Prospects for CP measurements with charmless hadronic B decays @ LHCb

Ignacio Bediaga, on behalf of the LHCb collaboration
Centro Brasileiro de Pesquisas Físicas (CBPF-Brazil)
Outline

- Motivation and Analysis strategies
- $B^0, B_s^0$ and $\Lambda^0_b \to hh$ and $B^+ \to hhh$ selections.
- Yields for 1fb$^{-1}$: first charmless B decay signal at 122nb$^{-1}$
- CP sensitivity studies
- Summary
Motivation

- Study of the known sources of direct CP with the high LHCb statistics.
- Search for new sources of CP.
- Independent extraction of CKM phase $\gamma$.
- Search for new charmless $B$ decays.
- Study of $\Delta \Gamma_s$ linked to the $B_s^0 \rightarrow (K^+K^-)$ lifetime.
**Charmless two and three body $B$ and $\Lambda^{0}_b$ decays @ LHCb**

**Neutral two body**
- $B^0 \rightarrow \pi^- \pi^+$
- $B^0 \rightarrow K^+ \pi^-$
- $B^o_s \rightarrow K^- \pi^+$
- $B^o_s \rightarrow K^+ K^-$
- $\Lambda^{0}_b \rightarrow \rho \pi^-$
- $\Lambda^{0}_b \rightarrow \rho K^-$

**Charged three body**
- $B^+ \rightarrow \pi^+ \pi^+ \pi^-$
- $B^+ \rightarrow K^+ \pi^+ \pi^-$
- $B^+ \rightarrow \pi^+ K^+ K^-$
- $B^+ \rightarrow K^+ K^+ K^-$
- $B^+ \rightarrow \rho \rho$
- $B^+ \rightarrow K^+ \rho \rho$

**Neutral three body**
- $B^0, B^0_s \rightarrow K^0_s \pi^- \pi^+$ and $B^0, B^0_s \rightarrow K^0_s K^- K^+$
- $B^+ \rightarrow \pi^- K^+ K^+$ \text{(BR~10^{-11})}
- $B^+ \rightarrow K^- \pi^+ \pi^+$ \text{(BR~10^{-14})}

Not observed yet
**CP in Standard Model:**

contributions to the charmless $B$ decays

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**Tree**

**Penguin**

+ Penguin Annihilation + Electroweak Penguin + $W$-Exchange
**CP beyond Standard Model:** contributions to the charmless B decays

- **Tree**
- **Penguin**

+ Penguin Annihilation + Electroweak Penguin + W-Exchange
Analysis implemented for $B^0, \overline{B}^0_s, B^+ and \Lambda^0_b$ decays for $1\text{fb}^{-1}$

- Direct CP in two body decays:
  - $A_{\text{cp}}(B^0_s \rightarrow \pi^+ K)$,
  - $A_{\text{cp}}(\Lambda^0_b \rightarrow p \pi)$,
  - $A_{\text{cp}}(\Lambda^0_b \rightarrow p K)$

- Sources of CP in three body decay through interference in the Dalitz

- Search for $B^0 \rightarrow p\overline{p}$ and other two and three body charged decays

- $B^0 \rightarrow K^+ K^-$ lifetime: indirect measurement $\Delta \Gamma_s$

- Tagged and time dependent studies for:
  - $A_{\text{cp}}(B^0_s \rightarrow K^+ K^-)$,
  - $A_{\text{cp}}(B^0 \rightarrow \pi^+ \pi^-)$ and CKM $\gamma$

- Dalitz Analysis: CP asymmetry in resonant intermediary states $A_{\text{cp}}(B^+ \rightarrow \text{Resonances}^0 h^+)$ and CKM $\gamma$
**Selection**

- Inclusive pre-selection: 2 or 3 tracks without particle identification
- Pion mass hypothesis for all $hh$ and $hhh$ decays
- Vertex cuts

**Exclusive pre-selection for $B^0_s \rightarrow K^+K^-$ lifetime:** uses PID with kaon mass hypothesis
Vertex selection

PV resolution

Z resolution

Mass resolution in Charm signal

Vertex selection based on transverse momentum, impact parameter, displacement significances, vertex $\chi^2$

Special attention to avoid bias with these cuts:
- Time resolution study: avoid Displacement and Impact Parameter cuts
- Dalitz plot acceptance: avoid Impact Parameter and PT all three tracks
Particle ID selection

$\Delta \log \mathcal{L}(K - \pi) > 5$

Final selection with the good LHCb particles identification distinguish between different modes

See, A. Powell in PID @ LHCb ICHEP2010

$\Phi \to KK$

LHCb simulation
**hh Yields**
run 2010-2011 $\rightarrow 1fb^{-1}$

<table>
<thead>
<tr>
<th>Estimated Luminosity 1 fb$^{-1}$</th>
<th>Total Efficiency*</th>
<th>Branching Fraction ($10^{-6}$)</th>
<th>Estimated** Number of events</th>
</tr>
</thead>
<tbody>
<tr>
<td>$B \rightarrow \pi\pi$</td>
<td>1.4%</td>
<td>$5.13 \pm 0.24$</td>
<td>40 K</td>
</tr>
<tr>
<td>$B \rightarrow K\pi$</td>
<td>1.4%</td>
<td>$19.4 \pm 0.06$</td>
<td>130 K</td>
</tr>
<tr>
<td>$B_s \rightarrow \pi K$</td>
<td>1.4%</td>
<td>$5.27 \pm 1.17$</td>
<td>10K</td>
</tr>
<tr>
<td>$B_s \rightarrow K K$</td>
<td>1.4%</td>
<td>$25.8 \pm 4.2$</td>
<td>40 K</td>
</tr>
<tr>
<td>$\Lambda \rightarrow p\pi$</td>
<td>1.2%</td>
<td>$3.1 \pm 0.9$</td>
<td>4 K</td>
</tr>
<tr>
<td>$\Lambda \rightarrow p K$</td>
<td>1.2%</td>
<td>$5.0 \pm 1.2$</td>
<td>7 K</td>
</tr>
</tbody>
</table>

* Total Efficiency = Geometry \times Trigger \times Selection efficiency

** B cross section preliminary LHCb measurement: see S. Stone ICHEP2010
$B^0 \rightarrow K^+ \pi^- \text{ signal } 122 \text{nb}^{-1}$

K, π:  
- IP/σ > 6
- $P_T > 1 \text{GeV}$

K:  
- $\Delta_{LL}(K-\pi) > 0$

π:  
- $\Delta_{LL}(\pi-K) > 0$

B0:  
- $\chi^2(\text{vertex}) < 5$
- $P_T > 1.0 \text{GeV}$
- $L/\sigma > 18$
- IP/σ < 2.5

First charmless decay signal
**hh' CP sensitivity at 1fb⁻¹**

<table>
<thead>
<tr>
<th>Estimated Luminosity 1 fb⁻¹</th>
<th>Current experiment or prediction</th>
<th>LHCb statistic sensitivity</th>
</tr>
</thead>
<tbody>
<tr>
<td>( A_{cp}(B \rightarrow K^+\pi^-) )</td>
<td>(-0.098 \pm 0.012)</td>
<td>0.004</td>
</tr>
<tr>
<td>( A_{cp}(B_s \rightarrow \pi^+K^-) )</td>
<td>(0.39 \pm 0.15)</td>
<td>0.025</td>
</tr>
<tr>
<td>( A_{cp}(\Lambda_b \rightarrow p\pi^-) )</td>
<td>(0.03 \pm 0.17)</td>
<td>0.025</td>
</tr>
<tr>
<td>( A_{cp}(\Lambda_b \rightarrow pK^-) )</td>
<td>(0.37 \pm 0.17)</td>
<td>0.015</td>
</tr>
</tbody>
</table>

Substantial improvement for \( B^0_s \) and \( \Lambda^0_b \)

Contribution to understand the ACP Puzzle
**Sensitivity for** $B^0 \rightarrow p\bar{p}$

**run 2010-2011 → 1 fb^{-1}**

**Observation for BR > 4 \times 10^{-8}**
$B^0_s \rightarrow K^+K^-$ Precise lifetime measurement

- Special unbiased trigger line for this channel
- Sensitivity for $\sigma (c\tau) \sim 10 \, \mu m$ at 5K events with low bias
**hhh Yields**  
*run 2010-2011 →1fb⁻¹*

<table>
<thead>
<tr>
<th>Estimated Luminosity 1 fb⁻¹</th>
<th>Total Efficiency*</th>
<th>Branching Fraction(10⁻⁵)</th>
<th>Estimated Number of events</th>
</tr>
</thead>
<tbody>
<tr>
<td>πππ</td>
<td>2.4%</td>
<td>1.62 ± 0.15</td>
<td>100K</td>
</tr>
<tr>
<td>Kππ</td>
<td>2.4%</td>
<td>5.5 ± 0.70</td>
<td>300K</td>
</tr>
<tr>
<td>KKπ</td>
<td>2.4%</td>
<td>0.50 ± 0.07</td>
<td>30K</td>
</tr>
<tr>
<td>KKK</td>
<td>2.4%</td>
<td>3.37 ± 0.22</td>
<td>200K</td>
</tr>
<tr>
<td>ppπ</td>
<td>2.3%</td>
<td>0.16 ± 0.02</td>
<td>10K</td>
</tr>
<tr>
<td>ppK</td>
<td>2.3%</td>
<td>0.59 ± 0.05</td>
<td>30K</td>
</tr>
</tbody>
</table>

* Total Efficiency = Geometry X Trigger X Selection efficiency  
** B cross section preliminary LHCb measurement: see S. Stone ICHEP2010
Search for sources of CP in $B^+ \rightarrow hhh$: Mirandizing

Possibility of probing regions of the Dalitz plot looking at interference with CP:
1- resonant intermediary asymmetries like: $A_{cp} (B^+ \rightarrow K^+ \rho^0)$
2- CP in interferences between intermediary resonant states with CP

model independent method

For $B^+ \equiv B^- \implies CP$

Subtract $B^+$ and $B^-$ Dalitz surface and write the significance of each bin:

$$D_P S_{CP}(i) = \frac{(N^+(i) - N^-(i))}{\sqrt{(N^+(i) + N^-(i))}}$$

“imported” from astrophysical community:
-Phys. Rev. D 80, 096006 (2009)

Pure statistical fluctuation: centred Gaussian of unit width $g_0(0,1)$. CP invariance $\implies g(0,1)$
Search for sources of $CP$ in $B^+ \rightarrow hhh$: Mirandizing

$B^+ \neq B^- \implies CP$

$DP S_{CP}$

$CP \implies g(0,1)$
Search for sources of CP in $B^+ \to hhh$: Mirandizing

$B^+ \neq B^- \implies \text{CP}$

probing regions of the Dalitz plot

$\text{CP} \implies g(0,1)$
Summary

- Study of the charmless two and three charged body B decays @ LHCb in good shape.

- The estimated 1fb^{-1} for the 2010-2011 run, would give at least, one order of magnitude more events than the nowadays world statistic.

- Analysed strategies well defined.

- Expected important reduction in the CP measurement

- Expected important reduction in the measurement in the γ CKM phase