Decay asymmetries in $B \to K^* \ell^+ \ell^-$

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1. Introduction

2. QCD aspects
   - "factorisable" vs. "non-factorisable"

3. Phenomenology
   - forward-backward and isospin asymmetry

4. Conclusions

M. Beneke, TF, D. Seidel [NPB612, 25 (2001)]

TF, J. Matias [JHEP 0301:074 (2003)]

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- Exclusive decay modes: [→ A. Ali's talk and references therein]

  ⋆ easier accessible in experiment
  ⋆ may provide complementary constraints on NP (spectator effects)
  ⋆ test our understanding of QCD in exclusive decays

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- "naive" factorisation:

  ⋆ photon/lepton-pair radiation through H_{eff}
  $\to$ short-distance dynamics included in Wilson coefficients $C_i(m_b)$
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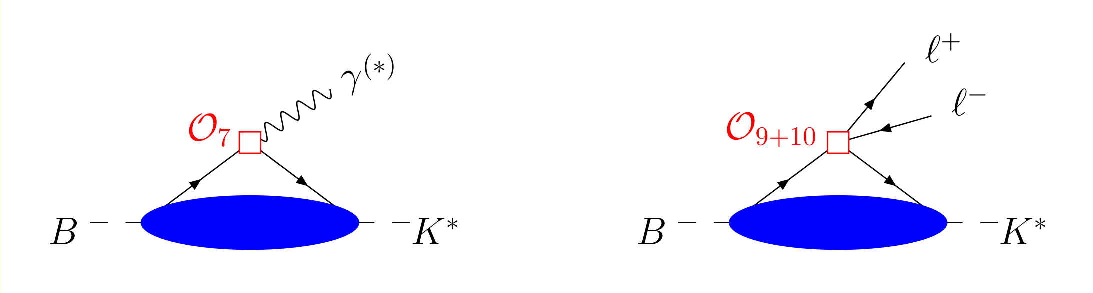
- “non-factorisable” corrections:

  ⋆ photon radiation from internal lines
  $\rightarrow$ contributions cannot be absorbed into $B \to K^*$ form factors

(a) "naively-factorisable" contributions (LO)



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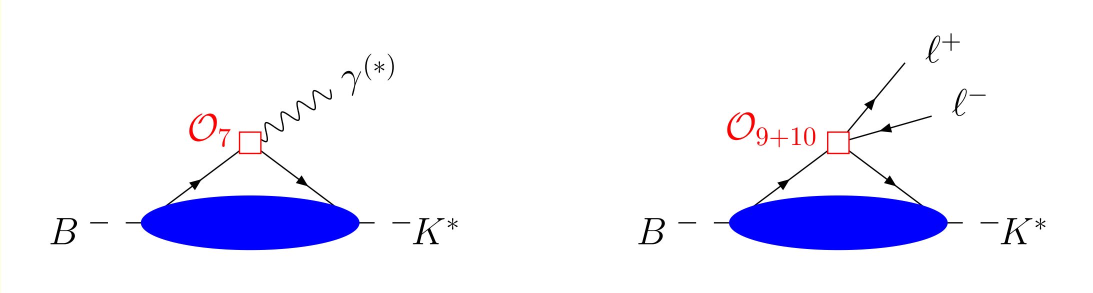

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- soft form factor relations at leading order in α_s and $1/m_b$ [Charles et al. 98]

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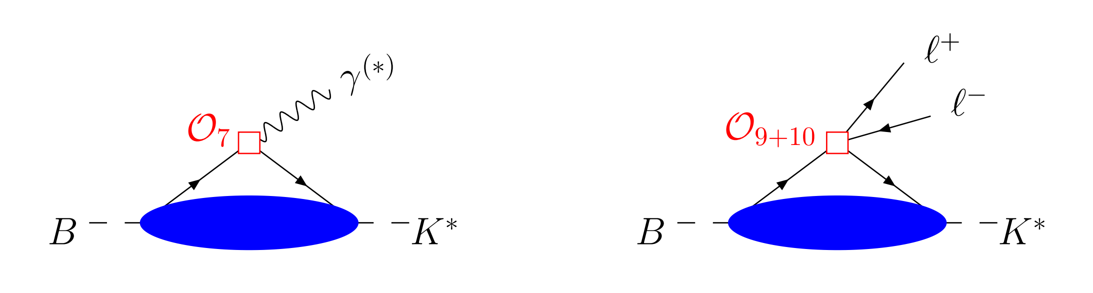

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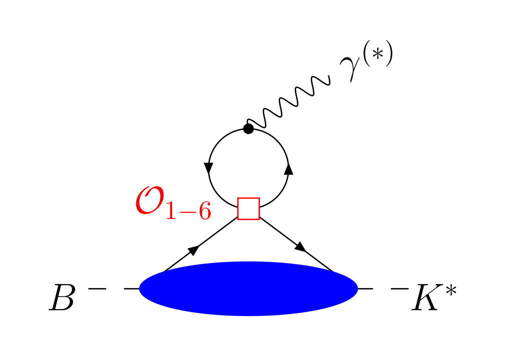
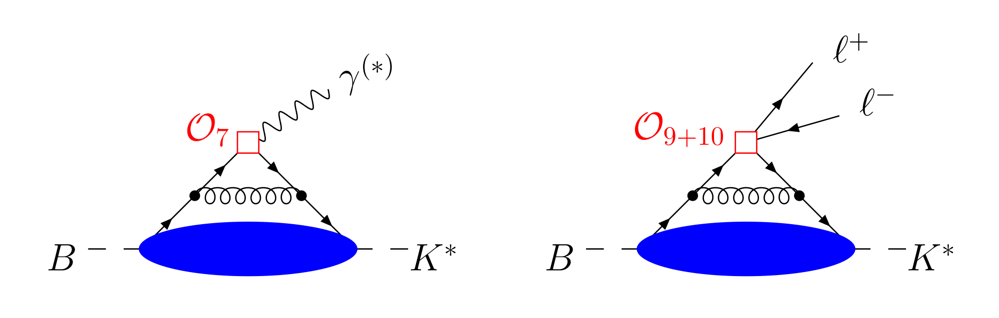
- 

  Contributions from quark loops induced by $\mathcal{O}_{1-6}$
  absorbed into effective quantities $C_7^{\rm eff}$, $C_9^{\rm eff}(q^2)$.
  Perturbative treatment of $C_9^{\rm eff}$ requires $0 < q^2 < 4m_c^2$.

(b) higher-order corrections to $b \to s$ transition

(i) "factorisable" vertex corrections [Beneke/TF 2000]



⇒ scale-dependence of tensor form factors

⇒ multiplicative corrections to soft form factor relations

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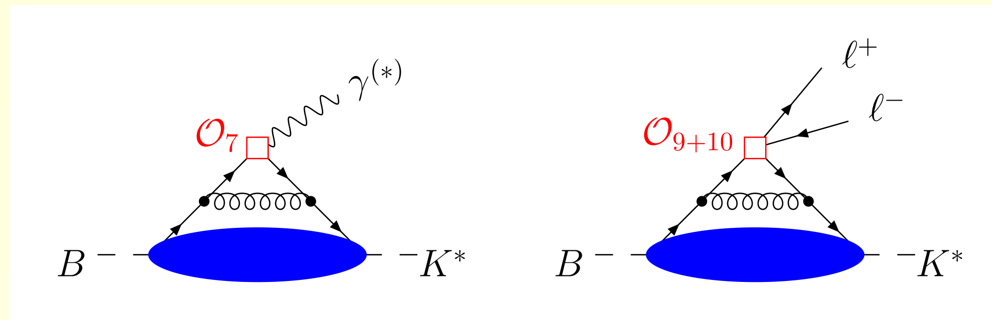

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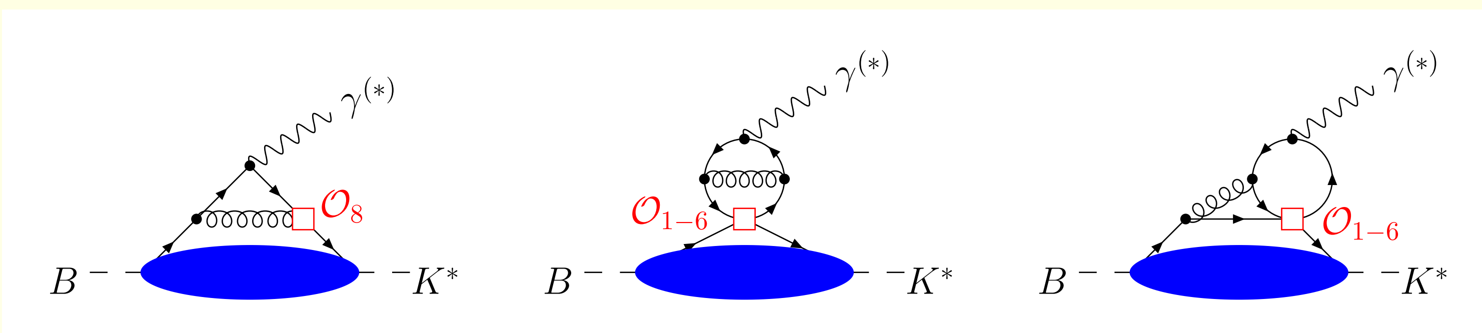


etc.

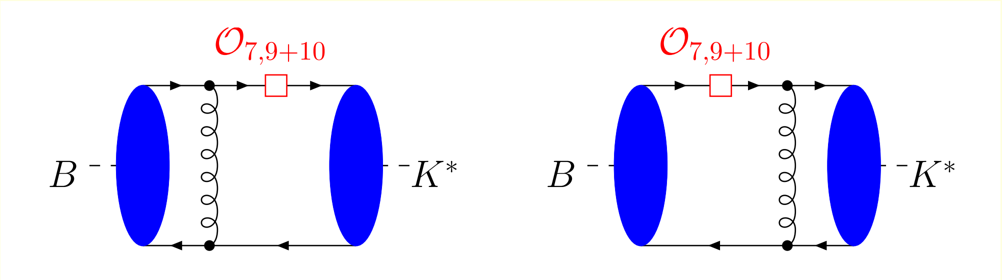
- calculated in context of inclusive $b \to s\ell^+\ell^-$ decays $(q^2 \ll m_b^2)$
- contributions from small penguin coefficients C_{3-6} neglected

[Asatrian, Asatryan, Greub, Walker 01]

(c) spectator interactions

(i) “factorisable” form factor corrections [Beneke/TF 2000]

⇒ additive corrections to soft form factor relations



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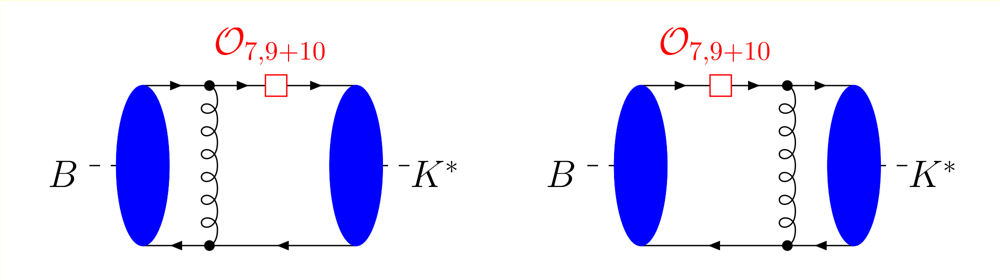

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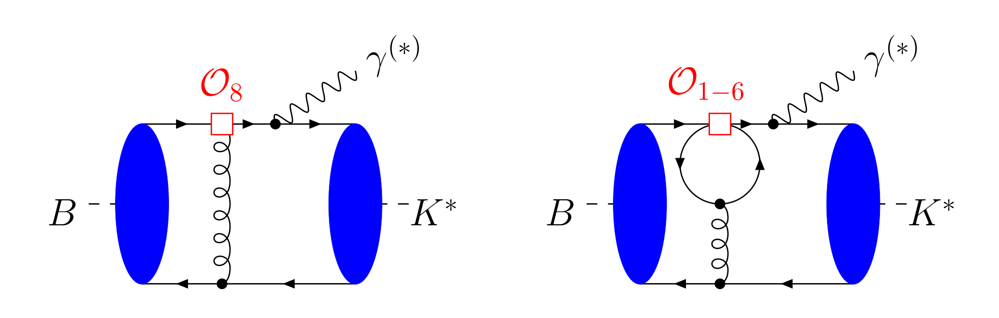

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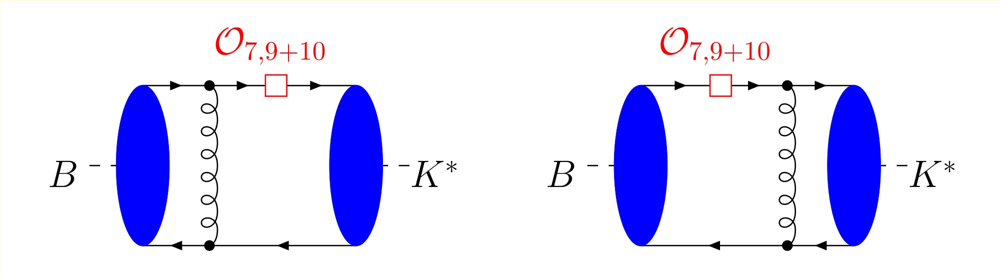

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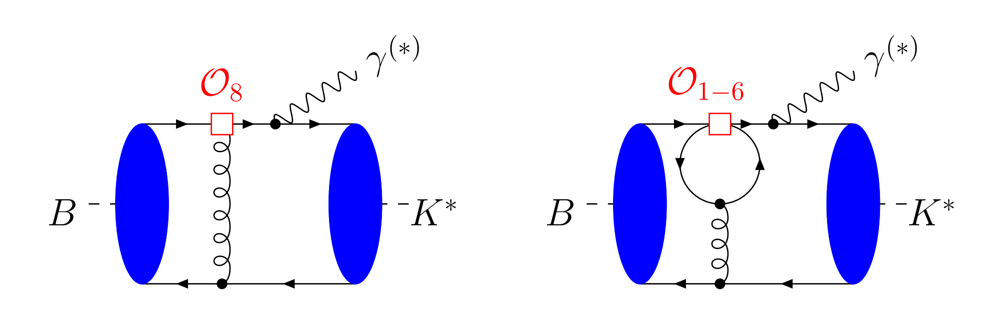
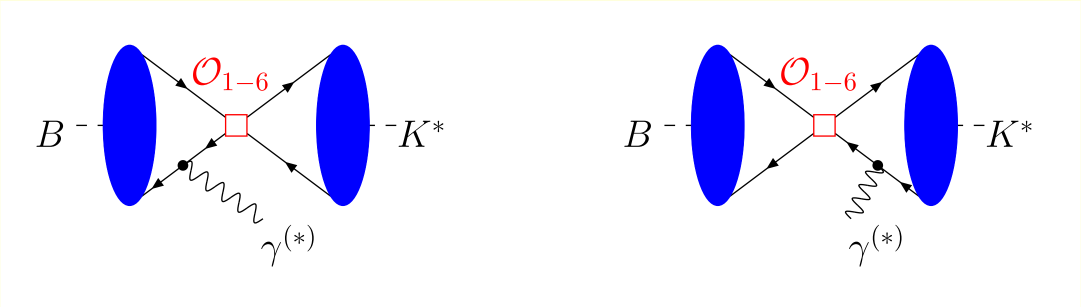


etc.

- leading contributions of $1/m_b$ expansion calculable in terms of light-cone wave functions for B and K^* and perturbative hard-scattering kernels

$(q^2 \ll m_b^2)$

(d) annihilation topologies (LO)



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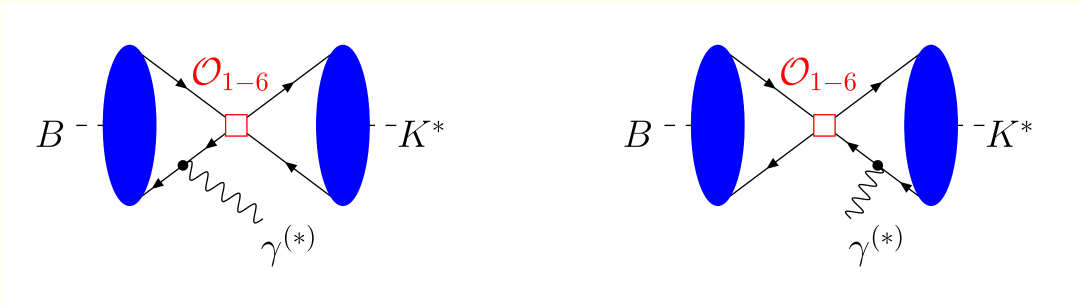

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- At leading power only photon radiation from B meson spectator contributes

  (small but non-zero q^2)

  ⋆ in case of $b \longrightarrow s$ suppressed by small Wilson coefficients or CKM factors

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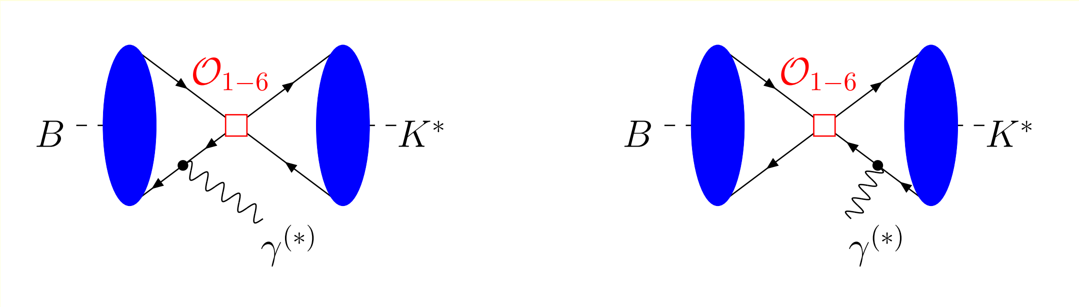

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  [Kagan/Neubert 01, TF/Matias 03]

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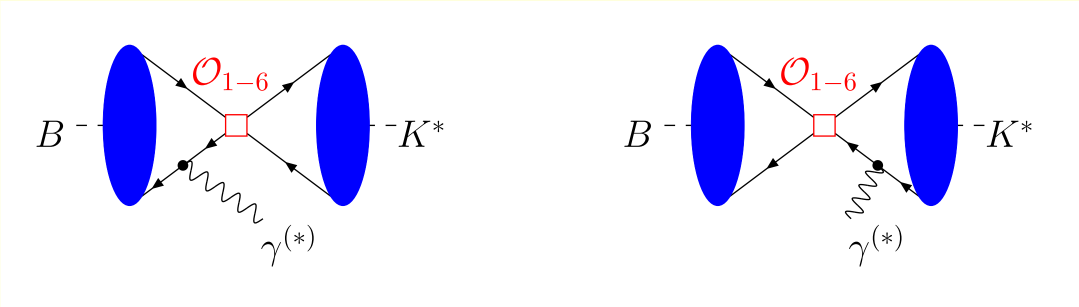

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- Radiative corrections and scale-dependence:
  - ⋆ interesting for theoretical considerations related to factorisation
  - ⋆ (at present level of accuracy) less important for $B \to K^*$ phenomenology

$\longrightarrow$ Description of exclusive $b \to s$ decays beyond LO

- In the heavy quark limit decay amplitudes can be expressed in terms of
  - ⋆ soft form factors $\xi_\perp(q^2)$, $\xi_\parallel(q^2)$
  - ⋆ generalised "exclusive Wilson coefficients"

$$
\begin{aligned}
\mathcal{C}_7 &= C_7^{\rm eff} + \text{"(b) + (c) + (d)"} \\
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\end{aligned}$$

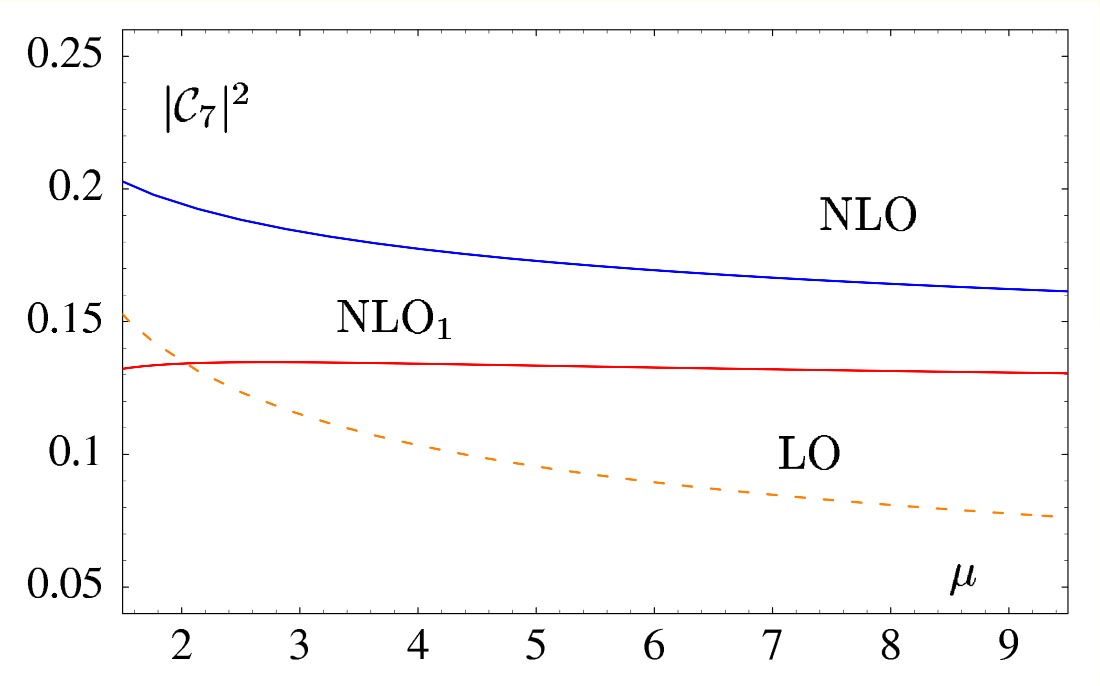
- Inclusion of NLO terms reduces renormalisation scale-dependence

In our case:

$$\mu \frac{d}{d\mu}\left\{m_b \mathcal{C}_7,\ \mathcal{C}_{9,\perp},\ \mathcal{C}_{9,\parallel}\right\} = \mathcal{O}(\alpha_s^2,\ \underline{\alpha_s C_{3-6}})$$

(unknown two-loop matrix elements of penguin operators, radiative corrections to annihilation effects in $\mathcal{C}_{9,\parallel}$)

Example: Scale-dependence of $|\mathcal{C}_7|^2$



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— "NLO$_1$": without spectator effects
— "NLO": with spectator effects

[from Beneke/TF/Seidel 01]

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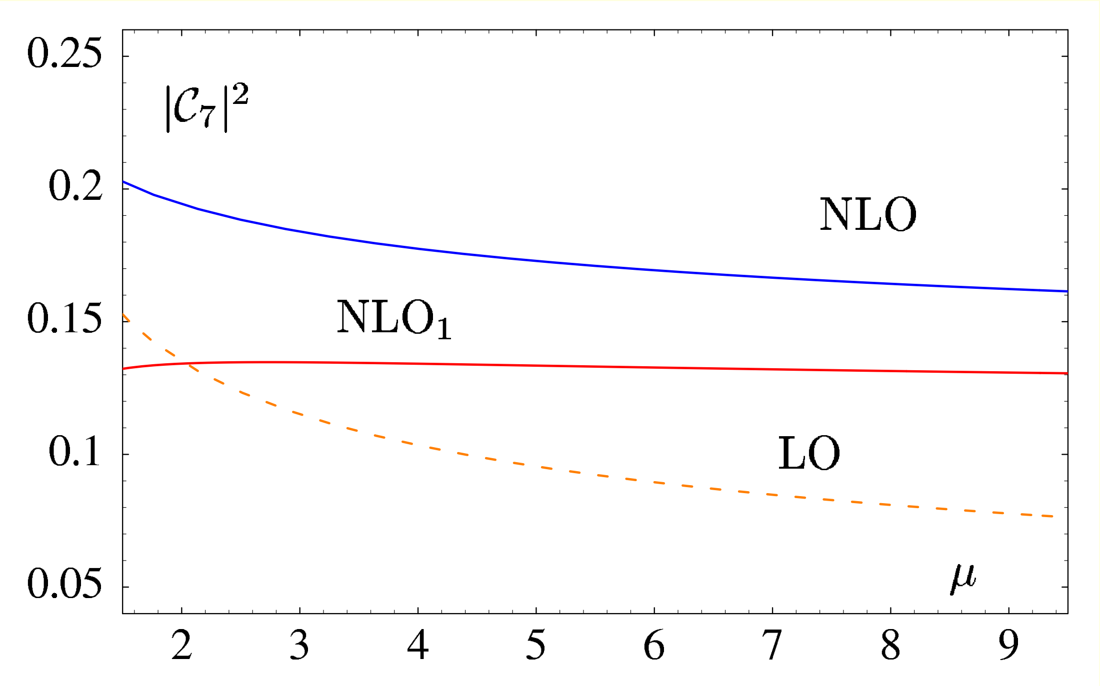

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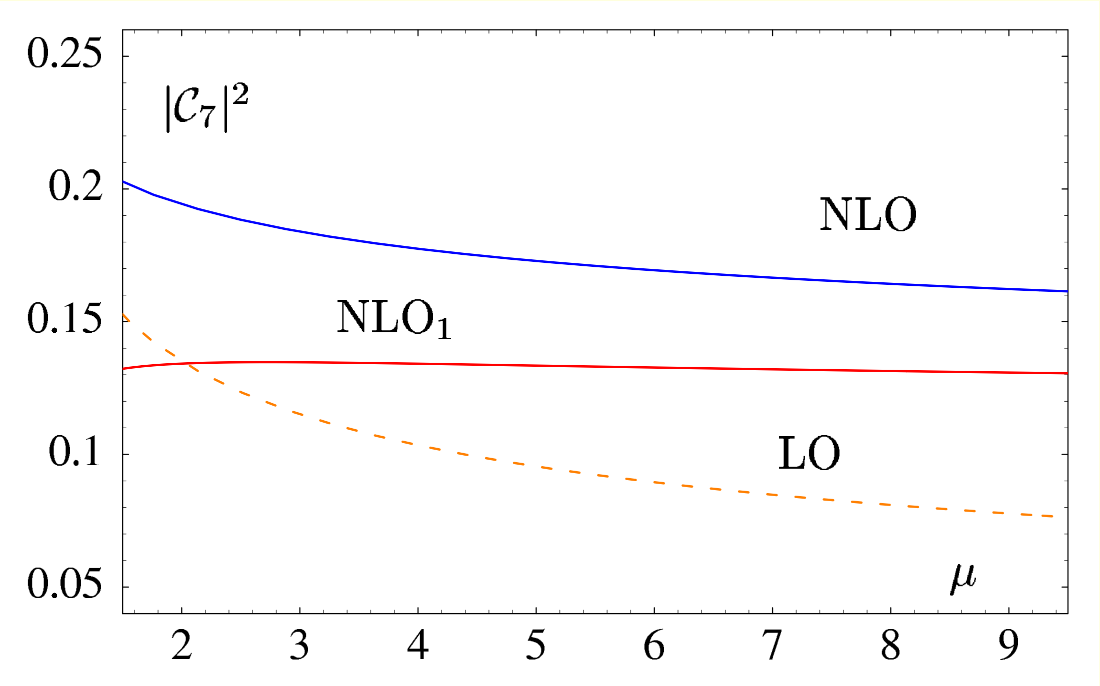

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- NLO gives $\sim 30\%$ enhancement on amplitude level!
- spectator effects only enter at NLO, related scale-dependence still sizeable $(\mu' = \sqrt{0.5 \text{ GeV} \cdot \mu})$

Including $1/m_b$ effects relevant for isospin asymmetry

- Define

$$\mathcal{C}_{9,\perp}(q^2) \;=\; \left[1 + b_q^{\perp}(q^2)\right] \mathcal{C}_{9,\perp}^{(0)}(q^2)$$

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where $\mathcal{C}_9^{(0)}$ only contains terms which are insensitive to the spectator charge $(q = u, d)$

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$\Rightarrow$ $b_q^{\perp}$ and $b_q^{\|}$ determine size of asymmetry between decays of neutral and charged B mesons into transversely or longitudinally polarised K^* mesons

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into transversely or longitudinally polarised K^* mesons

- Calculation of $b_q^{\perp}$ requires inclusion of $1/m_b$ effects

[Kagan/Neubert 01, TF/Matias 03]

3. Phenomenology

- SM and non-perturbative input parameters:

M_W	80.4 GeV	f_B	180 ± 30 MeV
$\hat{m}_t(\hat{m}_t)$	167 ± 5 GeV	$\lambda_{B,+}^{-1}$	(3 ± 1) GeV^{-1}
$\vert V_{ts}\vert$	0.041 ± 0.003	$f_{K^*,\perp}$(1 GeV)	185 ± 10 MeV
$\alpha_{\rm em}$	$1/137$	$f_{K^*,\parallel}$	225 ± 30 MeV
$\Lambda_{\rm QCD}^{(n_f=5)}$	220 ± 40 MeV	$a_1(K^*)_{\perp,\parallel}$	0.2 ± 0.1
$m_{b,\rm PS}$(2 GeV)	4.6 ± 0.1 GeV	$a_2(K^*)_{\perp,\parallel}$	0.05 ± 0.1
m_c	1.4 ± 0.2 GeV	$M_B\,\xi_\parallel(0)/(2m_{K^*})$	0.47 ± 0.09
		$\xi_\perp(0)$	0.35 ± 0.07

from [Beneke/TF/Seidel 01]

- variation of renormalisation scales:

$$m_b/2 < \mu < 2m_b\ , \qquad \mu' = \sqrt{0.5\ \text{GeV} \cdot \mu}$$

◦ remaining systematic uncertainty: neglect of $1/m_b$ effects (model-dependent)

3.1 Forward-backward asymmetry

$$\frac{dA_{\mathrm{FB}}}{dq^2} \equiv \frac{1}{d\Gamma/dq^2}\left\{\int_0^1 d(\cos\theta) - \int_{-1}^0 d(\cos\theta)\right\}\frac{d^2\Gamma[B \longrightarrow K^*\ell^+\ell^-]}{dq^2 d\cos\theta}$$

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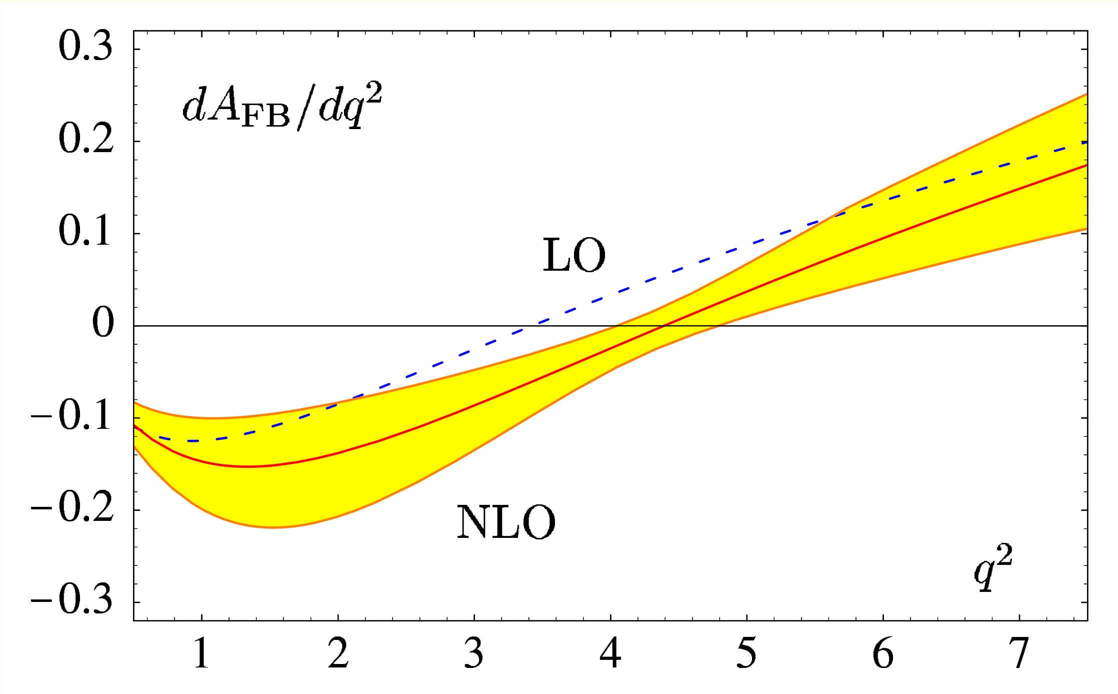
- In the SM ${\rm Re}[\mathcal{C}_{9,\perp}(q^2)]$ changes sign $\longrightarrow$ FB asymmetry zero q_0^2
- Leading-order in $1/m_b$ and α_s: $$C_9 + {\rm Re}(Y(q_0^2)) = -\frac{2M_B m_b}{q_0^2}\,C_7^{\rm eff}\,.$$

  ⋆ free of hadronic uncertainties (consequence of soft form factor relations) [Burdman 98]
  ⋆ perturbative corrections are calculable → precise test of the SM [Beneke/TF/Seidel 01]

Forward-backward asymmetry (SM)



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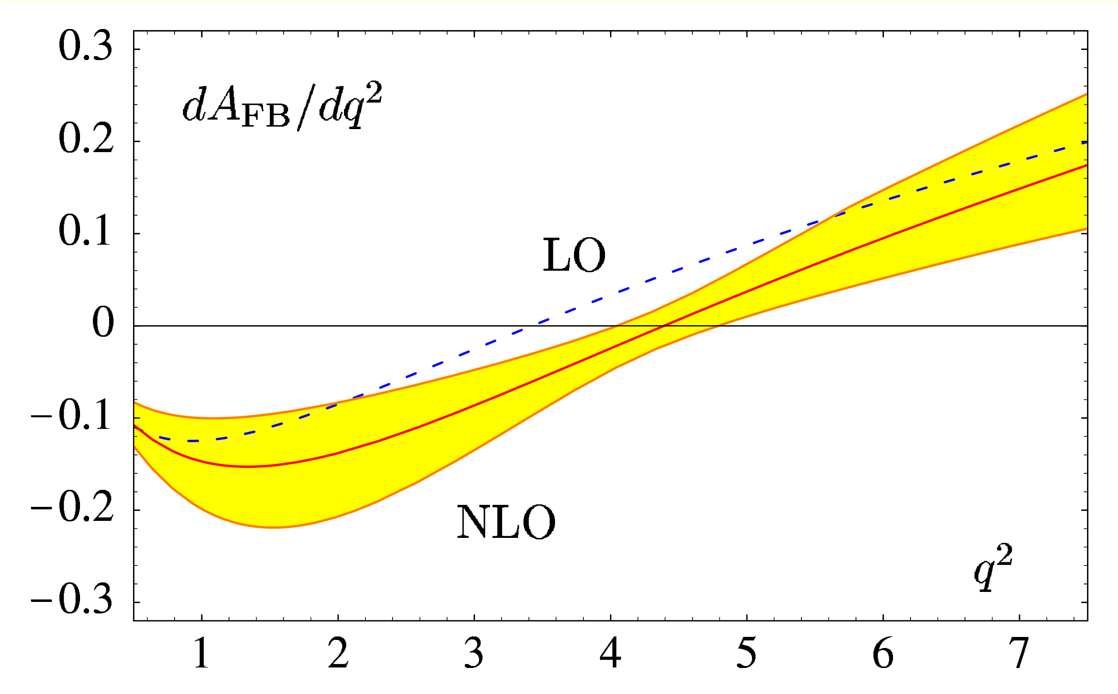

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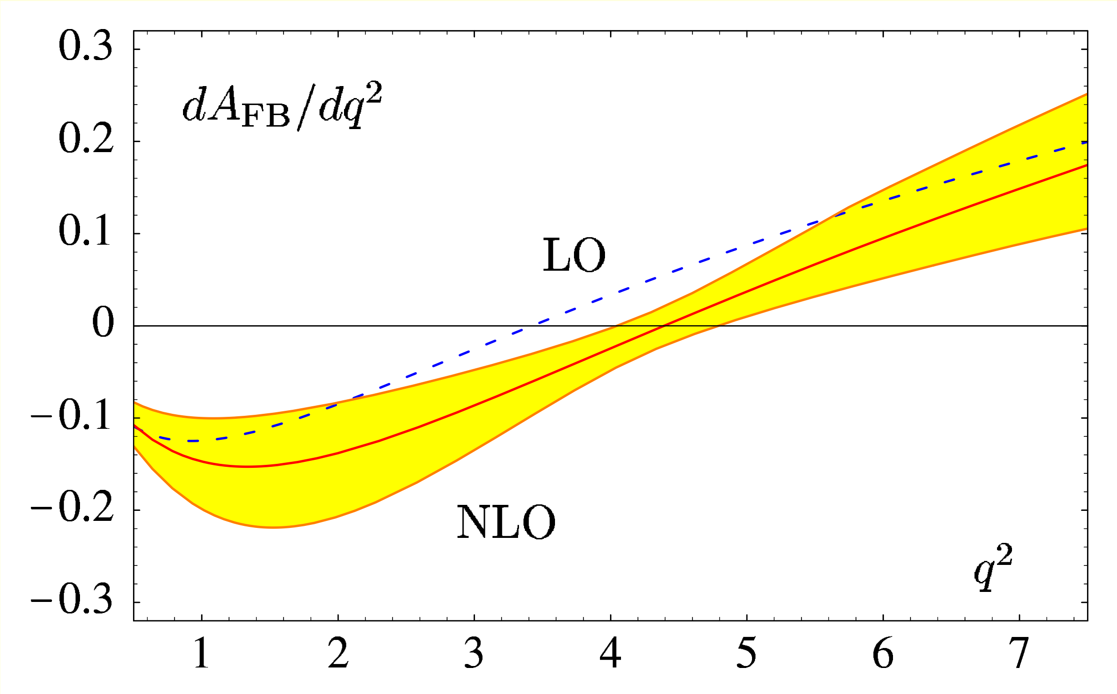

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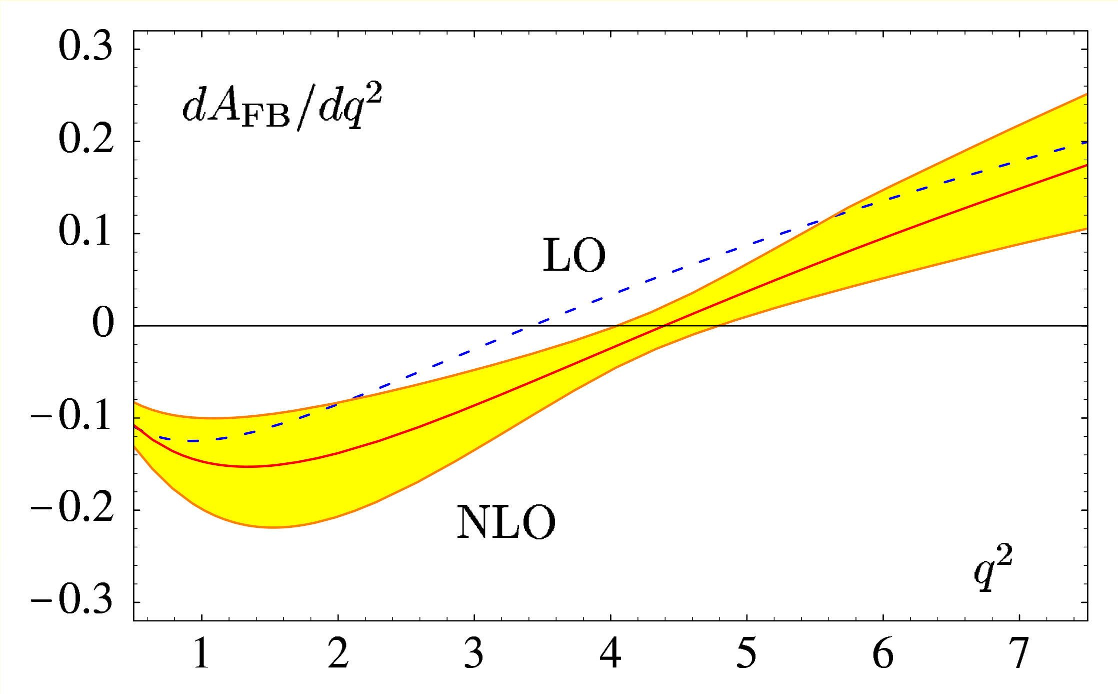

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- NLO corrections shift asymmetry zero toward higher values
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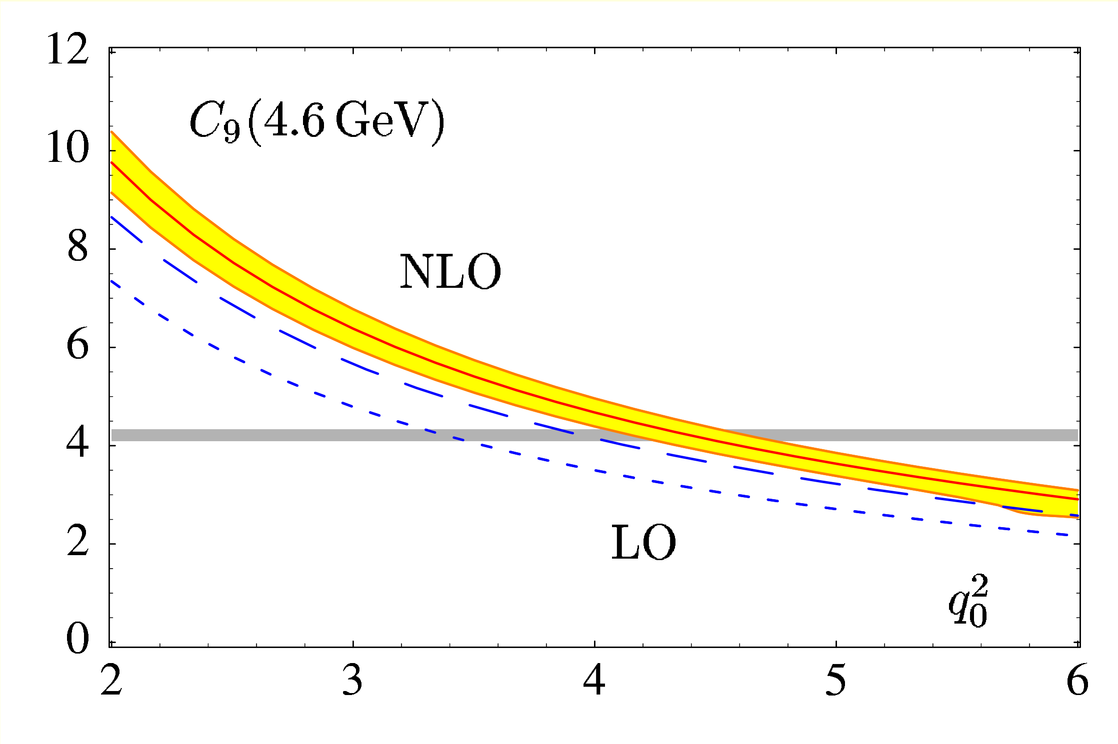
- reduction of hadronic uncertainties around q_0^2 due to form factor relations

C_9 from FB asymmetry



[from Beneke/TF/Seidel 01]

Test of Wilson coefficient $C_9(m_b)$ with $\sim 10\%$ theoretical accuracy!

3.2 Isospin asymmetry

$$\frac{dA_I}{dq^2} \equiv \frac{d\Gamma[B^0 \to K^{*0}\ell^+\ell^-]/dq^2 - d\Gamma[B^\pm \to K^{*\pm}\ell^+\ell^-]/dq^2}{d\Gamma[B^0 \to K^{*0}\ell^+\ell^-]/dq^2 + d\Gamma[B^\pm \to K^{*\pm}\ell^+\ell^-]/dq^2}$$

3.2 Isospin asymmetry

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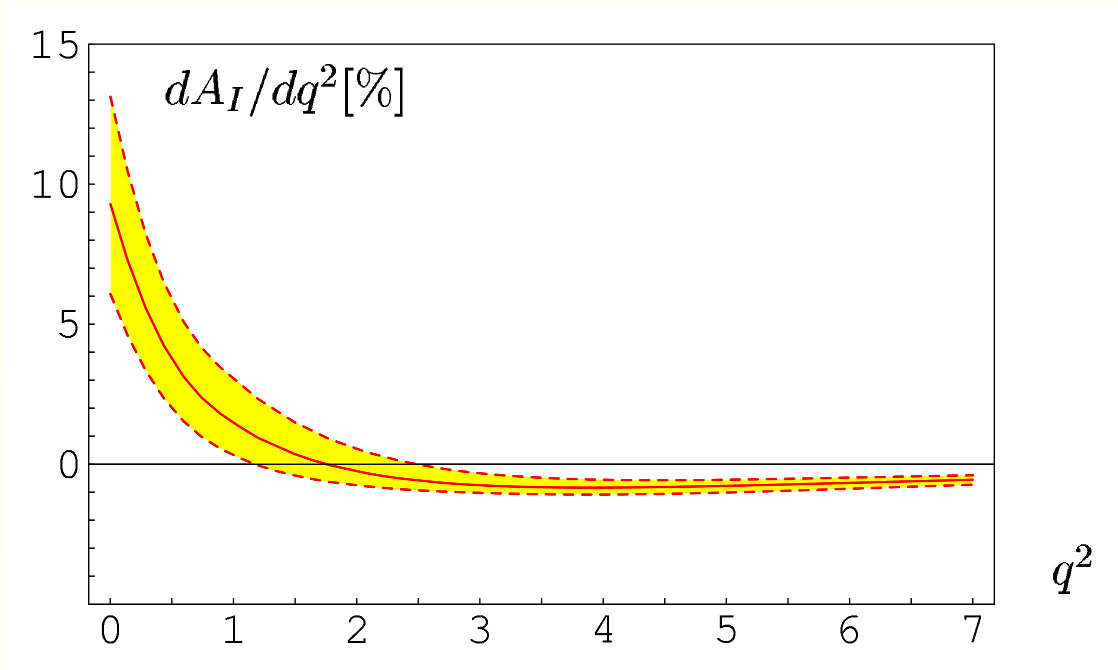
Test of four-quark penguin-coefficients

(basis defined in Buchalla/Buras/Lautenbacher)

Isospin asymmetry (SM)



[from TF/Matias 03]

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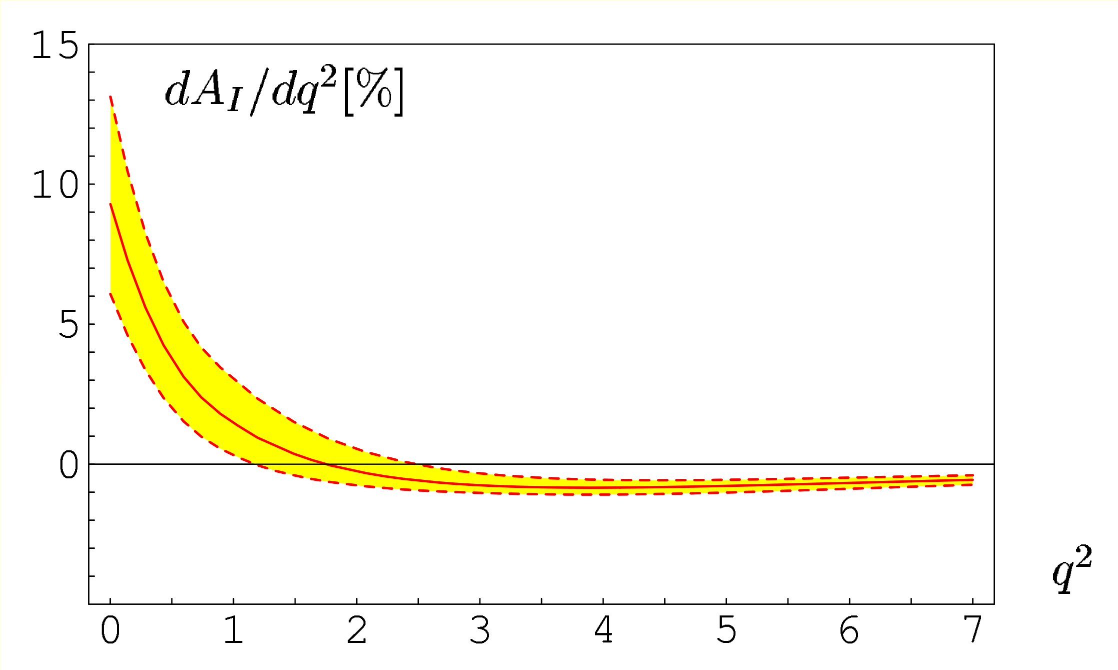

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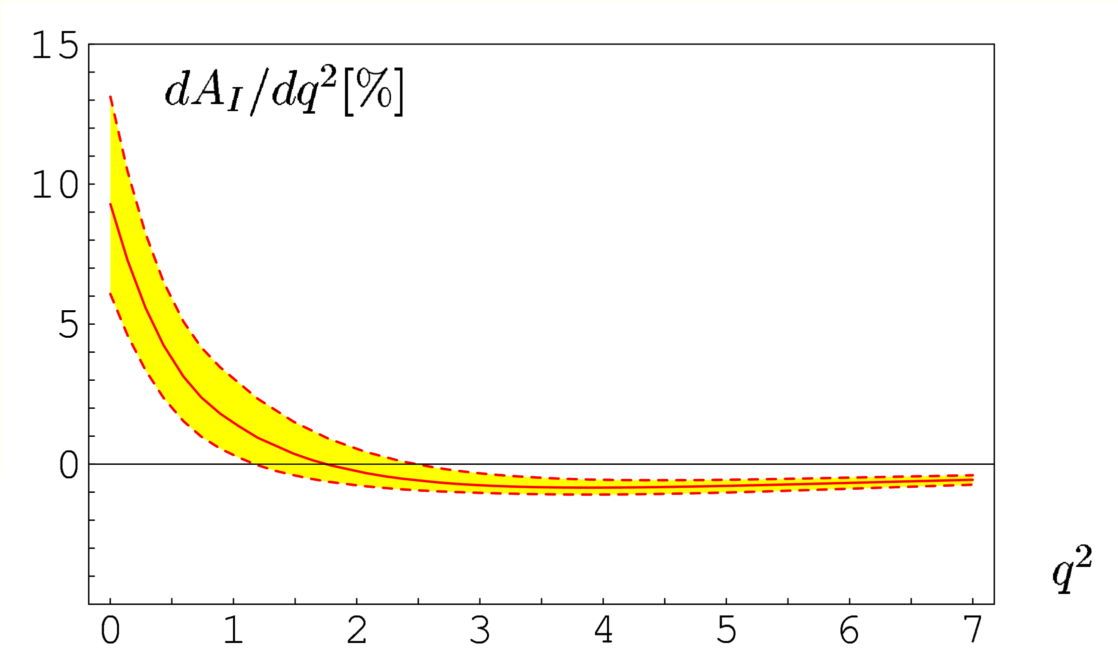

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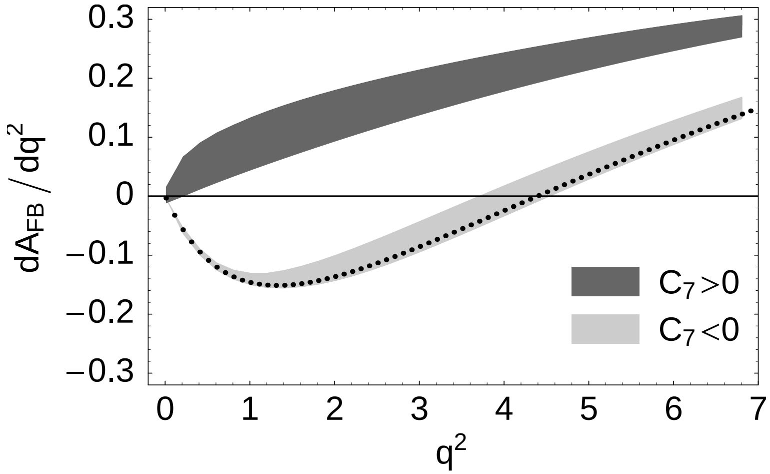
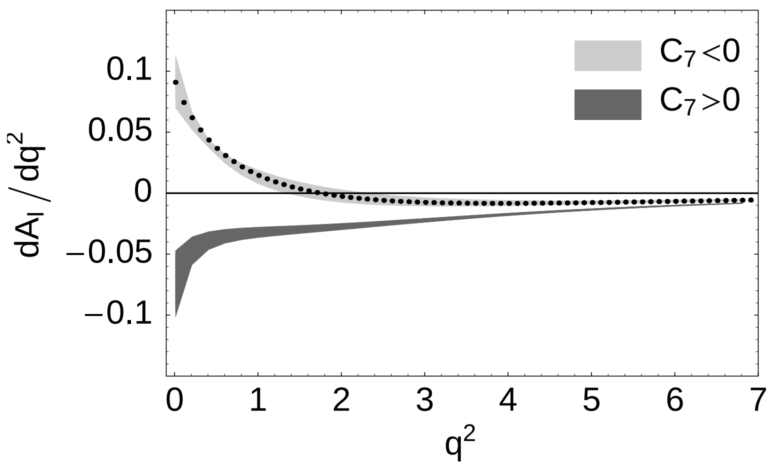
- isospin asymmetry decreases with q^2 and changes sign around $q^2 \simeq 2$ GeV^2

3.3 Asymmetries in constrained MSSM model

illustration of new physics effects (for model set-up see [TF/Matias 03])





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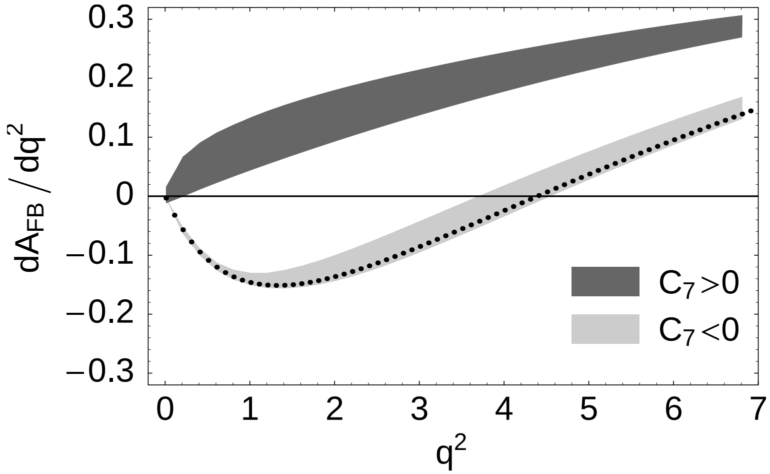

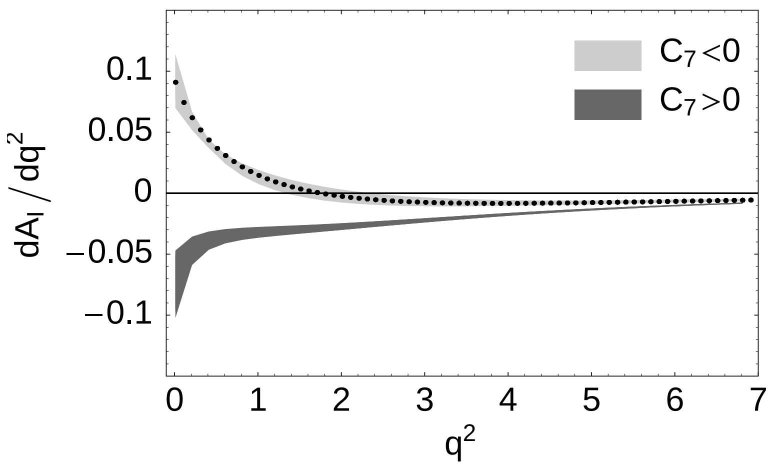

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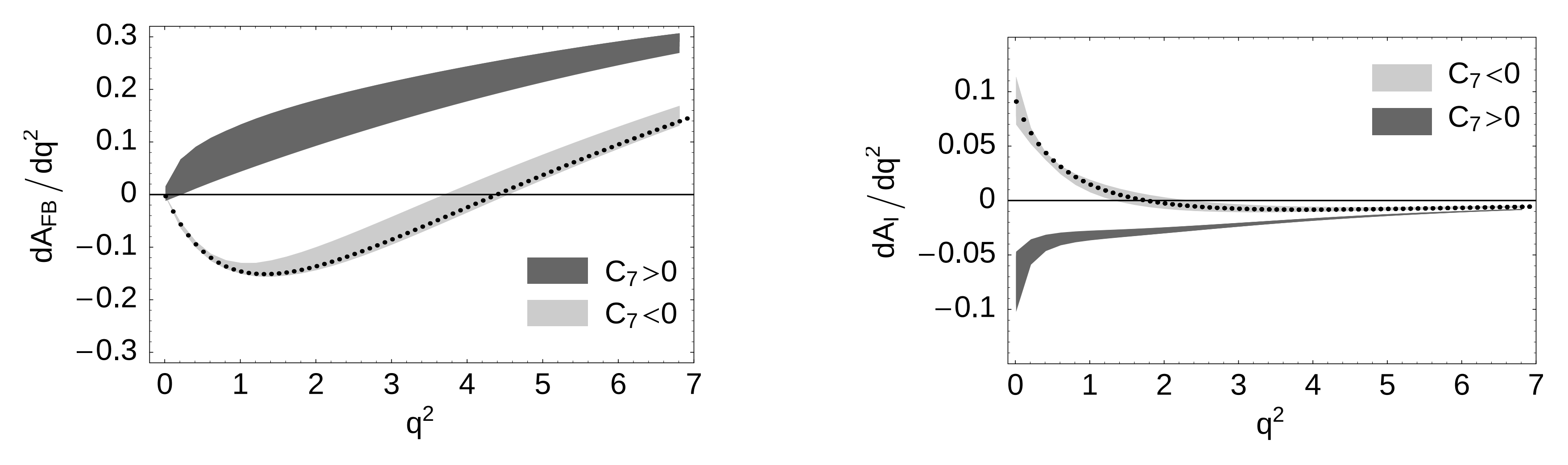

- Constraint from $B \to X_s\gamma$ allows two narrow bands, corresponding to parameter sets with same/flipped-sign solution for C_7
- Parameter spread within one band indistinguishable from theoretical uncertainties
- Sensitivity to penguin operators C_{3-6} may be more important in models beyond MSSM with extended operator basis etc.

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  - ⋆ provide consistency check of the SM,
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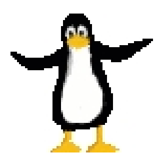
◦ not discussed: CP asymmetry (generically small in SM + QCD factorisation)



"that's all, folks ... "