Prospects of top coupling measurements

Eleni Vryonidou
University of Manchester

Based mainly on arXiv:2205.02140 and 2208.04962

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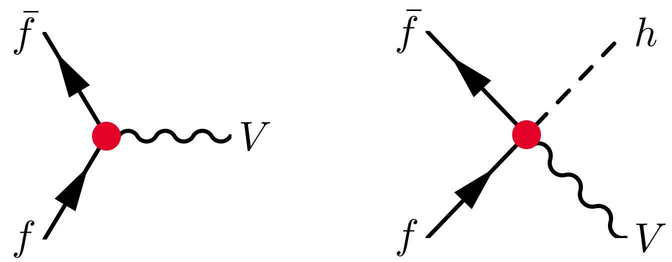
Outline

- Prospects for top couplings at the HL-LHC
- Prospects for lepton colliders
- Future for 4-tops in 4-tops
- Future for 4-tops outside 4-tops

Operator map

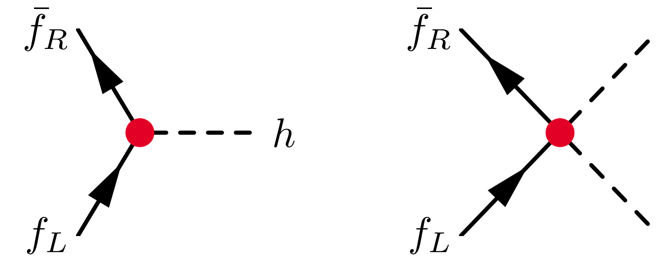
currents $i(\varphi^\dagger \overleftrightarrow{D}^\mu \varphi)(\bar{Q}\gamma^\mu Q)$



$C_{\phi f}$

- Shift SM $f\bar{f}V$ couplings
- $f\bar{f}Vh$ contact interactions

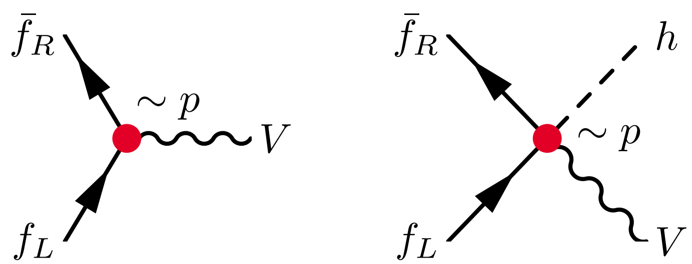
Yukawa $(\bar{q}\, t\, \tilde{\varphi})(\varphi^\dagger \varphi)$



$C_{t\phi}$

- Decouple m_t & y_t
- $t\bar{t}hh(h)$ contact interactions

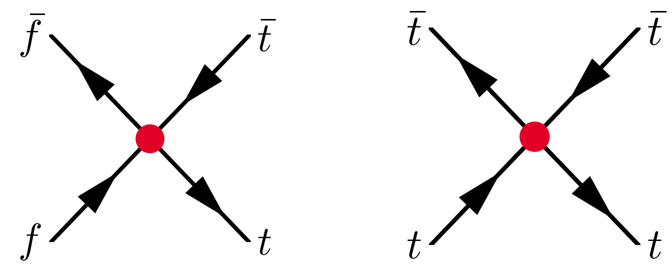
dipole $(\bar{q}\, \sigma_{\mu\nu}\, t\, \tilde{\varphi})V^{\mu\nu}$



C_{tV}

- Chirality flipping $f\bar{f}V$ couplings
- $f\bar{f}V(V)h$ contact interactions
- W, B & G fields

4 fermion $(\bar{q}\gamma_\mu q)(\bar{Q}\gamma^\mu Q)$ $(\bar{Q}\gamma^\mu Q)(\bar{\ell}\gamma_\mu \ell)$



C_{ft}

- Contact interactions
- 2-heavy-2-light or 4-heavy
- Numerous (~O(20) w/ top)

From K. Mimasu

LHC top observables

LHC Data

Top-pair production W-helicities, asymmetry

Dataset	$\sqrt{s}$, $\mathcal{L}$	Info	Observables	n_{dat}	Ref
ATLAS_tt_8TeV_ljets	**8 TeV, 20.3 fb^{-1}**	lepton+jets	$d\sigma/dm_{t\bar{t}}$	7	[46]
CMS_tt_8TeV_ljets	**8 TeV, 20.3 fb^{-1}**	lepton+jets	$1/\sigma d\sigma/dy_{t\bar{t}}$	10	[47]
CMS_tt2D_8TeV_dilep	**8 TeV, 20.3 fb^{-1}**	dileptons	$1/\sigma d^2\sigma/dy_{t\bar{t}}dm_{t\bar{t}}$	16	[48]
ATLAS_tt_8TeV_dilep (*)	**8 TeV, 20.3 fb^{-1}**	dileptons	$d\sigma/dm_{t\bar{t}}$	6	[54]
CMS_tt_13TeV_ljets_2015	**13 TeV, 2.3 fb^{-1}**	lepton+jets	$d\sigma/dm_{t\bar{t}}$	8	[51]
CMS_tt_13TeV_dilep_2015	**13 TeV, 2.1 fb^{-1}**	dileptons	$d\sigma/dm_{t\bar{t}}$	6	[53]
CMS_tt_13TeV_ljets_2016	**13 TeV, 35.8 fb^{-1}**	lepton+jets	$d\sigma/dm_{t\bar{t}}$	10	[52]
CMS_tt_13TeV_dilep_2016 (*)	**13 TeV, 35.8 fb^{-1}**	dileptons	$d\sigma/dm_{t\bar{t}}$	7	[56]
ATLAS_tt_13TeV_ljets_2016 (*)	**13 TeV, 35.8 fb^{-1}**	lepton+jets	$d\sigma/dm_{t\bar{t}}$	9	[55]
ATLAS_WhelF_8TeV	**8 TeV, 20.3 fb^{-1}**	W hel. fract	F_0, F_L, F_R	3	[49]
CMS_WhelF_8TeV	**8 TeV, 20.3 fb^{-1}**	W hel. fract	F_0, F_L, F_R	3	[50]
ATLAS_CMS_tt_AC_8TeV (*)	**8 TeV, 20.3 fb^{-1}**	charge asymmetry	A_C	6	[57]
ATLAS_tt_AC_13TeV (*)	**8 TeV, 20.3 fb^{-1}**	charge asymmetry	A_C	5	[58]

Dataset	$\sqrt{s}, \mathcal{L}$	Info	Observables	N_{dat}	Ref
CMS_t_tch_8TeV_inc	**8 TeV, 19.7 fb^{-1}**	t-channel	$\sigma_{\mathrm{tot}}(t), \sigma_{\mathrm{tot}}(\bar{t})$	2	[83]
ATLAS_t_tch_8TeV	**8 TeV, 20.2 fb^{-1}**	t-channel	$d\sigma(tq)/dy_t$	4	[85]
CMS_t_tch_8TeV_dif	**8 TeV, 19.7 fb^{-1}**	t-channel	$d\sigma/d\|y^{(t+\bar{t})}\|$	6	[84]
CMS_t_sch_8TeV	**8 TeV, 19.7 fb^{-1}**	s-channel	$\sigma_{\mathrm{tot}}(t+\bar{t})$	1	[87]
ATLAS_t_sch_8TeV	**8 TeV, 20.3 fb^{-1}**	s-channel	$\sigma_{\mathrm{tot}}(t+\bar{t})$	1	[86]
ATLAS_t_tch_13TeV	**13 TeV, 3.2 fb^{-1}**	t-channel	$\sigma_{\mathrm{tot}}(t), \sigma_{\mathrm{tot}}(\bar{t})$	2	[88]
CMS_t_tch_13TeV_inc	**13 TeV, 2.2 fb^{-1}**	t-channel	$\sigma_{\mathrm{tot}}(t), \sigma_{\mathrm{tot}}(\bar{t})$	2	[90]
CMS_t_tch_13TeV_dif	**13 TeV, 2.3 fb^{-1}**	t-channel	$d\sigma/d\|y^{(t+\bar{t})}\|$	4	[89]
CMS_t_tch_13TeV_2016 (*)	**13 TeV, 35.9 fb^{-1}**	t-channel	$d\sigma/d\|y^{(t)}\|$	5	[91]

Single top t-, s-channel

4 tops, ttbb, top-pair associated production

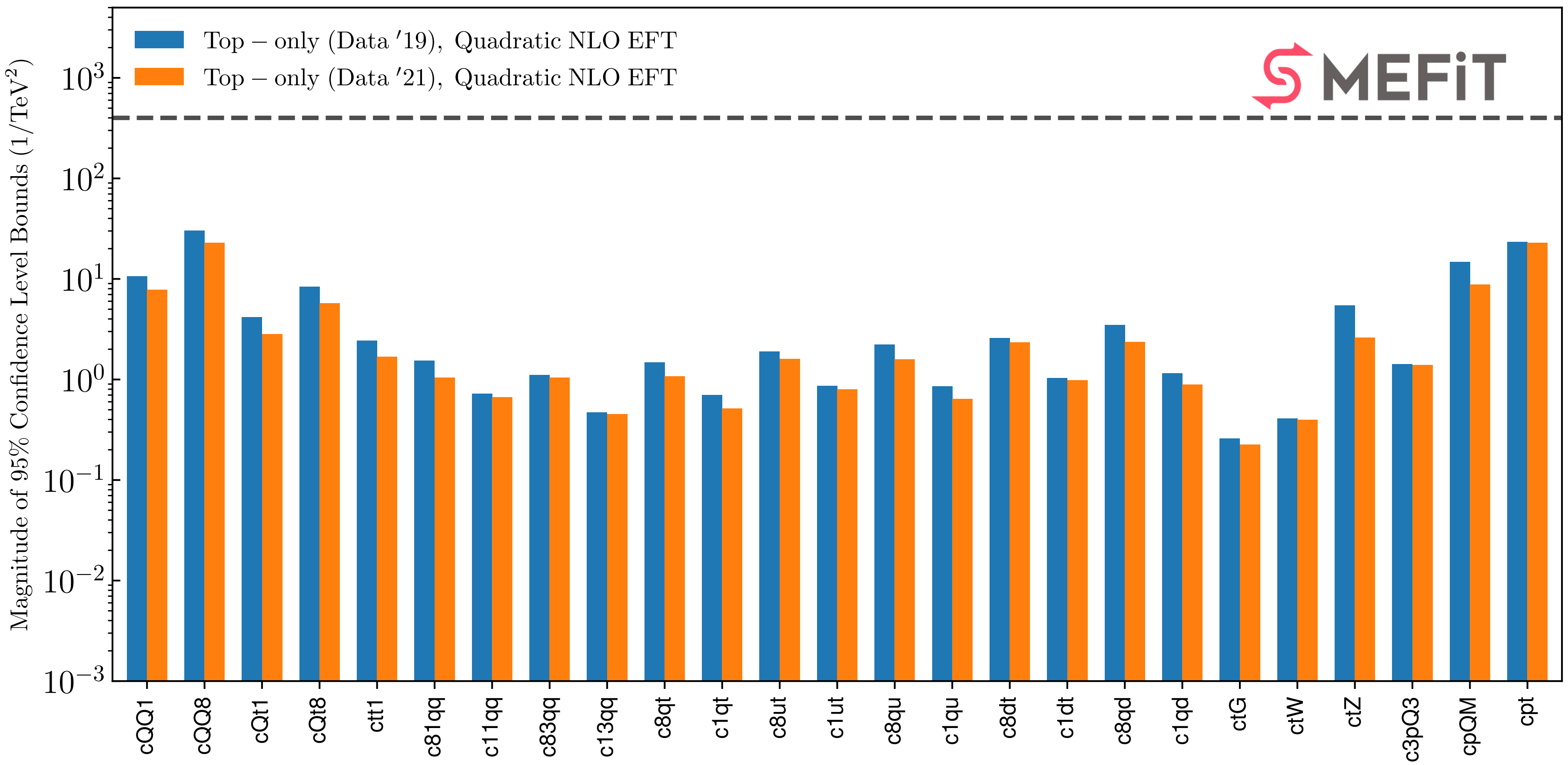
Dataset	$\sqrt{s}, \mathcal{L}$	Info	Observables	N_{dat}	Ref
CMS_ttbb_13TeV	**13 TeV, 2.3 fb^{-1}**	total xsec	$\sigma_{\mathrm{tot}}(t\bar{t}b\bar{b})$	1	[70]
CMS_ttbb_13TeV_2016 (*)	**13 TeV, 35.9 fb^{-1}**	total xsec	$\sigma_{\mathrm{tot}}(t\bar{t}b\bar{b})$	1	[79]
ATLAS_ttbb_13TeV_2016 (*)	**13 TeV, 35.9 fb^{-1}**	total xsec	$\sigma_{\mathrm{tot}}(t\bar{t}b\bar{b})$	1	[78]
CMS_tttt_13TeV	**13 TeV, 35.9 fb^{-1}**	total xsec	$\sigma_{\mathrm{tot}}(t\bar{t}t\bar{t})$	1	[71]
CMS_tttt_13TeV_run2 (*)	**13 TeV, 137 fb^{-1}**	total xsec	$\sigma_{\mathrm{tot}}(t\bar{t}t\bar{t})$	1	[76]
ATLAS_tttt_13TeV_run2 (*)	**13 TeV, 137 fb^{-1}**	total xsec	$\sigma_{\mathrm{tot}}(t\bar{t}t\bar{t})$	1	[77]
CMS_ttZ_8TeV	**8 TeV, 19.5 fb^{-1}**	total xsec	$\sigma_{\mathrm{tot}}(t\bar{t}Z)$	1	[72]
CMS_ttZ_13TeV	**13 TeV, 35.9 fb^{-1}**	total xsec	$\sigma_{\mathrm{tot}}(t\bar{t}Z)$	1	[73]
CMS_ttZ_ptZ_13TeV (*)	**13 TeV, 77.5 fb^{-1}**	total xsec	$d\sigma(t\bar{t}Z)/dp_T^Z$	4	[81]
ATLAS_ttZ_8TeV	**8 TeV, 20.3 fb^{-1}**	total xsec	$\sigma_{\mathrm{tot}}(t\bar{t}Z)$	1	[74]
ATLAS_ttZ_13TeV	**13 TeV, 3.2 fb^{-1}**	total xsec	$\sigma_{\mathrm{tot}}(t\bar{t}Z)$	1	[75]
ATLAS_ttZ_13TeV_2016 (*)	**13 TeV, 36 fb^{-1}**	total xsec	$\sigma_{\mathrm{tot}}(t\bar{t}Z)$	1	[80]
CMS_ttW_8_TeV	**8 TeV, 19.5 fb^{-1}**	total xsec	$\sigma_{\mathrm{tot}}(t\bar{t}W)$	1	[72]
CMS_ttW_13TeV	**13 TeV, 35.9 fb^{-1}**	total xsec	$\sigma_{\mathrm{tot}}(t\bar{t}W)$	1	[73]
ATLAS_ttW_8TeV	**8 TeV, 20.3 fb^{-1}**	total xsec	$\sigma_{\mathrm{tot}}(t\bar{t}W)$	1	[74]
ATLAS_ttW_13TeV	**13 TeV, 3.2 fb^{-1}**	total xsec	$\sigma_{\mathrm{tot}}(t\bar{t}W)$	1	[75]
ATLAS_ttW_13TeV_2016 (*)	**13 TeV, 36 fb^{-1}**	total xsec	$\sigma_{\mathrm{tot}}(t\bar{t}W)$	1	[80]

tW, tZ

Dataset	$\sqrt{s}, \mathcal{L}$	Info	Observables	N_{dat}	Ref
ATLAS_tW_8TeV_inc	**8 TeV, 20.2 fb^{-1}**	inclusive (dilepton)	$\sigma_{\mathrm{tot}}(tW)$	1	[95]
ATLAS_tW_inc_slep_8TeV (*)	**8 TeV, 20.2 fb^{-1}**	inclusive (single lepton)	$\sigma_{\mathrm{tot}}(tW)$	1	[101]
CMS_tW_8TeV_inc	**8 TeV, 19.7 fb^{-1}**	inclusive	$\sigma_{\mathrm{tot}}(tW)$	1	[96]
ATLAS_tW_inc_13TeV	**13 TeV, 3.2 fb^{-1}**	inclusive	$\sigma_{\mathrm{tot}}(tW)$	1	[97]
CMS_tW_13TeV_inc	**13 TeV, 35.9 fb^{-1}**	inclusive	$\sigma_{\mathrm{tot}}(tW)$	1	[98]
ATLAS_tZ_13TeV_inc	**13 TeV, 36.1 fb^{-1}**	inclusive	$\sigma_{\mathrm{tot}}(tZq)$	1	[100]
ATLAS_tZ_13TeV_run2_inc (*)	**13 TeV, 139.1 fb^{-1}**	inclusive	$\sigma_{\mathrm{fid}}(t\ell^+\ell^-q)$	1	[102]
CMS_tZ_13TeV_inc	**13 TeV, 35.9 fb^{-1}**	inclusive	$\sigma_{\mathrm{fid}}(Wb\ell^+\ell^-q)$	1	[99]
CMS_tZ_13TeV_2016_inc (*)	**13 TeV, 77.4 fb^{-1}**	inclusive	$\sigma_{\mathrm{fid}}(t\ell^+\ell^-q)$	1	[103]

Category	Processes	n_{dat}
Top quark production	$t\bar{t}$ (inclusive)	94
	$t\bar{t}Z$, $t\bar{t}W$	14
	single top (inclusive)	27
	tZ, tW	9
	$t\bar{t}t\bar{t}$, $t\bar{t}b\bar{b}$	6
	Total	**150**

What do we (not) know about top couplings



Ethier, Maltoni, Mantani, Nocera, Rojo, Slade, EV and Zhang arXiv:2105.00006

- More data always helps
- Bounds vary between operators
- ttZ ones and 4-heavy ones loosely constrained

See Maeve's talk on Tuesday

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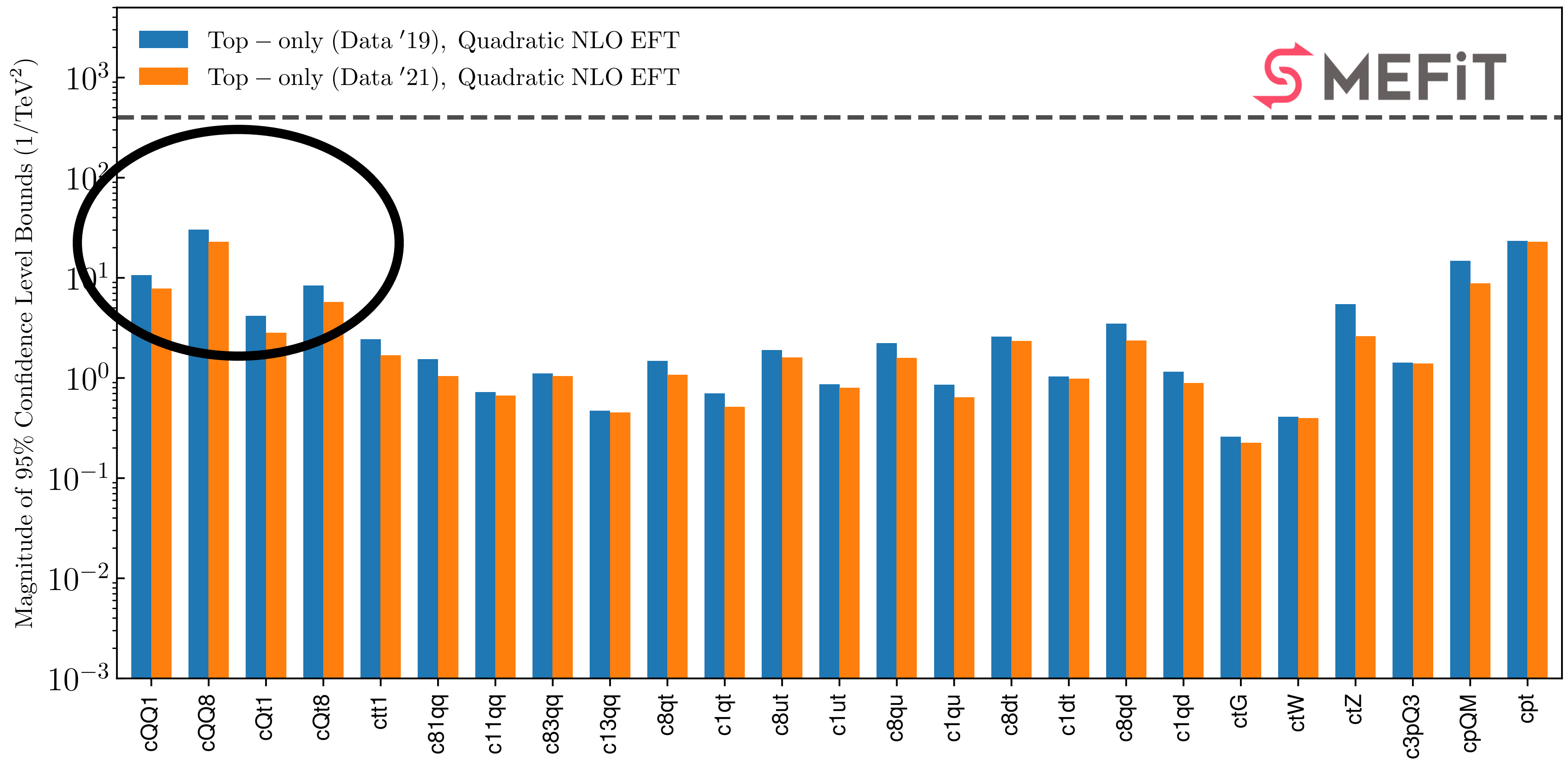

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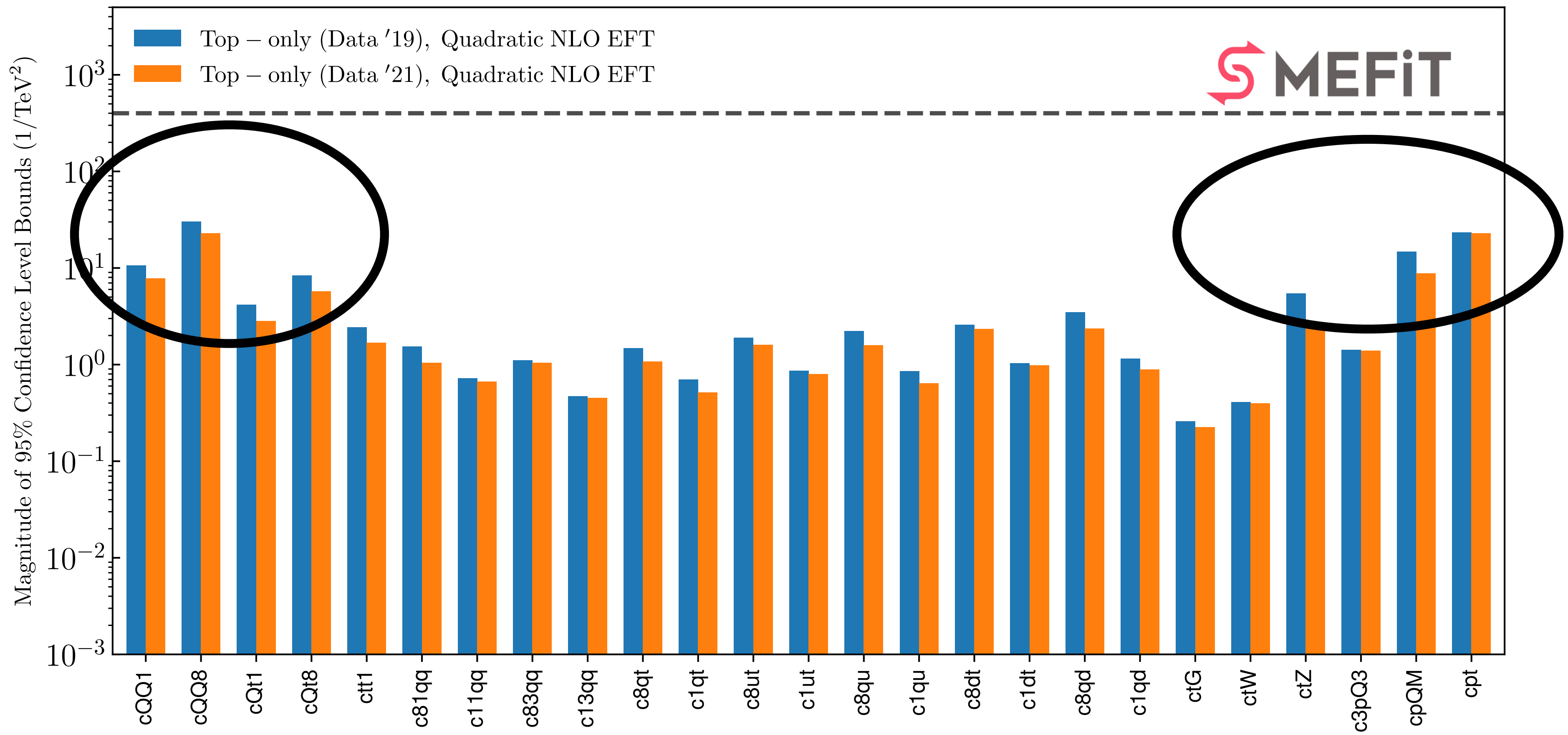

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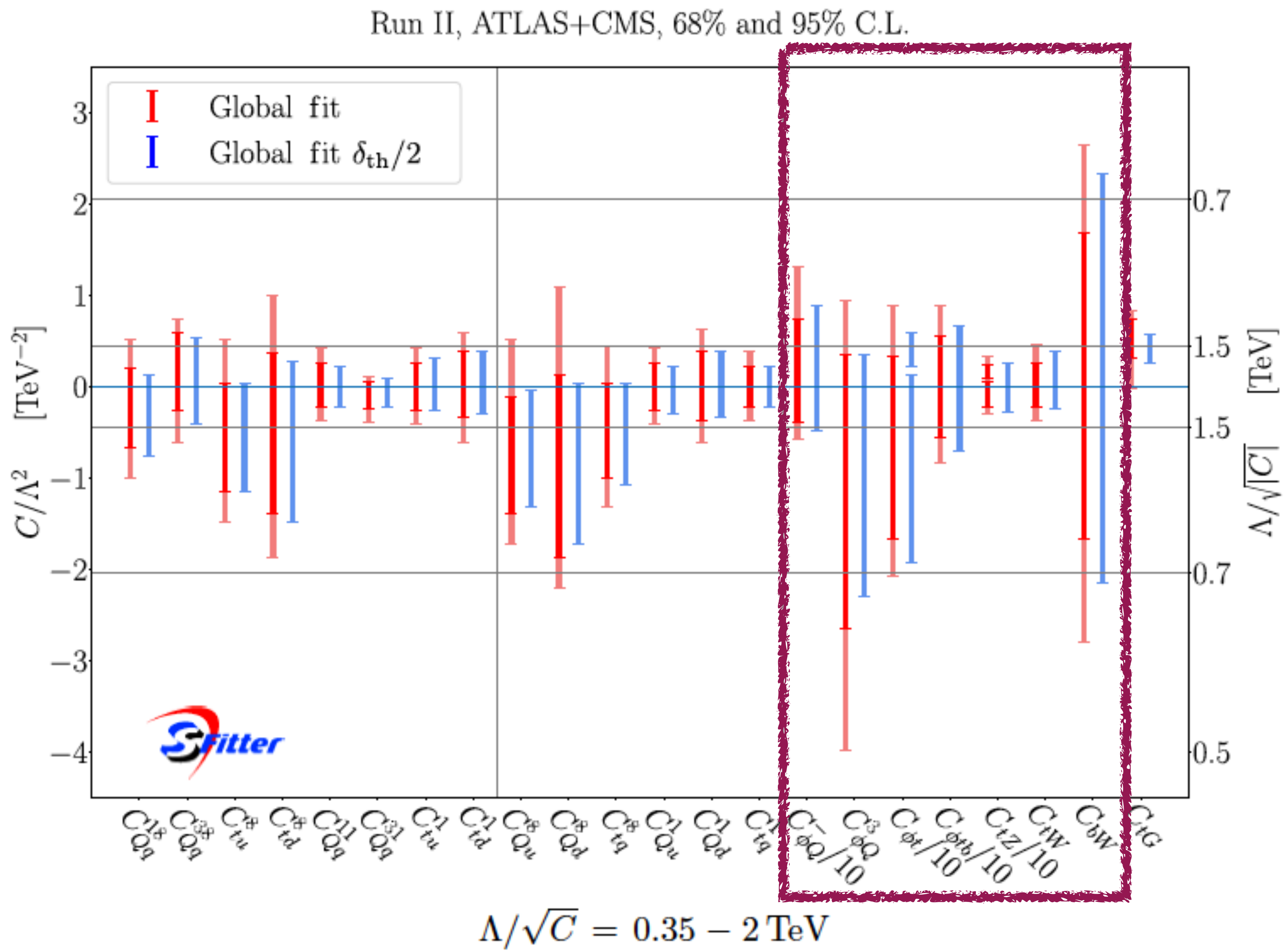


Brivio, Bruggisser, Maltoni, Moutafis, Plehn, EV, Westhoff, Zhang arXiv:1910.03606 (SFitter analysis)

The future

HiLumi
HL-LHC PROJECT

CLIC

International
MUON Collider
Collaboration

FCC
hh ee he

CEPC

ilc
international linear collider

What we can hope to know in the future

Goals:

- Explore HL-LHC prospects
- Explore future collider prospects
- Do this in some some unified fit setup, with reasonable uncertainty assumptions

Snowmass: A good motivation!

Coefficients fitted			
2-quark	C_{tG} $C_{\varphi t}$ –	$C^3_{\varphi Q}$ $C_{\varphi b}$ $C_{t\varphi}$	$C^-_{\varphi Q} = C^1_{\varphi Q} - C^3_{\varphi Q}$ $C_{tZ} = c_W C_{tW} - s_W C_{tB}$ C_{tW}
4-quark	$C^8_{tu} = \sum_{i=1,2} 2C^{(i33i)}_{uu}$ $C^8_{Qu} = \sum_{i=1,2} C^{8(33ii)}_{qu}$ –	$C^8_{td} = \sum_{i=1,2,3} C^{8(33ii)}_{ud}$ $C^8_{Qd} = \sum_{i=1,2,3} C^{8(33ii)}_{qd}$ –	$C^{1,8}_{Qq} = \sum_{i=1,2} C^{1(i33i)}_{qq} + 3C^{3(i33i)}_{qq}$ $C^{3,8}_{Qq} = \sum_{i=1,2} C^{1(i33i)}_{qq} - C^{3(i33i)}_{qq}$ $C^8_{tq} = \sum_{i=1,2} C^{8(ii33)}_{uq}$
2-quark 2-lepton	C_{eb} C_{lb} –	C_{et} C_{lt} –	$C^+_{lQ} = C^1_{lQ} + C^3_{lQ}$ $C^-_{lQ} = C^1_{lQ} - C^3_{lQ}$ C_{eQ}

- Following Top WG note
- Only colour octet 2-light-2-heavy operators
- No 4-heavy operators (see later)
- Only linear $\mathcal{O}(1/\Lambda^2)$ contributions

Durieux, Gutierez, Mantani, Miralles, Mirrales, Moreno, Poncelet, EV, Vos arXiv:2205.02140

Observables and projections

Process	Observable	$\sqrt{s}$	$L_{\rm int}$	Experiment	SM	Ref.
$pp \to t\bar{t}$	$d\sigma/dm_{t\bar{t}}$ (15+3 bins)	13 TeV	140 fb^{-1}	CMS	[19]	[20]
$pp \to t\bar{t}$	$dA_C/dm_{t\bar{t}}$ (4+2 bins)	13 TeV	140 fb^{-1}	ATLAS	[19]	[21]
$pp \to t\bar{t}H + tHq$	σ	13 TeV	140 fb^{-1}	ATLAS	[22]	[23]
$pp \to t\bar{t}Z$	$d\sigma/dp_T^Z$ (7 bins)	13 TeV	140 fb^{-1}	ATLAS	[24]	[25]
$pp \to t\bar{t}\gamma$	$d\sigma/dp_T^\gamma$ (11 bins)	13 TeV	140 fb^{-1}	ATLAS	[26, 27]	[28]
$pp \to tZq$	σ	13 TeV	77.4 fb^{-1}	CMS	[29]	[30]
$pp \to t\gamma q$	σ	13 TeV	36 fb^{-1}	CMS	[31]	[31]
$pp \to t\bar{t}W$	σ	13 TeV	36 fb^{-1}	CMS	[22, 32]	[33]
$pp \to t\bar{b}$ (s-ch)	σ	8 TeV	20 fb^{-1}	LHC	[34, 35]	[36]
$pp \to tW$	σ	8 TeV	20 fb^{-1}	LHC	[37]	[36]
$pp \to tq$ (t-ch)	σ	8 TeV	20 fb^{-1}	LHC	[34, 35]	[36]
$t \to Wb$	F_0, F_L	8 TeV	20 fb^{-1}	LHC	[38]	[39]
$p\bar{p} \to t\bar{b}$ (s-ch)	σ	1.96 TeV	9.7 fb^{-1}	Tevatron	[40]	[41]
$e^-e^+ \to b\bar{b}$	R_b , A_{FBLR}^{bb}	$\sim$ 91 GeV	202.1 pb^{-1}	LEP/SLD	-	[42]

For HL-LHC assume S2:

- Experimental uncertainties scale as $1/\sqrt{L_{int}}$. Reduced by a factor of 5 for full HL-LHC dataset (except for the top pair production + asymmetry)
- Theory and modelling uncertainties are divided by 2

observable	binning					
σ vs. $m_{t\bar{t}}$ [GeV]	bin 1	bin 2	bin 3	bin 4	bin 5	bin 6
	250-400	400-480	480-560	560-640	640-720	720-800
	bin 7	bin 8	bin 9	bin 10	bin 11	bin 12
	800-900	900-1000	1000-1150	1150-1300	1300-1500	1500-1700
	bin 13	bin 14	bin 15	bin 16	bin 17	bin 18
	1700-2000	2000-2300	2300-2600*	2600-3000*	3000-3500*	3500-4000*
A_C vs. $m_{t\bar{t}}$ [GeV]	bin 1	bin 2	bin 3	bin 4	bin 5	bin 6
	500-750	750-1000	1000-1500	1500-2000*	2000-2500*	2500-3000*

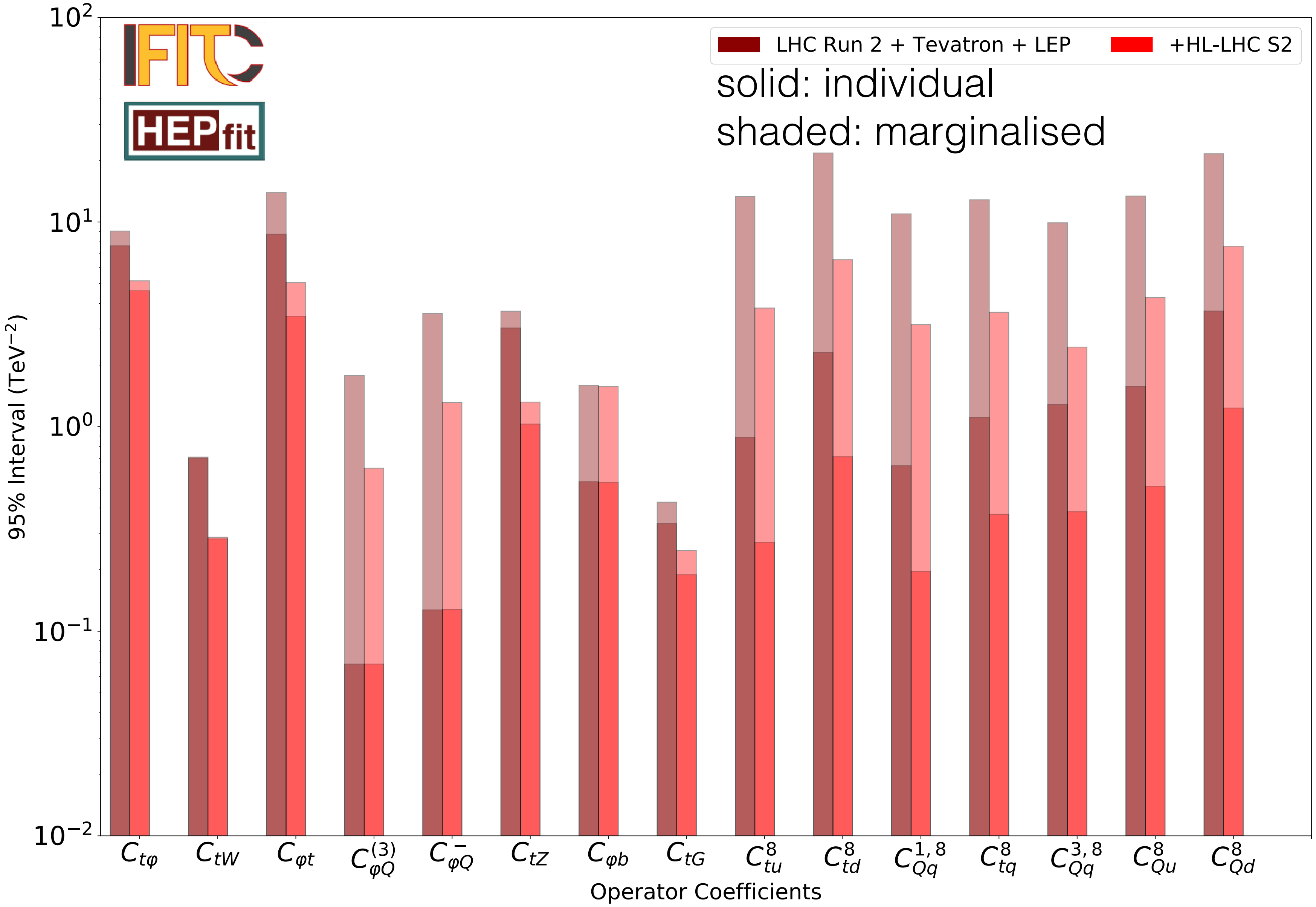
Additional bins added for HL-LHC

$pp \to t\bar{t}\gamma$
p_T^γ : (20-25)
p_T^γ : (25-30)
p_T^γ : (30-35)
p_T^γ : (35-40)
p_T^γ : (40-47)
p_T^γ : (47-55)
p_T^γ : (55-70)
p_T^γ : (70-85)
p_T^γ : (85-132)
p_T^γ : (132-180)
p_T^γ : (180-300)

$pp \to t\bar{t}Z$
p_T^Z : (0-40)
p_T^Z : (40-70)
p_T^Z : (70-110)
p_T^Z : (110-160)
p_T^Z : (160-220)
p_T^Z : (220-290)
p_T^Z : (290-400)

Noteby: One could include more differential information
Difficulty is always to assign uncertainties

LHC vs HL-LHC



arXiv:2205.02140

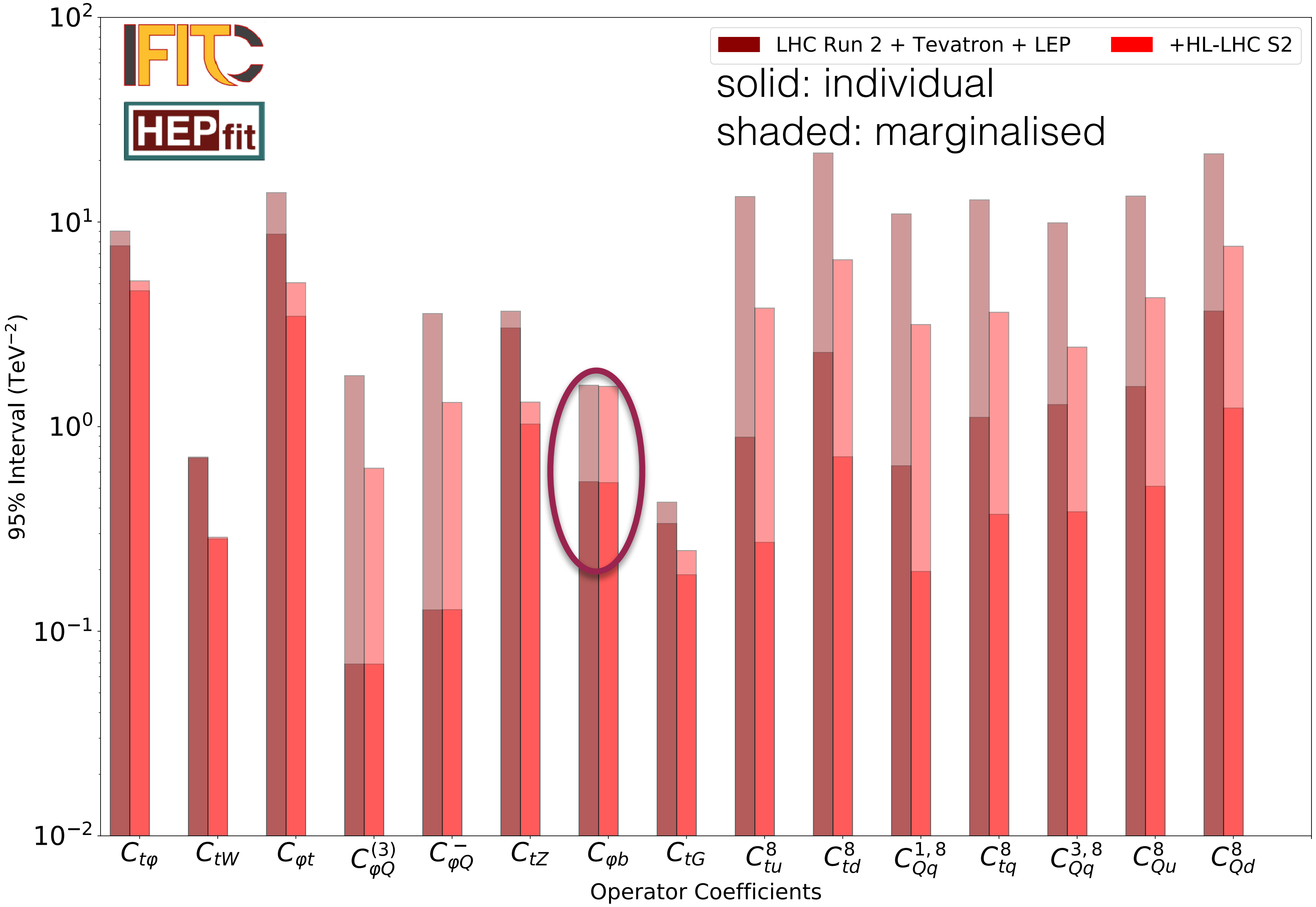
Best improvement: 4-fermion operators driven by differential measurements extending to higher energies

Not much improvement $C_{\phi Q}^{-}$ and $C_{\phi Q}^{3}$ (dominated by bLEP)

Limited by theory and modelling uncertainties

2-quark-2-lepton not fitted (need $t\bar{t}\ell\bar{\ell}$)

Difference in individual and marginalised limits persists at HL for 4-fermion operators



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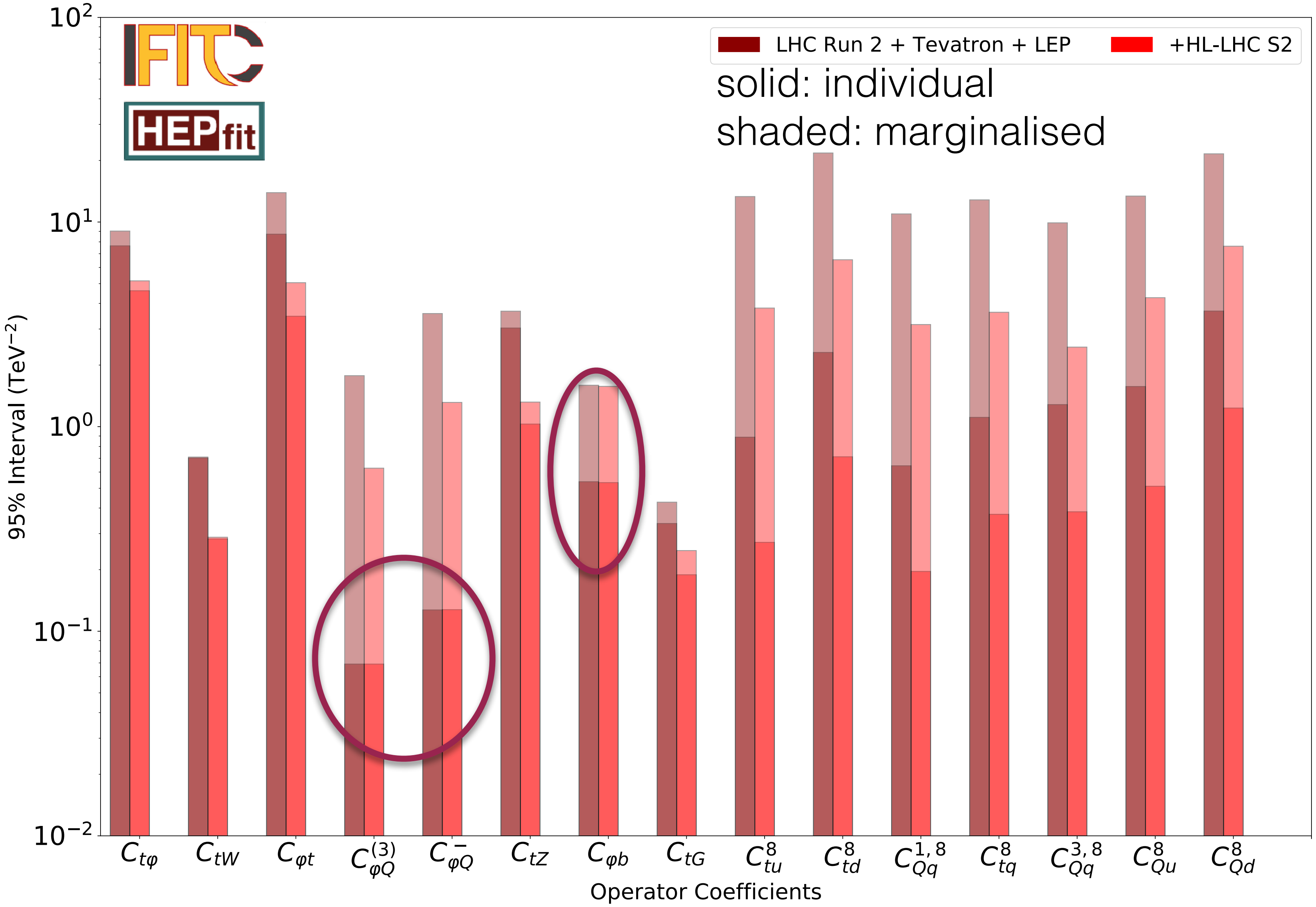
LHC vs HL-LHC



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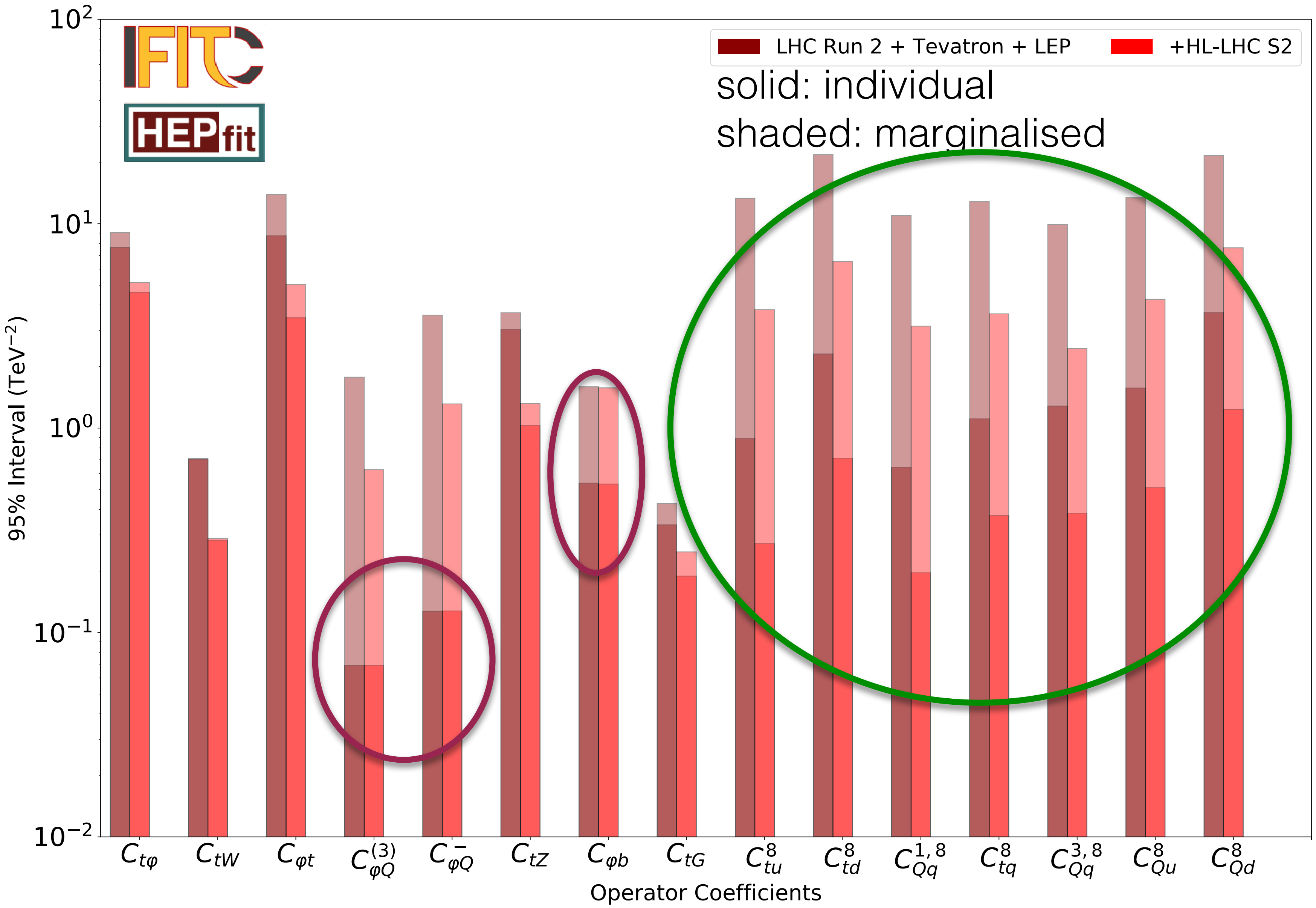

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Lepton colliders

Scenarios considered:

Machine	Polarisation	Energy	Luminosity	Reference
ILC	P(e^+, e^-):(±30%, ∓80%)	250 GeV 500 GeV 1 TeV	2 ab^{-1} 4 ab^{-1} 8 ab^{-1}	[56]
CLIC	P(e^+, e^-):(0%, ±80%)	380 GeV 1.4 TeV 3 TeV	1 ab^{-1} 2.5 ab^{-1} 5 ab^{-1}	[57]
FCC-ee	Unpolarised	Z-pole 240 GeV 350 GeV 365 GeV	150 ab^{-1} 5 ab^{-1} 0.2 ab^{-1} 1.5 ab^{-1}	[58]
CEPC	Unpolarised	Z-pole 240 GeV 350 GeV 360 GeV	57.5 ab^{-1} 20 ab^{-1} 0.2 ab^{-1} 1 ab^{-1}	[58]

Observables:

$e^+e^- \to b\bar{b}$: σ_b, A^b_{FB}

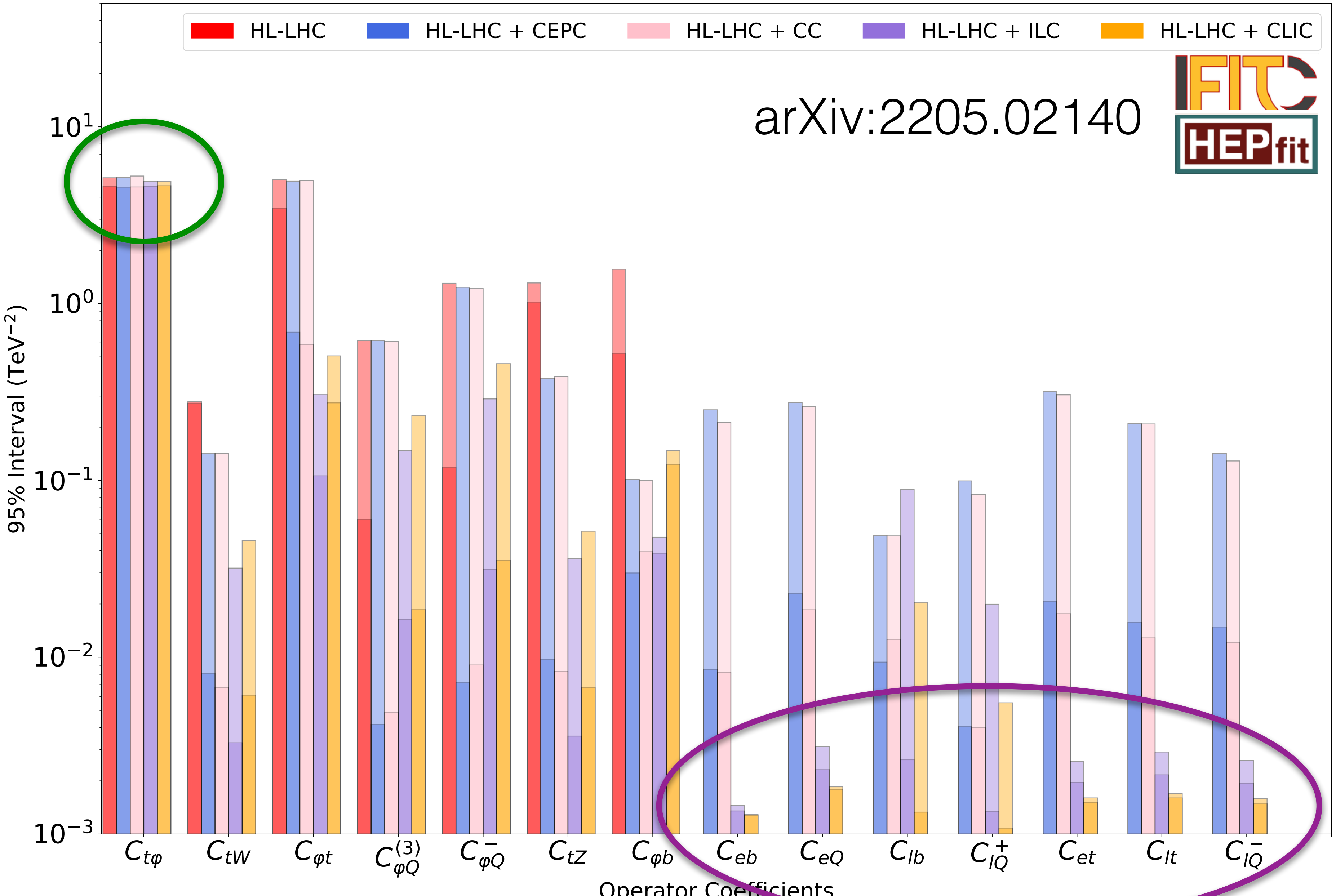
$e^+e^- \to t\bar{t}$: optimal observable constraints from arXiv:1807.02121 for ILC, CLIC, FCC-ee, CEPC

Optimal observables based on $WbWb$ distribution

Input from arXiv:1807.02121 bounds for ttZ and top-lepton 4F operators

ttH is not included here for ILC and CLIC

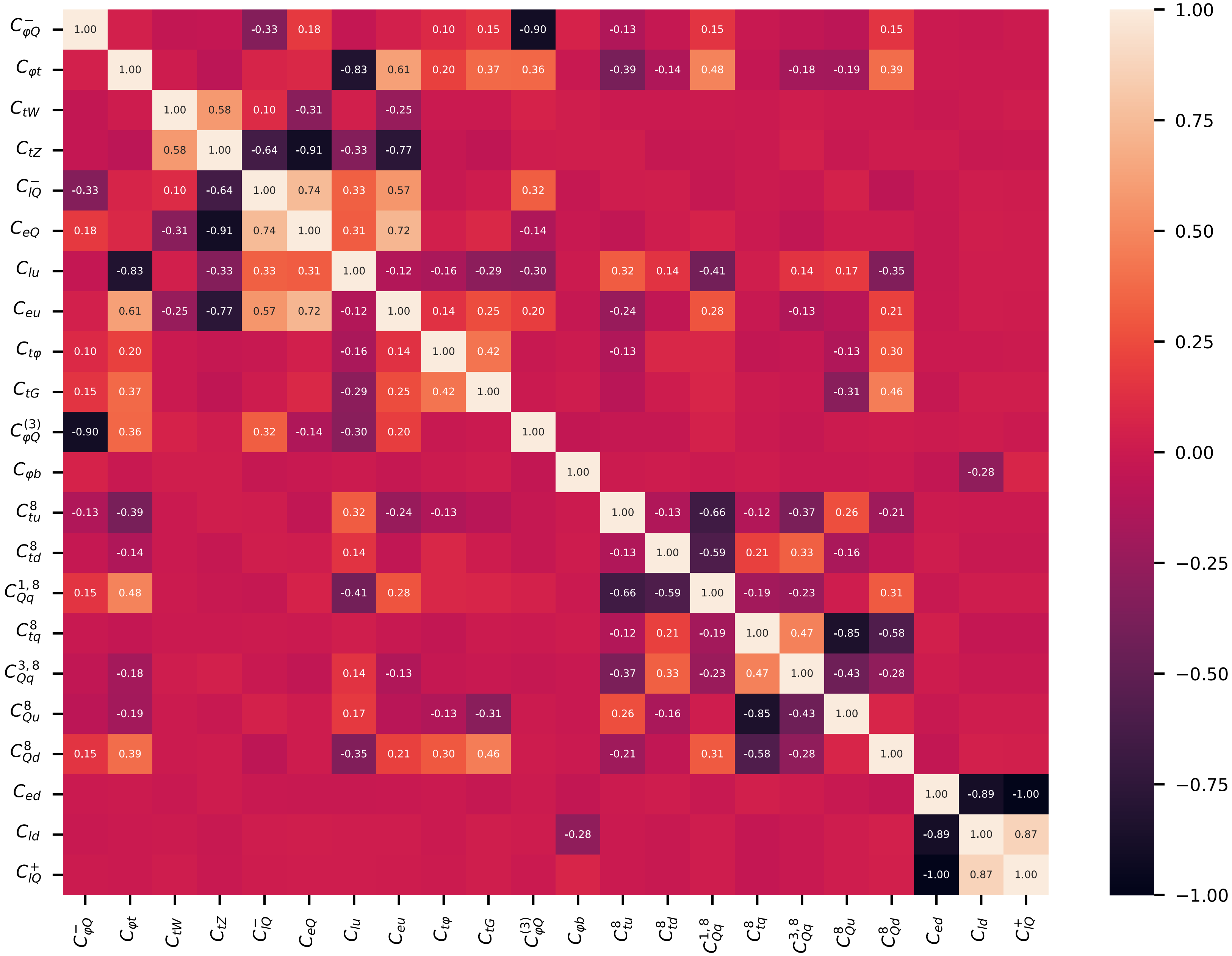
Putting everything together



No improvement for top Yukawa due to missing ttH (expect factor of two improvement for ILC1000)

No bounds for 2Q2l operators at the (HL)LHC, no 4Q bounds for lepton colliders
Runs above ttbar threshold needed for constraining 2Q2l well
Extremely well bounded at ILC and CLIC (10^{-3})

Correlations



Block structure seen:

- 2-light-2-heavy operators
- 2-heavy-2-lepton operators
- top-Z and b-Z operators

arXiv:2205.02140

Correlation for HL- LHC, Tevatron, LEP and the final stage of FCC-ee fit

Pushing the energy frontier

How about the FCC-hh?

No full study but expect much better sensitivity:

LHC14

$$\sigma(m_{t\bar{t}} > 1.4 \text{ TeV }) = 1.8 \text{ pb} \times [1 + 0.3 \cdot C_{tG} + 0.1 \cdot C_{tG}^2 + 0.1 \cdot C_{tu}^8 + 0.3 \cdot (C_{tu}^8)^2 + ...]$$

FCC-hh

$$\sigma(m_{t\bar{t}} > 10 \text{ TeV }) = 0.1 \text{ pb} \times [1 + 0.3 \cdot C_{tG} + 1.8 \cdot C_{tG}^2 + 3 \cdot C_{tu}^8 + 256 \cdot (C_{tu}^8)^2 + ...]$$

Expect bounds to improve from $\mathcal{O}(1\text{TeV}^{-2})$ down to $\mathcal{O}(0.1\text{TeV}^{-2})$

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$$\sigma(m_{t\bar{t}} > 1.4 \text{ TeV}) = 1.8 \text{ pb} \times [1 + 0.3 \cdot C_{tG} + 0.1 \cdot C_{tG}^2 + 0.1 \cdot C_{tu}^8 + 0.3 \cdot (C_{tu}^8)^2 + \ldots]$$

FCC-hh

$$\sigma(m_{t\bar{t}} > 10 \text{ TeV}) = 0.1 \text{ pb} \times [1 + 0.3 \cdot C_{tG} + 1.8 \cdot C_{tG}^2 + 3 \cdot C_{tu}^8 + 256 \cdot (C_{tu}^8)^2 + \ldots]$$

Expect bounds to improve from $\mathcal{O}(1\text{TeV}^{-2})$ down to $\mathcal{O}(0.1\text{TeV}^{-2})$

Future directions for top projections

Improving projections fits:

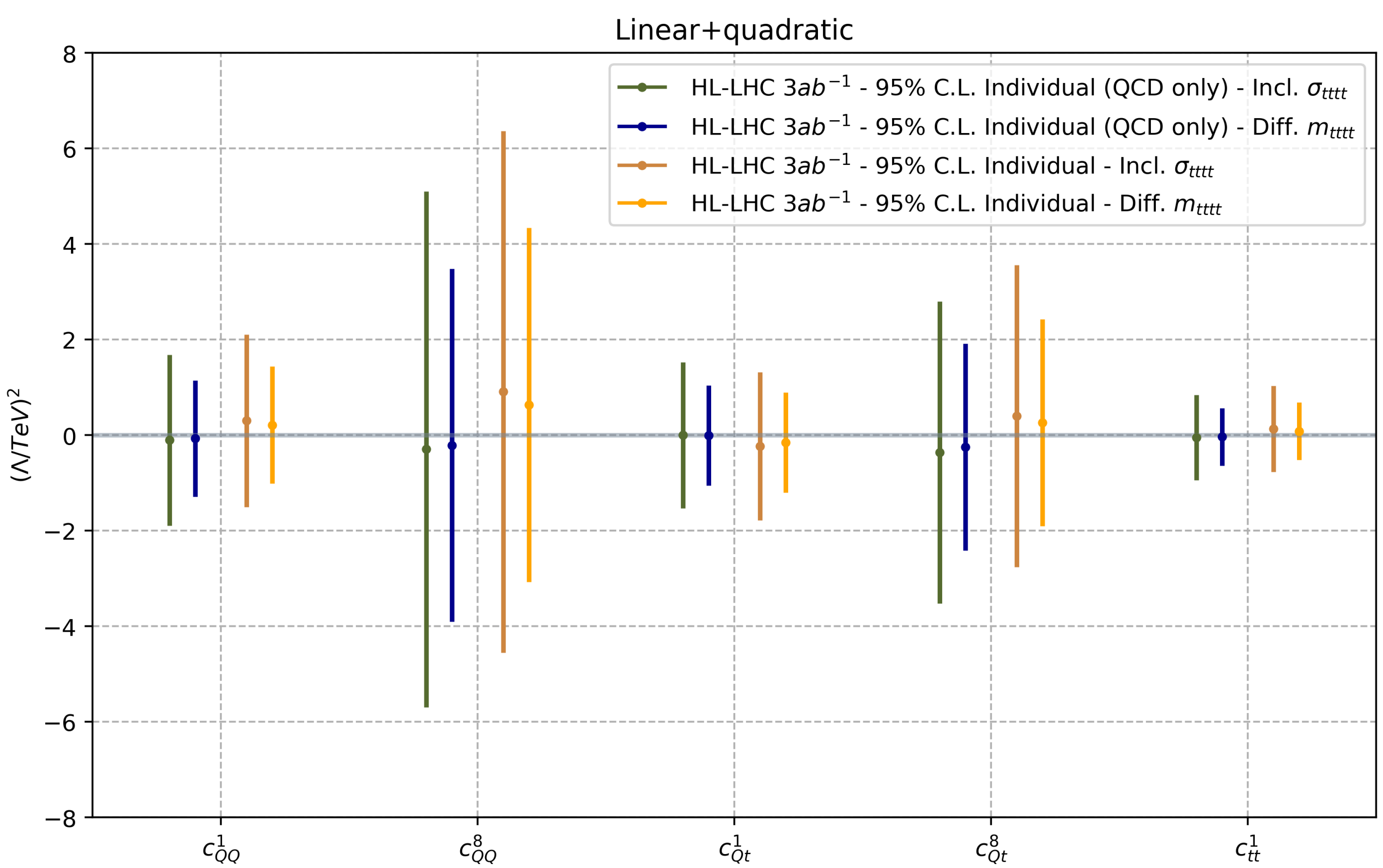
- Additional potentially sensitive top observables: spin correlations, differential information in other channels (for HL-LHC)
- Add colour singlet 2-light-2-heavy operators
- Add 4-heavy operators
- Check impact of quadratic terms

More operators, more observables, new probes

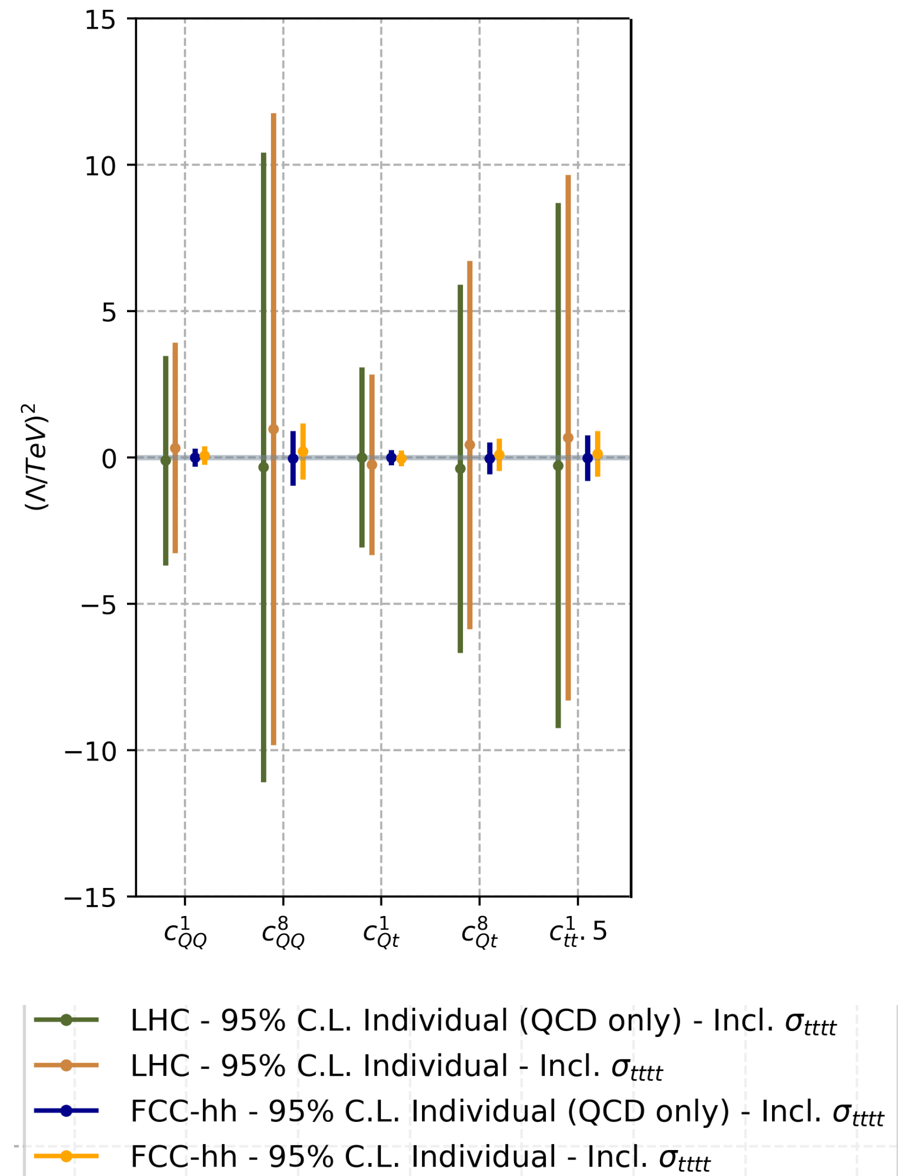
The future of 4tops

4-heavy

$\mathcal{O}^1_{QQ}$	cQQ1	$2[C^{(1)}_{qq}]^{3333} - \frac{2}{3}[C^{(3)}_{qq}]^{3333}$	$\mathcal{O}^8_{QQ}$	cQQ8	$8[C^{(3)}_{qq}]^{3333}$
$\mathcal{O}^1_{Qt}$	cQt1	$[C^{(1)}_{qu}]^{3333}$	$\mathcal{O}^8_{Qt}$	cQt8	$[C^{(8)}_{qu}]^{3333}$
$\mathcal{O}^1_{tt}$	ctt1	$[C^{(1)}_{uu}]^{3333}$			



Aoude, El Faham, Maltoni, EV arXiv:2208.04962

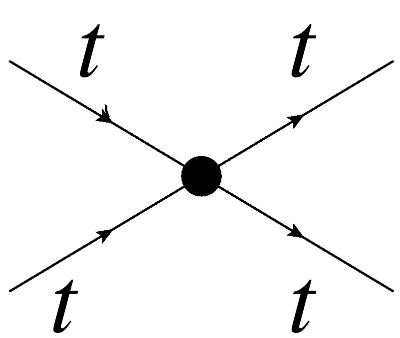


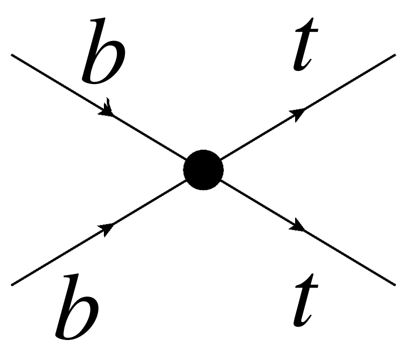
HL-LHC differential information helps
FCC needed to really pin down these coefficients

See Hesham's talk

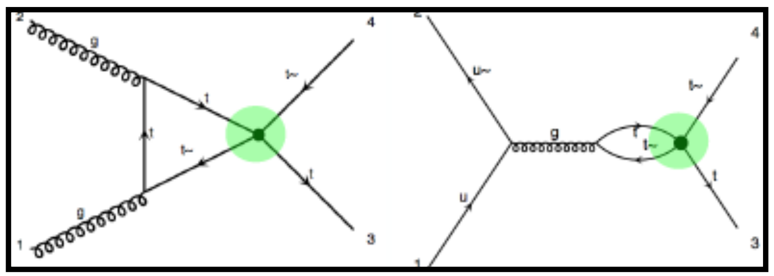
Anything else we can do?

4-heavy operators in top pair production



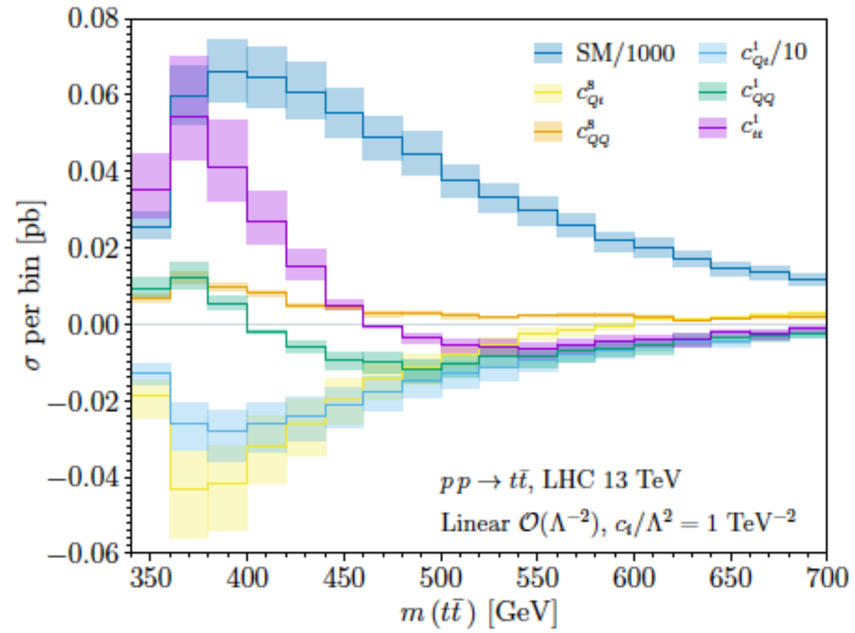


At NLO:



c^8_{QQ}	$0.0586^{+27\%}_{-25\%}$	$0.125^{+10\%}_{-11\%}$		$0.00628^{+13\%}_{-16\%}$	$0.0133^{+7\%}_{-5\%}$
c^8_{Qt}	$0.0583^{+27\%}_{-25\%}$	$-0.107(6)^{+40\%}_{-33\%}$		$0.00619^{+13\%}_{-16\%}$	$0.0118^{+8\%}_{-5\%}$
c^1_{QQ}	$[-0.11^{+15\%}_{-18\%}]$	$-0.039(4)^{+51\%}_{-33\%}$	$[-0.12^{+7\%}_{-5\%}]$	$0.0282^{+13\%}_{-16\%}$	$0.0651^{+5\%}_{-6\%}$
c^1_{Qt}	$[-0.068^{+16\%}_{-18\%}]$	$-2.51^{+29\%}_{-21\%}$	$[-0.12^{+3\%}_{-6\%}]$	$0.0283^{+13\%}_{-16\%}$	$0.066^{+5\%}_{-6\%}$
c^1_{tt}	×	$0.215^{+23\%}_{-18\%}$		×	×

Degrande, Durieux, Maltoni, Mimasu, EV, Zhang arXiv:2008.11743

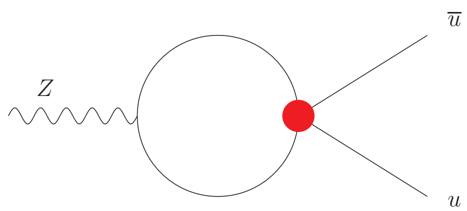


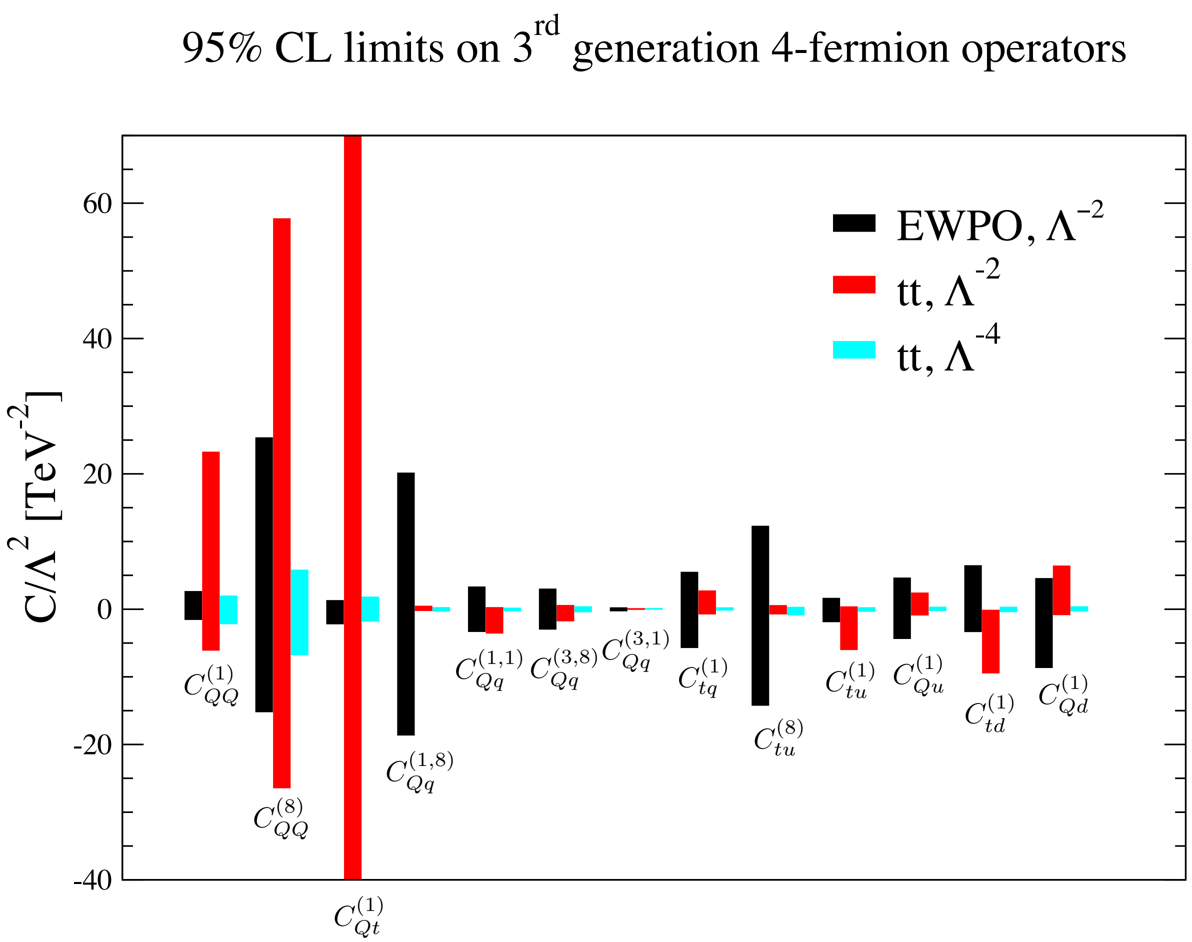
Loop-induced sensitivity

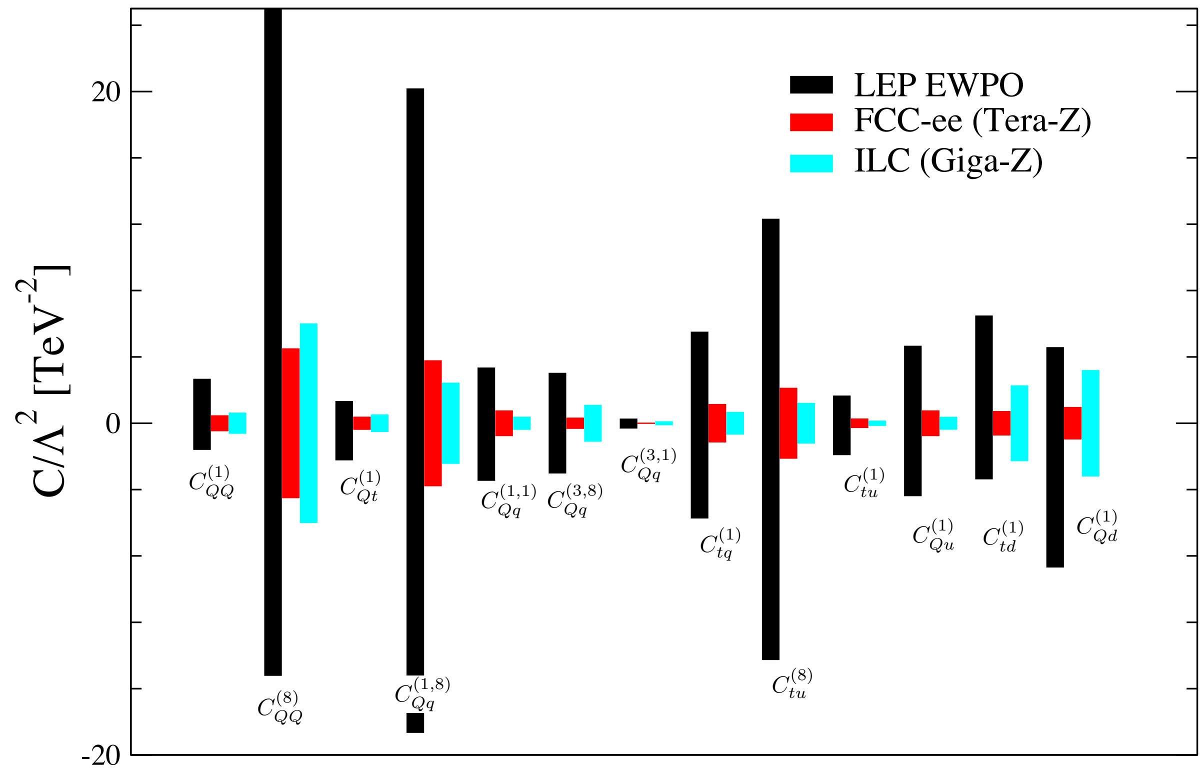
Complimentary information to ttbb and 4top production

One-loop probes (1)

4-heavy operators in EWPO



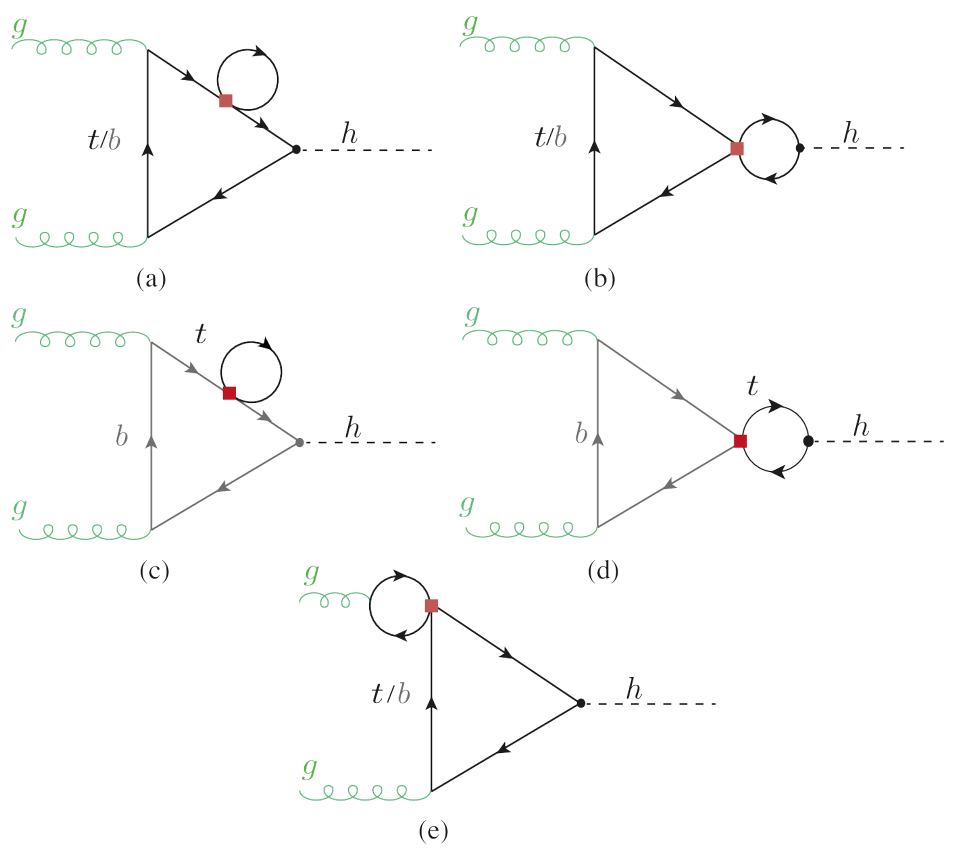




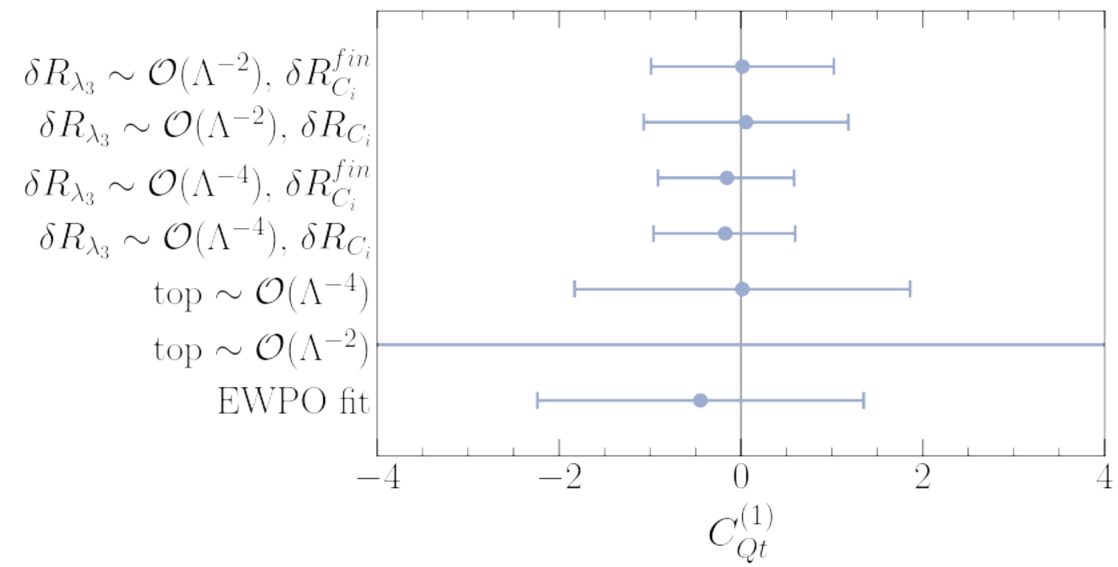
Dawson and Giardino arXiv: 2201.09887

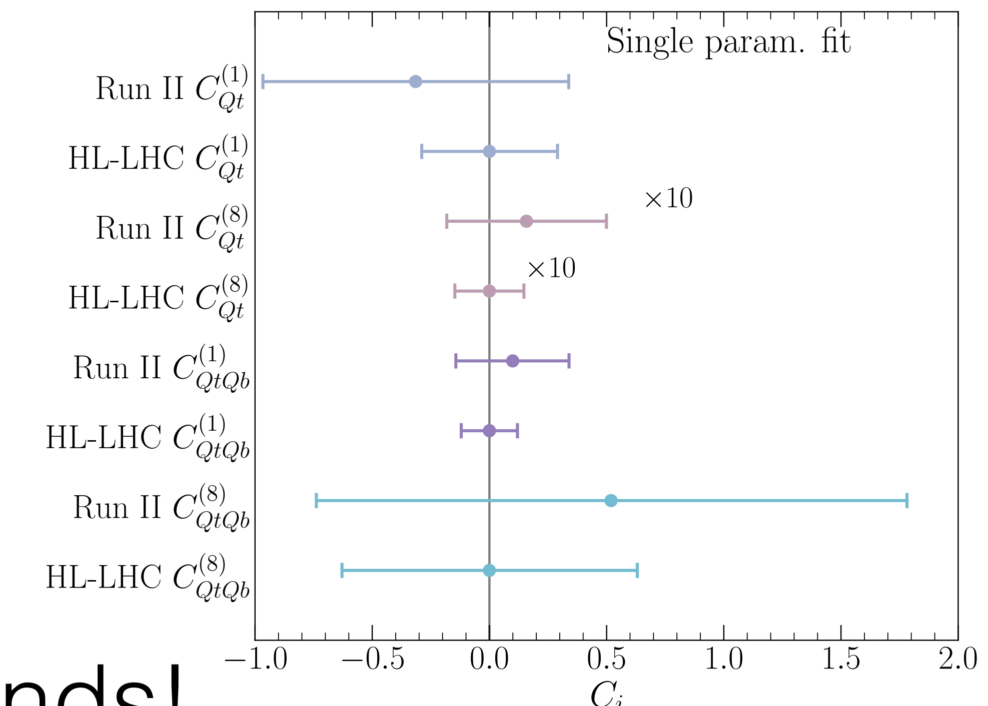
New loop-induced sensitivity
Competitive to 4top production

4-heavy operators in Higgs production



Alasfar, de Blas, Gröber arXiv:2202.02333





Again competitive with top fit bounds!

Conclusions

- HL-LHC can improve bounds on top operators due to extended kinematic reach and reduced uncertainties
- HL-LHC improves Wilson coefficients by a factor three
- Degeneracies between 4-fermion operators persist
- Lepton colliders can constrain top operators very well if they run above the threshold, in particular the 2-quark-2-lepton operators
- FCC-hh is expected to further improve 4-quark operator bounds which remain poorly constrained due to degeneracies
- One loop probes for 4-heavy operators can be a promising new direction

Thank you for your attention