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PHENO AT A DISTANCE

A GLOBAL SEARCH FOR NEW PHYSICS WITH TOP QUARKS

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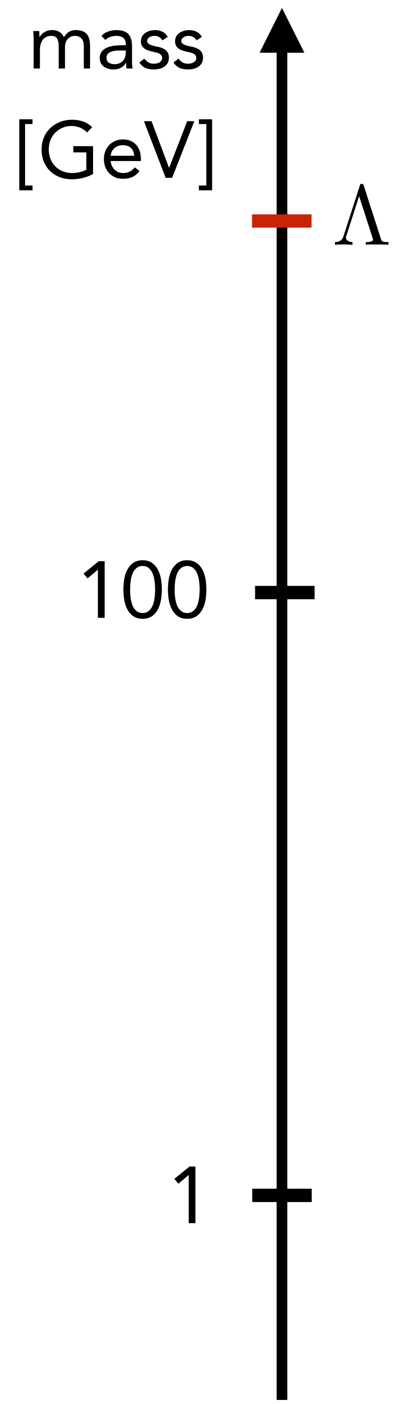
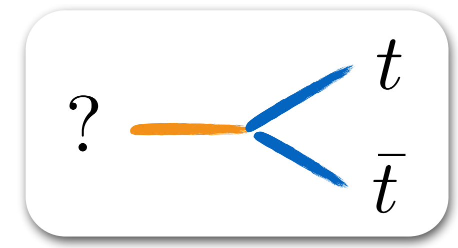
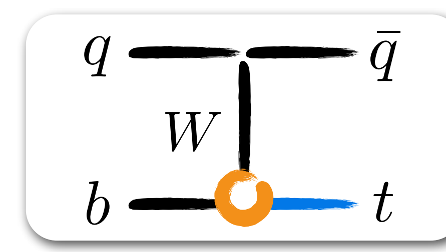
New physics at a distance



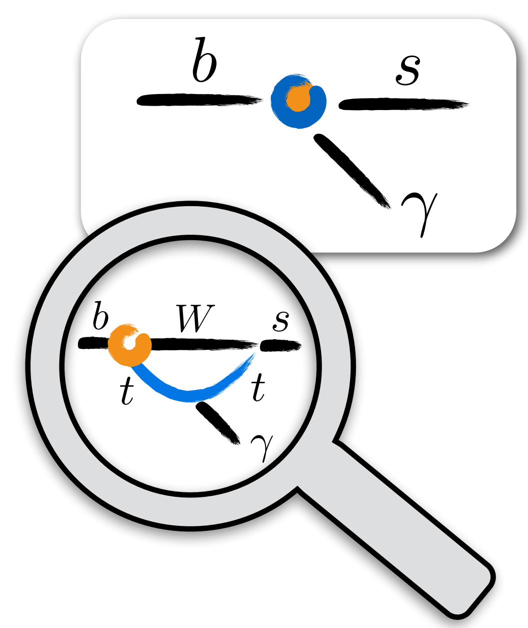
$$\mathcal{L}_f = ???$$



$$\mathcal{L}_{\rm SM} + \sum_i \frac{C_i}{\Lambda^2} O_i + \dots$$



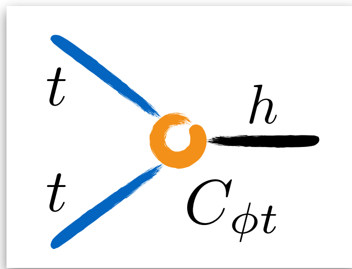
$$\mathcal{H}_{\rm eff} = \sum_i \frac{\mathcal{C}_i}{\Lambda^2} \mathcal{O}_i + \dots$$



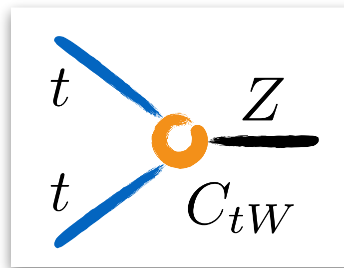
Focus on effective interactions with top quarks.

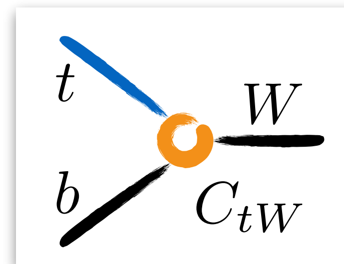
Effective top interactions

Higgs

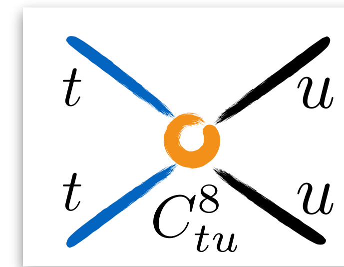


gauge bosons





light quarks



$O_{t\phi} = (\overline{Q}\, t\, \widetilde{\phi})(\phi^\dagger \phi)$

${}^{\ddagger}O_{tW} = (\bar{Q}\sigma^{\mu\nu}t)\,\tau^I \widetilde{\phi}\, W^I_{\mu\nu}$

$O^8_{tu} = (\bar{t}\gamma_\mu T^A t)(\bar{u}_i \gamma^\mu T^A u_i)$

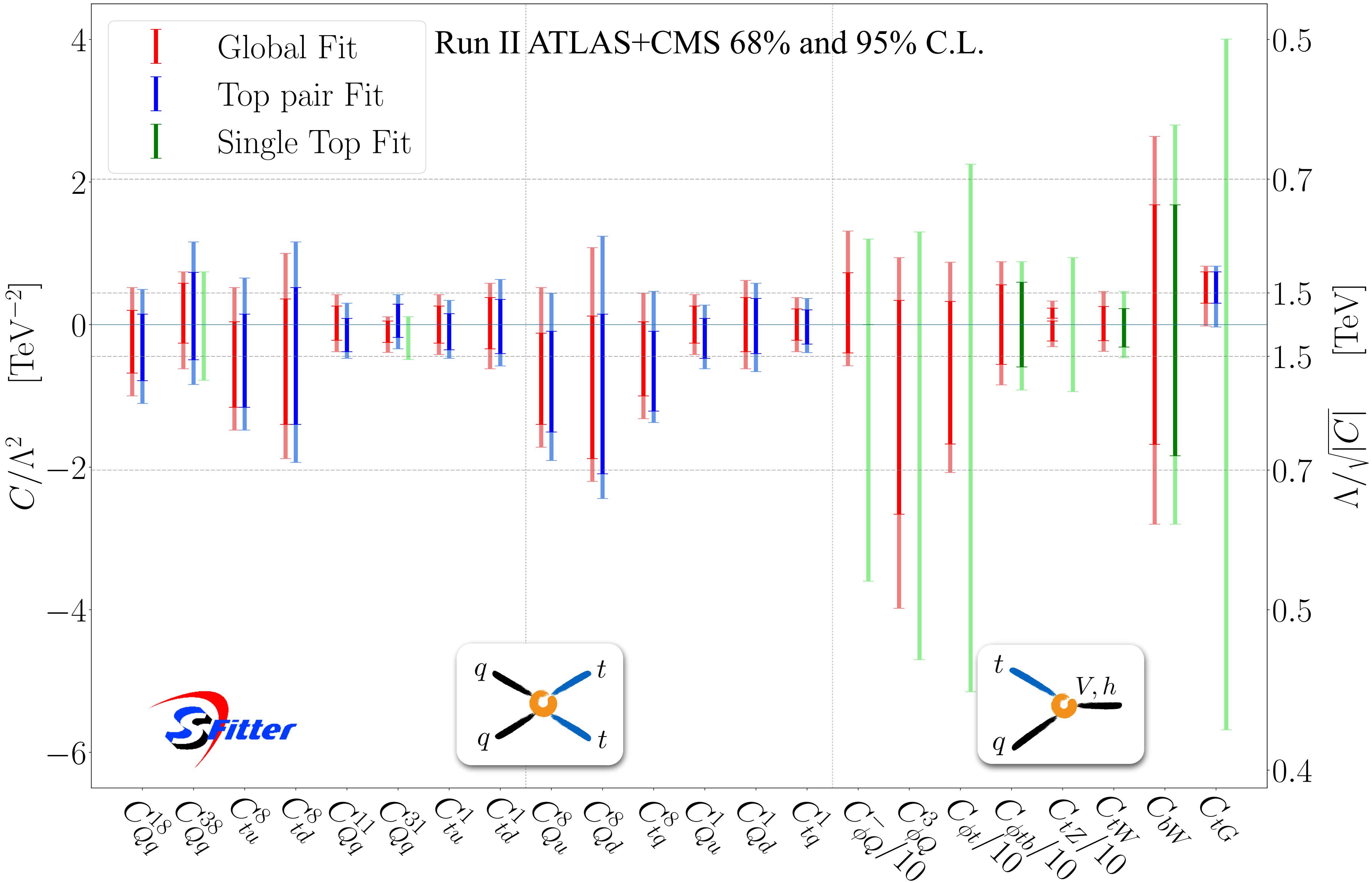
Top sector of Standard Model Effective Field Theory:

- flavor symmetry $U(2)_q \times U(2)_u \times U(2)_d$
- O(20) dim-6 operators with tops
- observables computed at NLO QCD:

$$\sigma = \sigma_{\rm SM} + \sum_i \frac{C_i}{\Lambda^2}\sigma_i + \sum_{i,j} \frac{C_i C_j}{\Lambda^4}\sigma_{ij}$$

analysis framework (LHC Top WG): Aguilar Saavedra et al. 2018

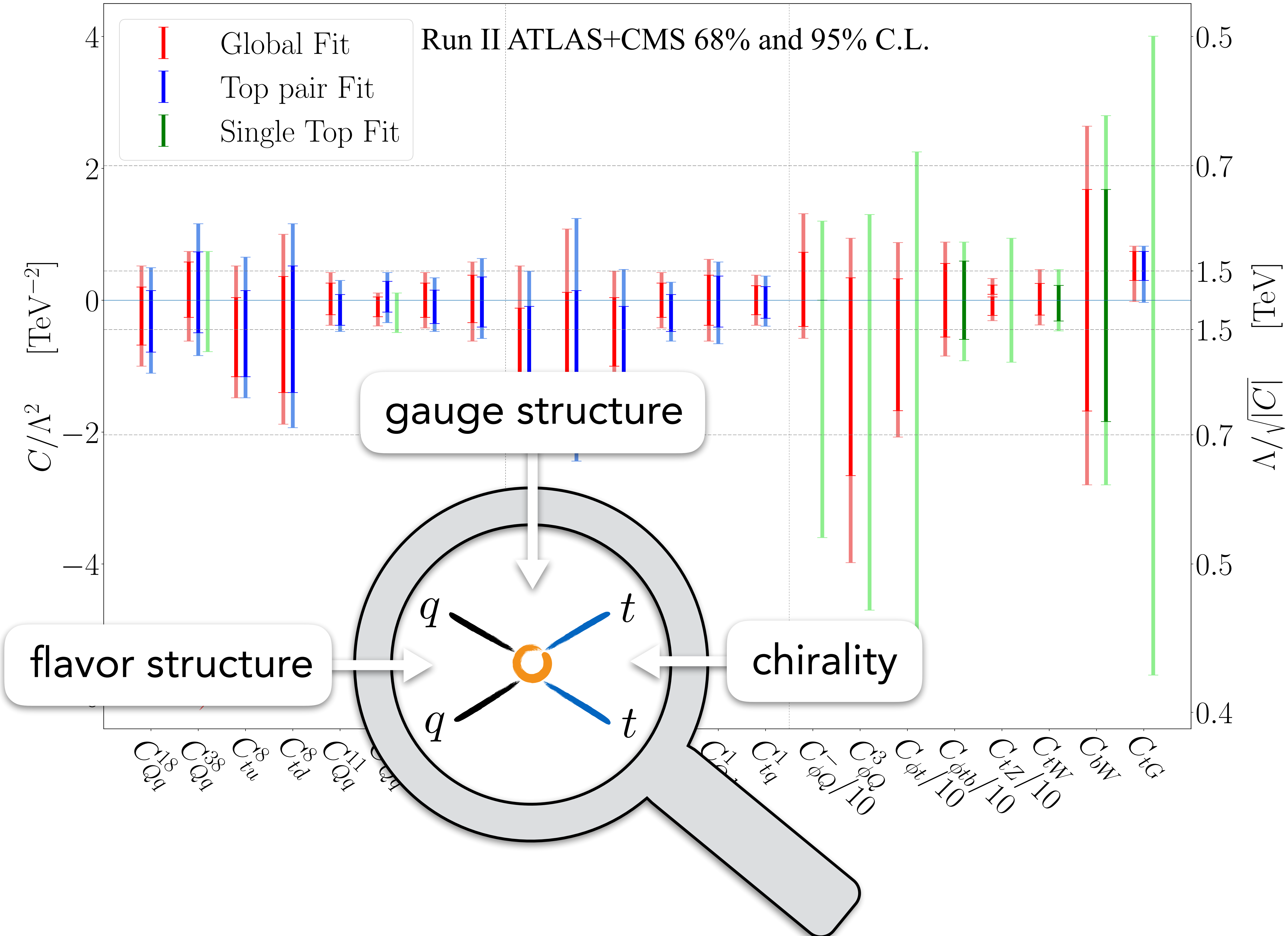
Global analysis of top LHC data



Brivio, Bruggisser, Maltoni, Moutafis, Plehn, Vryonidou, **Westhoff**, Zhang 2019

other global top fits: Englert et al. 2016+; Hartland et al. 2019; Durieux et al. 2019

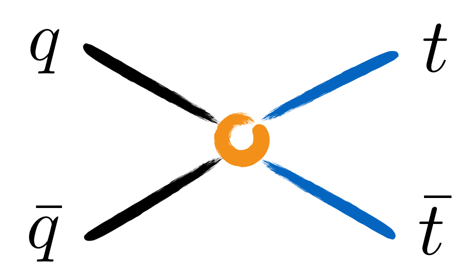
Global analysis of top LHC data



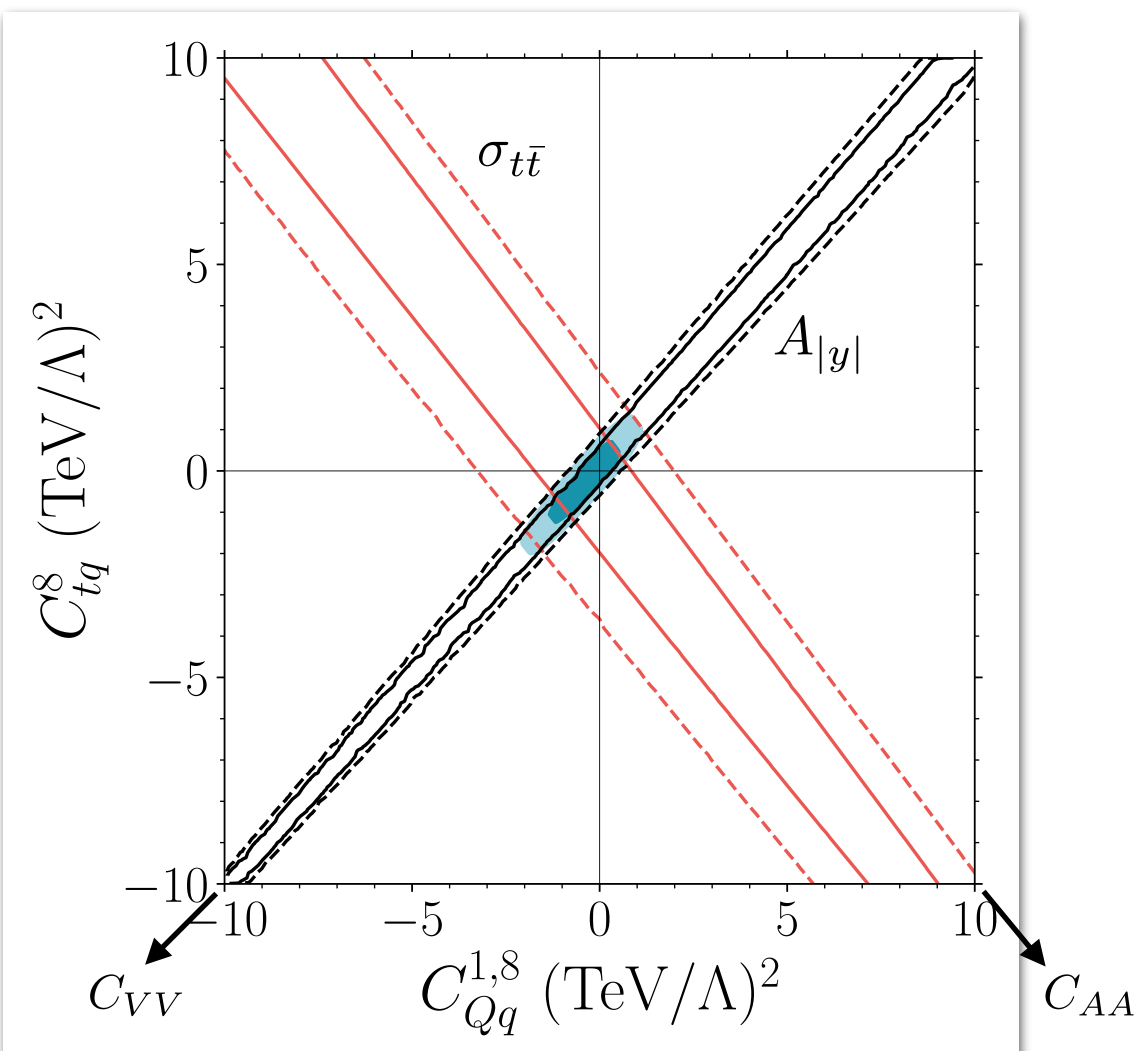
Top chirality

$$O_{tq}^{8} = (\bar{q}_i \gamma^\mu T^A q_i)(\bar{t}\gamma_\mu T^A t) \qquad \sim LR$$

$$O_{Qq}^{1,8} = (\bar{Q}\gamma_\mu T^A Q)(\bar{q}_i \gamma^\mu T^A q_i) \quad \sim LL$$



- linear Wilson contributions $O(C/\Lambda^2)$



top-antitop cross section:

$$\sigma_{t\bar{t}} = \sigma_{\mathrm{SM}} + \sigma_{VV}\left(C_{Qq}^{1,8} + C_{tq}^{8}\right)$$

charge asymmetry:

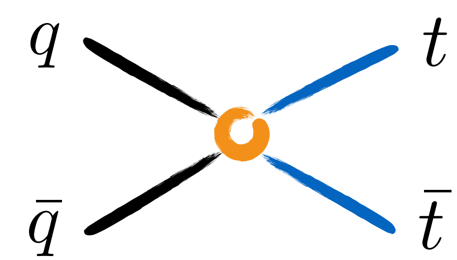
$$A_{|y|} = \frac{\sigma_{\mathrm{SM}}^{A} + \sigma_{AA}\left(C_{Qq}^{1,8} - C_{tq}^{8}\right)}{\sigma_{t\bar{t}}}$$

Brivio et al. 2019

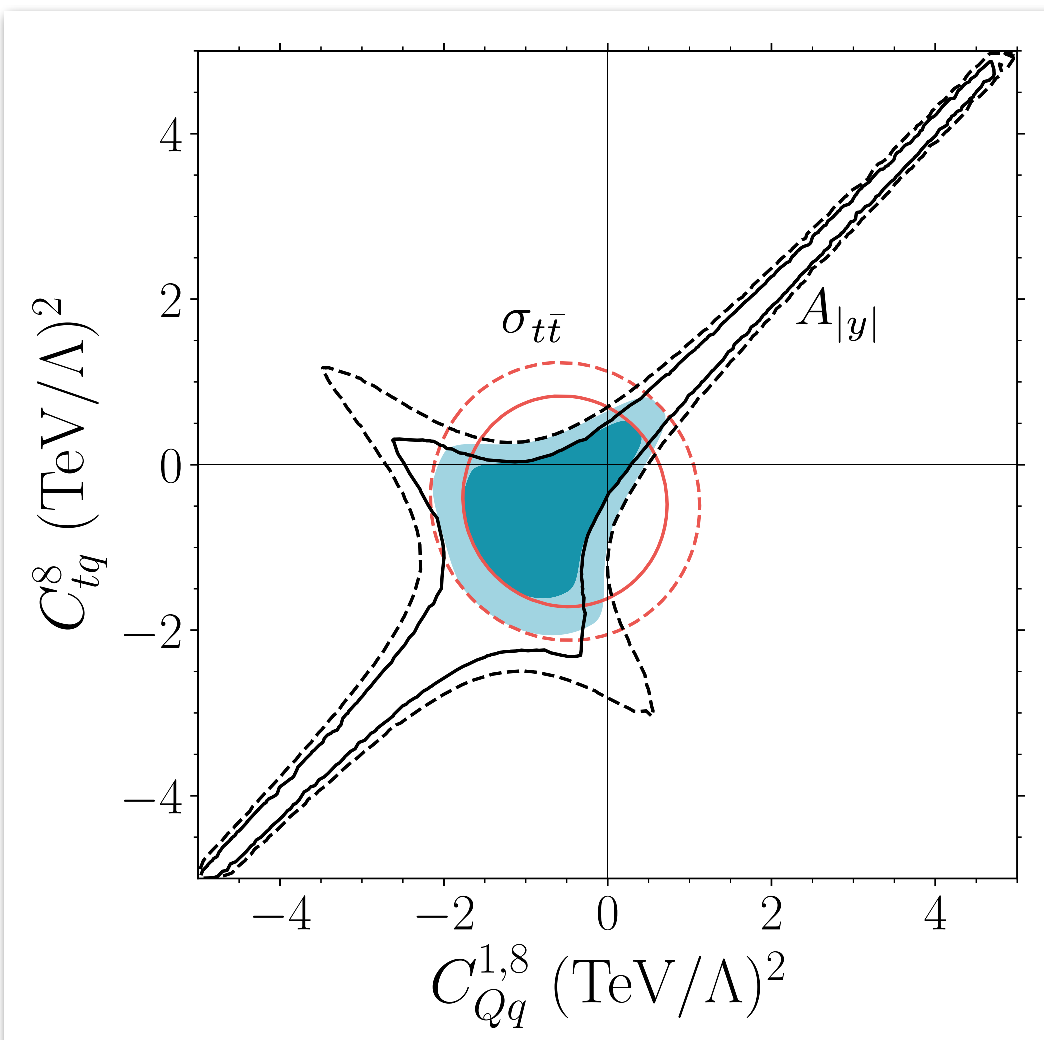
Top chirality

$$O_{tq}^{8} = (\bar{q}_i \gamma^{\mu} T^{A} q_i)(\bar{t}\gamma_{\mu} T^{A} t) \qquad \sim LR$$

$$O_{Qq}^{1,8} = (\bar{Q}\gamma_{\mu} T^{A} Q)(\bar{q}_i \gamma^{\mu} T^{A} q_i) \qquad \sim LL$$



- quadratic Wilson contributions $O(C^2/\Lambda^4)$



top-antitop cross section:

$$\sigma_{t\bar{t}} = \sigma_{\mathrm{SM}} + \sigma_{VV}\left(C_{Qq}^{1,8} + C_{tq}^{8}\right)$$

$$+\, \sigma_{V+A}\left(|C_{Qq}^{1,8}|^2 + |C_{tq}^{8}|^2\right) + \sigma_{V-A}\, C_{Qq}^{1,8} C_{tq}^{8}$$

charge asymmetry:

$$A_{|y|} = \frac{\sigma_{\mathrm{SM}}^{A} + \sigma_{AA}\left(C_{Qq}^{1,8} - C_{tq}^{8}\right)}{\sigma_{t\bar{t}}}$$

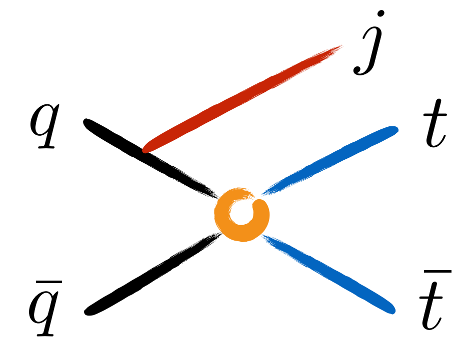
$$+\, \sigma_{VVAA}\left(|C_{Qq}^{1,8}|^2 - |C_{tq}^{8}|^2\right)/\sigma_{t\bar{t}}$$

Brivio et al. 2019

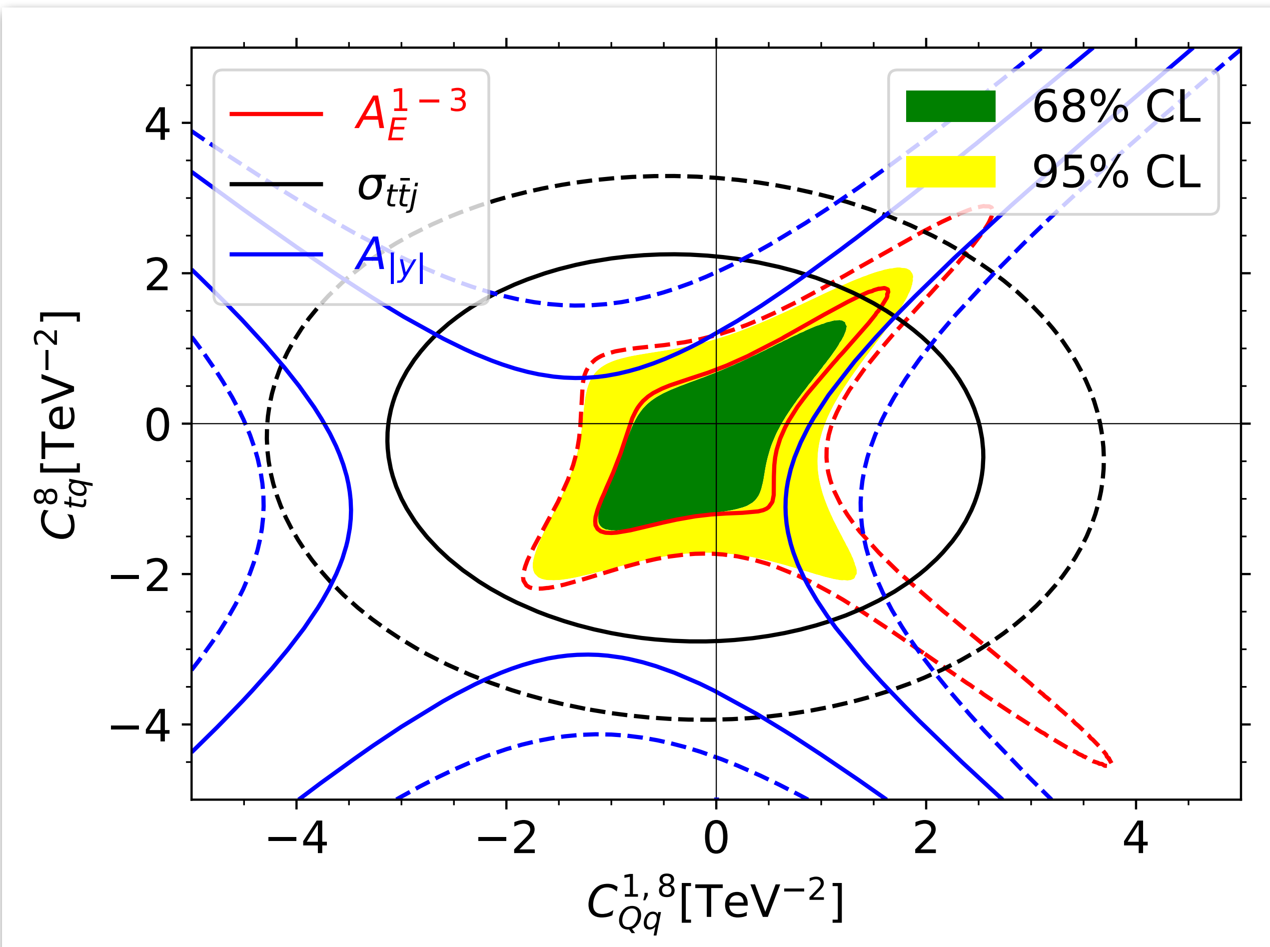
Resolving blind directions

$$O_{tq}^{8} = (\bar{q}_i \gamma^\mu T^A q_i)(\bar{t}\gamma_\mu T^A t) \quad \sim LR$$

$$O_{Qq}^{1,8} = (\bar{Q}\gamma_\mu T^A Q)(\bar{q}_i \gamma^\mu T^A q_i) \quad \sim LL$$



bounds from LHC Run-2 data



measured:

rapidity asymmetry $A_{|y|}\,(t\bar{t})$

projected:

energy asymmetry $A_E\,(t\bar{t}j)$

measurement in progress

Basan, Berta, Masetti (ATLAS), Vryonidou, **Westhoff** 2020

Gauge structure: weak isospin

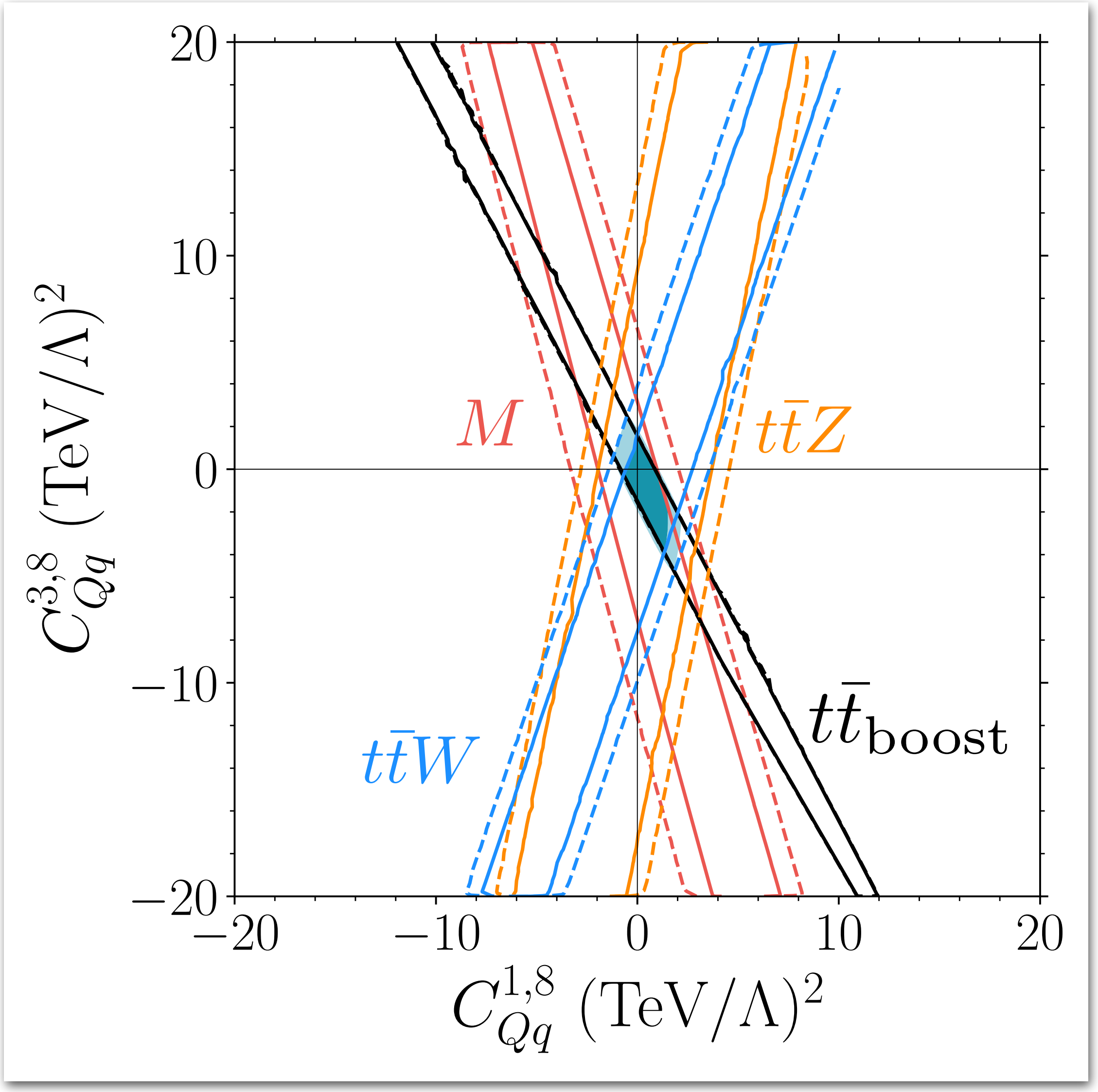
$$O_{Qq}^{1,8} = (\bar{Q}\gamma_\mu T^A Q)(\bar{q}_i \gamma^\mu T^A q_i)$$

$$O_{Qq}^{3,8} = (\bar{Q}\gamma_\mu T^A \tau^I Q)(\bar{q}_i \gamma^\mu T^A \tau^I q_i)$$

Key: up vs. down in proton

$$r(x) = \frac{f_u(x) f_{\bar{u}}(s/(xS))}{f_d(x) f_{\bar{d}}(s/(xS))}$$

- linear Wilson contributions $O(C/\Lambda^2)$



top-antitop cross section:

$$\sigma_{t\bar{t}} \sim (r+1) C_{Qq}^{1,8} + (r-1) C_{Qq}^{3,8}$$

$$\approx 3 C_{Qq}^{1,8} + C_{Qq}^{3,8}$$

ttW associated production:

$$\sigma_{t\bar{t}W} \sim C_{Qq}^{1,8} (\sigma_{uu} + \sigma_{dd}) + C_{Qq}^{3,8} \sigma_{ud}$$

Brivio et al. 2019

Gauge structure: weak isospin

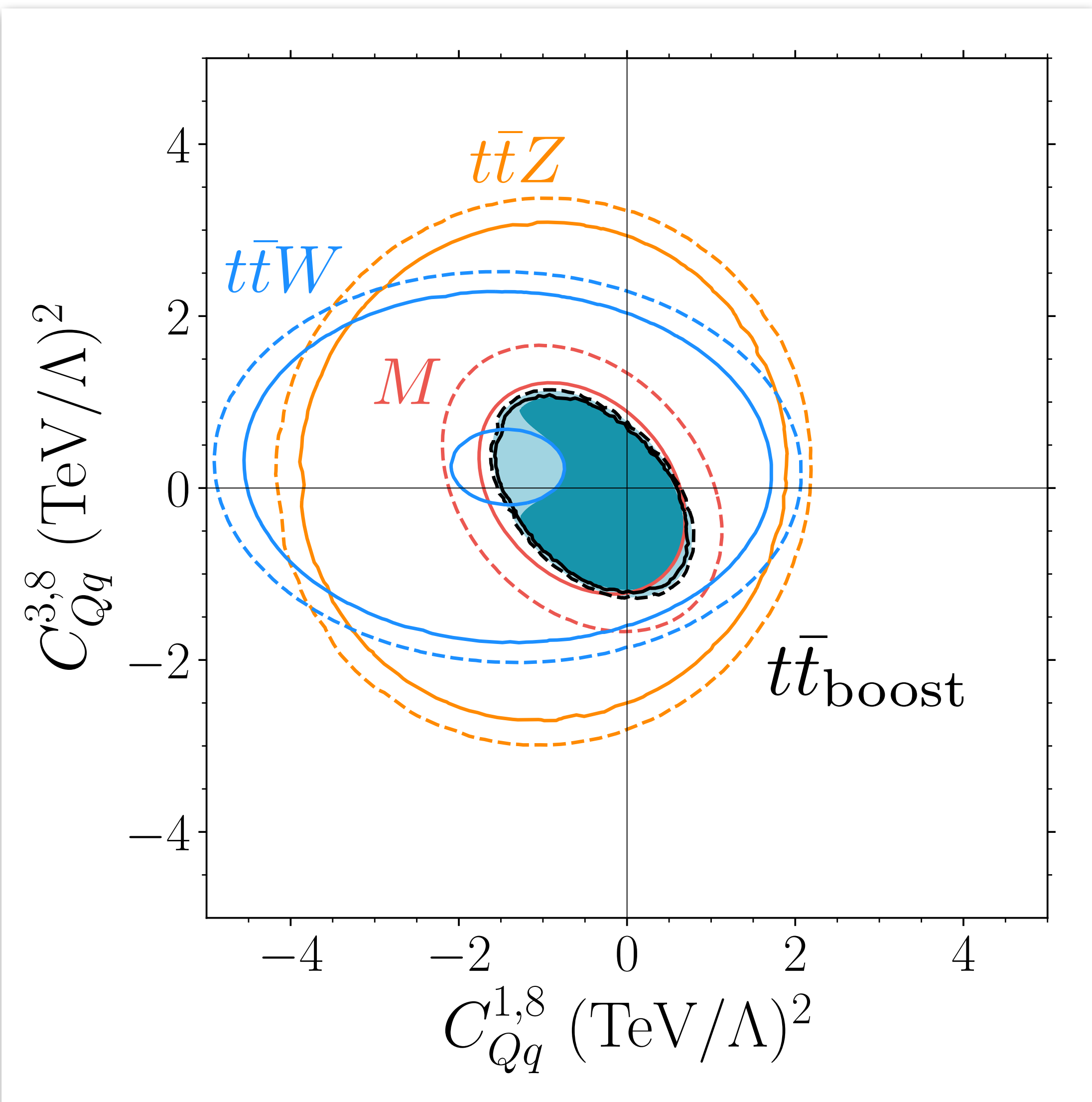
$$O_{Qq}^{1,8} = (\bar{Q}\gamma_\mu T^A Q)(\bar{q}_i \gamma^\mu T^A q_i)$$

$$O_{Qq}^{3,8} = (\bar{Q}\gamma_\mu T^A \tau^I Q)(\bar{q}_i \gamma^\mu T^A \tau^I q_i)$$

Key: up vs. down in proton

$$r(x) = \frac{f_u(x) f_{\bar{u}}(s/(xS))}{f_d(x) f_{\bar{d}}(s/(xS))}$$

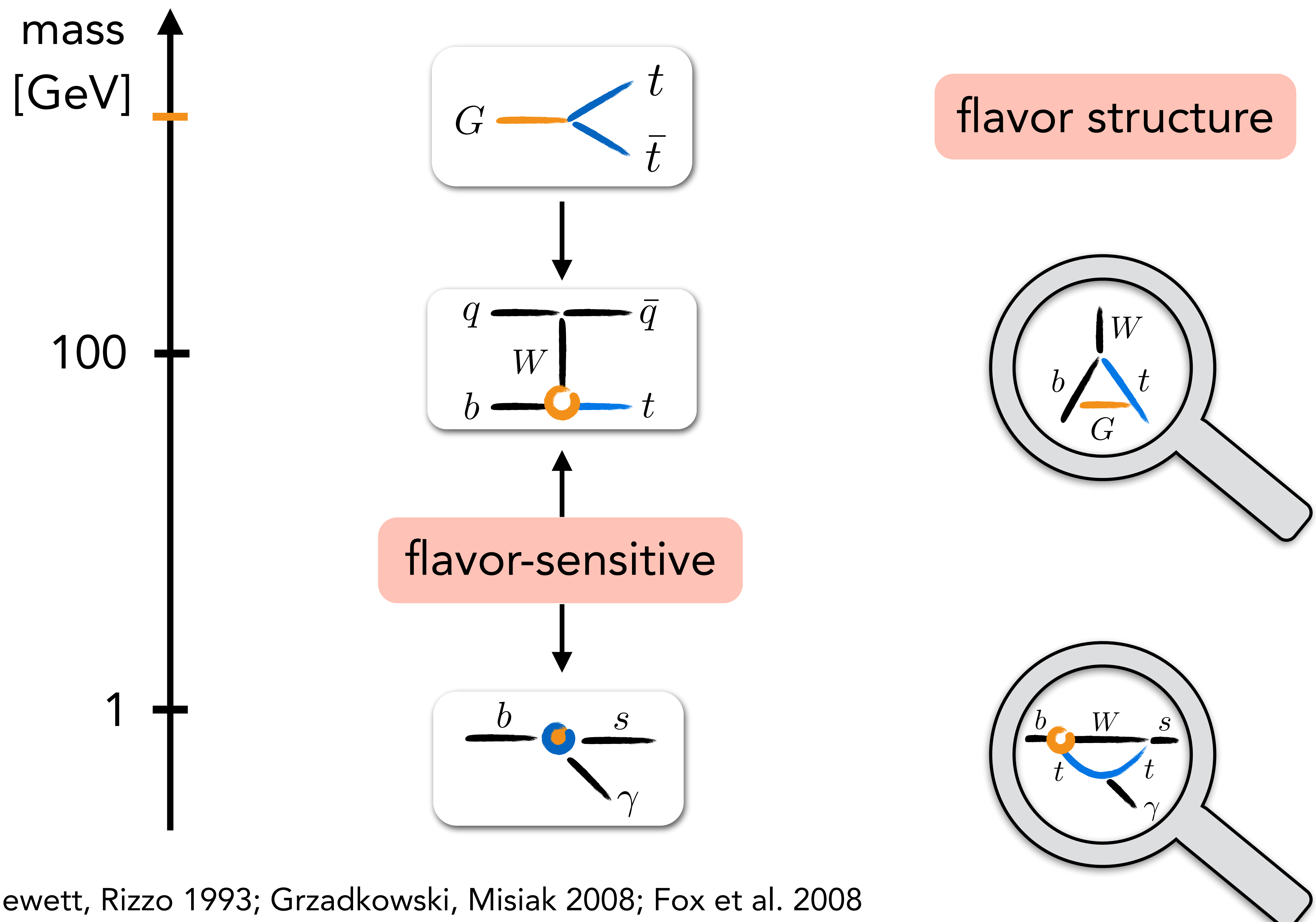
- quadratic Wilson contributions $O(C^2/\Lambda^4)$



All Wilson coefficients bounded.
Remaining blind directions in fit.

Brivio et al. 2019

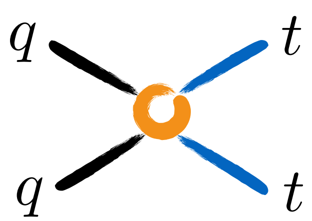
Flavor structure



Hewett, Rizzo 1993; Grzadkowski, Misiak 2008; Fox et al. 2008
Brod et al. 2014; Cirigliano et al. 2016
Bissmann et al. 2019; Aoude et al. 2020

work in progress with Bruggisser, Cata, van Dyk, Schaefer

Summary



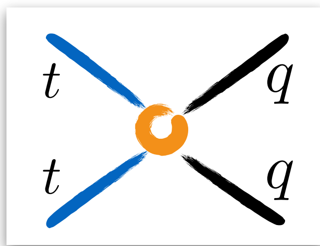
Search for heavy new physics with top-quarks:

- Probe indirect effects with precise observables.
- Use kinematics to decipher gauge and chiral structure.
- New observables resolve blind directions.
- Combine top and flavor for new insights.

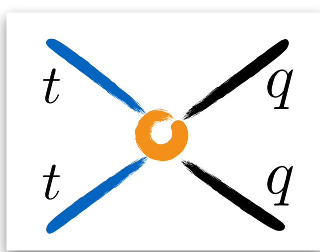
Thank you!

Backup

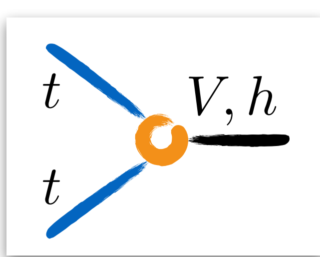
Top production at the LHC in SMEFT



LL, RR



LR, RL



parameter	$t\bar{t}$	single t	tW	tZ	t decay	$t\bar{t}Z$	$t\bar{t}W$
$C_{Qq}^{1,8}$	Λ^{-2}	–	–	–	–	Λ^{-2}	Λ^{-2}
$C_{Qq}^{3,8}$	Λ^{-2}	Λ^{-4} [Λ^{-2}]	–	Λ^{-4} [Λ^{-2}]	Λ^{-4} [Λ^{-2}]	Λ^{-2}	Λ^{-2}
C_{tu}^{8}, C_{td}^{8}	Λ^{-2}	–	–	–	–	Λ^{-2}	–
$C_{Qq}^{1,1}$	Λ^{-4} [Λ^{-2}]	–	–	–	–	Λ^{-4} [Λ^{-2}]	Λ^{-4} [Λ^{-2}]
$C_{Qq}^{3,1}$	Λ^{-4} [Λ^{-2}]	Λ^{-2}	–	Λ^{-2}	Λ^{-2}	Λ^{-4} [Λ^{-2}]	Λ^{-4} [Λ^{-2}]
C_{tu}^{1}, C_{td}^{1}	Λ^{-4} [Λ^{-2}]	–	–	–	–	Λ^{-4} [Λ^{-2}]	–
C_{Qu}^{8}, C_{Qd}^{8}	Λ^{-2}	–	–	–	–	Λ^{-2}	–
C_{tq}^{8}	Λ^{-2}	–	–	–	–	Λ^{-2}	Λ^{-2}
C_{Qu}^{1}, C_{Qd}^{1}	Λ^{-4} [Λ^{-2}]	–	–	–	–	Λ^{-4} [Λ^{-2}]	–
C_{tq}^{1}	Λ^{-4} [Λ^{-2}]	–	–	–	–	Λ^{-4} [Λ^{-2}]	Λ^{-4} [Λ^{-2}]
$C_{\phi Q}^{-}$	–	–	–	Λ^{-2}	–	Λ^{-2}	–
$C_{\phi Q}^{3}$	–	Λ^{-2}	Λ^{-2}	Λ^{-2}	Λ^{-2}	–	–
$C_{\phi t}$	–	–	–	Λ^{-2}	–	Λ^{-2}	–
$C_{\phi tb}$	–	Λ^{-4}	Λ^{-4}	Λ^{-4}	Λ^{-4}	–	–
C_{tZ}	–	–	–	Λ^{-2}	–	Λ^{-2}	–
C_{tW}	–	Λ^{-2}	Λ^{-2}	Λ^{-2}	Λ^{-2}	–	–
C_{bW}	–	Λ^{-4}	Λ^{-4}	Λ^{-4}	Λ^{-4}	–	–
C_{tG}	Λ^{-2}	[Λ^{-2}]	Λ^{-2}	–	[Λ^{-2}]	Λ^{-2}	Λ^{-2}

Brivio, Bruggisser, Maltoni, Moutafis, Plehn, Vryonidou, **Westhoff**, Zhang 2019