$10^{36}$ Workshop, SLAC, Oct 22nd-24th 2003

# *Comments on uncertainties and SUSY effects in*
# $B \to K^* \gamma \ , \ B \to \rho \gamma \ , \ B \to K^* l^+ l^-$


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# The Effective Hamiltonian

$$H_{\text{eff}} = -\frac{4G_F}{\sqrt{2}} V_{tb} V_{tq}^{*} \left( \sum_{i=1}^{10} C_i(\mu) O_i(\mu) + \epsilon_q \sum_{i=1}^{2} C_i(\mu) \left[ O_i(\mu) - O_i^u(\mu) \right] \right)$$

$$\epsilon_q = \frac{V_{ub} V_{uq}^{*}}{V_{tb} V_{tq}^{*}} = \begin{cases} -0.01 + i\,0.02 & \text{for q=s} \\ +0.02 - i\,0.42 & \text{for q=d} \end{cases}$$

From the CKM workshop (Durham 03)

## Magnetic moment operators:

$$O_7 = \frac{e}{16\pi^2} m_b (\bar{s}_L \sigma^{\mu\nu} b_R) F_{\mu\nu} \qquad O_8 = \frac{g_s}{16\pi^2} m_b (\bar{s}_L \sigma^{\mu\nu} T^a b_R) G^a_{\mu\nu}$$

## Semi-leptonic operators:

$$O_9 = \bar{s}_L \gamma^\mu b_L \; \bar{e} \gamma_\mu e \qquad O_{10} = \bar{s}_L \gamma^\mu b_L \; \bar{e} \gamma_\mu \gamma_5 e$$

## Four-Quark operators:

$$O_1 = (\bar{s}_L \gamma_\mu T^a c_L)(\bar{c}_L \gamma^\mu T^a b_L)$$

$$O_2 = (\bar{s}_L \gamma_\mu c_L)(\bar{c}_L \gamma^\mu b_L)$$

$$O_1^u = (\bar{s}_L \gamma_\mu T^a u_L)(\bar{u}_L \gamma^\mu T^a b_L)$$

$$O_2^u = (\bar{s}_L \gamma_\mu u_L)(\bar{u}_L \gamma^\mu b_L)$$

$$O_3 = (\bar{s}_L \gamma_\mu b_L) \sum_q (\bar{q}_L \gamma^\mu q_L)$$

$$O_4 = (\bar{s}_L \gamma_\mu T^a b_L) \sum_q (\bar{q}_L \gamma^\mu T^a q_L)$$

$$O_5 = (\bar{s}_L \gamma_{\mu_1} \gamma_{\mu_2} \gamma_{\mu_3} b_L) \sum_q (\bar{q}_L \gamma^{\mu_1} \gamma^{\mu_2} \gamma^{\mu_3} q_L)$$

$$O_6 = (\bar{s}_L \gamma_{\mu_1} \gamma_{\mu_2} \gamma_{\mu_3} T^a b_L) \sum_q (\bar{q}_L \gamma^{\mu_1} \gamma^{\mu_2} \gamma^{\mu_3} T^a q_L)$$

# $B \to K^* \gamma$ decays

[Beneke, Feldmann, Seidel; Ali, Parkhomenko; Bosch, Buchalla]

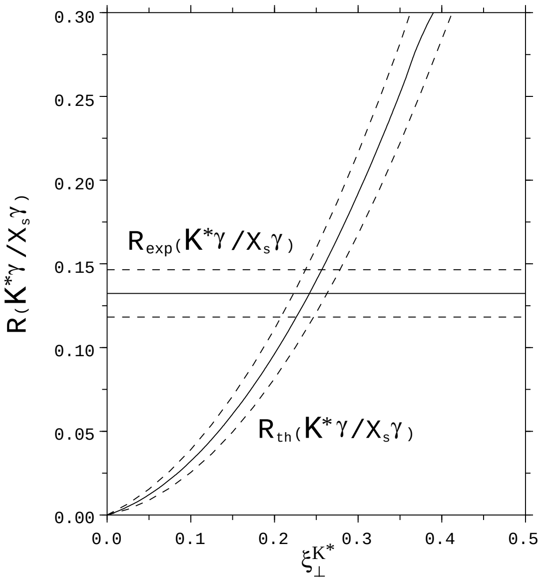
$$BR(B \to K^* \gamma) = \tau_B G_F^2 \alpha \frac{|V_{tb} V_{ts}^*|^2}{32\pi^4} m_{b,pole}^2 m_B^3 \left(1 - \frac{m_{K^*}^2}{m_B^2}\right)^3 \left[\xi_\perp^{K^*}\right]^2 \left|C_7^{(0),eff} + A^{(1)}(\mu)\right|^2$$

$$BR(B^0 \to K^{*0}\gamma)_{SM} = (6.9 \pm 1.1) \times 10^{-5} \left(\xi_\perp^{K^*}/0.35\right)^2$$

$$BR(B^\pm \to K^{*\pm}\gamma)_{SM} = (7.4 \pm 1.2) \times 10^{-5} \left(\xi_\perp^{K^*}/0.35\right)^2$$

$$BR(B^0 \to K^{*0}\gamma)_{exp} = (4.17 \pm 0.23) \times 10^{-5}$$

$$BR(B^\pm \to K^{*\pm}\gamma)_{exp} = (4.18 \pm 0.32) \times 10^{-5}$$




[Ali, Parkhomenko]

$$\xi_\perp^{K^*} = 0.25 \pm 0.04$$

$$\left(F_7^{B \to K^*} = 0.27 \pm 0.04\right)$$

$F_7^{B \to K^*}(0)$

$0.38 \pm 0.05$ (LCSR)

[Ball, Braun; Ali, Ball, Handoko, Hiller]

$0.32^{+0.04}_{-0.02}$ (Lattice)

[Del Bibbio et al.]

$0.25 \pm 0.05$ (Lattice - new)

[Becirevic et al. - preliminary]

# $B \to \rho\,\gamma$ decays

[Ali, Parkhomenko; Bosch, Buchalla]

- Important role of annihilation topologies
  [Braun, Ali; Khodjamirian, Stoll, Wyler; Pirjol, Grinstein; Byer, Melikhov, Stech]

$$\frac{WA}{P}(\rho^{\pm}) \;\to\; \epsilon_A(\rho^{\pm}) \;=\; 0.30 \pm 0.07 \qquad\qquad \frac{WE}{P}(\rho^{0}) \;\to\; \epsilon_A(\rho^{0}) \;\sim\; 0.05$$

W Exchange is smaller than Weak Annihilation because of colour suppression (1/3)
$Q_d / Q_u = 1/2$

- Large Form Factors uncertainties are reduced considering:

$$R(\rho\gamma / K^{*}\gamma) = \frac{\Gamma(B \to \rho\,\gamma)}{\Gamma(B \to K\,\gamma)} = S_{\rho} \left| \frac{V_{td}}{V_{ts}} \right|^{2} \frac{(m_B^2 - m_\rho^2)^3}{(m_B^2 - m_{K^*}^2)^3} [\zeta]^2 [1 + \Delta R(\rho / K^{*})]$$

averaged widths

$S_\rho$: 1 for $\rho^{\pm}$, 1/2 for $\rho^{0}$

$\zeta = F_7^{\rho}(0) / F_7^{K^*}(0) = 0.76 \pm 0.10$
[Braun, Simma, Ali; Khodjamirian et al.; Narison]

- $B \to \omega\,\gamma$ channels differ for SU(3) breaking corrections ( <~ 10% ?)

# Isospin and CP asymmetries

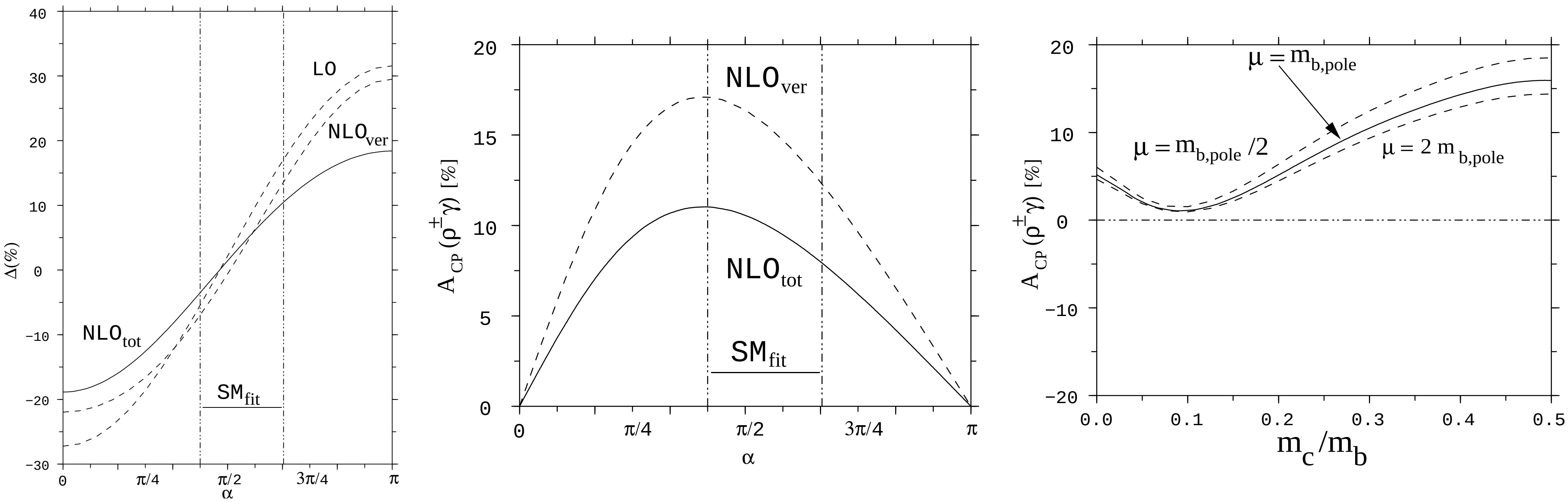
[Ali, Parkhomenko; Bosch, Buchalla, Handoko, London, Ali]

- Isospin breaking ratio:

$$\Delta(\rho\gamma) = \frac{\Gamma(B^{\pm}\to\rho^{\pm}\gamma)}{2\,\Gamma(B^{0}(\bar{B}^{0})\to\rho^{0}\gamma)} - 1 = \frac{|1+\lambda_u\epsilon_A(\rho^{\pm})|^2}{|1+\lambda_u\epsilon_A(\rho^{0})|^2} - 1 + (\text{NLO corrections})$$

- CP asymmetry (it is a NLO effect):

$$A_{CP}^{\pm}(\rho\gamma) = \frac{\Gamma(B^{+}\to\rho^{+}\gamma) - \Gamma(B^{-}\to\rho^{-}\gamma)}{\Gamma(B^{+}\to\rho^{+}\gamma) + \Gamma(B^{-}\to\rho^{-}\gamma)} \sim O(\alpha_s)$$




[Ali, Parkhomenko]

# Analysis in the SM

[Ali, E.L.]

- Experimental upper bound:

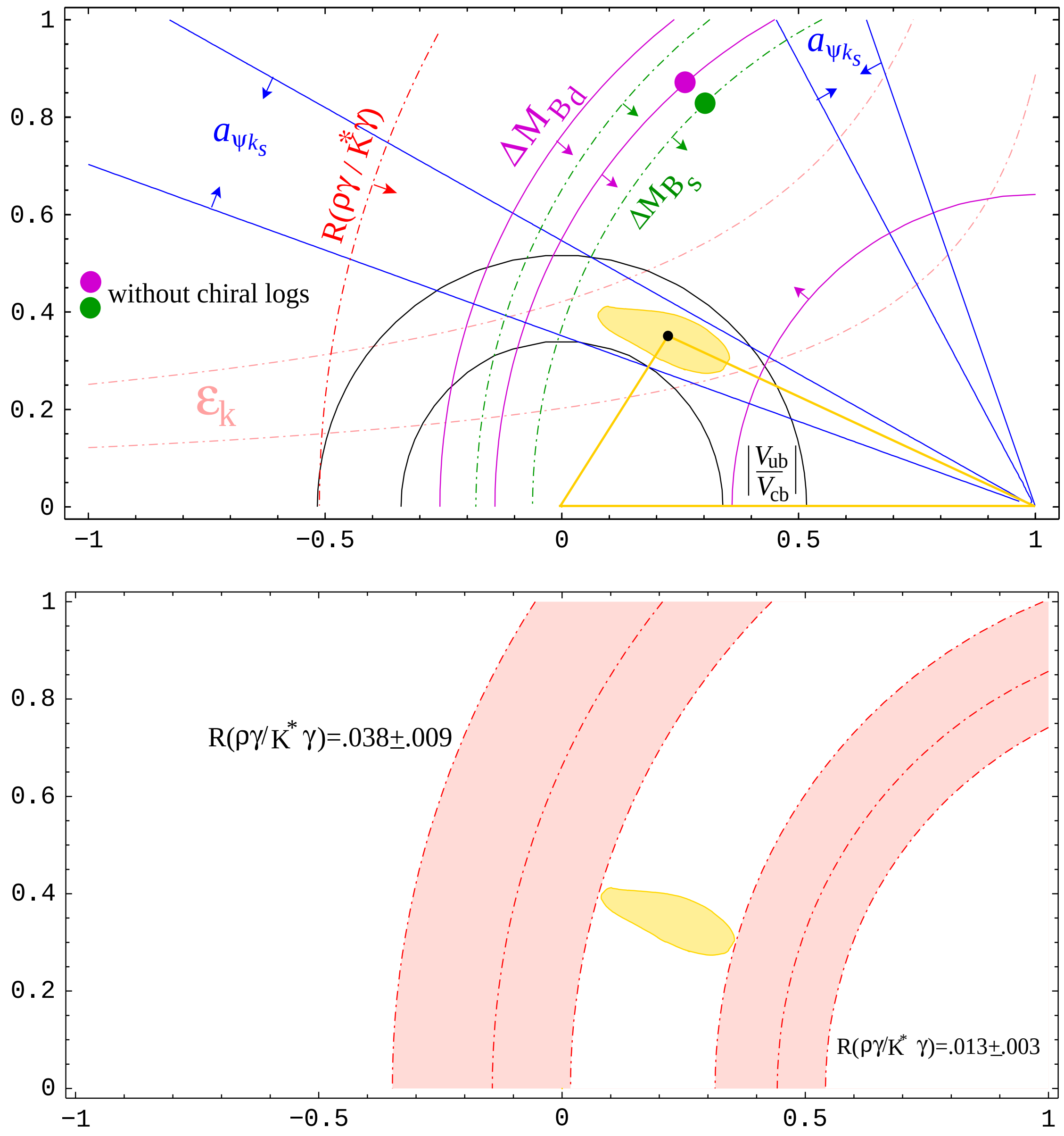
  $R(\rho\gamma) < 0.047$ at 90% C.L.

- SM predictions:

  $$R^{\pm}(\rho\gamma) = 0.023 \pm 0.012$$
  $$R^{0}(\rho\gamma) = 0.011 \pm 0.006$$
  $$\Delta(\rho\gamma) = (3.5^{+1.4}_{-0.7})\%$$
  $$A^{\pm}_{CP}(\rho\gamma) = (10^{+3}_{-2})\%$$
  $$A^{0}_{CP}(\rho\gamma) = (6 \pm 2)\%$$

- Compatibility with the SM:

  $R^{\pm}(\rho\gamma) \in [0.013, 0.038]$



# What can be improved?

- The main source of uncertainty is by far the form factor ratio $\zeta = 0.76 \pm 0.10$.
  A new lattice-QCD based estimate suggests $\zeta = 0.91 \pm 0.08$.
  Need for an independent check.

- Better knowledge of the B meson wave function.
  The annihilation diagrams can be computed in terms of the first negative moment of the B light-cone wave functions. This parameter can be extracted from $B \to \gamma e \nu$.

- Role of three-particle distribution amplitudes

- The $\mu$ dependence of the CP asymmetries is large (NNLO?)

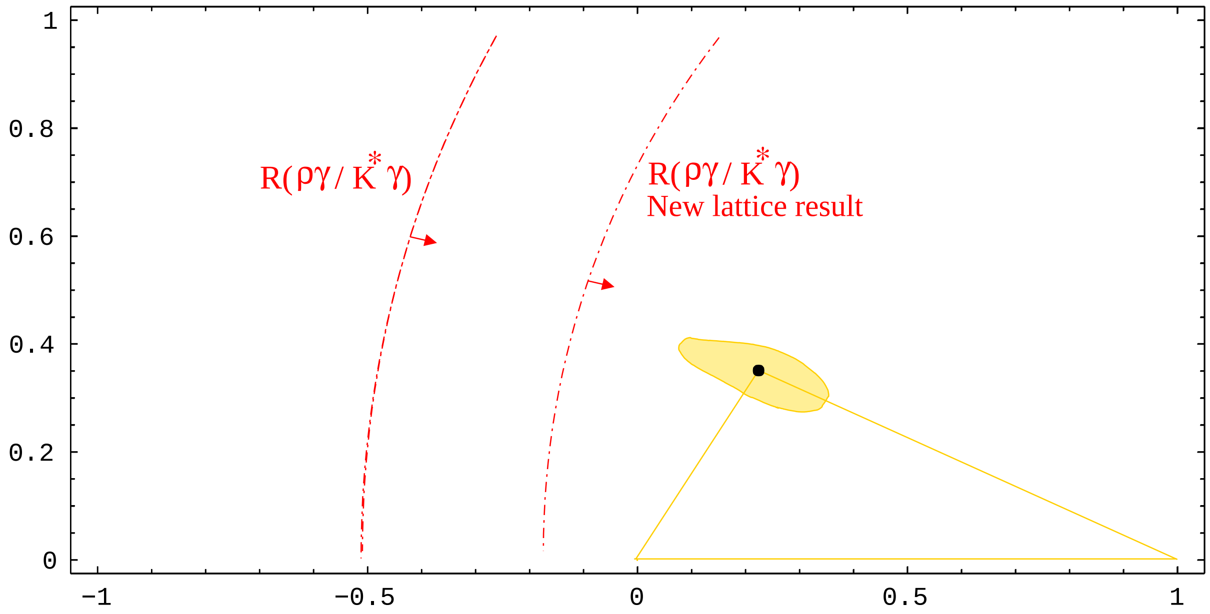
- Analysis of power corrections $\left(O(\Lambda_{QCD}/m_b)\right)$:
  - Some power corrections are computable (e.g. weak annihilation)

- Proof of factorization at all orders in $\alpha_s$ and at leading order in $\Lambda_{QCD}/m_b$

# Impact of the new lattice estimate

[E.L., Hurth]

$$\zeta = 0.76 \pm 0.10 \longrightarrow \zeta = 0.91 \pm 0.08$$

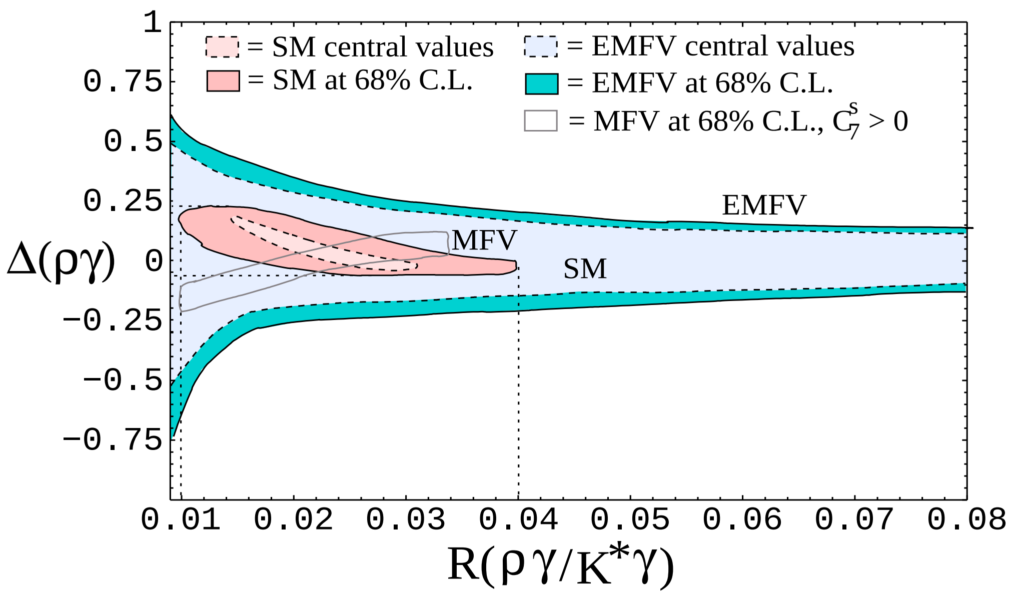


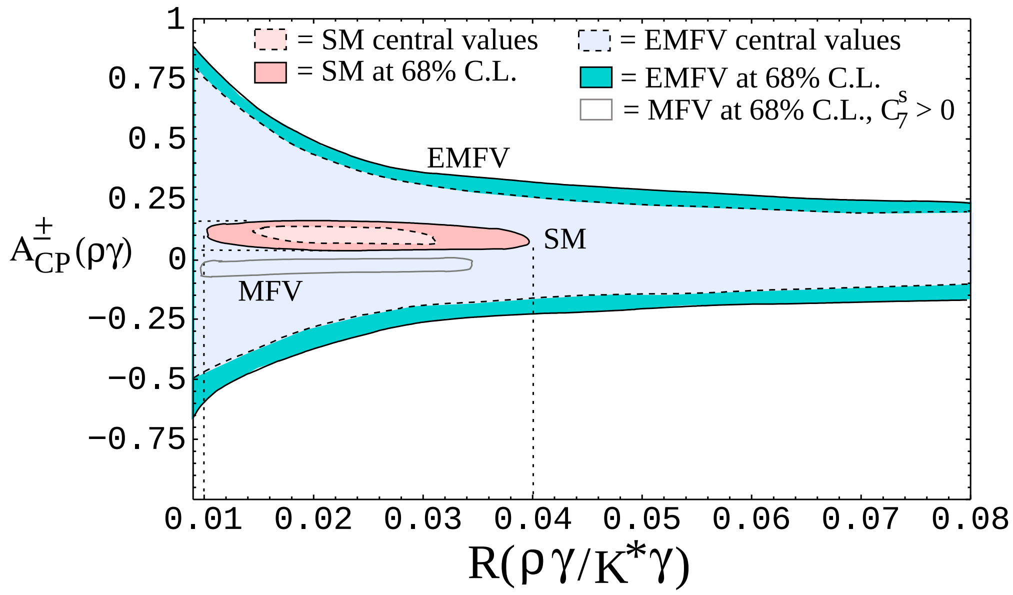

- The impact of the current upper bound on the UT analysis becomes similar to the constraints coming from $\Delta M_{Bd}$ and $\Delta M_{Bs}$

# Analysis in supersymmetry

[Ali, E.L.]

- Minimal Flavour Violation (MFV)
  - $C_7$ has the same value in the d and s sectors, hence the ratio R does not vary sizeably
  - The asymmetries can receive large corrections
- Models with extra sources of Flavour Changing (e.g. Extended-MFV, MIA)
  - Large deviations can be present in all the observables



[Feldmann, Matias]

# $B \to K^* l^+ l^-$ decays

- QCD factorization
  - only valid in the low s region
  - NLO in $\alpha_s$
  - LO in $\Lambda_{\rm QCD}/m_b$

- Forward-backward asymmetry

- Isospin asymmetry
  - large contributions at $O(\Lambda_{\rm QCD}/m_b)$
  - presence of endpoint singularities in $\langle O_8 \rangle$

- Non-perturbative parameters:

$$\xi_{||}(q^2) \;,\; \xi_{\perp}(q^2) \;,\; \int \phi_+^B(\xi)/\xi \;,\; \int \phi_-^B(\xi)/\xi \;,\; K^* \,\mathrm{LCDA}$$

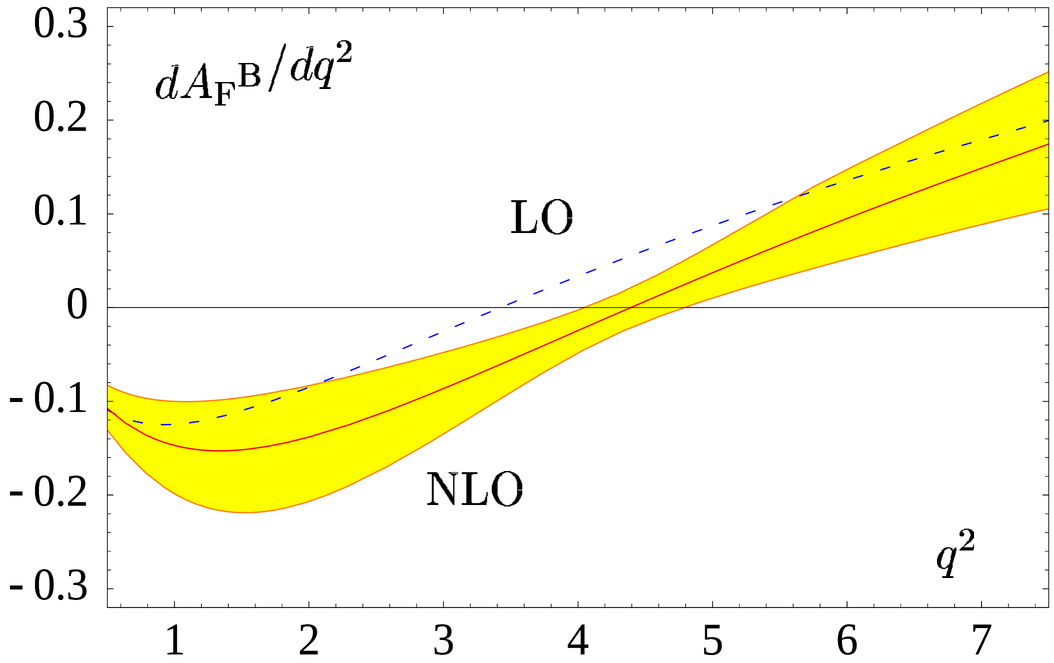
# Forward-backward asymmetry

$$\frac{dA_{FB}}{dq^2} = \frac{1}{d\Gamma/dq^2}\left(\int_0^1 d(\cos\theta)\frac{d^2\Gamma}{dq^2\,d\cos\theta} - \int_{-1}^0 d(\cos\theta)\frac{d^2\Gamma}{dq^2\,d\cos\theta}\right)$$

- presence of a zero in the spectrum:

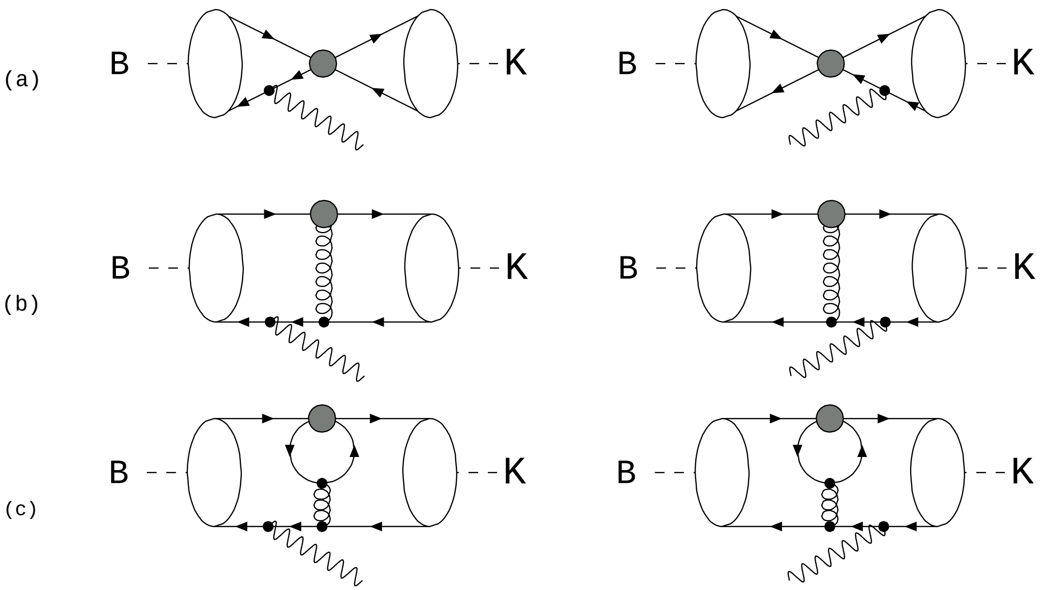
$$C_9 + \mathrm{Re}\left[Y(q_0^2)\right] = -2M_B\frac{m_b}{q_0^2}C_7^{\mathrm{eff}}$$

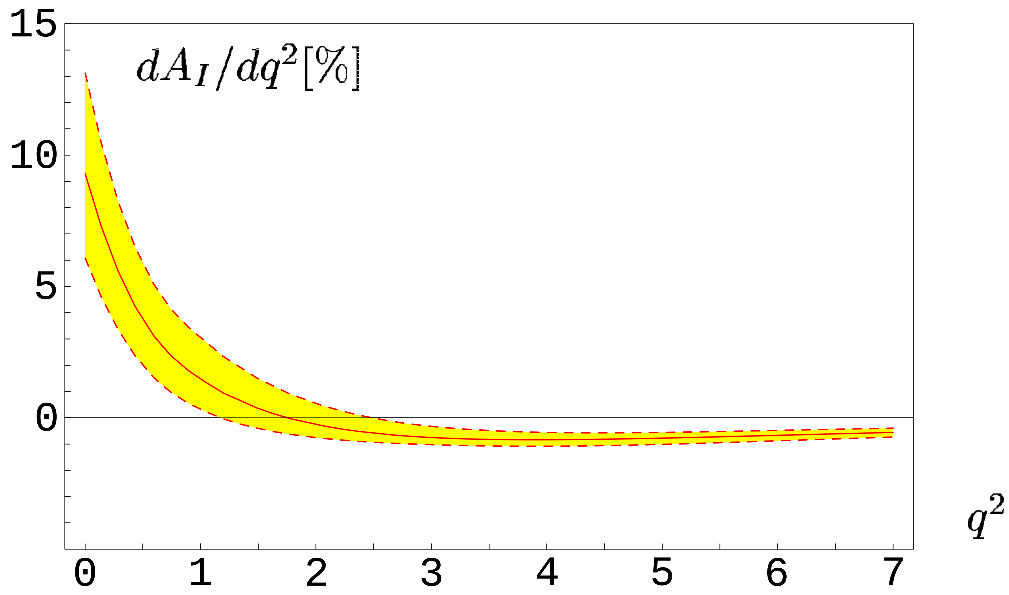
$$q_0^2 = (4.2 \pm 0.6)\ \mathrm{GeV}^2$$



# Isospin asymmetry

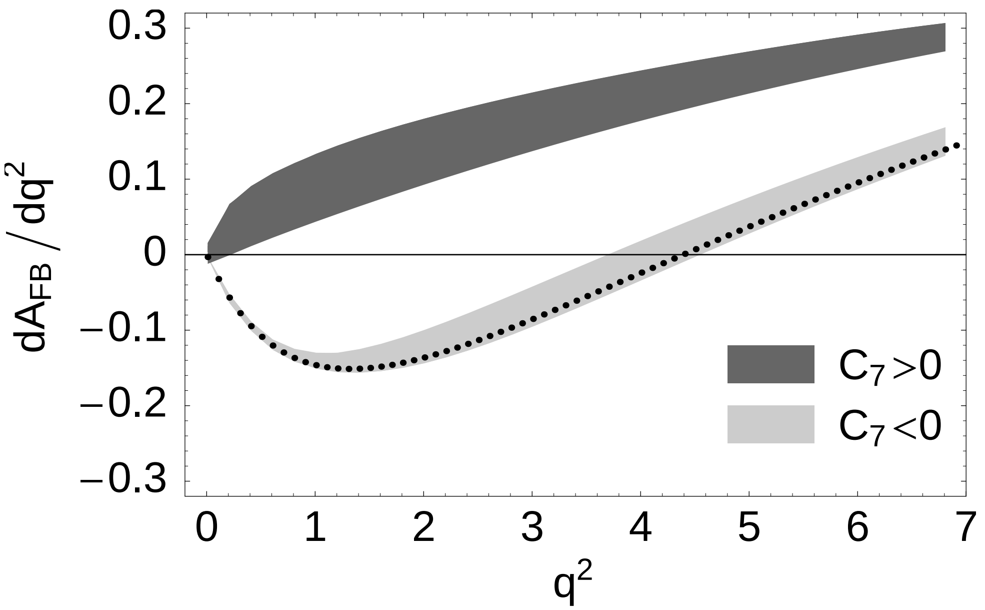
$$\frac{dA_I}{dq^2} = \frac{d\Gamma[B^0 \to K^{*0} l\, l]/dq^2 - d\Gamma[B^\pm \to K^{*\pm} l\, l]/dq^2}{d\Gamma[B^0 \to K^{*0} l\, l]/dq^2 + d\Gamma[B^\pm \to K^{*\pm} l\, l]/dq^2}$$

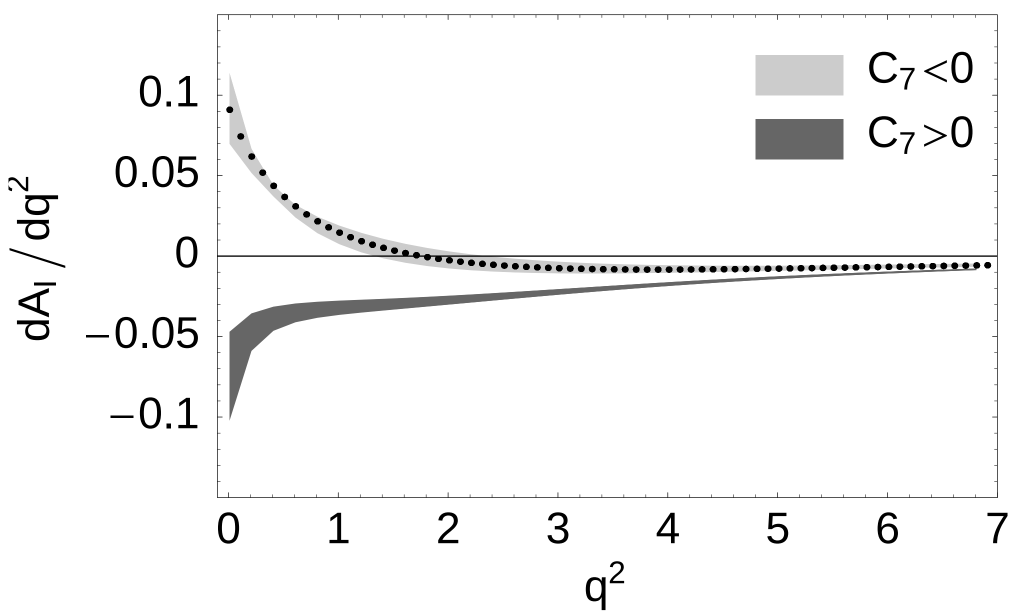


# Analysis in supersymmetry (MFV)

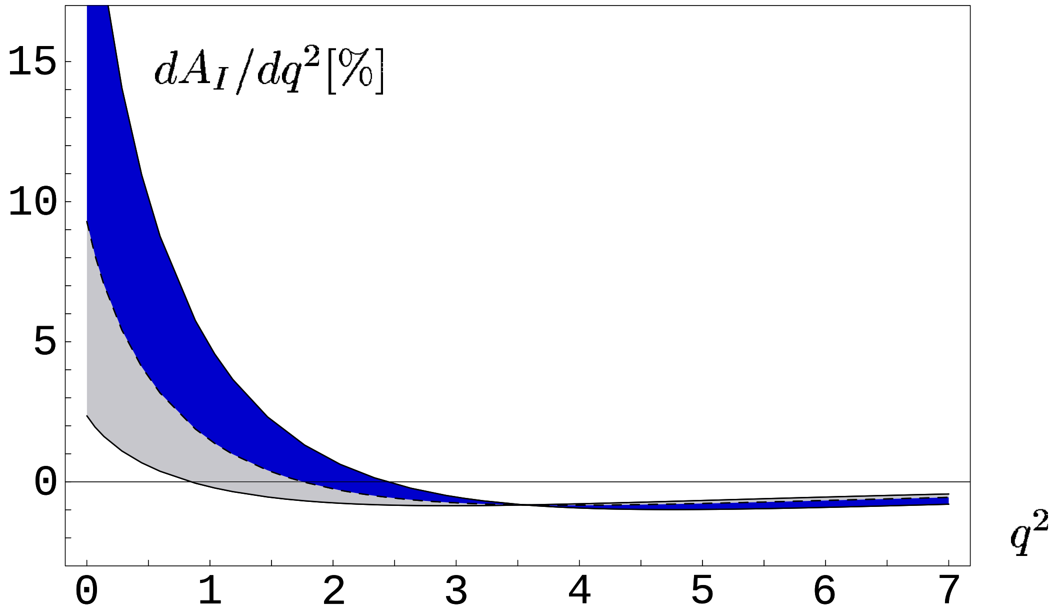
- If $C_7<0$, MFV is indistinguishable from the SM
- The zero of the FB asymmetry moves to lower $q^2$ values
- The asymmetries can discriminate the $C_7<0$ & $C_7>0$ scenarios
- A large isospin asymmetry kills SUSY with MFV

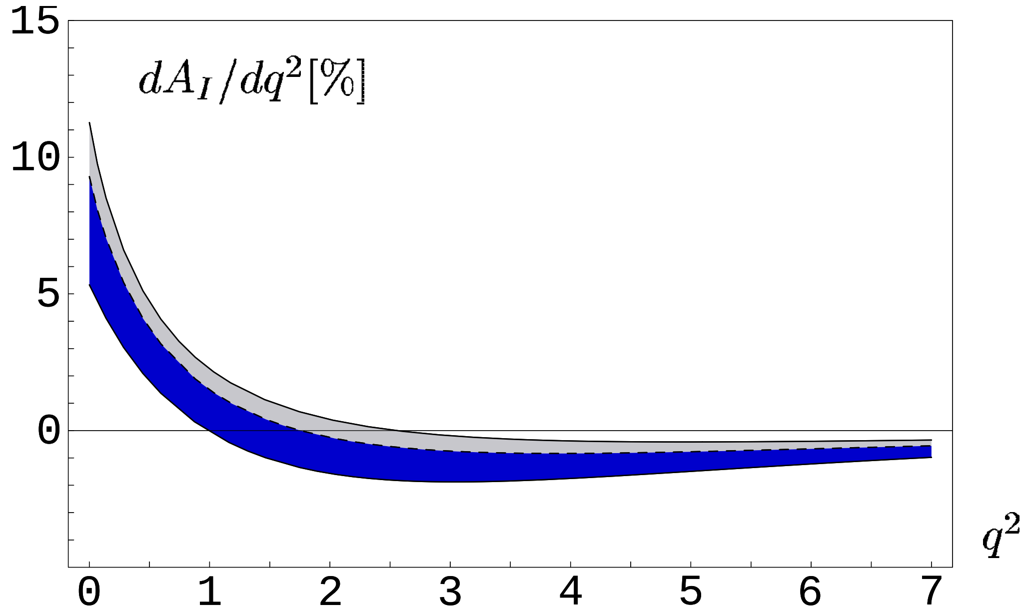


# More esotic scenarios

- New Physics in the QCD penguin WCs ($C_{3\text{-}6}$)




- $C_{10} > 0$: the FB asymmetry changes sign
- ...