Flavour Tagging and Mixing @ LHCb

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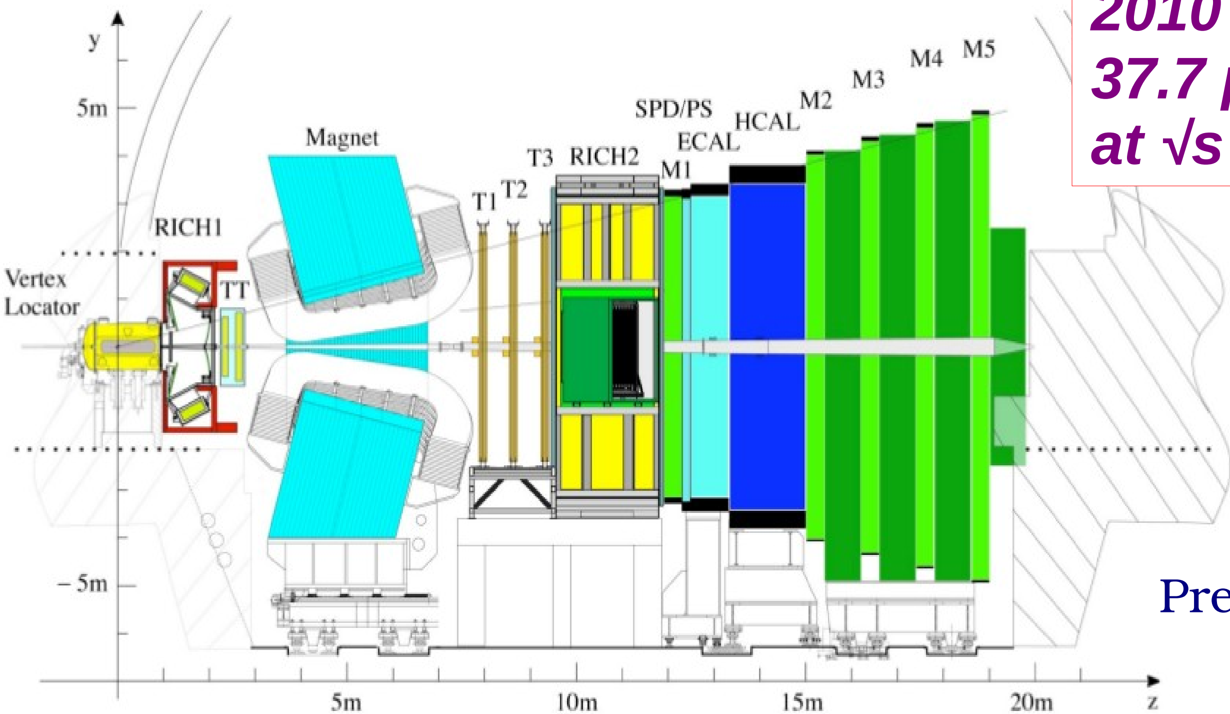
Outline

LHCb experiment
Motivation and requirements

Flavour Tagging
Algorithms
Optimization and calibration

B^0 - $\bar{B}^0$ oscillations
Status
Measurement of Δm_d
Measurement of Δm_s



2010 data:
37.7 pb^{-1} collected
at $\sqrt{s}$ = 7 TeV

LHCb

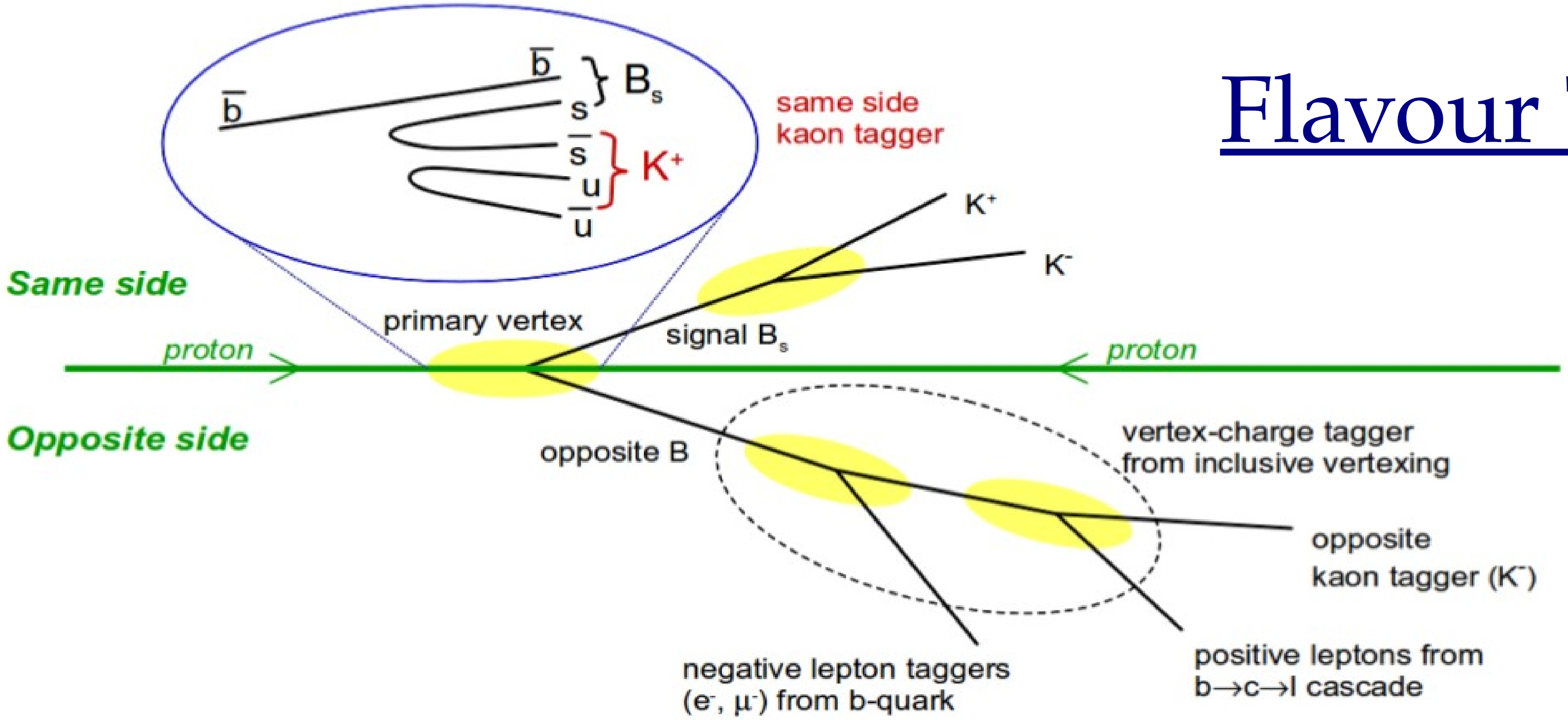
Precision studies of b-hadron decays:
Search for new physics,
CP violation, rare decays

Forward physics experiment
$1.9 < \eta < 4.9$

Detector requirements

- Efficient **trigger** for both leptonic and hadronic final states
  → 3-Level trigger: L0, (hardware), HLT1-HLT2 (software)
- High resolution for **vertex reconstruction** (VELO) and good **tracking efficiency**
- **Particle Identification**
  → π/K/p (RICH), π/e/γ (ECAL), μ (MUON)

Flavour Tagging



CP asymmetries or flavour oscillations need to identify the initial flavour of reconstructed B_d^0 and B_s^0 mesons (initial state with a b or b-bar quark).

OS (opposite side) → muon, electron, kaon and inclusive secondary vertex.
The charge of the **lepton** from semileptonic b decay or the **kaon** from the b→c→s decay chain or an inclusive reconstruction of **secondary vertex** can be used to tag the flavour of the B meson opposite to the signal.

SS (same side) → pion (B^0_d or B^+) or kaon (B^0_s).
These algorithms determine the flavour of the B signal meson by exploiting the correlation in the fragmentation decay chain.

Flavour Tagging Procedure

The sensitivity of the measured asymmetry is directly related to the effective tagging efficiency, ε_{eff} , or ***tagging power***:

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

R (right tagged)
W (wrong tagged)
U (untagged)

Where:

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

Mistag fraction: calibrated with control channels (flavour specific)

Different taggers decisions are combined to built the combination OS or OS+SS using the single tagger mistag probabilities.

For each tagger:

→ A tag decision $\mathbf{q_i = \pm 1,0}$ for the initial signal b-hadron containing a b/b-bar quark

→ An estimate of the mistag probability $\boldsymbol{\eta_i}$ based on a Neural Network (using kinematical & geometrical information on the tagger and the event properties as inputs).

Flavour Tagging optimization

- **Each tagger is optimized individually and in a second step the combination of taggers is optimized.**
- **We use 2 flavour specific channels ($B^0 \rightarrow D^{*-} \mu^+ \nu$ and $B^+ \rightarrow J/\psi K^+$), with high yield in LHCb.**
- **Then the performance obtained using the set of optimized cuts is measured in $B^0 \rightarrow J/\psi K^{*0}$.**

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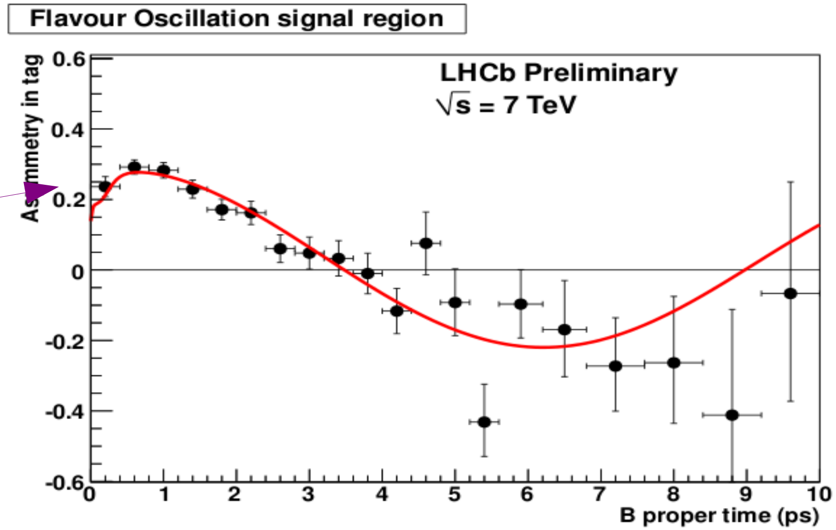
$B^0 \rightarrow D^{*-} \mu^+ \nu$ → ~48K signal events, B/S=0.3, fit to time dependent B_d oscillation to measure ω

$$A(t) = (1 - 2\omega)\cos(\Delta m_d t)$$



$B^+ \rightarrow J/\psi K^+$ → ~11k signal events, B/S~0.065 (t>0.3ps); compare the tag decision with the $B^\pm$ charge, count W, R events to get ω

$B^0 \rightarrow J/\psi K^{*0}$ ~3.3k signal evens, B/S~15: fit to time dependent B_d oscillation to measure ω (cross-check)

$B_s \rightarrow D_s (K^+K^-\pi^-)(3)\pi$ ~1 300 signal events. This is a control channel for SSK tagger studies: too little statistic to optimize

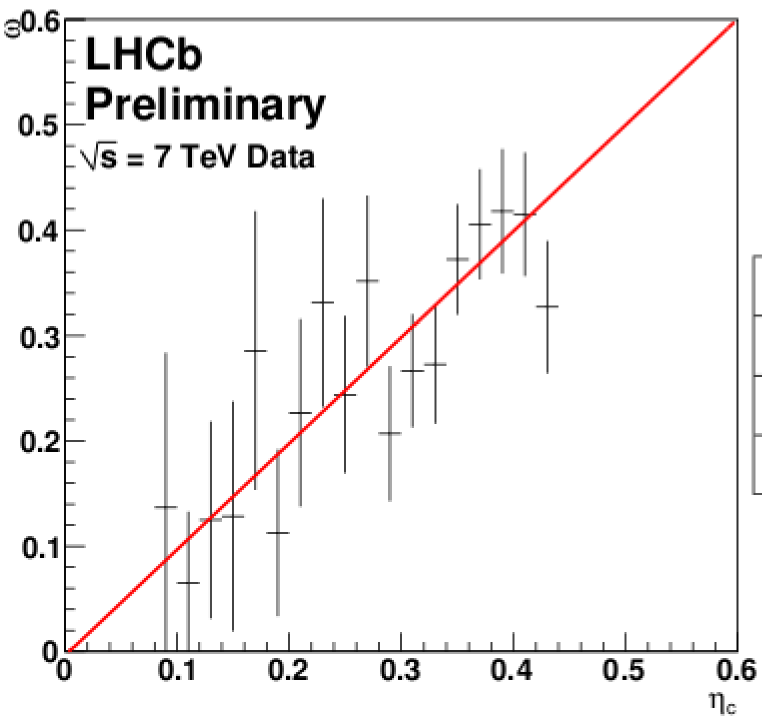
Flavour Tagging calibration

The tagging optimization requires the predicted mistag η to be calibrated.
First we use $B^+ \to J/\psi K^+$ channel to perform the calibration of the single tagger, then of the combination of all taggers.
Linear dependency of measured mistag fraction and calculated mistag probability:

$$\omega = p_0 + p_1 \cdot (\eta - \bar{\eta})$$

ω → measured mistag
η → calculated mistag
$\bar{\eta}$ → mean value in the sample

OS combination calibration

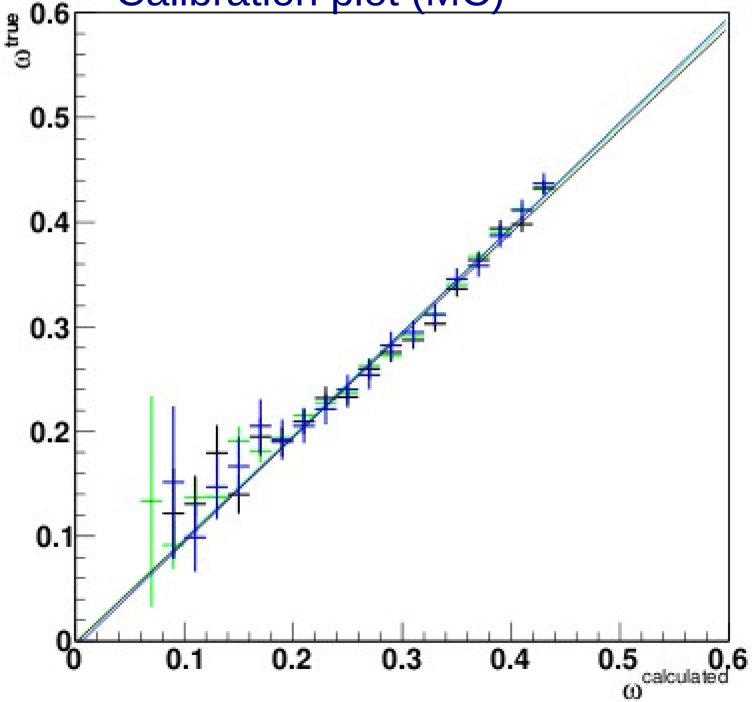


Good calibration → p0 = $\bar{\eta}$, p1 = 1

$B^+ \to J/\psi K^+$			
	p_0	p_1	$<\eta_c>$
OS	0.338±0.012±0.004	1.01±0.12±0.01	0.339
SSπ+OS	0.354±0.010±0.004	1.00±0.11±0.01	0.354

Flavour Tagging: validity & results

Calibration plot (MC)



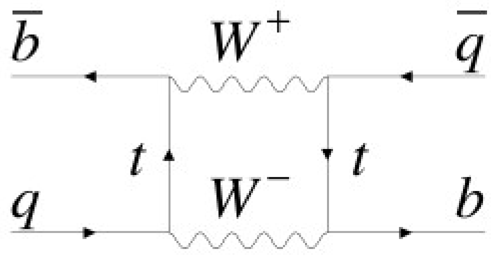
Studies of tagging performance in MC
$B^+ \rightarrow J/\psi K^+$
$B_d \rightarrow J/\psi K^{*0}$
$B_s \rightarrow J/\psi \varphi$

Similar performance → tagging parameters measured in $B^+ \rightarrow J/\psi K^+$ can be used in the other $B \rightarrow J/\psi X$ analyses

OS	ϵ_{tag} (%)	ω (%)	ϵ_{eff} (%)
$B^0 \rightarrow D^{*-}\mu^+\nu_\mu$	18.3±0.2	33.6±0.8	1.97±0.18
$B^+ \rightarrow J/\psi K^+$	15.4±0.3	32.2±1.2	1.97±0.31
$B^0 \rightarrow J/\psi K^{*0}$	15.8±0.7	30.0±6.6	2.52±0.82
SSπ+OS	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

Mixing

$B^0 - \bar{B}^0$ oscillations



In the Standard Model the mixing is described by the box diagram.

$$\frac{\Delta m_s}{\Delta m_d} = \frac{m_{B_s}}{m_{B_d}} \xi^2 \left| \frac{V_{ts}}{V_{td}} \right|^2$$

In the ratio most of theoretical uncertainties have been cancelled

$$\xi = (f_{B_s}\sqrt{B_{B_s}})/(f_{B_d}\sqrt{B_{B_d}}) = 1.210\,^{+0.047}_{-0.035}$$

$$\left| \frac{V_{td}}{V_{ts}} \right| = 0.2061 \pm 0.0012(\mathrm{exp})\,^{+0.0080}_{-0.0060}(\mathrm{lattice})$$

Present experimental status

$$\Delta m_d = 0.507 \pm 0.005\ ps^{-1} \text{ world average, PDG}$$

$$\Delta m_s = 17.77 \pm 0.10(\mathrm{stat}) \pm 0.07(\mathrm{sys})\ ps^{-1} \text{ CDF}$$

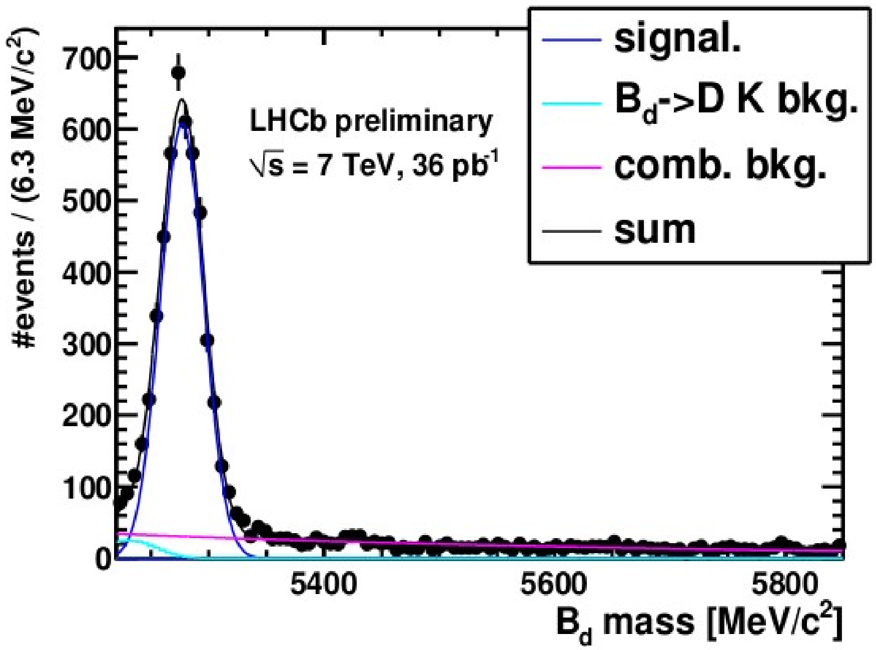
K. Nakamura et al. (Particle Data Group), J. Phys. G 37, 075021 (2010).

B^0 oscillations

WHY:
→ Validate flavour tagging calibration in an hadronic decay
→ Proof for LHCb to perform a measurement of a time dependent asymmetry

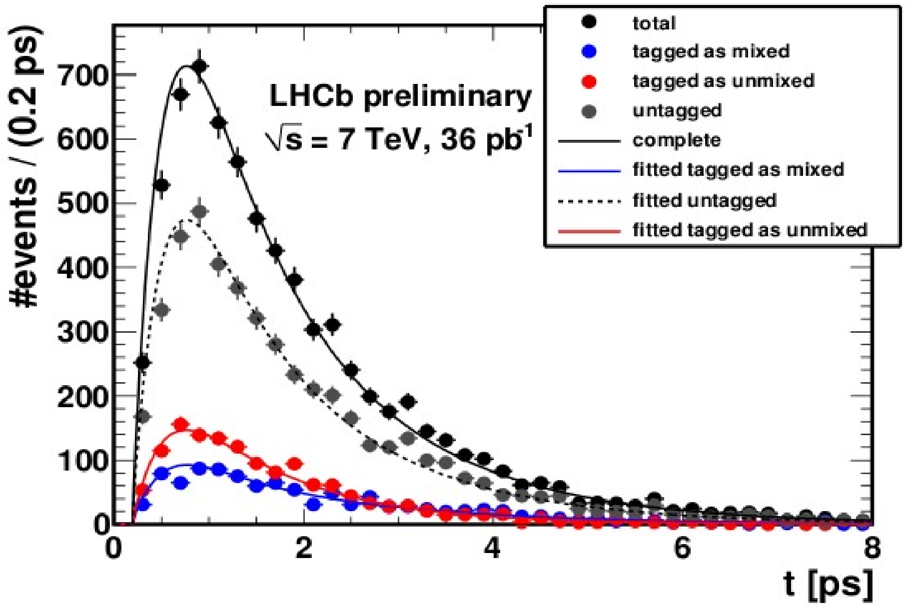
Signal: $\mathbf{B^0 \rightarrow D^- (K^+ \pi^- \pi^-) \pi^+}$ (~6k events)

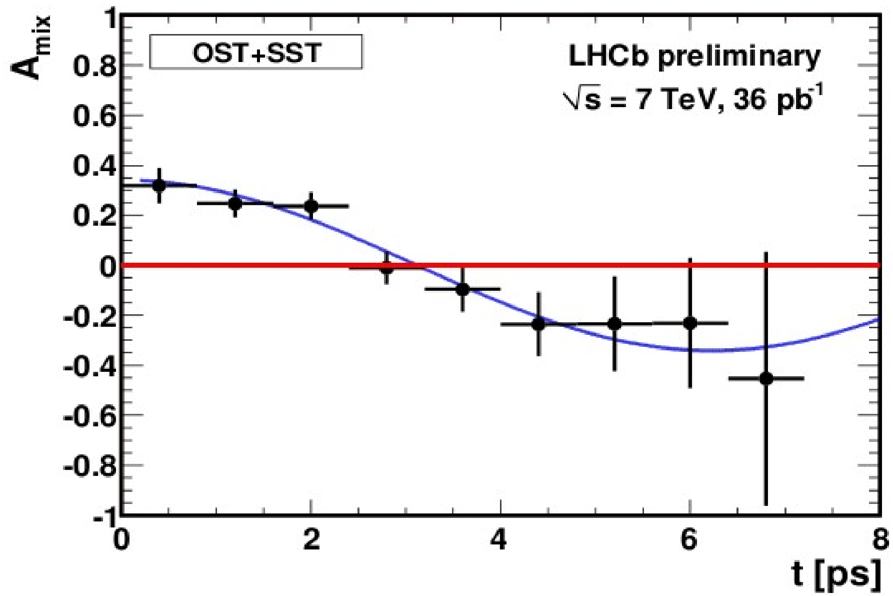
- Mass
- Propertime
- Flavour Tagging Decision
- Calibrated Mistag Probability



B^0 oscillations

$B^0 \rightarrow D^- (K^+ \pi^- \pi^-) \pi^+$

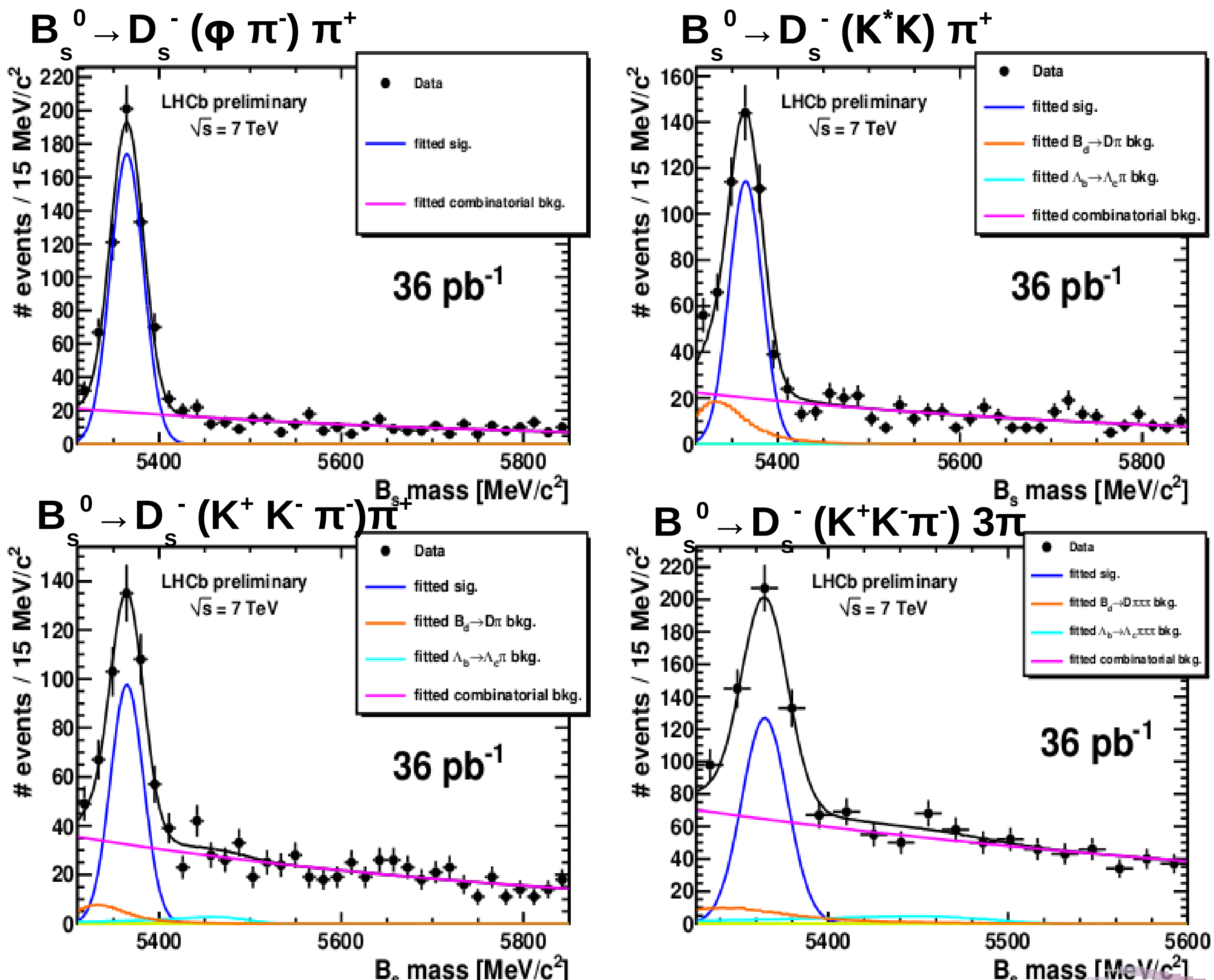




$$\Delta m_d = 0.499 \pm 0.032 \text{ (stat.)} \pm 0.003 \text{ (syst.) ps}^{-1}$$

Study	$\Delta(\Delta m_d)$ [ps^{-1}]	p_0	p_1
proper time resolution	0.000	0.000	0.00
proper time acceptance	0.002	0.001	0.00
variation of η_c PDF	0.000	0.002	0.05
floating fit parameters	0.001	0.0001	0.00
double Gaussian mass signal PDF	0.001	0.000	0.00
z-scale	0.0005	-	-
momentum scale	0.0005	-	-
Sum	0.003	0.002	0.05

B_s oscillations



Necessary *ingredients* for likelihood:

- Mass
- Propertime
- ProperTime Resolution
  - $<\sigma_t> = 44$ fs ($D_s\pi$)
  - $<\sigma_t> = 36$ fs ($D_s3\pi$)
- Flavour Tagging Decision
- Calibrated Mistag Probability
  - $\to$ re-calibrated using $B^0 \to D^-\pi^+$

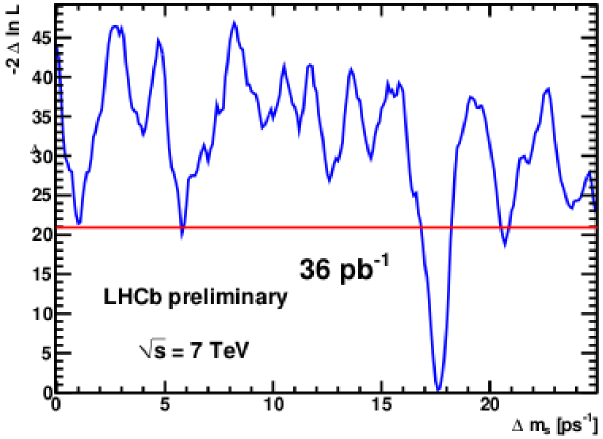
decay mode	# signal candidates
$B_s \to D_s^-(\phi\pi^-)\pi^+$	515 ± 25
$B_s \to D_s^-(K^*K)\pi^+$	338 ± 27
$B_s \to D_s^-(K^+K^-\pi^-)\pi^+$	283 ± 27
$B_s \to D_s^-(K^+K^-\pi^-)3\pi$	245 ± 46

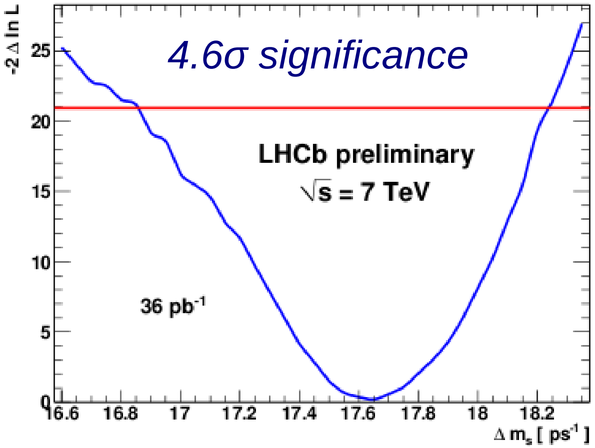
$\sigma = 18.1$ MeV/c^2 ($D_s\pi$)
$\sigma = 12.7$ MeV/c^2 ($D_s3\pi$)

B_s oscillations

LHCb-CONF-2011-005

$\Delta ms = 17.63 \pm 0.11(stat) \pm 0.04(sys) ps^{-1}$





B_s oscillations

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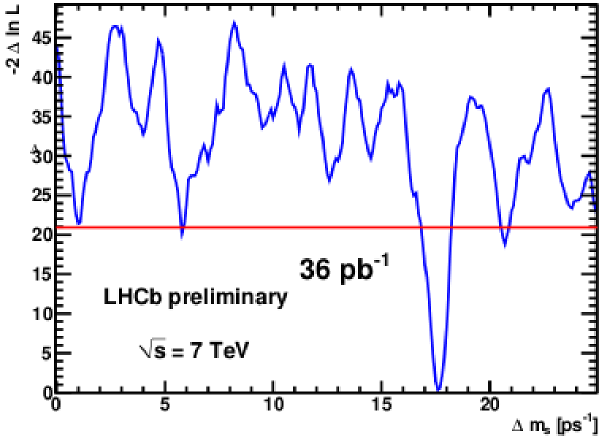
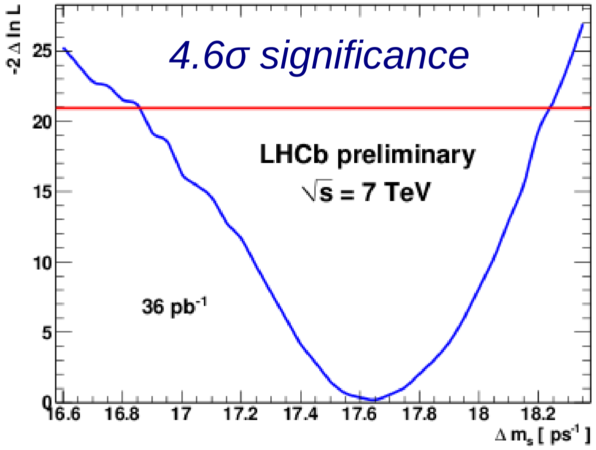
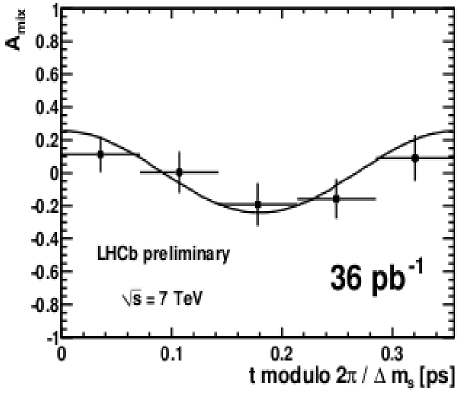


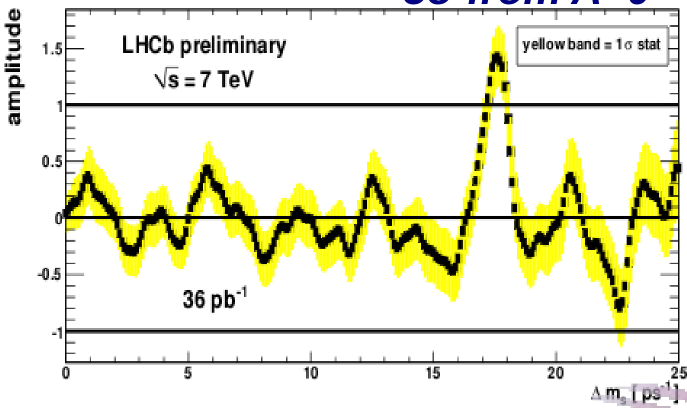


Amplitude Scan

1.6σ from A=1
5σ from A=0

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





Conclusions

With 2010 data: ~36 pb^{-1} collected at $\sqrt{s}$ = 7 TeV

→ optimization and calibration of OS & OS+SS flavour tagging using different control channels.

→ Mistag probability calibrated on $B^+ \rightarrow J/\psi\ K^+$ and cross checked on $B^0 \rightarrow J/\psi\ K^{*0}$

Tagging power & mistag:

$\langle\varepsilon_{tag}^{OS}\rangle = 1.97 \pm 0.31\%$ $\langle\omega^{OS}\rangle = 32.2 \pm 1.2\%$

$\langle\varepsilon_{tag}^{OS+SS}\rangle = 2.38 \pm 0.33\%$ $\langle\omega^{OS+SS}\rangle = 33.9 \pm 1.1\%$

→ Using the flavour tagging results, we perform a study on B^0-$\bar{B}^0$ oscillations obtaining results compatible with CDF. Improvement with new 2011 data.

$\Delta m_d = 0.499 \pm 0.032(stat) \pm 0.003(sys) ps^{-1}$

$\Delta m_s = 17.63 \pm 0.11(stat) \pm 0.04(sys) ps^{-1}$