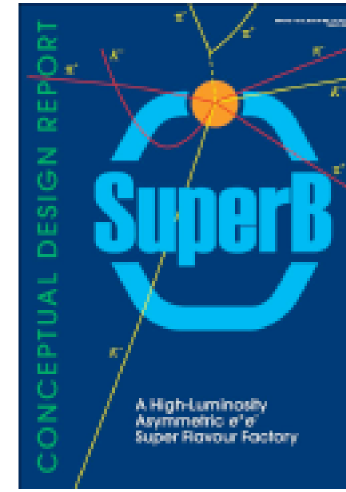
Exclusive and Inclusive $b \to s\ell^+\ell^-$ Transitions

Tobias Hurth

JG|U JOHANNES GUTENBERG UNIVERSITÄT MAINZ

Physics case of a Super-B factory



Well explored issue: several studies existing

- SuperKEKb Book: "Physics at a Super B Factory"
  Akeroyd et al., hep-ex/0406071
- SuperBabar Book: "The Discovery Potential of a Super B factory"
  Hewett et al., hep-ph/0503261
- CDR of SuperB: Chapter I "The Physics"
  Bona et al.,arXiv:0709.0451 [hep-ex]
- "On the Physics Case of a Super Flavour Factory"
  Browder,Ciuchini,Gershon,Hazumi,Hurth,Okada,Stocchi,arXiv:0710.3799
- Valencia Physics Report
  arXiv:0810.1312 [hep-ph]
- SuperB Progress Report – Physics
  arXiv:1008.1541 [hep-ex]

Super-B is a Super Flavour factory: besides precise B measurements, CP violation in charm, lepton flavour violating modes $\tau \to \mu\gamma, \ldots$

What is left over for the TDR phase?

At least two issues

- Experimental sensitivity studies beyond simple extrapolation of statistical errors
- Super-B physics case in view of the LHCb and Super-LHCb

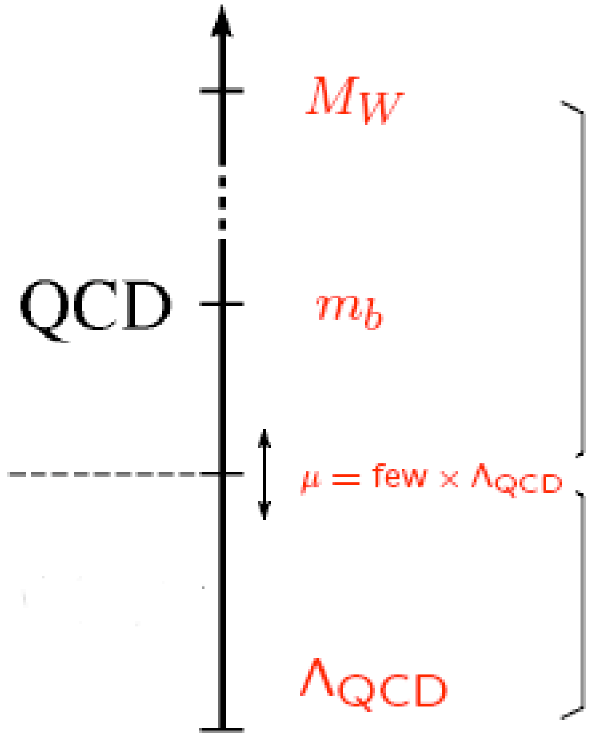
The physics case of a SFF has to be established beyond LHCb reach !

- Comparison of measurable channels is not sufficient
- One needs clear reasons why higher precision of a SFF is necessary when the possible new physics structures can already be tested at LHCb
- One needs new physics structures which cannot be tested at LHCb
- Possible upgrade of LHCb: $10 fb^{-1} \rightarrow 100 fb^{-1}$

- Theoretical tools

Separation of new physics and hadronic effects

Challenge for our understanding of QCD



Strong interaction in B decays

short-distance physics
perturbative

long-distance physics
nonperturbative

Factorization theorems: separating long- and short-distance physics

- Electroweak effective Hamiltonian: $H_{eff} = -\frac{4G_F}{\sqrt{2}} \sum C_i(\mu, M_{heavy})\ \mathcal{O}_i(\mu)$

- $\mu^2 \approx M_{New}^2 >> M_W^2$: 'new physics' effects: $C_i^{SM}(M_W) + C_i^{New}(M_W)$

How to compute the hadronic matrix elements $\mathcal{O}_i(\mu = m_b)$?

Inclusive modes $B \to X_s\gamma$ or $B \to X_s\ell^+\ell^-$

- Heavy mass expansion for inclusive modes (in general restricted to e^+e^-)

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

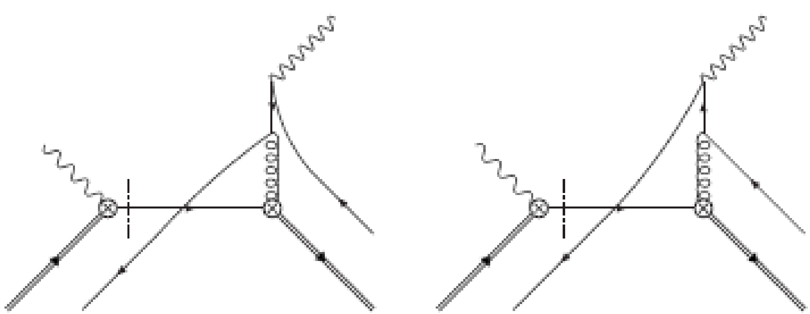
No linear term Λ_{QCD}/m_b (perturbative contributions dominant)

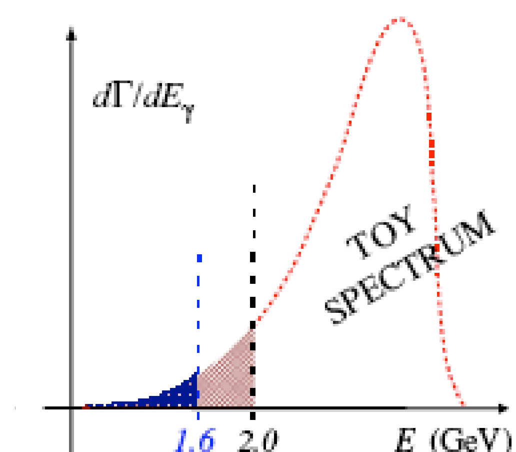
– More sensitivities to nonperturbative physics due to kinematical cuts: shape functions; multiscale OPE (SCET) with $\Delta = m_b - 2E_\gamma^0$

Becher,Neubert,hep-ph/0610067

– Breakdown of local expansion: class of nonlocal power corrections identified; naive estimates lead to 5% uncertainty.

Benzke,Lee,Neubert,Paz,arXiv:1003.5012





Exclusive modes $B \to K^*\gamma$ or $B \to K^*\ell^+\ell^-$

- QCD factorization/SCET analysis for exclusive decays with fast light particles in final state; BBNS 1999

$$\mathcal{T}_a^{(i)} = C_a^{(i)}\xi_a + \phi_B \otimes T_a^{(i)} \otimes \phi_{a,K^*} + O(\Lambda/m_b)$$

  - Separation of perturbative hard kernels from process-independent nonperturbative functions like form factors

  - Relations between formfactors in large-energy limit

  - Limitation: insufficient information on power-suppressed Λ/m_b terms (breakdown of factorization: 'endpoint divergences')

    Phenomenolgically highly relevant issue:

    general strategy of LHCb to look at ratios of exclusive modes

Egede,Hurth,Matias,Ramon,Reece
arXiv:0807.2589

However, exclusive observables in the high-q^2

talk of Christoph Bobeth

- Recall results achieved in Warwick 2009 on b>sll transitions
- Additional comments

WG2 Summary   Open Problems

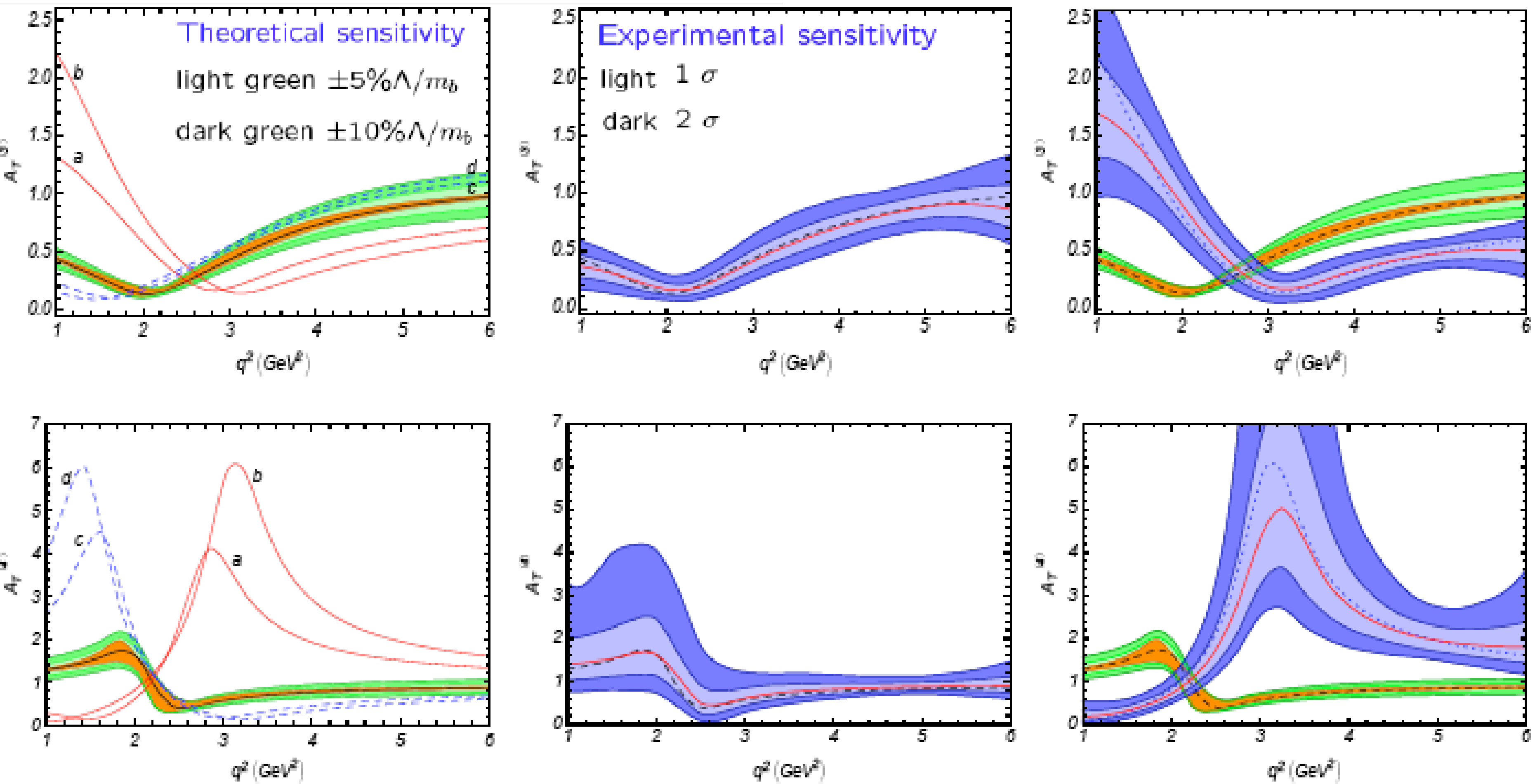
Tobias Hurth (CERN, SLAC)

SuperB Physics Workshop, Warwick, 14.-17.4.2009

- Exclusive $b \to s\ell^+\ell^-$

Full angular fit: many theoretical clean observables accessible for LHCb

Egede,Hurth,Matias,Ramon,Reece, arXiv:0807.2589

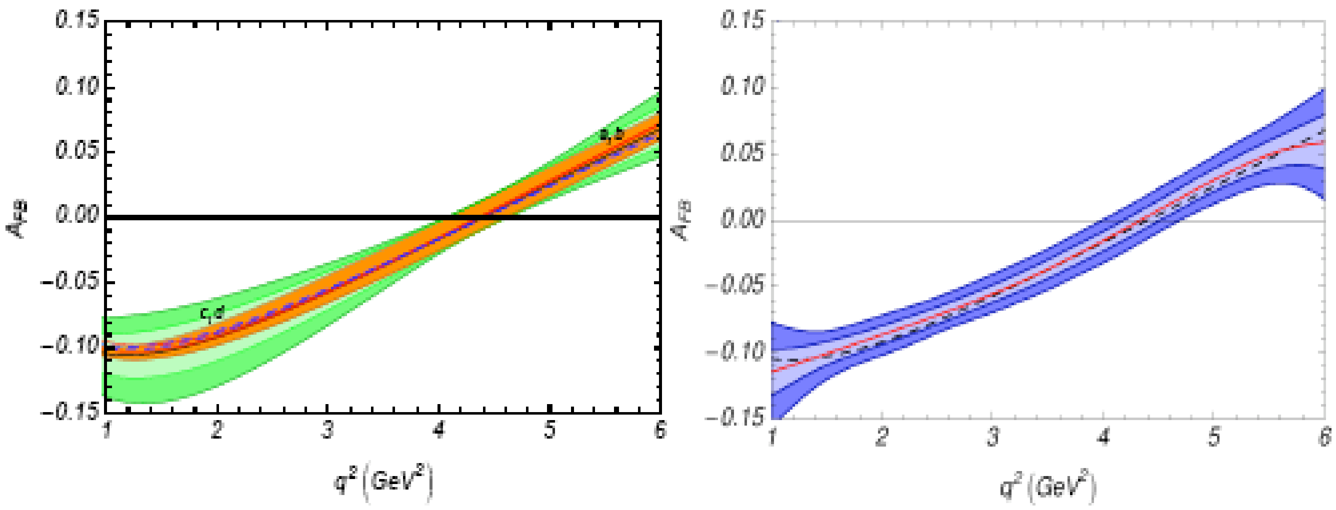


Theory

LHCb 10 fb^-1

Sensitivity to right-handed currents

Λ/m_b corrections assumed to be O(10%)



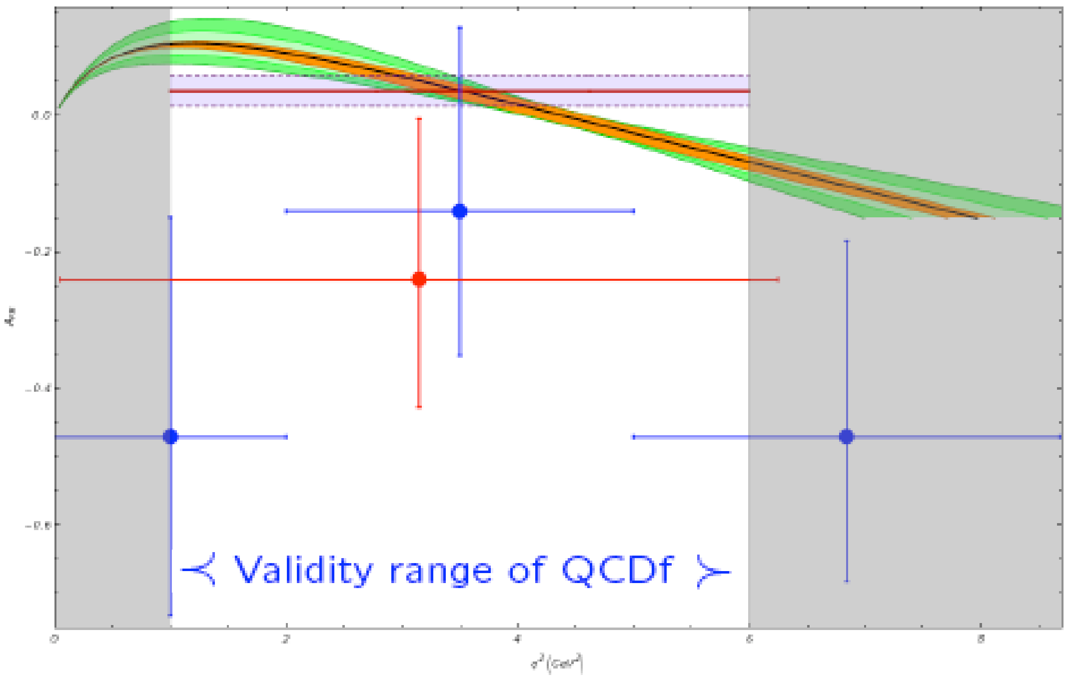
A_FB

not sensitive

Question:

What can inclusive observable at a SuperB add ?

Forward-backward asymmetry: New measurements of Babar and Belle

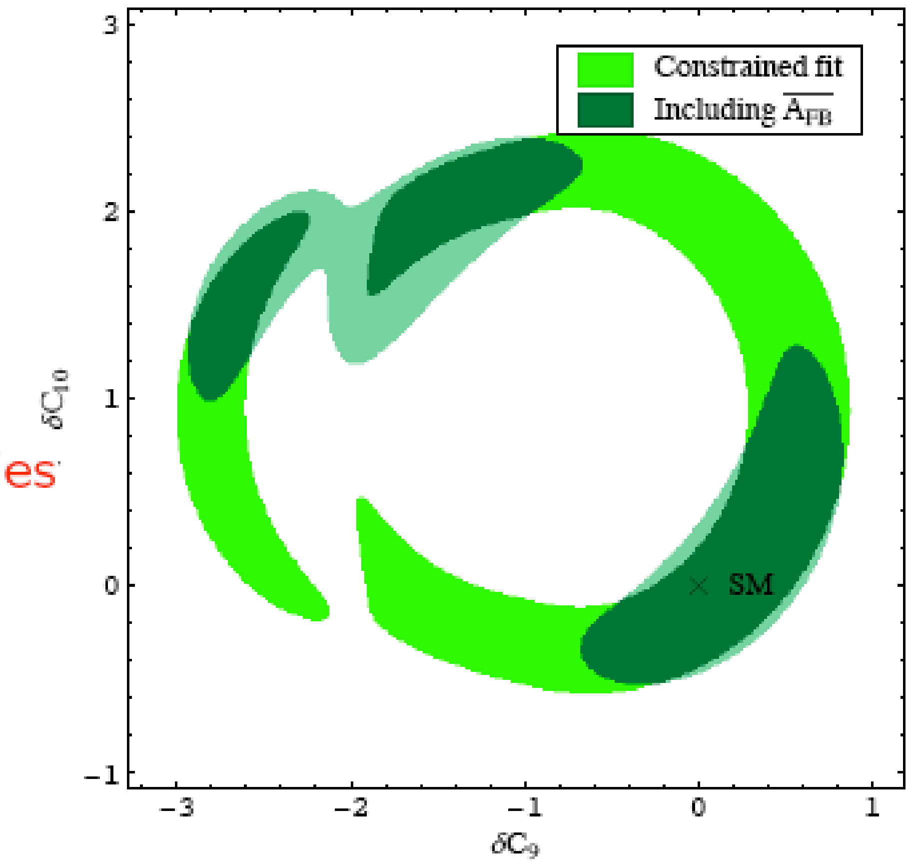


Babar FPCP 2008

Belle ICHEP 2008

:

Impact on MFV constraints



(only Babar data included yet)

Hurth,Isidori,Kamenik,Mescia,arXiv:0807.5039

LO: Zero free from hadronic uncertainties

NLO contribution within QCDf

Beneke,Feldmann,Seidel,hep-ph/0412400

Issue of Λ/m_b corrections

CP violating observables

Egede,Hurth,Matias,Ramon,Reece, arXiv:1005.0571

- Angular distributions allow for the measurement of 7 CP asymmetries
  (Krüger,Seghal,Sinha^2 2000,2005)

- NLO (α_s) corrections included: scale uncertainties reduced
  (however, some CP asymmetries start at NLO only)
  (Bobeth,Hiller,Piranishvili 2008)

- New CP-violating phases in C_{10},C'_{10}, C_9, and C'_9 are by now NOT very much constrained and enhance the CP-violating observables drastically
  (Bobeth,Hiller,Piranishvili 2008; Buras et al. 2008)

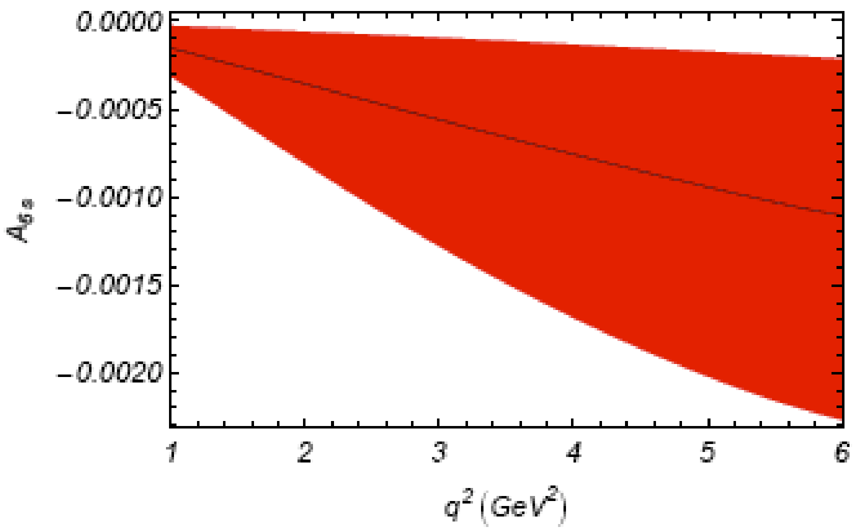
- New physics reach of CP-violating observables of the angular distributions depends on the theoretical and experimental uncertainties:

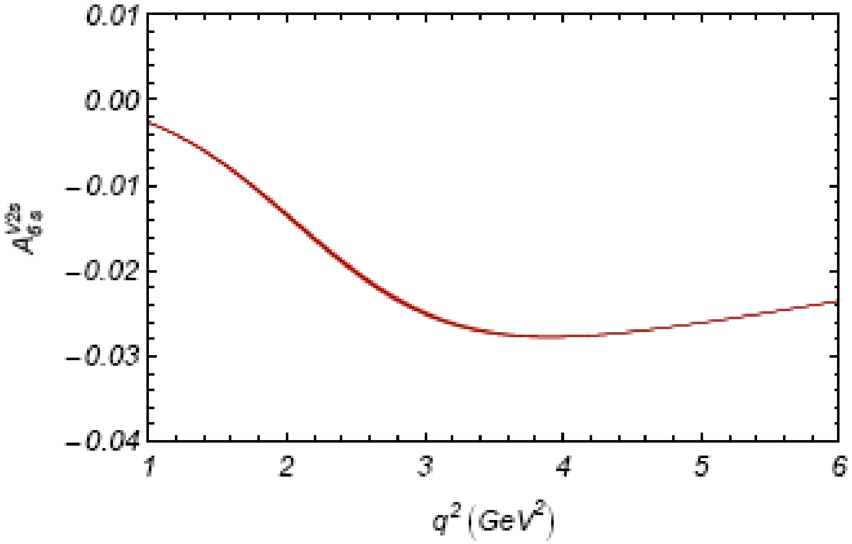
  - soft/QCD formfactors
  - other input parameters
  - scale dependences
  - Λ/m_b corrections
  - experimental sensitivity in the full angular fit

Appropriate normalization eliminates the uncertainty due to form factors

Example

$$A^{6s} = \frac{I^{6s} - \bar{I}^{6s}}{d(\Gamma + \bar{\Gamma})/dq^2} \qquad A^{6s}_{V2s} = \frac{I^{6s} - \bar{I}^{6s}}{I^{2s} + \bar{I}^{2s}}$$





Red bands: conservative estimate of uncertainty due to formfactors only

Relative error drops dramatically

However:

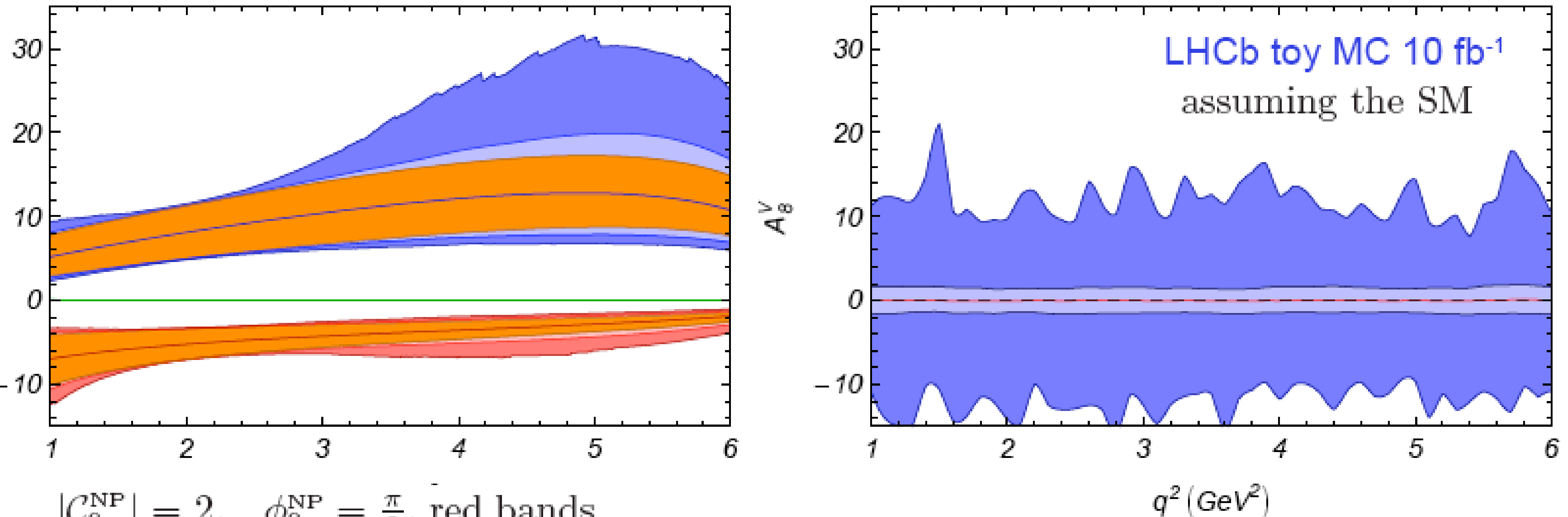
Λ/m_b corrections very small in SM due to small weak SM phase

but sizeable if NP CPV effects are large!

In addition poor experimental uncertainty !

Hard to see these will ever be useful observables

$$A_8^V = \frac{J_8 - \bar{J}_8}{J_8 + \bar{J}_8}$$



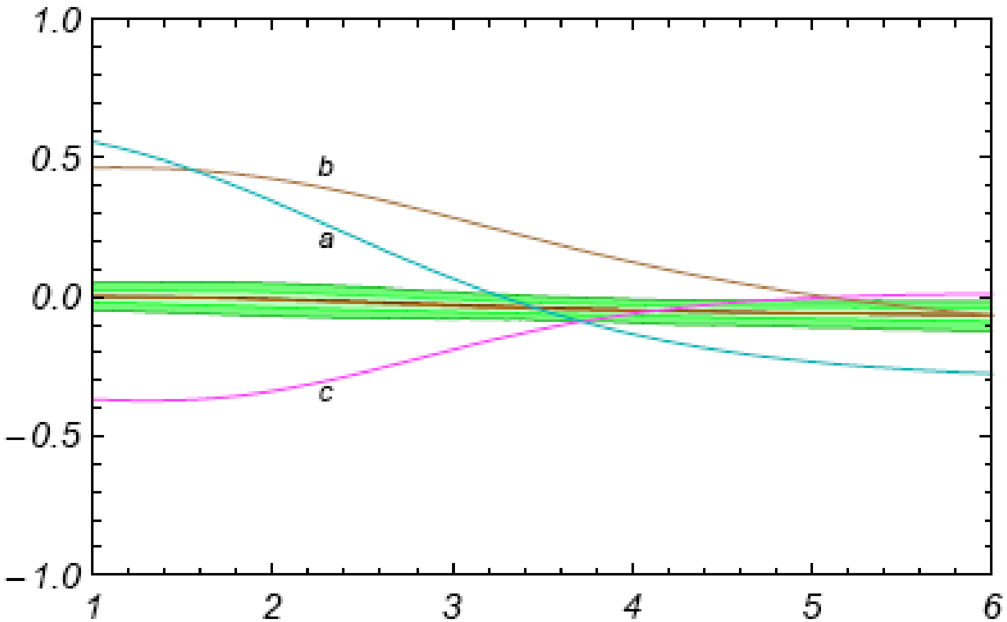
$|\mathcal{C}_9^{\rm NP}| = 2, \quad \phi_9^{\rm NP} = \frac{\pi}{2}$, red bands

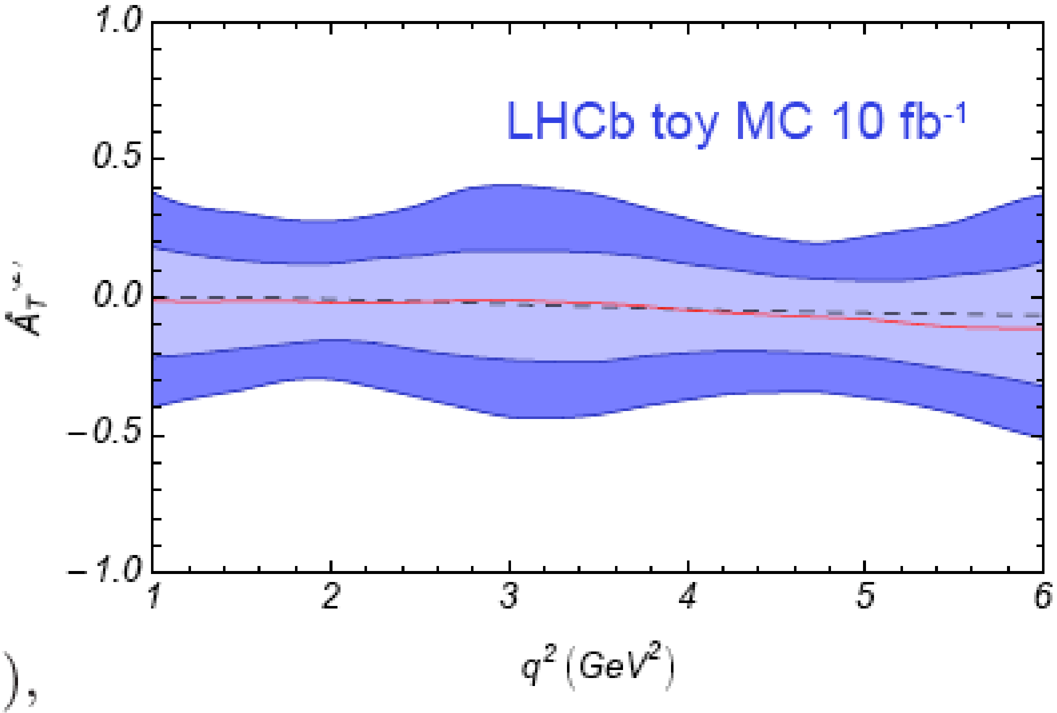
$|\mathcal{C}'_{10}| = 3,\ \phi'_{10} = \frac{\pi}{2}$, blue bands

Note: poor experimental sensitivity NOT due to normalisation !

CP conserving $A_T^{(i)}$ observables more sensitive to complex phases

$A_T^{(2)}$





$a \quad (\mathcal{C}_7^{\rm NP}, \mathcal{C}_7^{'}) = (0.26e^{-i\frac{7\pi}{16}}, 0.2e^{i\pi}),$

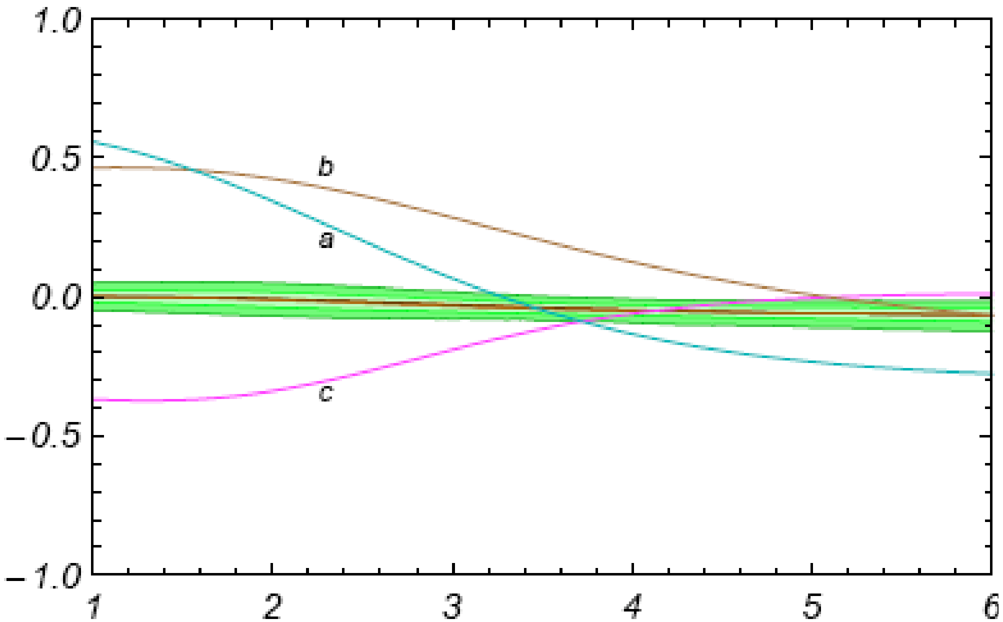
$b \quad (0.07e^{i\frac{3\pi}{5}}, 0.3e^{i\frac{3\pi}{5}})$

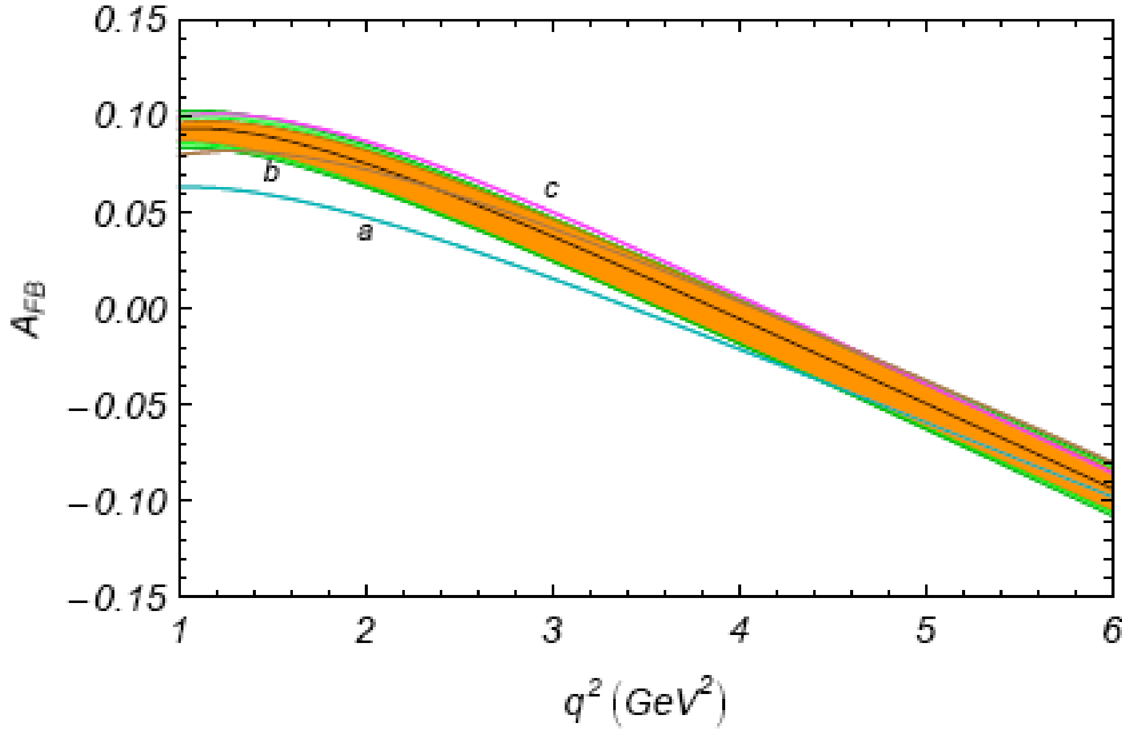
$c \quad (0.03e^{i\pi}, 0.07)$

All benchmarks currently experimentally allowed

CP conserving $A_T^{(i)}$ observables more sensitive to complex phases

$A_T^{(2)}$ $\qquad\qquad$ A_{FB}





$a \quad (\mathcal{C}_7^{\rm NP}, \mathcal{C}_7') = (0.26e^{-i\frac{7\pi}{16}}, 0.2e^{i}$

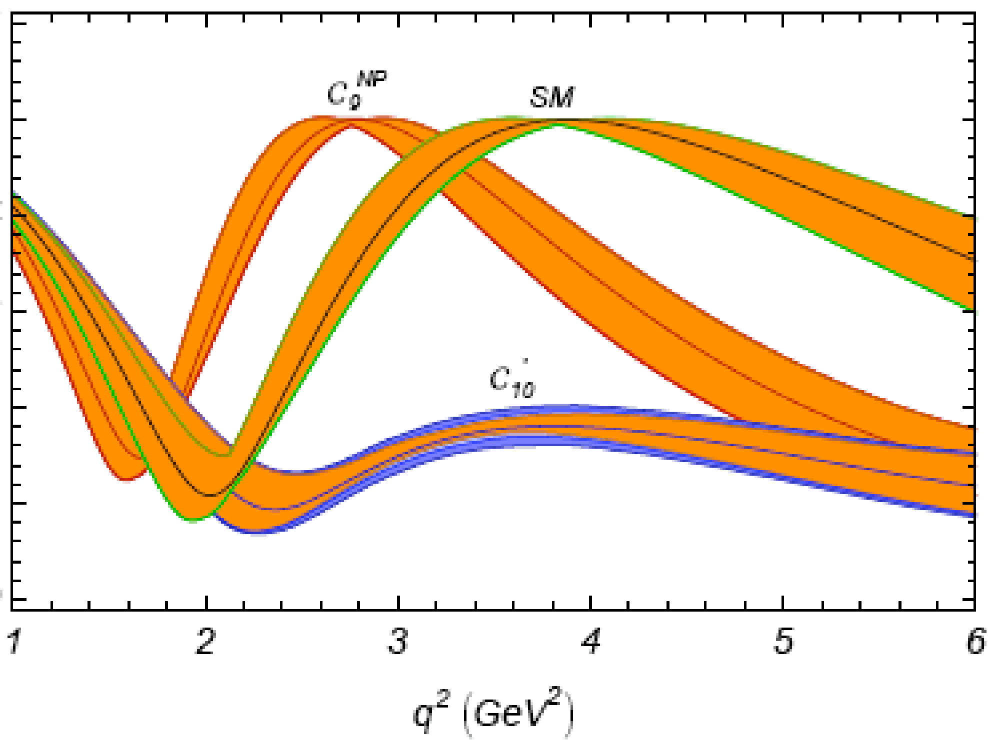
$b \quad (0.07e^{i\frac{3\pi}{5}}, 0.3e^{i\frac{3\pi}{5}})$

$c \quad (0.03e^{i\pi}, 0.07)$

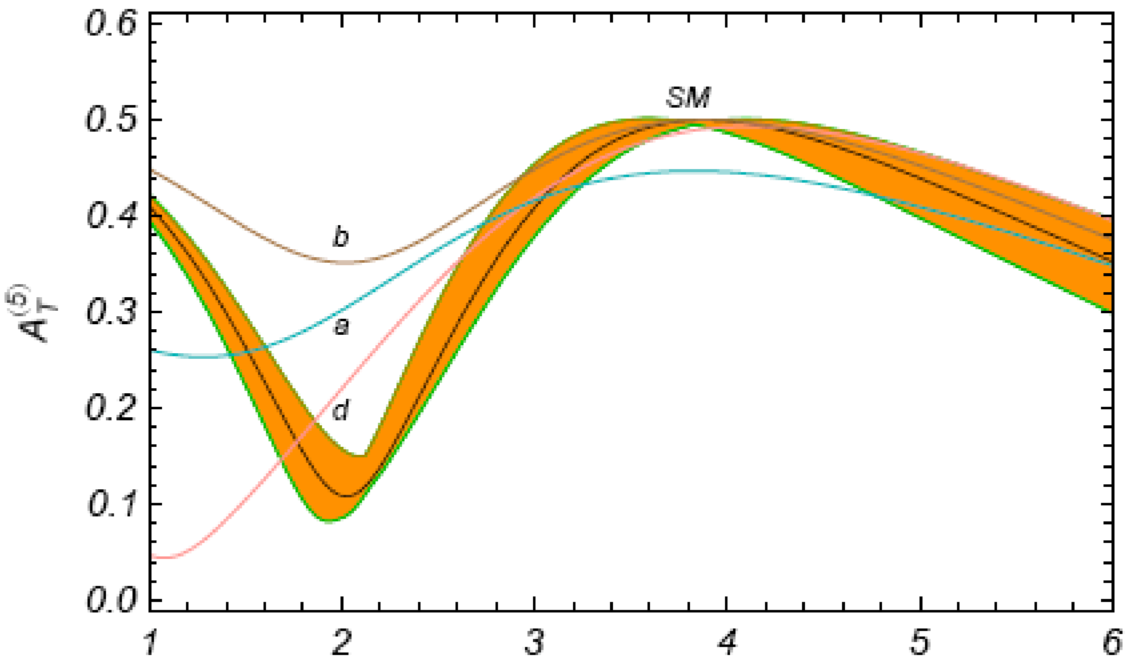
All benchmarks currently experimentally allowed

$A_T^{(5)}$

$$A_{\rm T}^{(5)} = \frac{\left|A_\perp^L A_\parallel^{R*} + A_\perp^{R*} A_\parallel^L\right|}{\left|A_\perp^L\right|^2 + \left|A_\perp^R\right|^2 + \left|A_\parallel^L\right|^2 + \left|A_\parallel^R\right|^2} \qquad A_{\rm T}^{(5)}\Big|_{m_\ell=0} = \frac{\sqrt{16 J_1^{s\,2} - 9 J_6^{s\,2} - 36(J_3^2 + J_9^2)}}{8 J_1^s}$$



NP in $\mathcal{C}_{10}' = 3e^{i\frac{\pi}{8}}$ and $\mathcal{C}_9^{\rm NP} = 2e^{i\frac{\pi}{8}}$



(a) $(\mathcal{C}_7^{\rm NP}, \mathcal{C}_7') = (0.26 e^{-i\frac{7\pi}{16}}, 0.2 e^{i\pi})$

(b) $(0.07 e^{i\frac{3\pi}{5}}, 0.3 e^{i\frac{3\pi}{5}})$

(d) $(0.18 e^{-i\frac{\pi}{2}}, 0)$

Very different behaviour for different NP contributions

When making measurements in $B \to K^* \ell^+ \ell^+$ great care has to be taken to

- Minimise theoretical errors due formfactors and Λ/m_b corrrections
- Design observables that satisfy symmetries and that have optimised specific NP sensitivity

Framework developed for how to get such observables

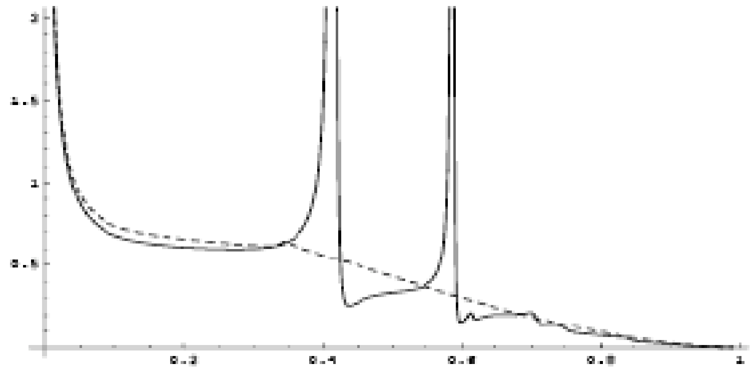
- Theoretical and experimental errors estimated
- CPV observables have no experimental sensitivity

Most important pending issue for NP sensitivity

- Getting bounds on Λ/m_b corrections
- Highly relevant for LHCb measurements

- Inclusive $b \to s\ell^+\ell^-$

$\frac{d}{d\hat{s}} BR(\bar{B} \to X_s l^+ l^-) \times 10^{-5}$



$\hat{s} = q^2/m_b^2$

NNLL prediction of $\bar{B} \to X_s \ell^+\ell^-$: dilepton mass spectrum
Asatryan, Asatrian, Greub, Walker, hep-ph/0204341;
Ghinculov, Hurth, Isidori, Yao hep-ph/0312128:

NNLL QCD corrections $q^2 \in [1 GeV^2, 6 GeV^2]$

central value: -14%, perturbative error: $13\% \to 6.5\%$

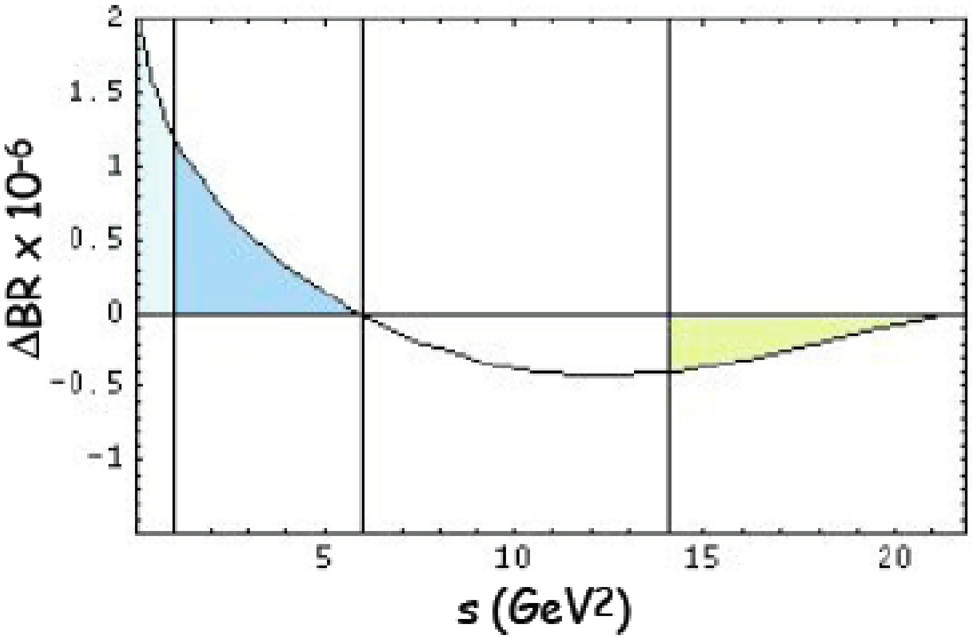
NNLL prediction of $\bar{B} \to X_s \ell^+\ell^-$: forward-backward-asymmetry (FBA)
Asatrian, Bieri, Greub, Hovhannisyan, hep-ph/0209006;
Ghinculov, Hurth, Isidori, Yao, hep-ph/0208088, hep-ph/0312128:

Update with electromagnetic corrections for dilepton mass spectrum
and FBA including the high-q^2 region Huber, Hurth, Lunghi arXiv/0712.3009[hep-ph]

Electromagnetic corrections

Huber, Hurth, Lunghi arXiv/0712.3009[hep-ph]

- Focus on corrections to the Wilson coefficients which are enhanced by a large logarithm $\alpha_{em} Log(m_W/m_b)$
- Corrections to matrix elements lead to large collinear logarithm $Log(m_b/m_\ell)$ which survive intregration if a restricted part of the dilepton mass spectrum is considered
  - $+2\%$ effect in the low-q^2 region for muons, for the electrons the effect depends on the experimental cut parameters:
  - Note that the coefficient of this logarithm vanishes when integrated over the whole spectrum



$\Rightarrow$ Relative effect of this logarithm in the high-q^2 region much larger : we find -8% !

- Our theory predictions correspond to a Super-B measurement not to the present Babar/Belle set-up see Huber, Hurth, Lunghi, arXiv:0807.1940 [hep-ph]

Further refinements:

Recent proposal: normalization to semileptonic $B \to X_u \ell \nu$ decay rate with the same cut reduces the impact of $1/m_b$ corrections in the high-q^2 region significantly. Ligeti, Tackmann, hep-ph/0707.1694

Hadronic invariant-mass cut is imposed in order to eliminate the background like $b \to c\,(\to s e^+ \nu) e^- \bar{\nu} = b \to s e^+ e^- +$ missing energy   Lee, Stewart, hep-ph/0511334

Additional $O(5\%)$ uncertainty due to nonlocal power corrections $O(\alpha_s \Lambda / mb)$

Third independent combination of Wilson coefficents in $\bar{B} \to X_s \ell^+ \ell^-$ $(z = cos\theta)$

$$\frac{d^2\Gamma}{dq^2\,dz} = 3/8\,\left[(1 + z^2)\,H_T(q^2) + 2\,z\,H_A(q^2) + 2\,(1 - z^2)\,H_L(q^2)\right]$$

$$\frac{d\Gamma}{dq^2} = H_T(q^2) + H_L(q^2)\,, \qquad \frac{dA_{\rm FB}}{dq^2} = 3/4\,H_A(q^2)$$

Theory of inclusive $\bar{B} \to X_s \ell^+ \ell^-$ decays

Huber

- $BR(\bar{B} \to X_s \mu\mu) = \quad (1.59 \pm 0.11) \cdot 10^{-6}$ [Lunghi, Misiak, Wyler, TH]

- Introduction of the ratio $\mathcal{R}(s_0) = \dfrac{\int_{s_0}^1 \mathrm{d}\hat{s}\ \ d\Gamma(\bar{B} \to X_s \ell^+ \ell^-)/d\hat{s}}{\int_{s_0}^1 \mathrm{d}\hat{s}\ \ d\Gamma(\bar{B}^0 \to X_u \ell \nu)/d\hat{s}}$ [Ligeti, Tackmann]

  Normalize to semileptonic $\bar{B}^0 \to X_u \ell \nu$ rate with the same cut

  $$\mathcal{R}(s_0)_{\mu\mu} \quad = \quad 2.29 \times 10^{-3} (1 \pm 0.13)$$ [Hurth, Lunghi, TH]

  Uncertainties from $O(1/m_b^3)$ corrections under control. Largest source of error is V_{ub}

- $(q_0^2)_{\mu\mu} = \quad (3.50 \pm 0.12)\,\mathrm{GeV}^2$ [Hurth, Lunghi, TH]

All errors are parametric and perturbative only. No $\mathcal{O}(\alpha_s \Lambda / m_b) \sim 5\%$

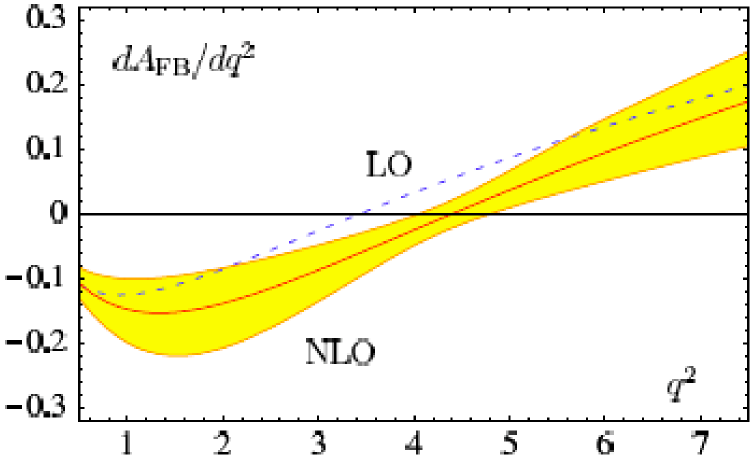
Theoretically clean observable, even in high-q^2 region

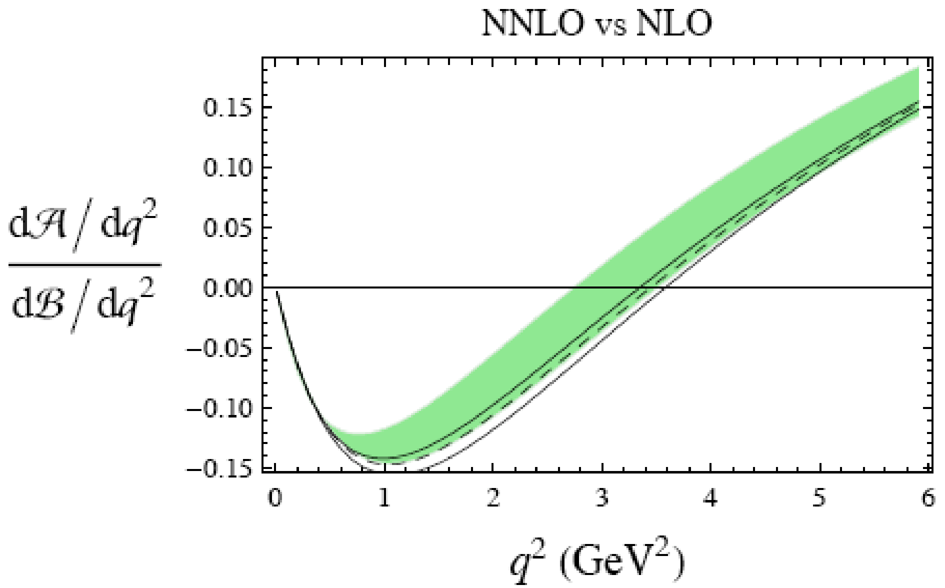
Exclusive versus Inclusive

SLHCb versus SFF — Important role of Λ/m_b corrections

Measurement of inclusive modes restricted to e^+e^- machines.
(S)LHC experiments: Focus on theoretically clean exclusive modes necessary.

Well-known example: Zero of forward-backward-charge asymmetry in $b \to s\ell^+\ell^-$





Exclusive Zero:

Theoretical error: $9\% + O(\Lambda/m_b)$ uncertainty — Egede,Hurth,Matias,Ramon,Reece arXiv:0807.2589

Experimental error at SLHC: 2.1% Libby

Inclusive Zero:

Theoretical error: $O(5\%)$ — Huber,Hurth,Lunghi,arXiv:0712.3009

Experimental error at SFF: $4-6\%$ Browder,Ciuchini,Gershon,Hazumi,Hurth,Okada,Stocchi arXiv:0710.3799

However, exclusive observables in the high-q^2

Magnitude of Λ/m_b can be estimated due to existence of an OPE/HQET

Formfactors at high-q^2: extrapolation, future unquenched lattice results

Theoretically cleaner than observables in low-q^2

Grinstein,Pirjol hep-ph/0404250, Beylich,Buchalla,Feldmann arXiv:1101.5118

Bobeth,Hiller,van Dyk arXiv:1006.5013,1105.0376

More details talk of Christoph Bobeth

- Summary of experimental talks in Warwick

Inclusive $B \to X_s l^+ l^-$: Signal & Backgrounds

Eigen

Measurements: $B(B \to X_s e^+ e^-) = (4.7 \pm 1.3) \times 10^{-6}$ PDG 2008
$B(B \to X_s \mu^+ \mu^-) = (4.3 \pm 1.2) \times 10^{-6}$

Dominant backgrounds from double B, D semileptonic decays (e or μ)

- $B(B^+ \to \overline{X}_c l^+ \nu) \times B(B^- \to X_c l^- \nu) = (1.07 \pm 0.05) \times 10^{-2}$
- $B(B^0 \to X^-_c l^+ \nu) \times B(\overline{B}^0 \to X^+_c l^- \nu) = (1.21 \pm 0.06) \times 10^{-2}$
- $B(B^+ \to \overline{X}_c l^+ \nu) \times B(\overline{D}^0 \to X_s l^- \nu) = (1.65 \pm 0.08) \times 10^{-2}$
- $B(B^0 \to X^-_c l^+ \nu) \times B(D^- \to X_s l^- \nu) = (0.72 \pm 0.04) \times 10^{-2}$
- $B(D^+ \to \overline{X}_s l^+ \nu) \times B(D^- \to X_s l^{+-} \nu) \times f_{D+} = (0.58 \pm 0.06) \times 10^{-2}$
- $B(D^0 \to \overline{X}_s l^+ \nu) \times B(\overline{D}^0 \to X_s l^- \nu) \times f_{D0} = (0.24 \pm 0.05) \times 10^{-2}$
- $B(D^+_S \to \overline{X}_s l^+ \nu) \times B(D^-_S \to X_s l^- \nu) \times f_{Ds} = (0.06 \pm 0.045) \times 10^{-2}$

Before cuts background from sl decays is 2-3.5 (4) orders of magnitude bigger than signal for individual (summed) backgrounds

For 75 ab^{-1} in SuperB expect 48000 events, ~21000 for $q^2 < 6$ GeV^2
➔ statistical errors of ~0.8% and <1.2%

Inclusive measurement will be limited by systematics

Angular Distributions in $B \to X_s l^+l^-$

The $B \to X_s l^+l^-$ angular distribution depends on θ_l

$$W(\cos\theta_\ell) = \frac{3}{8}\left[\left(1+\cos^2\theta_\ell\right)H_T(q^2) + 2\cos\theta_\ell H_A(q^2) + 2\left(1-\cos^2\theta_\ell\right)H_L(q^2)\right]$$

H_L, H_T, H_A are 3 independent (q^2 dep) functions of Wilson coefficients

$$H_A(q^2) \sim A_{FB}(q^2)$$

All three functions can be measured with high precision at 75 fb^{-1} in 12 (6) bins of q^2 below $q^2<6$ GeV^2

For $B \to X_s l^+l^-$ (exclusive sum) expect statistical uncertainty of ~0.033 per bin (12 bins) systematic error expected around 0.04-0.06

Physics impact beyond LHCb still to be explored

- Extra slides

Theoretical framework

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

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

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

- Crucial 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 $(\xi_\perp, \xi_\parallel)$

  Form factor relations broken by α_s and Λ/m_b corrections

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

- Large Energy Effective Theory $\Rightarrow$ QCD factorization/SCET

  (IR structure of QCD)

- 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

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

$$\begin{aligned}
A_{\perp L,R} &= N\sqrt{2}\lambda^{1/2}\left[(C_9^{\text{eff}} \mp C_{10})\frac{V(s)}{m_B + m_{K^*}} + \frac{2m_b}{s}(C_7^{\text{eff}} + C_7^{\text{eff}\prime})T_1(s)\right] \\
A_{\parallel L,R} &= -N\sqrt{2}(m_B^2 - m_{K^*}^2)\left[(C_9^{\text{eff}} \mp C_{10})\frac{A_1(s)}{m_B - m_{K^*}} + \frac{2m_b}{s}(C_7^{\text{eff}} - C_7^{\text{eff}\prime})T_2(s)\right] \\
A_{0L,R} &= -\frac{N}{2m_{K^*}\sqrt{s}}\left[(C_9^{\text{eff}} \mp C_{10})\left\{(m_B^2 - m_{K^*}^2 - s)(m_B + m_{K^*})A_1(s) - \lambda\frac{A_2(s)}{m_B + m_{K^*}}\right\}\right. \\
&\left. + 2m_b(C_7^{\text{eff}} - C_7^{\text{eff}\prime})\left\{(m_B^2 + 3m_{K^*}^2 - s)T_2(s) - \frac{\lambda}{m_B^2 - m_{K^*}^2}T_3(s)\right\}\right]
\end{aligned}$$

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

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

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

Careful design of observables

- Good sensitivity to NP contribitions, i.e. to $C_7^{eff'}$
- Small theoretical uncertainties
  - Dependence of soft form factors, $\xi_\perp$ and $\xi_\parallel$, to be minimized !
    form factors should cancel out exactly at LO, best for all s
  - unknown Λ/m_b power corrections
    $A_{\perp,\parallel,0} = A^0_{\perp,\parallel,0}\left(1 + c_{\perp,\parallel,0}\right)$ vary c_i in a range of ±10% and also of ±5%
  - Scale dependence of NLO result
  - Input parameters
- Good experimental resolution

New observables

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

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

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