ϕ_s and B_s^0 mixing at LHCb

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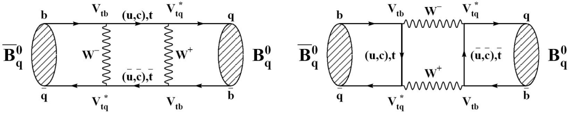
6 February 2012

B physics workshop
Genova

OUTLINES

PHENOMENOLOGY

In the Standard Model, neutral B_s^0 mesons oscillate via box diagrams



B_s^0 meson evolves as a superposition of flavour eigenstates:

$$i\frac{\partial}{\partial t}\begin{pmatrix}|B_s^0(t)\rangle\\|\overline{B}_s^0(t)\rangle\end{pmatrix} = \left(\mathbf{M} - i\frac{\mathbf{\Gamma}}{2}\right)\begin{pmatrix}|B_s^0(t)\rangle\\|\overline{B}_s^0(t)\rangle\end{pmatrix}$$

- Mass difference : $\Delta m_s = M_H - M_L$
- Width difference : $\Delta\Gamma_s = \Gamma_L - \Gamma_H$

PHENOMENOLOGY: ϕ_s

Interference between mixing and decay :

$$\phi_s = \Phi_M - 2\Phi_D$$

Standard Model:

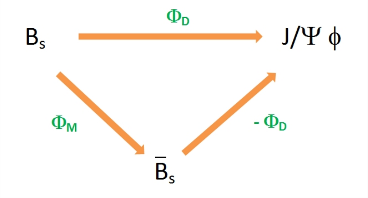
$$\phi_s^{SM} = -2\arg\left(-\frac{V_{ts}V_{tb}^\star}{V_{cs}V_{cb}^\star}\right) + \delta_{penguins}^{SM}$$

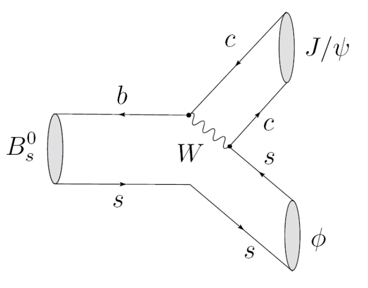
Neglecting penguins:

$$\phi_s^{SM} = -(0.0363 \pm 0.0017)\ \text{rad}$$

If New Physics: ϕ_s can be larger !

ϕ_s golden decay: $B_s^0 \rightarrow J/\psi\phi$



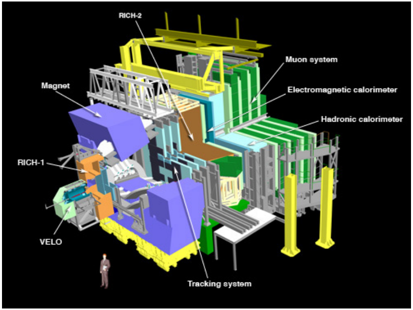


LHCb DETECTOR

LHCb designed to study CP violation and rare decays in B and charm sector

Single-arm forward spectrometer

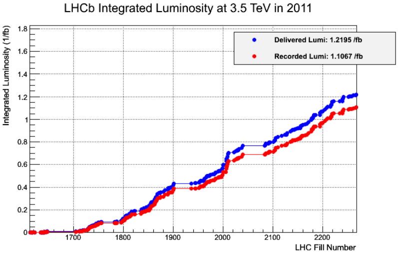
- Tracking system:
  IP resolution $\sim 15\ \mu$m (at high p_T),
  $\delta p/p = 0.4\%$
- RICH system:
  Good separation (3σ) between hadrons
  ($p \sim [2, 100]$ GeV$/c$)
- Calorimeters:
  Energy measurement, identify π^0, γ,e
- Muon detector
- Trigger:
  Rate: 40MHz reduce to 3kHz



LHCb: 2011 data taking

2011 data taking at LHCb, at $\sqrt{s}$ =7 TeV

- Detector's efficiency $> 90\,\%$
- $1.1\,\text{fb}^{-1}$ of data recorded
- $99\,\%$ of data good for physics



Δm_s and ϕ_s measurement presented here are made with $340\,\text{pb}^{-1}$

Δm_s measurement

LHCb-CONF-2011-050

Δm_s MEASUREMENTS

Experimental status :

- CDF, Phys. Rev. Lett. 97 062003 (2006), $\mathcal{L} = 1\ \text{fb}^{-1}$
  $\Delta m_s = 17.77 \pm 0.10(\text{stat}) \pm 0.07(\text{syst})\ \text{ps}^{-1}$
- LHCb, LHCb-PAPER-2011-010, $\mathcal{L} = 36\ \text{pb}^{-1}$
  $\Delta m_s = 17.63 \pm 0.11(\text{stat}) \pm 0.02(\text{syst})\ \text{ps}^{-1}$

LHCb was already competitive with the most precise published measurement

Presentation of the LHCb measurement with $\mathcal{L} = 340\ \text{pb}^{-1}$

Analysis of $B_s^0 \to D_s^- \pi^+$ channels :

- $B_s^0 \to D_s^- (\phi(K^+K^-)\pi^-)\pi^+$
- $B_s^0 \to D_s^- (K^{*0}(K^+\pi^-)K^-)\pi^+$
- $B_s^0 \to D_s^- (K^+K^-\pi^-)\pi^+$

Δm_s STRATEGY

1. Trigger and select $B_s^0 \to D_s^- \pi^+$ events
2. Measure mass
3. Measure decay time : resolution and acceptances
4. Tag initial flavour of B_s^0 meson
5. Simultaneous unbinned maximum likelihood fit
   Common physical parameters: $M_{B_s^0}$, Γ_s, Δm_s
6. Evaluate the systematics

SIGNAL DESCRIPTION

$$\mathcal{S} = \underbrace{\mathcal{S}_m(m)}_{\text{Mass}}\underbrace{\mathcal{S}_t(t,q|\sigma_t,\eta)}_{\text{Time, Tagging}}\ \underbrace{\mathcal{S}_{\sigma_t}(\sigma_t)\mathcal{S}_\eta(\eta)}_{\text{PDF evt-by-evt variables}}$$

$\mathcal{S}_m(m)$: single gaussian distribution (same mean and width for all decays)

$\mathcal{S}_t(t,q|\sigma_t,\eta)$ depends on tagging decision

- Untagged event:
  $$\mathcal{S}_t(t,q|\sigma_t,\eta) \propto (\Gamma_s e^{-\Gamma_s t}\cosh(\tfrac{\Delta\Gamma_s}{2}t)) \otimes \underbrace{G(t,\sigma_t)}_{\text{t resolution}} \times \underbrace{\epsilon(t)}_{\text{t acceptance}} \times (1-\epsilon_{sig})$$
- Tagged event: $\mathcal{S}_t(t,q|\sigma_t,\eta) \propto$
  $$\left(\Gamma_s e^{-\Gamma_s t}(\cosh(\tfrac{\Delta\Gamma_s}{2}t) + q\,(1-2\omega(\eta))\ \cos(\Delta m_s\, t))\right) \otimes \underbrace{G(t,\sigma_t)}_{\text{t resolution}} \times \underbrace{\epsilon(t)}_{\text{t acceptance}} \times \epsilon_{sig}$$

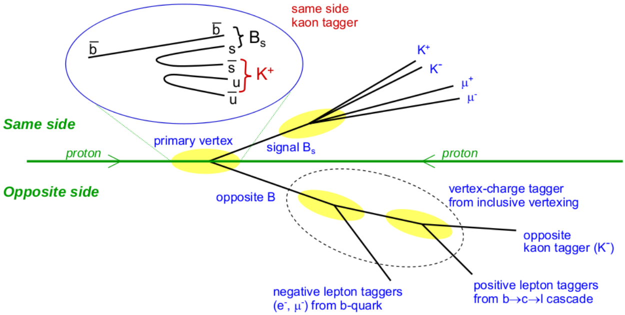
ϵ_{sig}: signal tagging efficiency
ω: mistag
q: state of the mixing: $+1$ ($B_s^0 \to B_s^0$ or $\overline{B}_s^0 \to \overline{B}_s^0$), -1 ($B_s^0 \to \overline{B}_s^0$ or $\overline{B}_s^0 \to B_s^0$)

FLAVOUR TAGGING

LHCb-PAPER-2011-027, LHCb-CONF-2011-003

Determination of the initial flavor of the B particle :

- Opposite-side tag: charge from leptons, K, inclusive vertex
- Same-side tag: K from fragmentation quark

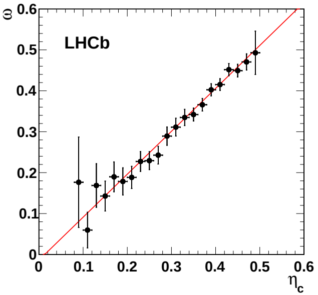


Quantification of the performances: tagging efficiency $\varepsilon_{tag} = \frac{\#\text{ tagged evt}}{\#\text{ evt}}$,

mistag $\omega = \frac{\#\text{ wrongly tagged evt}}{\#\text{ tagged events}}$, tagging power $\varepsilon_{tag} D^2 = \varepsilon_{tag}(1-2\omega)^2$

OPTIMISATION, CALIBRATION OF OS TAGGING

1. Selection of the taggers (μ, e, K, Vtx)
   Optimization of the cuts to maximize the tagging power, in $B^+ \to J/\psi K^+$ channel
2. Combination of the taggers decision:
   $\rightarrow$ Neural Network to obtain the OS mistag probability η
   Trained on MC $B^+ \to J/\psi K^+$, based on topological and kinematic event properties
   $\rightarrow$ Calculation to obtain the OS single tagging decision
3. Calibration of mistag probability (η) wrt measured mistag fraction (ω)
   Correction function: $\omega = p_0 + p_1(\eta - \langle\eta\rangle)$ extracted from $B^+ \to J/\psi K^+$
   If calculated mistag is well calibrated: $p_0 - p_1\langle\eta\rangle = 0$



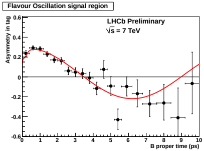
PERFORMANCE OF THE FLAVOUR TAGGING

OS tagging performances are checked in $B^+ \to J/\psi K^+$, $B^0 \to J/\psi K^{*0}$, $B^0 \to D^{*-}\mu^+\nu_\mu$

Channels	ε_{tag} [%]	ω [%]	$\varepsilon_{tag} D^2$ [%]
Evt-by-evt values: using η			
$B^+ \to J/\psi K^+$	27.3 ± 0.1	36.1 ± 0.8	2.10 ± 0.24
$B^0 \to J/\psi K^{*0}$	27.3 ± 0.3	36.2 ± 0.8	2.09 ± 0.24
$B^0 \to D^{*-}\mu^+\nu_\mu$	30.5 ± 0.1	35.6 ± 0.8	2.53 ± 0.27
$B_s^0 \to J/\psi\phi$	24.9 ± 0.5	36.1 ± 0.8	1.91 ± 0.23

OS tagging performance at CDF: $\varepsilon_{tag} D^2 = 1.2 \pm 0.2\%$ (arXiv.1112.1726v1)

Asymmetry $\propto (1 - 2\omega)\cos(\Delta m_d\, t)$



$B^0 \to D^{*-}\mu^+\nu_\mu$

For Δm_s measurement:

- If OS tagging decision, use mistag probability η
- If no OS tagging decision, but SS tagging decision
  $\to$ use free global ω_{SS} (as not enough statistics to perform the calibration)
- If OS and SS tagging decisions: keep the one with the smallest η

Performances in $B_s^0 \to D_s^-\pi^+$:

Opposite side: $\varepsilon_{tag} = 29.0 \pm 0.5\%$, $\varepsilon_{tag} D^2 = 3.1 \pm 0.8\%$

Same side: $\varepsilon_{tag} = 12.2 \pm 0.4\%$ $\varepsilon_{tag} D^2 = 1.2 \pm 0.4\%$

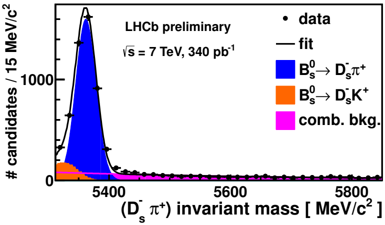
Mass distribution

Trigger and selection: lifetime bias

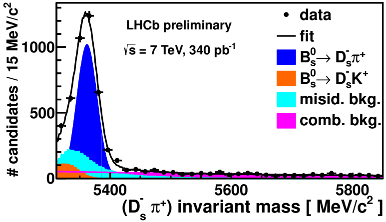
Background:

- Physical: B_d^0, Λ_b with 1 misidentified daughter
- Combinatorial

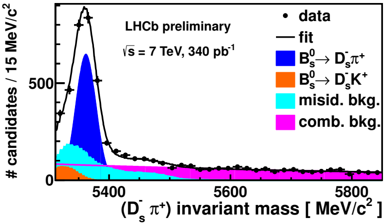
$B_s^0 \to D_s^- (\phi(K^+K^-)\pi^-)\pi^+$: 4371±91



$B_s^0 \to D_s^- (K^{*0}(K^+\pi^-)K^-)\pi^+$: 2910±89



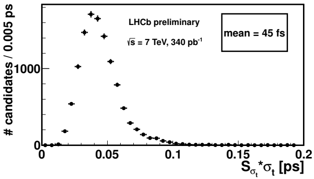
$B_s^0 \to D_s^- (K^+K^-\pi^-)\pi^+$: 1908±74



DECAY TIME RESOLUTION AND ACCEPTANCE

Decay time resolution

- Single gaussian, event-by-event time uncertainty
- Imperfect alignment or material description:
  Scale factor $S_{\sigma_t} = 1.37$
  calibrated using prompt $D_s + \pi$
- Average decay time resolution : 45 fs



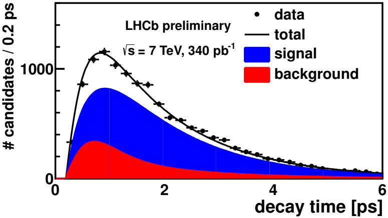
Decay time acceptance

- Selection and trigger require several displaced tracks
  $\rightarrow$ decay time distribution is distorted
- Correction with acceptance function $\epsilon(t)$: derived from MC

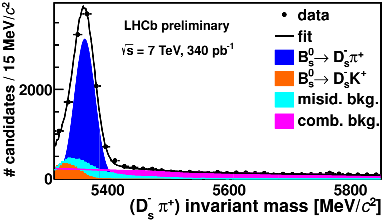
SIMULTANEOUS FIT PROJECTIONS

Using $\mathcal{L} = 340\,\text{pb}^{-1}$ of 2011 data, the simultaneous fit gives:

Decay time

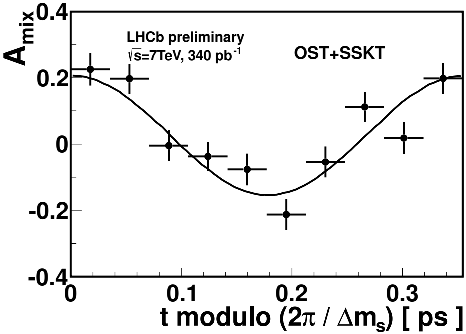


Mass



Δm_s: RESULT

Using $\mathcal{L} = 340\,\text{pb}^{-1}$ of 2011 data, asymmetry: $A_{mix}(t) = \frac{N_{unmixed}(t) - N_{mixed}(t)}{N_{unmixed}(t) + N_{mixed}(t)}$



$$\Delta m_s = 17.725 \pm 0.041(stat) \pm 0.026(syst)\ \text{ps}^{-1}$$

→ Most precise measurement

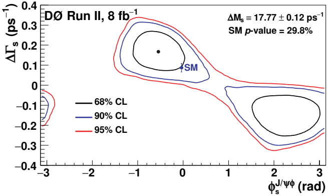
CDF, 2006: $\Delta m_s = 17.77 \pm 0.10(stat) \pm 0.07(syst)\ \text{ps}^{-1}$

ϕ_s measurement

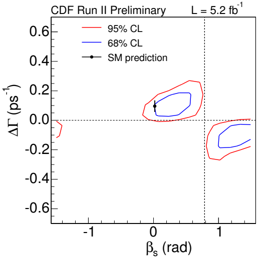
arXiv:1112.3183 accepted by PRL
LHCb-CONF-2011-049
arXiv:1112.3056
LHCb-CONF-2011-056

Experimental status

D0: *arXiv* : 1109.3166

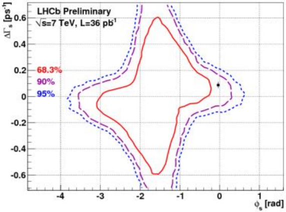


CDF: *arXiv* : 1112.1726v1



LHCb: $\mathcal{L} = 36\,\mathrm{pb}^{-1}$

LHCb-CONF-2011-006



Presentation of ϕ_s measurement at LHCb with $\mathcal{L} = 340\,\mathrm{pb}^{-1}$

ϕ_s STRATEGY

1. Trigger and select $B_s^0 \to J/\psi(\mu\mu)\phi(KK)$ events
2. Measure mass
3. Measure decay time : resolution and acceptances
4. Measure decay angles, with acceptances
   - P→VV decay: mixture of CP odd and CP event states
     → need angular analysis to disentangle statistically the 3 polarisations amplitudes: $|A_0|^2$, $|A_{\|}|^2$ (CP even), $|A_{\perp}|^2$ (CP-odd)
   - S-wave component (KK non resonant) add a CP odd polarisation $|A_S|^2$
5. Tag initial flavour of B meson
6. Unbinned maximum likelihood fit
   Physical parameters: $\phi_s, \Delta\,\Gamma_s, \Gamma_s, \Delta m_s, M_{B_s^0}, |A_{\perp}|, |A_{\|}|, |A_S|, \delta_{\perp}, \delta_{\|}, \delta_S$
7. Evaluate the systematics

$B_s^0 \to J/\psi\phi$ SIGNAL DESCRIPTION

- Mass: sum of 2 gaussians
- Time, angle, tagging : sum of ten terms, corresponding to 4 polarization amplitudes and their interferences (S wave included)

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

k	$f_k(\theta,\psi,\varphi)$
1	$2\cos^2\psi\left(1-\sin^2\theta\cos^2\phi\right)$
2	$\sin^2\psi\left(1-\sin^2\theta\sin^2\phi\right)$
3	$\sin^2\psi\sin^2\theta$
4	$-\sin^2\psi\sin 2\theta\sin\phi$
5	$\frac{1}{2}\sqrt{2}\sin 2\psi\sin^2\theta\sin 2\phi$
6	$\frac{1}{2}\sqrt{2}\sin 2\psi\sin 2\theta\cos\phi$
7	$\frac{2}{3}(1-\sin^2\theta\cos^2\phi)$
8	$\frac{1}{3}\sqrt{6}\sin\psi\sin^2\theta\sin 2\phi$
9	$\frac{1}{3}\sqrt{6}\sin\psi\sin 2\theta\cos\phi$
10	$\frac{4}{3}\sqrt{3}\cos\psi(1-\sin^2\theta\cos^2\phi)$

The time-dependent functions

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

k	N_k	a_k	b_k	c_k	d_k
1	$\lvert A_0(0)\rvert^2$	1	$-\cos\phi_s$	0	$\sin\phi_s$
2	$\lvert A_\vert(0)\rvert^2$	1	$-\cos\phi_s$	0	$\sin\phi_s$
3	$\lvert A_\perp(0)\rvert^2$	1	$\cos\phi_s$	0	$-\sin\phi_s$
4	$\lvert A_\parallel(0)A_\perp(0)\rvert$	0	$-\cos(\delta_\perp-\delta_\parallel)\sin\phi_s$	$\sin(\delta_\perp-\delta_\parallel)$	$-\cos(\delta_\perp-\delta_\parallel)\cos\phi_s$
5	$\lvert A_0(0)A_\parallel(0)\rvert$	$\cos(\delta_\parallel-\delta_0)$	$-\cos(\delta_\parallel-\delta_0)\cos\phi_s$	0	$\cos(\delta_\parallel-\delta_0)\sin\phi_s$
6	$\lvert A_0(0)A_\perp(0)\rvert$	0	$-\cos(\delta_\perp-\delta_0)\sin\phi_s$	$\sin(\delta_\perp-\delta_0)$	$-\cos(\delta_\perp-\delta_0)\cos\phi_s$
7	$\lvert A_s(0)\rvert^2$	1	$\cos\phi_s$	0	$-\sin\phi_s$
8	$\lvert A_s(0)A_\parallel(0)\rvert$	0	$-\sin(\delta_\parallel-\delta_S)\sin\phi_s$	$\cos(\delta_\parallel-\delta_S)$	$-\sin(\delta_\parallel-\delta_S)\cos\phi_s$
9	$\lvert A_s(0)A_\perp(0)\rvert$	$\sin(\delta_\perp-\delta_S)$	$\sin(\delta_\perp-\delta_S)\cos\phi_s$	0	$-\sin(\delta_\perp-\delta_S)\sin\phi_s$
10	$\lvert A_s(0)A_0(0)\rvert$	0	$-\sin(\delta_0-\delta_S)\sin\phi_s$	$\cos(\delta_0-\delta_S)$	$-\sin(\delta_0-\delta_S)\cos\phi_s$

TRIGGER AND SELECTION

Trigger lines

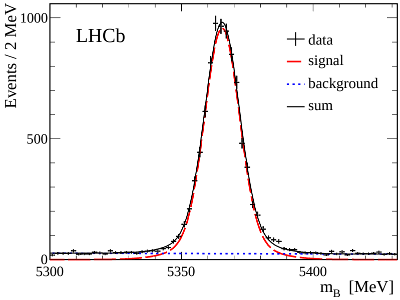
- Lifetime unbiased
- Lifetime biased ($\sim 14\%$ signal events): cut on impact parameter

Offline selection

- Squared cuts
- $t > 0.3$ps

Background

- Remain only few $\%$
- Large reconstructed decay time: $B \to J/\psi X$, combinatorial bkg
- Mass description: exponential
- Time description: 2 exponentials

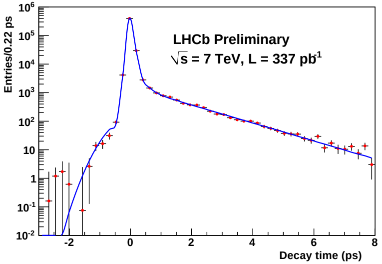


8276 ± 94
$B_s^0 \to J/\psi\phi$ signal events

Proper time

Time resolution

- Sum of 3 gaussians, with common mean, different widths
- Calibration from prompt J/ψ peak
- Average decay time resolution: 50 fs



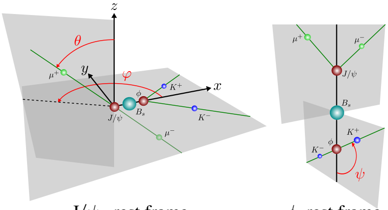
Background only

Time acceptance

- Reconstruction slightly bias the time distribution: shallow fall at high t $\rightarrow$ Correction parametrized in MC : $1 + \beta t$
- Selection does NOT bias the time distribution
- Biased trigger: strong drop at small t
  Correction parametrized by comparing the t distribution of biased events with unbiased, in data : $\epsilon(t) = \frac{n}{1+(at)^{-c}}$

ANGULAR ACCEPTANCES

$B_s^0 \to J/\psi\phi$ is a mixture of CP odd and even states
$\to$ need angular analysis to disentangle statistically the 3 amplitudes



J/ψ rest frame ϕ rest frame

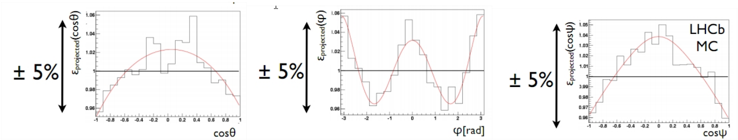
In the J/ψ rest frame:

- $\cos\theta$: cosine of μ^+ polar angle
- φ: μ^+ azimuthal angle

In the ϕ rest frame:

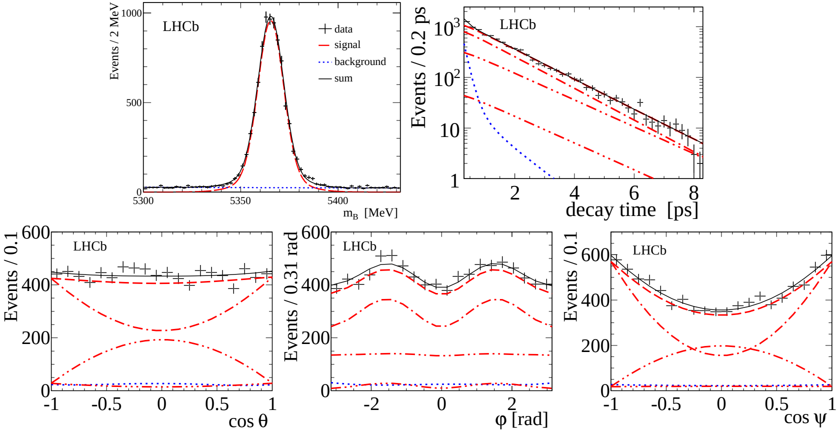
- $\cos\psi$: cosine of K^+ polar angle

Angular distributions are distorted, mainly by the detector asymmetric shape ($\sim$ 5% wrt theory)



$\to$ Correction determined from MC

FIT PROJECTIONS



Dashed lines: signal components

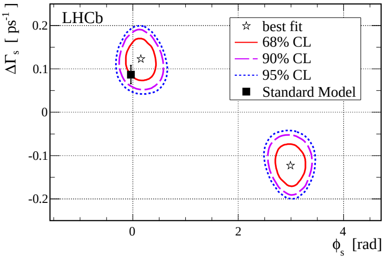
_._ CP even P-wave

_.._ CP odd P-wave

_..._ S-wave

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

Likelihood profile in $\phi_s - \Delta\Gamma_s$ plane



- Most precise measurements:
  $\Gamma_s = 0.656 \pm 0.009$ (stat)± 0.008 (syst) ps^{-1}
  $\phi_s = 0.15 \pm 0.18$ (stat)± 0.07 (syst) rad
  $\Delta\Gamma_s = 0.123 \pm 0.029$ (stat)± 0.011 (syst) ps^{-1}
- First direct evidence of non-zero $\Delta\Gamma_s$
- Good agreement with SM predictions $\to$ Still room for New Physics

ϕ_s: SOLVING THE AMBIGUITY (LHCb-PAPER-2011-028-001)

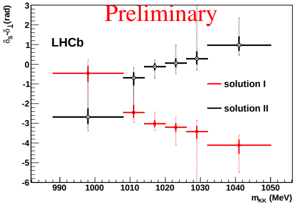
2 solutions due to the invariance of the differential decay rate :
$(\phi_s, \Delta\Gamma_s, \delta_{\parallel} - \delta_0, \delta_{\perp} - \delta_0, \delta_s - \delta_0) \leftrightarrow (\pi - \phi_s, -\Delta\Gamma_s, \delta_0 - \delta_{\parallel}, \delta_0 - \delta_{\perp}, \delta_0 - \delta_s)$

Ambiguity is solved by studying the interferences between S-wave and P-wave: following BaBar $\cos 2\beta$ measurement (Phys. Rev. D 71 (2007) 032005)

- P-wave strong phases: $\delta_0, \delta_{\parallel}, \delta_{\perp}$
  $\rightarrow$ P-wave phase increases rapidly as a function of m_{KK},
- S-wave strong phase: δ_S
  $\rightarrow$ S-wave phase δ_S vary slowly as a function of m_{KK}

$\delta_S - \delta_{\perp}$:

- extracted from a simultaneous fit in 4 intervals of m_{KK}
- expected to decrease as a function of m_{KK}
  $\rightarrow$ Solution 1 is correct



The chosen solution is the one compatible with SM

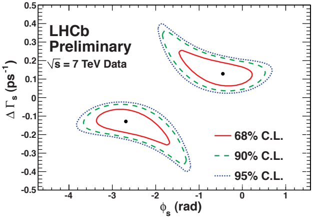
ϕ_s MEASUREMENT IN $B_s^0 \to J/\psi f_0$ (ARXIV:1112.3056)

History

- 2008: Prediction of S-wave interference in $B_s^0 \to J/\psi\phi$ decay (arXiv:0812.2832)
  $\to$ S-wave could manifest as $f_0(980)$, CP odd eigenstate
- Feb. 2011: 1st observation of $B_s^0 \to J/\psi f_0$ decays at LHCb, then Belle, CDF, D0
  $R_{f_0/\phi} = \frac{\Gamma(B_s^0 \to J/\psi f_0)}{\Gamma(B_s^0 \to J/\psi\phi)} = 0.252^{+0.046+0.027}_{-0.032-0.033}$, (arXiv.1102.0206)

Analysis

- f_0 is a spin-0 resonance $\to$ no angular analysis
- Signal time function is simpler
  $\mathcal{S}(t,q) = e^{-\Gamma_s t}(\cosh\frac{\Delta\Gamma_s t}{2} + \cos\phi_s \sinh\frac{\Delta\Gamma_s t}{2} - qD\sin\phi_s \sin(\Delta m_s t))$
- In $\mathcal{L} = 378\,\text{pb}^{-1}$ (2010 + 2011 data),
  1428±47 signal events

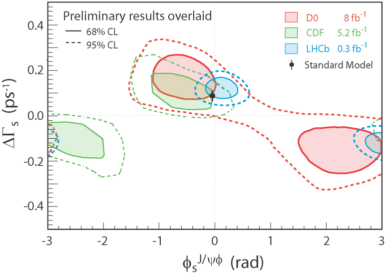


Constraining $\Delta\Gamma_s$ and Γ_s to $B_s^0 \to J/\psi\phi$ values : $\phi_s = -0.44 \pm 0.44$ (stat) ± 0.02 (syst) rad

ϕ_s: Combination of $B_s^0 \to J/\psi\phi$ and $B_s^0 \to J/\psi f_0$

Combination of the 2 ϕ_s measurement using a simultaneous unbinned maximum likelihood fit with common $\phi_s, \Gamma_s, \Delta\Gamma_s, \Delta m_s$:

Artist's view



$$\phi_s = 0.03 \pm 0.16(\text{stat}) \pm 0.07(\text{syst}) \text{ rad}$$

Main systematics come from:

- Decay angle acceptance
- CP in mixing and decay
- Background modelling

Conclusions and prospects

2011 has been an excellent year for LHCb

- Most precise measurement :
  $\Delta m_s = 17.725 \pm 0.041 \pm 0.026\ \mathrm{ps}^{-1}$
  $\Delta\Gamma_s = 0.123 \pm 0.029\ \text{(stat)} \pm 0.011\ \text{(syst)}\ \mathrm{ps}^{-1}$
  $\phi_s = 0.03 \pm 0.16\ \text{(stat)} \pm 0.07\ \text{(syst)}$ rad
  $\rightarrow$ Compatible with Standard Model but still room for New Physics

Prospects on ϕ_s: short term

- Use the whole 2011 statistics (1 fb^{-1})$\rightarrow$ Expected $\sigma_{\phi_s} = 0.10$ rad for $B_s^0 \rightarrow J/\psi\phi$ only
- Add tagging information: SS kaon
- Add new channels:
  - $B_s^0 \rightarrow J/\psi\pi\pi$
  - $B_s^0 \rightarrow \psi(2S)\phi$
  - Control penguin pollution with $B_s^0 \rightarrow J/\psi K^{*0}$

PROSPECTS ON ϕ_s

ϕ_s statistical sensitivities at LHCb:

- Current ($\mathcal{L} = 340\text{pb}^{-1}$) : 0.16 rad
- Expected with $\mathcal{L} = 2\text{fb}^{-1}$ (2012): 0.05 rad
- Expected with $\mathcal{L} = 5\text{fb}^{-1}$ (2017): 0.03 rad

ϕ_s statistical sensitivity at SuperLHCb ($\sqrt{s} = 14\text{TeV}$):

- Expected with $\mathcal{L} = 50\text{fb}^{-1}$: 0.006 rad (LOI: CERN-LHCC-2011-001)

$\rightarrow$ Precision measurement $\sim$ SM ($\sigma(\phi_s) = 0.003\text{rad}$)

ϕ_s measurement gets in excited times !

BACK UP

Δm_s: Background description

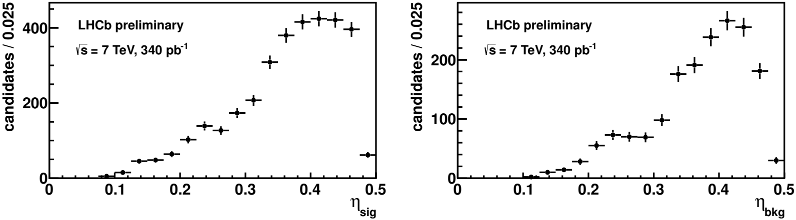
2 kinds of backgrounds

- Physical : B_d^0 and λ_b decays with 1 misidentified daughter
  - $\mathcal{B}_{physical}(m)$: single gaussian
  - $\mathcal{B}_{physical}(t)$: same way as signal ($\Delta\Gamma = 0, \tau$ fixed to PDG value)
- Combinatorial
  - $\mathcal{B}_{comb}(m)$: exponential (different parameters for 3 decays)
  - $\mathcal{B}_{comb}(t)$: shape is extraced from high mass side bands

Δm_s: Per event variable

In the fit, 2 per event variables are used: σ_t, and η
$\rightarrow$ Need to use σ_t and η separate pdf for signal and bkg

For instance: η distribution for signal (left), bkg (right)



Δm_s: SYSTEMATIC STUDIES

Systematic	$\Delta_{\Delta m_s}$ (ps^{-1})
Acceptance function	0.000
Resolution	0.001
$z-$scale	0.018
momentum scale	0.018
σ_t and η PDFs	0.000
$\Delta\Gamma_s$	0.002
Resolution model	0.001
Mass model	0.003
Total	0.026

Details:

- Resolution: vary S_{σ_t} in $[1.25, 1.45]$
- Scale: may improve with better alignment
- Evt by Evt pdf: ignore these PDFs
- Resolution: use double Gaussian for proper time resolution
- Mass shape: use 2 crytal ball

ϕ_S: RESULTS

PARAMETER	VALUE	$\sigma_{\text{STAT.}}$	$\sigma_{\text{SYST.}}$
Γ_s [PS^{-1}]	0.657	0.009	0.008
$\Delta\Gamma_s$ [PS^{-1}]	0.123	0.029	0.011
$\lvert A_\perp(0)\rvert^2$	0.237	0.015	0.012
$\lvert A_0(0)\rvert^2$	0.497	0.013	0.030
$\lvert A_S(0)\rvert^2$	0.042	0.015	0.018
$\delta_\perp$ [RAD]	2.95	0.37	0.12
δ_S [RAD]	2.98	0.36	0.12
ϕ_s[RAD]	0.15	0.18	0.06

ϕ_s, $\Delta\Gamma_s$: SYSTEMATIC STUDIES

Details:

- Angular acceptances: significant data/MC differences affect angular acceptance $\rightarrow$ toy studies with reweighted MC to estimate effect
- CPV in mixing and decay: no production/tagging/direct CPV asymmetry included in the fit so far (toy experiment to estimate effect of neglecting up to 10% nuisance asymmetry)

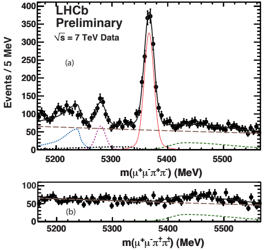
ϕ_s: $B_s^0 \to J/\psi f_0$

Signal:

- Mass: Sum of 2 gaussians

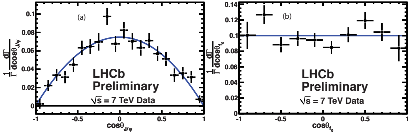
Background:

- Misidentified $B^0 \to J/\psi K^{*0}$
- $B_d^0 \to J/\psi \pi^+ \pi^-$
- Combinatorial



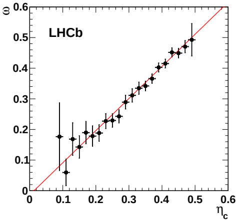
Angles consideration :

- B_s^0 spin: 0
- J/ψ spin: 1
- f_0 spin: 0
- CP odd



Optimisation, calibration of OS tagging

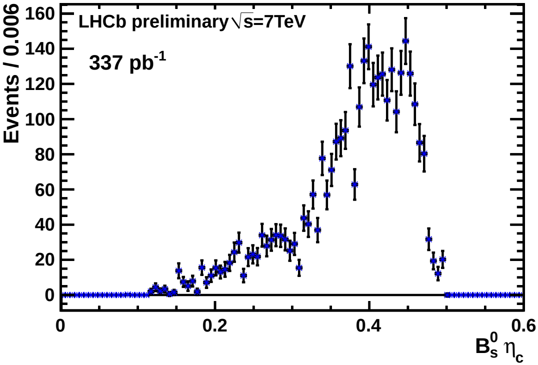
1. Selection of the taggers
   Optimization of the cuts to maximize the tagging power, in $B^+ \to J/\psi K^+$ channel
   Performances are checked in $B^0 \to J/\psi K^{*0}$, $B^0 \to D^{*-}\mu^+\nu_\mu$ channels
2. Combination of the taggers decision:
   $\to$ Calculation to obtain the OS single tagging decision
   $\to$ Neural Network to obtain the OS mistag probability η
   Trained on MC $B^+ \to J/\psi K^+$, based on topological and kinematic event properties
3. Calibration of mistag probability (η) wrt measured mistag fraction (ω)
   Correction function: $\omega = p_0 + p_1(\eta - <\eta>)$ extracted from $B^+ \to J/\psi K^+$
   If calculated mistag is well calibrated: $p_0 - p_1 <\eta> = 0$
   Check in $B^+ \to J/\psi K^+$, $B^0 \to J/\psi K^{*0}$, $B^0 \to D^{*-}\mu^+\nu_\mu$



Channels	p_0	p_1	$<\eta_c>$
$B^+ \to J/\psi K^+$	0.384 ± 0.003	1.037 ± 0.038	0.379
$B^0 \to J/\psi K^{*0}$	0.399 ± 0.008	1.02 ± 0.10	0.378
$B^0 \to D^{*-}\mu^+\nu_\mu$	0.395 ± 0.002	1.022 ± 0.026	0.375

ϕ_s: Flavour tagging

OS per event mistag probability with calibration parameters from $B^+ \to J/\psi K^+$
$\omega = p_0 + p_1(\eta - <\eta>)$

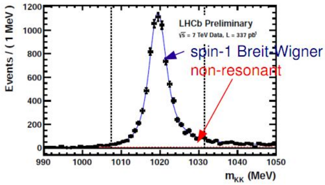


Tagging power: $\varepsilon_{tag} D^2 = 2.08 \pm 0.17(stat) \pm 0.37(syst)$ %

S WAVE

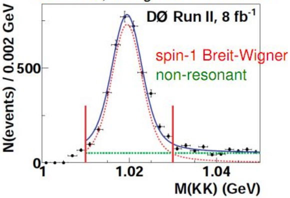
S-wave accounts for a small fraction on non-ϕ in the J/ψ KK final state

mKK in LHCb, background subtracted



LHCb, in range [1008,1032]
- from angle fit: (4 +/- 2)%
- from mass fit: (2+/-1) %

mKK in D0, background subtracted

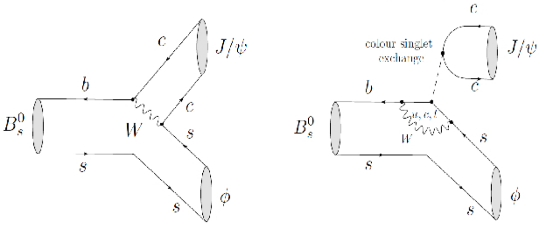


D0, in range [1010,1030]:
- from angle fit: (17+/-4)%
- from mass fit: (14+/-2)%

LHCb and D0 disagree on fraction of S-wave
CDF measures $< 6.7\%$ at 95% CL

PENGUIN POLLUTION

- In the SM, $B_s \to J/\psi\phi$ decay is dominated by a single weak phase: $V_{cs}V_{cb}^*$



$$A(\overline{b} \to \overline{c}c\overline{s}) = V_{cs}V_{cb}^*(A_T + P_c) + V_{us}V_{ub}^*P_u + V_{ts}V_{tb}^*P_t$$
$$= V_{cs}V_{cb}^*(A_T + P_c - P_t) + V_{us}V_{ub}^*(P_u - P_t)$$

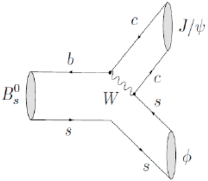
$V_{ts}V_{tb}^* = -V_{us}V_{ub}^* - V_{cs}V_{cb}^*$

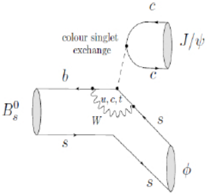
$\sim A\lambda^2(1 - \lambda^2/2)$

$\sim A\lambda^4(\rho + i\eta)$

- Various penguin pollution estimates:
  - $\delta P \sim 10^{-4}$ [H. Boos et al., Phys.Rev. D70 (2004) 036006]
  - $\delta P \sim 10^{-3}$ [M. Gronau et al., arXiv:0812.4796]
  - δP up to ~0.1 [S. Faller et al., arXiv:0810.4248v1]

PENGUIN POLLUTION (2)

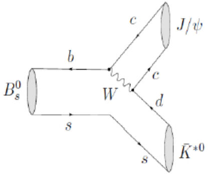


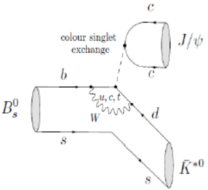


$$\bar b \to \bar s c \bar c$$

Penguins suppressed by λ^2

$$A(B_s^0 \to (J/\psi\phi)_f) = \left(1 - \frac{\lambda^2}{2}\right) \mathcal{A}_f \left[1 + \epsilon a_f e^{i\theta_f} e^{i\gamma}\right] \qquad \epsilon \equiv \lambda^2/(1-\lambda^2)$$



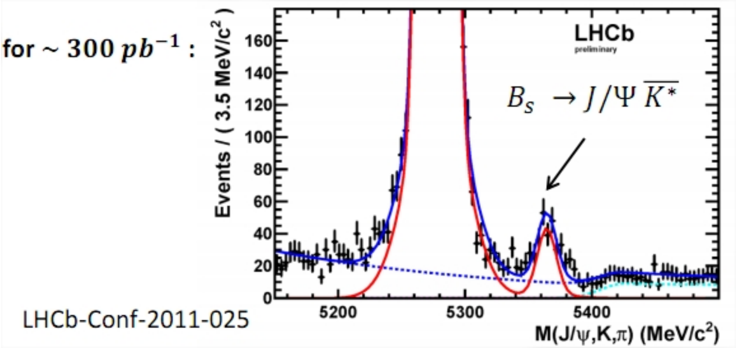


$$\bar b \to \bar d c \bar c$$

Penguins NOT suppressed wrt tree

$$A(B_s^0 \to (J/\psi \bar K^{*0})_f) = \lambda \mathcal{A}'_f \left[1 - a'_f e^{i\theta'_f} e^{i\gamma}\right]$$

PENGUIN POLLUTION: LHCB



$$BR(B^0_s \to J/\psi K^{*0}) = \left(3.5^{+1.1}_{-1.0}(\text{stat}) \pm 0.9(\text{syst})\right)\ 10^{-5}$$

A_{SL}

Measuring A_{SL} is hard at LHCb because:

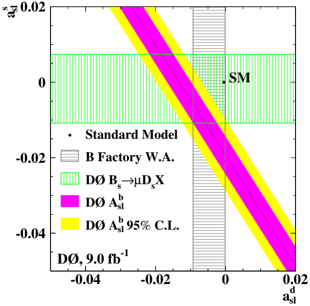
- proton-proton machine $\rightarrow$ production asymmetries
- LHCb $\rightarrow$ asymmetric detector
  $\rightarrow$ cannot count like-sign muons when one of them is not in LHCb acceptance

LHCb has 2 independant analyses :

- Time integrated A_{SL} in $B_s^0 \rightarrow D_s X \mu^+ \nu_\mu$
  Production asymmetry is washed out by fast B_s^0-$\overline{B}_s^0$ mixing
  Fewer parameters to constrain
- Time dependent subtraction
  $\Delta A_{fs}^{s,d} = A_{fs}^s - A_{fs}^d$
  $B_s^0 \rightarrow D_s X \mu^+ \nu_\mu$ and $B_d^0 \rightarrow D_s X \mu^+ \nu_\mu$ channels
  Production asymmetries cancel out
  Fewer systematics
  Cancellation of cross-feed backgrounds

Results are expected soon

D0 result
*Phys.Rev.D*84, 052007 (2011)
Deviation from SM: 3.9σ



Flavour-specific asymmetry in B_s^0, B_d^0 decays

- Physical asymmetry :

$$a_{fs}^{s} = \frac{\Delta\Gamma_s}{\Delta m_s}\tan(\phi_s)$$

$$a_{fs}^{d}(SM) = (-6.4^{+1.6}_{-1.8}) \times 10^{-4} \quad , \quad a_{fs}^{s}(SM) = (3.0^{+1.2}_{-1.3}) \times 10^{-5}$$ [arXiv:1008.1593]

- Measured asymmetry :

$$A_{fs}^{q} = \frac{\Gamma(f)-\Gamma(\bar{f})}{\Gamma(f)+\Gamma(\bar{f})}$$

$$A_{fs}^{q} = \frac{\Gamma(f)-\Gamma(\bar{f})}{\Gamma(f)+\Gamma(\bar{f})}$$

$$A_{fs}^{q}(t) = \frac{a_{fs}^{q}}{2} - \frac{\delta_c^q}{2} - \left(\frac{a_{fs}^{q}}{2} + \frac{\delta_p^q}{2}\right)\frac{\cos(\Delta m_q t)}{\cosh(\Delta\Gamma_q t/2)} + \frac{\delta_b^q}{2}\left(\frac{B}{S}\right)^q \qquad \text{q=s,b}$$

- In LHCb, polluting symmetries are much larger than a_{fs}:
  - Detector asymmetry $\delta_c^q \sim 10^{-2}$
    - Matter detector $\rightarrow$ hadronic interaction asymmetric
    - At LHCb: reduced by swapping the magnetic field
  - Production asymmetry $\delta_p^q \sim 10^{-2}$
    - LHC is a proton-proton collider
  - Background asymmetry $\delta_b^q \sim 10^{-3}$
    - Calculated using sidebands