B Physics expectations at LHCb

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New Physics is expected to play a role at LHC, but difficult to be characterized.

SM: CP violation is described by a complex phase in the unitarity CKM matrix. Unitary Triangles.
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CP Violation before LHC

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- SM: CP violation is described by a complex phase in the unitarity CKM matrix. Unitary Triangles

\[ \bar{\rho} = \rho(1 - \lambda^2/2) \quad \bar{\eta} = \eta(1 - \lambda^2/2) \]
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CP Violation before LHC

- New Physics is expected to play a role at LHC, but difficult to be characterized.
- SM: CP violation is described by a complex phase in the unitarity CKM matrix. Unitary Triangles.
- Belle and Babar.
Standard Model can not explain the baryon asymmetry of the Universe ⇒ CP violation is a probe to new Physics.

LHCb is a precision experiment designed to study the b sector:
- CP violation and rare decays
- Elie Aslanides’ talk
CP Violation at LHC

- Standard Model can not explain the baryon asymmetry of the Universe \(\Rightarrow\) CP violation is a probe to new Physics.
- LHCb is a precision experiment designed to study the b sector:
  - CP violation and rare decays
  - Elie Aslanides’ talk
- LHCb precision \(\Rightarrow\) 2 Unitary Triangles
CP Violation at LHC

- Standard Model can not explain the baryon asymmetry of the Universe ⇒ CP violation is a probe to new Physics.
- LHCb is a precision experiment designed to study the b sector: CP violation and rare decays
  Elie Aslanides’ talk
- LHCb precision ⇒ 2 Unitary Triangles
- LHCb will over constrain the Triangles
LHCb Physics Program

- $\Delta m_s, \phi_s$ and $\Delta \Gamma_s$: $B_s \to D_s \pi, J/\psi \Phi, J/\psi \eta$ and $\eta_c \Phi$
- $\alpha$: $B_d \to \pi^0 \pi^- \pi^+$
- $\beta$: $B_d \to J/\psi K_S$ and $B_s \to \Phi K_S$ (penguin)
- $\gamma$
  - $\text{CP}_{\text{asym}}(t)$: $B_s \to D_s^\pm K^\mp, K^+ K^-$ and $B_d \to \pi^+ \pi^-$
  - Decay Rates: $B_d^0 \to D^0(K^+ \pi^+; K^- \pi^-; K^+ K^-)K^{*0}$
    - $B_d^0 \to D^0(K^- \pi^+; K^+ \pi^-; K^+ K^-)K^{*0}$
  - Dalitz analysis: $B_d^{-,0} \to D^0(K_s \pi^- \pi^+, K_s K^- K^+)K^-, \ast^0$

Rare Decays

- Penguins: Radiative: $B_d \to (K^*, \omega)\gamma$, $B_s \to \Phi \gamma$; Electroweak $B_d \to K^* \mu^- \mu^+$; Gluonic: $B_s \to \Phi \Phi$ and $B_d \to \Phi K_s$
- Box diagram: $B_s \to \mu^- \mu^+$

$B_s$, b-baryon Physics, c Physics ...
LHCb Physics Program (in 15 minutes!)

- $\Delta m_s$, $\phi_s$ and $\Delta \Gamma_s$: $B_s \rightarrow D_s \pi$, $J/\psi \Phi$, $J/\psi \eta$ and $\eta_c \Phi$
- $\alpha$: $B_d \rightarrow \pi^0 \pi^- \pi^+$
- $\beta$: $B_d \rightarrow J/\psi K_S$ and $B_s \rightarrow \Phi K_S$ (penguin)
- $\gamma$
  - CP asym(t): $B_s \rightarrow D_s^{\pm} K^\mp$, $K^+ K^-$ and $B_d \rightarrow \pi^+ \pi^-$
  - Decay Rates: $B_d^0 \rightarrow D^0(K^+ \pi^-)$
  - Dalitz analysis: $B_d^{0,0} \rightarrow D^0(K_s^- \pi^- \pi^+, K_s K^- K^+)K^-, K^-$

Rare Decays

- Penguins: Radiative: $B_d \rightarrow (K^*, \omega) \gamma$, $B_s \rightarrow \Phi \gamma$;
  Electroweak $B_d \rightarrow K^* \mu^- \mu^+$;
  Gluonic: $B_s \rightarrow \Phi \Phi$ and $B_d \rightarrow \Phi K_s$
- Box diagram: $B_s \rightarrow \mu^- \mu^+$

- $B_s$, $b$-baryon Physics, $c$ Physics ...
Flavour Tagging

MC Simulation: 40M $b\bar{b}$ and 70M minimum bias events

How to know the b-flavor at $t=0$?

- detecting the flavor of the other $B$ on the opposite side: $e$, $\mu$, $K$, $B_{\text{charge}}$
- using $K^{\pm}$ for $B_s$ or $\pi^{\pm}$ for $B_s$ on the same side: $\pi/K$
Flavour Tagging

MC Simulation: 40M b\bar{b} and 70M minimum bias events

How to know the b-flavor at t=0?

- detecting the flavor of the other B:
  - opposite side: e, \mu, K, B_{\text{charge}}
  - using K^\pm for B_s or \pi^\pm for B_s - same side: \pi/K

- Tagging power characterized by \epsilon(1 - 2\omega)^2, where \epsilon is the efficiency and \omega the mistag

<table>
<thead>
<tr>
<th></th>
<th>B_d</th>
<th>B_s</th>
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<tbody>
<tr>
<td>\epsilon(1 - 2\omega)^2</td>
<td>4%-5%</td>
<td>6%-9%</td>
</tr>
</tbody>
</table>
**B_s Oscillation Frequency: \( \Delta m_s \)**

Needed for B_s time dependent CP asymmetries

\[ B_s \rightarrow D_s \pi^+ \]

- 2 fb\(^{-1}\) (one year of data taking)
- can observe \( > 5\sigma \) oscillation signal if \( \Delta m_s < 68 \text{ ps}^{-1} \)
- proper time resolution \( \approx 35 \text{ fs} \)
**B_s Oscillation Frequency: $\Delta m_s$**

Needed for $B_s$ time dependent CP asymmetries

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- 2 fb$^{-1}$ (one year of data taking)
- can observe $> 5\sigma$ oscillation signal if $\Delta m_s < 68$ ps$^{-1}$
- proper time resolution $\approx 35$ fs

LHCb: if $\Delta m_s = 20$ ps$^{-1}$ $\Rightarrow$

$\sigma_{LHCb}(\Delta m_s) = 0.01$ ps$^{-1}$
**B<sub>s</sub> Mixing Phase $\Phi_s$**

- CP asymmetry from interference: $B_s \rightarrow J/\psi \Phi$ and $B_s \rightarrow \bar{B}_s \rightarrow J/\psi \Phi$. **New Physics?**
- $B_s$ counter part of the golden mode $B_d \rightarrow J/\psi K_S (\beta)$

![Diagram of B_s and B_d decays](image_url)
**B\(_s\) Mixing Phase \(\Phi_s\)**

- CP asymmetry from interference: \(B_s \rightarrow J/\psi \Phi\) and \(B_s \rightarrow \bar{B}_s \rightarrow J/\psi \Phi\).
- \(B_s\) counter part of the golden mode \(B_d \rightarrow J/\psi K_S (\beta)\).
- Final state is a mixture of CP-even and odd contributions → angular analysis of decay products required.
- Also from pure CP eigenstates: \(J/\psi \eta(\gamma\gamma, \pi^+\pi^-\pi^0)\), \(\eta_c \Phi \Rightarrow\) no need of angular analysis, but lower statistics.
- Standard Model: \(\Phi_s = -2\chi = -0.036 \pm 0.003\) (CKM fitter)

10 fb\(^{-1}\) - 5 years

\[
\sigma(\Phi_s) = 0.013
\]
\(\alpha\) from \(B_d \rightarrow \pi^0 \pi^+ \pi^-\)

- Selection based in a multivariable analysis
- Dalitz plot analysis - Quinn Snyder method

- 14 kevents/year with B/S = 0.8
- 11-parameter likelihood fits in time-dependent Dalitz space
α from $B_d \rightarrow \pi^0 \pi^+ \pi^-$

- Selection based in a multivariable analysis
- Dalitz plot analysis - Quinn Snyder method

- 14 kevents/year with B/S = 0.8
- 11-parameter likelihood fits in time-dependent Dalitz space

$\alpha_{fit} = (102 \pm 9)^o$
Toy MC - 2 fb$^{-1}$
$\sigma(\alpha) = 10^o$
$\beta$ from $B_d \rightarrow J/\psi \ K_S$

- Well measured by Belle and Babar
  - $\langle \sin 2\beta \rangle_{\text{meas}} = 0.687 \pm 0.032$
  - in agreement with fitted value
  - $\langle \sin 2\beta \rangle_{\text{fit}} = 0.738 \pm 0.023$

$\sin 2\beta$
$\beta$ from $B_d \rightarrow J/\psi \ K_S$

To be measured as a proof of principle

- Well measured by Belle and Babar
  - $\sin 2\beta_{\text{meas}} = 0.687 \pm 0.032$
  - in agreement with fitted value
  - $\sin 2\beta_{\text{fit}} = 0.738 \pm 0.023$
- $2 \text{ fb}^{-1}$ LHCb
  - control channel: $B_d \rightarrow J/\psi \ K^*$
  - 216 kevents
  - $\sigma(\sin 2\beta) = 0.022$

$\sin 2\beta$

To be compared with values obtained from $b \rightarrow s$ penguin
\( \gamma \) from \( B_d \to D^0 K^{*0} \) - Gronau-London-Wyler Method

### 6 self tagging decays

\[
\begin{align*}
A_1 & \equiv A(B_d \to D^0 [K^+\pi^-] K^*[K^+\pi^-]) = \overline{A}_1 \\
A_2 & \equiv A(B_d \to D^0 [K^-\pi^+] K^*[K^+\pi^-]) = \overline{A}_2 e^{2i\gamma} \\
A_3 & \equiv A(B_d \to D_{CP}[KK,\pi\pi] K^*[K^+\pi^-]) \\
A_4 & \equiv A(\overline{B}_d \to D_{CP}[KK,\pi\pi] \overline{K}^*[K^-\pi^+]) 
\end{align*}
\]

A counting experiment: no tagging or proper time needed

- 6 measurements: \( A_i \)
- \( A_3 \neq A_4 \to \text{CPV} \)
- \( r_B \) - known
- \( \delta \) strong phase
**Physics Motivation**

**LHCb**

**B_s Mixing**

**CKM Angles**

**Rare Decay**

**Conclusions**

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**γ from B_d → D^0 K^{*0} - Gronau-London-Wyler Method**

**6 self tagging decays**

\[ A_1 \equiv A(B_d \rightarrow \bar{D}^0 [K^+ \pi^-] K^{*0}[K^+ \pi^-]) = \bar{A}_1 \]

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\[ A_3 \equiv A(B_d \rightarrow D_{CP}[KK, \pi\pi] K^{*0}[K^+ \pi^-]) \]

\[ A_4 \equiv A(\bar{B}_d \rightarrow D_{CP}[KK, \pi\pi] \bar{K}^{*0}[K^- \pi^+]) \]

- 6 measurements: \( A_i \)
- \( A_3 \neq A_4 \rightarrow CPV \)
- \( r_B \) - known
- \( \delta \) strong phase
- 8 ambiguities!

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**Insensitive to new Physics**

**UTFIT**

\[ \gamma_{UTFIT} = (71 \pm 16)^\circ \]

\[ \sigma_{1\text{year}}(\gamma) = 8^\circ \]

\[ \sigma_{5\text{years}}(\gamma) = 4^\circ \]
Rare Decay: $B_d \rightarrow K^{*0} \mu^- \mu^+$

Forward-backward asymmetry $A_{FB}(s)$ in the $\mu\mu$ rest-frame is a sensitive probe to New Physics

- Suppressed decay. $BR_{SM} \approx 10^{-6}$
- $2 \text{ fb}^{-1} \rightarrow 4.4$ kevents with $B/S < 2.6$
Rare Decay: $B_d \rightarrow K^{*0}_\mu \mu^-$

Forward-backward asymmetry $A_{FB}(s)$ in the $\mu\mu$ rest-frame is a sensitive probe to New Physics

- Suppressed decay. $BR_{SM} \approx 10^{-6}$
- $2 \text{ fb}^{-1} \rightarrow 4.4$ kevents with $B/S < 2.6$
- $10 \text{ fb}^{-1}$: zero of $A_{FB}$ located to $\pm 0.53$ GeV$^2$
## LHCb performance with 2fb\(^{-1}\) (1 year)

<table>
<thead>
<tr>
<th>Channel</th>
<th>Yield</th>
<th>(B_{bb}/S)</th>
<th>Precision</th>
</tr>
</thead>
<tbody>
<tr>
<td>(B_s \rightarrow D_s K)</td>
<td>5.4k</td>
<td>(&lt; 1)</td>
<td>(\sigma(\gamma) \approx 14^\circ)</td>
</tr>
<tr>
<td>(B_d \rightarrow \pi\pi)</td>
<td>26k</td>
<td>(&lt; 0.6)</td>
<td>Fleicher (\sigma(\gamma) \approx 6^\circ)</td>
</tr>
<tr>
<td>(B_d \rightarrow K K)</td>
<td>37k</td>
<td>0.3</td>
<td></td>
</tr>
<tr>
<td>(\gamma)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(B_d \rightarrow D^0(K^+\pi^-) K^*)</td>
<td>0.5k</td>
<td>(&lt; 0.3)</td>
<td></td>
</tr>
<tr>
<td>(B_d \rightarrow D^0(K^-\pi^+) K^*)</td>
<td>2.4k</td>
<td>(&lt; 2)</td>
<td>GLW+D (\sigma(\gamma) \approx 8^\circ)</td>
</tr>
<tr>
<td>(B_d \rightarrow \overline{D}_CP (KK,\pi\pi) K^*)</td>
<td>0.6k</td>
<td>(&lt; 0.3)</td>
<td></td>
</tr>
<tr>
<td>(B^- \rightarrow D^0(K^+\pi^-) K^-)</td>
<td>60k</td>
<td>0.5</td>
<td>ADS (\sigma(\gamma) \approx 5^\circ)</td>
</tr>
<tr>
<td>(B^- \rightarrow \overline{D}^0(K^-\pi^+) K^-)</td>
<td>2k</td>
<td>0.5</td>
<td></td>
</tr>
<tr>
<td>(\alpha)</td>
<td>(B_d \rightarrow \pi^0\pi^+\pi^-)</td>
<td>14k</td>
<td>0.8</td>
</tr>
<tr>
<td>(\beta)</td>
<td>(B_d \rightarrow J/\Psi K_S)</td>
<td>216k</td>
<td>0.8</td>
</tr>
<tr>
<td>(\phi_s)</td>
<td>(B_s \rightarrow J/\Psi \Phi)</td>
<td>125k</td>
<td>0.3</td>
</tr>
<tr>
<td></td>
<td>(B_s \rightarrow J/\Psi \eta)</td>
<td>12k</td>
<td>2.3</td>
</tr>
<tr>
<td></td>
<td>(B_s \rightarrow \eta_c \Phi)</td>
<td>3k</td>
<td>0.7</td>
</tr>
<tr>
<td>(\Delta m_s)</td>
<td>(B_s \rightarrow D_s \pi)</td>
<td>80k</td>
<td>0.8</td>
</tr>
<tr>
<td>rare decays</td>
<td>(B_d \rightarrow K^*\mu\mu)</td>
<td>4.4k</td>
<td>(&lt; 2.6)</td>
</tr>
<tr>
<td></td>
<td>(B_s \rightarrow \mu\mu)</td>
<td>17</td>
<td>(&lt; 5.7)</td>
</tr>
<tr>
<td></td>
<td>(B_d \rightarrow K^*\gamma)</td>
<td>35k</td>
<td>(&lt; 0.7)</td>
</tr>
</tbody>
</table>
Conclusions

- $B_d$, $B_u$, $B_s$ and $B_c$ systems studied at an unprecedented level of accuracy
- $B_s - \bar{B}_s$ oscillations measured
- CP angles determined via channels with different sensitivity to NP
- Many measurements of rare decays and CP asymmetries performed
- $b$-baryon, $c$ Physics ...
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\[
\begin{align*}
\Delta m_s < 68 \text{ ps}^{-1} & \quad (5\sigma) \\
\sigma(\Delta m_s) & \approx 0.02 \text{ ps}^{-1} \\
\sigma(\phi_s) & \approx 2^\circ \\
\sigma(\alpha) & \approx 10^\circ \\
\sigma(\beta) & \approx 0.9^\circ \\
\sigma(\gamma) & \approx 5^\circ 
\end{align*}
\]
LHCb offers an excellent opportunity to spot New Physics signals beyond Standard Model and will be ready in 2007

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- $B_s - \bar{B}_s$ oscillations measured
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### 2 fb$^{-1}$ (1 year)

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