Flavor Pheno $\leftrightarrow$ Lattice QCD

auxiliary slides

Discussion based on 1204.4444, 1308.4379, 1506.06699

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1. Low recoil Region – power corrections

In SM+SM' basis (V,A operators and flipped ones only) the effective Wilson coefficients $C_{\pm}^{\rm eff}(q^2) \equiv C^{\rm eff}(q^2) \pm C^{\rm eff\prime}(q^2)$ are independent of the polarization Bobeth,GH,van Dyk'12 (and as they should in agreement with endpoint relations GH,Zwicky14)

$$B \to V \ell\ell : \quad H_{0,\|} = C_{-}^{\rm eff}(q^2) f_{0,\|}(q^2) \,, \quad H_{\perp} = C_{+}^{\rm eff}(q^2) f_{\perp}(q^2) \,,$$

$$B \to P \ell\ell : \quad H = C_{+}^{\rm eff}(q^2) f(q^2)$$

$f_i, i = 0, \perp, \|$ (f) : usual $B \to V$ ($B \to P$) form factors

Parameterize corrections to the lowest order OPE results as

$f_\lambda(q^2) \to f_\lambda(q^2)(1 + \epsilon_\lambda(q^2)) \,, \quad \epsilon_\lambda(q^2) = \mathcal{O}(\alpha_s/m_b, [\mathcal{C}_7/\mathcal{C}_9]/m_b)$ $\lambda = 0, \pm 1$

The endpoint relations imply degeneracy at endpoint

$\epsilon_\lambda(q^2_{\rm max}) \equiv \epsilon \,, \quad \lambda = 0, \pm 1, \|, \perp$ with the endpoint relations already enforced by $f_\|(q^2_{\rm max}) = \sqrt{2} f_0(q^2_{\rm max})$, $f_\perp(q^2_{\rm max}) = 0$. $\rightarrow$

1. Low recoil Region – power corrections

”There are no genuine non-factorizable contributions ($1/m_b$, resonances,..) at zero recoil.” GH,Zwicky14

consider this in scans, uncertainty estimations.

Why is it short-distance universal?

$$B \to V\ell\ell: \quad H_{0,\|} = C_-^{\rm eff}(q^2) f_{0,\|}(q^2)\ , \quad H_\perp = C_+^{\rm eff}(q^2) f_\perp(q^2)\ ,$$
$$B \to P\ell\ell: \quad H = C_+^{\rm eff}(q^2) f(q^2)$$

because the short-distance coefficients $C_-^{\rm eff}(q^2), C_+^{\rm eff}(q^2)$ dont know about the endpoint.

Applications in many modes $B \to X_J ll$, $J = 0, 1, 2, \ldots$.

Universality in $B \to K^* ll$ allow to extract form factor ratios (assuming no right-handed currents) Hambrock, GH ’12, Hambrock, GH, Schacht, Zwicky13

2012:

	BaBar	CDF		LHCb	
q^2 [GeV^2]	F_L	F_L	$A_T^{(2)}$	F_L	$A_T^{(2)}$
$[14.18, 16]$	$0.43^{+0.13}_{-0.16}$	$0.40^{+0.12}_{-0.12}$	$0.11^{+0.65}_{-0.65}$	$0.35^{+0.10}_{-0.06}$	$0.06^{+0.24}_{-0.29}$
$[16, 19.xx]$	$0.55^{+0.15}_{-0.17}$	$0.19^{+0.14}_{-0.13}$	$-0.57^{+0.60}_{-0.57}$	$0.37^{+0.07}_{-0.08}$	$-0.75^{+0.35}_{-0.20}$

2013:

	BaBar	CDF		LHCb			ATLAS	CMS
q^2	F_L	F_L	$A_T^{(2)}$	F_L	$A_T^{(2)}$	$^a\, P_4'$	F_L	F_L
bin1	$0.43^{+0.13}_{-0.16}$	$0.40^{+0.12}_{-0.12}$	$0.11^{+0.65}_{-0.65}$	$0.33^{+0.08}_{-0.08}$	$0.07^{+0.26}_{-0.28}$	$-0.18^{+0.54}_{-0.70}$	$0.28^{+0.16}_{-0.16}$	$0.53^{+0.12}_{-0.12}$
bin2	$0.55^{+0.15}_{-0.17}$	$0.19^{+0.14}_{-0.13}$	$-0.57^{+0.60}_{-0.57}$	$0.38^{+0.09}_{-0.08}$	$-0.71^{+0.36}_{-0.26}$	$0.70^{+0.44}_{-0.52}$	$0.35^{+0.08}_{-0.08}$	$0.44^{+0.08}_{-0.08}$

in these observables, SD-coeffs and fact. stuff drops out!

At endpoint: $F_L = 1/3, A_T^{(2)} = -1, P_4' = \sqrt{2}$

Benefits of $B \to K^*$ at low recoil

At low hadr. recoil transversity amplitudes $A_i^{L,R}$, $i = \perp, ||, 0$ related *:

$$A_i^{L,R} \propto C^{L,R} \cdot f_i$$

$C^{L,R}$: <u>universal</u> short-dist.-physics; $C^{L,R} = (C_9^{\text{eff}} \mp C_{10}) + \kappa \frac{2\hat{m}_b}{\hat{s}} C_7^{\text{eff}}$

$1/m_b$- corrections parametrically suppressed $\sim \alpha_s/m_b, C_7/(C_9 m_b)$

f_i: form factors

$C^{L,R}$ drops out in ratios:

$$F_L = \frac{|A_0^L|^2 + |A_0^R|^2}{\sum_{X=L,R}(|A_0^X|^2 + |A_\perp^X|^2 + |A_\parallel^X|^2)} = \frac{f_0^2}{f_0^2 + f_\perp^2 + f_\parallel^2}$$

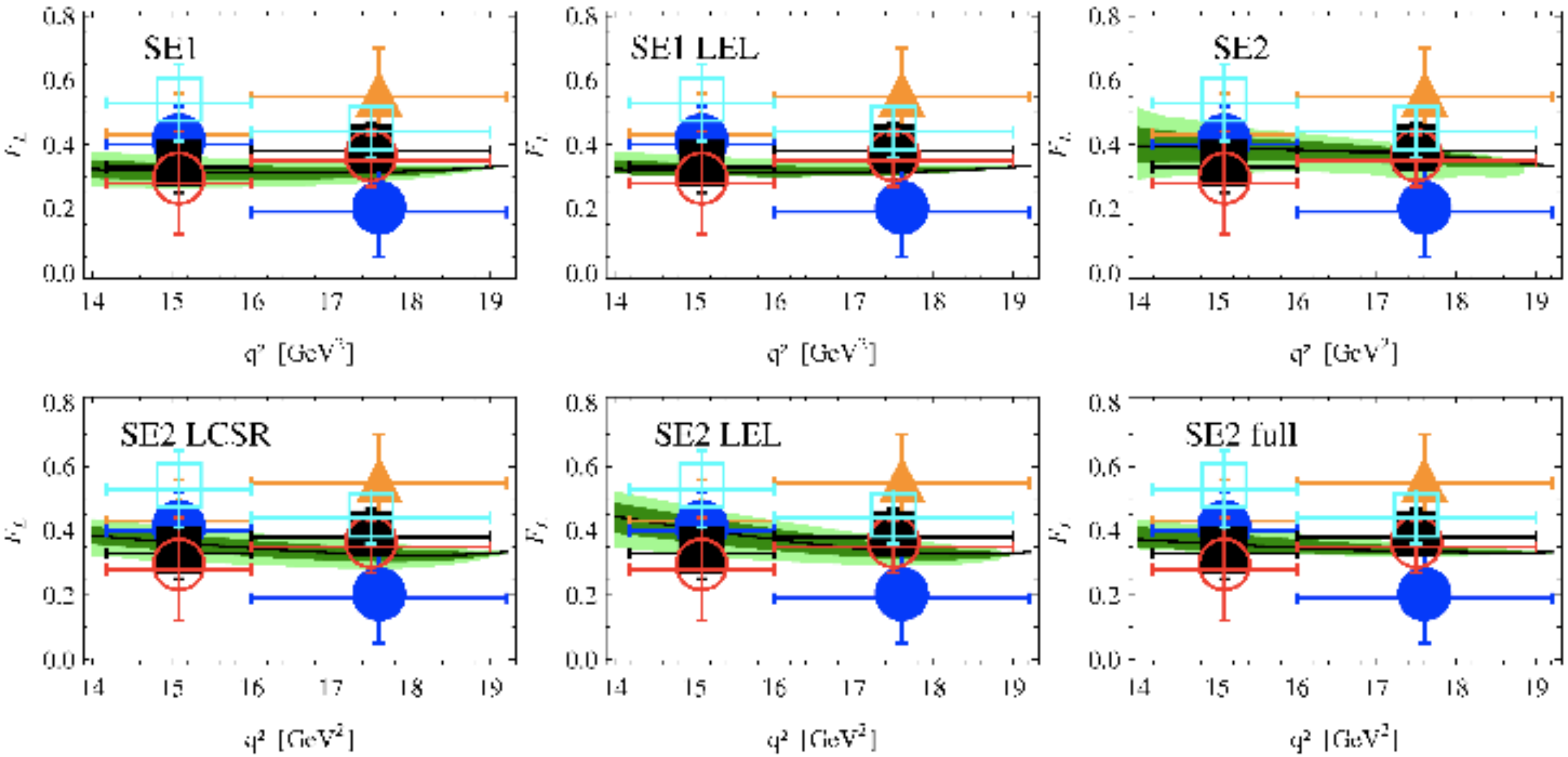
$$A_T^{(2)} = \frac{|A_\perp^L|^2 + |A_\perp^R|^2 - |A_\parallel^L|^2 - |A_\parallel^R|^2}{|A_\perp^L|^2 + |A_\perp^R|^2 + |A_\parallel^L|^2 + |A_\parallel^R|^2} = \frac{f_\perp^2 - f_\parallel^2}{f_\perp^2 + f_\parallel^2}$$

$$P_4'(q^2) = \frac{\sqrt{2} f_\parallel(q^2)}{\sqrt{f_\parallel^2(q^2) + f_\perp^2(q^2)}}$$

$*$ assuming only V-A operators

Higher order Series Expansion; use theory input from low q^2: LCSR (sum rules) or $V(0)/A_1(0) = (m_B + m_{K^*})^2/(2m_B E_{K^*}) + \mathcal{O}(1/m_b) = 1.33 \pm 0.4$ (LEL)

F_L:



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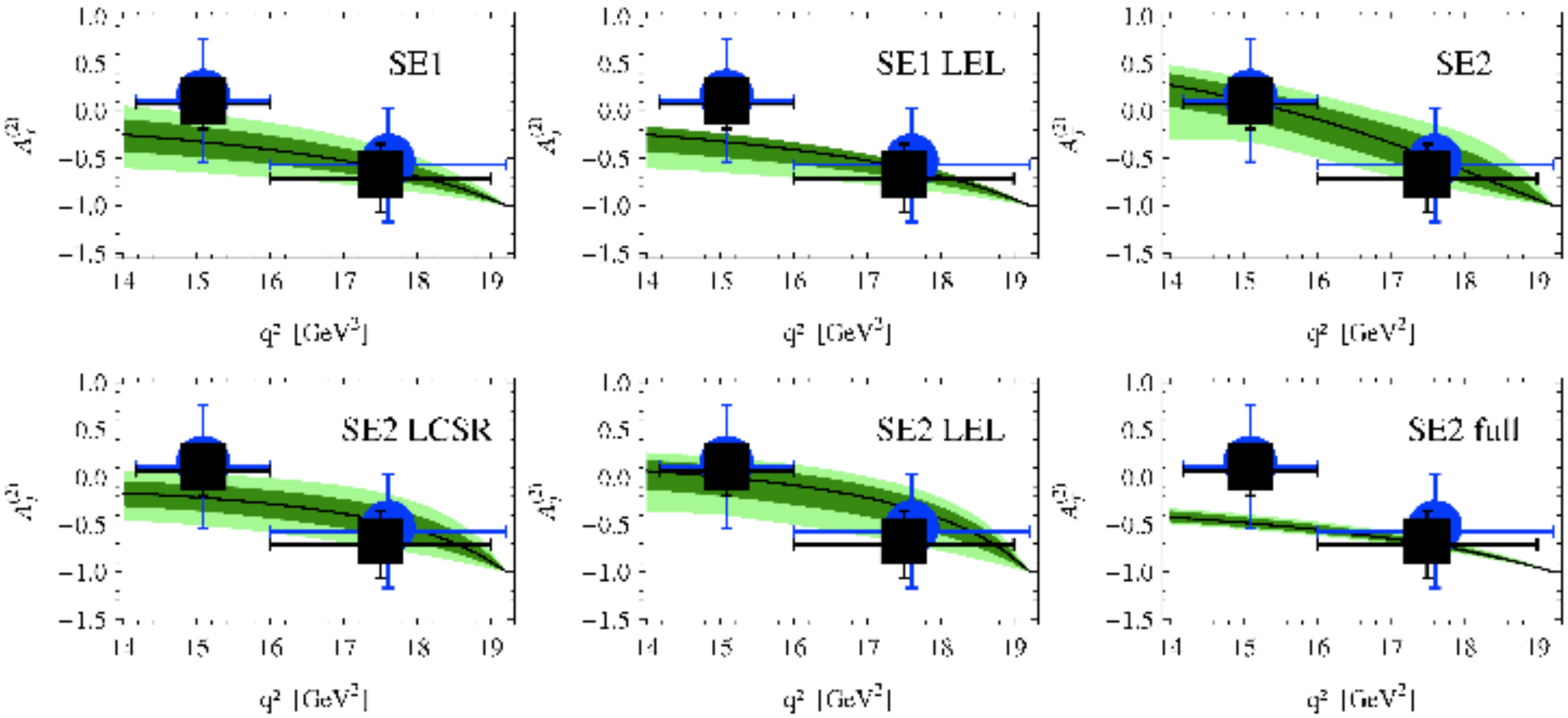
$A_T^{(2)}$:



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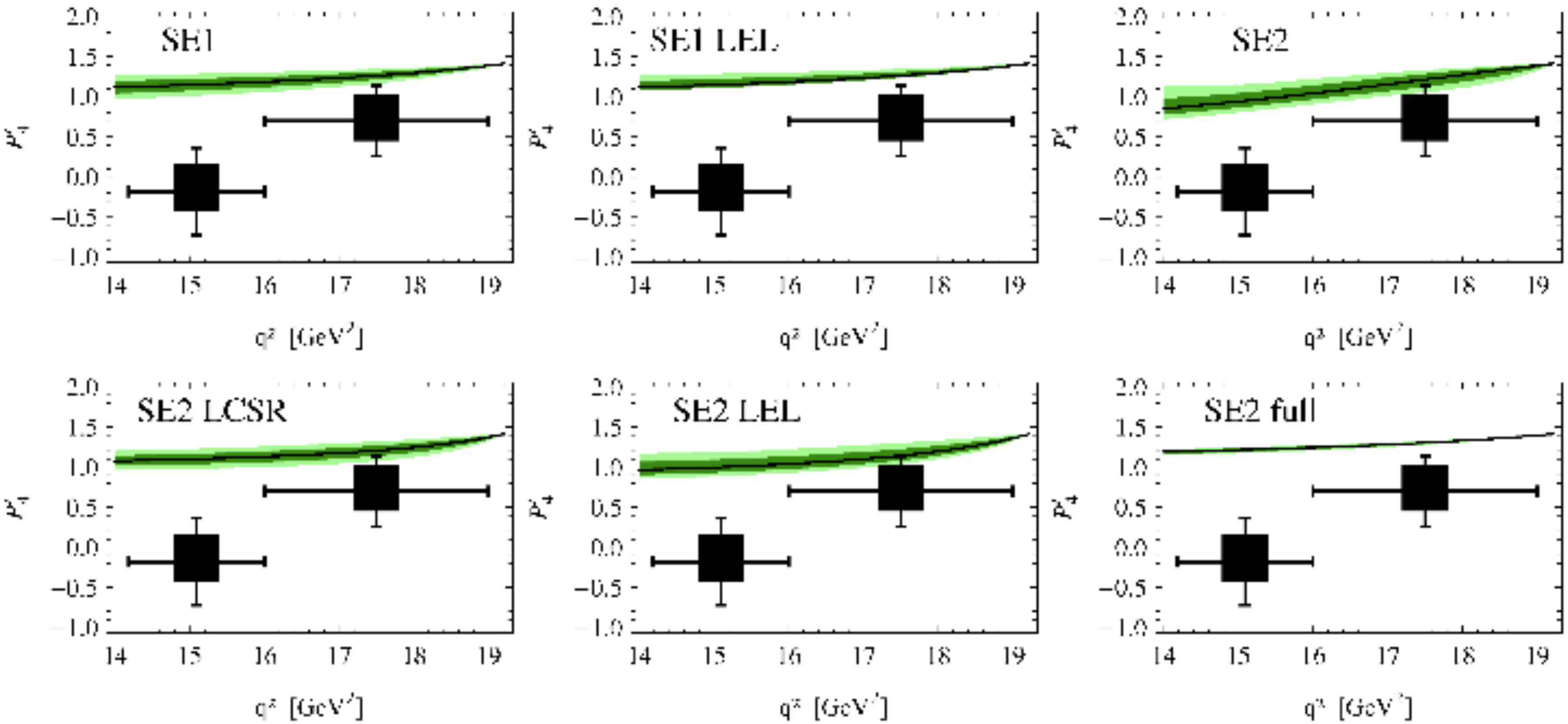
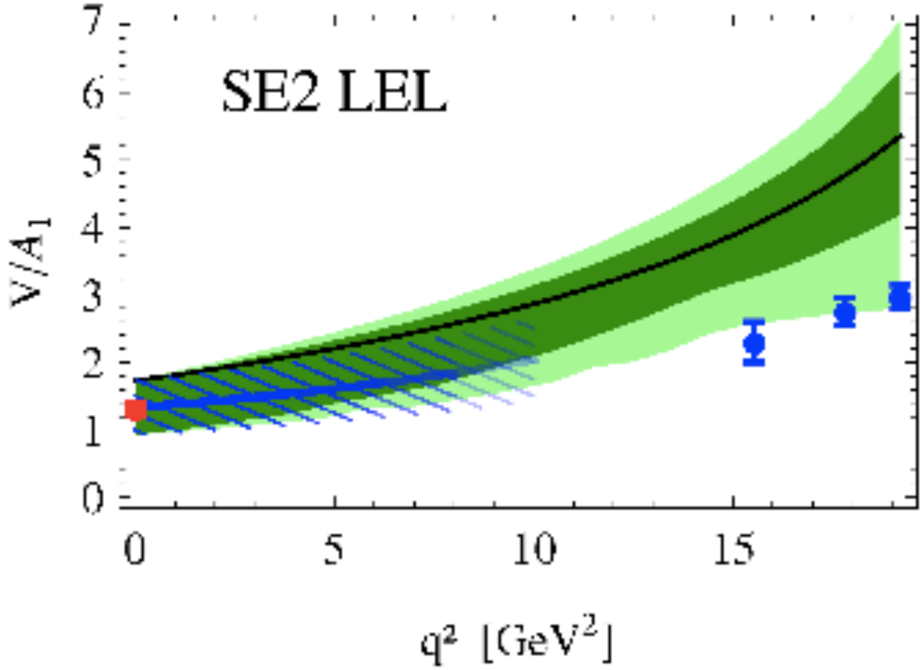
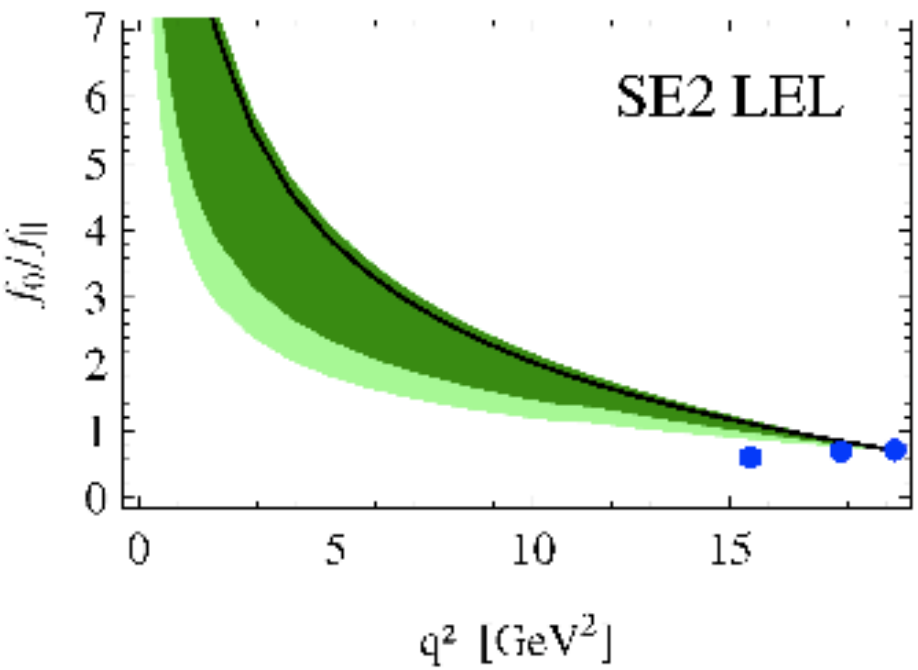
P_4':



Advances in ... Extracting $B \to K^*$ form factors

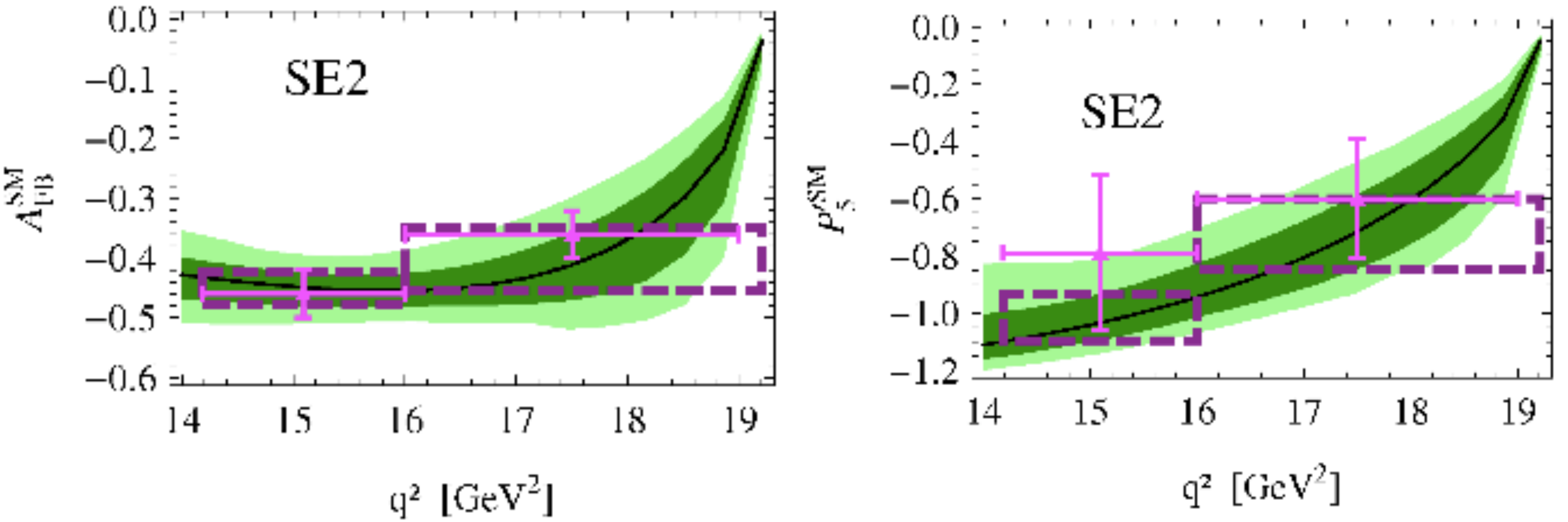




Predictivity at low q^2 is obtained from low q^2 input. (Required at higher order)

Data-extracted form factor ratios constitute benchmark for lattice form factor estimations at low recoil. Blue points: Wingate '13 et al, red: LCSR, band:LEL

Advances in ... Extracting $B \to K^*$ form factors



SM predictions for A_{FB} and P_5' at low recoil (assuming $V - A$ currents). Good agreement with data in fits in both low recoil bins.

P_4' escapes explanation within factorizaton Altmannshofer, Straub '13, Hambrock, GH, Schacht, Zwicky '13, Beaujean, Bobeth, vanDyk '13, Descotes-Genon, Matias, Virto '13

Yes, we would like to have correlations between them.

At least, please provide ratios, we use them.

LCSR example:

$\delta V(0)/A_1(0) = 15\%$ (gaussian error prop. of Ball,Zwicky)
$\delta V(0)/A_1(0) = 8\%$ including error correlations a la Hambrock,GH, Schacht Zwicky '13 (parametric, continuum threshold and EOM)

Status Low recoil $B \to K^*(\to K\pi)\mu\mu$ –largest bin

observable	LHCb[15,19][a,b]	SM$[15,19]^d$
F_L	0.344 ± 0.031	$0.351(0.342) \pm 0.010 \pm 0.003$
$A_{\rm FB}$	-0.355 ± 0.029	$-0.391(-0.396) \pm 0.016 \pm 0.005$
S_3	-0.122 ± 0.026	$-0.129(-0.131) \pm 0.009 \pm 0.007$
S_4	0.214 ± 0.029	$0.215(0.218) \pm 0.005 \pm 0.002$
S_5	-0.244 ± 0.029	$-0.230(-0.233) \pm 0.009 \pm 0.006$

[a]Uncertainties added in quadrature and symmetrized. [b]Values adopted to common theory definitions.

LHCb (3 fb^{-1}): LHCb-CONF-2015-002, CERN-LHCb-CONF-2015-002

[d]OPE with $K\pi$ background; central values in parenthesis S-wave subtracted; second uncertainty due to interference (unknown strong phase) 1506.06699

Status Low recoil $B \to K^*(\to K\pi)\mu\mu$ –endpoint bin

observable	LHCb$[17, 19]^{a,b}$	SM$[17, 19]^{d}$	endpoint
F_L	0.354 ± 0.054	$0.338(0.333) \pm 0.006 \pm 0.002$	$1/3$
$A_{\rm FB}$	-0.306 ± 0.049	$-0.349(-0.351) \pm 0.015 \pm 0.007$	0^c
S_3	-0.145 ± 0.062	$-0.167(-0.169) \pm 0.007 \pm 0.005$	$-1/4$
S_4	0.202 ± 0.052	$0.226(0.227) \pm 0.003 \pm 0.002$	$+1/4$
S_5	-0.245 ± 0.050	$-0.191(-0.193) \pm 0.008 \pm 0.006$	0^c

^{a}Uncertainties added in quadrature and symmetrized. ^{b}Values adopted to common theory definitions.

LHCb (3 fb^{-1}): LHCb-CONF-2015-002, CERN-LHCb-CONF-2015-002

^{d}OPE with $K\pi$ background; central values in parenthesis S-wave subtracted; second uncertainty due to interference (unknown strong phase) 1506.06699 ^{c}goes to zero with non-negligible slope