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The Importance of Flavor in SMEFT Electroweak Precision Fits

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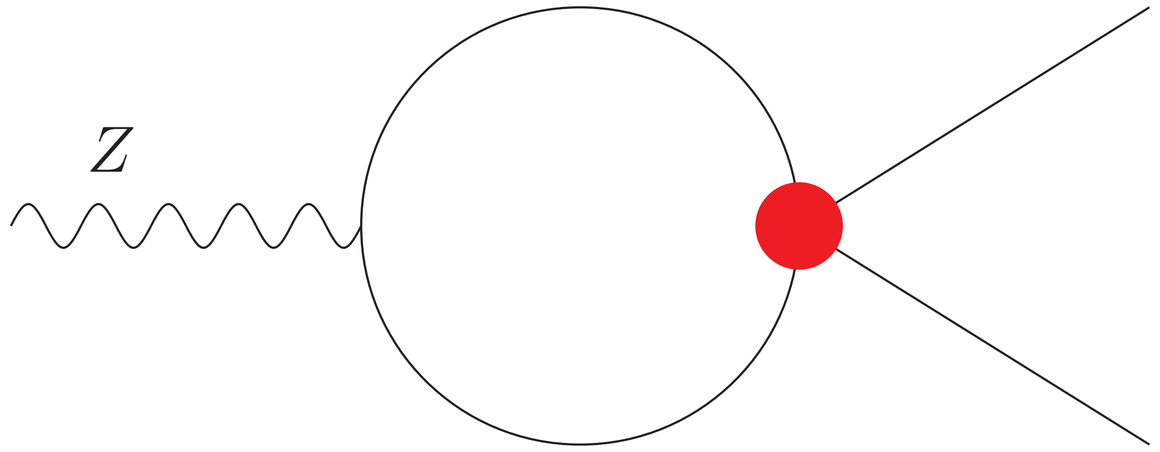
Motivation



- No direct evidence of new physics -> SMEFT

- EWPOs provided strong evidence that the SM describes physics at EW scale.

- Similarly, in the SMEFT approach, comparisons of EWPOs with theoretical predictions severely constrain the coefficients associated to the new physics.

- NLO SMEFT calculation of EWPOs -> New 2- and 4-fermion operators.

- Assumptions on the flavor structure introduce significant model dependence into the SMEFT predictions.

Measurement	Experiment	"Best" theory
Γ_Z(GeV)	2.4955 ± 0.0023	2.4943 ± 0.0006 [62–64]
R_e	20.804 ± 0.05	20.732 ± 0.009 [62–64]
R_μ	20.784 ± 0.034	20.732 ± 0.009 [62–64]
R_τ	20.764 ± 0.045	20.779 ± 0.009 [62–64]
R_b	0.21629 ± 0.00066	0.2159 ± 0.0001[62–64]
R_c	0.1721 ± 0.0030	0.1722 ± 0.00005[62–64]
σ_h	41.481 ± 0.033	41.492 ± 0.008[62–64]
A_e(from A_{LR} had	0.15138 ± 0.00216	0.1469 ± 0.0004 [64, 65]
A_e(from A_{LR} lep)	0.1544 ± 0.0060	0.1469 ± 0.0004 [64, 65]
A_e(from Bhabba pol)	0.1498 ± 0.0049	0.1469 ± 0.0004 [64, 65]
A_μ	0.142 ± 0.015	0.1469 ± 0.0004 [64, 65]
A_τ(from SLD)	0.136 ± 0.015	0.1469 ± 0.0004 [64, 65]
A_τ(τ pol)	0.1439 ± 0.0043	0.1469 ± 0.0004 [64, 65]
A_c	0.670 ± 0.027	0.66773 ± 0.0002[64, 65]
A_b	0.923 ± 0.020	0.92694 ± 0.00006[64–66]
A_s	0.895 ± 0.091	0.93563 ± 0.00004[64, 65]
$A_{e,FB}$	0.0145 ± 0.0025	0.0162 ± 0.0001 [64, 65]
$A_{\mu,FB}$	0.0169 ± 0.0013	0.0162 ± 0.0001 [64, 65]
$A_{\tau,FB}$	0.0188 ± 0.0017	0.0162 ± 0.0001 [64, 65]
$A_{b,FB}$	0.0996 ± 0.0016	0.1021 ± 0.0003 [64–66]
$A_{c,FB}$	0.0707 ± 0.0035	0.0736 ± 0.0003 [64, 65]
$A_{s,FB}$	0.0976 ± 0.0114	0.10308 ± 0.0003 [64, 65]
M_W(GeV) PDG World Ave	80.377 ± 0.012	80.357 ± 0.006[67, 68]
Γ_W(GeV)	2.085 ± 0.042	2.0903 ± 0.0003[69]

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Definitions

$$V_{CKM} \sim 1 \quad \text{and} \quad m_{u,d,c,s,\ldots} = 0$$

4 Bosonic Operators

$\mathcal{O}_{\phi B}, \mathcal{O}_{\phi W}, \mathcal{O}_{\Box}, \mathcal{O}_{W}$

Flavor structure

- **Class A (2 fermion operators)**

$$\mathcal{O}_{\phi e}[ij], \mathcal{O}_{\phi u}[ij], \mathcal{O}_{\phi d}[ij], \mathcal{O}^{(3)}_{\phi q}[ij], \mathcal{O}^{(1)}_{\phi q}[ij], \mathcal{O}^{(3)}_{\phi l}[ij], \mathcal{O}^{(1)}_{\phi l}[ij], \mathcal{O}_{uB}[33], \mathcal{O}_{uW}[33]$$

$$C_X[ij] = E^{(i)}_X \delta_{ij} \quad i,j = 1,2,3$$

23 Independent Coefficients

- **Class B (4 fermion with identical f. r)**

$$\mathcal{O}_{ee}[ijkl], \mathcal{O}^{(3)}_{qq}[ijkl], \mathcal{O}^{(1)}_{qq}[ijkl], \mathcal{O}_{uu}[ijkl], \mathcal{O}_{dd}[ijkl], \mathcal{O}_{ll}[ijkl]$$

$$C_Y[iiii] = F^{(i)}_Y, \quad C_Y[iijj] = A^{(ij)}_Y, \quad C_Y[ijji] = B^{(ij)}_Y,$$
$$A^{(ij)}_Y = A^{(ji)}, \quad B^{(ij)}_Y = B^{(ji)}_Y, \quad i \neq j \;\&\; i,j = 1,2,3$$

50 Independent Coefficients

- **Class C (4 fermion with different f. r)**

$$\mathcal{O}_{ed}[ijkl], \mathcal{O}_{eu}[ijkl], \mathcal{O}_{lu}[ijkl], \mathcal{O}_{ld}[ijkl], \mathcal{O}_{le}[ijkl], \mathcal{O}^{(1)}_{lq}[ijkl], \mathcal{O}^{(3)}_{lq}[ijkl], \mathcal{O}_{qe}[ijkl],$$
$$\mathcal{O}^{(1)}_{qd}[ijkl], \mathcal{O}^{(1)}_{qu}[ijkl], \mathcal{O}^{(1)}_{ud}[ijkl]\,.$$

$$C_Z[iijj] = D^{(ij)}_z \quad i,j = 1,2,3$$

99 Independent Coefficients

Method

- In total we have 178 independent coefficients and the calculation is performed without any further hypothesis. We use $\{\alpha, M_Z, G_\mu\}$ set of EW input parameters.

- To carry out the analysis, in order to reduce the number of coefficients that need to be considered, we examine different flavor scenario.

Operator	$U(3)^5$	MFV	$U(2)^5$	3^{rd} gen specific	3^{rd} gen phobic	3^{rd} gen phobic + $U(2)^5$	Flavorless
Class A	7	12	16	9	14	7	9
Class B	11	17	27	5	23	11	6
Class C	11	21	44	11	44	11	11
Total	29	50	87	25	81	29	26

Number of independent coefficients contributing to NLO predictions for EWPOs in various flavor scenarios

Method

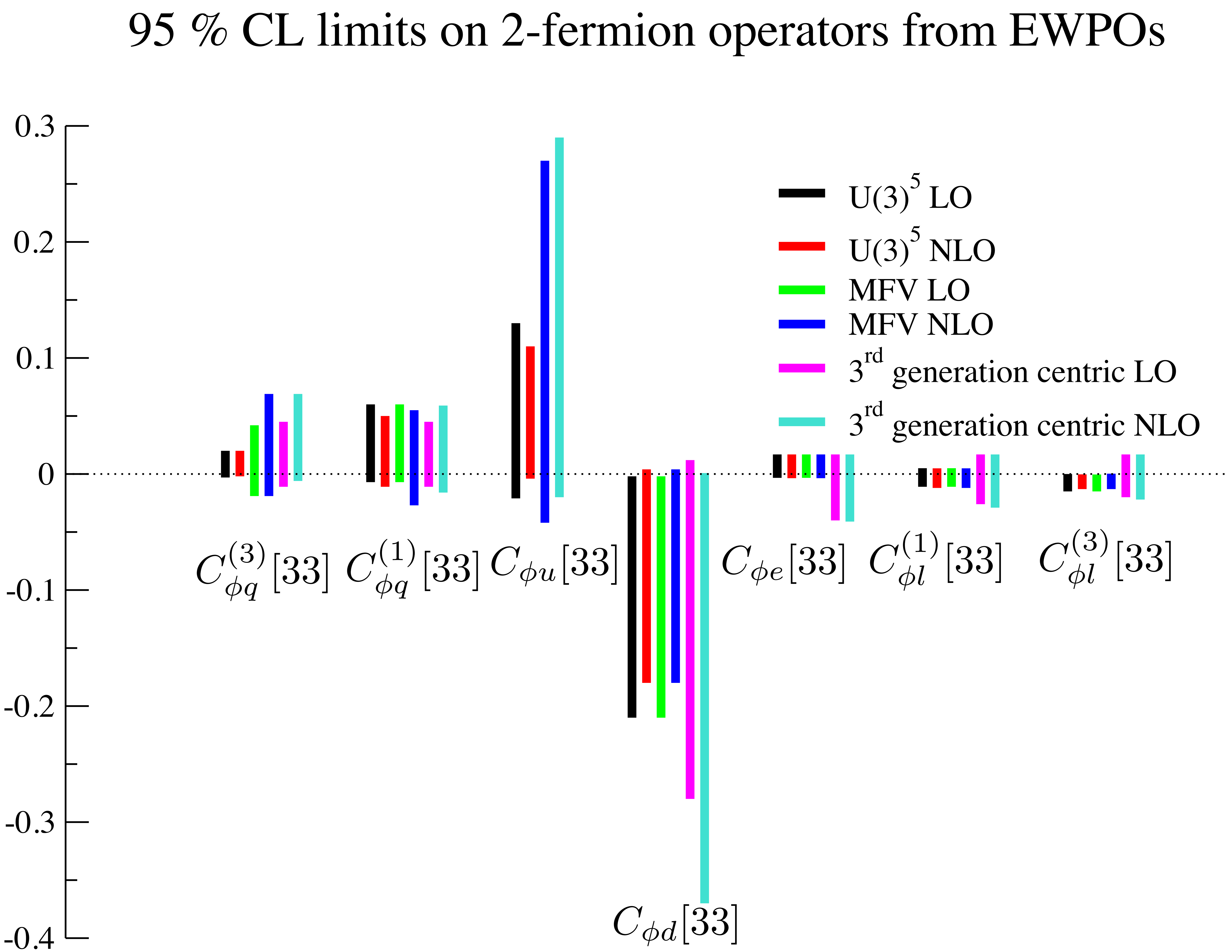
- **Our evaluation starts by considering only one non-zero operator type, O[ijkl], at a time and imposing the flavor symmetries. In general, we can write:**

$$\chi^2(\bar{C}, \hat{C}) = \sum_{i,j} (O_i^{exp} - O_i^{th}) \sigma_{ij}^{-2} (O_j^{exp} - O_j^{th}) \,.$$

- **The marginalisation is carried out by**

$$\frac{\partial \chi^2}{\partial \hat{C}} = 0 \quad \Longrightarrow \quad \hat{C}_m = c_0 + \sum_i \bar{C}_i \quad \Longrightarrow \quad \chi^2(\bar{C}, \hat{C}_m) \equiv \chi^2_M(\bar{C})$$

Class A



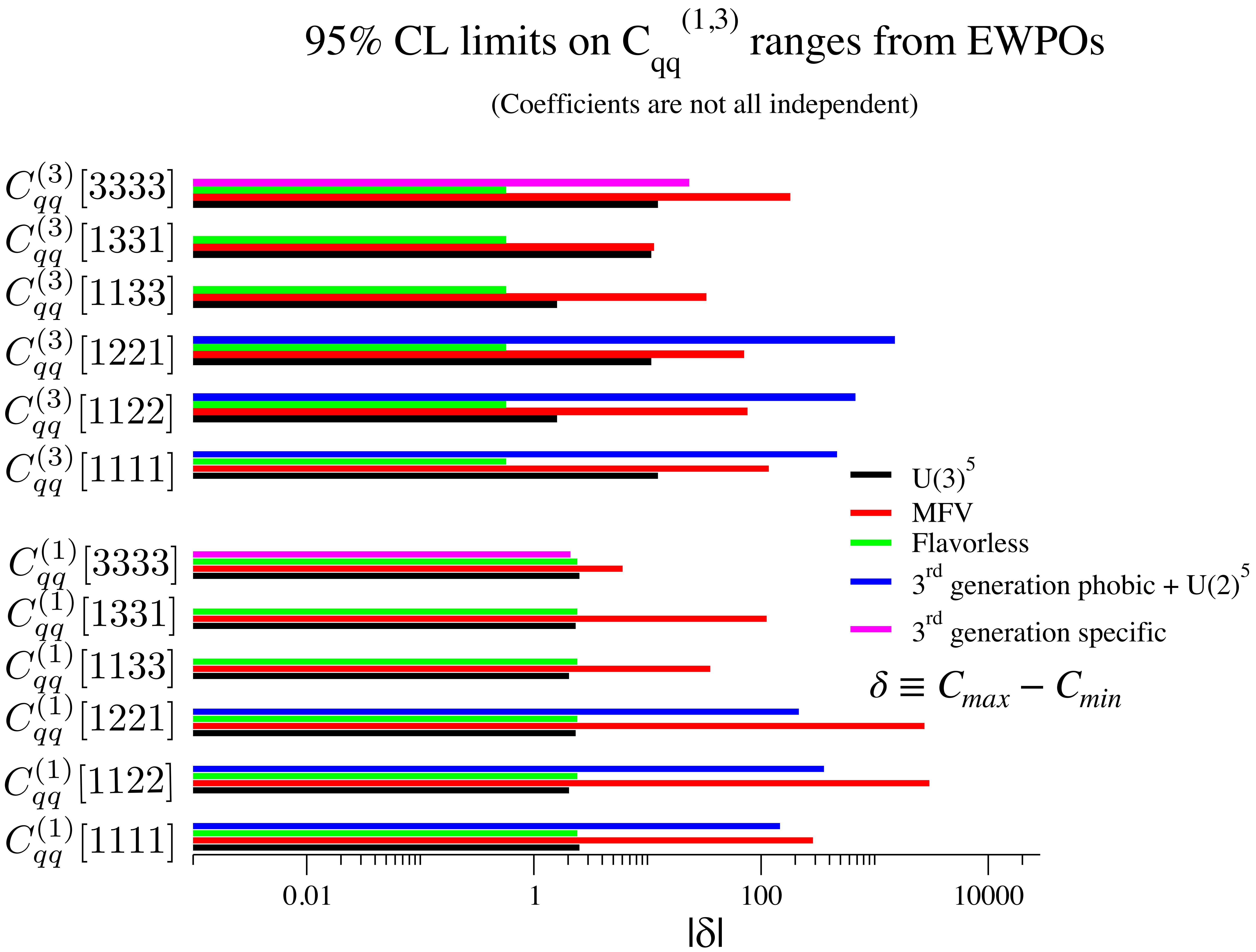
NLO ~ LO

- **Comparing the NLO and LO bounds on 2-fermion operators in different flavor scenarios.**

Correlation for $C_{\phi q}^{(1)}$

- **It is interesting to note the large differences in the shapes of the LO and NLO fits in the MFV and 3rd generation phobic scenarios. The limits on these operators are highly dependent on the assumed flavor scenario.**

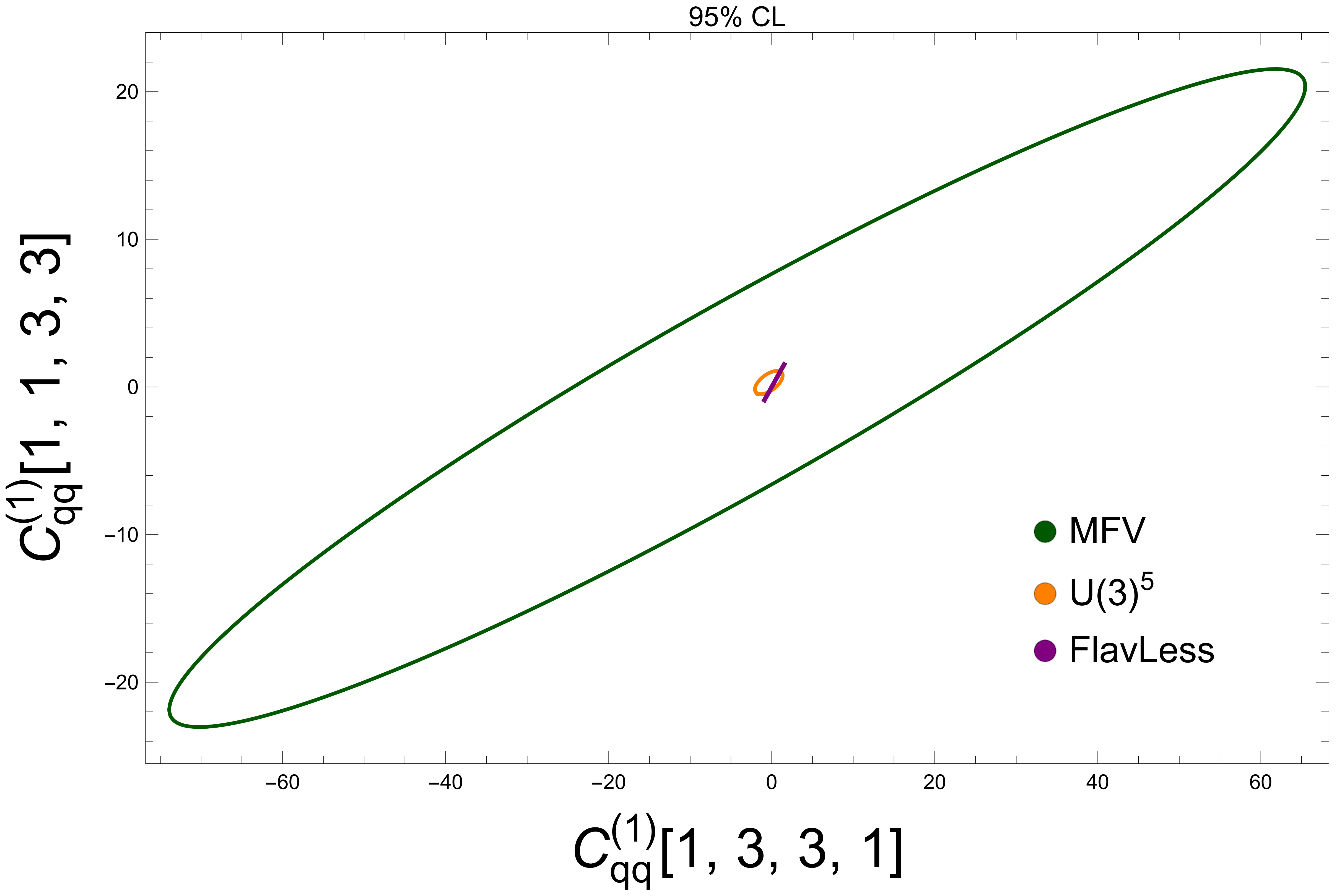
Class B

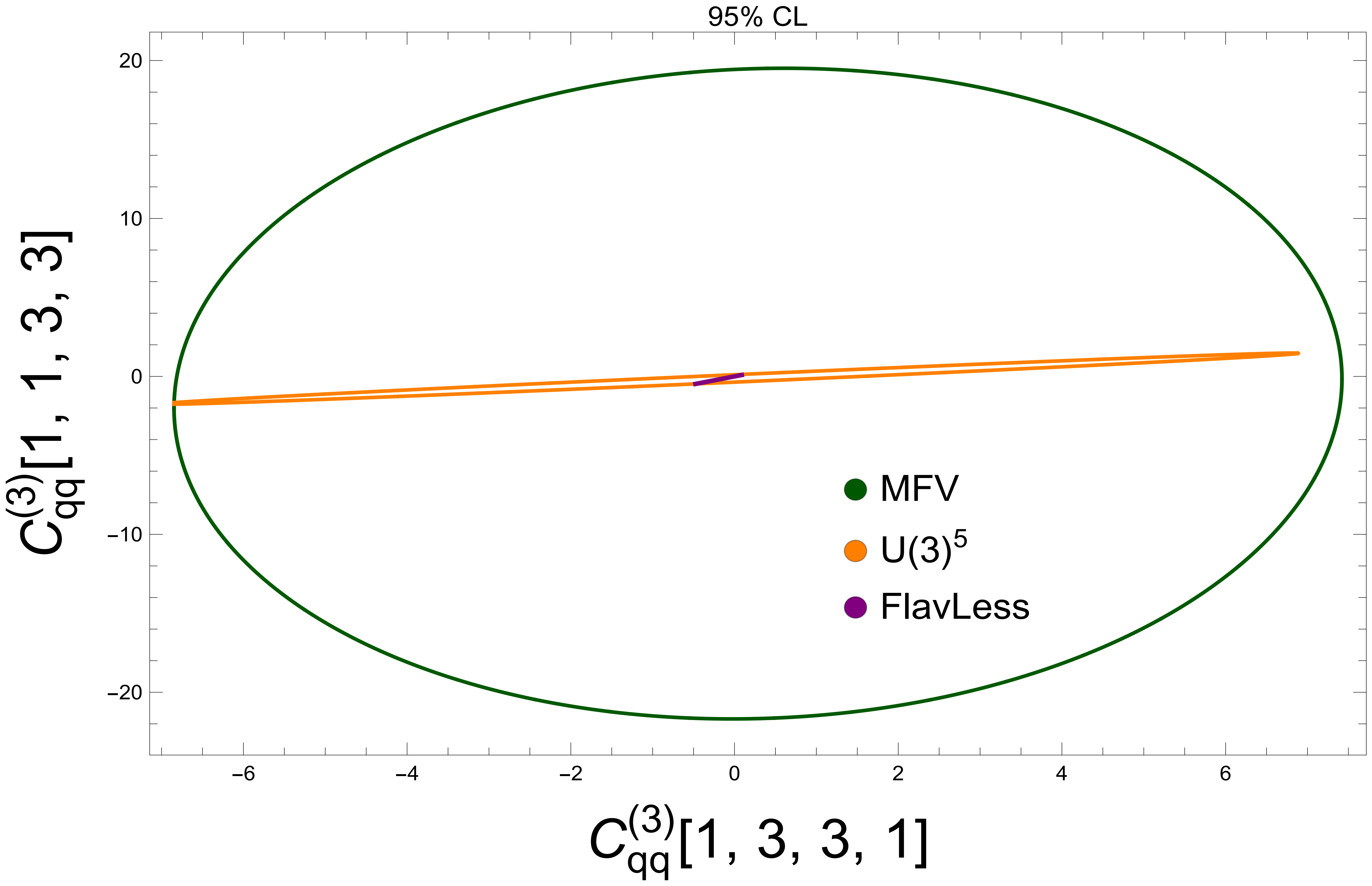


$\sim O(50)$

- The U(3)^5 results for these operators are more constrained than the MFV scenarios and the 3rd generation phobic scenarios are weakly constrained for both the operators.

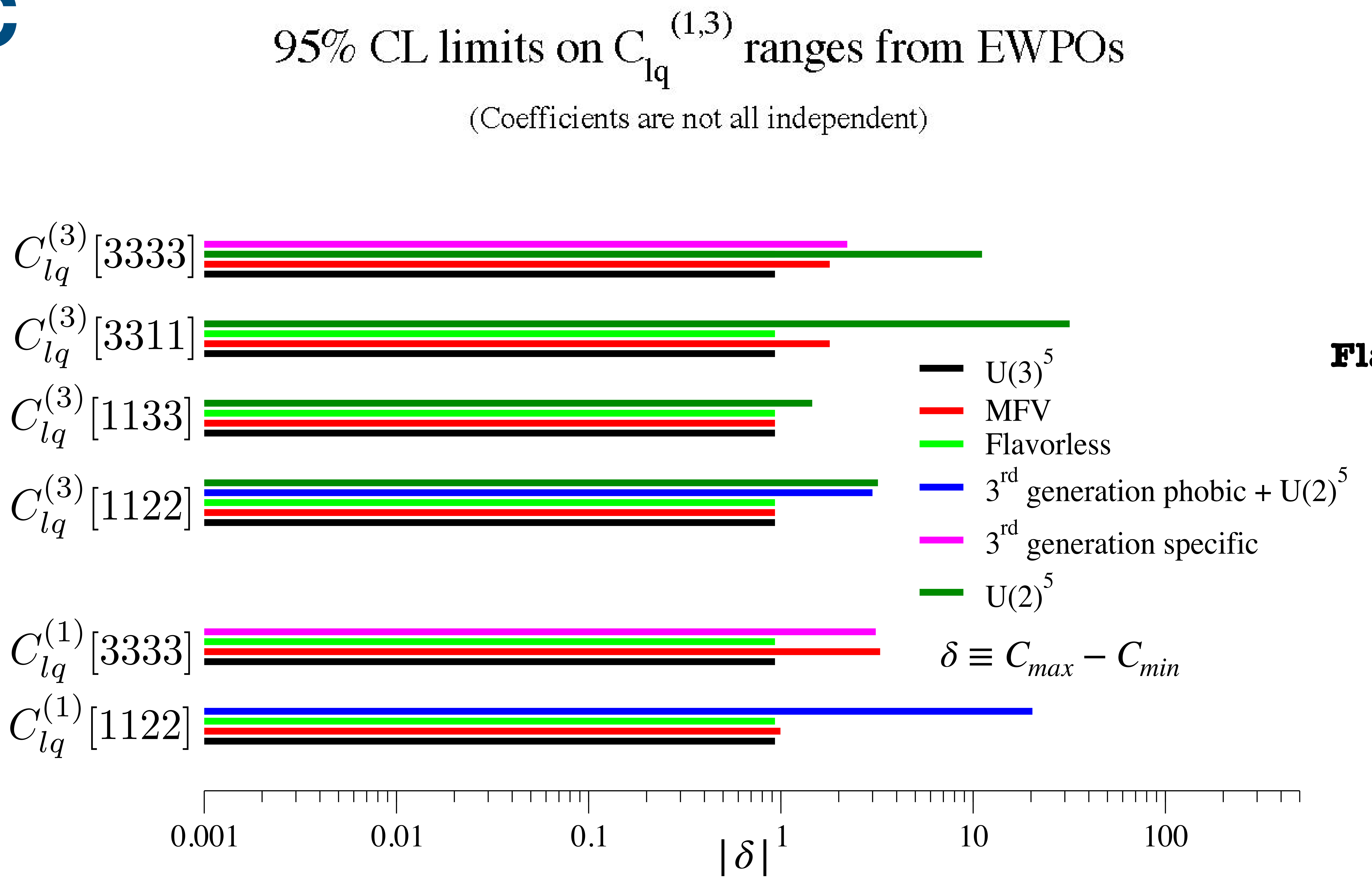
$C_{qq}^{(1)}$ $C_{qq}^{(3)}$





- **All the independent flavor structures not present in the plots are marginalized over. The correlation of the coefficients shows the dramatic impact of flavor assumptions on these operators.**

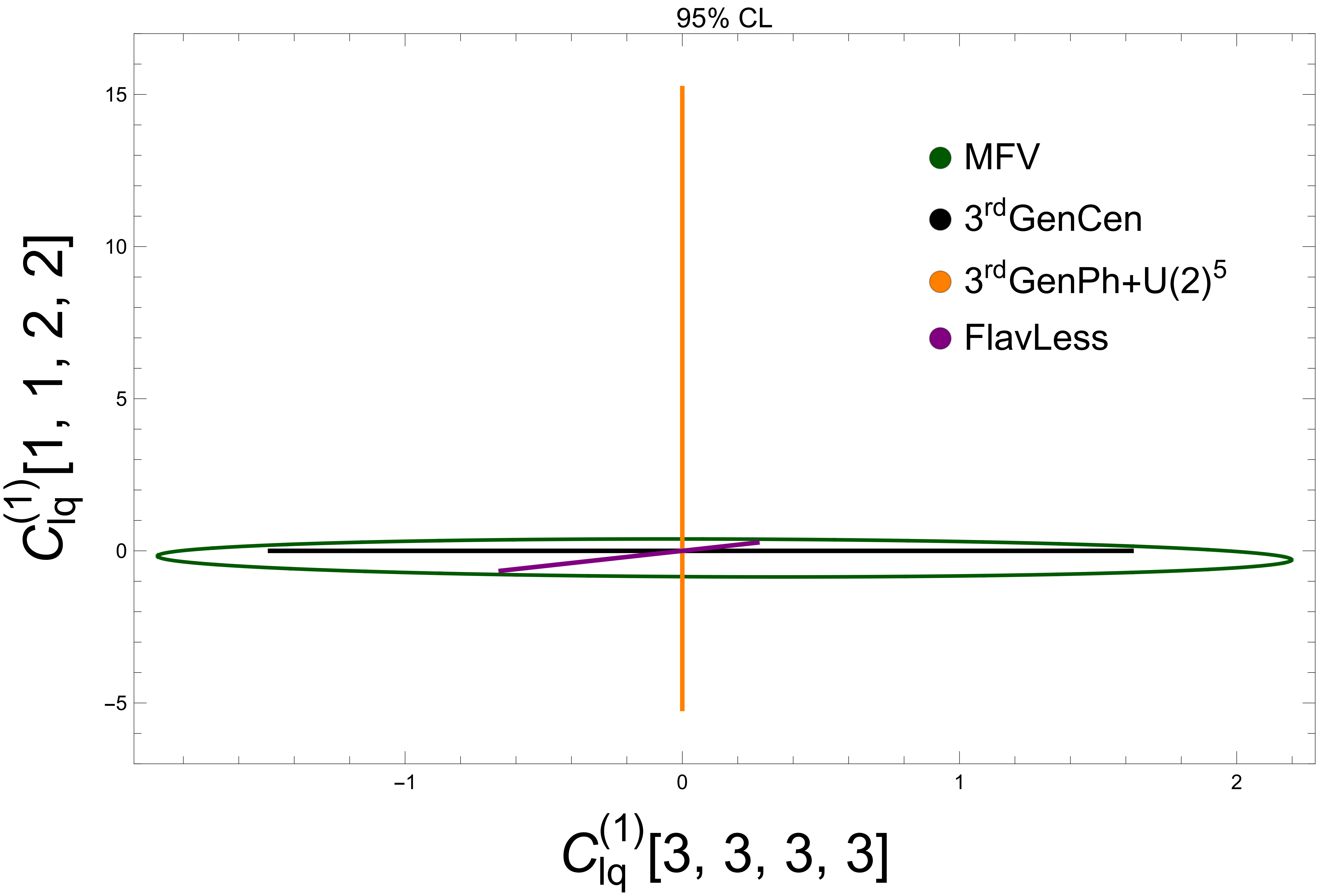
Class C



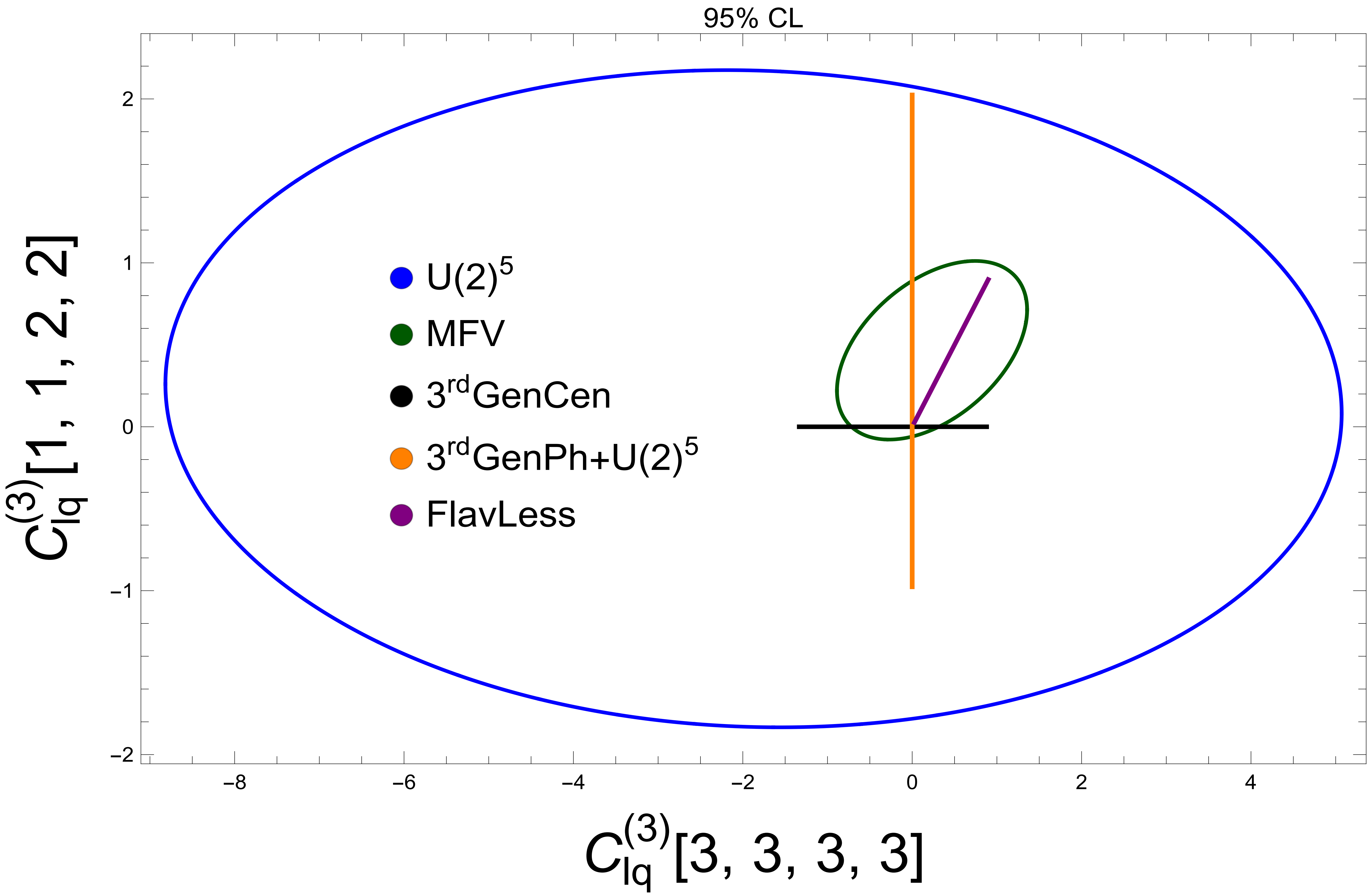
Flavorless = U(3)

- **The limits obtained in the flavorless setup are also similar to those of the MFV structures. The U(2)^5 and 3rd generation phobic scenarios give the weakest bounds for these operators.**

$C_{lq}^{(1)}$



$C_{lq}^{(3)}$



- **There are large correlations in different flavour structure, but in this case the bounds are less dependent on the flavor scenario.**

Conclusion

- We have computed the NLO contributions to EWPOs including an arbitrary flavor structure for the fermion operators.

- Comparing the bounds on 2-fermion operators we have seen that the differences between the LO and NLO fits are in general quite small, but the flavor scenario is relevant.

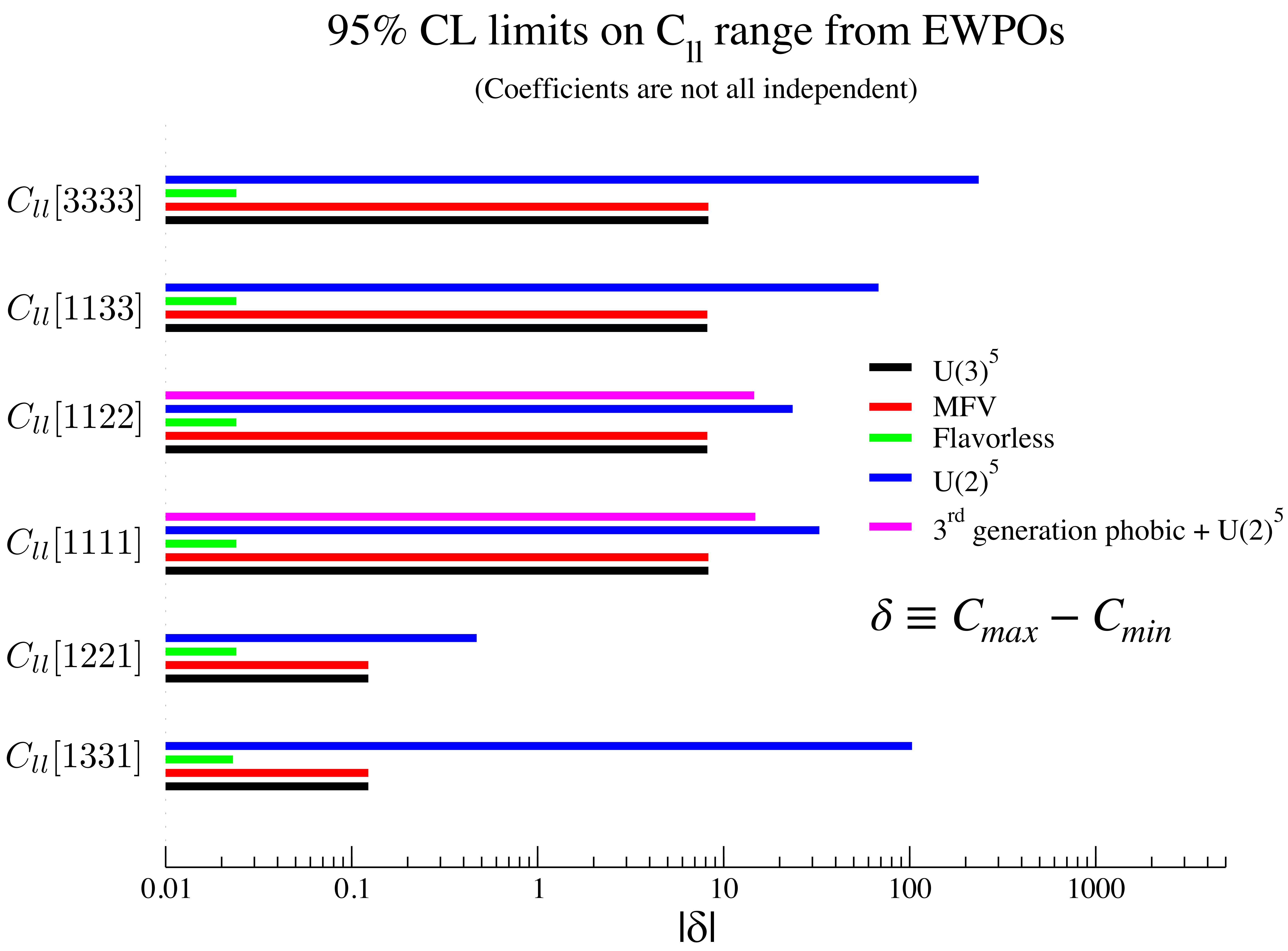
- The flavor structure has a dramatic effect on the bounds derived on the 4-fermion operators which first contribute to EWPOs at NLO.

- Different flavor scenarios lead to a significant correlations between the parameters.

- We have explicitly demonstrated that ignoring flavor typically leads to much tighter bounds on the SMEFT coefficients than in a more general flavor scenario.

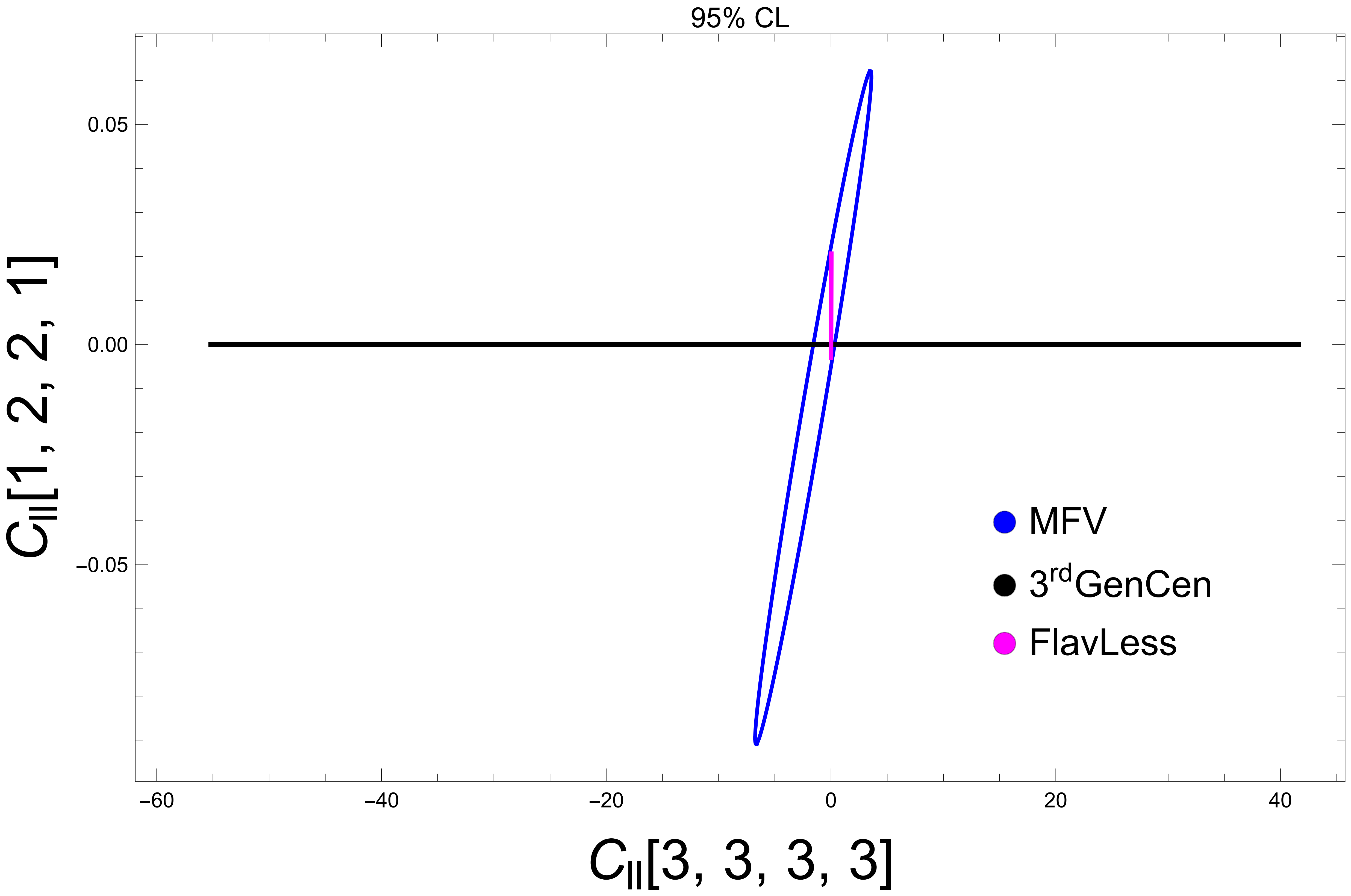
Backup slides

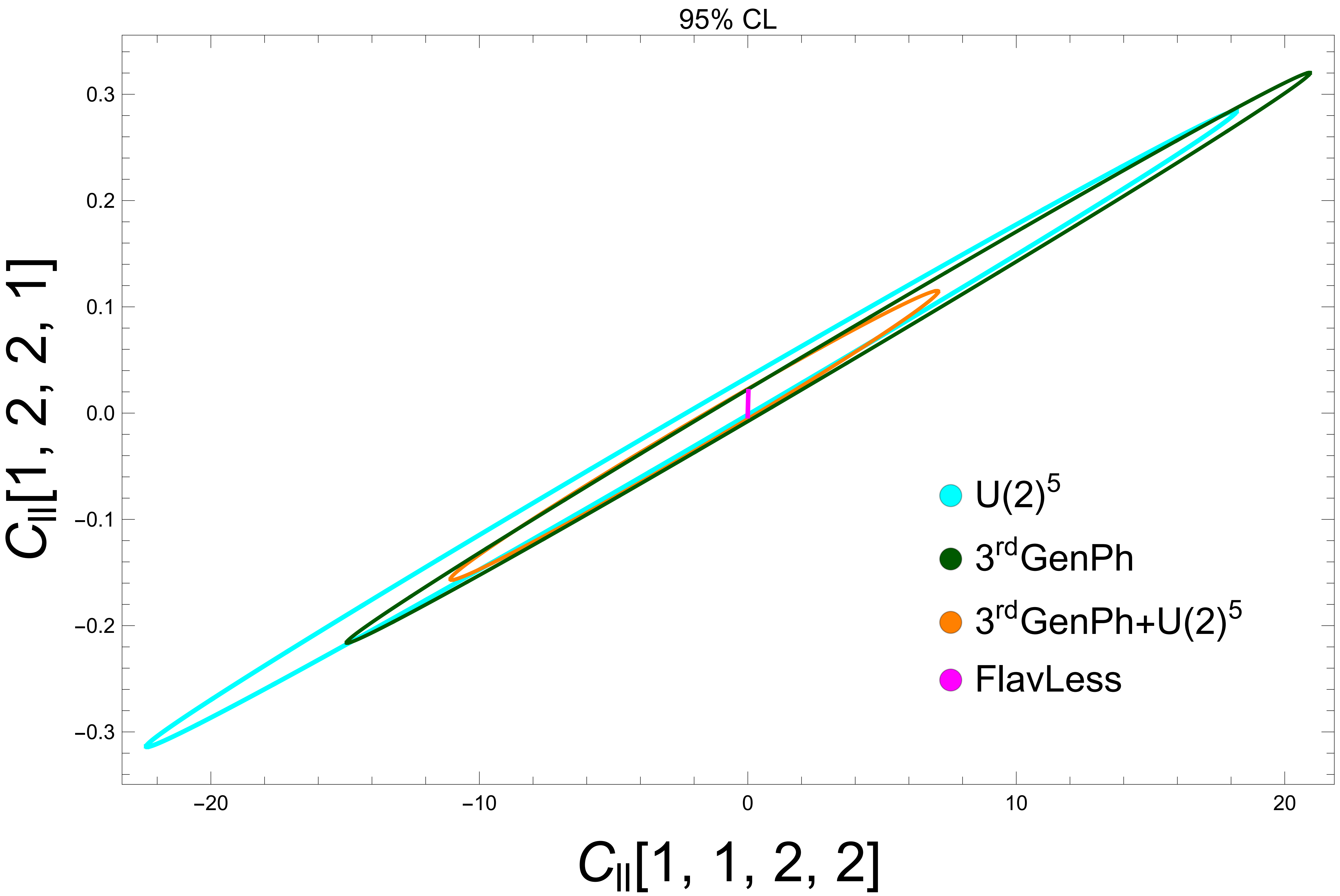
Cll



- **Limits on coefficients of Cll[ijkl] in various flavor scenarios, where i, j, k, l = 1; 2; 3. Only Cll is taken to be non-zero in this figure.**

Cll





- **The plots show the strong correlation between Cll[1221] and Cll[3333] in the MFV scenario and between Cll[1221] and Cll[1122] in the U(2)^5 and 3rd generation phobic scenarios.**

Class B

Operator Class B	$U(3)^5$	MFV	$U(2)^5$	3^{rd} gen specific	3^{rd} gen phobic	3^{rd} gen phobic+$U(2)^5$	Flavorless
$\mathcal{C}_{ee}$	✓	✓	x	✓	x	✓	✓
$\mathcal{C}_{ll}$	✓	✓	✓	✓	✓	✓	✓
$\mathcal{C}_{uu}$	x	x	x	x	x	x	✓
$\mathcal{C}_{dd}$	x	x	x	✓	x	x	✓
$\mathcal{C}_{qq}^{(3)}$	✓	✓	x	✓	x	✓	✓
$\mathcal{C}_{qq}^{(1)}$	✓	✓	x	✓	x	✓	✓

Table I. Class B limits

Class C

Operator Class C	$U(3)^5$	MFV	$U(2)^5$	3^{rd} gen specific	3^{rd} gen phobic	3^{rd} gen phobic+$U(2)^5$	Flavorless
$\mathcal{C}_{lq}^{(3)}$	✓	✓	✓	✓	x	✓	✓
$\mathcal{C}_{lq}^{(1)}$	✓	✓	x	✓	x	✓	✓
$\mathcal{C}_{lu}$	✓	✓	x	✓	x	✓	✓
$\mathcal{C}_{qe}$	✓	✓	x	✓	x	✓	✓
$\mathcal{C}_{ed}$	✓	✓	x	✓	x	✓	✓
$\mathcal{C}_{ld}$	✓	✓	x	✓	x	✓	✓
$\mathcal{C}_{le}$	✓	✓	x	✓	x	✓	✓
$\mathcal{C}_{eu}$	✓	✓	x	✓	x	✓	✓
$\mathcal{C}_{ud}^{(1)}$	✓	✓	x	✓	x	✓	✓
$\mathcal{C}_{qd}^{(1)}$	✓	✓	x	✓	x	✓	✓
$\mathcal{C}_{qu}^{(1)}$	✓	x	x	✓	x	✓	✓

Table I. Class C limits