Control penguin effect in $B_s \to J/\psi\phi$ at LHCb

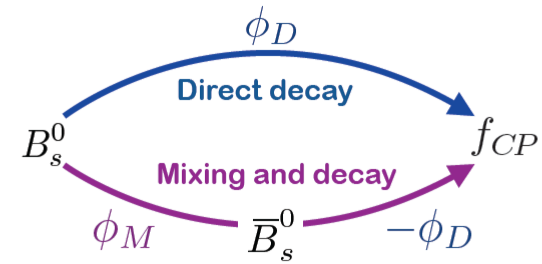
Liming Zhang
(Tsinghua University)

On behalf of LHCb Collaboration

CP violating phase ϕ_s

- Mixing induced CPV phase of B_s^0:

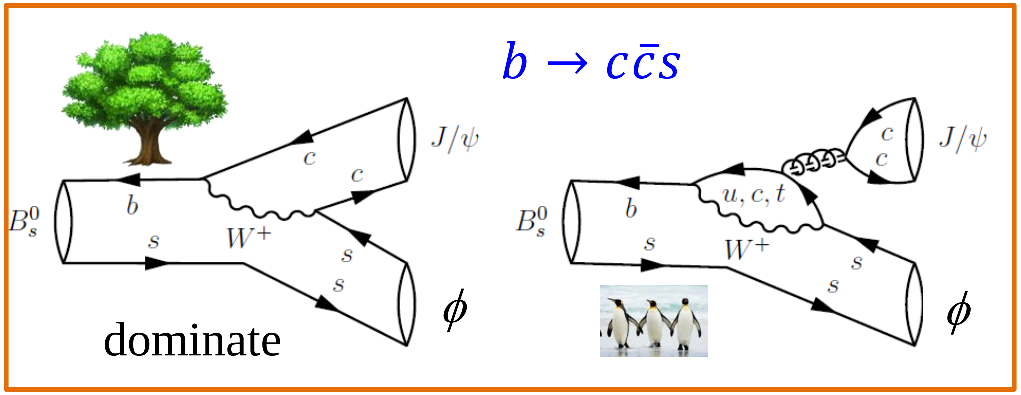
$$\phi_s = \phi_M - 2\phi_D$$



- Theoretical uncertainty on ϕ_s is mainly due to penguin contributions $\Delta\phi_s^{\text{peng}}$:

$$\phi_s^{\text{SM}} = -2\beta_s + \Delta\phi_s^{\text{peng}}$$

$$-2\beta_s = 2\arg\left(-\frac{V_{ts}V_{tb}^*}{V_{cs}V_{cb}^*}\right) = -0.0365^{+0.0013}_{-0.0012}\text{ rad}$$

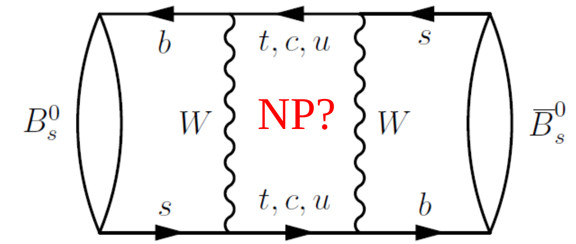


[CKMFitter, arXiv:1501.05013]

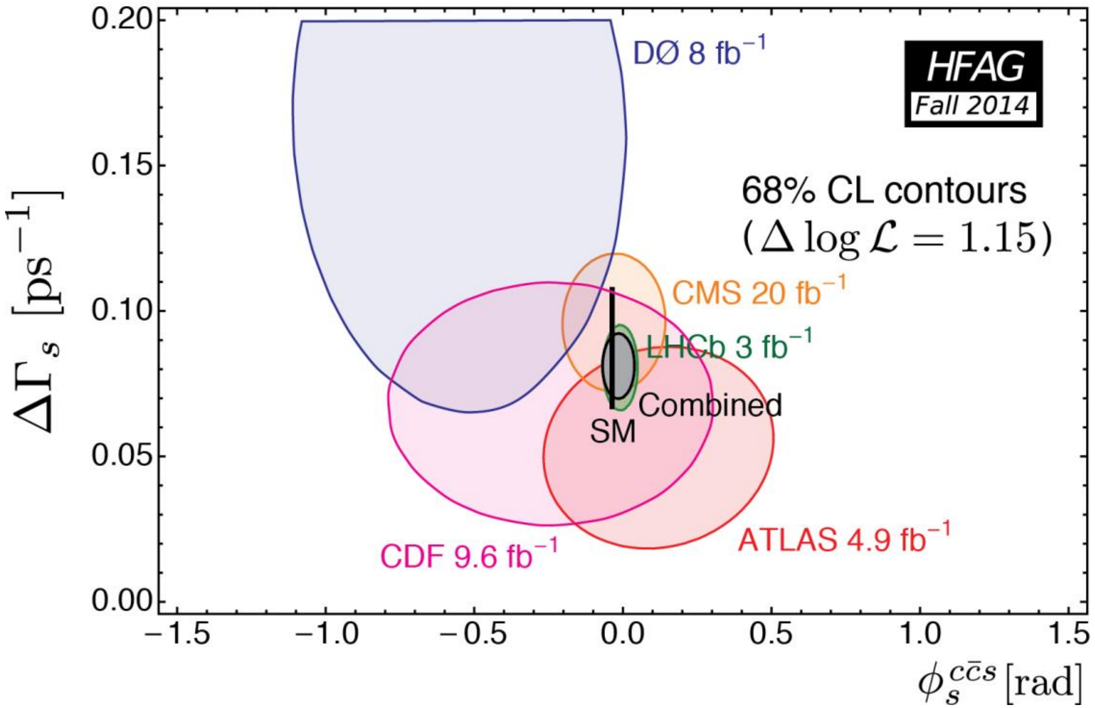
- New Physics (NP) in mixing box diagrams can modify ϕ_s:

$$\phi_s^{\text{meas}} = -2\beta_s + \Delta\phi_s^{\text{peng}} + \delta^{\text{NP}}$$

$\Rightarrow$We should control $\Delta\phi_s^{\text{peng}}$



World average on ϕ_s



World average:
$\phi_s = -15 \pm 35$ mrad

Combination of LHCb's J/ψϕ&J/ψππ:
$\phi_s = -10 \pm 39$ mrad

NP is not a large effect
⇒ Need to control SM effects (penguins).

Mode	$\sigma(\phi_s)$[rad]	Ref.	Exp
$B_s^0 \to J/\psi\,\phi$	$-0.058 \pm 0.049 \pm 0.006$	PRL 114 (2015) 041801	LHCb (3 fb^{-1})
$B_s^0 \to J/\psi\,\phi$	$-0.030 \pm 0.110 \pm 0.030$	CMS-PAC-BPH-13-012	CMS (20 fb^{-1})
$B_s^0 \to J/\psi\,\phi$	$+0.120 \pm 0.250 \pm 0.050$	PRD 90 (2014) 052007	ATLAS (4.9 fb^{-1})
$B_s^0 \to J/\psi\,\pi^+\pi^-$	$+0.070 \pm 0.068 \pm 0.008$	PLB 736 (2014)	LHCb (3 fb^{-1})
$B_s^0 \to D_s^+ D_s^-$	$+0.020 \pm 0.170 \pm 0.020$	PRL 113, (2014) 211801	LHCb (3 fb^{-1})

Recent updated ATLAS result (20fb^{-1}) : $\phi_s = -0.075 \pm 0.097 \pm 0.031$ rad *[arXiv:1507.07527]*

Motivation

- Penguin contributions can't be calculated reliably from QCD

- Experimental tools, decays via $b \to c\bar{c}d$ can be used as penguin/tree amplitude ratio is enhanced. [arXiv:0809.0842 & 0810.4248 & 1412.6834]

- LHCb used $B^0 \to \mathrm{J}/\psi\rho^0$ and $B_s^0 \to \mathrm{J}/\psi\bar{K}^{*0}$ (New!)

Penguin pollution in ϕ_s

Polarization dependent $i \in \{0, \perp, \parallel\}$

- Penguin parameters definition:

$$A(B_s^0 \to (J/\psi\,\phi)_i) = \left(1 - \frac{\lambda^2}{2}\right)\mathcal{A}'_i\left[1 + \epsilon a'_i e^{i\theta'_i} e^{i\gamma}\right]$$

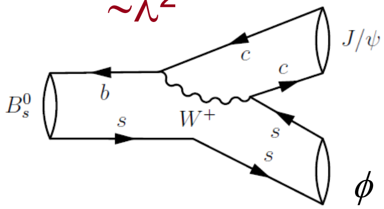
a'_i: size of "Penguin / tree" ratio, θ'_i: strong phase

"Penguin / tree" ratio is suppressed due to:

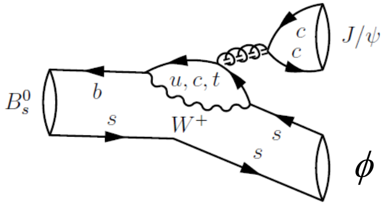
$\epsilon = \lambda^2/(1-\lambda^2)$=0.0536, $\lambda = |V_{us}| = 0.22$

$b \to c\bar{c}s$

$\sim\lambda^2$



$\sim\lambda^4$



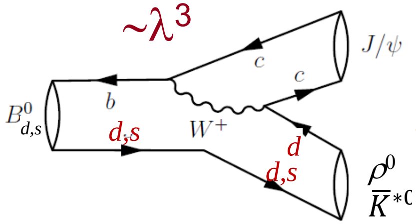
$$\sqrt{2}A(B^0 \to (J/\psi\,\rho^0)_i) = A(B_s^0 \to (J/\psi\,\overline{K}^{*0})_i) = -\lambda\mathcal{A}_i\left[1 - a_i e^{i\theta_i} e^{i\gamma}\right]$$

$b \to c\bar{c}d$

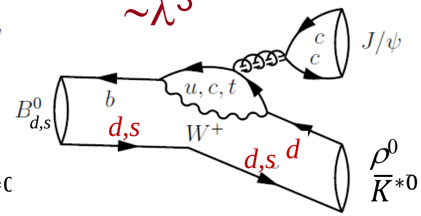
"Penguin / tree" ratio isn't suppressed anymore

Ideal to study penguin contribution

$\sim\lambda^3$



$\sim\lambda^3$



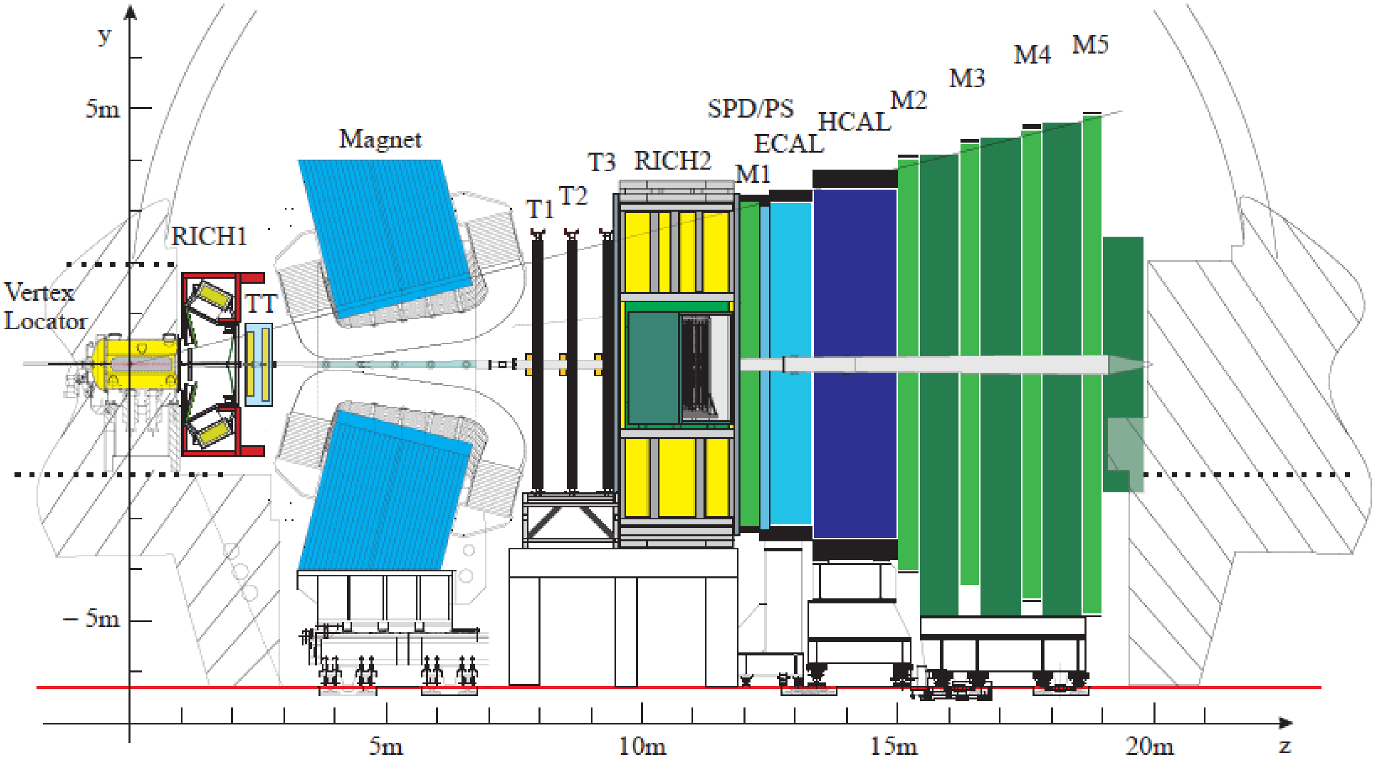
Penguin induced shift for ϕ_s in $J/\psi\phi$

$$\tan(\Delta\phi_{s,i}^{J/\psi\phi}) = \frac{2\epsilon a'_i \cos\theta'_i \sin\gamma + \epsilon^2 a_i'^2 \sin(2\gamma)}{1 + 2\epsilon a'_i \cos\theta'_i \cos\gamma + \epsilon^2 a_i'^2 \cos(2\gamma)}$$

Assuming perfect SU(3) flavor symmetry: $a'_i = a_i$, $\theta'_i = \theta_i$

SU(3) breaking for $a' = a$ & $\theta' = \theta$ need to considered

LHCb detector

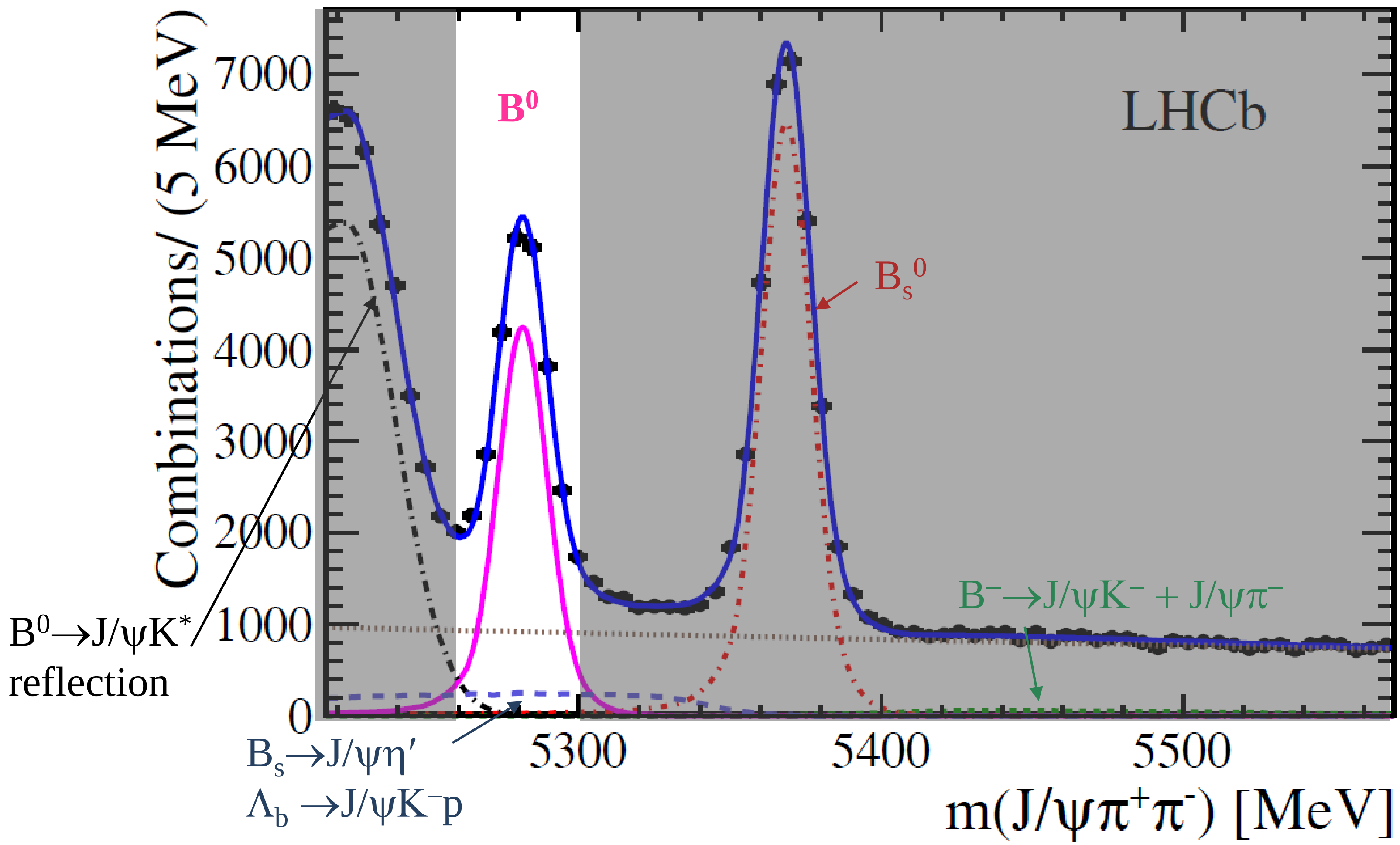


Impact parameter:	$\sigma_{IP} = 20\ \mu\mathrm{m}$
Proper time:	$\sigma_\tau = 45$ fs for $B_s^0 \to J/\psi\phi$ or $D_s^+\pi^-$
Momentum:	$\Delta p/p = 0.4 \sim 0.6\%\ (5 - 100\ \mathrm{GeV}/c)$
Mass :	$\sigma_m = 8\ \mathrm{MeV}/c^2$ for $B \to J/\psi X$ (constrained $\mathrm{m}_{J/\psi}$)
RICH $K - \pi$ separation:	$\epsilon(K \to K) \sim 95\%$ mis-ID $\epsilon(\pi \to K) \sim 5\%$
Muon ID:	$\epsilon(\mu \to \mu) \sim 97\%$ mis-ID $\epsilon(\pi \to \mu) \sim 1 - 3\%$
ECAL:	$\Delta E/E = 1 \oplus 10\%/\sqrt{E(\mathrm{GeV})}$

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

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

[PLB 742 (2015) 38-49]



- ±20 MeV of peaks: 17650 B^0 signal purity 65%

Differential decay rates

- Initial $\overset{(-)}{B}{}_q^0$ decay to self-charge-conjugated final states $J/\psi h^+ h^-$

$$\overset{(-)}{\Gamma}(t, m_{hh}, \Omega) = \mathcal{N} e^{-\Gamma t} \left\{ \frac{|\mathcal{A}|^2 + |\overline{\mathcal{A}}|^2}{2} \cosh\frac{\Delta\Gamma t}{2} \pm \frac{|\mathcal{A}|^2 - |\overline{\mathcal{A}}|^2}{2} \cos(\Delta m t) - \mathcal{Re}(\mathcal{A}^*\overline{\mathcal{A}}) \sinh\frac{\Delta\Gamma t}{2} \pm \mathcal{Im}(\mathcal{A}^*\overline{\mathcal{A}}) \sin(\Delta m t) \right\}$$

CPV phase mainly enters

$\mathcal{A} \equiv \sum_i A_i$ Total resonant transversity amplitudes of B_q^0 decays at $t = 0$

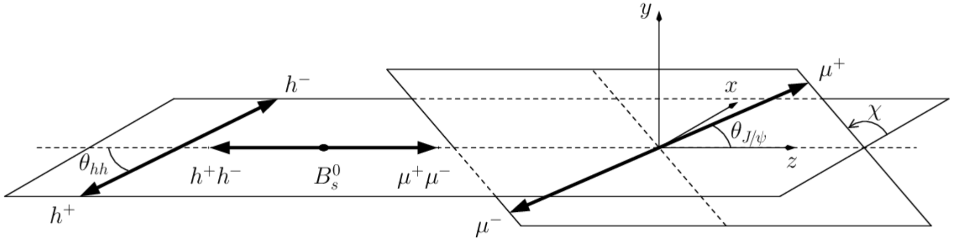
$$\overline{\mathcal{A}} \equiv \sum_i \frac{q}{p}\overline{A}_i = \sum_i \lambda_i A_i$$

The amplitudes are function of m_{hh} and three decay angles $\Omega = (\cos\theta_{hh}, \cos\theta_{J/\psi}, \chi)$

$$\lambda_i \equiv \frac{q}{p}\frac{\overline{A}_i}{A_i}$$

$$\arg(\eta_i \lambda_i) \equiv -\phi_q^i$$

CPV parameter



η_i is CP eigenvalue for amplitude A_i

measure CPV phase ϕ_q^i and magnitude $|\lambda_i|$

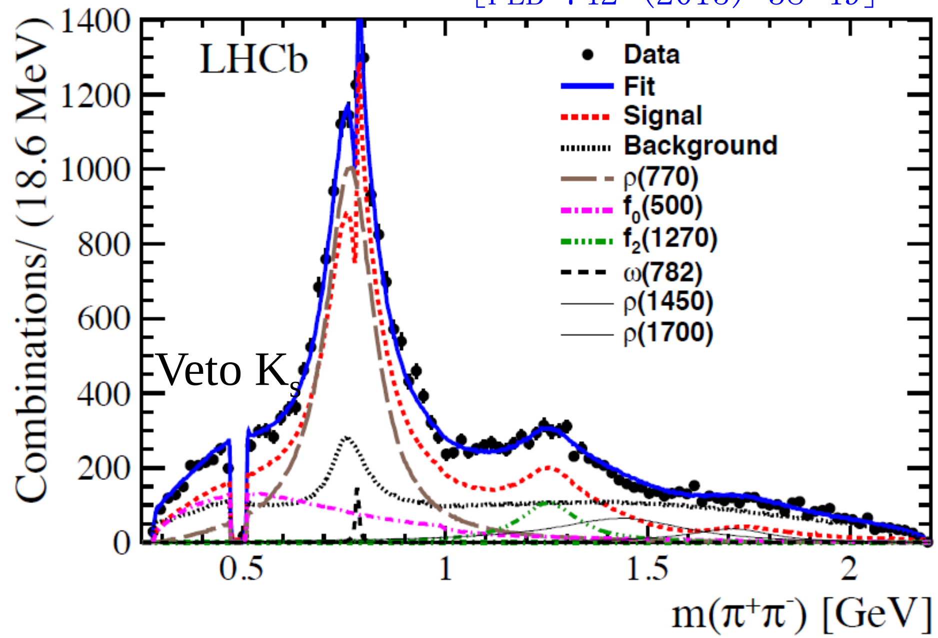
i can be polarization dependent for each resonance

[Zhang&Stone PLB **719** (2013) 383]

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

[PLB 742 (2015) 38-49]

- Time-dependent tagged full amplitude analysis fits to
  - m(ππ) and 3 decay angles
  - Flavour-tagging & decay time



Component	Fit fraction (%)	Transversity fractions (%) 0	∥	⊥
$\rho(770)$	65.6 ± 1.9	56.7 ± 1.8	23.5 ± 1.5	19.8 ± 1.7
$f_0(500)$	20.1 ± 0.7	1	0	0
$f_2(1270)$	7.8 ± 0.6	64 ± 4	9 ± 5	27 ± 5
$\omega(782)$	$0.64^{+0.19}_{-0.13}$	44 ± 14	53 ± 14	3^{+10}_{-3}
$\rho(1450)$	9.0 ± 1.8	47 ± 11	39 ± 12	14 ± 8
$\rho(1700)$	3.1 ± 0.7	29 ± 12	42 ± 15	29 ± 15

Measurements of CP asymmetry

[PLB 742 (2015) 38–49]

Polarization-independent results

$$\phi_d^{J/\psi\rho^0} = (41.7 \pm 9.6^{+2.8}_{-6.3})^\circ,$$

$$\alpha_{CP} \equiv \frac{1-|\lambda_i|}{1+|\lambda_i|} = (-32 \pm 28^{+9}_{-7}) \times 10^{-3}$$

$$\Rightarrow \phi_d^{J/\psi\rho^0} - \phi_d^{J/\psi K^0} = (-0.9 \pm 9.7^{+2.8}_{-6.3})^\circ$$

polarization-dependent results

	$\phi_{d,i}^{J/\psi\rho^0}$ [degrees]		$\alpha_{CP}^i [\times 10^{-3}]$
ρ_0	$44.1 \pm 10.2^{+3.0}_{-6.9}$	ρ_0	$-47 \pm 34^{+11}_{-10}$
$\rho_\parallel - \rho_0$	$-0.8 \pm 6.5^{+1.9}_{-1.3}$	$\rho_\parallel$	$-61 \pm 60^{+8}_{-6}$
$\rho_\perp - \rho_0$	$-3.6 \pm 7.2^{+2.0}_{-1.4}$	$\rho_\perp$	$17 \pm 109^{+22}_{-15}$

Consistent with no polarization-dependence

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Consistent with no polarization-dependence

$$S_f \equiv \frac{2\mathcal{I}m(\lambda_f)}{1+|\lambda_f|^2} \qquad C_f \equiv \frac{1-|\lambda_f|^2}{1+|\lambda_f|^2}$$

f	Experiment	S_f	C_f	Correlation
$\overset{(-)}{B}{}^0 \to J/\psi\,\rho^0$	LHCb	$-0.66^{+0.13+0.09}_{-0.12-0.03}$	$-0.063 \pm 0.056^{+0.019}_{-0.014}$	-0.01 (stat)
$\overset{(-)}{B}{}^0 \to J/\psi\,\pi^0$	Belle [33]	$-0.65 \pm 0.21 \pm 0.05$	$-0.08 \pm 0.16 \pm 0.05$	-0.10 (stat)
$\overset{(-)}{B}{}^0 \to J/\psi\,\pi^0$	BaBar [34]	$-1.23 \pm 0.21 \pm 0.04$	$-0.20 \pm 0.19 \pm 0.03$	0.20 (stat)

Our results are well consistent with the Belle results

Control penguin from $B^0 \to J/\psi\rho^0$

- Two observables to extract a_i and θ_i:

$\phi_d = 2\beta$

$$\tan\left(\phi_{d,i}^{J/\psi\rho^0} - \phi_d\right) = \frac{-2a_i\cos\theta_i\sin\gamma + a_i^2\sin 2\gamma}{1 - 2a_i\cos\theta_i\cos\gamma + a_i^2\cos 2\gamma}$$

Direct CPV
$$|\lambda_i| = \left|\frac{1 - a_i e^{i\theta_i} e^{-i\gamma}}{1 - a_i e^{i\theta_i} e^{i\gamma}}\right|$$

The penguin shift has a weak dependence on $|\lambda_i|$, resulting in

$$\Delta\phi_{s,i}^{J/\psi\phi} \approx -\epsilon \times (\phi_{d,i}^{J/\psi\rho^0} - \phi_d)$$

ϵ=0.0536

This factor greatly reduces uncertainty of the penguin shift

Control penguin from $B^0 \to J/\psi\rho^0$

- Two observables to extract a_i and θ_i:

$\phi_d = 2\beta$

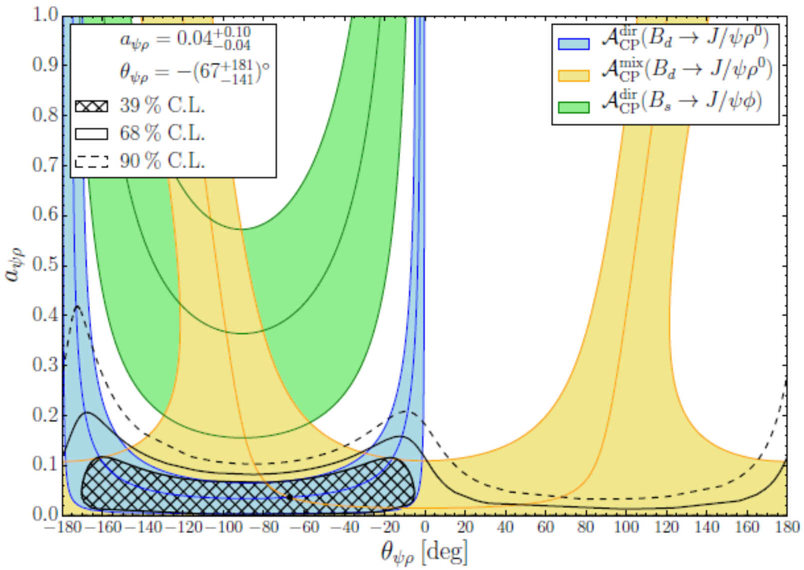
$$\tan\left(\phi_{d,i}^{J/\psi\rho^0} - \phi_d\right) = \frac{-2a_i\cos\theta_i\sin\gamma + a_i^2\sin 2\gamma}{1 - 2a_i\cos\theta_i\cos\gamma + a_i^2\cos 2\gamma}$$

Direct CPV $$|\lambda_i| = \left|\frac{1 - a_i e^{i\theta_i} e^{-i\gamma}}{1 - a_i e^{i\theta_i} e^{i\gamma}}\right|$$

- Use $\phi_d = (43.2^{+1.8}_{-1.7})^\circ$ measured from $B^0 \to J/\psi K^0$ with penguin correction
- Assuming a and θ are independent of polarization

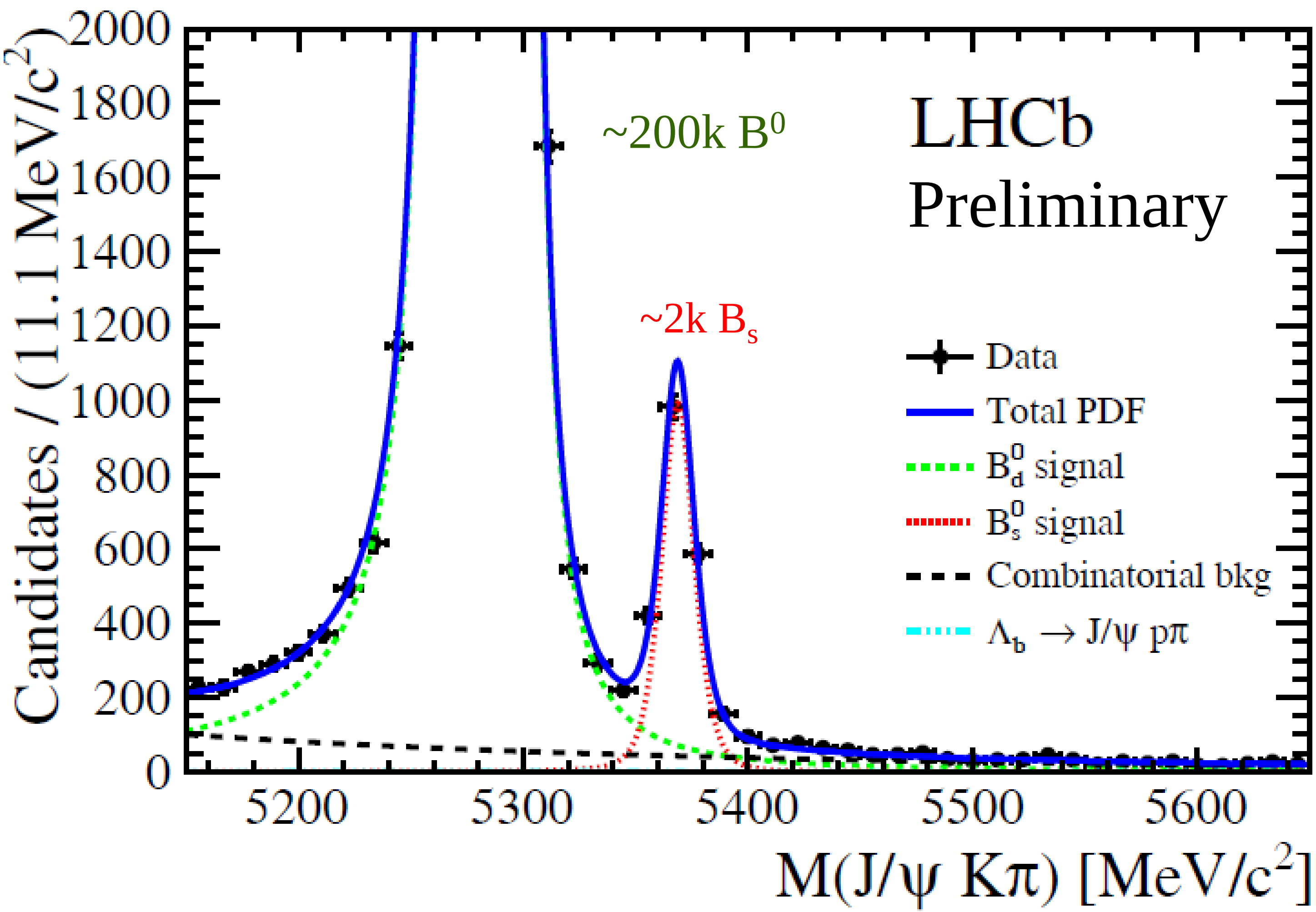
$$\Delta\phi_s^{J/\psi\phi} = \left(0.001^{+0.010}_{-0.013} \pm 0.003(\mathrm{SU3})\right)\ \mathrm{rad}$$

[Bruyn & Fleischer arXiv:1412.6834]



$$B_s^0 \rightarrow J/\psi \overline{K}^{*0}$$

$B^0_{(s)} \to J/\psi \bar{K}^{*0}$

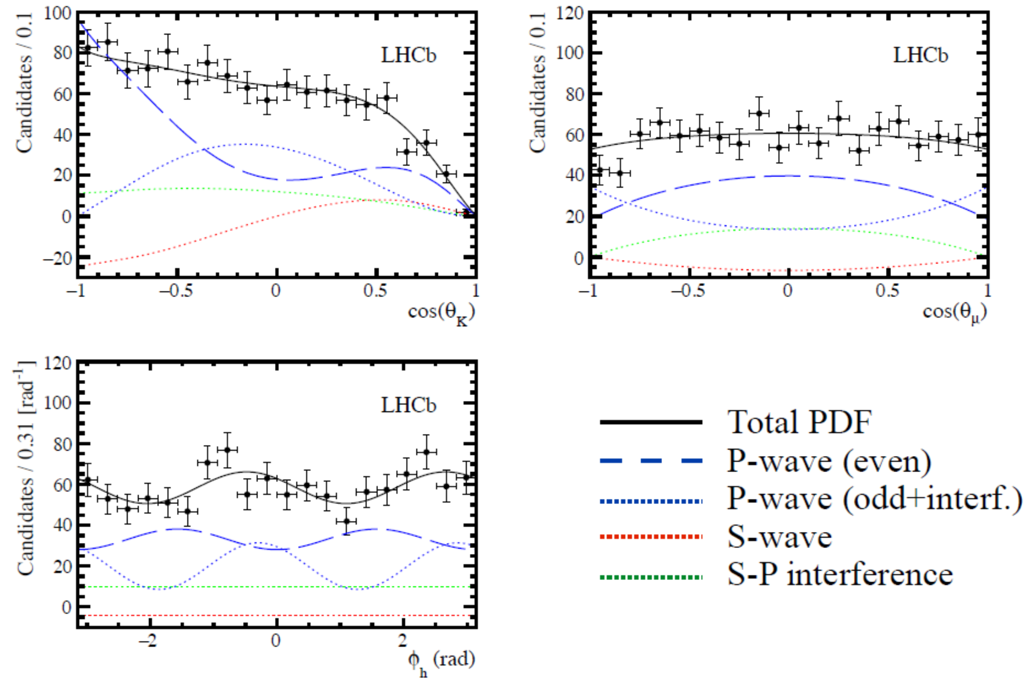


[LHCb-PAPER-2015-034]

Angular analysis

- Angular analysis used to measure S & P (0, ∥, ⊥) waves in 4 $m_{K\pi}$ bins around $K^*(892)^0$, and for B_s^0 and $\bar{B}_s^0$
- Angular efficiency from simulation (+calibrated by large signal of $B_d^0 \to J/\psi K^{*0}$)

LHCb preliminary



	Parameter	Fitted value
Fraction	f_0	$0.497^{+0.024}_{-0.025} \pm 0.025$
	$f_\parallel$	$0.179^{+0.027}_{-0.026} \pm 0.013$
Direct CP asymmetry	A_0^{CP}	$-0.048 \pm 0.057^{+0.019}_{-0.020}$
	$A_\parallel^{CP}$	$0.171 \pm 0.152^{+0.028}_{-0.027}$
	$A_\perp^{CP}$	$-0.049^{+0.095}_{-0.096} \pm 0.025$

$$\mathcal{B}(B_s^0 \to J/\psi \overline{K^{*0}}) = (4.13 \pm 0.16 \pm 0.25 \pm 0.24 (f_s/f_d)) \times 10^{-5}$$

$\theta_K = \theta_{hh}$
$\varphi_h = \chi$
$\theta_\mu = \theta_{J/\psi}$

[LHCb-PAPER-2015-034]

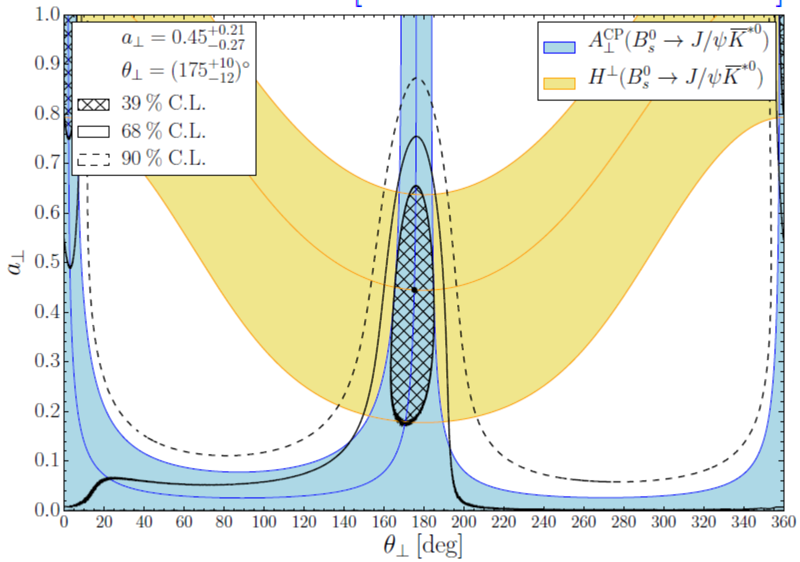
Control penguin from $B_s^0 \to J/\psi \bar{K}^{*0}$

- Use results from angular analysis and branching fractions

- $A_i^{CP} = \frac{\Gamma(\bar{B}_s^0 \to J/\psi(K^+\pi^-)_i) - \Gamma(B_s^0 \to J/\psi(K^-\pi^+)_i)}{\Gamma(\bar{B}_s^0 \to J/\psi(K^+\pi^-)_i) + \Gamma(B_s^0 \to J/\psi(K^-\pi^+)_i)} = -\frac{2a_i \sin\theta_i \sin\gamma}{1 - 2a_i \cos\theta_i \cos\gamma + a_i^2}$
- $H_i \propto \frac{1}{\epsilon}\left|\frac{\mathcal{A}_i'}{\mathcal{A}_i}\right|^2 \frac{\mathcal{B}(B_s^0 \to J/\psi \bar{K}^{*0})}{\mathcal{B}(B_s^0 \to J/\psi \phi)} \frac{f_i}{f_i'} = \frac{1 - 2a_i \cos\theta_i \cos\gamma + a_i^2}{1 + 2\epsilon a_i' \cos\theta_i' \cos\gamma + \epsilon^2 a_i'^2}$

Theory inputs computed with LCSR
[Barucha et al, arXiv:1503.05534]

[LHCb-PAPER-2015-034]



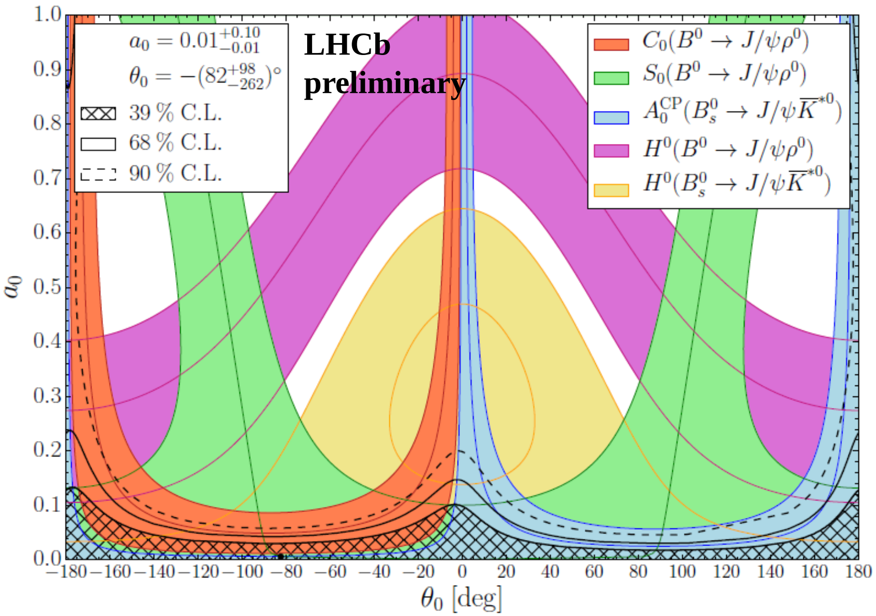
- Extract penguin parameters from χ^2 fit to H_i and A_i^{CP} information for each polarisation $i \in (0, \perp, \parallel, \mathrm{S})$.
- Translate to penguin phase shift:

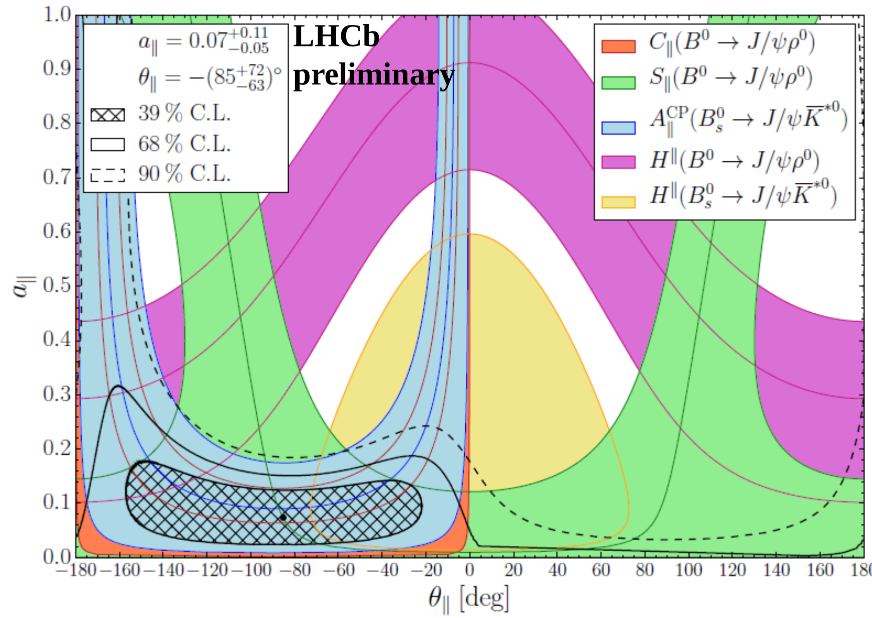
Param.	Value ± (stat)	± (syst)	$\pm(\lvert\mathcal{A}_i'/\mathcal{A}_i\rvert)$
$\Delta\phi_{s,0}^{J/\psi\phi}$	$0.001^{+0.087}_{-0.011}$	$^{+0.013}_{-0.008}$	$^{+0.048}_{-0.030}$
$\Delta\phi_{s,\parallel}^{J/\psi\phi}$	$0.031^{+0.049}_{-0.038}$	$^{+0.013}_{-0.013}$	$^{+0.031}_{-0.033}$
$\Delta\phi_{s,\perp}^{J/\psi\phi}$	$-0.046^{+0.012}_{-0.012}$	$^{+0.007}_{-0.008}$	$^{+0.017}_{-0.024}$

Current ϕ_s precision ±0.035 rad

Combined results

[LHCb-PAPER-2015-034]





polarization dependent measurements are used for both channels

- Now fit for $|\mathcal{A}_i'/\mathcal{A}_i|$ to limit sensitivity to hadronic uncertainties.
- Assume $|\mathcal{A}_i'/\mathcal{A}_i|(B_s^0 \to J/\psi\overline{K^{*0}}) = |\mathcal{A}_i'/\mathcal{A}_i|(B^0 \to J/\psi\rho^0)$

Parameter	Fitted value
$\Delta\phi_{s,0}^{J/\psi\phi}$	$0.000^{+0.009}_{-0.011}(\text{stat})^{+0.004}_{-0.009}(\text{syst})$
$\Delta\phi_{s,\parallel}^{J/\psi\phi}$	$0.001^{+0.010}_{-0.014}(\text{stat})^{+0.007}_{-0.008}(\text{syst})$
$\Delta\phi_{s,\perp}^{J/\psi\phi}$	$0.003^{+0.010}_{-0.014}(\text{stat})^{+0.007}_{-0.008}(\text{syst})$

- Combined results dominated by $B^0 \to J/\psi\rho^0$ (access to mixing induced asymmetry not available in flavor-specific $B_s^0 \to J/\psi\overline{K}^{*0}$)

Penguins are small!

Conclusion

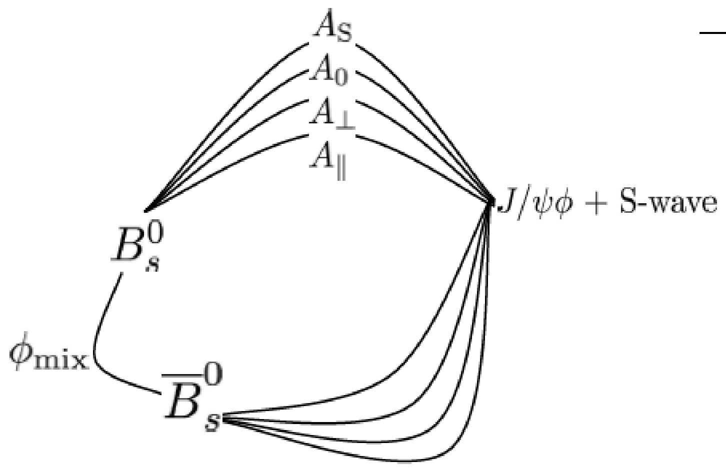
- The world average for ϕ_s is -15 ± 35 mrad
- The SM theoretical uncertainty is not limited by penguin contributions anymore
- We have experimental tools to control it with precision ± 14 mrad
  - $B^0 \to J/\psi \rho^0$ accesses to mixing induced asymmetry, thus is more powerful
  - While cross-check is needed between different modes

Backup

Polarisation-dependent ϕ_s?

PRL 114 (2015) 041801

- Penguin pollution and/or *CP* violation could be different for each polarisation state, $i \in (0, \perp, \parallel, \mathrm{S})$ [Bhattacharya et al., IJMP A28 (2013) 1350063].
- Relax assumption that $\lambda^i \equiv \eta_i \frac{q}{p}\frac{\bar{A}_i}{A_i}$ is same for all $(J/\psi K^+K^-)_i$ polarisation states.
  - Measure $\lambda^i = |\lambda^i| e^{-i\phi_s^i}$



Parameter	Fitted value
$\lvert\lambda^0\rvert$	$1.012 \pm 0.058 \pm 0.013$
$\lvert\lambda^\parallel/\lambda^0\rvert$	$1.02 \pm 0.12 \pm 0.05$
$\lvert\lambda^\perp/\lambda^0\rvert$	$0.97 \pm 0.16 \pm 0.01$
$\lvert\lambda^S/\lambda^0\rvert$	$0.86 \pm 0.12 \pm 0.04$
ϕ_s^0 [rad]	$-0.045 \pm 0.053 \pm 0.007$
$\phi_s^\parallel - \phi_s^0$ [rad]	$-0.018 \pm 0.043 \pm 0.009$
$\phi_s^\perp - \phi_s^0$ [rad]	$-0.014 \pm 0.035 \pm 0.006$
$\phi_s^S - \phi_s^0$ [rad]	$0.015 \pm 0.061 \pm 0.021$

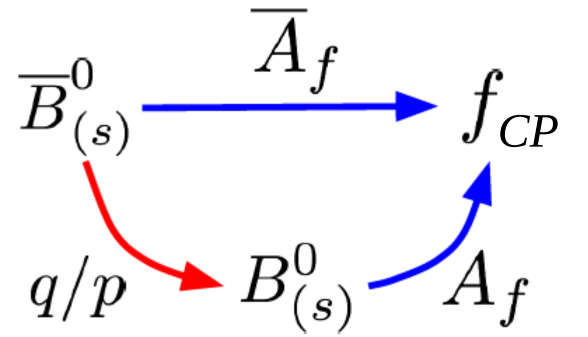
- Everything compatible with no polarisation dependence.

Time dependent asymmetry

- *CP* violation in interference between mixing and decay:

$$\phi_{d,s} \equiv -\arg \lambda_f$$

$$\lambda_f \equiv \frac{q}{p}\frac{\bar{A}_f}{A_f}$$



$$A_{CP}(t) \equiv \frac{\Gamma_{\bar{B}^0_{(s)}(t)\to f} - \Gamma_{B^0_{(s)}(t)\to f}}{\Gamma_{\bar{B}^0_{(s)}(t)\to f} + \Gamma_{B^0_{(s)}(t)\to f}} = \frac{S_f \sin(\Delta m t) - C_f \cos(\Delta m t)}{\cosh(\Delta\Gamma t/2) + A_{\Delta\Gamma}\sinh(\Delta\Gamma t/2)}$$

Two independent *CP* observables:

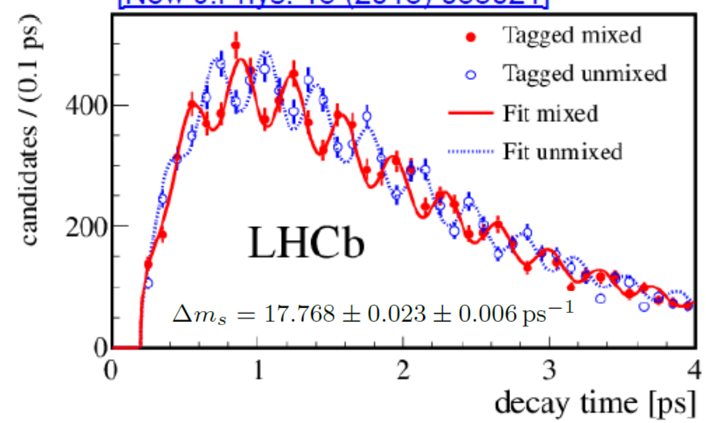
direct — mixing-induced

$$C_f \equiv \frac{1-|\lambda_f|^2}{1+|\lambda_f|^2} \quad S_f \equiv \frac{2\sin\phi_{d,s}}{1+|\lambda_f|^2} \quad A_{\Delta\Gamma} \equiv -\frac{2\cos\phi_{d,s}}{1+|\lambda_f|^2}$$

$$C_f^2 + S_f^2 + A_{\Delta\Gamma}^2 = 1$$

B_s oscillation

[New J.Phys. 15 (2013) 053021]



Penguin pollution in ϕ_s

- Penguin parameters definition:

Polarization dependent
$i \in \{0, \perp, \parallel\}$

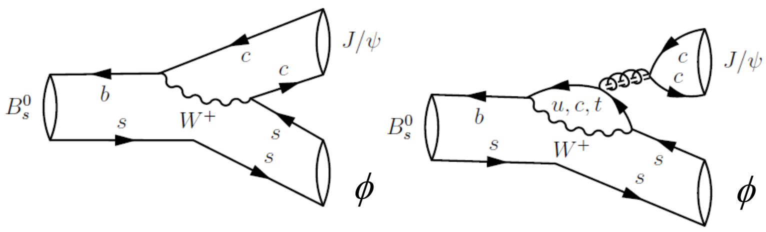
$$A(B_s^0 \to (J/\psi\,\phi)_i) = \left(1 - \frac{\lambda^2}{2}\right) \mathcal{A}'_i \left[1 + \epsilon a'_i e^{i\theta'_i} e^{i\gamma}\right]$$

a'_i: size of "Penguin / tree" ratio, θ'_i: strong phase

"Penguin / tree" ratio is suppressed due to:

$$\epsilon = \lambda^2/(1-\lambda^2) = 0.0536, \qquad \lambda = |V_{us}| = 0.22$$

$b \to c\bar{c}s$



Penguin parameters

$$a'_i e^{i\theta'_i} \equiv R_b \left[\frac{P'^{(u)} - P'^{(t)}}{T'^{(c)} + P'^{(c)} - P'^{(t)}}\right]$$

$$R_b \approx 0.4$$

$$\mathcal{A}'_i \propto \left(T'^{(c)} + P'^{(c)} - P'^{(t)}\right)$$

1 tree amplitude $V_{cs}V_{cb}^{*}\boldsymbol{T}'^{(c)}$ [$\boldsymbol{T}'$ & $\boldsymbol{P}'$ are strong amplitudes]

3 Penguin amplitudes: $V_{ts}V_{tb}^{*}\boldsymbol{P}'^{(t)}$, $V_{cs}V_{cb}^{*}\boldsymbol{P}'^{(c)}$, $V_{us}V_{ub}^{*}\boldsymbol{P}'^{(u)}$

Relations to $B_s^0 \to J/\psi\phi$

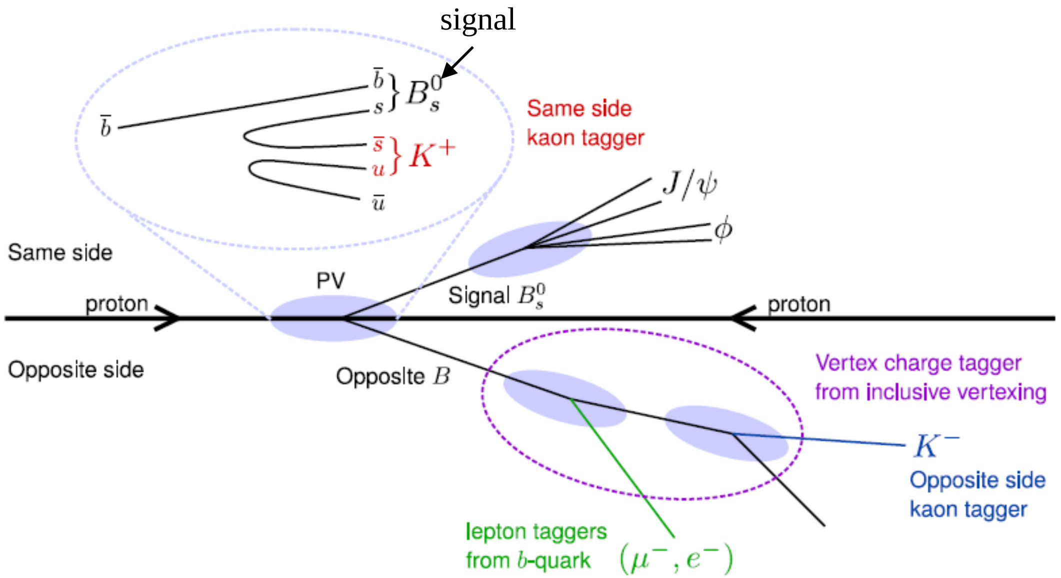
- All modes are P2VV decays
- SU(3) partners with s(J/ψϕ)↔d(control mode)
- Idea:
  - Measure two observables to solve two unknowns a_i and θ_i in the control channel
  - assume perfect SU(3) symmetry, i.e. $a_i' = a_i$ and $\theta_i' = \theta_i$
  - then we can calculate

$$\tan(\Delta\phi_{s,i}^{J/\psi\phi}) = \frac{2\epsilon a_i' \cos\theta_i' \sin\gamma + \epsilon^2 a_i'^2 \sin(2\gamma)}{1 + 2\epsilon a_i' \cos\theta_i' \cos\gamma + \epsilon^2 a_i'^2 \cos(2\gamma)}$$

SU(3) breaking for $a' = a$ & $\theta' = \theta$ at level of 20-30%

[Bruyn & Fleischer arXiv:1412.6834]

Flavour tagging



q: tagging decision
ε_{tag}: tagging efficiency
ω: wrong-tag rate
$D = 1 - 2\omega$: Dilution

Effective tagging power $\varepsilon_{\text{eff}} = \varepsilon_{\text{tag}} \langle D^2 \rangle$

$B_s^0 \to J/\psi\pi^+\pi^-$	3.89 ± 0.25%
$B_s^0 \to J/\psi\phi$	3.73 ± 0.15%
$B^0 \to J/\psi\pi^+\pi^-$	3.26 ± 0.17%

$$\sigma \propto 1/\sqrt{N_{\text{sig}}\varepsilon_{\text{eff}}}$$