Prospects for CP violation in $\mathrm{B}_s^0 \rightarrow \mathrm{J}/\psi\phi$ from first LHCb data

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on behalf of the LHCb collaboration

NEW RESULTS PRESENTED FOR THE FIRST TIME AT THIS CONFERENCE!

Les Rencontres de Physique de la Vallée d'Aoste

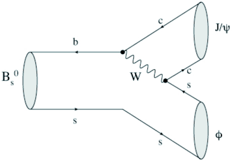
27 February – 5 March 2011, Hotel Planibel, La Thuile, Italy

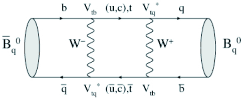
Outline

Introduction

- WHAT: interference between $\mathrm{B_s^0}$ decay to $\mathrm{J}/\psi\phi$ either directly or via $\mathrm{B_s^0}$–$\mathrm{\overline{B}_s^0}$ oscillation gives rise to a CP violating phase $\phi_s^{\mathrm{J}/\psi\phi} \equiv \phi_s = \Phi_M - 2\Phi_D$

$$\begin{tikzcd}
B_s \arrow[rr, "\Phi_D"] \arrow[dr, "\Phi_M"'] & & J/\psi\phi \\
& \overline{B}_s \arrow[ur, "-\Phi_D"'] &
\end{tikzcd}$$





- WHY:
  1. In SM, $\phi_s^{\mathrm{J}/\psi\phi} \simeq -2\beta_s = -(0.0363 \pm 0.0017)\,\mathrm{rad}$, $\beta_s = \arg\left(-V_{ts}V_{tb}^* / V_{cs}V_{cb}^*\right)$
  2. In presence of NP in the mixing box, $\phi_s^{\mathrm{J}/\psi\phi}$ can be larger

- HOW: fit differential decay rates (for $\mathrm{B_s^0}$ and $\mathrm{\overline{B}_s^0}$):

$$\frac{\mathrm{d}^4\Gamma(\mathrm{B_s^0} \to \mathrm{J}/\psi\phi)}{\mathrm{d}t\,\mathrm{d}\cos\theta\,\mathrm{d}\phi\,\mathrm{d}\cos\psi} = f(\phi_s, \Delta\Gamma_s, \Gamma_s, \Delta m_s, M_{\mathrm{B_s^0}}, |A_\perp|, |A_\parallel|, \delta_\perp, \delta_\parallel)$$

Roadmap for the $\phi_s^{J/\psi\phi}$ measurement at LHCb

1. Trigger & select $B_s^0 \to J/\psi\phi$ events
   - Together with control channels, $B^+ \to J/\psi K^+$, $B^0 \to J/\psi K^{*0}$, ...
2. Measure proper time
   - *Proof of principle:* measure $B \to J/\psi X$ lifetimes
3. Measure decay angles
   - P→VV decay: $J/\psi\phi$ is a mixture of CP odd and CP even states
     → angular analysis to disentangle statistically the 3 amplitudes
   - *Proof of principle:* measure transversity amplitudes in $B^0 \to J/\psi K^{*0}$ and $B_s^0 \to J/\psi\phi$ and $\Delta\Gamma_s$
4. Tag initial flavour
   - Calibration using control channels:
     $B^0 \to J/\psi K^{*0}$, $B^+ \to J/\psi K^+$, $B^0 \to D^{*-}\mu^+\nu_\mu$, $B_s^0 \to D_s^-\pi^+$, ...
   - *Proof of principle:* measure Δm_d and Δm_s
5. Fit differential decay rates (for B_s^0 and $\overline{B}_s^0$)

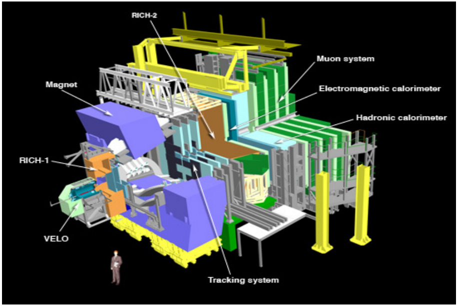
$$\frac{d^4\Gamma(B_s^0 \to J/\psi\phi)}{dt\, d\cos\theta\, d\phi\, d\cos\psi} = f(\phi_s, \Delta\Gamma_s, \Gamma_s, \Delta m_s, M_{B_s^0}, |A_\perp|, |A_\parallel|, \delta_\perp, \delta_\parallel)$$

depends on 9 physics parameters and $>$ 15 detector parameters

LHCb detector at the LHC

See A. Golutvin's talk this morning

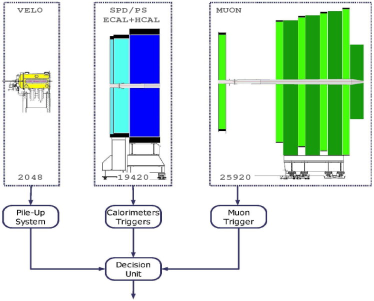
- LHC: p–p collider, $\sqrt{s} = 7\,\mathrm{TeV}$
- LHCb: single-arm forward spectrometer:
  - Tracking system
    IP resolution $\sim$ 15μm (at high p_{T})
    $\delta p/p \sim$ 0.45%
  - RICH system
    Very good $K - \pi$ identification for
    $p \sim 2 - 100\,\mathrm{GeV}/c$
  - Calorimeter
    Energy measurement, identify π^0,γ,e
    + trigger
  - Muon detector
    muon identification + trigger



- Luminosity used in this talk $\sim 35 - 36\,\mathrm{pb}^{-1}$

Trigger

- L0 hardware trigger:
  - Find lepton, hadron with high p_T
  - Reduce the rate from 40 MHz to 1 MHz
- HLT1 software trigger:
  - Finds vertexes in VELO
  - Tracks with high IP & p_T
- HLT2 software trigger:
  - Reconstruct all tracks in event
  - Select inclusive/exclusive B meson
  - Output rate = 2 kHz



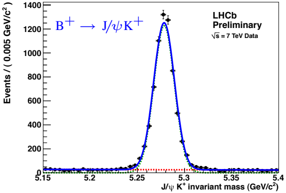
All $\mathrm{J}/\psi(\mu\mu)$ channels triggered in the same way with no lifetime biasing cuts

Selections

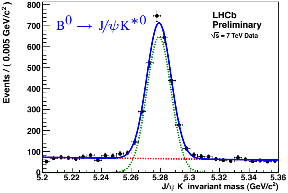
[LHCb-CONF-2011-001]

- Similar selection for all channels $B_s^0 \to J/\psi\phi$, $B^+ \to J/\psi K^+$, $B^0 \to J/\psi K^{*0}$, $B^0 \to J/\psi K_S^0$ and $\Lambda_b \to J/\psi\Lambda$ → cross-check and systematics
- Reconstruct $J/\psi \to \mu^+\mu^-$, then simple and small number of cuts
- No lifetime biasing cuts (IP, decay length, ...) → significant prompt background at small proper time
  Plots with $t > 0.3\,\mathrm{ps}$, J/ψ mass constrained:

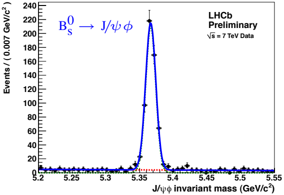
$\sigma_m = 10.7\,\mathrm{MeV}/c^2$



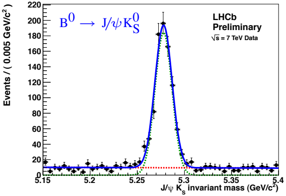
$\sigma_m = 8\,\mathrm{MeV}/c^2$



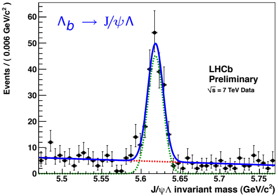
$\sigma_m = 7\,\mathrm{MeV}/c^2$



$\sigma_m = 8.8\,\mathrm{MeV}/c^2$



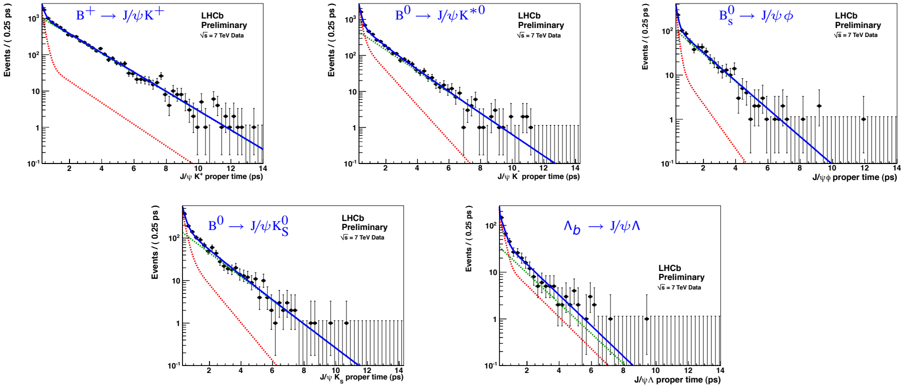
$\sigma_m = 9\,\mathrm{MeV}/c^2$



- Excellent mass resolution, very low background

$b \longrightarrow J/\psi X$ lifetimes (1)

[LHCb-CONF-2011-001]



Channel	LHCb yield	LHCb “lifetime”(*) stat. and sys. (ps)	PDG (ps)
$B^+ \longrightarrow J/\psi K^+$	6 741 ± 85	1.689 ± 0.022 ± 0.047	1.638 ± 0.011
$B^0 \longrightarrow J/\psi K^{*0}$	2 668 ± 58	1.512 ± 0.032 ± 0.042	1.525 ± 0.009
$B^0 \longrightarrow J/\psi K^0_S$	838 ± 31	1.558 ± 0.056 ± 0.022	1.525 ± 0.009
$B^0_s \longrightarrow J/\psi \phi$	570 ± 24	1.447 ± 0.064 ± 0.056	1.477 ± 0.046
$\Lambda_b \longrightarrow J/\psi \Lambda$	187 ± 16	1.353 ± 0.108 ± 0.035	$1.391^{+0.038}_{-0.037}$

using only lifetime unbiased trigger and $t \in [0.3,\ 14]$ ps

(*) $B^0_s \longrightarrow J/\psi \phi$ proper time fitted by a single exponential!

$b \longrightarrow J/\psi X$ lifetimes (2)

[LHCb-CONF-2011-001]

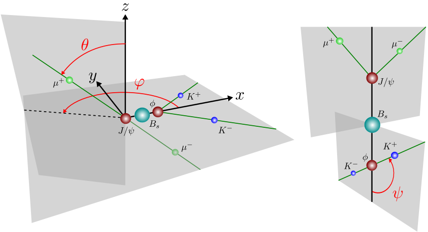
- LHCb measures B lifetimes!
- Will be competitive with world average in 2011
- Excellent proper time resolution $\sim$ 50 fs $\rightarrow$ promising for ϕ_s!
- Conservative systematics can be reduced with deeper studies

Systematics:

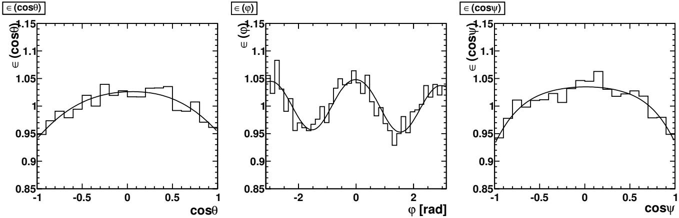
(ps)	$B^+ \rightarrow J/\psi K^+$	$B^0 \rightarrow J/\psi K^{*0}$	$B_s^0 \rightarrow J/\psi\phi$	$B^0 \rightarrow J/\psi K_S^0$	$\Lambda_b \rightarrow J/\psi\Lambda$
Signal mass model	0.002	0.002	0.010	0.014	0.012
Bkg. mass model	0.009	0.020	0.005	0.008	0.023
Bkg. time model	0.003	0.006	0.003	0.006	0.006
Time resolution model	0.005	0.005	0.005	0.005	0.005
Momentum scale	0.001	0.001	0.001	0.001	0.001
Decay length scale	0.001	0.001	0.001	0.001	0.001
Decaytime acceptance	0.043	0.038	0.040	0.015	0.022
Total	0.047	0.042	0.056	0.022	0.035

Angles

- LHCb forward geometry → small distortions of angular acceptance → corrected with MC



$B_s^0 \rightarrow J/\psi\phi$ angular accptance (MC)



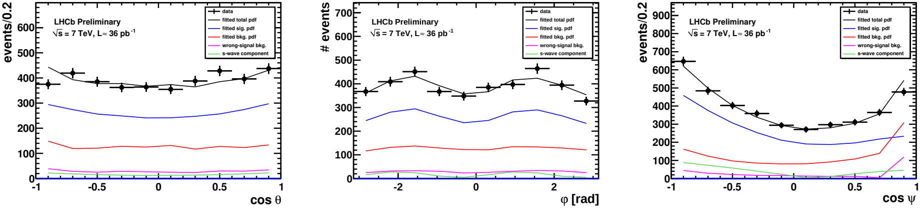
- Validity of MC-angular acceptance corrections tested measuring known values of polarization amplitude in $B^0 \rightarrow J/\psi K^{*0}$

Untagged angular analysis of $\mathrm{B}^0 \to \mathrm{J}/\psi \mathrm{K}^{*0}$

[LHCb-CONF-2011-002]

5D unbinned likelihood fit $(m, t, \cos\theta, \varphi, \cos\psi)$

Projection on transversity angles:



$$\begin{aligned}
|A_{||}|^2 &= 0.252 \pm 0.020(\mathrm{stat}) \pm 0.016(\mathrm{sys}) \\
|A_{\perp}|^2 &= 0.178 \pm 0.022(\mathrm{stat}) \pm 0.017(\mathrm{sys}) \\
\delta_{||}\ (\mathrm{rad}) &= -2.87 \pm 0.11(\mathrm{stat}) \pm 0.10(\mathrm{sys}) \\
\delta_{\perp}\ (\mathrm{rad}) &= 3.02 \pm 0.10(\mathrm{stat}) \pm 0.07(\mathrm{sys})
\end{aligned}$$

BaBar, Phys. Rev. D76, 031102 (2007),

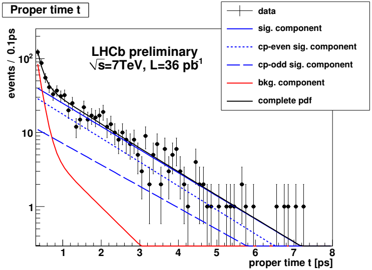
$$\begin{aligned}
|A_{||}|^2 &= 0.211 \pm 0.010 \pm 0.006 \\
|A_{\perp}|^2 &= 0.233 \pm 0.010 \pm 0.005 \\
\delta_{||}\ (\mathrm{rad}) &= -2.93 \pm 0.08 \pm 0.04 \\
\delta_{\perp}\ (\mathrm{rad}) &= 2.91 \pm 0.05 \pm 0.03
\end{aligned}$$

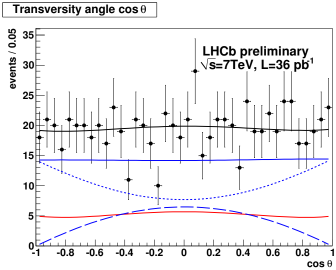
- Compatible with world best measurements
- Will be competitive in 2011

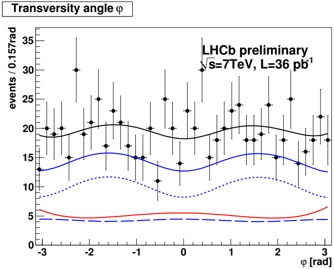
Untagged angular analysis of $B_s^0 \to J/\psi\phi$ (ϕ_s fixed to 0) [LHCb-CONF-2011-002]

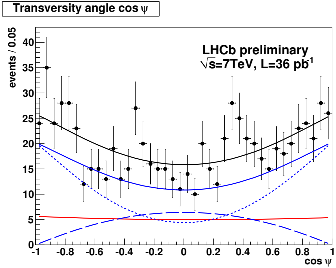
5D unbinned likelihood fit ($m, t, \cos\theta, \varphi, \cos\psi$)

Projection on proper time and transversity angles:


Proper time t


Transversity angle cos θ


Transversity angle φ


Transversity angle cos ψ

Untagged angular analysis of $\mathrm{B_s^0} \to \mathrm{J}/\psi\phi$ (ϕ_s fixed to 0)

[LHCb-CONF-2011-002]

$$\begin{aligned}
\Gamma_\mathrm{s}\ (\mathrm{ps}^{-1}) &= 0.679 \pm 0.036(\mathrm{stat}) \pm 0.027(\mathrm{sys})\\
\Delta\Gamma_\mathrm{s}\ (\mathrm{ps}^{-1}) &= 0.077 \pm 0.119(\mathrm{stat}) \pm 0.021(\mathrm{sys})\\
|A_0|^2 &= 0.528 \pm 0.040(\mathrm{stat}) \pm 0.028(\mathrm{sys})\\
|A_\perp|^2 &= 0.263 \pm 0.056(\mathrm{stat}) \pm 0.014(\mathrm{sys})\\
\delta_{\|}\ (\mathrm{rad}) &= 3.14 \pm 0.52(\mathrm{stat}) \pm 0.13(\mathrm{sys})
\end{aligned}$$

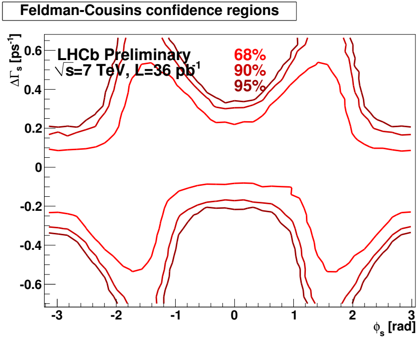
CDF note 10206:

$$\begin{aligned}
\Gamma_\mathrm{s}\ (\mathrm{ps}^{-1}) &= 0.653 \pm 0.011(\mathrm{stat}) \pm 0.005(\mathrm{syst})\\
\Delta\Gamma_\mathrm{s}\ (\mathrm{ps}^{-1}) &= 0.075 \pm 0.035(\mathrm{stat}) \pm 0.010(\mathrm{syst})\\
|A_0|^2 &= 0.524 \pm 0.013(\mathrm{stat}) \pm 0.015(\mathrm{syst})
\end{aligned}$$

- Compatible with world best measurements
- Systematic uncertainties $<$ statistical ones
- Will be competitive in 2011

Untagged angular analysis of $\mathrm{B_s^0} \to \mathrm{J}/\psi\phi$ (ϕ_s floating)

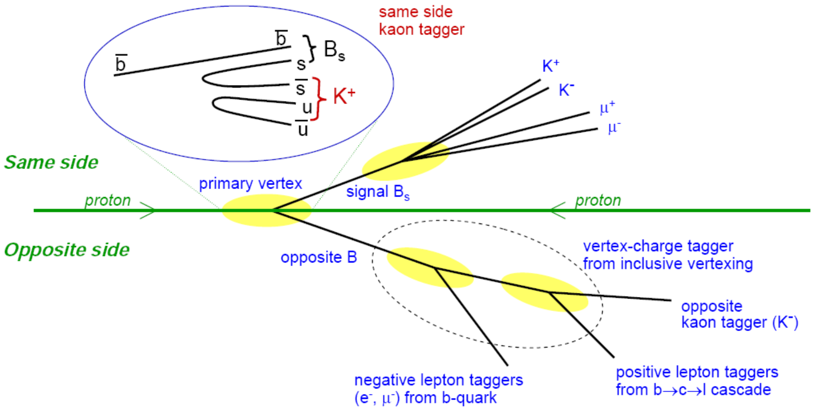
[LHCb-CONF-2011-002]



Coverage-adjusted two-dimensional profile likelihood of $\Delta\Gamma_\mathrm{s} - \phi_\mathrm{s}$

- As expected, ∼no constraint on ϕ_s. However, can still limit $\Delta\Gamma_\mathrm{s}$
- 4-fold ambiguity
  → use flavour tagging to discard two solutions

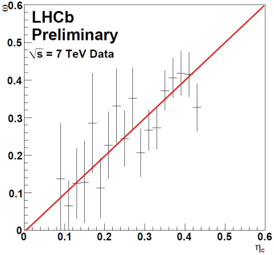
Tag initial $\mathrm{B_s^0}$ flavour



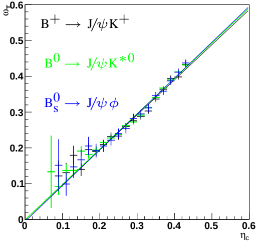
- $\varepsilon_{\mathrm{tag}} = \frac{R+W}{R+W+U}$, $\omega = \frac{W}{R+W}$, Tagging power = $\varepsilon_{\mathrm{eff}} = \varepsilon_{\mathrm{tag}} D^2 = \varepsilon_{\mathrm{tag}}(1 - 2\omega)^2$
- Mistag fraction, ω, estimated event by event
- Tagging algorithm optimized and calibrated on real data with $\mathrm{B^0} \to \mathrm{D^{*-}}\mu^+\nu_\mu$, $\mathrm{B^+} \to \mathrm{J}/\psi\mathrm{K^+}$ and $\mathrm{B^0} \to \mathrm{J}/\psi\mathrm{K^{*0}}$

Flavour tagging: calibration and performance [LHCb-CONF-2011-003]

Output of calibration $B^+ \rightarrow J/\psi K^+$



Check calibration in MC



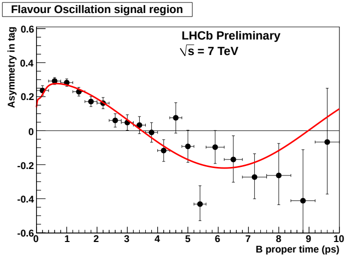
- Measured per event mistag matches mistag calculated after the calibration
- Mistag calibrated in $B^+ \rightarrow J/\psi K^+$ can be used in $B^0 \rightarrow J/\psi K^{*0}$ and $B_s^0 \rightarrow J/\psi \phi$
- Precision of calibration parameters dominated by statistics (shift±0.012, slope±0.11)

OS+SS-π	ε_{tag}(%)	ω(%)	ε_{eff}(%)
$B^0 \rightarrow D^{*-}\mu^+\nu_\mu$	28.9 ± 0.2	34.2 ± 0.8	2.87 ± 0.32
$B^+ \rightarrow J/\psi K^+$	23.0 ± 0.5	33.9 ± 1.1	2.38 ± 0.33
$B^0 \rightarrow J/\psi K^{*0}$	26.1 ± 0.9	33.6 ± 5.1	2.82 ± 0.87

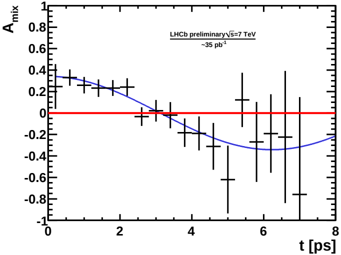
B^0–$\overline{B}^0$ mixing frequency

[LHCb-CONF-2011-003] and [LHCb-CONF-2011-010]

48 k $B^0 \longrightarrow D^{*-}\mu^+\nu_\mu$



6 k $B^0 \longrightarrow D^-\pi^+$



- Proof of principle that flavour tagging is working: measure Δm_d in $B^0 \to D^-(K^+\pi^-\pi^-)\pi^+$:

  $\boxed{\Delta m_\mathrm{d} = 0.499 \pm 0.032(\mathrm{stat}) \pm 0.003(\mathrm{sys})\ \mathrm{ps}^{-1}}$

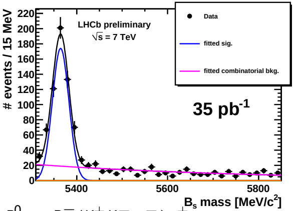
  (World average: $\Delta m_\mathrm{d} = 0.507 \pm 0.005\ \mathrm{ps}^{-1}$)

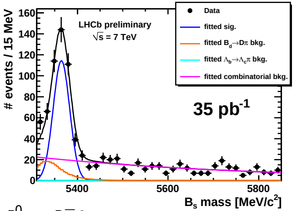
- OS tagging calibration used in Δm_s measurement

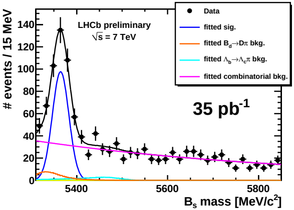
B_s^0–$\overline{B}_s^0$ mixing frequency (1)

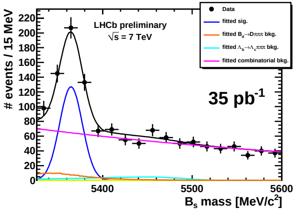
[LHCb-CONF-2011-005]

Decay mode	# signal candidates
$B_s \longrightarrow D_s(\phi\pi)\pi$	515 ± 25
$B_s \longrightarrow D_s(K^*K)\pi$	338 ± 27
$B_s \longrightarrow D_s\pi$ non-resonant	283 ± 27
$B_s \longrightarrow D_s 3\pi$	245 ± 46


$B_s^0 \longrightarrow D_s^-(\phi\pi^-)\pi^+$


$B_s^0 \longrightarrow D_s^-(K^*K^-)\pi^+$


$B_s^0 \longrightarrow D_s^-(K^+K^-\pi^-)\pi^+$

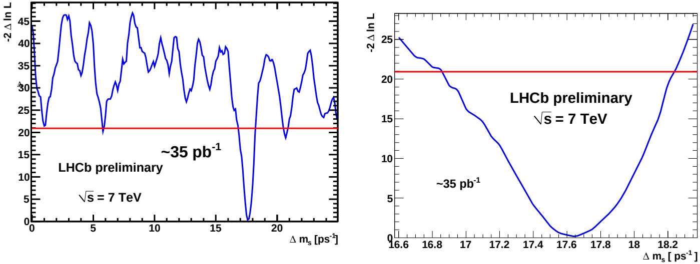

$B_s^0 \longrightarrow D_s^- 3\pi$

B_s^0–$\overline{B}_s^0$ mixing frequency (2)

[LHCb-CONF-2011-005]

Use:

- per event proper time uncertainties, $\langle\sigma_t\rangle = 36 - 44\,\mathrm{fs}$
- per event mistag rate, $\varepsilon_{\mathrm{eff}} = 3.8 \pm 2.1\%$ (OS only)

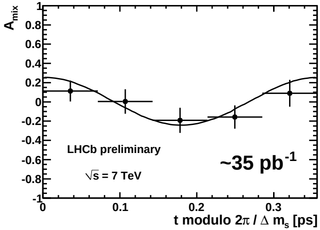


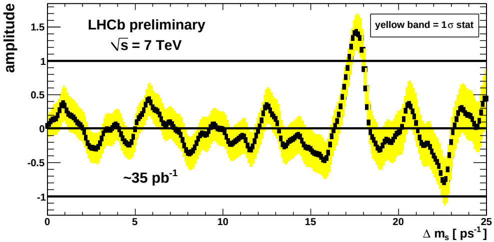
The line at 20.94 indicates the likelihood value evaluated in the limit of infinite mixing frequency

- $\boxed{\Delta m_s = 17.63 \pm 0.11(\mathrm{stat}) \pm 0.04(\mathrm{sys})\,\mathrm{ps}^{-1}}$ (4.6σ stat. significance)
- CDF: Δm_s = 17.77 ± 0.10 (stat) ± 0.07 (sys) ps^{-1}

B_s^0–$\overline{B}_s^0$ mixing frequency (3)

[LHCb-CONF-2011-005]





Summary of the systematic uncertainties on Δm_s and their quadratic sum:

source	$\Delta_{\Delta m_s} [ps^{-1}]$
proper time resolution	0.006
proper time resolution model	0.001
proper time acceptance function	0.000
fixed parameters floating	0.003
diff. background shape in mass fit	0.010
phys. bkg mass templates	0.002
variation of σ_t and η_c PDFs	0.026
z-scale	0.018
momentum scale	0.018
$\Delta\Gamma_s$	0.002
total systematic uncertainties	0.038

Fit the $\phi_s^{J/\psi\phi}$ phase

- Expected sensitivity using toy MC [arXiv:0912.4175]:
  $\sigma_{stat}(\phi_s^{J/\psi\phi}) \sim 0.03\,\mathrm{rad}$ for $2\,\mathrm{fb}^{-1}$ at $14\,\mathrm{TeV}$ $(\phi_s^{SM} = -0.0363 \pm 0.0017\,\mathrm{rad})$

Today performance measured on real data:

	LHCb $36\,\mathrm{pb}^{-1}$	CDF $5.2\,\mathrm{fb}^{-1}$
$B_s^0 \to J/\psi\phi$	960	6500
Proper time resolution	$50\,\mathrm{fs}$	$100\,\mathrm{fs}$
OS tagging power	$2.5 \pm 0.8\%$	$1.2 \pm 0.2\%$
SS tagging power	work ongoing	$3.5 \pm 1.4\%$

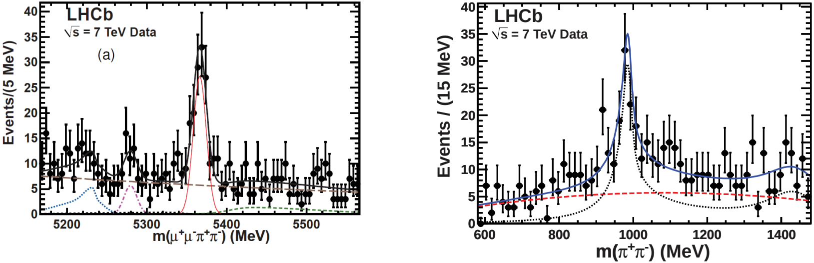
$\Rightarrow$ expect world best measurement of $\phi_s^{J/\psi\phi}$ very soon!

First observation of $B_s^0 \to J/\psi f_0$

[arXiv:1102.0206], accepted by PLB

Many other ways to measure ϕ_s will be used at LHCb:

$B_s^0 \to J/\psi\eta(\gamma\gamma)$, $B_s^0 \to J/\psi\eta(\pi^+\pi^-\pi^0)$, $B_s^0 \to \eta_c(4h)\phi$, $B_s^0 \to D_s^- D_s^+$, $B_s^0 \to J/\psi\eta'(\rho^0\gamma)$, $B_s^0 \to J/\psi\eta'(\eta\pi^+\pi^-)$,
$B_s^0 \to J/\psi f_0(\pi^+\pi^-)$, $B_s^0 \to D_s^{(*)-} D_s^{(*)+}$, $B_s^0 \to \psi(2S)\phi$, $B_s^0 \to J/\psi(ee)\phi$, ...



$$R_{f_0/\phi} \equiv \frac{\Gamma(B_s^0 \to J/\psi f_0,\ f_0 \to \pi^+\pi^-)}{\Gamma(B_s^0 \to J/\psi\phi,\ \phi \to K^+K^-)} = 0.252^{+0.046+0.027}_{-0.032-0.033}$$

- Can be used to improve precision on the B_s^0 mixing phase
- Pure CP-eigenstate, hence simpler analysis

Conclusions and prospects

- Excellent performance of LHC and LHCb in 2010
- Many new results presented today for the first time
- Most of milestones towards $\phi_s^{J/\psi\phi}$ already achieved with only $\sim$36 pb^{-1}
  - Hundreds of $B_s^0 \rightarrow J/\psi\phi$ reconstructed with $\sigma_M \sim 7\,\mathrm{MeV}/c^2$ and $\sigma_t \sim 50\,\mathrm{fs}$
  - $b \rightarrow J/\psi X$ lifetime measurement

    $\tau(B^+ \rightarrow J/\psi K^+)$ = 1.689 $\pm$ 0.022 (stat) $\pm$ 0.047 (sys) ps
    $\tau(B^0 \rightarrow J/\psi K^{*0})$ = 1.512 $\pm$ 0.032 (stat) $\pm$ 0.042 (sys) ps
    $\tau(B^0 \rightarrow J/\psi K_S^0)$ = 1.558 $\pm$ 0.056 (stat) $\pm$ 0.022 (sys) ps
    $\tau^{single}(B_s^0 \rightarrow J/\psi\phi)$ = 1.447 $\pm$ 0.064 (stat) $\pm$ 0.056 (sys) ps
    $\tau(\Lambda_b \rightarrow J/\psi\Lambda)$ = 1.353 $\pm$ 0.108 (stat.) $\pm$ 0.035 (sys) ps
  - Untagged angular analyses of $B^0 \rightarrow J/\psi K^{*0}$ and $B_s^0 \rightarrow J/\psi\phi$
    - $\Delta\Gamma_s = 0.0774 \pm 0.119(\mathrm{stat}) \pm 0.021(\mathrm{sys})\,\mathrm{ps}^{-1}$ ($\phi_s = 0$)
  - OS and SS-π tagging calibrated
    - $\Delta m_d = 0.499 \pm 0.032(\mathrm{stat}) \pm 0.003(\mathrm{sys})\,\mathrm{ps}^{-1}$ with 6 k $B^0 \rightarrow D^-\pi^+$
    - $\Delta m_s = 17.63 \pm 0.11(\mathrm{stat}) \pm 0.04(\mathrm{sys})\,\mathrm{ps}^{-1}$ with 1 382 $B_s^0 \rightarrow D_s^-(3)\pi^+$
      already competitive with world average!
- Systematics very small → expect many improvements with the 2011 run
- Expect world best measurement of $\phi_s^{J/\psi\phi}$ in 2011!

Backup

References

References

- LHCb Collaboration, "Selections and lifetime measurements for exclusive $b \to J/\psi X$ decays with $J/\psi \to \mu\mu$ with 2010 data", CERN-LHCb-CONF-2011-001.
- LHCb Collaboration,"Untagged angular analysis of $B_s^0 \to J/\psi\phi$ and $B^0 \to J/\psi K^{*0}$ with the 2010 data", CERN-LHCb-CONF-2011-002.
- LHCb Collaboration, "Optimization and calibration of flavour tagging", CERN-LHCb-CONF-2011-003.
- LHCb Collaboration, "Measurement of Δm_d in the decay $B^0 \to D^-(K^+\pi-\pi-)\pi^+$", CERN-LHCb-CONF-2011-010.
- LHCb Collaboration,"Measurement of Δm_s in the decay $B_s^0 \to D_s(K^+K^-\pi^-)\pi^+$ ", CERN-LHCb-CONF-2011-005.

Phenomenology

B mixing and lifetime I

The neutral B_q $(q = d, s)$ system is described by the following equation

$$i\frac{d}{dt}\begin{pmatrix} |B_q(t)\rangle \\ |\bar{B}_q(t)\rangle \end{pmatrix} = \left(\hat{M}^q - \frac{i}{2}\hat{\Gamma}^q\right)\begin{pmatrix} |B_q(t)\rangle \\ |\bar{B}_q(t)\rangle \end{pmatrix}$$

The famous box diagrams give rise to off-diagonal elements M_{12}^q and Γ_{12}^q in the mass matrix $\hat{M}^q$ and the decay rate matrix $\hat{\Gamma}^q$

Diagonalization of $\hat{M}^q$ and $\hat{\Gamma}^q$ gives the mass eigenstates

$$\text{CP-odd:} \quad B_H := p\,B + q\,\bar{B} \quad , \quad \text{CP-even:} \quad B_L := p\,B - q\,\bar{B}$$

$$\text{with} \qquad |p|^2 + |q|^2 = 1$$

with the corresponding masses M_H^q, M_L^q and decay rates Γ_H^q, Γ_L^q

B mixing and lifetime II

$|M_{12}^q|$, $|\Gamma_{12}^q|$ and $\phi_q = \arg(-M_{12}^q/\Gamma_{12}^q)$ are related to three observables:

- **Mass difference:** $\Delta M_q := M_H^q - M_L^q = 2|M_{12}^q| \left(1 + \frac{1}{8}\frac{|\Gamma_{12}^q|^2}{|M_{12}^q|^2}\sin^2\phi_q + ...\right)$
  $|M_{12}^q|$: heavy virtual particles: t, SUSY, ...

- **Decay rate difference:**
  $\Delta\Gamma_q := \Gamma_L^q - \Gamma_H^q = 2|\Gamma_{12}^q|\cos\phi_q \left(1 - \frac{1}{8}\frac{|\Gamma_{12}^q|^2}{|M_{12}^q|^2}\sin^2\phi_q + ...\right)$
  $|\Gamma_{12}^q|$: light real particles: u, c, ... no NP – below hadronic uncertainties

- **Flavour specific / semi leptonic CP asymmetries:**

$$a_{sl}^q \quad = \quad \mathrm{Im}\frac{\Gamma_{12}^q}{M_{12}^q} + \mathcal{O}\left(\frac{\Gamma_{12}^q}{M_{12}^q}\right)^2 = \frac{\Delta\Gamma_q}{\Delta M_q}\tan\phi_q + \mathcal{O}\left(\frac{\Gamma_{12}^q}{M_{12}^q}\right)^2$$

B mixing and lifetime III

In the SM one obtains

$$\begin{aligned} M_{12,q} &= \frac{G_F^2}{12\pi^2}(V_{tq}^* V_{tb})^2 M_W^2 S_0(x_t) B_{B_q} f_{B_q}^2 M_{B_q}\hat{\eta}_B \\ \Delta\Gamma_s &= \left(\frac{f_{B_s}}{240\,\mathrm{MeV}}\right)^2 \left[0.105 B + 0.024 \tilde{B}'_S - 0.027 B_R\right] \\ \frac{\Delta\Gamma_s}{\Delta M_s} &= 10^{-4}\cdot\left[46.2 + 10.6\frac{\tilde{B}'_S}{B} - 11.9\frac{B_R}{B}\right] \end{aligned}$$

$\mathrm{B}_s^0 \to \mathrm{J}/\psi\phi$ decay rates (1)

$$\frac{d^4\Gamma(\mathrm{B}_s^0 \to \mathrm{J}/\psi\phi)}{dt\, d\Omega} \propto \sum_{k=1}^{6} h_k(t) f_k(\Omega)\,, \quad \text{and} \quad \frac{d^4\Gamma(\overline{\mathrm{B}}_s^0 \to \mathrm{J}/\psi\phi)}{dt\, d\Omega} \propto \sum_{k=1}^{6} \bar{h}_k(t) f_k(\Omega)\,.$$

B_s^0 time and angular terms:

k	$h_k(t)$	$\bar{h}_k(t)$	$f_k(\theta,\psi,\varphi)$
1	$\lvert A_0(t)\rvert^2$	$\lvert \bar{A}_0(t)\rvert^2$	$2\cos^2\psi(1-\sin^2\theta\cos^2\varphi)$
2	$\lvert A_{\lvert\lvert}(t)\rvert^2$	$\lvert \bar{A}_{\lvert\lvert}(t)\rvert^2$	$\sin^2\psi(1-\sin^2\theta\sin^2\varphi)$
3	$\lvert A_\perp(t)\rvert^2$	$\lvert \bar{A}_\perp(t)\rvert^2$	$\sin^2\psi\sin^2\theta$
4	$\Im\{A_{\lvert\lvert}^*(t)A_\perp(t)\}$	$\Im\{\bar{A}_{\lvert\lvert}^*(t)\bar{A}_\perp(t)\}$	$-\sin^2\psi\sin 2\theta\sin\varphi$
5	$\Re\{A_0^*(t)A_{\lvert\lvert}(t)\}$	$\Re\{\bar{A}_0^*(t)\bar{A}_{\lvert\lvert}(t)\}$	$\frac{1}{\sqrt{2}}\sin 2\psi\sin^2\theta\sin 2\varphi$
6	$\Im\{A_0^*(t)A_\perp(t)\}$	$\Im\{\bar{A}_0^*(t)\bar{A}_\perp(t)\}$	$\frac{1}{\sqrt{2}}\sin 2\psi\sin 2\theta\cos\varphi$

$\mathrm{B_s^0} \rightarrow J/\psi\phi$ decay rates (2)

Time dependent amplitude for $\mathrm{B_s^0}$:

$$|A_0(t)|^2 = |A_0(0)|^2 e^{-\Gamma_s t}\left[\cosh\left(\frac{\Delta\Gamma_s t}{2}\right) - \cos\phi_s \sinh\left(\frac{\Delta\Gamma_s t}{2}\right) + \sin\phi_s \sin(\Delta m_s t)\right],$$

$$|A_{||}(t)|^2 = |A_{||}(0)|^2 e^{-\Gamma_s t}\left[\cosh\left(\frac{\Delta\Gamma_s t}{2}\right) - \cos\phi_s \sinh\left(\frac{\Delta\Gamma_s t}{2}\right) + \sin\phi_s \sin(\Delta m_s t)\right],$$

$$|A_{\perp}(t)|^2 = |A_{\perp}(0)|^2 e^{-\Gamma_s t}\left[\cosh\left(\frac{\Delta\Gamma_s t}{2}\right) + \cos\phi_s \sinh\left(\frac{\Delta\Gamma_s t}{2}\right) - \sin\phi_s \sin(\Delta m_s t)\right],$$

$$\Re\{A_0^*(t)A_{||}(t)\} = |A_0(0)||A_{||}(0)| e^{-\Gamma_s t} \cos\delta_{||}\left[\cosh\left(\frac{\Delta\Gamma_s t}{2}\right) - \cos\phi_s \sinh\left(\frac{\Delta\Gamma_s t}{2}\right) + \sin\phi_s \sin(\Delta m_s t)\right]$$

$$\begin{aligned}\Im\{A_{||}^*(t)A_{\perp}(t)\} = {} & |A_{||}(0)||A_{\perp}(0)| e^{-\Gamma_s t}\left[-\cos(\delta_{\perp} - \delta_{||})\sin\phi_s \sinh\left(\frac{\Delta\Gamma_s t}{2}\right)\right. \\ & \left. + \sin(\delta_{\perp} - \delta_{||})\cos(\Delta m_s t) - \cos(\delta_{\perp} - \delta_{||})\cos\phi_s \sin(\Delta m_s t)\right],\end{aligned}$$

$$\Im\{A_0^*(t)A_{\perp}(t)\} = |A_0(0)||A_{\perp}(0)| e^{-\Gamma_s t}\left[-\cos\delta_{\perp}\sin\phi_s \sinh\left(\frac{\Delta\Gamma_s t}{2}\right) + \sin\delta_{\perp}\cos(\Delta m_s t) - \cos\delta_{\perp}\cos\phi_s \sin(\Delta m_s t)\right].$$

- For $\overline{\mathrm{B}}{}_s^0$: change sign → loose sensitivity if no tagging

New physics effects

General parametrization of new physics effects in mixing

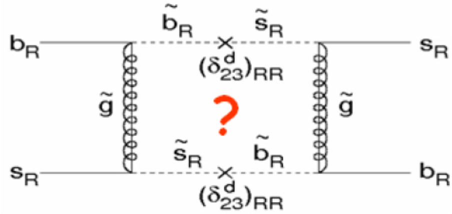
$$\Gamma_{12,s} = \Gamma_{12,s}^{\mathrm{SM}}\,, \qquad M_{12,s} = M_{12,s}^{\mathrm{SM}} \cdot \Delta_s\,; \qquad \Delta_s = |\Delta_s| e^{i\phi_s^\Delta}$$

leads to the following relations for observables

$$\begin{aligned}
\Delta M_s &= 2|M_{12,s}^{\mathrm{SM}}| \cdot |\Delta_s| \\
\Delta \Gamma_s &= 2|\Gamma_{12,s}| \cdot \cos\left(\phi_s^{\mathrm{SM}} + \phi_s^\Delta\right) \\
a_{fs}^s &= \frac{|\Gamma_{12,s}|}{|M_{12,s}^{\mathrm{SM}}|} \cdot \frac{\sin\left(\phi_s^{\mathrm{SM}} + \phi_s^\Delta\right)}{|\Delta_s|} \\
\phi_s^{J/\Psi\phi} &= -2\beta_s + \phi_s^\Delta + \delta_{\mathrm{Peng.}}^{\mathrm{SM}} + \delta_{\mathrm{Peng.}}^{\mathrm{NP}}
\end{aligned}$$

Remember: $\phi_s^{\mathrm{SM}} = \arg(-M_{12}^s/\Gamma_{12}^s)$ and $\beta_s = \arg\left(-V_{\mathrm{ts}} V_{\mathrm{tb}}^* / V_{\mathrm{cs}} V_{\mathrm{cb}}^*\right)$

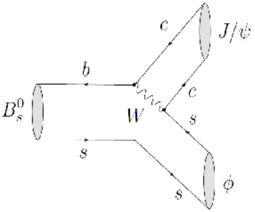
New physics in B_s^0-mixing

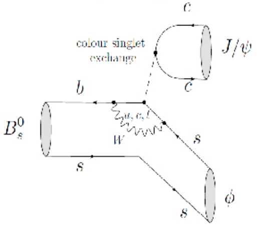


- **Examples of NP affecting Φ and being compatible with $\Delta m_s = 17.8 ps^{-1}$**
  - hep-ph/0703117 (little higgs model with T parity)
  - hep-ph/0703112 (susy, extra Z', little Higgs)
  - Hou et al., hep-ph/0810.3396 (4th generation; top')
  - ...

Penguin pollution in $B_s^0 \to J/\psi\phi$

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





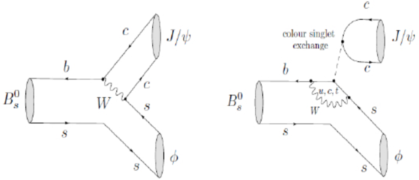
$$
\begin{aligned}
A(\bar{b} \to \bar{c}c\bar{s}) &= V_{cs}V_{cb}^*(A_T + P_c) + V_{us}V_{ub}^*P_u + V_{ts}V_{tb}^*P_t \\
&= V_{cs}V_{cb}^*(A_T + P_c - P_t) + V_{us}V_{ub}^*(P_u - P_t)
\end{aligned}
$$

$$\boxed{V_{ts}V_{tb}^* = -V_{us}V_{ub}^* - V_{cs}V_{cb}^*} \qquad \boxed{\sim A\lambda^2(1-\lambda^2/2)} \qquad \boxed{\sim A\lambda^4(\rho + i\eta)}$$

- 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 in $B_s^0 \to J/\psi\phi$

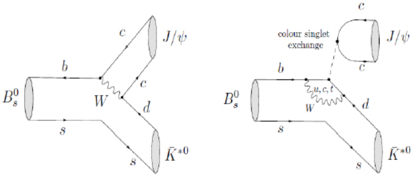
[S. Faller et al. arXiv:0810.4248v1]



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

Penguins suppressed by λ^2

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



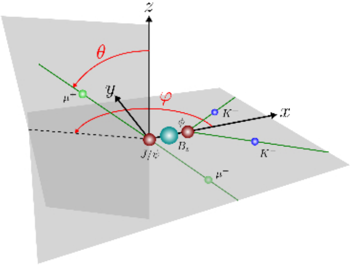
$\bar{b} \to \bar{d}c\bar{c}$

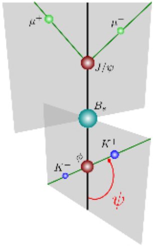
Penguins NOT suppressed wrt tree

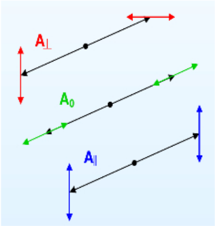
$$A(B_s^0 \to (J/\psi \bar{K}^{*0})_f) = \lambda \mathcal{A}'_f\left[1 - a'_f e^{i\theta'_f} e^{i\gamma}\right]$$

P$\rightarrow$ VV decays

- B_s is a pseudo scalar (spin=0), ϕ and J/ψ are vectors mesons ($J^{\pi} = 1^{-}$)
- Total angular momentum conservation $\Rightarrow$
  in the B_s rest frame, ϕ and J/ψ have relative orbital momentum ℓ =0,1,2
- Since CP|$J/\psi\ \phi$>= $(-1)^{\ell}$|$J/\psi\ \phi$>,
  final state is mixture of CP even (ℓ=0,2) and CP odd (ℓ=1)
- Decompose decay amplitudes in term of linear polarization, when J/ψ and ϕ are:
  - A_0: longitudinally polarized (CP-even)
  - $A_\perp$: transversely polarized and $\perp$ to each other (CP-odd)
  - $A_\parallel$: transversely polarized and $\parallel$ to each other (CP-even)
- $\Rightarrow$ 3 angles θ, ϕ, ψ describe directions of final decay products $J/\psi\rightarrow\mu\mu$ and $\phi\rightarrow K^+K$







A way to introduce β_s

V_{CKM} can be written with 4 independent parameters:

- the « usual » Wolfenstein parameters λ,A,ρ,η

$$V_{\mathrm{CKM}} = \begin{pmatrix} 1-\frac{1}{2}\lambda^2 & \lambda & A\lambda^3(\rho - i\eta) \\ -\lambda & 1-\frac{1}{2}\lambda^2 & A\lambda^2 \\ A\lambda^3(1-\rho-i\eta) & -A\lambda^2 & 1 \end{pmatrix} + \mathcal{O}(\lambda^4)$$

- Or $|V_{us}|$, $|V_{ub}|$, $|V_{cb}|$, $|V_{td}|$ [Branco 1988]
- Or 4 independent phases: γ, β, β_s, β_K

$$\gamma = \arg\left(-\frac{V_{\mathrm{ud}}V^*_{\mathrm{ub}}}{V_{\mathrm{cd}}V^*_{\mathrm{cb}}}\right)$$

$$\beta = \arg\left(-\frac{V_{\mathrm{cd}}V^*_{\mathrm{cb}}}{V_{\mathrm{td}}V^*_{\mathrm{tb}}}\right)$$

$$\beta_{\mathrm{s}} = \arg\left(-\frac{V_{\mathrm{ts}}V^*_{\mathrm{tb}}}{V_{\mathrm{cs}}V^*_{\mathrm{cb}}}\right)$$

$$\beta_{\mathrm{K}} = \arg\left(-\frac{V_{\mathrm{us}}V^*_{\mathrm{ud}}}{V_{\mathrm{cs}}V^*_{\mathrm{cd}}}\right)$$

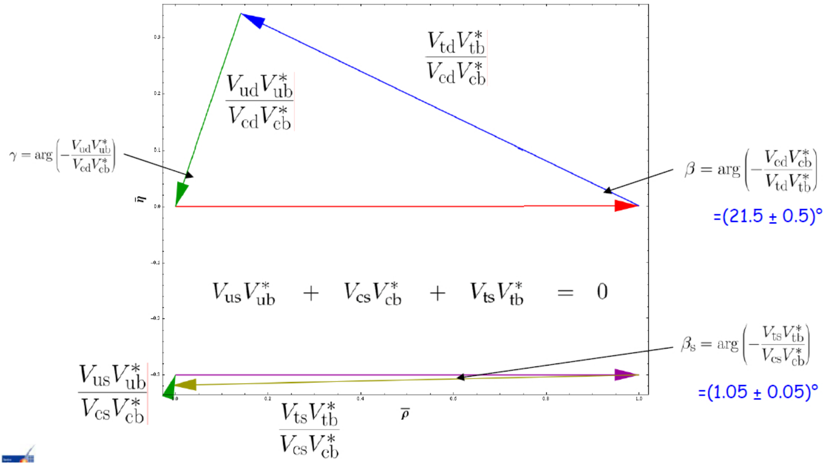
- References:
  - G. C. Branco and L. Lavoura, Phys. Lett. B 208, 123 (1988).
  - G. C. Branco et al., CP violation, Oxford University Press, (1999)
  - R. Aleksan, B. Kayser, and D. London. Determining the Quark Mixing Matrix from CP-Violating Asymmetries. *Phys. Rev. Lett.*, 73:18.20, 1994, hep-ph/9403341
  - See also: J. Silva, hep-ph/0410351

b–d and b–s unitarity triangles

SM values, both triangles on the same scale, bs triangle shifted by etabar-0.3 to be visible

b-d triangIde divided by VcdVcb*; while bs triangle divided by VcsVcb*

$$V_{ud}V_{ub}^* + V_{cd}V_{cb}^* + V_{td}V_{tb}^* = 0$$



$\gamma = \arg\left(-\frac{V_{ud}V_{ub}^*}{V_{cd}V_{cb}^*}\right)$

$\beta = \arg\left(-\frac{V_{cd}V_{cb}^*}{V_{td}V_{tb}^*}\right)$

=(21.5 ± 0.5)°

$\beta_s = \arg\left(-\frac{V_{ts}V_{tb}^*}{V_{cs}V_{cb}^*}\right)$

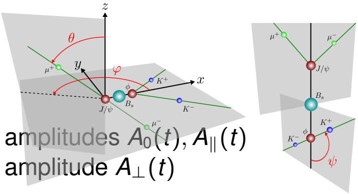
=(1.05 ± 0.05)°

Challenges

- $\mathrm{B_s^0} \to \mathrm{J}/\psi\phi$ is a P→VV decay
  - $\mathrm{J}/\psi\phi$ final state is a mixture of CP odd and CP even states
  - Angular analysis to disentangle statistically the 3 amplitudes:

    $\propto e^{-\Gamma_L t}$ CP-even[1] with decay amplitudes $A_0(t), A_\parallel(t)$

    $\propto e^{-\Gamma_H t}$ CP-odd with decay amplitude $A_\perp(t)$



- $\mathrm{B_s^0}$ system oscillates rapidly
  - Need fine proper time resolution
- $\Delta\Gamma_\mathrm{s} \gg \Delta\Gamma_\mathrm{d}$
  - Correlation between proper time and angular variables

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[1] For $\phi_\mathrm{s} = 0$, $\phi_\mathrm{s}^\mathrm{SM} = -0.0368$

$\mathrm{b} \rightarrow \mathrm{J}/\psi\mathrm{X}$ lifetimes

[LHCb-CONF-2011-001]

LHCb $\mathrm{b} \to \mathrm{J}/\psi \mathrm{X}$ yield with 36 pb^{-1}

[LHCb-CONF-2011-001]

Channel	All triggers	Unbiased trigger and $t > 0.3\,\mathrm{ps}$
$\mathrm{B}^+ \to \mathrm{J}/\psi \mathrm{K}^+$	12265 ± 297	6741 ± 85
$\mathrm{B}^0 \to \mathrm{J}/\psi \mathrm{K}^{*0}$	4883 ± 354	2668 ± 58
$\mathrm{B}^0 \to \mathrm{J}/\psi \mathrm{K}^0_\mathrm{S}$	1462 ± 88	838 ± 31
$\mathrm{B}^0_\mathrm{s} \to \mathrm{J}/\psi \phi$	959 ± 89	570 ± 24
$\Lambda_b \to \mathrm{J}/\psi \Lambda$	443 ± 71	187 ± 16

More on lifetimes

- $\mathrm{B_s^0}$–$\mathrm{\overline{B}_s^0}$ system has two lifetimes, τ_L and τ_H.
  When fitting a single exponential to the proper time distribution of $\mathrm{B_s^0} \rightarrow \mathrm{J}/\psi\phi$, we measure:

  $$\tau^{\mathrm{single}} = \frac{A\tau_\mathrm{H}^2 + B\tau_\mathrm{L}^2}{A\tau_\mathrm{H} + B\tau_\mathrm{L}}$$

  with

  $$A = (1 - \cos\phi_\mathrm{s})\frac{|A_0(0)|^2}{2} + (1 - \cos\phi_\mathrm{s})\frac{|A_\parallel(0)|^2}{2} + (1 + \cos\phi_\mathrm{s})\frac{|A_\perp(0)|^2}{2}$$

  $$B = (1 + \cos\phi_\mathrm{s})\frac{|A_0(0)|^2}{2} + (1 + \cos\phi_\mathrm{s})\frac{|A_\parallel(0)|^2}{2} + (1 - \cos\phi_\mathrm{s})\frac{|A_\perp(0)|^2}{2}$$
- $|\mathrm{A}_0(0)|, |\mathrm{A}_\parallel(0)|, |\mathrm{A}_\perp(0)|$ and ϕ_s are the angular amplitudes and the CP-violating phase in $\mathrm{B_s^0} \rightarrow \mathrm{J}/\psi\phi$.
- Using MC10 input parameters, we calculate $\tau_{\mathrm{B_s^0}}^{\mathrm{single}} = 1.430\,\mathrm{ps}$.
- τ^{single} IS NOT the $\mathrm{B_s^0}$ lifetime, defined by $\tau_{\mathrm{B_s^0}} = 1/\Gamma_\mathrm{s}$

Lifetime: LHCb / CDF comparison

	LHCb 33.6 pb^{-1}(1)	Fitted τ (ps)	CDF (4.3 fb^{-1})	Fitted τ(2) (ps)
$B^+ \to J/\psi K^+$	6 741 ± 85	1.689 ± 0.022 ± 0.047	45 000 ± 230	1.639 ± 0.009 ± 0.009
$B^0 \to J/\psi K^{*0}$	2 668 ± 58	1.512 ± 0.032 ± 0.042	16 860 ± 140	1.502 ± 0.013 ± 0.016
$B^0 \to J/\psi K^0_S$	838 ± 31	1.558 ± 0.056 ± 0.022	12 070 ± 120	1.513 ± 0.016 ± 0.010
$B^0_s \to J/\psi \phi$	570 ± 24	1.473 ± 0.078 ± 0.059	6 504 ± 85	1.530 ± 0.025 ± 0.012
$\Lambda_b \to J/\psi \Lambda$	187 ± 16	1.353 ± 0.108 ± 0.035	1 710 ± 50	1.537 ± 0.045 ± 0.014

(1) Lifetime unbiased trigger only, $t > 0.3\,\mathrm{ps}$; LHCb-CONF-2011-001.
$B^0_s \to J/\psi\phi$: LHCb-CONF-2011-002
(2) CDF note 10071, 23 Feb 2010. $B^0_s \to J/\psi\phi$: CDF note 10206 5.2 fb^{-1}
The B^0_s lifetime on this slide is $1/\Gamma_s$

Untagged angular analysis of $\mathrm{B}^0 \rightarrow \mathrm{J}/\psi \mathrm{K}^{*0}$ and $\mathrm{B}_s^0 \rightarrow \mathrm{J}/\psi \phi$

[LHCb-CONF-2011-002]

Untagged angular analysis of $\mathrm{B}^0 \to \mathrm{J}/\psi \mathrm{K}^{*0}$ [LHCb-CONF-2011-002]

- Perform Unbinned Maximum Likelihood fit
  in B-mass m, proper time t and decay angles $\Omega = \{\cos\theta, \varphi, \cos\psi\}$
- Probability density function
  $\mathcal{P}(m,t,\Omega) = f_{\text{sig}}\mathcal{S}(m)\mathcal{S}(t,\Omega) + (1-f_{\text{sig}})\mathcal{B}(m)\mathcal{B}(t)\mathcal{B}(\Omega)$
- Signal description given by diff. decay rate

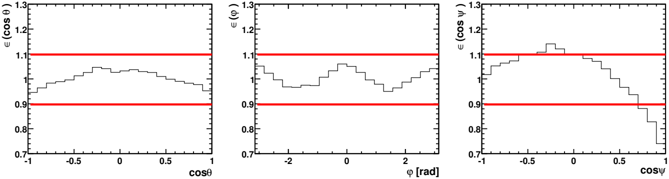
$$\mathcal{S}(t,\Omega;\lambda_{\text{Phys.}}) \quad = \quad \frac{d\Gamma(\mathrm{B}^0 \to \mathrm{J}/\psi \mathrm{K}^{*0} \text{ or } \mathrm{B}_s^0 \to \mathrm{J}/\psi\phi)}{d\Omega\, dt}$$

- Physics parameters
  $\mathrm{B}^0 \to \mathrm{J}/\psi \mathrm{K}^{*0}$: $\lambda_{\text{Phys.}} = \{\Gamma_d, |A_0(0)|^2, |A_\parallel(0)|^2, |A_\perp(0)|^2, \delta_\parallel, \delta_\perp\}$
  $\mathrm{B}_s^0 \to \mathrm{J}/\psi\phi$: $\lambda_{\text{Phys.}} = \{\Delta\Gamma_s, \Gamma_s, |A_0(0)|^2, |A_\parallel(0)|^2, |A_\perp(0)|^2, \delta_\parallel\}$
- Background description
  $\mathcal{B}(t)$ double exponential
  $\mathcal{B}(\Omega)$ flat/histogram/parametrization using Legendre polynomials
  Alternative background treatment: S-weights
- Cross-check results from three groups using three independent fitters

Angular Acceptances from Monte Carlo [LHCb-CONF-2011-002]

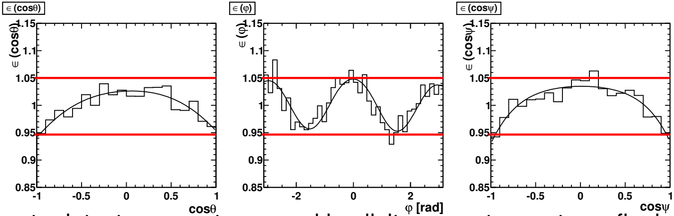
$B^0 \to J/\psi K^{*0}$

±10%



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

±5%



- Nonflat due to detector acceptance and implicit momentum cuts on final state particles
- Implemented via 3D histogram/analytic parametr./norm. weights
- Shapes taken from MC, extensive crosschecks performed

Fitting $\mathrm{B}^0 \to \mathrm{J}/\psi \mathrm{K}^{*0}$

- Signal PDF for the decay $\mathrm{B}^0 \to \mathrm{J}/\psi \mathrm{K}^{*0}$

$$\begin{aligned}\frac{\mathrm{d}^4\Gamma}{dtd\Omega} \quad = \quad & e^{-\Gamma_{\mathrm{d}}t}\big[f_1(\Omega)|A_0(0)|^2 + f_2(\Omega)|A_{\|}(0)|^2 + f_3(\Omega)|A_{\perp}(0)|^2 \\ & \pm f_4(\Omega)\sin(\delta_{\perp} - \delta_{\|})|A_{\|}(0)||A_{\perp}(0)| \\ & + f_5(\Omega)\cos\delta_{\|}|A_0(0)||A_{\|}(0)| \\ & \pm f_6(\Omega)\sin\delta_{\perp}|A_0(0)||A_{\perp}(0)|\big]\end{aligned}$$

- ± for $K^+\pi^-(K^-\pi^+)$ in final state
- Terms $f_i(\Omega)$ describe angular dependence of the amplitudes/interference terms
- Nonresonant $K\pi$ S-wave contribution also included
- Angular and time acceptance included in the fit
- Convoluted with triple gaussian proper time resolution as described in LHCb-CONF-2011-001

Untagged angular analysis of $\mathrm{B}^0 \to \mathrm{J}/\psi \mathrm{K}^{*0}$ [LHCb-CONF-2011-002]

Parameter	Result
$\lvert A_{\parallel}\rvert^2$	0.252 ± 0.020
$\lvert A_{\perp}\rvert^2$	0.178 ± 0.022
$\delta_{\parallel}\,[\mathrm{rad}]$	-2.87 ± 0.11
$\delta_{\perp}\,[\mathrm{rad}]$	3.02 ± 0.10
$\lvert A_{\mathrm{s}}\rvert^2$	0.051 ± 0.022
$\delta_{\mathrm{s}}\,[\mathrm{rad}]$	2.16 ± 0.15
$\Gamma_{\mathrm{d}}\,[\mathrm{ps}^{-1}]$	0.659 ± 0.015

$B^0 \to J/\psi K^{*0}$ Systematics

	$\lvert A_{\parallel}\rvert^2$	$\lvert A_{\perp}\rvert^2$	$\delta_{\parallel}$ [rad]	$\delta_{\perp}$ [rad]	$\lvert A_s\rvert^2$	δ_s [rad]	Γ_d [ps^{-1}]
proper time acceptance	-	-	-	-	-	-	0.018
data/MC differences	0.008	0.006	**0.07**	**0.05**	0.006	**0.22**	0.001
statistical error of acceptance	0.002	0.001	-	0.01	0.001	0.01	0.002
wrong-signal fraction	0.004	0.001	-	0.01	0.005	0.01	0.012
background treatment	0.002	0.008	0.04	0.01	**0.008**	0.09	**0.032**
statistical error of background	0.008	0.005	0.02	0.01	0.005	0.03	0.003
mass model	**0.010**	0.002	0.01	0.01	0.007	0.07	0.015
s-wave treatment	0.001	**0.013**	0.05	**0.05**	-	-	0.002
sum	0.016	0.017	0.10	0.07	0.014	0.25	0.042

- Sideband subtracted data shows slight disagreement with signal MC
- The MC is reweighted in several distributions
- The fit is then repeated with acceptance corrections determined from reweighted MC

$B^0 \to J/\psi K^{*0}$ Systematics

	$\|A_{\|\|}\|^2$	$\|A_\perp\|^2$	$\delta_{\|\|}$ [rad]	$\delta_\perp$ [rad]	$\|A_s\|^2$	δ_s [rad]	Γ_d [ps^{-1}]
proper time acceptance	-	-	-	-	-	-	0.018
data/MC differences	0.008	0.006	**0.07**	**0.05**	0.006	**0.22**	0.001
statistical error of acceptance	0.002	0.001	-	0.01	0.001	0.01	0.002
wrong-signal fraction	0.004	0.001	-	0.01	0.005	0.01	0.012
background treatment	0.002	0.008	0.04	0.01	**0.008**	0.09	**0.032**
statistical error of background	0.008	0.005	0.02	0.01	0.005	0.03	0.003
mass model	**0.010**	0.002	0.01	0.01	0.007	0.07	0.015
s-wave treatment	0.001	**0.013**	0.05	**0.05**	-	-	0.002
sum	0.016	0.017	0.10	0.07	0.014	0.25	0.042

- Use legendre polynomials instead of the 3D histogram as background parametrization

$B^0 \to J/\psi K^{*0}$ Systematics

	$\|A_\parallel\|^2$	$\|A_\perp\|^2$	$\delta_\parallel\,[\mathrm{rad}]$	$\delta_\perp\,[\mathrm{rad}]$	$\|A_s\|^2$	$\delta_s\,[\mathrm{rad}]$	$\Gamma_d\,[\mathrm{ps}^{-1}]$
proper time acceptance	-	-	-	-	-	-	0.018
data/MC differences	0.008	0.006	**0.07**	**0.05**	0.006	**0.22**	0.001
statistical error of acceptance	0.002	0.001	-	0.01	0.001	0.01	0.002
wrong-signal fraction	0.004	0.001	-	0.01	0.005	0.01	0.012
background treatment	0.002	0.008	0.04	0.01	**0.008**	0.09	**0.032**
statistical error of background	0.008	0.005	0.02	0.01	0.005	0.03	0.003
mass model	**0.010**	0.002	0.01	0.01	0.007	0.07	0.015
s-wave treatment	0.001	**0.013**	0.05	**0.05**	-	-	0.002
sum	0.016	0.017	0.10	0.07	0.014	0.25	0.042

- Fit a double gaussian instead of a single gaussian to describe the signal mass distribution.

$B^0 \to J/\psi K^{*0}$ Systematics

	$\|A_\parallel\|^2$	$\|A_\perp\|^2$	$\delta_\parallel$ [rad]	$\delta_\perp$ [rad]	$\|A_s\|^2$	δ_s [rad]	Γ_d [ps^{-1}]
proper time acceptance	-	-	-	-	-	-	0.018
data/MC differences	0.008	0.006	**0.07**	**0.05**	0.006	**0.22**	0.001
statistical error of acceptance	0.002	0.001	-	0.01	0.001	0.01	0.002
wrong-signal fraction	0.004	0.001	-	0.01	0.005	0.01	0.012
background treatment	0.002	0.008	0.04	0.01	**0.008**	0.09	**0.032**
statistical error of background	0.008	0.005	0.02	0.01	0.005	0.03	0.003
mass model	**0.010**	0.002	0.01	0.01	0.007	0.07	0.015
s-wave treatment	0.001	**0.013**	0.05	**0.05**	-	-	0.002
sum	0.016	0.017	0.10	0.07	0.014	0.25	0.042

- Effect of neglecting the S-wave contribution

$B^0 \to J/\psi K^{*0}$ Systematics

	$\lvert A_\parallel\rvert^2$	$\lvert A_\perp\rvert^2$	$\delta_\parallel\,[\mathrm{rad}]$	$\delta_\perp\,[\mathrm{rad}]$	$\lvert A_s\rvert^2$	$\delta_s\,[\mathrm{rad}]$	$\Gamma_d\,[\mathrm{ps}^{-1}]$
proper time acceptance	-	-	-	-	-	-	0.018
data/MC differences	0.008	0.006	**0.07**	**0.05**	0.006	**0.22**	0.001
statistical error of acceptance	0.002	0.001	-	0.01	0.001	0.01	0.002
wrong-signal fraction	0.004	0.001	-	0.01	0.005	0.01	0.012
background treatment	0.002	0.008	0.04	0.01	**0.008**	0.09	**0.032**
statistical error of background	0.008	0.005	0.02	0.01	0.005	0.03	0.003
mass model	**0.010**	0.002	0.01	0.01	0.007	0.07	0.015
s-wave treatment	0.001	**0.013**	0.05	**0.05**	-	-	0.002
sum	0.016	0.017	0.10	0.07	0.014	0.25	0.042

S-wave implementation in $\mathrm{B}^0 \to \mathrm{J}/\psi \mathrm{K}^{*0}$ fit [LHCb-CONF-2011-002]

The implementation of a $m_{K\pi}$ dependent S-wave amplitude follows the prescription of the BABAR collaboration. When a $(K\pi)$ S-wave in the B decay amplitude is included in addition to the $(K\pi)$ P-wave the differential decay rate, $g(\Omega, \mathbf{A})$, becomes:

$$\frac{d\Gamma}{d\Omega} = \left[g(\Omega, \mathbf{A}) + |A_S|^2 f_7(\Omega) + \left[f_8(\Omega)\Re(A_\parallel A_S^*) + f_9(\Omega)\Im(A_\perp A_S^*) f_{10}\Re(A_0 A_S^*)\right]\right],$$

where $A_S = |A_S|\, e^{i\delta_S}$ is the complex S-wave amplitude. P and S-wave component should should sum to one, i.e. $|A_0|^2 + |A_\perp|^2 + \left|A_\parallel\right|^2 + |A_S|^2 = 1$.
The additional angular functions $f_{7\ldots10}$ of the transversity angles Ω are defined as:

$$\begin{aligned}
f_7(\Omega) &= \frac{3}{32\pi} 2\left[1 - \sin^2\theta \cos^2\phi\right], \\
f_8(\Omega) &= \frac{3}{32\pi} \sqrt{6} \sin\psi \sin^2\theta \sin 2\phi, \\
f_9(\Omega) &= \frac{3}{32\pi} \sqrt{6} \sin\psi \sin 2\theta \cos\phi, \\
f_{10}(\Omega) &= \frac{3}{32\pi} 4\sqrt{3} \cos\psi \left[1 - \sin^2\theta \cos^2\phi\right]
\end{aligned} \tag{1}$$

Untagged angular analysis of $B^0 \to J/\psi K^{*0}$

World results:

Parameters	CDF result (2007)	DØ result (2009)	BaBar result (2007)	Belle result (2002)
$\lvert A_{\parallel}\rvert^2$	$0.211 \pm 0.012 \pm 0.006$	$0.230 \pm 0.013 \pm 0.025$	$0.211 \pm 0.010 \pm 0.006$	-
$\lvert A_0\rvert^2$	$0.569 \pm 0.009 \pm 0.009$	$0.587 \pm 0.011 \pm 0.013$	$0.556 \pm 0.009 \pm 0.010$	$0.618 \pm 0.020 \pm 0.027$
$\lvert A_{\perp}\rvert$	-	-	$0.233 \pm 0.010 \pm 0.005$	$0.191 \pm 0.023 \pm 0.026$
$\delta_{\parallel}$ [rad]	$-2.96 \pm 0.08 \pm 0.03$	-	$-2.93 \pm 0.08 \pm 0.04$	$2.83 \pm 0.19 \pm 0.08$
$\delta_{\perp}$ [rad]	$2.97 \pm 0.06 \pm 0.01$	-	$2.91 \pm 0.05 \pm 0.03$	$3.05 \pm 0.13 \pm 0.06$

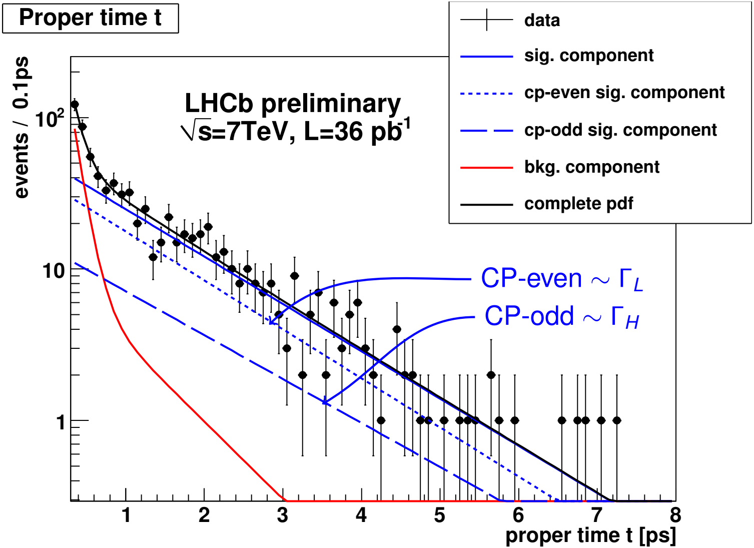
Fitting $\mathrm{B_s^0} \to \mathrm{J}/\psi\phi$ (Untagged) [LHCb-CONF-2011-002]

- Signal PDF for the decay $\mathrm{B_s^0} \to \mathrm{J}/\psi\phi$

$$\begin{aligned}\frac{\mathrm{d}^4\Gamma}{dtd\Omega} = & \; e^{-\Gamma_s t}\Big[|A_0(0)|^2 f_1(\Omega) e^{-\frac{\Delta\Gamma_\mathrm{s}}{2}t} \\ & + |A_\parallel(0)|^2 f_2(\Omega) e^{-\frac{\Delta\Gamma_s}{2}t} \\ & + |A_\perp(0)|^2 f_3(\Omega) e^{+\frac{\Delta\Gamma_s}{2}t} \\ & + \cos\delta_\parallel |A_0(0)||A_\parallel(0)| f_5(\Omega) e^{-\frac{\Delta\Gamma_s}{2}t}\Big]\end{aligned}$$

- This PDF assumes $\phi_\mathrm{s} = 0$, additional terms appear for $\phi_\mathrm{s} \neq 0$
- Angular and time acceptance included in the fit
- Convoluted with triple gaussian proper time resolution (LHCb-CONF-2011-001)

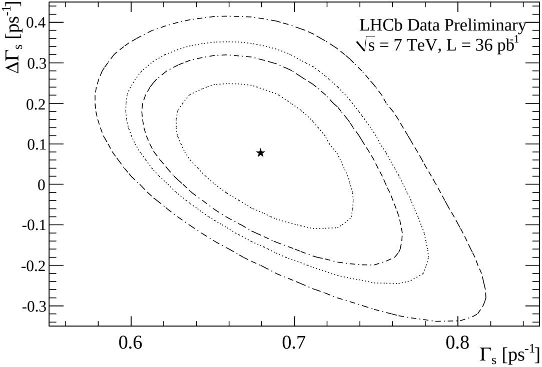
$B_s^0 \rightarrow J/\psi\phi$ Proper time projection



CP-even $\sim \Gamma_L$

CP-odd $\sim \Gamma_H$

$B_s^0 \to J/\psi\phi$ Likelihood projection $\Gamma_s - \Delta\Gamma_s$ [LHCb-CONF-2011-002]



The contour is obtained using the “profile likelihood method”. For every grid point a likelihood fit is performed in which $(\Gamma_s, \Delta\Gamma_s)$ are fixed to the grid point and all other parameters are floating. The negative log-likelihood $(-\ln\mathcal{L})$ of the fit is assigned to the grid point. The regions corresponding to confidence levels of 68.3, 90, 95 and 99% are given by the grid points for which $2\Delta\ln\mathcal{L} < X$ with $X = 2.30, 4.61, 5.99$ and 9.21 respectively.

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

[LHCb-CONF-2011-002]

Systematic effect	Abs. deviation for parameter				
	$\Gamma_s[\mathrm{ps}^{-1}]$	$\Delta\Gamma_s[\mathrm{ps}^{-1}]$	$\lvert A_\perp(0)\rvert^2$	$\lvert A_\parallel(0)\rvert^2$	$\delta_\parallel[\mathrm{rad}]$
Lifetime resolution	0.0001	-	-	-	-
Angular acceptance	-	-	-	0.0007	-
Acceptance parametrization	0.0002	0.001	0.0017	0.0013	-
Lifetime acceptance	**0.0272**	0.001	0.0003	0.0002	-
S-wave	0.003	0.003	**0.013**	**0.028**	**0.13**
Background description	0.0002	**0.02**	0.0016	0.0012	-
Mass model	0.0004	0.004	0.0032	0.0006	-
Σ (quadratic)	0.0274	0.0206	0.0136	0.0281	0.13

- Neglecting the Lifetime acceptance correction $\epsilon(t) = 1 + \beta t$

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

[LHCb-CONF-2011-002]

Systematic effect	Abs. deviation for parameter $\Gamma_s[\mathrm{ps}^{-1}]$	$\Delta\Gamma_s[\mathrm{ps}^{-1}]$	$\|A_\perp(0)\|^2$	$\|A_\parallel(0)\|^2$	$\delta_\parallel[\mathrm{rad}]$
Lifetime resolution	0.0001	-	-	-	-
Angular acceptance	-	-	-	0.0007	-
Acceptance parametrization	0.0002	0.001	0.0017	0.0013	-
Lifetime acceptance	**0.0272**	0.001	0.0003	0.0002	-
S-wave	0.003	0.003	**0.013**	**0.028**	**0.13**
Background description	0.0002	**0.02**	0.0016	0.0012	-
Mass model	0.0004	0.004	0.0032	0.0006	-
Σ (quadratic)	0.0274	0.0206	0.0136	0.0281	0.13

- Fit with S-wave is unstable with the low $B_s^0 \to J/\psi\phi$ statistics
- The effect of neglecting a 6.7% S-wave contribution is determined using toy MC

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

[LHCb-CONF-2011-002]

Systematic effect	Abs. deviation for parameter				
	$\Gamma_s\,[\mathrm{ps}^{-1}]$	$\Delta\Gamma_s\,[\mathrm{ps}^{-1}]$	$\lvert A_\perp(0)\rvert^2$	$\lvert A_\parallel(0)\rvert^2$	$\delta_\parallel\,[\mathrm{rad}]$
Lifetime resolution	0.0001	-	-	-	-
Angular acceptance	-	-	-	0.0007	-
Acceptance parametrization	0.0002	0.001	0.0017	0.0013	-
Lifetime acceptance	**0.0272**	0.001	0.0003	0.0002	-
S-wave	0.003	0.003	**0.013**	**0.028**	**0.13**
Background description	0.0002	**0.02**	0.0016	0.0012	-
Mass model	0.0004	0.004	0.0032	0.0006	-
Σ (quadratic)	0.0274	0.0206	0.0136	0.0281	0.13

- A flat background is used instead of the analytic parametrization

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

[LHCb-CONF-2011-002]

Parameter	Result ± stat. ± syst.
$\Gamma_s[\mathrm{ps}^{-1}]$	$0.679 \pm 0.036 \pm 0.027$
$\Delta\Gamma_s[\mathrm{ps}^{-1}]$	$0.077 \pm 0.119 \pm 0.021$
$\lvert A_0(0)\rvert^2$	$0.528 \pm 0.040 \pm 0.028$
$\lvert A_\perp(0)\rvert^2$	$0.263 \pm 0.056 \pm 0.014$
$\delta_\parallel$ [rad]	$3.14 \pm 0.52 \pm 0.13$

$$\Rightarrow |A_\parallel(0)|^2 = 1 - |A_0(0)|^2 - |A_\perp(0)|^2 = 0.209$$

CDF untagged PRL 100, 121803 (2008)	
Parameter	Result ± stat. ± syst.
$\Gamma_s[\mathrm{ps}^{-1}]$	$0.658 \pm 0.017 \pm 0.009$
$\Delta\Gamma_s[\mathrm{ps}^{-1}]$	$0.076^{+0.059}_{-0.063} \pm 0.006$
$\lvert A_0(0)\rvert^2$	$0.531 \pm 0.020 \pm 0.007$
$\lvert A_\perp(0)\rvert^2$	$0.239 \pm 0.029 \pm 0.011$
$\lvert A_\parallel(0)\rvert^2$	$0.230 \pm 0.026 \pm 0.009$

- Good agreement
- Results not yet competitive with the Tevatron (will be in 2011)

More on coverage correction

[LHCb-CONF-2011-002]

For low statistics the Likelihood projection method can lead to significant undercoverage. We therefore performed a study using the Feldman-Cousins method which gives correct coverage by design [PhysRevD.57.3873]. This computation intensive method determines the coverage contours in the $\phi_{\mathrm{s}} - \Delta\Gamma_{\mathrm{s}}$ plane by repeatedly generating and fitting toy Monte Carlo data sets for every grid point. For every toy data sample two fits are performed, one with ϕ_{s} and $\Delta\Gamma_{\mathrm{s}}$ fixed to the values at the grid point given by $\hat{\phi}_{\mathrm{s}}$ and $\Delta\hat{\Gamma}_{\mathrm{s}}$ and one fit which leaves these two parameters free. Every toy at every gridpoint therefore results in a Likelihood ratio $\Delta \ln \mathcal{L}_{\text{toy}} = \ln \mathcal{L}_{\text{toy}}(\hat{\phi}_{\mathrm{s}}, \Delta\hat{\Gamma}_{\mathrm{s}}, \lambda) / \ln \mathcal{L}_{\text{toy}}(\phi_{\mathrm{s}}, \Delta\Gamma_{\mathrm{s}}, \lambda)$, where λ denotes the remaining physics parameters which are varied in the fit. For every grid point the *p*-value is then given by the ratio of all toy data sets which have a larger $\Delta \ln \mathcal{L}$ than the data sample at this point. The coverage is then given by C.L. $= 1 - p$. We finally give coverage contours obtained from a Feldman-Cousins study performed using 1000 toy data sets at every point of a 40×40 grid.

Flavour Tagging

[LHCb-CONF-2011-003]

Flavour tagging

[LHCb-CONF-2011-003]

Combination of taggers & tagging categories

- Individual tag response are combined to form **OS** and **SS+OS tagging combinations**

$$P(b) = \frac{p(b)}{p(b) + p(\bar{b})}, \qquad P(\bar{b}) = 1 - P(b),$$

$$p(b) = \prod_i \left(\frac{1+q_i}{2} - q_i p_i\right), \qquad p(\bar{b}) = \prod_i \left(\frac{1-q_i}{2} + q_i p_i\right).$$

- OS are common to all the channels and allow to study the SSπ and SSK.
- $P = 1 - \eta = 1 - \omega^{calculated}$ is the event weight that can be used to separate the events in **categories** of events with similar mistag & gain in tagging performances (statistical independent samples)

NB: to get the best tagging performances, to have correct categories and to be able to use the ω per event the probabilities to tag correctly must be calibrated.
Since MC doesn't fully represent data, the calibration is done on data.

Detailed tagging performance

[LHCb-CONF-2011-003]

	$\varepsilon_{\rm tag}$(%)	ω(%)	$\varepsilon_{\rm eff}$(%)
$B^0 \longrightarrow D^{*-}\mu^+\nu_\mu$			
average OS	18.2±0.2	34.3±0.8	1.79±0.18
combined OS	18.3±0.2	33.6±0.8	1.97±0.18
average SSπ+OS	29.1±0.2	35.8±0.8	2.36±0.26
combined SS-π+OS	28.9±0.2	34.2±0.8	2.87± 0.32
$B^+ \longrightarrow J/\psi K^+$			
average OS	15.4±0.4	33.3±1.2	1.71±0.29
combined OS	15.4±0.3	32.2±1.2	1.97±0.31
average SSπ+OS	22.7±0.4	35.5±1.0	1.92±0.30
combined SSπ+OS	23.0±0.5	33.9±1.1	2.38±0.33
$B^0 \longrightarrow J/\psi K^{*0}$			
average OS	15.7 ± 0.6	33.1 ± 3.0	1.79 ± 0.71
combined OS	15.8 ± 0.7	30.0 ± 6.6	2.52 ± 0.82
average SSπ+OS	25.9 ± 0.8	37.0 ± 2.4	1.75 ± 0.70
combined SSπ+OS	26.1 ± 0.9	33.6 ± 5.1	2.82 ± 0.87

B^0–$\overline{B}^0$ and B_s^0–$\overline{B}_s^0$ mixing frequency

[LHCb-CONF-2011-010] and [LHCb-CONF-2011-005]

B–$\overline{\mathrm{B}}$ mixing frequency

[LHCb-CONF-2011-010]

Systematics

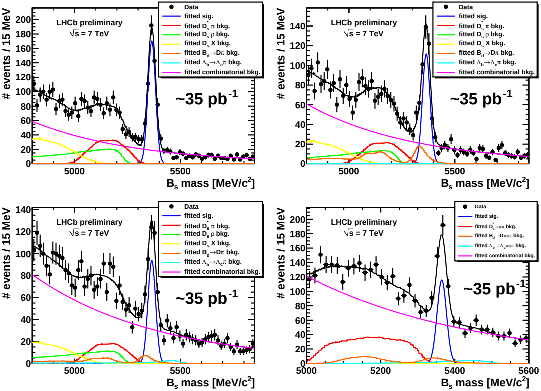
Study	$\Delta(\Delta m_d)$ [ps^{-1}]	p_0	p_1
proper time resolution	0.000	0.000	0.00
proper time acceptance	0.003	0.001	0.01
variation of η_c PDF	0.002	0.004	0.15
floating fit parameters	-	0.001	0.01
double Gaussian mass signal PDF	-	0.001	0.01
z-scale	0.0005	-	-
momentum scale	0.0005	-	-
Sum	0.004	0.004	0.15

Systematic uncertainties for opposite side taggers only

B_s^0–$\overline{B}_s^0$ mixing frequency

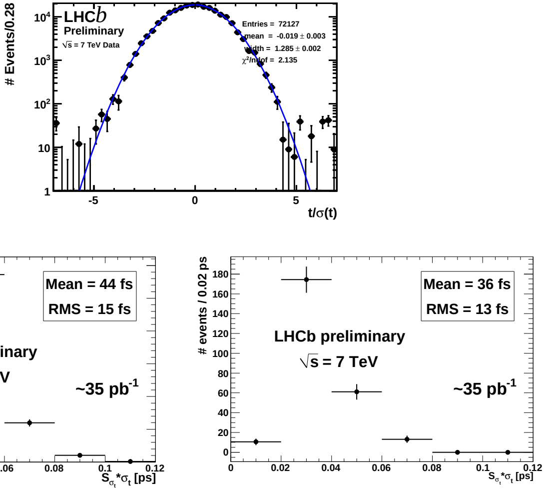
[LHCb-CONF-2011-005]

Decay mode	# signal candidates
$B_s \rightarrow D_s(\phi\pi)\pi$	515 ± 25
$B_s \rightarrow D_s(K^*K)\pi$	338 ± 27
$B_s \rightarrow D_s\pi$ non-resonant	283 ± 27
$B_s \rightarrow D_s 3\pi$	245 ± 46



B_s^0–$\overline{B}_s^0$ mixing frequency

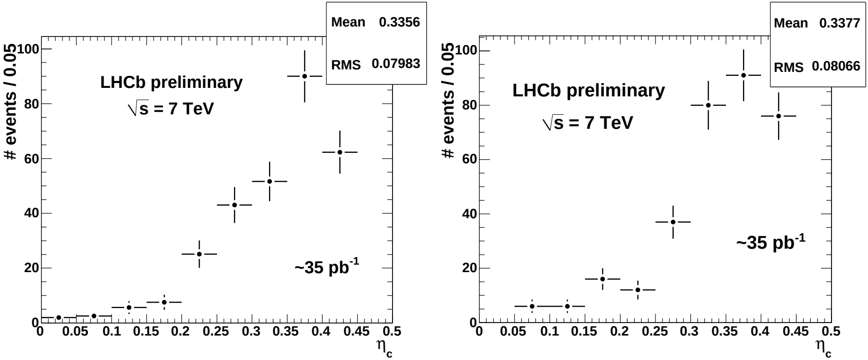
[LHCb-CONF-2011-005]



Proper time pull distribution of fake B_s^0 candidates (top). Scaled proper time uncertainties for signal B_s^0 candidates in the $B_s^0 \rightarrow D_s^-(K^+\pi^-\pi^-)\pi$ (left) and $B_s^0 \rightarrow D_s^-(K^+\pi^-\pi^-)3\pi$ mode (right) respectively.

B_s^0–$\overline{B}_s^0$ mixing frequency

[LHCb-CONF-2011-005]



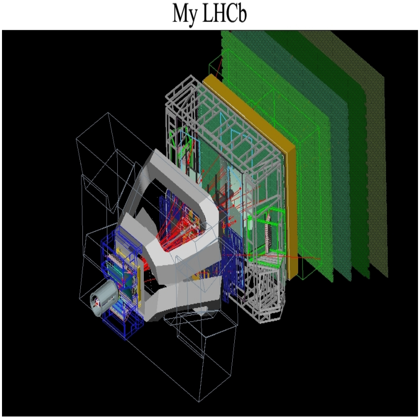
Predicted mis-tag probability η_c for B_s^0 signal (left) and combinatorial background candidates (right) together for the four B_s^0 decay modes used in the Δm_s measurement.

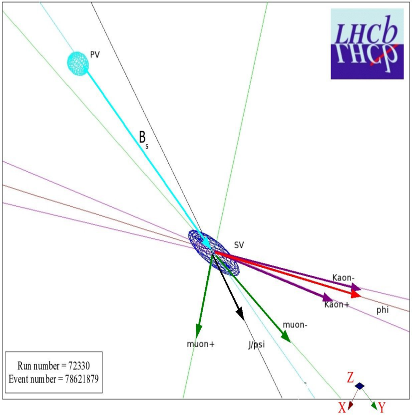
More on systematics related to lifetime

We estimate the “alignment” uncertainty from absolute uncertainties in the survey of the vertex detector and the agreement of the track based alignment with the survey. The CDF detector is a central detector, thus the detector has cylinders with a given radii. The tracks are curled in x/y plane. The momentum measurement is obtained by the curvature in x/y plane. The decay length (namely L_{xy} in CDF) is as well only measured in x/y projection. It is harder to align the position of the radii of the CDF detector due to the additional degree of freedom of the momentum of the tracks. Hence the absolute position is less well known than at LHCb. In addition, the boost at LHCb is much larger than at the Tevatron: B’s fly 9 mm in average, while only 1.5 mm at the Tevatron. So we have smaller relative uncertainties.

Uncertainties related to the momentum scale are estimated from the measured invariant mass of known resonances, most notably charmonium and b-hadrons.

First $B_s^0 \rightarrow J/\psi\phi$ candidate (flight distance $\sim 2\,\mathrm{cm}$!


My LHCb


Run number = 72330
Event number = 78621879

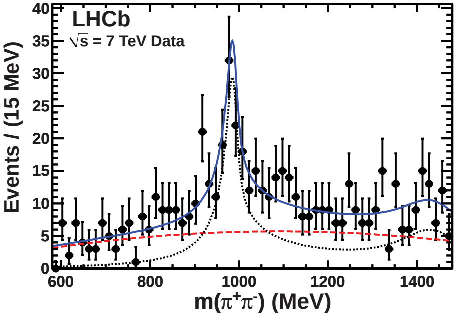
Other

LHCb: toyMC sensitivity to $\mathrm{B_s^0} \to \mathrm{J}/\psi\phi$-related parameters [arXiv:0912.4175]

Parameter	Units	Sensitivity $\times 10^3$: $\sigma \pm \delta_\sigma$	
		Only phys. parameters free	All parameters free
ϕ_s	rad	30 ± 2	31 ± 2
Γ_s	ps^{-1}	3.1 ± 0.1	2.9 ± 0.1
$\Delta\Gamma_s$	ps^{-1}	9.1 ± 0.4	9.1 ± 0.5
$R_\perp$		4.2 ± 0.2	4.2 ± 0.2
R_0		3.1 ± 0.1	3.0 ± 0.2
$\delta_\parallel$	rad	74 ± 3	72 ± 3
$\delta_\perp$	rad	89 ± 4	130 ± 7
Δm_s	ps^{-1}	–	44 ± 2
$M_{\mathrm{B_s}}$	MeV/c^2	–	52 ± 3
ω		–	13 ± 1
$f^s_{m,1}$		–	32 ± 2
$\sigma_{m,1}$	MeV/c^2	–	180 ± 10
$\sigma_{m,2}$	MeV/c^2	–	840 ± 40
$f^s_{t,1}$		–	20 ± 10(*)
μ^s_t	ps	–	3.6 ± 0.2
$\sigma^s_{t,1}$	ps	–	8.6 ± 0.4
$\sigma^s_{t,2}$	ps	–	14 ± 1
α^{Pr}_m	$(\mathrm{MeV}/c^2)^{-1}$	–	0.016 ± 0.001
μ^{Pr}_t	ps	–	0.082 ± 0.004
σ^{Pr}_t	ps	–	0.081 ± 0.004
α^{LL}_m	$(\mathrm{MeV}/c^2)^{-1}$	–	0.032 ± 0.002
$f^{\mathrm{LL}}_{\tau_1}$		–	3.8 ± 0.2
$\tau^{\mathrm{LL}}_{t,1}$	ps^{-1}	–	9.7 ± 0.5
$\tau^{\mathrm{LL}}_{t,2}$	ps^{-1}	–	1.5 ± 0.1
μ^{LL}_t	ps	–	3.0 ± 0.2
σ^{LL}_t	ps	–	1.16 ± 0.06

Parameter precisions and corresponding error obtained from simultaneous three-angle fit to different set of parameters using tagged and untagged events. Each value is the mean (and its uncertainty) of a single-Gaussian fit to the parameter distribution obtained in 300 toy Monte Carlo experiments, each corresponding to a dataset equivalent to 2 fb^{-1}. The value marked with (*) represent the error mean and RMS, since the distribution is not Gaussian.

More on $B_s^0 \to J/\psi f_0$ [arXiv:1102.0206]



The invariant mass of $\pi^+\pi^-$ combinations when the $J/\psi\pi^+\pi^-$ is required to be within ±30 MeV o f the B_s^0 mass. The dashed curve is the like-sign background that is taken from the data both in shape and absolute normal ization. The dotted curve is the result of the fit using Equation:

$$|A(m)|^2 = N_0 m p(m) q(m) \left| \text{Flatté}[f_0(980)] + A_1 \exp^{(i\delta)} \text{BW}[f_0(1370)] \right|^2 ,$$

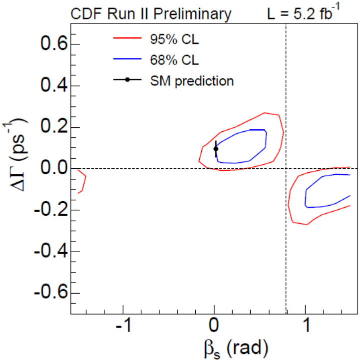
with

$$\text{Flatté}(m) = \frac{1}{m_0^2 - m^2 - i m_0 (g_1 \rho_{\pi\pi} + g_2 \rho_{KK})} ,$$

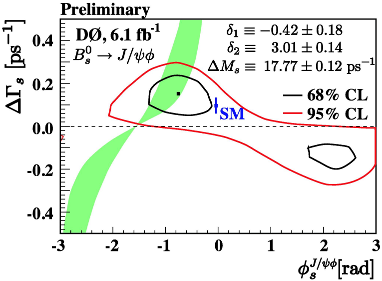
and the solid curve the total.

Reminder: Tevatron results

CDF, FPCP'2010



DØ, ICHEP'2010

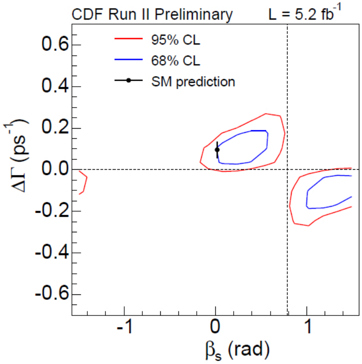


	Signal yield (lumi)	$\phi_s^{J/\psi\phi}$ (rad)	Ref.
CDF	6 500 (5.2 pb^{-1})	$-0.54 \pm 0.50^{(*)}$	CDF Note 10206
DØ	3 400 (6.1 fb^{-1})	$-0.76^{+0.38}_{-0.36}(\mathrm{stat}) \pm 0.02(\mathrm{syst})$	DØ 6098-CONF

(*) CDF quotes $\beta_s \in [0.02,\ 0.52] \cup [1.08,\ 1.55]$ rad at 68%CL. "-0.54 ± 0.50" is my estimate.

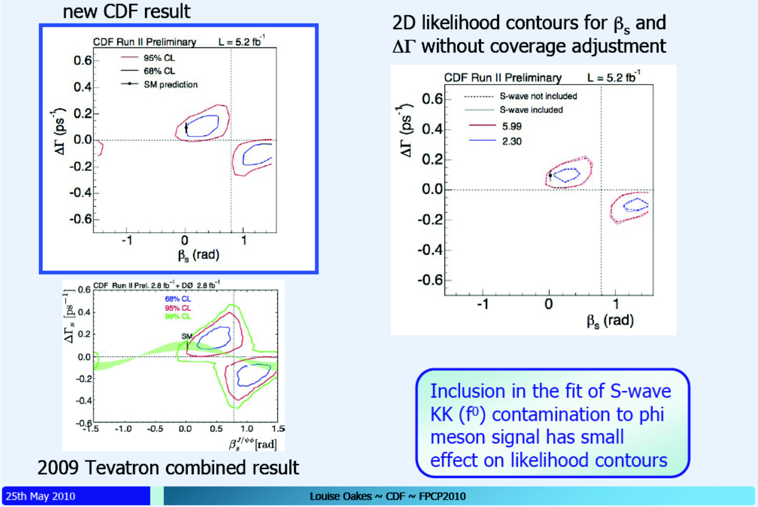
CDF FPCP $\mathrm{B_s^0} \to \mathrm{J}/\psi\phi$ results

CDF Public Note 10206 (18 July 2010)



- 5.2 fb^{-1}, $\beta_\mathrm{s} \in$ [0.02, 0.52] $\cup$ [1.08, 1.55] rad at 68%CL
  $\Rightarrow \quad \phi_\mathrm{s}^{\mathrm{J}/\psi\phi} = -0.54 \pm 0.50\,\mathrm{rad}$ (my estimate)
- S-wave taken into account in the fit
- Selection: optimized directly stat uncertainty on β_s (before was $S/\sqrt{S+B}$)
- 6500 $\mathrm{B_s^0} \to \mathrm{J}/\psi\phi$ candidates
- SSK calibration checked on data with $\mathrm{B_s^0} \to \mathrm{D_s^-}\pi^+$

CDF FPCP $B_s^0 \to J/\psi\phi$ results



new CDF result

2D likelihood contours for β_s and $\Delta\Gamma$ without coverage adjustment

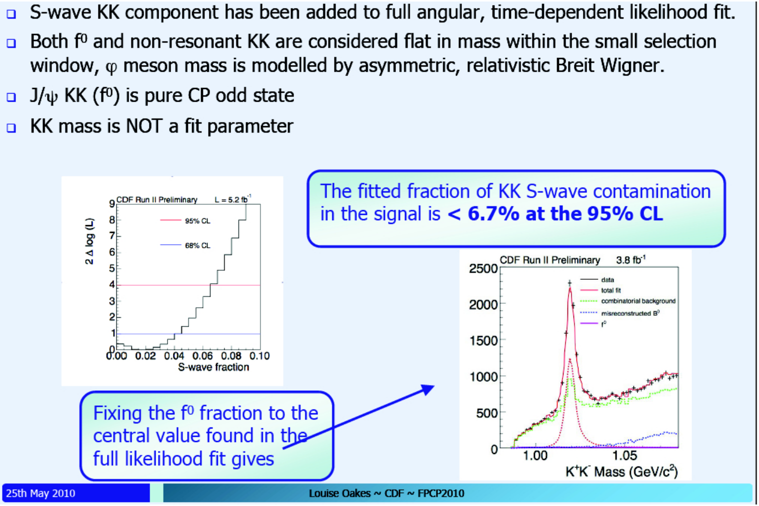
2009 Tevatron combined result

Inclusion in the fit of S-wave KK (f^0) contamination to phi meson signal has small effect on likelihood contours

25th May 2010

Louise Oakes ~ CDF ~ FPCP2010

CDF FPCP $B_s^0 \to J/\psi\phi$ results



- S-wave KK component has been added to full angular, time-dependent likelihood fit.
- Both f⁰ and non-resonant KK are considered flat in mass within the small selection window, φ meson mass is modelled by asymmetric, relativistic Breit Wigner.
- J/ψ KK (f⁰) is pure CP odd state
- KK mass is NOT a fit parameter

The fitted fraction of KK S-wave contamination in the signal is **< 6.7% at the 95% CL**

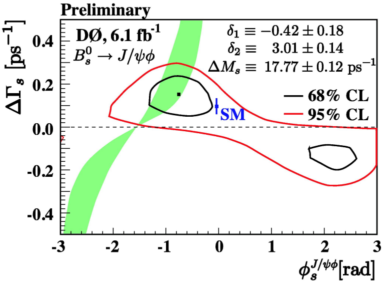
Fixing the f⁰ fraction to the central value found in the full likelihood fit gives

25th May 2010

Louise Oakes ~ CDF ~ FPCP2010

DØ ICHEP $B_s^0 \to J/\psi\phi$ results

DØ note 6098-CONF (22 July 2010)



- About 3400 signal events ($\sim$ 2 times less than CDF with similar lumi)
- 6.1 fb^{-1}: $\phi_s^{J/\psi\phi} = -0.76^{+0.38}_{-0.36}(\text{stat}) \pm 0.02(\text{syst})$ rad
- Use only OS tag
- Checks F-B asymmetry of $\cos(\psi)$ distribution versus K^+K^- mass that there is no significant s-wave contribution, but do not account for possible contribution in the fit
- Constraints strong phases to the values from $B^0 \to J/\psi K^{*0}$

Flavour-specific asymmetry in $\mathrm{B}^0_{\mathrm{d,s}}$ decays

- Physical asymmetry :

$$a^s_{\mathrm{fs}} = \frac{\Delta\Gamma_{\mathrm{s}}}{\Delta m_{\mathrm{s}}} \tan(\phi_{\mathrm{s}})$$

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

- Measured asymmetry :

$$A^q_{\mathrm{fs}} = \frac{\Gamma(f)-\Gamma(\bar{f})}{\Gamma(f)+\Gamma(\bar{f})}$$

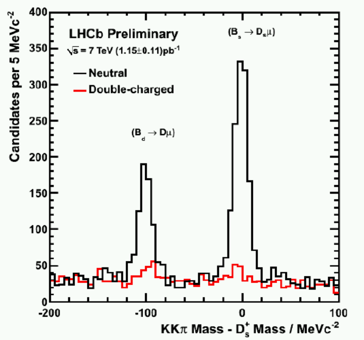
$$A^q_{\mathrm{fs}}(t) = \frac{a^q_{fs}}{2} - \frac{\delta^q_c}{2} - \left(\frac{a^q_{fs}}{2} + \frac{\delta^q_p}{2}\right)\frac{\cos(\Delta m_{\mathrm{q}} t)}{\cosh(\Delta\Gamma_{\mathrm{q}} t/2)} + \frac{\delta^q_b}{2}\left(\frac{B}{S}\right)^q \qquad \text{q=s,b}$$

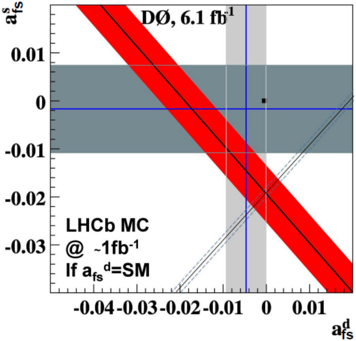
- In LHCb, polluting symmetries are much larger than a_{fs}:
  - Detector asymmetry $\delta^q_c \sim 10^{-2}$
    - Matter detector → hadronic interaction asymmetric
    - At LHCb: reduced by swapping the magnetic field
  - Production asymmetry $\delta^q_p \sim 10^{-2}$
    - LHC is a proton-proton collider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

Subtraction method in semi-leptonic modes

[R. Lambert, CERN-THESIS-2009-001]

- Use $\mathrm{B_s^0} \to \mathrm{D_s^-}\mu^+\nu$ and $\mathrm{B^0} \to \mathrm{D^-}\mu^+\nu$ with the same final state $K^+K^-\pi^-\mu^+$ → same detector asymmetry δ_c^q for these modes.
- Measure the difference between $\mathrm{B_s^0}$ and $\mathrm{B^0}$: $\Delta A_{fs}^{s,d} \simeq \frac{a_{fs}^s - a_{fs}^d}{2}$ → most of background and production asymmetries also cancel





(LHCb MC: stat uncertainty only)