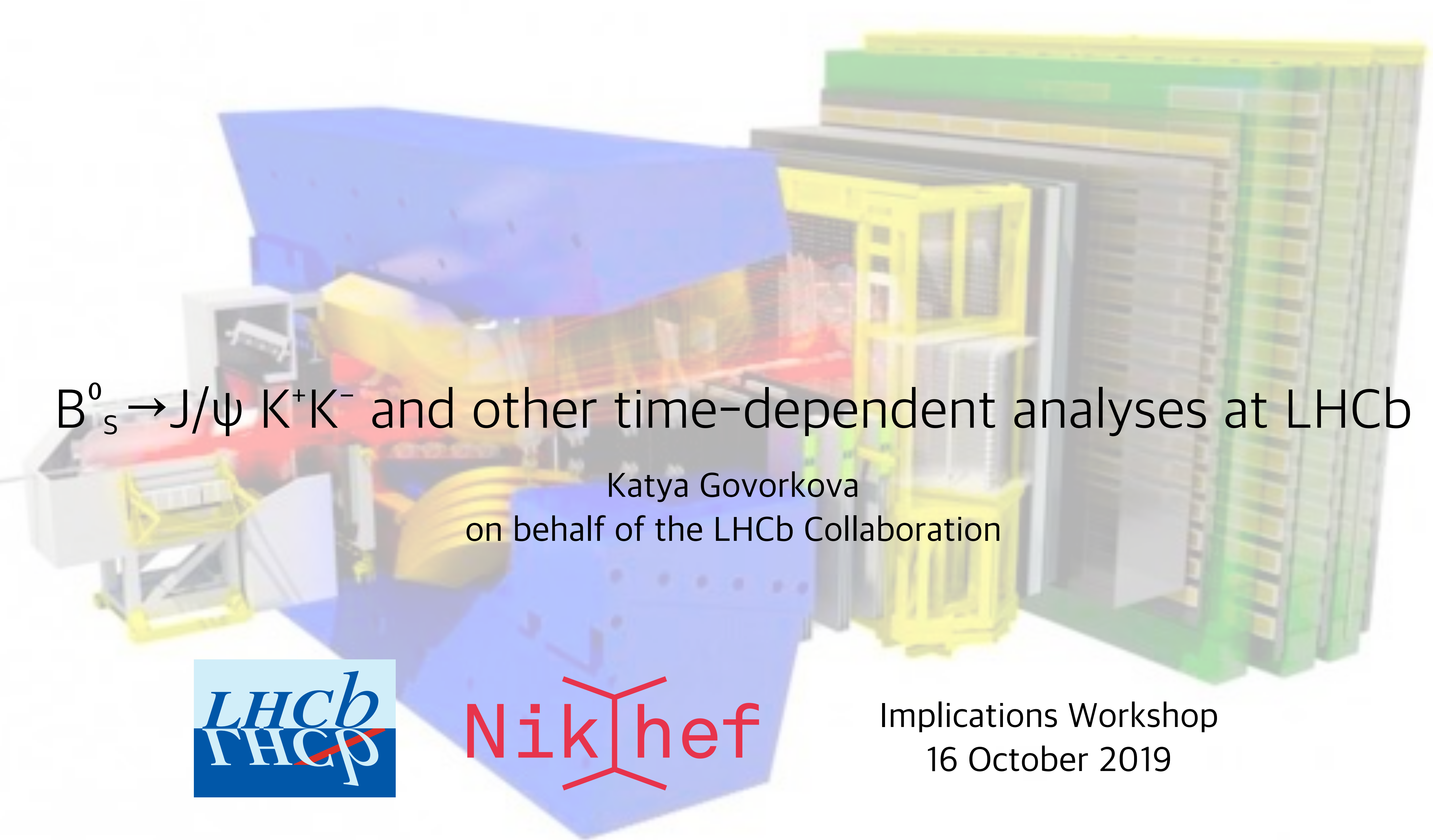


$B^0_s \to J/\psi\ K^+K^-$ and other time-dependent analyses at LHCb

Katya Govorkova
on behalf of the LHCb Collaboration

Implications Workshop
16 October 2019

$\sin(2\beta)$

$B^0 \rightarrow \psi(2S) K_s$

Run1 JHEP 11 (2017) 170

$B^0 \rightarrow J/\psi K_s$

Run1 PRL 115 (2015) 031601

$B^0 \rightarrow D^+ D^-$

Run1 PRL 117 (2016) 261801

$B^0 \rightarrow D^{*\pm} D^{\mp}$

Run1+2 LHCb-PAPER-2019-036 in preparation

γ

See talk by Hannah Pullen

$B^0_s \rightarrow D_s^{*\mp} K^\pm$

Run1 JHEP 06 (2015) 130

$B^0_s \rightarrow D_s K$

Run1 JHEP 03 (2018) 059

$B^0 \rightarrow D^\mp \pi^\pm$

Run2(15+16) JHEP 06 (2018) 084

α

$B^0_{(s)} \rightarrow h^\pm h^\mp$

Run1 PRD 98 (2018) 032004

ϕ_s from penguins

$B^0_s \rightarrow (K^+\pi^-)(K^-\pi^+)$

Run1 JHEP 03 (2018) 140

$B^0_s \rightarrow \varphi \varphi$

Run1+2(15,16) arXiv:1907.10003

$B^0_s \rightarrow \varphi \gamma$

Run1 PRL 123 (2019) 081802

ϕ_s

$B^0_s \rightarrow D_s D_s$

Run1 PRL 113 (2014) 211801

$B^0_s \rightarrow \psi(2S) \varphi$

Run1 PHYS. LETT. B762 (2016) 253

$B^0_s \rightarrow J/\psi K^+K^-$ high mass

Run1 JHEP 08 (2017) 037

$B^0_s \rightarrow J/\psi K^+K^-$

Run2(15+16) EPJC 79 (2019) 706

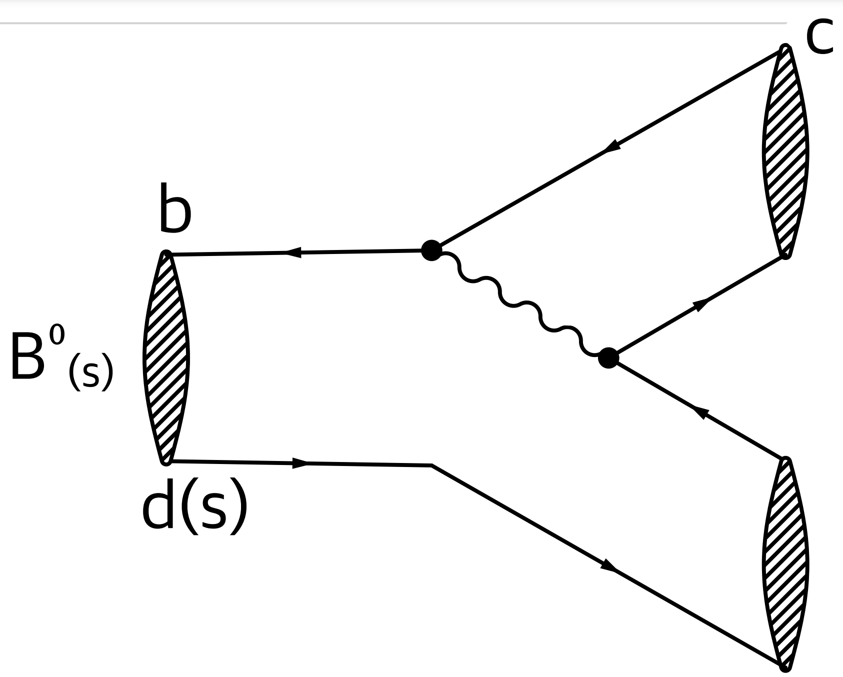
$B^0_s \rightarrow J/\psi \pi^+\pi^-$

Run2(15+16) to appear in PLB 797 (2019)

*incomplete overview

Tree dominated decays of $B^0_{(s)}$ ($\overline{B}^0_{(s)}$) via $b \rightarrow c\bar{c}s$ transition

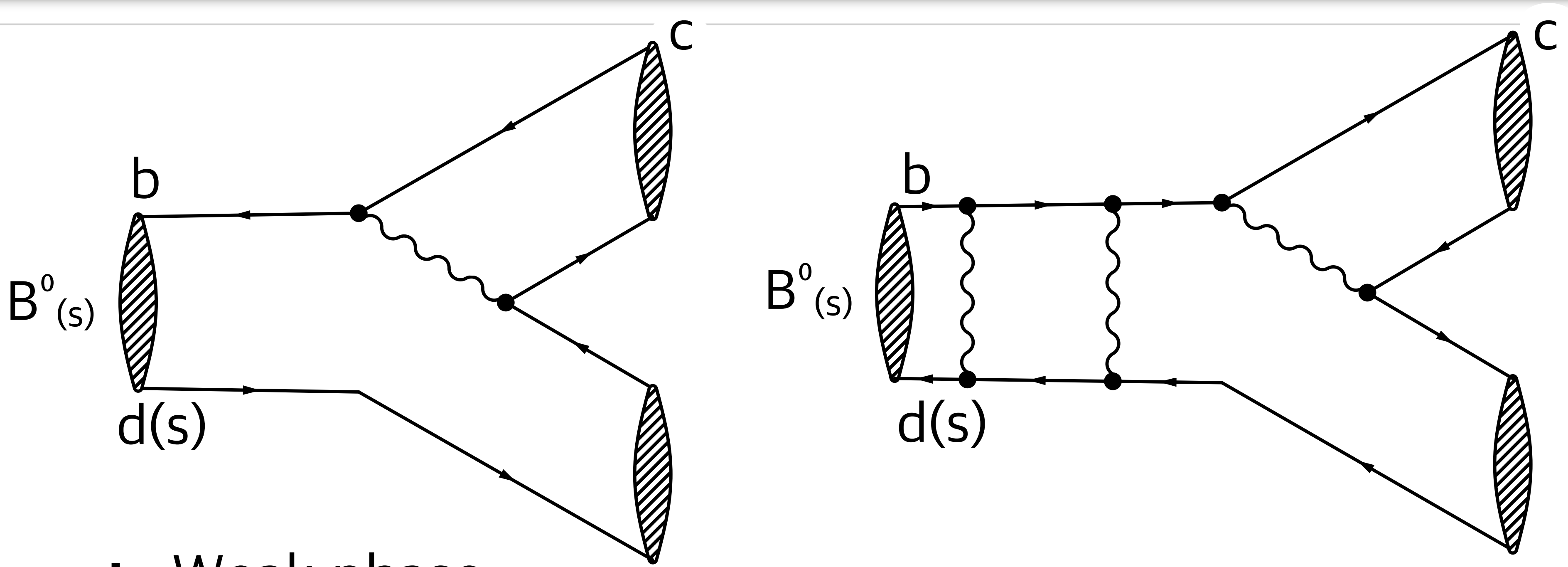
CP violation in interference between direct decay and decay after mixing



Example of time-dependent CPV

Tree dominated decays of $B^0_{(s)}$ ($\overline{B}^0_{(s)}$) via $b \rightarrow c\bar{c}s$ transition

CP violation in interference between direct decay and decay after mixing



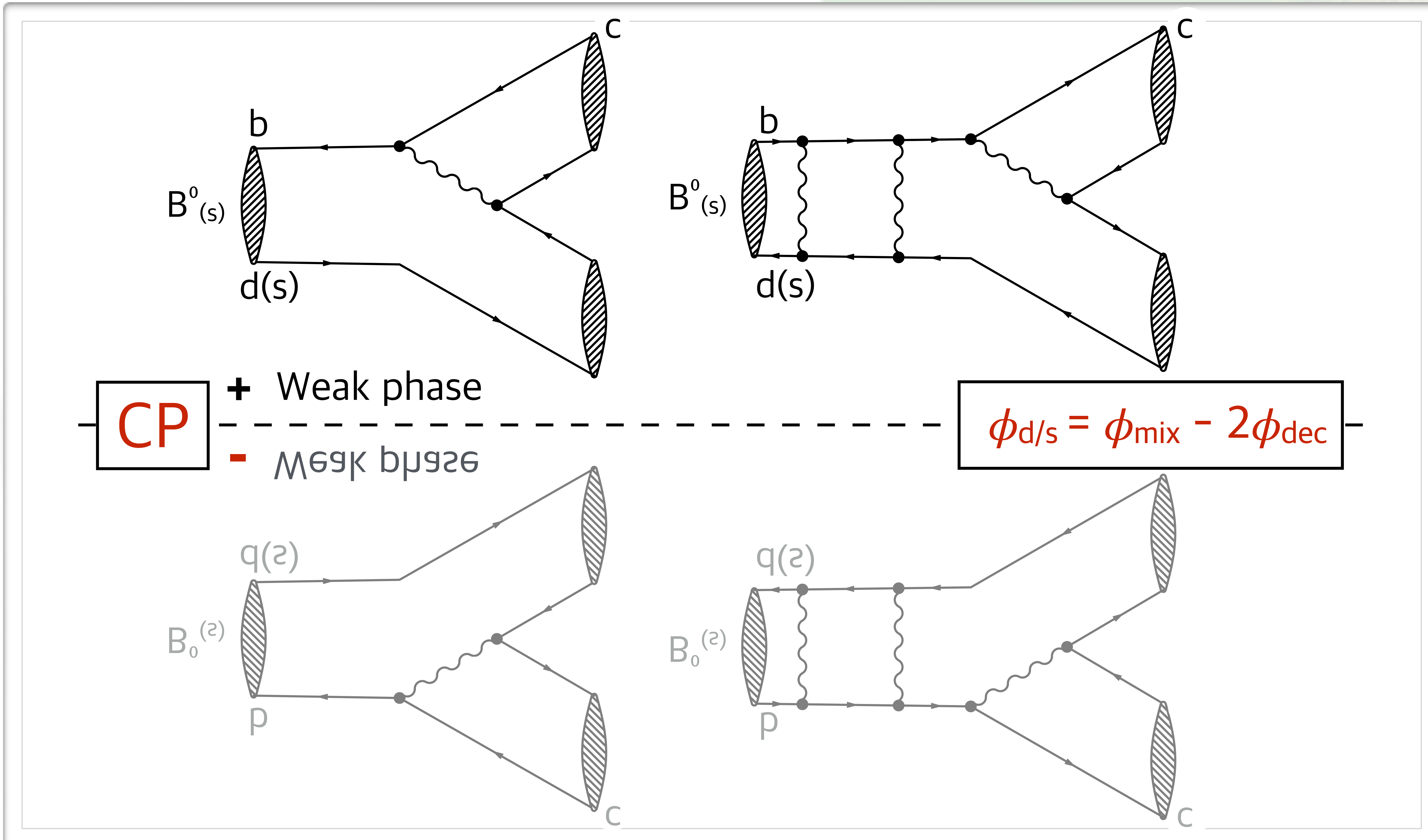
+ Weak phase

$$\phi_{d/s} = \phi_{mix} - 2\phi_{dec}$$

Example of time-dependent CPV

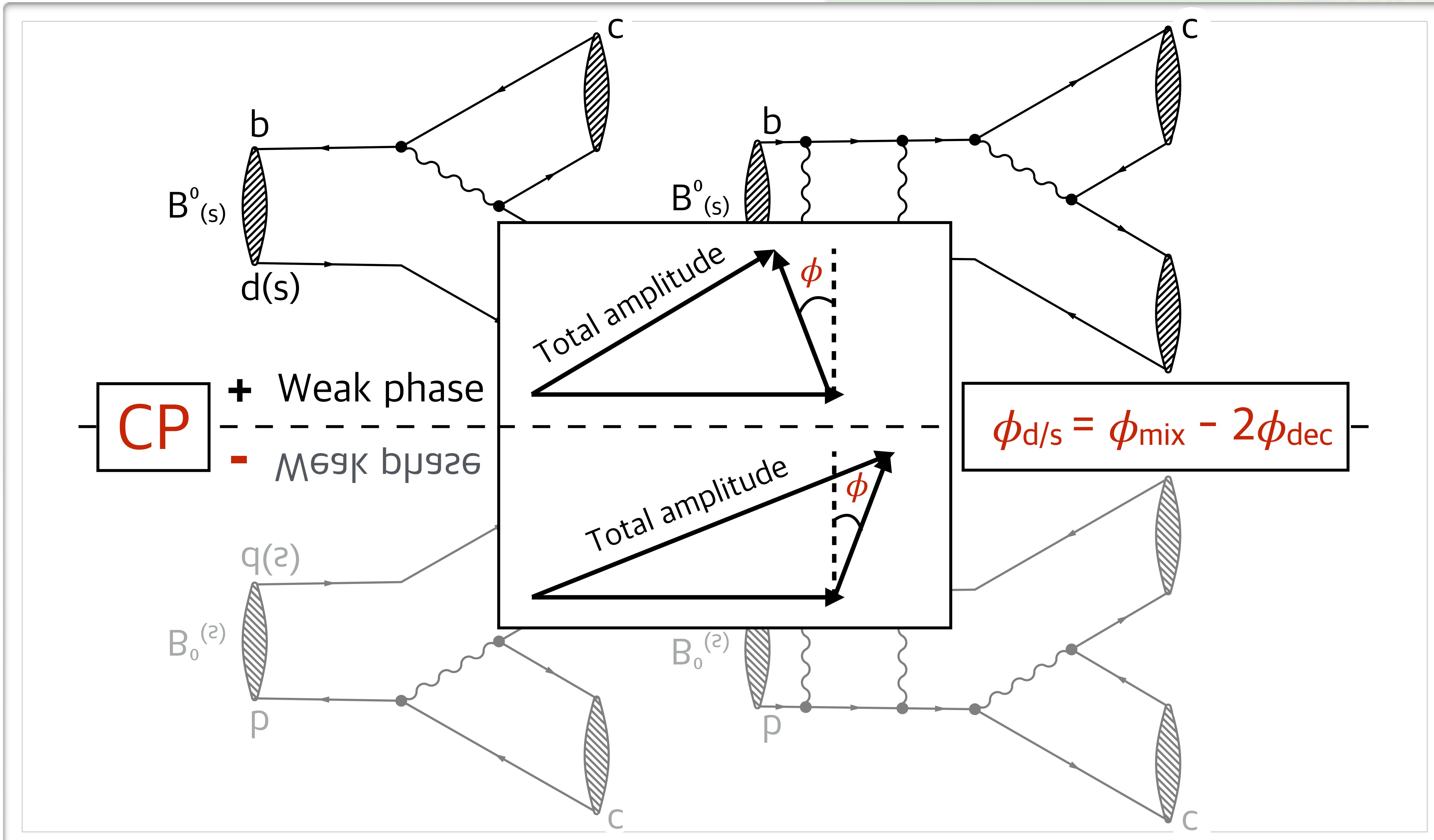
Tree dominated decays of $B^0_{(s)}$ ($\bar{B}^0_{(s)}$) via $b \to c\bar{c}s$ transition

CP violation in interference between direct decay and decay after mixing



Tree dominated decays of $B^0_{(s)}$ ($\bar{B}^0_{(s)}$) via $b \to c\bar{c}s$ transition

CP violation in interference between direct decay and decay after mixing



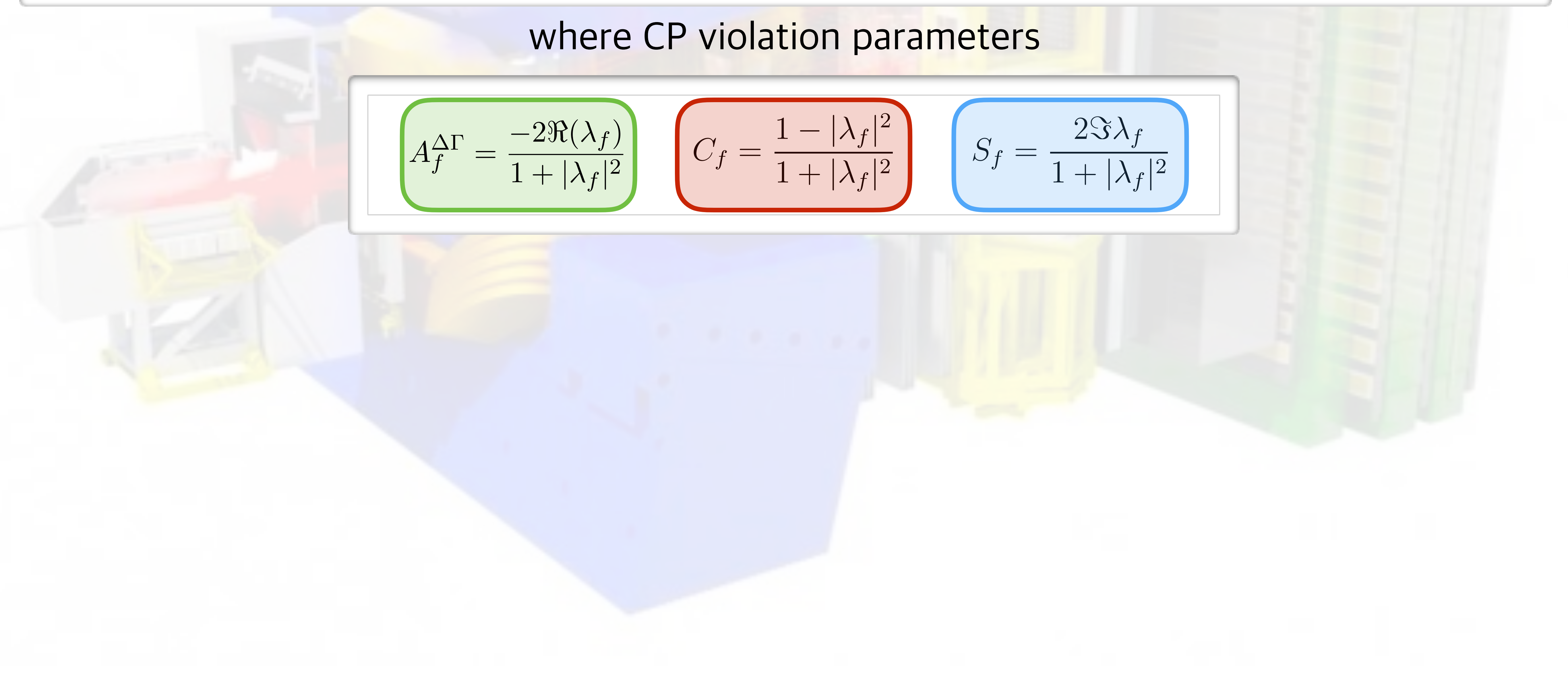
Master equations for time-dependent decay rates of neutral mesons

$$\frac{d\Gamma_{B_s^0\to f}(t)}{dt\, e^{-\Gamma_s t}} = \frac{1}{2}|A_f|^2(1+|\lambda_f|^2)\left[\cosh\left(\frac{\Delta\Gamma_s t}{2}\right) + A_f^{\Delta\Gamma}\sinh\left(\frac{\Delta\Gamma_s t}{2}\right) + C_f\cos(\Delta m_s t) - S_f\sin(\Delta m_s t)\right]$$

$$\frac{d\Gamma_{\bar{B}_s^0\to f}(t)}{dt\, e^{-\Gamma_s t}} = \frac{1}{2}|A_f|^2\left|\frac{p}{q}\right|^2(1+|\lambda_f|^2)\left[\cosh\left(\frac{\Delta\Gamma_s t}{2}\right) + A_f^{\Delta\Gamma}\sinh\left(\frac{\Delta\Gamma_s t}{2}\right) - C_f\cos(\Delta m_s t) + S_f\sin(\Delta m_s t)\right]$$

where CP violation parameters

$$A_f^{\Delta\Gamma} = \frac{-2\Re(\lambda_f)}{1+|\lambda_f|^2} \qquad C_f = \frac{1-|\lambda_f|^2}{1+|\lambda_f|^2} \qquad S_f = \frac{2\Im\lambda_f}{1+|\lambda_f|^2}$$



Master equations for time-dependent decay rates of neutral mesons

$$\frac{d\Gamma_{B_s^0\to f}(t)}{dt\, e^{-\Gamma_s t}} = \frac{1}{2}|A_f|^2(1+|\lambda_f|^2)\left[\cosh\left(\frac{\Delta\Gamma_s t}{2}\right) + A_f^{\Delta\Gamma}\sinh\left(\frac{\Delta\Gamma_s t}{2}\right) + C_f\cos(\Delta m_s t) - S_f\sin(\Delta m_s t)\right]$$

$$\frac{d\Gamma_{\bar{B}_s^0\to f}(t)}{dt\, e^{-\Gamma_s t}} = \frac{1}{2}|A_f|^2\left|\frac{p}{q}\right|^2(1+|\lambda_f|^2)\left[\cosh\left(\frac{\Delta\Gamma_s t}{2}\right) + A_f^{\Delta\Gamma}\sinh\left(\frac{\Delta\Gamma_s t}{2}\right) - C_f\cos(\Delta m_s t) + S_f\sin(\Delta m_s t)\right]$$

where CP violation parameters

$$A_f^{\Delta\Gamma} = \frac{-2\Re(\lambda_f)}{1+|\lambda_f|^2} \qquad C_f = \frac{1-|\lambda_f|^2}{1+|\lambda_f|^2} \qquad S_f = \frac{2\Im\lambda_f}{1+|\lambda_f|^2}$$

experimental effects that have to be taken care of in CPV measurements

$$pdf \propto \varepsilon(t)\left(\frac{d\Gamma}{dt}\otimes G(t\,|\,\sigma_t)\right)(1-2\omega)$$

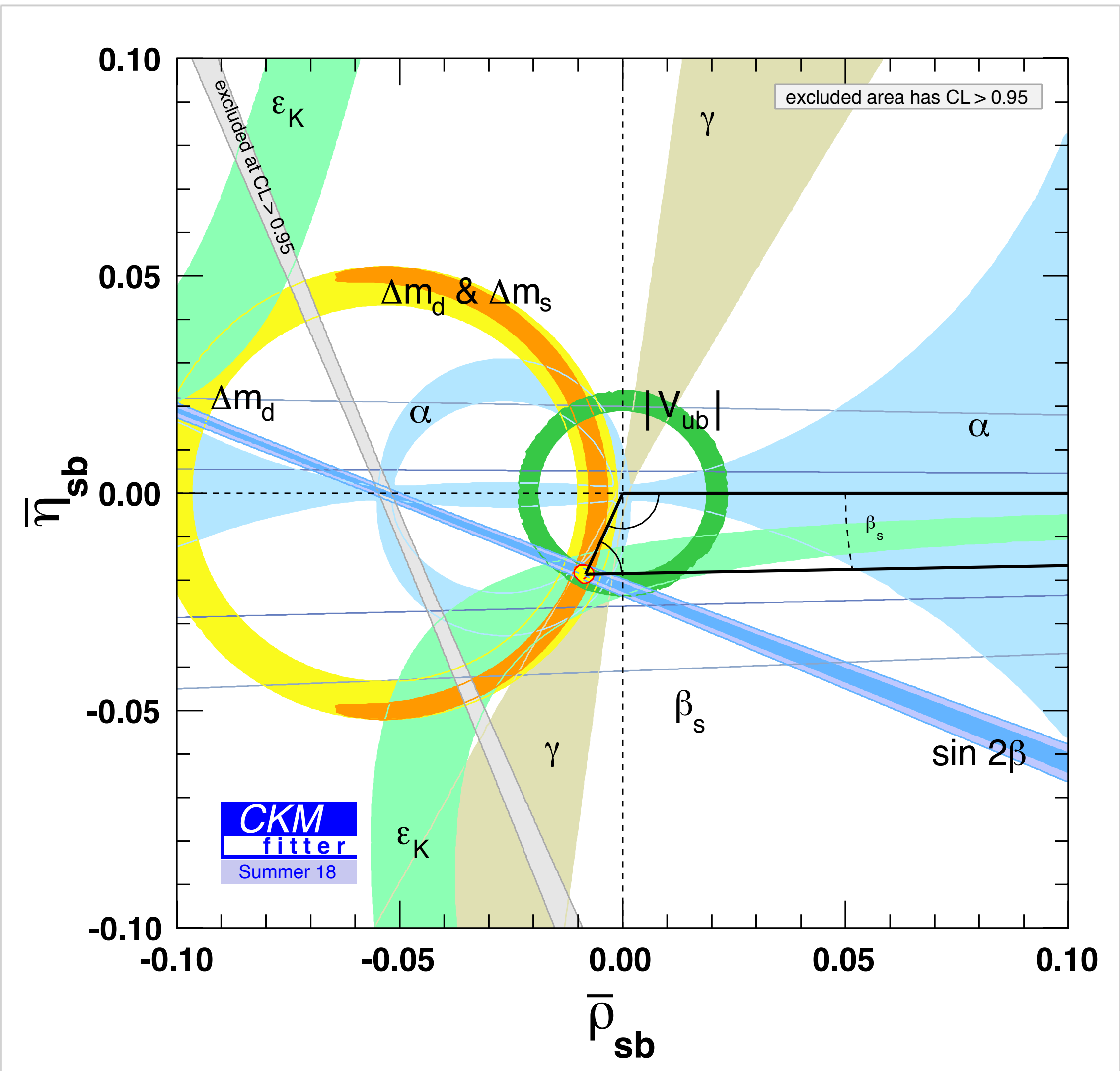
ω - mistag probability of flavour tagging

ε - efficiency as a function of observables

σ_t - decay time resolution

- Sensitive probe of New Physics in B^0_s mixing
- Precise test of Standard Model through the measurement of ϕ_s

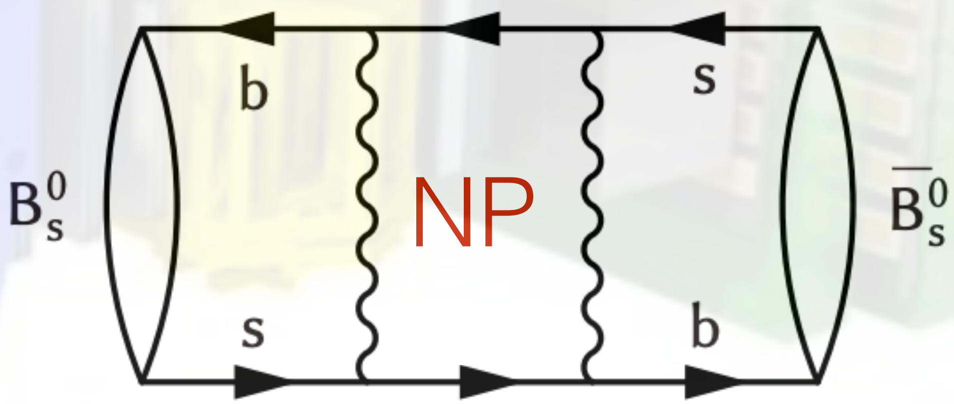
[CKM fitter]



$$\phi_s^{SM} \approx -2\arg\left(\frac{V_{ts}V_{tb}^*}{V_{cs}V_{cb}^*}\right) = -0.03686\,^{+0.00096}_{-0.00068}\ \text{rad}$$

If $\phi_s^{exp} \not\approx \phi_s^{SM}$

New Physics!



- Sensitive probe of New Physics in B^0_s mixing
- Precise test of Standard Model through the measurement of ϕ_s

[CKM fitter]

$$\phi_s^{SM} \approx -2\arg\left(\frac{V_{ts}V_{tb}^*}{V_{cs}V_{cb}^*}\right) = -0.03686\,^{+0.00096}_{-0.00068}\ \text{rad}$$

Access to penguin contribution with SU(3) counterparts not suppressed relative to tree level

$B^0_s \to J/\psi\ \bar{K}^{*0}$

Run1 JHEP 11 (2015) 082

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

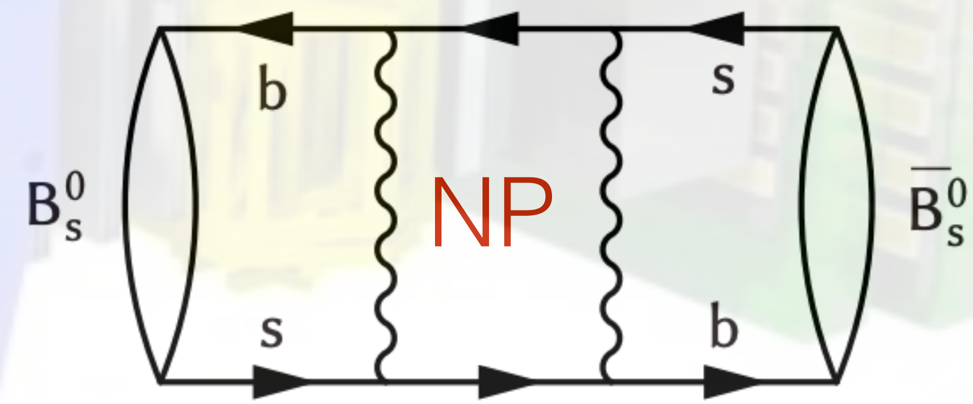
Run1 PHYS. LETT. B742 (2015) 38

$B^0_s \to J/\psi\ K^0_s$

Run1 JHEP 06 (2015) 131

If $\phi_s^{exp} \not\approx \phi_s^{SM}$ New Physics!

Assuming contribution from penguins is negligible



CP-violating phase ϕ_s

- Sensitive probe of New Physics in B^0_s mixing
- Precise test of Standard Model through the measurement of ϕ_s

[CKM fitter]

$B^0_s \to D_s D_s$

Run1 PRL 113 (2014) 211801

$B^0_s \to \psi(2S)\,\varphi$

Run1 PHYS. LETT. B762 (2016) 253

$B^0_s \to J/\psi K^+K^-$ high mass

Run1 JHEP 08 (2017) 037

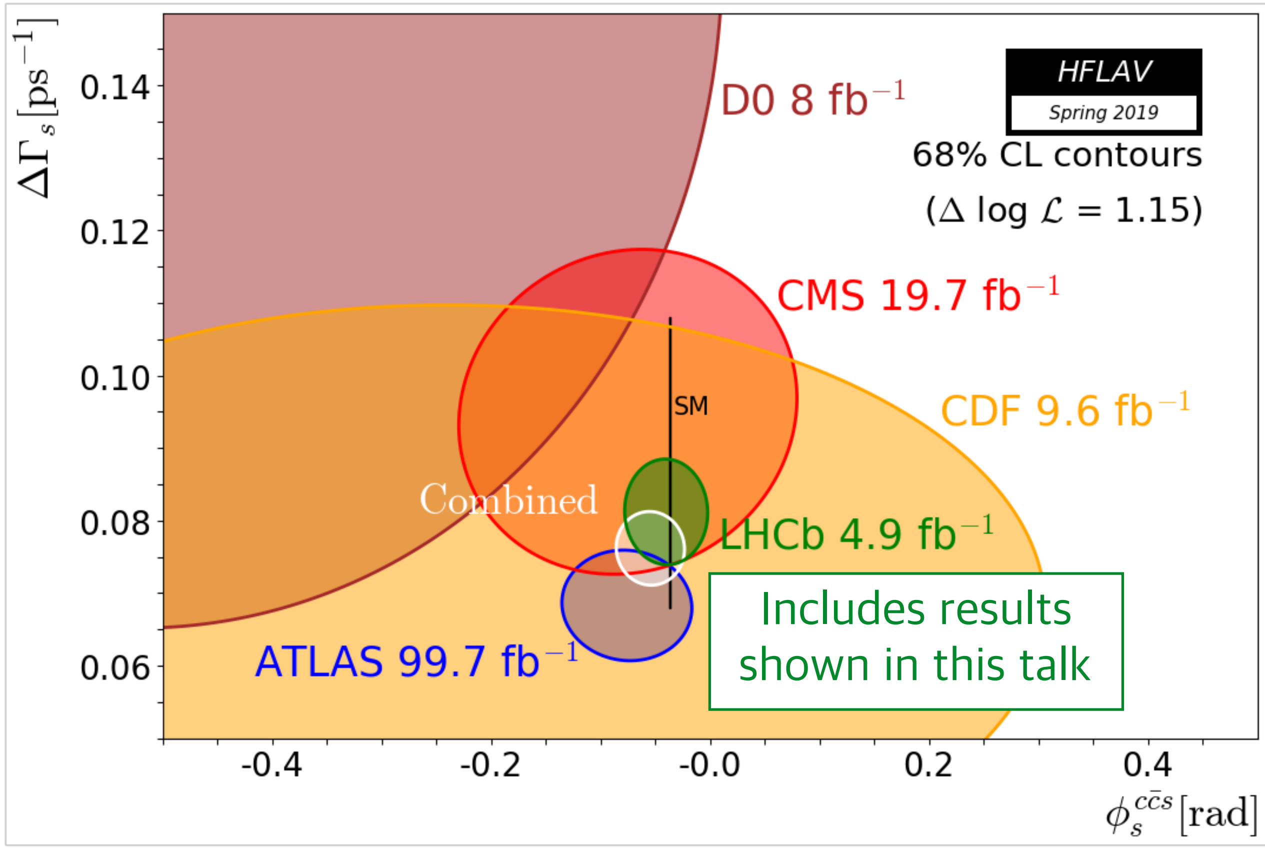
$B^0_s \to J/\psi K^+K^-$

Run2(15+16) EPJC 79 (2019) 706

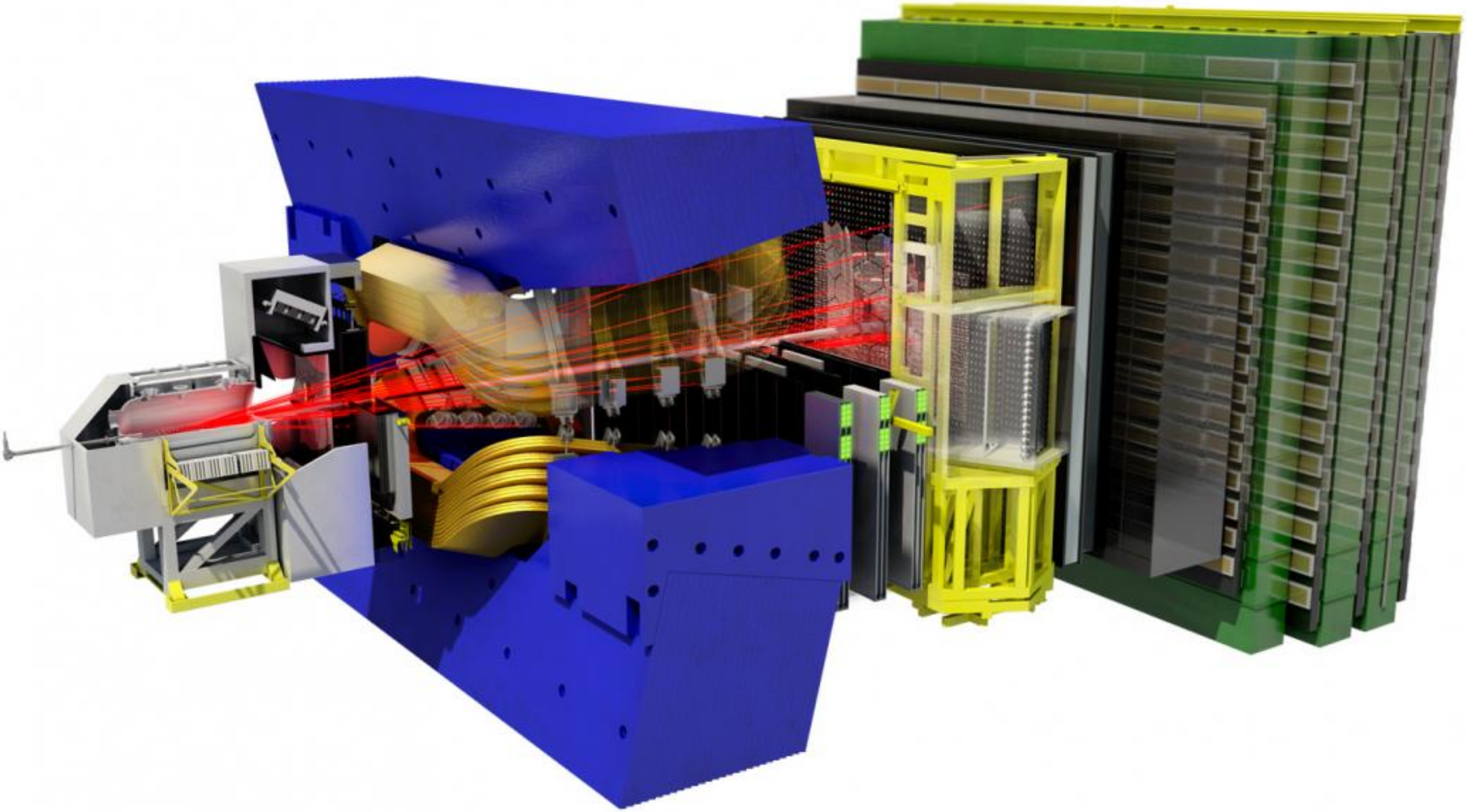
$B^0_s \to J/\psi \pi^+\pi^-$

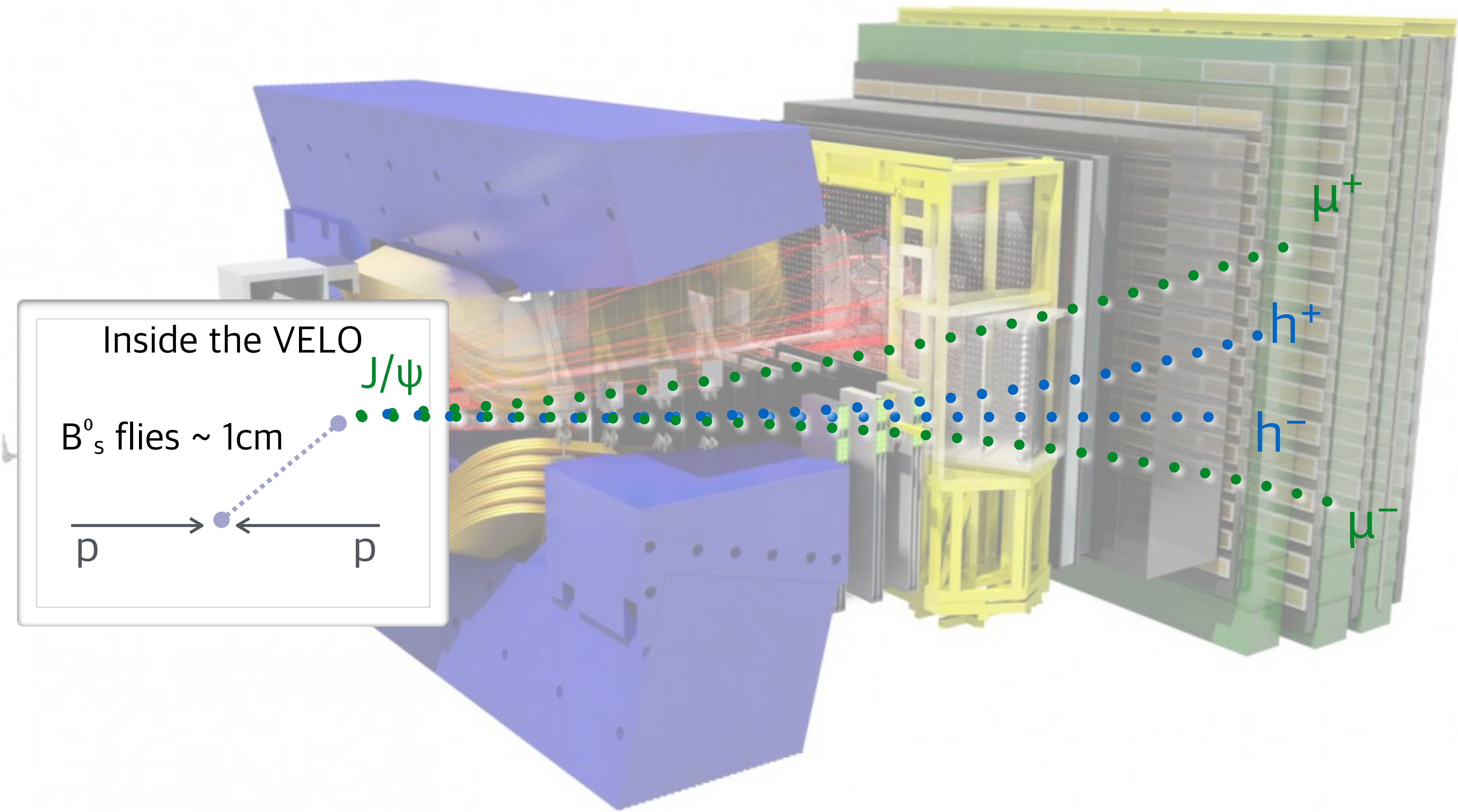
Run2(15+16) to appear in PLB 797 (2019)

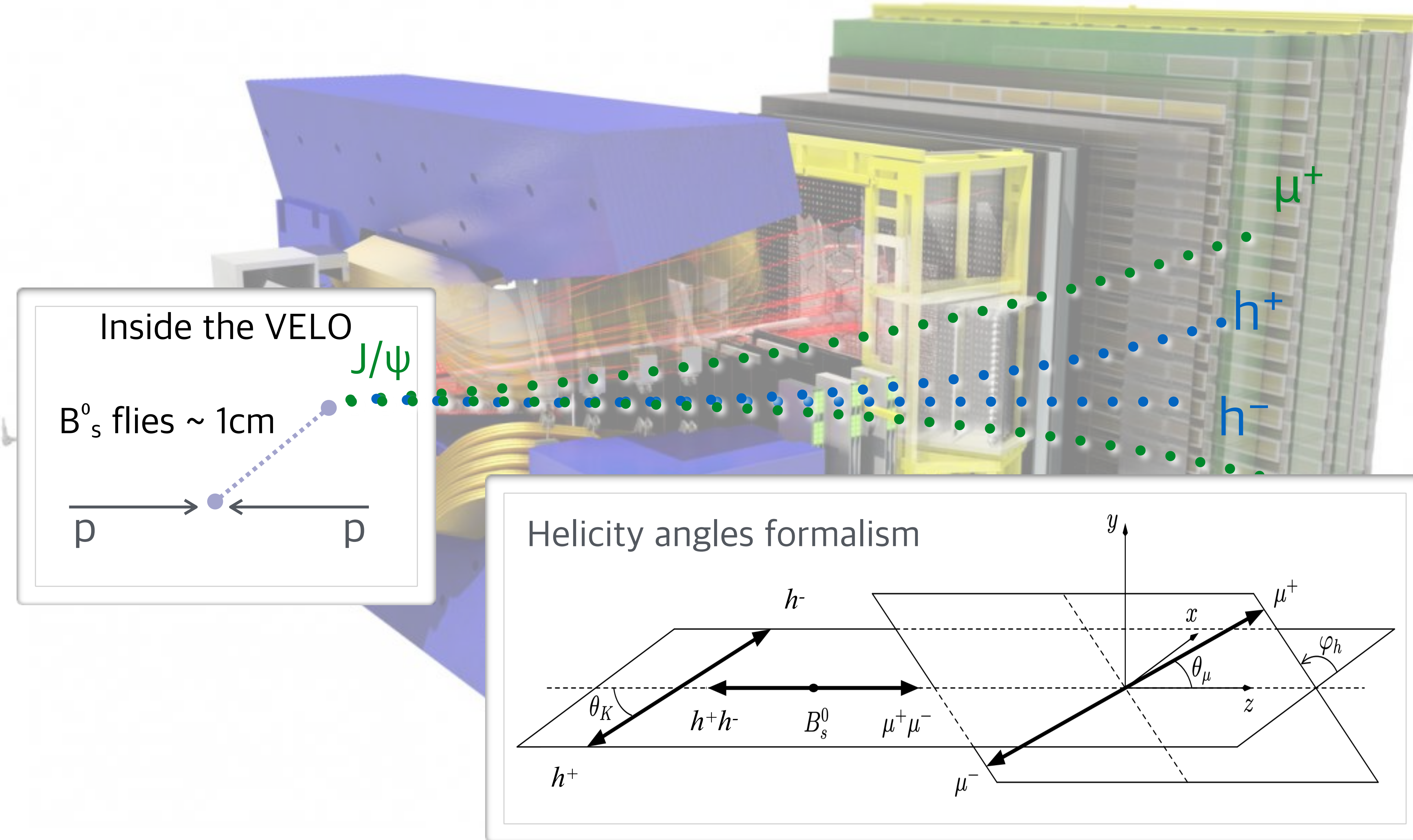
$$\phi_s^{SM} \approx -2\arg\left(\frac{V_{ts}V_{tb}^*}{V_{cs}V_{cb}^*}\right) = -0.03686\,^{+0.00096}_{-0.00068}\ \text{rad}$$



Measurement of ϕ_s at LHCb



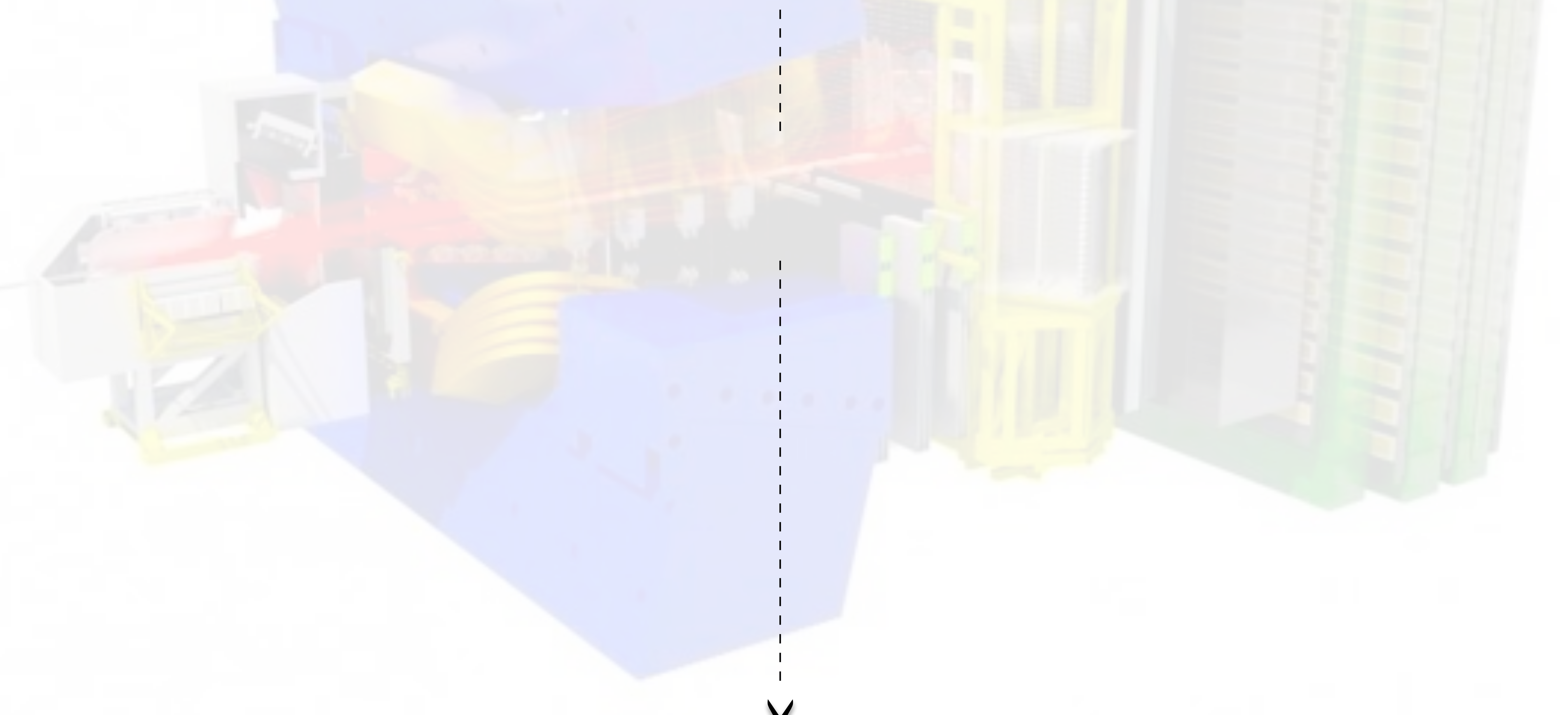

Inside the VELO
J/ψ
B^0_s flies ~ 1cm
p
p
μ^+
h^+
h^-
μ^-


μ+
h+
h−
Inside the VELO
J/ψ
B°s flies ~ 1cm
p
p
Helicity angles formalism
y
h-
μ+
x
φh
θμ
θK
h+h-
B0s
μ+μ−
z
h+
μ−

$B^0_s \to J/\psi\, K^+K^-$	$B^0_s \to J/\psi\, \pi^+\pi^-$
EPJC 79 (2019) 706	To appear in PLB 797 (2019)

Using 2015 (0.3 fb^{-1}) and 2016 (1.6 fb^{-1}) data

measure ϕ_s , $|\lambda|$ and



$B^0_s \to J/\psi K^+K^-$

EPJC 79 (2019) 706

$B^0_s \to J/\psi \pi^+\pi^-$

To appear in PLB 797 (2019)

Using 2015 (0.3 fb^{-1}) and 2016 (1.6 fb^{-1}) data

measure ϕ_s , $|\lambda|$ and

$\Delta\Gamma_s$ and $\Gamma_s - \Gamma_{B^0}$

to test the Heavy Quark Expansion

prediction of $\Gamma_s / \Gamma_{B^0} = 1.0006 \pm 0.0025$ [ref]

Analyses strategy

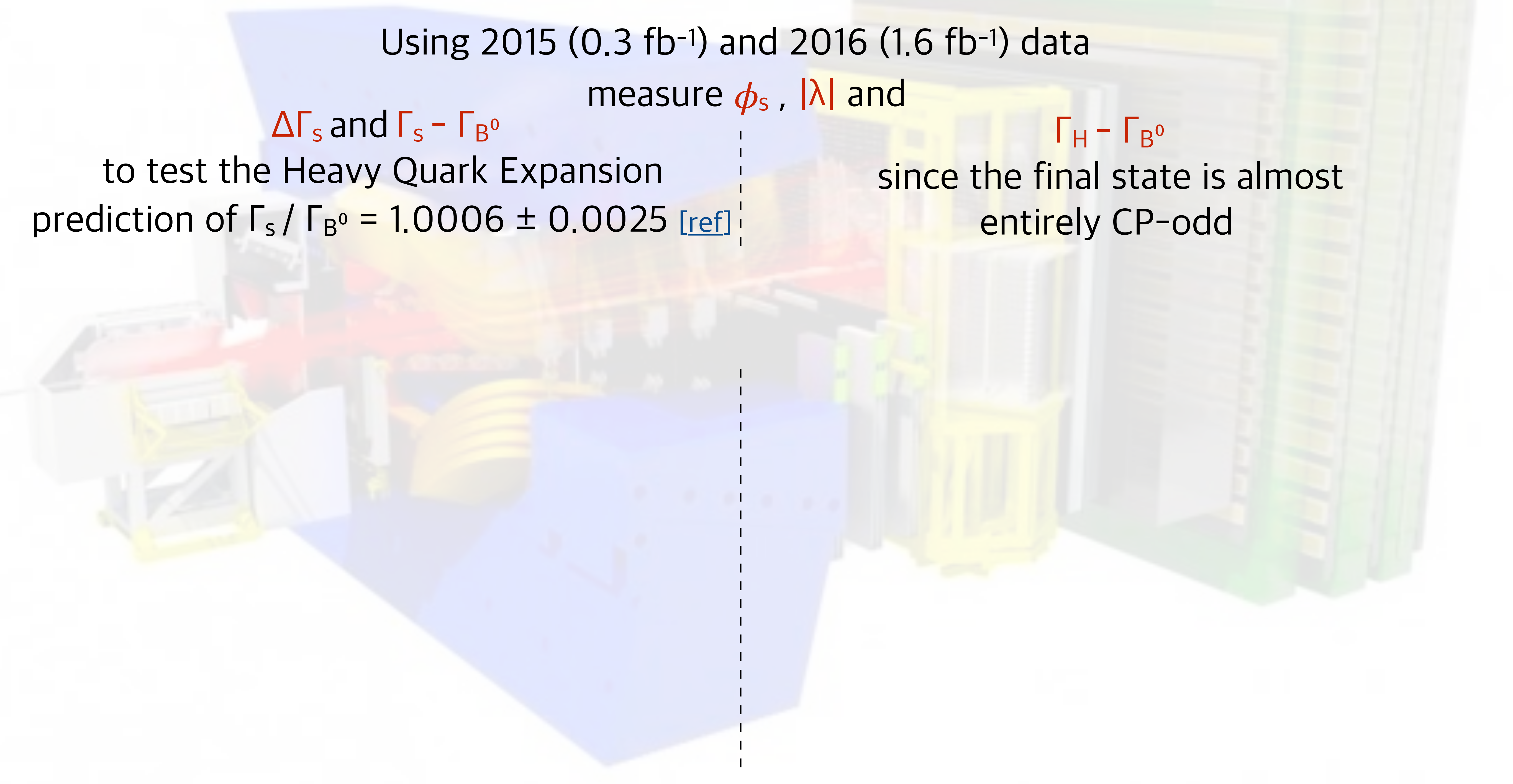
$B^0_s \to J/\psi\, K^+K^-$	$B^0_s \to J/\psi\, \pi^+\pi^-$
EPJC 79 (2019) 706	To appear in PLB 797 (2019)

Using 2015 (0.3 fb^{-1}) and 2016 (1.6 fb^{-1}) data

measure ϕ_s , $|\lambda|$ and

$\Delta\Gamma_s$ and $\Gamma_s - \Gamma_{B^0}$
to test the Heavy Quark Expansion prediction of $\Gamma_s / \Gamma_{B^0} = 1.0006 \pm 0.0025$ [ref]

$\Gamma_H - \Gamma_{B^0}$
since the final state is almost entirely CP-odd



Analyses strategy

$B^0_s \to J/\psi K^+K^-$	$B^0_s \to J/\psi \pi^+\pi^-$
EPJC 79 (2019) 706	To appear in PLB 797 (2019)

Using 2015 (0.3 fb^{-1}) and 2016 (1.6 fb^{-1}) data

measure ϕ_s , $|\lambda|$ and

$\Delta\Gamma_s$ and $\Gamma_s - \Gamma_{B^0}$
to test the Heavy Quark Expansion prediction of $\Gamma_s / \Gamma_{B^0} = 1.0006 \pm 0.0025$ [ref]

$\Gamma_H - \Gamma_{B^0}$
since the final state is almost entirely CP-odd

Simultaneous fit to the decay time and three helicity angles

$B^0_s \to J/\psi K^+K^-$

EPJC 79 (2019) 706

$B^0_s \to J/\psi \pi^+\pi^-$

To appear in PLB 797 (2019)

Using 2015 (0.3 fb^{-1}) and 2016 (1.6 fb^{-1}) data

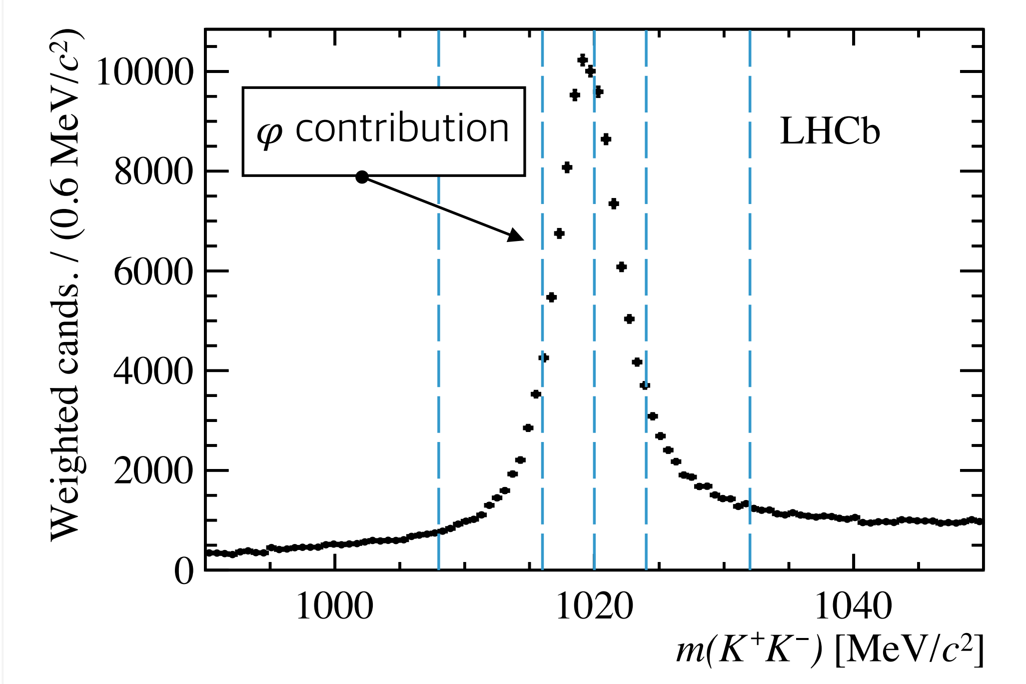
measure ϕ_s , $|\lambda|$ and

$\Delta\Gamma_s$ and $\Gamma_s - \Gamma_{B^0}$
to test the Heavy Quark Expansion prediction of $\Gamma_s / \Gamma_{B^0} = 1.0006 \pm 0.0025$ [ref]

$\Gamma_H - \Gamma_{B^0}$
since the final state is almost entirely CP-odd

Simultaneous fit to the decay time and three helicity angles

in 6 $m(K^+K^-)$ bins



$B^0_s \to J/\psi K^+K^-$	$B^0_s \to J/\psi \pi^+\pi^-$
EPJC 79 (2019) 706	To appear in PLB 797 (2019)

Using 2015 (0.3 fb^{-1}) and 2016 (1.6 fb^{-1}) data

measure ϕ_s , $|\lambda|$ and

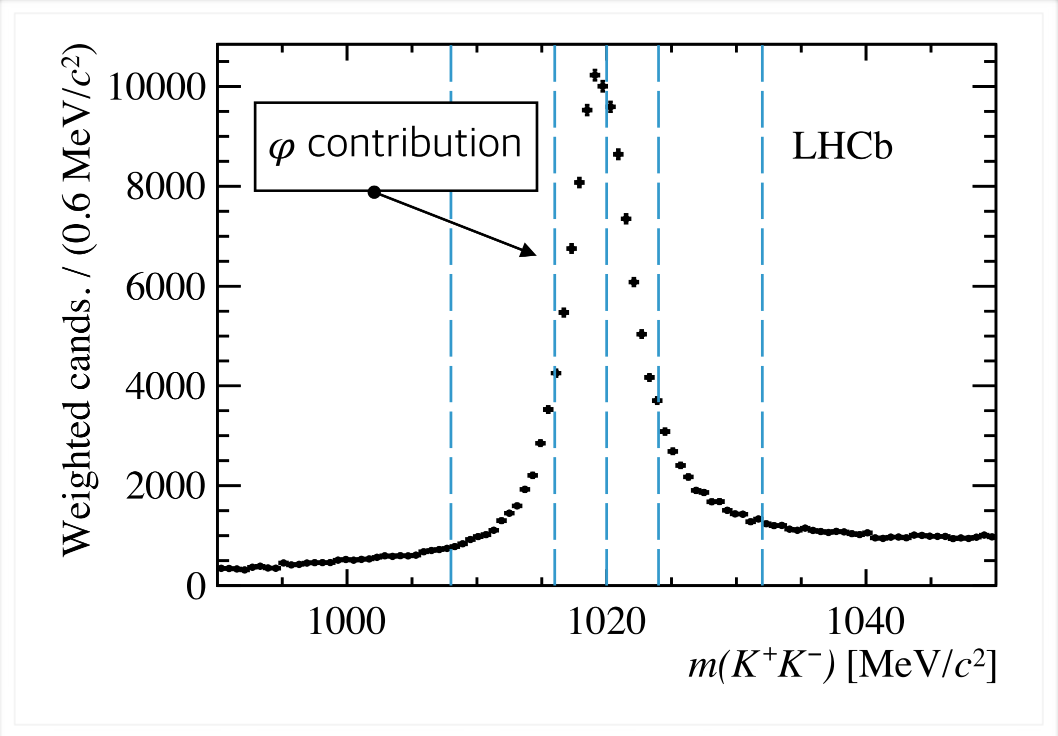
$\Delta\Gamma_s$ and $\Gamma_s - \Gamma_{B^0}$ to test the Heavy Quark Expansion prediction of $\Gamma_s / \Gamma_{B^0} = 1.0006 \pm 0.0025$ [ref]

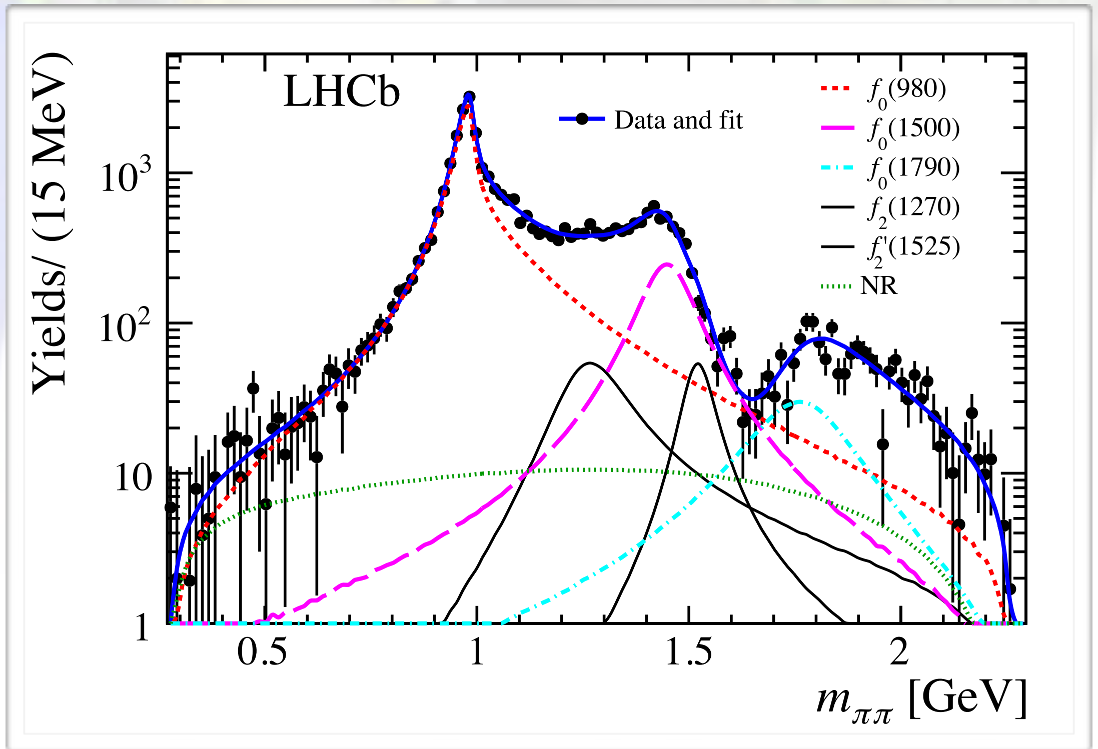
$\Gamma_H - \Gamma_{B^0}$ since the final state is almost entirely CP-odd

Simultaneous fit to the decay time and three helicity angles

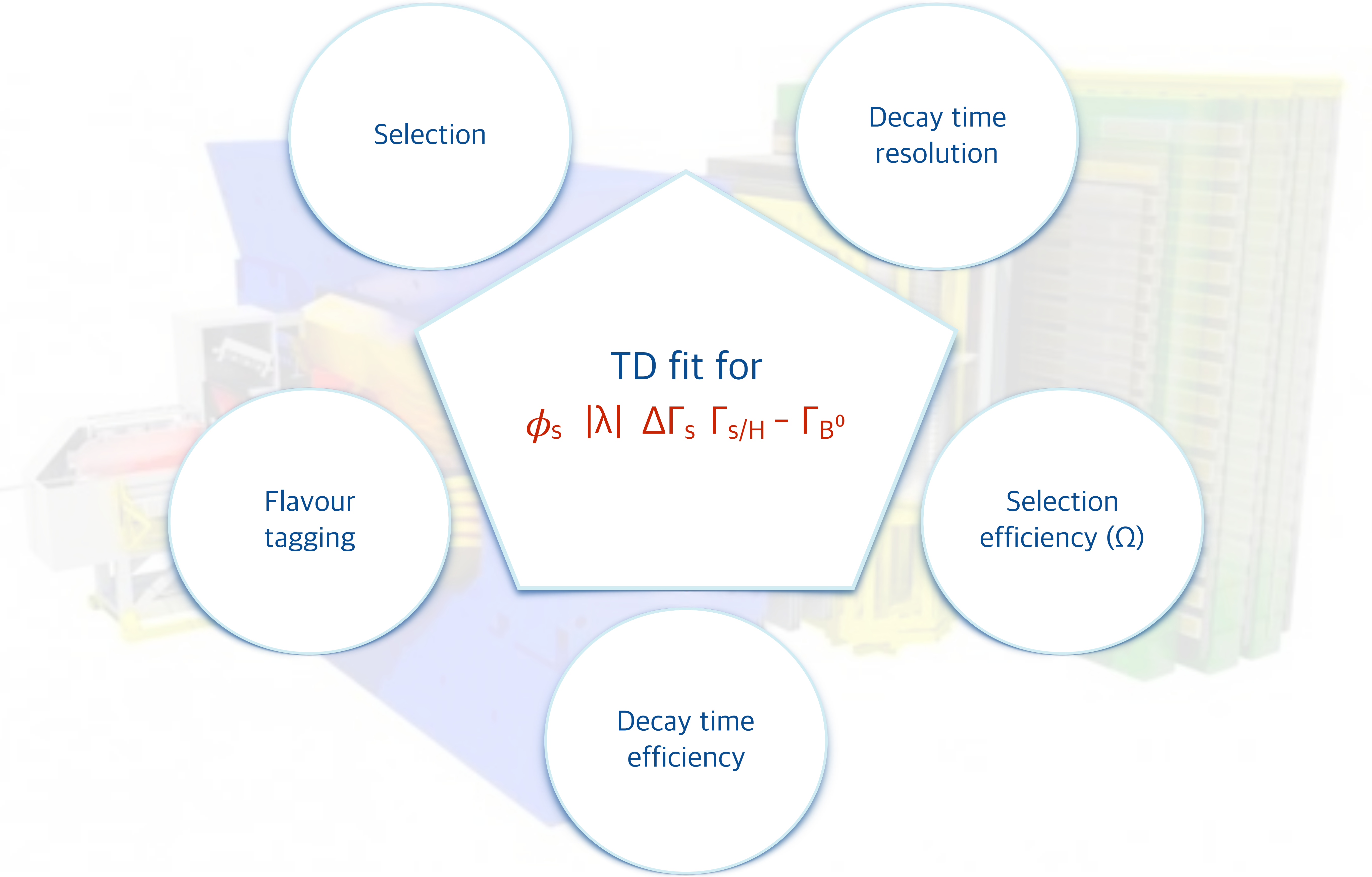
in 6 $m(K^+K^-)$ bins

and $m(\pi^+\pi^-)$





Measurement of ϕ_s



Selection

Decay time resolution

TD fit for

ϕ_s $|\lambda|$ $\Delta\Gamma_s$ $\Gamma_{s/H} - \Gamma_{B^0}$

Flavour tagging

Selection efficiency (Ω)

Decay time efficiency

$B^0_s \to J/\psi\, K^+K^-$

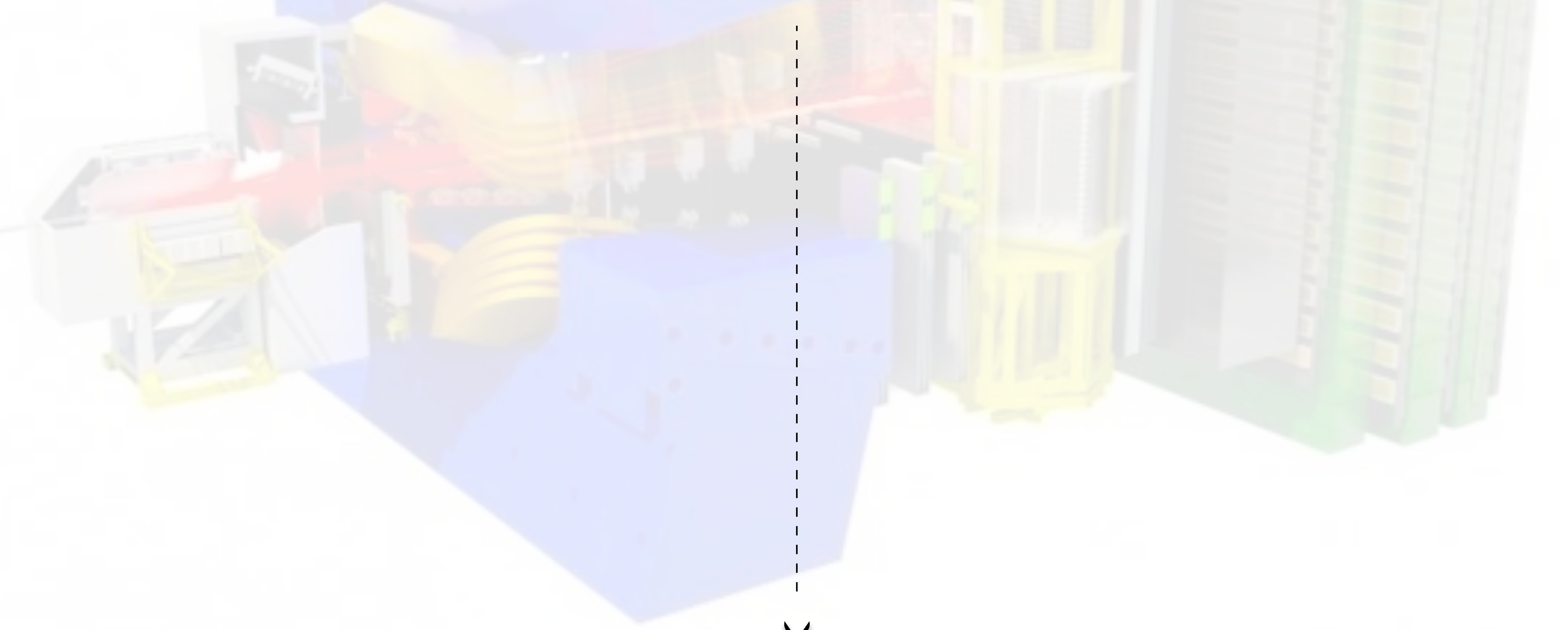
EPJC 79 (2019) 706

$B^0_s \to J/\psi\, \pi^+\pi^-$

To appear in PLB 797 (2019)

Boosted decision tree is trained to select signal candidates

$$\sigma^{-1}(\phi_s) \sim \sqrt{N}\, Q_{eff}^{1/2}\, e^{-\frac{\sigma_t^2 \Delta m^2}{2}}$$



Selection and mass fit

$B^0_s \to J/\psi\, K^+K^-$

EPJC 79 (2019) 706

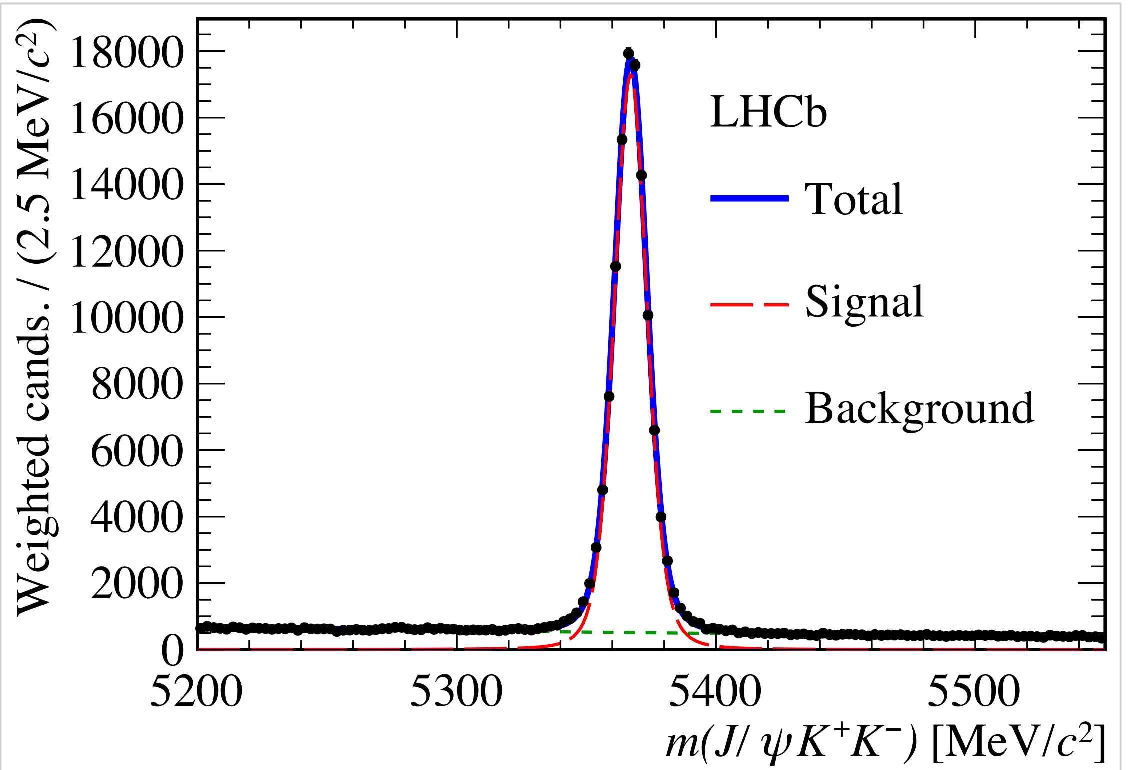
$B^0_s \to J/\psi\, \pi^+\pi^-$

To appear in PLB 797 (2019)

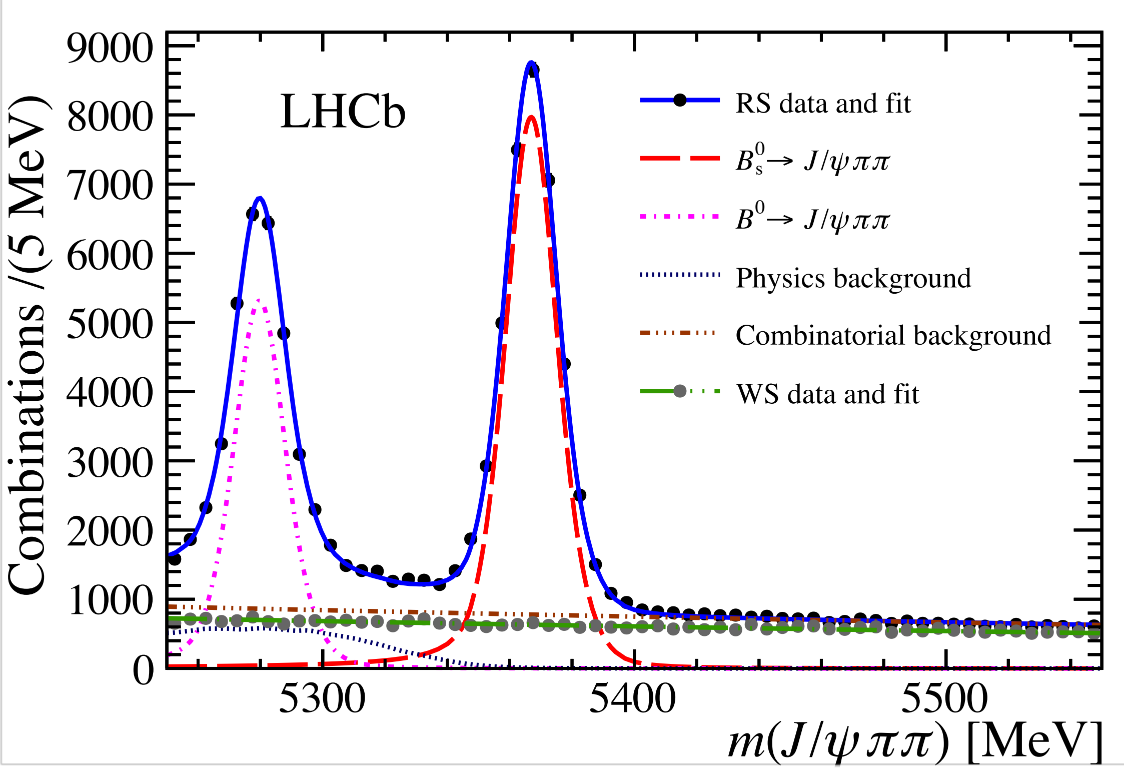
Boosted decision tree is trained to select signal candidates

$$\sigma^{-1}(\phi_s) \sim \sqrt{N}\, Q_{eff}^{1/2}\, e^{-\frac{\sigma_t^2 \Delta m^2}{2}}$$

$N(B^0_s \to J/\psi\, K^+K^-) \simeq 117\,000$



$N(B^0_s \to J/\psi\, \pi^+\pi^-) \simeq 33\,530$



Measurement of ϕ_s

Selection

Decay time resolution

TD fit for

ϕ_s $|\lambda|$ $\Delta\Gamma_s$ $\Gamma_{s/H} - \Gamma_{B^0}$

Flavour tagging

Selection efficiency (Ω)

Decay time efficiency

Decay time resolution

$B^0_s \to J/\psi K^+K^-$

EPJC 79 (2019) 706

σ_{eff} = 45.5 fs

$B^0_s \to J/\psi \pi^+\pi^-$

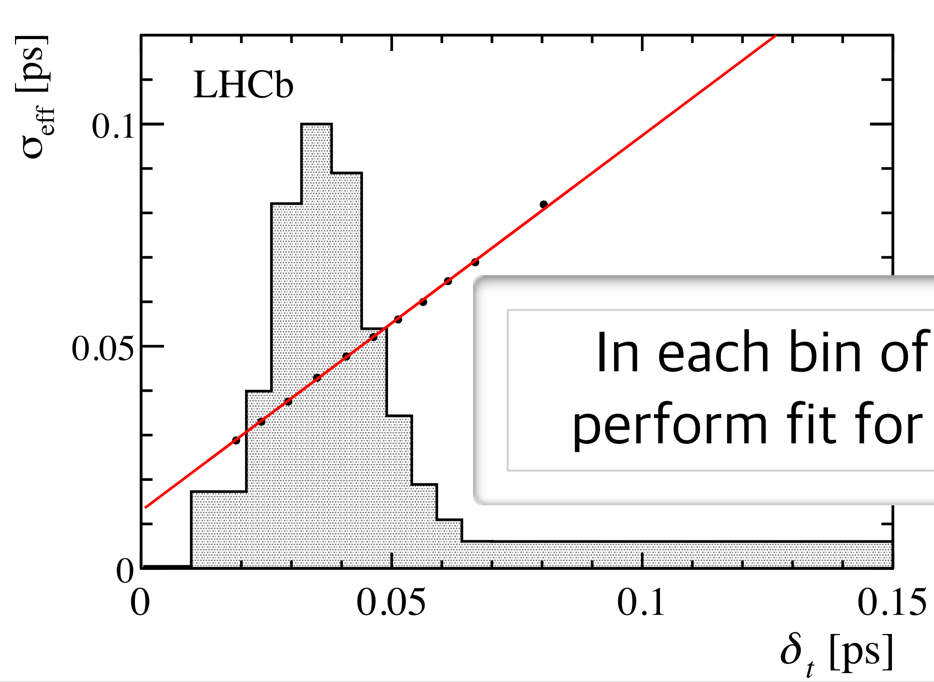
To appear in PLB 797 (2019)

σ_{eff} = 41.5 fs

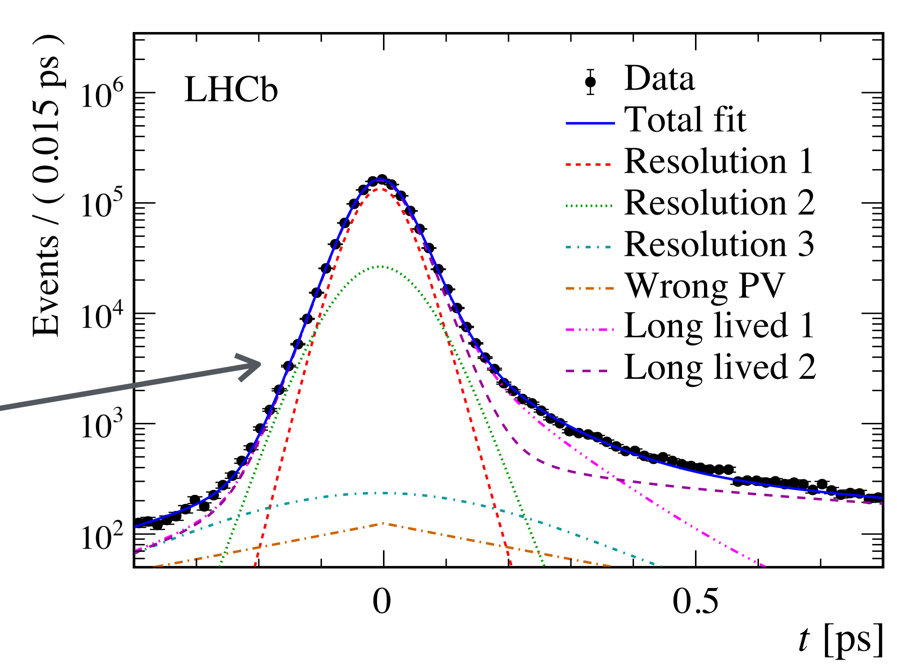
$$\sigma^{-1}(\phi_s) \sim \sqrt{N}\, Q_{eff}^{1/2}\, e^{-\frac{\sigma_t^2 \Delta m^2}{2}}$$

Per-candidate decay time error (δ_t) is calibrated using prompt J/ψ sample

$$\sigma_{eff} = \sqrt{(-2/\Delta m_s^2)\ln D}\,, D = \sum_{i=1}^{3} f_i e^{-\sigma_i^2 \Delta m_s^2/2}$$



In each bin of δ_t perform fit for σ_{eff}



Selection

Decay time resolution

TD fit for

ϕ_s $|\lambda|$ $\Delta\Gamma_s$ $\Gamma_{s/H} - \Gamma_{B^0}$

Flavour tagging

Selection efficiency (Ω)

Decay time efficiency

Selection efficiency

$B^0_s \to J/\psi K^+K^-$

[EPJC 79 (2019) 706]

$B^0_s \to J/\psi \pi^+\pi^-$

To appear in [PLB 797 (2019)]

Data-driven approach
using $B^0 \to J/\psi K^*(892)$
Method is verified with B^0 and B^+

$$\varepsilon^{B^0_s}_{\mathrm{data}}(t) = \varepsilon^{B^0}_{\mathrm{data}}(t) \times \frac{\varepsilon^{B^0_s}_{\mathrm{sim}}(t)}{\varepsilon^{B^0}_{\mathrm{sim}}(t)}$$

Selection efficiency

$B^0_s \to J/\psi K^+K^-$

EPJC 79 (2019) 706

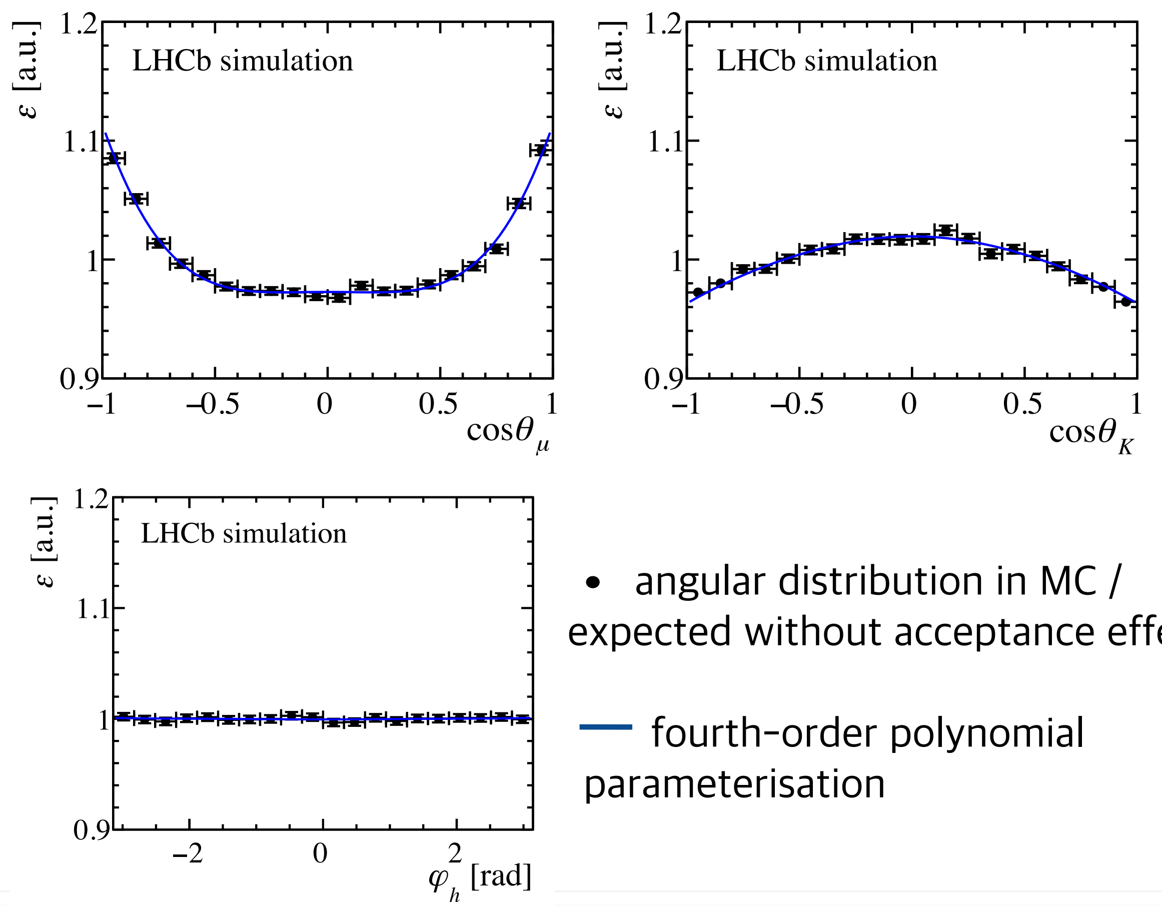
$B^0_s \to J/\psi \pi^+\pi^-$

To appear in PLB 797 (2019)

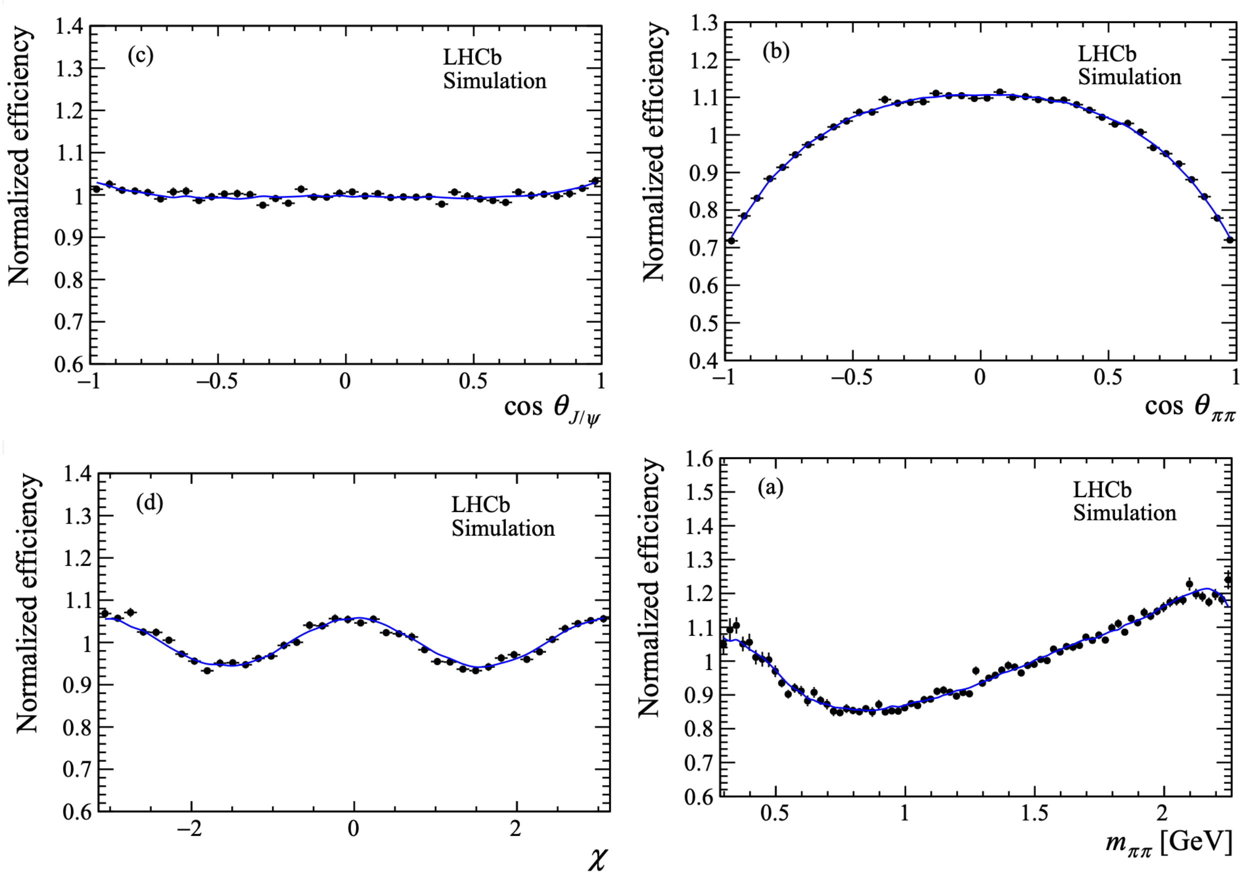
Data-driven approach
using $B^0 \to J/\psi K^*(892)$
Method is verified with B^0 and B^+

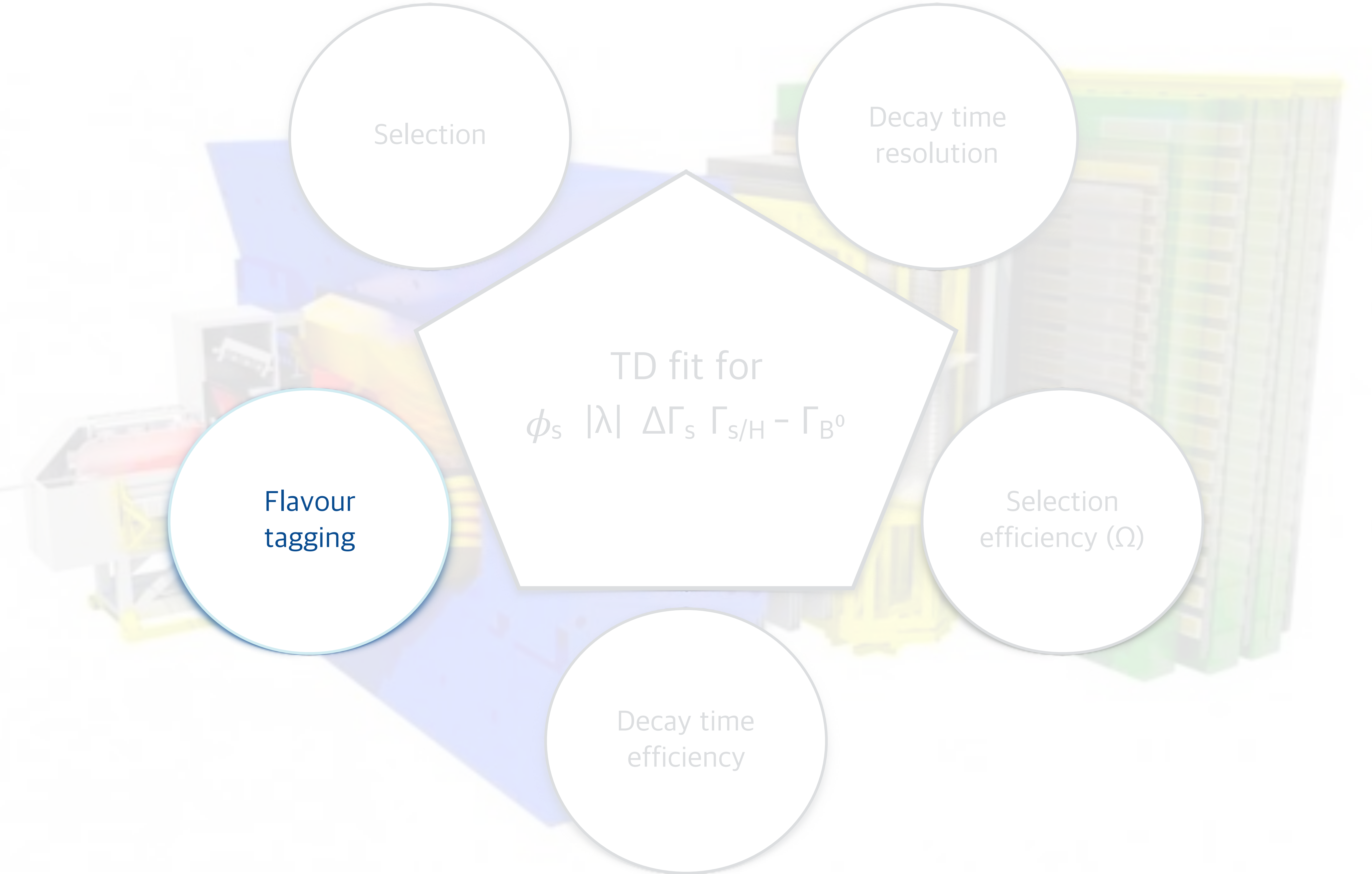
$$\varepsilon^{B^0_s}_{\text{data}}(t) = \varepsilon^{B^0}_{\text{data}}(t) \times \frac{\varepsilon^{B^0_s}_{\text{sim}}(t)}{\varepsilon^{B^0}_{\text{sim}}(t)}$$

Kinematic selection and detector acceptance are causing non uniform efficiency as function of decay angles



- angular distribution in MC / expected without acceptance effect
- fourth-order polynomial parameterisation




Selection
Decay time resolution
TD fit for
ϕ_s $|\lambda|$ $\Delta\Gamma_s$ $\Gamma_{s/H} - \Gamma_{B^0}$
Flavour tagging
Selection efficiency (Ω)
Decay time efficiency

Flavour tagging

$B^0_s \to J/\psi K^+K^-$

EPJC 79 (2019) 706

$B^0_s \to J/\psi \pi^+\pi^-$

To appear in PLB 797 (2019)

$$\sigma^{-1}(\phi_s) \sim \sqrt{N}\, Q_{eff}^{1/2}\, e^{-\frac{\sigma_t^2 \Delta m^2}{2}}$$

The effective tagging power is defined as $Q_{eff} = \varepsilon_{tag}(1-2\omega)^2$

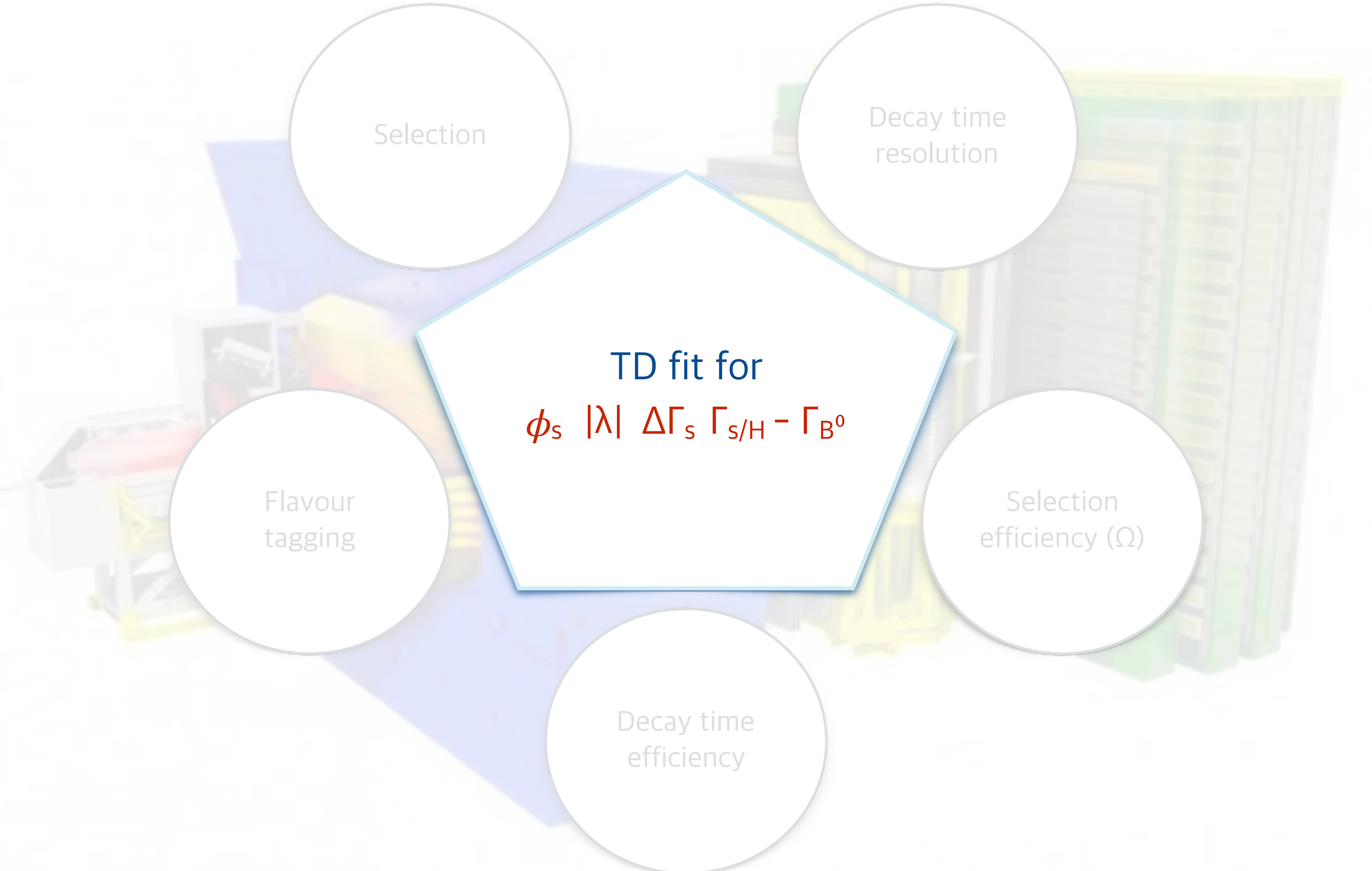
where ε_{tag} is tagging efficiency and $(1-2\omega)^2$ is dilution

In Run1 $Q_{eff} \approx 3.73$ %

$$Q_{eff} = 4.73 \pm 0.34\,\%$$

In Run1 $Q_{eff} \approx 3.89$ %

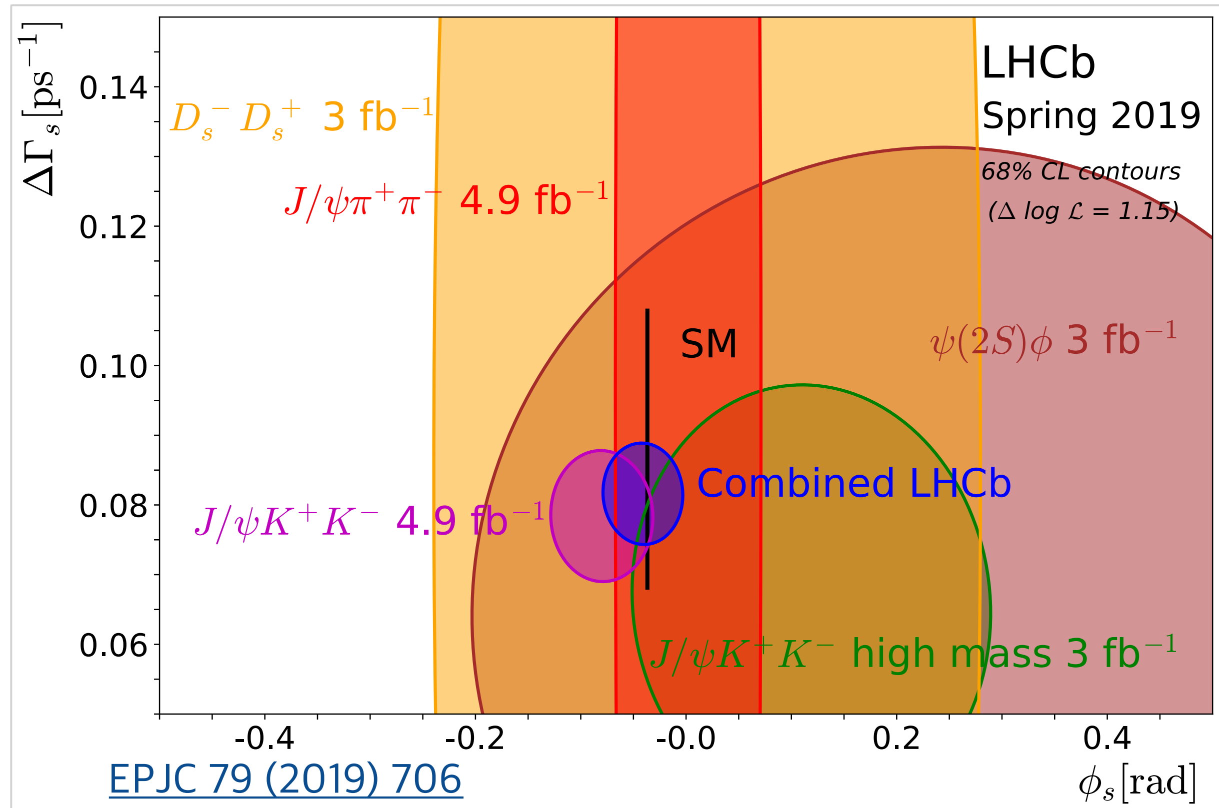
$$Q_{eff} = 5.06 \pm 0.38\,\%$$



Selection
Decay time resolution
TD fit for
ϕ_s $|\lambda|$ $\Delta\Gamma_s$ $\Gamma_{s/H} - \Gamma_{B^0}$
Flavour tagging
Selection efficiency (Ω)
Decay time efficiency

ϕ_s = −0.041 ± 0.025 [rad]
|λ| = 0.993 ± 0.010
$\Delta\Gamma_s$ = 0.0816 ± 0.0048 [ps^{-1}]
Γ_s = 0.6562 ± 0.0021 [ps^{-1}]

ϕ_s 0.1σ from SM
consistent with Standard Model
ϕ_s 1.6σ from 0
consistent with no CPV in interference between direct decay and after mixing
|λ| consistent with 1 within 0.7σ
consistent with no direct CPV
Γ_s/Γ_{B^0} consistent with HQE prediction within 1σ



EPJC 79 (2019) 706

Dominated by penguin $b \to s s\bar{s}(d\bar{d}/\gamma)$ transition

In the first order

$$\phi_s^{SM} \propto \arg\left(\frac{V_{ts}V_{tb}^*}{V_{ts}^*V_{tb}}\frac{V_{ts}^*V_{tb}}{V_{ts}V_{tb}^*}\right) = 0$$

$B^0_s \to (K^+\pi^-)(K^-\pi^+)$

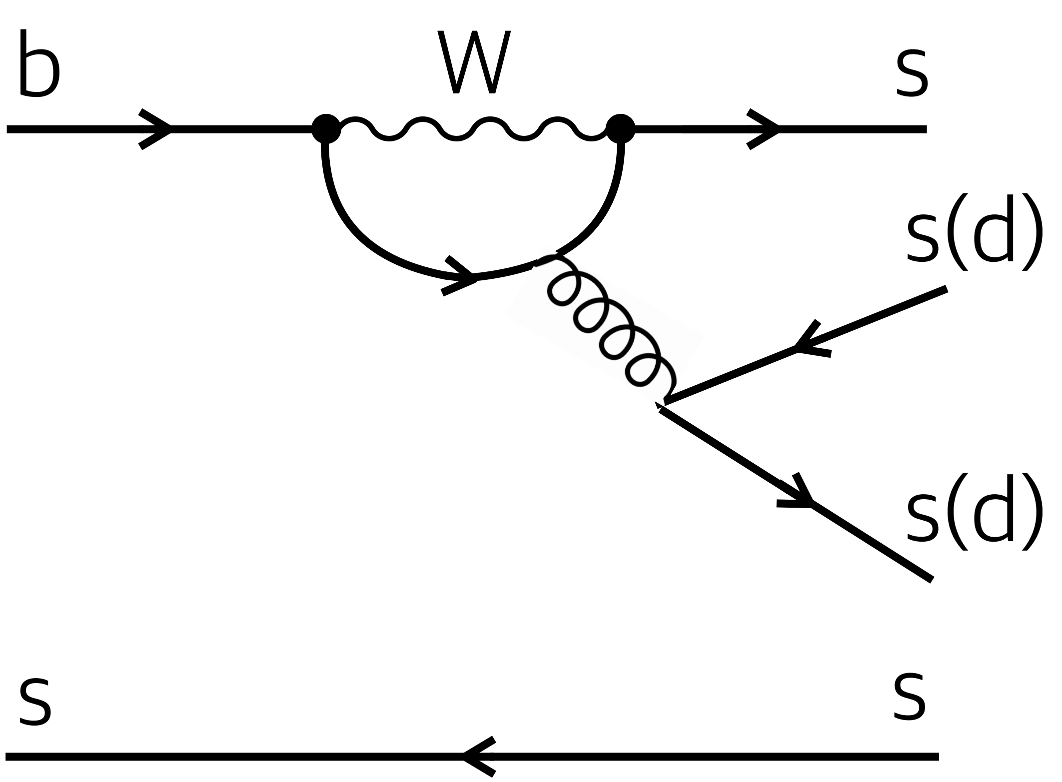
Run1 JHEP 03 (2018) 140

$B^0_s \to \varphi\,\varphi$

Run1+2(15,16) arXiv:1907.10003

$B^0_s \to \varphi\,\gamma$

Run1 PRL 123 (2019) 081802



ϕ_s from $b \to s s \bar{s}(\gamma)$ transition

$B^0_s \to \varphi\gamma$
PRL 123 (2019) 081802

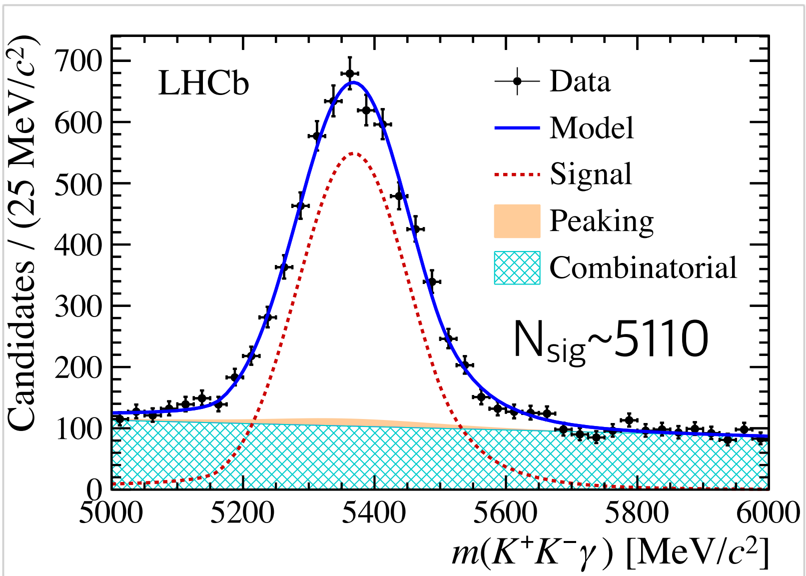
$B^0_s \to (K^+\pi^-)(K^-\pi^+)$
JHEP 03 (2018) 140

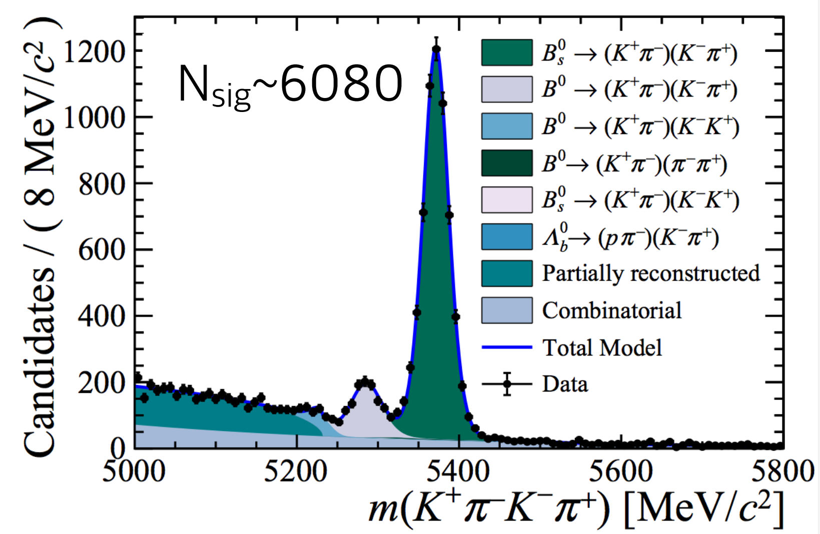
$B^0_s \to \varphi\varphi$
arXiv:1907.10003

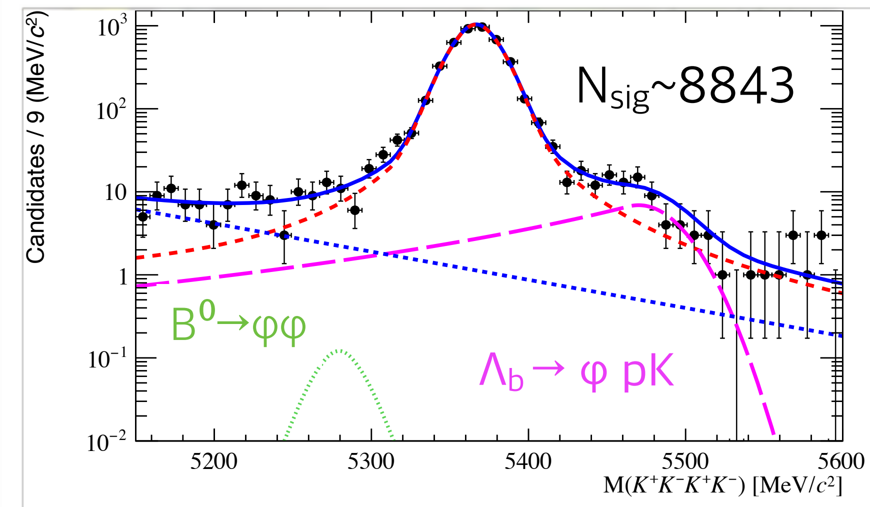
Based on Run1 (3 fb^{-1}) dataset

Based on Run1 (3 fb^{-1}), 2015 (0.3 fb^{-1}) and 2016 (1.6 fb^{-1}) dataset

See talk by Vitalii Lisovskyi







The SM predictions for the S, C and A in $B^0_s \to \varphi\gamma$ are close to zero [ref]

$$S_{\phi\gamma} = 0.43 \pm 0.30 \pm 0.11$$
$$C_{\phi\gamma} = 0.11 \pm 0.29 \pm 0.11$$
$$\mathcal{A}^{\Delta}_{\phi\gamma} = -0.67^{+0.37}_{-0.41} \pm 0.17$$

The longitudinal polarisation fraction is measured

$$f_L = 0.208 \pm 0.032 \pm 0.046$$

$$\phi_s^{s\bar{d}d} = -0.10 \pm 0.13 \pm 0.14 \text{ [rad]}$$
$$|\lambda| = 1.035 \pm 0.034 \pm 0.089$$

Complimentary search for new B^0 decay mode

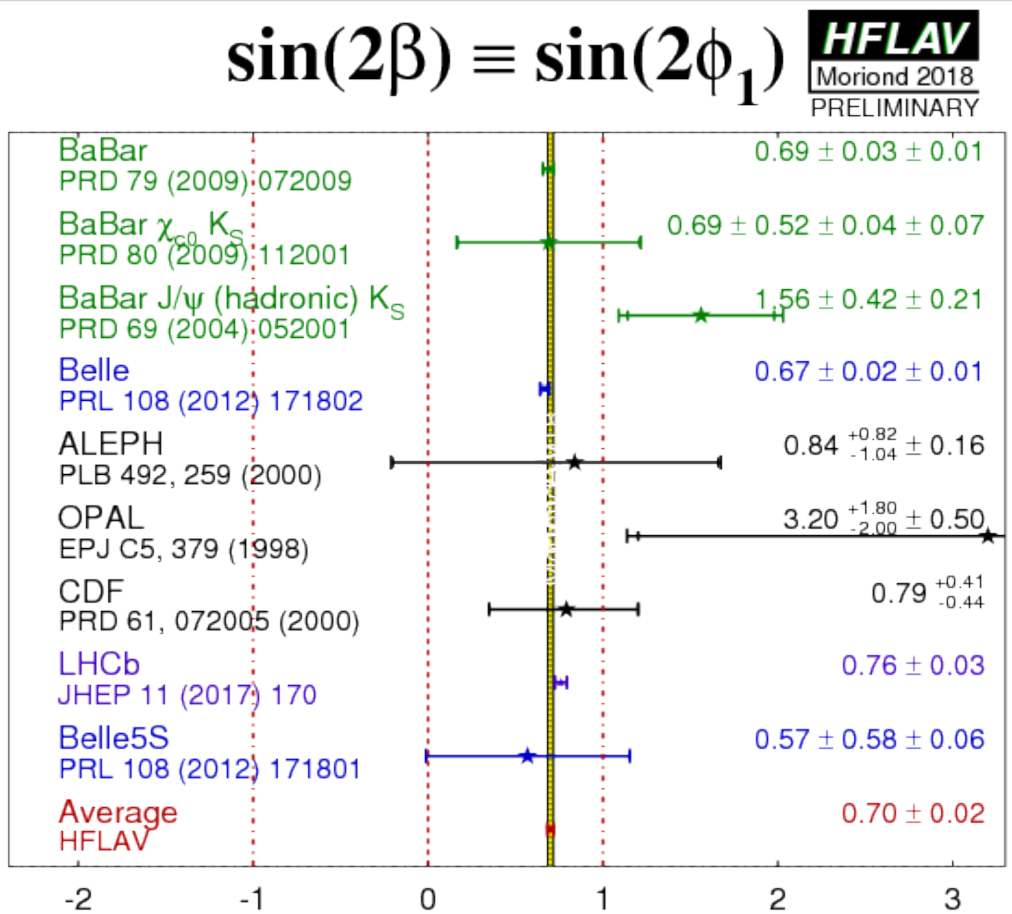
$$\mathcal{B}(B^0 \to \phi\phi) < 2.7 \times 10^{-8} \text{ at } 90\,\%\text{ CL}$$

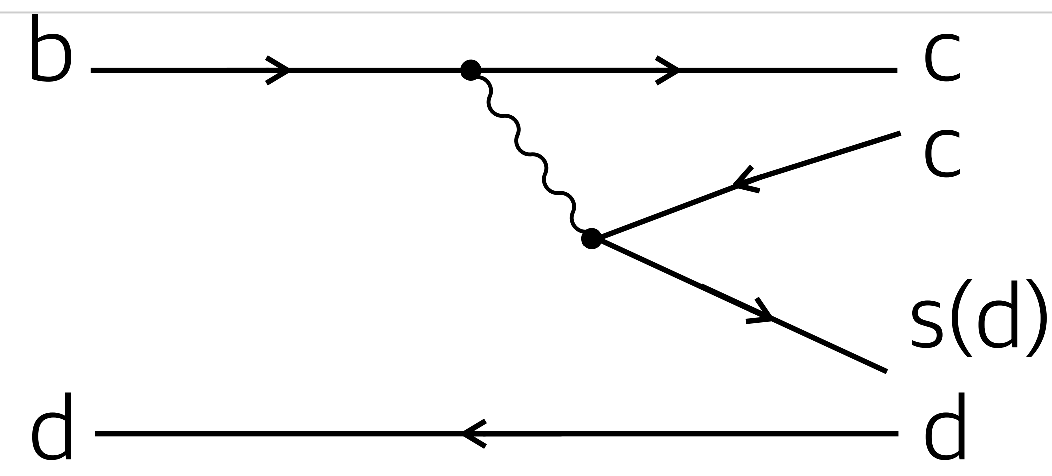
$$\phi_s^{s\bar{s}s} = -0.073 \pm 0.115 \pm 0.027 \text{ [rad]}$$
$$|\lambda| = 0.99 \pm 0.05 \pm 0.01$$

Decays of B^0 dominated by tree $b \to c\bar{c}s(d)$ transition

$$\sin(2\beta)^{SM} = \sin 2\arg\left(-\frac{V_{cd}V_{cb}^*}{V_{td}V_{tb}^*}\right) = 0.708^{+0.013}_{-0.010}$$

[CKM fitter]





$B^0 \to \psi(2S) K_s$

Run1 JHEP 11 (2017) 170

$B^0 \to J/\psi K_s$

Run1 PRL 115 (2015) 031601

$B^0 \to D^+ D^-$

Run1 PRL 117 (2016) 261801

$B^0 \to D^{*\pm}D^{\mp}$

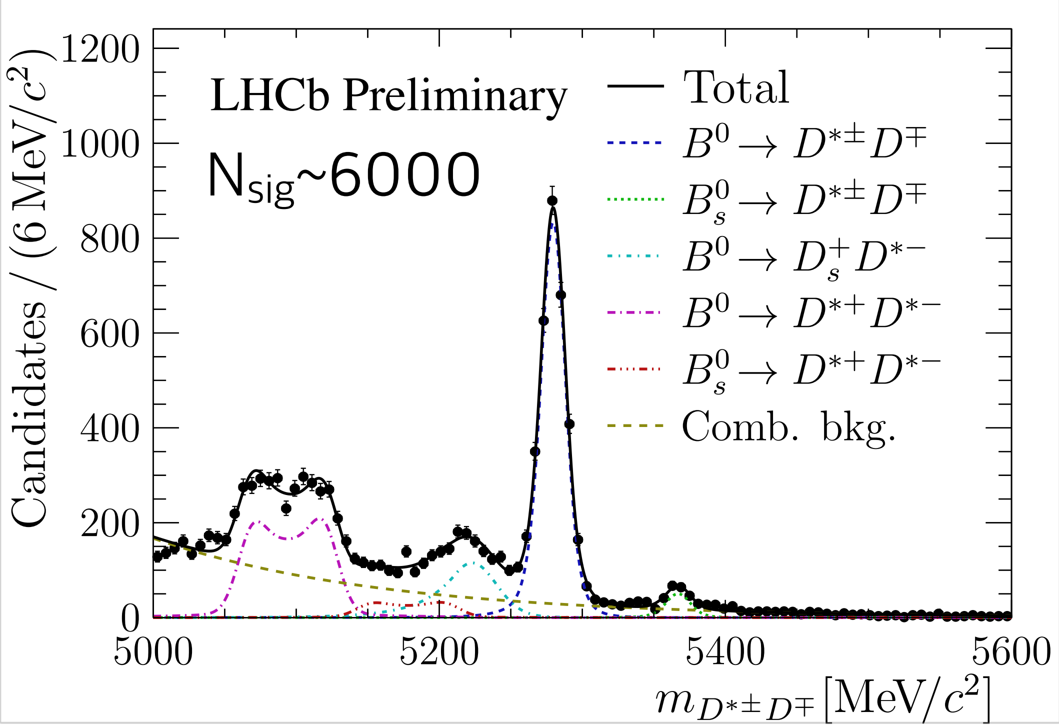
Run1+2 LHCb-PAPER-2019-036 in preparation

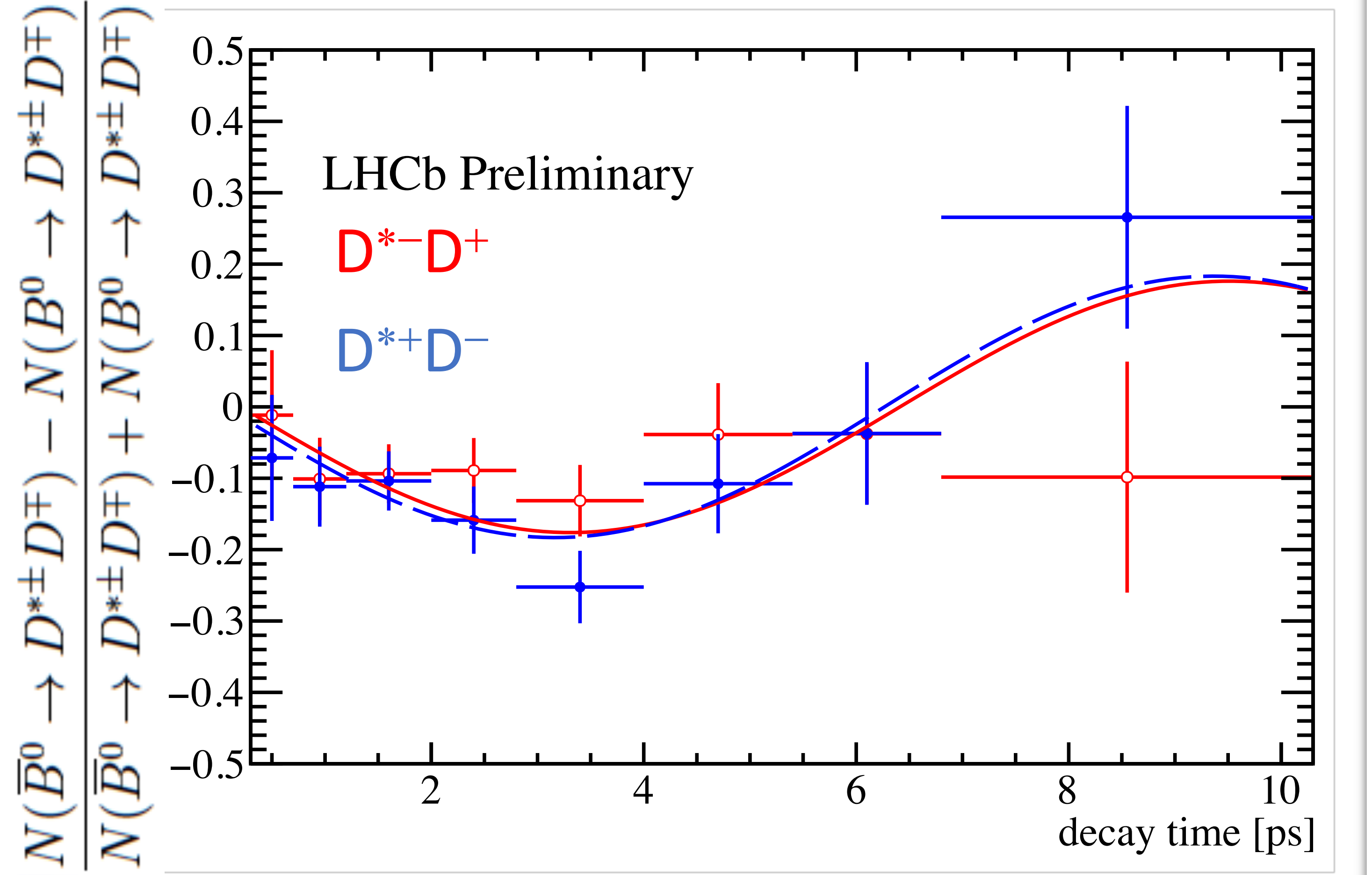
$B^0 \to D^{*\pm}D^{\mp}$

LHCb-PAPER-2019-036 in preparation

Based on full Run1 (3 fb^{-1}) and Run2 (6 fb^{-1}) dataset
Result is consistent with sin(2β) measured in $b \to c\bar{c}s$

$B^0 \to D^{*\pm}D^{\mp}$ with $D^{*\pm} \to D^0\pi^{\pm}$ and $D^{\mp} \to K^{\mp}\pi^+\pi^-$
D^0 is reconstructed in two modes
studied separately $D^0 \to K^-\pi^+$
$D^0 \to K^-\pi^+\pi^-\pi^+$

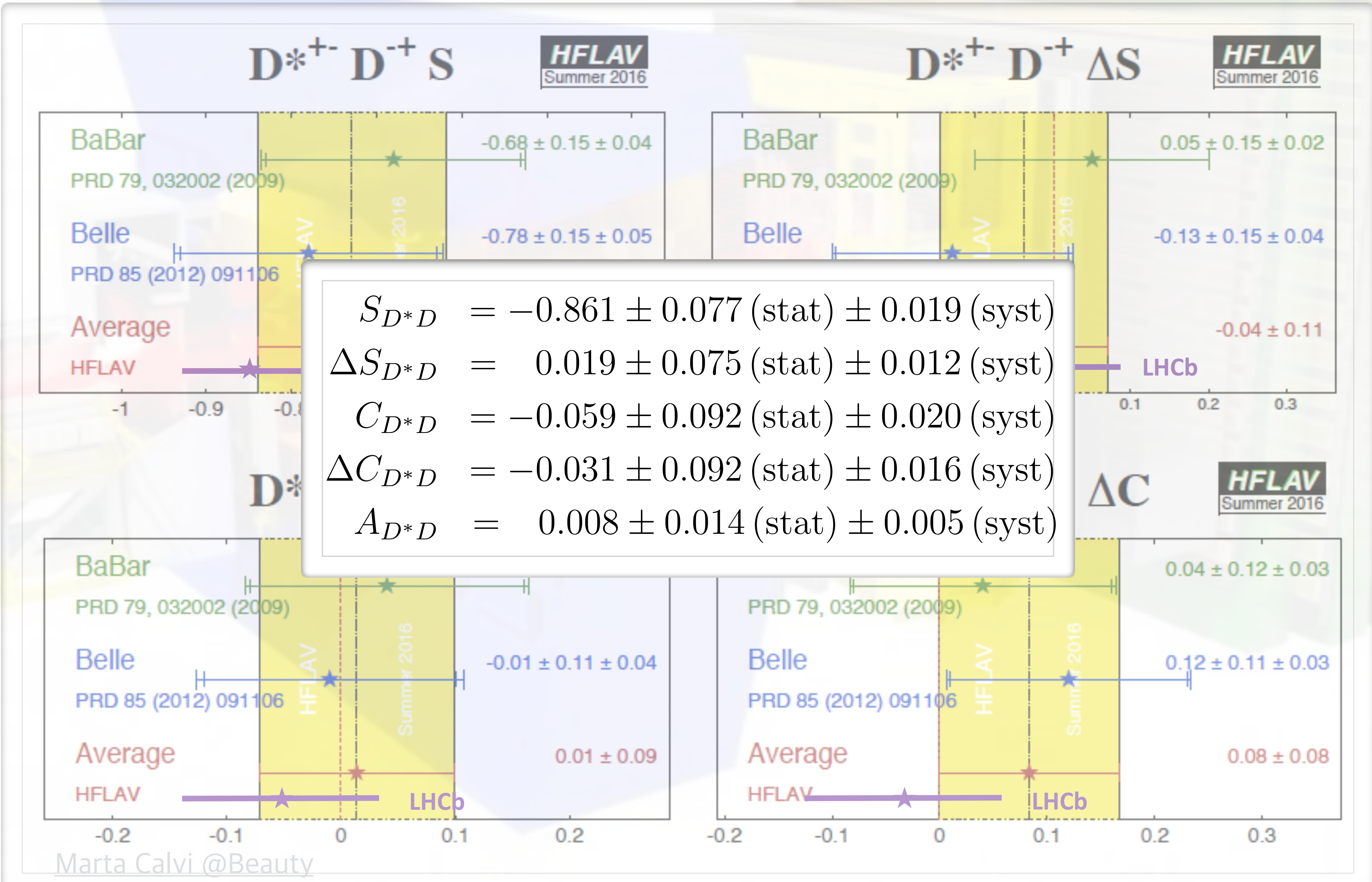




Measurement of sin(2β)

$B^0 \to D^{*\pm} D^{\mp}$

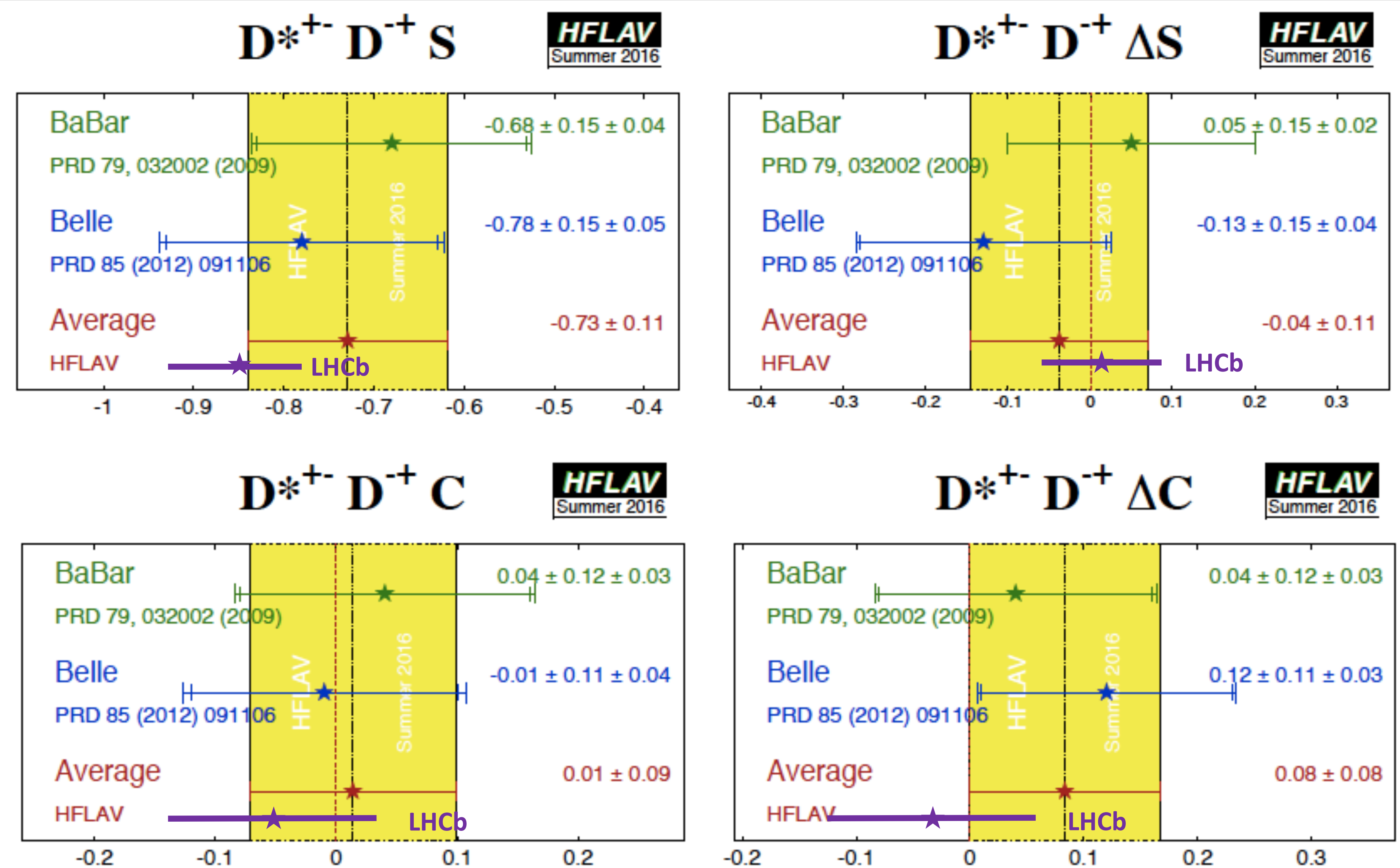
LHCb-PAPER-2019-036 in preparation



$$S_{D^*D} = -0.861 \pm 0.077\,(\text{stat}) \pm 0.019\,(\text{syst})$$
$$\Delta S_{D^*D} = 0.019 \pm 0.075\,(\text{stat}) \pm 0.012\,(\text{syst})$$
$$C_{D^*D} = -0.059 \pm 0.092\,(\text{stat}) \pm 0.020\,(\text{syst})$$
$$\Delta C_{D^*D} = -0.031 \pm 0.092\,(\text{stat}) \pm 0.016\,(\text{syst})$$
$$A_{D^*D} = 0.008 \pm 0.014\,(\text{stat}) \pm 0.005\,(\text{syst})$$

$B^0 \rightarrow D^{*\pm}D^{\mp}$

LHCb-PAPER-2019-036 in preparation



Marta Calvi @Beauty

Recent measurements of ϕ_s

- $B^0_s \to J/\psi\, K^+K^-$ EPJC 79 (2019) 706
- $B^0_s \to J/\psi\, \pi^+\pi^-$ to appear in PLB 797 (2019)

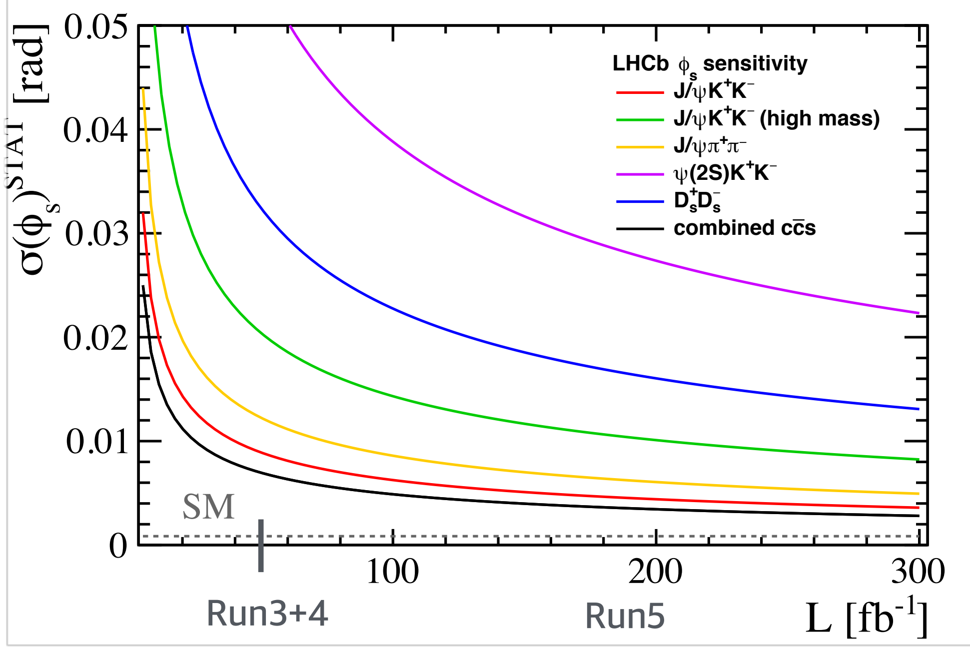
- $B^0_s \to (K^+\pi^-)(K^-\pi^+)$ JHEP 03 (2018) 140
- $B^0_s \to \varphi\, \varphi$ arXiv:1907.10003
- $B^0_s \to \varphi\, \gamma$ PRL 123 (2019) 081802

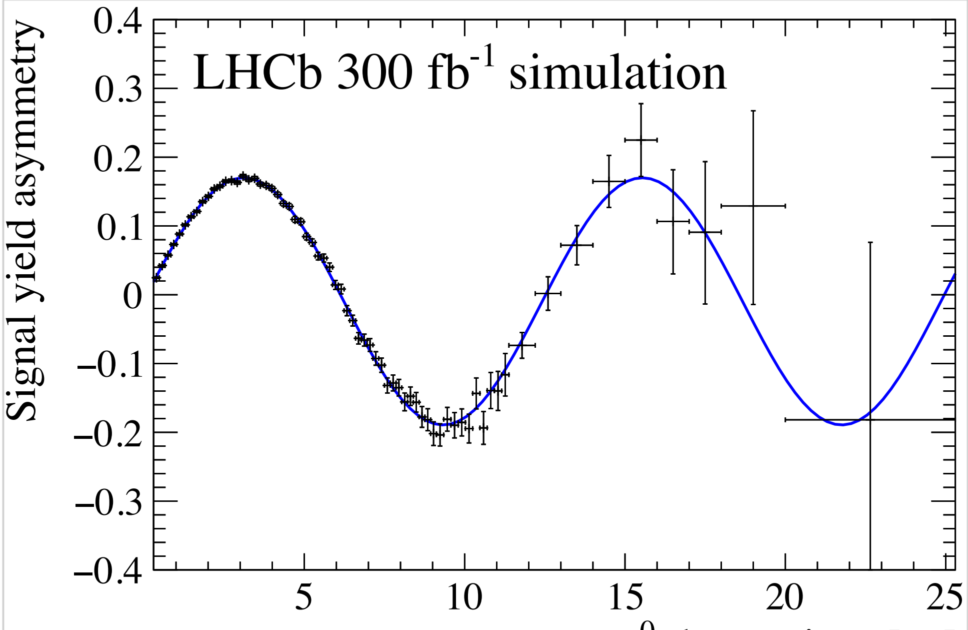
Recent measurements of sin(2β)

- $B^0 \to D^{*\pm}D^{\mp}$ LHCb-PAPER-2019-036 in preparation

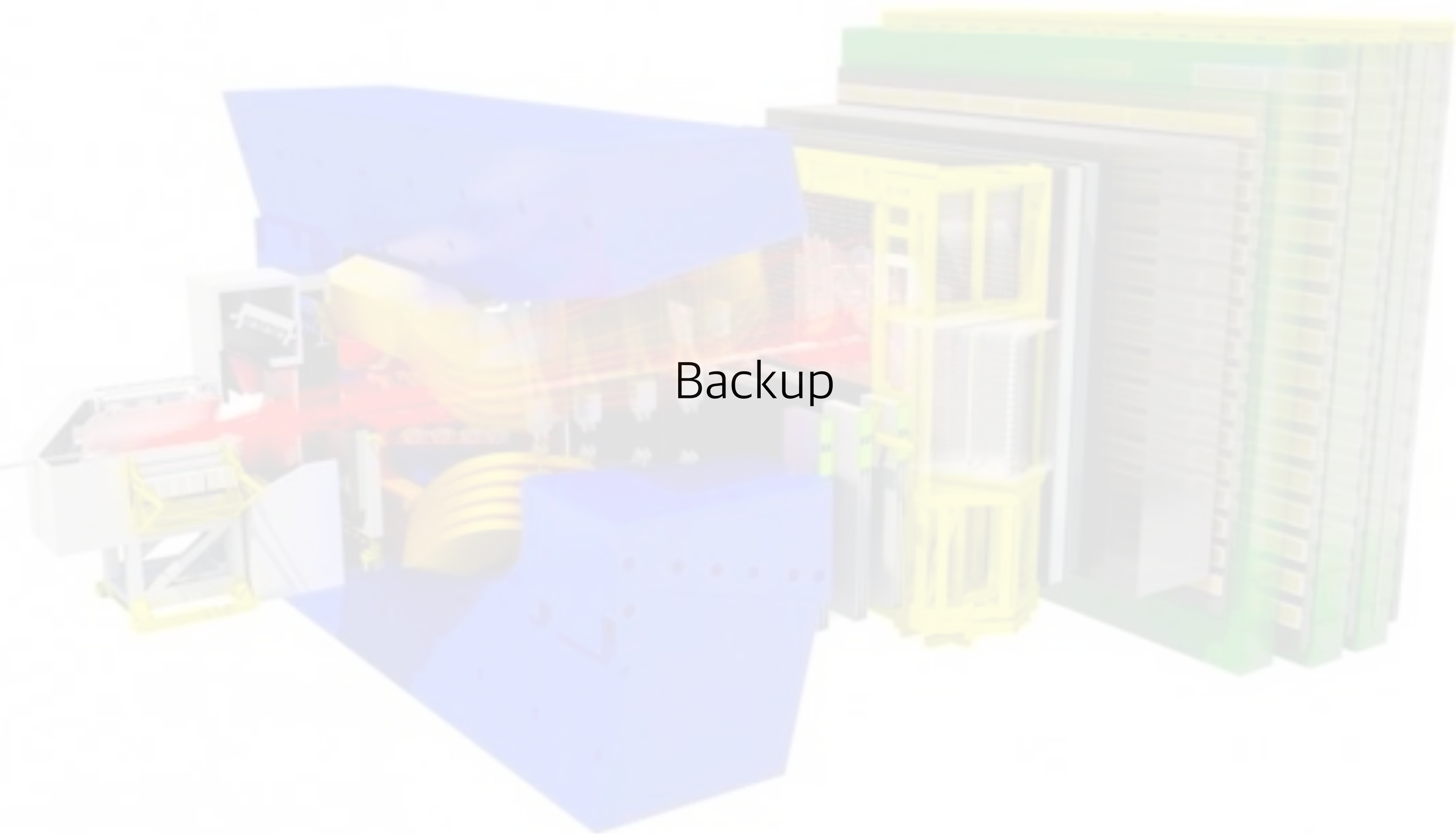
With current precision all measurements are consistent with SM

Further analysis of available dataset is in progress for most of the modes





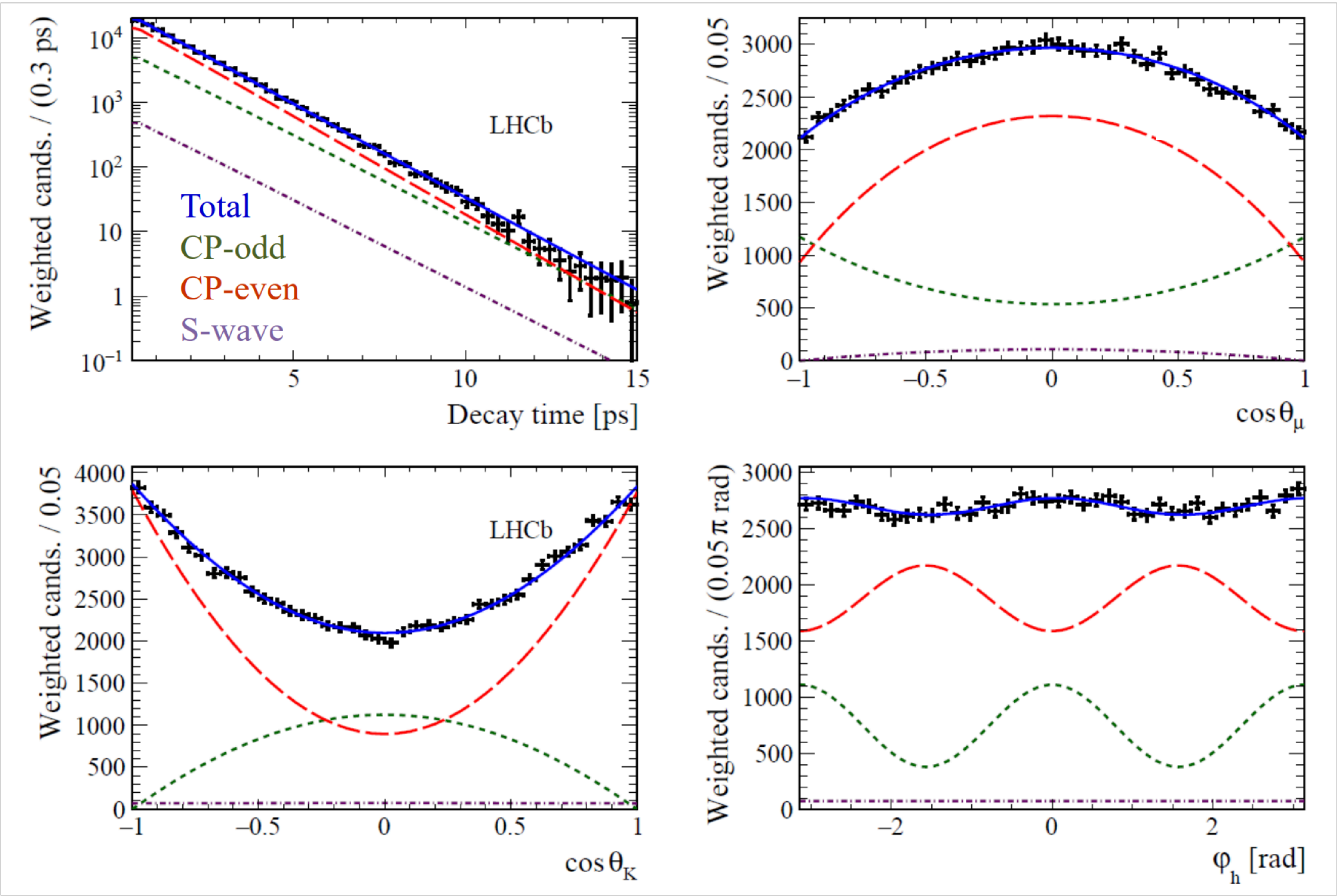
arXiv:1808.08865



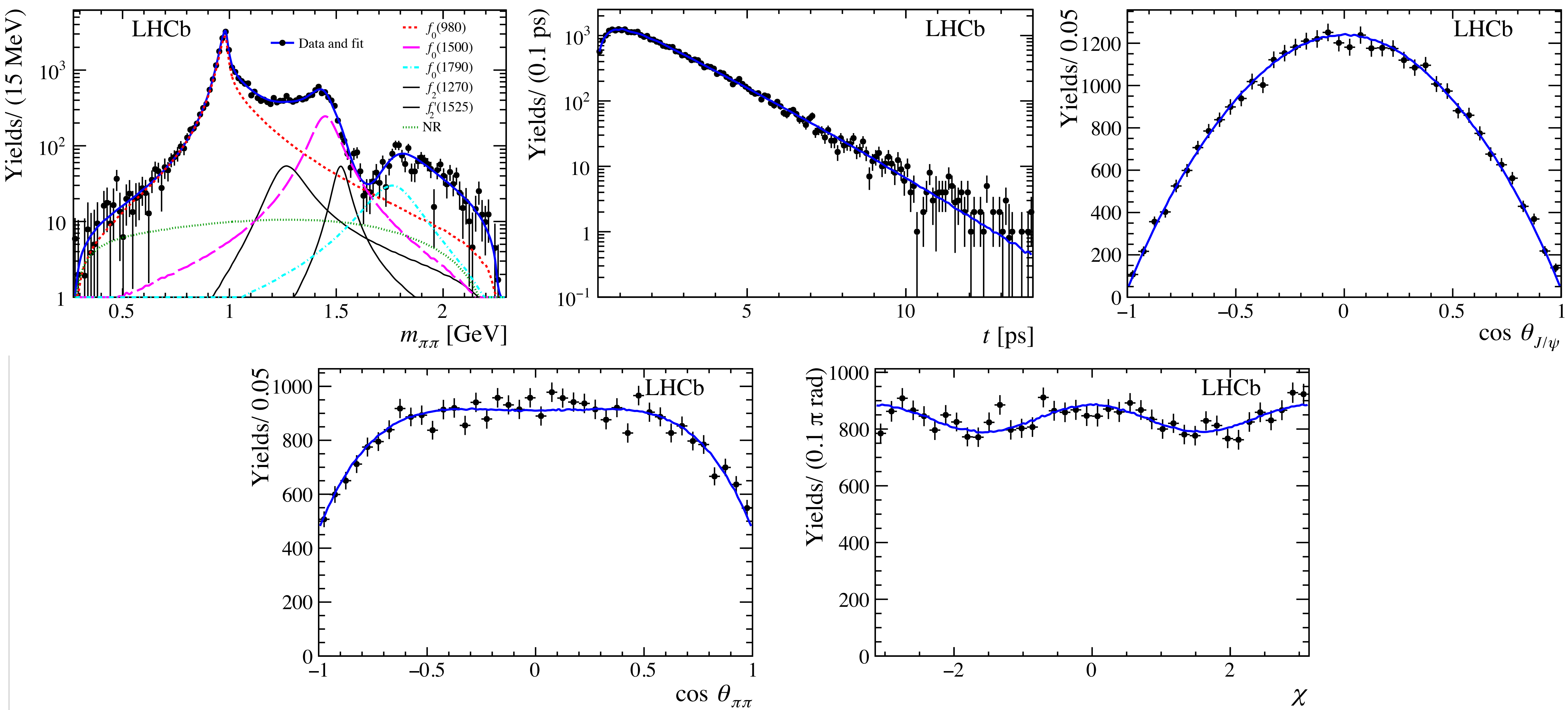
Backup

Parameter	Value
ϕ_s [rad]	$-0.080 \pm 0.041 \pm 0.006$
$\|\lambda\|$	$1.006 \pm 0.016 \pm 0.006$
$\Gamma_s - \Gamma_d$ [ps^{-1}]	$-0.0041 \pm 0.0024 \pm 0.0015$
$\Delta\Gamma_s$ [ps^{-1}]	$0.0772 \pm 0.0077 \pm 0.0026$
Δm_s [ps^{-1}]	$17.705 \pm 0.059 \pm 0.018$
$\|A_\perp\|^2$	$0.2457 \pm 0.0040 \pm 0.0019$
$\|A_0\|^2$	$0.5186 \pm 0.0029 \pm 0.0024$
$\delta_\perp - \delta_0$	$2.64 \pm 0.13 \pm 0.10$
$\delta_\parallel - \delta_0$	$3.061^{+0.084}_{-0.073} \pm 0.037$

Fit projections for $B^0_s \to J/\psi K^+K^-$



Fit projections for $B^0_s \to J/\psi\ \pi^+\pi^-$



Systematics for $B^0_s \to J/\psi K^+K^-$

Source	$\lvert A_0\rvert^2$	$\lvert A_\perp\rvert^2$	ϕ_s [rad]	$\lvert\lambda\rvert$	$\delta_\perp - \delta_0$ [rad]	$\delta_\parallel - \delta_0$ [rad]	$\Gamma_s - \Gamma_d$ [ps^{-1}]	$\Delta\Gamma_s$ [ps^{-1}]	Δm_s [ps^{-1}]
Mass width parametrisation	0.0006	0.0005	-	-	0.05	0.009	-	0.0002	0.001
Mass factorisation	0.0002	0.0004	0.004	0.0037	0.01	0.004	0.0007	0.0022	0.016
Multiple candidates	0.0006	0.0001	0.0011	0.0011	0.01	0.002	0.0003	0.0001	0.001
Fit bias	0.0001	0.0006	0.001	-	0.02	0.033	-	0.0003	0.001
C_{SP} factors	-	0.0001	0.001	0.0010	0.01	0.005	-	0.0001	0.002
Quadratic OS tagging	-	-	-	-	-	-	-	-	-
Time res.: statistical	-	-	-	-	-	-	-	-	-
Time res.: prompt	-	-	-	-	-	0.001	-	-	0.001
Time res.: mean offset	-	-	0.0032	0.0010	0.08	0.001	0.0002	0.0003	0.005
Time res.: Wrong PV	-	-	-	-	-	0.001	-	-	0.001
Ang. acc.: statistical	0.0003	0.0004	0.0011	0.0018	-	0.004	-	-	0.001
Ang. acc.: correction	0.0020	0.0011	0.0022	0.0043	0.01	0.008	0.0001	0.0002	0.001
Ang. acc.: low-quality tracks	0.0002	0.0001	0.0005	0.0014	-	0.002	0.0002	0.0001	-
Ang. acc.: t & σ_t dependence	0.0008	0.0012	0.0012	0.0007	0.03	0.006	0.0002	0.0010	0.003
Dec.-time eff.: statistical	0.0002	0.0003	-	-	-	-	0.0012	0.0008	-
Dec.-time eff.: $\Delta\Gamma_s = 0$ sim.	0.0001	0.0002	-	-	-	-	0.0003	0.0005	-
Dec.-time eff.: knot pos.	-	-	-	-	-	-	-	-	-
Dec.-time eff.: p.d.f. weighting	-	-	-	-	-	-	0.0001	0.0001	-
Dec.-time eff.: kin. weighting	-	-	-	-	-	-	0.0002	-	-
Length scale	-	-	-	-	-	-	-	-	0.004
Quadratic sum of syst.	0.0024	0.0019	0.0061	0.0064	0.10	0.037	0.0015	0.0026	0.018

Fit result $B^0_s \to J/\psi\, \pi^+\pi^-$

Table 5: Fit results of the resonant structure for both Solutions I and II. These results do not supersede those in Ref. [21] for the resonant fractions.

Component	Fit fractions (%)	Transversity fractions (%)		
		0	$\parallel$	$\perp$
Solution I				
$f_0(980)$	60.09 ± 1.48	100	–	–
$f_0(1500)$	8.88 ± 0.87	100	–	–
$f_0(1790)$	1.72 ± 0.29	100	–	–
$f_2(1270)$	3.24 ± 0.48	13 ± 3	37 ± 9	50 ± 10
$f_2'(1525)$	1.23 ± 0.86	40 ± 13	31 ± 14	29 ± 25
NR	2.64 ± 0.73	100	–	–
Solution II				
$f_0(980)$	93.05 ± 1.12	100	–	–
$f_0(1500)$	6.47 ± 0.41	100	–	–
$f_0(1710)$	0.74 ± 0.11	100	–	–
$f_2(1270)$	3.22 ± 0.44	17 ± 4	30 ± 8	53 ± 10
$f_2'(1525)$	1.44 ± 0.36	35 ± 8	31 ± 12	34 ± 17
NR	8.13 ± 0.79	100	–	–

Systematics for $B^0_s \to J/\psi\ \pi^+\pi^-$

Source	$\Gamma_{\mathrm{H}} - \Gamma_{B^0}$ [fs^{-1}]	$\lvert\lambda\rvert$ [$\times 10^{-3}$]	ϕ_s [mrad]
t acceptance	2.0	0.0	0.3
τ_{B^0}	0.2	0.5	0.0
Efficiency ($m_{\pi\pi}$, Ω)	0.2	0.1	0.0
t resolution width	0.0	4.3	4.0
t resolution mean	0.3	1.2	0.3
Background	3.0	2.7	0.6
Flavour tagging	0.0	2.2	2.3
Δm_s	0.3	4.6	2.5
Γ_{L}	0.3	0.4	0.4
B_c^+	0.5	-	-
Resonance parameters	0.6	1.9	0.8
Resonance modelling	0.5	28.9	9.0
Production asymmetry	0.3	0.6	3.4
Total	3.8	29.9	11.0

Decay time acceptance is approximately:

$$\varepsilon_{\text{data}}^{B_s^0}(t) \propto \frac{N(t)}{e^{-\Gamma_d t} \otimes G(t, \sigma_t)}$$

Given a parameterisation of Γ_d around the used value Γ_{d0} = 1/1.520ps-1

$$\begin{aligned} \varepsilon_{\text{data}}^{B_s^0}(t; \Gamma_d) &\propto \frac{N(t)}{e^{-(\Gamma_d^0 + \delta\Gamma_d)t} \otimes G(t, \sigma_t)} \\ &\approx \frac{N(t)}{e^{-\Gamma_d^0 t} \otimes G(t, \sigma_t)} \times e^{\delta\Gamma_d t} \\ &= \varepsilon_{\text{data}}^{B_s^0}(t, \Gamma_d^0) \times e^{\delta\Gamma_d t}. \end{aligned}$$

$$\Delta\Gamma_d^s = \Gamma_s - \Gamma_d \text{ and } \Gamma_d = \Gamma_d^0 + \delta\Gamma_d\text{:} \quad \Gamma_s = \Gamma_d^0 + \delta\Gamma_d + \Delta\Gamma_d^s$$

$$\begin{aligned} \text{pdf}(t) &\approx \varepsilon_{\text{data}}^{B_s^0}(t, \Gamma_d^0) \times e^{\delta\Gamma_d t} \times \left[e^{-(\Delta\Gamma_d^s + \Gamma_d^0 + \delta\Gamma_d)t} \otimes G(t, \sigma_t) \right] \\ &\approx \varepsilon_{\text{data}}^{B_s^0}(t, \Gamma_d^0) \times e^{\delta\Gamma_d t} \times e^{-\delta\Gamma_d t} \left[e^{-(\Delta\Gamma_d^s + \Gamma_d^0)t} \otimes G(t, \sigma_t) \right] \\ &= \varepsilon_{\text{data}}^{B_s^0}(t, \Gamma_d^0) \times \left[e^{-(\Delta\Gamma_d^s + \Gamma_d^0)t} \otimes G(t, \sigma_t) \right], \end{aligned}$$

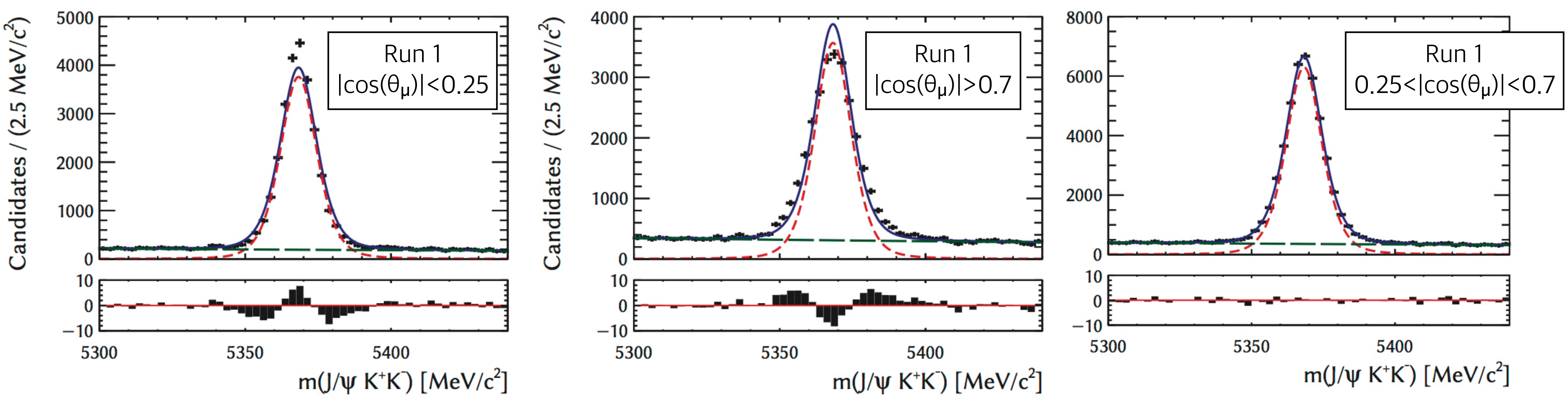
Signal model: Double-sided Crystal Ball function (CB2) with per-event mass error used as conditional observable

Quadratic dependence on the per-event mass error: $\sigma = s_1\sigma_i + s_2\sigma_i^2$ (s_1~0.8; s_2~0.05)

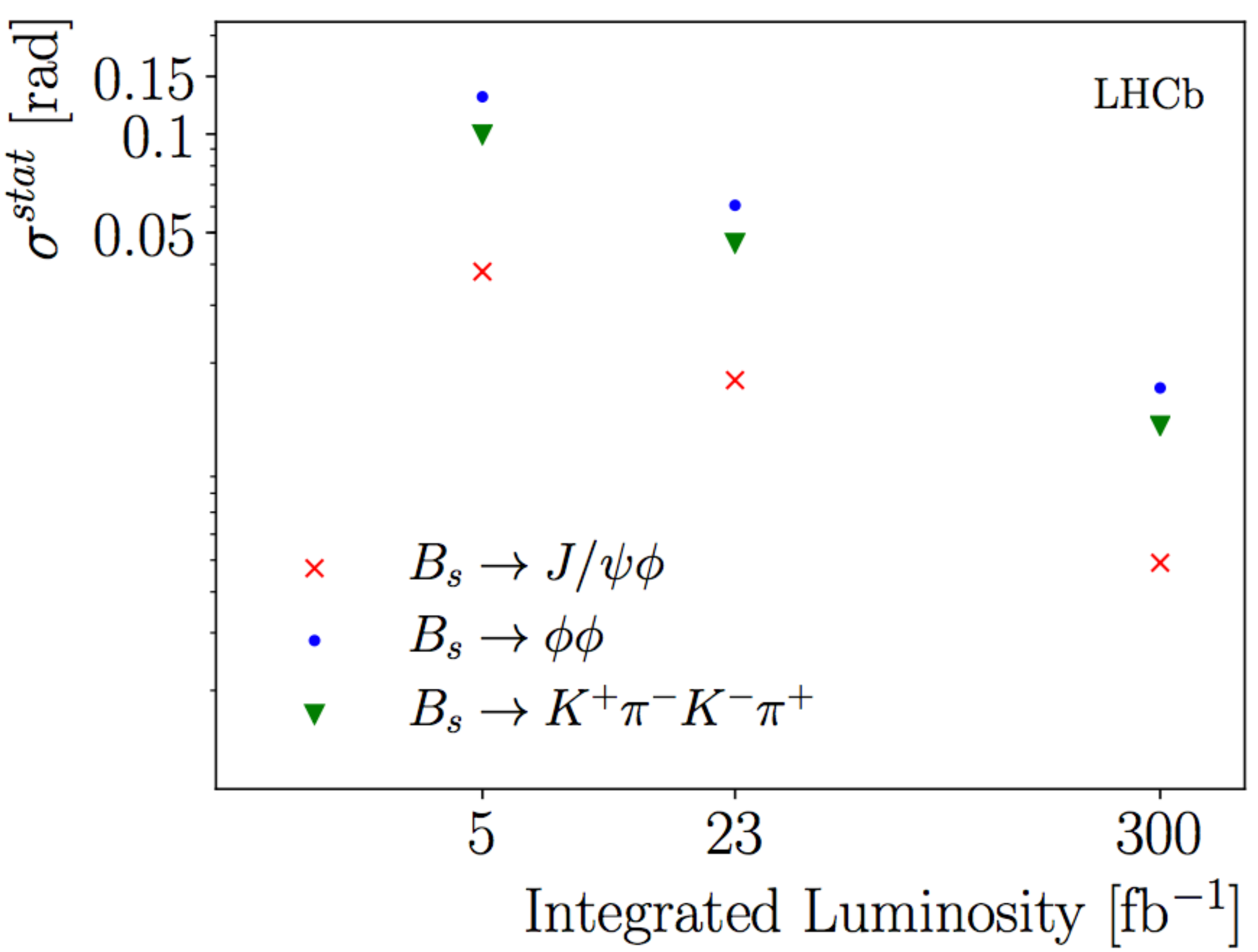
- Tails of the CB2 are fixed from the fit to MC
- Fit in 6 $m(K^+K^-)$ bins [990, 1008, 1016, 1020, 1024, 1032, 1050] MeV/c^2

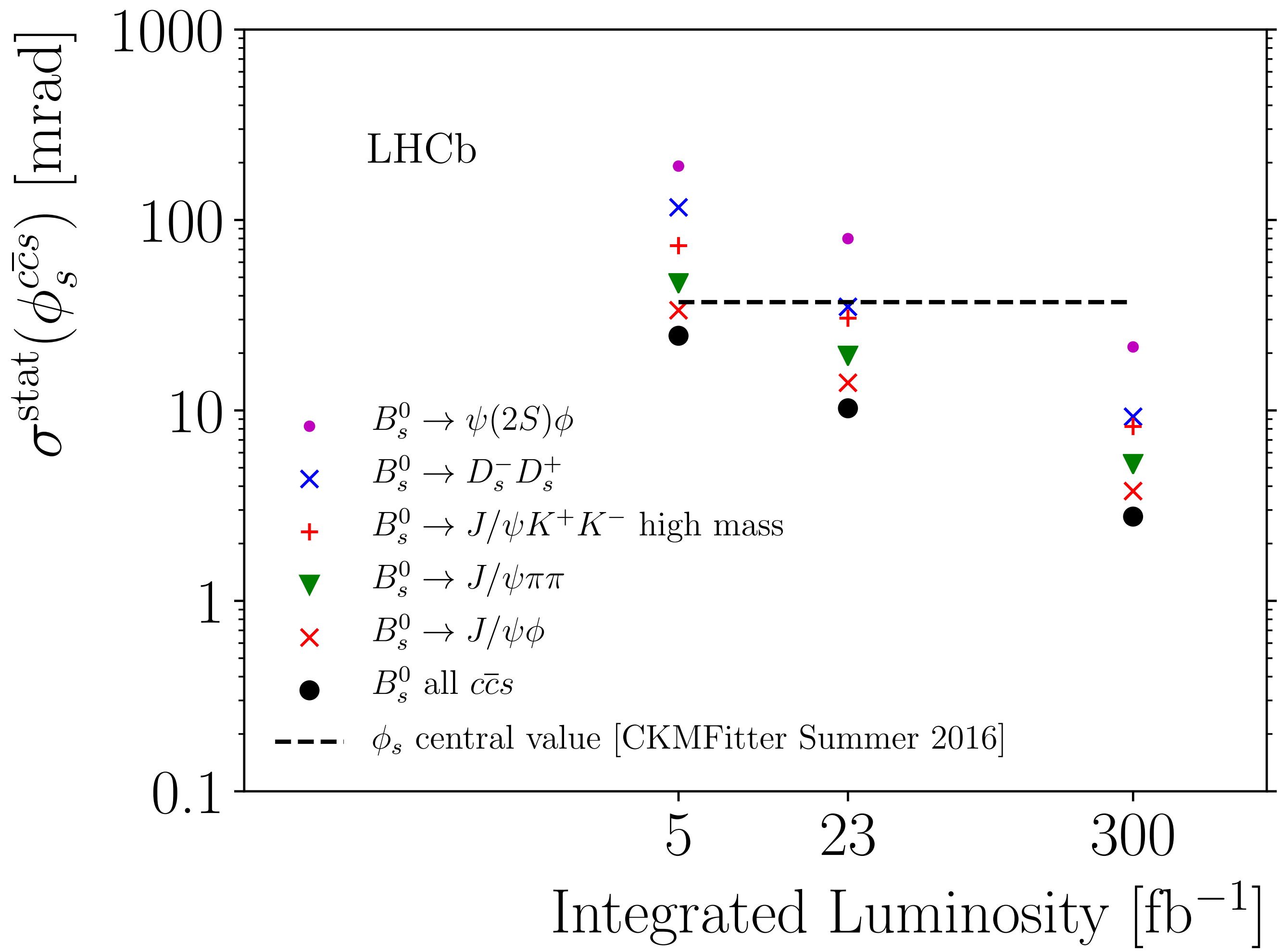
Background: Exponential for the combinatorial and gaussian for the $B^0 \to J/\psi\, K^+K^-$ contribution

Why? To take into account this correlation. Mass resolution comes from the angles between muons, therefore per-candidate mass error and $\cos(\theta_\mu)$ are highly correlated



Comparison of φ_s sensitivity from different decay modes



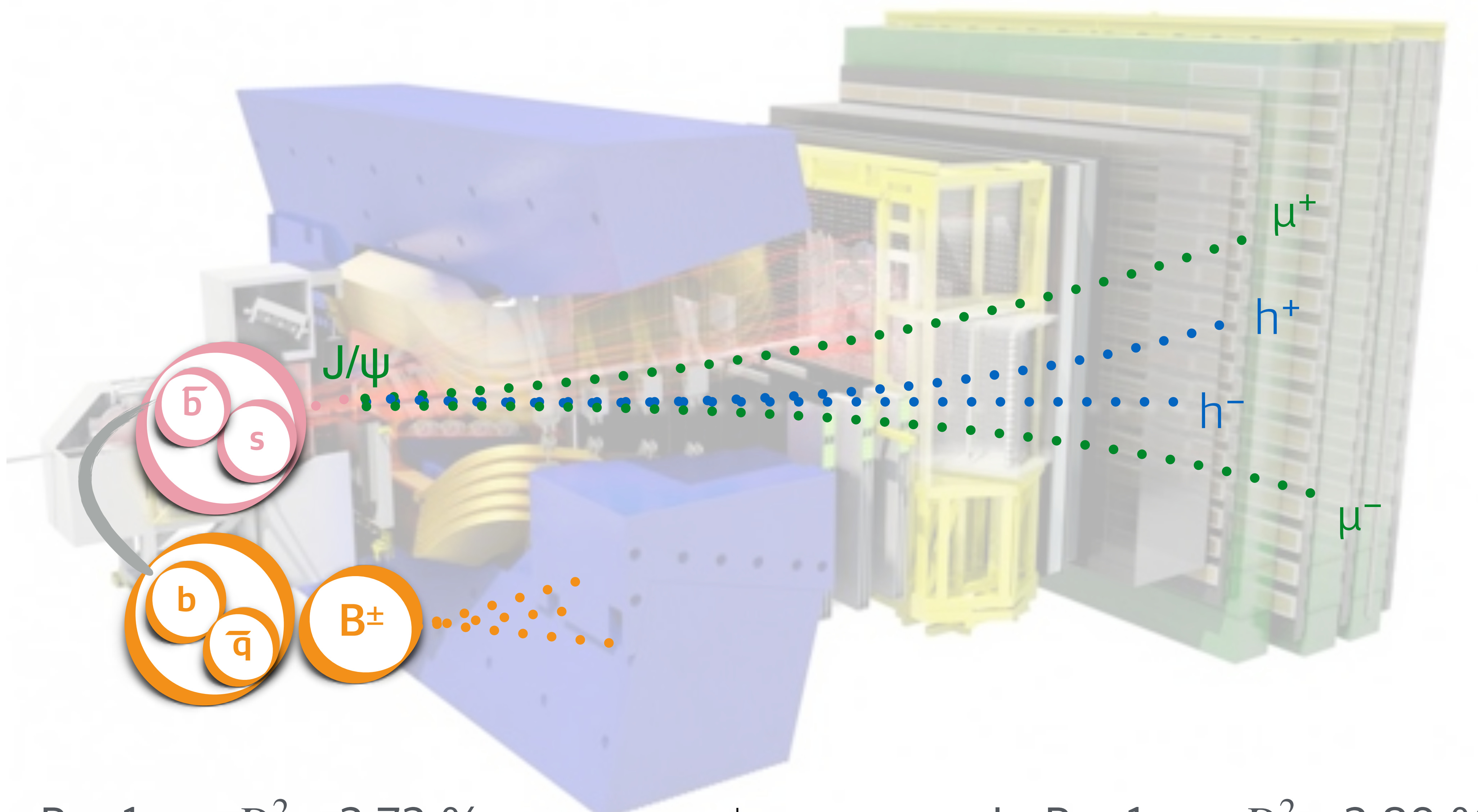


$B^0_s \to J/\psi\ K^+K^-$

EUR.PHYS.J.C 79 (2019) 706

$B^0_s \to J/\psi\ \pi^+\pi^-$

To appear in PLB 797 (2019)



In Run1 $\varepsilon_{tag} D^2 \approx 3.73$ %

$$\varepsilon_{tag} D^2 = 4.73 \pm 0.34\ \%$$

In Run1 $\varepsilon_{tag} D^2 \approx 3.89$ %

$$\varepsilon_{tag} D^2 = 5.06 \pm 0.38\ \%$$

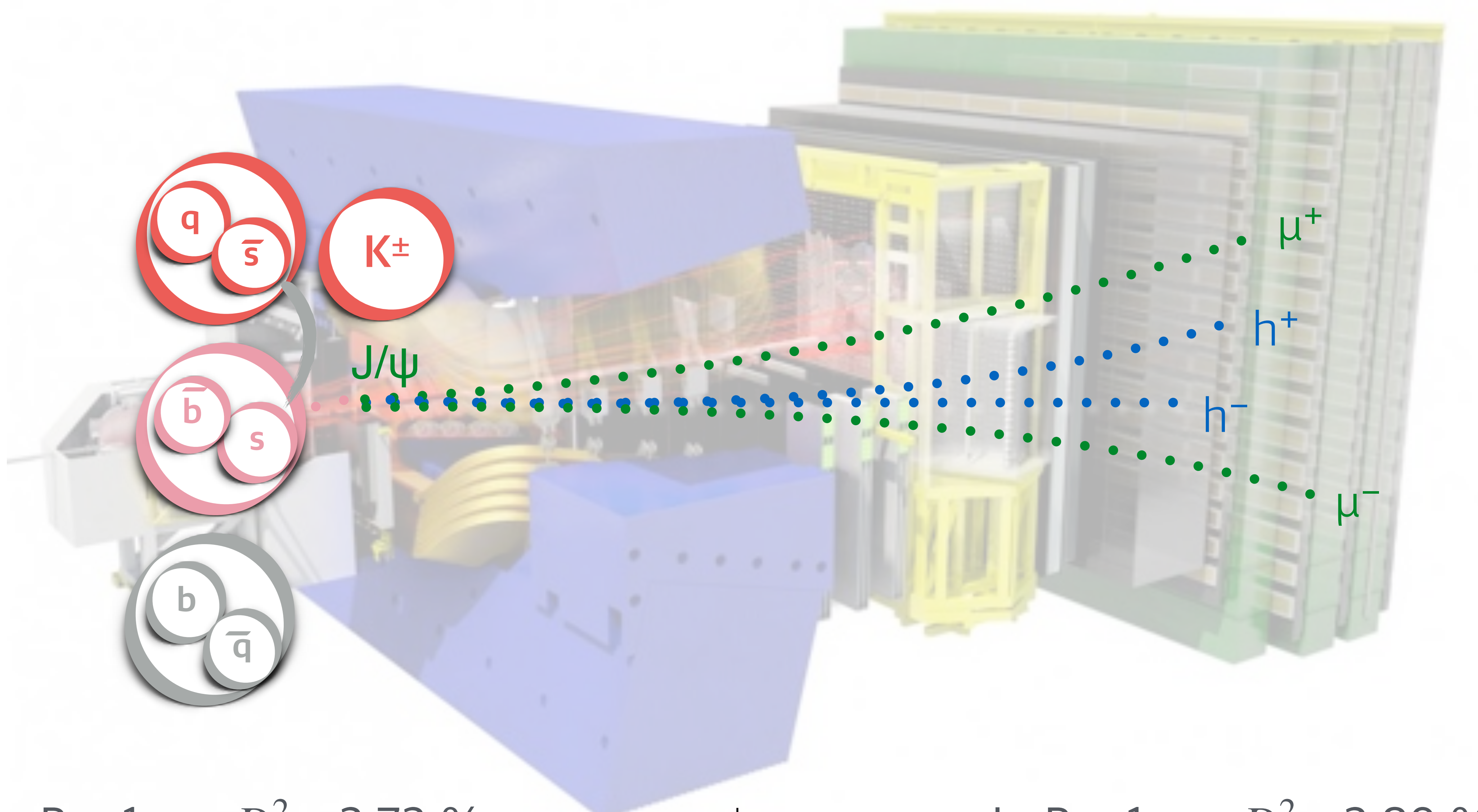
Same side tagging

$B^0_s \to J/\psi\ K^+K^-$

EUR.PHYS.J.C 79 (2019) 706

$B^0_s \to J/\psi\ \pi^+\pi^-$

To appear in PLB 797 (2019)



In Run1 $\varepsilon_{\rm tag} D^2 \approx 3.73$ %

$$\varepsilon_{\rm tag} D^2 = 4.73 \pm 0.34\ \%$$

In Run1 $\varepsilon_{\rm tag} D^2 \approx 3.89$ %

$$\varepsilon_{\rm tag} D^2 = 5.06 \pm 0.38\ \%$$

Measure $\varphi_s^{d\bar{d}}$ using $B^0_s \to (K^+\pi^-)(K^-\pi^+)$

[LHCb-PAPER-2017-048]

Fit projections in decay time, three angles and $m(K\pi)$