CP Violation in B Decays

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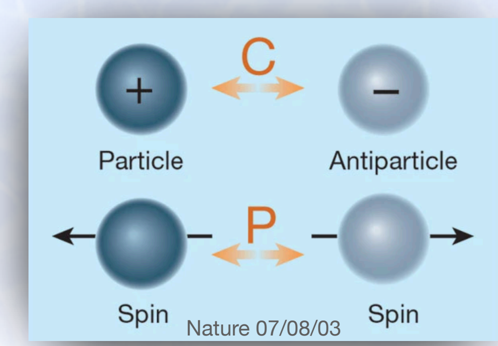
Introduction

- **B physics: reliable tests of SM and information for NP**
  - ***<u>Key point</u>*: one can probe very high scales for NP, much higher than in direct colliders**
  - **Precision Physics - Indirect Searches**

- **Importance of CP Violation**
  - **Firstly discovered in 1964, through the observation of** $K_L \to \pi^+\pi^-$
  - **It is now established in all systems**

non-invariance of the weak interactions with respect to a combined charge-conjugation (C) and parity (P) transformation



CP Violation in different manifestations

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Decays with Different Dynamics

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$B_s \to D_s^{\pm} K^{\mp}$ and related modes

pure tree decays

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$B_d \to J/\psi K_S \,, \quad B_s \to J/\psi \phi$

dominated by trees but
also penguin contamination

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$B \to \pi K, \; B \to K^+ K^-$

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Rare Decays

$B \to \mu\mu, \quad B \to K\ell\ell$

from EW penguins and box topologies

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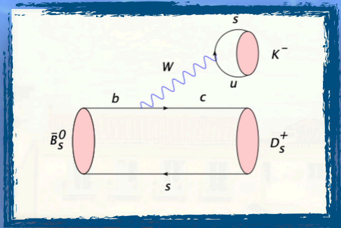
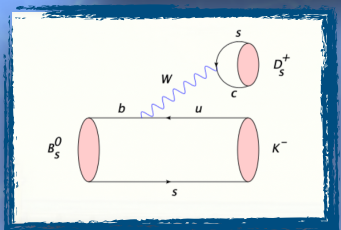
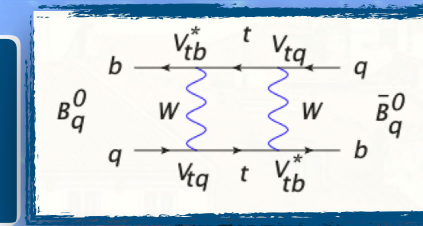
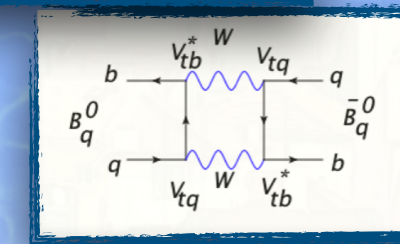
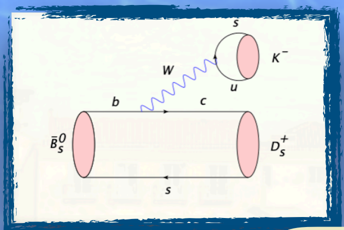


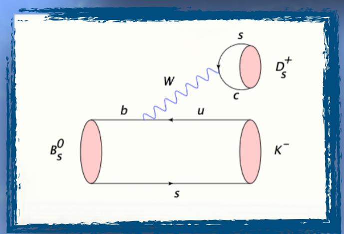


Anomalies in the $B_s \to D_s^{\pm} K^{\mp}$









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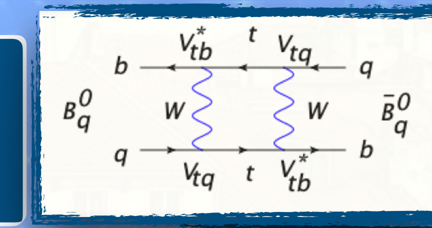

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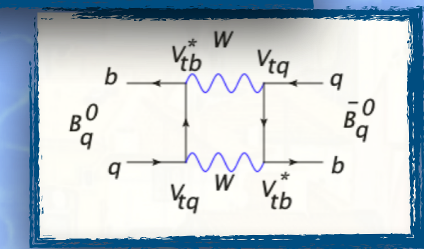

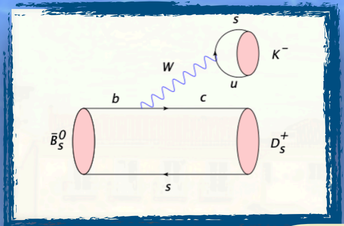

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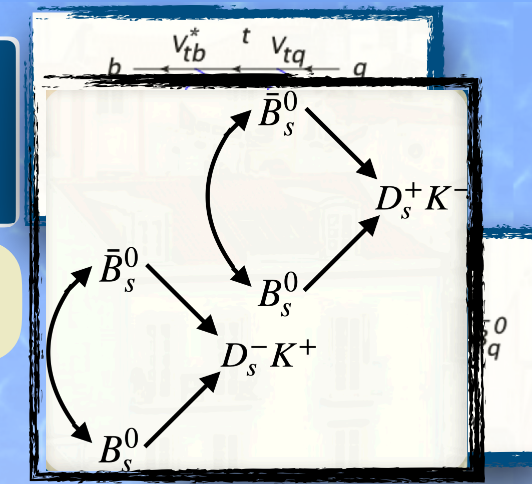

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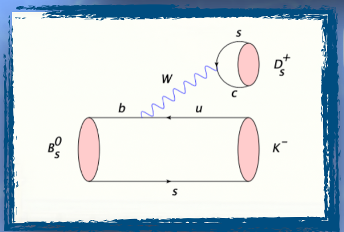

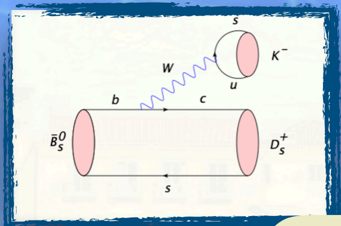

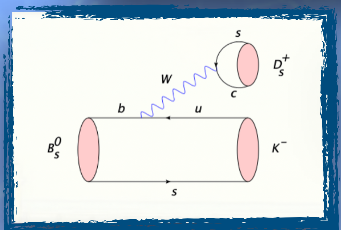

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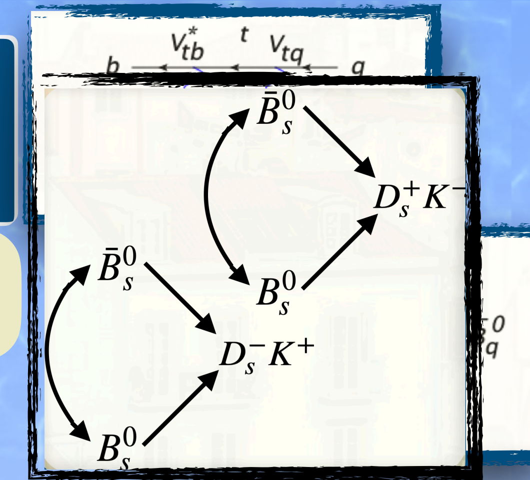
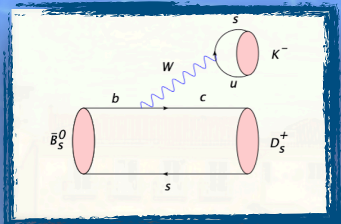
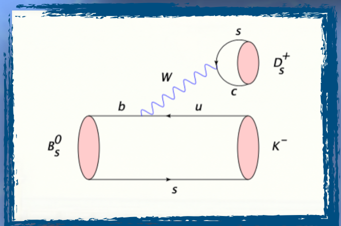


leading to
time dependent CP asymmetry

$$\frac{\Gamma(B_s^0(t)\to f)-\Gamma(\overline{B}_s^0(t)\to f)}{\Gamma(B_s^0(t)\to f)+\Gamma(\overline{B}_s^0(t)\to f)} = \left[\frac{C\ \cos(\Delta M_s\ t)+S\ \sin(\Delta M_s\ t)}{\cosh(\Delta\Gamma_s\ t/2)+\mathscr{A}_{\Delta\Gamma}\sinh(\Delta\Gamma_s\ t/2)}\right]$$

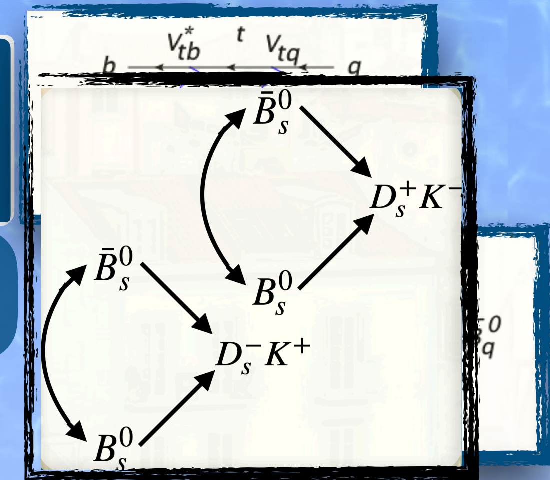
[R. Fleischer (2003)]





Anomalies in the $B_s \to D_s^{\pm} K^{\mp}$

The observables $C,\ S,\ \mathscr{A}_{\Delta\Gamma},\ \bar{C},\ \bar{S},\ \overline{\mathscr{A}}_{\Delta\Gamma}$ **allow a theoretically clean determination of the angle γ of the Unitarity Triangle**



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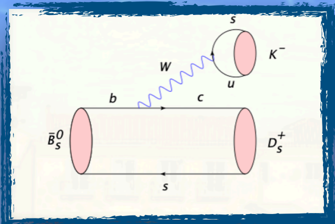

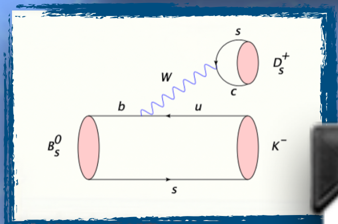

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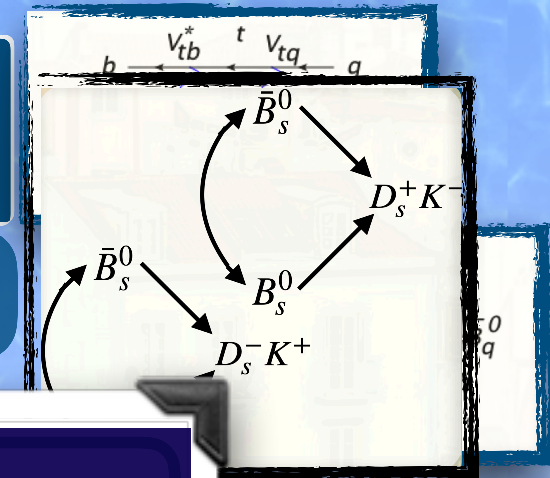


Puzzle in CP Violation:
$B_s^0 \to D_s^{\mp} K^{\pm}$ system

UT angle γ | Theoretically clean

tension with SM: 3σ level

New Physics → in the amplitudes?

Puzzle in Branching Ratios:
$B_s^0 \to D_s^{\mp} K^{\pm}$ & similar modes

clean extractions of $|a_1|$

tensions theory vs experiment: up to 4.8σ level

Towards New Physics

Model Independent Strategy

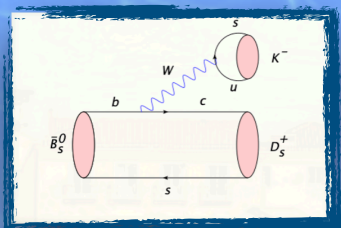
NP parameters
$\rho, \bar{\rho}, \varphi, \bar{\varphi}$

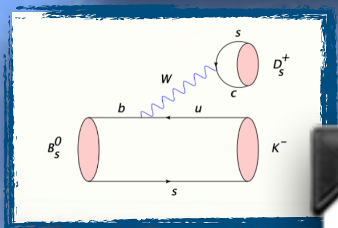
Effective NP angle
$\gamma_{eff} = \gamma + \gamma_{NP}$
$\gamma_{NP} = f(\rho, \bar{\rho}, \varphi, \bar{\varphi})$

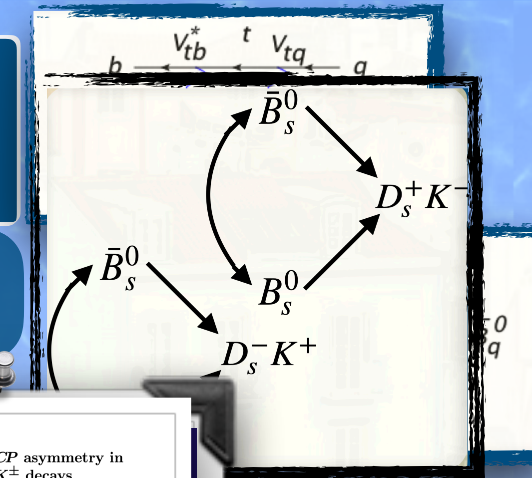
Correlations between NP parameters
$\rho(\varphi),\ \bar{\rho}(\bar{\varphi})$

New Physics contributions at the $30\,\%$ level

Anomalies in the $B_s \to D_s^{\pm} K^{\mp}$







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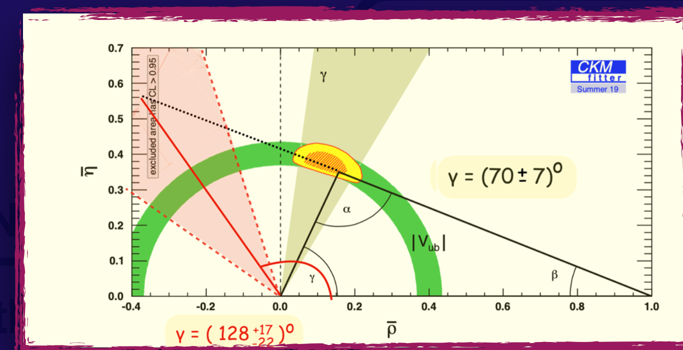
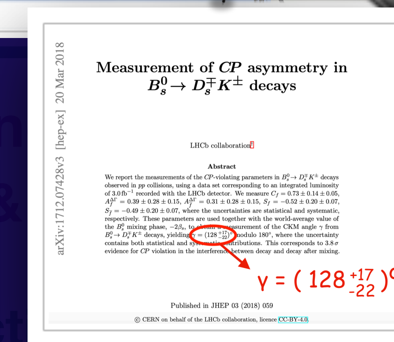
UT angle γ **Theoretically clean**

tension with SM: 3σ level




Measurement of CP asymmetry in $B_s^0 \to D_s^{\mp} K^{\pm}$ decays

LHCb collaboration

Abstract

γ = (128 $^{+17}_{-22}$)°

tensions theory vs experiment: up to 4.8σ level

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THE EUROPEAN PHYSICAL JOURNAL C

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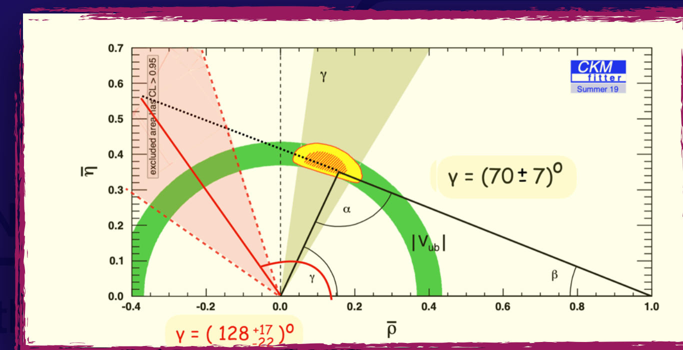

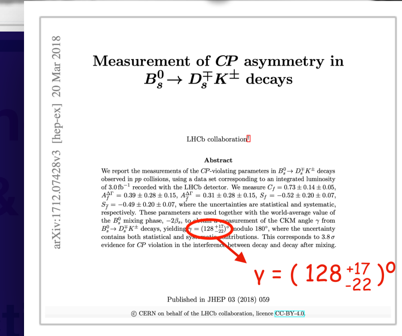

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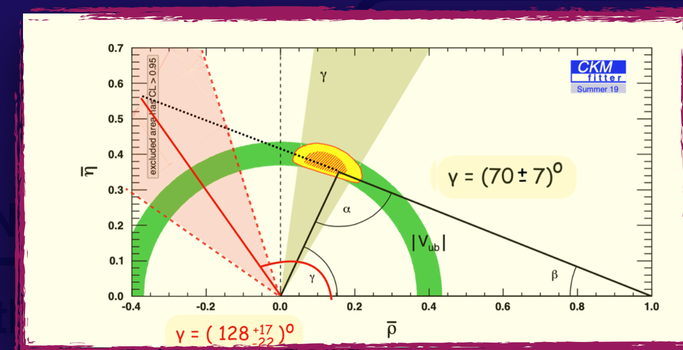

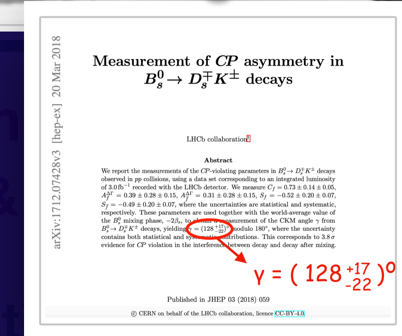

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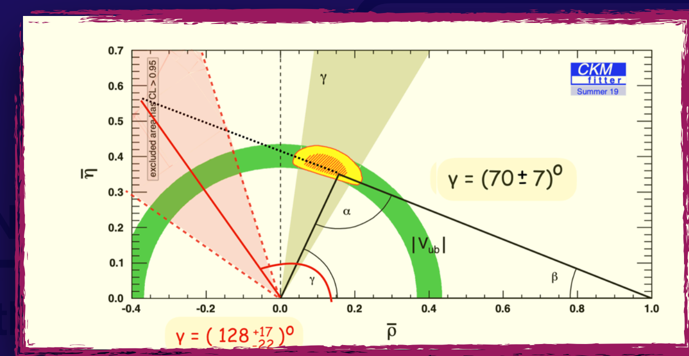

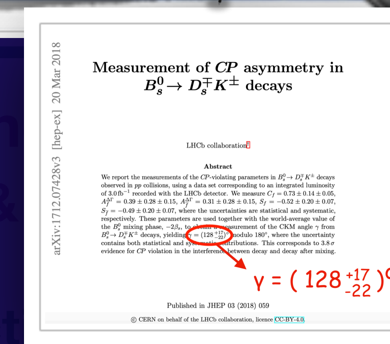

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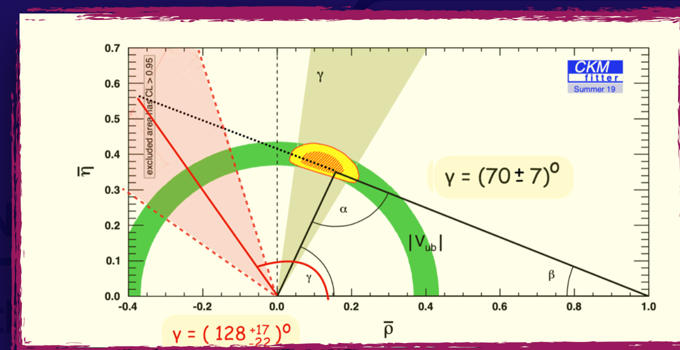

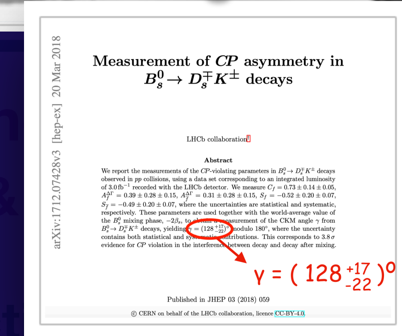

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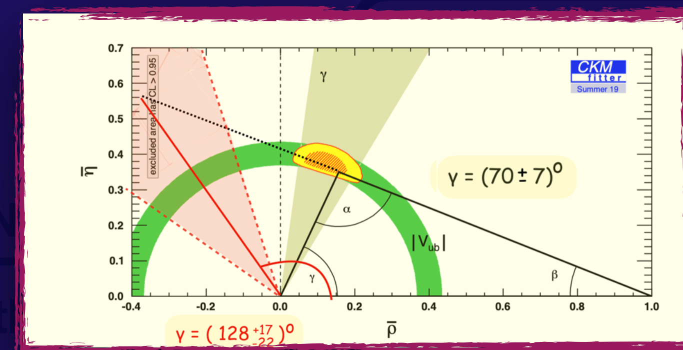

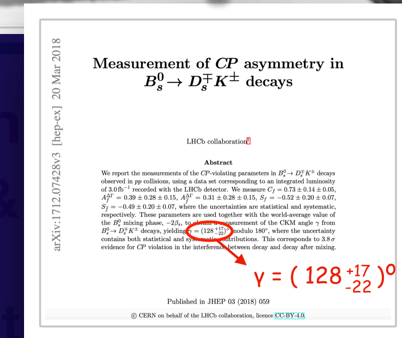

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[R. Aaij *et al* (2018)]

Observables	
$C = -0.73 \pm 0.15$	$\overline{C} = +0.73 \pm 0.15$
$S = +0.49 \pm 0.21$	$\overline{S} = +0.52 \pm 0.21$
$\mathcal{A}_{\Delta\Gamma} = +0.31 \pm 0.32$	$\overline{\mathcal{A}}_{\Delta\Gamma} = +0.39 \pm 0.32$

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THE EUROPEAN PHYSICAL JOURNAL C

Regular Article - Theoretical Physics

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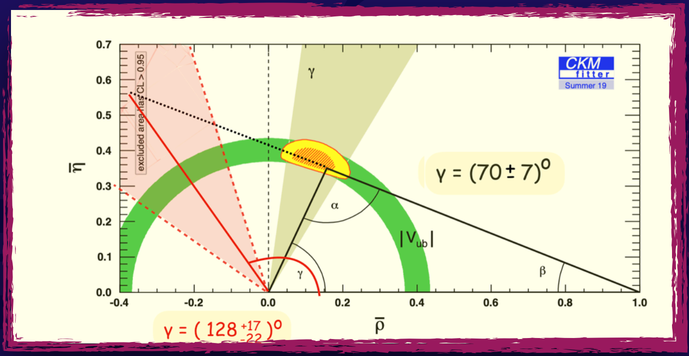
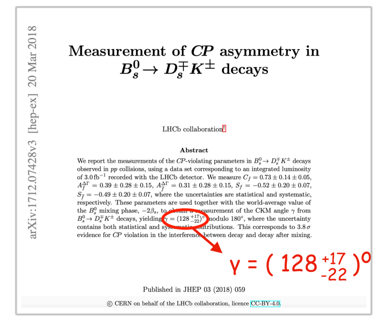
UT angle γ — Theoretically clean

tension with SM: 3σ level





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→ Allowing to resolve ambiguities

Key relation

$$\xi \times \bar{\xi} = e^{-i2(\phi_s + \gamma)}$$

$\phi_s = (-5^{+1.6}_{-1.5})^\circ$ penguin effects included

[M.Z. Barel, K. De Bruyn, R. Fleischer, & E.M. (2020)]

Determined with the help of the asymmetries

$C,\ S,\ \mathcal{A}_{\Delta\Gamma},\ \bar{C},\ \bar{S},\ \bar{\mathcal{A}}_{\Delta\Gamma}$

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Anomalies in the $B_s \to D_s^{\pm}K^{\mp}$

PHYSICAL REVIEW D **106**, 056004 (2022)

DOI: 10.1103/PhysRevD.106.056004

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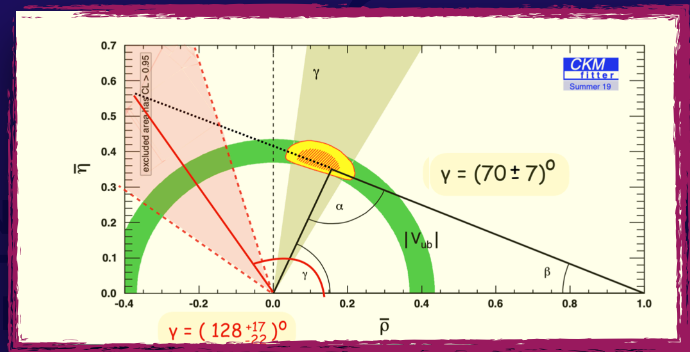

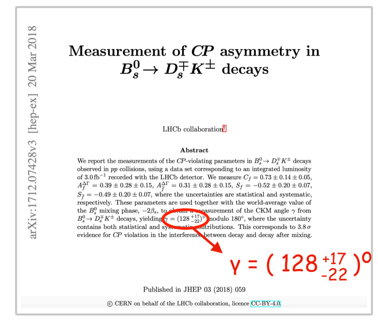

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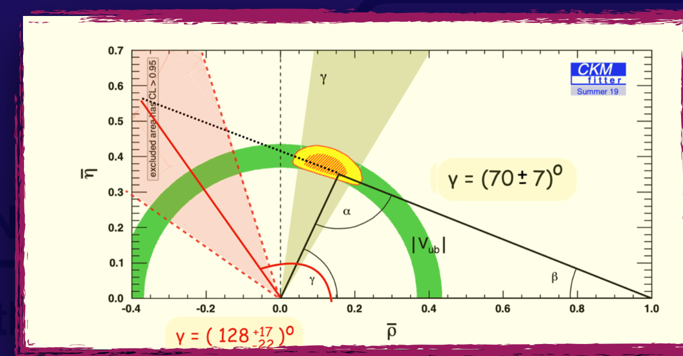

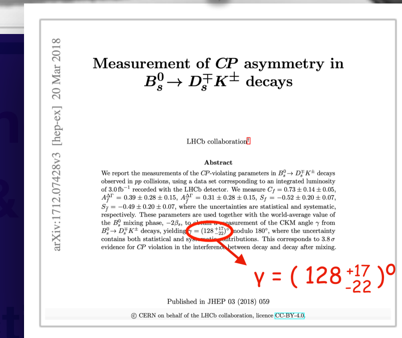

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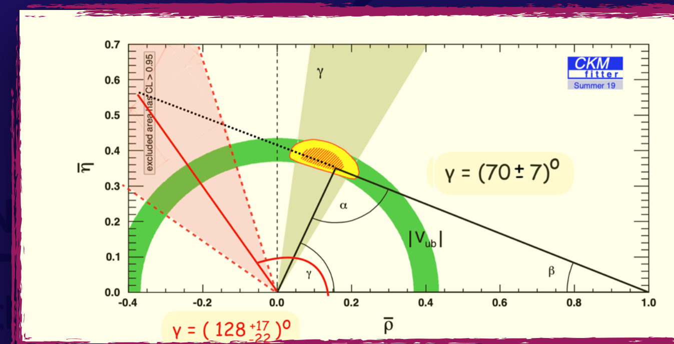

Measurement of *CP* asymmetry in $B_s^0 \to D_s^{\mp} K^{\pm}$ decays

LHCb collaboration

γ = (128 +17 -22)°

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$$\rightarrow \quad |\xi| = 2.53^{+1.43}_{-0.59}, \qquad |\bar{\xi}| = 0.40 \pm 0.13.$$

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$$\phi_s + \gamma = \left(126^{+17}_{-22}\right)^\circ, \quad \delta_s = (-2^{+13}_{-14})^\circ, \quad x_s = |\bar{\xi}| = 0.37^{+0.10}_{-0.09}$$

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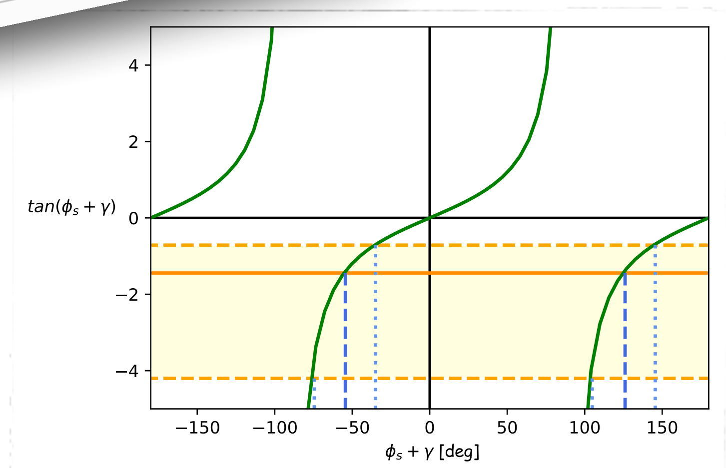

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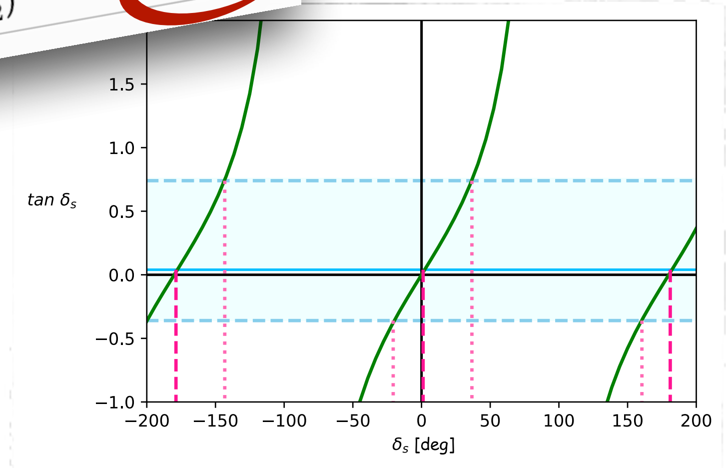

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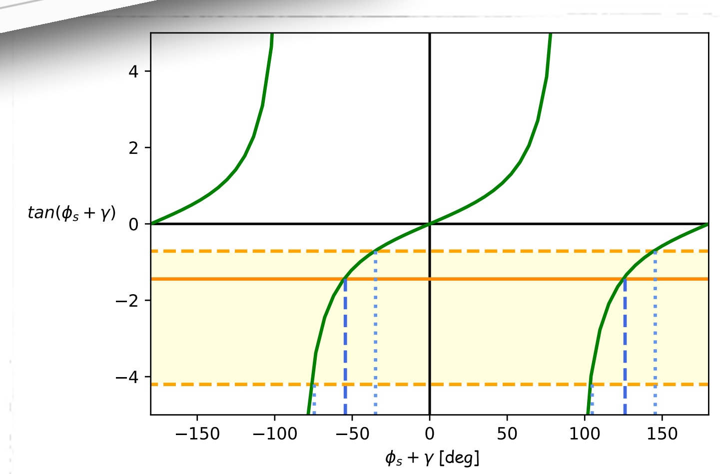

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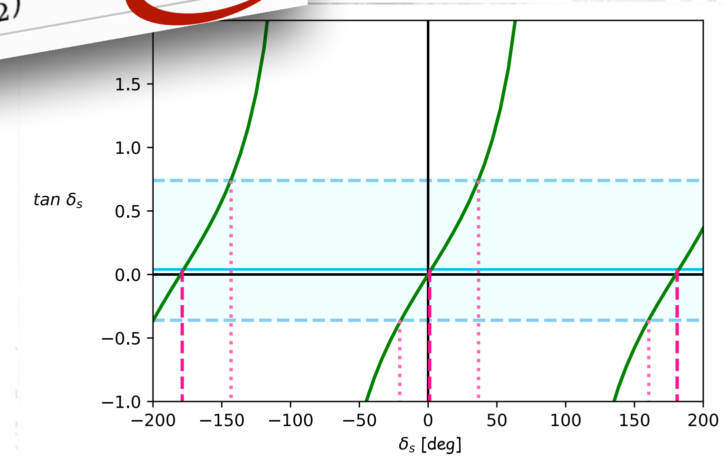

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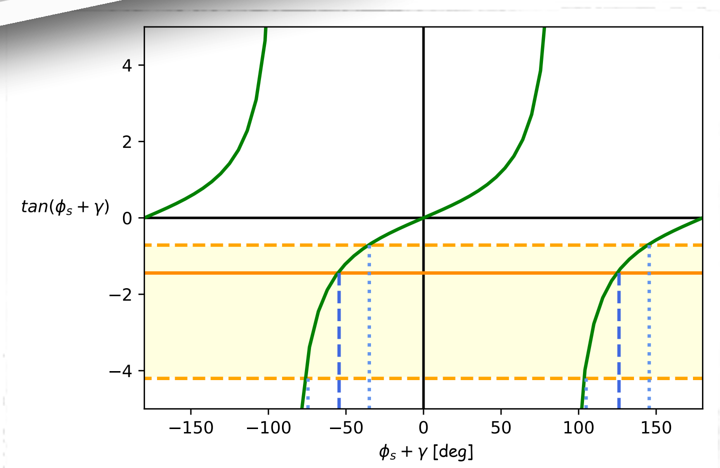

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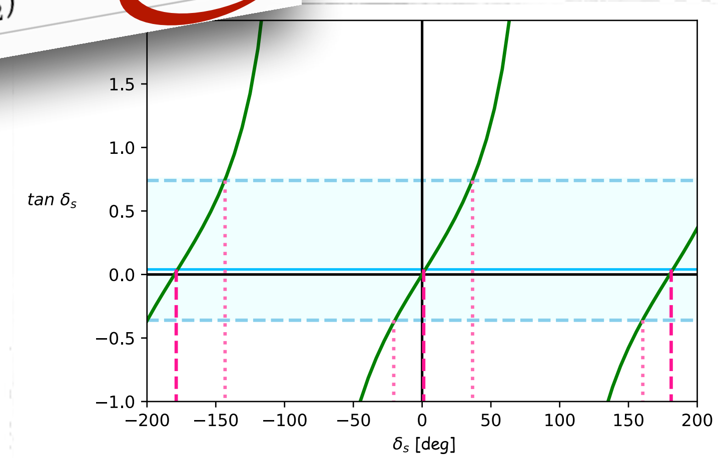

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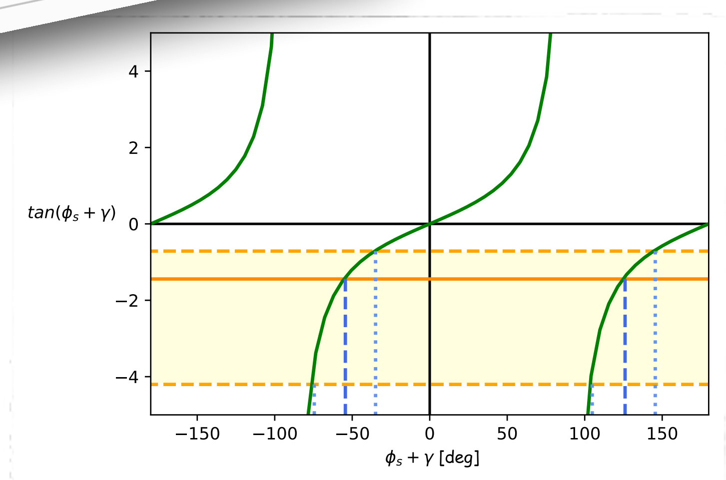

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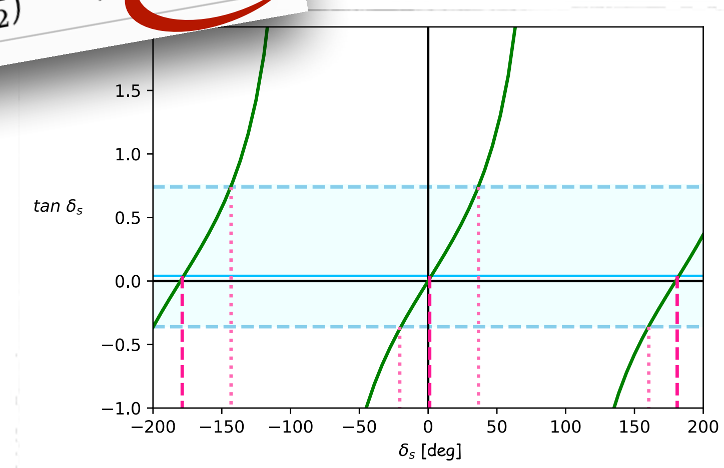

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Could this puzzle come from NP effects entering at the decay amplitude level?

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clean extractions of $|a_1|$

tensions theory vs experiment: up to 4.8σ level

[redacted]

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[K. De Bruyn *et al* (2013)]

The conversion relation between experimental and theoretical branching ratio:

$$\mathcal{B}_{\text{th}} = \bar{\mathcal{B}}_{\text{th}} = \left[\frac{1-y_s^2}{1+y_s\langle\mathcal{A}_{\Delta\Gamma}\rangle_+}\right]\langle\mathcal{B}_{\text{exp}}\rangle, \quad \text{where} \quad \langle\mathcal{B}_{\text{exp}}\rangle \equiv \frac{1}{2}\left(\mathcal{B}_{\text{exp}} + \bar{\mathcal{B}}_{\text{exp}}\right) = \frac{1}{2}\mathcal{B}_{\Sigma}^{\text{exp}}$$

(where mixing effects are switched off)

NP parameters: $\rho, \bar{\rho}, \varphi, \bar{\varphi}$

Effective NP angle: $\gamma_{eff} = \gamma + \gamma_{NP}$, $\gamma_{NP} = f(\rho, \bar{\rho}, \varphi, \bar{\varphi})$

Correlations between NP parameters: $\rho(\varphi)$, $\bar{\rho}(\bar{\varphi})$

New Physics contributions at the 30 % level

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$$\mathcal{B}_{\Sigma}^{\text{exp}} = (2.27 \pm 0.19) \times 10^{-4}$$ [P. A. Zyla *et al.* (2020)]

$$\mathcal{B}(\bar{B}_s^0 \to D_s^+ K^-)_{\text{th}} = 2\left(\frac{|\xi|^2}{1+|\xi|^2}\right)\mathcal{B}_{\text{th}}$$

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tensions theory vs experiment: up to 4.8σ level

[K. De Bruyn *et al* (2013)]

The conversion relation between experimental and theoretical branching ratio: (where mixing effects are switched off)

$$\mathcal{B}_{\text{th}} = \bar{\mathcal{B}}_{\text{th}} = \left[\frac{1-y_s^2}{1+y_s\langle\mathcal{A}_{\Delta\Gamma}\rangle_+}\right]\langle\mathcal{B}_{\text{exp}}\rangle, \quad \text{where} \quad \langle\mathcal{B}_{\text{exp}}\rangle \equiv \frac{1}{2}\left(\mathcal{B}_{\text{exp}} + \bar{\mathcal{B}}_{\text{exp}}\right) = \frac{1}{2}\mathcal{B}_{\Sigma}^{\text{exp}}$$

$$\mathcal{B}_{\Sigma}^{\text{exp}} = (2.27 \pm 0.19) \times 10^{-4}$$ [P. A. Zyla *et al.* (2020)]

$$\mathcal{B}(\bar{B}_s^0 \to D_s^+ K^-)_{\text{th}} = 2\left(\frac{|\xi|^2}{1+|\xi|^2}\right)\mathcal{B}_{\text{th}}$$

$$\mathcal{B}(B_s^0 \to D_s^+ K^-)_{\text{th}} = 2\left(\frac{1}{1+|\xi|^2}\right)\mathcal{B}_{\text{th}}$$

Parameters	Values
$\mathcal{B}_{\text{th}}$	$(1.10 \pm 0.09) \times 10^{-4}$
$\mathcal{B}(\bar{B}_s^0 \to D_s^+ K^-)_{\text{th}}$	$(1.94 \pm 0.21) \times 10^{-4}$
$\mathcal{B}(B_s^0 \to D_s^+ K^-)_{\text{th}}$	$(0.26 \pm 0.12) \times 10^{-4}$

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Using $B_s^0 \to D_s^{\mp} K^{\pm}$ decays as a portal to new physics

Robert Fleischer[1,2] and Eleftheria Malami[1]

Anomalies in the $B_s \to D_s^{\pm} K^{\mp}$

Puzzle in CP Violation:
$B_s^0 \to D_s^{\mp} K^{\pm}$ **system**

UT angle γ **Theoretically clean**

tension with SM: 3σ **level**

New Physics
→
in the amplitudes?

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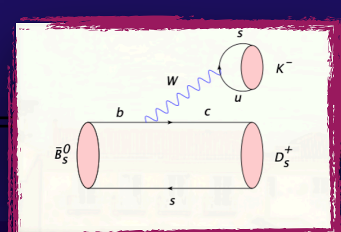
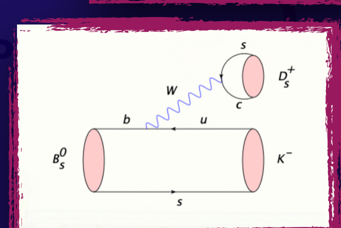
colour-allowed trees





Key quantity $|a_1|$

Puzzle #2: the phenomenological colour factor $|a_1|$

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b $\rightarrow c$ modes

- **Theoretical Prediction: Utilising "Factorisation"**

Puzzle #2: the phenomenological colour factor $|a_1|$

b → c modes

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$$A^{\mathrm{SM}}_{\bar{B}^0_s \to D^+_s K^-} = \frac{G_{\mathrm{F}}}{\sqrt{2}} V^*_{us} V_{cb}\; f_K\; F_0^{B_s \to D_s}(m_K^2)\; (m_{B_s}^2 - m_{D_s}^2)\; a_{1\,\mathrm{eff}}^{D_s K}$$

decay constant

CKM matrix elements

form factor

deviation from naive factorisation

additional contribution from exchange topology

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T_{D_sK} : colour-allowed tree amplitude

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✳ Experimental Values: Utilising Semileptonic partner decays

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b → c modes

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$a^{D_sK}_{1\,\mathrm{eff}}$: deviation from naive factorisation

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✳ Experimental Values: Utilising Semileptonic partner decays

minimizes the form factor dependence

$$R_{D_s^+K^-} \equiv \frac{\mathcal{B}(\bar{B}^0_s \to D_s^+ K^-)_{\mathrm{th}}}{\mathrm{d}\mathcal{B}\left(\bar{B}^0_s \to D_s^+ \ell^- \bar{\nu}_\ell\right)/\mathrm{d}q^2|_{q^2=m_K^2}} = 6\pi^2 f_K^2 |V_{us}|^2 |a^{D_sK}_{1\,\mathrm{eff}}|^2 \Phi_{\mathrm{ph}} \left[\frac{F_0^{B_s\to D_s}(m_K^2)}{F_1^{B_s\to D_s}(m_K^2)}\right]^2$$

$f_K|V_{us}| = (35.09 \pm 0.04 \pm 0.04)\ \mathrm{MeV}$

$\Phi_{\mathrm{ph}} \approx 1$

$$\left[\frac{F_0^{B_s\to D_s}(m_K^2)}{F_1^{B_s\to D_s}(m_K^2)}\right] = 1.00 \pm 0.03$$

$\mathcal{B}(\bar{B}^0_s \to D_s^+ K^-)_{\mathrm{th}} = (1.94 \pm 0.21) \times 10^{-4}$

$$\left.\frac{\mathrm{d}\mathcal{B}\left(\bar{B}^0_s \to D_s^+ \ell^- \bar{\nu}_\ell\right)}{\mathrm{d}q^2}\right|_{q^2=m_K^2} = (3.97 \pm 0.47) \times 10^{-3}\ \mathrm{GeV}^{-2}$$

$|a_1^{D_sK}| = 0.82 \pm 0.11$

[R. Aaij et al. (2020)], [J. L. Rosner, S. Stone and R. S. Van de Water (2015)], [FLAG (2019)]

Puzzle #2: the phenomenological color factor $|a_1|$

$b \to c$ modes

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$$A^{\rm SM}_{\bar{B}^0_s \to D_s^+ K^-} = \frac{G_F}{\sqrt{2}} V^*_{us} V_{cb}\, f_K\, F_0^{B_s \to D_s}(m_K^2)\,(m_{B_s}^2 - m_{D_s}^2)\, a_{1\,\text{eff}}^{D_s K}$$

decay constant

CKM matrix elements

form factor

deviation from naive factorisation

The exchange topology is constrained through $r_E^{D_s K} = \left|1 + \frac{E_{D_s K}}{T_{D_s K}}\right| = 1.00 \pm 0.08$ from the data

No anomalous behaviour from exchange topology

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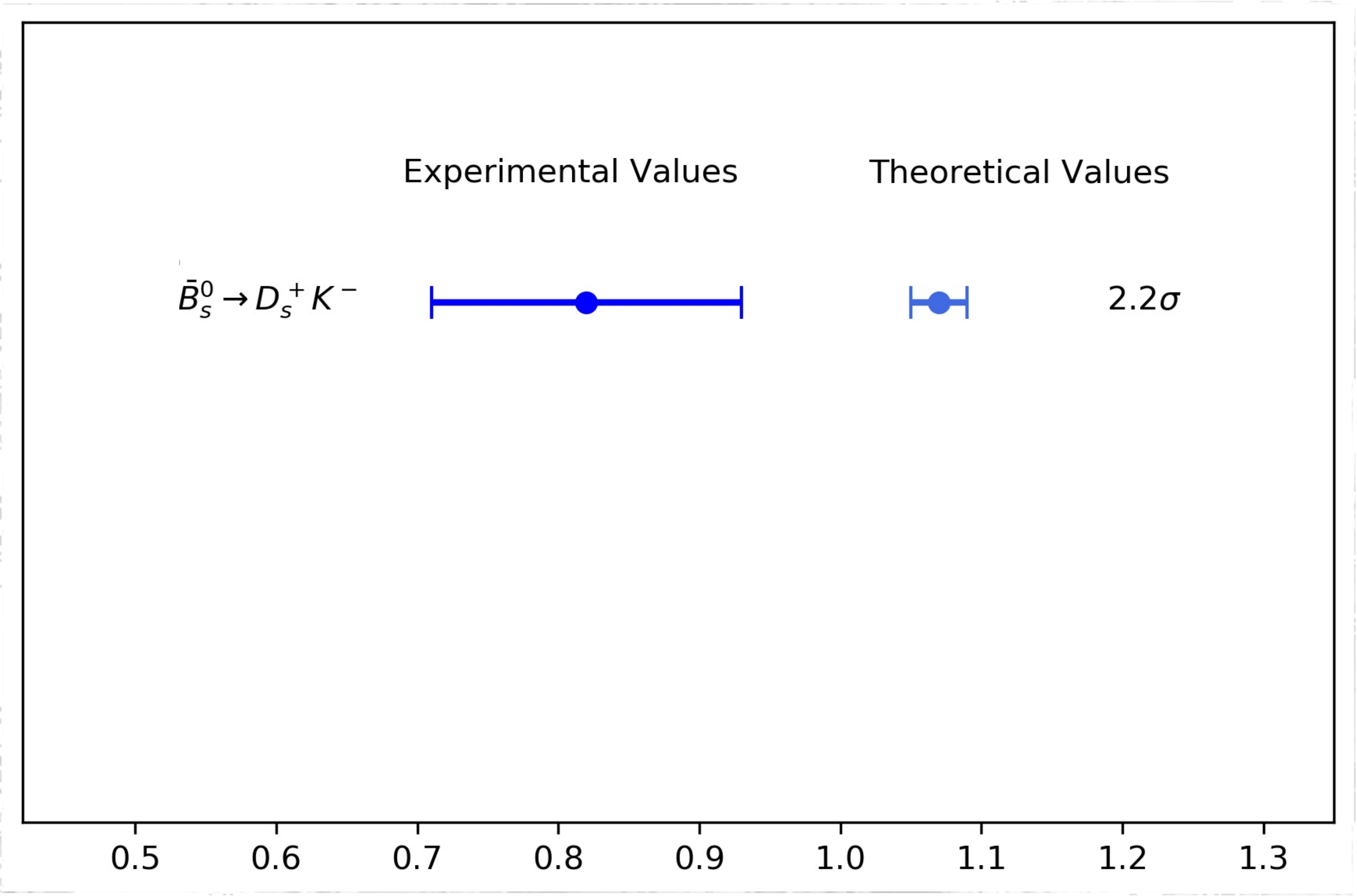


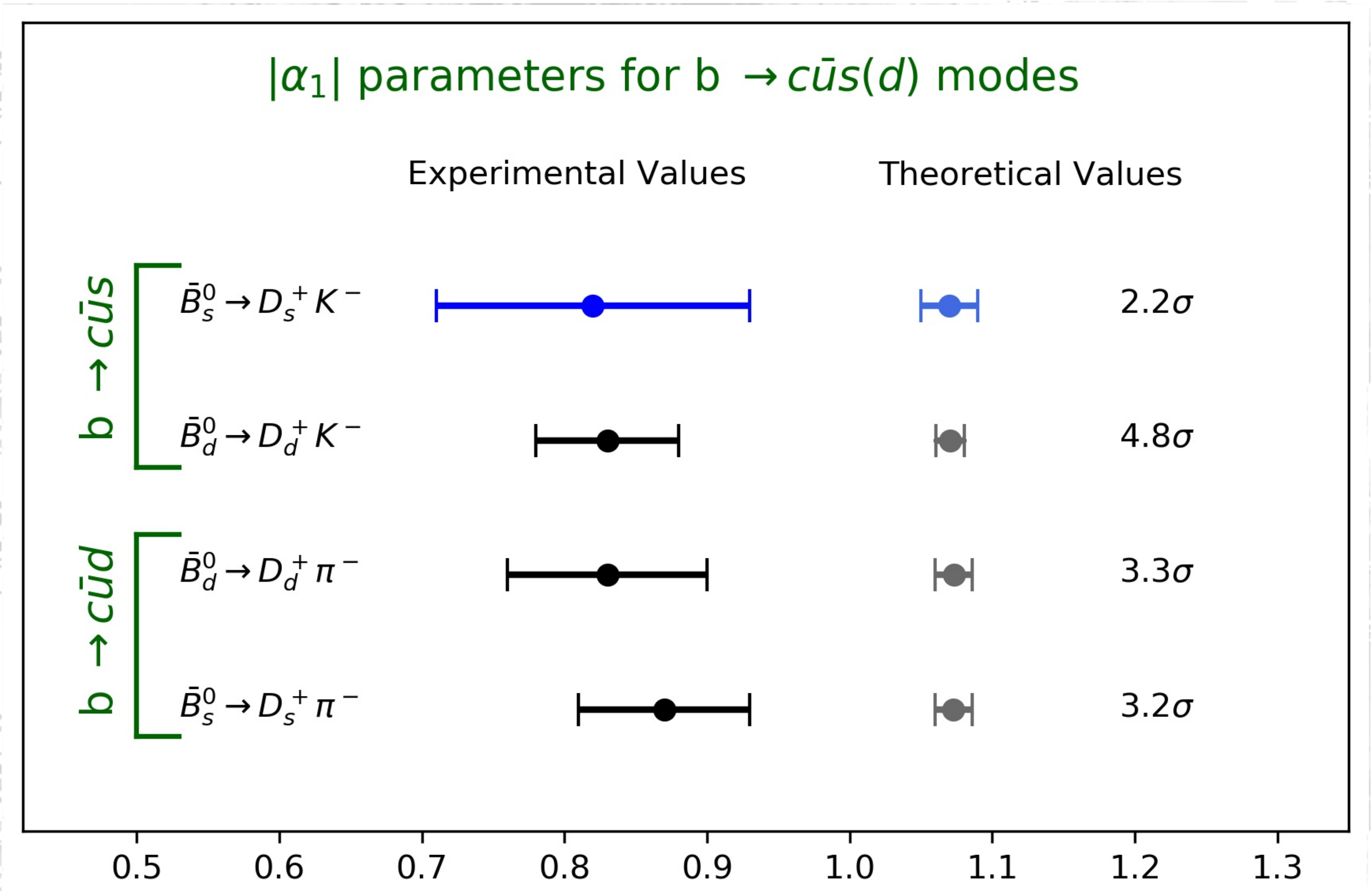
Puzzle #2: the phenomenological color factor $|a_1|$

* Comparing with decays with similar dynamics

No exchange topologies

$$R_{D_d^+K^-} \equiv \frac{\mathcal{B}(\bar{B}_d^0 \to D_d^+ K^-)}{\mathrm{d}\mathcal{B}\left(\bar{B}_d^0 \to D_d^+ \ell^- \bar{\nu}_\ell\right)/\mathrm{d}q^2|_{q^2=m_K^2}} = 6\pi^2 f_K^2 |V_{us}|^2 |a_1^{D_dK}|^2 X_{D_dK}$$

$|a_1^{D_dK}| = 0.83 \pm 0.05$



$$R_{D^+\pi^-} \equiv \frac{\mathcal{B}(\bar{B}_d^0 \to D_d^+ \pi^-)}{\mathrm{d}\mathcal{B}\left(\bar{B}_d^0 \to D_d^+ \ell^- \bar{\nu}_\ell\right)/\mathrm{d}q^2|_{q^2=m_\pi^2}} = 6\pi^2 f_\pi^2 |V_{ud}|^2 |a_{1\,\mathrm{eff}}^{D_d\pi}|^2 X_{D_d\pi}$$

$|a_1^{D_d\pi}| = 0.83 \pm 0.07$

No exchange topologies

$$R_{D_s^+\pi^-} \equiv \frac{\mathcal{B}(\bar{B}_s^0 \to D_s^+ \pi^-)_{\mathrm{th}}}{\mathrm{d}\mathcal{B}\left(\bar{B}_s^0 \to D_s^+ \ell^- \bar{\nu}_\ell\right)/\mathrm{d}q^2|_{q^2=m_\pi^2}} = 6\pi^2 f_\pi^2 |V_{ud}|^2 |a_1^{D_s\pi}|^2 X_{D_s\pi}$$

$|a_1^{D_s\pi}| = 0.87 \pm 0.06$

* Intriguing situation

Puzzle #2: the phenomenological color factor $|a_1|$

$$A^{\rm SM}_{\bar{B}^0_s\to K^+D_s^-} = \frac{G_{\rm F}}{\sqrt{2}}\, V_{cs}^* V_{ub}\, f_{D_s}\, F_0^{B_s\to K}(m_{D_s}^2)\,(m_{B_s}^2 - m_K^2)\, a_{1\,\rm eff}^{KD_s}$$

b → *u* modes

- ✳ **Similar strategy can be applied**
- **- Factorisation is on less solid ground though**

$$R_{K^+D_s^-} \equiv \frac{\mathcal{B}(\bar{B}^0_s \to D_s^- K^+)_{\rm th}}{{\rm d}\mathcal{B}(\bar{B}^0_s \to K^+\ell^-\bar{\nu}_\ell)/{\rm d}q^2|_{q^2=m^2_{D_s}}}$$

not measured → **use instead**

$$R^{SU(3)}_{K^+D_s^-} \equiv \frac{\mathcal{B}(\bar{B}^0_s \to D_s^- K^+)_{\rm th}}{{\rm d}\mathcal{B}(\bar{B}^0 \to \pi^+\ell^-\bar{\nu}_\ell)/{\rm d}q^2|_{q^2=m^2_{D_s}}} = 6\pi^2 f_{D_s}^2 |V_{cs}|^2 |a_{1\,\rm eff}^{KD_s}|^2 X_{SU(3)},$$

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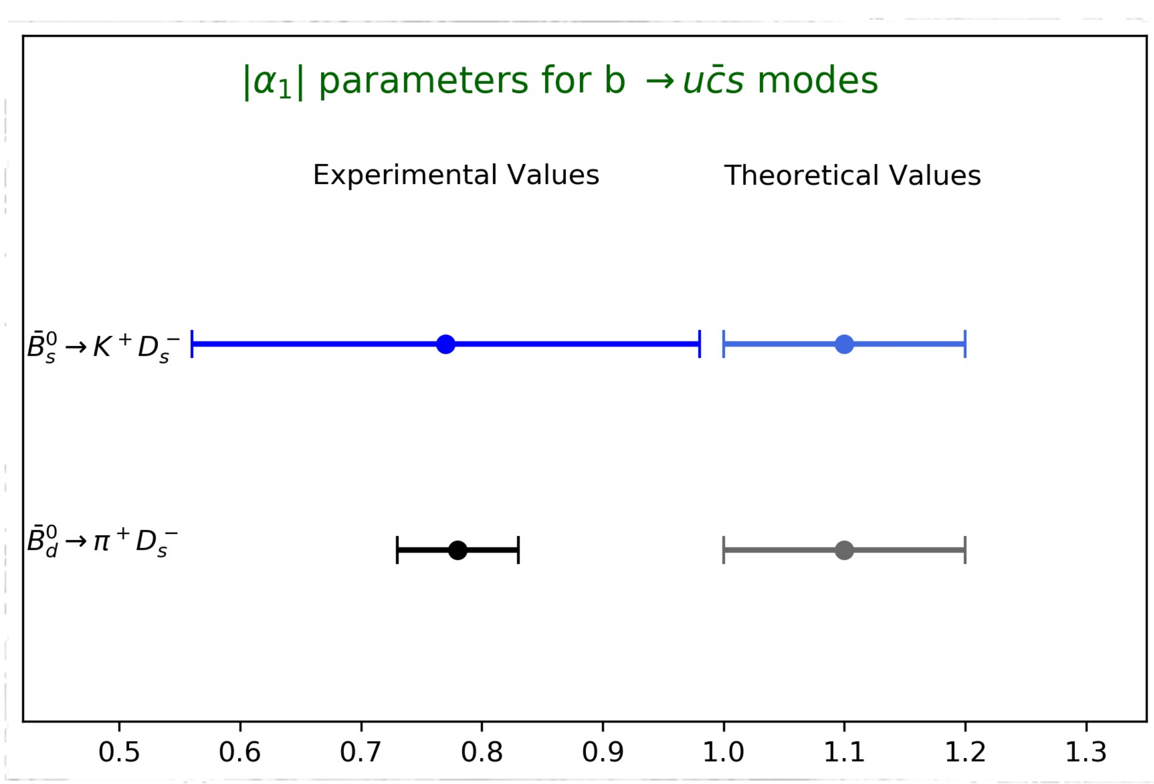
✳ **Comparing with decay with similar dynamics**



No exchange topologies

$$R_{\pi^+D_s^-} \equiv \frac{\mathcal{B}(\bar B^0_d\to\pi^+D_s^-)}{{\rm d}\mathcal{B}\left(\bar B^0\to\pi^+\ell^-\bar\nu_\ell\right)/{\rm d}q^2|_{q^2=m^2_{D_s}}} = 6\pi^2 f^2_{D_s}|V_{cs}|^2|a_1^{\pi D_s}|^2 X_{\pi D_s}$$

$$|a_1^{\pi D_s}| = 0.78\pm0.05$$

The current uncertainties are too large to draw further conclusions

Anomalies in the $B_s \to D_s^{\pm} K^{\mp}$

Puzzle in CP Violation:
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UT angle γ — Theoretically clean

tension with SM: 3σ level

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Towards New Physics

[redacted]

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Towards New Physics

* NP parameter

$$\bar{\rho}\, e^{i\bar{\delta}} e^{i\bar{\varphi}} \equiv \frac{A(\bar{B}_s^0 \to D_s^+ K^-)_{\rm NP}}{A(\bar{B}_s^0 \to D_s^+ K^-)_{\rm SM}}$$

$\bar{\varphi}$ and $\bar{\delta}$ denote CP-violating and CP-conserving phases

Independent Strategy

NP parameters
$\rho, \bar{\rho}, \varphi, \bar{\varphi}$

Effective NP angle
$\gamma_{eff} = \gamma + \gamma_{NP}$
$\gamma_{NP} = f(\rho, \bar{\rho}, \varphi, \bar{\varphi})$

Correlations between NP parameters
$\rho(\varphi), \bar{\rho}(\bar{\varphi})$

New Physics contributions at the 30 % level

Anomalies in the $B_s \to D_s^{\pm} K^{\mp}$

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* "effective" angle

$$\gamma_{\rm eff} \equiv \gamma + \gamma_{\rm NP}$$

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$\bar{\varphi}$ and $\bar{\delta}$ denote CP-violating and CP-conserving phases

* "effective" angle

$$\gamma_{\mathrm{eff}} \equiv \gamma + \gamma_{\mathrm{NP}}$$

* Generalised expression

$$\xi \times \bar{\xi} = \sqrt{1 - 2\left[\frac{C + \bar{C}}{(1 + C)\,(1 + \bar{C})}\right] e^{-i[2(\phi_s + \gamma_{\mathrm{eff}})]}}$$

theoretical clean relation

Available space for NP

$\delta = \bar{\delta} = 0^\circ$

$\gamma = (70 \pm 7)^\circ$

$\gamma_{\rm eff} = \left(131^{+17}_{-22}\right)^\circ$

$$b = 1 + 2\rho\cos\delta\cos\phi + \rho^2 = \frac{\langle R_{D_s^+K^-}\rangle}{6\pi^2 f_K^2 |V_{us}|^2 |a_1^{D_sK}|^2 X_{D_sK}} = 0.58 \pm 0.16,$$

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PHYSICAL REVIEW D **106**, 056004 (2022)

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$$\Delta\varphi = \Delta\bar{\varphi} = \gamma - \gamma_{\rm eff} = -(61 \pm 20)^\circ$$

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NP Parameters Correlation

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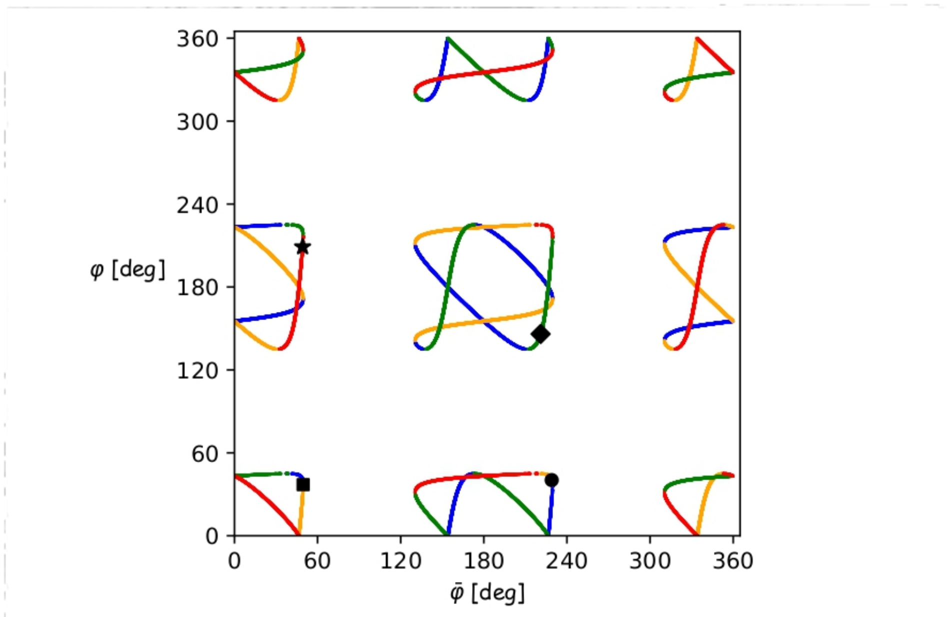

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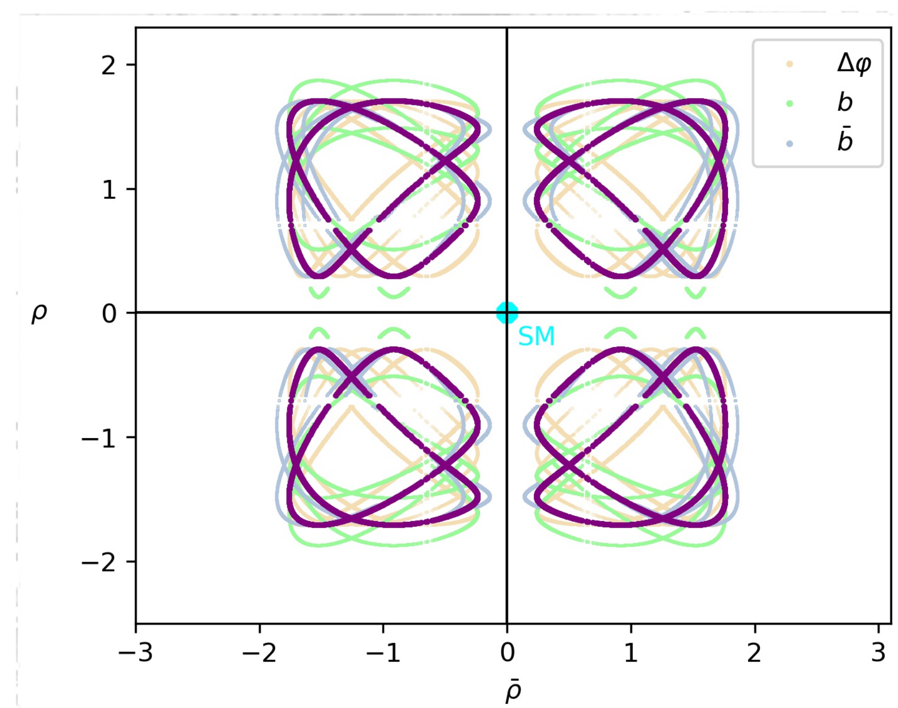

We could accommodate the data with NP contributions as small as about 30% of the SM amplitudes

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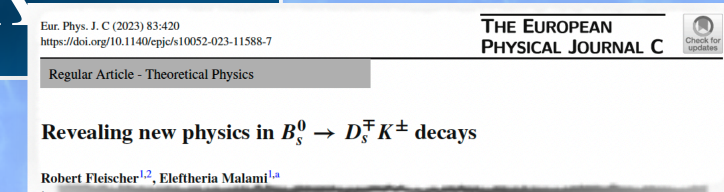
Anomalies in the $B_s \to D_s^{\pm} K^{\mp}$



Eur. Phys. J. C (2023) 83:420
https://doi.org/10.1140/epjc/s10052-023-11588-7

THE EUROPEAN PHYSICAL JOURNAL C

Regular Article - Theoretical Physics

Revealing new physics in $B_s^0 \to D_s^{\mp} K^{\pm}$ decays

Robert Fleischer[1,2], Eleftheria Malami[1,a]

Puzzle in CP Violation:
$B_s^0 \to D_s^{\mp} K^{\pm}$ system

UT angle γ — Theoretically clean

tension with SM: 3σ level

New Physics → in the amplitudes?

Puzzle in Branching Ratios:
$B_s^0 \to D_s^{\mp} K^{\pm}$ & similar modes

clean extractions of $|a_1|$

tensions theory vs experiment: up to 4.8σ level

Towards New Physics

Model Independent Strategy

NP parameters

$\rho, \bar{\rho}, \varphi, \bar{\varphi}$

Effective NP angle

$\gamma_{eff} = \gamma + \gamma_{NP}$

$\gamma_{NP} = f(\rho, \bar{\rho}, \varphi, \bar{\varphi})$

Correlations between NP parameters

$\rho(\varphi), \bar{\rho}(\bar{\varphi})$

New Physics contributions at the $30\,\%$ level

Decays with Different Dynamics

$B_s \to D_s^{\pm} K^{\mp}$ and related modes

pure tree decays

$B_d \to J/\psi K_S \quad B_s \to J/\psi \phi$

dominated by trees but also penguin contamination

CP Violation in different manifestations

$B \to \pi K,\ B \to K^+ K^-$

dominated by penguins

Rare Decays

$B \to \mu\mu,\ B \to K\ell\ell$

from EW penguins and box topologies

The $B_d^0 \to J/\psi K_s^0$ and $B_s^0 \to J/\psi \phi$ modes

- The golden modes for establishing CP violation in B system
  - historically received a lot of attention
- With impressive experimental progress
  we have reached the level of precision where we have to start including the penguin contribution

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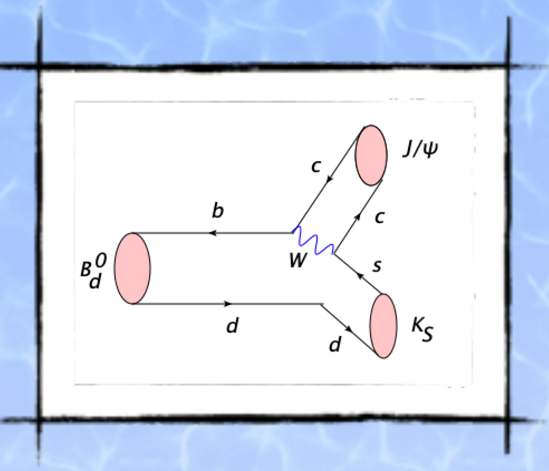
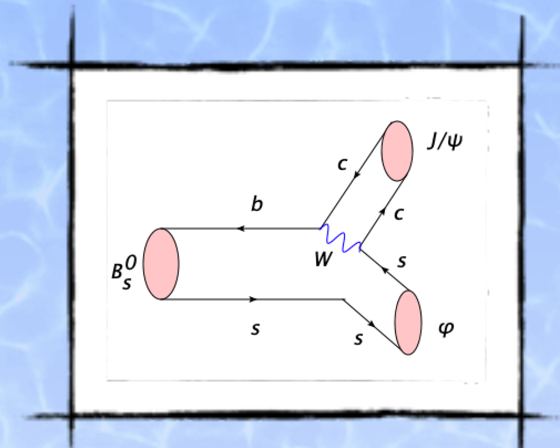
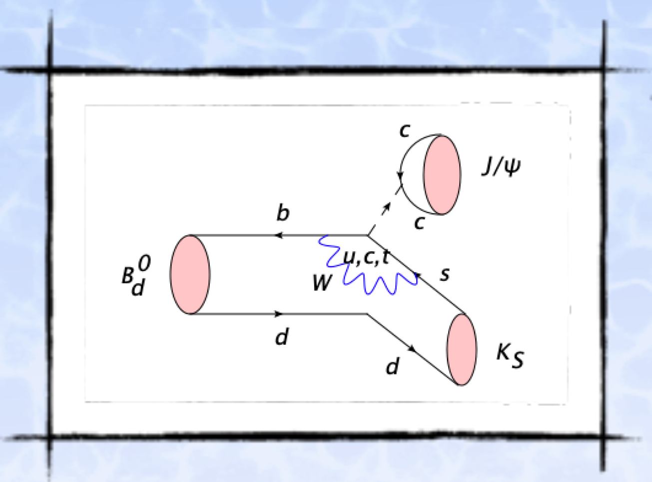
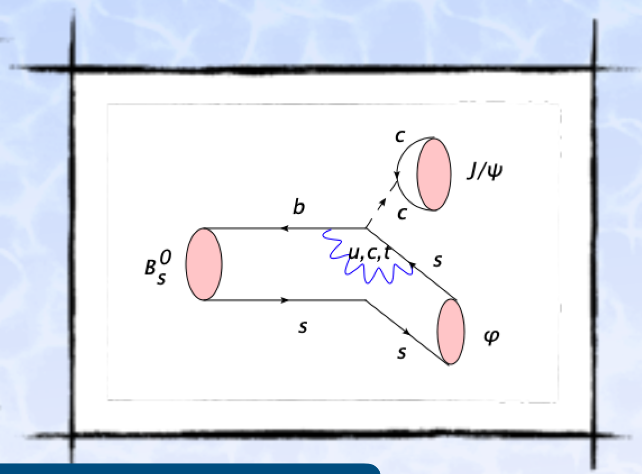




tree diagrams (colour suppressed)





penguin diagrams

→ doubly Cabibbo suppressed : λ^2

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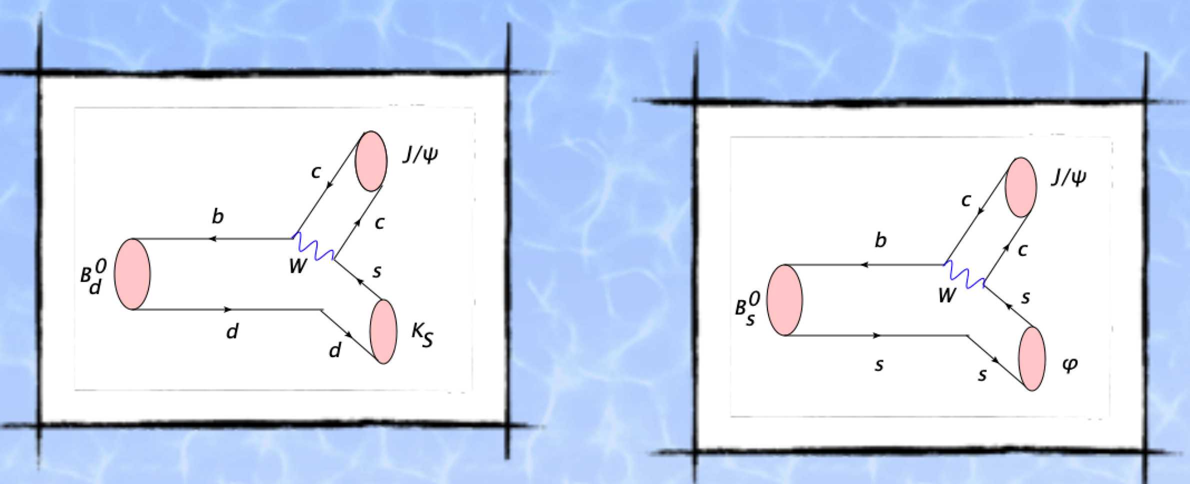

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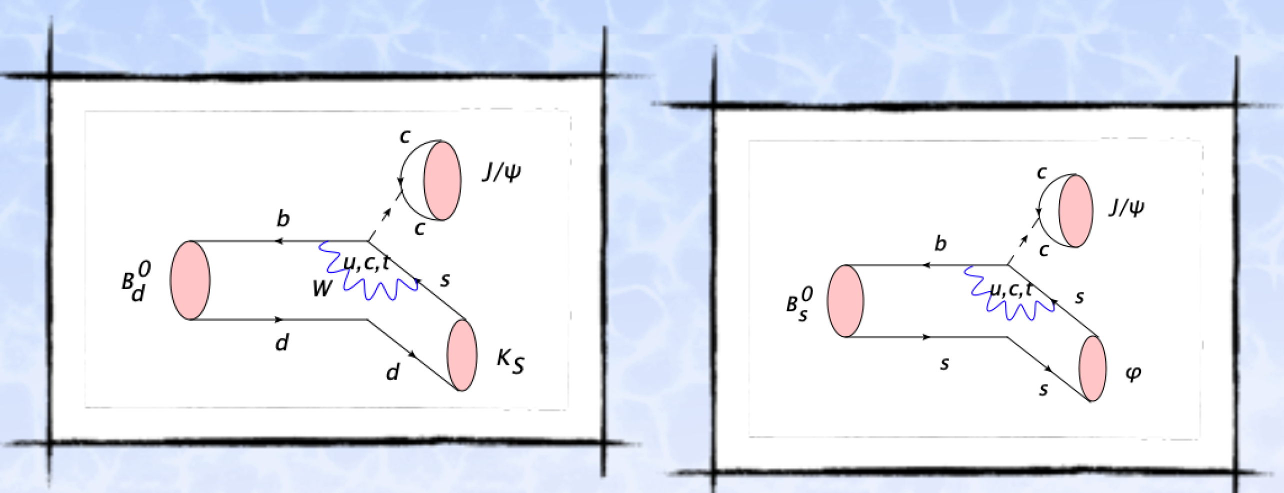

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CP Violating phases

$$\phi_q = \phi_q^{SM} + \phi_q^{NP}$$

ϕ_q: experimentally accessible

ϕ_q^{SM}: determined with Unitarity Triangle

ϕ_q^{NP}: contribution from CP violation from BSM

Associated to doubly Cabibbo suppression

$$\phi_q^{eff} = \phi_q + \Delta\phi_q$$

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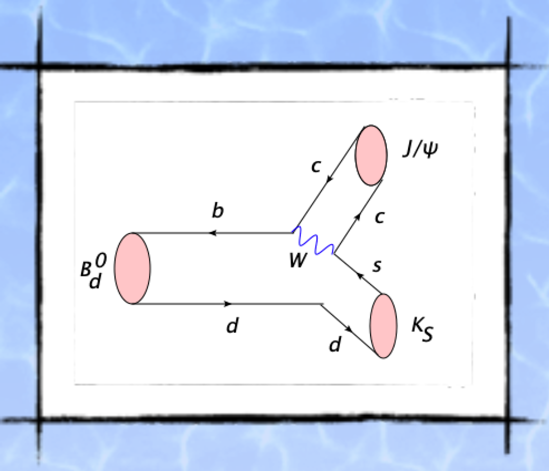

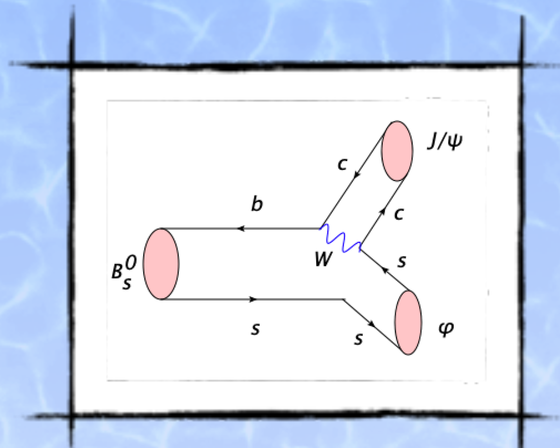

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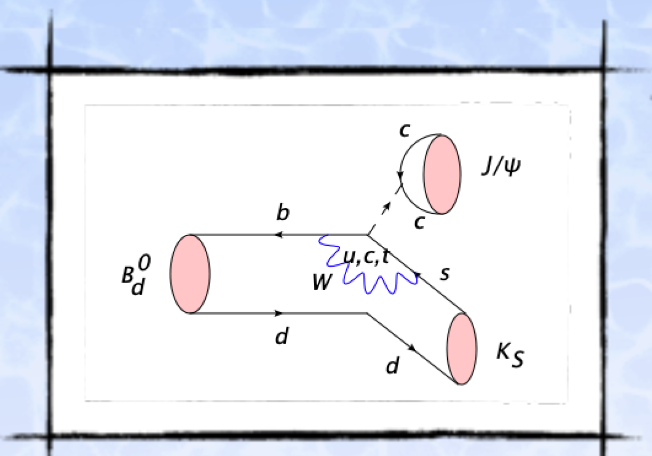

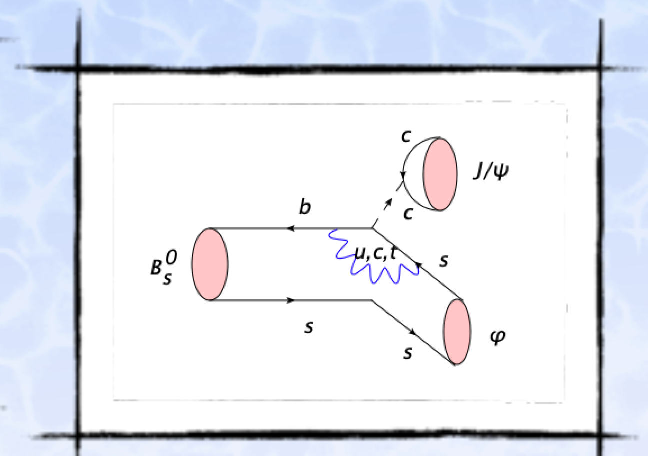

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Associated to doubly Cabibbo suppression

- function of penguin parameters: a,θ
- measures ratio of penguin over tree

$$\phi_q^{eff} = \phi_q + \Delta\phi_q$$

$\Delta\phi_q$:

- hadronic phase shift
- decay-channel specific
- from non-perturbative, strong interaction effects

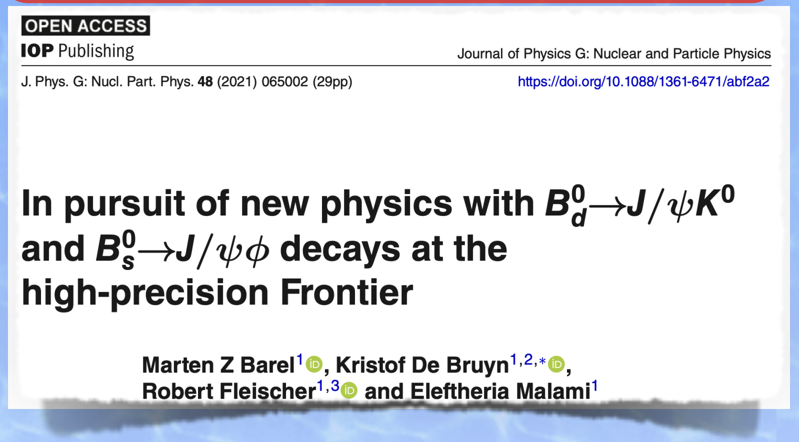
➡ impact of penguins on effective mixing phases

The $B_d^0 \to J/\psi K_s^0$ and $B_s^0 \to J/\psi \phi$ modes

non-perturbative part

- These hadronic effects are challenging to be calculated in QCD
- Instead of calculating them,
  we utilise control modes,
  where these effects are not doubly Cabibbo suppressed

[M.Z. Barel, K. De Bruyn, R. Fleischer, & E.M. (2020)]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J. Phys. G: Nucl. Part. Phys. 48 (2021) 065002 (29pp) https://doi.org/10.1088/1361-6471/abf2a2

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Marten Z Barel[1], Kristof De Bruyn[1,2,*], Robert Fleischer[1,3] and Eleftheria Malami[1]

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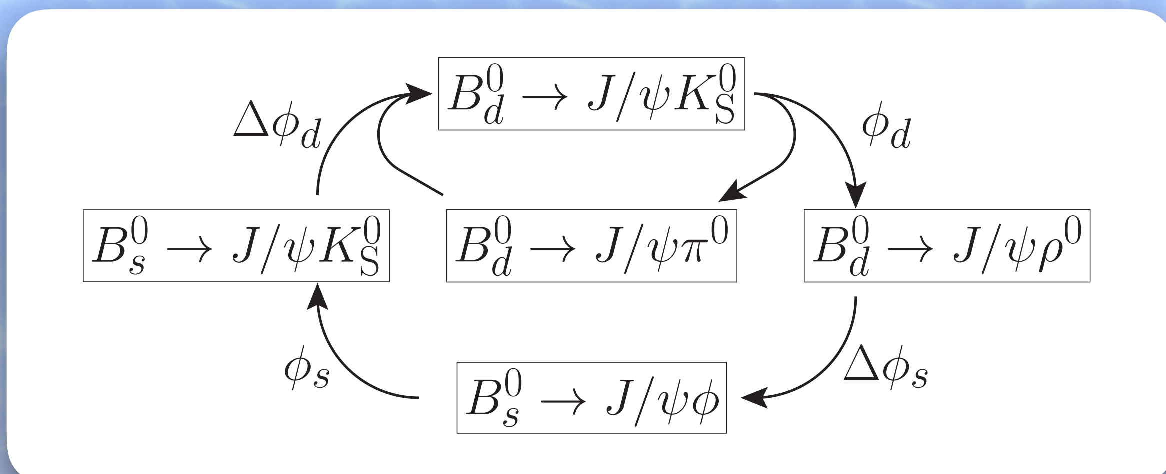

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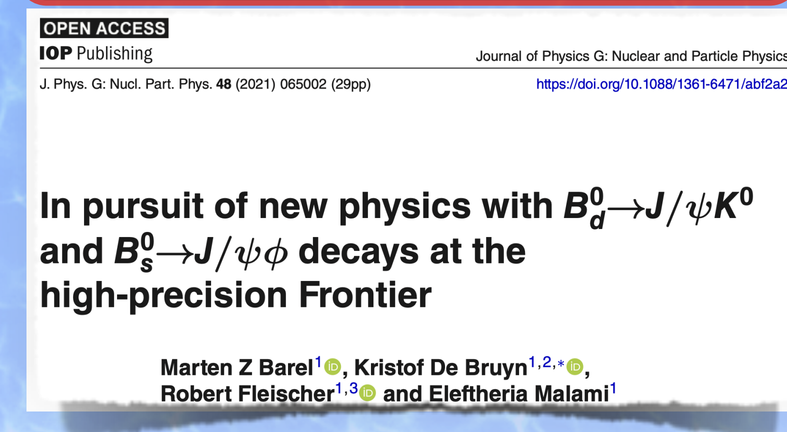
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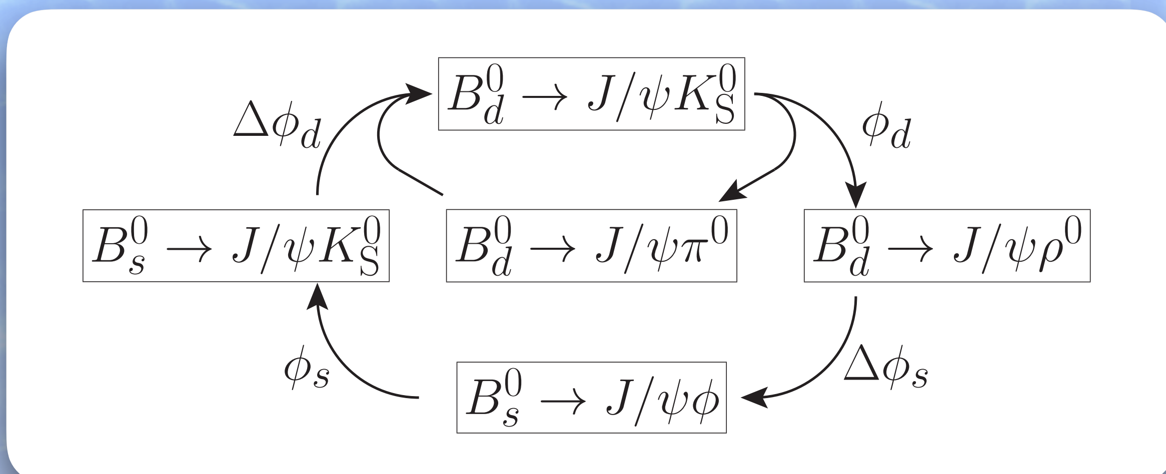

No λ^2 suppression

$$a' e^{i\theta'} = a e^{i\theta}$$

$$B_d^0 \to J/\psi K_S^0 \longrightarrow B_s^0 \to J/\psi K_S^0 \longrightarrow B_d^0 \to J/\psi \pi^0$$

$$B_s^0 \to J/\psi \phi \longrightarrow B_d^0 \to J/\psi \rho^0$$

[S. Faller, M. Jung, R. Fleischer & T. Mannel (2009)]
[K. De Bruyn, R. Fleischer & P. Koppenburg (2009)]
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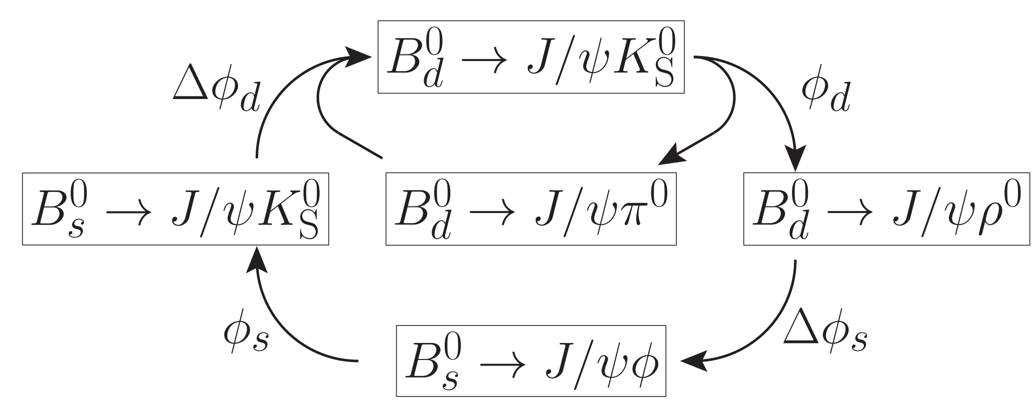

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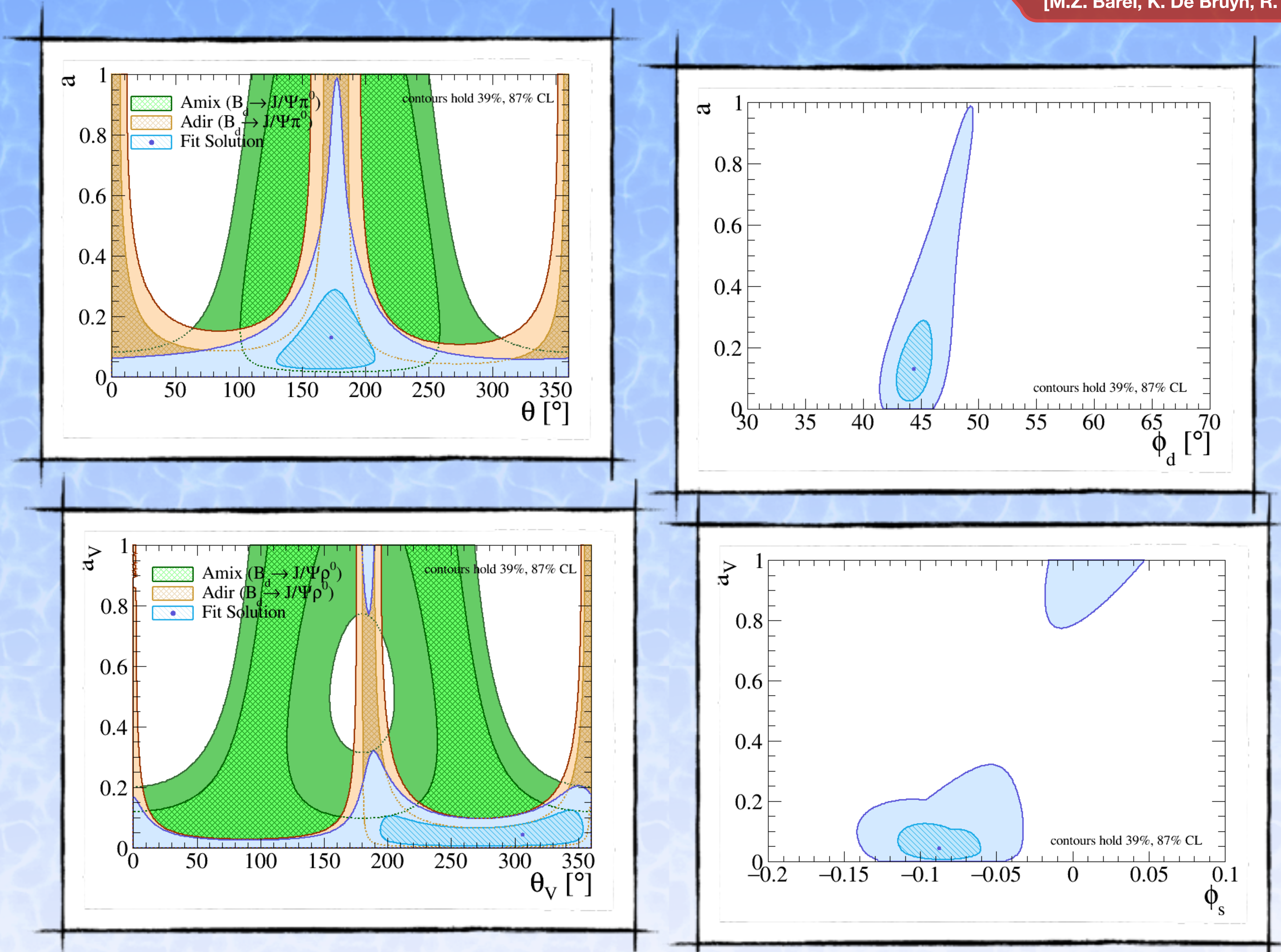
extract the relevant hadronic parameters and the mixing phases

$$a = 0.13^{+0.16}_{-0.10}\,, \qquad \theta = \left(173^{+34}_{-43}\right)^\circ\,, \qquad \phi_d = \left(44.4^{+1.6}_{-1.5}\right)^\circ$$

$$a_V = 0.043^{+0.082}_{-0.037}\,, \qquad \theta_V = \left(306^{+\ 48}_{-112}\right)^\circ\,, \qquad \phi_s = -0.088^{+0.028}_{-0.027} = \left(-5.0^{+1.6}_{-1.5}\right)^\circ$$

Determination of ϕ_d and ϕ_s : Simultaneous analysis

[M.Z. Barel, K. De Bruyn, R. Fleischer, & E.M. (2020)]



Two-dimensional confidence regions of the fit for the penguin parameters and mixing phases from the CP Asymmetries in the $B_s \to J/\psi X$ decays

Information from Semileptonic Decays

[M.Z. Barel, K. De Bruyn, R. Fleischer, & E.M. (2020)

Information from Semileptonic Decays

Determining the colour-suppression factor a_2 in the cleanest possible way from the data

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Using the CP averaged branching fraction, which depends on form factors:

$$2\,\mathcal{B}(B_d \to J/\psi\pi^0) = \tau_{B_d}\frac{G_F^2}{32\pi}|V_{cd}V_{cb}|^2 m_{B_d}^3\left[f_{J/\psi}f^+_{B_d\to\pi}(m^2_{J/\psi})\right]^2\left[\Phi\left(\frac{m_{J/\psi}}{m_{B_d}},\frac{m_{\pi^0}}{m_{B_d}}\right)\right]^3$$

$$\times\,(1-2a\cos\theta\cos\gamma+a^2)\times\left[a_2(B_d\to J/\psi\pi)\right]^2$$

yielding

$$a_2(B_d^0 \to J/\psi\pi^0) = 0.363^{+0.066}_{-0.079}$$

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Agrees better with naive factorisation than the form-factor based result

$$a_2 = 0.21 \pm 0.05$$

[A.J. Buras and L. Silvestrini (1998)]

[M.Z. Barel, K. De Bruyn, R. Fleischer & E.M. (2020

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$$\times\,(1-2a\cos\theta\cos\gamma + a^2)\times\left[a_2(B_d\to J/\psi\pi)\right]^2$$

yielding

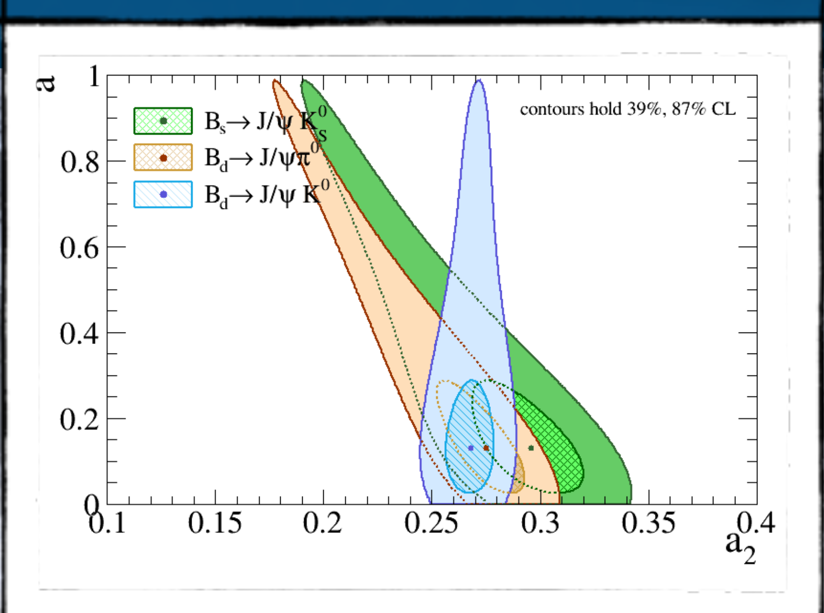
$$a_2(B_d^0\to J/\psi\pi^0) = 0.363^{+0.066}_{-0.079}$$

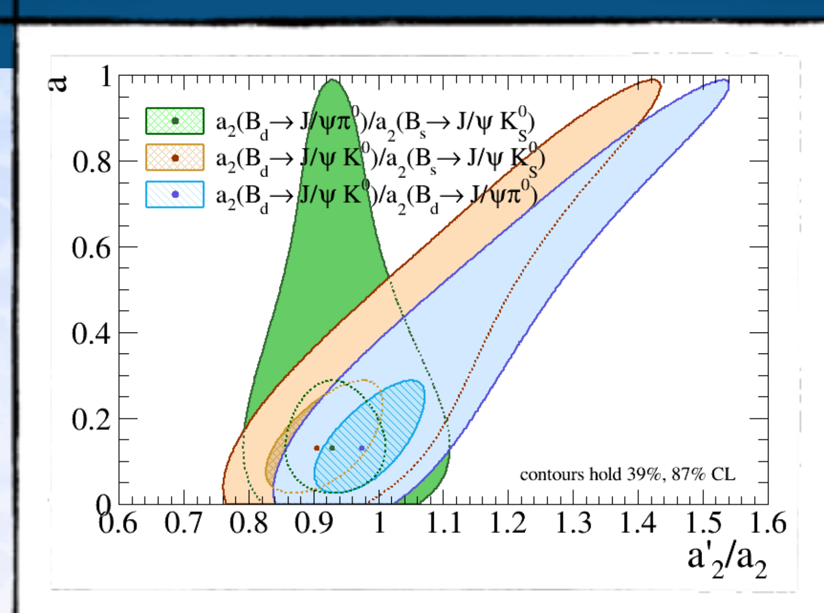
Using semileptonic decays, the hadronic form factors cancel in the following ratio:

$$R_d^\pi \equiv \frac{\Gamma(B_d\to J/\psi\pi)}{d\Gamma/dq^2|_{q^2=m^2_{J/\psi}}(B_d\to\pi\ell\nu)} = \frac{\mathcal{B}(B_d\to J/\psi\pi)}{d\mathcal{B}/dq^2|_{q^2=m^2_{J/\psi}}(B_d\to\pi\ell\nu)}$$

yielding

$$a_2(B_d^0\to J/\psi\pi^0) = 0.275^{+0.018}_{-0.023}$$





$$a_2 = 0.21\pm 0.05$$

[A.J. Buras and L. Silvestrini (1998)]

[M.Z. Barel, K. De Bruyn, R. Fleischer & E.M. (202

Decays with Different Dynamics

$B_s \to D_s^{\pm} K^{\mp}$ and related modes

pure tree decays

$B_d \to J/\psi K_S, \quad B_s \to J/\psi \phi$

dominated by trees but also penguin contamination

CP Violation in different manifestations

$B \to \pi K, \; B \to K^+ K^-$

dominated by penguins

Rare Decays

$B \to \mu\mu, \; B \to K\ell\ell$

from EW penguins and box topologies

The $B \to \pi K$ Puzzle

The $B \to \pi K$ Puzzle

$B_d^0 \to \pi^0 K_S$

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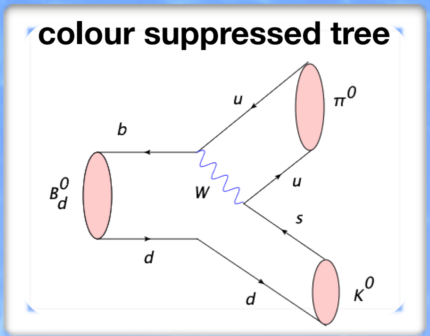
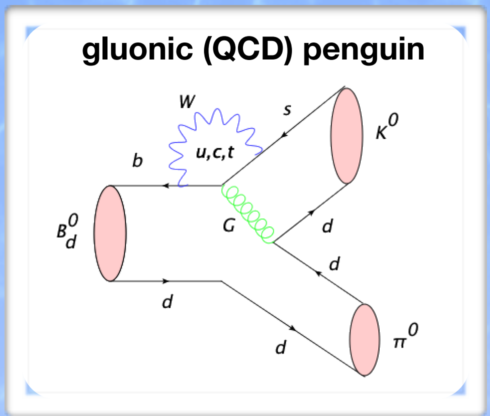
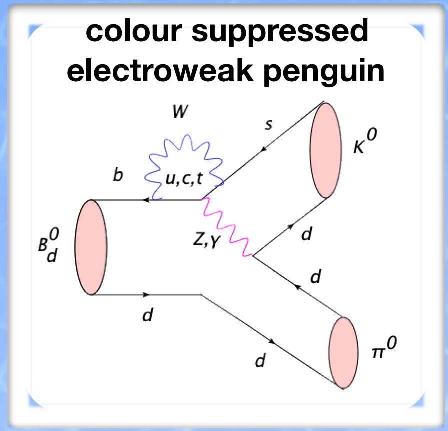


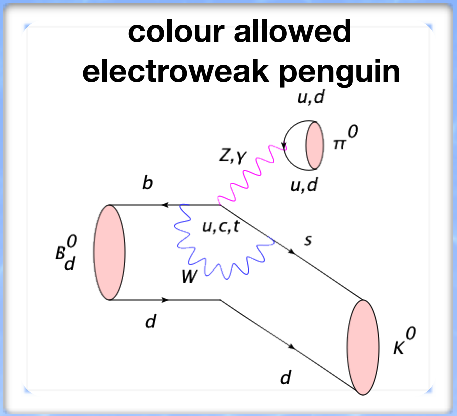
colour suppressed tree



gluonic (QCD) penguin



colour suppressed electroweak penguin



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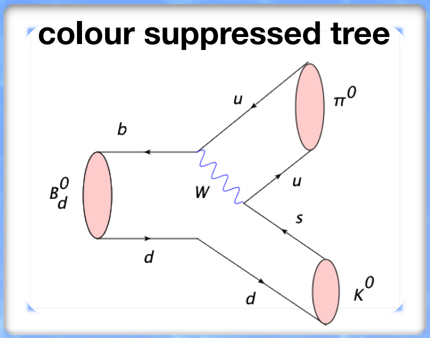

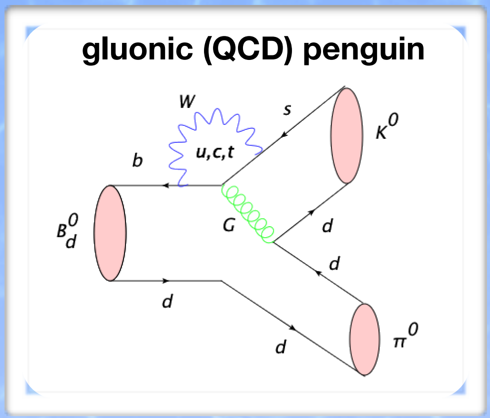

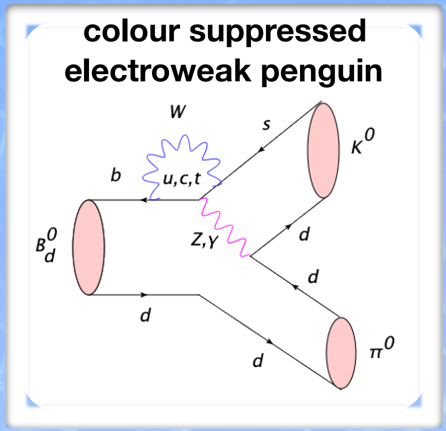

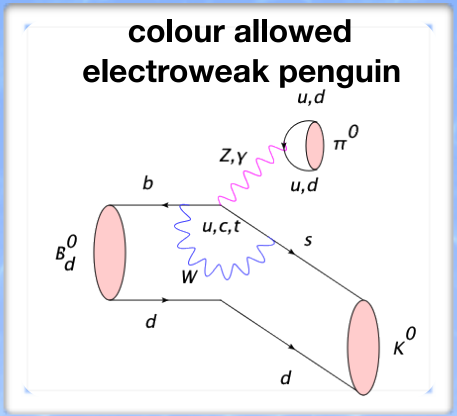

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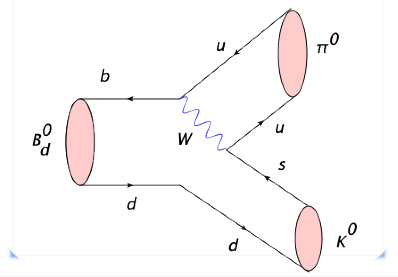

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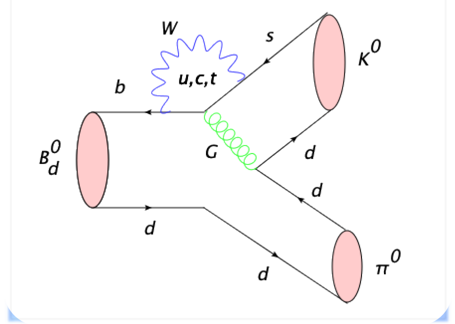

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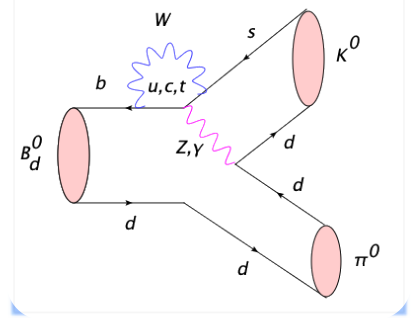
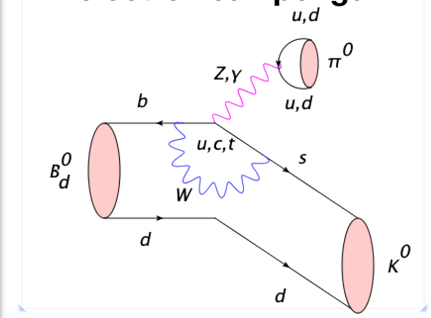


colour suppressed electroweak penguin



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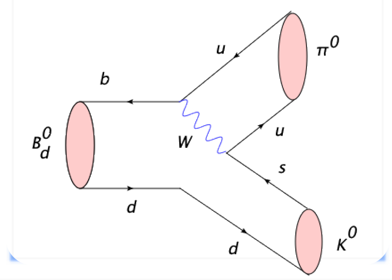

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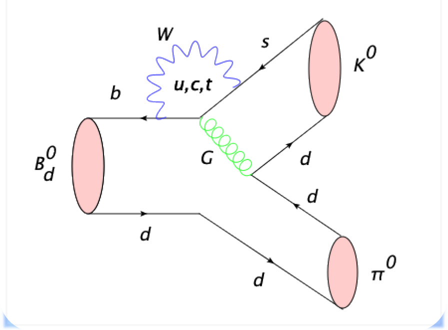

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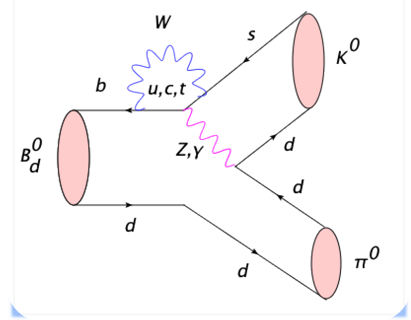

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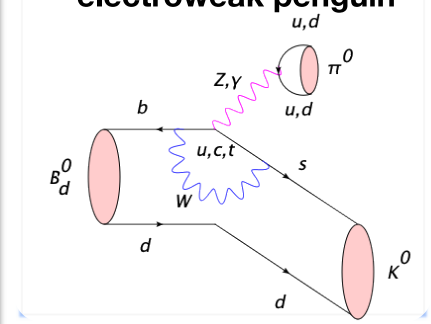

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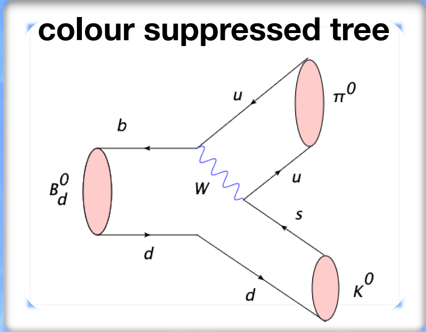

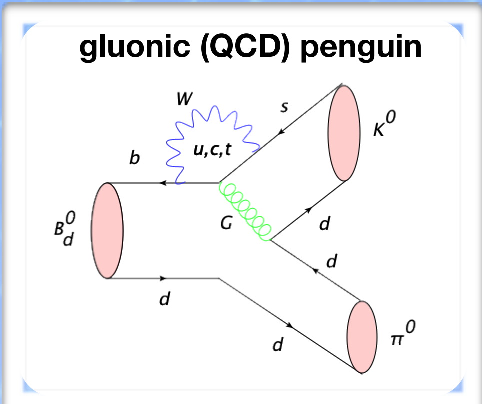

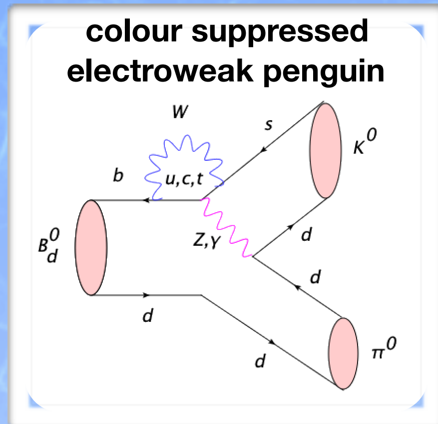

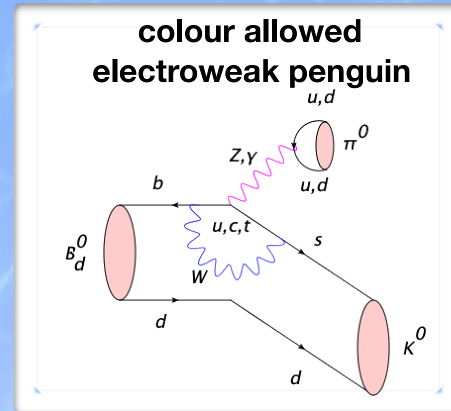

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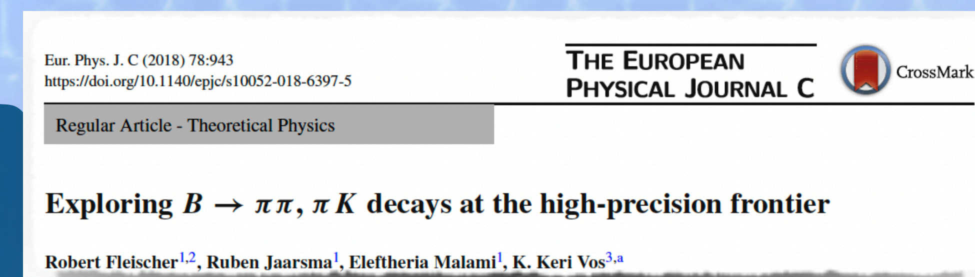
Eur. Phys. J. C (2018) 78:943
https://doi.org/10.1140/epjc/s10052-018-6397-5
THE EUROPEAN PHYSICAL JOURNAL C
CrossMark
Regular Article - Theoretical Physics

Exploring $B \to \pi\pi, \pi K$ decays at the high-precision frontier

Robert Fleischer[1,2], Ruben Jaarsma[1], Eleftheria Malami[1], K. Keri Vos[3,a]

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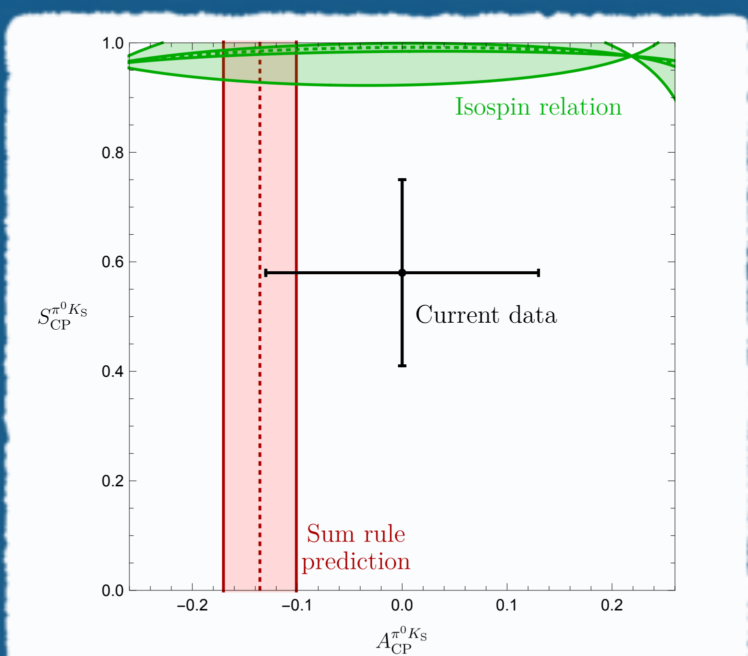
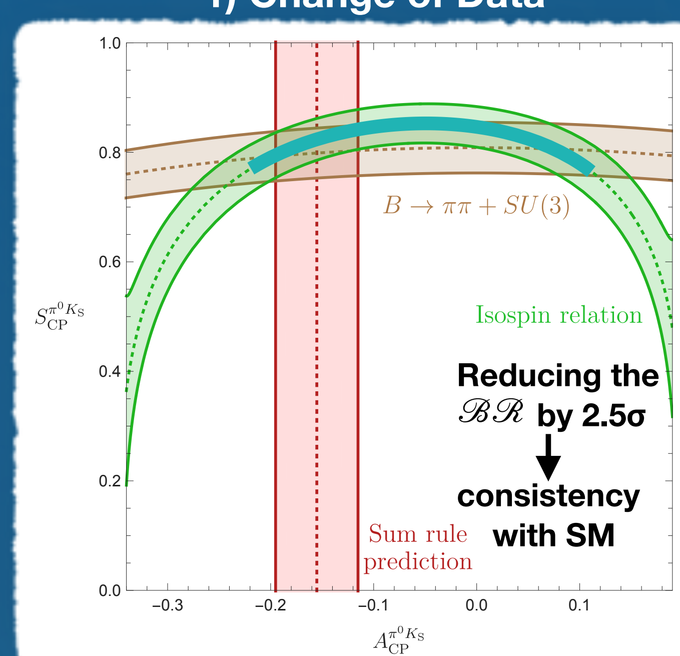
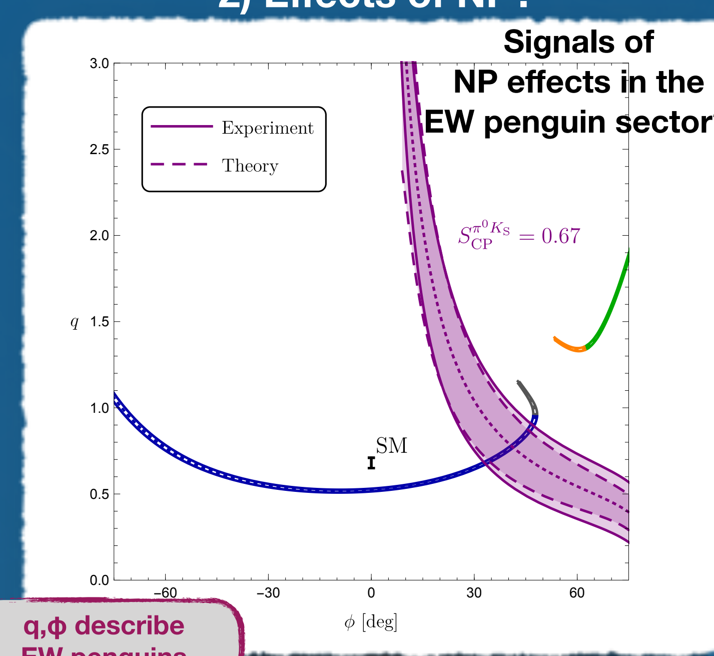


How to resolve this puzzle?

1) Change of Data



2) Effects of NP?



q,ϕ describe EW penguins

see Sagar Hazra's talk

New Belle II measurement for $B_d^0 \to \pi^0 K_S$

arXiv:2305.09153

Time-dependent *CP* violation results at Belle II

Michele Veronesi

We report updates on time-dependent CP-violation observables at Belle II. The benchmark measurements of the B^0 lifetime τ_{B^0} and mixing frequency Δm_d using flavor specific hadronic decays and the determination of the CP-violating phase $\sin 2\phi_1$ in $b \to c\bar{c}s$ transitions have been performed using data collected between 2019-2021. These analyses use only half of the current available dataset and are still statistically limited, showing the excellent performance of the detector and readiness of the analysis tools. We present three new results on the effective value of $\sin 2\phi_1$ in $b \to q\bar{q}s$ transitions, which are highly sensitive to generic non-Standard Model (SM) physics amplitudes, using the full dataset collected between 2019-2022.

Comments: Contribution to the 2023 Electroweak session of the 57th Rencontres de Moriond
Subjects: **High Energy Physics - Experiment (hep-ex)**
Cite as: arXiv:2305.09153 **[hep-ex]**
(or arXiv:2305.09153v1 **[hep-ex]** for this version)
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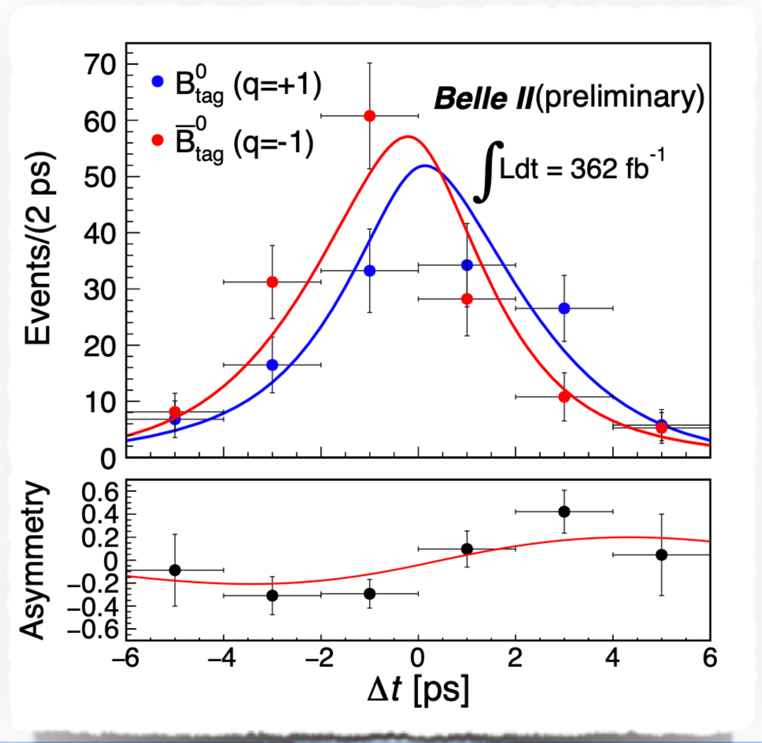

Table 2: Comparison of recent Belle II results (where the first uncertainties are statistical, while the second are systematic) and world average of CP asymmetries in $b \to q\bar{q}s$ transitions.

Observable		Belle II ($362\,\mathrm{fb}^{-1}$)	World Average
$B^0 \to \phi K^0_S$	A	$0.31 \pm 0.20^{+0.05}_{-0.06}$	-0.01 ± 0.14
	S	$0.54 \pm 0.26^{+0.06}_{-0.08}$	$0.74^{+0.11}_{-0.13}$
$B^0 \to K^0_S K^0_S K^0_S$	A	$0.07^{+0.15}_{-0.20} \pm 0.02$	0.15 ± 0.12
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$B^0 \to K^0_S \pi^0$	A	$0.04^{+0.15}_{-0.14} \pm 0.05$	-0.01 ± 0.10
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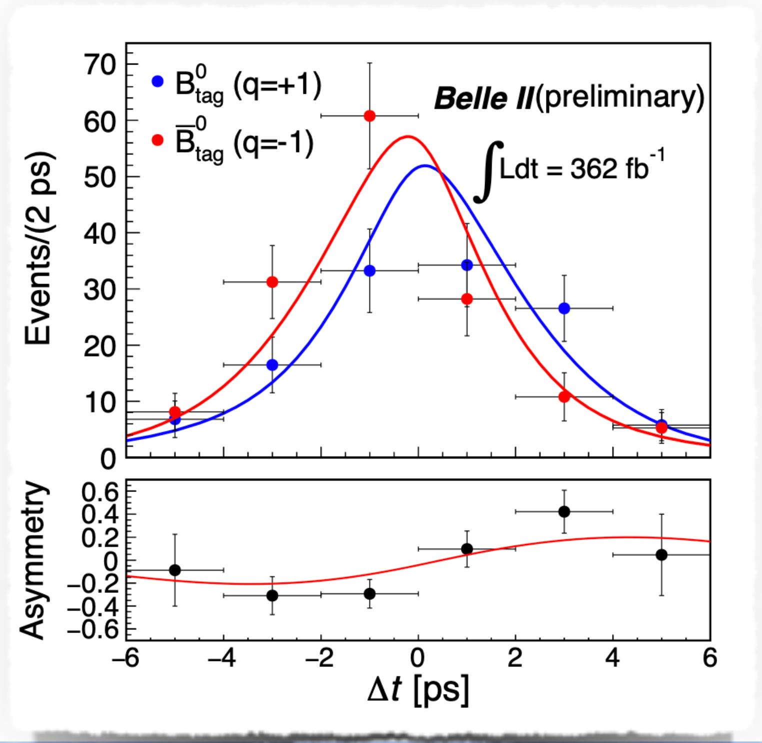

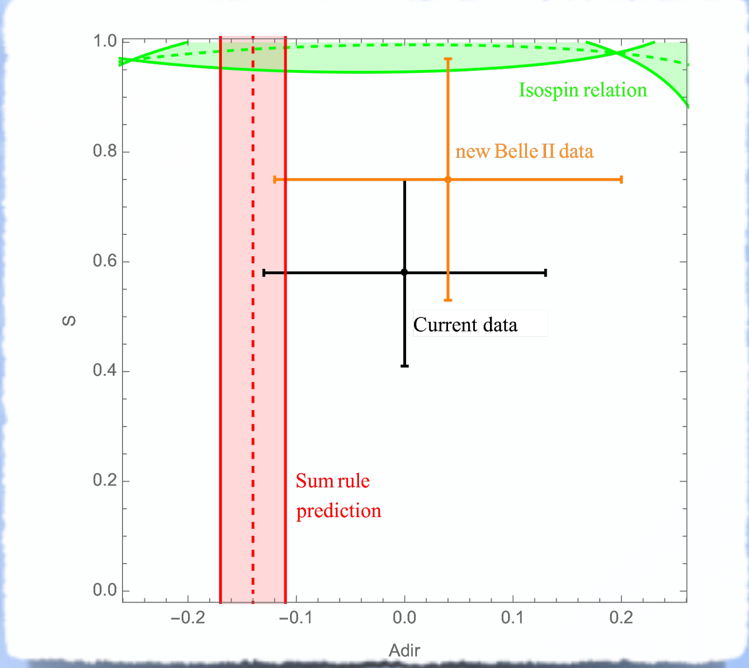

The $B_s \to KK$ System

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Zooming into CP violation in $B_{(s)} \to hh$ decays

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Decays differ only via spectator quark

-Thus, unlikely that it is New Physics
-Same quark level transition entering

can be accommodated
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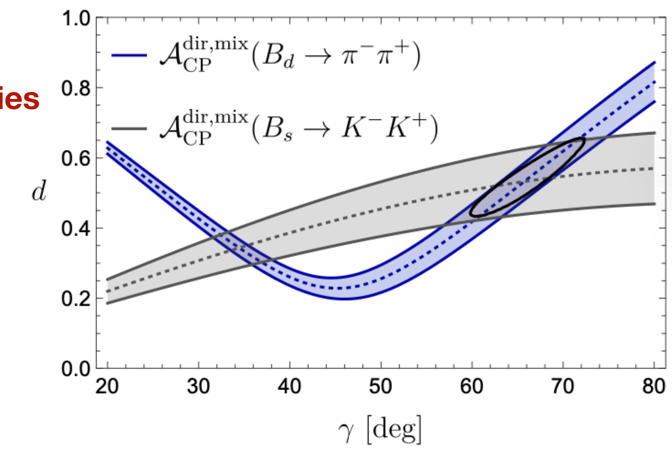
2 determination of the UT angle γ and the B_s^0–$\bar{B}_s^0$ mixing phase ϕ_s

•Only CP asymmetries
•No branching ratio information



$\gamma = (65^{+11}_{-7})^\circ$

Excellent agreement with γ from $B \to DK$

Figure 1: Determination of γ from the CP asymmetries of the $B_d \to \pi^-\pi^+$ and $B_s \to K^-K^+$ modes from the LHCb data in Table 2.

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Zooming into CP violation in $B_{(s)} \to hh$ decays

Robert Fleischer,[a,b] Ruben Jaarsma[a] and K. Keri Vos[a,c]

ABSTRACT: The LHCb collaboration has recently reported the first observation of CP violation in the penguin-dominated $B_s^0 \to K^-K^+$ decay and further new measurements, indicating differences between the direct CP asymmetries of both the $B_s^0 \to K^-K^+$, $B_d^0 \to \pi^-K^+$ and the $B_d^0 \to \pi^-\pi^+$, $B_s^0 \to K^-\pi^+$ modes. We show that these puzzling differences can be accommodated through sizeable penguin annihilation and exchange topologies in the Standard Model, and constrain them. Utilising the U-spin symmetry, we extract the angle γ of the unitarity triangle from the CP asymmetries in the $B_s^0 \to K^-K^+$, $B_d^0 \to \pi^-\pi^+$ system alone, finding $\gamma = (65^{+11}_{-7})^\circ$, in perfect agreement with the determination from tree-level $B \to DK$ decays. The B_s^0-$\bar{B}_s^0$ mixing phase ϕ_s can be extracted from CP violation measurements in $B_s^0 \to K^-K^+$ in a clean way. We present a new strategy and extract $\phi_s = -(3.6 \pm 5.4)^\circ$. This result is in agreement with the determination from $B_s^0 \to J/\psi\phi$ decays. New CP-violating contributions would influence these determinations differently. Hence it is interesting to keep monitoring both as the experimental picture sharpens.

The first observation of CP violation in $B_s^0 \to K^-K^+$ by the LHCb

1 pointed out a surprising difference in the direct CP asymmetries

$$\mathcal{A}_{\rm CP}^{\rm dir}(B_d^0 \to \pi^-\pi^+) - \mathcal{A}_{\rm CP}^{\rm dir}(B_s^0 \to K^-\pi^+) = -0.095 \pm 0.040$$
$$\mathcal{A}_{\rm CP}^{\rm dir}(B_s^0 \to K^-K^+) - \mathcal{A}_{\rm CP}^{\rm dir}(B_d^0 \to \pi^-K^+) = 0.089 \pm 0.031$$

Decays differ only via spectator quark

-Thus, unlikely that it is New Physics
-Same quark level transition entering

can be accommodated
through exchange and penguin-annihilation topologies at the level of 20%.

2 determination of the UT angle γ and the B_s^0–$\bar{B}_s^0$ mixing phase ϕ_s

•Only CP asymmetries
•No branching ratio information

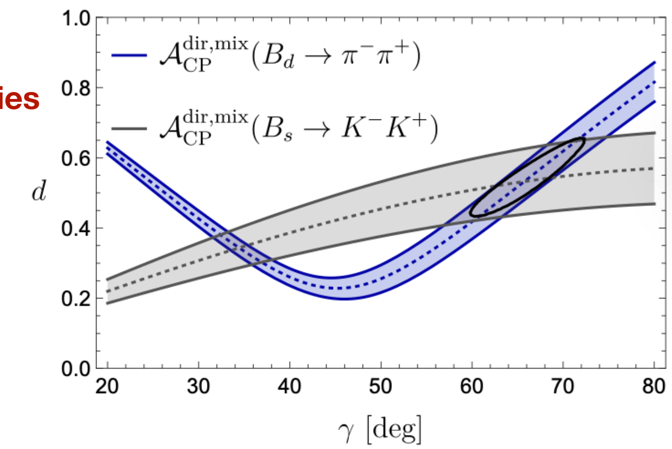

Figure 1: Determination of γ from the CP asymmetries of the $B_d \to \pi^-\pi^+$ and $B_s \to K^-K^+$ modes from the LHCb data in Table 2.

$\gamma = (65^{+11}_{-7})^\circ$

Excellent agreement with γ from $B \to DK$

3 ϕ_s can be obtained clean way
using semileptonic B_s^0 and B_d^0 differential rates

$$R_\pi \equiv \frac{\Gamma(B_d^0 \to \pi^-\pi^+)}{|d\Gamma(B_d^0 \to \pi^-\ell^+\nu_\ell)/dq^2|_{q^2=m_\pi^2}}$$

$$R_K \equiv \frac{\Gamma(B_s^0 \to K^-K^+)_{\rm theo}}{|d\Gamma(B_s^0 \to K^-\ell^+\nu_\ell)/dq^2|_{q^2=m_K^2}}$$

$B_s^0 \to K^-\ell^+\nu_\ell$ rate is not yet available
replace by the $B_d^0 \to \pi^-\ell^+\nu_\ell$ rate

$\phi_s = -(3.6 \pm 5.4)^\circ$

Decays with Different Dynamics

$B_s \to D_s^{\pm} K^{\mp}$ and related modes

pure tree decays

$B_d \to J/\psi K_S\,, \quad B_s \to J/\psi \phi$

dominated by trees but
also penguin contamination

Intermezzo

$B \to \pi K,\ B \to K^+ K^-$

dominated by penguins

Rare Decays

$B \to \mu\mu,\ B \to K\ell\ell$

from EW penguins
and box topologies

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The Unitarity Triangle

$B \to \pi K, \; B \to K^+ K^-$

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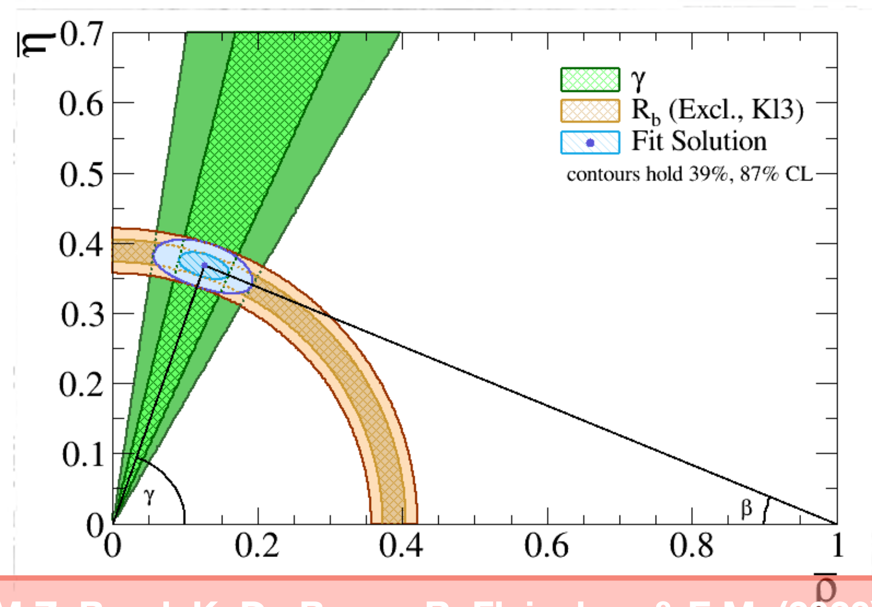

[M.Z. Barel, K. De Bruyn, R. Fleischer, & E.M. (2020)]

$$\bar{\rho} \equiv \left(1 - \frac{\lambda^2}{2}\right)\rho$$

$$\bar{\eta} \equiv \left(1 - \frac{\lambda^2}{2}\right)\eta$$

$$R_b\, e^{i\gamma} = \bar{\rho} + i\bar{\eta}$$

$B \to$

dom

$\to$ $K\ell\ell$

penguins
and box topologies

Unitarity Triangle Apex Determination

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- Utilising γ and R_b

Unitarity Triangle Apex Determination

Utilising γ and R_b

Decay-time-independent $B \to DK$

sensitivity to γ $\longrightarrow$ from direct CP violation

$$\gamma_{B\to DK} = (64.9^{+3.9}_{-4.5})^\circ$$

[LHCb Collaboration(2021)]

assume free from NP.

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Through interference effects with the $B_s^0 - \bar{B}_s^0$ mixing the CP asymmetry parameters allow determination of

$\phi_s + \gamma$ **Theoretically clean**

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[M.Z. Barel, K. De Bruyn, R. Fleischer, & E.M. (2020)]

$(-4.2 \pm 1.4)^\circ$

determined with $B_s^0 \to J/\psi\phi$

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[R. Fleischer and E.M. (2021)]

$$\gamma_{B_s\to D_sK} = \left(131^{+17}_{-22}\right)^\circ$$

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$\phi_d = (44.4^{+1.6}_{-1.5})^\circ$

penguin effects included

$\gamma_{\rm iso} = (72.6^{+4.3}_{-4.9})^\circ$

possible NP at the amplitudes through penguin

Using ϕ_d the UT angle α is converted into γ

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$\lambda \equiv |V_{us}|, |V_{ub}|$ and $|V_{cb}|$

$|V_{us}| = 0.22309 \pm 0.00056$

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$|V_{us}| = 0.22309 \pm 0.00056$

HFLAV(2022), arXiv:2107.00604 arXiv:0707.2493

3.9σ

$|V_{ub}|_{\rm incl} = (4.19 \pm 0.17) \times 10^{-3}$

$|V_{ub}|_{\rm excl} = (3.51 \pm 0.12) \times 10^{-3}$

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4.3σ

$|V_{cb}|_{\rm incl} = (42.16 \pm 0.50) \times 10^{-3}$

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We calculate the UT side R_b :

$$R_{b,\text{incl},K\ell3} = 0.434 \pm 0.018$$

$$R_{b,\text{excl},K\ell3} = 0.392 \pm 0.014$$

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Third possibility: hybrid combination of exclusive $|V_{ub}|$ with inclusive $|V_{cb}|$

$R_{b,{\rm hybrid},K\ell3} = 0.364 \pm 0.013$

3.7σ (incl vs hybrid)

1.5σ (excl vs hybrid)

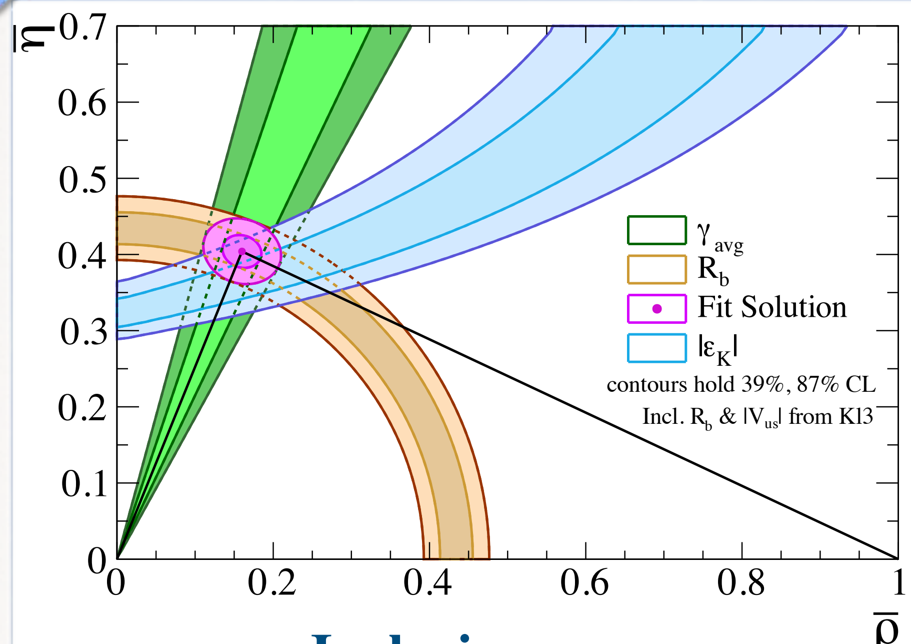
Unitarity Triangle Apex Determination

▶ Utilising γ and R_b

	Inclusive	Exclusive	Hybrid
α	$(85.2^{+4.8}_{-4.3})^\circ$		
ϕ_d	$(44.4^{+1.6}_{-1.5})^\circ$		
$\gamma_{B\to DK}$	$(64.9^{+3.9}_{-4.5})^\circ$		
$\gamma_{\rm iso}$	$(72.6^{+4.3}_{-4.9})^\circ$		
$\gamma_{\rm avg}$	$(68.4 \pm 3.3)^\circ$		
$\|V_{us}\|$	0.22309 ± 0.00056		
$\|V_{ub}\| \times 10^3$	4.19 ± 0.17	3.51 ± 0.12	3.51 ± 0.12
$\|V_{cb}\| \times 10^3$	42.16 ± 0.50	39.10 ± 0.50	42.16 ± 0.50
R_b	0.434 ± 0.018	0.392 ± 0.014	0.364 ± 0.013
$\bar\rho$	0.160 ± 0.025	0.144 ± 0.022	0.134 ± 0.021
$\bar\eta$	0.404 ± 0.022	0.365 ± 0.018	0.338 ± 0.017

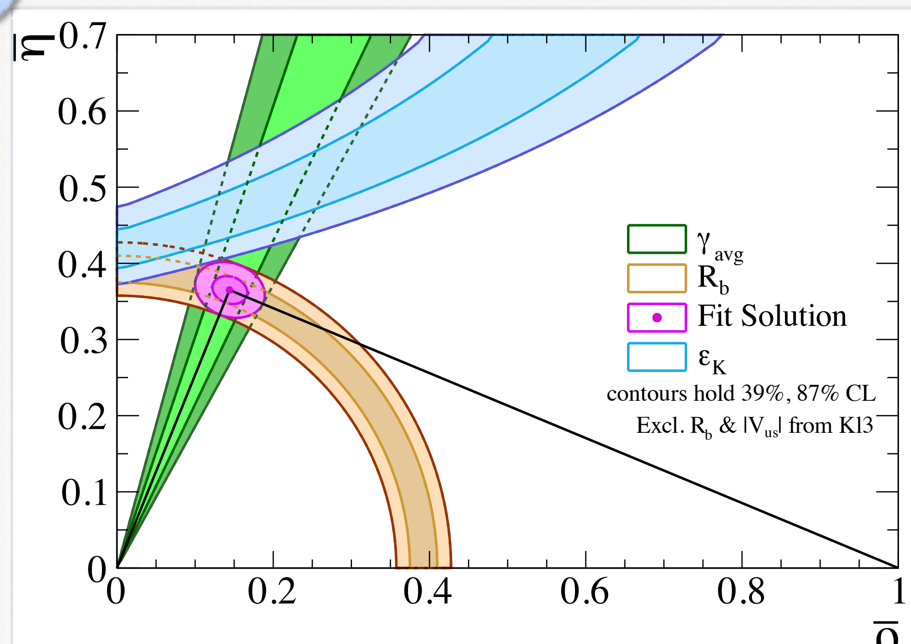
$$|\varepsilon_K| = \frac{G_{\rm F}^2 m_W^2 m_K f_K^2}{6\sqrt{2}\pi^2 \Delta m_K} \kappa_\varepsilon \hat{B}_K |V_{cb}|^2 \lambda^2 \bar\eta \left[|V_{cb}|^2 (1-\bar\rho)\, \eta_{tt}^{\rm EW} \eta_{tt}\, \mathcal{S}(x_t) - \eta_{ut}\, \mathcal{S}(x_c, x_t)\right]$$

arXiv:1911.06822

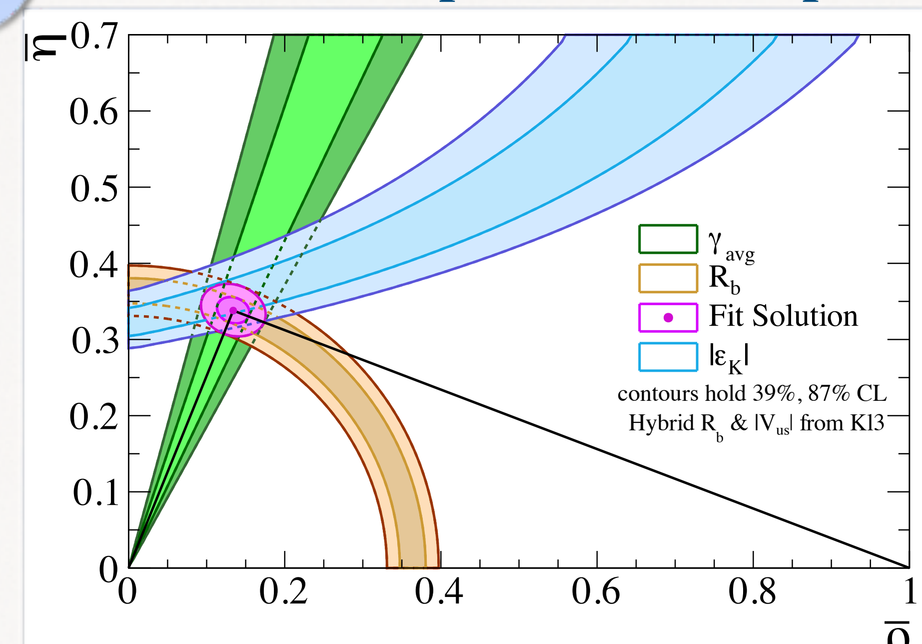


Inclusive case

Most consistent picture of UT apex



Exclusive case



Hybrid case

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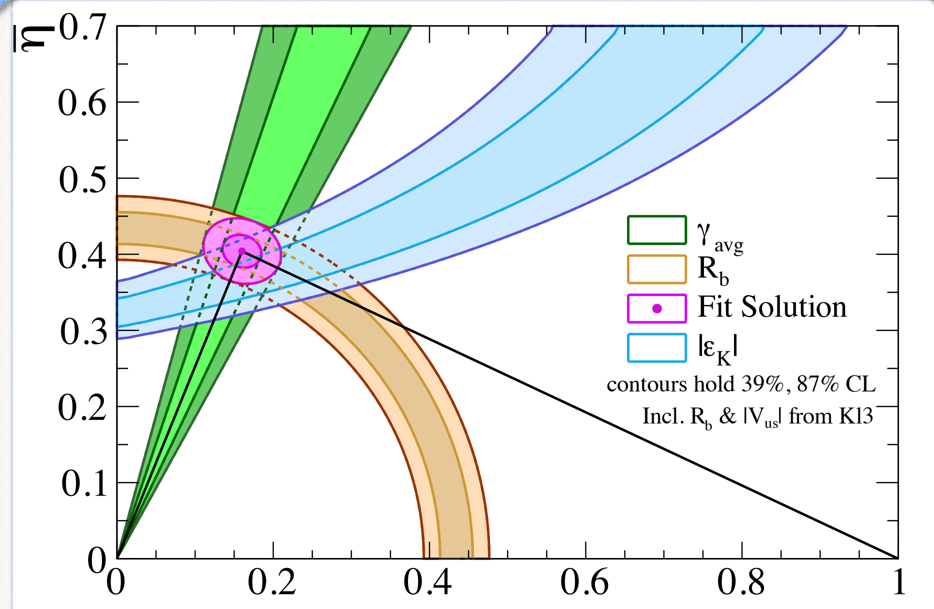
Utilising γ and R_b



Inclusive case

	Inclusive	Exclusive	Hybrid
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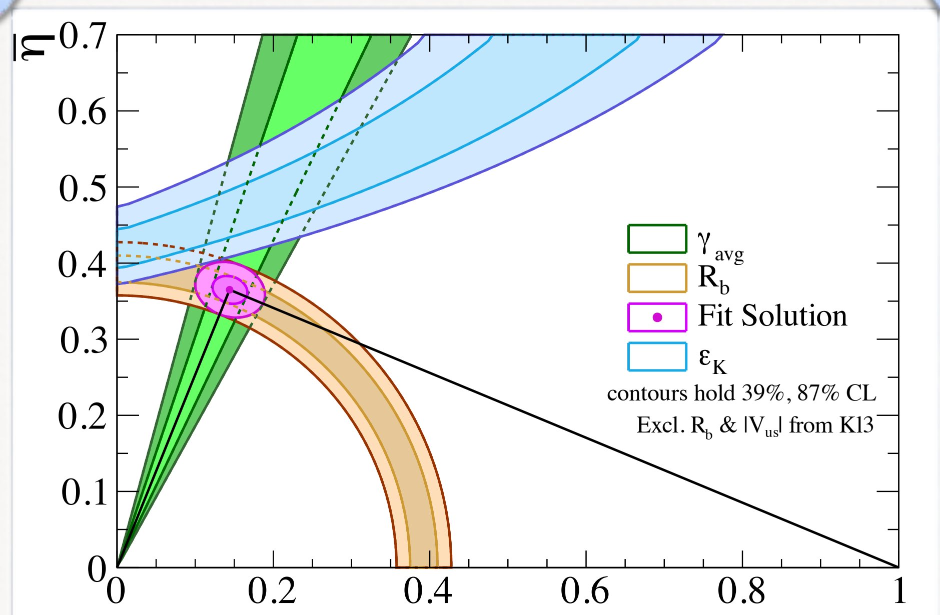
$\gamma_{\rm avg}$		$(68.4 \pm 3.3)^\circ$	
$\lvert V_{us}\rvert$		0.22309 ± 0.00056	
$\lvert V_{ub}\rvert \times 10^3$	4.19 ± 0.17	3.51 ± 0.12	3.51 ± 0.12
$\lvert V_{cb}\rvert \times 10^3$	42.16 ± 0.50	39.10 ± 0.50	42.16 ± 0.50
R_b	0.434 ± 0.018	0.392 ± 0.014	0.364 ± 0.013
$\bar{\rho}$	0.160 ± 0.025	0.144 ± 0.022	0.134 ± 0.021
$\bar{\eta}$	0.404 ± 0.022	0.365 ± 0.018	0.338 ± 0.017

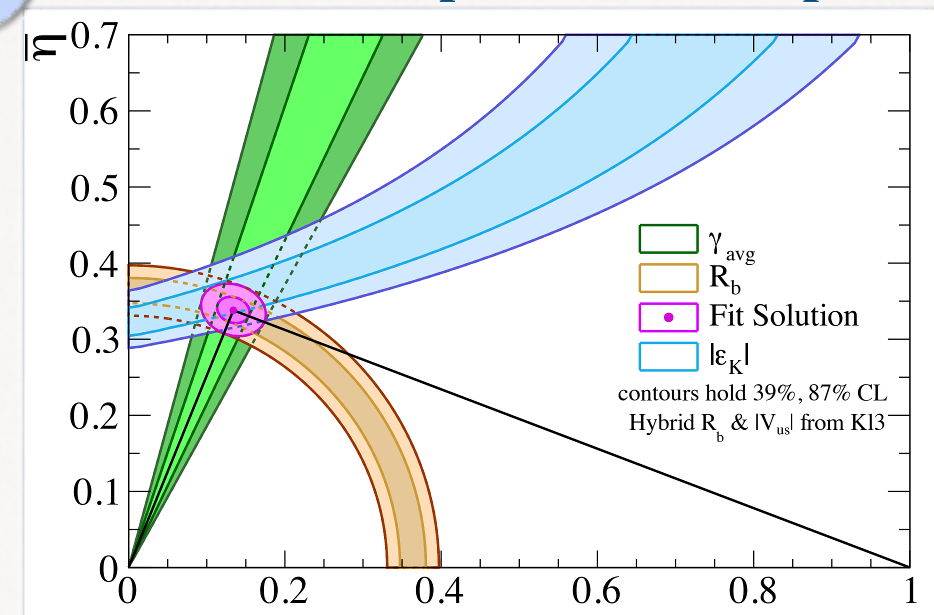
$$|\varepsilon_K| = \frac{G_F^2 m_W^2 m_K f_K^2}{6\sqrt{2}\pi^2 \Delta m_K} \kappa_\varepsilon \hat{B}_K |V_{cb}|^2 \lambda^2 \bar{\eta} \left[|V_{cb}|^2 (1-\bar{\rho})\, \eta_{tt}^{\rm EW} \eta_{tt}\, \mathcal{S}(x_t) - \eta_{ut}\, \mathcal{S}(x_c, x_t) \right]$$

arXiv:1911.06822



Exclusive case

Most consistent picture of UT apex



Hybrid case

Unitarity Triangle Apex Determination

▶ Utilising γ and R_b

	Inclusive	Exclusive	Hybrid
α		$(85.2^{+4.8}_{-4.3})^\circ$	
ϕ_d		$(44.4^{+1.6}_{-1.5})^\circ$	
$\gamma_{B\to DK}$		$(64.9^{+3.9}_{-4.5})^\circ$	
$\gamma_{\rm iso}$		$(72.6^{+4.3}_{-4.9})^\circ$	
$\gamma_{\rm avg}$		$(68.4 \pm 3.3)^\circ$	
$\|V_{us}\|$		0.22309 ± 0.00056	
$\|V_{ub}\| \times 10^3$	4.19 ± 0.17	3.51 ± 0.12	3.51 ± 0.12
$\|V_{cb}\| \times 10^3$	42.16 ± 0.50	39.10 ± 0.50	42.16 ± 0.50
R_b	0.434 ± 0.018	0.392 ± 0.014	0.364 ± 0.013
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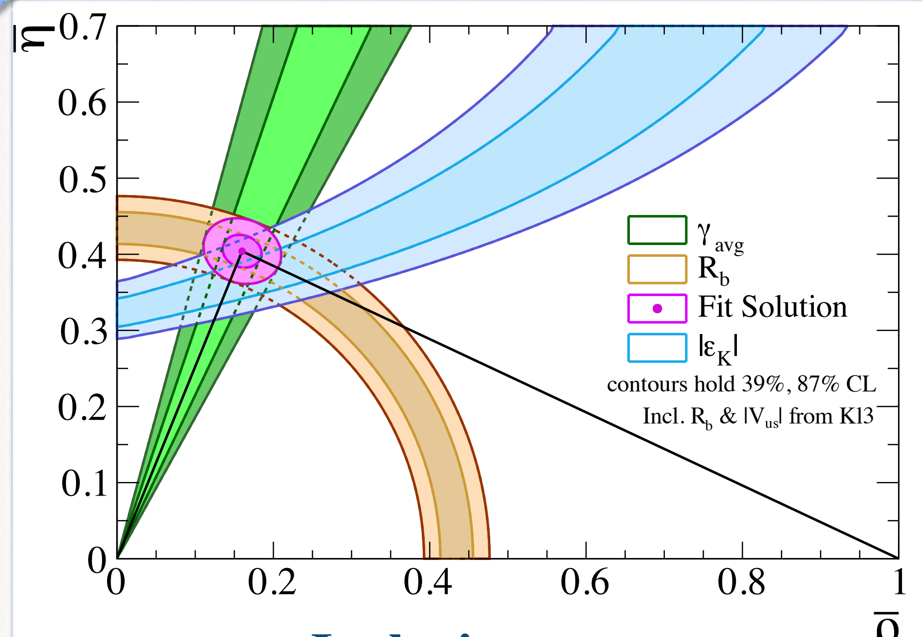
$\bar\eta$	0.404 ± 0.022	0.365 ± 0.018	0.338 ± 0.017

$|\varepsilon_K| = \ldots \eta_{ut}\, \mathcal{S}(x_c, x_t)]$

arXiv:1911.06822

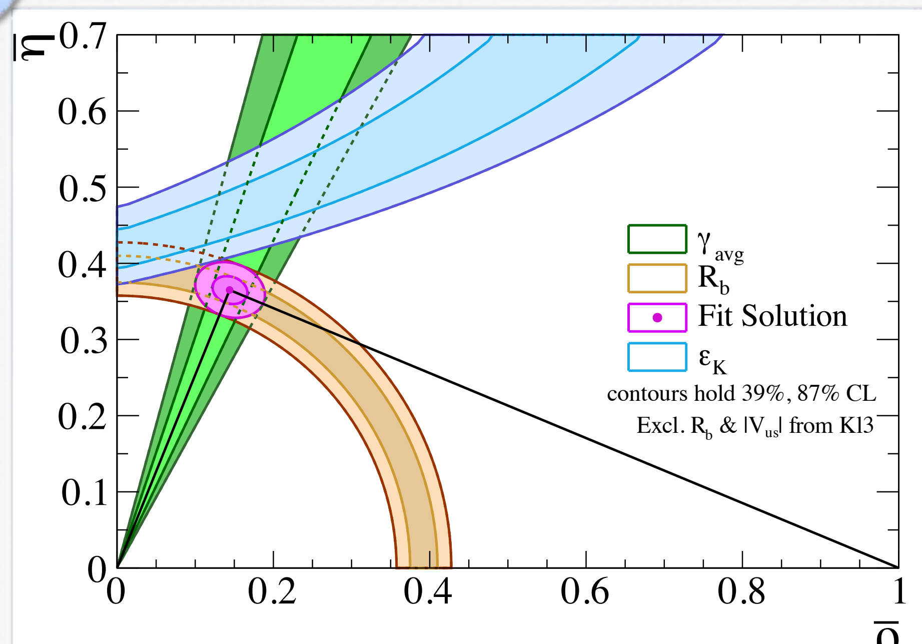
Strong dependence of value of $|V_{cb}|$

In the future: it could help to understand the inclusive-exclusive puzzle, if NP in kaon can be controlled/ignored



Inclusive case

Most consistent picture of UT apex



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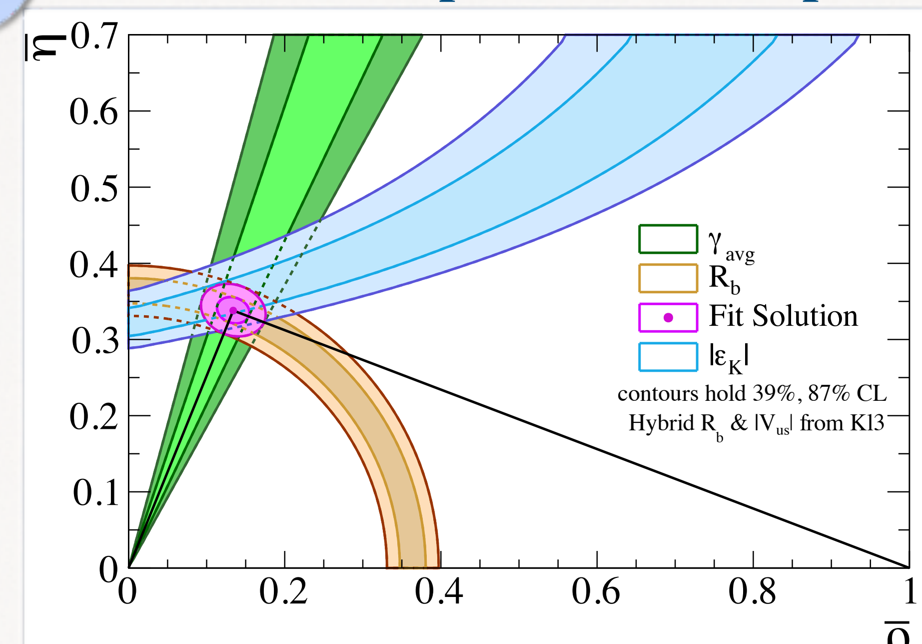

Hybrid case

Exploring the $\varkappa_q$-σ_q correlations

size of the NP effects is described by κ_q

σ_q is a complex phase for additional CP-violating effects

Exploring the $\varkappa_q$-σ_q correlations

We can study different NP scenarios

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Scenario I

No NP in γ

UT apex fit
R_b and γ

→

determine (κ_d, σ_d) and (κ_s, σ_s)
independently from each other

Exploring the $\varkappa_q$-σ_q correlations

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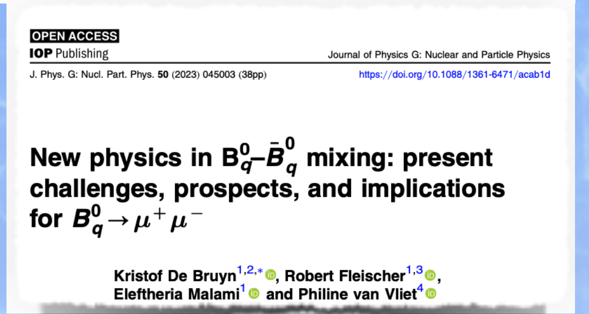

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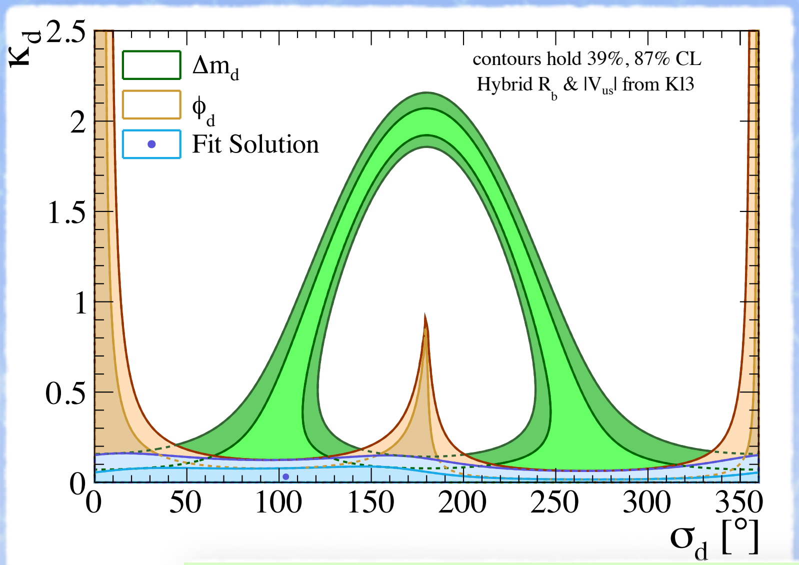

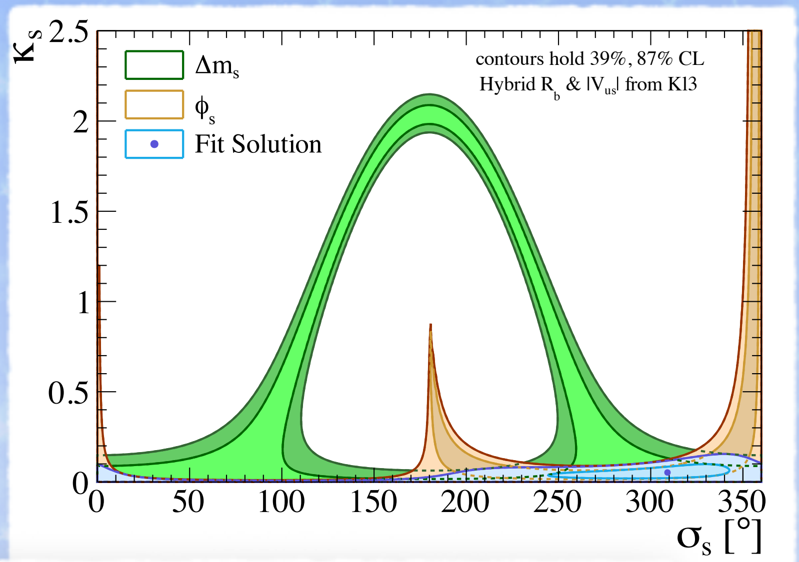

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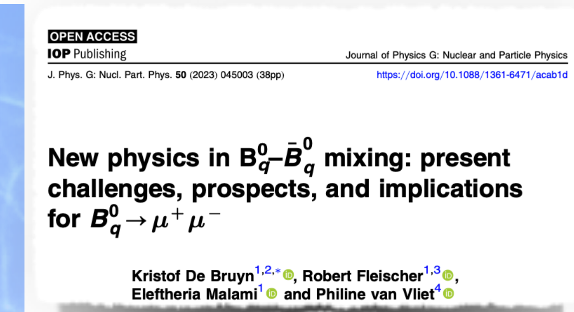
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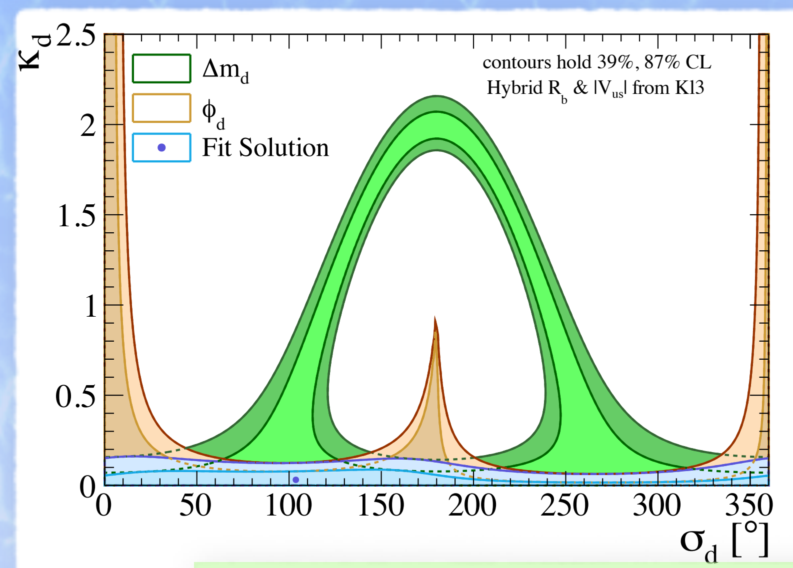

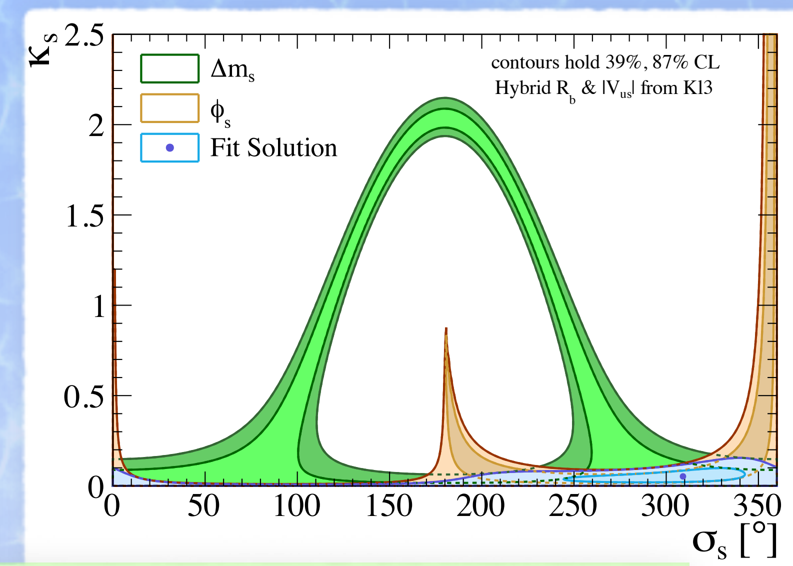

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Scenario II

FUNP

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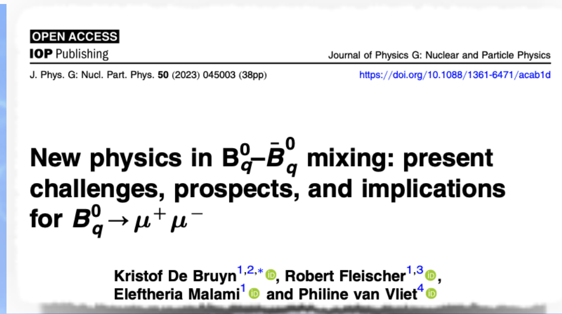
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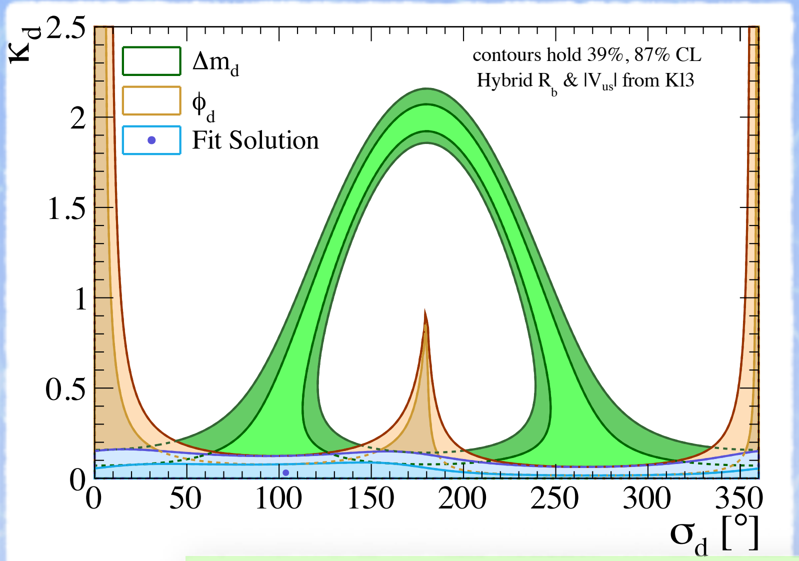

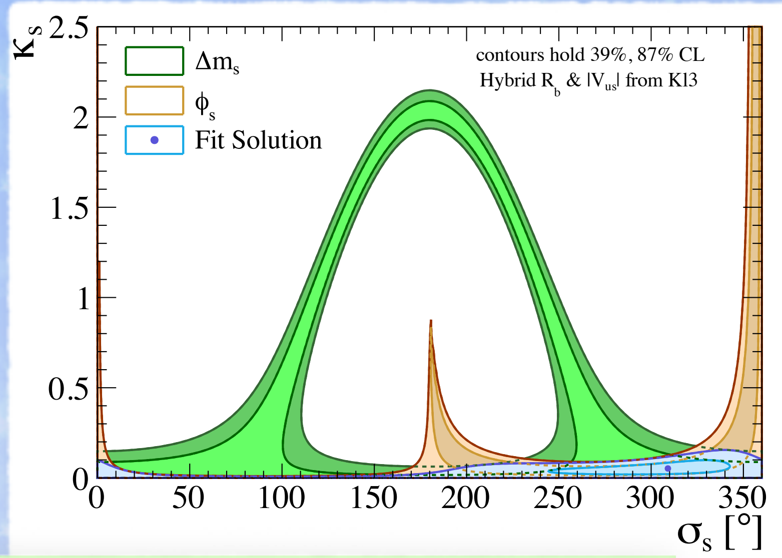

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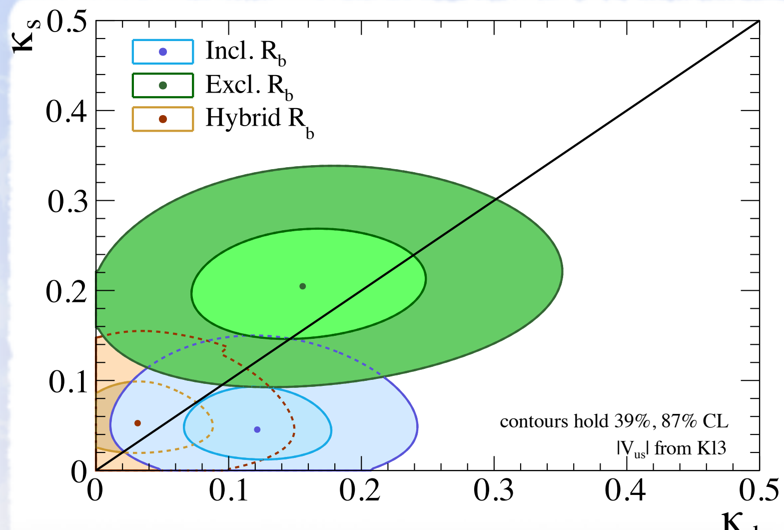

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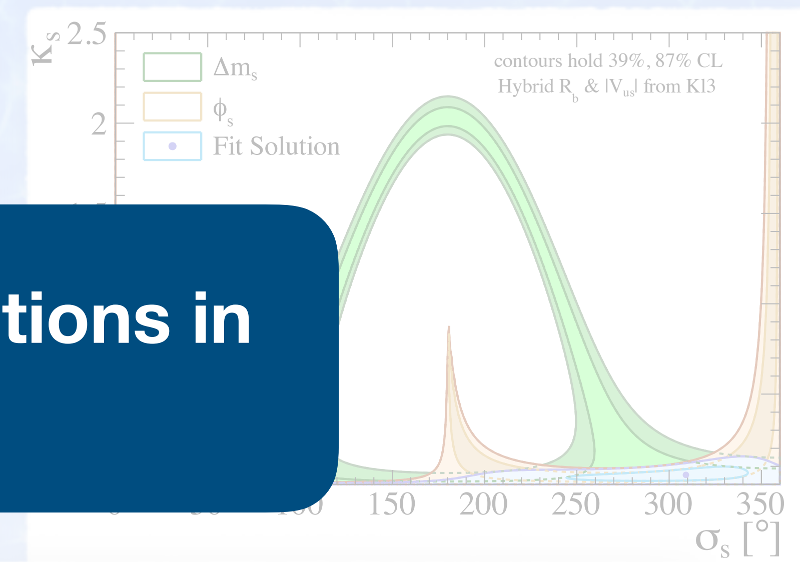

These results have interesting applications in rare leptonic decays

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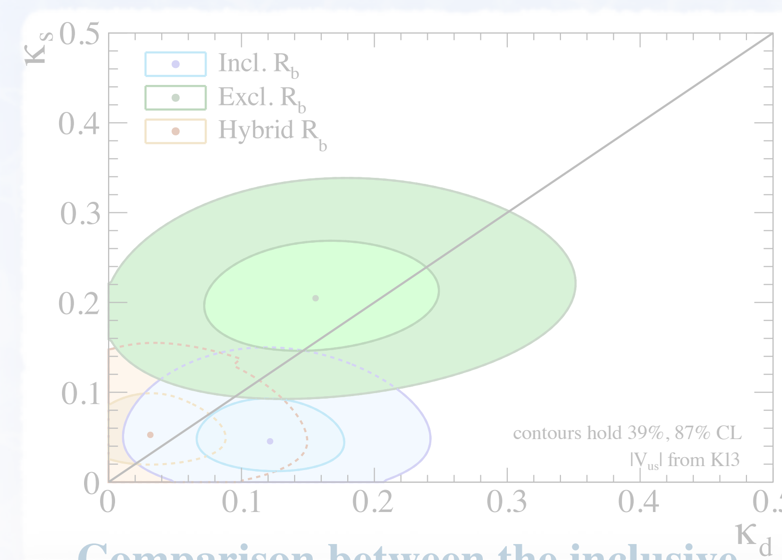

Comparison between the inclusive, exclusive and hybrid scenarios

Decays with Different Dynamics

$B_s \to D_s^{\pm} K^{\mp}$ and related modes

pure tree decays

$B_d \to J/\psi K_S$, $B_s \to J/\psi \phi$

dominated by trees but also penguin contamination

CP Violation in different manifestations

$B \to \pi K$, $B \to K^+ K^-$

dominated by penguins

Rare Decays

$B \to \mu\mu$, $B \to K\ell\ell$

from EW penguins and box topologies

Applications on Leptonic Decays

Applications on Leptonic Decays

Determining NP in $B_s^0 \to \mu^+\mu^-$

we can minimise the impact of the CKM parameters

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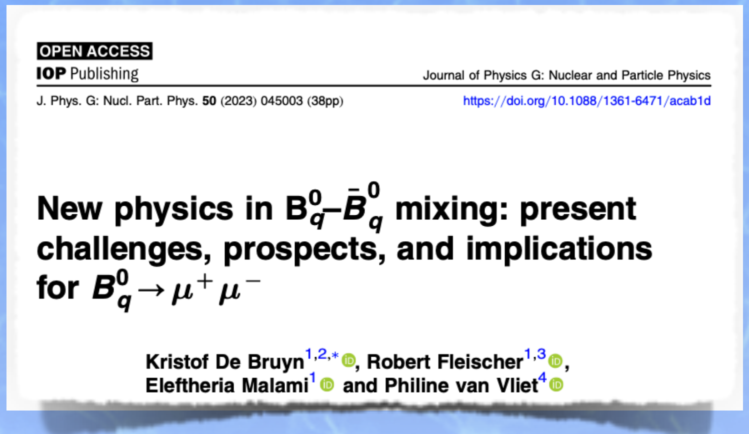
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How?

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How?

NP can modify its branching ratio

(Pseudo-)Scalar — $B_s^0 - \bar{B}_s^0$ **mixing**

create the ratio →

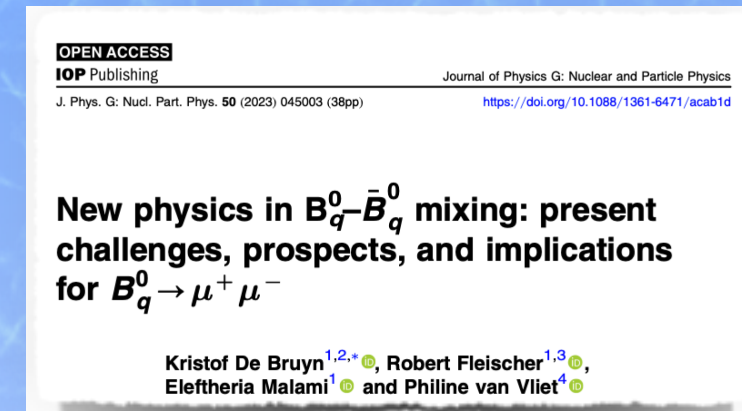
$$\mathcal{R}_{s\mu} \equiv \left|\frac{\bar{\mathcal{B}}(B_s \to \mu^+\mu^-)}{\Delta m_s}\right|$$

arXiv:hep-ph/0303060
arXiv:2104.09521
arXiv:2109.11032

↓

CKM elements drop out in the SM ratio

Applications on Leptonic Decays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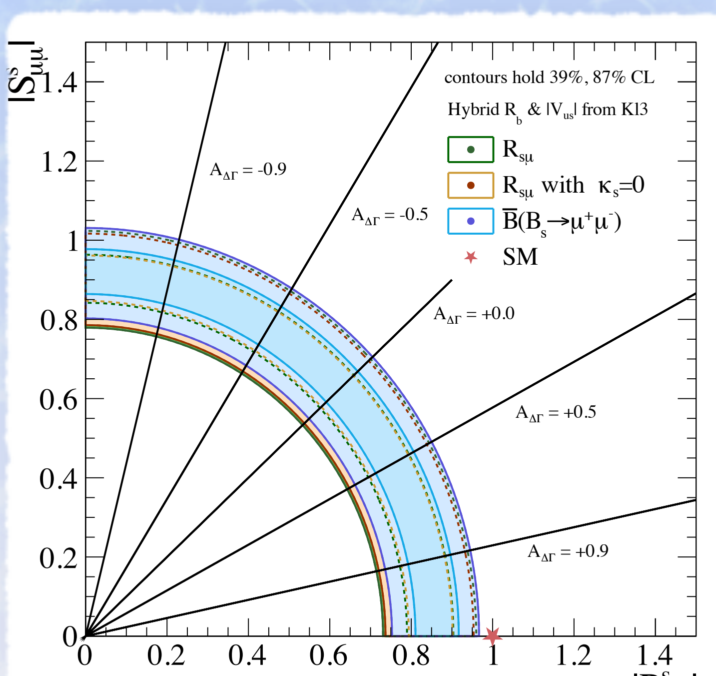
CKM elements drop out in the SM ratio

we can constrain the parameters $|P_{\mu\mu}^s|$ and $|S_{\mu\mu}^s|$ from $\mathcal{B}(B_s \to \mu^+\mu^-)$ and $R_{s\mu}$



Hybrid

Rare Leptonic and Semileptonic Decays

- These rare decays have interesting phenomenology related to CP violation
- Time dependent CP asymmetries have similar structure as the non-leptonic decays

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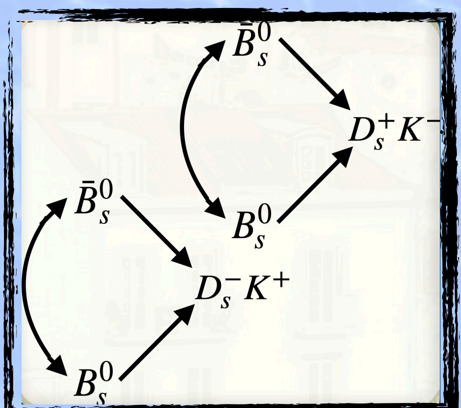
CP-violating rate asymmetry which is generated through the interference between B^0_s–$\bar{B}^0_s$ mixing and decay processes

↓

It would be very interesting to measure this observable



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In pursuit of new physics with $B^0_{s,d} \to \ell^+\ell^-$

Robert Fleischer,[a,b] Ruben Jaarsma[a] and Gilberto Tetlalmatzi-Xolocotzi[a]

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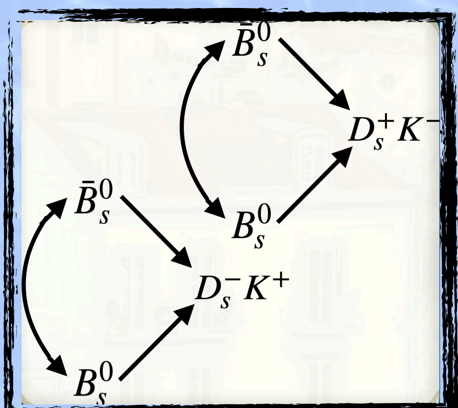

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2 $B \to K\mu^+\mu^-$

$B^0_d \to K_S\mu^+\mu^-$ channel these interference effects are present leading to mixing-induced CP violation

$$\frac{\Gamma(B^0_q(t)\to f)-\Gamma(\bar{B}^0_q(t)\to f)}{\Gamma(B^0_q(t)\to f)+\Gamma(\bar{B}^0_q(t)\to f)} = \frac{\mathcal{C}\cos(\Delta M t)+\mathcal{S}\sin(\Delta M t)}{\cosh\left(\frac{\Delta\Gamma_q}{2}t\right)+\mathcal{A}_{\Delta\Gamma}\sinh\left(\frac{\Delta\Gamma_q}{2}t\right)}$$

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Fingerprinting CP-violating New Physics with $B \to K\mu^+\mu^-$

Robert Fleischer,[a,b] Eleftheria Malami,[a,c] Anders Rehult[a] and K. Keri Vos[a,d]

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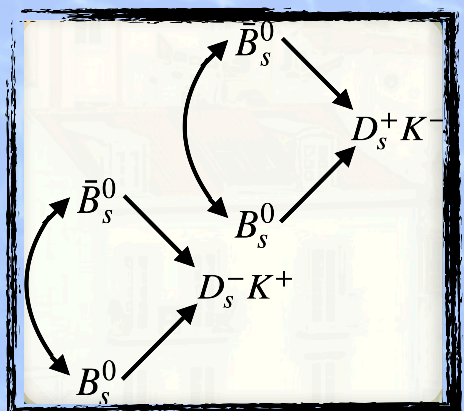

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In pursuit of new physics with $B^0_{s,d} \to \ell^+\ell^-$

Robert Fleischer,[a,b] Ruben Jaarsma[a] and Gilberto Tetlalmatzi-Xolocotzi[a]

experimentally challenging to measure

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$B^0_d \to K_S\mu^+\mu^-$ channel these interference effects are present leading to mixing-induced CP violation

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Fingerprinting CP-violating New Physics with $B \to K\mu^+\mu^-$

Robert Fleischer,[a,b] Eleftheria Malami,[a,c] Anders Rehult[a] and K. Keri Vos[a,d]

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- These rare decays have interesting phenomenology related to CP violation
- Time dependent CP asymmetries have similar structure as the non-leptonic decays

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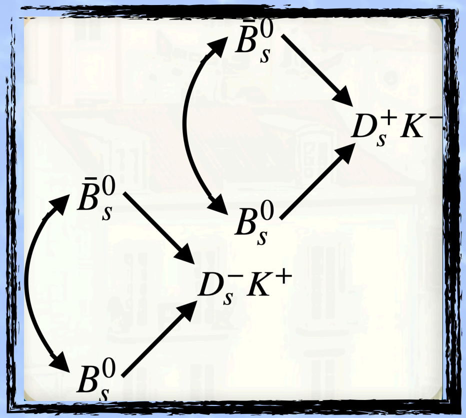

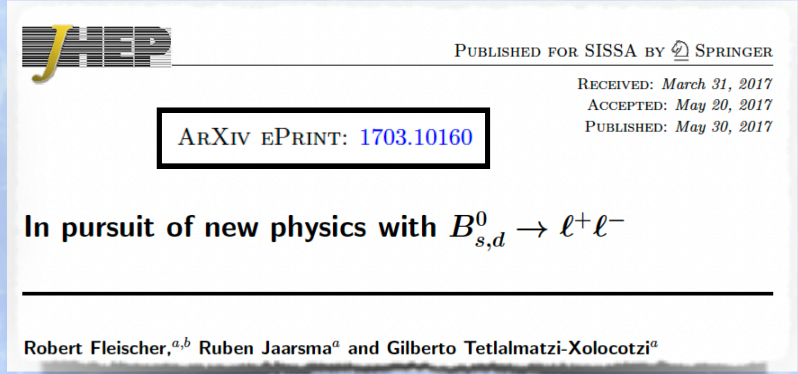

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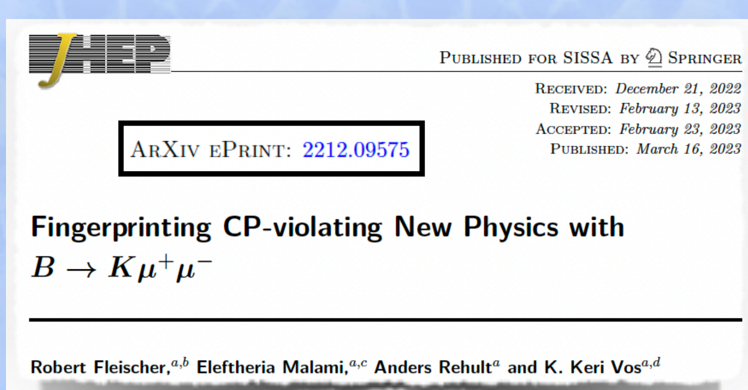

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Measurement of lepton universality parameters in $B^+ \to K^+\ell^+\ell^-$ and $B^0 \to K^{*0}\ell^+\ell^-$ decays

LHCb collaboration

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Submitted to Phys. Rev. D

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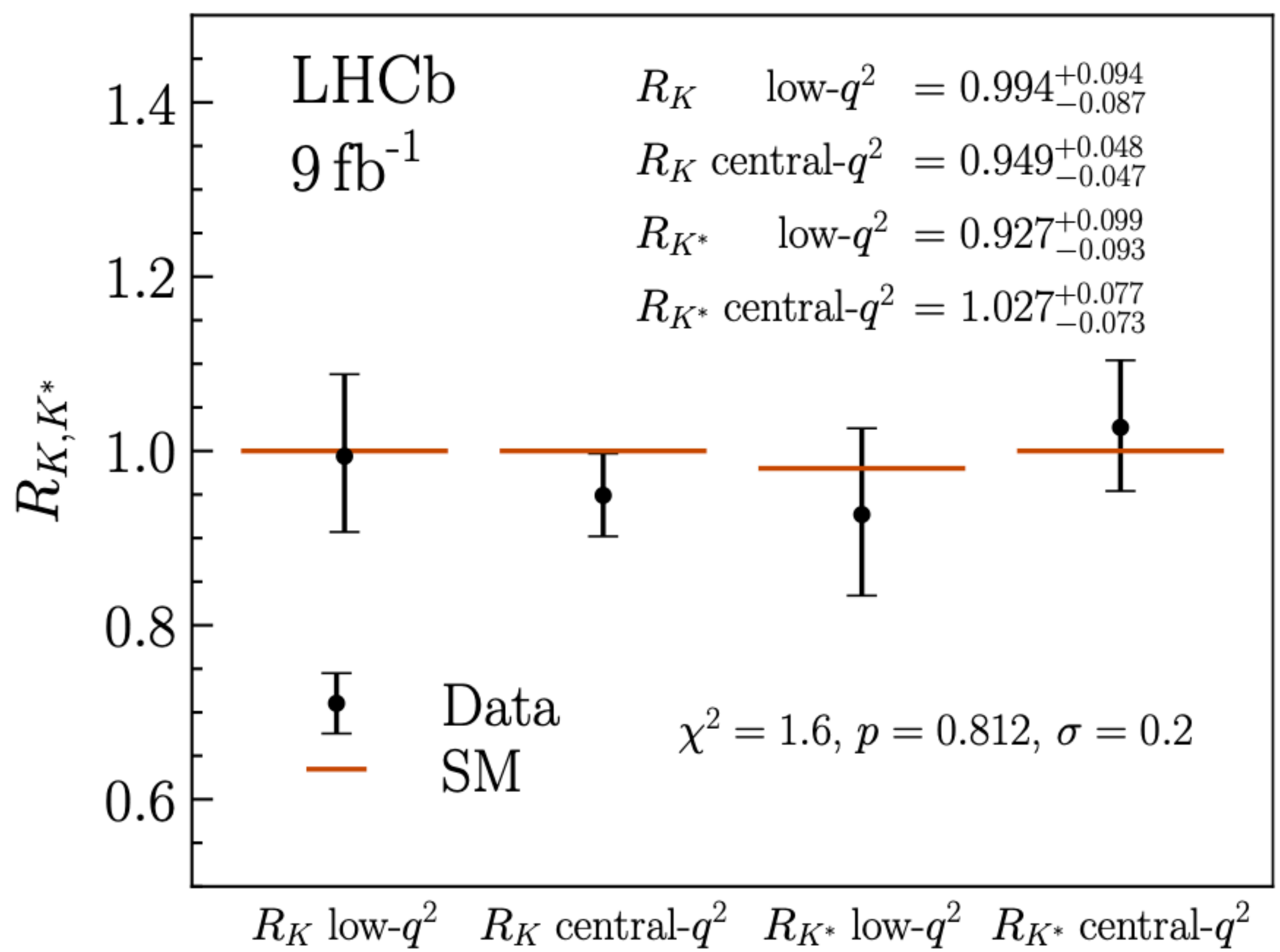

Figure 28: Measured values of LU observables in $B^+ \to K^+\ell^+\ell^-$ and $B^0 \to K^{*0}\ell^+\ell^-$ decays and their overall compatibility with the SM.

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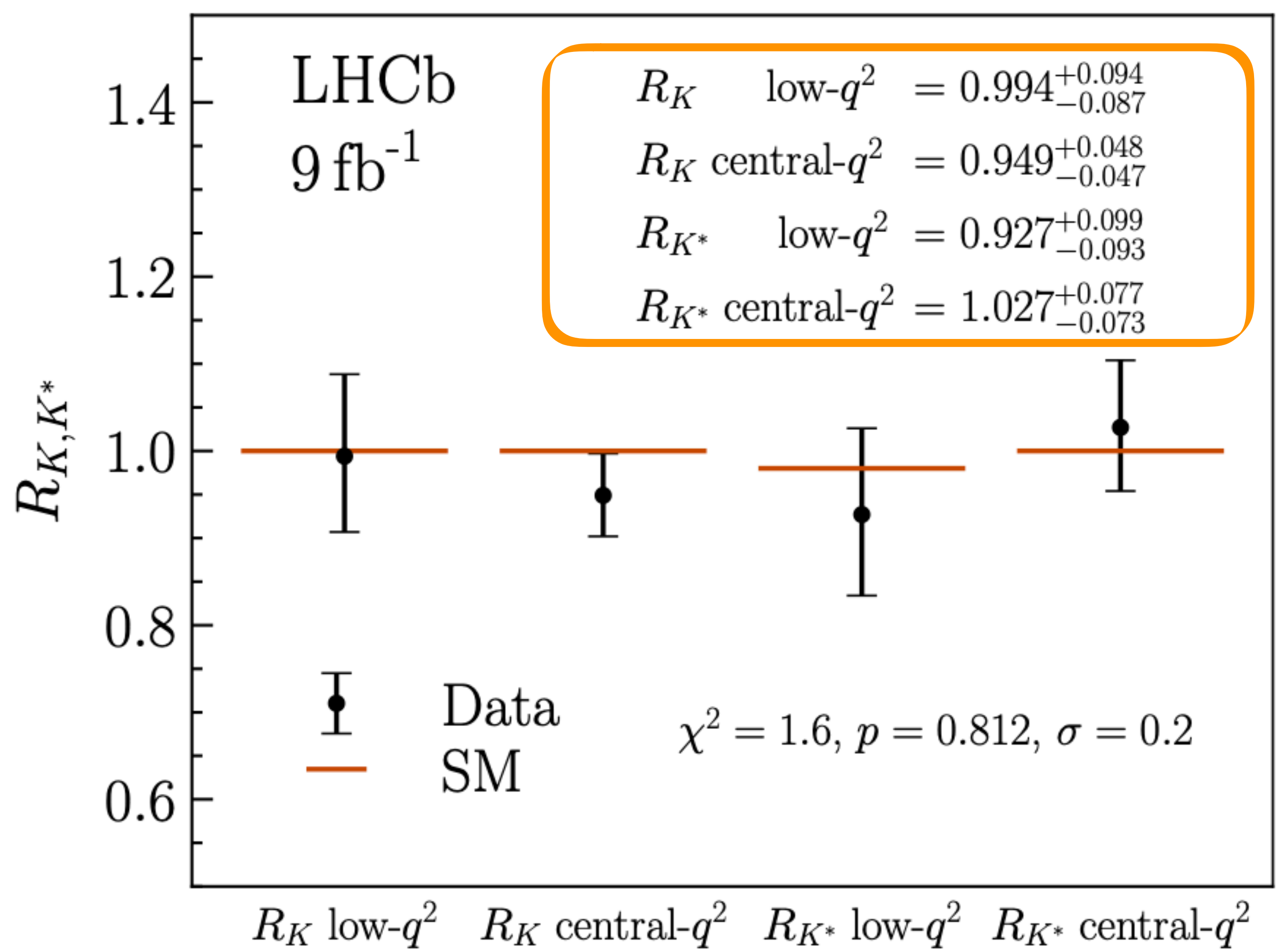

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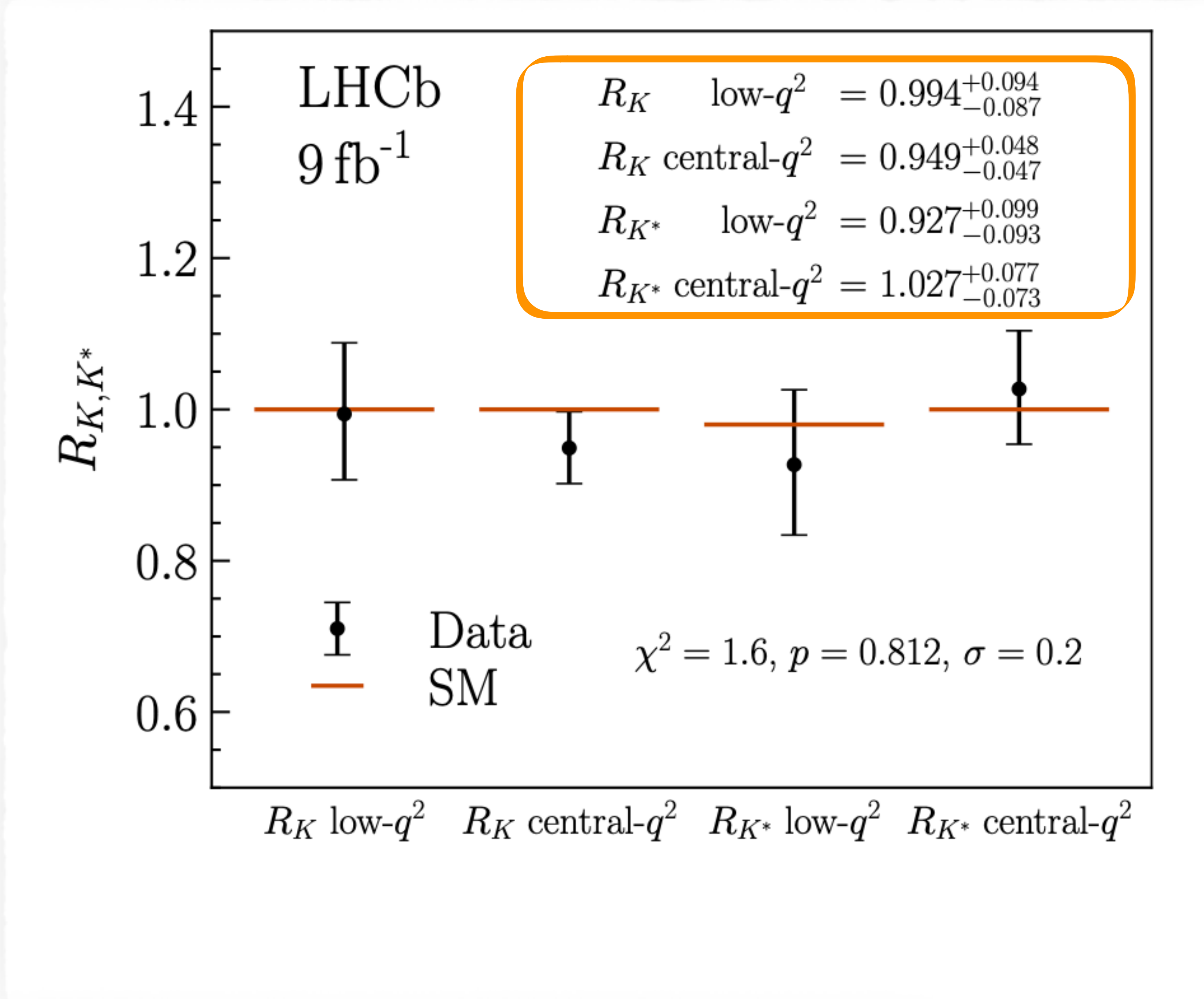

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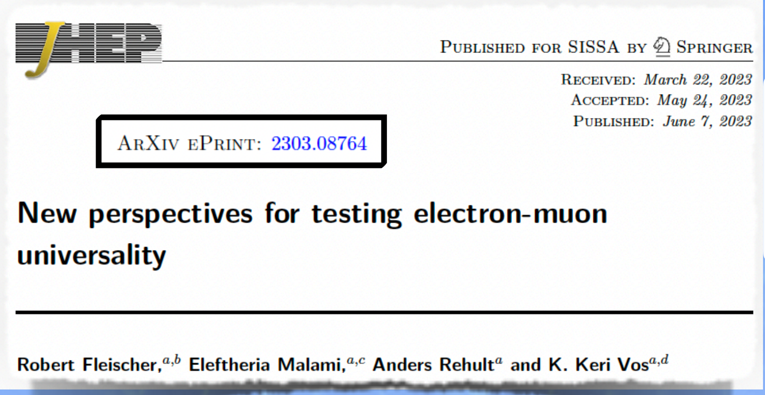
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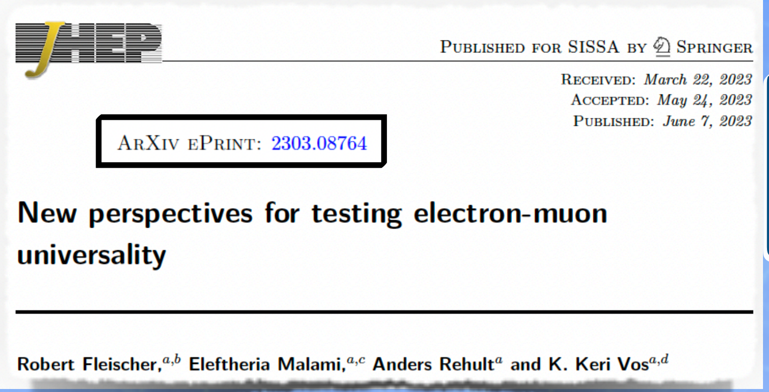
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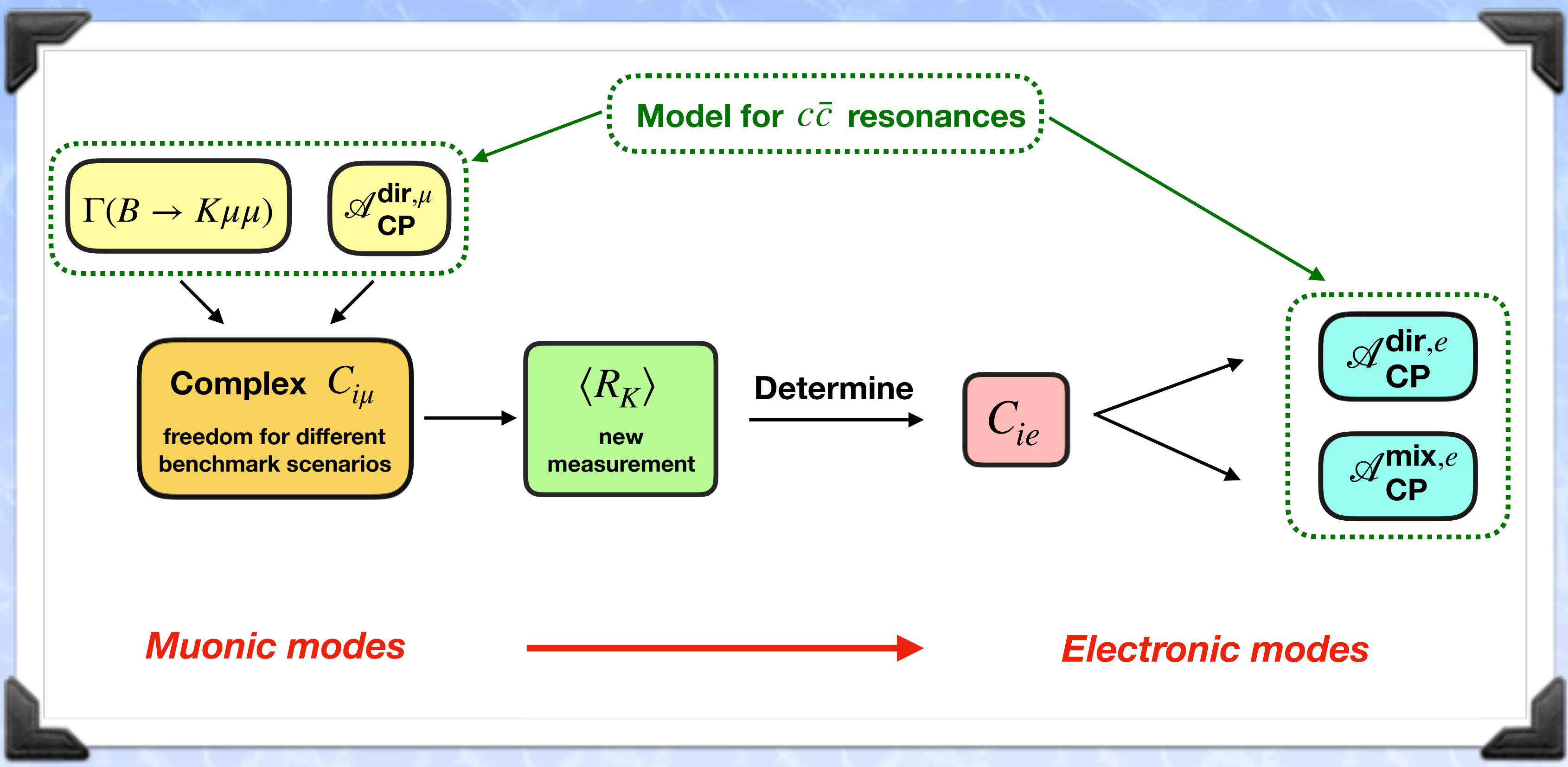

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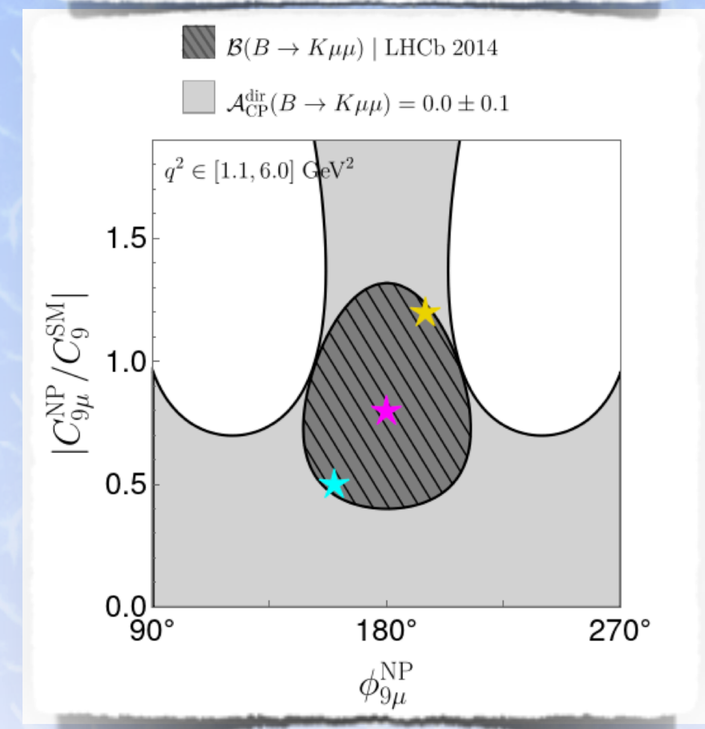

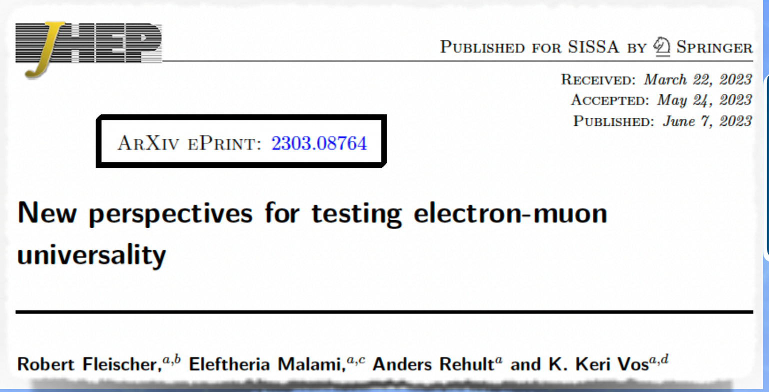
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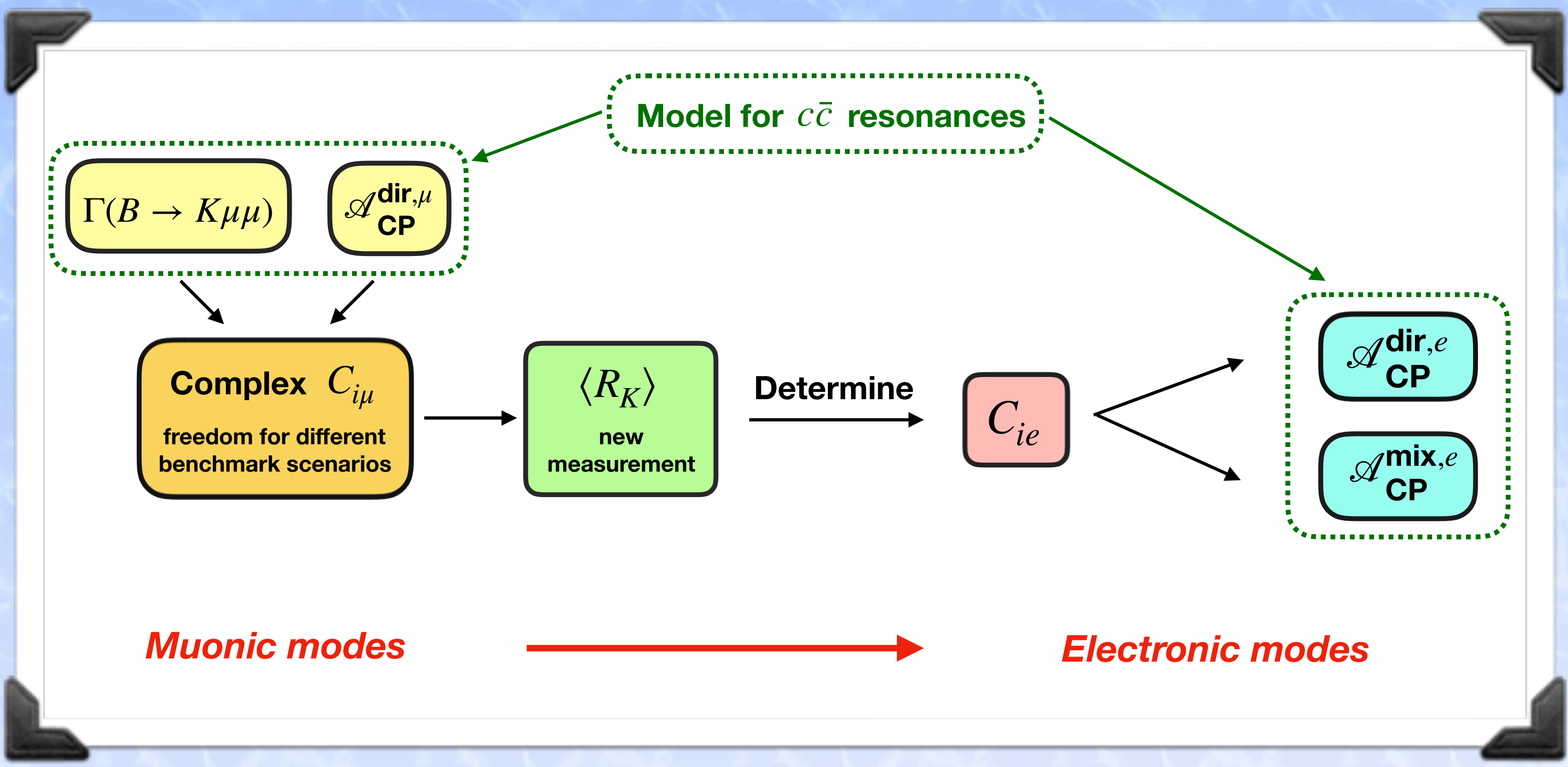

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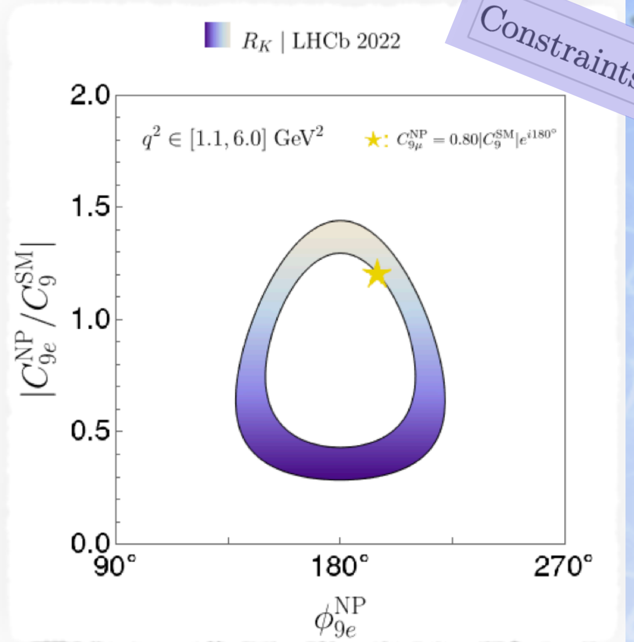

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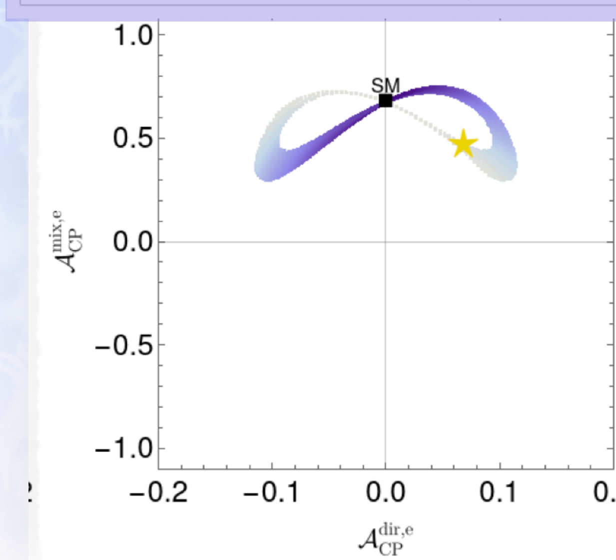

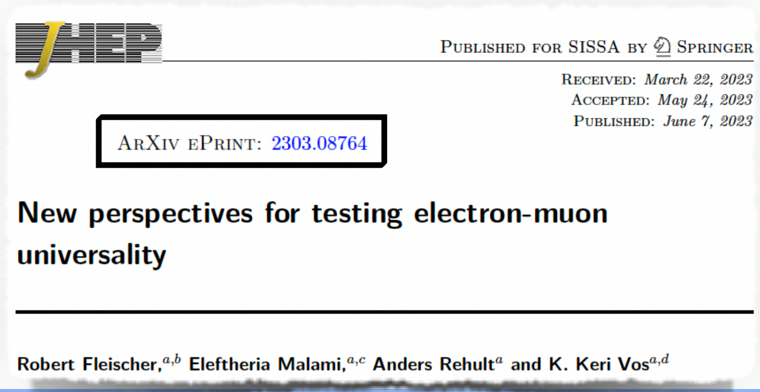
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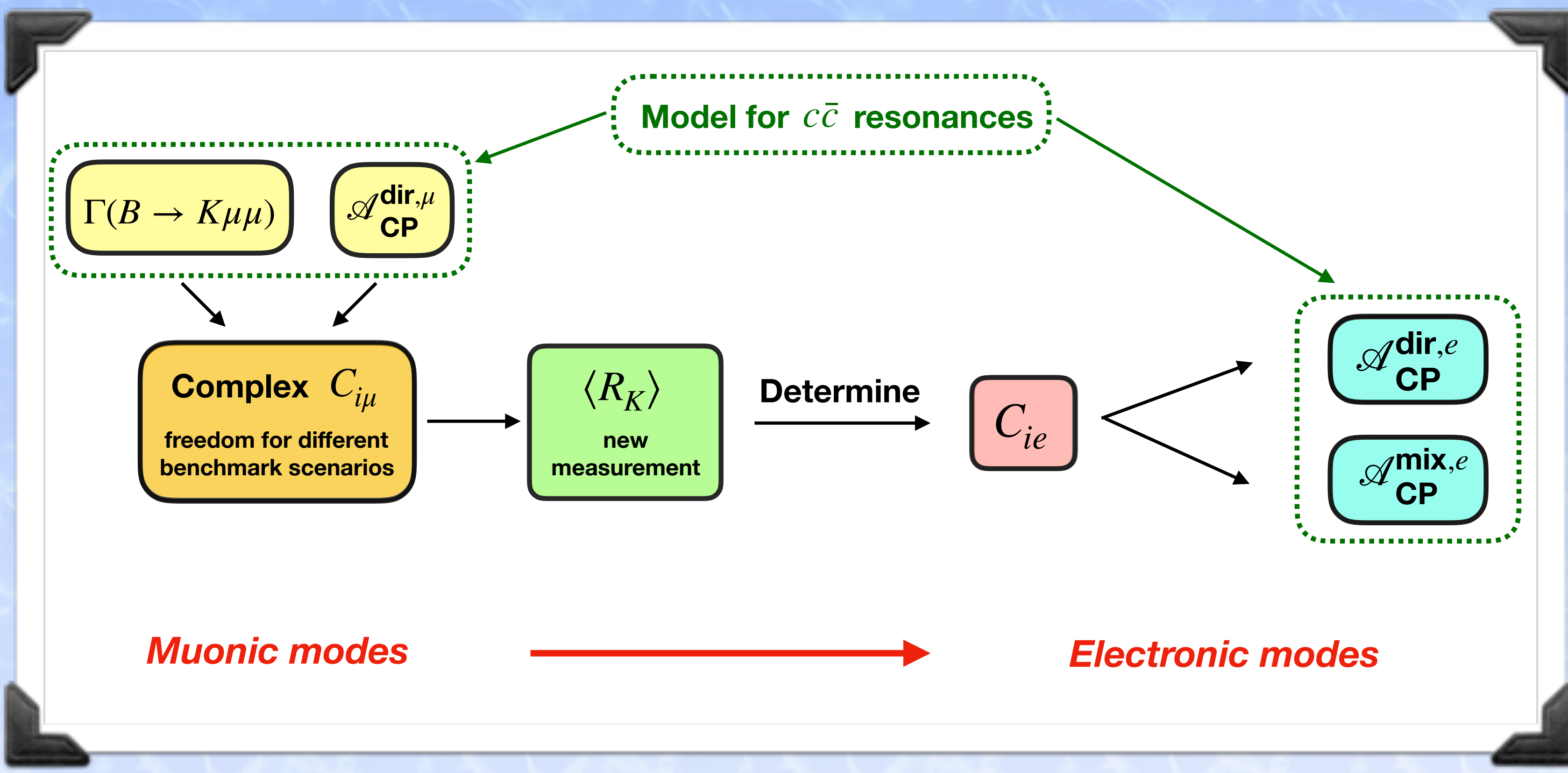

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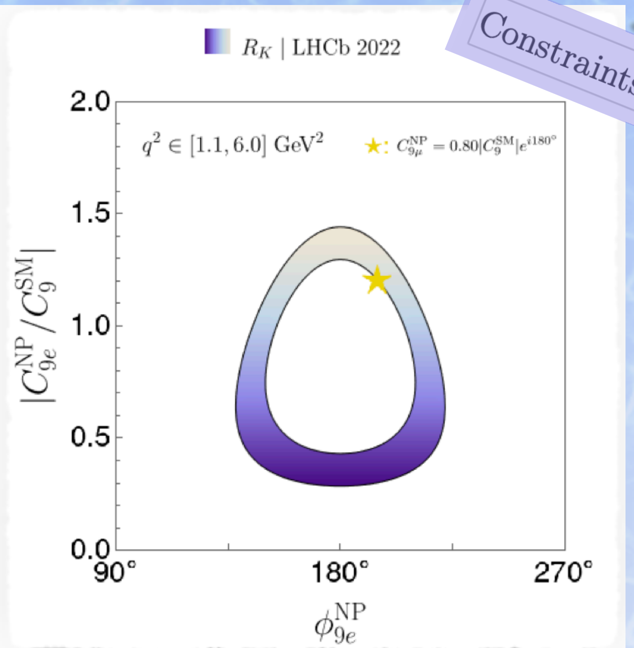

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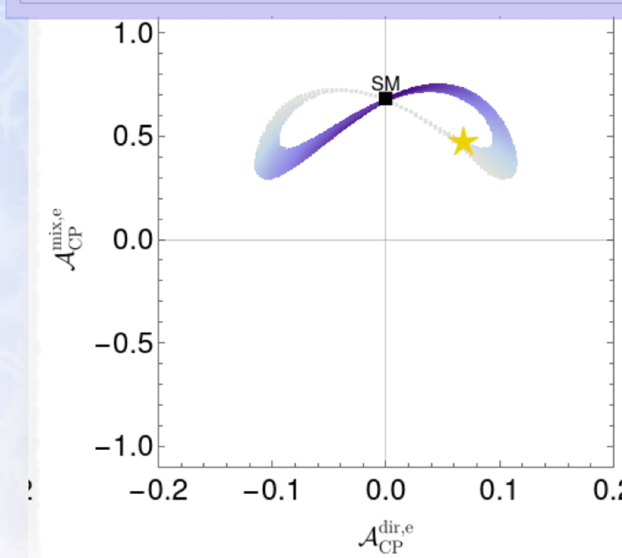

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Message to take home...

$B_s \to D_s^{\pm} K^{\mp}$ and related modes

$B_d \to J/\psi K_S \quad B_s \to J/\psi \phi$

CP Violation in different manifestations

$B \to \pi K, \; B \to K^+ K^-$

Rare Decays

$B \to \mu\mu, \; B \to K\ell\ell$

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CP violation continues to be a key player for exploring the flavour sector and New Physics searches for both theorists and experimentalists

Exciting times ahead!!

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