



ϕ_S measurements at LHCb

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ϕ_S at LHCb

Introduction

ϕ_S , the CP phase

Measuring ϕ_S

Flavour Tagging

Decay time resolution

$J/\psi \pi^+ \pi^-$ results

$J/\psi \phi$ results

The sign of $\Delta\Gamma_S$

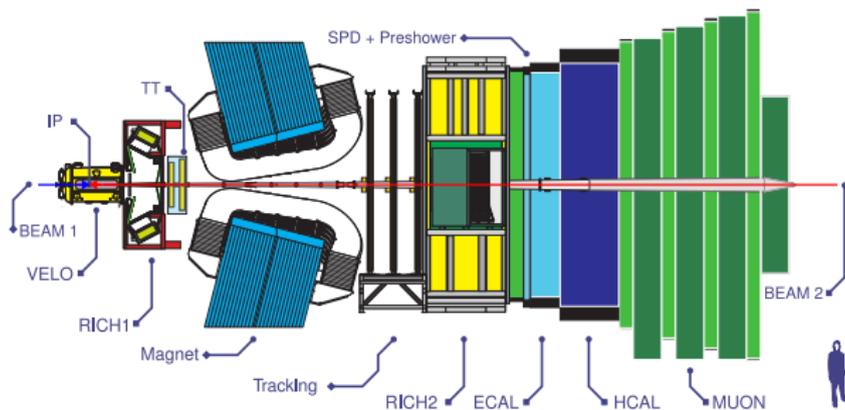
Conclusions

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- ▶ The LHC is a copious source of b, c in the forward region
- ▶ CP -violation measurements are a great way to test the SM...
- ▶ ... but require precision:
 - ▶ Time dependent analyses need **good time resolution**
 - ▶ Flavour tagging needs **particle ID**
 - ▶ High statistics, **purity and efficiency** needed to reach SM predictions
- ▶ LHCb was built *precisely* for this purpose! [JINST 3 S08005]
VELO RICH trigger



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\mathcal{CP} in B_s^0 mixing

- ▶ \mathcal{CP} in interference between mixing and decay of B_s^0, \bar{B}_s^0 to the same final state is parameterised by a phase difference ϕ_s

- ▶ Mixing phase $\phi_M = 2\arg V_{ts} V_{tb}^* \simeq -2\beta_s$

- ▶ Decay dominated by tree level for $B_s^0 \rightarrow J/\psi\phi$

- ▶ $\phi_D = \arg V_{cs} V_{cb}^* \simeq 0$

- ▶ similarly for $J/\psi\pi^+\pi^-$ and other $b \rightarrow \bar{c}cs$ transitions

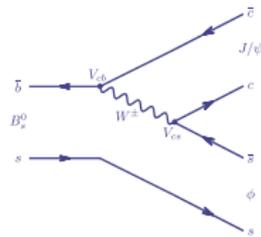
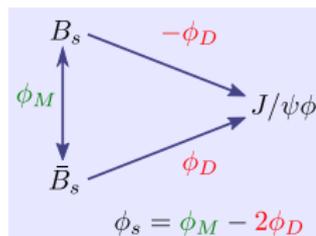
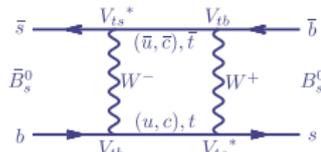
- ▶ ϕ_D in $b \rightarrow \bar{c}cs$ is robust to NP, but ϕ_M sensitive to eg: 4th generation in the box

- ▶ $\phi_s \rightarrow \phi_s^{SM} + \phi^{NP}$

- ▶ Theory prediction very precise:

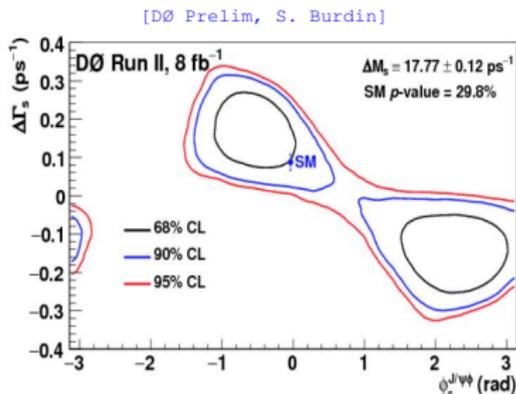
$$\phi_s^{SM} = -2\beta_s = (-0.0363 \pm 0.0016) \text{ rad}$$

[PRD 84 3 (2011)]

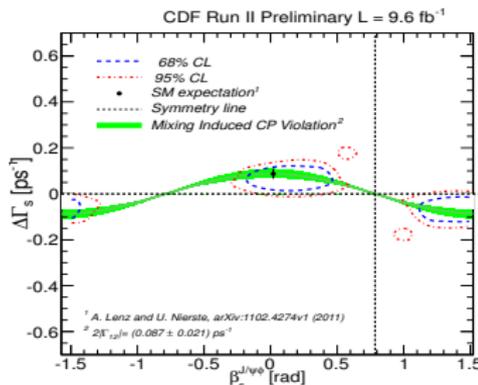


ϕ_S : A continuing saga

- ▶ Tevatron experiments have measured ϕ_S in $B_S^0 \rightarrow J/\psi \phi$, originally finding a combined $\sim 2\sigma$ deviation from $-2\beta_S$
- ▶ Deviation has decreased with more data, but $\sigma(\phi_S)$ still much larger than $\sigma(-2\beta_S)$



[CDF Public Note 10778]



- ▶ Note 2-fold ambiguity: Decay rates invariant under transform:

$$\phi_S \Leftrightarrow \pi - \phi_S \quad \Delta\Gamma_S \Leftrightarrow -\Delta\Gamma_S + \text{phases}$$

- ▶ LHCb results for $B_S^0 \rightarrow J/\psi \phi$ and $B_S^0 \rightarrow J/\psi f_0(980)$ with $\sim 0.4 \text{ fb}^{-1}$
[PRL 108 10 (2012)] [PLB 707 5 (2012)]

ϕ_S in $B_s^0 \rightarrow J/\psi \pi^+ \pi^-$

- $B_s^0 \rightarrow J/\psi f_0(980)$ has been used to measure ϕ_S at LHCb before [PLB 707 5 (2012)]
- Pure \mathcal{CP} -odd final state means decay rate used to fit for ϕ_S is relatively straightforward:

$$\Gamma(B_s^0 \rightarrow J/\psi f_{\text{odd}}) = \frac{\mathcal{N}}{2} e^{-\Gamma t} \left\{ e^{\Delta\Gamma st/2} (1 + \cos \phi_S) + e^{-\Delta\Gamma st/2} (1 - \cos \phi_S) - \sin \phi_S \sin(\Delta m_S t) \right\}$$

$$\Gamma(\bar{B}_s^0 \rightarrow J/\psi f_{\text{odd}}) = \frac{\mathcal{N}}{2} e^{-\Gamma t} \left\{ e^{\Delta\Gamma st/2} (1 + \cos \phi_S) + e^{-\Delta\Gamma st/2} (1 - \cos \phi_S) + \sin \phi_S \sin(\Delta m_S t) \right\}$$

- The fundamental quantity we measure is:
 $\sin(\phi_S) \times D(\sigma_t) \times (1 - 2\omega_{\text{tag}}) \times \sin(\Delta m_S t)$
 - B_s^0 mixing frequency Δm_S is fast: decay time resolution σ_t must be excellent $\ll (350\text{fs})$
 - Measurement depends on knowledge of the B_s^0 flavour: Dilution due to flavour tagging $(1 - 2\omega_{\text{tag}})$ must be understood
- Dalitz analysis of $B_s^0 \rightarrow J/\psi \pi^+ \pi^-$ has found $775 < M(\pi^+ \pi^-) < 1550$ MeV to be \mathcal{CP} -odd (>97.7% @ 95% C.L.) [LHCb-PAPER-2012-005]

Angular analysis of $B_s^0 \rightarrow J/\psi \phi$

- ▶ $B_s^0 \rightarrow J/\psi \phi$ has BR $5 \times B_s^0 \rightarrow J/\psi \pi^+ \pi^-$ **but**:
- ▶ Pseudoscalar to vector vector decay: final state \mathcal{CP} odd and \mathcal{CP} even

- ▶ Three polarisation amplitudes and phases:

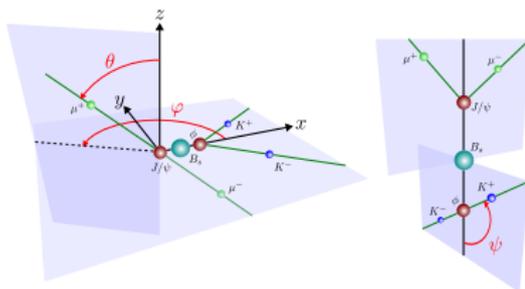
- ▶ $|A_0|^2, |A_{\parallel}|^2, \delta_0, \delta_{\parallel}$ (CP-even)
- ▶ $|A_{\perp}|^2, \delta_{\perp}$ (CP-odd)

- ▶ Angular analysis to disentangle amplitudes and extract ϕ_s

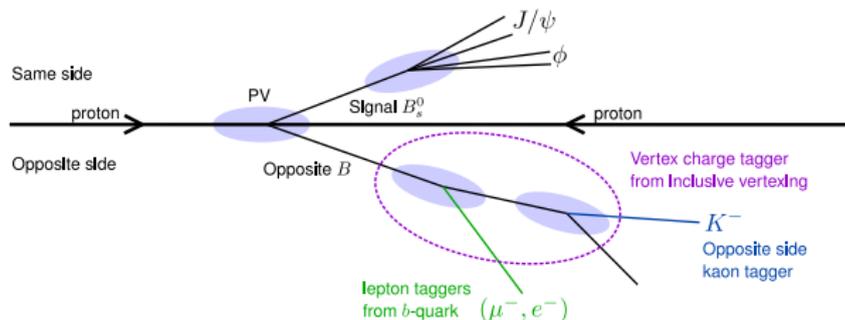
- ▶ LHCb uses the transversity basis

θ, φ, ψ :

- ▶ Nonresonant $K^+ K^-$ s-wave component fraction and phase: F_S, δ_S
- ▶ Decay rate is sum of 10 terms, but ultimately still measure $\sin(\phi_s) \times D(\sigma_t) \times (1 - 2\omega_{tag}) \times \sin(\Delta m_{st})$



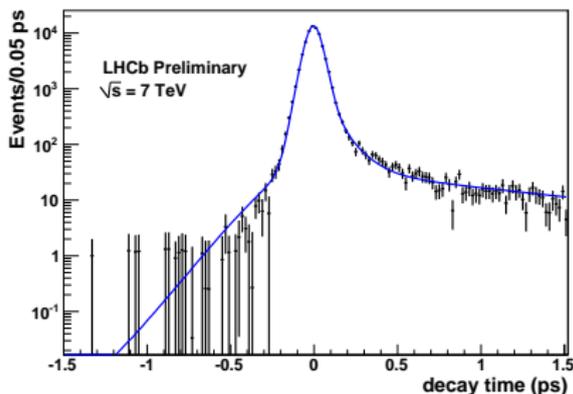
- B_s^0 flavour is determined using flavour tagging algorithms:



- These look at the properties of the B produced in association with the signal B_s^0
- Combined per-event tag and mistag calibrated on $B^\pm \rightarrow J/\psi K^\pm$ in data
 - tagging efficiency $\epsilon_{tag} = (32.99 \pm 0.33)\%$
 - effective mistag $\omega_{tag} = (36.81 \pm 0.18 \pm 0.74)\%$
 - effective tagging power $\epsilon_{tag} \times (1 - 2\omega_{tag})^2 = (2.29 \pm 0.07 \pm 0.26)\%$

Decay time resolution

- ▶ Decay time resolution measured in data [LHCb-CONF-2012-002]
- ▶ Prompt J/ψ : $\tau = 0 \pm \sigma_t$
- ▶ $J/\psi\phi$ selection is a pure source of J/ψ candidates:



- ▶ Decay time resolution $\sigma_t \approx 45$ fs
- ▶ Calibrated per-event decay time resolution used in analysis
- ▶ This is estimated from the uncertainty on the decay vertex and decay length

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$B_s^0 \rightarrow J/\psi \pi^+ \pi^-$ results



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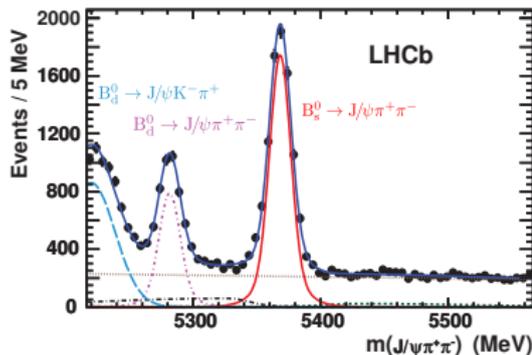
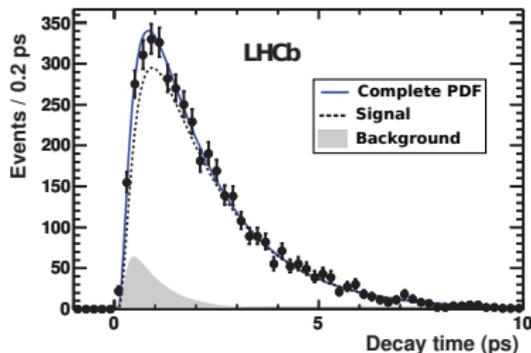
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$B_s^0 \rightarrow J/\psi \pi^+ \pi^-$ results

- ▶ Selection uses BDT to enhance purity, inputs:
 - ▶ μ^\pm ID quality
 - ▶ π^\pm Impact Parameter χ^2 , p_T
 - ▶ B_s^0 vertexing, flight. dist.
- ▶ 7421 ± 105 signal events,
 $S/B \approx 4.2$ in mass ranges:



$$775 < M(\pi^+ \pi^-) < 1550 \text{ MeV}/c^2,$$
$$M(J/\psi \pi^+ \pi^-) \pm 20 \text{ MeV}/c^2$$

- ▶ Simultaneous fit to $M(J/\psi \pi^+ \pi^-)$, decay time.
- ▶ $\Delta\Gamma_S$, Γ_S constrained in the fit with $B_s^0 \rightarrow J/\psi \phi$ values + correlations

- ▶ Result, LHCb 1 fb^{-1} [LHCb-PAPER-2012-006]:

$$\phi_s = -0.02 \pm 0.17 \text{ (stat.)} \pm 0.02 \text{ (syst.) rad}$$

$B_s^0 \rightarrow J/\psi \phi$ results



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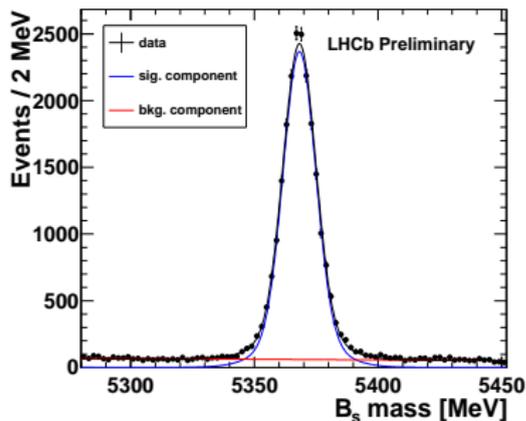
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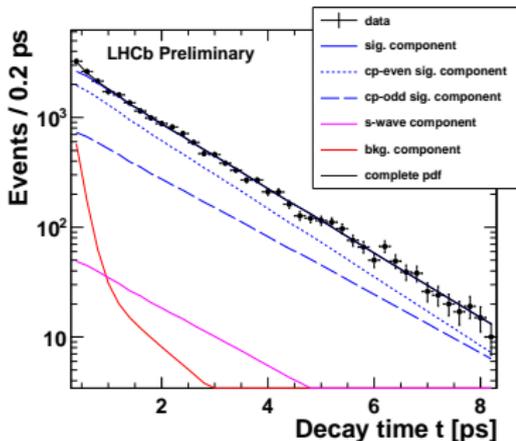
Yield and lifetime with 1 fb^{-1}

[LHCb-CONF-2012-002]

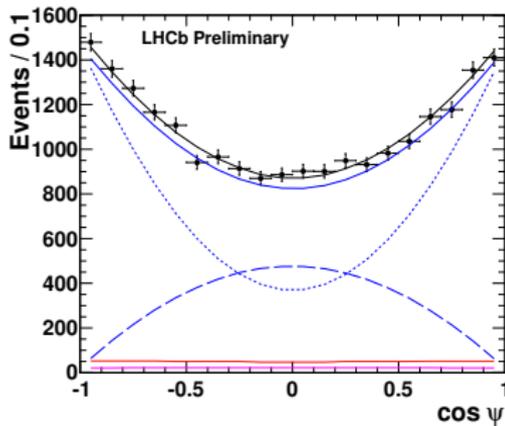
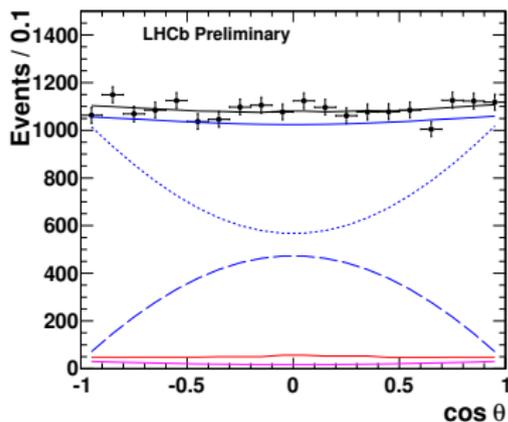
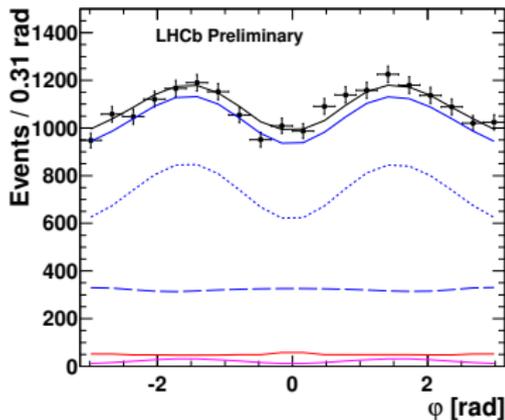
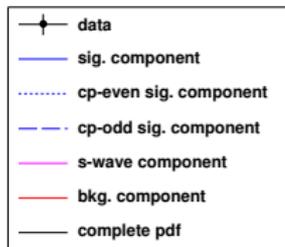


- ▶ Decay time distribution
- ▶ Effect of $\Delta\Gamma_S$ clearly visible
- ▶ s-wave fraction:
 $F_S = (2.2 \pm 1.2 \pm 0.7)\%$

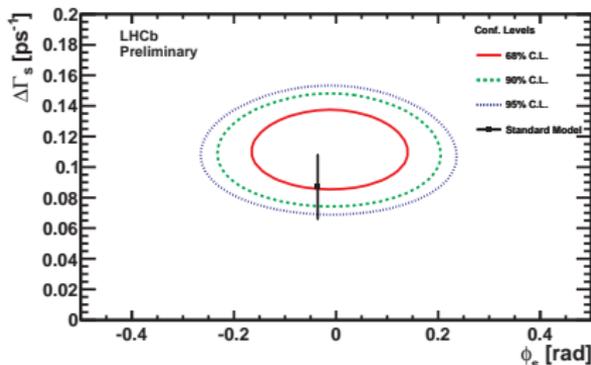
- ▶ Simple rectangular cut selection
- ▶ $t > 0.3 \text{ ps}$ to remove prompt J/ψ
- ▶ Very pure sample:
 ~ 21200 signal candidates
Background $\mathcal{O}(\%)$
- ▶ World's largest $B_S^0 \rightarrow J/\psi \phi$ dataset



$B_s^0 \rightarrow J/\psi \phi$ angular distributions



- Profile likelihood contour in $\Delta\Gamma_s$ - ϕ_s plane:



- Result, LHCb 1 fb⁻¹ (Preliminary) [LHCb-CONF-2012-002]:

$$\begin{aligned}
 \Gamma_s &= 0.6580 \pm 0.0054(\text{stat.}) \pm 0.0066(\text{syst.}) \text{ ps}^{-1} \\
 \Delta\Gamma_s &= 0.116 \pm 0.018(\text{stat.}) \pm 0.006(\text{syst.}) \text{ ps}^{-1} \\
 \phi_s &= -0.001 \pm 0.101(\text{stat.}) \pm 0.027(\text{syst.}) \text{ rad}
 \end{aligned}$$

- Simultaneous fit to both $B_s^0 \rightarrow J/\psi\pi^+\pi^-$, $B_s^0 \rightarrow J/\psi\phi$:

$$\phi_s = -0.002 \pm 0.083(\text{stat.}) \pm 0.027(\text{syst.}) \text{ rad}$$

- But what about the second solution?

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Determining the sign of $\Delta\Gamma_s$

- Two solutions to decay rates in $B_s^0 \rightarrow J/\psi \phi$:

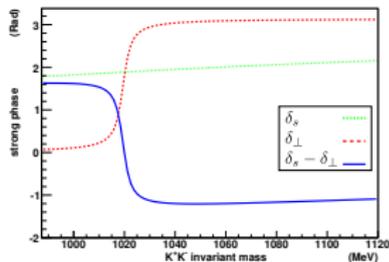
Solution I

$$\begin{aligned} \delta_{\parallel} - \delta_0 \\ \delta_{\perp} - \delta_0 \\ \delta_s - \delta_0 \\ \phi_s \\ \Delta\Gamma_s \end{aligned}$$

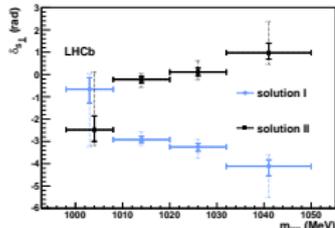
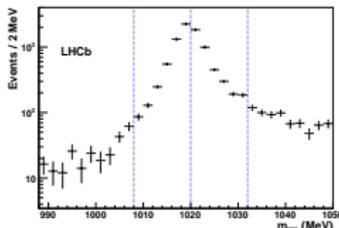
 \Leftrightarrow

Solution II

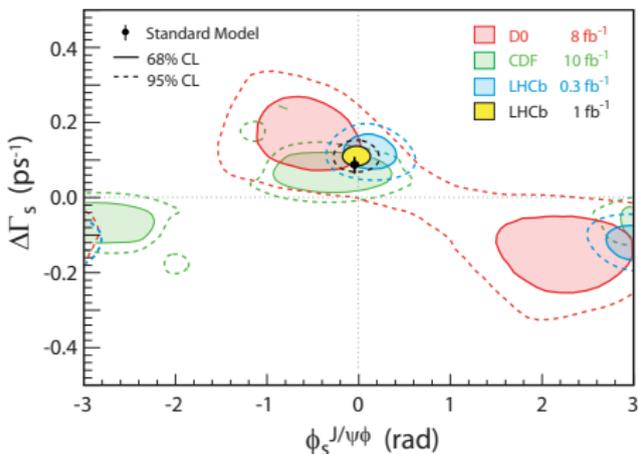
$$\begin{aligned} \delta_0 - \delta_{\perp} \\ \pi + \delta_0 - \delta_{\perp} \\ \delta_0 - \delta_s \\ \pi - \phi_s \\ -\Delta\Gamma_s \end{aligned}$$



- P-wave phase (δ_{\perp}) increases rapidly across $\phi(1020)$ mass resonance, S-wave phase (δ_s) varies slowly
- Measuring $\delta_s - \delta_{\perp}$ in bins of $M(K^+K^-)$ resolves the ambiguity [arXiv:0908.3627 \[hep-ph\]](https://arxiv.org/abs/0908.3627)
- LHCb results, 0.37 fb^{-1} in 4 bins of $M(K^+K^-)$:



- Solution I** preferred at 4.7σ from flat phase difference: $\Delta\Gamma_s$ is positive. Same hierarchy as in K^0 system [arXiv:1202.4717 \[hep-ex\]](https://arxiv.org/abs/1202.4717)



- LHCb has made two measurements of ϕ_S with the 2011 dataset of 1 fb^{-1}

- With $B_S^0 \rightarrow J/\psi \phi$ we find (Preliminary):

$$\begin{aligned} \Gamma_S &= 0.6580 \pm 0.0054(\text{stat.}) \pm 0.0066(\text{syst.}) \text{ ps}^{-1} \\ \Delta\Gamma_S &= 0.116 \pm 0.018(\text{stat.}) \pm 0.006(\text{syst.}) \text{ ps}^{-1} \\ \phi_S &= -0.001 \pm 0.101(\text{stat.}) \pm 0.027(\text{syst.}) \text{ rad} \end{aligned}$$

- With $B_S^0 \rightarrow J/\psi \pi^+ \pi^-$ we find:

$$\phi_S = -0.02 \pm 0.17(\text{stat.}) \pm 0.02(\text{syst.}) \text{ rad}$$

- Combining both measurements we find (Preliminary):

$$\phi_S = -0.002 \pm 0.083(\text{stat.}) \pm 0.027(\text{syst.}) \text{ rad}$$

- With 0.37 fb^{-1} we determine the sign of $\Delta\Gamma_S$ to be positive

This talk has presented recent measurements of the \mathcal{CP} phase ϕ_s and related parameters at LHCb

- ▶ ϕ_s from $B_s^0 \rightarrow J/\psi \pi^+ \pi^-$ with 1 fb^{-1} : [LHCb-PAPER-2012-006]
 - ▶ First observation of $B_s^0 \rightarrow J/\psi f_0(980)$: [PLB 698 2 2011]
 - ▶ ϕ_s measurement with 0.41 fb^{-1} [PLB 707 5 (2012)]
 - ▶ First observation of $B_s^0 \rightarrow J/\psi \Gamma_2'(1525)$: arXiv:1112.4695 [hep-ex]
 - ▶ $M(\pi^+ \pi^-)$ found to be \mathcal{CP} -odd: Preliminary [LHCb-PAPER-2012-005]
- ▶ $\phi_s, \Gamma_s, \Delta\Gamma_s$ from $B_s^0 \rightarrow J/\psi \phi$ with 1 fb^{-1} Preliminary [LHCb-CONF-2012-002]
 - ▶ Previous LHCb result with 0.37 fb^{-1} : [PRL 108 10 (2012)]
- ▶ Determination of the sign of $\Delta\Gamma_s$ with 0.37 fb^{-1} arXiv:1202.4717 [hep-ex]

$B_s^0 \rightarrow J/\psi \phi$ Systematics

Parameter	Value	Stat.	Syst.
Γ_s [ps^{-1}]	0.6580	0.0054	0.0066
$\Delta\Gamma_s$ [ps^{-1}]	0.116	0.018	0.006
$ A_{\perp} ^2$	0.246	0.010	0.013
$ A_0 ^2$	0.523	0.007	0.024
F_s	0.022	0.012	0.007
δ_{\perp} [rad]	2.90	0.36	0.07
δ_{\parallel} [rad]	[2.81, 3.47]		0.13
δ_s [rad]	2.90	0.36	0.08
ϕ_s [rad]	-0.001	0.101	0.027

- ▶ Full physics parameter results including phases
- ▶ δ_{\parallel} non-parabolic likelihood, 95% CL presented
- ▶ Parameter correlation matrix:

	Γ_s	$\Delta\Gamma_s$	$ A_{\perp} ^2$	$ A_0 ^2$	ϕ_s
Γ_s	1.00	-0.38	0.39	0.20	-0.01
$\Delta\Gamma_s$		1.00	-0.67	0.63	-0.01
$ A_{\perp} ^2$			1.00	-0.53	-0.01
$ A_0 ^2$				1.00	-0.02
ϕ_s					1.00

- ▶ Systematic uncertainties
- ▶ Systematic uncert. due to flavor tagging, Δm_s explicitly included as Gaussian constraint in fit

Source	Γ_s [ps^{-1}]	$\Delta\Gamma_s$ [ps^{-1}]	A_{\perp}^2	A_0^2	F_s	δ_{\parallel} [rad]	δ_{\perp} [rad]	δ_s [rad]	ϕ_s [rad]
Description of background	0.0010	0.004	-	0.002	0.005	0.04	0.04	0.06	0.011
Angular acceptances	0.0018	0.002	0.012	0.024	0.005	0.12	0.06	0.05	0.012
t acceptance model	0.0062	0.002	0.001	0.001	-	-	-	-	-
z and momentum scale	0.0009	-	-	-	-	-	-	-	-
Production asymmetry ($\pm 10\%$)	0.0002	0.002	-	-	-	-	-	-	0.008
CPV mixing & decay ($\pm 5\%$)	0.0003	0.002	-	-	-	-	-	-	0.020
Fit bias	-	0.001	0.003	-	0.001	0.02	0.02	0.01	0.005
Quadratic sum	0.0066	0.006	0.013	0.024	0.007	0.13	0.07	0.08	0.027

- ▶ Largest systematic uncertainties on ϕ_s :
 - ▶ Ignoring possible direct \mathcal{CP}
 - ▶ Angular acceptance modelling

$B_S^0 \rightarrow J/\psi \pi^+ \pi^-$ Systematics

- Normalised fractions of $M(\pi^+ \pi^-)$ components
- $\rho(770)$, $f_2(1270)$ CP -even, remainder CP -odd = 97.7% @ 95% C.L.

Resonance	(%)
$f_0(980)$	69.7 ± 2.3
$f_0(1370)$	21.2 ± 2.7
non-resonant $\pi^+ \pi^-$	8.4 ± 1.5
$f_2(1270), \Lambda = 0$	0.49 ± 0.16
$f_2(1270), \Lambda = 1 $	0.21 ± 0.65
$\rho(770)$	$< 1.5\% @ 95\% \text{ C.L.}$

Quantity (Q)	$\pm \Delta Q$	Change	
		+Change in ϕ_S (rad)	-Change in ϕ_S (rad)
β	4.4×10^{-3}	0.0008	-0.0007
τ_{bkg_1} (ps)	0.046	-0.0006	0.0014
τ_{bkg_2} (ps)	0.8	-0.0014	0.0014
f_2	0.02	-0.0006	0.0012
N_{bkg}	38	0.0009	-0.0001
$N_{\eta'}$	9	0.0006	0.0001
N_{sig}	105	0.0021	0.0006
m_0 (MeV)	0.12	0.0012	-0.0004
σ_1^m (MeV)	0.1	-0.0002	0.0008
α	1.1×10^{-4}	0.0003	0.0003
T function	5%	0.0005	0.0005
CP -even	increase mistag by 2.3%	-0.0160	0
Direct CP	free in fit	-0.0020	0
Total systematic error on ϕ_S		-0.017	+0.004

- Largest systematic is due to possible CP -even pollution

ϕ_S at LHCb

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Further reading

Results + Systematics

More Theory

$J/\psi \phi$ Decay Rates

$PJ\psi\pi^+\pi^-$ CP asym.

More LHCb

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Parameter	Solution I	Solution II
ϕ_S (rad)	0.167 ± 0.175	2.975 ± 0.175
$\Delta\Gamma$ (ps^{-1})	0.120 ± 0.028	-0.120 ± 0.028
$F_{S;1}$	0.283 ± 0.113	0.283 ± 0.113
$F_{S;2}$	0.061 ± 0.022	0.061 ± 0.022
$F_{S;3}$	0.044 ± 0.022	0.044 ± 0.022
$F_{S;4}$	0.269 ± 0.067	0.269 ± 0.067
$\delta_{S\perp;1}$ (rad)	$-0.46^{+0.35}_{-0.42}$	$-2.68^{+0.42}_{-0.35}$
$\delta_{S\perp;2}$ (rad)	$-2.92^{+0.15}_{-0.13}$	$-0.22^{+0.13}_{-0.15}$
$\delta_{S\perp;3}$ (rad)	$-3.25^{+0.16}_{-0.18}$	$0.11^{+0.18}_{-0.16}$
$\delta_{S\perp;4}$ (rad)	$-4.11^{+0.28}_{-0.43}$	$0.97^{+0.43}_{-0.28}$

- ▶ Simultaneous fit to the 4 bins of $M(K^+K^-)$
- ▶ Separate S-wave fraction and phase difference parameter for each bin.

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J/ψ ϕ Decay Rates

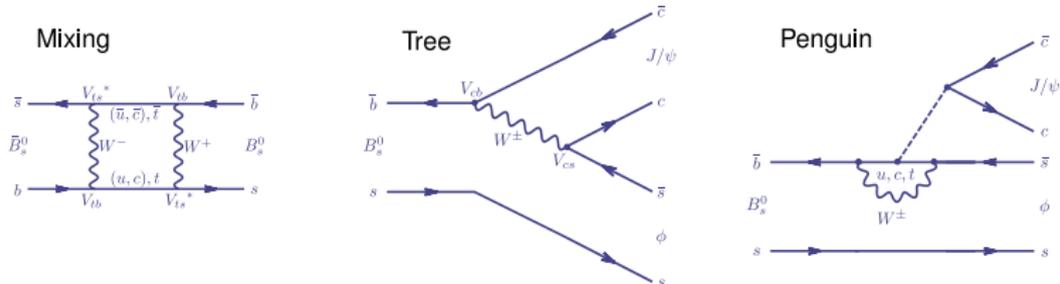
$PJ\psi\pi^+\pi^-\mathcal{CP}$
asym.

More LHCb

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- ▶ Mixing phase: $\phi_M = \arg(V_{ts} V_{tb}^*)^2$
- ▶ $B_s^0 \rightarrow J/\psi \phi$ is a $b \rightarrow c \bar{c} s$ transition, Tree (T) and Penguin (P_q) terms:

$$\begin{aligned} A_{c\bar{c}s} &= V_{cs} V_{cb}^* (T + P_c) + V_{us} V_{ub}^* P_u + V_{ts} V_{tb}^* P_t \\ &= V_{cs} V_{cb}^* (T + P_c - P_t) + V_{us} V_{ub}^* (P_u - P_t) \end{aligned}$$

- ▶ $V_{us} V_{ub}^*$ suppressed by $O(\lambda^2)$ WRT $V_{cs} V_{cb}^*$ so $(P_u - P_t)$ penguin pollution (δP) small
- ▶ This leaves $\phi_D = \arg(V_{cs} V_{cb}^*)$

$$\begin{aligned} \phi_s &= \phi_M - 2\phi_D = \arg(V_{ts} V_{tb}^*)^2 - 2\arg(V_{cs} V_{cb}^*) + \delta P \\ &= 2\arg\left[\frac{V_{ts} V_{tb}^*}{V_{cs} V_{cb}^*}\right] = -2\beta_s = -2\eta\lambda^2 - \eta\lambda^4 - O(\lambda^6) \end{aligned}$$

$B_s^0 \rightarrow J/\psi \phi$ Decay Rates

▶ Signs in blue are tag dependent and change for \bar{B}_s^0

$$A_1 = |A_0|^2 e^{-\Gamma_s t} \left[\cosh\left(\frac{\Delta\Gamma_s}{2} t\right) - \cos\phi_s \sinh\left(\frac{\Delta\Gamma_s}{2} t\right) + \sin\phi_s \sin(\Delta m_s t) \right]$$

$$A_2 = |A_{\parallel}|^2 e^{-\Gamma_s t} \left[\cosh\left(\frac{\Delta\Gamma_s}{2} t\right) - \cos\phi_s \sinh\left(\frac{\Delta\Gamma_s}{2} t\right) + \sin\phi_s \sin(\Delta m_s t) \right]$$

$$A_3 = |A_{\perp}|^2 e^{-\Gamma_s t} \left[\cosh\left(\frac{\Delta\Gamma_s}{2} t\right) + \cos\phi_s \sinh\left(\frac{\Delta\Gamma_s}{2} t\right) - \sin\phi_s \sin(\Delta m_s t) \right]$$

$$A_4 = |A_{\parallel}| |A_{\perp}| e^{-\Gamma_s t} \left[-\cos(\delta_{\perp} - \delta_{\parallel}) \sin\phi_s \sinh\left(\frac{\Delta\Gamma_s}{2} t\right) \right. \\ \left. - \cos(\delta_{\perp} - \delta_{\parallel}) \cos\phi_s \sin(\Delta m_s t) + \sin(\delta_{\perp} - \delta_{\parallel}) \cos(\Delta m_s t) \right]$$

$$A_5 = |A_0| |A_{\parallel}| e^{-\Gamma_s t} \cos(\delta_{\parallel} - \delta_0) \left[\cosh\left(\frac{\Delta\Gamma_s}{2} t\right) - \cos\phi_s \sinh\left(\frac{\Delta\Gamma_s}{2} t\right) \right. \\ \left. + \sin\phi_s \sin(\Delta m_s t) \right]$$

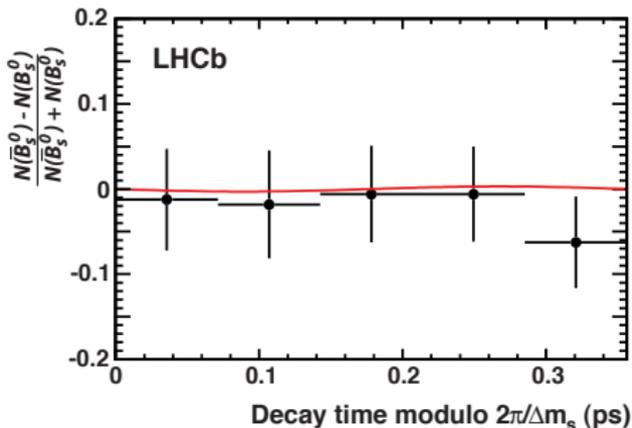
$$A_6 = |A_0| |A_{\perp}| e^{-\Gamma_s t} \left[-\cos(\delta_{\perp} - \delta_0) \sin\phi_s \sinh\left(\frac{\Delta\Gamma_s}{2} t\right) \right. \\ \left. - \cos(\delta_{\perp} - \delta_0) \cos\phi_s \sin(\Delta m_s t) + \sin(\delta_{\perp} - \delta_0) \cos(\Delta m_s t) \right]$$

$$A_7 = |A_s|^2 e^{-\Gamma_s t} \left[\cosh\left(\frac{\Delta\Gamma_s}{2} t\right) + \cos\phi_s \sinh\left(\frac{\Delta\Gamma_s}{2} t\right) - \sin\phi_s \sin(\Delta m_s t) \right]$$

$$A_8 = |A_s| |A_{\parallel}| e^{-\Gamma_s t} \left[-\sin(\delta_{\parallel} - \delta_s) \sin\phi_s \sinh\left(\frac{\Delta\Gamma_s}{2} t\right) \right. \\ \left. - \sin(\delta_{\parallel} - \delta_s) \cos\phi_s \sin(\Delta m_s t) + \cos(\delta_{\parallel} - \delta_s) \cos(\Delta m_s t) \right]$$

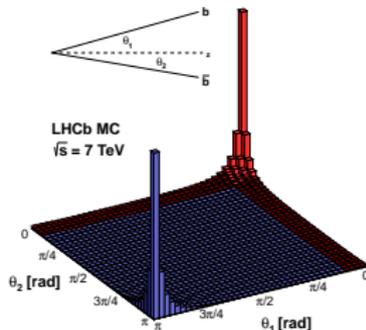
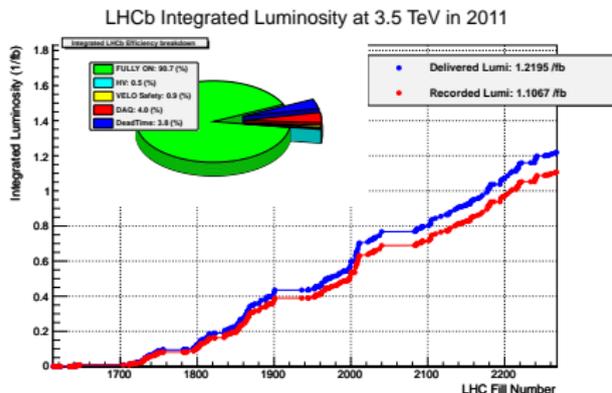
$$A_9 = |A_s| |A_{\perp}| e^{-\Gamma_s t} \sin(\delta_{\perp} - \delta_s) \left[\cosh\left(\frac{\Delta\Gamma_s}{2} t\right) + \cos\phi_s \sinh\left(\frac{\Delta\Gamma_s}{2} t\right) \right. \\ \left. - \sin\phi_s \sin(\Delta m_s t) \right]$$

$$A_{10} = |A_s| |A_0| e^{-\Gamma_s t} \left[-\sin(\delta_0 - \delta_s) \sin\phi_s \sinh\left(\frac{\Delta\Gamma_s}{2} t\right) \right. \\ \left. - \sin(\delta_0 - \delta_s) \cos\phi_s \sin(\Delta m_s t) + \cos(\delta_0 - \delta_s) \cos(\Delta m_s t) \right]$$



- ▶ Raw \mathcal{CP} asymmetry as a function of decay time modulo ($2\pi/\Delta m_S$).
- ▶ in red is the expectation for $\phi_S = -0.019$ rad
- ▶ datapoints are consistently lower as we select more B_S^0 than \bar{B}_S^0

- ▶ At LHC, $b\bar{b}$ pairs produced with correlated polar angle distribution
- ▶ LHCb fully instrumented on $2 < \eta < 5$ to exploit the forward pairs



- ▶ 1.1fb^{-1} collected in 2011 at $\sim 99\%$ efficiency
- ▶ Lumi levelling keeps luminosity constant by separating beams

Backup Slides
 Further reading
 Results + Systematics
 More Theory
 J/ψ ϕ Decay Rates
 $PJ\psi i\pi^+\pi^-CP$
 asym.

More LHCb

C. Fitzpatrick

13th April 2012

