Recent LHCb results on CP violation in beauty decays to charmonia

Valeriia Lukashenko

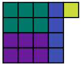
Nikhef on behalf of LHCb collaboration

EPS-HEP 2021

Introduction

UT

Precision measurements



Test Standard Model

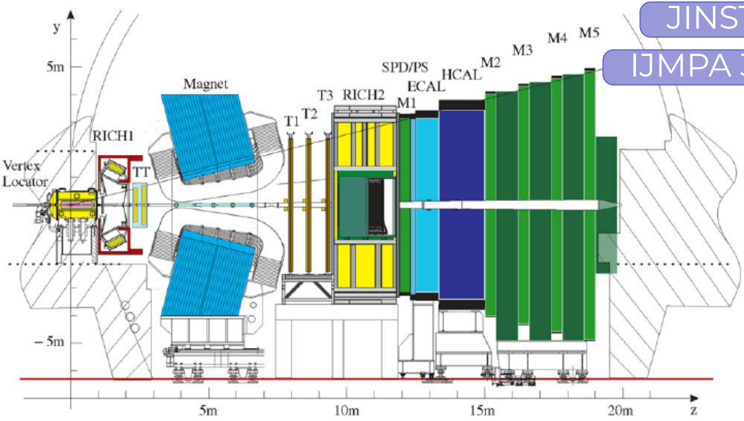
LQ, Z'...

New Physics

LHCb detector

JINST 3, S08005

IJMPA 30, 1530022

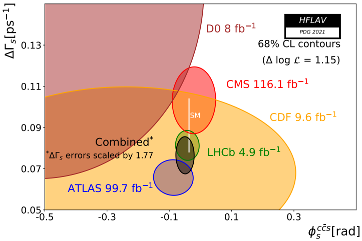


- Forward spectrometer: $2 < \eta < 5$
- High momentum and mass resolution
- Precise vertex reconstruction
- High decay time resolution

First measurement of CP-violating phase in $B_s^0 \to J/\psi(e^+e^-)\phi(1020)$ decays

arXiv:2105.14738

$$\phi_s = \phi_s^{SM,tree} + \phi_s^{SM,penguin} + \Delta\phi_s^{NP}$$



from Eur. Phys. J. C (2021) 81: 226

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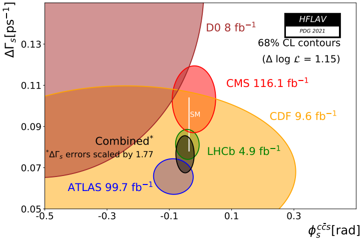

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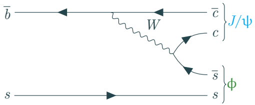
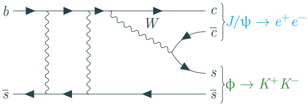


direct



mixing

- 10% of the $\mu\mu$ sample
- Observables: decay time, 3 angles
- $\mathcal{L} = 3fb^{-1}$ (7 TeV 2011, 8 TeV 2012)

First measurement of CP-violating phase in $B_s^0 \to J/\psi(e^+e^-)\phi(1020)$ decays

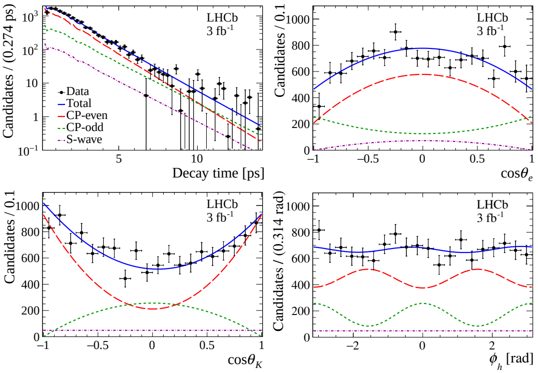
arXiv:2105.14738

1 $\phi_s = 0.00 \pm 0.28 \pm 0.05$ rad

2 $\Delta\Gamma_s = 0.115 \pm 0.045 \pm 0.011$ ps^{-1}

3 $\Gamma_s = 0.608 \pm 0.018 \pm 0.011$ ps^{-1}

- Biggest systematic sources: mass factorisation with final observables, mass model, decay time resolution.



Search for the rare decay $B^0 \to J/\psi\phi(1020)$

arXiv:2011.06847v2

OZI[1] rule | suppresses disconnected quark lines

[1] Okubo, Zweig, Iizuka

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- $\phi(1020)$ generation mechanism?

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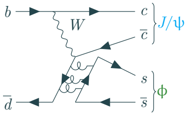

tri-gluon

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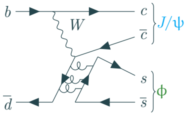

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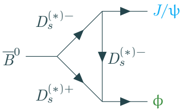

rescattering

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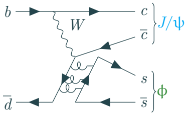

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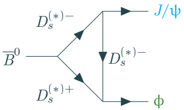

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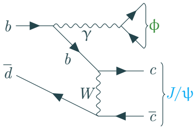

photoproduction

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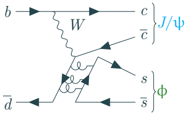

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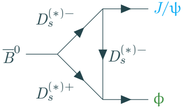

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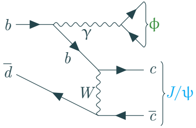

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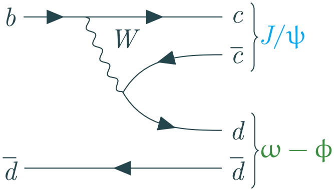

$\omega - \phi$ mixing

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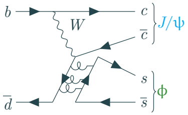

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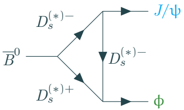

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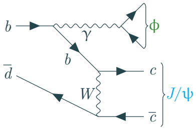

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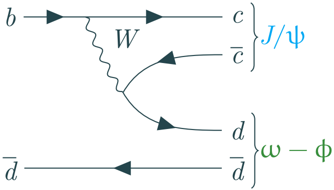

$\omega - \phi$ mixing

- $\mathcal{L} = 9fb^{-1}$ (7 TeV 2011, 8 TeV 2012, 13 TeV 2015-2018)

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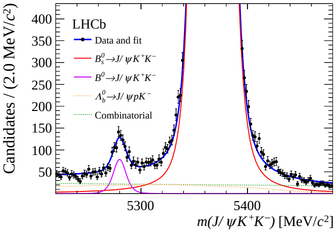
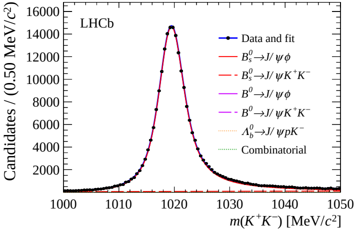
1

sequential mass fit

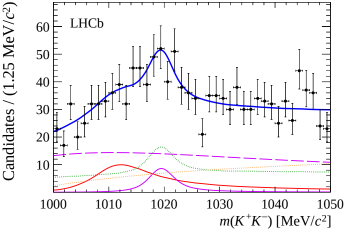


$m(J/\psi K^+K^-)$ fit

2



$m(B_s^0) \pm 15$ MeV/c^2



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Search for the rare decay $B^0 \to J/\psi\phi(1020)$

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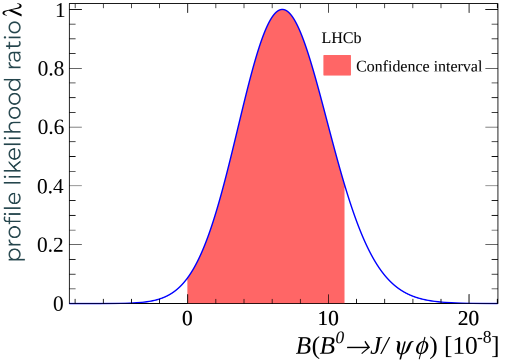
$\mathcal{B}(B^0 \to J/\psi\phi) < 1.1 \cdot 10^{-7}$ at 90% CL

1.73 improvement in comparison to the $3fb^{-1}$ result



Precise measurement of the f_s/f_d fragmentation fractions and of B_s^0 decay branching fractions

arXiv:2103.06810v1

$f_{u,d,s}$ | probability for a b quark to hadronize into a B^+, B^0, B_s^0

- Input for $\mathcal{B}(B)$ measurements and major systematics for many
- p_T and $\sqrt{s}$ dependence
- Note: correlations between measurements

Precise measurement of the f_s/f_d fragmentation fractions

arXiv:2103.06810v1

Semileptonic inputs
$H_b \to H_c X \mu^- \overline{\nu}_\mu$

$B_s^0 \to D_s^+ X \mu^- \overline{\nu}_\mu$
$B_s^0 \to D K \mu^- \overline{\nu}_\mu$
$B \to D^0 X \mu^- \overline{\nu}_\mu$
$B \to D^+ X \mu^- \overline{\nu}_\mu$

Hadronic inputs
$B^0_{(s)} \to D^-_{(s)} h^+$

$B_s^0 \to D_s^- \pi^+$
$B^0 \to D^- K^+$
$B^0 \to D^- \pi^+$

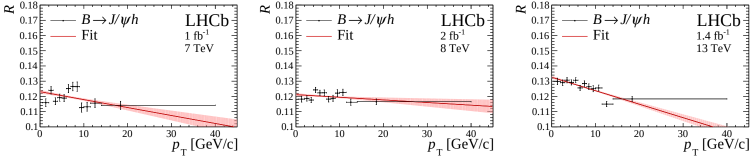
Charmonium inputs
$B \to J/\psi X$

$B_s^0 \to J/\psi \phi(1020) / B^+ \to J/\psi K^+$

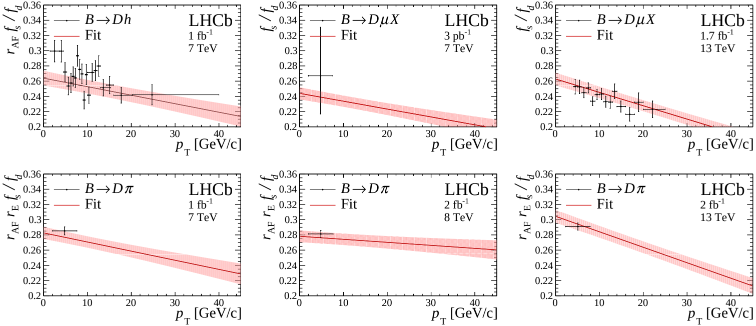
Precise measurement of the f_s/f_d fragmentation fractions

$\frac{f_s}{f_d}(p_T, \sqrt{s}) = a_i + b_i \cdot p_T$, **where i = 7, 8, 13 TeV.**

arXiv:2103.06810v1



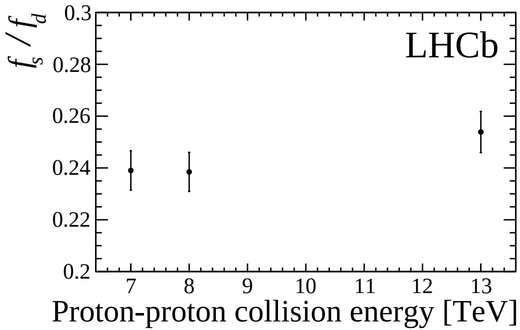
R - ratio of corrected yields



f_s/f_d multiplied by theoretical factors

Precise measurement of the f_s/f_d fragmentation fractions

arXiv:2103.06810v1



$$f_s/f_d(7\,TeV) = 0.2390 \pm 0.0076$$
$$f_s/f_d(8\,TeV) = 0.2385 \pm 0.0075$$
$$f_s/f_d(13\,TeV) = 0.2539 \pm 0.0079$$

About 60! $\mathcal{B}$ are updated with new $\frac{f_s}{f_d}$ and input normalization $\mathcal{B}$

$$\mathcal{B}(B_s^0 \to J/\psi\phi) = (1.018 \pm 0.032 \pm 0.037) \cdot 10^{-3}$$
$$\mathcal{B}(B_s^0 \to D_s^- \pi^+) = (3.20 \pm 0.10 \pm 0.16) \cdot 10^{-3}$$

Conclusions

1. First measurement of the CP-violating ϕ_s phase in the $B_s^0 \to J/\psi(e^- e^+)\phi$ is consistent with no CP-violation.

2. An upper limit on the $B^0 \to J/\psi\phi$ is updated

3. Updated the f_s/f_d with a new combination

Thank you for your attention.

Backup

Updated $\mathcal{B}$ from arXiv:2103.06810v1

Decay mode	Updated result	Previous result	
$B_s^0 \to J/\psi K_S^0$	$(2.03 \pm 0.08 \pm 0.06 \pm 0.07 \pm 0.07) \times 10^{-5}$	$(1.93 \pm 0.08 \pm 0.05 \pm 0.11 \pm 0.07) \times 10^{-5}$	
$B_s^0 \to J/\psi K_S^0 K^\pm \pi^\mp$	$(4.95 \pm 0.35 \pm 0.33 \pm 0.16 \pm 0.42) \times 10^{-4}$	$(4.6 \pm 0.3 \pm 0.3 \pm 0.3 \pm 0.4) \times 10^{-4}$	$\star$
$B_s^0 \to \psi(2S)\overline{K}^{*0}$	$(3.57 \pm 0.36 \pm 0.26 \pm 0.12 \pm 0.24) \times 10^{-5}$	$(3.35 \pm 0.34 \pm 0.24 \pm 0.19 \pm 0.22) \times 10^{-5}$	
$B_s^0 \to \psi(2S)K^+\pi^-$	$(3.39 \pm 0.23 \pm 0.14 \pm 0.11 \pm 0.23) \times 10^{-5}$	$(3.12 \pm 0.21 \pm 0.13 \pm 0.18 \pm 0.22) \times 10^{-5}$	
$B_s^0 \to J/\psi\eta$	$(3.99 \pm 0.34^{+0.31}_{-0.43} \pm 0.13 \pm 0.27) \times 10^{-4}$	$(3.79 \pm 0.31^{+0.20}_{-0.41} \pm 0.28 \pm 0.56) \times 10^{-4}$	$\star$
$B_s^0 \to J/\psi\eta'$	$(3.62 \pm 0.31^{+0.14}_{-0.37} \pm 0.12 \pm 0.24) \times 10^{-4}$	$(3.42 \pm 0.30^{+0.14}_{-0.35} \pm 0.26 \pm 0.51) \times 10^{-4}$	$\star$
$B_s^0 \to \psi(2S)\phi$	$(4.99 \pm 0.27 \pm 0.25 \pm 0.21) \times 10^{-4}$	$(5.33 \pm 0.28 \pm 0.26^{+1.37}_{-1.12}) \times 10^{-4}$	$\star$
$B_s^0 \to \chi_{c1}\phi$	$(1.93 \pm 0.18 \pm 0.14 \pm 0.08) \times 10^{-5}$	$(1.98 \pm 0.19 \pm 0.15 \pm 0.20) \times 10^{-5}$	$\star$
$B_s^0 \to J/\psi\pi^+\pi^-$	$(2.02 \pm 0.05 \pm 0.05 \pm 0.09) \times 10^{-4}$	$(2.16 \pm 0.05 \pm 0.06^{+0.51}_{-0.42}) \times 10^{-4}$	$\star$
$B_s^0 \to J/\psi\phi\phi$	$(1.17 \pm 0.12^{+0.05}_{-0.09} \pm 0.05) \times 10^{-5}$	$(1.19 \pm 0.12^{+0.05}_{-0.09} \pm 0.10) \times 10^{-5}$	$\star$
$B_s^0 \to J/\psi\overline{K}^{*0}$	$(4.14 \pm 0.19 \pm 0.13 \pm 0.17) \times 10^{-5}$	$(4.20 \pm 0.20 \pm 0.13 \pm 0.36) \times 10^{-5}$	$\star$
$B_s^0 \to J/\psi p\bar{p}$	$(3.54 \pm 0.19 \pm 0.24 \pm 0.15) \times 10^{-6}$	$(3.58 \pm 0.19 \pm 0.24 \pm 0.30) \times 10^{-6}$	$\star$
$B^0 \to J/\psi p\bar{p}$	$(3.95 \pm 0.35 \pm 0.26 \pm 0.10) \times 10^{-7}$	$(4.51 \pm 0.40 \pm 0.30 \pm 0.32) \times 10^{-7}$	$\star$
$B_s^0 \to \psi(2S)\eta$	$(3.31 \pm 0.56 \pm 0.48 \pm 0.49) \times 10^{-4}$	$(3.15 \pm 0.53 \pm 0.45^{+0.61}_{-0.67}) \times 10^{-4}$	$\star$
$B_s^0 \to \psi(2S)\eta'$	$(1.40 \pm 0.33 \pm 0.06 \pm 0.19) \times 10^{-4}$	$(1.32 \pm 0.31 \pm 0.05^{+0.26}_{-0.28}) \times 10^{-4}$	$\star$
$B_s^0 \to J/\psi\pi^+\pi^-\pi^+\pi^-$	$(7.49 \pm 0.30 \pm 0.44 \pm 0.42) \times 10^{-5}$	$(7.62 \pm 0.36 \pm 0.64 \pm 0.42) \times 10^{-5}$	$\star$
$B_s^0 \to \psi(2S)\pi^+\pi^-$	$(6.87 \pm 0.81 \pm 0.65 \pm 0.39) \times 10^{-5}$	$(7.3 \pm 0.9 \pm 0.6^{+1.9}_{-1.6}) \times 10^{-5}$	$\star$

Decay mode	Updated result	Previous result	
$B_s^0 \to \pi^+\pi^-$	$(7.50 \pm 0.57 \pm 0.68 \pm 0.25 \pm 0.20) \times 10^{-7}$	$(6.91 \pm 0.54 \pm 0.63 \pm 0.40 \pm 0.19) \times 10^{-7}$	
$B_s^0 \to K^-\pi^+$	$(6.07 \pm 0.48 \pm 0.48 \pm 0.20 \pm 0.16) \times 10^{-6}$	$(5.4 \pm 0.4 \pm 0.4 \pm 0.4 \pm 0.2) \times 10^{-6}$	$\star$
$B_s^0 \to K^+K^-$	$(2.59 \pm 0.08 \pm 0.16 \pm 0.08 \pm 0.07) \times 10^{-5}$	$(2.30 \pm 0.07 \pm 0.14 \pm 0.17 \pm 0.07) \times 10^{-5}$	$\star$
$B_s^0 \to K_S^0 K_S^0$	$(8.17 \pm 1.58 \pm 0.89 \pm 0.25 \pm 0.78) \times 10^{-6}$	$(8.3 \pm 1.6 \pm 0.9 \pm 0.3 \pm 0.8) \times 10^{-6}$	
$B_s^0 \to K_S^0 \pi^+\pi^-$	$(5.15 \pm 0.73 \pm 0.84 \pm 0.17 \pm 0.19) \times 10^{-6}$	$(4.7 \pm 0.7 \pm 0.8 \pm 0.3 \pm 0.2) \times 10^{-6}$	
$B_s^0 \to K_S^0 K^\pm\pi^\mp$	$(4.58 \pm 0.19 \pm 0.30 \pm 0.15 \pm 0.17) \times 10^{-5}$	$(4.22 \pm 0.18 \pm 0.28 \pm 0.25 \pm 0.17) \times 10^{-5}$	
$B_s^0 \to K^{*0}\overline{K}^{*0}$	$(2.67 \pm 0.44 \pm 0.43 \pm 0.09 \pm 0.18) \times 10^{-5}$	$(2.81 \pm 0.46 \pm 0.43 \pm 0.34 \pm 0.13) \times 10^{-5}$	$\star$
$B_s^0 \to K^{*\pm}K^\mp$	$(1.21 \pm 0.18 \pm 0.13 \pm 0.04 \pm 0.06) \times 10^{-5}$	$(1.27 \pm 0.19 \pm 0.13 \pm 0.07 \pm 0.10) \times 10^{-5}$	
$B_s^0 \to K^{*-}\pi^+$	$(3.17 \pm 1.06 \pm 0.41 \pm 0.10 \pm 0.17) \times 10^{-6}$	$(3.3 \pm 1.1 \pm 0.4 \pm 0.2 \pm 0.3) \times 10^{-6}$	
$B_s^0 \to p\bar{p}K^\pm\pi^\mp$	$(1.41 \pm 0.23 \pm 0.12 \pm 0.05 \pm 0.11) \times 10^{-6}$	$(1.30 \pm 0.21 \pm 0.11 \pm 0.09 \pm 0.08) \times 10^{-6}$	
$B_s^0 \to \overset{(-)}{p}\,\overset{(-)}{\Lambda}K^\mp$	$(5.93 \pm 0.65 \pm 0.61 \pm 0.19 \pm 0.55) \times 10^{-6}$	$(5.46 \pm 0.61 \pm 0.57 \pm 0.32 \pm 0.50) \times 10^{-6}$	
$B_s^0 \to \phi\overline{K}^{*0}$	$(1.25 \pm 0.27 \pm 0.16 \pm 0.04 \pm 0.06) \times 10^{-6}$	$(1.10 \pm 0.24 \pm 0.13 \pm 0.08 \pm 0.06) \times 10^{-6}$	$\star$
$B_s^0 \to \phi\phi$	$(2.00 \pm 0.05 \pm 0.08 \pm 0.07 \pm 0.10) \times 10^{-5}$	$(1.84 \pm 0.05 \pm 0.07 \pm 0.11 \pm 0.12) \times 10^{-5}$	
$B_s^0 \to \phi\pi^+\pi^-$	$(3.78 \pm 0.25 \pm 0.18 \pm 0.28) \times 10^{-6}$	$(3.48 \pm 0.23 \pm 0.17 \pm 0.35) \times 10^{-6}$	$\star$
$B_s^0 \to \phi\phi\phi$	$(2.34 \pm 0.60 \pm 0.30 \pm 0.18) \times 10^{-6}$	$(2.15 \pm 0.54 \pm 0.28 \pm 0.21) \times 10^{-6}$	$\star$

Decay mode	Updated result	Previous result	
$B_s^0 \to \phi\gamma$	$(3.80 \pm 0.18 \pm 0.12 \pm 0.12 \pm 0.23) \times 10^{-5}$	$(3.52 \pm 0.17 \pm 0.11 \pm 0.29 \pm 0.12) \times 10^{-5}$	$\star$
$B_s^0 \to \mu^+\mu^-$	$(3.26 \pm 0.65^{+0.22}_{-0.11} \pm 0.10) \times 10^{-9}$	$(3.0 \pm 0.6^{+0.2}_{-0.1}) \pm 0.2 \times 10^{-9}$	
$B_s^0 \to \overline{K}^{*0}\mu^+\mu^-$	$(3.05 \pm 1.05 \pm 0.21 \pm 0.09 \pm 0.21) \times 10^{-8}$	$(2.9 \pm 1.0 \pm 0.2 \pm 0.2 \pm 0.2) \times 10^{-8}$	
$B_s^0 \to \pi^+\pi^-\mu^+\mu^-$	$(8.54 \pm 1.48 \pm 0.47 \pm 0.28 \pm 0.57) \times 10^{-8}$	$(8.6 \pm 1.5 \pm 0.5 \pm 0.5 \pm 0.7) \times 10^{-8}$	$\star$
$B_s^0 \to \phi\mu^+\mu^-$	$(7.57^{+0.43}_{-0.41} \pm 0.30 \pm 0.32) \times 10^{-7}$	$(7.97^{+0.45}_{-0.43} \pm 0.32 \pm 0.60) \times 10^{-7}$	$\star$
$q^2 \in [1.0 - 6.0]$	$(2.45^{+0.31}_{-0.30} \pm 0.07 \pm 0.10) \times 10^{-8}$	$(2.58^{+0.33}_{-0.31} \pm 0.08 \pm 0.19) \times 10^{-8}$	$\star$
$q^2 \in [15.0 - 19.0]$	$(3.83^{+0.38}_{-0.36} \pm 0.12 \pm 0.16) \times 10^{-8}$	$(4.04^{+0.39}_{-0.38} \pm 0.13 \pm 0.30) \times 10^{-8}$	$\star$
$q^2 \in [0.1 - 2.0]$	$(5.55^{+0.69}_{-0.65} \pm 0.13 \pm 0.23) \times 10^{-8}$	$(5.85^{+0.73}_{-0.69} \pm 0.14 \pm 0.44) \times 10^{-8}$	$\star$
$q^2 \in [2.0 - 5.0]$	$(2.43^{+0.40}_{-0.38} \pm 0.06 \pm 0.10) \times 10^{-8}$	$(2.56^{+0.42}_{-0.39} \pm 0.06 \pm 0.19) \times 10^{-8}$	$\star$
$q^2 \in [5.0 - 8.0]$	$(3.04^{+0.42}_{-0.40} \pm 0.07 \pm 0.13) \times 10^{-8}$	$(3.21^{+0.44}_{-0.42} \pm 0.08 \pm 0.24) \times 10^{-8}$	$\star$
$q^2 \in [11.0 - 12.5]$	$(4.46^{+0.65}_{-0.62} \pm 0.14 \pm 0.19) \times 10^{-8}$	$(4.71^{+0.69}_{-0.65} \pm 0.15 \pm 0.36) \times 10^{-8}$	$\star$
$q^2 \in [15.0 - 17.0]$	$(4.29^{+0.54}_{-0.51} \pm 0.11 \pm 0.18) \times 10^{-8}$	$(4.52^{+0.57}_{-0.54} \pm 0.12 \pm 0.34) \times 10^{-8}$	$\star$
$q^2 \in [17.0 - 19.0]$	$(3.76^{+0.54}_{-0.51} \pm 0.13 \pm 0.16) \times 10^{-8}$	$(3.96^{+0.57}_{-0.54} \pm 0.14 \pm 0.30) \times 10^{-8}$	$\star$

$\star$: also updated input $\mathcal{B}$