Experimental overview of recent mixing and CP-violation results in semileptonic $B$ decays

Lucia Grillo
Heidelberg University

LHCb Implications workshop
03.11.2015
Neutral $B$ meson mixing

- Oscillation and decay description:
  \[
  i \frac{d}{dt} \left( \begin{array}{c} |B_q(t)\rangle \\ \overline{|B_q(t)\rangle} \end{array} \right) = \left( \begin{array}{cc} M_{11} - i \frac{\Gamma_{11}}{2} & M_{12} - i \frac{\Gamma_{12}}{2} \\ M_{12}^* - i \frac{\Gamma_{12}^*}{2} & M_{22} - i \frac{\Gamma_{22}}{2} \end{array} \right) \left( \begin{array}{c} |B_q(t)\rangle \\ \overline{|B_q(t)\rangle} \end{array} \right)
  \]

- Mass eigenstates are superpositions of flavor eigenstates:
  \[
  |B_L\rangle = p|B_q\rangle + q|\overline{B_q}\rangle
  
  |B_H\rangle = p|B_q\rangle - q|\overline{B_q}\rangle
  \]

- Mixing observables
  \[
  \Delta \Gamma = \Gamma_L - \Gamma_H
  \]
  \[
  \Delta m = m_H - m_L
  \]
Neutral $B$ meson mixing

- Oscillation and decay description:

\[
i \frac{d}{dt} \left( \begin{array}{c} |B_q(t)\rangle \\ |\overline{B}_q(t)\rangle \end{array} \right) = \left( \begin{array}{cc} M_{11} - i \frac{\Gamma_{11}}{2} & M_{12} - i \frac{\Gamma_{12}}{2} \\ M_{12}^* - i \frac{\Gamma_{12}^*}{2} & M_{22} - i \frac{\Gamma_{22}}{2} \end{array} \right) \left( \begin{array}{c} |B_q(t)\rangle \\ |\overline{B}_q(t)\rangle \end{array} \right)
\]

- Mass eigenstates are superpositions of flavor eigenstates:

\[
|B_L\rangle = p|B_q\rangle + q|\overline{B}_q\rangle
\]

\[
|B_H\rangle = p|B_q\rangle - q|\overline{B}_q\rangle
\]

- Mixing observables

\[
\Delta \Gamma = \Gamma_L - \Gamma_H
\]

\[
\Delta m = m_H - m_L
\]

\[
\Delta m \propto (V_{tb}^* V_{tq})^2
\]
Precision measurement of $\Delta m_d$

- Oscillation frequency measured with $2.2(0.8) \cdot 10^6 B^0 \rightarrow D^{(*)-} \mu^+ \nu_\mu X$ decays

$$A(t) = \frac{N^{unmix}(t) - N^{mix}(t)}{N^{unmix}(t) + N^{mix}(t)} = \frac{\cos(\Delta m_d t)}{\cosh(\Delta \Gamma_d t/2)} + \frac{a}{2} \left[ 1 - \frac{\cos^2(\Delta m_d t)}{\cosh^2(\Delta \Gamma_d t/2)} \right]$$

$\Delta \Gamma_d \sim 0$

CP violation in mixing $\sim 10^{-4} (SM)$
Precision measurement of $\Delta m_d$

- Mixing asymmetry measured with $2.2(0.8) \cdot 10^6 B^0 \rightarrow D^{(*)-} \mu^+ \nu_\mu X$ decays

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

- Flavor tagging $\mathcal{P} = \epsilon_{tag}(1 - 2\omega)^2 \sim 2.4\%$

\[
P = P_{\mu} + P_{\tau} = 1 - 2\omega
\]
Precision measurement of $\Delta m_d$

- Mixing asymmetry measured with $2.2(0.8) \cdot 10^6 B^0 \rightarrow D^{(*)} - \mu^+ \nu_\mu X$ decays

\[ A(t) = \frac{N_{unmix}(t) - N_{mix}(t)}{N_{unmix}(t) + N_{mix}(t)} = \cos(\Delta m_d t) \]

- Flavor tagging

- Background rejection

\[ B^+ \rightarrow D^{(*)} - \mu^+ \nu_\mu X^+ \] background rejection with a Multivariate Classifier
Precision measurement of $\Delta m_d$

- Mixing asymmetry measured with $2.2(0.8) \cdot 10^6 B^0 \rightarrow D^{(*)-} \mu^+ \nu_\mu X$ decays

$$A(t) = \frac{N^{unmix}(t) - N^{mix}(t)}{N^{unmix}(t) + N^{mix}(t)} = \cos(\Delta m_d t)$$

- Flavor tagging
- Background rejection
- Decay time reconstruction
**B** decay time and resolutions ($\Delta m_d$ and $\alpha_{s1}^d$)

- The momentum of the B meson cannot be measured precisely due to the partial reconstruction of the decay.
- The B decay time is corrected using the factor:
  \[
  k = \frac{p_{\text{reco}}}{p_{\text{true}}} \]
- The k-factors are also used to model the decay time resolution:

\[
B \text{ decay time and resolutions (} \Delta m_d \text{ and } \alpha_{s1}^d \text{)}
\]

\[
t = \frac{L \cdot M_{PDG}}{\overline{|p|}} \cdot k_{av}(M)
\]

\[
\mathcal{P}_{\text{sig}} = (T(t) \otimes_t R(t) \otimes_k F(k)) \cdot A(t)
\]

"L resolution"

LHCb simulation

<table>
<thead>
<tr>
<th>B mass</th>
<th>k factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>3000</td>
<td>0.4</td>
</tr>
<tr>
<td>3500</td>
<td>0.6</td>
</tr>
<tr>
<td>4000</td>
<td>0.8</td>
</tr>
<tr>
<td>4500</td>
<td>1.0</td>
</tr>
<tr>
<td>5000</td>
<td>1.2</td>
</tr>
</tbody>
</table>
Precision measurement of $\Delta m_d$

- Fit to the mixing asymmetry distributions in four bins of increasing mistag probability

$$\Delta m_d = 503.6 \pm 2.0\text{(stat)} \pm 1.3\text{(syst)}\text{ns}^{-1}$$

$$\Delta m_d^{HFAG\ 2015} = 505.5 \pm 2.0\ \text{ns}^{-1}$$

$$\Delta m_d^{SM} = 543 \pm 91\ \text{ns}^{-1}$$

A.Lenz, arXiv:1409.6963
Neutral $B$ meson mixing

- Oscillation and decay description:

$$i \frac{d}{dt} \left( \begin{array}{c} |B_q(t)\rangle \\ |\overline{B}_q(t)\rangle \end{array} \right) = \left( \begin{array}{cc} M_{11} - i \frac{\Gamma_{11}}{2} & M_{12} - i \frac{\Gamma_{12}}{2} \\ M_{12}^* - i \frac{\Gamma_{12}^*}{2} & M_{22} - i \frac{\Gamma_{22}}{2} \end{array} \right) \left( \begin{array}{c} |B_q(t)\rangle \\ |\overline{B}_q(t)\rangle \end{array} \right)$$

- Mass eigenstates are superpositions of flavor eigenstates:

$$|B_L\rangle = p|B_q\rangle + q|\overline{B}_q\rangle$$

$$|B_H\rangle = p|B_q\rangle - q|\overline{B}_q\rangle$$

- Mixing observables

$$\Delta \Gamma = \Gamma_L - \Gamma_H$$

$$\Delta m = m_H - m_L$$
Neutral $B$ meson mixing

- Oscillation and decay description:

$$i \frac{d}{dt} \left( \begin{array}{c} |B_q(t)\rangle \\ \overline{|B_q(t)\rangle} \end{array} \right) = \left( \begin{array}{cc} M_{11} - i \frac{\Gamma_{11}}{2} & M_{12} - i \frac{\Gamma_{12}}{2} \\ M_{12}^* - i \frac{\Gamma_{12}^*}{2} & M_{22} - i \frac{\Gamma_{22}}{2} \end{array} \right) \left( \begin{array}{c} |B_q(t)\rangle \\ \overline{|B_q(t)\rangle} \end{array} \right)$$

- Mass eigenstates are superpositions of flavor eigenstates:

$$|B_L\rangle = p|B_q\rangle \quad |B_H\rangle = p|\overline{B_q}\rangle \quad \mathcal{P}(\overline{B} \to B) \neq \mathcal{P}(B \to \overline{B})$$

- Mixing observables

$$\Delta \Gamma = \Gamma_L - \Gamma_H$$
$$\Delta m = m_H - m_L$$
Semileptonic $CP$ asymmetries

- Using semileptonic flavor specific $B$ meson decays:

$$a_{sl} = \frac{N(\bar{B} \rightarrow B \rightarrow f) - N(B \rightarrow \bar{B} \rightarrow \bar{f})}{N(\bar{B} \rightarrow B \rightarrow f) + N(B \rightarrow \bar{B} \rightarrow \bar{f})}$$

- SM predictions:

  - $a_{sl}^s = (1.9 \pm 0.3) \times 10^{-5}$
  - $a_{sl}^d = (-4.1 \pm 0.6) \times 10^{-4}$

  TINY!!

A. Lenz and U. Nierste, arXiv:1102.4274

- Experimental landscape without LHCb

New asymmetries (and $\Delta \Gamma_d$) measurements needed

arXiv:1409.6963
Semileptonic $CP$ asymmetries

- Using semileptonic flavor specific $B$ meson decays:

$$a_{sl} = \frac{N(\bar{B} \rightarrow B \rightarrow f) - N(B \rightarrow \bar{B} \rightarrow \bar{f})}{N(\bar{B} \rightarrow B \rightarrow f) + N(B \rightarrow \bar{B} \rightarrow \bar{f})}$$

- SM predictions:

$$a_{sl}^s = (1.9 \pm 0.3) \times 10^{-5}$$

$$a_{sl}^d = (-4.1 \pm 0.6) \times 10^{-4}$$

- Experimental landscape without LHCb

\[ a_{sl}^d \text{ and } a_{sl}^s \text{ measurement from LHCb using 3} \text{ fb}^{-1} \text{ of data} \]
Semileptonic CP asymmetries @ LHCb

• Using semileptonic flavor specific $B$ meson decays:

\[ a_{sl} = \frac{N(\bar{B} \to B \to f) - N(B \to \bar{B} \to \bar{f})}{N(\bar{B} \to B \to f) + N(B \to \bar{B} \to \bar{f})} \]

\[ B^0 \longrightarrow f \quad \overline{B^0} \longrightarrow \bar{f} \quad B^0 \swarrow \]

• Untagged charge asymmetry:

\[ A_{\text{meas}}(t) = \frac{\Gamma(f, t) - \Gamma(\bar{f}, t)}{\Gamma(f, t) + \Gamma(\bar{f}, t)} = \frac{a_{sl}^q}{2} - \frac{a_{sl}^q}{2} \frac{\cos(\Delta m_q t)}{\cosh(\Delta \Gamma_q t/2)} \]

No need to know the flavor of the $B$ meson at the production
Hadron production asymmetries

\[ A_P = \frac{\sigma(\bar{B}) - \sigma(B)}{\sigma(\bar{B}) + \sigma(B)} \]

\[ A_{\text{meas}}(t) = \frac{\Gamma(f, t) - \Gamma(f, t)}{\Gamma(f, t) + \Gamma(f, t)} = \frac{a_{\text{sl}}^d}{2} - \left( A_P + \frac{a_{\text{sl}}^d}{2} \right) \frac{\cos(\Delta m_d t)}{\cosh(\Delta \Gamma_d t/2)} \]
Time-dependent: $a_{s1}^d$

- Untagged, time dependent, charge asymmetry of the final state particles:

$$A_{\text{meas}}(t) = \frac{\Gamma(f, t) - \Gamma(\bar{f}, t)}{\Gamma(f, t) + \Gamma(\bar{f}, t)} = \frac{a_{s1}^d}{2} + A_D - \left(A_P + \frac{a_{s1}^d}{2}\right) \frac{\cos(\Delta m_d t)}{\cosh(\Delta \Gamma_d t/2)}$$

- Time-dependent fit to disentangle the $CP$ violating asymmetry from the $B^0$ production asymmetry

- Independent determination of the detection asymmetries with control samples

$A_P = \frac{\sigma(\bar{B}) - \sigma(B)}{\sigma(\bar{B}) + \sigma(B)}$

$-2(A_P + \frac{a_{s1}}{2})$
Time-integrated: $a_{s1}^{s}$

- Untagged, time integrated semileptonic asymmetry:

$$A_{\text{meas}} = \frac{\Gamma(f) - \Gamma(\bar{f})}{\Gamma(f) + \Gamma(\bar{f})} = \frac{a_{s1}^{s}}{2} + (A_{D} + \frac{a_{s1}^{s}}{2}) \left( \frac{\int e^{\Gamma_{s}t_{c} \cos(\Delta m_{s}t)} \epsilon(t) dt}{\int e^{\Gamma_{s}t_{c} \cosh(\Delta \Gamma_{s}t/2)} \epsilon(t) dt} \right) \sim 10^{-4}$$

- Fast $B_{s}^{0}$ oscillation dilutes second term below precision of this measurement

- $\mathcal{L} = 1 \text{ fb}^{-1}$ analysis
  
  $1.8 \cdot 10^{5} \ B_{s}^{0} \rightarrow D_{s} \mu \nu \mu X$ decays

- Signal yields for each charge extracted from KKπ invariant mass distributions

- Correct raw asymmetry for detection and background asymmetries

$$a_{s1}^{s} = (-0.06 \pm 0.50(\text{stat}) \pm 0.36(\text{syst}))\%$$
Time-integrated: $a_{s1}^s$

- Untagged, time integrated semileptonic asymmetry:

$$A_{\text{meas}} = \frac{\Gamma(f) - \Gamma(\bar{f})}{\Gamma(f) + \Gamma(\bar{f})} = \frac{a_{s1}^s}{2} + A_D \left( A_P + \frac{a_{s1}^s}{2} \right) \underbrace{\int e^{\Gamma_s t \cos(\Delta m_s t)\epsilon(t)} dt}_{\sim 10^{-4}}$$

- Fast $B_s^0$ oscillation dilutes second term below precision of this measurement

• $L = 3 \text{ fb}^{-1}$ analysis

$$B_s^0 \rightarrow D_s \mu \nu \mu X$$

$$\frac{a_{s1}^s}{2} = \frac{S + B}{S} (A_{\text{meas}} - A_D) - \frac{B}{S} A_{\text{bkg}}$$

- Inclusion of the full KK$\pi$ Dalitz region
- Novel techniques to control detection asymmetries
Data samples

- $B^0 \rightarrow D^{(*)-} \mu^+ \nu_\mu X$ decays in Run-I
- $B_s^0 \rightarrow D_s^- \mu^+ \nu_\mu X$ decays in Run-I
- Using the full KKπ Dalitz region for 3 fb$^{-1}$

A factor 6 MORE SIGNAL wrt 1 fb$^{-1}$
Detection asymmetries

- Detection/reconstruction asymmetry of the final state:
  \[ A_D = \frac{\epsilon(f) - \epsilon(\bar{f})}{\epsilon(f) + \epsilon(\bar{f})} \]

- Sources of asymmetry:
  - Different interaction with the detector material
  - Detector inefficiency/mis-alignment/inhomogeneities

E.g.: charged kaons

- Evaluated by using data-driven techniques on dedicated samples
Detection asymmetries

- Detection/reconstruction asymmetry of the final state:

\[ A_D = \frac{\epsilon(f) - \epsilon(\bar{f})}{\epsilon(f) + \epsilon(\bar{f})} \]

- Sources of asymmetry:
  - Different interaction with the detector material
  - Detector inefficiency/mis-alignment/inhomogeneities

- Evaluated by using data-driven techniques on dedicated samples

E.g.: charged kaons

\[ A_{K\pi} \] measured using prompt \( D^\pm \rightarrow K^{\pm} \pi^\mp \pi^\pm \) and \( D^\pm \rightarrow K_S^0 \pi^\pm \) decays

\( \sim (1.0 +/- 0.1)\% \)
Detection asymmetries

- Need to account for all possible detection and reconstruction asymmetries: *nuclear interaction, particle identification, tracking, trigger*

\[
A_D = A_{\mu\pi}^{(\text{track})} + A_{\pi}^{(\text{PID}\mid\text{track})} + A_{\text{track}+\text{PID}}^{KK} + A_{\text{PID}+L0\mid\text{track}}^{\mu}
\]

- Novel tag-and-probe method using $J/\psi \rightarrow \mu^+\mu^-$ decays combined with the method using partially reconstructed $D^* \rightarrow (D^0 \rightarrow K\pi\pi\pi)\pi$ decays

expected uncertainty on $A_{\mu\pi}^{(\text{track})} < 0.1\%$ in $3 \text{ fb}^{-1}$ analysis
Results

$$a_{s1}^d = (-0.02 \pm 0.19\text{(stat)} \pm 0.30\text{(syst)})\%$$

expected $$a_{s1}^s = (X.XX \pm 0.2\text{(stat)} \pm 0.25\text{(syst)})\%$$

$$ (a_{s1}^s = (-0.06 \pm 0.50\text{(stat)} \pm 0.36\text{(syst)})\% )$$
Results

\[ a_{s1}^d = (-0.02 \pm 0.19\text{ (stat)} \pm 0.30\text{ (syst)})\% \]

expected \[ a_{s1}^s = (X.XX \pm 0.2\text{ (stat)} \pm 0.25\text{ (syst)})\% \]

\[ (a_{s1}^s = (-0.06 \pm 0.50\text{ (stat)} \pm 0.36\text{ (syst)})\%) \]
Results

\[ a_{sl}^d = (-0.02 \pm 0.19\text{(stat)} \pm 0.30\text{(syst)})\% \]

expected \[ a_{sl}^s = (X.XX \pm 0.2\text{(stat)} \pm 0.25\text{(syst)})\% \]

\((a_{sl}^s = (-0.06 \pm 0.50\text{(stat)} \pm 0.36\text{(syst)})\%\)\

### Table: Sources of Uncertainty

<table>
<thead>
<tr>
<th>Source</th>
<th>(\delta(%))</th>
</tr>
</thead>
<tbody>
<tr>
<td>(A_D)</td>
<td>0.26</td>
</tr>
<tr>
<td>B+ bkg</td>
<td>0.13</td>
</tr>
<tr>
<td>(\Lambda_b) bkg</td>
<td>0.07</td>
</tr>
<tr>
<td>fit model</td>
<td>0.05</td>
</tr>
<tr>
<td>other bkg</td>
<td>0.04</td>
</tr>
<tr>
<td>quadratic sum</td>
<td>0.30</td>
</tr>
</tbody>
</table>

**Example:**

Limited by control sample statistics (0.19\%)

~0.16

3 fb\(^{-1}\)

Limited by assumptions, e.g. production asymmetries

---


$B^+$ Production asymmetry

• Samples: $B^+ \to [K^- \pi^+]\pi^+$ and $B^+ \to [K^- \pi^+ \pi^- \pi^+]\pi^+$

• Charge asymmetry:

$$A_{B^+ \text{ meas}}^{B_u} = \frac{N(B^- \to D^0\pi^-) - N(B^+ \to \bar{D}^0\pi^+)}{N(B^- \to D^0\pi^-) + N(B^+ \to \bar{D}^0\pi^+)}$$

• Production asymmetry

$$A_P(B^+) = A_{B^+ \text{ meas}}^{B_u} - A_D - A_{CP}^{D\pi^\pm}$$

• Expected uncertainty $\sim 0.33\%$ (8 TeV), $0.47\%$ (7 TeV)
  to be compared with $0.6\%$
  (systematic on $a^d_{sl} \sim 0.07\%$ (8 TeV) $\sim 0.09\%$ (7 TeV)

And Measurement of $A_{CP}(B^\pm \to J/\psi K^\pm)$

defining $\Delta A_{CP} = A_{CP}^{J\psi K} - A_{CP}^{D\pi} = A_{CP}^{J\psi K} \text{ meas} - A_{CP}^{D\pi} \text{ meas} + \delta A_{D}^{K\pi}$

and assuming no CPV in $B \to D\pi$ decays
Summary and perspectives

- **$B^0$ mixing frequency**: world’s best measurement and uncertainty well below the theory uncertainty

- **Semileptonic asymmetries**:
  - Run-I measurement of $a_{s1}^s$ is coming soon!
  - A number of improvements are available to improve the $a_{s1}^d$ measurement
    (about at least 15% reduction of the current systematic uncertainty is expected)
  - Increase in the statistics of the samples to come...

  *With the current techniques and tools:*
  
  At the end of Run-II uncertainties on $a_{s1}^s$ and $a_{s1}^d$ are expected to be ~50-60% of the current Run-I uncertainties

  With additional 50 fb$^{-1}$ (upgrade), uncertainties on $a_{s1}^s$ and $a_{s1}^d$ are expected to be at the order of one per mille or below
Backup
Measurement: Tracking asymmetries

- Efficiency of track reconstruction depends on the momentum of the particle

\[
A_{\text{tracking}}(\mu^+\pi^-) = \int_{\mu_{p_T \text{ range}}} P_\mu(p_T)dp_T A_{\text{tracking}}(\mu^+,p_T) + \int_{\pi_{p_T \text{ range}}} P_\pi(p_T)dp_T A_{\text{tracking}}(\pi^-,p_T)
\]

- Checked with pseudo-experiments
Measurement: $\mu \pi$ detection asymmetry

- Transverse momentum dependence of the tracking efficiencies

  re-weight the data sample to obtain a good overlapping kinematic phase space between $\mu$ and $\pi$. Residual asymmetry (0.00 +/- 0.02)%

- Muon-ID and trigger asymmetries: A tag-and-probe method is applied to $J/\psi \rightarrow \mu \mu$ decays

Few per-mille corrections, depending on run period, magnet polarity. **Overall uncertainty 0.04%**
\( a_{s1}^d \) Measurement: \( K\pi \) detection asymmetry

- Using prompt D+ decays into \( K\pi\pi \) and \( K_S\pi \)

\[
A_{K\pi} \equiv \frac{\epsilon(K^+\pi^-) - \epsilon(K^-\pi^+)}{\epsilon(K^+\pi^-) + \epsilon(K^-\pi^+)}
= A(D \rightarrow K\pi\pi)
- A(D \rightarrow K_S\pi)
- A(K_S)
\]

- Re-weighting needed to map: the \( K\pi \) pair of the control sample to match the signal, the D kinematics to cancel the D production asymmetry, the pion in the two control samples.

- Neutral kaon asymmetry : \( A(K_S) = (0.054 \pm 0.011)\% \) \( \text{JHEP 07 (2014) 041} \)

\[
A_{K\pi} = (1.15 \pm 0.08(\text{stat}) \pm 0.07(\text{syst}))\%
\text{Reweighted (for the D+ mode)}
\]

- Main contribution: nuclear kaon interaction, the method accounts for all possible sources of detection asymmetry
**$a_{S1}^{d}$ Measurement: Backgrounds**

- **Main background:** $B^+ \rightarrow D^{(*)-} \mu^+ X^+$
  
  Fractions and shapes are taken from simulation and measured Branching Fractions.
  
  $$f_{B^+}(D^{*-} \mu^+ X^+) = (8.8 \pm 2.2)\% \quad f_{B^+}(D^- \mu^+ X^+) = (12.7 \pm 2.2)\%$$
  
  B+ production asymmetry from LHCb measurement using $B^+\rightarrow J/\psi K^+$ decays [arXiv:1408.0978](http://example.com) corrected by the CP asymmetry (PDG 2014)
  
  $$A_P(B^+) = (-0.6 \pm 0.6)\%$$

- **Other backgrounds:** $\Lambda_b^0 \rightarrow D^{(*)-} \mu^+ X_n$
  
  $$f_{\Lambda_b^0} \sim 2\%$$
  
  From production ratio, [Phys. Rev.D85 (2012) 032008](http://example.com) efficiency ratio branching ratio of $\Lambda_b^0 \rightarrow \Lambda_c^+ \pi^-$ and $\Lambda_b^0 \rightarrow D^0 p \pi^-$ [Phys. Rev.D89 (2014) 032001](http://example.com)
  
  $$A_P(\Lambda_b^0) \sim (-0.9 \pm 1.5)\%$$
  
  Raw asymmetry in $\Lambda_b^0 \rightarrow J/\psi pK^+$ subtracting kaon and proton detection asymmetries [JHEP 07(2014) 103](http://example.com)
\( a_{sl}^d \)  Measurement: Systematic uncertainties

<table>
<thead>
<tr>
<th>Source of uncertainty</th>
<th>( a_{sl}^d )</th>
<th>( A_P(7 \text{ TeV}) )</th>
<th>( A_P(8 \text{ TeV}) )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Detection asymmetry</td>
<td>0.26</td>
<td>0.20</td>
<td>0.14</td>
</tr>
<tr>
<td>( B^+ ) background</td>
<td>0.13</td>
<td>0.06</td>
<td>0.06</td>
</tr>
<tr>
<td>( \Lambda_b^0 ) background</td>
<td>0.07</td>
<td>0.03</td>
<td>0.03</td>
</tr>
<tr>
<td>( B_s^0 ) background</td>
<td>0.03</td>
<td>0.01</td>
<td>0.01</td>
</tr>
<tr>
<td>Combinatorial ( D ) background</td>
<td>0.03</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>( k )-factor distribution</td>
<td>0.03</td>
<td>0.01</td>
<td>0.01</td>
</tr>
<tr>
<td>Decay time acceptance</td>
<td>0.03</td>
<td>0.07</td>
<td>0.07</td>
</tr>
<tr>
<td>Knowledge on ( \Delta m_d )</td>
<td>0.02</td>
<td>0.01</td>
<td>0.01</td>
</tr>
<tr>
<td>Quadratic sum</td>
<td>0.30</td>
<td>0.22</td>
<td>0.17</td>
</tr>
</tbody>
</table>

- **Leading contribution:** uncertainty on the measurement of the detection asymmetries

- **B+ background** second largest contribution. Different strategy foreseen for the future

- In general the **systematics related to the fit model** are small.
\[ a_{s1}^d \quad \text{Measurement: Results (II)} \]

\[ A_P(7 \, \text{TeV}) = (-0.66 \pm 0.26(\text{stat}) \pm 0.22(\text{syst}))\% \]

\[ A_P(8 \, \text{TeV}) = (-0.48 \pm 0.15(\text{stat}) \pm 0.17(\text{syst}))\% \]