$b \rightarrow (s, d)\mu\mu$ decays at LHCb

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New particles, if they exist, enter into loop diagrams
Their influence may measurably change observables:
  • Branching fraction (total or differential)
  • Angular distribution
  • CP asymmetry

Look in processes which only occur at loop level in SM -
Flavour Changing Neutral Current decays (FCNCs)
Minimal Flavour Violation

- If new physics is allowed to violate flavour generically, B and Kaon physics set a lower bound on the mass scale for new physics at $10^3 - 10^4$ TeV (for O(1) couplings)
- Assume new physics only violates flavour in same pattern as SM
  - Only source of flavour violation in SM is CKM matrix
  - CKM matrix arises from Yukawa couplings
- Minimal Flavour Violation (MFV): hypothesis that the only sources of flavour violation are the Yukawa couplings
  - Common assumption in new physics models
Consequences of MFV

- MFV does not mean no deviations from SM possible in flavour physics
- Constrains ratios of observables
  - In SM & MFV, ratio of branching fractions for $b \to s \mu^+ \mu^-$ and $b \to d \mu^+ \mu^-$ is given by the CKM factor $|V_{td}|^2/|V_{ts}|^2$ ($\sim 1/25$)
  - Measuring a deviation from this would indicate new non-MFV physics
  - Can test this using exclusive modes $B^+ \to K^+ \mu^+ \mu^-$ and $B^+ \to \pi^+ \mu^+ \mu^-$
\[ B^+ \rightarrow K^+ \mu^+ \mu^- \]

- \( B^+ \rightarrow K^+ \mu^+ \mu^- \) previously measured by BaBar (shown), BELLE and CDF (rarest B decay seen before LHCb)
- Combined world sample: \( \sim 250 \) signal candidates
\[ B^+ \rightarrow K^+ \mu^+ \mu^- \]

- \( B^+ \rightarrow K^+ \mu^+ \mu^- \) now also measured by LHCb, using 2011 dataset (1 fb\(^{-1}\))
  - \( \sim 1200 \) signal candidates
- \( \mathcal{B}(B^+ \rightarrow K^+ \mu^+ \mu^-) = (4.36 \pm 0.15 \pm 0.18) \times 10^{-7} \)
- Differential BR and angular observables also measured, all consistent with SM (LHCB-PAPER-2012-263)
- Is a background to \( B^+ \rightarrow \pi^+ \mu^+ \mu^- \)
1. Introduction

\[ B^+ \rightarrow \pi^+ \mu^+ \mu^- \]

- Search for \( B^+ \rightarrow \pi^+ \mu^+ \mu^- \) using 2011 dataset (LHCB-PAPER-2012-020)
- No \( b \rightarrow d \mu^+ \mu^- \) transition has previously been observed
- Previous best limit is \(< 6.9 \times 10^{-8}\), from BELLE
- SM prediction \((1.96 \pm 0.21) \times 10^{-8}\)
Selection

- Use a Boosted Decision Tree (BDT) to separate signal (black) from combinatorial background (red)
- Use simulated $B^+ \rightarrow \pi^+ \mu^+ \mu^-$ events for signal sample, portion of mass sidebands in data for background sample
  - Background sample used is excluded from remainder of analysis
- Hadron particle identification requirements suppress $B^+ \rightarrow K^+ \mu^+ \mu^-$ by a factor $\sim 100$
Fit strategy

- Signal and misidentified background mass shapes both taken from data:
- Signal taken from $B^+ \rightarrow J/\psi K^+$ under the correct $(M_{K\mu\mu})$ mass hypothesis (left)
- Misidentified $B^+ \rightarrow K^+ \mu^+ \mu^-$ taken from $B^+ \rightarrow J/\psi K^+$ under the $(M_{\pi\mu\mu})$ mass hypothesis (left)
Fit validation

- Fit strategy validated on $B^+ \rightarrow J/\psi \pi^+$ in data
- Observed $B^+ \rightarrow J/\psi K^+$ yield $(1024 \pm 61)$ consistent with expectation $(958 \pm 31)$
• $25.3^{+6.7}_{-6.4} \ B^+ \to \pi^+ \mu^+ \mu^- \ \text{candidates, corresponding to a significance of } 5.2 \ \sigma$
• $\mathcal{B}(B^+ \to \pi^+ \mu^+ \mu^-) = (2.3 \pm 0.6 \ (\text{stat}) \pm 0.1 \ (\text{syst})) \times 10^{-8}$
• Consistent with SM prediction of $(1.96 \pm 0.21) \times 10^{-8}$
Measure ratio between $B^+ \rightarrow \pi^+ \mu^+ \mu^-$ and $B^+ \rightarrow K^+ \mu^+ \mu^-$ directly

Determine $|V_{td}|/|V_{ts}| = 0.266 \pm 0.035 \text{ (stat)} \pm 0.003 \text{ (syst)}$

- Theory uncertainty not yet available
- Consistent with previous determinations
Conclusion

- $B^+ \rightarrow \pi^+ \mu^+ \mu^-$ observed at 5.2 $\sigma$
  - First observation
  - First $b \rightarrow d \mu^+ \mu^-$ transition observed
- $\mathcal{B}(B^+ \rightarrow \pi^+ \mu^+ \mu^-) = (2.3 \pm 0.6 \text{ (stat)} \pm 0.1 \text{ (syst)}) \times 10^{-8}$
  - Rarest B decay observed
  - Agrees with SM prediction
- Ratio of $\mathcal{B}(B^+ \rightarrow \pi^+ \mu^+ \mu^-)$ and $\mathcal{B}(B^+ \rightarrow K^+ \mu^+ \mu^-)$ used to extract $|V_{td}|/|V_{ts}| = 0.266 \pm 0.035 \text{ (stat)} \pm 0.003 \text{ (syst)}$
  - Agrees with previous determinations
- No evidence for non-MFV physics
- SM wins again