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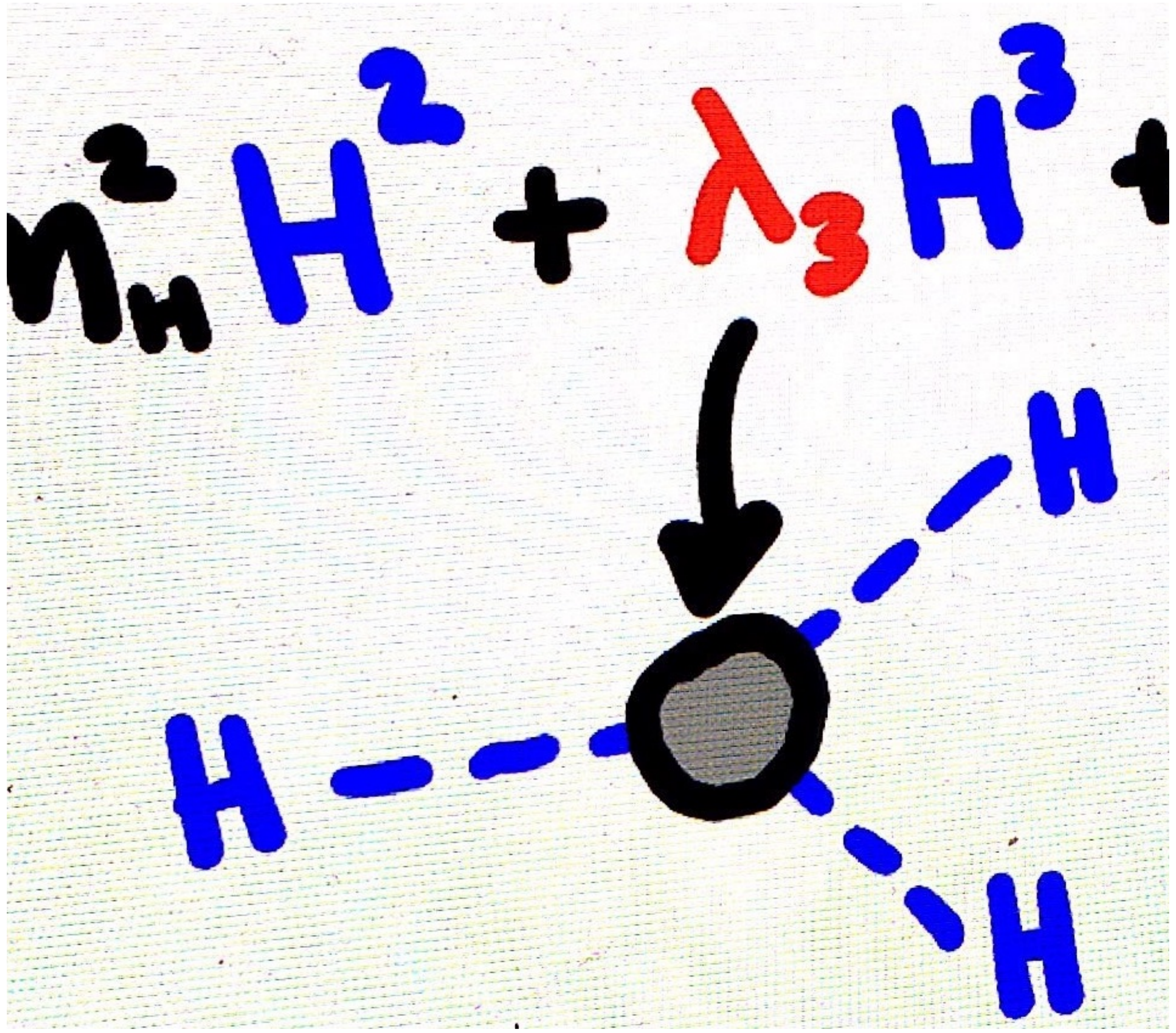
Trilinear Higgs coupling and 4-quark operators from single Higgs data



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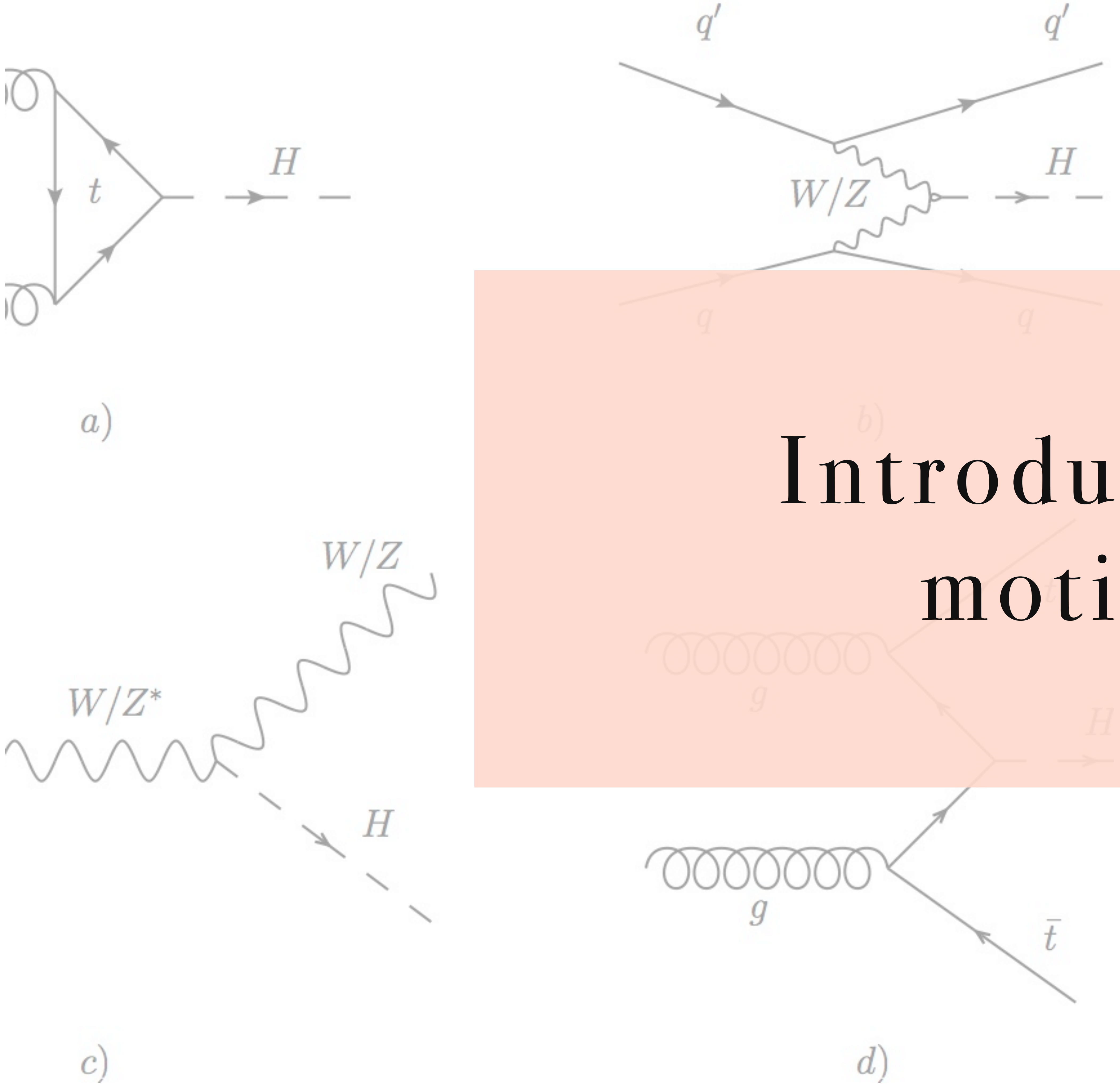
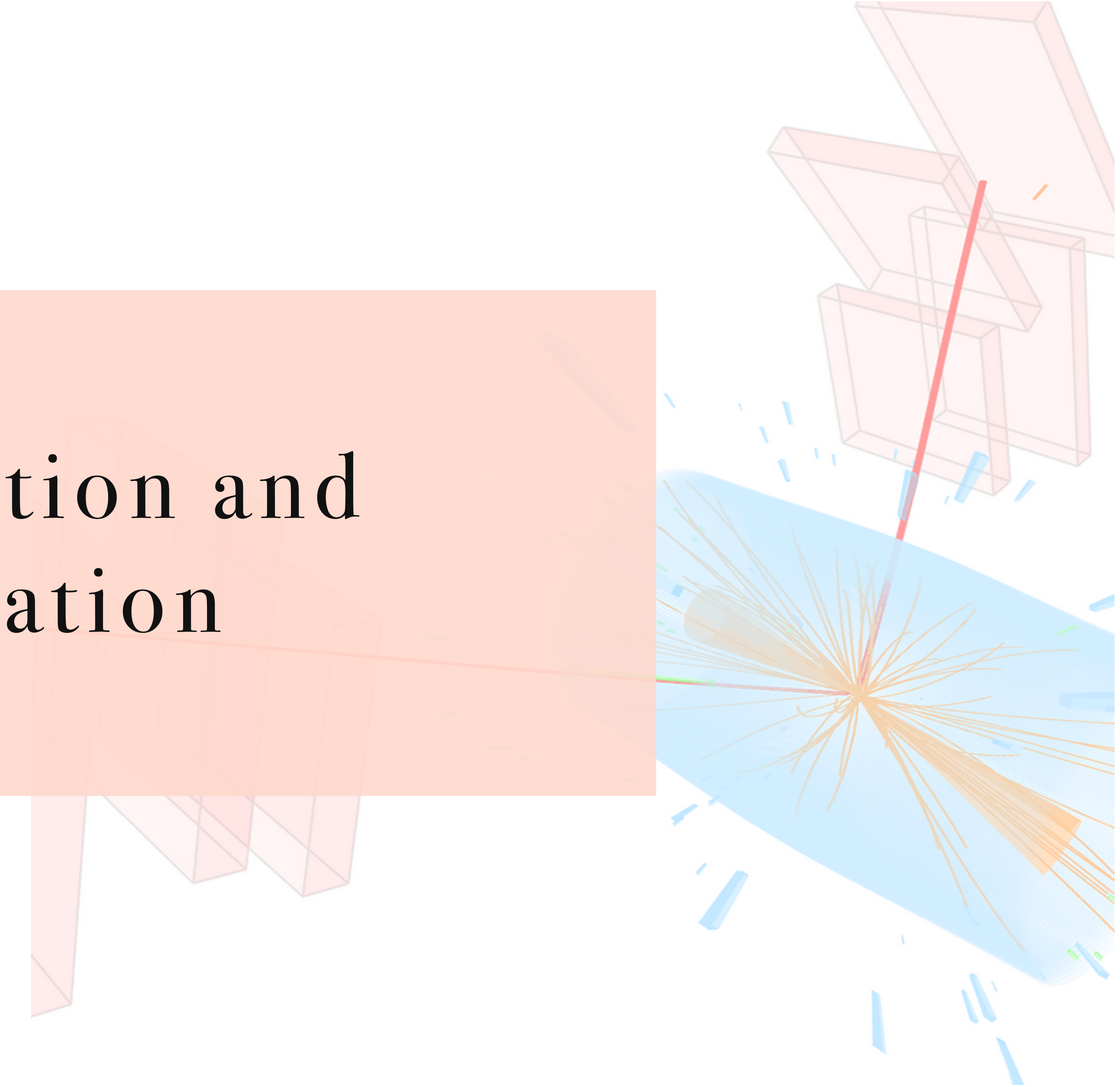
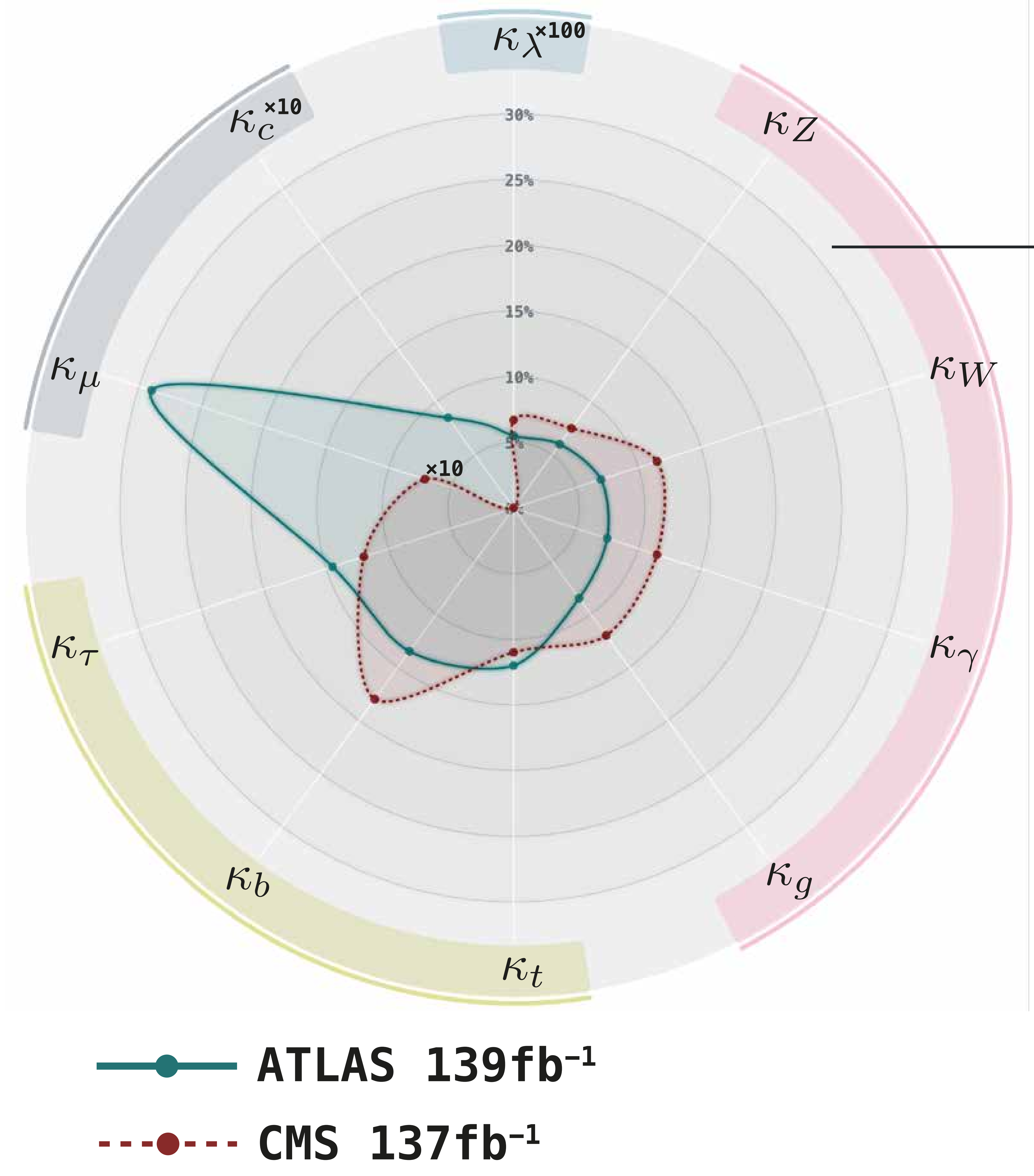
Humboldt-Universität zu Berlin

WG2 meeting on κλ measurements in single-Higgs channels
23.09.2021





Introduction and motivation



Higgs couplings

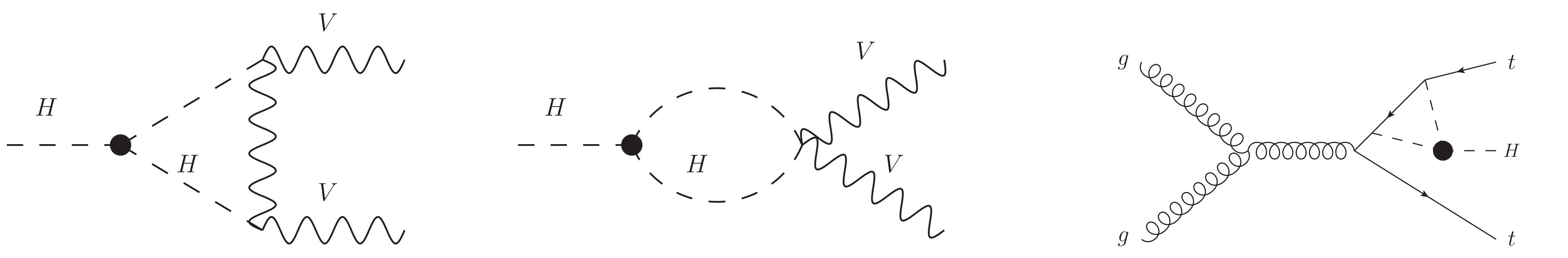
@ Run-II LHC

The coupling between the Higgs and gauge bosons and 3rd generation quarks are approaching precision. However we are still missing

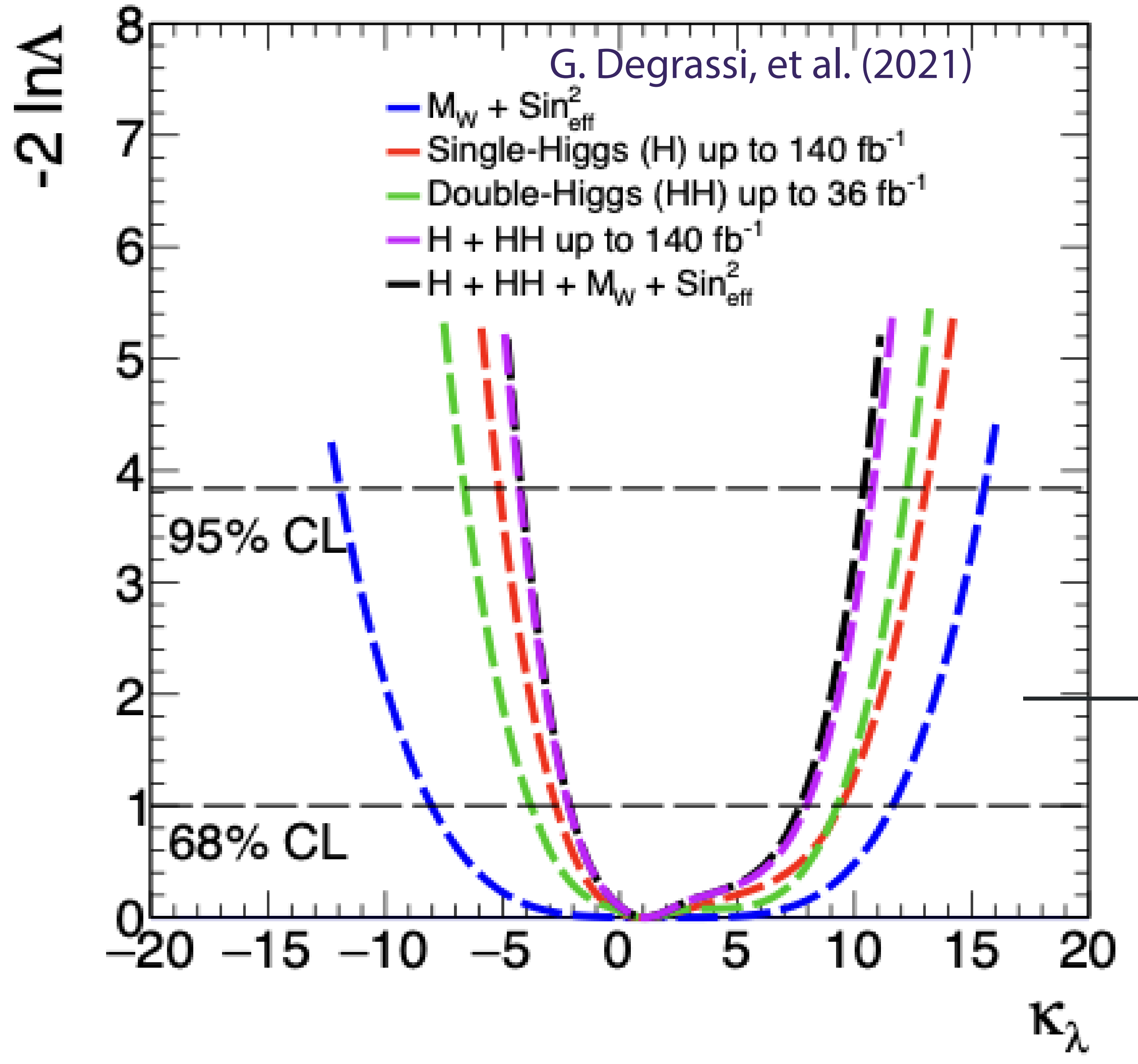
Higgs self-interaction (trilinear & quartic)

Light Yukawa coupling

Higgs trilinear coupling in single Higgs rates.



NLO-corrections to single Higgs processes

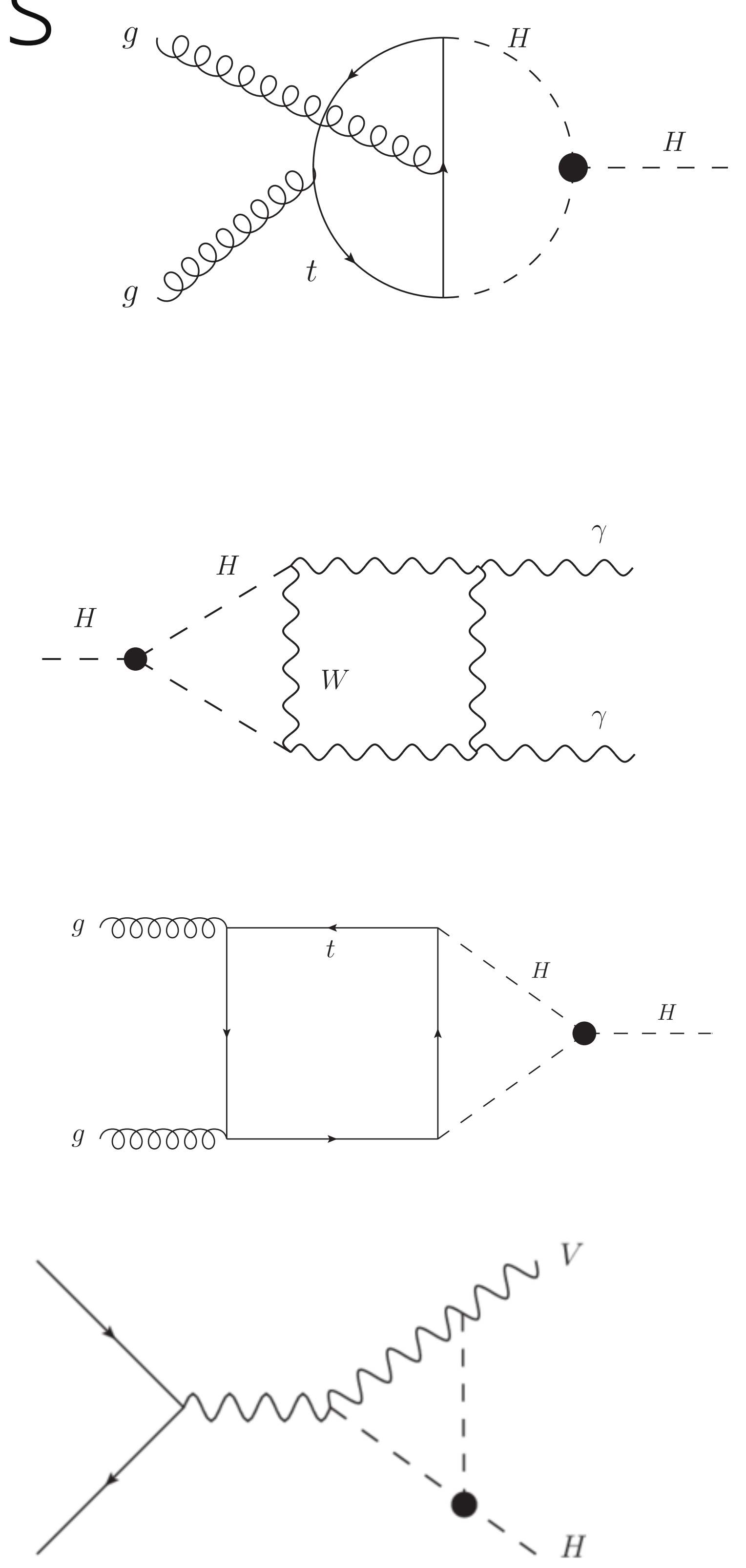


The trilinear Higgs couplings appear in single Higgs production and decay processes at NLO.
By computing these NLO correction, it is possible to set constraints on κ_λ from single Higgs measurements.

Bizon et al. '16, Gorbahn & Haisch '16 and Degrassi et al. '16

A global EW fit from Higgs data including the trilinear Higgs coupling can be added to increase the sensitivity of Run-II di-Higgs constraint on κ_λ.

Degrassi et al. '17, Di Vita et al. '17, Kribs et al. '17, ATLAS '20 Degrassi et al. '21



SMEFT vs κ -formalism

Will be used in the fit

Strongly constrained by EWPO

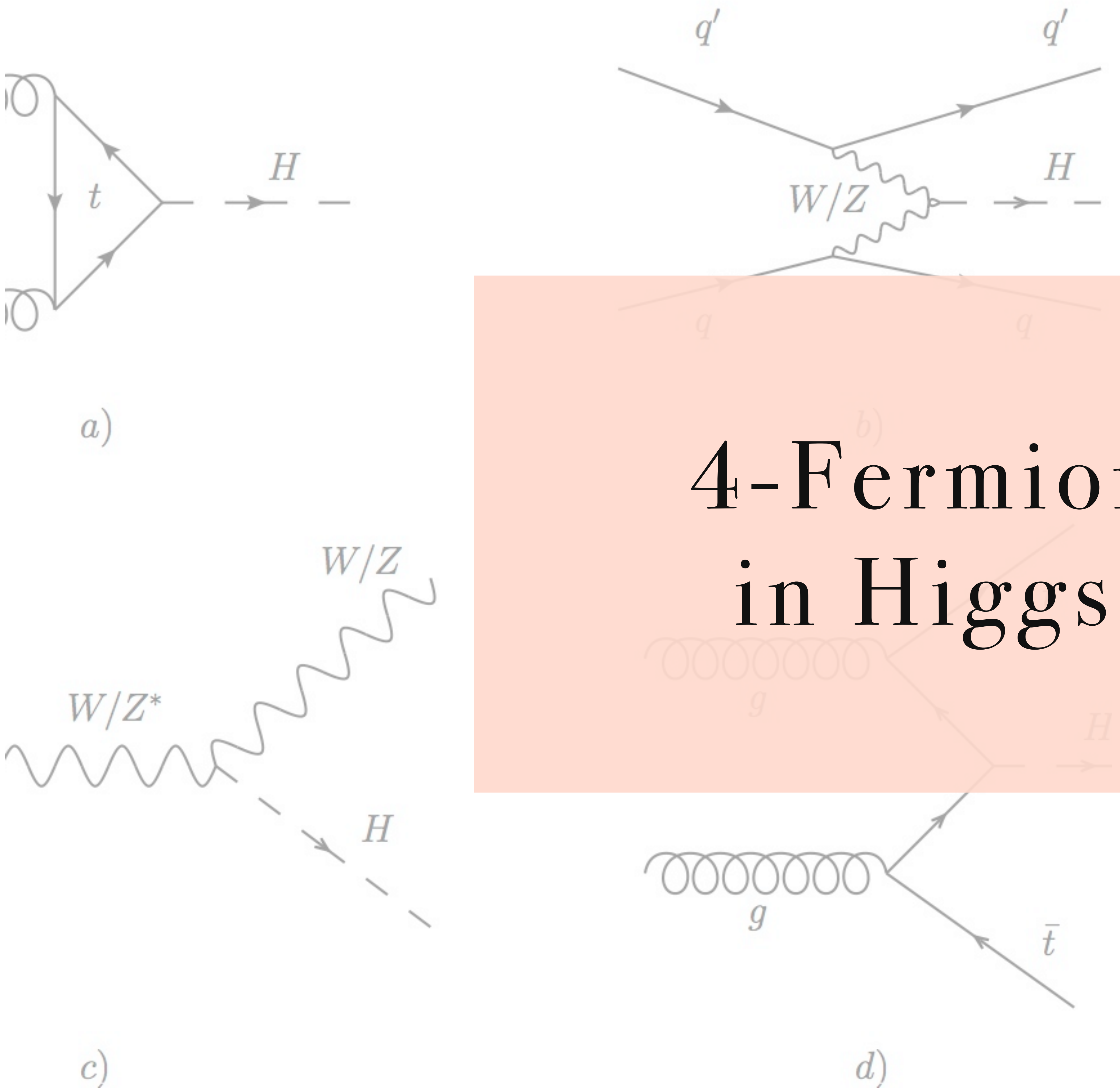
$$\kappa_\lambda = 1 - 2\frac{v^4}{M_h^2}\frac{C_\phi}{\Lambda^2} + 3C_H$$

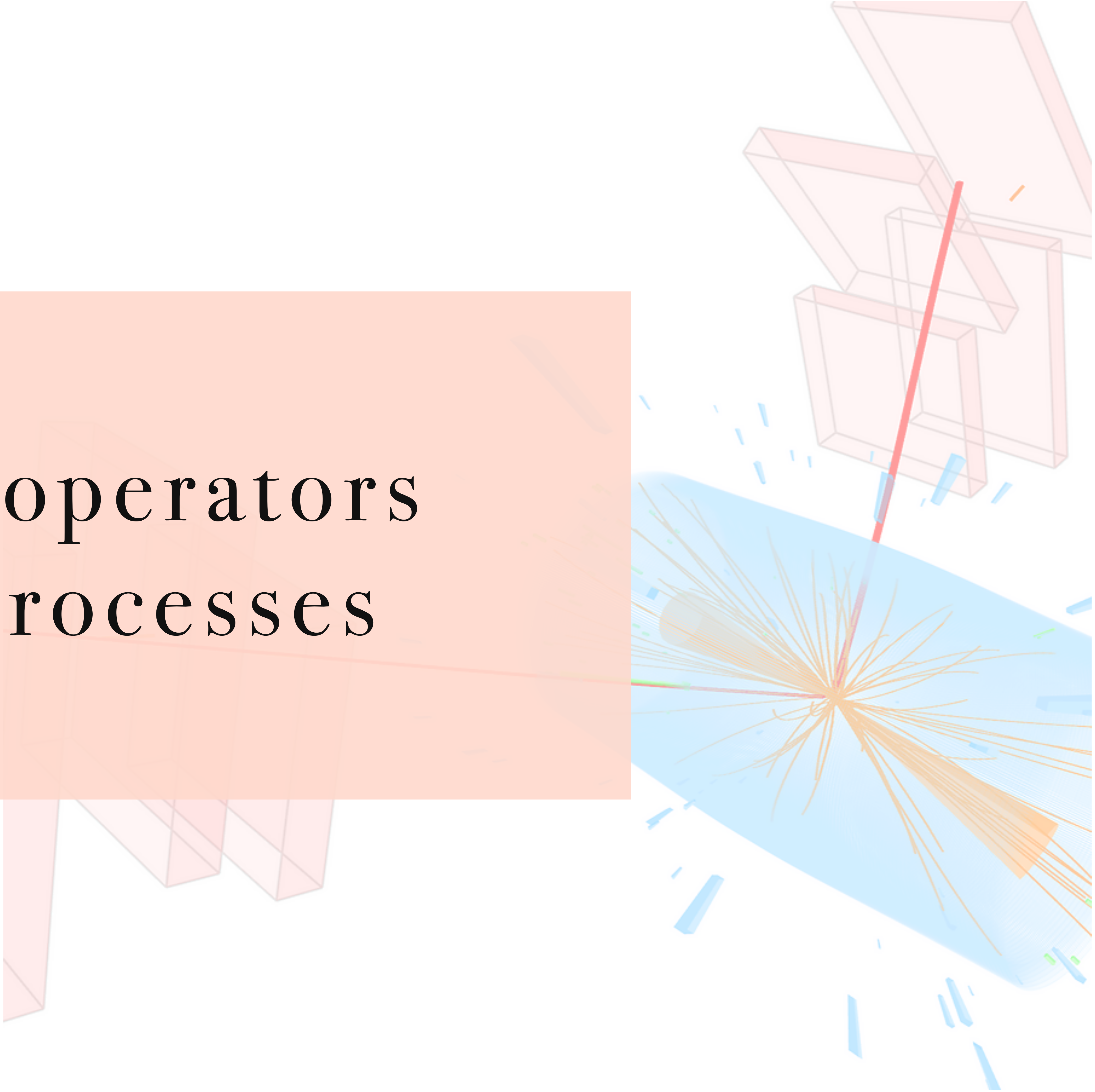
$$C_H = \frac{C_{H,\Box}}{\Lambda^2} - \frac{1}{4}\frac{C_{HD}}{\Lambda^2}$$

X^3		φ^6 and $\varphi^4 D^2$		$\psi^2\varphi^3$	
Q_G	$f^{ABC} G_\mu^{A\nu} G_\nu^{B\rho} G_\rho^{C\mu}$	Q_φ	$(\varphi^\dagger\varphi)^3$	$Q_{e\varphi}$	$(\varphi^\dagger\varphi)(\bar{l}'_p e'_r \varphi)$
$Q_{\widetilde{G}}$	$f^{ABC} \widetilde{G}_\mu^{A\nu} G_\nu^{B\rho} G_\rho^{C\mu}$	$Q_{\varphi\Box}$	$(\varphi^\dagger\varphi)\Box(\varphi^\dagger\varphi)$	$Q_{u\varphi}$	$(\varphi^\dagger\varphi)(\bar{q}'_p u'_r \widetilde{\varphi})$
Q_W	$\varepsilon^{IJK} W_\mu^{I\nu} W_\nu^{J\rho} W_\rho^{K\mu}$	$Q_{\varphi D}$	$\left(\varphi^\dagger D^\mu\varphi\right)^* \left(\varphi^\dagger D_\mu\varphi\right)$	$Q_{d\varphi}$	$(\varphi^\dagger\varphi)(\bar{q}'_p d'_r \varphi)$
$Q_{\widetilde{W}}$	$\varepsilon^{IJK} \widetilde{W}_\mu^{I\nu} W_\nu^{J\rho} W_\rho^{K\mu}$				
$X^2\varphi^2$		$\psi^2 X\varphi$		$\psi^2\varphi^2 D$	
$Q_{\varphi G}$	$\varphi^\dagger\varphi\, G_{\mu\nu}^A G^{A\mu\nu}$	Q_{eW}	$(\bar{l}'_p \sigma^{\mu\nu} e'_r)\tau^I \varphi W_{\mu\nu}^I$	$Q_{\varphi l}^{(1)}$	$(\varphi^\dagger i\overleftrightarrow{D}_\mu \varphi)(\bar{l}'_p \gamma^\mu l'_r)$
$Q_{\varphi\widetilde{G}}$	$\varphi^\dagger\varphi\, \widetilde{G}_{\mu\nu}^A G^{A\mu\nu}$	Q_{eB}	$(\bar{l}'_p \sigma^{\mu\nu} e'_r)\varphi B_{\mu\nu}$	$Q_{\varphi l}^{(3)}$	$(\varphi^\dagger i\overleftrightarrow{D}_\mu^I \varphi)(\bar{l}'_p \tau^I \gamma^\mu l'_r$
$Q_{\varphi W}$	$\varphi^\dagger\varphi\, W_{\mu\nu}^I W^{I\mu\nu}$	Q_{uG}	$(\bar{q}'_p \sigma^{\mu\nu} \mathcal{T}^A u'_r)\widetilde{\varphi}\, G_{\mu\nu}^A$	$Q_{\varphi e}$	$(\varphi^\dagger i\overleftrightarrow{D}_\mu \varphi)(\bar{e}'_p \gamma^\mu e'_r)$
$Q_{\varphi\widetilde{W}}$	$\varphi^\dagger\varphi\, \widetilde{W}_{\mu\nu}^I W^{I\mu\nu}$	Q_{uW}	$(\bar{q}'_p \sigma^{\mu\nu} u'_r)\tau^I \widetilde{\varphi}\, W_{\mu\nu}^I$	$Q_{\varphi q}^{(1)}$	$(\varphi^\dagger i\overleftrightarrow{D}_\mu \varphi)(\bar{q}'_p \gamma^\mu q'_r)$
$Q_{\varphi B}$	$\varphi^\dagger\varphi\, B_{\mu\nu} B^{\mu\nu}$	Q_{uB}	$(\bar{q}'_p \sigma^{\mu\nu} u'_r)\widetilde{\varphi}\, B_{\mu\nu}$	$Q_{\varphi q}^{(3)}$	$(\varphi^\dagger i\overleftrightarrow{D}_\mu^I \varphi)(\bar{q}'_p \tau^I \gamma^\mu q'_r$
$Q_{\varphi\widetilde{B}}$	$\varphi^\dagger\varphi\, \widetilde{B}_{\mu\nu} B^{\mu\nu}$	Q_{dG}	$(\bar{q}'_p \sigma^{\mu\nu} \mathcal{T}^A d'_r)\varphi\, G_{\mu\nu}^A$	$Q_{\varphi u}$	$(\varphi^\dagger i\overleftrightarrow{D}_\mu \varphi)(\bar{u}'_p \gamma^\mu u'_r$
$Q_{\varphi WB}$	$\varphi^\dagger\tau^I\varphi\, W_{\mu\nu}^I B^{\mu\nu}$	Q_{dW}	$(\bar{q}'_p \sigma^{\mu\nu} d'_r)\tau^I \varphi\, W_{\mu\nu}^I$	$Q_{\varphi d}$	$(\varphi^\dagger i\overleftrightarrow{D}_\mu \varphi)(\bar{d}'_p \gamma^\mu d'_r)$
$Q_{\varphi\widetilde{W}B}$	$\varphi^\dagger\tau^I\varphi\, \widetilde{W}_{\mu\nu}^I B^{\mu\nu}$	Q_{dB}	$(\bar{q}'_p \sigma^{\mu\nu} d'_r)\varphi\, B_{\mu\nu}$	$Q_{\varphi ud}$	$i(\widetilde{\varphi}^\dagger D_\mu\varphi)(\bar{u}'_p \gamma^\mu d'_r)$

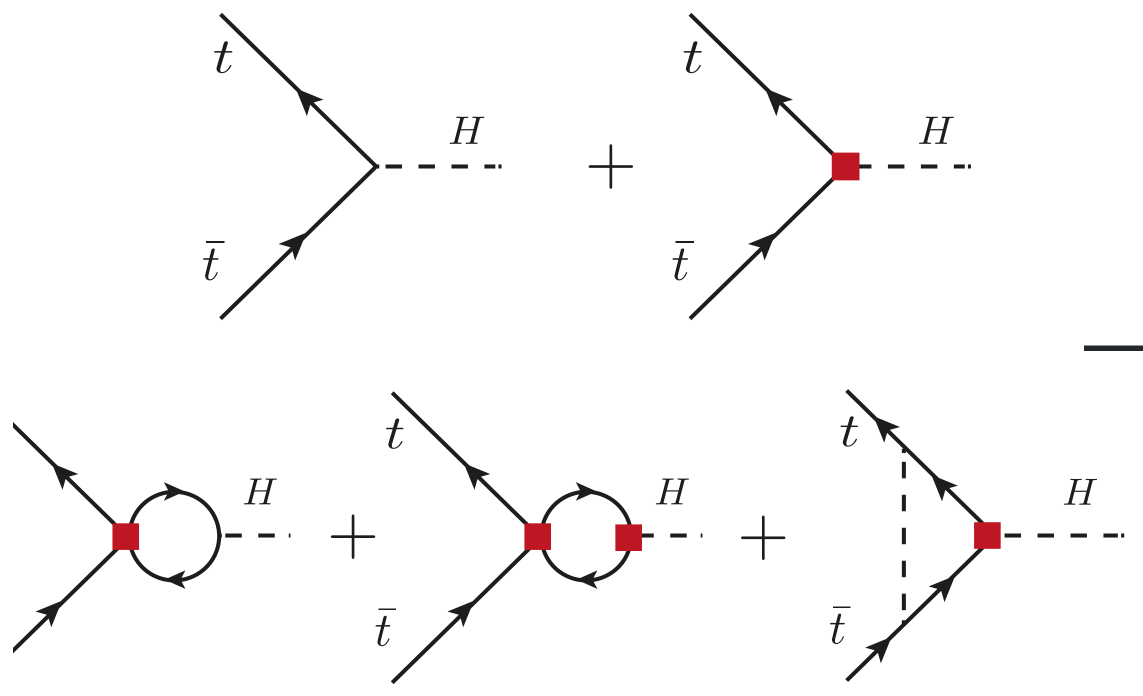
In order to preform the fits with SMEFT Wilson-coefficients in a consistent manner, we introduce a mapping that links the the SMEFT Wilson coefficients to κ_λ.

4-Fermion operators in Higgs processes





SMEFT RGE analysis

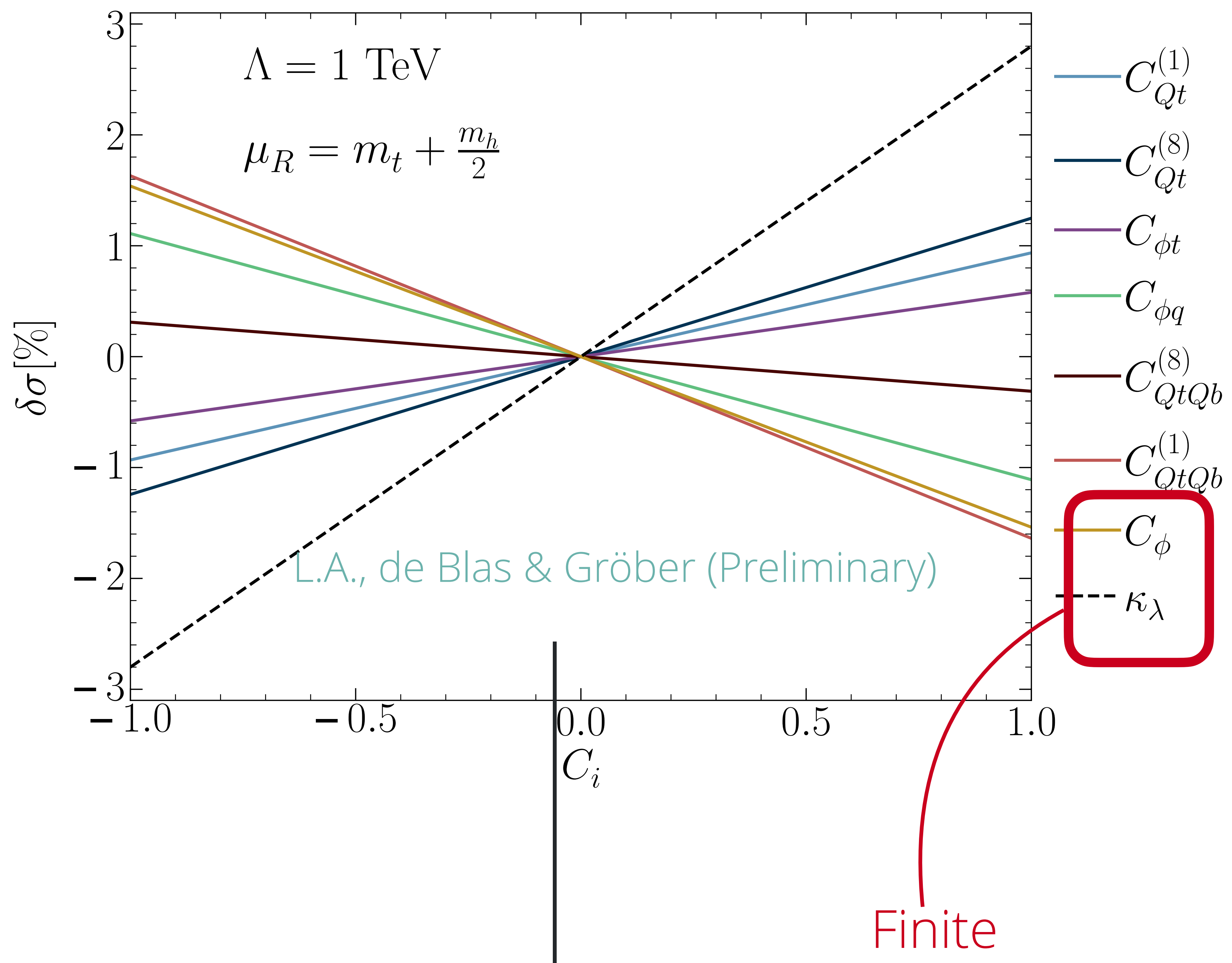


The top Yukawa is modified by SMEFT - same story for the bottom-.

$$-\mathcal{L}_{\phi tt} = y_t\,\bar{t}_R\tilde{\phi}q_L + \frac{C_{t\phi}}{\Lambda^2}\phi\phi^\dagger\,\bar{t}_R\tilde{\phi}q_L \text{ h.c.}$$

The mass becomes:

$$m_t = \frac{v}{\sqrt{2}}\left(y_t - \frac{v^2}{\sqrt{2}}\frac{C_{t\phi}}{\Lambda^2}\right).$$



Examining the SMEFT running of the top Yukawa modifier, we see that several of SMEFT Wilson-coefficient appear:

$$\mu\frac{dC_{t\phi}}{d\mu} = \frac{y_t^2}{16\pi^2}\left(2N_c C_{t\phi} - 2\left(C_{\phi Q}^{(1)} + (3-4N_c)C_{\phi Q}^{(3)}\right)y_t + 2C_{\phi t}\,y_t + C_{\phi t}\,y_t + 8\left(C_{Qt}^{(1)} + \langle C_F\rangle C_{Qt}^{(8)}\right)y_t\right)$$

And for the bottom quark, considering the most relevant

$$\mu\frac{dC_{b\phi}}{d\mu} = \frac{y_t^2}{16\pi^2}\left(-2\left((2N_c+1)\,C_{QtQb}^{(1)*} + \langle C_F\rangle C_{QtQb}^{(8)*}\right)y_t\right)$$

The RGE correction by the 4-heavy quark operators to Higgs processes via the top/bottom Yukawa is significant.

Moreover, these operators' Wilson coefficients themselves are weakly constrained

Hartland et al. '19, Degrande et al. '20, Ethier et al. '21 ATLAS '18 and CMS '20.

Four-heavy-quark operators in single Higgs rates.

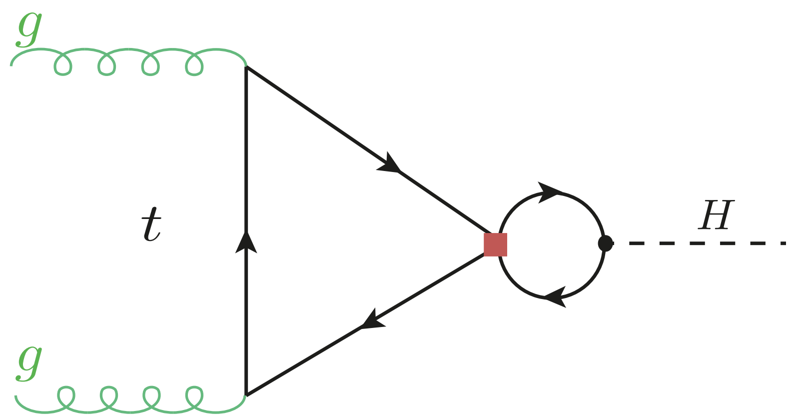
$(\bar{L}L)(\bar{L}L)$		$(\bar{R}R)(\bar{R}R)$		$(\bar{L}L)(\bar{R}R)$	
Q_{ll}	$(\bar{l}'_p\gamma_\mu l'_r)(\bar{l}'_s\gamma^\mu l'_t)$	Q_{ee}	$(\bar{e}'_p\gamma_\mu e'_r)(\bar{e}'_s\gamma^\mu e'_t)$	Q_{le}	$(\bar{l}'_p\gamma_\mu l'_r)(\bar{e}'_s\gamma^\mu e'_t)$
$Q_{qq}^{(1)}$	$(\bar{q}'_p\gamma_\mu q'_r)(\bar{q}'_s\gamma^\mu q'_t)$	Q_{uu}	$(\bar{u}'_p\gamma_\mu u'_r)(\bar{u}'_s\gamma^\mu u'_t)$	Q_{lu}	$(\bar{l}'_p\gamma_\mu l'_r)(\bar{u}'_s\gamma^\mu u'_t)$
$Q_{qq}^{(3)}$	$(\bar{q}'_p\gamma_\mu\tau^I q'_r)(\bar{q}'_s\gamma^\mu\tau^I q'_t)$	Q_{dd}	$(\bar{d}'_p\gamma_\mu d'_r)(\bar{d}'_s\gamma^\mu d'_t)$	Q_{ld}	$(\bar{l}'_p\gamma_\mu l'_r)(\bar{d}'_s\gamma^\mu d'_t)$
$Q_{lq}^{(1)}$	$(\bar{l}'_p\gamma_\mu l'_r)(\bar{q}'_s\gamma^\mu q'_t)$	Q_{eu}	$(\bar{e}'_p\gamma_\mu e'_r)(\bar{u}'_s\gamma^\mu u'_t)$	Q_{qe}	$(\bar{q}'_p\gamma_\mu q'_r)(\bar{e}'_s\gamma^\mu e'_t)$
$Q_{lq}^{(3)}$	$(\bar{l}'_p\gamma_\mu\tau^I l'_r)(\bar{q}'_s\gamma^\mu\tau^I q'_t)$	Q_{ed}	$(\bar{e}'_p\gamma_\mu e'_r)(\bar{d}'_s\gamma^\mu d'_t)$	$Q_{qu}^{(1)}$	$(\bar{q}'_p\gamma_\mu q'_r)(\bar{u}'_s\gamma^\mu u'_t)$
		$Q_{ud}^{(1)}$	$(\bar{u}'_p\gamma_\mu u'_r)(\bar{d}'_s\gamma^\mu d'_t)$	$Q_{qu}^{(8)}$	$(\bar{q}'_p\gamma_\mu\mathcal{T}^A q'_r)(\bar{u}'_s\gamma^\mu\mathcal{T}^A u'_t)$
		$Q_{ud}^{(8)}$	$(\bar{u}'_p\gamma_\mu\mathcal{T}^A u'_r)(\bar{d}'_s\gamma^\mu\mathcal{T}^A d'_t)$	$Q_{qd}^{(1)}$	$(\bar{q}'_p\gamma_\mu q'_r)(\bar{d}'_s\gamma^\mu d'_t)$
				$Q_{qd}^{(8)}$	$(\bar{q}'_p\gamma_\mu\mathcal{T}^A q'_r)(\bar{d}'_s\gamma^\mu\mathcal{T}^A d'_t)$

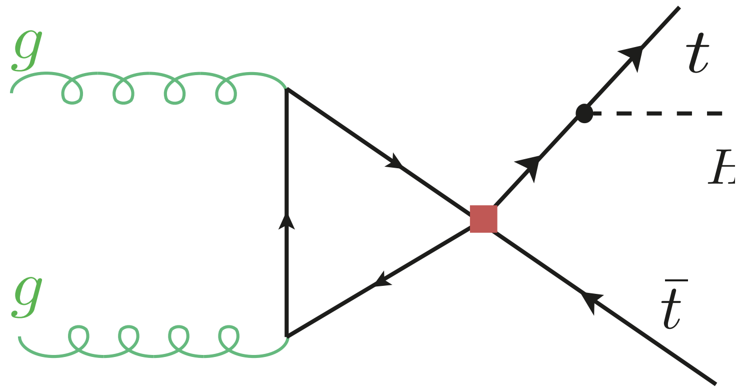
$(\bar{L}R)(\bar{R}L)$ and $(\bar{L}R)(\bar{L}R)$		B-violating	
Q_{ledq}	$(\bar{l}'^j_p e'_r)(\bar{d}'_s q'^j_t)$	Q_{duq}	$\varepsilon^{\alpha\beta\gamma}\varepsilon_{jk}\left[(d'^\alpha_p)^T\mathbb{C}u'^\beta_r\right]\left[(q'^{\gamma j}_s)^T\mathbb{C}l'^k_t\right]$
$Q_{quqd}^{(1)}$	$(\bar{q}'^j_p u'_r)\varepsilon_{jk}(\bar{q}'^k_s d'_t)$	Q_{qqu}	$\varepsilon^{\alpha\beta\gamma}\varepsilon_{jk}\left[(q'^{\alpha j}_p)^T\mathbb{C}q'^{\beta k}_r\right]\left[(u'^\gamma_s)^T\mathbb{C}e'_t\right]$
$Q_{quqd}^{(8)}$	$(\bar{q}'^j_p\mathcal{T}^A u'_r)\varepsilon_{jk}(\bar{q}'^k_s\mathcal{T}^A d'_t)$	Q_{qqq}	$\varepsilon^{\alpha\beta\gamma}\varepsilon_{jn}\varepsilon_{km}\left[(q'^{\alpha j}_p)^T\mathbb{C}q'^{\beta k}_r\right]\left[(q'^{\gamma m}_s)^T\mathbb{C}l'^n_t\right]$
$Q_{lequ}^{(1)}$	$(\bar{l}'^j_p e'_r)\varepsilon_{jk}(\bar{q}'^k_s u'_t)$	Q_{duu}	$\varepsilon^{\alpha\beta\gamma}\left[(d'^\alpha_p)^T\mathbb{C}u'^\beta_r\right]\left[(u'^\gamma_s)^T\mathbb{C}e'_t\right]$
$Q_{lequ}^{(3)}$	$(\bar{l}'^j_p\sigma_{\mu\nu}e'_r)\varepsilon_{jk}(\bar{q}'^k_s\sigma^{\mu\nu}u'_t)$		

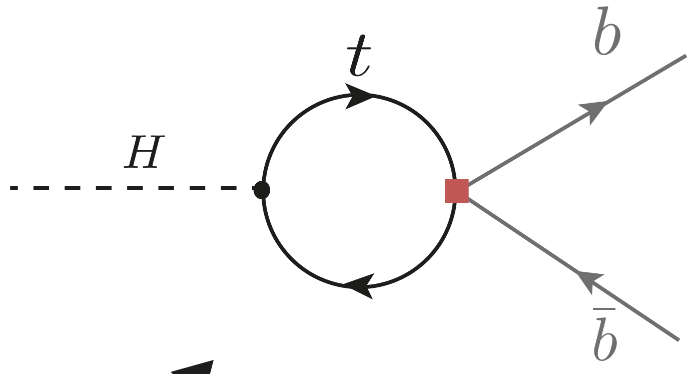
Full NLO calculation with these 4-heavy quark operators was carried out

The gluon fusion, and $h \to \gamma\gamma$ @ 2 loop and the decay $h \to b\bar{b}$ @ 1 loop were calculated manually.

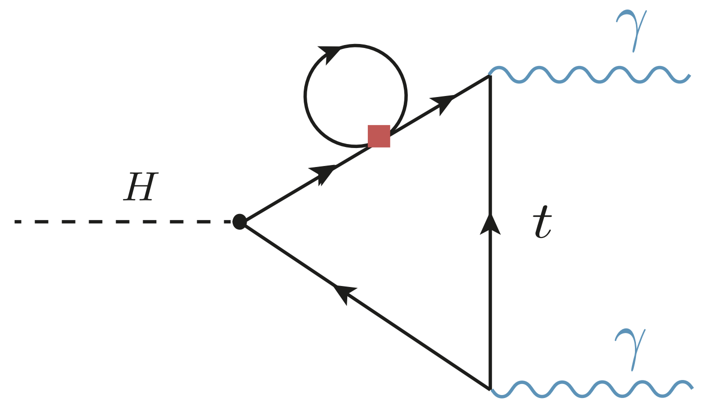
For $t\bar{t}h$ a modified SMEFT@NLO model was used to cross-check the manual calculation @ 1loop with MadGraph.



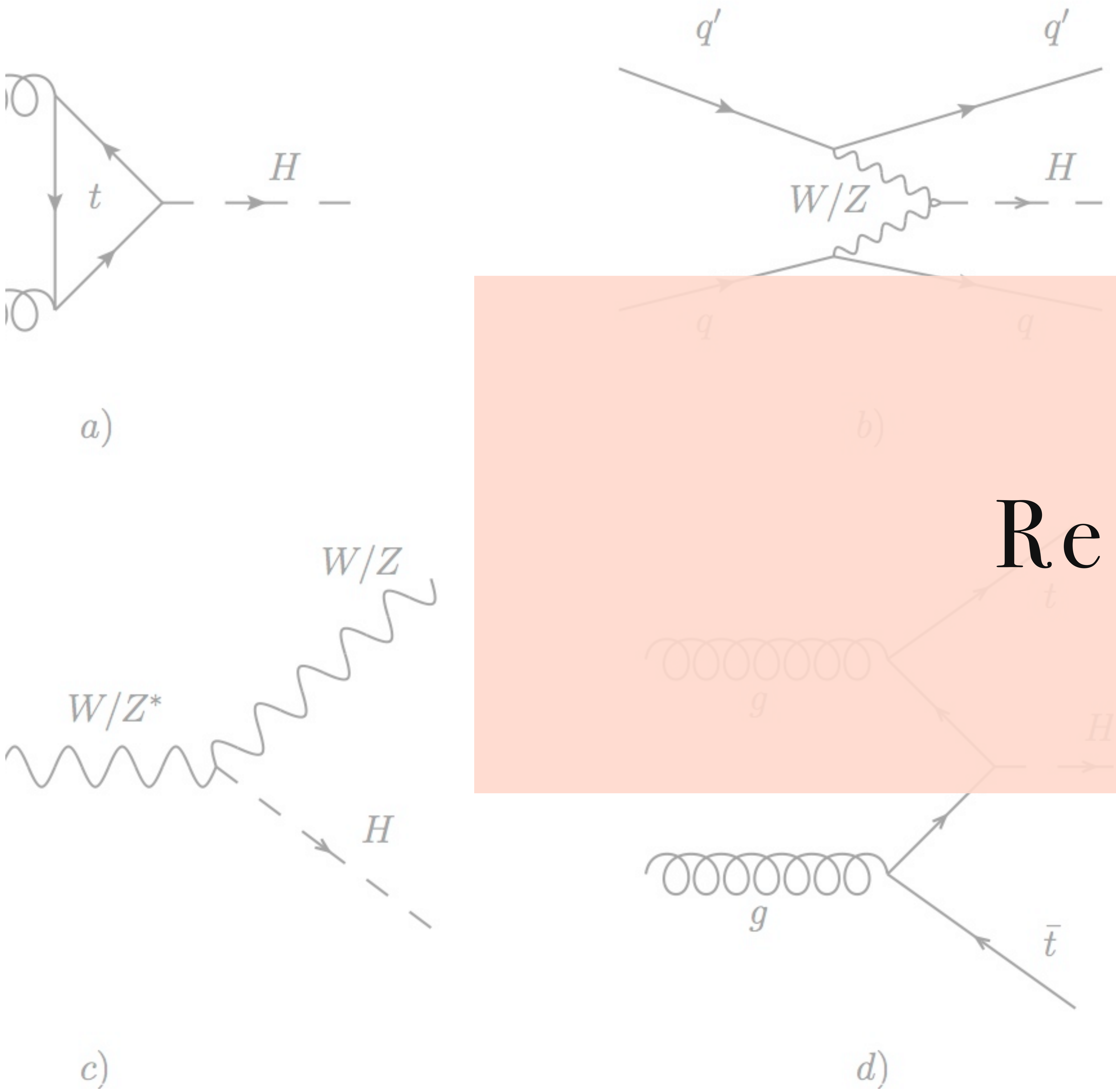


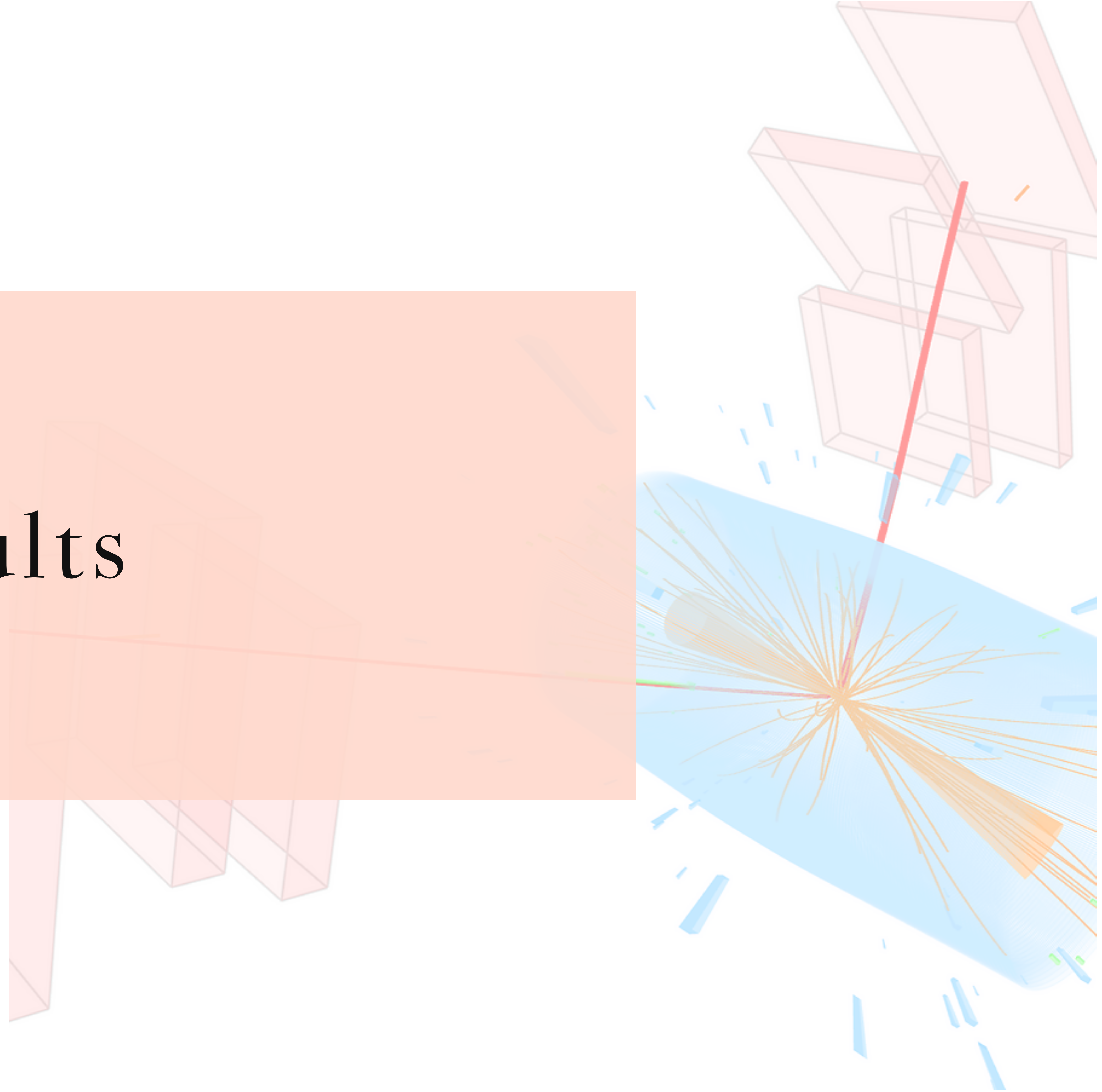


Cross-checked with Gauld, Becjak and Scott '16



Results





NLO Calculation results

Doing the NLO calculations, we find the Higgs rate correction dependence on the 4-heavy quark Wilson coefficients to be

L.A., de Blas & Gröber (Preliminary)

$\delta R(C_i)\cdot 10^{-2}$	$C_{Qt}^{(1)}$	$C_{Qt}^{(8)}$	$C_{QtQb}^{(1)}$	$C_{QtQb}^{(8)}$
ggF/ $gg \to h$	0.950	1.267	-2.230	-0.425
$t\bar{t}h$	-31.390	4.250	-0.781	0.315
$h \to \gamma\gamma$	-0.291	-0.388	0.173	0.033
$h \to b\bar{b}$	——	——	-59.035	-11.029

Degrassi et al '16

$\delta R(C_i)\cdot 10^{-2}$	C_ϕ
ggF/ $gg \to h$	-0.31
$t\bar{t}h$	-1.64
$gg \to \gamma$	-0.23
$gg \to b\bar{b}$	0.00
$gg \to W^+W^-$	-0.34
$gg \to ZZ$	-0.39
$pp \to Zh$	-0.56
$pp \to W^\pm h$	-0.48
VBF	-0.30

Compared to C_ϕ, we observe that the NLO corrections to Higgs rates from 4-heavy quark coefficients are overall large.

Higgs Rate correction

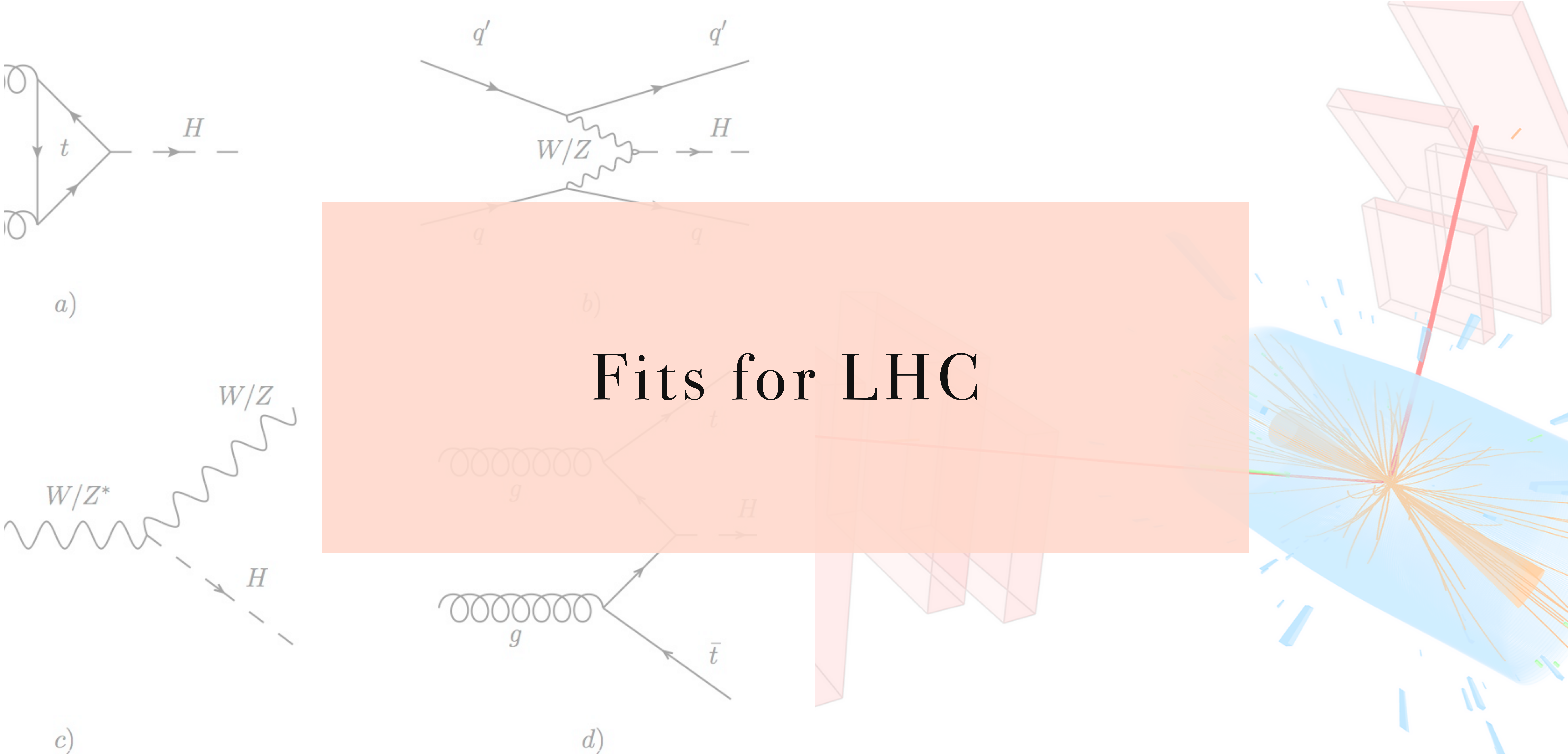
We adopt the definition of Degrassi et al. '16 for the Higgs rates dependence on Wilson-coefficients δR:

$$\delta\sigma = \frac{\sum_{ij}\int dx_1 dx_2 f_i(x_1) f_j(x_2) 2\Re(\mathcal{M}_{NLO}(C_i)\mathcal{M}_{LO})}{\sum_{ij}\int dx_1 dx_2 f_i(x_1) f_j(x_2)|\mathcal{M}_{LO}|^2},$$

$$\delta\Gamma = \frac{\int d\Phi 2\Re(\mathcal{M}_{NLO}(C_i)\mathcal{M}_{LO})}{\int d\Phi|\mathcal{M}_{LO}|^2}.$$

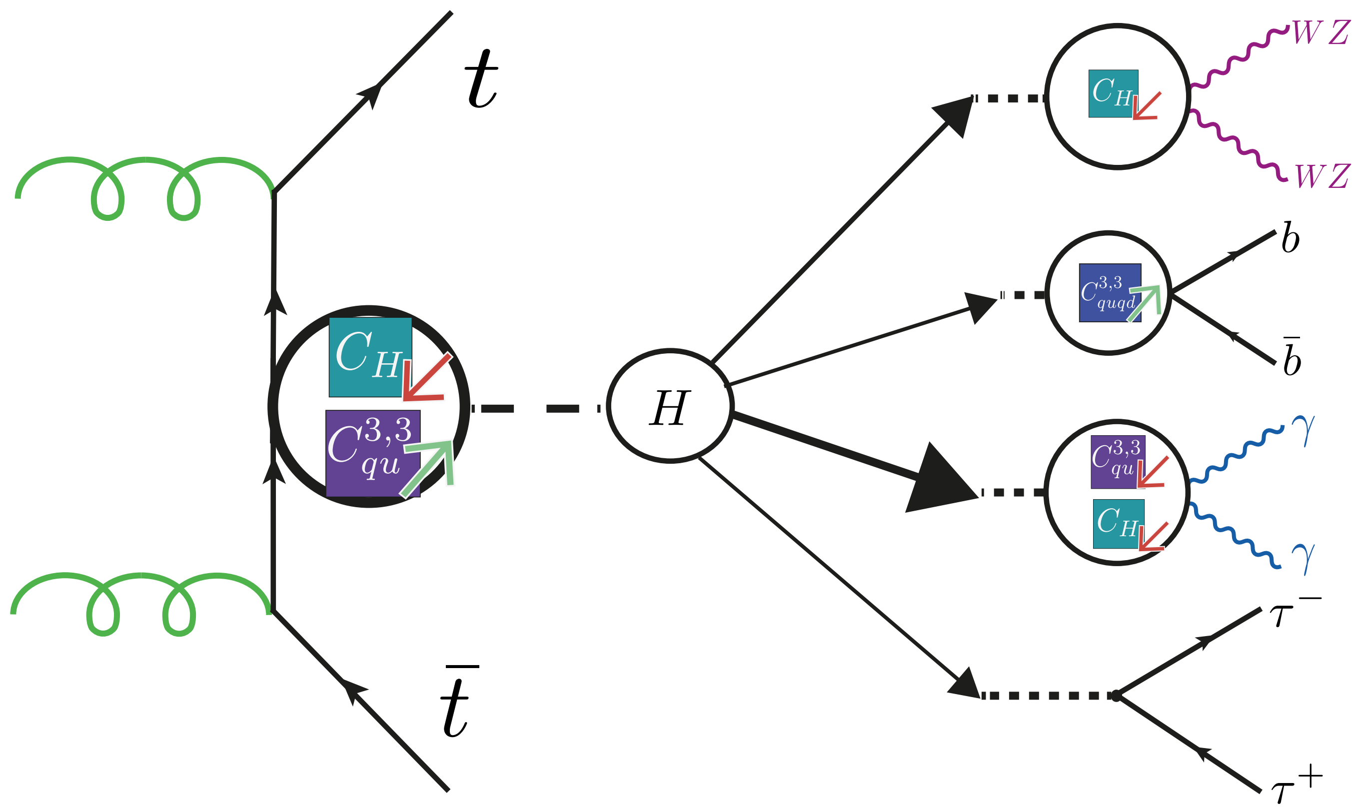
The finite contributions are significant, particularly for $t\bar{t}h$. Hence, the use of RGE analysis in the fit won't be sufficient.

Fits for LHC



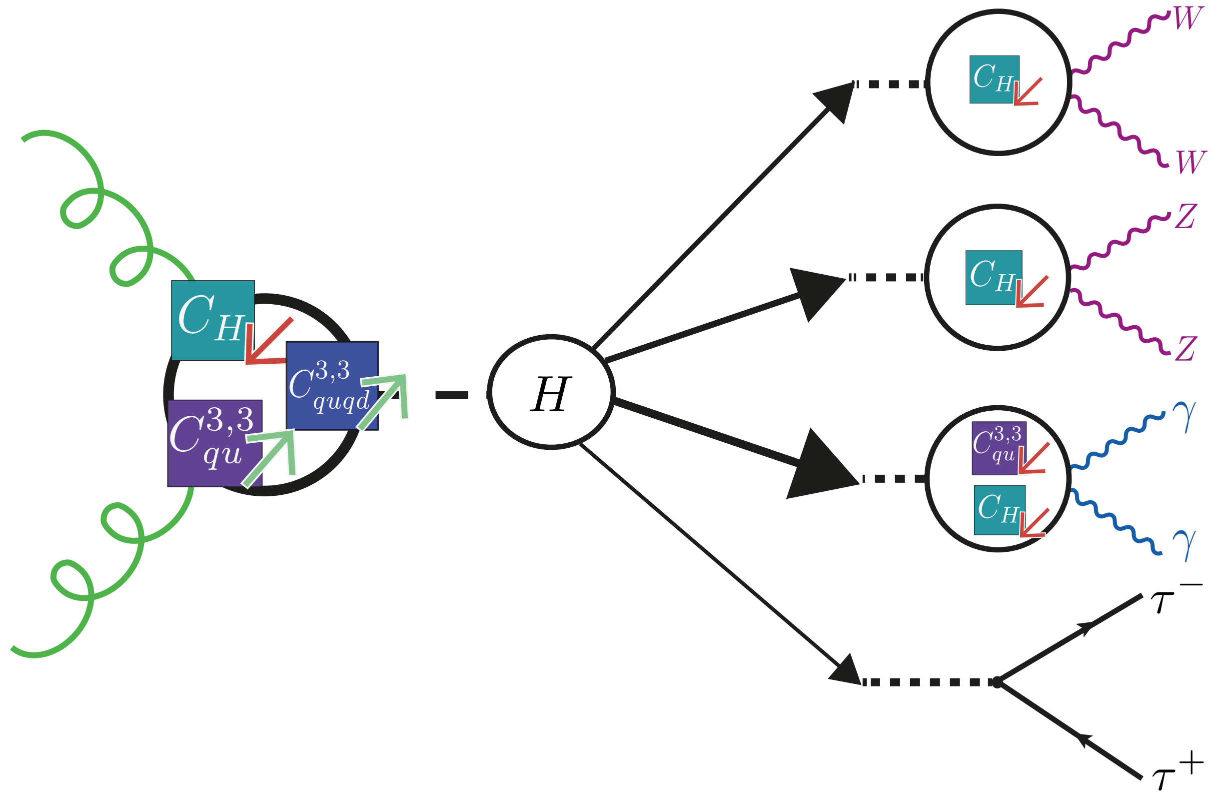
Experimental input

$t\bar{t}h$

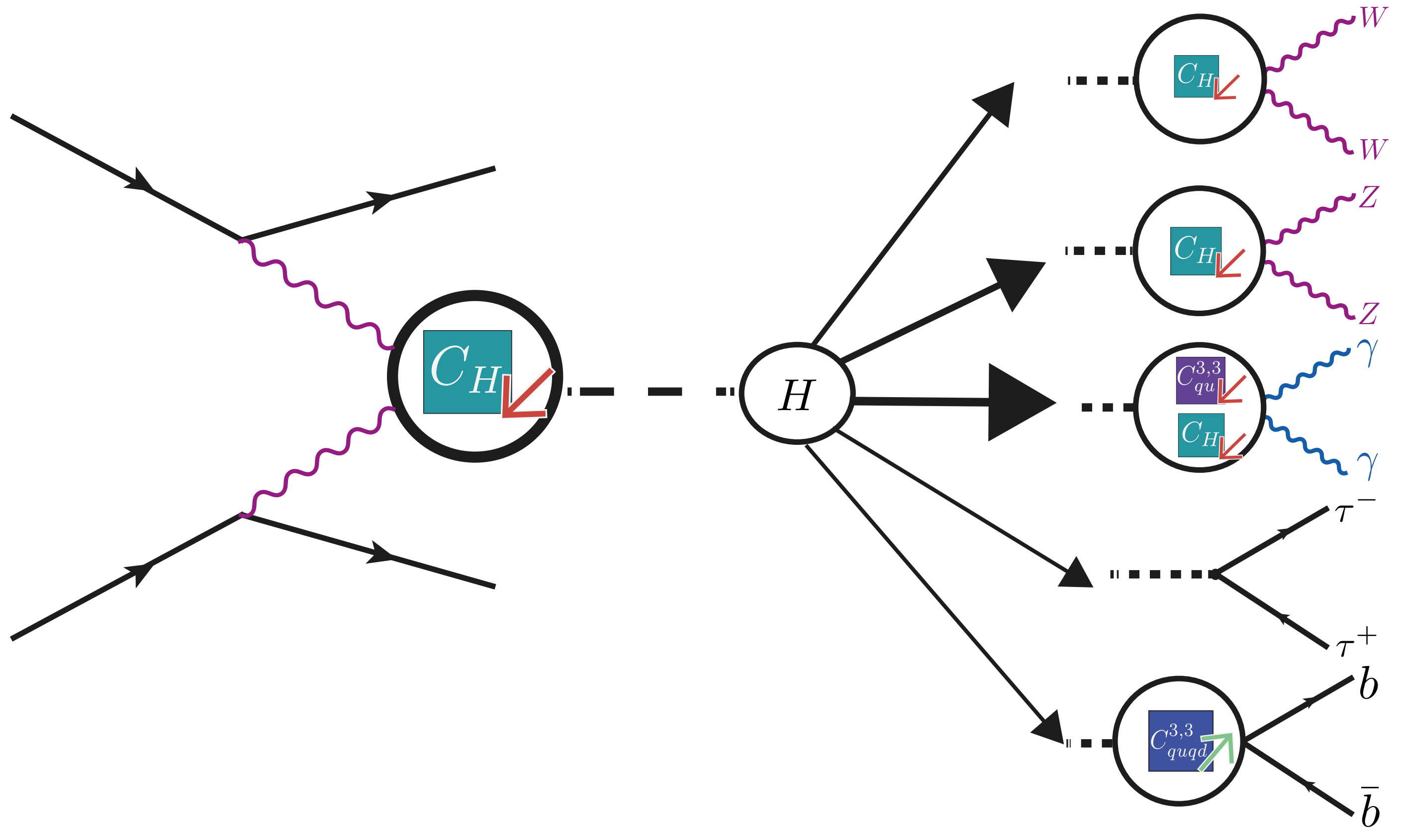


We use Run-II inclusive Higgs measurements from both CMS ($137\ \mathrm{fb}^{-1}$) and ATLAS ($139\ \mathrm{fb}^{-1}$)

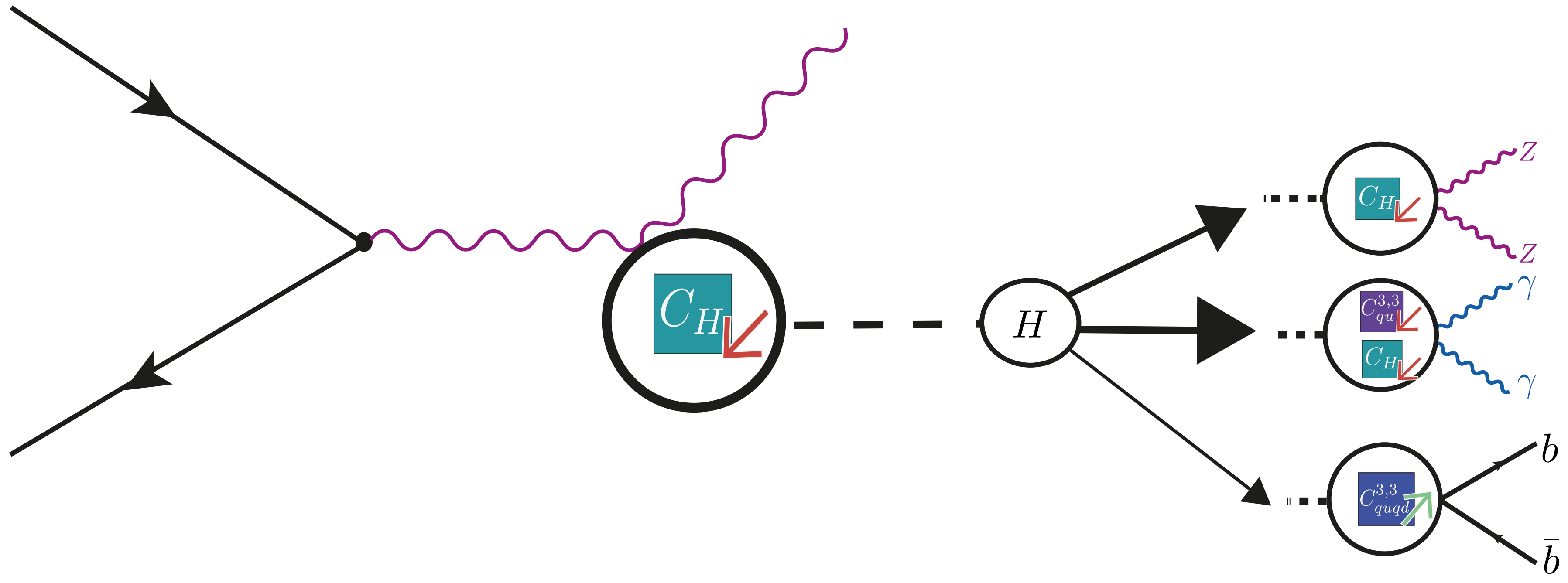
ggF



VBF



Vh



2 parameter fits

Trilinear coupling schemes λ_3:

There are two possibilities to define the Higgs rates as a function of C_ϕ .

The first is the **resummed** definition

$$\Sigma_{\lambda_3} = -2\frac{C_\phi v^2}{\Lambda^2 m_h^2} C_1 + \left(-4\frac{C_\phi v^4}{\Lambda^2 m_h^2} + 4\frac{C_\phi^2 v^8}{m_h^2 \Lambda^4}\right) C_2$$

Where $C_2 = \dfrac{\delta Z_h}{1 + \left(4\frac{C_\phi v^4}{\Lambda^2 m_h^2} - 4\frac{C_\phi^2 v^8}{m_h^2 \Lambda^4}\right)\delta Z_H}$,

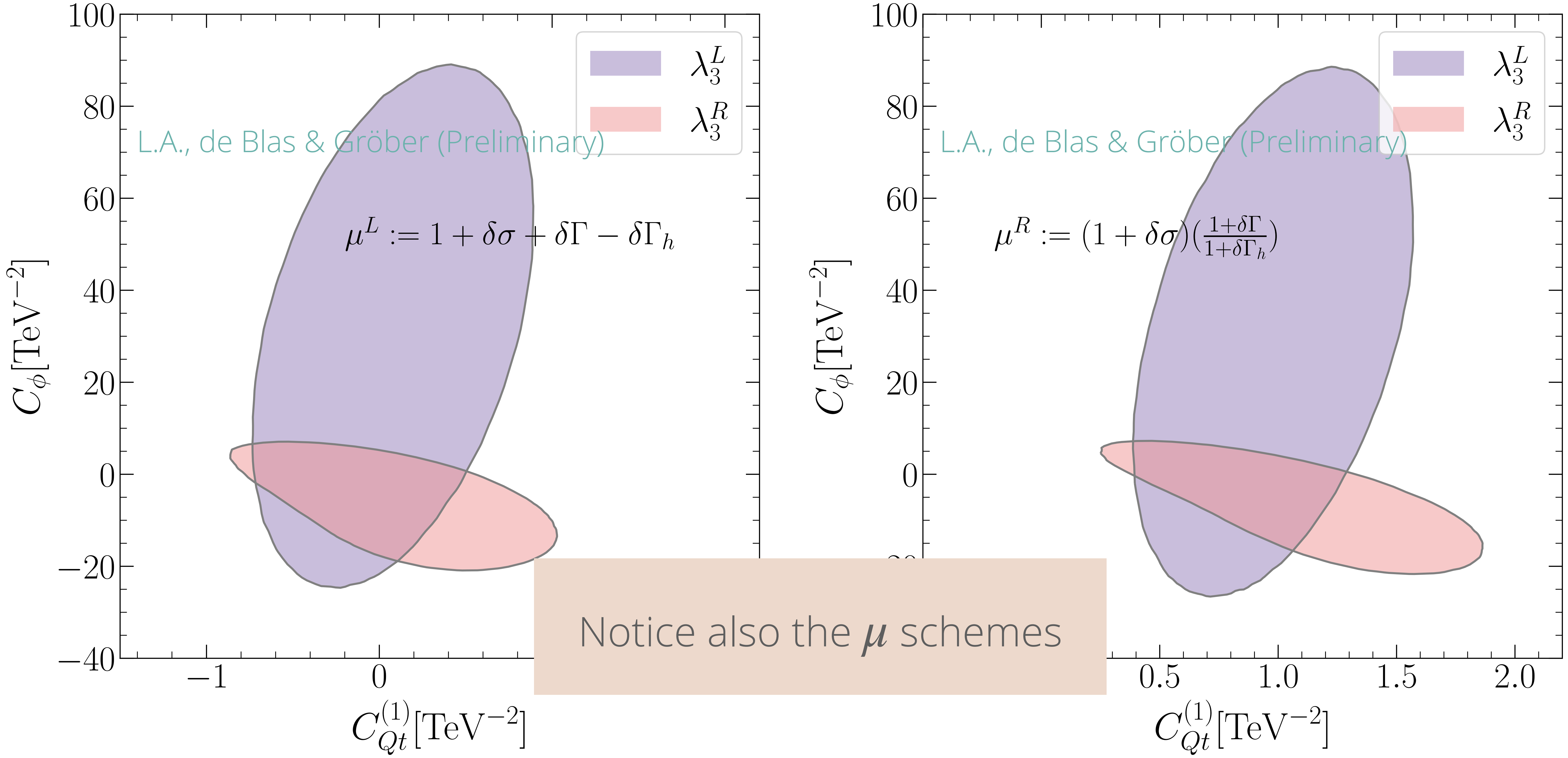
and $\delta Z_h = -\dfrac{9}{16}\dfrac{G_F m_h^2}{\sqrt{2}\pi^2}\left(\dfrac{2\pi}{3\sqrt{3}} - 1\right)$.

While the second is the **linear** SMEFT :

$$\Sigma_{\lambda_3} = -2\frac{C_\phi v^2}{\Lambda^2 m_h^2} C_1 - 4\frac{C_\phi v^4 \delta Z_h}{\Lambda^2 m_h^2}$$

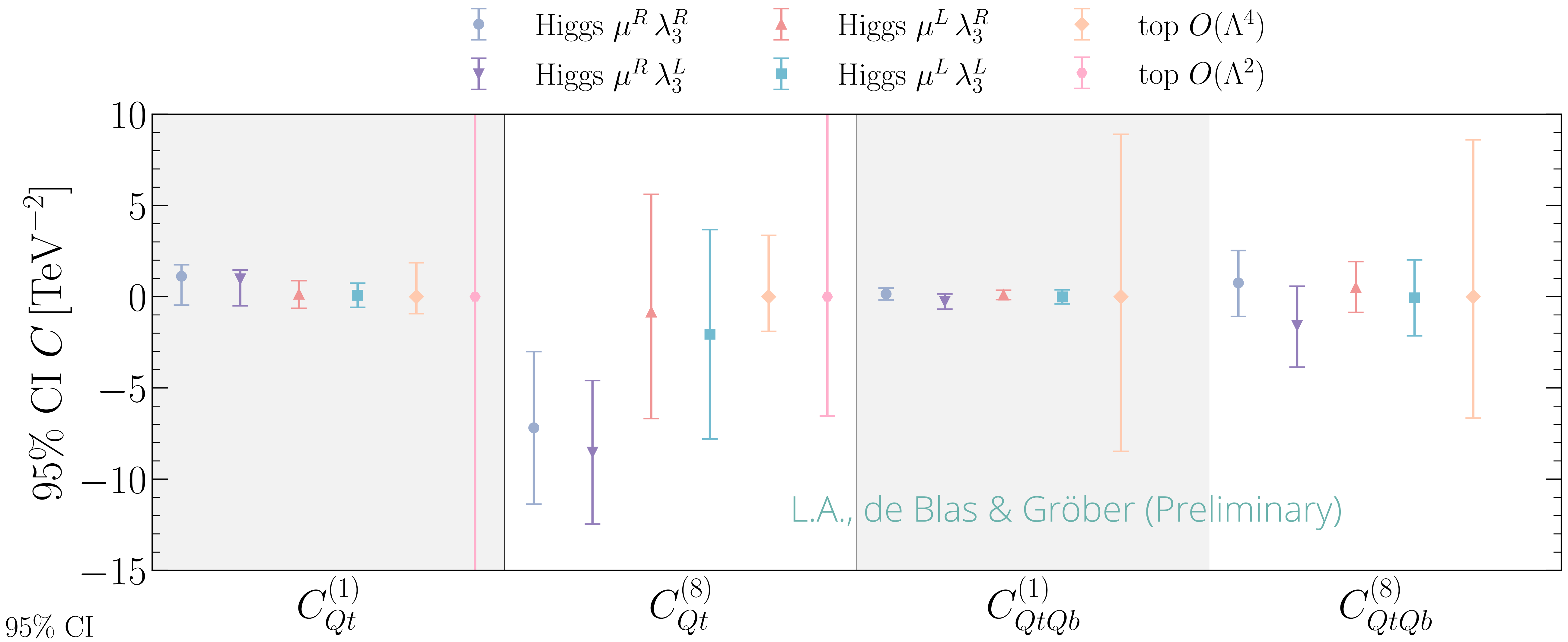
The fit highly depend on which λ_3 scheme that is used in it.

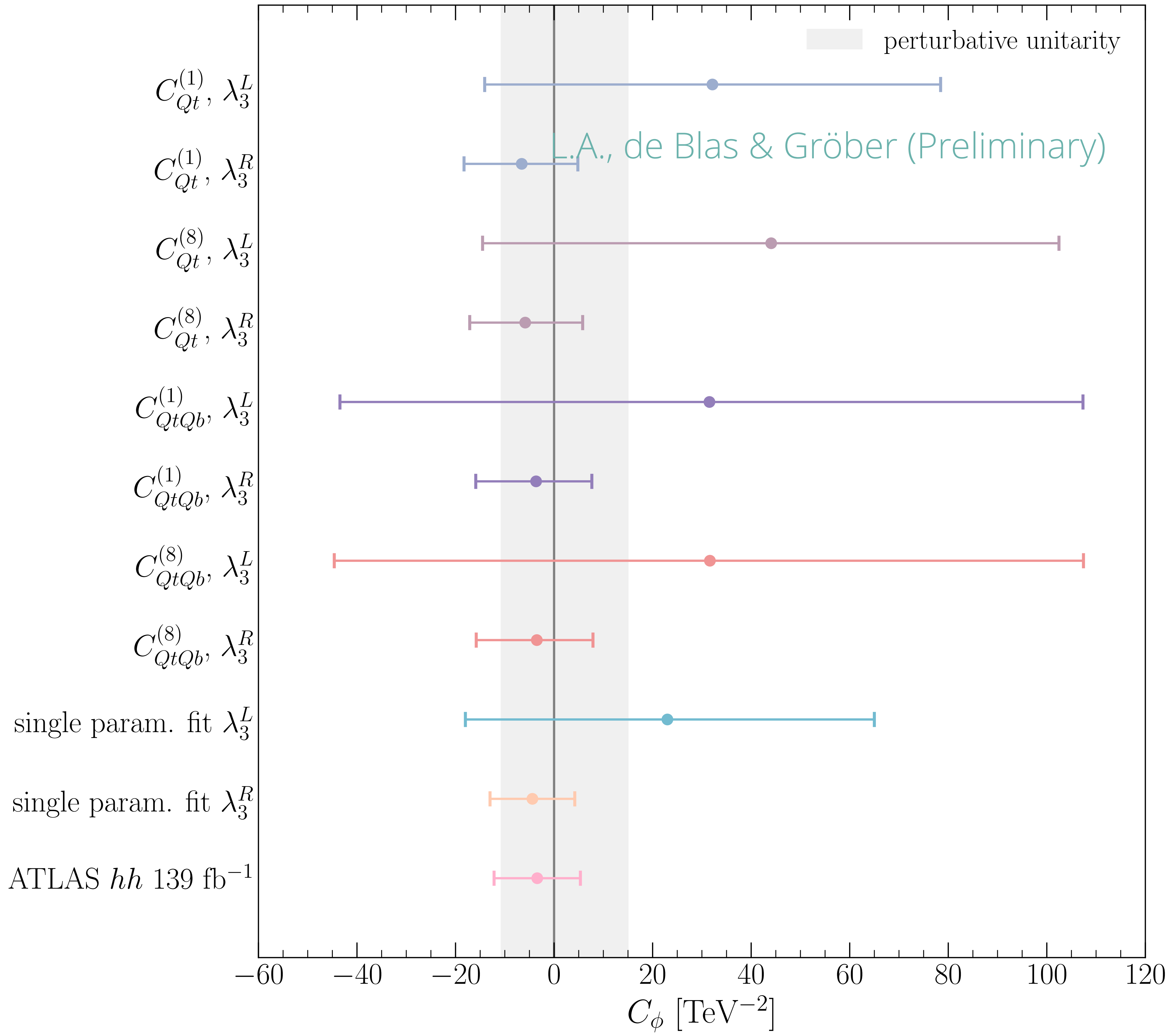
An MCMC-based Bayesian fit was conducted with a Likelihood build from C_ϕ and a 4-Fermion Wilson coefficient .



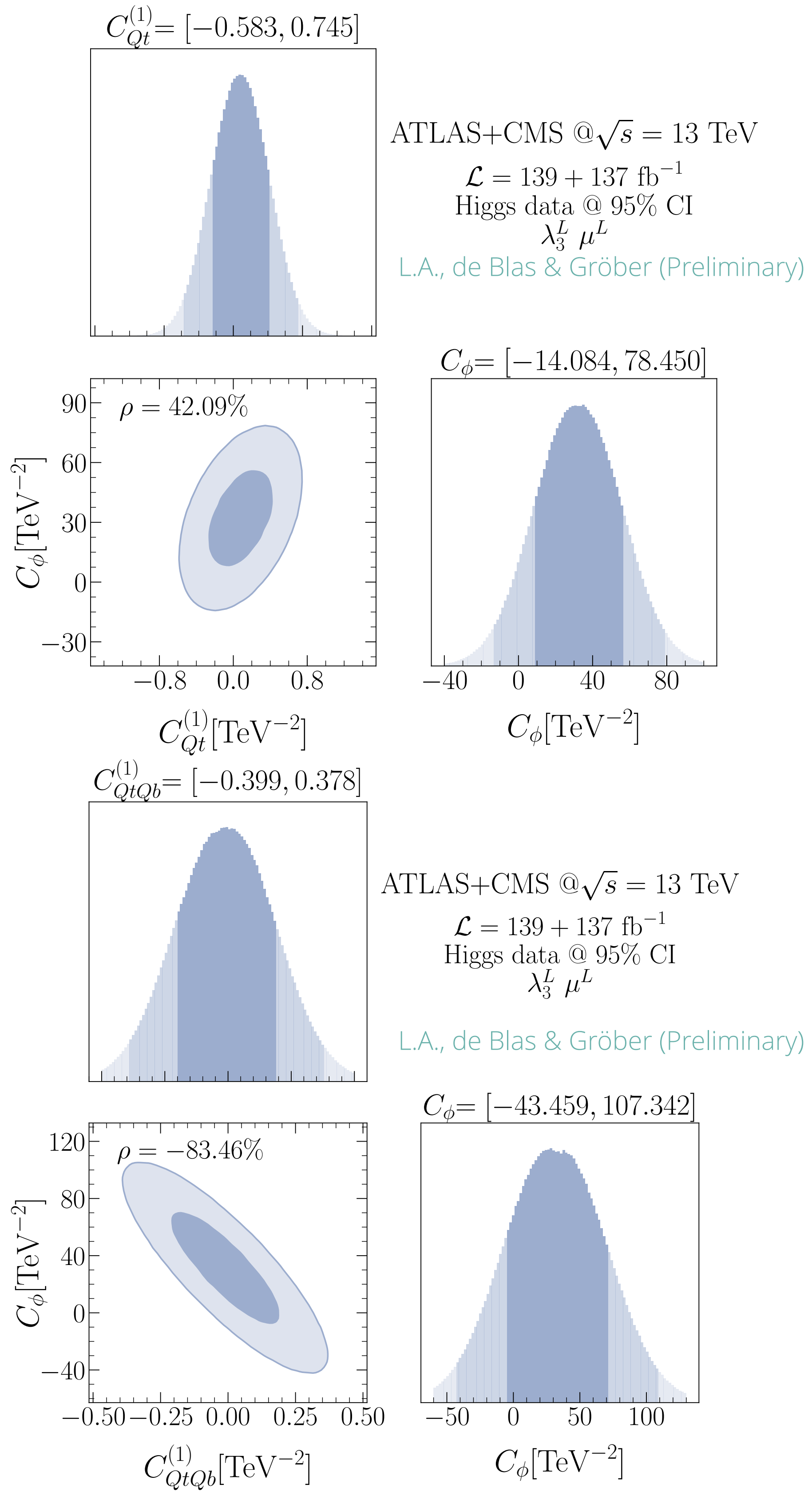
Notice also the μ schemes

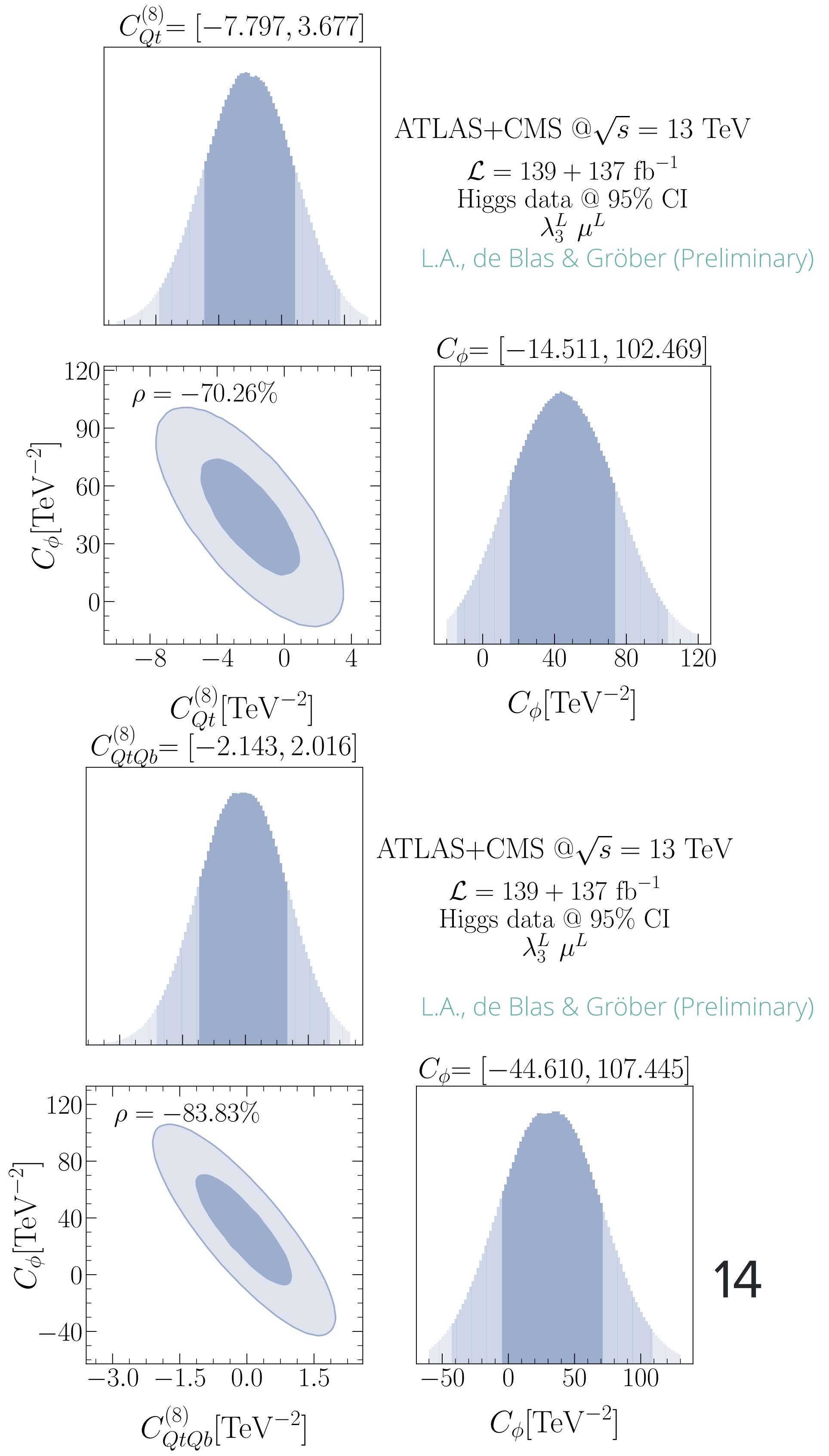
2 parameter fits summary



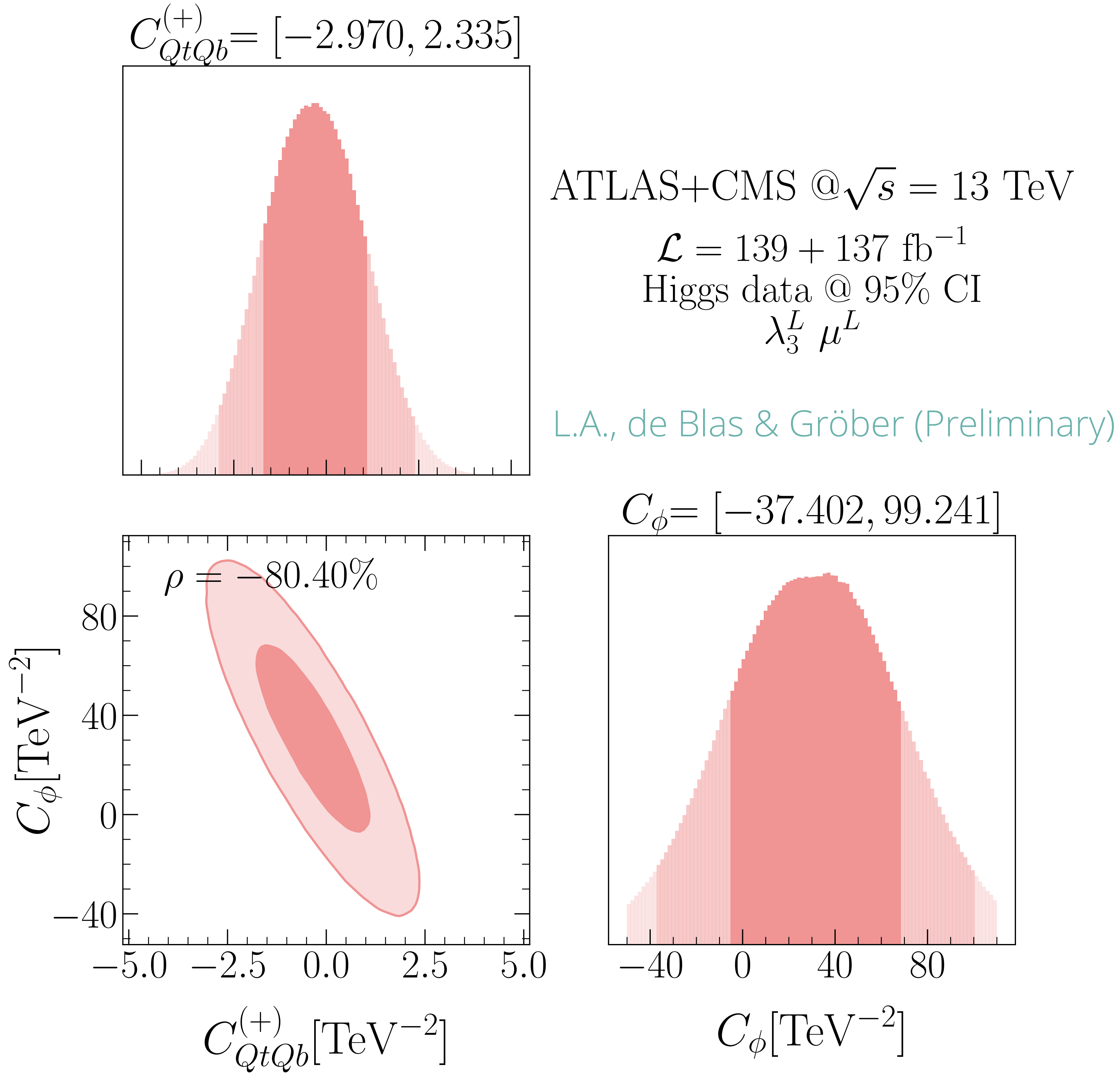


	$\langle C_\phi \rangle$	95% CI
$C_{Qt}^{(1)}$, λ_3^L	32.137	[-14.084, 78.45]
$C_{Qt}^{(1)}$, λ_3^R	-6.566	[-18.277, 4.826]
$C_{Qt}^{(8)}$, λ_3^L	44.066	[-14.511, 102.469]
$C_{Qt}^{(8)}$, λ_3^R	-5.857	[-17.118, 5.802]
$C_{QtQb}^{(1)}$, λ_3^L	31.531	[-43.459, 107.342]
$C_{QtQb}^{(1)}$, λ_3^R	-3.648	[-15.895, 7.665]
$C_{QtQb}^{(8)}$, λ_3^L	31.628	[-44.61, 107.445]
$C_{QtQb}^{(8)}$, λ_3^R	-3.502	[-15.798, 7.895]
single param. fit λ_3^L	23.0	[-18.0, 65.0]
single param. fit λ_3^R	-4.4	[-13.0, 4.2]
ATLAS hh 139 fb^{-1}	-3.419	[-12.179, 5.342]





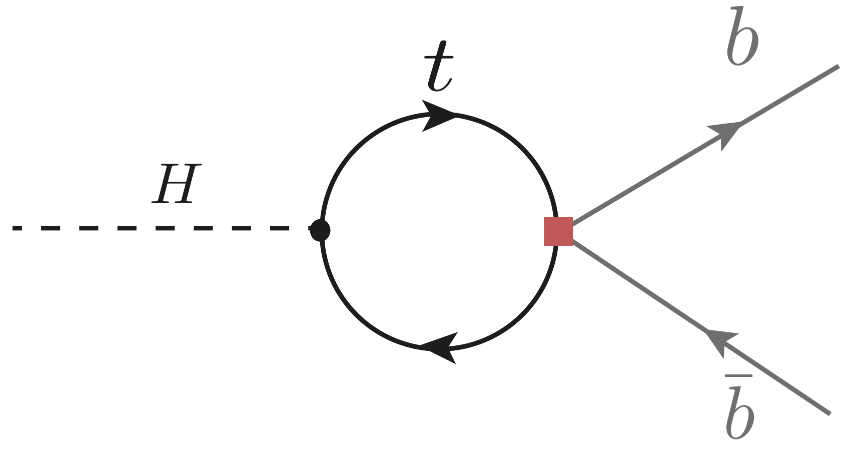
Alternative Wilson coefficients



To capture the actual d.o.f we are constraining. We have defined new coefficients:

$$C^{\pm}_{QtQb} = (2N_c + 1)C^{(1)}_{QtQb} \pm c_F C^{(8)}_{QtQb},$$

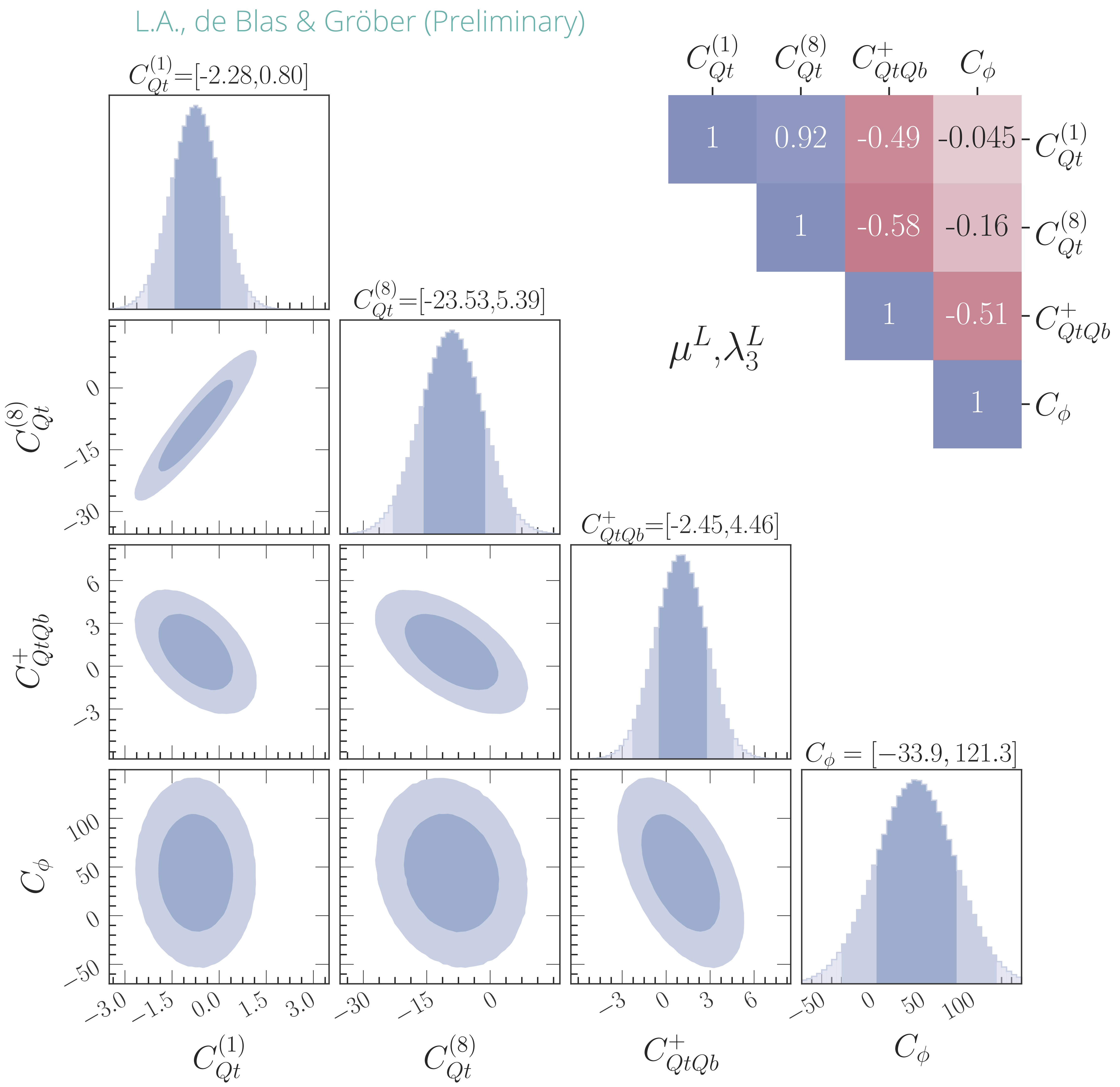
where only C^{+}_{QtQb} could be constrained.



$$\frac{\Gamma_{h\to b\bar{b}}}{\Gamma^{\rm SM}_{h\to b\bar{b}}} = 1 + \frac{1}{16\pi^2}\frac{m_t}{2m_b}(m_h^2 - 4m_t^2)\boxed{\frac{(2N_c+1)C^{(1)}_{QtQb} + c_F C^{(8)}_{QtQb}}{\Lambda^2}} \times \left[2 - \sqrt{1 - \frac{4m_t^2}{m_h^2}}H(0,x) - \log\left(\frac{\mu^2}{m_t^2}\right)\right].$$

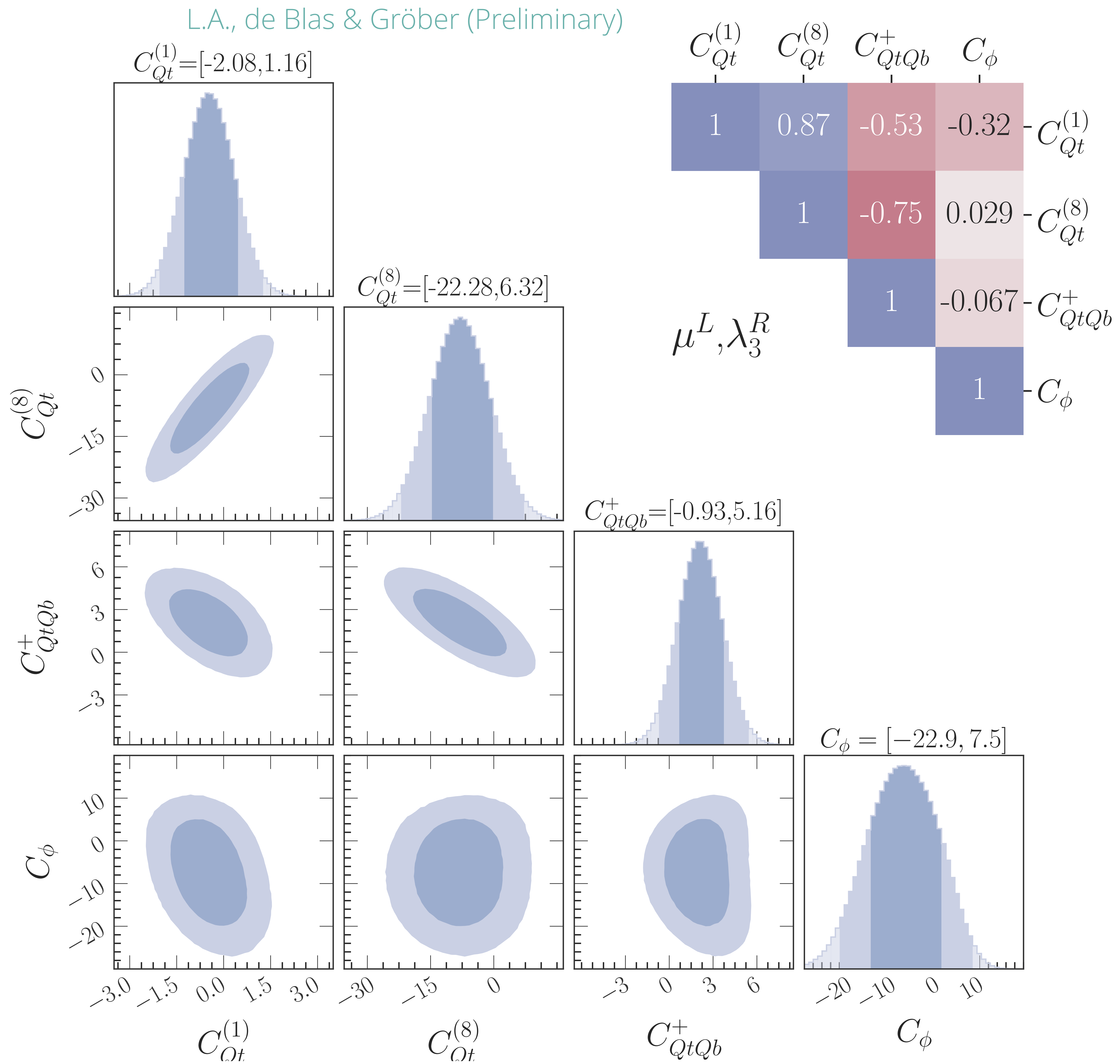
Except for $t\bar{t}h$, all the NLO corrections contain this Wilson coefficients' combination.

Since $t\bar{t}h$ is small for these coefficients, the actual d.o.f is this combination and not $C^{(1)}_{QtQb}$ & $C^{(8)}_{QtQb}$ separately.



4 parameter fit

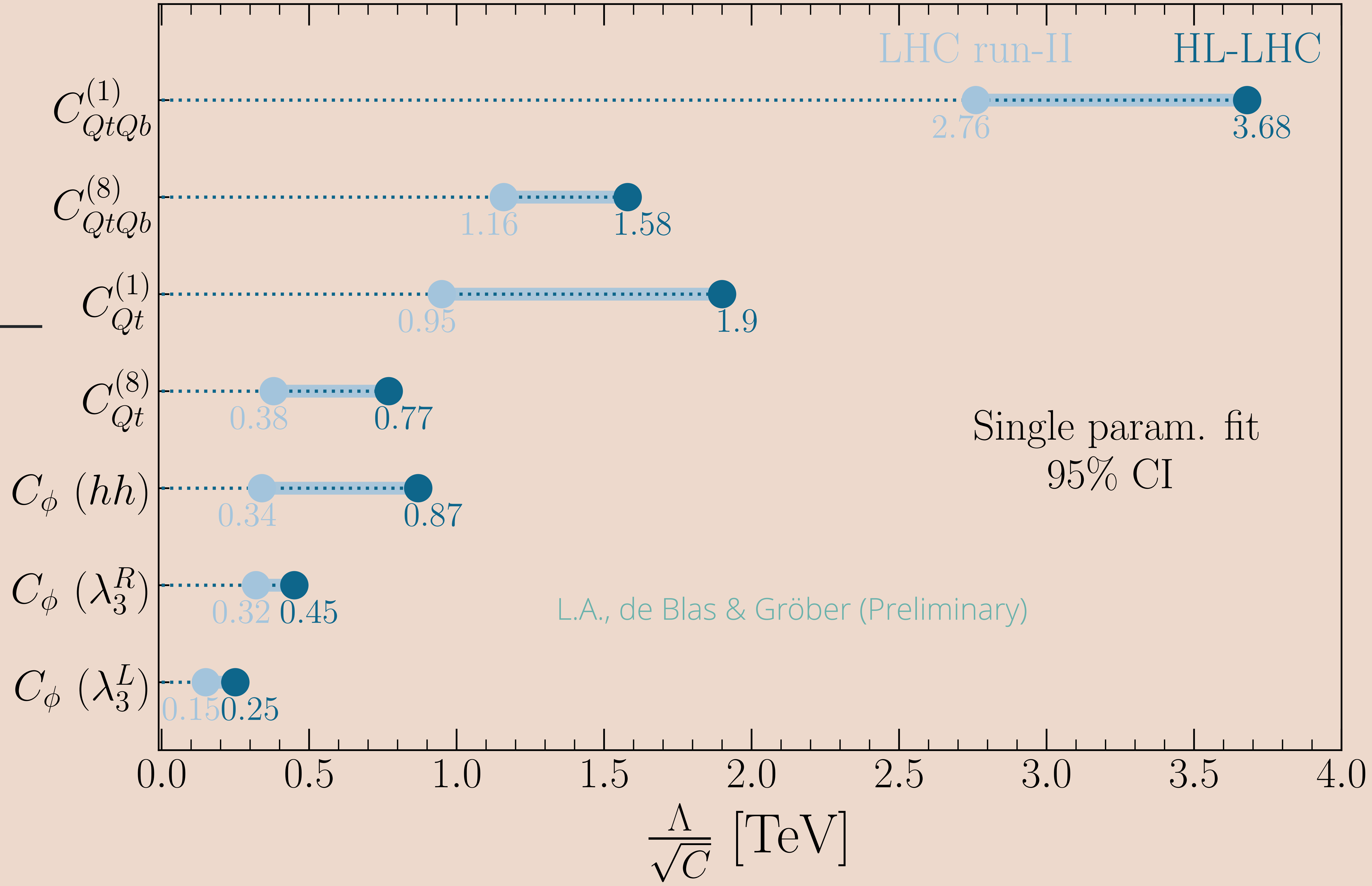
Combined fit using the linear λ_3 scheme.



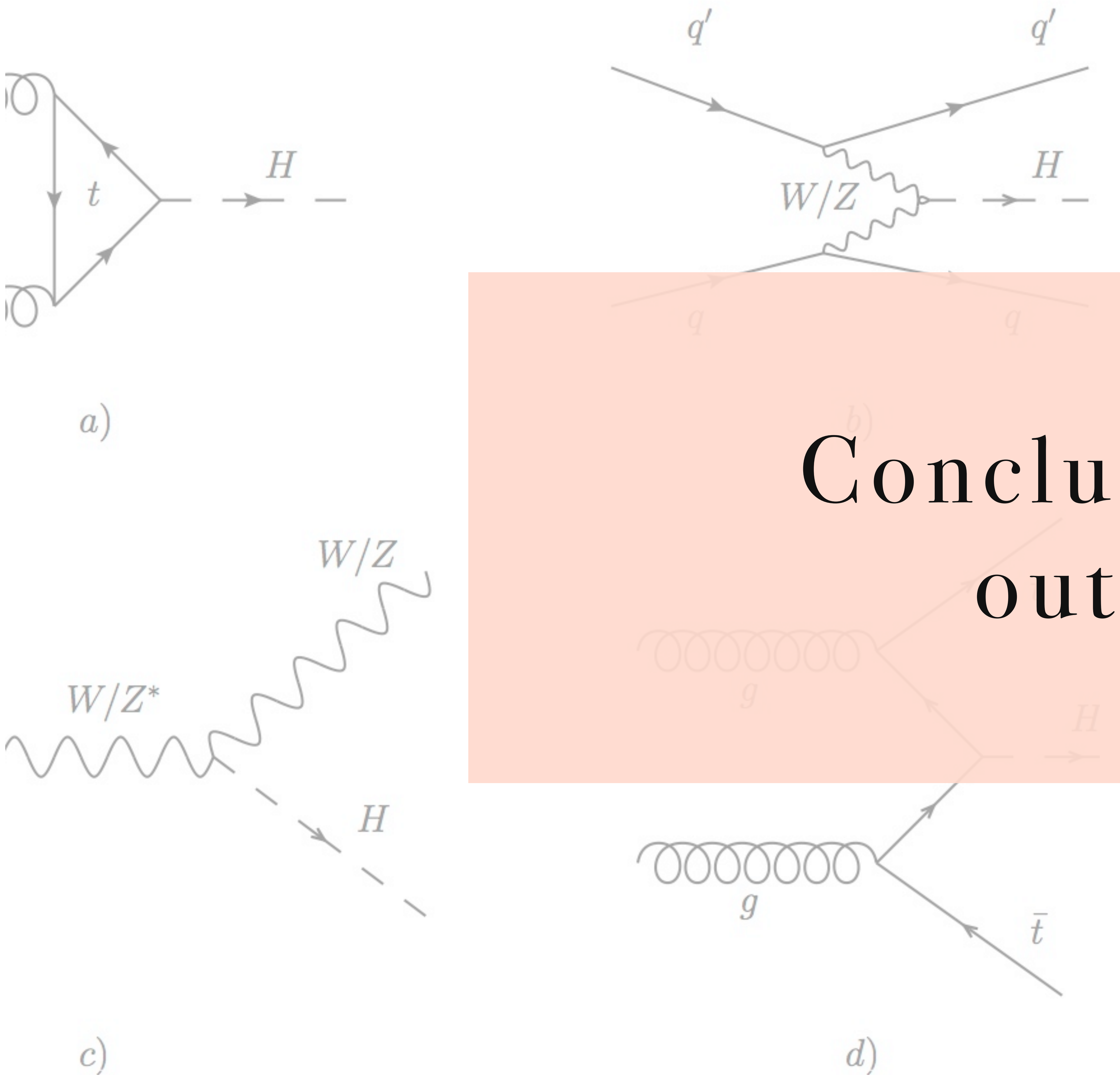
4 parameter fit

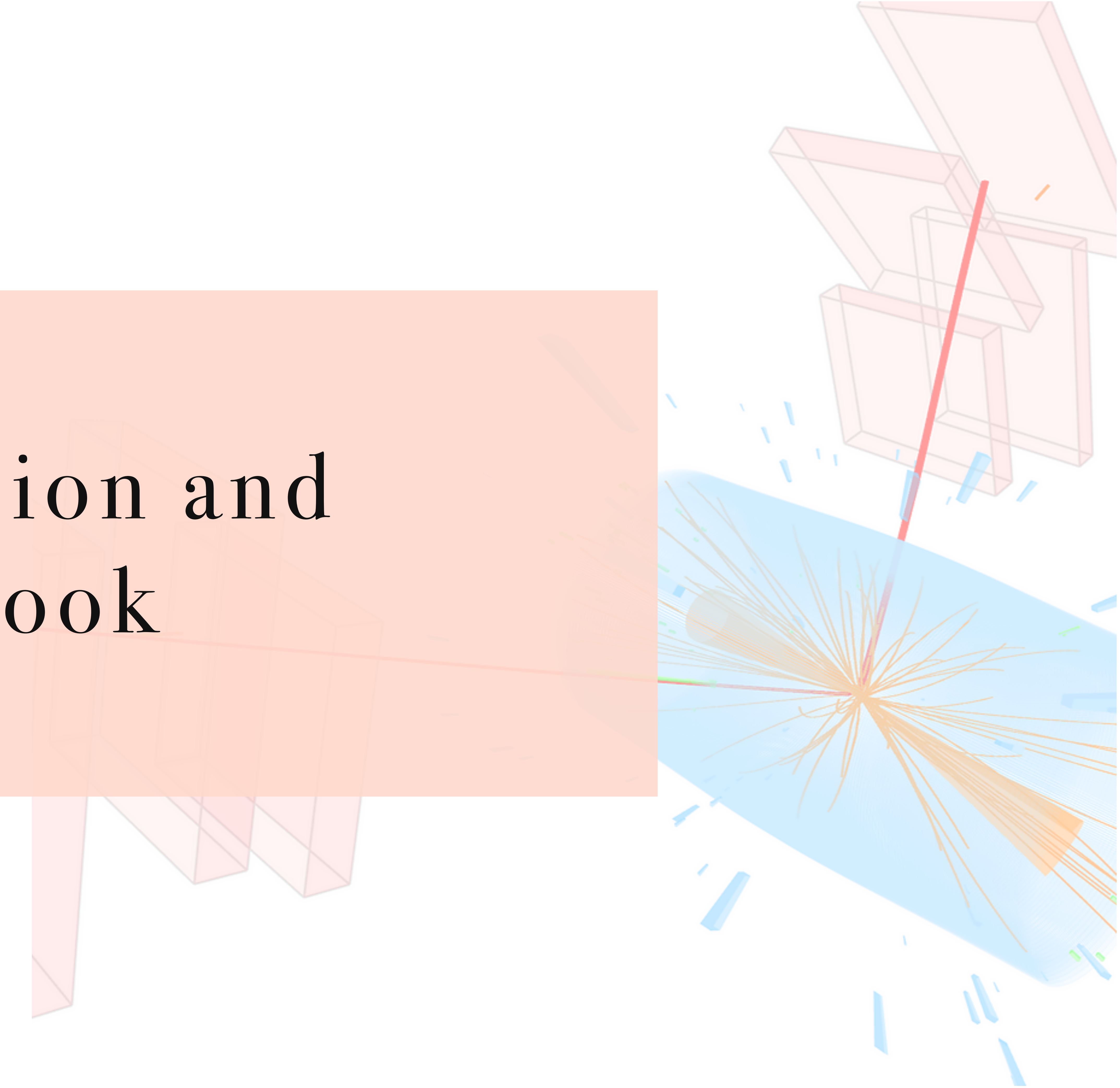
Combined fit using the ressumed λ_3 scheme.

HL-LHC reach



LHC run-II
HL-LHC
$C_{QtQb}^{(1)}$
2.76
3.68
$C_{QtQb}^{(8)}$
1.16
1.58
$C_{Qt}^{(1)}$
0.95
1.9
$C_{Qt}^{(8)}$
0.38
0.77
$C_\phi\ (hh)$
0.34
0.87
$C_\phi\ (\lambda_3^R)$
0.32
0.45
$C_\phi\ (\lambda_3^L)$
0.15
0.25
Single param. fit
95% CI
L.A., de Blas & Gröber (Preliminary)
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
$\frac{\Lambda}{\sqrt{C}}$ [TeV]





Conclusion and outlook

CONCLUSION

Constraining the trilinear coupling from single Higgs measurements is faced with many challenges.

1 Better constraints

were achieved on the 4-heavy quark operators from Higgs data compared to top data.

2 Strong correlation

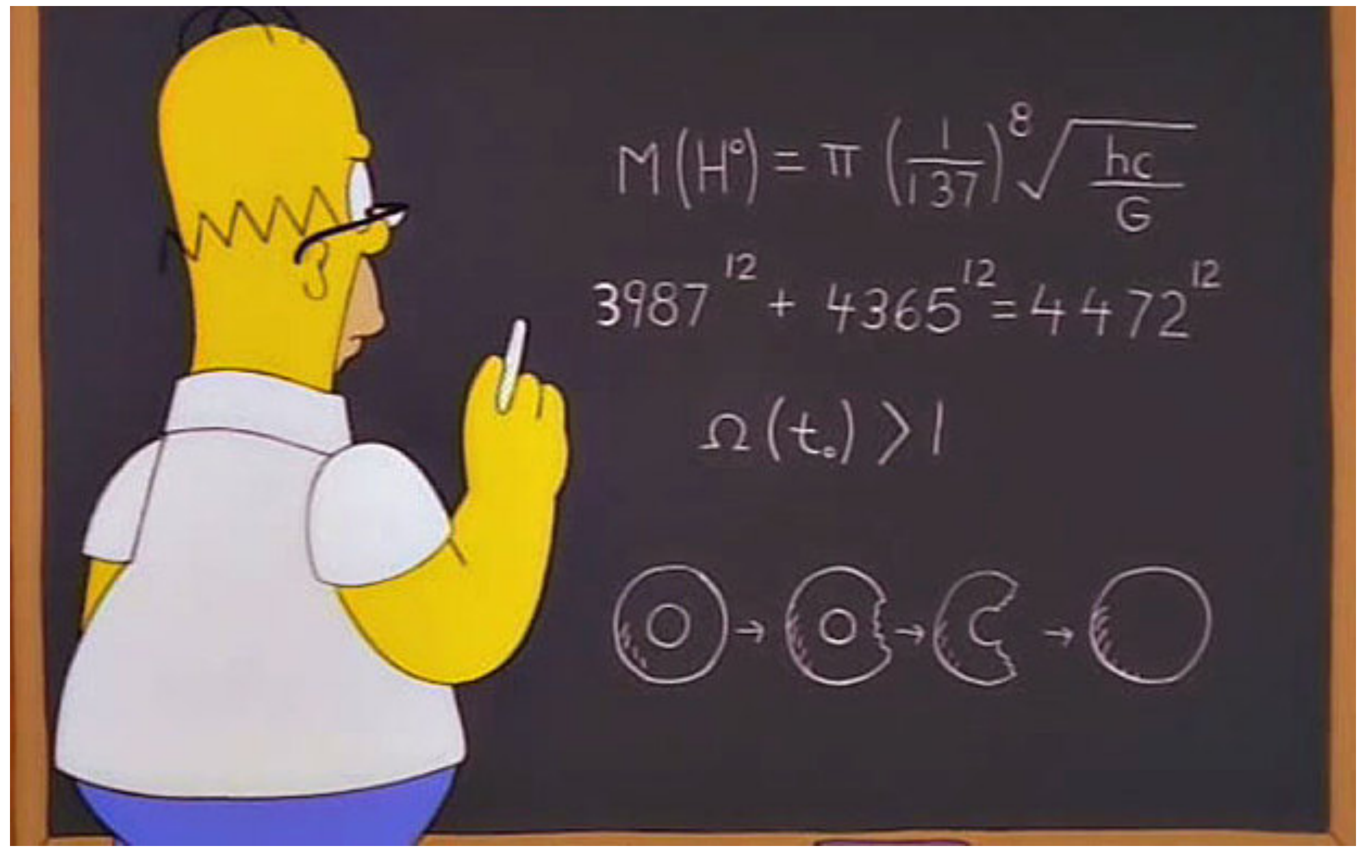
between the 4 heavy quark Wilson coefficients and Higgs trilinear coupling has been observed.

3 The fit dependence

on the λ_3 scheme, and potential contributions from dim 8 operators, adds more challenges.

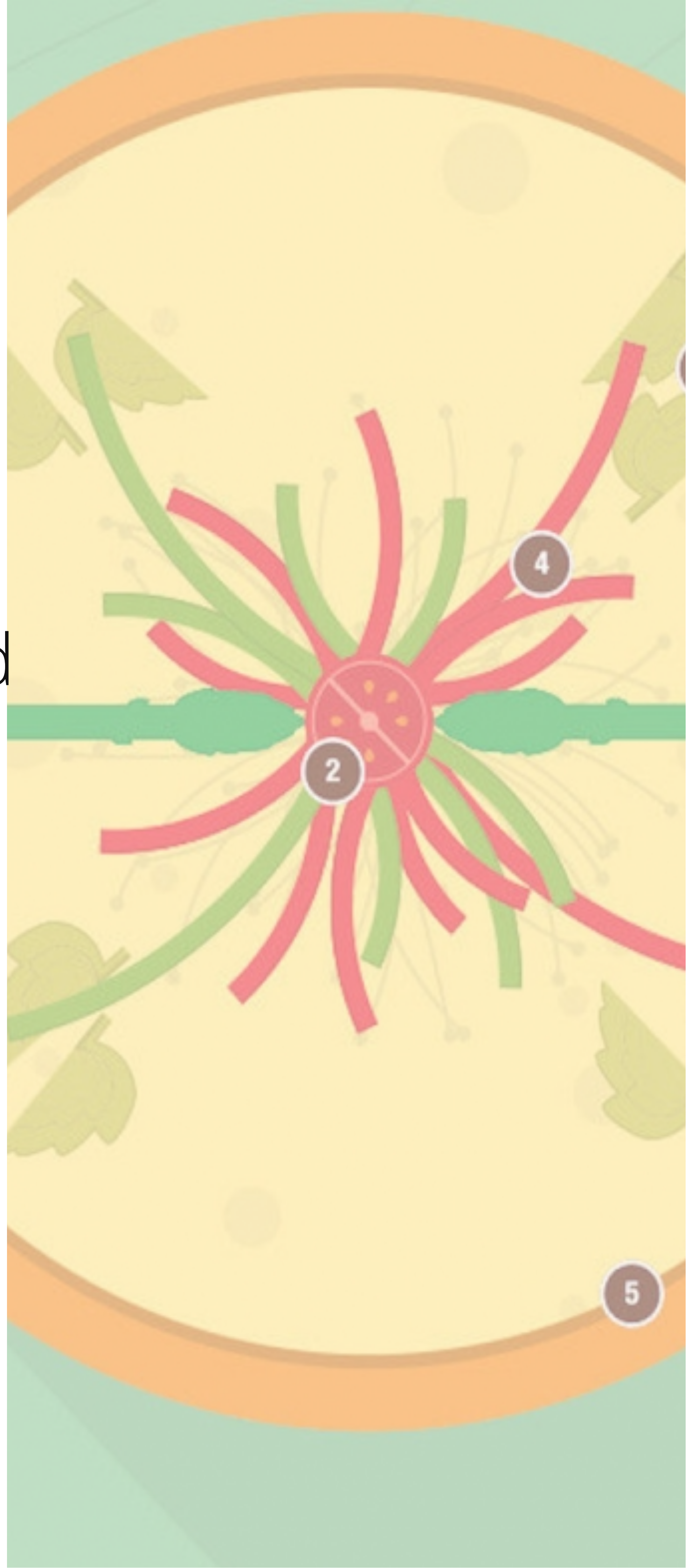
4 Di-Higgs

seems to be our best shot to constraining the trilinear coupling.



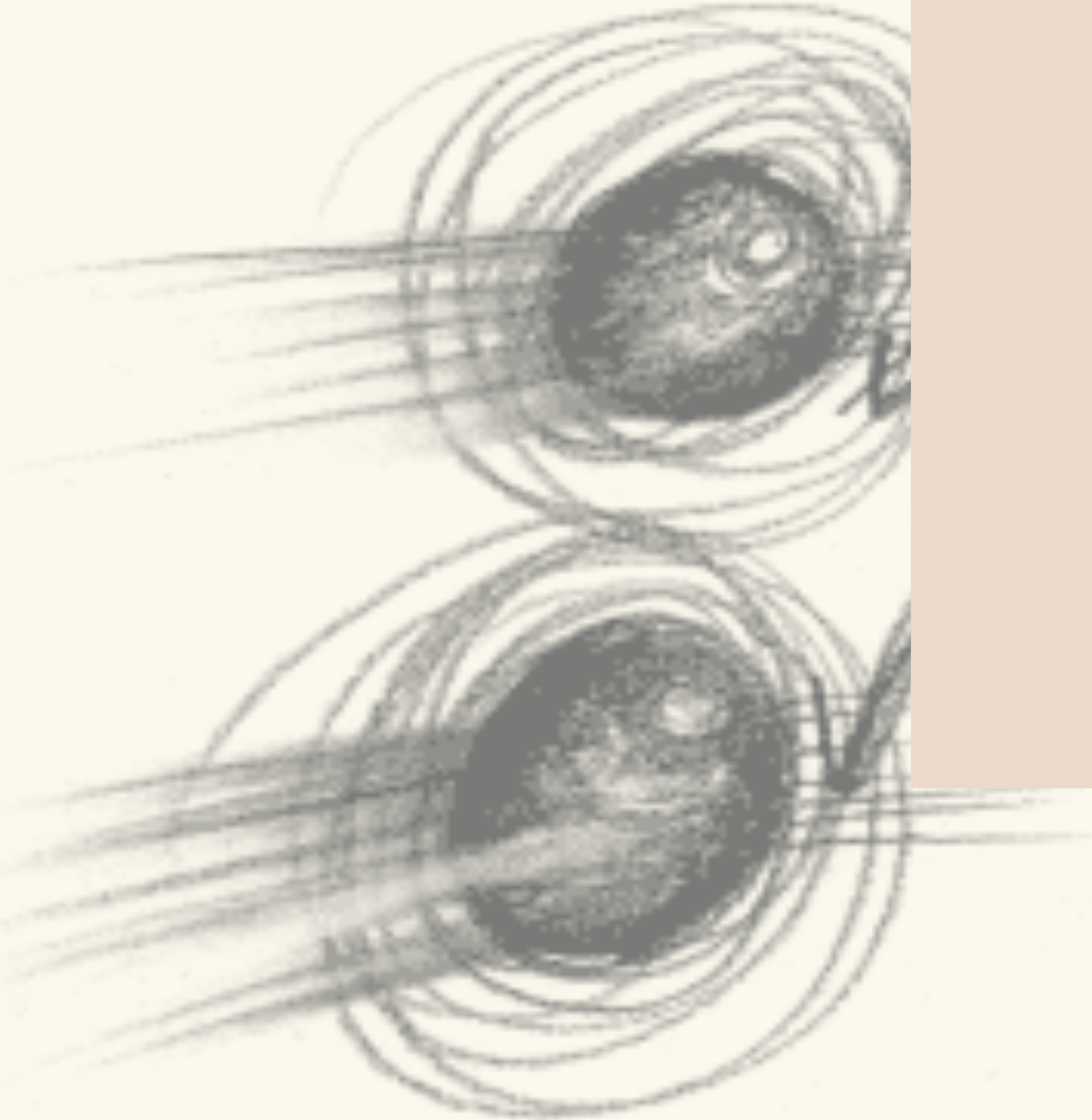
OUTLOOK

A global SMEFT fit including operators entering at NLO and flavour is the next natural step



- Calculate the NLO contributions to Higgs rates for more weakly bound operators.
- Compute the contribution of these operators for STXS not just inclusive rates.
- Do a fit including Light quark Yukawa modifiers C_{qH} with C_ϕ using single Higgs data.
- Preform - hopefully- a global fit including NLO operators and flavour

Thank You !



Backup

Production	Decay	$\mu_{\text{Exp}} \pm \delta\mu_{\text{Exp}}$ @$\sqrt{s} = 13$ TeV (symmetrised) ATLAS 139 fb^{-1}	CMS 137 fb^{-1}	Refs
ggF	$h \to \gamma\gamma$	1.030 ± 0.110	1.07 ± 0.12	[36, 37]
	$h \to ZZ$	0.9375 ± 0.105	0.98 ± 0.115	
	$h \to W^+W^-$	1.080 ± 0.185	1.28 ± 0.195	[36, 38]
	$h \to \tau^+\tau^-$	0.995 ± 0.575	0.39 ± 0.385	
	$h \to b\bar{b}$	——	2.45 ± 2.44	[38]
VBF	$h \to \gamma\gamma$	1.295 ± 0.245	1.04 ± 0.32	[36, 37]
	$h \to ZZ$	1.295 ± 0.455	0.57 ± 0.41	
	$h \to W^+W^-$	0.610 ± 0.350	0.63 ± 0.63	[36, 38]
	$h \to \tau^+\tau^-$	1.130 ± 0.55	1.05 ± 0.295	
	$h \to b\bar{b}$	3.005 ± 1.645	——	[36]
$t\bar{t}h$	$h \to \gamma\gamma$	0.885 ± 0.255	1.35 ± 0.31	[36, 37]
	$h \to VV$	1.705 ± 0.545	——	
	$h \to \tau^+\tau^-$	1.13 ± 1.0	——	[36]
	$h \to b\bar{b}$	0.78 ± 0.595	——	
	$h \to VV + \tau^+\tau^-$	——	0.92 ± 0.24	[39]
Vh	$h \to \gamma\gamma$	1.305 ± 0.315	1.34 ± 0.345	[36, 37]
	$h \to ZZ$	1.425 ± 1.025	1.10 ± 0.85	[36, 38]
	$h \to W^+W^-$	——	1.85 ± 0.438	[40]
	$h \to b\bar{b}$	1.015 ± 0.175	——	[36]
Zh	$h \to \tau^+\tau^-$	——	1.53 ± 1.30	[38]
	$h \to b\bar{b}$	——	0.93 ± 0.32	
$W^\pm h$	$h \to \tau^+\tau^-$	——	3.01 ± 1.60	
	$h \to b\bar{b}$	——	1.27 ± 0.41	

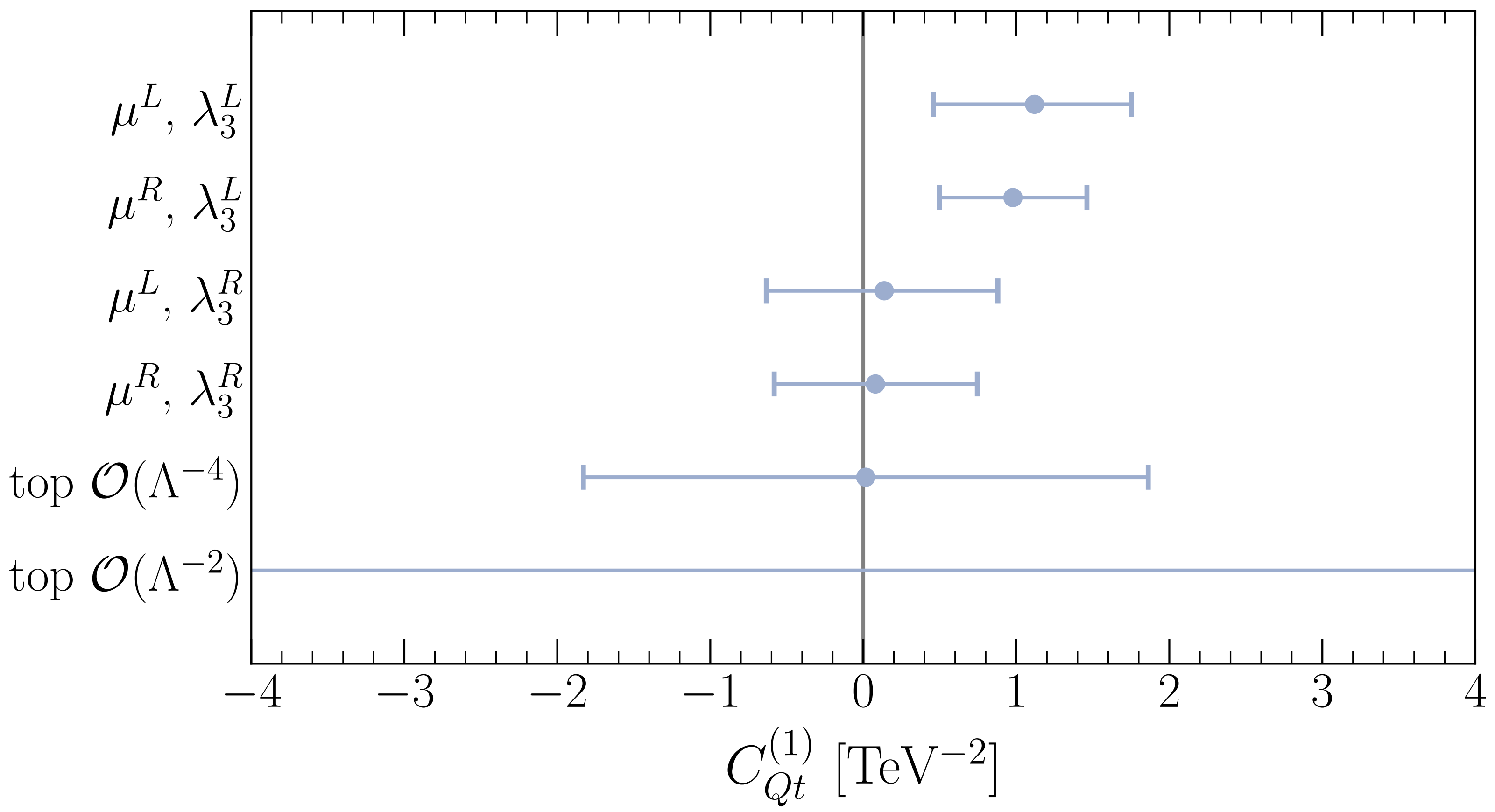
- [36] ATLAS-CONF-2020-027
- [37] CMS CERN-EP-2021-038
- [38] CMS-PAS-HIG-19-005
- [39] CMS-PAS-HIG-19-008
- [40] CMS-PAS-HIG-19-017

Numeric values of the experimental data

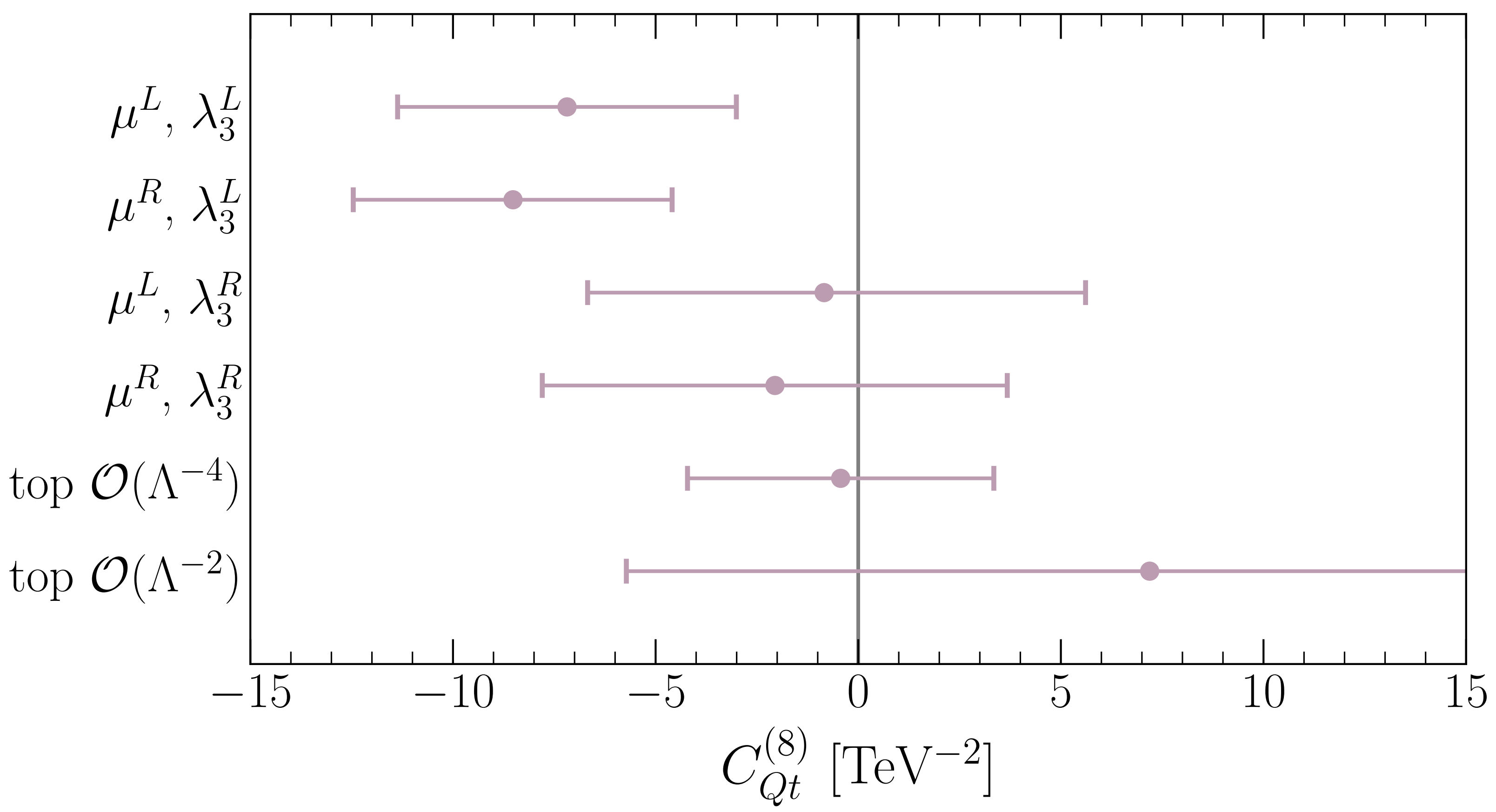
- Measurements of the Higgs rates' signal strengths from both CMS and ATLAS were used.
- If the uncertainties were not symmetric, they have been symmetrised.
- For the HL-LHC the sensitivity estimates from WG2 report . Using combination of CMS and ATLAS.

Notice how the fit is changes when changing the $\boldsymbol{\mu}$ scheme .

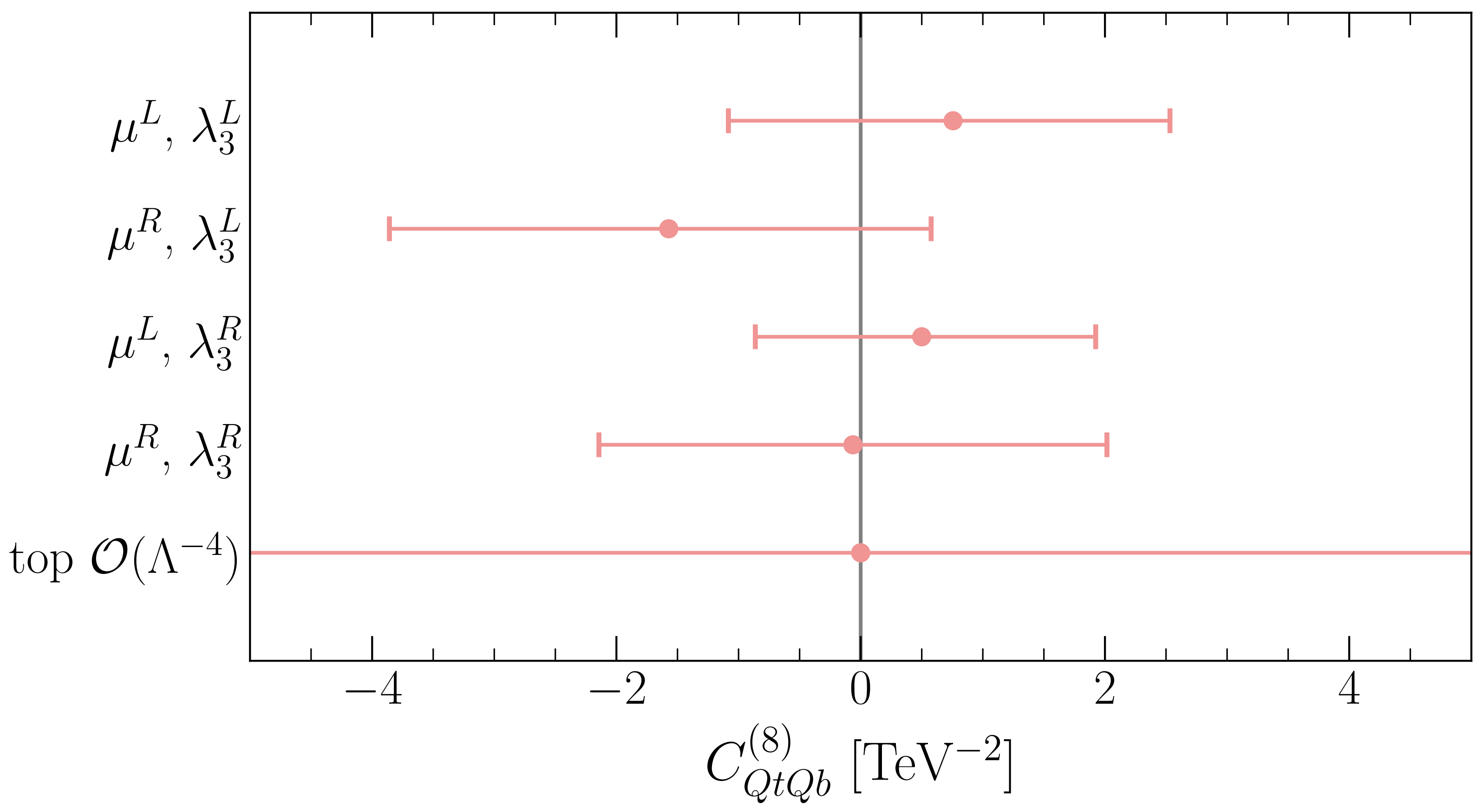
2 parameter fits (more details)



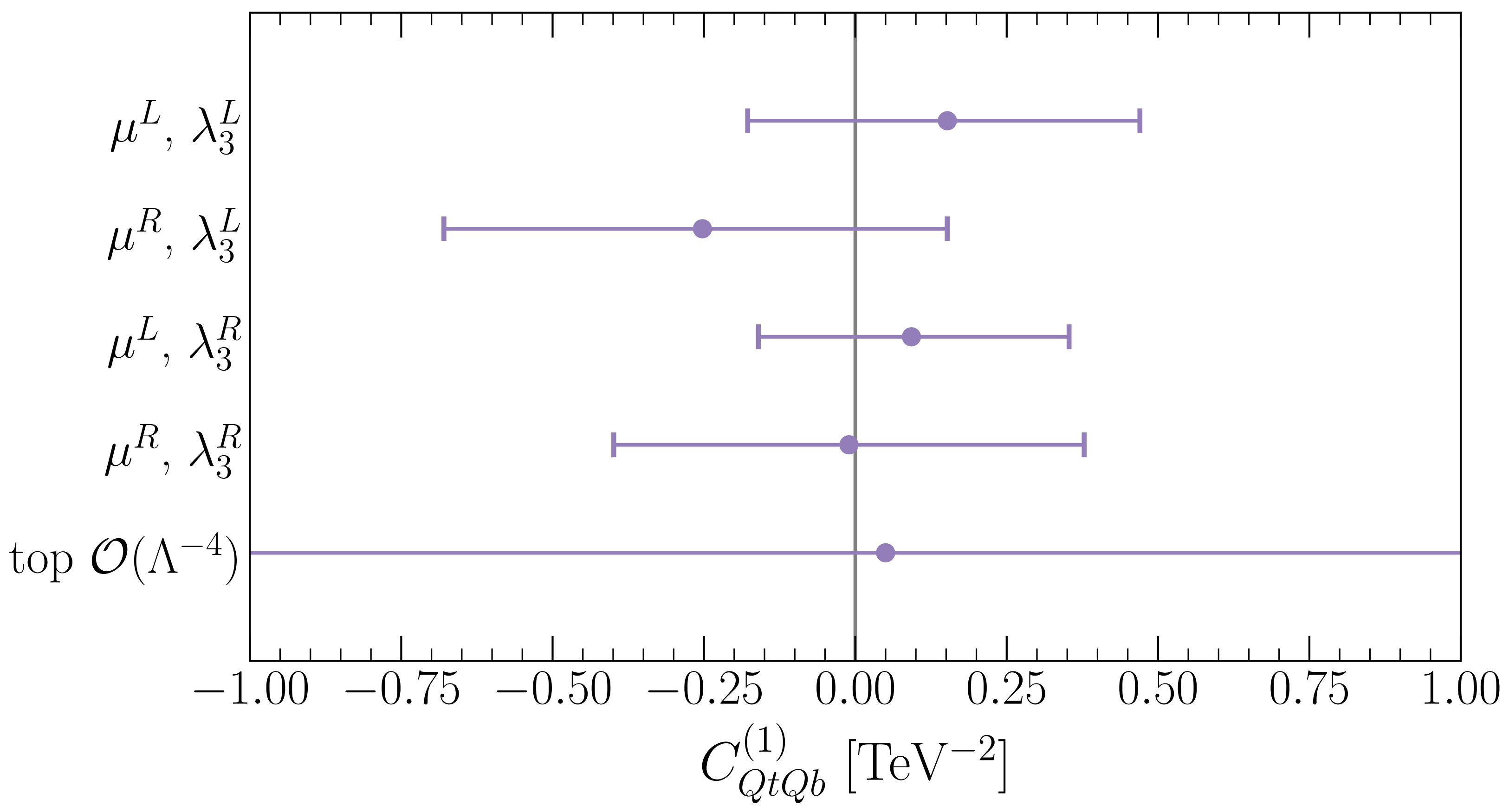
	$\langle C_{Qt}^{(1)} \rangle$	95% CI
$\mu^L,\ \lambda_3^L$	1.119	[0.46, 1.753]
$\mu^R,\ \lambda_3^L$	0.978	[0.498, 1.461]
$\mu^L,\ \lambda_3^R$	0.137	[-0.634, 0.88]
$\mu^R,\ \lambda_3^R$	0.079	[-0.583, 0.745]
top $\mathcal{O}(\Lambda^{-4})$	0.016	[-1.83, 1.862]
top $\mathcal{O}(\Lambda^{-2})$	-18.0	[-195.0, 159.0]



	$\langle C_{Qt}^{(8)} \rangle$	95% CI
$\mu^L,\ \lambda_3^L$	-7.186	[-11.367, -3.008]
$\mu^R,\ \lambda_3^L$	-8.519	[-12.461, -4.593]
$\mu^L,\ \lambda_3^R$	-0.842	[-6.678, 5.609]
$\mu^R,\ \lambda_3^R$	-2.055	[-7.797, 3.677]
top $\mathcal{O}(\Lambda^{-4})$	-0.434	[-4.213, 3.346]
top $\mathcal{O}(\Lambda^{-2})$	7.192	[-5.722, 20.105]



	$\langle C_{QtQb}^{(8)} \rangle$	95% CI
$\mu^L,\ \lambda_3^L$	0.757	[-1.083, 2.532]
$\mu^R,\ \lambda_3^L$	-1.572	[-3.859, 0.577]
$\mu^L,\ \lambda_3^R$	0.5	[-0.863, 1.924]
$\mu^R,\ \lambda_3^R$	-0.064	[-2.143, 2.016]
top $\mathcal{O}(\Lambda^{-4})$	0.0	[-14.0, 14.0]



	$\langle C_{QtQb}^{(1)} \rangle$	95% CI
$\mu^L,\ \lambda_3^L$	0.152	[-0.178, 0.47]
$\mu^R,\ \lambda_3^L$	-0.252	[-0.68, 0.152]
$\mu^L,\ \lambda_3^R$	0.093	[-0.16, 0.353]
$\mu^R,\ \lambda_3^R$	-0.01	[-0.399, 0.378]
top $\mathcal{O}(\Lambda^{-4})$	0.05	[-5.4, 5.5]