Goals of SMEFT fits and SMEFT perspectives

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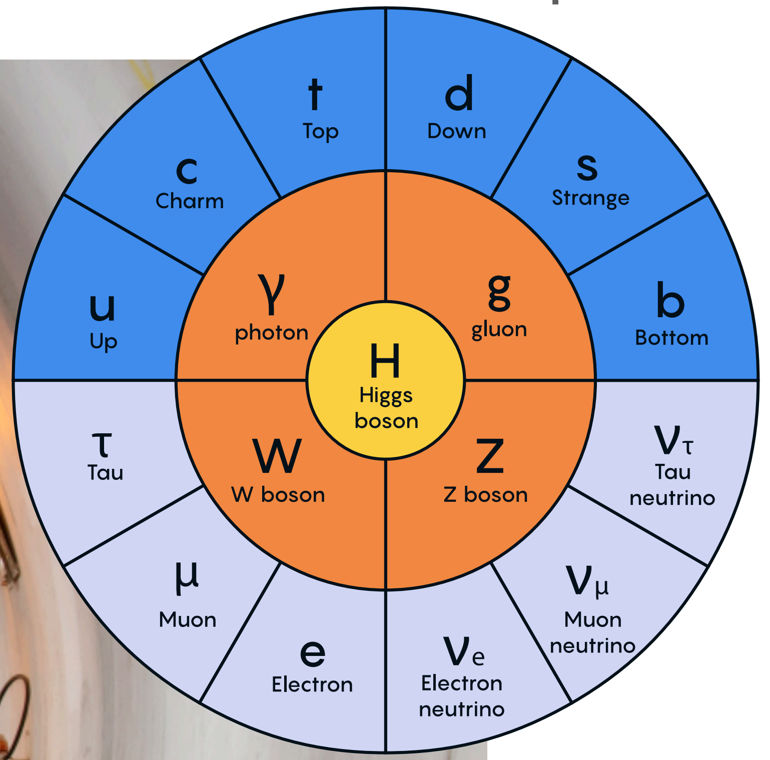
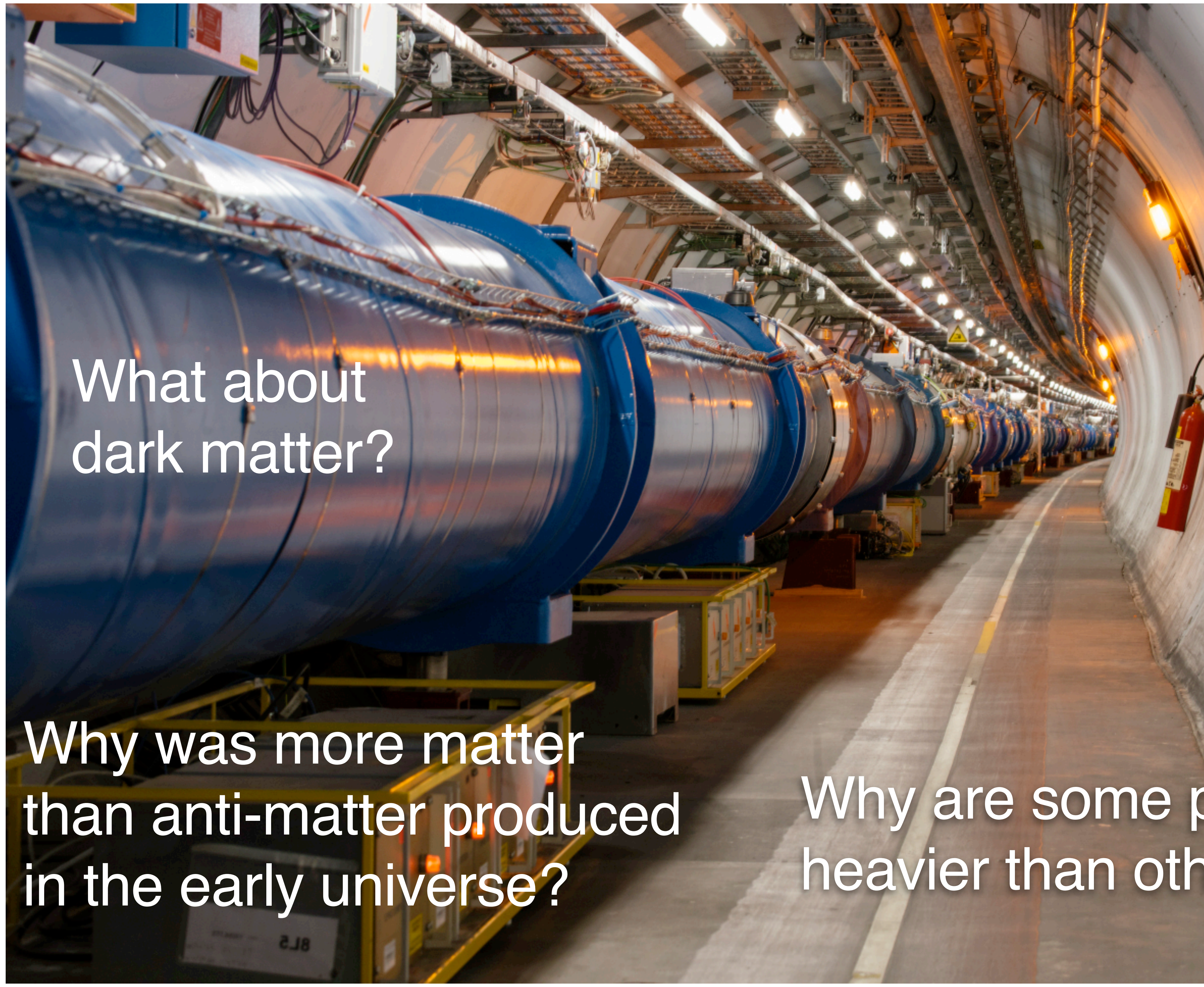
Hunting for new physics

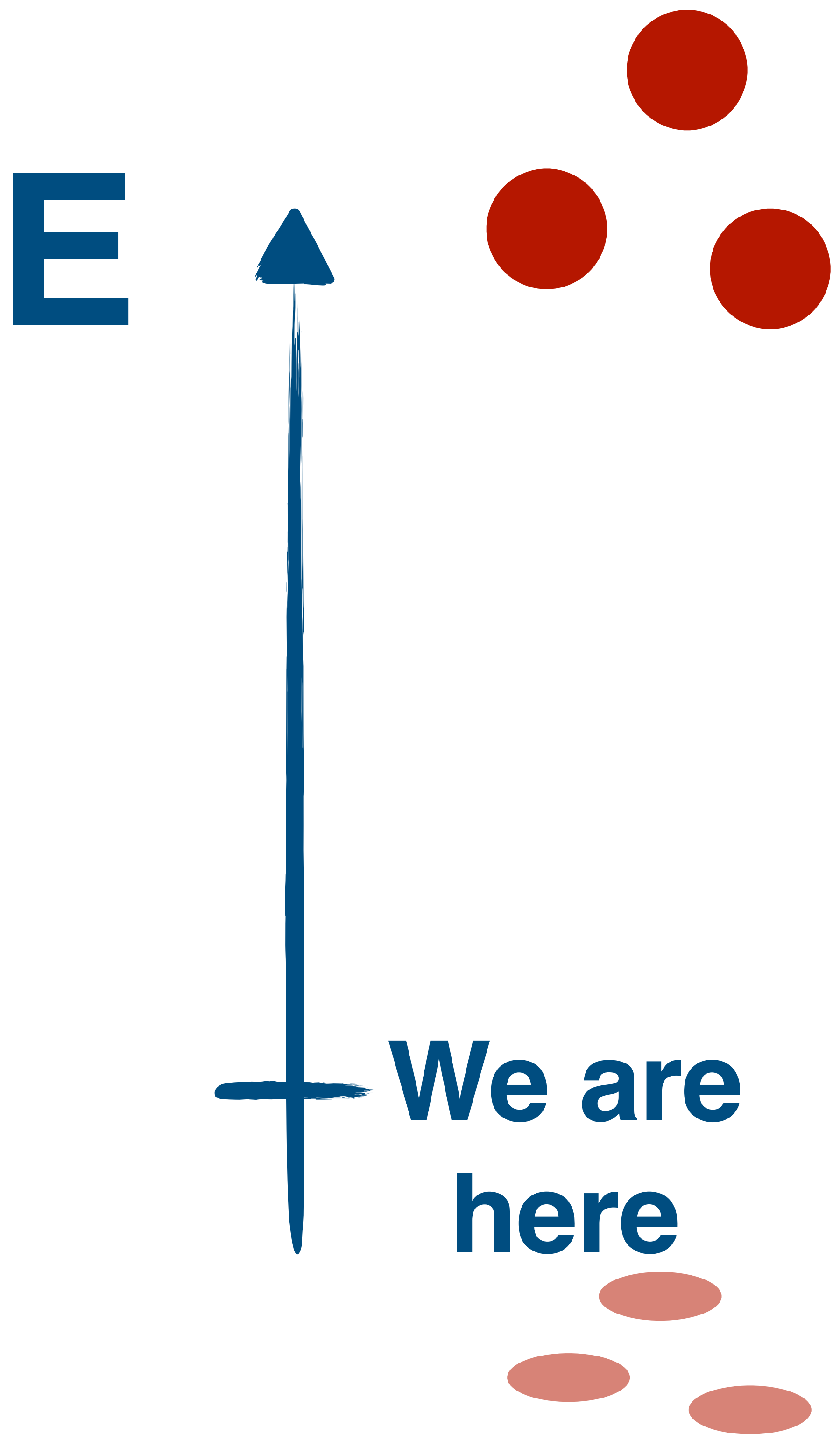
quantamagazine.org





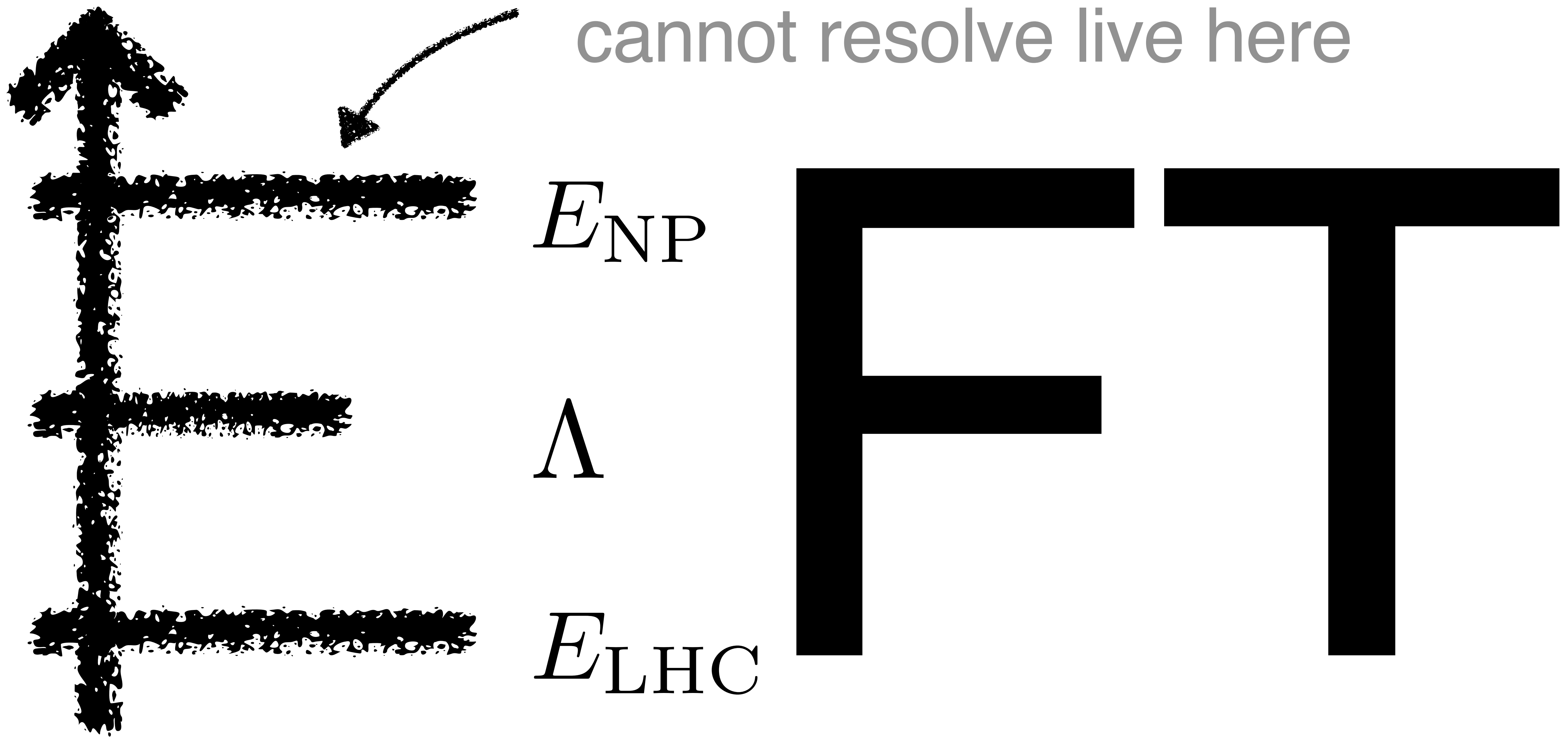
[cern.ch]

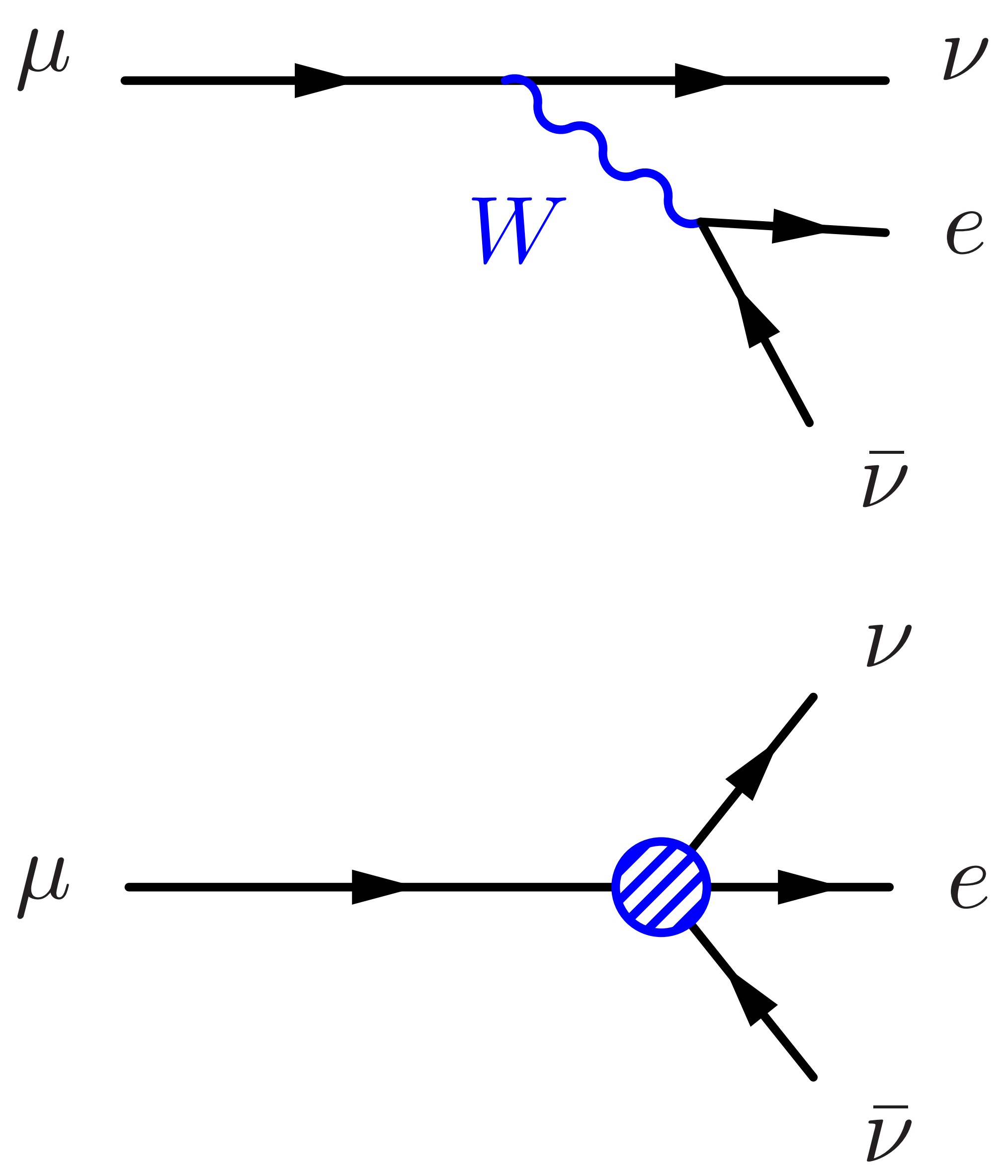
Large Hadron Collider (LHC)



Effective field theory - EFT

Heavy particles that we cannot resolve live here



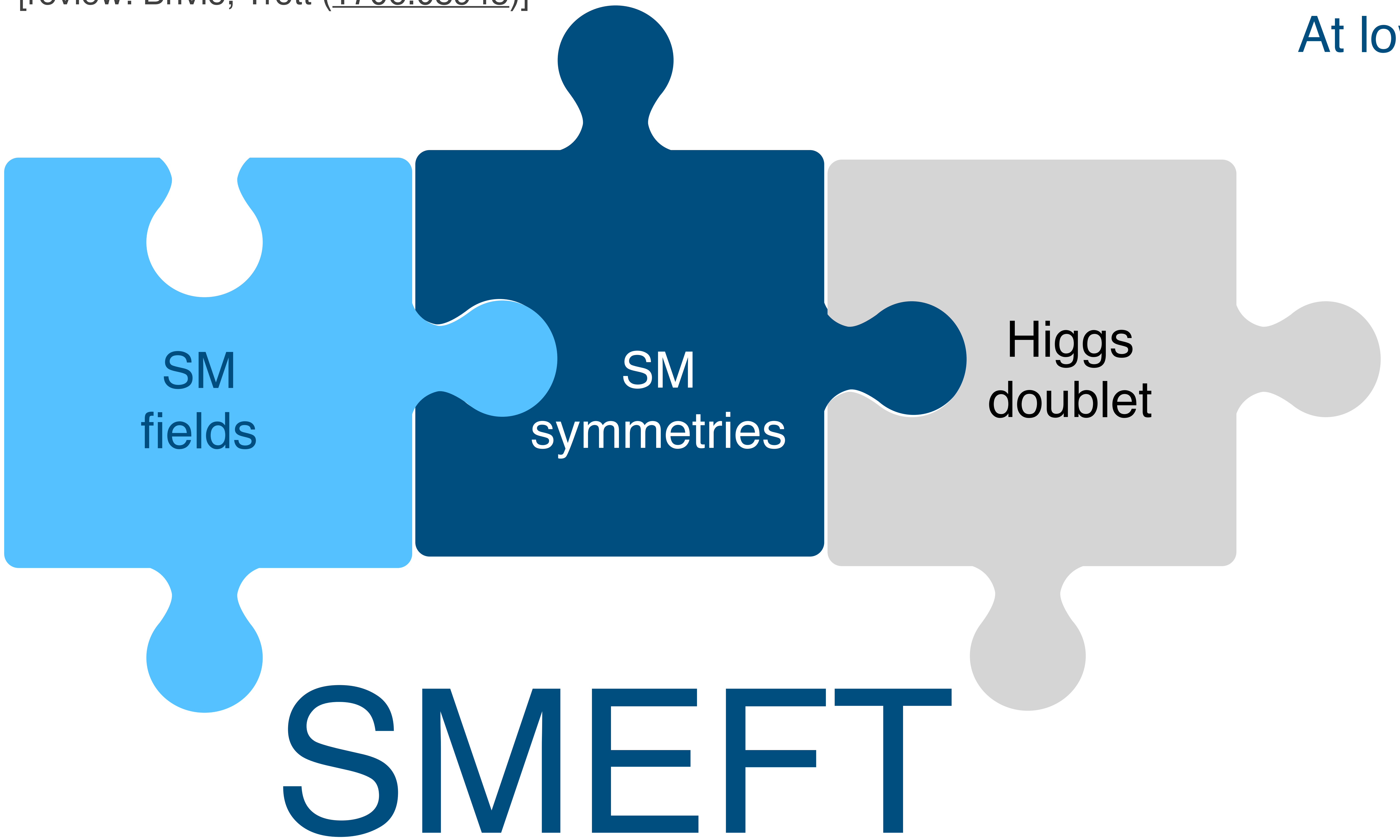


Hierarchy of scales

Describe NP by higher-order interactions of fields living at low energy

Standard Model Effective Field Theory

[review: Brivio, Trott (1706.08945)]



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

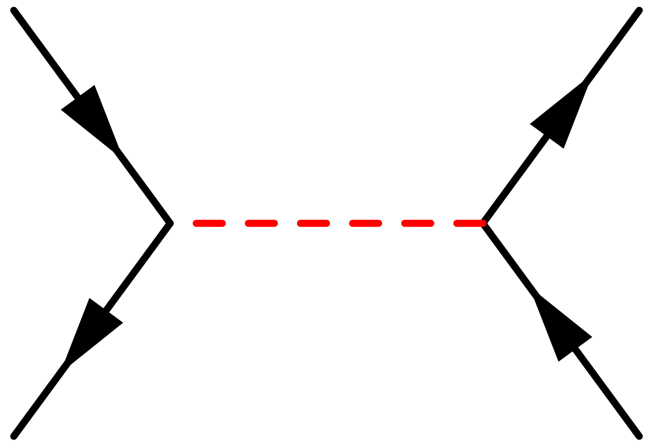
- Proper, renormalisable **quantum field theory**
- **Minimal assumptions** on UV completion
- **Universal language** for data interpretation

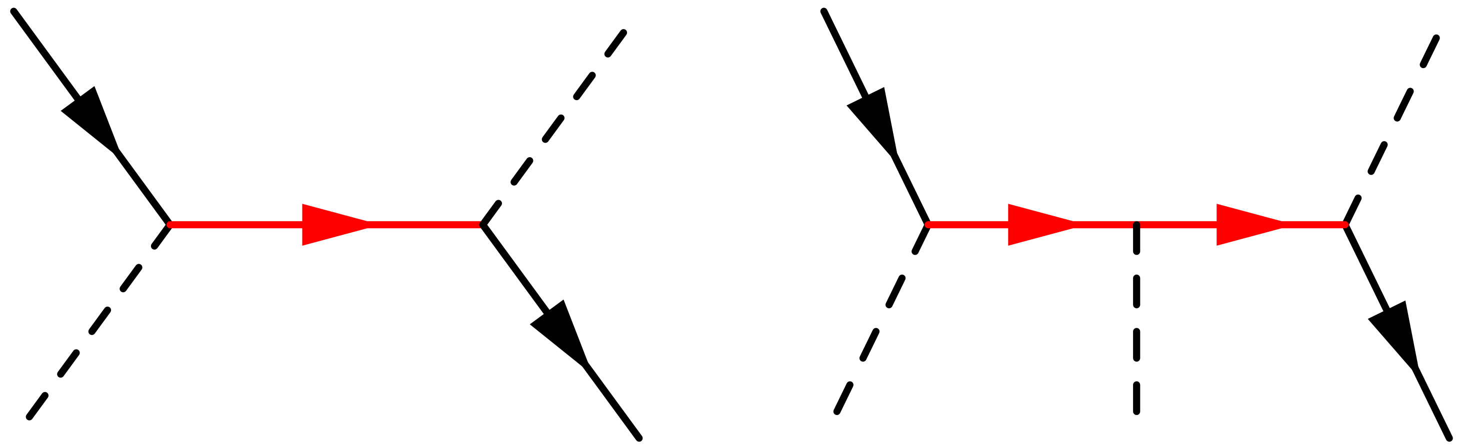
What do EFTs tell us about new physics?

New scalar

New vector-like lepton

UV model



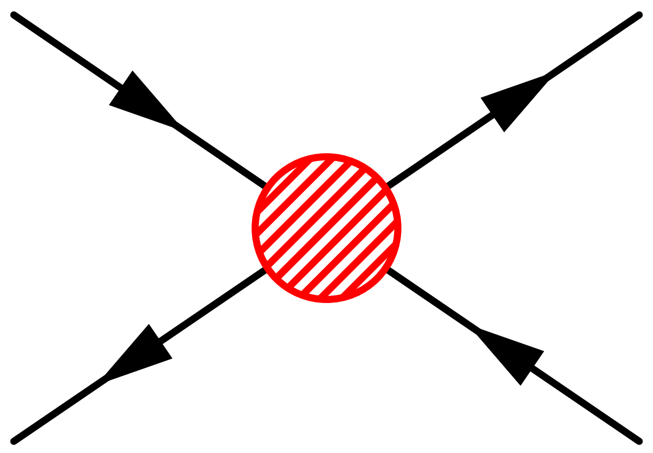


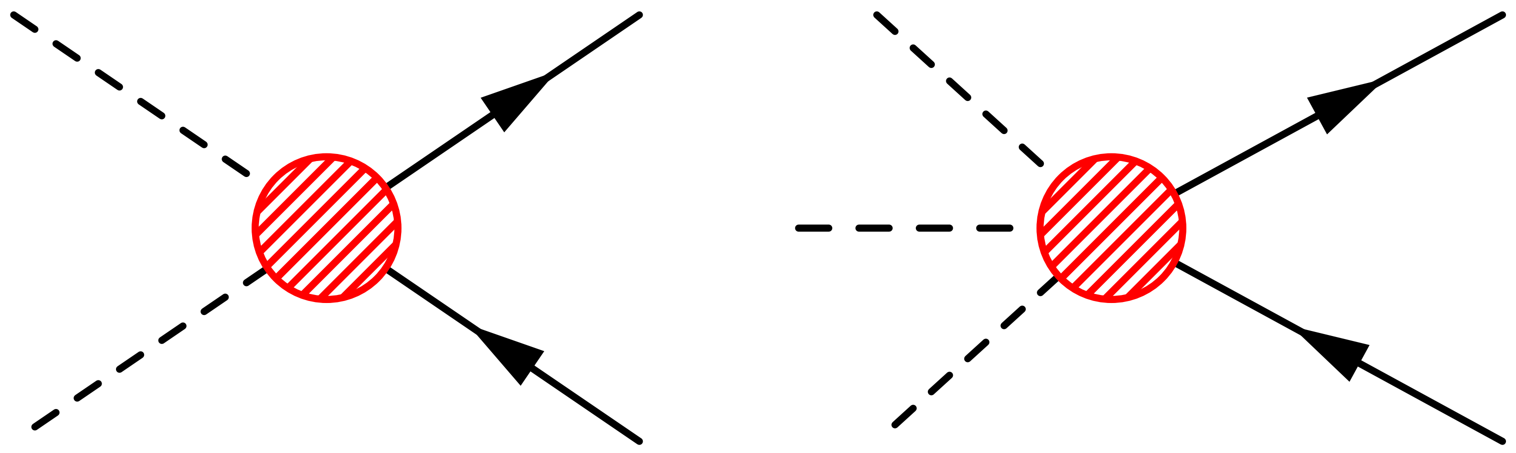
MatchmakerEFT [Carmona et al. (2112.10787)]

CoDEx [Bakshi, Chakrabortty, Patra (1808.04403)]

Matchete [Fuentes-Martín et al. (2212.04510)]

SMEFT





Subset of operators induced

Correlations

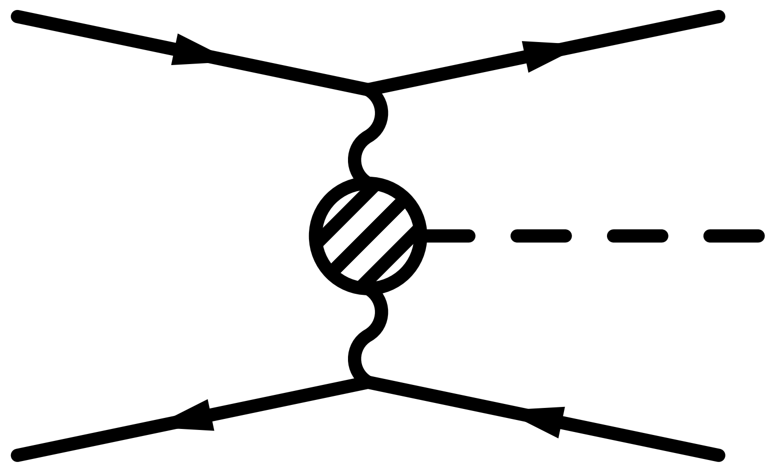
C_{ll}

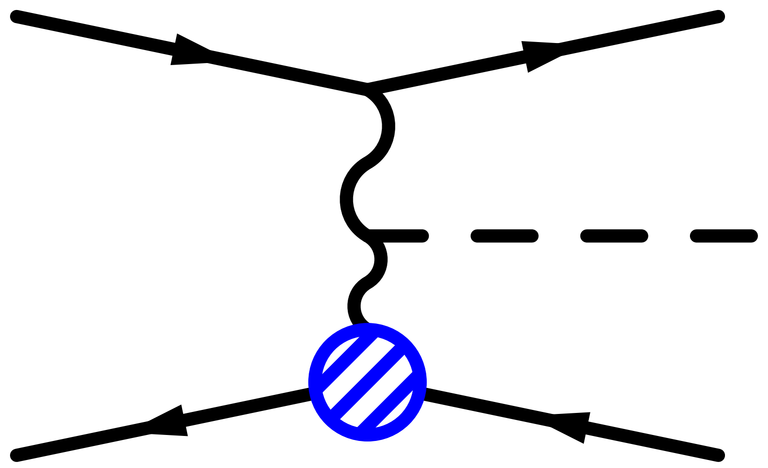
$C_{Hl}^{(3)}, C_{Hl}^{(1)}, C_{eH}$

Why global fits?

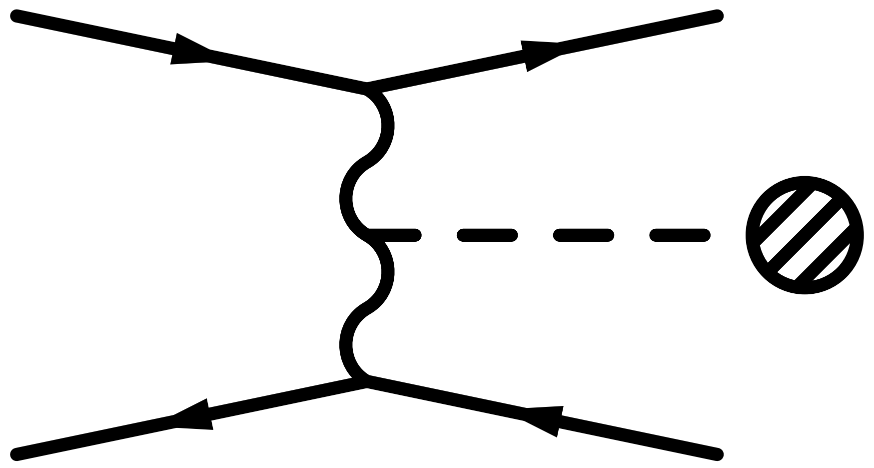
Need a **global analysis** of all EFT coefficients to map all direction of new fundamental physics

One observable can be influenced by many operators





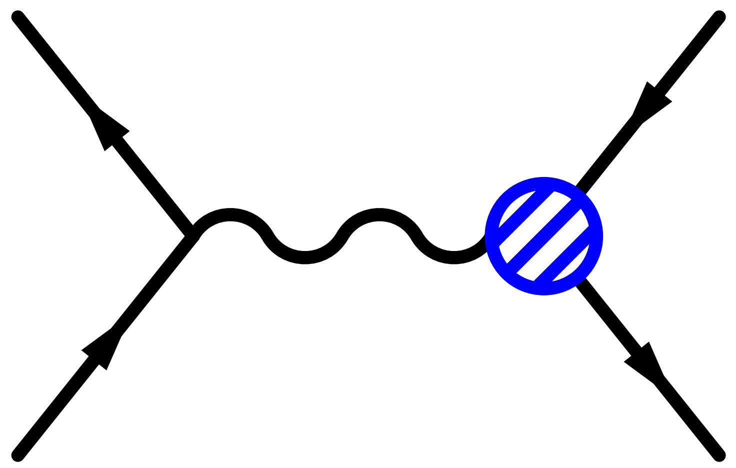
Higgs decay



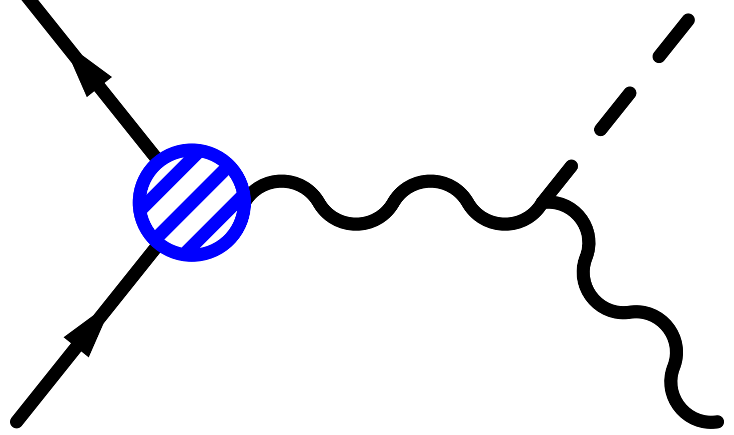
Global in …

… the operator set

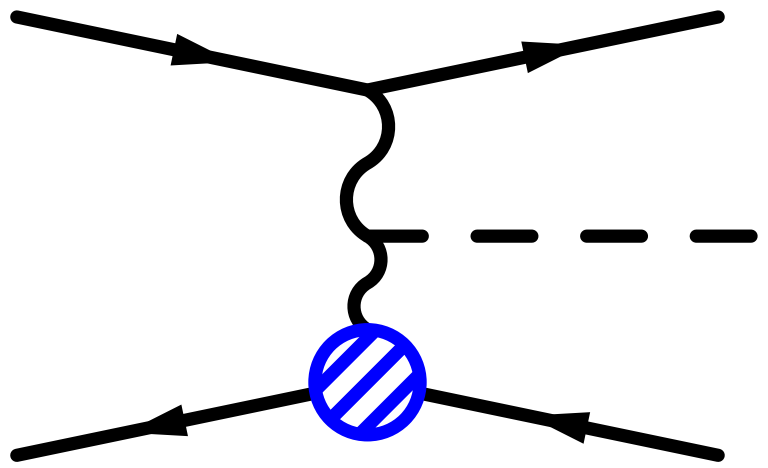
One operator can contribute to many different observables



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



Zh production



Weak boson fusion
Higgs production

… the data

Goals of SMEFT fits and SMEFT perspectives

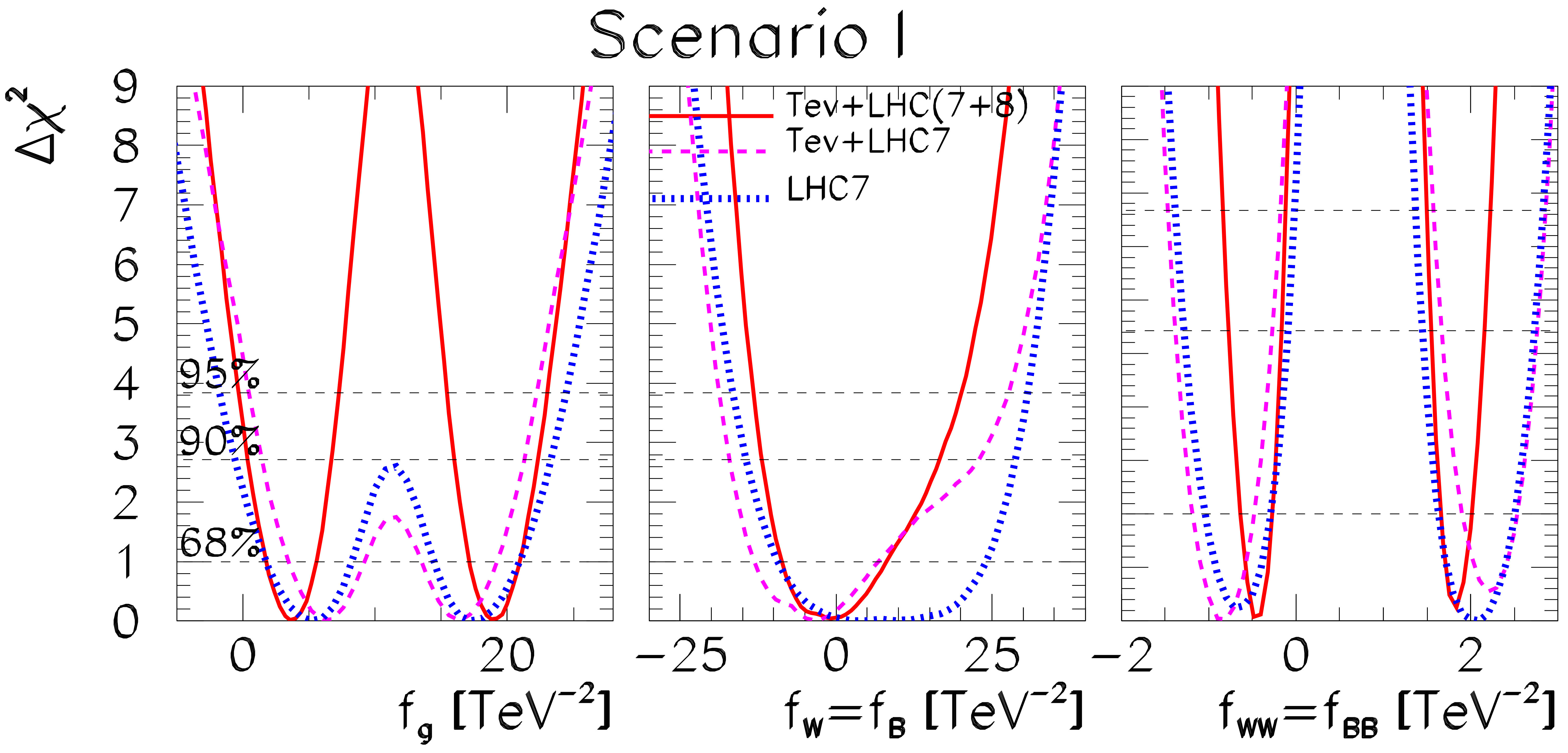
- What has been achieved in the field after the Higgs discovery?
- What are the perspectives of the field?
- What needs to be developed to create further advance
  - … regarding HL-LHC?
  - … regarding future collider projects?

The following discussion is obviously heavily biased by my interests!

SMEFT fits after the Higgs discovery

[Corbett et al. (1207.1344)]

- 2-3 independent directions (7 operators, Higgs-gauge interactions)
- 17 (LHC 7 TeV, Tevatron) + 12 (LHC 8 TeV) observables (Higgs, diboson)
- Signal strength only



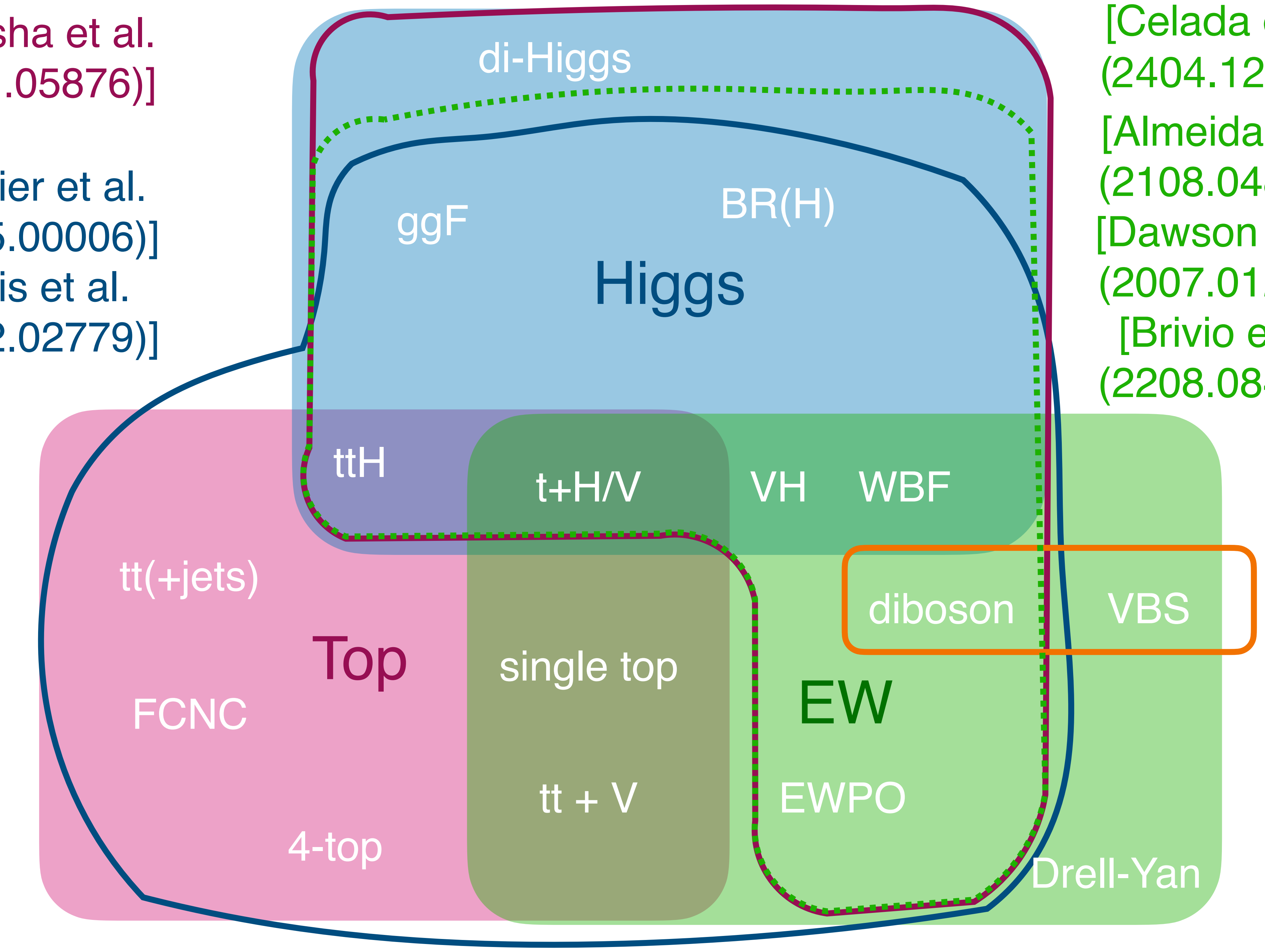
Scenario I:

$(f_g,\, f_W = f_B,\, f_{WW} = f_{BB})$

SMEFT fits today

[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)]

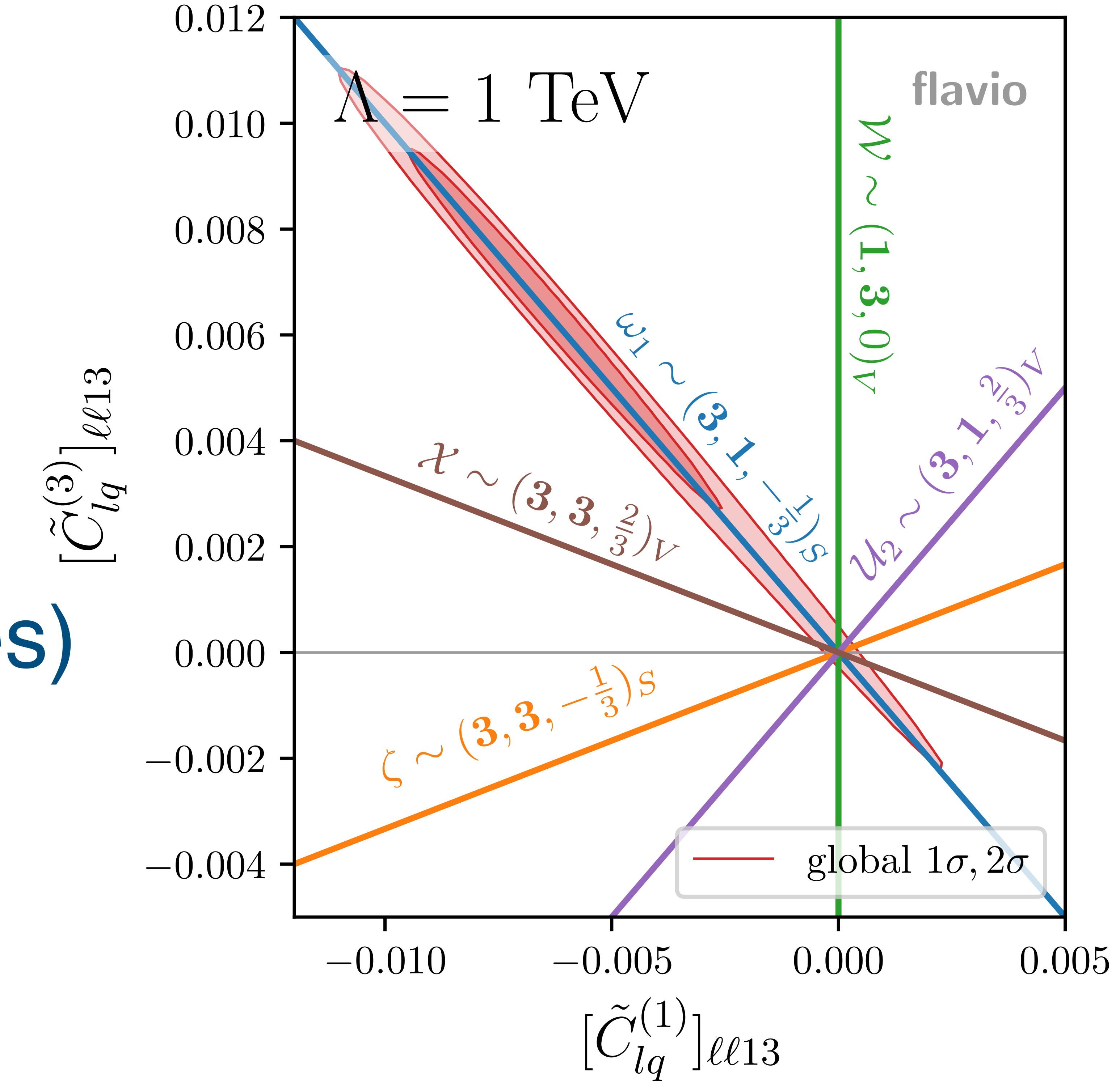
[Ethier et al. (2101.03180)]
[Bellan et al. (2108.03199)]

[de Blas et al. (2507.06191)]

- 40+ operators/directions (motivated by data/symmetries)
- $>$ 500 observables
- Signal strength + kinematic distributions
- Beyond Higgs + gauge, beyond LHC only

- SMEFT + PDF fits
- SMEFT + EW fits
- Fits by experimentalists
- Reinterpretation in terms of UV models

[Greljo et al. (2306.09401)]



Current and future directions in SMEFT (fits)

SMEFiT [Celada et al. (2404.12809)]

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

Generality

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

Dim6^2 effects

Dim8 effects

[Dawson et al. (2205.01561)]
[Boughezal et al. (2207.01703)]
[Heinrich, Lang (2212.00711)]
[Degrande, Li (2303.10493)]
[Ellis et al. (2304.06663)]
[Corbett et al. (2304.03305)]

Combine more datasets

[Degrande et al. (2008.11743)]

SMEFT@NLO

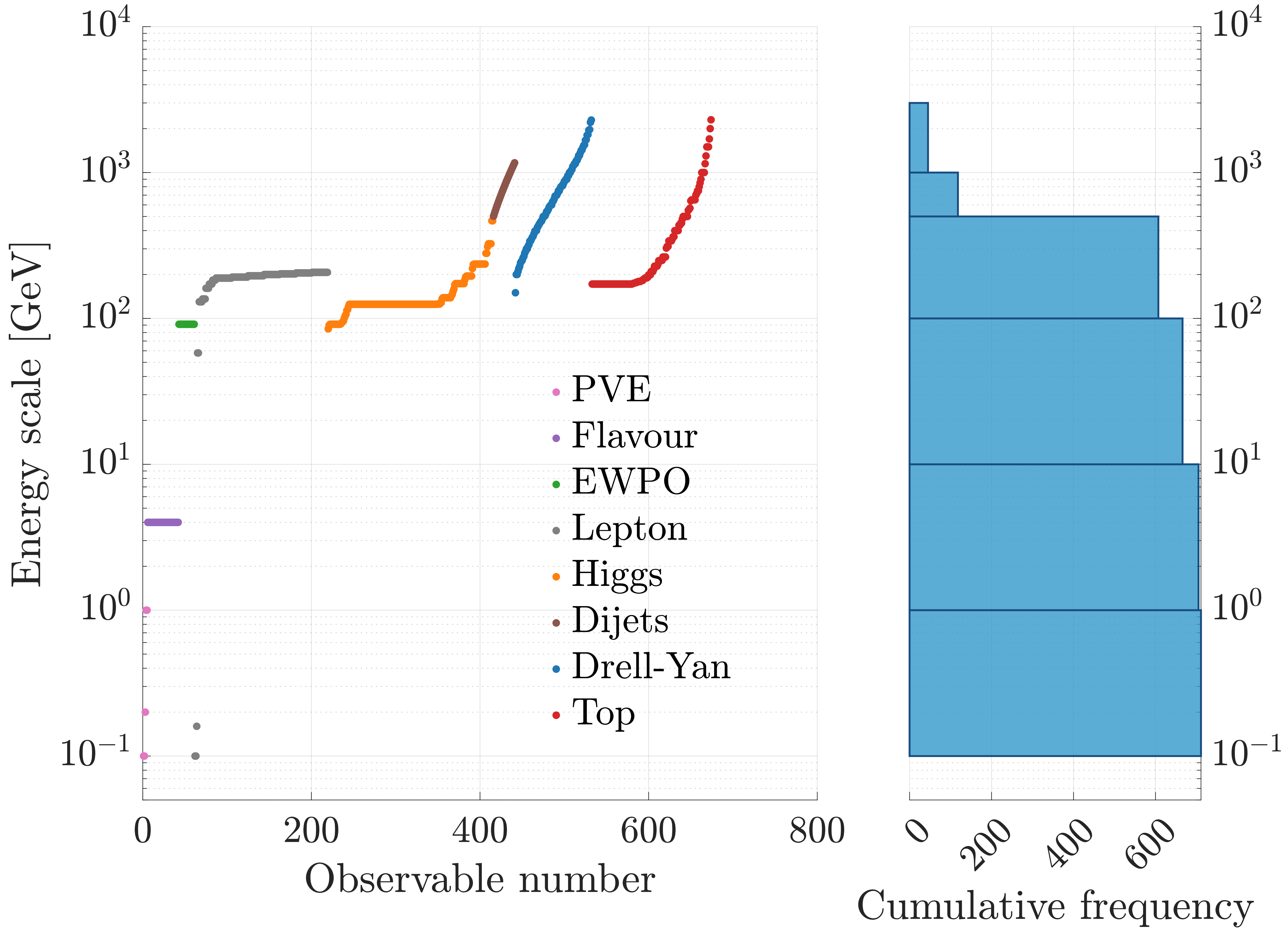
RGE effects

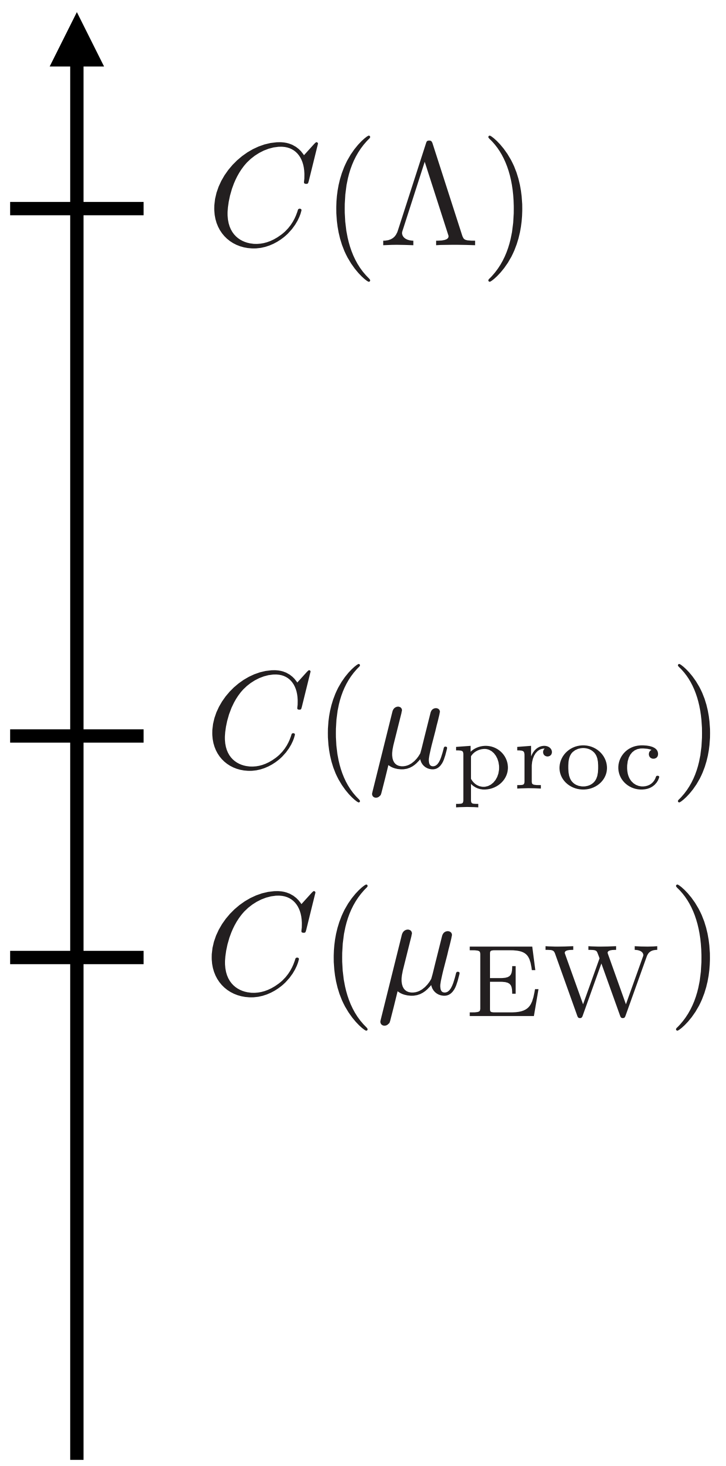
Precision

Renormalization group evolution

Observables and scales

[Bartocci, AB, Hurth (2412.09674)]





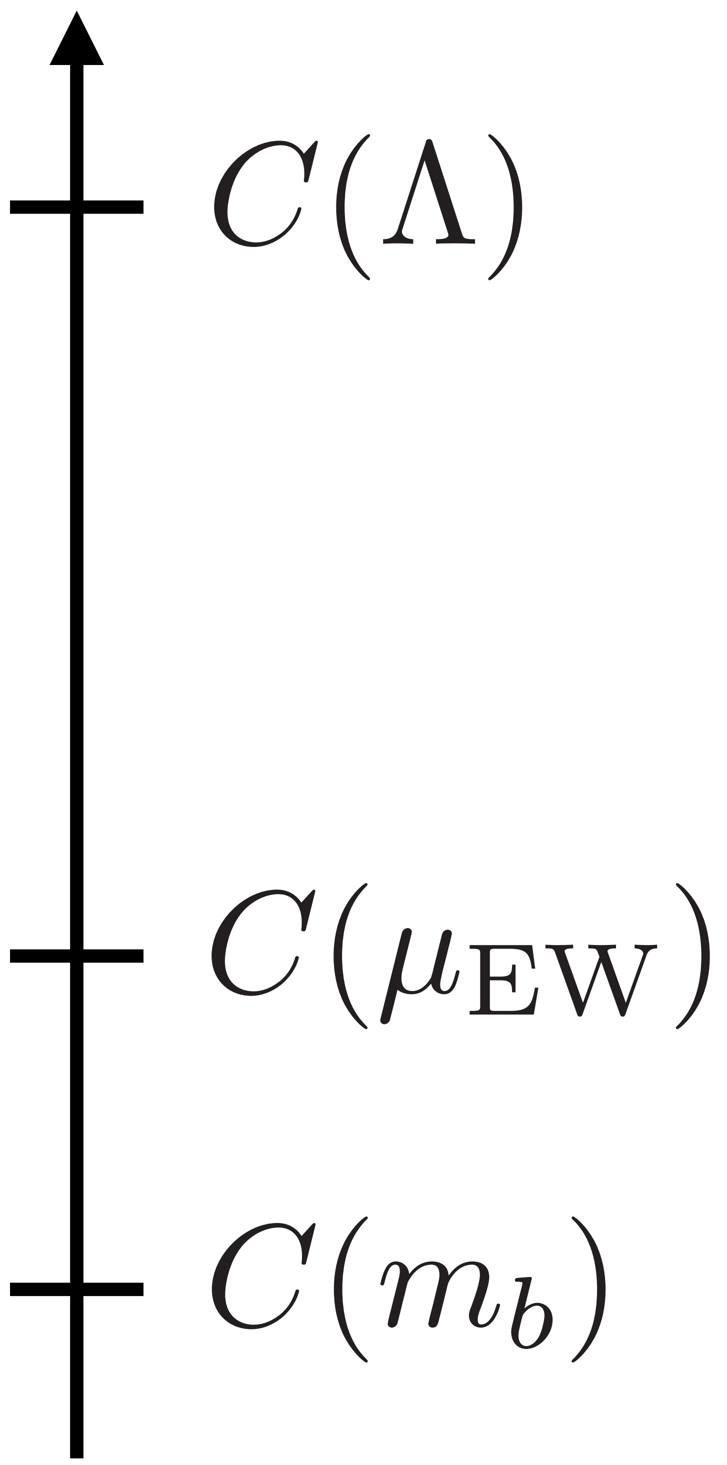
~ 700 observables

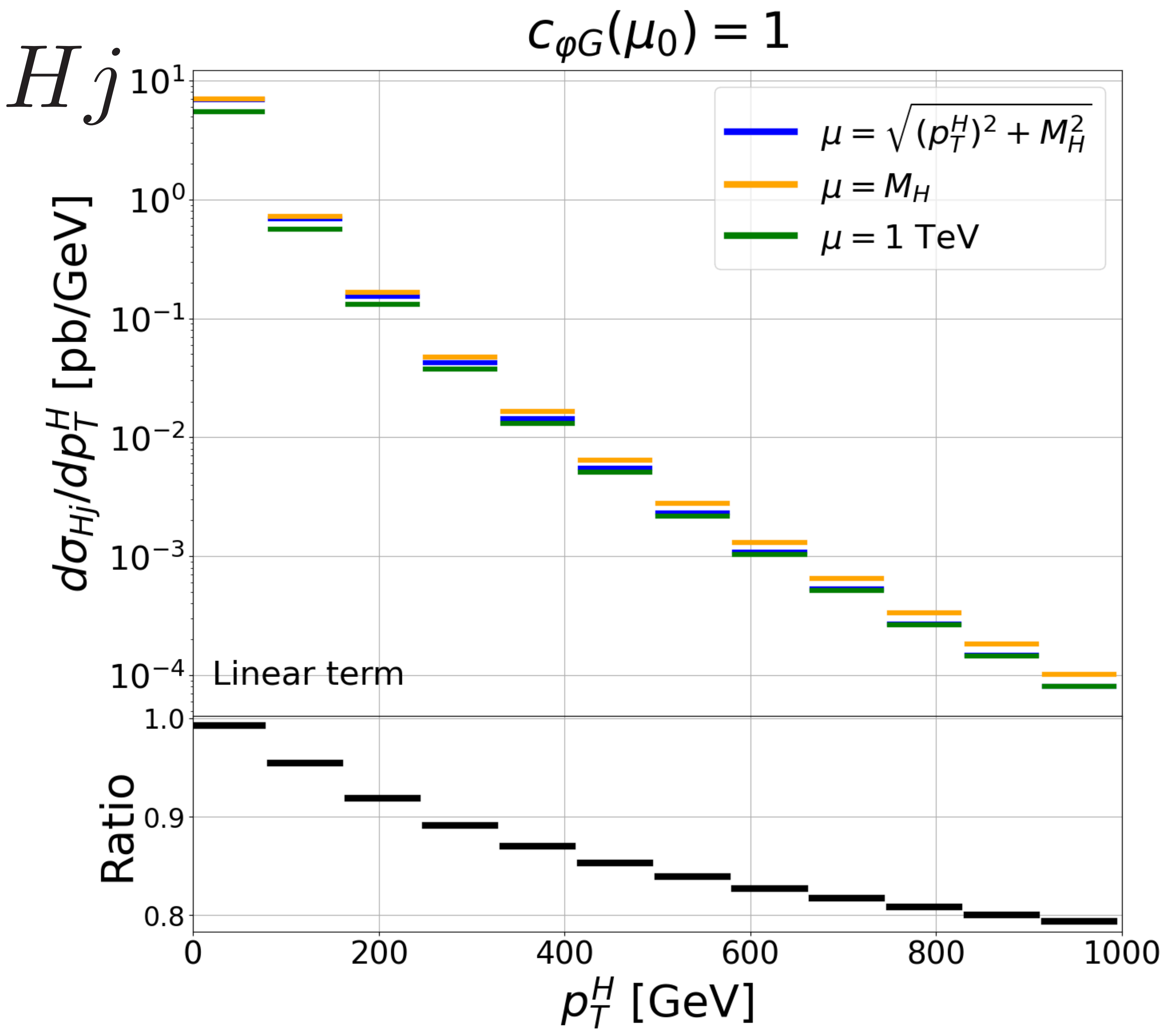
Broad range of scales

Only 118 (45) observables at scales > 500 GeV (> 1 TeV)

All observables at scales < 2.5 TeV

Renormalisation group evolution





[Maltoni, Ventura, Vryonidou (2406.06670)]

RG effects particularly relevant for differential distributions

[Alasfar, de Blas, Gröber (2202.02333)]

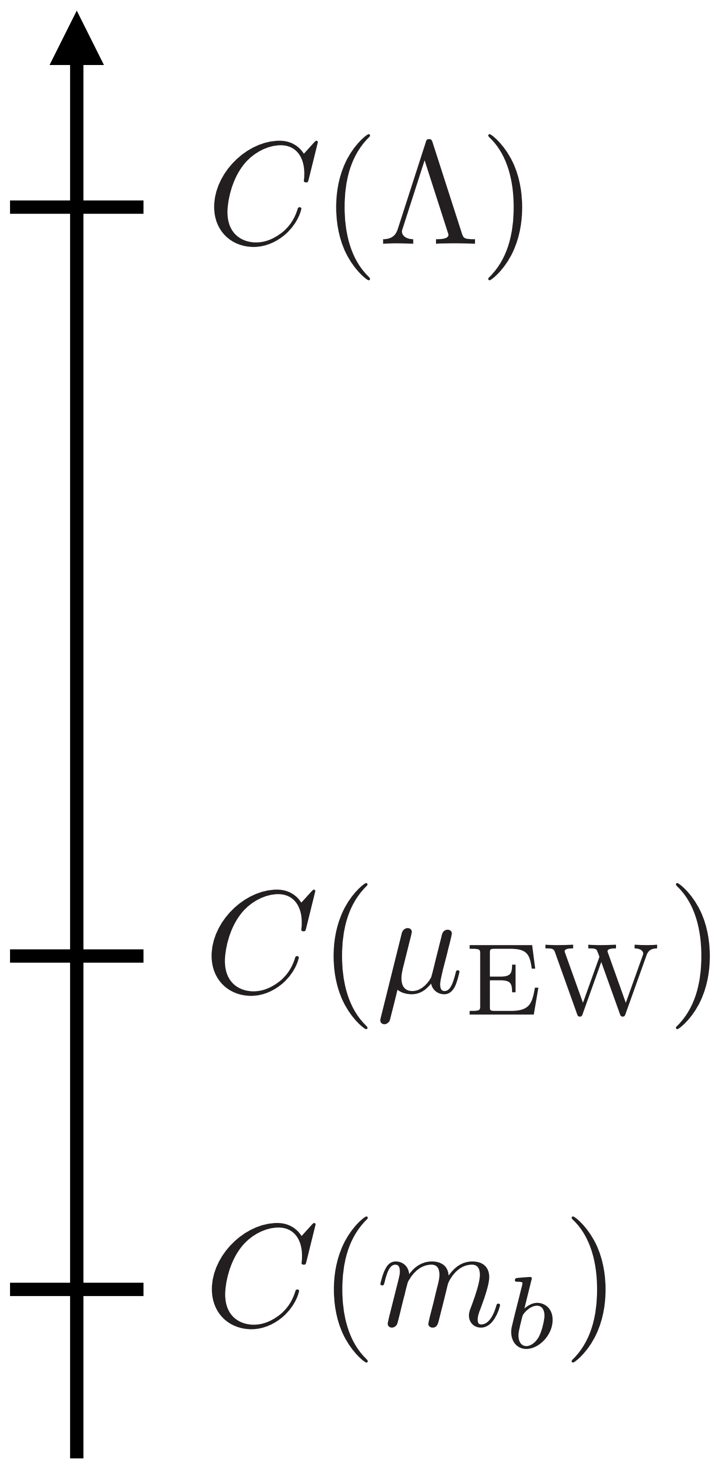
[Aoude, Maltoni, Mattelaer, Severi, Vryonidou (2212.05067)]

[Di Noi, Gröber (2312.11327)]

[Di Noi, Gröber, Mandal (2408.03252)]

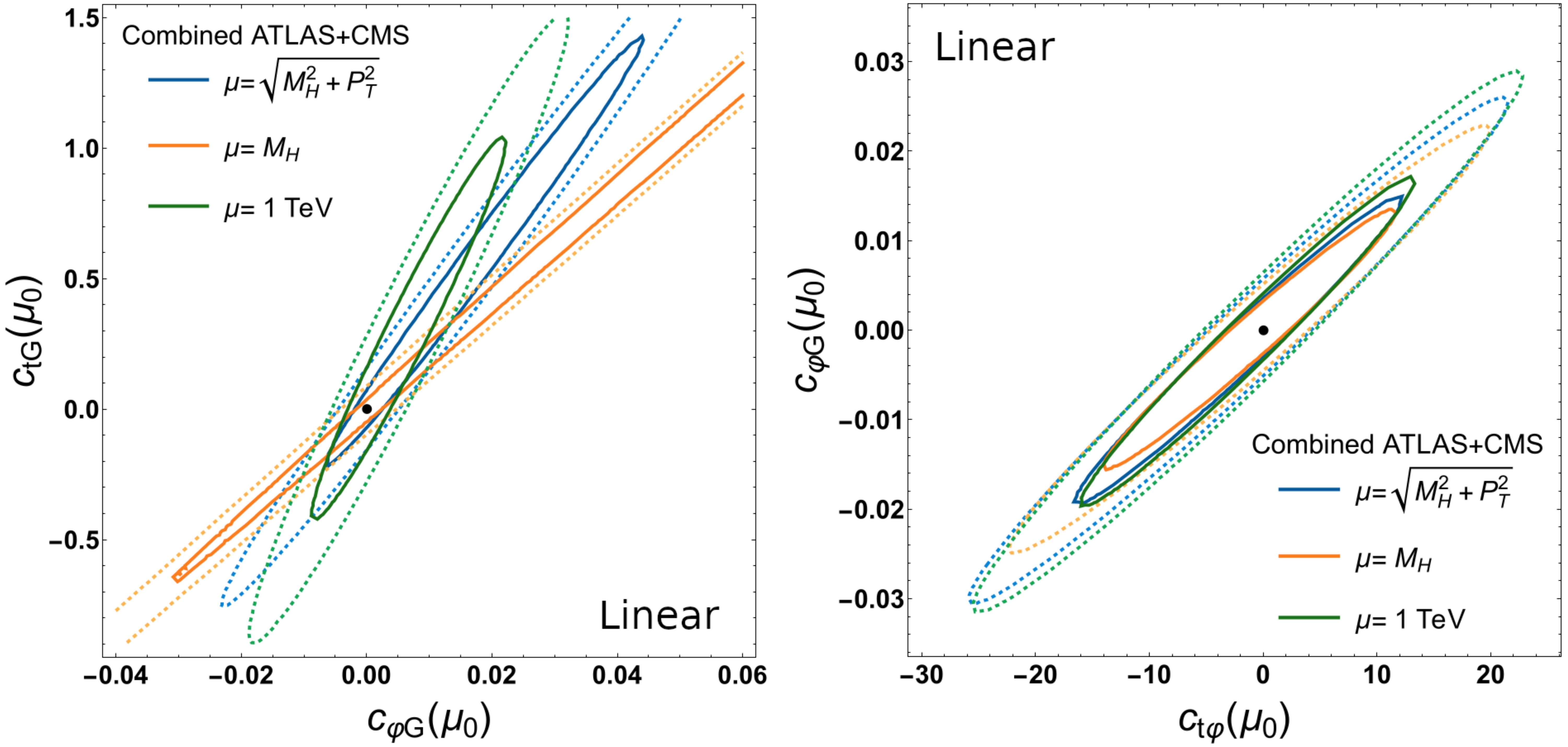
[Heinrich, Lang (2409.19578)]

Renormalisation group evolution



Running affects correlations

[Maltoni, Ventura, Vryonidou (2406.06670)]



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)]

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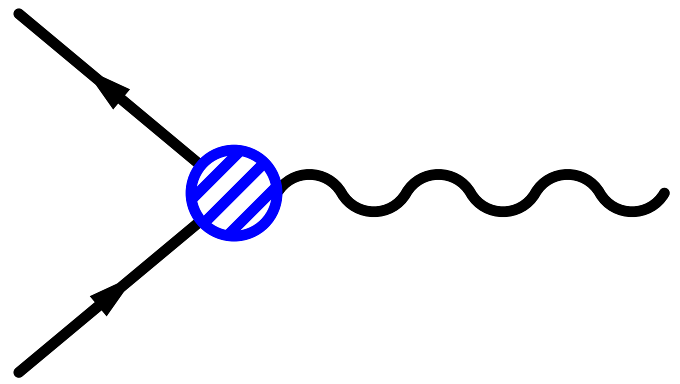
[Heinrich, Lang (2409.19578)]

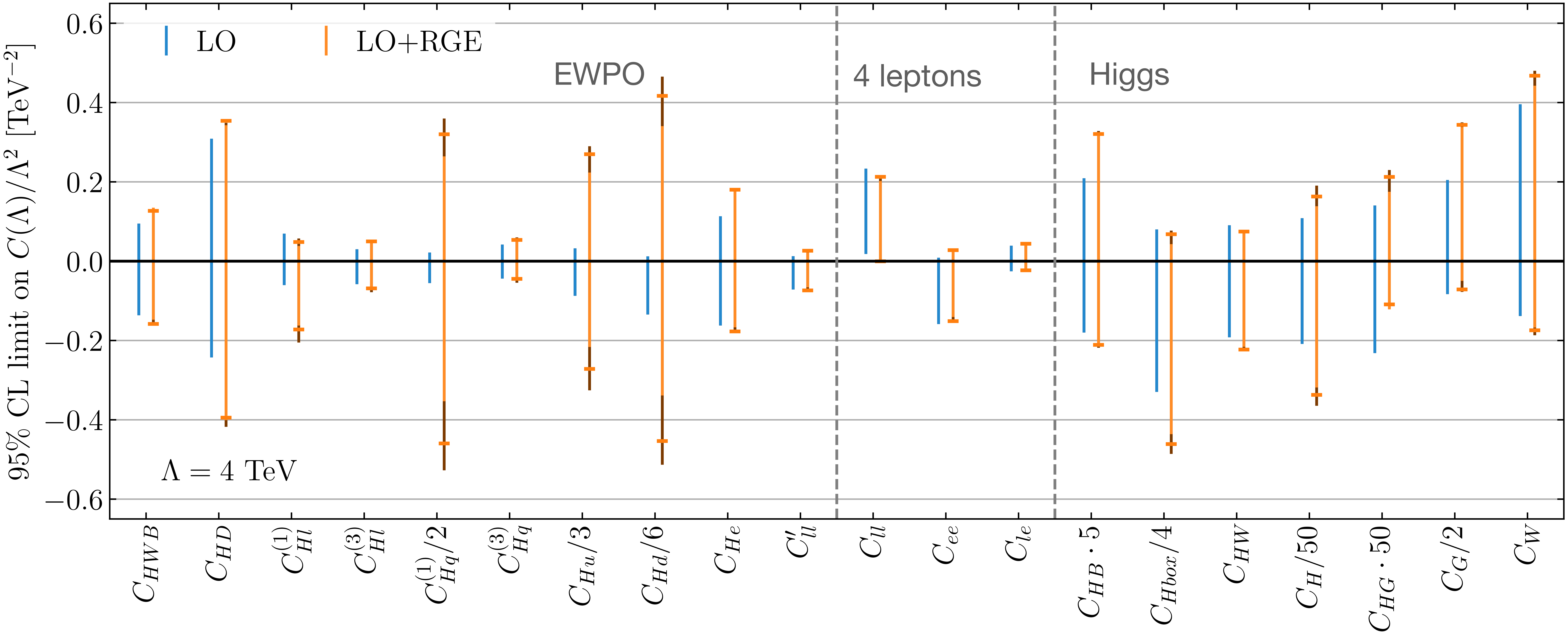
See also: [SMEFit: ter Hoeve et al. (2502.20453)], [HEPfit (preliminary): Miralles (@SMEFTtools2025)]

RG evolution



[Bartocci, AB, Hurth (2412.09674)]

Shaded region: scale variation by factor 2



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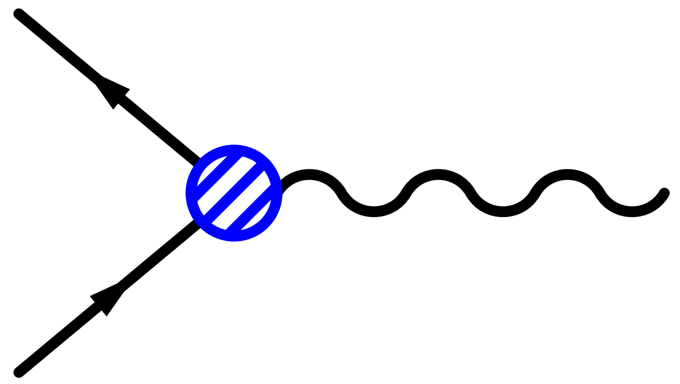

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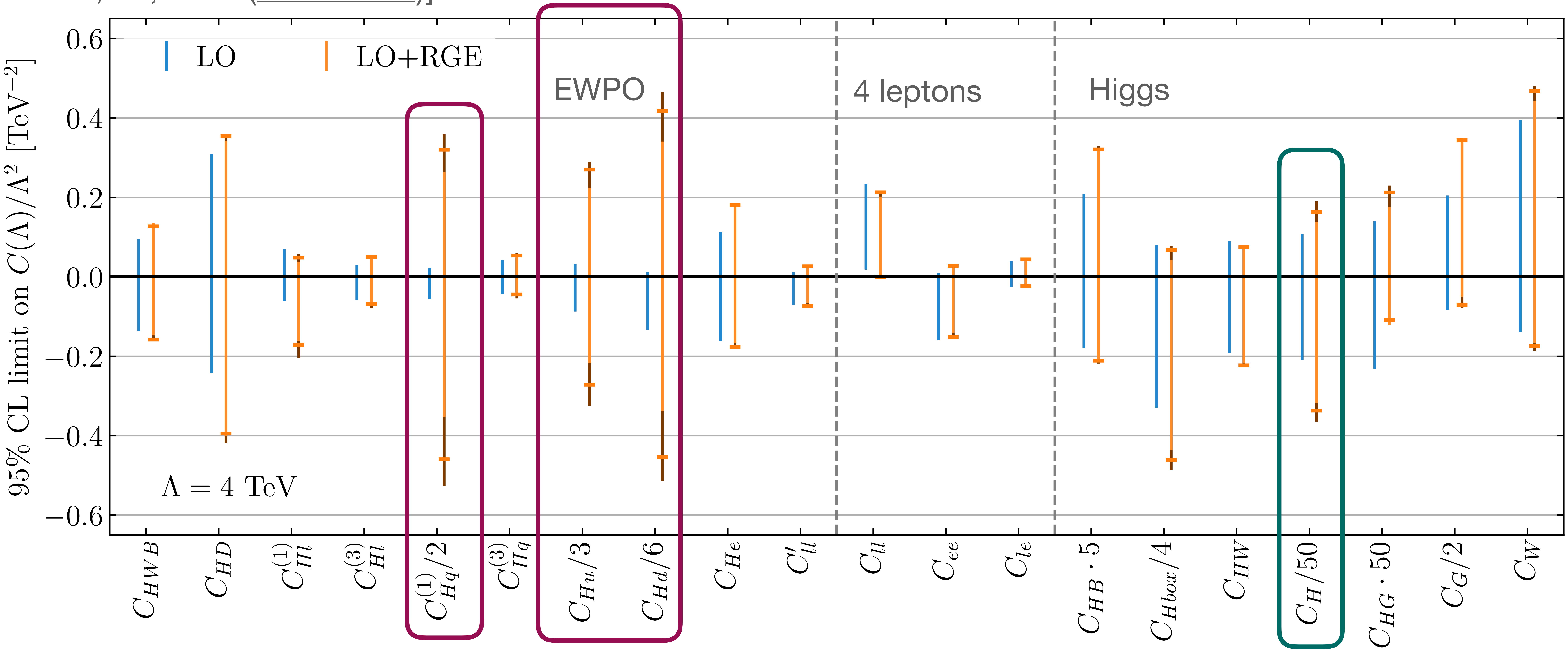


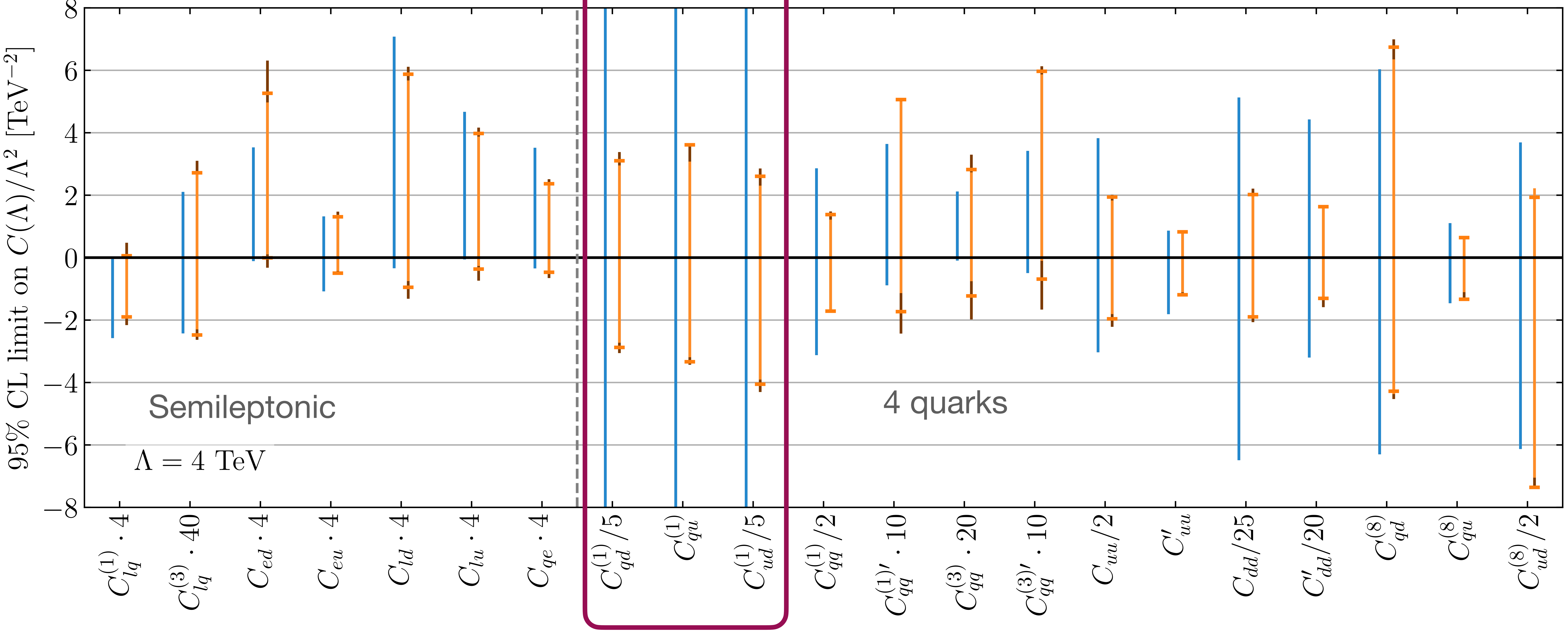
Cross-talk for operators involving quarks

[Machado, Renner, Sutherland (2210.09316)]

RG evolution - 4-fermion ops

Bounds on some four-quark operators drastically improved

[Bartocci, AB, Hurth (2412.09674)]



SMEFT at NLO

NLO vs RG evolution

Alternative constraints:
Consider **D6 squared** effects

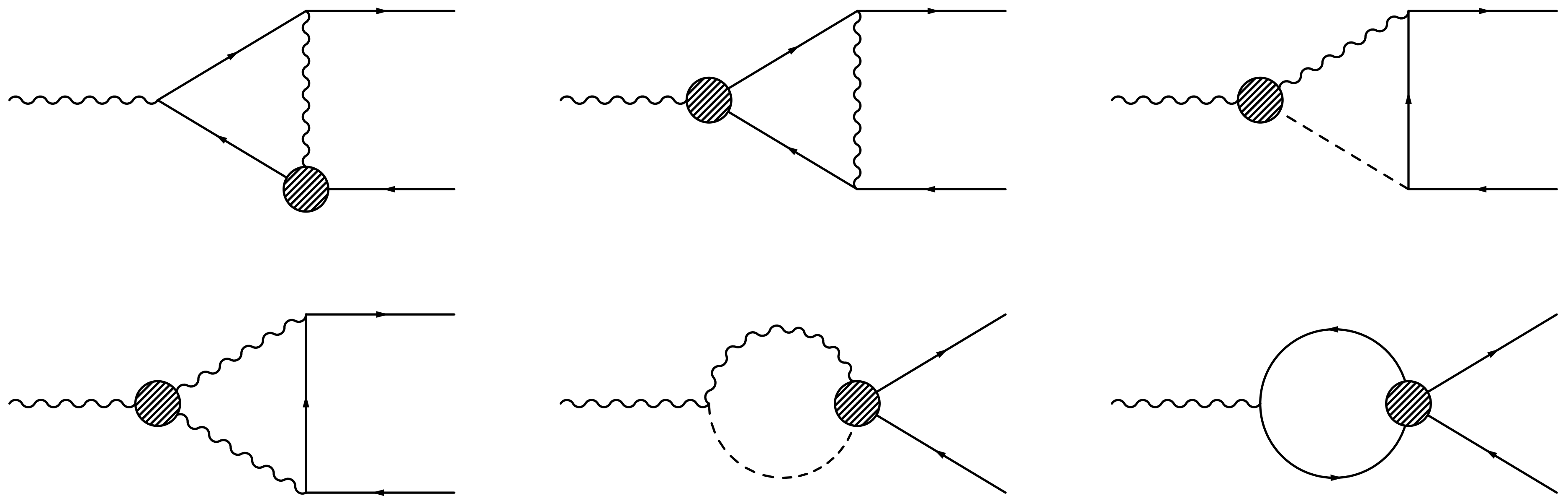
Same diagrams relevant for RG and at next-to-leading-order (NLO)

EWPO: 10 ops @LO, 32 ops @NLO
(suppressing flavour indices)

[Dawson, Giardino (1909.02000)], [AB, Pecjak, (Scott), (Smith) (2305.03763), (2503.07724)]

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

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

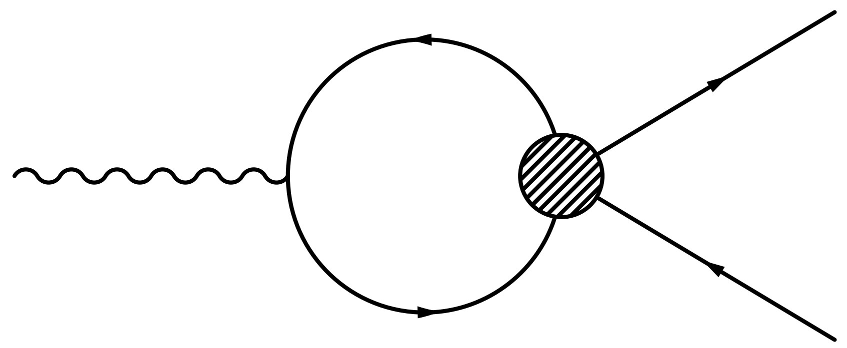


SMEFT@NLO: blessing & curse

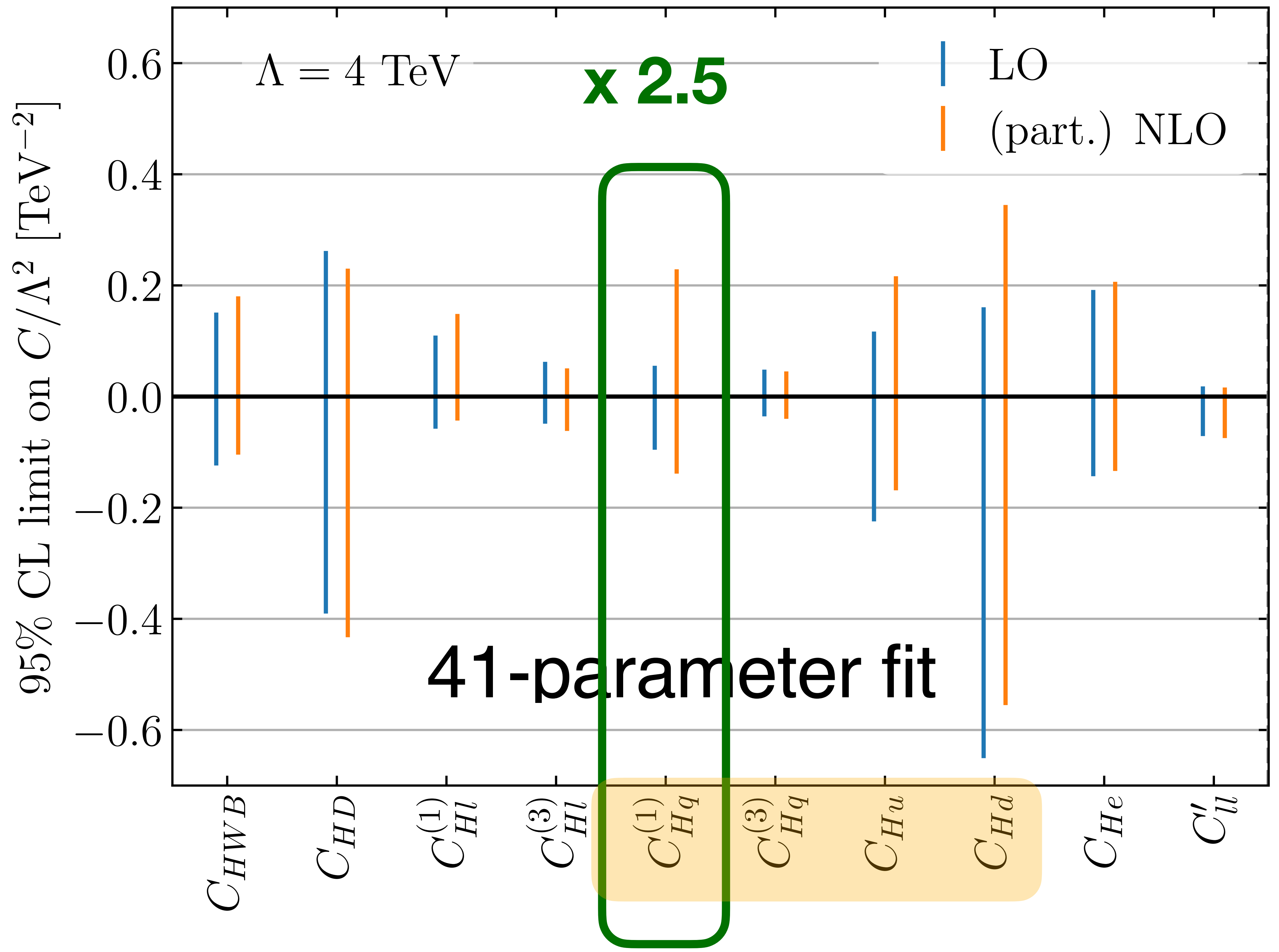
precision & degeneracies

EWPO@NLO

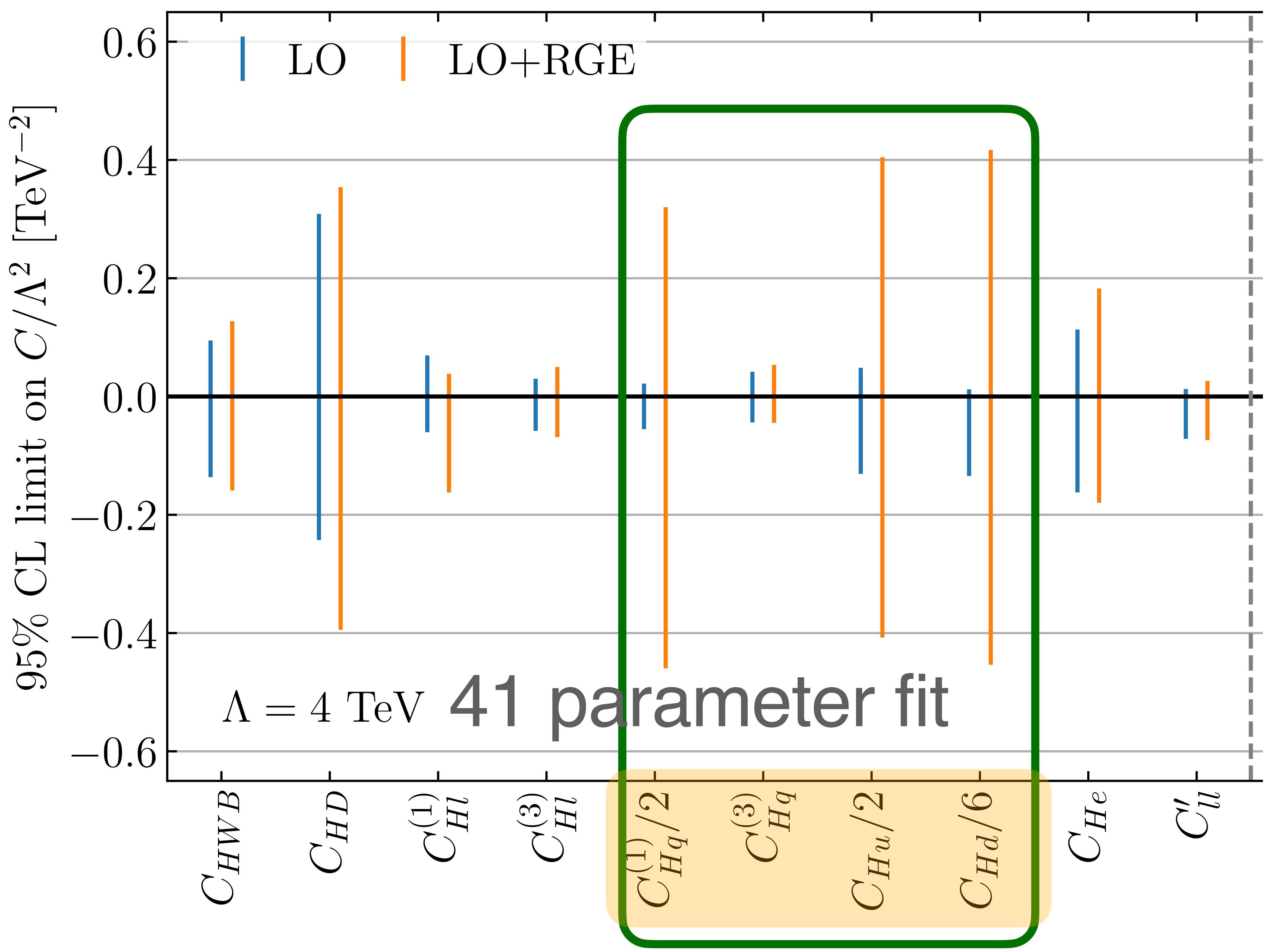
[Bartocci, AB, Hurth (2311.04963) (2412.09674)]

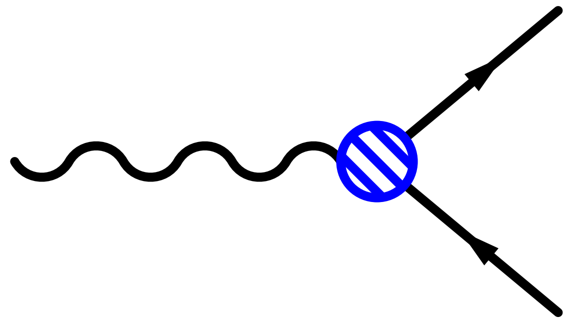


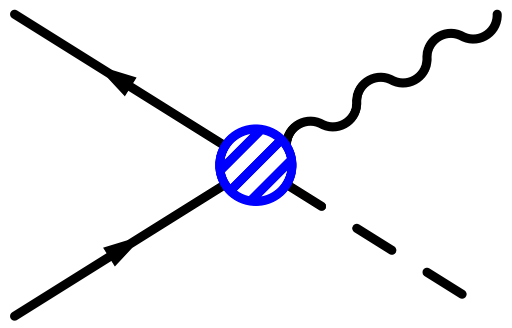
Not all datasets are known to NLO precision!



EWPO







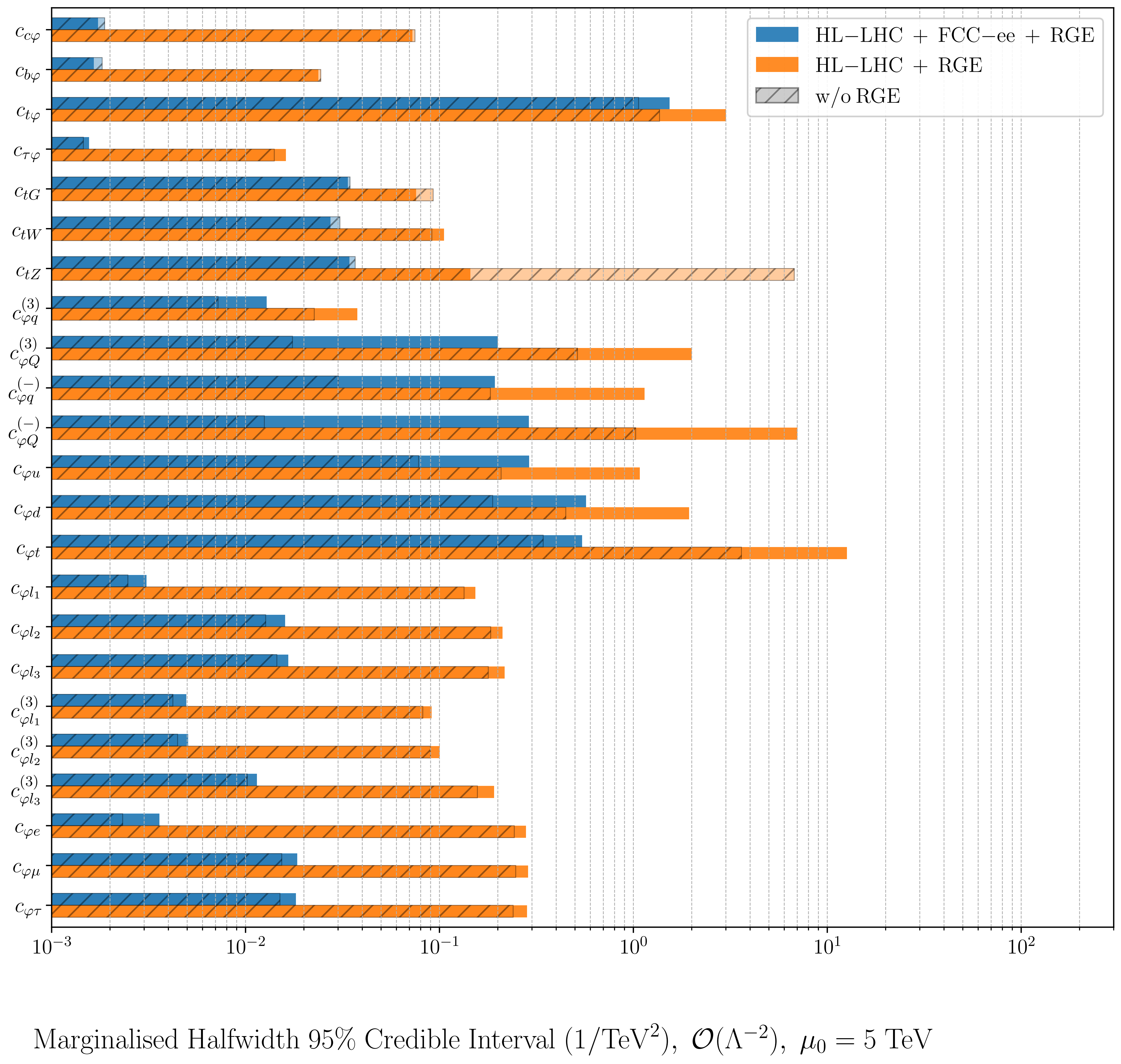
hZ production at LO

Future colliders

FCC-ee

- Very precise EWPO measurements
- RG effects will also lead to stronger bounds on operators not contributing to EWPO at LO
- Given the interplay of operators contributing to EWPO and four-quark operators, how much of the improvement will survive?

SMEFiT [ter Hoeve et al. (2502.20453)]



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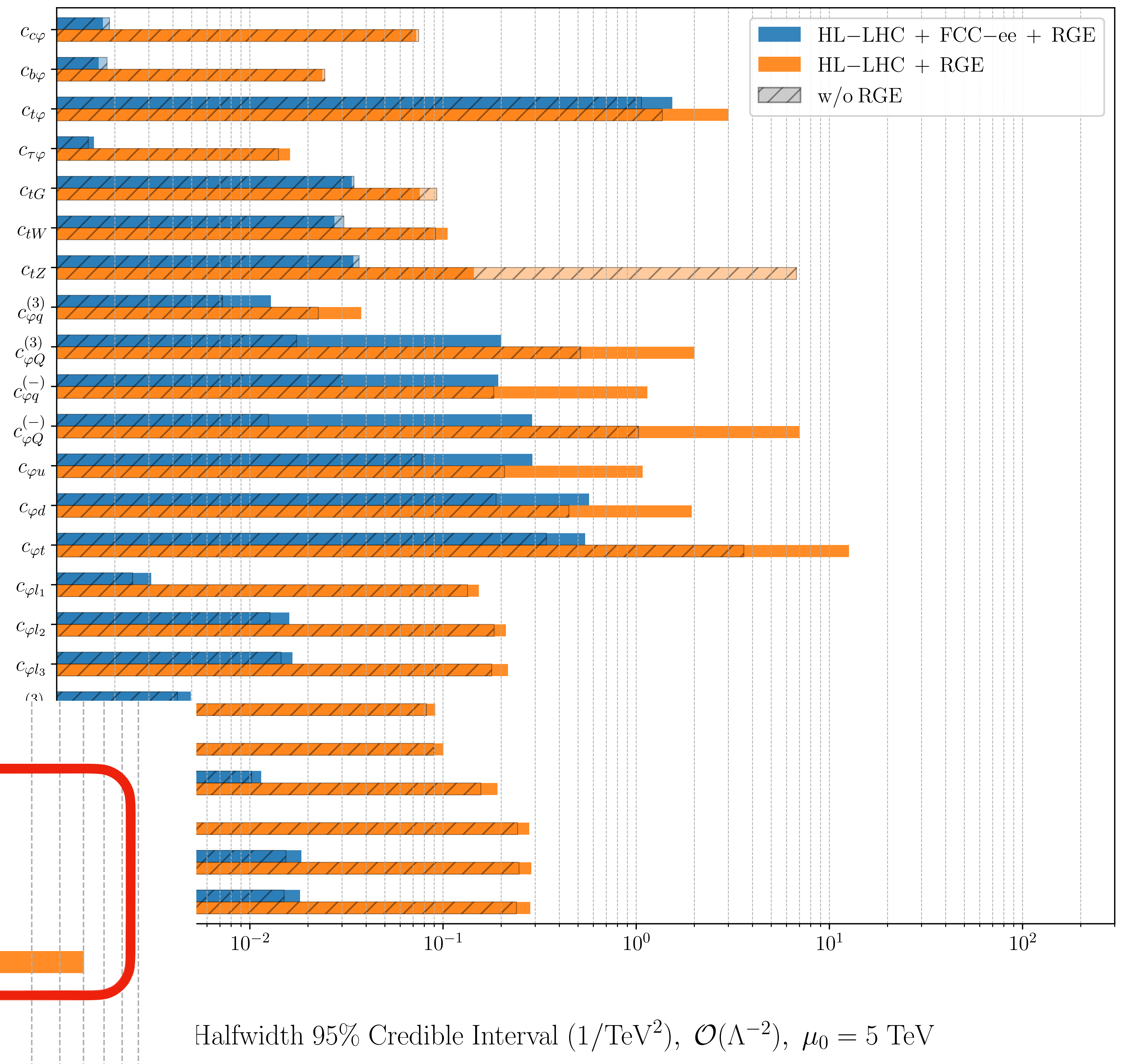
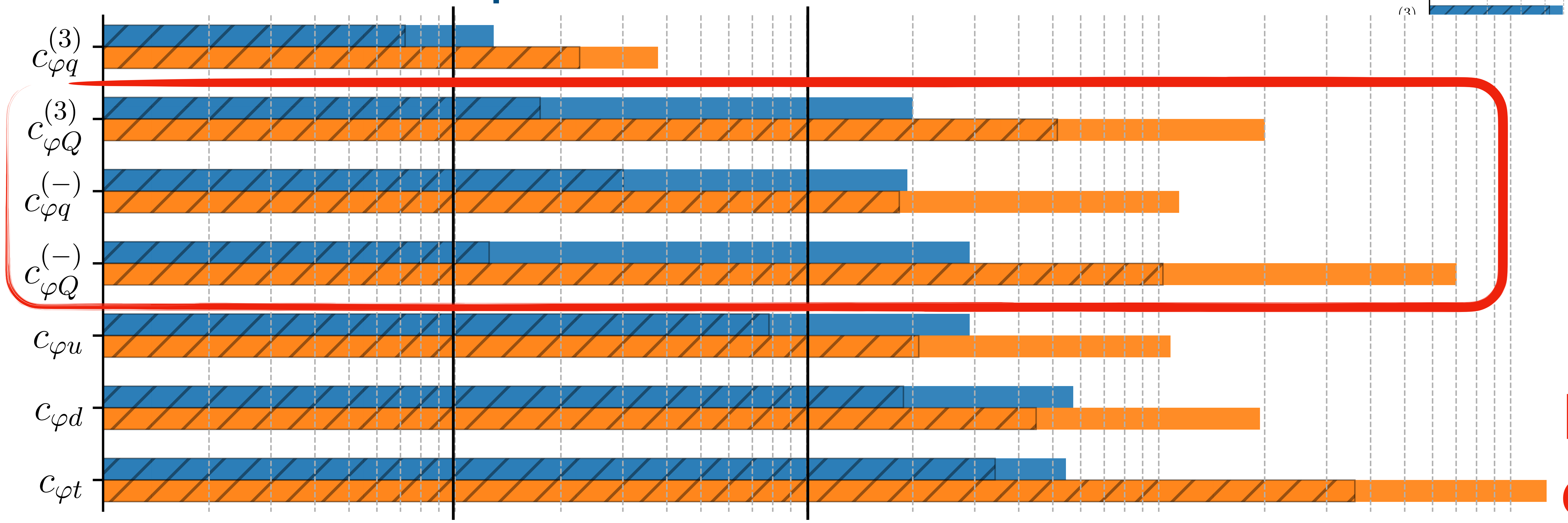
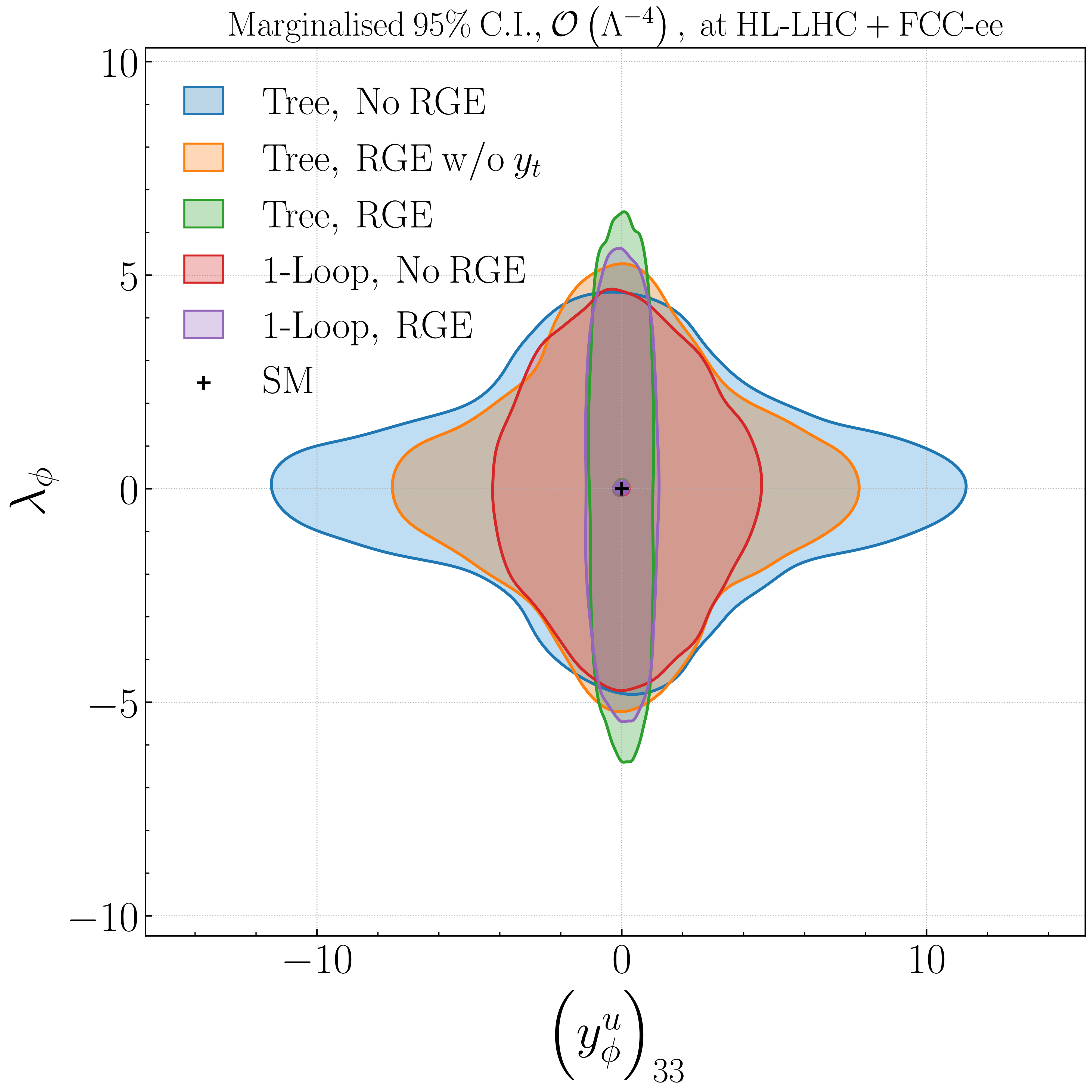




RGE: Order of magnitude difference for some Wilson coefs!

FCC-ee II



SMEFiT [ter Hoeve et al. (2502.20453)]

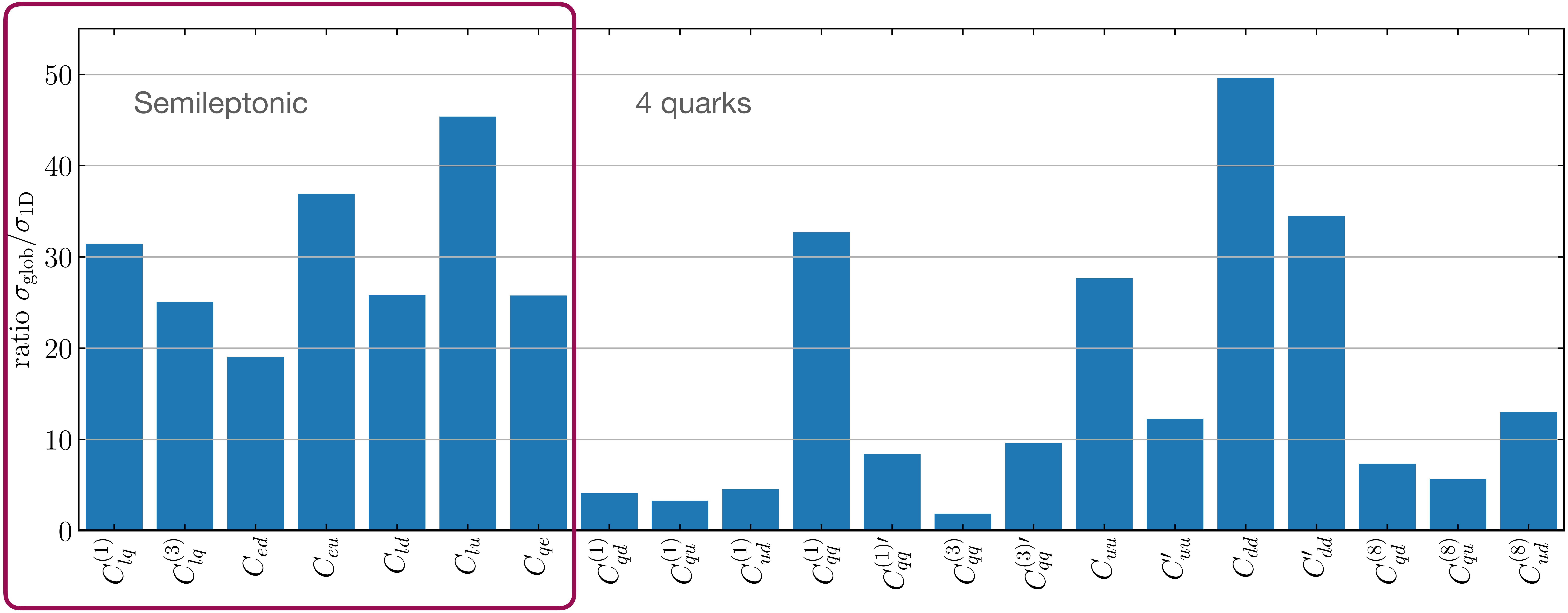
Heavy scalar doublet model:

Stronger constraints after RGE improvement

Electron-ion collider

Relevant for semileptonic operators

1D vs global limits

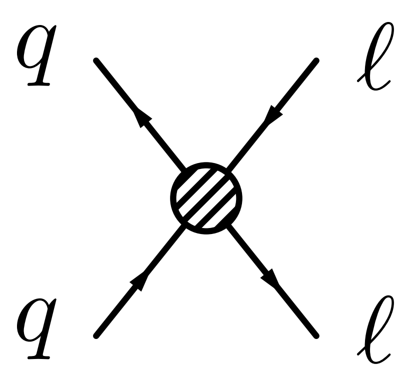


[Bartocci, AB, Hurth (2311.04963)]

Semileptonic operators at the LHC

Drell-Yan is the strongest probe of semileptonic operators at the LHC

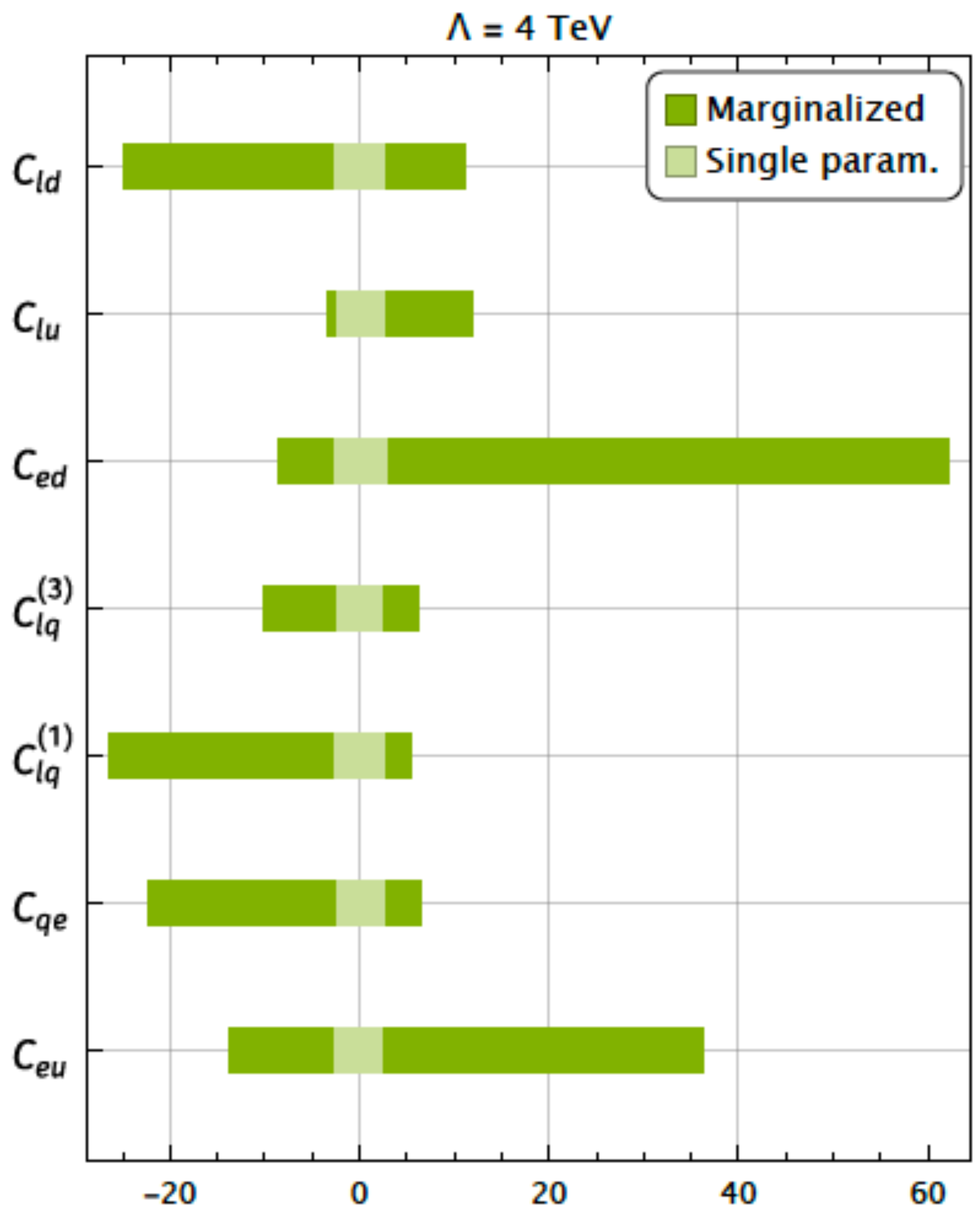
- 7 operators contribute



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

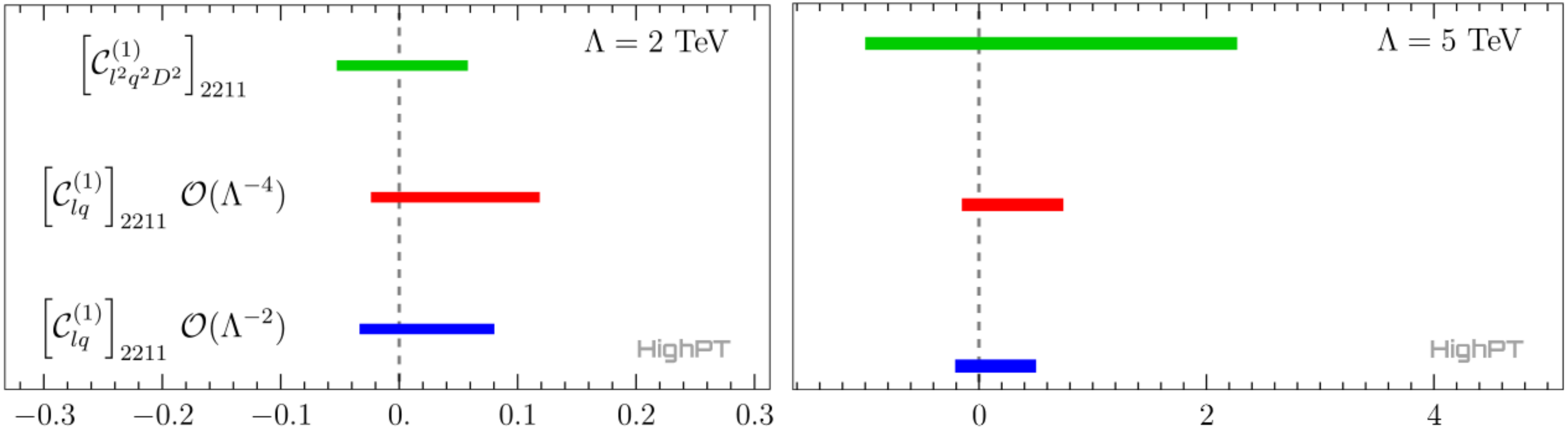
Distinguished by PDFs

[Boughezal, Huang, Petriello (2303.08257)]



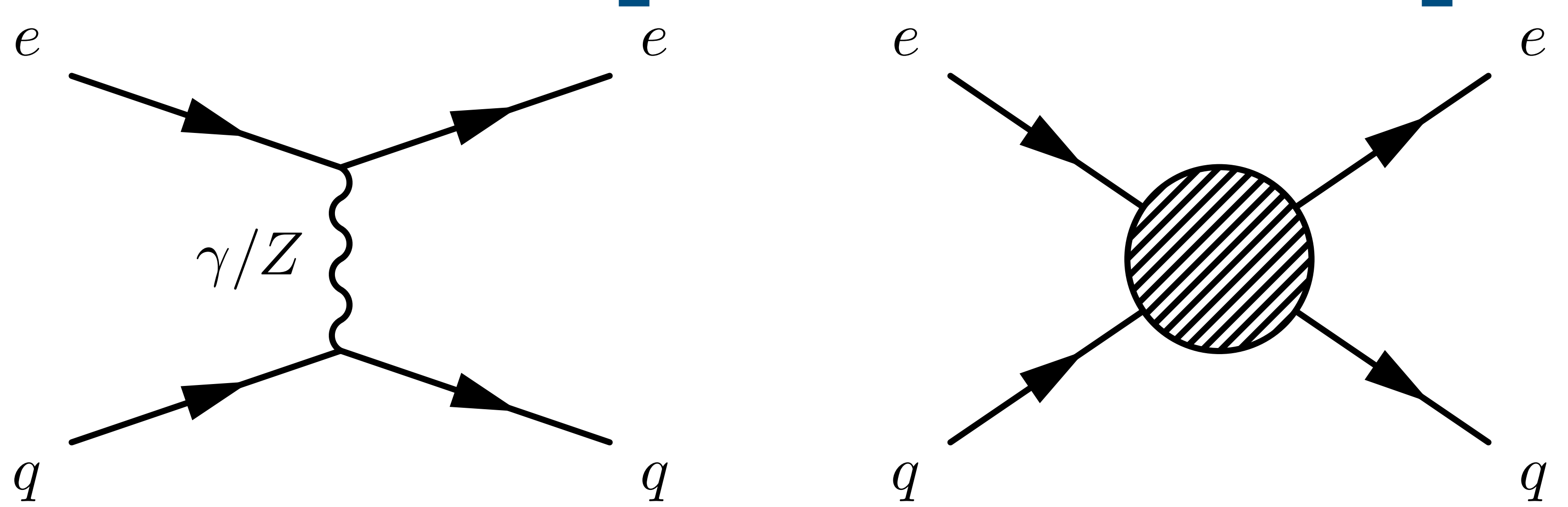
LHC - D6 vs D6^2 vs D8

[Allwicher et al. (2207.10756)]



Also: Measurement at high energies increases the relevance of D6^2 and D8 effects

Semileptonic operators at the EIC



[Boughezal, Petriello, Wiegand (2004.00748)]

u (RH) e (RH) q (LH) l (LH)

$$\frac{d^2\sigma_u^{ZSMEFT}}{dxdQ^2} = -x\frac{N_{\gamma Z}Q^2}{8\pi\alpha}\Big[g_R^u g_R^e C_{eu}\boxed{(1+\lambda_u)}\boxed{(1+\lambda_e)} + g_L^u g_L^e (C_{lq}^{(1)} - C_{lq}^{(3)})\boxed{(1-\lambda_u)}\boxed{(1+\lambda_e)}$$
$$+g_R^u g_L^e (1-y)^2 C_{lu}\boxed{(1+\lambda_u)}\boxed{(1-\lambda_e)} + g_L^u g_R^e (1-y)^2 C_{qe}\boxed{(1-\lambda_u)}\boxed{(1+\lambda_e)}\Big] . (7)$$

u (RH) l (LH) q (LH) e (RH)

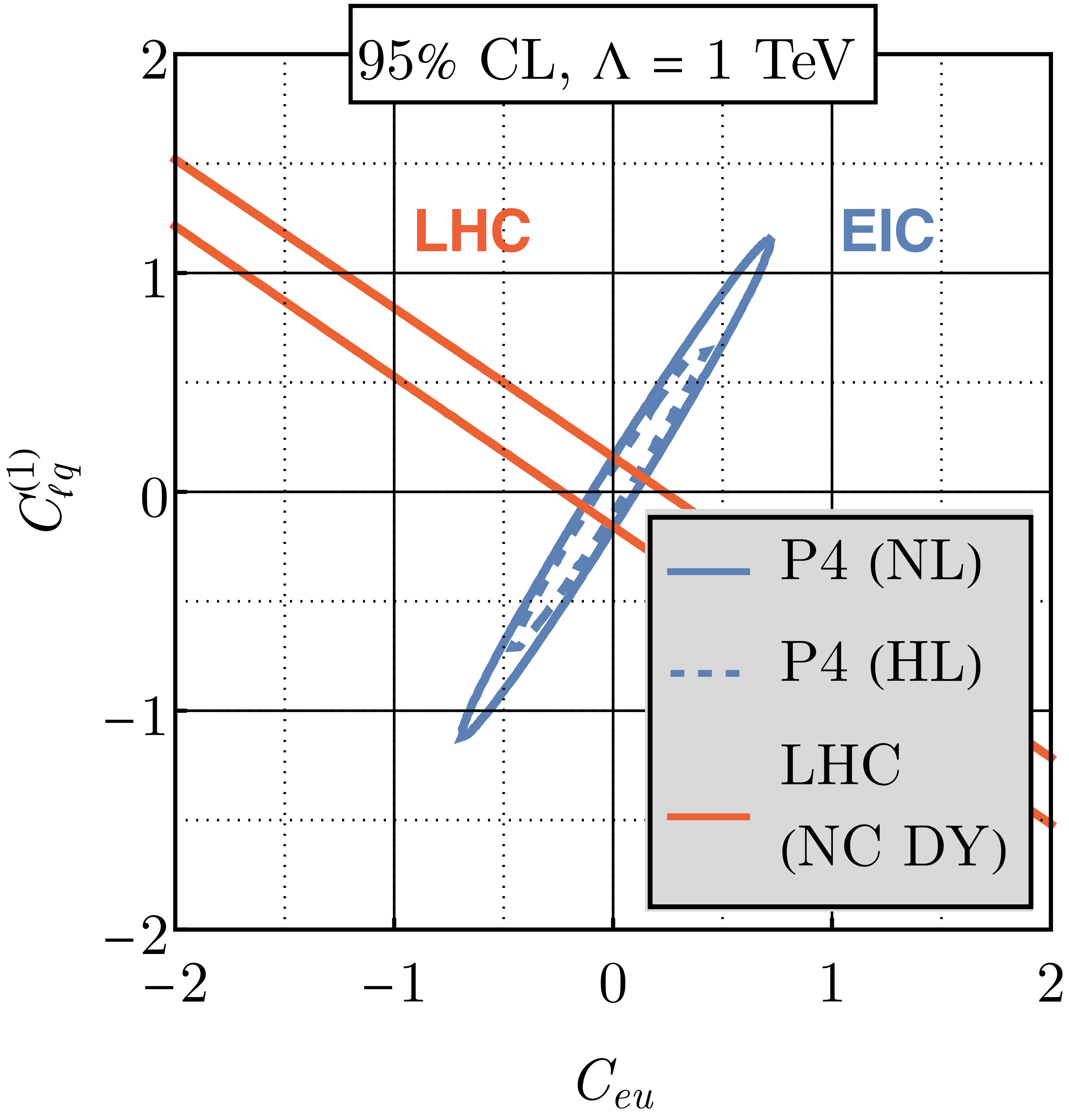
λ polarization

Polarization of the beams allows to **disentangle** different Wilson coefficients

Measurement at **lower energies** decreases relevance of D6^2 and D8 effects

LHC vs EIC

[Boughezal et al. (2204.07557)]



Combining LHC and EIC data

(plus PVES experiments)

we can obtain the strongest bounds on semileptonic operators

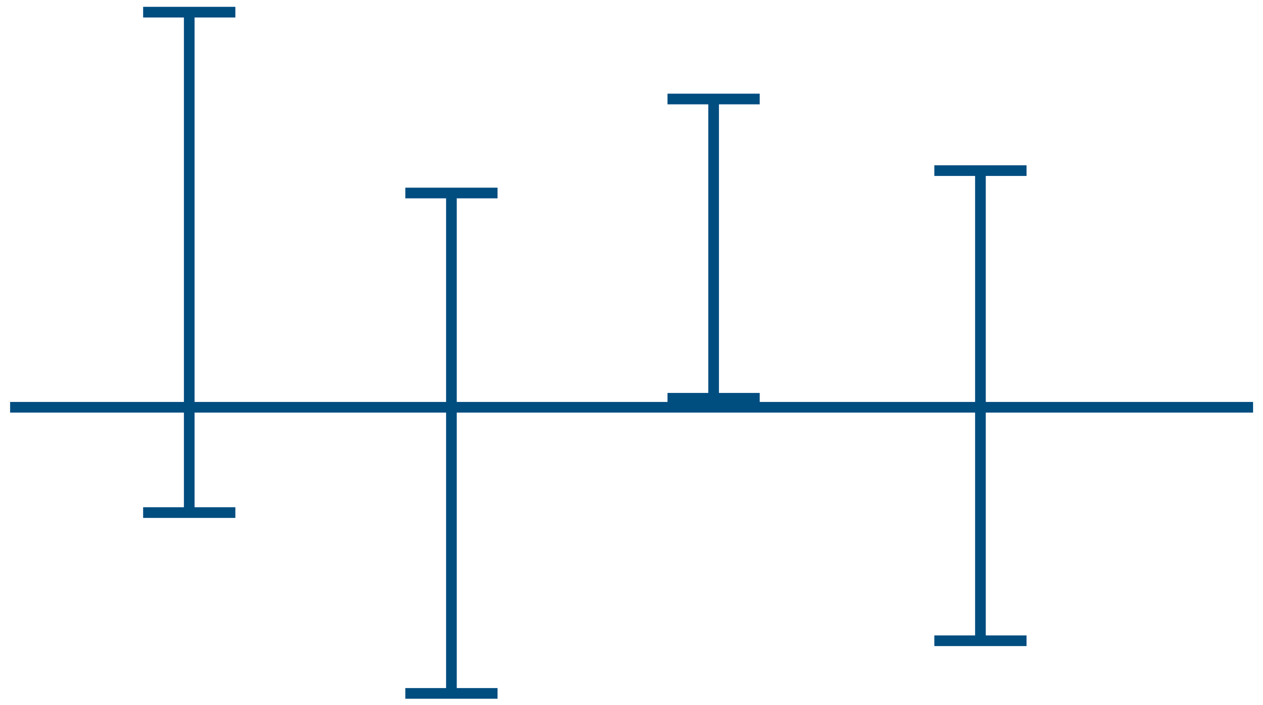
Summary

SMEFT

- Universal description of the effects of heavy new physics
- A lot of recent progress, a lot still to do for us

Wishlist

- SMEFT@NLO predictions
- Going beyond the LHC
- Better constraints on four-quark operators



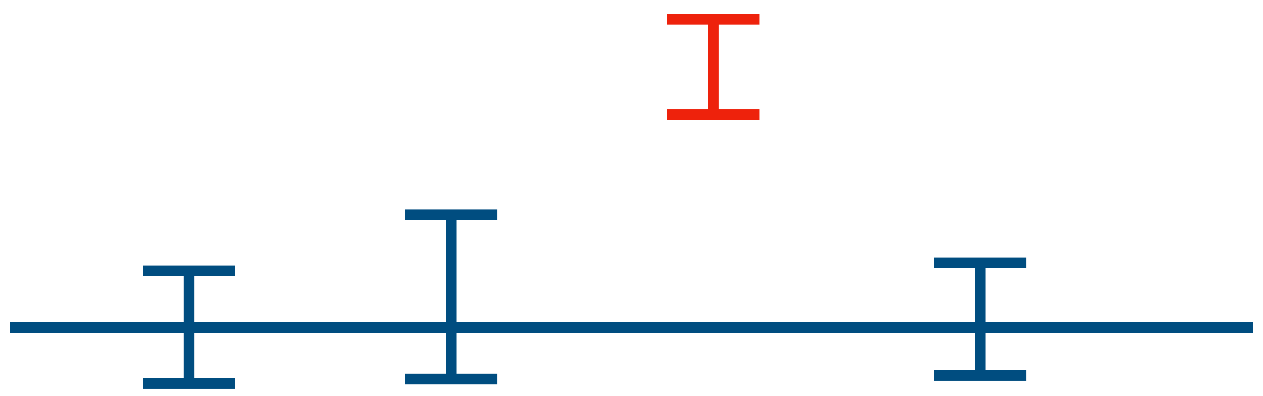
Summary

SMEFT

- Universal description of the effects of heavy new physics
- A lot of recent progress, a lot still to do for us

Wishlist

- SMEFT@NLO predictions
- Going beyond the LHC
- Better constraints on four-quark operators



Thank you for your attention!