



**HEP 2013**  
**Stockholm**  
**18-24 July 2013**



# Measurement of $\phi_s$ at LHCb

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**On behalf of the LHCb collaboration**

**EPSHEP 2013**

*EPS-HEP 2013 Stockholm*  
Sebastian Wandernoth



# $B_s^0$ mixing

Phenomenological Schroedinger equation describing oscillation and decay

$$i \frac{d}{dt} \left( \frac{B_s^0}{B_s^0} \right) = \left( M - \frac{i}{2} \Gamma \right) \left( \frac{B_s^0}{B_s^0} \right)$$

$$M = \begin{pmatrix} M_{11} & M_{12} \\ M_{12}^* & M_{22} \end{pmatrix}; \Gamma = \begin{pmatrix} \Gamma_{11} & \Gamma_{12} \\ \Gamma_{12}^* & \Gamma_{22} \end{pmatrix}$$



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Mass eigenstates  $\neq$  flavour eigenstates  $\rightarrow$  mass difference  $\propto$  osc. frequency

$$|B_L\rangle = p|B_s^0\rangle + q|\overline{B}_s^0\rangle \quad \Delta m_s = m_H - m_L = 2|M_{12}|$$

$$|B_H\rangle = p|B_s^0\rangle - q|\overline{B}_s^0\rangle \quad \Delta\Gamma_s = \Gamma_L - \Gamma_H$$

$$\phi_M = \arg(M_{12})$$



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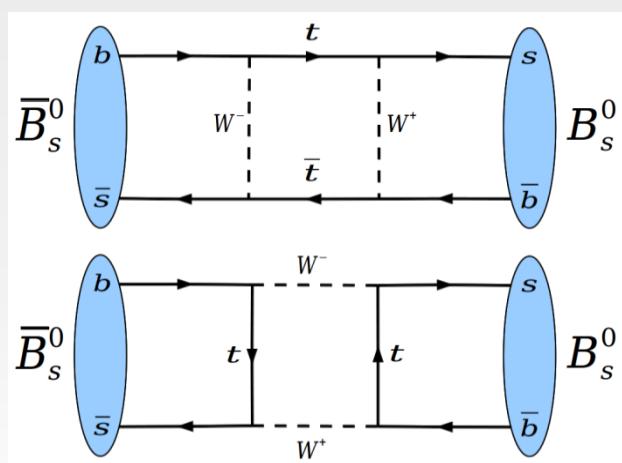
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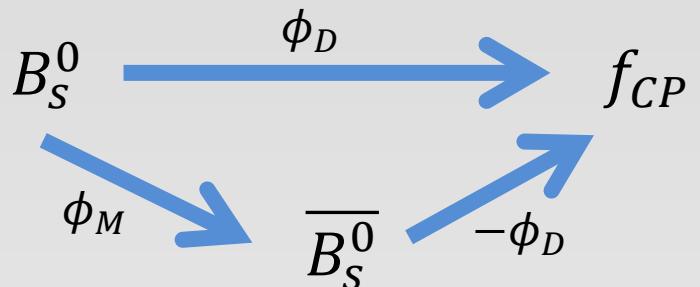
Dominant Feynman diagrams  
(Standard Model)



# $B_s^0$ CP violating phase $\phi_s$

Interference between mixing and decay:  
→ measure relative phase  $\phi_s$

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



CP asymmetry (for CP eigenstates):

$$A_{CP}(t) = \frac{\Gamma(\overline{B_s^0}(t) \rightarrow f_{CP}) - \Gamma(B_s^0(t) \rightarrow f_{CP})}{\Gamma(\overline{B_s^0}(t) \rightarrow f_{CP}) + \Gamma(B_s^0(t) \rightarrow f_{CP})} = -\eta_{CP} \sin(\phi_s) \sin(\Delta m_s t)$$

**Standard Model prediction:  $\phi_s^{SM} = -0.036 \pm 0.002$  rad**

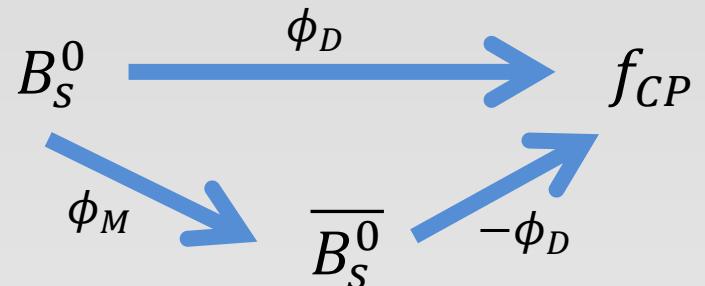
CKM-Fitter (*Phys. Rev. D* 84 (2011), 033005)



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Need excellent Flavour tagging  
→ tagging power  $\varepsilon D^2 \approx 3.1\%$

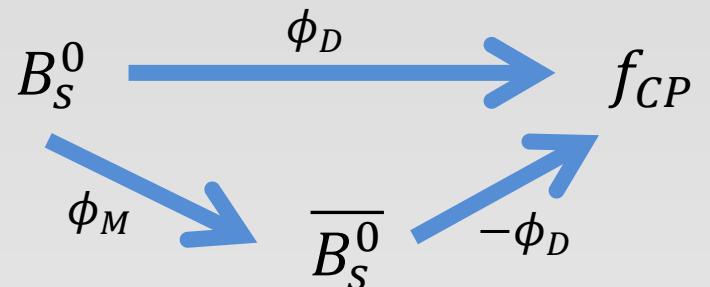
time-dependent analysis  
& fast  $B_s^0 - \overline{B}_S^0$  oscillation  
→ need excellent decay time resolution  
(45 fs)



# $B_s^0$ mixing phase $\phi_s$

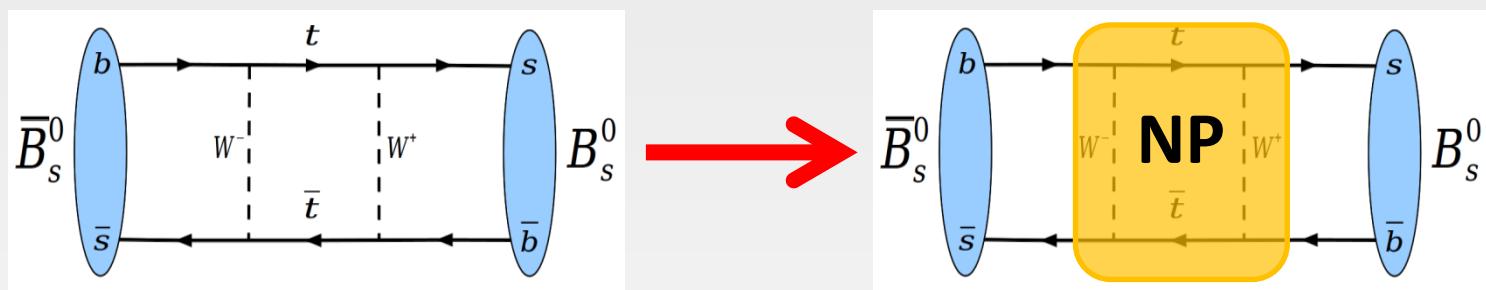
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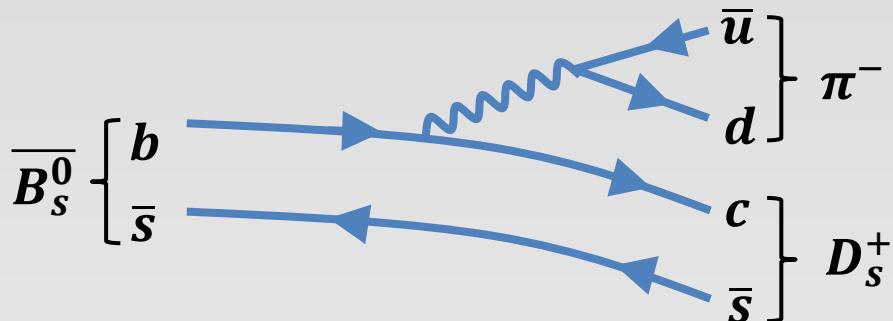
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New Physics:  $\phi_s = \phi_s^{SM} + \phi_s^{NP}$



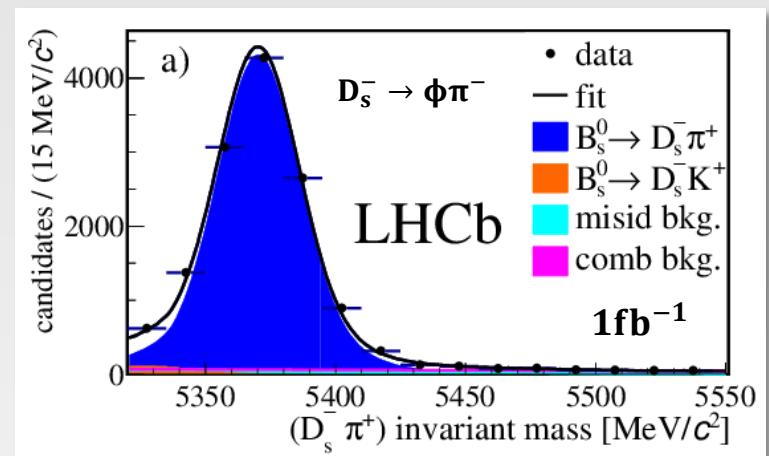
# $\Delta m_s$ from $B_s^0 \rightarrow D_s^- \pi^+$



New J. Phys. 15 (2013) 053021

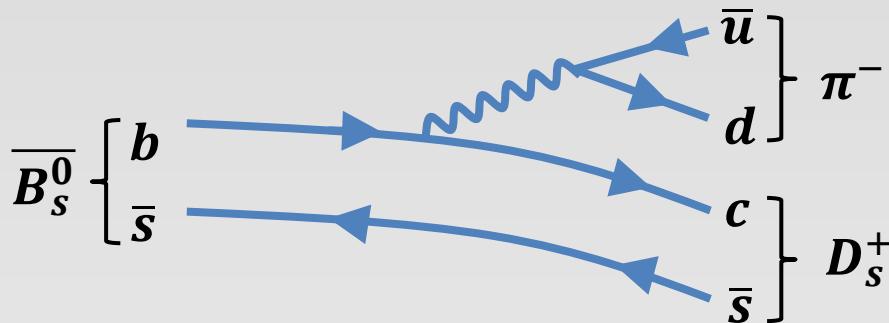
	# candidates	Signal fraction
$D_s^- \rightarrow \phi\pi^-$	14691	$0.8337 \pm 0.0081$
$D_s^- \rightarrow K^*K^-$	10866	$0.8573 \pm 0.0088$
$D_s^- \rightarrow K^-K^+\pi^-$ n.r.	11262	$0.5952 \pm 0.0093$
$D_s^- \rightarrow K^-\pi^+\pi^-$	4288	$0.4366 \pm 0.0137$
$D_s^- \rightarrow \pi^-\pi^+\pi^-$	6674	$0.5990 \pm 0.0081$
<b>Total</b>	<b>47781</b>	<b><math>0.7144 \pm 0.0040</math></b>

- High statistics ( $\sim 34k$  signal candidates)
- Fit to 5 different  $D_s^-$  decay modes
- Very low background

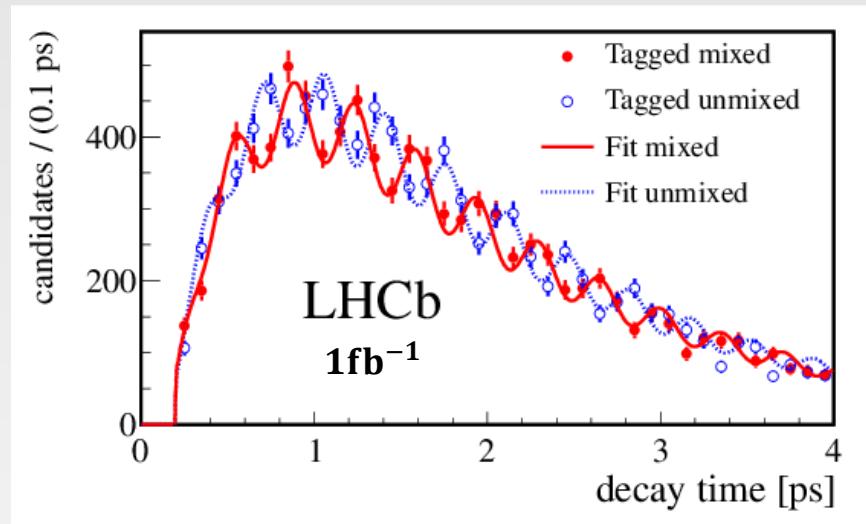




# $\Delta m_s$ from $B_s^0 \rightarrow D_s^- \pi^+$



New J. Phys. 15 (2013) 053021



- High statistics ( $\sim 34k$  signal candidates)
- Fit to 5 different  $D_s^-$  decay modes
- Very low background

Uses flavour tagging:  
opposite side (*Eur.Phys.J. C72(2012) 2022*)  
same side (LHCb-CONF-2012-033)

$$\Delta m_s = 17.768 \pm 0.023(\text{stat}) \pm 0.006(\text{syst}) \text{ ps}^{-1}$$

World's most precise measurement

EPS-HEP 2013 Stockholm  
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Measuring  $\phi_s$ 

- $B_s^0 \rightarrow J/\Psi \phi$
- $B_s^0 \rightarrow J/\Psi \pi^+ \pi^-$
- $B_s^0 \rightarrow \phi \phi$

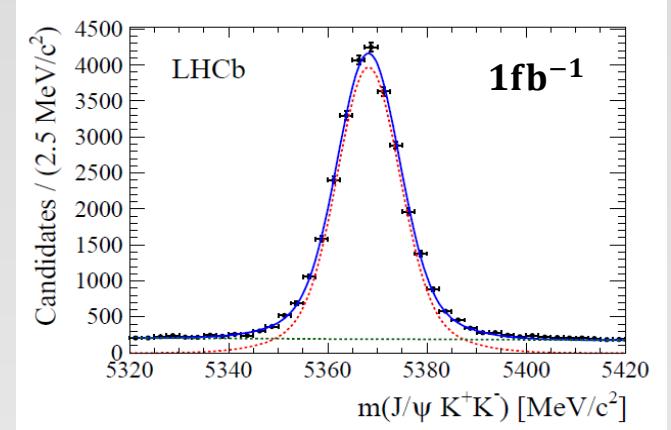
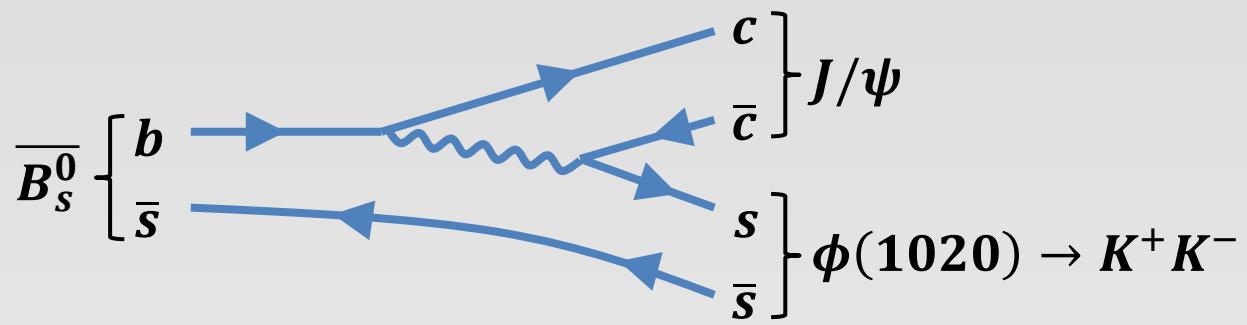
Measuring  $\phi_s$ 

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

Phys. Rev. D 87, 112010 (2013)

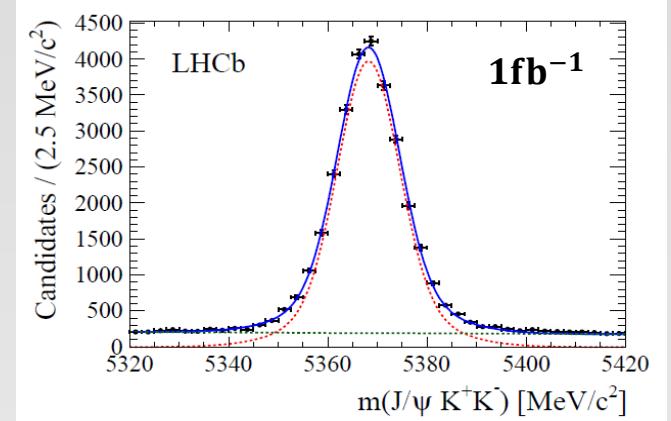
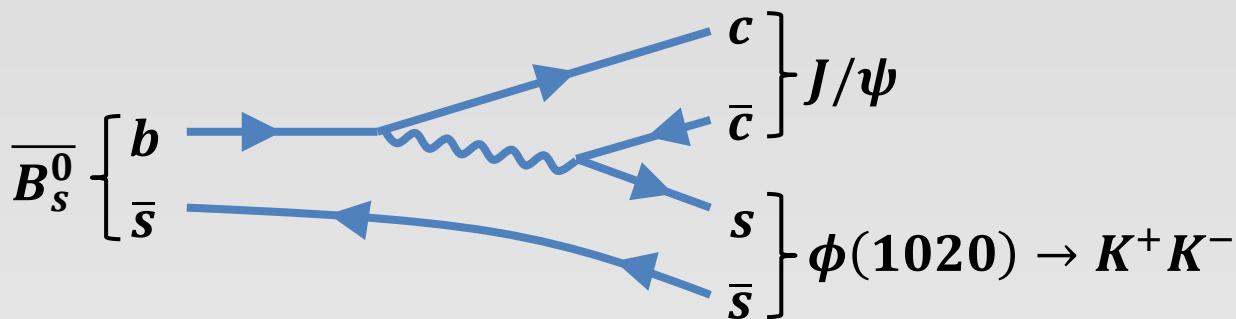


High statistics ( $\sim 27k$  signal events)  
Low bkg (narrow  $J/\psi$  resonance  
+ cut on  $B_s^0$  decay time)



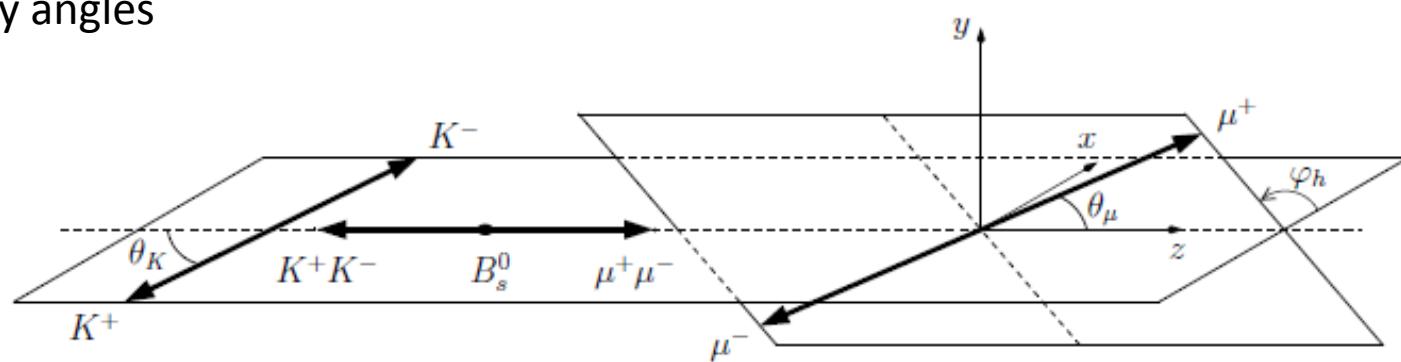
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Phys. Rev. D 87, 112010 (2013)



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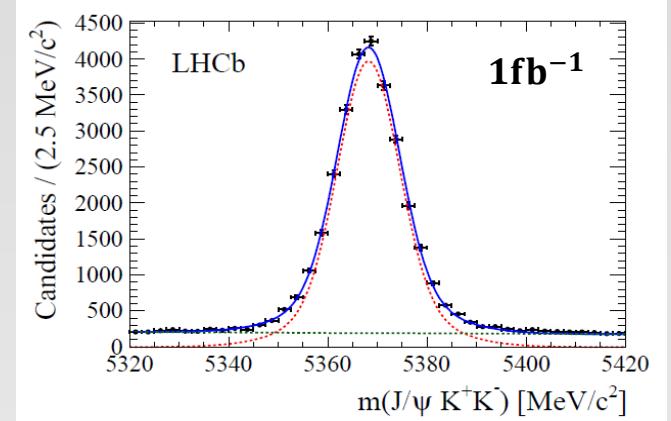
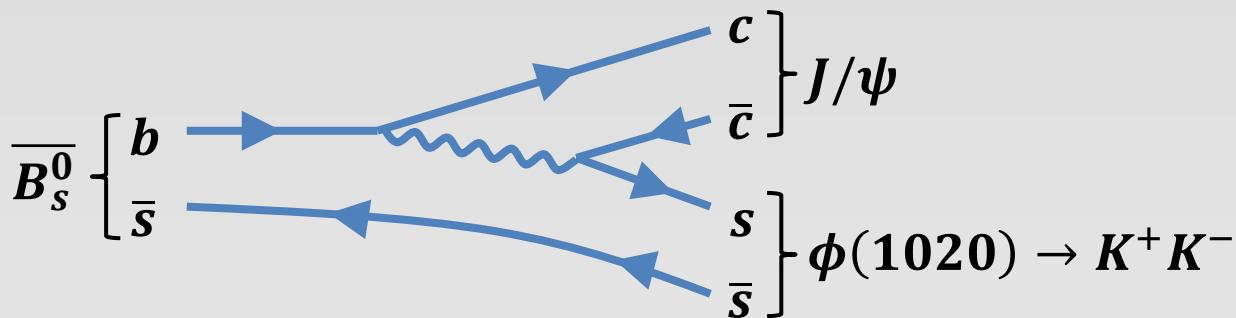
No CP eigenstate  
→ need angular analysis  
in three decay angles





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

Phys. Rev. D 87, 112010 (2013)

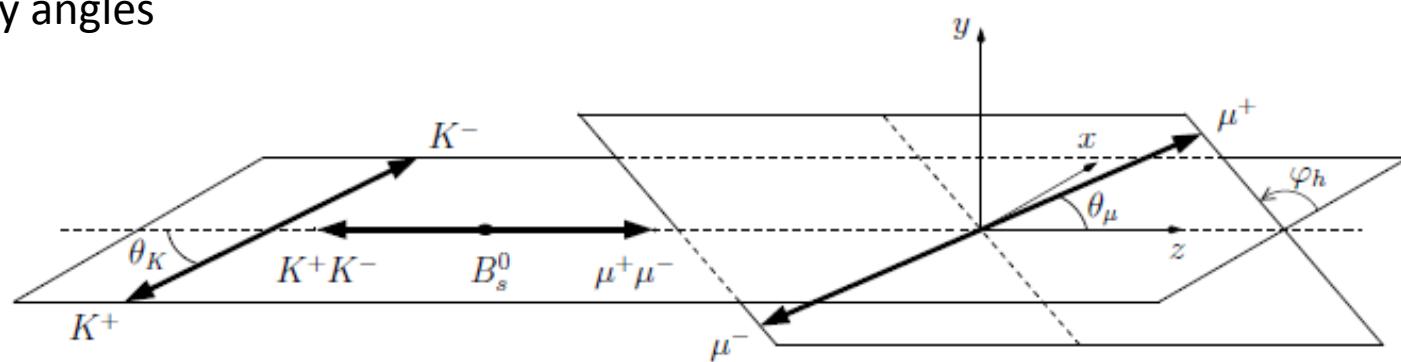


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No CP eigenstate

→ need angular analysis  
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**This way we can fit for  $\Delta\Gamma_s$**

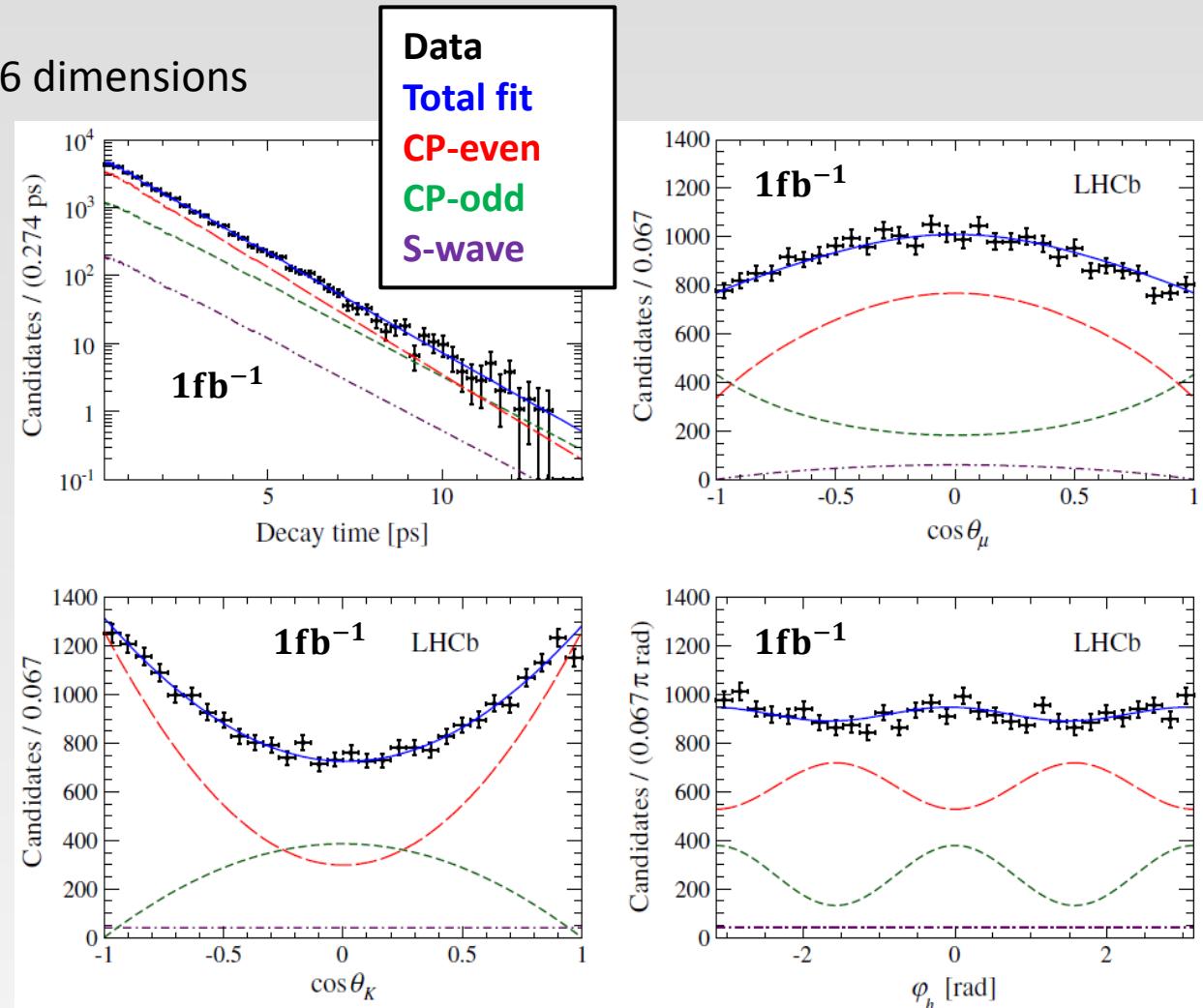




## MLL Fit

Phys. Rev. D 87, 112010 (2013)

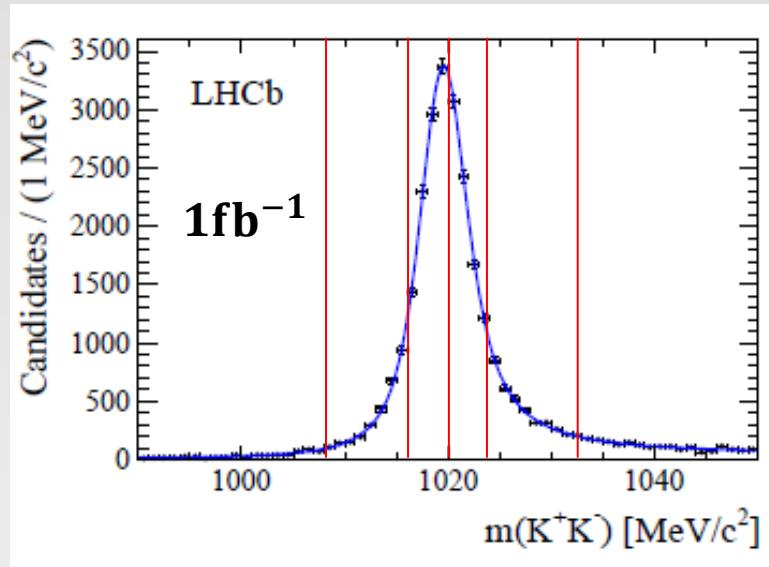
- Unbinned maximum likelihood fit in 6 dimensions
  - Invariant mass
  - Three decay angles
  - Decay time
  - Tagging decision
- Take  $\Delta m_s$  from  $B_s^0 \rightarrow D_s^- \pi^+$
- Allow for direct CP-violation
- Use opposite and same side flavour tagger
  - $\varepsilon D_{OST}^2 = 2.29 \pm 0.06\%$
  - $\varepsilon D_{SST}^2 = 0.89 \pm 0.17\%$





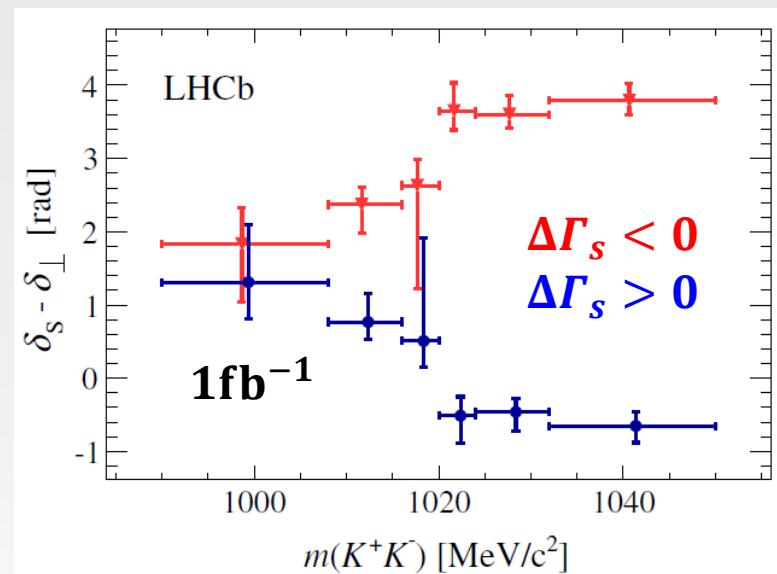
# Ambiguity

2-fold ambiguity  $(\phi_s, \Delta\Gamma_s) \longleftrightarrow (\pi - \phi_s, -\Delta\Gamma_s)$



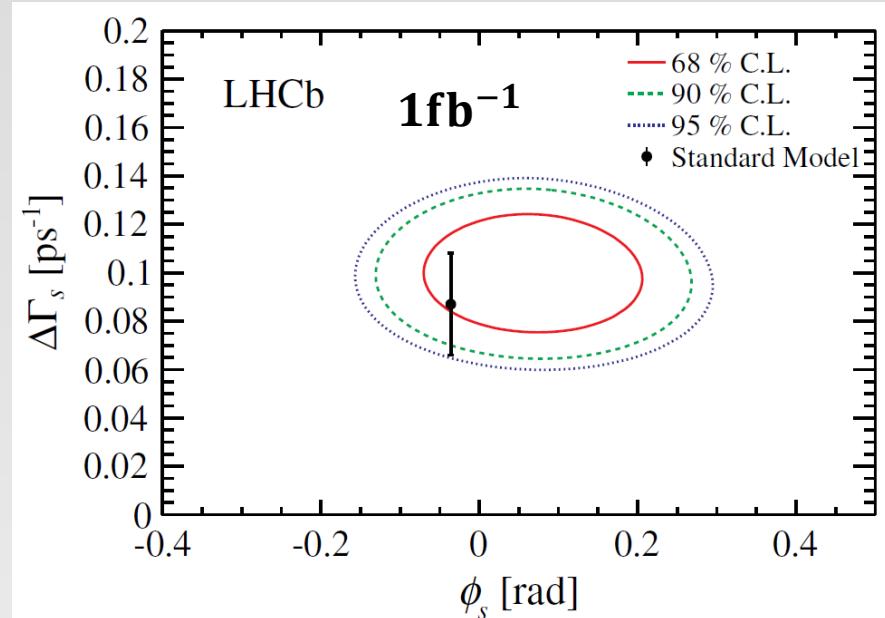
only  $\Delta\Gamma_s > 0$  fits expectation

Resolve ambiguity:  
Look at strong phase difference  
between p- and s-wave in bins of  $K^+K^-$  mass





# Fit results



Phys. Rev. D 87, 112010 (2013)

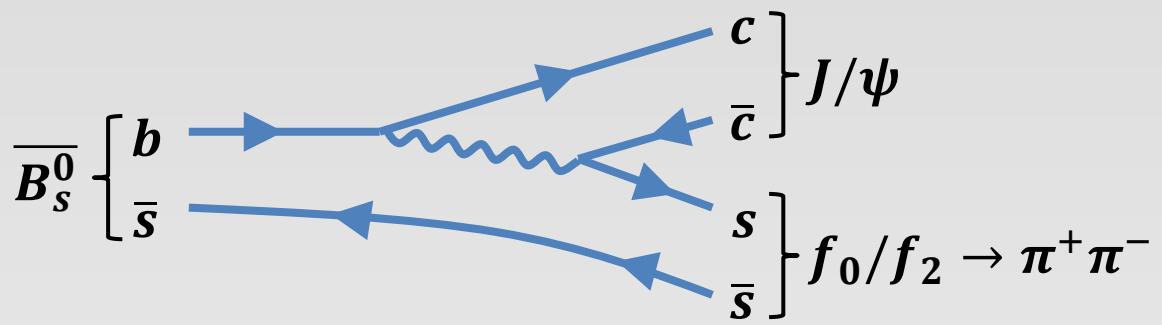
$$\begin{aligned}\phi_s &= 0.07 \pm 0.09 \text{ (stat)} \pm 0.01 \text{ (syst) rad} \\ \Gamma_s &= 0.663 \pm 0.005 \text{ (stat)} \pm 0.006 \text{ (syst) ps}^{-1} \\ \Delta\Gamma_s &= 0.100 \pm 0.016 \text{ (stat)} \pm 0.003 \text{ (syst) ps}^{-1}\end{aligned}$$

Dominant systematics:  
angular and decay time acceptance

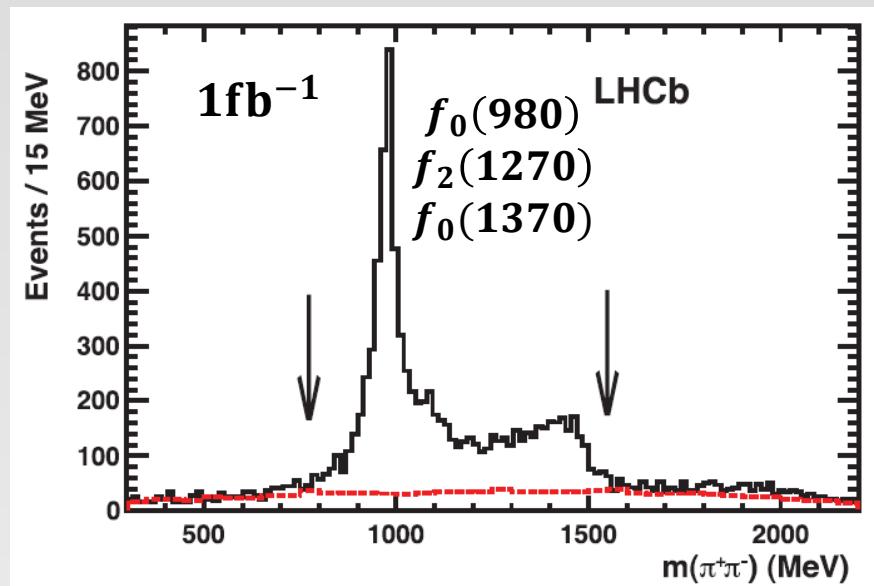
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- $B_s^0 \rightarrow J/\Psi \phi$
- $B_s^0 \rightarrow J/\Psi \pi^+ \pi^-$
- $B_s^0 \rightarrow \phi \phi$


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


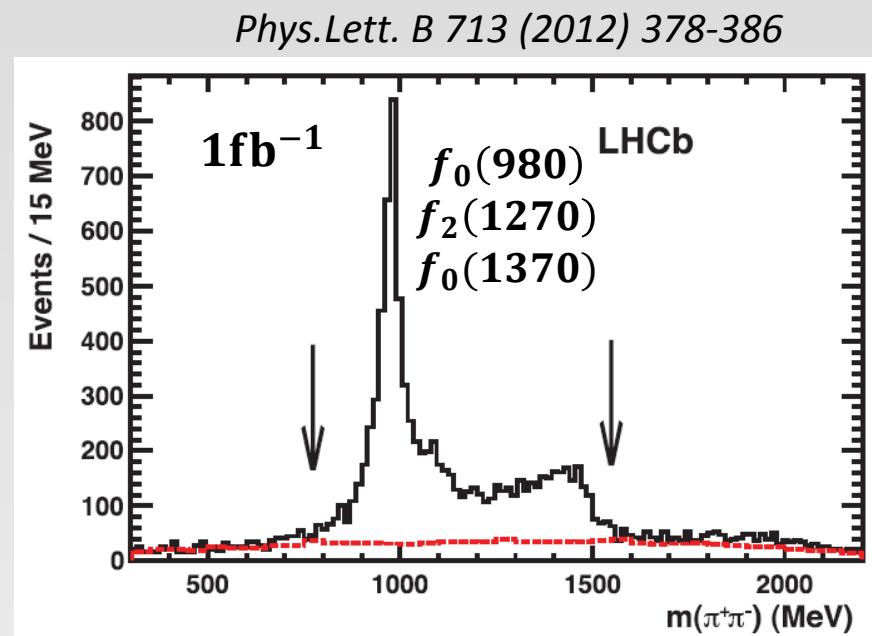
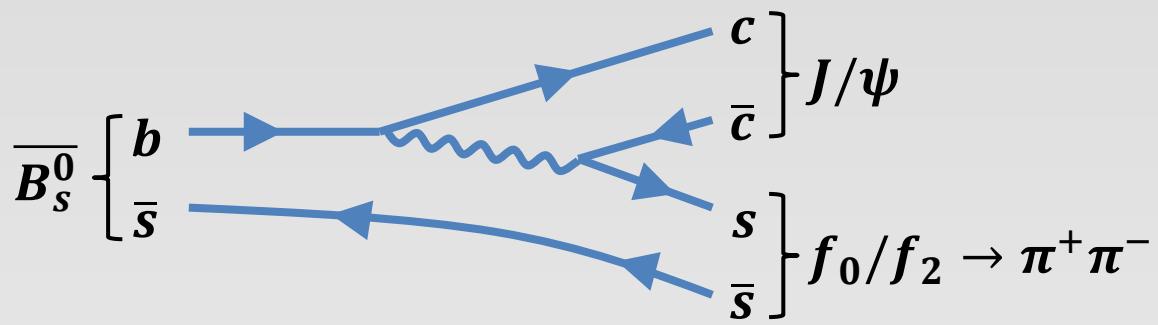
*Phys.Lett. B 713 (2012) 378-386*



- Final state is purely CP-odd ( $> 98\%$  see *Phys.Rev D 86, 052006 (2012)*)  
 $\rightarrow$  no angular analysis needed
- $\Gamma_s$  and  $\Delta\Gamma_s$  constrained to values from  $B_s^0 \rightarrow J/\psi\phi$
- Signal yield is  $\sim 1/3$  of  $B_s^0 \rightarrow J/\psi\phi$



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



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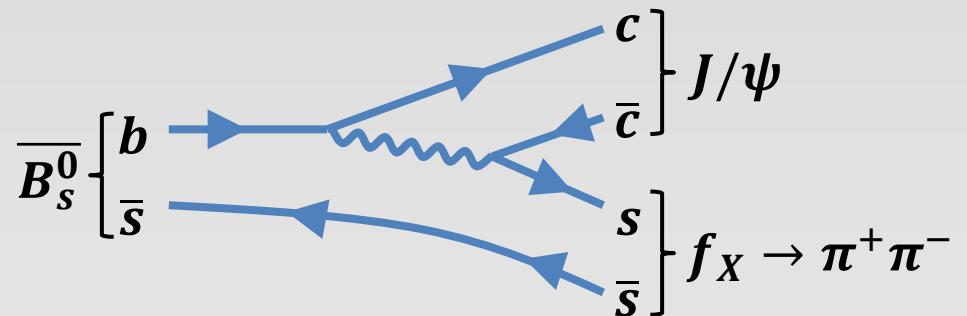
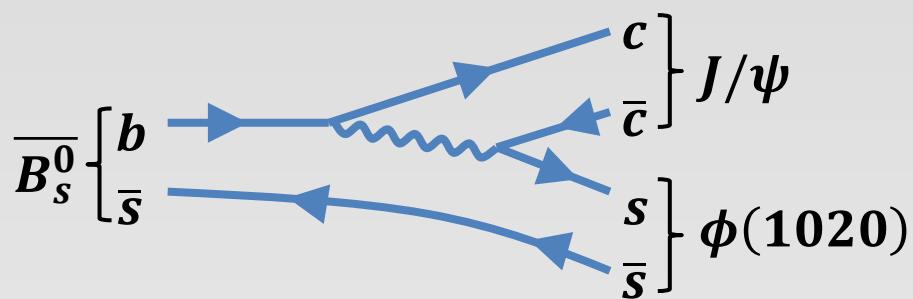
$$\phi_s = -0.14^{+0.17}_{-0.16} \pm 0.01 \text{ rad}$$



- $B_s^0 \rightarrow J/\Psi \phi$
- $B_s^0 \rightarrow J/\Psi \pi^+ \pi^-$
- $B_s^0 \rightarrow \phi \phi$



Phys. Rev. D 87, 112010 (2013)

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

$$\Phi_s = 0.01 \pm 0.07 \text{ (stat)} \pm 0.01 \text{ (syst) rad}$$

$$\Gamma_s = 0.661 \pm 0.004 \text{ (stat)} \pm 0.006 \text{ (syst) ps}^{-1}$$

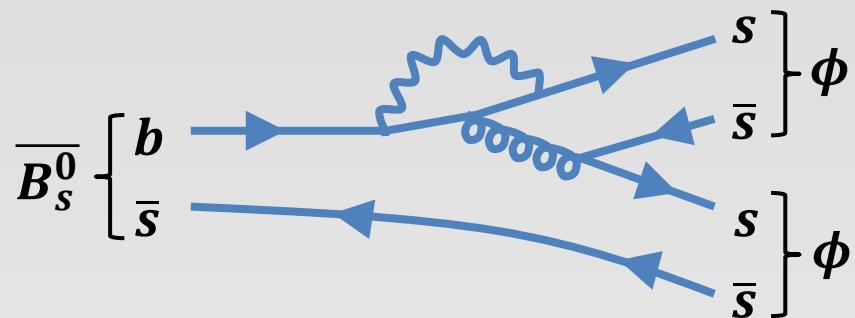
$$\Delta\Gamma_s = 0.106 \pm 0.011 \text{ (stat)} \pm 0.007 \text{ (syst) ps}^{-1}$$

Measuring  $\phi_s$ 

- $B_s^0 \rightarrow J/\Psi \phi$
- $B_s^0 \rightarrow J/\Psi \pi^+ \pi^-$
- $B_s^0 \rightarrow \phi \phi$

 $B_s^0 \rightarrow \phi\phi$ 

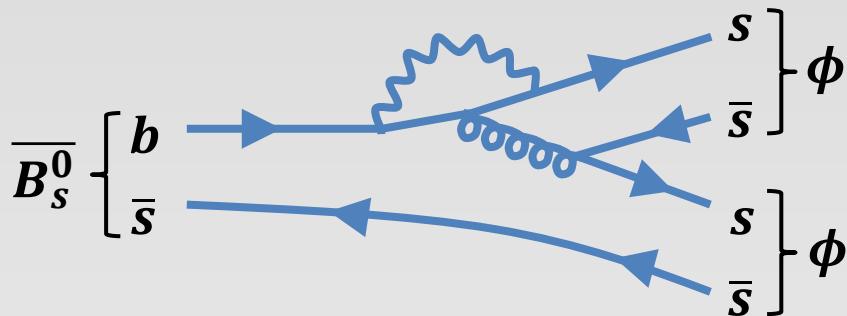
Phys. Rev. Lett. 110, 241802 (2013)



- Pure penguin mode  $\rightarrow$  small statistics
- Similar CKM phases as  $B_s^0 \rightarrow J/\psi\phi$
- SM expectation for CPV phase very small:  $|\phi_s^{s\bar{s}s}| < 0.02$
- Requires also tagged, time-dependent, angular analysis

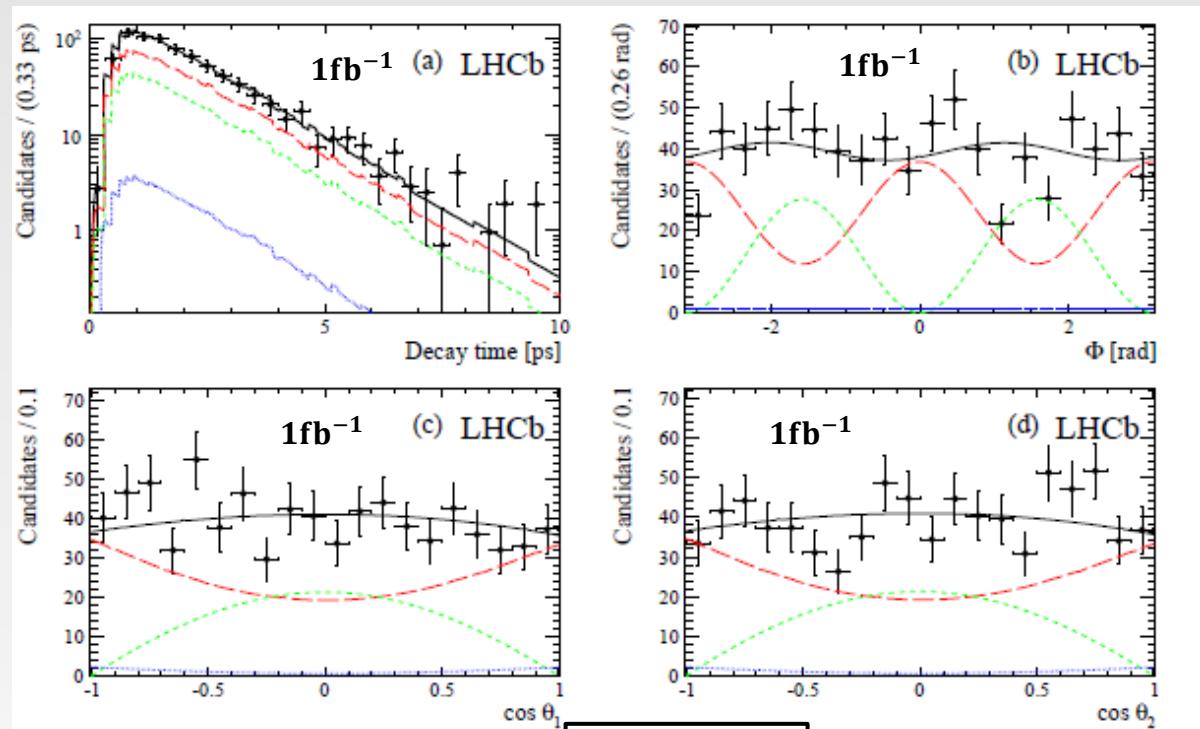
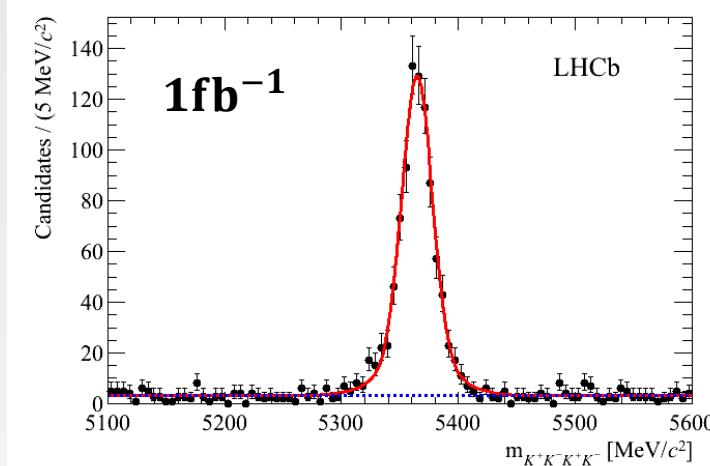

 $B_s^0 \rightarrow \phi\phi$ 

Phys. Rev. Lett. 110, 241802 (2013)



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$880 \pm 31$  signal candidates

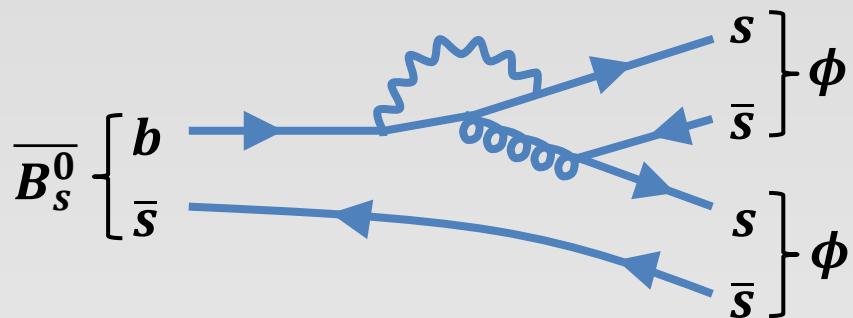


CP-even
CP-odd
S-wave

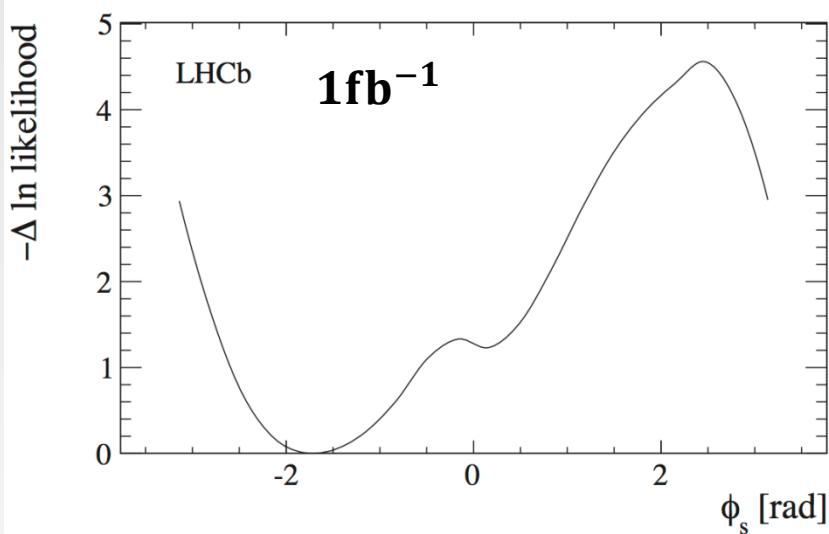


# $B_s^0 \rightarrow \phi\phi$

Phys. Rev. Lett. 110, 241802 (2013)



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- Requires also tagged, time-dependent, angular analysis



- Likelihood shows non-parabolic behaviour
- Use Feldman Cousins method to provide 68% C.L. interval
- P-value of SM hypothesis is 16%

$$\phi_s^{s\bar{s}s} \in [-2.46, -0.76] \text{ rad}$$

First constraints on  $\phi_s$  from a pure penguin mode



# Summary

- LHCb showed the most accurate measurements of the CP violating phase  $\phi_s$
- A combination of the modes  $B_s^0 \rightarrow J/\psi\phi$  and  $B_s^0 \rightarrow J/\psi\pi^+\pi^-$  gives:

$$\phi_s = 0.01 \pm 0.07 \text{ (stat)} \pm 0.01 \text{ (syst) rad}$$

$$\Gamma_s = 0.661 \pm 0.004 \text{ (stat)} \pm 0.006 \text{ (syst) ps}^{-1}$$

$$\Delta\Gamma_s = 0.106 \pm 0.011 \text{ (stat)} \pm 0.007 \text{ (syst) ps}^{-1}$$

- First constraints on  $\phi_s$  from a pure penguin mode ( $B_s^0 \rightarrow \phi\phi$ )

$$\phi_s^{s\bar{s}s} \in [-2.46, -0.76] \text{ rad, at 68% C.L.}$$

- Future
  - Analysis of 2012 data in progress (soon 3x statistics)
  - Improvements of flavour tagging algorithms



# Backup

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# Flavour Tagging

Tagging efficiency

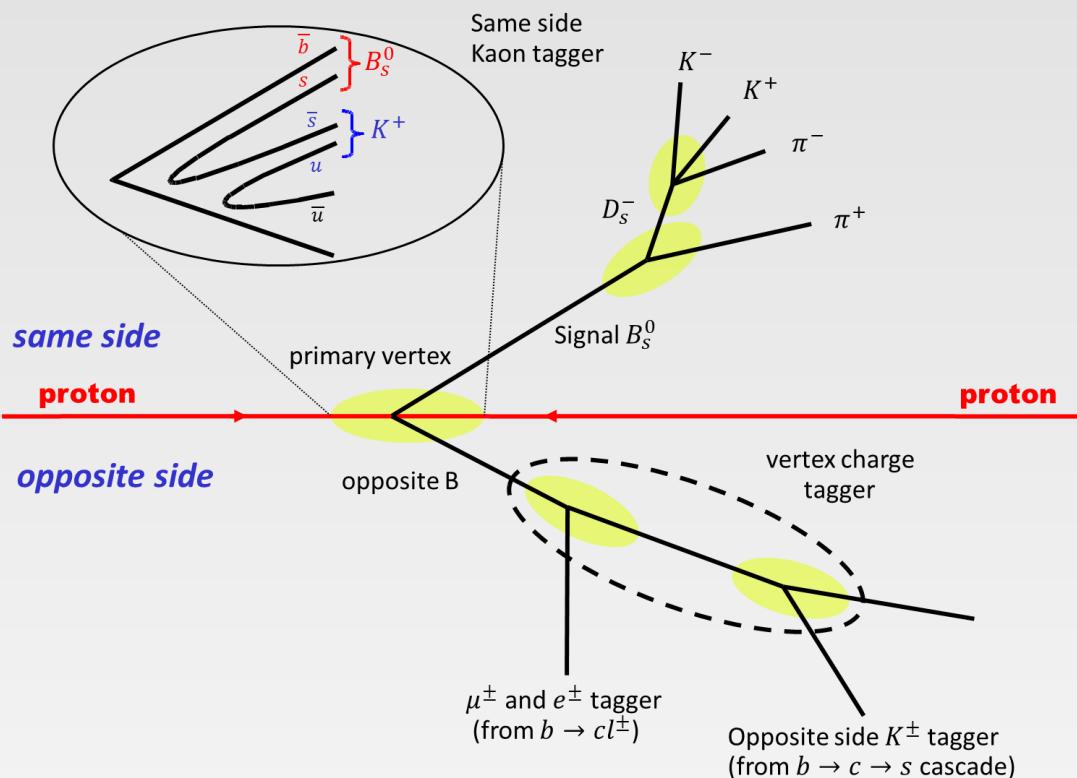
$$\varepsilon = \frac{\# \text{ tagged candidates}}{\# \text{ all candidates}}$$

Mistag probability

$$\omega = \frac{\# \text{ tagged wrong}}{\# \text{ tagged}}$$

Dilution

$$D = (1 - 2\omega)$$



- **Opposite side taggers**
  - exploits  $b\bar{b}$  pair production by partially reconstructing the second B-hadron in the event
- **Same side kaon tagger**
  - exploits hadronization of signal  $B_S^0$ -meson
- **Combined tagging power (in  $B_S^0 \rightarrow D_S^- \pi^+$ )**
  - $\varepsilon D^2 = 3.5 \pm 0.5\%$



# $B_s^0 \rightarrow J/\psi \phi$ mass plots

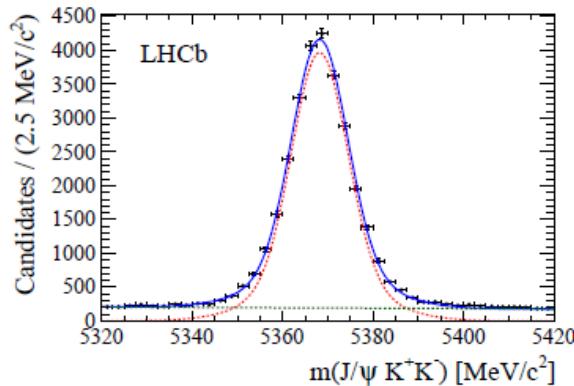


Figure 4: Invariant mass distribution of the selected  $B_s^0 \rightarrow J/\psi K^+ K^-$  candidates. The mass of the  $\mu^+ \mu^-$  pair is constrained to the  $J/\psi$  mass [7]. Curves for the fitted contributions from signal (dotted red), background (dotted green) and their combination (solid blue) are overlaid.

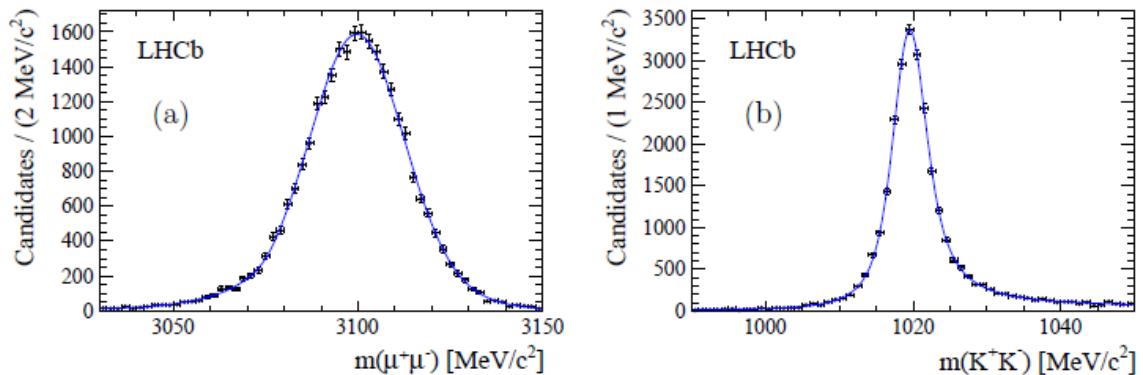


Figure 5: Background subtracted invariant mass distributions of the (a)  $\mu^+ \mu^-$  and (b)  $K^+ K^-$  systems in the selected sample of  $B_s^0 \rightarrow J/\psi K^+ K^-$  candidates. The solid blue line represents the fit to the data points described in the text.



# $B_s^0 \rightarrow J/\psi\phi$ decay time resolution

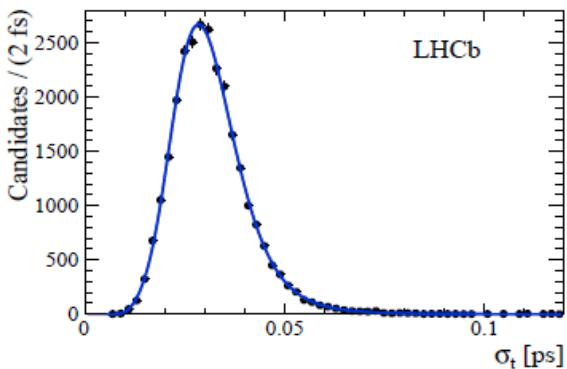


Figure 6: Decay time resolution,  $\sigma_t$ , for selected  $B_s^0 \rightarrow J/\psi K^+ K^-$  signal events. The curve shows a fit to the data of the sum of two gamma distributions with a common mean.

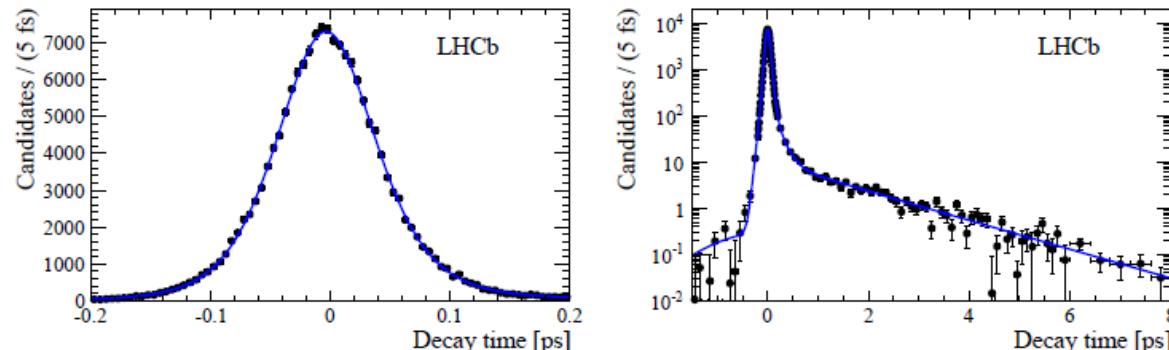


Figure 7: Decay time distribution of prompt  $J/\psi K^+ K^-$  candidates. The curve (solid blue) is the decay time model convolved with a Gaussian resolution model. The decay time model consists of a delta function for the prompt component and two exponential functions with different decay constants, which represent the  $B_s^0 \rightarrow J/\psi K^+ K^-$  signal and long-lived background, respectively. The decay constants are determined from the fit. The same dataset is shown in both plots, on different scales.

- Use per-event error estimate
- Calibrated on data
- Effective resolution  $\approx 45 \text{ fb}^{-1}$



# $B_s^0 \rightarrow J/\psi\phi$ acceptances

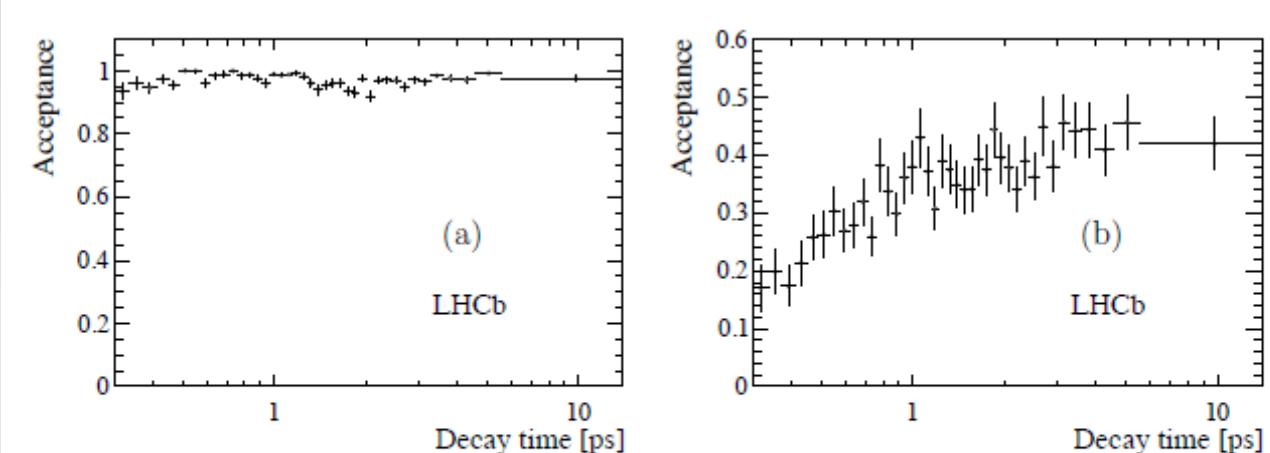


Figure 8:  $B_s^0$  decay time trigger-acceptance functions obtained from data. The unbiased trigger category is shown on (a) an absolute scale and (b) the biased trigger category on an arbitrary scale.

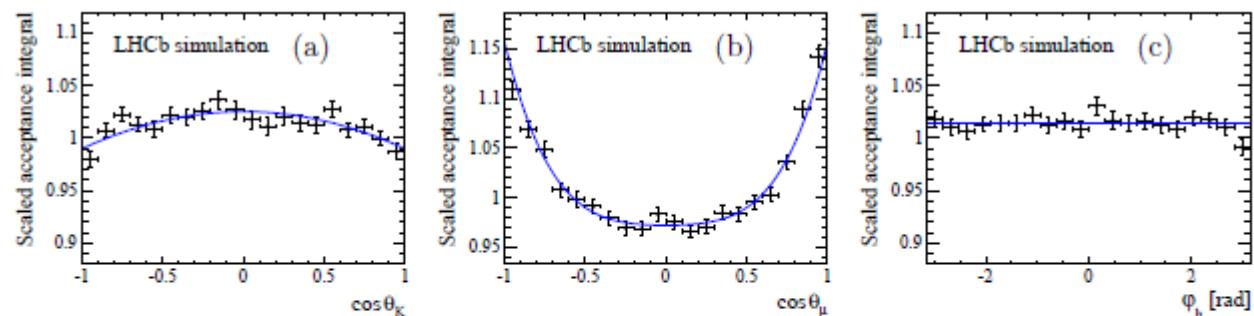


Figure 9: Angular acceptance function evaluated with simulated  $B_s^0 \rightarrow J/\psi\phi$  events, scaled by the mean acceptance. The acceptance is shown as a function of (a)  $\cos\theta_K$ , (b)  $\cos\theta_\mu$  and (c)  $\varphi_h$ , where in all cases the acceptance is integrated over the other two angles. The points are obtained by summing the inverse values of the underlying physics PDF for simulated events and the curves represent a polynomial parameterisation of the acceptance.



# $B_s^0 \rightarrow J/\psi \phi$ Flavour Tagging

Use per event mistag probability estimate  $\eta$

$$\omega = p_0 + \frac{\Delta p_0}{2} + p_1 \cdot (\eta - \langle \eta \rangle)$$
$$\bar{\omega} = p_0 - \frac{\Delta p_0}{2} + p_1 \cdot (\eta - \langle \eta \rangle)$$

Calibrated on data  
separately for  $B$  and  $\bar{B}$

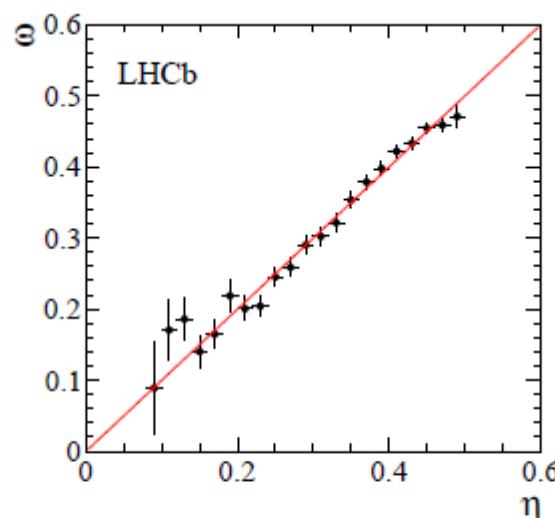


Figure 10: Average measured wrong-tag probability ( $\omega$ ) versus estimated wrong-tag probability ( $\eta$ ) calibrated on  $B^+ \rightarrow J/\psi K^+$  signal events for the OS tagging combinations for the background subtracted events in the signal mass window. Points with errors are data, the red curve represents the result of the wrong-tag probability calibration, corresponding to the parameters of Table 3.



# $B_s^0 \rightarrow J/\psi\phi$ Flavour Tagging

Use per event mistag probability estimate  $\eta$

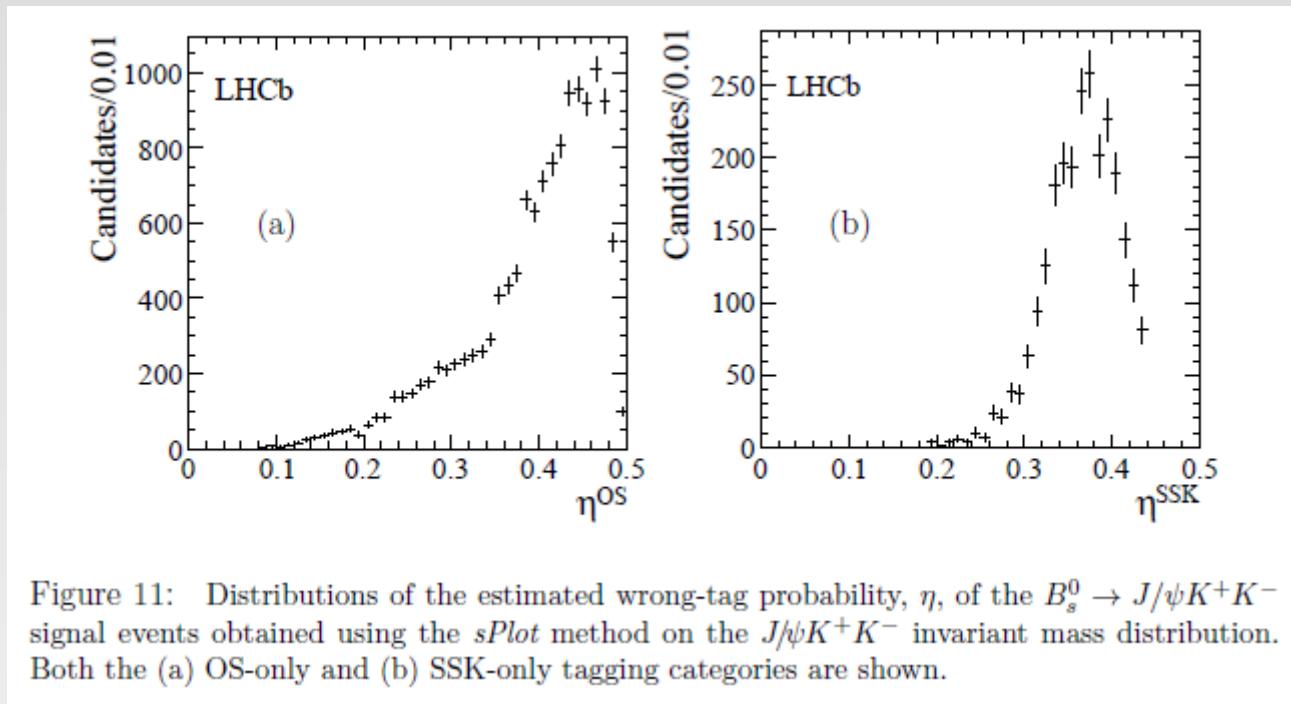


Figure 11: Distributions of the estimated wrong-tag probability,  $\eta$ , of the  $B_s^0 \rightarrow J/\psi K^+ K^-$  signal events obtained using the *sPlot* method on the  $J/\psi K^+ K^-$  invariant mass distribution. Both the (a) OS-only and (b) SSK-only tagging categories are shown.

Tagging power  
 $\varepsilon D_{OST}^2 = 2.29 \pm 0.06\%$   
 $\varepsilon D_{SST}^2 = 0.89 \pm 0.17\%$

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



Table 6: Results of the maximum likelihood fit for the principal physics parameters. The first uncertainty is statistical and the second is systematic. The value of  $\Delta m_s$  was constrained to the measurement reported in Ref. [38]. The evaluation of the systematic uncertainties is described in Sect. 10.

Parameter	Value
$\Gamma_s$ [ps $^{-1}$ ]	$0.663 \pm 0.005 \pm 0.006$
$\Delta\Gamma_s$ [ps $^{-1}$ ]	$0.100 \pm 0.016 \pm 0.003$
$ A_\perp ^2$	$0.249 \pm 0.009 \pm 0.006$
$ A_0 ^2$	$0.521 \pm 0.006 \pm 0.010$
$\delta_{\parallel}$ [rad]	$3.30^{+0.13}_{-0.21} \pm 0.08$
$\delta_{\perp}$ [rad]	$3.07 \pm 0.22 \pm 0.07$
$\phi_s$ [rad]	$0.07 \pm 0.09 \pm 0.01$
$ \lambda $	$0.94 \pm 0.03 \pm 0.02$

Table 7: Correlation matrix for the principal physics parameters.

	$\Gamma_s$ [ps $^{-1}$ ]	$\Delta\Gamma_s$ [ps $^{-1}$ ]	$ A_\perp ^2$	$ A_0 ^2$	$\delta_{\parallel}$ [rad]	$\delta_{\perp}$ [rad]	$\phi_s$ [rad]	$ \lambda $
$\Gamma_s$ [ps $^{-1}$ ]	1.00	-0.39	0.37	-0.27	-0.09	-0.03	0.06	0.03
$\Delta\Gamma_s$ [ps $^{-1}$ ]		1.00	-0.68	0.63	0.03	0.04	-0.04	0.00
$ A_\perp ^2$			1.00	-0.58	-0.28	-0.09	0.08	-0.04
$ A_0 ^2$				1.00	-0.02	-0.00	-0.05	0.02
$\delta_{\parallel}$ [rad]					1.00	0.32	-0.03	0.05
$\delta_{\perp}$ [rad]						1.00	0.28	0.00
$\phi_s$ [rad]							1.00	0.04
$ \lambda $								1.00

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



## S-wave fraction in bins of the $K^+K^-$ invariant mass

Table 8: Results of the maximum likelihood fit for the S-wave parameters, with asymmetric statistical and symmetric systematic uncertainties. The evaluation of the systematic uncertainties is described in Sect. 10.

$m(K^+K^-)$ bin [ MeV/ $c^2$ ]	Parameter	Value	$\sigma_{\text{stat}}$ (asymmetric)	$\sigma_{\text{syst}}$
990 – 1008	$F_S$	0.227	+0.081, -0.073	0.020
	$\delta_S - \delta_\perp$ [rad]	1.31	+0.78, -0.49	0.09
1008 – 1016	$F_S$	0.067	+0.030, -0.027	0.009
	$\delta_S - \delta_\perp$ [rad]	0.77	+0.38, -0.23	0.08
1016 – 1020	$F_S$	0.008	+0.014, -0.007	0.005
	$\delta_S - \delta_\perp$ [rad]	0.51	+1.40, -0.30	0.20
1020 – 1024	$F_S$	0.016	+0.012, -0.009	0.006
	$\delta_S - \delta_\perp$ [rad]	-0.51	+0.21, -0.35	0.15
1024 – 1032	$F_S$	0.055	+0.027, -0.025	0.008
	$\delta_S - \delta_\perp$ [rad]	-0.46	+0.18, -0.26	0.05
1032 – 1050	$F_S$	0.167	+0.043, -0.042	0.021
	$\delta_S - \delta_\perp$ [rad]	-0.65	+0.18, -0.22	0.06



# $\Delta m_s$ from $B_s^0 \rightarrow J/\psi\phi$

Independent measurement of  $\Delta m_s$

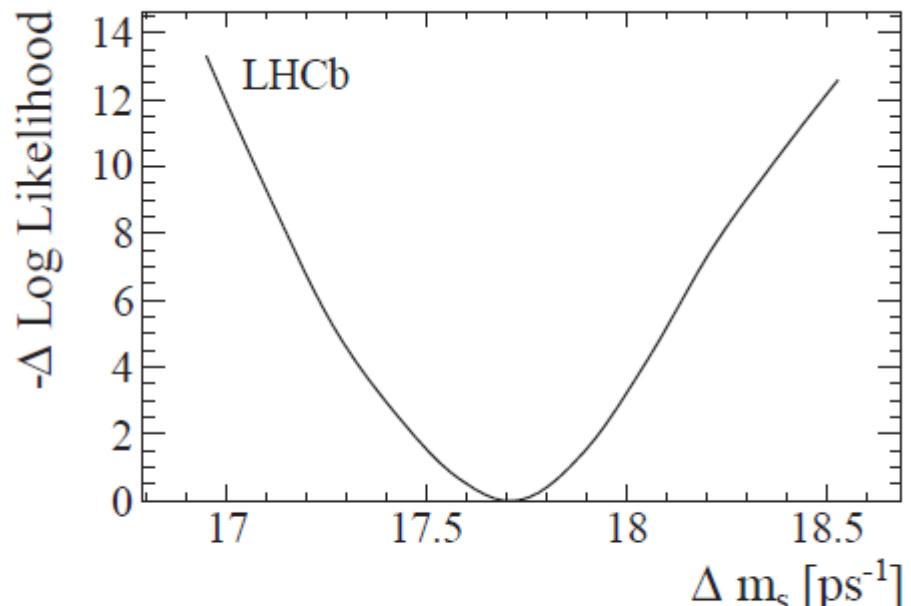


Figure 15: Profile likelihood for  $\Delta m_s$  from a fit where  $\Delta m_s$  is unconstrained.

$$\Delta m_s = 17.70 \pm 0.10(\text{stat}) \pm 0.01(\text{syst}) \text{ ps}^{-1}$$

Better sensitivity as CDF result

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

Table 9: Statistical and systematic uncertainties.

Source	$\Gamma_s$ [ps $^{-1}$ ]	$\Delta\Gamma_s$ [ps $^{-1}$ ]	$ A_{\perp} ^2$	$ A_0 ^2$	$\delta_{\parallel}$ [rad]	$\delta_{\perp}$ [rad]	$\phi_s$ [rad]	$ \lambda $
Stat. uncertainty	0.0048	0.016	0.0086	0.0061	$+0.13$ $-0.21$	0.22	0.091	0.031
Background subtraction	0.0041	0.002	–	0.0031	0.03	0.02	0.003	0.003
$B^0 \rightarrow J/\psi K^{*0}$ background	–	0.001	0.0030	0.0001	0.01	0.02	0.004	0.005
Ang. acc. reweighting	0.0007	–	0.0052	0.0091	0.07	0.05	0.003	0.020
Ang. acc. statistical	0.0002	–	0.0020	0.0010	0.03	0.04	0.007	0.006
Lower decay time acc. model	0.0023	0.002	–	–	–	–	–	–
Upper decay time acc. model	0.0040	–	–	–	–	–	–	–
Length and mom. scales	0.0002	–	–	–	–	–	–	–
Fit bias	–	–	0.0010	–	–	–	–	–
Quadratic sum of syst.	0.0063	0.003	0.0064	0.0097	0.08	0.07	0.009	0.022
Total uncertainties	0.0079	0.016	0.0107	0.0114	$+0.15$ $-0.23$	0.23	0.091	0.038

Table 10: Statistical and systematic uncertainties for S-wave fractions in bins of  $m(K^+K^-)$ .

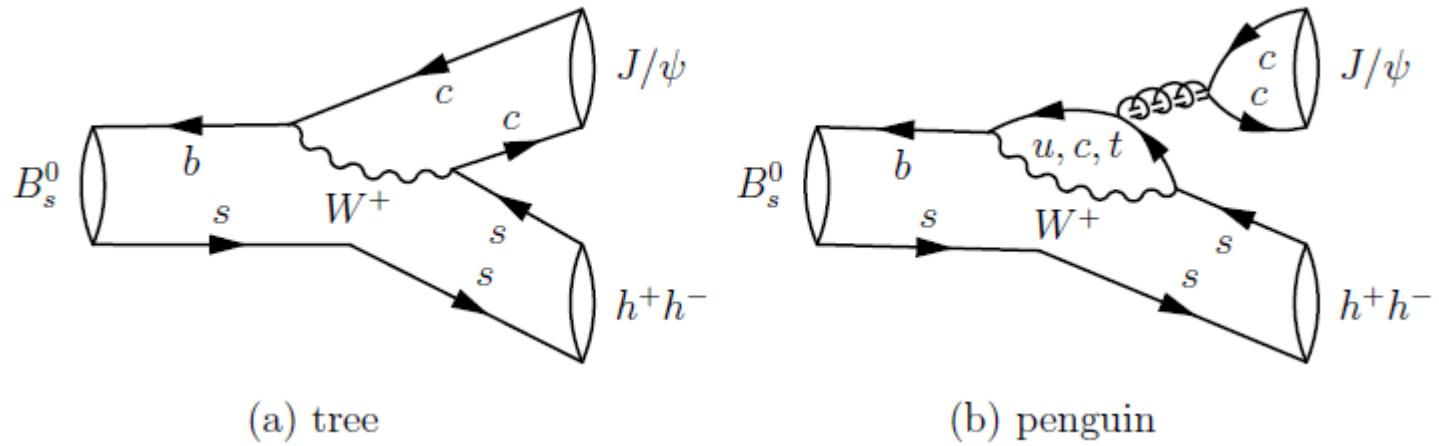
Source	bin 1 $F_S$	bin 2 $F_S$	bin 3 $F_S$	bin 4 $F_S$	bin 5 $F_S$	bin 6 $F_S$
Stat. uncertainty	$+0.081$ $-0.073$	$+0.030$ $-0.027$	$+0.014$ $-0.007$	$+0.012$ $-0.009$	$+0.027$ $-0.025$	$+0.043$ $-0.042$
Background subtraction	0.014	0.003	0.001	0.002	0.004	0.006
$B^0 \rightarrow J/\psi K^{*0}$ background	0.010	0.006	0.001	0.001	0.002	0.018
Angular acc. reweighting	0.004	0.006	0.004	0.005	0.006	0.007
Angular acc. statistical	0.003	0.003	0.002	0.001	0.003	0.004
Fit bias	0.009	–	0.002	0.002	0.001	0.001
Quadratic sum of syst.	0.020	0.009	0.005	0.006	0.008	0.021
Total uncertainties	$+0.083$ $-0.076$	$+0.031$ $-0.029$	$+0.015$ $-0.009$	$+0.013$ $-0.011$	$+0.028$ $-0.026$	$+0.048$ $-0.047$

Table 11: Statistical and systematic uncertainties for S-wave phases in bins of  $m(K^+K^-)$ .

Source	bin 1 $\delta_S - \delta_\perp$ [rad]	bin 2 $\delta_S - \delta_\perp$ [rad]	bin 3 $\delta_S - \delta_\perp$ [rad]	bin 4 $\delta_S - \delta_\perp$ [rad]	bin 5 $\delta_S - \delta_\perp$ [rad]	bin 6 $\delta_S - \delta_\perp$ [rad]
Stat. uncertainty	+0.78 -0.49	+0.38 -0.23	+1.40 -0.30	+0.21 -0.35	+0.18 -0.26	+0.18 -0.22
Background subtraction	0.03	0.02	–	0.03	0.01	0.01
$B^0 \rightarrow J/\psi K^{*0}$ background	0.08	0.04	0.08	0.01	0.01	0.05
Angular acc. reweighting	0.02	0.03	0.12	0.13	0.03	0.01
Angular acc. statistical	0.033	0.023	0.067	0.036	0.019	0.015
Fit bias	0.005	0.043	0.112	0.049	0.022	0.016
$C_{SP}$ factors	0.007	0.028	0.049	0.025	0.021	0.020
Quadratic sum of syst.	0.09	0.08	0.20	0.15	0.05	0.06
Total uncertainties	+0.79 -0.50	+0.39 -0.24	+1.41 -0.36	+0.26 -0.38	+0.19 -0.26	+0.19 -0.23



# Penguin pollution



- Angular analysis in  $B_s^0 \rightarrow J/\psi K^*$  can give information about penguin contribution for  $B_s^0 \rightarrow J/\psi \phi$

First step:

- Branching Fraction of  $B_s^0 \rightarrow J/\psi K^*$  measured to be  $4.4^{+0.5}_{-0.4} \pm 0.8 \times 10^{-5}$

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Table 12: Results of combined fit to the  $B_s^0 \rightarrow J/\psi K^+K^-$  and  $B_s^0 \rightarrow J/\psi\pi^+\pi^-$  datasets. The first uncertainty is statistical and the second is systematic.

Parameter	Value
$\Gamma_s$ [ps $^{-1}$ ]	$0.661 \pm 0.004 \pm 0.006$
$\Delta\Gamma_s$ [ps $^{-1}$ ]	$0.106 \pm 0.011 \pm 0.007$
$ A_\perp ^2$	$0.246 \pm 0.007 \pm 0.006$
$ A_0 ^2$	$0.523 \pm 0.005 \pm 0.010$
$\delta_{\parallel}$ [rad]	$3.32^{+0.13}_{-0.21} \pm 0.08$
$\delta_{\perp}$ [rad]	$3.04 \pm 0.20 \pm 0.07$
$\phi_s$ [rad]	$0.01 \pm 0.07 \pm 0.01$
$ \lambda $	$0.93 \pm 0.03 \pm 0.02$

Table 13: Correlation matrix for statistical uncertainties on combined results.

	$\Gamma_s$ [ps $^{-1}$ ]	$\Delta\Gamma_s$ [ps $^{-1}$ ]	$ A_\perp ^2$	$ A_0 ^2$	$\delta_{\parallel}$ [rad]	$\delta_{\perp}$ [rad]	$\phi_s$ [rad]	$ \lambda $
$\Gamma_s$ [ps $^{-1}$ ]	1.00	0.10	0.08	0.03	-0.08	-0.04	0.01	0.00
$\Delta\Gamma_s$ [ps $^{-1}$ ]		1.00	-0.49	0.47	0.00	0.00	0.00	-0.01
$ A_\perp ^2$			1.00	-0.40	-0.37	-0.14	0.02	-0.05
$ A_0 ^2$				1.00	-0.05	-0.03	-0.01	0.01
$\delta_{\parallel}$ [rad]					1.00	0.39	-0.01	0.13
$\delta_{\perp}$ [rad]						1.00	0.21	0.03
$\phi_s$ [rad]							1.00	0.06
$ \lambda $								1.00

# $B_s^0 \rightarrow \phi\phi$ fit results



Table 2: Fit results with statistical and systematic uncertainties. A 68% statistical confidence interval is quoted for  $\phi_s$ . Amplitudes are defined at  $t = 0$ .

Parameter	Value	$\sigma_{\text{stat.}}$	$\sigma_{\text{syst.}}$
$\phi_s$ [rad] (68 % CL)		[-2.37, -0.92]	0.22
$ A_0 ^2$	0.329	0.033	0.017
$ A_\perp ^2$	0.358	0.046	0.018
$ A_S ^2$	0.016	+0.024 -0.012	0.009
$\delta_1$ [rad]	2.19	0.44	0.12
$\delta_2$ [rad]	-1.47	0.48	0.10
$\delta_S$ [rad]	0.65	+0.89 -1.65	0.33