Global SMEFT Fits at Future Colliders

A Snowmass 2021 Whitepaper

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Contents

main goal: coherent projections on precision EW/Higgs/Top couplings @ future colliders

welcome to join the team and to make your contribution

recent progress

- conventions / basis: independent fitting codes, same basis (original Warsaw), same assumptions, same inputs (nominal, statistically consistent, to be updated with EF01/03/04)
- exploring various flavor assumptions (promising without any flavor universality in some fits)
- preliminary result on Fit-1: Higgs/EW sector for HL-LHC, low energy stage of future linear & circular e+e-
- global fit of 4-fermion operators & 2-fermion at Z-pole / W-pole
- developing strategy for top-quark sector fit & interplay with Higgs/EW

Fit-1: Higgs/EW

observables

Electroweak Precision Observables	(α, G_F, m_Z…)
+	
e+e- —> WW	(Optimal Obv.)
+	
Higgs observables at LHC & e+e-	(σ, σxBR)
Drell-Yan at LHC	(WW, A_{FB}…)

assumptions

w/o 4-f contact interactions

flavor diagonal

CP-even

w/ & w/o lepton flavor univ.

w/ & w/o Higgs exotic decays

operators (Warsaw)

$$
\begin{aligned}
\mathscr{L}_{\mathrm{SMEFT}_{\mathrm{ND,FU}}} = \; & \frac{C_\phi}{\Lambda^2}(\phi^\dagger\phi)^3 + \frac{C_{\phi\Box}}{\Lambda^2}(\phi^\dagger\phi)\Box(\phi^\dagger\phi) \\
& + \frac{C_W}{\Lambda^2}\varepsilon_{abc}W_\mu^{a\nu}W_\nu^{b\rho}W_\rho^{c\mu} \\
& + \frac{C_{\phi B}}{\Lambda^2}\phi^\dagger\phi B_{\mu\nu}B^{\mu\nu} + \frac{C_{\phi W}}{\Lambda^2}\phi^\dagger\phi W^a_{\mu\nu}W^{a\mu\nu} + \frac{C_{\phi G}}{\Lambda^2}\phi^\dagger\phi G^A_{\mu\nu}G^{A\mu\nu} \\
& + \frac{C_{\phi D}}{\Lambda^2}(\phi^\dagger D_\mu\phi)((D^\mu\phi)^\dagger\phi) \quad + \frac{C_{\phi WB}}{\Lambda^2}\phi^\dagger\sigma_a\phi W^a_{\mu\nu}B^{\mu\nu} \\
& + \left(\frac{(C_{e\phi})_{ii}}{\Lambda^2}(\phi^\dagger\phi)(\bar{l}^i_L\phi e^i_R) + \frac{(C_{d\phi})_{ii}}{\Lambda^2}(\phi^\dagger\phi)(\bar{q}^i_L\phi d^i_R) + \frac{(C_{u\phi})_{ii}}{\Lambda^2}(\phi^\dagger\phi)(\bar{q}^i_L\tilde{\phi}u^i_R) + \text{h.c.}\right) \\
& + \frac{\left(C^{(1)}_{\phi l}\right)_{ii}}{\Lambda^2}(\phi^\dagger i\overleftrightarrow{D}_\mu\phi)(\bar{l}^i_L\gamma^\mu l^i_L) + \frac{\left(C^{(3)}_{\phi l}\right)_{ii}}{\Lambda^2}(\phi^\dagger i\overleftrightarrow{D}^a_\mu\phi)(\bar{l}^i_L\gamma^\mu\sigma_a l^i_L) \\
& + \frac{(C_{\phi e})_{ii}}{\Lambda^2}(\phi^\dagger i\overleftrightarrow{D}_\mu\phi)(\bar{e}^i_R\gamma^\mu e^i_R) \\
& + \frac{\left(C^{(1)}_{\phi q}\right)_{ii}}{\Lambda^2}(\phi^\dagger i\overleftrightarrow{D}_\mu\phi)(\bar{q}^i_L\gamma^\mu q^i_L) + \frac{\left(C^{(3)}_{\phi l}\right)_{ii}}{\Lambda^2}(\phi^\dagger i\overleftrightarrow{D}^a_\mu\phi)(\bar{q}^i_L\gamma^\mu\sigma_a q^i_L) \\
& + \frac{(C_{\phi u})_{ii}}{\Lambda^2}(\phi^\dagger i\overleftrightarrow{D}_\mu\phi)(\bar{u}^i_R\gamma^\mu u^i_R) + \frac{(C_{\phi d})_{ii}}{\Lambda^2}(\phi^\dagger i\overleftrightarrow{D}_\mu\phi)(\bar{d}^i_R\gamma^\mu d^i_R) \\
& + \frac{(C_{ll})_{1221}}{\Lambda^2}(\bar{l}_1\gamma_\mu l_2)(\bar{l}_2\gamma^\mu l_1)\,.
\end{aligned}
$$

Input: EWPO @ future e+e-

	ILC	FCC-ee
$\Delta\alpha^{-1}$	0.0178	0.00387
ΔG_F	$6.0\text{x}10^{-7}$	$6.0\text{x}10^{-7}$
Δm_W	2.4MeV	0.5MeV
Δm_Z	2.1MeV	0.1MeV
Δm_H	14MeV	11MeV
$\Delta\Gamma_W$	2MeV	1.2MeV
$\Delta\Gamma_Z$	2.3MeV	0.1MeV
ΔA_e	0.00014	0.000017
ΔA_μ	0.00082	0.000023
ΔA_τ	0.00086	0.000045
ΔA_b	0.00060	0.0028
ΔA_c	0.0014	0.0053
δR_e	0.0011	0.0003
δR_μ	0.0011	0.00005
δR_τ	0.0011	0.0001
δR_b	0.0011	0.0003
δR_c	0.0050	0.0015

Δ: absolute error
δ: relative error

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Δ: absolute error
δ: relative error

wishlist: agreed treatment on experimental systematics

Input: Higgs @ HL-LHC

HL-LHC	3 ab-1 @ 14 TeV ATLAS+CMS (S2)				
prod.	ggH	VBF	WH	ZH	ttH
σ	-	-	-	-	
$\sigma x BR_{bb}$	19.1	-	8.3	4.6	10.2
$\sigma x BR_{cc}$	-	-	-	-	-
$\sigma x BR_{gg}$	-	-	-	-	-
$\sigma x BR_{ZZ}$	2.5	9.5	32.1	58.3	15.2
$\sigma x BR_{WW}$	2.5	5.5	9.9	12.8	6.6
$\sigma x BR_{\tau\tau}$	4.5	3.9	-	-	10.2
$\sigma x BR_{\gamma\gamma}$	2.5	7.9	9.9	13.2	5.9
$\sigma x BR_{\gamma Z}$	24.4	51.2	-	-	-
$\sigma x BR_{\mu\mu}$	11.1	30.7	-	-	-
$\sigma x BR_{inv.}$	-	2.5	-	-	-
m_H	10-20MeV				

wishlist: correlation matrix; differential x-section is not included now, but can be accommodated if available

Input: Higgs @ future e+e-

in unit of %

250GeV	0.9 ab^{-1} @ (-0.8,+0.3)		0.9 ab^{-1} @ (+0.8,-0.3)		5 ab^{-1} @ (0,0)	
prod.	ZH	ννH	ZH	ννH	ZH	ννH
σ	1.07	-	1.07	-	0.537	-
$\sigma \times BR_{bb}$	0.714	4.27	0.714	17.4	0.380	2.78
$\sigma \times BR_{cc}$	4.38	-	4.38	-	2.08	-
$\sigma \times BR_{gg}$	3.69	-	3.69	-	1.75	-
$\sigma \times BR_{ZZ}$	9.49	-	9.49	-	4.49	-
$\sigma \times BR_{WW}$	2.43	-	2.43	-	1.16	-
$\sigma \times BR_{\tau\tau}$	1.70	-	1.70	-	0.822	-
$\sigma \times BR_{\gamma\gamma}$	17.9	-	17.9	-	8.47	-
$\sigma \times BR_{\mu\mu}$	37.9	-	37.9	-	17.9	-
$\sigma \times BR_{inv.}$	0.336	-	0.277	-	0.226	-

***toy fit: inputs are consistently extrapolated from same set of full simulation analyses for both polarized and unpolarized cases, including common 0.2% systematic errors for all channels except for H—>bb (0.3%)

Input: Higgs @ future e+e-

in unit of %

350GeV	135 fb^{-1} @ (-0.8,+0.3)		45 fb^{-1} @ (+0.8,-0.3)		1.5 ab^{-1} @ (0,0)	
prod.	ZH	ννH	ZH	ννH	ZH	ννH
σ	2.46	-	4.25	-	0.842	-
$\sigma \times BR_{bb}$	2.05	2.46	3.54	17.7	0.711	1.14
$\sigma \times BR_{cc}$	15.0	25.9	25.9	186	5.00	11.9
$\sigma \times BR_{gg}$	11.4	10.5	19.8	75.4	3.82	4.82
$\sigma \times BR_{ZZ}$	34.0	27.2	58.9	191	11.4	12.5
$\sigma \times BR_{WW}$	7.62	7.76	13.2	56.6	2.55	3.57
$\sigma \times BR_{\tau\tau}$	5.45	21.8	9.43	156	1.83	10
$\sigma \times BR_{\gamma\gamma}$	53.1	61.2	91.9	424	17.7	28.1
$\sigma \times BR_{\mu\mu}$	118	218	205	1580	39.6	100
$\sigma \times BR_{inv.}$	1.15	-	1.83	-	0.416	-

***to be updated later with exact running scenarios, e.g. 365 GeV for FCC-ee

Input: Higgs @ future e+e-

in unit of %

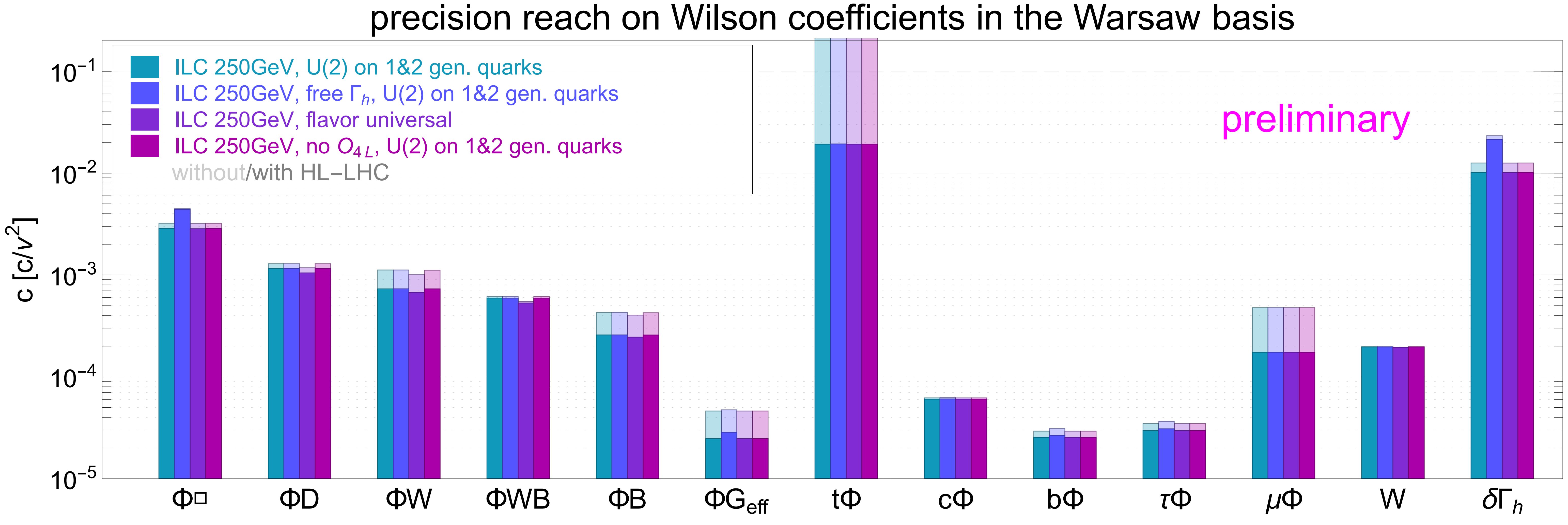
500GeV	1.6 ab^{-1} @ (-0.8,+0.3)		1.6 fb^{-1} @ (+0.8,-0.3)	
prod.	ZH	vvH	ZH	vvH
σ	1.67	-	1.67	-
$\sigma x BR_{bb}$	1.01	0.418	1.01	1.52
$\sigma x BR_{cc}$	7.12	3.48	7.12	14.2
$\sigma x BR_{gg}$	5.93	2.30	5.93	9.49
$\sigma x BR_{ZZ}$	13.8	4.75	13.8	19.0
$\sigma x BR_{WW}$	3.05	1.36	3.05	5.54
$\sigma x BR_{\tau\tau}$	2.42	3.88	2.42	15.8
$\sigma x BR_{\gamma\gamma}$	18.6	10.7	18.6	43.5
$\sigma x BR_{\mu\mu}$	47.4	39.5	47.4	166
$\sigma x BR_{inv.}$	0.825	-	0.599	-

***to be added: angular measurements in e+e- —> ZH

Preliminary results: bounds on operators

U(2) on 1&2 generation quarks are assumed for now

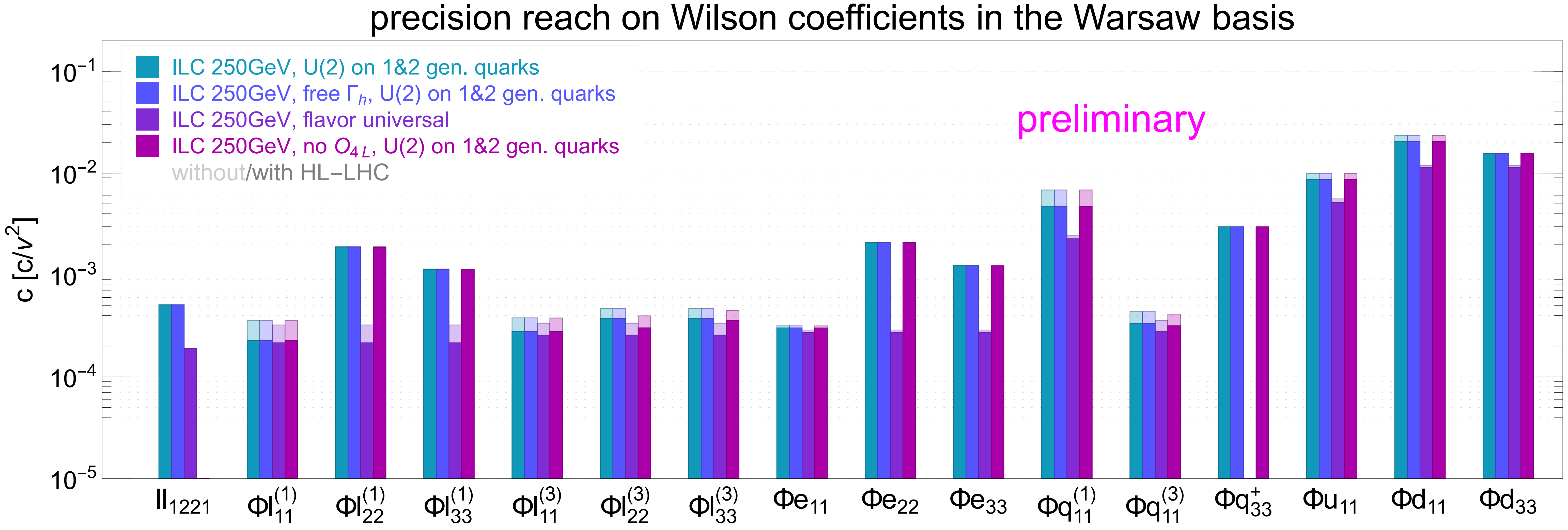
likely to be completely eased



$$+\frac{(C^{(1)}_{\phi q})_{ii}}{\Lambda^2}(\phi^\dagger i\overleftrightarrow{D}_\mu\phi)(\bar q^i_L\gamma^\mu q^i_L) + \frac{(C^{(3)}_{\phi l})_{ii}}{\Lambda^2}(\phi^\dagger i\overleftrightarrow{D}^a_\mu\phi)(\bar q^i_L\gamma^\mu\sigma_a q^i_L)$$
$$+\frac{(C_{\phi u})_{ii}}{\Lambda^2}(\phi^\dagger i\overleftrightarrow{D}_\mu\phi)(\bar u^i_R\gamma^\mu u^i_R) + \frac{(C_{\phi d})_{ii}}{\Lambda^2}(\phi^\dagger i\overleftrightarrow{D}_\mu\phi)(\bar d^i_R\gamma^\mu d^i_R)$$

for each gen., 4 ops.

using Γ(Z->f), Γ(W->f), +A_{LR} for c,s; +R^{uc} + ? for u,d



Preliminary results: bounds on effective couplings

defined from Z/W/H partial decay width