by **unfolding** experimental data to the fiducial phase space at **generator level**
- The definition of the **phase space** is the same as in **HIG-21-009**



Model independent measurement ✓

Easy re-interpretability ✓

Z1: OSSF pair of leptons closest to the Z mass

Z2: second OSSF pair of leptons; in case of more than a pair the one with the highest scalar pT is chosen

Requirements for the $H \rightarrow 4\ell$ fiducial phase space	
Lepton kinematics and isolation	
leading lepton p_T	$p_T > 20 \text{ GeV}$
next-to-leading lepton p_T	$p_T > 10 \text{ GeV}$
additional electrons (muons) p_T	$p_T > 7(5) \text{ GeV}$
pseudorapidity of electrons (muons)	$ \eta < 2.5(2.4)$
p_T sum of all stable particles within $\Delta R < 0.3$ from lepton	less than $0.35 \cdot p_T$
Event topology	
existence of at least two SFOS lepton pairs, where leptons satisfy criteria above	
inv. mass of the Z₁ candidate	$40 \text{ GeV} < m(Z_1) < 120 \text{ GeV}$
inv. mass of the Z₂ candidate	$12 \text{ GeV} < m(Z_2) < 120 \text{ GeV}$
distance between selected four leptons	$\Delta R(\ell_i \ell_j) > 0.02$ for any $i \neq j$
inv. mass of any opposite sign lepton pair	$m(\ell^+ \ell'^-) > 4 \text{ GeV}$
inv. mass of the selected four leptons	$105 \text{ GeV} < m_{4\ell} < 160 \text{ GeV}$
the selected four leptons must originate from the $H \rightarrow 4\ell$ decay	

Gen-level isolation is included to reduce the model dependence on the efficiency