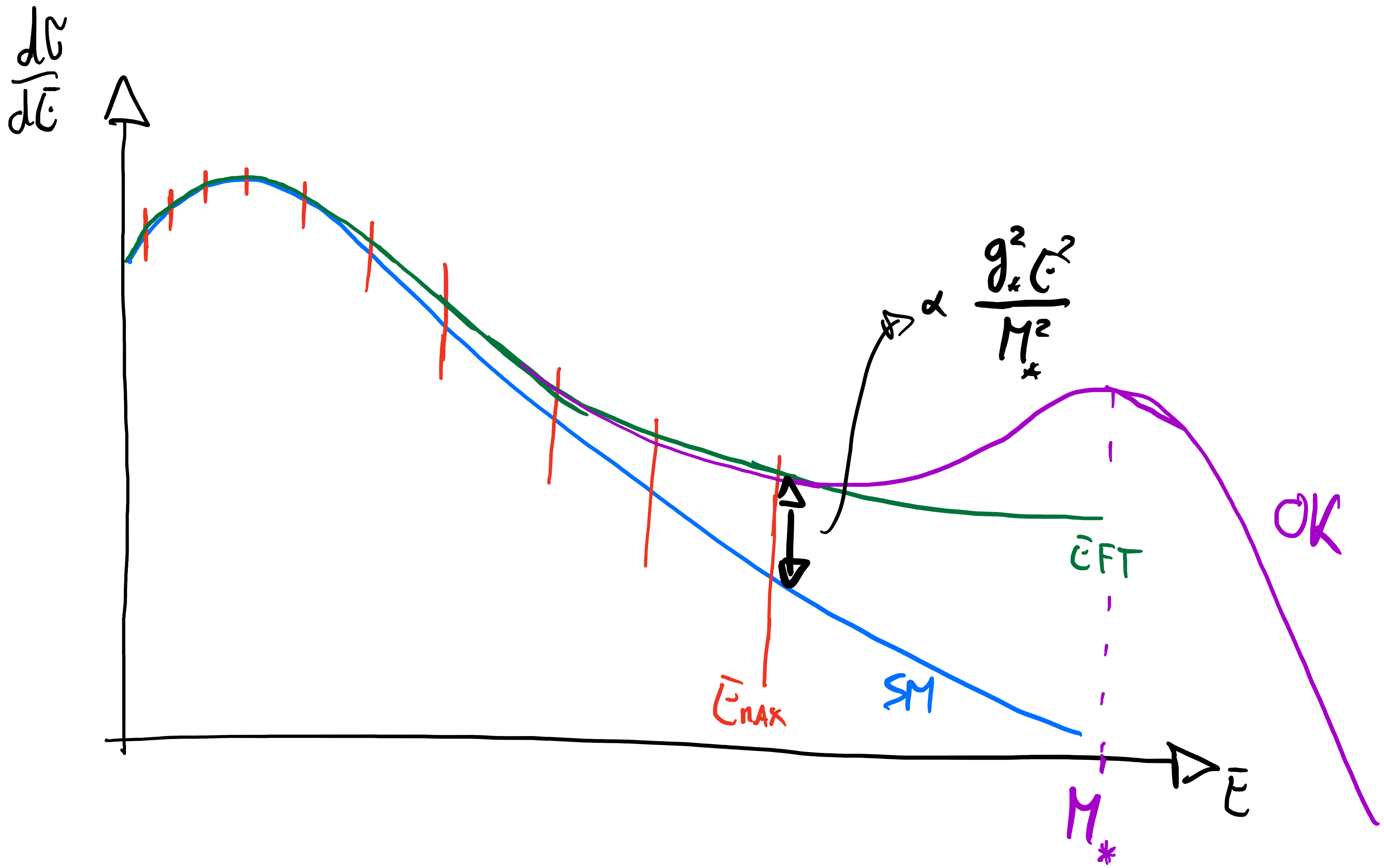
Combining
Higgs and diboson data
in the EFT approach

David Marzocca

Universität Zürich[UZH]

Deviations in high energy tails



Deviations in the
tails of 2 → 2 processes

$$\delta_{\text{tail}} \sim \mathcal{O}\left(g_*^2 \frac{p^2}{\Lambda^2}\right)$$

The SM Effective Field Theory

$$\Lambda \gg E_{\rm exp}, m_h$$

particle content + symmetries as in the SM + L and B conservation

(Higgs is a $SU(2)_L$ doublet)

Leading deformations of the SM

$$\mathcal{L}^{\rm eff} = \mathcal{L}_{\rm SM} + \sum_i \frac{c_i^{(6)}}{\Lambda^2}\mathcal{O}_i^{(6)} + \sum_j \frac{c_j^{(8)}}{\Lambda^4}\mathcal{O}_j^{(8)} + \ldots$$

59 independent dim-6 operators if flavour universality.
2499 parameters for a generic flavour structure.

[Buchmuller and Wyler '86, Grzadkowski et al. 1008.4884, Alonso et al. 1312.2014]

A step-by-step approach

i.e. how to successfully make sense of 2499 parameters

★ Any given on-shell process receives contributions from a limited number of operators $\# \lesssim \mathcal{O}(10)$.

★ Hierarchy of precision.
Some observables are much more precise than others.
Impose these bounds before going on to less precise ones.
e.g. Corbett et al. [1211.4580], Pomarol and Riva [1308.2803], ecc..

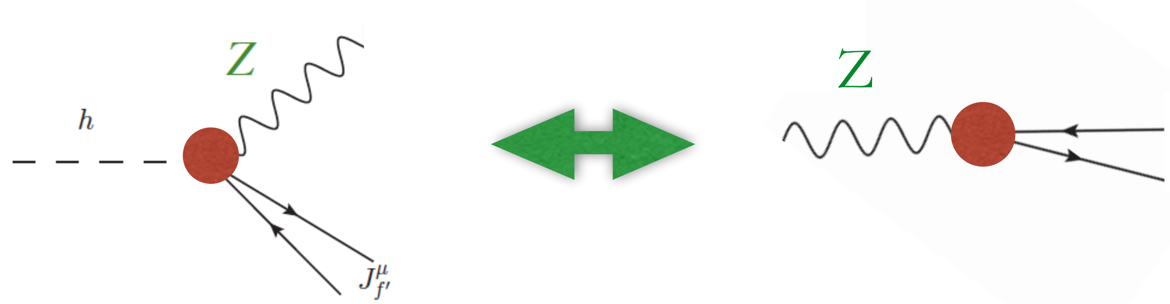
→ Impose precise LEP-1 constraints BEFORE doing Higgs or diboson physics.

Note: This process, when correctly done, is basis-independent.

Why a combination?

The same operator can contribute to different processes.

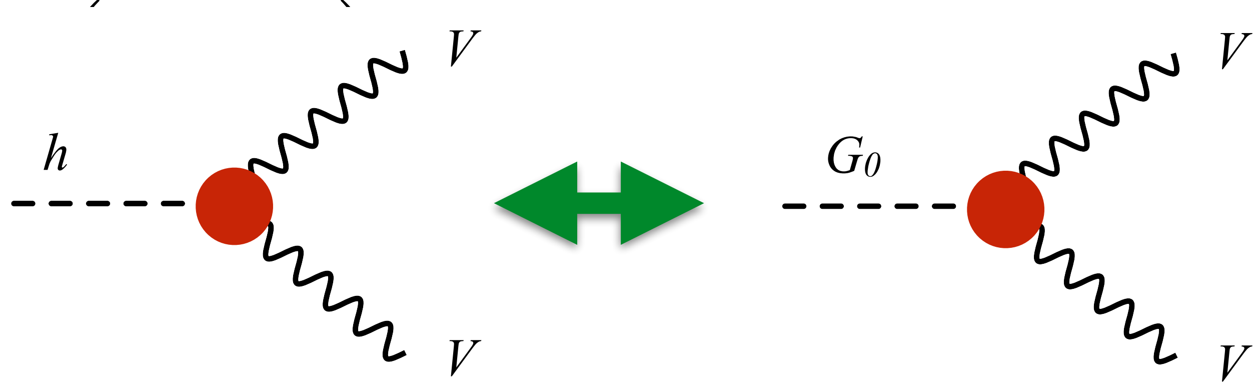
For example: $O_{Hf} = i(H^\dagger \overleftrightarrow{D}_\mu H)\bar{f}\gamma^\mu f = -\frac{1}{2}\sqrt{g^2+g'^2}Z_\mu(v+h)^2\bar{f}\gamma^\mu f$



Z couplings δg_{Zf}

&

$$\mathcal{O}_W = ig\left(H^\dagger\tau^a \overleftrightarrow{D}^\mu H\right) D^\nu W^a_{\mu\nu}$$



Triple Gauge Couplings
$\delta\kappa_z$, $\delta g_{1,z}$, λ_Z

(also aQGC)

Combine Z-pole, WW, and WZ data with Higgs data to derive stronger constraints for the EFT.

aTGC in the SMEFT

After imposing Z(W)-pole limits, **3 unconstrained combinations** of SMEFT coefficients contribute to the diboson processes:

Warsaw basis:

$$\delta g_{1,z} = -\frac{v^2}{\Lambda^2}\frac{g_L^2+g_Y^2}{4(g_L^2-g_Y^2)}\left(4\frac{g_Y}{g_L}w_{\phi WB} + w_{\phi D} - [w_{\ell\ell}]_{1221} + 2[w_{\phi\ell}^{(3)}]_{11} + 2[w_{\phi\ell}^{(3)}]_{22}\right)$$

$$\delta\kappa_\gamma = \frac{v^2}{\Lambda^2}\frac{g_L}{g_Y}w_{\phi WB}\ , \qquad \lambda_z = -\frac{v^2}{\Lambda^2}\frac{3}{2}g_L w_W\ ,$$

SILH basis:

$$\delta g_{1z} = -\frac{g_L^2+g_Y^2}{g_L^2-g_Y^2}\left[\frac{g_L^2-g_Y^2}{g_L^2}\bar{c}_{HW} + \bar{c}_W + \bar{c}_{2W} + \frac{g_Y^2}{g_L^2}\bar{c}_B + \frac{g_Y^2}{g_L^2}\bar{c}_{2B} - \frac{1}{2}\bar{c}_T\right]$$

$$\delta\kappa_\gamma = -\bar{c}_{HW} - \bar{c}_{HB}\ , \qquad \lambda_z = -6g_L^2\bar{c}_{3W}\ ,$$

note that here $\bar{c}_i \sim \frac{m_W^2}{\Lambda^2}c_i$

Higgs basis:

$$\delta g_{1,z} = \frac{1}{2(g^2-g'^2)}\left[-g^2(g^2+g'^2)c_{z\Box} - g'^2(g^2+g'^2)c_{zz} + \right.$$
$$\left. + e^2g'^2c_{\gamma\gamma} + g'^2(g^2-g'^2)c_{z\gamma}\right]\ ,$$
$$\delta\kappa_\gamma = -\frac{g^2}{2}\left(c_{\gamma\gamma}\frac{e^2}{g^2+g'^2} + c_{z\gamma}\frac{g^2-g'^2}{g^2+g'^2} - c_{zz}\right)\ . \qquad \text{(A.3)}$$

10 Operators for Higgs + TGC

E.g:

SILH' basis

Operator	Coefficient
$\mathcal{O}_W = \frac{ig}{2}\left(H^\dagger \sigma^a \overleftrightarrow{D}^\mu H\right) D^\nu W^a_{\mu\nu}$ $\mathcal{O}_B = \frac{ig'}{2}\left(H^\dagger \overleftrightarrow{D}^\mu H\right) \partial^\nu B_{\mu\nu}$	$\frac{m_W^2}{\Lambda^2}(c_W - c_B)$
$\mathcal{O}_{HW} = ig(D^\mu H)^\dagger \sigma^a (D^\nu H) W^a_{\mu\nu}$	$\frac{m_W^2}{\Lambda^2} c_{HW}$
$\mathcal{O}_{HB} = ig'(D^\mu H)^\dagger (D^\nu H) B_{\mu\nu}$	$\frac{m_W^2}{\Lambda^2} c_{HB}$
$\mathcal{O}_{3W} = \frac{1}{3!} g \epsilon_{abc} W^{a\,\nu}_\mu W^b_{\nu\rho} W^{c\,\rho\mu}$	$\frac{m_W^2}{\Lambda^2} c_{3W}$
$\mathcal{O}_g = g_s^2 \lvert H\rvert^2 G^A_{\mu\nu} G^{A\mu\nu}$	$\frac{m_W^2}{\Lambda^2} c_g$
$\mathcal{O}_\gamma = g'^2 \lvert H\rvert^2 B_{\mu\nu} B^{\mu\nu}$	$\frac{m_W^2}{\Lambda^2} c_\gamma$
$\mathcal{O}_H = \frac{1}{2}(\partial^\mu \lvert H\rvert^2)^2$	$\frac{v^2}{\Lambda^2} c_H$
$\mathcal{O}_f = y_f \lvert H\rvert^2 \bar{F}_L H^{(c)} f_R + \text{h.c.}$	$\frac{v^2}{\Lambda^2} c_f$

f=u,d,e

Pomarol, Riva 1308.2803
Ellis, Sanz, You 1410.7703
Falkowski et al.1508.00581
Tilman et al. 1604.03105
…

In the *Higgs basis*: $\delta c_z,\ c_{zz},\ c_{z\Box},\ c_{\gamma\gamma},\ c_{z\gamma},\ c_{gg},\ \delta y_u,\ \delta y_d,\ \delta y_e,\ \lambda_z.$

In terms of aTGC: $\delta c_z,\ c_{\gamma\gamma},\ c_{z\gamma},\ c_{gg},\ \delta y_u,\ \delta y_d,\ \delta y_e,\ \delta g_{1,z},\ \delta\kappa_\gamma,\ \lambda_z.$

Example: LEP-2 + Higgs global fit

Falkowski, Gonzalez-Alonso, Greljo, D.M. 1508.00581

Higgs basis

[YR4 LHCHXSWG 2016]

$$\begin{pmatrix} \delta c_z \\ c_{zz} \\ c_{z\Box} \\ c_{\gamma\gamma} \\ c_{z\gamma} \\ c_{gg} \\ \delta y_u \\ \delta y_d \\ \delta y_e \\ \lambda_z \end{pmatrix} = \begin{pmatrix} -0.02 \pm 0.17 \\ 0.69 \pm 0.42 \\ -0.32 \pm 0.19 \\ 0.009 \pm 0.015 \\ 0.002 \pm 0.098 \\ -0.0052 \pm 0.0027 \\ 0.57 \pm 0.30 \\ -0.24 \pm 0.35 \\ -0.12 \pm 0.20 \\ -0.162 \pm 0.073 \end{pmatrix}$$

$$\begin{pmatrix} 1 & -.04 & -.21 & -.76 & -.15 & .15 & .12 & .88 & .71 & -.22 \\ \cdot & 1 & -.96 & .37 & .19 & .03 & .04 & -.12 & -.31 & -.88 \\ \cdot & \cdot & 1 & -.17 & -.10 & -.07 & -.06 & -.10 & .12 & .93 \\ \cdot & \cdot & \cdot & 1 & .20 & -.12 & -.07 & -.79 & -.74 & -.13 \\ \cdot & \cdot & \cdot & \cdot & 1 & -.01 & -.01 & -.15 & -.18 & -.10 \\ \cdot & \cdot & \cdot & \cdot & \cdot & 1 & -.87 & .26 & .17 & -.07 \\ \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & 1 & .13 & .11 & -.06 \\ \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & 1 & .81 & -.11 \\ \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & 1 & .09 \\ \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & 1 \end{pmatrix}$$

Warsaw

$$\begin{pmatrix} c_H & = 0.11 \pm 0.15 \\ c_T & = 0.034 \pm 0.021 \\ c_{WB} & = 0.34 \pm 0.20 \\ c_{WW} & = 0.69 \pm 0.43 \\ c_{BB} & = 0.69 \pm 0.42 \\ c_{GG} & = -0.0052 \pm 0.0027 \\ \hat{c}_u & = 0.65 \pm 0.32 \\ \hat{c}_d & = -0.16 \pm 0.23 \\ \hat{c}_e & = -0.03 \pm 0.13 \\ c_{3W} & = 0.63 \pm 0.29 \end{pmatrix}$$

1008.4884
(with a different notation)

SILH'

$$\begin{pmatrix} s_H & = 0.02 \pm 0.17 \\ \frac{1}{2}(s_W - s_B) & = 0.37 \pm 0.30 \\ s_{HW} & = -0.69 \pm 0.43 \\ s_{HB} & = -0.68 \pm 0.42 \\ s_{BB} & = 0.094 \pm 0.015 \\ s_{GG} & = -0.0052 \pm 0.0027 \\ \hat{s}_u & = 0.59 \pm 0.33 \\ \hat{s}_d & = -0.23 \pm 0.22 \\ \hat{s}_e & = -0.10 \pm 0.15 \\ s_{3W} & = 0.63 \pm 0.29 \end{pmatrix}$$

hep-ph/0703164 + 1308.2803

HISZ

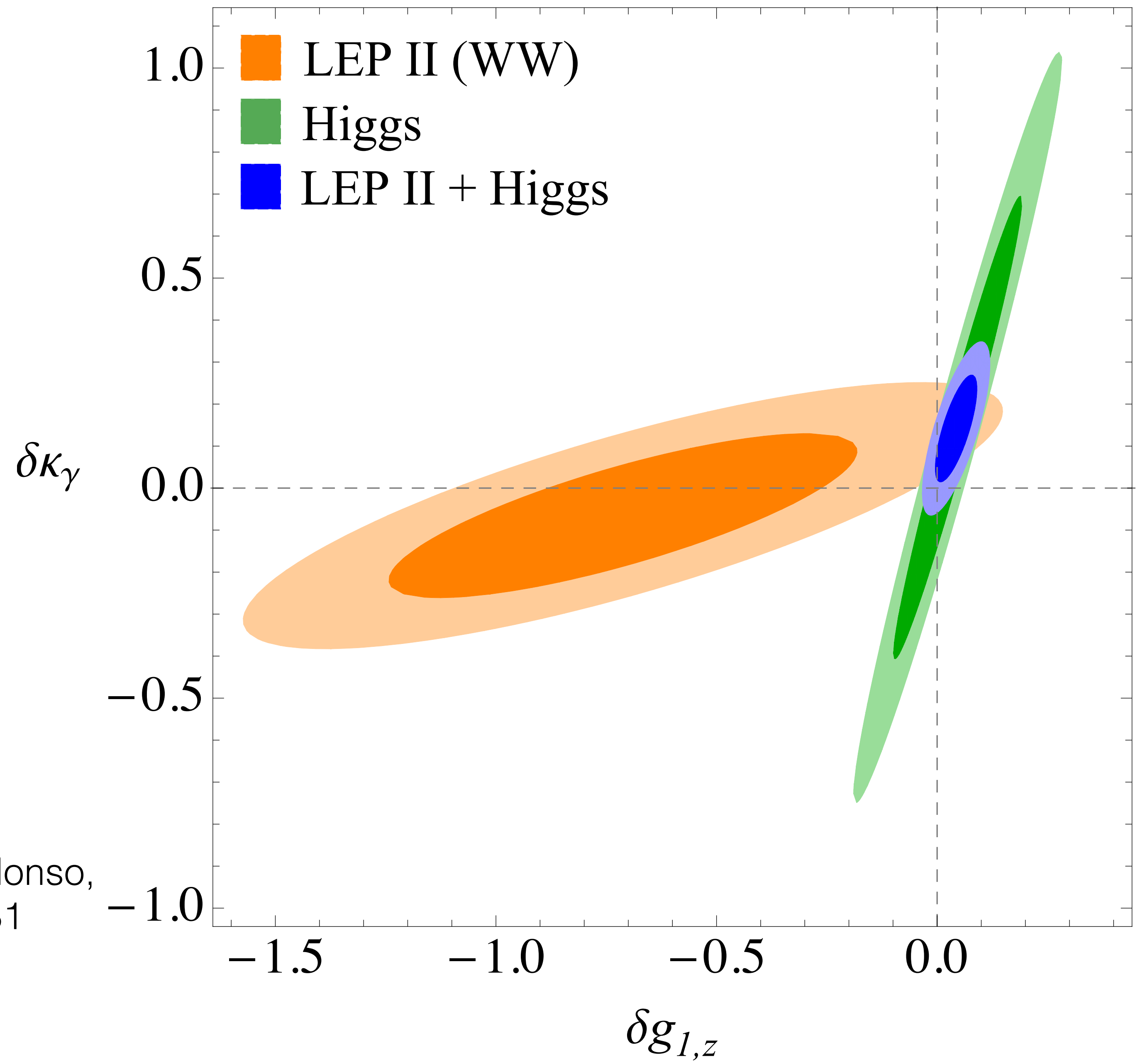
$$\begin{pmatrix} f_{H,2} & = 0.03 \pm 0.34 \\ f_W & = 0.64 \pm 0.46 \\ f_B & = 2.11 \pm 1.33 \\ f_{WW} & = -0.37 \pm 0.30 \\ f_{BB} & = 0.36 \pm 0.29 \\ f_{GG} & = 0.41 \pm 0.21 \\ f_u & = -0.83 \pm 0.46 \\ f_d & = 0.32 \pm 0.31 \\ f_e & = 0.14 \pm 0.20 \\ f_{3W} & = -2.53 \pm 1.14 \end{pmatrix}$$

Phys.Rev. D48 (1993) 2182–2203

Such a fit can be rotated in any basis.

LEP-2 + Higgs global fit

The other EFT coefficients have been marginalised.



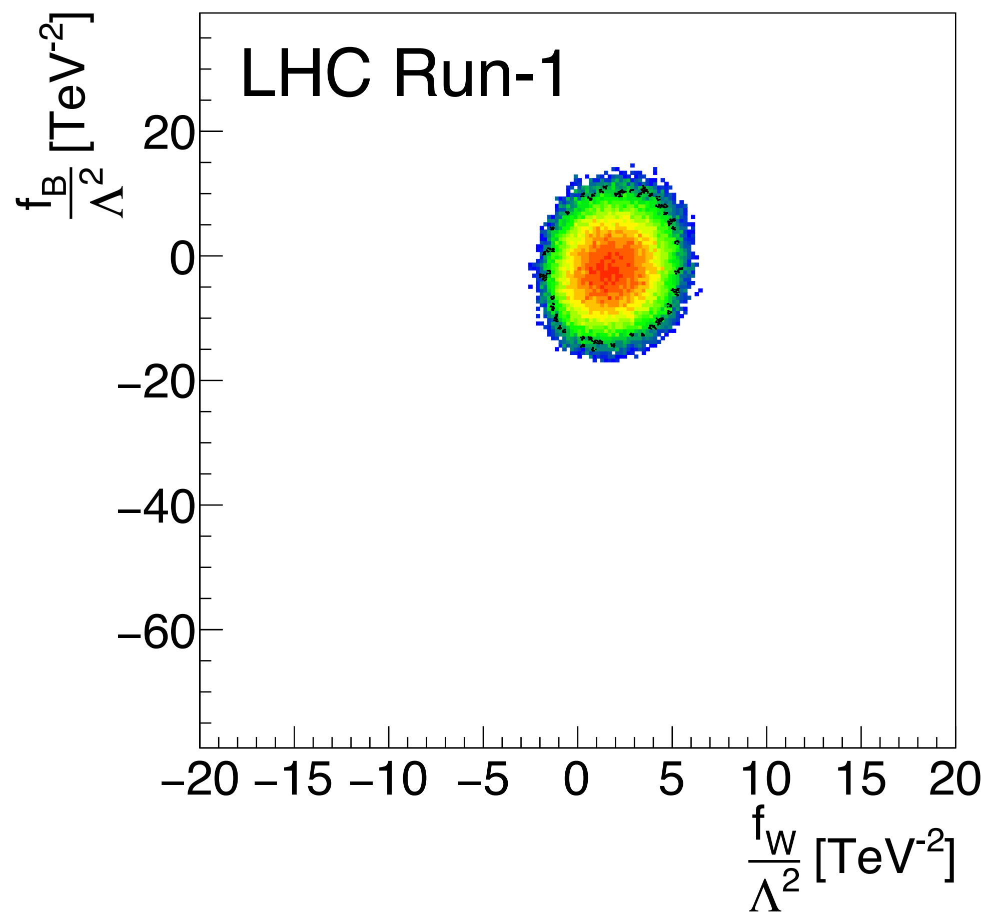
Falkowski, Gonzalez-Alonso, Greljo, D.M. 1508.00581

Combining Higgs and diboson data provides much stronger constraints.

WW/WZ production at LHC

Taken at face value, LHC already provides much stronger constraints than LEP.

[Tilman et al. 1604.03105]



(these operators generate two aTGC)

However, the validity of the EFT assumption is more delicate and has to be considered carefully, see discussion by Francesco.

Important observables for the aTGC

Diboson: - distributions in m_{VV}, $p_T(V)$, $m_{\ell\ell}$, etc..

Higgs:

- VH: $p_T(V)$, m_{VV} distr.
- VBF: $p_T(j_1)$, $p_T(j_2)$ distr.
- $h \to 4\ell$: $m_{\ell\ell}$ distr.