Effective Field Theory fits of the electroweak sector CMS data

Ankita Mehta (On behalf of the CMS Collaboration)

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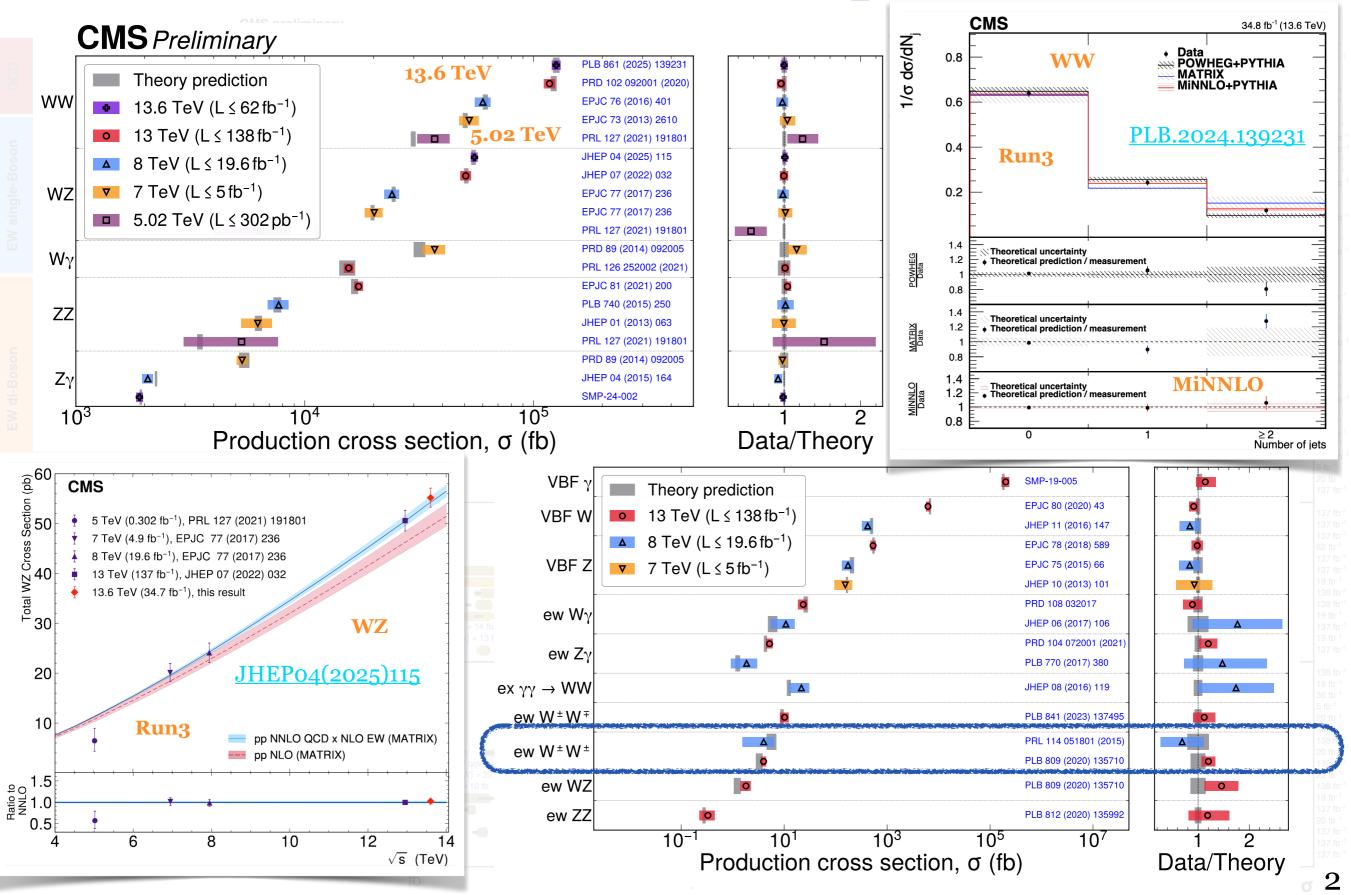


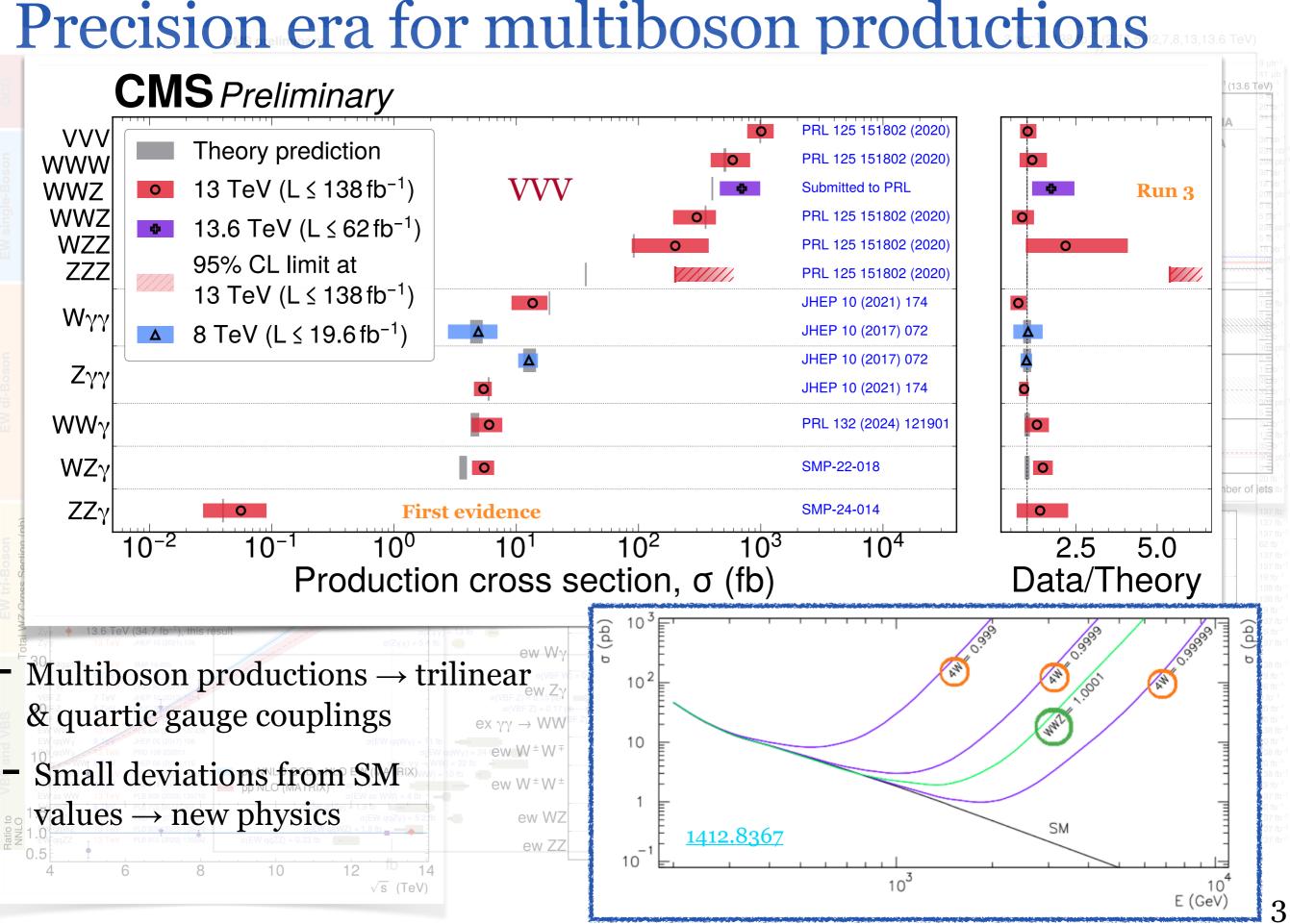




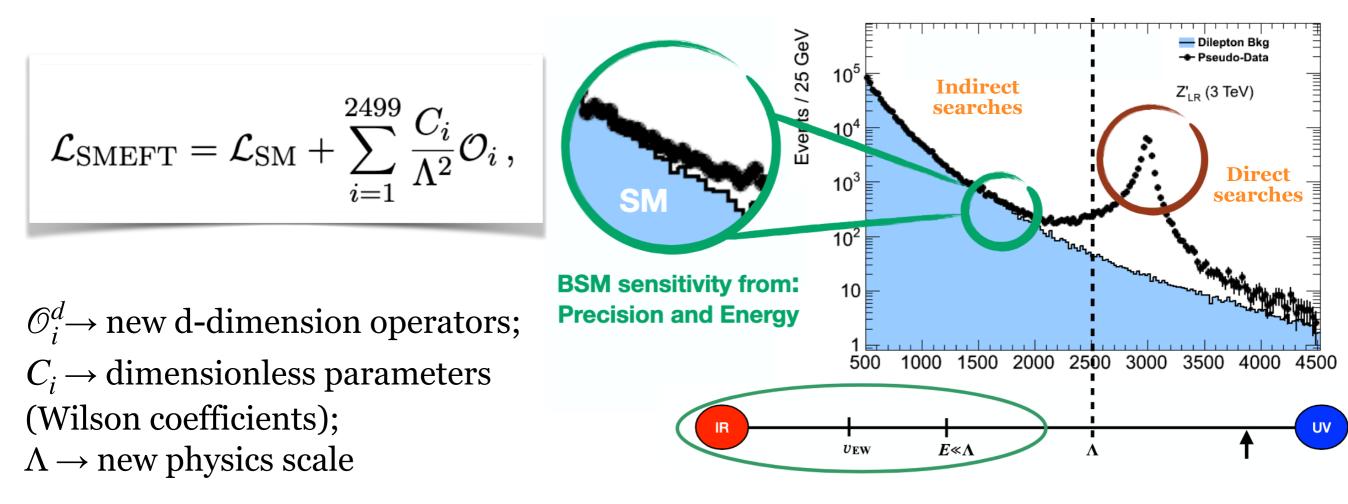


Precision era for multiboson productions





Standard Model Effective Field Theory



- 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

Diboson analyses with EFT interpretations

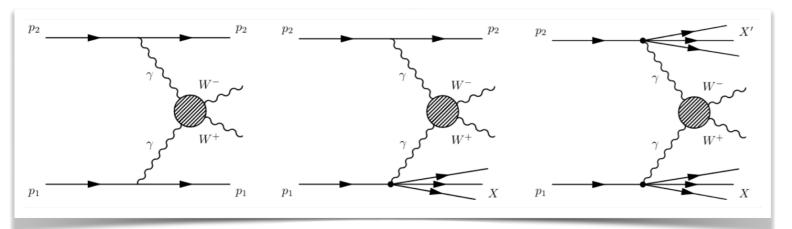
Process	Reference
VBS W±W±(→2l2v)	PhysLetB.2020.135710
VBS WZ(→3lv)	PhysLetB.2020.135710
VBS W±W±(\rightarrow lth2v)	<u>CERN-EP-2024-234</u>
VBS ZZ(→4l)	PhysLetB.2020.135992
VBS Z(→ll)γ	<u>JHEP06(2020)076</u>
VBS W(→lν)γ	PhysRevD.108.032017
VBS ZV+WV Today!	<u>CDSid:2926224</u>
W±W∓ (→2l2v)	PhysRevD.102.092001
WV	JHEP12(2019)062
W(→lν)γ	PhysRevD.105.052003
Z(→ll)γ	CDSid:2928843
$Z(\rightarrow vv)\gamma$	CDSid:2895314
(ex.)γγ→WW,ZZ (→jets)	<u>JHEP07(2023)229</u>
$(ex.)\gamma\gamma \rightarrow WW (\rightarrow 2l_{2}v)$ Today!	<u>CMS-SMP-24-019</u>
Combination of EW, Higgs, Top,QCD Today!	<u>CERN-EP-2025-035</u>

$\gamma\gamma \rightarrow WW$ using run2 dataset

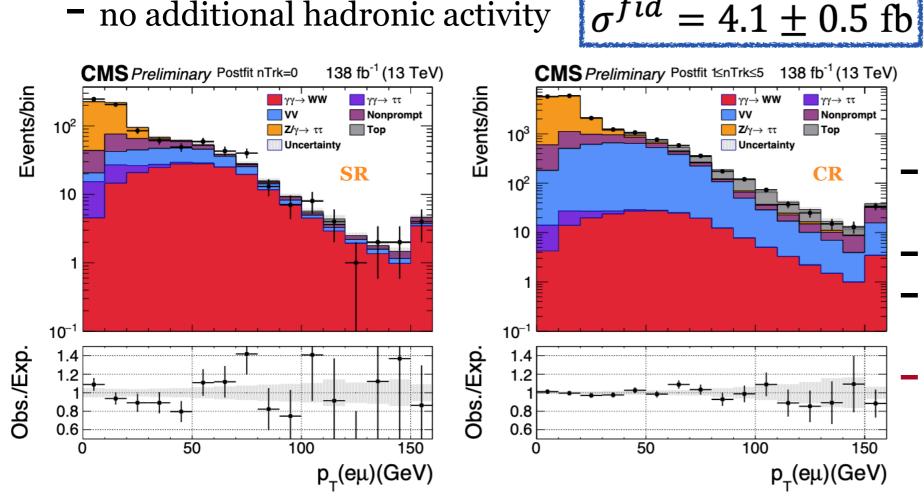




 $\gamma\gamma$ fusion \rightarrow pure QED process at leading order \rightarrow theoretical predictions @1%



- Elastic component
 - clean final state with back to back Ws σ^{fid}
 - no additional hadronic activity



R	<u>Rep. Pro</u>	g. Phys	. 87 1	07801							
CERNCOURIER Reporting on international high-energy physics											
Physics -	Technology -	Community -	In focus	Magazine							
t ∎ 15 M A A A	A report from the CL	in on tau g- MS experiment		225							

- Leptonic W decays with eµ final state
- Exclusivity condition

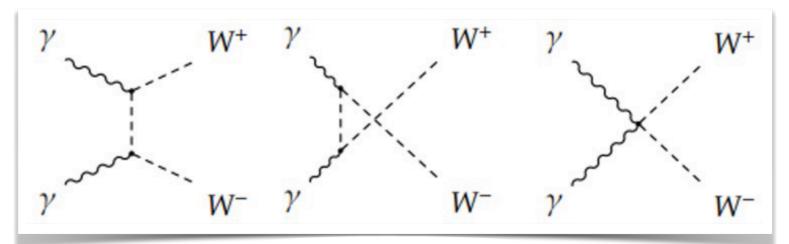
150

- 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



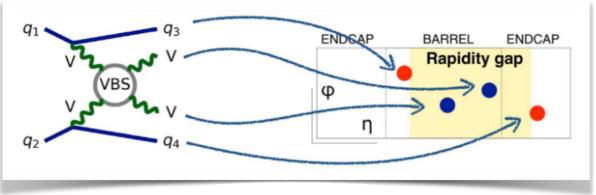
CMS Preliminary, July 2025	channel limits Unter CMS Prelimin			CMS Preliminary	, July 2025	channel	limits	U ^{boun} TeV	
f _{M,0} / Λ ⁴	WV&ZV+jj (CMS-SMP-22-011) WW(ss)&WZ+jj (PLB 809 (2020) 13571 γγ→WW(eμ) (CMS-SMP-24-019) Wγ+jj (PRD 108 (2023) 032017)	[-0.539, 0.534] 0) [-2.700, 2.900] [-3.470, 3.470] [-5.600, 5.500]	∞ ∞ ∞ 1.7	$f_{T,0} / \Lambda^4$		WV&2V+jj (CMS-SMP-22-011) W+-jj (PRD 108 (2023) 032017) 17→WW(eµ) (CMS-SMP-24-019) Z+-jj (PRD (2021) 072001) W+7, Z+7 (JHEP 10 (2021) 174) WW(ss)&WZ+jj (PLB 809 (2020) 135710)	[-0.138, 0.127] [-0.470, 0.510] [-0.560, 0.450] [-0.640, 0.570] [-1.300, 1.300] [-1.100, 1.600]	∞ 1.9 ∞ 1.9 ∞	
×10	Zγ+jj (PRD (2021) 072001) γγ→VV(had) (JHEP 07 (2023) 229) WV&ZV+jj (CMS-SMP-22-011)	[-15.80, 16.00] [-66.00, 66.00] [-1.590, 1.620]	1.3 ∞ ∞	$f_{T,1}/\Lambda^4$	[[]] I I	WV&ZV+jj (CMS-SMP-22-011) Wy+ij (PRD 108 (2023) 032017) WW(ss)SMZ+jj (PLB 809 (2020) 135710) Z₁+jj (PRD (2021) 072001) Wŋ-, Z₁r (JHEP 10 (2021) 174) Yŋ-WW(ss) (CMS-SMP-24-019)	[-0.140, 0.147] [-0.310, 0.340] [-0.690, 0.970] [-0.810, 0.900] [-1.700, 1.660] [-1.820, 1.700]	∞ 2.5 ∞ 2.0 ∞	
$f_{M,1} / \Lambda^4$	WW(ss)&WZ+jj (PLB 809 (2020) 13571 Wγ+jj (PRD 108 (2023) 032017) γγ→WW(eμ) (CMS-SMP-24-019) Zγ+jj (PRD (2021) 072001) γγ→VV(had) (JHEP 07 (2023) 229)	0) [-4.100, 4.200] [-7.800, 8.100] [-13.11, 12.88] [-35.00, 34.70] [-245.5, 245.5]	∞ 2.1 ∞ 1.5 ∞	$f_{T,2} / \Lambda^4$		WV&ZV-ij (CMS-SMP-22-011) W+4[/PRD 108 (2023) 032017) Zγ-4j (PRD 108 (2023) 032017) Tγ-WWeb() (CMS-SMP-24-019) WW(ss)&WZ-ij (PLB 806 (2020) 135710) WY _T , Z _T (JHEP 10 (2021) 174)	[-1.220, 1.700] [-0.331, 0.332] [-0.850, 1.000] [-1.680, 1.540] [-2.150, 1.680] [-1.600, 3.100] [-3.640, 3.640]	∞ 2.3 1.9 ∞ ∞	
f _{M,2} / Λ ⁴	γγ→WW(eµ) (CMS-SMP-24-019) WV&ZV+jj (CMS-SMP-22-011) Wγ+jj (PRD 108 (2023) 032017) Zγ+jj (PRD (2021) 072001) γγ→VV(had) (JHEP 07 (2023) 229)	[-0.530, 0.530] [-0.703, 0.703] [-1.900, 1.900] [-6.550, 6.490] [-9.800, 9.800]	∞ ∞ 2.0 1.5 ∞	$f_{T,3} / \Lambda^4$	<u>н</u>	WV&ZV+jj (CMS-SMP-22-011) γγWW(σμ) (CMS-SMP-24-019)	[-0.305, 0.305] [-2.840, 2.070]	00 00	
f _{M,3} / Λ ⁴	γγ→WW(eμ) (CMS-SMP-24-019) WV&ZV+jj (CMS-SMP-22-011) Wγ+jj (PRD 108 (2023) 032017)	[-2.000, 1.960] [-2.550, 2.550] [-2.700, 2.700]	∞ ∞ 2.7	$f_{T,4} / \Lambda^4$			[-0.870, 0.630] [-1.400, 1.350]	80	
×10	Zγ+jj (PRD (2021) 072001) γγ→VV(had) (JHEP 07 (2023) 229)	[-13.00, 13.00] [-73.00, 73.00]	1.8 ∞	f _{T,5} / Λ ⁴	[]]11	Wy+ij (PRD 108 (2023) 032017) WV&ZV+ij (CMS-SMP-22-011) Wyγ, Zγγ (JHEP 10 (2021) 174) Zγ+ij (PRD (2021) 072001)	[-0.170, 0.140] [-0.310, 0.330] [-0.382, 0.373] [-0.520, 0.600] [-0.580, 0.640]	2.6 ∞ ∞ 2.2	
$f_{M,4} / \Lambda^4$	WV&ZV+jj (CMS-SMP-22-011) γγ→WW(eμ) (CMS-SMP-24-019) Wγ+jj (PRD 108 (2023) 032017) Zγ+jj (PRD (2021) 072001) γγ→VV(had) (JHEP 07 (2023) 229)	[-1.480, 1.480] [-1.910, 1.920] [-3.700, 3.600] [-13.00, 12.70] [-36.00, 36.00]	∞ ∞ 2.3 1.7 ∞	$f_{T,6}$ / Λ^4	[[]]I	W ₁ +ij (PRD 108 (2023) 032017) γ₁→WW(e ₁) (CMS-SMP-24-019) W ₁ , 2 ₁₇ (JHEP 10 (2021) 174) WV&ZV-ij (CMS-SMP-22-011) Z ₁ +ij (PRD (2021) 072001)	[-0.250, 0.270] [-0.560, 0.520] [-0.600, 0.680] [-0.794, 0.775] [-1.300, 1.330]	2.9 ∞ ∞ 2.0	
$f_{M,5} / \Lambda^4$ $=$	WV&ZV+jj (CMS-SMP-22-011) γγ→WW(eμ) (CMS-SMP-24-019) Wγ+jj (PRD 108 (2023) 032017) WW(ss)&WZ+jj (PLB 809 (2020) 13571 Zγ+jj (PRD (2021) 072001)	[-2.140, 2.130] [-3.560, 3.620] [-3.900, 3.900] 0) [-5.400, 5.800] [-22.20, 21.30]	∞ ∞ 2.7 ∞ 1.7	$f_{T,7} / \Lambda^4$		TI→WW(eµ) (CMS-SMP-24-019) Wj+ij (PRD 108 (2023) 032017) Wyr, Zr, (JHEP 10 (2021) 174) WV&ZV-ij (CMS-SMP-22-011) Z₁+ij (PRD (2021) 072001)	[-0.660, 0.510] [-0.670, 0.730] [-1.160, 1.160] [-1.340, 1.290] [-2.150, 2.430]	∞ 3.1 ∞ 2.2	
	γγ→VV(had) (JHEP 07 (2023) 229) WV&ZV+jj (CMS-SMP-22-011) WW(ss)&WZ+jj (PLB 809 (2020) 13571)	[-67.00, 67.00] [-2.630, 2.580]	20 20 20 20	$f_{T,8} / \Lambda^4$		Z ₁ +jj (PRD (2021) 072001) WV&ZV+jj (CMS-SMP-22-011)	[-0.470, 0.470] [-0.670, 0.670]	1.8 ∞	
$f_{M,7} / \Lambda^4$	$ \begin{array}{c} W\gamma(s)(k^{2}Y_{1})(Y_{2}) & 0.05 (2000) (50.47) \\ W\gamma+jj (PRD 108 (2023) 0.32017) \\ \gamma\gamma\rightarrow WW(e\mu) (CMS-SMP-24-019) \\ Z\gamma+jj (PRD (2021) 0.72001) \\ \gamma\gamma\rightarrow VV(had) (JHEP 07 (2023) 229) \\ \end{array} $	[-14.00, 14.00] [-25.76, 26.22] [-56.60, 55.90] [-490.9, 490.9]	∞ 2.2 ∞ 1.6 ∞	$f_{T,9}$ / Λ^4		Z ₁ +jj (PRD (2021) 072001) WV&ZV+j (CMS-SMP-22-011)	[-0.910, 0.910] [-1.470, 1.450]	1.9 ∞	
0 –20 0 2	20 40 aQGC Limits @95%	60	80	-10 -5	0	5	10		

Limits competitive with VBS processes for some operators

<u>2411.02483</u>

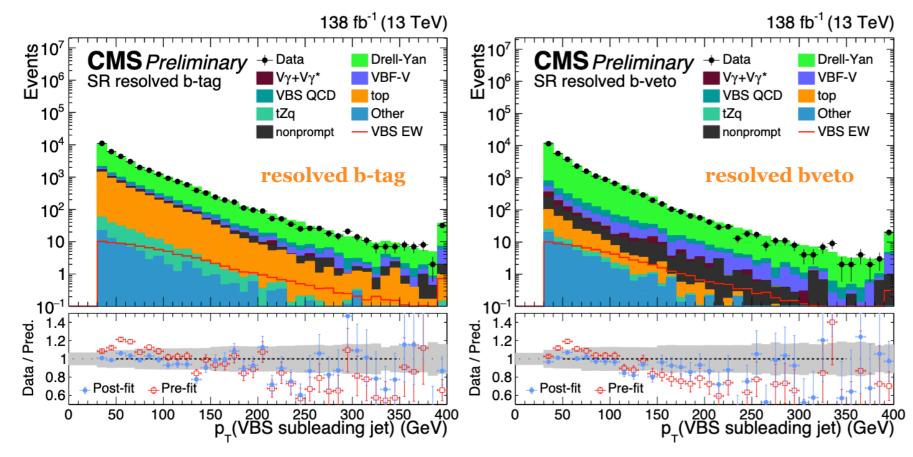
VBS in ZV and WV @run2

- Vector boson scattering \rightarrow 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 semileptonic decays PLB 2022 137438

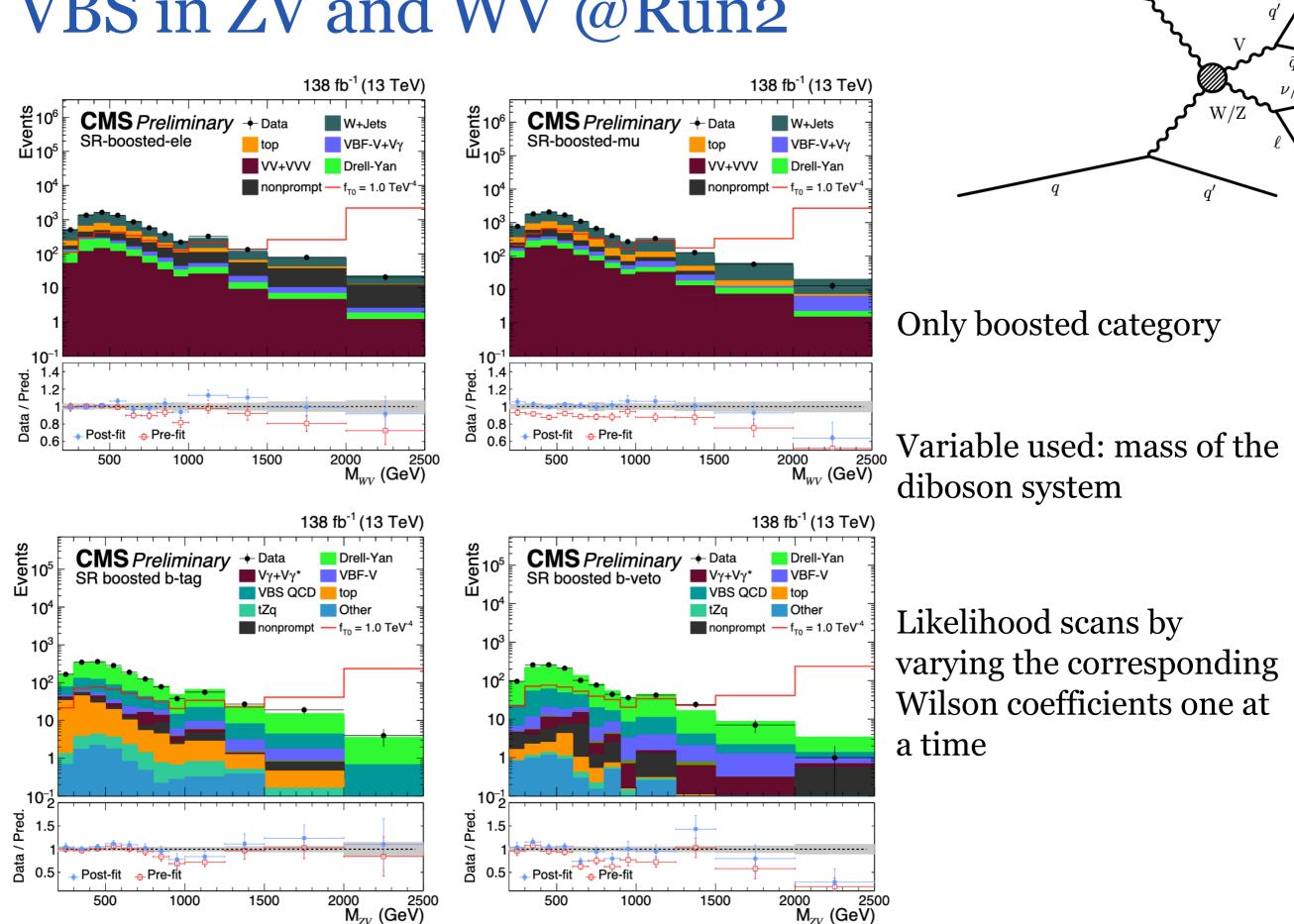
- First evidence for WV VBS from CMS @run2
- VBS production with ZV not been observed yet



ZV channel

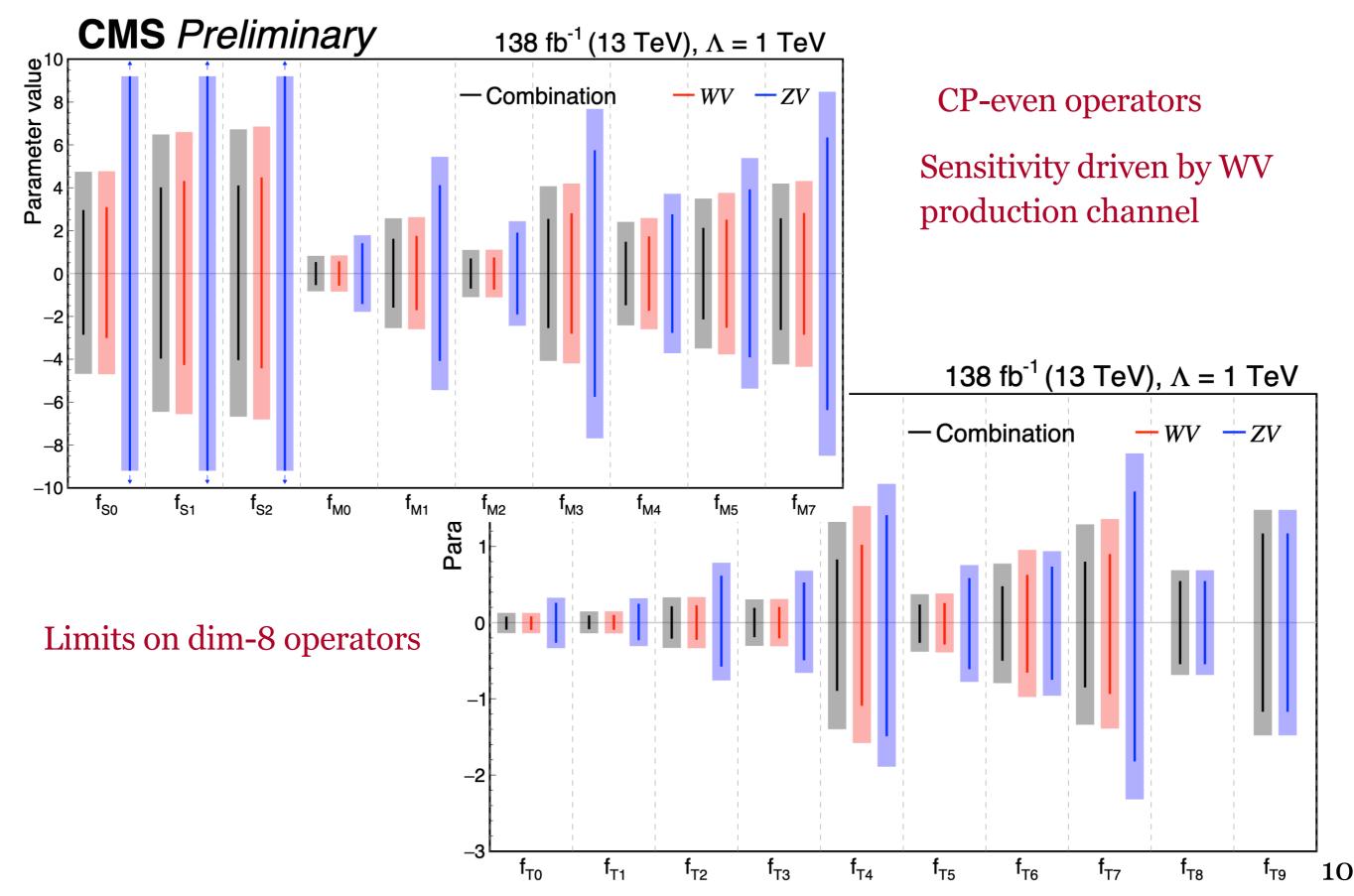
- Events with two leptons, two VBS-tagged jets
- Boosted & resolved categories
 - b-vetoed & b-tagged regions

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



VBS in ZV and WV @Run2

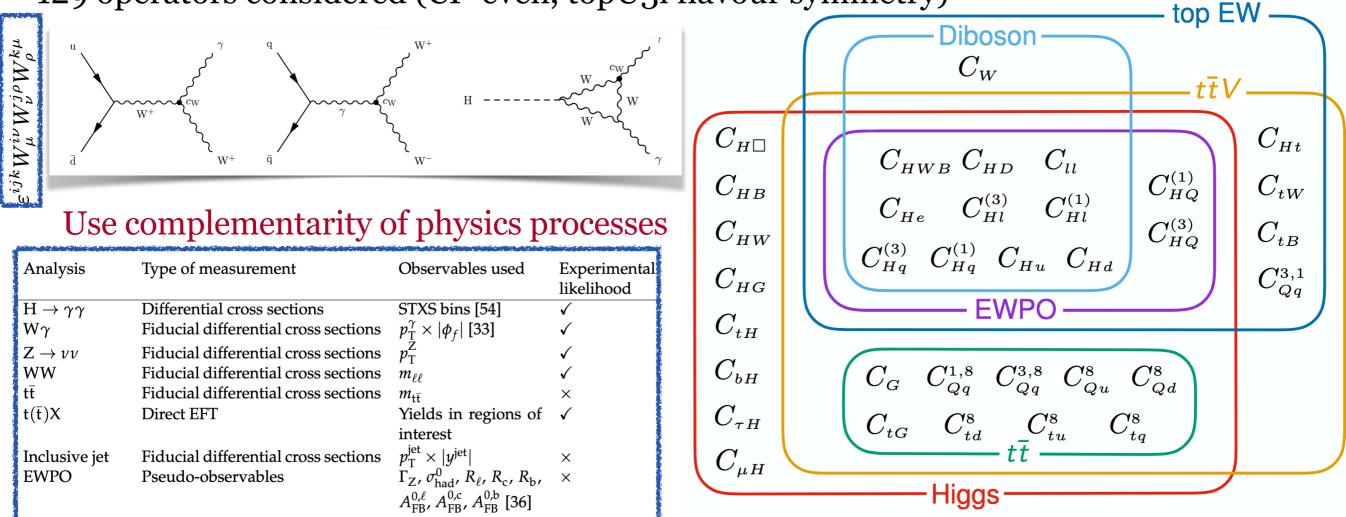
VBS in ZV and WV @run2



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)



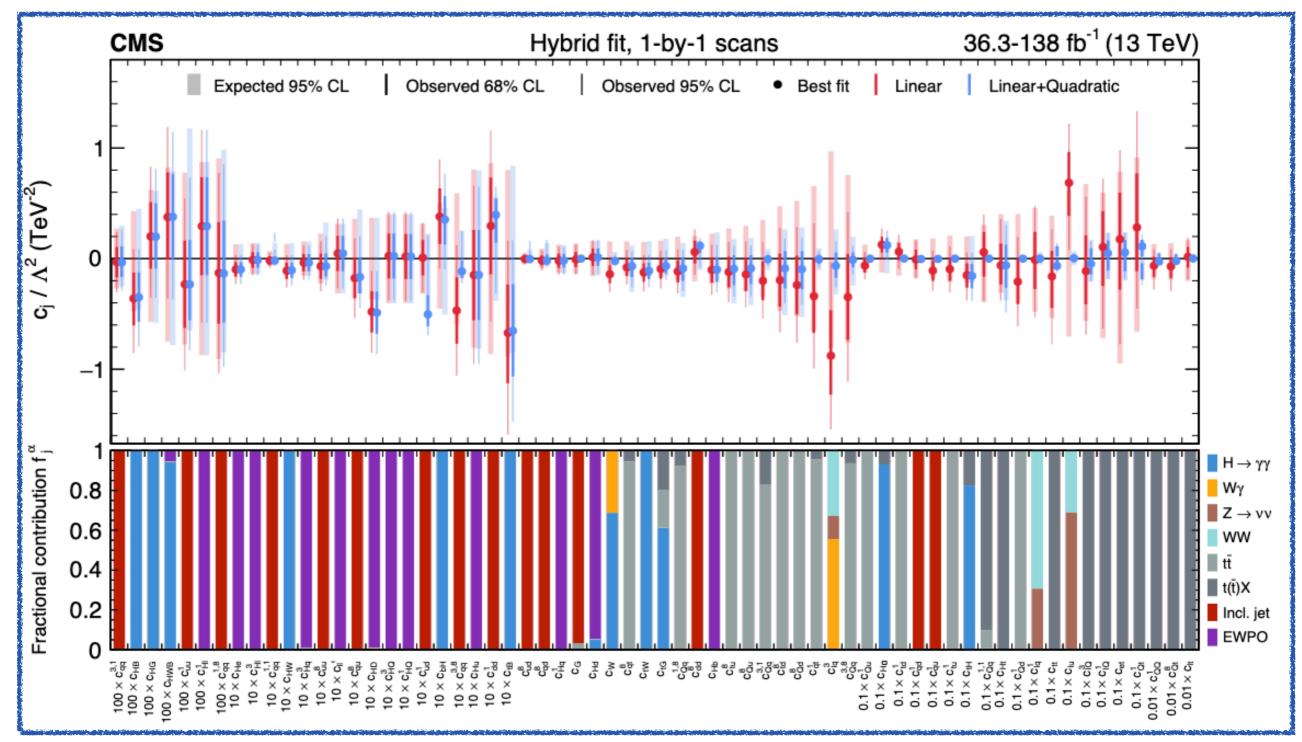
Combination of 7 CMS measurements (@13TeV), & EWPO measured at LEP and SLC Inputs chosen to provide sensitivity to broad set of operators, have negligible overlap in event selection, and background contributions are either small or estimated from data

Individual constraints on coefficients

- Constraints on 64 Wilson coefficients

Linear-only & linear+quadratic constraints

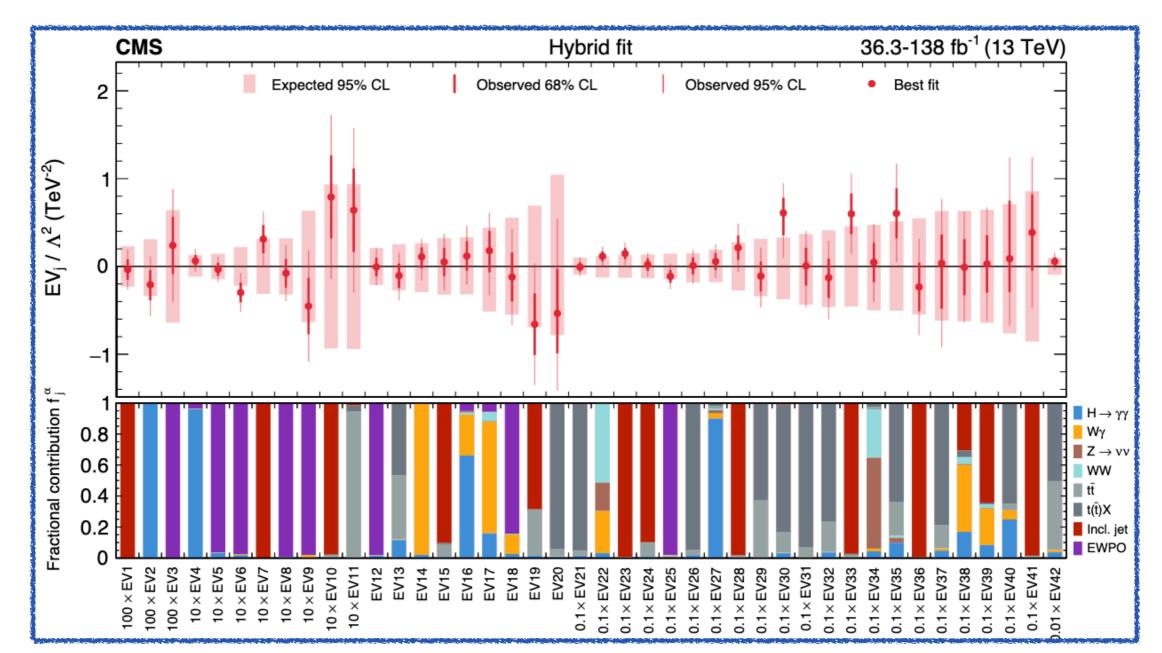
- Combination of Wy & H \rightarrow yy \rightarrow improved constraint on cW
- Stronger constraints on the two-heavy-two-light-quark coefficients



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, & ttX contribute differently to each eigenvector
- 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 \rightarrow 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