Exploring New Physics in the $C_7, C_{7'}$ plane

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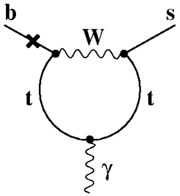
Radiative decays as probes of New Physics



$b \to D\gamma^{(*)}$ with $D = d, s$

- access to $|V_{t(d,s)}|$ within SM
- cross-check of neutral B mixing (box/penguin)
- loop processes very sensitive to NP
- studied at B factories and hadronic machines

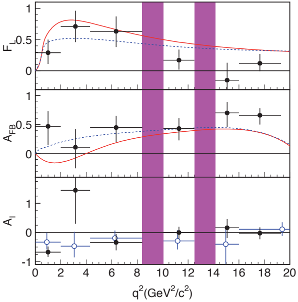
In terms of effective Hamiltonian (integrating d.o.f above b quark) $\mathcal{H}_{\rm eff} = \sum_i C_i O_i$, main contributions to radiative decays from:

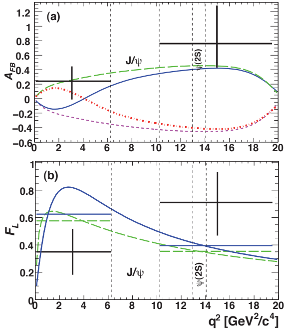
- Electromagnetic dipole: $O_7 = \frac{e}{16\pi^2} m_b \bar{D}\sigma^{\mu\nu}(1+\gamma_5)F_{\mu\nu}\, b$
- Semileptonic (vector) operator: $O_9 = \frac{e^2}{16\pi^2} \bar{D}\gamma_\mu(1-\gamma_5)b\, \bar{\ell}\gamma_\mu\ell$
- Semileptonic (axial) operator: $O_{10} = \frac{e^2}{16\pi^2} \bar{D}\gamma_\mu(1-\gamma_5)b\, \bar{\ell}\gamma_\mu\gamma_5\ell$
- New physics changes Wilson coeffs and/or adds new operators
- In SM, NNLO C_i in MS-bar with fully anticommuting γ_5 including em corrections [Chetyrkin, Misiak and Münz, Bobeth et al., Huber et al.]

The example of the flipped-sign solution

$C_7 \to -C_7^{SM}$

- No change for $\mathcal{B}(B \to X_s\gamma)$ (not sensitive to phase of C_7)





- Indication in Belle/Babar data on $B \to K^*\ell^+\ell^-$
- Accomodate no zero in FB asymmetry

- In "contradiction" with $B \to X_s\ell^+\ell^-$ [Gambino, Haisch, Misiak]
- Issue related to NP in operators that contribute to $B \to K^*\ell^+\ell^-$ (dipole, semileptonic, chirally-flipped, scalar and tensor)

Framework, scenarios and classes

How to discuss NP contributions to radiative decays,
such as the possibility of flipped-sign solution for C_7 ?
SDG, D. Gosh, J. Matias, M. Ramon, hep-ph/1104.3342

Generally, discussion on radiative and leptonic b decays
to be addressed in given framework, specific scenarios & observables

- Framework: NP in C_7, C_9, C_{10} and $C_{7'}, C_{9'}, C_{10'}$ [chirally-flipped operators $\gamma_5 \to -\gamma_5$] as a real shift in the Wilson coefficients
- Scenarios (from the more specific to the more general)
  - A : NP in 7,7' only
  - B : NP in 7,7', 9,10 only
  - C : NP in 7,7',9,10,9',10' only
- Classes
  - I: observables sensitive only to 7,7'
  - II: observables sensitive only to 7,7',9,9',10,10'
  - III: observables sensitive to 7,7',9,9',10,10' and more

Observables

Limited sensitivity to hadronic inputs, or strong impact on analysis

- Class-I
  - $\mathcal{B}(B \to X_s\gamma)$ with $E_\gamma > 1.6\,\mathrm{GeV}$ [Misiak, Steinhauser, Haisch]
  - exclusive time-dependent CP asymmetry $S_{K^*\gamma}$ [Kagan, Neubert, Feldman, Matias]
  - isospin asymmetry $A_I(B \to K^*\gamma)$ [Beneke, Feldman, Seidel]
- Class-II
  - Integrated transverse asym. $\tilde{A}^2_{\mathrm{T}}$ in $B \to K^* l^+ l^-$ over low-q^2 region [Kruger and Matias]
- Class-III
  - $\mathcal{B}(B \to X_s l^+ l^-)$ [Bobeth et al., Huber et al.]
  - Integrated $\tilde{F}_{\mathrm{L}}$ and $\tilde{A}_{\mathrm{FB}}$ in $B \to K^* l^+ l^-$ [1-6 GeV^2] [Beneke, Feldman]

For each observable

- Include the effect of chirally-flipped operators
- Simple numerical parametrisation as $\delta C_i = C_i(\mu_b) - C_i^{SM}(\mu_b)$
- "naive" constraints $|X_{th}(\delta C_i) - X_{exp}| \leq \Delta X_{th} + \Delta X_{exp}$
- Uncertainties ΔX_{th} from SM analysis (assumed similar with NP)

Form factors for $B \to K^*\gamma(*)$

- full q^2-range using light-cone sum rules
- large recoil for NLO QCD factorisation with soft form factors $\xi_{\perp,||}$ + hard gluon corrections (+ 10% Λ/m_b corrections)

$\Longrightarrow$we use the latter to treat exclusive observables for q^2=1-6 GeV^2, extracting 2 soft form factors from LCSR determinations

$$\xi_\perp(q^2) = \frac{m_B}{m_B+m_{K^*}} V(q^2), \quad \xi_{||}(q^2) = \frac{m_B+m_{K^*}}{2E_{K^*}} A_1(q^2) - \frac{m_B-m_{K^*}}{m_B} A_2(q^2)$$

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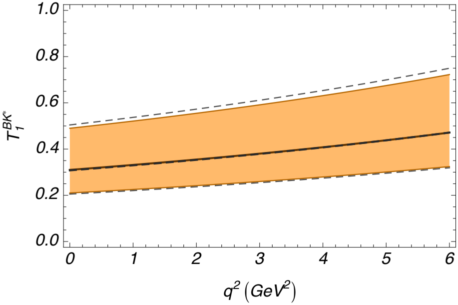
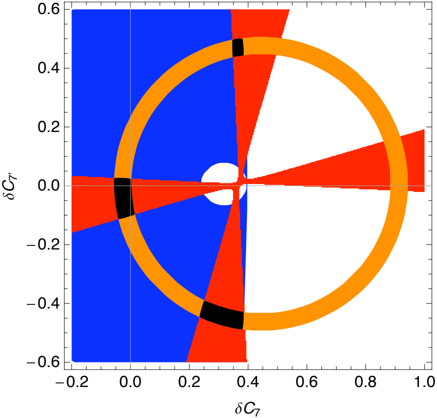


5 other form factors then consistent, e.g. $T_1^{B\to K^*}$

- orange : full form factor from LCSR [Khodjamirian et al]
- grey lines : NLO QCD factorisation [Beneke et al.] using our $\xi_\perp(q^2)$

$C_7, C_{7'}$ plane : constraints at 1 σ



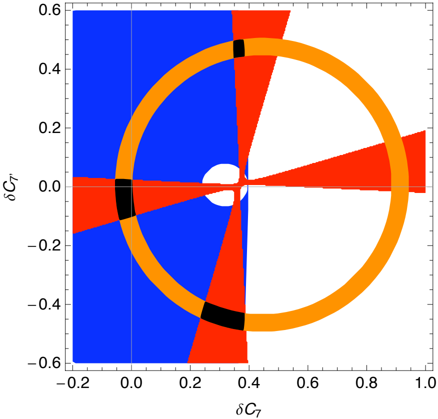
Class I observables

- A_I (blue)
- $B(B \to X_s\gamma)$ (brown)
- $S_{K^*\gamma}$ (red)

Overlap regions (black)

- SM solution $(C_7, C_{7'}) = (C_7^{SM}, 0)$
- two non-SM solutions $(C_7, C_{7'}) = (0, \pm 0.4)$

$C_7, C_{7'}$ plane : constraints at 1 σ



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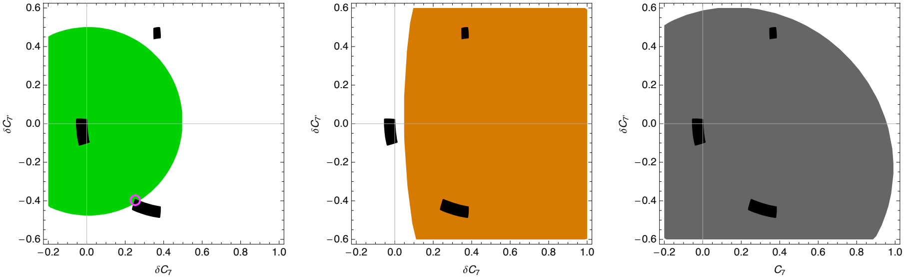
- SM solution $(C_7, C_{7'}) = (C_7^{SM}, 0)$
- two non-SM solutions $(C_7, C_{7'}) = (0, \pm 0.4)$

- In qualitative agreement with [Bobeth et al, Hurth et al]
- A_I disfavours flipped-sign solution $(C_7, C_{7'}) = (-C_7^{SM}, 0)$
  $\Longrightarrow$Same conclusion as [Gambino, Haisch, Misiak], without using Class-III $B \to X_s \ell^+ \ell^-$ (less dep. on NP scenario)

Scenario A : class-III observables

Scenario A: NP only in $C_7, C_{7'}$

$\Longrightarrow$class-III observables constrain also the shifts $\delta C_7, \delta C_{7'}$



$B(B \to X_s \mu^+ \mu^-)$ $(\delta C_7, \delta C_{7'})$

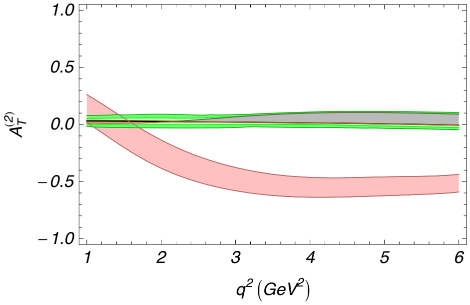
$\tilde{A}_{FB}$ $(\delta C_7, \delta C_{7'})$

$\tilde{F}_L$ $(\delta C_7, \delta C_{7'})$

- $B(B \to X_s \mu^+ \mu^-)$ more for SM-like region [Gambino, Haisch, Misiak]
- $\tilde{A}_{FB}$ in favour of non-SM regions

$\Longrightarrow$Only a small region around $(C_7, C_{7'}) = (0, -0.4)$ with overlap

Scenario A : prediction for class-II observable A_T^2

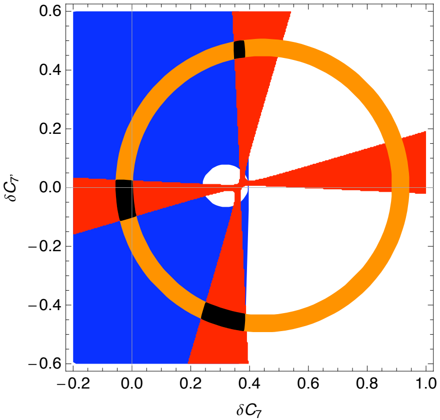


- In the SM (green, including uncertainties from form factors and estimate of $1/m_b$-suppressed corrections)
- Under scenario A (pink), including errors from varying $C_7, C_{7'}$
- Enhancement understood from LO expression in large-recoil limit

Scenario B : class-I constraints in $(\delta C_7, \delta C_{7'})$

In Scenario B, NP in

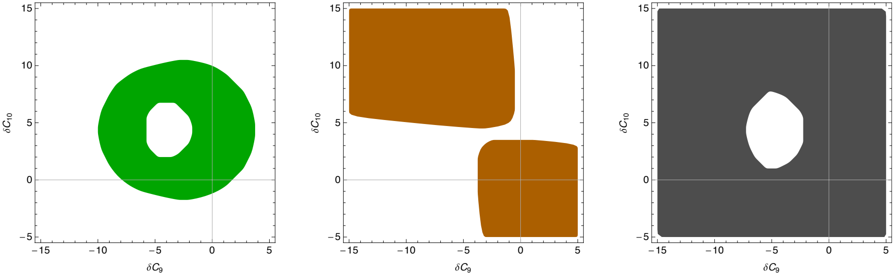
- $C_7, C_{7'}$: same constraints as before from class-I observables



Scenario B : class-III constraints in $(\delta C_9, \delta C_{10})$

In Scenario B, NP in

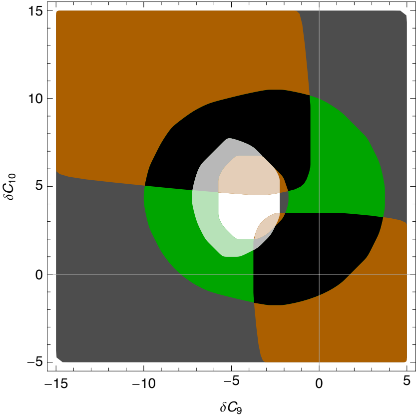
- $C_7, C_{7'}$: same constraints as before from class-I observables
- C_9, C_{10}: to be fixed from class-III observables
  (in principle, class-III could also constrain $C_7, C_{7'}$ but not here)



$B(B \to X_s\mu^+\mu^-)$ $(\delta C_9, \delta C_{10})$ | $\tilde{A}_{FB}$ $(\delta C_9, \delta C_{10})$ | $\tilde{F}_L$ $(\delta C_9, \delta C_{10})$

- Small absolute values of (C_9, C_{10}) disfavoured
- Qualitative agreement with [Hurth et al.]

Scenario B : overlap and non-SM regions

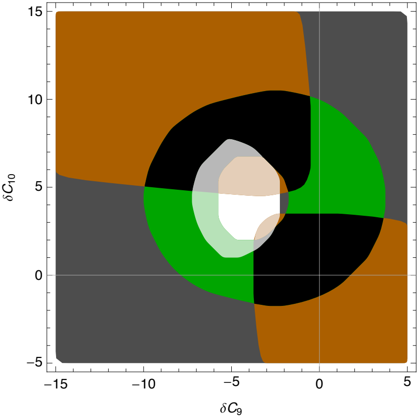


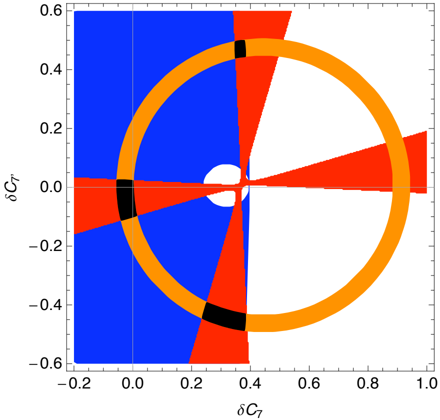
- $\mathcal{B}(B \to X_s\mu^+\mu^-)$ (green)
- $A_{\rm FB}$ (brown)
- $F_{\rm L}$ (grey)

Two overlap regions (black)

- SM region around $(C_9, C_{10}) = (C_9^{SM}, C_{10}^{SM})$
- non-SM region around $(C_9, C_{10}) = (-C_9^{SM}, -C_{10}^{SM})$

Scenario B : overlap and non-SM regions

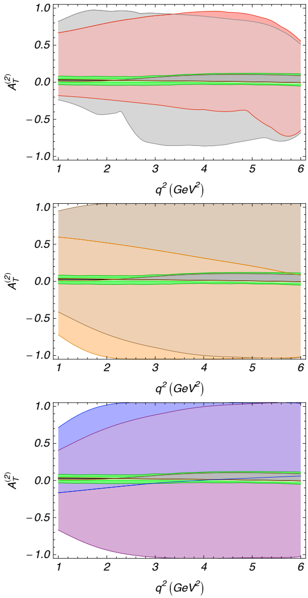




Both combined regions in (C_9, C_{10}) can accomodate values of $(C_7, C_{7'})$ either in the SM region or the two non-SM ones.

$\Longrightarrow$Scenario B NP may alter (C_7, C_7') and/or (C_9, C_{10}) and reproduce the experimental value $B \to X_s \mu^+ \mu^-$ at the same time

Scenario B : prediction for class-II obs. $A_T^2(q^2)$



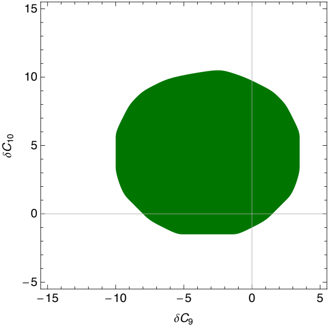
- $A_T^2(q^2)$ for $q^2 = 1\ldots 6$ GeV^2
- Different shapes for the three regions in $(C_7, C_{7'})$
  - $(\delta C_7, \delta C_{7'}) \simeq (0,0)$
  - $(\delta C_7, \delta C_{7'}) \simeq (0.3, -0.4)$
  - $(\delta C_7, \delta C_{7'}) \simeq (0.3, 0.4)$
  - two possibilities for SM and non-SM regions for (C_9, C_{10})
- Very large uncertainties due to the size of the two regions for (C_9, C_{10}) (in particular from non-SM region)

Scenario C : class-III observables

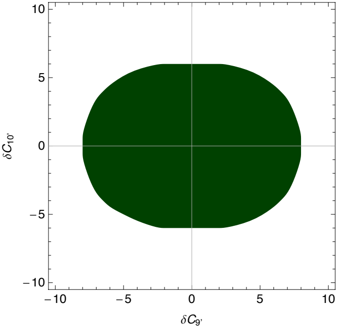
In Scenario B, NP in

- $C_7, C_{7'}$: same constraints as before from class-I observables
- $C_9, C_{10}, C_{9'}, C_{10'}$: to be fixed from class-III observables

Actually, only B($B \to X_s \mu^+ \mu^-$) elliptic constraint still yields constraints



$(\delta C_9, \delta C_{10})$



$(\delta C'_9, \delta C'_{10})$

$\Longrightarrow$Too many possibilities to get a prediction for A_T^2

Conclusion

- Effective Hamiltonian to probe NP in radiative/leptonic decays
- Need to define framework/scenario
  with classification of observables (A_T^2 interesting with that respect)
- Starting point: $C_7, C_{7'}$ plane from class-I observables
  - Flipped-sign solution disfavoured by $A_I(B \to K^* \gamma)$
    irrespective of NP in semileptonic operators
  - Funny non-SM regions ($C_7 = 0, C_{7'} = \pm 0.4$)
- Various scenarios of NP considered
  - A (NP in $C_{7,7'}$ only): small region in $(C_7, C_{7'})$, with prediction for A_T^2
  - B (NP in $C_{7,7',9,10}$): two regions in (C_9, C_{10})
  - C (NP in $C_{7,7',9,10,9',10'}$): only weak bounds from $B \to X_s \ell^+ \ell^-$

Outlook

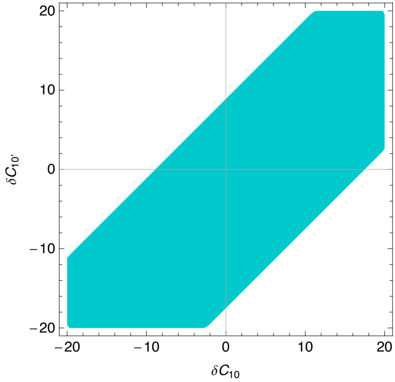
- Scalar, tensors ? Other (well-controlled) observables ?
- Bin-by-bin information at low q^2 rather than averages
- Proper statistical treatment for combination

Thanks for your attention !

Back-up

Constraint on $C_{10}, C_{10'}$ from $B_s \to \mu^+\mu^-$

$$\mathcal{B}(\bar{B}_s \to \mu^+\mu^-)|_{\text{axial}} = \frac{G_F^2\alpha^2}{16\pi^3} f_{B_s}^2 m_{B_s}\tau_{B_s}|V_{tb}V_{ts}^*|^2 m_\mu^2\sqrt{1-\frac{4m_\mu^2}{m_{B_s}^2}}|C_{10}-C_{10'}|^2$$



Using our inputs, we get

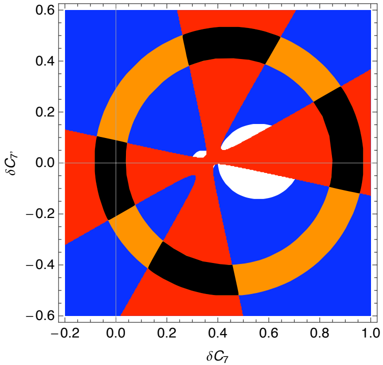
$$\mathcal{B}(\bar{B}_s \to \mu^+\mu^-)^{\text{SM}} = (3.44\pm0.32)\cdot10^{-9}$$

one order of magnitude smaller than 90% CL exp bound

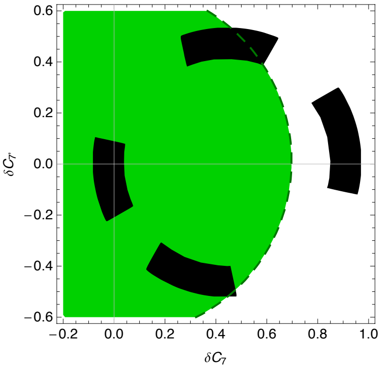
$$\mathcal{B}(\bar{B}_s \to \mu^+\mu^-)^{\text{exp}} < 3.2\cdot10^{-8}.$$

and only weak constraints on $C_{10}, C_{10'}$

At two sigmas : $(C_7, C_{7'})$ and scenario A

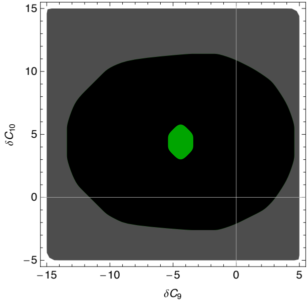


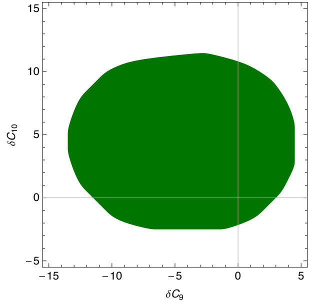
$(C_7, C_{7'})$ from class-I

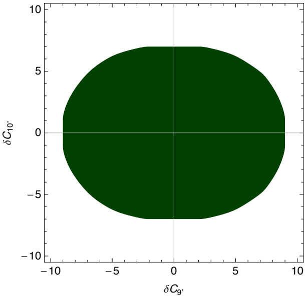


$B \to X_s \mu^+ \mu^-$ in scenario A

At two sigmas : scenario B and C

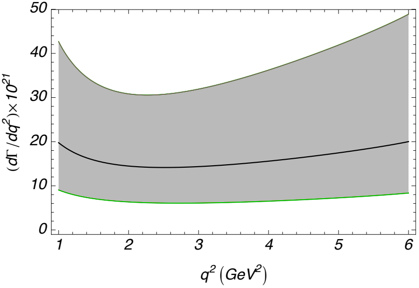


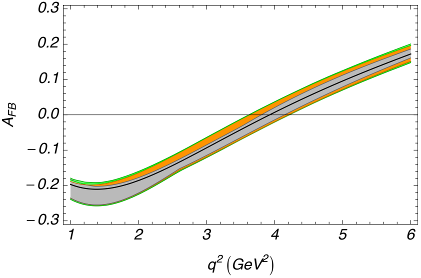




- Scenario B (up): $B \to X_s \mu^+ \mu^-$ and $\tilde{F}_L$
- Scenario C (down): $B \to X_s \mu^+ \mu^-$

SM prediction for $B \to K^*\ell^+\ell^-$: $d\Gamma/dq^2$ and A_{FB}





Inputs

$\mu_b = 4.8\ \mathrm{GeV}\ [/2 \to \times 2]$	$\mu_0 = 2M_W\ [/2 \to \times 2]$
$\sin^2\theta_W = 0.2313$ $\alpha_{em}(M_Z) = 1/128.940$	$\alpha_s(M_Z) = 0.1184 \pm 0.0007$
$m_t^{\mathrm{pole}} = 173.3 \pm 1.1\ \mathrm{GeV}$ $m_c^{\overline{MS}}(m_c) = 1.27 \pm 0.09\ \mathrm{GeV}$	$m_b^{1S} = 4.68 \pm 0.03\ \mathrm{GeV}$ $m_s^{\overline{MS}}(2\ \mathrm{GeV}) = 0.101 \pm 0.029\ \mathrm{GeV}$
$\lambda_{CKM} = 0.22543 \pm 0.0008$ $\bar{\rho} = 0.144 \pm 0.025$	$A_{CKM} = 0.805 \pm 0.020$ $\bar{\eta} = 0.342 \pm 0.016$
$\mathcal{B}(B \to X_c e\bar{\nu}) = 0.1061 \pm 0.00017$ $\lambda_2 = 0.12\ \mathrm{GeV}^2$	$C = 0.58 \pm 0.016$
$\Lambda_h = 0.5\ \mathrm{GeV}$ $f_{K^*,\vert\vert} = 0.220 \pm 0.005\ \mathrm{GeV}$ $\xi_\perp(0) = 0.31^{+0.20}_{-0.10}$ $a_{1,\vert\vert,\perp}(2\ \mathrm{GeV}) = 0.03 \pm 0.03$ $\lambda_B(\mu_h) = 0.51 \pm 0.12\ \mathrm{GeV}$	$f_B = 0.200 \pm 0.025\ \mathrm{GeV}$ $f_{K^*,\perp}(2\ \mathrm{GeV}) = 0.163 \pm 0.008\ \mathrm{GeV}$ $\xi_{\vert\vert}(0) = 0.10 \pm 0.03$ $a_{2,\vert\vert,\perp}(2\ \mathrm{GeV}) = 0.08 \pm 0.06$
$f_{B_s} = 0.2358 \pm 0.0089\ \mathrm{GeV}$	$\tau_{B_s} = 1.472 \pm 0.026\ \mathrm{ps}$

Effective Hamiltonian

$$\mathcal{H}_{\rm eff} = -\frac{4G_F}{\sqrt{2}}\left(V_{tb}V_{ts}^*\mathcal{H}_{\rm eff}^{(t)} + V_{ub}V_{us}^*\mathcal{H}_{\rm eff}^{(u)}\right) + h.c.,$$

[Chetyrkin, Misiak and Münz, Bobeth et al., Huber et al.]

$$\mathcal{H}_{\rm eff}^{(t)} = \sum_{i=1}^{6} C_i\mathcal{O}_i + \sum_{i=7}^{10}(C_i\mathcal{O}_i + C_{i'}\mathcal{O}_{i'}),$$

with dipole and semileptonic operators, SM and chirally-flipped

$$\mathcal{O}_7 = \frac{e}{16\pi^2}m_b(\bar{s}\sigma_{\mu\nu}P_Rb)F^{\mu\nu}, \qquad \mathcal{O}_{7'} = \frac{e}{16\pi^2}m_b(\bar{s}\sigma_{\mu\nu}P_Lb)F^{\mu\nu},$$

$$\mathcal{O}_9 = \frac{e^2}{16\pi^2}(\bar{s}\gamma_\mu P_Lb)(\bar{\ell}\gamma^\mu\ell), \qquad \mathcal{O}_{9'} = \frac{e^2}{16\pi^2}(\bar{s}\gamma_\mu P_Rb)(\bar{\ell}\gamma^\mu\ell),$$

$$\mathcal{O}_{10} = \frac{e^2}{16\pi^2}(\bar{s}\gamma_\mu P_Lb)(\bar{\ell}\gamma^\mu\gamma_5\ell), \qquad \mathcal{O}_{10'} = \frac{e^2}{16\pi^2}(\bar{s}\gamma_\mu P_Rb)(\bar{\ell}\gamma^\mu\gamma_5\ell),$$

where $P_{L,R} = (1 \mp \gamma_5)/2$ projection over the chiralities

Standard Model values

In the SM, NNLO in MS-bar with fully anticommuting γ_5 including electromagnetic corrections [Chetyrkin, Misiak and Münz, Bobeth et al., Huber et al.]

$C_1(\mu_b)$	$C_2(\mu_b)$	$C_3(\mu_b)$	$C_4(\mu_b)$	$C_5(\mu_b)$
-0.263	1.011	-0.006	-0.081	0.000
$C_6(\mu_b)$	$C_7^{\text{eff}}(\mu_b)$	$C_8^{\text{eff}}(\mu_b)$	$C_9(\mu_b)$	$C_{10}(\mu_b)$
0.001	-0.292	-0.166	4.075	-4.308

- High-scale $\mu_0 = 2M_W$ [uncertainty: varied from M_W to $4M_W$]
- Low-scale $\mu_b = 4.8$ GeV [uncertainty: varied from 2.4 to 9.6 GeV]

For the chirally-flipped operators, we have the SM values

$$C_{7'}^{SM} = \frac{m_s}{m_b} C_7^{SM}, \qquad C_{9',10'}^{SM} = 0$$

Class-I observables: inclusive $\mathcal{B}(\bar{B} \to X_s\gamma)$

Class-I : only depending on C_7, $C_{7'}$, related to radiative decays

[Misiak, Gambino, Steinhauser. . .]

$$\mathcal{B}(\bar{B} \to X_s\gamma)^{exp}_{E_\gamma > 1.6\,\mathrm{GeV}} = (3.55 \pm 0.24 \pm 0.09) \times 10^{-4}$$

$$\mathcal{B}(\bar{B} \to X_s\gamma)^{th}_{E_\gamma > 1.6\,\mathrm{GeV}} = \Big[a_{(0,0)} + a_{(7,7)} \left[(\delta C_7)^2 + (\delta C_{7'})^2\right] + a_{(0,7)}\, \delta C_7 + a_{(0,7')}\, \delta C_{7'}\Big] \times 10^{-4}$$

$$\mathcal{B}(\bar{B} \to X_s\gamma)^{SM}_{E_\gamma > 1.6\,\mathrm{GeV}} = (3.15 \pm 0.23) \times 10^{-4}$$

Class-I observables: inclusive $\mathcal{B}(\bar{B} \to X_s\gamma)$

Class-I : only depending on $C_7, C_{7'}$, related to radiative decays

[Misiak, Gambino, Steinhauser. . .]

$$\mathcal{B}(\bar{B} \to X_s\gamma)^{exp}_{E_\gamma > 1.6\,\mathrm{GeV}} = (3.55 \pm 0.24 \pm 0.09) \times 10^{-4}$$

$$\mathcal{B}(\bar{B} \to X_s\gamma)^{th}_{E_\gamma > 1.6\,\mathrm{GeV}} = \Big[a_{(0,0)} + a_{(7,7)} \left[(\delta C_7)^2 + (\delta C_{7'})^2 \right] + + a_{(0,7)}\, \delta C_7 + a_{(0,7')}\, \delta C_{7'} \Big] \times 10^{-4}$$

$$\mathcal{B}(\bar{B} \to X_s\gamma)^{SM}_{E_\gamma > 1.6\,\mathrm{GeV}} = (3.15 \pm 0.23) \times 10^{-4}$$

- SM value $[a_{(0,0)}]$ expressed as

$$\mathcal{B}(B \to X_s\gamma)^{SM}_{E_\gamma > E_0} = \mathcal{B}(B \to X_c e \bar{\nu}) \left| \frac{V^*_{ts} V_{tb}}{V_{cb}} \right|^2 \frac{6\alpha_{\mathrm{em}}}{\pi} [P(E_0) + N(E_0)]$$

$$P(E_0) = \sum_{i,j=1\ldots 8} C^{\mathrm{eff}}_i(\mu) C^{\mathrm{eff}*}_j(\mu) K_{ij}(E_0, \mu)$$

- left- and right-handed polarisations add up incoherently
  - $a_{(7,7)} = a_{(7',7')}$ same structure for C_7 and $C_{7'}$ $\gamma_5 \to -\gamma_5$
  - $a_{(0,7)} \neq a_{(0,7')}$ since no 4-quark chirally flipped operators
- numerical a's reproducing [Misiak, Steinhauser, Haisch]

Class-I observables: isospin asymmetry in $B \to K^*\gamma$

[Kagan and Neubert...]

$$A_I(B \to K^*\gamma) = \frac{\Gamma(\bar{B}^0 \to \bar{K}^{*0}\gamma) - \Gamma(B^- \to K^{*-}\gamma)}{\Gamma(\bar{B}^0 \to \bar{K}^{*0}\gamma) + \Gamma(B^- \to K^{*-}\gamma)}$$

- NLO QCD factorisation : isospin asymmetry from nonfactorisable contributions where spectator quark emits the photon
- from 4-quark and chromomagnetic operators
- thus no change once chirally-flipped operators included, apart from normalisation to isospin-averaged branching ratio

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$$\begin{aligned} A_I(B \to K^*\gamma)^{exp} &= 0.052 \pm 0.026 \\ A_I(B \to K^*\gamma)^{th} &= c \times \frac{\sum_k d_k(\delta C_7)^k}{\sum_{k,l} e_{k,l}(\delta C_7)^k(\delta C_{7'})^l} \pm \delta c\,. \\ A_I(B \to K^*\gamma)^{SM} &= 0.041 \pm 0.025 \end{aligned}$$

- c, d, e determined numerically,
  reproducing [Kagan and Neubert, Feldmann and Matias]

Class-I observables: $B \to K^*\gamma$ CP-asymmetry

[Beneke Feldmann Seidel, Ball and Zwicky]

$$\frac{\Gamma(\bar{B}^0(t)\to\bar{K}^{*0}\gamma)-\Gamma(B^0(t)\to K^{*0}\gamma)}{\Gamma(\bar{B}^0(t)\to\bar{K}^{*0}\gamma)+\Gamma(B^0(t)\to K^{*0}\gamma)} = S_{K^*\gamma}\sin(\Delta m_B t) - C_{K^*\gamma}\cos(\Delta m_B t)$$

- Probe of photon helicity $S_{K^*\gamma} = \frac{2\,\mathrm{Im}\left[e^{-2i\beta}\left(\mathcal{A}_L^*\bar{\mathcal{A}}_L + \mathcal{A}_R^*\bar{\mathcal{A}}_R\right)\right]}{|\mathcal{A}_L|^2+|\mathcal{A}_R|^2+|\bar{\mathcal{A}}_L|^2+|\bar{\mathcal{A}}_R|^2}$
- Cam be determined at NLO in QCD factorisation. At LO,

$$S_{K^*\gamma}^{(\mathrm{LO})} = \frac{-2\left|C_{7'}/C_7\right|}{1+\left|C_{7'}/C_7\right|^2}\sin\left(2\beta - \arg\left(C_7 C_{7'}\right)\right)$$

[Grinstein et al, Bobeth et al]

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[Grinstein et al, Bobeth et al]

$$\begin{aligned} S^{\mathrm{exp}}_{K^*\gamma} &= -0.16 \pm 0.22 \\ S_{K^*\gamma} &= f\,{}^{+\delta_f^u}_{-\delta_f^d} + \frac{\sum_{k,l} g_{k,l}(\delta C_7)^k(\delta C_{7'})^l}{\sum_{k,l} h_{k,l}(\delta C_7)^k(\delta C_{7'})^l} \\ S^{SM}_{K^*\gamma} &= -0.30 \pm 0.01 \end{aligned}$$

- f, g, h fitting coefficients and uncertainties determined numerically

Class-II observables: A_T^2 asymmetry

Class-II : depending only on dipole and semileptonic operators

$B \to K^* \ell^+ \ell^-$ asymmetry $A_T^2(q^2) = \frac{|A_\perp|^2 - |A_\parallel|^2}{|A_\perp|^2 + |A_\parallel|^2}$, [Kruger and Matias]

- $B \to K^* \ell^+ \ell^-$ expressed in terms of 7 spin amplitudes
- $A_\perp$ and $A_\parallel$ depend only on $C_{7,7',9,9',10,10'}$ (no tensors or scalars)
- can be determined from $d\Gamma/d\phi$
- weakly sensitive to soft form factors (only at NLO QCDF)
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At low q^2, at NLO QCD factorisation $A_T^2(q^2) = A_{\rm T}^{(2),\,CV}(q^2)^{+\delta_u(q^2)}_{-\delta_d(q^2)}$
with fitting q^2-polynomials for errors δ_u, δ_d and central value

$$A_T^{(2),\,CV}(q^2) = \frac{\sum_{i=0,7,7',9,9',10,10'} \sum_{j=i,..10'} F_{(i,j)}(q^2)\delta C_i \delta C_j}{\sum_{i=0,7,7',9,9',10,10'} \sum_{j=i,..10'} G_{(i,j)}(q^2)\delta C_i \delta C_j}$$

[$\delta C_0 = 1$ to deal with constant, linear and quadratic terms]

Class-III observables: $\bar{B} \to X_s \mu^+ \mu^-$

Class-III: depending on dipole and semileptonic operators, but also others (scalar, tensors) $\Longrightarrow$ most of semileptonic observables

- $\bar{B} \to X_s \mu^+ \mu^-$ at low q^2 [1-6 GeV^2]

$$\begin{aligned} \mathcal{B}(\bar{B} \to X_s \mu^+ \mu^-)^{exp} &= (1.60 \pm 0.50) \times 10^{-6} \\ \mathcal{B}(B \to X_s \mu^+ \mu^-) &= 10^{-7} \times \sum_{i,j=0,7,7',9,9',10,10'} b_{(i,j)} \delta C_i \delta C_j \\ \mathcal{B}(\bar{B} \to X_s \mu^+ \mu^-)^{SM} &= (1.59 \pm 0.15) \times 10^{-6} \end{aligned}$$

  - $\delta C_7, \delta C_9, \delta C_{10}$-only contributions known up to NNLO including e.m. corrections [Bobeth et al, Huber et al]
  - $\delta C_{7'}, \delta C_{9'}, \delta C_{10'}$-only contributions with similar structure ($\gamma_5 \to -\gamma_5$)
  - crossed terms (primed-unprimed) only at LO in α_s, and are suppressed by m_s/m_b [Guetta Nardi]
  - b coefficients determined numerically agreeing with [Huber et al]

Class-III observables: $\tilde{A}_{\mathrm{F}B}$ and $\tilde{F}_L$

Average forward-backward asymmetry $\tilde{A}_{\mathrm{F}B}$
and longitudinal polarisation $\tilde{F}_L$ over low $q^2 =$1-6 GeV^2

$$\frac{dA_{\mathrm{FB}}}{dq^2} = \left(\int_0^1 d(\cos\theta_l)\frac{d^2\Gamma}{dq^2 d\cos\theta_l} - \int_{-1}^0 \ldots\right) / \frac{d\Gamma}{dq^2} \qquad F_{\mathrm{L}} = |A_0|^2 / \frac{d\Gamma}{dq^2}$$

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$$\tilde{A}_{FB}^{\mathrm{exp}} = 0.33^{+0.22}_{-0.24} \qquad \tilde{F}_L^{\mathrm{exp}} = 0.60^{+0.18}_{-0.19}$$

$$\tilde{A}_{FB} = \frac{\int_{1\mathrm{GeV}^2}^{6\mathrm{GeV}^2} \sum_{i=0,7,7',9,9',10,10'} \sum_{j=i,..10'} H_{(i,j)}(q^2)\delta C_i \delta C_j dq^2}{\int_{1\mathrm{GeV}^2}^{6\mathrm{GeV}^2} \sum_{i=0,7,7',9,9',10,10'} \sum_{j=i,..10'} I_{(i,j)}(q^2)\delta C_i \delta C_j dq^2} {}^{+\tilde{\delta}_u}_{-\tilde{\delta}_d}$$

computed at NLO in QCD factorisation [Beneke and Feldmann]
with fitting q^2-polynomials for central value and errors (same for $\tilde{F}_L$)

$$\tilde{A}_{FB}^{SM} = 0.022^{+0.028}_{-0.028} \qquad \tilde{F}_L^{SM} = 0.732^{+0.021}_{-0.031}$$