# SFitter Higgs Fits for LHC Run II and the HE-LHC

[1812.xxxxx,1811.08401]

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# Outline

- dimension-6 Lagrangian
- LHC Run-II fit
- HE-LHC fit
- Conclusion

# Dimension-6 Lagrangian

HISZ basis [Hagiwara, Ishihara, Szalapski, Zeppenfeld]

$$\mathcal{L} = \mathcal{L}_{\text{SM}} + \sum_x \frac{f_x}{\Lambda^2} \mathcal{O}_x$$

$$\mathcal{O}_{GG} = \phi^\dagger \phi \, G^a_{\mu\nu} G^{a\mu\nu} \qquad \mathcal{O}_{WW} = \phi^\dagger \hat{W}_{\mu\nu} \hat{W}^{\mu\nu} \phi \qquad \mathcal{O}_{BB} = \phi^\dagger \hat{B}_{\mu\nu} \hat{B}^{\mu\nu} \phi$$

$$\mathcal{O}_W = (D_\mu \phi)^\dagger \hat{W}^{\mu\nu} (D_\nu \phi) \qquad \mathcal{O}_B = (D_\mu \phi)^\dagger \hat{B}^{\mu\nu} (D_\nu \phi) \qquad \mathcal{O}_{\phi,2} = \frac{1}{2} \partial^\mu \left( \phi^\dagger \phi \right) \partial_\mu \left( \phi^\dagger \phi \right)$$

$$\mathcal{O}_{e\phi,33} = (\phi^\dagger \phi)(\bar{L}_3 \phi e_{R,3}) \qquad \mathcal{O}_{u\phi,33} = (\phi^\dagger \phi)(\bar{Q}_3 \tilde{\phi} u_{R,3}) \qquad \mathcal{O}_{d\phi,33} = (\phi^\dagger \phi)(\bar{Q}_3 \phi d_{R,3})$$

$$\mathcal{O}_{WWW} = \text{Tr} \left( \hat{W}_{\mu\nu} \hat{W}^{\nu\rho} \hat{W}_\rho^\mu \right)$$

correlation of dominant systematic uncertainties

flat theory uncertainties

di-higgs not included

# Dimension-6 Lagrangian

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$$\mathcal{O}_{WWW} = \mathrm{Tr}\left(\hat{W}_{\mu\nu} \hat{W}^{\nu\rho} \hat{W}^\mu_\rho\right) \qquad \mathcal{O}_{BW} = \phi^\dagger \hat{B}_{\mu\nu} \hat{W}^{\mu\nu} \phi \qquad \mathcal{O}_{\phi,1} = (D_\mu \phi)^\dagger \phi \phi^\dagger (D^\mu \phi)$$

$$\mathcal{O}^{(1)}_{\phi Q} = \phi^\dagger (i \overleftrightarrow{D}_\mu \phi)(\bar{Q} \gamma^\mu Q) \qquad \mathcal{O}^{(3)}_{\phi Q} = \phi^\dagger (i \overleftrightarrow{D}^a_\mu \phi)(\bar{Q} \gamma^\mu \sigma^a Q) \qquad \mathcal{O}^{(1)}_{\phi u} = \phi^\dagger (i \overleftrightarrow{D}_\mu \phi)(\bar{u}_R \gamma^\mu u_R)$$

$$\mathcal{O}^{(1)}_{\phi d} = \phi^\dagger (i \overleftrightarrow{D}_\mu \phi)(\bar{d}_R \gamma^\mu d_R) \qquad \mathcal{O}^{(1)}_{\phi e} = \phi^\dagger (i \overleftrightarrow{D}_\mu \phi)(\bar{e}_R \gamma^\mu e_R) \qquad \mathcal{O}_{LLLL} = \phi^\dagger (\bar{L} \gamma_\mu)(\bar{L} \gamma^\mu L)$$

correlation of dominant systematic uncertainties

flat theory uncertainties

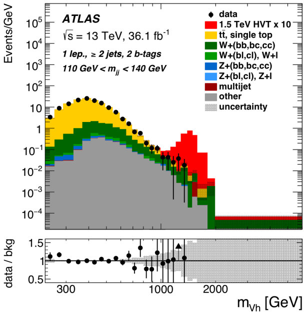
di-higgs not included

# LHC Run II fit - What's new?

- fermionic operators
- data
  - Run II rate measurements
  - ATLAS WZ distribution

    [ATLAS-CONF-2018-034]
  - ATLAS Vh distribution

    [CERN-EP-2017-250,1712.06518v2]
  - EWPD




$$\Gamma_Z,\ \sigma_h^0, \mathcal{A}_l(\tau^{\text{pol}}),\ R_l^0,\ \mathcal{A}_l(\text{SLD}),\ A_{\text{FB}}^{0,l},\ R_c^0,\ R_b^0, \mathcal{A}_c,\ \mathcal{A}_b,\ A_{\text{FB}}^{0,c},\ A_{\text{FB,SLD/LEP}}^{0,b}$$

$$M_W,\ \Gamma_W,\ \text{BR}(W \to l\nu)$$

[LEP/SLD 0509008, PDG]

# LHC Run II fit - Rate measurements

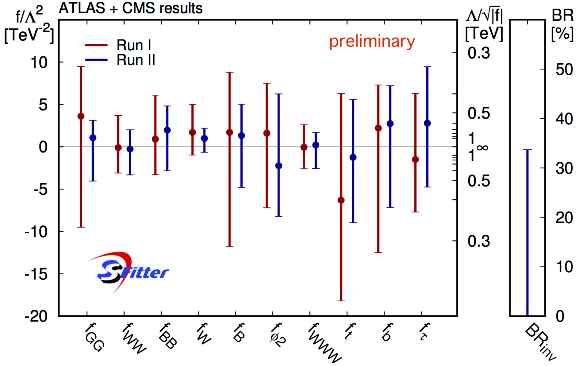
| production/decay mode | ATLAS | CMS |
|---|---|---|
| $H \to WW$ | Ref. [11] | Ref. [12] |
| $H \to ZZ$ | Ref. [15] | Ref. [16, 17] |
| $H \to \gamma\gamma$ | Ref. [1] | Ref. [2] |
| $H \to \tau\bar{\tau}$ | | Ref. [9, 10] |
| $H \to \mu\bar{\mu}$ | Ref. [7] | Ref. [8] |
| $H \to b\bar{b}$ | Ref. [3] | Ref. [4] |
| $H \to Z\gamma$ | Ref. [13] | Ref. [14] |
| $H \to$ invisible | | Ref. [5, 6] |
| $t\bar{t}H$ production | | |
| $H \to \gamma\gamma$ | Ref. [18] | Ref. [2] |
| $H \to$ leptons | Ref. [19] | Ref. [20, 21] |
| $H \to b\bar{b}$ | Ref. [18] | Ref. [22] |
| kinematic distributions | Vh EXO Ref. [25] | |
| | WZ Ref. [23] | |

# LHC Run II fit

[SFitter Run I: Butter, Éboli, Gonzalez-Fraile, Gonzalez-Garcia, Plehn, Rauch (1604.03105)]

[Ellis, Murphy, Sanz, You (1803.03252)] ➜ see Tevong You's talk

95% CL without fermionic operators




tth measurements disentangle $\mathcal{O}_{GG}$ and $\mathcal{O}_t$

limits on bosonic operators improved by distributions

# LHC Run II fit

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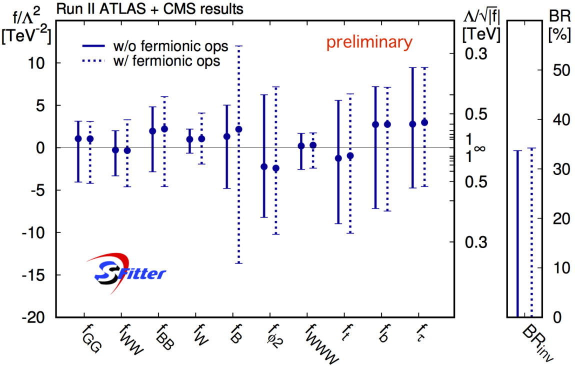



inclusion of fermionic operators weakens limits on bosonic operators

# Higgs limits at a 27 TeV collider

# Higgs limits at a 27 TeV collider

interpolated from 8 TeV results

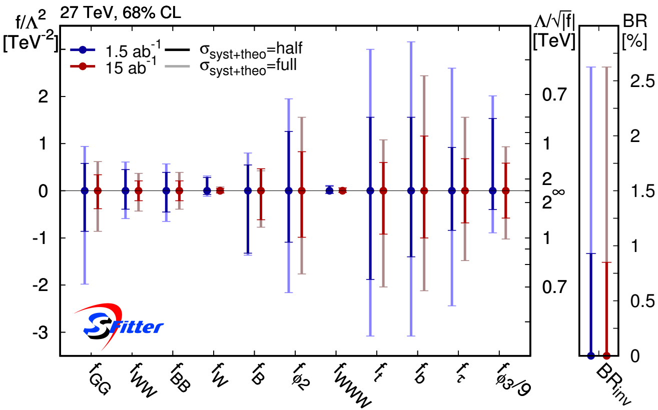
Higgs self-coupling included [Gonçalves, Han, Kling, Plehn, Takeuchi]

10 operators $+\mathcal{O}_{\phi 3}$ (no fermionic operators)

$$\mathcal{O}_{\phi 3} = -(\phi^\dagger \phi)^3/3 \qquad \left| \frac{\Lambda}{\sqrt{f_{\phi 3}}} \right| \gtrsim \begin{cases} 1\ \text{TeV} & 68\%\ \text{C.L.} \\ 700\ \text{GeV} & 95\%\ \text{C.L.} \end{cases}$$

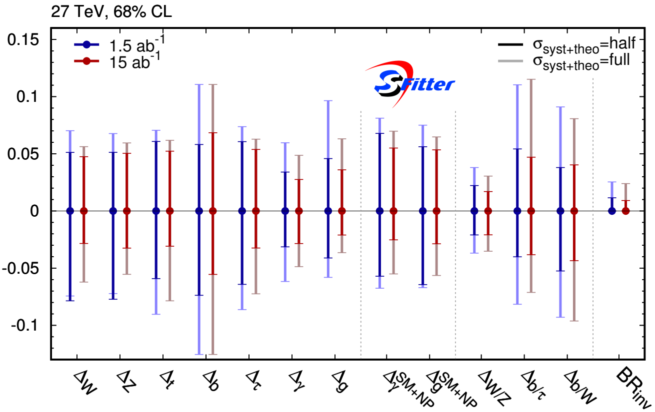
| channel | observable | # bins | range [GeV] |
|---|---|---|---|
| $WW \to (\ell\nu)(\ell\nu)$ | $m_{\ell\ell'}$ | 10 | $0 - 4500$ |
| $WW \to (\ell\nu)(\ell\nu)$ | $p_T^{\ell_1}$ | 8 | $0 - 1750$ |
| $WZ \to (\ell\nu)(\ell\ell)$ | $m_T^{WZ}$ | 11 | $0 - 5000$ |
| $WZ \to (\ell\nu)(\ell\ell)$ | $p_T^{\ell\ell}$ $(p_T^Z)$ | 9 | $0 - 2400$ |
| WBF, $H \to \gamma\gamma$ | $p_T^{\ell_1}$ | 9 | $0 - 2400$ |
| $VH \to (0\ell)(b\bar{b})$ | $p_T^V$ | 7 | $150 - 750$ |
| $VH \to (1\ell)(b\bar{b})$ | $p_T^V$ | 7 | $150 - 750$ |
| $VH \to (2\ell)(b\bar{b})$ | $p_T^V$ | 7 | $150 - 750$ |
| $HH \to (b\bar{b})(\gamma\gamma)$, $2j$ | $m_{HH}$ | 9 | $200 - 1000$ |
| $HH \to (b\bar{b})(\gamma\gamma)$, $3j$ | $m_{HH}$ | 9 | $200 - 1000$ |

# Higgs limits at a 27 TeV collider




full = current systematic and theory uncertainties

# Higgs limits at a 27 TeV collider




full = current systematic and theory uncertainties

rate measurements systematics dominated

# Conclusions

## LHC Run II

- tth measurements disentangle top and gluon couplings
- fermionic operators and EWPD included
- inclusion of fermionic operators weakens limits on (some) operators

## HE-LHC

- Higgs self coupling
- TeV-scale reach for $\mathcal{O}(1)$ couplings

Thank you for your attention!

Backup

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