

A NEW CLASS OF FAMILY NON-UNIVERSAL Z' MODELS



ALEJANDRO CELIS



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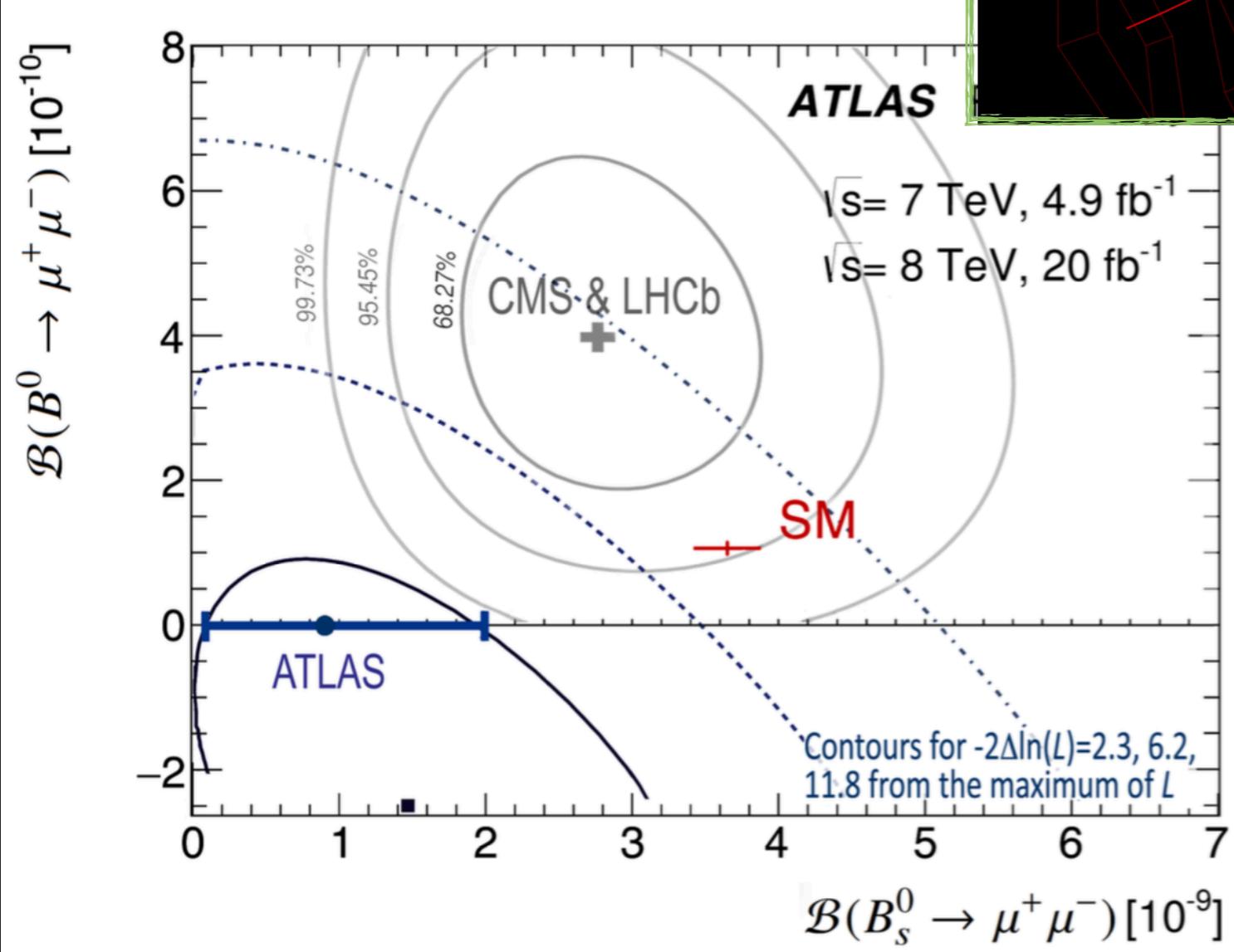
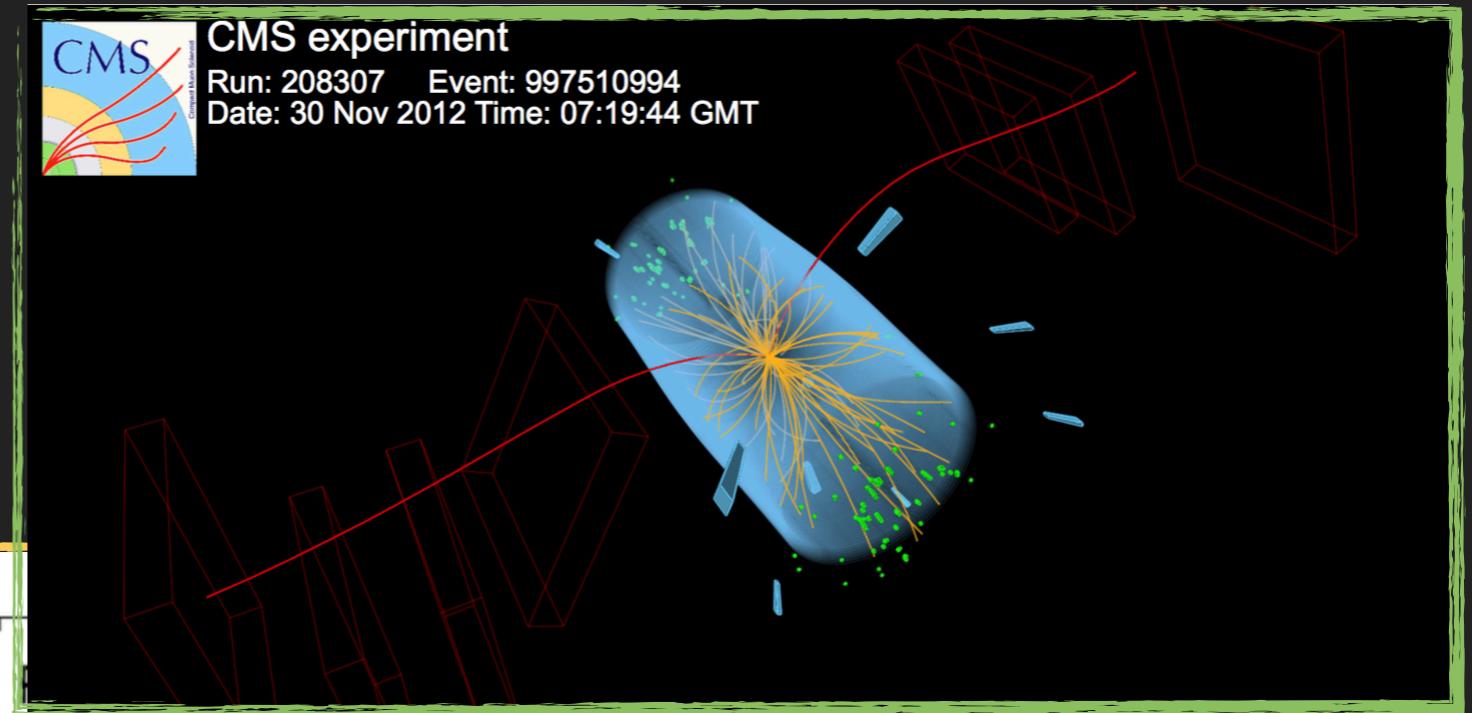
Alexander von Humboldt
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MOTIVATION

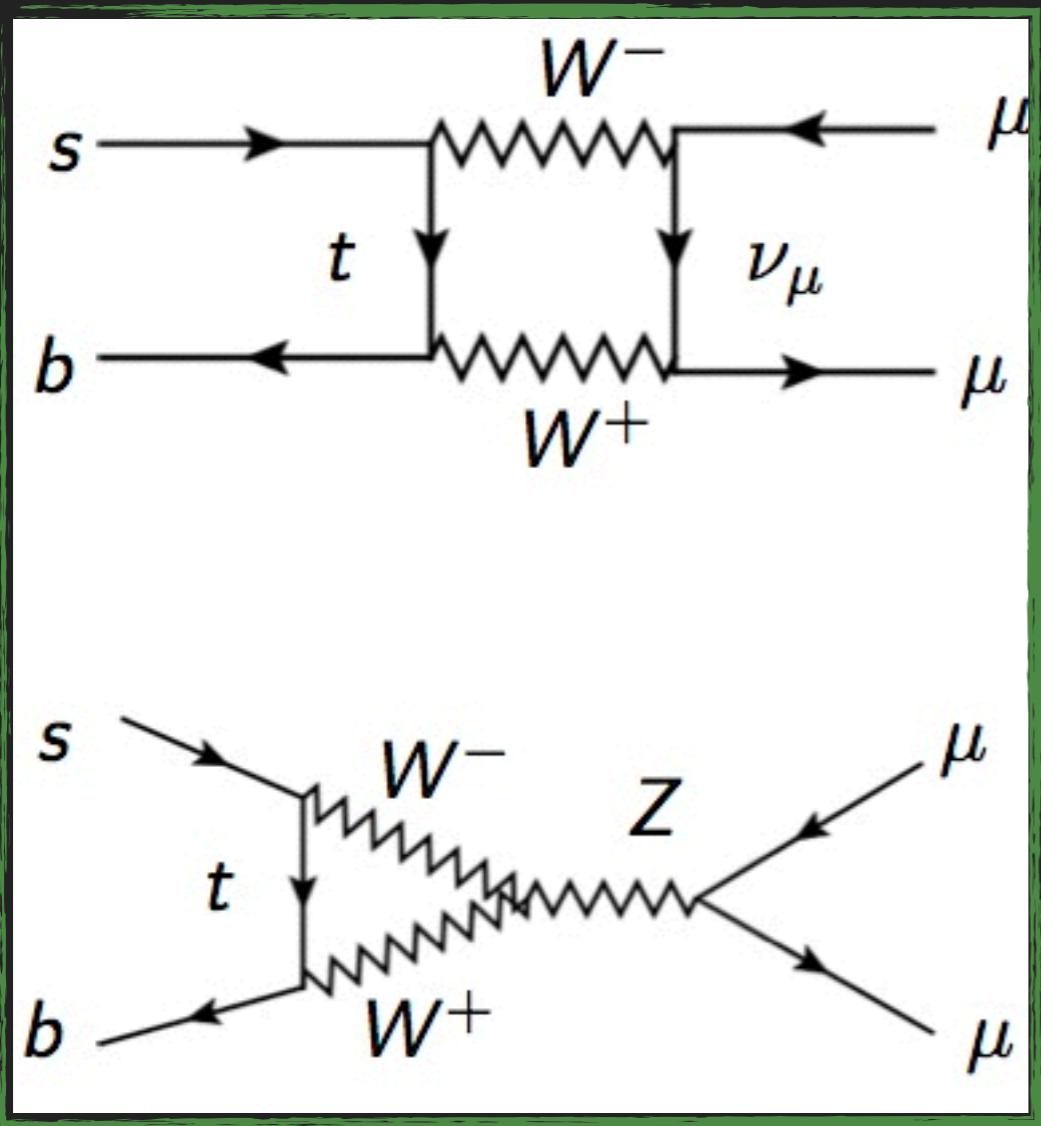
$$B_s^0 \rightarrow \mu^+ \mu^-$$

In the SM

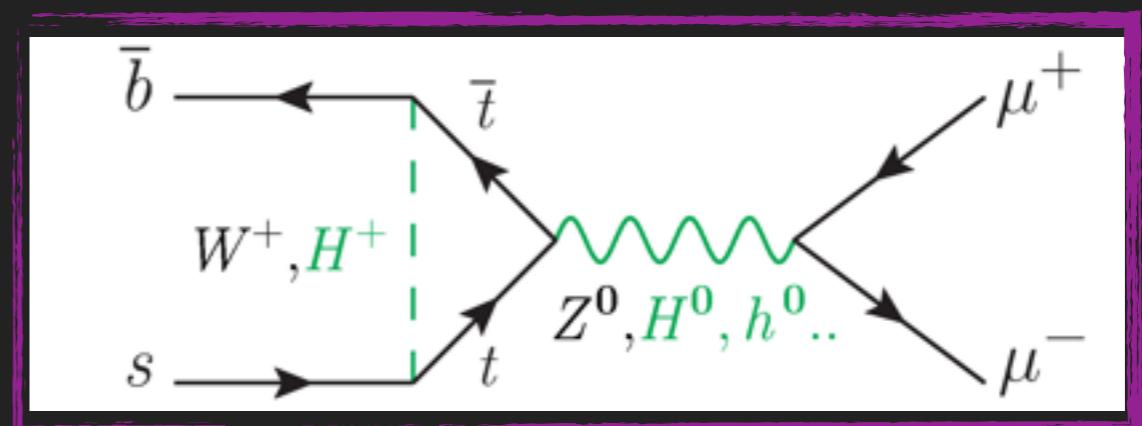
$$\text{BR} \sim 3.65 \times 10^{-9}$$



$$B_s^0 \rightarrow \mu^+ \mu^-$$



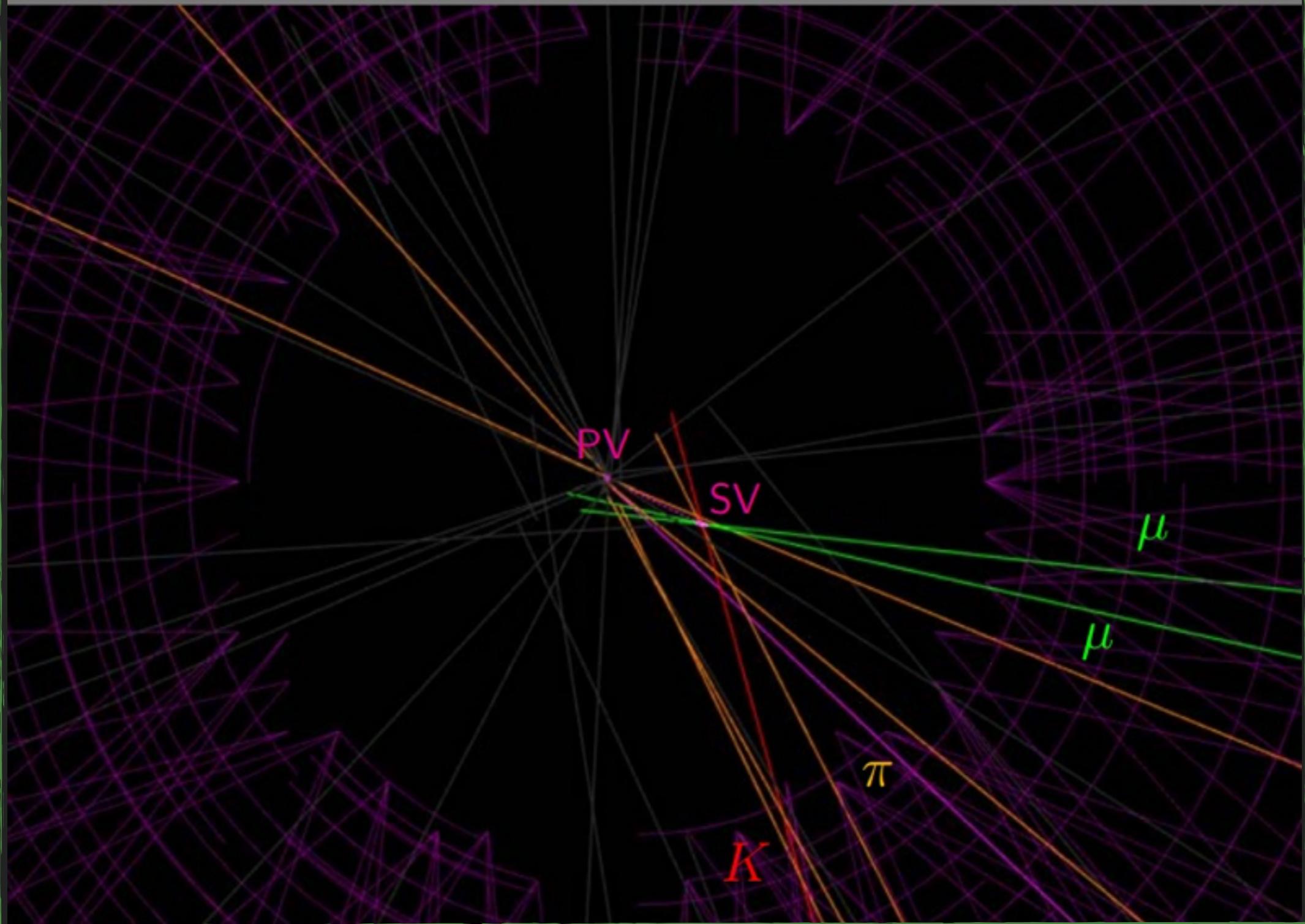
Possible NP contributions



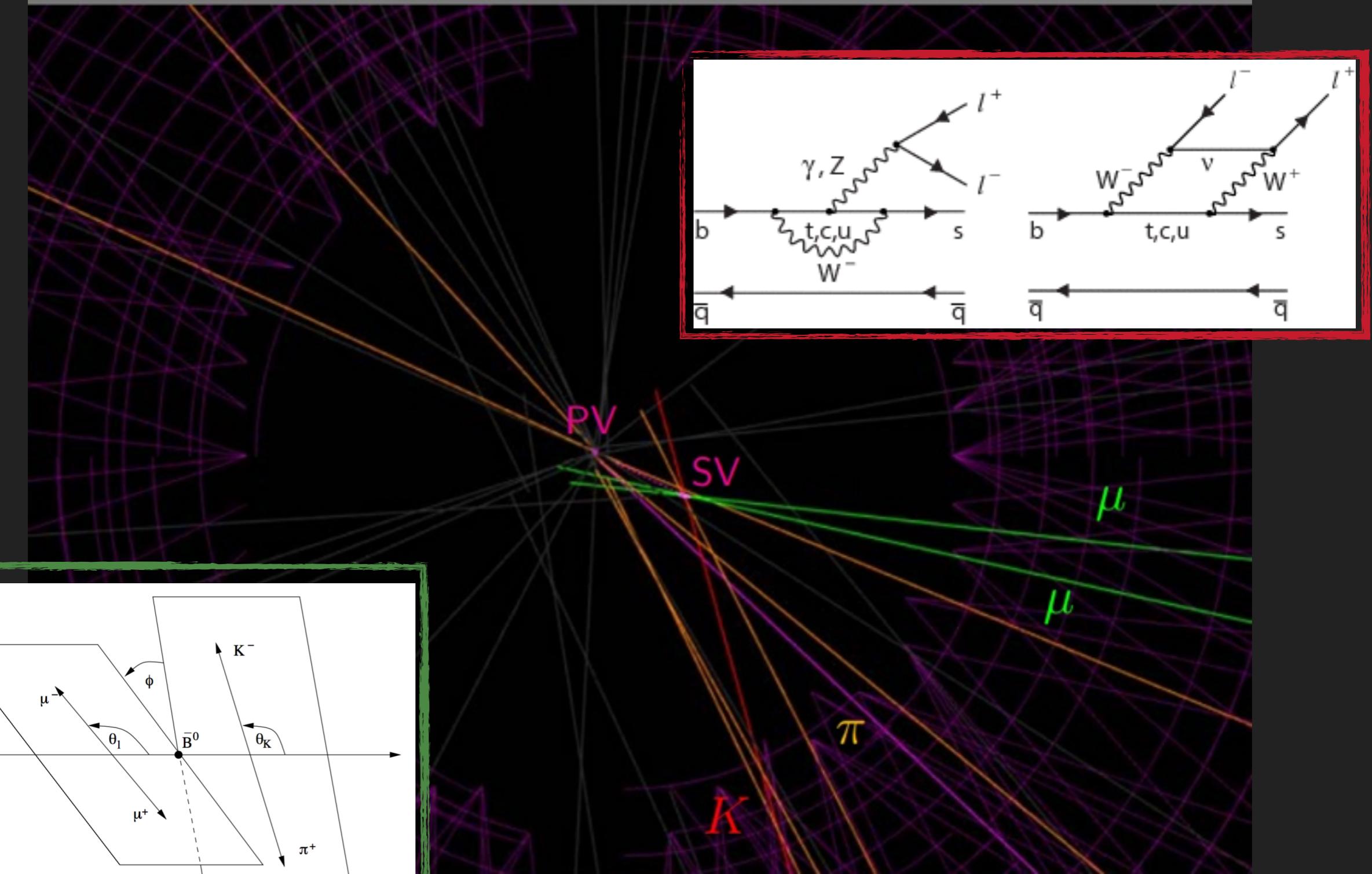
BR in SM \sim

$$\frac{G_F^2}{\pi} \left[\frac{\alpha_{\text{em}}(M_Z)}{4\pi \sin^2 \theta_W} \right]^2 \tau_{B_s} f_{B_s}^2 m_{B_s} m_\mu^2 \sqrt{1 - \frac{4m_\mu^2}{m_{B_s}^2}} |V_{tb}^* V_{ts}|^2$$

Angular analysis of $B^0 \rightarrow K^{*0} \mu^+ \mu^-$ using 3 fb^{-1}



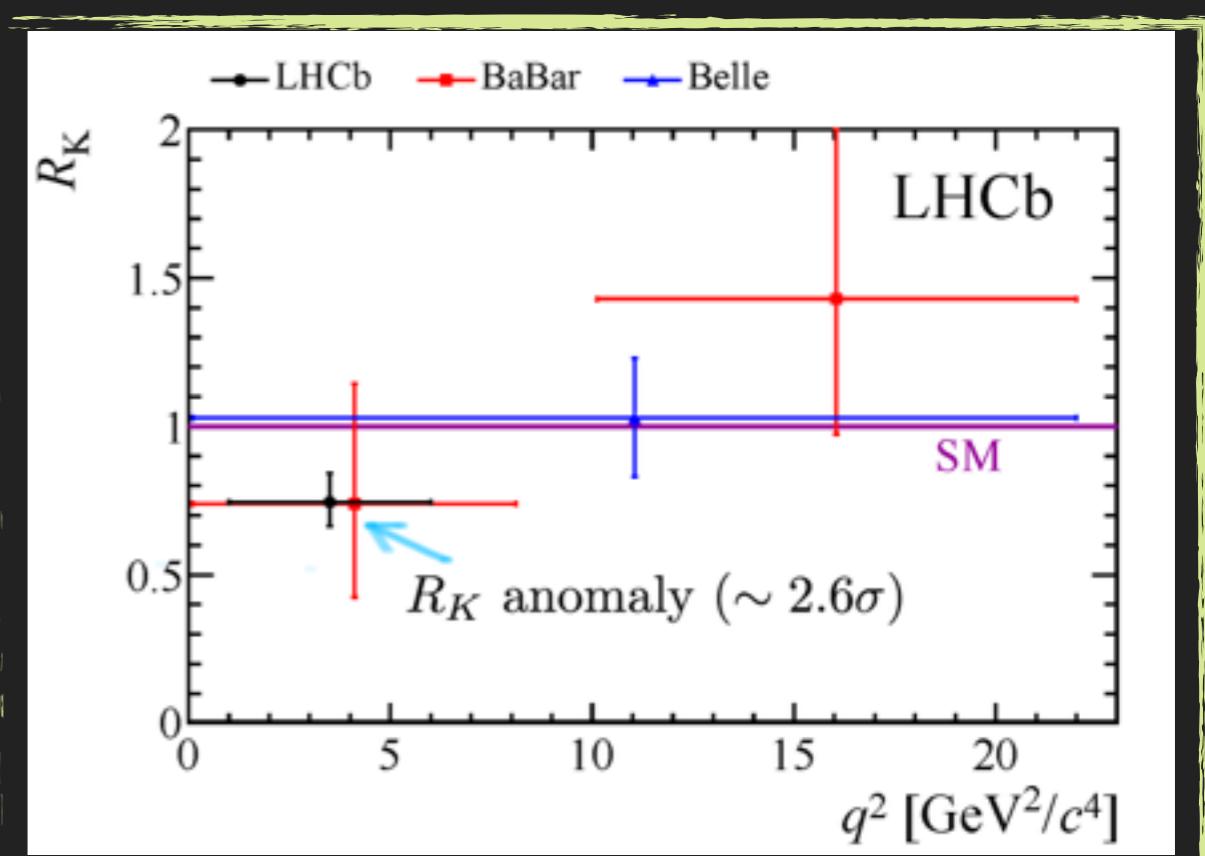
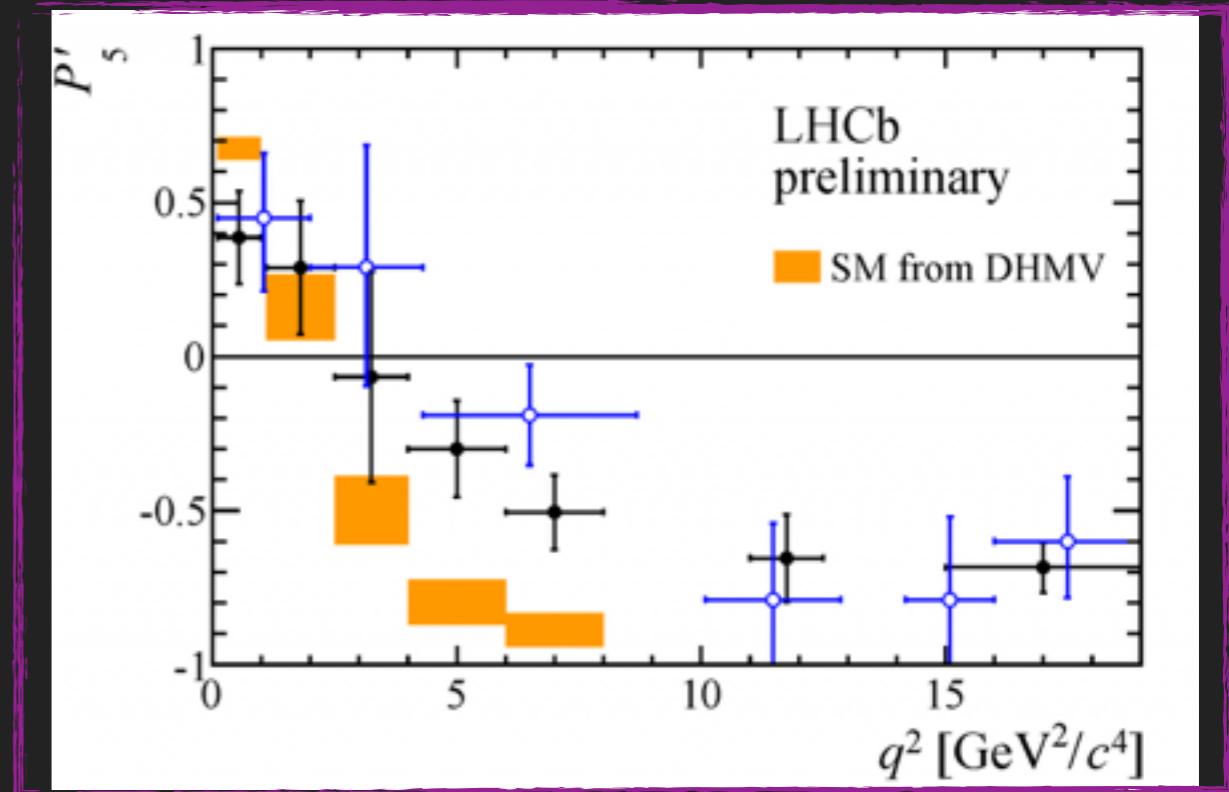
Angular analysis of $B^0 \rightarrow K^{*0} \mu^+ \mu^-$ using 3 fb^{-1}



LHCb ANOMALIES

- ▶ Recent anomalies observed by the LHCb collaboration in $b \rightarrow s \mu \mu$ transitions
- ▶ Crucial to control hadronic uncertainties. Descotes-Genon et al. (15), Altmannshofer-Straub (15), Jäger-Camalich (14), Hurth et al. (16) Ciuchini et al. (15)
- ▶ Hints of Lepton Flavor Universality (LFU) violation in the ratio

$$R_K \equiv \frac{\text{Br}(B \rightarrow K \mu^+ \mu^-)}{\text{Br}(B \rightarrow K e^+ e^-)}$$



- ▶ Recent anomalies observed by the LHCb collaboration in $b \rightarrow s \mu \mu$ transitions.
- ▶ Observables where a single measurement deviates from the SM by 1.9σ or more *Altmannshofer-Straub (15)*

Decay	obs.	q^2 bin	SM pred.	measurement	pull
$\bar{B}^0 \rightarrow \bar{K}^{*0} \mu^+ \mu^-$	F_L	[2, 4.3]	0.81 ± 0.02	0.26 ± 0.19	ATLAS +2.9
$\bar{B}^0 \rightarrow \bar{K}^{*0} \mu^+ \mu^-$	F_L	[4, 6]	0.74 ± 0.04	0.61 ± 0.06	LHCb +1.9
$\bar{B}^0 \rightarrow \bar{K}^{*0} \mu^+ \mu^-$	S_5	[4, 6]	-0.33 ± 0.03	-0.15 ± 0.08	LHCb -2.2
$\bar{B}^0 \rightarrow \bar{K}^{*0} \mu^+ \mu^-$	P'_5	[1.1, 6]	-0.44 ± 0.08	-0.05 ± 0.11	LHCb -2.9
$\bar{B}^0 \rightarrow \bar{K}^{*0} \mu^+ \mu^-$	P'_5	[4, 6]	-0.77 ± 0.06	-0.30 ± 0.16	LHCb -2.8
$B^- \rightarrow K^{*-} \mu^+ \mu^-$	$10^7 \frac{d\text{BR}}{dq^2}$	[4, 6]	0.54 ± 0.08	0.26 ± 0.10	LHCb +2.1
$\bar{B}^0 \rightarrow \bar{K}^0 \mu^+ \mu^-$	$10^8 \frac{d\text{BR}}{dq^2}$	[0.1, 2]	2.71 ± 0.50	1.26 ± 0.56	LHCb +1.9
$\bar{B}^0 \rightarrow \bar{K}^0 \mu^+ \mu^-$	$10^8 \frac{d\text{BR}}{dq^2}$	[16, 23]	0.93 ± 0.12	0.37 ± 0.22	CDF +2.2
$B_s \rightarrow \phi \mu^+ \mu^-$	$10^7 \frac{d\text{BR}}{dq^2}$	[1, 6]	0.48 ± 0.06	0.23 ± 0.05	LHCb +3.1

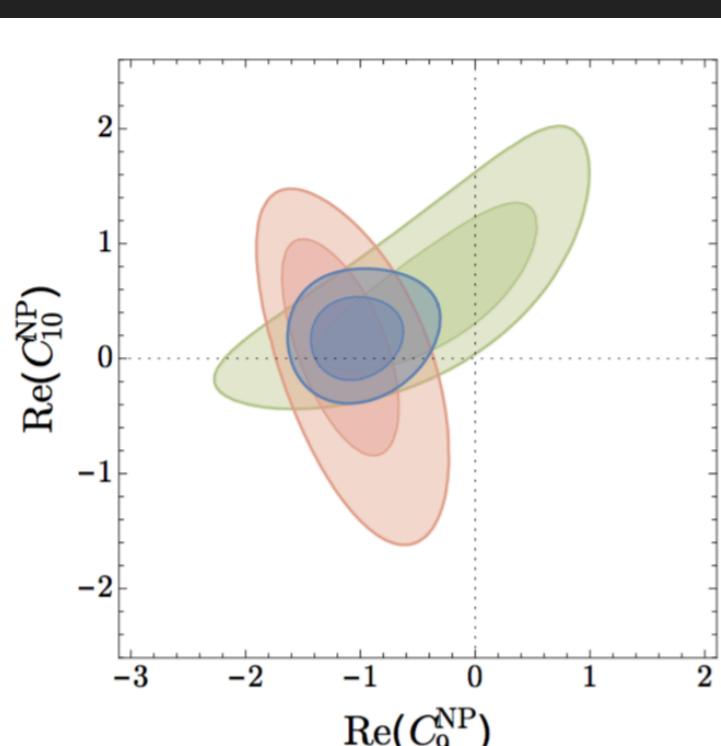
- ▶ Large number of observables calls for global analyses of $b \rightarrow s l^+ l^-$ data
- ▶ Different statistical treatments and hadronic uncertainties
- ▶ Effective weak Hamiltonian at the B-meson scale provides a common theoretical framework in these works.

$$\mathcal{H}_{eff} = \mathcal{H}_{eff}^{b \rightarrow s \gamma} - \frac{4G_F}{\sqrt{2}} \frac{\alpha}{4\pi} V_{ts}^* V_{tb} \boxed{\sum_{i=9,10} [C_i^\ell Q_i^\ell + C'_i Q'_i^\ell]}$$

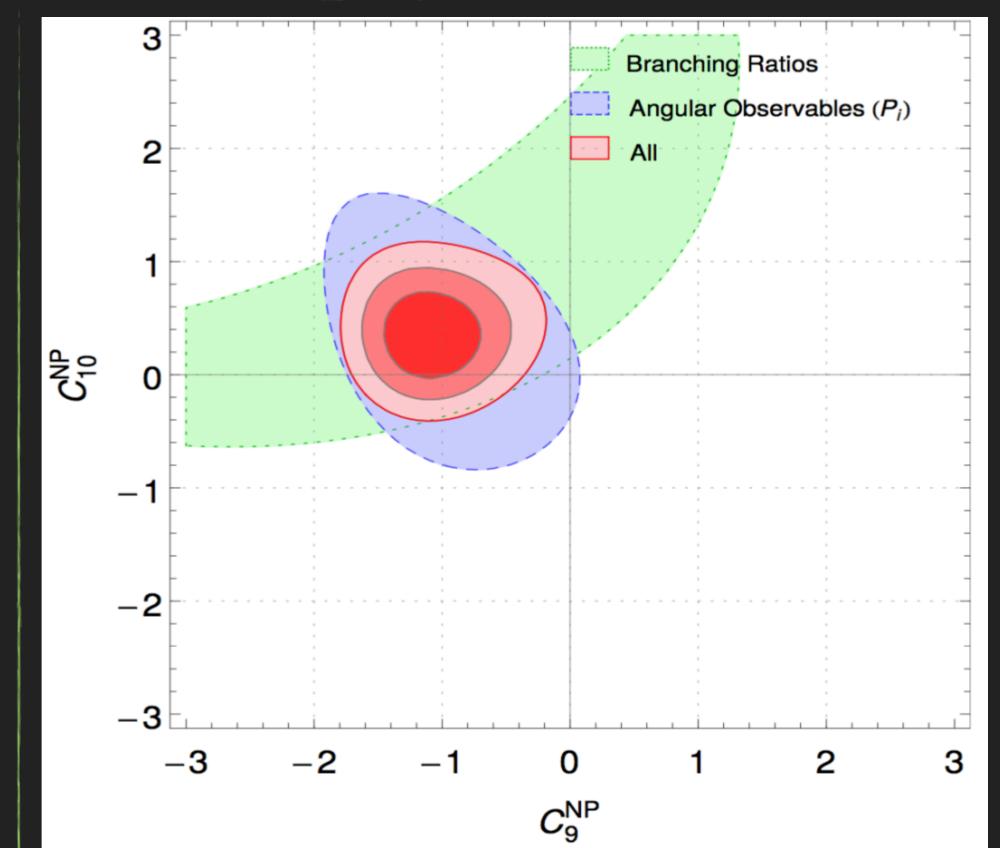
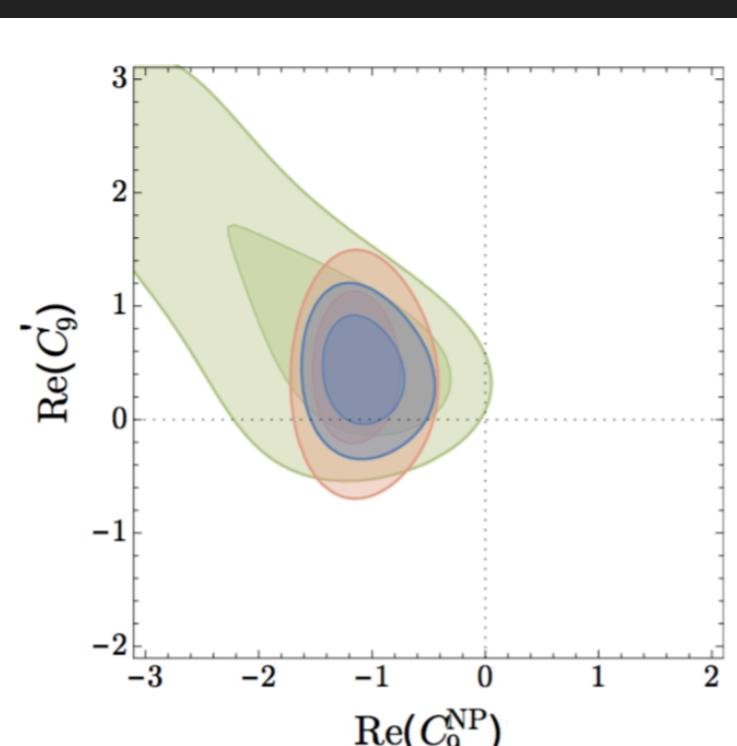
$$Q_9^\ell = (\bar{s}\gamma_\alpha P_L b)(\bar{\ell}\gamma^\alpha \ell), \quad Q'_9^\ell = (\bar{s}\gamma_\alpha P_R b)(\bar{\ell}\gamma^\alpha \ell),$$

$$Q_{10}^\ell = (\bar{s}\gamma_\alpha P_L b)(\bar{\ell}\gamma^\alpha \gamma_5 \ell), \quad Q'_{10}^\ell = (\bar{s}\gamma_\alpha P_R b)(\bar{\ell}\gamma^\alpha \gamma_5 \ell).$$

$$\begin{aligned}
 Q_9^\ell &= (\bar{s}\gamma_\alpha P_L b)(\bar{\ell}\gamma^\alpha \ell), & Q_9'^\ell &= (\bar{s}\gamma_\alpha P_R b)(\bar{\ell}\gamma^\alpha \ell), \\
 Q_{10}^\ell &= (\bar{s}\gamma_\alpha P_L b)(\bar{\ell}\gamma^\alpha \gamma_5 \ell), & Q_{10}'^\ell &= (\bar{s}\gamma_\alpha P_R b)(\bar{\ell}\gamma^\alpha \gamma_5 \ell).
 \end{aligned}$$

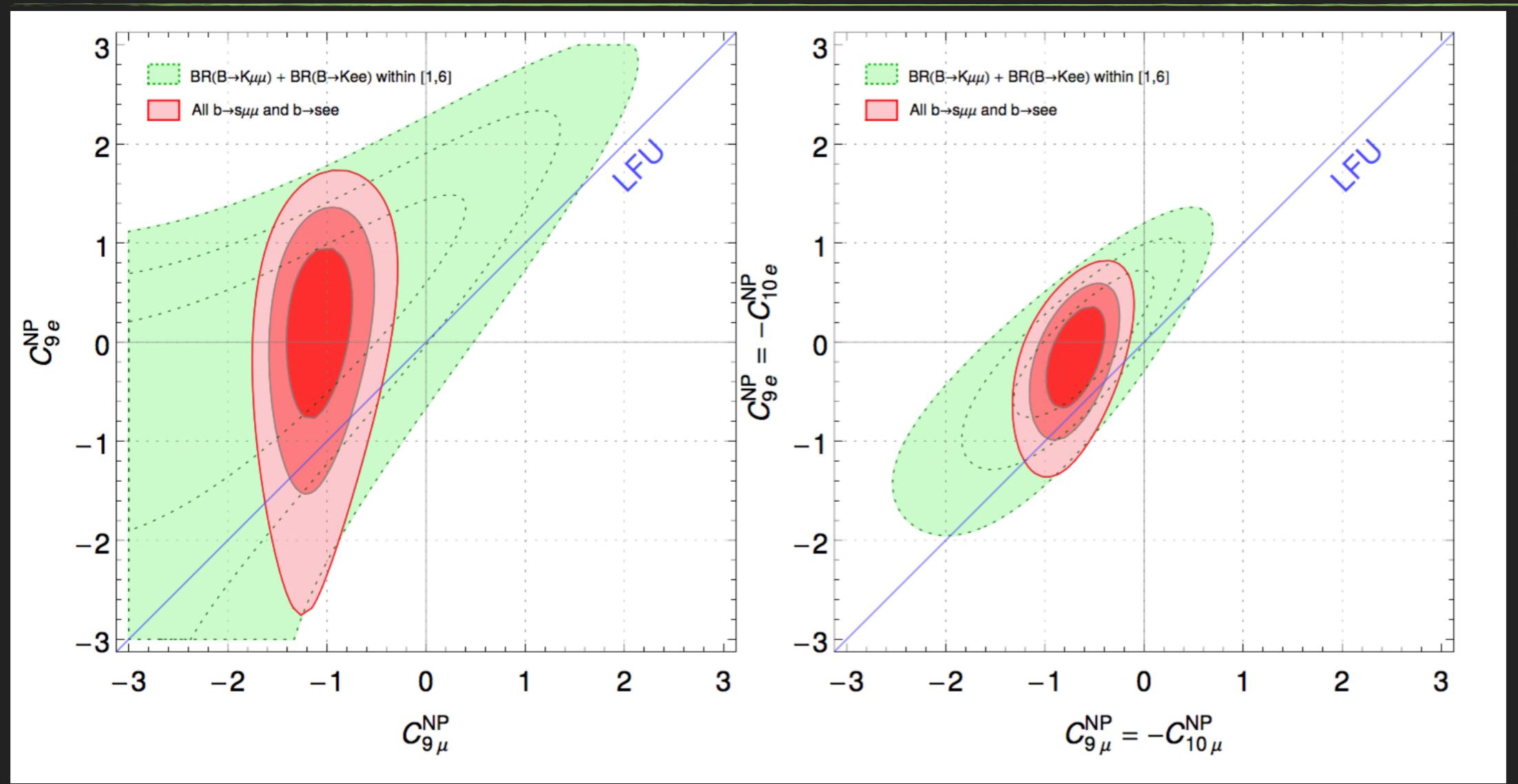


► Altmannshofer-Straub (15)



► Virto et al (15)

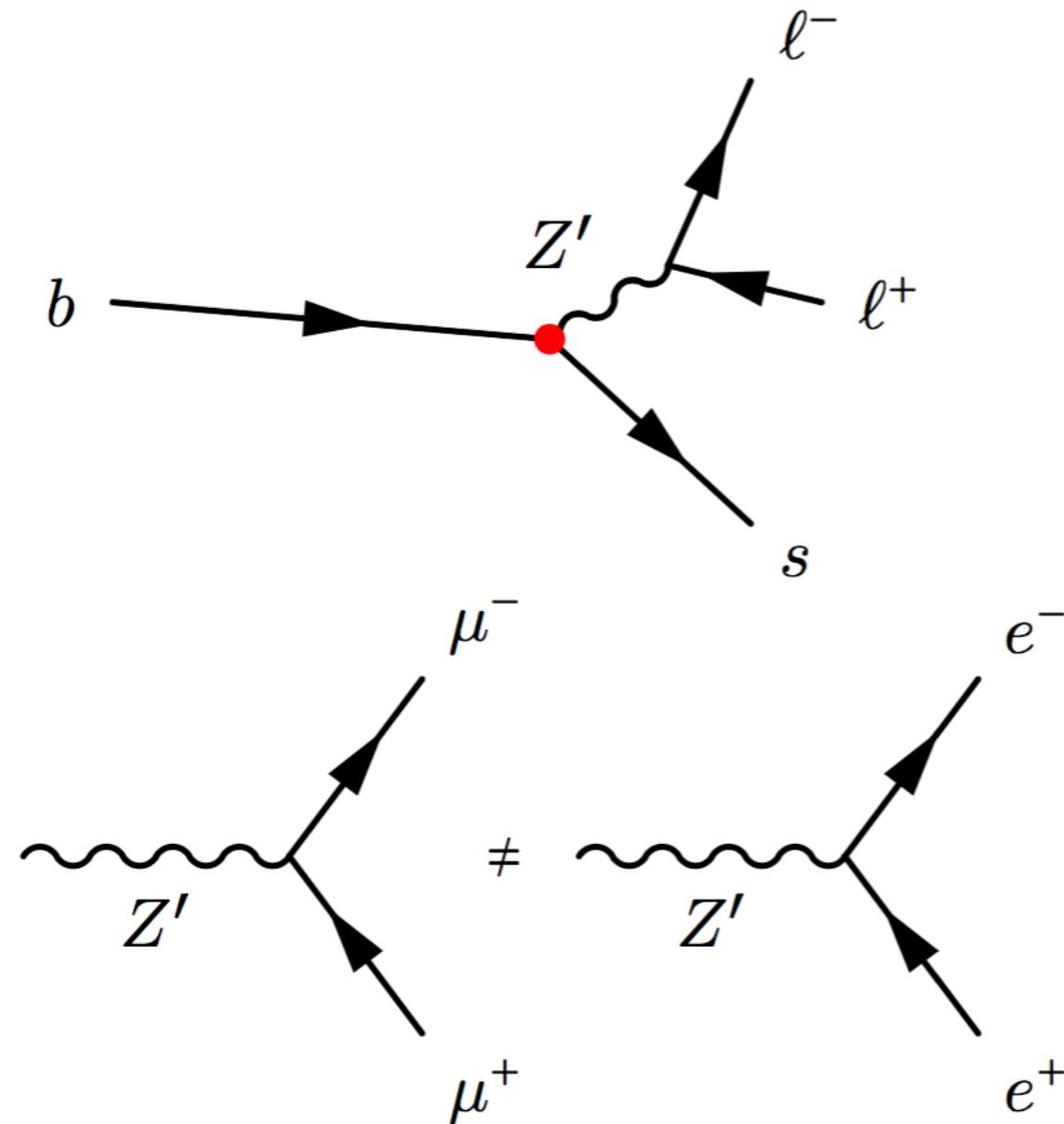
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 \end{aligned}$$



Z' EXPLANATION

A possibility ?

Talk by A. Crivellin



★ $L_\mu - L_\tau$

Altmannshofer, Gori, Pospelov, Yavin [1403.1269]

C_9^μ and $C_9'^\mu$ uncorrelated. $C_9^{(\prime)\tau} = -C_9^{(\prime)\mu}$

★ $L_\mu - L_\tau - a(B_1 + B_2 - 2B_3)$

Crivellin, Ambrosio, Heeck

Generates $C_9^\mu = -C_9^\tau$

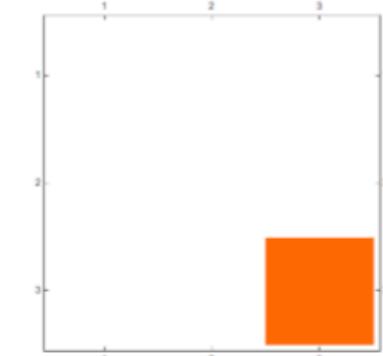
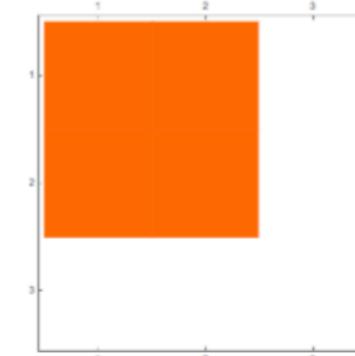
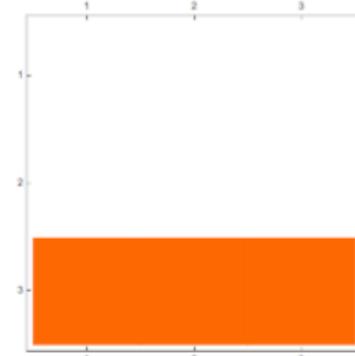
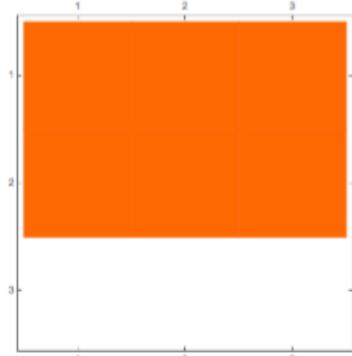
BRANCO-GRIMUS-LAVOURA (BGL) 2HDM

BGL Yukawa textures

Branco, Grimus, Lavoura Phys.Lett. B380 (1996)

Textures imposed by global symmetry $U(1)$ or Z_N

$$-\mathcal{L}_Y = \overline{Q_L^0} [\Gamma_1^{BGL} \Phi_1 + \Gamma_2^{BGL} \Phi_2] d_R^0 + \overline{Q_L^0} [\Delta_1^{BGL} \tilde{\Phi}_1 + \Delta_2^{BGL} \tilde{\Phi}_2] u_R^0$$



Higgs FCNCs at tree-level controlled by CKM matrix elements

$$H \bar{d}_i d_j \propto (V_{CKM})_{ti}^* (V_{CKM})_{tj} m_{d_j}$$

MFV structure

Promoting global to local $U(1)'$.

Important constraint **Anomaly Cancellation**.

- $U(1)'[SU(3)_c]^2$
- $U(1)'[SU(2)_L]^2$
- $U(1)'[U(1)_Y]^2$
- $[U(1)']^2 U(1)_Y$
- $[U(1)']^3$
- $U(1)'[\text{Gravity}]^2$

Most general BGL implementation $\psi \rightarrow e^{i\chi^\psi \alpha} \psi$

$$\chi_L^q = \frac{1}{2} [\text{diag}(X_{uR}, X_{uR}, X_{tR}) + X_{dR} \mathbb{I}]$$

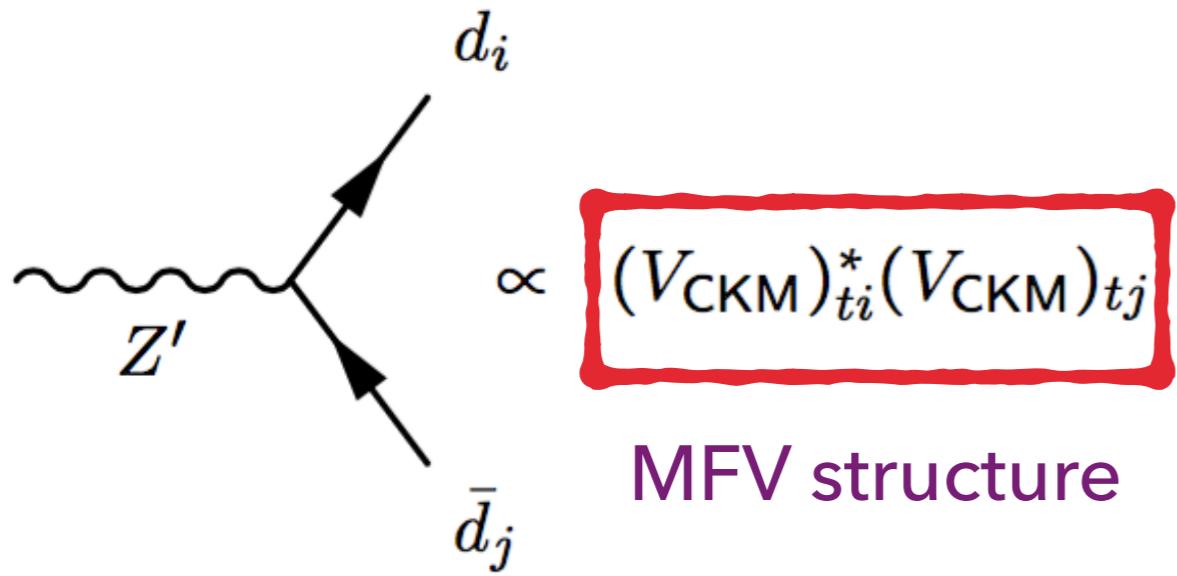
$$\chi_R^u = \text{diag}(X_{uR}, X_{uR}, X_{tR})$$

$$\chi_R^d = X_{dR} \mathbb{I}$$

- ✗ The quark sector alone is not enough;
- ✓ Adding the charged leptons allow anomaly cancellation;
- ✓ Only one class of solutions is possible.;

GAUGED BGL SYMMETRY

AC, Fuentes, Jung, Serodio [1505.03079]



Model	$C_{10}^{\text{NP}\mu}/C_9^{\text{NP}\mu}$	$C_9^{\text{NP}\tau}/C_9^{\text{NP}\mu}$	$C_{10}^{\text{NP}\tau}/C_9^{\text{NP}\mu}$
(1,2,3)	3/17	-8/17	0
(1,3,2)	0	-17/8	-3/8
(2,1,3)	1/3	-8/9	0
(2,3,1)	0	-9/8	-3/8
(3,1,2)	1/3	17/9	1/3
(3,2,1)	3/17	9/17	3/17

Only left-handed Z' FCNCs \Rightarrow No contributions to $C'_{9,10}$

$$\mathcal{O}_9^{\ell\prime} = (\bar{s}\gamma_\mu P_R b) (\bar{\ell}\gamma^\mu \ell)$$

$$\mathcal{O}_{10}^{\ell\prime} = (\bar{s}\gamma_\mu P_R b) (\bar{\ell}\gamma^\mu \gamma_5 \ell)$$

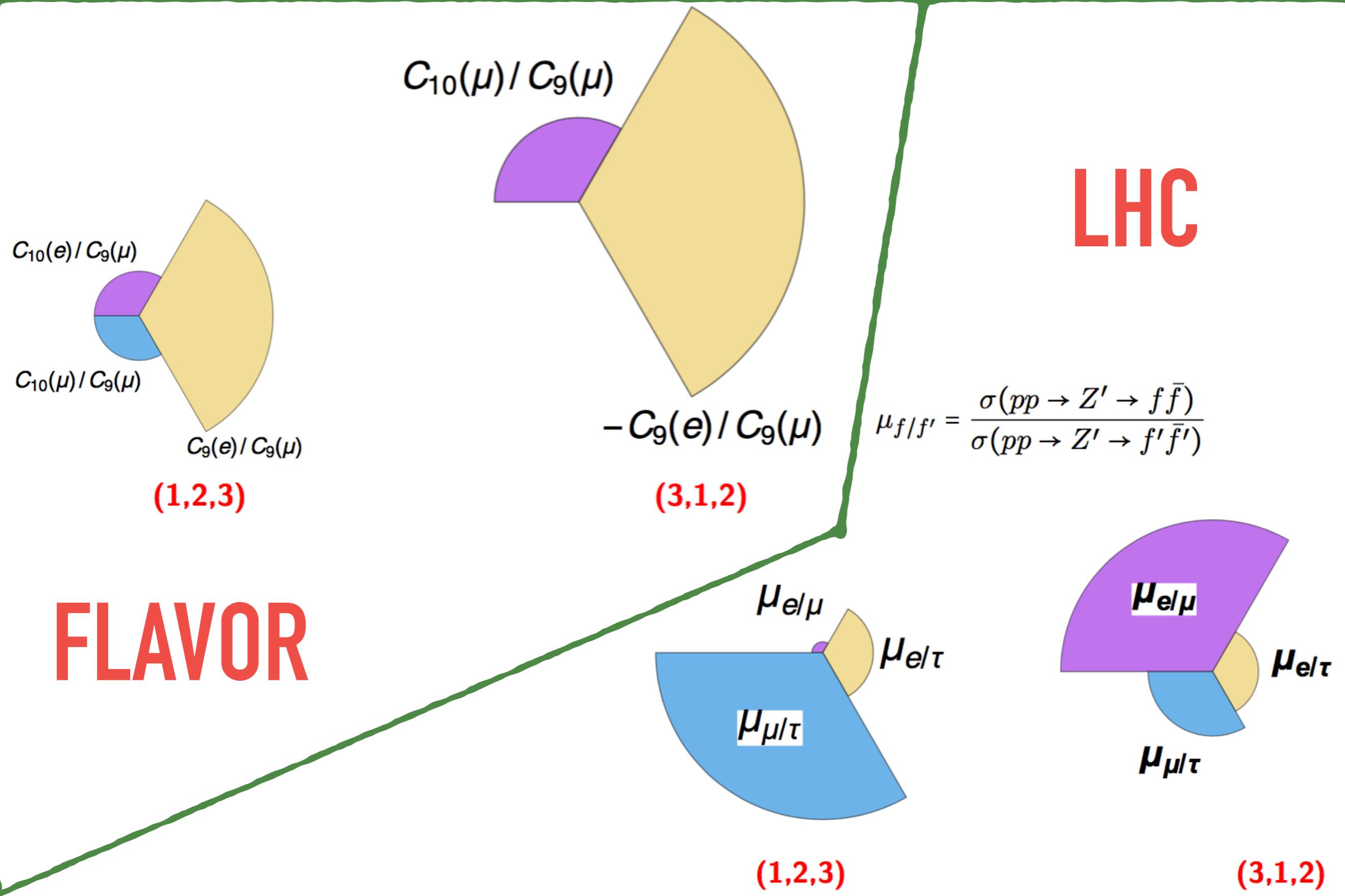
Prediction in our models $\Rightarrow R_K = R_{K^*} = R_\phi$ Hiller, Schmaltz'14

Correlations between $C_{9,10}$ for $\ell = e, \mu, \tau$.

$$\mathcal{O}_9^\ell = (\bar{s}\gamma_\mu P_L b) (\bar{\ell}\gamma^\mu \ell)$$

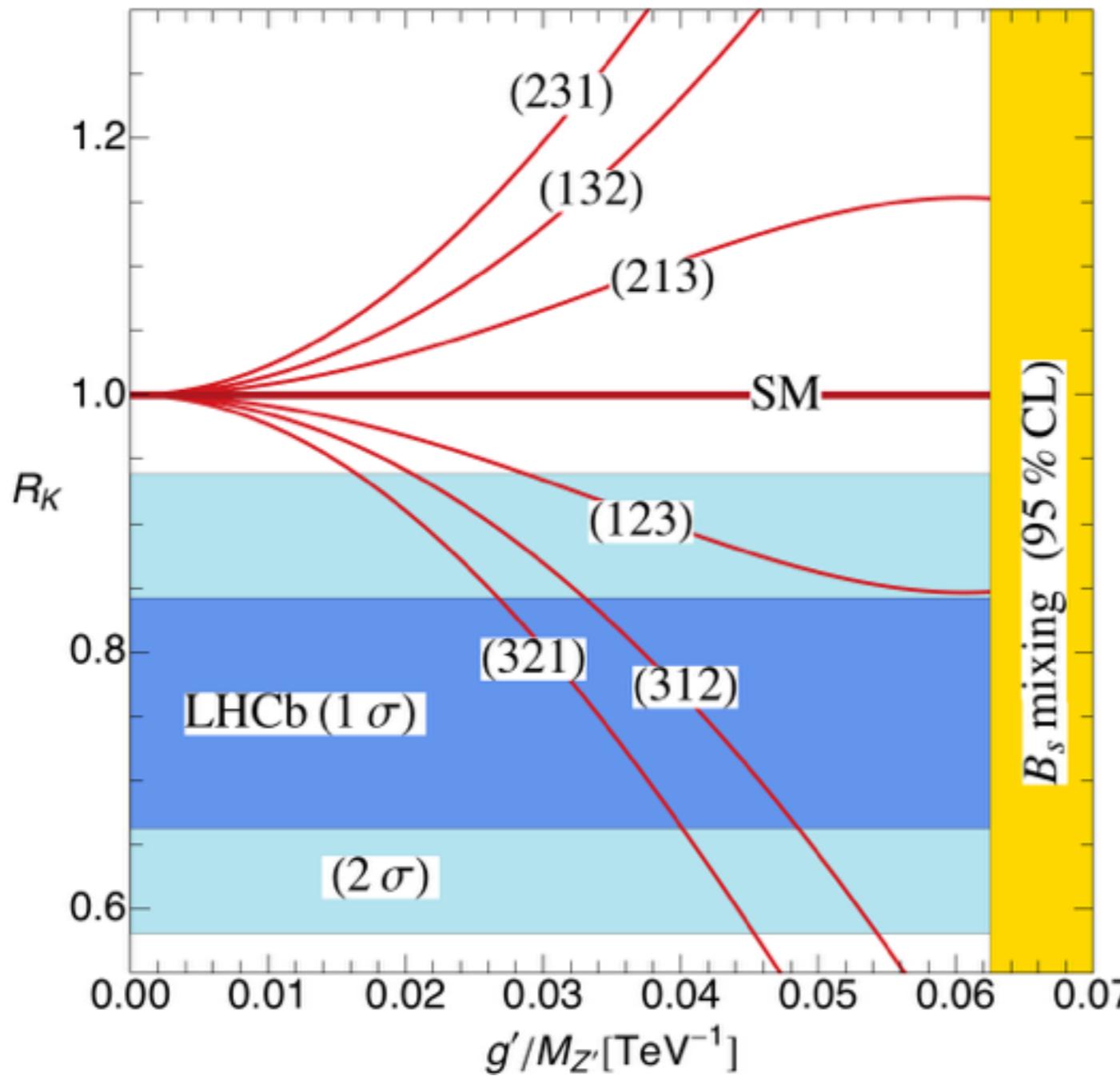
$$\mathcal{O}_{10}^\ell = (\bar{s}\gamma_\mu P_L b) (\bar{\ell}\gamma^\mu \gamma_5 \ell)$$

GAUGED BGL SYMMETRY



GAUGED BGL SYMMETRY

AC, Fuentes, Jung, Serodio [1505.03079]



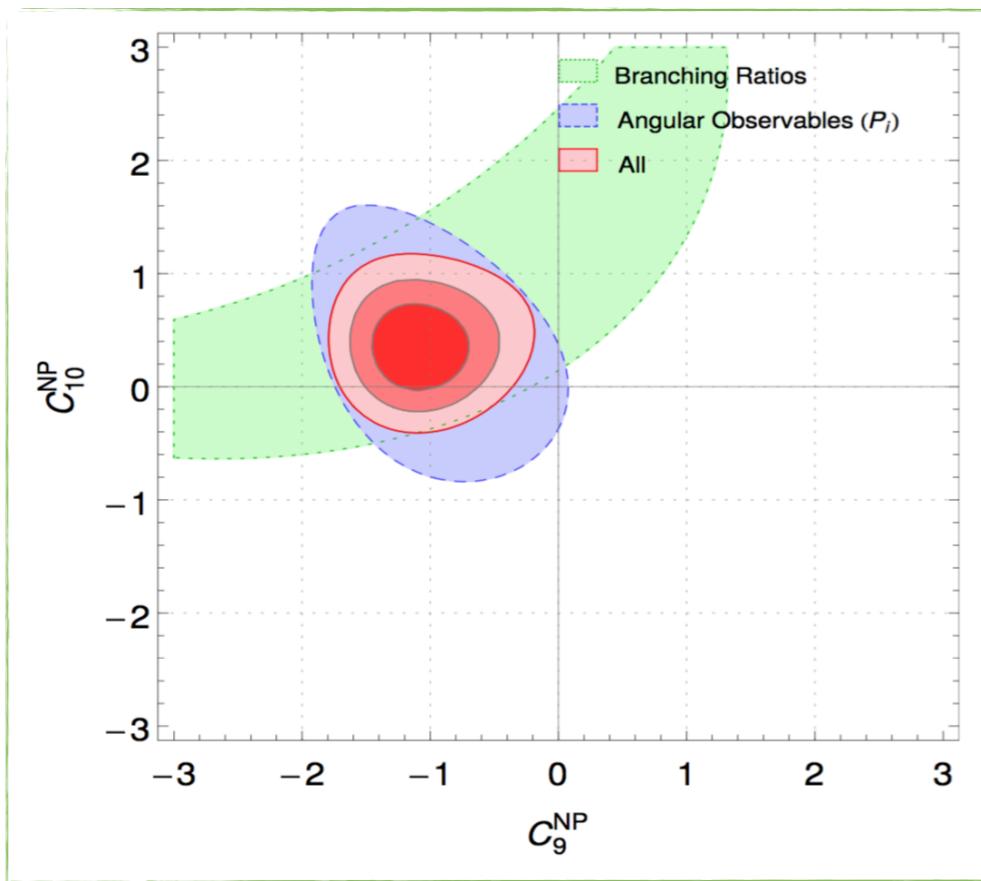
R_K and B_s mixing give

Model	$C_9^{\text{NP}\mu}(2\sigma)$
(1,2,3)	[-2.92, -0.61]
(3,1,2)	[-1.16, -0.17]
(3,2,1)	[-1.54, -0.20]

Smoking gun test of these models $R_{K^*} = R_K$

SUMMARY

LHCb ANOMALIES



Z' EXPLANATION

Only left-handed Z' FCNCs \Rightarrow No contributions to $C'_{9,10}$

$$\mathcal{O}_9^{\ell'} = (\bar{s} \gamma_\mu P_R b) (\bar{\ell} \gamma^\mu \ell)$$

$$\mathcal{O}_{10}^{\ell'} = (\bar{s} \gamma_\mu P_R b) (\bar{\ell} \gamma^\mu \gamma_5 \ell)$$

Prediction in our models $\Rightarrow R_K = R_{K^*} = R_\phi$ Hiller, Schmaltz'14

Correlations between $C_{9,10}$ for $\ell = e, \mu, \tau$.

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A possibility ?

