New results in semileptonic beauty decays with LHCb

LHCP 2016

June 16th 2016
Laurent Dufour, on behalf of the LHCb collaboration
The LHCb detector

- K/π/p separation
- Muon identification

Δp/p = 0.4 - 0.8% (5-100 GeV/c)
Semileptonic b-decays

$b$ decays with a missing daughter (e.g. neutrino)

✔ Large statistics: high precision measurements
❌ Technical: always partially reconstructed decays
Physics
Production asymmetry & cross-sections
Physics

Production asymmetry & cross-sections

Mixing process: $\Delta m$, CP violation in mixing
Physics

Production asymmetry & cross-sections

Mixing process: $\Delta m$, CP violation in mixing

Lepton Universality
Physics

Production asymmetry & cross-sections

Mixing process: $\Delta m$, CP violation in mixing

CKM matrix tests, Form factors

Lepton Universality
Physics

This talk: $\Delta m_d$, $a^{s_{sl}}$

Mixing process: $\Delta m$, CP violation in mixing

Production asymmetry & cross-sections

CKM matrix tests, Form factors

Lepton Universality
• Neutral B mesons: $|B_{H,L}^0\rangle = p|B_q^0\rangle \pm q|\bar{B}_q^0\rangle$
  ‣ Hamiltonian eigenstates ≠ flavour eigenstates

• Mass difference determines the oscillation frequency, $\Delta m$

• CP violation in mixing as measured in flavour specific decays? $|p/q| \neq 1.$
B_d OSCILLATIONS: ΔM_d

- Tag initial flavour of the B. Track flavour at decay, as function of decay time
- Correct for missing momentum to estimate the decay time of the B
- Flavour at production: deduce from opposite B (flavour tagging)
- Flavour at decay: determined by the charge of the muon (flavour specific)
- Make sure charm was from B: use track isolation & minimal IP requirement.
The flavour asymmetry between unmixed and mixed events is described in Sec. 4. A summary of the systematic uncertainties is given in Sec. 5, and the method chosen to reconstruct the elements different from flavour eigenstates. In the Model [1], measurements of the flavour asymmetry between unmixed and mixed events is based on the flavours of the decay, which may be the same (unmixed) or opposite (mixed). In Eq. 1, the state assignment is based on the flavours of the decay, where the state assignment is based on the flavours of the decay, which may be the same (unmixed) or opposite (mixed). In Eq. 1, the mixing between unmixed and mixed events is described in Sec. 4.

The inclusion of charge-conjugate processes is implied throughout.

\[ A(t) = \frac{N^{\text{unmix}}(t) - N^{\text{mix}}(t)}{N^{\text{unmix}}(t) + N^{\text{mix}}(t)} \propto \cos(\Delta m_d t) \]

\[ B^0_d \rightarrow D^{*-} \mu^+ X \]

2012, best tagging category
**B_d OSCILLATIONS: $\Delta M_d$**

- **ALEPH (3 analyses)**: $446 \pm 6 \pm 19$
- **DELPHI (5 analyses)**: $519 \pm 18 \pm 11$
- **L3 (3 analyses)**: $444 \pm 28 \pm 28$
- **OPAL (5 analyses)**: $479 \pm 18 \pm 15$
- **CDF1 (4 analyses)**: $495 \pm 33 \pm 27$
- **D0 (1 analysis)**: $506 \pm 20 \pm 16$
- **BABAR (4 analyses)**: $506 \pm 6 \pm 4$
- **BELLE (3 analyses)**: $509 \pm 4 \pm 5$
- **LHCb (3 analyses)**: $514 \pm 5 \pm 3$

**This measurement**
- $505.0 \pm 2.1 \pm 1.0$

**Average (w/o this meas.)**
- $510 \pm 5$

**Most precise single measurement**

(Theory [arXiv:1602.03560]: $630 \pm 69$ ns$^{-1}$)
CP violation in $B$-$\bar{B}$ mixing

\[ P(B \rightarrow \bar{B}) \neq P(\bar{B} \rightarrow B) \]

- Observed (only) in the neutral Kaon system.
- Use a flavour specific final state: semileptonics.

\[ a_{sl} = \frac{N(\bar{B} \rightarrow B \rightarrow f) - N(B \rightarrow \bar{B} \rightarrow \bar{f})}{N(\bar{B} \rightarrow B \rightarrow f) + N(B \rightarrow \bar{B} \rightarrow \bar{f})} = \frac{1 - |q/p|^4}{1 + |q/p|^4} \]

- Standard Model values: effectively 0.

\[ a_{sl}^d = (-4.7 \pm 0.6) \times 10^{-4} \]
\[ a_{sl}^s = (2.22 \pm 0.27) \times 10^{-5} \]

Artuso, Borissov, Lenz [arXiv:1511.09466]
Asymmetries and yields for the final state are extracted from data. This quantity by itself must be corrected: what is the detector response for $f$ relative to $\bar{f}$?
METHOD

The knowledge of the flavour of the B at production is not needed, but the raw asymmetry becomes dependent on the production asymmetry and the detection asymmetry.

$$A_{raw} = \frac{N(f,t) - N(\bar{f},t)}{N(f,t) + N(\bar{f},t)} = A_{det} + \frac{a_{sl}}{2} + (A_P - \frac{a_{sl}}{2}) \cos(\Delta m t)$$

S.L. MIXING ASYMMETRY: $a_{sl}$

For $B_s$ mesons: high frequency, time-integrated analysis.

For $B_d$ mesons: low frequency, time-dependent analysis. Add $A_P$ in data fit.
Analysis split up in Dalitz plot regions. Levels of backgrounds vary between these regions and thus call for different selection strategies.

$m(K\pi)$ in [806, 986] MeV/c²

$m(KK)$ in [1000, 1040] MeV/c²
YIELDS $a_{SL}^S$
One of the ways of determining the detection asymmetry, is via a tag & probe method for (partially) reconstructed prompt charm decays.

Know with high certainty the track must have been there, then compute efficiency.

\[ \epsilon = \frac{\text{found}}{\text{total}} \]

Relative difference

[Graph showing the asymmetry in p values for Magnet up and Magnet down]
RESULTS

<table>
<thead>
<tr>
<th>Source</th>
<th>Value</th>
<th>Stat. uncert.</th>
<th>Syst. uncert.</th>
</tr>
</thead>
<tbody>
<tr>
<td>$A_{raw}$</td>
<td>0.11</td>
<td>0.09</td>
<td>0.02</td>
</tr>
<tr>
<td>$A_{track}(K^+K^-)$</td>
<td>-0.01</td>
<td>0.00</td>
<td>0.03</td>
</tr>
<tr>
<td>$A_{track}(\pi^-\mu^+)$</td>
<td>-0.01</td>
<td>0.05</td>
<td>0.04</td>
</tr>
<tr>
<td>$A_{PID}$</td>
<td>0.01</td>
<td>0.02</td>
<td>0.03</td>
</tr>
<tr>
<td>$A_{trig}$ (hardware)</td>
<td>-0.03</td>
<td>0.02</td>
<td>0.02</td>
</tr>
<tr>
<td>$A_{trig}$ (software)</td>
<td>0.00</td>
<td>0.01</td>
<td>0.02</td>
</tr>
<tr>
<td>$f_{bkg}$ $A_{bkg}$</td>
<td>-0.02</td>
<td>–</td>
<td>0.03</td>
</tr>
<tr>
<td>$f_{bkg}$</td>
<td>–</td>
<td>–</td>
<td>0.06</td>
</tr>
<tr>
<td>Total $a_s^{sl}$</td>
<td>0.39</td>
<td>0.26</td>
<td>0.20</td>
</tr>
</tbody>
</table>

The measured values of all detection asymmetries with their statistical and systematic uncertainties are shown in Table 1. The overall corrections are small and compatible with zero. In contrast, corrections for separate magnet polarities are more significant (at most 1.1% in 2011 and 0.3% in 2012), as expected for most of the detector-induced charge asymmetries. The corrections for the detection asymmetries are almost fully correlated between the Dalitz regions.

The previous analysis, based on 1 fb$^{-1}$, used only candidates in the $\pi$ region of the Dalitz plot, with different selection criteria, and used a different fit method to determine the signal yields [7]. A more stringent selection resulted in a cleaner signal sample, but with roughly 30% fewer signal candidates in the $\pi$ region. As a cross check, the approach...
THE BIG PICTURE

Standard Model

LHCb $D_s^{(*)} \mu \nu X$
D0 $D_s^{(*)} \mu \nu X$
BaBar $D^* l \nu$
BaBar $ll$
Belle $ll$

Laurent Dufour
Conclusion

Using **semileptonic** decays, LHCb has provided the most precise measurements of the mixing parameters for $B_s$ & $B_d$ mesons.

Very recent result of CP Violation in mixing compatible with the Standard Model. Long standing discrepancy reduced.

The prospects for Run-II are promising, as the results are limited by statistics.
New results in semileptonic beauty decays with LHCb

LHCP 2016

June 16th 2016
Laurent Dufour, on behalf of the LHCb collaboration
CP violation in $B$-$B$ mixing

$$a_{s1} = \frac{N(\bar{B} \rightarrow B \rightarrow f) - N(B \rightarrow \bar{B} \rightarrow \bar{f})}{N(\bar{B} \rightarrow B \rightarrow f) + N(B \rightarrow \bar{B} \rightarrow \bar{f})} = \frac{1 - |q/p|^4}{1 + |q/p|^4}$$

$$\frac{\Delta \Gamma}{\Delta m} \tan(\phi) = 2 \left( 1 - \left| \frac{q}{p} \right| \right)$$
$B_d$ OSCILLATIONS: $\Delta M_d$

![Diagram showing $k$-factor distribution and average $k$-factor as a function of the visible mass of the $B$ candidate, with polynomial fits shown as a solid red line.](image-url)