Beauty 2013, Bologna

Measurements of *CP* violation and mixing in B_s^0 decays at LHCb

Frédéric Dupertuis

on behalf of the LHCb collaboration

Laboratoire de Physique des Hautes Energies (LPHE)
Ecole Polytechnique Fédérale de Lausanne (EPFL), Switzerland

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Outline

In this talk:

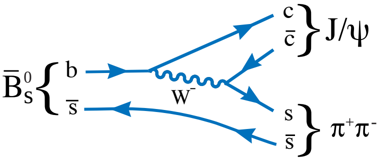
- "Analysis of the resonant components in $B_s^0 \to J/\psi\pi^+\pi^-$."
  $\to$ [Phys. Rev. **D86** (2012) 052006]
- "Measurement of CP-violation and the B_s^0-meson decay width difference with $B_s^0 \to J/\psi K^+K^-$ and $B_s^0 \to J/\psi\pi^+\pi^-$ decays."
  $\to$ [arXiv:1304.2600] to be submitted to PRD
- "Precision measurement of the $B_s^0 - \bar{B}_s^0$ oscillation frequency in the decay $B_s^0 \to D_s^+\pi^-$." (*preliminary*)
  $\to$ [LHCB-PAPER-2013-006] to be submitted to NJP

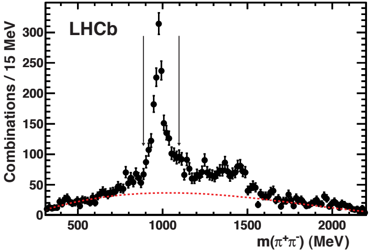
$B_s^0 \to J/\psi\pi^+\pi^-$ decays: Introduction

Phys. Lett. **B707** (2012) 497–505

- With 0.41 fb^{-1}, LHCb measured the *CP* content of the $\pi\pi$ system around the $f_0(980)$ resonance ($\pm$90 MeV) in $B_s^0 \to J/\psi\pi^+\pi^-$ decays.
  $\to$ Pure *CP*-odd final states!

- Next step: Analyse the full $\pi\pi$ range.
  $\to$ Improve sensitivity to *CP* violation parameters in this mode.

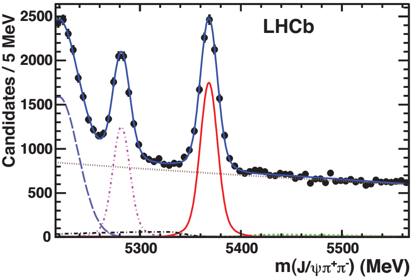




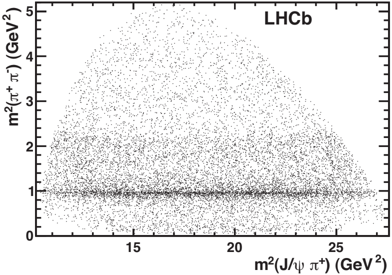
$B_s^0 \to J/\psi\pi^+\pi^-$ decays

Phys. Rev. **D86** (2012) 052006

- With 1 fb^{-1}, $B_s^0 \to J/\psi\pi^+\pi^-$ candidates are reconstructed in the full $\pi\pi$ mass range.

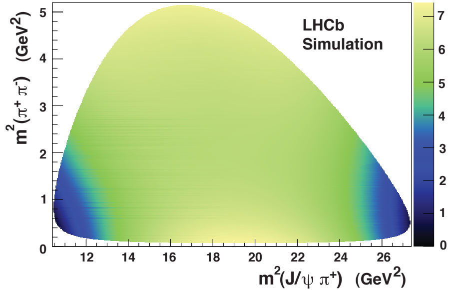


- To analyse the resonant component, a modified Dalitz plot analysis of the final states has been used:
  - $s_{13} = m^2(J/\psi\pi^+)$
  - $s_{23} = m^2(\pi^+\pi^-)$
  - Helicity angle $\theta_{J/\psi}$



Detection efficiency

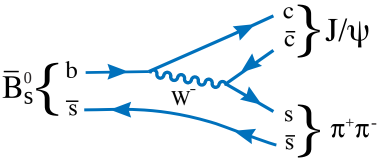
- A sample of $B_s^0 \to J/\psi\phi$ obtained from data is used to reweight the $B_s^0 \to J/\psi\pi^+\pi^-$ MC sample and obtain the parameters of detection efficiency 2D function.



- Acceptance in $\theta_{J/\psi}$ is uniform.

Resonance models

- $s\bar{s}$ system is in an isoscalar state at leading order.
- $\pi\pi$ wavefunction must be symmetric. $\rightarrow$ Only spin-0 and -2 mesons.
- $\rho(770)$ component added to test high order processes.
- Several scenarios have been tried to get the best significant Poisson likelihood χ^2 (goodness-of-fit).



Resonance	Spin	Helicity	Resonance formalism
$f_0(600)$	0	0	BW
$\rho(770)$	1	0, ± 1	BW
$f_0(980)$	0	0	Flatté
$f_2(1270)$	2	0, ± 1	BW
$f_0(1370)$	0	0	BW
$f_0(1500)$	0	0	BW

Name	Components
Single R	$f_0(980)$
2R	$f_0(980) + f_0(1370)$
3R	$f_0(980) + f_0(1370) + f_2(1270)$
3R + NR	$f_0(980) + f_0(1370) + f_2(1270)$ + nonresonant
3R + NR + $\rho(770)$	$f_0(980) + f_0(1370) + f_2(1270)$ + nonresonant + $\rho(770)$
3R + NR + $f_0(1500)$	$f_0(980) + f_0(1370) + f_2(1270)$ + nonresonant + $f_0(1500)$
3R + NR + $f_0(600)$	$f_0(980) + f_0(1370) + f_2(1270)$ + nonresonant + $f_0(600)$

- The background PDF is parametrised from a wrong-sign $J/\psi\pi^{\pm}\pi^{\pm}$ sample and random $J/\psi + \rho(770)$ from MC.
- The best significant χ^2 is obtained with the $f_0(980)+f_2(1270)+f_0(1370)$ and non-resonant model.
- Existence of $B_s^0 \to J/\psi f_0(1370)$ clearly established now.

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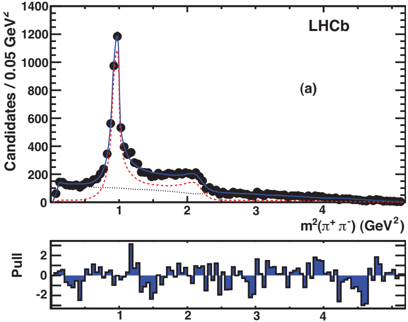
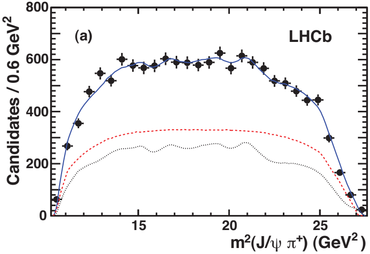
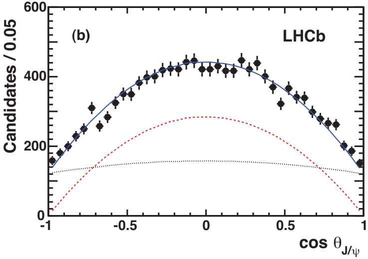






Branching fraction ratio and *CP* content results

Phys. Rev. **D86** (2012) 052006

- Branching fraction ratio with $B_s^0 \to J/\psi\phi$ as normalisation.
- With $\mathcal{B}(\phi \to K^+K^-) = (48.7 \pm 0.5)\%$, we find:

$$\frac{\mathcal{B}(B_s^0 \to J/\psi\pi^+\pi^-)}{\mathcal{B}(B_s^0 \to J/\psi\phi)} = (19.79 \pm 0.47(\text{stat}) \pm 0.52(\text{syst}))\%$$

Main systematics are detection efficiencies.

- Largest component comes from the $f_0(980)$ resonance:

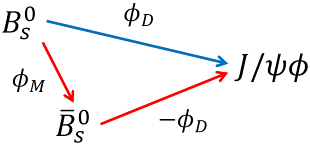
$$\frac{\mathcal{B}(B_s^0 \to J/\psi f_0(980))\mathcal{B}(f_0(980) \to \pi^+\pi^-)}{\mathcal{B}(B_s^0 \to J/\psi\phi)} = (13.9 \pm 0.6(\text{stat})^{+2.5}_{-1.2}(\text{syst}))\%$$

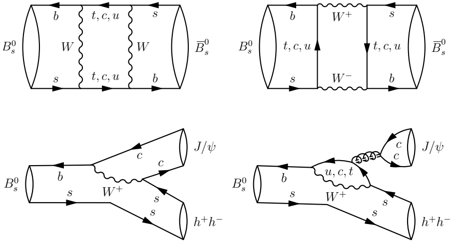
- Except a *CP* admixture from $f_2(1270)$ with $|\lambda| = 1$ of $(0.2 \pm 0.7)\%$ and a $\rho(770)$ component less than 1.5% @ 95% CL, we find:

CP-odd fraction in $B_s^0 \to J/\psi\pi^+\pi^-$ is greater than 97.7% @ 95% CL.

$B_s^0 \to J/\psi h^+ h^-$ decays with $h = K, \pi$ phenomenology

- *CP* phase ϕ_s arising in the interference between direct decay (ϕ_D) and decay via mixing ($\phi_M - \phi_D$).
- In Standard Model: ϕ_s
  $= \phi_{s,M} - 2\phi_{s,D} =$
  $= -2\beta_s + \phi_s^{\text{penguin}} \approx$
  $\approx -2\beta_s$
- CKMFitter (global SM fit):
  $-2\beta_s = (-0.036 \pm 0.002)$ rad
- How to control penguin pollution:
  $\rightarrow$ Stephen's talk on Tuesday.
- New physics in box or/and penguin diagrams:
  $\rightarrow \phi_s = \phi_s^{SM} + \phi_s^{\text{NP}}$
  ϕ_s^{SM} small
  $\rightarrow \phi_s$ can be enlarged by ϕ_s^{NP}.





How to measure ϕ_s with $B_s^0 \to J/\psi h^+ h^-$ decays?

- In $B_s^0 \to J/\psi h^+ h^-$ decays, the final states are in CP eigenstates f with eigenvalues η_f. ϕ_s is included in terms that look like, for example:

$$\eta_f \sin(\phi_s) \sin(\Delta m_s t)$$

$\to$ Measuring $\phi_s \Leftrightarrow$ measuring amplitude of the sinusoid.

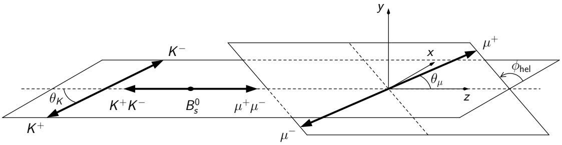
Ingredients:

- Δm_s from $B_s^0 \to D_s^- \pi^+$ decays (*in this talk*).
- Decays in a CP admixture need to be disentangled in CP-even/-odd states.
  $\to$ Angular analysis is required $\to \eta_f = +1, -1$.
- Flavour of the B_s^0 meson at production ($t = 0$).
  $\to$ Flavour tagging algorithm with wrong-tag probability ω.
- Decay time t.
  $\to$ Finite resolution σ_t.

$$\approx (1 - 2\omega) e^{-\frac{1}{2} {\Delta m_s}^2 {\sigma_t}^2} \eta_f \sin(\phi_s) \sin(\Delta m_s t)$$

$B_s^0 \to J/\psi h^+ h^-$ CP content

- $B_s^0 \to J/\psi K^+ K^-$ around $\phi(1020)$ resonance:
  - $B_s^0 \to J/\psi\phi$: P→VV decay → CP admixture.
    → Angular analysis is required.
    → Three amplitudes: A_0, $A_{||}$ (CP-even) and $A_\perp$ (CP-odd)



  - $B_s^0 \to J/\psi K^+ K^-$ non-resonant: S-wave → CP-odd.
    → One amplitude: A_S
- $B_s^0 \to J/\psi \pi^+\pi^-$ is pure CP-odd ($> 97.7\%$ @ 95% CL)
  → No angular analysis is needed!

$B_s^0 \to J/\psi h^+ h^-$ differential decay rates

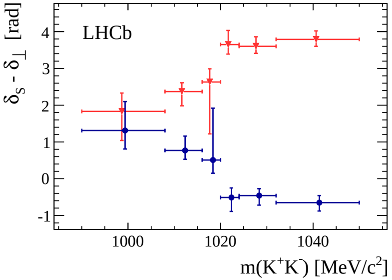
- $B_s^0 \to J/\psi K^+ K^-$: Four amplitudes + interference terms → ten terms

$$\frac{\mathrm{d}^4\Gamma(B_s^0 \to J/\psi K^+ K^-)}{\mathrm{d}\Omega \mathrm{d}t} \propto \sum_{k=1}^{10} h_k(t) f_k(\Omega)$$

- Two fold ambiguity in the differential decay rates:

$$(\phi_s, \Delta\Gamma_s, \delta_0, \delta_\parallel, \delta_\perp, \delta_\mathrm{S}) \longmapsto (\pi - \phi_s, -\Delta\Gamma_s, -\delta_0, -\delta_\parallel, \pi - \delta_\perp, -\delta_\mathrm{S})$$

- Ambiguity resolved by LHCb using the running of phase difference between P-wave and S-wave.
  → (Physical solution: $\delta_s - \delta_\perp \searrow$)
  → $\Delta\Gamma_s > 0$.



arXiv:1304.2600

- $B_s^0 \to J/\psi \pi^+ \pi^-$: Only $h_7(t)$ term!

What's new in $B_s^0 \to J/\psi h^+ h^-$ analysis?

$B_s^0 \to J/\psi K^+ K^-$
wrt 1 fb^{-1} preliminary results of $B_s^0 \to J/\psi \phi$ analysis [LHCB-CONF-2012-002]

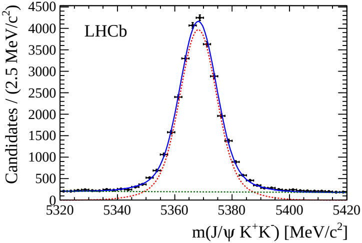
- Enlarge m_{KK} mass window: $|m_{KK} - m_{\phi(1020)}| < 12$ MeV $\to$ 30 MeV.
- m_{KK} range divided in 6 bins (gain sensitivity to CP parameters).
- Switch to new fitting procedure (${}_s\mathcal{F}it$).
- Use the Same Sign Kaon (SSK) tagger in addition to the Opposite Side (OS) tagger.
- Enlarge the set of trigger lines to be used.
- Switch from transversity angles to helicity angles (better description of background).

$B_s^0 \to J/\psi \pi^+ \pi^-$
wrt 1 fb^{-1} results of $B_s^0 \to J/\psi \pi^+ \pi^-$ analysis [Phys. Lett. **B713** (2012) 378–386]

- Use the Same Sign Kaon (SSK) tagger in addition to the Opposite Side (OS) tagger.
- New decay time acceptance parametrised using $B^0 \to J/\psi K^*$ in data + corrections between $B_s^0 \to J/\psi \pi^+ \pi^-$ and $B^0 \to J/\psi K^*$ from MC.

$B_s^0 \to J/\psi K^+ K^-$ fit procedure and signal PDF

- ${}_s\mathcal{F}it$: A weighted maximum negative log likelihood fit where the weights (${}_s\mathcal{W}eights$) are coming from the ${}_s\mathcal{P}lot$ technique when fitting the B_s^0 mass with two Gaussians + exponential background.
  $\rightarrow$ Only signal PDF is required!

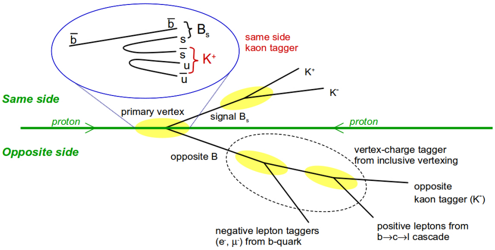


- Signal PDF for tag decision $q = \{+1, 0, -1\}$ are, for $q = +1$ for example:

$$s_{+1} \quad = \quad \Big[\big[\, (1-\omega) \, X(t,\Omega;Z) + \bar{\omega} \, \overline{X}(t,\Omega;Z) \, \big] \otimes R(t;\sigma_t) \Big] \, \varepsilon_t(t) \, \varepsilon_\Omega(\Omega).$$

$$\text{where } X \text{ is } \frac{d^4\Gamma(B_s^0 \to J/\psi K^+ K^-)}{d\Omega dt} \text{ and } \overline{X} \text{ is } \frac{d^4\Gamma(\overline{B}_s^0 \to J/\psi K^+ K^-)}{d\Omega dt}$$

Flavour tagging



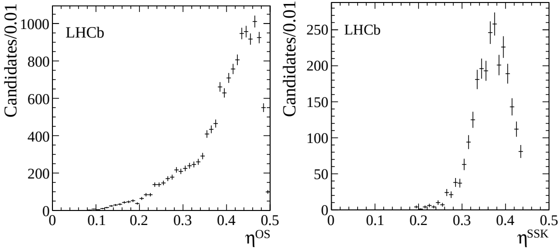
Opposite Side (OS) tagger

- Charge of opposite side muons, electrons, kaon
- Charge of opposite side vertex

Same Side Kaon (SSK) tagger

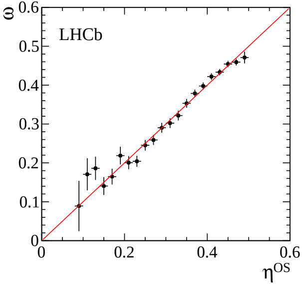
- Charge of same side kaon

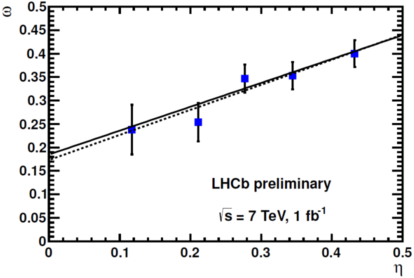
Each tagger provides a flavour tag q with a wrong-tag probability estimate η.



Flavour tagging performance

- The OS tagger is calibrated using $B^{\pm} \to J/\psi K^{\pm}$ decays and SSK tagger using $B_s^0 \to D_s^- \pi^+$ decays with linear dependence between true wrong-tag probability ω and estimate η:





- The OS and SSK effective tagging power $\epsilon_{\text{tag}}\mathcal{D}^2$:

$B_s^0 \to D_s^- \pi^+$

$$\epsilon_{\text{tag}}\mathcal{D}^2_{OS} = (2.6 \pm 0.4)\%$$
$$\epsilon_{\text{tag}}\mathcal{D}^2_{SSK} = (1.2 \pm 0.3)\%$$

$B_s^0 \to J/\psi K^+ K^-$

$$\epsilon_{\text{tag}}\mathcal{D}^2_{OS} = (2.29 \pm 0.06)\%$$
$$\epsilon_{\text{tag}}\mathcal{D}^2_{SSK} = (0.89 \pm 0.17)\%$$

(see poster by Antonio Falabella: "B mesons Flavour Tagging at LHCb")

Eur. Phys. J **C72** (2012) 2022

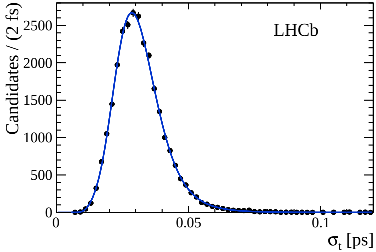
LHCB-PAPER-2013-006

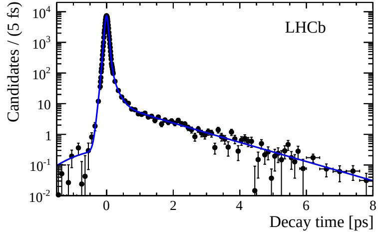
LHCB-CONF-2012-003

arXiv:1304.2600

Decay time resolution

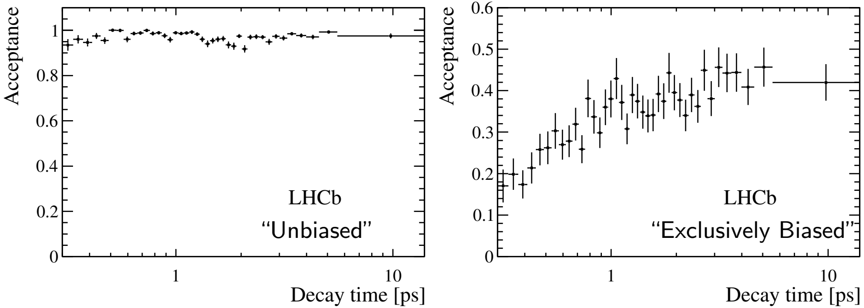
- From vertex and track fits, an estimated per-event decay time resolution σ_t is obtained.
- σ_t is calibrated by fitting three Gaussians to prompt J/ψ + two random kaons events decay time.
- Only events with t $>$ 0.3 ps are used in the analysis.
  $\rightarrow$ Not sensitive to resolution details.
  $\rightarrow$ A single Gaussian resolution is used (with equal dilution).
  $\rightarrow$ Scale factor: 1.45 ± 0.06
  $\rightarrow$ Single Gaussian resolution: $\approx$ 45 fs.





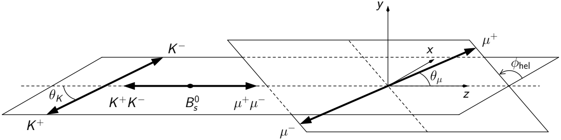
$B_s^0 \to J/\psi K^+K^-$ decay time acceptances

- The first decay time biasing cuts are coming from the trigger.
- The trigger decay time acceptances are obtained directly from data.
- Using prescaled unbiased events as normalisation, we get:

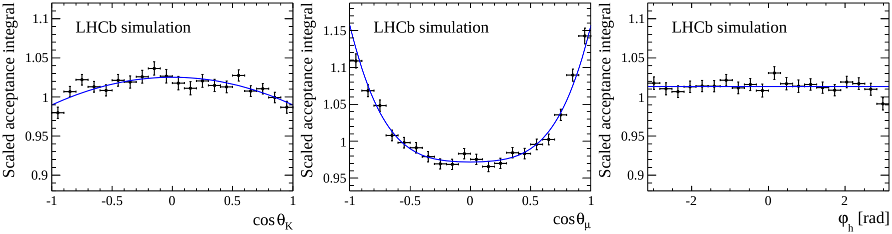


- Second acceptance at high decay time is due to time-dependent Velo reconstruction inefficiencies and some selection cuts.
- This acceptance is parametrised as $(1 + \beta t)$ with $\beta = (-8.3 \pm 4.0) \cdot 10^{-3}$ ps^{-1} obtained from a mix of data and MC samples.

$B_s^0 \to J/\psi K^+ K^-$ decay angles acceptance



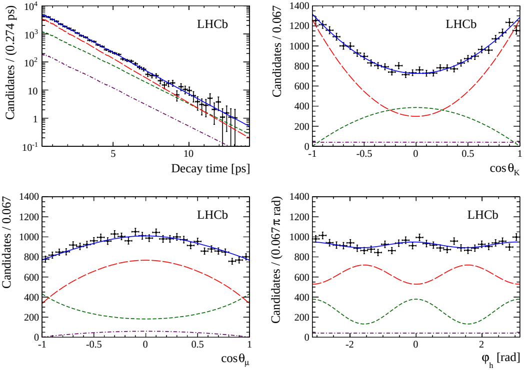
- Using MC simulation, the decay angle acceptance function:



- Acceptances vary up to 20% peak-to-peak. Effects due mainly to:
  - Forward geometry of LHCb.
  - Implicit cut on the momentum track to reach the LHCb tracking stations downstream the magnet.

$B_s^0 \to J/\psi h^+ h^-$ results

- With 1 fb^{-1}, about 27,600 $B_s^0 \to J/\psi K^+ K^-$ are reconstructed:



- The updated analysis of $B_s^0 \to J/\psi K^+ K^-$ decays gives:

$$\begin{aligned}
\phi_s &= 0.07 \pm 0.09 \text{ (stat)} \pm 0.01 \text{ (syst) rad},\\
\Gamma_s &= 0.663 \pm 0.005 \text{ (stat)} \pm 0.006 \text{ (syst) ps}^{-1},\\
\Delta\Gamma_s &= 0.100 \pm 0.015 \text{ (stat)} \pm 0.003 \text{ (syst) ps}^{-1}.
\end{aligned}$$

arXiv:1304.2600

$B_s^0 \to J/\psi h^+ h^-$ results (2)

- Main systematics on ϕ_s, $\Delta\Gamma_s$ and Γ_s:

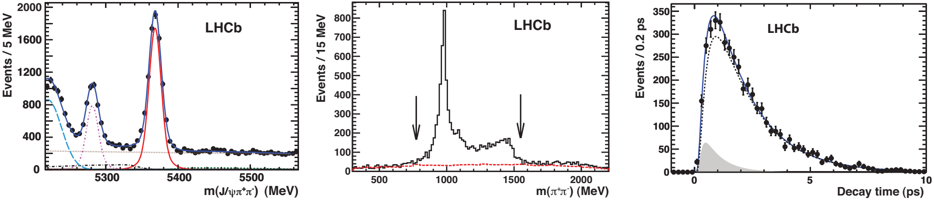
Source	Γ_s [ps^{-1}]	$\Delta\Gamma_s$ [ps^{-1}]	ϕ_s [rad]
Stat. uncertainty	0.0048	0.016	0.091
Background subtraction	0.0041	0.002	0.003
$B^0 \to J/\psi K^{*0}$ background	–	0.001	0.004
Ang. acc. reweighting	0.0007	–	0.003
Ang. acc. statistical	0.0002	–	0.007
Lower decay time acc. model	0.0023	0.002	–
Upper decay time acc. model	0.0040	–	–
Length and mom. scales	0.0002	–	–
Fit bias	–	–	–
Quadratic sum of syst.	0.0063	0.003	0.009
Total uncertainties	0.0079	0.016	0.091

arXiv:1304.2600

- The tagging and decay time resolution uncertainties on the *CP* parameters are included in the statistical errors.

$B_s^0 \to J/\psi h^+ h^-$ results (3)

- With 1 fb^{-1}, about 7400 $B_s^0 \to J/\psi\pi^+\pi^-$ are reconstructed:



- The updated analysis of $B_s^0 \to J/\psi\pi^+\pi^-$ decays gives:

$$\phi_s = -0.14 \,^{+\,0.17}_{-\,0.16}\,(\text{stat}) \pm 0.01\,(\text{syst})\ \text{rad}$$

- Main systematics are coming from:
  - Direct *CP* parameter fixed to 1.
  - Mass signal-background and decay time background PDF parameters fixed.

arXiv:1304.2600

$B_s^0 \to J/\psi h^+ h^-$ results (4)

arXiv:1304.2600

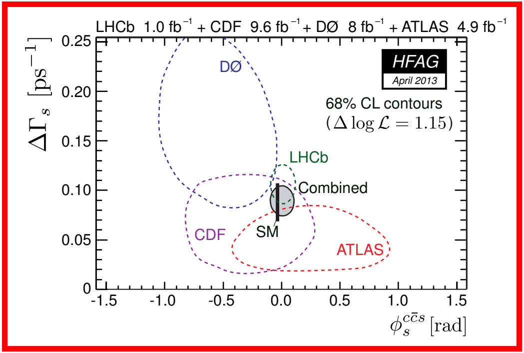
- The combined fit to $B_s^0 \to J/\psi K^+ K^-$ and $B_s^0 \to J/\psi \pi^+ \pi^-$ decays gives:

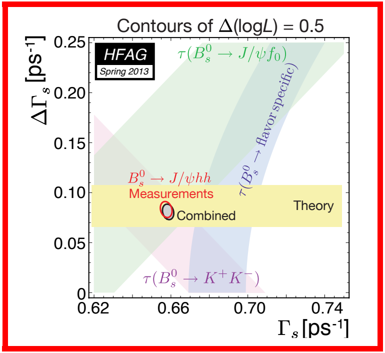
$$\begin{aligned}\phi_s &= 0.01 \pm 0.07 \text{ (stat)} \pm 0.01 \text{ (syst) rad},\\ \Gamma_s &= 0.661 \pm 0.004 \text{ (stat)} \pm 0.006 \text{ (syst) ps}^{-1},\\ \Delta\Gamma_s &= 0.106 \pm 0.011 \text{ (stat)} \pm 0.007 \text{ (syst) ps}^{-1}.\end{aligned}$$

World's best measurements!

- New $\Delta\Gamma_s - \phi_s$ / $\Delta\Gamma_s - \Gamma_s$ HFAG result:

HFAG





$B_s^0 \to J/\psi\pi^+\pi^-$ effective lifetime result

Phys. Rev. **D86** (2012) 014027

- Theorically, the B_s^0 effective lifetime is given by:

$$\tau_{\text{eff}} = \frac{\Gamma_s^{-1}}{1-y_s^2}\left[\frac{1+2\mathcal{A}^f y_s + y_s^2}{1+\mathcal{A}^f y_s}\right] \tag{1}$$

where $y_s = \frac{\Delta\Gamma_s}{2\Gamma_s}$. (see previous talk by Robert Knegjens).

- $B_s^0 \to J/\psi\pi^+\pi^-$: $-1 < \mathcal{A}^{B_s^0\to J/\psi\pi^+\pi^-}(\phi_s) < 1$.
- In the limit $\phi_s \to 0 \to \mathcal{A}^{B_s^0\to J/\psi\pi^+\pi^-} = +1$.
  $\to \tau_{\text{eff}}^{B_s^0\to J/\psi\pi^+\pi^-} \xrightarrow{\phi_s\to 0} \Gamma_{s,H}^{-1}$
- Experimentally, τ_{eff} is obtained from a single exponential $e^{-t/\tau_{\text{eff}}}$ likelihood fit to the decay time spectrum.
- $B_s^0 \to J/\psi\pi^+\pi^-$ effective lifetime measurement:

$$\tau^{\text{eff}}_{B_s^0\to J/\psi\pi^+\pi^-} = 1.652 \pm 0.024\,(\text{stat}) \pm 0.024\,(\text{syst})\ \text{ps},$$

$$\Gamma^{\text{eff}}_{B_s^0\to J/\psi\pi^+\pi^-} = 0.605 \pm 0.009\,(\text{stat}) \pm 0.009\,(\text{syst})\ \text{ps}^{-1} \xrightarrow{\phi_s\to 0} \Gamma_{s,H}.$$

arXiv:1304.2600

ϕ_s prospects

- ϕ_s from $B_s^0 \to J/\psi\phi$ and $B_s^0 \to J/\psi\pi^+\pi^-$ decays:

$\sigma_{\phi_s}^{\text{stat}}$	LHCb (1 fb^{-1})	LHCb 2018	Upgrade (50 fb^{-1})	Theory uncertainty
$B_s^0 \to J/\psi\phi$	0.10	0.025	0.008	0.003
$B_s^0 \to J/\psi\pi^+\pi^-$	0.17	0.045	0.014	0.01

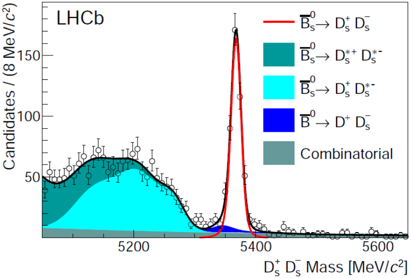
For more details on the LHCb upgrade $\to$ Maurizio's talk, next session.

- ϕ_s results from $B_s^0 \to J/\psi\eta$, $B_s^0 \to J/\psi\eta'$ and $B_s^0 \to D_s^+D_s^-$ decays
  - 451 ± 23 $B_s^0 \to D_s^+D_s^-$ (1 fb^{-1})

$\to$ ϕ_s may start with LHCb.

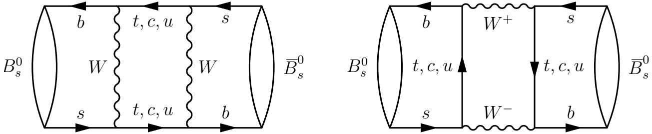
arXiv:1208.3355

arXiv:1302.5854



Δm_s measurement with $B_s^0 \to D_s^- \pi^+$ decays

- Δm_s is the oscillation frequency of the $B_s^0 - \overline{B}_s^0$ mixing:



- Sensitivity: $\sigma(\Delta m_s) \propto \sqrt{\epsilon(1-2\omega)^2} e^{-\frac{1}{2}{\Delta m_s}^2 {\sigma_t}^2} = \sqrt{\epsilon \mathcal{D}^2} e^{-\frac{1}{2}{\Delta m_s}^2 {\sigma_t}^2}$
  $\to$ Important to have an excellent decay time resolution σ_t and great tagging performance (best $\epsilon \mathcal{D}^2$).

Ingredients:

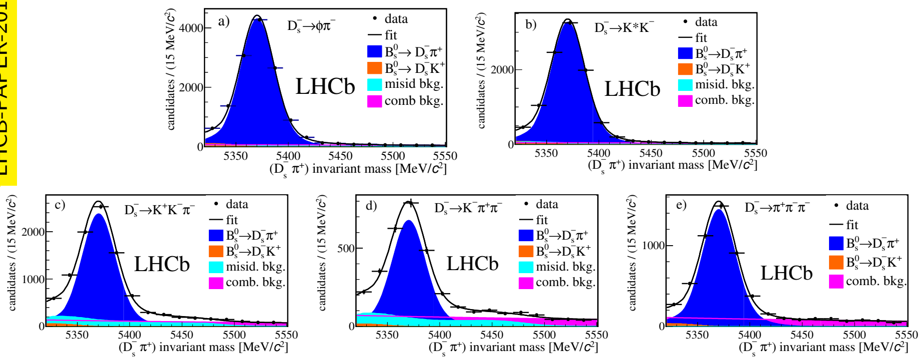
- Flavour tag at production using OS and SSK tagging algorithms.
- Decay time with per-event resolution σ_t and scale factor S_{σ_t}.

$\to$ Same ingredients than $B_s^0 \to J/\psi h^+ h^-$ analysis.

$B_s^0 \to D_s^- \pi^+$ decays (*preliminary*)

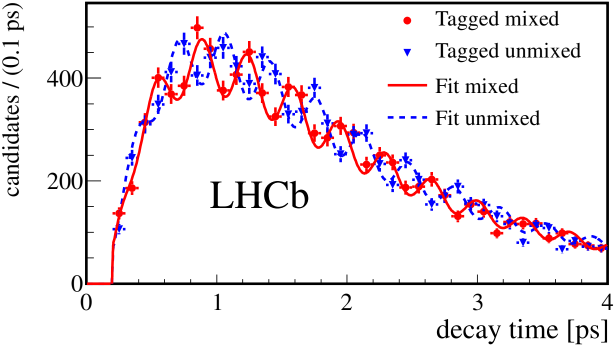
LHCB-PAPER-2013-006

- $B_s^0 \to D_s^- \pi^+$ decays are reconstructed in five D_s^- decay channels:



- With 1 fb^{-1} $\to \approx$ 34,000 $B_s^0 \to D_s^- \pi^+$ candidates.
- $\Delta\Gamma_s$ from latest $B_s^0 \to J/\psi h^+ h^-$ analysis and Γ_s from PDG.
- σ_t is calibrated by fitting a single Gaussian to prompt D_s^- + random π^+ events decay time. $\to$ Scale factor: $1.25 < S_{\sigma_t} < 1.45$ $\to$ Average resolution: ≈ 44 fs.
- Decay time acceptance $\mathcal{E}_t(t)$ parametrised from MC and free in the fit.

Δm_s *preliminary* result



LHCB-PAPER-2013-006

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

World's best measurement of Δm_s!

Main systematics coming from the z- and momentum scale.

Conclusion

Phys. Rev. **D86** (2012) 052006

- Analysis of the resonant components in $B_s^0 \to J/\psi\pi^+\pi^-$.

$$\frac{\mathcal{B}(B_s^0 \to J/\psi\pi^+\pi^-)}{\mathcal{B}(B_s^0 \to J/\psi\phi)} = (19.79 \pm 0.47(\text{stat}) \pm 0.52(\text{syst}))\%$$

CP-odd fraction in $B_s^0 \to J/\psi\pi^+\pi^-$ is greater than 97.7% @ 95% CL.

- Measurement of *CP*-violation and the B_s^0-meson decay width difference with $B_s^0 \to J/\psi K^+K^-$ and $B_s^0 \to J/\psi\pi^+\pi^-$ decays.

arXiv:1304.2600

$$\begin{aligned}
\phi_s &= 0.01 \pm 0.07\ (\text{stat}) \pm 0.01\ (\text{syst})\ \text{rad},\\
\Gamma_s &= 0.661 \pm 0.004\ (\text{stat}) \pm 0.006\ (\text{syst})\ \text{ps}^{-1},\\
\Delta\Gamma_s &= 0.106 \pm 0.011\ (\text{stat}) \pm 0.007\ (\text{syst})\ \text{ps}^{-1}.
\end{aligned}$$

LHCB-PAPER-2013-006

- Precision measurement of the $B_s^0 - \bar{B}_s^0$ oscillation frequency in the decay $B_s^0 \to D_s^+\pi^-$ (*preliminary*).

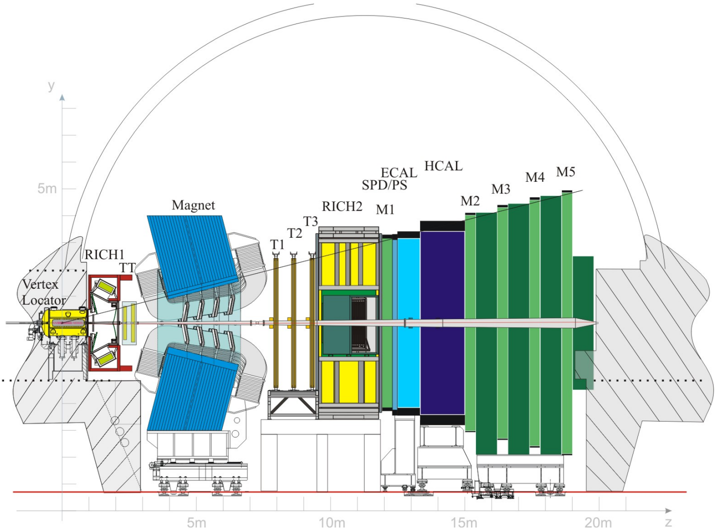
$$\Delta m_s = (17.768 \pm 0.023(\text{stat}) \pm 0.006(\text{syst}))\ \text{ps}^{-1}$$

- Results with 1 fb^{-1} here, we have 3 fb^{-1} in total on tape! → Stay tuned!

Thank you for your attention!

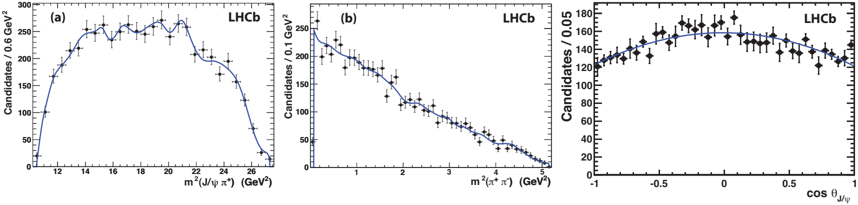
Backup Slides

LHCb detector



Detection efficiency and background composition

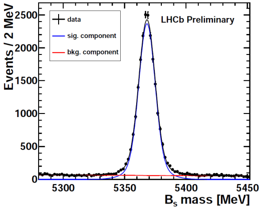
- The background PDF is parametrised from a wrong-sign $J/\psi\pi^{\pm}\pi^{\pm}$ sample and a MC sample of random $J/\psi + \rho^0(770)$.



ϕ_s status before Moriond 2013

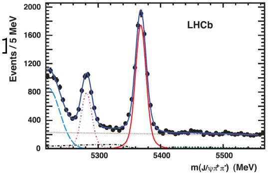
- Tagged angular time-dependent analysis of $B_s^0 \to J/\psi$ (1 fb^{-1}, prel.)

$$\phi_s^{J/\psi\phi} = -0.001 \pm 0.101\,(\text{stat}) \pm 0.027\,(\text{syst})\ \text{rad}$$



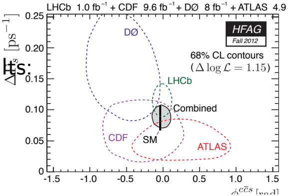
- Tagged time-dependent analysis of $B_s^0 \to J/\psi\pi^+\pi^-$ (1 fb^{-1})

$$\phi_s^{J/\psi\pi\pi} = -0.019\,^{+\,0.173}_{-\,0.174}\,(\text{stat})\,^{+\,0.004}_{-\,0.003}\,(\text{syst})\ \text{rad}$$



- Combination of $B_s^0 \to J/\psi\phi$ and $B_s^0 \to J/\psi\pi^+\pi^-$ results:

$$\phi_s^{J/\psi\phi+J/\psi\pi\pi} = -0.002 \pm 0.083\,(\text{stat}) \pm 0.027\,(\text{syst})\ \text{rad}$$



$B_s^0 \to J/\psi K^+K^-$ differential decay rates

$$\frac{\mathrm{d}^4\Gamma(B_s^0 \to J/\psi K^+K^-)}{\mathrm{d}\Omega \mathrm{d}t} \propto \sum_{k=1}^{10} h_k(t) f_k(\Omega)$$

$$h_k(t) = N_k e^{-\Gamma_s t}\left[a_k \cosh\left(\tfrac{1}{2}\Delta\Gamma_s t\right) + b_k \sinh\left(\tfrac{1}{2}\Delta\Gamma_s t\right) + c_k \cos(\Delta m_s t) + d_k \sin(\Delta m_s t)\right]$$

k	$f_k(\theta_\mu, \theta_K, \varphi_h)$	N_k	a_k	b_k	c_k	d_k
1	$2\cos^2\theta_K \sin^2\theta_\mu$	$\lvert A_0(0)\rvert^2$	1	D	C	$-S$
2	$\sin^2\theta_K\left(1-\sin^2\theta_\mu\cos^2\varphi_h\right)$	$\lvert A_\parallel(0)\rvert^2$	1	D	C	$-S$
3	$\sin^2\theta_K\left(1-\sin^2\theta_\mu\sin^2\varphi_h\right)$	$\lvert A_\perp(0)\rvert^2$	1	$-D$	C	S
4	$\sin^2\theta_K \sin^2\theta_\mu \sin 2\varphi_h$	$\lvert A_\parallel(0)A_\perp(0)\rvert$	$C\sin(\delta_\perp-\delta_\parallel)$	$S\cos(\delta_\perp-\delta_\parallel)$	$\sin(\delta_\perp-\delta_\parallel)$	$D\cos(\delta_\perp-\delta_\parallel)$
5	$\frac{1}{2}\sqrt{2}\sin 2\theta_K \sin 2\theta_\mu \cos\varphi_h$	$\lvert A_0(0)A_\parallel(0)\rvert$	$\cos(\delta_\parallel-\delta_0)$	$D\cos(\delta_\parallel-\delta_0)$	$C\cos(\delta_\parallel-\delta_0)$	$-S\cos(\delta_\parallel-\delta_0)$
6	$-\frac{1}{2}\sqrt{2}\sin 2\theta_K \sin 2\theta_\mu \sin\varphi_h$	$\lvert A_0(0)A_\perp(0)\rvert$	$C\sin(\delta_\perp-\delta_0)$	$S\cos(\delta_\perp-\delta_0)$	$\sin(\delta_\perp-\delta_0)$	$D\cos(\delta_\perp-\delta_0)$
7	$\frac{2}{3}\sin^2\theta_\mu$	$\lvert A_S(0)\rvert^2$	1	$-D$	C	S
8	$\frac{1}{3}\sqrt{6}\sin\theta_K \sin 2\theta_\mu \cos\varphi_h$	$\lvert A_S(0)A_\parallel(0)\rvert$	$C\cos(\delta_\parallel-\delta_S)$	$S\sin(\delta_\parallel-\delta_S)$	$\cos(\delta_\parallel-\delta_S)$	$D\sin(\delta_\parallel-\delta_S)$
9	$-\frac{1}{3}\sqrt{6}\sin\theta_K \sin 2\theta_\mu \sin\varphi_h$	$\lvert A_S(0)A_\perp(0)\rvert$	$\sin(\delta_\perp-\delta_S)$	$-D\sin(\delta_\perp-\delta_S)$	$C\sin(\delta_\perp-\delta_S)$	$S\sin(\delta_\perp-\delta_S)$
10	$\frac{4}{3}\sqrt{3}\cos\theta_K \sin^2\theta_\mu$	$\lvert A_S(0)A_0(0)\rvert$	$C\cos(\delta_0-\delta_S)$	$S\sin(\delta_0-\delta_S)$	$\cos(\delta_0-\delta_S)$	$D\sin(\delta_0-\delta_S)$

$$C \equiv \frac{1-|\lambda|^2}{1+|\lambda|^2}, \quad S \equiv -\frac{2|\lambda|\sin\phi_s}{1+|\lambda|^2}, \quad D \equiv -\frac{2|\lambda|\cos\phi_s}{1+|\lambda|^2}.$$

Δm_s measurement with $B_s^0 \to D_s^- \pi^+$ decays

- The signal decay time PDF looks like:

$$\mathcal{P}_t^{\text{sig}}(t, q|\sigma_t, \eta) \propto \{\Gamma_s e^{-\Gamma_s t} \frac{1}{2}[\cosh(\frac{\Delta\Gamma_s}{2} t) + q[1 - 2\omega(\eta)] \cos(\Delta m_s t)]\theta(t)\}$$
$$\otimes G(t, S_{\sigma_t}, \sigma_t)\mathcal{E}_t(t)\epsilon$$