Diboson production at FCC-ee and impact on global fits

Milan Christmas Meeting
Università degli Studi di Milano
22 Dicembre 2023

Eugenia Celada
University of Manchester

MANCHESTER 1824
The University of Manchester

erc

7. Multiboson production at a multi-TeV muon collider

Eugenia Celada

21/12/22, 17:30

MCM22

EC, T. Han, W. Kilian, N. Kreher, Y. Ma, F. Maltoni, D. Pagani, J. Reuter, T. Striegl, K. Xie [2312.13082]

Diboson FCC-ee

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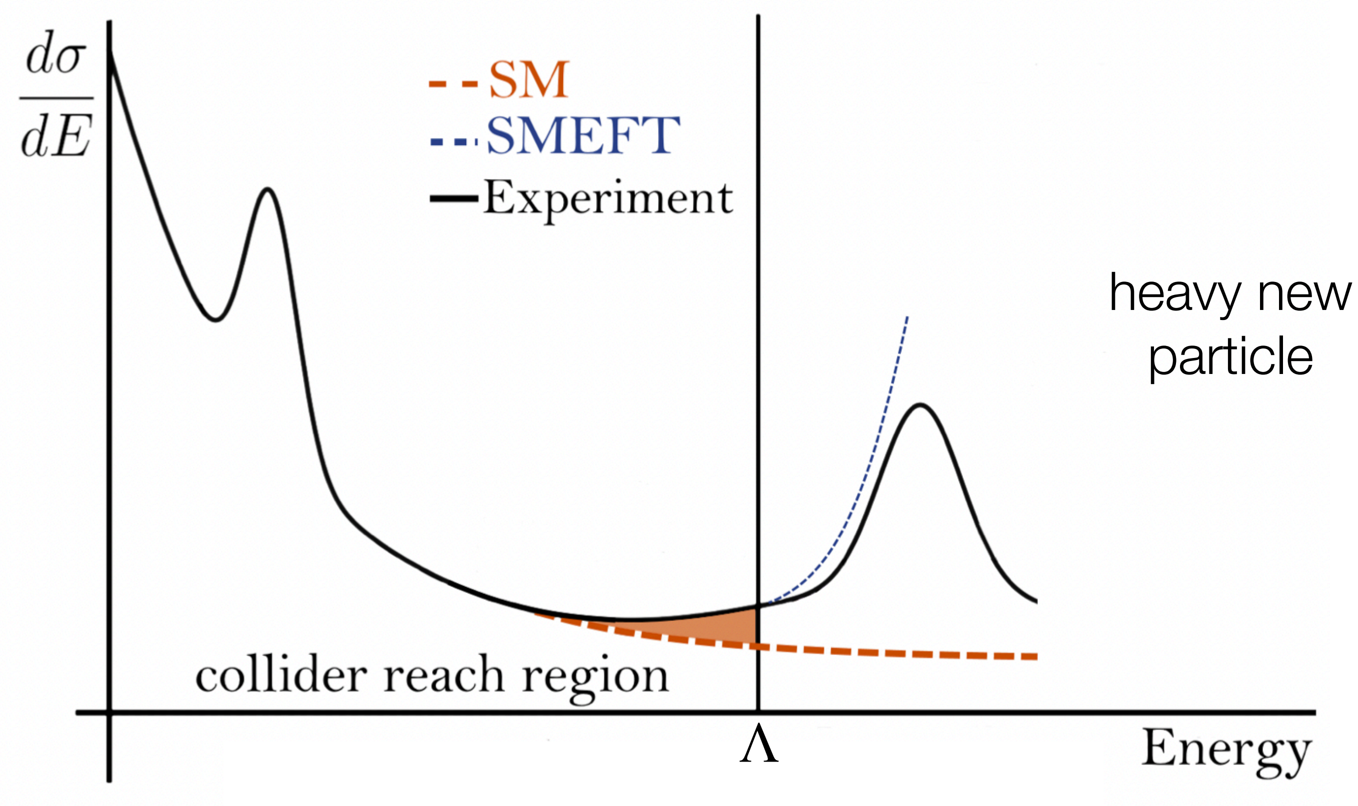
The SMEFT



Original fig. by C. Severi, M. Thomas, E. Vryonidou

$$\mathcal{L}_{\text{EFT}} = \sum_i \frac{c_i}{\Lambda^{d-4}} \mathcal{O}_i^{(d)} = \mathcal{L}_{\text{SM}}^{(4)} + \sum_i \frac{c_i^{(5)}}{\Lambda} \mathcal{O}_i^{(5)} + \sum_i \frac{c_i^{(6)}}{\Lambda^2} \mathcal{O}_i^{(6)} + \ldots$$

SM fields and symmetries

Ultimate goal: bounds on Wilson coefficients → constraints on UV models

Higgs and EW physics at FCC-ee

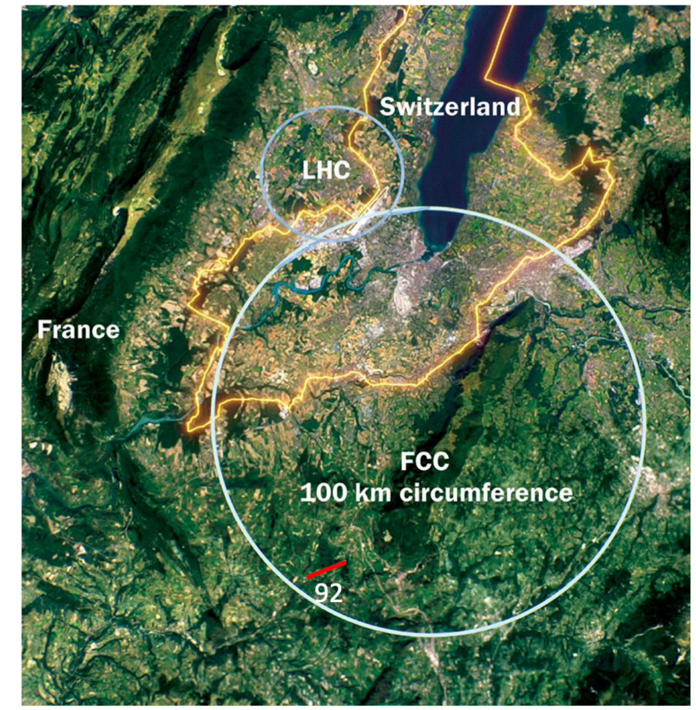
FCC-ee

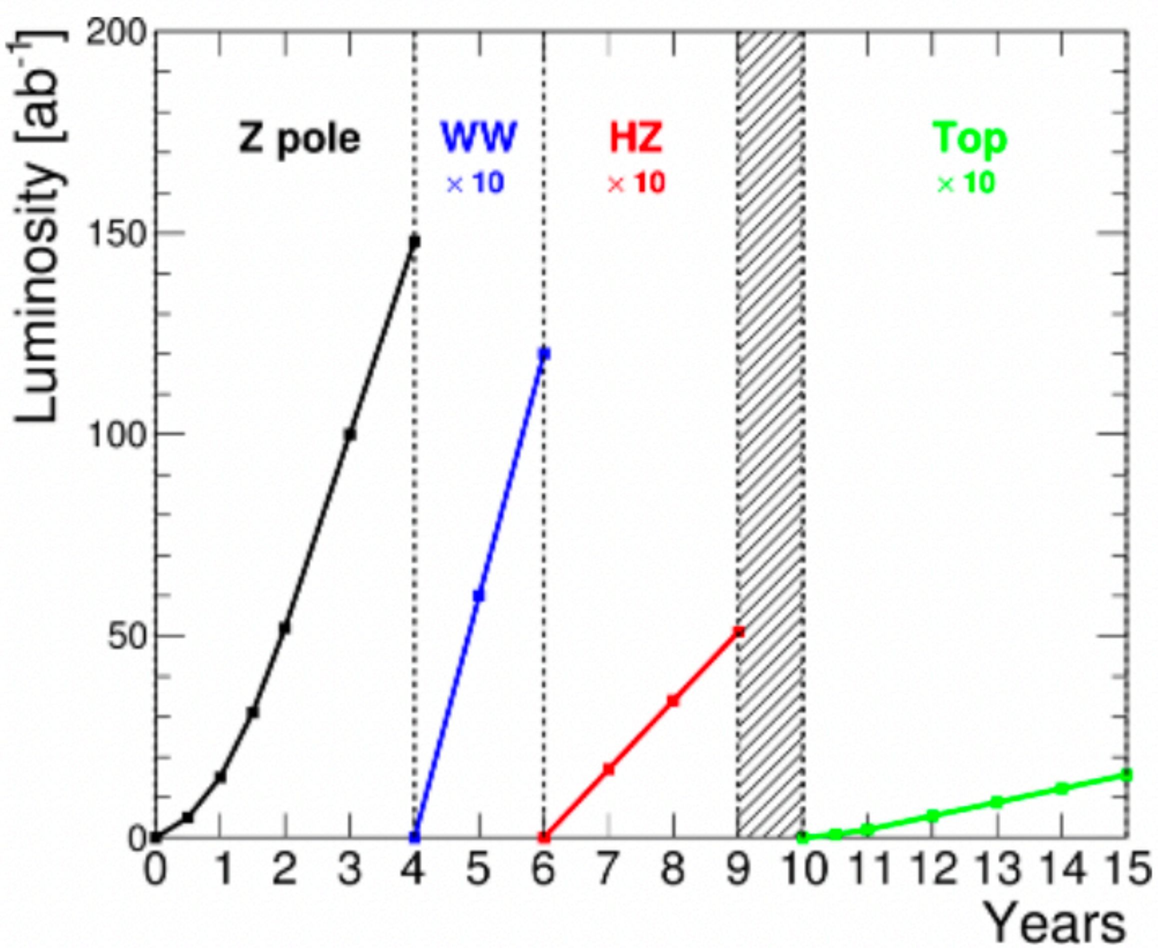
- circular electron-positron collider

Higgs and EW physics at FCC-ee

FCC-ee

- circular electron-positron collider
- to be built at CERN
- four operation energies over a 15-year program
  $\sqrt{s} = 90, 160, 240, 365$ GeV





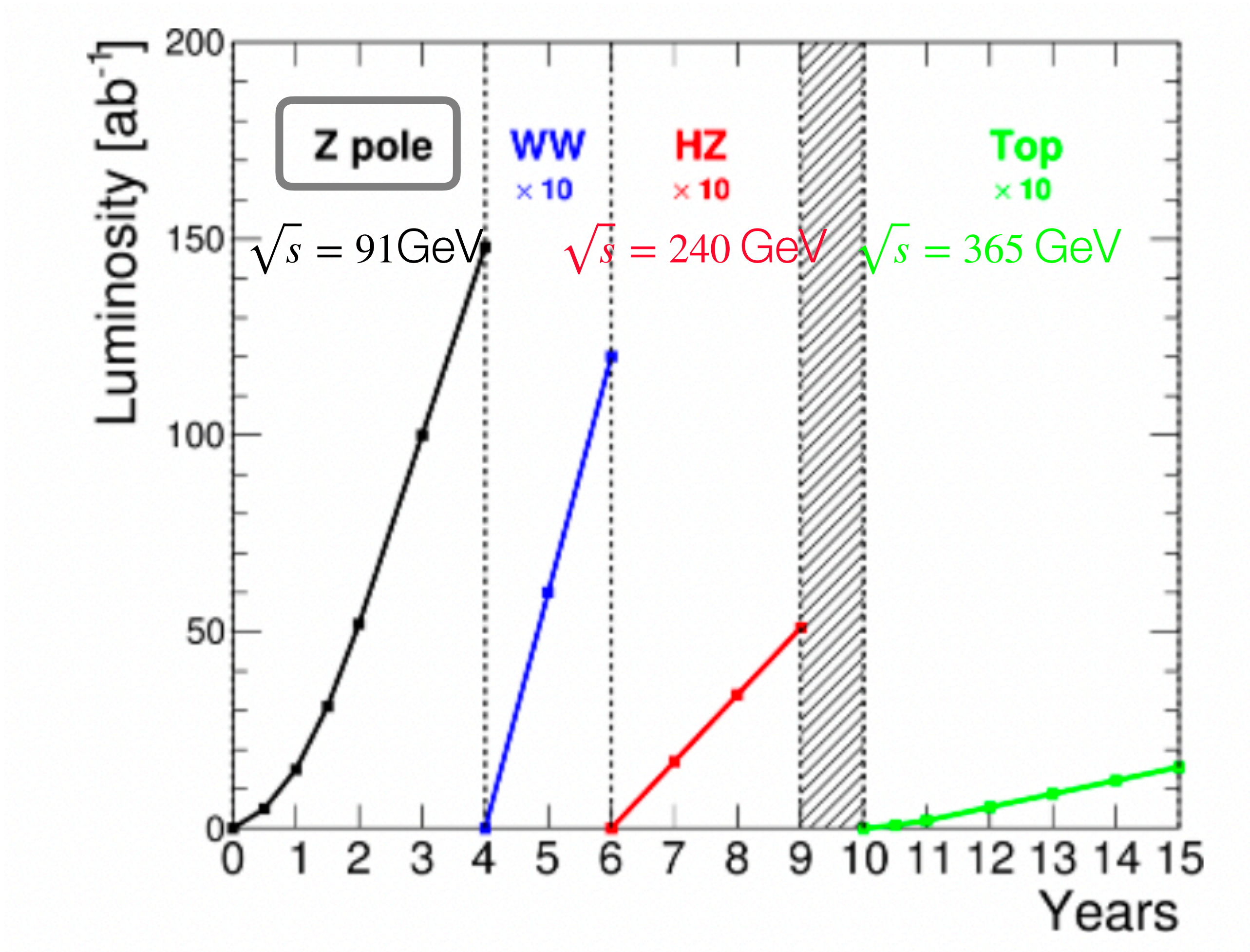
FCC-ee design report [e2019-900045-4]

Higgs and EW physics at FCC-ee

EWPOs

$$\alpha_{\rm EW}(m_Z), \Gamma_Z, A_e, A_\mu, A_\tau, A_b, A_c, \sigma^0_{\rm had}, R_e, R_\mu, R_\tau, R_b, R_c$$

$$A_f = \frac{2 g_V^f g_A^f}{\left(g_V^f\right)^2 + \left(g_A^f\right)^2} \qquad \sigma^0_{\rm had} = \frac{12\pi}{\hat{m}_Z^2}\frac{\Gamma_e \Gamma_{\rm had}}{\Gamma_Z^2} \qquad R_f = \frac{\Gamma_f}{\Gamma_{\rm had}}$$



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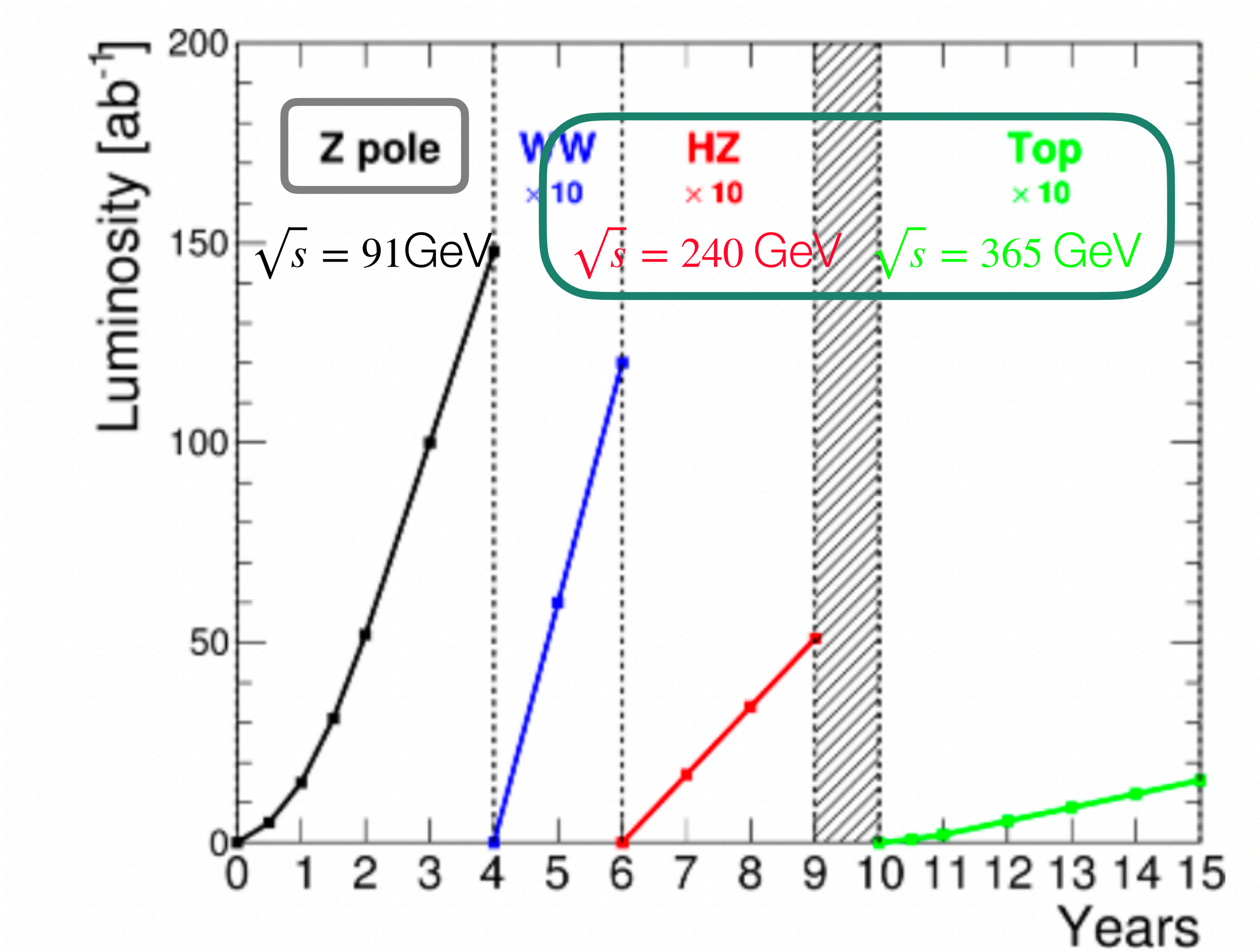
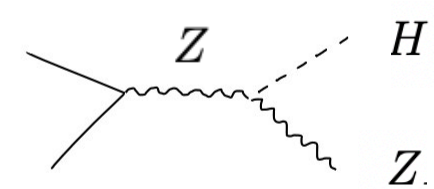
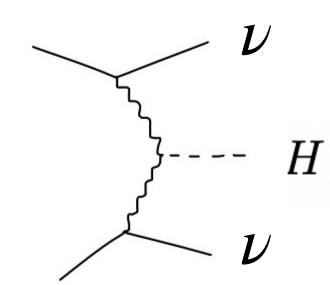


Higgs production

- Higgsstrahlung $\sigma(ZH)$, $\sigma(ZH) \times BR(H)$



- W^+W^- fusion $\sigma(\nu\nu H) \times BR(H)$



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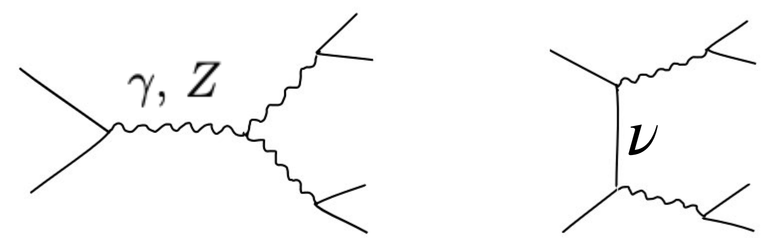
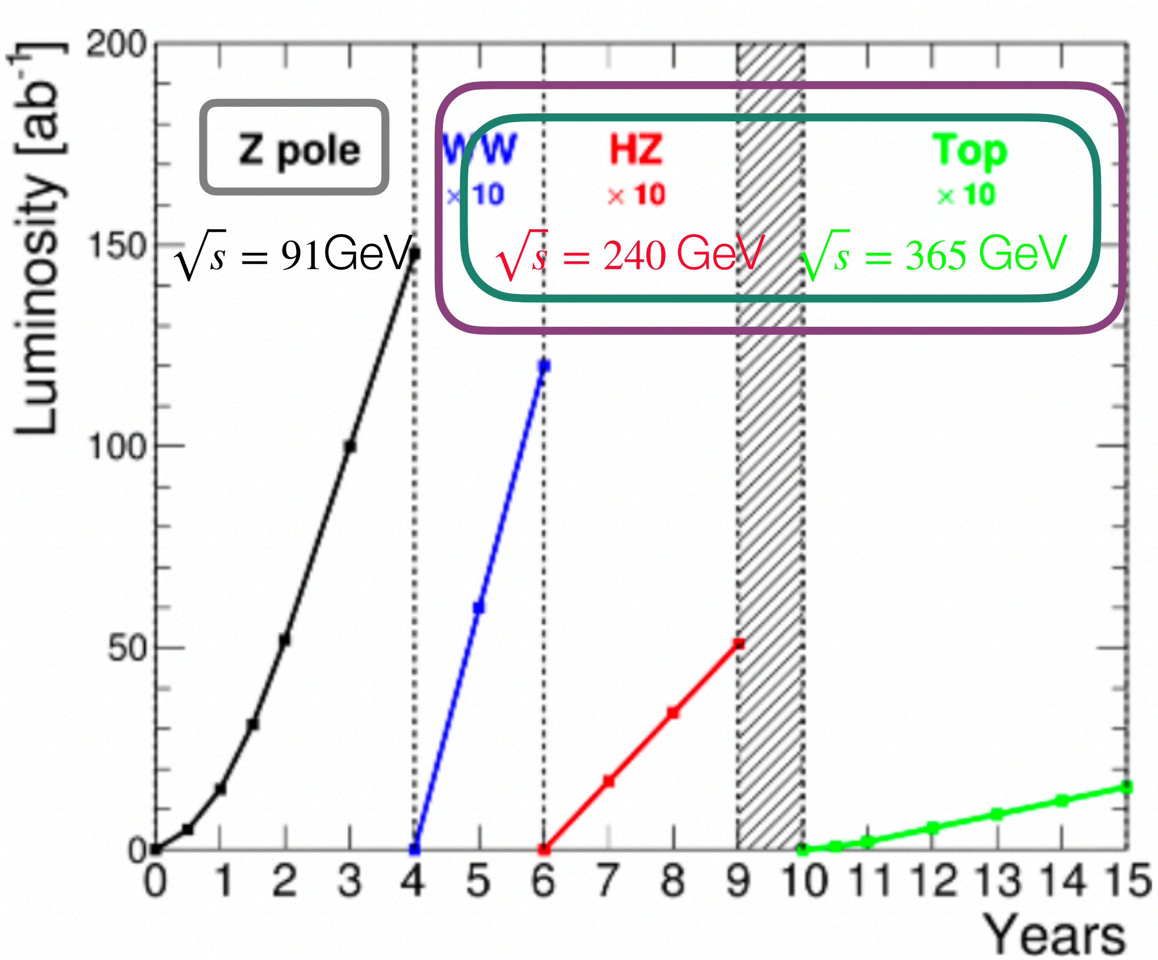
$$e^- e^+ \to (W^- W^+) \to \ 4f$$



Optimal Observables



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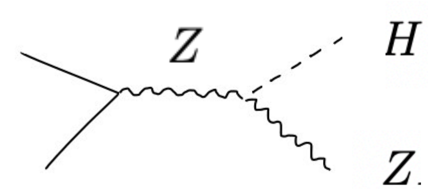

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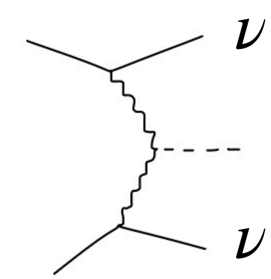
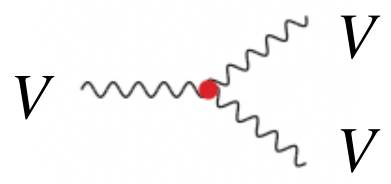


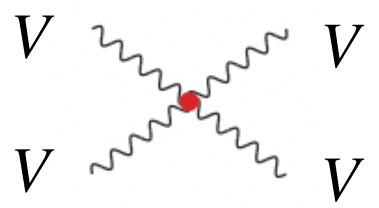
Diboson in SMEFT

- probe of the non abelian nature of the EW gauge group

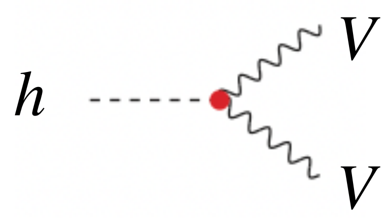
triple gauge couplings (**TGC**)

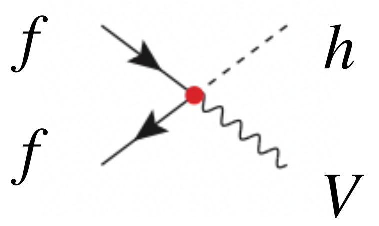


quartic gauge couplings (**QGC**)



- interplay with the Higgs sector





- constrain operators that do not enter in EWPOs

Bosonic operators

Warsaw basis

Operator	Definition
bosonic	
$\mathcal{O}_{\phi B}$	$(\phi^\dagger\phi)B^{\mu\nu}B_{\mu\nu}$
$\mathcal{O}_{\phi W}$	$(\phi^\dagger\phi)W_I^{\mu\nu}W^I_{\mu\nu}$
$\mathcal{O}_{\phi WB}$	$(\phi^\dagger\tau_I\phi)B^{\mu\nu}W^I_{\mu\nu}$
$\mathcal{O}_{\phi d}$	$\partial_\mu(\phi^\dagger\phi)\partial^\mu(\phi^\dagger\phi)$
$\mathcal{O}_{\phi D}$	$(\phi^\dagger D^\mu\phi)^\dagger(\phi^\dagger D_\mu\phi)$
$\mathcal{O}_{WWW}$	$\epsilon_{IJK}W^I_{\mu\nu}W^{J,\nu\rho}W^{K,\mu}_\rho$

W^-W^+ ZH

EWPOs : $\mathcal{O}_{\phi D}$, $\mathcal{O}_{\phi WB}$

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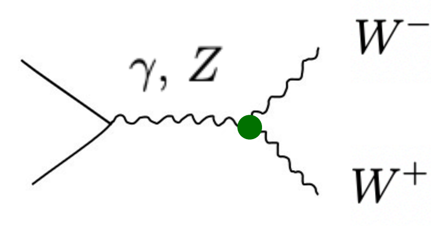
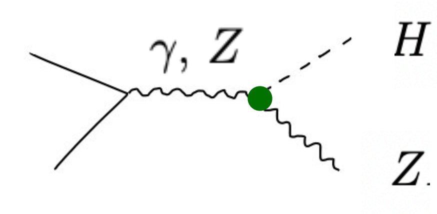
W^-W^+



ZH



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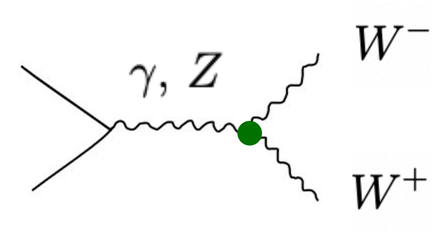
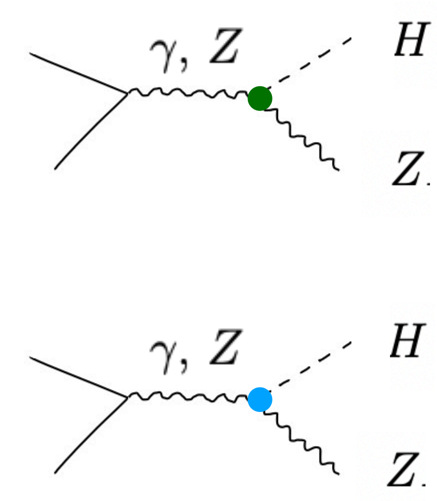


ZH



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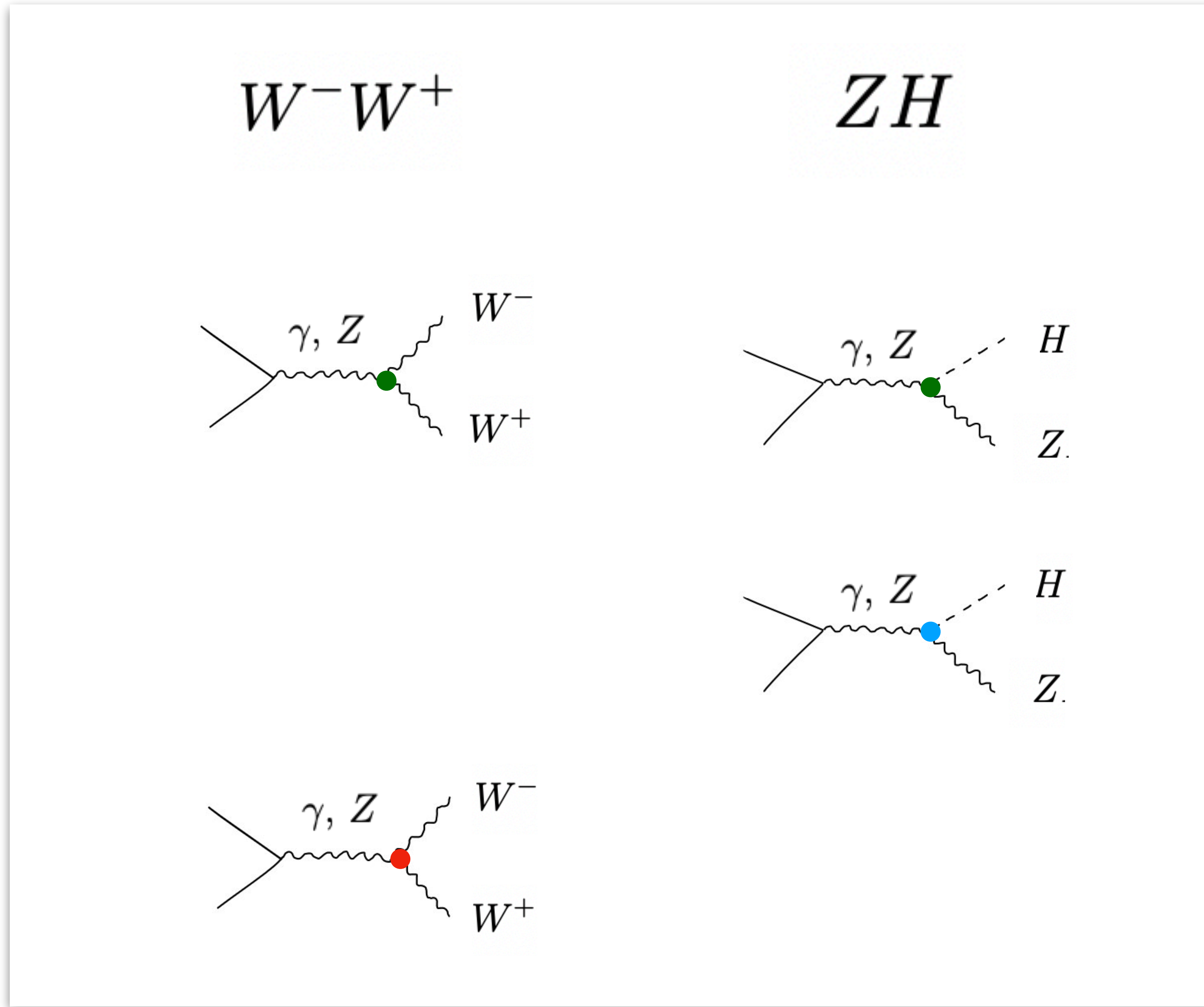

EWPOs : $\mathcal{O}_{\phi D}$ $\mathcal{O}_{\phi WB}$

Two-fermion operators

Warsaw basis

Operator	Definition
two-fermion	
$\mathcal{O}_{\phi\ell_1}^{(1)}$	$i(\phi^\dagger \overleftrightarrow{D}_\mu \phi)(\bar{\ell}_1 \gamma^\mu \ell_1)$
$\mathcal{O}_{\phi\ell_1}^{(3)}$	$i(\phi^\dagger \overleftrightarrow{D}_\mu \tau_I \phi)(\bar{\ell}_1 \gamma^\mu \tau^I \ell_1)$
$\mathcal{O}_{\phi\ell_2}^{(3)}$	$i(\phi^\dagger \overleftrightarrow{D}_\mu \tau_I \phi)(\bar{\ell}_2 \gamma^\mu \tau^I \ell_2)$
$\mathcal{O}_{\phi e}$	$i(\phi^\dagger \overleftrightarrow{D}_\mu \phi)(\bar{e} \gamma^\mu e)$
$\mathcal{O}_{\phi q}^{(3)}$	$\sum_{i=1,2} i(\phi^\dagger \overleftrightarrow{D}_\mu \tau_I \phi)(\bar{q}_i \gamma^\mu \tau^I q_i)$
four-fermion	
$\mathcal{O}_{\ell\ell}$	$(\bar{\ell}_1 \gamma_\mu \ell_2)(\bar{\ell}_2 \gamma^\mu \ell_1)$

$W^- W^+$ $\qquad$ ZH

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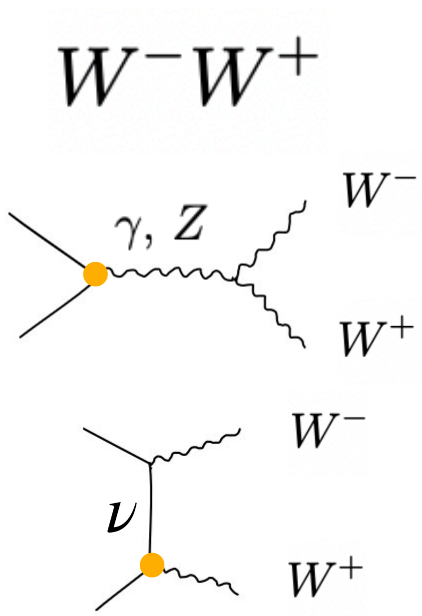

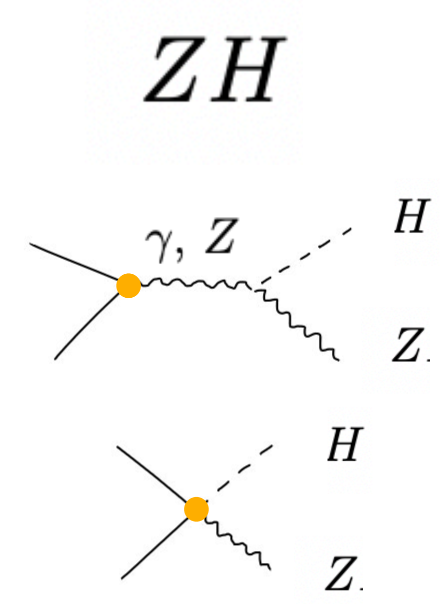

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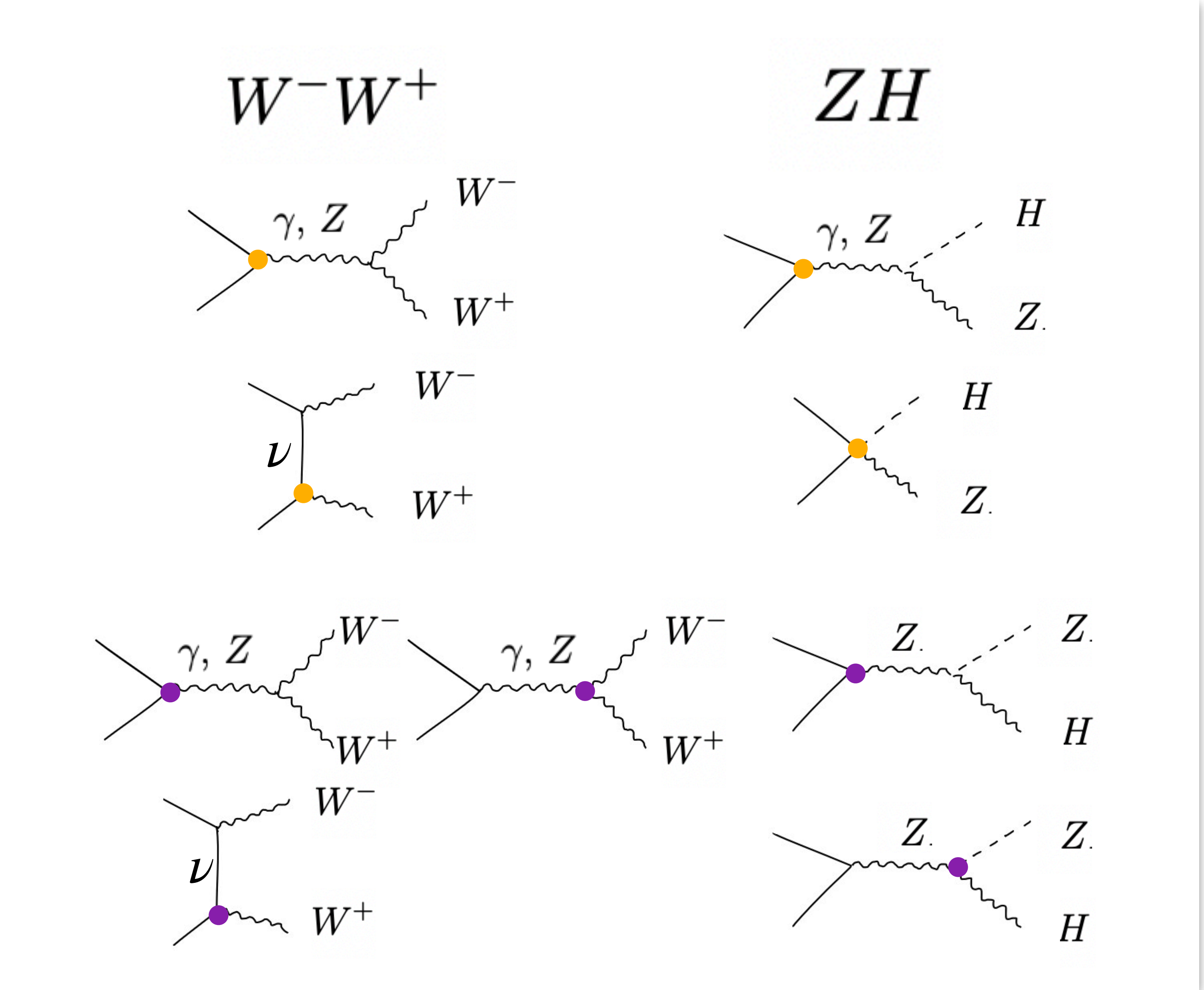

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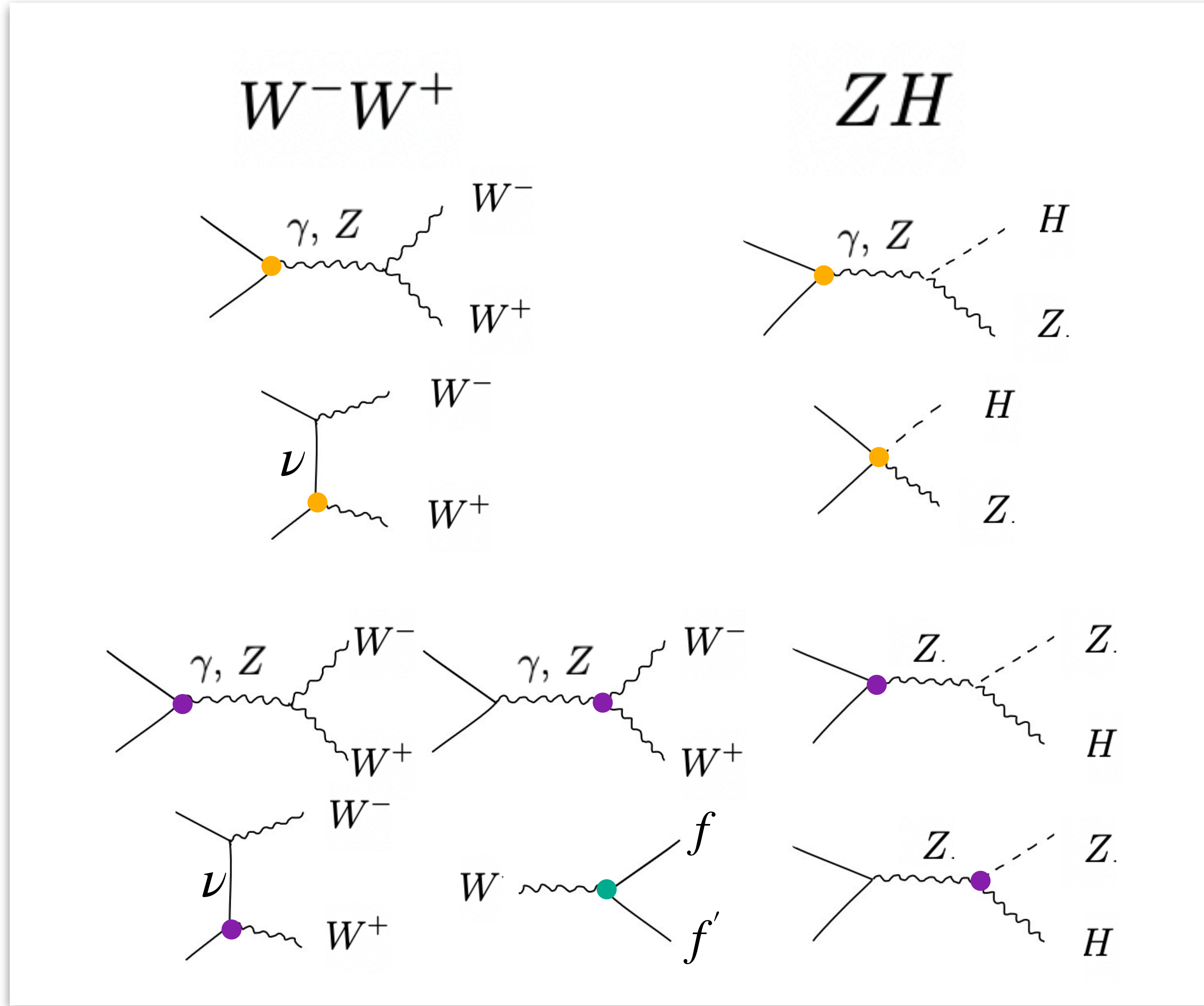

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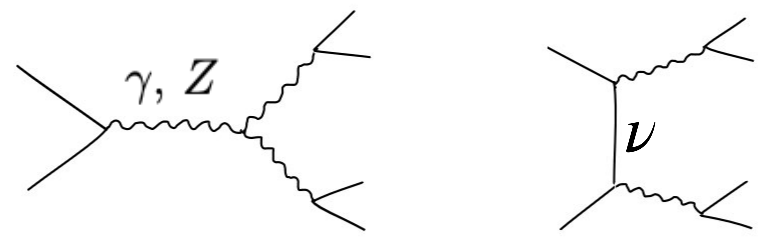
W^+W^- with Optimal Observables

Doubly resonant 4 fermion production

- fully leptonic
- semileptonic
- hadronic

$$e^-e^+ \to (W^-W^+) \to \ 4f$$



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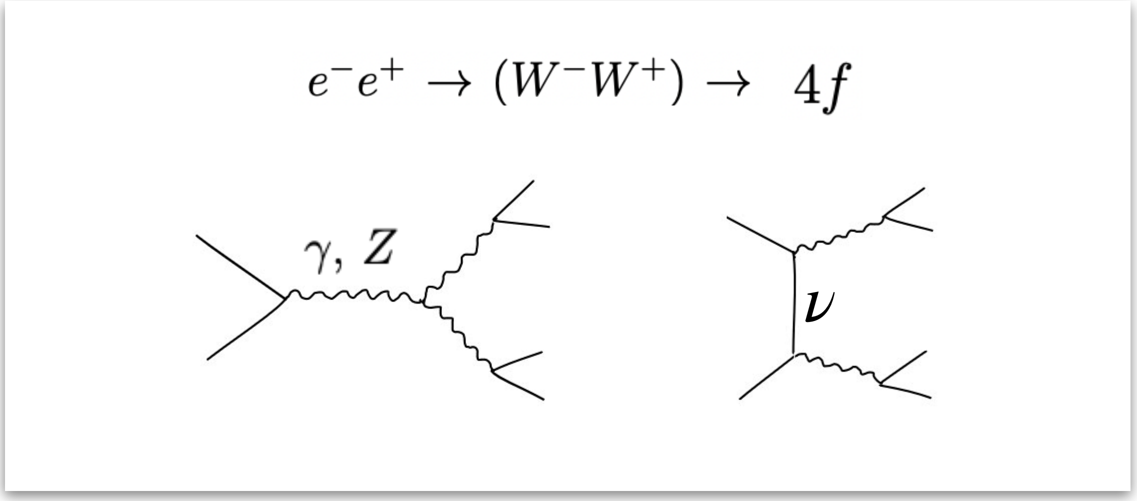

If

- linear dependence on Wilson coeffs.
- systematics is negligible

we can define **Optimal Observables**

- retain all the differential information
- maximal sensitivity to the Wilson coefficients

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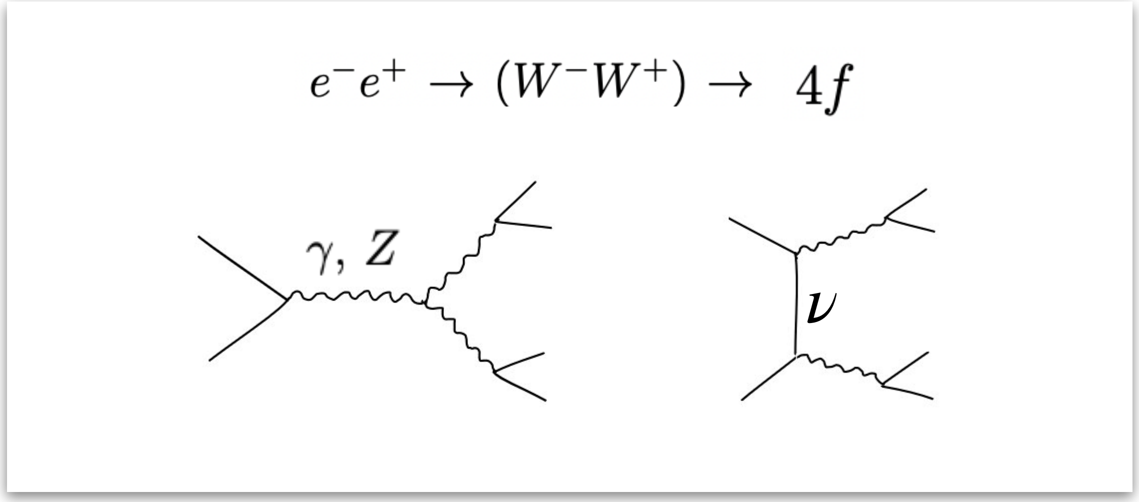

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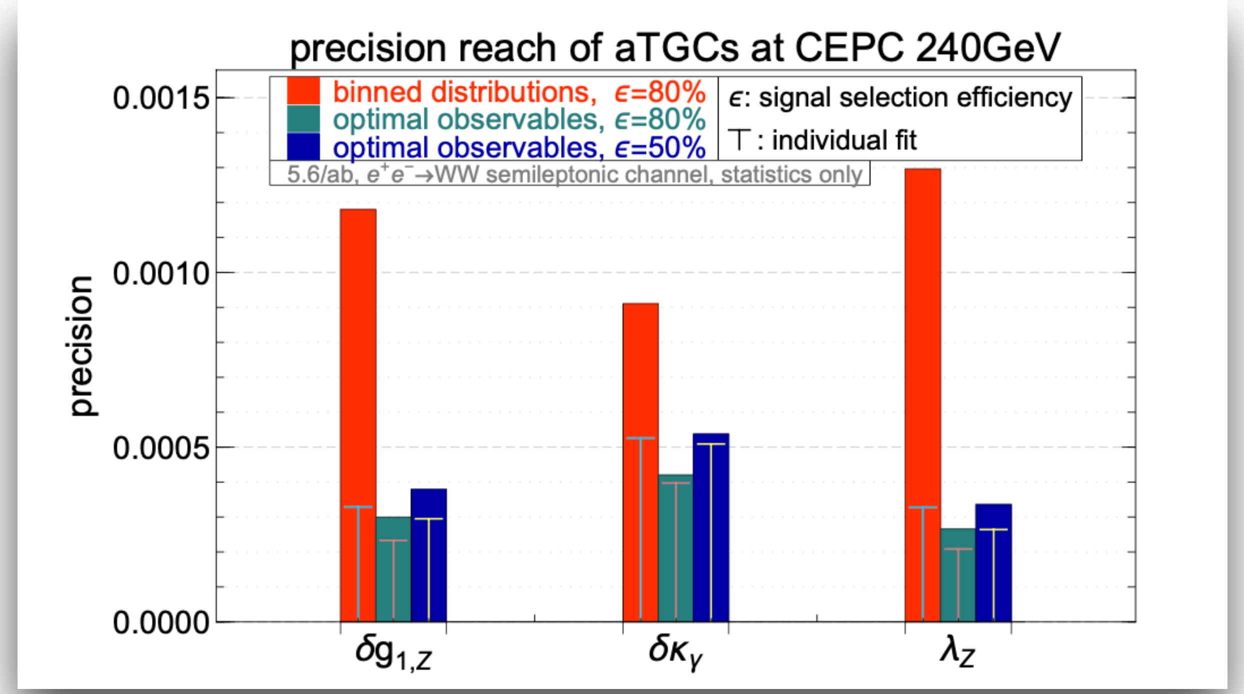


J. de Blas et al. [1907.04311]

Optimal Observables

- Consider a differential distribution

$$\frac{d\sigma}{d\Phi} = S_0(\Phi) + \sum_i c_i S_i(\Phi) \equiv S(\Phi)$$

SM — *set of m Wilson coeffs.* — *linear contribution*

- The Optimal Observables are defined as

n events $n = \mathcal{L}\sigma$

n sets of kinematic variables $\Phi_1, \ldots, \Phi_n$

$$O_i = \frac{1}{n}\sum_k^n \frac{S_i(\Phi_k)}{S_0(\Phi_k)}$$ *~ signal / background*

M. Diehl and O. Nachtmann [9402271]

- The χ^2 is defined as

$$\chi^2 = \sum_i \sum_j (E[O_i] - O_i^{\mathrm{meas}})\ \mathrm{cov}(O_i, O_j)^{-1}\ (E[O_j] - O_j^{\mathrm{meas}})$$

theoretical — *experimental*

Optimal Observables

ASSUMPTIONS

- linear dependence over Wilson coeffs.
- experimental results = SM theory prediction

→ observables redefinition: $\widetilde{\mathcal{O}}_k = c_k$

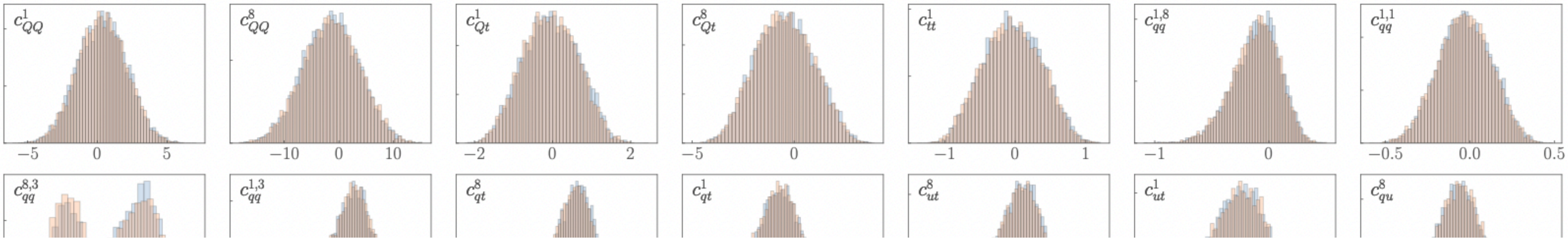
- The new χ^2 is defined as

$$\Delta\chi^2(\boldsymbol{c}) = \sum_{k,k'=1}^{n} c_k \left(\mathrm{cov}\left(c_k, c_{k'}\right)\right)^{-1} c_{k'}$$

- The inverse covariance is given by

$$\mathrm{cov}(c_i, c_j)^{-1} = \mathcal{L}\left(\int \frac{S_i S_j}{S_0} \mathrm{d}\Phi - \frac{1}{\sigma_0} \int S_i \mathrm{d}\Phi \int S_j \mathrm{d}\Phi\right)$$

Global fits with SMEFiT

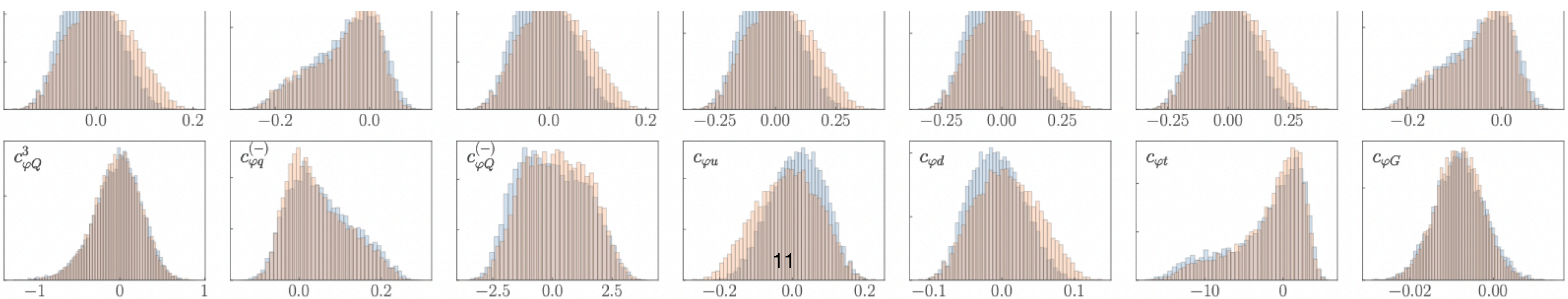


- open source python package for global SMEFT fits

T. Giani, G. Magni, J. Rojo [2302.06660]

- large HEP dataset (LHC Run I and II, LEP EWPOs)

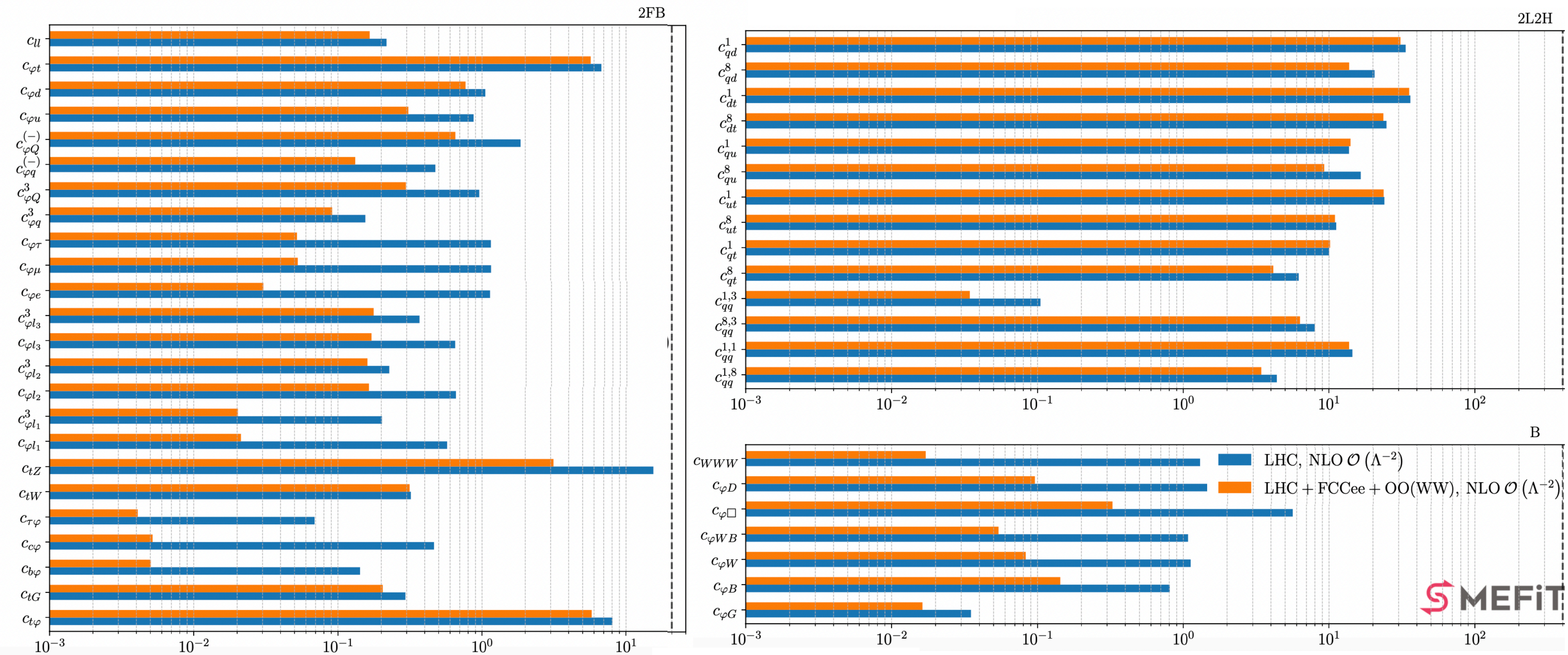
- **soon will support future collider projections (HL-LHC, FCC-ee)**



Results

95% Confidence Level Bounds $(1/\mathrm{TeV}^2)$

Preliminary



EC et al, in preparation

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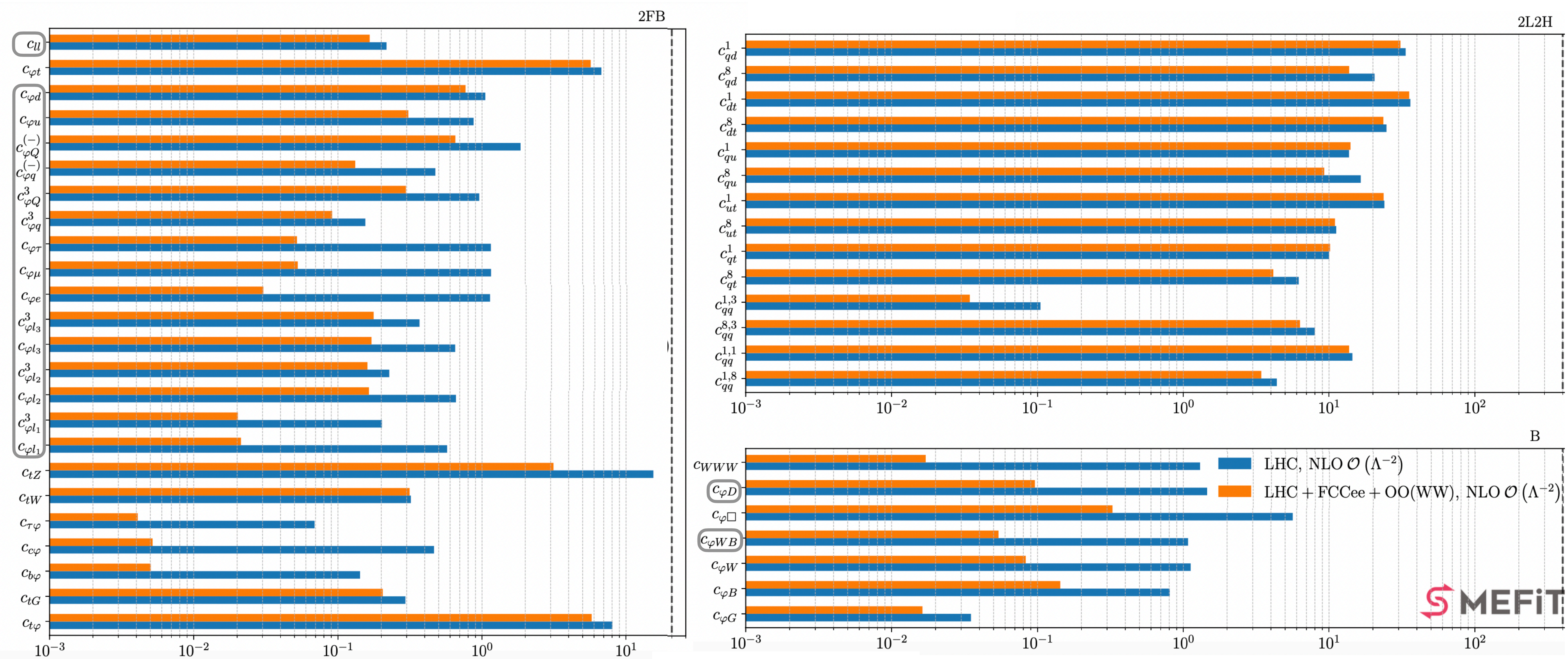

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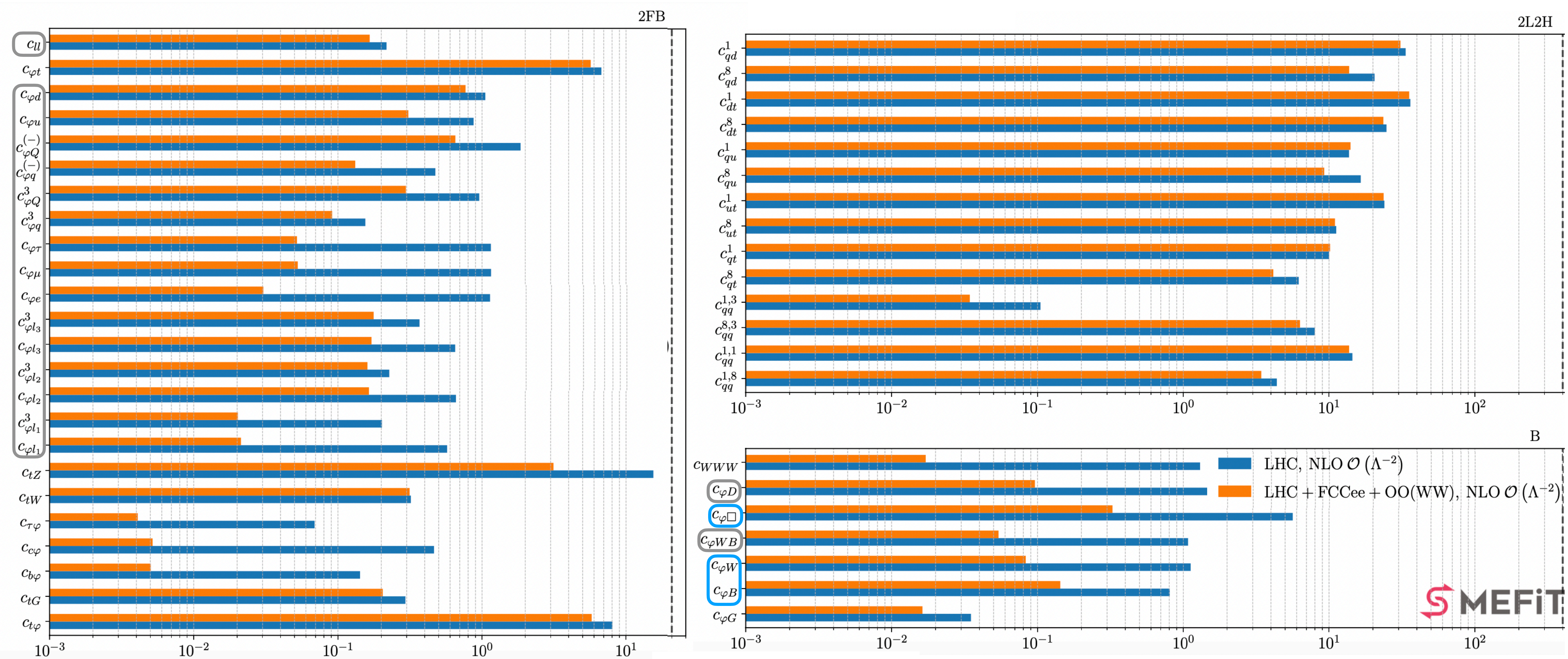
95% Confidence Level Bounds $(1/\text{TeV}^2)$

Preliminary



EC et al, in preparation

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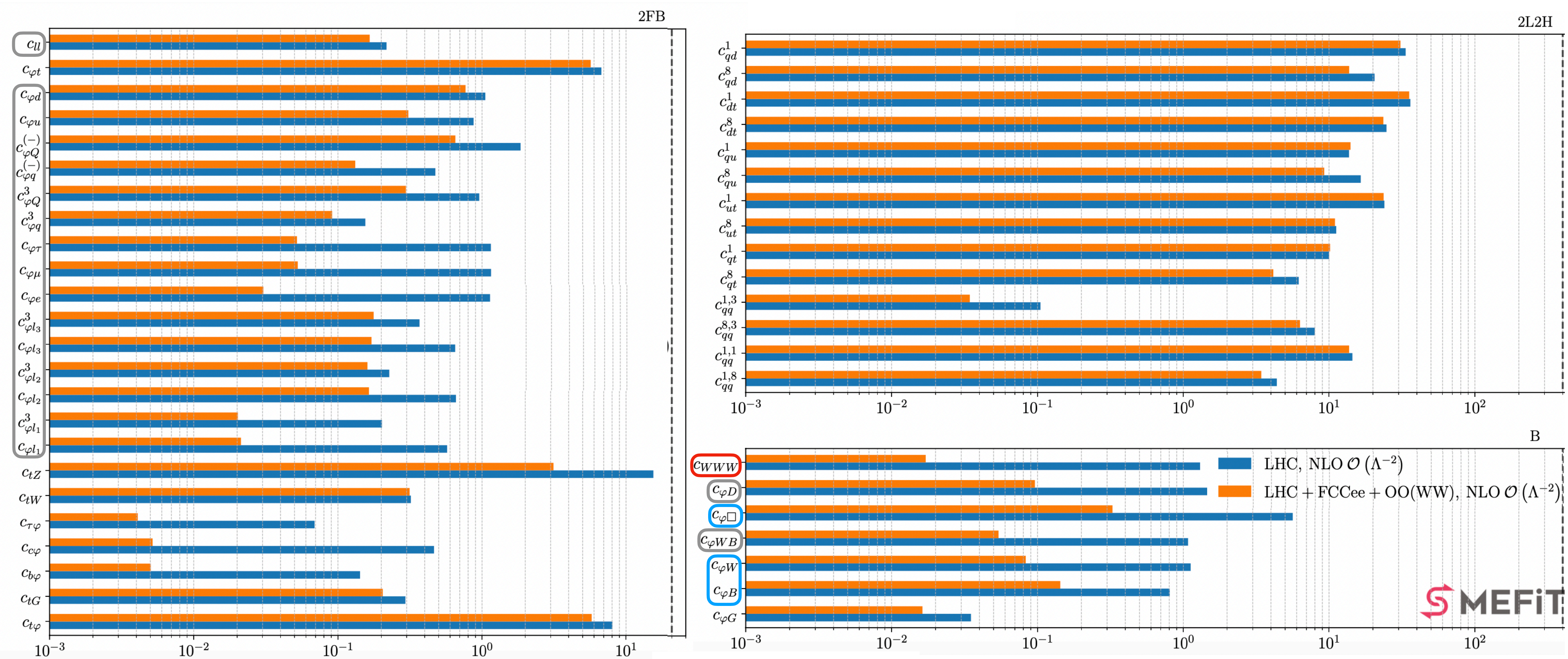

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- **EWPOs dominate the bounds**
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stay tuned for more exciting results