

# COMETA WG1 Motivation & Targets: EFT point of view

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COMETA is a newborn COST Action with a focus on **multiboson** measurements @LHC and their interpretation

[www.cost.eu/actions/CA22130/](http://www.cost.eu/actions/CA22130/)

 @multibosons

 COMETA

 twiki

- |   |                                       |
|---|---------------------------------------|
| <b>WG1</b> Theoretical framework, precision calculations and simulation | G. Pelliccioli + R. Gröber            |
| <b>WG2</b> Technological innovation in data analysis                    | A. Cappati + C. Krause + R. Finotello |
| <b>WG3</b> Experimental measurements                                    | V. Cairo + M. Presilla                |
| <b>WG4</b> Management and event organization                            | P. Govoni + A. Ferrari                |
| <b>WG5</b> Inclusiveness and Outreach                                   | F. Dias + K. Dreimanis                |

**7 in-person events** planned for 2024. will appear on [indico.cern.ch/category/17113/](http://indico.cern.ch/category/17113/)

**1st General Meeting:** Izmir (TR), 28 February - 1 March 2024 [indico.cern.ch/event/1334055/](http://indico.cern.ch/event/1334055/)

**Open call for internal grants:** funds to visit institutes in other countries + ITC conference grants

## Scientific areas

EFT interpretation

BSM models

precision calculations

EFT  $W, Z$  polarisations

## 🎯 Goals for today:

- ▶ present motivation & targets
- ▶ pick your interest, stimulate discussion, collect feedback and new ideas!

## 📅 In-person/Hybrid events for year 1

- ▶ meeting on **EFT** for multiboson: Padova, June 10-11, 2024 [HEFT: Bologna, June 12-14]
- ▶ meeting on **polarizations**: Toulouse, end of September 2024 [adjacent to MBI]

## COST approach

- promote research by creating **new connections** among research groups
- promote **community efforts**
- **inclusivity** towards under-funded EU countries, young scientists, female researchers

## What do we do in practice?

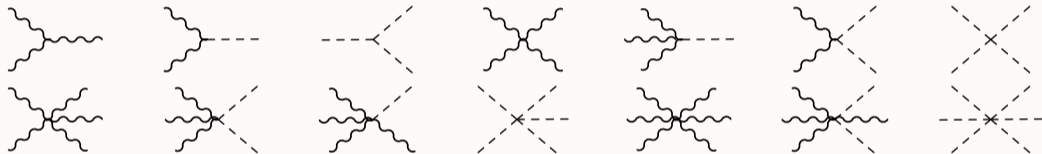
- ▶ offer a platform for **exchanging knowledge and collaborating** on various-size projects
- ▶ offer a platform for **enlarging each others' scientific network** and get to know other groups work
- ▶ encourage the development of projects that benefit from new collaborations
- ▶ encourage the write up of **reviews and reports** that can be useful to the community
- ▶ offer a **transversal** forum, that complements existing LHC Working Groups
- ▶ boost the participation of groups based eg. in eastern European Countries

original scientific proposal 

# WG1: EFT perspective

## Effective Field Theory approach

- describes indirect impact of New Physics with  $\Lambda_{NP} \gg v$
- introduces **anomalous couplings** among SM fields, both SM-like and new interactions



**COMETA's Focus:** EFT couplings involving **Higgses, Goldstones, W/Z/ $\gamma$  bosons, gluons**  
(primarily interacting amongst them, but also with tops and other fermions!)

## Ultimate Goal

- **chart the scalar sector** of the SM as a whole, *measuring* the relevant EFT parameters
- gain an understanding of **EWSB dynamics**, as accurately as possible
- preparing to make the most out of the HL-LHC dataset

# Two main EFTs of interest: SMEFT and HEFT

## SMEFT

$$\text{doublet } H = \frac{1}{\sqrt{2}} \begin{pmatrix} \phi_2 + i\phi_1 \\ \phi_4 - i\phi_3 \end{pmatrix}$$

$h$  interactions in  $\phi^4 = (v + h)$  pattern

expansion in canonical dimensions ( $v/\Lambda$ )

$$\mathcal{L} = \mathcal{L}_{SM} + \mathcal{L}_5 + \mathcal{L}_6 + \mathcal{L}_7 + \mathcal{L}_8 + \dots$$

expands around **point of preserved sym.**

$$H \equiv 0$$

## HEFT

$$H = \frac{v+h}{\sqrt{2}} \mathbf{U} \begin{pmatrix} 0 \\ 1 \end{pmatrix}, \quad \mathbf{U} = \exp\left(\frac{\phi^i \sigma^i}{v}\right)$$

$h$  is a **singlet**  $\rightarrow$  completely free interactions

mixed  $\chi$ PT and dimensional counting

$$\mathcal{L} = \mathcal{L}_0 + \mathcal{L}_1 + \mathcal{L}_2 + \dots$$

expands around the **EW vacuum**


$$\text{SM} \subset \text{SMEFT} \subset \text{HEFT}$$

 HEFT: is more general, has more parameters at each order, is more complex to handle

# Topics of interest for COMETA WG1 – EFT

1. Improvement and harmonization of EFT parameterizations across analyses ↔ Ramona's talk
2. Promotion of combined analyses of different classes of multiboson measurements
3. Interpretation within geometric description of the scalar sector
4. Investigation of the impact of high-multiplicity multiboson production
5. Interplay with direct searches ↔ Josemi's talk
6. Study of the impact of  $W, Z$  polarization measurements on EFT measurements ↔ Giovanni's talk
7. Development of ML-based tools to improve EFT studies
8. ...

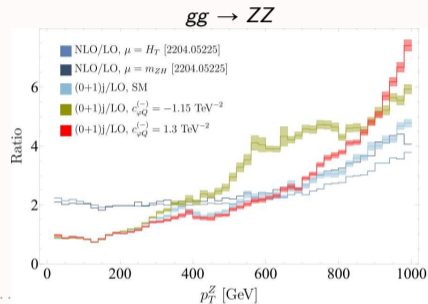
# 1 – Improvement and Harmonization of EFT frameworks

 SMEFT + HEFT + precision experts

## Status

- ▶ SMEFT dim-6 available: automated up to 1-loop in QCD. dedicated NLO studies for VV,HH,VH
- ▶ SMEFT dim-8 op. generating VVVV, VVHH studied in VBS, VVV, VBF-HH, ggF-VV
- ▶  $\kappa$  framework in ggF-HH (1-loop QCD + approx 2-loop), VBF-HH
- ▶ HEFT in VBS, VBF-HH (up to 1-loop for select channels)

Buchalla,Heirich,Herrero,Morales,Zeppenfeld,Gröber,Baglio,Dawson,Spira,Vryonidou,Ellis,Sanz-Cillero. .



Rossia,Thomas,Vryonidou 2306.09963

## Possible directions

- ▶ calculation of missing higher order corrections
- ▶  $d \geq 8$  SMEFT operators: impact on predictions, interplay of VBS, VH and HH. . .
- ▶ HEFT for HH beyond  $\kappa$ 's, HEFT for single H production
- ▶ harmonization of SMEFT parameterizations for H and HH HWG note on EFT in HH: 2304.01968



## 2 – Promote combined analyses of multiboson processes

 H + HH + VV + VBS experts  TH + EXP

### Status

- ▶ H + VV (+ top) and VV + VBS combinations performed in  $d = 6$  SMEFT  
fitmaker, SMEFiT, SFitter, HEPfit, ATLAS, CMS...
- ▶ Comparison VBS, HH, ZHH, ZZH for VVVV, VVHH  $d = 8$  SMEFT operators (1/time)  
Cappati, Covarelli, Torrielli, Zaro 2205.15959
- ▶ a few HEFT fits to H + EW IB et al 1311.1823, 1604.06801, Buchalla et al 1511.00988  
Corbett et al 1511.08188, Éboli et al 2112.11468

### Possible directions

- ▶ Incorporating HH in SMEFT fits
- ▶ Validation / Comparison of existing fits
- ▶ H + HH combination and further exploration of H, HH, VBS, VH, VV... interplay
- ▶ Global analyses in HEFT?
- ▶ Providing guidelines for experimental combinations

# 3 – Interpretation within geometric approach to the scalar sector

🔗 geometry + pheno + BSM experts

Geometric formulation proposed in recent years, independent of SMEFT/HEFT notation

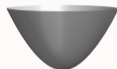
Alonso, Jenkins, Manohar 1511.00724, 1605.03602

Cheung, Helset, Parra-Martinez 2111.03045, 2202.06972 Helset, Jenkins, Manohar 2210.08000

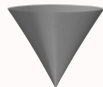
- ▶ scalar operators with 2 derivatives  $\leftrightarrow$  **metric** on a 4D differentiable manifold
- ▶ scattering amplitudes  $\leftrightarrow$  geometric invariants (eg. Riemann curvatures)
- ▶ geometric properties (singularities, holes...)  $\leftrightarrow$  features of BSM physics
- ▶ recently: proposals to extend to higher derivatives

Falkowski, Rattazzi 1902.05936, Cohen, Craig, Lu, Sutherland 2008.0597, 2108.03240

Craig et al 2202.06965, 2305.09722, Alminawi, IB, Davighi 2308.00017



✓ SMEFT



✗ HEFT



## Possible directions

- ▶ phenomenological analysis of scenarios that do not admit SMEFT (loryons)
- ▶ interpretation of measurements in terms of curvature and free parameters of the potential
- ▶ what measurements are most relevant to determine the geometrical properties?

# 4 – Multiboson processes with high-multiplicity final states

🔗 geometry + pheno experts   🔗 TH + EXP

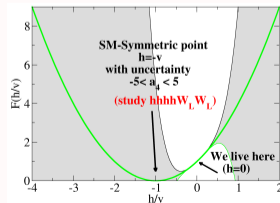
- ▶ many-point contact vertices generically present in EFT
- ▶ can be relevant to reconstruct field space geometry and/or the analyticity of the potential at  $H = 0$   
e.g.  $W_L W_L \rightarrow h^n$  Gomez-Ambrosio et al 2204.01763,2207.09848  
Delgado et al 2311.04280
- ▶ interactions among Goldstones related to Higgs vertices
- ▶ can help tackling  $d \geq 8$  interactions  
e.g.  $gg \rightarrow ZZH$ ,  $qq \rightarrow ZHH$  Cappati,Covarelli,Torrielli,Zaro 2205.15959

		HC	HwH	Growth
$\kappa_t$	$\mathcal{O}_{y_t}$			$\sim \frac{E^2}{\Lambda^2}$
$\kappa_\lambda$	$\mathcal{O}_6$			$\sim \frac{vE}{\Lambda^2}$
$\kappa_{Z\gamma}$ $\kappa_{\gamma\gamma}$ $\kappa_V$	$\mathcal{O}_{WW}$ $\mathcal{O}_{BB}$ $\mathcal{O}_r$			$\sim \frac{E^2}{\Lambda^2}$
$\kappa_g$	$\mathcal{O}_{gg}$			$\sim \frac{E^2}{\Lambda^2}$

Henning, Lombardo, Rimbau, Riva  
1812.09299

## Possible directions

- ▶ investigate relevance of other processes with  $n \geq 3$  bosons
- ▶ phenomenological sensitivity studies at HL-LHC and beyond
- ▶ if relevant, design new experimental searches



Gomez-Ambrosio et al  
2204.01763

# 5 – Interplay with direct searches

EFT + BSM experts

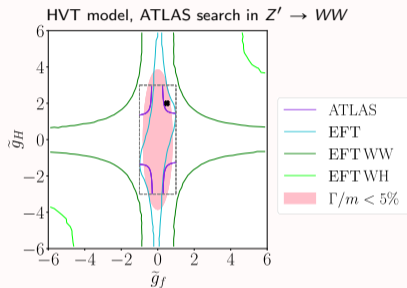
EFT and direct searches can **cover complementary regions** of a model's parameter space

- ▶ direct search sensitive to narrow resonances. shape can depend on benchmarks / assumptions considered
- ▶ EFT sensitive around decoupling region. non-trivial shape depending on constraints included
- ▶ low-E precision  $\leftrightarrow$  high-E tail complementarity

there is space for nontrivial interplay in the few TeV mass region


## Possible directions

- ▶ compare EFT and direct searches reach, for relevant extensions of SM
- ▶ for models with large BSM sectors, could EFT and direct searches see different states?



B, Bruggisser, Geoffray, Kilian, Krämer,  
Luchmann, Plehn, Summ 2108.01094

# 6 – Impact of polarization and spin-correlation measurements

 EFT + polarizations experts

## Status

- ▶ ongoing theory efforts to define and simulate production of polarised  $W$  and  $Z$
- ▶ first evidence/observation of polarized final states in ATLAS/CMS CMS:  $ssWW$ ,  $WZ$ . ATLAS:  $ZZ$ ,  $WZ$   
Experiments aiming at discriminating  $V_{L/T}$  with better accuracy starting from Run 3
- ▶ related: **spin-correlations** in di-boson systems (also  $t\bar{t}$ ) Aoude,Madge,Maltoni,Mantani 2307.09675  
Severi,degliEsposti,Maltoni,Sioli 2110.10112

## Possible directions

- ▶ phenomenological studies of how polarized measurements could improve EFT sensitivity.  
relevant for  $d \geq 8$ , SMEFT/HEFT discrimination
- ▶ collaborate with ML experts and EXP groups to devise polarization/spin-correlation discriminators

# 7 – Development of ML-based tools for EFT sensitivity

EFT + ML experts    WG1 + WG2

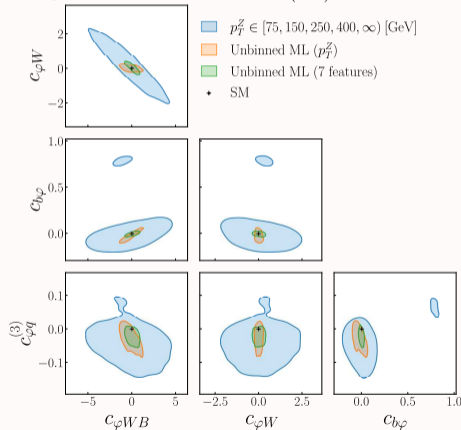
several ML applications, towards improving sensitivity to EFT effects and discrimination among operators

- ▶ new observables Long, Nachman '23
- ▶ classifiers Chen, Glioti, Panico, Wulzer '21 '23  
Chatterjee, Rohshap, Frohner, Schöfbeck, Schwarz '21'22  
Butter, Plehn, Soybelman '21
- ▶ unbinned likelihoods Gomez-Ambrosio, Rojo, ter Hoeve, Sanz, Madigan...
- ▶ likelihood-free inference MadMiner: Cranmer, Brehmer, Louppe, Pavez...
- ▶ ...


## COMETA WG2

- ▶ focuses on ML, includes experts outside physics
- ▶ planning their first virtual meeting in  $\sim 2$  weeks

Marginalised 95 % C.L. intervals,  $\mathcal{O}(\Lambda^{-4})$  at  $\mathcal{L} = 300 \text{ fb}^{-1}$



Gomez-Ambrosio, terHoeve, Madigan, Rojo, Sanz 2211.02058

- ▶  **COMETA** aims at providing a fruitful collaboration platform, with an eye on young scientists and disadvantaged communities
  - funding for organization of meetings and schools
  - funding for networking
- ▶ starting ~now, will end in September 2027
  - preparation time to HL-LHC and future colliders!
- ▶ **WG1** focuses on theoretical aspects, with a broad range. we welcome activity proposals!
- ▶ **EFT(s)** plays a central role to COMETA's goals
- ▶ many relevant EFT-related aspects to develop.  
could take great advantage from an exchange across different communities