Rare Semileptonic B Decays

$$B_d \to K^{(*)}\ell^+\ell^-$$
$$B_s \to \eta\ell^+\ell^-$$
$$B_s \to \phi\ell^+\ell^-$$

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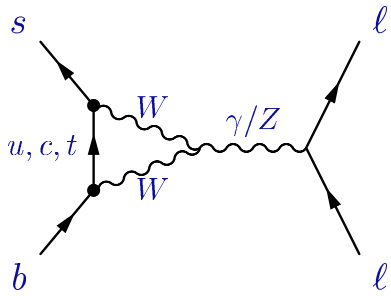
Rare Decays: FCNC Reminder.

- FCNC: Flavour Changing Neutral Currents
- FCNC absent at tree level, since no flavour changing Z in SM.

$\Longrightarrow$ Lowest Order contributions are loops.



If loop quark masses very close, GIM mechanism efficient.

$\Longrightarrow \begin{cases} \text{FCNC charm decays very suppressed.} \\ \text{FCNC beauty decays observable now/soon.} \end{cases}$

- New Physics $\Longrightarrow$ New loop particles appearing at same order in couplings = potential for (large?) observable effects.

Calculation:

- OPE formulation. Short-distance physics (including e.g. SUSY particles) universal and calculable by perturbation theory at EW (or GUT) scale. Renormalization group equations can be used to obtain the result at $\mu = m_b$.

- Formulation in terms of effective 4-fermion operators with effective coupling constants (Wilson coefficients) at the scale m_b.

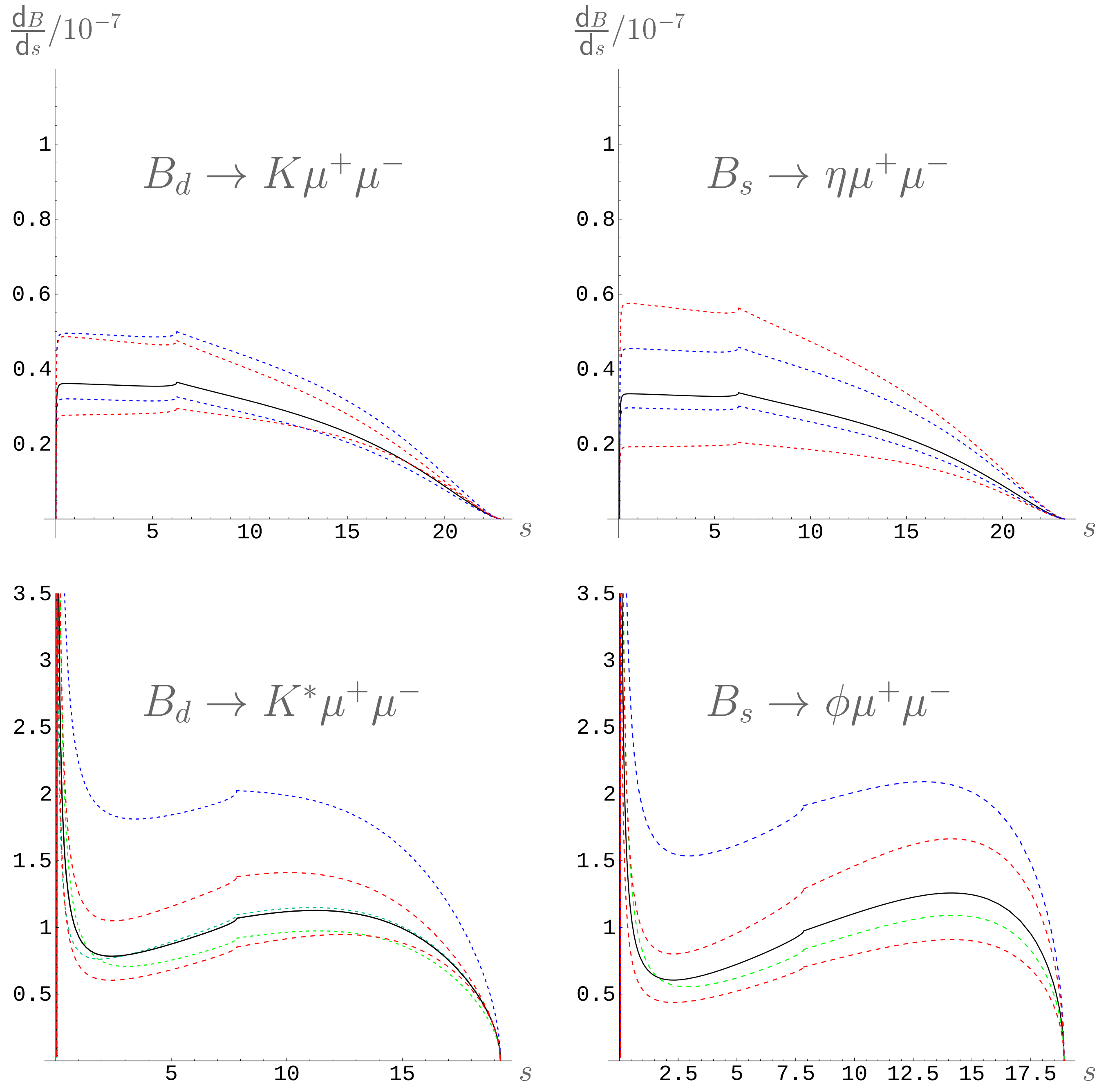
- Semileptonic final state $\Longrightarrow$ matrix elements factorize into two parts.

- $\Longrightarrow$ Hadron current is universal and can be paramemtrized using form factors. Lepton current straightforwardly calculable.

- Complications due to resonant intermediate states difficult to handle, but can be eliminated in the experiment (by mass reconstruction).

RESULTS IN SM AND SUGRA

DILEPTON INVARIANT MASS SPECTRA



- Effects of intermediate on-shell ψ states not shown.
- Form factors – ($B_s \to \phi$: Ball & Braun; $B_d \to K^{(*)}$: Ali et al.)
- $B_s \to \eta$ obtained from $B_d \to K$ by SU(3) relation
  (See slides from previous workshop).

Estimated Branching Fractions in the SM:

(uncertainties: form factors, m_c varied between 1.0 and 1.8, θ_P varied between -10° and -20°)

$$\begin{array}{lcl} \mathrm{BR}(B_d \to K\mu^+\mu^-) & = & \mathbf{5.8^{+1.7}_{-1.0} \times 10^{-7}} \\ \mathrm{BR}(B_s \to \eta\mu^+\mu^-) & = & \mathbf{5.4^{+3.5}_{-2.1} \times 10^{-7}} \\ \hline \mathrm{BR}(B_d \to K^*\mu^+\mu^-) & = & \mathbf{18.4^{+4.8}_{-3.3} \times 10^{-7}} \\ \mathrm{BR}(B_s \to \phi\mu^+\mu^-) & = & \mathbf{16.7^{+5.2}_{-4.1} \times 10^{-7}} \end{array}$$

- Should be observable at Tevatron or LHC
  (see slides by P.Z.S. from previous workshop, hep-ph/0010115, and the ATLAS and CDF II TDRs.)

- Introducing e.g. Supersymmetry results in ≤ 2 times larger branching fractions (in mSUGRA and SUGRA, $\tan\beta = 2$ and $\tan\beta = 30$).

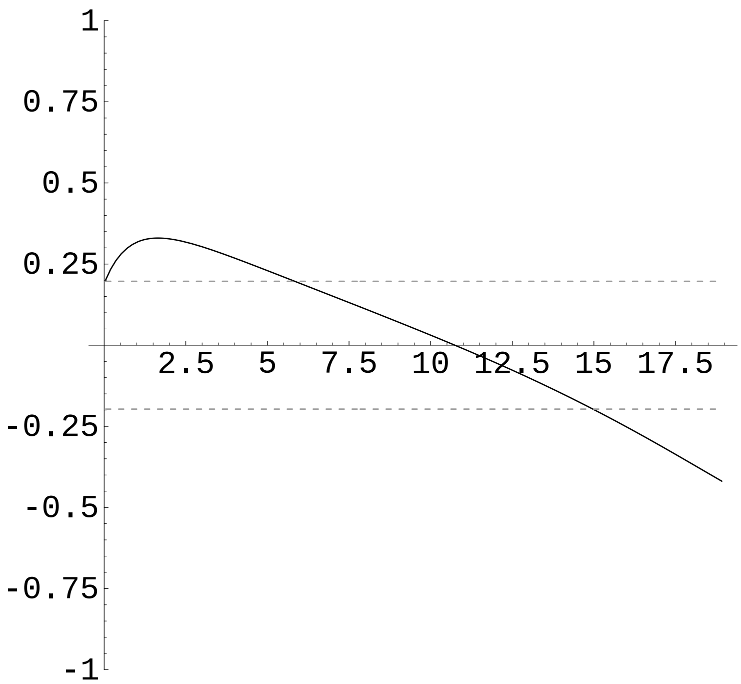
$\Longrightarrow$ Branching fractions not ideally suited due to large theoretical uncertainties (form factors and SU(3) breaking).

SU(3) Breaking

- $B_d \to K^*$ and $B_s \to \phi$ equivalent in SU(3) symmetric case.

- Degree of SU(3) breaking estimated by plugging (central) $B \to K^*$ form factors into $B \to \phi$ calculation (letting all else be equal) and forming

$$A_{SU(3)}(s) = \frac{\frac{dBR}{ds}(s)|_\phi - \frac{dBR}{ds}(s)|_{K*}}{\frac{dBR}{ds}(s)|_\phi}$$



$$\left\langle |A_{SU(3)}| \right\rangle = 19.7\%$$

ATLAS (after 30 fb^{-1}):

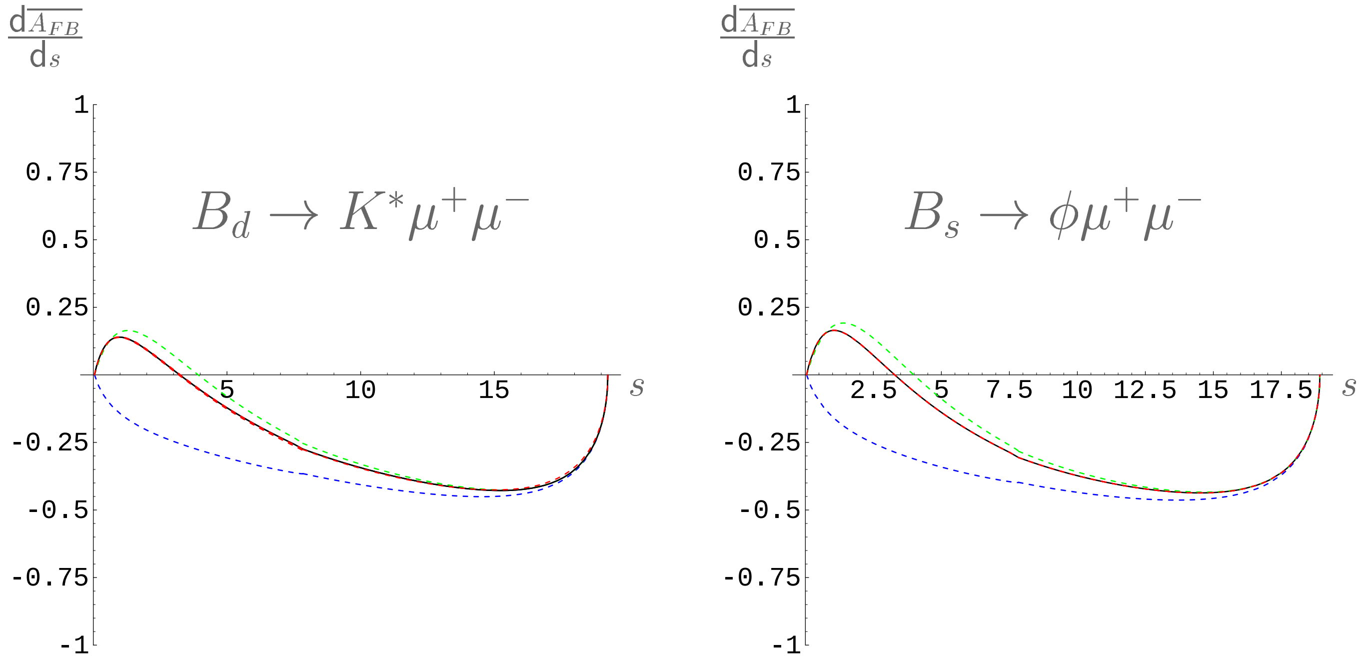
Channel	Branching Ratio	Signal	Background
$B_d \to K^* \mu^+ \mu^-$	$18.4^{+4.8}_{-3.3} \times 10^{-7}$	2500	290
$B_s \to \phi \mu^+ \mu^-$	$16.7^{+5.2}_{-4.1} \times 10^{-7}$	700	140
$B_d \to K \mu^+ \mu^-$	$5.8^{+1.7}_{-1.0} \times 10^{-7}$	$\frac{\epsilon_K}{20\%} \times 400$	?
$B_s \to \eta \mu^+ \mu^-$	$5.4^{+3.5}_{-2.1} \times 10^{-7}$	$\frac{\epsilon_\eta}{5\%} \times 15$	?

ALTERNATIVE: LEPTON FORWARD-BACKWARD ASYMMETRY

- A_{FB}: Does the negative lepton go along or opposite the direction of the B (in the dilepton CM)? $\overline{\mathrm{d}A_{FB}} = \mathrm{d}A_{FB}/\mathrm{d}\Gamma$.

- FBA exists only for vector modes.

- Need spectrum, so statistics will be less, but:



- Theoretical uncertainties cancel (as well as experimental systematics) $\Longrightarrow$ significantly better sensitivity!

- Expected $\delta\overline{A_{FB}}$(stat.) with 3 intervals (excluding resonant region) is approx. 5% for each bin (for $B_d \to K^* \mu^+ \mu^-$[ATLAS TDR]).

- Look at small s behaviour. Models with positive C_7 should be easy to distinguish. Models with negative C_7 (as in SM) significantly harder.

CONCLUSIONS

- Rare decays accessible at LHC. Interesting for new physics search.

- Theoretical estimates for $B_s \to \phi\ell^+\ell^-$ as well as for $B_d \to K^{(*)}\ell^+\ell^-$ and $B_s \to \eta\ell^+\ell^-$ available, but form factor calculation for $B_s \to \eta$ desireable.

- Calculation of Wilson coefficients in New Physics models (e.g. R-Violating SUSY) can easily be plugged in to calculate resulting decay distributions.

- SU(3) breaking between $B_d \to K^*$ and $B_s \to \phi$ is $\approx 20\%$.

- Study of experimental sensitivity to $\overline{A}_{FB}$ in $B_s \to \phi\mu^+\mu^-$ desireable.

- Here come the Americans...