EW processes & EFT fits

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Framework: SMEFT at dim. 6

Standard **M**odel **E**ffective **F**ield **T**heory:
The EFT constructed with **Standard Model** fields & symmetries

→ expansion in canonical dimensions d (Taylor series in v/Λ or E/Λ)

$$\mathcal{L}_{\rm SMEFT} = \mathcal{L}_{\rm SM} + \frac{1}{\Lambda}\mathcal{L}_5 + \frac{1}{\Lambda^2}\mathcal{L}_6 + \dots$$

$$\mathcal{L}_d = \sum_i C_i \, \mathcal{O}_i^{(d)}$$

C_i: Wilson coefficients

$\mathcal{O}_i^{(d)}$: basis of gauge-invariant operators

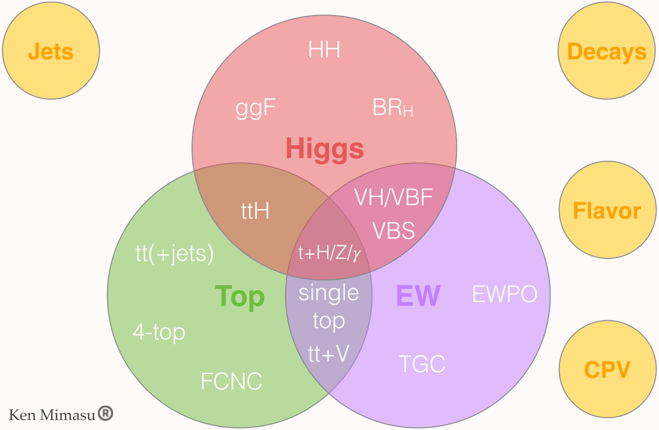
SMEFT describes $\sim$ **any beyond-SM physics living at $\Lambda \gg v$**

→ vast program for model-independent new physics searches at LHC

"let measurements identify preferred values of C_i/Λ^2, minimizing th. bias"

Global analyses in SMEFT

- maximize # of free parameters
- combining several measurements crucial to disentangle fit directions and reduce interpretation bias



Global analyses in SMEFT

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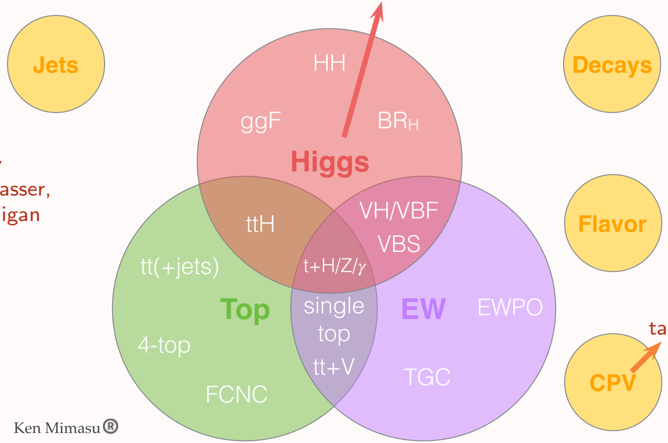
talks by Zhijun Liang, Matthew Knight

talks by Kristin Lohwasser, Maeve Madigan

talk by Quentin Bonnefoy



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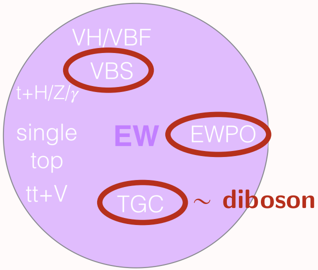

SMEFT EW fits – status

recent examples: Baglio,Dawson,Homiller 2003.07862, Dawson,Homiller,Lane 2007.01296, Ellis et al 2012.02779, Ethier et al 2105.00006, 2101.03180, da Silva Almeida et al 2108.04828, Dawson,Giardino 2201.09887. . .

- Typically $15 - 30$ parameters simultaneously

→ depend on Higgs obs. included, CP/flavor assum., loop order. . .

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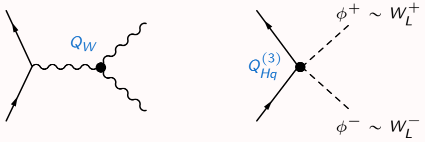
→ depend on Higgs obs. included, CP/flavor assum., loop order...

- Strongest constraints from EWPO and diboson (WW, WZ, Wγ)

sensitive to **bulk** corrections (scaling of SM coupl.)

sensitive to new **kinematics**



Falkowski et al 1609.06312

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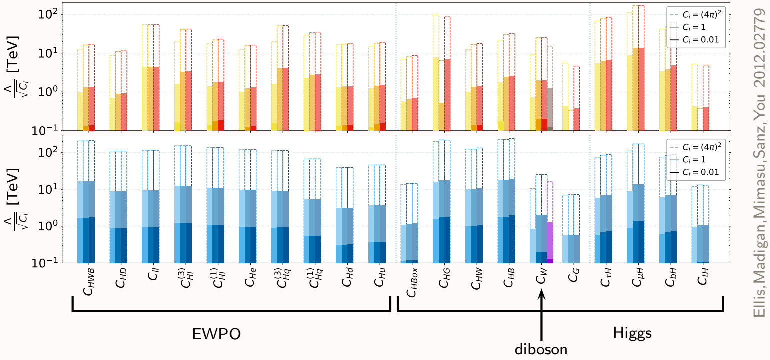
- Profiled constraints reach **multi-TeV** range, individual above 10 TeV



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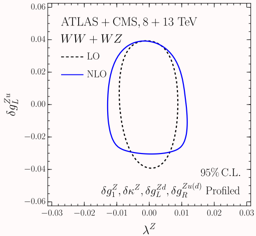
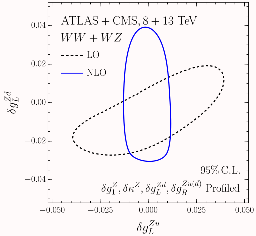
- Strongest constraints from EWPO and diboson (WW, WZ, Wγ)
- Profiled constraints reach **multi-TeV** range, individual above 10 TeV
- SMEFT effects at NLO available

  EWPO at NLO QCD+EW Hartmann,Shepherd,Trott 1611.09879, Dawson,Ismail 1808.05948, Dawson,Giardino 1909.02000

  diboson at NLO QCD Baglio,Dawson,(Homiller,Lewis) 1708.03332,1812.00214,1909.11576

  → add dependence on new C_i, modify likelihood structure





Baglio,Dawson,Homiller 1909.11576

(Near) future directions

- More refined SMEFT **predictions**
  higher orders in loops and in EFT ($d \geqslant 8$), EFT in backgrounds,
  improved technology for predictions (Monte Carlo, ML...)

- **More observables** included in global fits
  more complex processes → sensitivity to new parameters/directions in par. space
  (VBS, tWZ, CP violation, flavor...)

- **Better constraints**: smaller uncertainties, more information
  more accurate measurements and SM predictions, more differential measurements,
  better understanding of PDF/scale dependence in EFT predictions,
  experiments to provide more information and do combined analyses directly

- Fits moving to **Bayesian** inference
  marginalization easier in many dimensions

- More studies of interplay with **(simplified) models**
  "make the ends meet" in top-down vs bottom-up approaches

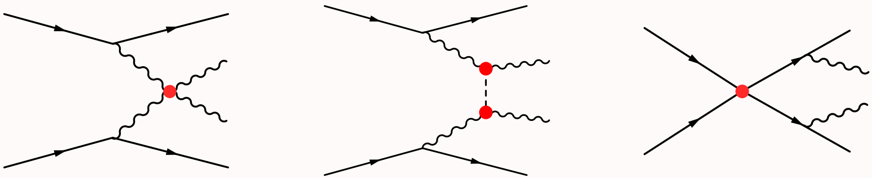
New processes: VBS

Vector Boson Scattering

⇝ talks by Matteo Magherini, Bianca Pinolini, Mathieu Pellen, Roberto Covarelli...

interesting because

- gives access to $VV \to VV$ scattering, crucial probe of EWSB dynamics
- probes simultaneously $qqqq$, HVV and TGC/QGC operators
- comes in several $V_1V_2 = \{W^\pm, Z, \gamma\}$ channels → discrimination power
- bound to improve significantly at next Runs



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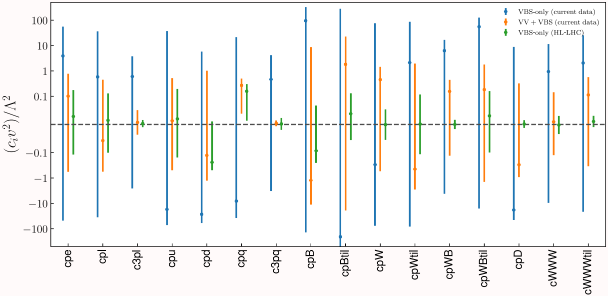
Ethier,Gomez-Ambrosio,Magni,Rojo 2101.03180



SMEFT corrections to VBS at $d = 6$

Bellan, Boldrini, Brambilla, IB, Brusa, Cetorelli, Chiusi, Covarelli, Del Tatto, Govoni, Massironi, Olivi, Ortona, Pizzati, Tarabini, Vagnerini, Vernazza, Xiao 2108.03199

- representative set of 14 operators

$Q_{Hl}^{(1)}$	$= (H^\dagger i\overleftrightarrow{D} H)(\bar{l}_p\gamma^\mu l_p)$	$Q_{Hl}^{(3)}$	$= (H^\dagger i\overleftrightarrow{D}^i H)(\bar{l}_p\sigma^i\gamma^\mu l_p)$
$Q_{Hq}^{(1)}$	$= (H^\dagger i\overleftrightarrow{D} H)(\bar{q}_p\gamma^\mu q_p)$	$Q_{Hq}^{(3)}$	$= (H^\dagger i\overleftrightarrow{D}^i H)(\bar{q}_p\sigma^i\gamma^\mu q_p)$
$Q_{qq}^{(1)}$	$= (\bar{q}_p\gamma_\mu q_p)(\bar{q}_r\gamma^\mu q_r)$	$Q_{qq}^{(1,1)}$	$= (\bar{q}_p\gamma_\mu q_r)(\bar{q}_r\gamma^\mu q_p)$
$Q_{qq}^{(3)}$	$= (\bar{q}_p\gamma_\mu\sigma^i q_p)(\bar{q}_r\gamma^\mu\sigma^i q_r)$	$Q_{qq}^{(3,1)}$	$= (\bar{q}_p\gamma_\mu\sigma^i q_r)(\bar{q}_r\gamma^\mu\sigma^i q_p)$
Q_{HD}	$= (H^\dagger D_\mu H)(H^\dagger D^\mu H)$	$Q_{H\square}$	$= (H^\dagger H)\square(H^\dagger H)$
Q_{HWB}	$= (H^\dagger\sigma^i H)W^i_{\mu\nu}B^{\mu\nu}$	Q_{HW}	$= (H^\dagger H)W^i_{\mu\nu}W^{i\mu\nu}$
Q_W	$= \varepsilon^{ijk}W^{i\nu}_\mu W^{j\rho}_\nu W^{k\mu}_\rho$	$Q_{ll}^{(1)}$	$= (\bar{l}_p\gamma_\mu l_r)(\bar{l}_r\gamma^\mu l_p)$

- 4 VBS$\to\ell$ processes ($W^\pm W^\pm$, W^+W^-, $W^\pm Z$, ZZ)
  + 1 VBS$\to\ell J$ process ($VZ, V = Z, W$)
  + 1 diboson process ($qq\to W^+W^-$)
- simulated **full 2** $\to$ **6**(**4**) processes, incl. non-resonant diagrams
- parton level analysis: only **expected limits**, no comparison to data yet

similar studies: Gomez-Ambrosio 1809.04189, Dedes Kozow, Szleper 2011.07367, Ethier et al 2101.03180

Optimal observables

for each operator & channel, fit the distribution that gives the best constraint

for 1D fits:

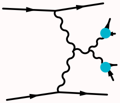
Op.	SSWW+2j		OSWW+2j		WZ+2j		ZZ+2j		ZV+2j		WW	
	L	L+Q	L	L+Q	L	L+Q	L	L+Q	L	L+Q	L	L+Q
$c_{Hl}^{(1)}$	-	m_{ll}	-	MET	$m_{ee}{}^\dagger$	m_{WZ}	$p_{T,e^-\mu^-}{}^\dagger$	$p_{T,e^-\mu^-}{}^\dagger$	p^V_{T,j_1}	p^V_{T,j_1}	p_{T,l^1}	MET
$c_{Hq}^{(1)}$	p_{T,j^1}	p_{T,j^1}	m_{jj}	m_{ll}	m_{jj}	p_{T,j^1}	m_{jj}	p_{T,j^1}	m_{jj}^{VBS}	m_{jj}^{VBS}	MET	MET
$c_{Hq}^{(3)}$	$\Delta\phi_{jj}$	$\Delta\phi_{jj}$	m_{ll}	m_{ll}	$\Delta\phi_{jj}{}^\dagger$	p_{T,l^1}	$\Delta\phi_{jj}{}^\dagger$	p_{T,l^4}	p^{VBS}_{T,j_2}	p^{VBS}_{T,j_2}	p_{T,l^1}	p_{T,l^1}
$c_{qq}^{(3)}$	$m_{ll}{}^\dagger$	p_{T,j^2}	m_{jj}	p_{T,j^2}	m_{jj}	p_{T,j^2}	m_{jj}	p_{T,j^1}	$p_{T,l^1}{}^\dagger$	$\Delta\phi_{jj}^{VBS}$	-	-
$c_{qq}^{(3,1)}$	$\Delta\phi_{jj}$	p_{T,j^2}	m_{jj}	p_{T,j^2}	m_{jj}	p_{T,j^2}	m_{jj}	p_{T,j^1}	$\Delta\eta_{jj}^{V\,\dagger}$	$\Delta\phi_{jj}^{VBS}$	-	-
$c_{qq}^{(1,1)}$	$\Delta\phi_{jj}$	p_{T,j^1}	p_{T,j^2}	p_{T,j^2}	p_{T,j^2}	p_{T,j^1}	p_{T,j^2}	p_{T,j^2}	$\Delta\phi_{jj}^{VBS}$	p^{VBS}_{T,j_1}	-	-
$c_{qq}^{(1)}$	p_{T,j^1}	p_{T,j^1}	p_{T,j^2}	p_{T,j^2}	p_{T,j^2}	p_{T,j^2}	p_{T,j^2}	p_{T,j^2}	$\Delta\phi_{jj}^{VBS}$	p^{VBS}_{T,j_1}	-	-
$c_{Hl}^{(3)}$	$\Delta\eta_{jj}{}^\dagger$	$\Delta\eta_{jj}{}^\dagger$	$m_{jj}{}^\dagger$	$m_{jj}{}^\dagger$	$m_{jj}{}^\dagger$	m_{jj}	$m_{jj}{}^\dagger$	$m_{jj}{}^\dagger$	$\Delta\eta_{jj}^V$	$\Delta\eta_{jj}^V$	$m_{ll}{}^\dagger$	$m_{ll}{}^\dagger$
$c_{ll}^{(1)}$	$m_{jj}{}^\dagger$	$m_{jj}{}^\dagger$	$m_{jj}{}^\dagger$	$m_{jj}{}^\dagger$	$m_{jj}{}^\dagger$	m_{jj}	$m_{jj}{}^\dagger$	$m_{jj}{}^\dagger$	$\Delta\eta_{jj}^{V\,\dagger}$	$\Delta\eta_{jj}^{V\,\dagger}$	$p_{T,ll}{}^\dagger$	p_{T,l^2}
c_{HD}	p_{T,j^1}	m_{ll}	$\Delta\eta_{jj}$	$\Delta\eta_{jj}$	m_{ee}	$\Delta\eta_{jj}{}^\dagger$	$p_{T,e^+\mu^+}$	$p_{T,e^+\mu^+}{}^\dagger$	p_{T,l^2}	p_{T,l^2}	p_{T,l^1}	p_{T,l^1}
c_{HWB}	p_{T,j^1}	p_{T,j^1}	$\Delta\eta_{jj}$	m_{ll}	m_{ee}	m_{WZ}	$m_{\mu\mu}{}^\dagger$	$\Delta\eta_{jj}$	$\Delta\eta_{jj}^V$	$\Delta\eta_{jj}^V$	p_{T,l^1}	MET
$c_{H\Box}$	p_{T,j^1}	m_{ll}	m_{ll}	m_{ll}	-	m_{WZ}	-	$\Delta\eta_{jj}$	p^V_{T,j_2}	p^V_{T,j_2}	-	-
c_{HW}	$\Delta\phi_{jj}$	m_{ll}	$\Delta\phi_{jj}$	m_{ll}	$\eta_{l^3}{}^\dagger$	m_{WZ}	m_{jj}	m_{4l}	p^{VBS}_{T,j_1}	p^V_{T,j_2}	-	-
c_W	$\Delta\phi_{jj}$	$p_{T,ll}$	$\Delta\phi_{jj}$	m_{ll}	p_{T,l^1}	m_{WZ}	$\Delta\phi_{jj}$	p_{T,l^4}	$\Delta\phi_{jj}^{VBS\,\dagger}$	$\Delta\phi_{jj}^{VBS\,\dagger}$	MET	MET

† = no strong preference over other obs.

Optimal observables

for each operator & channel, fit the distribution that gives the best constraint

for 1D fits:



Op.	SSWW+2j		OSWW+2j		WZ+2j		ZZ+2j		ZV+2j		WW	
	L	L+Q	L	L+Q	L	L+Q	L	L+Q	L	L+Q	L	L+Q
$c_{Hl}^{(1)}$	-	m_{ll}	-	MET	$m_{ee}{}^{\dagger}$	m_{WZ}	$p_{T,e^-\mu^-}{}^{\dagger}$	$p_{T,e^-\mu^-}{}^{\dagger}$	p^V_{T,j_1}	p^V_{T,j_1}	p_{T,l^1}	MET
$c_{Hq}^{(1)}$	p_{T,j^1}	p_{T,j^1}	m_{jj}	m_{ll}	m_{jj}	p_{T,j^1}	m_{jj}	p_{T,j^1}	m_{jj}^{VBS}	m_{jj}^{VBS}	MET	MET
$c_{Hq}^{(3)}$	$\Delta\phi_{jj}$	$\Delta\phi_{jj}$	m_{ll}	m_{ll}	$\Delta\phi_{jj}{}^{\dagger}$	p_{T,l^1}	$\Delta\phi_{jj}{}^{\dagger}$	p_{T,l^4}	p^{VBS}_{T,j_2}	p^{VBS}_{T,j_2}	p_{T,l^1}	p_{T,l^1}
$c_{qq}^{(3)}$	$m_{ll}{}^{\dagger}$	p_{T,j^2}	m_{jj}	p_{T,j^2}	m_{jj}	p_{T,j^2}	m_{jj}	p_{T,j^1}	$p_{T,l^1}{}^{\dagger}$	$\Delta\phi_{jj}^{VBS}$	-	-
$c_{qq}^{(3,1)}$	$\Delta\phi_{jj}$	p_{T,j^2}	m_{jj}	p_{T,j^2}	m_{jj}	p_{T,j^2}	m_{jj}	p_{T,j^1}	$\Delta\eta_{jj}^{V\,\dagger}$	$\Delta\phi_{jj}^{VBS}$	-	-
$c_{qq}^{(1,1)}$	$\Delta\phi_{jj}$	p_{T,j^1}	p_{T,j^2}	p_{T,j^2}	p_{T,j^2}	p_{T,j^1}	p_{T,j^2}	p_{T,j^2}	$\Delta\phi_{jj}^{VBS}$	p^{VBS}_{T,j_1}	-	-
$c_{qq}^{(1)}$	p_{T,j^1}	p_{T,j^1}	p_{T,j^2}	p_{T,j^2}	p_{T,j^2}	p_{T,j^2}	p_{T,j^2}	p_{T,j^2}	$\Delta\phi_{jj}^{VBS}$	p^{VBS}_{T,j_1}	-	-
$c_{Hl}^{(3)}$	$\Delta\eta_{jj}{}^{\dagger}$	$\Delta\eta_{jj}{}^{\dagger}$	$m_{jj}{}^{\dagger}$	$m_{jj}{}^{\dagger}$	$m_{jj}{}^{\dagger}$	m_{jj}	$m_{jj}{}^{\dagger}$	$m_{jj}{}^{\dagger}$	$\Delta\eta_{jj}^{V}$	$\Delta\eta_{jj}^{V}$	$m_{ll}{}^{\dagger}$	$m_{ll}{}^{\dagger}$
$c_{ll}^{(1)}$	$m_{jj}{}^{\dagger}$	$m_{jj}{}^{\dagger}$	$m_{jj}{}^{\dagger}$	$m_{jj}{}^{\dagger}$	$m_{jj}{}^{\dagger}$	m_{jj}	$m_{jj}{}^{\dagger}$	$m_{jj}{}^{\dagger}$	$\Delta\eta_{jj}^{V\,\dagger}$	$\Delta\eta_{jj}^{V\,\dagger}$	$p_{T,ll}{}^{\dagger}$	p_{T,l^2}
c_{HD}	p_{T,j^1}	m_{ll}	$\Delta\eta_{jj}$	$\Delta\eta_{jj}$	m_{ee}	$\Delta\eta_{jj}{}^{\dagger}$	$p_{T,e^+\mu^+}$	$p_{T,e^+\mu^+}{}^{\dagger}$	p_{T,l^2}	p_{T,l^2}	p_{T,l^1}	p_{T,l^1}
c_{HWB}	p_{T,j^1}	p_{T,j^1}	$\Delta\eta_{jj}$	m_{ll}	m_{ee}	m_{WZ}	$m_{\mu\mu}{}^{\dagger}$	$\Delta\eta_{jj}$	$\Delta\eta_{jj}^{V}$	$\Delta\eta_{jj}^{V}$	p_{T,l^1}	MET
$c_{H\Box}$	p_{T,j^1}	m_{ll}	m_{ll}	m_{ll}	-	m_{WZ}	-	$\Delta\eta_{jj}$	p^V_{T,j_2}	p^V_{T,j_2}	-	-
c_{HW}	$\Delta\phi_{jj}$	m_{ll}	$\Delta\phi_{jj}$	m_{ll}	$\eta_{l3}{}^{\dagger}$	m_{WZ}	m_{jj}	m_{4l}	p^{VBS}_{T,j_1}	p^V_{T,j_2}	-	-
c_W	$\Delta\phi_{jj}$	$p_{T,ll}$	$\Delta\phi_{jj}$	m_{ll}	p_{T,l^1}	m_{WZ}	$\Delta\phi_{jj}$	p_{T,l^4}	$\Delta\phi_{jj}^{VBS\,\dagger}$	$\Delta\phi_{jj}^{VBS\,\dagger}$	MET	MET

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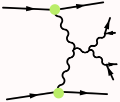

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	L	L+Q	L	L+Q	L	L+Q	L	L+Q	L	L+Q	L	L+Q
$c_{Hl}^{(1)}$	-	m_{ll}	-	MET	$m_{ee}{}^\dagger$	m_{WZ}	$p_{T,e^-\mu^-}{}^\dagger$	$p_{T,e^-\mu^-}{}^\dagger$	p^V_{T,j_1}	p^V_{T,j_1}	p_{T,l^1}	MET
$c_{Hq}^{(1)}$	p_{T,j^1}	p_{T,j^1}	m_{jj}	m_{ll}	m_{jj}	p_{T,j^1}	m_{jj}	p_{T,j^1}	m_{jj}^{VBS}	m_{jj}^{VBS}	MET	MET
$c_{Hq}^{(3)}$	$\Delta\phi_{jj}$	$\Delta\phi_{jj}$	m_{ll}	m_{ll}	$\Delta\phi_{jj}{}^\dagger$	p_{T,l^1}	$\Delta\phi_{jj}{}^\dagger$	p_{T,l^4}	p^{VBS}_{T,j_2}	p^{VBS}_{T,j_2}	p_{T,l^1}	p_{T,l^1}
$c_{qq}^{(3)}$	$m_{ll}{}^\dagger$	p_{T,j^2}	m_{jj}	p_{T,j^2}	m_{jj}	p_{T,j^2}	m_{jj}	p_{T,j^1}	$p_{T,l^1}{}^\dagger$	$\Delta\phi_{jj}^{VBS}$	-	-
$c_{qq}^{(3,1)}$	$\Delta\phi_{jj}$	p_{T,j^2}	m_{jj}	p_{T,j^2}	m_{jj}	p_{T,j^2}	m_{jj}	p_{T,j^1}	$\Delta\eta_{jj}^{V\,\dagger}$	$\Delta\phi_{jj}^{VBS}$	-	-
$c_{qq}^{(1,1)}$	$\Delta\phi_{jj}$	p_{T,j^1}	p_{T,j^2}	p_{T,j^2}	p_{T,j^2}	p_{T,j^1}	p_{T,j^2}	p_{T,j^2}	$\Delta\phi_{jj}^{VBS}$	p^{VBS}_{T,j_1}	-	-
$c_{qq}^{(1)}$	p_{T,j^1}	p_{T,j^1}	p_{T,j^2}	p_{T,j^2}	p_{T,j^2}	p_{T,j^2}	p_{T,j^2}	p_{T,j^2}	$\Delta\phi_{jj}^{VBS}$	p^{VBS}_{T,j_1}	-	-
$c_{Hl}^{(3)}$	$\Delta\eta_{jj}{}^\dagger$	$\Delta\eta_{jj}{}^\dagger$	$m_{jj}{}^\dagger$	$m_{jj}{}^\dagger$	$m_{jj}{}^\dagger$	m_{jj}	$m_{jj}{}^\dagger$	$m_{jj}{}^\dagger$	$\Delta\eta_{jj}^V$	$\Delta\eta_{jj}^V$	$m_{ll}{}^\dagger$	$m_{ll}{}^\dagger$
$c_{ll}^{(1)}$	$m_{jj}{}^\dagger$	$m_{jj}{}^\dagger$	$m_{jj}{}^\dagger$	$m_{jj}{}^\dagger$	$m_{jj}{}^\dagger$	m_{jj}	$m_{jj}{}^\dagger$	$m_{jj}{}^\dagger$	$\Delta\eta_{jj}^{V\,\dagger}$	$\Delta\eta_{jj}^{V\,\dagger}$	$p_{T,ll}{}^\dagger$	p_{T,l^2}
c_{HD}	p_{T,j^1}	m_{ll}	$\Delta\eta_{jj}$	$\Delta\eta_{jj}$	m_{ee}	$\Delta\eta_{jj}{}^\dagger$	$p_{T,e^+\mu^+}$	$p_{T,e^+\mu^+}{}^\dagger$	p_{T,l^2}	p_{T,l^2}	p_{T,l^1}	p_{T,l^1}
c_{HWB}	p_{T,j^1}	p_{T,j^1}	$\Delta\eta_{jj}$	m_{ll}	m_{ee}	m_{WZ}	$m_{\mu\mu}{}^\dagger$	$\Delta\eta_{jj}$	$\Delta\eta_{jj}^V$	$\Delta\eta_{jj}^V$	p_{T,l^1}	MET
$c_{H\Box}$	p_{T,j^1}	m_{ll}	m_{ll}	m_{ll}	-	m_{WZ}	-	$\Delta\eta_{jj}$	p^V_{T,j_2}	p^V_{T,j_2}	-	-
c_{HW}	$\Delta\phi_{jj}$	m_{ll}	$\Delta\phi_{jj}$	m_{ll}	$\eta_{l3}{}^\dagger$	m_{WZ}	m_{jj}	m_{4l}	p^{VBS}_{T,j_1}	p^V_{T,j_2}	-	-
c_W	$\Delta\phi_{jj}$	$p_{T,ll}$	$\Delta\phi_{jj}$	m_{ll}	p_{T,l^1}	m_{WZ}	$\Delta\phi_{jj}$	p_{T,l^4}	$\Delta\phi_{jj}^{VBS\,\dagger}$	$\Delta\phi_{jj}^{VBS\,\dagger}$	MET	MET

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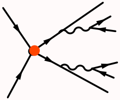

Op.	SSWW+2j		OSWW+2j		WZ+2j		ZZ+2j		ZV+2j		WW	
	L	L+Q	L	L+Q	L	L+Q	L	L+Q	L	L+Q	L	L+Q
$c_{Hl}^{(1)}$	-	m_{ll}	-	MET	$m_{ee}^\dagger$	m_{WZ}	$p_{T,e^-\mu^-}^\dagger$	$p_{T,e^-\mu^-}^\dagger$	p_{T,j_1}^V	p_{T,j_1}^V	p_{T,l^1}	MET
$c_{Hq}^{(1)}$	p_{T,j^1}	p_{T,j^1}	m_{jj}	m_{ll}	m_{jj}	p_{T,j^1}	m_{jj}	p_{T,j^1}	m_{jj}^{VBS}	m_{jj}^{VBS}	MET	MET
$c_{Hq}^{(3)}$	$\Delta\phi_{jj}$	$\Delta\phi_{jj}$	m_{ll}	m_{ll}	$\Delta\phi_{jj}^\dagger$	p_{T,l^1}	$\Delta\phi_{jj}^\dagger$	p_{T,l^4}	p_{T,j_2}^{VBS}	p_{T,j_2}^{VBS}	p_{T,l^1}	p_{T,l^1}
$c_{qq}^{(3)}$	$m_{ll}^\dagger$	p_{T,j^2}	m_{jj}	p_{T,j^2}	m_{jj}	p_{T,j^2}	m_{jj}	p_{T,j^1}	$p_{T,l^1}^\dagger$	$\Delta\phi_{jj}^{VBS}$	-	-
$c_{qq}^{(3,1)}$	$\Delta\phi_{jj}$	p_{T,j^2}	m_{jj}	p_{T,j^2}	m_{jj}	p_{T,j^2}	m_{jj}	p_{T,j^1}	$\Delta\eta_{jj}^{V\dagger}$	$\Delta\phi_{jj}^{VBS}$	-	-
$c_{qq}^{(1,1)}$	$\Delta\phi_{jj}$	p_{T,j^1}	p_{T,j^2}	p_{T,j^2}	p_{T,j^2}	p_{T,j^1}	p_{T,j^2}	p_{T,j^2}	$\Delta\phi_{jj}^{VBS}$	p_{T,j_1}^{VBS}	-	-
$c_{qq}^{(1)}$	p_{T,j^1}	p_{T,j^1}	p_{T,j^2}	p_{T,j^2}	p_{T,j^2}	p_{T,j^2}	p_{T,j^2}	p_{T,j^2}	$\Delta\phi_{jj}^{VBS}$	p_{T,j_1}^{VBS}	-	-
$c_{Hl}^{(3)}$	$\Delta\eta_{jj}^\dagger$	$\Delta\eta_{jj}^\dagger$	$m_{jj}^\dagger$	$m_{jj}^\dagger$	$m_{jj}^\dagger$	m_{jj}	$m_{jj}^\dagger$	$m_{jj}^\dagger$	$\Delta\eta_{jj}^V$	$\Delta\eta_{jj}^V$	$m_{ll}^\dagger$	$m_{ll}^\dagger$
$c_{ll}^{(1)}$	$m_{jj}^\dagger$	$m_{jj}^\dagger$	$m_{jj}^\dagger$	$m_{jj}^\dagger$	$m_{jj}^\dagger$	m_{jj}	$m_{jj}^\dagger$	$m_{jj}^\dagger$	$\Delta\eta_{jj}^{V\dagger}$	$\Delta\eta_{jj}^{V\dagger}$	$p_{T,ll}^\dagger$	p_{T,l^2}
c_{HD}	p_{T,j^1}	m_{ll}	$\Delta\eta_{jj}$	$\Delta\eta_{jj}$	m_{ee}	$\Delta\eta_{jj}^\dagger$	$p_{T,e^+\mu^+}$	$p_{T,e^+\mu^+}^\dagger$	p_{T,l^2}	p_{T,l^2}	p_{T,l^1}	p_{T,l^1}
c_{HWB}	p_{T,j^1}	p_{T,j^1}	$\Delta\eta_{jj}$	m_{ll}	m_{ee}	m_{WZ}	$m_{\mu\mu}^\dagger$	$\Delta\eta_{jj}$	$\Delta\eta_{jj}^V$	$\Delta\eta_{jj}^V$	p_{T,l^1}	MET
$c_{H\Box}$	p_{T,j^1}	m_{ll}	m_{ll}	m_{ll}	-	m_{WZ}	-	$\Delta\eta_{jj}$	p_{T,j_2}^V	p_{T,j_2}^V	-	-
c_{HW}	$\Delta\phi_{jj}$	m_{ll}	$\Delta\phi_{jj}$	m_{ll}	$\eta_{l3}^\dagger$	m_{WZ}	m_{jj}	m_{4l}	p_{T,j_1}^{VBS}	p_{T,j_2}^V	-	-
c_W	$\Delta\phi_{jj}$	$p_{T,ll}$	$\Delta\phi_{jj}$	m_{ll}	p_{T,l^1}	m_{WZ}	$\Delta\phi_{jj}$	p_{T,l^4}	$\Delta\phi_{jj}^{VBS\dagger}$	$\Delta\phi_{jj}^{VBS\dagger}$	MET	MET

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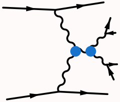

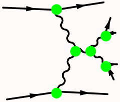

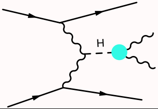

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$c_{Hq}^{(3)}$	$\Delta\phi_{jj}$	$\Delta\phi_{jj}$	m_{ll}	m_{ll}	$\Delta\phi_{jj}{}^\dagger$	p_{T,l^1}	$\Delta\phi_{jj}{}^\dagger$	p_{T,l^4}	p_{T,j_2}^{VBS}	p_{T,j_2}^{VBS}	p_{T,l^1}	p_{T,l^1}
$c_{qq}^{(3)}$	$m_{ll}{}^\dagger$	p_{T,j^2}	m_{jj}	p_{T,j^2}	m_{jj}	p_{T,j^2}	m_{jj}	p_{T,j^1}	$p_{T,l^1}{}^\dagger$	$\Delta\phi_{jj}^{VBS}$	-	-
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$c_{qq}^{(1,1)}$	$\Delta\phi_{jj}$	p_{T,j^1}	p_{T,j^2}	p_{T,j^2}	p_{T,j^2}	p_{T,j^1}	p_{T,j^2}	p_{T,j^2}	$\Delta\phi_{jj}^{VBS}$	p_{T,j_1}^{VBS}	-	-
$c_{qq}^{(1)}$	p_{T,j^1}	p_{T,j^1}	p_{T,j^2}	p_{T,j^2}	p_{T,j^2}	p_{T,j^2}	p_{T,j^2}	p_{T,j^2}	$\Delta\phi_{jj}^{VBS}$	p_{T,j_1}^{VBS}	-	-
$c_{Hl}^{(3)}$	$\Delta\eta_{jj}{}^\dagger$	$\Delta\eta_{jj}{}^\dagger$	$m_{jj}{}^\dagger$	$m_{jj}{}^\dagger$	$m_{jj}{}^\dagger$	m_{jj}	$m_{jj}{}^\dagger$	$m_{jj}{}^\dagger$	$\Delta\eta_{jj}^V$	$\Delta\eta_{jj}^V$	$m_{ll}{}^\dagger$	$m_{ll}{}^\dagger$
$c_{ll}^{(1)}$	$m_{jj}{}^\dagger$	$m_{jj}{}^\dagger$	$m_{jj}{}^\dagger$	$m_{jj}{}^\dagger$	$m_{jj}{}^\dagger$	m_{jj}	$m_{jj}{}^\dagger$	$m_{jj}{}^\dagger$	$\Delta\eta_{jj}^{V\,\dagger}$	$\Delta\eta_{jj}^{V\,\dagger}$	$p_{T,ll}{}^\dagger$	p_{T,l^2}
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c_{HWB}	p_{T,j^1}	p_{T,j^1}	$\Delta\eta_{jj}$	m_{ll}	m_{ee}	m_{WZ}	$m_{\mu\mu}{}^\dagger$	$\Delta\eta_{jj}$	$\Delta\eta_{jj}^V$	$\Delta\eta_{jj}^V$	p_{T,l^1}	MET
$c_{H\Box}$	p_{T,j^1}	m_{ll}	m_{ll}	m_{ll}	-	m_{WZ}	-	$\Delta\eta_{jj}$	p_{T,j_2}^V	p_{T,j_2}^V	-	-
c_{HW}	$\Delta\phi_{jj}$	m_{ll}	$\Delta\phi_{jj}$	m_{ll}	$\eta_{l3}{}^\dagger$	m_{WZ}	m_{jj}	m_{4l}	p_{T,j_1}^{VBS}	p_{T,j_2}^V	-	-
c_W	$\Delta\phi_{jj}$	$p_{T,ll}$	$\Delta\phi_{jj}$	m_{ll}	p_{T,l^1}	m_{WZ}	$\Delta\phi_{jj}$	p_{T,l^4}	$\Delta\phi_{jj}^{VBS\,\dagger}$	$\Delta\phi_{jj}^{VBS\,\dagger}$	MET	MET

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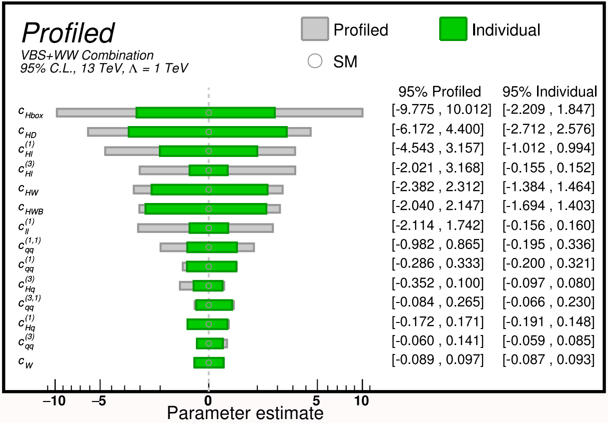
SMEFT in VBS: fit results and main conclusions

- VBS constrains the most 4-quark operators and Q_W
  all these are dominated by **ssWW**



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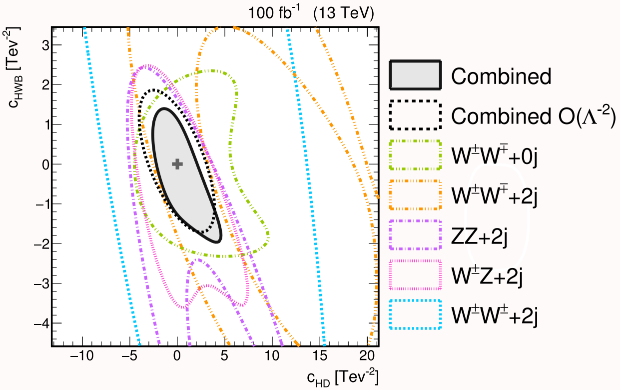

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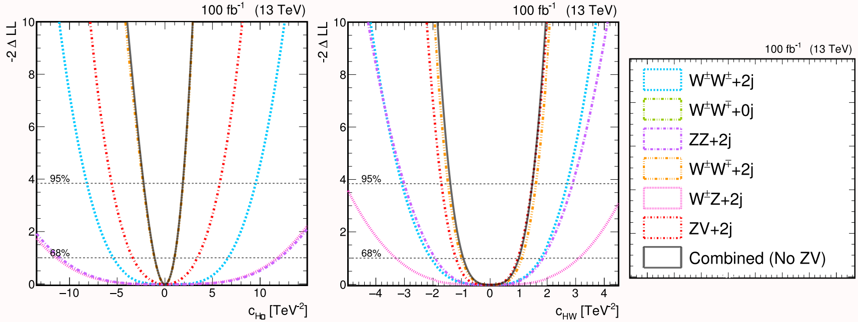

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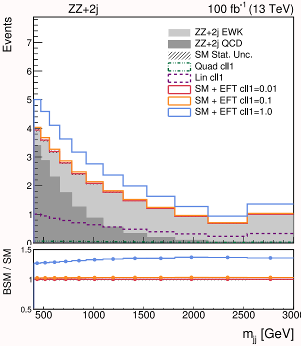

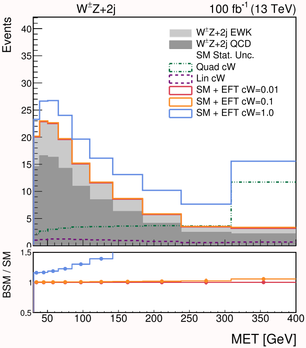

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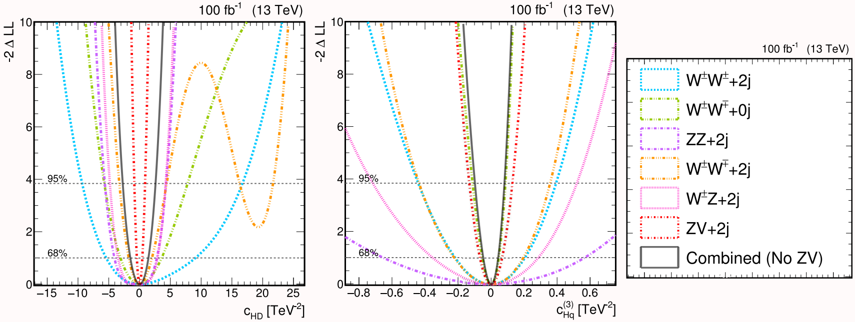

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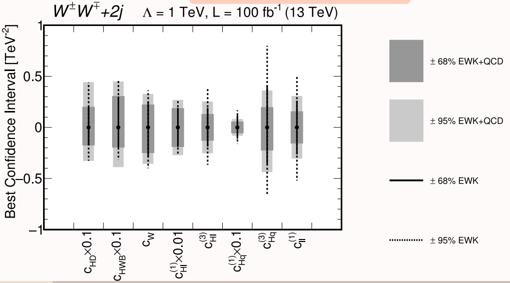
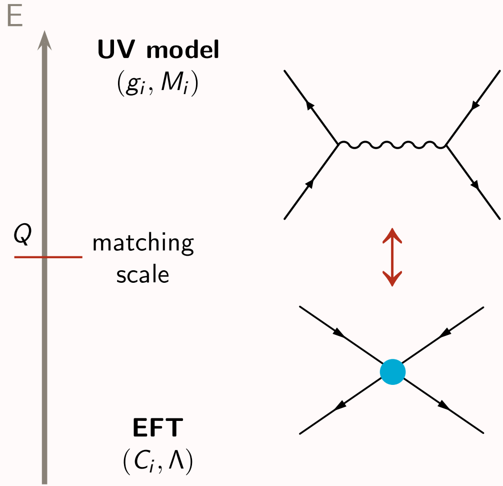
- adding SMEFT corrections to QCD backgrounds never worsens the results



EFT $\leftrightarrow$ models interplay

Matching to UV models

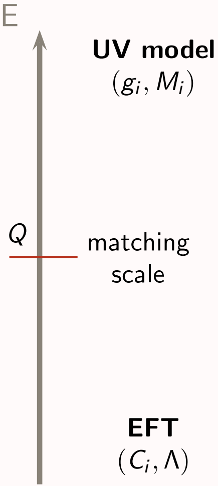


imposing all matrix elements are equal at $\mu = Q$

$\downarrow$

C_i, Λ as function of (g_i, M_i)

Matching to UV models



done efficiently up to 1-loop in UV model via functional methods:

Covariant Derivative Expansion or

Universal One-Loop Effective Action

$$S_{eff}[\phi] = S[\Phi_0] + \frac{i}{2} \,\mathrm{Tr} \log \left(- \frac{\delta^2 S}{\delta \Phi^2}\bigg|_{\Phi_0} \right)$$

light fields

heavy fields. $\Phi = \Phi_0 + \eta$

Henning,Lu,Murayama,deAguila,Santiago,Ellis,Quevillon,You,Fuentes-Martin, Cohen,Lu,Zhang,Krämer,Summ,Voigt,Dittmaier,Passarino. . .

A case study: SM + Heavy Vector Triplet

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

$$\mathcal{L}_{HVT} = -\frac{1}{4} V^i_{\mu\nu} V^{i\mu\nu} - \frac{g_M}{2} V^i_{\mu\nu} W^{i\mu\nu} + \frac{m_V^2}{2} V^i_\mu V^{i\mu} + \frac{g_H}{2} V^i_\mu (H^\dagger i \overleftrightarrow{D}^{i\mu} H)$$
$$+ \frac{g_l}{2} V^-_\mu \bar{\ell}\gamma^\mu \sigma^i \ell + \frac{g_q}{2} V^-_\mu \bar{q}\gamma^\mu \sigma^i q + \frac{g_{VH}}{2} (H^\dagger H) V^i_\mu V^{i\mu}$$

del Aguila,de Blas,Perez-Victoria 1005.399
de Blas,Lizana,Perez-Victoria 1211.2229
Pappadopulo,Thamm,Torre,Wulzer 1402.4431

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field redefinition to remove kinetic mixing

$$\begin{cases} V^i_\mu \to \dfrac{1}{\sqrt{1-g_M^2}} V^i_\mu \\ W^i_\mu \to W^i_\mu - \dfrac{g_M}{\sqrt{1-g_M^2}} V^i_\mu \end{cases}$$

$$(C_i/\Lambda^2) = f_i(g_M, g_H, g_l, g_q, g_{VH}; m_V)$$

C_i in **Warsaw basis**, f_i at **1-loop** in model

constraints on model ↑ **fit directly to g_i**

similar approach in: daSilva Almeida,Alves,Éboli,González-García 2108.04828

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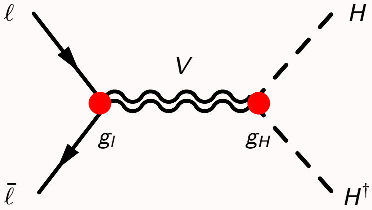
e.g. $Q^{(3)}_{Hl} = (H^\dagger i \overleftrightarrow{D}^i_\mu H)(\bar{\ell}\gamma^\mu \sigma^i \ell)$

$$(C^{(3)}_{Hl})_{ij} = -\frac{g_l g_H}{4 m_V^2} \delta_{ij}$$



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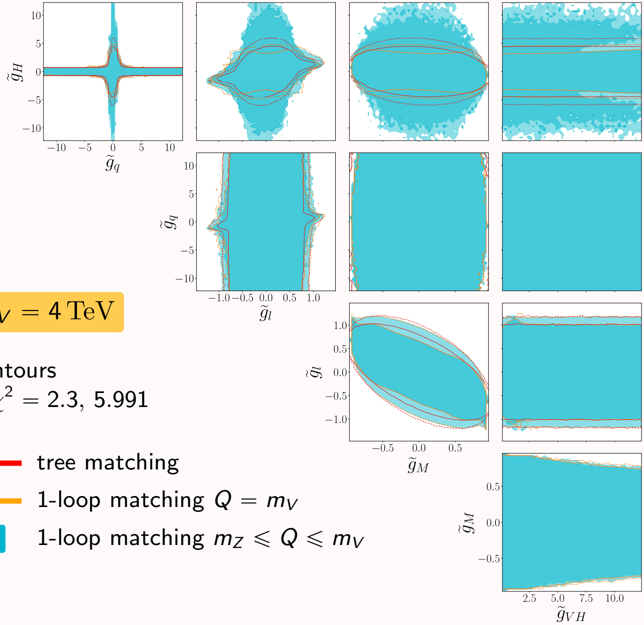
Heavy vector triplet: tree vs loop matching

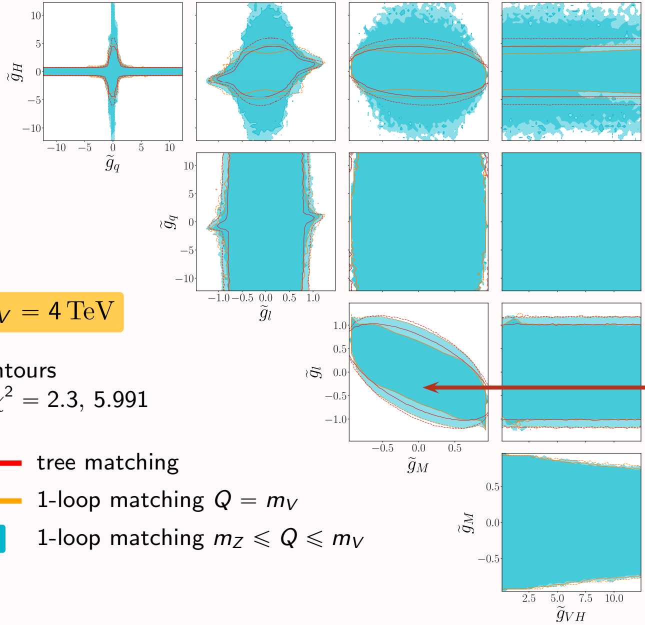


$m_V = 4\,\mathrm{TeV}$

contours
$\Delta\chi^2 = 2.3,\ 5.991$

- tree matching
- 1-loop matching $Q = m_V$
- 1-loop matching $m_Z \leqslant Q \leqslant m_V$

Heavy vector triplet: tree vs loop matching



$m_V = 4\,\mathrm{TeV}$

contours
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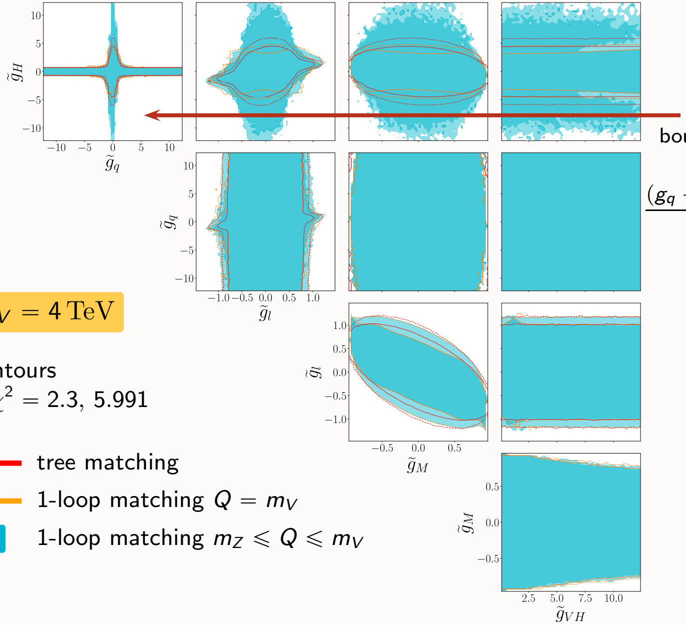
- tree matching (red line)
- 1-loop matching $Q = m_V$ (orange line)
- 1-loop matching $m_Z \leqslant Q \leqslant m_V$ (blue area)

always $(g_l + g_2 g_M)$ in tree matching

bound dominated by
$$C_{ll} \simeq \frac{(g_l + g_2 g_M)^2}{m_V^2}$$
$\rightarrow$ EWPO

Heavy vector triplet: tree vs loop matching



bound dominated by
$C_{HQ}^{(3)} \simeq \dfrac{(g_q + g_2 g_M)(g_H + g_2 g_M)}{m_V^2}$

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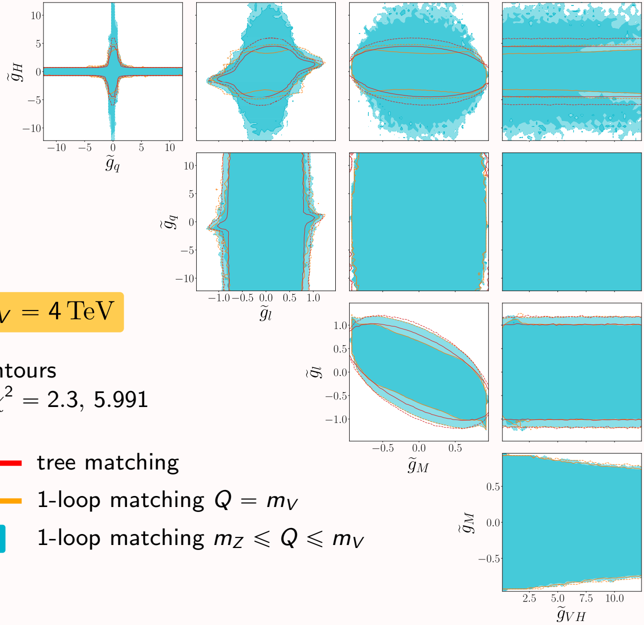

profiling over Q worsens g_H bound by a factor 2

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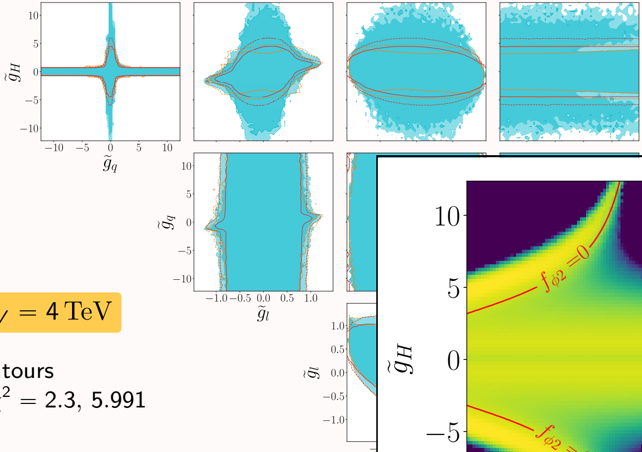
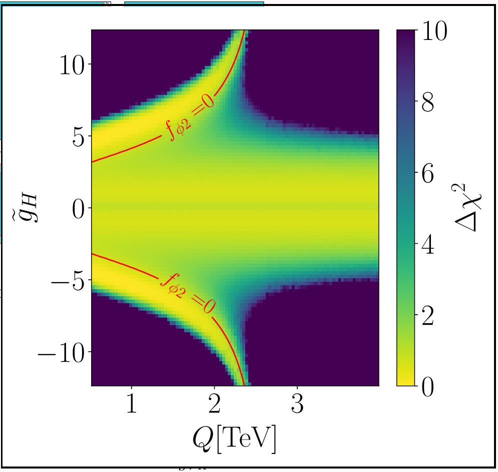


profiling over Q worsens g_H bound by a factor 2

$m_V = 4\,\mathrm{TeV}$

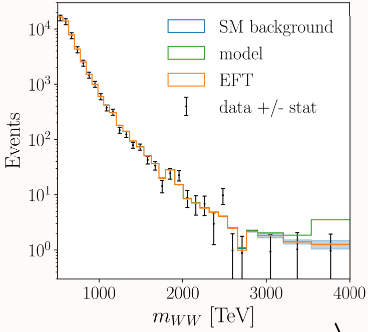
contours
$\Delta\chi^2 = 2.3,\ 5.991$

- tree matching
- 1-loop matching $Q = m_V$
- 1-loop matching $m_Z \leqslant Q \leqslant m_V$

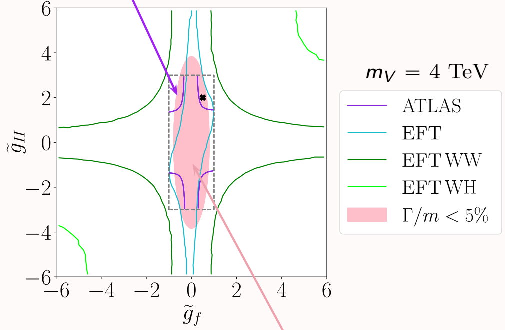


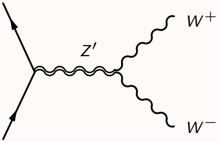
SMEFT vs direct searches

high complementarity



bound from
WW resonance search

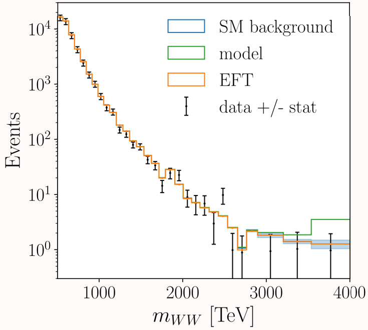


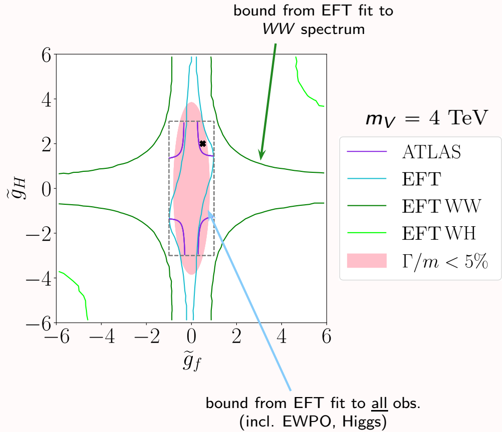


resonance s. only valid
for narrow Z'

SMEFT vs direct searches

high complementarity

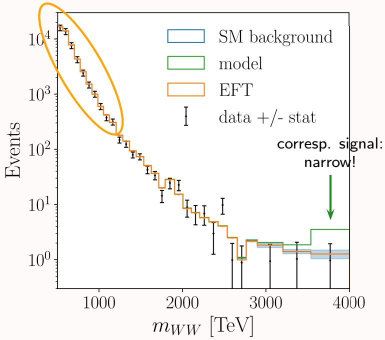




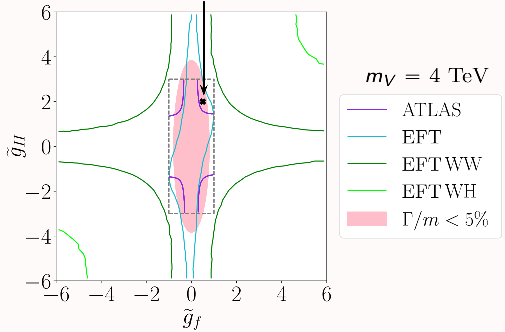
SMEFT vs direct searches

high complementarity

best EFT sensitivity to this peak: bins with smallest uncertainties!



point excluded by resonance s. but allowed by EFT



Summary

- **Global SMEFT analyses** are undergoing great developments
- Fits to **EW processes** already at a very mature stage:
  combination with Higgs is standard. constraints reach multi-TeV range
- Several improvement directions ahead
  - add **new processes** sensitive to new directions in parameter space.
    example: VBS
    → very good probe for 4-quark and TGC/QGC operators
    → absolute sensitivity smaller than diboson, but can be competitive
    → including SMEFT in irred. background (QCD) improves constraints
  - interplay between **EFT and models**. example: Heavy Vector Triplet
    → we can fit model parameters "through" SMEFT
    → new systematic uncertainty associated with matching scale
    → complementarity of EFT and resonance-search bounds