CP violation study in B physics with LHCb

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On behalf of the LHCb Collaboration

Recontres de Moriond
EW session, March 2011

Outline

- LHCb physics goals
- LHCb detector
- Results using 2010 data
  - Analysis of $B_s \rightarrow J/\psi\phi$ and control channels
  - First observation of $B_s \rightarrow J/\psi f_0$
  - First observation of $B_s \rightarrow K^{*0}\overline{K}^{*0}$
- Conclusions and prospect

(Some) LHCb physics goals

- LHCb physics objective: search for new physics (NP) effects in loop-mediated processes
  - CP violation: this talk
  - rare decays: talk by Diego Martinez
- Separate probes of CP-violating NP effects in
  - box diagrams: B_s mixing phase measured using $B_s \to J/\psi\phi$, $B_s \to J/\psi f_0$
  - penguin diagrams: CP asymmetries measured in $B_s \to \phi\phi$, $B_s \to K^{*0}\overline{K}^{*0}$ and $B \to hh$

(direct CP violation in $B \to hh$: talk by Stefano Perazzini in YSF2 session)

LHCb detector

LHCb is a single arm forward spectrometer: $1.9 < \eta < 4.9$

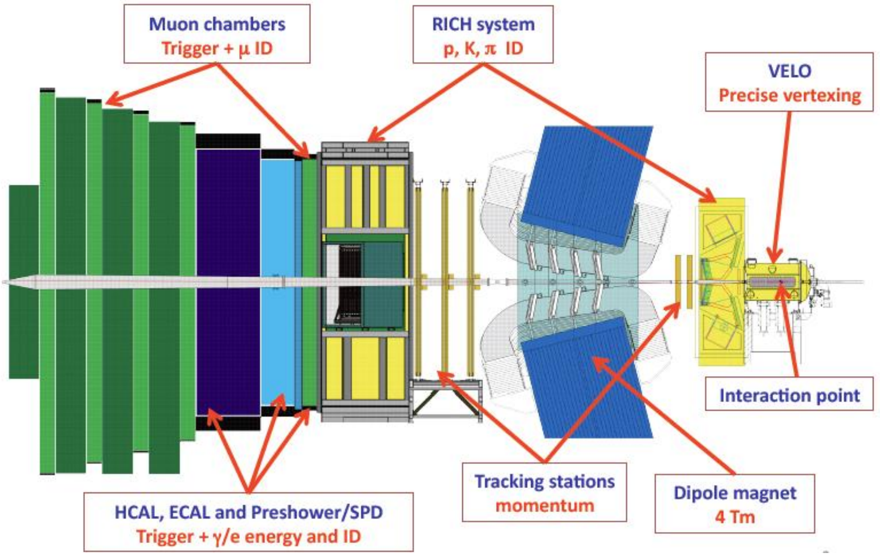
Dedicated for study of CP violation and rare B decays:

all B species; large B cross section; efficient, flexible trigger

Features:

Precise and robust vertexing and tracking

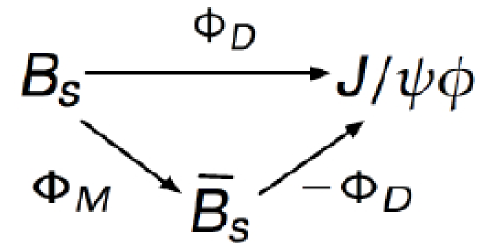
Good particle identification (hadron, muon, electron, photon)



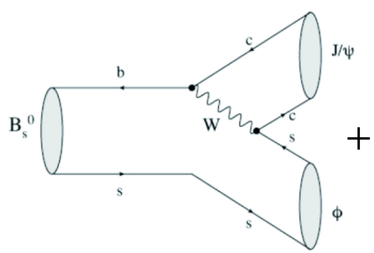
About 37 pb^{-1} collected at 7 TeV in 2010 run

Probe of NP in B_s mixing

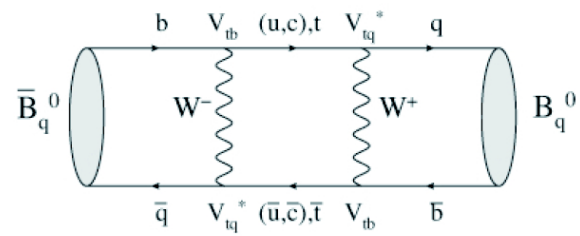
- Weak phase difference between interfering amplitudes: $\phi_s = \Phi_M - 2\Phi_D$



- Precise SM prediction $\phi_s^{SM} = -0.036 \pm 0.002$ rad



+ penguin diagrams



dominated by SM contribution

could have large NP contribution

- Decay width difference: $\Delta\Gamma_s = \Gamma_L - \Gamma_H$
- Both ϕ_s and $\Delta\Gamma_s$ sensitive to NP in B_s mixing
- Weakly constrained by experiments

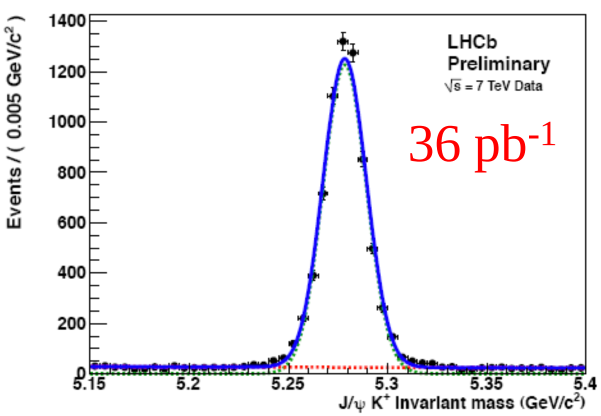
$B_s \to J/\psi\phi$ analysis ingredients

- Trigger and select signals and control channels in a similar way to understand detector effects
  - demonstration: measure lifetimes of b-hadron $\to J/\psi X$
- Disentangle polarizations of $P \to VV$ decays
  - demonstration: measure polarization parameters in $B_d \to J/\psi K^*$
- Determine initial flavour of B mesons
  - demonstration: measure Δm_d and Δm_s
- Fit differential rates of initial B_s and $\overline{B}_s$
  - first step: untagged analysis of $B_s \to J/\psi\phi$

Selection of $b \to J/\psi X$

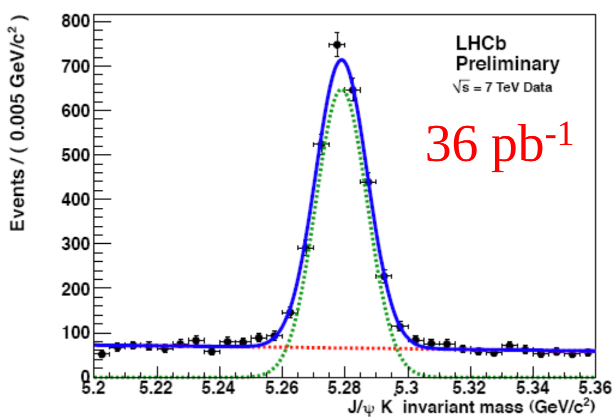
- Time unbiased trigger/selection as baseline, complemented by time-biased trigger to increase statistics
- Retain prompt background events ($t \sim 0$) for time resolution calibration: $\sigma_t \sim 50$ fs
- Excellent mass resolutions
- Very low background with $t>0.3$ ps, shown below:

$\sigma_m = 10.7$ MeV



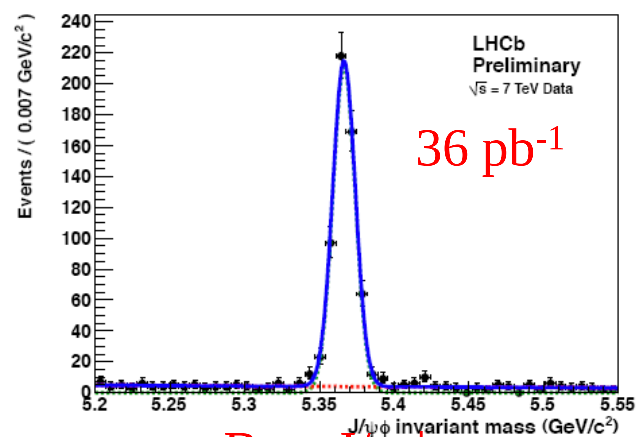
$B^+ \to J/\psi K^+$

$\sigma_m = 8$ MeV



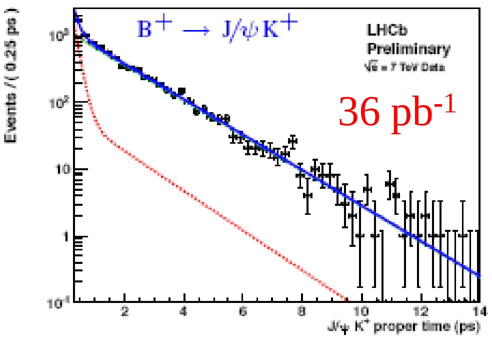
$B^0 \to J/\psi K^*$

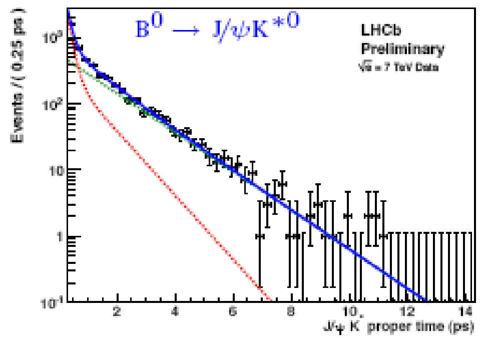
$\sigma_m = 7$ MeV

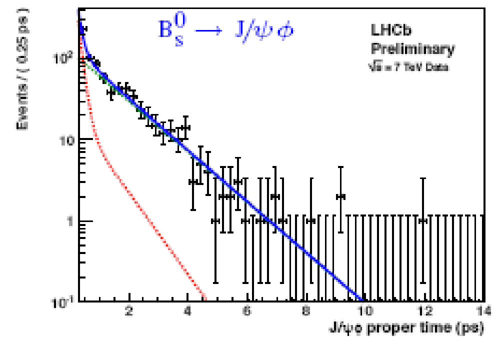


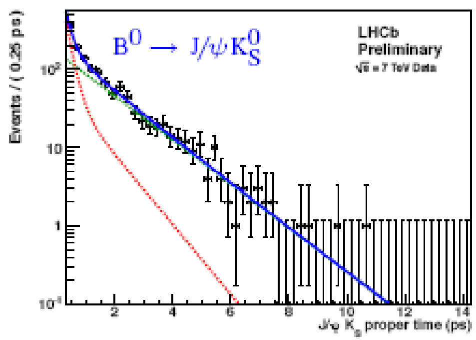
$B_s \to J/\psi \phi$

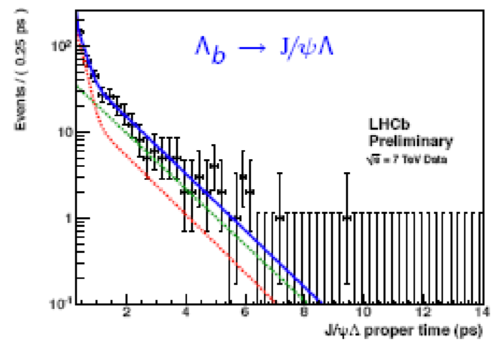
b→J/ψX lifetimes (LHCb-CONF-2011-001)









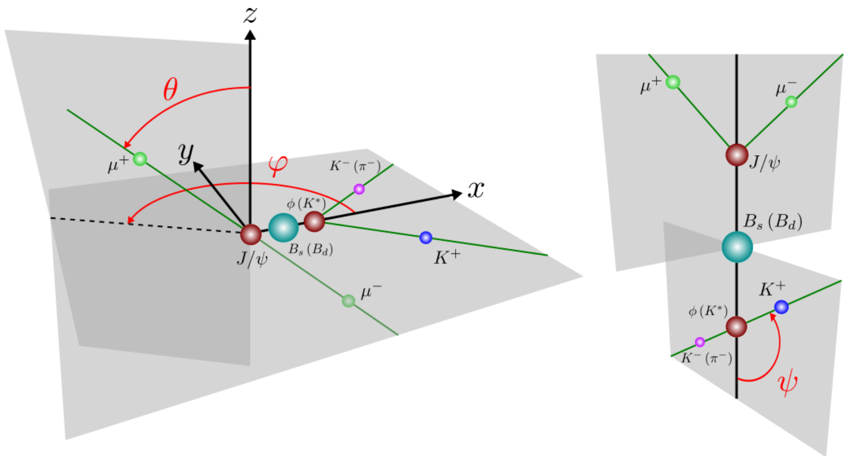


Channel	LHCb yield	LHCb “lifetime”(*) stat. and sys. (ps)	PDG (ps)
$B^+ \to J/\psi K^+$	6741 ± 85	$1.689 \pm 0.022 \pm 0.047$	1.638 ± 0.011
$B^0 \to J/\psi K^{*0}$	2668 ± 58	$1.512 \pm 0.032 \pm 0.042$	1.525 ± 0.009
$B^0 \to J/\psi K^0_S$	838 ± 31	$1.558 \pm 0.056 \pm 0.022$	1.525 ± 0.009
$B^0_s \to J/\psi\phi$	570 ± 24	$1.447 \pm 0.064 \pm 0.056$	1.477 ± 0.046
$\Lambda_b \to J/\psi\Lambda$	187 ± 16	$1.353 \pm 0.108 \pm 0.035$	$1.391^{+0.038}_{-0.037}$

* All “lifetimes” are fitted with a single exponential

Angular analysis of $B_d \to J/\psi K^*$
(LHCb-CONF-2011-002)

- P→VV polarization amplitudes (A_0, $A_\parallel$, $A_\perp$) can be measured in distribution of transversitiy angles (θ, ϕ, ψ)
- Correct for angular efficiency using simulation
- $K\pi$ S-wave included

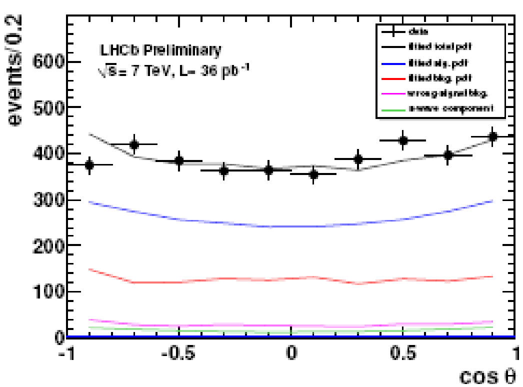


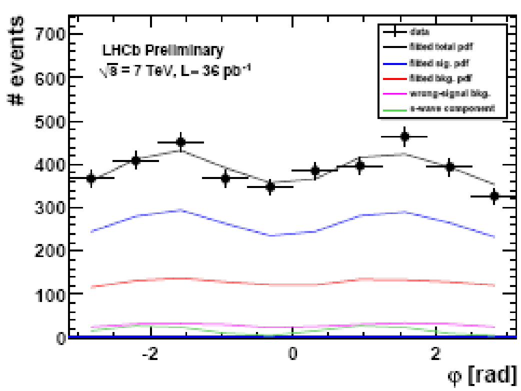
LHCb preliminary

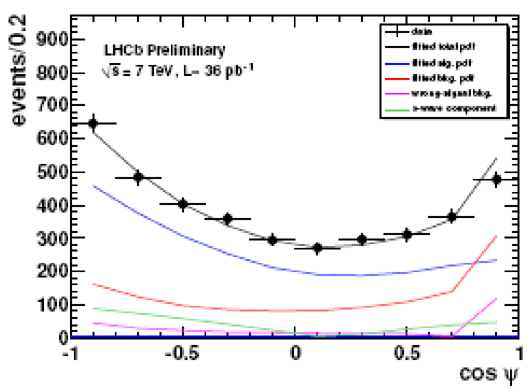
$|A_\parallel|^2 = 0.252 \pm 0.020 \pm 0.016$
$|A_\perp|^2 = 0.178 \pm 0.020 \pm 0.017$
$\delta_\parallel\,(\text{rad}) = -2.87 \pm 0.11 \pm 0.10$
$\delta_\perp\,(\text{rad}) = 3.02 \pm 0.10 \pm 0.07$

Babar, PRD 76, 031002

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



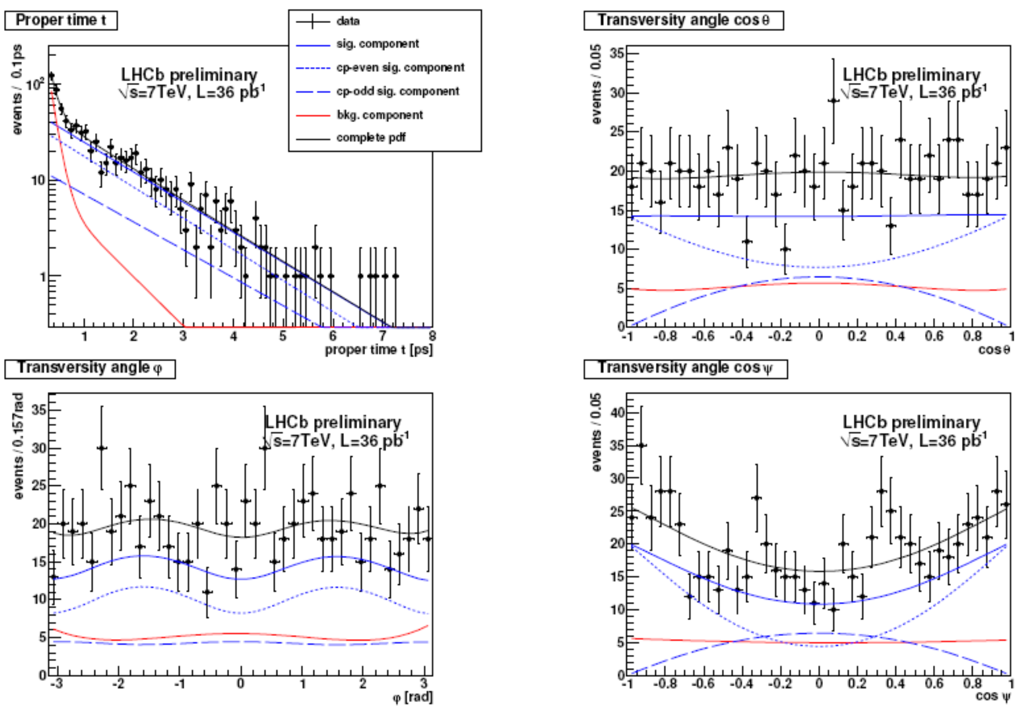




Untagged analysis of $B_s \to J/\psi\phi$
(LHCb-CONF-2011-002)

Fix ϕ_s to zero, and fit

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



LHCb preliminary (36 pb^{-1})

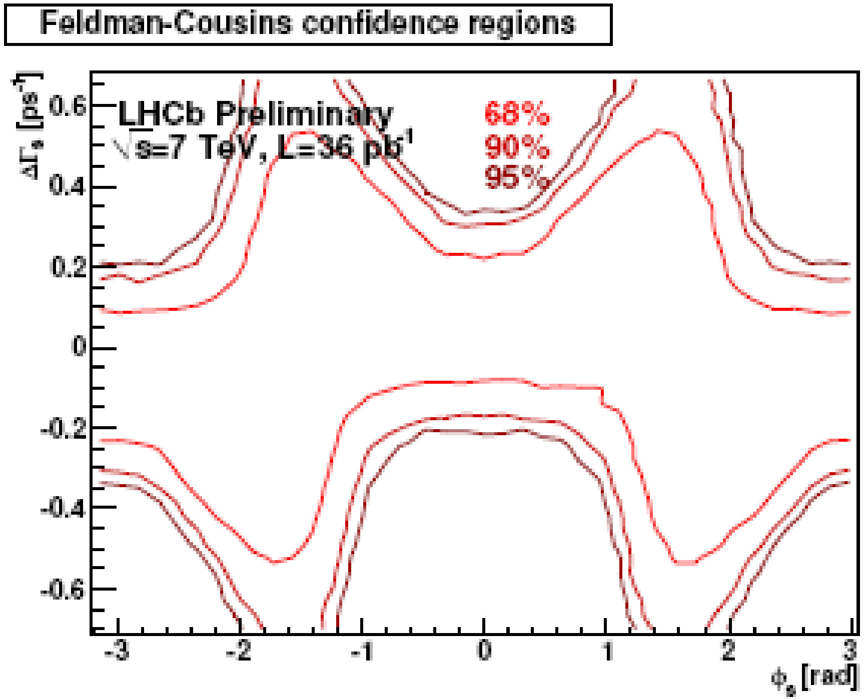
Γ_s (ps^{-1})	0.679 ± 0.036 ± 0.027
$\Delta\Gamma_s$ (ps^{-1})	0.077 ± 0.119 ± 0.021
$\lvert A_0\rvert^2$	0.528 ± 0.040 ± 0.028
$\lvert A_\perp\rvert^2$	0.263 ± 0.056 ± 0.014
$\delta_\parallel$ (rad)	3.14 ± 0.52 ± 0.13

CDF note 10206 (5.2 fb^{-1})

Γ_s (ps^{-1})	0.653 ± 0.011 ± 0.005
$\Delta\Gamma_s$ (ps^{-1})	0.075 ± 0.035 ± 0.010
$\lvert A_0\rvert^2$	0.524 ± 0.013 ± 0.015

Feldman-cousins confidence regions

(LHCb-CONF-2011-002)



No constraints on ϕ_s; can limit $\Delta\Gamma_s$

4 ambiguities: reduced to 2 using flavour tagging;

completely resolved using interferences between K^+K^- P-wave and S-wave.

Flavour tagging (LHCb-CONF-2011-003)

- Initial flavour of B can be inferred from
  - Opposite Side: products of the other B meson
  - Same Side: fragmentation particles associated to signal B
- OS (and SS pion) taggers optimized and calibrated

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

$$\varepsilon_{\rm tag} = \frac{R+W}{R+W+U} \qquad \omega = \frac{W}{R+W}$$

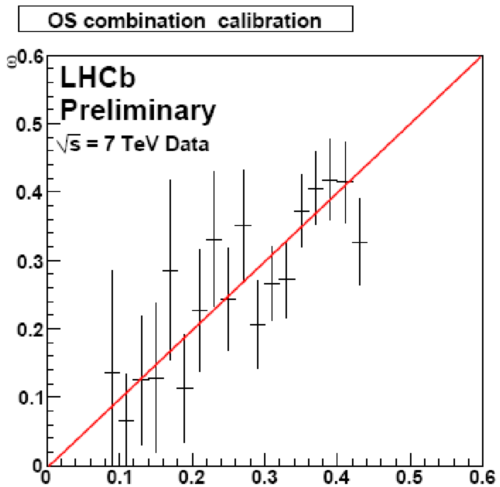
$$\varepsilon_{\rm eff} = \varepsilon_{\rm tag} D^2 = \varepsilon_{\rm tag}(1-2\omega)^2$$

$B^+ \to J/\psi K^+$

Y: estimated per event mistag

X: calibrated mistag

Fitted to a linear function

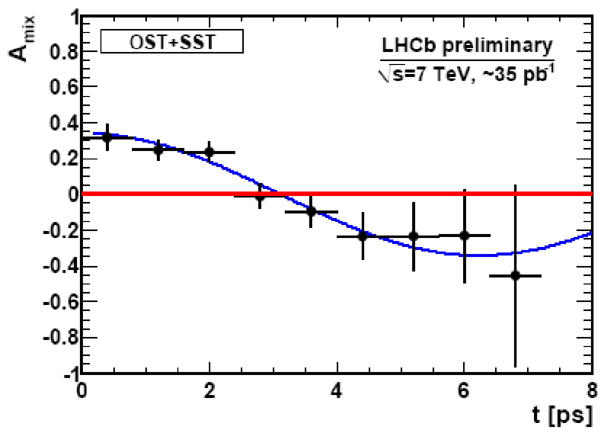


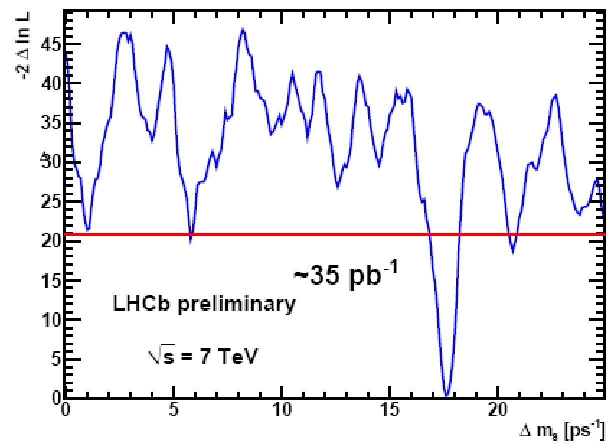
- Optimization and calibration of SS kaon tagger ongoing

Δm_d and Δm_s

(LHCb-CONF-2011-010, LHCb-CONF-2011-005)

$B_d \to D^-(K^+\pi^-\pi^-)\pi^+$





LHCb: $\Delta m_d = 0.499 \pm 0.032 \pm 0.003\ \mathrm{ps}^{-1}$
World average $\Delta m_d = 0.507 \pm 0.005\ \mathrm{ps}^{-1}$

Redline: evaluated at infinite oscillation frequency

4.6 σ significance

LHCb: $\Delta m_s = 17.63 \pm 0.11 \pm 0.04\ \mathrm{ps}^{-1}$
CDF: $\Delta m_s = 17.77 \pm 0.10 \pm 0.07\ \mathrm{ps}^{-1}$
(PRL 97, 242003)

Only OST used, ε_{eff} =(3.5 ±2.1)%
Per event time resolution $<\sigma_t>$ ~ 40 fs

Tagged analysis of $B_s \rightarrow J/\psi\phi$

- Analysis ongoing
- Precision in ϕ_s will be comparable to the CDF precision very soon (thanks to factor of 10 better time resolution in terms of statistical power)

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

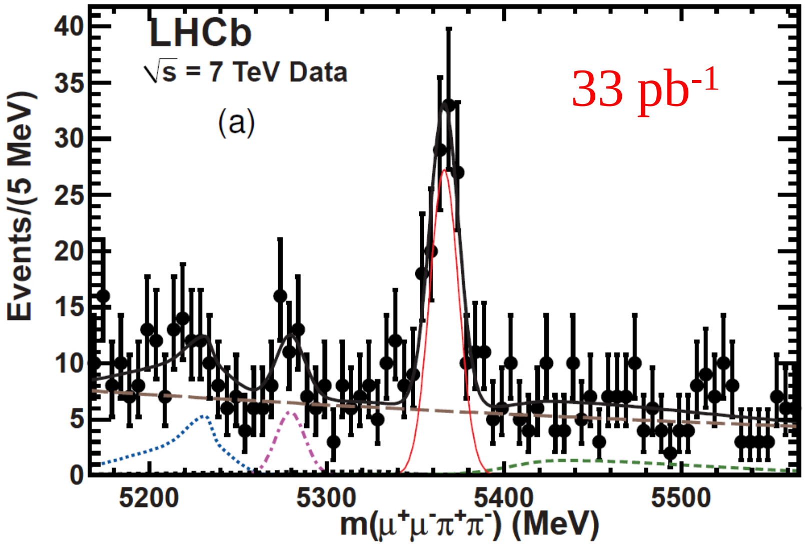
(* also including time biased trigger lines)

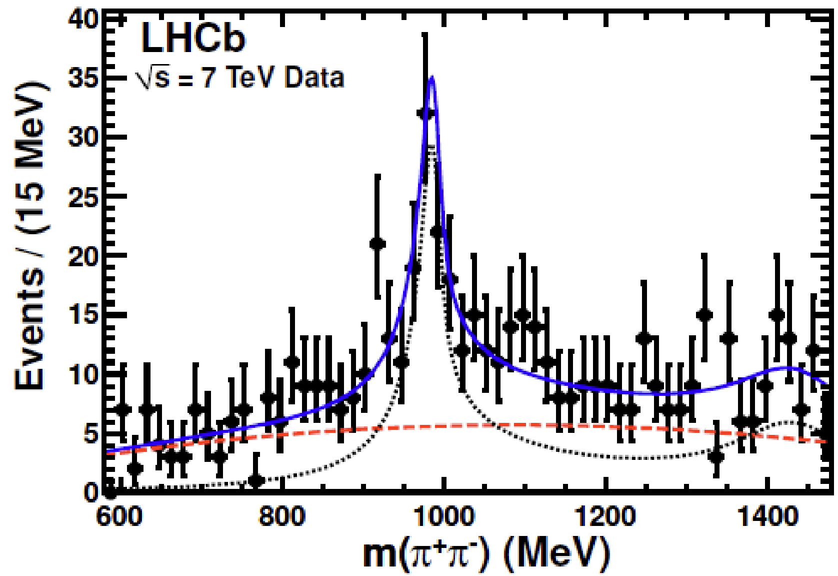
LHCb aims to make world's best measurement of ϕ_s with data from 2011 run

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

LHCb, PLB 698 (2011) 115

12.8 σ significance; 111 ±14 signals





$$R_{f_0/\phi} \equiv \frac{\Gamma\left(B_s^0 \to J/\psi f_0,\, f_0 \to \pi^+\pi^-\right)}{\Gamma\left(B_s^0 \to J/\psi \phi,\phi \to K^+K^-\right)} = 0.252^{+0.046+0.2027}_{-0.032-0.003}$$

Consistent with prediction
(S. Stone and L. Zhang, PRD 79, 074024)

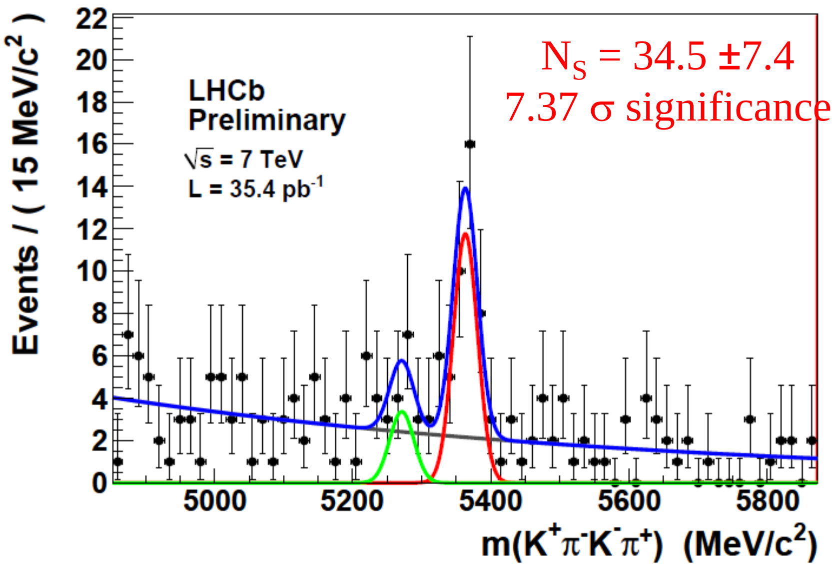
- CP odd, no need for angular analysis
- Good precision to complement $B_s \to J/\psi\phi$
- Can use $f_0 \to KK$ to resolve sign ambiguity in ϕ_s (JHEP 0909:074, 2009, Y. Xie *et al.*)

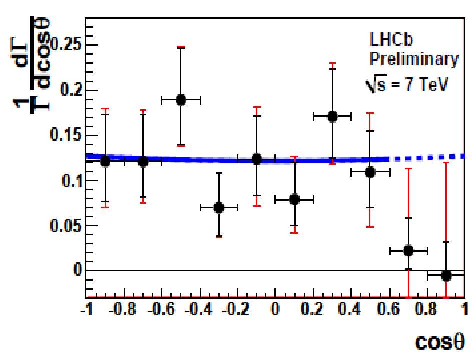
First observation of $B_s \to K^{*0}\overline{K}^{*0}$
(and first report in conference)

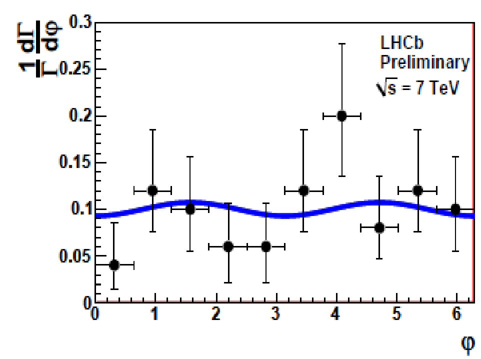
Mixing-induced and direct CP asymmetries sensitive to NP that affects weak phases of box and penguin diagrams differently

Using known BR($B_d \to J/\psi K^*$), LHCb measures

$$\mathcal{B}(\overline{B}^0_s \to K^{*0}\overline{K}^{*0}) = (1.95 \pm 0.47(\mathrm{stat.}) \pm 0.66(\mathrm{syst.}) \pm 0.29\,(f_d/f_s)) \times 10^{-5}$$







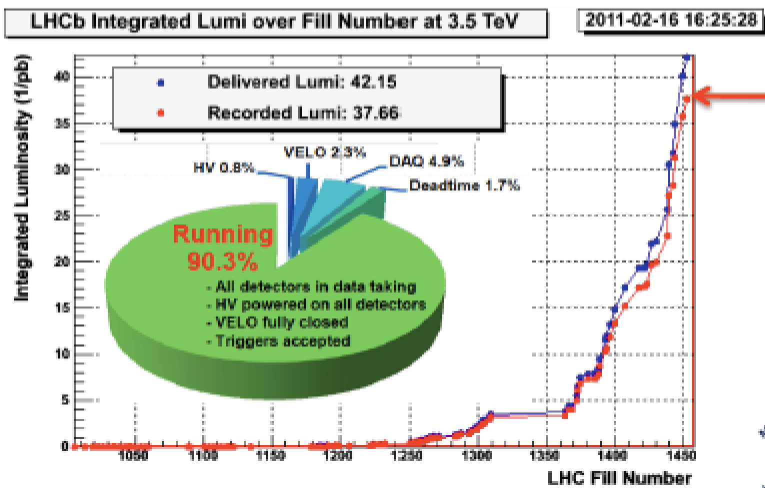
Parameter	Value
$f_L = \|A_0\|^2$	0.34 ± 0.19
$\|A_\parallel\|^2$	0.30 ± 0.15
$\delta_\parallel$	1.56 ± 0.64

Conclusions and prospect

- LHCb has produced interesting results using 2010 data and tested the machinery for CP violation study in B decays
  - b-hadron lifetimes
  - Polarization parameters of $B_d \rightarrow J/\psi K^*$ and $B_s \rightarrow J/\psi\phi$
  - B_s mass difference Δm_s
  - First observation of $B_s \rightarrow J/\psi f_0$ and $B_s \rightarrow K^{*0}\overline{K}^{*0}$
  - Direct CP violation in $B_{d/s} \rightarrow K\pi$
- High precision results from flavour-tagged time-dependent analyses of $B_s \rightarrow J/\psi\phi$, $B_s \rightarrow J/\psi f_0$ and $B \rightarrow hh$ can be expected with 2011 data

Backup slides

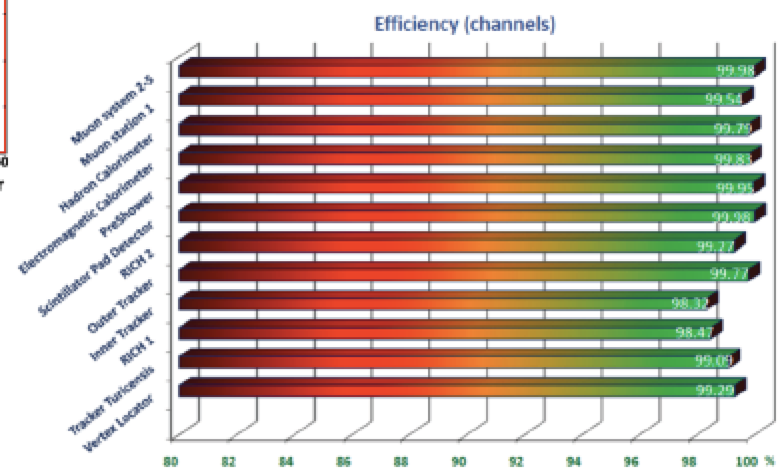
LHCb operation in 2010



Recorded approximately 37 pb^{-1} in 2010 run with all detectors fully operational

Data taking efficiency around 90% over the year

Largest part of data taken during last month of running

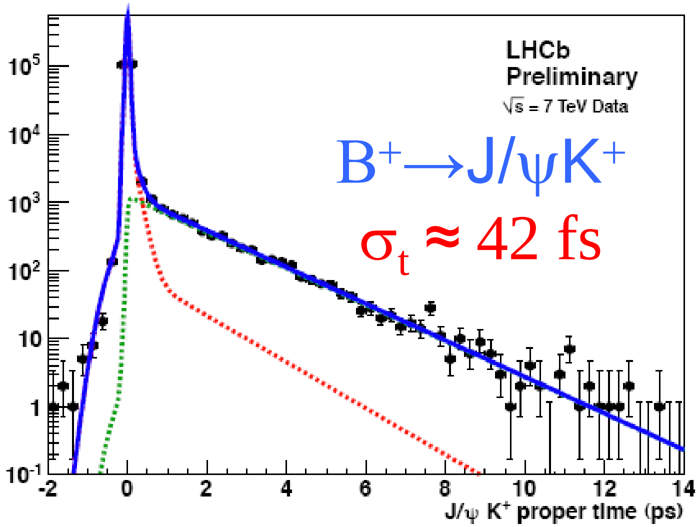


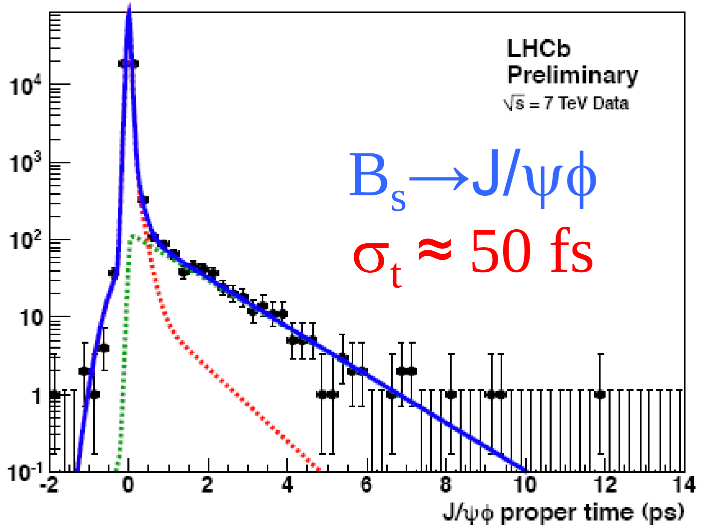
all sub-detectors >99% efficient

LHC operated at 7 TeV in 2010

Time resolution

- Fit time distribution including t~0 region
- Prompt background: all tracks from same pp interaction: modeled with triple Gaussian
- Fit results are turned into a single indicative resolution number





Lifetime systematics

- Systematic uncertainties are very conservative and can be largely reduced with increased statistics and better understanding of data and simulation

	$B^+ \to J/\psi K^+$	$B^0 \to J/\psi K^{*0}$	$B_s^0 \to J/\psi \phi$	$B^0 \to J/\psi K_S^0$	$\Lambda_b \to J/\psi \Lambda$
signal mass model	0.001	0.001	0.004	0.015	0.014
background mass model	0.008	0.023	0.004	0.007	0.025
background time model	0.001	0.004	0.002	0.008	0.007
time resolution model	0.005	0.005	0.005	0.005	0.005
momentum scale	0.0008	0.0008	0.0007	0.0008	0.0007
decay length scale	0.0005	0.0005	0.0004	0.0005	0.0004
proper time acceptance	0.046	0.035	0.055	0.009	0.019
Total systematic uncertainty	0.047	0.042	0.056	0.022	0.035

Table 37: Summary table of systematic uncertainties in the lifetime measurements (ps).

Fitting $B_d \to J/\psi K^*$

- Signal PDF for the decay $B_d \to J/\psi K^*$

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

- $\pm$ for $K^+\pi^-(K^-\pi^+)$ in final state
- Terms $f_i(\Omega)$ describe angular dependence of the amplitudes/interference terms
- Also need to account for nonresonant $K\pi$ S-wave contribution

$B_d \to J/\psi K^*$ 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

Fitting $B_s \rightarrow J/\psi\phi$

- Signal PDF for the decay $B_s \to J/\psi\,\phi$

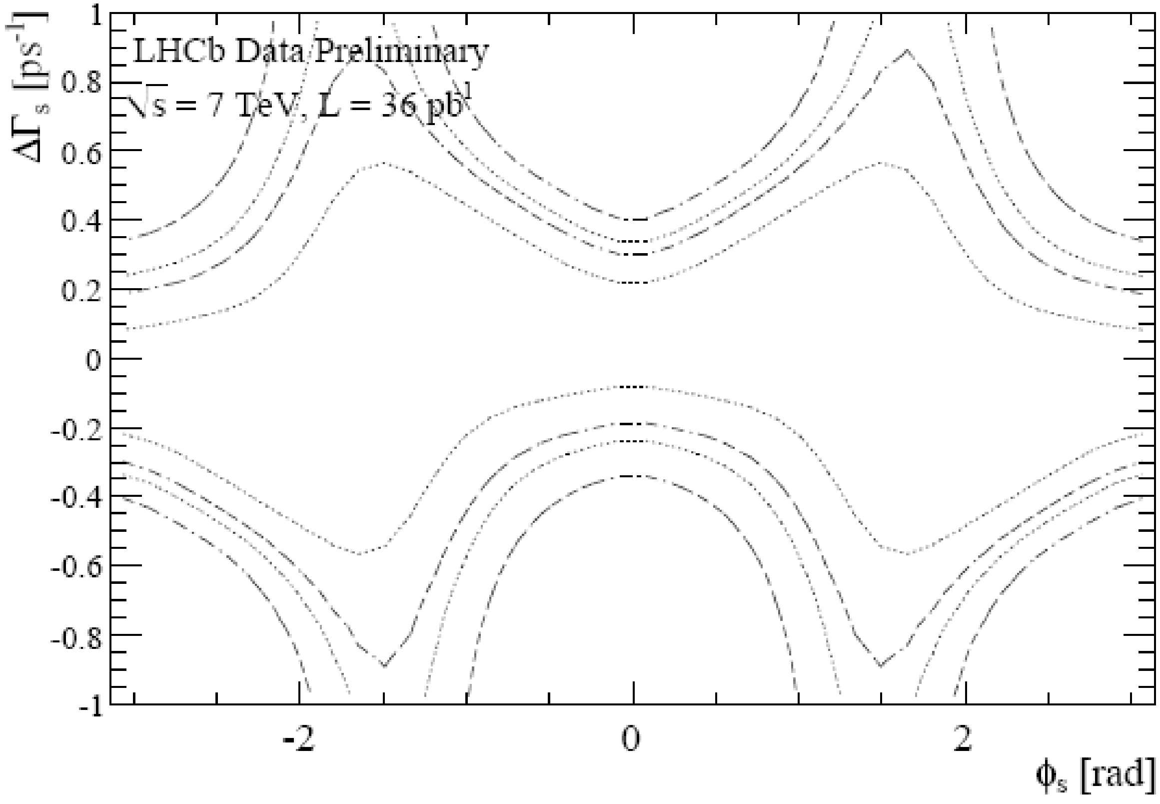
$$
\begin{aligned}
\frac{\mathrm{d}^4\Gamma}{dtd\Omega} \quad = \quad & e^{-\Gamma_s t}\Big[|A_0(0)|^2 f_1(\Omega) e^{-\frac{\Delta\Gamma_s}{2}t} \\
& + |A_{\parallel}(0)|^2 f_2(\Omega) e^{-\frac{\Delta\Gamma_s}{2}t} \\
& + |A_{\perp}(0)|^2 f_3(\Omega) e^{+\frac{\Delta\Gamma_s}{2}t} \\
& + \cos\delta_{\parallel}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

- This PDF assumes $\phi_s = 0$, additional terms appear for $\phi_s \neq 0$

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

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

$B_s \to J/\psi\phi$ likelihood scan
(LHCb-CONF-2011-002)



- Likelihood scan over the $\phi_s/\Delta\Gamma_s$ plane
- 68.3%, 90%, 95% and 99% contour shown

Flavour tagging (LHCb-CONF-2011-003)

- Initial flavour of B can be inferred from
  - Opposite Side: products of the other B meson
  - Same Side: fragmentation particles associated to signal B
- Optimized and calibrated using control channels

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

$$\varepsilon_{\mathrm{tag}} = \frac{R+W}{R+W+U} \qquad \omega = \frac{W}{R+W}$$

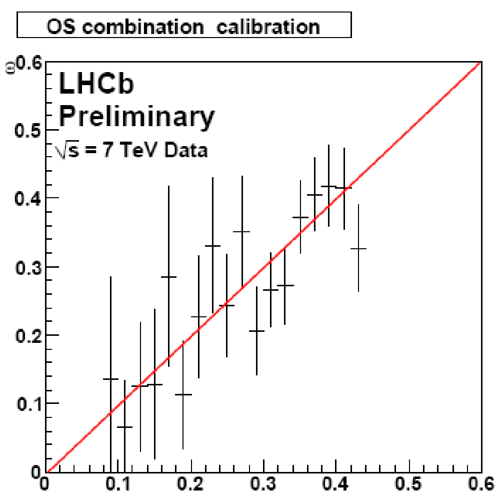
$$\varepsilon_{\mathrm{eff}} = \varepsilon_{\mathrm{tag}} D^2 = \varepsilon_{\mathrm{tag}}(1-2\omega)^2$$

$B^+ \to J/\psi K^+$

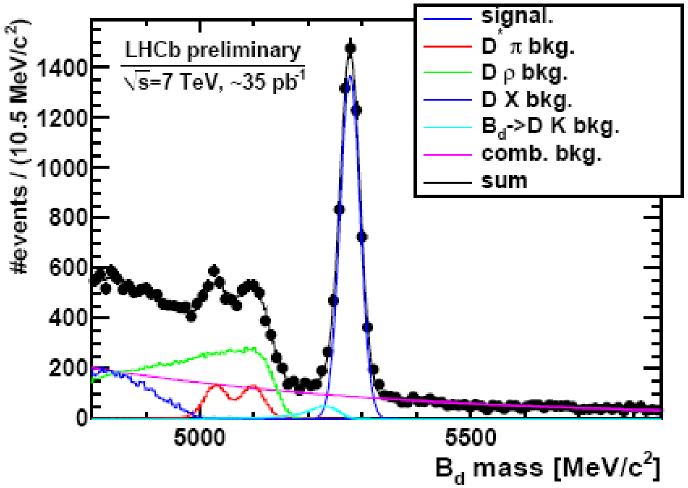
Y: estimated per event mistag

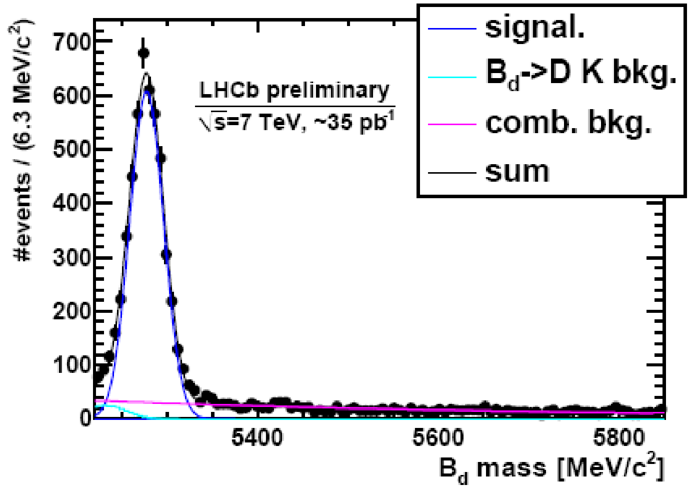
X: calibrated mistag

Fitted to a linear function



$B_d \rightarrow D^-(K^+\pi^-\pi^-)\pi^+$ for Δm_d



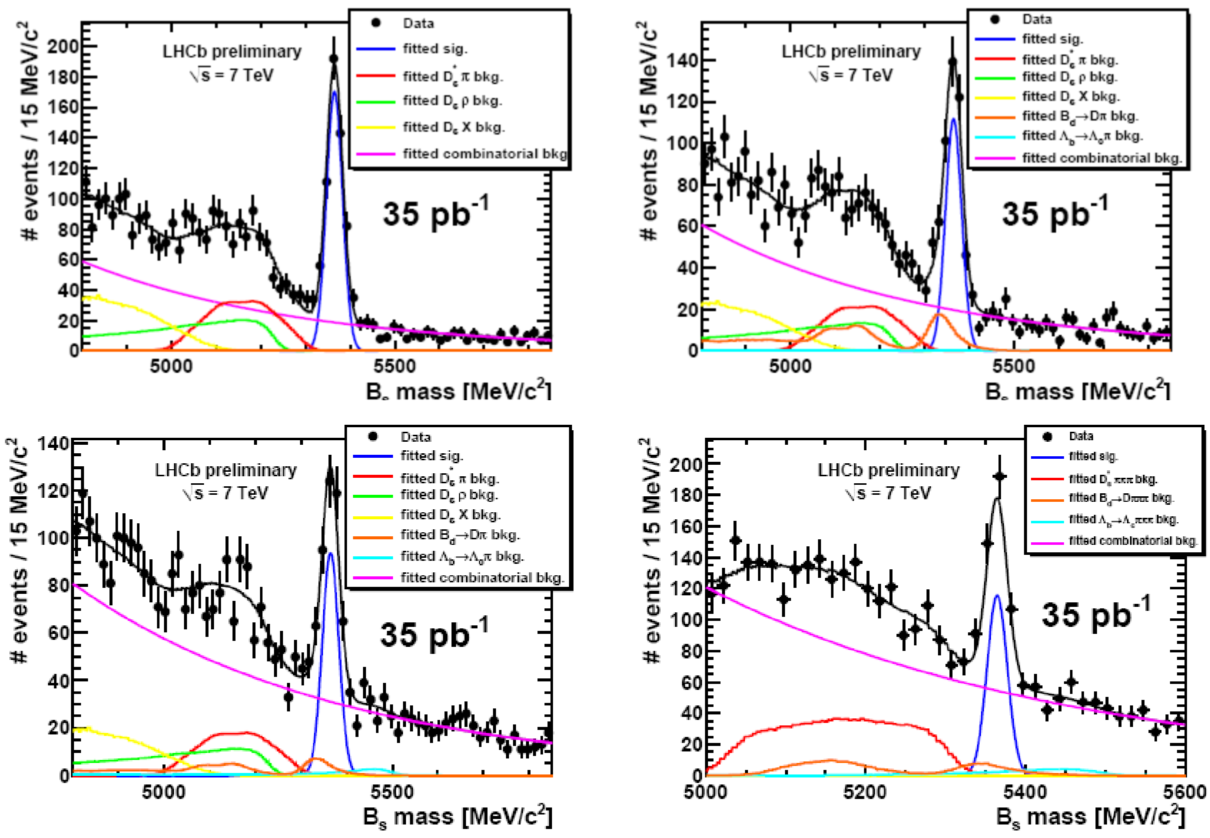


Systematics

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

$B_s \to D_s^-(K^+K^-\pi^-)(3)\pi^+$ for Δm_s

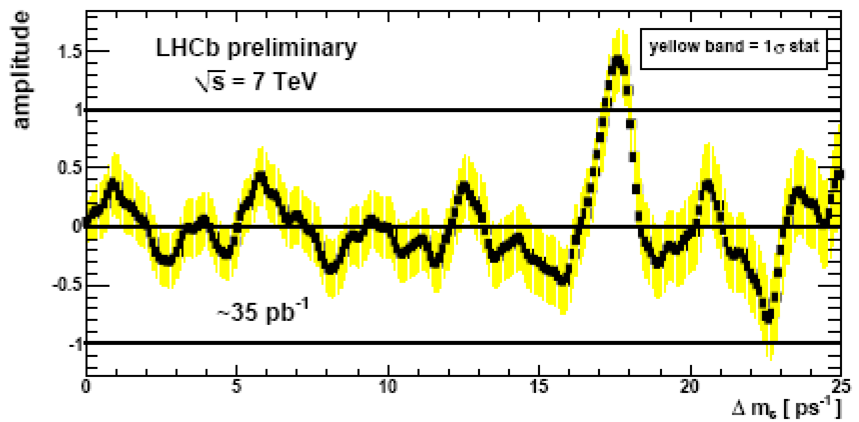


More on Δm_s

Systematics

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 η_c and σ_t PDFs	0.026
z-scale	0.018
momentum scale	0.018
$\Delta\Gamma_s$	0.002
total systematic uncertainties	0.038

Amplitude scan



LHCb (35 pb^{-1})		cf. CDF (1 fb^{-1})	
$B_s \to D_s(\phi\pi)\pi$	515 ± 25	$B_s \to D_s\pi$	4100
$B_s \to D_s(K^*K)\pi$	338 ± 27	$B_s \to D_s\pi$ partial	3100
$B_s \to D_s\pi$ non-reso	283 ± 27	$B_s \to D_s 3\pi$	1500
$B_s \to D_s 3\pi$	245 ± 46	semileptonic	61500

Remove ambiguity in ϕ_s

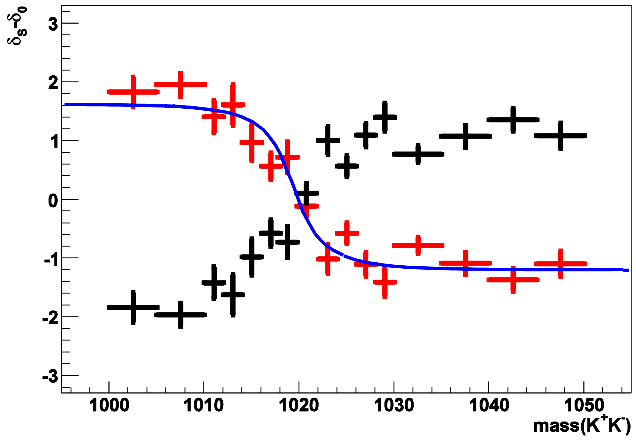
two-fold ambiguity in ϕ_s

from $B_s \rightarrow J/\psi\phi$

$$\left(\delta_{//}-\delta_0,\delta_{\perp}-\delta_0,\delta_S-\delta_0,\Phi_s,\Delta\Gamma_s\right)\Leftrightarrow$$
$$\left(\delta_0-\delta_{//},\pi+\delta_0-\delta_{\perp},\delta_0-\delta_S,\pi-\Phi_s,-\Delta\Gamma_s\right)$$

Including S-wave ($J/\psi f_0$):

two branches when plotting δ_S-δ_0 versus m(KK)



(JHEP 0909:074, 2009, Y. Xie *et al.*)

Blue: simulated dependence

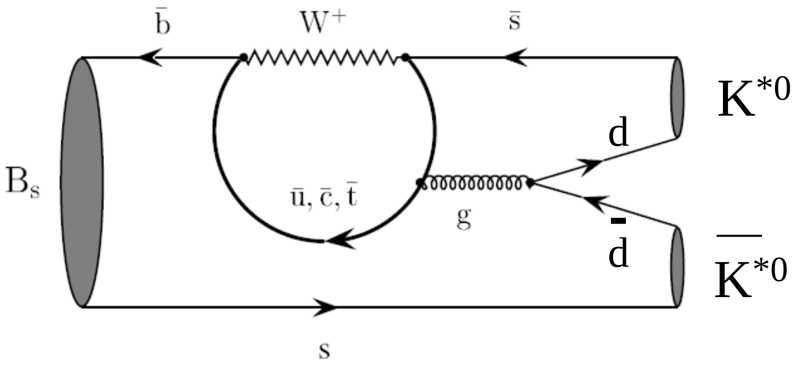
Red: physical solution

Black: mirror solution

The branch falling rapidly across the $\phi(1020)$ resonance mass region provides the physical solution

Physics in $B_s \to K^{*0}\overline{K}^{*0}$

b→s penguin process



SM decay amplitude

$$A(B_s \to K^{*0}\bar{K}^{*0}) = -V_{tb}^* V_{ts}\, P_s - V_{ub}^* V_{us}\, P_s^{\mathrm{GIM}}$$

dominated by top loop P_s

Null test of SM

$\Phi_M - 2\Phi_D = 0$ ⇨ mixing-induced asymmetry
direct CP asymmetry

$$S\left(B_s \to K^{*0}\overline{K}^{*0}\right) = 0$$
$$C\left(B_s \to K^{*0}\overline{K}^{*0}\right) = 0$$

CKM suppressed up and charm loops P_s^{GIM}
controlled using d↔s channel $B_d \to K^{*0}\overline{K}^{*0}$
(M. Ciuchini, M. Pierini, L. Silvestrini, PRL 100, 031802)

Sensitive to NP that affects weak phases of box and penguin diagrams differently

$B_s \to K^{*0}\overline{K}^{*0}$ angular distr.

$$\begin{aligned} I(\theta_1,\theta_2,\varphi) = \frac{1}{\Gamma}\frac{d^3\Gamma}{d\cos\theta_1\, d\cos\theta_2\, d\varphi} = \Bigg(& \frac{1}{\Gamma_L} \quad |A_0|^2 \quad \cos^2\theta_1 \cos^2\theta_2 + \\ & \frac{1}{\Gamma_L} \quad |A_\parallel|^2 \quad \frac{1}{2}\sin^2\theta_1 \sin^2\theta_2 \cos^2\varphi + \\ & \frac{1}{\Gamma_H} \quad |A_\perp|^2 \quad \frac{1}{2}\sin^2\theta_1 \sin^2\theta_2 \sin^2\varphi + \\ & \frac{1}{\Gamma_L} \quad |A_0| \quad |A_\parallel| \cos\delta_\parallel \frac{1}{2\sqrt{2}} \sin 2\theta_1 \sin 2\theta_2 \cos\varphi \Bigg) \end{aligned}$$

BR($B_s \to K^{*0}\overline{K}^{*0}$)

$$\mathcal{B}\left(\overline{B}^0_s \to K^{*0}\overline{K}^{*0}\right) = \lambda_{f_L} \times \frac{N_{\overline{B}^0_s \to K^{*0}\overline{K}^{*0}}}{\epsilon^{gen}_{\overline{B}^0_s \to K^{*0}\overline{K}^{*0}} \times \epsilon^{sel/gen}_{\overline{B}^0_s \to K^{*0}\overline{K}^{*0}} \times \epsilon^{trig/sel}_{\overline{B}^0_s \to K^{*0}\overline{K}^{*0}}}$$

$$\times \frac{\epsilon^{gen}_{\overline{B}^0 \to J/\psi\,\overline{K}^{*0}} \times \epsilon^{sel/gen}_{\overline{B}^0 \to J/\psi\,\overline{K}^{*0}} \times \epsilon^{trig/sel}_{\overline{B}^0 \to J/\psi\,\overline{K}^{*0}}}{N_{\overline{B}^0 \to J/\psi\,\overline{K}^{*0}}}$$

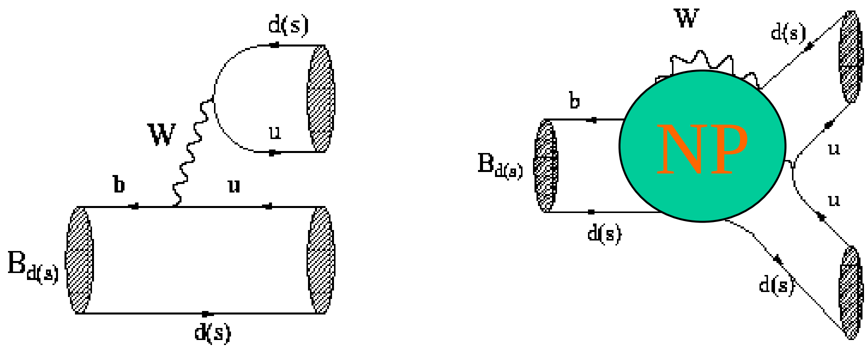
$$\times \mathcal{B}(vis)_{\overline{B}^0 \to J/\psi\,\overline{K}^{*0}} \times \frac{f_d}{f_s} \times \frac{9}{4}$$

$\mathcal{B}(\overline{B}^0 \to J/\psi\,\overline{K}^{*0})$ of 5.25×10^{-5},

$\lambda_{fL:}$ overall efficiency correction depending on f_L

$B \to hh$

- Sensitive probe of NP in penguin diagrams

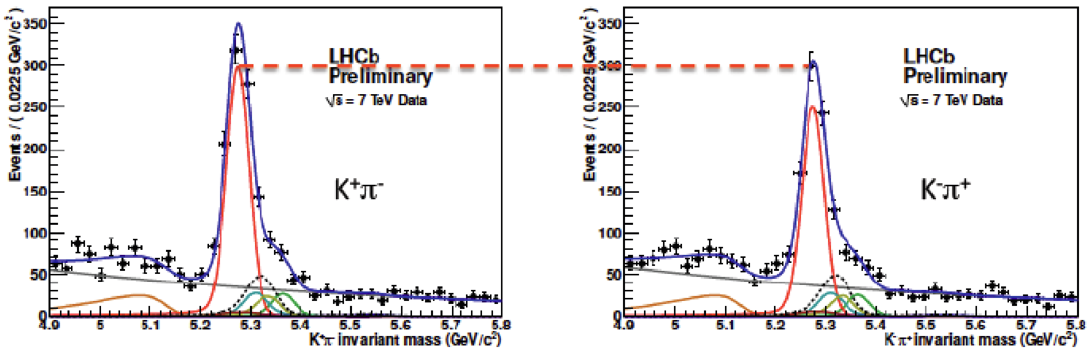


- Observables
  - Time-dependent CP asymmetries in $B_d \to \pi^+\pi^-$ and $B_s \to K^+K^+$
  - Direct CP asymmetries

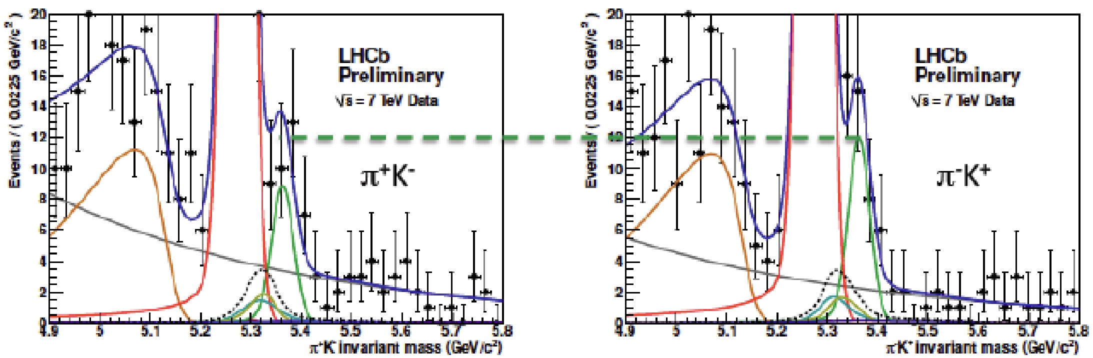
$$A_{CP} = (N_{\bar{B}\to\bar{f}} - N_{B\to f})/(N_{\bar{B}\to\bar{f}} + N_{B\to f})$$

Direct CP violation in $B_{d/s} \to K\pi$

Raw CP asymmetry in $B^0 \to K\pi$ decays: -0.086 ± 0.033



Raw CP asymmetry in $B_s \to \pi K$ decays: 0.15 ± 0.19



$$\boxed{\begin{aligned} A_{CP}\left(B^0 \to K^+\pi^-\right) &= -0.074 \pm 0.033 \pm 0.008 \\ A_{CP}\left(B_s^0 \to \pi^+K^-\right) &= 0.15 \pm 0.19 \pm 0.02 \end{aligned}}$$

Data-driven correction:

$$A_{CP} = A_{CP}^{RAW} - A_D(K\pi) - \kappa A_P$$

detector asymmetry

A_d = -0.004±0.004

production asymmetry

A_p = -0.025±0.014±0.010

Oscillation factors *k*

Channel	κ
$B^0 \to K^+\pi^-$	0.33
$B_s^0 \to \pi^+K^-$	0.015

HFAG

$$\boxed{\begin{aligned} A_{CP}\left(B^0 \to K^+\pi^-\right) &= -0.098^{0.012}_{-0.011} \\ A_{CP}\left(B_s^0 \to \pi^+K^-\right) &= 0.39 \pm 0.17 \end{aligned}}$$

Production asymmetries

- Physical asymmetry is related to raw asymmetry

$$A_{CP} = A_{CP}^{RAW} - A_D(K\pi) - \kappa A_P$$

- Production asymmetry measured in $B^+ \to J/\psi K^+$

$$A_P = \frac{N_{\bar{B}} - N_B}{N_{\bar{B}} + N_B}$$

$A_p = -0.025 \pm 0.014 \pm 0.010$

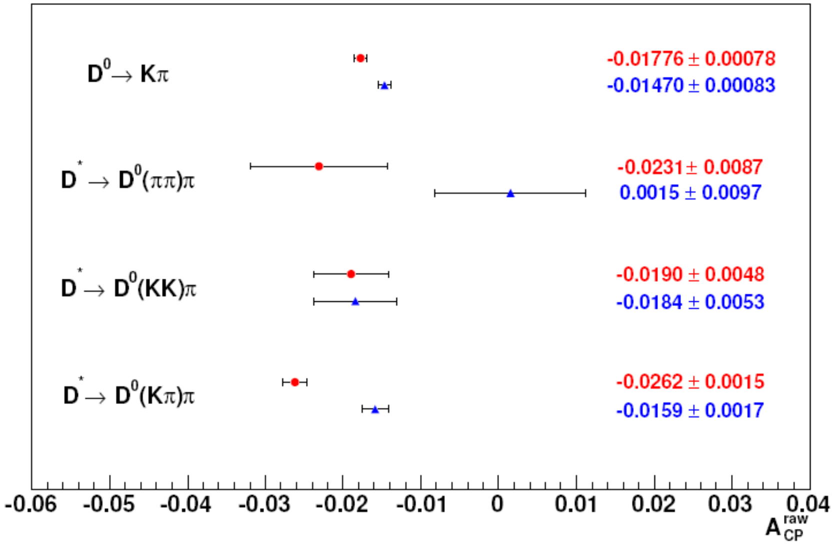
- Factor to take account of oscillation

$$\kappa = \frac{\int \left(e^{-\Gamma t'} \cos \Delta m t'\right) \varepsilon(t) dt}{\int \left(e^{-\Gamma t'} \cosh \frac{\Delta\Gamma}{2} t'\right) \varepsilon(t) dt}$$

Channel	κ
$B^0 \to K^+\pi^-$	0.33
$B_s^0 \to \pi^+K^-$	0.015

Detector asymmetries

- Use $D^* \to D^0(KK, \pi\pi, K\pi)\pi_s$ and untagged $D^0 \to K\pi$ of both magnet polarities to disentangle various contributions to the raw asymmetries
  - D^* and D^0 production asymmetries
  - Detector asymmetries
  - Known CP asymmetries
  - (negligible for $K\pi$)



World average

Channel	A_{CP}
$D^0 \to K^+K^-$	-0.0016 ± 0.0023
$D^0 \to \pi^+\pi^-$	0.0022 ± 0.0021

$A_d = -0.004 \pm 0.004$

Flavour specific asymmetry

- Physical asymmetry :

$$a_{\rm fs}^{s} = \frac{\Delta\Gamma_{\rm s}}{\Delta m_{\rm s}} \tan(\phi_{\rm s})$$

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

- Measured asymmetry :

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

$$A_{\rm fs}^{q}(t) = \frac{a_{fs}^{q}}{2} - \frac{\delta_{c}^{q}}{2} - \left(\frac{a_{fs}^{q}}{2} + \frac{\delta_{p}^{q}}{2}\right)\frac{\cos(\Delta m_{\rm q} t)}{\cosh(\Delta\Gamma_{\rm q} t/2)} + \frac{\delta_{b}^{q}}{2}\left(\frac{B}{S}\right)^{q} \qquad \text{q=s,b}$$

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

R. Lambert, CERN-Thesis-2009-001