B^0_s mass difference $\Delta M_s$ and mixing phase $\phi_s$ at LHCb

Luis Fernández
LPHE - EPFL Lausanne

November 8th, 2005
'Flavour in the era of the LHC workshop', CERN

On behalf of the LHCb collaboration

- $B^0_s - \overline{B}^0_s$ mixing
- LHCb full Monte Carlo simulation
- Sensitivity studies
- $\Delta M_s$ from $B^0_s \rightarrow D_s \pi$
- $\phi_s$ from $B^0_s \rightarrow J/\psi \phi$ and $\overline{b} \rightarrow \overline{c}c\overline{s}$ transitions to pure CP eigenstates
Neutral $B^0_q$ are *not* eigenstates of the weak interaction

→ “mixing”: particle–anti-particle oscillations ($|\Delta B = 2|$)

**Time evolution of $B^0_q$ and $\bar{B}^0_q$**

$$i \frac{d}{dt} \left( \begin{array}{c} B^0_q(t) \\ \bar{B}^0_q(t) \end{array} \right) = \left( M - \frac{i}{2} \Gamma \right) \left( \begin{array}{c} B^0_q(t) \\ \bar{B}^0_q(t) \end{array} \right) \implies$$

**Physical (mass) eigenstates**

$$|B_{L/H}\rangle = p|B^0_q\rangle \pm q|\bar{B}^0_q\rangle$$

$B^0_s$ ČP phase $\phi = \text{arg} \left( -\frac{M_{12}^{(s)}}{\Gamma_{12}^{(s)}} \right) \approx 2 \text{arg}[V_{ts}^*V_{tb}] \sim -2\lambda^2\eta = O(-0.04)\text{ rad in SM}$

where $\text{arg}(-\Gamma_{12}^{(s)}) = 2 \text{arg}(V_{cb}V_{cs}^*) + O(\lambda^2)$ suppressed contributions $\rightarrow \text{arg}(-\Gamma_{12}^{(s)}) \approx 0$

- $M_{12}^{(s)}$: virtual intermediate states $\Rightarrow$ sensitive to New Physics
- $\Gamma_{12}^{(s)}$: on-shell contributions $\Rightarrow$ insensitive to New Physics

**En route for NP with $B^0_s - \bar{B}^0_s$ mixing?**

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$B^0_s$ mass difference $\Delta M_s$ and mixing phase $\phi_s$ at LHCb (2)  

Luis Fernández  
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Mixing observables

\[ B^0_d - \bar{B}^0_d \text{ (well measured) versus } B^0_s - \bar{B}^0_s \text{ (Terra incognita) in SM} \]

- \( \Delta M_d \sim 0.5 \text{ ps}^{-1} \)
- \( \Delta \Gamma_d / \Gamma_d \sim 0 \)
- \( \phi_d \equiv 2 \arg[V_{td}^* V_{tb}] \approx 2\beta = \mathcal{O}(0.8) \text{ rad} \)
- \( \Delta M_s \sim 20 \text{ ps}^{-1} \sim 40 \text{ times faster than } B^0_d! \)
- \( \Delta \Gamma_s / \Gamma_s \sim 10\% \)
- \( \phi_s \equiv 2 \arg[V_{ts}^* V_{tb}] \approx -2\beta_s = \mathcal{O}(-0.04) \text{ rad} \)

\[ \text{✵ Oscillation frequency } \Delta M_s \text{ measurement} \]

\[ \star \text{ constrain } V_{td}: \quad \frac{\Delta M_s}{\Delta M_d} \propto \frac{m_{B^0_d}}{m_{B^0_d}} \frac{\xi^2 |V_{ts}|^2}{|V_{td}|^2} \rightarrow \text{ theoretical errors from } \Delta M_d \text{ partly cancel in ratio} \]

\[ \star \text{ } \Delta M_s \text{ beyond SM prediction (} \Delta M_s^{\text{SM}} > 14.5 \text{ ps}^{-1} \text{ at 95\%): } \Delta M_s = \Delta M_s^{\text{SM}} + \Delta M_s^{\text{NP}}? \]

\[ \star \text{ prerequisite for time-dependent CP-asymmetries!} \]

\[ \text{✵ Determination of: } \phi_s = \phi_s^{\text{SM}} + \phi_s^{\text{NP}}? \]

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\[ B^0_s \text{ mass difference } \Delta M_s \text{ and mixing phase } \phi_s \text{ at LHCb (3)} \]
Estimate LHCb performances in reconstructing $b$-decays

- time-dependent asymmetry and $\Delta M_s$ measurements strongly depend on:
  - proper-time resolution: must be good enough to resolve fast $B^0_s - \bar{B}^0_s$ oscillations
  - tagging: knowledge of initial $b$-hadron flavour, dilution of CP-asymmetries (wrong tag)
  - decay channels selection (yields, trigger efficiencies), background sources / levels

Full MC simulation main steps:

- **Pythia**: generation of $p - p$ collisions at $\sqrt{s} = 14$ TeV (including pile-up)
- **Geant**: detector response, spill-over and tracking through material
- on/offline pattern recognition, full trigger chain, tagging, offline selections, …
Full MC performances

- mass resolutions
  - $\sim 15\text{ MeV}/c^2$ for charged final states
  - $\sim 30 - 70\text{ MeV}/c^2$ when involving $\gamma(s)$
- vertex
  - primaries $\sigma_z \sim 50\text{ }\mu\text{m}$
  - $b$-decay vertices $\sigma_z < 200\text{ }\mu\text{m}$
- proper-time
  - $\sigma_T \sim 30 - 40\text{ fs}$

Flavour tagging power: $\varepsilon_{\text{eff}} = \varepsilon_{\text{tag}}(1 - 2\omega_{\text{tag}})^2$

- for $B_s^0 \rightarrow 2003\text{ MC}$: $\varepsilon_{\text{eff}} \sim 6\%$, 2004 MC (neural network): $\varepsilon_{\text{eff}} \sim 7 - 9\%$

Presentation results based on:
- for $\Delta M_s$: studies with 2003 MC data (re-opt. TDR CERN/LHCC 2003-030)
- for $\phi_s$: new study with recent MC data
  → improved tagging, L1 trigger, high-level trigger design ($\sim 2\text{ kHz}$), ...

$L^0_s \rightarrow J/\psi(\mu^+\mu^-)\eta(\gamma\gamma)$: $\sigma_{\text{m}} \sim 34\text{ MeV}/c^2$
Sensitivity to mixing observables

Statistical sensitivities to mixing observables assessed using fast MC

- generate event samples with LHCb expected statistics
- characteristics of samples taken from full simulation (resolutions, acceptance, tagging)
- background levels from fully-simulated inclusive $b\bar{b}$ events

Unbinned maximum likelihood fits to proper-time to extract expected statistical uncertainties

$$\mathcal{L} = \prod_i \left[ f_i^{\text{sig}} R_i^{\text{sig}} + (1 - f_i^{\text{sig}}) R_i^{\text{bkg}} \right]$$

- $f_i^{\text{sig}}$: signal probability based on reconstructed mass; $R_i^{\text{sig}}$, $R_i^{\text{bkg}}$: signal, bkg decay rates
- rates convoluted with proper-time resolution and weighted with acceptance
- proper-time resolution based on per-candidate computed errors from full MC
**$B^0_s \rightarrow D_s \pi$ reconstruction**

$\Delta M_s$ measurement with $B^0_s \rightarrow D_s^- \pi^+$: flavour specific decay

* flavour asymmetry $A_f^{obs}(t) = -D \cdot \frac{\cos(\Delta M_s t)}{\cosh\left(\frac{\Delta M_s t}{2}\right)}$, $D = (1 - 2w)$ if perfect resolution

Full MC study (LHCb 2003-127)

* reconstructed with $D_s \Rightarrow \text{KK} \pi$ mode, expect $\sim 80 \text{ k events per year (2 fb}^{-1})$

* $B/S \sim 0.3$ from fully-simulated inclusive $b\bar{b}$ events

Proper time resolution $\sim 40 \text{ fs}$

Acceptance (proper-time efficiency)

$\Rightarrow$ characteristics from full MC used as inputs for toy studies (LHCb 2003-103)

\[ B^0_s \text{ mass difference } \Delta M_s \text{ and mixing phase } \phi_s \text{ at LHCb (7)} \]
$B_s^0$ oscillation frequency with $B_s^0 \to D_s \pi$

Unbinned likelihood fit:

- rates weighted with acceptance, tagging dilution
- proper-time error $\sigma_t$ obtained from full MC → uncertainty to generated events
- $\Delta \Gamma_s/\Gamma_s = 0.1$

Once oscillations observed, precise value of $\Delta M_s$ obtained: uncertainty $\sim 0.06\%$ ($2 \text{ fb}^{-1}$)

Statistical precision on $\Delta M_s$ after 1 year ($2 \text{ fb}^{-1}$)

<table>
<thead>
<tr>
<th>$\Delta M_s \text{ [ps}^{-1}]$</th>
<th>15</th>
<th>20</th>
<th>25</th>
<th>30</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\sigma(\Delta M_s) \text{ [ps}^{-1}]$</td>
<td>0.009</td>
<td>0.011</td>
<td>0.013</td>
<td>0.016</td>
</tr>
</tbody>
</table>

$\sigma(\Delta M_s)$ will probably be dominated by systematics, e.g. $t$ scale

→ even if $\sigma_{\text{sys}} \sim 10 \cdot \sigma_{\text{stat}}$, uncertainty $< 1\%$

Decay rate for unmixed $B_s^0$
'Amplitude method' used to evaluate maximum value of $\Delta M_s$ measurable ($2 \text{ fb}^{-1}$)

$\rightarrow$ fit factor $A$ in front of $\cos (\Delta M_s t)$ term in asymmetry for different $\Delta M_s$ values

Statistical uncertainty on amplitude factor $A$ ($\sigma_A$) versus $\Delta M_s$

Sensitivity limit:
$\Delta M_s$ for which $5 \cdot \sigma_A = 1 = A$

In 1 year, $\geq 5\sigma$ observation of $B^0_s$ oscillations up to $\Delta M_s = 68 \text{ ps}^{-1}$

$\rightarrow$ could exclude full SM range

'Immediate' measure of $\Delta M_s$ if small: 1/8 year LHCb running! ($0.25 \text{ fb}^{-1}$, $\Delta M_s = 40 \text{ ps}^{-1}$)
**CP violation and $\bar{b} \to \bar{c}c\bar{s}$ transitions**

* $B_s^0 \to J/\psi \phi$: admixture of CP eigenstates ($\eta_{J/\psi\phi} = +1, -1, +1$)
  
  $\to$ one-angle $\theta_{tr}$ angular analysis (Phys.Rev. D63 (2001) 114015, hep-ph/0012219)

- fraction of CP-odd decays defined as $R_T \equiv |A_\perp(0)|^2 / \sum_{i=0,\|,\perp} |A_f(0)|^2 \sim \mathcal{O}(0.2)$

* $B_s^0 \to \eta_c \phi$, $B_s^0 \to J/\psi \eta^{(')}$: pure CP-even eigenstates $\to$ no angular analysis needed

* Mixing-induced CP violation: phase mismatch $\phi_s - 2\phi_D \approx \phi_s \neq 0, \pi$

  "first mix, then decay"

\[ \phi_s = \mathcal{O}(-0.04) \text{ rad (for given } \eta_{fCP}) \]

$A_{CP}(t) = \frac{-\eta_{fCP} \sin(\phi_s) \sin(\Delta M_s t)}{\cosh(\Delta\Gamma_s t/2) - \eta_{fCP} \cos(\phi_s) \sinh(\Delta\Gamma_s t/2)}$

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$B_s^0$ mass difference $\Delta M_s$ and mixing phase $\phi_s$ at LHCb (10)
Physics model: $\bar{b} \rightarrow \bar{c}c\bar{s}$ to pure CP eigenstates

- Final states $f = \eta_c \phi$, $J/\psi \eta^{(')}$ CP-even eigenstates: $(\mathcal{CP}) | f \rangle = \eta_f | f \rangle$, $\eta_f = +1$

- Transition rates of initially pure $B_s^0$ and $\bar{B}_s^0$ states (perfect resolution)

$$R(B_s^0(t) \rightarrow f) = |A_f(0)|^2 \times e^{-\Gamma_s t} \times \left[ \cosh \left( \frac{\Delta \Gamma_s t}{2} \right) - \eta_f \cos(\phi_s) \sinh \left( \frac{\Delta \Gamma_s t}{2} \right) + qD \eta_f \sin(\phi_s) \sin(\Delta M_s t) \right]$$

- Tagging categories: $q = +1, -1$ for $R(B_s^0, \bar{B}_s^0(t) \rightarrow f)$, $q = 0$ untagged

- $D = (1 - 2\omega)$: tagging dilution; $\omega$: wrong tag fraction

- Both $D$ and $\phi_s$ modulate the oscillating term: need a control channel to extract $\omega$
  $\rightarrow B_s^0 \rightarrow D_s \pi$ is used

- Untagged events: access to $\Delta \Gamma_s$ and $\phi_s$ (small sensitivity to $\phi_s$, since $\mathcal{O}(\phi_s^2)$ in SM)
Inputs from full MC simulation for $\phi_s$ study

Decay channels considered to assess LHCb sensitivity to $\phi_s$:

- $B^0_s \to J/\psi(\mu^+\mu^-)\phi(K^+K^-)$
- $B^0_s \to J/\psi(\mu^+\mu^-)\eta(\gamma\gamma, \pi^+\pi^-\pi^0)$: pure CP eigenstate
- $B^0_s \to \eta_c(\pi^+\pi^-\pi^+\pi^-, \pi^+\pi^-K^+K^-, K^+K^-K^+K^-)\phi(K^+K^-)$: pure CP eigenstate

These channels were studied in the full MC (2004 MC data), and inputs used for toys

Most relevant parameters (yields after high-level trigger):

<table>
<thead>
<tr>
<th>Parameters</th>
<th>$J/\psi \eta(\gamma\gamma)$</th>
<th>$J/\psi \eta(\pi^+\pi^-\pi^0)$</th>
<th>$\eta_c\phi$</th>
<th>$J/\psi \phi$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Untagged yield [k events] (2 fb$^{-1}$)</td>
<td>8.9</td>
<td>3.1</td>
<td>3</td>
<td>125</td>
</tr>
<tr>
<td>$B/S$</td>
<td>2.0</td>
<td>3.0</td>
<td>0.7</td>
<td>0.3</td>
</tr>
<tr>
<td>Mean $\sigma_{\text{rec}}$ [fs]</td>
<td>30.4</td>
<td>25.5</td>
<td>26.2</td>
<td>35.8</td>
</tr>
<tr>
<td>$\omega_{\text{tag}} / \varepsilon_{\text{tag}}$ [%]</td>
<td>35/63</td>
<td>30/62</td>
<td>31/66</td>
<td>33/60</td>
</tr>
</tbody>
</table>

These $\bar{b} \to c\bar{c}\bar{s}$ transitions will be fitted simultaneously with $B^0_s \to D_s\pi$ sample
$\phi_s$ likelihood fit strategy

- Generate and fit $\sim 250$ toy experiments corresponding to 1 year data taking at $2 \text{ fb}^{-1}$

- Unbinned (extended) likelihood fit to $L^\text{b-\bar{c}c\bar{s}}_{\text{tot}}$

$$
L^\text{b-\bar{c}c\bar{s}}_{\text{tot}} = \prod_{i \in \text{B}_s^0 \rightarrow f} L^\text{b-\bar{c}c\bar{s}}_i(m_i, \theta_{\text{tri}}, t_{\text{rec}}^i, \sigma_{t_i}, q_i)
$$

1. Mass distributions fitted to determine signal and background probabilities

2. Sidebands: background parameters determined, acceptance fitted

3. Signal window: physics parameters $\tilde{\alpha} = (\Delta \Gamma_s / \Gamma_s, \Delta M_s, \phi_s, \tau_{\text{B}_s^0}(, R_T))$ and wrong tag fraction $\omega$ fitted

- $L^\text{b-\bar{c}c\bar{s}}_{\text{tot}}$ simultaneously maximized with likelihood of the $\text{B}_s^0 \rightarrow D_s \pi$ control sample

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$\text{B}_s^0$ mass difference $\Delta M_s$ and mixing phase $\phi_s$ at LHCb (13)
Likelihood: rate parts

\[ \mathcal{L}_{t, even}^{\text{sig}}(t_i^{\text{rec}}, \sigma_i, q_i \mid \vec{\alpha}, \omega, acc_s) \propto A(t_i^{\text{rec}}) \times \left[ (1 - \omega) \Gamma^\text{even}_{B_s^0 \rightarrow f}(t_i^{\text{true}}) + \omega \Gamma^\text{even}_{\overline{B}_s^0 \rightarrow f}(t_i^{\text{true}}) \right] \}
\]

\[ \propto G(t_i^{\text{rec}} - t_i^{\text{true}}, S\sigma_i; \mu \sigma_i) \]

\[ \mathcal{L}_{t}^{\text{bkg}}(t_i^{\text{rec}}, \tau_{\text{bkg}}, acc_s) \propto A(t_i^{\text{rec}}) \times E(t_i^{\text{true}}; \tau_{\text{bkg}}) \otimes \delta(t_i^{\text{rec}} - t_i^{\text{true}}) \]

\[ \vec{\alpha} = (\Delta \Gamma_s / \Gamma_s, \Delta M_s, \phi_s, \tau_{B_s^0}(, R_T)): \text{vector of physics parameters} \]

*\( B_s^0 \rightarrow \eta_c \phi \) lifetime

*\( B_s^0 \rightarrow J/\psi \eta(\gamma \gamma) \) lifetime

Signal: red, Background: black, Total: blue
### $\phi_s$ sensitivities

<table>
<thead>
<tr>
<th>$\phi_s$ [rad]</th>
<th>$\Delta M_s$ [ps$^{-1}$]</th>
<th>$\Delta \Gamma_s / \Gamma_s$</th>
<th>$\tau_{B^0_s}$ [ps]</th>
<th>$R_T$</th>
</tr>
</thead>
<tbody>
<tr>
<td>-0.04</td>
<td>20.0</td>
<td>0.1</td>
<td>1.472</td>
<td>0.2</td>
</tr>
</tbody>
</table>

#### Fit results (2 fb$^{-1}$)

<table>
<thead>
<tr>
<th>Sensitivity</th>
<th>$J/\psi \eta(\gamma \gamma)$</th>
<th>$J/\psi \eta(3\pi)$</th>
<th>$\eta_c \phi$</th>
<th>$J/\psi \phi$</th>
<th>$\sigma(R_T) = 0.0047$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\sigma(\Delta \Gamma_s / \Gamma_s)$</td>
<td>0.019</td>
<td>0.024</td>
<td>0.025</td>
<td>0.011</td>
<td></td>
</tr>
</tbody>
</table>

#### Channels

<table>
<thead>
<tr>
<th>Channel</th>
<th>$\sigma(\phi_s)$ [rad]</th>
<th>Weight $(\sigma/\sigma_i)^2$ [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>$B^0_s \to J/\psi \eta(\gamma \gamma)$</td>
<td>0.112</td>
<td>6.4</td>
</tr>
<tr>
<td>$B^0_s \to J/\psi \eta(\pi^+ \pi^- \pi^0)$</td>
<td>0.148</td>
<td>3.6</td>
</tr>
<tr>
<td>$B^0_s \to \eta_c \phi$</td>
<td>0.106</td>
<td>7.1</td>
</tr>
<tr>
<td>Combined three pure CP eigenstates channels</td>
<td>0.068</td>
<td>17.1</td>
</tr>
<tr>
<td>$B^0_s \to J/\psi \phi$</td>
<td>0.031</td>
<td>82.9</td>
</tr>
<tr>
<td>Combined all four CP eigenstates channels</td>
<td>0.028</td>
<td>100.0</td>
</tr>
</tbody>
</table>

#### Contribution from pure CP eigenstates: $\sim 17\%$

With 10 fb$^{-1}$ (5 years): $\sigma(\phi_s) \sim 0.013$ rad $\rightarrow \sim 3\sigma$ for $\phi_s = -0.04$ rad (SM)

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$B^0_s$ mass difference $\Delta M_s$ and mixing phase $\phi_s$ at LHCb (15)
\( \Delta M_s \) with \( B_s^0 \to D_s \pi \)

\* very good precision after 1 year LHCb. If SM \( \Delta M_s \), do not need 2 fb\(^{-1} \) to measure it

\* could exclude full SM range in 1 year

\( \phi_s \) with \( B_s^0 \to J/\psi \phi(K^+K^-) \), \( B_s^0 \to J/\psi \eta(\gamma\gamma, \pi^+\pi^-\pi^0) \), \( B_s^0 \to \eta_c(4h) \phi(K^+K^-) \)

\* 3\( \sigma \) measurement within 5 year for SM \( \phi_s \), \( \sim 17\% \) contribution from pure CP eigenstates

\* \( \geq 5\sigma \) after 1 year if \( \phi_s \sim -0.2 \) rad

\* other channels could be added: \( B_s^0 \to J/\psi(e^+e^-)\phi(K^+K^-) \), \( B_s^0 \to J/\psi\eta' \)

\* lifetime unbiased selections and trigger to be explored (flat proper-time efficiency)

\[ \Rightarrow B_s^0 - \overline{B_s^0} \] represents a sensitive probe for New Physics \[ \Leftarrow \]

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BACK-UP SLIDES

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\[ \Delta M_S \] and mixing phase \[ \phi_S \] at LHCb (17)

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Physics model: $B^0_s \rightarrow J/\psi \phi$

• Final state $f$ is an admixture of CP eigenstates
  - $f = 0, \parallel$: CP-even, $\eta_f = +1$
  - $f = \perp$: CP-odd, $\eta_f = -1$

• Linear polarization amplitudes: $A_f(t)$
  - Fraction of CP-odd decays defined as $R_T \equiv |A_\perp(0)|^2 / \sum_{i=0,\parallel,\perp} |A_f(0)|^2 \sim \mathcal{O}(0.2)$
  - $R_T = (0.2 \pm 0.1)$, CDF: Phys.Rev.Lett. 94 (2005) 101803 (hep-ex/0412057)

• The one-angle $\theta_{tr}$ distribution enables to disentangle the different CP eigenstates

\[
\frac{d\Gamma(t)}{d(\cos(\theta_{tr}))} \propto \left[ |A_0(t)|^2 + |A_\parallel(t)|^2 \right] \frac{3}{8} (1 + \cos^2 \theta_{tr}) + |A_\perp(t)|^2 \frac{3}{4} \sin^2 \theta_{tr}
\]


Transversity angle $\theta_{tr}$: angle between positive lepton from the $J/\psi$ and the normal to the $\phi$ decay plane, in the $J/\psi$ rest frame
**Parameter scans**

Scans: input values to nominal, except for parameter under study (2 fb$^{-1}$)

<table>
<thead>
<tr>
<th>$\sigma(\phi_s)$ [rad]</th>
<th>Nominal</th>
<th>$\Delta M_s = 15$ ps$^{-1}$</th>
<th>$\Delta M_s = 25$ ps$^{-1}$</th>
<th>$\Delta \Gamma_s / \Gamma_s = 0.2$</th>
<th>$R_T = 0$</th>
<th>$R_T = 0.5$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$J/\psi \eta(\gamma\gamma)$</td>
<td>0.112</td>
<td>0.102</td>
<td>0.126</td>
<td>0.099</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>$J/\psi \eta(3\pi)$</td>
<td>0.148</td>
<td>0.136</td>
<td>0.161</td>
<td>0.139</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>$\eta_c \phi$</td>
<td>0.106</td>
<td>0.100</td>
<td>0.113</td>
<td>0.097</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>$J/\psi \phi$</td>
<td>0.031</td>
<td>0.028</td>
<td>0.034</td>
<td>0.030</td>
<td>0.021</td>
<td>0.062</td>
</tr>
</tbody>
</table>

- Sensitivity to $\phi_s$ increases by $\sim 10\%$ per 5 ps$^{-1}$ step in $\Delta M_s$.

- $R_T = 0$: pure CP eigenstate limit for $B_s^0 \rightarrow J/\psi \phi$, $\sigma(\phi_s)$ 1.5 times better w.r.t nominal.

- $R_T = 0.5$: $\sigma(\phi_s)$ gets 2 times worse for equal CP-even and CP-odd fractions.

Good precision for larger $\phi_s \sim -0.2$ rad: more than 5$\sigma$ in one year.

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$B_s^0$ mass difference $\Delta M_s$ and mixing phase $\phi_s$ at LHCb (19)

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

$$\mathcal{L}_{\text{tot}}^{\bar{b} \to \bar{c}c\bar{s}} = \prod_{i \in B_0^s \to f} \mathcal{L}_{i}^{\bar{b} \to \bar{c}c\bar{s}}(m_i, \theta_{\text{tri}}, t_{i}^{\text{rec}}, \sigma_{t_i}, q_i)$$

$$\mathcal{L}_{i}^{\bar{b} \to \bar{c}c\bar{s}}(m_i, \theta_{\text{tri}}, t_{i}^{\text{rec}}, \sigma_{t_i}, q_i) = \mathcal{L}_m^{\text{sig}}(m_i) \left[ R_T \mathcal{L}_{\theta_{\text{tri}}}^{\text{sig, odd}}(\theta_{\text{tri}}) \mathcal{L}_{t, \text{odd}}^{\text{sig}}(t_{i}^{\text{rec}}, \sigma_{t_i}, q_i) + (1 - R_T) \mathcal{L}_{\theta_{\text{tri}}}^{\text{sig, even}}(\theta_{\text{tri}}) \mathcal{L}_{t, \text{even}}^{\text{sig}}(t_{i}^{\text{rec}}, \sigma_{t_i}, q_i) \right]$$

$$\times \mathcal{L}_{m}^{\text{bkg}}(m_i) \mathcal{L}_{\theta_{\text{tri}}}^{\text{bkg}}(\theta_{\text{tri}}) \mathcal{L}_{t}^{\text{bkg}}(t_{i}^{\text{rec}})$$

- $\mathcal{L}_m^{\text{sig}}(m_i), \mathcal{L}_m^{\text{bkg}}(m_i)$: signal, background probabilities based on the reconstructed mass $m_i$
- $\mathcal{L}_m^{\text{sig}}(t_{i}^{\text{rec}}, \sigma_{t_i}, q_i), \mathcal{L}_m^{\text{bkg}}(t_{i}^{\text{rec}})$: signal, background decay rates
- $\mathcal{L}_{\theta_{\text{tri}}}^{\text{sig}}(\theta_{\text{tri}}), \mathcal{L}_{\theta_{\text{tri}}}^{\text{bkg}}(\theta_{\text{tri}})$: angular parts for $B_0^s \to J/\psi \phi$ with transversity angle $\theta_{\text{tri}}$

November 8th, 2005

'Flavour in the era of the LHC workshop', CERN

B$^0_s$ mass difference $\Delta M_\phi$ and mixing phase $\phi_\phi$ at LHCb (20)

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