DataSMEFT23

Searching for new physics in the era of ChatGPT

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LHCP Belgrade

26/05/2023

Outline

- PART I: Introduction
  - Indirect searches for new physics: SMEFT and HEFT
- PART II:
  - LHC RUN 1 & 2: Searching for deviations
  - SMEFT after RUN-2: defining unbinned objects and the rise of ML
- PART III:
  - Other routes: the HiggsFlare

PART I

Introduction

$$\mathcal{L}_{SM}$$

26 Free parameters: Now mostly determined experimentally (it's a *deterministic theory*)

(Only freedom on input parameter scheme and renormalisation scales)

$$\mathcal{L}_{SMEFT} = \mathcal{L}_{SM} + c_1 \frac{\mathcal{O}_1^{(6)}}{\Lambda^2} + c_2 \frac{\mathcal{O}_2^{(6)}}{\Lambda^2} + \ldots + c_3 \frac{\mathcal{O}_3^{(8)}}{\Lambda^4} + c_4 \frac{\mathcal{O}_1^{(8)}}{\Lambda^4} + \ldots$$

$$\mathcal{L}_{HEFT} = \frac{1}{2} \partial_\mu h \, \partial^\mu h + \left(1 + \frac{h}{v}\right) \partial_\mu w^+ \partial^\mu w^-$$

Define an extension of the SM: sticking to the known symmetries or allowing for new ones

Classic EWSB:

$$\mathscr{L}_{SMEFT} = \mathscr{L}_{SM} + c_1 \frac{\mathcal{O}_1^{(6)}}{\Lambda^2} + c_2 \frac{\mathcal{O}_2^{(6)}}{\Lambda^2} + \ldots + c_3 \frac{\mathcal{O}_3^{(8)}}{\Lambda^4} + c_4 \frac{\mathcal{O}_1^{(8)}}{\Lambda^4} + \ldots$$

Non-linear alternative:

$$\mathscr{L}_{HEFT} = \frac{1}{2} \partial_\mu h \, \partial^\mu h + \frac{1}{2} \left(1 + 2a \frac{h}{v} + b \left(\frac{h}{v} \right)^2 \right) \partial_\mu w^+ \partial^\mu w^-$$

PART II

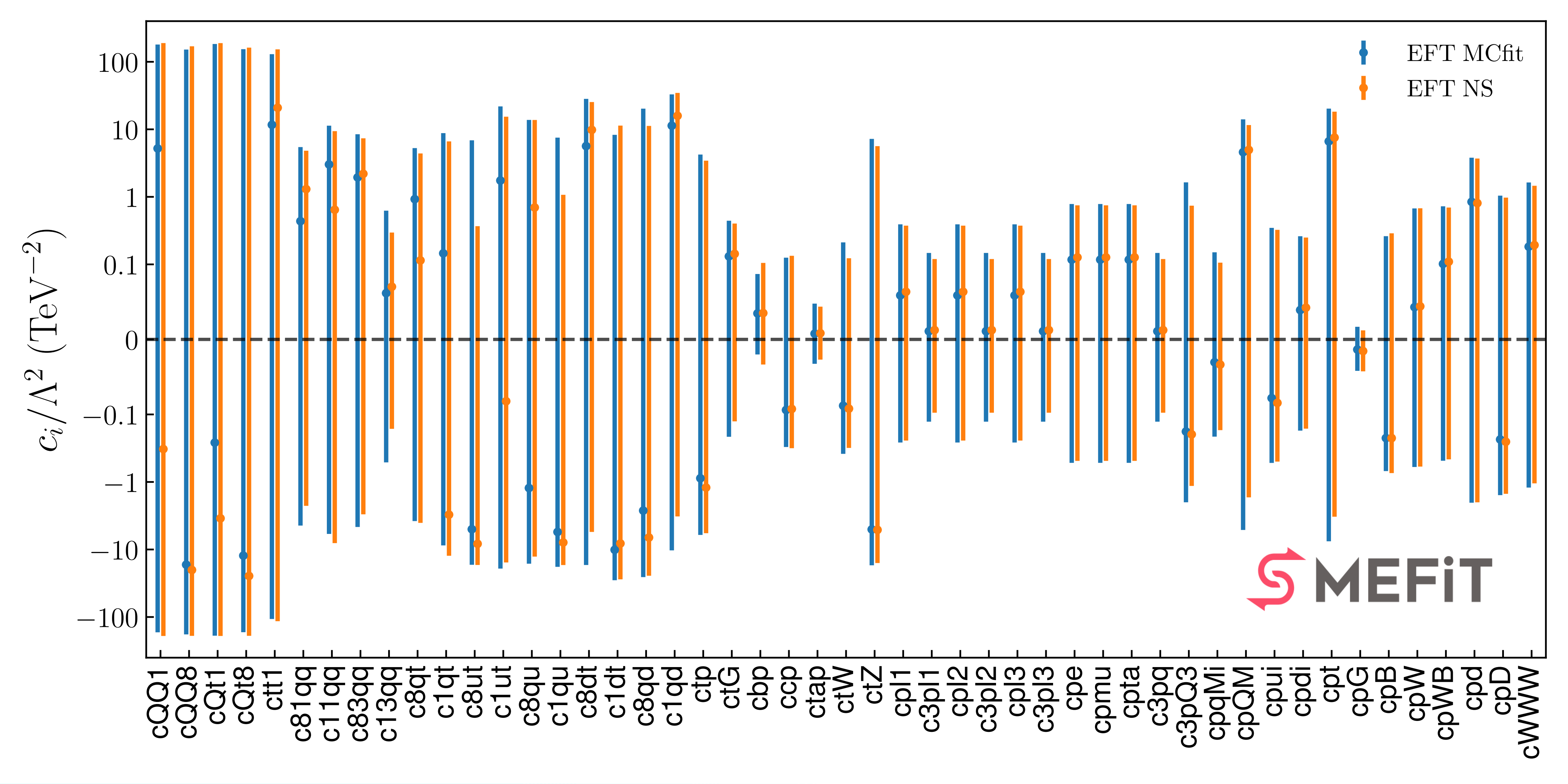
SMEFT after RUN-II: fitting differential distributions and unbinned objects

LHC RUN 2

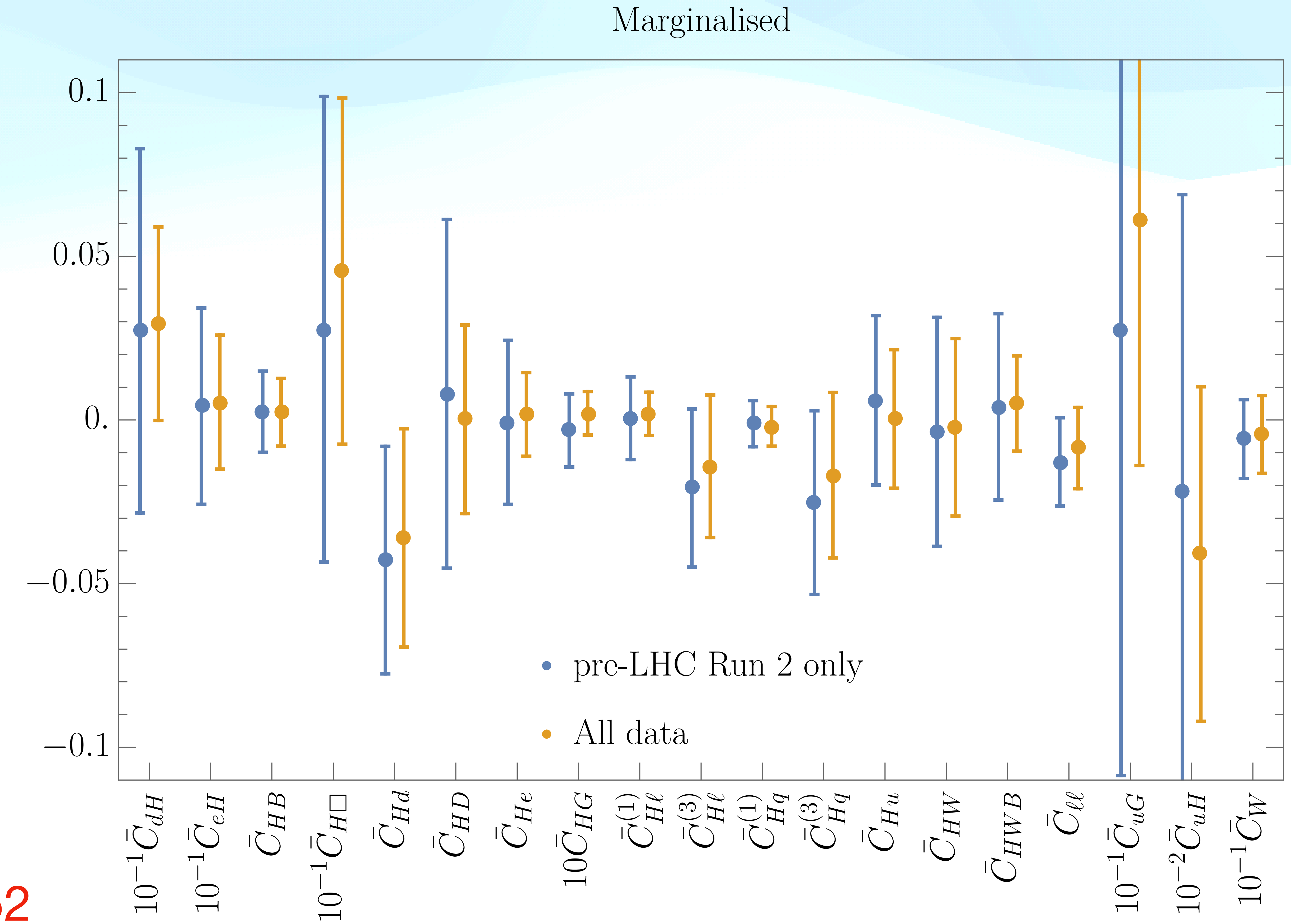
Global search for deviatons

For the first time we can perform "local" fits outside of the Higgs sector

Global fits of the whole SMEFT picture come out



arXiv 2105.00006



arXiv 1803.03252

LHC RUN 2

Several new measurements in the EW sector

How do these fits work?

1. Select a theory (usually SMEFT, dim6, leading order, with 10-20 operators)
2. Perform simulations with MonteCarlo generators with the SEMFT coefficients as free parameters
3. Select from the available EXP data
4. Perform a fit (simple chi2, nested sampling, machine learning…)

LHC RUN 2

Several new measurements in the EW sector

Happy to discuss a common strategy with experimental groups!

How do these fits work?

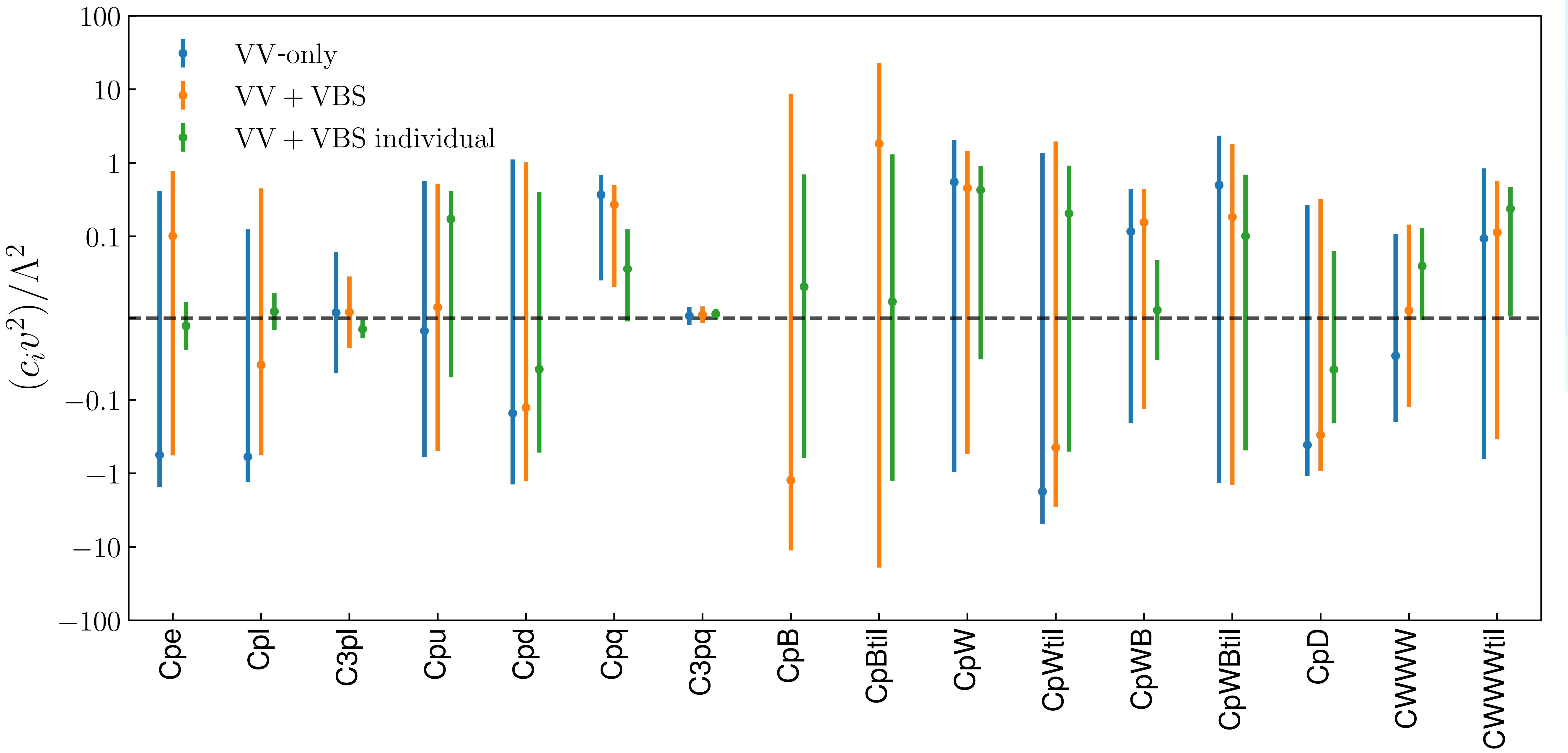
1. Select a theory (usually SMEFT, dim6, leading order, with O(10) operators)
2. Perform simulations with MonteCarlo generators with the SEMFT coefficients as free parameters
3. Select from the available EXP data
4. Perform a fit (simple chi2, nested sampling, machine learning…)

LHC RUN 2

Example: analysis of VBS and diboson

https://arxiv.org/abs/2101.03180

- Fit of dim-6 EFT
- Include only VBS and diboson data (independent of Higgs sector)
- Interesting results, but unfortunately no new physics -yet - in the VBS sector
- Would be great to see this implemented in the exp analyses
- Many improvements can be done



Regular Article - Theoretical Physics

Studies of dimension-six EFT effects in vector boson scattering

Raquel Gomez-Ambrosio[a]

Institute for Particle Physics Phenomenology, Durham University, Durham DH1 3LE, UK

https://arxiv.org/abs/1809.04189

LHC RUN 2

Several new measurements in the EW sector

Handicaps:

- we can only use 1 measurement per analysis, sometimes even incurring in double counting of events
- The measured distributions are not always the ones with more EFT sensitivity

Final state	Selection	Observable	n_{dat}	$\mathcal{L}$ (fb^{-1})
$W^\pm W^\pm jj$	EW-only	σ_{fid}	1	36.1
	EW-only	σ_{fid}	4	137
	EW+QCD	$\mathrm{d}\sigma/\mathrm{d}m_{ll}$ $^{(*)}$		
$ZW^\pm jj$	EW+QCD	$\mathrm{d}\sigma/\mathrm{d}m_{T_{WZ}}$	5	36.1
	EW-only	σ_{fid}	4	137
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$ZZjj$	EW+QCD	σ_{fid}	1	139
	EW-only	σ_{fid}	1	139
γZjj	EW-only	σ_{fid}	1	36.1
	EW-only	σ_{fid}	1	35.9
VBS total (unfolded)			**18**	

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Several new measurements in the EW sector

LHC RUN 2

Handicaps: we can only use 1 measurement per analysis, sometimes even incurring in double counting of events, we don’t always get the distribution that we would like

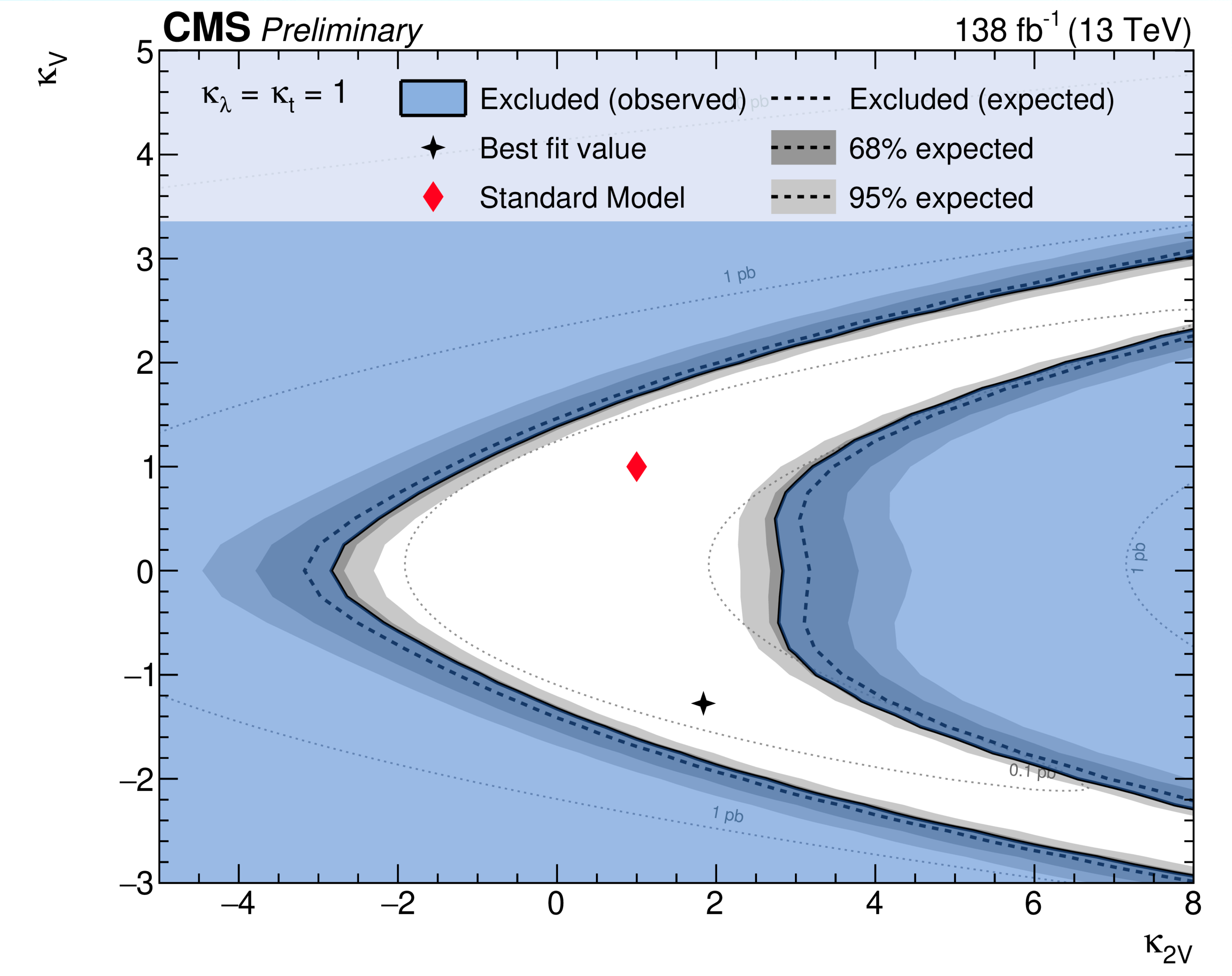
(One) Solution: Accounting for correlations between different distribution of the same channel -> available for the Higgs sector, also for the EW? If not, when?

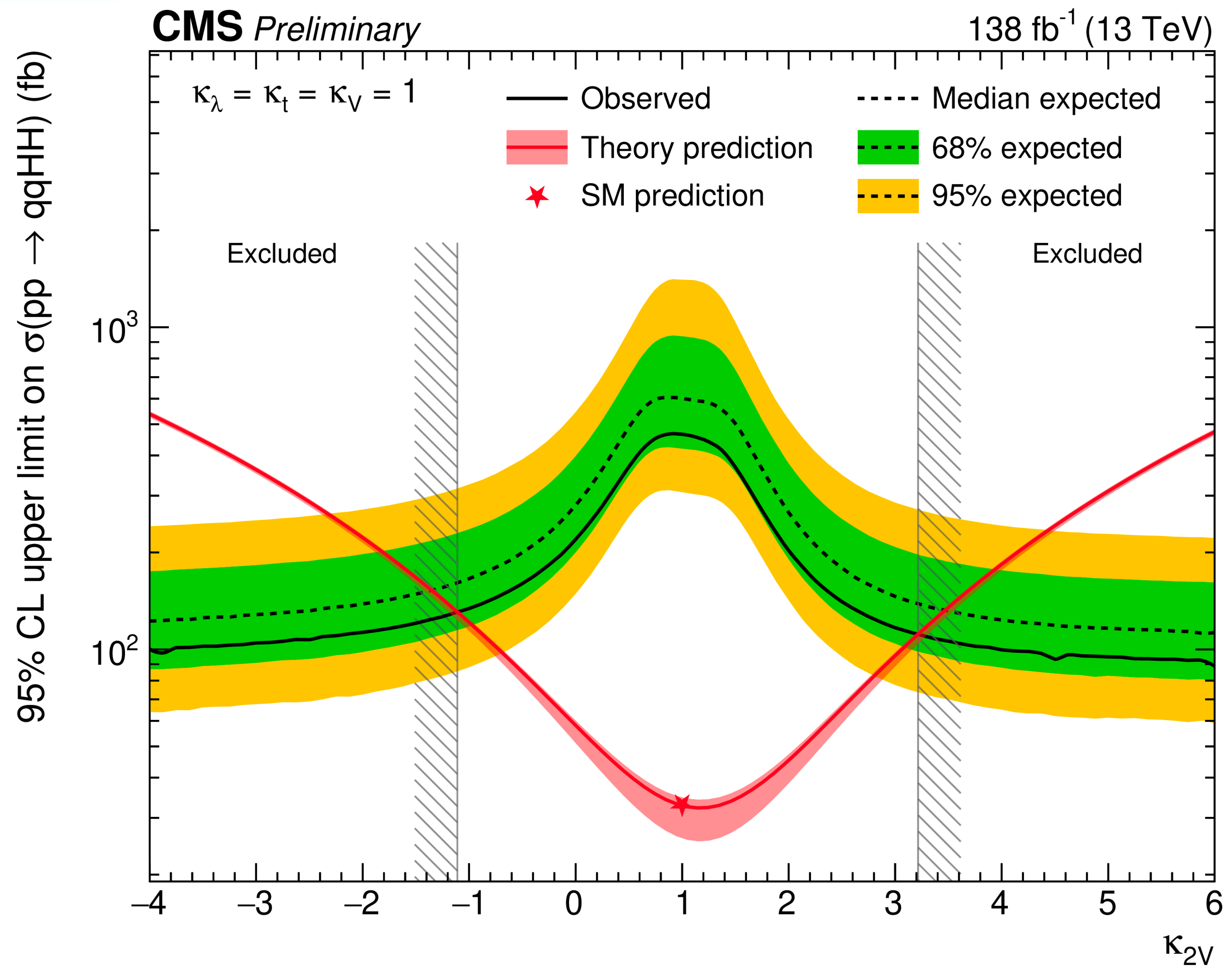
(Another) Solution: keep all the differential information, without projecting into variables (more on this later)

LHC RUN 2

What about HEFT? …
Some recent results, but all quite cryptic

Measurements of HVV and HHVV can be mapped to HEFTs “a” and “b” couplings. So far no results on KV and K2V from the EW sector but could be an interesting challenge for Run-3





LHC Run-3

The experiments have been done this for a long time, see P. Vischia's talk!

2023: The advent of Machine Learning, Quantum computing, and the fits of the future.

It's time to define new strategies for the future data-taking and a analysis. One strong proposal is the one of *unbinned cross sections* some multidifferential objects that conserve information and correlations of all kinematic variables

LHC Run-3

The experiments have been done this for a long time, see P. Vischia's talk!

1. Define an unbinned likelihood
2. Parametrise an unbinned cross section as a likelihood ratio
3. An infinitely large sample, can be described by a neural network (NN)

$$\hat{r}_\sigma(\boldsymbol{x}, \boldsymbol{c}) = 1 + \sum_{j=1}^{n_{\rm eft}} \mathrm{NN}^{(j)}(\boldsymbol{x}) c_j + \sum_{j=1}^{n_{\rm eft}} \sum_{k \geq j}^{n_{\rm eft}} \mathrm{NN}^{(j,k)}(\boldsymbol{x}) c_j c_k$$

Unbinned multivariate observables for global SMEFT analyses from machine learning

Raquel Gomez Ambrosio,[1] Jaco ter Hoeve,[2,3] Maeve Madigan,[4] Juan Rojo,[2,3] and Veronica Sanz[5,6]

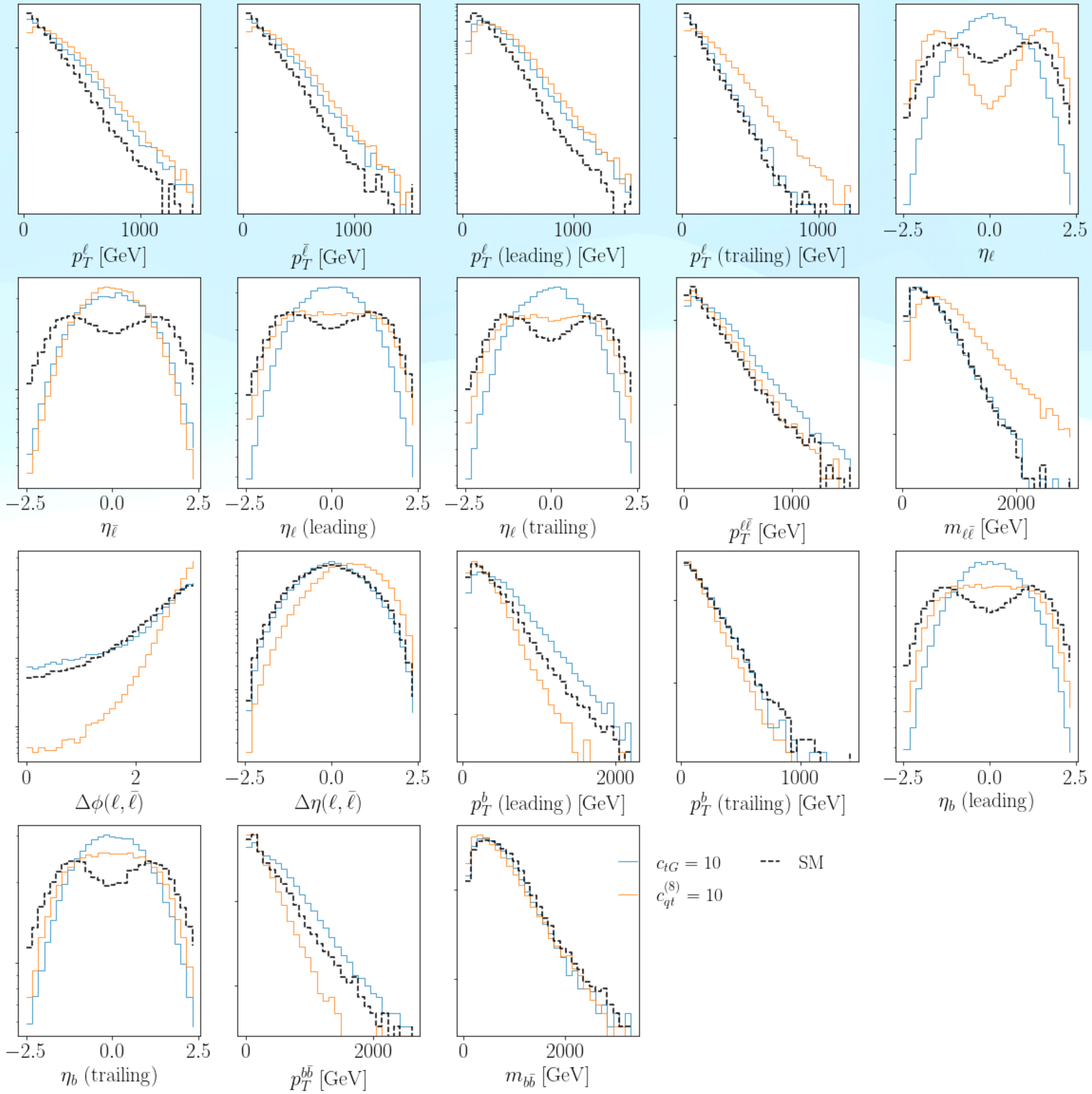
(Maeve's talk)

https://arxiv.org/abs/2211.02058

LHC Run-3

More details: https://lhcfitnikhef.github.io/ML4EFT

- Generate EFT events for a certain process (pp -> ttbar)
- Train on the unprojected events (multi differential)
- Main obstacle: systematic unc.



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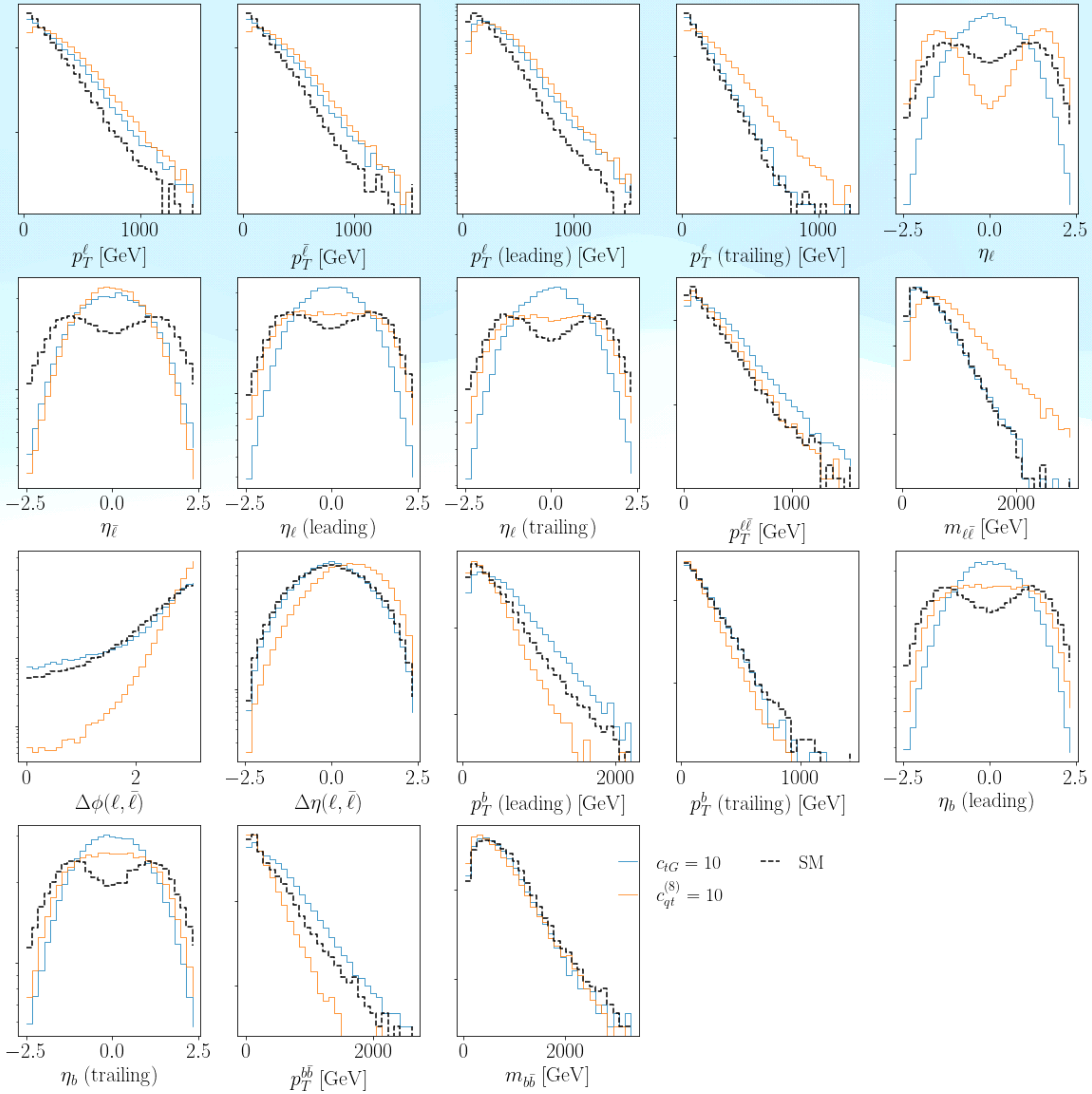

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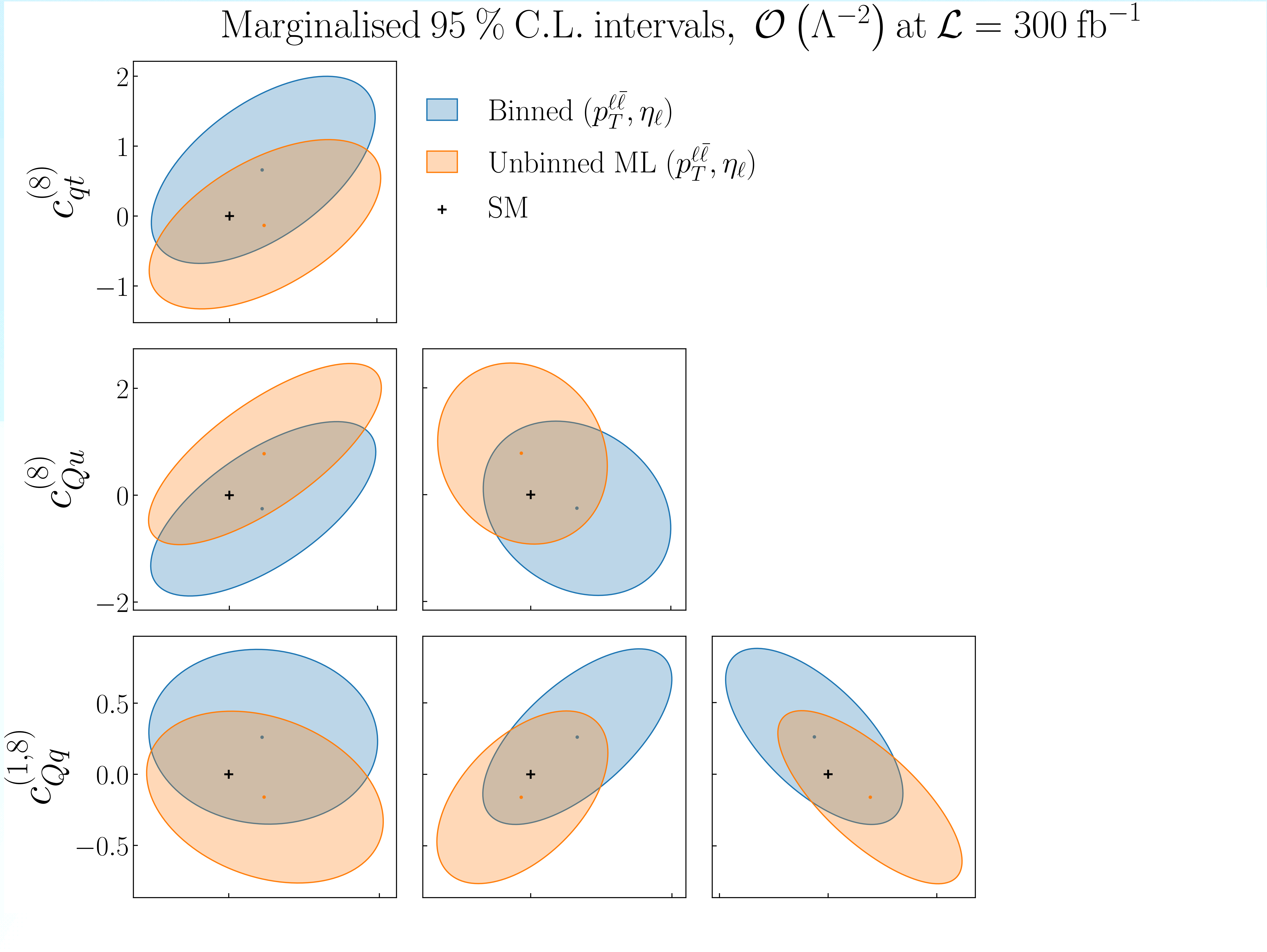

LHC Run-3

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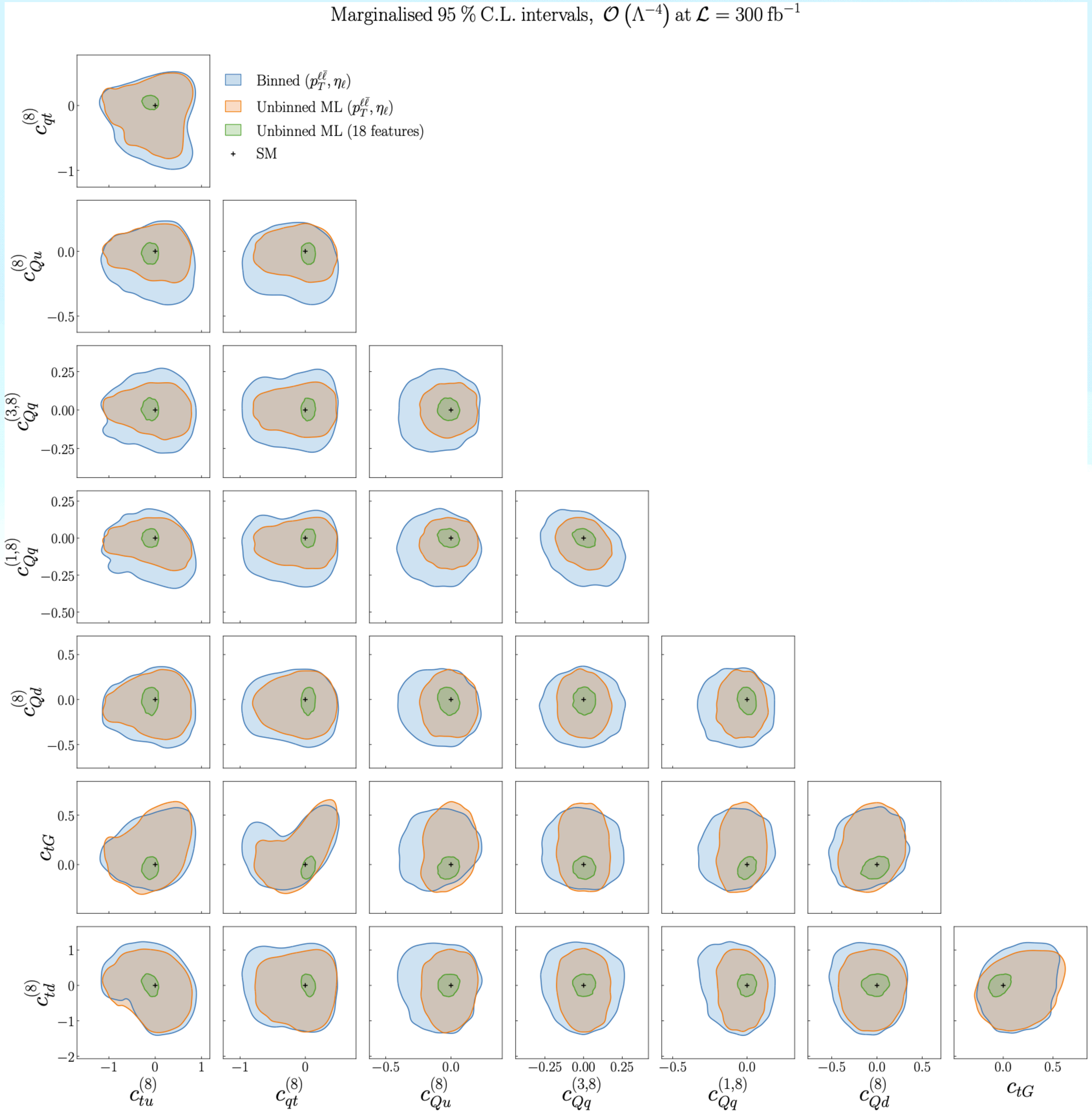
The unbinned object with all the features (ie, kinematic variables) can constrain the result largely compared with an analysis based on only 2 projections



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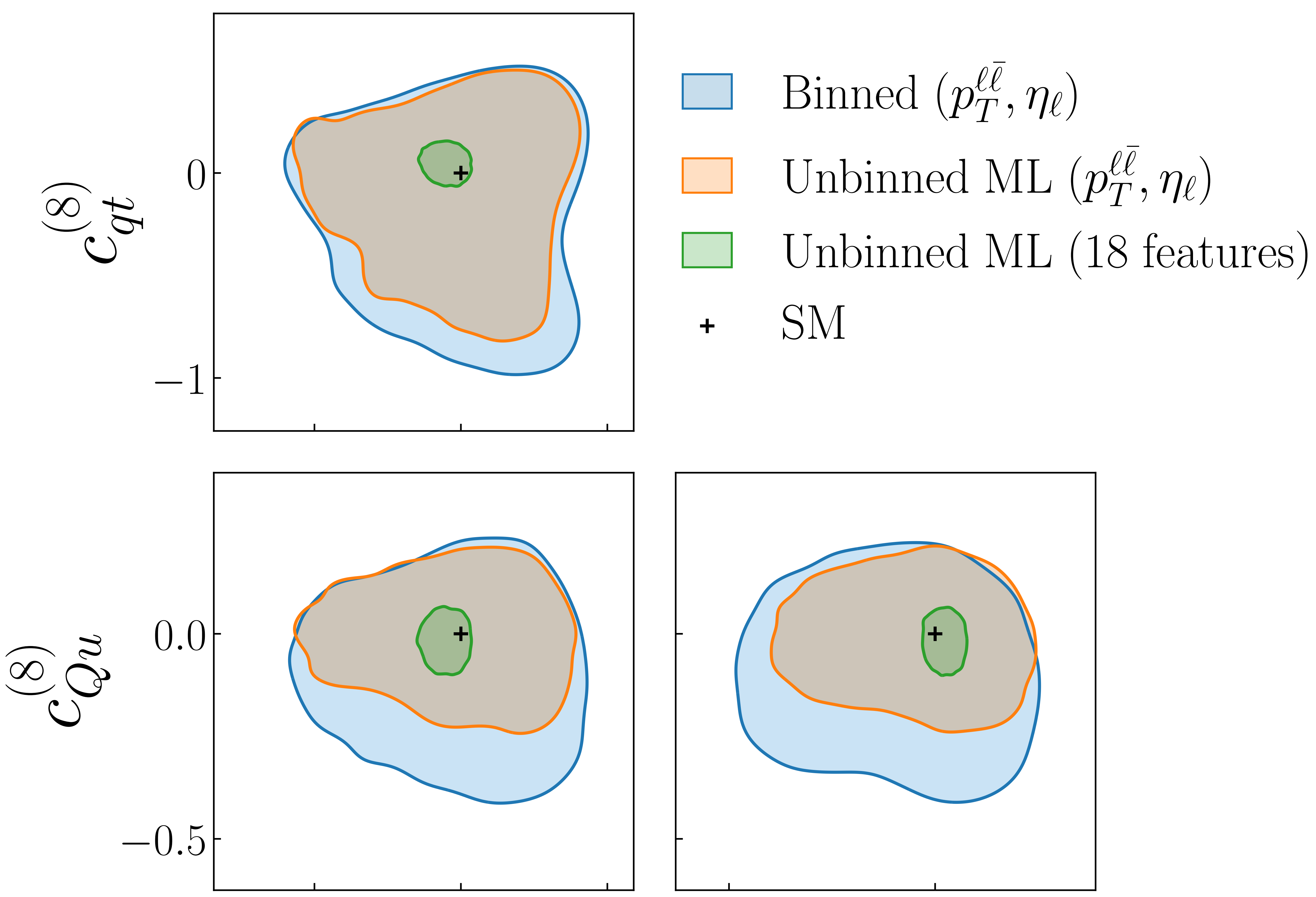


PART III

Other routes: the HiggsFlare

Assuming the global fit has been taken care of…

We can also have some fun

The Higgsflare function

$\mathcal{F}(h)$

$$\mathcal{L}_{HEFT} = \frac{1}{2}\partial_\mu h\, \partial^\mu h + \left(1 + a_1\frac{h}{v} + a_2\left(\frac{h}{v}\right)^2 + a_3\left(\frac{h}{v}\right)^3 + \ldots + a_n\left(\frac{h}{v}\right)^n\right)\partial_\mu w^+ \partial^\mu w^-$$

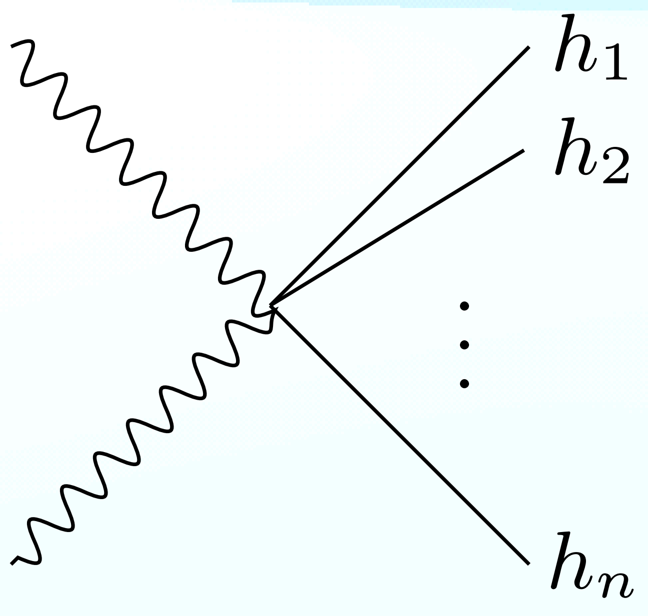
On the contrary to the SM(EFT), it allows vertices with a growing number of Higges attached to the goldstone (gauge) bosons. Whereas the SM stops at HHWW and the SMEFT grow in a contained manner (H4WW for dimension 6, H6WW for dim8, etc), the HEFT predicts as many independent HW vertices as we can imagine.

In this spirit….

$$T_{\omega\omega\to n\times h} = \frac{s}{v^n}\sum_{i=1}^{p(n)}\left(\psi_i(q_1,q_2,\{p_k\})\prod_{j=1}^{|\mathrm{IP}[n]_i|} a_{\mathrm{IP}[n]_i^j}\right)$$

Look at scattering of Goldstone bosons (comparable to VBF at LHC) to *n* Higgses

(Double H production, Triple H production etc)



$$= -\frac{n!a_n}{2v^n}\, s$$

The flair of Higgsflare:
Distinguishing electroweak EFTs with $W_LW_L \to n\times h$

Raquel Gómez-Ambrosio,
Dipartimento di Fisica "G. Occhialini", Università degli Studi di Milano-Bicocca,
and INFN, Sezione di Milano Bicocca, Piazza della Scienza 3, I – 20126 Milano, Italy

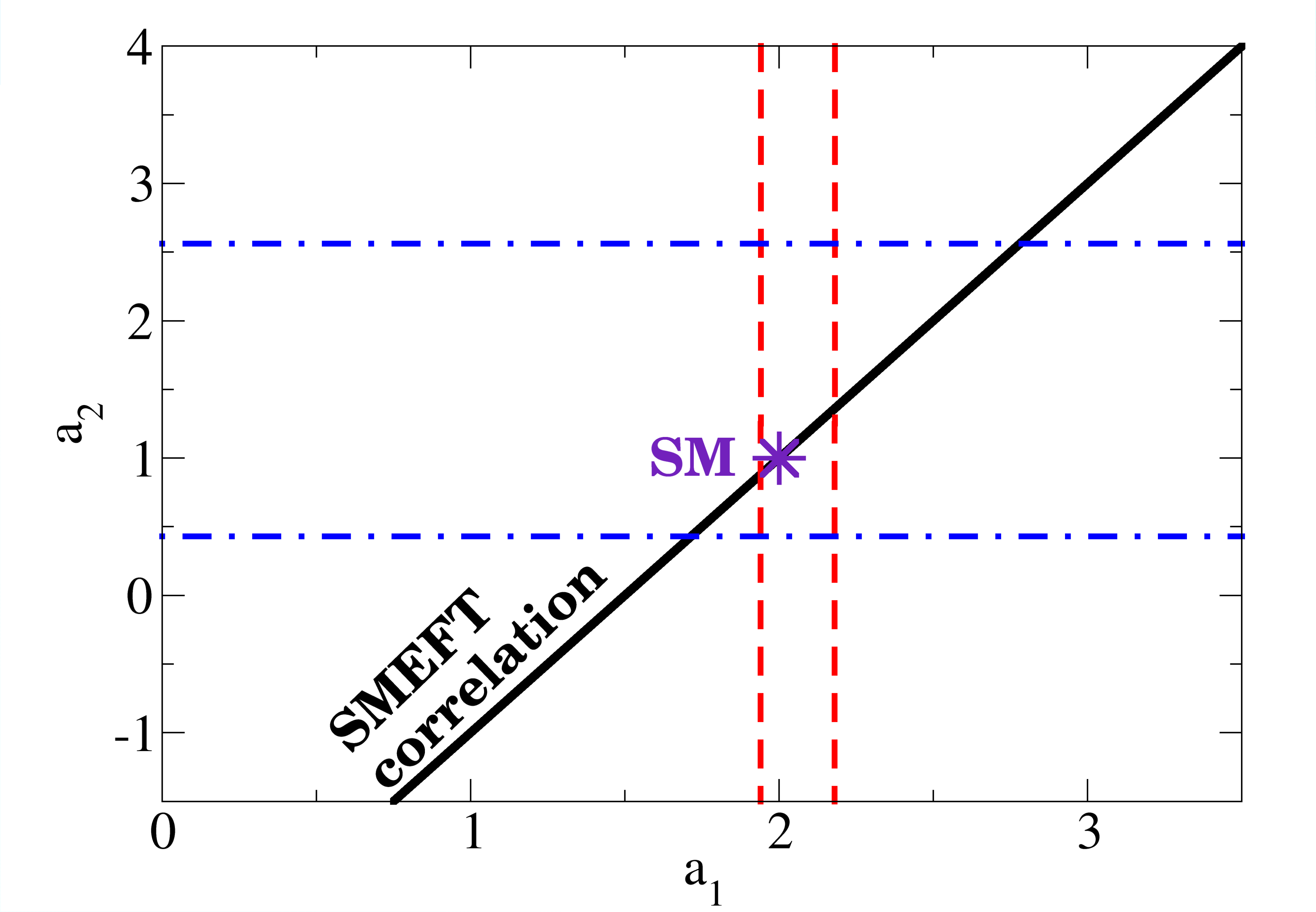
Felipe J. Llanes-Estrada, Alexandre Salas-Bernárdez and Juan J. Sanz-Cillero
Univ. Complutense de Madrid, Dept. Física Teórica and IPARCOS, Plaza de las Ciencias 1, 28040 Madrid, Spain

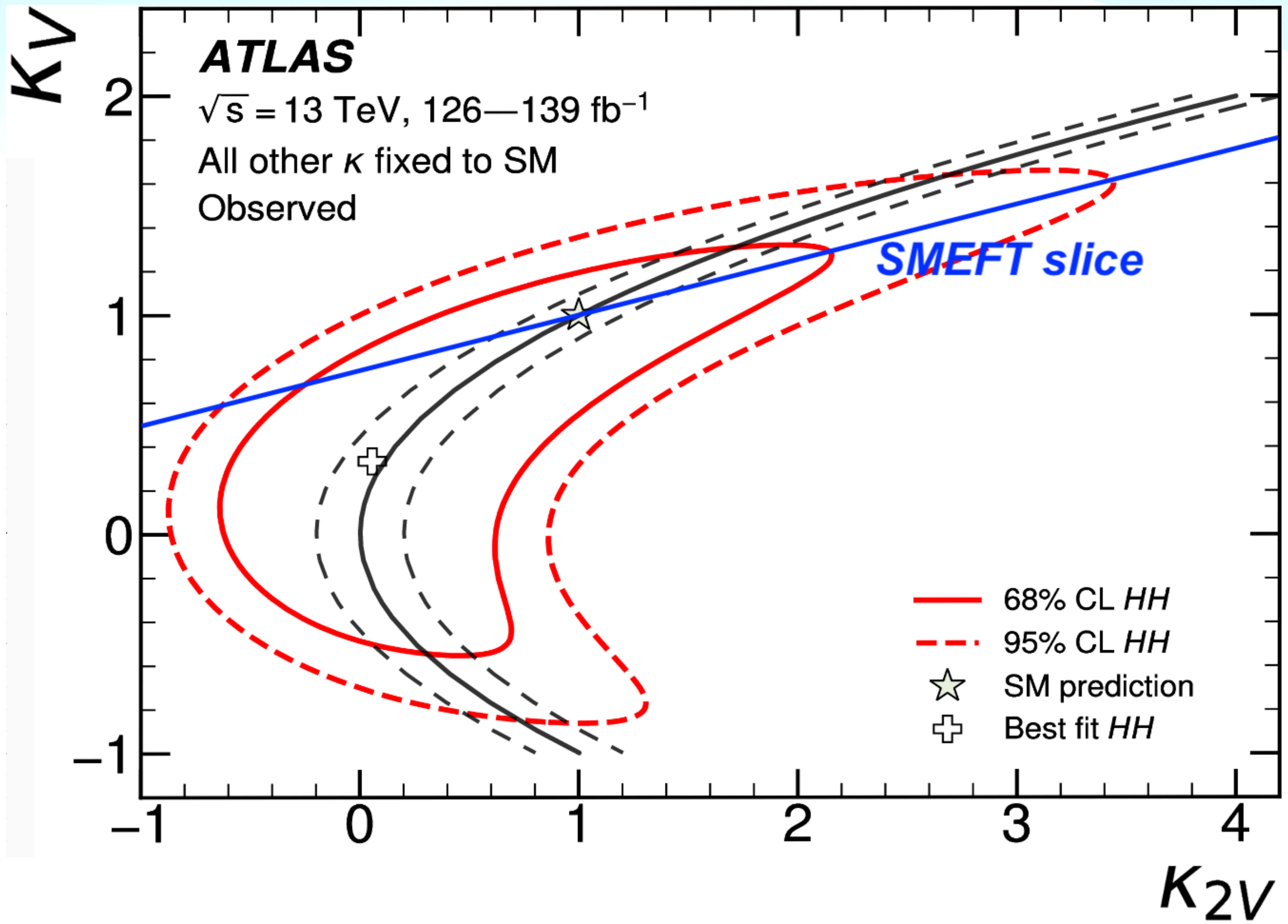
(Dated: April 6, 2022)

https://arxiv.org/abs/2204.01763

Measurements of HWW and HHWW

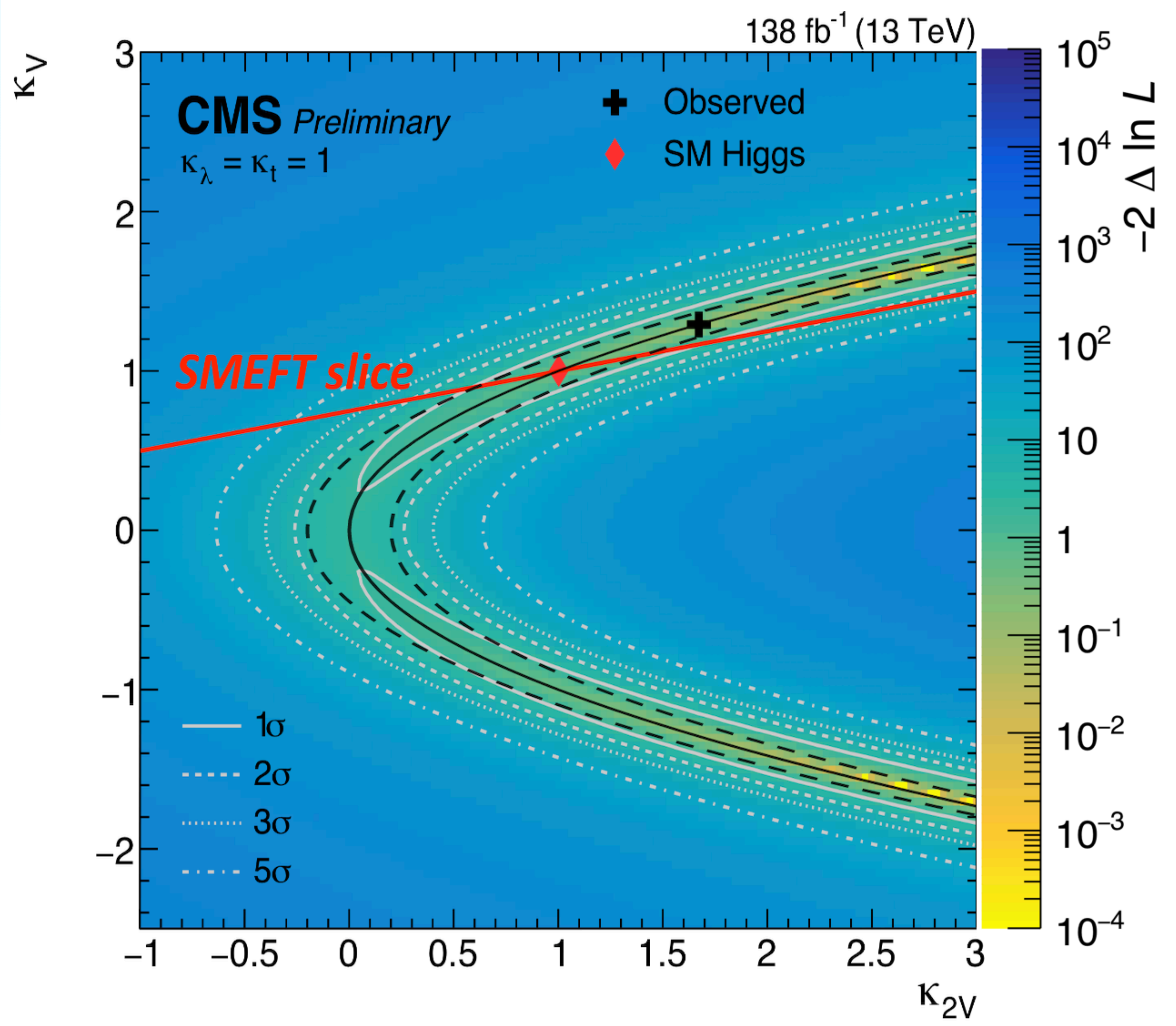
Whereas the HWW and HHWW vertices are set in stone for the SM, and strongly related in the SMEFT, they are completely independent in the HiggsFlare function





Measurements of HWW and HHWW

If a experimental analysis of KV and K2V gives a result incompatible with the red line, we could just rule out the SMEFT completely, and conclude a new structure for the EWSB mechanism



Work in progress with JJ. Sanz-Cillero, R.Delgado-Lopez, A. Salas-Bernardez, J. Martinez-Matin

Conclusions….

- Lots of experimental analyses have been performed in Runs 1 and 2, but the amount of data that is “usable” for pheno is rather limited
- Machine learning applications are in their infancy and fun to play with. They might lead to a ***Higgsplosion*** of datapoints for future fits
- Still, it is fun to look at the heart of the theory, and explore the possibilities that different Lagrangians can offer to us

Thank you!