



LFU and CP violation

Aleks Smolkovic

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SMEFT and flavour

single CPV phase

$$\mathcal{L} = \mathcal{L}_{\text{SM}} + \frac{1}{\Lambda^2} \sum_i C_i Q_i$$

59 operators for a single generation

$$Q_{lq}^{(1)} = (\bar{L}_p \gamma^\mu L_r)(\bar{Q}_s \gamma_\mu Q_t),$$

$$Q_{lq}^{(3)} = (\bar{L}_p \gamma^\mu \tau^I L_r)(\bar{Q}_s \gamma_\mu \tau^I Q_t)$$

...

E.g. B. Grzadkowski et al. - JHEP 10 (2010) 085

Adding flavour to the SMEFT:

increasing symmetry

A. Greljo et al. - 2203.09561

SMEFT $\mathcal{O}(1)$ terms (dim-6, $\Delta B = 0$)		Lepton sector								
		MFV _L	U(3) _V	U(2) ² × U(1) ²	U(2) ²	U(2) _V	U(1) ⁶	U(1) ³	No symm.	
Quark sector	MFV _Q	41 6	45 9	59 6	62 9	67 13	81 6	93 18	207 132	
	U(2) ² × U(3) _d	72 10	78 15	95 10	100 15	107 21	122 10	140 28	281 169	
	U(2) ³ × U(1) _{d₃}	86 10	92 15	111 10	116 12	123 21	140 10	158 28	305 175	
	U(2) ³	93 17	100 23	118 17	124 23	132 30	147 17	168 38	321 191	
	No symmetry	703 570	734 600	756 591	786 621	818 652	813 612	906 705	1350 1149	

[See also talk by A. Greljo]

CP conserving

CP violating

Where is all the CPV?

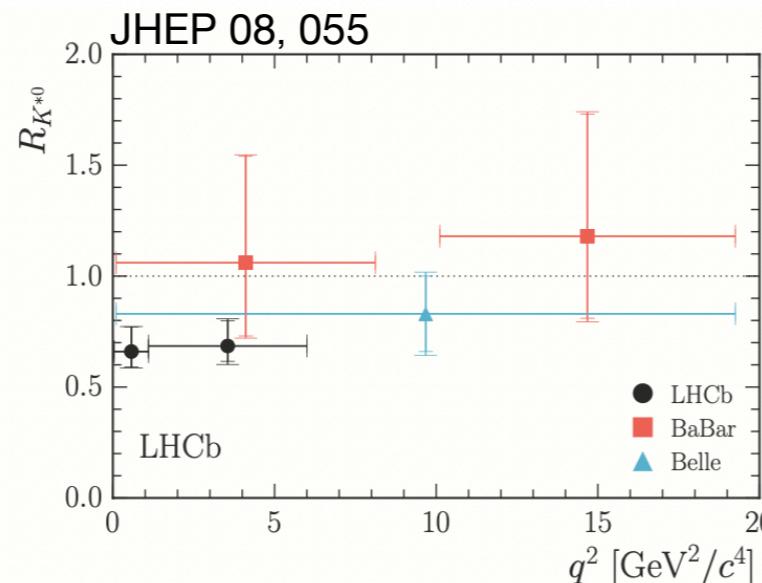
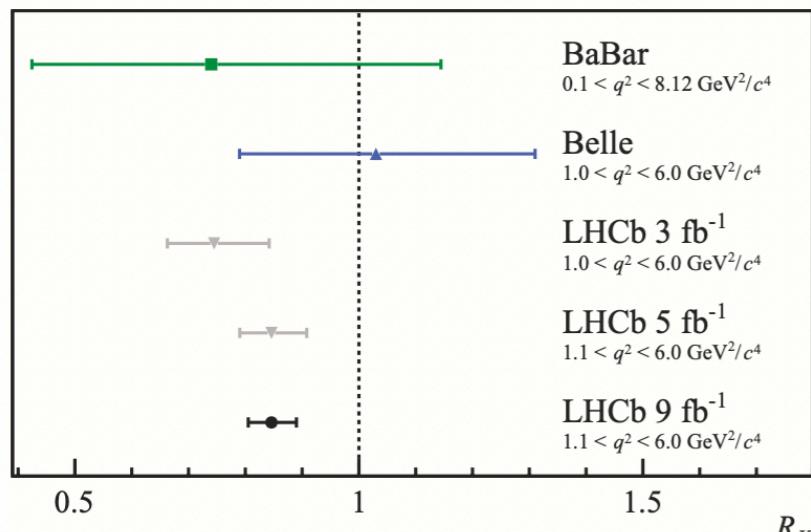
See also:

D. A. Faroughy et al. - JHEP 08 (2020) 166

Q. Bonnefoy et al. - 2112.03889

LFUV and CPV

Nature Physics 18, 277–282 (2022)



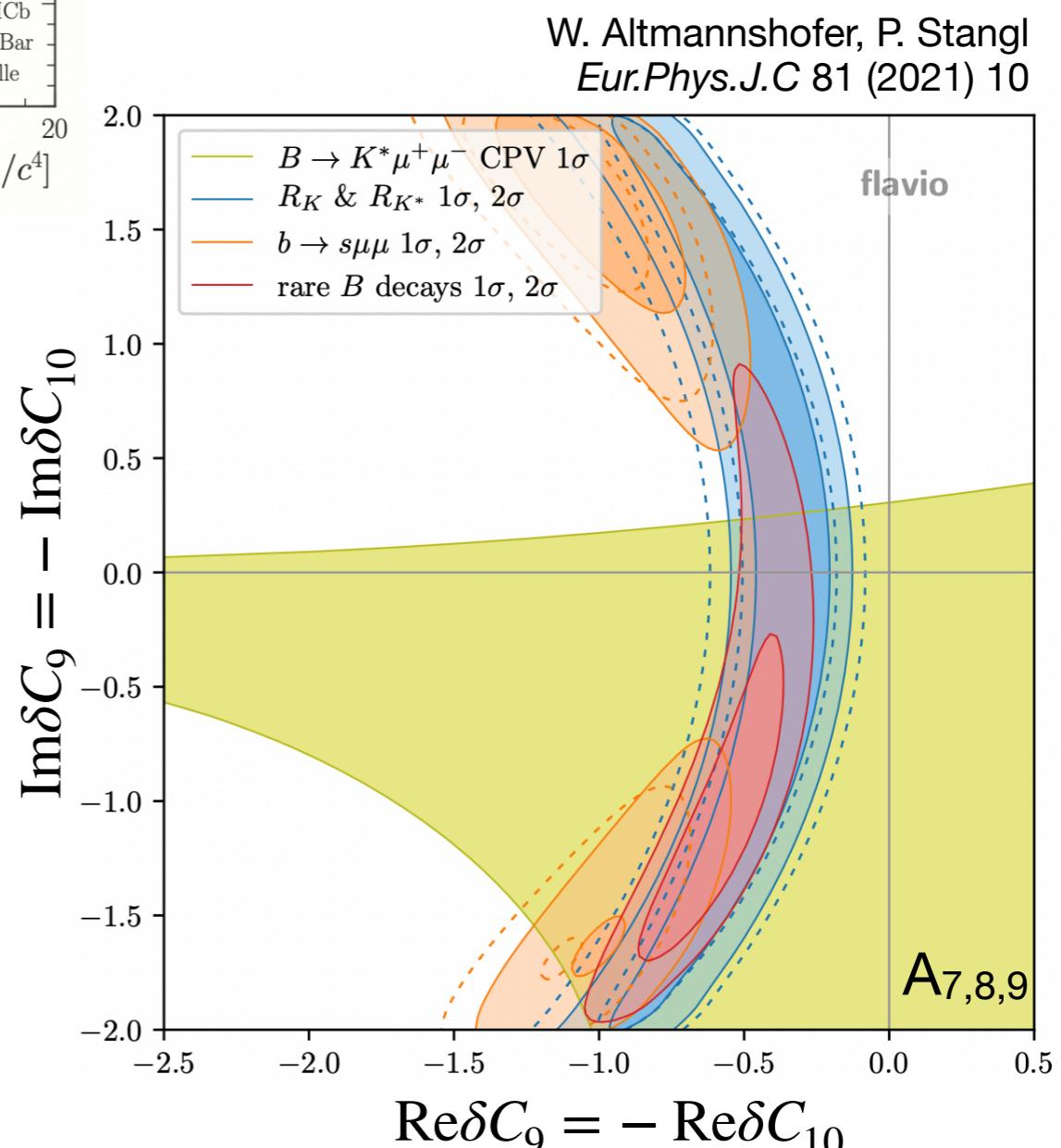
$$R_K = \left. \frac{\Gamma(B \rightarrow K\mu^+\mu^-)}{\Gamma(B \rightarrow Ke^+e^-)} \right|_{[q^2_{\min}, q^2_{\max}]}$$

$$\mathcal{H}_{\text{eff}} = \mathcal{H}_{\text{eff}}^{\text{SM}} - \frac{4G_F}{\sqrt{2}} V_{tb} V_{ts}^* \frac{e^2}{16\pi^2} \sum_i \delta C_i O_i$$

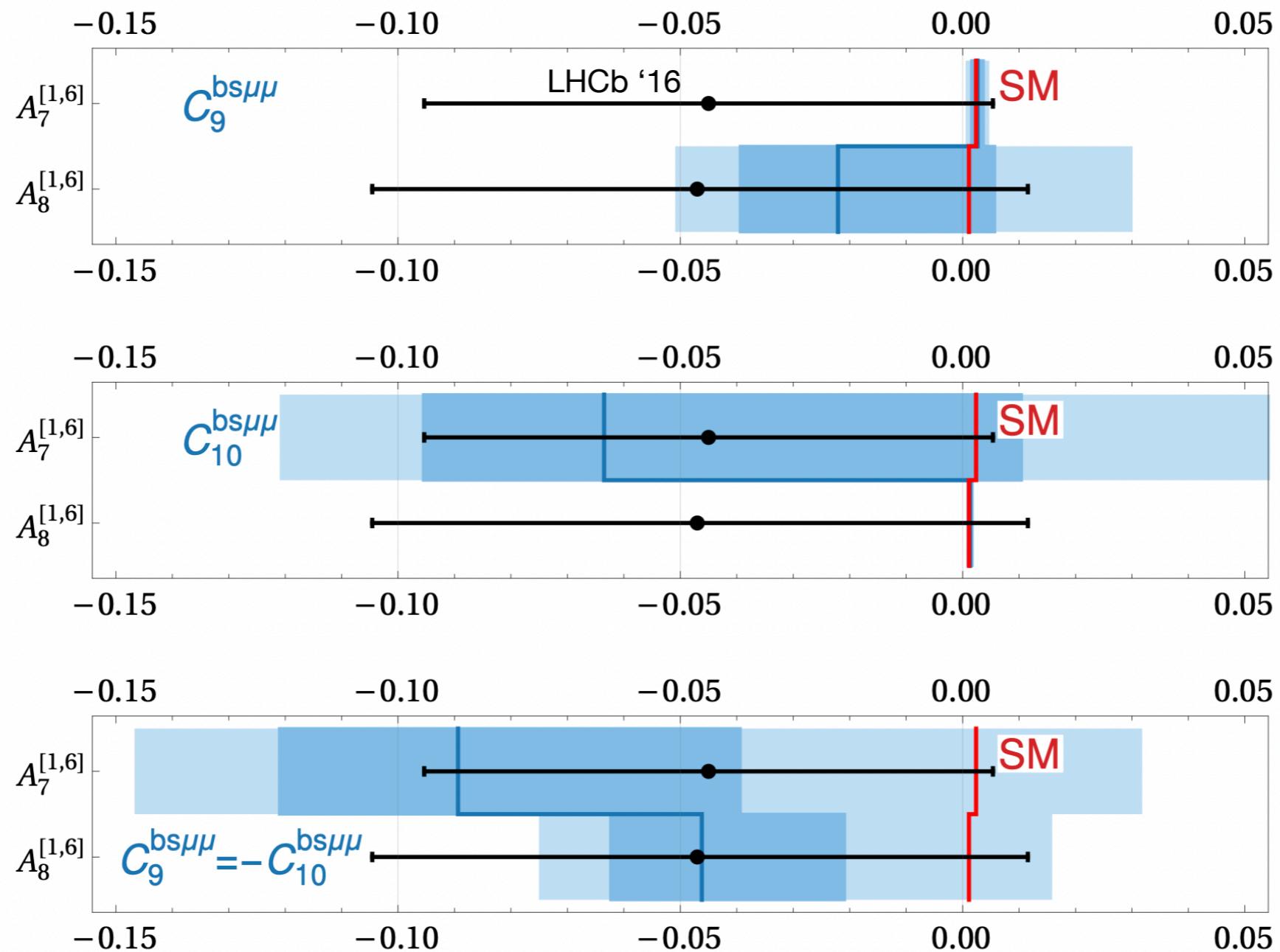
$$O_9^{bs\ell\ell} = (\bar{s}\gamma_\mu P_L b)(\bar{\ell}\gamma^\mu \ell),$$

$$O_{10}^{bs\ell\ell} = (\bar{s}\gamma_\mu P_L b)(\bar{\ell}\gamma^\mu \gamma_5 \ell)$$

- Allow for NP contributions to be complex
- Large CPV phase consistent with data



Discriminating power of CPV



W. Altmannshofer, P. Stangl
Eur.Phys.J.C 81 (2021) 10

See also:

A. Alok et al. - Phys.Rev.D 96 (2017) 1

A S_3 LQ model

S_3 is the only scalar LQ that resolves the R_K tension

[See also talk by O. Sumensari]

Model	$R_{K^{(*)}}$	$R_{D^{(*)}}$	$R_{K^{(*)}} \& R_{D^{(*)}}$
S_3 ($\bar{\mathbf{3}}, \mathbf{3}, 1/3$)	✓	✗	✗
S_1 ($\bar{\mathbf{3}}, \mathbf{1}, 1/3$)	✗	✓	✗
R_2 ($\mathbf{3}, \mathbf{2}, 7/6$)	✗	✓	✗
U_1 ($\mathbf{3}, \mathbf{1}, 2/3$)	✓	✓	✓
U_3 ($\mathbf{3}, \mathbf{3}, 2/3$)	✓	✗	✗

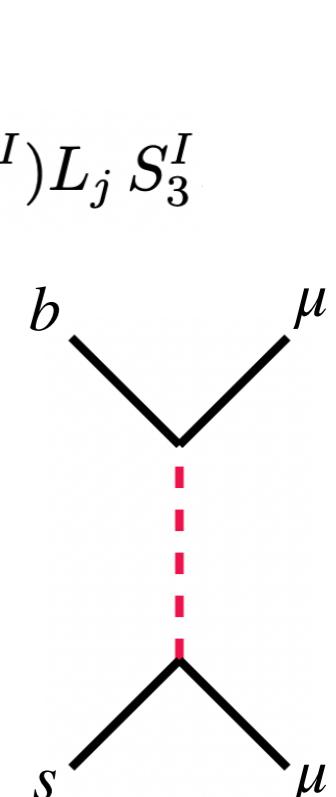
$$\mathcal{L} = |D_\mu S_3|^2 - m_{S_3}^2 |S_3|^2 + y_{ij} \overline{Q_i^C} (i\tau^2 \tau^I) L_j S_3^I$$

SMEFT:

$$C_{lq}^{(1)} = \frac{3y_{b\mu}y_{s\mu}^*}{4m_{S_3}^2}, \quad C_{lq}^{(3)} = \frac{y_{b\mu}y_{s\mu}^*}{4m_{S_3}^2},$$

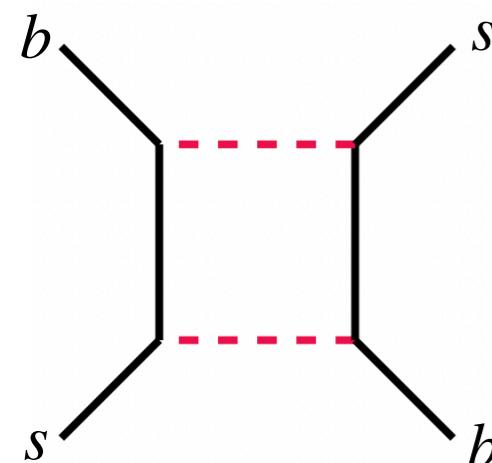
WET:

$$\delta C_9 = -\delta C_{10} = \frac{\pi y_{b\mu}y_{s\mu}^*}{\sqrt{2}G_F V_{tb} V_{ts}^* \alpha_{\text{em}} m_{S_3}^2}$$



A. Angelescu et al. Phys.Rev.D 104 (2021) 5, 055017

At 1-loop level we generate contributions to CP even/odd B_s mixing observables



$$\mathcal{L}_{bs} = -\frac{4G_F}{\sqrt{2}} (V_{tb} V_{ts}^*)^2 C_{bs}^{LL}(\mu) (\bar{s}_L \gamma^\mu b_L)^2$$

$$C_{bs}^{LL} = C_{bs}^{LL(\text{SM})} + \delta C_{bs}^{LL}$$

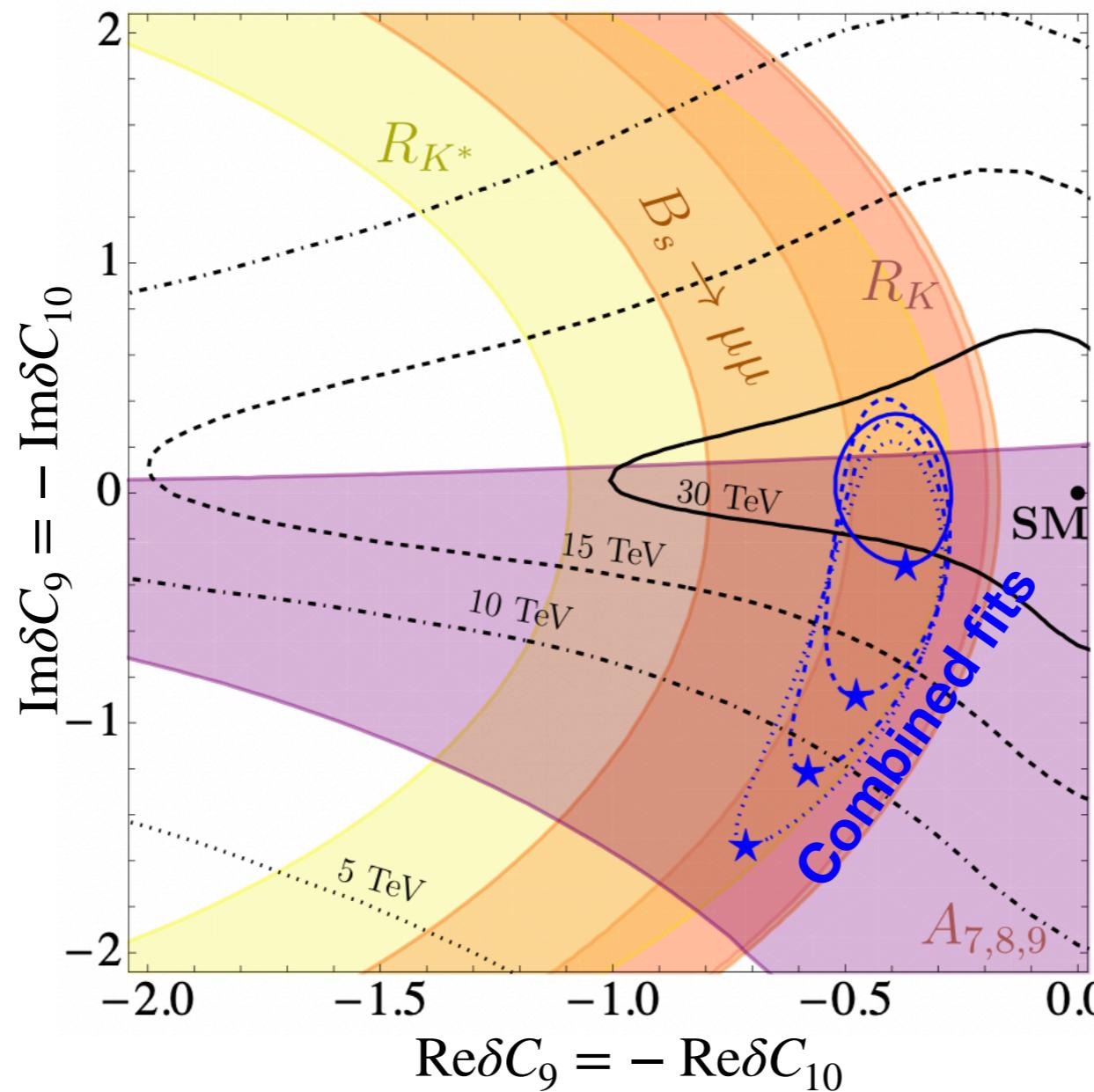
$$\delta C_{bs}^{LL} = \eta^{6/23} \frac{5G_F \alpha_{\text{em}}^2}{128\sqrt{2}\pi^4} (\delta C_9)^2 m_{S_3}^2$$

Bounds in the complex plane:

$$\delta C_{bs}^{LL} = \eta^{6/23} \frac{5G_F\alpha_{em}^2}{128\sqrt{2}\pi^4} (\delta C_9)^2 m_{S_3}^2$$



B_s mixing more constraining for larger masses
(black contours)



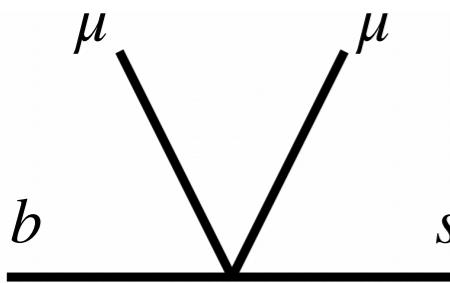
O(1) $\text{Im}\delta C_9$ possible for LQ of few TeV

Resonantly enhanced \mathcal{A}_{CP}

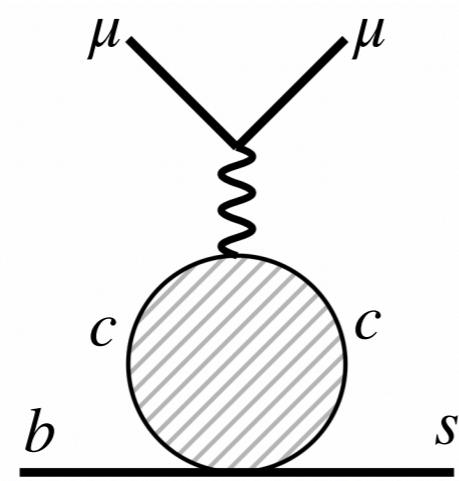
$$\mathcal{A}_{\text{CP}} = \frac{\mathcal{B}(\bar{B} \rightarrow \bar{K}\mu\mu) - \mathcal{B}(B \rightarrow K\mu\mu)}{\mathcal{B}(\bar{B} \rightarrow \bar{K}\mu\mu) + \mathcal{B}(B \rightarrow K\mu\mu)}$$

interference of two amplitudes with differing weak and strong phases needed

Short-distance C_9 :

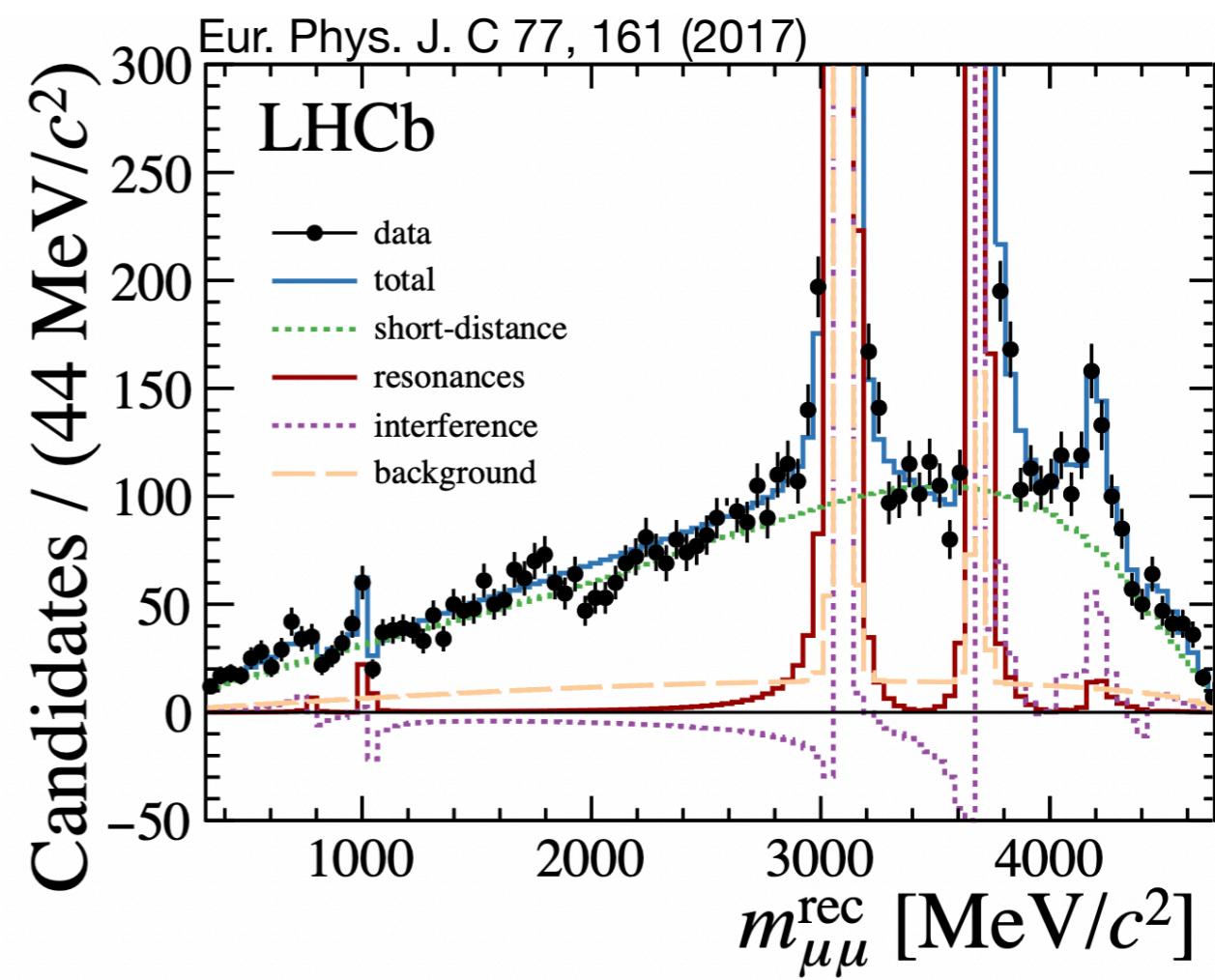


Long-distance $C_9(q^2)$:



Effective model of charmonium contributions:

$$\begin{aligned} C_9^{\text{eff}}(q^2) &= C_9 + C_9^{\text{res}}(q^2) \\ &= C_9 + \sum_j \frac{m_j \Gamma_j \eta_j e^{i\delta_j}}{m_j^2 - q^2 - i m_j \Gamma_j(q^2)} \end{aligned}$$



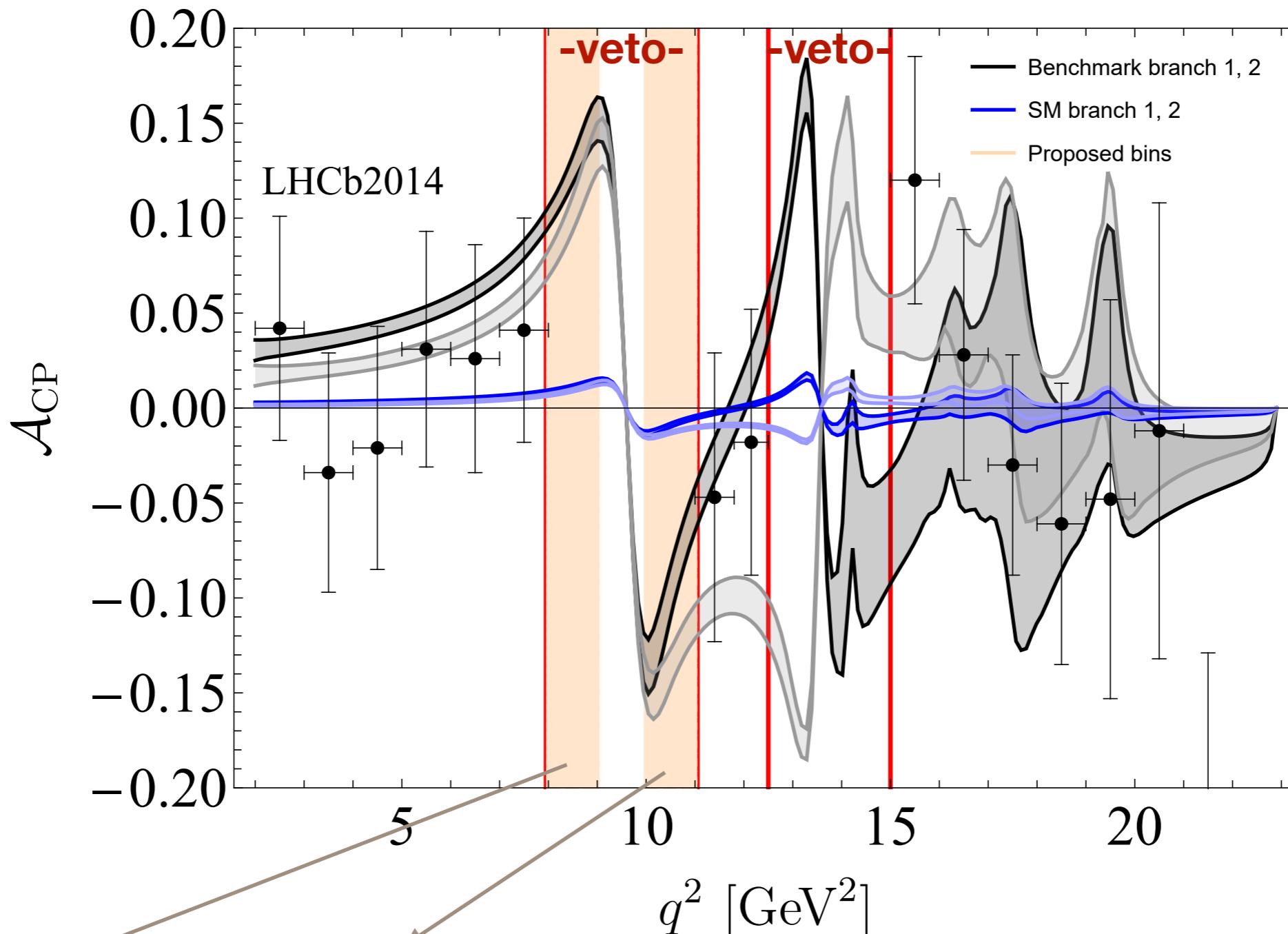
We use the extracted η_j and δ_j to predict \mathcal{A}_{CP}

See also:

T. Blake et al. - Eur.Phys.J.C 78 (2018) 6

Prediction for a benchmark scenario:

$$\delta C_9 = -\delta C_{10} = -0.46 - 0.71i$$

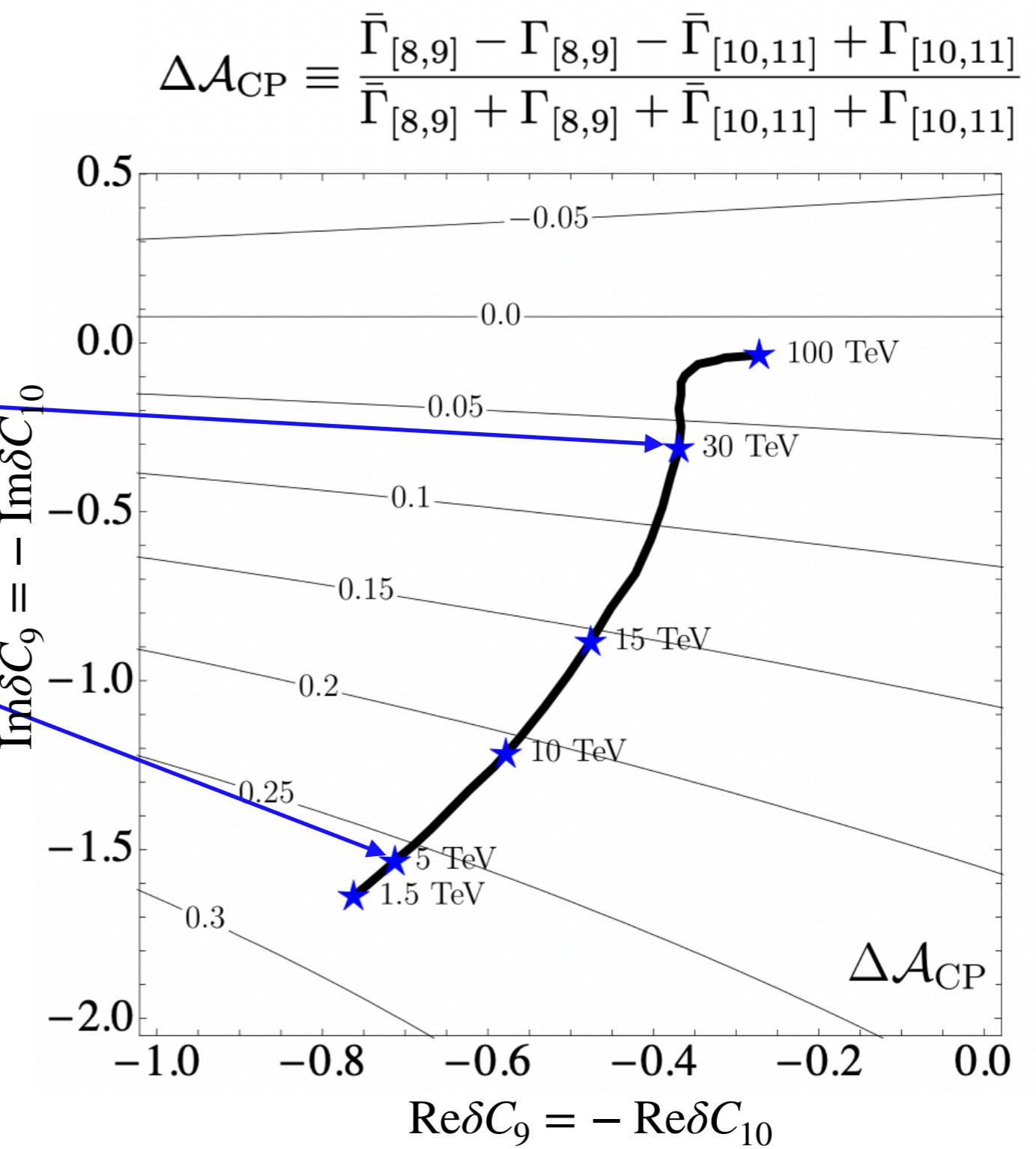
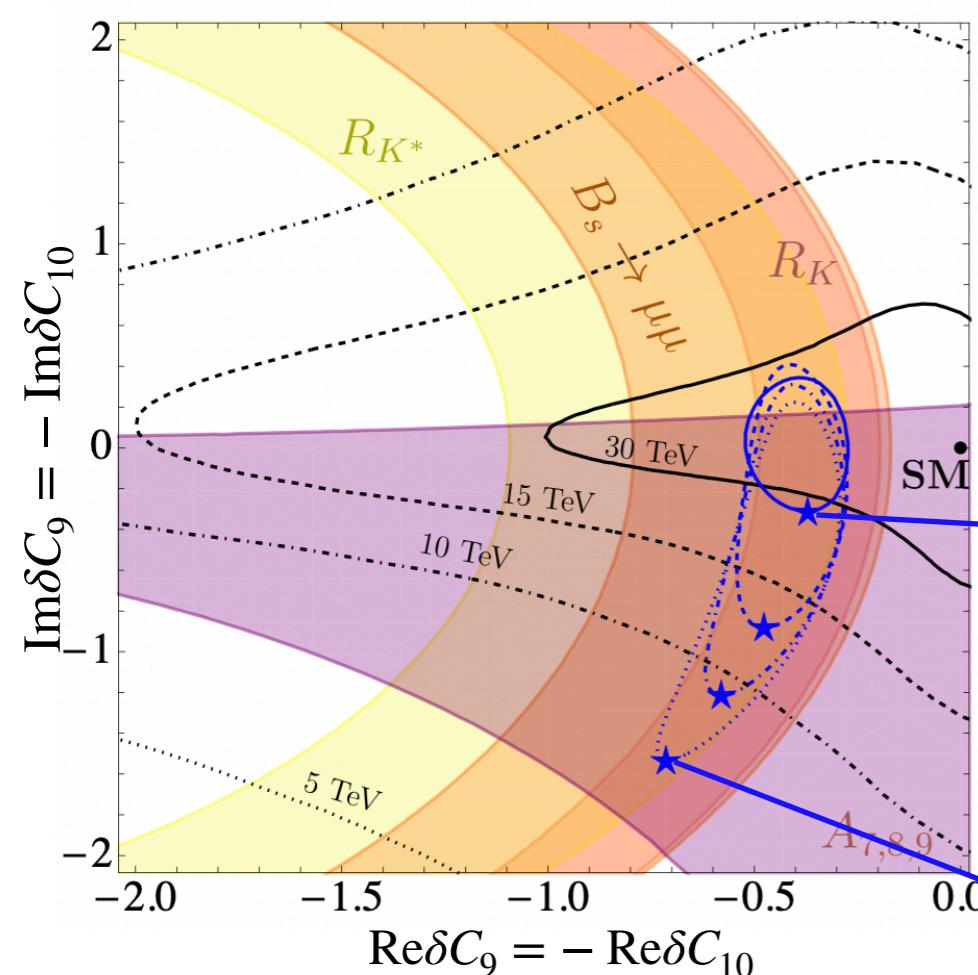


Proposal:

$$\Delta A_{CP} \equiv \frac{\bar{\Gamma}_{[8,9]} - \Gamma_{[8,9]} - \bar{\Gamma}_{[10,11]} + \Gamma_{[10,11]}}{\bar{\Gamma}_{[8,9]} + \Gamma_{[8,9]} + \bar{\Gamma}_{[10,11]} + \Gamma_{[10,11]}}$$

**Measurement of a nonzero value
would be a clean sign of (CPV) NP**

Back to S_3 :



~25% effect for LQ of few TeV

Conclusions

- CP nature of potential NP in LFUV ratios should be scrutinised
- Discriminating power of CPV (NP scenarios, NP vs hadronic effects)
- Proposal: to measure enhanced CPA around J/ψ
nonzero measurement: clean sign of CPV NP
- In S_3 model: Large CPV possible for $O(\text{TeV})$ mass with up to $\sim 25\%$ effect in $\Delta \mathcal{A}_{\text{CP}}$