Electroweak penguin decays to leptons at LHCb

PHENO 2014  PITTSBURGH, USA

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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
\( B_s \rightarrow \mu \mu \) 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.

Candidates for \( B_s \rightarrow \mu \mu \) and \( B_d \rightarrow \mu \mu \), LHCb

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

LHCb: arXiv:1307.5024
CMS: arXiv:1307.5025
$B^+ \rightarrow K^+ \mu^+ \mu^-$ resonance

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

arXiv:1307.7595

Spectrum in high mass region of the dimuon system

Profile likelihood ratios for $\mathcal{B}(B^+ \rightarrow \psi(4160)K^+)$

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

\[
\frac{1}{d\Gamma/dq^2} \frac{d^4\Gamma}{d\cos\theta_e d\cos\theta_K d\phi dq^2} = \frac{9}{32\pi} \left[ \frac{3}{4} (1 - F_L)\sin^2\theta_K + \frac{1}{4} (1 - F_L)\sin^2\theta_K \cos2\theta_e \right.
- \left. F_L\cos^2\theta_K \cos2\theta_e + S_3\sin^2\theta_K \sin^2\theta_e \cos\phi + S_4\sin2\theta_K \sin2\theta_e \cos\phi \right.
+ \left. S_5\sin2\theta_K \sin\theta_e \cos\phi + S_6\sin^2\theta_K \cos\theta_e + S_7\sin2\theta_K \sin\theta_e \sin\phi \right.
+ \left. S_8\sin2\theta_K \sin2\theta_e \sin\phi + S_9\sin^2\theta_K \sin^2\theta_e \sin2\phi \right],
\]
\[ B^0 \rightarrow K^* \mu^+ \mu^- \] angular analysis

- Mostly consistent with SM predictions
- However, deviation seen in \( P_5' \) region
- Comparison with theory:
  
  Descotes-Genon, et al \[ \text{arXiv:1303.5794} \]
  - 3.7\( \sigma \) when looking at local discrepancy.
  - 0.5\% chance of such discrepancy occurring in one of 24 bins.

  Jäger et al \[ \text{arXiv:1212.2263} \]
  - More conservative theoretical uncertainties calculations at low \( q^2 \)
  - Significance reduced

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

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

- 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 $B^0$)

$B^+ \rightarrow K^+\mu^+\mu^-$

1.1 < $q^2$ < 6.0 GeV$^2$/c$^4$

15.0 < $q^2$ < 22.0 GeV$^2$/c$^4$
$B \rightarrow K\mu^+\mu^-$ 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
$B^0 \rightarrow K^* \mu^+ \mu^-$ isospin asymmetry

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

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

- In the SM $A_I$ is small
  - $\mathcal{O}(1\%)$ 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 ($2fb^{-1}$)
$B \to K^{(*)} \mu^+ \mu^-$ branching fraction updates

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

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

\*statistical uncertainty \quad \dagger systematic uncertainty

arXiv:1403.8044

Phenomenology 2014 Pittsburgh, USA LHCb: Electroweak penguins to two leptons Peter Griffith
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
\[ B^0 \rightarrow \phi \mu^+ \mu^- \] BR and angular analysis

- Interesting counterpart to \( B^0 \rightarrow K^* \mu^+ \mu^- \) 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 $\Lambda^0_b \rightarrow \Lambda^{*} (\rightarrow pK)\mu^+\mu^-$

LHCb-PAPER-2013-025