Remarks on next theoretical activities

a general and a few topical ones

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Our program: Test the SM, explore its borders and the physics beyond!

- $\Lambda_{NP} \gtrsim m_W$: Effective $|\Delta B| = |\Delta S| = 1$ Hamiltonian
  $\mathcal{H}_{\text{eff}} = \sum C_i O_i = \sum C_i O_i^{SM} + \sum C_i O_i^{NP}$

  O_i: SM operators, chirality-flipped ones, tensors, including CPX

  $b \to s$, possibly vs $b \to d$ processes (CKM-link in MFV-models), e.g.

$$R_{\mu\mu} = \frac{\mathcal{B}(B_s \to \mu^+\mu^-)}{\mathcal{B}(B_d \to \mu^+\mu^-)} \sim \frac{m_{B_s} f_{B_s}^2 \tau_{B_s}}{m_{B_d} f_{B_d}^2 \tau_{B_d}} r_{\text{ps}} \times \begin{cases} \frac{|V_{ts}|^2}{|V_{td}|^2} & \text{for } (\text{MFV}, (\delta_{i3}^d)_L) \\ \frac{|m_s V_{td}|^2}{|m_d V_{ts}|^2} & \text{for } ((\delta_{i3}^d)_R) \\ \frac{m_s}{m_d} & \text{for } (\langle \delta_{i3}^d \rangle) \end{cases}$$

lepton-flavor non-universality; $b \to see$ vs $b \to s\mu\mu$ vs $b \to s\tau\tau$,

e.g. $B \to Kll$ 0709.4174 [hep-ph]:

$$\frac{1}{\Gamma}\frac{d\Gamma}{d\cos\Theta_l} = \frac{3}{4}(1 - F_H^l)(1 - \cos^2\Theta_l) + F_H^l/2 + A_{FB}^l \cos\Theta_l$$

in general: lepton flavor dependence in $d\Gamma^l/dq^2$, F_H^l and A_{FB}^l.

study ratios, e.g. $R_K = \mathcal{B}(B \to K\mu\mu)/\mathcal{B}(B \to Kee)$ hep-ph/0310219

In SM: $R_K - 1$, F_H^l and A_{FB}^l are suppressed by lepton mass.

hep-ph/0310219

Probe of Higgs-exchanges, lepto-quarks, R-parity violation etc.

Model-independently w. scalar/tensor couplings (for low q^2):

$$|A_{FB}^e| < 13\%, \quad |A_{FB}^\mu| < 15\%, \quad R_K - 1 = \mathcal{O}(1), \quad F_H^{e,\mu} < O(0.5)$$

inclusive decays: $B \to X_s ll$ observed when $l = e$ and $l = \mu$ are averaged, for $q^2 > 0.04 GeV^2$) $Br(B \to X_s l^+ l^-) = 3.66^{+0.76}_{-0.77} \cdot 10^{-6}$
Belle, Talk LP'09 by T.Iijima:
$Br(B \to X_s e^+ e^-) = 4.56 \pm 1.15^{+0.33}_{-0.40} \cdot 10^{-6}$
$Br(B \to X_s \mu^+ \mu^-) = 1.91 \pm 1.02^{+0.16}_{-0.18} \cdot 10^{-6}$.

Full fit: $O_{7,9,10}$ + $O_{S,P}$+tensors + $V + A$ times 2dof (CP) times 3 lepton flavors times 2 (s vs d): $12 \times 2 \times 3 \times 2 = 144$ Wilson coefficient dofs (still neglecting NP in QCD penguins ...)

There is no such thing as a truly model-independent analysis possible.

..even if the hadronic understanding of the decay observables would be perfect.

Presently, we have already a precision program ongoing. tool for flavor observables: EOS project http://project.het.physik.tu-dortmund.de/eos/

Dedicated observables are sensitive to subsets of the operators.

In BSM models, also often only a limited, much smaller number of Wilson coefficients needs to be considered (MFV SUSY, 2HDM,..)

- $m_{NP} < m_B$: dark matter, axion-like particles, missing energy-signatures, NMSSM light pseudo-scalars, ...

If there is a signal, there are 2 avenues: fit model-independently, fit your model and check direct searches, EDMs, kaon, charm, top physics etc.

Theory tasks:

precision (QCD) [a]

interpretations,fits, correlations

model-building

[a] not required for null tests

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 $f_\|(q^2_{\rm max}) = \sqrt{2} f_0(q^2_{\rm max})$, $f_\perp(q^2_{\rm max}) = 0$. $\longrightarrow$

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

$B \to K^* \mu^+ \mu^-$ data progress 2012 to 2013

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 *:

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

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

$1/m_b$- 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:

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

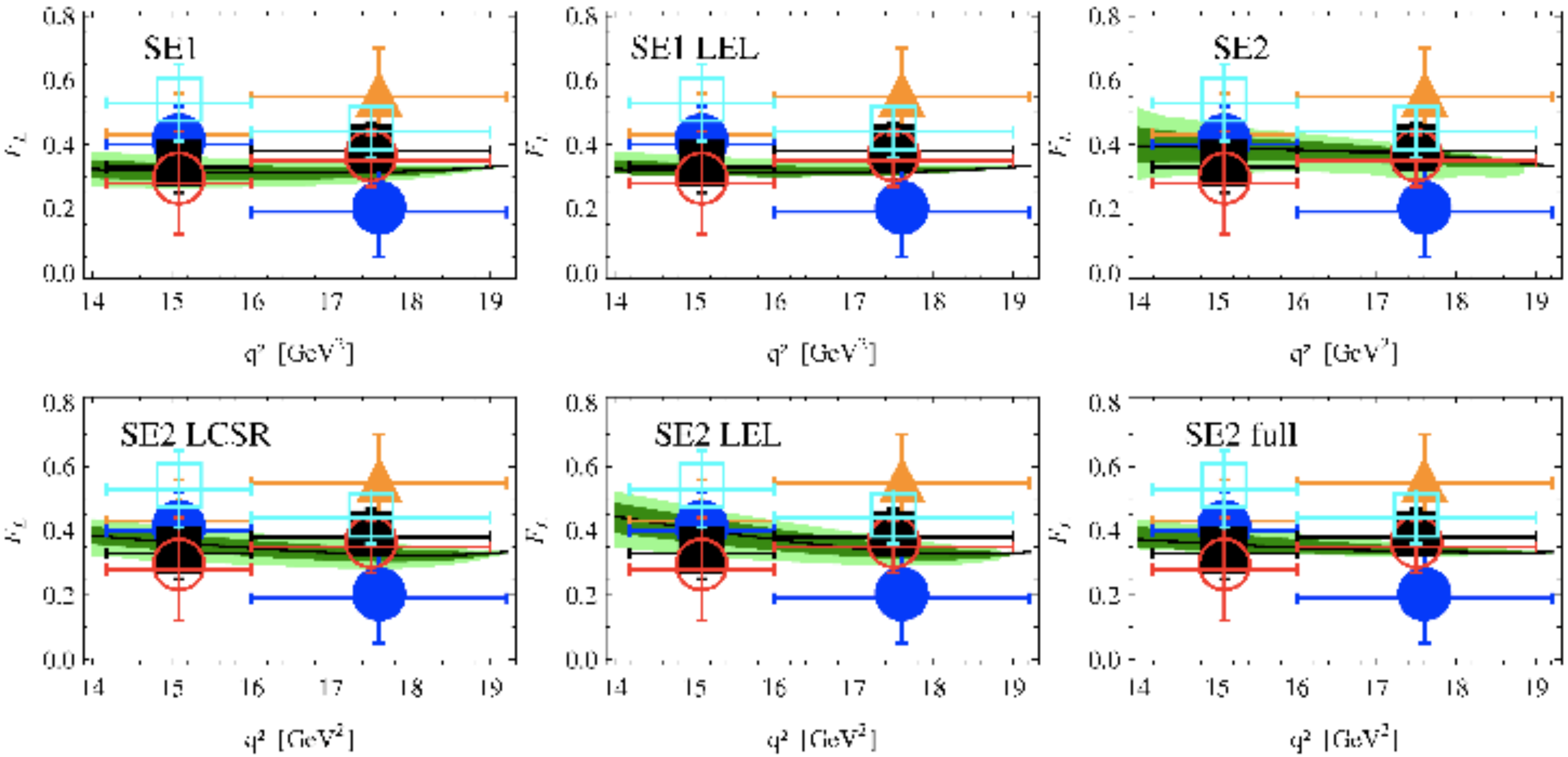
$$A_T^{(2)} = \frac{|A_\perp^L|^2 + |A_\perp^R|^2 - |A_\parallel^L|^2 - |A_\parallel^R|^2}{|A_\perp^L|^2 + |A_\perp^R|^2 + |A_\parallel^L|^2 + |A_\parallel^R|^2} = \frac{f_\perp^2 - f_\parallel^2}{f_\perp^2 + f_\parallel^2}$$

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

$*$ 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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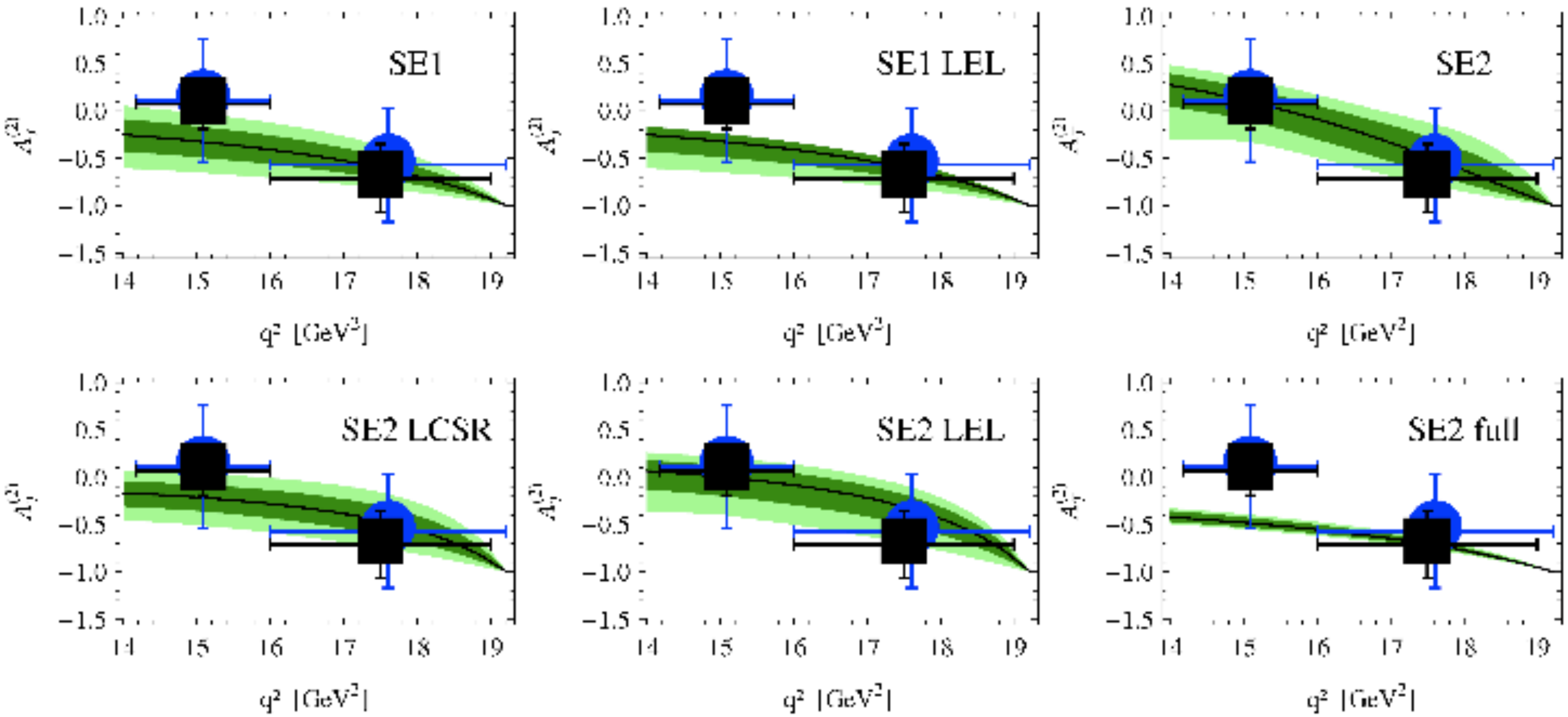
$A_T^{(2)}$:



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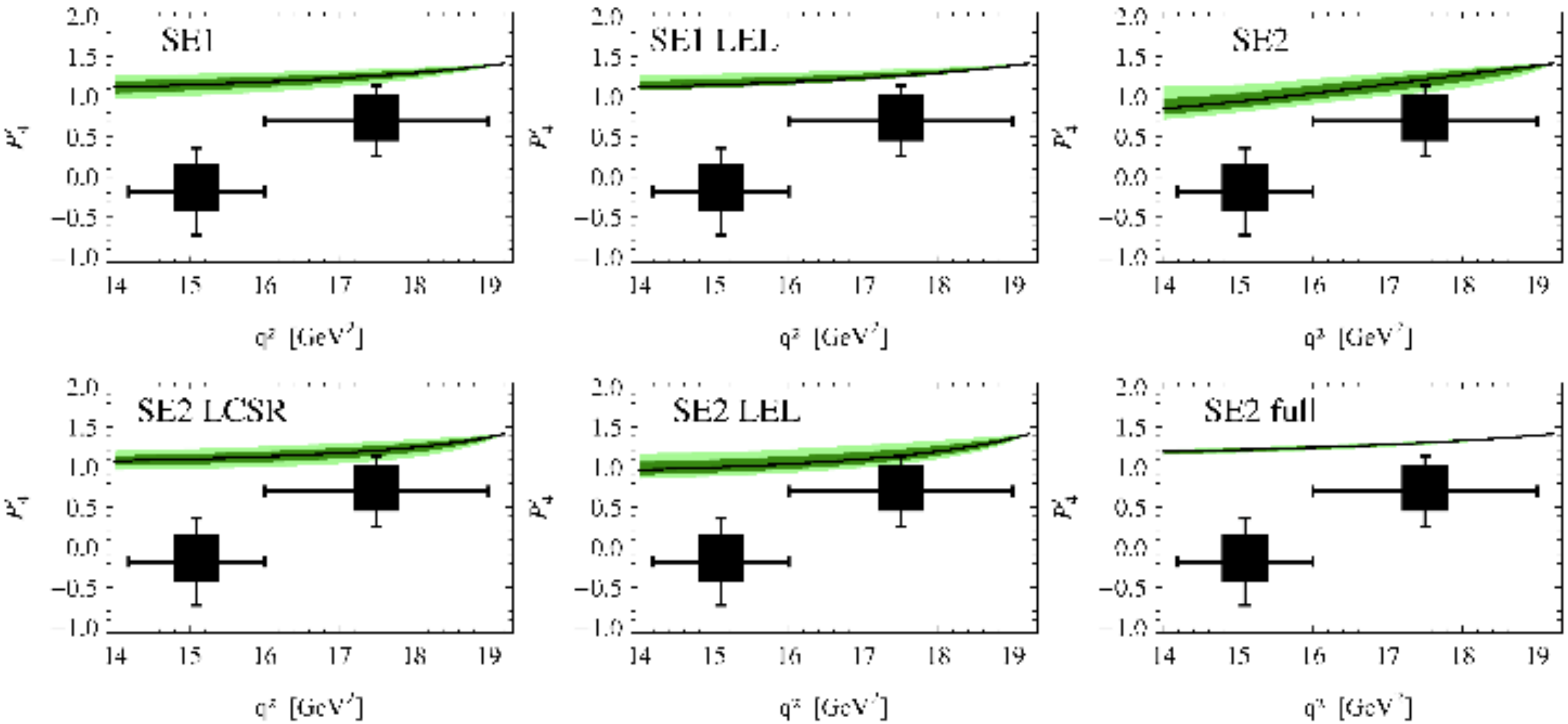
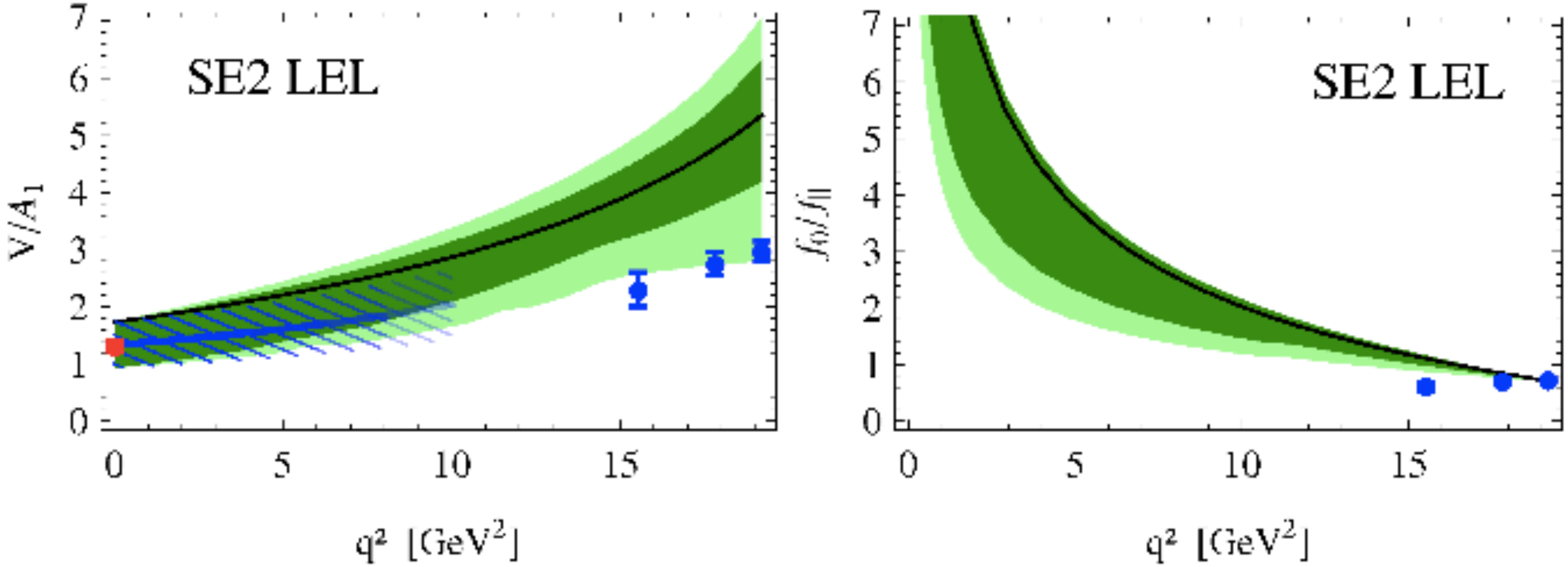
P_4':



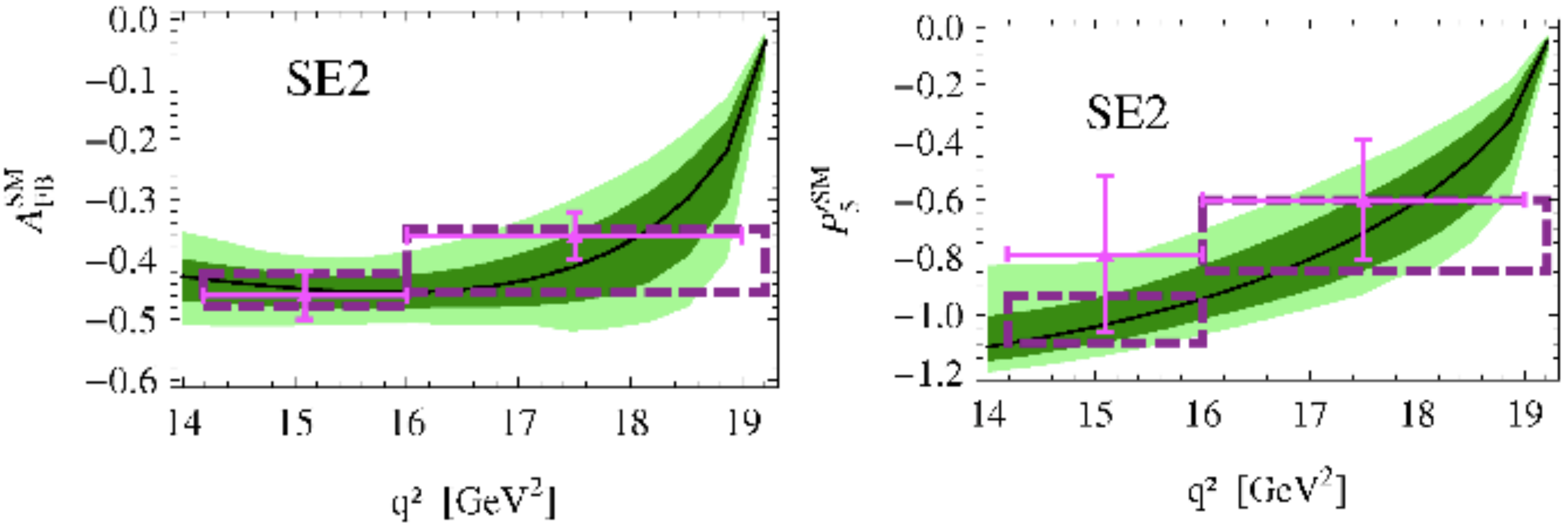
Advances in ... Extracting $B \to K^*$ form factors



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)

Ongoing th activities (selected, this workshop):

Relations from kinematics (GH, Zwicky)
Relations by overconstraining observables (Serra, Quim)
Form factors low recoil (Meinel)
Fitting data (Bobeth, Quim, Van Dyk, Jäger,Hofer, Meinel, Straub, et al)
Interpreting $b \to s$ data with a BSM model (Haisch)

More data, more backgrounds..
S-wave et al (Das, GH, Jung,Shires, in preparation)

It is about time to think about B-factory observables again, too.