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Durham University

Asymmetries of the decay $B \to \bar{K}^* \mu^+ \mu^-$ in the Standard Model and Beyond

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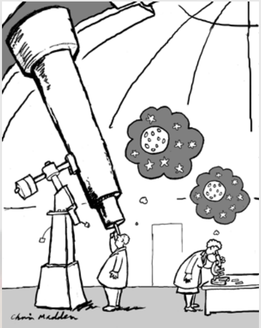
Euroflavour 08

23rd September

Flavour physics experiments..



...act as a telescope to probe beyond the energy frontier of colliders.

eg. Belle, BaBar, LHCb

OBVIOUS QUESTIONS:

- Can we predict the SM well enough to spot the New Physics?
- Can we distinguish between various BSM scenarios?

It Depends..

..on the decay channel and the observables

So why choose $B \to \bar{K}^*(\to K^-\pi^+)\mu^+\mu^-$?

- **FCNC** (..SM suppressed so NP shows up)
- **4 body decay** (..wealth of angular obervables)
- LHCb will have 4032 Signal/1168 Background events with $2fb^{-1}$[1]

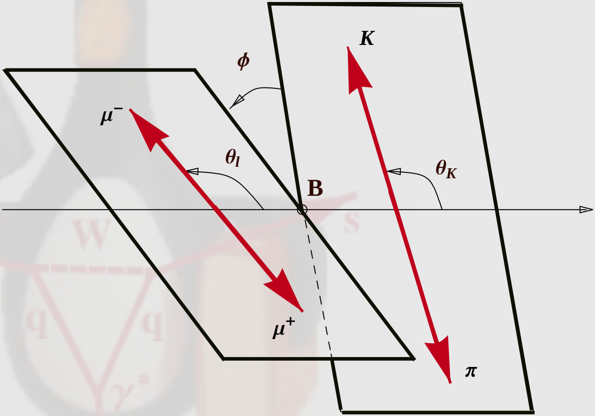
[1] U. Egede, "Angular correlations in the $\bar{B}_d \to K^*\mu^+\mu^-$ decay,", CERN-LHCB-2007-057

Some Structure

- Angular Observables
- Form Factors
- New Physics Models
- Prospects at LHCb

Angular Distribution:
$\mathbf{B} \rightarrow \bar{K}^*(\rightarrow K^-\pi^+)\mu^+\mu^-$

- 4 body decay: Many Observables
- Full angular reconstruction at LHCb
- $2fb^{-1}$ will allow a resolution in q^2 of $0.5GeV^2$ [1]
- With $10fb^{-1}$ the resolution improves to $0.25GeV^2$



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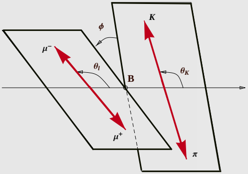
[1] J. Dickens, V. Gibson, C. Lazzeroni and M. Patel, "A study of the sensitivity to the forward-backward asymmetry in $B_d \rightarrow K^*\mu^+\mu^-$ decays at LHCb," ,CERN-LHCB-2007-039

Angular Observables

$$\frac{d^4\Gamma}{dq^2 d\Omega} = \frac{9}{32\pi} I(q^2, \theta_l, \theta_K, \phi)$$ [1]

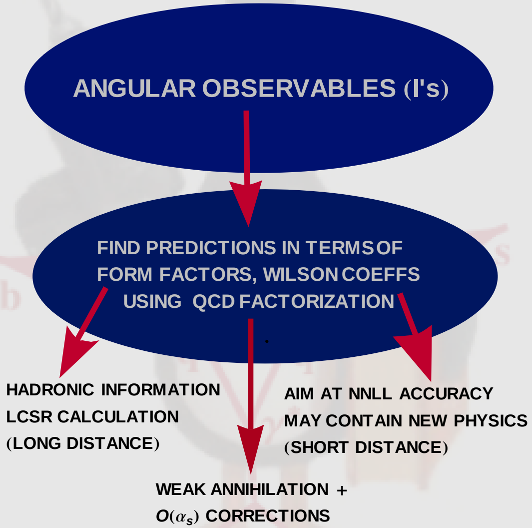


....where $I(q^2, \theta_l, \theta_K, \phi) =$

$$\begin{aligned} &I_1^s \sin^2\theta_K + I_1^c \cos^2\theta_K + (I_2^s \sin^2\theta_K + I_2^c \cos^2\theta_K)\cos 2\theta_l \\ &+ I_3 \sin^2\theta_K \sin^2\theta_l \cos 2\phi + I_4 \sin 2\theta_K \sin 2\theta_l \cos\phi \\ &+ I_5 \sin 2\theta_K \sin\theta_l \cos\phi + (I_6^s \sin^2\theta_K + I_6^c \cos^2\theta_K)\cos\theta_l \\ &+ (I_7 \sin\theta_l + I_8 \sin 2\theta_l)\sin 2\theta_K \sin\phi + I_9 \sin^2\theta_K \sin^2\theta_l \sin 2\phi \end{aligned}$$

[1] F. Kruger and J. Matias, Phys. Rev. D **71**, 094009 (2005)

Relating I’s to New Physics



Form Factors-Our Approach

Matrix elements responsible for this decay can be expressed as:

7 Full form factors (FF's)- Light Cone Sum Rules

$$\langle K^*(p)|\bar{s}\gamma_\mu\gamma_L b|\bar{B}(p_B)\rangle = -ie^*_\mu(m_B+m^*_K)\mathbf{A_1}(q^2) + i(p_B+p)_\mu e^*.q\frac{\mathbf{A_2}(q^2)}{m_B+m^*_K}$$

$$+ iq_\mu(e^*.q)\frac{2m_{K^*}}{q^2}\left(\mathbf{A_3}(q^2)-\mathbf{A_0}(q^2)\right) + \epsilon_{\mu\nu\rho\sigma}e^{*\nu}p^\rho_B\, p^\sigma\,\frac{2\mathbf{V}(q^2)}{m_B+m^*_K}$$

$$\langle K^*(p)|\bar{s}\sigma_{\mu\nu}q^\nu\gamma_L b|\bar{B}(p_B)\rangle = i\epsilon_{\mu\nu\rho\sigma}e^{*\nu}p^\rho_B p^\sigma 2\mathbf{T_1}(q^2) + \mathbf{T_2}(q^2)e^*_\mu(m^2_B-m^2_{K^*})$$

$$-\mathbf{T_2}(q^2)(e^*.q)\,(p_B+p)_\mu + \mathbf{T_3}(q^2)(e^*.q)\left\{q_\mu - \frac{q^2}{m^2_B-m^2_{K^*}}\,(p_B+p)_\mu\right\}$$

Form Factors-Our Approach (cont'd)

QCD factorization results in terms of reduced form factors

As energy of K^*, $E \to m_b$, Full form factors $\to \xi_\perp(E), \xi_\|(E)$

eg.

$$\langle K^*(p)|\bar{s}\gamma_\mu\gamma_L b|\bar{B}(p_B)\rangle = 2iE\,\xi_\perp(E)\,\epsilon^{\mu\nu\rho\sigma}e^*_\nu\,n_{-\rho}v_\sigma$$
$$-\,2E\,\left(\xi_\perp(E)\,(e^{*\mu} - e^*\cdot v\,n_-^\mu) + \xi_\|(E)\,e^*\cdot v\,n_-^\mu\right),$$

This is not an exact limit, therefore our approach involves:

- Include additional QCDf corrections in terms of $\xi_\perp(E), \xi_\|(E)$
- Determine $\xi_\perp(E), \xi_\|(E)$ from LCSR Full form factors

What will the Flavour Telescope see?

FOCUS ON..

- Additional CP violating phases
- New Operators
- Modified Flavour Structure

Keeping in Mind..

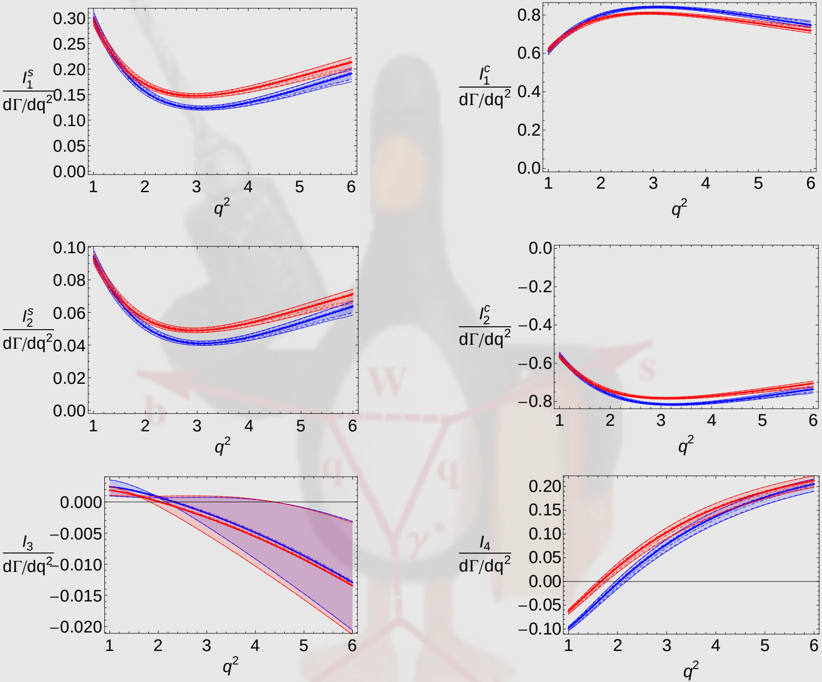
- Strict bounds on NP scale from $b \to s\gamma$
- Possible B_s Mixing Phase at CDF/D0

New Physics via Wilson Coefficients

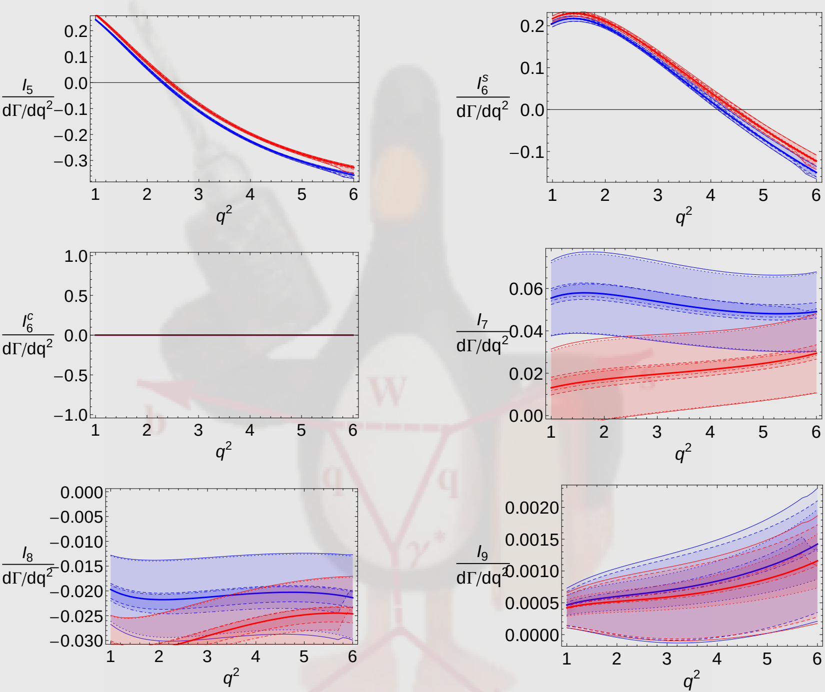
Propose three models in a variety of NP senarios..... [2]

- **General MSSM**
  - Many additional operators: O_S, O_P, O_7'...
  - Additional CP violating phases
- **ABP (Altmannshofer/Buras/Paradisi) Model**
  - Modify MFV MSSM, V_{ckm} only source of flavour violation
  - Introduce 2 flavour conserving but CP violating phases
- **Littlest Higgs Model with T Parity**
  - Higgs protected from quadratic divergences by approximate global symmetries (SU(5))
  - T parity imposed (like R parity), EW bounds less stringent
  - No new Operators but new sources of Flavour Violation
  - 3 new mixing angles and 3 new CP violating phases

[2] Wilson Coefficients calculated by group at TU Munich



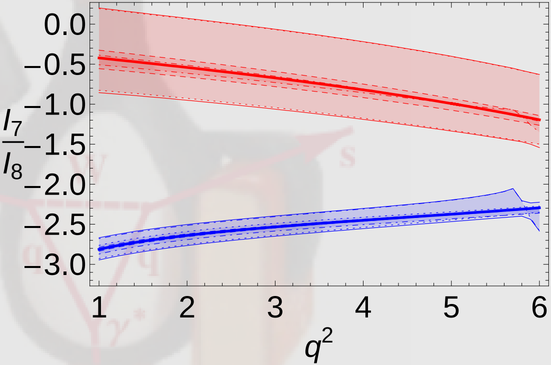
$\frac{I_1^s}{d\Gamma/dq^2}$
$\frac{I_1^c}{d\Gamma/dq^2}$
$\frac{I_2^s}{d\Gamma/dq^2}$
$\frac{I_2^c}{d\Gamma/dq^2}$
$\frac{I_3}{d\Gamma/dq^2}$
$\frac{I_4}{d\Gamma/dq^2}$
q^2



$\frac{I_5}{d\Gamma/dq^2}$
0.2
0.1
0.0
−0.1
−0.2
−0.3
1 2 3 4 5 6
q^2
$\frac{I_6^s}{d\Gamma/dq^2}$
0.2
0.1
0.0
−0.1
1 2 3 4 5 6
q^2
$\frac{I_6^c}{d\Gamma/dq^2}$
1.0
0.5
0.0
−0.5
−1.0
1 2 3 4 5 6
q^2
$\frac{I_7}{d\Gamma/dq^2}$
0.06
0.04
0.02
0.00
1 2 3 4 5 6
q^2
$\frac{I_8}{d\Gamma/dq^2}$
0.000
−0.005
−0.010
−0.015
−0.020
−0.025
−0.030
1 2 3 4 5 6
q^2
$\frac{I_9}{d\Gamma/dq^2}$
0.0020
0.0015
0.0010
0.0005
0.0000
1 2 3 4 5 6
q^2

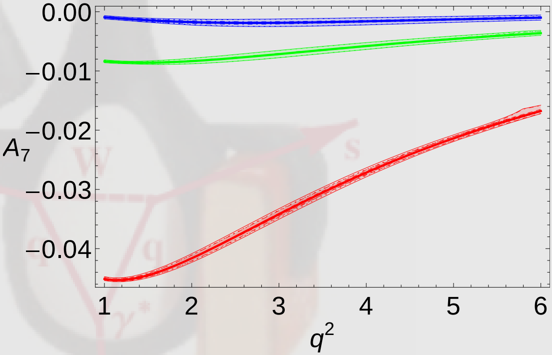
Differentiating the NP from the SM

- The complex phases allowed in the LHT model can create interesting effects
- The ratio I_7/I_8 shows a clear differentiation from the SM



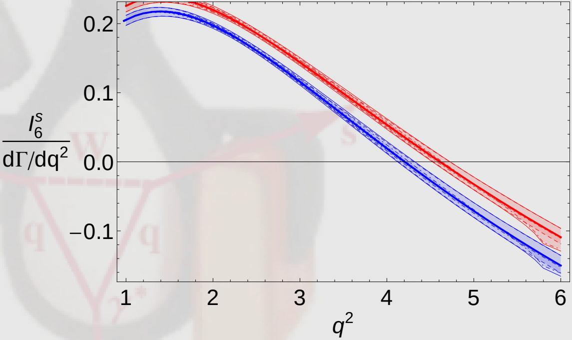
Differentiating the NP from the SM

- Normalized CP Asymmetry $A_7 \sim I_7 - \bar{I}_7$
- Dramatically reduced hadronic dependence



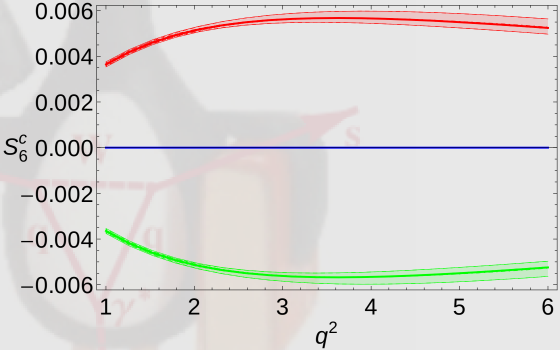
Forward-Backward Asymmetry A_{FB}

- The normalized I_6^scorresponds to the popular A_{FB}
- LHCb will measure the position of the zero of A_{FB}, q_0^2
- The resolution in q^2 at $2fb^{-1}$ will be $0.5GeV^2$
- At $10fb^{-1}$ the resolution will drop to $0.25GeV^2$



Scalar Operators: General MSSM

- I_6^c is zero in the SM
- Any BSM scalar operator will be instantly noticeable
- $S_6^c \sim I_6^c + \bar{I}_6^c$ is plotted in the MSSM for parameters saturating boundary from $B \to \mu^+\mu^-$



Summary

- The LHC will offer exciting new opportunities to test **BSM physics** to unheard of precision
- $\mathrm{B} \to \bar{\mathrm{K}}^* \mu^+ \mu^-$ is a sensitive channel to look for this physics:
  - FCNC
  - 4 body decay
- Our approach involves (state of the art):
  - **LCSR Full Form Factors**
  - **New Physics Wilson Coefficients**
- **Visible effects at the LHC:** LHCb, ATLAS, CMS
  - The full Angular Distribution will be measured
  - Any deviations from the SM will be seen