Effective Field Theory fits of the electroweak sector CMS data

Ankita Mehta
(On behalf of the CMS Collaboration)

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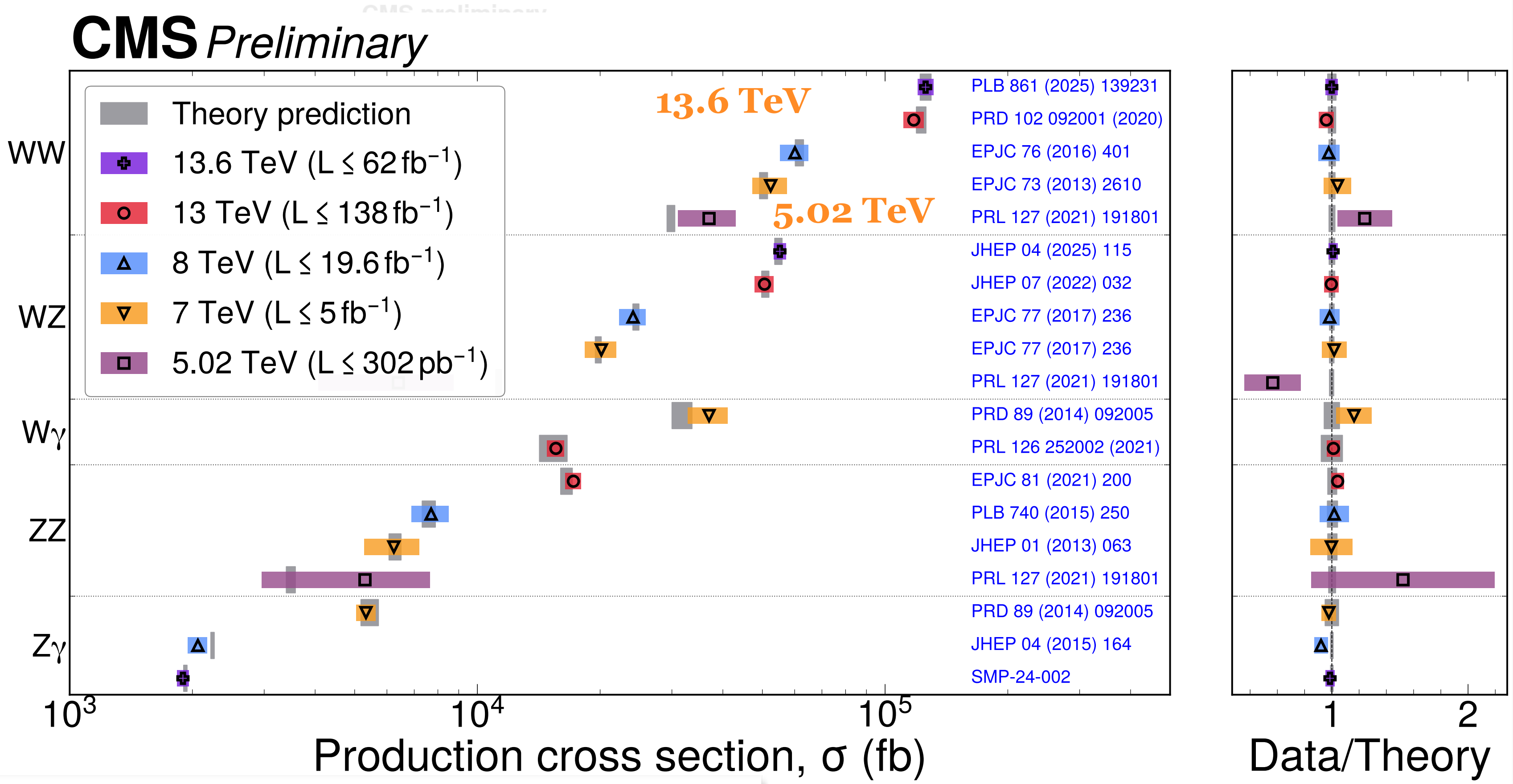
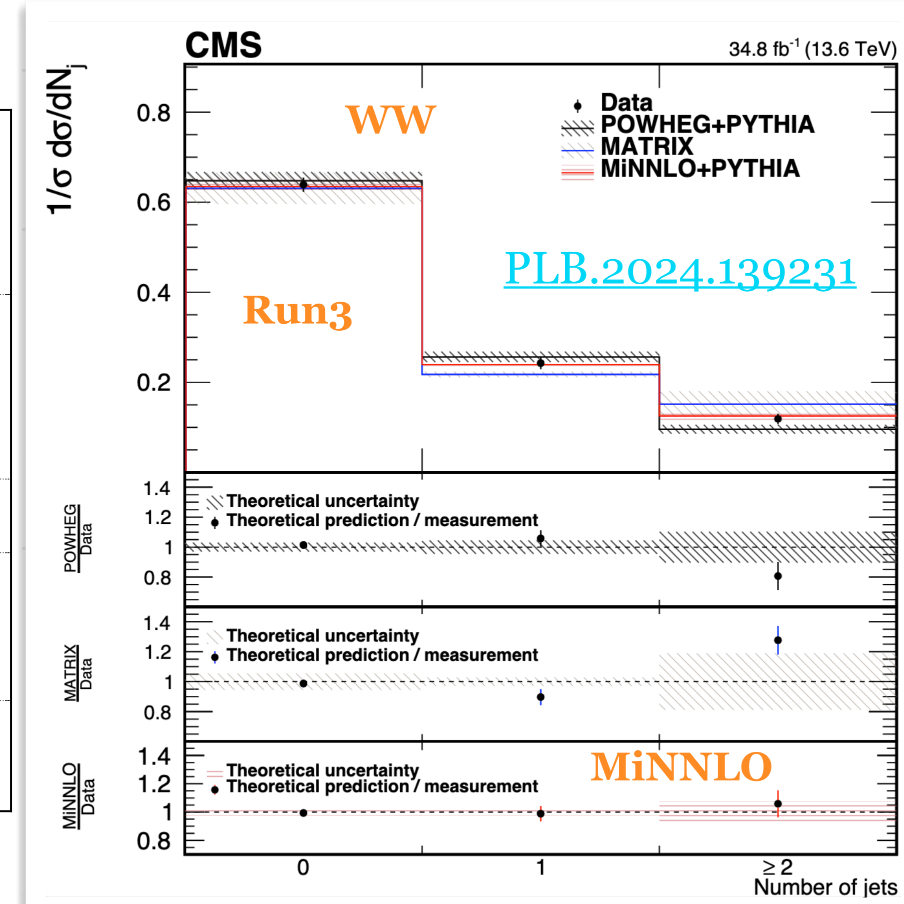
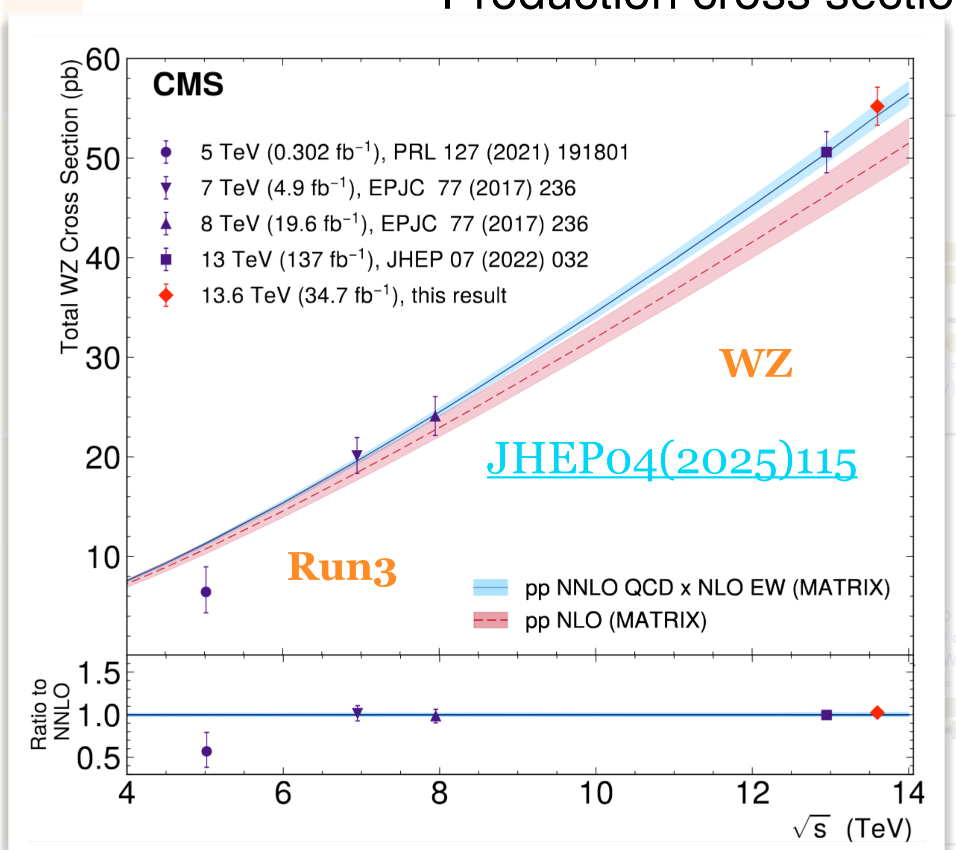
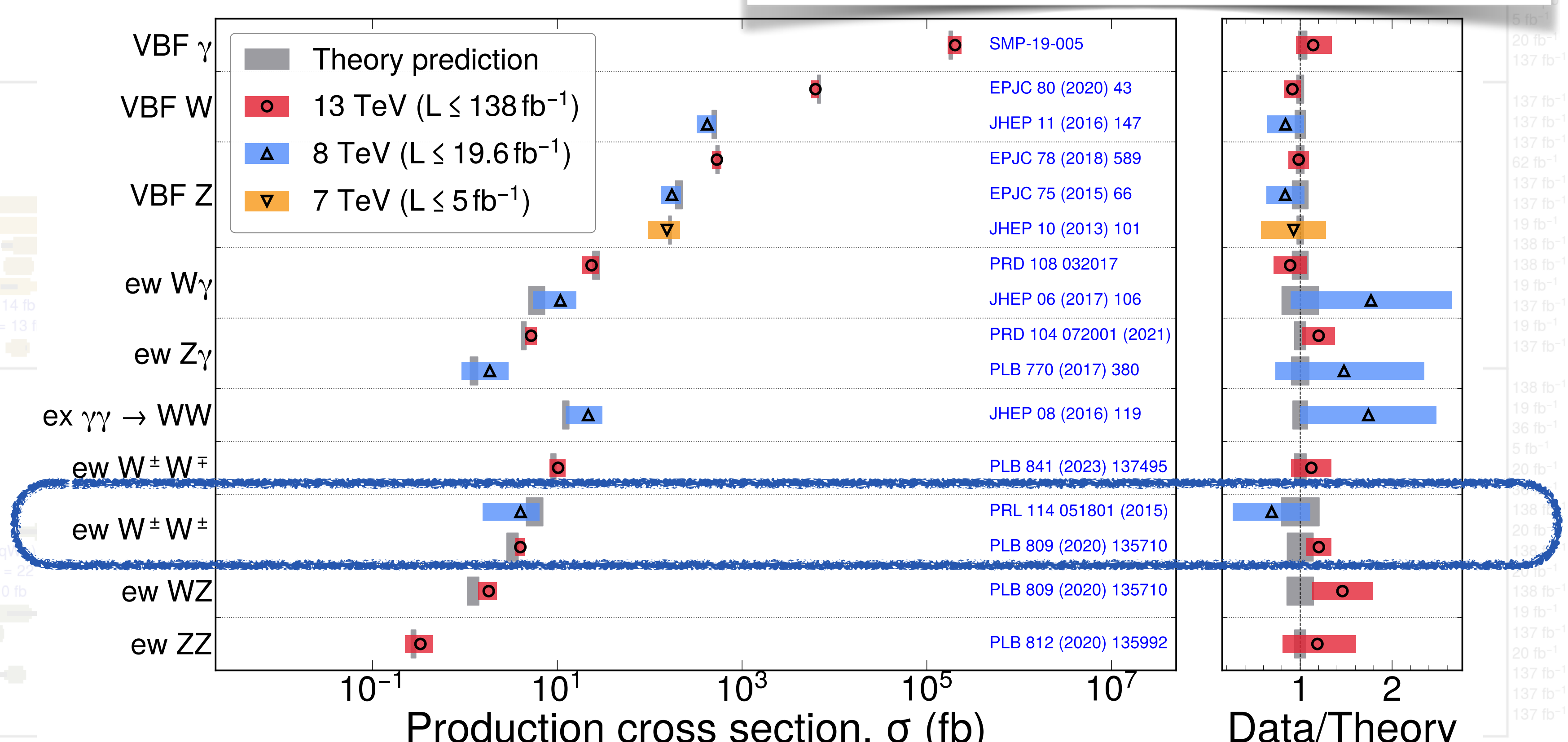
Precision era for multiboson productions

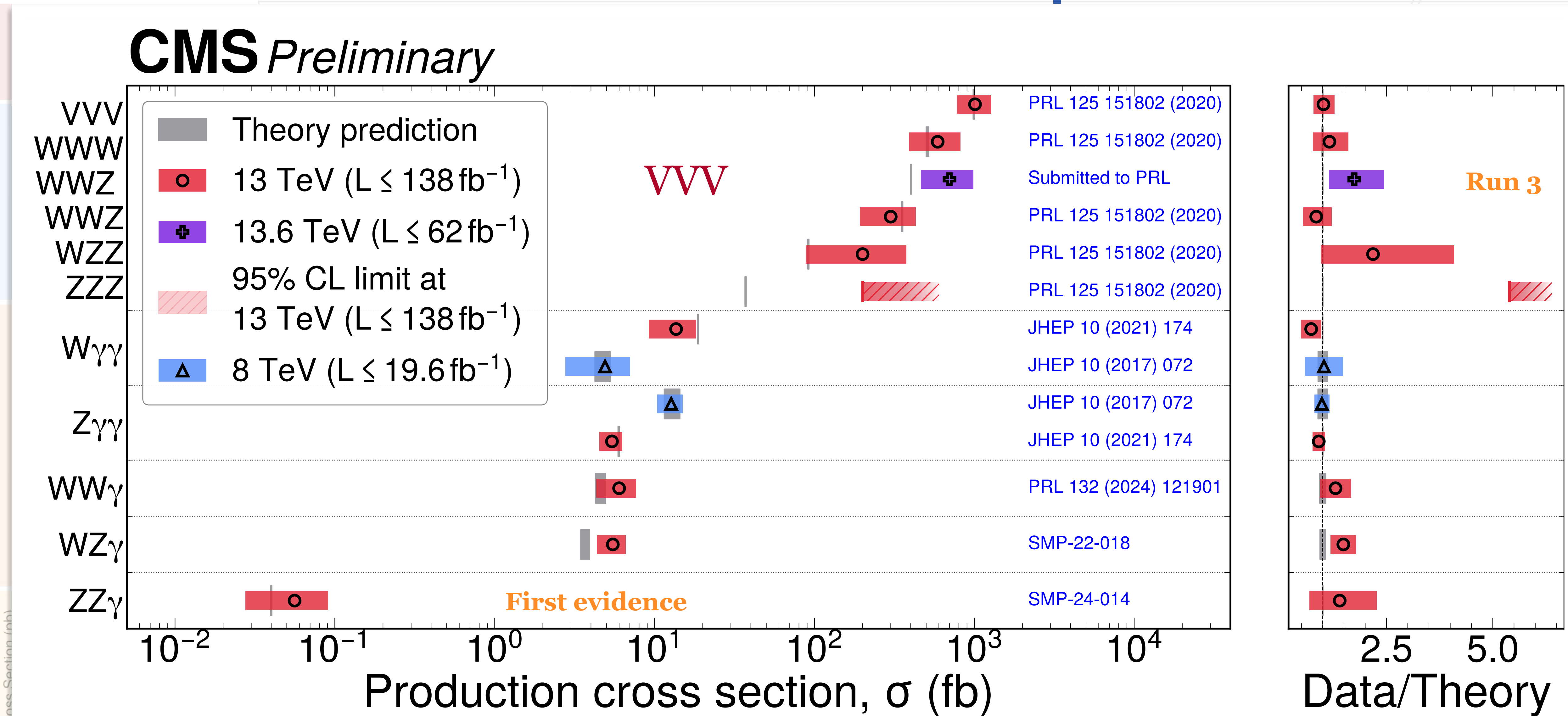




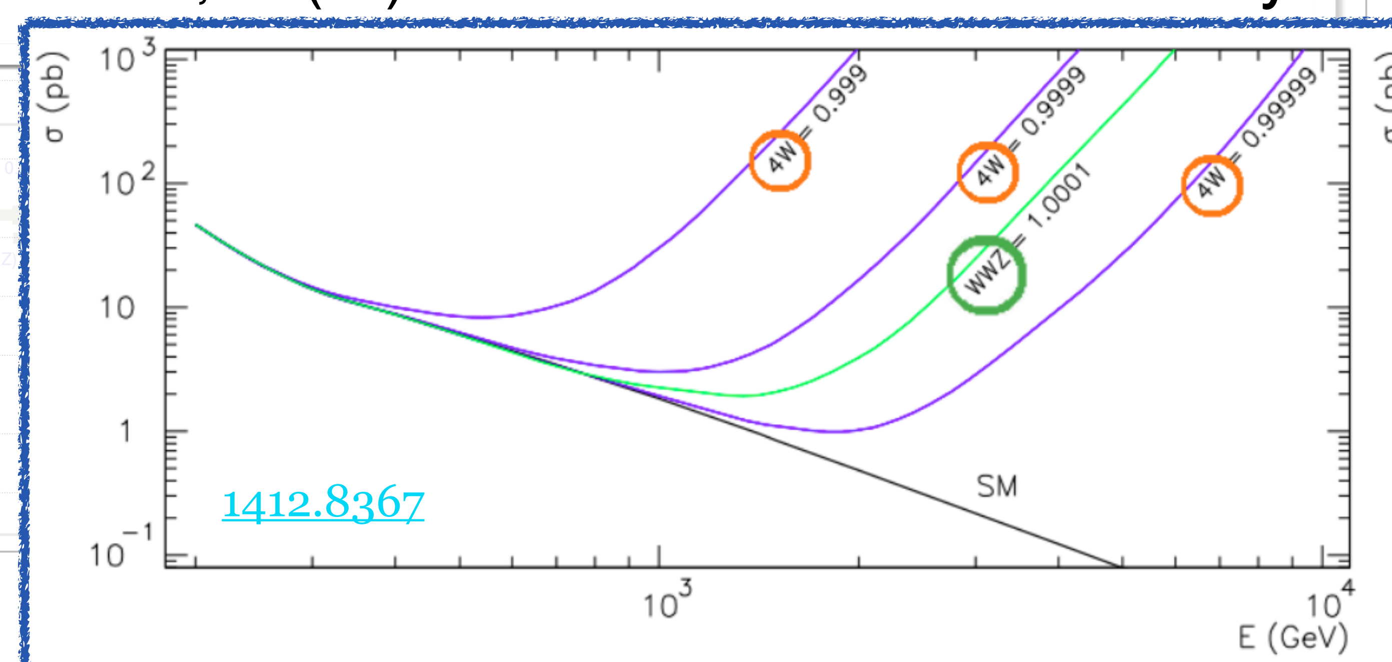




Precision era for multiboson productions



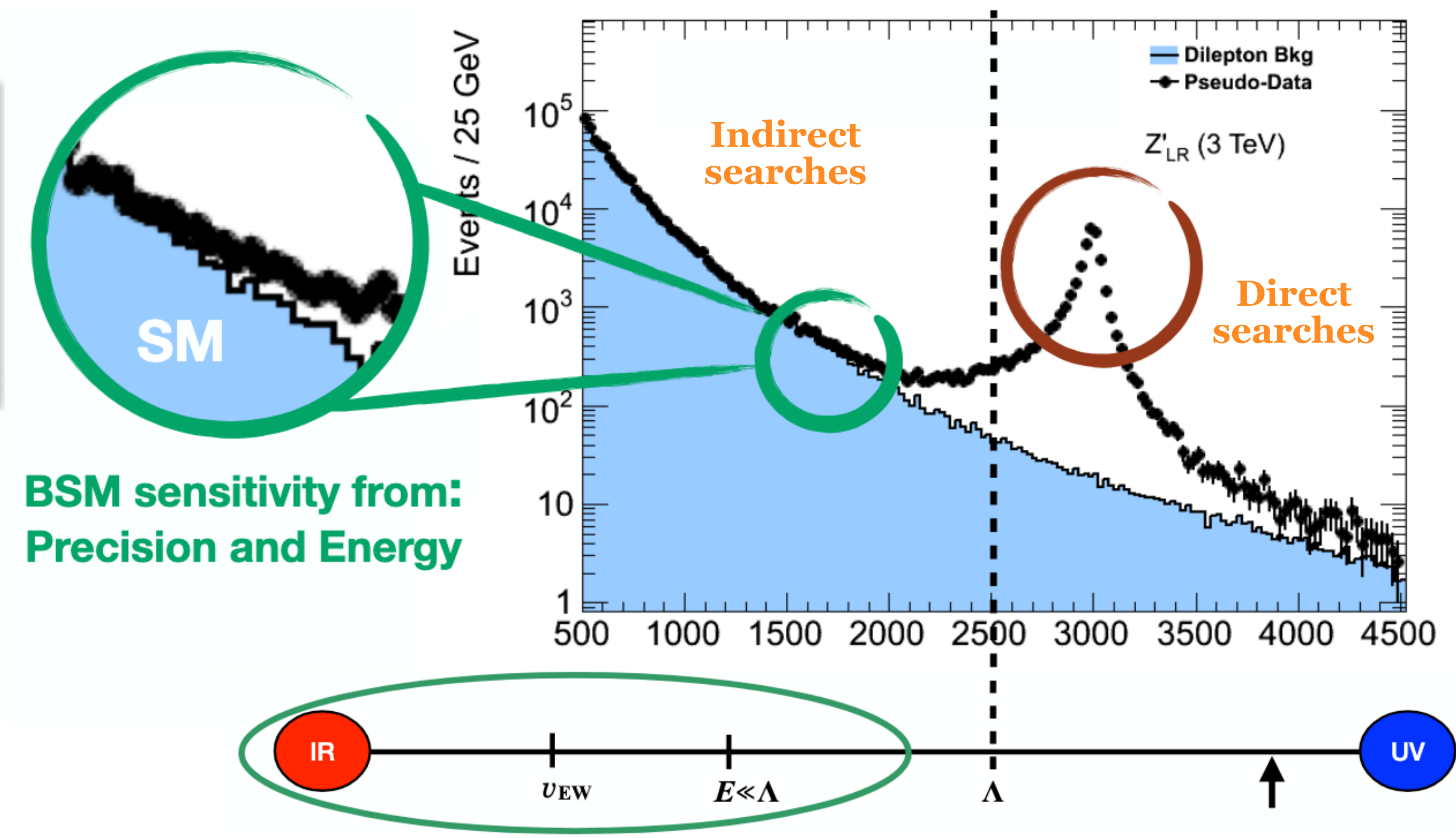
- Multiboson productions → trilinear & quartic gauge couplings
- Small deviations from SM values → new physics



Standard Model Effective Field Theory

$$\mathcal{L}_{\rm SMEFT} = \mathcal{L}_{\rm SM} + \sum_{i=1}^{2499} \frac{C_i}{\Lambda^2} \mathcal{O}_i \,,$$

$\mathcal{O}_i^d \rightarrow$ new d-dimension operators;
$C_i \rightarrow$ dimensionless parameters (Wilson coefficients);
$\Lambda \rightarrow$ new physics scale



- Generic approach → consistent and model independent way to parametrise deviations in all SM processes
- EFT models are available at LO or NLO

- Well-motivated phenomenologically & mature in terms of tools and techniques
- Not perfect, but it is arguably today's best choice for a comparison exercise without going directly into specific models

Sketch from Jorge's talk at ESPP 2025

Diboson analyses with EFT interpretations

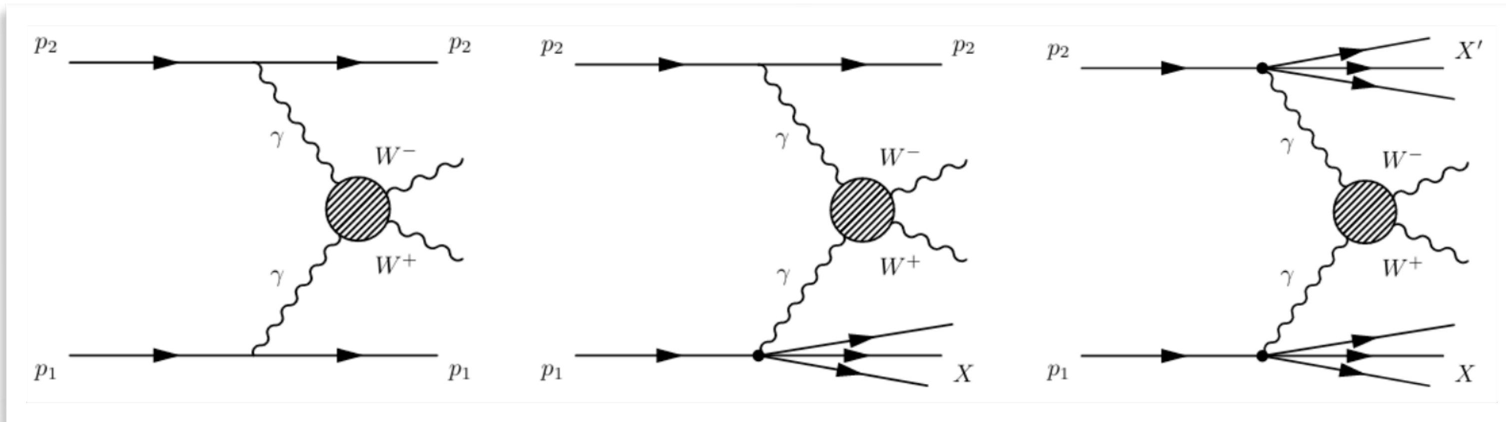
Process	Reference
VBS W±W±(→2l2ν)	PhysLetB.2020.135710
VBS WZ(→3lν)	PhysLetB.2020.135710
VBS W±W±(→$l\tau_h$2ν)	CERN-EP-2024-234
VBS ZZ(→4l)	PhysLetB.2020.135992
VBS Z(→ll)γ	JHEP06(2020)076
VBS W(→lν)γ	PhysRevD.108.032017
VBS ZV+WV **Today!**	CDSid:2926224
W±W∓ (→2l2ν)	PhysRevD.102.092001
WV	JHEP12(2019)062
W(→lν)γ	PhysRevD.105.052003
Z(→ll)γ	CDSid:2928843
Z(→νν)γ	CDSid:2895314
(ex.)γγ→WW,ZZ (→jets)	JHEP07(2023)229
(ex.)γγ→WW (→2l2ν) **Today!**	CMS-SMP-24-019
Combination of EW, Higgs, Top,QCD **Today!**	CERN-EP-2025-035

CMS-SMP-24-019

New

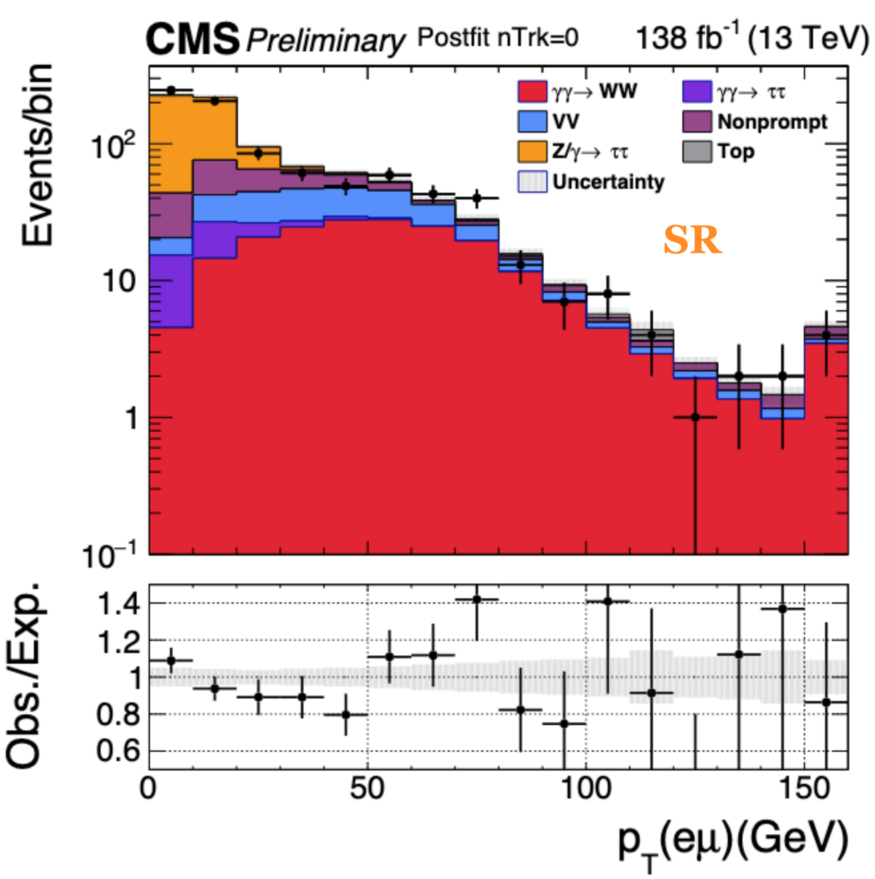
γγ→WW using run2 dataset

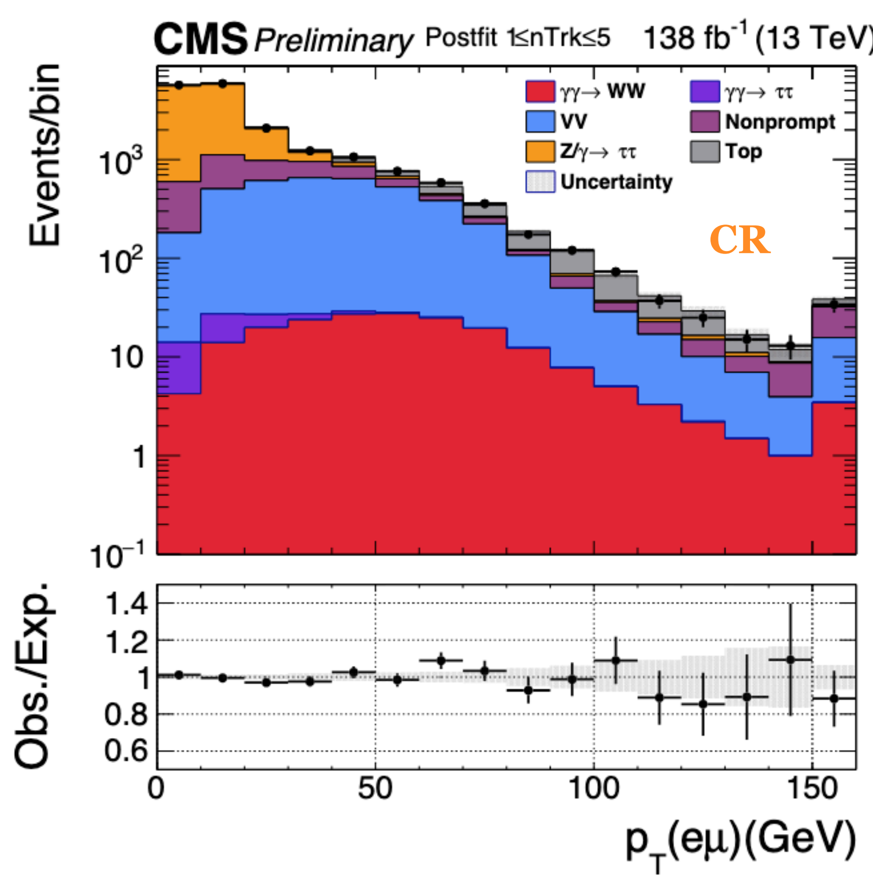
γγ fusion → pure QED process at leading order → theoretical predictions @1%



- Elastic component
  - clean final state with back to back Ws
  - no additional hadronic activity

$$\sigma^{fid} = 4.1 \pm 0.5 \text{ fb}$$





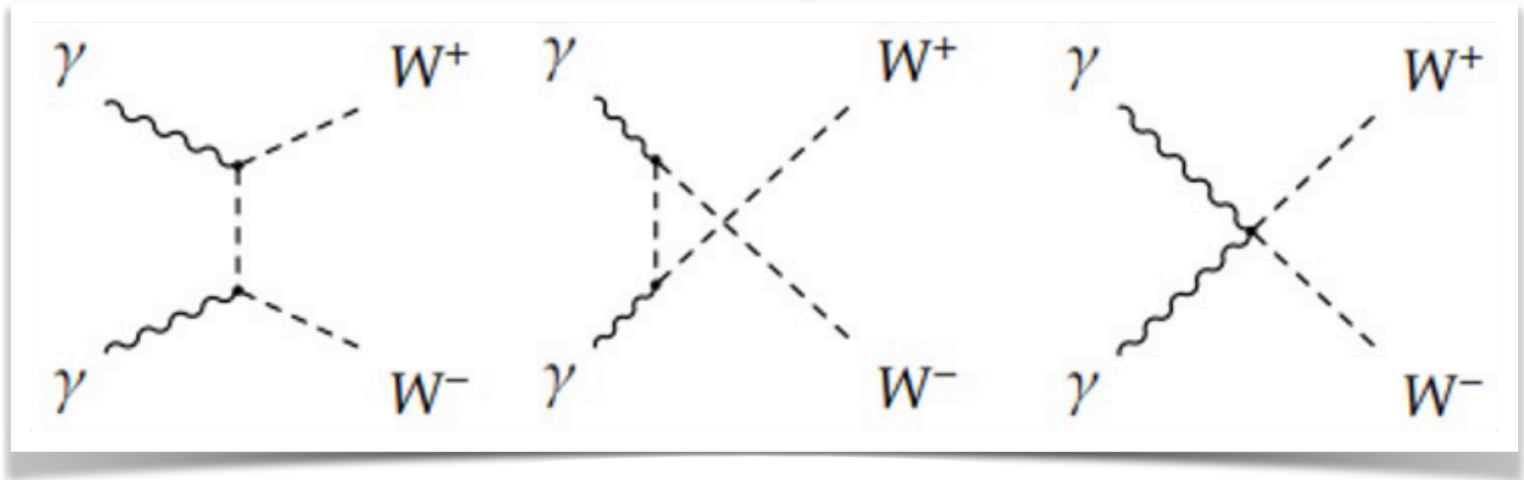
Rep. Prog. Phys. 87 107801

- Leptonic W decays with eμ final state
- Exclusivity condition
- Corrections to simulated track multiplicity
- Observed significance > 7σ

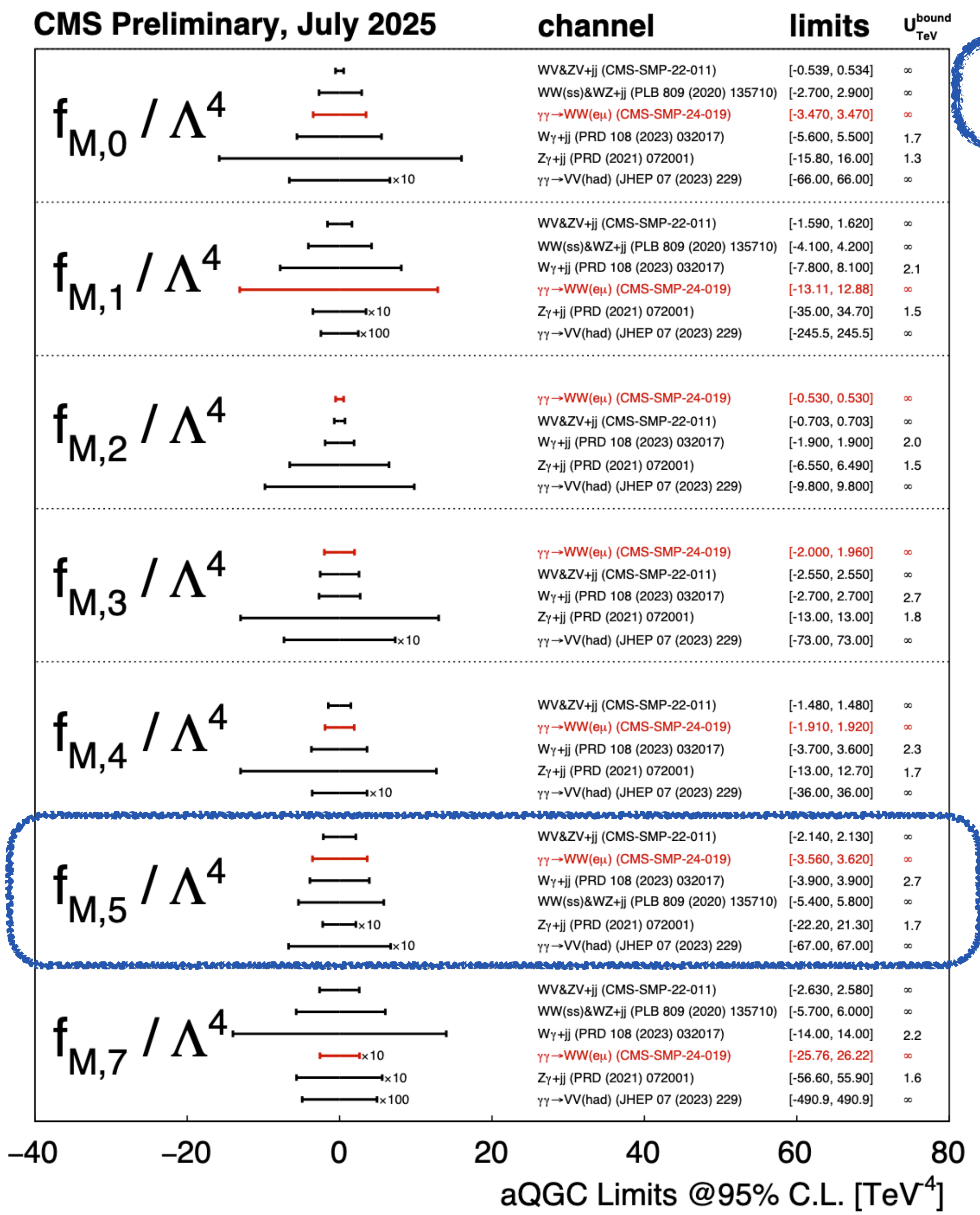
details in Mario's and Zongsheng's talks

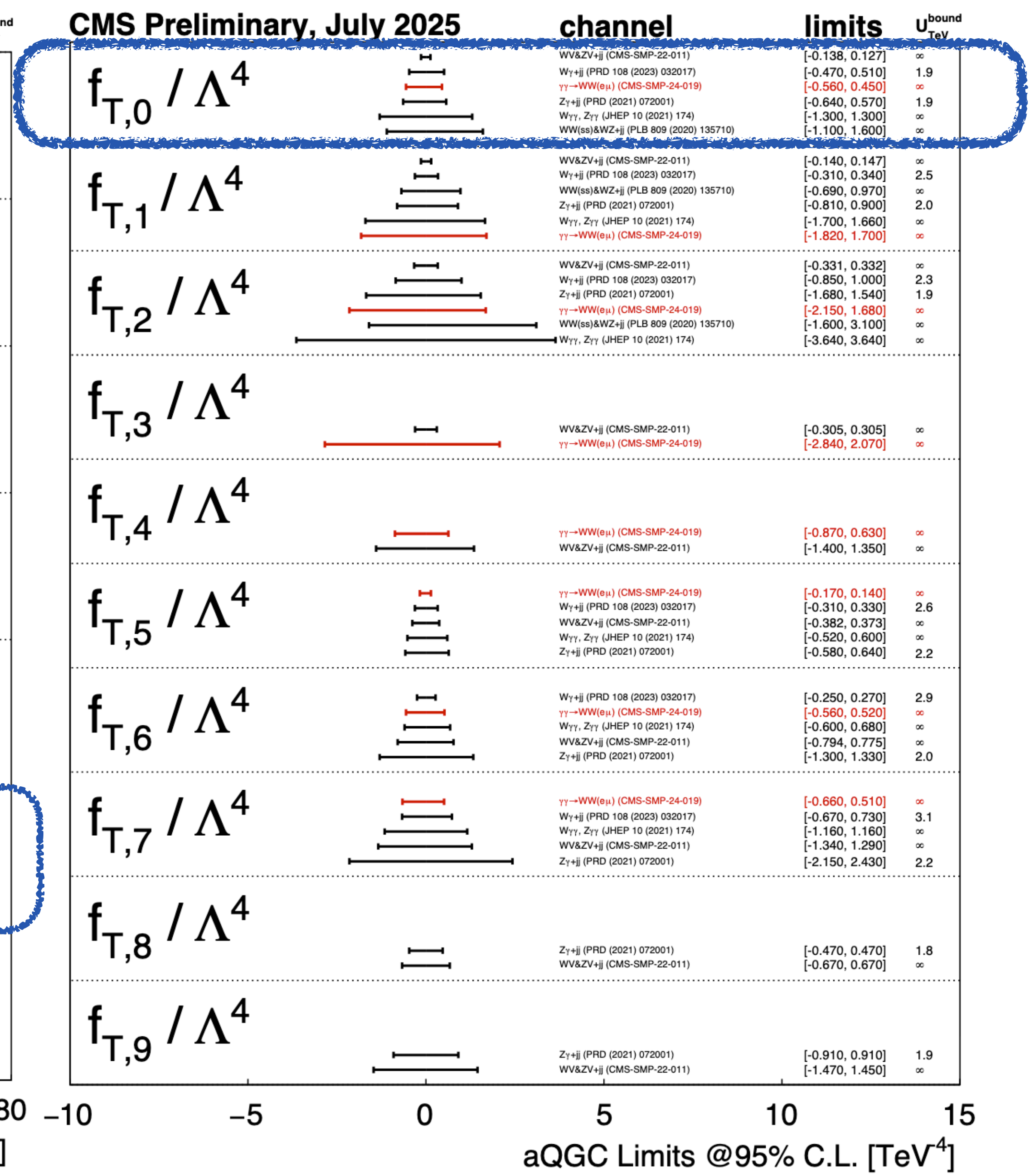
Results

Sensitive to quartic gauge couplings
SMEFT at mass dimension 8



Stronger bounds as compared to $\gamma\gamma \to VV$ (had.) analysis with tagged protons





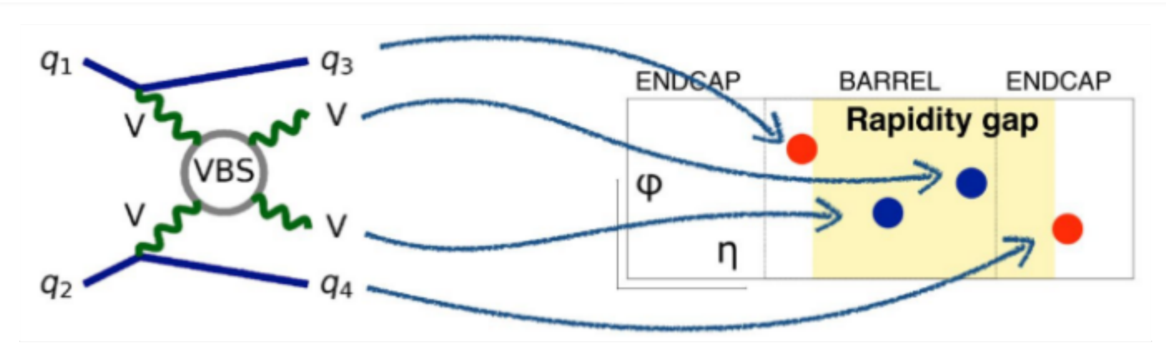
Limits competitive with VBS processes for some operators

2411.02483

CMS-SMP-22-011

VBS in ZV and WV @run2

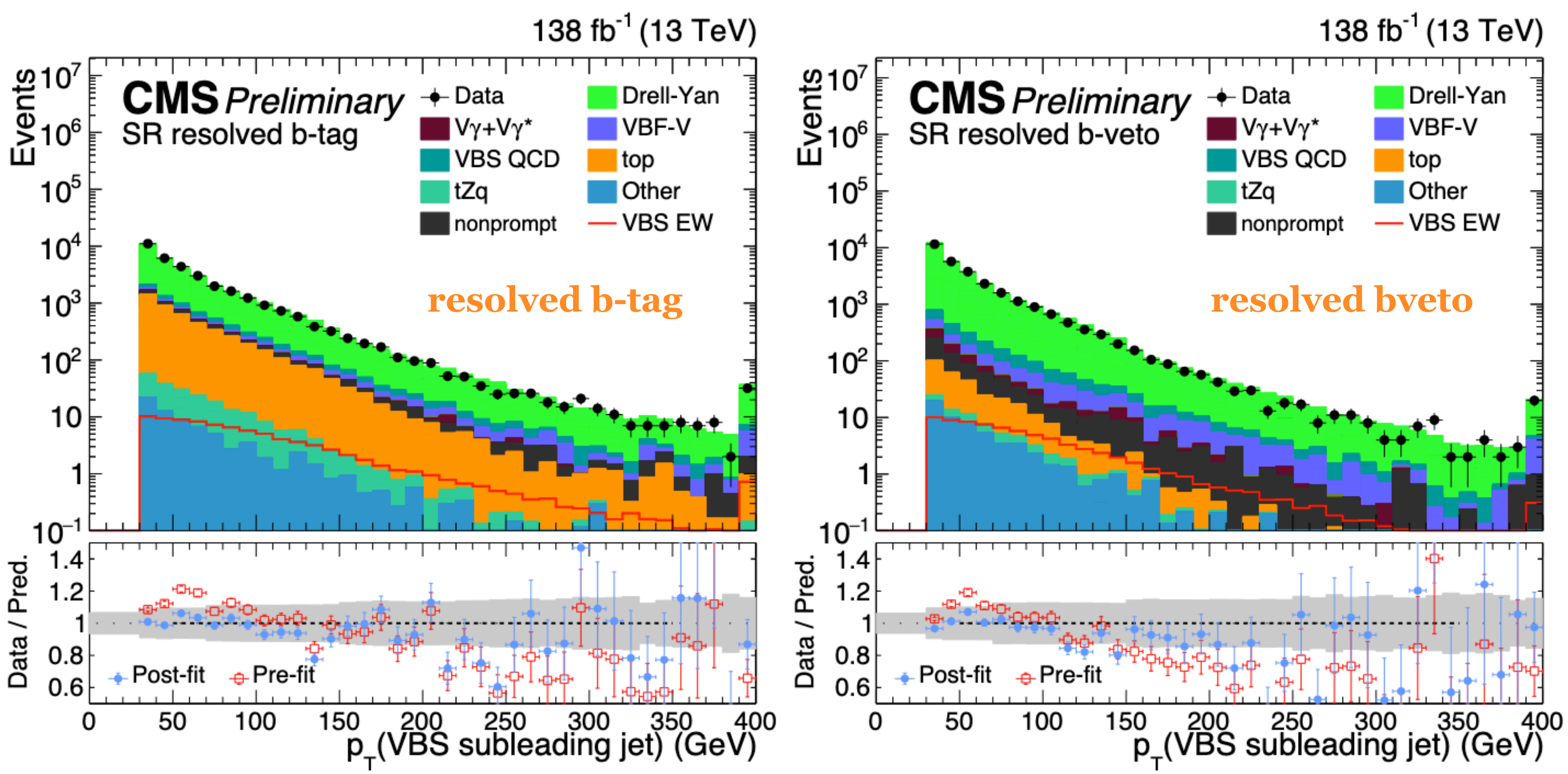
- Vector boson scattering → pure electroweak process with $\mathcal{O}(\alpha_{EW}^6)$; additional contributions from $\mathcal{O}(\alpha_{EW}^4\alpha_S^2)$
- Semi-leptonic final states challenging but larger cross section → enhanced sensitivity to anomalous gauge couplings



First ever combination of VBS data with semi-leptonic decays

PLB 2022 137438

- First evidence for WV VBS from CMS @run2
- VBS production with ZV not been observed yet



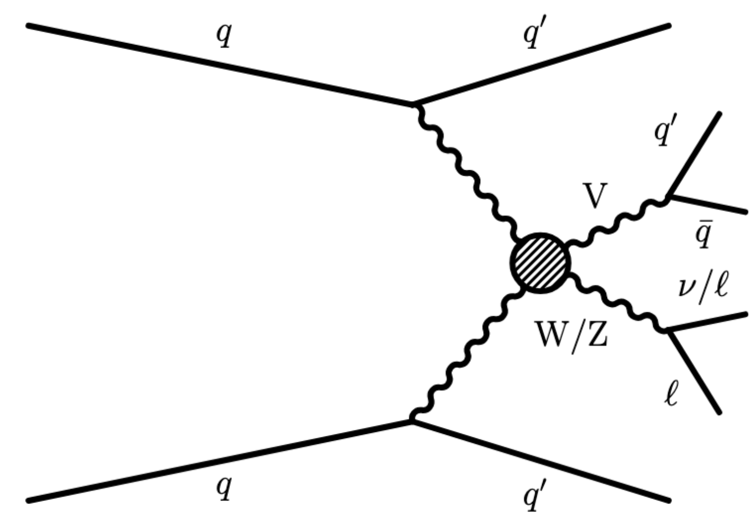
ZV channel

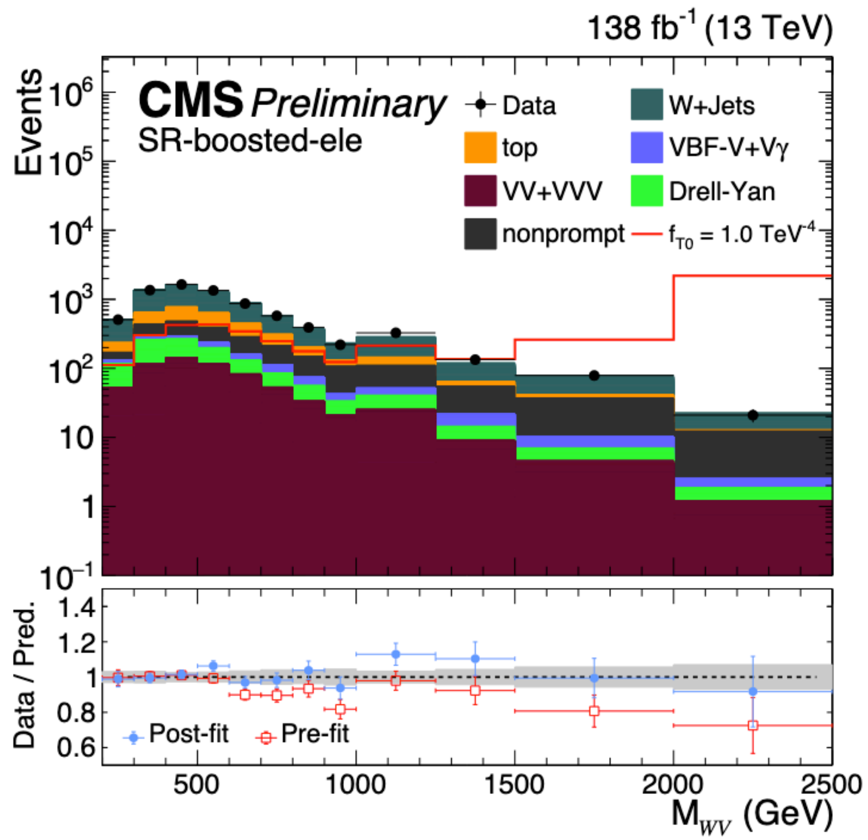
- Events with two leptons, two VBS-tagged jets
- Boosted & resolved categories
  - b-vetoed & b-tagged regions

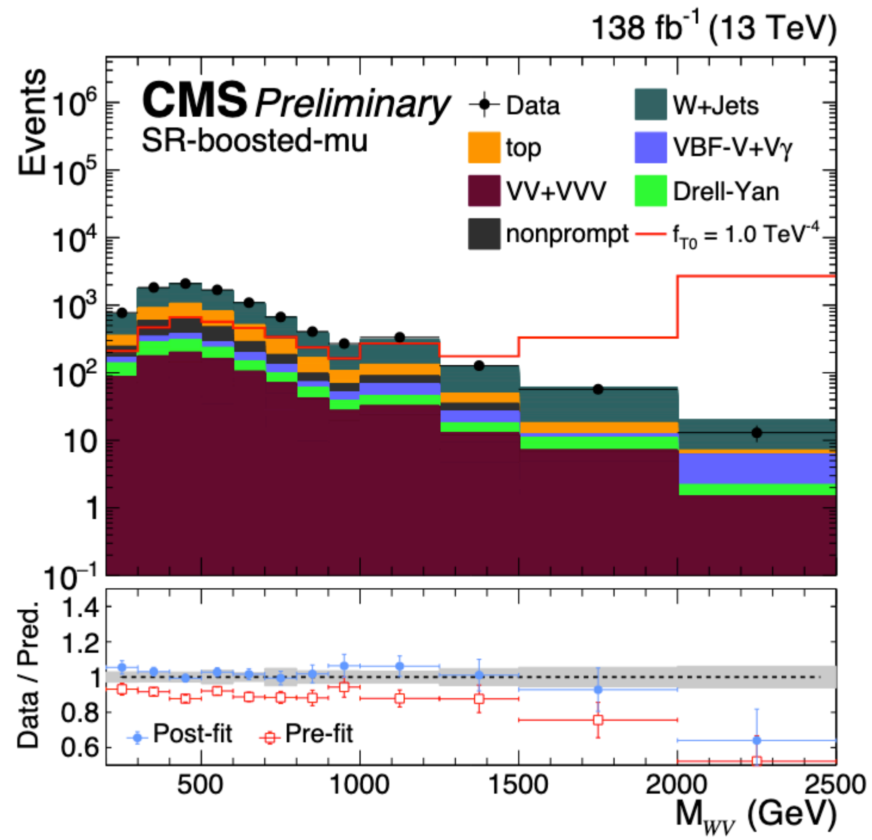
Observed (expected) significance for EW ZV: 1.3 (1.8)σ

More in Andrea's talk

VBS in ZV and WV @Run2

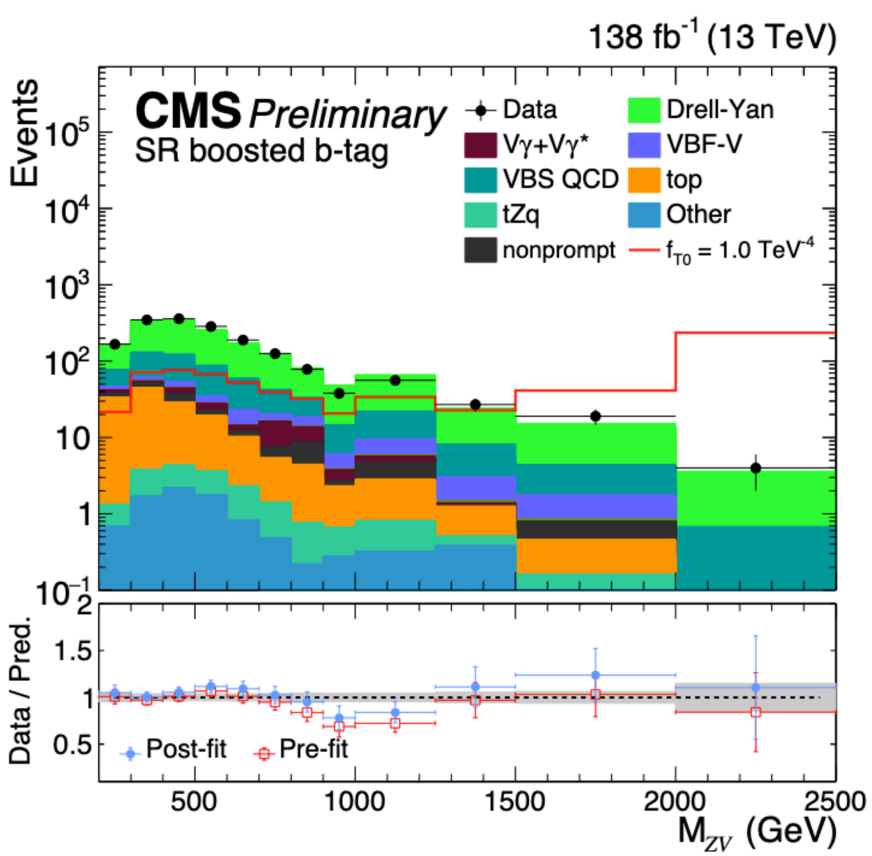


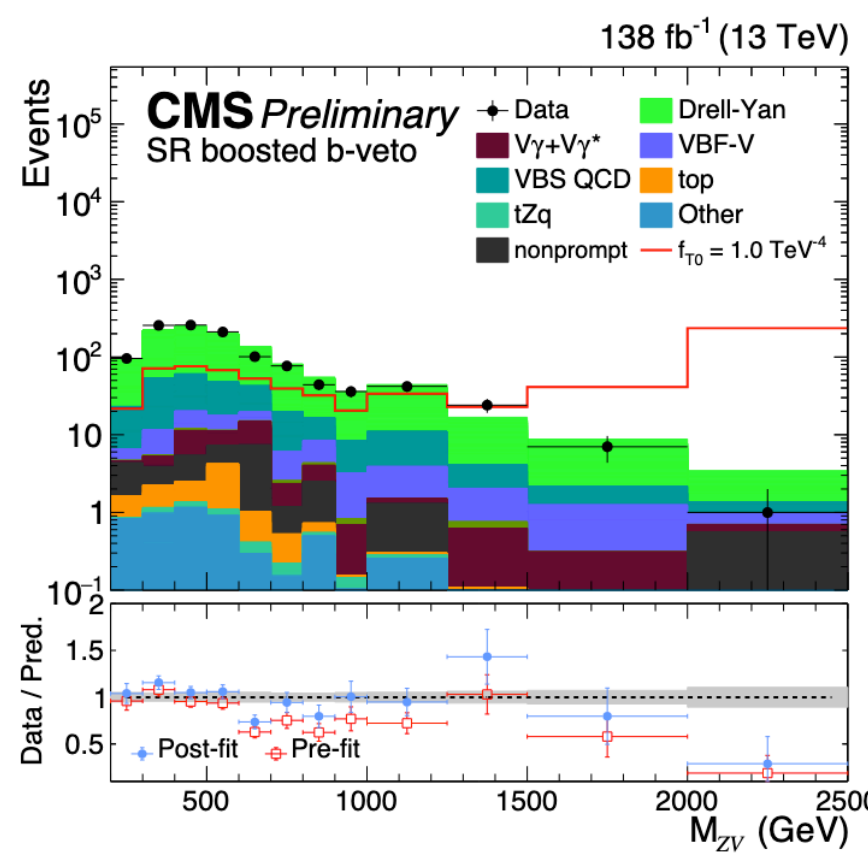




Only boosted category

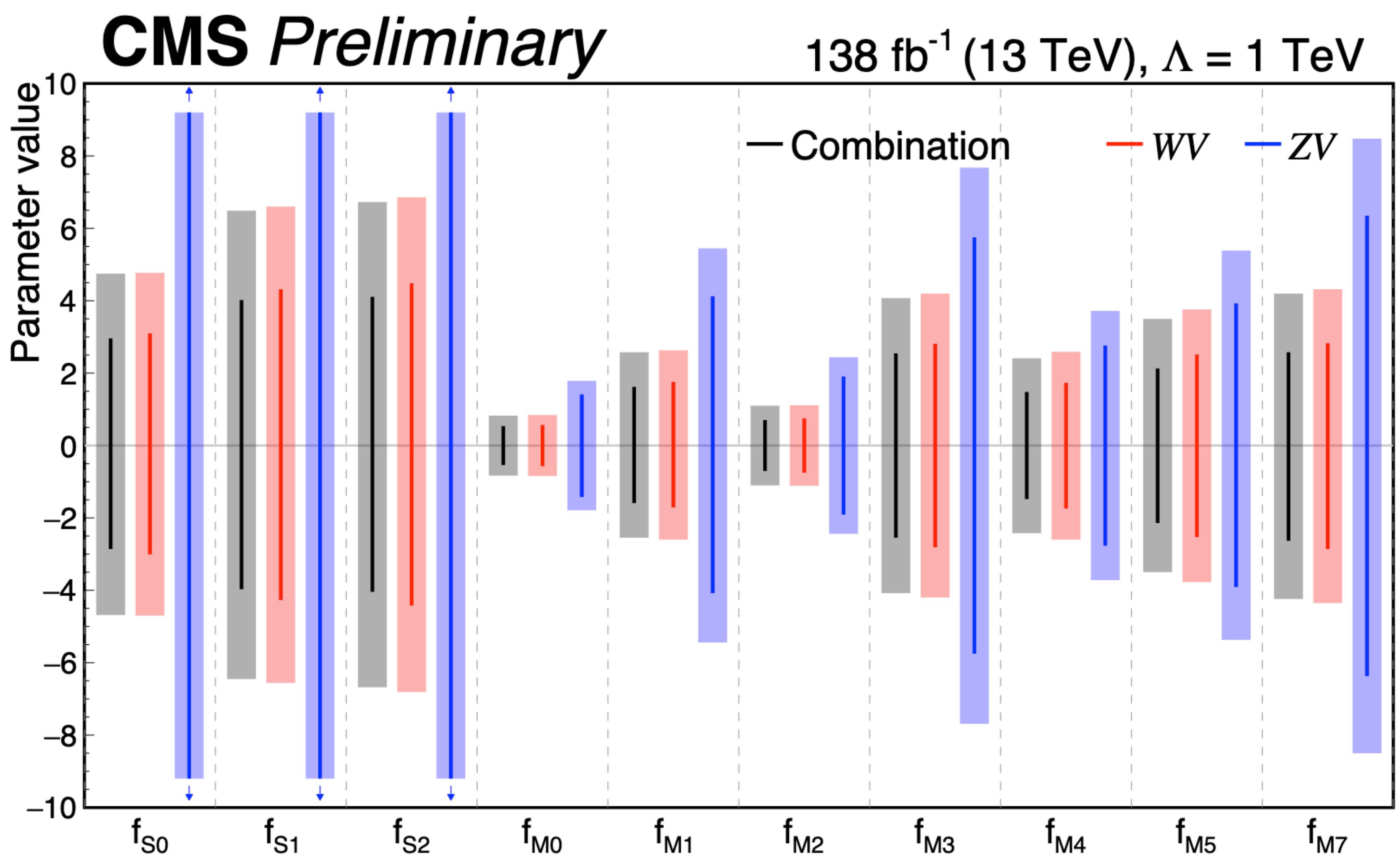
Variable used: mass of the diboson system





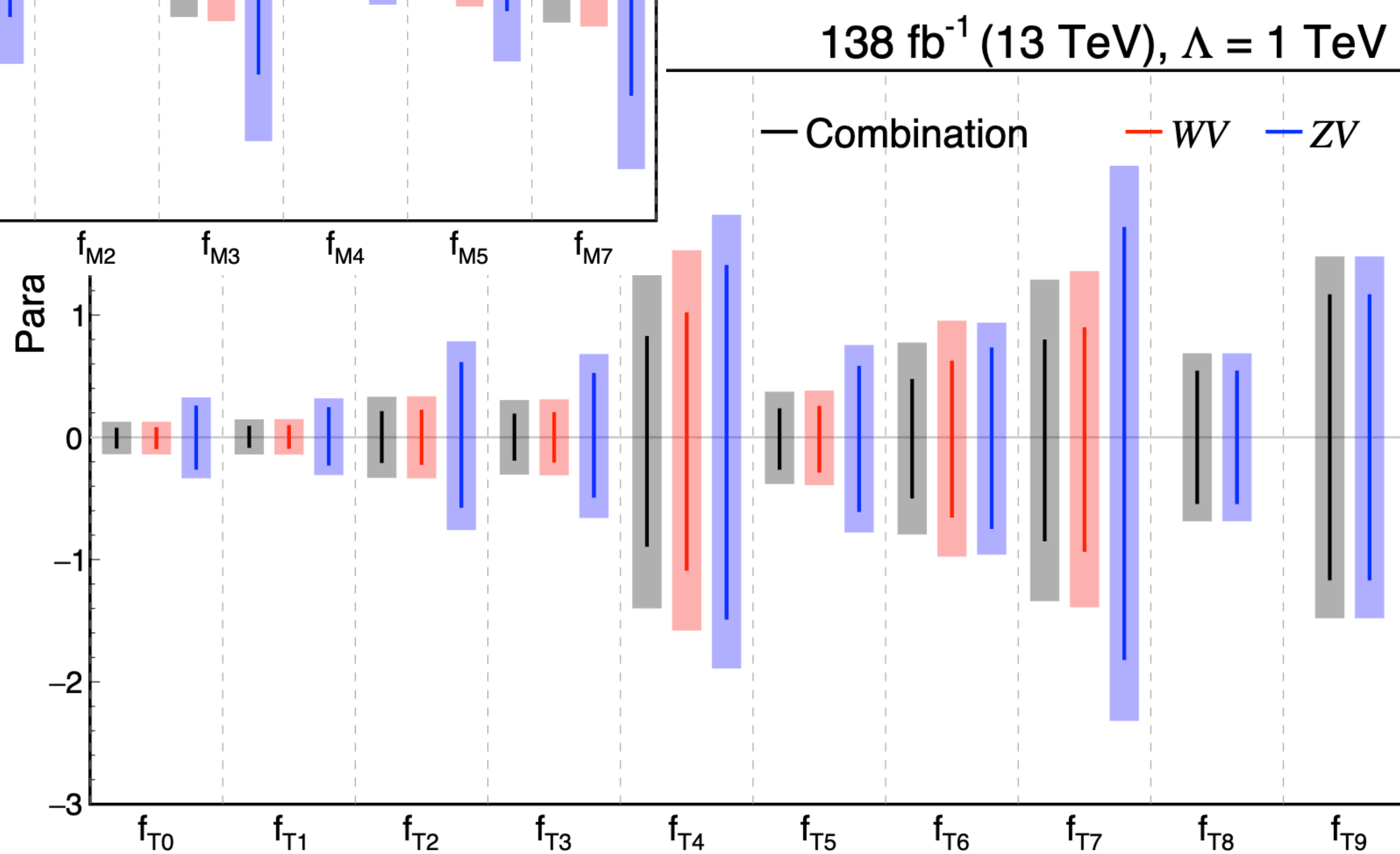
Likelihood scans by varying the corresponding Wilson coefficients one at a time

VBS in ZV and WV @run2



CP-even operators

Sensitivity driven by WV production channel



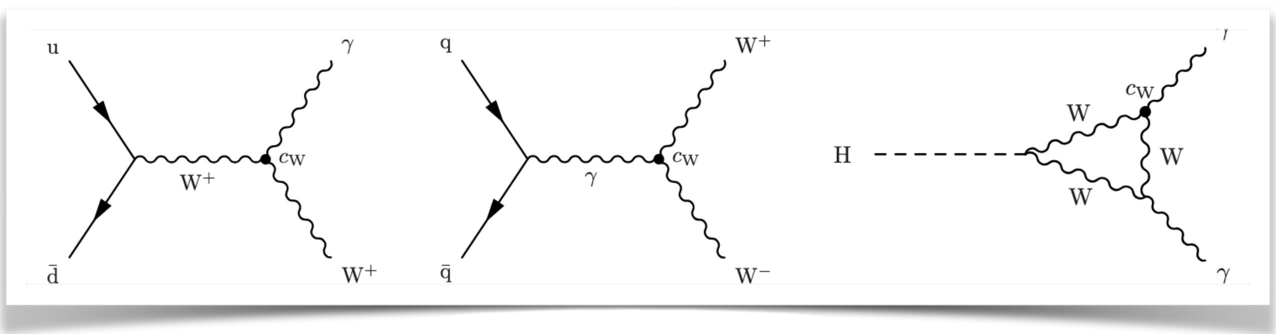
Limits on dim-8 operators

2504.02958
Submitted to EPJC

Combined SMEFT interpretation

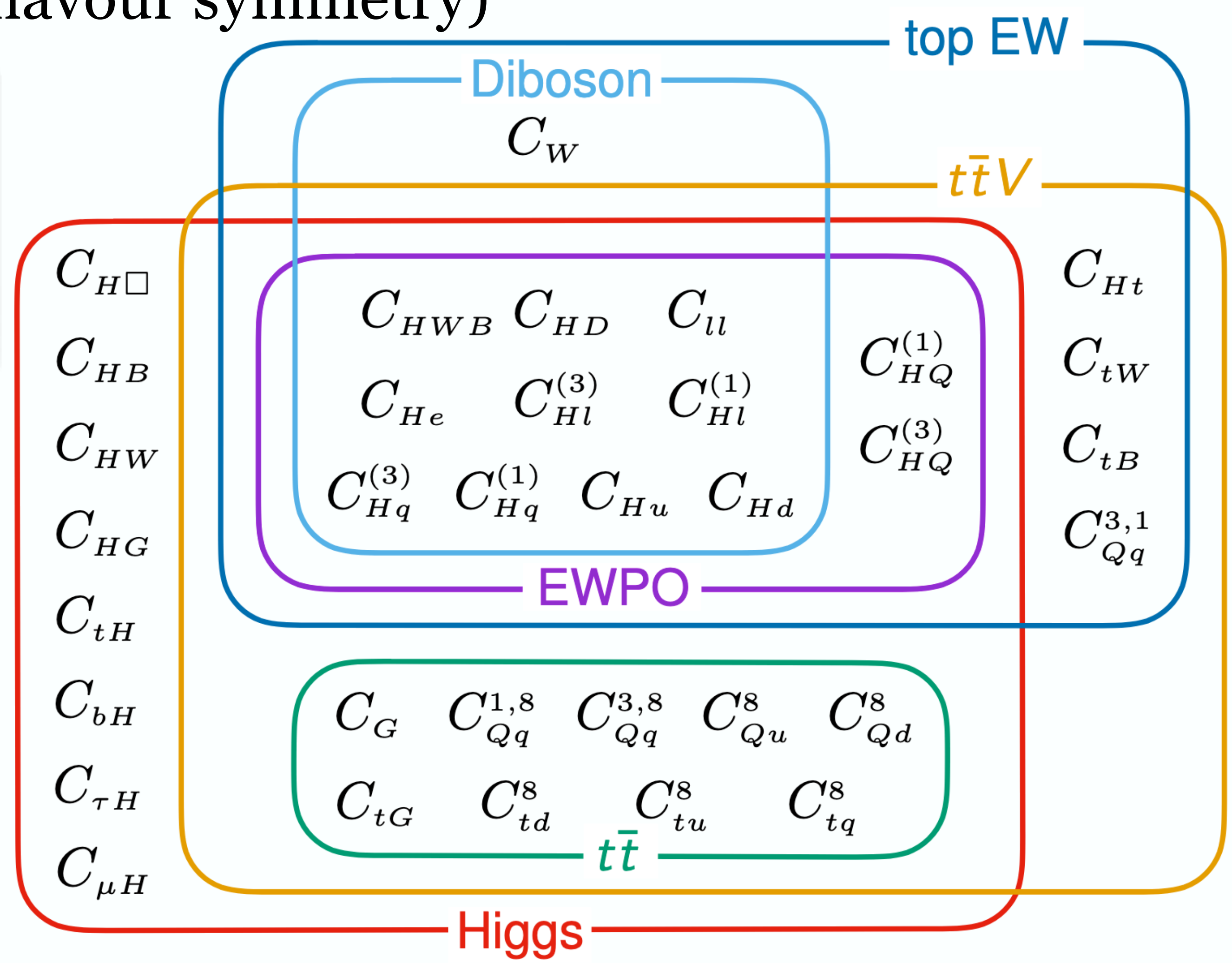
- First combined SMEFT interpretation by CMS with Higgs, Top, QCD, and EW sectors
- Each operator can impact multiple processes, and each process is sensitive to multiple operators
- 129 operators considered (CP-even, topU3l flavour symmetry)

$$\epsilon^{ijk} W_{\mu}^{i\nu} W_{\nu}^{j\rho} W_{\rho}^{k\mu}$$



Use complementarity of physics processes

Analysis	Type of measurement	Observables used	Experimental likelihood
$H \to \gamma\gamma$	Differential cross sections	STXS bins [54]	✓
$W\gamma$	Fiducial differential cross sections	$p_T^{\gamma} \times \lvert\phi_f\rvert$ [33]	✓
$Z \to \nu\nu$	Fiducial differential cross sections	p_T^{Z}	✓
WW	Fiducial differential cross sections	$m_{\ell\ell}$	✓
$t\bar{t}$	Fiducial differential cross sections	$m_{t\bar{t}}$	×
$t(\bar{t})X$	Direct EFT	Yields in regions of interest	✓
Inclusive jet	Fiducial differential cross sections	$p_T^{jet} \times \lvert y^{jet}\rvert$	×
EWPO	Pseudo-observables	Γ_Z, σ^0_{had}, R_ℓ, R_c, R_b, $A_{FB}^{0,\ell}$, $A_{FB}^{0,c}$, $A_{FB}^{0,b}$ [36]	×



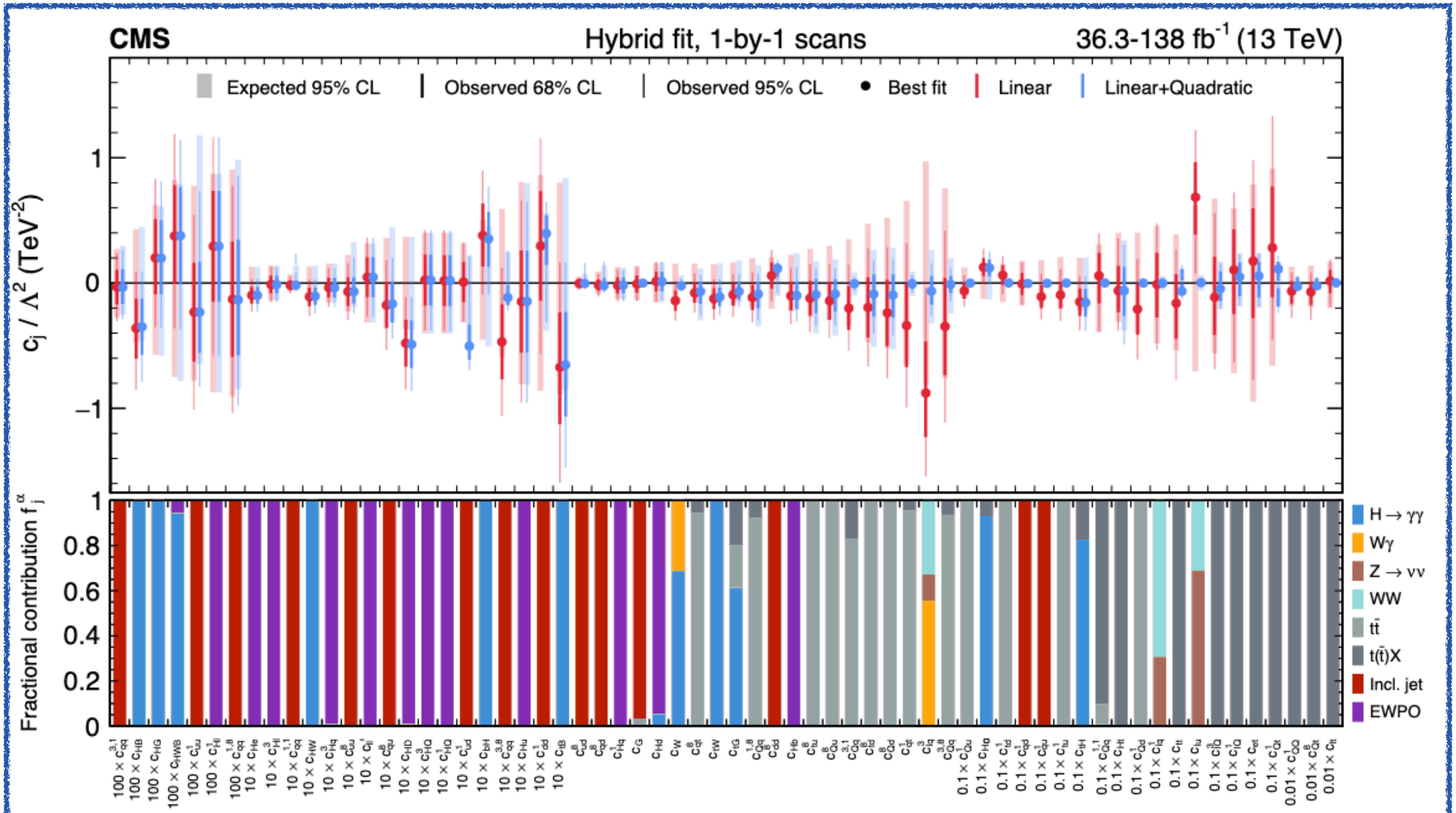
Combination of 7 CMS measurements (@13TeV), & EWPO measured at LEP and SLC

Inputs chosen to provide sensitivity to broad set of operators, have negligible overlap in event selection, and background contributions are either small or estimated from data

Individual constraints on coefficients

- Constraints on 64 Wilson coefficients
- Combination of Wγ & H → γγ → improved constraint on cW
- Stronger constraints on the two-heavy-two-light-quark coefficients

Linear-only & linear+quadratic constraints



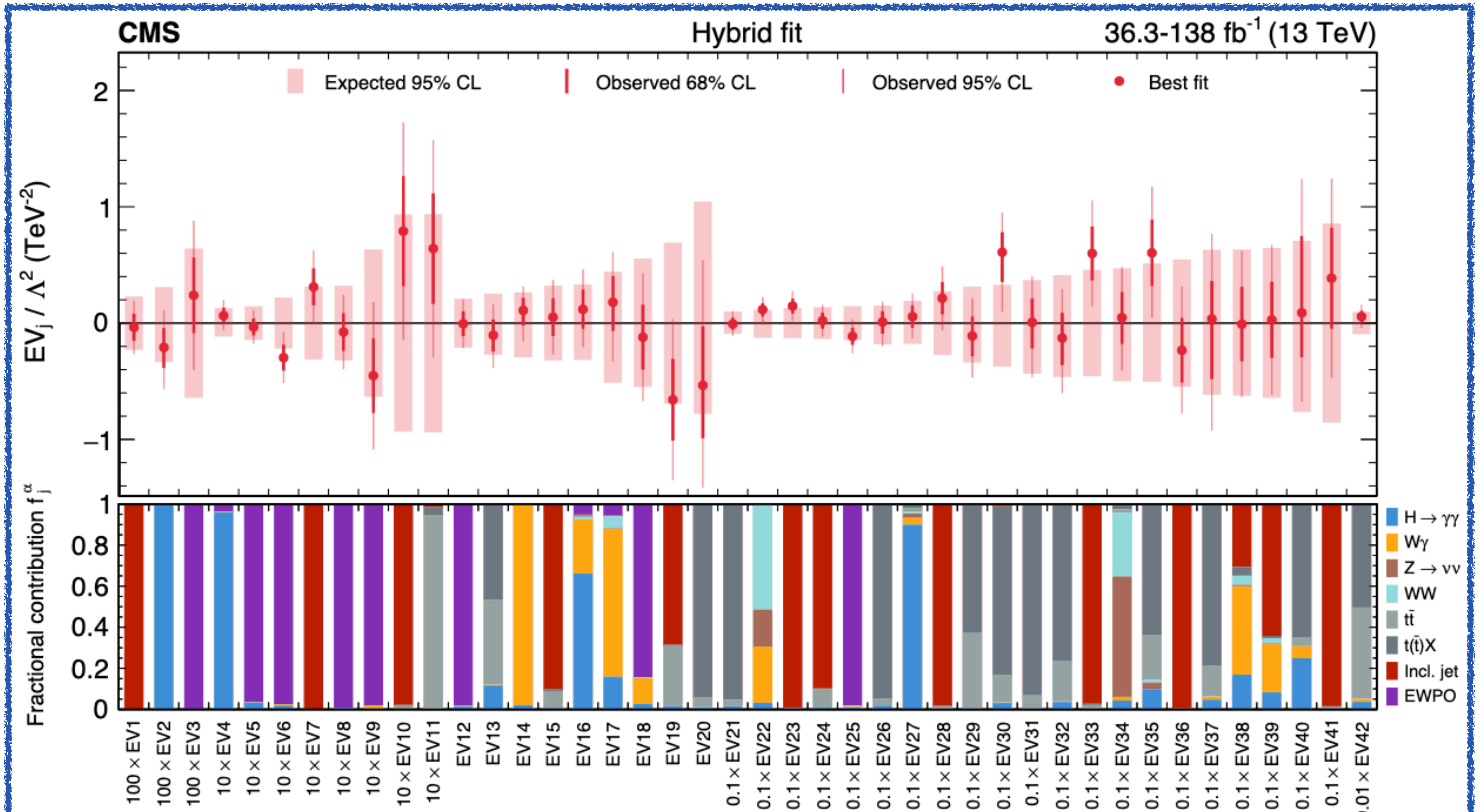
Simultaneous constraints on coefficients

1D limits with other Wilson coefficients profiled

- Constraints on 42 linear combinations of Wilson coefficients; remaining 22 linear combinations (flat directions) are fixed to zero **(PCA analysis)**
- Channels like H→γγ, EWPO, incl. jets, & $t\bar{t}X$ contribute differently to each eigenvector

More in Jiwon's talk

- p-value for the compatibility with the SM (all $c_i = 0$) 1.7%



Summary

- Effective field theories → Probe BSM scale much higher than experimental scale, i.e. probing BSM via indirect loop effects
- Model independent → different measurements can be combined
  - SMEFT framework is often used
- Multiple EWK measurements in CMS with added SMEFT interpretations (several in pipeline)
- Several channels/data samples not yet included in current ATLAS +CMS EFT combinations
  - Many potential challenges and open points
    - Overlap between input analyses
    - Harmonisation of systematics & phase-space across analyses
    - SMEFT assumptions/tools
  - Unitarity bounds
- Larger run3 dataset with improved analysis techniques + rare processes + lessons learnt from run2-based combinations → possible to set tighter constraints on operators