Mixing and time-dependent CP violation in beauty at LHCb

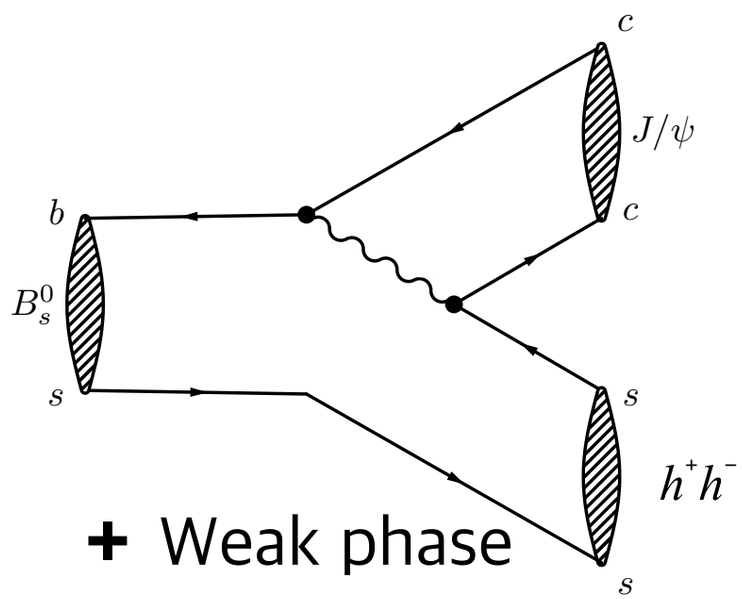
Katya Govorkova
on behalf of the LHCb Collaboration

Moriond EW 2019

CP violation in B^0_s

Decays of B^0_s ($\overline{B}^0_s$) to $J/\psi\ h^+h^-$

CP violation in interference between direct decay and decay after mixing



+ Weak phase

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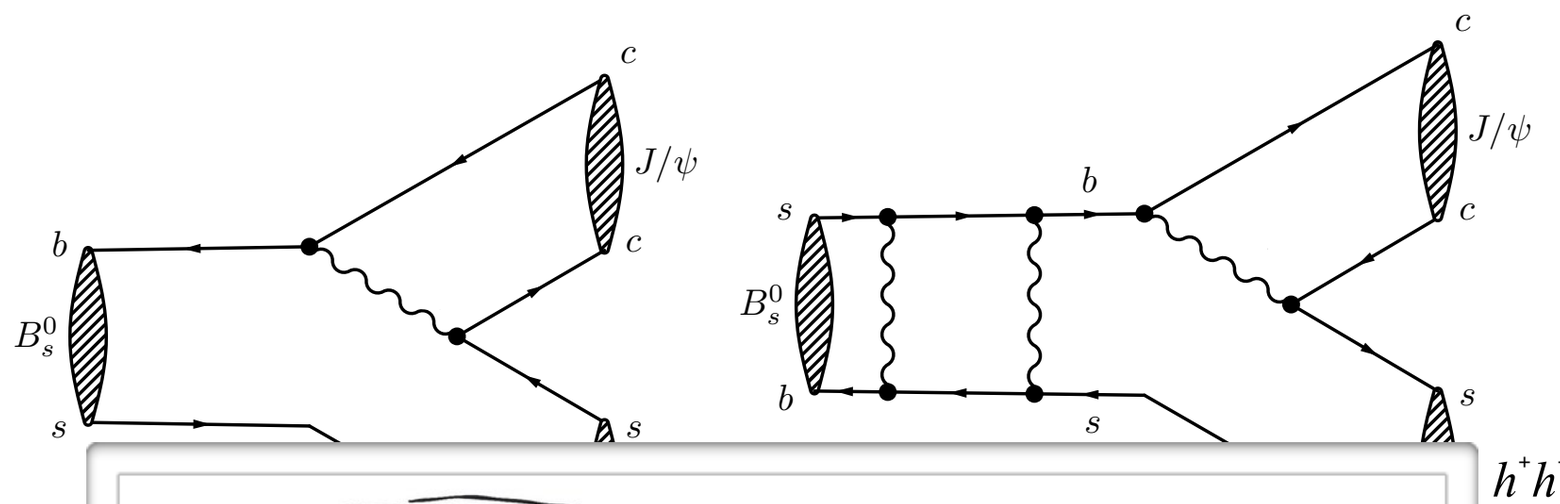

@lisbouche

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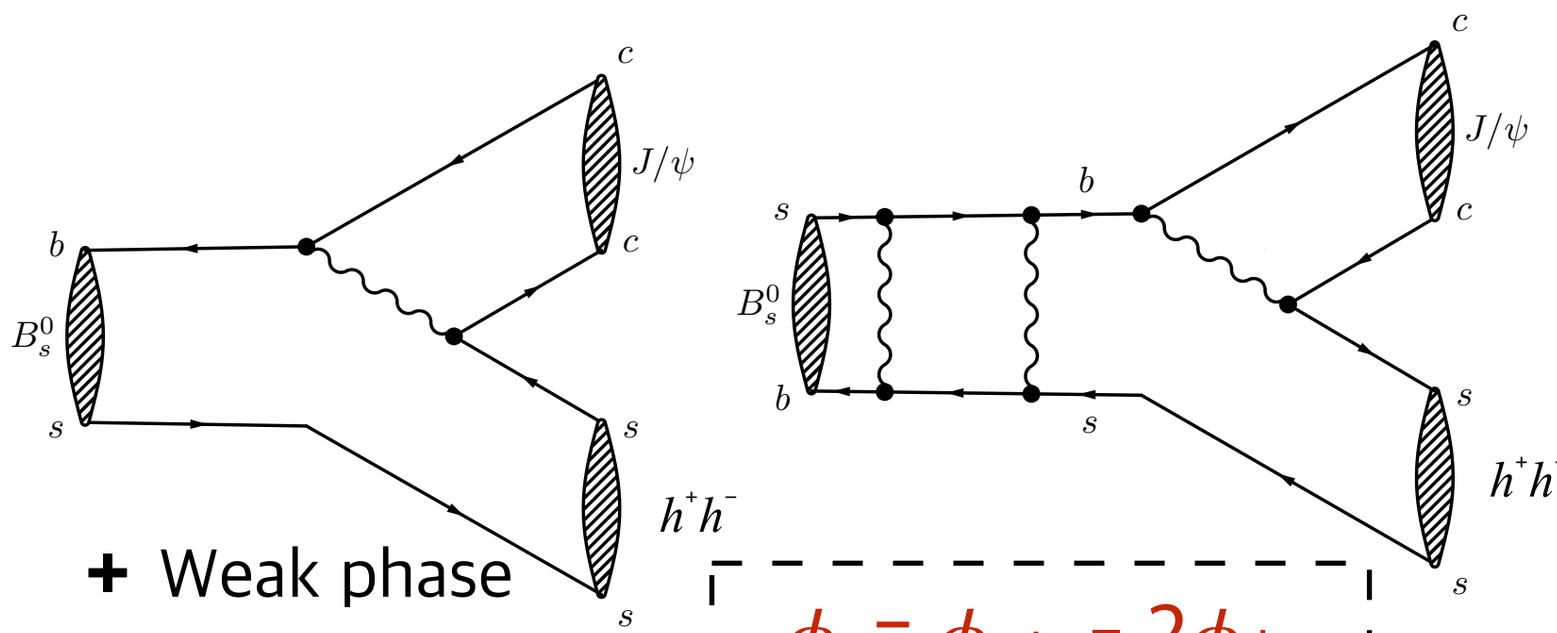

$\phi_s = \phi_{mix} - 2\phi_{dec}$

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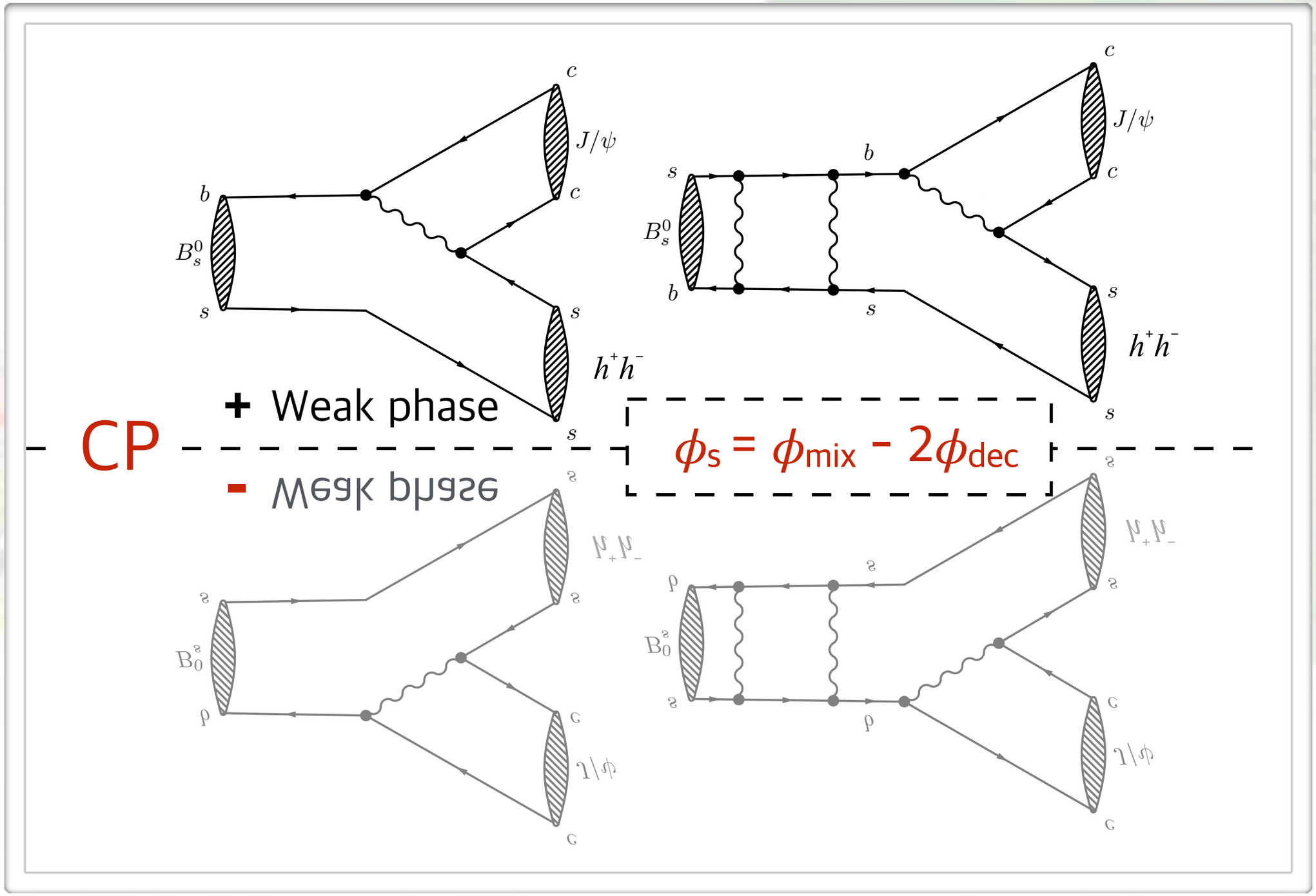
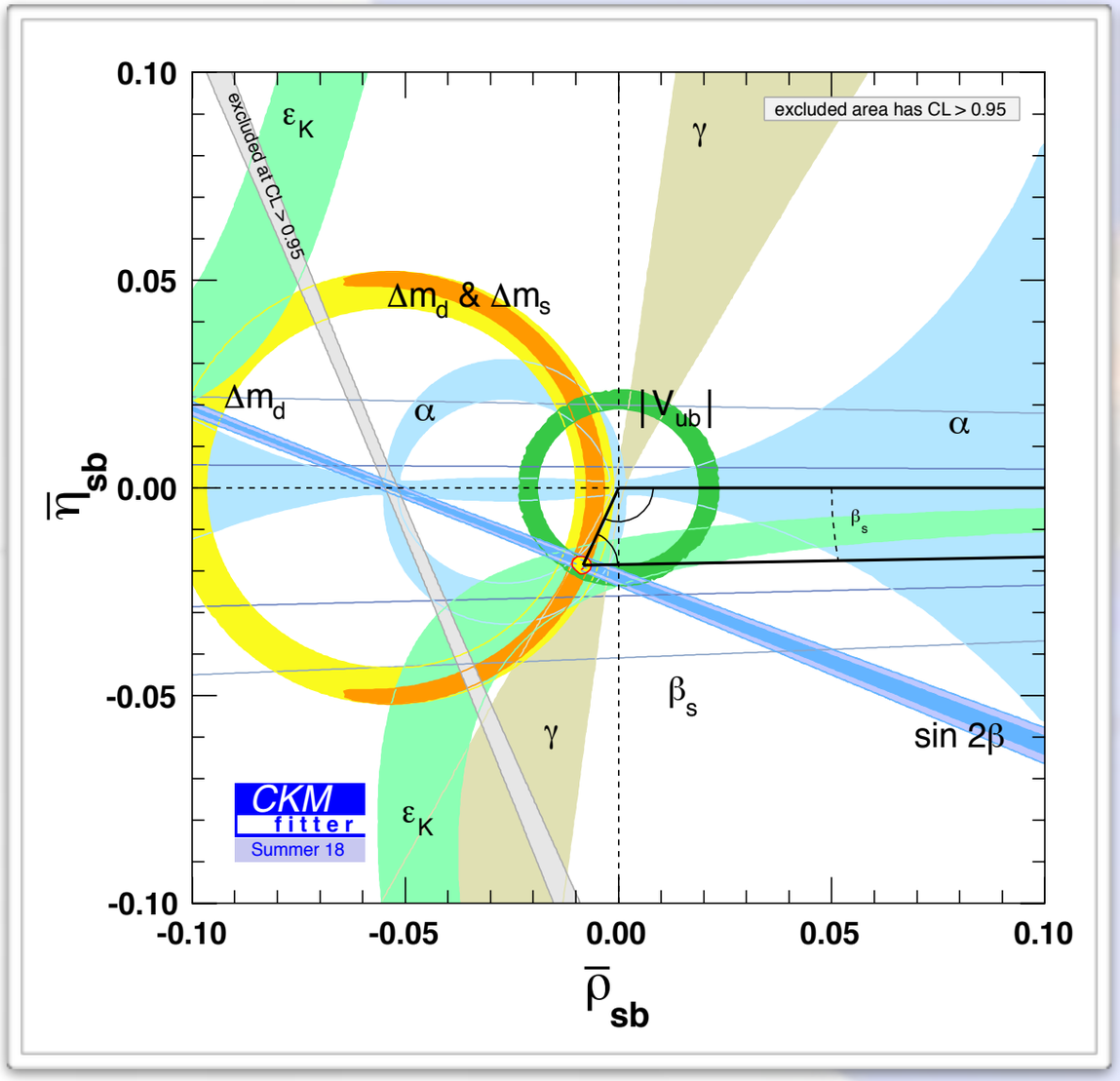


CP violation in B^0_s

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

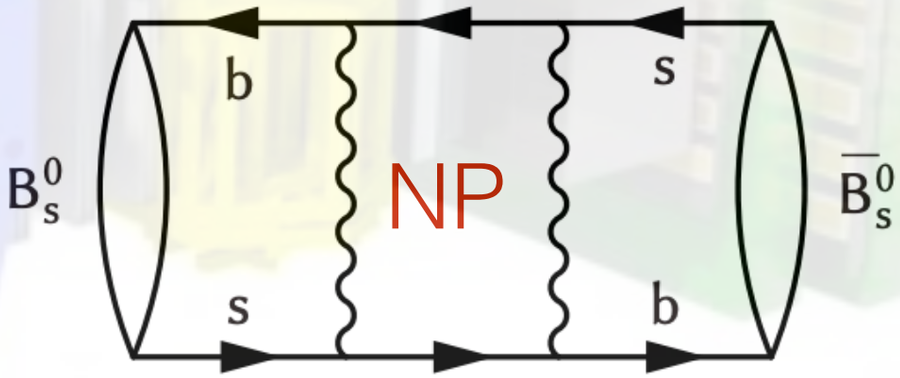
[CKM fitter]



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

If $\phi_s^{exp} \neq \phi_s^{SM}$

New Physics!



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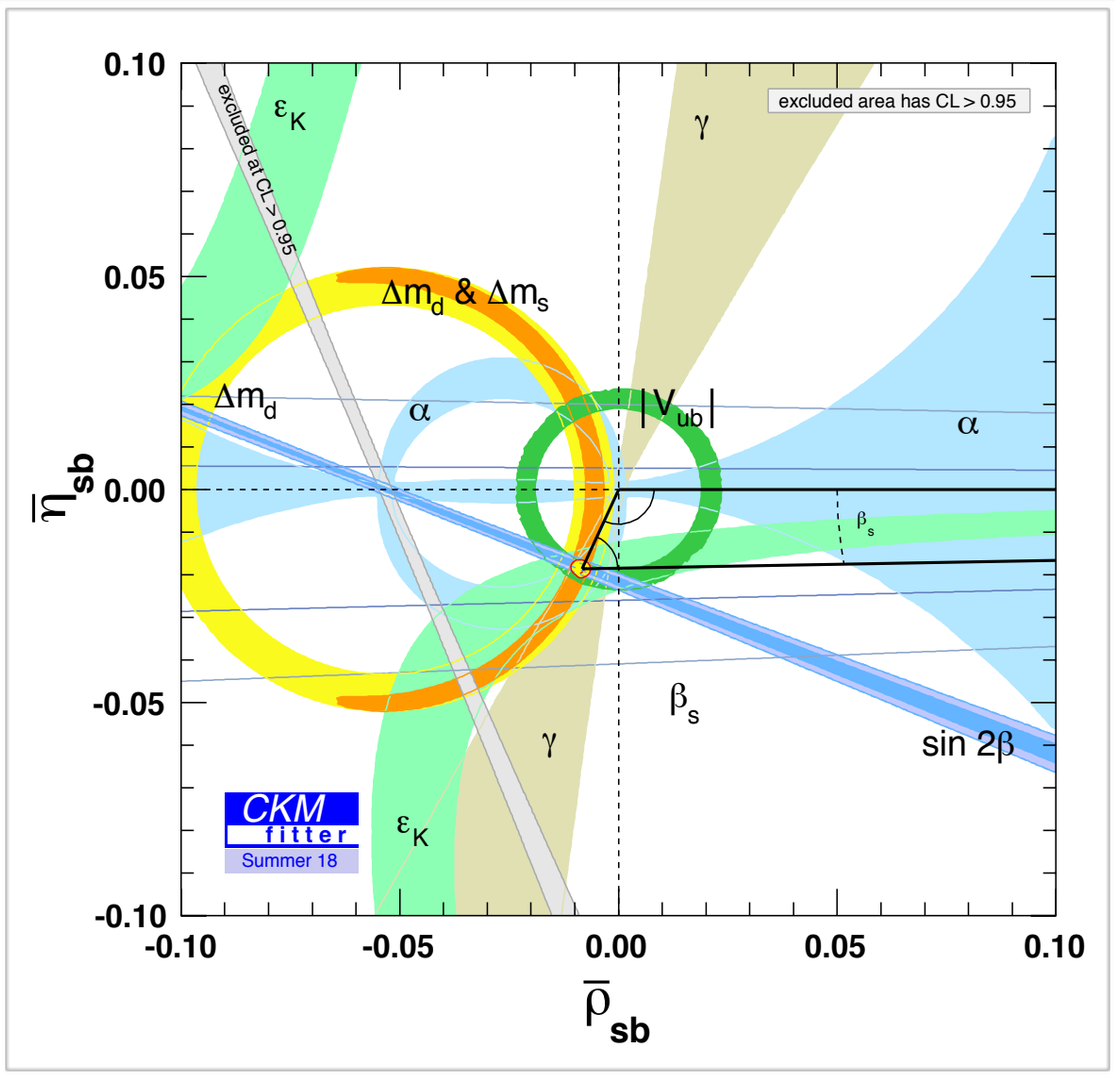

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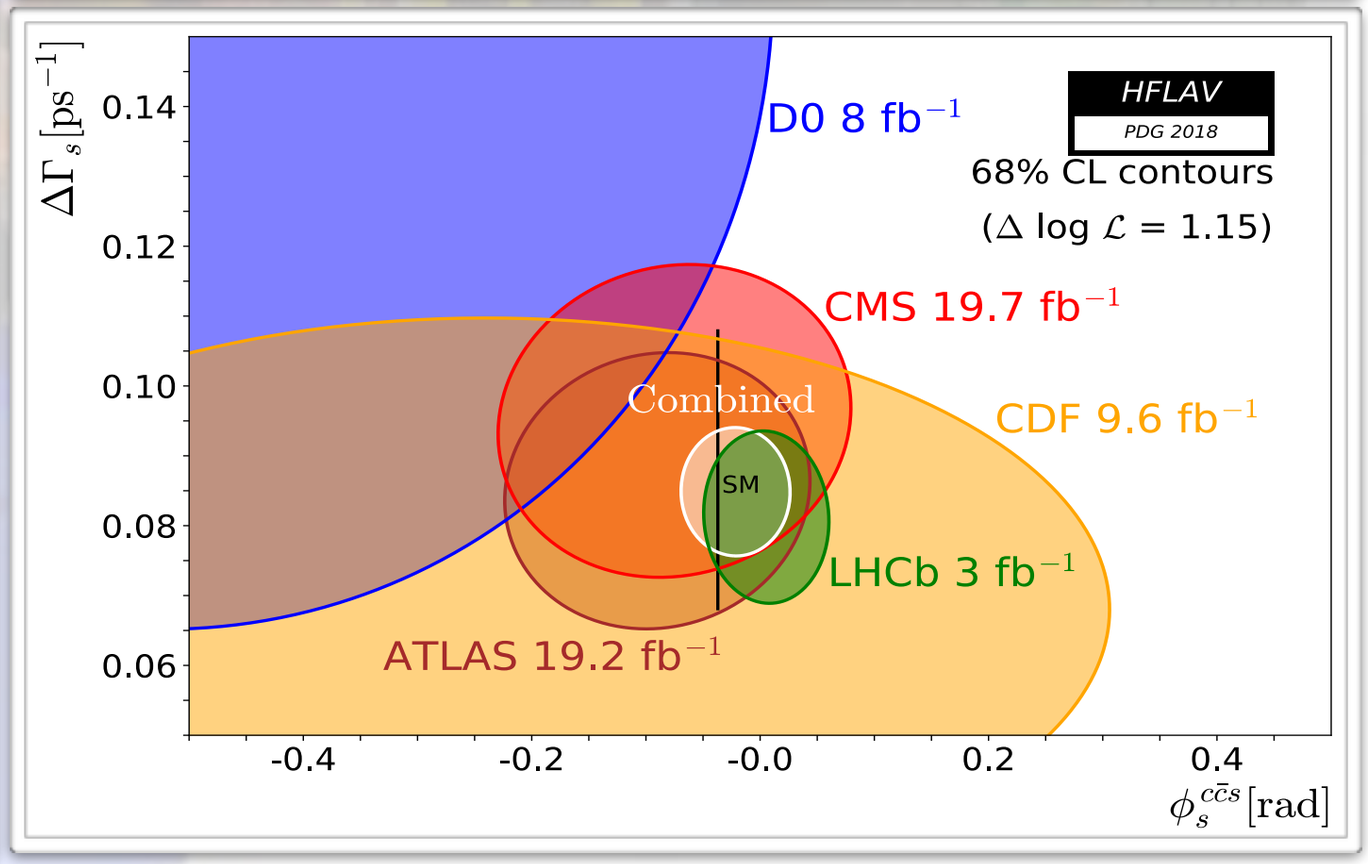
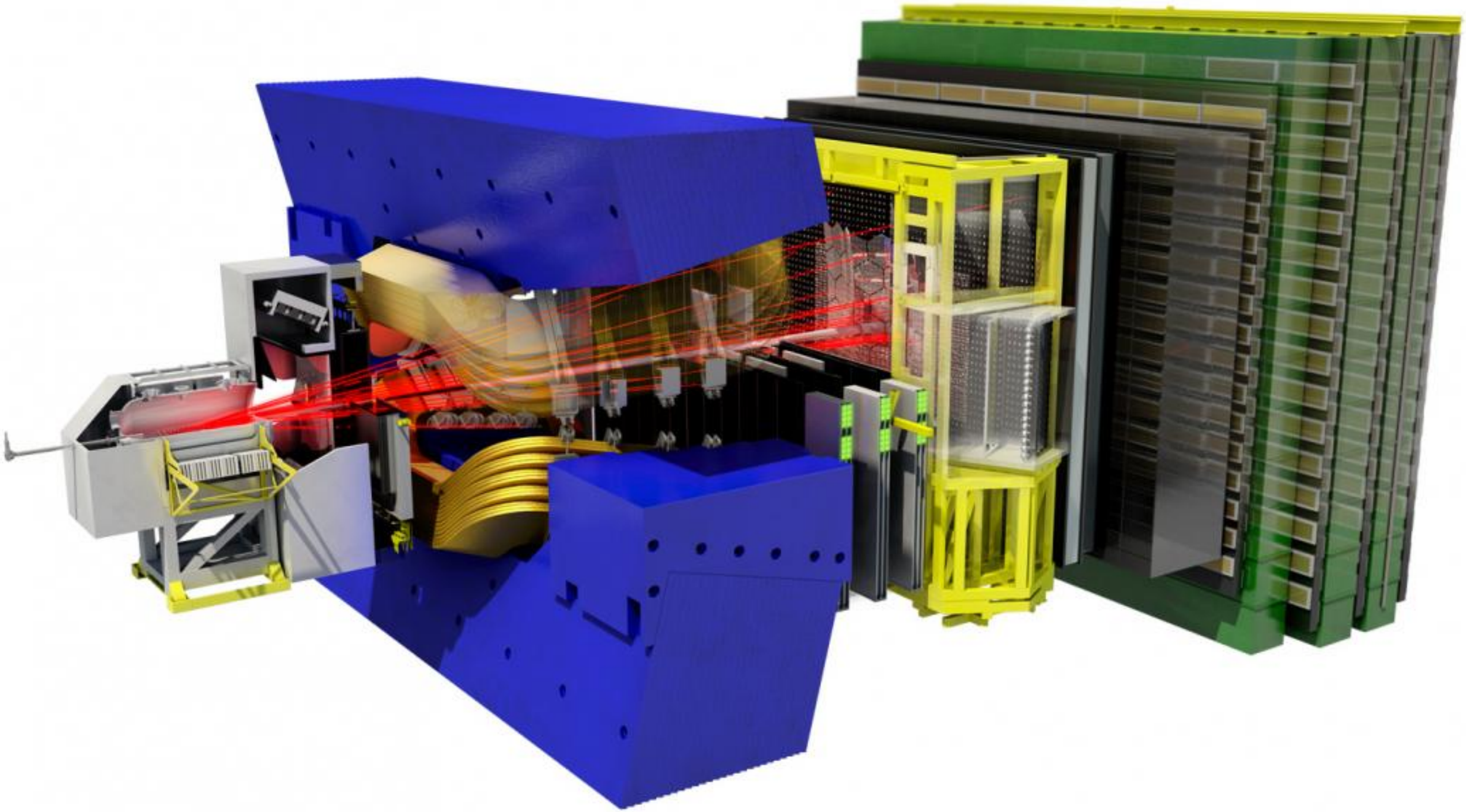
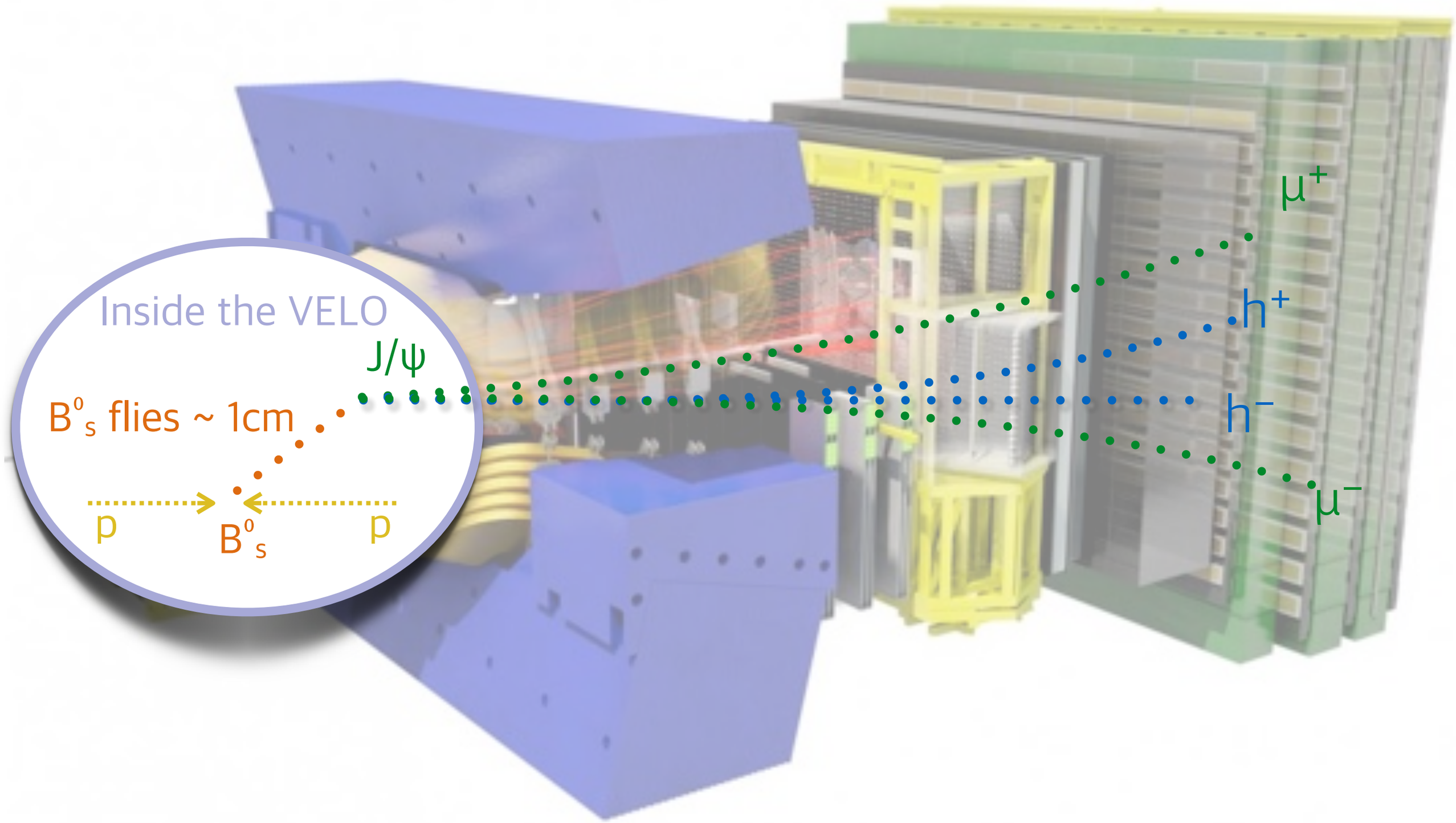
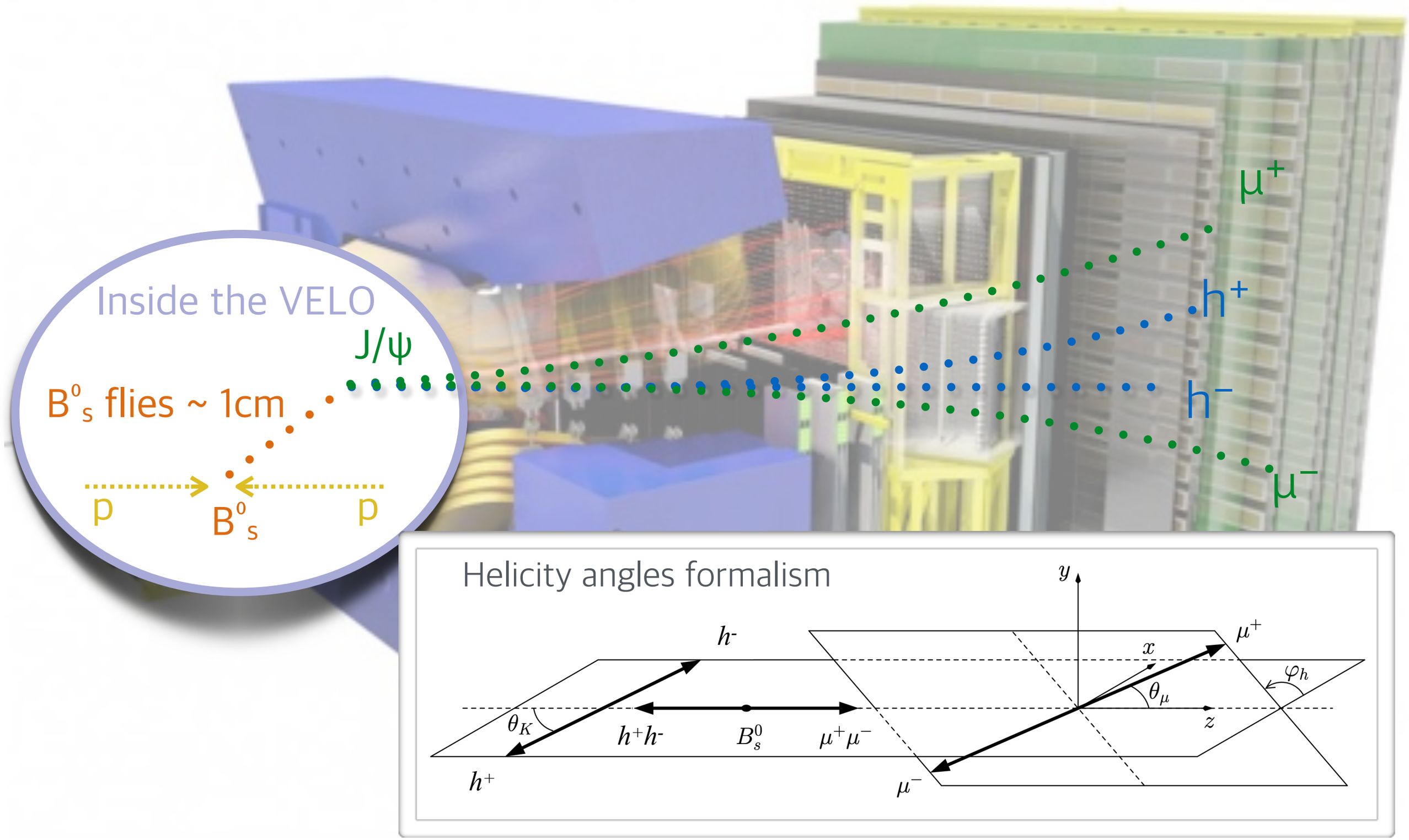





Inside the VELO
J/ψ
B^0_s flies ~ 1cm
p
B^0_s
p
μ^+
h^+
h^-
μ^-


Inside the VELO
J/ψ
B⁰s flies ~ 1cm
p
B⁰s
p
μ+
h+
h−
μ−
Helicity angles formalism
y
h-
μ+
x
φh
θμ
θK
h+h-
B⁰s
μ+μ−
z
h+
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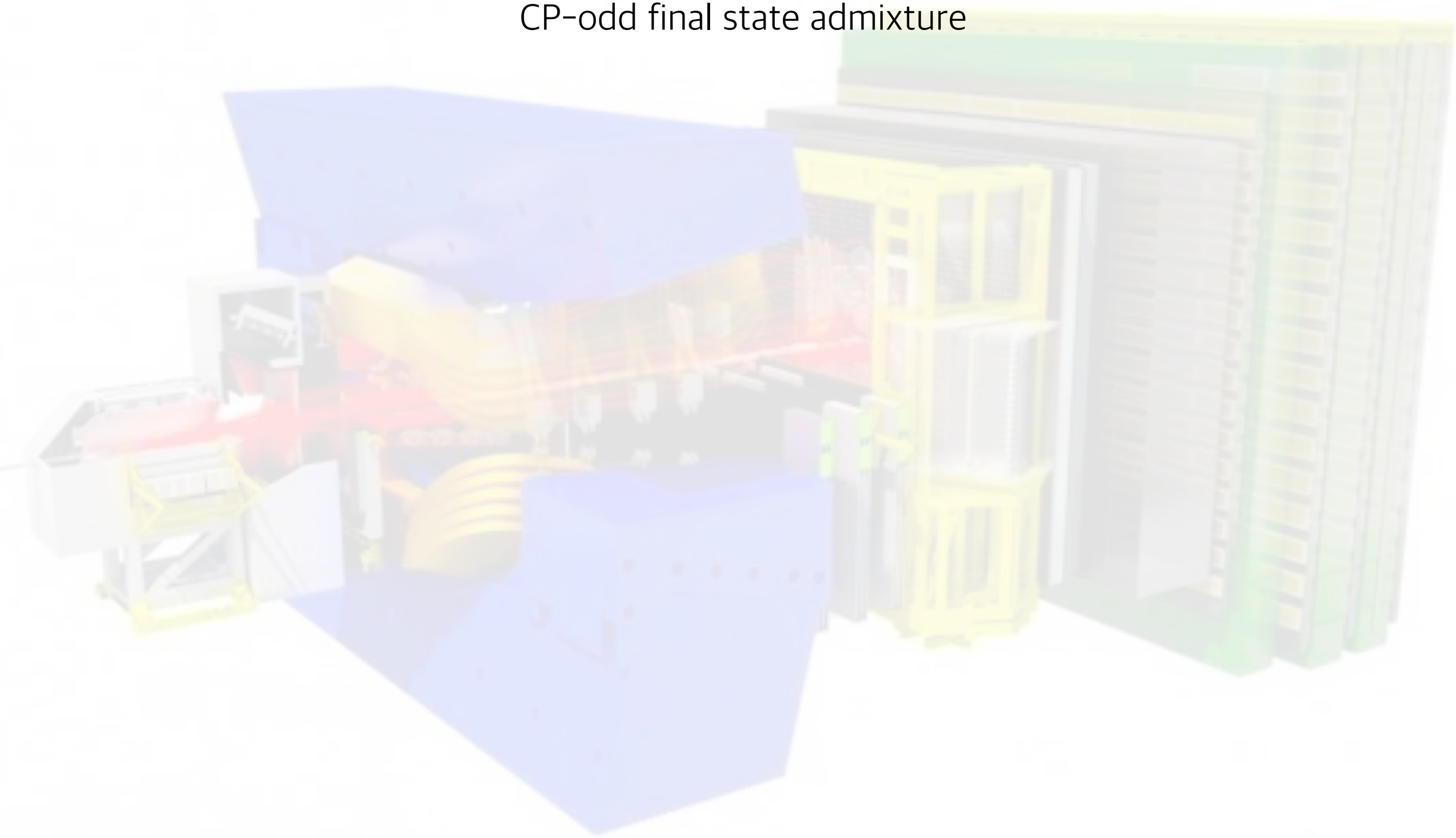
Measurement of CPV at LHCb

Angular analysis is required to disentangle CP-even and CP-odd final state admixture



Measurement of CPV at LHCb

Angular analysis is required to disentangle CP-even and CP-odd final state admixture

$$\frac{d^4\Gamma}{dt\,d\Omega} \sim \sum_k f_k(\Omega)\,\varepsilon(t,\Omega)\,(1-2\omega)\,h_k(t\,|\,B_s^0) \otimes G(t\,|\,\sigma_t)$$

ω - mistag probability of flavour tagging

ε - efficiency as a function of decay time and angles

σ_t - decay time resolution

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$$h_k = e^{-\Gamma_s t}\left(a_k \cosh\frac{\Delta\Gamma_s t}{2} + b_k \sinh\frac{\Delta\Gamma_s t}{2} + c_k \cos(\Delta m_s t) + d_k \sin(\Delta m_s t)\right)$$

$$\Gamma_s = \frac{\Gamma_H + \Gamma_L}{2} \qquad \Delta\Gamma_s = \Gamma_L - \Gamma_H$$

$$|B_L> = p\,|B_s^0> + q\,|\bar{B}_s^0> \quad \approx \text{CP-even}$$

$$|B_H> = p\,|B_s^0> - q\,|\bar{B}_s^0> \quad \approx \text{CP-odd}$$

$$\lambda = \eta\frac{q}{p}\frac{\bar{A}_f}{A_f}$$

Analyses strategy

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

[LHCB-PAPER-2019-013]

in preparation

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

arXiv:1903.05530

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

measure ϕ_s , $|\lambda|$ and

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to test the Heavy Quark Expansion

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

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since the final state is almost entirely CP-odd

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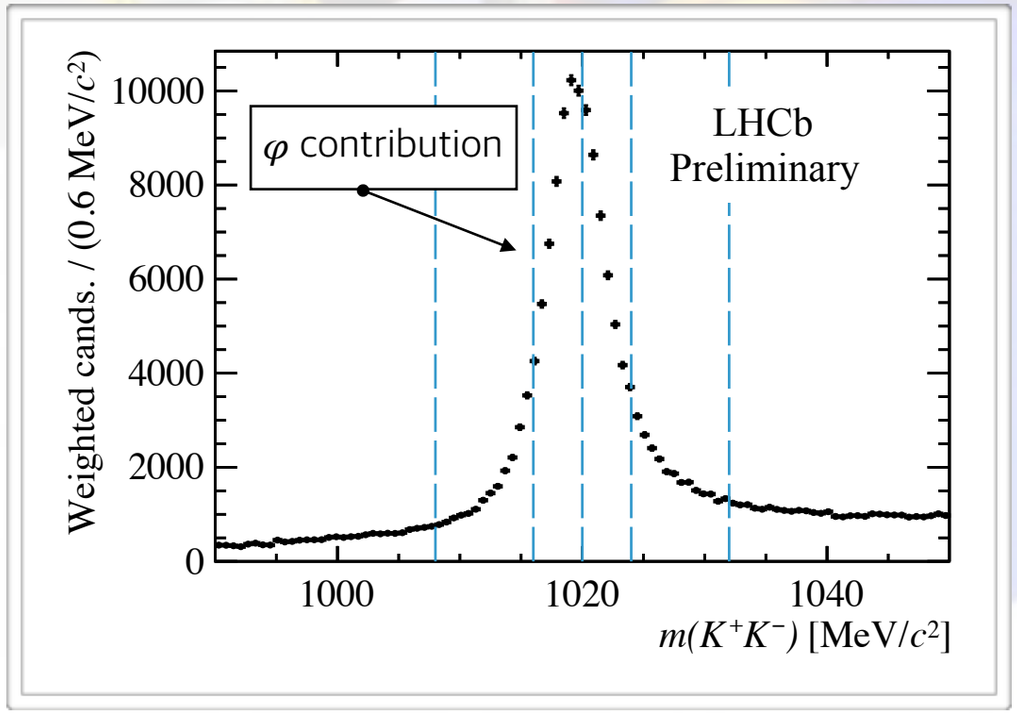
See YS talk by J.Zonneveld

Simultaneous fit to the decay time and three helicity angles

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



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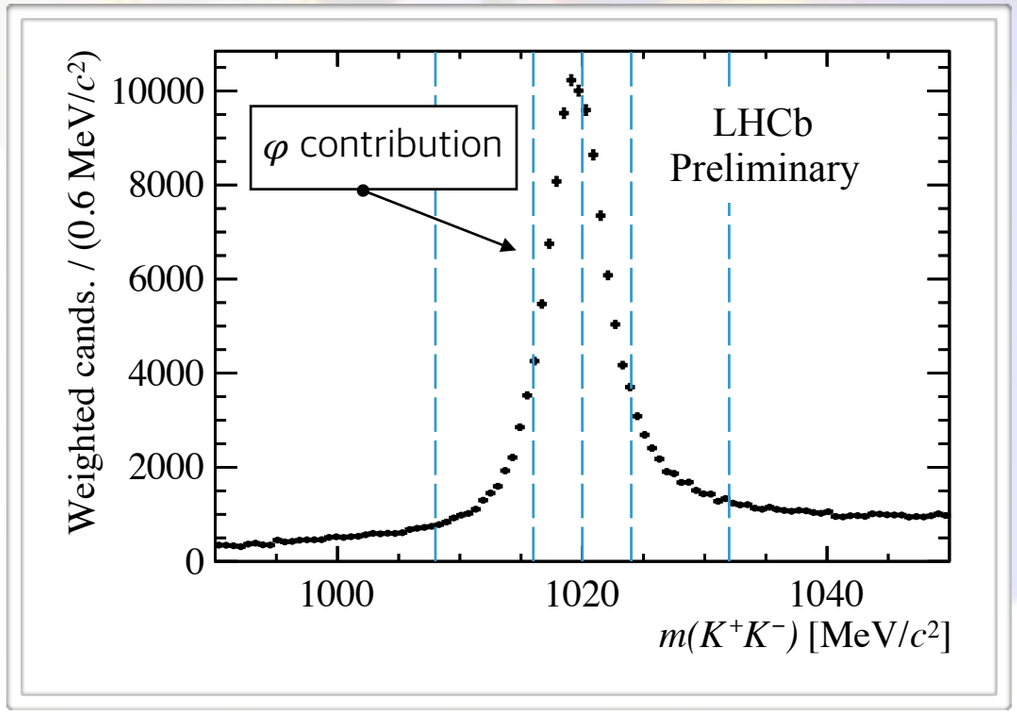
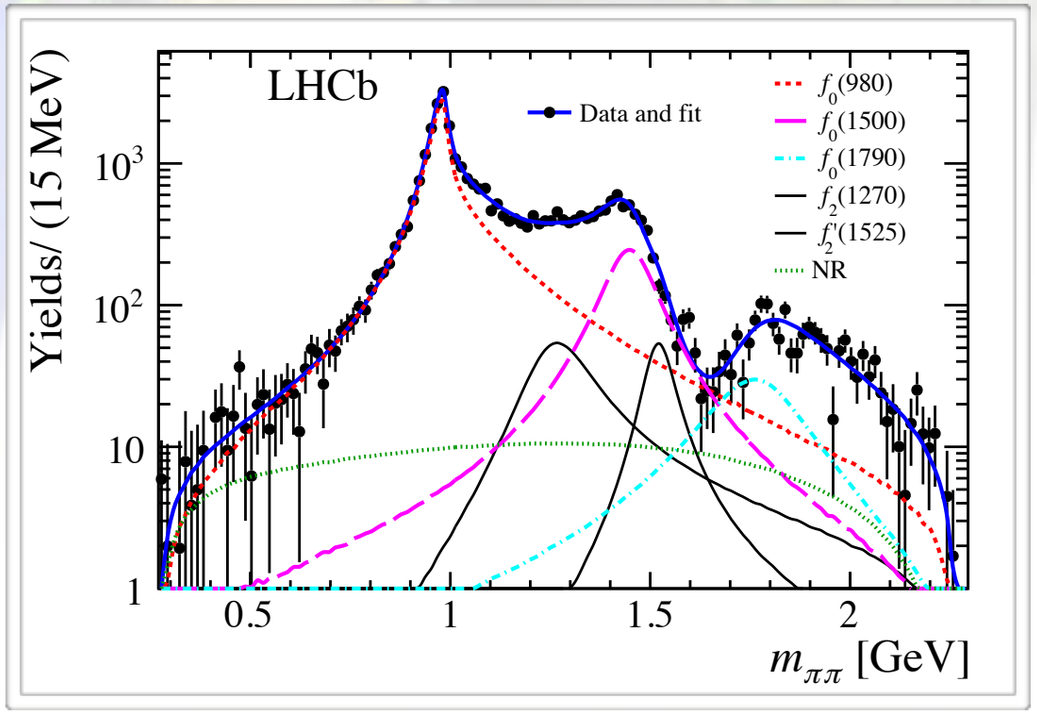


and $m(\pi^+\pi^-)$



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

Measurement of φ_s

Selection and mass fit

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

[LHCB-PAPER-2019-013]

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Boosted decision tree is trained to select signal candidates

Selection and mass fit

$B^0_s \to J/\psi\, K^+K^-$
[LHCB-PAPER-2019-013]

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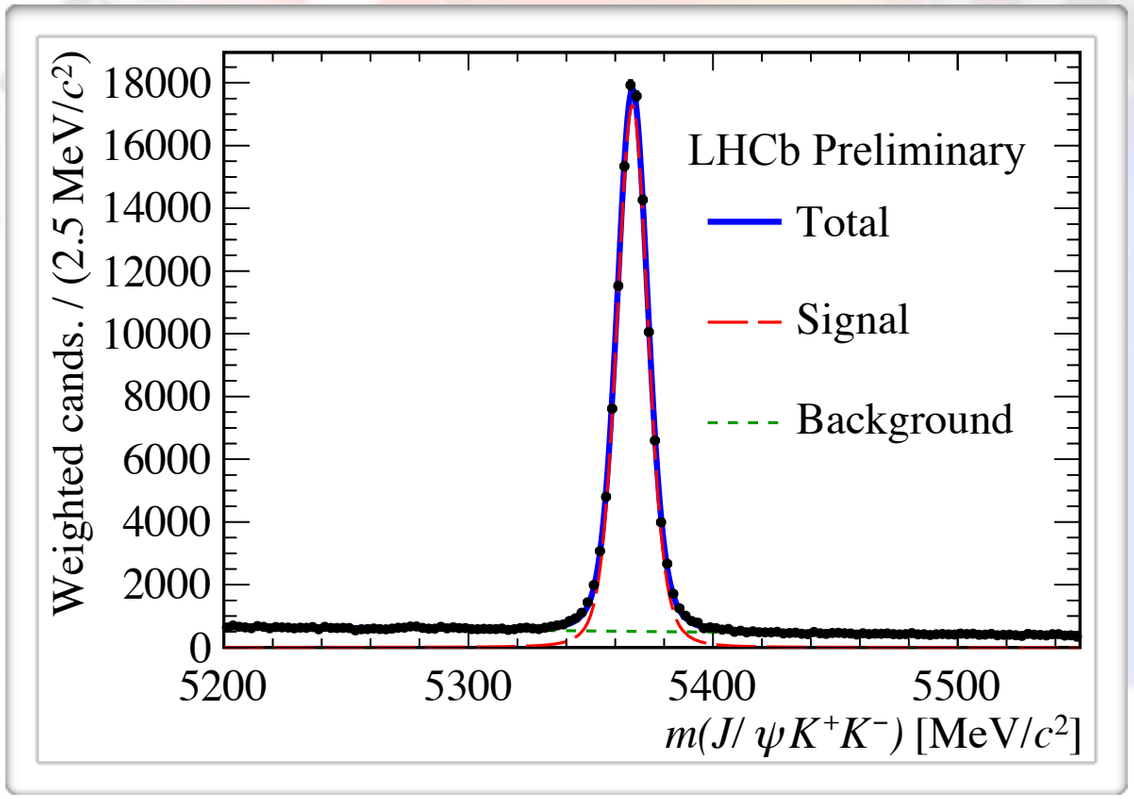
Boosted decision tree is trained to select signal candidates

Injected negative weighted MC to subtract $\Lambda_b \to J/\psi\, p\, K$ background

Signal width is a function of per-candidate mass error to account for correlation with $\cos(\theta_\mu)$

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



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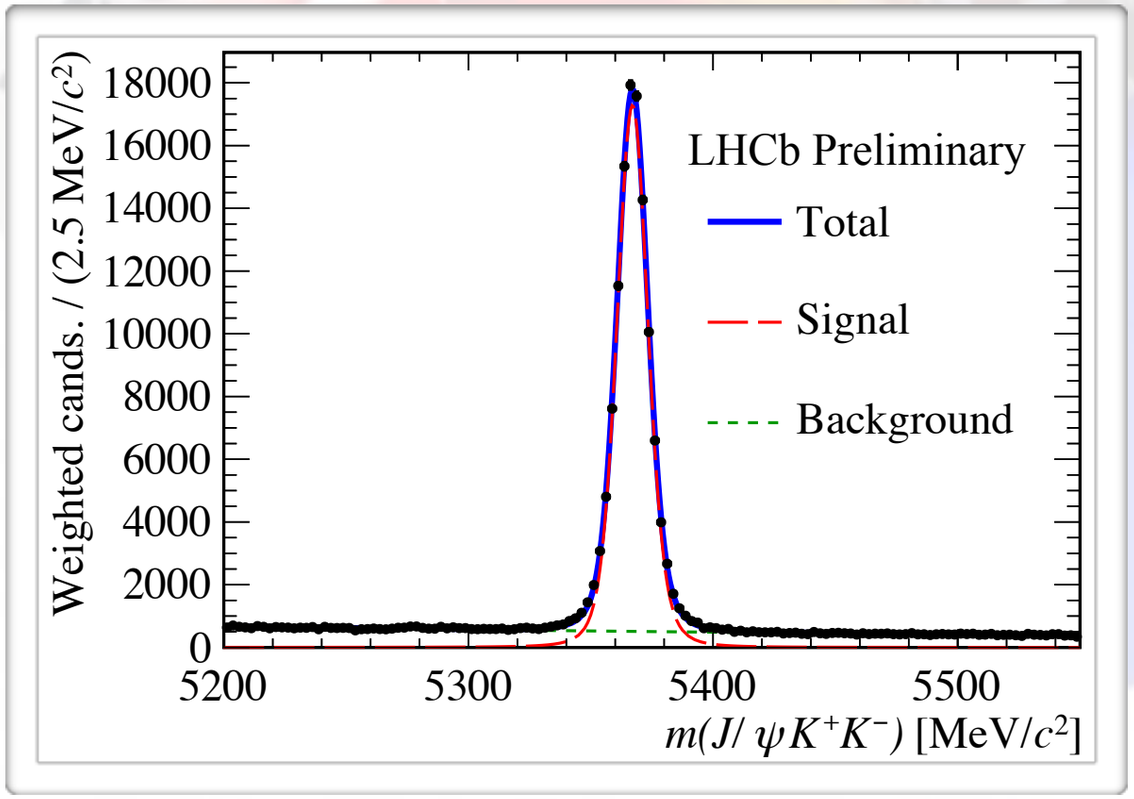
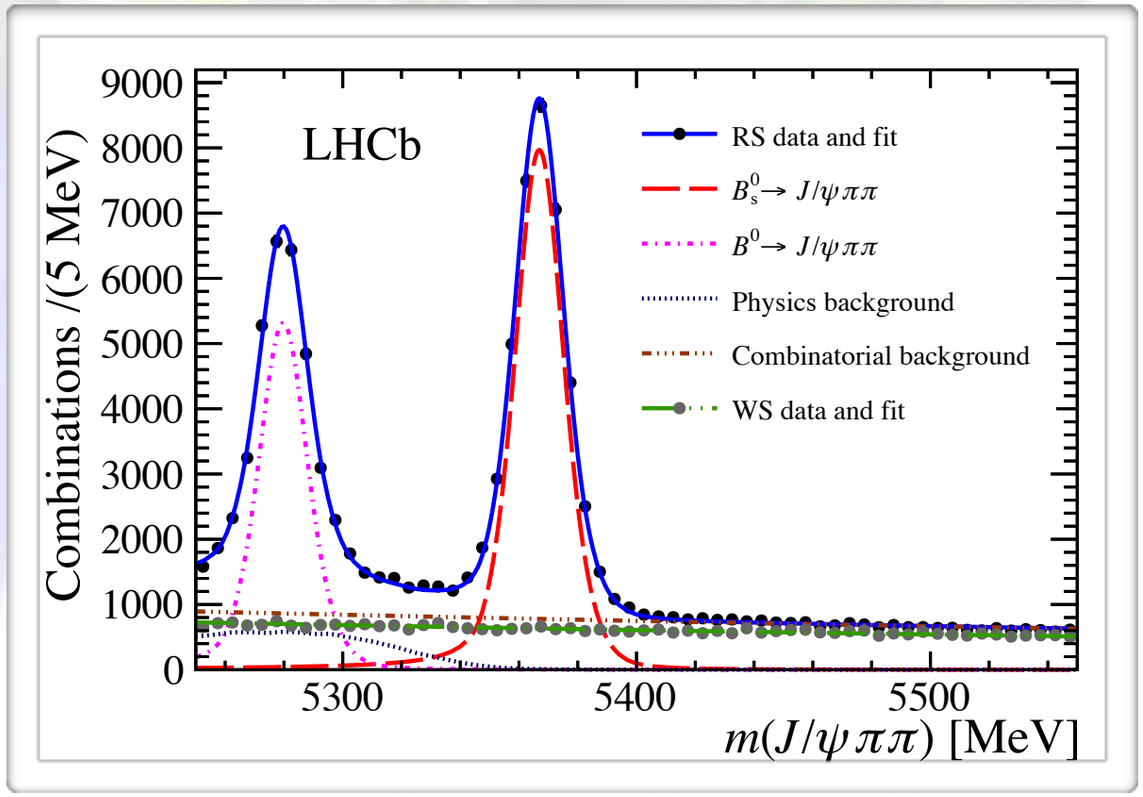
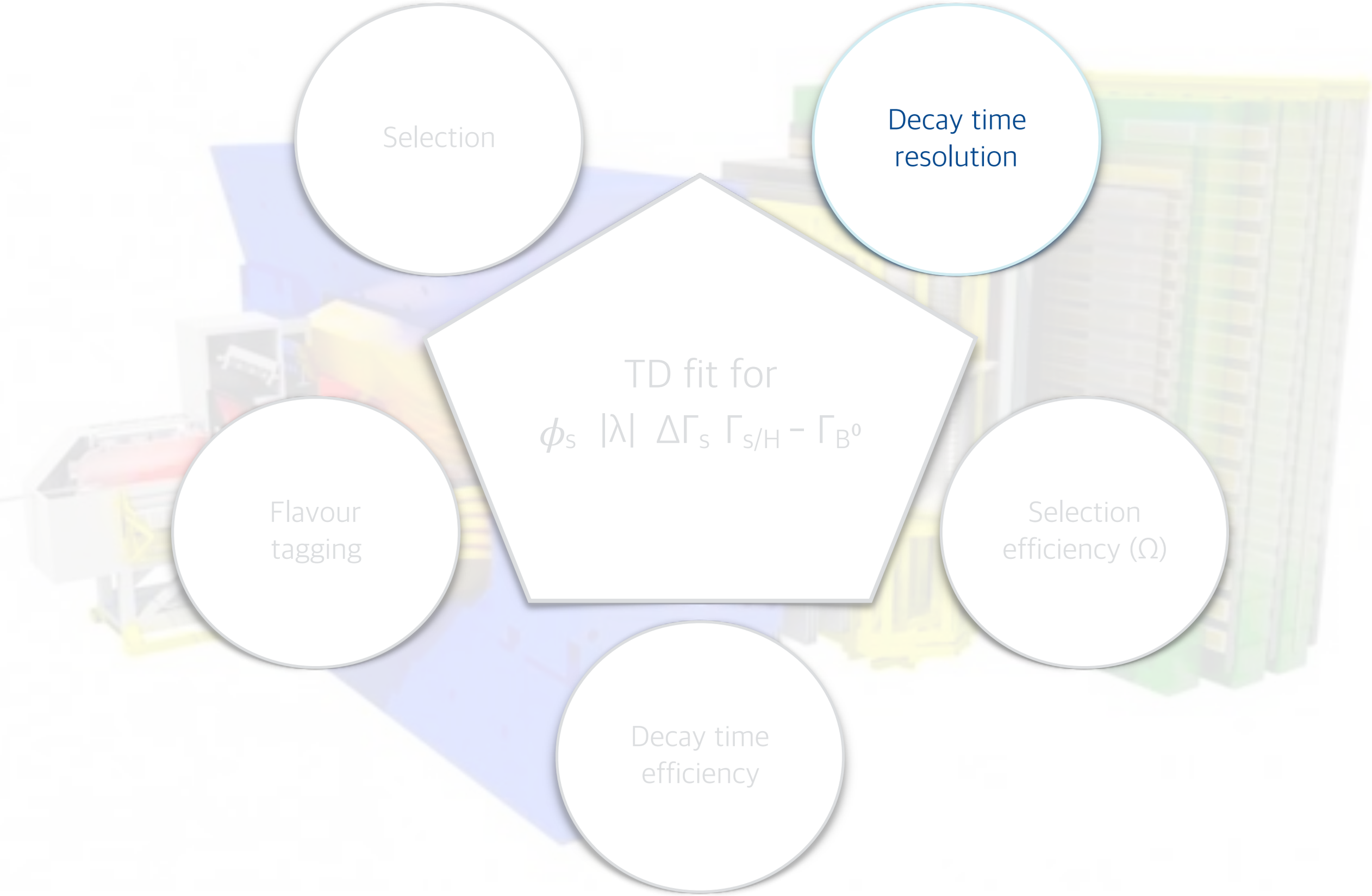


Use the wrong sign (WS) combination ($\pi^\pm\pi^\pm$) to determine the shape of the combinatorial background

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



Measurement of φ_s



Decay time resolution

$B^0_s \to J/\psi\, K^+K^-$
[LHCB-PAPER-2019-013]

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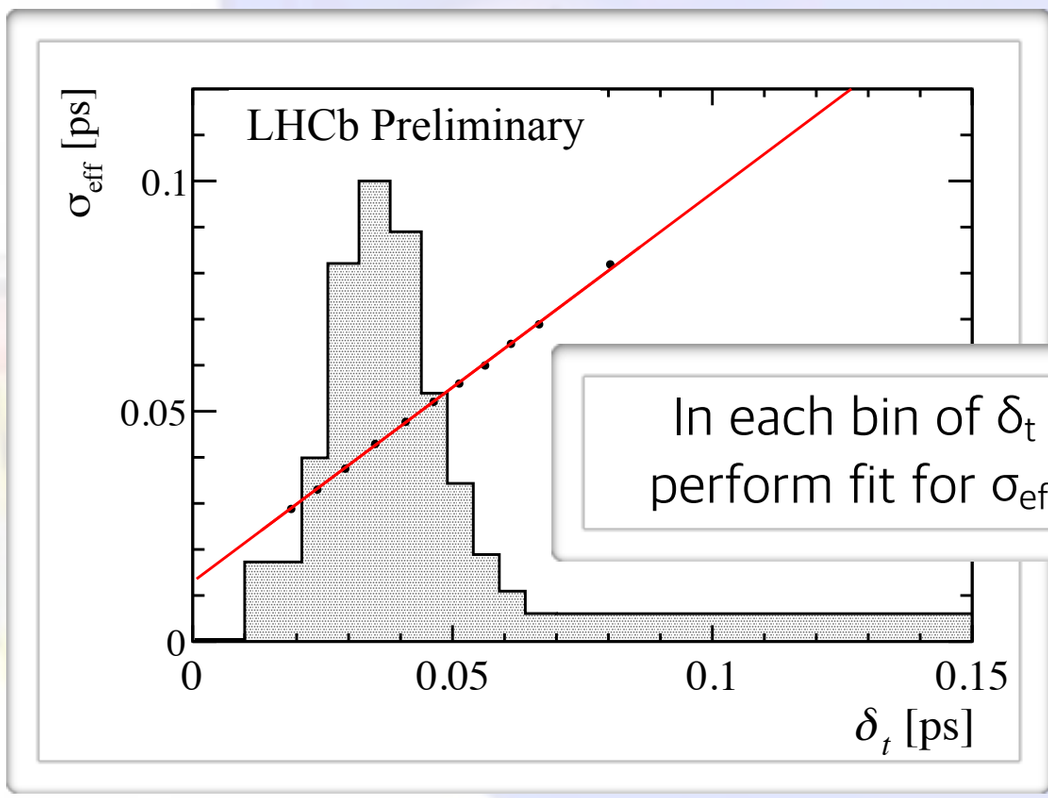
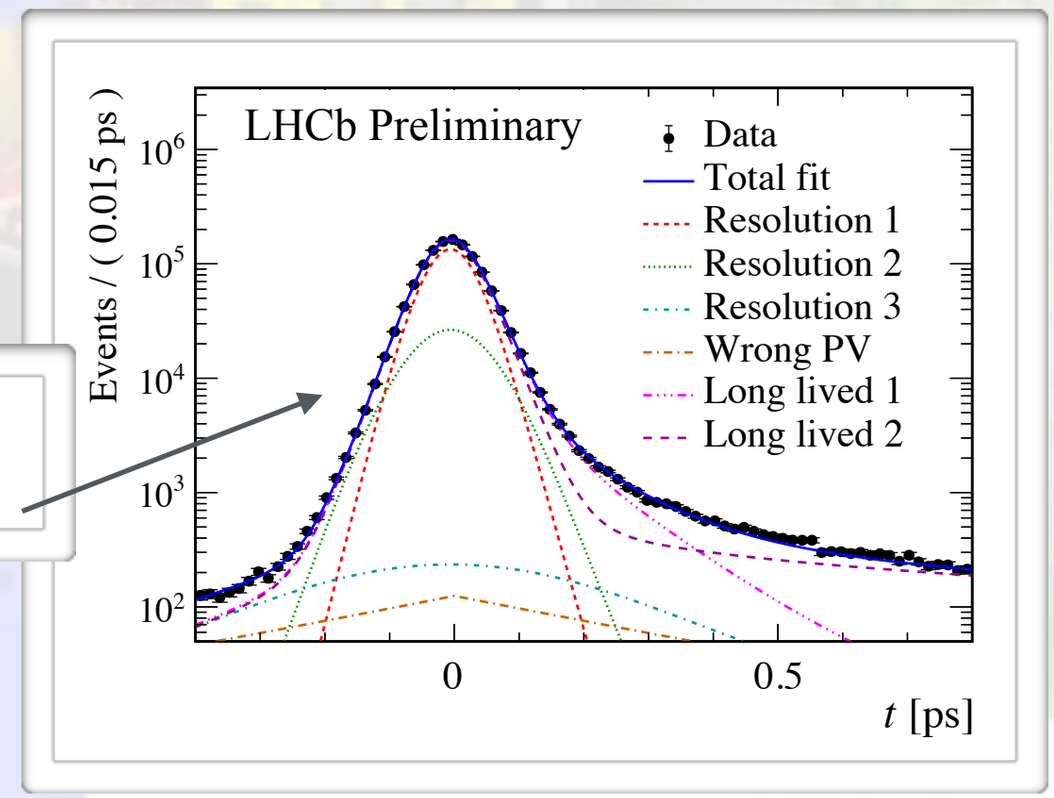
Per-candidate decay time error is calibrated using prompt J/ψ sample

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



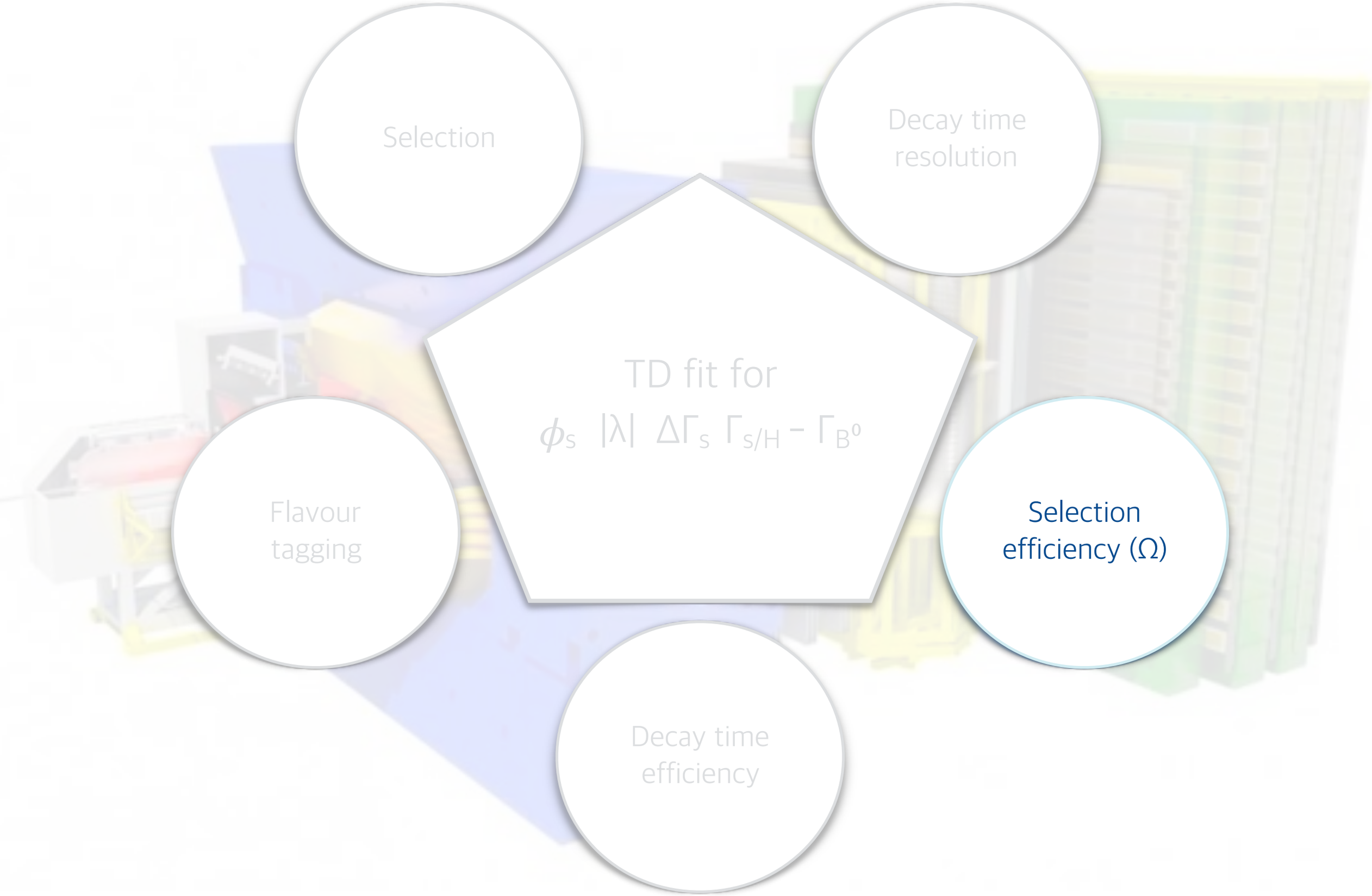
In each bin of δ_t perform fit for σ_{eff}



σ_{eff} = 45.5 fs

σ_{eff} = 41.5 fs

Measurement of φ_s



Selection efficiency as a function of angles

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

[LHCB-PAPER-2019-013]

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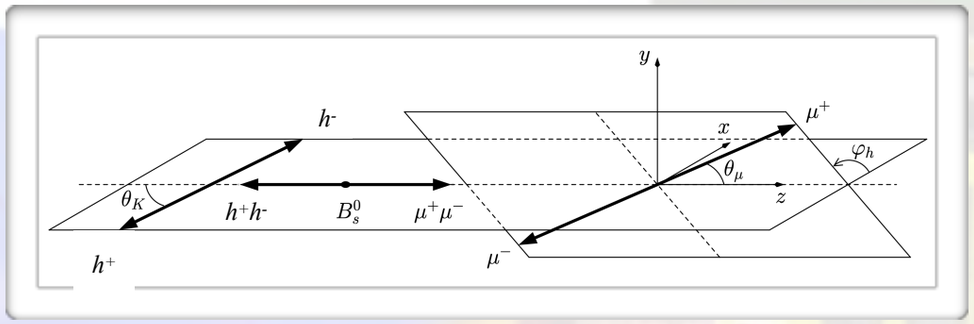

Kinematic selection and detector acceptance are causing non uniform efficiency as function of decay angles

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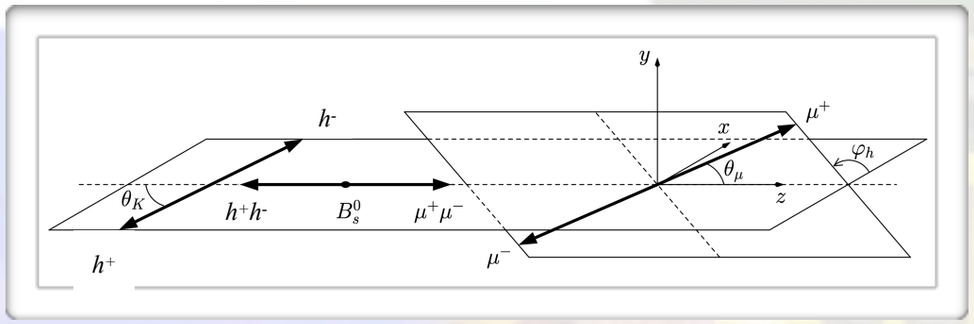

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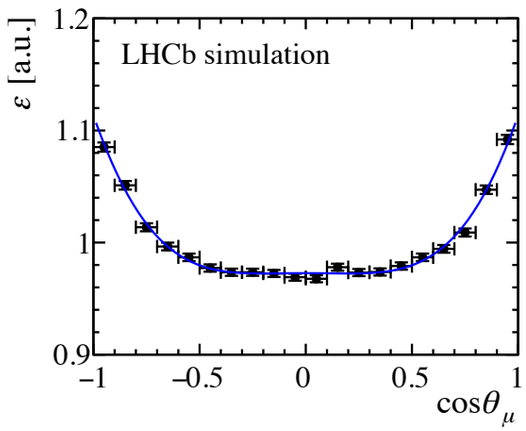

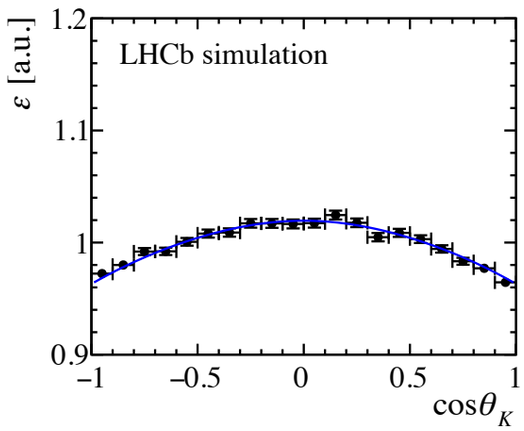

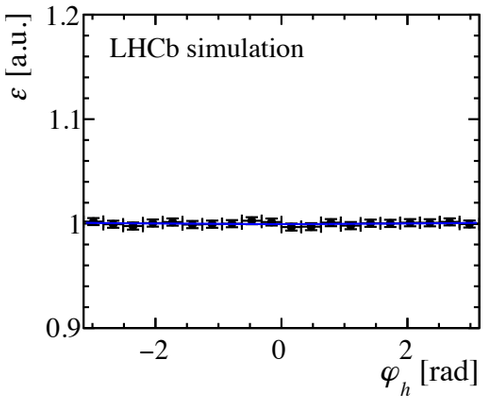

- angular distribution in MC / expected without acceptance effect

— fourth-order polynomial parameterisation

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[LHCB-PAPER-2019-013]

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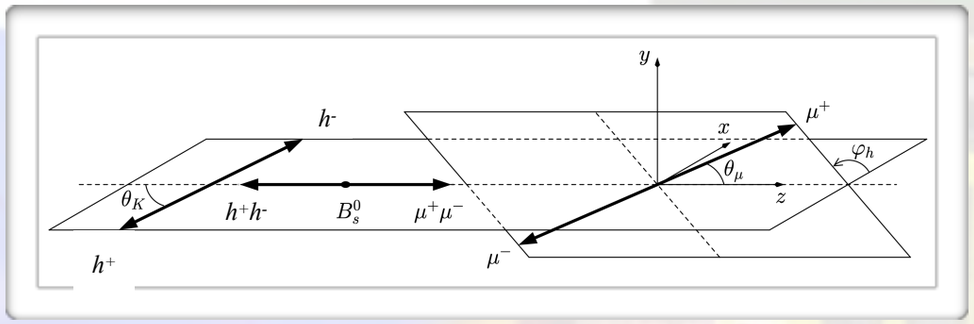

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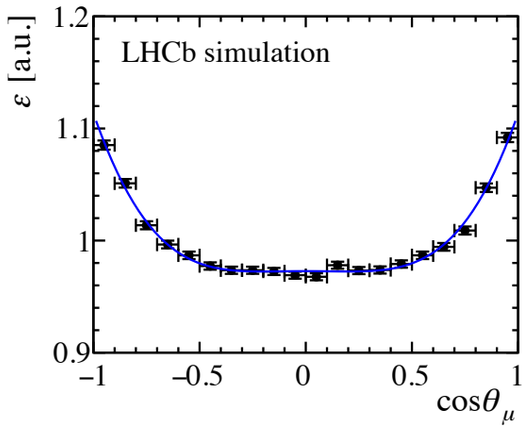

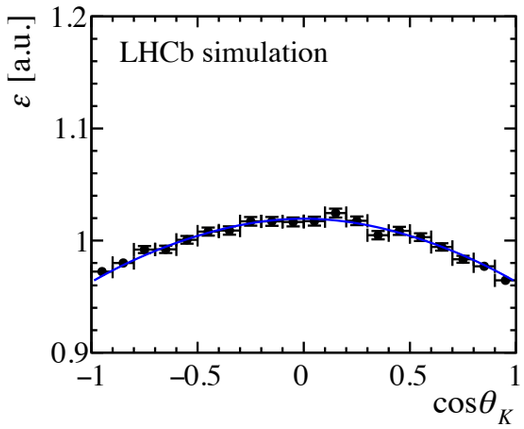

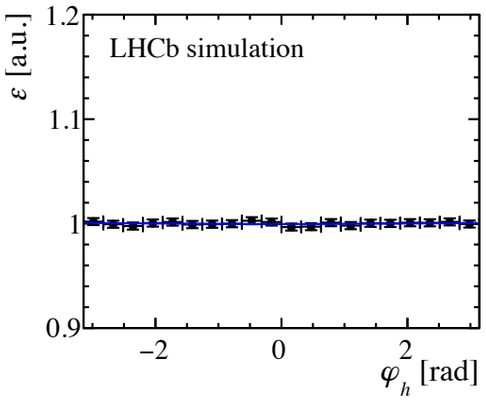

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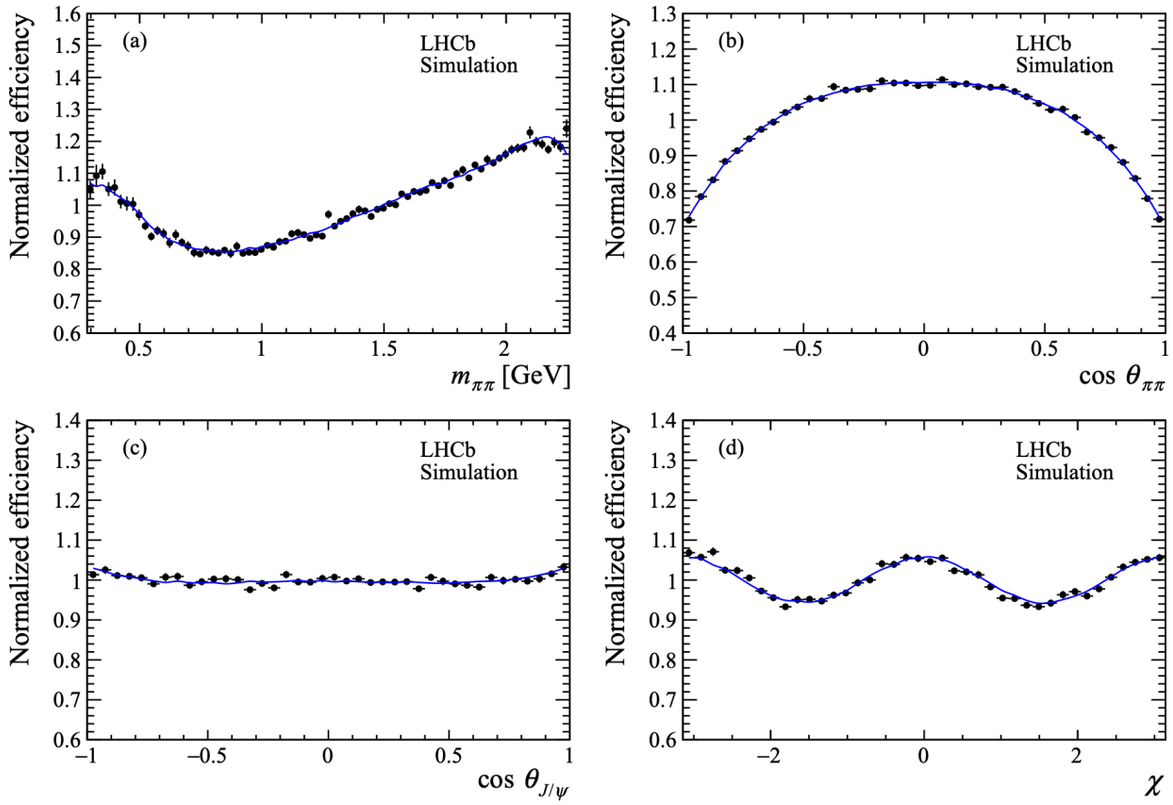
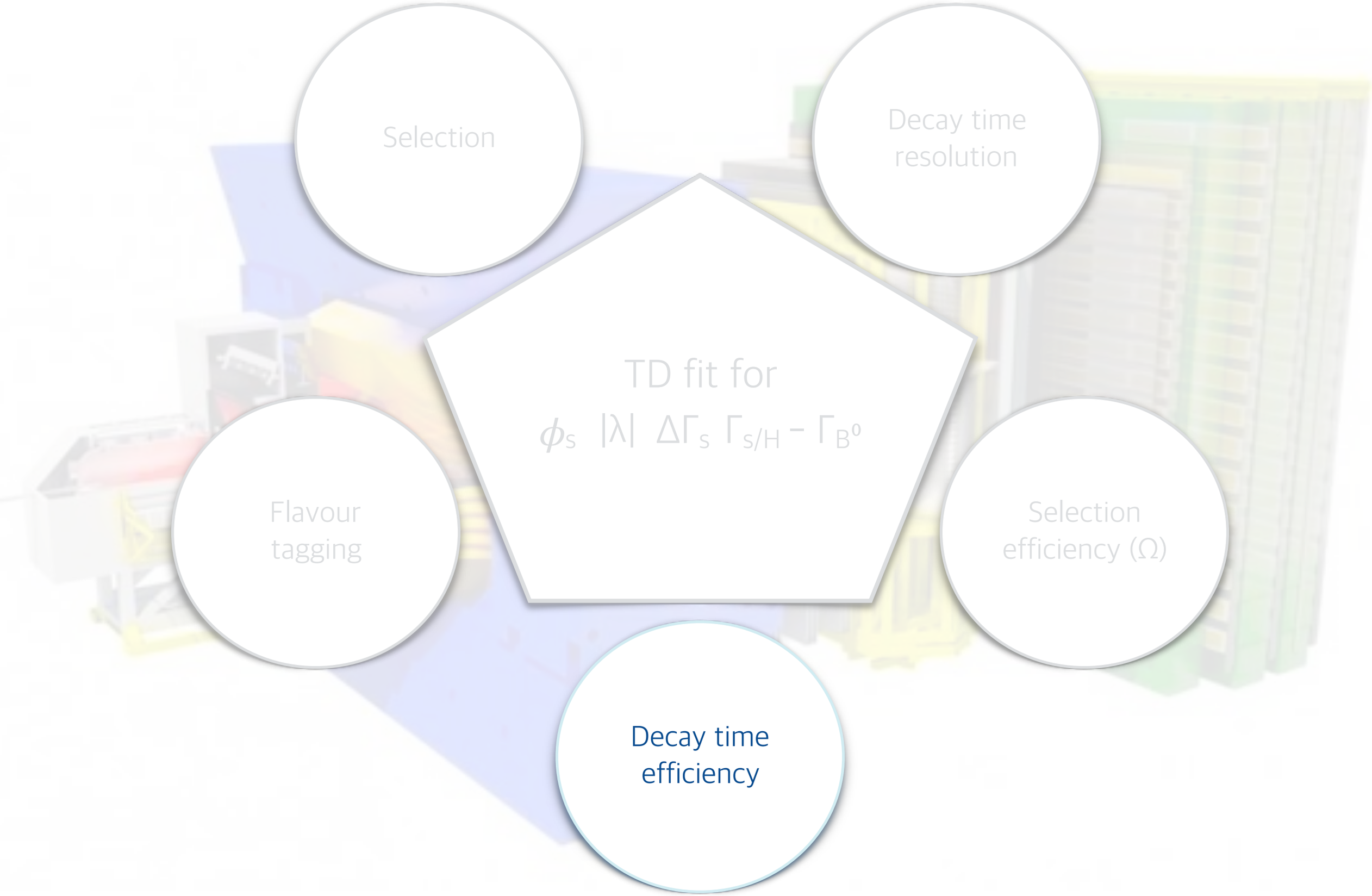


Measurement of φ_s



Decay time efficiency

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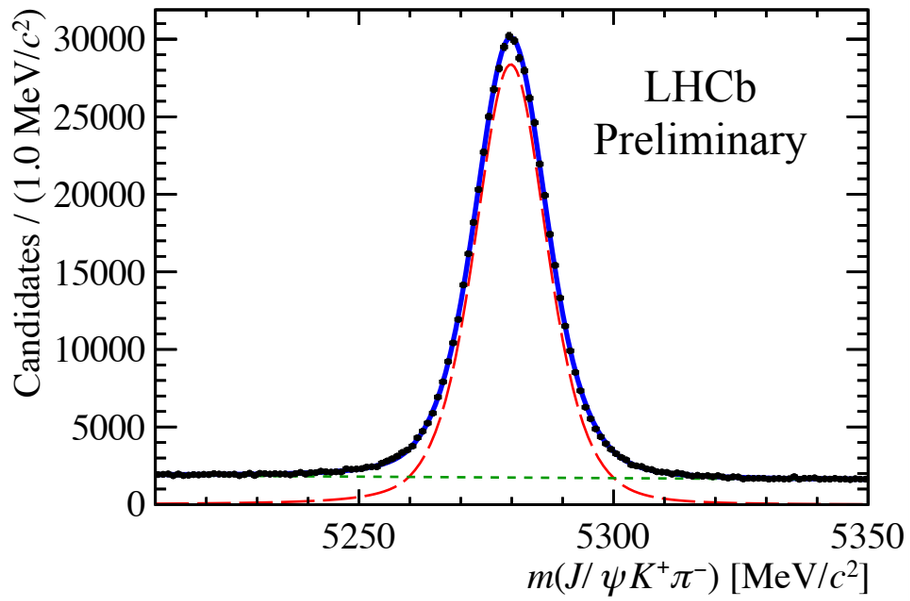
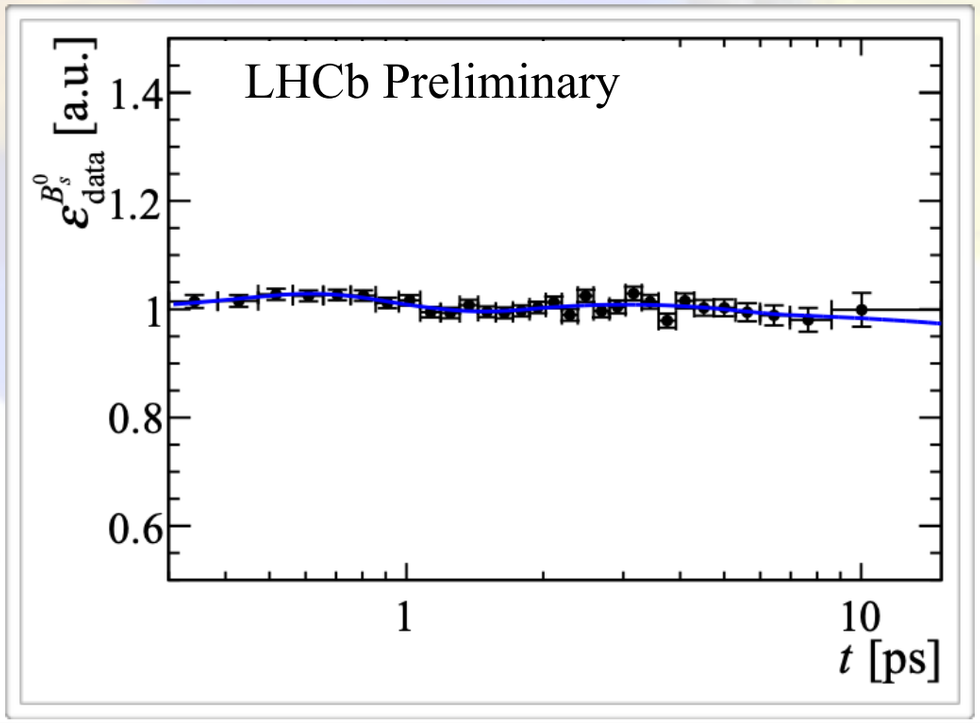


Use $B^0 \to J/\psi\, K^*(892)$
Fit simultaneously B^0 data, simulation and B^0_s simulation

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



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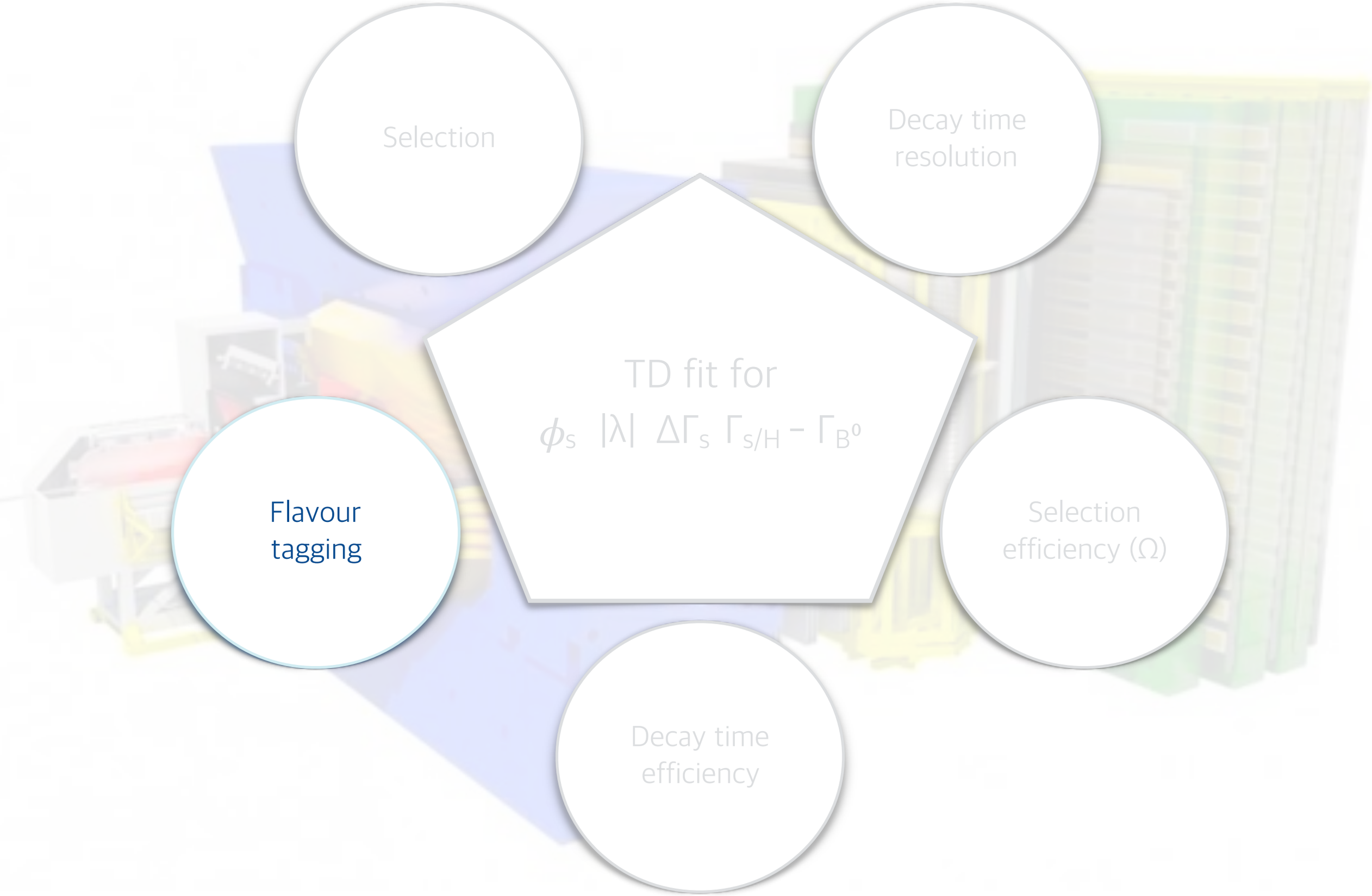


Flavour tagging

$B^0_s \to J/\psi\, K^+K^-$ [LHCB-PAPER-2019-013]	$B^0_s \to J/\psi\, \pi^+\pi^-$ arXiv:1903.05530

Two tagging algorithms are used: opposite side and same side
For each algorithm true mistag probability is calibrated assuming linear dependency with estimated one

$$\omega = p_0 + p_1(\eta - \langle\eta\rangle)$$

Tagging power is given as tagging efficiency times dilution squared

$$\varepsilon_{tag} D^2 \text{, where } D = (1 - 2\omega)$$

Run1 ≈ 3.73 %	Run1 ≈ 3.89 %
$\varepsilon_{tag} D^2 = 4.73 \pm 0.34\,\%$	$\varepsilon_{tag} D^2 = 5.06 \pm 0.38\,\%$

Measurement of φ_s

Selection

Decay time resolution

Flavour tagging

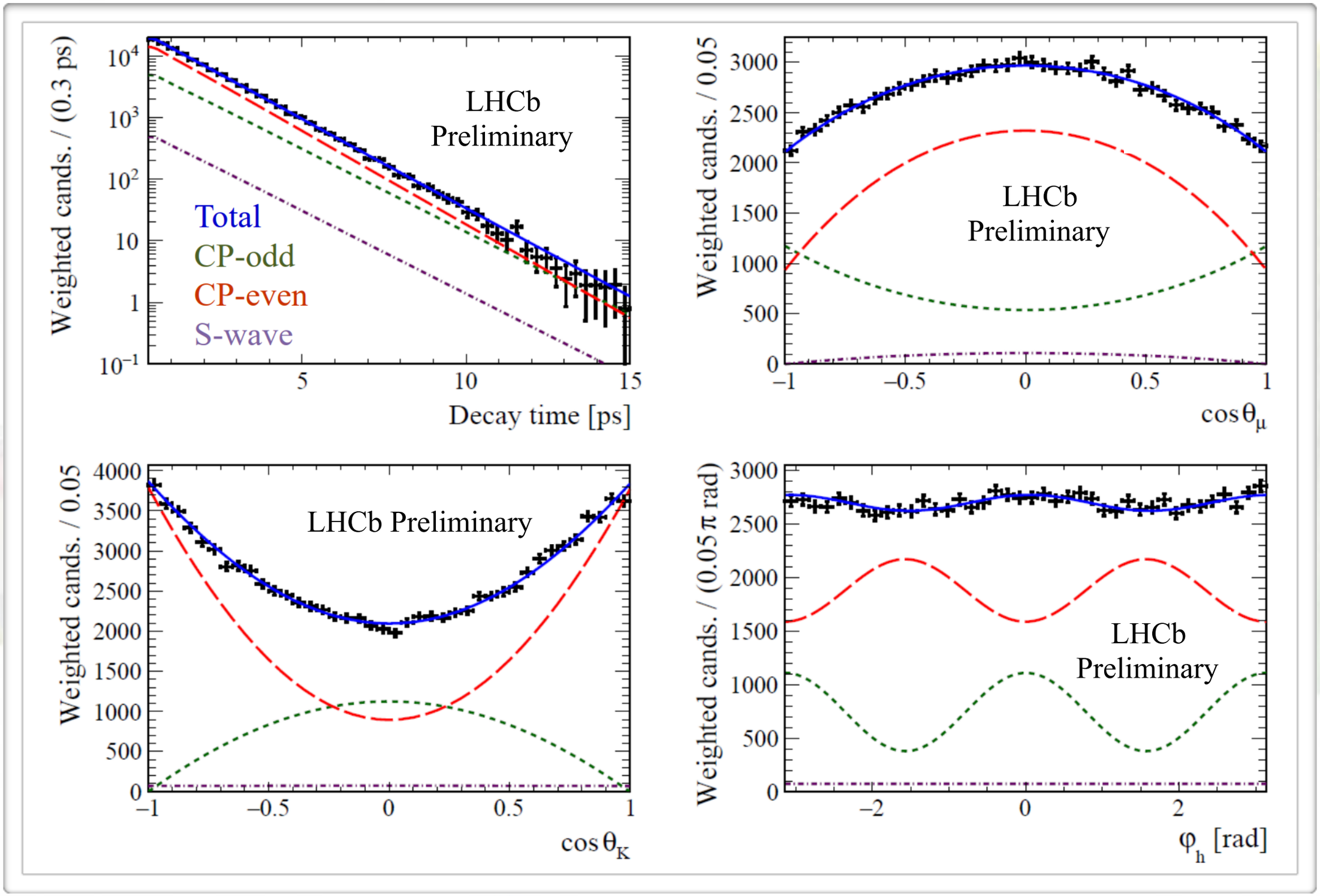
TD fit for

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

Selection efficiency (Ω)

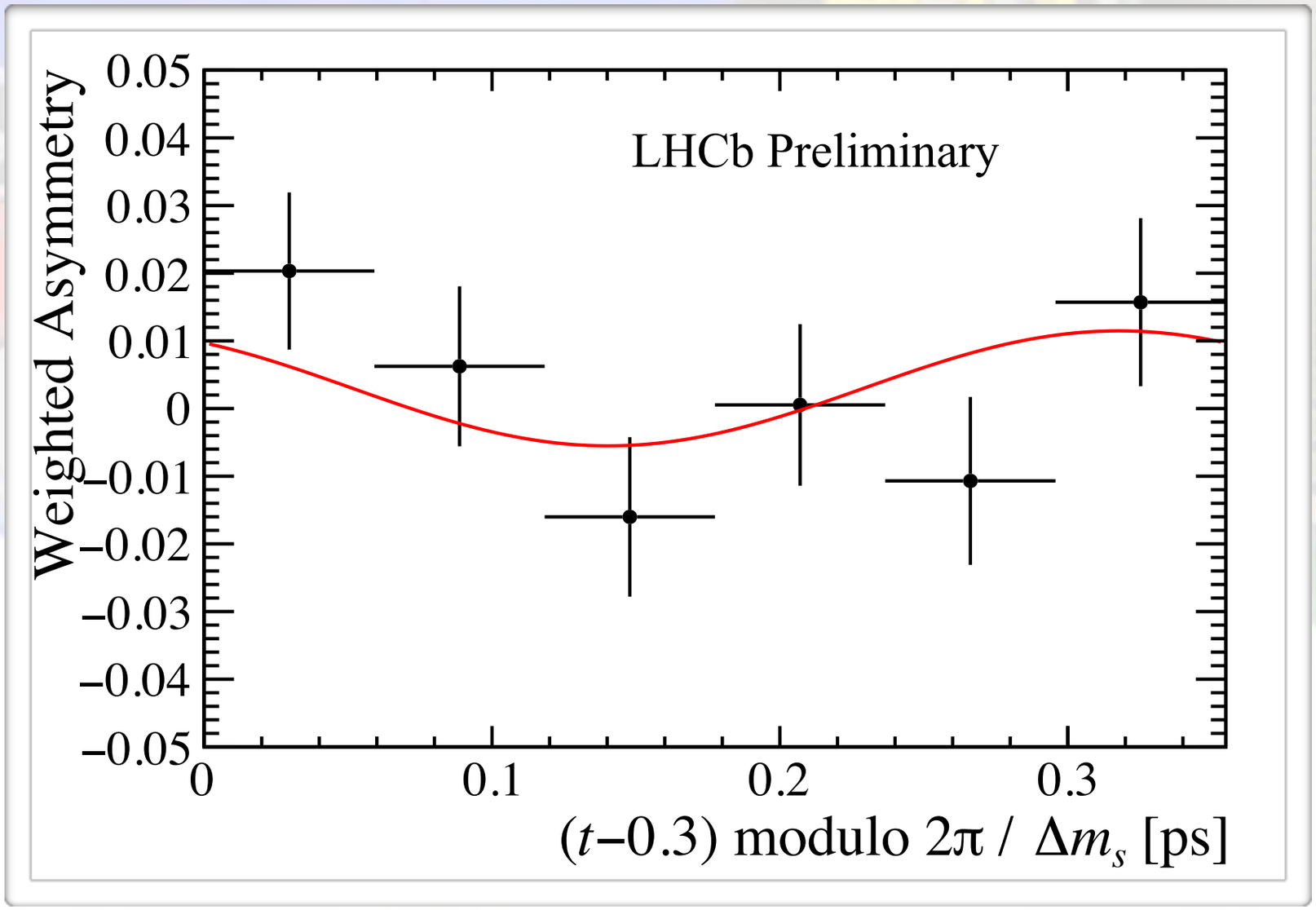
Decay time efficiency

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

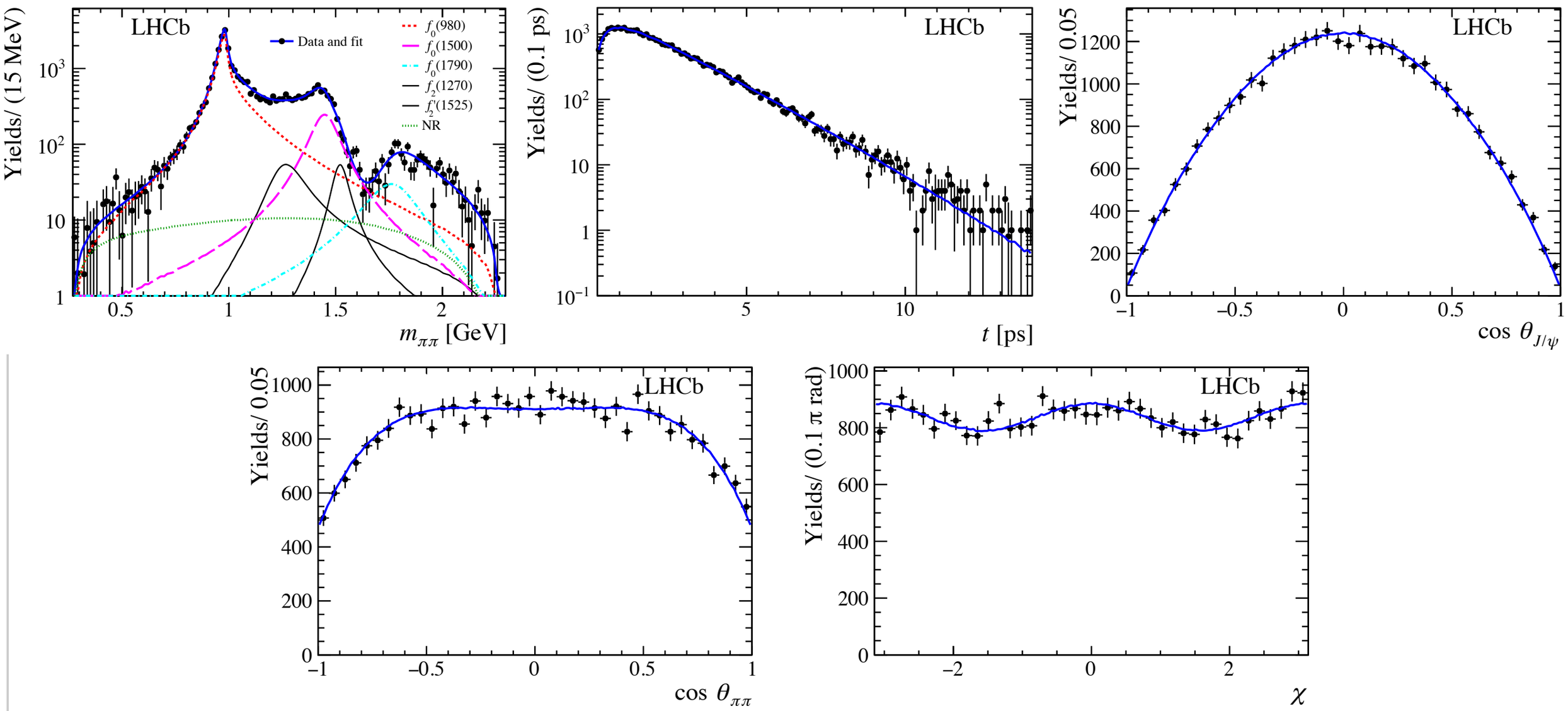


CP asymmetry in $B^0_s \to J/\psi\, K^+K^-$

$$A_{CP}(t) = \frac{\Gamma_{\bar{B}^0_s \to f}(t) - \Gamma_{B^0_s \to f}(t)}{\Gamma_{\bar{B}^0_s \to f}(t) + \Gamma_{B^0_s \to f}(t)} \sim \sin(\phi_s)\sin(\Delta m_s t)$$



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



Results

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

[LHCB-PAPER-2019-013]

Most precise measurement of ϕ_s $\Delta\Gamma_s$ $\Gamma_s - \Gamma_{B^0}$

New

$\phi_s = -0.080 \pm 0.041 \pm 0.006$ [rad]

$|\lambda| = 1.006 \pm 0.016 \pm 0.006$

$\Gamma_s - \Gamma_{B^0} = -0.0041 \pm 0.0024 \pm 0.0015$ [ps^{-1}]

$\Delta\Gamma_s = 0.0772 \pm 0.0077 \pm 0.0026$ [ps^{-1}]

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

arXiv:1903.05530

$\phi_s = -0.057 \pm 0.060 \pm 0.011$ [rad]

$|\lambda| = 1.01\,^{+0.08}_{-0.06} \pm 0.03$

$\Gamma_H - \Gamma_{B^0} = -0.050 \pm 0.004 \pm 0.004$ [ps^{-1}]

Combination of LHCb results

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

+

[$B^0_s \to D_s D_s$]

+

[$B^0_s \to J/\psi\, K^+K^-$ High mass Run 1]

+

[$B^0_s \to J/\psi\, K^+K^-$ Run 1]

+

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

[LHCB-PAPER-2019-013]

+

[$B^0_s \to J/\psi\, \pi^+\pi^-$ Run 1]

+

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

arXiv:1903.05530

$$\phi_s = -0.040 \pm 0.025\ [\mathrm{rad}]$$

$$|\lambda| = 0.991 \pm 0.010$$

$$\Delta\Gamma_s = 0.0813 \pm 0.0048\ [\mathrm{ps}^{-1}]$$

$$\Gamma_s - \Gamma_{B^0} = -0.0024 \pm 0.0018\ [\mathrm{ps}^{-1}]$$

Conclusions

$B^0_s \to J/\psi\, K^+K^-$
[LHCB-PAPER-2019-013]

$B^0_s \to J/\psi\, \pi^+\pi^-$
arXiv:1903.05530

$$\phi_s = -0.040 \pm 0.025\ [\mathrm{rad}]$$
$$|\lambda| = 0.991 \pm 0.010$$
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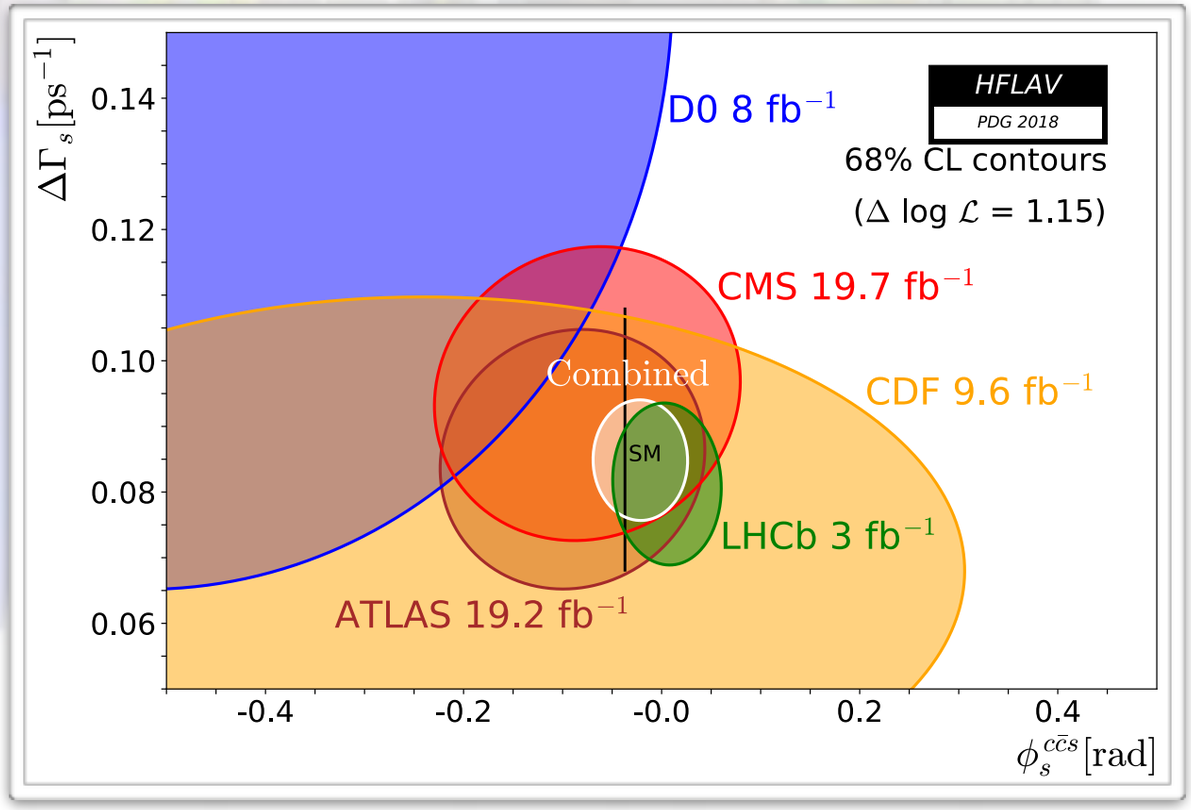
$$\Gamma_s - \Gamma_{B^0} = -0.0024 \pm 0.0018\ [\mathrm{ps}^{-1}]$$

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



Conclusions

$B^0_s \to J/\psi\, K^+K^-$
[LHCB-PAPER-2019-013]

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arXiv:1903.05530

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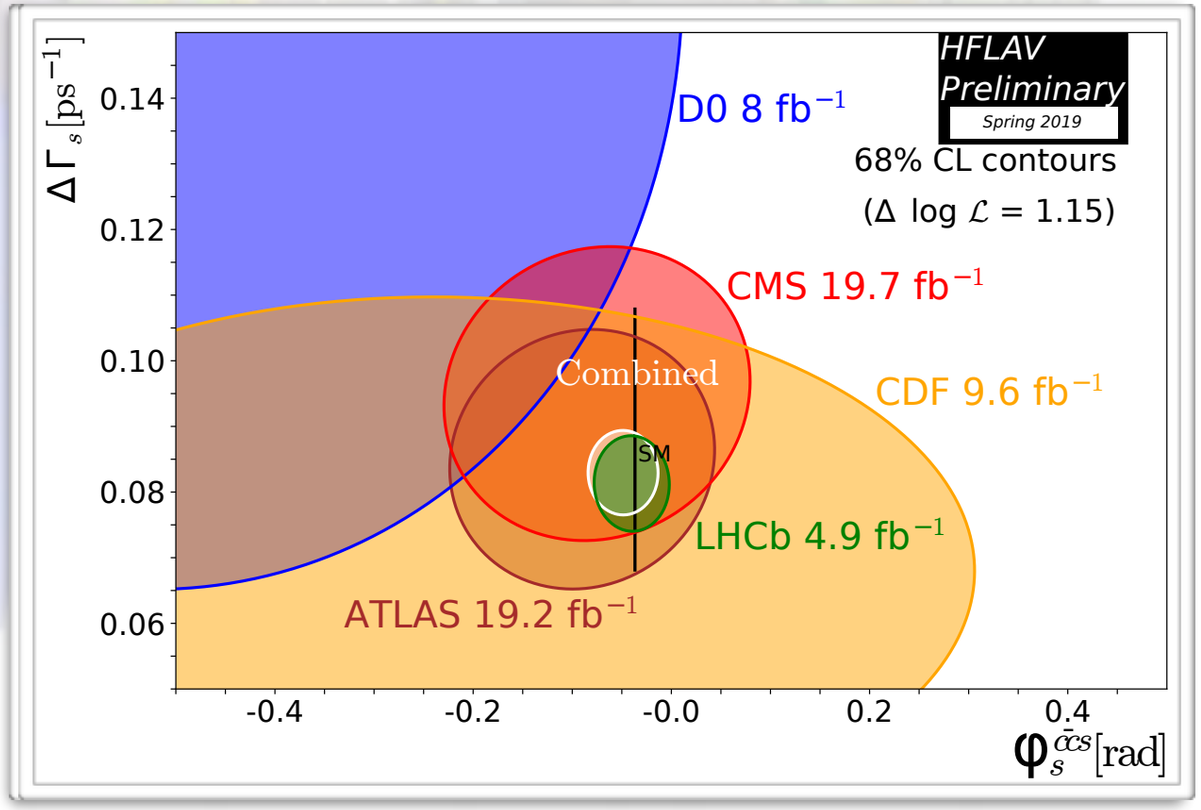
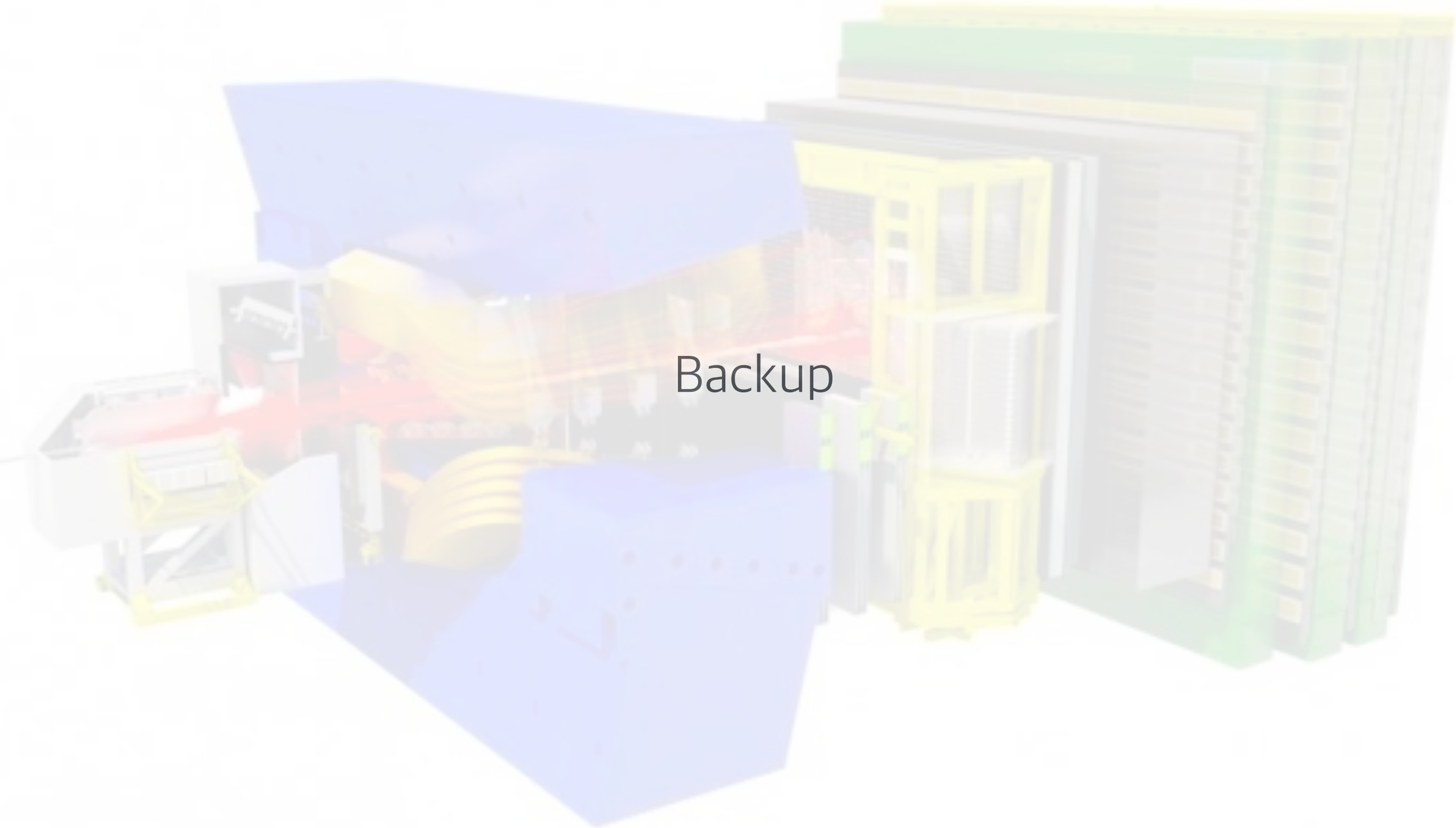




Backup

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

Parameter	Value
ϕ_s [rad]	$-0.080 \pm 0.041 \pm 0.006$
$\lvert\lambda\rvert$	$1.006 \pm 0.016 \pm 0.006$
$\Gamma_s - \Gamma_d$ [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}]	$17.705 \pm 0.059 \pm 0.018$
$\lvert A_\perp\rvert^2$	$0.2457 \pm 0.0040 \pm 0.0019$
$\lvert A_0\rvert^2$	$0.5186 \pm 0.0029 \pm 0.0024$
$\delta_\perp - \delta_0$	$2.64 \pm 0.13 \pm 0.10$
$\delta_\parallel - \delta_0$	$3.061^{+0.084}_{-0.073} \pm 0.037$

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
$C_{\rm SP}$ 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	$\Gamma_{\rm H} - \Gamma_{B^0}$ [$\rm fs^{-1}$]	$\lvert\lambda\rvert$ [$\times 10^{-3}$]	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
$\Gamma_{\rm L}$	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

Decay time acceptance is approximately:

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

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

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

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

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

Details on the $B^0_s \to J/\psi\, K^+K^-$ mass model

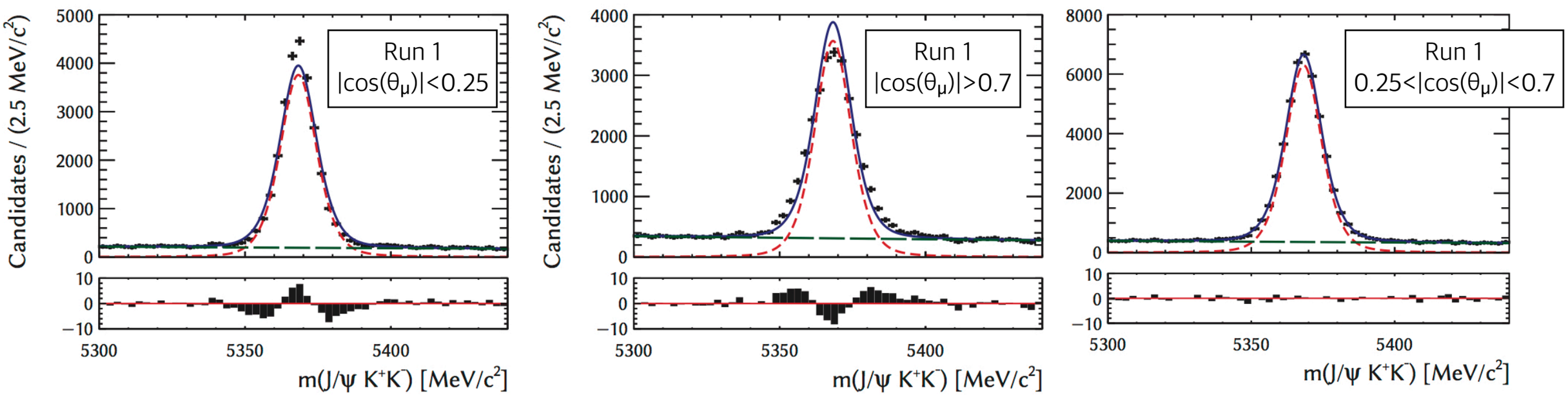
Signal model: Double-sided Crystal Ball function (CB2) with per-event mass error used as conditional observable

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)

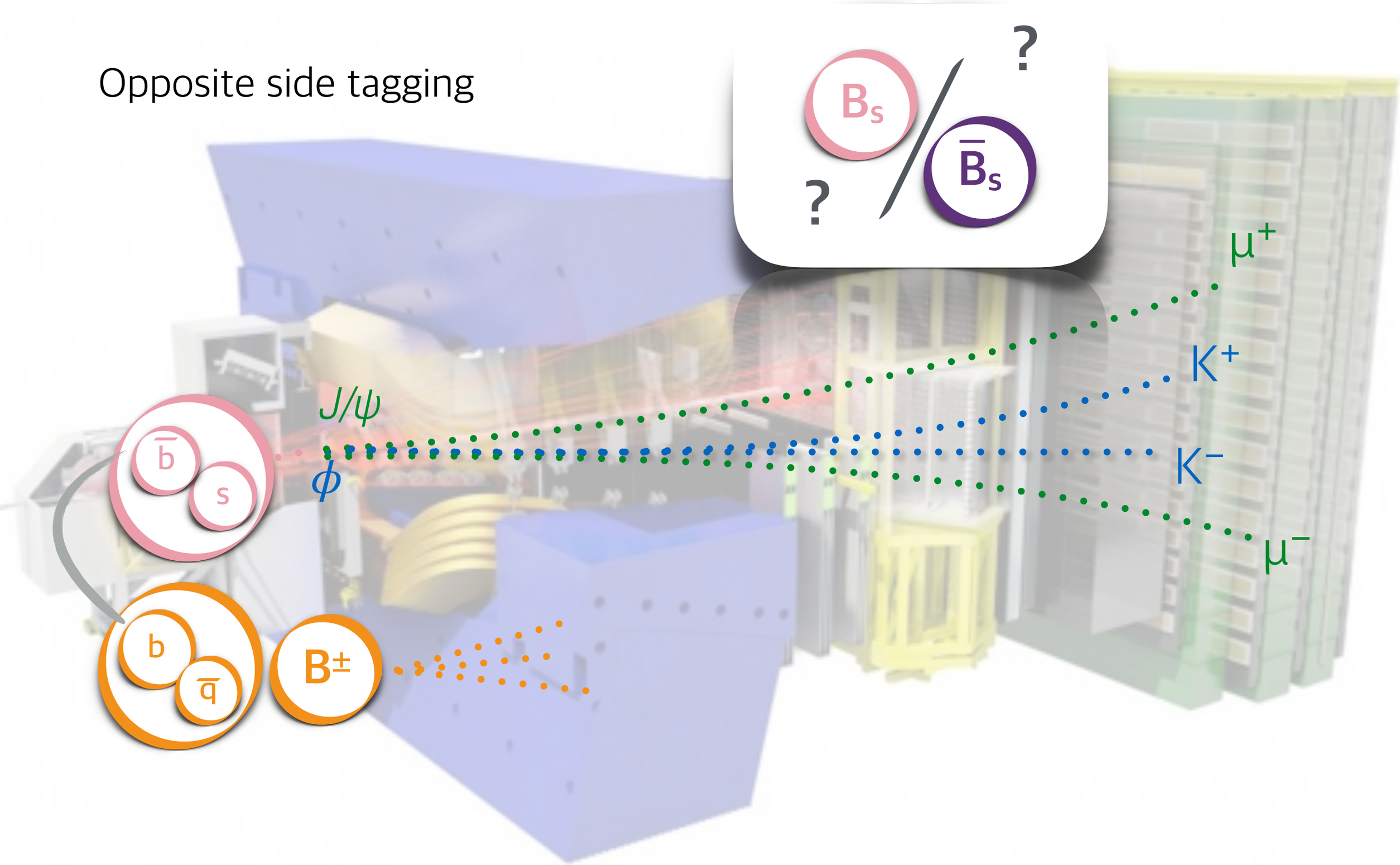
- Tails of the CB2 are fixed from the fit to MC
- Fit in 6 $m(K^+K^-)$ bins [990, 1008, 1016, 1020, 1024, 1032, 1050] MeV/c^2

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

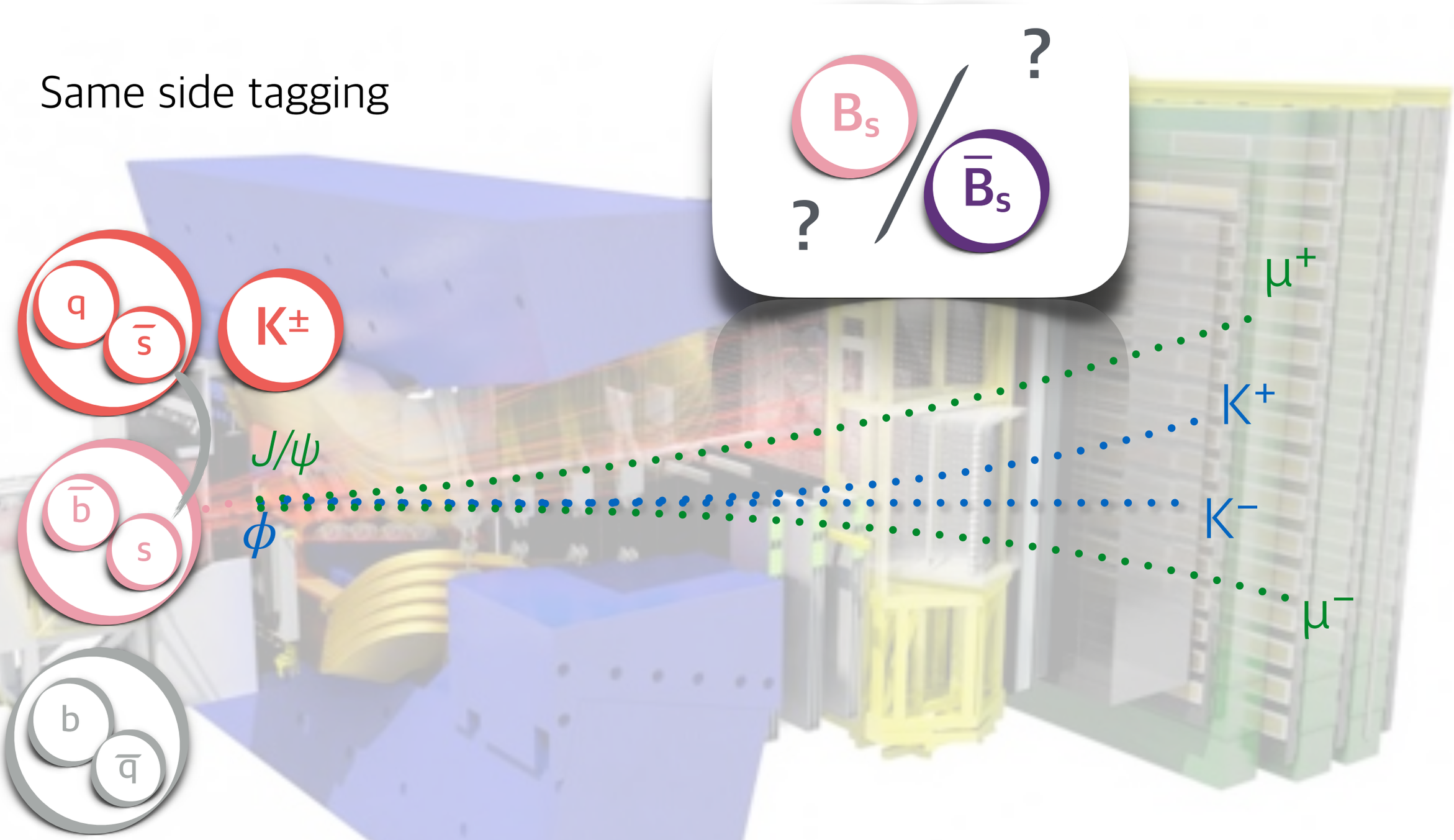
Why? To take into account this correlation. Mass resolution comes from the angles between muons, therefore per-candidate mass error and $\cos(\theta_\mu)$ are highly correlated



Opposite side tagging



Same side tagging

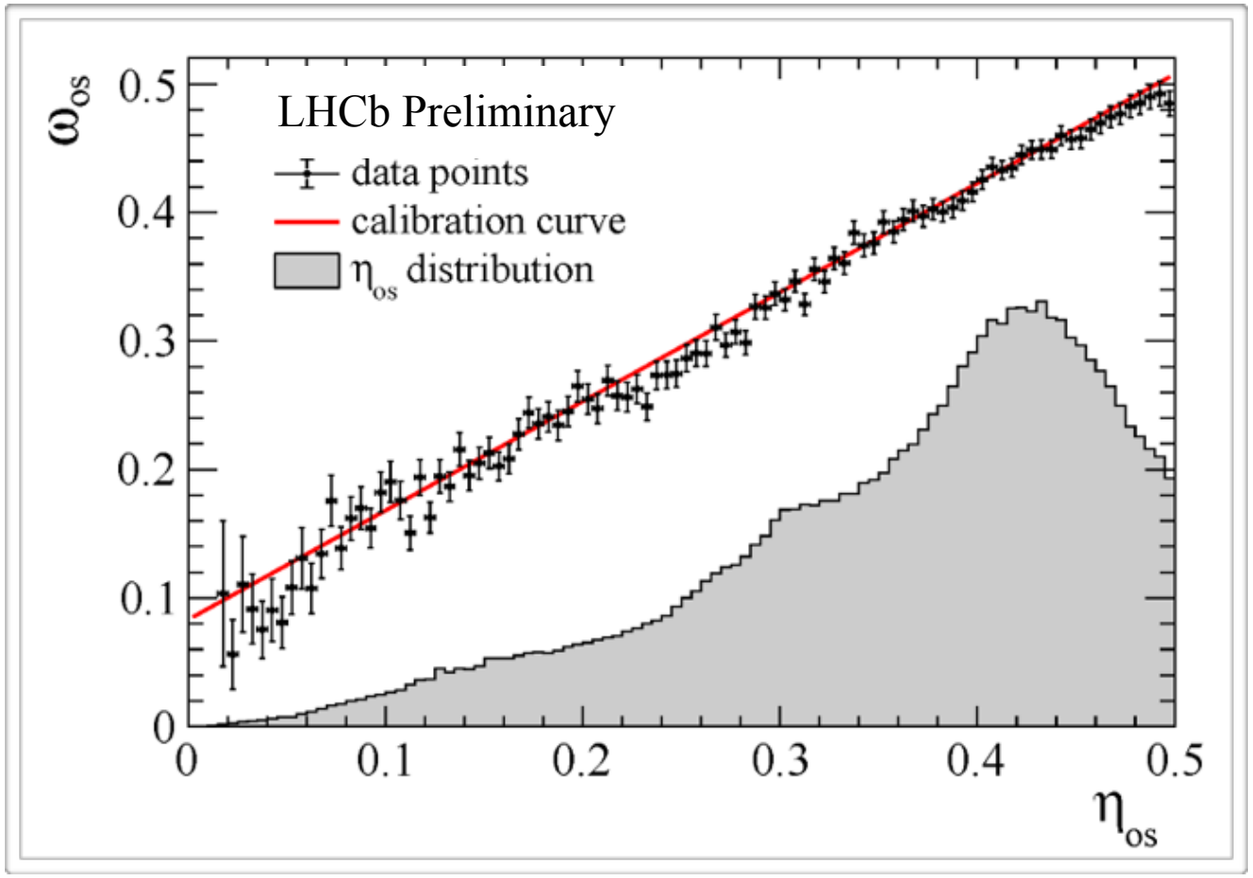


Flavour tagging calibration

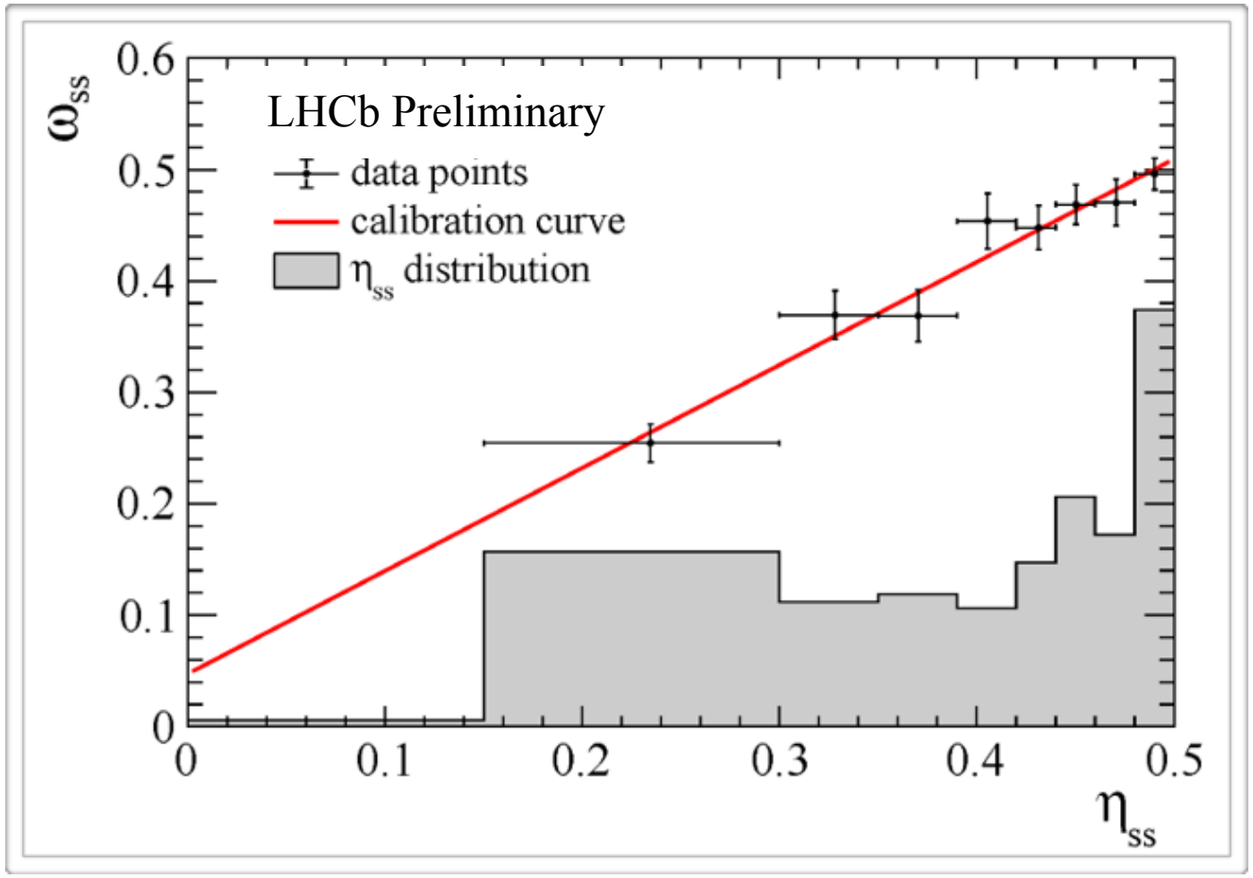
Two tagging algorithms are used: opposite side and same side
For each algorithm true mistag probability is calibrated assuming linear dependency with estimated one

$$\omega = p_0 + p_1(\eta - \langle\eta\rangle)$$

OS tagger calibrated using $B^+ \to J/\psi\, K^+$ decays



SSK tagger calibrated using $B^0_s \to D^-_s\, \pi^+$ decays



PDF for data fit

$$\mathcal{P}\left(t,\Omega|q^{\mathrm{OS}},q^{\mathrm{SSK}},\eta^{\mathrm{OS}},\eta^{\mathrm{SSK}},\sigma_t\right) = \frac{1}{\mathcal{N}}\sum_{i=1}^{6}\sum_{k=1}^{10}\mathcal{P}_{i,k}\left(t,\Omega|q^{\mathrm{OS}},q^{\mathrm{SSK}},\eta^{\mathrm{OS}},\eta^{\mathrm{SSK}},\sigma_t\right)$$

$$= \frac{1}{\mathcal{N}}\sum_{i=1}^{6}\sum_{k=1}^{10}\tilde{N}_{i,k}f_k(\Omega)\varepsilon(t)$$

$$\cdot\left\{\left[\left(1-2\omega^{\mathrm{OS}}\left(\eta^{\mathrm{OS}}\right)\right)\left(1-2\omega^{\mathrm{SSK}}\left(\eta^{\mathrm{SSK}}\right)\right)q^{\mathrm{OS}}q^{\mathrm{SSK}}h_k\left(t|B_s^0\right)\right.\right.$$

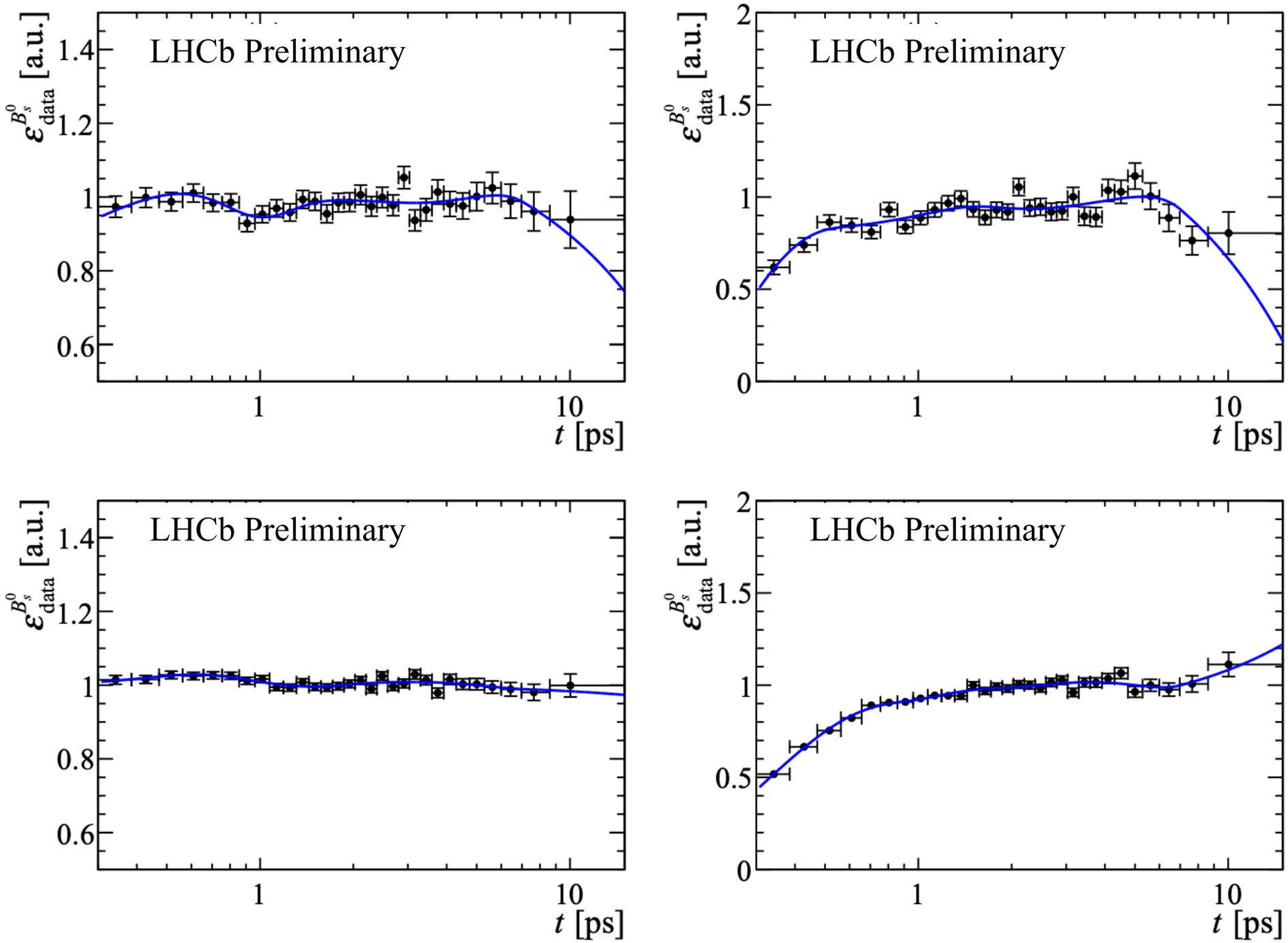
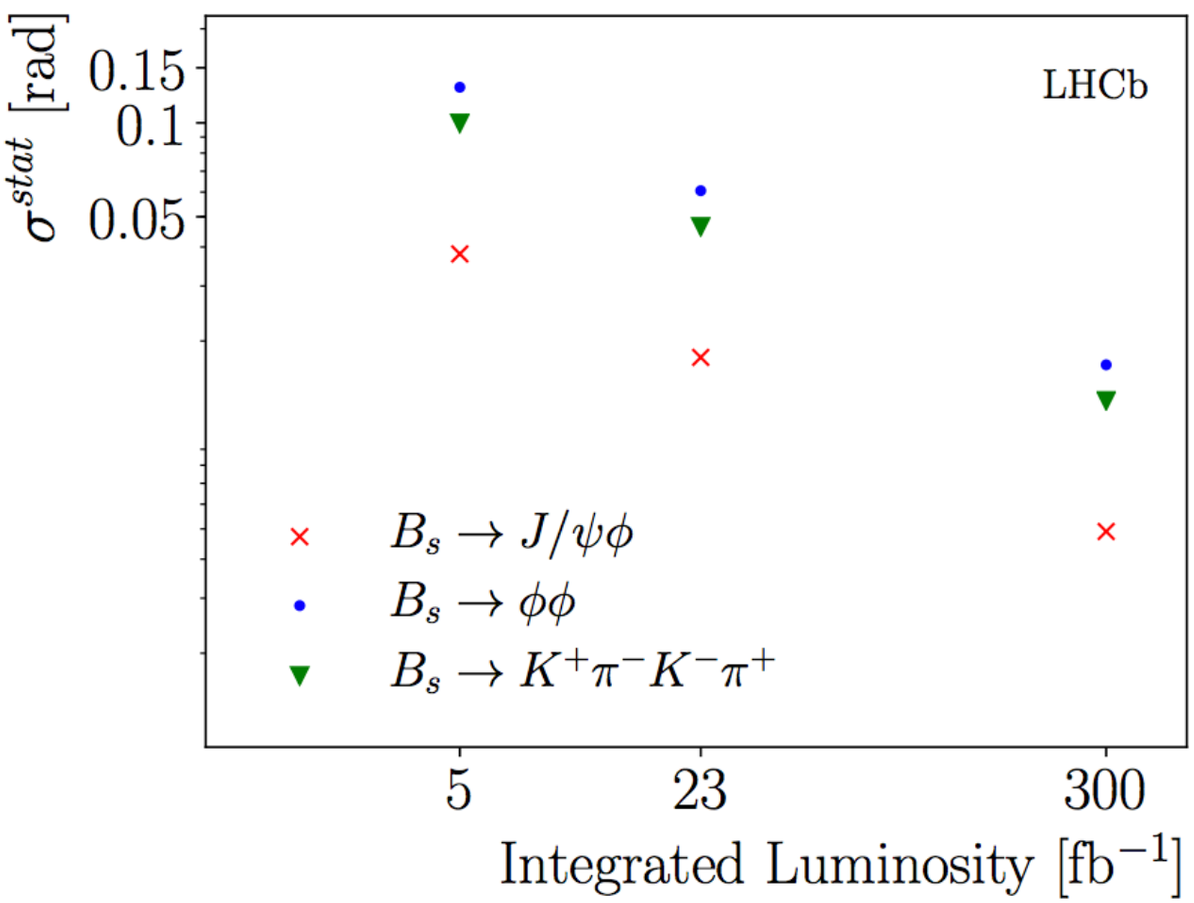
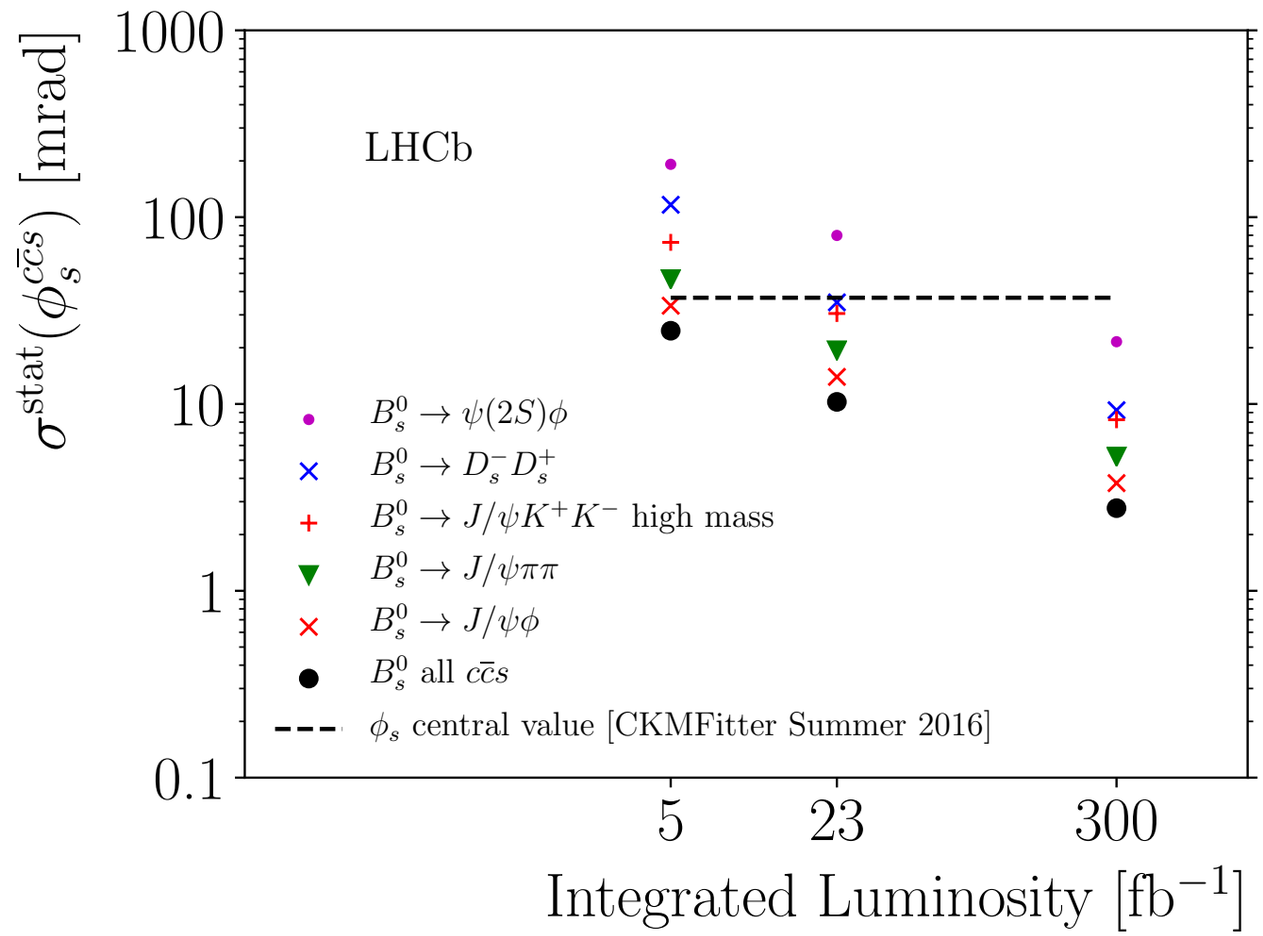
$$\left.+\left(1-2\bar{\omega}^{\mathrm{OS}}\left(\eta^{\mathrm{OS}}\right)\right)\left(1-2\bar{\omega}^{\mathrm{SSK}}\left(\eta^{\mathrm{SSK}}\right)\right)q^{\mathrm{OS}}q^{\mathrm{SSK}}h_k\left(t|\overline{B}_s^0\right)\right]$$

$$\left.\otimes\, G\left(t|\sigma_t\right)\right\}, \qquad (37)$$

PDF for data fit

f_k	N_k	a_k	b_k	c_k	d_k
$c_K^2 s_l^2$	$\|A_0\|^2$	$\frac{1}{2}(1+\|\lambda_0\|^2)$	$-\|\lambda_0\|\cos(\phi_0)$	$\frac{1}{2}(1-\|\lambda_0\|^2)$	$\|\lambda_0\|\sin(\phi_0)$
$\frac{1}{2}s_K^2(1-c_\phi^2 s_l^2)$	$\|A_{\|\|}\|^2$	$\frac{1}{2}(1+\|\lambda_{\|\|}\|^2)$	$-\|\lambda_{\|\|}\|\cos(\phi_{\|\|})$	$\frac{1}{2}(1-\|\lambda_{\|\|}\|^2)$	$\|\lambda_{\|\|}\|\sin(\phi_{\|\|})$
$\frac{1}{2}s_K^2(1-s_\phi^2 s_l^2)$	$\|A_\perp\|^2$	$\frac{1}{2}(1+\|\lambda_\perp\|^2)$	$\|\lambda_\perp\|\cos(\phi_\perp)$	$\frac{1}{2}(1-\|\lambda_\perp\|^2)$	$-\|\lambda_\perp\|\sin(\phi_\perp)$
$s_K^2 s_l^2 s_\phi c_\phi$	$\|A_\perp A_{\|\|}\|$	$\frac{1}{2}\Big[\sin(\delta_\perp-\delta_{\|\|})-\|\lambda_\perp\lambda_{\|\|}\| \sin(\delta_\perp-\delta_{\|\|}-\phi_\perp+\phi_{\|\|})\Big]$	$\frac{1}{2}\Big[\|\lambda_\perp\|\sin(\delta_\perp-\delta_{\|\|}-\phi_\perp) +\|\lambda_{\|\|}\|\sin(\delta_{\|\|}-\delta_\perp-\phi_{\|\|})\Big]$	$\frac{1}{2}\Big[\sin(\delta_\perp-\delta_{\|\|})+\|\lambda_\perp\lambda_{\|\|}\| \sin(\delta_\perp-\delta_{\|\|}-\phi_\perp+\phi_{\|\|})\Big]$	$-\frac{1}{2}\Big[\|\lambda_\perp\|\cos(\delta_\perp-\delta_{\|\|}-\phi_\perp) +\|\lambda_{\|\|}\|\cos(\delta_{\|\|}-\delta_\perp-\phi_{\|\|})\Big]$
$\sqrt{2}s_K c_K s_l c_l c_\phi$	$\|A_0 A_{\|\|}\|$	$\frac{1}{2}\Big[\cos(\delta_0-\delta_{\|\|})+\|\lambda_0\lambda_{\|\|}\| \cos(\delta_0-\delta_{\|\|}-\phi_0+\phi_{\|\|})\Big]$	$-\frac{1}{2}\Big[\|\lambda_0\|\cos(\delta_0-\delta_{\|\|}-\phi_0) +\|\lambda_{\|\|}\|\cos(\delta_{\|\|}-\delta_0-\phi_{\|\|})\Big]$	$\frac{1}{2}\Big[\cos(\delta_0-\delta_{\|\|})-\|\lambda_0\lambda_{\|\|}\| \cos(\delta_0-\delta_{\|\|}-\phi_0+\phi_{\|\|})\Big]$	$-\frac{1}{2}\Big[\|\lambda_0\|\sin(\delta_0-\delta_{\|\|}-\phi_0) +\|\lambda_{\|\|}\|\sin(\delta_{\|\|}-\delta_0-\phi_{\|\|})\Big]$
$-\sqrt{2}s_K c_K s_l c_l s_\phi$	$\|A_0 A_\perp\|$	$-\frac{1}{2}\Big[\sin(\delta_0-\delta_\perp)-\|\lambda_0\lambda_\perp\| \sin(\delta_0-\delta_\perp-\phi_0+\phi_\perp)\Big]$	$\frac{1}{2}\Big[\|\lambda_0\|\sin(\delta_0-\delta_\perp-\phi_0) +\|\lambda_\perp\|\sin(\delta_\perp-\delta_0-\phi_\perp)\Big]$	$-\frac{1}{2}\Big[\sin(\delta_0-\delta_\perp)+\|\lambda_0\lambda_\perp\| \sin(\delta_0-\delta_\perp-\phi_0+\phi_\perp)\Big]$	$-\frac{1}{2}\Big[\|\lambda_0\|\cos(\delta_0-\delta_\perp-\phi_0) +\|\lambda_\perp\|\cos(\delta_\perp-\delta_0-\phi_\perp)\Big]$
$\frac{1}{3}s_l^2$	$\|A_S\|^2$	$\frac{1}{2}(1+\|\lambda_S\|^2)$	$\|\lambda_S\|\cos(\phi_S)$	$\frac{1}{2}(1-\|\lambda_S\|^2)$	$-\|\lambda_S\|\sin(\phi_S)$
$\frac{2}{\sqrt{6}}s_K s_l c_l c_\phi$	$\|A_S A_{\|\|}\|$	$\frac{1}{2}\Big[\cos(\delta_S-\delta_{\|\|})-\|\lambda_S\lambda_{\|\|}\| \cos(\delta_S-\delta_{\|\|}-\phi_S+\phi_{\|\|})\Big]$	$\frac{1}{2}\Big[\|\lambda_S\|\cos(\delta_S-\delta_{\|\|}-\phi_S) -\|\lambda_{\|\|}\|\cos(\delta_{\|\|}-\delta_S-\phi_{\|\|})\Big]$	$\frac{1}{2}\Big[\cos(\delta_S-\delta_{\|\|})+\|\lambda_S\lambda_{\|\|}\| \cos(\delta_S-\delta_{\|\|}-\phi_S+\phi_{\|\|})\Big]$	$\frac{1}{2}\Big[\|\lambda_S\|\sin(\delta_S-\delta_{\|\|}-\phi_S) -\|\lambda_{\|\|}\|\sin(\delta_{\|\|}-\delta_S-\phi_{\|\|})\Big]$
$-\frac{2}{\sqrt{6}}s_K s_l c_l s_\phi$	$\|A_S A_\perp\|$	$-\frac{1}{2}\Big[\sin(\delta_S-\delta_\perp)+\|\lambda_S\lambda_\perp\| \sin(\delta_S-\delta_\perp-\phi_S+\phi_\perp)\Big]$	$-\frac{1}{2}\Big[\|\lambda_S\|\sin(\delta_S-\delta_\perp-\phi_S) -\|\lambda_\perp\|\sin(\delta_\perp-\delta_S-\phi_\perp)\Big]$	$-\frac{1}{2}\Big[\sin(\delta_S-\delta_\perp)-\|\lambda_S\lambda_\perp\| \sin(\delta_S-\delta_\perp-\phi_S+\phi_\perp)\Big]$	$-\frac{1}{2}\Big[-\|\lambda_S\|\cos(\delta_S-\delta_\perp-\phi_S) +\|\lambda_\perp\|\cos(\delta_\perp-\delta_S-\phi_\perp)\Big]$
$\frac{2}{\sqrt{3}}c_K s_l^2$	$\|A_S A_0\|$	$\frac{1}{2}\Big[\cos(\delta_S-\delta_0)-\|\lambda_S\lambda_0\| \cos(\delta_S-\delta_0-\phi_S+\phi_0)\Big]$	$\frac{1}{2}\Big[\|\lambda_S\|\cos(\delta_S-\delta_0-\phi_S) -\|\lambda_0\|\cos(\delta_0-\delta_S-\phi_0)\Big]$	$\frac{1}{2}\Big[\cos(\delta_S-\delta_0)+\|\lambda_S\lambda_0\| \cos(\delta_S-\delta_0-\phi_S+\phi_0)\Big]$	$\frac{1}{2}\Big[\|\lambda_S\|\sin(\delta_S-\delta_0-\phi_S) -\|\lambda_0\|\sin(\delta_0-\delta_S-\phi_0)\Big]$

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



Comparison of φ_s sensitivity from different decay modes