B anomalies in the post-R_K era

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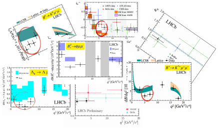
In collaboration with T. Hurth and S. Neshatpour

Workshop on Standard Model and Beyond
Corfu, 27 August - 7 September 2023

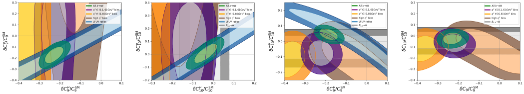
- **Status of anomalies**



- **Theoretical framework and issues**

$$\mathcal{A}_\lambda^{(\mathrm{had})} = -\,i\frac{e^2}{q^2}\int d^4x e^{-iq\cdot x}\langle \ell^+\ell^-|j_\mu^{\mathrm{em,lept}}(x)|0\rangle \times \int d^4y\, e^{iq\cdot y}\langle \bar{K}_\lambda^*|T\{j^{\mathrm{em,had},\mu}(y)\mathcal{H}_{\mathrm{eff}}^{\mathrm{had}}(0)\}|\bar{B}\rangle$$

- **New Physics implications**



- **Conclusions**

Tension in the angular observables

$B^0 \to K^{*0}\mu^+\mu^-$ angular observables, in particular P_5' / S_5

- 2013 (1 fb^{-1}): disagreement with the SM for P_2 and P_5' (PRL 111, 191801 (2013))
- March 2015 (3 fb^{-1}): confirmation of the deviations (LHCb-CONF-2015-002)
- Dec. 2015: 2 analysis methods, both show the deviations (JHEP 1602, 104 (2016))

3.7σ deviation in the 3rd bin

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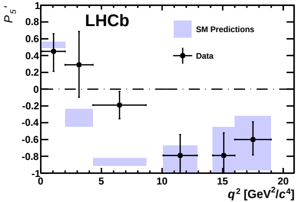

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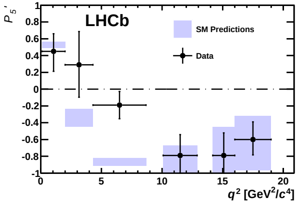

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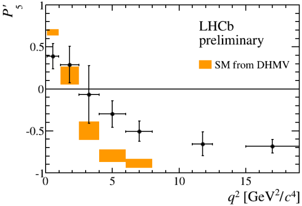

2.9σ in the 4th and 5th bins
(3.7σ combined)

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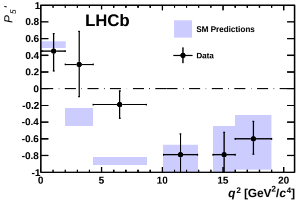

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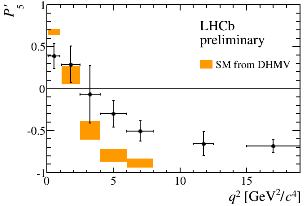

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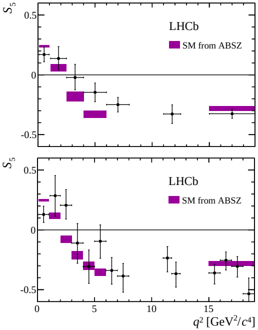

3.4σ combined fit (likelihood)

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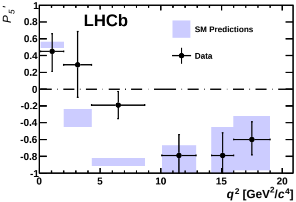

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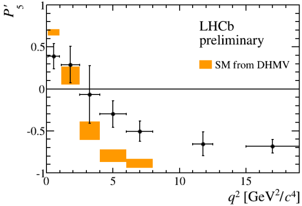

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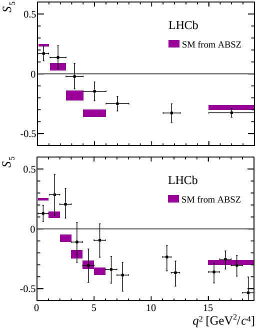
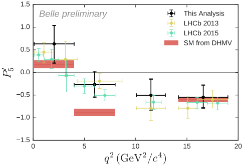


3.4σ combined fit (likelihood)

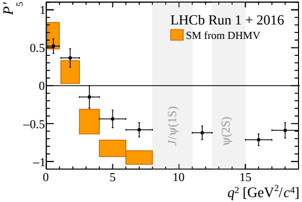
Belle supports LHCb

(arXiv:1604.04042)

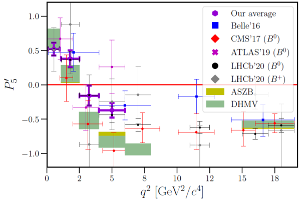
tension at 2.1σ



$P_5'(B^0 \to K^{*0}\mu^+\mu^-)$: 2020 LHCb update with 4.7 fb^{-1}: $\sim 2.9\sigma$ local tension



Phys. Rev. Lett. 125, 011802 (2020)



ATLAS-CONF-2017-023; CMS-PAS-BPH-15-008

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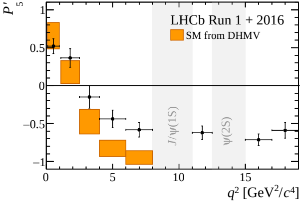

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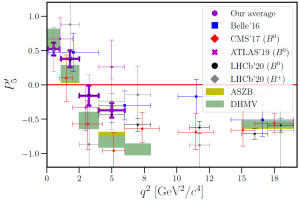
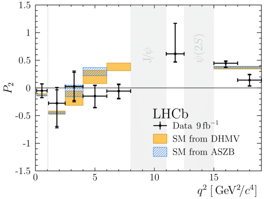
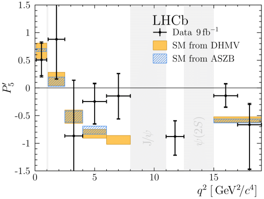


ATLAS-CONF-2017-023; CMS-PAS-BPH-15-008

First measurement of $B^+ \to K^{*+}\mu^+\mu^-$ angular observables

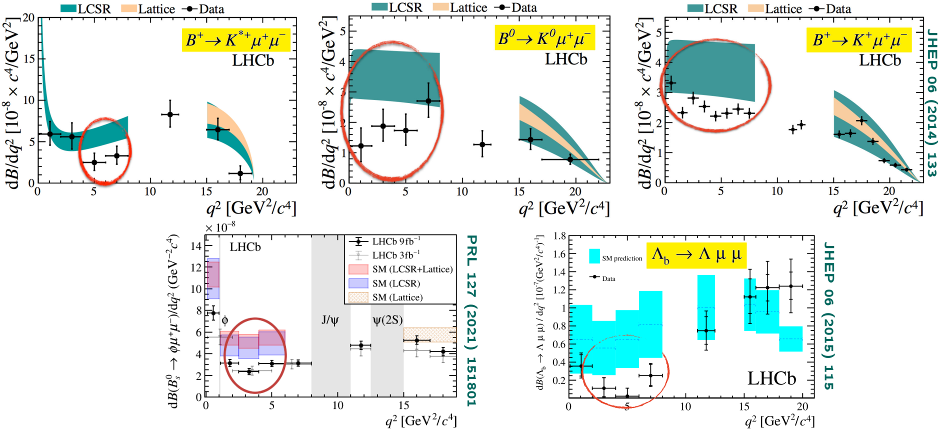
using the full Run 1 and Run 2 dataset (9 fb^{-1}):





Phys. Rev. Lett. 126, 161802 (2021)

The results confirm the global tension with respect to the SM!



- consistent deviation pattern with the SM predictions
- significance of the deviations between ~ 2 and $3.5\,\sigma$
- general trend: EXP $<$ SM in low q^2 regions
- ... but the branching ratios have very large theory uncertainties!

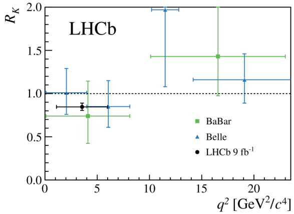
Lepton flavour universality in $B^+ \to K^+ \ell^+ \ell^-$

$$R_K = BR(B^+ \to K^+ \mu^+ \mu^-)/BR(B^+ \to K^+ e^+ e^-)$$

- SM prediction very accurate: $R_K^{\rm SM} = 1.0006 \pm 0.0004$
- March 2021 using 9 fb^{-1}

$$R_K^{\rm exp} = 0.846^{+0.042}_{-0.039}({\rm stat})^{+0.013}_{-0.012}({\rm syst})$$

- **3.1**σ tension in the [1.1-6] GeV^2 bin



Nature Phys. 18 (2022) 3, 277

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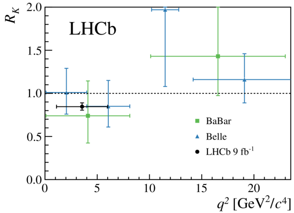


Nature Phys. 18 (2022) 3, 277

Lepton flavour universality in $B^0 \to K^{*0}\ell^+\ell^-$

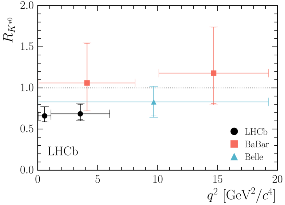
$$R_{K^*} = BR(B^0 \to K^{*0}\mu^+\mu^-)/BR(B^0 \to K^{*0}e^+e^-)$$

- LHCb measurement from April 2017 using 3 fb^{-1}
- Two q^2 regions: [0.045-1.1] and [1.1-6.0] GeV^2

$$R_{K^*}^{\rm exp,bin1} = 0.66^{+0.11}_{-0.07}({\rm stat}) \pm 0.03({\rm syst})$$

$$R_{K^*}^{\rm exp,bin2} = 0.69^{+0.11}_{-0.07}({\rm stat}) \pm 0.05({\rm syst})$$

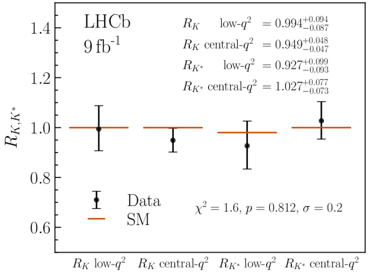
- **2.2-2.5σ** tension in each bin



JHEP 08 (2017) 055

December 2022 update

- LHCb measurement from Dec 2022 using 9 fb^{-1}
- New modelling of residual backgrounds due to misidentified hadronic decays
- Results fully compatible with the SM



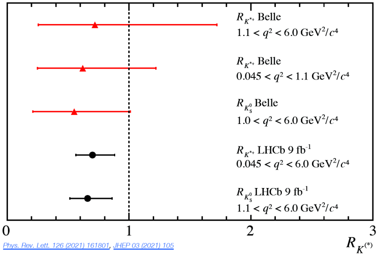
LHCb, arXiv:2212.09152, arXiv:2212.09153

Two other LFU measurements (October 2021) with 9 fb^{-1}:

$B^+ \to K^{*+}\ell^+\ell^-$ and $B^0 \to K^0_S\,\ell^+\ell^-$

$R_{K^{*+}} = 0.70^{+0.18}_{-0.13}(stat)^{+0.03}_{-0.04}(syst)$ and $R_{K^0_S} = 0.66^{+0.20}_{-0.15}(stat)^{+0.02}_{-0.04}(syst)$

Phys.Rev.Lett. 128 (2022) 19, 191802



More measurements to come:

$B^0_s \to \phi\ell^+\ell^-$, $B \to \pi\ell^+\ell^-$, $B \to K\pi^+\pi^-\ell^+\ell^-$,...

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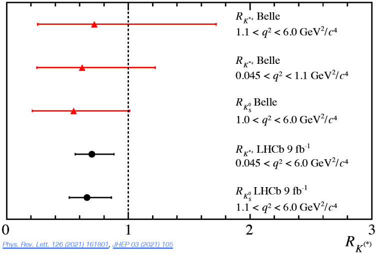
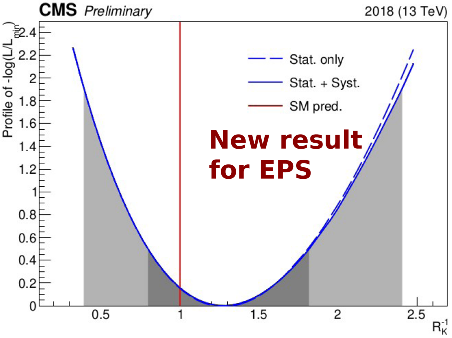


More measurements to come:

$$B^0_s \to \phi\ell^+\ell^-,\ B \to \pi\ell^+\ell^-,\ B \to K\pi^+\pi^-\ell^+\ell^-, \ldots$$

First R_K measurement by CMS (August 2023):



NEW

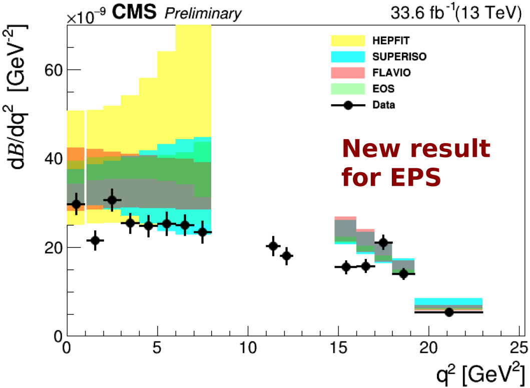
$$R_K = 0.78^{+0.46}_{-0.23}(\mathrm{stat})^{+0.09}_{-0.05}(\mathrm{syst})$$

Uncertainty dominated by the low stats of $B \to Kee$

See G. Karathanasis' talk at EPS 2023

Differential BR measurement of $B^+ \to K^+\mu^+\mu^-$ (August 2023):

NEW



New result for EPS

See G. Karathanasis' talk at EPS 2023

Effective field theory

$$\mathcal{H}_{\rm eff} = -\frac{4G_F}{\sqrt{2}} V_{tb} V_{ts}^* \Big(\sum_{i=1\cdots 10,S,P} \big(C_i(\mu)\mathcal{O}_i(\mu) + C'_i(\mu)\mathcal{O}'_i(\mu) \big) \Big)$$

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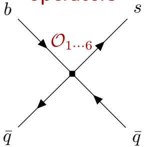
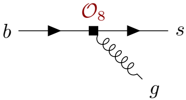
Operator set for $b \to s$ transitions:

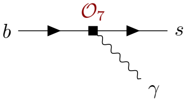
4-quark operators



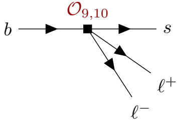
chromomagnetic dipole operator



electromagnetic dipole operator



semileptonic operators



$\mathcal{O}_{1,2} \propto (\bar{s}\Gamma_\mu c)(\bar{c}\Gamma^\mu b)$

$\mathcal{O}_{3,4} \propto (\bar{s}\Gamma_\mu b)\sum_q(\bar{q}\Gamma^\mu q)$

$\mathcal{O}_8 \propto (\bar{s}\sigma^{\mu\nu}T^a P_R)G^a_{\mu\nu}$

$\mathcal{O}_7 \propto (\bar{s}\sigma^{\mu\nu}P_R)F^a_{\mu\nu}$

$\mathcal{O}_9^\ell \propto (\bar{s}\gamma^\mu b_L)(\bar{\ell}\gamma_\mu\ell)$

$\mathcal{O}_{10}^\ell \propto (\bar{s}\gamma^\mu b_L)(\bar{\ell}\gamma_\mu\gamma_5\ell)$

+ the chirality flipped counter-parts of the above operators, $\mathcal{O}'_i$

Effective field theory

$$\mathcal{H}_{\rm eff} = -\frac{4G_F}{\sqrt{2}} V_{tb} V_{ts}^* \Bigl(\sum_{i=1\cdots 10,S,P} \bigl(C_i(\mu)\mathcal{O}_i(\mu) + C'_i(\mu)\mathcal{O}'_i(\mu)\bigr)\Bigr)$$

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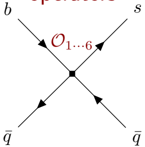

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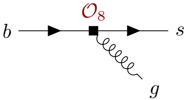
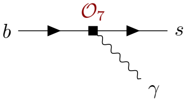


electromagnetic dipole operator



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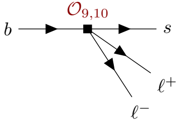

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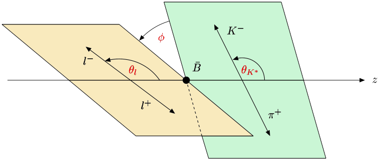
Wilson coefficients:

The Wilson coefficients are calculated perturbatively and are process independent.
SM contributions known to NNLL **(Bobeth, Misiak, Urban '99; Misiak, Steinhauser '04, Gorbahn, Haisch '04; Gorbahn, Haisch, Misiak '05; Czakon, Haisch, Misiak '06,...)**

$$C_7 \sim -0.3 \qquad C_9 \sim 4.2 \qquad C_{10} \sim -4.2$$

$B \to K^*(\to K^+\pi^-)\mu^+\mu^-$ Angular distributions



Angular behavior of K^+ and π^- $\to$ additional information on the helicity of K^*

Differential decay distribution:

$$\frac{d^4\Gamma}{dq^2\, d\cos\theta_\ell\, d\cos\theta_{K^*}\, d\phi} = \frac{9}{32\pi} J(q^2, \theta_\ell, \theta_{K^*}, \phi)$$

$J(q^2, \theta_\ell, \theta_{K^*}, \phi) = \sum_i J_i(q^2)\, f_i(\theta_\ell, \theta_{K^*}, \phi)$

↘ angular coefficients J_{1-9}

↘ functions of the spin amplitudes A_0, $A_\parallel$, $A_\perp$, A_t, and A_S

Spin amplitudes: functions of Wilson coefficients and form factors

Main operators:

$$\mathcal{O}_9 = \frac{e^2}{(4\pi)^2}(\bar{s}\gamma^\mu b_L)(\bar{\ell}\gamma_\mu \ell), \quad \mathcal{O}_{10} = \frac{e^2}{(4\pi)^2}(\bar{s}\gamma^\mu b_L)(\bar{\ell}\gamma_\mu\gamma_5 \ell)$$

$$\mathcal{O}_S = \frac{e^2}{16\pi^2}(\bar{s}_L^\alpha b_R^\alpha)(\bar{\ell}\,\ell), \quad \mathcal{O}_P = \frac{e^2}{16\pi^2}(\bar{s}_L^\alpha b_R^\alpha)(\bar{\ell}\gamma_5 \ell)$$

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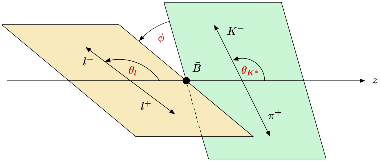

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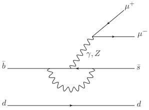
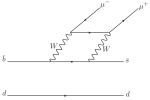
$\mathcal{O}_S = \frac{e^2}{16\pi^2}(\bar{s}_L^\alpha b_R^\alpha)(\bar{\ell}\,\ell)$, $\quad \mathcal{O}_P = \frac{e^2}{16\pi^2}(\bar{s}_L^\alpha b_R^\alpha)(\bar{\ell}\gamma_5 \ell)$



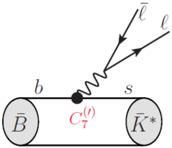


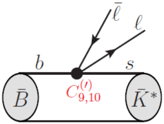
Effective Hamiltonian for $b \to s\ell^+\ell^-$ transitions: $\mathcal{H}_{\rm eff} = \mathcal{H}_{\rm eff}^{\rm had} + \mathcal{H}_{\rm eff}^{\rm sl}$

Matrix elements of $B \to K^*\ell^+\ell^-$ decay:

$$\mathcal{H}_{\rm eff}^{\rm sl} = -\frac{4G_F}{\sqrt{2}} V_{tb}V_{ts}^* \Big[\sum_{i=7,9,10} C_i^{(\prime)}(\mu) O_i^{(\prime)}(\mu) \Big]$$

$\langle \bar{K}^* \ell^+ \ell^- | H_{\rm eff}^{\rm sl} | \bar{B} \rangle$:





⇨ $B \to K^*$ form factors $V, A_{0,1,2}, T_{1,2,3}$ or alternatively $\tilde{V}_\lambda, \tilde{T}_\lambda, \tilde{S}$ (λ = helicity of K^*)

Helicity amplitudes:

$$H_V(\lambda) \approx -i\,N' \Big\{ (C_9 - C_9') \tilde{V}_\lambda(q^2) + \frac{m_B^2}{q^2} \Big[\frac{2\,\hat{m}_b}{m_B} (C_7^{\rm eff} - C_7') \tilde{T}_\lambda(q^2) \Big] \Big\}$$

$$H_A(\lambda) = -i\,N' (C_{10} - C_{10}') \tilde{V}_\lambda(q^2)$$

$$H_P = i\,N' \Big\{ \frac{2\,m_\ell \hat{m}_b}{q^2} (C_{10} - C_{10}') \Big(1 + \frac{m_s}{m_b} \Big) \tilde{S}(q^2) \Big\}$$

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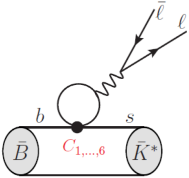

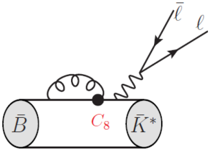

$H_{\rm eff}^{\rm had}$ contributes to $b \to s\bar\ell\ell$ through virtual photon exchange $\Rightarrow$ affect only the $H_V(\lambda)$

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Issue of the hadronic power corrections

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$$\langle \bar{K}^*\ell^+\ell^- | H_{\rm eff}^{\rm had} | \bar{B} \rangle: \; \mathcal{A}_\lambda^{\rm (had)} = -i\frac{e^2}{q^2} \int d^4x e^{-iq\cdot x} \langle \ell^+\ell^- | j_\mu^{\rm em,lept}(x) | 0 \rangle \times \int d^4y\, e^{iq\cdot y} \langle \bar{K}_\lambda^* | T\{ j^{\rm em,had,\mu}(y) \mathcal{H}_{\rm eff}^{\rm had}(0) \} | \bar{B} \rangle$$

In general "naïve" factorization not applicable

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$$\longrightarrow \frac{e^2}{q^2}\epsilon_\mu L_V^\mu \Big[\underbrace{Y(q^2)\tilde{V}_\lambda}_{\text{fact., perturbative}} + \underbrace{\text{LO in } \mathcal{O}(\frac{\Lambda}{m_b}, \frac{\Lambda}{E_{K^*}})}_{\text{non-fact., QCDf}} + \underbrace{h_\lambda(q^2)}_{\text{power corrections, unknown}} \Big]$$

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$\left(C_9^{\rm eff} \equiv C_9 + Y(q^2)\right)$

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$$H_V(\lambda) = -i\,N'\Big\{(C_9^{\rm eff} - C_9')\tilde{V}_\lambda(q^2) + \frac{m_B^2}{q^2}\Big[\frac{2\,\hat{m}_b}{m_B}(C_7^{\rm eff} - C_7')\tilde{T}_\lambda(q^2) - 16\pi^2\mathcal{N}_\lambda(q^2)\Big]\Big\}$$

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Relevant operators:

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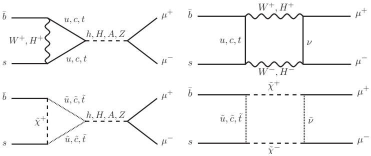

$$\mathrm{BR}(B_s \to \mu^+\mu^-) = \frac{G_F^2\alpha^2}{64\pi^3} f_{B_s}^2 \tau_{B_s} m_{B_s}^3 |V_{tb}V_{ts}^*|^2 \sqrt{1-\frac{4m_\mu^2}{m_{B_s}^2}}$$
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Largest contributions in SM from a Z penguin top loop and a W box diagram

Main source of uncertainty:

- f_{B_s} : $\sim 1.5\%$
- CKM : $\sim 2.5\%$
- Other (masses, α_s,...) : $\sim 1\%$

BR($B_s \to \mu^+\mu^-$)

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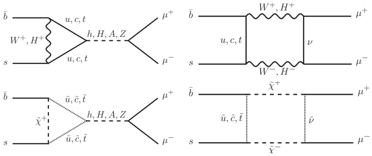

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T. Hurth, FM, D. Martinez Santos, S. Neshatpour, 2210.07221

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SuperIso v4.1
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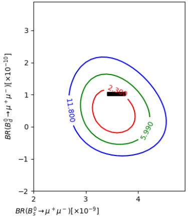

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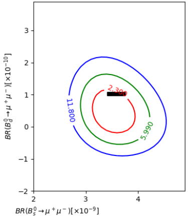

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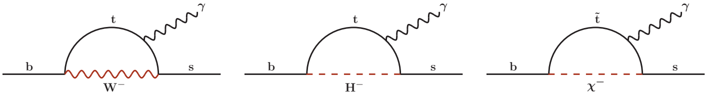
Inclusive branching ratio of $B \to X_s\gamma$

Contributing loops:



Main operator: $\mathcal{O}_7$
but higher order contributions from $\mathcal{O}_1$, ..., $\mathcal{O}_8$

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- Very precise theory prediction (at NNLO)

$$\mathrm{BR}(\bar{B} \to X_s\gamma)_{E_\gamma > E_0} = \mathrm{BR}(\bar{B} \to X_c e\bar{\nu}) \left|\frac{V_{ts}^* V_{tb}}{V_{cb}}\right| \frac{6\alpha_{em}}{\pi C} [P(E_0) + N(E_0)]$$

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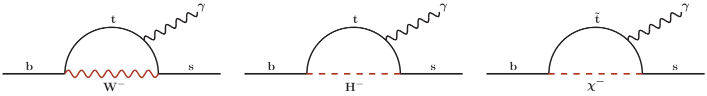

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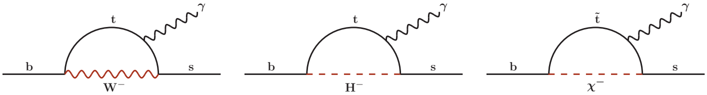

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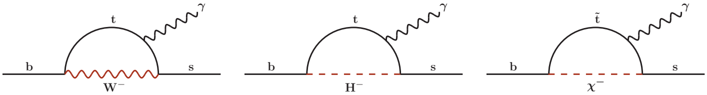

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Global fits

IF the deviations are from New Physics...

Many observables $\rightarrow$ **Global fits** of the available data

Relevant $\mathcal{O}$perators:

$$\mathcal{O}_7,\ \mathcal{O}_8,\ \mathcal{O}_{9\mu,e}^{(\prime)},\ \mathcal{O}_{10\mu,e}^{(\prime)} \quad \text{and} \quad \mathcal{O}_{S-P} \propto (\bar{s}P_R b)(\bar{\mu}P_L\mu)$$

NP manifests itself in the shifts of the individual coefficients with respect to the SM values:

$$C_i(\mu) = C_i^{\rm SM}(\mu) + \delta C_i$$

- $\rightarrow$ Scans over the values of δC_i
- $\rightarrow$ Calculation of flavour observables
- $\rightarrow$ Comparison with experimental results
- $\rightarrow$ Constraints on the Wilson coefficients C_i

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$$C_i(\mu) = C_i^{\rm SM}(\mu) + \delta C_i$$

- $\rightarrow$ Scans over the values of δC_i
- $\rightarrow$ Calculation of flavour observables
- $\rightarrow$ Comparison with experimental results
- $\rightarrow$ Constraints on the Wilson coefficients C_i

Theoretical uncertainties and correlations

- Monte Carlo analysis
- variation of the "standard" input parameters: masses, scales, CKM, ...
- decay constants taken from the latest lattice results
- $B \to K^{(*)}$ and $B_s \to \phi$ form factors are obtained from the lattice+LCSR combinations, including all the correlations
- Parameterisation of uncertainties from power corrections:

$$A_k \to A_k \left(1 + a_k \exp(i\phi_k) + \frac{q^2}{6\ \mathrm{GeV}^2} b_k \exp(i\theta_k)\right)$$

$|a_k|$ between 10 to 60%, $b_k \sim 2.5 a_k$
Low recoil: $b_k = 0$

$\Rightarrow$ Computation of a (theory + exp) correlation matrix

Global fits of the observables obtained by minimisation of

$$\chi^2 = \left(\vec{O}^{\rm th} - \vec{O}^{\rm exp}\right) \cdot (\Sigma_{\rm th} + \Sigma_{\rm exp})^{-1} \cdot \left(\vec{O}^{\rm th} - \vec{O}^{\rm exp}\right)$$

$(\Sigma_{\rm th} + \Sigma_{\rm exp})^{-1}$ is the inverse covariance matrix.

198 observables relevant for leptonic and semileptonic decays:

- $\mathrm{BR}(B \to X_s\gamma)$
- $\mathrm{BR}(B \to X_d\gamma)$
- $\mathrm{BR}(B \to K^*\gamma)$
- $\Delta_0(B \to K^*\gamma)$
- $\mathrm{BR}^{\rm low}(B \to X_s\mu^+\mu^-)$
- $\mathrm{BR}^{\rm high}(B \to X_s\mu^+\mu^-)$
- $\mathrm{BR}^{\rm low}(B \to X_s e^+e^-)$
- $\mathrm{BR}^{\rm high}(B \to X_s e^+e^-)$
- $\mathrm{BR}(B_s \to \mu^+\mu^-)$
- $\mathrm{BR}(B_s \to e^+e^-)$
- $\mathrm{BR}(B_d \to \mu^+\mu^-)$
- R_K in the low q^2 bin
- R_{K^*} in 2 low q^2 bins
- $\mathrm{BR}(B \to K^0\mu^+\mu^-)$
- $B \to K^+\mu^+\mu^-$: BR, F_H
- $B \to K^*e^+e^-$: BR, F_L, A_T^2, A_T^{Re}
- $B \to K^{*0}\mu^+\mu^-$: BR, F_L, A_{FB}, S_3, S_4, S_5, S_7, S_8, S_9 in 8 low q^2 and 4 high q^2 bins
- $B^+ \to K^{*+}\mu^+\mu^-$: BR, F_L, A_{FB}, S_3, S_4, S_5, S_7, S_8, S_9 in 5 low q^2 and 2 high q^2 bins
- $B_s \to \phi\mu^+\mu^-$: BR, F_L, S_3, S_4, S_7 in 3 low q^2 and 2 high q^2 bins
- $\Lambda_b \to \Lambda\mu^+\mu^-$: BR, A_{FB}^{ℓ}, A_{FB}^{h}, $A_{FB}^{\ell h}$, F_L in the high q^2 bin

Computations performed using **SuperIso** public program

Single operator fits

Comparison of one-operator NP fits:

All observables **2022** ($\chi^2_{\rm SM} = 253.3$)			
	b.f. value	$\chi^2_{\rm min}$	$\mathrm{Pull}_{\rm SM}$
δC_9	-0.95 ± 0.13	215.8	6.1σ
δC_9^e	0.82 ± 0.19	232.4	4.6σ
δC_9^μ	-0.92 ± 0.11	195.2	7.6σ
δC_{10}	0.08 ± 0.16	253.2	0.5σ
δC_{10}^e	-0.77 ± 0.18	230.6	4.8σ
δC_{10}^μ	0.43 ± 0.12	238.9	3.8σ
$\delta C_{\rm LL}^e$	0.42 ± 0.10	231.4	4.7σ
$\delta C_{\rm LL}^\mu$	-0.43 ± 0.07	213.6	6.3σ

$\delta C_{\rm LL}^\ell$ basis corresponds to $\delta C_9^\ell = -\delta C_{10}^\ell$.

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All observables 2023 ($\chi^2_{\rm SM} = 271$)			
	b.f. value	$\chi^2_{\rm min}$	${\rm Pull}_{\rm SM}$
δC_9	-0.96 ± 0.13	230.7	6.3σ
δC_9^e	0.21 ± 0.16	269.2	1.3σ
δC_9^μ	-0.69 ± 0.12	240.4	5.5σ
δC_{10}	0.15 ± 0.15	270.0	1.0σ
δC_{10}^e	-0.18 ± 0.14	269.3	1.3σ
δC_{10}^μ	0.16 ± 0.10	268.3	1.6σ
$\delta C_{\rm LL}$	-0.54 ± 0.12	249.1	4.7σ
$\delta C_{\rm LL}^e$	0.10 ± 0.08	269.2	1.3σ
$\delta C_{\rm LL}^\mu$	-0.23 ± 0.06	257.4	3.7σ

$\delta C_{\rm LL}^\ell$ basis corresponds to $\delta C_9^\ell = -\delta C_{10}^\ell$.

Set: real $C_7, C_8, C_9, C_{10}, C_S, C_P$ + primed coefficients, 12 degrees of freedom

All observables with $\chi^2_{\rm SM} = 271.0$			
August 2023 ($\chi^2_{\rm min} = 222.5$; $\mathrm{Pull}_{\rm SM} = 4.7\sigma$)			
δC_7		δC_8	
0.07 ± 0.03		-0.70 ± 0.50	
$\delta C_7'$		$\delta C_8'$	
-0.01 ± 0.01		-0.50 ± 1.20	
δC_9	$\delta C_9'$	δC_{10}	$\delta C_{10}'$
-1.18 ± 0.19	0.06 ± 0.31	0.23 ± 0.20	-0.05 ± 0.19
C_{Q_1}	C_{Q_1}'	C_{Q_2}	C_{Q_2}'
-0.30 ± 0.14	-0.18 ± 0.14	0.01 ± 0.02	-0.03 ± 0.07

- Many parameters are weakly constrained at the moment
- The global tension is at the level of 4.7σ (assuming 10% uncertainty for the power corrections)

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δC_9	$\delta C_9'$	δC_{10}	$\delta C_{10}'$
-1.18 ± 0.19	0.06 ± 0.31	0.23 ± 0.20	-0.05 ± 0.19
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Wilks' test

Pull_{SM} of $1, 2, 4, 6$ and 12 dimensional fit:

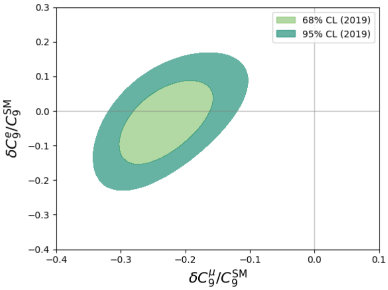
All observables ; **August 2023**				
Set of WC	param.	χ^2_{min}	Pull_{SM}	Improvement
SM	0	271.0	–	–
C_9	1	230.7	6.3σ	6.3σ
C_9, C_{10}	2	230.3	6.0σ	0.6σ
C_7, C_8, C_9, C_{10}	4	225.3	5.9σ	1.7σ
C_7, C_8, C_9, C_{10}, C_{Q_1}, C_{Q_2}	6	224.7	5.6σ	0.3σ
All WC (incl. primed)	12	222.5	4.7σ	0.1σ

The last row also includes the chirality-flipped counterparts of the Wilson coefficients.

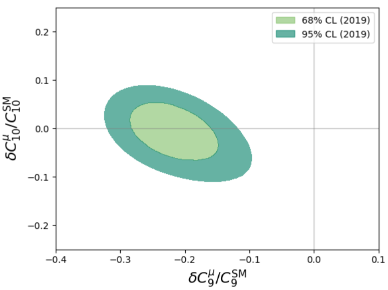
In the last column the significance of improvement of the fit compared to the scenario of the previous row is given.

2D fits to all available data:

$(C_9^\mu - C_9^e)$



$(C_9^\mu - C_{10}^\mu)$



2019: Run I results

2D fits to all available data:

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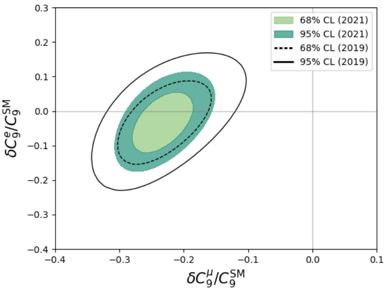
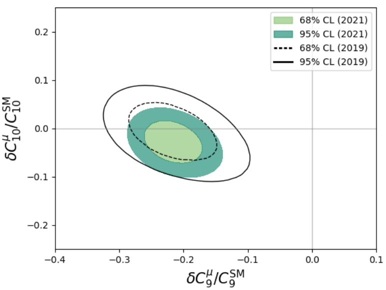


$(C_9^\mu - C_{10}^\mu)$



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2021: (partial) Run II updates, mainly for $B \to K^* \mu^+\mu^-$, R_K and $B_s \to \mu^+\mu^-$ (LHCb)

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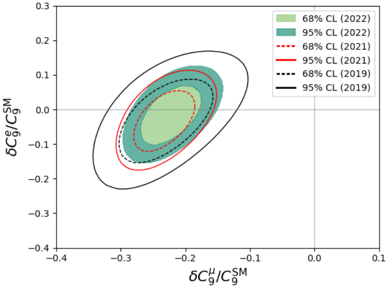
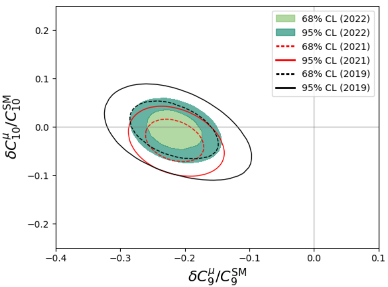


$(C_9^\mu - C_{10}^\mu)$

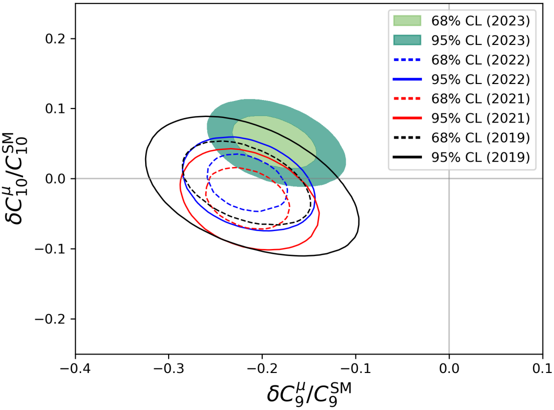


2019: Run I results

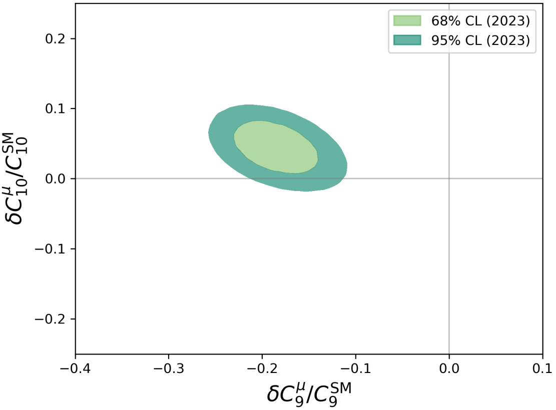
2021: (partial) Run II updates, mainly for $B \to K^* \mu^+\mu^-$, R_K and $B_s \to \mu^+\mu^-$ (LHCb)

2022: (partial) Run II updates, mainly for $B_s \to \mu^+\mu^-$ (CMS), $R_{K^{*+}}$, $R_{K_S^0}$ and $B_s \to \phi\mu^+\mu^-$

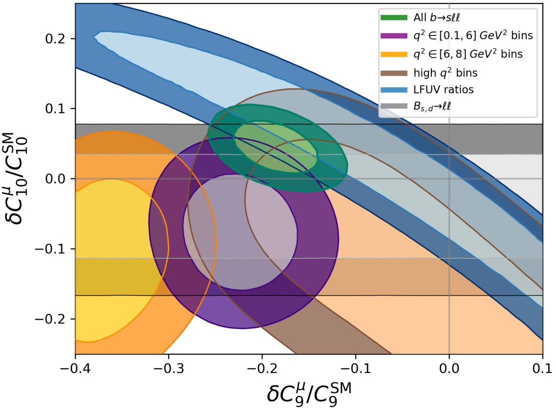
2023 (pre-CMS)


68% CL (2023)
95% CL (2023)
68% CL (2022)
95% CL (2022)
68% CL (2021)
95% CL (2021)
68% CL (2019)
95% CL (2019)
0.2
0.1
0.0
−0.1
−0.2
−0.4
−0.3
−0.2
−0.1
0.0
0.1
$\delta C_{10}^{\mu}/C_{10}^{\rm SM}$
$\delta C_{9}^{\mu}/C_{9}^{\rm SM}$

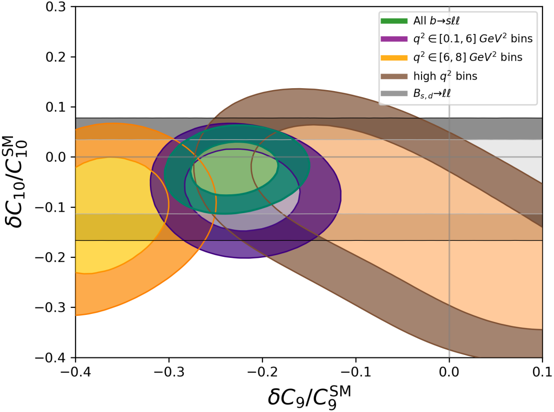
Current situation (all observables, including CMS Aug. 2023)



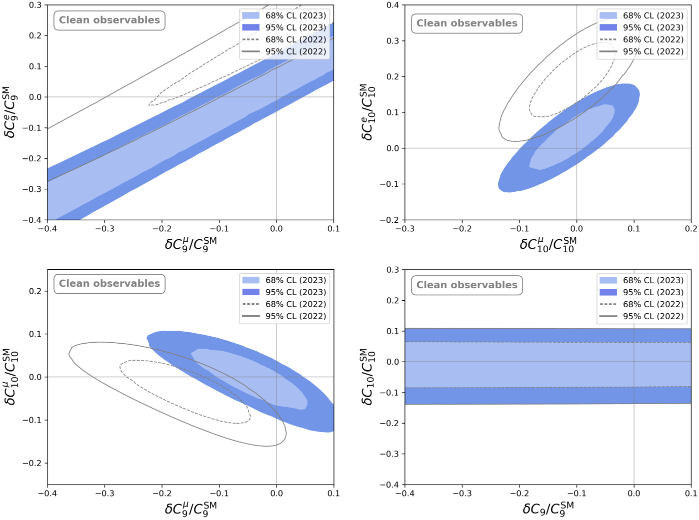
Current situation (all observables, including CMS Aug. 2023)



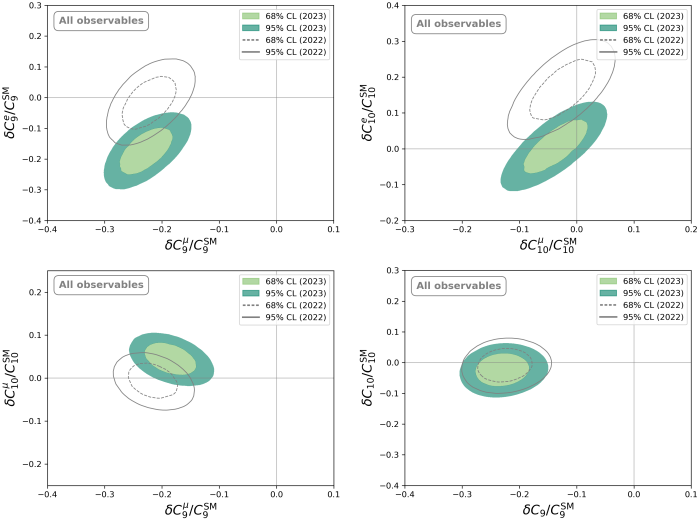
Fit to universal Wilson coefficients



Clean observables only



All observables



Conclusion

- Reduction of the significance of the most preferred NP scenarios
- C_9 continues to be the Wilson coeffcient which includes most of the NP effects
- LFUV components are mostly suppressed
- High significances for scenarios with universal NP in C_9
- Some tensions in the inner structure of the fit:
  - LFU ratios are SM-like
  - $B \to K^{(*)}\mu\mu$ observables continue to deviate with high significance

New Physics or Not New Physics?

- More work is needed to assess the hadronic uncertainties
- The measurement of the electron modes will be very important
- Cross-check with other ratios, and also inclusive modes will be very useful

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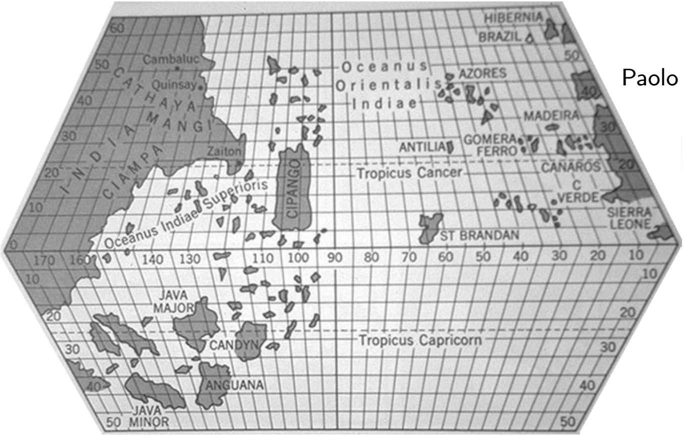
We may be in such a situation:



Paolo Toscanelli
1474

Columbus had Toscanelli's map.
It was terribly wrong, but served the purpose!