Summary of WG4: Mixing and mixing-related CP violation in B system: Δm, $\Delta\Gamma$, ϕ_s, ϕ_1/β, ϕ_2/α, ϕ_3/γ

Vladyslav Shtabovenko [1],
Agnieszka Dziurda [2], **Thibaud Humair** [3]

[1]Center for Particle Physics Siegen, University of Siegen,
[2]Henryk Niewodniczanski Institute of Nuclear Physics PAS, Cracow
[3]DESY, Hamburg

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the CKM Unitarity Triangle

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Outline

1. Introduction
2. B-meson mixing
3. CP violation and mixing angles
4. Summary and Outlook

Introduction

- $B_s^0 - \bar{B}_s^0$ oscillations between flavor eigenstates $|B_s^0\rangle$ and $|\bar{B}_s^0\rangle$

$$i\frac{d}{dt}\begin{pmatrix}|B_s^0(t)\rangle\\|\bar{B}_s^0(t)\rangle\end{pmatrix} = \left(\hat{M} - \frac{i}{2}\hat{\Gamma}\right)\begin{pmatrix}|B_s^0(t)\rangle\\|\bar{B}_s^0(t)\rangle\end{pmatrix},$$

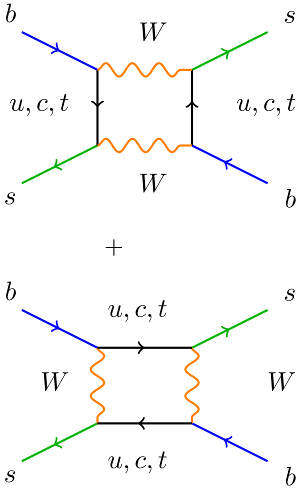
$$\hat{M} = \begin{pmatrix}M_{11} & M_{12}\\M_{12}^* & M_{22}\end{pmatrix}, \quad \hat{\Gamma} = \begin{pmatrix}\Gamma_{11} & \Gamma_{12}\\\Gamma_{12}^* & \Gamma_{22}\end{pmatrix}$$

- Diagonalize the matrices

$$|B_{s,L}\rangle = p\,|B_s^0\rangle + q\,|\bar{B}_s^0\rangle$$
$$|B_{s,H}\rangle = p\,|B_s^0\rangle - q\,|\bar{B}_s^0\rangle$$

- Mass eigenstates: $|B_{s,L}\rangle$ (lighter) and $|B_{s,H}\rangle$ (heavier)

$$M_{12} - \frac{i}{2}\Gamma_{12} \propto$$



- Physical observables depend on: $|M_{12}|$, $|\Gamma_{12}|$, ϕ_s
- Δm_s: $B_s^0 - \bar{B}_s^0$ oscillation frequency

$$\Delta M_s = M_H - M_L \approx 2|M_{12}|$$

  t quark is dominant in SM, sensitivity to NP in the loops

- $\Delta\Gamma_s$: $B_s^0 - \bar{B}_s^0$ width difference

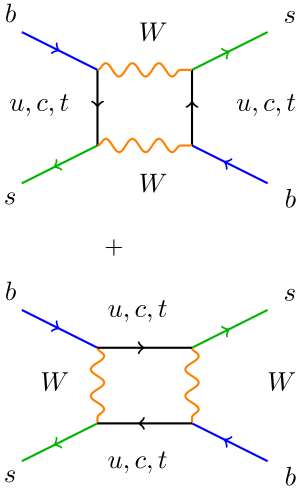
$$\Delta\Gamma_s = \Gamma_L - \Gamma_H \approx 2|\Gamma_{12}|\cos\phi_s$$

  only u and c contribute, precision probe of SM, little room for NP

- ϕ_s: CP-asymmetry in the mixing

$$a_{\mathrm{fs}} = \mathrm{Im}\left(\frac{\Gamma_{12}}{M_{12}}\right) = \left|\frac{\Gamma_{12}}{M_{12}}\right| \sin\phi_s$$

$$M_{12} - \frac{i}{2}\Gamma_{12} \propto$$



Introduction

In this talk: constraints SM by studying the time-evolution of $B^0_{(s)}$-$\bar{B}^0_{(s)}$:

- Recent LHCb & measurements of ϕ_s, Δm_s, γ
- Recent LHCb & Belle II measurements of mixing-induced CPV in penguin decays
- Theory progress in understanding perturbative and nonperturbative aspects of B-mixing
- Theory determinations of γ and ϕ_s

B-meson mixing

Numerical results

KIT Karlsruhe Institute of Technology

ΔΓ to NNLO (Gerlach, Nierste, Shtabovenko, Steinhauser 2022)

$$\left.\frac{\Delta\Gamma_s}{\Delta M_s}\right|_{\text{pole}} = \left(3.79\,^{+0.53}_{-0.58}{}_{\text{scale}}\,^{+0.09}_{-0.19}{}_{\text{scale},1/m_b} \pm 0.11_{B\tilde{B}_S} \pm 0.78_{1/m_b} \pm 0.05_{\text{input}}\right) \times 10^{-3}, \tag{33}$$

$$\left.\frac{\Delta\Gamma_s}{\Delta M_s}\right|_{\overline{\text{MS}}} = \left(4.33\,^{+0.23}_{-0.44}{}_{\text{scale}}\,^{+0.09}_{-0.19}{}_{\text{scale},1/m_b} \pm 0.12_{B\tilde{B}_S} \pm 0.78_{1/m_b} \pm 0.05_{\text{input}}\right) \times 10^{-3}, \tag{34}$$

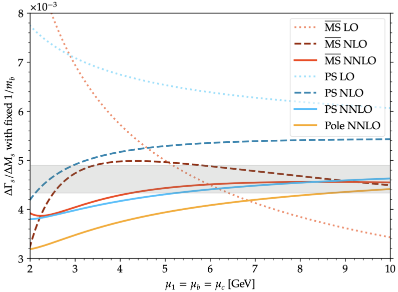
$$\left.\frac{\Delta\Gamma_s}{\Delta M_s}\right|_{\text{PS}} = \left(4.20\,^{+0.36}_{-0.39}{}_{\text{scale}}\,^{+0.09}_{-0.19}{}_{\text{scale},1/m_b} \pm 0.12_{B\tilde{B}_S} \pm 0.78_{1/m_b} \pm 0.05_{\text{input}}\right) \times 10^{-3}. \tag{35}$$

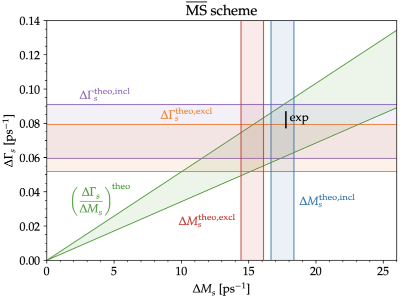
Overall result:

$$\Delta\Gamma^{th} = (0.076 \pm 0.017)\,\text{ps}^{-1} \tag{36}$$

Source: NNLO QCD corrections to $\Delta\Gamma_{(s)}$ in the $B_{(s)} - \bar{B}_{(s)}$ system by **Pascal Reeck**

Visualisation of results





Source: NNLO QCD corrections to $\Delta\Gamma_{(s)}$ in the $B_{(s)} - \bar{B}_{(s)}$ system by **Pascal Reeck**

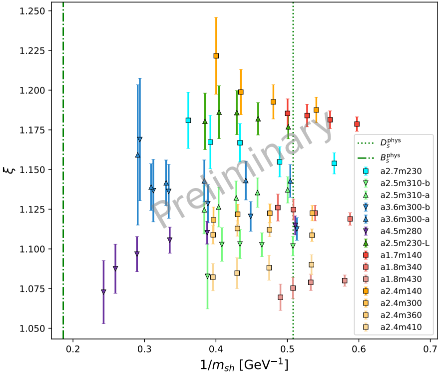
Outlook

Contribution	(Gerlach, Nierste, Shtabovenko, Steinhauser 2022)	WIP (Chen, Nierste, Reeck, Shtabovenko, Steinhauser)
$P_{1,2} \times P_{3-6}$	2 loops, $\mathcal{O}(z)$	3 loops, $\mathcal{O}(z^{10})$
$P_{1,2} \times P_8$	2 loops, $\mathcal{O}(z)$	3 loops, $\mathcal{O}(z^{10})$
$P_{3-6} \times P_{3-6}$	2 loops, $\mathcal{O}(z)$	3 loops, $\mathcal{O}(z^{10})$
$P_{3-6} \times P_8$	2 loops, $\mathcal{O}(z)$	3 loops, $\mathcal{O}(z^{10})$
$P_8 \times P_8$	2 loops, $\mathcal{O}(z)$	3 loops, $\mathcal{O}(z^{10})$
$P_{1,2} \times P_{1,2}$	3 loops, $\mathcal{O}(z)$	3 loops, $\mathcal{O}(z^{10})$

Source: NNLO QCD corrections to $\Delta\Gamma_{(s)}$ in the $B_{(s)} - \bar{B}_{(s)}$ system by **Pascal Reeck**

MIXING RATIOS ξ

- update of RBC/UKQCD work
  [Boyle et al., arxiv 1812.08791]
- includes JLQCD ensembles
- completely new, fully correlated fitting strategy
- cancellation of renormalisation constants
- relatively flat $1/m_{sh}$ dependence with improved reach towards m_b^{phys}
- we are currently investigating various global fits on the data



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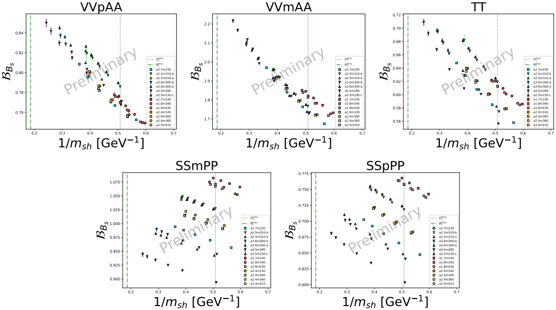
Source: Update on $SU(3)$-breaking ratios and bag parameters for $B_{(s)}$ mesons by **Felix Erben**

BAG PARAMETER $\mathcal{B}_{hs}$ - ALL 5 OPERATORS

- heavy-strange bag parameters, renormalised at mass scale μ
- O_1, O_2: mild a^2 dependence
- O_3, O_4: strong a^2 dependence
- O_5: medium a^2 dependence and curvature in $1/m_{sh}$
- very similar for heavy-light sector



Source: Update on $SU(3)$-breaking ratios and bag parameters for $B_{(s)}$ mesons by **Felix Erben**

CP violation and mixing angles

$B^0 \to J/\psi K^+K^-$ at CMS Alberto Bragagnolo

CMS performed time-dependent analysis of $B^0 \to J/\psi(\nu^+\mu^-)K^+K^-$ using:

- 2017-2018 data ($L = 96$ fb^{-1})

  $\Rightarrow 48500 \pm 250$ signal candidates
- Opposit-side muon tag

  $\Rightarrow$ improvement in Run 3 using SS, electron, & jet-tagging

First measurement of Δm_s at CMS:

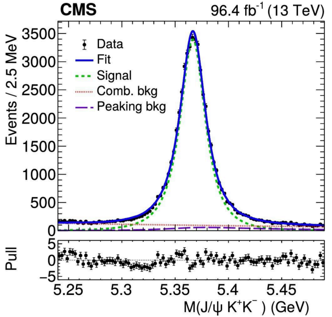
$$\Delta m_s = 17.51^{+0.10}_{0.09} \pm 0.03 \text{ ps}^{-1}$$

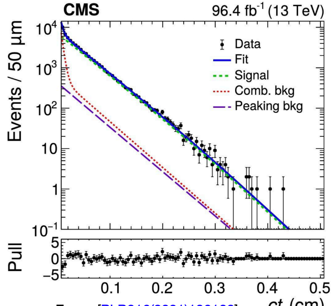
Measurement of ϕ_s and $\Delta\Gamma_s$ combined with previous analysis at 8 TeV:

$$\phi_s = 0.021 \pm 0.044 \pm 0.010 \text{ rad}$$

$$\Delta\Gamma_s = 0.1032 \pm 0.0095 \pm 0.0048 \text{ ps}^{-1}$$

- Compatible with SM expectation
- no evidence for CPV



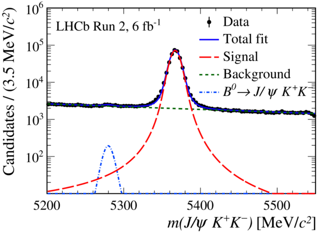


From: [PLB816(2021)136188]

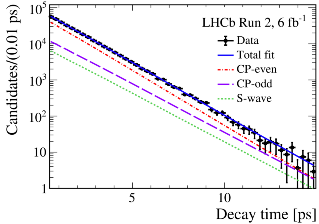
$B^0 \to J/\psi K^+ K^-$ at LHCb   Melissa Cruz Torres

LHCb recently updated time-dependent analysis of $B^0 \to J/\psi(\mu^+\mu^-)K^+K^-$ using:

- Full Run 2 dataset
  $\Rightarrow \sim 349000$ signal candidates
- Combination of various OS and SS taggers
  tagging efficiency comparable as Run 1



(arXiv: 2308.01468)



Result:

- $\phi_s = -0.039 \pm 0.022 \pm 0.006$ rad
- $\Gamma_s - \Gamma_d = -0.0056^{+0.0013}_{-0.0015} \pm 0.0014$
- $|\lambda| = 1.001 \pm 0.011 \pm 0.005$
- $\Delta\Gamma_s = 0.0845 \pm 0.0044 \pm 0.0024$

Combined with Run 1 data:

$$\phi_s = -0.044 \pm 0.020 \text{ rad}$$

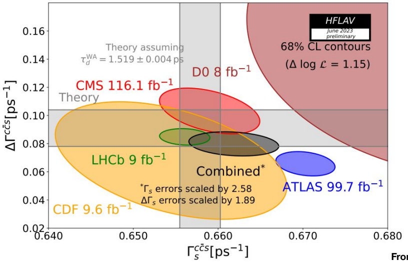
$$|\lambda| = 0.990 \pm 0.010$$

Good compatibility with SM and no evidence for CPV

ϕ_s, Γ_s, $\Delta\Gamma_s$: state of the art

State of the art (w. latest preliminary results from LHCb)

- Measurement **statistically limited** ➜ long-term commitment by multiple experimental collaborations
- Very active theoretical community (NP limits, penguin pollutions, predictions, …)
- Precision on ϕ_s **close** to 3 s.d. sensitivity for CPV in decay/mixing interference
  - $\sigma^{WA}(\phi_s) \approx 15$ mrad (40% relative uncertainty)



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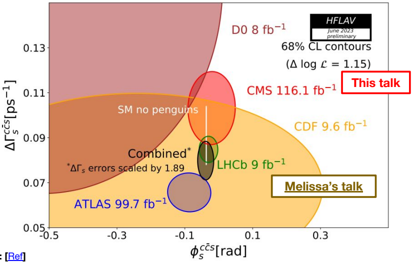

Alberto Bragagnolo (UNIPD) **Measurement of the CPV phase ϕ_s** 4/15

Source: Measurement of the CP-violating phase ϕ_s with CMS: present and future by **Alberto Bragagnolo**

CP violation measurements in the penguin-mediated decay $B_s^0 \to \phi\phi$

Measured observables in the polarization-independent fit

arXiv:2304.06198

Parameter	Result
$\phi_s^{s\bar{s}s}$ [rad]	$-0.042 \pm 0.075 \pm 0.009$
$\lvert\lambda\rvert$	$1.004 \pm 0.030 \pm 0.009$
$\lvert A_0\rvert^2$	$0.384 \pm 0.007 \pm 0.003$
$\lvert A_\perp\rvert^2$	$0.310 \pm 0.006 \pm 0.003$
$\delta_\parallel - \delta_0$ [rad]	$2.463 \pm 0.029 \pm 0.009$
$\delta_\perp - \delta_0$ [rad]	$2.769 \pm 0.105 \pm 0.011$

The following parameters have been constrained to the measurements by LHCb collaboration

$\Delta m_s = 17.766 \pm 0.006$ ps^{-1}

$\Gamma_s = 0.657 \pm 0.002$ ps^{-1}

$\Delta\Gamma_s = 0.078 \pm 0.006$ ps^{-1} with correlation coefficient of -0.35

In combination with LHCb Run 1 measurements

$\phi^{s\bar{s}s} = -0.074 \pm 0.069$ rad **and** $\lvert\lambda\rvert = 1.009 \pm 0.07 \pm 0.030$

arXiv:2304.06198

This is the most precise measurement of *CP* violation in $B_s^0 \to \phi\phi$ to date

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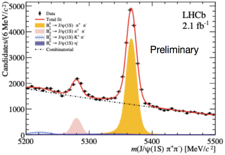
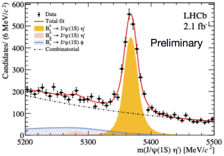
Source: Measurement of the CP violating phase ϕ_s and $\phi_s^{sq\bar{q}}$ by **Melissa Cruz Torres (LHCb)**

$B_s^0 \to J\psi\eta'$, $B_s^0 \to J\psi\pi^+\pi^-$ at LHCb ($\Delta\Gamma_s$)

$B_s^0 \to J/\psi\pi^+\pi^-$



$B_s^0 \to J/\psi\eta'$



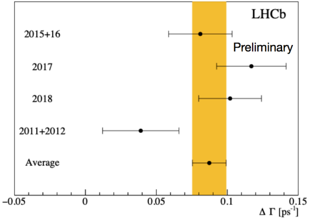
- $\mathcal{L}$ = 9 fb^{-1} , Run 1 2011 + 2012 and Run 2 2015 to 2018 data,

LHCb-PAPER-2023-025

$\Delta\Gamma_s$ results and probability of χ^2

Dataset	$\Delta\Gamma_s$ [ps^{-1}]	P(χ^2)
2011+12	0.039 ± 0.026	0.83
2015+16	0.081 ± 0.022	0.77
2017	0.117 ± 0.024	0.57
2018	0.102 ± 0.021	0.78

Comparison between the four data sets



Orange band is 1σ error band

Summary

Using full pp-collision dataset between 2011 and 2018, $B_s^0 \to J/\psi\eta'$ and $B_s^0 \to J/\psi\pi^+\pi^-$, $\Delta\Gamma_s$ is measured to be

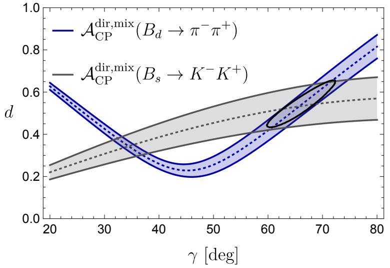
$$\Delta\Gamma_s = 0.087 \pm 0.012 \pm 0.009 \text{ ps}^{-1}$$

➡ **This is the first $\Delta\Gamma_s$ measurement using the $B_s^0 \to J/\psi\eta'$**

Source: Measurement of the CP violating phase ϕ_s and $\phi_s^{sq\bar{q}}$ by **Melissa Cruz Torres (LHCb)**

CKM-angle γ from non-tree decays

Fleischer [1999,2007]; Fleischer, Knegjens [2011]; Fleischer, Malami, Jaarsma, KKV [2016]
Cuichini, Franco, Mishima, Silvestrini [2012], Data from LHCb [2022]Fleischer, Jaarsma, KKV [2211.08346]



- New! First observation of CP violation in penguin dominated $B_s \to K^+ K^-$ LHCb 2022
- New! First determination of γ with only CP asymmetries
- $\gamma = (65^{+7}_{-5})^\circ$ Fleischer, Jaarsma, KKV [2111.08346]
- Agrees with tree determinations: $\gamma = (64.9 \pm 4.5)^\circ$ LHCb [2021] without B_s modes
- Limited by U-spin breaking corrections

Source: Theory determination of γ and ϕ_s from $B_{(s)} \to hh$ decays by **Keri Vos**

Determination of ϕ_s (II)

Fleischer, Jaarsma, KKV, JHEP 02 (2023) 081 [2211.08346]

Strategy II:

- Use ratio of branching ratios of $B_d \to \pi\pi$ and $B_s \to KK$ decays $K = 105.3 \pm 9.6$
- Non-factorisable U-spin-breaking contributions:

$$\xi^a_{\rm NF} \equiv \left|\frac{1+r_P}{1+r'_P}\right| \left|\frac{1+x}{1+x'}\right| \left|\frac{a^T_{\rm NF}}{a^{T'}_{\rm NF}}\right| = 1.00 \pm 0.07,$$

- $\Delta\phi_{KK} = -(4.5 \pm 5.3)^\circ$
- With $\phi_s^{\rm eff} = -(8.1 \pm 1.9)^\circ \to \phi_s = -(3.6 \pm 5.7)^\circ$

Remarkable agreement with $B_s^0 \to J/\psi\phi$ determination: $\phi_s = -(4.2 \pm 1.4)^\circ$

Source: Theory determination of γ and ϕ_s from $B_{(s)} \to hh$ decays by **Keri Vos**

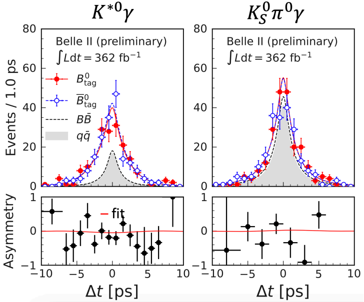
$\sin 2\beta^{\text{eff}} / \phi_1^{\text{eff}}$: Belle II summer 23 results   Yuma Uematsu

$B^0 \to K_S^0 \pi^0 \gamma$

- Radiative penguin, fully neutral final state
- Most precise result to date:

$$S = 0.00^{+0.27}_{-0.26} \pm 0.03$$
$$C = 0.10 \pm 0.13 \pm 0.03$$

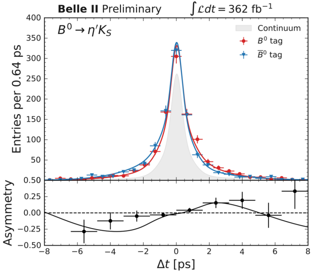
in K^{*0} resonance region



$B^0 \to \eta' K_S^0$

- Most abundant $b \to s$ had. penguin
- Precision approaching world best:

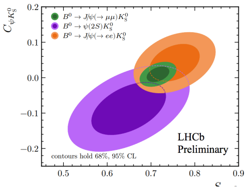
$$S = 0.67 \pm 0.10 \pm 0.04$$
$$C = -0.19 \pm 0.08 \pm 0.03$$

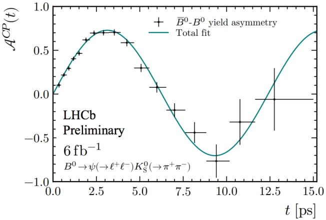


Precision of TD analyses will increase w/ new flavor tagger: $\sim 37\%$ eff vs $\sim 29\%$ at Belle.

$\sin(2\beta)$ at LHCb

Mode	S	C	ρ	
$J/\psi(\to \mu^+\mu^-)\,K_S^0$	$0.716 \pm 0.015 \pm 0.007$	$+0.010 \pm 0.014 \pm 0.003$	0.446	~306k signal decays
$\psi(2S)(\to \mu^+\mu^-)\,K_S^0$	$0.649 \pm 0.053 \pm 0.018$	$-0.087 \pm 0.048 \pm 0.005$	0.503	~23k signal decays
$J/\psi(\to e^+e^-)\,K_S^0$	$0.754 \pm 0.037 \pm 0.008$	$+0.042 \pm 0.034 \pm 0.008$	0.374	~43k signal decays





Combination from simultaneous fit of the three decay modes:

$$S_{\psi K_S^0} = 0.717 \pm 0.013 \pm 0.008$$

$$C_{\psi K_S^0} = 0.008 \pm 0.012 \pm 0.003$$

$$\rho = 0.441$$

- To date, most precise single measurement of $\sin(2\beta)$
- Should improve precision of world average by $\sim 35\%$
- Still statistically limited

Source: Measurements of $\sin(2\beta)$ at LHCb by **Thomas Latham** - LHCb-PAPER-2023-013

LHCb-PAPER-2023-013

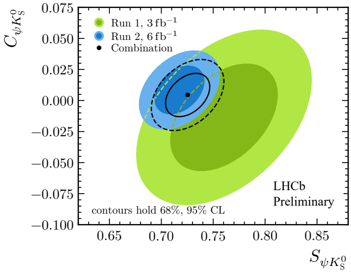
Combination with Run 1

- Combination with the previous Run 1 results
  - Assumes sources of systematic uncertainties from external parameters $\Delta m_d, \Delta\Gamma_d, A_P$ are fully correlated

$$S_{\psi K_S^0} = 0.724 \pm 0.014$$

$$C_{\psi K_S^0} = 0.004 \pm 0.012$$

$$\rho = 0.40$$



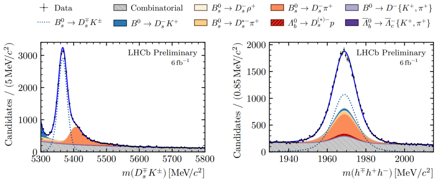
Source: Measurements of $\sin(2\beta)$ at LHCb by **Thomas Latham**

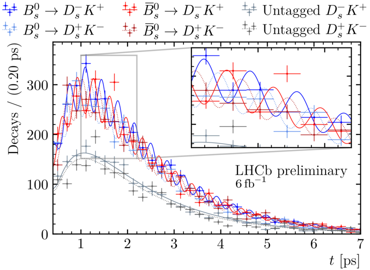
γ/ϕ_3 at LHCb

$B_s^0 \to D_s^{\mp} K^{\pm}$ - Run2

[4] LHCb-CONF-2023-004

- 20950 ± 180 candidates





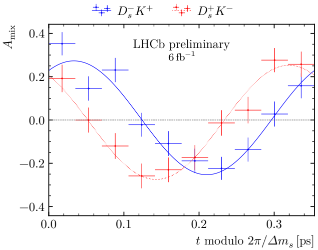
- Significant $C\!P$ violation in the interference $S_f \neq -S_{\bar{f}}$ at $8.8\,\sigma$

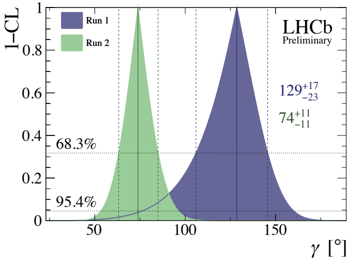
$$
\begin{aligned}
C_f &= 0.791 \pm 0.061 \pm 0.022 \\
A_f^{\Delta\Gamma} &= 0.051 \pm 0.134 \pm 0.037 \\
S_f &= -0.571 \pm 0.084 \pm 0.023 \\
A_{\bar{f}}^{\Delta\Gamma} &= 0.303 \pm 0.125 \pm 0.036 \\
S_{\bar{f}} &= -0.503 \pm 0.084 \pm 0.025
\end{aligned}
$$

- No systematic limitation expected in Run3

Source: Decay-time-dependent measurements of the CKM angle γ at LHCb by **Quentin Führing**

γ/ϕ_3 at LHCb





- **Extraction of physics parameters**
  - External input [9]

    $-2\beta_s = \phi_s = (-0.031 \pm 0.018)$ rad
- **Run2 standalone result:**

$$\gamma = (74 \pm 11)^\circ$$

$$\delta = (346.9 \pm 6.6)^\circ \quad r_{D_sK} = 0.327 \pm 0.038$$

- **Compatibility to Run1** [2] **at 1.3 σ**
  - Driven by γ at $2\,\sigma$ and Re[λ_f]
  - r_{D_sK} and δ at $0.6\,\sigma$ each
- **Updated machinery reproduces Run1 result** [2]
- **Combination in preparation**

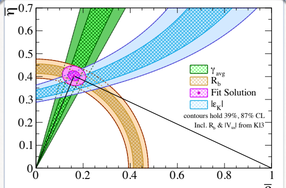
[4] LHCb-CONF-2023-004

Source: Decay-time-dependent measurements of the CKM angle γ at LHCb by **Quentin Führing**

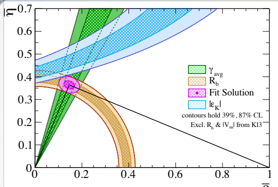
Unitarity Triangle Apex Determination

▹ Making a fit to γ and R_b

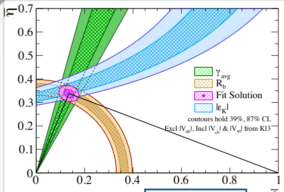
Incl	$\bar\rho = 0.161 \pm 0.025\,,$	$\bar\eta = 0.403 \pm 0.022$
Excl	$\bar\rho = 0.146 \pm 0.022\,,$	$\bar\eta = 0.364 \pm 0.018$
$(\lvert V_{ub}^{\rm excl}\rvert, \lvert V_{cb}^{\rm incl}\rvert)$	$\bar\rho = 0.135 \pm 0.021\,,$	$\bar\eta = 0.338 \pm 0.017$
$(\lvert V_{ub}^{\rm incl}\rvert, \lvert V_{cb}^{\rm excl}\rvert)$	$\bar\rho = 0.174 \pm 0.027\,,$	$\bar\eta = 0.435 \pm 0.023$



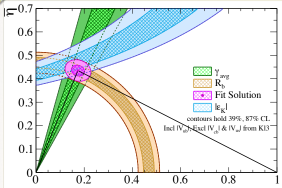
Inclusive case



Exclusive case



Hybrid case $(\lvert V_{ub}^{\rm excl}\rvert, \lvert V_{cb}^{\rm incl}\rvert)$



$(\lvert V_{ub}^{\rm incl}\rvert, \lvert V_{cb}^{\rm excl}\rvert)$

Source: New Physics in $B_q - \bar{B}_q$ mixing in connection with CKM angle γ by **Eleftheria Malami**

How can we determine the Unitarity Triangle Apex?

2) Utilising Mixing and R_b - without γ

assume Δm_s^{SM}, Δm_d^{SM}

- The UT side R_t is defined as:

$$R_t \equiv \left|\frac{V_{td}V_{tb}}{V_{cd}V_{cb}}\right| = \sqrt{(1-\bar\rho)^2+\bar\eta^2} = \frac{1}{\lambda}\left|\frac{V_{td}}{V_{ts}}\right|\left[1-\frac{\lambda^2}{2}(1-2\bar\rho)\right]+\mathcal{O}(\lambda^4)$$

$$\left|\frac{V_{td}}{V_{ts}}\right| = \xi\sqrt{\frac{m_{B_s}\Delta m_d^{SM}}{m_{B_d}\Delta m_s^{SM}}}$$

lattice $\xi \equiv \frac{f_{B_s}\sqrt{\hat B_{B_s}}}{f_{B_d}\sqrt{\hat B_{B_d}}}$

FLAG(2021), arXiv:1907.01025

$\xi = 1.212 \pm 0.016$

$$\left|\frac{V_{td}}{V_{ts}}\right| = 0.2063 \pm 0.0004 \pm 0.0027$$

0.0004: due to experiment; 0.0027: due to lattice input

Incl	$\Delta m_d^{SM} = (0.511 \pm 0.040)\ \text{ps}^{-1}$,	$\Delta m_s^{SM} = (17.23 \pm 0.87)\ \text{ps}^{-1}$
Excl	$\Delta m_d^{SM} = (0.438 \pm 0.033)\ \text{ps}^{-1}$,	$\Delta m_s^{SM} = (14.80 \pm 0.76)\ \text{ps}^{-1}$
$(\lvert V_{ub}^{excl}\rvert, \lvert V_{cb}^{incl}\rvert)$	$\Delta m_d^{SM} = (0.509 \pm 0.037)\ \text{ps}^{-1}$,	$\Delta m_s^{SM} = (17.19 \pm 0.87)\ \text{ps}^{-1}$
$(\lvert V_{ub}^{incl}\rvert, \lvert V_{cb}^{excl}\rvert)$	$\Delta m_d^{SM} = (0.442 \pm 0.036)\ \text{ps}^{-1}$,	$\Delta m_s^{SM} = (14.84 \pm 0.76)\ \text{ps}^{-1}$

fit to the sides R_b and R_t

Incl, $K\ell3$	$\bar\rho = 0.180 \pm 0.014$,	$\bar\eta = 0.395 \pm 0.020$
Excl, $K\ell3$	$\bar\rho = 0.163 \pm 0.013$,	$\bar\eta = 0.357 \pm 0.017$
Hybrid, $K\ell3$	$\bar\rho = 0.153 \pm 0.013$,	$\bar\eta = 0.330 \pm 0.016$

↓

scenarios with γ are a factor 2 less precise than the scenarios without γ

- ✻ UT apex determination through R_b and R_t is more precise
- ✻ R_t determined assuming SM Δm_d and Δm_s

  ↓

  ignores possible NP in $B_q^0 - \bar B_q^0$ mixing
  - NP will contaminate R_t determination
- ✻ To determine NP in $B_q^0 - \bar B_q^0$ mixing in a general scenario: UT apex determination through R_b and γ

Source: New Physics in $B_q - \bar B_q$ mixing in connection with CKM angle γ by **Eleftheria Malami**

Introducing NP Parameters

$$\Delta m_q = \Delta m_q^{\mathrm{SM}} \left(1 + \kappa_q e^{i\sigma_q}\right)$$

$$\phi_q = \phi_q^{\mathrm{SM}} + \phi_q^{\mathrm{NP}} = \phi_q^{\mathrm{SM}} + \arg\left(1 + \kappa_q e^{i\sigma_q}\right)$$

Model independent parametrization

size of the NP effects is described by κ_q

σ_q is a complex phase for additional CP-violating effects

We explore 2 different NP scenarios

Scenario I → most general case

utilise UT apex determination for the SM predictions of Δm_q and ϕ_q

↓

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

Scenario II

we consider NP contributions are equal in the B_d and the B_s systems — FUNP

↓

UT apex determination that only relies on R_b and mixing parameters without information on γ.

↓

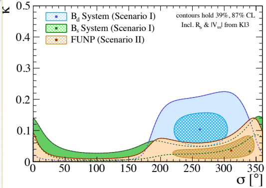
NP in γ will not affect the results

Comparing FUNP with Scenario I

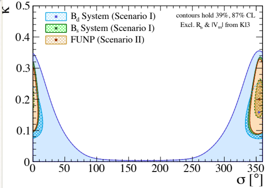
- **test of FUNP assumption**
- **Impact of the assumptions on the constraints on parameters space of NP in mixing**

Source: New Physics in $B_q - \bar{B}_q$ mixing in connection with CKM angle γ by **Eleftheria Malami**

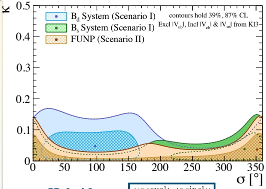
Comparison between Scenarios I and II for $\varkappa_q$ and σ_q



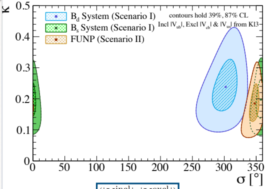
Inclusive case



Exclusive case



Hybrid case $(|V_{ub}^{\rm excl}|, |V_{cb}^{\rm incl}|)$



$(|V_{ub}^{\rm incl}|, |V_{cb}^{\rm excl}|)$

Source: New Physics in $B_q - \bar{B}_q$ mixing in connection with CKM angle γ by **Eleftheria Malami**

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

NP can modify its branching ratio

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

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

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

CKM elements drop out in the SM ratio

Including NP effects in both $B(B_s \to \mu^+\mu^-)$ and Δm_s we get the generalised expression

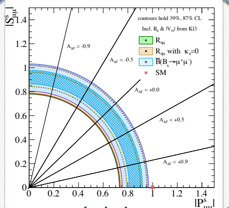
$$\mathcal{R}_{s\mu} = (1.60 \pm 0.19) \times 10^{-10}$$

Comparing with the SM, we obtain extra contours

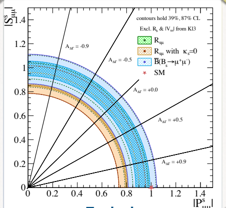
$$\mathcal{R}_{s\mu}^{\rm SM} = \frac{\tau_{B_s}}{1-y_s} \frac{3G_F^2 m_W^2 \sin^4\theta_W}{4\pi^3} \frac{|C_{10}^{\rm SM}|^2}{S_0(x_t)\eta_{2B}\hat{B}_{B_s}} m_\mu^2 \sqrt{1-4\frac{m_\mu^2}{m_{B_s}^2}}$$

$$\mathcal{R}_{s\mu}^{\rm SM} = (2.22 \pm 0.10) \times 10^{-10}\ \text{ps}$$

introduces a dependence on the CKM matrix elements through the NP parameters ($\varkappa_s$, σ_s)



Inclusive



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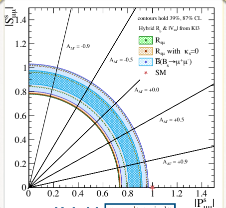

Hybrid $(|V_{ub}^{\rm excl}|, |V_{cb}^{\rm incl}|)$

We can minimise this dependence, creating the following ratio $R_{s\mu}$

Source: New Physics in $B_q - \bar{B}_q$ mixing in connection with CKM angle γ by **Eleftheria Malami**

Summary and Outlook

Summary

- Many exciting new experimental results utilizing large datasets
- Increased precision due to higher statistics
- Theory doing its best to keep up