\[ B \rightarrow K^* \mu^+ \mu^- \]: SM and Beyond


IPPP/TU,Munich

\[ XLIV^{th} \] Rencontres de Moriond, 9th March 2009
Soon Launching Expedition to 14TeV

$B \rightarrow K^* \mu^+ \mu^-$
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$B \rightarrow K^* \mu^+ \mu^-$
Some Structure

- Angular Observables via B Physics Tool Box
- Major Milestones and Recent Developments
- Effects of Different categories of NP models on Observables
- Some Concrete Examples
Angular Observables

\[
\frac{d^4 \Gamma}{dq^2 d\Omega} = \frac{9}{32\pi} I(q^2, \theta_l, \theta_K, \phi)
\]

....where \( I(q^2, \theta_l, \theta_K, \phi) = \)

\[
I^s_1 \sin^2 \theta_K + I^c_1 \cos^2 \theta_K + (I^s_2 \sin^2 \theta_K + I^c_2 \cos^2 \theta_K) \cos 2\theta_l \\
+ I_3 \sin^2 \theta_K \sin^2 \theta_l \cos 2\phi + I_4 \sin 2\theta_K \sin 2\theta_l \cos \phi \\
+ I_5 \sin 2\theta_K \sin \theta_l \cos \phi + (I^s_6 \sin^2 \theta_K + I^c_6 \cos^2 \theta_K) \cos \theta_l \\
+ (I_7 \sin \theta_l + I_8 \sin 2\theta_l) \sin 2\theta_K \sin \phi + I_9 \sin^2 \theta_K \sin^2 \theta_l \sin 2\phi
\]
Relating I’s to New Physics

**ANGULAR OBSERVABLES (I’s)**

FIND PREDICTIONS IN TERMS OF FORM FACTORS, WILSON COEFFS USING QCD FACTORIZATION

- HADRONIC INFORMATION
- LCSR CALCULATION (LONG DISTANCE)

- AIM AT NNLL ACCURACY
- MAY CONTAIN NEW PHYSICS (SHORT DISTANCE)

- WEAK ANNIHILATION + $O(\alpha_s)$ CORRECTIONS
**EFFECTIVE FIELD THEORIES**

- Disentangle physics governed by different mass scales
- Write $\mathcal{L}$ in terms of ‘Effective Operators’ and Effective Coupling Constants known as ‘Wilson Coefficients’

$$\mathcal{L} = \sum_i C_i O_i$$

For $B \rightarrow K^* (\rightarrow K^- \pi^+) \mu^+ \mu^-$, important Operators are:

- Electromagnetic Dipole $O_7$
- Vector/Axial Current $O_{9(10)}$
HADRONIC MATRIX ELEMENTS

- eg. $\langle B | J | K^* \rangle$ described by Form Factors
- QCD Sum Rules on the Light Cone\(^1\)/Lattice QCD

HARD SPECTATOR EFFECTS- QCD factorization/ SCET/ HQET...

\(^1\)Ball/Zwicky 04, Ball 08
Major Milestones and Recent Developments

Emphasize CP Conserving Effects

\[ S_i^{(a)} = \frac{I_i^{(a)} + \bar{I}_i^{(a)}}{d(\Gamma + \bar{\Gamma})/dq^2} \]
Emphasize CP Violating Effects

\[ A_i^{(a)} = \frac{I_i^{(a)} - \bar{I}_i^{(a)}}{d(\Gamma + \bar{\Gamma})/dq^2} \]
What will the Flavour Telescope see?

FOCUS ON ADDITIONAL..

- **Operators** eg. Scalar
- **CP Violation**
- **Flavour** structure

Keeping in Mind Bounds from..

- $B_s \rightarrow \mu^+\mu^-$
- EDM’s, CP Asymmetries....
- $B \rightarrow X_s\gamma, B \rightarrow X_s\mu^+\mu^-$
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What kind of New Operators?

For $B \to K^*(\to K^-\pi^+)\mu^+\mu^-$, important NP O’s are:

Spin-Flipped EM Dipole $O'_7$  
Scalar/Pseudoscalar Current $O_{S(P)}$

\begin{align*}
&O'_7 \quad O_{S(P)}
\end{align*}
### New Physics via Wilson Coefficients

<table>
<thead>
<tr>
<th>Model</th>
<th>Additional Operators</th>
<th>CP/Flavour Violation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constrained MFV</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>MFV MSSM</td>
<td>$O_S, O_P$</td>
<td>No</td>
</tr>
<tr>
<td>Flavour Blind MSSM</td>
<td>$O_S, O_P$</td>
<td>Yes/No</td>
</tr>
<tr>
<td>General MSSM</td>
<td>$O_S, O_P, O_7'$</td>
<td>Yes</td>
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<td>Littlest Higgs + T Parity</td>
<td>No</td>
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Effects for CMFV at most 50%

Correlate zeros of $S_4$, $S_5$, $S_6^s$ with $B(b \to s\gamma)$

In MSSSM with MFV Scalar Operators affect $S_6^c$
Effects for CMFV at most 50% 
Correlate zeros of $S_4$, $S_5$, $S_6^s$ with $B(b \rightarrow s\gamma)$
In MSSSSM with MFV Scalar Operators affect $S_6^c$

Model Independent Correlation
Bound on $C_7$ from $b \rightarrow s\gamma$ weakened if complex FBMSSM has additional CP violating phases.
Large no. of free parameters $\Rightarrow$ Concentrate on complex $C_7''$
Generate $C_7'$ via down squark gluino loops
Sizeable effects in $S_3^{(i)}/A_9^{(i)}$, $A_7/8$, and uniquely in $S_3/A_9$
- Smaller effects DESPITE complex phases
- $C_{7}^{np}$ small, but large complex $C_{9}^{np}$, $C_{10}^{np}$
- Most sensitive: $A_7$ and $A_8$
Summary

- $B \rightarrow \bar{K}^* \mu^+ \mu^-$ will provide a multitude of sensitive observables at the LHC.

Visible effects at the LHC: LHCb, ATLAS, CMS. Full Angular Distribution will be measured, deviations from SM will be seen.
**Summary**

- \( B \to \bar{K}^* \mu^+ \mu^- \) will provide a multitude of sensitive observables at the LHC

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<td>( C_S - C'_S )</td>
<td>( S_6^c ), Zero in SM</td>
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<td>( \text{BR}(B_s \to \mu^+ \mu^-) )</td>
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<td>( C_P - C'_P )</td>
<td>( S_1^c + S_2^c ), ( \text{BR}(B_s \to \mu^+ \mu^-) )</td>
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Aoife Bharucha (IPPP/TU, Munich)