$B \to K^* \ell^+ \ell^-$ decay at the low-q^2 endpoint

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Interest & problems at very low q^2

- The contribution of $\mathcal{O}_7^{(\prime)}$ is enhanced by $1/q^2$
  Sensitivity to BSM right-handed FCNC?
  Melikhov, Nikitin & Simula'98, . . . Lunghi&Matias'06, Becirevic *et al.*'12
- Factorization breaks down at $q^2 \to 0$
  Hadron (light resonances) pollution in the observables?
  Beneke, Feldmann & Seidel (BFS)'01

Our Goal:

- Discuss cleanness around the low-q^2 end-point
- Estimate uncertainties

Helicity amplitudes

$$H_{\lambda,L} = \mathcal{M}(\bar{B}^0 \to \bar{K}^{*0}(\lambda)\gamma^*(\lambda)), \qquad \lambda = +,-,0$$

$$A_\perp = \frac{1}{\sqrt{2}}(H_+ - H_-)\,, \qquad A_\parallel = \frac{1}{\sqrt{2}}(H_+ - H_+)$$

- In the **SM** ...

$$H_+ \simeq \Lambda_{\mathrm{QCD}}/m_b$$

... due to

  - $V - A$ structure of the flavor-changing weak interactions
  - Helicity conservation iof QCD at high energies

Detect BSM right-handed FCNC currents

- Understand the $\Lambda_{\mathrm{QCD}}/m_b$ uncertainties in the SM!!
  - Work in the helicity basis!

$\bar{B} \to \bar{K}^* \ell^+ \ell^-$ amplitude up to $\alpha_{\rm em}^2 \ldots$

$$\mathcal{A}(\bar{B} \to V \ell^- \ell^+) = \sum_i C_i \langle \ell^- \ell^+ | \bar{l} \Gamma_i l | 0 \rangle \langle V | \bar{s} \Gamma_i' b | \bar{B} \rangle + \frac{e^2}{q^2} \langle \ell^- \ell^+ | \bar{l} \gamma^\mu l | 0 \rangle F.T. \langle V | T(j_{\mu,\rm em}^{\rm had}(x) \mathcal{H}_W^{\rm had}(0)) | \bar{B} \rangle$$

We have 2 types of uncertainties

- Hadronic parameters (**form factors**)
  - **QCDf** + estimated power-corrections BFS'01, Egede *et al.*'08
  - Theoretical prediction (LCSRs) Altmannshofer *et al.*'09
- Non-local contribution from $\mathcal{H}_W^{\rm had}$ in **QCDf**
  - Non-factorizable charm-loop effects BFS'01, Khodjamiran *et al.*'10
  - Non-factorizable light-quark effects BFS'01

Re-asses uncertainties at low-q^2

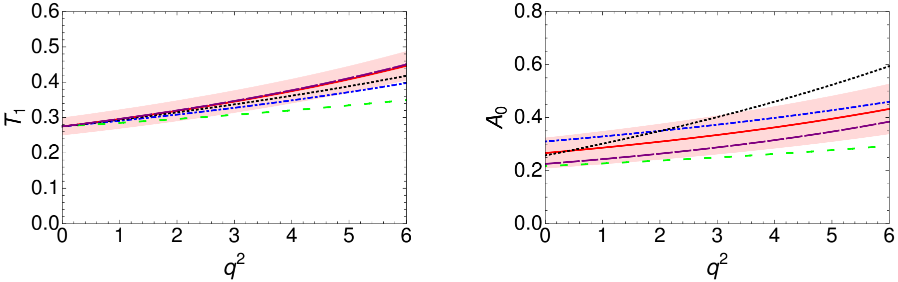
Form factors

$$
\begin{aligned}
-im_B V_\lambda(q^2) &= \langle M(\lambda)|\bar{s}\not{\epsilon}^*(\lambda)P_L b|\bar{B}\rangle, \\
m_B^2 T_\lambda(q^2) &= \epsilon^{*\mu}(\lambda)q^\nu\langle M(\lambda)|\bar{s}\sigma_{\mu\nu}P_R b|\bar{B}\rangle, \\
im_B S(q^2) &= \langle M(\lambda=0)|\bar{s}P_R b|\bar{B}\rangle
\end{aligned}
$$

(similar to Bharucha *et al.*'10)

- **Form factors** in the **helicity basis**
  - $T_\pm$ related to $T_{1,2}$, T_0 related to $T_{2,3}$
  - $V_\pm$ related to V, A_1 and V_0 to $A_{1,2}$, S related to A_0
- These form factors verify

$$
\begin{aligned}
T_+(q^2) &= \mathcal{O}(q^2)\times\mathcal{O}(\Lambda/m_b), \\
V_+(q^2) &= \mathcal{O}(\Lambda/m_b).
\end{aligned}
$$



- We use HQ-LE relations (Beneke&Feldmann'01)

$$\xi_\perp(0) = T_1(0) = 0.275(26), \qquad \xi_\parallel(0) = \frac{2m_{K^*}}{m_B} A_0(0) = 0.09(2)$$

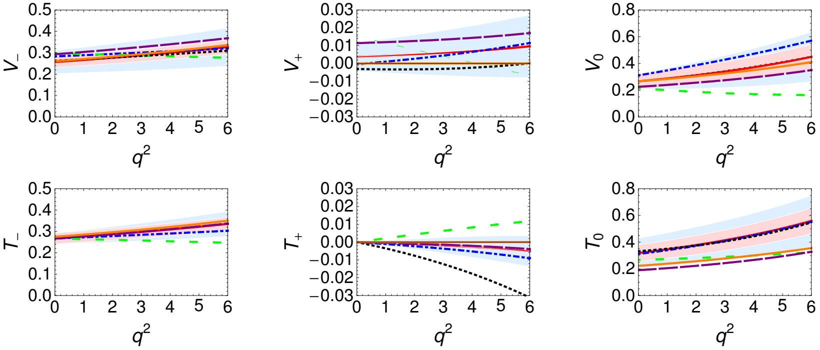
- We fix (for numerics) $\xi_\perp(0)$ with $\mathcal{B}(\bar{B}^0 \to K^{*0}\gamma)_{\rm expt}$ and $C_7^{\rm SM}$ (BFS'01)
- We fix $\xi_\parallel(0)$ using (normalized) theoretical predictions on A_0
  - **Light-cone SRs** (Ball&Zwicky'05, Khodjamirian *et al.*'10)
  - **QCD SRs** (Colangelo *et al.*'96)
  - **Dyson-Schwinger** (Ivanov *et al.*'07)

Factorizable power-corrections

- Power corrections to the HQ-LE relations

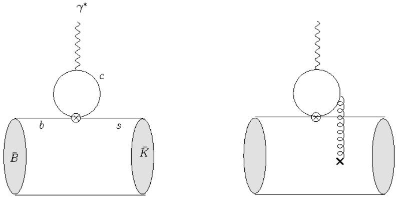
$$F^{\mathrm{p.c.},\pm} = \pm a_F \pm b_F \frac{q^2}{m_B^2}$$

a_F and $b_F \equiv$spread of th.predictions



$T_+(q^2)$ has a negligible uncertainty at low q^2 ($a_{T_+} \equiv 0$!)

Non-factorizable charm-loop contribution



- The LHS diagram and α_s corrections are treated in **QCDf** (BFS'01)
- Soft-gluon contributions: $\delta H_- \sim 8\% C_7^{eff}$ (Khodjamirian *et al.*'10)
- For the numerics, our NF charm-loop uncertainty is

$$\delta H_- = (0.1 \times C_7^{eff}) e^{i\phi_-}, \qquad \delta H_+ = (0.1 \times C_7^{eff} \times \Lambda/m_b) e^{i\phi_+}$$

Recent discussion in Becirevic *et al.*'12 and JMC and Jäger, to appear

Non-factorizable light-quark contribution

$$a_\mu^{\rm had,\,l-q} = \int d^4x\, e^{-iq\cdot x} \langle K^* | T\{ j_\mu^{\rm em,\,l-q}(x),\, H_W^{\rm had}(0)\} | B\rangle$$

Probing the *hadronic* structure of the photon! BFS'01

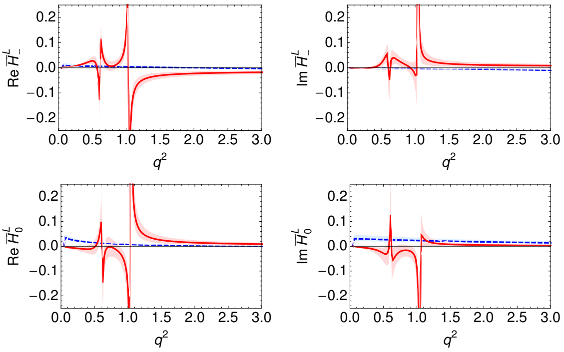
$$a_\mu^{\rm had,\,l-q} \equiv \int d^4x\, e^{-iq\cdot x} \sum_{P,P'} \langle 0 | j_\mu^{\rm em,\,l-q}(x) | P'\rangle \langle P'(x) | P(0)\rangle \langle K^* P | H_W^{\rm had}(0) | B\rangle$$

- We assume **Vector-Meson Dominance** P, $P' \equiv \rho^0, \omega, \phi$ (Korchin *et al.*'10)
  - $\langle 0 | j_\mu^{\rm em,\,l-q}(x) | P'\rangle \equiv f_V$
  - $\langle P'(x) | P(0)\rangle \equiv$(Dressed) V propagator
  - $\langle K^* P | H_W^{\rm had}(0) | B\rangle \equiv B \to V K^{*0}$ computed in **QCDf** (Beneke *et al.*'06*)
- We treat these contributions as **uncertainties**

* **QCDf** predictions are consistent within errors with experimental data

$$H^{0,\pm}_{\mathrm{sl},\,L,R} = \frac{\alpha_{\mathrm{em}}\, G_F\, \lambda_t}{2\sqrt{2}} \overbrace{\frac{8\pi\, Q_V\, f_{K^*}\, f_V}{(q^2 - m_V^2 + i m_V \Gamma_V)}}^{F(q^2)} \left(\frac{m_B}{m_V}\right) H_V^{0,\pm}$$

- $H_V^{0,\pm}$ *CKM* suppressed or hadronic-penguin dominated: $\lambda \sim \mathcal{O}(0.01)$
- However in $\sqrt{q^2} \sim m_V$ and $\Gamma_{\phi,\omega} \sim 1$ MeV$\rightarrow$ $F(q^2)$ is $\sim \mathcal{O}(100)$



- ***V−A* structure of the hadronic weak decays**

$$H_V^0 : H_V^- : H_V^+ = 1 : \frac{\Lambda}{m_b} : \left(\frac{\Lambda}{m_b}\right)^2$$

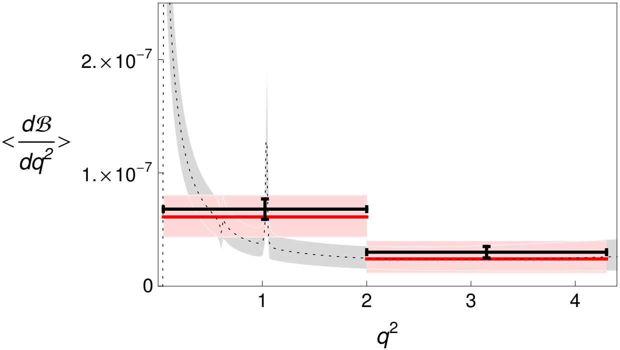
- **Binned results**

$$\begin{aligned} |\mathcal{M}_{\mathrm{T}}|^2 &= |\mathcal{M}|^2 + \lambda^2 F(q^2)^2 |\mathcal{M}'|^2 \\ &+ 2\lambda F(q^2)\left\{(q^2 - m_V^2)\mathrm{Re}[\mathcal{M}^*\mathcal{M}'] + m_V\,\Gamma_V\,\mathrm{Im}[\mathcal{M}^*\mathcal{M}']\right\} \end{aligned}$$

  - Relative contibution in q^2-integrals is suppressed by $\sim m_V\Gamma_V/\Delta q^2$ ($m_{\omega\phi}\Gamma_{\omega,\phi} \sim 0.005$ GeV^2)

- Hadronic contributions
  - **Do not pollute H_+!**
  - **Get diluted in binned results!**

Differential decay rate



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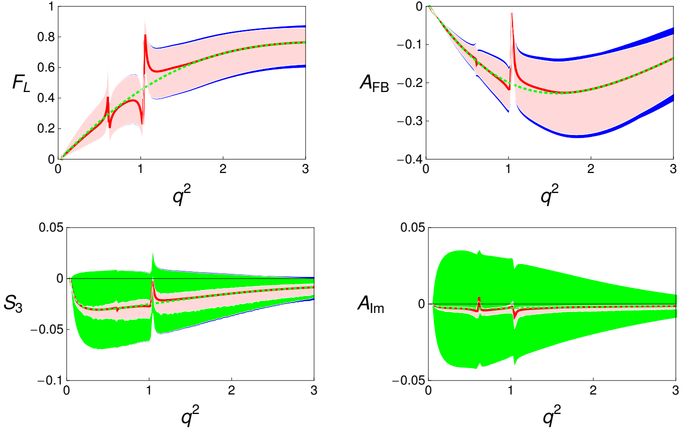
	Theo. μ	Expt.
[0.05,0.5]	$1.43^{+0.36}_{-0.35}$	–
[0.05,2]	$0.61^{+0.18}_{-0.16}$	$0.68 \pm 0.07 \pm 0.05$
[2,4.3]	$0.24^{+0.15}_{-0.12}$	$0.30 \pm 0.05 \pm 0.02$
[1,6]	$0.27^{+0.14}_{-0.12}$	$0.42 \pm 0.04 \pm 0.04$

F_L and asymmetries



- We have separated the uncertainties into
  - Soft-form factors and other hadronic uncertainties
  - Factorizable power corrections
  - Non-factorizable charm-loop contribution

Binned observables

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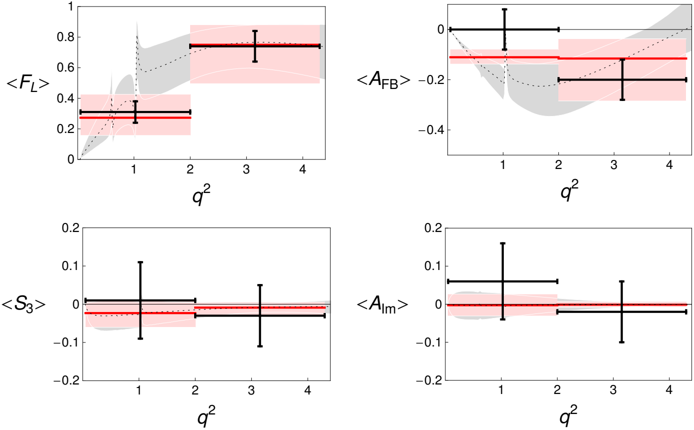


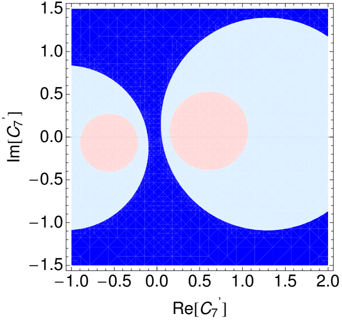
Binned theoretical results compared TO LHCb data

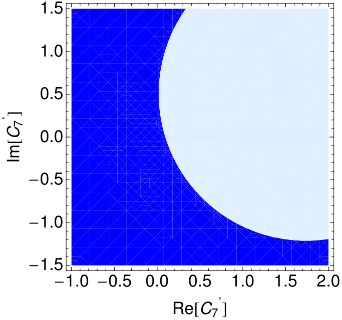
- Th. uncertainty in S_3 and A_{Im} is dominated by charm-loop!

Example of a contour plot for C_7'

- Fits of $\{\mathrm{Re}[C_7'], \mathrm{Im}[C_7']\}$ to LHCb data on S_3

Δq^2 [GeV^2]	[0.05, 2]	[1, 6]





The interval at the end-point has more sensitivity C_7'