$B_d \rightarrow K^{*0}\mu^+\mu^-$ selection and analysis in LHCb

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on behalf of LHCb collaboration

Flavour in the era of LHC workshop
From theoretical point of view inclusive process is far preferable.

But at least initially we have to limit ourselves to

\[ B_d \rightarrow K^* \mu^+ \mu^-; \]
\[ B^+ \rightarrow K^+ \mu^+ \mu^-; \]
\[ \Lambda_b \rightarrow \Lambda \mu^+ \mu^-; \]
\[ B_s \rightarrow \phi \mu^+ \mu^-; \]

Will today look at \( B_d \rightarrow K^* \mu^+ \mu^- \) selection and subsequent fits.

Deviations from SM by

SUSY, graviton exchanges, extra dimensions ...
$B_d \rightarrow K^{*0}\mu^+\mu^-$ selection
Update on offline selection for $B_d \rightarrow K^{*0}\mu^+\mu^-$

Looked at 53k fully reconstructed signal events
Resolution in B mass is 14.3 MeV
Have tried to avoid cuts that bias the $\mu\mu$ mass-spectrum
Achieved by cutting looser on the muon kinematics
For example, the impact parameter significance cut
Plots show signal and inclusive b events (after a loose pre-selection)
μμ mass distribution

Selection slightly favours low μμ mass

This is good as the theoretical errors in general are much smaller in the region below the J/Ψ resonance.

J/Ψ and Ψ(2S) mass regions excluded.
Background

6 events from ~24M inclusive b events survive the selection cuts

Loose $B_d$ mass window ($\pm 500$ MeV/c$^2$)
- 2 low-mass events (missing pion, missing photon)
- 1 irreducible event (non-resonant $B_d \rightarrow K\pi\mu\mu$ event)
- 3 combinatoric events (two muons taken from separate B-decays)

Run on higher significance background samples:

$B_d \rightarrow s\mu\mu$ (includes the non-resonant $B_d \rightarrow K\pi\mu\mu$ events)
- 136,500 events with $Br = 4 \times 10^{-6}$ ($\approx 1900 \times$ inclusive b sample)

$B_u \rightarrow s\mu\mu$

$b \rightarrow \mu$, $b \rightarrow \mu$
- 8.85M events with $Br = 0.012$ ($\approx 31 \times$ inclusive b sample)

$B_d$, $B_u$, $B_s$, $\Lambda_b \rightarrow \mu c$ ($\rightarrow \mu$)
### Summary of yields after trigger

<table>
<thead>
<tr>
<th>Sample</th>
<th>Trigger eff (#evt trg / #evt sel)</th>
<th>Yield in 2 fb⁻¹ (tight mass window)</th>
</tr>
</thead>
<tbody>
<tr>
<td>(B_d \rightarrow s \mu \mu)</td>
<td>Non-resonant (K_{\pi\mu\mu})</td>
<td>86%</td>
</tr>
<tr>
<td></td>
<td>All other</td>
<td>68%</td>
</tr>
<tr>
<td>(B_u \rightarrow s \mu \mu)</td>
<td></td>
<td>71%</td>
</tr>
<tr>
<td>(b \rightarrow \mu), (b \rightarrow \mu)</td>
<td></td>
<td>79%</td>
</tr>
<tr>
<td>(B_d \rightarrow \mu) (c(\mu))</td>
<td></td>
<td>60%</td>
</tr>
<tr>
<td>(B_u \rightarrow \mu) (c(\mu))</td>
<td></td>
<td>68%</td>
</tr>
<tr>
<td>(B_s \rightarrow \mu) (c(\mu))</td>
<td></td>
<td>-</td>
</tr>
<tr>
<td>(\Lambda_b \rightarrow \mu) (c(\mu))</td>
<td></td>
<td>75%</td>
</tr>
<tr>
<td>TOTAL</td>
<td></td>
<td>84%</td>
</tr>
<tr>
<td>SIGNAL ((K'_{\mu\mu}))</td>
<td></td>
<td>88%</td>
</tr>
</tbody>
</table>

\(B/S\) is in the range \([0.86 - 1.10]@90\%CL\)

for ±50 Mev B mass window, ±100 MeV K*0 mass window
Non-resonant $K\pi\mu\mu$ events

The non-resonant $K\pi\mu\mu$ dominate the background

Simulation of these events is currently just Jetset fragmentation
Spectra and rate are very uncertain!
$\text{BR}(B_d \to K\pi\mu\mu)$ (non-res) is $1 \times 10^{-6}$ in LHCb simulation
Seems to be an overestimate; eventually we will measure this.

Identical from a selection point of view, but without the $K^*$ mass constraint
Concerning FB asymmetry can be treated as signal, under certain conditions…

Region I: soft pion, energetic kaon
Shifts zero of FBA and has larger uncertainties

Region II: energetic $K\pi$ pair
Can be treated as $B \to X\mu\mu$ and $X \to K\pi$

Region III: soft kaon, energetic pion
Amplitude suppressed so very few events…
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Non-resonant $K\pi\mu\mu$ events

For the smallest theory error, we want just those events in region II

Most of the $K^*\mu\mu$ events are at pion-energies lower than region II

Theory predicts that the $K^*\mu\mu$ FBA will be shifted in region I
Non-resonant $K\pi\mu\mu$ events

Fraction of events in Region II depends strongly on where we place the cut on the pion energy

$E_\pi > 800$ MeV $\rightarrow$ 37%
$E_\pi > 1000$ MeV $\rightarrow$ 25%!

How low can we bring this cut and still feel safe?
$B_d \rightarrow K^{*0} \mu^+ \mu^-$ angular analysis
Kinematic measurables in $B \rightarrow K^{*0}\mu^+\mu^-$

$q^2$ : The invariant mass squared of the dilepton system

$\theta_l$ : The angle of the positive lepton in the dimuon rest frame wrt the B flight direction.

$\theta_K$ : The angle of the Kaon in the $K\pi$ rest frame wrt the B flight direction.

$\varphi$ : The angle between the dilepton and the $K\pi$ decay planes in the B rest frame.
Variables in $B \rightarrow K^{*0}\mu^+\mu^-$

Look at decay in terms of transversity amplitudes $A_\perp, A_\parallel, A_0$ for left and right handed currents.

Good variables with small theoretical error in the Standard Model are:

Transverse asymmetries (insignificant error at $q<3$ GeV):

\[ A_T^{(1)}(s) = \frac{-2\text{Re}(A_\parallel A_\perp^*)}{|A_\perp|^2 + |A_\parallel|^2}, \quad A_T^{(2)}(s) = \frac{|A_\perp|^2 - |A_\parallel|^2}{|A_\perp|^2 + |A_\parallel|^2}. \]

Fraction of $K^*$ polarization (small error):

\[ F_L(s) = \frac{|A_0|^2}{|A_0|^2 + |A_\parallel|^2 + |A_\perp|^2}, \quad F_T(s) = \frac{|A_\perp|^2 + |A_\parallel|^2}{|A_0|^2 + |A_\parallel|^2 + |A_\perp|^2}. \]

$K^*$ polarization parameter (significant error):

\[ \alpha_{K^*}(s) = \frac{2|A_0|^2}{|A_\parallel|^2 + |A_\perp|^2} - 1. \]
Standard Model predictions including uncertainties

$A_T(1)$

$A_T(2)$

$\alpha_{K^*}$

$F_L$

$F_T$

J Matias, EPS 2005
New physics predictions

Small RH contribution in $C'_7$ produce big effect. Sensitive to sign of $C'_7$ as well.
**φ distribution**

All angular distributions simplify if we ignore $m_l^2/q^2$ terms,

The $\phi$ distribution carries information about $A_T^2$ in the amplitude of the oscillation.

$$A_T^2 = \frac{8e}{(1 - F_L)} \frac{d \Gamma}{dq^2}$$

Clearly hard to distinguish from zero in SM but can we see the difference compared to New Physics scenarios?

$$\frac{d^2 \Gamma}{dq^2 d \phi} = \frac{1}{2\pi} (e \cos 2\phi + m \sin 2\phi) + \frac{1}{2\pi} \frac{d \Gamma}{dq^2}$$
\[ \frac{d^2 \Gamma}{dq^2 d \theta_K} = \frac{3}{4} \sin \theta_K (2 F_L \cos^2 \theta_K + (1 - F_L) \sin^2 \theta_K) \frac{d \Gamma}{dq^2} \]

For \( K^* \) angle

Normalisation of \( A_T^2 \) is extracted from \( \Theta_{K^*} \) distribution.

Also determinate the \( K^* \) polarisation.

\[ d^2 \Gamma \frac{d^2}{dq^2 d \theta_l} = \sin \theta_l \left[ \frac{3}{4} F_L \sin^2 \theta_l + \frac{3}{8} F_T (1 + \cos^2 \theta_l) + A_{FB} \cos \theta_l \right] \frac{d \Gamma}{dq^2} \]

Has information on forward backward asymmetry as well as \( F_L \).
A toy model has been created in RooFit to describe the $\phi, \Theta_{K^*}$ and $\Theta_l$ distributions.

Standard model predictions are used for the input of all parameters.

Analysis is performed in 4 bins of $q^2$ for $0.05 \text{ GeV}^2 < q^2 < 8.95 \text{ GeV}^2$

Background is added according to selection study

Non resonant $K\pi$ contribution left out at the moment.

Will update statistics when we understand Region I/II issue

Background assumed perfectly known in amount and shape of variables.

<table>
<thead>
<tr>
<th>Sample</th>
<th>Events</th>
</tr>
</thead>
<tbody>
<tr>
<td>Signal</td>
<td>7345</td>
</tr>
<tr>
<td>Background</td>
<td>2733</td>
</tr>
</tbody>
</table>
Fit for $K^*$ longitudinal polarisation $F_L$

Fits are well behaved.

Resolution is good and the same in each bin.

All pull distributions are centred at zero with unit width.

Central value of fits

![Central value of fits graph]

Pulls

![Pulls graph]

Fits to other angles are well behaved as well.
Summary of resolutions

For each variable the average resolution in a large set of toy simulations is given.

<table>
<thead>
<tr>
<th>Bin</th>
<th>Range in $q^2$</th>
<th>$A_T^2$</th>
<th>$A_{FB}$</th>
<th>$F_L$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.05 – 0.49</td>
<td>0.180</td>
<td>0.050</td>
<td>0.037</td>
</tr>
<tr>
<td>2</td>
<td>0.49 – 1.96</td>
<td>0.400</td>
<td>0.042</td>
<td>0.033</td>
</tr>
<tr>
<td>3</td>
<td>1.96 – 6.25</td>
<td>0.470</td>
<td>0.025</td>
<td>0.018</td>
</tr>
<tr>
<td>4</td>
<td>6.25 – 9.0</td>
<td>0.31</td>
<td>0.026</td>
<td>0.020</td>
</tr>
</tbody>
</table>

All resolutions are for a 2 fb$^{-1}$ sample

There is a weak correlation between $A_T^2$ and $F_L$ due to $1-F_L$ normalising $A_T^2$. 
Possible measurement with 2 fb$^{-1}$

Results from a single toy Monte Carlo fit.
Measurements we can do

Differential width
- As function of $q^2$ in $K^{*0}$ resonance region
- As function of $(K\pi)$ invariant mass
  Maybe even in a few $q^2$ bins

Forward backward asymmetry
$K^{*0}$ polarisation with higher precision than current SM theory errors
Transversity asymmetry $A_T^2$ with reasonable precision

Look at the $B \rightarrow K^{*2}_- \mu^+ \mu^-$ channel.
  Width a factor 2 larger, $BR(K^{*2}_- \rightarrow K\pi)$ factor 2 smaller, $BR(B \rightarrow K^{*2}_- \mu \mu)$ similar.

More or less problematic regarding non-resonant background?
Spin 2 state so we have new variables in this system.
Unresolved issues

What is the limit we should place on the π energy to get a theoretical error on the zero point below our statistical error.

Is it correct that we can treat resonant and non-resonant contributions together in this region II?

How are the angular correlations affected by the non resonant background?

Can we use the same region II or are we in further trouble?

Can we get any estimate for the non-resonant contribution or should we just wait and measure it?

Can we agree on some standard binning in $q^2$ for the report?

How low in $q^2$ should we go? How close to the J/Ψ resonance?
Conclusion

Updated study of selection points to 7.3k events in 2 fb$^{-1}$ (previously 4.4k)

- B/S ratio kept at same level and much better understood.
- A need to understand how to deal with non-resonant $K\pi$ background

Resolution in measurables

- First estimate for precision in transversity asymmetry and $K^*$ polarisation available with 2 fb$^{-1}$ of data.
  - Polarisation measurement resolution very good.
  - $A_T^2$ asymmetry resolution more marginal but still interesting.

- Progress in updated resolution numbers for $A_{FB}$ and zero point,
- Treatment of background still very simplistic
- No estimates of systematics yet