New results in B decays

Mark Whitehead – for the LHCb collaboration
LHCb experiment

- VELO: Precise tracking
- RICH: Particle ID
- HCAL: Triggering

Data samples:
- 2011 - 1fb\(^{-1}\)
- 2012 - 2fb\(^{-1}\)
- 3fb\(^{-1}\) combined

Overview:
- γ studies
- Baryons
Why always $\gamma$?

- The least well measured angle of the unitarity triangle
  - CKM fitter FPCP 2013: $(68.0 \pm 8.0)^\circ$
  - UT fit Post EPS 2013: $(70.1 \pm 7.1)^\circ$
  - Key goal of LHCb is to improve this situation

- A probe for new physics?
  - Tree processes theoretically very clean
  - Loop processes may see deviations

- Focus so far has been on $B^\pm \rightarrow DK^\pm$ decays
  - Interference of $b \rightarrow c$ and $b \rightarrow u$ transitions
B^{±} \rightarrow D K^{±} decays

- The flagship γ channel at LHCb

\[ \gamma = \text{arg} \left( -\frac{V_{ud} V_{ub}^*}{V_{cd} V_{cb}^*} \right) \]

- The angle γ is the weak phase between b→c and b→u transitions
  - Interference occurs when D^0 and \overline{D}^0 decay to the same final state
Methods to measure $\gamma$

- **GLW**
  
  $$B^- \xrightarrow{r_B e^{i(\delta_B - \gamma)}} (K^+K^-)_{DK^-} \xrightarrow{DK^-} (K^+\pi^-)_{DK^-} \xrightarrow{DK^-} \bar{D}K^-$$

  $$A_{CP+} = \frac{2r_B \sin \delta_B \sin \gamma}{R_{CP+}}$$

  $$R_{CP+} = 1 + r_B^2 + 2r_B \cos \delta_B \cos \gamma$$


- **ADS**

  $$B^- \xrightarrow{r_B e^{i(\delta_B - \gamma)}} (K^+K^-)_{DK^-} \xrightarrow{DK^-} (K^+\pi^-)_{DK^-} \xrightarrow{DK^-} \bar{D}K^-$$

  $$A^{\delta}_{ADS} = \frac{2r_B r_D \sin(\delta_B + \delta_D) \sin \gamma}{R_{ADS}}$$

  $$R^{\delta}_{ADS} = r_B^2 + r_D^2 + 2r_B r_D \cos(\delta_B + \delta_D) \cos \gamma$$


- **GGSZ**
  - 3 body self conjugate decays
  - Eg: $D \rightarrow K_S \pi\pi$

  $$x_+ = r_B \cos(\delta_B + \gamma)$$

  $$y_+ = r_B \sin(\delta_B + \gamma)$$

\[ B^{\pm} \rightarrow D(K_S K \pi) h^{\pm} \]

- Recent result from $B \rightarrow D K$ studies
  - ADS-like analysis using a singly Cabibbo-suppressed decay
  - Split the decay modes by the charge of the charged $K_D$ and $B$ mesons
  - Same sign (SS) and opposite sign (OS)

- Take input from CLEO measurements
  - Coherence factor ($\kappa$) and the average strong phase difference ($\delta$)
  - Both measured over the full Dalitz plot and a $K^{*}(892)^{\pm}$ region.

- Full 3fb$^{-1}$ 2011+2012 data sample used
Same sign $B^\pm \rightarrow D(K_S^0 K\pi) h^\pm$

Fig. 1: Distributions of $m(K_S^0 K\pi)^+ \rightarrow D \pi^+$ and $m(K_S^0 K\pi)^- \rightarrow D \pi^-$ for $B^\pm$ candidates in the full data sample. The fits are shown for the (a, c, e, g) efficiency and in the restricted region of phase space around the Dalitz plot.

Entries / (15 MeV/c^2)

$B^+ \rightarrow [K_S^0 K\pi]^+ D \pi^+$

Sum, incl. combinatorics
Signal
Partially reconstructed

Entries / (15 MeV/c^2)

$B^- \rightarrow [K_S^0 K\pi^-]^+ D \pi^-$

Sum, incl. combinatorics
Signal
Partially reconstructed

$B^+ \rightarrow [K_S^0 K\pi^-]^+ D K^+$

Entries / (15 MeV/c^2)

$B^- \rightarrow [K_S^0 K\pi^-]^+ D K^-$

Entries / (15 MeV/c^2)

$B^+ \rightarrow [K_S^0 K\pi^-]^+ D \pi^+$

$B^- \rightarrow [K_S^0 K\pi^-]^+ D \pi^-$

$B^+ \rightarrow [K_S^0 K\pi^-]^+ D K^+$

$B^- \rightarrow [K_S^0 K\pi^-]^+ D K^-$

1841 ± 47

145 ± 15


Opposite sign $B^\pm \rightarrow D(K_S K \pi)h^\pm$

$$B^+ \rightarrow [K^0_S K^- \pi^+]_D \pi^+$$

LHCb

Entries / (15 MeV/c^2)

$B^+ \rightarrow [K^0_S K^- \pi^+]_D \pi^+$

$B^- \rightarrow [K^0_S K^+ \pi^-]_D K^-$

$B^- \rightarrow [K^0_S K^+ \pi^-]_D K^-$

$B^+ \rightarrow [K^0_S K^- \pi^+]_D K^+$

$B^+ \rightarrow [K^0_S K^- \pi^+]_D K^+$

1267 ± 37

71 ± 10
\( B^{\pm} \rightarrow D(K_S K\pi)h^{\pm} \)

- 7 observables calculated from the 8 yields
  - 3 yield ratios and 4 asymmetries

<table>
<thead>
<tr>
<th>Observable</th>
<th>Whole Dalitz plot</th>
<th>( K^*(892)^{\pm} ) region</th>
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<tbody>
<tr>
<td>( R_{SS/OS} )</td>
<td>1.528 ± 0.058 ± 0.025</td>
<td>2.57 ± 0.13 ± 0.06</td>
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<tr>
<td>( R_{DK/D\pi, SS} )</td>
<td>0.092 ± 0.009 ± 0.004</td>
<td>0.084 ± 0.011 ± 0.003</td>
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<tr>
<td>( R_{DK/D\pi, OS} )</td>
<td>0.066 ± 0.009 ± 0.002</td>
<td>0.056 ± 0.013 ± 0.002</td>
</tr>
<tr>
<td>( A_{SS, DK} )</td>
<td>0.040 ± 0.091 ± 0.018</td>
<td>0.026 ± 0.109 ± 0.029</td>
</tr>
<tr>
<td>( A_{OS, DK} )</td>
<td>0.233 ± 0.129 ± 0.024</td>
<td>0.336 ± 0.208 ± 0.026</td>
</tr>
<tr>
<td>( A_{SS, D\pi} )</td>
<td>−0.025 ± 0.024 ± 0.010</td>
<td>−0.012 ± 0.028 ± 0.010</td>
</tr>
<tr>
<td>( A_{OS, D\pi} )</td>
<td>−0.052 ± 0.029 ± 0.017</td>
<td>−0.054 ± 0.043 ± 0.017</td>
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- Higher sensitivity in the \( K^* \) region
  - As expected from larger coherence factor
  - Good future prospects
$B^\pm \rightarrow D(K_S\pi\pi)h^\pm$

- Model dependent GGSZ amplitude analysis
  - Use Babar model for the fit to the D decay
  - 1fb$^{-1}$ data sample

- Fit B mass to extract signal and backgrounds yields
  - Define signal region as $\pm 50$MeV/c$^2$
  - Downstream and Long refer to track types used to make the $K_S$

420\pm 27

217\pm 17

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\[ B^\pm \rightarrow D(K_S\pi\pi)h^\pm \]

- **Dalitz plot fit**
  - \( K^*(892) \) dominates
  - Split \( B^+ \) and \( B^- \)
  - Backgrounds
  - Efficiency

- **Cartesian parameters**
  - \( D^0 \) mixing negligible

\[
\begin{align*}
  x_- &= +0.027 \pm 0.044 \pm^{+0.010}_{-0.008} \pm 0.001 \\
  y_- &= +0.013 \pm 0.048 \pm^{+0.008}_{-0.006} \pm 0.003 \\
  x_+ &= -0.084 \pm 0.045 \pm 0.009 \pm 0.003 \\
  y_+ &= -0.032 \pm 0.048 \pm 0.009 \pm 0.007
\end{align*}
\]

- **B- only, \( m_+ = m(K_S\pi_+) \)**
$B^{\pm} \rightarrow D(K_{S} \pi \pi) h^{\pm}$

- Convert the Cartesian parameters
  \[ \gamma = (84^{+49}_{-42})^{\circ} \]  
  - Includes all uncertainties
  - Choose solution < 180°

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$\Xi_b^0 \rightarrow \Xi_c^+ \pi^-$

- Aim to measure the mass and lifetime of $\Xi_b$
  - Lifetime expected to be equal to that of $\Lambda_b$ (Leading order HQE)
  - Large sample of $\sim 3800$ decays available from 3fb-1 data set
  - $\Lambda_b \rightarrow \Lambda_c \pi$ provides the ideal control channel, kinematics are $\sim$-identical
  - Decays of $\Lambda_c$ and $\Xi_c$ to the same final state of $pK\pi$
\[ \Xi_b^0 \rightarrow \Xi_c^+ \Pi^- \]

- Float the mass difference in the fit to data

\[
M(\Xi_b^0) - M(\Lambda_b^0) = 172.44 \pm 0.39 \text{(stat)} \pm 0.17 \text{(syst)} \text{ MeV}/c^2
\]

\[
M(\Xi_b^0) = 5791.80 \pm 0.39 \text{(stat)} \pm 0.17 \text{(syst)} \pm 0.26 (\Lambda_b^0) \text{ MeV}/c^2
\]

- Measure lifetime from yield ratio as a function of decay time
  - Fit with the function \( e^{\beta t} \) where \( \beta = 1/\tau_{\Lambda_b^0} - 1/\tau_{\Xi_b^0} \)
  - Efficiency corrected

![Graph showing yield ratio as a function of decay time](image-url)
World first lifetime measurement

\[
\frac{\tau_{\Xi_b^0}}{\tau_{\Lambda_b^0}} = 1.006 \pm 0.018 \text{ (stat)} \pm 0.010 \text{ (syst)}
\]

\[
\tau_{\Xi_b^0} = 1.477 \pm 0.026 \text{ (stat)} \pm 0.014 \text{ (syst)} \pm 0.013 (\Lambda_b^0) \text{ ps}
\]

Two world best mass measurements

\[
M(\Xi_b^0) = 5791.80 \pm 0.39 \text{ (stat)} \pm 0.17 \text{ (syst)} \pm 0.26 (\Lambda_b^0) \text{ MeV}/c^2
\]

\[
M(\Xi_c^+)= 2467.97 \pm 0.14 \text{ (stat)} \pm 0.10 \text{ (syst)} \pm 0.14 (\Lambda_c^+) \text{ MeV}/c^2
\]
Summary

• Latest updates from $B^{±} \rightarrow DK^{±}$ γ studies
  • Using a new D decay mode, $D \rightarrow K_{S}K\pi$
  • First model dependent GGSZ results

• Much more still to come on γ
  • Update all 1fb$^{-1}$ analyses to the full 3fb$^{-1}$ data sample
  • Other B decays e.g. $B^{0} \rightarrow DK\pi$ and $B^{0} \rightarrow DK^{*}$, $B_{s} \rightarrow D_{s}K$ and $B^{±} \rightarrow DK^{±}\pi\pi$

• Progress on b-Baryon decays
  • Precise lifetime and mass measurements of the $\Xi_{b}$

• Stay tuned for all of our new results in this sector
Back ups
Luminosity

- **2012**: 4 + 4 TeV
  - Delivered Luminosity: 2.21 fb\(^{-1}\)
  - Recorded Luminosity: 2.08 fb\(^{-1}\)

- **2011**: 3.5 + 3.5 TeV
  - Delivered Luminosity: 1.21 fb\(^{-1}\)
  - Recorded Luminosity: 1.10 fb\(^{-1}\)

- **2010**: 3.5 TeV
  - Delivered Luminosity: 0.04 fb\(^{-1}\)
  - Recorded Luminosity: 0.04 fb\(^{-1}\)
Methods to measure $\gamma$

- **GLW**
  - CP eigenstate $D$ decays
  - Eg: $D \rightarrow K K$, $D \rightarrow \pi \pi$

- **ADS**
  - Quasi flavour specific decays
  - Eg: $D \rightarrow K \pi$, $D \rightarrow K \pi \pi \pi$

- **GGSZ**
  - 3 body self conjugate decays
  - Eg: $D \rightarrow K_S \pi \pi$

\[
A_{CP}^+ = \frac{2r_B \sin \delta_B \sin \gamma}{R_{CP}^+}
\]
\[
R_{CP}^+ = 1 + r_B^2 + 2r_B \cos \delta_B \cos \gamma
\]
\[
A_{ADS}^K = \frac{2r_B r_D \sin(\delta_B + \delta_D) \sin \gamma}{R_{ADS}}
\]
\[
R_{ADS}^K = r_B^2 + r_D^2 + 2r_B r_D \cos(\delta_B + \delta_D) \cos \gamma
\]
\[
x_+ = r_B \cos(\delta_B + \gamma)
\]
\[
y_+ = r_B \sin(\delta_B + \gamma)
\]


1 fb$^{-1}$ γ combination

- Combination includes the following results
  - 2 body GLW/ADS ($D \to KK, K\pi, \pi\pi$)  [Phys. Lett. B 712 (2012) 203]
  - 4 body ADS ($D \to K\pi\pi\pi$)  [Phys. Lett. B 723 (2013) 44]
  - GGSZ ($D \to K_S\pi\pi, K_SKK$)  [Phys. Lett. B 718 (2012) 43]
  - Information on the strong phase from CLEO

- Additionally:
  - $D^0$ mixing, CPV in charm decays
    \[ \gamma = (72.0^{+14.7}_{-15.6})^\circ \text{ at 68\% CL} \]
  - $B \to D\pi$ decays also used
    \[ \gamma = (72.6^{+9.1}_{-15.9})^\circ \text{ at 68\% CL} \]

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1 fb$^{-1}$ $\gamma$ combination + 2 fb$^{-1}$ GGSZ

- **Update to include 2012 GGSZ result**
  - LHCb-CONF-2013-004

- **B$\rightarrow$DK only here**
  - Green is the old B$\rightarrow$DK curve
  - Purple shows the updated interval

\[
\gamma = (67 \pm 12)° \text{ at } 68\% \text{ CL}
\]

Preliminary

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2 body GLW

![2 body GLW Diagram](image-url)
Figure 4: Invariant mass distributions of selected candidates, as partially reconstructed events and the total PDF includes the combinatorial component. The left plots are LHCb candidates, the right plots are LHCb candidates. See the caption of Fig. 1 for a full description. The dashed line here represents the background, while the solid line represents the signal. The shaded contribution is due to the signal. The light (green) curve is the invariant mass distributions of selected candidates. The dark (red) curve represents the invariant mass distributions of selected candidates. The shaded contribution is due to the signal. The light (green) curve is the invariant mass distributions of selected candidates. The dark (red) curve represents the invariant mass distributions of selected candidates. The shaded contribution is due to the signal. The light (green) curve is the invariant mass distributions of selected candidates. The dark (red) curve represents the invariant mass distributions of selected candidates. The shaded contribution is due to the signal.

B → [Kπ]_L K^-
B → [Kπ]_L K^+

B → [Kπ]_S K^-
B → [Kπ]_S K^+

B → [κK]_L K^-
B → [κK]_L K^+

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B → [κK]_S K^+
4 body ADS

Table 2: Systematic uncertainties on the observables. Bachelor PID refers to the fixed e where the pion is not reconstructed. The favoured mode cross-feed is included in the fit, but is uncertainty is the sum in quadrature of the individual components. Correlations between the uncertainties are considered negligible, so the total systematic is taken as the systematic uncertainty on that quantity and is summarised in Table 2.

The fit is constructed such that the observables of interest are free parameters. To estimate the systematic uncertainties arising from the imperfect knowledge of several of the external parameters discussed above, the fit is performed many times varying each estimate by its assigned error. The resulting spread (RMS) in the value of each observable is input by its assigned error. The remaining candidates are placed in the sample displayed on the bottom row and are partially reconstructed, but Cabibbo favoured, too small to be seen.

Figure 1: Invariant mass distributions of selected candidates, separated by charge. The left plots are for the bachelor track reconstructed with a pion mass hypothesis. The dark (red) and light (green) curves represent the fit to the mass distribution for the bachelor track and the full sample. The black dots and error bars are the data. The pink dashed line is the fit used for the bachelor track which has been used to correct the full sample.

Figure 2: Invariant mass distributions of selected candidates, separated by charge. See the caption of Fig. 1 for a full description. The dashed line here represents the fit used for the bachelor track which has been used to correct the full sample.
In that analysis the shape was constructed by applying the selection to a large simulated...

Figure 3: Invariant mass distributions of (a,c) $K^{0}\pi^{+}\pi^{-}$, divided between the (a,b) long and (c,d) downstream $K^{0}\pi^{+}\pi^{-}$ categories combined. Fit results, including the signal and background invariant mass distributions are fixed to the values determined from the data the fit is expected to be the same in the limit that there are no charge-dependent reconstruction...
Table 1 shows the purity, defined as the ratio of the signal yield to the total yield in the data for (top row) LL and (bottom row) DD. 

Figure 2: 

Candidates / (10 MeV/

Figure 3: 

Candidates / (10 MeV/

Figure 4: 

Candidates / (10 MeV/

Figure 5: 

Candidates / (10 MeV/
The lower parts of the figures are normalised residual candidates. The fit results, including signal and background, are superimposed. The lower parts of the figures are normalised residual candidates. The fit results, including signal and background, are superimposed.
asymmetry for bachelor pion tracks. The

Figure 4: Dalitz plot and its projections, with fit result superimposed, for

Candidates / (0.026 GeV^2/c^4)

5/6/2014

Preliminary

Preliminary

LHCb

LHCb

LHCb

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LHCb