Electromagnetic Logarithms in $\bar{B} \to X_s\, l^+\, l^-$

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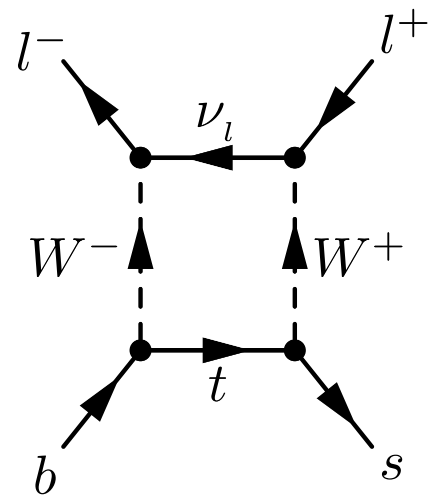
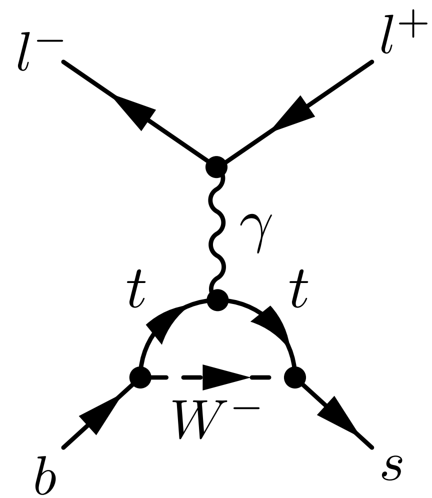
Contents

- Status of $\bar{B} \to X_s\, l^+\, l^-$
- QED corrections
- Results
- Outlook: $\mathscr{A}_{FB}$, high-$\hat{s}$, NP

General Features of $\bar{B} \to X_s l^+ l^-$

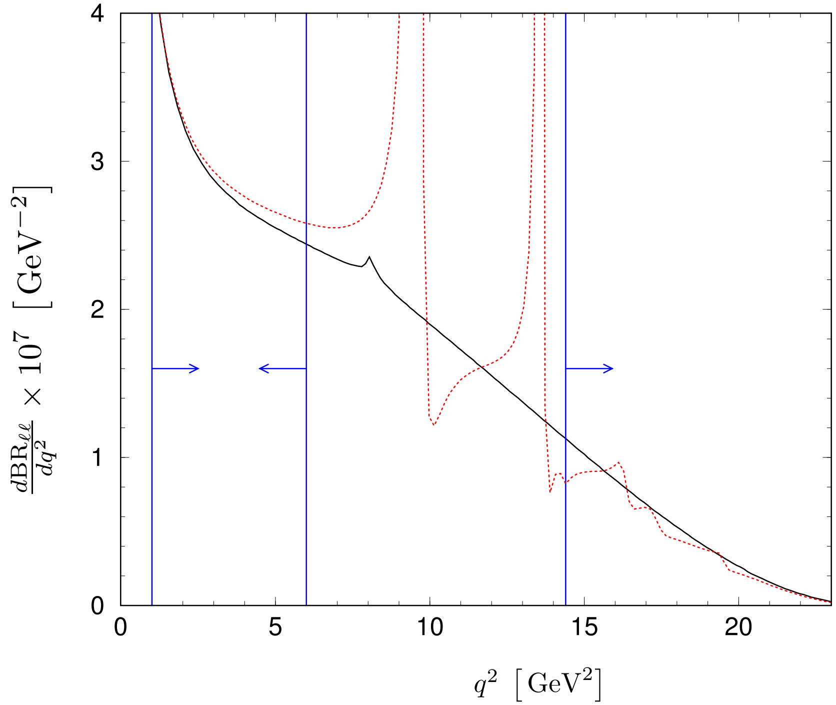
- Rare decay
- FCNC process.
  Probes the SM directly at the loop level
- A complementary SM test to $\bar{B} \to X_s \gamma$
- Precision in both experiment
  and theory needed and achievable





General Features of $\bar{B} \to X_s l^+ l^-$

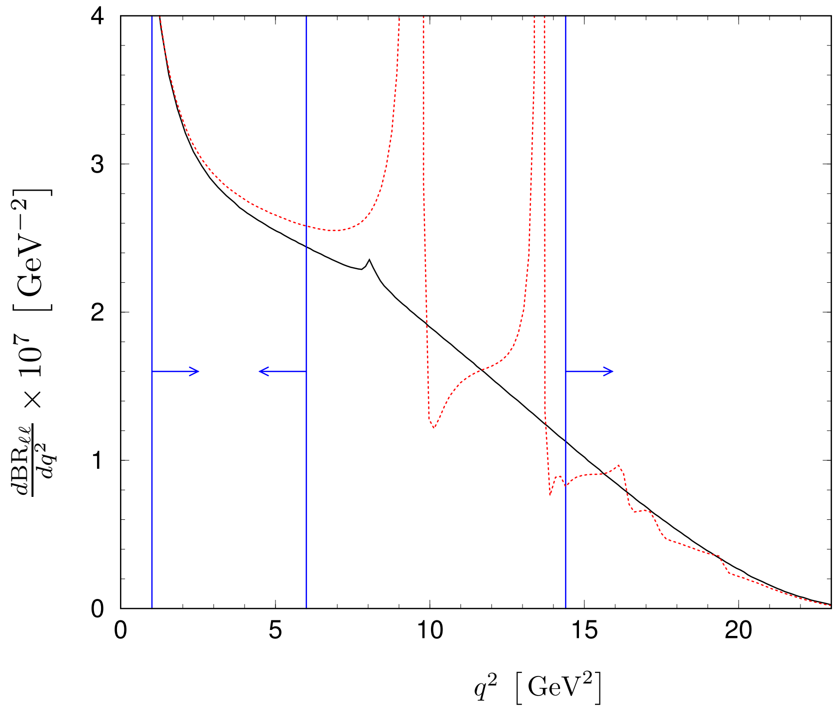
- Differential branching ratio $d\text{BR}_{\ell\ell}/dq^2$; with $q^2 \equiv m_{ll}^2$
- Low q^2-region: $1 \leq q^2/\,\text{GeV}^2 \leq 6$
  - high rate
  - sensitive to interference of C_7 and C_9
  - small $1/m_b$-corrections
  - fully inclusive measurement difficult due to cuts
  - non-negligible scale and m_c dependence



[Ghinculov,Hurth,Isidori,Yao]

General Features of $\bar{B} \to X_s\, l^+ l^-$

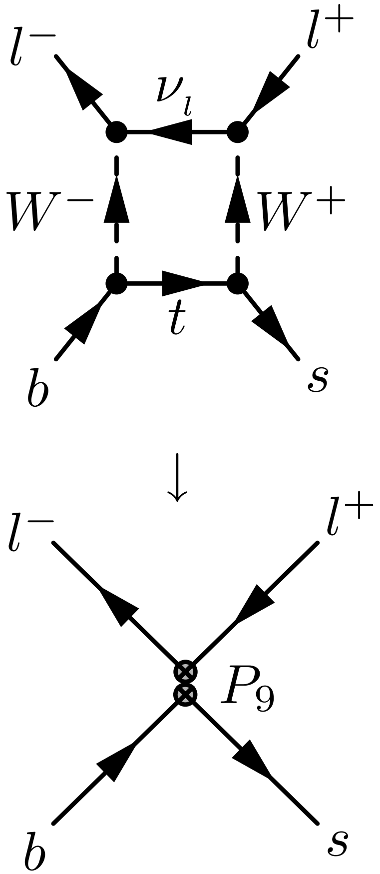
- Differential branching ratio $d\mathrm{BR}_{\ell\ell}/dq^2$; with $q^2 \equiv m_{ll}^2$
- High q^2-window: $q^2 \geq 14.4\,\mathrm{GeV}^2$.
  - tiny scale and m_c dependences
  - fully inclusive measurement easier
  - sizable $1/m_b^2$ corrections
  - low rate (but higher efficiency)
- $\bar{B} \to X_s\, \gamma$ - tail for $q^2 \leq 1\,\mathrm{GeV}^2$.
- On-shell $c\bar{c}$-resonances: J/Ψ and Ψ'.



[Ghinculov,Hurth,Isidori,Yao]

Effective Lagrangian

$$\mathscr{L}_{eff} = \mathscr{L}_{QCD\times QED}(u,..,b,e,\mu,\tau) + \frac{4G_F}{\sqrt{2}}\; V_{ts}^* V_{tb} \cdot \left[\sum_{i=1}^{10} C_i\, P_i + \underbrace{\sum_{i=3}^{6} C_{iQ}\, P_{iQ} + C_b\, P_b}_{for\ QED\ corrections} \right]$$



- C_i: Wilson Coefficients
  - scale dependent effective couplings
  - $C_i(\mu_W)$ obtained by matching on full theory
  - $C_i(\mu_b)$ obtained by solving perturbatively the RGE $\quad \mu \frac{d}{d\mu}\vec{C}(\mu) = \hat{\gamma}^T(\mu)\, \vec{C}(\mu)$
  - $\vec{C}(\mu_b) = \hat{R}\, \vec{C}(\mu_W)$

Operators in the EFT

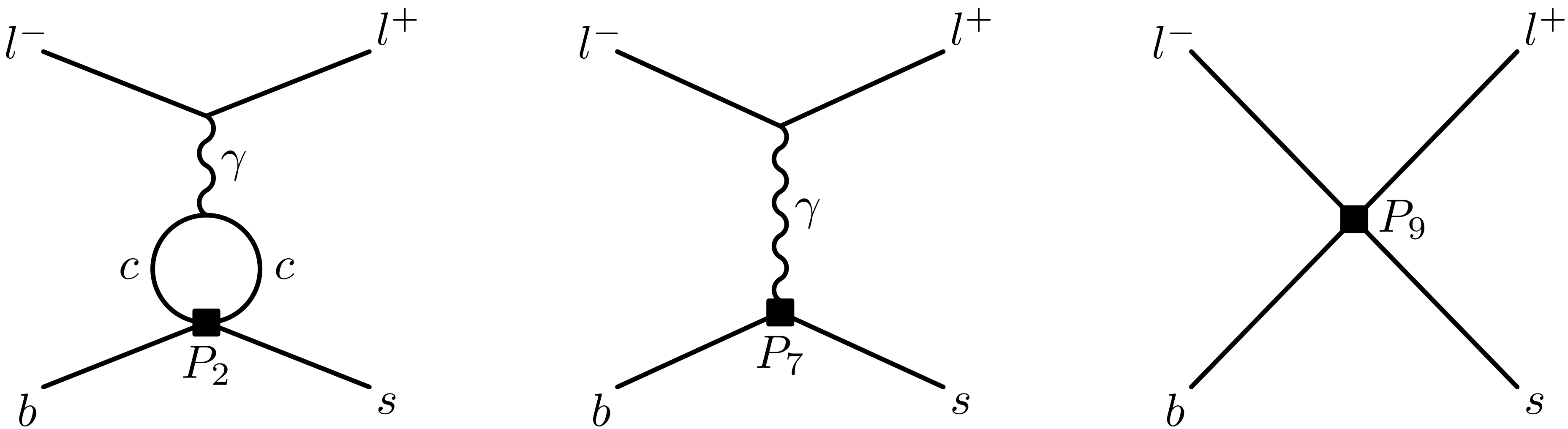
$$P_1 = (\bar{s}_L \gamma_\mu T^a c_L)(\bar{c}_L \gamma^\mu T^a b_L), \qquad P_4 = (\bar{s}_L \gamma_\mu T^a b_L) \sum_q (\bar{q} \gamma^\mu T^a q),$$

$$P_2 = (\bar{s}_L \gamma_\mu c_L)(\bar{c}_L \gamma^\mu b_L), \qquad P_5 = (\bar{s}_L \gamma_\mu \gamma_\nu \gamma_\sigma b_L) \sum_q (\bar{q} \gamma^\mu \gamma^\nu \gamma^\sigma q),$$

$$P_3 = (\bar{s}_L \gamma_\mu b_L) \sum_q (\bar{q} \gamma^\mu q), \qquad P_6 = (\bar{s}_L \gamma_\mu \gamma_\nu \gamma_\sigma T^a b_L) \sum_q (\bar{q} \gamma^\mu \gamma^\nu \gamma^\sigma T^a q),$$

$$P_7 = \frac{e}{16\pi^2} m_b (\bar{s}_L \sigma^{\mu\nu} b_R) F_{\mu\nu}, \qquad P_9 = (\bar{s}_L \gamma_\mu b_L) \sum_l (\bar{l} \gamma^\mu l),$$

$$P_8 = \frac{g}{16\pi^2} m_b (\bar{s}_L \sigma^{\mu\nu} T^a b_R) G^a_{\mu\nu}, \qquad P_{10} = (\bar{s}_L \gamma_\mu b_L) \sum_l (\bar{l} \gamma^\mu \gamma_5 l),$$



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$$P_{3Q} = (\bar{s}_L\gamma_\mu b_L)\sum_q Q_q(\bar{q}\gamma^\mu q),$$

$$P_{4Q} = (\bar{s}_L\gamma_\mu T^a b_L)\sum_q Q_q(\bar{q}\gamma^\mu T^a q),$$

$$P_{5Q} = (\bar{s}_L\gamma_\mu\gamma_\nu\gamma_\sigma b_L)\sum_q Q_q(\bar{q}\gamma^\mu\gamma^\nu\gamma^\sigma q),$$

$$P_{6Q} = (\bar{s}_L\gamma_\mu\gamma_\nu\gamma_\sigma T^a b_L)\sum_q Q_q(\bar{q}\gamma^\mu\gamma^\nu\gamma^\sigma T^a q),$$

$$P_b = \frac{1}{12}\left[(\bar{s}_L\gamma_\mu\gamma_\nu\gamma_\sigma b_L)(\bar{b}\gamma^\mu\gamma^\nu\gamma^\sigma b) - 4(\bar{s}_L\gamma_\mu b_L)(\bar{b}\gamma^\mu b)\right].$$

Decay Width

- Differential decay width: $(\hat{s} \equiv q^2/m_b^2)$

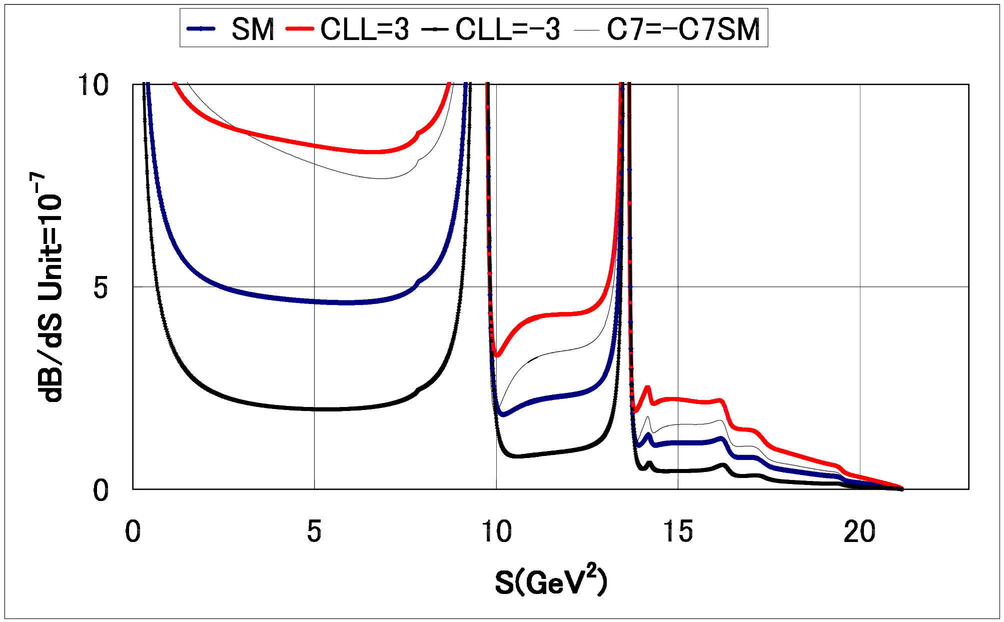
$$\frac{d\Gamma(\bar{B} \to X_s\, l^+ l^-)}{d\hat{s}} = \frac{G_F^2 m_b^5 |V_{ts}^* V_{tb}|^2 \alpha_{em}^2(\mu)(1-\hat{s})^2}{768\pi^5}$$

$$\times\left\{\left(4+\frac{8}{\hat{s}}\right)\left|\tilde{C}_7^{eff}\right|^2 + (1+2\hat{s})\left(\left|\tilde{C}_9^{eff}\right|^2+\left|\tilde{C}_{10}^{eff}\right|^2\right) + 12\,\mathrm{Re}\left(\tilde{C}_7^{eff}\tilde{C}_9^{*\,eff}\right) + \frac{d\Gamma^{brems}}{d\hat{s}}\right\}$$

- Compare to:

$$\Gamma(\bar{B} \to X_s\, \gamma) \propto \left|\tilde{C}_7^{eff}\right|^2$$

- SM size and signs of amplitudes
  - $\tilde{C}_7^{eff} \simeq -0.30$
  - $\tilde{C}_9^{eff} \simeq +4.05$
  - $\tilde{C}_{10}^{eff} \simeq -4.26$

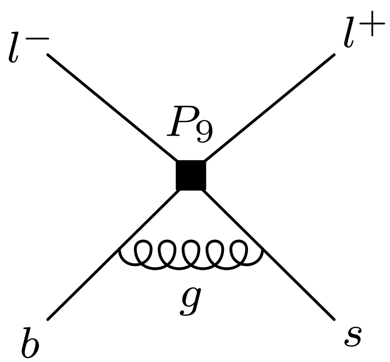


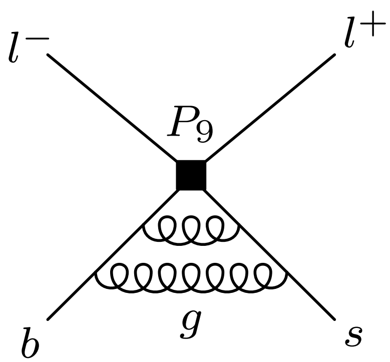
[Akeroyd et. al.]

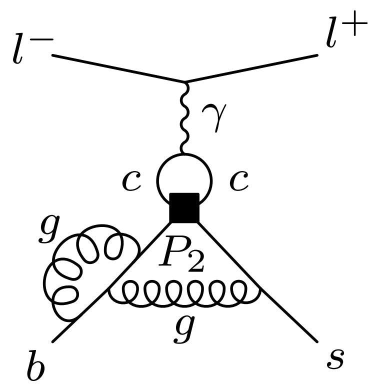
QCD and Power Corrections

$$\Gamma(\bar{B} \to X_s\, l^+\, l^-) = \Gamma(b \to s\, l^+\, l^-) \quad + \quad \text{power corrections}$$

- $1/m_b^2$, $1/m_b^3$ and $1/m_c^2$ corrections *[Falk, Luke, Savage, Ali, Hiller, Handoko, Morozumi]* *[Bauer, Burrell, Buchalla, Isidori, Rey]*
  - impact the BR at the few percent level
- QCD corrections to quark level decay rate are known to NNLO
  [Misiak, Buras, Münz, Bobeth, Urban, Asatrian, Asatryan, Greub, Walker]
  [Bobeth, Gambino, Gorbahn, Haisch, Bieri, Ghinculov, Hurth, Isidori, Yao]
  - reduce NLO diff. BR by about $20 - 25\%$
  - reduce scale uncertainties from $15 - 20\%$ to $3 - 5\%$







QED Corrections

- NLO QED corrections
  - are expected to be larger than N^3LO QCD corrections.
  - reduce $\pm 4\%$ scale uncertainty due to
    $\alpha_e(m_b) \approx 1/133$ vs. $\alpha_e(m_Z) \approx 1/128$.
  - This $\pm 4\%$ uncertainty is as large as NNLO QCD precision.

- Perturbative corrections come in powers of coupling constants α_e and α_s and of $L := \log(M_H/M_L)$.
- $\alpha_e \cdot L \ll 1$ whereas $\alpha_s \cdot L \approx \mathcal{O}(1)$
  $\Rightarrow$ Resum QCD-logs, but not QED ones
- Doing so yields an expansion in α_s and $\kappa = \alpha_e/\alpha_s \sim \alpha_e L$

Organizing the Expansion

- Amplitude:

$$\mathscr{A} = \kappa \left[\mathscr{A}_{LO} + \widetilde{\alpha}_{\mathrm{s}}\, \mathscr{A}_{NLO} + \widetilde{\alpha}_{\mathrm{s}}^2\, \mathscr{A}_{NNLO} + \mathcal{O}(\widetilde{\alpha}_{\mathrm{s}}^3)\right]$$
$$+ \kappa^2 \left[\mathscr{A}_{LO}^{em} + \widetilde{\alpha}_{\mathrm{s}}\, \mathscr{A}_{NLO}^{em} + \widetilde{\alpha}_{\mathrm{s}}^2\, \mathscr{A}_{NNLO}^{em} + \mathcal{O}(\widetilde{\alpha}_{\mathrm{s}}^3)\right] + \mathcal{O}(\kappa^3)$$

- Decay width:

$$|\mathscr{A}|^2 = \kappa^2 \left[\mathscr{A}_{LO}^2 + 2\,\widetilde{\alpha}_{\mathrm{s}}\, \mathscr{A}_{LO}\mathscr{A}_{NLO} + \widetilde{\alpha}_{\mathrm{s}}^2\, \mathscr{A}_{NLO}^2\right] \quad \Leftarrow \text{QCD, NLO}$$
$$\text{QCD, NNLO} \Rightarrow \quad + \kappa^2 \left[2\,\widetilde{\alpha}_{\mathrm{s}}^2\, \mathscr{A}_{LO}\mathscr{A}_{NNLO} + 2\,\widetilde{\alpha}_{\mathrm{s}}^3\, \mathscr{A}_{NLO}\mathscr{A}_{NNLO} + \ldots\right]$$
$$\text{QED} \Rightarrow \quad + \kappa^3 \left[2\, \mathscr{A}_{LO}\mathscr{A}_{LO}^{em} + 2\,\widetilde{\alpha}_{\mathrm{s}} \left(\mathscr{A}_{NLO}\mathscr{A}_{LO}^{em} + \mathscr{A}_{LO}\mathscr{A}_{NLO}^{em}\right)\right.$$
$$+2\,\widetilde{\alpha}_{\mathrm{s}}^2 \left(\mathscr{A}_{NLO}\mathscr{A}_{NLO}^{em} + \mathscr{A}_{NNLO}\mathscr{A}_{LO}^{em} + \mathscr{A}_{LO}\mathscr{A}_{NNLO}^{em}\right)$$
$$\left.+2\,\widetilde{\alpha}_{\mathrm{s}}^3 \left(\mathscr{A}_{NLO}\mathscr{A}_{NNLO}^{em} + \mathscr{A}_{NNLO}\mathscr{A}_{NLO}^{em}\right) + \ldots\right]$$

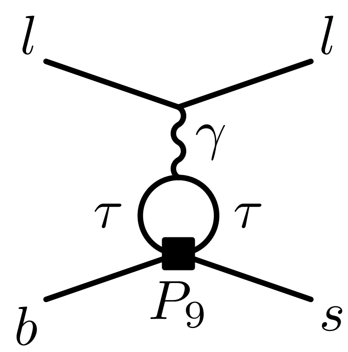
- Accidentially: $\mathscr{A}_{LO} \sim \widetilde{\alpha}_{\mathrm{s}}\, \mathscr{A}_{NLO}$ and $A_{LO}^{em} \sim \widetilde{\alpha}_{\mathrm{s}}\, \mathscr{A}_{NLO}^{em}$

  $\Rightarrow$ quite high terms in the expansion remain numerically important

Details of NLO QED Corrections

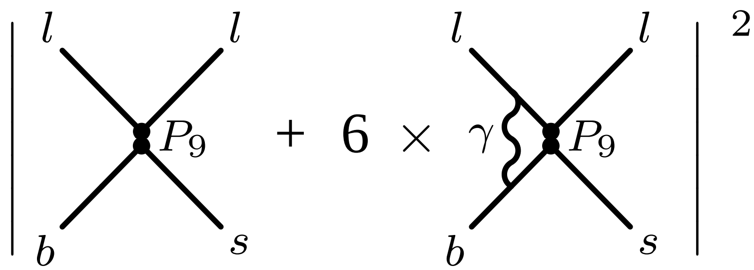
- Calculation of NLO QED corrections is threefold
  - Matching and running calculation; checked to agree with *[Bobeth, Gambino, Gorbahn, Haisch]*
  - Finite corrections, *i.e.* matrix elements of the P_i
- IR finite contributions $\langle P_i \rangle = H_i^9 \, \langle P_9 \rangle_{\rm tree} + H_i^7 \, \frac{\langle P_7 \rangle_{\rm tree}}{\widetilde{\alpha}_{\rm s} \kappa} + H_i^{10} \, \langle P_{10} \rangle_{\rm tree}$

	H_i^9	H_i^7	H_i^{10}
$i = 1, 2$	$\widetilde{\alpha}_{\rm s} \kappa \; f_i(\hat{s}) - \widetilde{\alpha}_{\rm s}^2 \kappa \; F_i^9(\hat{s})$	$-\widetilde{\alpha}_{\rm s}^2 \kappa \; F_i^7(\hat{s})$	0
$i = 3-6, 3Q-6Q, b$	$\widetilde{\alpha}_{\rm s} \kappa \; f_i(\hat{s})$	0	0
$i = 7$	0	$\widetilde{\alpha}_{\rm s} \kappa$	0
$i = 8$	$-\widetilde{\alpha}_{\rm s}^2 \kappa \; F_8^9(\hat{s})$	$-\widetilde{\alpha}_{\rm s}^2 \kappa \; F_8^7(\hat{s})$	0
$i = 9$	$1 + \widetilde{\alpha}_{\rm s} \kappa \; f_9^{\rm pen}(\hat{s})$	0	0
$i = 10$	0	0	1

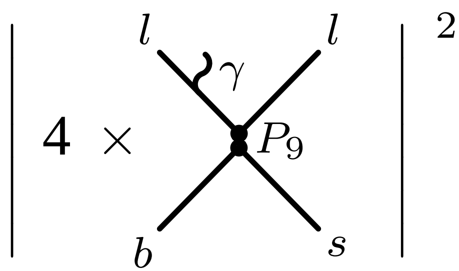


NLO QED Matrix Elements

- IR divergent contributions: Photon-loop corrections to P_9
- Consider massless final state, work in $D = 4 - 2\,\epsilon$ dimensions
- Virtual corrections: $\int dPS_3$



- Real corrections: $\int dPS_4$



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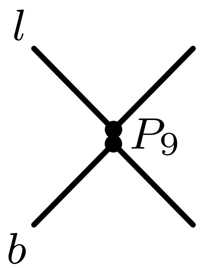
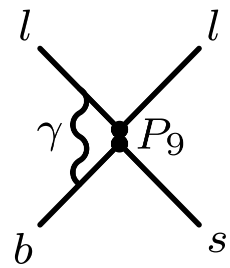
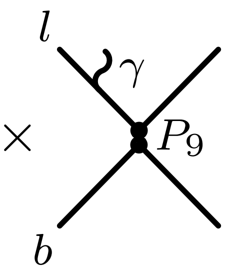
- Virtual corrections: $\int dPS_3 \Bigg|$ 

$+ \; 6 \times$ 

$\Bigg|^2$
- Real corrections: $\int dPS_4 \Bigg| \; 4 \times$ 

$\Bigg|^2$
- Residual collinear divergence $\propto \dfrac{\alpha_e}{4\pi}\dfrac{Q_l^2}{\epsilon}$
- Contrary to the integrated BR, the differential BR is not an infrared safe object with respect to the emission of collinear photons from lepton lines.

NLO QED Matrix Elements

- Choosing $m_l \neq 0$ from the beginning yields a finite sum of virtual and real corrections that contains an electromagnetic logarithm $\frac{\alpha_e}{4\pi} \log\left(\frac{m_b^2}{m_l^2}\right)$.

  However: diagrams more difficult, massive phase space

NLO QED Matrix Elements

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  However: diagrams more difficult, massive phase space

- Change of scheme from NDR to mass regularization:
  perturbative fragmentation (splitting) function $f_\gamma(x, E)$ *[Terazawa, Mele, Nason]*

- Collinear singularity $f_\gamma(x, E)$ can be regularized using dim. reg. or using a non-vanishing lepton mass

- Translation of collinear divergence into an electromagnetic logarithm:

$$\frac{\alpha_e}{4\pi} \frac{Q_l^2}{\epsilon} \longrightarrow \frac{\alpha_e}{4\pi} \left[\log\left(\frac{m_b^2}{m_l^2}\right) \cdot h(\hat{s}) + k(\hat{s})\right] \quad \text{with} \quad \int_0^1 d\hat{s}\ h(\hat{s}) = 0.$$

NLO QED Matrix Elements

- Additional remarks
  - Single EM log $\frac{\alpha_e}{4\pi} \log\left(\frac{m_b^2}{m_l^2}\right)$ does not get resummed
  - include also log-enhanced corrections to $|\langle P_7 \rangle|^2$, $|\langle P_{10} \rangle|^2$, $Re\left[\langle P_7 \rangle \langle P_9 \rangle^*\right]$, $|\langle P_{1,2} \rangle|^2$, $Re\left[\langle P_{1,2} \rangle \langle P_9 \rangle^*\right]$ and $Re\left[\langle P_{1,2} \rangle \langle P_7 \rangle^*\right]$
  - Presence of $\log\left(\frac{m_b^2}{m_l^2}\right)$ depends on experimental setup due to finite detector resolution for collinear photons
    - not a problem for muons
    - For electrons: cone of opening angle θ_c inside which collinear γ's are included in the reconstructed 4-momentum *[Berryhill, Ishikawa]*

$$q^2 = (p_+ + p_- + p_\gamma)^2 \qquad m_\ell^2 \leq (p_\ell + p_\gamma)^2 \leq \Lambda^2 \simeq 2E_\ell^2(1 - \cos\theta_c) \qquad \Lambda \sim \mathcal{O}(m_\mu)$$

Branching Ratio

- We normalize the differential decay width to the semileptonic $\bar{B} \to X_u e\bar{\nu}$ rate
  - removes $m_{b,pole}^5$-factor
  - better than normalization to $\bar{B} \to X_c e\bar{\nu}$ due to absence of phase space factors involving $m_{c,pole}$
- $$\frac{d\, BR(\bar{B} \to X_s ll)}{d\, \hat{s}} = BR^{exp.}_{b \to c\, e\, \nu} \left| \frac{V_{ub}}{V_{cb}} \right|^2 \frac{1}{C} \, \frac{d\Gamma(\bar{B} \to X_s\, ll)/d\hat{s}}{\Gamma(\bar{B} \to X_u e\bar{\nu})}$$

$$C = \left| \frac{V_{ub}}{V_{cb}} \right|^2 \frac{\Gamma(\bar{B} \to X_c e\bar{\nu})}{\Gamma(\bar{B} \to X_u e\bar{\nu})} = 0.58 \pm 0.01$$

[Bauer,Ligeti,Luke,Manohar,Trott]

  - we assume 100% correlation between the errors on C and m_c
- BR expressed in terms of $m_{b,pole}$ and $m_{c,pole}$ contains renormalon ambiguities. They are removed if $1S$ or $\overline{MS}$-masses are used [Hoang,Ligeti,Manohar,Trott]

Numerical Inputs

$\alpha_s(M_z) = 0.1182 \pm 0.0027$	$m_e = 0.51099892$ MeV
$\alpha_e(M_z) = 1/127.918$	$m_\mu = 105.658369$ MeV
$s_W^2 \equiv \sin^2\theta_W = 0.2312$	$m_\tau = 1.77699$ GeV
$\lvert V_{ts}^* V_{tb}/V_{cb}\rvert^2 = 0.967 \pm 0.009$	$m_c(m_c) = (1.224 \pm 0.017 \pm 0.054)$ GeV
$BR(B \to X_c e\bar{\nu})_{\rm exp} = 0.1061 \pm 0.0017$	$m_b^{1S} = (4.68 \pm 0.03)$ GeV
$M_Z = 91.1876$ GeV	$m_{t,\rm pole} = (172.7 \pm 2.9)$ GeV
$M_W = 80.426$ GeV	$m_B = 5.2794$ GeV
$\lambda_2 \simeq \frac{1}{4}\left(m_{B^*}^2 - m_B^2\right) \simeq 0.12\ \mathrm{GeV}^2$	$C = 0.58 \pm 0.01$

Results (low-q^2-region)

- Including QED corrections to the WC's: *[Bobeth, Gambino, Gorbahn, Haisch]*
  - $BR(\bar{B} \to X_s ll) = 1.56 \cdot 10^{-6}$
  - agreement with result of BGGH if we use their inputs
- Including all NLO-QED corrections: *[Lunghi, Misiak, Wyler, TH]*
  - $$BR(\bar{B} \to X_s ee) = (1.64 \pm 0.08_{scale} \pm 0.06_{m_t} \pm 0.015_{m_b} \pm 0.025_{C,m_c} \pm 0.02_{\alpha_s(M_Z)} \pm 0.015_{CKM} \pm 0.026_{\mathrm{BR}_{sl}}) \cdot 10^{-6}$$
  - $$BR(\bar{B} \to X_s \mu\mu) = (1.59 \pm 0.08_{scale} \pm 0.06_{m_t} \pm 0.015_{m_b} \pm 0.024_{C,m_c} \pm 0.02_{\alpha_s(M_Z)} \pm 0.015_{CKM} \pm 0.026_{\mathrm{BR}_{sl}}) \cdot 10^{-6}$$
- Experimental values:
  - $BR(\bar{B} \to X_s ll) = (1.493 \pm 0.504_{stat.} {}^{+0.411}_{-0.321}{}_{sys.}) \cdot 10^{-6}$ *[Belle, 152 M evts.]*
  - $BR(\bar{B} \to X_s ll) = (1.8 \pm 0.7_{stat.} \pm 0.5_{sys.}) \cdot 10^{-6}$ *[BaBar, 89 M events]*
  - weighted average: $(1.60 \pm 0.51) \cdot 10^{-6}$

Results (low-q^2-region)

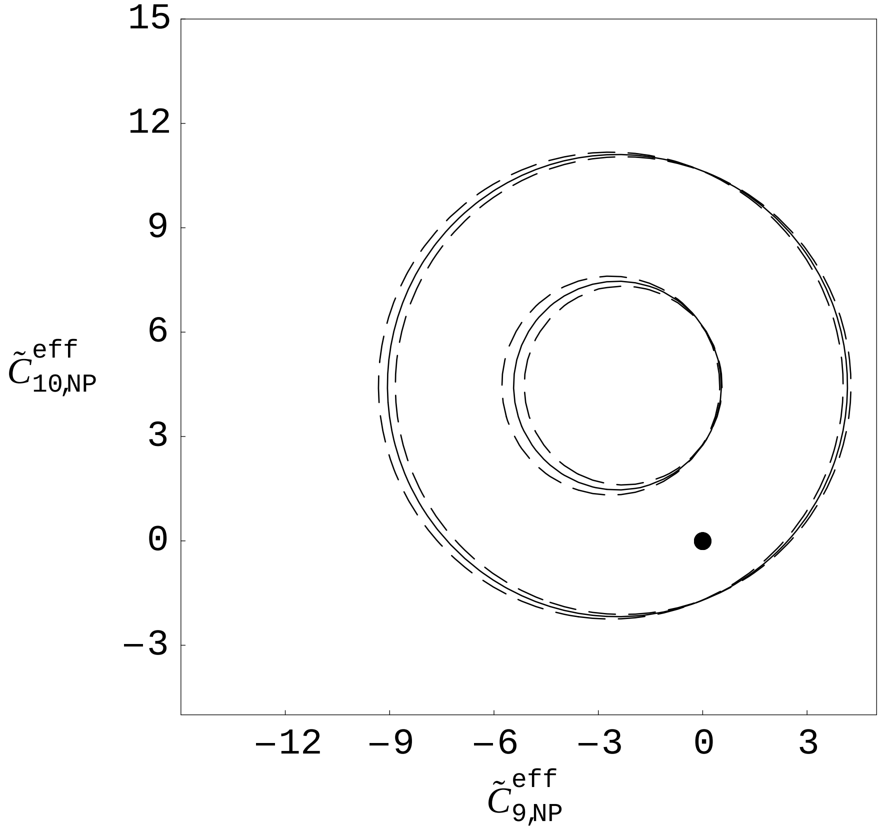
- Anatomy of QCD and QED corrections

NLO ($\alpha_{em}(\mu_0)$)	1.81×10^{-6}	NLO ($\alpha_{em}(\mu_b)$)	1.68×10^{-6}
NNLO ($\alpha_{em}(\mu_0)$)	1.65×10^{-6}	NNLO ($\alpha_{em}(\mu_b)$)	1.54×10^{-6}
QED (only WC's)	1.56×10^{-6}		
QED (muons)	1.59×10^{-6}	QED (electrons)	1.64×10^{-6}

- With reversed sign of C_7
  - $BR(\bar{B} \to X_s ee) = 3.19 \cdot 10^{-6}$
  - $BR(\bar{B} \to X_s \mu\mu) = 3.11 \cdot 10^{-6}$

  $\Rightarrow$ SM-sign of $\widetilde{C}_7^{\text{eff}}$ is favored

More on sign of $\widetilde{C}_7^{\rm eff}$



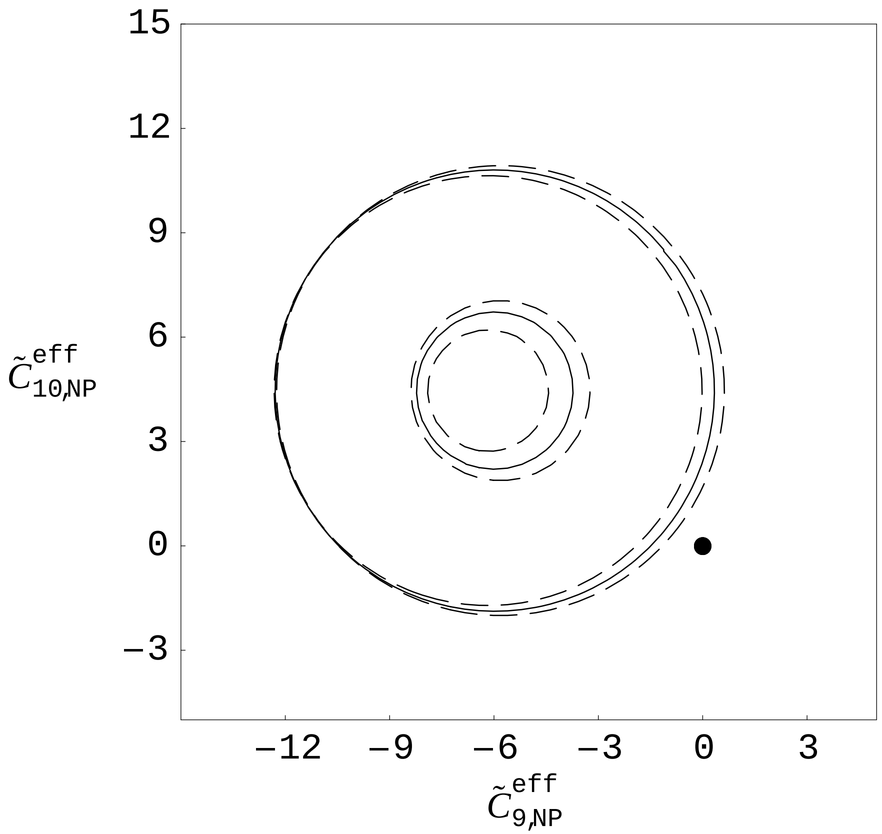
Model-independent constraints on additive new physics contributions to $\widetilde{C}_{9,10}^{\rm eff}$ at 90% C.L.

SM-like sign of $\widetilde{C}_7^{\rm eff}$

[Gambino,Haisch,Misiak]

- Extract bounds on $|\widetilde{C}_7^{eff}|$ from $\mathcal{B}(\bar{B} \to X_s\gamma) = (3.52{\pm}0.70){\cdot}10^{-4}$
- Use bounds on low q^2-region from $\mathcal{B}(\bar{B} \to X_s ll) = (1.60{\pm}0.90){\cdot}10^{-6}$ to extract allowed region for $\widetilde{C}_{9,10}^{\rm eff}$
- Regions outside the rings are excluded
- Dot at the origin indicates the SM case for $\widetilde{C}_{9,10}^{\rm eff}$.

More on sign of $\widetilde{C}_7^{\rm eff}$



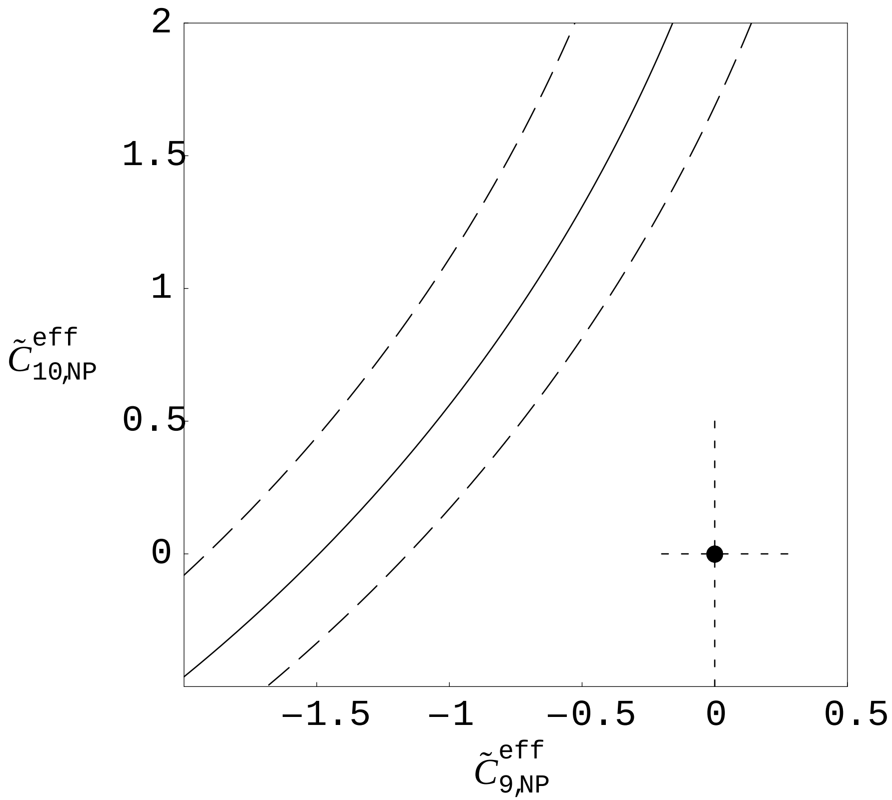
Model-independent constraints on additive new physics contributions to $\widetilde{C}^{\rm eff}_{9,10}$ at 90% C.L.

opposite sign of $\widetilde{C}^{\rm eff}_7$

[Gambino,Haisch,Misiak]

- Extract bounds on $|\widetilde{C}_7^{eff}|$ from $\mathcal{B}(\bar{B} \to X_s\gamma) = (3.52\pm0.70)\cdot10^{-4}$
- Use bounds on low q^2-region from $\mathcal{B}(\bar{B} \to X_s ll) = (1.60\pm0.90)\cdot10^{-6}$ to extract allowed region for $\widetilde{C}^{\rm eff}_{9,10}$
- Regions outside the rings are excluded
- Dot at the origin indicates the SM case for $\widetilde{C}^{\rm eff}_{9,10}$.

More on sign of $\widetilde{C}_7^{\rm eff}$



Enlarged surroundings of the origin.

opposite sign of $\widetilde{C}_7^{\rm eff}$

[Gambino,Haisch,Misiak]

- Dashed cross:
  Maximal MFV MSSM
  contributions to $\widetilde{C}_{9,10}^{\rm eff}$

  [Ali,Lunghi,Greub,Hiller]
- Dashed cross too small to reach border of allowed region
- Extensions of SM with reversed sign of $\widetilde{C}_7^{\rm eff}$ but only small corrections to $\widetilde{C}_{9,10}^{\rm eff}$ are disfavored
- Models with positive $\widetilde{C}_7^{\rm eff}$ require sizable contributions to $\widetilde{C}_9^{\rm eff}$ and $\widetilde{C}_{10}^{\rm eff}$

To-do list

- Forward backward asymmetry:

$$\mathscr{A}_{FB}(q^2) \equiv \frac{d\mathrm{BR}_{\ell\ell}/dq^2(\cos\theta_l > 0) - d\mathrm{BR}_{\ell\ell}/dq^2(\cos\theta_l < 0)}{d\mathrm{BR}_{\ell\ell}/dq^2(\cos\theta_l > 0) + d\mathrm{BR}_{\ell\ell}/dq^2(\cos\theta_l < 0)}$$

$$= \frac{G_F^2 m_b^5 |V_{ts}^* V_{tb}|^2 \alpha_{em}^2(\mu)(1-\hat{s})^2}{768\pi^5} \Big\{ -6\,\mathrm{Re}\big(\tilde{C}_{7,FB}^{eff} \tilde{C}_{10,FB}^{*\,eff}\big) - 3\hat{s}\,\mathrm{Re}\big(\tilde{C}_{9,FB}^{eff} \tilde{C}_{10,FB}^{*\,eff}\big) + A_{FB}^{brems} \Big\}$$

  - Determine $C_9 \cdot C_{10}$ and C_7

- High-q^2 region
  - NNLO QCD result:

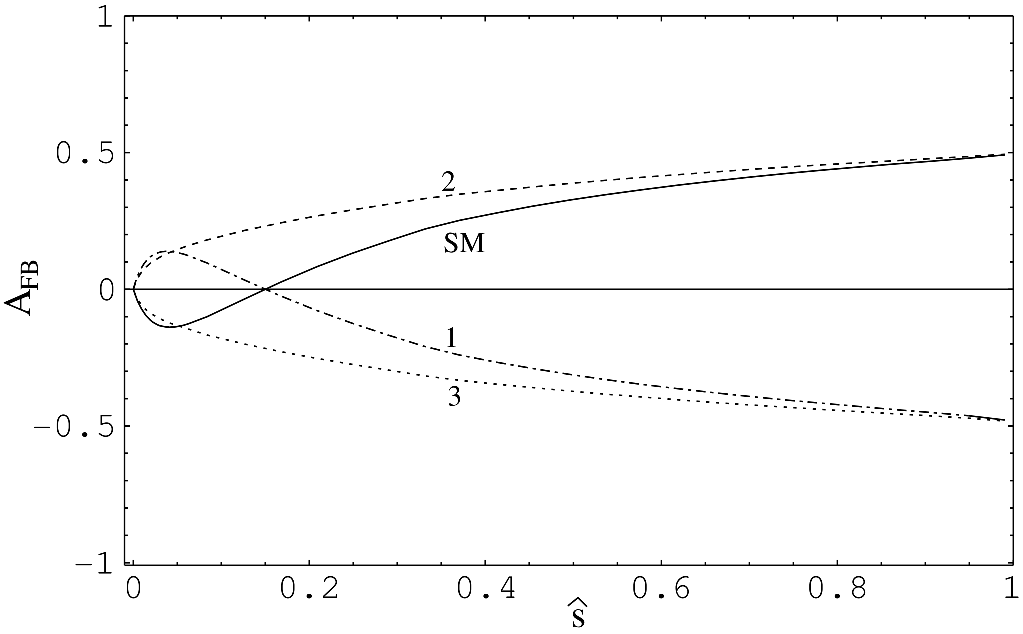
$$BR(\bar{B} \to X_s ll) = (4.04 \pm 0.78)\ 10^{-7}$$

[Ghinculov,Hurth,Isidori,Yao]

  - World average:

$$BR(\bar{B} \to X_s ll) = (4.3 \pm 1.2)\ 10^{-7}$$

  - QED corr. will lower BR



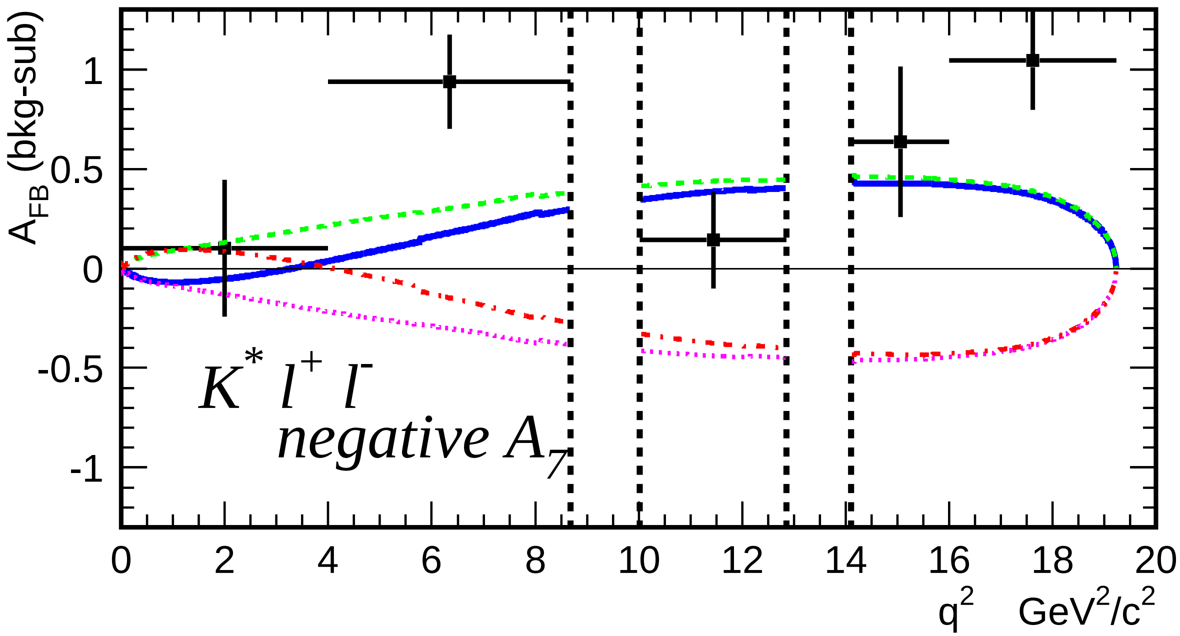
[Ali, Greub, Hiller, Lunghi, $\hat{s} \equiv q^2/m_b^2$]

Backup slides

Amplitude signs from $\mathscr{A}_{FB}$

- Recent measurement of $\mathscr{A}_{FB}$ at *Belle*.

[386 M events, hep-ex/0603018]
[hep-ex/0508009]

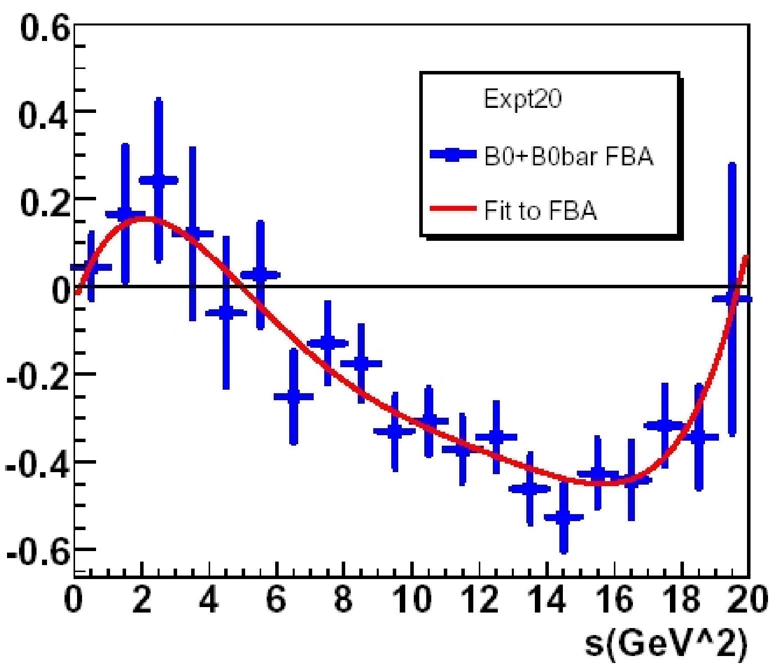


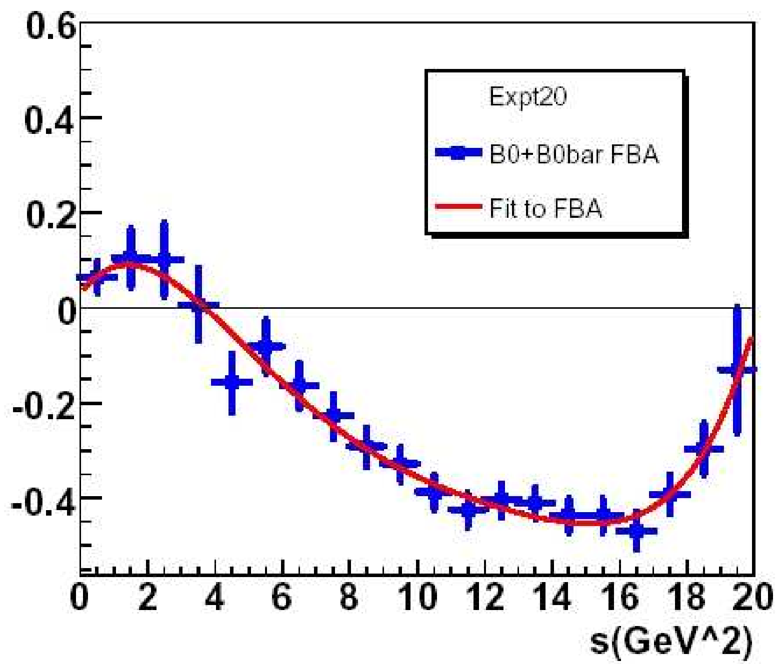
- blue: SM signs
- green: reversed sign of C_7
- red: reversed sign of C_{10} excluded
- magenta: reversed signs of C_7 and C_{10} excluded

- Results compatible with either sign of C_7
- Positive sign of $C_9 \cdot C_{10}$ is excluded at 98.2 % C.L.

Outlook to LHCb

- Relative errors on branching ratio after 1 year *[P. Koppenburg, J. H. Lopes]*
  - Low q^2-region: $1 \le q^2/\,\mathrm{GeV}^2 \le 6$: $\pm\,5.7\%$
  - High q^2-region: $q^2 \ge 14.4\ \mathrm{GeV}^2$: $\pm\,3.2\%$
  - Much less than hadronic uncertainties
- $\mathscr{A}_{FB}$ at $2\,fb^{-1}$ and at $10\,fb^{-1}$. Obtain $C_7\,/\,C_9$ with 13 % accuracy





General Features of $\bar{B} \to X_s l^+ l^-$

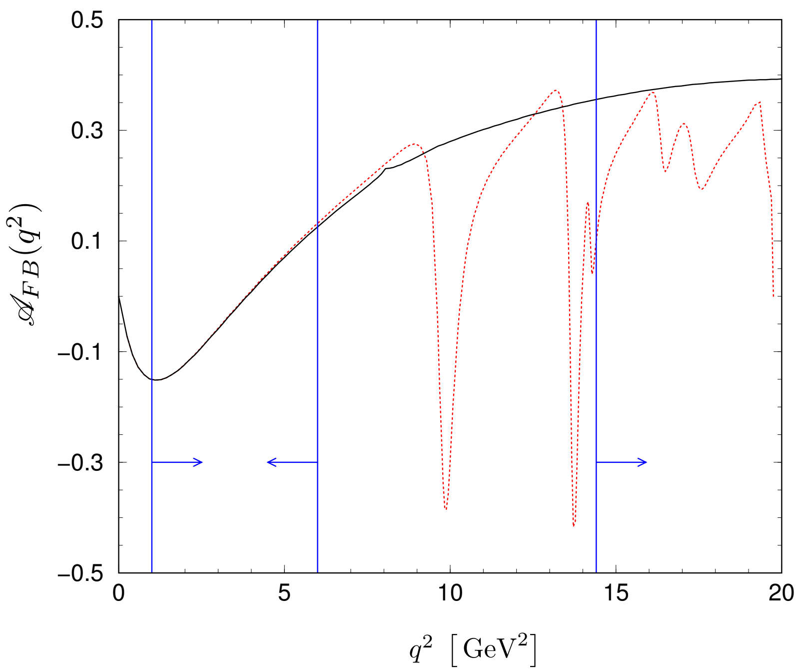
- Forward backward asymmetry:
  - $$\mathscr{A}_{FB}(q^2) \equiv \frac{d\text{BR}_{\ell\ell}/dq^2(\cos\theta_l > 0) - d\text{BR}_{\ell\ell}/dq^2(\cos\theta_l < 0)}{d\text{BR}_{\ell\ell}/dq^2(\cos\theta_l > 0) + d\text{BR}_{\ell\ell}/dq^2(\cos\theta_l < 0)}$$

- SM: $\mathscr{A}_{FB}(q_0^2) = 0$ for

  $q_0^2 = (3.76 \pm 0.22_{th} \pm 0.24_{m_b})\ \text{GeV}^2$

  [Bobeth,Gambino,Gorbahn,Haisch]

- Zero of $\mathscr{A}_{FB}(q^2)$ almost insensitive to hadronic uncertainties



[Ghinculov,Hurth,Isidori,Yao]

Observable

- $\frac{d\Gamma}{d\hat{s}}$ is IR finite if $\hat{s} = \begin{cases} (p_{\ell_1} + p_{\ell_2} + p_\gamma)^2/m_b^2 & \text{if } \vec{p}_\gamma \parallel (\vec{p}_{\ell_1} \text{ or } \vec{p}_{\ell_2}) \\ (p_{\ell_1} + p_{\ell_2})^2/m_b^2 & \text{otherwise.} \end{cases}$
- $f_\gamma^{(\epsilon)}(x, E) = 4\tilde{\alpha}_e \left[\frac{1+(1-x)^2}{x} \left(-\frac{1}{2\epsilon} + \ln\frac{E}{\mu} + \ln(2-2x) \right) - \frac{(2-x)^2}{2x} \ln\frac{2-x}{x} \right]$
- $f_\gamma^{(m)}(x, E)$
  $$= 4\tilde{\alpha}_e \left[\frac{1+(1-x)^2}{x} \left(\ln\frac{E}{m_\ell} + \ln(2-2x) \right) - 1 + x - \frac{x^2}{2} \ln x - \frac{(2-x)^2}{2} \ln(2-x) \right]$$
- $\frac{T_s}{2m_b} = \left(\frac{\mathrm{d}\Gamma^{(m)}_{\mathrm{coll},2}}{d\hat{s}} - \frac{\mathrm{d}\Gamma^{(\epsilon)}_{\mathrm{coll},2}}{d\hat{s}} \right) - \left(\frac{\mathrm{d}\Gamma^{(m)}_{\mathrm{coll},3}}{d\hat{s}} - \frac{\mathrm{d}\Gamma^{(\epsilon)}_{\mathrm{coll},3}}{d\hat{s}} \right)$