Prospects for $b \to s ll$ and $b \to s \gamma$ analyses at LHCb

**LHCB-THEORY WORKSHOP**
**CERN FRIDAY 63**

N. SERRA ON BEHALF THE LHCB COLLABORATION
• $b \to s l^+l^-$ analyses:
  • AFB of the $B_d \to K^*\mu\mu$ decay
  • $A_T^2$ observable in the $B_d \to K^*\mu\mu$
  • $B_d \to K^*ee$ Analysis
  • Isospin asymmetry in the $B \to K^{(*)}\mu\mu$
  • Other channels: $\Lambda_b \to \Lambda^{(*)}\mu\mu$, $B_s \to \phi\mu\mu$, $B^+ \to \pi^+\mu\mu$

• Radiative decays
  • $B_d \to K^*\gamma$, $B_s \to \phi\gamma$, $\Lambda_b \to \Lambda^{(*)}\gamma$
$B_d \rightarrow K^* \mu \mu$ at LHCb

FCNC sensitive to interference between the operators:

$O_{7\gamma}$  $O_{9,10}$

Several observables for which hadronic uncertainties cancels out (at some order).

The most popular is AFB

Other observables are $A_T^{(i)}$ asymmetries

(see U.Egede et al., JHEP 1010:056,2010
And reference therein)

Based on
W. Altmannshofer et al., JHEP 0901:019,2009
$B_d \rightarrow K^* \mu \mu$ invariant mass (EPS)

![Graph showing the invariant mass distribution for $B_d \rightarrow K^* \mu \mu$ with full $q^2$ range]
EPS 2011 Results

The positive deviation at low $q^2$ seen by other experiments is not confirmed.

Theory prediction from C. Bobeth et al., JHEP 1107:067, 2011 (and reference therein)

Results in the $1\text{GeV}^2 < q^2 < 6\text{GeV}^2$:
- $A_{FB} = -0.10 \pm 0.14 \pm 0.05$
- $F_L = 0.57^{+0.11}_{-0.10} \pm 0.03$
- $d\Gamma/dq^2 = 0.39 \pm 0.06 \pm 0.02$

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Winter Conferences

• For next winter we will have about 3 times as much statistics, which means that our precision on the AFB is expected to be about a factor $\sqrt{3}$ better.

WE ALREADY HAVE ON DISK $1.1\text{fb}^{-1}$

• Measurement of the Zero-Crossing point of AFB

• We will include the angle $\phi$ in the analysis and make a measurement of $A_T^2$ and $A_{\text{Im}}$
Including $\phi$ in the fit

Possible scenario for $A_T^2$.
Update of S. Descotes-Genon et al., JHEP 1106:099 (2011)

- $A_T^2$ is sensitive to NP through $C_7'$
- $A_{IM}$ is sensitive through $C_9$ (deviations are expected to be small)

Applying the transformation $\phi \rightarrow \pi - \phi$

$$
\frac{d^4\Gamma}{d \cos \theta_{\ell} d \cos \theta_K d \phi dq^2} \propto \left[ l_1^5 + l_1^C + (l_2^5 + l_2^C) \cos 2\theta_{\ell} + l_3 \sin^2 \theta_{\ell} \cos 2\phi + \\
l_4 \sin 2\theta_{\ell} \cos \phi + l_5 \sin \theta_{\ell} \cos \phi + l_6 \cos \theta_{\ell} + l_7 \sin \theta_{\ell} \sin \phi + \\
l_8 \sin 2\theta_{\ell} \sin \phi + l_9 \sin^2 \theta_{\ell} \sin 2\phi \right]
$$

[LHCb-PUB-2009-008]

The fit will allow to extract $A_T^2$ and $A_{IM}$.
We are working to include the non-resonant $K\pi$ contribution.

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Analysis with $B_d \rightarrow K^* e^+ e^-$

At low $q^2$ the $O_{7\gamma}$ contribution dominates.

Analysis restricted to the low $q^2$ region $30\text{MeV} < M(\text{ee}) < 1\text{GeV}$.

Electron reconstruction is experimentally more difficult than muons.

For LHCb MC study see [LHCb-PUB-2009-008]

We expect to have a significant evidence of $B_d \rightarrow K^* e^+ e^-$ for winter conferences.
Isospin asymmetry

- The spectator quark can also radiate a photon giving a isospin asymmetry
- Sensitive to the operators $O_{1-6}$, $O_8$ and the sign of $O_7$

The Isospin asymmetry is given by

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

Babar found a large deviation from SM expectations.

List of channels which will be used at LHCb:

- $B_d \rightarrow K^{*}(\rightarrow K^{+}\pi^{-})\mu^{+}\mu^{-}$ (easy)
- $B^{+} \rightarrow K^{*+}(\rightarrow K_{s}\pi^{+})\mu^{+}\mu^{-}$ (less easy)
- $B_d \rightarrow K_{s} \mu^{+}\mu^{-}$ (less easy)
- $B^{+} \rightarrow K^{+}\mu^{+}\mu^{-}$ (easy)

Measurement by LHCb expected for next winter conferences.

We expect to have a very significant evidence of $B_d \rightarrow K_{s} \mu^{+}\mu^{-}$ and $B^{+} \rightarrow K^{*+}(\rightarrow K_{s}\pi^{+})\mu^{+}\mu^{-}$
Analysis of $\Lambda_b \to \Lambda^{(*)}\mu\mu$

- $\Lambda_b$ production fraction is not small!
- Experimentally a bit more difficult than $B_d \to K^*\mu\mu$
- Sensitive to NP in a similar way as $B_d \to K^*\mu\mu$
- Measurement of the baryon polarization

Figure: SM prediction of AFB in $\Lambda_b \to \Lambda\mu^+\mu^-$. From PLB 516 (2001) 327-336

$\frac{f_{\Lambda_b}}{f_u + f_d} = (0.404 \pm 0.017 \pm 0.027 \pm 0.105) \times [1 - (0.031 \pm 0.004 \pm 0.003) \times p_T/\text{GeV}]$

$\Lambda_b$ fraction measured in arXiv:111.2357
Analysis of $\Lambda_b \rightarrow \Lambda^{(*)}\mu\mu$

- First observation ($5.8\sigma$) recently made by CDF with 6.8fb$^{-1}$.
- Observed 24±5 signal events.

For winter conferences we can:

- Measure the Branching ratio with respect to $\Lambda_b \rightarrow \Lambda J/\psi$
- Significant observation of the decay $\Lambda_b \rightarrow \Lambda(1520)\mu\mu$ (expected for next year)
- $\Lambda_b \rightarrow \Lambda(1520)\mu\mu$ experimentally attractive since the $\Lambda(1520)$ is narrow and decays quickly in pK

Longer term:

- Differential branching ratio as a function of $q^2$
- Measurement of the AFB
- Other angular observables
Other channels under study

Other channels under study are:

- \( B_s \to \phi \mu\mu \):
  - Measurement of the branching ratio
  - Longer term: Measurement of angular observables

- \( B^+ \to K^+ \mu\mu \) (expect to see 1000-1200 events ~1fb\(^{-1}\)):
  - Measurement of the differential branching ratio
  - Measurement of the AFB (which is expected to be zero)

- Other branching ratio measurements:
  - \( B \to \rho \mu\mu \) under study
  - \( B \to \pi \mu\mu \) → we expect to have significant observation next year (assuming SM)

- Longer term: Measurement of the branching ratio and angular distribution of \( B \to K^{*}_2 \mu\mu \)
**$B_s \rightarrow \phi \gamma$ decay**

- Radiative $b \rightarrow s$ penguin decay, $B^0 \rightarrow K^* \gamma$ first seen by CLEO in 1993.

- Broader signal peak (compared to charged final states) implies more work on backgrounds and cross-feed

- Simultaneous fit on $B_d \rightarrow K^* \gamma$ and $B_s \rightarrow \phi \gamma$ with mass difference fixed from the PDG

\[
\frac{\mathcal{B}(B^0 \rightarrow K^{*0} \gamma)}{\mathcal{B}(B_s^0 \rightarrow \phi \gamma)} = 1.52 \pm 0.15\text{(stat)} \pm 0.10\text{(syst)} \pm 0.12\left(\frac{f_s}{f_d}\right)
\]

Expectation $1.0 \pm 0.2$

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B\rightarrow K^*\gamma \text{ and } B_s\rightarrow \phi\gamma \text{ prospects}

- The invariant mass resolution is now closer to MC (100 MeV instead of 150 MeV) thanks to ECAL recalibration 😊

- We expect to see about 5000 \text{B} \rightarrow K^*\gamma \text{ and about 700 } B_s \rightarrow \phi\gamma \text{ for winter conferences}

- Based on statistic we should have the competitive } A_{CP} \text{ measurement for } B \rightarrow K^*\gamma \text{ next year

- Measurement of the branching ratio of } \Lambda_b \rightarrow \Lambda^*\gamma

Further steps for radiative decays

- Measurement of CP asymmetry in } B_s \rightarrow \phi\gamma \text{ (extraction of photon polarization)

- Measurement of the polarization of the photon in the channels } \Lambda_b \rightarrow \Lambda^{(*)}\gamma

- Photon polarization in the decay } B^+ \rightarrow K^+\phi\gamma

For details see the LHCb roadmap arxiv:0912.4179v3
Conclusions

• $B_d \rightarrow K^*\mu\mu$ next year:
  • Measurement of the ZCP
  • Measurement of $A_T^2$

• Measurement of the isospin asymmetry for $B \rightarrow K^{(*)} \mu\mu$

• Measurement of the branching ratio of $\Lambda_b \rightarrow \Lambda^{(*)}\gamma$

• Measurements of $B_d \rightarrow K^*\gamma$ and $B_s \rightarrow \phi\gamma$

• Measurement of $\Lambda_b \rightarrow \Lambda^{(*)} \mu\mu$
BACKUP
\[
\frac{1}{\Gamma} \frac{d^4 \Gamma}{d \cos \theta_\ell \, d \cos \theta_K \, d \phi \, dq^2} = \frac{9}{32\pi} \left[ F_L \cos^2 \theta_K + \frac{3}{4} F_T (1 - \cos^2 \theta_K) + \right.
\frac{1}{4} F_T (1 - \cos^2 \theta_K) \cos 2\theta_\ell - \left( F_L \cos^2 \theta_K \right) \cos 2\theta_\ell + \frac{1}{4} A_T^2 F_T (1 - \cos^2 \theta_\ell) (1 - \cos^2 \theta_K) \cos 2\phi + \frac{4}{3} A_{FB} (1 - \cos^2 \theta_K) \cos \theta_\ell + A_{Im} (1 - \cos^2 \theta_K) (1 - \cos^2 \theta_\ell) \sin 2\phi \left. \right]
\]

\[ F_T = 1 - F_L \]