Results and Prospects for Charm Physics at LHCb

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On behalf of the LHCb Collaboration
Overview

• The LHCb detector.

• Search for CPV in $D^+ \rightarrow K^- K^+ \pi^+$

• $\Delta A_{CP}$ with $D^0 \rightarrow KK, \pi\pi$

• $A_{\Gamma}$ with $D^0 \rightarrow KK$ – New LHCb Result!
The LHCb Detector

- 38 pb\(^{-1}\) taken in 2010.
- \(~425\) pb\(^{-1}\) taken in 2011 so far!
- All results shown from 2010 data.
Detector Performance

- **Vertex LOcator (VELO) provides excellent impact parameter resolution:** 38 \( \mu \text{m} \) @ 1 GeV.
- Reflected in vertex resolution: 13 \( \mu \text{m} \) in x & y, 69 \( \mu \text{m} \) in z, from 25 tracks.
- And proper time resolution: \( \sim 50 \) fs (3\% of \( \tau( \text{B} ) \), 12\% of \( \tau( \text{D} ) \)).

**Two Ring Imaging CHERenkov (RICH) detectors provide excellent PID.**
- Clean separation of \( \pi \) & K over broad momentum range.

Tracks making PV hidden.

\[ IP_x \text{ Resolution Vs } 1/p_T \]

\[ \sigma = 13.2 + 24.7/p_T \mu \text{m} \]

\( S = 7 \text{ TeV} \)

2011 Data
Search for CPV in D$^+$ → K$^-$K$^+$π$^+$

Paper in preparation
Search for CPV in $D^+ \rightarrow K^-K^+\pi^+$

- Model-independent search for CPV in Dalitz plot.
- Compare binned, normalised Dalitz plots for $D^+$, $D^-$.
- $\chi^2$ test for asymmetry – “Miranda” method:
  \[
  \chi^2_{bin} = \frac{(N(D^+) - N(D^-))^2}{\sigma(N(D^+))^2 + \sigma(N(D^-))^2}
  \]
- Evaluate $P(\chi^2 | n \text{df})$ to check consistency with 0.
- Check for false asymmetries on control samples:
  - Simulation.
  - $D_s^+ \rightarrow K^+K^-\pi^+$.
  - Mass sidebands.
  - $D^+ \rightarrow K^-\pi^+\pi^+$.
- Combine data with opposite magnet polarities to cancel left-right asymmetries.

K-K⁺π⁺ Control Modes

- No evidence of fake asymmetries.
- Method very robust against systematic effects.

<table>
<thead>
<tr>
<th>Window</th>
<th>MagUp</th>
<th>MagDown</th>
<th>Combined</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lower sideband</td>
<td>32.7%</td>
<td>10.1%</td>
<td>8.7%</td>
</tr>
<tr>
<td>Middle sideband</td>
<td>31.4%</td>
<td>27.7%</td>
<td>50.8%</td>
</tr>
<tr>
<td>D_s⁺ window</td>
<td>88.9%</td>
<td>15.5%</td>
<td>34.4%</td>
</tr>
<tr>
<td>Upper sideband</td>
<td>1.3%</td>
<td>50.7%</td>
<td>26.5%</td>
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\[ D^+ \rightarrow K^- K^+ \pi^+ \text{ Results} \]

- No evidence of CP violation in 2010 data (38 pb\(^{-1}\)).

<table>
<thead>
<tr>
<th>LHCB Preliminary</th>
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<tbody>
<tr>
<td>MagUp</td>
<td>6.0%</td>
</tr>
<tr>
<td>MagDown</td>
<td>28.5%</td>
</tr>
<tr>
<td>Combined</td>
<td>12.7%</td>
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\[ \mu = -0.024 \pm 0.043 \]
\[ \sigma = 0.985 \pm 0.031 \]
$\Delta A_{CP}$ with $D^0 \rightarrow KK, \pi\pi$

LHCb-CONF-2011-023
\[ A_{\text{RAW}}(f) = \frac{N(D^0 \to f) - N(D^0 \to \bar{f})}{N(D^0 \to f) + N(D^0 \to \bar{f})} \]

\[ A_{\text{RAW}}(f)^* = \frac{N(D^{*-} \to D^0(f)\pi^-) - N(D^{*-} \to \bar{D}^0(f)\pi^-)}{N(D^{*-} \to D^0(f)\pi^+) + N(D^{*-} \to \bar{D}^0(f)\pi^-)} \]

\[ = A_{\text{CP}}(f) + A_D(f) + A_D(\pi_s) + A_P(D^{*-}) \]

- Taking \( A_{\text{RAW}}(f)^* - A_{\text{RAW}}(f')^* \) production & \( \pi_s \) detection asymmetries cancel.

- Detection asymmetry for self-conjugate final states is 0.

\[ A_{\text{RAW}}(K^-K^+)^* - A_{\text{RAW}}(\pi^-\pi^+)^* = A_{\text{CP}}(K^-K^+) - A_{\text{CP}}(\pi^-\pi^+) \]

\[ \equiv \Delta A_{\text{CP}} \]
$\Delta A_{\text{CP}}$ with $D^0 \rightarrow KK, \pi\pi$

- Fits to $m(D^*) - m(D^0)$.
- Yields:
  - 116k tagged $D^0 \rightarrow K^-K^+$
  - 36k tagged $D^0 \rightarrow \pi^-\pi^+$

$$A_{\text{CP}}( KK ) - A_{\text{CP}}( \pi\pi ) = ( -0.28 \pm 0.70 \pm 0.25 ) \%$$

LHCb Preliminary
$A_\Gamma$ with $D^0 \rightarrow KK$

LHCb-CONF-2011-046 in preparation

New LHCb Result – First Public Presentation!
Formalism

- Direct measure of CPV in $D^0$ mixing:

$$A_{\Gamma} = \frac{\tau(D^0 \rightarrow K^- K^+ - \tau(D^0 \rightarrow K^- K^+)}{\tau(D^0 \rightarrow K^- K^+) + \tau(D^0 \rightarrow K^- K^+)} \approx \frac{A_M}{2} y \cos \phi - x \sin \phi$$

- Flavour tag using $D^{*+} \rightarrow D^0 \pi^+$.
- Control mode: $D^0 \rightarrow K\pi$.

- Predicted very near 0 by SM.
- Observation of non-zero value clear sign of new physics.

Kagan, FPCP 2011
Method

- Unbinned likelihood fit $m(D^0)$ to determine signal yield & $m(D^*)_m(D^0)$ to determine mistag.
- Unbinned likelihood fit to proper time to determine $\tau$ directly.
- Distinguish prompt $D^0$ & $D^0$ from B with simultaneous fit to $\chi^2(IP(D^0))$. 

![Graph showing data, fit, prompt, and secondary components](image)
Method contd.

- Correct trigger & selection acceptance using per-candidate acceptance functions – ‘Swimming method’.
- Move PV along direction of $D^0$ momentum to artificially change $D^0$ proper time.
- Store trigger & selection decision for each proper time to build acceptance function.
Cross check with $D^0 \rightarrow K\pi$

- Proof of principle: apply same procedure to $D^0 \rightarrow K\pi$.
- 110k candidates of each tag.

$$\tau = 410.6 \pm 1.3\text{ fs}$$

$$A_{\Gamma}^{K\pi,\text{eff}} = (-0.09 \pm 0.22 \pm 1.6)\%$$

LHCb Preliminary

- Consistent with 0 as expected!
- Lifetimes consistent with PDG average of 410.1 ± 1.5 fs.
- Acceptance well modelled by ‘Swimming’.
\[ \Lambda_{\Gamma} \text{ with } D^0 \rightarrow KK \]

- 15k candidates of each tag.
- \[ \Lambda_{\Gamma} = ( -0.59 \pm 0.59 \pm 0.21 ) \% \]

LHCb Preliminary
First public presentation!

- With just 28 pb\(^{-1}\) not yet competitive:
HFAG World Average

- Preliminary average courtesy of HFAG.
- Slope in LHCb $\Delta A_{CP}$ result due to small KK/$\pi\pi$ lifetime acceptance difference: $\Delta \langle t \rangle / \tau = 0.10 \pm 0.01$
Conclusions & Outlook

• Many charm analyses ongoing at LHCb.

• LHCb Preliminary Results on 2010 data (~38 pb\(^{-1}\)):
  – No CPV in \(D^+ \rightarrow K^-K^+\pi^+\).
  – \(A_{CP}(KK) - A_{CP}(\pi\pi) = ( -0.28 \pm 0.70 \pm 0.25 )\) %
  – \(A_{\Gamma} = ( -0.59 \pm 0.59 \pm 0.21 )\) % (28 pb\(^{-1}\))

• Study of \(x^2\) & \(y\)' with wrong sign \(D^0 \rightarrow K\pi\) well advanced.
• Many production & spectroscopy measurements also being made.

• 425 pb\(^{-1}\) collected in 2011 so far!
• Sufficient to really probe new physics in many key areas!
Backup
Time-integrated wrong-sign $D^0 \rightarrow K\pi$

Three contributions with different lifetime dependence:

$$\Gamma_{WS}(t) = e^{-\Gamma t} \left( \frac{R_D}{\text{DCS}} + \sqrt{\frac{R_D}{\text{Interference}}} (\Gamma t) + \frac{x'^2 + y'^2}{4} (\Gamma t)^2 \right)$$

[Limit of $|x| < 1, |y| < 1,$ and no CPV]

Our lifetime acceptance is not flat $\Rightarrow$ affects relative weighting.

- Start with raw WS/RS time-integrated ratio.
- Determine our efficiency(t) using PDG D0 lifetime as input.
- Determine correction using HFAG mixing parameters as input.
- Compute lifetime-acceptance-corrected WS/RS ratio.

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<th>WS/RS of $D \rightarrow K\pi$ decays (%)</th>
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<tr>
<td>$R_{\text{measured}}$</td>
<td>$0.442 \pm 0.033 \ (\text{stat.}) \pm 0.042 \ (\text{sys.})$</td>
</tr>
<tr>
<td>$R_{\text{corrected}}$</td>
<td>$0.409 \pm 0.031 \ (\text{stat.}) \pm 0.039 \ (\text{sys.}) \pm 0.028 \ (\text{sys. mixing})$</td>
</tr>
<tr>
<td>$R(\text{PDG})$</td>
<td>$0.380 \pm 0.018$</td>
</tr>
</tbody>
</table>

Cross-check consistent with PDG average.