SMEFT analysis of VBS and VV data

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Introduction:

Present *a SMEFiT " stand-alone study"*, results based on:

10.1140/epjc/s10052-021-09347-7

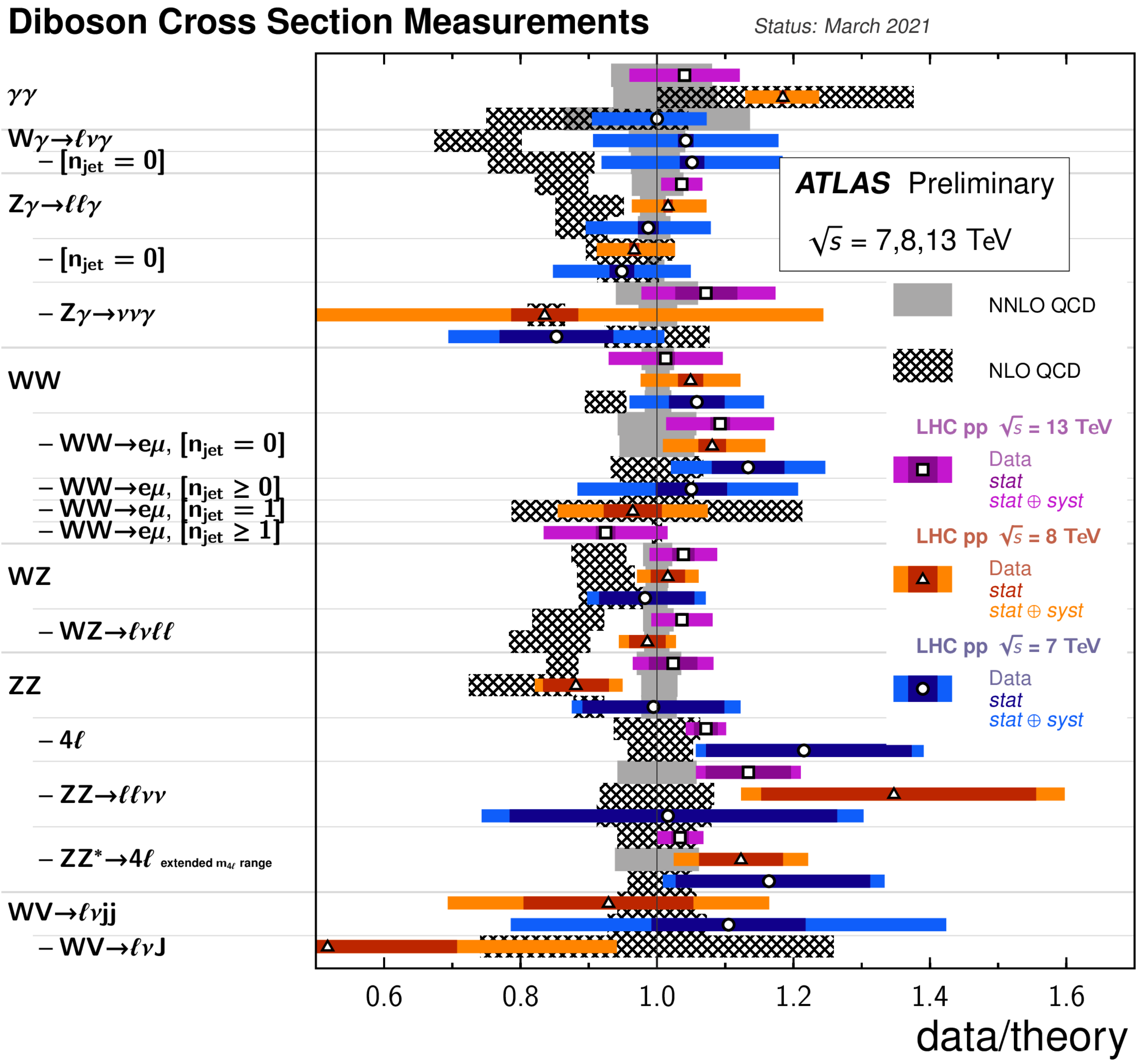
J.J. Ethier, R. Gomez-Ambrosio, G. Magni and J. Rojo

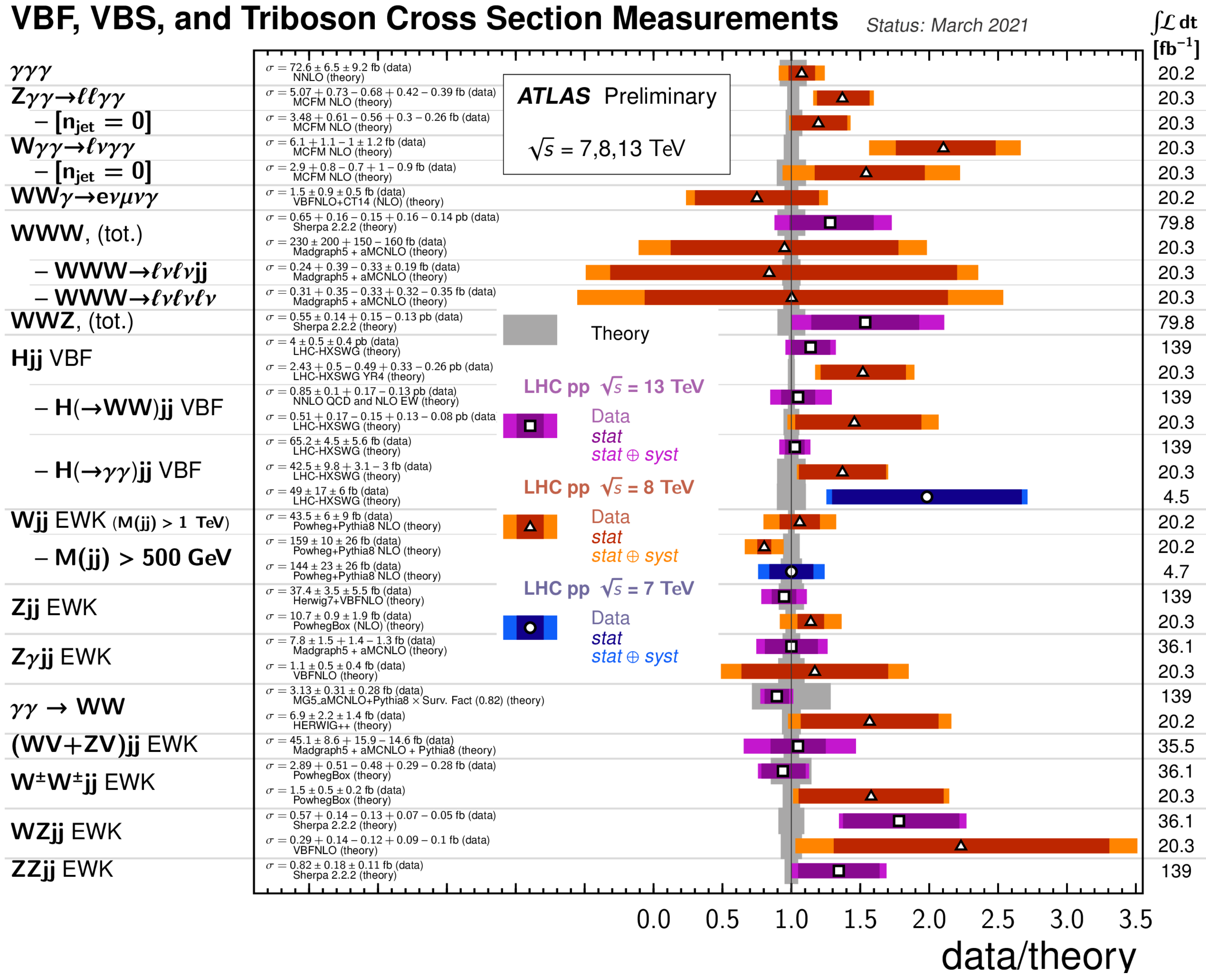
- ✦ Motivation and SMEFT theory settings
- ✦ Combined VV + VBS EFT data analysis with **SMEFiT**
- ✦ Future Prospects: a toy model for HL-LHC

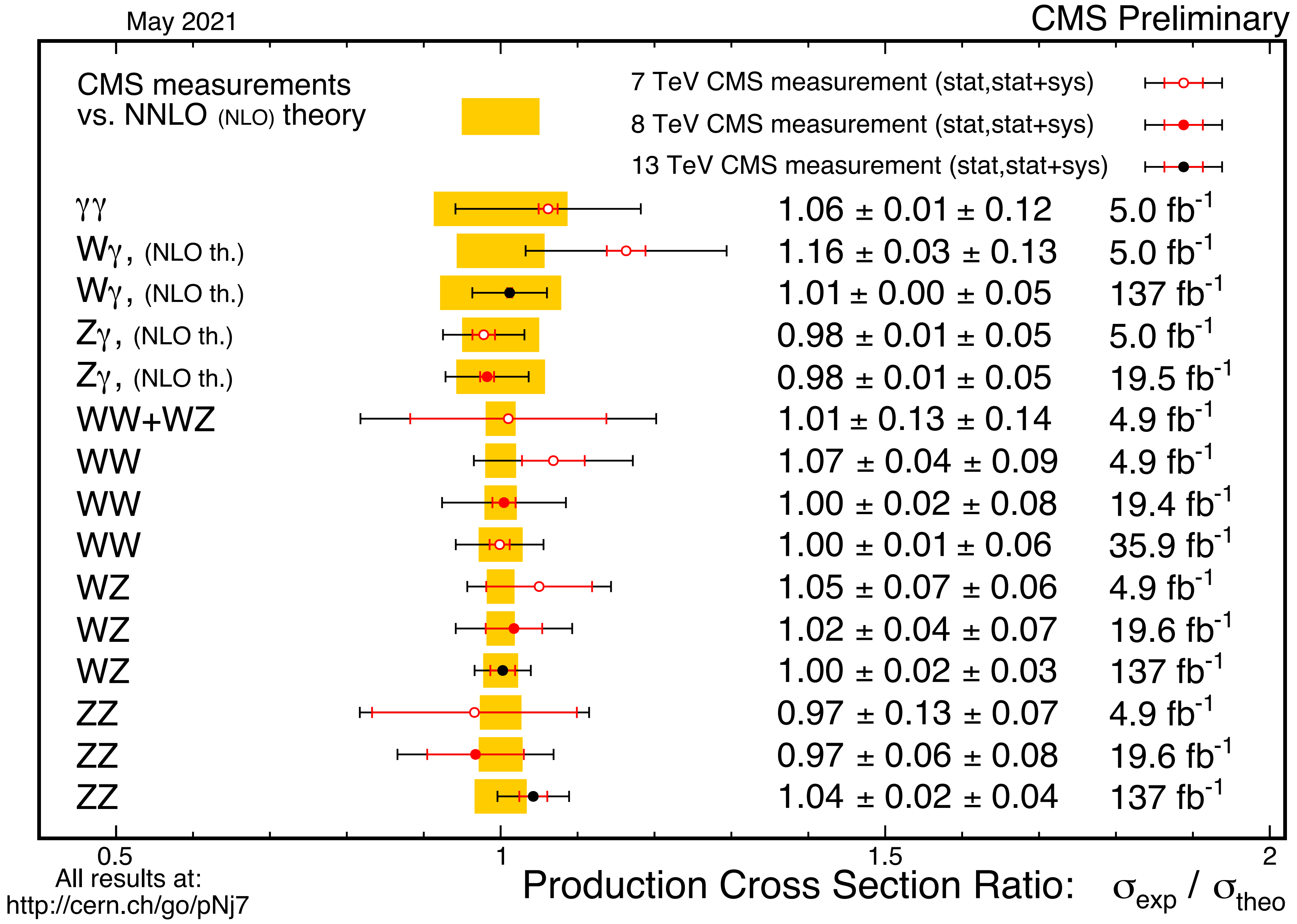
Further details on SMEFiT in J. Rojo talk (Wed 28th)

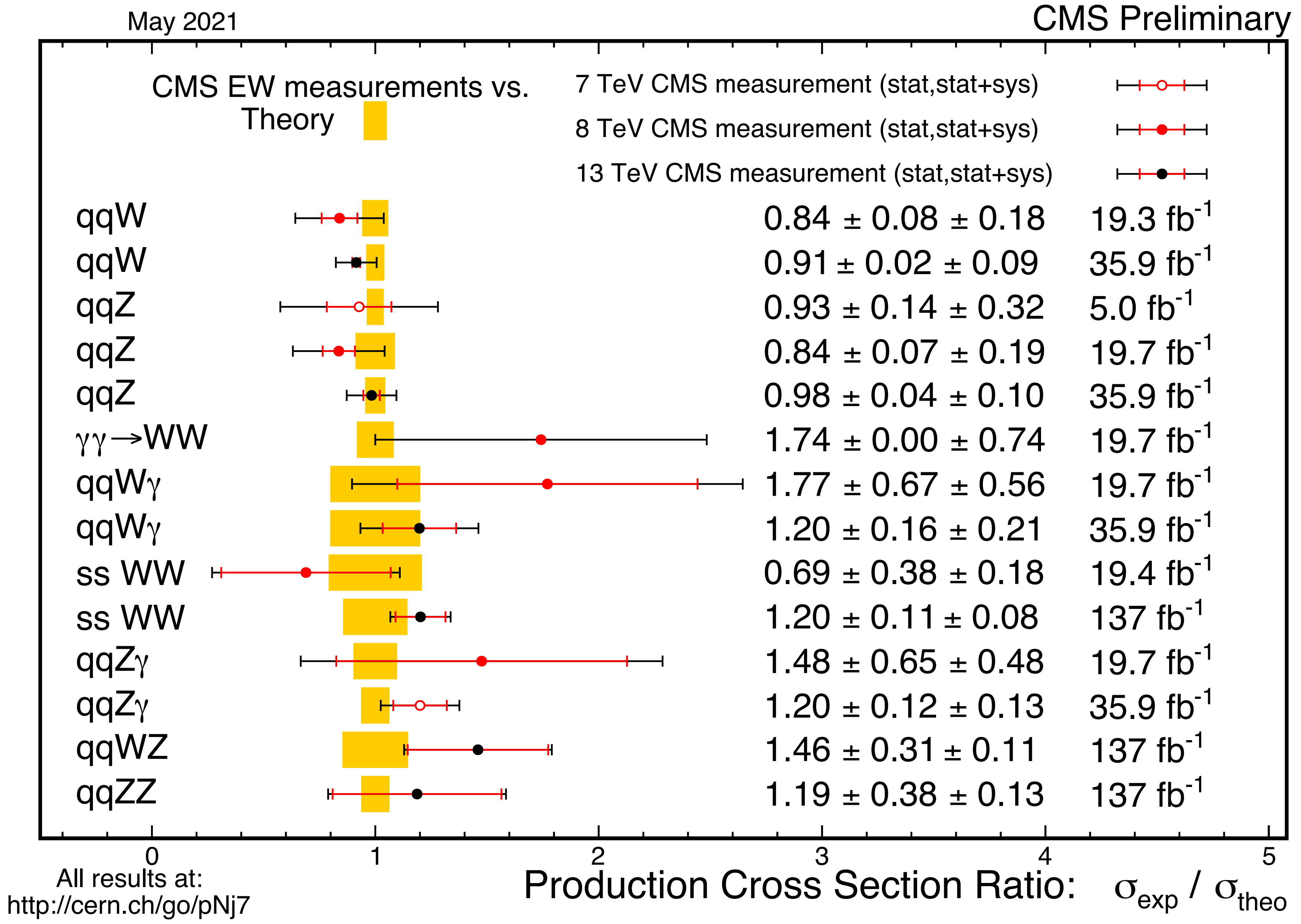
Motivation

- ✦ Several Run-II VBS measurements are now available
- ✦ Very challenging analysis
- ✦ Precision still far from Higgs and diboson
- ✦ Room for BSM effects (heart of EWSB)









Goals of the project:

- ✦ Study VBS in a combined fit with VV
- ✦ interplay between VBS and VV in a dim6 SMEFT study

Theory

SMEFT in VBS and VV

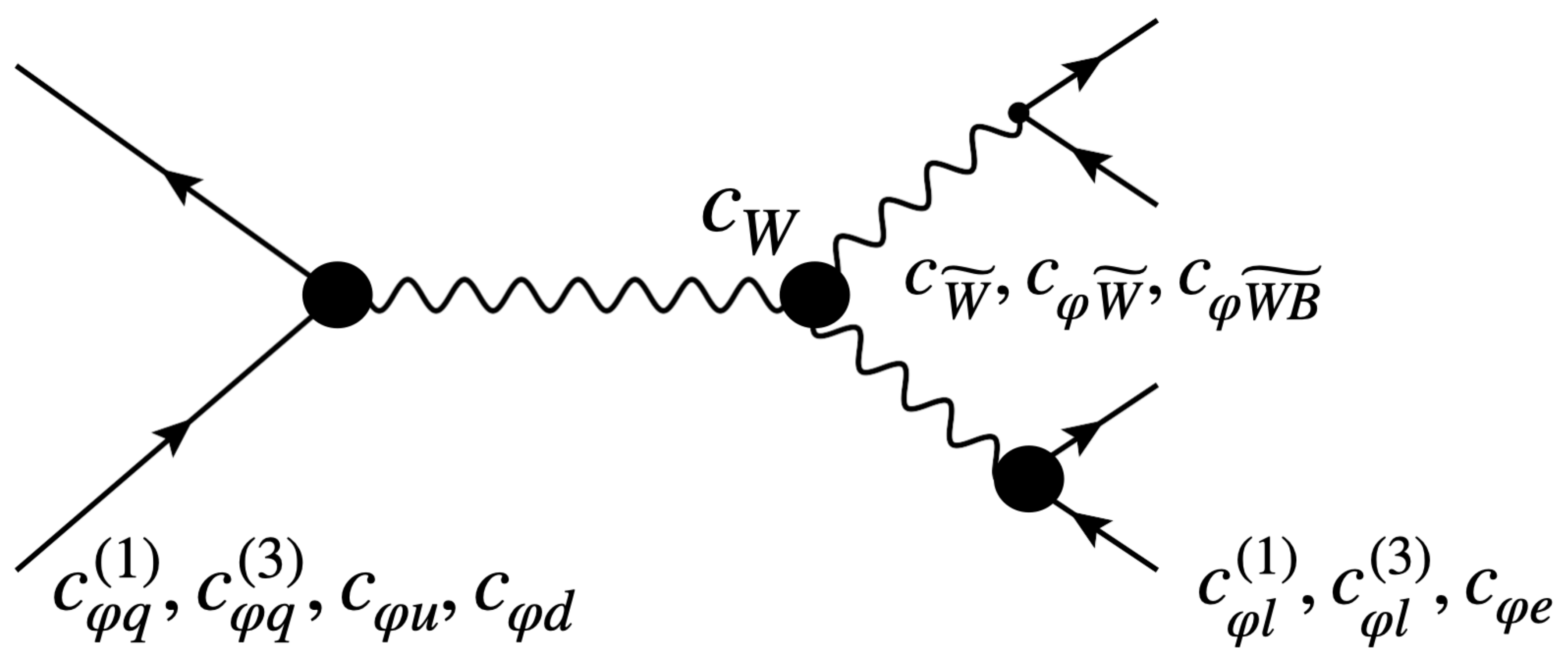
Expand SM Lagrangian as:

$$\mathscr{L}_{SMEFT} = \mathscr{L}_{SM} + \sum_i \frac{c_i}{\Lambda^2}\mathcal{O}_i$$

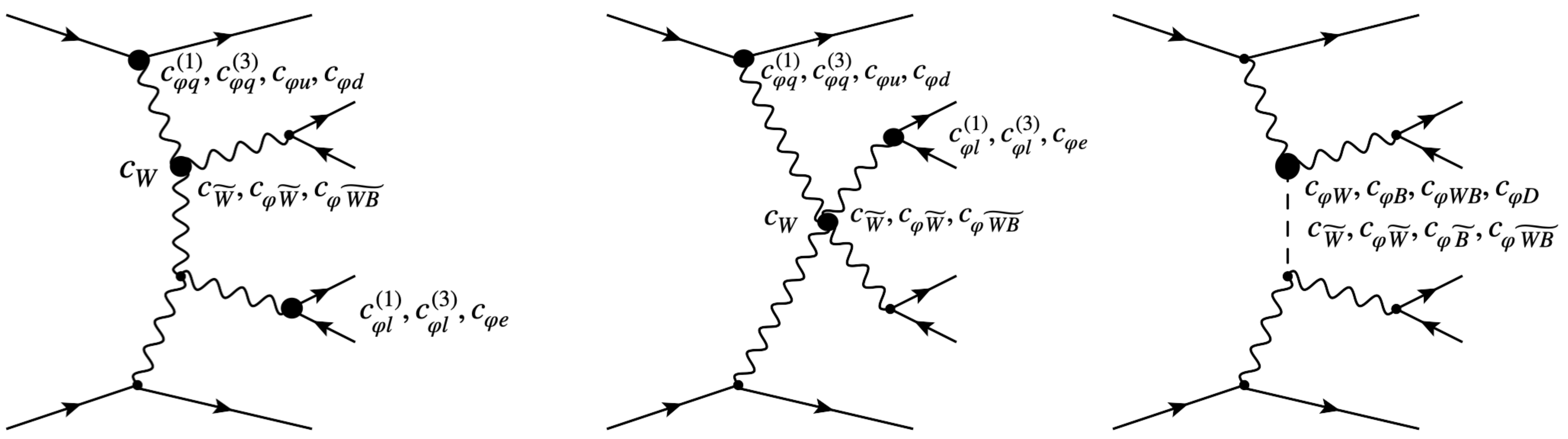
- ✦ Operators from the Warsaw basis (dim 6)
- ✦ Including only **bosonic** operators:

  2F2H, 2H2V, HDH^2, 3V
- ✦ CP violating operators
- ✦ Restrict to linear dim 6
- ✦ dim8 and quadratics for the future

Diboson VV



VBS VVjj



Methodology

Experimental datasets

Dataset available by end of 2020

- Dataset from LHC Run II
- Unfolded fiducial and differential cross sections of VV and VBS
- All vectors decay into leptons
- EFT effects in “signal” region only

Final state	Selection	Observable	$n_{\rm dat}$	$\mathcal{L}$ (fb^{-1})	Label
$W^\pm W^\mp$	VV	$d\sigma/dm_{e\mu}$	13	36.1	ATLAS_WW_memu
		$d\sigma/dm_{e\mu}$	13	35.9	CMS_WW_memu
$W^\pm Z$	VV	$d\sigma/dp_{T_Z}$	7	36.1	ATLAS_WZ_ptz
		$d\sigma/dp_{T_Z}$	11	35.9	CMS_WZ_ptz
ZZ	VV	$d\sigma/dm_{ZZ}$	8	137	CMS_ZZ_mzz
Total diboson			**52**		

Final state	Selection	Observable	$n_{\rm dat}$	$\mathcal{L}$ (fb^{-1})	Label
$W^\pm W^\pm jj$	EW-only	$\sigma_{\rm fid}$	1	36.1	ATLAS_WWjj_fid
	EW-only	$\sigma_{\rm fid}$	4	137	CMS_WWjj_fid
	EW+QCD	$d\sigma/dm_{ll}$ $^{(*)}$			CMS_WWjj_mll
$ZW^\pm jj$	EW+QCD	$d\sigma/dm_{T_{WZ}}$	5	36.1	ATLAS_WZjj_mwz
	EW-only	$\sigma_{\rm fid}$	4	137	CMS_WZjj_fid
	EW+QCD	$d\sigma/dm_{jj}$ $^{(*)}$			CMS_WZjj_mjj
$ZZjj$	EW+QCD	$\sigma_{\rm fid}$	1	139	ATLAS_ZZjj_fid
	EW-only	$\sigma_{\rm fid}$	1	139	CMS_ZZjj_fid
γZjj	EW-only	$\sigma_{\rm fid}$	1	36.1	ATLAS_AZjj_fid
	EW-only	$\sigma_{\rm fid}$	1	35.9	CMS_AZjj_fid
VBS total (unfolded)			**18**		
$ZZjj$	EW+QCD+Bkg	Events/m_{ZZ}	4	139	CMS_ZZjj_mzz
γZjj	EW+QCD+Bkg	Events/$p_{T_{\ell\ell\gamma}}$	11	36.1	ATLAS_AZjj_ptlla
VBS total (detector-level)			**15**		

Other channels for future update: $Z\gamma$ CMS, Zjj …

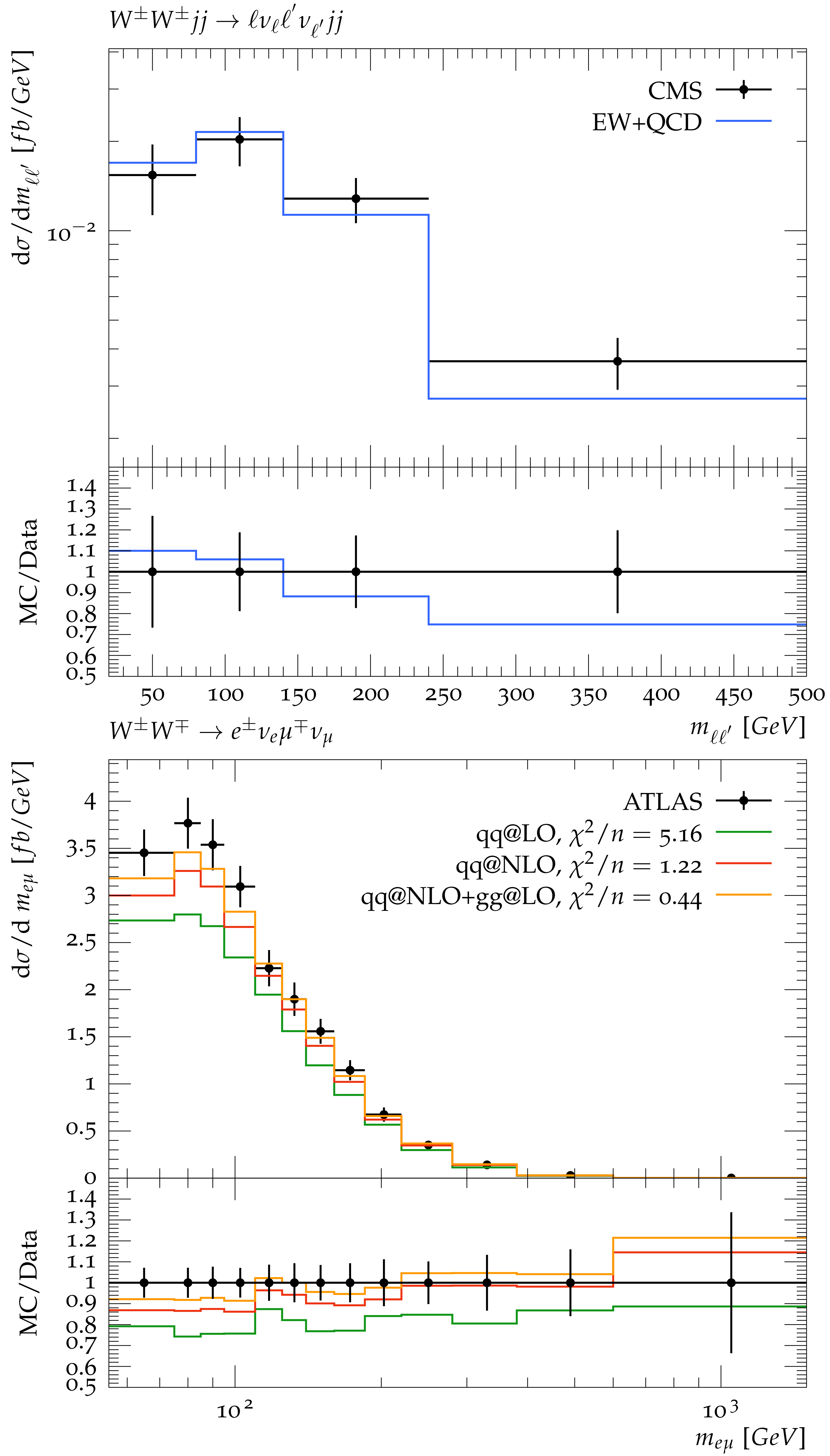
Methodology

Theoretical calculations

$$\sigma_{SMEFT} = \sigma_{SM} + \sum_{i=1}^{N_{dof}=16} \frac{c_i}{\Lambda^2} \sigma_i^{(int)}$$

Combining many HEP tools to achieve good predictions:

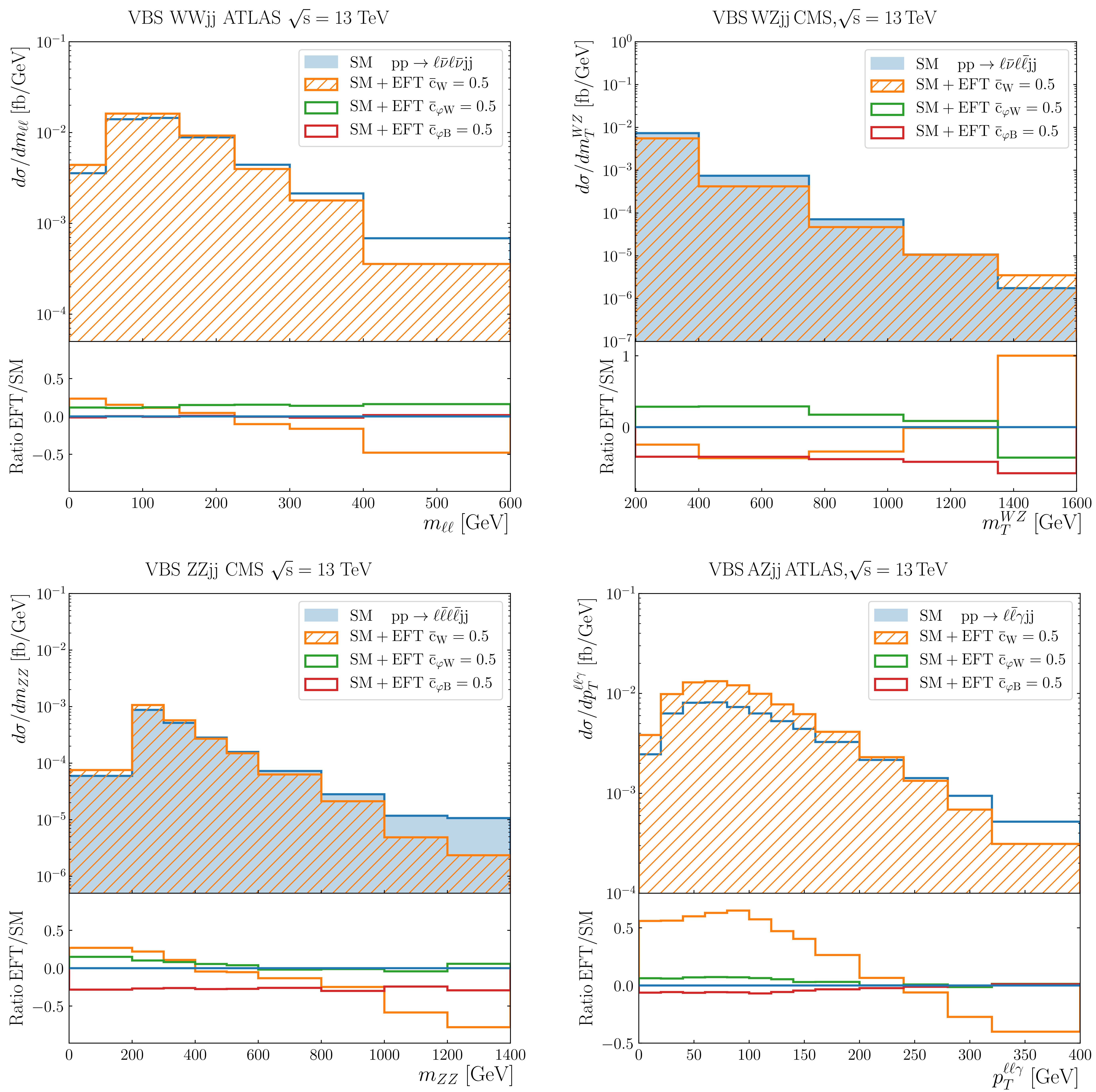
1. **SM** MC event generation with *Madgraph* and/or *PowhegBox* @ ***NLO***
2. **EFT linear** contribution @ LO with: *SmeftSim* UFO model ($SU(3)^5$ symmetry)
3. **Parton shower** using *Pythia8* and experimental phase space selection with ***ad-hoc Rivet*** analysis
4. Experimental data with corresponding uncertainties collected from *Hepdata*



Methodology

Sensitivity plots

Study the impact of each operator in the experimental phase space region, fixing the Wilson coefficient to a reference value



We observe:

- ✦ Larger effects not only in the high energy tails
- ✦ What are the optimal observables to include in the fit?

Methodology

Fisher information

Trace of:

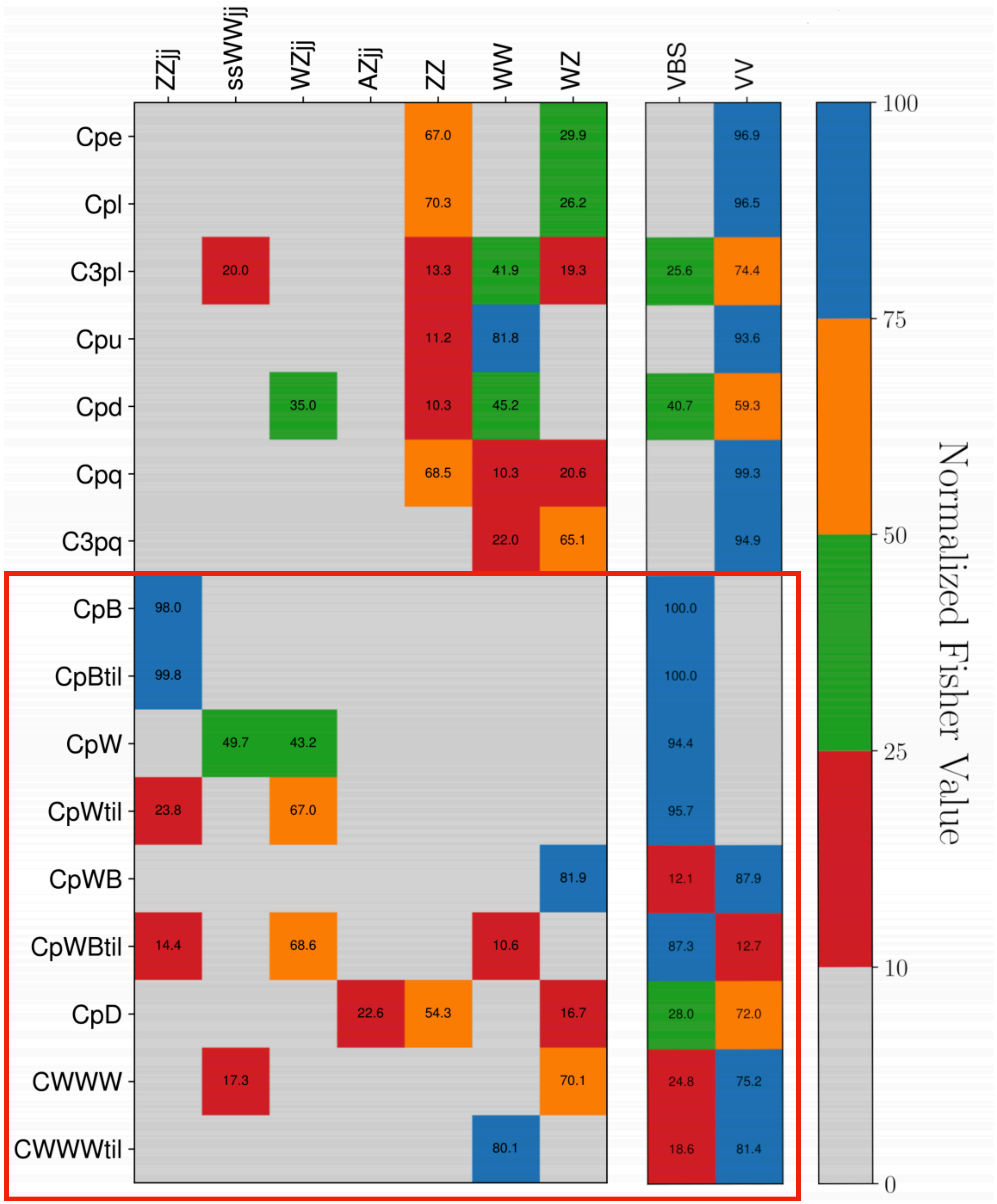
$$I_{i,j} = E\left[\frac{\partial^2 \ln f(\sigma_{exp}\,|\,c)}{\partial c_i \partial c_j}\right] = \sum_{m=1}^{n_{dat}} \frac{\sigma^{(eft)}_{(m,i)} \sigma^{(eft)}_{m,j}}{\delta^2_{exp,m}}, \quad i,j = 1 \ldots n_{op}$$

And normalised per operator.

- ✦ It shows how each channel contribute to the fit result.
- ✦ Computed before fitting

We observe:

- ✦ *2F2H* operators dominated by VV
- ✦ VBS plays a role for purely boson operators: *HDH^2, 2H2V, 3V*



Methodology

Fitting strategy

✦ Fit the data with ***SMEFiT*** *[Web site]* *(see J. Rojo talk):*

Define the figure of merit to minimise as:

$$\chi^2(c_k) = \frac{1}{N_{data}} \sum (O_{exp,i} - O_{th,i})(cov^{-1})_{ij} O_{exp,j} - O_{th,j})$$

✦ Include available experimental uncertainties, correlations and theory uncertainties (*from MC and pdfs*).

✦ Use **NESTED SAMPLING** : sampling the posterior as :

$$p(c_k \,|\, data) = \frac{1}{Z} \mathscr{L}(data \,|\, c_k) \Pi(c_k)$$

Multi Gaussian Likelihood *Prior, assumed flat*

Fit Output

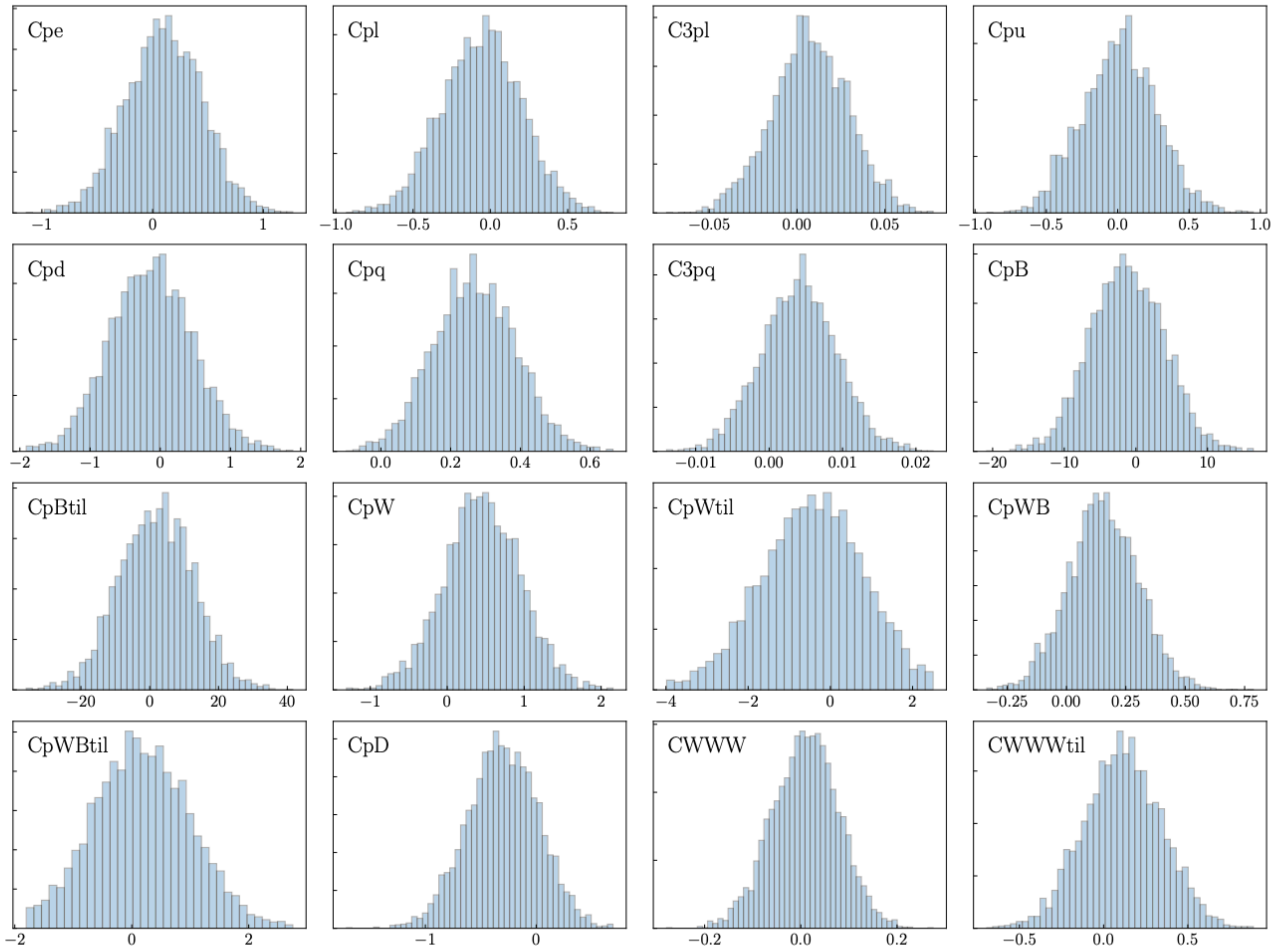
& dataset quality

- Some statistical fluctuations for individual VBS measurements *(should improve when more data points will be available)*
- Global reduced chi2: $\chi^2 \approx 1$
- MHOU (SM and EFT) not included

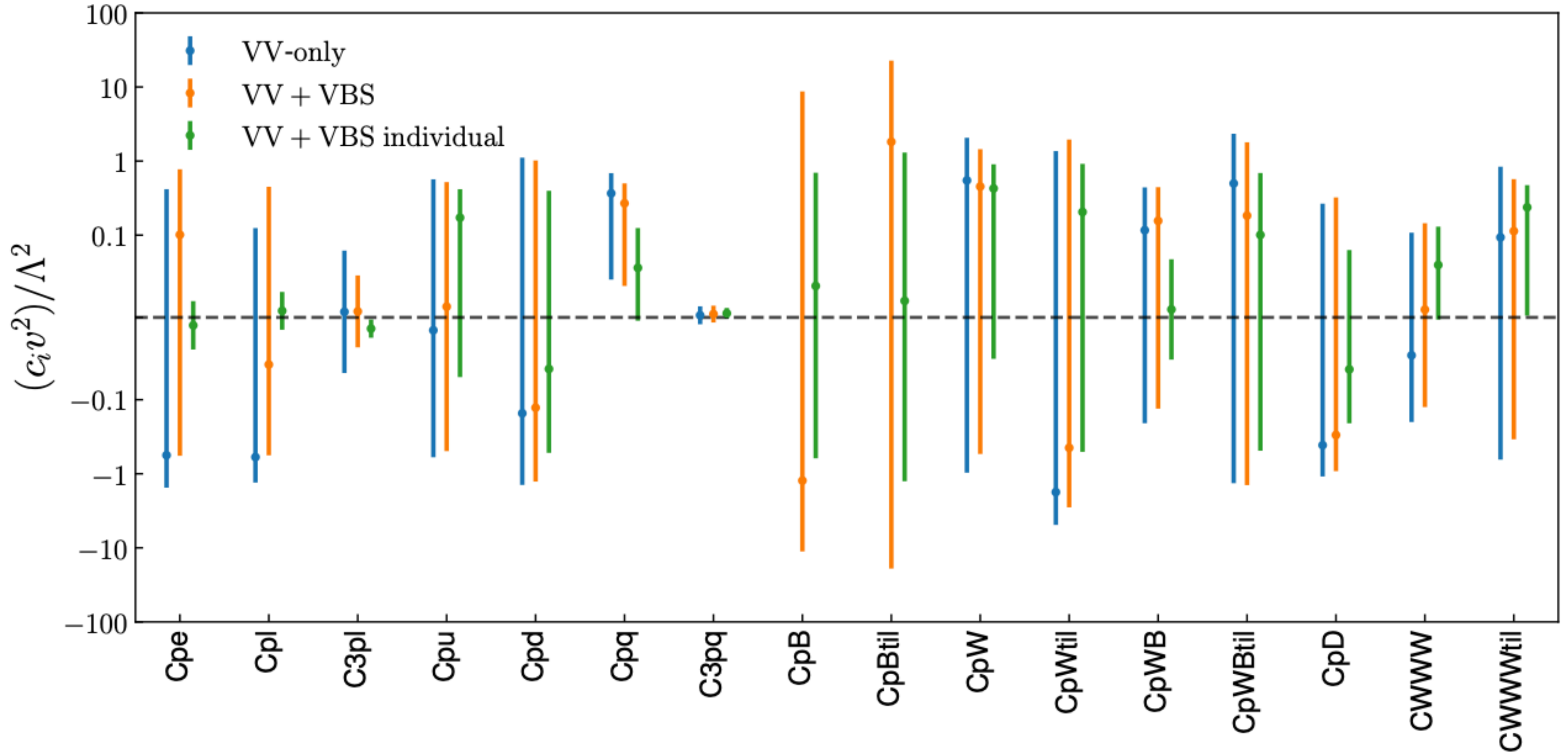
Process	Dataset	$n_{\rm dat}$	$\chi^2/n_{\rm dat}$ (SM)	$\chi^2/n_{\rm dat}$ (EFT)
Diboson	ATLAS_WW_memu	13	0.70	0.66
	CMS_WW_memu	13	1.28	1.32
	ATLAS_WZ_ptz	7	1.38	0.93
	CMS_WZ_ptz	11	1.48	1.14
	CMS_ZZ_mzz	8	1.17	0.74
	Total diboson	**52**	**1.17**	**0.97**
VBS	ATLAS_WWjj_fid	1	0.01	0.67
	CMS_WWjj_fid	1	2.17	0.15
	CMS_WWjj_mll	3	0.31	0.45
	ATLAS_WZjj_mwz	5	1.60	1.52
	CMS_WZjj_fid	1	0.38	0.79
	CMS_WZjj_mjj	3	1.10	0.73
	ATLAS_ZZjj_fid	1	0.09	0.15
	CMS_ZZjj_fid	1	0.02	0.02
	ATLAS_AZjj_fid	1	0.00	0.25
	CMS_AZjj_fid	1	0.03	0.38
	Total VBS	**18**	**0.83**	**0.75**
	Total	**70**	**1.084**	**0.917**

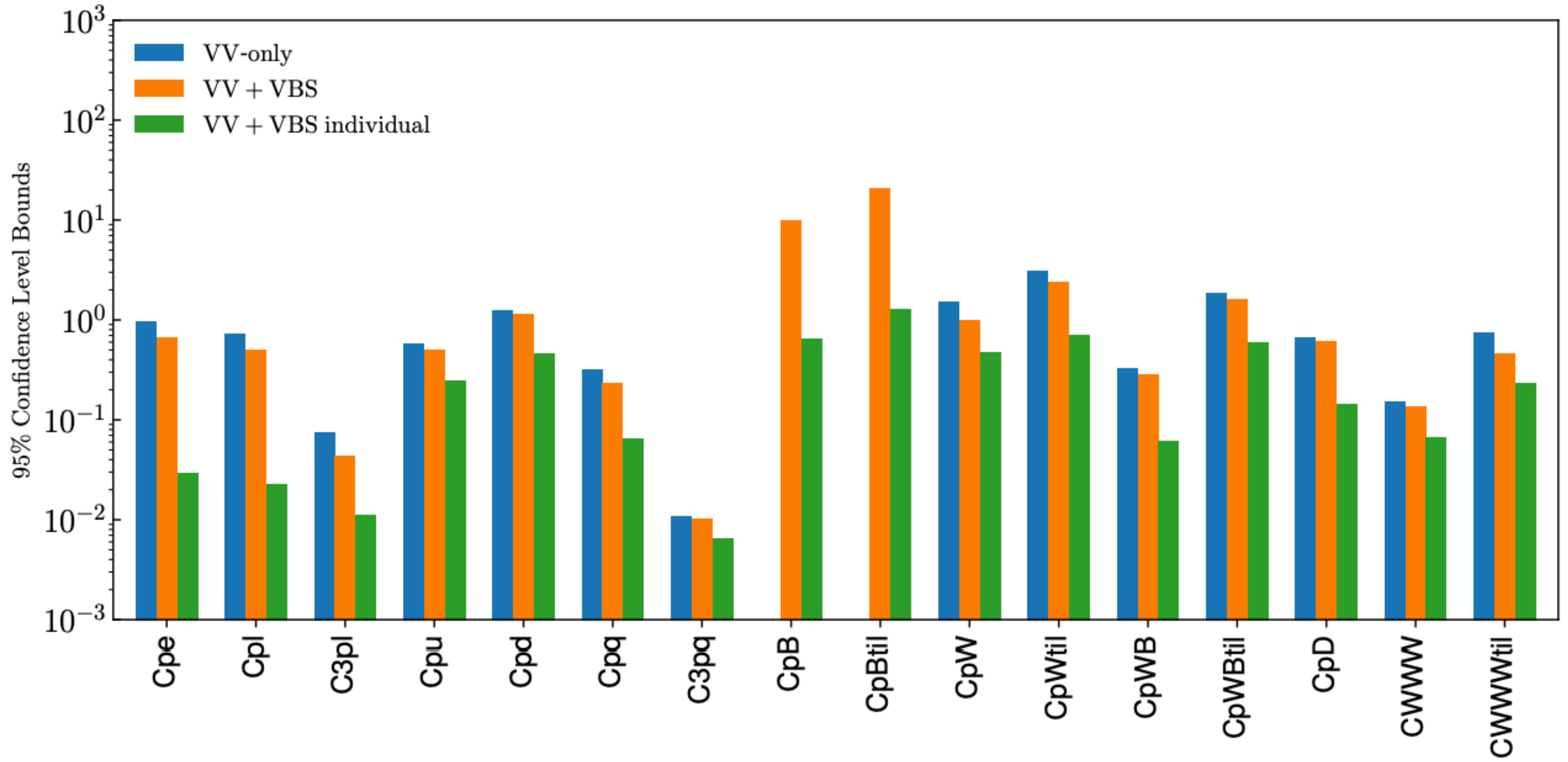
Fit output

VV+VBS fit



Posterior distribution VV+VBS





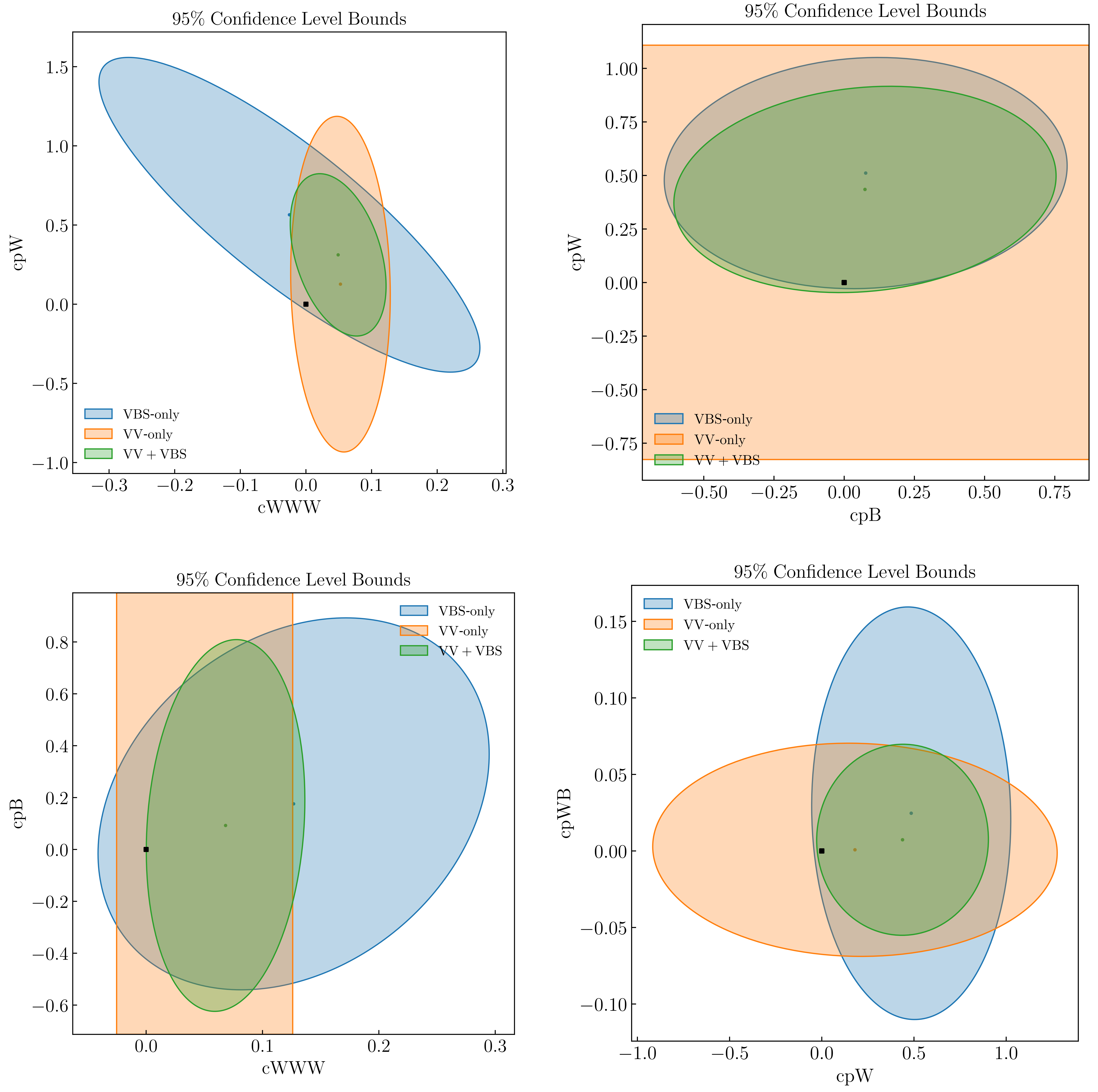
Central values and 95 % CL

Fit output

2D Fits

- ✦ Useful to spot correlation between operators.
- ✦ Understand how the combined fit behaves with respect to the VV-only or VBS-only

Complementarity between VBS and VV data when looking at dim6 EFT effects !



Toy model

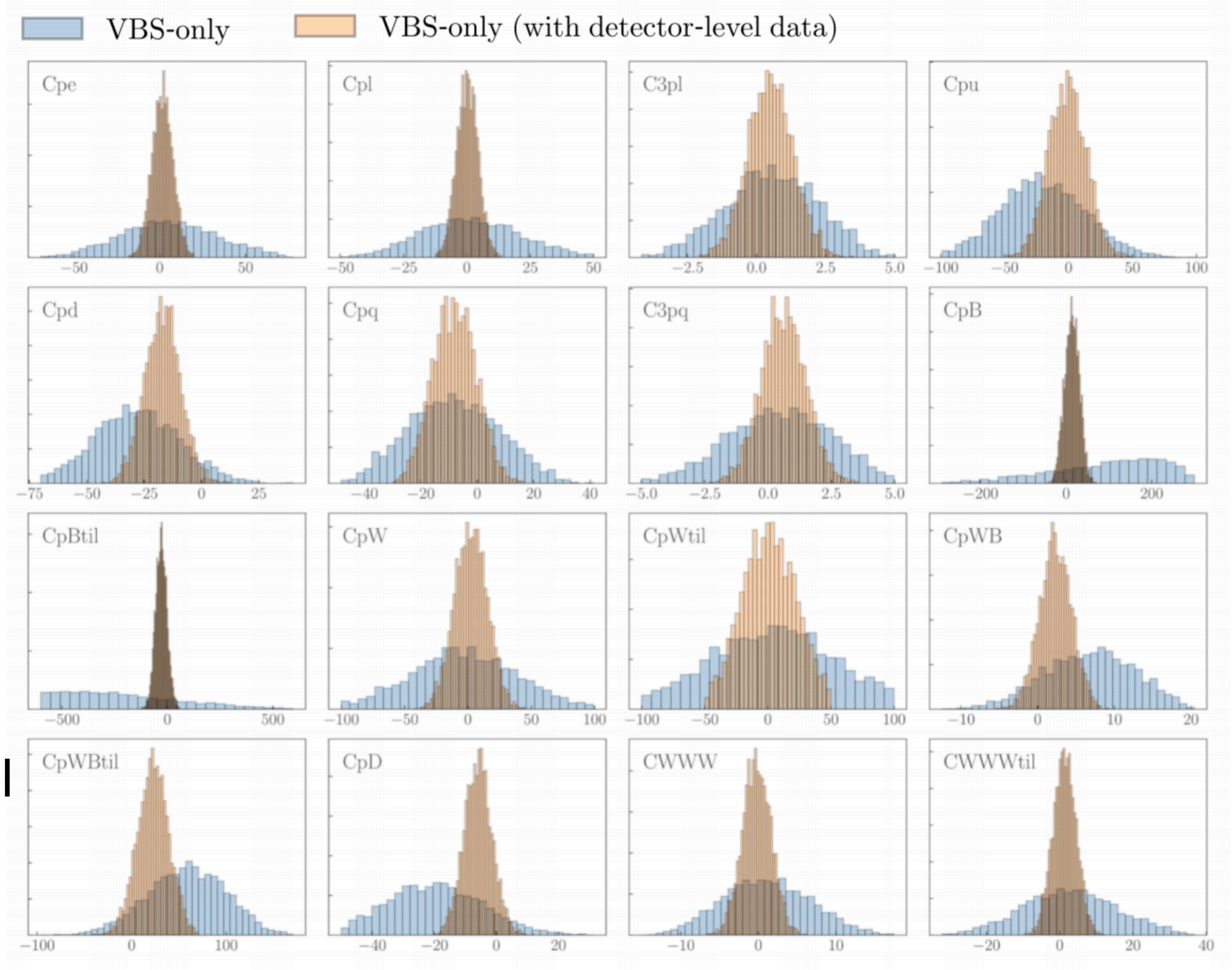
Dataset variation

Effect of differential ZZjj and Zγjj:

1. Break degeneracy on c_{pB} and $c_{p\widetilde{B}}$
2. Improve globally the VBS only fit.

$ZZjj$	EW+QCD+Bkg	Events/m_{ZZ}	4	139	CMS_ZZjj_mzz
γZjj	EW+QCD+Bkg	Events/$p_{T_{\ell\ell\gamma}}$	11	36.1	ATLAS_AZjj_ptlla
VBS total (detector-level)			**15**		

To test this, add to our baseline two detector level distributions (only bins with high statistics)



Differential results make a big difference!

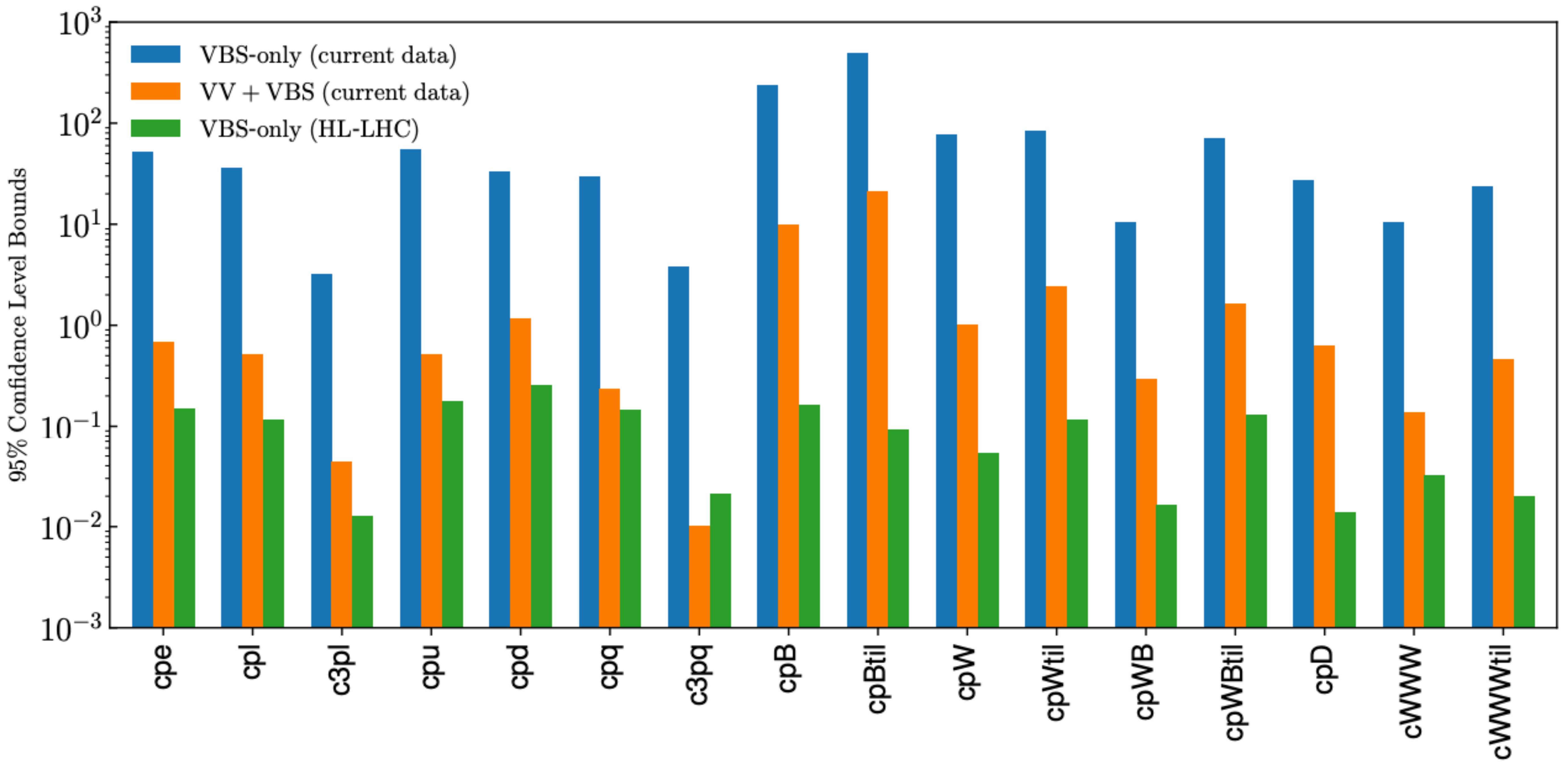
Posterior distribution

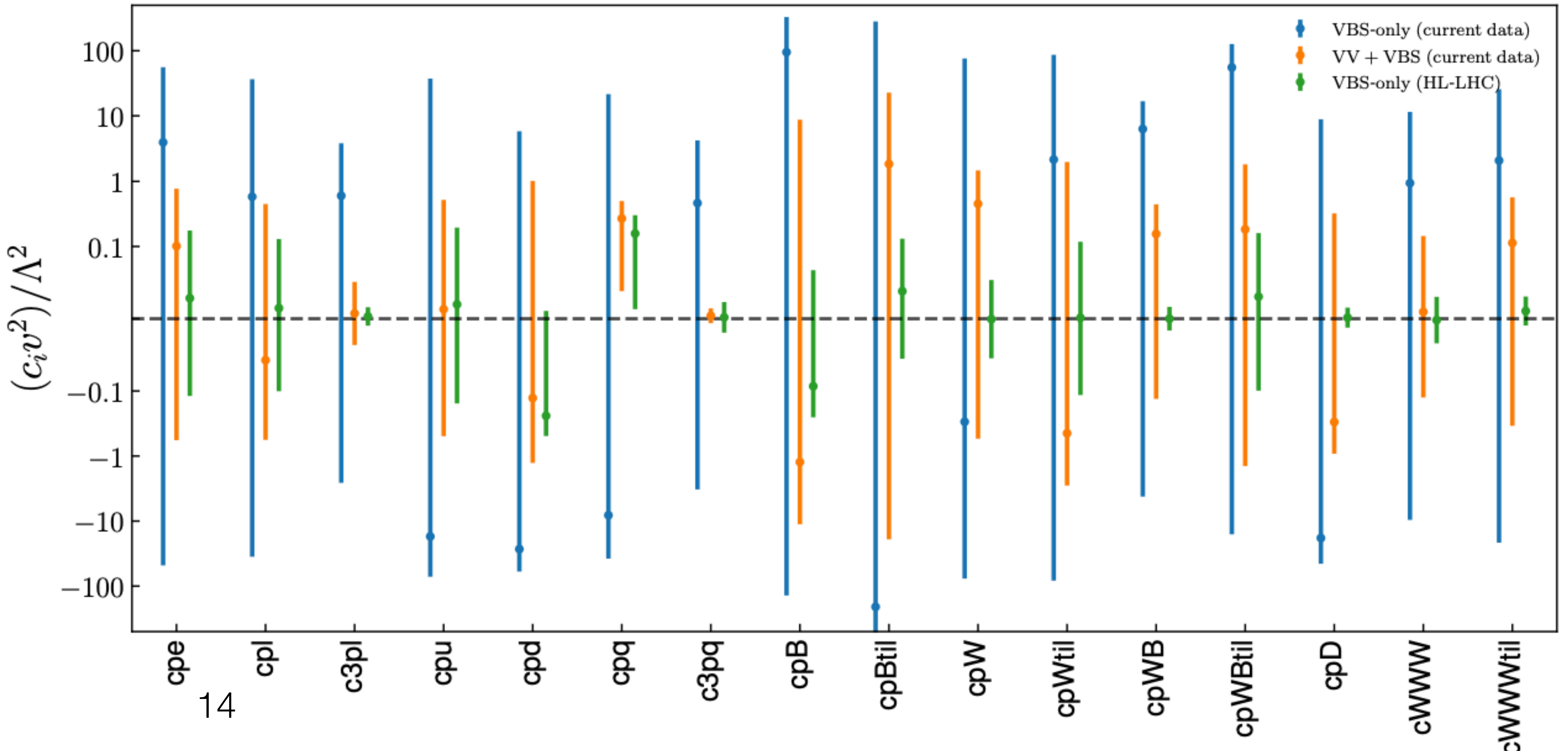
Toy model

VBS at HL-LHC

$$\sigma_i^{HL-LHC} = \sigma_i^{th}(1 + r_i \delta_{tot,i}^{exp})$$

- Assume the systematic errors reduce by 50% while statistical by 80 %
- Create gaussian dataset
- Keep LHC binning
- 61 data points from VBS





Central values and 95 % CL

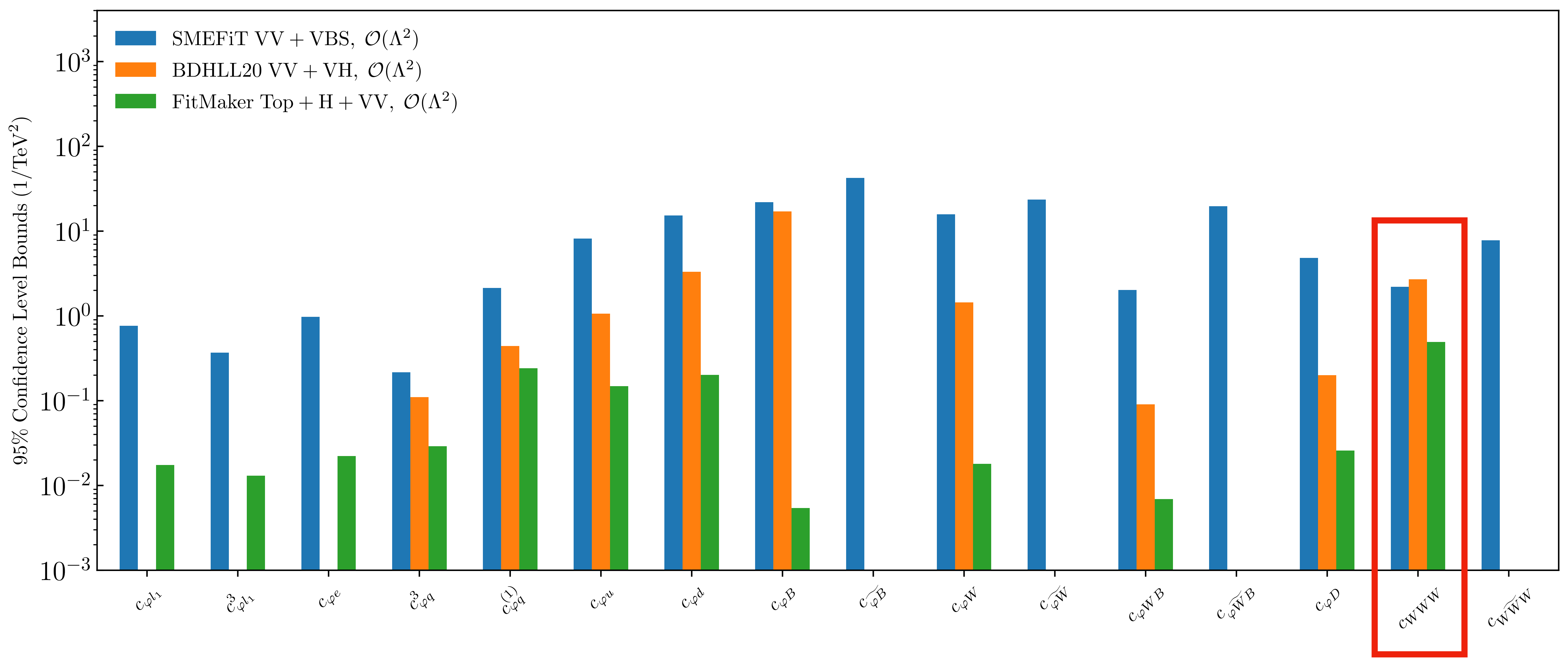
Summary and outlook

VBS can be used to check TGC and QGC,

but can validate also the Higgs sector

On the way towards a "global" fit:

$Top + H + VV + VBS$ *and* $\approx \mathcal{O}(100)$ *operators*



BDHLL: J. Baglio, S.Dawson, S.Homiller, S.Lane and I.Lewis

FitMaker: J.Ellis, M.Madigan,K.Mimasu,V.Sanz and T.You

Theory improvements:

- ✦ Including Dim 6 quadratics terms
- ✦ Account for NLO effects in EFT
- ✦ Can VBS give indirect information about Higgs potential?
- ✦ Can we compare with Dim 8 EFT operators?

Fit improvements:

- ✦ Add more experimental data

  (ex: Zjj, Wjj, EWPO …)
- ✦ Optimal observables

Thanks for your attention!

Fit output

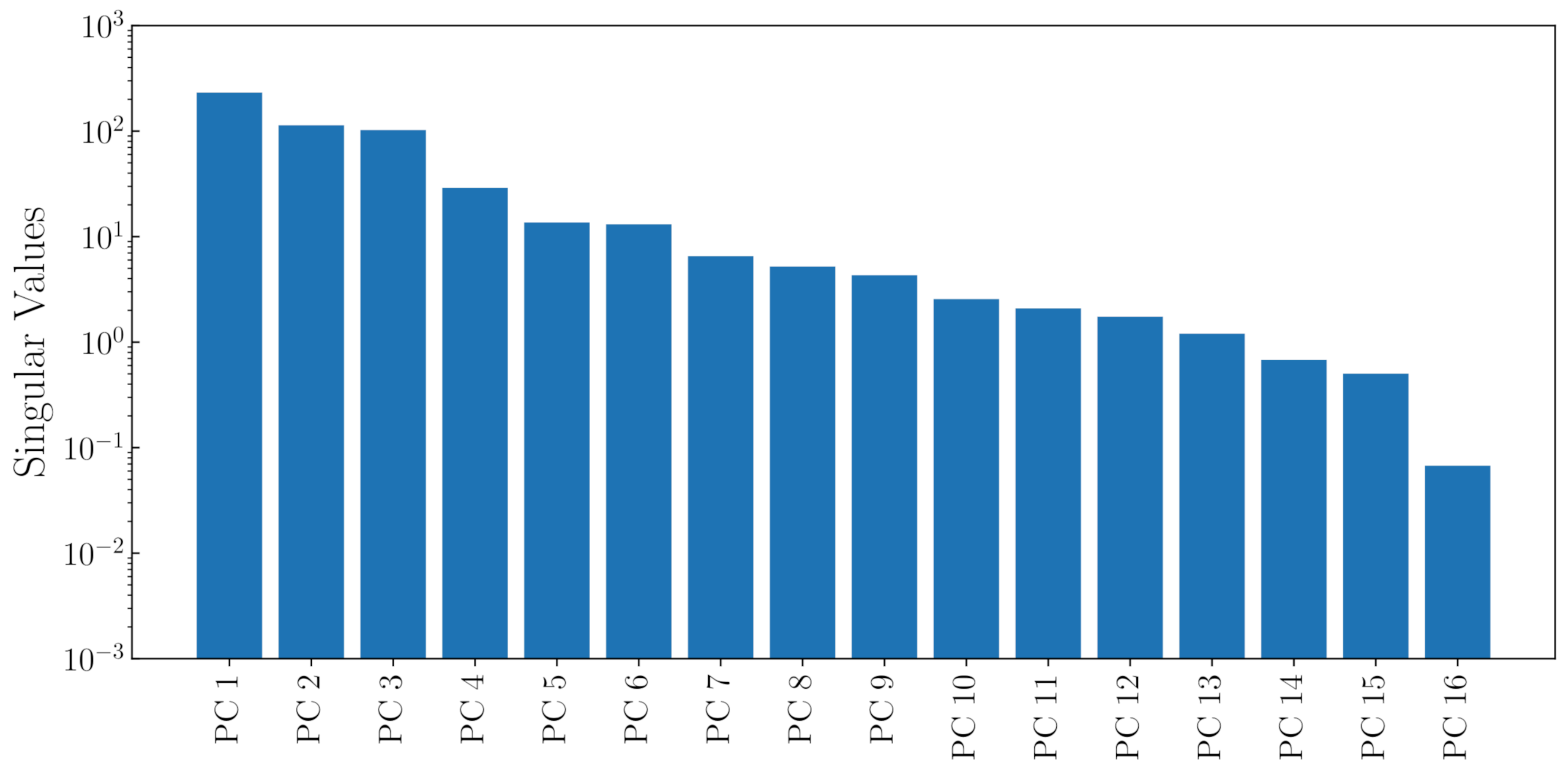
Principal Components Analysis

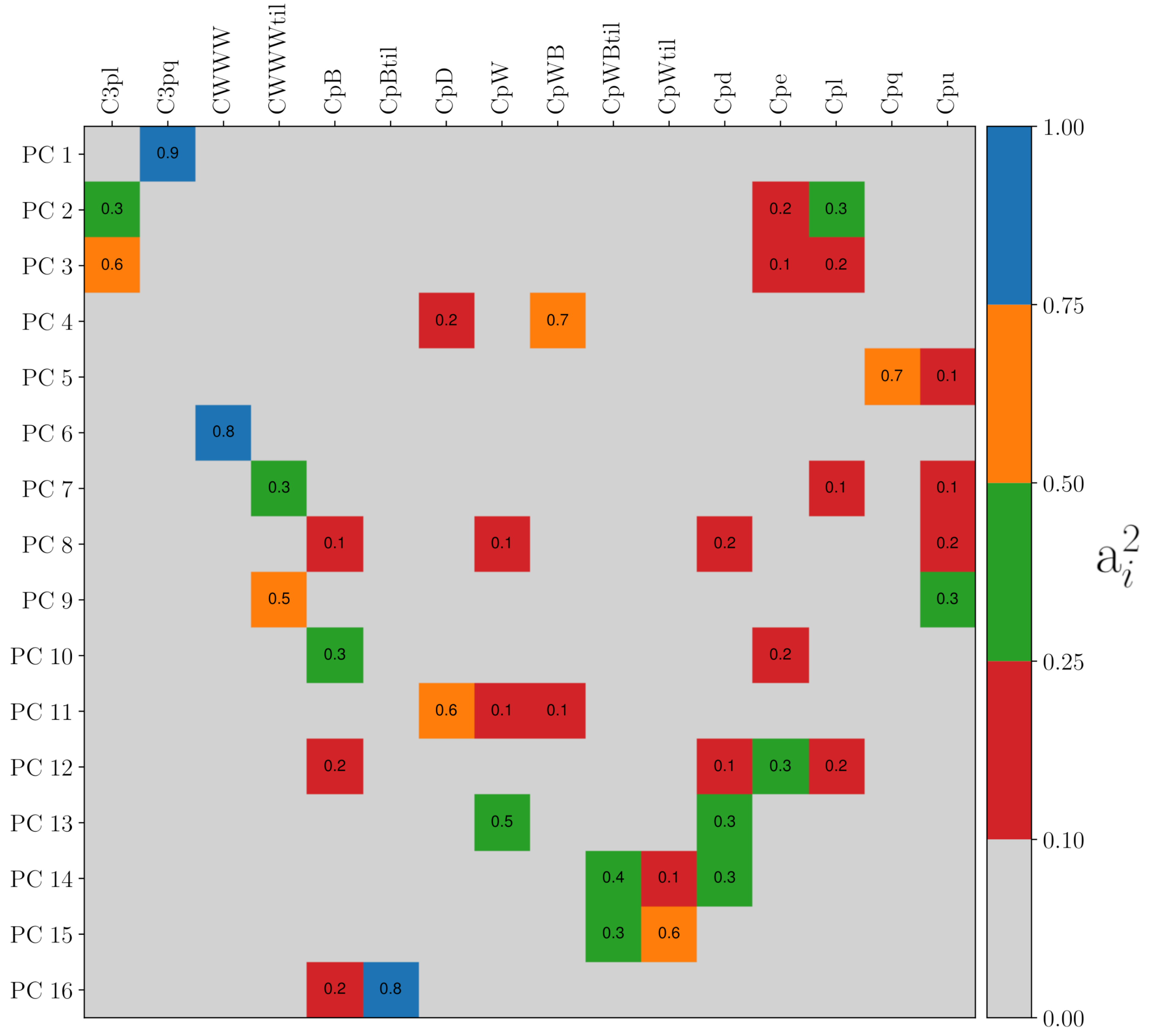
Trace of:

$$PC_k = \sum_{i=1}^{n_{op}} = a_{k,i} c_i \quad k = 1, \ldots n_{op}$$

And normalised per operator.

- There are NO flat directions in a VV + VBS fit
- First PCs contains 2F2H operators.





Fit output

CP EVEN only fit

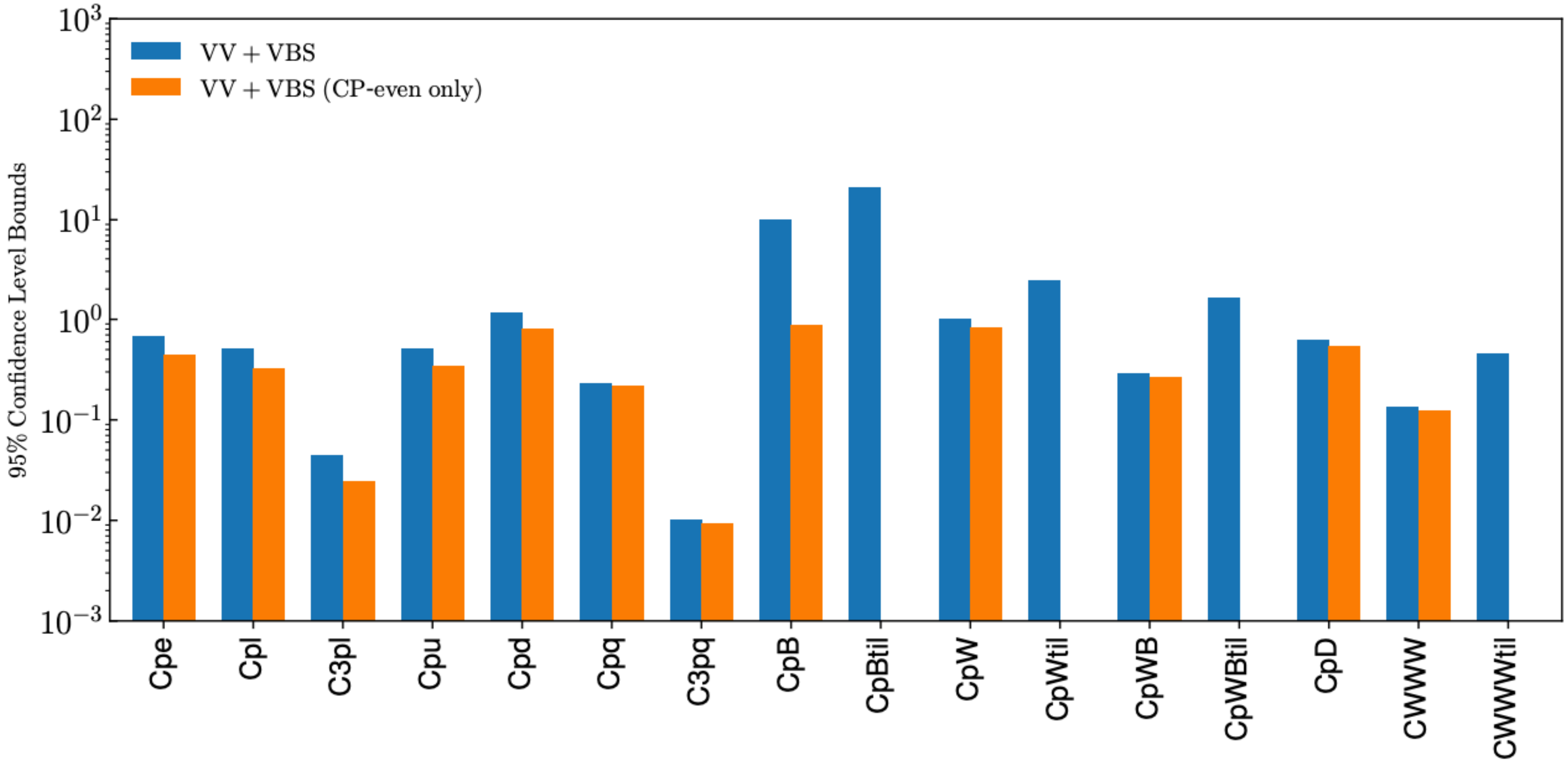
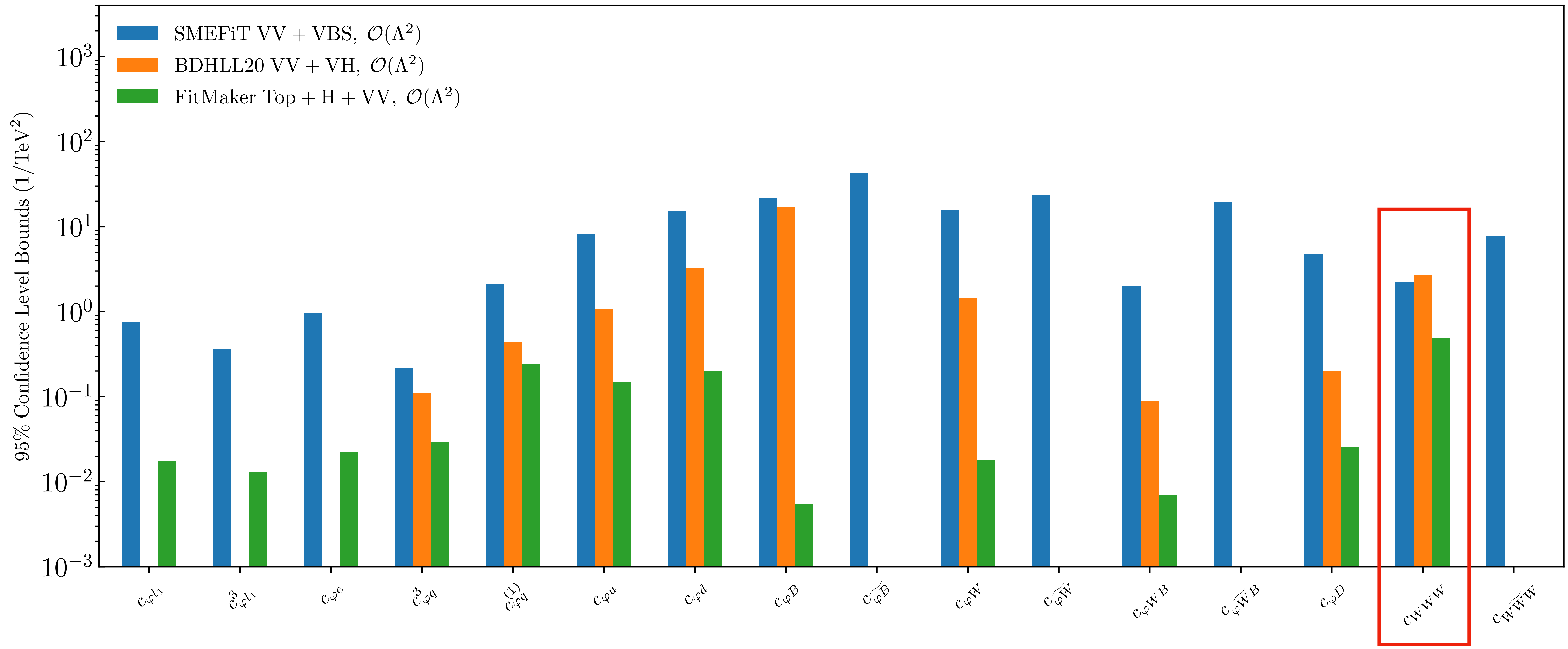


Figure 4.12. Comparing the results of the baseline fit with those of the same fit where the CP-odd operators have been set to zero, such that only the CP-even ones remain.

Comparison with the literature



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