Measurement of the isospin asymmetry in $B \to K^{(*)}$ $\mu^+ \mu^-$ decays

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Outline

- Introduction
  - Rare decays and new physics
  - Isospin asymmetry of $B \rightarrow K^{(*)} \mu^+ \mu^-$
- Analysis
- Results [JHEP 1207:133, 2012]
New physics through rare decays

- Decays discussed today are flavour changing neutral current transitions.
- Forbidden at tree level in the SM, and must proceed through penguin/box diagrams.
- New particles can 'enter into the loop' and add possible diagrams, altering observables.
- Measurements usually depend on the 4-momentum transferred to the two muons, \( q^2 \).

\[ \begin{align*}
  b & \rightarrow V_{tb} W^- V_{ts} s \\
  t & \rightarrow \gamma, Z^0 \ell^+ \ell^- \\
  \end{align*} \]
New physics through rare decays

- Rare decays NP searches complementary to direct approach:
  - Probe particle masses beyond $\sqrt{s}$.
  - Model independent interpretation (Wilson Coefficients)
  - Study gauge structure of new physics.

- For example, new physics with electromagnetic gauge structure must be $\gtrsim 50$ TeV for naive $O(1)$ flavour violating couplings [JHEP 1208:121, 2012].
LHCb

- LHCb is a heavy flavour experiment situated at the LHC.
- Hadronic environment is tough, but make up for it due to huge heavy flavour cross-section at high energies.
- Good momentum resolution and particle identification crucial.
- Results presented today use $1 \text{ fb}^{-1}$ of integrated luminosity - the 2011 dataset. Have another $2 \text{ fb}^{-1}$ from 2012 running.
Isospin asymmetry of $B \rightarrow K^{(*)} \mu^+ \mu^-$ decays

The isospin asymmetry of $B \rightarrow K^{(*)} \mu^+ \mu^-$, $A_I$, is defined as:

$$A_I = \frac{B(B^0 \rightarrow K^{(*)0} \mu^+ \mu^-) - \frac{\tau_0}{\tau_+} B(B^\pm \rightarrow K^{(*)\pm} \mu^+ \mu^-)}{B(B^0 \rightarrow K^{(*)0} \mu^+ \mu^-) + \frac{\tau_0}{\tau_+} B(B^\pm \rightarrow K^{(*)\pm} \mu^+ \mu^-)}$$

- $A_I$ expected to be $\mathcal{O}(1\%)$ in the SM
- In 2009, BABAR measured a surprising $3.9 \sigma$ deviation from zero at low $q^2$
  - [Phys. Rev. Lett. 102, 091803].
- Now significance down to $\sim 2 \sigma$ and only in the $B \rightarrow K \mu^+ \mu^-$ mode.
Isospin asymmetry analysis

- Analysis boils down to branching fraction measurements of 4 decays:
  - \( B^+ \rightarrow (K^{*+} \rightarrow K_S^0 \pi^+) \mu^+ \mu^- \)
  - \( B^0 \rightarrow (K^0 \rightarrow K_S^0) \mu^+ \mu^- \)
  - \( B^0 \rightarrow (K^{*0} \rightarrow K^+ \pi^-) \mu^+ \mu^- \)
  - \( B^+ \rightarrow K^+ \mu^+ \mu^- \)

- \( K_S^0 \) mesons are reconstructed through the \( K_S^0 \rightarrow \pi^+ \pi^- \) decay mode.
- Do not consider decays involving a \( \pi^0 \) or \( K_L^0 \)
- \( K_S^0 \) channels have lower reconstruction efficiency and visible branching fraction than \( K^+ \) channels.
Isospin asymmetry analysis

- Split data into categories depending on whether the $K_S^0$ daughters leave hits in the vertex detector or not (long (L) and down (D)).

- Each decay is normalised to the corresponding $B \rightarrow (J/\psi \rightarrow \mu^+ \mu^-)K^{(*)}$ decay, which have the identical final state.

- These normalisation decays proceed at tree level $\rightarrow O(100)$ times more common than the signal.
Selection

- Reduce combinatorial background using kinematic, geometric and particle identification (PID) information.
- Use multivariate techniques to boost sensitivity.
- Consider exclusive backgrounds and use PID/kinematics to reduce them - negligible after selection.

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

\[ B^0 \rightarrow K^0_S \mu^+ \mu^- \]
Acceptance correction

- Correct for acceptance effects due to geometry, trigger, reconstruction & selection.
- Bin this acceptance in $q^2$.
- $B \rightarrow (J/\psi \rightarrow \mu^+ \mu^-)K^{(*)}$ decays are used to normalise each decay which simplifies systematic uncertainties.
5. Analysis techniques

\( \mathcal{B}(B^0 \to K^0 \mu^+ \mu^-) \)

Signal yields determined using unbinned extended maximum likelihood fits.

60-70 signal candidates for the \( K_S^0 \) channels.
dBf/q^2 (B^0 \rightarrow K^0 \mu^+ \mu^-)

- Branching fraction results, errors are stat + syst.
- There is a deficit of \( B^0 \rightarrow K^0 \mu^+ \mu^- \) signal in the \( q^2 \) regions which are not adjacent to the charmonium resonances.

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SM predictions based on [JHEP 1201:107, 2012] (\( B^+ \rightarrow K^{*+} \mu^+ \mu^- \)) and [JHEP 1107:067, 2011] (\( B^0 \rightarrow K^0 \mu^+ \mu^- \)).
Isospin asymmetry of $B \to K^{*} \mu^{+} \mu^{-}$

- $A_I$ for $B \to K^{*} \mu^{+} \mu^{-}$ consistent with zero, as predicted by the SM.
- $A_I (B^0 \to K^{*} \gamma) = 0.07 \pm 0.03$.
- All experimental results agree with each other.

Isospin asymmetry of $B \to K \mu^+ \mu^-$

- $A_I$ for $B \to K \mu^+ \mu^-$ tends to sit below the SM prediction, due to the deficit of $B^0 \to K^0 \mu^+ \mu^-$ shown on the previous slide.
- LHCb measurements alone are over $4\sigma$ from zero.
- Nearly all the measurements of $A_I$ are negative - see [HFAG combination].

Summary

- LHCb measurement of the isospin asymmetry in $B \rightarrow K \mu^+ \mu^-$ decays is over $4\sigma$ away from zero ($\sim$ SM expectation).
- No physics model proposed yet can explain this result.
- Looking forward to updating to the full $3\, \text{fb}^{-1}$ dataset where we expect to halve the statistical errors.
Charmonium resonances

- $B \rightarrow (J/\psi \rightarrow \mu^+ \mu^-)K^(*)$ and $B \rightarrow \psi(2S)h$ are irreducible backgrounds and are $\sim 100$ and 10 times more common than signal.

- Regions (a) due to FSR, (b) due to mis-reconstruction and (c) due to partially reconstructed background.