Signal of right handed currents using $B \to K^* \ell^+ \ell^-$ observables at kinematic endpoint

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Rare B Decays: Theory and Experiment 2016

Barcelona

18-20 April 2016

Anirban Karan, Rusa Mandal, Abinash K. Nayak, R.S. and Thomas E. Browder, arXiv:1603.04355

Apologies for incomplete citations. Happy to add citations. Please let me know

13 April 2016

Why $B \to K^* \ell^+ \ell^-$?

1. *Penguin process. Rare FCNC decay. Good place to look for NP.*
2. *One has a large number of related observables each measured as a function of the dilepton invariant mass. This mode that get contribution from variety of operators i.e. various new particles in the loop*
3. *Clean mode. Can be studied in a manner where there is almost none or reduced hadronic uncertainty.* *J. Matias et.al Das, Mandal, R.S. …*
4. *Several asymmetries $(A_4, A_5, A_{FB} \ldots)$ can be measured which are sensitive to NP via interference as linear effects.*

Matrix element for $B \to K^* \ell^+ \ell^-$

The decay mode

$$B(p) \to K^*(k)\ell^-(q_1)\ell^+(q_2) \to K(k_1)\pi(k_2)\ell^-(q_1)\ell^+(q_2)$$

$$q = q_1 + q_2 = p - k$$

$$\mathcal{M} = \frac{G_F \alpha}{\sqrt{2}\pi} V_{tb} V_{ts}^* \{ C_9 \langle K^* | \bar{s}\gamma^\mu P_L b | \bar{B} \rangle \bar{\ell}\gamma_\mu \ell + C_{10} \langle K^* | \bar{s}\gamma^\mu P_L b | \bar{B} \rangle \bar{\ell}\gamma_\mu \gamma_5 \ell - \frac{2m_b}{q^2} C_7 \underbrace{\langle K^* | \bar{s} i \sigma^{\mu\nu} q_\nu P_R b | \bar{B} \rangle}\bar{\ell}\gamma_\mu \ell \}$$

Wilson coefficients

C_7, C_9, C_{10}

Hadronic matrix element – challenge to reliably calculate.

Estimated in various theories: LCSR, Lattice QCD, HQET, LEET … tremendous effort in past literature

Unfortunately simple picture of decay presented above is not accurate enough

Non-local contributions

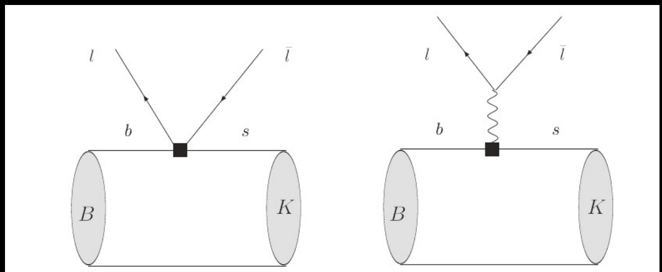
Exist additional non-factorizable and long-distance contributions
Electromagnetic corrections of purely hadronic operators
⇒ Complete Hamiltonian

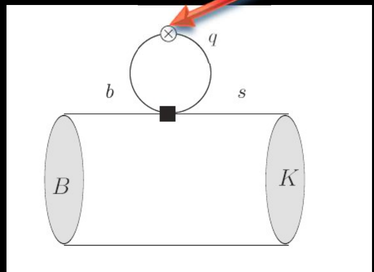
$$A(B(p) \to K^*(k)\ell^+\ell^-)$$
$$= \frac{G_F\alpha}{\sqrt{2}\pi} V_{tb}V_{ts}^* \Bigg[\Bigg\{ C_9 \langle K^*|\bar{s}\gamma^\mu P_L b|\bar{B}\rangle - \frac{2C_7}{q^2}\langle K^*|\bar{s}i\sigma^{\mu\nu}q_\nu(m_b P_R + m_s P_L)b|\bar{B}\rangle$$
$$- \frac{16\pi^2}{q^2}\sum_{i=\{1-6,8\}} C_i \mathcal{H}_i^\mu \Bigg\} \bar{\ell}\gamma_\mu\ell + C_{10}\langle K^*|\bar{s}\gamma^\mu P_L b|\bar{B}\rangle \bar{\ell}\gamma_\mu\gamma_5\ell \Bigg]$$

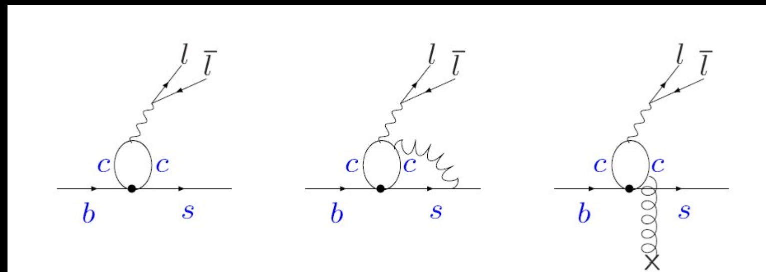
nonlocal hadronic matrix elements

M. Beneke and T. Feldmann, Nucl. Phys. B 592 (2001) 3
A. Khodjamirian, T. Mannel, A. A. Pivovarov and Y.-M. Wang, JHEP 1009, 089 (2010).
A. Khodjamirian arXiv:1312.6480

non-local contribution







Hadronic matrix elements

Lorentz invariance to write the most general form of the Matrix element

$$\langle K^*(\epsilon^*,k)|\bar{s}\gamma^\mu P_L b|B(p)\rangle$$
$$= \epsilon^*_\nu\left(\mathcal{X}_0 q^\mu q^\nu + \mathcal{X}_1\left(g^{\mu\nu} - \frac{q^\mu q^\nu}{q^2}\right) + \mathcal{X}_2\left(k^\mu - \frac{k.q}{q^2}q^\mu\right)q^\nu + i\mathcal{X}_3\epsilon^{\mu\nu\rho\sigma}k_\rho q_\sigma\right)$$

Vector current conserved and only the $\mathcal{X}_0$ term in divergence of axial part survives.

$$\left\langle K^*(\epsilon^*,k)\middle|i\bar{s}\sigma^{\mu\nu}q_\nu P_{R,L}b\middle|B(p)\right\rangle$$
$$= \epsilon^*_\nu\left(\pm\mathcal{Y}_1\left(g^{\mu\nu} - \frac{q^\mu q^\nu}{q^2}\right) \pm \mathcal{Y}_2\left(k^\mu - \frac{k.q}{q^2}q^\mu\right)q^\nu + i\mathcal{Y}_3\epsilon^{\mu\nu\rho\sigma}k_\rho q_\sigma\right)$$

Ensure that $q_\mu\left\langle K^*(\epsilon^*,k)\middle|i\bar{s}\sigma^{\mu\nu}q_\nu P_{R,L}b\middle|B(p)\right\rangle = 0$

Nonlocal hadronic matrix elements

$$\mathcal{H}^\mu_i = \left\langle K^*(\epsilon^*,k)\middle|i\int d^4x\, e^{iq.x}\, T\{j^\mu_{em}(x),\mathcal{O}_i(0)\}\middle|B(p)\right\rangle$$
$$= \epsilon^*_\nu\left(\mathcal{Z}^i_1\left(g^{\mu\nu} - \frac{q^\mu q^\nu}{q^2}\right) + \mathcal{Z}^i_2\left(k^\mu - \frac{k.q}{q^2}q^\mu\right)q^\nu + i\mathcal{Z}^i_3\,\epsilon^{\mu\nu\rho\sigma}k_\rho q_\sigma\right)$$

Effects of non-factorizable contributions

$$-\frac{16\,\pi^2}{q^2}\sum_{i=\{1-6,8\}} C_i\,\frac{\mathcal{Z}_j^i}{\mathcal{X}_j} = \Delta C_9^{(\mathrm{fac})}(q^2) + \Delta C_9^{j,(\mathrm{non-fac})}(q^2) \quad j = 1,2,3$$

$$C_9 \to C_9^j = C_9 + \Delta C_9^{(\mathrm{fac})}(q^2) + \Delta C_9^{j,(\mathrm{non-fac})}(q^2)$$

$$\frac{2(m_b + m_s)}{q^2}\,C_7\mathcal{Y}_j \to \tilde{\mathcal{Y}}_j = \frac{2(m_b + m_s)}{q^2}\,C_7\mathcal{Y}_j + \cdots$$

factorizable & non factorizable contributions

Effective helicity index due to non-factorizable corrections in C_9:

$$C_9^{\perp} \equiv C_9^{(3)},\, C_9^{\parallel} \equiv C_9^{(1)},\, C_9^{0} \equiv C_9^{(2)}\kappa$$

$$\kappa = 1 + \frac{C_9^{(1)} - C_9^{(2)}}{C_9^{(2)}}\,\frac{4\,k.q\mathcal{X}_1}{4\,k.q\mathcal{X}_1 + \lambda(m_B^2, m_{K^*}^2, q^2)\mathcal{X}_2}$$

The seven amplitudes can be written in terms of the form-factors $\mathcal{X}_{0,1,2,3}$ *and* $\mathcal{Y}_{1,2,3}$

$$\mathcal{A}_{\perp}^{L,R} = \sqrt{2}\, N \sqrt{\lambda(m_B^2, m_{K^*}^2, q^2)}\left[(C_9^{\perp} \mp C_{10})\mathcal{X}_3 - \tilde{\mathcal{Y}}_3\right]$$

$$\mathcal{A}_{\parallel}^{L,R} = 2\sqrt{2}\, N\left[\left(C_9^{\parallel} \mp C_{10}\right)\mathcal{X}_1 - \zeta_0 \tilde{\mathcal{Y}}_1\right]$$

$$\mathcal{A}_0^{L,R} = \frac{N}{2m_{K^*}\sqrt{q^2}}\begin{bmatrix} (C_9^0 \kappa \mp C_{10})\left(4\, k.q\mathcal{X}_1 + \lambda\left(m_B^2, m_{K^*}^2, q^2\right)\mathcal{X}_2\right) \\ -\zeta_0\left(4\, k.q\tilde{\mathcal{Y}}_1 + \lambda\left(m_B^2, m_{K^*}^2, q^2\right)\tilde{\mathcal{Y}}_2\right) \end{bmatrix}$$

$$\mathcal{A}_t = -\frac{N}{m_{K^*}}\sqrt{q^2}\sqrt{\lambda(m_B^2, m_{K^*}^2, q^2)}\; C_{10}\mathcal{X}_0 \qquad \zeta_0 = \frac{m_b - m_s}{m_b + m_s}$$

Vanishes in the limit of of massless lepton. Can be safely ignored for large q^2.

Note the amplitude $\mathcal{A}_{0,\parallel,\perp}^{L,R}$ *have the form:*

$$\mathcal{A}_{\lambda}^{L,R} = C_{L,R}^{\lambda}\mathcal{F}_{\lambda} - \tilde{\mathcal{G}}_{\lambda} = \left(C_9^{\lambda} \mp C_{10}\right)\mathcal{F}_{\lambda} - \tilde{\mathcal{G}}_{\lambda}$$

where

$$\mathcal{F}_\perp = \sqrt{2}\,N\sqrt{\lambda(m_B^2, m_{K^*}^2, q^2)}\,\mathcal{X}_3 \qquad \mathcal{F}_\parallel = 2\sqrt{2}\,N\,\mathcal{X}_1$$

$$\mathcal{F}_0 = \frac{N}{2m_{K^*}\sqrt{q^2}}\left(4\,k.q\,\mathcal{X}_1 + \lambda\left(m_B^2, m_{K^*}^2, q^2\right)\mathcal{X}_2\right)$$

$$\tilde{\mathcal{G}}_0 = \sqrt{2}\,N\sqrt{\lambda(m_B^2, m_{K^*}^2, q^2)}\,\frac{2\,(m_b - m_s)}{q^2}\,\hat{C}_7\mathcal{Y}_3 + \cdots$$

$$\tilde{\mathcal{G}}_\parallel = 2\sqrt{2}\,N\,\frac{2\,(m_b - m_s)}{q^2}\,\hat{C}_7\mathcal{Y}_1 + \cdots$$

$$\tilde{\mathcal{G}}_0 = \frac{N}{2m_{K^*}\sqrt{q^2}}\,\frac{2\,(m_b - m_s)}{q^2}\,\hat{C}_7\left(4\,k.q\,\mathcal{Y}_1 + \lambda\left(m_B^2, m_{K^*}^2, q^2\right)\mathcal{Y}_2\right) + \cdots$$

$$\mathcal{X}_1 = -\frac{(m_B + m_{K^*})}{2}A_1(q^2) \qquad \mathcal{X}_2 = \frac{A_2(q^2)}{m_B + m_{K^*}} \qquad \mathcal{X}_3 = \frac{V\,(q^2)}{m_B + m_{K^*}}$$

$$\mathcal{Y}_1 = \frac{(m_B^2 - m_{K^*}^2)}{2}T_2(q^2) \qquad \mathcal{Y}_2 = -T_2\left(q^2\right) - \frac{q^2}{m_B^2 - m_{K^*}^2}T_3(q^2) \qquad \mathcal{Y}_3 = -T_1\left(q^2\right)$$

We have the helicity amplitudes (massless limit):

Simple to define amplitudes in terms of some new form factors as

$$\mathcal{A}_\lambda^{L,R} = C_{L,R}^\lambda \mathcal{F}_\lambda - \widetilde{\mathcal{G}}_\lambda = \left(\widetilde{C}_9^\lambda \mp C_{10}\right)\mathcal{F}_\lambda - \widetilde{\mathcal{G}}_\lambda$$

← *includes C_7*

implicit dependence on q^2

$\mathcal{F}_\lambda, \tilde{\mathcal{G}}_\lambda$ *new form factors that can be related to conventional form factors at a given order*

An important step is to separate the real and imaginary parts of the amplitude. Three observables are non-zero only if the amplitude has an imaginary part

$$\mathcal{A}_\lambda^{L,R} = \left(\tilde{C}_9^\lambda \mp \hat{C}_{10}\right)\mathcal{F}_\lambda - \tilde{\mathcal{G}}_\lambda = \left(\mp\hat{C}_{10} - r_\lambda\right)\mathcal{F}_\lambda + i\varepsilon_\lambda$$

$$r_\lambda = \frac{Re\,(\tilde{\mathcal{G}}_\lambda)}{\mathcal{F}_\lambda} - Re\left(\tilde{C}_9^\lambda\right)$$

$$\varepsilon_\lambda = Im\left(\tilde{C}_9^\lambda\right)\mathcal{F}_\lambda - Im(\tilde{\mathcal{G}}_\lambda)$$

9 observables in terms of 10 parameters

$$F_L\Gamma_f = 2\mathcal{F}_0^2(r_0^2 + C_{10}^2) + 2\,\varepsilon_0^2$$

$$F_\parallel\Gamma_f = 2\mathcal{F}_\parallel^2\left(r_\parallel^2 + C_{10}^2\right) + 2\,\varepsilon_\parallel^2$$

$$F_\perp\Gamma_f = 2\mathcal{F}_\perp^2(r_\perp^2 + C_{10}^2) + 2\,\varepsilon_\perp^2$$

$$2\frac{\varepsilon_0^2}{\Gamma_f} \le F_L \qquad 2\frac{\varepsilon_\parallel^2}{\Gamma_f} \le F_\parallel \qquad 2\frac{\varepsilon_\perp^2}{\Gamma_f} \le F_\perp$$

$$\sqrt{2}\pi A_4\Gamma_f = 4\mathcal{F}_0\mathcal{F}_\parallel(r_0 r_\parallel + C_{10}^2) + 4\varepsilon_0\varepsilon_\parallel$$

$$\sqrt{2}A_5\Gamma_f = 3\mathcal{F}_0\mathcal{F}_\perp C_{10}(r_0 + r_\perp)$$

$$A_{FB}\Gamma_f = 3\mathcal{F}_\parallel\mathcal{F}_\perp C_{10}(r_\parallel + r_\perp)$$

$$\sqrt{2}A_7\Gamma_f = 3C_{10}(\mathcal{F}_0\varepsilon_\parallel - \mathcal{F}_\parallel\varepsilon_0)$$

$$\pi A_8\Gamma_f = 2\sqrt{2}(\mathcal{F}_0 r_0\varepsilon_\perp - \mathcal{F}_\perp r_\perp\varepsilon_0)$$

$$\pi A_9\Gamma_f = 3(\mathcal{F}_\perp r_\perp\varepsilon_\parallel - \mathcal{F}_\parallel r_\parallel\varepsilon_\perp)$$

C_{10} and $\mathcal{F}_\lambda$ are real in SM

Define new form factors

Useful definitions

$$\mathrm{P}_1 = \frac{\mathcal{F}_\perp}{\mathcal{F}_\parallel}$$

$$\mathrm{P}_2 = \frac{\mathcal{F}_\perp}{\mathcal{F}_0}$$

$$\mathrm{P}_3 = \frac{\mathcal{F}_\perp}{\mathcal{F}_0 + \mathcal{F}_\parallel} = \frac{\mathrm{P}_1\mathrm{P}_2}{\mathrm{P}_1 + \mathrm{P}_2}$$

Observables recast (last one not independent)

$$F'_{\parallel}\Gamma_f = 2\mathcal{F}_{\parallel}^2(r_{\parallel}^2 + C_{10}^2)$$

$$F'_{\perp}\Gamma_f = 2\mathcal{F}_{\perp}^2(r_{\perp}^2 + C_{10}^2)$$

$$F'_{\lambda} \equiv F_{\lambda} - \frac{2\varepsilon_{\lambda}^2}{\Gamma_f}$$

$$F'_{L}\Gamma_f = 2\mathcal{F}_{0}^2(r_{0}^2 + C_{10}^2)$$

$$(F'_L + F_{\parallel}^2 + \sqrt{2}\pi A_4)\Gamma_f = 2(\mathcal{F}_0^2 + \mathcal{F}_{\parallel}^2)(r_{\wedge}^2 + C_{10}^2)$$

$$\sqrt{2}A_5\Gamma_f = 3\mathcal{F}_{\perp}\mathcal{F}_0 C_{10}(r_0 + r_{\perp})$$

$$A_{FB}\Gamma_f = 3\mathcal{F}_{\perp}\mathcal{F}_{\parallel} C_{10}(r_{\parallel} + r_{\perp})$$

$\longrightarrow$ $A_{FB} = 0 \Rightarrow (r_{\parallel} + r_{\perp})$

$$(A_{FB} + \sqrt{2}A_5)\Gamma_f = 3\mathcal{F}_{\perp}(\mathcal{F}_{\parallel} + \mathcal{F}_0)C_{10}\,(r_{\wedge} + r_{\perp})$$

where $r_{\wedge} = \dfrac{r_{\parallel}\mathrm{P}_2 + r_0\mathrm{P}_1}{\mathrm{P}_2 + \mathrm{P}_1}$

$\to$ $\begin{cases} F'_{\parallel} \to F'_L\,,\; A_{FB} \to \sqrt{2}A_5 \\ \mathcal{F}_{\parallel} \to \mathcal{F}_0 \end{cases}$

Each set solve for $r_{\perp}, \hat{C}_{10}$ *and* $(r_{||}, r_0, r_{\wedge})$

In the presence of right-handed currents $\mathcal{A}_\lambda^{L,R} = (\widetilde{C}_9^\lambda \mp C_{10})\mathcal{F}_\lambda - \widetilde{\mathcal{G}}_\lambda$ *becomes:*

$$\mathcal{A}_\perp^{L,R} = \left((\widetilde{C}_9^\perp + C_9') \mp (C_{10} + C_{10}')\right)\mathcal{F}_\perp - \widetilde{\mathcal{G}}_\perp \qquad \xi = \frac{C_{10}'}{C_{10}}$$

$$\mathcal{A}_{\parallel,0}^{L,R} = \left((\widetilde{C}_9^\parallel - C_9') \mp (C_{10} - C_{10}')\right)\mathcal{F}_{\parallel,0} - \widetilde{\mathcal{G}}_{\parallel,0} \qquad \xi' = \frac{C_9'}{C_{10}}$$

$$F_\perp = 2\,\zeta\,(1+\xi)^2(1+R_\perp^2)$$

$$F_\parallel \mathrm{P}_1^2 = 2\,\zeta(1-\xi)^2(1+R_\parallel^2)$$

$$F_L \mathrm{P}_2^2 = 2\,\zeta(1-\xi)^2(1+R_0^2)$$

$$A_{FB}\mathrm{P}_1 = 3\zeta(1-\xi^2)(R_\parallel + R_\perp)$$

$$\sqrt{2}A_5\mathrm{P}_2 = 3\zeta(1-\xi^2)(R_0 + R_\perp)$$

$$R_\perp = \frac{{r_\perp}/{C_{10}} - \xi'}{1+\xi}$$

$$R_\parallel = \frac{{r_\parallel}/{C_{10}} + \xi'}{1-\xi}$$

$$R_0 = \frac{{r_0}/{C_{10}} + \xi'}{1-\xi}$$

$$\zeta = \frac{\mathcal{F}_\perp^2 C_{10}^2}{\Gamma_f}$$

$$R_\perp = \pm\frac{3}{2}\frac{\left(\frac{1-\xi}{1+\xi}\right)F_\perp + \frac{1}{2}\mathrm{P}_1 Z_1}{\mathrm{P}_1 A_{FB}}$$

$$R_\perp = \pm\frac{3}{2}\frac{\left(\frac{1+\xi}{1-\xi}\right)\mathrm{P}_1 F_\parallel + \frac{1}{2}Z_1}{A_{FB}}$$

$$R_0 = \pm\frac{3}{2\sqrt{2}}\frac{\left(\frac{1+\xi}{1-\xi}\right)\mathrm{P}_2 F_L + \frac{1}{2}Z_2}{A_5}$$

4 independent observables to solve for 4 parameters

For the moment we assume that the amplitudes are real. Simplicity of expressions. Non-zero imaginary part have also be included.

$$\mathrm{P}_2 = \frac{\left(\frac{1-\xi}{1+\xi}\right)2\mathrm{P}_1 A_{FB}\, F_\perp}{\sqrt{2}A_5\left(\left(\frac{1-\xi}{1+\xi}\right)F_\perp + Z_1\,\mathrm{P}_1\right) - Z_2\mathrm{P}_1 A_{FB}}$$

$$\left(\frac{1-\xi}{1+\xi}\right)\mathrm{P}_1 \rightarrow \mathrm{P}_1$$

$$Z_1 = \sqrt{4F_\parallel\, F_\perp - \frac{16}{9}A_{FB}^2} \qquad Z_2 = \sqrt{4F_L\, F_\perp - \frac{32}{9}A_5^2}$$

One extra parameter hence expressions depend on P_1

At $q^2 = q^2_{\max} = (m_B - m_{K^*})^2$ *the* K^* *meson is at rest and the two leptons travel back to back in the B meson rest frame. There is no preferred direction in the decay kinematics. Hence, the differential decay distribution in this kinematic limit must be independent of the angles* θ_ℓ *and* ϕ.

- *The entire decay, including the decay* $K^* \to K\pi$ *takes place in a plane resulting in a vanishing contribution to the "⊥" helicity or* $F_\perp = 0$.
- *Since the* K^* *decays at rest, the distribution of* K^* *is isotropic and cannot depend on* θ_K. *It can easily be seen that this is only possible if* $F_\parallel = 2F_L$.

At $q^2 = q^2_{\max}$, $\Gamma_f \to 0$ *as all the transversity amplitudes vanish in this limit. The constraints on the amplitudes result in unique values of the helicity fractions and the asymmetries at this kinematical end-point.* $F_L(q^2_{\max}) = \frac{1}{3}$ $F_\parallel(q^2_{\max}) = \frac{2}{3}$ $F_\perp(q^2_{\max}) = 0$ *Hiller, Ziwcky '14*

$$A_{FB}(q^2_{\max}) = 0 = A_{5,7,8,9}(q^2_{\max}) \quad A_4(q^2_{\max}) = \frac{2}{3\pi}$$

The large q^2 region where the K^* has low-recoil energy has been studied in a modified heavy quark effective theory framework. In the limit $q^2 \to q^2_{\max}$ the hadronic form factors satisfy the conditions

Grinstein, Prijol '04

$$\frac{\tilde{\mathcal{G}}_\perp}{\mathcal{F}_\perp} = \frac{\tilde{\mathcal{G}}_\parallel}{\mathcal{F}_\parallel} = \frac{\tilde{\mathcal{G}}_0}{\mathcal{F}_0} = -\kappa \frac{2\, m_b\, m_B\, C_7}{q^2} \Rightarrow r_\perp = r_\parallel = r_0 \equiv r$$

Thus only in the presence of right handed currents can one expect

$$R_0 = R_\parallel \neq R_\perp$$

We study the values of R_λ, ζ and $\mathrm{P}_{1,2}$ in the large q^2 region and consider the kinematic limit $q^2 \to q^2_{\max}$.

$$F_\perp(q^2_{\max}) = 0 \Rightarrow \zeta = 0 \text{ at } q^2 \to q^2_{\max}$$

$$R_\parallel(q^2_{\max}) = R_0(q^2_{\max}) \Rightarrow \mathrm{P}_2 = \sqrt{2}\,\mathrm{P}_1 \text{ at } q^2 \to q^2_{\max}$$

Both P_1 and P_2 go to zero at $q^2_{\max}$. Hence take into account limiting values very carefully.

Taylor expand all observables around the endpoint $\mathbf{q^2_{max}}$ *in terms of the variable* $\delta \equiv \mathbf{q^2_{max}} - q^2$. *Leading power of* δ *in the Taylor expansion must take into account relative momentum dependence of amplitudes* $\boldsymbol{\mathcal{A}^{L,R}_{\lambda}}$

$$F_L = \frac{1}{3} + F_L^{(1)}\delta + F_L^{(2)}\delta^2 + F_L^{(3)}\delta^3$$

$$F_\perp = F_\perp^{(1)}\delta + F_\perp^{(2)}\delta^2 + F_\perp^{(3)}\delta^3$$

$$A_{FB} = A_{FB}^{(1)}\delta^{1/2} + A_{FB}^{(2)}\delta^{3/2} + A_{FB}^{(3)}\delta^{5/2}$$

$$A_5 = A_5^{(1)}\delta^{1/2} + A_5^{(2)}\delta^{3/2} + A_5^{(3)}\delta^{5/2}$$

Unfortunately, very bad approximation in the strict sense. However, works reasonably well. Resonances cannot be accommodated in a Taylor expansion and there exist resonances. Experimental binned measurements include resonance contributions. We calculate these errors as systematics.

Thank Marcin, Nicola, Danny, Gino… for discussions on this

Compare form-factor generated binned data without resonances with similar data generated using resonances observed in $B \to K\ell\ell$. Discrepancy will be a rough guide to errors because of resonances. Full study under way.

Taylor expansion of form factors:

$$q^2 \frac{\tilde{\mathcal{G}}_\lambda}{\mathcal{F}_\lambda} = q^2_{\max} \frac{\tilde{\mathcal{G}}_\lambda^{(1)} + \delta\left(\tilde{\mathcal{G}}_\lambda^{(2)} - \frac{\tilde{\mathcal{G}}_\lambda^{(1)}}{q^2_{\max}}\right) + \mathcal{O}(\delta^2)}{\mathcal{F}_\lambda^{(1)} + \delta\mathcal{F}_\lambda^{(2)} + \mathcal{O}(\delta^2)}$$

Assume that relation is valid up to order δ

$$\Rightarrow \mathcal{F}_\lambda^{(1)} = c\, \mathcal{F}_\lambda^{(2)} \textit{ and}$$

$$\left(q^2_{\max}\ \mathcal{G}_\lambda^{(2)} - \mathcal{G}_\lambda^{(1)}\right) = c\, q^2_{\max}\ \mathcal{G}_\lambda^{(1)}$$

$$\Rightarrow \mathrm{P}_2^{(1)} = \sqrt{2}\,\mathrm{P}_1^{(1)} \text{ and } \mathrm{P}_2^{(2)} = \sqrt{2}\,\mathrm{P}_1^{(2)}$$

The expressions for R_λ in the limit $q^2 \to q^2_{\rm max}$ are

$$R_\perp(q^2_{\rm max}) = \frac{8A^{(1)}_{\rm FB}(-2A^{(2)}_5 + A^{(2)}_{\rm FB}) + 9(3F^{(1)}_L + F^{(1)}_\perp)F^{(1)}_\perp}{8\,(2A^{(2)}_5 - A^{(2)}_{\rm FB})\sqrt{\frac{3}{2}F^{(1)}_\perp - A^{(1)\,2}_{\rm FB}}}$$

$$= \frac{\omega_2 - \omega_1}{\omega_2\sqrt{\omega_1 - 1}}, \qquad (30)$$

$$R_\parallel(q^2_{\rm max}) = \frac{3(3F^{(1)}_L + F^{(1)}_\perp)\sqrt{\frac{3}{2}F^{(1)}_\perp - A^{(1)\,2}_{\rm FB}}}{-8A^{(2)}_5 + 4A^{(1)}_{\rm FB} + 3A^{(1)}_{\rm FB}(3F^{(1)}_L + F^{(1)}_\perp)}$$

$$= \frac{\sqrt{\omega_1 - 1}}{\omega_2 - 1} = R_0(q^2_{\rm max}) \qquad (31)$$

$$\omega_1 = \frac{3}{2}\frac{F^{(1)}_\perp}{A^{(1)\,2}_{\rm FB}} \quad \text{and} \quad \omega_2 = \frac{4\,(2A^{(2)}_5 - A^{(2)}_{\rm FB})}{3\,A^{(1)}_{\rm FB}(3F^{(1)}_L + F^{(1)}_\perp)}.$$

Including the imaginary part

$$\varepsilon_\perp = \frac{\sqrt{2}\pi\Gamma_f}{(r_0 - r_\parallel)\mathcal{F}_\perp}\left[\frac{A_9 \mathsf{P}_1}{3\sqrt{2}} + \frac{A_8 \mathsf{P}_2}{4} - \frac{A_7 \mathsf{P}_1 \mathsf{P}_2 r_\perp}{3\pi \hat{C}_{10}}\right]$$

$$\varepsilon_\parallel = \frac{\sqrt{2}\pi\Gamma_f}{(r_0 - r_\parallel)\mathcal{F}_\perp}\left[\frac{A_9 r_0}{3\sqrt{2} r_\perp} + \frac{A_8 \mathsf{P}_2 r_\parallel}{4\mathsf{P}_1 r_\perp} - \frac{A_7 \mathsf{P}_2 r_\parallel}{3\pi \hat{C}_{10}}\right]$$

$$\varepsilon_0 = \frac{\sqrt{2}\pi\Gamma_f}{(r_0 - r_\parallel)\mathcal{F}_\perp}\left[\frac{A_9 \mathsf{P}_1 r_0}{3\sqrt{2}\mathsf{P}_2 r_\perp} + \frac{A_8 r_\parallel}{4 r_\perp} - \frac{A_7 \mathsf{P}_1 r_0}{3\pi \hat{C}_{10}}\right]$$

ε_λ can easily be solved in terms of A_7, A_8, A_9. Note $\frac{\varepsilon_\lambda}{\sqrt{\Gamma_f}}$ free from the form factor $\mathcal{F}_\lambda$ and Γ_f.

It leads to a modification of the expressions for ω_1 and ω_2

$$\widehat{\varepsilon}_\perp = \widehat{\varepsilon}_\perp^{(1)}\delta + \widehat{\varepsilon}_\perp^{(2)}\delta^2 + \widehat{\varepsilon}_\perp^{(3)}\delta^3$$

$$\widehat{\varepsilon}_0 = \widehat{\varepsilon}_0^{(0)} + \widehat{\varepsilon}_0^{(1)}\delta + \widehat{\varepsilon}_0^{(2)}\delta^2$$

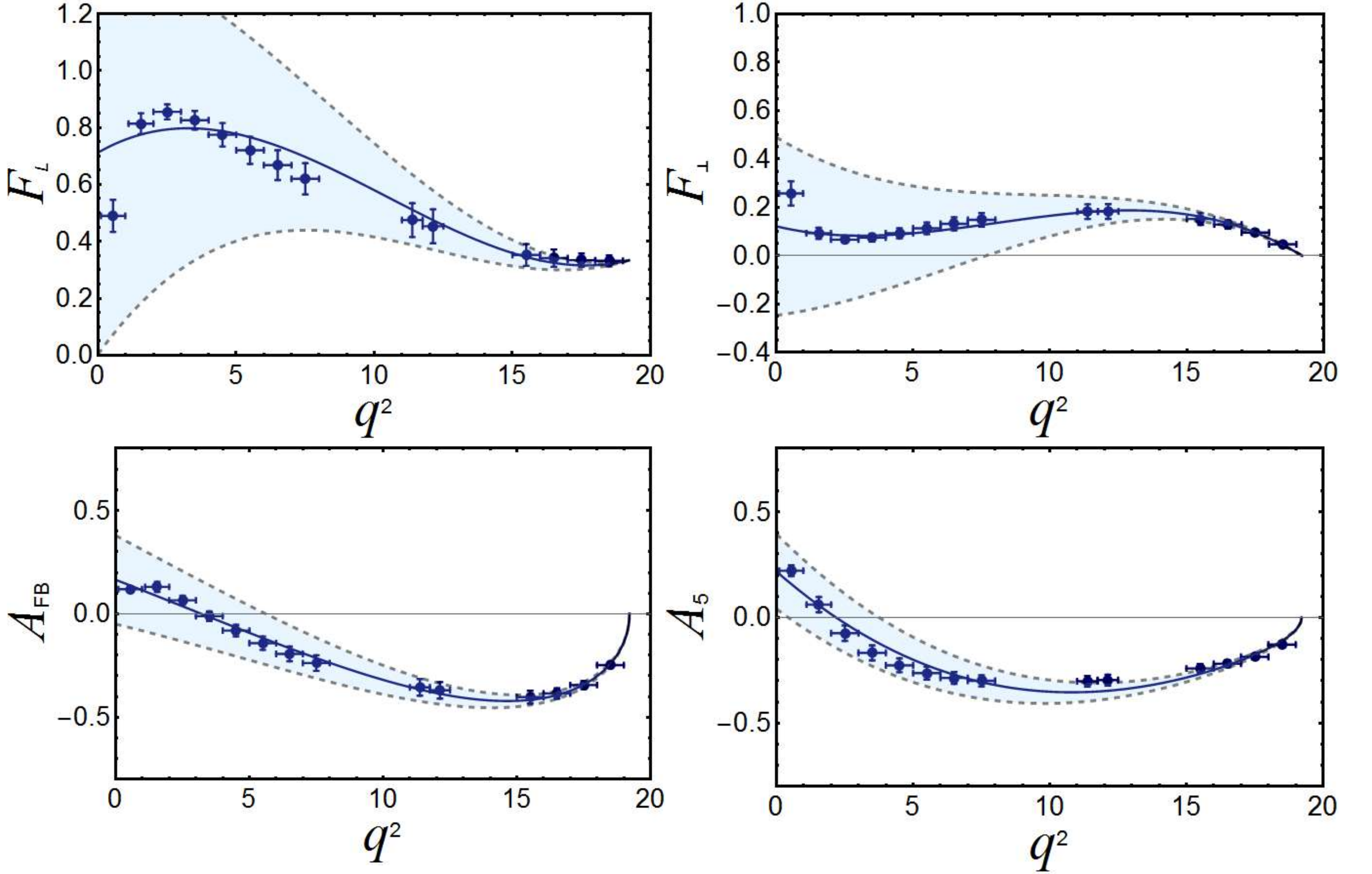
$$\widehat{\varepsilon}_\parallel = \widehat{\varepsilon}_\parallel^{(0)} + \widehat{\varepsilon}_\parallel^{(1)}\delta + \widehat{\varepsilon}_\parallel^{(2)}\delta^2$$

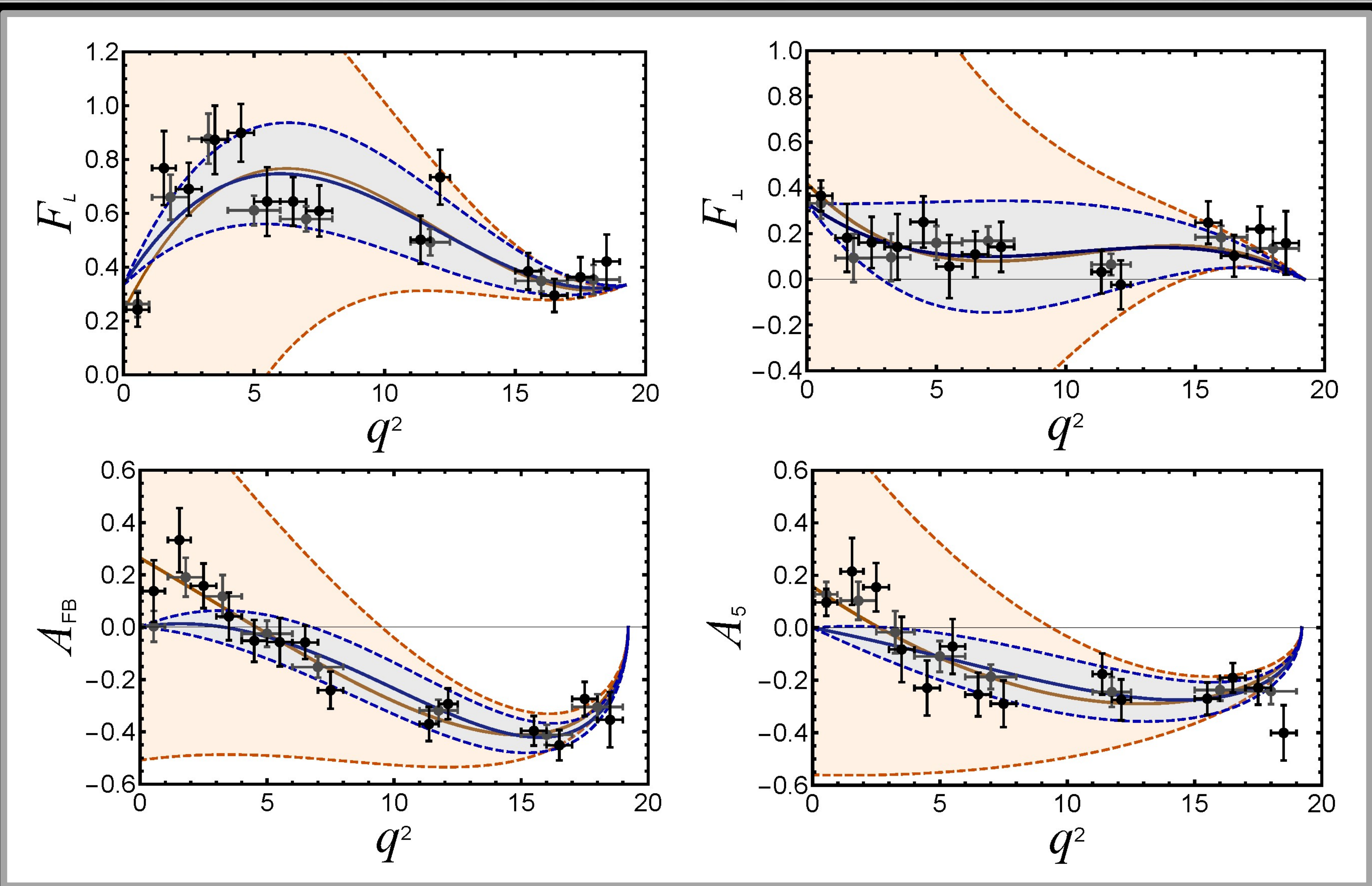
$$\hat{\epsilon}_\lambda \equiv 2\frac{\epsilon_\lambda^2}{\Gamma_f} \qquad \hat{\epsilon}_\parallel^{(0)} = 2\hat{\epsilon}_0^{(0)}$$

$$\omega_1 = \frac{9}{4}\frac{\left(\frac{2}{3} - 2\,\widehat{\varepsilon}_0^{(0)}\right)\left(F_\perp^{(1)} - \widehat{\varepsilon}_\perp^{(1)}\right)}{A_{\rm FB}^{(1)\,2}}$$

$$\omega_2 = \frac{4\left(2A_5^{(2)} - A_{\rm FB}^{(2)}\right)\left(1 - 3\,\widehat{\varepsilon}_0^{(0)}\right)}{3\,A_{\rm FB}^{(1)}\left(3F_L^{(1)} + F_\perp^{(1)} + \widehat{\varepsilon}_\parallel^{(1)} - 2\,\widehat{\varepsilon}_0^{(1)}\right)}$$

Fits to form-factors derived observables





An analytic fit to 14-bin LHCb data using a Taylor expansion at q^2_{max} for the observables F_L, $F_\perp$, A_{FB} and A_5 are shown as the blue curves. The $\pm 1\sigma$ error bands are indicated by light shaded regions. The points with the blue are LHCb 14-bin measurements. The fit near q^2_{max} is good, which is the relevant region for this analysis.

	$\mathcal{O}^{(1)}(\mathbf{10^{-2}})$	$\mathcal{O}^{(2)}(\mathbf{10^{-3}})$	$\mathcal{O}^{(3)}(\mathbf{10^{-4}})$
F_L	-2.96 ± 1.37	12.31 ± 2.05	-5.74 ± 0.72
$F_\perp$	6.82 ± 1.75	-9.67 ± 2.60	3.77 ± 0.90
A_{FB}	-30.66 ± 2.38	26.86 ± 4.43	-4.04 ± 1.83
A_5	-16.56 ± 2.36	6.76 ± 4.19	1.94 ± 1.62

$$factorization\ condition\ \ 2\,\mathrm{A}_5^{(1)} = \mathrm{A}_{\mathrm{FB}}^{(1)}\ holds\ at\ 1\sigma$$

$$\omega_1 = 1.09 \pm 0.33\ (0.93 \pm 0.36)$$
$$\omega_2 = -2.81 \pm 6.38\ (-2.60 \pm 5.91)$$

	$\mathcal{O}(10^{-2})$	$\mathcal{O}(10^{-3})$	$\mathcal{O}(10^{-4})$
A_7	0.96 ± 1.26	2.34 ± 1.77	0.96 ± 1.26
A_8	0.87 ± 2.18	4.15 ± 3.55	1.92 ± 2.44
A_9	-1.99 ± 1.45	2.74 ± 2.22	0.89 ± 1.55

$A_{FB}^{(1)}$ *and* $A_9^{(1)}$ $2A_5^{(1)}$ *and* $-\frac{2}{3}A_8^{(1)}$

$$\omega_1 = 0.70 \pm 0.22(0.57 \pm 0.17)$$

$$\omega_2 = -8.73 \pm 104.42\ (-6.77 \pm 70.17)$$

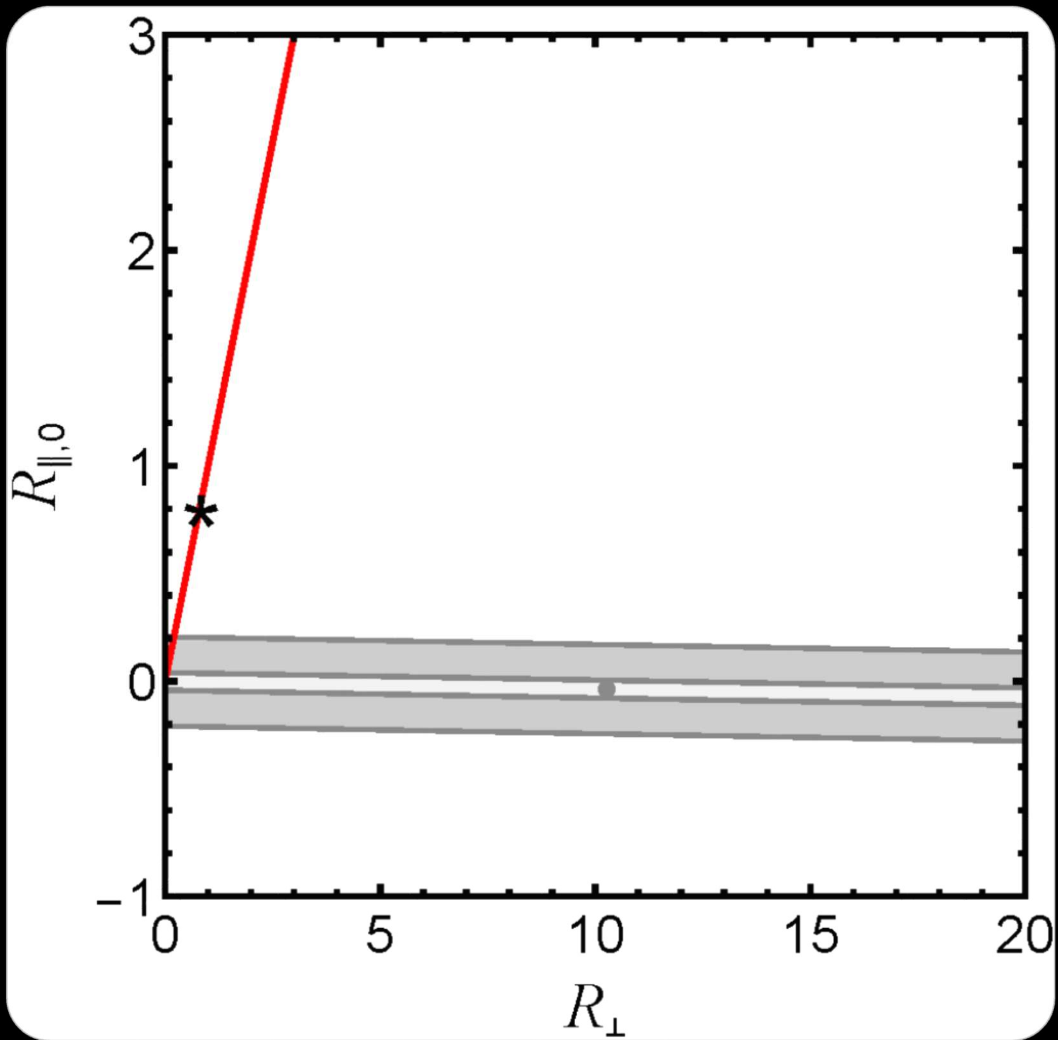
$A_9^{(1)} = -\frac{2}{3}A_8^{(1)}$ *holds at* 1σ

Values without imaginary part

$$\omega_1 = 0.71 \pm 0.22\ (0.57 \pm 0.21)$$

$$\omega_2 = -8.50 \pm 96.81\ (-7.65 \pm 87.16)$$

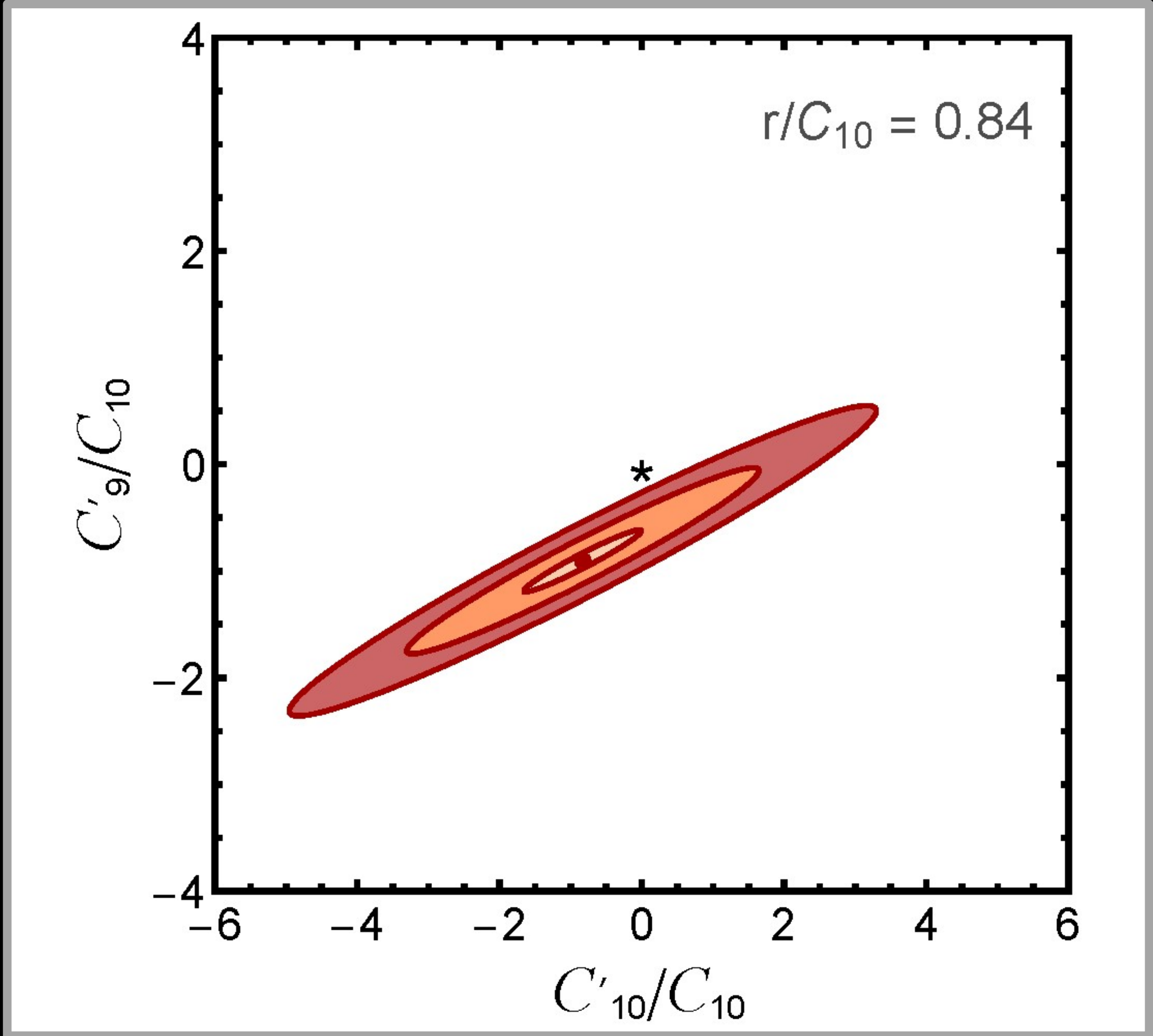
Very large contributions from RH currents are not possible, as they would have been seen elsewhere $\Rightarrow$ $R_\lambda(q^2_{\max}) > 0 \Rightarrow 1 \le \omega_1 \le \omega_2$
Estimate $R_\perp$ *and* $R_{\parallel,0}$ *with two approaches (results agree).*



Randomly choose $F_L^{(1)}$, $F_\perp^{(1)}$, $A_{FB}^{(1)}$, $A_5^{(1)}$, $A_{FB}^{(2)}$ *and* $A_5^{(2)}$ *from a Gaussian distribution central value as the mean and errors from Table.*

We find a slope is nearly 0^o, *indicating* $R_\perp \gg R_{\parallel,0}$. *The deviation of slope from a* 45^o *provides evidence of a contribution from RH currents.*
Alternate approach is to fit $R_\perp$ *and* $R_{\parallel,0}$ *with the two estimated values of* ω_1, ω_2.

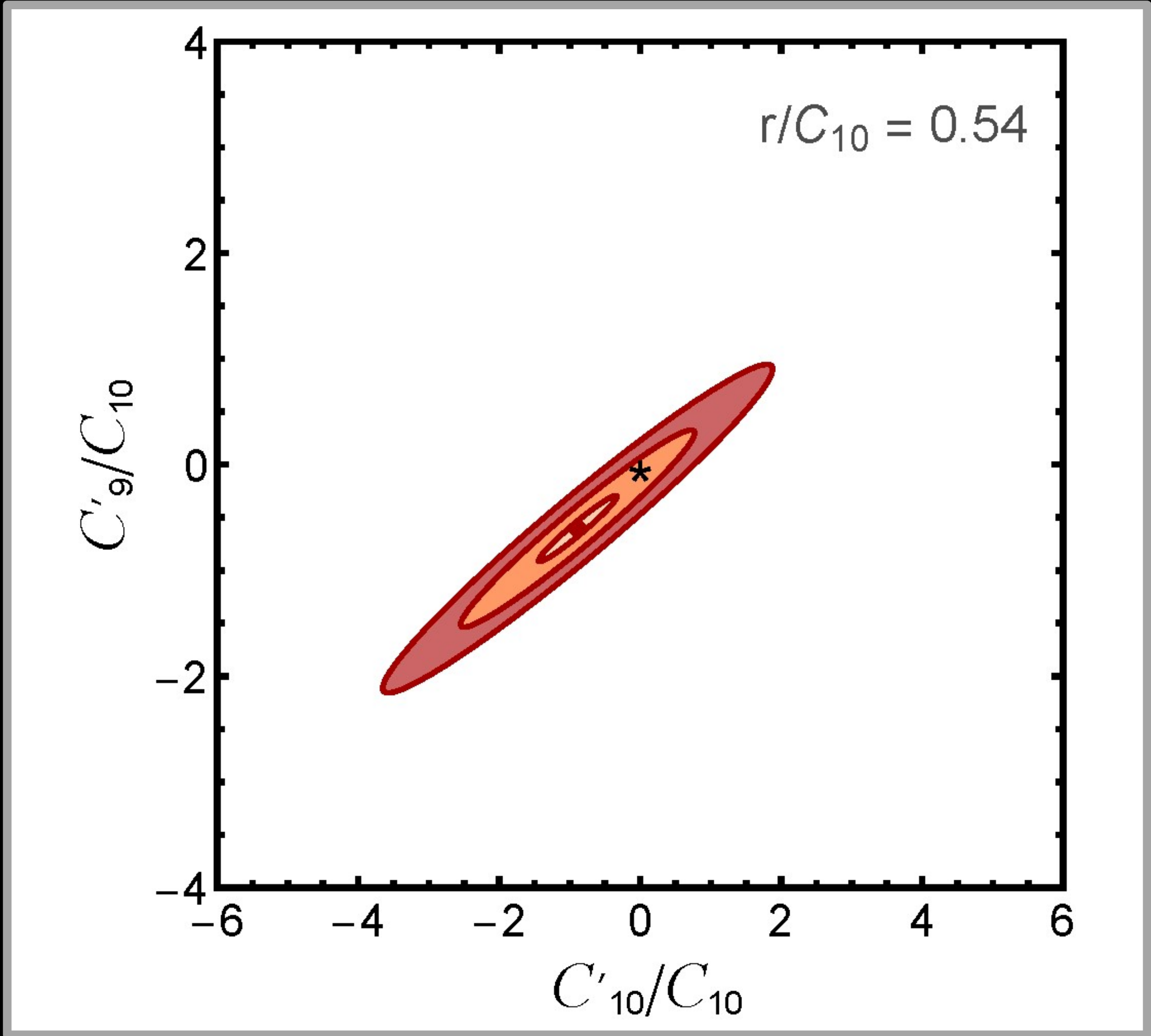
$r/C_{10} = 0.84$



$\xi = -0.83 \pm 0.82$

$\xi' = -0.90 \pm 0.28$

$r/C_{10} = 0.54$

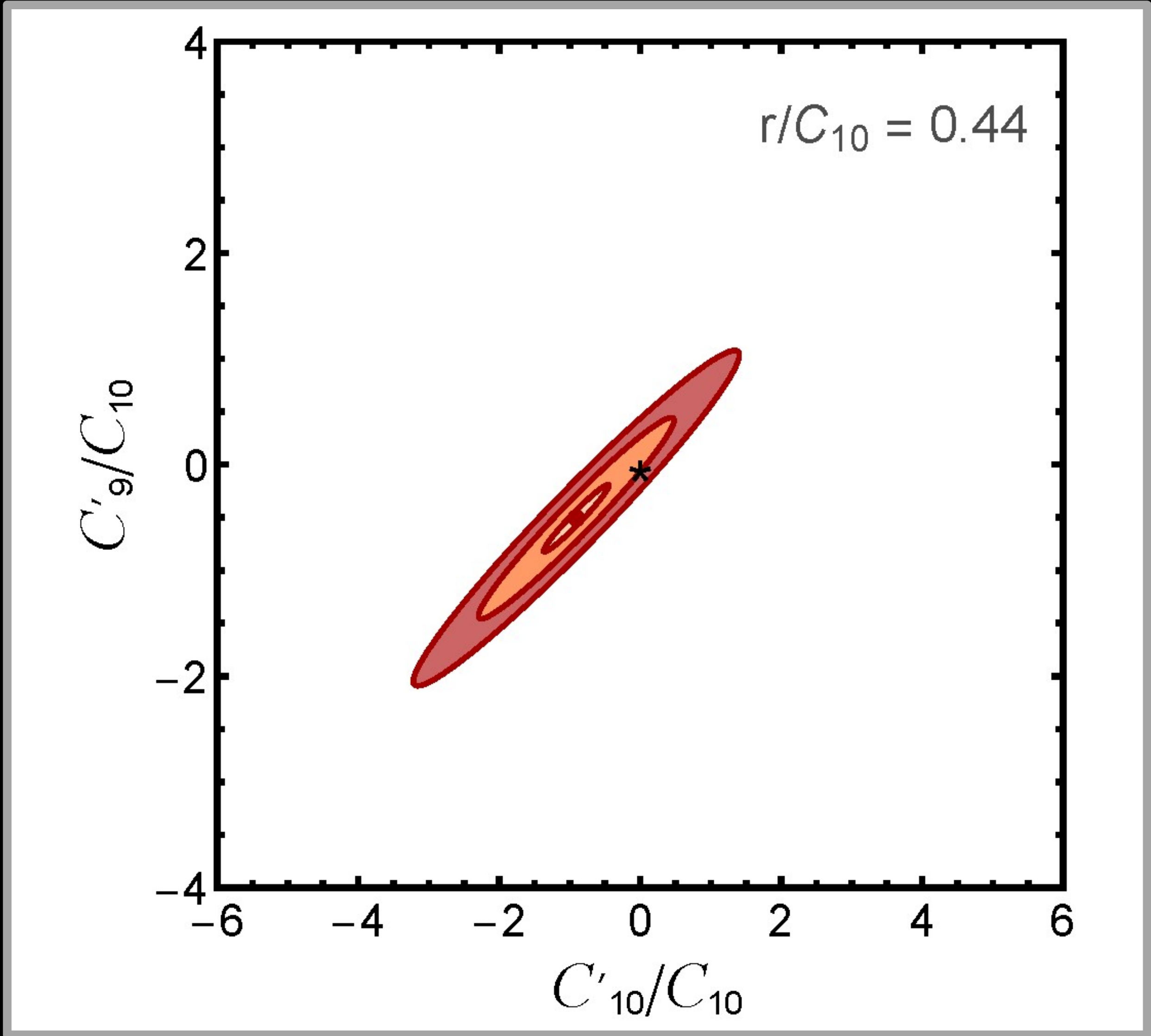


$\xi = -0.89 \pm 0.55$

$\xi' = -0.61 \pm 0.30$

Value of ξ, ξ' reduced by reducing r/C_{10}. May also indicate the existence of Z'

$r/C_{10} = 0.44$



$\xi = -0.91 \pm 0.46$

$\xi' = -0.51 \pm 0.31$

Value of ξ, ξ' reduced by reducing r/C_{10}. May also indicate the existence of Z'

Conclusion

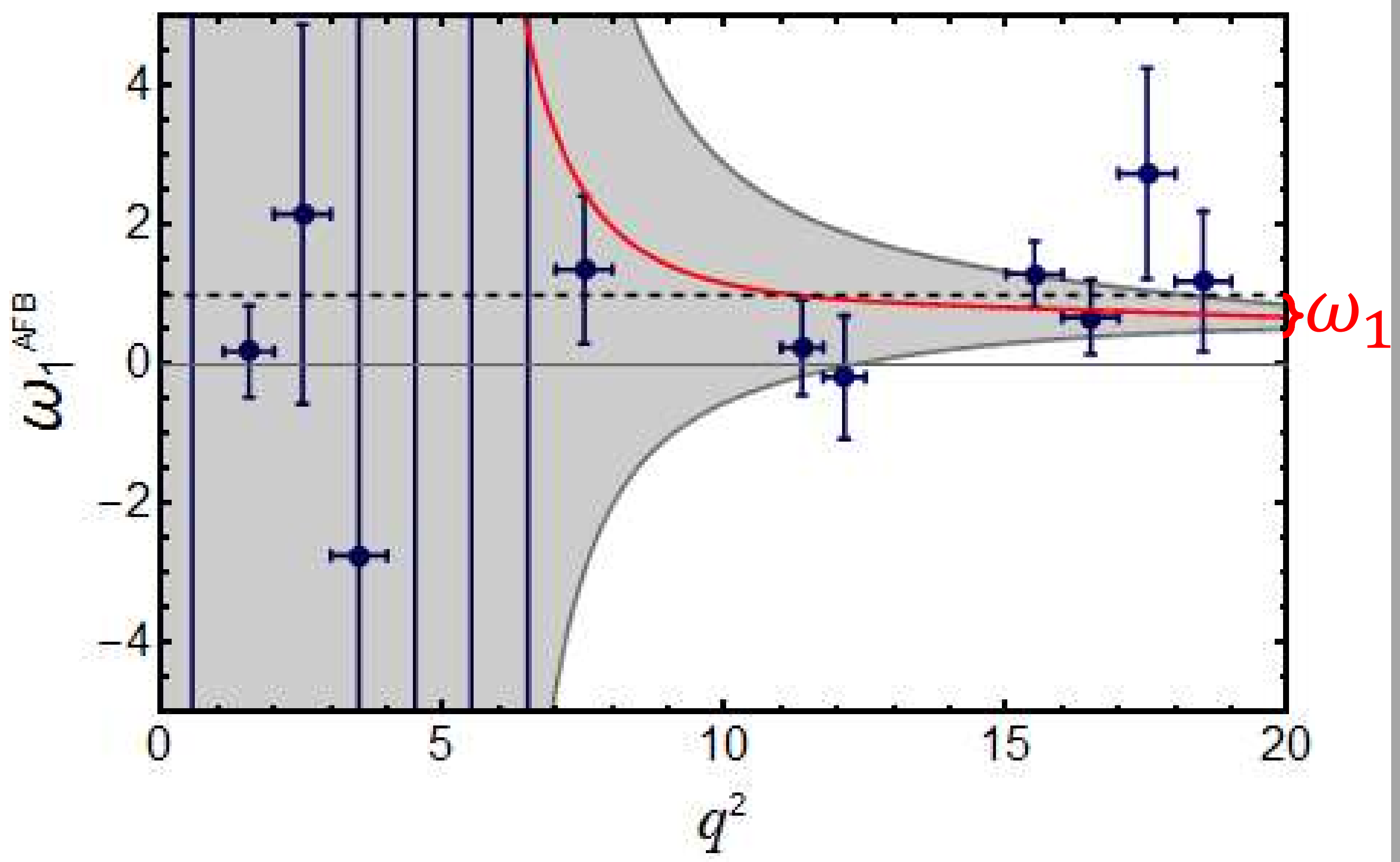
SM

L

R

Z' S P

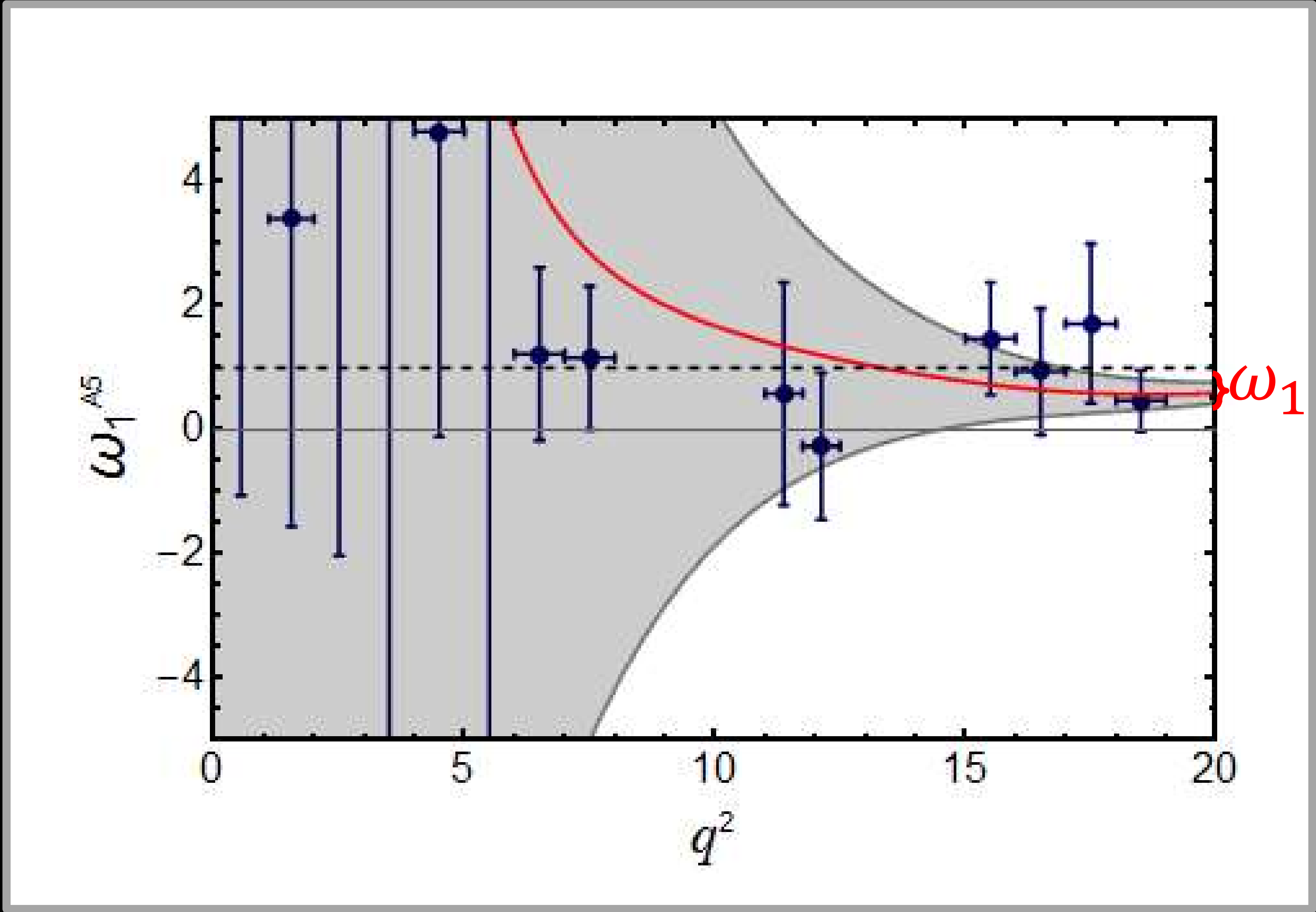
ω_1^{AFB}



$$\omega_1^{AFB} = \frac{9}{4}\frac{F_\parallel F_\perp}{A_{FB}^2}$$

$$Z_1 = \sqrt{4F_\parallel F_\perp - \frac{16}{9}A_{FB}^2}$$

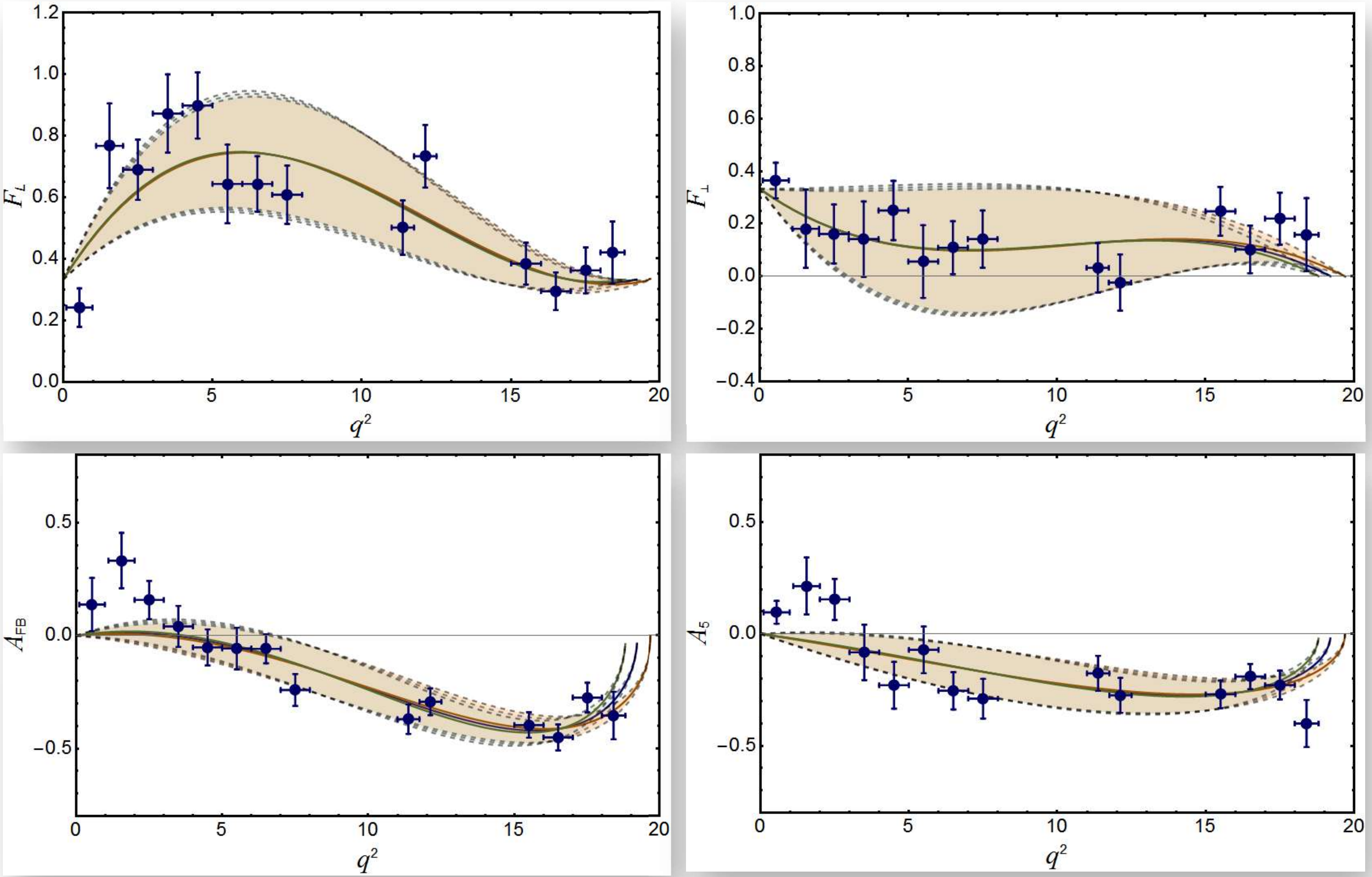
ω_1^{A5}



$$\omega_1^{A5} = \frac{9}{8}\frac{F_L F_\perp}{A_5^2}$$

$$Z_2 = \sqrt{4F_L\,F_\perp - \frac{32}{9}A_5^2}$$

K^* width effects 50MeV



ω values on account of K^* width

The finite width of the K can alter the position of the kinematic endpoint q^2_{max} *value. We varied the* q^2_{max} *value in the Taylor expansion of observables by including the* K^* *width of 50MeV. The observables* ω_1 *and* ω_2 *are evaluated for each case and a weighted average over the Breit-Wigner shape for a* K^* *gives*

$$\omega_1 = 0.70 \pm 0.22\ (0.57 \pm 0.21)$$

$$\omega_2 = -5.99 \pm 75.41\ (-5.40 \pm 67.88)$$

Without K^* *width effect*

$$\omega_1 = 0.71 \pm 0.22\ (0.57 \pm 0.21)$$

$$\omega_2 = -8.50 \pm 96.81\ (-7.65 \pm 87.16)$$