Electroweak penguin decays to leptons at LHCb

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Overview:

• Reminders:
  • $B_s \rightarrow \mu^+\mu^-$ and $B_d \rightarrow \mu^+\mu^-$
  • Resonance observed in $B^+ \rightarrow K^+\mu^+\mu^-$ decays
  • $B^0 \rightarrow K^*\mu^+\mu^-$ and $P'_5$

• Hot off the press:
  • Angular analysis of charged and neutral $B \rightarrow K\mu\mu$ decays
  • $B^0 \rightarrow K^*\mu^+\mu^-$ isospin asymmetry and branching ratios

• Conclusions and looking forward
Rare Decays at LHCb

- FCNC’s can occur through loops
  - Highly suppressed
  - Sensitive to new physics e.g. additional diagrams from new BSM particles in loops
  - Numerous observables – many very sensitive to NP

- LHCb ideal for studying rare FCNC decays of mesons and baryons, e.g. $b \rightarrow s$
  - High resolution tracking
  - High performance PID
  - Muon signals ‘clean’ at LHCb

Phenomenology 2014 Pittsburgh, USA
$B_s \rightarrow \mu\mu$ and $B_d \rightarrow \mu\mu$ reminder

- Highly suppressed from helicity and GIM
- Possible contributions from tree level BSM diagrams
  - Highly sensitive to new physics
- Branching fraction measured at both LHCb and CMS. Combined result highly constrains SUSY models.

Allowed space for SUSY models in 2010 with CMS and LHCb constraints overlaid roughly in blue

LHCb: arXiv:1307.5024
CMS: arXiv:1307.5025

Combined LHCb and CMS results
Candidates for $B_s \rightarrow \mu\mu$ and $B_d \rightarrow \mu\mu$, LHCb
$B^+ \to K^+ \mu^+ \mu^-$ resonance

• Resonance observed in the dimuon system
• In region where $K$ has low recoil to $\mu^+ \mu^-$
• Corresponds to $\psi(4160)$
• $\mathcal{B} (B^+ \to \psi(4160)K^+)$ probed

[Graphs and data showing likelihood scan of resonance mass and width]
$B^0 \rightarrow K^* \mu^+ \mu^-$ angular analysis

- Looks at the differential angular distribution as functions of $\theta_L, \theta_K, \phi$ and $q^2$.

- Contains observables $P_{4,5,7,8}' = \frac{S_j=4,5,7,8}{\sqrt{F_L(1-F_L)}}$.

- Reduced form-factor uncertainties in SM predictions

\[
\frac{1}{d\Gamma/dq^2} \frac{d^4\Gamma}{d\cos\theta_\ell d\cos\theta_K d\phi d\phi^2} = \frac{9}{32\pi} \left[ \frac{3}{4} (1-F_L) \sin^2 \theta_K + F_L \cos^2 \theta_K + \frac{1}{4} (1-F_L) \sin^2 \theta_K \cos 2\theta_\ell 
  - F_L \cos^2 \theta_K \cos 2\theta_\ell 
  + S_3 \sin^2 \theta_K \sin^2 \theta_\ell \cos 2\phi 
  + S_4 \sin 2\theta_K \sin 2\theta_\ell \cos 2\phi 
  + S_5 \sin 2\theta_K \sin \theta_\ell \cos \phi 
  + S_6 \sin^2 \theta_K \cos \theta_\ell 
  + S_7 \sin 2\theta_K \sin \theta_\ell \sin \phi 
  + S_8 \sin 2\theta_K \sin 2\theta_\ell \sin \phi 
  + S_9 \sin^2 \theta_K \sin^2 \theta_\ell \sin 2\phi \right].
\]
\[ B^0 \rightarrow K^* \mu^+ \mu^- \text{ angular analysis} \]

- Mostly consistent with SM predictions
- However, deviation seen in \( P_5' \) region
- Comparison with theory:
  
  
  - 3.7\( \sigma \) when looking at local discrepancy.
  - 0.5\% chance of such discrepancy occurring in one of 24 bins.

  Jäger et al. arXiv:1212.2263
  
  - More conservative theoretical uncertainties calculations at low \( q^2 \)
  - Significance reduced

arXiv:1308.1707
\[ B \to K\mu^+\mu^- \text{ angular analysis (} B^+ \text{ and } B^0 \) \]

- Differential branching fraction of charged and neutral \( B \to K\mu\mu \) decays as function of the angle between one of the muons and the kaon in the dimuon rest frame

\[
\frac{1}{\Gamma} \frac{d\Gamma}{d\cos \theta_l} = \frac{3}{2} (1 - \left(F_H\right)(1 - \cos^2 \theta_l)) + \frac{1}{2} F_H + A_{FB} \cos \theta_l F_H
\]

- NP models can give non-negligible values of \( F_H \) or \( A_{FB} \)

arXiv:1403.8045
$B \rightarrow K \mu^+ \mu^-$ angular analysis ($B^+$ and $B^0$)

$1.1 < q^2 < 6.0 \text{ GeV}^2/c^4$

$15.0 < q^2 < 22.0 \text{ GeV}^2/c^4$

$B^+ \rightarrow K^+ \mu^+ \mu^-$
$B \rightarrow K\mu^+\mu^-$ angular analysis ($B^+$ and $B^0$)

- The most precise measurements to date
- Highly consistent with the SM
- Imposes much tighter constraints on tensor amplitudes
- Rules out cancellation effects for (pseudo)scalars in $B_s \rightarrow \mu\mu$ to explain results in non-SM case
B^0 \rightarrow K^* \mu^+ \mu^-\text{ isospin asymmetry}

- Isospin asymmetry an ideal probe due to the cancellation of form-factor uncertainties

\[
A_I = \frac{\Gamma(B^0 \rightarrow K^{(*)0} \mu^+ \mu^-) - \Gamma(B^+ \rightarrow K^{(*)+} \mu^+ \mu^-)}{\Gamma(B^0 \rightarrow K^{(*)0} \mu^+ \mu^-) + \Gamma(B^+ \rightarrow K^{(*)+} \mu^+ \mu^-)} = \frac{B(B^0 \rightarrow K^{(*)0} \mu^+ \mu^-) - \left(\frac{\tau_0}{\tau_+}\right) \cdot B(B^+ \rightarrow K^{(*)+} \mu^+ \mu^-)}{B(B^0 \rightarrow K^{(*)0} \mu^+ \mu^-) + \left(\frac{\tau_0}{\tau_+}\right) \cdot B(B^+ \rightarrow K^{(*)+} \mu^+ \mu^-)}
\]

- In the SM $A_I$ is small
  - $\lesssim 1\%$ below $J/\psi$ mass and even smaller above $J/\psi$ mass

- Measured at BaBar and Belle

- Previous LHCb measurement on $1 fb^{-1}$ showed $> 4 \sigma$ deviation from zero
\[ B^0 \rightarrow K^* \mu^+ \mu^- \] isospin asymmetry

• With full LHCb data set, \( A_I \) more consistent with SM predictions (1.5\( \sigma \))

• What changed?
  • Assume isospin asymmetry in \( B \rightarrow J/\psi K^* \) is 0
  • New reconstruction and event selection
  • Inclusion of 2012 data (2\( fb^{-1} \))
$B \rightarrow K^{(*)} \mu^+ \mu^-$ branching fraction updates

\begin{align*}
(4.29 \pm 0.07^\dagger \pm 0.21^\star) \times 10^{-7} & \\
(3.27 \pm 0.34^\dagger \pm 0.17^\star) \times 10^{-7} & \\
(9.24 \pm 0.93^\dagger \pm 0.67^\star) \times 10^{-7} & \\
\end{align*}

- $B^+ \rightarrow K^+ \mu^+ \mu^-$, $B^{*+} \rightarrow K^{*+} \mu^+ \mu^-$ and $B^0 \rightarrow K^0 \mu^+ \mu^-$ BR’s updated in isospin analysis.
- Results consistent yet all systematically lower than SM predictions
- LHCb measurements more precise than current world average

\textsuperscript{†} statistical uncertainty \quad \textsuperscript{∗} systematic uncertainty
Conclusions

• Some very recent and interesting results from rare B decays to leptons
  • Measurements of $F_H, A_{FB}$ impose tight constraints on new physics
  • Branching fraction results on $B \rightarrow K\mu^+\mu^-$ like decays more precise than world average and largely consistent with SM
  • Still some interesting anomalies to be investigated

• Several analyses of new b-hadron channels in the pipeline

• Some analyses with interesting results from previous year still to be updated to current full dataset – (stay tuned!)
Backup Slides
$B^0 \to \phi \mu^+ \mu^-$ BR and angular analysis

- Interesting counterpart to $B^0 \to K^* \mu^+ \mu^-$ due to narrow $\phi$ peak.
- Results from $1 fb^{-1}$ consistent with SM across all observables.
- Imposes much tighter constraints on tensor amplitudes.
- Being updated to $3 fb^{-1}$.

LHCb-PAPER-2013-017
$\Lambda^0_b \rightarrow \Lambda \mu^+ \mu^-$ Branching ratio measurement

- Good cross-check for $B \rightarrow K\mu\mu$ channels
- Added interest due to non-zero spin
- No signal observed at low $q^2$ but results consistent with SM
- Being updated to $3f_b^{-1}$ with angular analysis
- Also investigating $\Lambda^0_b \rightarrow \Lambda^* (\rightarrow pK)\mu^+ \mu^-$