The effective landscape of new physics

Anke Biekötter - JGU Mainz

JOHANNES GUTENBERG UNIVERSITÄT MAINZ

QCD@LHC, Freiburg, Oct 8th, 2024

Outline

- Intro to effective field theory (EFT) and global fits

- How do we improve global EFT fits?

  - Are we ready for a global fit starting from an operator set defined by symmetries?

  - SMEFT@NLO: Curse or blessing?

More SMEFT talks

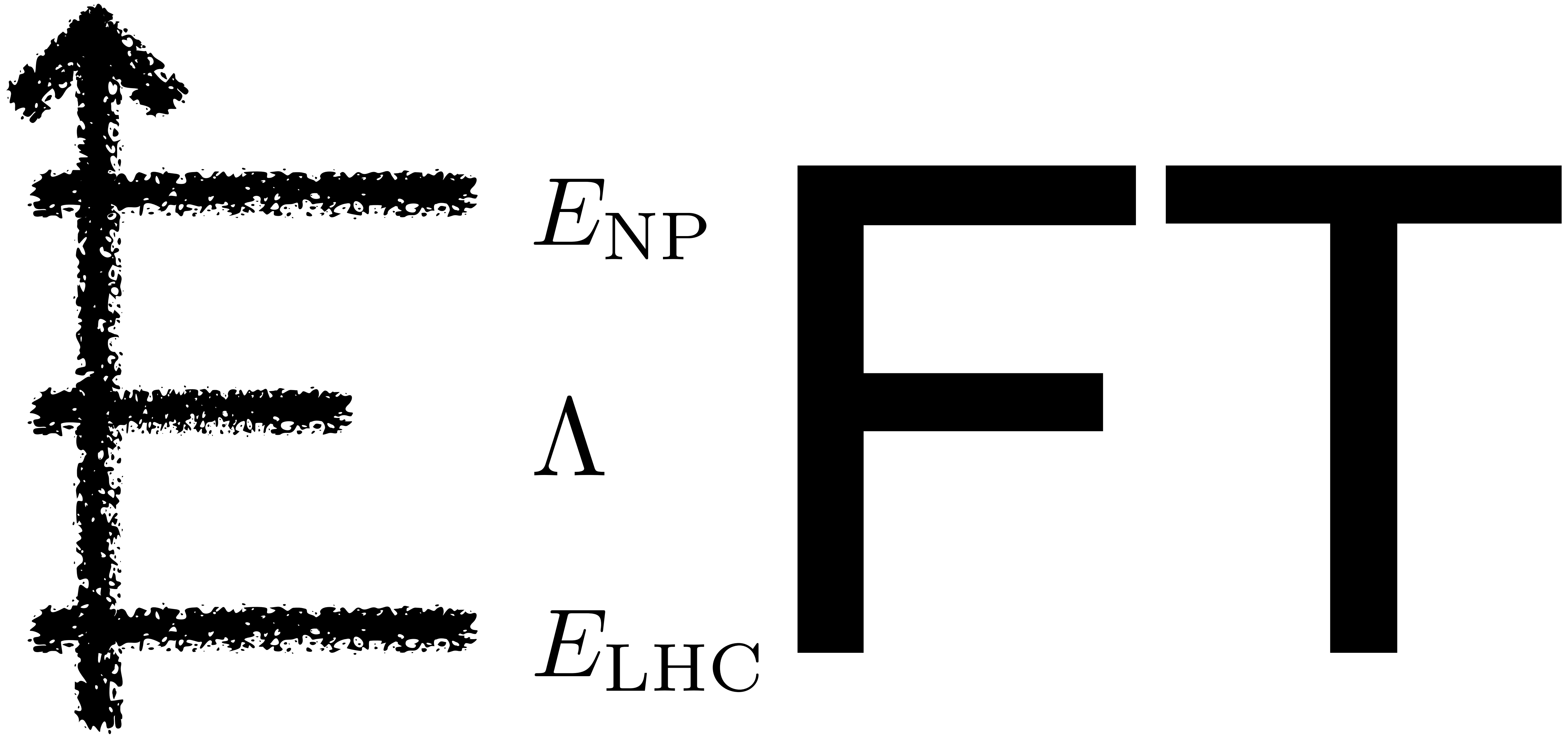
[Marco Vitti]

[Nathan Readioff]

Effective field theory - EFT

EFT

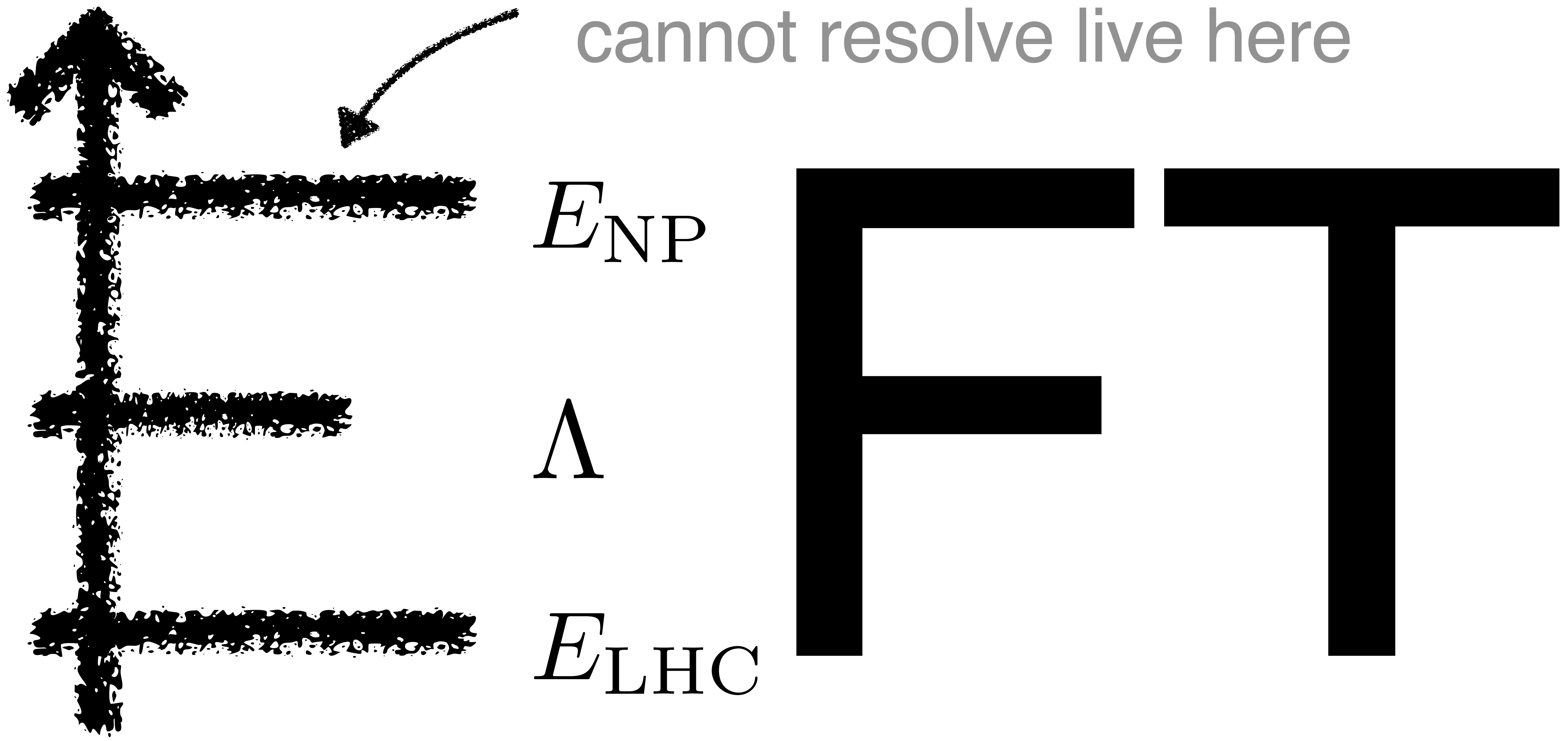
Effective field theory - EFT

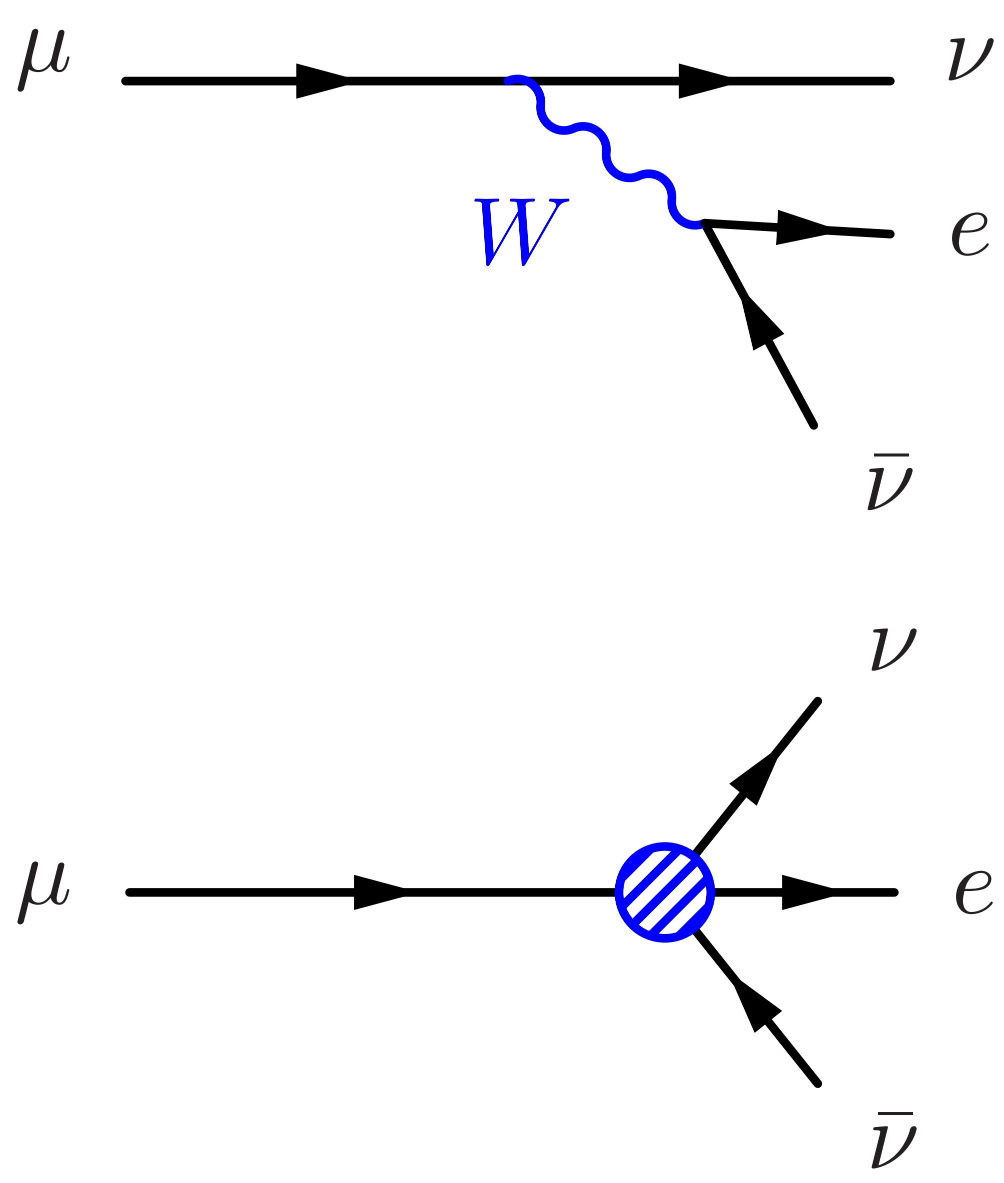


Hierarchy of scales

Effective field theory - EFT

Heavy particles that we cannot resolve live here





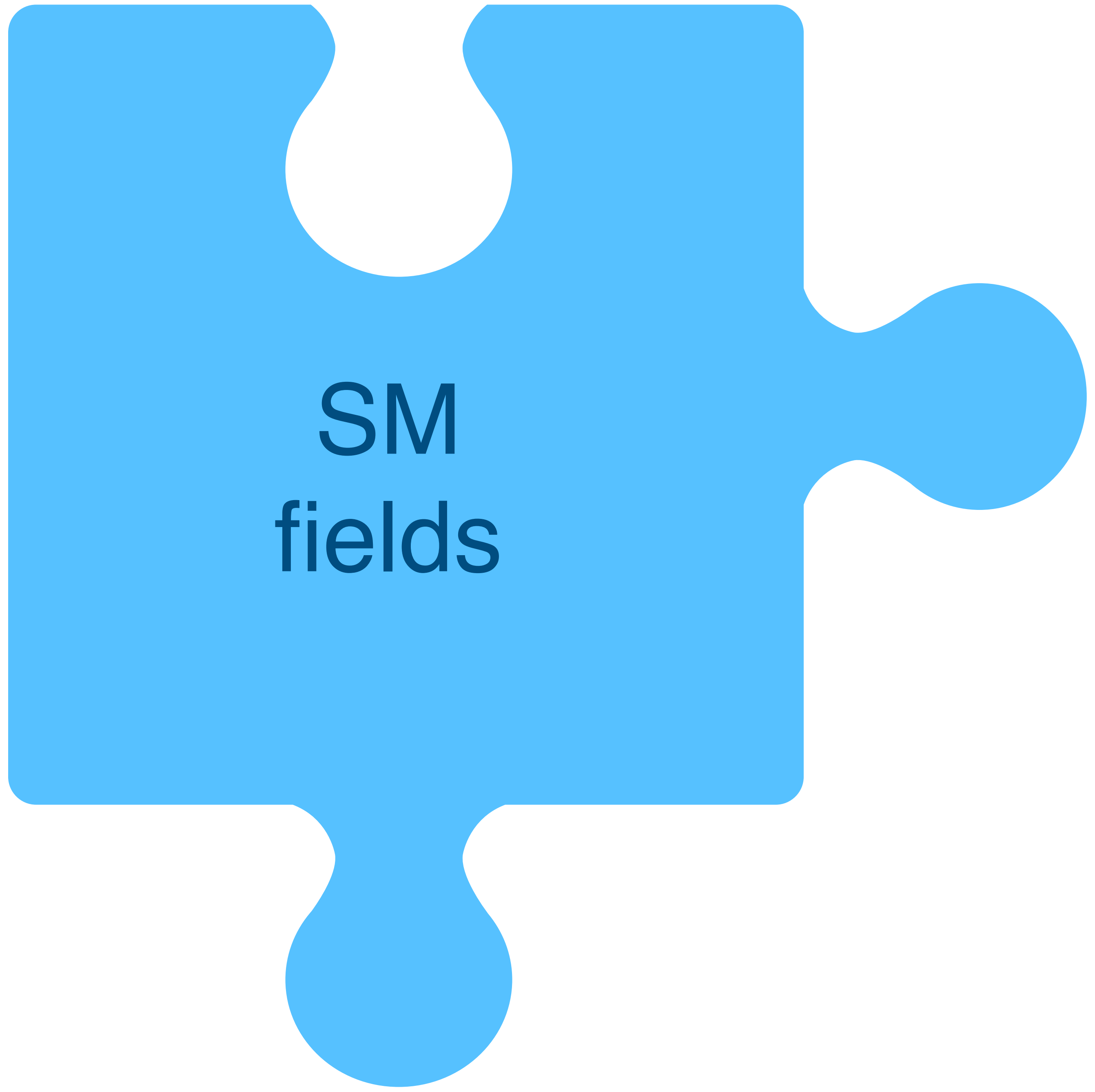
Hierarchy of scales

Describe NP by higher-order interactions of SM fields

EFTs from the bottom-up

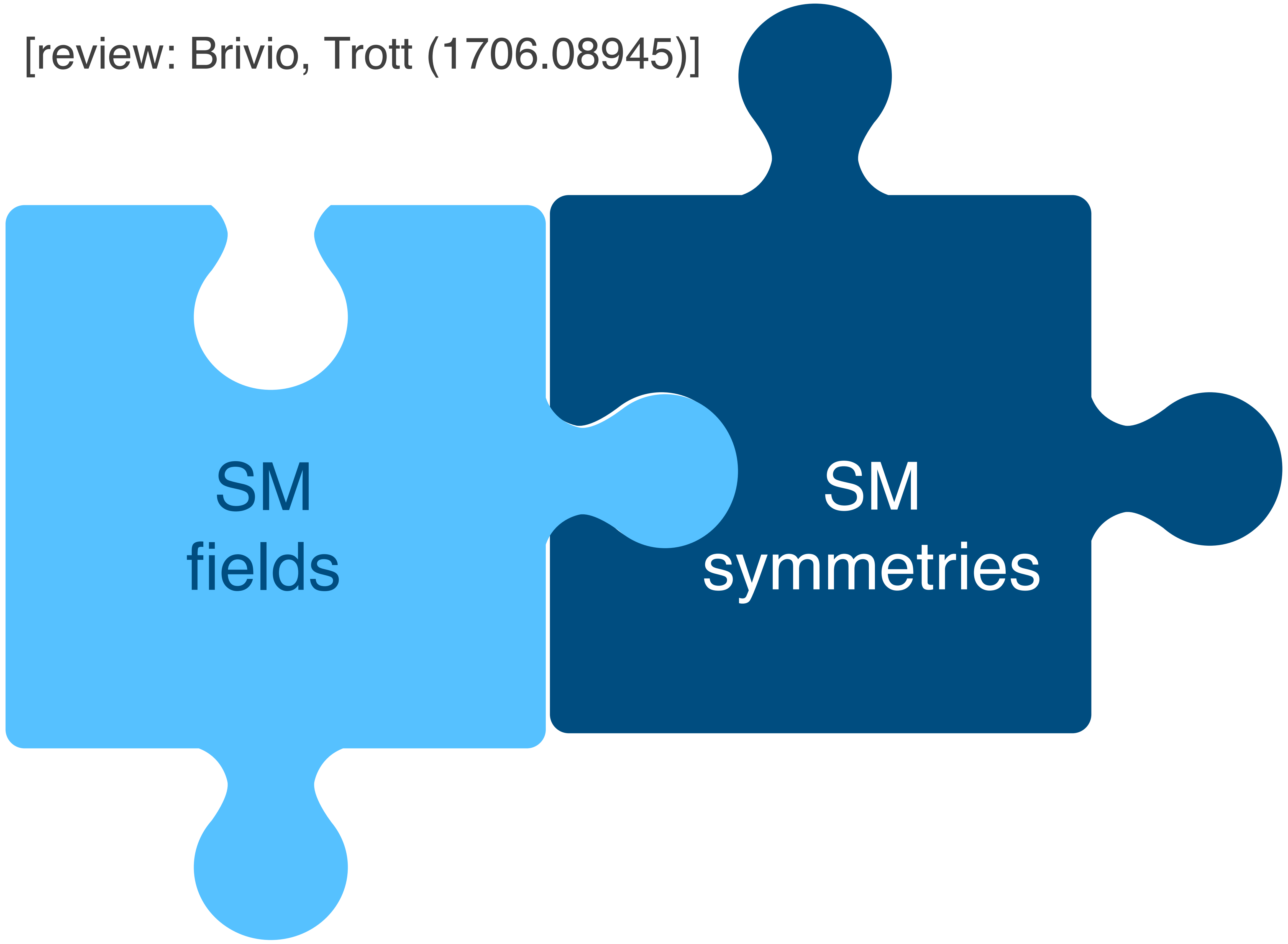
[review: Brivio, Trott (1706.08945)]

At low energies, the SM does a very good job.



EFTs from the bottom-up

[review: Brivio, Trott (1706.08945)]

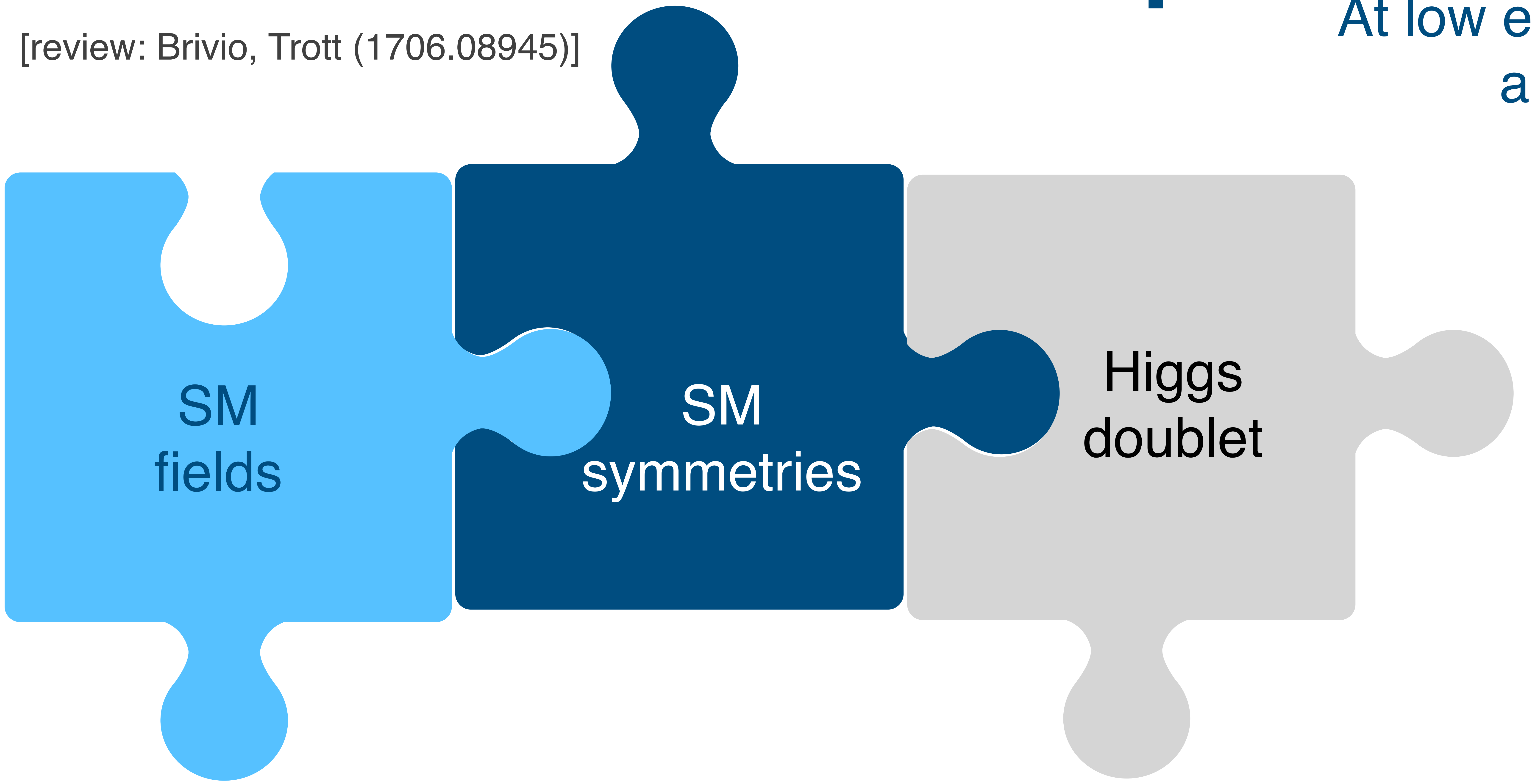


At low energies, the SM does a very good job.

EFTs from the bottom-up

[review: Brivio, Trott (1706.08945)]

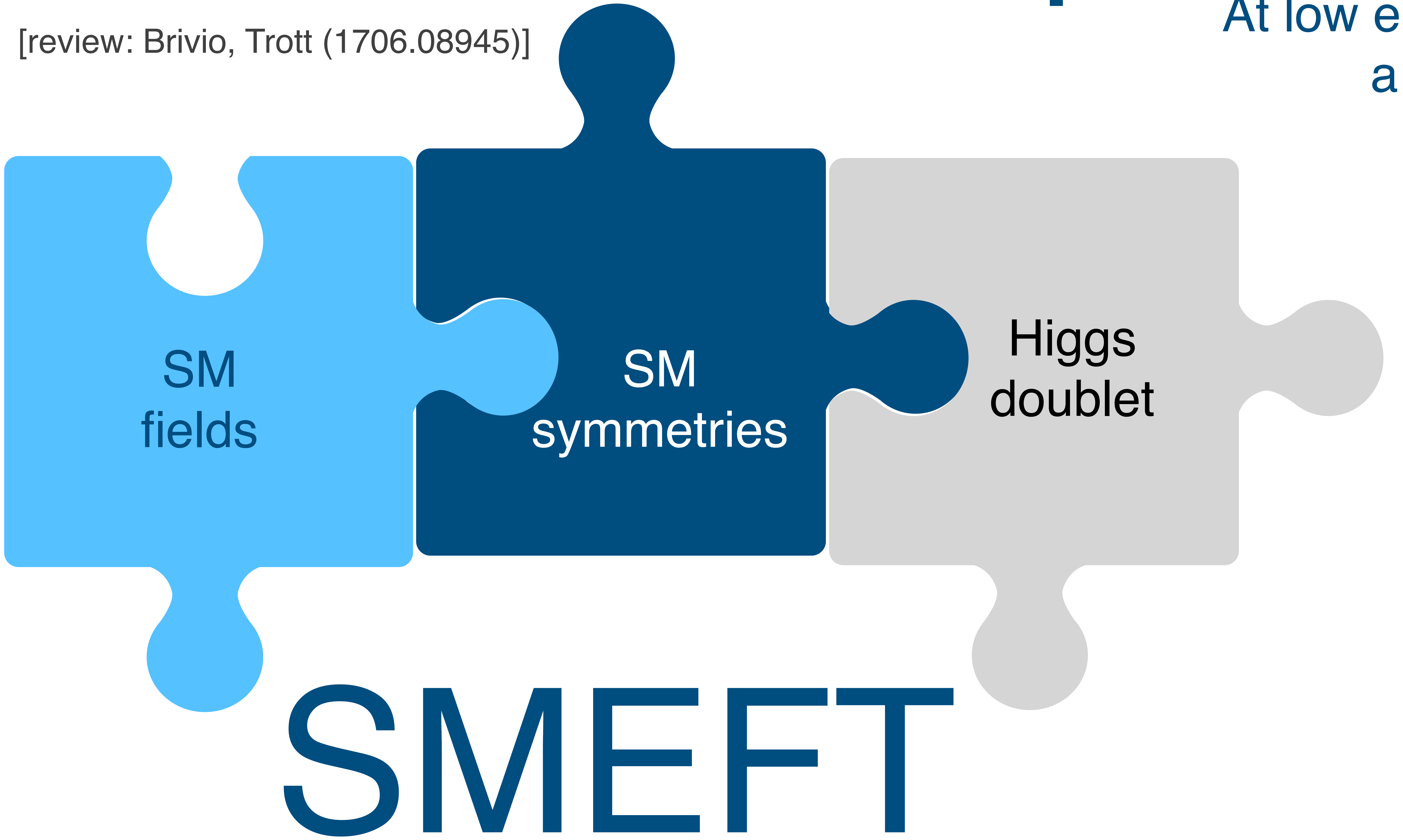
At low energies, the SM does a very good job.



EFTs from the bottom-up

[review: Brivio, Trott (1706.08945)]

At low energies, the SM does a very good job.



- **Minimal assumptions** on high-scale physics
- **Universal language** for data interpretation

Standard Model effective field theory (SMEFT)

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

Odd dimensions violate lepton or baryon number

Standard Model effective field theory (SMEFT)

Wilson coefficients

Operators

Dimension

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

Odd dimensions violate lepton or baryon number

Standard Model effective field theory (SMEFT)

Wilson coefficients

Operators

Dimension

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

Odd dimensions violate lepton or baryon number

Standard Model effective field theory (SMEFT)

Wilson coefficients

Operators

Dimension

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

Odd dimensions violate lepton or baryon number

2499 operators at D6

Many of these are different flavor combinations of the same structure

Reduce number of dof with flavor assumptions

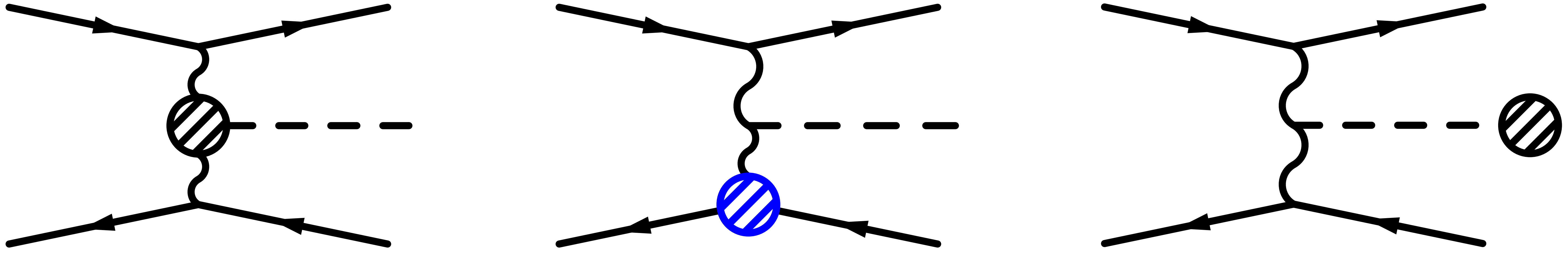
$$\mathcal{O}_{\substack{dH\\ ij}} = (H^\dagger H)(\bar{q}_i H d_j)$$

$3 \times 3 + \text{h.c.} \;\; = 18$ Flav. combinations

Why global fits?

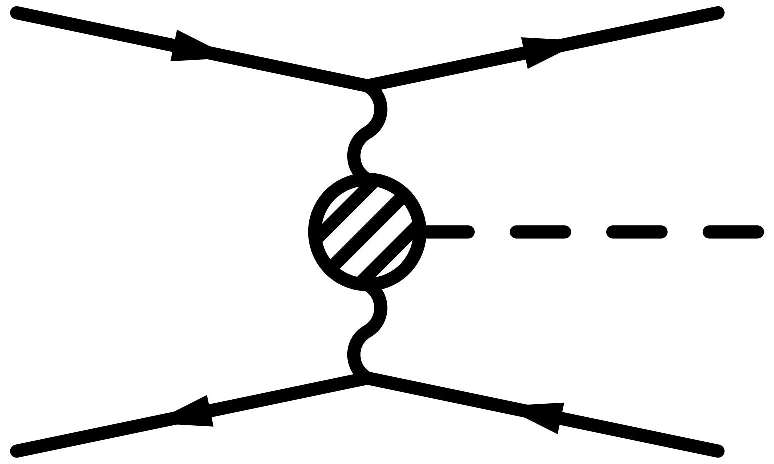
One observable can be influenced by many operators

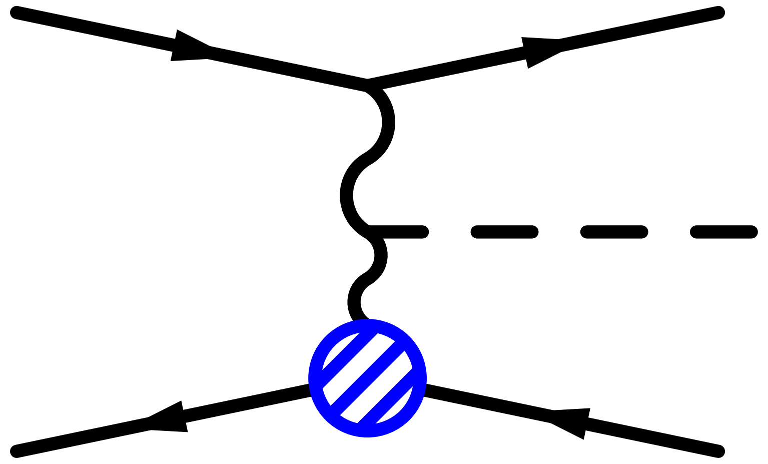
Higgs decay



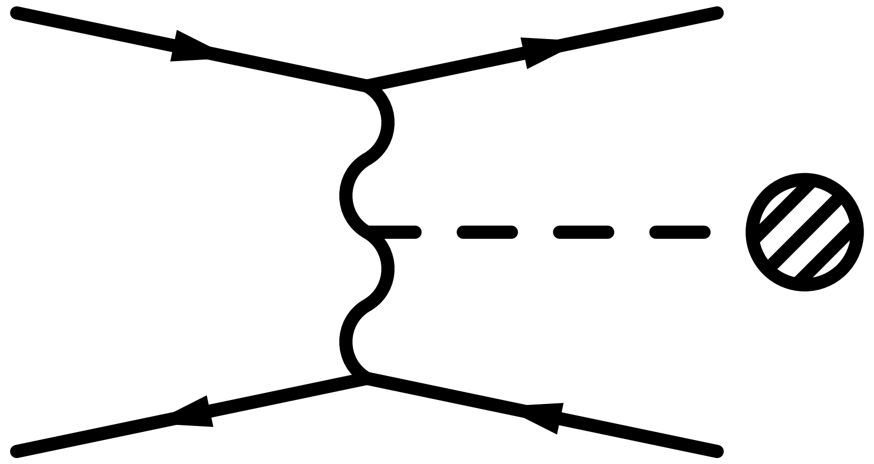
Why global fits?

One observable can be influenced by many operators

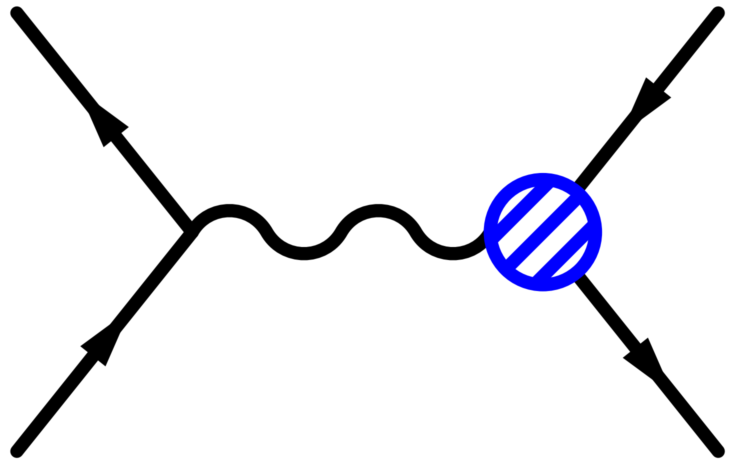




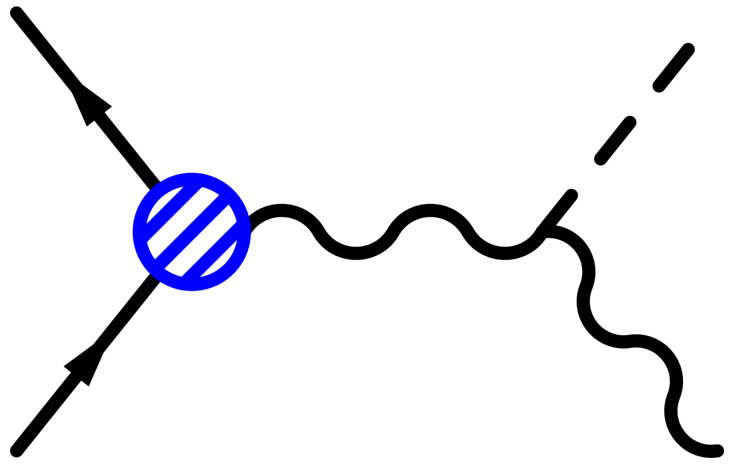
Higgs decay



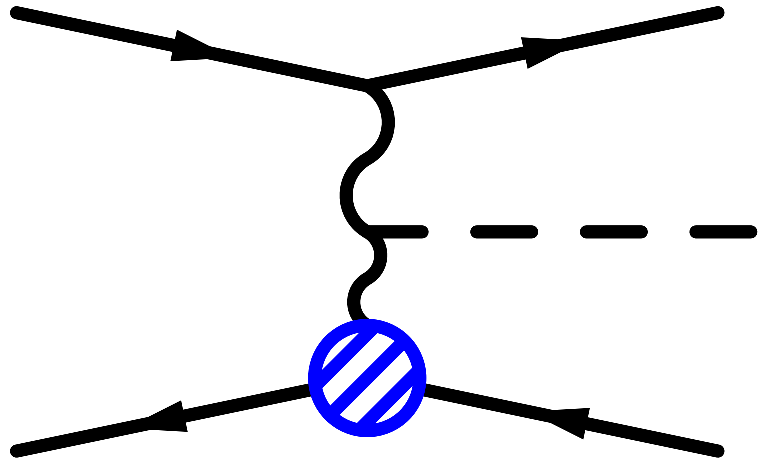
One operator can contribute to many different observables



$e^+e^- \to f\bar{f}$



Zh production

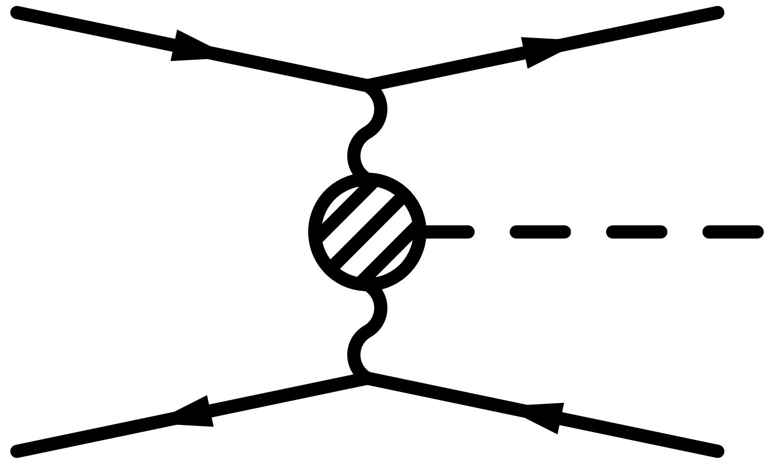


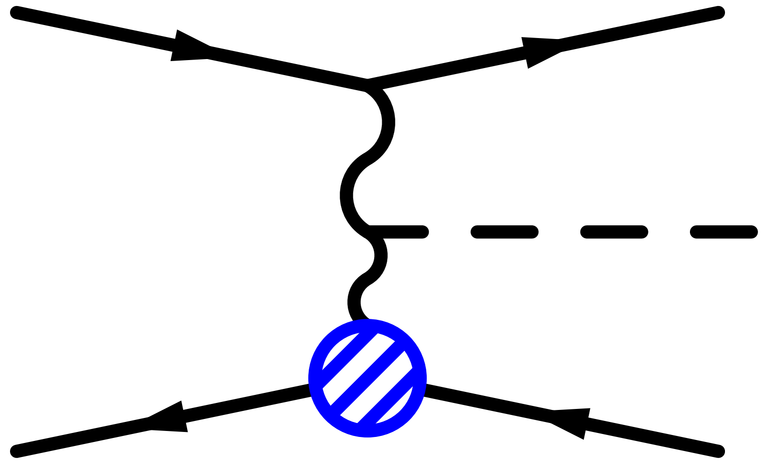
Weak boson fusion
Higgs production

Why global fits?

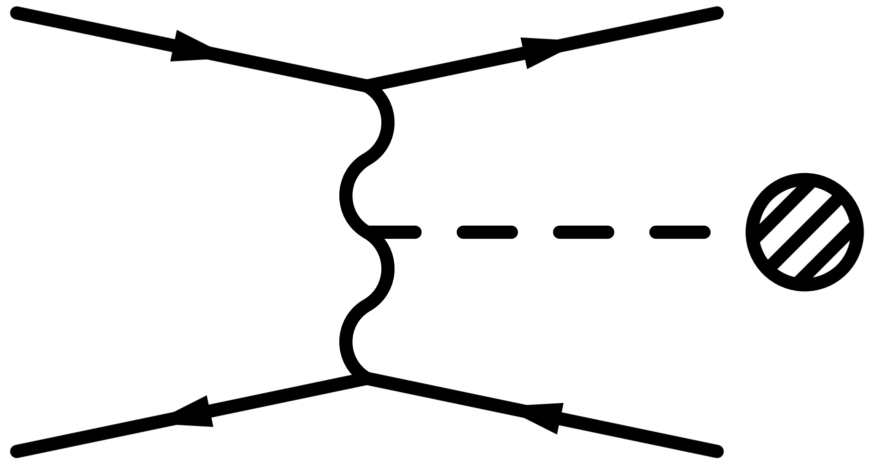
Need a **global analysis** of all EFT coefficients to map all direction of new fundamental physics

One observable can be influenced by many operators

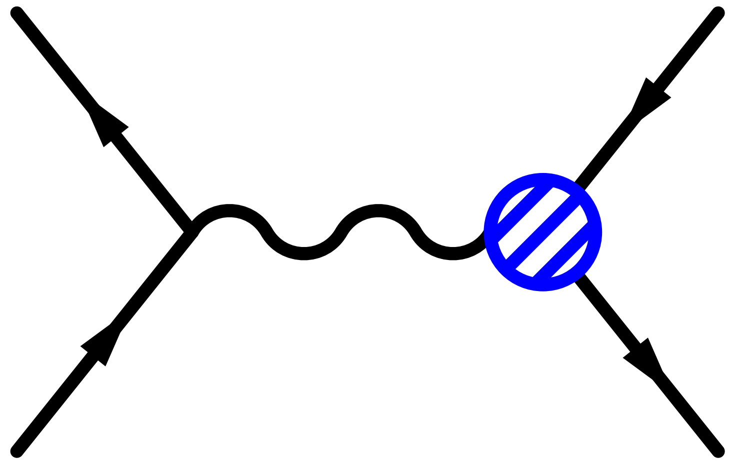




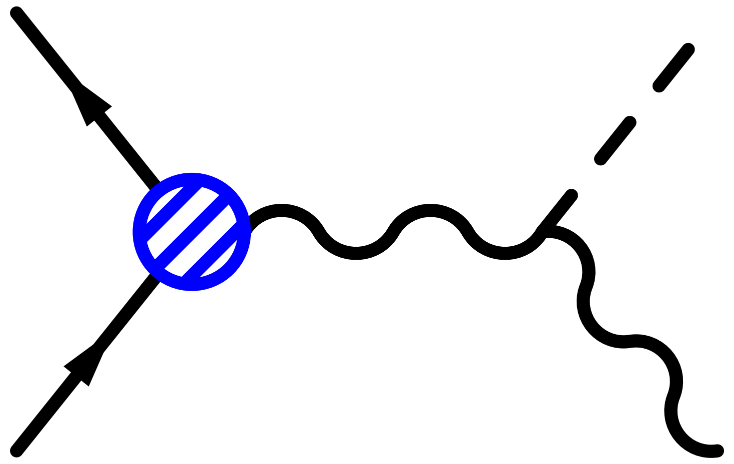
Higgs decay



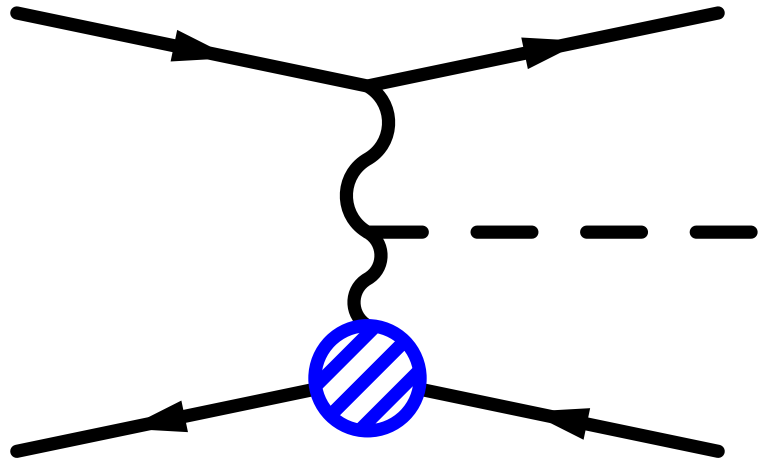
One operator can contribute to many different observables



$e^+e^- \to f\bar{f}$



Zh production



Weak boson fusion
Higgs production

Global in …

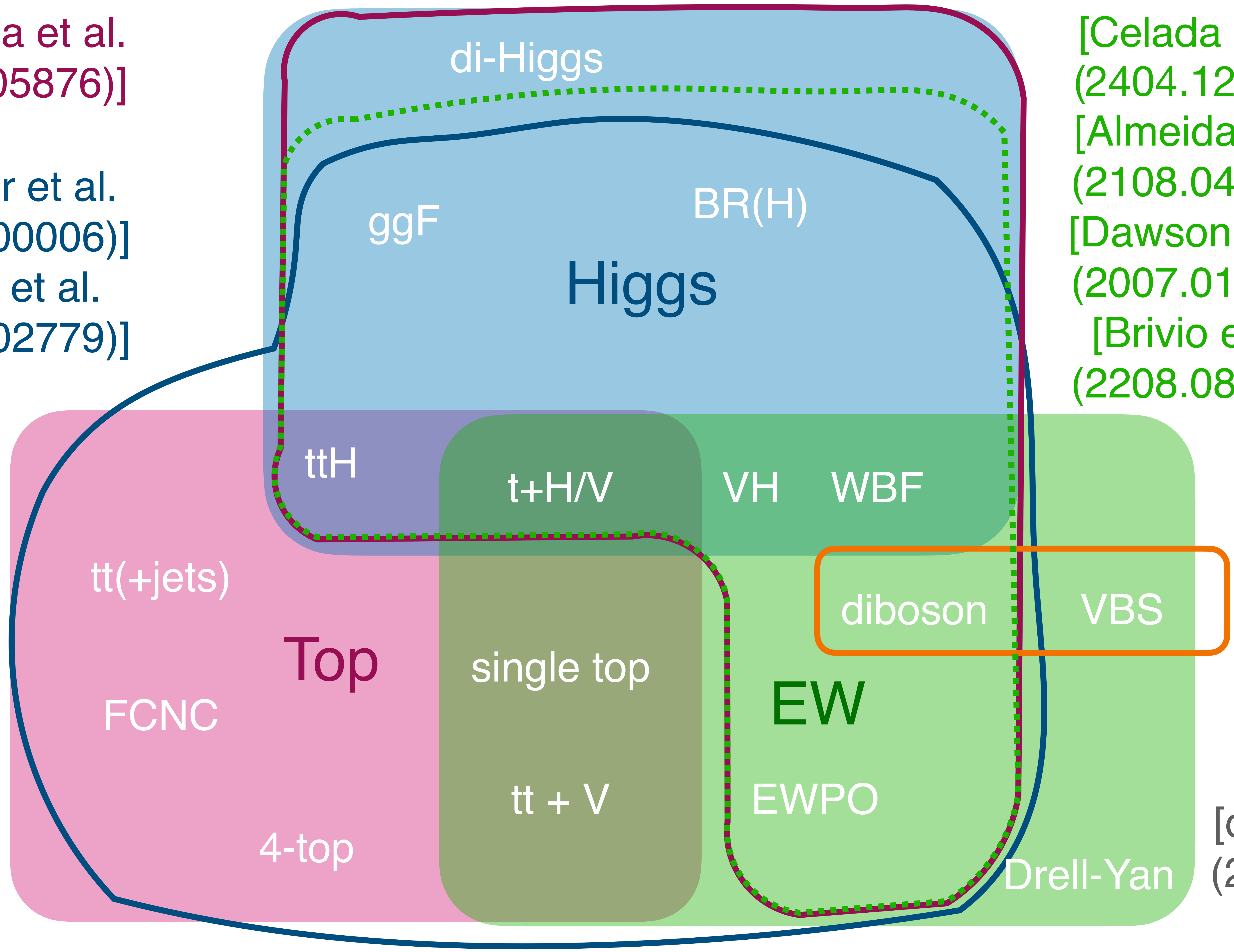
… the operator set

… the data

Confronting the SMEFT with data

[Anisha et al. (2111.05876)]

[Ethier et al. (2105.00006)]
[Ellis et al. (2012.02779)]



[Celada et al. (2404.12809)]
[Almeida et al. (2108.04828)]
[Dawson et al. (2007.01296)]
[Brivio et al. (2208.08454)]

[Ethier et al. (2101.03180)]
[Bellan et al. (2108.03199)]

[de Blas et al. (2204.04204)]

LHC+flavor

[Bruggisser et al. (2212.02532), (2101.07273)]

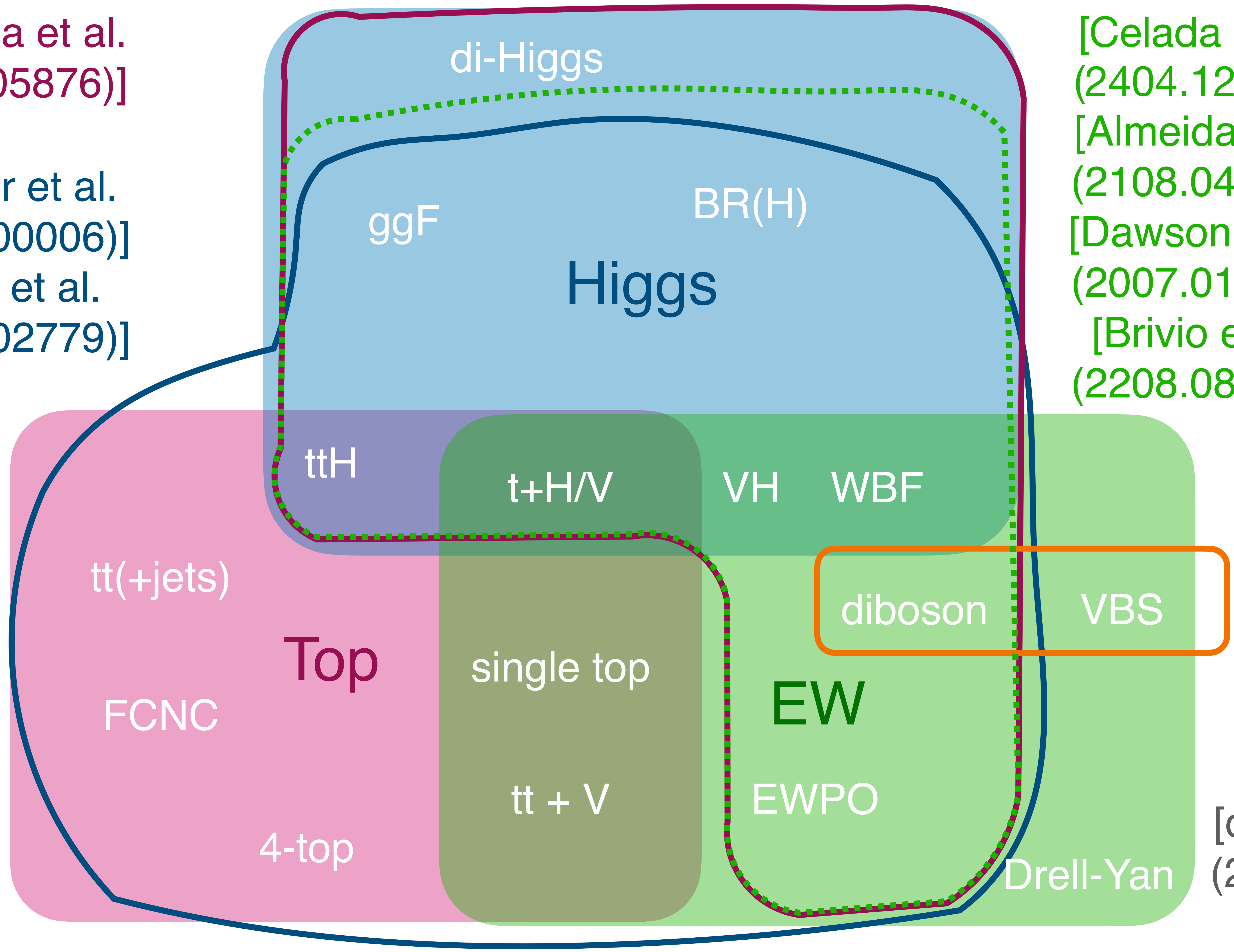
[Grunwald et al. (2304.12837)]

Adapted from Ken Mimasu

Confronting the SMEFT with data

[Anisha et al. (2111.05876)]

[Ethier et al. (2105.00006)]
[Ellis et al. (2012.02779)]



[Celada et al. (2404.12809)]
[Almeida et al. (2108.04828)]
[Dawson et al. (2007.01296)]
[Brivio et al. (2208.08454)]

Operator sets defined by the data

[Ethier et al. (2101.03180)]
[Bellan et al. (2108.03199)]

[de Blas et al. (2204.04204)]

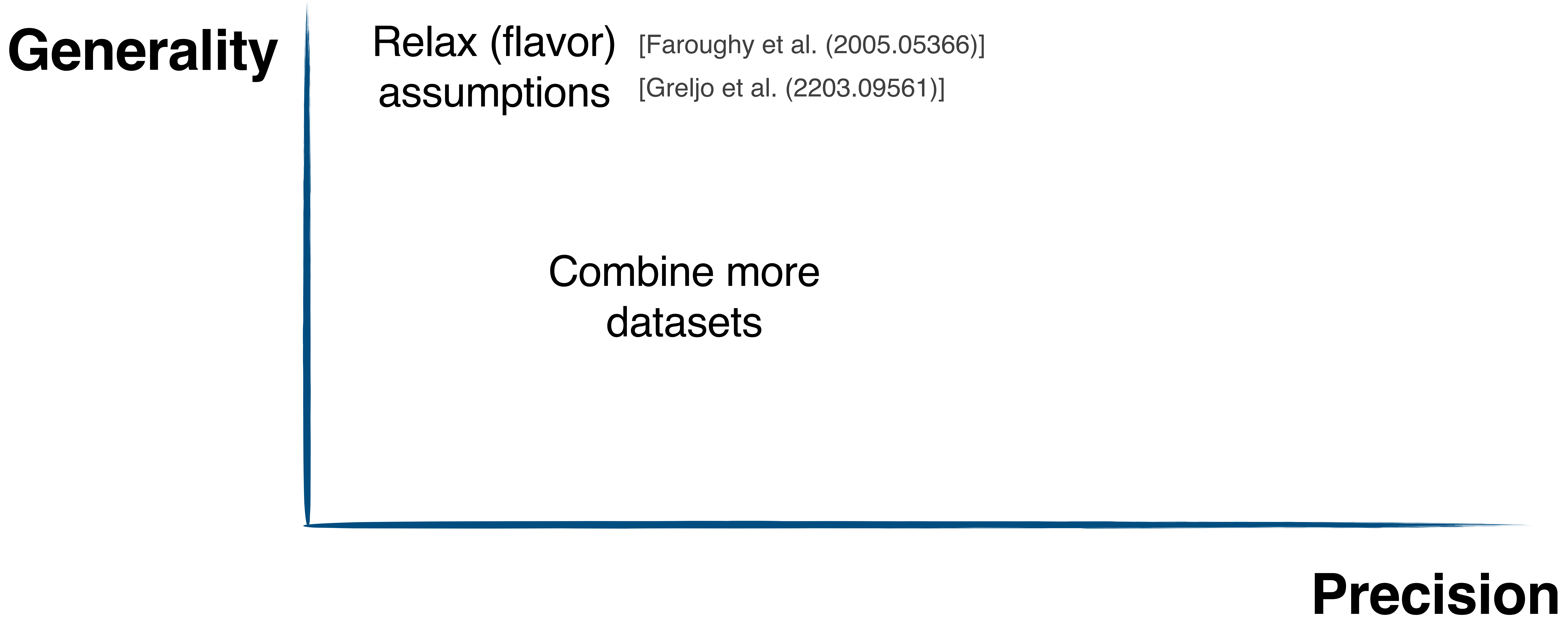
LHC+flavor

[Bruggisser et al. (2212.02532), (2101.07273)]

[Grunwald et al. (2304.12837)]

Adapted from Ken Mimasu

Future directions in SMEFT (fits)



Future directions in SMEFT (fits)

$$\mathcal{A} = \mathcal{A}_{\mathrm{SM}} + a_i \frac{C_i^{(6)}}{\Lambda^2} + b_{jk} \frac{C_j^{(6)} C_k^{(6)}}{\Lambda^4} + c_l \frac{C_l^{(8)}}{\Lambda^4} + \frac{1}{16\pi^2} \left[d_m \frac{C_m^{(6)}}{\Lambda^2} + e_n \frac{C_n^{(6)}}{\Lambda^2} \log\left(\frac{\mu^2}{\Lambda^2}\right) \right] + \cdots$$

Generality

Relax (flavor) assumptions [Faroughy et al. (2005.05366)] [Greljo et al. (2203.09561)]

Combine more datasets

Precision

Future directions in SMEFT (fits)

$$\mathcal{A} = \mathcal{A}_{\rm SM} + a_i \frac{C_i^{(6)}}{\Lambda^2} + b_{jk}\frac{C_j^{(6)} C_k^{(6)}}{\Lambda^4} + c_l \frac{C_l^{(8)}}{\Lambda^4} + \frac{1}{16\pi^2}\left[d_m \frac{C_m^{(6)}}{\Lambda^2} + e_n \frac{C_n^{(6)}}{\Lambda^2} \log\left(\frac{\mu^2}{\Lambda^2}\right)\right] + \cdots$$

Generality

Relax (flavor) assumptions [Faroughy et al. (2005.05366)] [Greljo et al. (2203.09561)]

Combine more datasets

Dim6^2 effects

Dim8 effects

[Dawson et al. (2205.01561)]
[Heinrich, Lang (2212.00711)]
[Degrande, Li (2303.10493)]
[Ellis et al. (2304.06663)]
[Corbett et al. (2304.03305)]

Precision

Future directions in SMEFT (fits)

$$\mathcal{A} = \mathcal{A}_{\mathrm{SM}} + a_i \frac{C_i^{(6)}}{\Lambda^2} + b_{jk}\frac{C_j^{(6)}C_k^{(6)}}{\Lambda^4} + c_l \frac{C_l^{(8)}}{\Lambda^4} + \frac{1}{16\pi^2}\left[d_m \frac{C_m^{(6)}}{\Lambda^2} + e_n \frac{C_n^{(6)}}{\Lambda^2}\log\left(\frac{\mu^2}{\Lambda^2}\right)\right] + \cdots$$

Generality

Relax (flavor) assumptions [Faroughy et al. (2005.05366)] [Greljo et al. (2203.09561)]

Combine more datasets

Dim6^2 effects
Dim8 effects

[Dawson et al. (2205.01561)]
[Heinrich, Lang (2212.00711)]
[Degrande, Li (2303.10493)]
[Ellis et al. (2304.06663)]
[Corbett et al. (2304.03305)]

SMEFT@NLO
RG effects

[Degrande et al. (2008.11743)]

Precision

Future directions in SMEFT (fits)

$$\mathcal{A} = \mathcal{A}_{\rm SM} + a_i \frac{C_i^{(6)}}{\Lambda^2} + b_{jk} \frac{C_j^{(6)} C_k^{(6)}}{\Lambda^4} + c_l \frac{C_l^{(8)}}{\Lambda^4} + \frac{1}{16\pi^2} \left[d_m \frac{C_m^{(6)}}{\Lambda^2} + e_n \frac{C_n^{(6)}}{\Lambda^2} \log\left(\frac{\mu^2}{\Lambda^2}\right) \right] + \cdots$$

Generality

Relax (flavor) assumptions [Faroughy et al. (2005.05366)] [Greljo et al. (2203.09561)]

Dim6^2 effects

Dim8 effects

[Dawson et al. (2205.01561)]
[Heinrich, Lang (2212.00711)]
[Degrande, Li (2303.10493)]
[Ellis et al. (2304.06663)]
[Corbett et al. (2304.03305)]

Combine more datasets

SMEFT@NLO

RG effects

[Degrande et al. (2008.11743)]

Precision

Future directions in SMEFT (fits)

$$\mathcal{A} = \mathcal{A}_{\text{SM}} + a_i \frac{C_i^{(6)}}{\Lambda^2} + \boxed{b_{jk} \frac{C_j^{(6)} C_k^{(6)}}{\Lambda^4} + c_l \frac{C_l^{(8)}}{\Lambda^4}} + \frac{1}{16\pi^2} \left[\boxed{d_m \frac{C_m^{(6)}}{\Lambda^2} + e_n \frac{C_n^{(6)}}{\Lambda^2} \log\left(\frac{\mu^2}{\Lambda^2}\right)} \right] + \cdots$$

Generality

Are we ready for a global fit starting from an operator set defined by symmetries?

[Dawson et al. (2205.01561)]
[Heinrich, Lang (2212.00711)]
[Degrande, Li (2303.10493)]
[Ellis et al. (2304.06663)]
[Corbett et al. (2304.03305)]

★ Combine more datasets

★ SMEFT@NLO
RG effects

[Degrande et al. (2008.11743)]

Precision

SMEFT flavor assumptions

More flavor symmetries:

[Faroughy, Isidori, Wilsch, Yamamoto (2005.05366)]

[Greljo, Palavric, Thomsen (2203.09561)]

Assume an exact $U(3)^5$ symmetry

$$U(3)^5 = U(3)_\ell \times U(3)_q \times U(3)_e \times U(3)_u \times U(3)_d$$

+ no CP odd interactions

Same couplings for top, charm, up quark.

$\mathcal{O}_{\substack{dH \\ ij}} = (H^\dagger H)(\bar{q}_i H d_j)$ Operator is forbidden under $U(3)^5$ symmetry

Left with 41 operators

SMEFT flavor assumptions

More flavor symmetries:
[Faroughy, Isidori, Wilsch, Yamamoto (2005.05366)]
[Greljo, Palavric, Thomsen (2203.09561)]

Assume an exact $U(3)^5$ symmetry

$$U(3)^5 = U(3)_\ell \times U(3)_q \times U(3)_e \times U(3)_u \times U(3)_d$$

+ no CP odd interactions

Same couplings for top, charm, up quark.

$\mathcal{O}_{\substack{dH\\ij}} = (H^\dagger H)(\bar{q}_i H d_j)$ Operator is forbidden under $U(3)^5$ symmetry

Left with 41 operators

Minimal flavor violation (MFV)

In the SM, the Yukawas $Y_e,\, Y_u,\, Y_d$ are the only sources of the breaking of this symmetry

[Gerard (1983)]
[Chivukula, Georgi (1987)]
[D'Ambrosio, Giudice, Isidori, Strumia (hep-ph/0207036)]

$$\mathcal{O}_{\substack{dH\\ij}} = (H^\dagger H)(\bar{q}_i H\, Y_d\, d_j)$$
$$\to (H^\dagger H)((\bar{q}\Omega_q^\dagger)_i H\, (\Omega_d Y_q \Omega_d^\dagger)\, (\Omega_d d)_j)$$

Warsaw basis

[Grzadkowski et al. (1008.4884)]

$1 : X^3$	
Q_G	$f^{ABC} G_\mu^{A\nu} G_\nu^{B\rho} G_\rho^{C\mu}$
$Q_{\widetilde{G}}$	$f^{ABC} \widetilde{G}_\mu^{A\nu} G_\nu^{B\rho} G_\rho^{C\mu}$
Q_W	$\epsilon^{IJK} W_\mu^{I\nu} W_\nu^{J\rho} W_\rho^{K\mu}$
$Q_{\widetilde{W}}$	$\epsilon^{IJK} \widetilde{W}_\mu^{I\nu} W_\nu^{J\rho} W_\rho^{K\mu}$

$2 : H^6$	
Q_H	$(H^\dagger H)^3$

$3 : H^4 D^2$	
$Q_{H\Box}$	$(H^\dagger H)\Box(H^\dagger H)$
Q_{HD}	$\left(H^\dagger D_\mu H\right)^* \left(H^\dagger D_\mu H\right)$

$5 : \psi^2 H^3 + \text{h.c.}$	
Q_{eH}	$(H^\dagger H)(\bar{l}_p e_r H)$
Q_{uH}	$(H^\dagger H)(\bar{q}_p u_r \widetilde{H})$
Q_{dH}	$(H^\dagger H)(\bar{q}_p d_r H)$

$4 : X^2 H^2$	
Q_{HG}	$H^\dagger H\, G_{\mu\nu}^A G^{A\mu\nu}$
$Q_{H\widetilde{G}}$	$H^\dagger H\, \widetilde{G}_{\mu\nu}^A G^{A\mu\nu}$
Q_{HW}	$H^\dagger H\, W_{\mu\nu}^I W^{I\mu\nu}$
$Q_{H\widetilde{W}}$	$H^\dagger H\, \widetilde{W}_{\mu\nu}^I W^{I\mu\nu}$
Q_{HB}	$H^\dagger H\, B_{\mu\nu} B^{\mu\nu}$
$Q_{H\widetilde{B}}$	$H^\dagger H\, \widetilde{B}_{\mu\nu} B^{\mu\nu}$
Q_{HWB}	$H^\dagger \tau^I H\, W_{\mu\nu}^I B^{\mu\nu}$
$Q_{H\widetilde{W}B}$	$H^\dagger \tau^I H\, \widetilde{W}_{\mu\nu}^I B^{\mu\nu}$

$6 : \psi^2 X H + \text{h.c.}$	
Q_{eW}	$(\bar{l}_p \sigma^{\mu\nu} e_r)\tau^I H W_{\mu\nu}^I$
Q_{eB}	$(\bar{l}_p \sigma^{\mu\nu} e_r) H B_{\mu\nu}$
Q_{uG}	$(\bar{q}_p \sigma^{\mu\nu} T^A u_r)\widetilde{H}\, G_{\mu\nu}^A$
Q_{uW}	$(\bar{q}_p \sigma^{\mu\nu} u_r)\tau^I \widetilde{H}\, W_{\mu\nu}^I$
Q_{uB}	$(\bar{q}_p \sigma^{\mu\nu} u_r)\widetilde{H}\, B_{\mu\nu}$
Q_{dG}	$(\bar{q}_p \sigma^{\mu\nu} T^A d_r) H\, G_{\mu\nu}^A$
Q_{dW}	$(\bar{q}_p \sigma^{\mu\nu} d_r)\tau^I H\, W_{\mu\nu}^I$
Q_{dB}	$(\bar{q}_p \sigma^{\mu\nu} d_r) H\, B_{\mu\nu}$

$7 : \psi^2 H^2 D$	
$Q_{Hl}^{(1)}$	$(H^\dagger i \overleftrightarrow{D}_\mu H)(\bar{l}_p \gamma^\mu l_r)$
$Q_{Hl}^{(3)}$	$(H^\dagger i \overleftrightarrow{D}_\mu^I H)(\bar{l}_p \tau^I \gamma^\mu l_r)$
Q_{He}	$(H^\dagger i \overleftrightarrow{D}_\mu H)(\bar{e}_p \gamma^\mu e_r)$
$Q_{Hq}^{(1)}$	$(H^\dagger i \overleftrightarrow{D}_\mu H)(\bar{q}_p \gamma^\mu q_r)$
$Q_{Hq}^{(3)}$	$(H^\dagger i \overleftrightarrow{D}_\mu^I H)(\bar{q}_p \tau^I \gamma^\mu q_r)$
Q_{Hu}	$(H^\dagger i \overleftrightarrow{D}_\mu H)(\bar{u}_p \gamma^\mu u_r)$
Q_{Hd}	$(H^\dagger i \overleftrightarrow{D}_\mu H)(\bar{d}_p \gamma^\mu d_r)$
Q_{Hud} + h.c.	$i(\widetilde{H}^\dagger D_\mu H)(\bar{u}_p \gamma^\mu d_r)$

$8 : (\bar{L}L)(\bar{L}L)$	
$Q_{\ell\ell}$	$(\bar{l}_p \gamma_\mu l_r)(\bar{l}_s \gamma^\mu l_t)$

Plus more four-fermion operators

Warsaw basis under U(3)^5

[Grzadkowski et al. (1008.4884)]

$1: X^3$	
Q_G	$f^{ABC} G_\mu^{A\nu} G_\nu^{B\rho} G_\rho^{C\mu}$
~~$Q_{\widetilde{G}}$~~	~~$f^{ABC} \widetilde{G}_\mu^{A\nu} G_\nu^{B\rho} G_\rho^{C\mu}$~~
Q_W	$\epsilon^{IJK} W_\mu^{I\nu} W_\nu^{J\rho} W_\rho^{K\mu}$
~~$Q_{\widetilde{W}}$~~	~~$\epsilon^{IJK} \widetilde{W}_\mu^{I\nu} W_\nu^{J\rho} W_\rho^{K\mu}$~~

$2: H^6$	
Q_H	$(H^\dagger H)^3$

$3: H^4 D^2$	
$Q_{H\Box}$	$(H^\dagger H)\Box(H^\dagger H)$
Q_{HD}	$\left(H^\dagger D_\mu H\right)^* \left(H^\dagger D_\mu H\right)$

~~$5: \psi^2 H^3 + \text{h.c.}$~~	
~~Q_{eH}~~	~~$(H^\dagger H)(\bar{l}_p e_r H)$~~
~~Q_{uH}~~	~~$(H^\dagger H)(\bar{q}_p u_r \widetilde{H})$~~
~~Q_{dH}~~	~~$(H^\dagger H)(\bar{q}_p d_r H)$~~

$4: X^2 H^2$	
Q_{HG}	$H^\dagger H\, G_{\mu\nu}^A G^{A\mu\nu}$
~~$Q_{H\widetilde{G}}$~~	~~$H^\dagger H\, \widetilde{G}_{\mu\nu}^A G^{A\mu\nu}$~~
Q_{HW}	$H^\dagger H\, W_{\mu\nu}^I W^{I\mu\nu}$
~~$Q_{H\widetilde{W}}$~~	~~$H^\dagger H\, \widetilde{W}_{\mu\nu}^I W^{I\mu\nu}$~~
Q_{HB}	$H^\dagger H\, B_{\mu\nu} B^{\mu\nu}$
~~$Q_{H\widetilde{B}}$~~	~~$H^\dagger H\, \widetilde{B}_{\mu\nu} B^{\mu\nu}$~~
Q_{HWB}	$H^\dagger \tau^I H\, W_{\mu\nu}^I B^{\mu\nu}$
~~$Q_{H\widetilde{W}B}$~~	~~$H^\dagger \tau^I H\, \widetilde{W}_{\mu\nu}^I B^{\mu\nu}$~~

~~$6: \psi^2 X H + \text{h.c.}$~~	
~~Q_{eW}~~	~~$(\bar{l}_p \sigma^{\mu\nu} e_r)\tau^I H W_{\mu\nu}^I$~~
~~Q_{eB}~~	~~$(\bar{l}_p \sigma^{\mu\nu} e_r) H B_{\mu\nu}$~~
~~Q_{uG}~~	~~$(\bar{q}_p \sigma^{\mu\nu} T^A u_r)\widetilde{H}\, G_{\mu\nu}^A$~~
~~Q_{uW}~~	~~$(\bar{q}_p \sigma^{\mu\nu} u_r)\tau^I \widetilde{H}\, W_{\mu\nu}^I$~~
~~Q_{uB}~~	~~$(\bar{q}_p \sigma^{\mu\nu} u_r)\widetilde{H}\, B_{\mu\nu}$~~
~~Q_{dG}~~	~~$(\bar{q}_p \sigma^{\mu\nu} T^A d_r) H\, G_{\mu\nu}^A$~~
~~Q_{dW}~~	~~$(\bar{q}_p \sigma^{\mu\nu} d_r)\tau^I H\, W_{\mu\nu}^I$~~
~~Q_{dB}~~	~~$(\bar{q}_p \sigma^{\mu\nu} d_r) H\, B_{\mu\nu}$~~

$7: \psi^2 H^2 D$	
$Q_{Hl}^{(1)}$	$(H^\dagger i\overleftrightarrow{D}_\mu H)(\bar{l}_p \gamma^\mu l_r)$
$Q_{Hl}^{(3)}$	$(H^\dagger i\overleftrightarrow{D}^I_\mu H)(\bar{l}_p \tau^I \gamma^\mu l_r)$
Q_{He}	$(H^\dagger i\overleftrightarrow{D}_\mu H)(\bar{e}_p \gamma^\mu e_r)$
$Q_{Hq}^{(1)}$	$(H^\dagger i\overleftrightarrow{D}_\mu H)(\bar{q}_p \gamma^\mu q_r)$
$Q_{Hq}^{(3)}$	$(H^\dagger i\overleftrightarrow{D}^I_\mu H)(\bar{q}_p \tau^I \gamma^\mu q_r)$
Q_{Hu}	$(H^\dagger i\overleftrightarrow{D}_\mu H)(\bar{u}_p \gamma^\mu u_r)$
Q_{Hd}	$(H^\dagger i\overleftrightarrow{D}_\mu H)(\bar{d}_p \gamma^\mu d_r)$
~~Q_{Hud} + h.c.~~	~~$i(\widetilde{H}^\dagger D_\mu H)(\bar{u}_p \gamma^\mu d_r)$~~

δ_{pr}

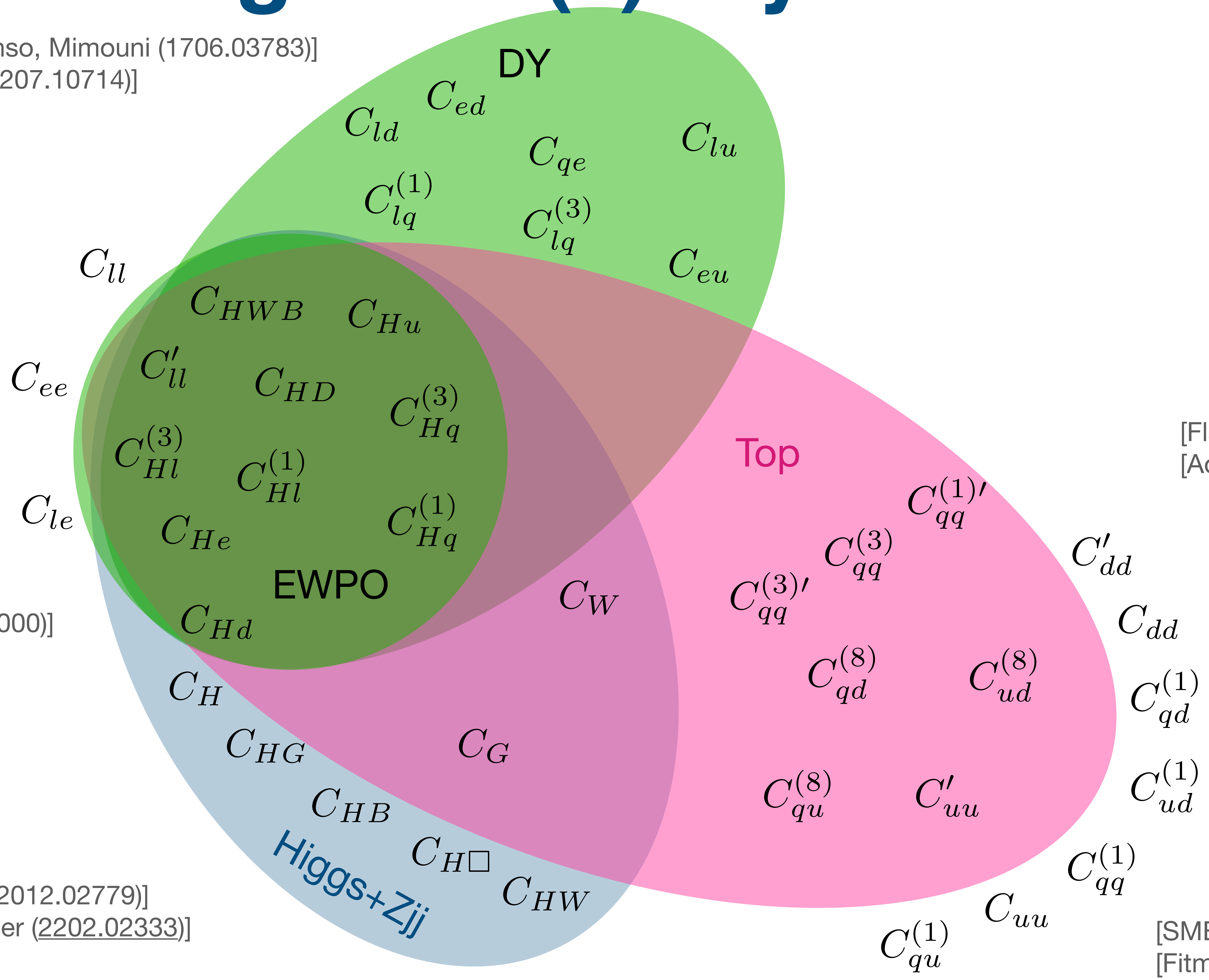
$8: (\bar{L}L)(\bar{L}L)$	
$Q_{\ell\ell}$	$(\bar{l}_p \gamma_\mu l_r)(\bar{l}_s \gamma^\mu l_t)$

Plus more four-fermion operators

41 parameters in total

Constraining the U(3)^5 symmetric SMEFT

[Falkowski, Gonzalez-Alonso, Mimouni (1706.03783)]
[HighPT: Allwicher et al. (2207.10714)]



[Flavio: Straub (1810.08132)]
[Aoude, Hurth, Renner, Shepherd (2003.05432)]

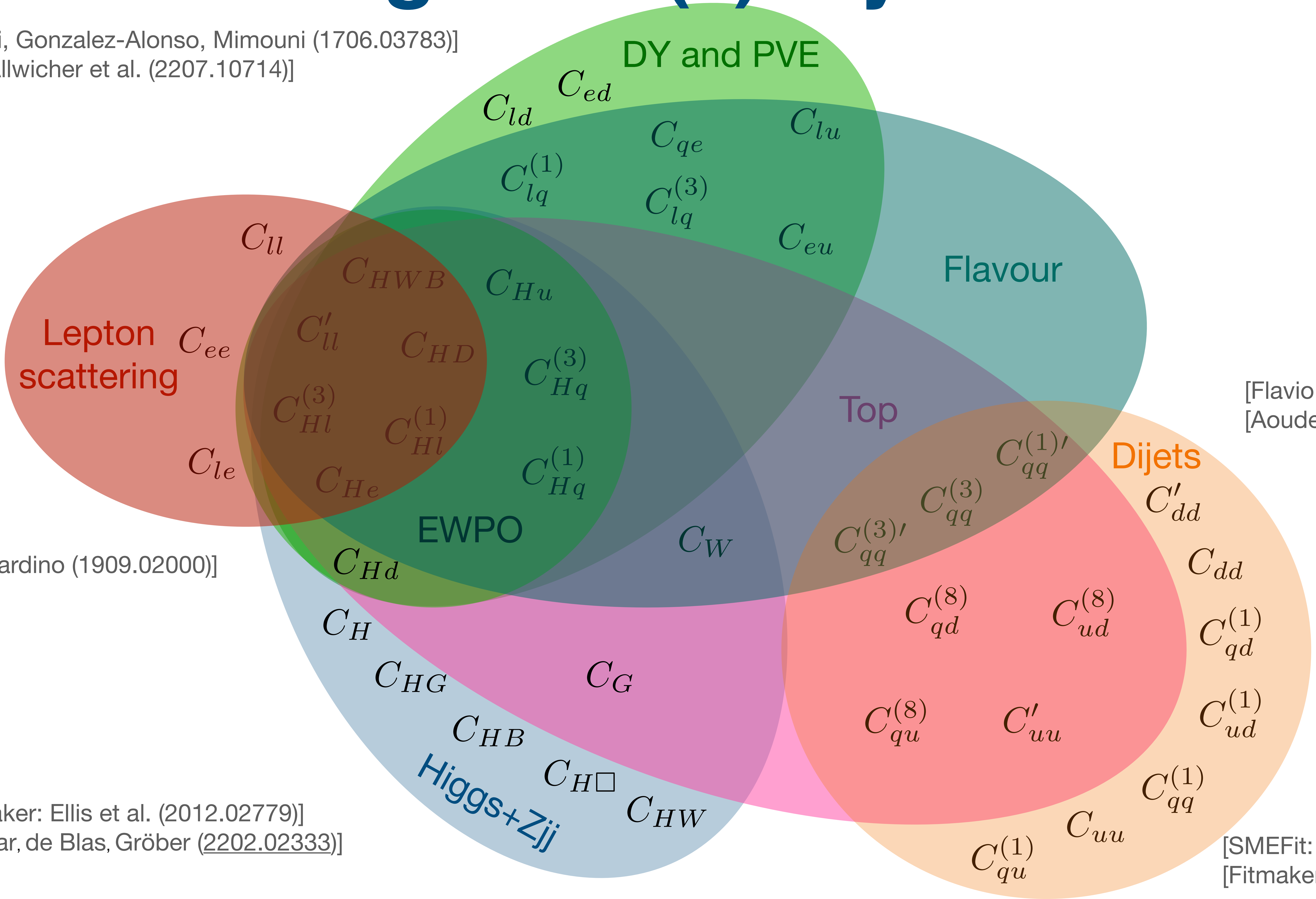
[Dawson, Giardino (1909.02000)]

[Fitmaker: Ellis et al. (2012.02779)]
[Alasfar, de Blas, Gröber (2202.02333)]

[SMEFit: Kassabov et al. (2303.06159)]
[Fitmaker: Ellis et al. (2012.02779)]

Constraining the U(3)^5 symmetric SMEFT

[Falkowski, Gonzalez-Alonso, Mimouni (1706.03783)]
[HighPT: Allwicher et al. (2207.10714)]



[Flavio: Straub (1810.08132)]
[Aoude, Hurth, Renner, Shepherd (2003.05432)]

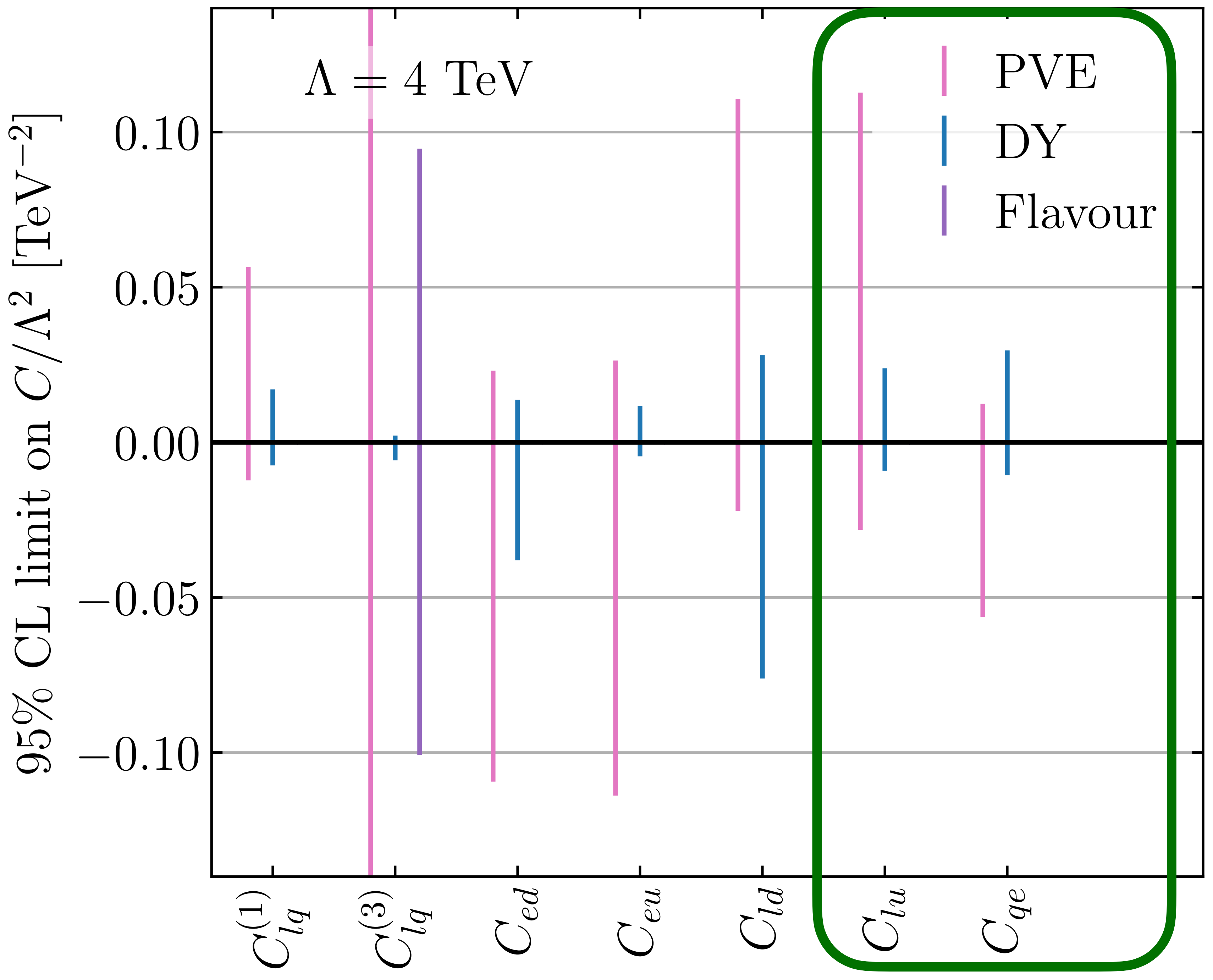
[Dawson, Giardino (1909.02000)]

[Fitmaker: Ellis et al. (2012.02779)]
[Alasfar, de Blas, Gröber (2202.02333)]

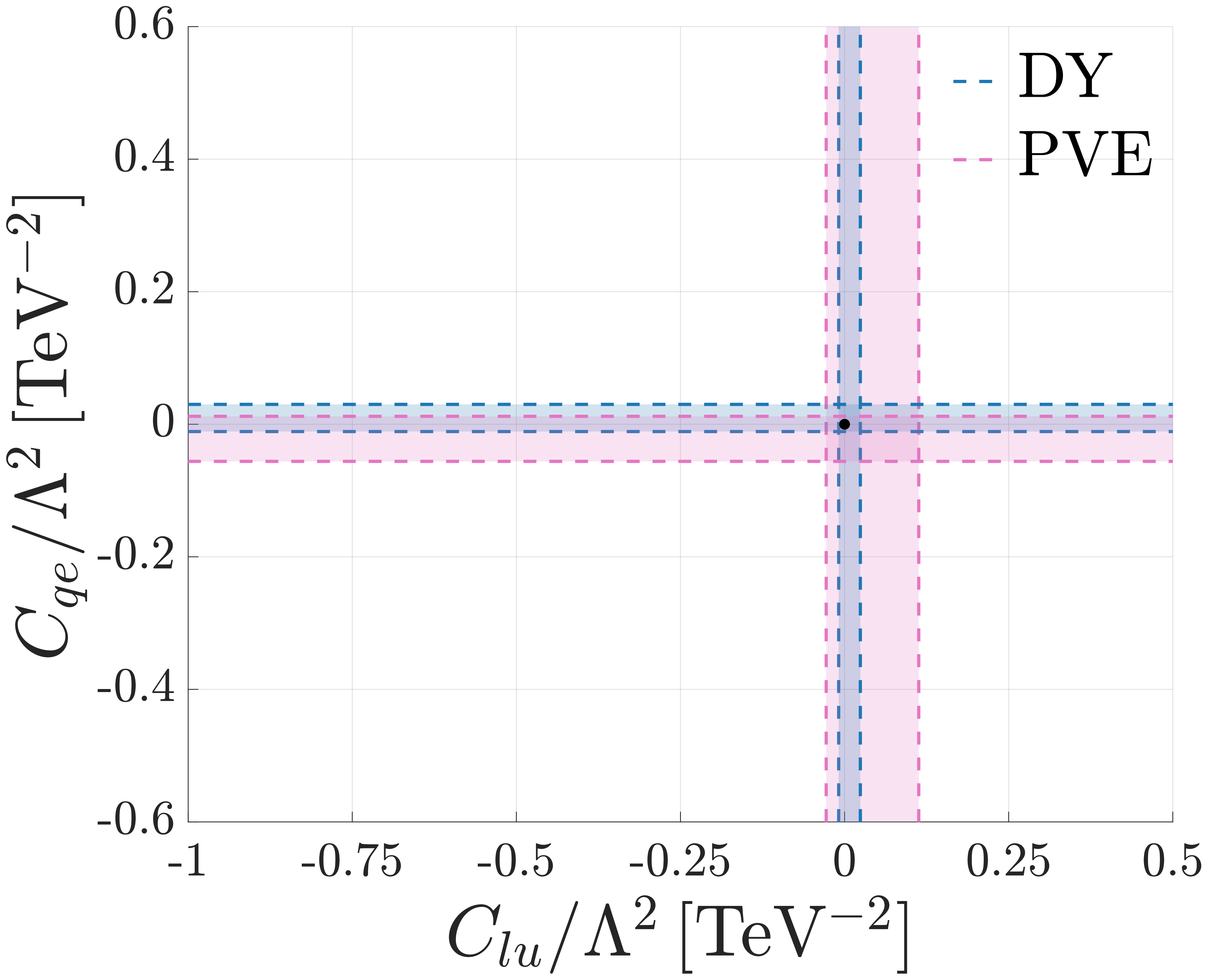
[SMEFit: Kassabov et al. (2303.06159)]
[Fitmaker: Ellis et al. (2012.02779)]

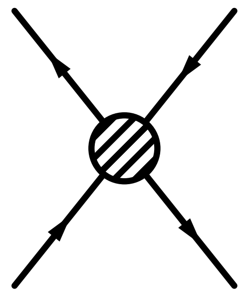
Combining sectors: Drell-Yan vs parity violation experiments

Single-parameter fits



[Bartocci, AB, Hurth (2311.04963)]



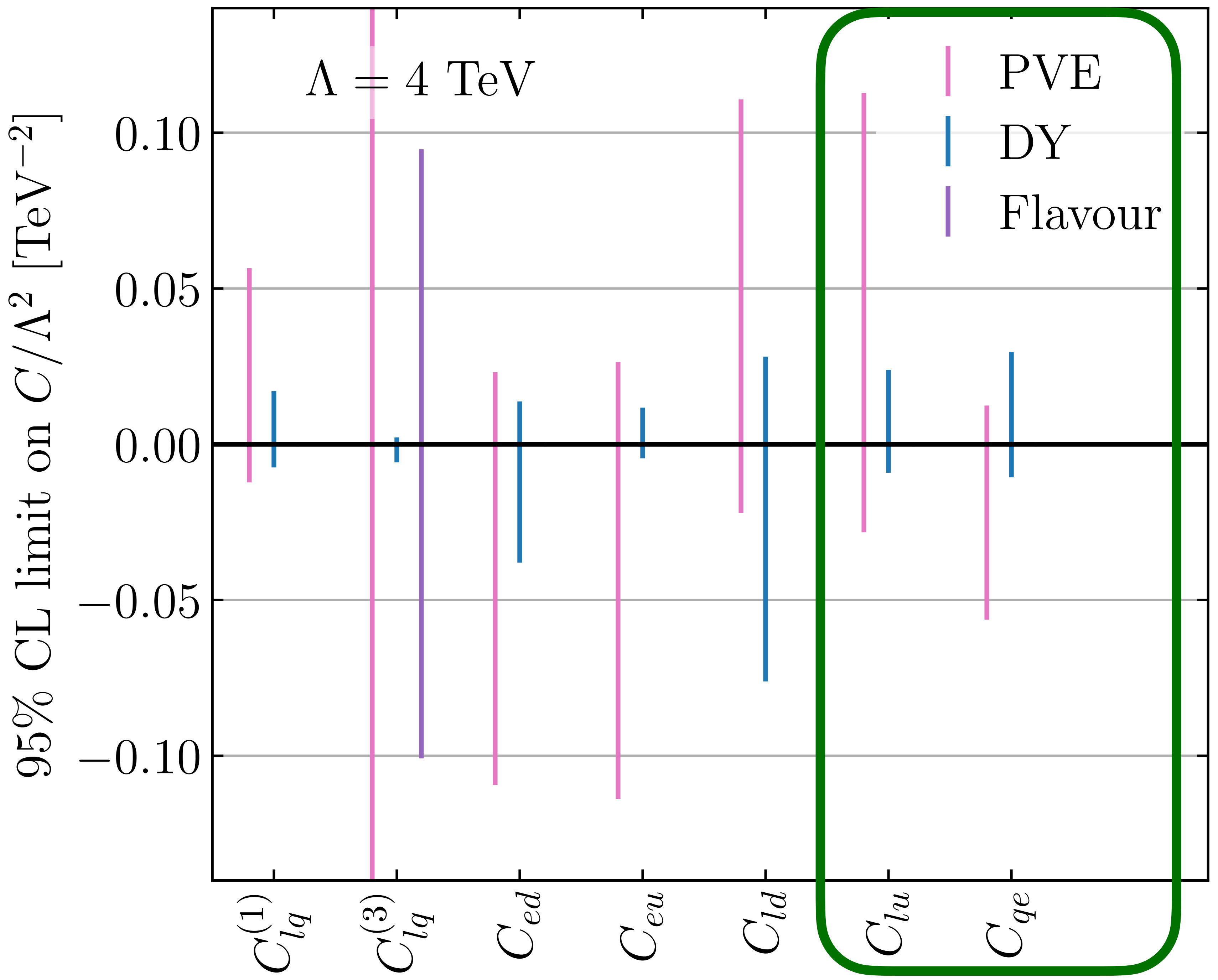


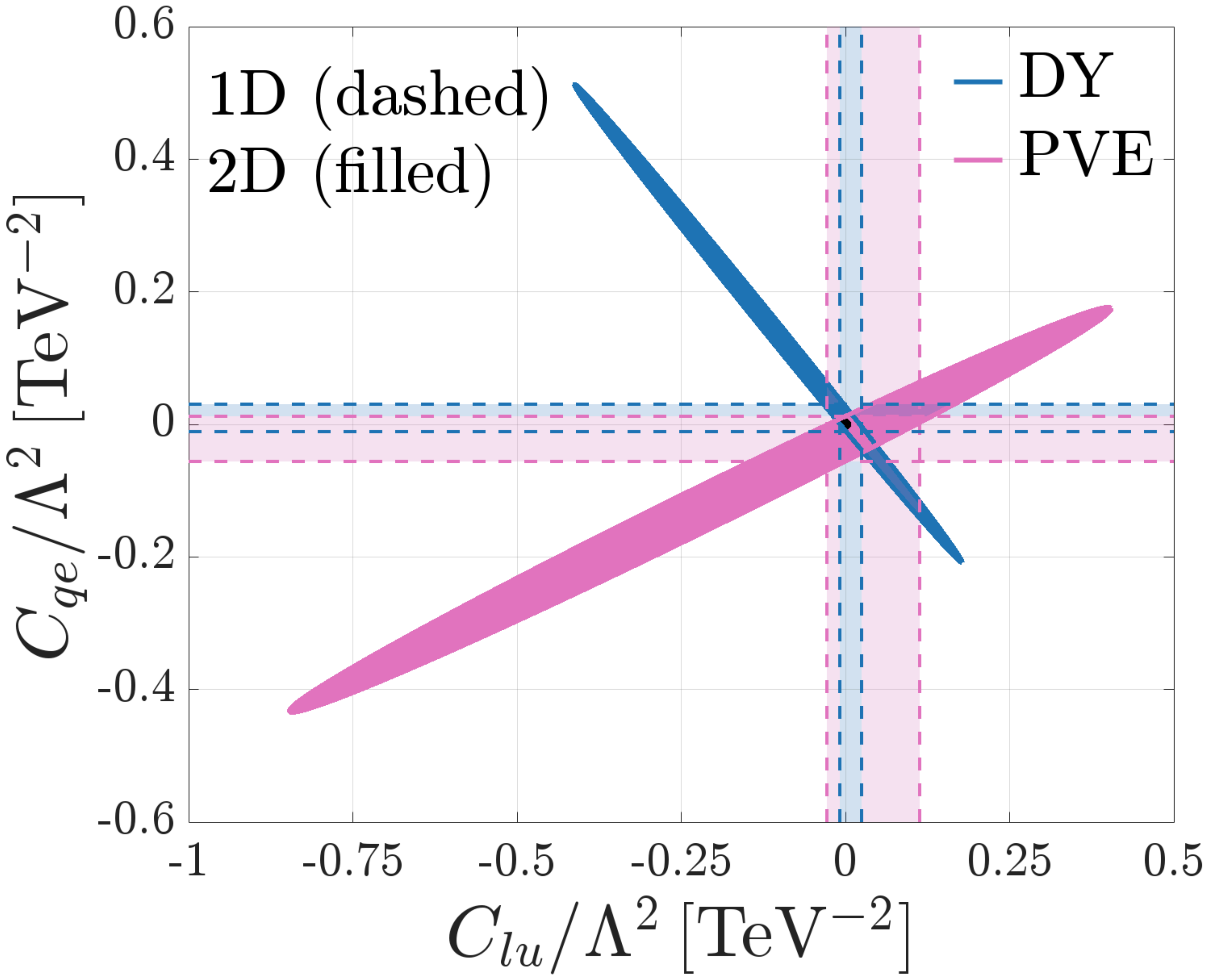
Energy growth is similar for all
Wilson coefficients in Drell-Yan (DY)

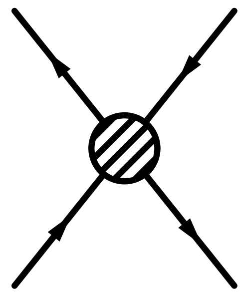
Combining sectors: Drell-Yan vs parity violation experiments

Single-parameter fits

[Bartocci, AB, Hurth (2311.04963)]





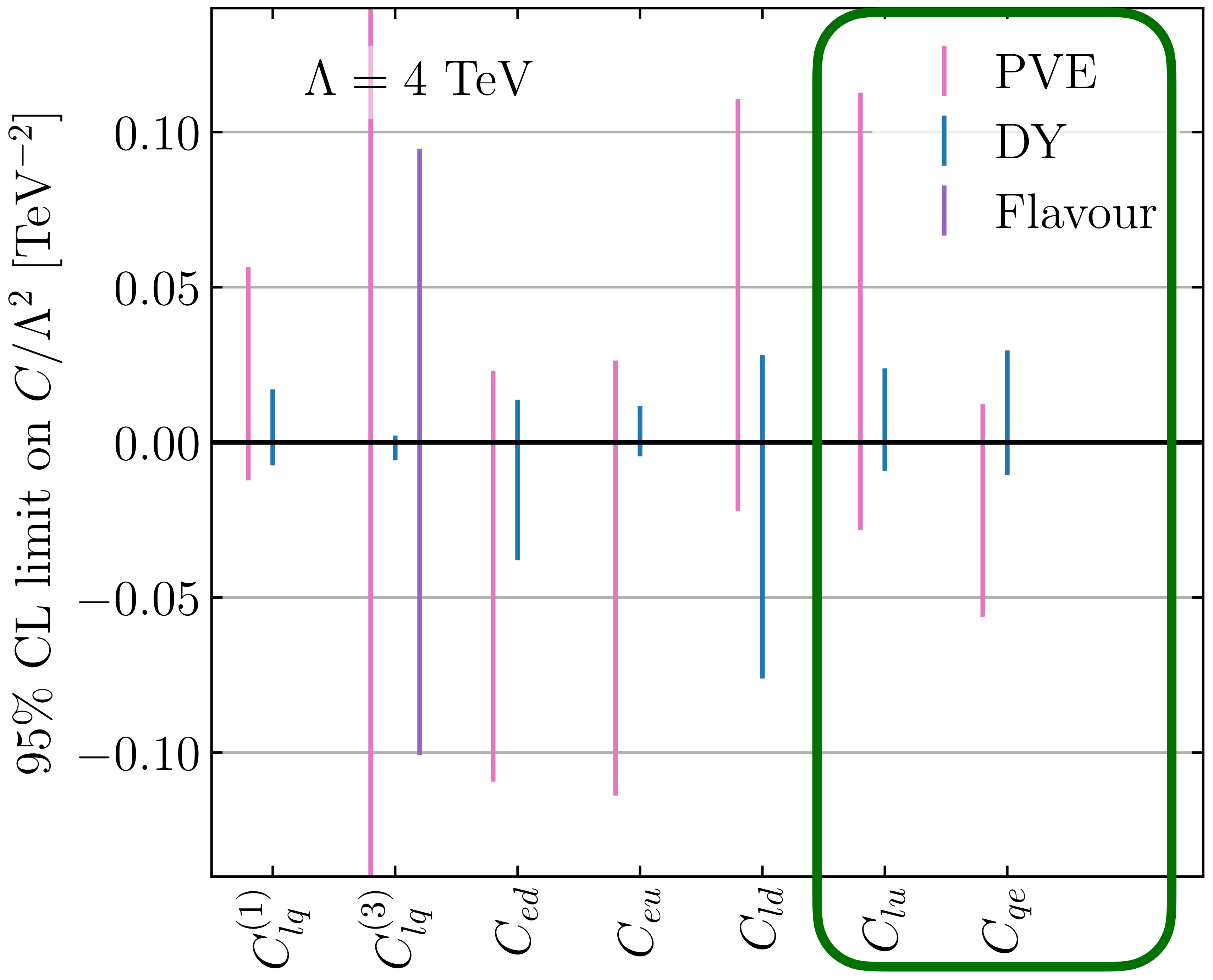


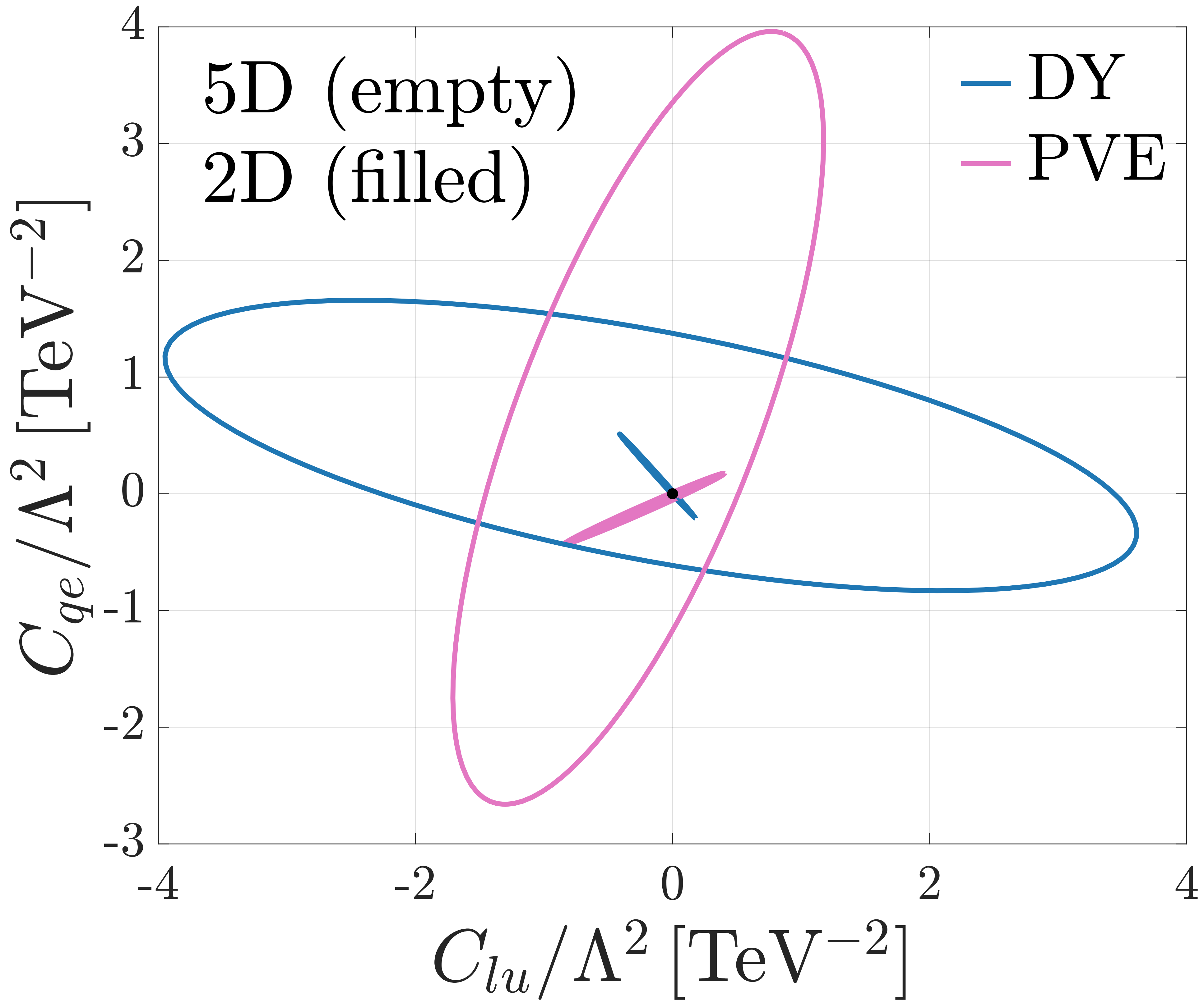
Energy growth is similar for all Wilson coefficients in Drell-Yan (DY)

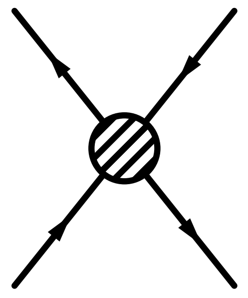
Combining sectors: Drell-Yan vs parity violation experiments

[Bartocci, AB, Hurth (2311.04963)]

Single-parameter fits

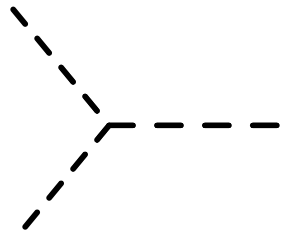


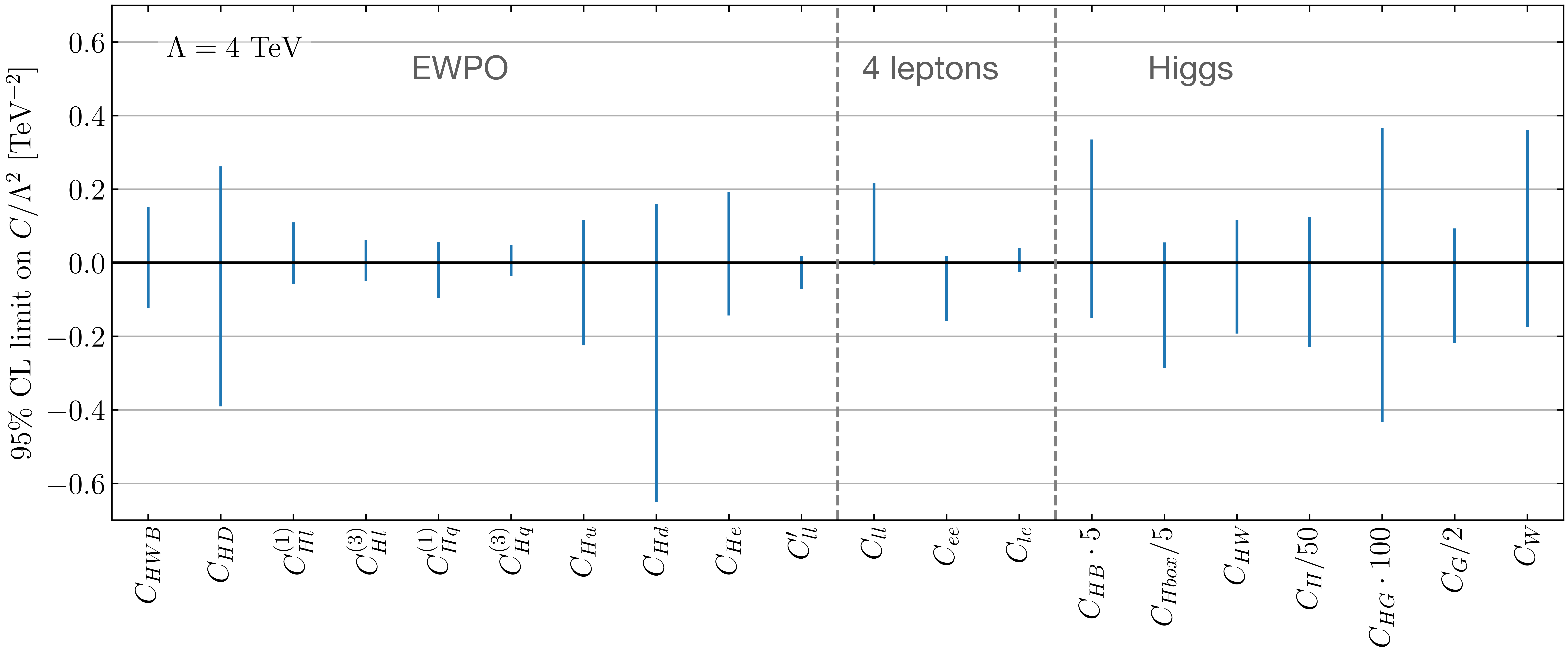




Energy growth is similar for all Wilson coefficients in Drell-Yan (DY)

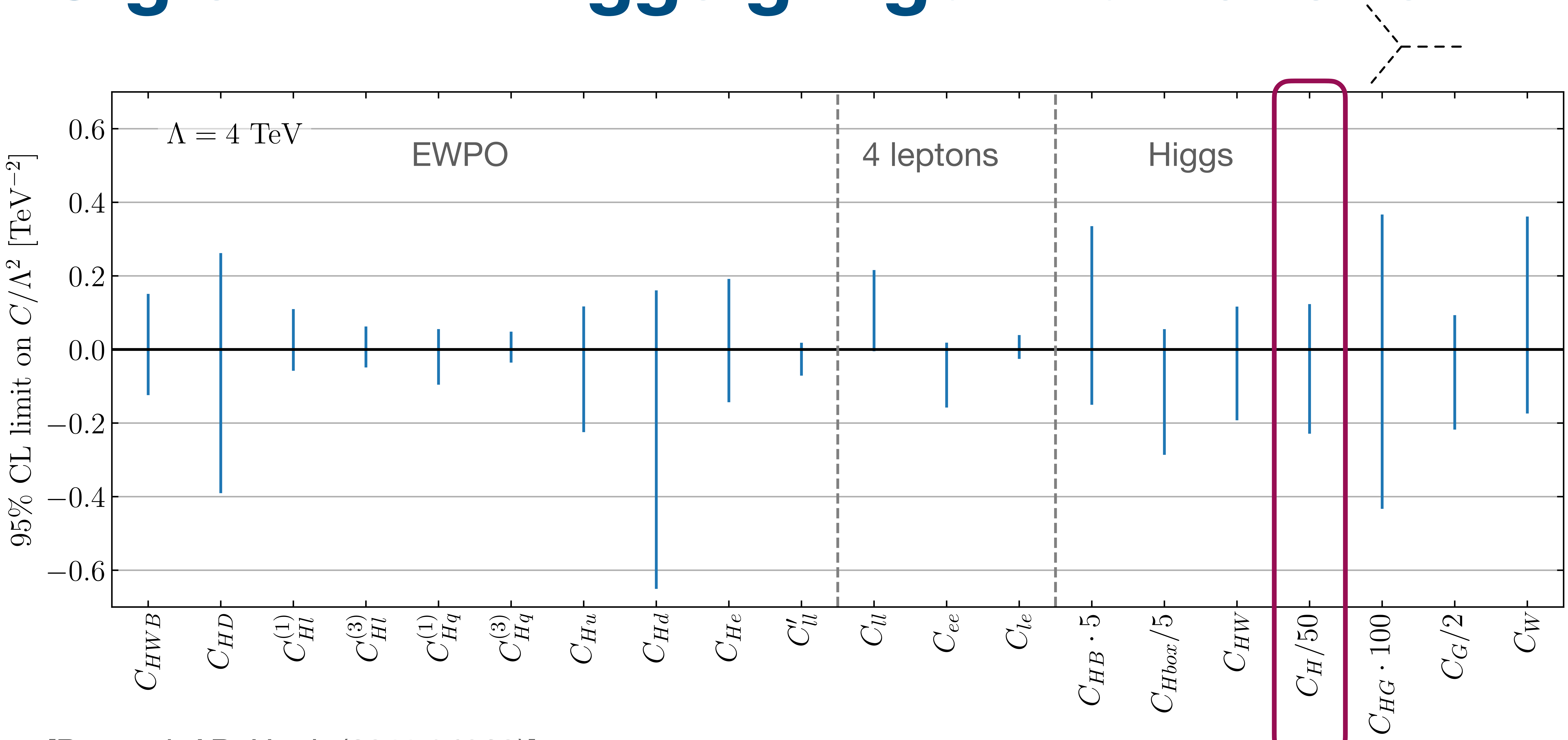
LO global fit - Higgs/gauge interactions





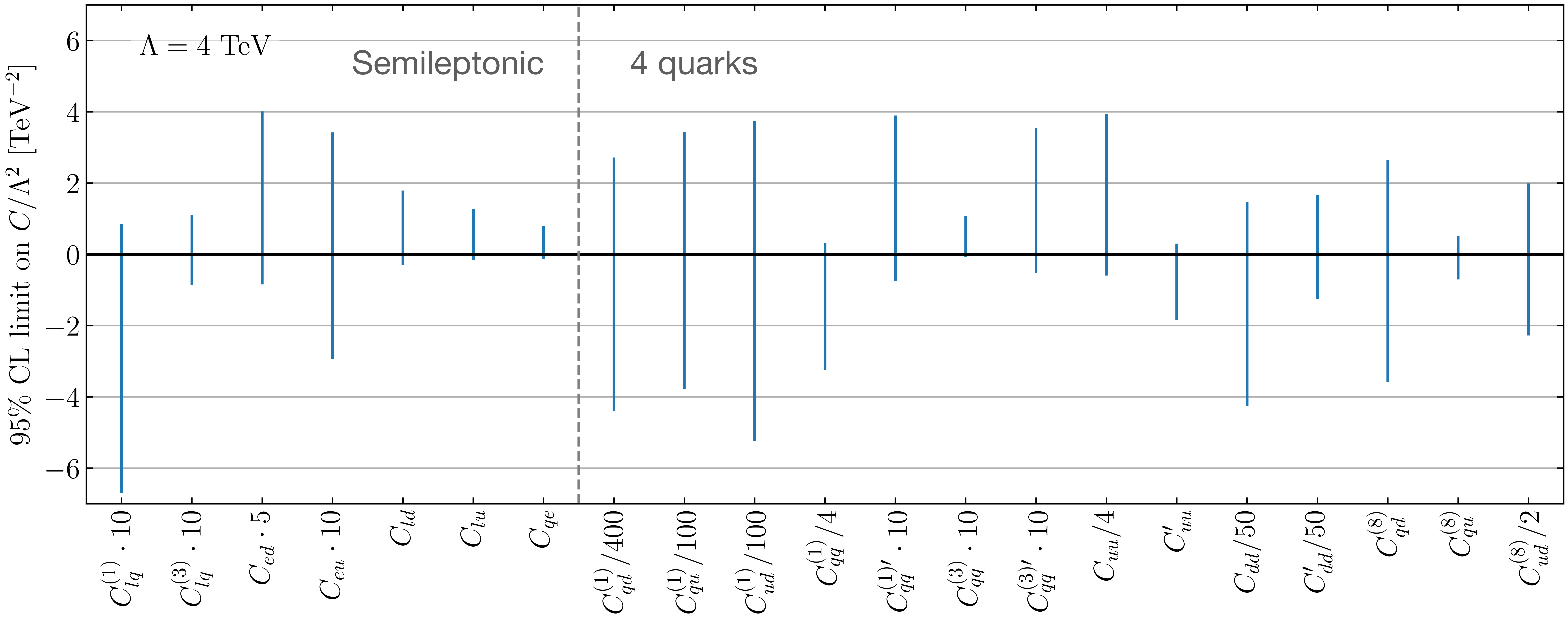
[Bartocci, AB, Hurth (2311.04963)]

LO global fit - Higgs/gauge interactions



[Bartocci, AB, Hurth (2311.04963)]

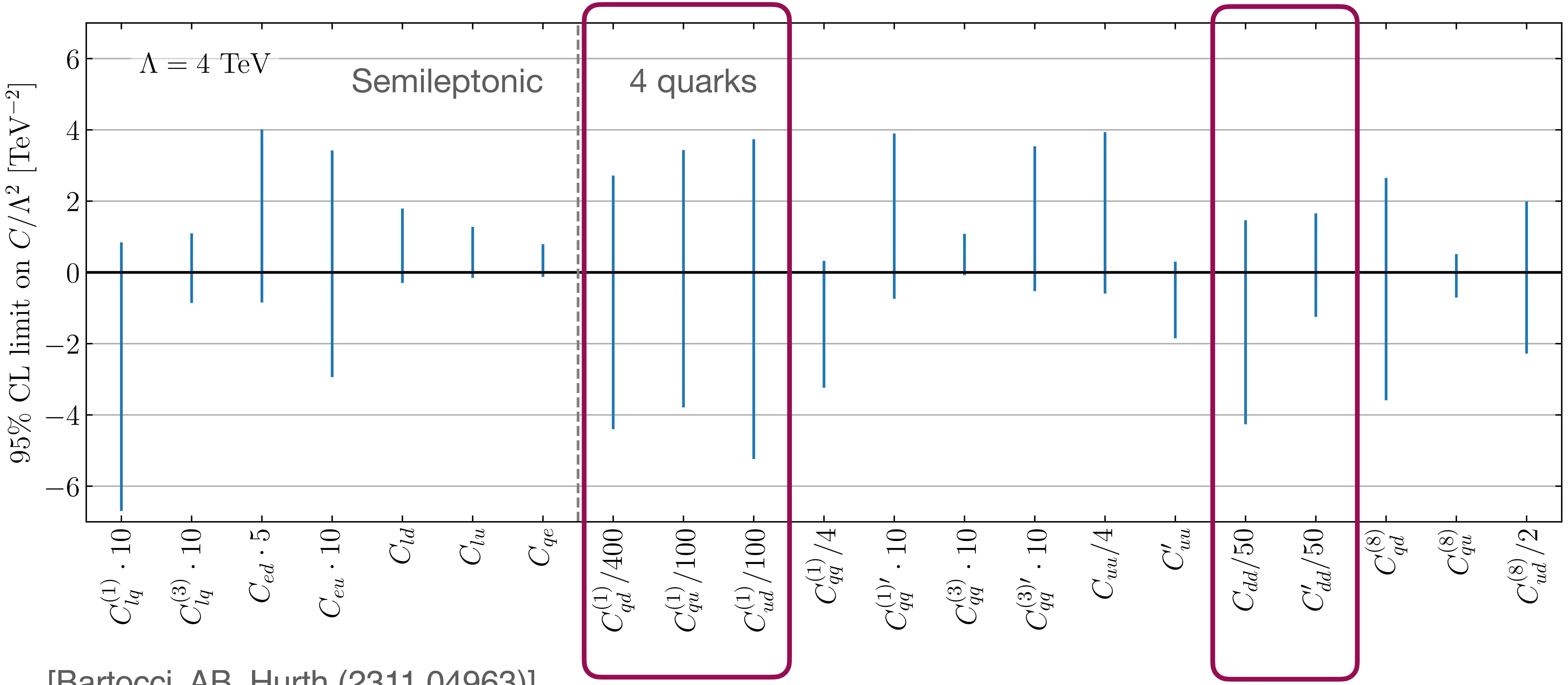
LO global fit - 2



[Bartocci, AB, Hurth (2311.04963)]

LO global fit - 2

Do not interfere with dominant SM diagram in dijet(+photon) production



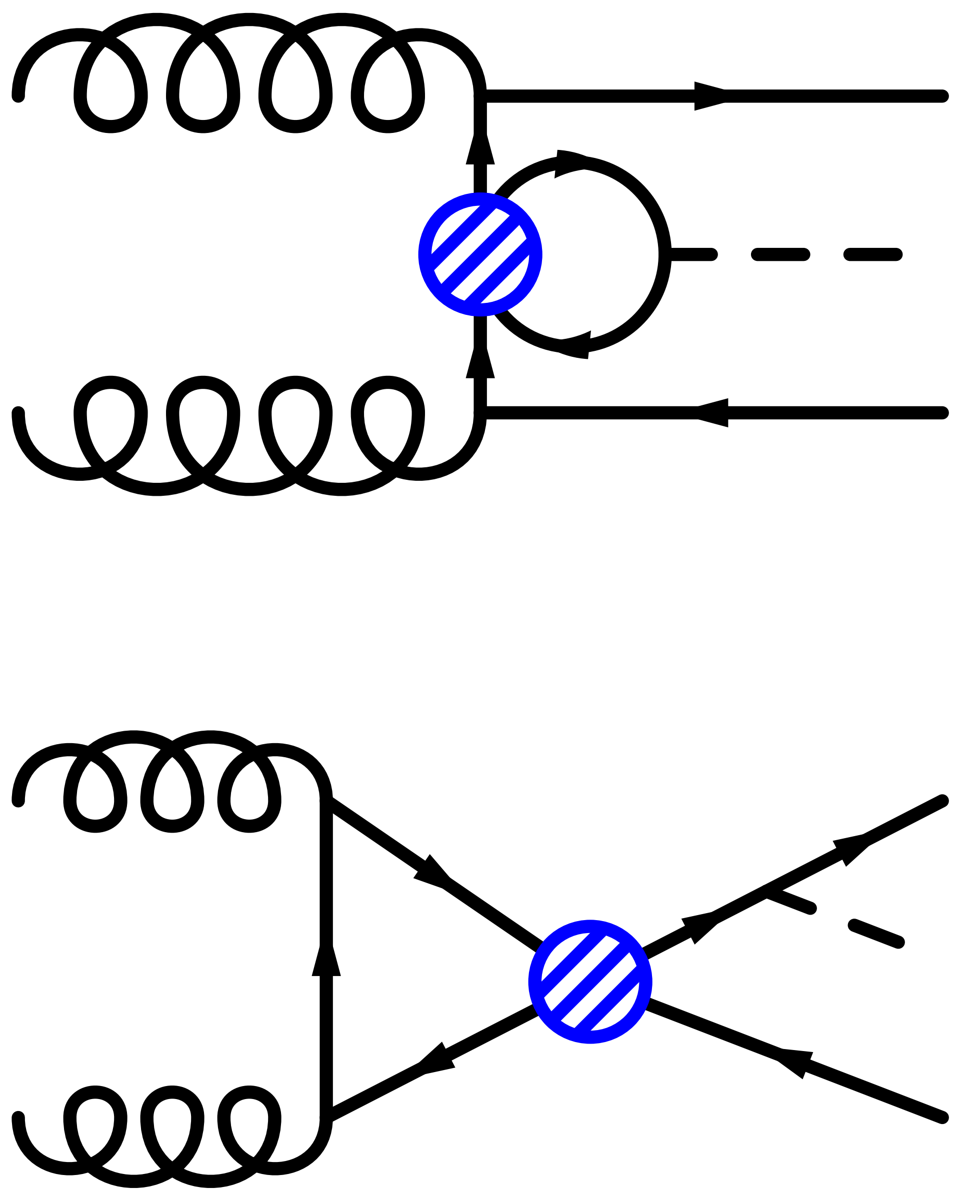
[Bartocci, AB, Hurth (2311.04963)]

NLO to the rescue?

Additional sensitivity from next-to-leading-order (NLO) SMEFT effects

Higgs: $C_{qu}^{(1)}$ $\bar{t}th$

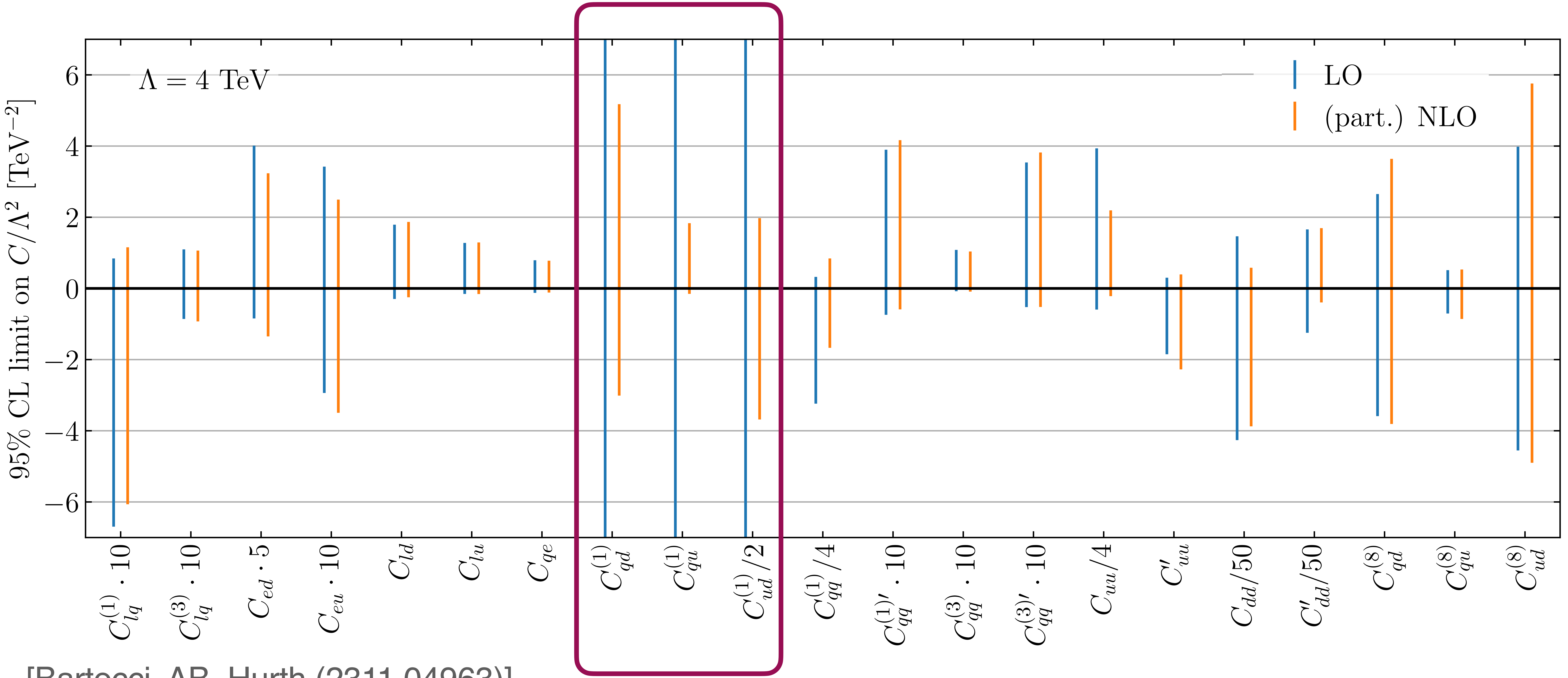
Top: $C_{qd}^{(1)}, C_{ud}^{(1)}$ $\bar{t}t$



[Alasfar, de Blas, Gröber (2202.02333)]
[SMEFit: Kassabov et al. (2303.06159)]

(Partial) NLO fit

Partial: Not all observables are available at NLO



[Bartocci, AB, Hurth (2311.04963)]

SMEFT@NLO: Blessing & curse

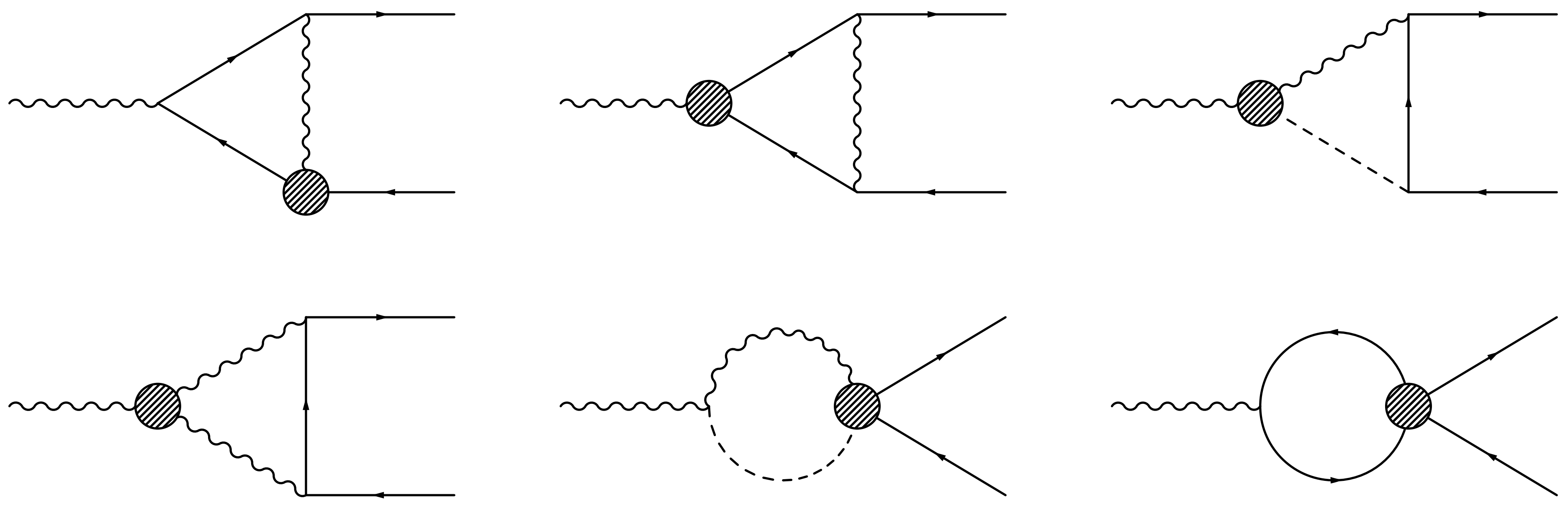
EWPO: 10 ops @LO, 32 ops @NLO (U(3)^5 sym)

[Dawson, Giardino (1909.02000)], [AB, Pecjak, Scott, Smith (2305.03763)]

$$\delta\Gamma(Z\to l^+l^-)^{LO} = \frac{v^2}{\Lambda^2}\Big\{-0.1408\mathcal{C}_{\phi e} + 0.191\mathcal{C}_{\phi l}^{(1)} - 0.037\mathcal{C}_{\phi l}^{(3)} + 0.114\mathcal{C}_{ll} - 0.057\mathcal{C}_{\phi D} - 0.0713\mathcal{C}_{\phi WB}\Big\}\,\mathrm{GeV}$$

$$\begin{aligned}\delta\Gamma(Z\to l^+l^-)^{NLO} = \frac{v^2}{\Lambda^2}\Big\{&-0.1596\mathcal{C}_{\phi e} + 0.1834\mathcal{C}_{\phi l}^{(1)} - 0.0221\mathcal{C}_{\phi l}^{(3)} + 0.0985\mathcal{C}_{ll} - 0.0508\mathcal{C}_{\phi D}\\ &-0.0349\mathcal{C}_{\phi WB} - 0.0001\mathcal{C}_{\phi W} - 0.0002\mathcal{C}_{ed} - 0.0005\mathcal{C}_{ee} + 0.0035\mathcal{C}_{eu}\\ &-0.0002\mathcal{C}_{\phi d} - 0.0042\mathcal{C}_{\phi q}^{(1)} + 0.0032\mathcal{C}_{\phi q}^{(3)} + 0.0049\mathcal{C}_{\phi u} + 0.0002\mathcal{C}_{ld}\\ &+0.0001\mathcal{C}_{le} + 0.0034\mathcal{C}_{lq}^{(1)} - 0.0031\mathcal{C}_{lq}^{(3)} - 0.0045\mathcal{C}_{lu} - 0.0001\mathcal{C}_{\phi\Box}\\ &-0.0027\mathcal{C}_{qe} - 0.0007\mathcal{C}_{uB} - 0.0007\mathcal{C}_{uW} - 0.0001\mathcal{C}_{W}\Big\}\,\mathrm{GeV}\end{aligned}$$

More degrees of freedom contribute to each observable at NLO

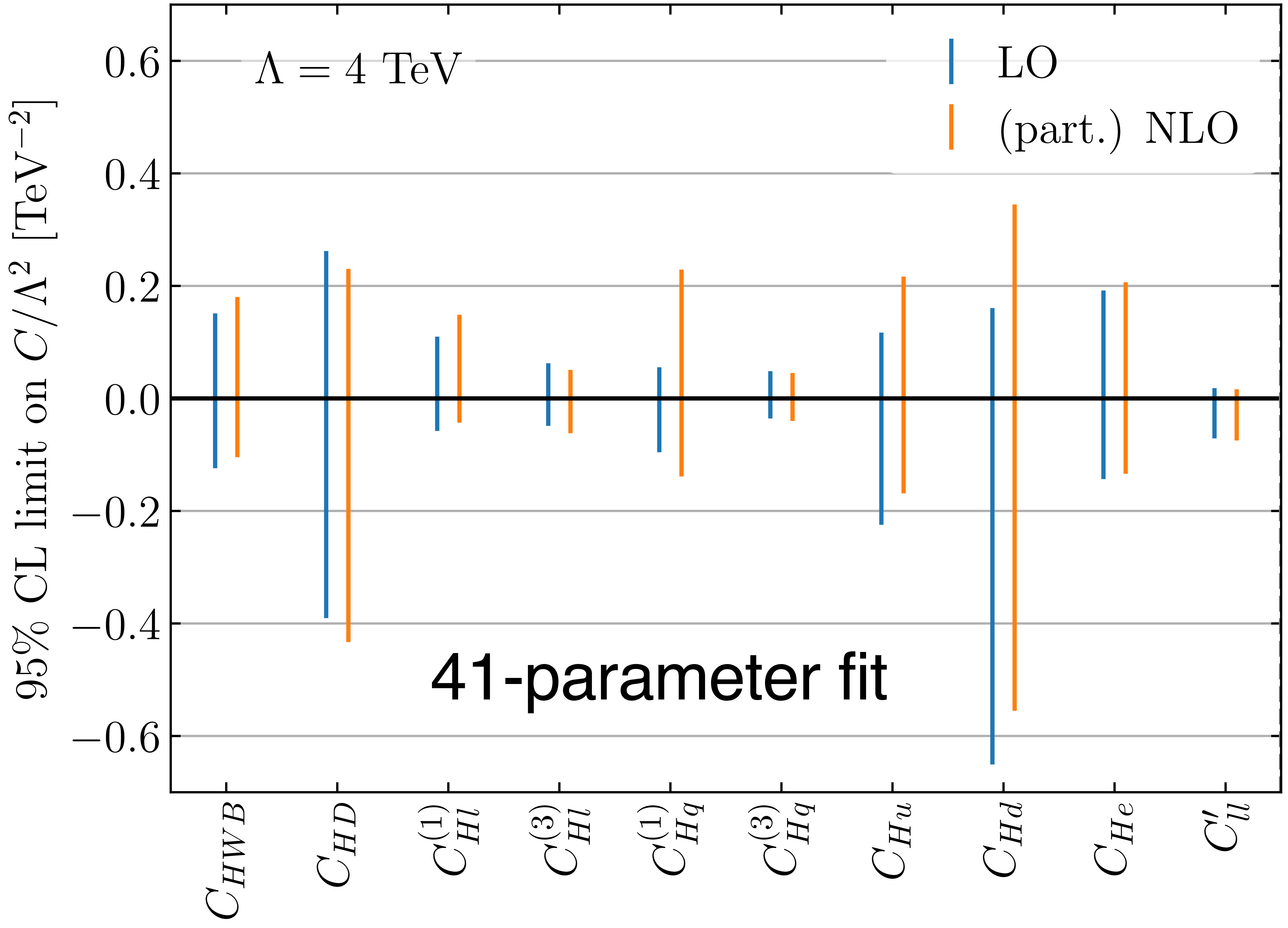


precision & degeneracies

NLO degeneracies

Higgs self coupling [Alasfar, de Blas, Gröber (2202.02333)]

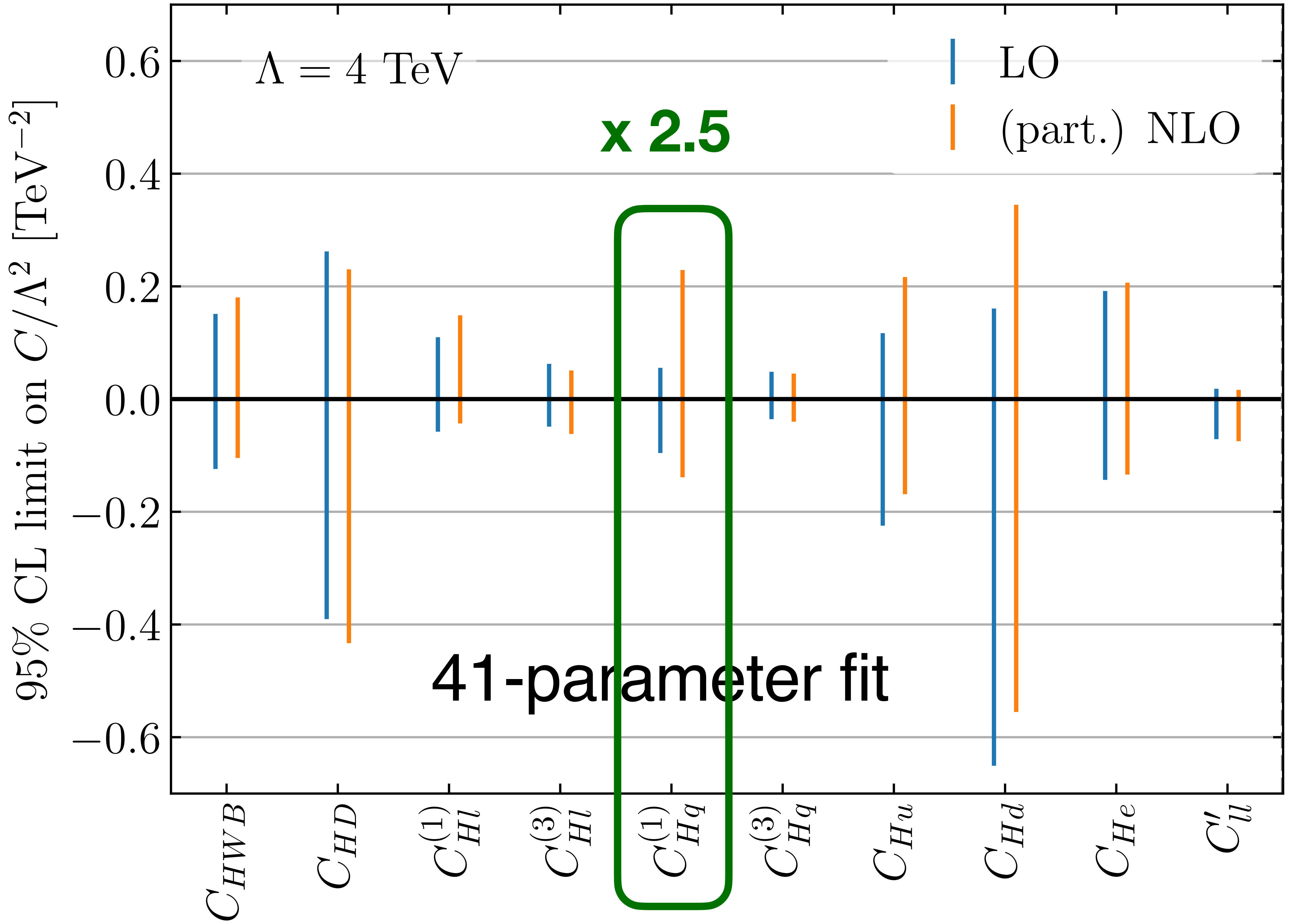
[Bartocci, AB, Hurth (2311.04963)]



NLO degeneracies

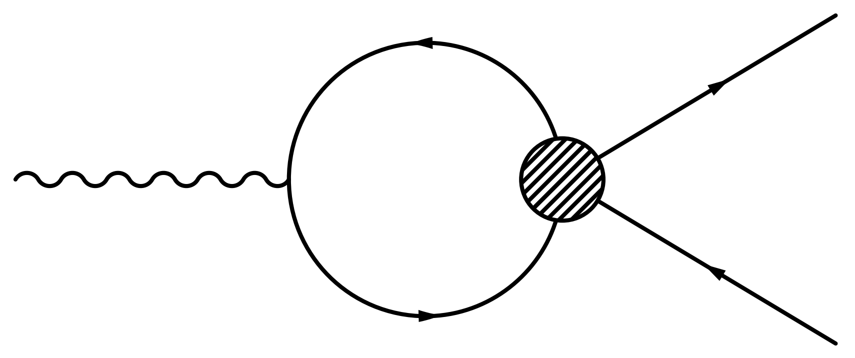
Higgs self coupling [Alasfar, de Blas, Gröber (2202.02333)]

[Bartocci, AB, Hurth (2311.04963)]

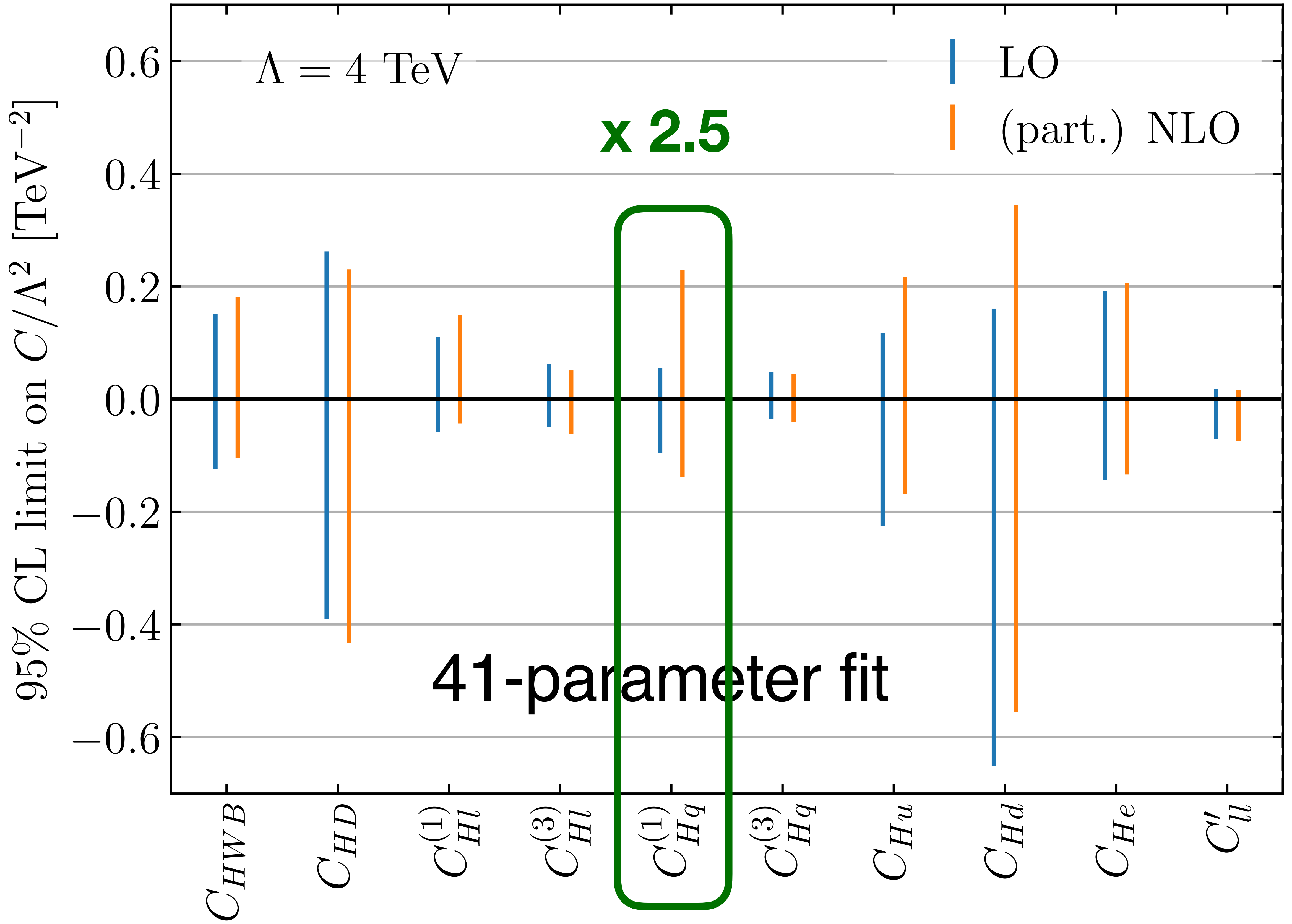


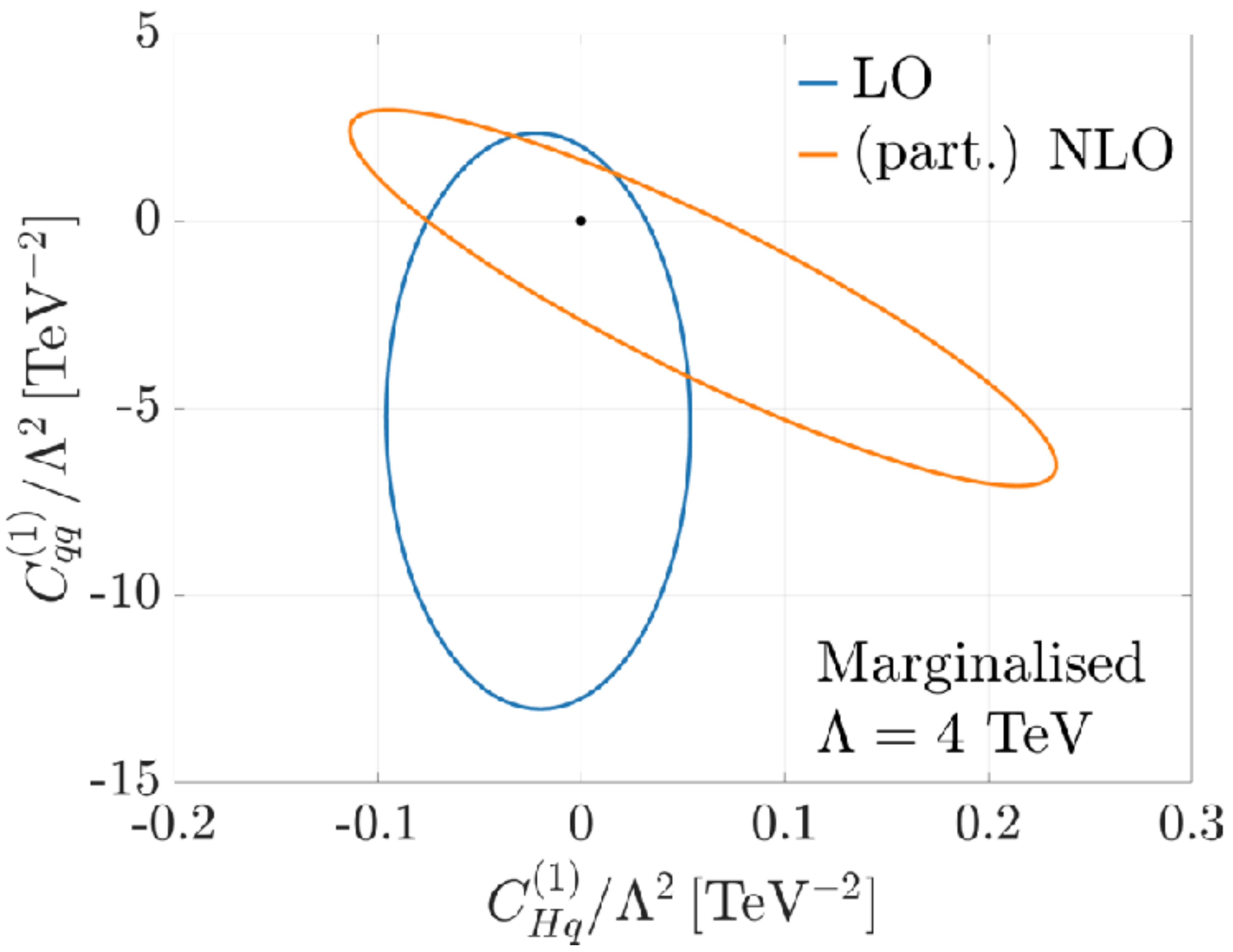
NLO degeneracies

Higgs self coupling [Alasfar, de Blas, Gröber (2202.02333)]



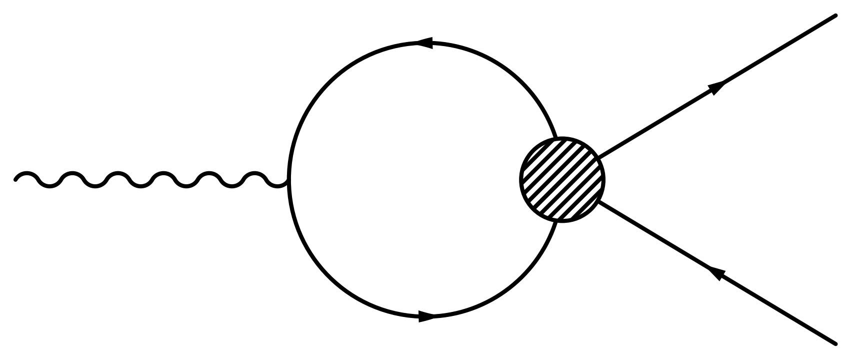
[Bartocci, AB, Hurth (2311.04963)]



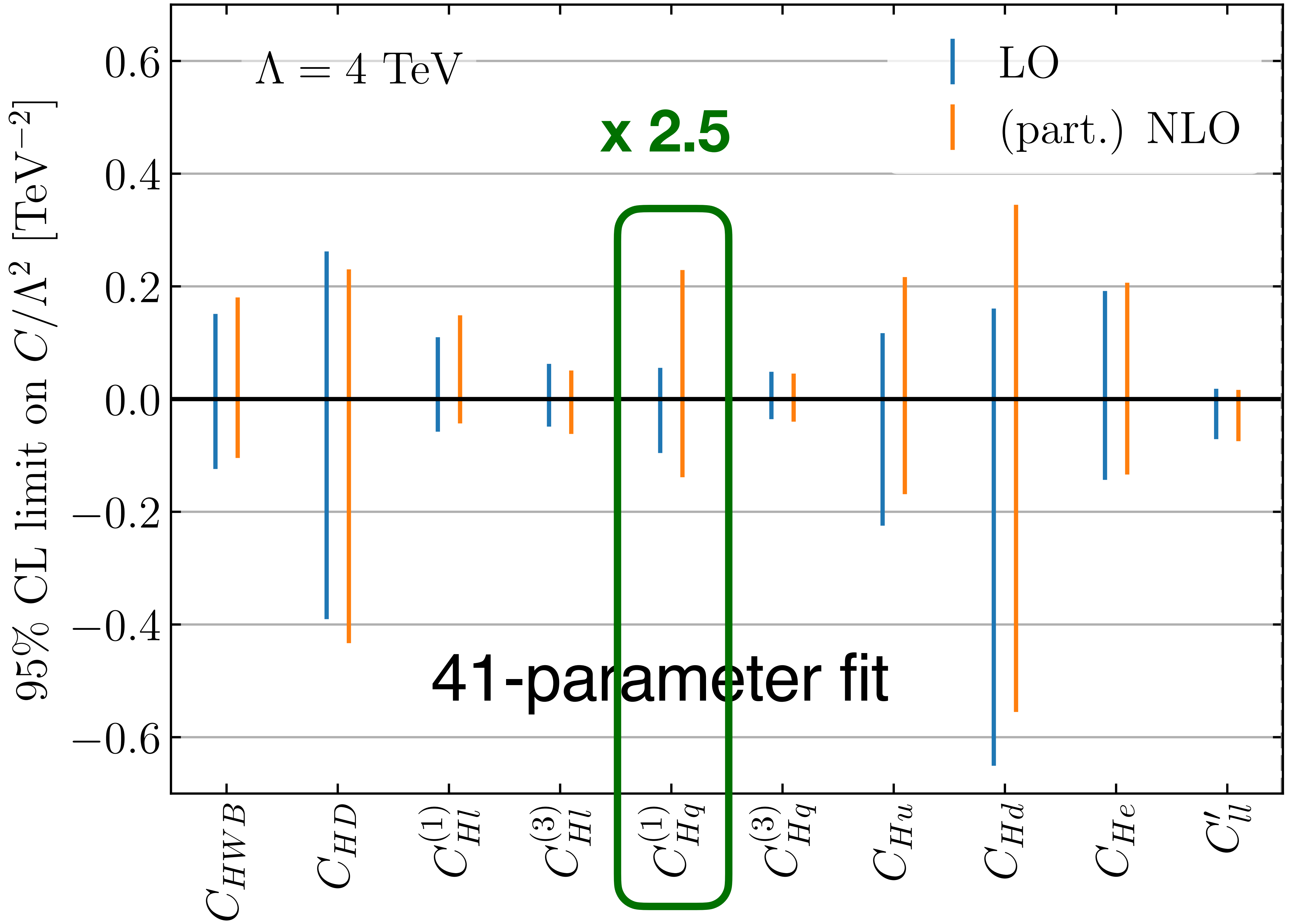


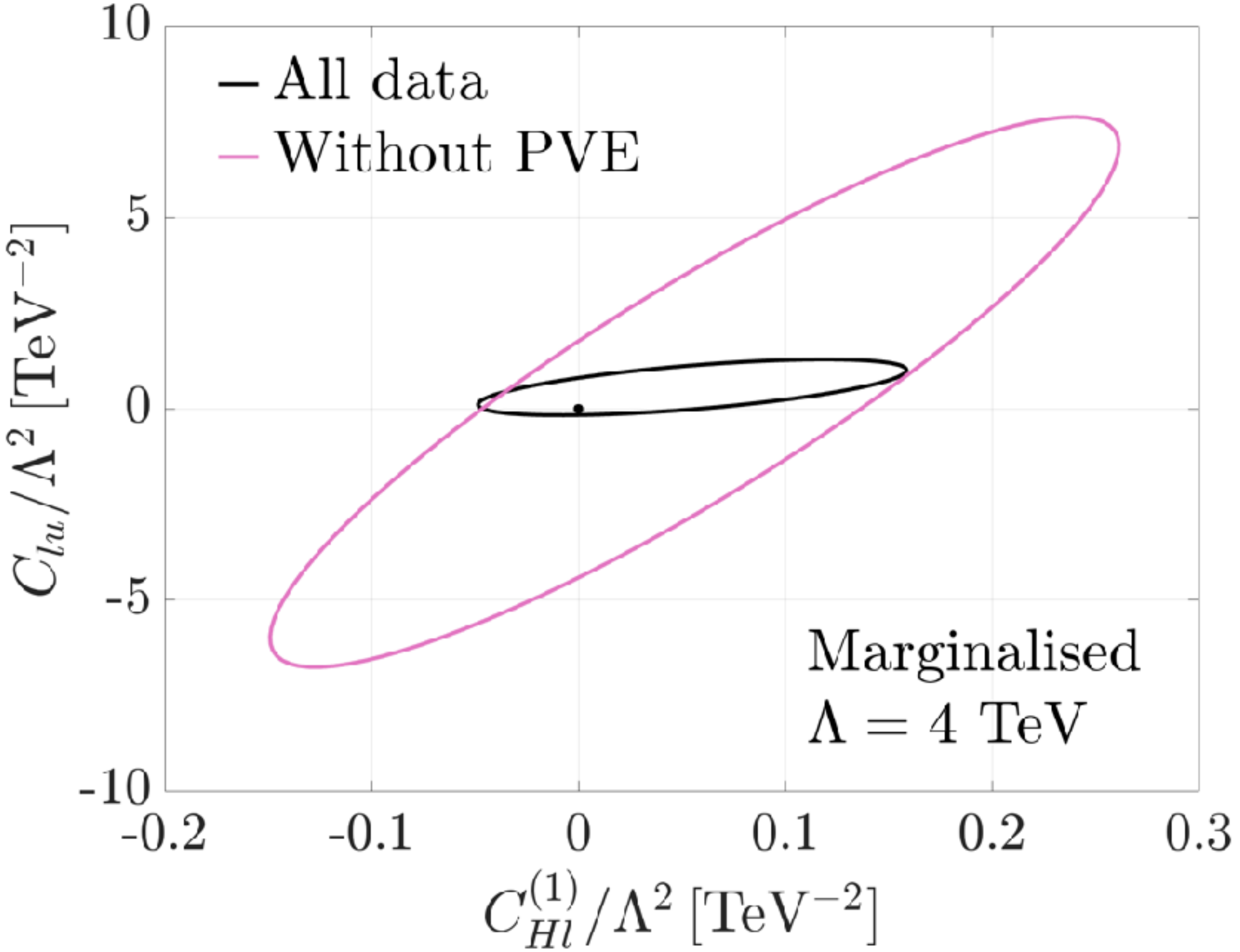
NLO degeneracies

Higgs self coupling [Alasfar, de Blas, Gröber (2202.02333)]

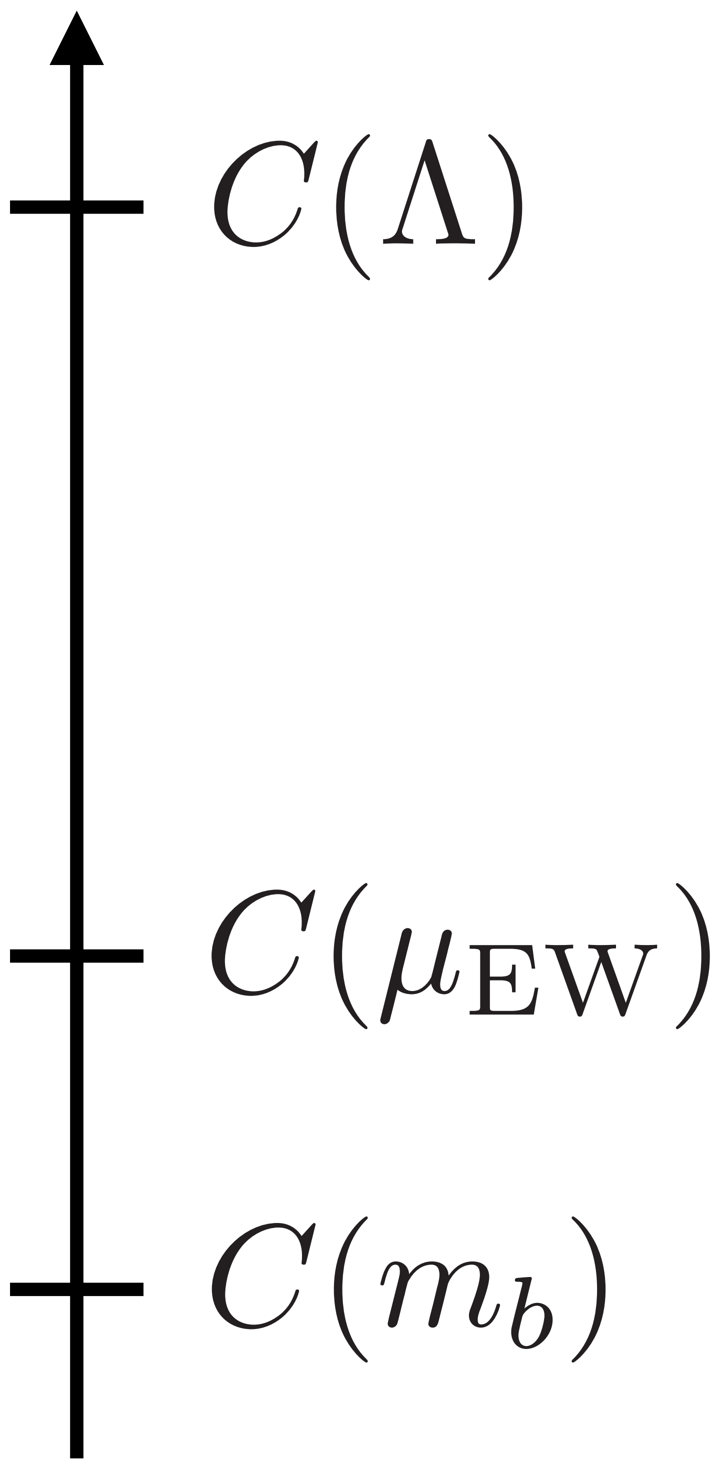


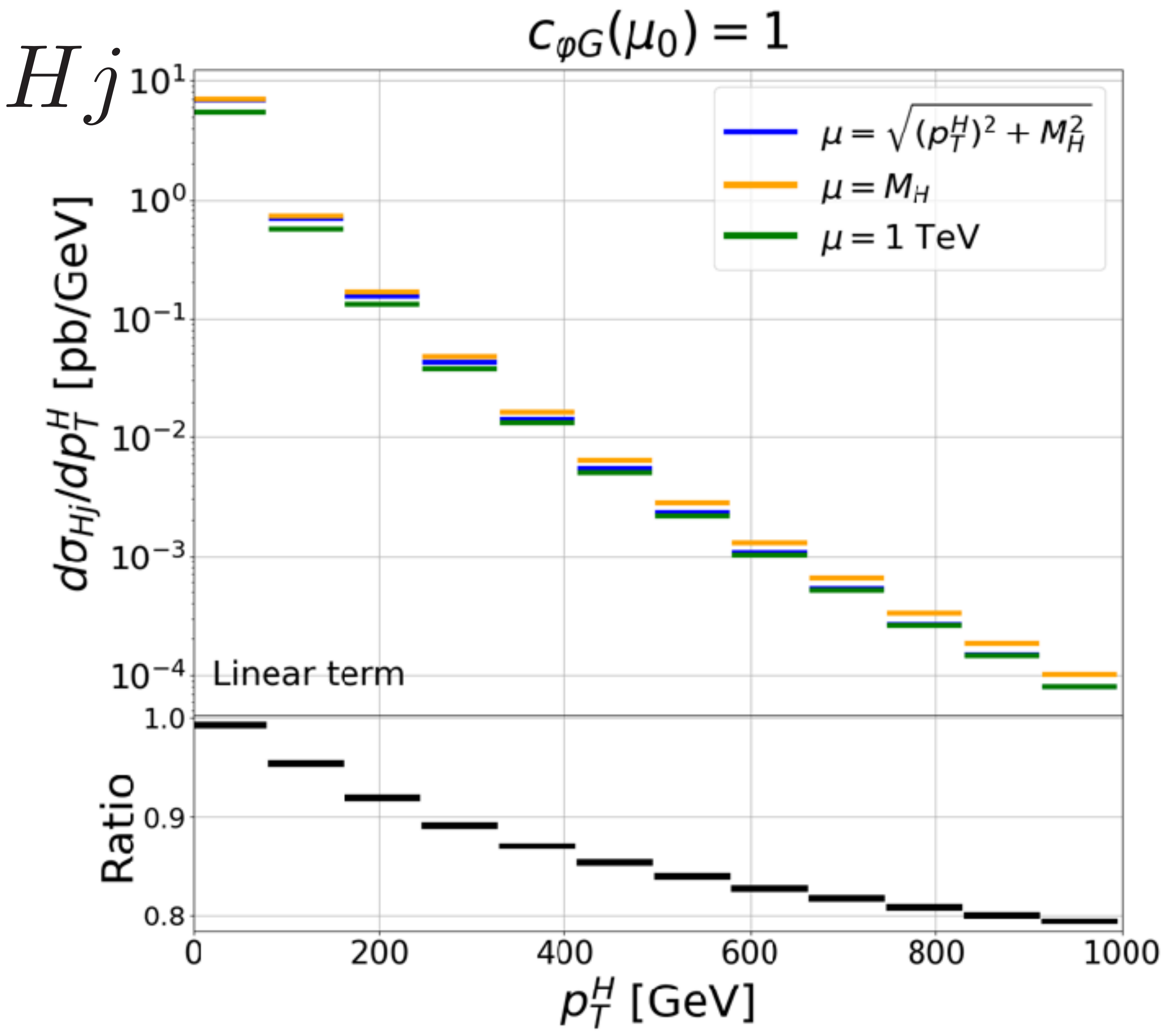
[Bartocci, AB, Hurth (2311.04963)]





Renormalisation group evolution





[Maltoni, Ventura, Vryonidou (2406.06670)]

RG effects particularly relevant for differential distributions

[Alasfar, de Blas, Gröber (2202.02333)]

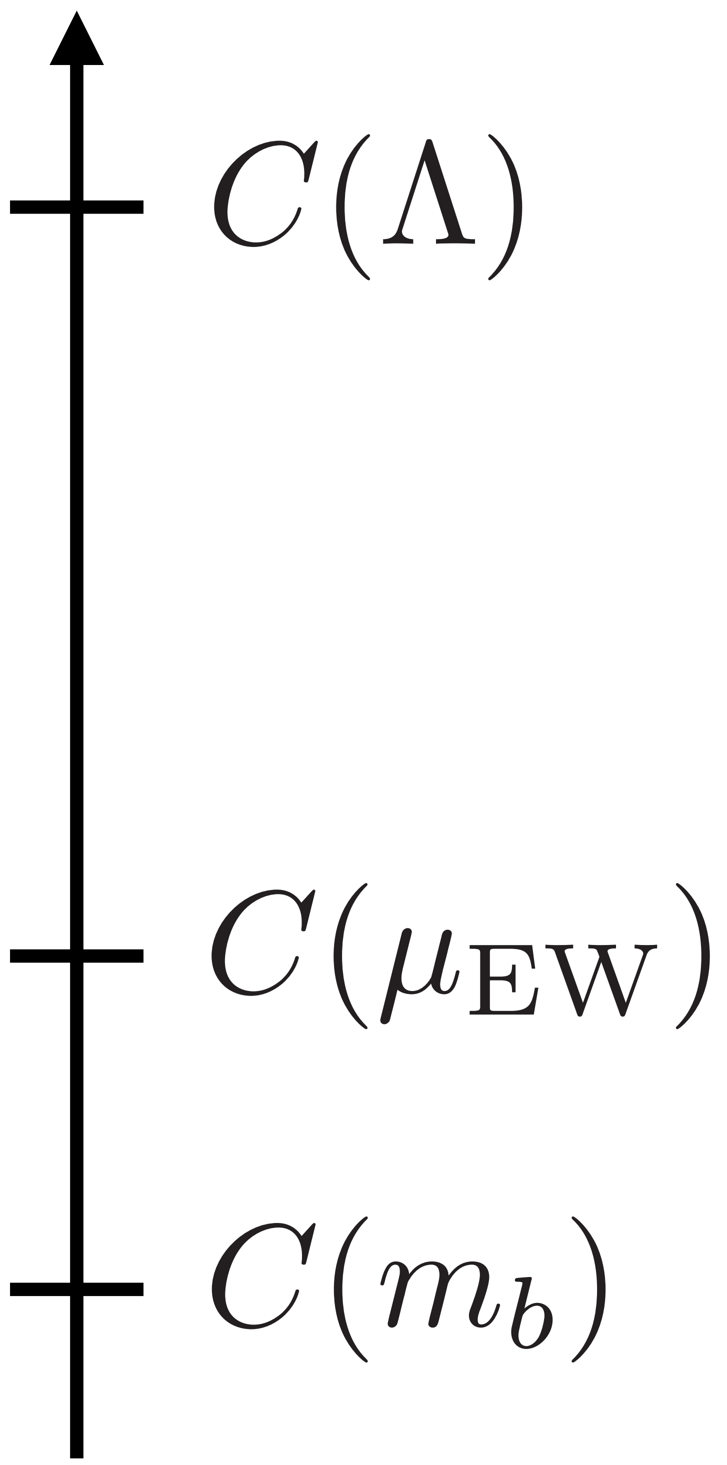
[Aoude, Maltoni, Mattelaer, Severi, Vryonidou (2212.05067)]

[Di Noi, Gröber (2312.11327)]

[Di Noi, Gröber, Mandal (2408.03252)]

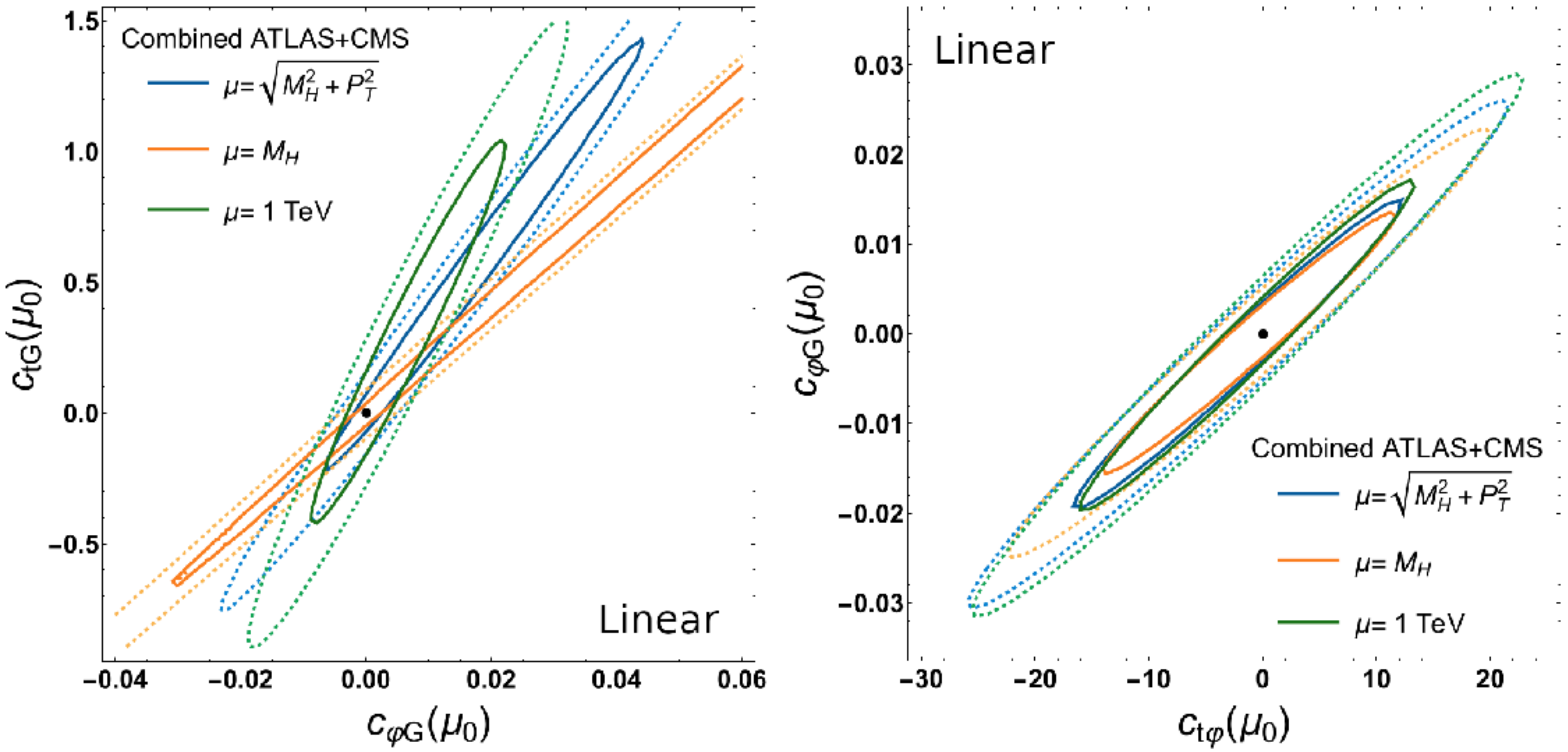
[Heinrich, Lang (2409.19578)]

Renormalisation group evolution



Running affects correlations

[Maltoni, Ventura, Vryonidou (2406.06670)]



Will be interesting to study effects on global fits

[Alasfar, de Blas, Gröber (2202.02333)]

[Aoude, Maltoni, Mattelaer, Severi, Vryonidou (2212.05067)]

[Di Noi, Gröber (2312.11327)]

[Di Noi, Gröber, Mandal (2408.03252)]

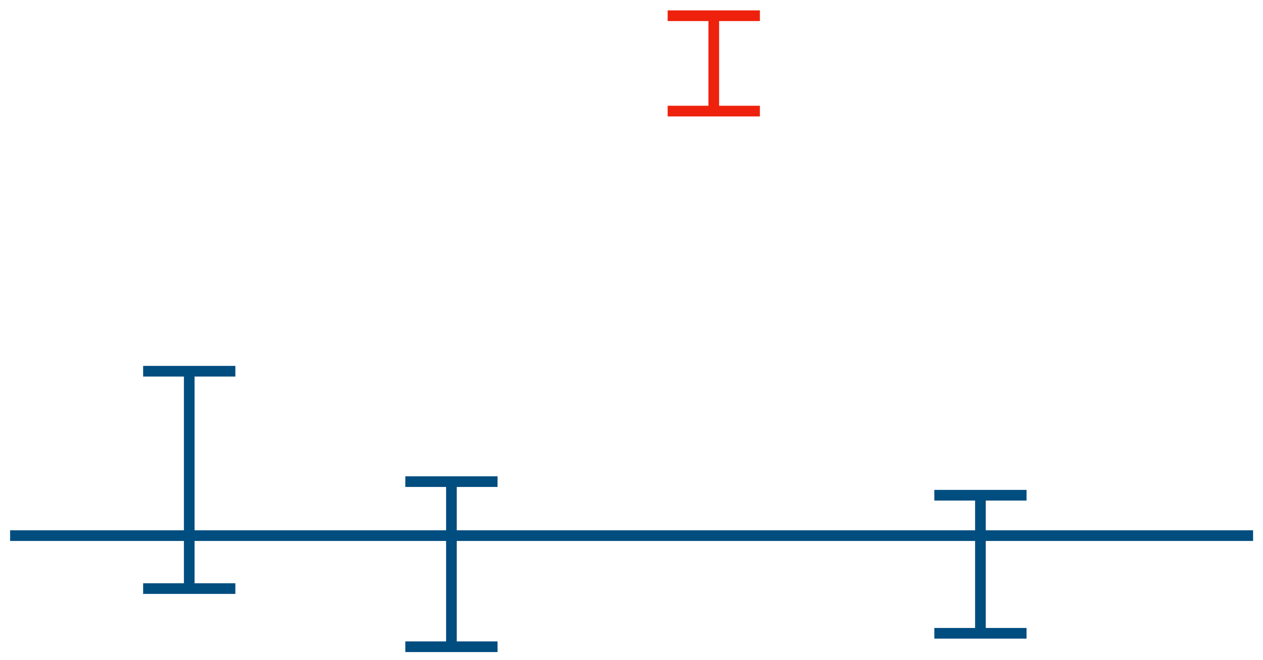
[Heinrich, Lang (2409.19578)]

Conclusions

- Fitting symmetry-motivated operator sets is becoming a reality
- Degeneracies in NLO SMEFT predictions are manageable with current data
- Will be interesting to include RG effects in global fits

Conclusions

- Fitting symmetry-motivated operator sets is becoming a reality
- Degeneracies in NLO SMEFT predictions are manageable with current data
- Will be interesting to include RG effects in global fits



Thank you for your attention!