Snowmass 2021- EF03 & EF04 WG meeting
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The Top sector in the Snowmass SMEFT fits

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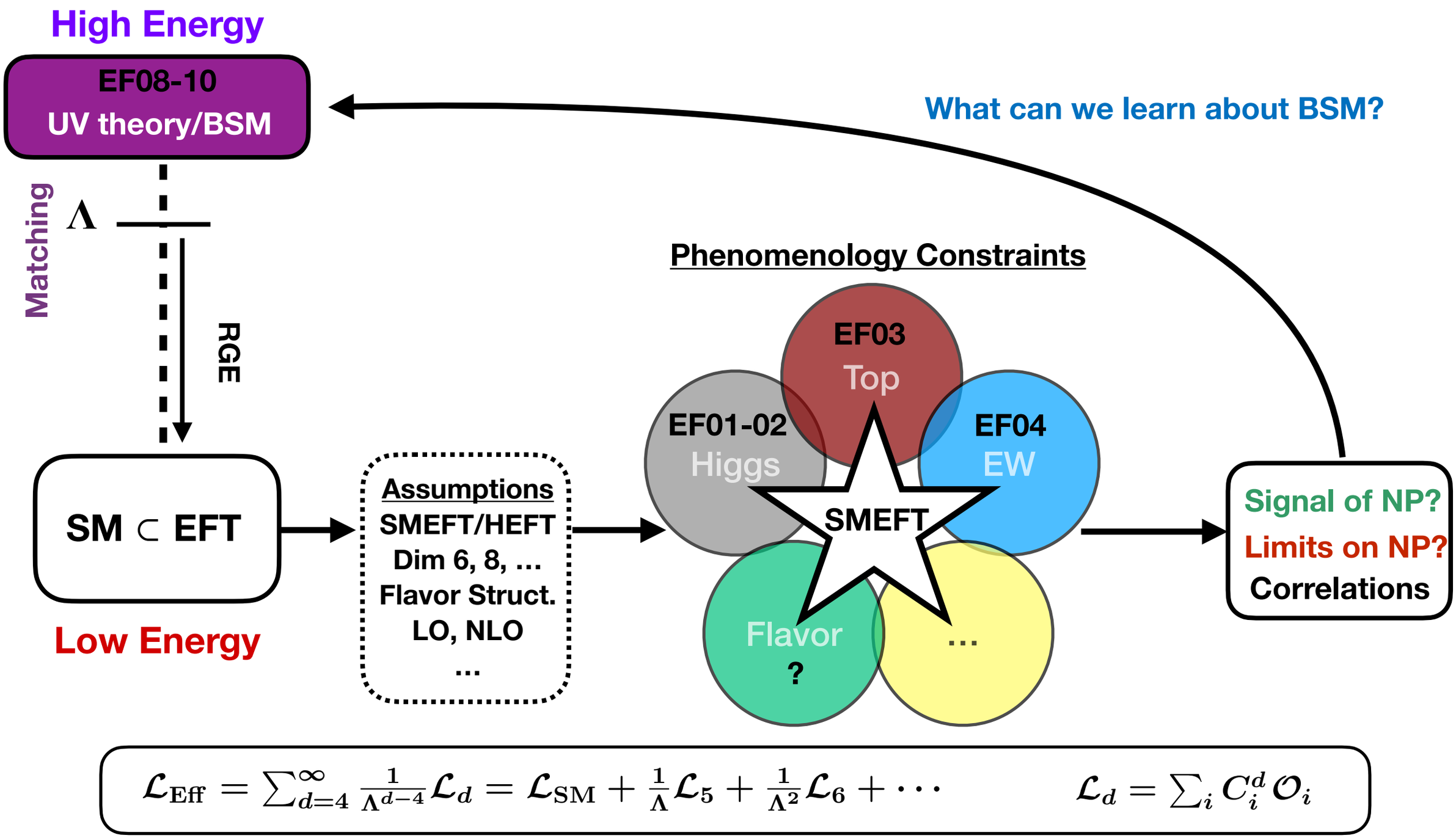
SMEFT studies

- **The Goal:** combine inputs from the different EF to obtain a global SMEFT fit which can be used to learn from BSM scenarios



$$\mathcal{L}_{\rm Eff} = \sum_{d=4}^{\infty} \frac{1}{\Lambda^{d-4}} \mathcal{L}_d = \mathcal{L}_{\rm SM} + \frac{1}{\Lambda}\mathcal{L}_5 + \frac{1}{\Lambda^2}\mathcal{L}_6 + \cdots \qquad \mathcal{L}_d = \sum_i C_i^d \mathcal{O}_i$$

SMEFT studies

- **The Goal:** combine inputs from the different EF to obtain a global SMEFT fit which can be used to learn from BSM scenarios, beyond the results presented at the European Strategy update 2020

Global SMEFT Fits at Future Colliders

A Snomwass 2021 Whitepaper

Jorge de Blas[a], Christophe Grojean[b], Jiayin Gu[c], Michael E. Peskin[d], and Junping Tian[e]

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Authors in the EFT studies of the main future collider projects

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TENTATIVE content table from first preliminary discussion in November

Contents

SMEFT studies

- **The Goal:** combine inputs from the different EF to obtain a global SMEFT fit which can be used to learn from BSM scenarios, beyond the results presented at the European Strategy update 2020

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This talk (Introduction)

SMEFT *fits*

Incorporating the sector of Top operators

SMEFT studies: ESU Inputs

- Inputs included in the fits. (Used **as provided** in the ESU input documents.)

Higgs

Rates (signal strength)

$$\mu \equiv \frac{\sigma \cdot \mathrm{BR}}{\sigma^{\mathrm{SM}} \cdot \mathrm{BR}^{\mathrm{SM}}}$$

(Inclusive) cross section

$$\sigma_{ZH} \equiv \sigma(e^+e^- \to ZH)$$

Only possible at lepton colliders

aTGC

$$\delta g_{1z}, \delta\kappa_\gamma, \lambda_z$$

EWPO

$$M_Z,\ \Gamma_Z,\ \Gamma_{Z\to f},\ A^f_{FB,LR},\ \cdots$$

$$M_W,\ \Gamma_W,\ \Gamma_{W\to f}$$

Z physics via Z-pole:

$$\sqrt{s} = M_Z:\quad e^+e^- \to Z \to X$$

or Rad. Return:

$$\sqrt{s} > M_Z:\quad e^+e^- \to \gamma Z \to \gamma X$$

	Higgs	aTGC	EWPO	Top EW
FCC-ee	Yes (μ, σ_{ZH}) (Complete with HL-LHC)	Yes (aTGC dom.)	Yes	Yes (365 GeV, Ztt)
ILC	Yes (μ, σ_{ZH}) (Complete with HL-LHC)	Yes (HE limit)	Yes (Rad. Return, Giga-Z)	Yes (500 GeV, Ztt)
CEPC	Yes (μ, σ_{ZH}) (Complete with HL-LHC)	Yes (aTGC dom)	Yes	No
CLIC	Yes (μ, σ_{ZH})	Yes (Full EFT parameterization)	Yes (Rad. Return, Giga-Z)	Yes
HE-LHC	Extrapolated from HL-LHC	N/A → LEP2	LEP/SLD + HL-LHC (M_W, $\sin^2\theta_w$)	-
FCC-hh	Yes (μ, BR_i/BR_j) Used in combination with FCCee/eh	From FCC-ee	From FCC-ee	-
LHeC	Yes (μ)	N/A → LEP2	LEP/SLD + HL-LHC (M_W, $\sin^2\theta_w$)	-
FCC-eh	Yes (μ) Used in combination with FCCee/hh	From FCC-ee	From FCC-ee + Zuu, Zdd	-

SMEFT studies: ESU Inputs

- Inputs included in the fits. (Used **as provided** in the ESU input documents.)

Higgs

Rates (signal strength)

$$\mu \equiv \frac{\sigma \cdot \mathrm{BR}}{\sigma^{\mathrm{SM}} \cdot \mathrm{BR}^{\mathrm{SM}}}$$

(Inclusive) cross section

$$\sigma_{ZH} \equiv \sigma(e^+e^- \to ZH)$$

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	Higgs	aTGC	EWPO	Top EW
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ILC	Yes (μ, σ_{ZH}) (Complete with HL-LHC)	Yes (HE limit)	Yes (Rad. Return, Giga-Z)	Yes (500 GeV, Ztt)
CEPC	Yes (μ, σ_{ZH}) (Complete with HL-LHC)	Yes (aTGC dom)	Yes	No
CLIC	Yes (μ, σ_{ZH})	Yes (Full EFT parameterization)	Yes (Rad. Return, Giga-Z)	Yes
HE-LHC	Extrapolated from HL-LHC	N/A → LEP2	LEP/SLD + HL-LHC (M_W, $\sin^2\theta_w$)	-
FCC-hh	Yes (μ, B… Used in cor… with FCC…			-
LHeC	Yes (μ)	N/A → LEP2	LEP/SLD + HL-LHC (M_W, $\sin^2\theta_w$)	-
FCC-eh	Yes (μ) Used in combination with FCCee/hh	From FCC-ee	From FCC-ee + Zuu, Zdd	-

Explored only superficially in ESU studies: *Ztt & ttH*

Operators in the Top quark sector

Warsaw basis

Operator	Notation	Operator	Notation
$\varepsilon_{abc} W_\mu^{a\,\nu} W_\nu^{b\,\rho} W_\rho^{c\,\mu}$	$\mathcal{O}_W$	$\varepsilon_{abc} \tilde{W}_\mu^{a\,\nu} W_\nu^{b\,\rho} W_\rho^{c\,\mu}$	$\mathcal{O}_{\tilde{W}}$
$f_{ABC} G_\mu^{A\,\nu} G_\nu^{B\,\rho} G_\rho^{C\,\mu}$	$\mathcal{O}_G$	$f_{ABC} \tilde{G}_\mu^{A\,\nu} G_\nu^{B\,\rho} G_\rho^{C\,\mu}$	$\mathcal{O}_{\tilde{G}}$
$\left(\phi^\dagger \phi\right)^3$	$\mathcal{O}_\phi$		
$\left(\phi^\dagger \phi\right) \Box \left(\phi^\dagger \phi\right)$	$\mathcal{O}_{\phi\Box}$	$\left(\phi^\dagger D_\mu \phi\right) \left(\left(D^\mu \phi\right)^\dagger \phi\right)$	$\mathcal{O}_{\phi D}$
$\left(\phi^\dagger \phi\right) \left(\bar{l}_L \phi e_R\right)$	$\mathcal{O}_{e\phi}$		
$\left(\phi^\dagger \phi\right) \left(\bar{q}_L \phi d_R\right)$	$\mathcal{O}_{d\phi}$	$\left(\phi^\dagger \phi\right) \left(\bar{q}_L \tilde{\phi} u_R\right)$	$\mathcal{O}_{u\phi}$
$\phi^\dagger \phi B_{\mu\nu} B^{\mu\nu}$	$\mathcal{O}_{\phi B}$	$\phi^\dagger \phi \tilde{B}_{\mu\nu} B^{\mu\nu}$	$\mathcal{O}_{\phi\tilde{B}}$
$\phi^\dagger \phi W_{\mu\nu}^a W^{a\,\mu\nu}$	$\mathcal{O}_{\phi W}$	$\phi^\dagger \phi \tilde{W}_{\mu\nu}^a W^{a\,\mu\nu}$	$\mathcal{O}_{\phi\tilde{W}}$
$\phi^\dagger \sigma_a \phi W_{\mu\nu}^a B^{\mu\nu}$	$\mathcal{O}_{\phi WB}$	$\phi^\dagger \sigma_a \phi \tilde{W}_{\mu\nu}^a B^{\mu\nu}$	$\mathcal{O}_{\phi\tilde{W}B}$
$\phi^\dagger \phi G_{\mu\nu}^A G^{A\,\mu\nu}$	$\mathcal{O}_{\phi G}$	$\phi^\dagger \phi \tilde{G}_{\mu\nu}^A G^{A\,\mu\nu}$	$\mathcal{O}_{\phi\tilde{G}}$
$\left(\bar{l}_L \sigma^{\mu\nu} e_R\right) \phi B_{\mu\nu}$	$\mathcal{O}_{eB}$	$\left(\bar{l}_L \sigma^{\mu\nu} e_R\right) \sigma^a \phi W_{\mu\nu}^a$	$\mathcal{O}_{eW}$
$\left(\bar{q}_L \sigma^{\mu\nu} u_R\right) \tilde{\phi} B_{\mu\nu}$	$\mathcal{O}_{uB}$	$\left(\bar{q}_L \sigma^{\mu\nu} u_R\right) \sigma^a \tilde{\phi} W_{\mu\nu}^a$	$\mathcal{O}_{uW}$
$\left(\bar{q}_L \sigma^{\mu\nu} d_R\right) \phi B_{\mu\nu}$	$\mathcal{O}_{dB}$	$\left(\bar{q}_L \sigma^{\mu\nu} d_R\right) \sigma^a \phi W_{\mu\nu}^a$	$\mathcal{O}_{dW}$
$\left(\bar{q}_L \sigma^{\mu\nu} T_A u_R\right) \tilde{\phi} G_{\mu\nu}^A$	$\mathcal{O}_{uG}$	$\left(\bar{q}_L \sigma^{\mu\nu} T_A d_R\right) \phi G_{\mu\nu}^A$	$\mathcal{O}_{dG}$
$\left(\phi^\dagger i \overleftrightarrow{D}_\mu \phi\right) \left(\bar{l}_L \gamma^\mu l_L\right)$	$\mathcal{O}_{\phi l}^{(1)}$	$\left(\phi^\dagger i \overleftrightarrow{D}_\mu^a \phi\right) \left(\bar{l}_L \gamma^\mu \sigma_a l_L\right)$	$\mathcal{O}_{\phi l}^{(3)}$
$\left(\phi^\dagger i \overleftrightarrow{D}_\mu \phi\right) \left(\bar{e}_R \gamma^\mu e_R\right)$	$\mathcal{O}_{\phi e}$		
$\left(\phi^\dagger i \overleftrightarrow{D}_\mu \phi\right) \left(\bar{q}_L \gamma^\mu q_L\right)$	$\mathcal{O}_{\phi q}^{(1)}$	$\left(\phi^\dagger i \overleftrightarrow{D}_\mu^a \phi\right) \left(\bar{q}_L \gamma^\mu \sigma_a q_L\right)$	$\mathcal{O}_{\phi q}^{(3)}$
$\left(\phi^\dagger i \overleftrightarrow{D}_\mu \phi\right) \left(\bar{u}_R \gamma^\mu u_R\right)$	$\mathcal{O}_{\phi u}$	$\left(\phi^\dagger i \overleftrightarrow{D}_\mu \phi\right) \left(\bar{d}_R \gamma^\mu d_R\right)$	$\mathcal{O}_{\phi d}$
$\left(\tilde{\phi}^\dagger i D_\mu \phi\right) \left(\bar{u}_R \gamma^\mu d_R\right)$	$\mathcal{O}_{\phi ud}$		

Operator	Notation	Operator	Notation
$\left(\bar{l}_L \gamma_\mu l_L\right) \left(\bar{l}_L \gamma^\mu l_L\right)$	$\mathcal{O}_{ll}$		
$\left(\bar{q}_L \gamma_\mu q_L\right) \left(\bar{q}_L \gamma^\mu q_L\right)$	$\mathcal{O}_{qq}^{(1)}$	$\left(\bar{q}_L \gamma_\mu \sigma_a q_L\right) \left(\bar{q}_L \gamma^\mu \sigma_a q_L\right)$	$\mathcal{O}_{qq}^{(3)}$
$\left(\bar{l}_L \gamma_\mu l_L\right) \left(\bar{q}_L \gamma^\mu q_L\right)$	$\mathcal{O}_{lq}^{(1)}$	$\left(\bar{l}_L \gamma_\mu \sigma_a l_L\right) \left(\bar{q}_L \gamma^\mu \sigma_a q_L\right)$	$\mathcal{O}_{lq}^{(3)}$
$\left(\bar{e}_R \gamma_\mu e_R\right) \left(\bar{e}_R \gamma^\mu e_R\right)$	$\mathcal{O}_{ee}$		
$\left(\bar{u}_R \gamma_\mu u_R\right) \left(\bar{u}_R \gamma^\mu u_R\right)$	$\mathcal{O}_{uu}$	$\left(\bar{d}_R \gamma_\mu d_R\right) \left(\bar{d}_R \gamma^\mu d_R\right)$	$\mathcal{O}_{dd}$
$\left(\bar{u}_R \gamma_\mu u_R\right) \left(\bar{d}_R \gamma^\mu d_R\right)$	$\mathcal{O}_{ud}^{(1)}$	$\left(\bar{u}_R \gamma_\mu T_A u_R\right) \left(\bar{d}_R \gamma^\mu T_A d_R\right)$	$\mathcal{O}_{ud}^{(8)}$
$\left(\bar{e}_R \gamma_\mu e_R\right) \left(\bar{u}_R \gamma^\mu u_R\right)$	$\mathcal{O}_{eu}$	$\left(\bar{e}_R \gamma_\mu e_R\right) \left(\bar{d}_R \gamma^\mu d_R\right)$	$\mathcal{O}_{ed}$
$\left(\bar{l}_L \gamma_\mu l_L\right) \left(\bar{e}_R \gamma^\mu e_R\right)$	$\mathcal{O}_{le}$	$\left(\bar{q}_L \gamma_\mu q_L\right) \left(\bar{e}_R \gamma^\mu e_R\right)$	$\mathcal{O}_{qe}$
$\left(\bar{l}_L \gamma_\mu l_L\right) \left(\bar{u}_R \gamma^\mu u_R\right)$	$\mathcal{O}_{lu}$	$\left(\bar{l}_L \gamma_\mu l_L\right) \left(\bar{d}_R \gamma^\mu d_R\right)$	$\mathcal{O}_{ld}$
$\left(\bar{q}_L \gamma_\mu q_L\right) \left(\bar{u}_R \gamma^\mu u_R\right)$	$\mathcal{O}_{qu}^{(1)}$	$\left(\bar{q}_L \gamma_\mu T_A q_L\right) \left(\bar{u}_R \gamma^\mu T_A u_R\right)$	$\mathcal{O}_{qu}^{(8)}$
$\left(\bar{q}_L \gamma_\mu q_L\right) \left(\bar{d}_R \gamma^\mu d_R\right)$	$\mathcal{O}_{qd}^{(1)}$	$\left(\bar{q}_L \gamma_\mu T_A q_L\right) \left(\bar{d}_R \gamma^\mu T_A d_R\right)$	$\mathcal{O}_{qd}^{(8)}$
$\left(\bar{l}_L e_R\right) \left(\bar{d}_R q_L\right)$	$\mathcal{O}_{ledq}$		
$\left(\bar{q}_L u_R\right) i\sigma_2 \left(\bar{q}_L d_R\right)^{\mathrm{T}}$	$\mathcal{O}_{quqd}^{(1)}$	$\left(\bar{q}_L T_A u_R\right) i\sigma_2 \left(\bar{q}_L T_A d_R\right)^{\mathrm{T}}$	$\mathcal{O}_{quqd}^{(8)}$
$\left(\bar{l}_L e_R\right) i\sigma_2 \left(\bar{q}_L u_R\right)^{\mathrm{T}}$	$\mathcal{O}_{lequ}^{(1)}$	$\left(\bar{l}_L \sigma_{\mu\nu} e_R\right) i\sigma_2 \left(\bar{q}_L \sigma^{\mu\nu} u_R\right)^{\mathrm{T}}$	$\mathcal{O}_{lequ}^{(3)}$

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$f_{ABC} G_\mu^{A\,\nu} G_\nu^{B\,\rho} G_\rho^{C\,\mu}$	$\mathcal{O}_G$	$f_{ABC} \tilde{G}_\mu^{A\,\nu} G_\nu^{B\,\rho} G_\rho^{C\,\mu}$	$\mathcal{O}_{\tilde{G}}$
$(\phi^\dagger \phi)^3$	$\mathcal{O}_\phi$		
$(\phi^\dagger \phi) \Box (\phi^\dagger \phi)$	$\mathcal{O}_{\phi\Box}$	$(\phi^\dagger D_\mu \phi) ((D^\mu \phi)^\dagger \phi)$	$\mathcal{O}_{\phi D}$
$(\phi^\dagger \phi) (\bar{l}_L \phi e_R)$	$\mathcal{O}_{e\phi}$		
$(\phi^\dagger \phi) (\bar{q}_L \phi d_R)$	$\mathcal{O}_{d\phi}$	$(\phi^\dagger \phi) (\bar{q}_L \tilde{\phi} u_R)$	$\mathcal{O}_{u\phi}$
$\phi^\dagger \phi B_{\mu\nu} B^{\mu\nu}$	$\mathcal{O}_{\phi B}$	$\phi^\dagger \phi \tilde{B}_{\mu\nu} B^{\mu\nu}$	$\mathcal{O}_{\phi \tilde{B}}$
$\phi^\dagger \phi W_{\mu\nu}^a W^{a\,\mu\nu}$	$\mathcal{O}_{\phi W}$	$\phi^\dagger \phi \tilde{W}_{\mu\nu}^a W^{a\,\mu\nu}$	$\mathcal{O}_{\phi \tilde{W}}$
$\phi^\dagger \sigma_a \phi W_{\mu\nu}^a B^{\mu\nu}$	$\mathcal{O}_{\phi WB}$	$\phi^\dagger \sigma_a \phi \tilde{W}_{\mu\nu}^a B^{\mu\nu}$	$\mathcal{O}_{\phi \tilde{W} B}$
$\phi^\dagger \phi G_{\mu\nu}^A G^{A\,\mu\nu}$	$\mathcal{O}_{\phi G}$	$\phi^\dagger \phi \tilde{G}_{\mu\nu}^A G^{A\,\mu\nu}$	$\mathcal{O}_{\phi \tilde{G}}$
$(\bar{l}_L \sigma^{\mu\nu} e_R) \phi B_{\mu\nu}$	$\mathcal{O}_{eB}$	$(\bar{l}_L \sigma^{\mu\nu} e_R) \sigma^a \phi W_{\mu\nu}^a$	$\mathcal{O}_{eW}$
$(\bar{q}_L \sigma^{\mu\nu} u_R) \tilde{\phi} B_{\mu\nu}$	$\mathcal{O}_{uB}$	$(\bar{q}_L \sigma^{\mu\nu} u_R) \sigma^a \tilde{\phi} W_{\mu\nu}^a$	$\mathcal{O}_{uW}$
$(\bar{q}_L \sigma^{\mu\nu} d_R) \phi B_{\mu\nu}$	$\mathcal{O}_{dB}$	$(\bar{q}_L \sigma^{\mu\nu} d_R) \sigma^a \phi W_{\mu\nu}^a$	$\mathcal{O}_{dW}$
$(\bar{q}_L \sigma^{\mu\nu} T_A u_R) \tilde{\phi} G_{\mu\nu}^A$	$\mathcal{O}_{uG}$	$(\bar{q}_L \sigma^{\mu\nu} T_A d_R) \phi G_{\mu\nu}^A$	$\mathcal{O}_{dG}$
$(\phi^\dagger i \overleftrightarrow{D}_\mu \phi) (\bar{l}_L \gamma^\mu l_L)$	$\mathcal{O}_{\phi l}^{(1)}$	$(\phi^\dagger i \overleftrightarrow{D}_\mu^a \phi) (\bar{l}_L \gamma^\mu \sigma_a l_L)$	$\mathcal{O}_{\phi l}^{(3)}$
$(\phi^\dagger i \overleftrightarrow{D}_\mu \phi) (\bar{e}_R \gamma^\mu e_R)$	$\mathcal{O}_{\phi e}$		
$(\phi^\dagger i \overleftrightarrow{D}_\mu \phi) (\bar{q}_L \gamma^\mu q_L)$	$\mathcal{O}_{\phi q}^{(1)}$	$(\phi^\dagger i \overleftrightarrow{D}_\mu^a \phi) (\bar{q}_L \gamma^\mu \sigma_a q_L)$	$\mathcal{O}_{\phi q}^{(3)}$
$(\phi^\dagger i \overleftrightarrow{D}_\mu \phi) (\bar{u}_R \gamma^\mu u_R)$	$\mathcal{O}_{\phi u}$	$(\phi^\dagger i \overleftrightarrow{D}_\mu \phi) (\bar{d}_R \gamma^\mu d_R)$	$\mathcal{O}_{\phi d}$
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$(\bar{l}_L \gamma_\mu l_L) (\bar{q}_L \gamma^\mu q_L)$	$\mathcal{O}_{lq}^{(1)}$	$(\bar{l}_L \gamma_\mu \sigma_a l_L) (\bar{q}_L \gamma^\mu \sigma_a q_L)$	$\mathcal{O}_{lq}^{(3)}$
$(\bar{e}_R \gamma_\mu e_R) (\bar{e}_R \gamma^\mu e_R)$	$\mathcal{O}_{ee}$		
$(\bar{u}_R \gamma_\mu u_R) (\bar{u}_R \gamma^\mu u_R)$	$\mathcal{O}_{uu}$	$(\bar{d}_R \gamma_\mu d_R) (\bar{d}_R \gamma^\mu d_R)$	$\mathcal{O}_{dd}$
$(\bar{u}_R \gamma_\mu u_R) (\bar{d}_R \gamma^\mu d_R)$	$\mathcal{O}_{ud}^{(1)}$	$(\bar{u}_R \gamma_\mu T_A u_R) (\bar{d}_R \gamma^\mu T_A d_R)$	$\mathcal{O}_{ud}^{(8)}$
$(\bar{e}_R \gamma_\mu e_R) (\bar{u}_R \gamma^\mu u_R)$	$\mathcal{O}_{eu}$	$(\bar{e}_R \gamma_\mu e_R) (\bar{d}_R \gamma^\mu d_R)$	$\mathcal{O}_{ed}$
$(\bar{l}_L \gamma_\mu l_L) (\bar{e}_R \gamma^\mu e_R)$	$\mathcal{O}_{le}$	$(\bar{q}_L \gamma_\mu q_L) (\bar{e}_R \gamma^\mu e_R)$	$\mathcal{O}_{qe}$
$(\bar{l}_L \gamma_\mu l_L) (\bar{u}_R \gamma^\mu u_R)$	$\mathcal{O}_{lu}$	$(\bar{l}_L \gamma_\mu l_L) (\bar{d}_R \gamma^\mu d_R)$	$\mathcal{O}_{ld}$
$(\bar{q}_L \gamma_\mu q_L) (\bar{u}_R \gamma^\mu u_R)$	$\mathcal{O}_{qu}^{(1)}$	$(\bar{q}_L \gamma_\mu T_A q_L) (\bar{u}_R \gamma^\mu T_A u_R)$	$\mathcal{O}_{qu}^{(8)}$
$(\bar{q}_L \gamma_\mu q_L) (\bar{d}_R \gamma^\mu d_R)$	$\mathcal{O}_{qd}^{(1)}$	$(\bar{q}_L \gamma_\mu T_A q_L) (\bar{d}_R \gamma^\mu T_A d_R)$	$\mathcal{O}_{qd}^{(8)}$
$(\bar{l}_L e_R) (\bar{d}_R q_L)$	$\mathcal{O}_{ledq}$		
$(\bar{q}_L u_R)\, i\sigma_2\, (\bar{q}_L d_R)^{\mathrm{T}}$	$\mathcal{O}_{quqd}^{(1)}$	$(\bar{q}_L T_A u_R)\, i\sigma_2\, (\bar{q}_L T_A d_R)^{\mathrm{T}}$	$\mathcal{O}_{quqd}^{(8)}$
$(\bar{l}_L e_R)\, i\sigma_2\, (\bar{q}_L u_R)^{\mathrm{T}}$	$\mathcal{O}_{lequ}^{(1)}$	$(\bar{l}_L \sigma_{\mu\nu} e_R)\, i\sigma_2\, (\bar{q}_L \sigma^{\mu\nu} u_R)^{\mathrm{T}}$	$\mathcal{O}_{lequ}^{(3)}$

Dim 6 Top operators interfering with SM at LO in 2→2, 2→3 Top production (*tt*, *tt*+*X*)

Operators in the Top quark sector

Warsaw basis

Operator	Notation	Operator	Notation
$\varepsilon_{abc} W_\mu^{a\,\nu} W_\nu^{b\,\rho} W_\rho^{c\,\mu}$	$\mathcal{O}_W$	$\varepsilon_{abc} \tilde{W}_\mu^{a\,\nu} W_\nu^{b\,\rho} W_\rho^{c\,\mu}$	$\mathcal{O}_{\tilde{W}}$
$f_{ABC} G_\mu^{A\,\nu} G_\nu^{B\,\rho} G_\rho^{C\,\mu}$	$\mathcal{O}_G$	$f_{ABC} \tilde{G}_\mu^{A\,\nu} G_\nu^{B\,\rho} G_\rho^{C\,\mu}$	$\mathcal{O}_{\tilde{G}}$
$(\phi^\dagger \phi)^3$	$\mathcal{O}_\phi$		
$(\phi^\dagger \phi) \Box (\phi^\dagger \phi)$	$\mathcal{O}_{\phi\Box}$	$(\phi^\dagger D_\mu \phi) ((D^\mu \phi)^\dagger \phi)$	$\mathcal{O}_{\phi D}$
$(\phi^\dagger \phi) (\bar{l}_L \phi e_R)$	$\mathcal{O}_{e\phi}$		
$(\phi^\dagger \phi) (\bar{q}_L \phi d_R)$	$\mathcal{O}_{d\phi}$		
$\phi^\dagger \phi B_{\mu\nu} B^{\mu\nu}$	$\mathcal{O}_{\phi B}$	$\phi^\dagger \phi \tilde{B}_{\mu\nu} B^{\mu\nu}$	$\mathcal{O}_{\phi\tilde{B}}$
$\phi^\dagger \phi W_{\mu\nu}^a W^{a\,\mu\nu}$	$\mathcal{O}_{\phi W}$	$\phi^\dagger \phi \tilde{W}_{\mu\nu}^a W^{a\,\mu\nu}$	$\mathcal{O}_{\phi\tilde{W}}$
$\phi^\dagger \sigma_a \phi W_{\mu\nu}^a B^{\mu\nu}$	$\mathcal{O}_{\phi WB}$	$\phi^\dagger \sigma_a \phi \tilde{W}_{\mu\nu}^a B^{\mu\nu}$	$\mathcal{O}_{\phi\tilde{W}B}$
$\phi^\dagger \phi G_{\mu\nu}^A G^{A\,\mu\nu}$	$\mathcal{O}_{\phi G}$	$\phi^\dagger \phi \tilde{G}_{\mu\nu}^A G^{A\,\mu\nu}$	$\mathcal{O}_{\phi\tilde{G}}$
$(\bar{l}_L \sigma^{\mu\nu} e_R) \phi B_{\mu\nu}$	$\mathcal{O}_{eB}$	$(\bar{l}_L \sigma^{\mu\nu} e_R) \sigma^a \phi W_{\mu\nu}^a$	$\mathcal{O}_{eW}$
$(\bar{q}_L \sigma^{\mu\nu} u_R) \tilde{\phi} B_{\mu\nu}$	$\mathcal{O}_{uB}$	$(\bar{q}_L \sigma^{\mu\nu} u_R) \sigma^a \tilde{\phi} W_{\mu\nu}^a$	$\mathcal{O}_{uW}$
$(\bar{q}_L \sigma^{\mu\nu} d_R) \phi B_{\mu\nu}$	$\mathcal{O}_{dB}$	$(\bar{q}_L \sigma^{\mu\nu} d_R) \sigma^a \phi W_{\mu\nu}^a$	$\mathcal{O}_{dW}$
$(\bar{q}_L \sigma^{\mu\nu} T_A u_R) \tilde{\phi} G_{\mu\nu}^A$	$\mathcal{O}_{uG}$	$(\bar{q}_L \sigma^{\mu\nu} T_A d_R) \phi G_{\mu\nu}^A$	$\mathcal{O}_{dG}$
$(\phi^\dagger i \overleftrightarrow{D}_\mu \phi) (\bar{l}_L \gamma^\mu l_L)$	$\mathcal{O}_{\phi l}^{(1)}$	$(\phi^\dagger i \overleftrightarrow{D}_\mu^a \phi) (\bar{l}_L \gamma^\mu \sigma_a l_L)$	$\mathcal{O}_{\phi l}^{(3)}$
$(\phi^\dagger i \overleftrightarrow{D}_\mu \phi) (\bar{e}_R \gamma^\mu e_R)$	$\mathcal{O}_{\phi e}$		
$(\phi^\dagger i \overleftrightarrow{D}_\mu \phi) (\bar{q}_L \gamma^\mu q_L)$	$\mathcal{O}_{\phi q}^{(1)}$	$(\phi^\dagger i \overleftrightarrow{D}_\mu^a \phi) (\bar{q}_L \gamma^\mu \sigma_a q_L)$	$\mathcal{O}_{\phi q}^{(3)}$
$(\phi^\dagger i \overleftrightarrow{D}_\mu \phi) (\bar{u}_R \gamma^\mu u_R)$	$\mathcal{O}_{\phi u}$	$(\phi^\dagger i \overleftrightarrow{D}_\mu \phi) (\bar{d}_R \gamma^\mu d_R)$	$\mathcal{O}_{\phi d}$
$(\tilde{\phi}^\dagger i \overleftrightarrow{D}_\mu \phi) (\bar{u}_R \gamma^\mu d_R)$	$\mathcal{O}_{\phi ud}$		

ttH: $(\phi^\dagger \phi) (\bar{q}_L \tilde{\phi} u_R)$ — $\mathcal{O}_{u\phi}$

Ztt: $(\phi^\dagger i \overleftrightarrow{D}_\mu \phi) (\bar{q}_L \gamma^\mu q_L)$, $(\phi^\dagger i \overleftrightarrow{D}_\mu^a \phi) (\bar{q}_L \gamma^\mu \sigma_a q_L)$, $(\phi^\dagger i \overleftrightarrow{D}_\mu \phi) (\bar{u}_R \gamma^\mu u_R)$

Due to limited input, only these operators covered in ESU studies

Operator	Notation	Operator	Notation
$(\bar{l}_L \gamma_\mu l_L) (\bar{l}_L \gamma^\mu l_L)$	$\mathcal{O}_{ll}$		
$(\bar{q}_L \gamma_\mu q_L) (\bar{q}_L \gamma^\mu q_L)$	$\mathcal{O}_{qq}^{(1)}$	$(\bar{q}_L \gamma_\mu \sigma_a q_L) (\bar{q}_L \gamma^\mu \sigma_a q_L)$	$\mathcal{O}_{qq}^{(3)}$
$(\bar{l}_L \gamma_\mu l_L) (\bar{q}_L \gamma^\mu q_L)$	$\mathcal{O}_{lq}^{(1)}$	$(\bar{l}_L \gamma_\mu \sigma_a l_L) (\bar{q}_L \gamma^\mu \sigma_a q_L)$	$\mathcal{O}_{lq}^{(3)}$
$(\bar{e}_R \gamma_\mu e_R) (\bar{e}_R \gamma^\mu e_R)$	$\mathcal{O}_{ee}$		
$(\bar{u}_R \gamma_\mu u_R) (\bar{u}_R \gamma^\mu u_R)$	$\mathcal{O}_{uu}$	$(\bar{d}_R \gamma_\mu d_R) (\bar{d}_R \gamma^\mu d_R)$	$\mathcal{O}_{dd}$
$(\bar{u}_R \gamma_\mu u_R) (\bar{d}_R \gamma^\mu d_R)$	$\mathcal{O}_{ud}^{(1)}$	$(\bar{u}_R \gamma_\mu T_A u_R) (\bar{d}_R \gamma^\mu T_A d_R)$	$\mathcal{O}_{ud}^{(8)}$
$(\bar{e}_R \gamma_\mu e_R) (\bar{u}_R \gamma^\mu u_R)$	$\mathcal{O}_{eu}$	$(\bar{e}_R \gamma_\mu e_R) (\bar{d}_R \gamma^\mu d_R)$	$\mathcal{O}_{ed}$
$(\bar{l}_L \gamma_\mu l_L) (\bar{e}_R \gamma^\mu e_R)$	$\mathcal{O}_{le}$	$(\bar{q}_L \gamma_\mu q_L) (\bar{e}_R \gamma^\mu e_R)$	$\mathcal{O}_{qe}$
$(\bar{l}_L \gamma_\mu l_L) (\bar{u}_R \gamma^\mu u_R)$	$\mathcal{O}_{lu}$	$(\bar{l}_L \gamma_\mu l_L) (\bar{d}_R \gamma^\mu d_R)$	$\mathcal{O}_{ld}$
$(\bar{q}_L \gamma_\mu q_L) (\bar{u}_R \gamma^\mu u_R)$	$\mathcal{O}_{qu}^{(1)}$	$(\bar{q}_L \gamma_\mu T_A q_L) (\bar{u}_R \gamma^\mu T_A u_R)$	$\mathcal{O}_{qu}^{(8)}$
$(\bar{q}_L \gamma_\mu q_L) (\bar{d}_R \gamma^\mu d_R)$	$\mathcal{O}_{qd}^{(1)}$	$(\bar{q}_L \gamma_\mu T_A q_L) (\bar{d}_R \gamma^\mu T_A d_R)$	$\mathcal{O}_{qd}^{(8)}$
$(\bar{l}_L e_R) (\bar{d}_R q_L)$	$\mathcal{O}_{ledq}$		
$(\bar{q}_L u_R)\, i\sigma_2\, (\bar{q}_L d_R)^{\mathrm{T}}$	$\mathcal{O}_{quqd}^{(1)}$	$(\bar{q}_L T_A u_R)\, i\sigma_2\, (\bar{q}_L T_A d_R)^{\mathrm{T}}$	$\mathcal{O}_{quqd}^{(8)}$
$(\bar{l}_L e_R)\, i\sigma_2\, (\bar{q}_L u_R)^{\mathrm{T}}$	$\mathcal{O}_{lequ}^{(1)}$	$(\bar{l}_L \sigma_{\mu\nu} e_R)\, i\sigma_2\, (\bar{q}_L \sigma^{\mu\nu} u_R)^{\mathrm{T}}$	$\mathcal{O}_{lequ}^{(3)}$

Dim 6 Top operators interfering with SM at LO in 2→2, 2→3 Top production (*tt*, *tt*+*X*)

But Top processes, e.g. *tt*, or *ttH* receive contributions from the other operators in this list:
4 Fermion operators or Dipoles

⇒ Non-Global analysis

Operators in the Top quark sector

Warsaw basis

Operator	Notation	Operator	Notation
$\varepsilon_{abc} W_\mu^{a\nu} W_\nu^{b\rho} W_\rho^{c\mu}$	$\mathcal{O}_W$	$\varepsilon_{abc} \tilde{W}_\mu^{a\nu} W_\nu^{b\rho} W_\rho^{c\mu}$	$\mathcal{O}_{\tilde{W}}$
$f_{ABC} G_\mu^{A\nu} G_\nu^{B\rho} G_\rho^{C\mu}$	$\mathcal{O}_G$	$f_{ABC} \tilde{G}_\mu^{A\nu} G_\nu^{B\rho} G_\rho^{C\mu}$	$\mathcal{O}_{\tilde{G}}$
$\left(\phi^\dagger \phi\right)^3$	$\mathcal{O}_\phi$		
$\left(\phi^\dagger \phi\right) \Box \left(\phi^\dagger \phi\right)$	$\mathcal{O}_{\phi\Box}$	$\left(\phi^\dagger D_\mu \phi\right) \left((D^\mu \phi)^\dagger \phi\right)$	$\mathcal{O}_{\phi D}$
$\left(\phi^\dagger \phi\right) \left(\bar{l}_L \phi e_R\right)$	$\mathcal{O}_{e\phi}$		
$\left(\phi^\dagger \phi\right) \left(\bar{q}_L \phi d_R\right)$	$\mathcal{O}_{d\phi}$	$\left(\phi^\dagger \phi\right) \left(\bar{q}_L \tilde{\phi} u_R\right)$	$\mathcal{O}_{u\phi}$
$\phi^\dagger \phi B_{\mu\nu} B^{\mu\nu}$	$\mathcal{O}_{\phi B}$	$\phi^\dagger \phi \tilde{B}_{\mu\nu} B^{\mu\nu}$	$\mathcal{O}_{\phi\tilde{B}}$
$\phi^\dagger \phi W_{\mu\nu}^a W^{a\,\mu\nu}$	$\mathcal{O}_{\phi W}$	$\phi^\dagger \phi \tilde{W}_{\mu\nu}^a W^{a\,\mu\nu}$	$\mathcal{O}_{\phi\tilde{W}}$
$\phi^\dagger \sigma_a \phi W_{\mu\nu}^a B^{\mu\nu}$	$\mathcal{O}_{\phi WB}$	$\phi^\dagger \sigma_a \phi \tilde{W}_{\mu\nu}^a B^{\mu\nu}$	$\mathcal{O}_{\phi\tilde{W}B}$
$\phi^\dagger \phi G_{\mu\nu}^A G^{A\,\mu\nu}$	$\mathcal{O}_{\phi G}$	$\phi^\dagger \phi \tilde{G}_{\mu\nu}^A G^{A\,\mu\nu}$	$\mathcal{O}_{\phi\tilde{G}}$
$\left(\bar{l}_L \sigma^{\mu\nu} e_R\right) \phi B_{\mu\nu}$	$\mathcal{O}_{eB}$	$\left(\bar{l}_L \sigma^{\mu\nu} e_R\right) \sigma^a \phi W_{\mu\nu}^a$	$\mathcal{O}_{eW}$
$\left(\bar{q}_L \sigma^{\mu\nu} u_R\right) \tilde{\phi} B_{\mu\nu}$	$\mathcal{O}_{uB}$	$\left(\bar{q}_L \sigma^{\mu\nu} u_R\right) \sigma^a \tilde{\phi} W_{\mu\nu}^a$	$\mathcal{O}_{uW}$
$\left(\bar{q}_L \sigma^{\mu\nu} d_R\right) \phi B_{\mu\nu}$	$\mathcal{O}_{dB}$	$\left(\bar{q}_L \sigma^{\mu\nu} d_R\right) \sigma^a \phi W_{\mu\nu}^a$	$\mathcal{O}_{dW}$
$\left(\bar{q}_L \sigma^{\mu\nu} T_A u_R\right) \phi G_{\mu\nu}^A$	$\mathcal{O}_{uG}$	$\left(\bar{q}_L \sigma^{\mu\nu} T_A d_R\right) \phi G_{\mu\nu}^A$	$\mathcal{O}_{dG}$
$\left(\phi^\dagger i \overleftrightarrow{D}_\mu \phi\right) \left(\bar{l}_L \gamma^\mu l_L\right)$	$\mathcal{O}_{\phi l}^{(1)}$	$\left(\phi^\dagger i \overleftrightarrow{D}_\mu^a \phi\right) \left(\bar{l}_L \gamma^\mu \sigma_a l_L\right)$	$\mathcal{O}_{\phi l}^{(3)}$
$\left(\phi^\dagger i \overleftrightarrow{D}_\mu \phi\right) \left(\bar{e}_R \gamma^\mu e_R\right)$	$\mathcal{O}_{\phi e}$		
$\left(\phi^\dagger i \overleftrightarrow{D}_\mu \phi\right) \left(\bar{q}_L \gamma^\mu q_L\right)$	$\mathcal{O}_{\phi q}^{(1)}$	$\left(\phi^\dagger i \overleftrightarrow{D}_\mu^a \phi\right) \left(\bar{q}_L \gamma^\mu \sigma_a q_L\right)$	$\mathcal{O}_{\phi q}^{(3)}$
$\left(\phi^\dagger i \overleftrightarrow{D}_\mu \phi\right) \left(\bar{u}_R \gamma^\mu u_R\right)$	$\mathcal{O}_{\phi u}$	$\left(\phi^\dagger i \overleftrightarrow{D}_\mu \phi\right) \left(\bar{d}_R \gamma^\mu d_R\right)$	$\mathcal{O}_{\phi d}$
$\left(\tilde{\phi}^\dagger i D_\mu \phi\right) \left(\bar{u}_R \gamma^\mu d_R\right)$	$\mathcal{O}_{\phi ud}$		

Operator	Notation	Operator	Notation
$\left(\bar{l}_L \gamma_\mu l_L\right) \left(\bar{l}_L \gamma^\mu l_L\right)$	$\mathcal{O}_{ll}$		
$\left(\bar{q}_L \gamma_\mu q_L\right) \left(\bar{q}_L \gamma^\mu q_L\right)$	$\mathcal{O}_{qq}^{(1)}$	$\left(\bar{q}_L \gamma_\mu \sigma_a q_L\right) \left(\bar{q}_L \gamma^\mu \sigma_a q_L\right)$	$\mathcal{O}_{qq}^{(3)}$
$\left(\bar{l}_L \gamma_\mu l_L\right) \left(\bar{q}_L \gamma^\mu q_L\right)$	$\mathcal{O}_{lq}^{(1)}$	$\left(\bar{l}_L \gamma_\mu \sigma_a l_L\right) \left(\bar{q}_L \gamma^\mu \sigma_a q_L\right)$	$\mathcal{O}_{lq}^{(3)}$
$\left(\bar{e}_R \gamma_\mu e_R\right) \left(\bar{e}_R \gamma^\mu e_R\right)$	$\mathcal{O}_{ee}$		
$\left(\bar{u}_R \gamma_\mu u_R\right) \left(\bar{u}_R \gamma^\mu u_R\right)$	$\mathcal{O}_{uu}$	$\left(\bar{d}_R \gamma_\mu d_R\right) \left(\bar{d}_R \gamma^\mu d_R\right)$	$\mathcal{O}_{dd}$
$\left(\bar{u}_R \gamma_\mu u_R\right) \left(\bar{d}_R \gamma^\mu d_R\right)$	$\mathcal{O}_{ud}^{(1)}$	$\left(\bar{u}_R \gamma_\mu T_A u_R\right) \left(\bar{d}_R \gamma^\mu T_A d_R\right)$	$\mathcal{O}_{ud}^{(8)}$
$\left(\bar{e}_R \gamma_\mu e_R\right) \left(\bar{u}_R \gamma^\mu u_R\right)$	$\mathcal{O}_{eu}$	$\left(\bar{e}_R \gamma_\mu e_R\right) \left(\bar{d}_R \gamma^\mu d_R\right)$	$\mathcal{O}_{ed}$
$\left(\bar{l}_L \gamma_\mu l_L\right) \left(\bar{e}_R \gamma^\mu e_R\right)$	$\mathcal{O}_{le}$	$\left(\bar{q}_L \gamma_\mu q_L\right) \left(\bar{e}_R \gamma^\mu e_R\right)$	$\mathcal{O}_{qe}$
$\left(\bar{l}_L \gamma_\mu l_L\right) \left(\bar{u}_R \gamma^\mu u_R\right)$	$\mathcal{O}_{lu}$	$\left(\bar{l}_L \gamma_\mu l_L\right) \left(\bar{d}_R \gamma^\mu d_R\right)$	$\mathcal{O}_{ld}$
$\left(q_L \gamma_\mu q_L\right) \left(u_R \gamma^\mu u_R\right)$	$\mathcal{O}_{qu}^{(1)}$	$\left(q_L \gamma_\mu T_A q_L\right) \left(u_R \gamma^\mu T_A u_R\right)$	$\mathcal{O}_{qu}^{(8)}$
$\left(\bar{q}_L \gamma_\mu q_L\right) \left(\bar{d}_R \gamma^\mu d_R\right)$	$\mathcal{O}_{qd}^{(1)}$	$\left(\bar{q}_L \gamma_\mu T_A q_L\right) \left(\bar{d}_R \gamma^\mu T_A d_R\right)$	$\mathcal{O}_{qd}^{(8)}$
$\left(\bar{l}_L e_R\right) \left(\bar{d}_R q_L\right)$	$\mathcal{O}_{ledq}$		
$\left(\bar{q}_L u_R\right) i\sigma_2 \left(\bar{q}_L d_R\right)^{\mathrm{T}}$	$\mathcal{O}_{quad}^{(1)}$	$\left(\bar{q}_L T_A u_R\right) i\sigma_2 \left(\bar{q}_L T_A d_R\right)^{\mathrm{T}}$	$\mathcal{O}_{quad}^{(8)}$
$\left(\bar{l}_L e_R\right) i\sigma_2 \left(\bar{q}_L u_R\right)^{\mathrm{T}}$	$\mathcal{O}_{lequ}^{(1)}$	$\left(\bar{l}_L \sigma_{\mu\nu} e_R\right) i\sigma_2 \left(\bar{q}_L \sigma^{\mu\nu} u_R\right)^{\mathrm{T}}$	$\mathcal{O}_{lequ}^{(3)}$

4-Fermion Top operators interfering with SM at in 2→2, 2→3 Top production (*tt*, *tt*+*X*)

Hadron colliders

Operators in the Top quark sector

Warsaw basis

Operator	Notation	Operator	Notation
$\varepsilon_{abc} W_\mu^{a\nu} W_\nu^{b\rho} W_\rho^{c\mu}$	$\mathcal{O}_W$	$\varepsilon_{abc} \tilde{W}_\mu^{a\nu} W_\nu^{b\rho} W_\rho^{c\mu}$	$\mathcal{O}_{\tilde{W}}$
$f_{ABC} G_\mu^{A\nu} G_\nu^{B\rho} G_\rho^{C\mu}$	$\mathcal{O}_G$	$f_{ABC} \tilde{G}_\mu^{A\nu} G_\nu^{B\rho} G_\rho^{C\mu}$	$\mathcal{O}_{\tilde{G}}$
$\left(\phi^\dagger \phi\right)^3$	$\mathcal{O}_\phi$		
$\left(\phi^\dagger \phi\right) \Box \left(\phi^\dagger \phi\right)$	$\mathcal{O}_{\phi\Box}$	$\left(\phi^\dagger D_\mu \phi\right) \left(\left(D^\mu \phi\right)^\dagger \phi\right)$	$\mathcal{O}_{\phi D}$
$\left(\phi^\dagger \phi\right) \left(\bar{l}_L \phi e_R\right)$	$\mathcal{O}_{e\phi}$		
$\left(\phi^\dagger \phi\right) \left(\bar{q}_L \phi d_R\right)$	$\mathcal{O}_{d\phi}$	$\left(\phi^\dagger \phi\right) \left(\bar{q}_L \tilde{\phi} u_R\right)$	$\mathcal{O}_{u\phi}$
$\phi^\dagger \phi B_{\mu\nu} B^{\mu\nu}$	$\mathcal{O}_{\phi B}$	$\phi^\dagger \phi \tilde{B}_{\mu\nu} B^{\mu\nu}$	$\mathcal{O}_{\phi\tilde{B}}$
$\phi^\dagger \phi W_{\mu\nu}^a W^{a\mu\nu}$	$\mathcal{O}_{\phi W}$	$\phi^\dagger \phi \tilde{W}_{\mu\nu}^a W^{a\mu\nu}$	$\mathcal{O}_{\phi\tilde{W}}$
$\phi^\dagger \sigma_a \phi W_{\mu\nu}^a B^{\mu\nu}$	$\mathcal{O}_{\phi WB}$	$\phi^\dagger \sigma_a \phi \tilde{W}_{\mu\nu}^a B^{\mu\nu}$	$\mathcal{O}_{\phi\tilde{W}B}$
$\phi^\dagger \phi G_{\mu\nu}^A G^{A\mu\nu}$	$\mathcal{O}_{\phi G}$	$\phi^\dagger \phi \tilde{G}_{\mu\nu}^A G^{A\mu\nu}$	$\mathcal{O}_{\phi\tilde{G}}$
$\left(\bar{l}_L \sigma^{\mu\nu} e_R\right) \phi B_{\mu\nu}$	$\mathcal{O}_{eB}$	$\left(\bar{l}_L \sigma^{\mu\nu} e_R\right) \sigma^a \phi W_{\mu\nu}^a$	$\mathcal{O}_{eW}$
$\left(\bar{q}_L \sigma^{\mu\nu} u_R\right) \tilde{\phi} B_{\mu\nu}$	$\mathcal{O}_{uB}$	$\left(\bar{q}_L \sigma^{\mu\nu} u_R\right) \sigma^a \tilde{\phi} W_{\mu\nu}^a$	$\mathcal{O}_{uW}$
$\left(\bar{q}_L \sigma^{\mu\nu} d_R\right) \phi B_{\mu\nu}$	$\mathcal{O}_{dB}$	$\left(\bar{q}_L \sigma^{\mu\nu} d_R\right) \sigma^a \phi W_{\mu\nu}^a$	$\mathcal{O}_{dW}$
$\left(\bar{q}_L \sigma^{\mu\nu} T_A u_R\right) \phi G_{\mu\nu}^A$	$\mathcal{O}_{uG}$	$\left(\bar{q}_L \sigma^{\mu\nu} T_A d_R\right) \phi G_{\mu\nu}^A$	$\mathcal{O}_{dG}$
$\left(\phi^\dagger i \overleftrightarrow{D}_\mu \phi\right) \left(\bar{l}_L \gamma^\mu l_L\right)$	$\mathcal{O}_{\phi l}^{(1)}$	$\left(\phi^\dagger i \overleftrightarrow{D}_\mu^a \phi\right) \left(\bar{l}_L \gamma^\mu \sigma_a l_L\right)$	$\mathcal{O}_{\phi l}^{(3)}$
$\left(\phi^\dagger i \overleftrightarrow{D}_\mu \phi\right) \left(\bar{e}_R \gamma^\mu e_R\right)$	$\mathcal{O}_{\phi e}$		
$\left(\phi^\dagger i \overleftrightarrow{D}_\mu \phi\right) \left(\bar{q}_L \gamma^\mu q_L\right)$	$\mathcal{O}_{\phi q}^{(1)}$	$\left(\phi^\dagger i \overleftrightarrow{D}_\mu^a \phi\right) \left(\bar{q}_L \gamma^\mu \sigma_a q_L\right)$	$\mathcal{O}_{\phi q}^{(3)}$
$\left(\phi^\dagger i \overleftrightarrow{D}_\mu \phi\right) \left(\bar{u}_R \gamma^\mu u_R\right)$	$\mathcal{O}_{\phi u}$	$\left(\phi^\dagger i \overleftrightarrow{D}_\mu \phi\right) \left(\bar{d}_R \gamma^\mu d_R\right)$	$\mathcal{O}_{\phi d}$
$\left(\tilde{\phi}^\dagger i D_\mu \phi\right) \left(\bar{u}_R \gamma^\mu d_R\right)$	$\mathcal{O}_{\phi ud}$		

Operator	Notation	Operator	Notation
$\left(\bar{l}_L \gamma_\mu l_L\right) \left(\bar{l}_L \gamma^\mu l_L\right)$	$\mathcal{O}_{ll}$		
$\left(\bar{q}_L \gamma_\mu q_L\right) \left(\bar{q}_L \gamma^\mu q_L\right)$	$\mathcal{O}_{qq}^{(1)}$	$\left(\bar{q}_L \gamma_\mu \sigma_a q_L\right) \left(\bar{q}_L \gamma^\mu \sigma_a q_L\right)$	$\mathcal{O}_{qq}^{(3)}$
$\left(l_L \gamma_\mu l_L\right) \left(\bar{q}_L \gamma^\mu q_L\right)$	$\mathcal{O}_{lq}^{(1)}$	$\left(l_L \gamma_\mu \sigma_a l_L\right) \left(\bar{q}_L \gamma^\mu \sigma_a q_L\right)$	$\mathcal{O}_{lq}^{(3)}$
$\left(\bar{e}_R \gamma_\mu e_R\right) \left(\bar{e}_R \gamma^\mu e_R\right)$	$\mathcal{O}_{ee}$		
$\left(\bar{u}_R \gamma_\mu u_R\right) \left(\bar{u}_R \gamma^\mu u_R\right)$	$\mathcal{O}_{uu}$	$\left(\bar{d}_R \gamma_\mu d_R\right) \left(\bar{d}_R \gamma^\mu d_R\right)$	$\mathcal{O}_{dd}$
$\left(\bar{u}_R \gamma_\mu u_R\right) \left(\bar{d}_R \gamma^\mu d_R\right)$	$\mathcal{O}_{ud}^{(1)}$	$\left(\bar{u}_R \gamma_\mu T_A u_R\right) \left(\bar{d}_R \gamma^\mu T_A d_R\right)$	$\mathcal{O}_{ud}^{(8)}$
$\left(\bar{e}_R \gamma_\mu e_R\right) \left(\bar{u}_R \gamma^\mu u_R\right)$	$\mathcal{O}_{eu}$	$\left(\bar{e}_R \gamma_\mu e_R\right) \left(\bar{d}_R \gamma^\mu d_R\right)$	$\mathcal{O}_{ed}$
$\left(\bar{l}_L \gamma_\mu l_L\right) \left(\bar{e}_R \gamma^\mu e_R\right)$	$\mathcal{O}_{le}$	$\left(\bar{q}_L \gamma_\mu q_L\right) \left(\bar{e}_R \gamma^\mu e_R\right)$	$\mathcal{O}_{qe}$
$\left(\bar{l}_L \gamma_\mu l_L\right) \left(\bar{u}_R \gamma^\mu u_R\right)$	$\mathcal{O}_{lu}$	$\left(\bar{l}_L \gamma_\mu l_L\right) \left(\bar{d}_R \gamma^\mu d_R\right)$	$\mathcal{O}_{ld}$
$\left(q_L \gamma_\mu q_L\right) \left(u_R \gamma^\mu u_R\right)$	$\mathcal{O}_{qu}^{(1)}$	$\left(q_L \gamma_\mu T_A q_L\right) \left(u_R \gamma^\mu T_A u_R\right)$	$\mathcal{O}_{qu}^{(8)}$
$\left(\bar{q}_L \gamma_\mu q_L\right) \left(\bar{d}_R \gamma^\mu d_R\right)$	$\mathcal{O}_{qd}^{(1)}$	$\left(\bar{q}_L \gamma_\mu T_A q_L\right) \left(\bar{d}_R \gamma^\mu T_A d_R\right)$	$\mathcal{O}_{qd}^{(8)}$
$\left(\bar{l}_L e_R\right) \left(\bar{d}_R q_L\right)$	$\mathcal{O}_{ledq}$		
$\left(\bar{q}_L u_R\right) i\sigma_2 \left(\bar{q}_L d_R\right)^T$	$\mathcal{O}_{quqd}^{(1)}$	$\left(\bar{q}_L T_A u_R\right) i\sigma_2 \left(\bar{q}_L T_A d_R\right)^T$	$\mathcal{O}_{quqd}^{(8)}$
$\left(l_L e_R\right) i\sigma_2 \left(\bar{q}_L u_R\right)^T$	$\mathcal{O}_{lequ}^{(1)}$	$\left(l_L \sigma_{\mu\nu} e_R\right) i\sigma_2 \left(\bar{q}_L \sigma^{\mu\nu} u_R\right)^T$	$\mathcal{O}_{lequ}^{(3)}$

4-Fermion Top operators interfering with SM at in 2→2, 2→3 Top production (*tt*, *tt*+*X*)

Hadron colliders

Lepton colliders

Lepton colliders, via polarization (non-interfering)

Operators in the Top quark sector

Warsaw basis

Operator	Notation	Operator	Notation
$\varepsilon_{abc} W_\mu^{a\nu} W_\nu^{b\rho} W_\rho^{c\mu}$	$\mathcal{O}_W$	$\varepsilon_{abc} \tilde{W}_\mu^{a\nu} W_\nu^{b\rho} W_\rho^{c\mu}$	$\mathcal{O}_{\tilde{W}}$
$f_{ABC} G_\mu^{A\nu} G_\nu^{B\rho} G_\rho^{C\mu}$	$\mathcal{O}_G$	$f_{ABC} \tilde{G}_\mu^{A\nu} G_\nu^{B\rho} G_\rho^{C\mu}$	$\mathcal{O}_{\tilde{G}}$
$\left(\phi^\dagger \phi\right)^3$	$\mathcal{O}_\phi$		
$\left(\phi^\dagger \phi\right) \Box \left(\phi^\dagger \phi\right)$	$\mathcal{O}_{\phi\Box}$	$\left(\phi^\dagger D_\mu \phi\right) \left(\left(D^\mu \phi\right)^\dagger \phi\right)$	$\mathcal{O}_{\phi D}$
$\left(\phi^\dagger \phi\right) \left(\bar{l}_L \phi e_R\right)$	$\mathcal{O}_{e\phi}$		
$\left(\phi^\dagger \phi\right) \left(\bar{q}_L \phi d_R\right)$	$\mathcal{O}_{d\phi}$	$\left(\phi^\dagger \phi\right) \left(\bar{q}_L \tilde{\phi} u_R\right)$	$\mathcal{O}_{u\phi}$
$\phi^\dagger \phi B_{\mu\nu} B^{\mu\nu}$	$\mathcal{O}_{\phi B}$	$\phi^\dagger \phi \tilde{B}_{\mu\nu} B^{\mu\nu}$	$\mathcal{O}_{\phi\tilde{B}}$
$\phi^\dagger \phi W_{\mu\nu}^a W^{a\mu\nu}$	$\mathcal{O}_{\phi W}$	$\phi^\dagger \phi \tilde{W}_{\mu\nu}^a W^{a\mu\nu}$	$\mathcal{O}_{\phi\tilde{W}}$
$\phi^\dagger \sigma_a \phi W_{\mu\nu}^a B^{\mu\nu}$	$\mathcal{O}_{\phi WB}$	$\phi^\dagger \sigma_a \phi \tilde{W}_{\mu\nu}^a B^{\mu\nu}$	$\mathcal{O}_{\phi\tilde{W}B}$
$\phi^\dagger \phi G_{\mu\nu}^A G^{A\mu\nu}$	$\mathcal{O}_{\phi G}$	$\phi^\dagger \phi \tilde{G}_{\mu\nu}^A G^{A\mu\nu}$	$\mathcal{O}_{\phi\tilde{G}}$
$\left(\bar{l}_L \sigma^{\mu\nu} e_R\right) \phi B_{\mu\nu}$	$\mathcal{O}_{eB}$	$\left(\bar{l}_L \sigma^{\mu\nu} e_R\right) \sigma^a \phi W_{\mu\nu}^a$	$\mathcal{O}_{eW}$
$\left(\bar{q}_L \sigma^{\mu\nu} u_R\right) \tilde{\phi} B_{\mu\nu}$	$\mathcal{O}_{uB}$	$\left(\bar{q}_L \sigma^{\mu\nu} u_R\right) \sigma^a \tilde{\phi} W_{\mu\nu}^a$	$\mathcal{O}_{uW}$
$\left(\bar{q}_L \sigma^{\mu\nu} d_R\right) \phi B_{\mu\nu}$	$\mathcal{O}_{dB}$	$\left(\bar{q}_L \sigma^{\mu\nu} d_R\right) \sigma^a \phi W_{\mu\nu}^a$	$\mathcal{O}_{dW}$
$\left(\bar{q}_L \sigma^{\mu\nu} T_A u_R\right) \tilde{\phi} G_{\mu\nu}^A$	$\mathcal{O}_{uG}$	$\left(\bar{q}_L \sigma^{\mu\nu} T_A d_R\right) \phi G_{\mu\nu}^A$	$\mathcal{O}_{dG}$
$\left(\phi^\dagger i \overleftrightarrow{D}_\mu \phi\right) \left(\bar{l}_L \gamma^\mu l_L\right)$	$\mathcal{O}_{\phi l}^{(1)}$	$\left(\phi^\dagger i \overleftrightarrow{D}_\mu^a \phi\right) \left(\bar{l}_L \gamma^\mu \sigma_a l_L\right)$	$\mathcal{O}_{\phi l}^{(3)}$
$\left(\phi^\dagger i \overleftrightarrow{D}_\mu \phi\right) \left(\bar{e}_R \gamma^\mu e_R\right)$	$\mathcal{O}_{\phi e}$		
$\left(\phi^\dagger i \overleftrightarrow{D}_\mu \phi\right) \left(\bar{q}_L \gamma^\mu q_L\right)$	$\mathcal{O}_{\phi q}^{(1)}$	$\left(\phi^\dagger i \overleftrightarrow{D}_\mu^a \phi\right) \left(\bar{q}_L \gamma^\mu \sigma_a q_L\right)$	$\mathcal{O}_{\phi q}^{(3)}$
$\left(\phi^\dagger i \overleftrightarrow{D}_\mu \phi\right) \left(\bar{u}_R \gamma^\mu u_R\right)$	$\mathcal{O}_{\phi u}$	$\left(\phi^\dagger i \overleftrightarrow{D}_\mu \phi\right) \left(\bar{d}_R \gamma^\mu d_R\right)$	$\mathcal{O}_{\phi d}$
$\left(\tilde{\phi}^\dagger i D_\mu \phi\right) \left(\bar{u}_R \gamma^\mu d_R\right)$	$\mathcal{O}_{\phi ud}$		

Operator	Notation	Operator	Notation
$\left(\bar{l}_L \gamma_\mu l_L\right) \left(\bar{l}_L \gamma^\mu l_L\right)$	$\mathcal{O}_{ll}$		
$\left(\bar{q}_L \gamma_\mu q_L\right) \left(\bar{q}_L \gamma^\mu q_L\right)$	$\mathcal{O}_{qq}^{(1)}$	$\left(\bar{q}_L \gamma_\mu \sigma_a q_L\right) \left(\bar{q}_L \gamma^\mu \sigma_a q_L\right)$	$\mathcal{O}_{qq}^{(3)}$
$\left(l_L \gamma_\mu l_L\right) \left(\bar{q}_L \gamma^\mu q_L\right)$	$\mathcal{O}_{lq}^{(1)}$	$\left(l_L \gamma_\mu \sigma_a l_L\right) \left(\bar{q}_L \gamma^\mu \sigma_a q_L\right)$	$\mathcal{O}_{lq}^{(3)}$
$\left(\bar{e}_R \gamma_\mu e_R\right) \left(\bar{e}_R \gamma^\mu e_R\right)$	$\mathcal{O}_{ee}$		
$\left(\bar{u}_R \gamma_\mu u_R\right) \left(\bar{u}_R \gamma^\mu u_R\right)$	$\mathcal{O}_{uu}$	$\left(\bar{d}_R \gamma_\mu d_R\right) \left(\bar{d}_R \gamma^\mu d_R\right)$	$\mathcal{O}_{dd}$
$\left(\bar{u}_R \gamma_\mu u_R\right) \left(\bar{d}_R \gamma^\mu d_R\right)$	$\mathcal{O}_{ud}^{(1)}$	$\left(\bar{u}_R \gamma_\mu T_A u_R\right) \left(\bar{d}_R \gamma^\mu T_A d_R\right)$	$\mathcal{O}_{ud}^{(8)}$
$\left(\bar{e}_R \gamma_\mu e_R\right) \left(\bar{u}_R \gamma^\mu u_R\right)$	$\mathcal{O}_{eu}$	$\left(\bar{e}_R \gamma_\mu e_R\right) \left(\bar{d}_R \gamma^\mu d_R\right)$	$\mathcal{O}_{ed}$
$\left(\bar{l}_L \gamma_\mu l_L\right) \left(\bar{e}_R \gamma^\mu e_R\right)$	$\mathcal{O}_{le}$	$\left(\bar{q}_L \gamma_\mu q_L\right) \left(\bar{e}_R \gamma^\mu e_R\right)$	$\mathcal{O}_{qe}$
$\left(\bar{l}_L \gamma_\mu l_L\right) \left(\bar{u}_R \gamma^\mu u_R\right)$	$\mathcal{O}_{lu}$	$\left(\bar{q}_L \gamma_\mu q_L\right) \left(\bar{d}_R \gamma^\mu d_R\right)$	$\mathcal{O}_{ld}$
$\left(q_L \gamma_\mu q_L\right) \left(u_R \gamma^\mu u_R\right)$	$\mathcal{O}_{qu}^{(1)}$	$\left(q_L \gamma_\mu T_A q_L\right) \left(u_R \gamma^\mu T_A u_R\right)$	$\mathcal{O}_{qu}^{(8)}$
$\left(\bar{q}_L \gamma_\mu q_L\right) \left(\bar{d}_R \gamma^\mu d_R\right)$	$\mathcal{O}_{qd}^{(1)}$	$\left(\bar{q}_L \gamma_\mu T_A q_L\right) \left(\bar{d}_R \gamma^\mu T_A d_R\right)$	$\mathcal{O}_{qd}^{(8)}$
$\left(\bar{l}_L e_R\right) \left(\bar{d}_R q_L\right)$	$\mathcal{O}_{ledq}$		
$\left(\bar{q}_L u_R\right) i\sigma_2 \left(\bar{q}_L d_R\right)^T$	$\mathcal{O}_{quad}^{(1)}$	$\left(\bar{q}_L T_A u_R\right) i\sigma_2 \left(\bar{q}_L T_A d_R\right)^T$	$\mathcal{O}_{quad}^{(8)}$
$\left(l_L e_R\right) i\sigma_2 \left(\bar{q}_L u_R\right)^T$	$\mathcal{O}_{lequ}^{(1)}$	$\left(l_L \sigma_{\mu\nu} e_R\right) i\sigma_2 \left(\bar{q}_L \sigma^{\mu\nu} u_R\right)^T$	$\mathcal{O}_{lequ}^{(3)}$

4-Fermion Top operators interfering with SM at in 2→2, 2→3 Top production (*tt*, *tt*+*X*)

Hadron colliders

Lepton colliders

Lepton colliders, via polarization (non-interfering)

Global EW/H + Top fit: Top adds large number of operators + Flavor (separate Top from light quarks) ⇒ Flavor assumptions?

Operators in the Top quark sector

Flavor assumptions: Separating Top effects

$$\mathcal{G}_F = SU(3)_q \times SU(3)_u \times SU(3)_d \times SU(3)_l \times SU(3)_e \times U(1)^5$$

MFV ansatz for the quark sector

$$SU(3)_q \times SU(3)_u \times SU(3)_d \longrightarrow SU(2)_q \times SU(2)_u \times SU(2)_d$$

Expansion of the quark bilinear coefficients

$$\begin{aligned}
\bar{q}_i q_j &: \quad a_1 1 + a_2 Y_u Y_u^\dagger + a_3 Y_d Y_d^\dagger + \dots \\
\bar{u}_i u_j &: \quad b_1 1 + b_2 Y_u Y_u^\dagger + \dots \\
\bar{d}_i d_j &: \quad c_1 1 + c_2 Y_d Y_d^\dagger + \dots \\
\bar{u}_i d_j &: \quad d_1 Y_u Y_d^\dagger + \dots \\
\bar{q}_i u_j &: \quad e_1 Y_u + e_2 Y_u Y_u^\dagger Y_u + e_3 Y_d Y_d^\dagger Y_u + \dots \\
\bar{q}_i d_j &: \quad e_1 Y_d + e_2 Y_d Y_d^\dagger Y_d + f_3 Y_u Y_u^\dagger Y_d + \dots
\end{aligned}$$

$$V_{\rm CKM} \approx 1$$

$$Y_u \approx \mathrm{diag}(0, 0, y_t)$$

$$Y_d \approx \mathrm{diag}(0, 0, y_b)$$

arXiv:1802.07237v1 [hep-ph]

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arXiv:1802.07237v1 [hep-ph]

Bilinears allowed

Light quarks: $\bar{q}_i q_i,\ \bar{u}_i u_i,\ \bar{d}_i d_i$

Top/Bottom: $\bar{q}_3 q_3,\ \bar{t}t,\ \bar{b}b,\ \bar{t}b,\ \bar{q}_3 t,\ \bar{q}_3 b$

Simplifies # of operators entering in Top processes, e.g. Four-fermion

Bilinears forbidden

Light quarks RH CC: $\bar{u}d,\ \bar{d}u$

Light quarks-chirality flipping: $\bar{q}u,\ \bar{q}d$

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\bar{q}_i u_j &: \quad e_1 Y_u + e_2 Y_u Y_u^\dagger Y_u + e_3 Y_d Y_d^\dagger Y_u + \dots \\
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$\mathcal{O}_{u\phi,22}$ **forbidden**

$H \to c\bar{c}$

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Light quarks-chirality flipping: $\bar{q}u,\ \bar{q}d$

$\mathcal{O}_{u\phi,22}$ **forbidden** $H \to c\bar{c}$

Use $SU(2)_{q+u+d}$ **?**

Operators in the Top quark sector

Flavor assumptions: Separating Top effects

MFV ansatz for the quark sector

$$SU(3)_q \times SU(3)_u \times SU(3)_d \longrightarrow SU(2)_q \times SU(2)_u \times SU(2)_d$$

Flavor diagonally in the lepton sector

$$SU(3)_l \times SU(3)_e \longrightarrow [U(1)_{l+e}]^3$$

Fermionic operators with impact in *tt*, *tt*+X processes

2 Fermions

$(\phi^\dagger\phi)\left(\bar{q}_L\tilde{\phi}u_R\right)$ **ttH: 1**

$(\bar{q}_L\sigma^{\mu\nu}u_R)\,\tilde{\phi}B_{\mu\nu}$
$(\bar{q}_L\sigma^{\mu\nu}u_R)\,\sigma^a\tilde{\phi}W^a_{\mu\nu}$
$(\bar{q}_L\sigma^{\mu\nu}T_Au_R)\,\tilde{\phi}G^A_{\mu\nu}$ **Dipoles: 3**

$\ominus$ $(\phi^\dagger i\overleftrightarrow{D}_\mu\phi)\,(\bar{q}_L\gamma^\mu q_L)$
$(\phi^\dagger i\overleftrightarrow{D}^a_\mu\phi)\,(\bar{q}_L\gamma^\mu\sigma_a q_L)$
$(\phi^\dagger i\overleftrightarrow{D}_\mu\phi)\,(\bar{u}_R\gamma^\mu u_R)$
$(\phi^\dagger i\overleftrightarrow{D}_\mu\phi)\,(\bar{d}_R\gamma^\mu d_R)$ **EW/H + Q:**
2-Top: 2
2-light (Had. coll.): 4

$\ominus$ $(\phi^\dagger i\overleftrightarrow{D}_\mu\phi)\,(\bar{l}_L\gamma^\mu l_L)$
$(\phi^\dagger i\overleftrightarrow{D}^a_\mu\phi)\,(\bar{l}_L\gamma^\mu\sigma_a l_L)$ **EW/H + e: 2**
(Lepton colliders)
$(\phi^\dagger i\overleftrightarrow{D}_\mu\phi)\,(\bar{e}_R\gamma^\mu e_R)$ **(Strong constr. from EWPO)**

4 Fermions

Hadron colliders

$(\bar{q}_L\gamma_\mu q_L)\,(\bar{q}_L\gamma^\mu q_L)$
$(\bar{q}_L\gamma_\mu\sigma_a q_L)\,(\bar{q}_L\gamma^\mu\sigma_a q_L)$
$(\bar{u}_R\gamma_\mu u_R)\,(\bar{u}_R\gamma^\mu u_R)$
$(\bar{u}_R\gamma_\mu u_R)\,(\bar{d}_R\gamma^\mu d_R)$
$(\bar{u}_R\gamma_\mu T_A u_R)\,(\bar{d}_R\gamma^\mu T_A d_R)$
$(\bar{q}_L\gamma_\mu q_L)\,(\bar{u}_R\gamma^\mu u_R)$
$(\bar{q}_L\gamma_\mu T_A q_L)\,(\bar{u}_R\gamma^\mu T_A u_R)$
$(\bar{q}_L\gamma_\mu q_L)\,(\bar{d}_R\gamma^\mu d_R)$
$(\bar{q}_L\gamma_\mu T_A q_L)\,(\bar{d}_R\gamma^\mu T_A d_R)$
$(\bar{q}_L u_R)\,i\sigma_2\,(\bar{q}_L d_R)^{\mathrm{T}}$
$(\bar{q}_L T_A u_R)\,i\sigma_2\,(\bar{q}_L T_A d_R)^{\mathrm{T}}$

2 heavy-2 light: 14
(4 heavy (4t prod): 11)

Lepton colliders

$\ominus$ $(\bar{l}_L\gamma_\mu l_L)\,(\bar{q}_L\gamma^\mu q_L)$
$(\bar{l}_L\gamma_\mu\sigma_a l_L)\,(\bar{q}_L\gamma^\mu\sigma_a q_L)$
$(\bar{e}_R\gamma_\mu e_R)\,(\bar{u}_R\gamma^\mu u_R)$
$(\bar{l}_L\gamma_\mu l_L)\,(\bar{u}_R\gamma^\mu u_R)$
$(\bar{q}_L\gamma_\mu q_L)\,(\bar{e}_R\gamma^\mu e_R)$

ee+tt: 4

Exploring EFT Top interactions at Future Colliders

Some recent Fut. Collider Studies of the Top sector

Global and optimal probes for the top-quark effective field theory at future lepton colliders

Gauthier Durieux,[a] Martín Perelló,[b] Marcel Vos[b] and Cen Zhang[c,d]

arXiv:1807.02121v1 [hep-ph]

Top-Quark Physics at the CLIC Electron-Positron Linear Collider

CLICdp collaboration

arXiv:1807.02441v5 [hep-ex]

Probing top-quark couplings indirectly at Higgs factories

Gauthier Durieux[1] Jiayin Gu (顾嘉荫)[2] Eleni Vryonidou[3] Cen Zhang (张岑)[4]

arXiv:1809.03520v1 [hep-ph]

Probing the top quark flavor-changing couplings at CEPC*

Liaoshan Shi (石辽珊)[1] Cen Zhang (张岑)[1,2]

arXiv:1906.04573v3 [hep-ph]

The electro-weak couplings of the top and bottom quarks – global fit and future prospects

Gauthier Durieux[a] Adrian Irles[b] Víctor Miralles[c] Ana Peñuelas[c] Martín Perelló[c] Roman Pöschl[b] Marcel Vos[c]

arXiv:1907.10619v3 [hep-ph]

Higgs, top and electro-weak precision measurements at future e^+e^- colliders; a combined effective field theory analysis with renormalization mixing

Sunghoon Jung,[a] Junghwan Lee,[a] Martin Perelló,[b] Junping Tian,[c] Marcel Vos[b]

arXiv:2006.14631v1

See M. Vos's talk for more studies

Some recent Fut. Collider Studies of the Top sector

Global and optimal probes for the top-quark effective field theory at future lepton colliders

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Probing top-quark cou … couplings at CEPC*

Gauthier Durieux[1] Jiayin Gu … (张岑)[1,2]

…4573v3 [hep-ph]

Studies explore sensitivity to Top interactions in 2 possible ways:

1. Indirectly, via effects in non-Top observables

2. Direct Top production

The electro-weak cou… quarks – global fit and future prospects

Gauthier Durieux[a] Adrian Irles[b] Víctor Miralles[c] Ana Peñuelas[c] Martín Perelló[c] Roman Pöschl[b] Marcel Vos[c]

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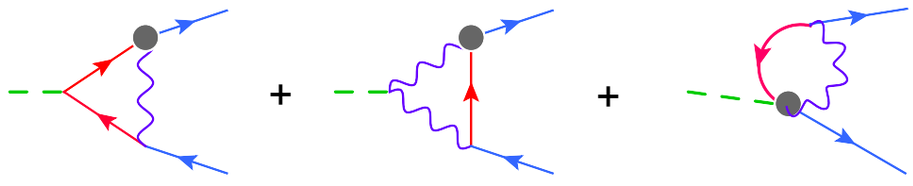
arXiv:2006.14631v1

See M. Vos's talk for more studies

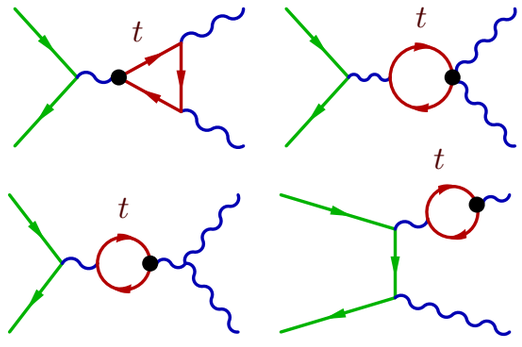
Indirect tests of Top interactions

- Indirect effects of Top interaction in observables via loop effects

H production and decay



EW production

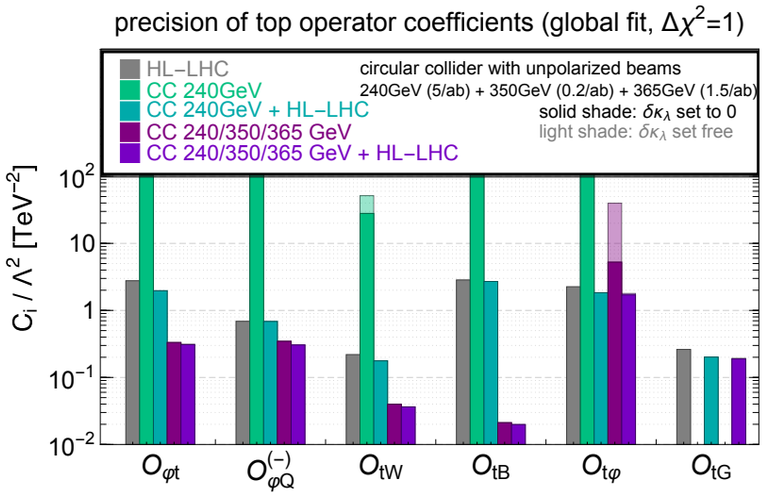


arXiv:1804.09766v2 [hep-ph]

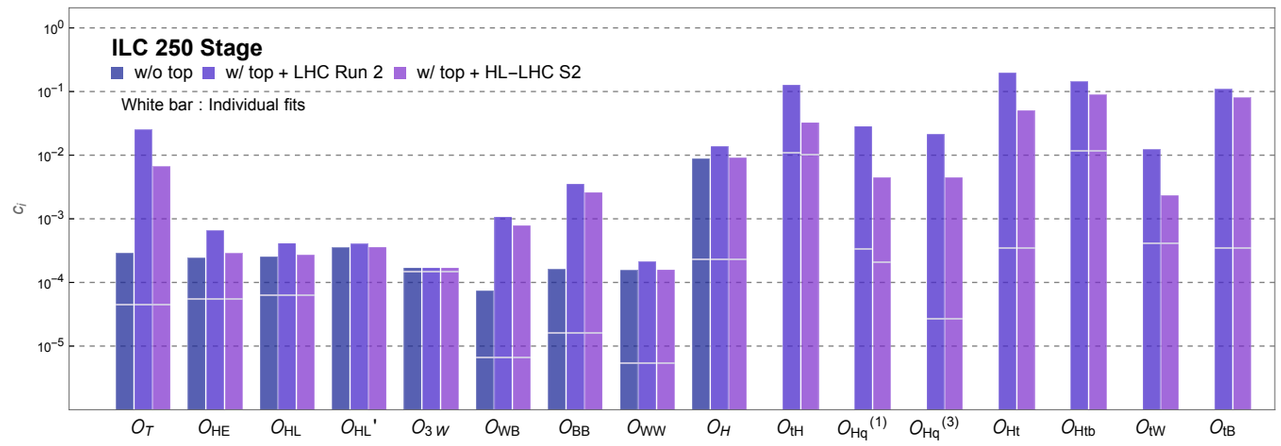
arXiv:1809.03520v1 [hep-ph]

Loop effects for EW Top ops. (RGE effects known for all ops.)

- Does not require specific Top measurements: effects in **precision** EW/Higgs observables → Accessible at low-E circular/linear colliders



arXiv:1809.03520v1 [hep-ph]



arXiv:2006.14631v1

See also M. Vos's talk

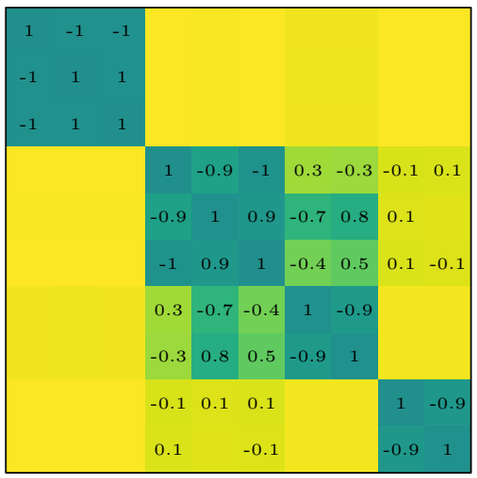
- Studies **restricted to EW top operators**. Large number of ops. in a global study would not permit to close the fit without adding direct Top measurements…

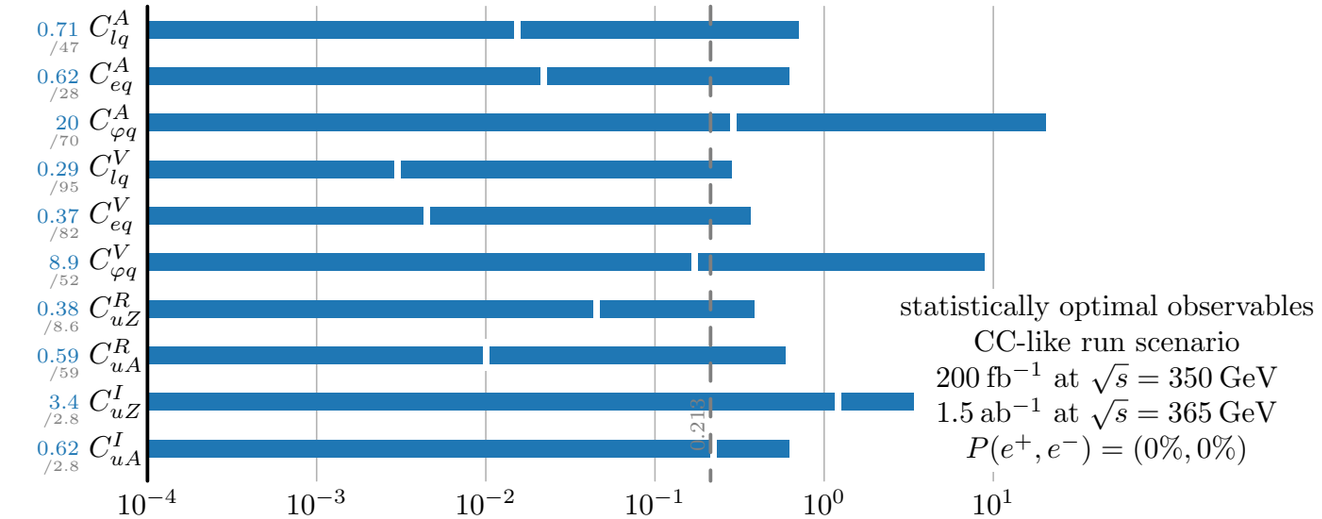
Direct tests of Top interactions

- Dedicated **Global EFT** analysis of $e^+e^- \rightarrow tt$ using statistical optimal observables
  - ✓ Covariance matrix available for FCCee (350-365 GeV), ILC (500-1000 GeV)) and CLIC (380-3000 GeV)

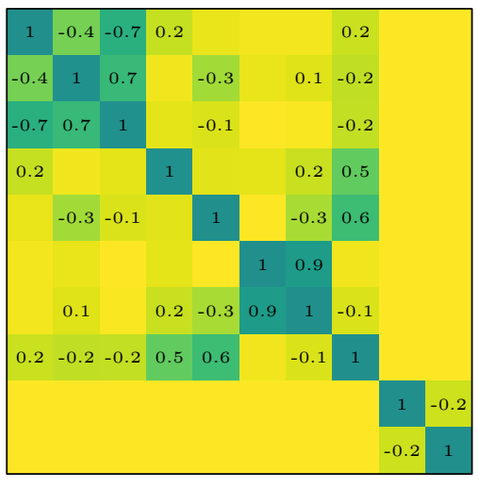
arXiv:1807.02121v1 [hep-ph]

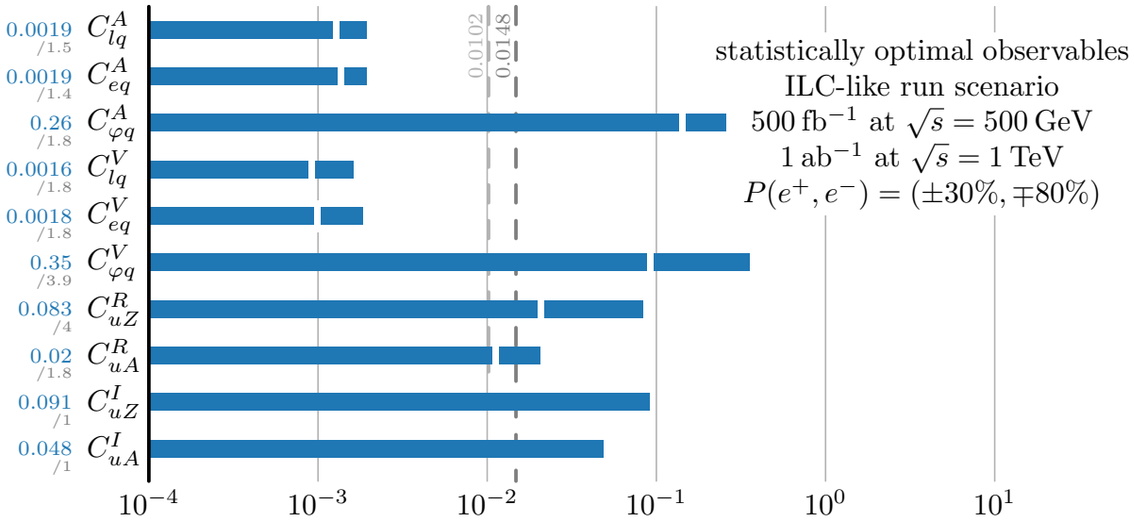
Circular Colliders





Linear Colliders





- **Idealized framework:** Only stat. error. What is the effect of Top systematics?

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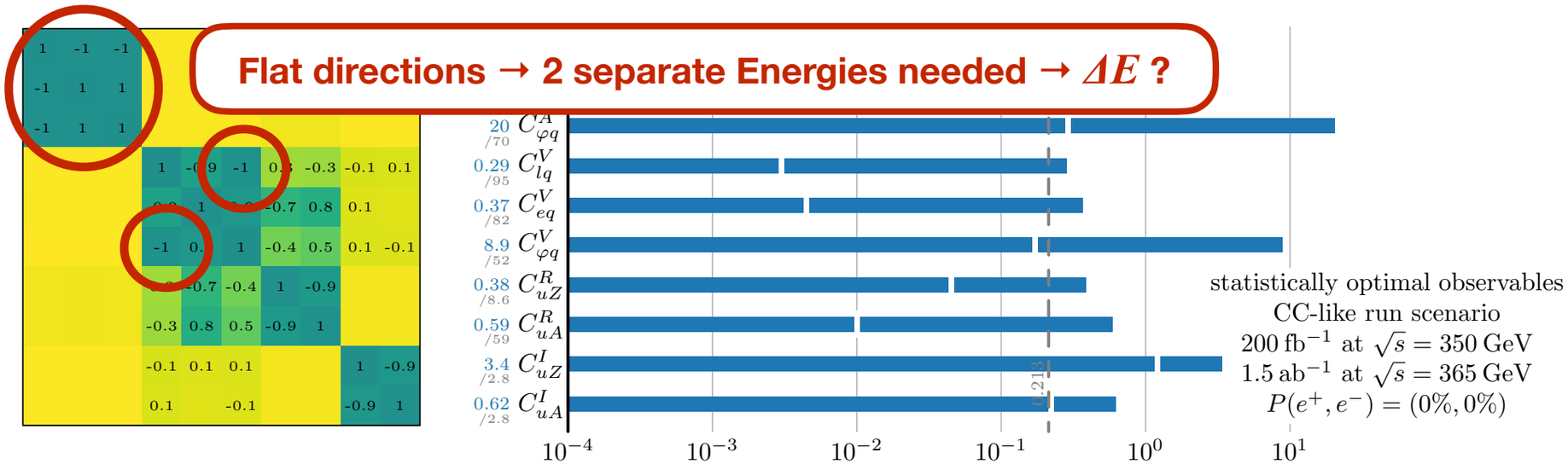
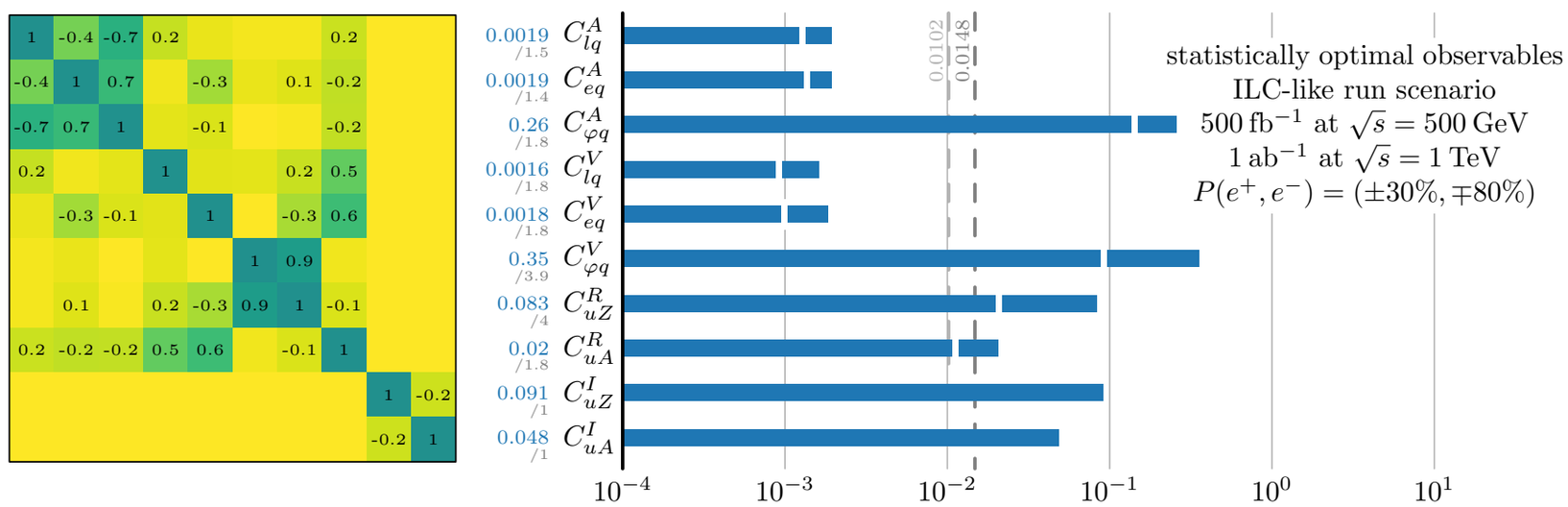
arXiv:1807.02121v1 [hep-ph]

Circular Colliders



Linear Colliders



- **Idealized framework:** Only stat. error. What is the effect of Top systematics?

Direct tests of Top interactions

- **High-Energy Future lepton colliders: Enough to close a global EW/H/Top fit**

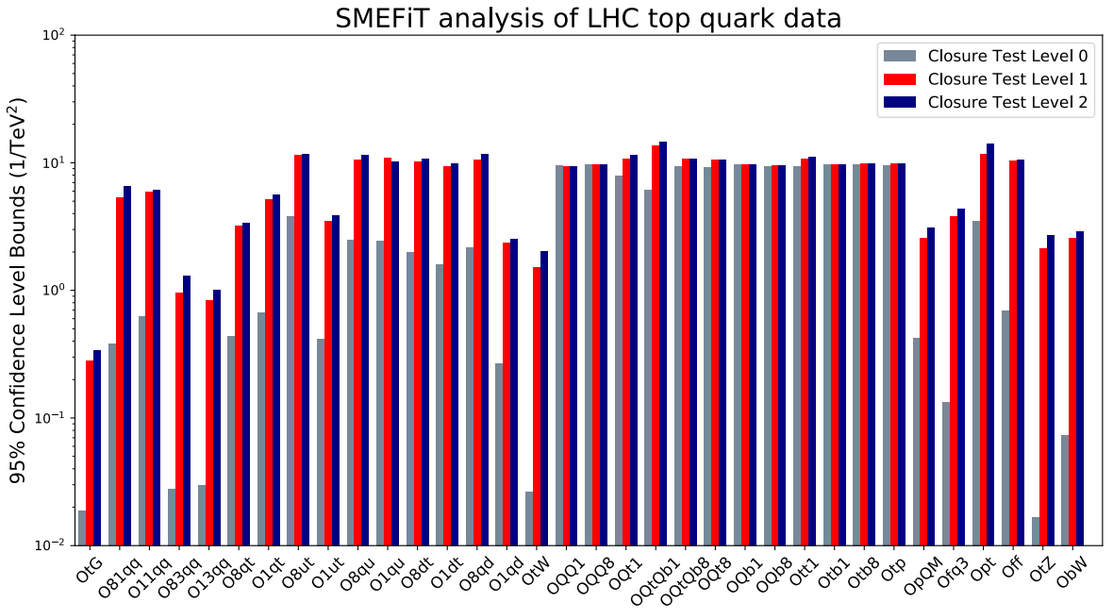
- **No similar global EFT studies available for the HL-LHC or 100 TeV pp collider (Also not in LOIs submitted to Snowmass2021)**
  - ✓ Needed for combination of HL-LHC + future lepton colliders
  - ✓ Results available from current LHC data ⇒ Extrapolation?

A Monte Carlo global analysis of the Standard Model Effective Field Theory: the top quark sector

Nathan P. Hartland,[1,2] Fabio Maltoni,[3,4] Emanuele R. Nocera,[2,5] Juan Rojo,[1,2] Emma Slade,[6] Eleni Vryonidou,[7] and Cen Zhang[8]

arXiv:1901.05965v2 [hep-ph]

See also K. Mimasu's talk, based on
arXiv:2012.02779v2 [hep-ph]



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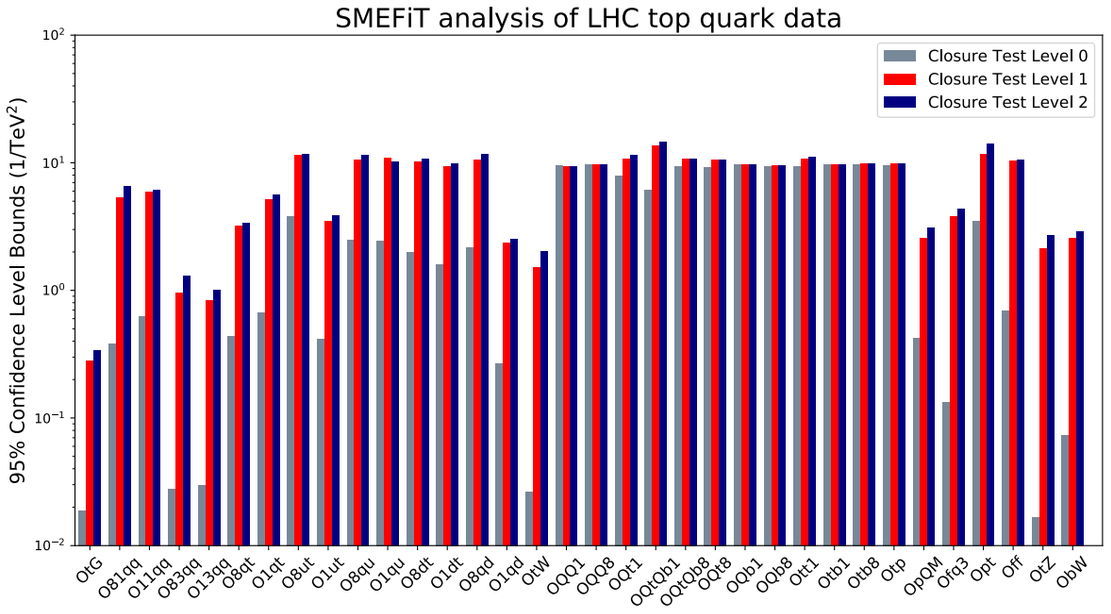

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- **Going beyond: Including Top FCNC?**

SNOWMASS21-EF3_EF0-265 ⇒

Precise predictions for top-quark flavor-changing neutral interactions at future lepton colliders

Snowmass letter of intent

Gauthier Durieux, Stefano Frixione, Benjamin Fuks, Hua-Sheng Shao, Liaoshan Shi, Marco Zaro, Cen Zhang, and Xiaoran Zhao

Summary

Summary

- The Top sector was only superficially explored in the 2020 European Strategy Update

- Extending the ESU 2020 SMEFT fits requires extra observables:
  - ✓ Depending on flavor assumptions
  - ✓ Future collider precision & energy gives access to direct ($tt+X$ production) and indirect (NLO effects in non-Top obs.) probes of Top EFT operators
  - ✓ Information available for future lepton colliders in the idealized framework of statistical optimal observables
    - Extend to more realistic study including systematics?
    - Flat directions with only one E (e.g. 365 GeV)
  - ✓ Need at least projections at HL-LHC to study combined reach with future lepton colliders
  - ✓ FCNC?

- Don't forget: bb observables also needed to resolve all operators involving the 3rd family:

$$(\mathcal{O}_{lq}^{(1)})_{ee33},\ (\mathcal{O}_{lq}^{(3)})_{ee33} \Longrightarrow \begin{array}{l} (\mathcal{O}_{lq}^{(1)})_{ee33} + (\mathcal{O}_{lq}^{(3)})_{ee33} \to e^+e^-\bar{b}b \\ (\mathcal{O}_{lq}^{(1)})_{ee33} - (\mathcal{O}_{lq}^{(3)})_{ee33} \to e^+e^-\bar{t}t \end{array}$$