Measurement of the Semileptonic CP Asymmetry in Bs-Bs Mixing
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WHAT
- Flavour eigenstates and mass eigenstates not aligned
- Quantum mechanics: neutral mesons mix over time:
  \[
  \frac{d}{dt} \left( \frac{|B_s(t)|}{|\overline{B}_s(t)|} \right) = \left( M_{1s} - M_{2s} \right) \frac{|B_s(t)|}{|\overline{B}_s(t)|} + \left( M_{1s} - M_{2s} \right) \frac{|B_s(t)|}{|\overline{B}_s(t)|} \]
- Diagonalize to get mass eigenstates:
  \[
  \Delta m_q = m_{1s} - m_{2s} \]
- CP-violation in mixing:

\[
P(B_s \rightarrow \overline{B}_s) \neq P(\overline{B}_s \rightarrow B_s)
\]
- Measure the flavour of the B, at decay by a flavour specific final state: semileptonic decays. No CP violation in decay.

\[
a_{\text{sl}} = \frac{\Gamma(B_s \rightarrow D^- \mu^+ \nu) - \Gamma(B_s \rightarrow D^- \mu^- \bar{\nu})}{\Gamma(B_s \rightarrow D^- \mu^+ \nu) + \Gamma(B_s \rightarrow D^- \mu^- \bar{\nu})}
\]
- Production asymmetry negligible: only count the number of final-state D^+ \mu^- and D^- \mu^+ \[\text{(i)}\]

\[
\frac{\Gamma(D^+ \mu^-)}{\Gamma(D^- \mu^+)} \approx |a_{\text{sl}}|^2
\]

\[
\Delta m_q = |m_{1s} - m_{2s}|
\]

How
- The LHCb detector at CERN
  - High number of produced B\(\to\) 93000 \(D^+ \mu^-\) candidates in 1 fb\(^{-1}\)
  - High momentum resolution, \(\Delta p/p = (0.4\% - 0.6\%)\)
  - Excellent vertex detector to record the B, decay vertex
  - Particle ID: separate K, \(\pi\), and \(p\) charged final state particles
  - Selected \(D^+\) decay products, K, \(\pi^\pm\), are all well identified.
  - Proton-proton collider: production asymmetry
  - Measured as percent-level\[^6]\): \(a_{\text{sl}}(B) = (1.06 \pm 2.60)\%

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 in 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\[^7\]
  \(a_{\text{sl}}^a = (-4.1 \pm 0.6) \times 10^{-4}\)
  \(a_{\text{sl}}^d = (1.9 \pm 0.3) \times 10^{-5}\)
- Measurements by B-factories\[^3\] (green) and D0\[^5\] (blue)
- D0 dimuon result: 3.6\(\sigma\) deviation from Standard Model\[^4\]

Results
- 1 fb\(^{-1}\) \(a_{\text{sl}}^a\) published in 2014\[^4\], 3 fb\(^{-1}\) \(a_{\text{sl}}^a\) result published in 2015\[^5\]
  \(a_{\text{sl}}^a = (-0.06 \pm 0.50)\%\)
  \(a_{\text{sl}}^d = (-0.02 \pm 0.19)\%\)
- In progress: improved \(a_{\text{sl}}^a\) with 3 fb\(^{-1}\) (blinded result):
  \(a_{\text{sl}}^a = XXX \pm 0.25\% \pm 0.20\%\)
- 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