New observables in $\bar{B}_d \to \bar{K}^*(K\pi)\ell^+\ell^-$ and their sensitivity to new physics

Tobias Hurth (CERN, SLAC)

in collaboration with

J.Matias, M.Ramon (Barcelona)
U.Egede, W. Reece (Imperial,LHCb)

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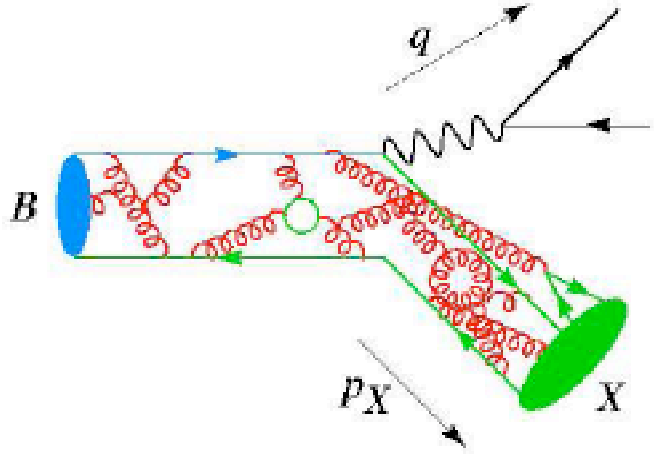
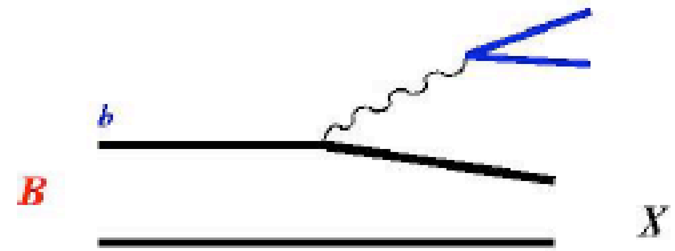
Plan of the Talk

New observables in $\bar{B}_d \to \bar{K}^*(K\pi)\ell^+\ell^-$ and their sensitivity to new physics

- Motivation
- Angular distributions in $B \to K^*(\to K\pi)\ell^+\ell^-$
- Symmetries of angular distributions
- Theoretical framework, SCET formfactors
- Phenomenological discussion of new observables
  - Theoretical uncertainties
  - New physics sensitivity
  - Experimental sensitivity at LHCb





Crucial problem: Separation of new physics effects and hadronic uncertainties!

Focus on theoretically clean observables is mandatory

Three strategies:

- focus on inclusive modes: operator product expansion (OPE)

$$\Gamma(\bar{B} \to X_s\gamma) \stackrel{m_b\to\infty}{\longrightarrow} \Gamma(b \to X_s^{parton}\gamma)\,, \quad \Delta^{nonpert.} \sim \Lambda_{QCD}^2/m_b^2$$

  No linear term Λ_{QCD}/m_b (perturbatively calculable contribution dominant)

  In general restricted to e^+e^- machines

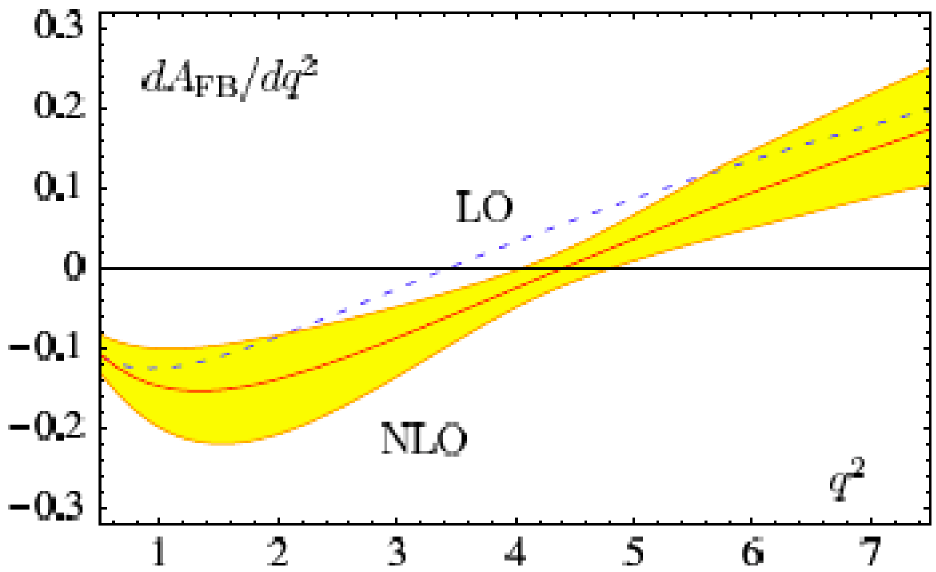
- focus on ratios of exclusive modes like asymmetries
  (hadronic uncertainties partially cancel out)

  General strategy followed at LHCb

- focus on specific decays like $K \to \pi\nu\bar{\nu}$
  (hadronic matrix elements known from experiment)

LHCb Strategy: Focus on ratios of exclusive modes

Well-known example: Forward-Backward-Charge-Asymmetry in $B \to K^* \ell^+ \ell^-$



- In contrast to the branching ratio the zero of the FBA is almost insensitive to hadronic uncertainties. At LO the zero depends on the short-distance Wilson coefficients only:

$$q_0^2 = q_0^2(C_7, C_9), \quad q_0^2 = (3.4 + 0.6 - 0.5) GeV^2 \quad (LO)$$

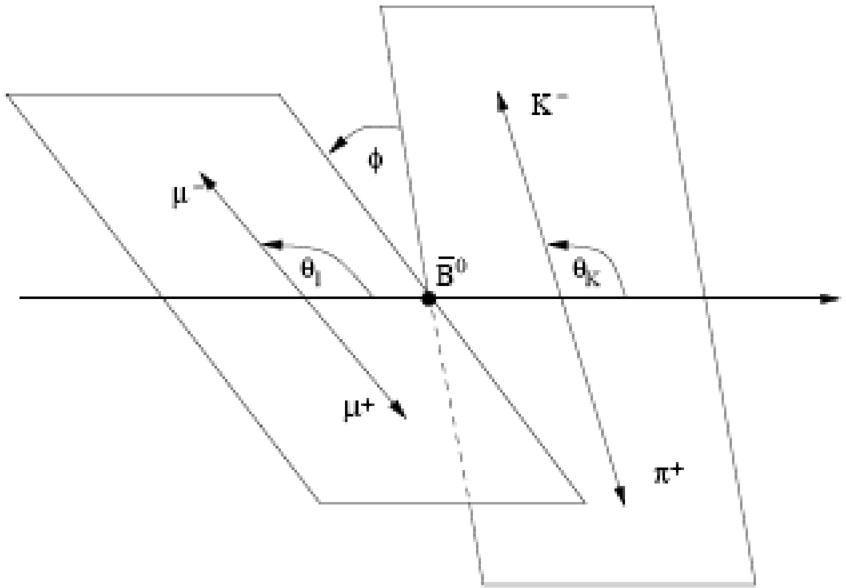
- NLO contribution calculated within QCD factorization approach leads to a large 30%-shift: (Beneke,Feldmann,Seidel 2001)

$$q_0^2 = (4.39 + 0.38 - 0.35) GeV^2 \quad (NLO)$$

- However: Issue of unknown power corrections (Λ/m_b) !

More opportunities in $B \to K^*(K\pi)\ell^+\ell^-$: angular distributions

Assuming the $\bar{K}^*$ to be on the mass shell, the decay $\bar{B}^0 \to \bar{K}^{*0}(\to K^-\pi^+)\ell^+\ell^-$ described by the lepton-pair invariant mass, s, and the three angles θ_l, θ_{K^*}, ϕ.



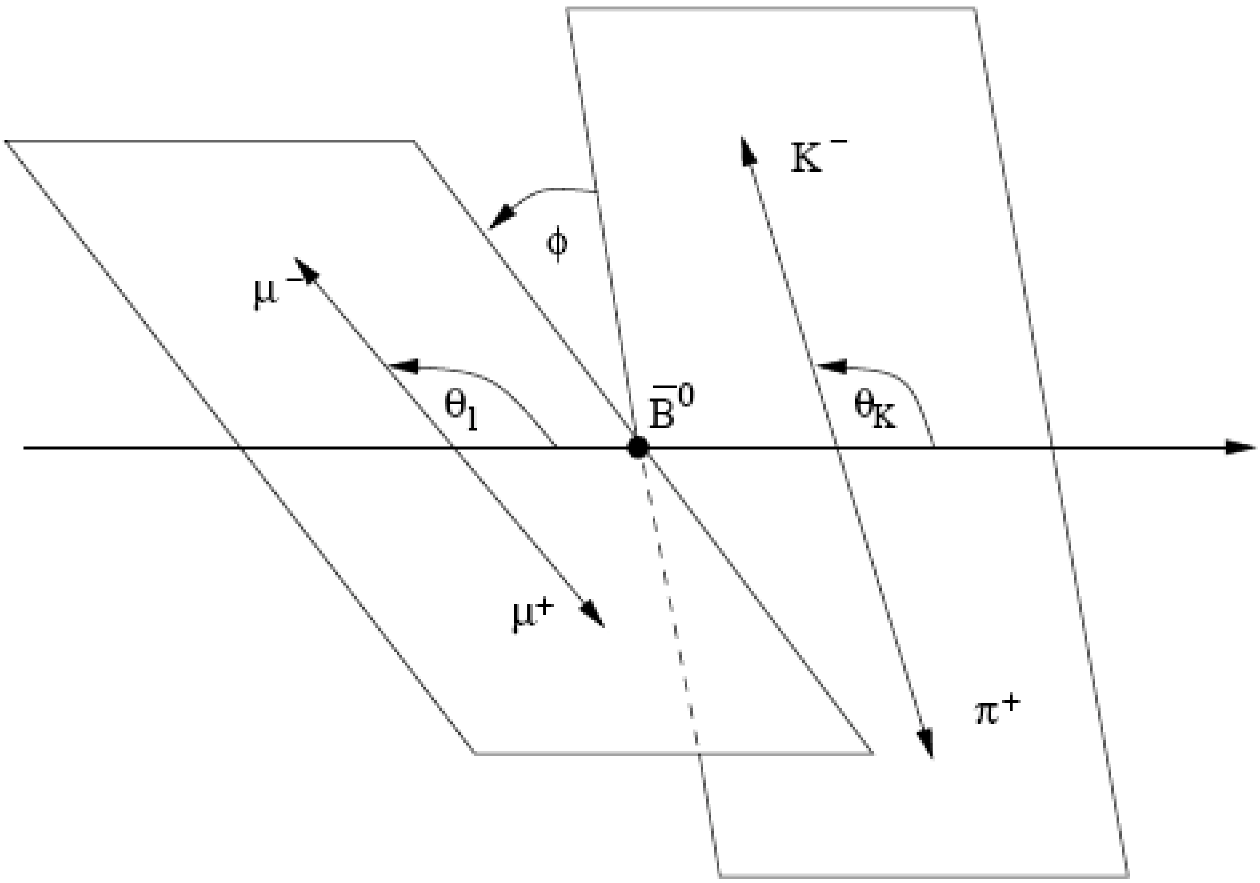
After summing over the spins of the final particles:

$$\frac{d^4\Gamma_{\overline{B}_d}}{dq^2\, d\theta_l\, d\theta_K\, d\phi} = \frac{9}{32\pi} I(q^2, \theta_l, \theta_K, \phi) \sin\theta_l \sin\theta_K$$

$$\begin{aligned} I = & \; I_1 + I_2 \cos 2\theta_l + I_3 \sin^2\theta_l \cos 2\phi + I_4 \sin 2\theta_l \cos\phi + I_5 \sin\theta_l \cos\phi + I_6 \cos\theta_l \\ & + I_7 \sin\theta_l \sin\phi + I_8 \sin 2\theta_l \sin\phi + I_9 \sin^2\theta_l \sin 2\phi . \end{aligned}$$

LHCb statistics $(10\, fb^{-1},\ \succ 2\, fb^{-1})$ allows for a full angular fit!

More on kinematics:



z axis: Direction of anti-K^{*0} in rest frame of anti-B_d

θ_l : Angle between μ^- and **z** axis in $\mu\mu$ rest frame

θ_K : Angle between K^- and **z** axis in anti-K^* rest frame

ϕ : Angle between the anti-K^* and $\mu\mu$ decay planes

$$\mathbf{e}_z = \frac{\mathbf{p}_{K^-} + \mathbf{p}_{\pi^+}}{|\mathbf{p}_{K^-} + \mathbf{p}_{\pi^+}|}, \quad \mathbf{e}_l = \frac{\mathbf{p}_{\mu^-} \times \mathbf{p}_{\mu^+}}{|\mathbf{p}_{\mu^-} \times \mathbf{p}_{\mu^+}|}, \quad \mathbf{e}_K = \frac{\mathbf{p}_{K^-} \times \mathbf{p}_{\pi^+}}{|\mathbf{p}_{K^-} \times \mathbf{p}_{\pi^+}|}$$

$$\cos\theta_l = \frac{\mathbf{q}_{\mu^-} \cdot \mathbf{e}_z}{|\mathbf{q}_{\mu^-}|}, \quad \cos\theta_K = \frac{\mathbf{r}_{K^-} \cdot \mathbf{e}_z}{|\mathbf{r}_{K^-}|}, \quad \sin\phi = (\mathbf{e}_l \times \mathbf{e}_K) \cdot \mathbf{e}_z, \quad \cos\phi = \mathbf{e}_K \cdot \mathbf{e}_l$$

Angular distributions functions depend on the 6 complex K^* spin amplitudes

$I_i = I_i(A_{\perp L/R}, A_{\parallel L/R}, A_{0L/R})$ (limit $m_{\text{lepton}} = 0$)

Helicity amplitudes: $A_{\perp,\parallel} = (H_{+1} \mp H_{-1})/\sqrt{2}, \quad A_0 = H_0,$

$$
\begin{aligned}
I_1 &= \frac{3}{4}\left(|A_{\perp L}|^2 + |A_{\parallel L}|^2 + (L \to R)\right)\sin^2\theta_K + \left(|A_{0L}|^2 + |A_{0R}|^2\right)\cos^2\theta_K \\
&\equiv a\sin^2\theta_K + b\cos^2\theta_K, \\
I_2 &= \frac{1}{4}(|A_{\perp L}|^2 + |A_{\parallel L}|^2)\sin^2\theta_K - |A_{0L}|^2\cos^2\theta_K + (L \to R) \\
&\equiv c\sin^2\theta_K + d\cos^2\theta_K, \\
I_3 &= \frac{1}{2}\left[(|A_{\perp L}|^2 - |A_{\parallel L}|^2)\sin^2\theta_K + (L \to R)\right] \equiv e\sin^2\theta_K, \\
I_4 &= \frac{1}{\sqrt{2}}\left[\mathrm{Re}(A_{0L}A^*_{\parallel L})\sin 2\theta_K + (L \to R)\right] \equiv f\sin 2\theta_K, \\
I_5 &= \sqrt{2}\left[\mathrm{Re}(A_{0L}A^*_{\perp L})\sin 2\theta_K - (L \to R)\right] \equiv g\sin 2\theta_K, \\
I_6 &= 2\left[\mathrm{Re}(A_{\parallel L}A^*_{\perp L})\sin^2\theta_K - (L \to R)\right] \equiv h\sin^2\theta_K, \\
I_7 &= \sqrt{2}\left[\mathrm{Im}(A_{0L}A^*_{\parallel L})\sin 2\theta_K - (L \to R)\right] \equiv j\sin 2\theta_K, \\
I_8 &= \frac{1}{\sqrt{2}}\left[\mathrm{Im}(A_{0L}A^*_{\perp L})\sin 2\theta_K + (L \to R)\right] \equiv k\sin 2\theta_K, \\
I_9 &= \left[\mathrm{Im}(A^*_{\parallel L}A_{\perp L})\sin^2\theta_K + (L \to R)\right] \equiv m\sin^2\theta_K.
\end{aligned}
$$

11 coefficients to be fixed in the full angular fit, but $a = 3c$ and $b = -d$

12 theoretical independent amplitudes $A_j \overset{?}{\Leftrightarrow}$ 9 independent coefficient functions in I

Symmetries of the angular distribution functions $I_i = I_i(A_{\perp L/R}, A_{\| L/R}, A_{0L/R})$

(angular distribution spin averaged)

- Global phase transformation of the L amplitudes

$$A'_{\perp L} = e^{i\phi_L} A_{\perp L},\ A'_{\| L} = e^{i\phi_L} A_{\| L},\ A'_{0L} = e^{i\phi_L} A_{0L}$$

- Global phase transformations of the R amplitudes

$$A'_{\perp R} = e^{i\phi_R} A_{\perp R},\ A'_{\| R} = e^{i\phi_R} A_{\| R},\ A'_{0R} = e^{i\phi_R} A_{0R}$$

- Continuous L-R rotation

$$\begin{aligned}
A'_{\perp L} &= +cos(\theta) A_{\perp L} - sin(\theta) A^*_{\perp R} \\
A'_{\perp R} &= +sin(\theta) A_{\perp L} + cos(\theta) A^*_{\perp R} \\
A'_{0L} &= +cos(\theta) A_{0L} - sin(\theta) A^*_{0R} \\
A'_{0R} &= +sin(\theta) A_{0L} + cos(\theta) A^*_{0R} \\
A'_{\| L} &= +cos(\theta) A_{\| L} + sin(\theta) A^*_{\| R} \\
A'_{\| R} &= -sin(\theta) A_{\| L} + cos(\theta) A^*_{\| R} \,.
\end{aligned}$$

Only 9 amplitudes A_j are independent in respect to the angular distribution

Observables as $F(I_i)$ are also invariant under the 3 symmetries !

Standard theoretical framework

- Effective Hamiltonian describing the quark transition $b \to s\ell^+\ell^-$:

$$\mathcal{H}_{\rm eff} = -\frac{4G_F}{\sqrt{2}} V_{tb}V_{ts}^* \sum_{i=1}^{10} [C_i(\mu)\mathcal{O}_i(\mu) + C_i'(\mu)\mathcal{O}_i'(\mu)]$$

We focus on magnetic and semi-leptonic operators and their chiral partners

$$\mathcal{O}_7 = \frac{e}{16\pi^2} m_b(\bar{s}\sigma_{\mu\nu}P_R b)F^{\mu\nu}, \quad \mathcal{O}_7' = \frac{e}{16\pi^2} m_b(\bar{s}\sigma_{\mu\nu}P_L b)F^{\mu\nu}$$

$$\mathcal{O}_9 = \frac{e^2}{16\pi^2}(\bar{s}\gamma_\mu P_L b)(\bar{\ell}\gamma^\mu \ell), \quad \mathcal{O}_{10} = \frac{e^2}{16\pi^2}(\bar{s}\gamma_\mu P_L b)(\bar{\ell}\gamma^\mu\gamma_5 \ell),$$

- Matrix element for the decay $\bar{B}_d \to \bar{K}^{*0}(\to K^-\pi^+)\ell^+\ell^-$:

$$\mathcal{M} = \frac{G_F\alpha}{\sqrt{2}\pi} V_{tb}V_{ts}^* \left\{ \left[C_9^{\rm eff} \langle K\pi|(\bar{s}\gamma^\mu P_L b)|B\rangle - \frac{2m_b}{q^2}\langle K\pi|\bar{s}i\sigma^{\mu\nu}q_\nu(C_7^{\rm eff} P_R + C_7^{\rm eff\prime} P_L)b|B\rangle \right] (\bar{\ell}\gamma_\mu \ell) \right.$$

$$\left. + C_{10} \langle K\pi|(\bar{s}\gamma^\mu P_L b)|B\rangle(\bar{\ell}\gamma_\mu\gamma_5 \ell) \right\}$$

- Hadronic matrix element parametrized in terms of $B \to K^*$ form factors:

$$\langle K^*(p_{K^*})|\bar{s}\gamma_\mu P_{L,R} b|B(p)\rangle = i\epsilon_{\mu\nu\alpha\beta}\epsilon^{\nu *} p^\alpha q^\beta \frac{V(s)}{m_B + m_{K^*}} \mp \frac{1}{2}\Big\{\epsilon^*_\mu (m_B + m_{K^*}) A_1(s) - (\epsilon^* \cdot q)(2p-q)_\mu \frac{A_2(s)}{m_B + m_{K^*}} - \frac{2m_{K^*}}{s}(\epsilon^* \cdot q)[A_3(s) - A_0(s)]q_\mu\Big\}$$

$$\langle K^*(p_{K^*})|\bar{s} i\sigma_{\mu\nu} q^\nu P_{R,L} b|B(p)\rangle = -i\epsilon_{\mu\nu\alpha\beta}\epsilon^{\nu *} p^\alpha q^\beta T_1(s) \pm \frac{1}{2}\Big\{[\epsilon^*_\mu (m_B^2 - m_{K^*}^2) - (\epsilon^* \cdot q)(2p-q)_\mu] T_2(s) + (\epsilon^* \cdot q)\Big[q_\mu - \frac{s}{m_B^2 - m_{K^*}^2}(2p-q)_\mu\Big] T_3(s)\Big\}$$

- Heavy-light form factors by means of QCD sum rules lead to uncertainties of 30% on the branching fractions

  (Ali,Ball,Handoko,Hiller 2000)

Crucial theoretical input

- In the $m_B \to \infty$ and $E_{K^*} \to \infty$ limit

  7 form factors ($A_i(s)/T_i(s)/V(s)$) reduce to 2 univeral form factors ($\xi_\perp, \xi_\parallel$)

  (Charles, Le Yaouanc, Oliver, Pène, Raynal 1999)

$$A_1(s) = \frac{2E_{K^*}}{m_B + m_{K^*}} \xi_\perp(E_{K^*}) \,,$$

$$A_2(s) = \frac{m_B}{m_B - m_{K^*}} \left[\xi_\perp(E_{K^*}) - \xi_\parallel(E_{K^*}) \right],$$

$$A_0(s) = \frac{E_{K^*}}{m_{K^*}} \xi_\parallel(E_{K^*}) \,,$$

$$V(s) = \frac{m_B + m_{K^*}}{m_B} \xi_\perp(E_{K^*}) \,,$$

$$T_1(s) = \xi_\perp(E_{K^*}) \,,$$

$$T_2(s) = \frac{2E_{K^*}}{m_B} \xi_\perp(E_{K^*}) \,,$$

$$T_3(s) = \xi_\perp(E_{K^*}) - \xi_\parallel(E_{K^*}) \,.$$

- Form factor relations broken by α_s and Λ/m_b corrections

- Large Energy Effective Theory $\Rightarrow$ QCD factorization/Soft Collinear Effective Theory (IR structure of QCD)

  Formal factorization formula for heavy-light formfactors within SCET approach (Beneke,Feldmann;Becher,Hill,Lange,Neubert;Bauer,Pirjol,Stewart)

- Factorizable and Non-factorizable α_s corrections have been calculated (NLO) (Beneke,Feldmann,Seidel 2001)

- Caveat: unknown Λ/m_b corrections to the factorization formula

- Above results are valid in the kinematic region in which

  $$E_{K^*} \simeq \frac{m_B}{2}\left(1 - \frac{s}{m_B^2} + \frac{m_{K^*}^2}{m_B^2}\right) \quad \text{is large.}$$

  We restrict our analysis to the dilepton mass region $s \in [1\text{GeV}^2, 6\text{GeV}^2]$

K^* spin amplitudes in the heavy quark and large energy limit

$$A_{\perp,\parallel} = (H_{+1} \mp H_{-1})/\sqrt{2}, \quad A_0 = H_0$$

$$A_{\perp L,R} = N\sqrt{2}\lambda^{1/2}\left[(C_9^{\text{eff}} \mp C_{10})\frac{V(s)}{m_B + m_{K^*}} + \frac{2m_b}{s}(C_7^{\text{eff}} + C_7^{\text{eff}\prime})T_1(s)\right]$$

$$A_{\parallel L,R} = -N\sqrt{2}(m_B^2 - m_{K^*}^2)\left[(C_9^{\text{eff}} \mp C_{10})\frac{A_1(s)}{m_B - m_{K^*}} + \frac{2m_b}{s}(C_7^{\text{eff}} - C_7^{\text{eff}\prime})T_2(s)\right]$$

$$A_{0L,R} = -\frac{N}{2m_{K^*}\sqrt{s}}\Bigg[(C_9^{\text{eff}} \mp C_{10})\left\{(m_B^2 - m_{K^*}^2 - s)(m_B + m_{K^*})A_1(s) - \lambda\frac{A_2(s)}{m_B + m_{K^*}}\right\} + 2m_b(C_7^{\text{eff}} - C_7^{\text{eff}\prime})\left\{(m_B^2 + 3m_{K^*}^2 - s)T_2(s) - \frac{\lambda}{m_B^2 - m_{K^*}^2}T_3(s)\right\}\Bigg]$$

$$A_{\perp L,R} = +\sqrt{2}N m_B(1-\hat{s})\left[(C_9^{\text{eff}} \mp C_{10}) + \frac{2\hat{m}_b}{\hat{s}}(C_7^{\text{eff}} + C_7^{\text{eff}\prime})\right]\xi_\perp(E_{K^*})$$

$$A_{\parallel L,R} = -\sqrt{2}N m_B(1-\hat{s})\left[(C_9^{\text{eff}} \mp C_{10}) + \frac{2\hat{m}_b}{\hat{s}}(C_7^{\text{eff}} - C_7^{\text{eff}\prime})\right]\xi_\perp(E_{K^*})$$

$$A_{0L,R} = -\frac{N m_B}{2\hat{m}_{K^*}\sqrt{\hat{s}}}(1-\hat{s})^2\left[(C_9^{\text{eff}} \mp C_{10}) + 2\hat{m}_b(C_7^{\text{eff}} - C_7^{\text{eff}\prime})\right]\xi_\parallel(E_{K^*})$$

In the SM ($C_7^{\text{eff}\prime} = 0$) we recover naive quark model prediction $A_\perp = -A_\parallel$ ($H_+ = 0$) in the $m_B \to \infty$ and $E_{K^*} \to \infty$ limit.

Careful construction of observables

- Observables have to respect all symmetries of the angular distribution

- Good sensitivity to NP contribitions, i.e. to $C_7^{eff'}$

- Small theoretical uncertainties
  - Dependence of soft form factors, $\xi_\perp$ and $\xi_\|$, to be minimized !
    form factors should cancel out exactly at LO, best for all s
  - unknown Λ/m_b power corrections

    $A_{\perp,\|,0} = A^0_{\perp,\|,0}\left(1 + c_{\perp,\|,0}\right)$ vary c_i in a range of $\pm10\%$ and also of $\pm5\%$
  - Scale dependence of NLO result
  - Input parameters

- Good experimental resolution

Interesting observables

- Forward-backward asymmetry

$$A_{\rm FB} \equiv \frac{1}{d\Gamma/dq^2}\left(\int_0^1 d(\cos\theta)\,\frac{d^2\Gamma[\bar{B}\to\bar{K}^*\ell^+\ell^-]}{dq^2 d\cos\theta} - \int_{-1}^0 d(\cos\theta)\,\frac{d^2\Gamma[\bar{B}\to\bar{K}^*\ell^+\ell^-]}{dq^2 d\cos\theta}\right)$$

$$A_{\rm FB} = \frac{3}{2}\frac{{\rm Re}(A_{\parallel L}A^*_{\perp L}) - {\rm Re}(A_{\parallel R}A^*_{\perp R})}{|A_0|^2+|A_\parallel|^2+|A_\perp|^2}$$

Form factors cancel out at LO only for Zero.

- Longitudinal polarisation of K^*

$$F_L(s) = \frac{|A_0|^2}{|A_0|^2+|A_\parallel|^2+|A_\perp|^2}$$

Form factors do not cancel at LO ($\to$ larger hadronic uncertainties)

- Transversity amplitude A_T^2 (Krüger,Matias 2005)

$$A_T^{(2)} = \frac{|A_\perp|^2-|A_\parallel|^2}{|A_\perp|^2+|A_\parallel|^2}$$

Sensitive to right-handed currents (in LO directly $\sim C_7^{eff'}$)

Formfactor cancel out at LO for all s

$$A_iA_j^* \equiv A_{iL}(q^2)A^*_{jL}(q^2) + A_{iR}(q^2)A^*_{jR}(q^2) \quad (i,j=0,\parallel,\perp)$$

Projection fit possible for $A_T^{(2)}$, F_L, A_{FB}

$$\frac{d\Gamma'}{d\phi} = \frac{\Gamma'}{2\pi}\left(1 + \frac{1}{2}(1 - F_{\rm L})A_T^{(2)} \cos 2\phi + A_{\rm Im} \sin 2\phi\right), \qquad \Gamma' = \frac{d\Gamma}{dq^2}$$

$$\frac{d\Gamma'}{d\theta_l} = \Gamma'\left(\frac{3}{4}F_{\rm L} \sin^2\theta_l + \frac{3}{8}(1 - F_{\rm L})(1 + \cos^2\theta_l) + A_{\rm FB}\cos\theta_l\right)\sin\theta_l,$$

$$\frac{d\Gamma'}{d\theta_K} = \frac{3\Gamma'}{4}\sin\theta_K\left(2F_{\rm L}\cos^2\theta_K + (1 - F_{\rm L})\sin^2\theta_K\right),$$

Observables appear linearly, fits performed on data binned in q^2

First experimental measurements with limited accuracy is possible

But: $A_T^{(2)}$ suppressed by $1 - F_L$

Full angular fit is superior, once the data set is large enough $(\succ 2fb^{-1})$

much better resolution (factor 3 even in $A_T^{(2)}$)

New observables are available

Unbinned analysis, q^2 dependence parametrised by polynomial

New observables

By inspection of the K^* spin amplitudes in terms of Wilson coefficients and SCET form factors one identifies further observables

- sensitive to $C_7^{eff'}$
- invariant under 3 $R-L$ symmetries
- theoretical clean
- with high experimental resolution

$$A_T^{(3)} = \frac{|A_{0L}A_{\|L}^* - A_{0R}^* A_{\|R}|}{\sqrt{|A_0|^2|A_\perp|^2}} \qquad A_T^{(4)} = \frac{|A_{0L}A_{\perp L}^* - A_{0R}^* A_{\perp R}|}{|A_{0L}^* A_{\|L} + A_{0R}A_{\|R}^*|}$$

Next step: design of observables sensitive to other new physics operators

- Transversity amplitude A_T^1

  Defining the helicity distributions $\Gamma_\pm$ as $\Gamma_\pm = |H^L_{\pm 1}|^2 + |H^R_{\pm 1}|^2$

  one can define (Melikhov,Nikitin,Simula 1998)

$$A_T^{(1)} = \frac{\Gamma_- - \Gamma_+}{\Gamma_- + \Gamma_+} \qquad A_T^{(1)} = \frac{-2\mathrm{Re}(A_\parallel A_\perp^*)}{|A_\perp|^2 + |A_\parallel|^2}$$

  Very sensitive to right-handed currents (Lunghi,Matias 2006)

  Very insensitive to Λ/m_b corrections

  Formfactor cancel out at LO for all s

Big surprise:

$A_T^{(1)}$ is not invariant under the symmetries of the angular distribution

- $A_T^{(1)}$ cannot be extracted from the full angular distribution
- LHCb: practically not possible to measure the helicity of the final states on a event-by-event basis (neither as statistical distribution)
- Not a principal problem, but $A_T^{(1)}$ not an observable at LHCb or at Super B (measure three-momentum and charge)

Phenomenological analysis

Analysis of SM and models with additional right handed currents ($C_7^{eff'}$)

Specific model:

MSSM with non-minimal flavour violation in the down squark sector

4 benchmark points

Diagonal: $\mu = M_1 = M_2 = M_{H^+} = m_{\tilde{u}_R} = 1$ TeV $\tan\beta = 5$

- Scenario A: $m_{\tilde{g}} = 1$ TeV and $m_{\tilde{d}} \in [200, 1000]$ GeV

  $-0.1 \leq (\delta^d_{LR})_{32} \leq 0.1$

  a) $m_{\tilde{g}}/m_{\tilde{d}} = 2.5$, $(\delta^d_{LR})_{32} = 0.016$

  b) $m_{\tilde{g}}/m_{\tilde{d}} = 4$, $(\delta^d_{LR})_{32} = 0.036$.

- Scenario B: $m_{\tilde{d}} = 1$ TeV and $m_{\tilde{g}} \in [200, 800]$ GeV

  mass insertion as in Scenario A.

  c) $m_{\tilde{g}}/m_{\tilde{d}} = 0.7$, $(\delta^d_{LR})_{32} = -0.004$

  d) $m_{\tilde{g}}/m_{\tilde{d}} = 0.6$, $(\delta^d_{LR})_{32} = -0.006$.

Check of compatibility with other constraints (B physics,ρ parameter, Higgs mass, particle searches, vacuum stability constraints

- NLO corrections included
- Λ/m_b corrections estimated for each amplitude as ±10% and ±5%

  this uncertainty fully dominant

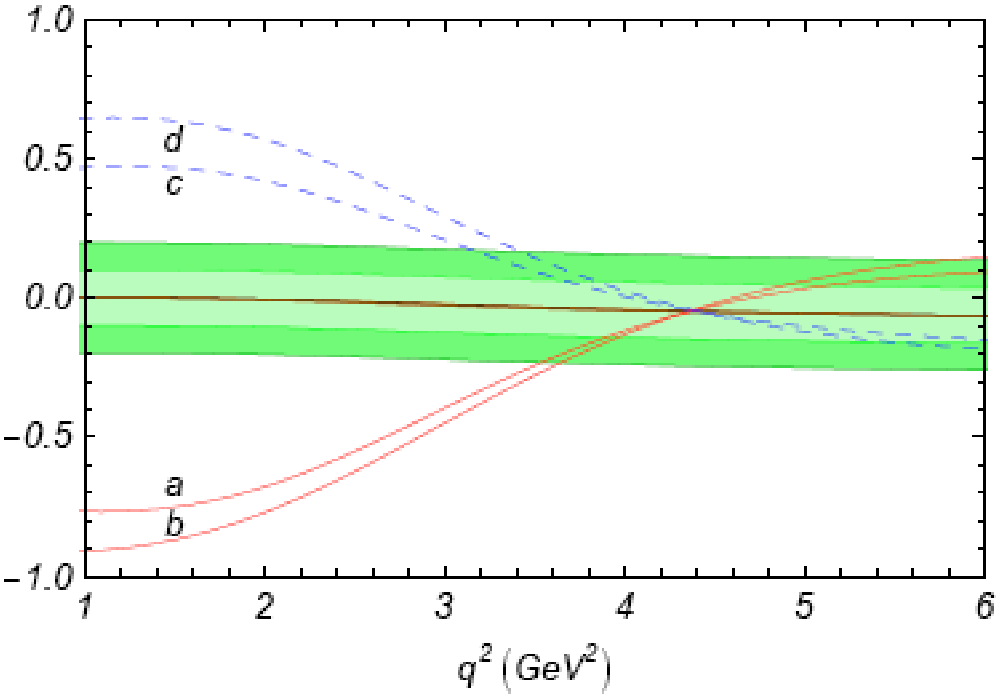
- Input parameters:

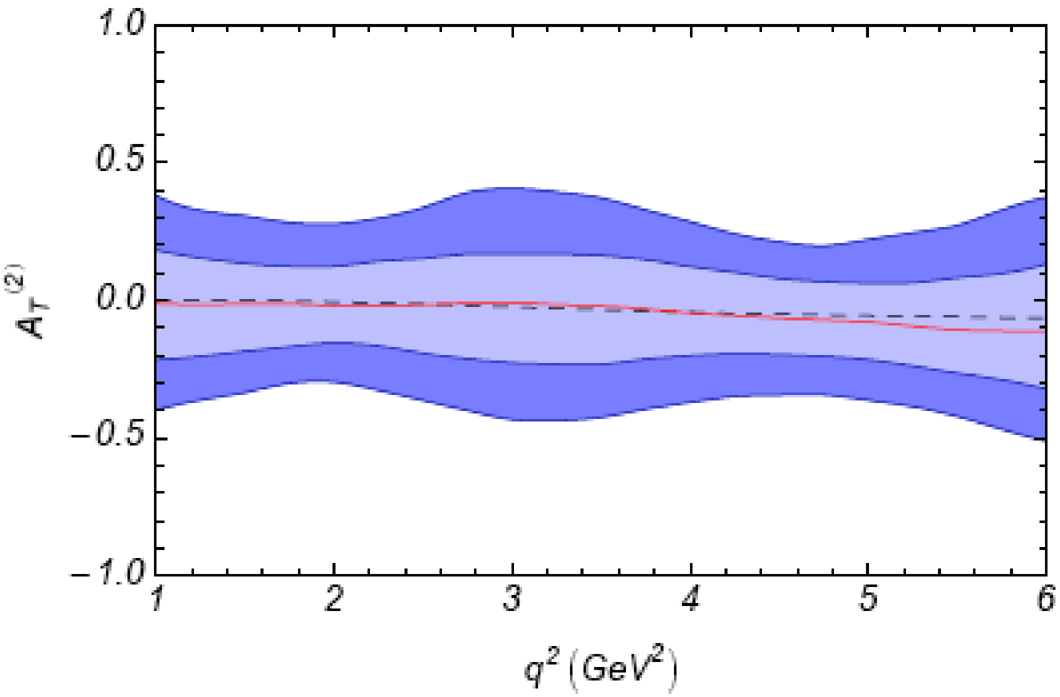
m_B	$5.27950 \pm 0.00033\,\mathrm{GeV}$	λ	0.2262 ± 0.0014
m_K	$0.896 \pm 0.040\,\mathrm{GeV}$	A	0.815 ± 0.013
M_W	$80.403 \pm 0.029\,\mathrm{GeV}$	$\bar{\rho}$	0.235 ± 0.031
M_Z	$91.1876 \pm 0.0021\,\mathrm{GeV}$	$\bar{\eta}$	0.349 ± 0.020
$\hat{m}_t(\hat{m}_t)$	172.5 ± 2.7 GeV	$\Lambda_{\mathrm{QCD}}^{(n_f=5)}$	$220 \pm 40\,\mathrm{MeV}$
$m_{b,\mathrm{PS}}(2\,\mathrm{GeV})$	4.6 ± 0.1 GeV	$\alpha_s(M_Z)$	0.1176 ± 0.0002
m_c	1.4 ± 0.2 GeV	α_{em}	$1/137.035999679$
f_B	200 ± 30 MeV	$a_1(K^*)_{\perp,\parallel}$	0.20 ± 0.05
$f_{K^*,\perp}(1\,\mathrm{GeV})$	185 ± 10 MeV	$a_2(K^*)_\perp$	0.06 ± 0.06
$f_{K^*,\parallel}$	218 ± 4 MeV	$a_2(K^*)_\parallel$	0.04 ± 0.04
$\xi_{K^*,\parallel}(0)$	0.16 ± 0.03	$\lambda_{B,+}(1.5\mathrm{GeV})$	$0.485 \pm 0.115\,\mathrm{GeV}$
$\xi_{K^*,\perp}(0)$¶	0.26 ± 0.02		

$\xi_{K^*,\perp}(0)$ has been determined from experimental data.

Results

$$A_T^{(2)} = \frac{|A_\perp|^2 - |A_\parallel|^2}{|A_\perp|^2 + |A_\parallel|^2}$$





Theoretical sensitivity

light green $\pm 5\% \Lambda/m_b$

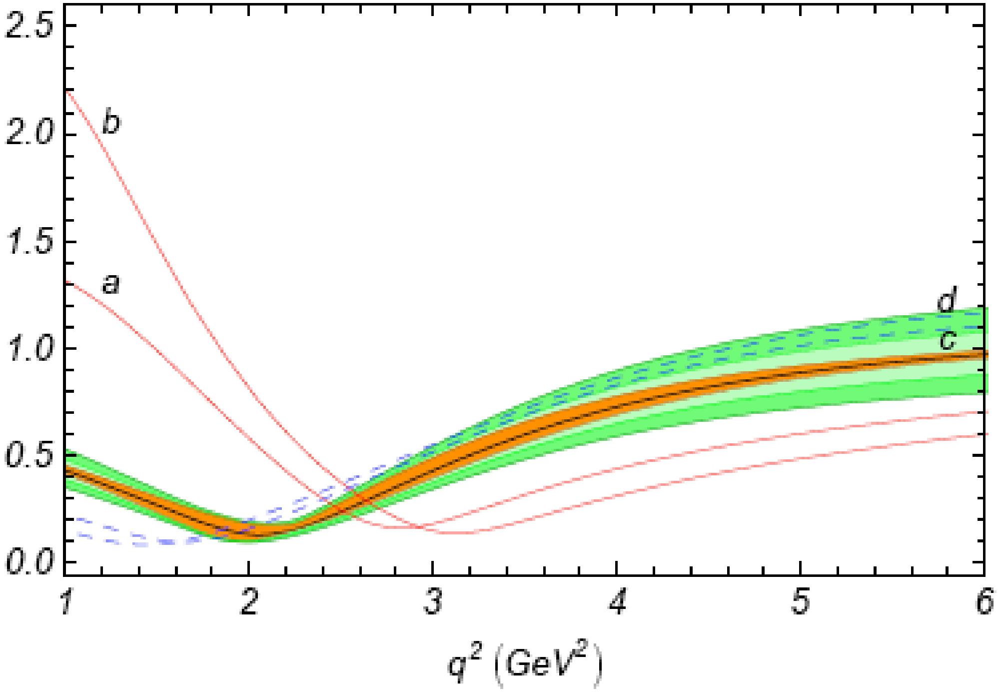
dark green $\pm 10\% \Lambda/m_b$

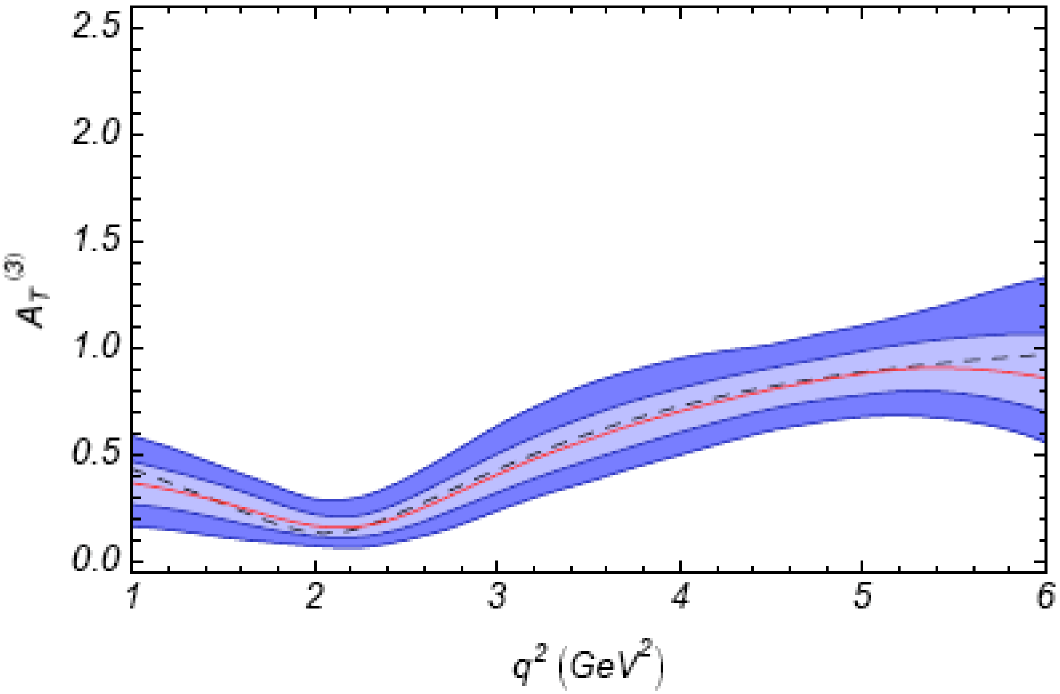
Experimental sensitivity $(10 fb^{-1})$

light green 1 σ

dark green 2 σ

$$A_T^{(3)} = \left| \frac{A_{0L}A_{\parallel L}^{*} - A_{0R}^{*}A_{\parallel R}}{\sqrt{|A_0|^2 \times |A_\perp|^2}} \right|$$

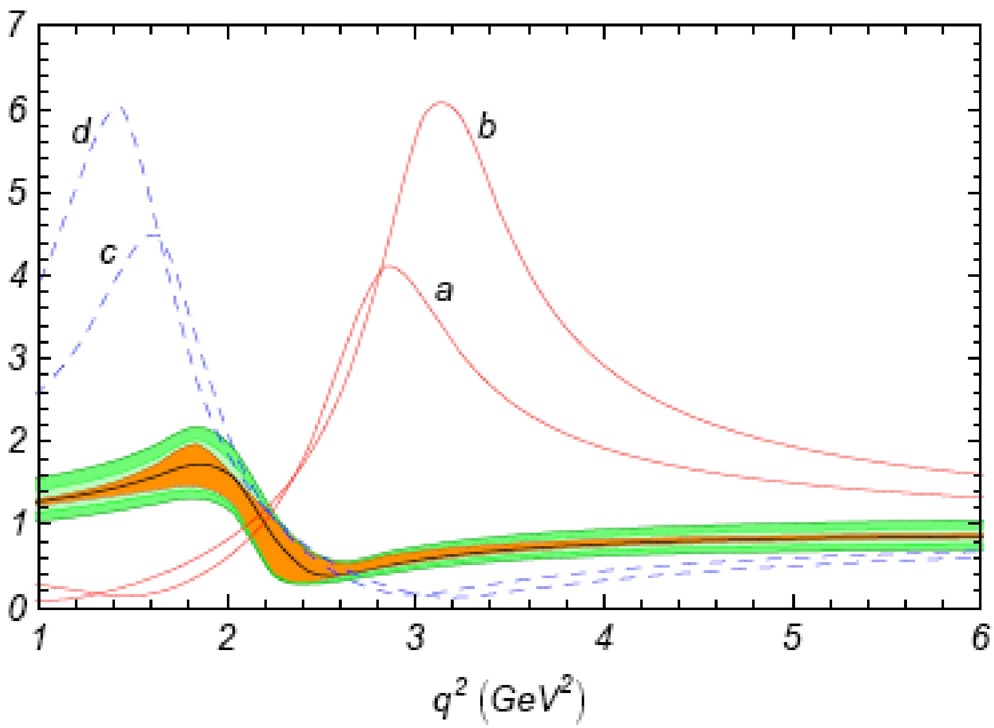


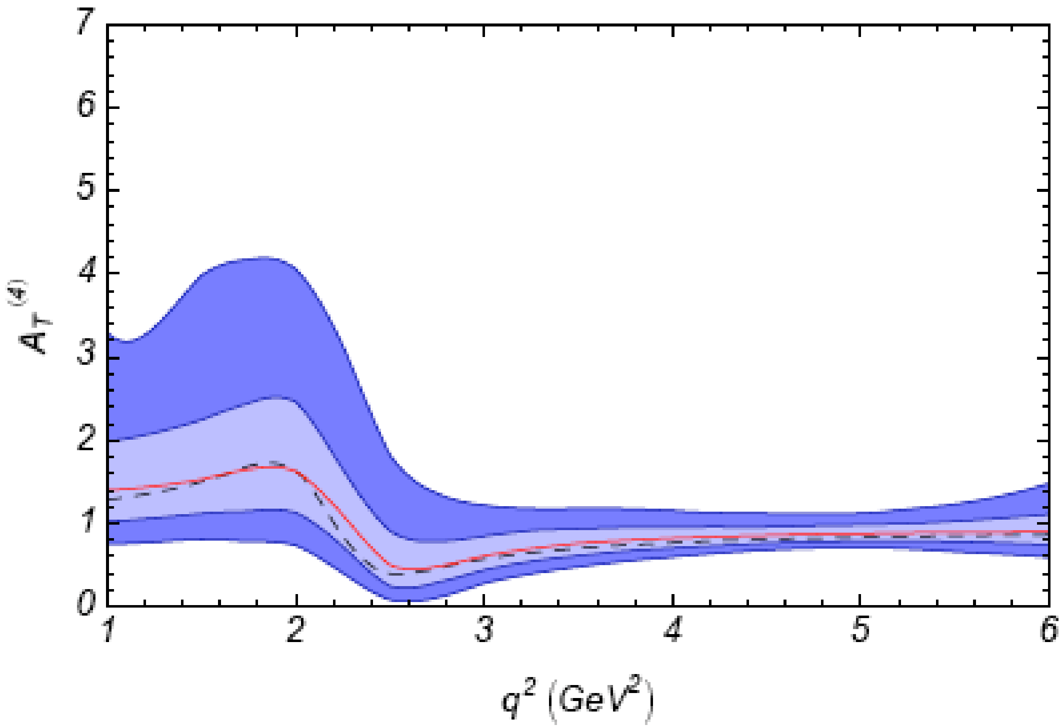


New observables allow crosSchecks

Different sensibility to $C_7^{eff'}$ via A_0 in $A_T^{(3)}$

$$A_T^{(4)} = \frac{|A_{0L}A^*_{\perp L} - A^*_{0R}A_{\perp R}|}{|A^*_{0L}A_{\parallel L} + A_{0R}A^*_{\parallel R}|}$$

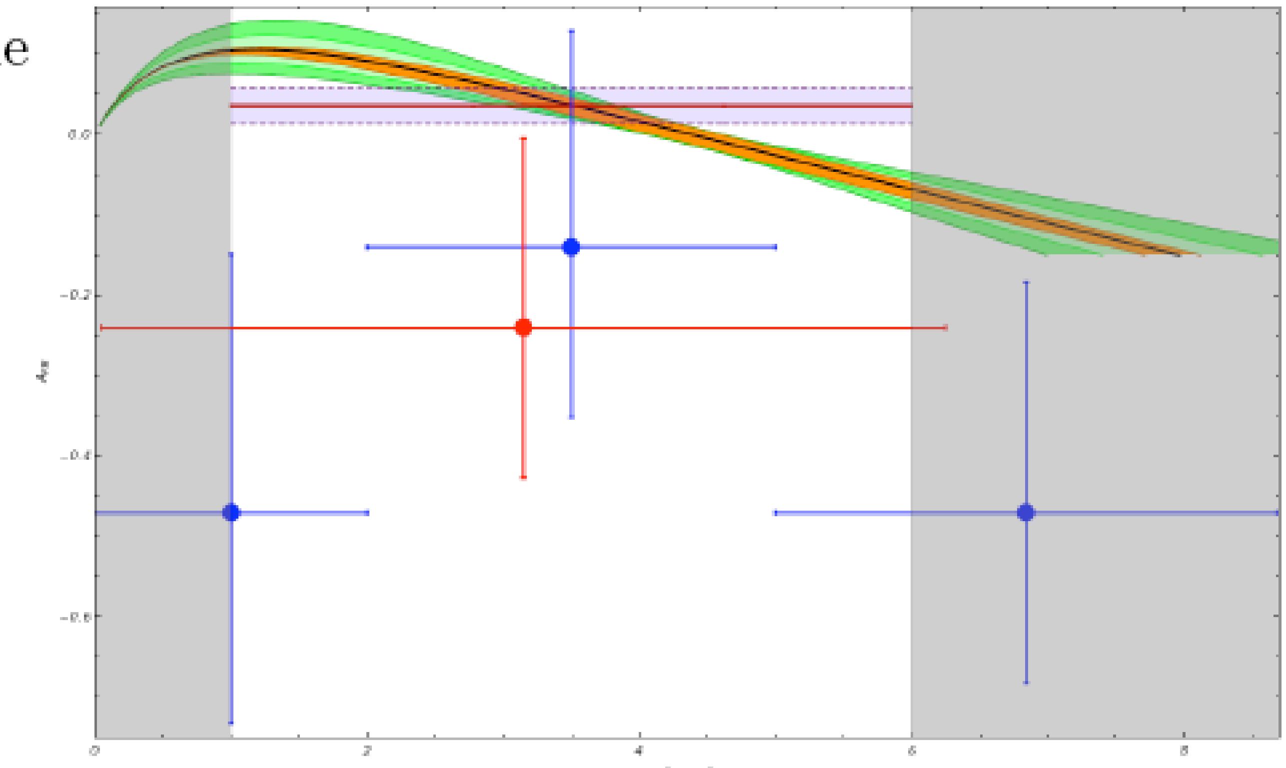




Agreement between the central values extracted from the fit and the theoretical input is reasonable

Polynomial of higher degree in fit needed in case of $100 fb^{-1}$

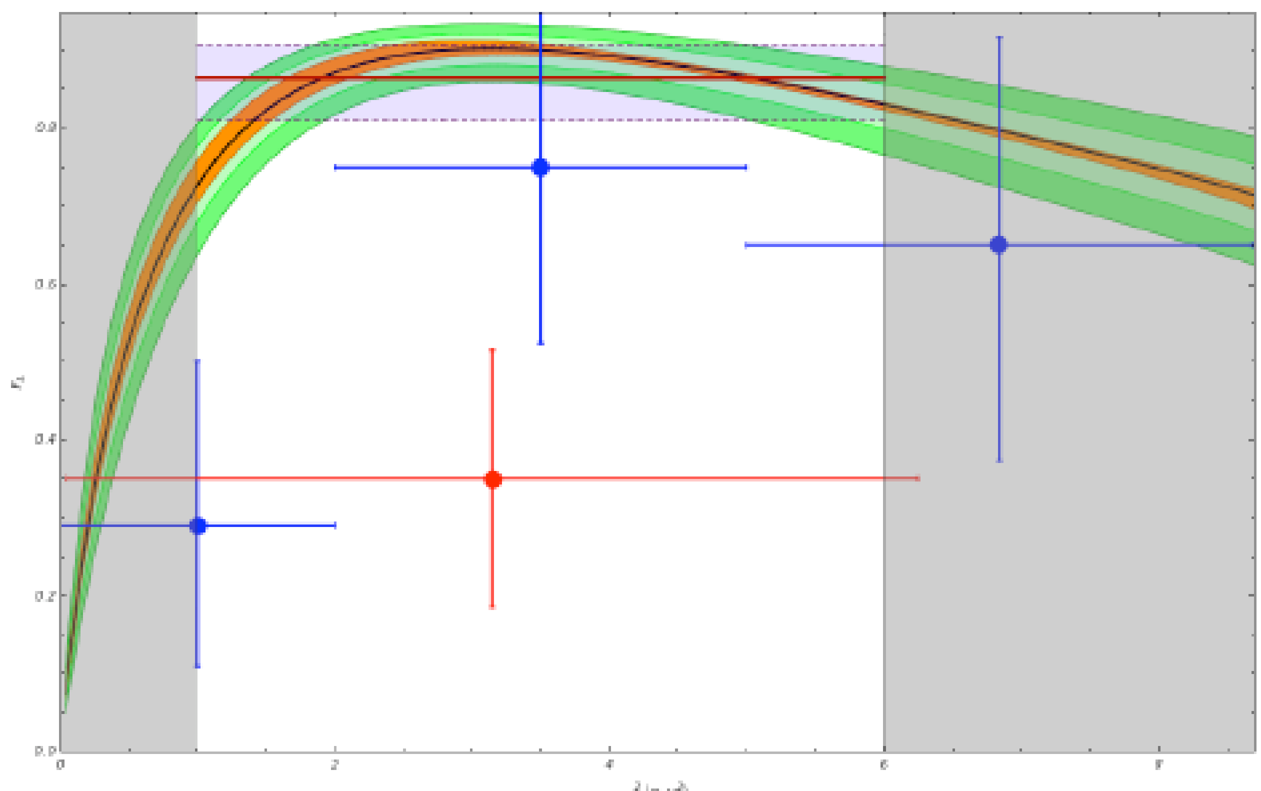
old observables : data available



Babar FPCP 2008

Belle ICHEP 2008

$$A_{\rm FB}=\frac{3}{2}\frac{{\rm Re}(A_{\parallel L}A^*_{\perp L})-{\rm Re}(A_{\parallel R}A^*_{\perp R})}{|A_0|^2+|A_\parallel|^2+|A_\perp|^2}$$

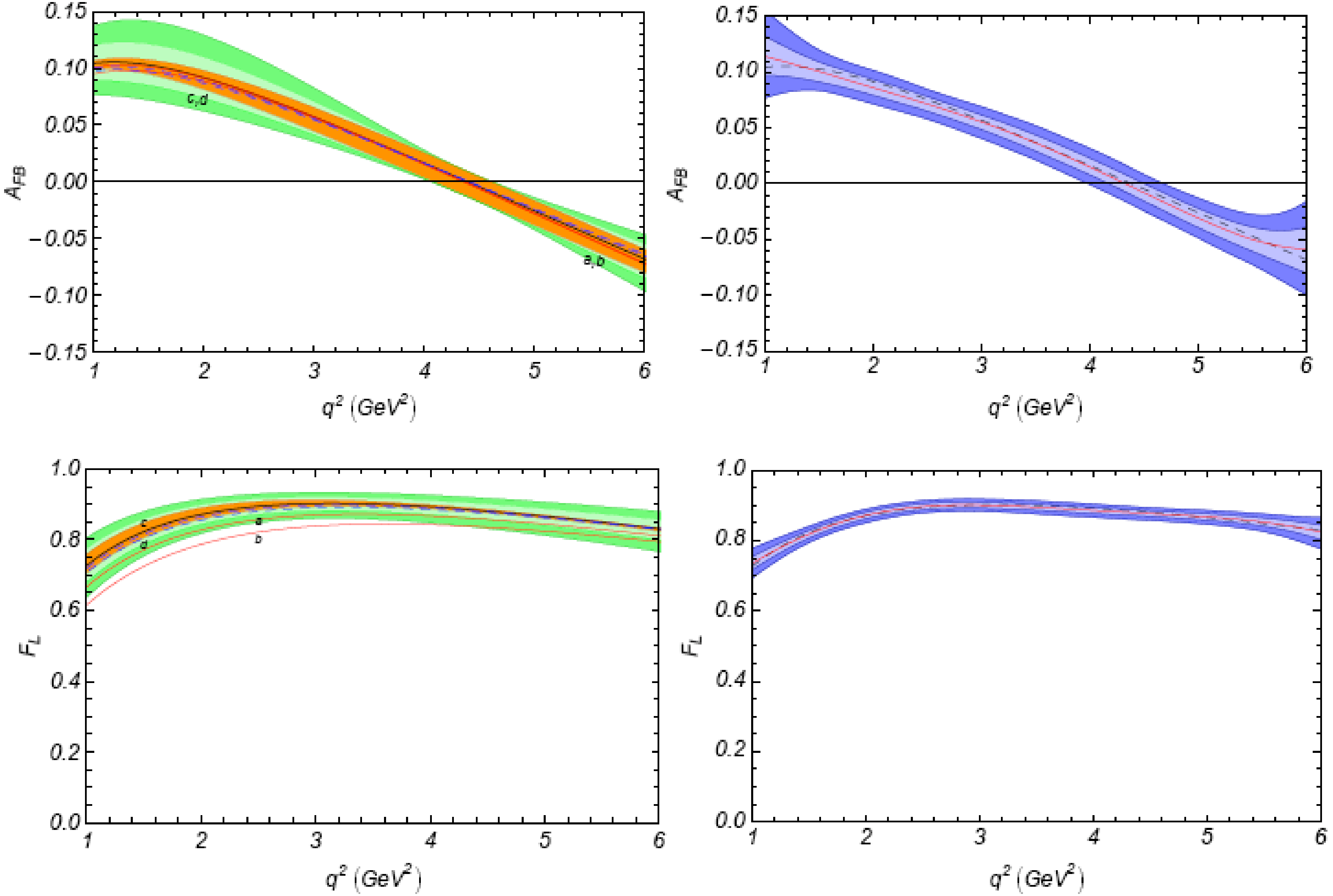


Babar FPCP 2008

Belle ICHEP 2008

$$F_L(s)=\frac{|A_0|^2}{|A_0|^2+|A_\parallel|^2+|A_\perp|^2}$$

LHCb ($10 fb^{-1}$) will clarify the situation



Side remark: Minimal Flavour Violation hypothesis

- MFV implies model-independent relations between FCNC processes

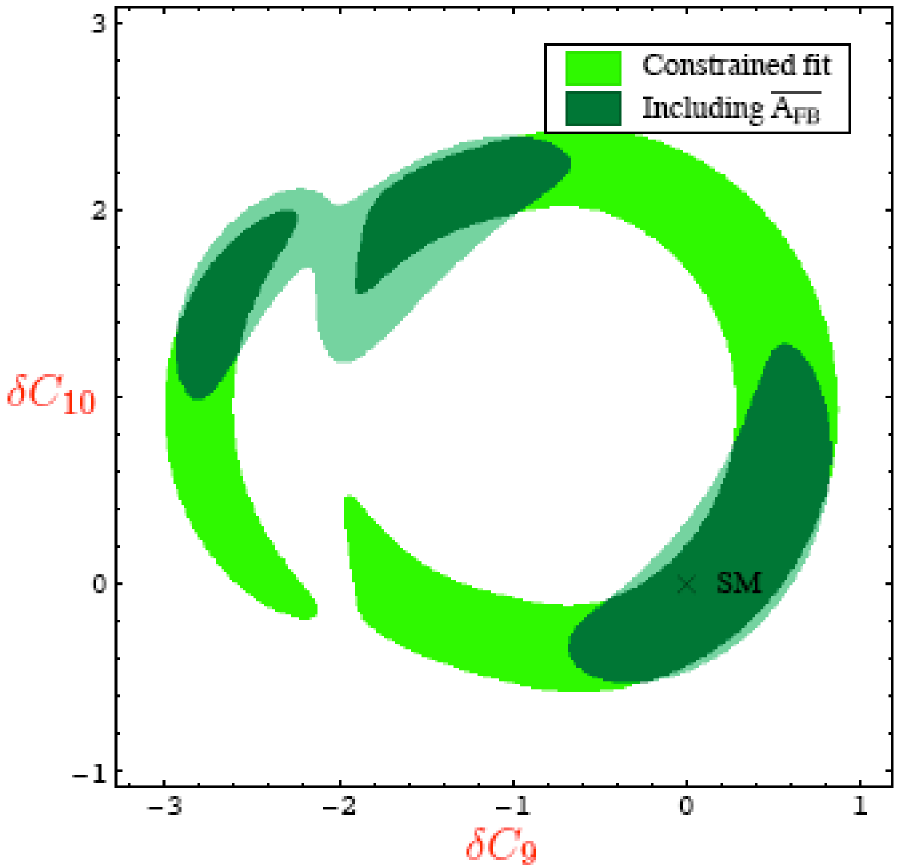
  $\Delta F = 2$ UTfit,arXiv:0707.0636 $\Delta F = 1$ H.,Isidori,Kamenik,Mescia,arXiv:0807.5039

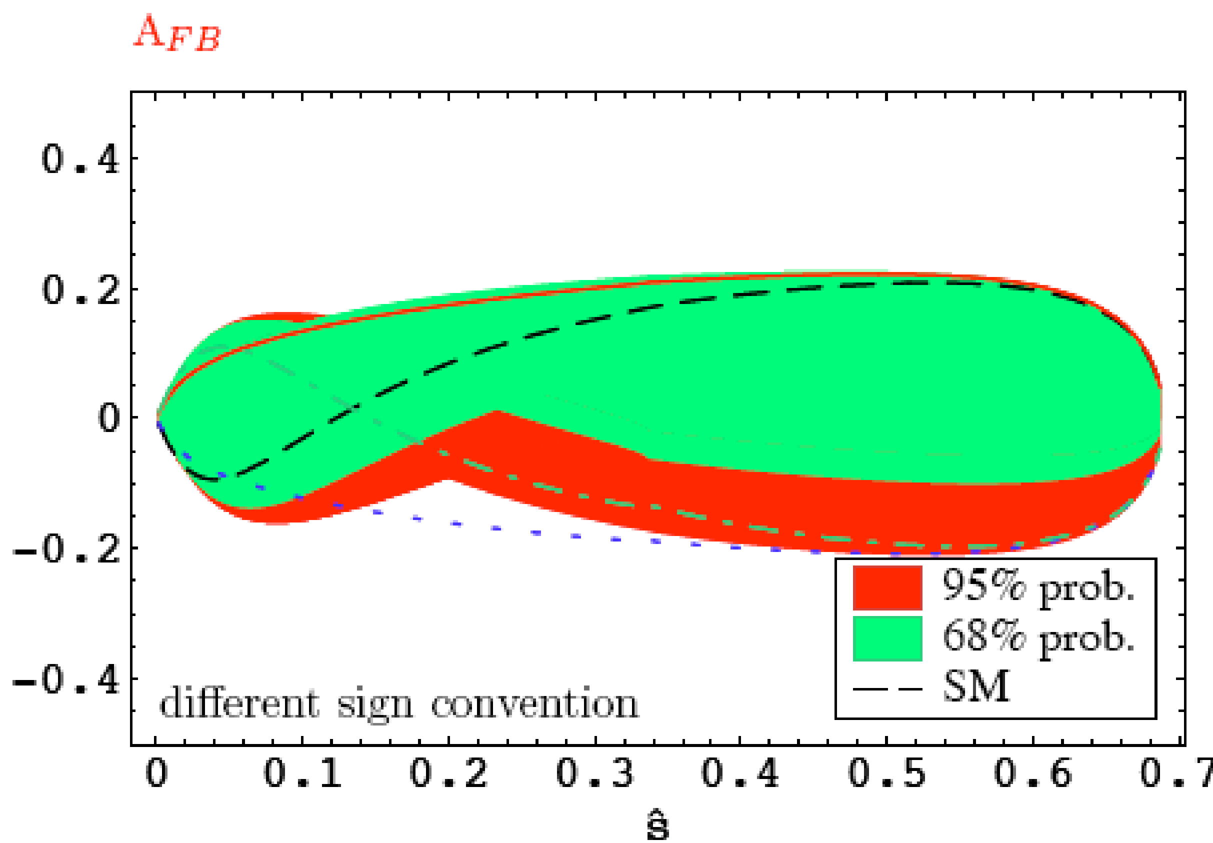
- The usefulness of MFV-bounds/relations is obvious; any measurement beyond those bounds indicate the existence of new flavour structures

$$\overline{B}_d \to \overline{K}^{*0}\mu^+\mu^-$$

Impact on MFV constraints (only Babar data included yet)

H.,Isidori,Kamenik,Mescia,arXiv:0807.5039





Remark:

* SuperLHCB/SuperB can offer more precision

  Crucial: theoretical status of Λ/m_b corrections has to be improved

Outlook:

* Angular distributions offer great opportunities in new physics search

* Sensitivity to other new physics operators, work in progress

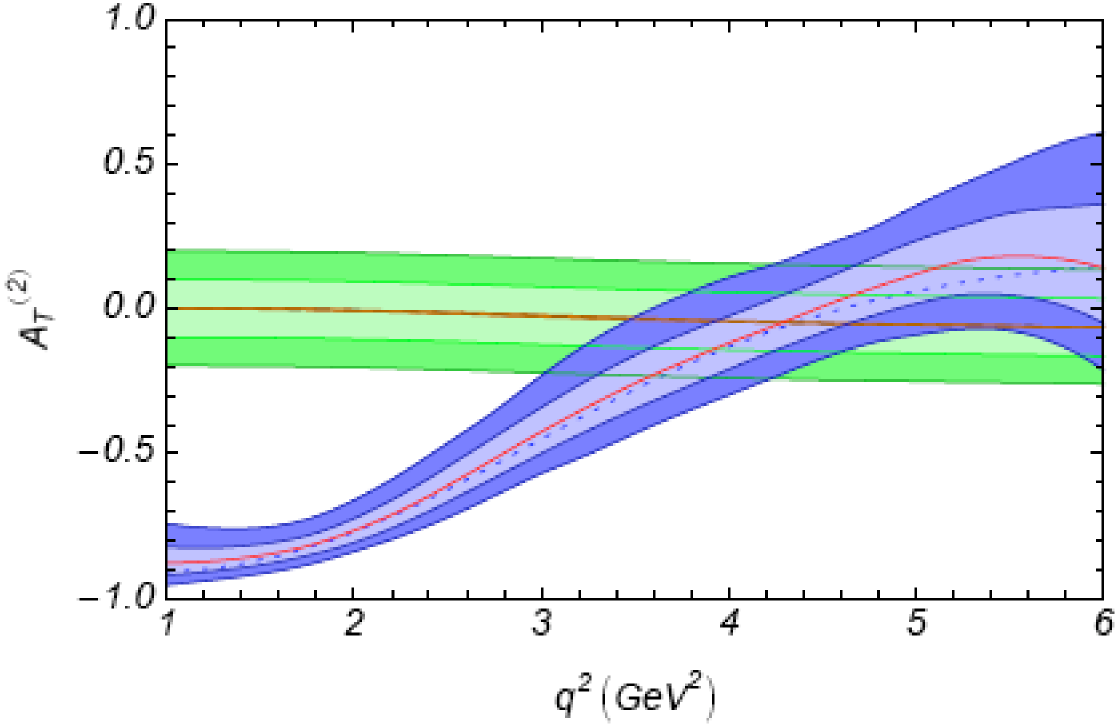
* Angular distributions allow for the measurement of 7 CP asymmetries

  (Krüger,Seghal,Sinha^2 2000,2005; Bobeth,Hiller,Piranishvili 2008)

Some slides for discussion session

More on right-handed currents

$A_T^{(2)}$

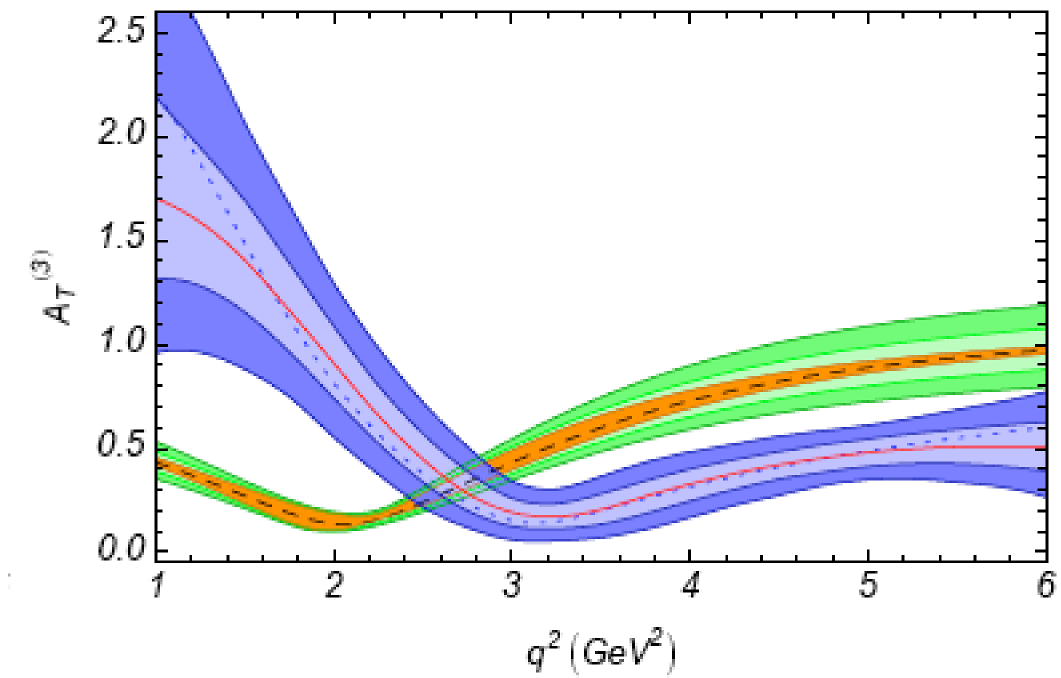


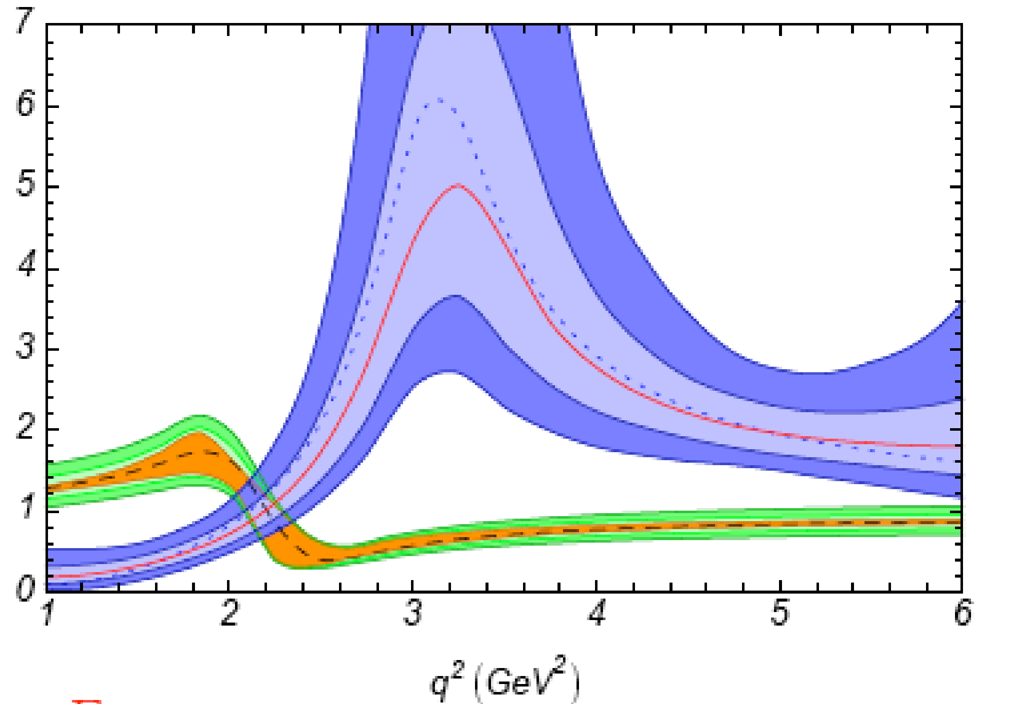
The experimental errors assuming SUSY scenario (b) with large-gluino mass and positive mass insertion, is compared to the theoretical errors assuming the SM.

Comparison between old and new observables

new observables

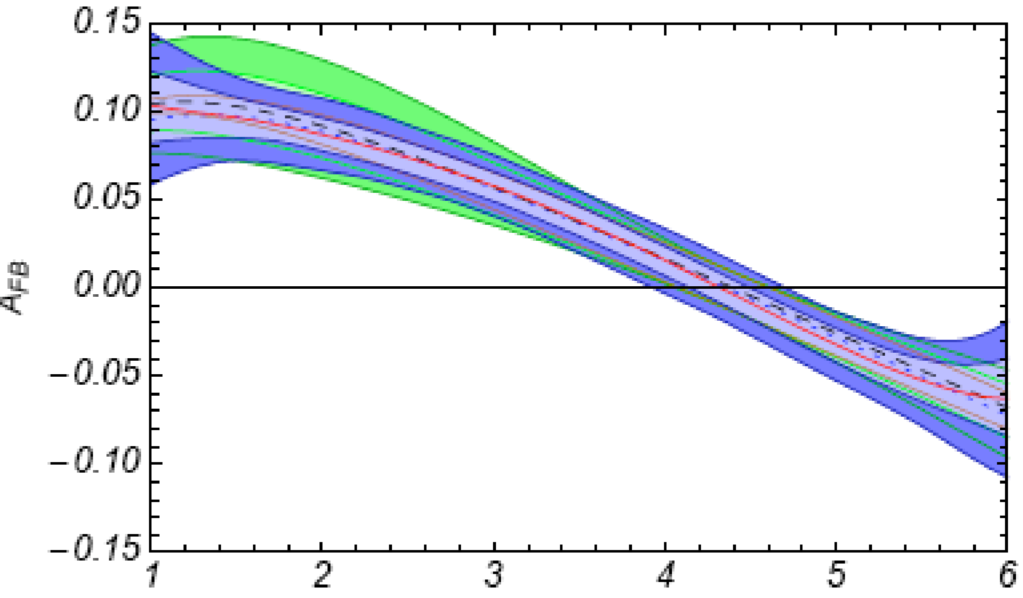
$A_T^{(3)}$ $A_T^{(4)}$

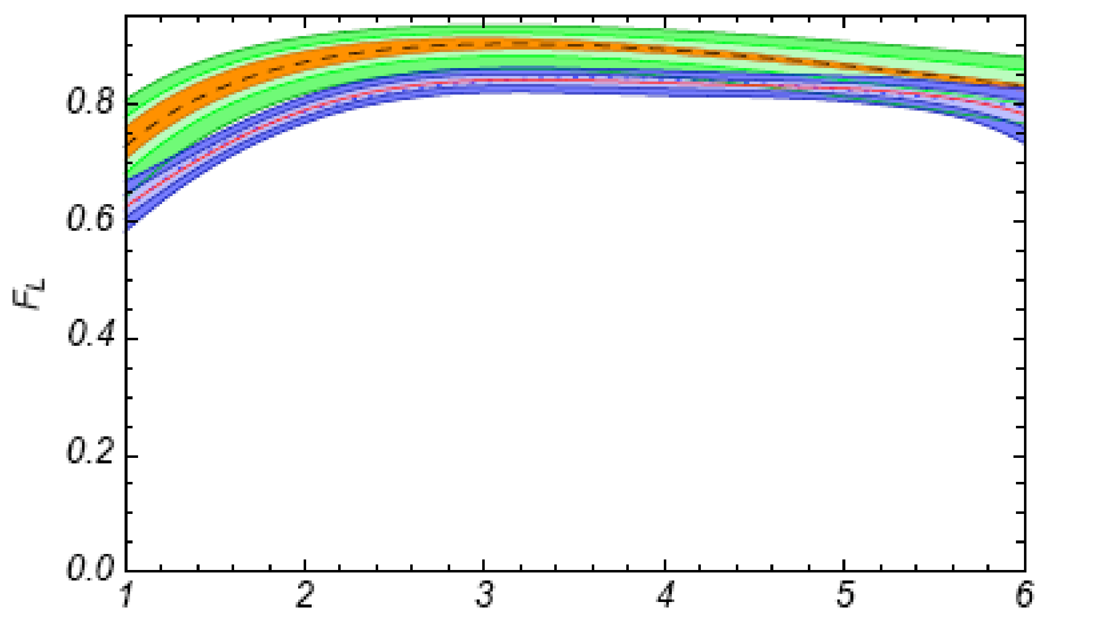




old observables

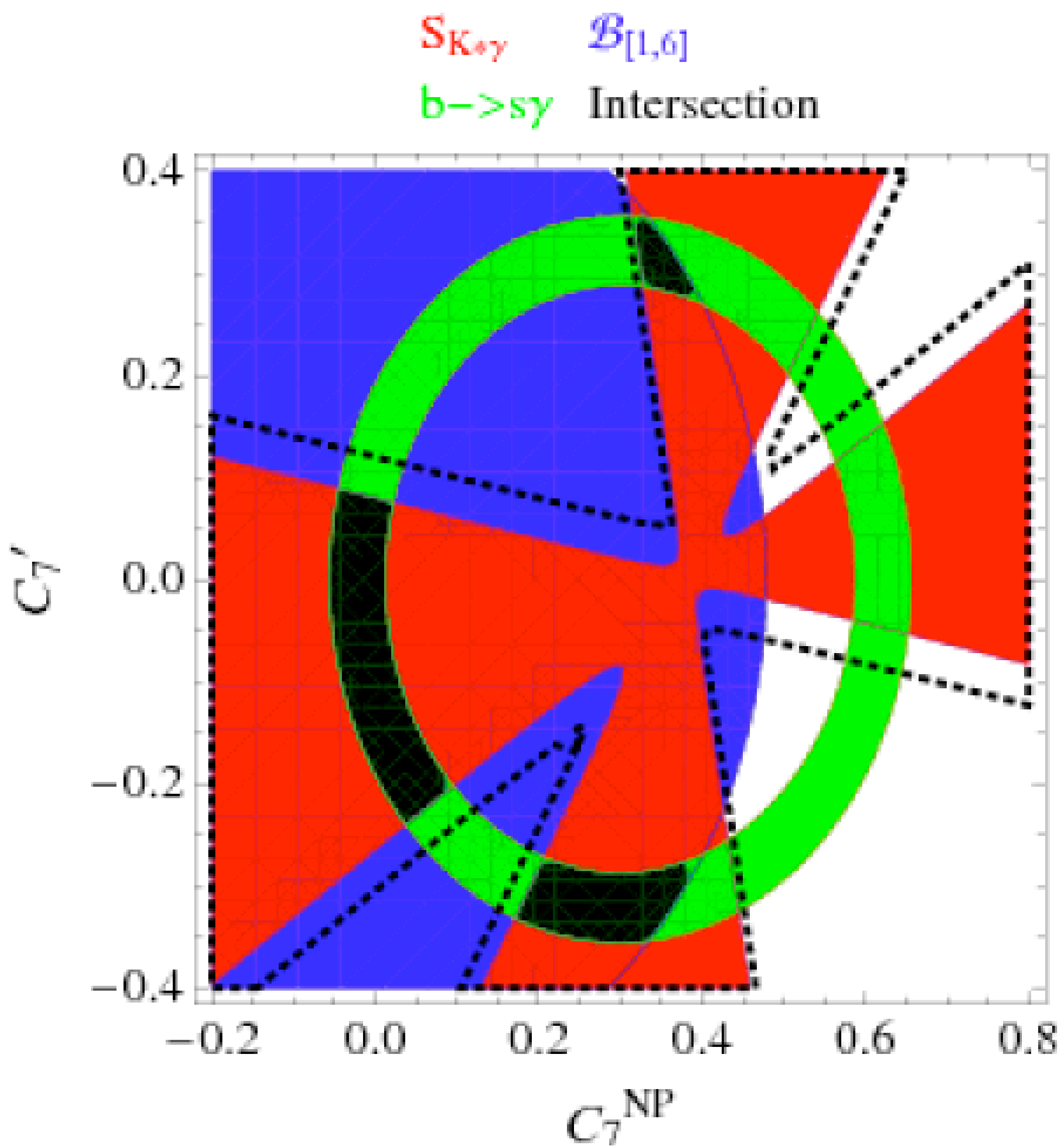
$A_{\rm FB}$ F_L





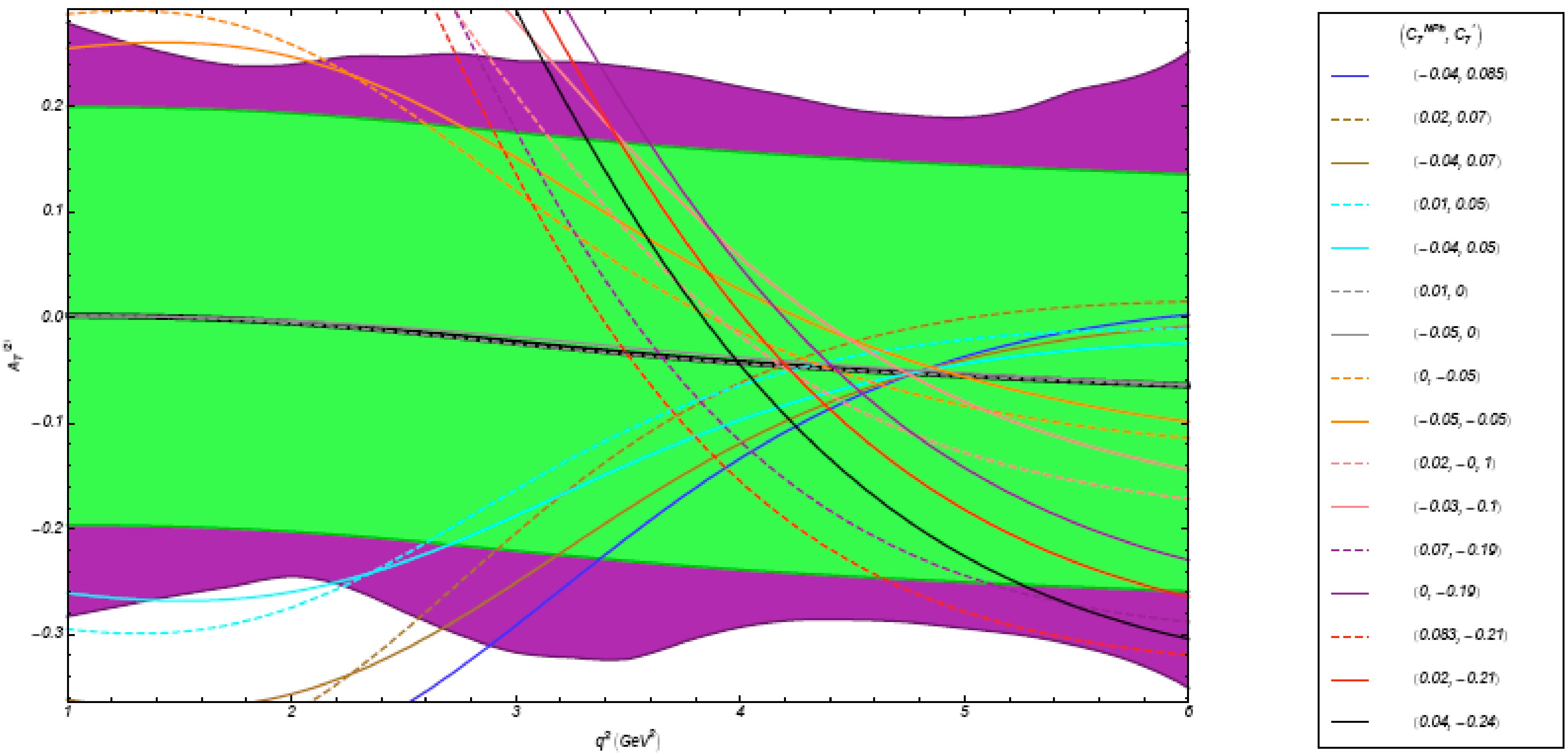
Present bounds on C_7 and C_7':

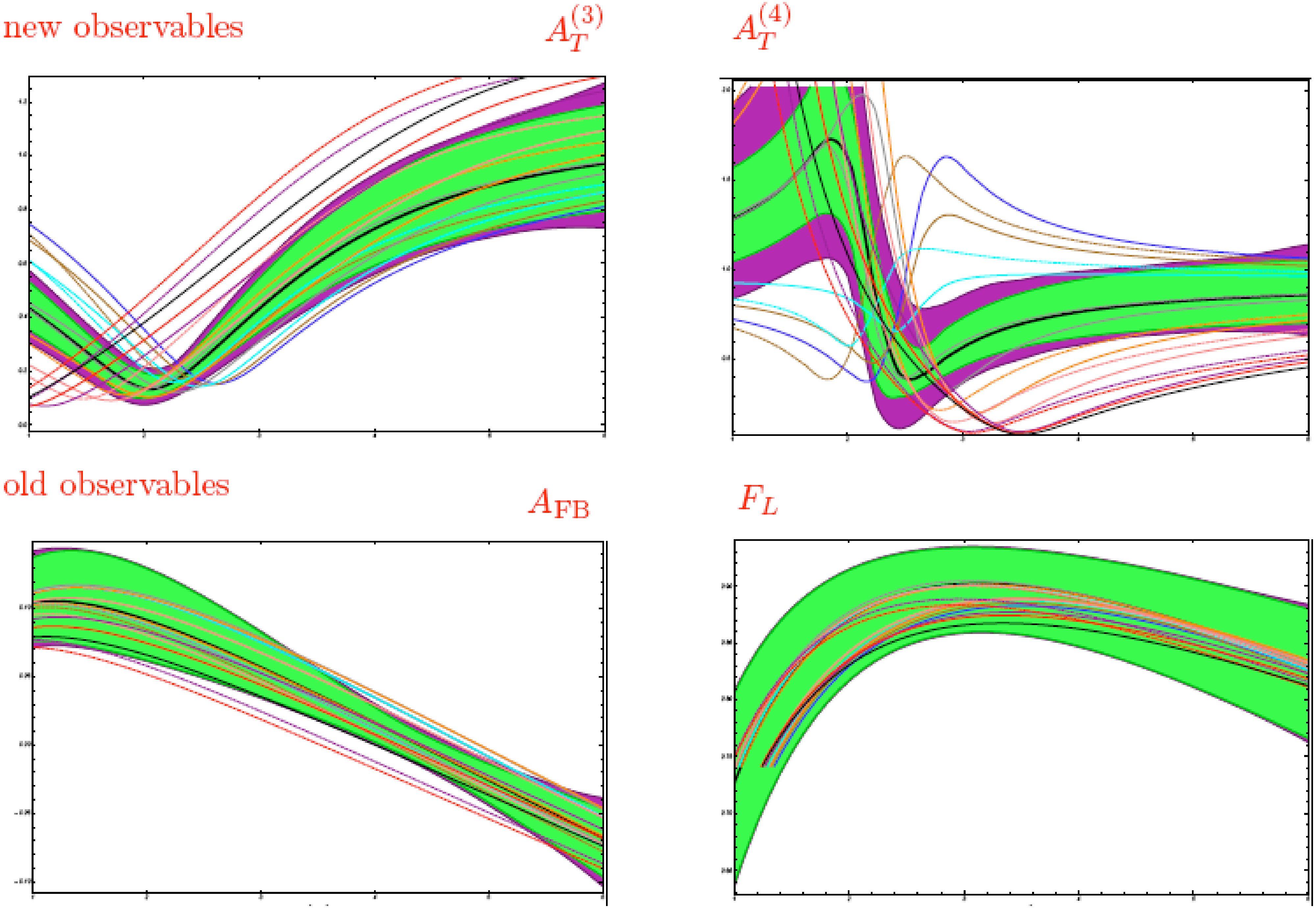
Bobeth et al, arXiv:0805.2525



Test of allowed region around $C_7' = 0$ in the C_7 and C_7' plane

$A_T^{(2)}$




new observables
$A_T^{(3)}$
$A_T^{(4)}$
old observables
A_{FB}
F_L

Present role of time-dependent CP asymmetry $B \to K^*\gamma$

Theoretical status of CP asymmetry

- General folklore: within the SM are small, $O(m_s/m_b)$

$$\mathcal{O}_{7L} \equiv \frac{e}{16\pi^2} m_b \, \bar{s}\sigma_{\mu\nu} P_R \, b F^{\mu\nu} \quad \mathcal{O}_{7R} \equiv \frac{e}{16\pi^2} m_{s/d} \, \bar{s}\sigma_{\mu\nu} P_L \, b F^{\mu\nu} \; .$$

  Mainly: $\bar{B} \to X_s \gamma_L$ and $B \to X_s \gamma_R$ $\Rightarrow$ almost no interference in the SM

- But: within the inclusive case the assumption of a two-body decay is made, the argument does not apply to $b \to s\gamma gluon$
  Corrections of order $O(\alpha_s)$, mainly due operator $\mathcal{O}_2$ $\Rightarrow \Gamma_{22}^{\text{brems}}/\Gamma_0 \sim 0.025$
  $\Rightarrow$ 11% right-handed contamination
  Grinstein,Grossman,Ligeti,Pirjol, hep-ph/0412019

- QCD sum rule estimate of the time-dependent CP asymmetry in $B^0 \to K^{*0}\gamma$ including long-distance contributions due to soft-gluon emission from quark loops versus dimensional estimate of the nonlocal SCET operator series:
  Ball,Zwicky,hep-ph/0609037 $\leftrightarrow$ Grinstein,Pirjol,hep-ph/0510104

$$S = -0.022 \pm 0.015^{+0}_{-0.01}, \; S^{sgluon} = -0.005 \pm 0.01 \leftrightarrow |S^{sgluon}| \approx 0.06$$

  Note: Expansion parameter is Λ_{QCD}/Q where Q is the kinetic energy of the hadronic part. There is no contribution at leading order. Therefore, the effect is expected to be larger for larger invariant hadronic mass, thus, the K^* mode has to have the smallest effect, below the 'average' 10%

Experiment: $S = 0.19 \pm 0.23$ (HFAG)

Future role of time-dependent CP asymmetry $B \to K^*\gamma$

$$S_{K^*\gamma} = -\frac{2|r|}{1+|r|^2} \sin\left(2\beta - \arg(C_7^{(0)} C_7')\right), \qquad r = C_7'/C_7^{(0)}$$

SuperB: $\Delta S = \pm 0.04$ arXiv:hep-ex/0406071

LHCb: $B_s \to \Phi\gamma$

$S_{\Phi\gamma} = 0 \pm 0.002$ $\sin(\phi_s)$! Muheim,Xie,Zwicky,arXiv:0802.0876

$A^{\Delta\Gamma}_{\Phi\gamma} = 0.047 \pm 0.025 + 0.015$ $\cos(\phi_s)$!

LHCb $(2fb^{-1})$: $\Delta A = 0.22$ Golutvin et al., LHCb-PHYS-2007-147