Measurement of the Semileptonic CP Asymmetry in $B_s$-$\bar{B}_s$ Mixing

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**WHAT**

- Flavour eigenstates and mass eigenstates not aligned
- Quantum mechanics: neutral mesons mix over time:
  \[
  \frac{d}{dt} \left( \frac{\langle \phi(t) | M | \phi(t) \rangle}{\langle \phi(t) | \phi(t) \rangle} \right) - \left( M_1 - M_2 \right) \frac{\langle \phi(t) | M_1 | \phi(t) \rangle}{\langle \phi(t) | \phi(t) \rangle} - \left( M_2 - M_3 \right) \frac{\langle \phi(t) | M_2 | \phi(t) \rangle}{\langle \phi(t) | \phi(t) \rangle} = \frac{\langle \phi(t) | M_3 | \phi(t) \rangle}{\langle \phi(t) | \phi(t) \rangle}
  \]
- Diagonalise to get mass eigenstates:
  \[
  \Delta m_3 = m_1 - m_3^2 \]
  \[
  \Delta m_2 = m_2 - m_3^2
  \]
- CP-violation in mixing:
  \[
  P(B_s \rightarrow \bar{B}_s) \neq P(\bar{B}_s \rightarrow B_s)
  \]
- Measure the flavour of the $B$, at decay by a flavour specific final state: semileptonic decays. No CP violation in decay.
- Production asymmetry negligible: only count the number of final-state $D_s^+$ $\mu^+$ and $D^-$ $\mu^+$~\cite{1}

\[
\frac{\Gamma(D_s^+ \rightarrow B_s \mu^+ \nu)}{\Gamma(D^- \rightarrow B_s \mu^- \bar{\nu})} \approx \frac{\langle \phi(t) | M_1 | \phi(t) \rangle}{\langle \phi(t) | \phi(t) \rangle} + \frac{\langle \phi(t) | M_2 | \phi(t) \rangle}{\langle \phi(t) | \phi(t) \rangle} \cos(\Delta M f t + \phi(0)) + \frac{\langle \phi(t) | M_3 | \phi(t) \rangle}{\langle \phi(t) | \phi(t) \rangle} \sin(\Delta M f t + \phi(0))
\]

- The LHCb detector at CERN
  - High number of produced $B$- 930000 $D_s^+$ $\mu^+$ candidates in 1 fb$^{-1}$
  - High momentum resolution, $\Delta p/p = (0.4\pm0.6)\%$
  - Excellent vertex detector to record the $B$, decay vertex
  - Particle ID: separate $K$, $x$, and $p$ charged final state particles
  - Selected $D_s^+$ decay products, $K^+$ $K^-$ $\pi^+$, are all well identified.
  - Proton-proton collider: production asymmetry
    - Measured as percent-level\(^{[6]}\): $a_0(B_0) = (1.06 \pm 2.69)\%$

**WHY**

- CP-asymmetry in the Standard Model too small
- Are new particles enhancing CP violation?
- Mixing observables important constraint for $Z'$ models
- CP violation in mixing sensitive to new physics e.g. $B_s \rightarrow \tau \tau$ decays, little experimental constraints
- Other measurement for the $B_s$ system: anomalous result?

**PREDICTION**

- Standard model prediction: extremely small\(^{[4]}\)
  \[
  a_0^d = ( -4.1 \pm 0.6 ) \times 10^{-4} \quad a_0^u = ( 1.9 \pm 0.3 ) \times 10^{-5}
  \]
- Measurements by B-factories\(^{[3]}\) (green) and D$^0$\(^{[3]}\) (blue)
- $D_0$ dimuon result: 3.6σ deviation from Standard Model\(^{[4]}\)

**RESULTS**

- 1 fb$^{-1}$ $a_0^u$ published in 2014\(^{[4]}\), 3 fb$^{-1}$ $a_0^u$ result published in 2015\(^{[5]}\)
  \[
  a_0^d = ( -0.06 \pm 0.50(\text{stat}) \pm 0.36(\text{syst}) ) \%
  \]
  \[
  a_0^u = ( -0.02 \pm 0.19(\text{stat}) \pm 0.30(\text{syst}) ) \%
  \]
- In progress: improved $a_0^u$ with 3 fb$^{-1}$ (blinded result):
  \[
  a_0^d = X \times X \% \pm 0.25\% \pm 0.20\%
  \]
- World’s best measurement of both quantities!

**DETECTION asymmetries**

Magnet bends charged particles: charge asymmetry found in left-right asymmetry... but what if LHCb is not perfectly symmetric?

- Largest correction to the measurement.
- Measure and correct for asymmetries from tracking, trigger and particle ID
- Hadronic tracking asymmetries: prompt $D^+$-tagged $D^0$ daughters
- Tag & probe: do we find all the tracks, or do we miss one?
- Average magnet polarities: most detection asymmetry cancel

**REFERENCES**

1. Nikhef national institute of subatomic physics, The Netherlands. Contact: laurent.dufour@cern.ch

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