Baryonic B decays ($B^{-\rightarrow \bar{p}\Lambda D^{(*)0}}$) at Belle

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for the Belle Collaboration

Outline
Introduction
$B^{-\rightarrow \bar{p}\Lambda D^{0}}$
$B^{-\rightarrow \bar{p}\Lambda D^{*0}}$
Summary
The unique feature of $B$ meson: Baryonic decay

$B \rightarrow p \bar{p} K^{(*)0}$, $p \bar{p} D^{(*)0}$, $p \bar{p} \pi$, $p \bar{p} K^*$, $p \bar{\Lambda} \pi^-$, $p \bar{\Lambda} \gamma$, $\Lambda \bar{\Lambda} K^+$, $\Lambda \bar{\Lambda} K^{(*)0}$, $p \bar{\Lambda} K^{*0}$

Threshold enhancement in the baryon-antibaryon system

For $B \rightarrow \bar{p} \Lambda D^{(*)0}$

the branching fraction for charmful modes are higher than charmless ones.

$b \rightarrow c$ tree dominant, penguin effect negligible.

Large Belle data sample may allow us to understand more about the mechanism of baryonic $B$ decays.
A test for generalized factorization

Three body charmful baryonic B decays with the D(*) meson

Under generalized factorization:
- Current type
- Transition type
- Hybrid type

C. Chen et al. predict:

\[
\mathcal{B}(B^- \rightarrow \bar{p}\Lambda D^0) = 11.4 \pm 2.6 \times 10^{-6}
\]

\[
\mathcal{B}(B^- \rightarrow \bar{p}\Lambda D^{*0}) = 32.3 \pm 3.2 \times 10^{-6}
\]

PRD 78:054016(2008)
Event Selection

- For $B \rightarrow \bar{p}\Lambda D^0$ reconstruction:
  - $|dr|<0.3\text{cm}$, $|dz|<3.0\text{cm}$
  - $\mathcal{L}(K, \pi) < 0.4$ for $\pi$ (Eff. 8%)
  - $\mathcal{L}(K, \pi) > 0.6$ for $K$
  - $\mathcal{L}(p, K) > 0.6$, $\mathcal{L}(p, \pi) > 0.6$ for $p$
  - Invariant mass of $p\pi$ for $\Lambda$
  - Invariant mass of $K^-\pi^+ (\pi^0)$ for $D^0$

\[ B \rightarrow \bar{p}\Lambda D^0 \rightarrow K^- \pi^+ (\pi^0) \]

\[ p \pi^- \]

\[ M_{bc} = \sqrt{E_{beam}^2 - P_B^2} \]

\[ \Delta E = E_B - E_{beam} \]

For $B \rightarrow \bar{p}\Lambda D^0$ reconstruction:

- Invariant mass of $p\pi$ for $\Lambda$
- Invariant mass of $K^-\pi^+ (\pi^0)$ for $D^0$

\[ M_{\Lambda} \]

\[ M_{k+\pi^-} : [1.855, 1.875] \text{ GeV/c}^2 \]

\[ M_{k\pi^0} : [1.837, 1.885] \text{ GeV/c}^2 \]
Result for $B^- \rightarrow \bar{p}\Lambda D^0$

We obtain
$BF(B^- \rightarrow \bar{p}\Lambda D^0) = (1.40^{+0.27}_{-0.24} \pm 0.16) \times 10^{-5}$

with significance 8.6 $\sigma$

prediction: $BF(B^- \rightarrow \bar{p}\Lambda D^0) = 1.14 \pm 0.16 \times 10^{-5}$

<table>
<thead>
<tr>
<th>Decays</th>
<th>$N_s$</th>
<th>$\sigma$</th>
<th>Eff.</th>
<th>$B(\times 10^{-5})$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$D^0 \rightarrow K^-\pi^+$</td>
<td>$28.0^{+6.6}_{-5.8}$</td>
<td>7.7</td>
<td>11.58%</td>
<td>$1.40^{+0.27}_{-0.24} \pm 0.16$</td>
</tr>
<tr>
<td>$D^0 \rightarrow K^-\pi^+\pi^0$</td>
<td>$35.9^{+11.7}_{-10.7}$</td>
<td>3.9</td>
<td>4.57%</td>
<td>$1.35^{+0.44}_{-0.40} \pm 0.18$</td>
</tr>
</tbody>
</table>

First observation
ICHEP 2010
BELLE-CONF-1038
Discussion of $B^- \rightarrow \bar{\rho} \Lambda D^0$ vs. $B^0 \rightarrow \bar{\rho} p D^0$ and $B^0 \rightarrow \rho \bar{\Lambda} \pi^+$

Threshold enhancement of the baryon pair mass

$B^- \rightarrow \bar{\rho} \Lambda D^0$

$BF(B^- \rightarrow \bar{\rho} \Lambda D^0) = (1.40^{+0.27}_{-0.24} \pm 0.16) \times 10^{-5}$

$B^0 \rightarrow \rho \bar{\Lambda} \pi$

$BF(B^0 \rightarrow \rho \bar{\Lambda} \pi) = (3.23^{+0.33}_{-0.29} \pm 0.29) \times 10^{-6}$

$B^0 \rightarrow \bar{\rho} p D^0$

$BF(B^0 \rightarrow \bar{\rho} p D^0) = (1.18 \pm 0.15 \pm 0.16) \times 10^{-4}$

PRD, 76, 052004(2007)

PRL 89, 151802 (2002)
B^- → ρ^-ΛD^*0 background study

- Dominate background
  \[ B^0 \rightarrow \bar{\rho} \Lambda D^*; D^* \rightarrow D^0 \pi^+ \]
- We miss the slow \( \pi^+ \) from \( D^{*+} \) and two random photons are combined as a \( \pi^0 \) candidate to reconstruct \( D^{*0} \)
- \( \Delta M \equiv M_{D^{*0}} - M_{D^0} \)

\[ B^0 \rightarrow \bar{\rho} \Lambda D^{*+} \text{ MC} \]

\[ B^- \rightarrow \bar{\rho} \Lambda D^{*0} \text{ MC} \]

By fixing PDF for misreconstructed signal.
The reason for misreconstructed signal of \( p\Lambda D^*0 \) and \( p\Lambda D^*+ \) are same due to a missing \( \pi^0(+) \) and PDFs of them are the same.

We should combine and discuss both of contributions as one background in this analysis.

They are denoted as self-cross feed (SCF).

SCF differs from correctly reconstructed (CR) signal by \( \Delta M \).
B⁻→\bar{\rho}\Lambda D*⁰ (CR signal vs. SCF)

- PDFs correlate with ∆M.
- Estimate and fix the contribution of SCF to fit CR signal
- Fraction of SCF in ∆M sideband/signal region is 0.26
- Obtain the N_{SCF} in sideband region and scale it to signal region N'_{SCF} by the area ratio 0.26
Result for $B^- \rightarrow \bar{p}\Lambda D^*$

**$\Delta M$ sideband region**

$N_{SCF} = 11.6 \pm 5.4$

$N_{SCF'} = 0.26 \times N_{SCF}$

$N_{SCF'} = 3.0 \pm 1.4$

Fix $N_{SCF'}$ to fit signal region

**$\Delta M$ signal region**

$BF(B^- \rightarrow \bar{p}\Lambda D^{*0}) < 4.6 \times 10^{-5}$ at 90% C.L.

Using Pole package

*prediction: $BF(B^- \rightarrow \bar{p}\Lambda D^0) = (3.23 \pm 0.32) \times 10^{-5}$*
**Summary**

\[ B^- \rightarrow \bar{p} \Lambda D^{(*)0} \] with 657M \( B \bar{B} \)

- \( BF(B^- \rightarrow \bar{p} \Lambda D^0) = (1.40^{+0.27}_{-0.24} \pm 0.16) \times 10^{-5} \)
- No significant signal \( \Rightarrow BF(B^- \rightarrow \bar{p} \Lambda D^{*0}) < 4.6 \times 10^{-5} \) at 90% C.L.
- The measurement of \( BF(B^- \rightarrow \bar{p} \Lambda D^0) \) shows consistent with prediction

\[
\mathcal{B}(B^- \rightarrow \Lambda \bar{p}D^0) = 1.1 \times 10^{-5}, \\
\mathcal{B}(B^- \rightarrow \Lambda \bar{p}D^{*0}) = 3.2 \times 10^{-5},
\]

Di-baryon enhancement at low mass for \( B^- \rightarrow \bar{p} \Lambda D^0 \)

- Need more data to study angular distribution and other properties \( \rightarrow \) Belle2
Backup slide
Event Selection

For $B^- \rightarrow p \Lambda D^0$

- $|dr| < 0.3\text{cm}$, $|dz| < 3.0\text{cm}$
- $\mathcal{L}(K, \pi) < 0.4$ for $\pi$
- $\mathcal{L}(K, \pi) > 0.6$ for $K$
- $\mathcal{L}(p, K) > 0.6$, $\mathcal{L}(p, \pi) > 0.6$ for $p$
- Invariant mass of $p\pi$ for $\Lambda$
- Invariant mass of $K^-\pi^+ (\pi^0)$ for $D^0$

$|M_{p\pi^+} - 1.116 \text{GeV/c}^2| < 5 \text{MeV/c}^2$

$|M_{K\pi^0} - 1.865 \text{GeV/c}^2| < 10 \text{MeV/c}^2$

$1.837 < M_{K\pi\pi0} < 1.885 \text{GeV/c}^2$
**Generic BB background**

\[ \Delta E \text{ when } M_{bc} > 5.2 \text{ GeV} \quad \text{Mbc when } -0.1 < \Delta E < 0.4 \text{ GeV} \]

We use 3Xdata generic MC to check background.

The dominant peaking bg is from \( B \to p \Lambda D^{**} \) and SCf of \( B \to p \Lambda D^{*0} \)

It will be discussed later.

Others bg is peaking at Mbc, but not DE. These else bg which might be due to PYTHIA fragmentation \((B \to \Delta^{0(++)} p D^{* (0)+}; B \to \Sigma^{0} p D^{* (0)+})\), which will be studied by considering as systematic error by the discrepancy with or w/o PDFs to final data fit in signal region. We will test it with generic samples later.
$B^0 \rightarrow p \Lambda D^{*+}$ vs SCF of $\bar{p} \Lambda D^{*0}$

$B \rightarrow p \Lambda D^{*+}$ ; $D^{*+} \rightarrow D^0 \pi^+$

We miss a slow $\pi^+$ and capture two random photons as a $\pi^0$ with an assigned $\pi^0$ mass in the $\pi^0$ bank. In such case, the reason for SCF of $p \Lambda D^{*0}$ and $p \Lambda D^{*+}$ are the same.

The further study to check if SCF of $p \Lambda D^{*0}$ and $p \Lambda D^{*+}$ are the same, is necessary. We check it by $\Delta M$, $\Delta E$ and $M_{bc}$ distributions.

2011/02/24  LLWI2011
By comparing signal truth yields obtained from fits to whole $p \Lambda D^{*0}$ signal MC (including truth and SCF) $\Delta M$ distribution with two threshold shape parameterizations.

1. Threshold function fixed to $p \Lambda D^{*+}$: $N_{\text{truth}} = 6737.7 \pm 107.1$

2. Floating threshold function: $N_{\text{truth}} = 6761.3 \pm 193.3$
If $\Delta E$ and $\Delta m_{bc}$ for SCF and $p\Lambda D^{*+}$ are the same, we check it with fit of $p\Lambda D^{*+}$ by fixed shape parameters of PDFs obtained from SCF fit in the both of signal and sideband region. The parameters are shown in backup slide.

Since $\Delta M$, $\Delta E$ and $M_{bc}$ for SCF and $p\Lambda D^{*+}$ are the same. We could not separate them by fit with these distributions, and with low statistic situation it is hard to separate truth signal also. We denote combination contribution of SCF and $p\Lambda D^{*+}$ as SCF'.
Extracted generic MC test with others bg

Sample is composed of $p\,\Lambda\,D^{*+}$ and $p\,\Lambda\,D^{*0}$ from generic MC and qq MC for test.

We have 3 trial MC sample for test. For the sample without other backgrounds besides $p\,\Lambda\,D^{*+}$ and $p\,\Lambda\,D^{*0}$ from generic MC, even though we add the PDFs of OthersB, the yield is still zero. The truth yield is consistent with truth events estimated from idhep.

$N_{\text{sum}} = 64.9 \pm 10.1$
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$N_{\text{sum}}' = R \times N_{\text{sum}}$
$R = 26.0 \pm 0.9\%$

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$N_{\text{sum}}' = R \times N_{\text{sum}}$
$R = 26.0 \pm 0.9\%$

For the sample without other backgrounds besides $p\,\Lambda\,D^{*+}$ and $p\,\Lambda\,D^{*0}$ from generic MC, even though we add the PDFs of OthersB, the yield is still zero. The truth yield is consistent with truth events estimated from idhep.
Whole Generic MC test with others bg

PDF_others: 1d smoothed histogram for $\Delta E$

![Graph showing histograms for $\Delta E$ and $M_{bc}$](image)

Fixed shape parameters table of Fit

<table>
<thead>
<tr>
<th>source (GeV)</th>
<th>$M_{bc}$ mean</th>
<th>width</th>
<th>$\Delta E$ mean</th>
<th>width</th>
<th>Width2/1</th>
<th>Area2/1</th>
</tr>
</thead>
<tbody>
<tr>
<td>truth signal</td>
<td>5.27902</td>
<td>0.00259</td>
<td>-0.00026</td>
<td>0.00748</td>
<td>2.70</td>
<td>0.10</td>
</tr>
<tr>
<td>error</td>
<td>0.00003</td>
<td>0.00002</td>
<td>0.00010</td>
<td>0.00013</td>
<td>0.19</td>
<td>0.02</td>
</tr>
<tr>
<td>SCF in signal region</td>
<td>5.27870</td>
<td>0.00332</td>
<td>-0.0031</td>
<td>0.0107</td>
<td>2.27</td>
<td>0.77</td>
</tr>
<tr>
<td>error</td>
<td>0.00005</td>
<td>0.00004</td>
<td>0.0005</td>
<td>0.0014</td>
<td>0.25</td>
<td>0.06</td>
</tr>
</tbody>
</table>

Pink line Others bg test by 3 models

Gaussian Chebshev fun.

<table>
<thead>
<tr>
<th>source (GeV)</th>
<th>$M_{bc}$ mean</th>
<th>width</th>
<th>$c1$</th>
<th>$c2$</th>
<th>-</th>
<th>-</th>
</tr>
</thead>
<tbody>
<tr>
<td>Others bg 1st</td>
<td>5.2763</td>
<td>0.00432</td>
<td>-1.0021</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>error</td>
<td>0.0008</td>
<td>0.00088</td>
<td>0.1142</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Others bg 2nd</td>
<td>5.2763</td>
<td>0.00432</td>
<td>-1.0039</td>
<td>0.2402</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>error</td>
<td>0.0008</td>
<td>0.00088</td>
<td>0.1034</td>
<td>0.1113</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Others bg 3rd</td>
<td>5.2763</td>
<td>0.00432</td>
<td>smoothed histogram</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

Here, the all PDF of blue, green, pink and # of green are fixed Other # parameters and PDF of qq are float

$$N_{sum} = R \times N_{sum'}$$  $$R = 26.0 \pm 0.9\%$$
Uncertainty due to OthersB

PDF_others: 1st Cheby. for ΔE

PDF_others: 1d smoothed histogram for ΔE

N_truth = 3.7 ± 2.7
N_qq = 131.5 ± 12.7
N_others = 10.9 ± 6.7
N_sum’ fixed to 3.0

Truth, SCF’, qq, othersB
Uncertainty due to OthersB or N_sum’

PDF_others: 2nd Cheby. for ΔE

N_truth  =  3.7 ± 2.7
N_qq     =  132.0 ± 12.7
N_others =  10.4 ± 6.7
N_sum’   fixed to 3.0

N_sum’ fixed to 4.4

N_truth  =  3.6 ± 2.7
N_qq     =  140.6 ± 12.0
N_others =  10.4 ± 6.7
N_sum’   fixed to 4.4
The shape parameters of pΛD*0 for fit

DE is modeled by two-Gaussian in each case.
Mbc is modeled by Gaussian function in each case, but Mbc for SCF in ΔM sideband region is modeled by a smoothed histogram function.
The parameters is shown in Table.

Continuum background is modeled by 2nd chebyshev for ΔE and argus function fo Mbc in both region, and parameters are floated in each case.

<table>
<thead>
<tr>
<th>source (GeV)</th>
<th>Mbc mean</th>
<th>width</th>
<th>ΔE mean</th>
<th>width</th>
<th>Width2/1</th>
<th>Area2/1</th>
</tr>
</thead>
<tbody>
<tr>
<td>truth signal</td>
<td>5.27802</td>
<td>0.00259</td>
<td>-0.00026</td>
<td>0.00748</td>
<td>2.70</td>
<td>0.10</td>
</tr>
<tr>
<td>error</td>
<td>0.00003</td>
<td>0.00002</td>
<td>0.00010</td>
<td>0.00013</td>
<td>0.19</td>
<td>0.02</td>
</tr>
<tr>
<td>SCF in signal region</td>
<td>5.27870</td>
<td>0.00332</td>
<td>-0.0031</td>
<td>0.0107</td>
<td>2.27</td>
<td>0.77</td>
</tr>
<tr>
<td>error</td>
<td>0.00006</td>
<td>0.00004</td>
<td>0.0005</td>
<td>0.0014</td>
<td>0.25</td>
<td>0.06</td>
</tr>
<tr>
<td>SCF in sideband</td>
<td>-</td>
<td>-</td>
<td>0.0090</td>
<td>0.03031</td>
<td>3.50</td>
<td>0.039</td>
</tr>
<tr>
<td>error</td>
<td>-</td>
<td>-</td>
<td>0.0003</td>
<td>0.00031</td>
<td>0.22</td>
<td>0.006</td>
</tr>
<tr>
<td>correction</td>
<td>0.00030</td>
<td>0.98709</td>
<td>-0.0016</td>
<td>1.18</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>
The shape parameter for OthersB.

<table>
<thead>
<tr>
<th>source (GeV)</th>
<th>(M_{bc}) mean</th>
<th>width</th>
<th>c1</th>
<th>c2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Others bg 1st</td>
<td>5.2763</td>
<td>0.00432</td>
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<tr>
<td>Others bg 2nd</td>
<td>5.2763</td>
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<td>0.00088</td>
<td>0.1034</td>
<td>0.1113</td>
</tr>
<tr>
<td>Others bg 3rd</td>
<td>5.2763</td>
<td>0.00432</td>
<td>smooth</td>
<td>histogram</td>
</tr>
</tbody>
</table>

For systematic uncertainty study due to OthersB in generic MC.

\(\Delta E\) is modeled by 3 kind of function which are 1st/2nd chebyshev polynomial and smoothed histogram

Mbc is modeled by Gaussian function in each case.

The fit and parameters are shown in left plot.
Strategy for data.

<table>
<thead>
<tr>
<th>parameter</th>
<th>data $\Delta M$ sideband region</th>
<th>data $\Delta M$ signal region</th>
</tr>
</thead>
<tbody>
<tr>
<td>Truth</td>
<td>number of events</td>
<td>PDFs</td>
</tr>
<tr>
<td>SCF</td>
<td>float $N_{sum}$</td>
<td>fixed</td>
</tr>
<tr>
<td>continuum</td>
<td>float</td>
<td>float</td>
</tr>
</tbody>
</table>

$N_{sum'} = R \times N_{sum}$

$R$ is the area ratio of $\Delta M$ for SCF' and the value of is obtain from $\Delta M$ distribution on page 9~10 as shown in below table.

$R = 26.0 \pm 0.9$ \% by maximum diff. in table.

The efficiency of truth signal is 3.2%

<table>
<thead>
<tr>
<th></th>
<th>$R$(counting)</th>
<th>$R$(integration)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SCF</td>
<td>$34.3 \pm 0.7$%</td>
<td>$26.0 \pm 0.7$%</td>
</tr>
<tr>
<td>$p\Lambda D^{*+}$</td>
<td>$26.6 \pm 0.6$%</td>
<td>$25.7 \pm 0.6$%</td>
</tr>
</tbody>
</table>

The parameters are shown in backup slide.