Theoretical Status of the Inclusive Modes

$\bar{B} \to X_s\gamma$ and $\bar{B} \to X_s\ell^+\ell^-$

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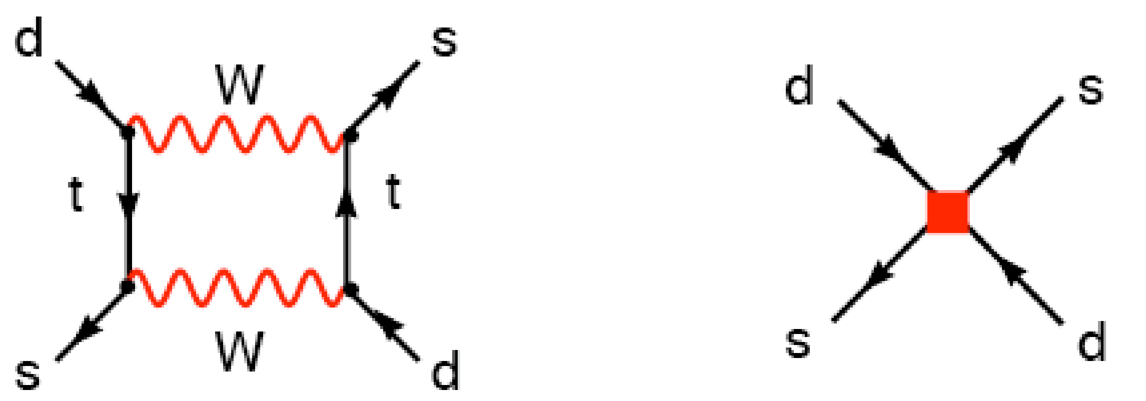
SuperB workshop VI, Valencia, 10th of January 2008

Flavour problem or how do FCNCs hide?

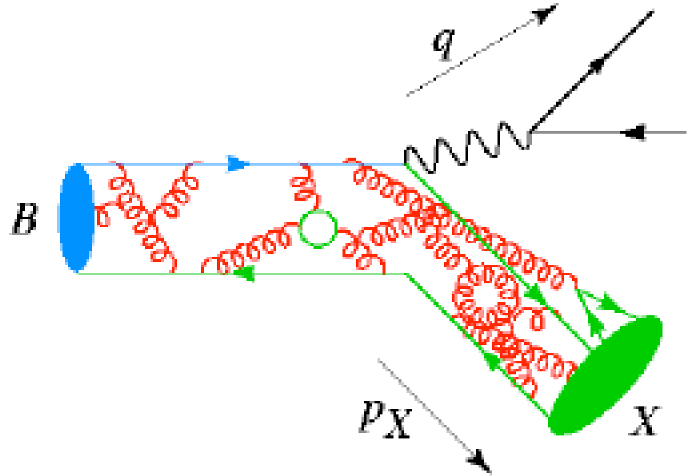
$$\mathcal{L} = \mathcal{L}_{Gauge} + \mathcal{L}_{Higgs} + \sum_i \frac{c_i^{New}}{\Lambda_{\rm NP}} \mathcal{O}_i^{(5)} + \ldots$$

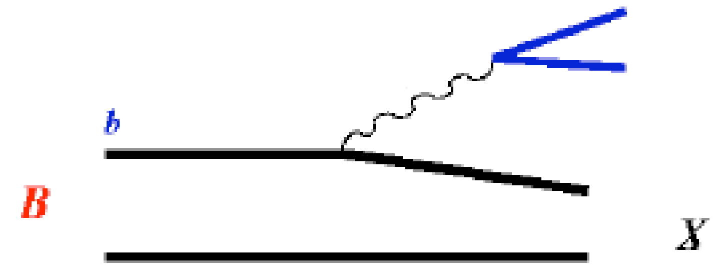
- SM as effective theory valid up to cut-off scale $\Lambda_{\rm NP}$
- $K^0 - \bar{K}^0$-mixing $\mathcal{O}^6 = (\bar{s}\, d)^2$: $c^{SM}/M_W^2 \times (\bar{s}\, d)^2 + c^{New}/\Lambda^2 \times (\bar{s}\, d)^2 \Rightarrow \Lambda_{\rm NP} > 100\,\text{TeV}$



- Natural stabilisation of Higgs boson mass (hierarchy problem) $\Rightarrow \Lambda_{\rm NP} \leq 1\text{TeV}$
  (i.e. supersymmetry, little Higgs, extra dimensions)
- In addition: EW precision data $\leftrightarrow$ little hierarchy problem $\Rightarrow \Lambda_{\rm NP} \sim 3 - 10\text{TeV}$

Possible New Physics at the TeV scale has to have a very non-generic flavour structure





Crucial problem: Separation of new physics effects and hadronic uncertainties!

Focus on theoretically clean observables is mandatory

Three strategies:

I focus on inclusive modes: operator product expansion (OPE)

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

No linear term Λ_{QCD}/m_b
(perturbatively calculable contribution dominant)

II focus on ratios of exclusive modes like asymmetries
(hadronic uncertainties partially cancel out)

III focus on specific decays like $K \to \pi\nu\bar{\nu}$
(hadronic matrix elements known from experiment)

Focus on theoretical uncertainties !

Status of the inclusive mode $\bar{B} \to X_s\gamma$

- Perturbative QCD corrections are dominant and lead to large logarithms
  $\alpha_s(M_W)Log(m_b^2\,/\,M_W^2) \to$ resummation of Logs necessary:

LL	Leading Logs	$G_F\,(\alpha_s\,Log\,)^N$	$N = 0, 1, 2, ...$
NLL	Next-to-leading Logs	$G_F\,\alpha_s\,(\alpha_s\,Log\,)^N$	
NNLL	Next-to-next-to-leading Logs	$G_F\,\alpha_s^2\,(\alpha_s\,Log\,)^N$	

- Previous NLL prediction Hurth,Lunghi,Porod,hep-ph/0312260

$$\mathcal{B}(\bar{B} \to X_s\gamma) \times 10^4|_{E_\gamma > 1.6GeV} = (3.61 \;{}^{+0.24}_{-0.40}\Big|_{m_c/m_b} \pm 0.02_{\text{CKM}} \pm 0.25_{\text{param}} \pm 0.15_{\text{scale}})$$

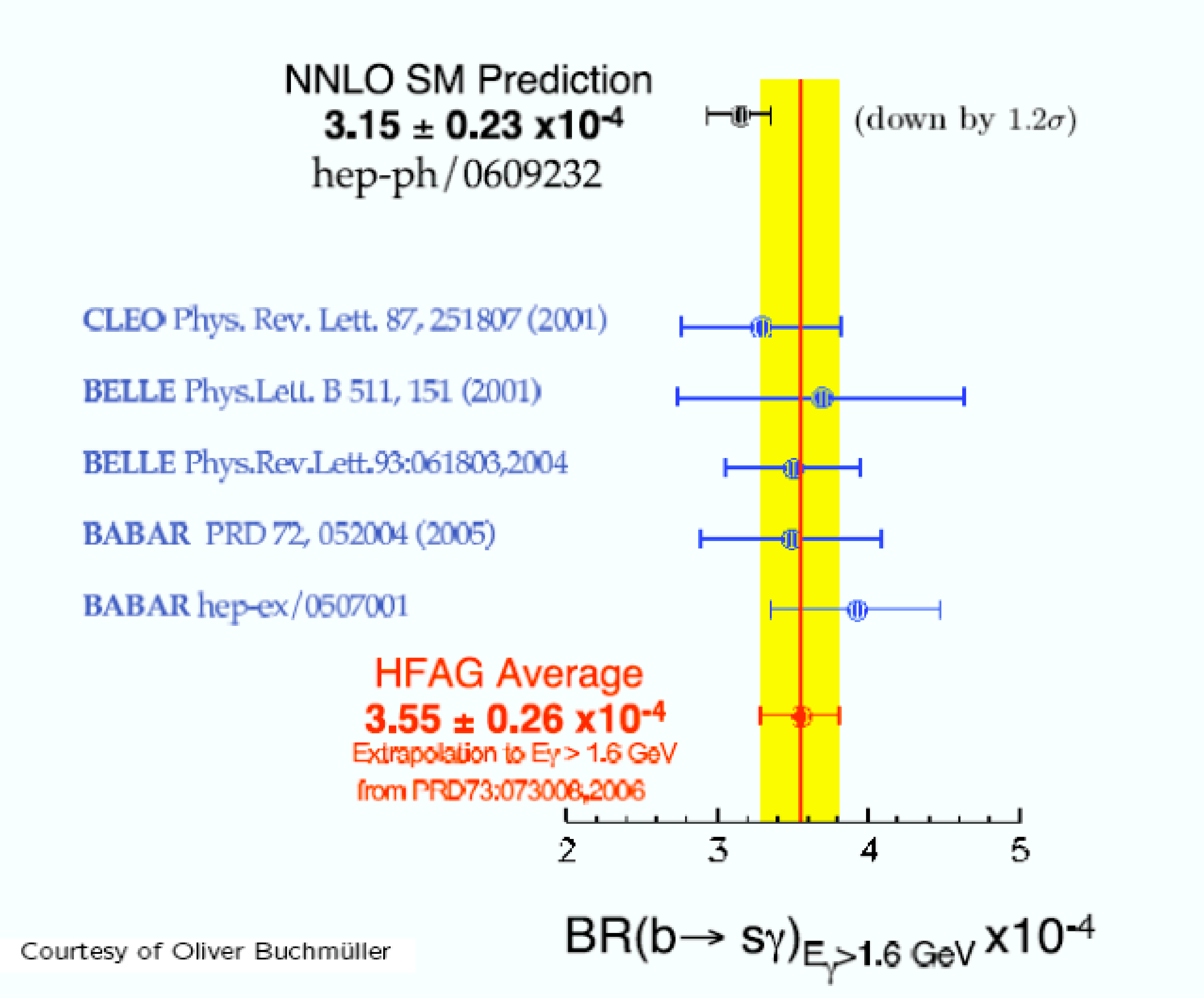
  First NNLL prediction of $\bar{B} \to X_s\gamma$ Misiak (spokesperson) et al.,hep-ph/0609232

$$\mathcal{B}(\bar{B} \to X_s\gamma) \times 10^4|_{E_\gamma > 1.6GeV} = (3.17 \pm 0.23)$$

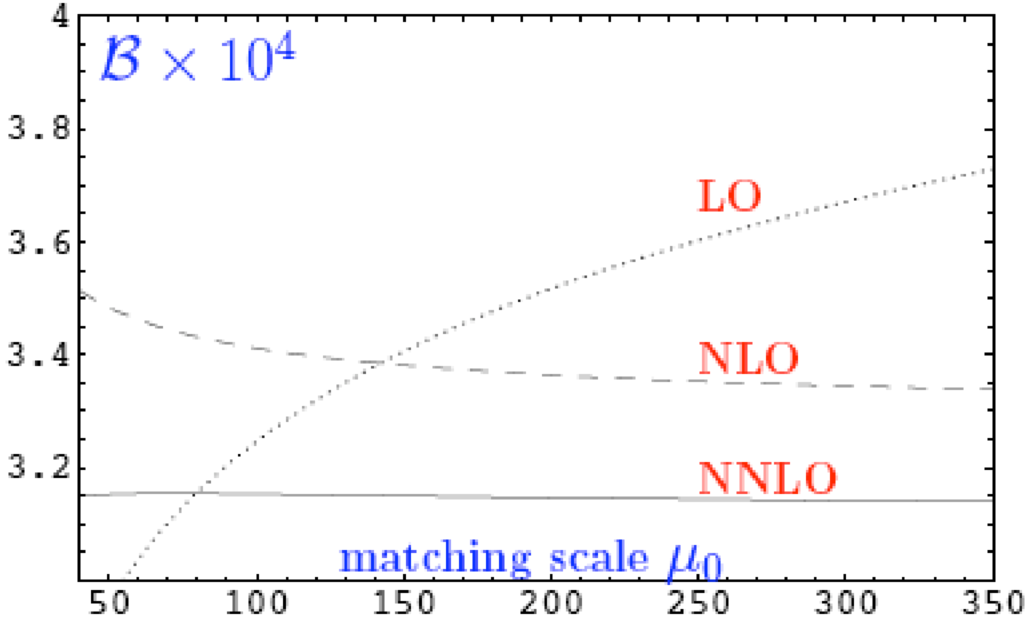
  Experimental world average HFAG

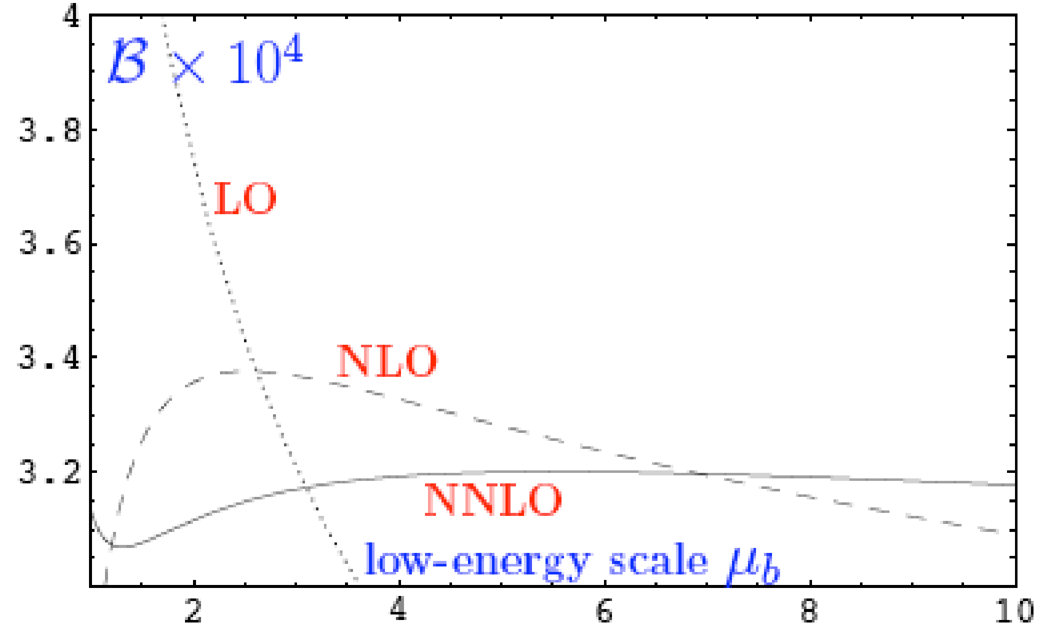
$$\mathcal{B}(\bar{B} \to X_s\gamma) \times 10^4|_{E_\gamma > 1.6GeV} = (3.55 \;{}^{+0.09}_{-0.10}\Big|_{syst} \pm 0.24_{\text{stat}} \pm 0.03_{\text{shape,dgamma}})$$

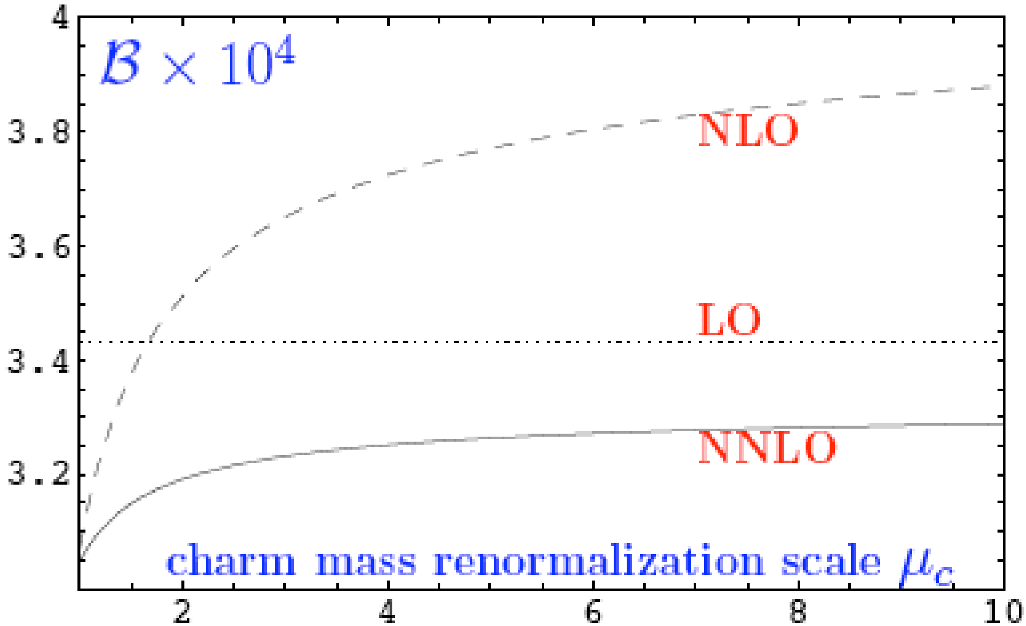
- Also in beyond-the-SM scenarios NLL calculations exist: $C_i^{SM}(M_W) + C_i^{New}(M_W)$
  NLL analysis in MFV-supersymmetry Degrassi,Gambino,Slavich, hep-ph/0601135
  NLL in general supersymmetry (uMSSM) Greub,Hurth,Steinhauser, work in progress



$$BR_{Babar 11/2007} = 3.91 \pm 0.91_{\text{stat}} \pm 0.64_{\text{syst}} \times 10^{-4}$$







"Central" values:

$\mu_0 = 160$ **GeV**

$\mu_b = 2.5$ **GeV**

$\mu_c = 1.5$ **GeV**

- Nonperturbative corrections $\Lambda^2/m_{b,c}^2$ to $\Gamma(\bar{B} \to X_s\gamma)$ are well under control

- However: Estimation of power corrections of $O(\alpha_s\Lambda/mb)$ should be improved:
  Largest uncertainty (5%) in our new NNLL prediction (see Lee et al)

- Further uncertainties: parametric (3%), higher-order (3%), mc-interpolation (3%)

$$BR(\bar{B} \to X_s\gamma)_{E_\gamma > 1.6\,\mathrm{GeV}} = BR(\bar{B} \to X_c e\bar{\nu})^{\exp} \left[\frac{\Gamma(b \to s\gamma)}{\Gamma(b \to ce\bar{\nu})}\right]_{\mathrm{LO\,EW}} f\left(\frac{\alpha_s(M_W)}{\alpha_s(m_b)}\right) \times$$

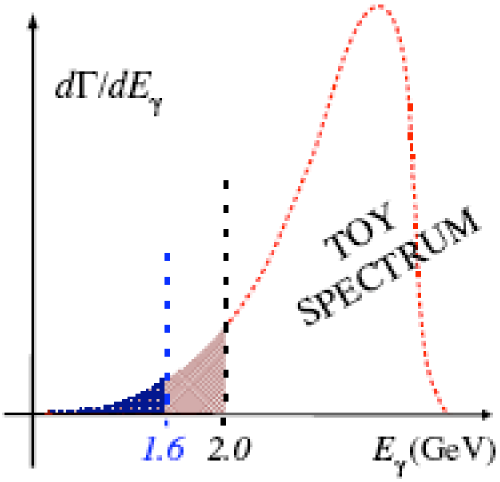
$$\times \left\{1 + \mathcal{O}(\alpha_s) + \mathcal{O}(\alpha_s^2) + \mathcal{O}(\alpha_{\mathrm{em}}) + \mathcal{O}\left(\frac{\Lambda^2}{m_b^2}\right) + \mathcal{O}\left(\frac{\Lambda^2}{m_c^2}\right) + \mathcal{O}\left(\frac{\alpha_s\Lambda}{m_b}\right)\right\}$$

NLO NNLO

~25% ~7% ~4% ~1% ~3% ~5%

- Additional sensitivities to nonperturbative physics
  due to necessary cuts in the photon energy spectrum
  to suppress the $B\bar{B}$ background:

  Shape function methods and multi-scale SCET analysis
  ⇒ Additional theoretical uncertainties



More details: Additional sensitivities to nonperturbative physics

- s-quark propagator in the correlator of OPE:

$$S_s(k) = \frac{\not k + i \not D}{k^2 + 2ik \cdot D - \not D \not D + i\varepsilon} \; .$$

- far away from singular kinematical points:

$k \sim m_b$, $k^2 \sim m_b^2 \;\Rightarrow\; k^2 \sim m_b^2 \gg k \cdot D \sim m_b \Lambda \gg \not D \not D \sim \Lambda^2$

Expansion $S_s(k) = \not k / k^2 + \mathcal{O}(\Lambda/m_b)$ valid !

- endpoint region of photon energy spectrum in $\bar B \to X_s \gamma$:

$k \sim m_b$ but $k^2 \sim m_b \Lambda \;\Rightarrow\; k^2 \sim m_b \Lambda \approx k \cdot D \sim m_b \Lambda \gg \not D \not D \sim \Lambda^2$

Expansion in Λ/m_b still possible, but $k \cdot D / k^2$ is $\mathcal{O}(1)$, partial resummation of these effects to all-orders in a nonperturbative shape-function necessary !

Neubert,Mannel; Bigi et al.

- General folklore: With $E_\gamma^0 \leq 1.9 GeV$ local OPE of the rate is valid again.

- But: Becher,Neubert,hep-ph/06100067
A low cut around $1.8 GeV$ might not guarantee that a theoretical description in terms of a local OPE is sufficient because of the sensitivity to the scale $\Delta = m_b - 2E_\gamma^0$.
  - Multiscale OPE with three short-distance scales $m_b, \sqrt{m_b \Delta}$ and Δ needed to connect the shape function and the local OPE region.
  - Using SCET, effects at the 3%-level found not by power corrections Λ_{QCD}/Δ, but by perturbative ones
  - $BR(\bar{B} \to X_s \gamma)_{E_\gamma > 1.6\,\mathrm{GeV}} = 2.98 \pm 0.26$

- Nevertheless: Misiak, 2.workshop on Flavour Dynamics, Albufeira, 3.-10.11.2007

For $E_\gamma^0 = 1.6 GeV$ or lower, the cutoff-enhanced perturbative corrections undergo a dramatic cancellation with the so-called power-suppressed terms. Consequently, both types of terms must be treated with the same precision. Until this is done, the fixed-order results should be considered more reliable.

$$\mathrm{const.} + \log(\Delta/m_b) + \log^2(\Delta/m_b) + \ldots$$
versus
$$(\Delta/m_b) + (\Delta/mb)^2 + (\Delta/m_b)\log(\Delta/m_b) + \ldots$$

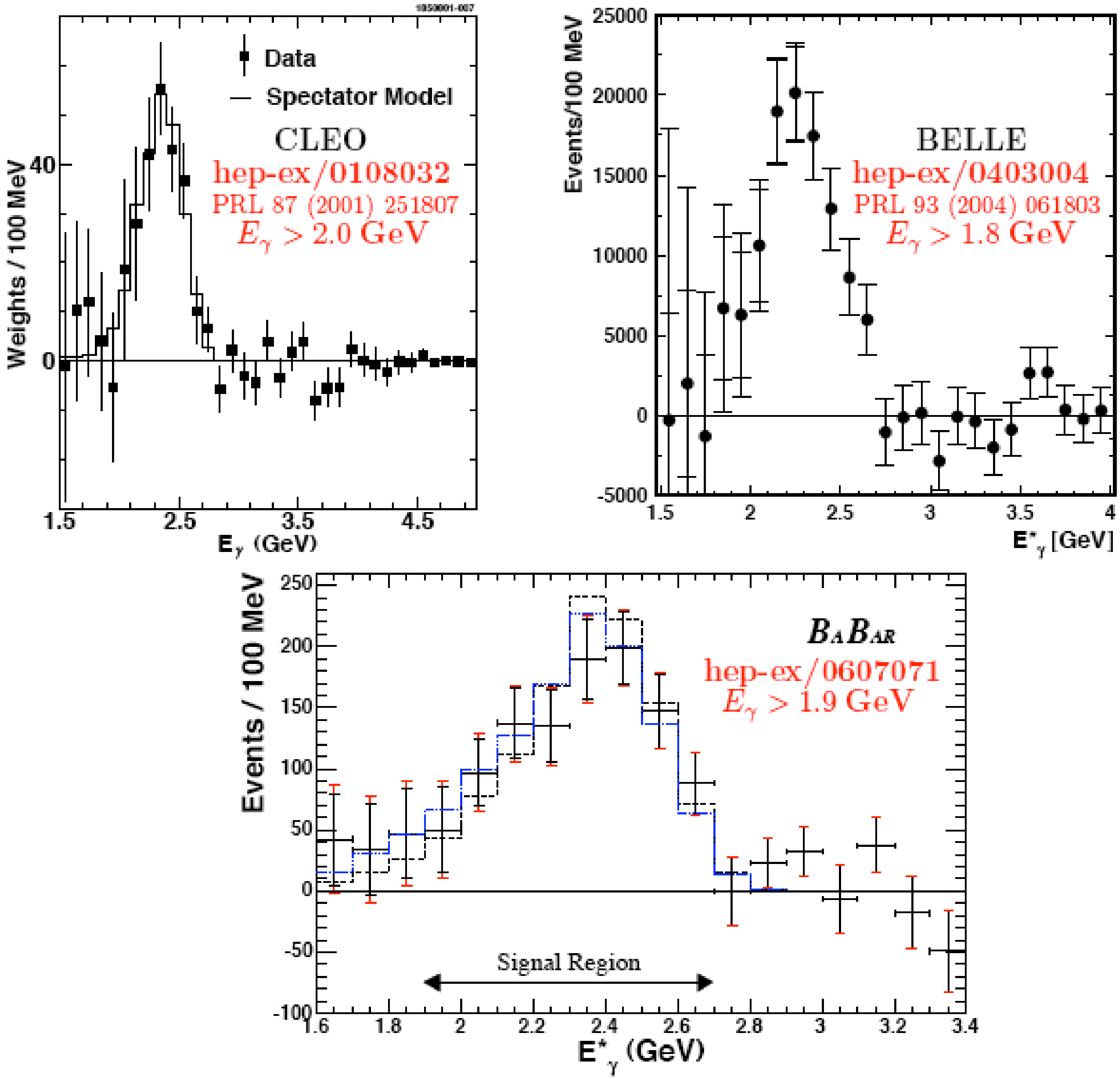
$\mathcal{O}(\alpha_s)\surd$; $\mathcal{O}(\alpha_s^2)\surd$; but not terms of $\mathcal{O}(\alpha_s^3)$

Currently known contributions $\mathcal{B}(\bar{B} \to X_s \gamma)$ that have not been included in the estimate $\underset{(\pm 7.3\%)}{(3.15 \pm 0.23)} \times 10^{-4}$ in hep-ph/0609232:

- New/old large-β_0 bremsstrahlung effects
  [Ligeti, Luke, Manohar, Wise, 1999]
  [Ferroglia, Haish, 2007, to be published] $\Rightarrow$ $+2.0\%$ in the BR
- Four-loop mixing into the $b \to sg$ operator Q_8
  [Czakon, Haisch, MM, hep-ph/0612329] $\Rightarrow$ -0.3% in the BR
- Charm mass effects in loops on gluon lines in K_{77}
  [Asatrian, Ewerth, Gabrielyan, Greub, hep-ph/0611123]
  [Czarnecki, Pak, to be published] $\Rightarrow$ $+0.3\%$ in the BR
- Charm and bottom mass effects in loops on gluon lines in the three-loop $b \to s\gamma$ matrix elements of Q_1 and Q_2
  [Boughezal, Czakon, Schutzmeier, arXiv:0707.3090] $\Rightarrow$ $+1.1\%$ in the BR
- Non-perturbative $\mathcal{O}\left(\alpha_s \frac{\Lambda}{m_b}\right)$ effects in the term $\sim C_7 C_8$
  [Lee, Neubert, Paz, hep-ph/0609224] $\Rightarrow$ -1.5% in the BR

Total: $+1.6\%$ in the BR

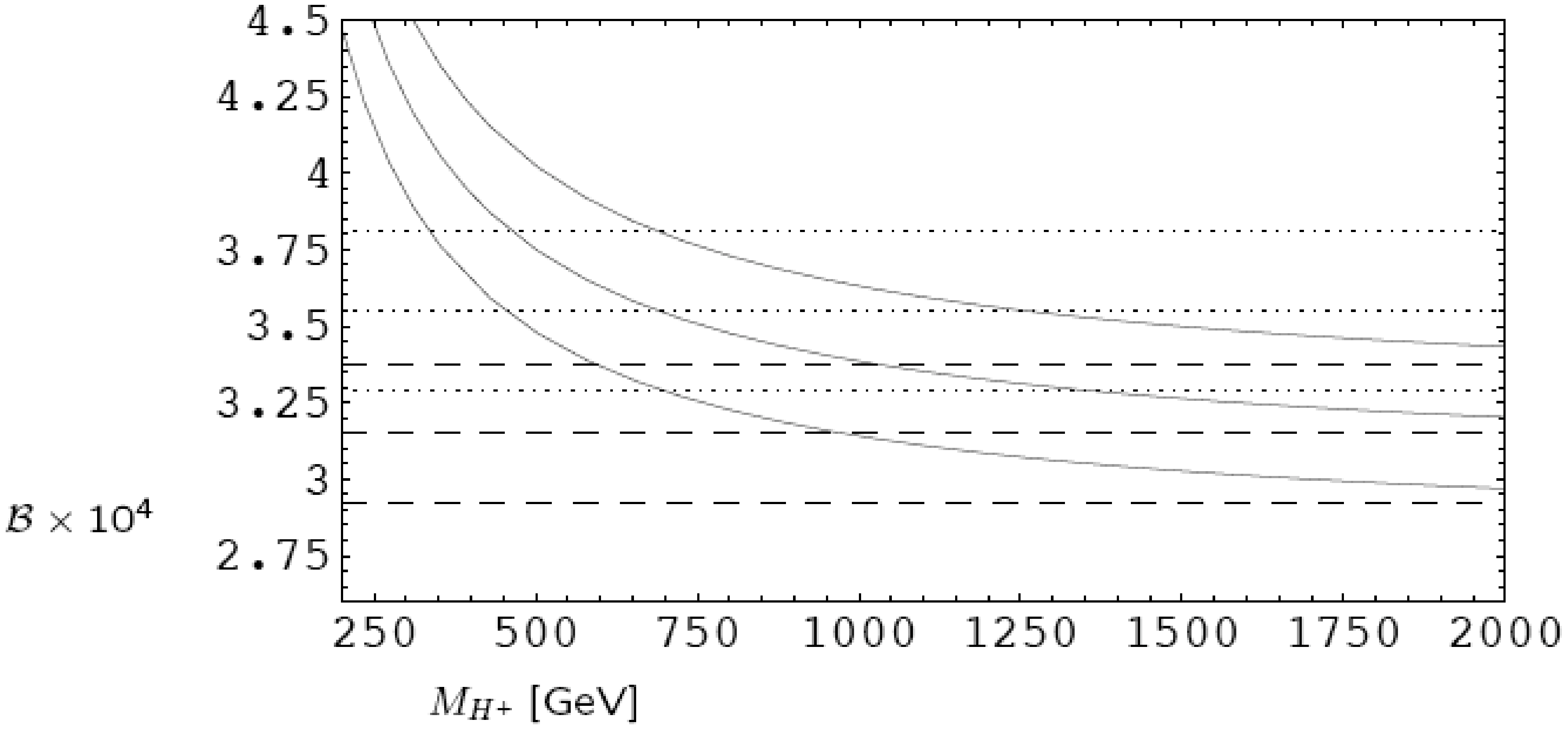
Courtesy of Mikolaj Misiak



Data
Spectator Model
CLEO
hep-ex/0108032
PRL 87 (2001) 251807
$E_\gamma > 2.0$ GeV
Weights / 100 MeV
40
0
1.5
2.5
3.5
4.5
E_γ (GeV)
BELLE
hep-ex/0403004
PRL 93 (2004) 061803
$E_\gamma > 1.8$ GeV
Events/100 MeV
25000
20000
15000
10000
5000
0
-5000
1.5
2
2.5
3
3.5
4
E^*_γ [GeV]
BABAR
hep-ex/0607071
$E_\gamma > 1.9$ GeV
Events / 100 MeV
250
200
150
100
50
0
-50
-100
1.6
1.8
2
2.2
2.4
2.6
2.8
3
3.2
3.4
Signal Region
E^*_γ (GeV)

Stringent bounds on new-physics models

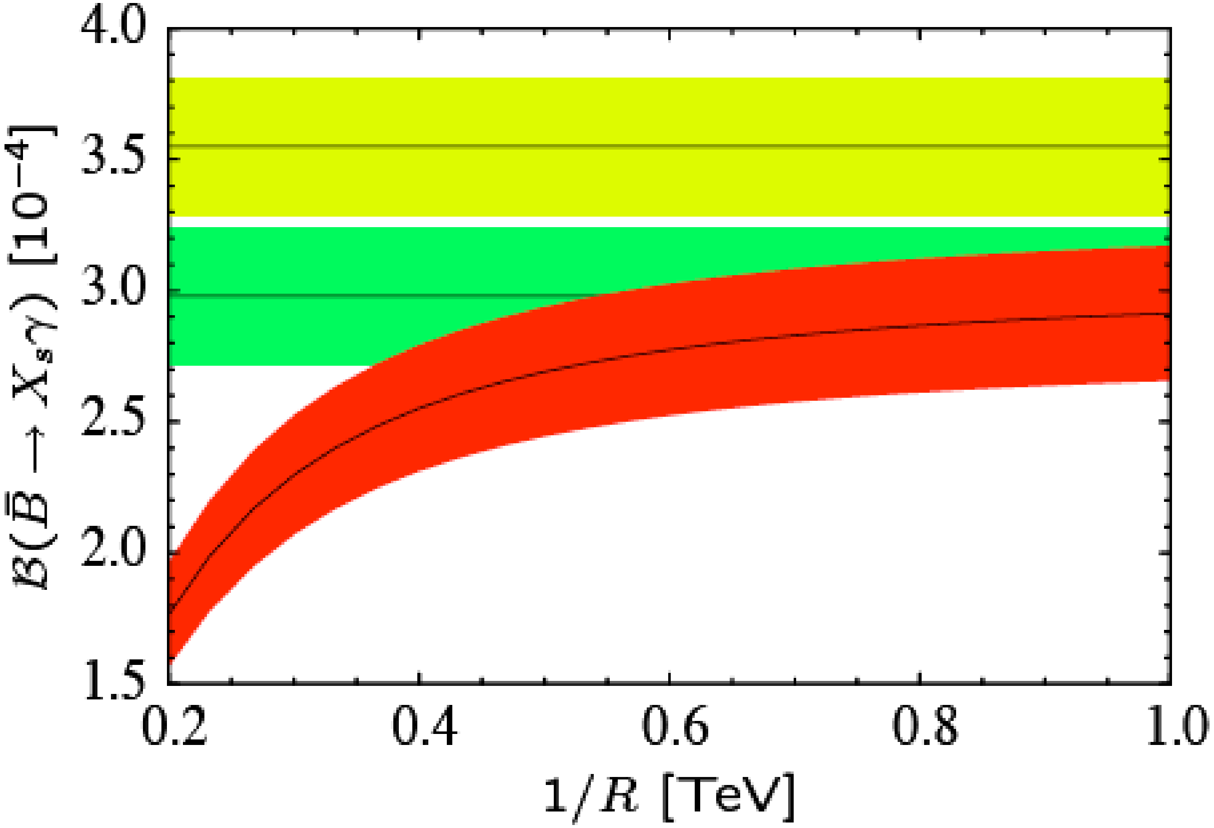
Example: Two-Higgs-Doublet Model-II at $\tan\beta = 2$: $\Rightarrow$ $M_{H+} \succ 295\text{GeV}$ at 95%CL



$\mathcal{B}(\bar{B} \to X_s\gamma)$ as a function of the charged Higgs boson mass (solid line)
Experiment/SM Theory, central values with 1σ bounds (dotted/dashed)

Misiak et al., hep-ph/0612231

Example: Bound on minimal universal extra dimensions $\Rightarrow 1/R \succ 600\text{GeV at } 95\%\text{CL}$



Red: LO-UED, Green: SM Theory, Yellow: Experiment By far best bound !

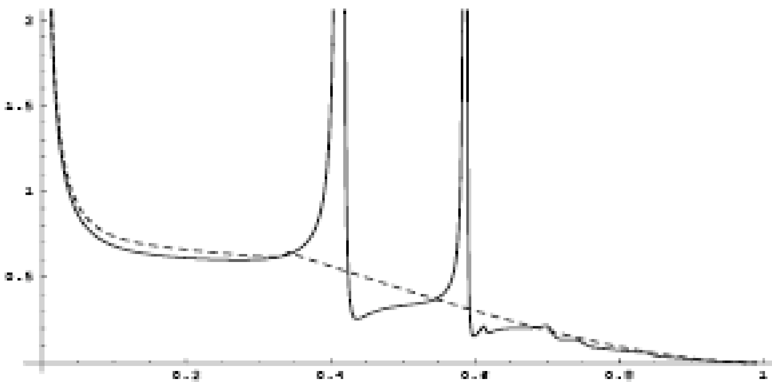
Haisch,Weiler,hep-ph/0703064

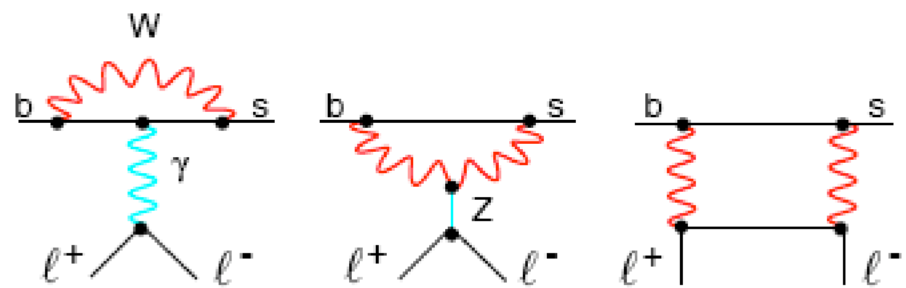
Note: Flavour non-universal boundary terms arise radiatively.

Status of the inclusive mode $\bar{B} \to X_s \ell^+ \ell^-$

- On-shell-$c\bar{c}$-resonances $\Rightarrow$ cuts in dlepton mass spectrum necessary :
  $1\mathrm{GeV}^2 < q^2 < 6\mathrm{GeV}^2$ and $14.4\mathrm{GeV}^2 < q^2$ $\Rightarrow$ perturbative contributions dominant

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





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

- 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 $q^2 \in [1GeV^2, 6GeV^2]$

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

- Further refinements:
  - Completing NNLL QCD corrections:
    Mixing into $\mathcal{O}_9$ (+1%), NNLL matrixelement of $\mathcal{O}_9$ (−4%)
  - NLL QED two-loop corrections to Wilson coefficients
    −1.5% shift for $\alpha_{em}(\mu = m_b)$, −8.5% for $\alpha_{em}(\mu = m_W)$
    Bobeth,Gambino,Gorbahn,Haisch, hep-ph/0312090
  - QED two-loop corrections to matrix elements in the low-q^2 region
    +2% effect in the low-q^2 region for muons
    Huber,Lunghi,Misiak,Wyler, hep-ph/0512066

- 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:

$$A_{\mathrm{FB}} \equiv \frac{1}{\Gamma_{semilep}} \left(\int_0^1 d(\cos\theta) \frac{d^2\Gamma}{dq^2 d\cos\theta} - \int_{-1}^0 d(\cos\theta) \frac{d^2\Gamma}{dq^2 d\cos\theta} \right)$$

(θ angle between ℓ^+ and B momenta in dilepton CMS)

$$A_{FB}(q_0^2) = 0 \quad \text{for} \quad q_0^2 \sim C_7/C_9$$

$$A_{\mathrm{FB}} \approx \left\{ -6\,\mathrm{Re}\left(\tilde{C}^{eff}_{7,FB}\tilde{C}^{*\,eff}_{10,FB}\right) - 3\hat{s}\,\mathrm{Re}\left(\tilde{C}^{eff}_{9,FB}\tilde{C}^{*\,eff}_{10,FB}\right) + A^{brems}_{FB} \right\}$$

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

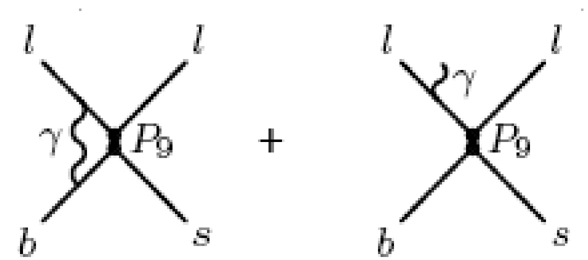
Electromagnetic corrections

- Focus on corrections to the Wilson coefficients which are enhanced by a large logarithm $\alpha_{em} Log(m_W/m_b)$

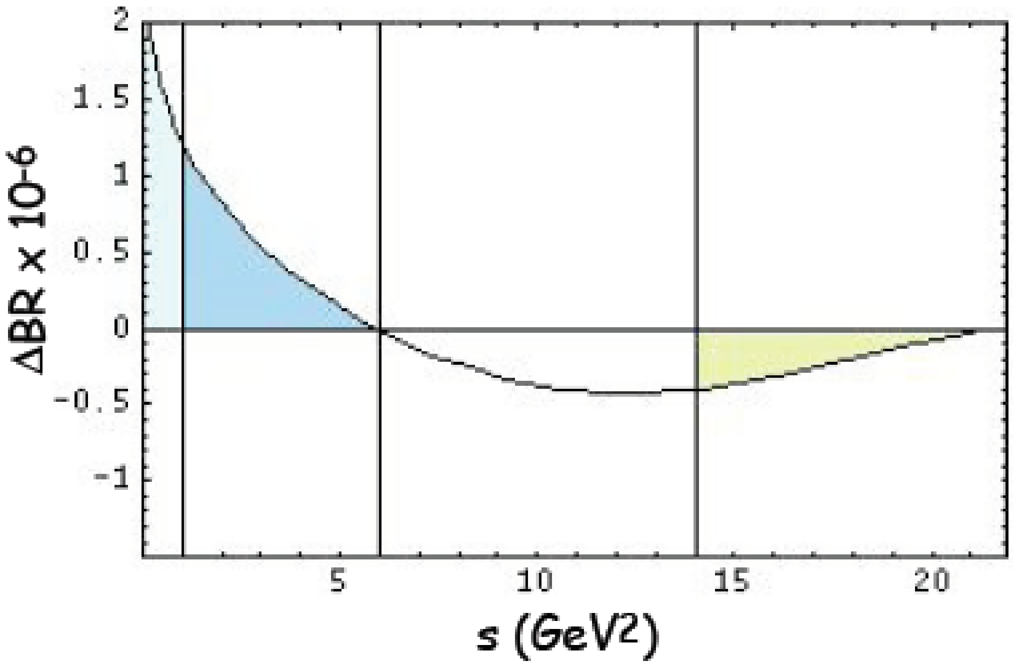
- Corrections to matrix elements lead to large collinear logarithm $Log(m_b/m_\ell)$ which survive intregration if a restricted part of the dilepton mass spectrum is considered

  – +2% effect in the low-q^2 region for muons, for the electrons the effect depends on the experimental cut parameters:
  Presence of this logarithm depends on the experimental set-up due to finite detector resolution for collinear photons. This is not a problem for muons, but for electrons in the present Babar and Belle set-up a cone of opening angle θ_c is used inside which collinear γ's are included in the reconstructed four-momentum:

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



– Note that the coefficient of this logarithm vanishes when integrated over the whole spectrum



⇒ Relative effect of this logarithm in the high-q^2 region much larger

Actually we find −8% !

Forward-backward-asymmetry

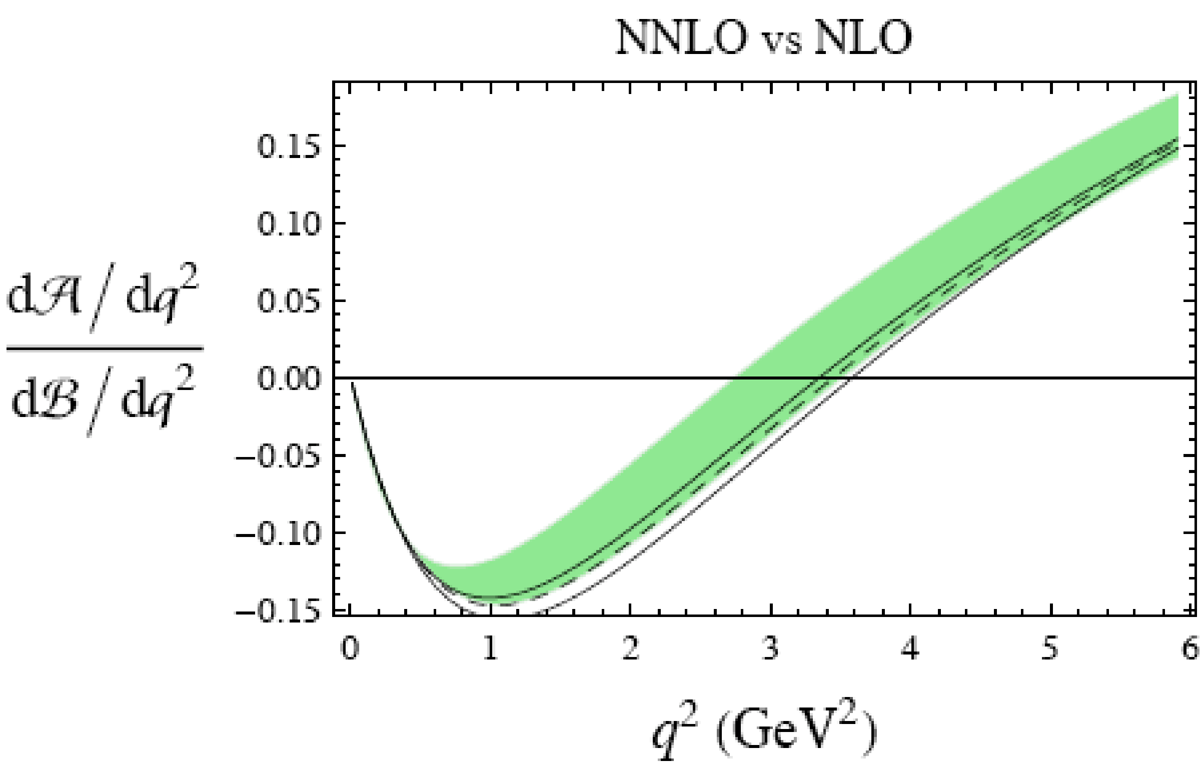
- Each of the brackets gets fully expanded in all couplings, but no overall expansion

$$[\frac{A_{FBbs\ell\ell}(q^2)}{\Gamma_u}] / [\frac{\Gamma_{bs\ell\ell}(q^2)}{\Gamma_u}]; \quad m_{b,\text{pole}} \leftrightarrow m_{b,\overline{\text{MS}}} \leftrightarrow m_{b,1\text{S}}$$

	1S	$\overline{\text{MS}}$	pole
μ	3.50	3.47	3.52
e	3.38	3.34	3.41

Large m_b scheme ambiguity of 10% of the Zero of FBA diminished.

- Residual μ-dependence also for the Zero of the AFB a good estimate of the perturbative error



Our perturbative expansion almost reach the formal N^3LO QCD accuracy

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

with $\mathcal{A}_{LO} \sim \alpha_s\ \mathcal{A}_{NLO}$ and $\mathcal{A}_{LO}^{em} \sim \alpha_s\ \mathcal{A}_{NLO}^{em}$ $\qquad \kappa = \alpha_{\rm em}/\alpha_s$

$$\begin{aligned}\mathcal{A}^2 &= \kappa^2\Big[\mathcal{A}_{LO}^2 + \alpha_s\,2\mathcal{A}_{LO}\mathcal{A}_{NLO} + \alpha_s^2\,(\mathcal{A}_{NLO}^2 + 2\mathcal{A}_{LO}\mathcal{A}_{NNLO}) \\ &\quad + \alpha_s^3\,2(\mathcal{A}_{NLO}\mathcal{A}_{NNLO} + \ldots) + \mathcal{O}(\alpha_s^4))\Big] \\ &+ \kappa^3\Big[2\mathcal{A}_{LO}\mathcal{A}_{LO}^{em} + \alpha_s\,2(\mathcal{A}_{NLO}\mathcal{A}_{LO}^{em} + \mathcal{A}_{LO}\mathcal{A}_{NLO}^{em}) \\ &\quad + \alpha_s^2\,2(\mathcal{A}_{NLO}\mathcal{A}_{NLO}^{em} + \mathcal{A}_{NNLO}\mathcal{A}_{LO}^{em} + \mathcal{A}_{LO}\mathcal{A}_{NNLO}^{em}) \\ &\quad + \alpha_s^3\,2(\mathcal{A}_{NLO}\mathcal{A}_{NNLO}^{em} + \mathcal{A}_{NNLO}\mathcal{A}_{NLO}^{em} + \ldots) + \mathcal{O}(\alpha_s^4)\Big] \\ &+ \mathcal{O}(\kappa^4)\ .\end{aligned}$$

$\mathcal{A}_{LO}\mathcal{A}_{NNNLO}$ and $\mathcal{A}_{LO}^{em}\mathcal{A}_{NNNLO}$ unknown, but can safely be neglected

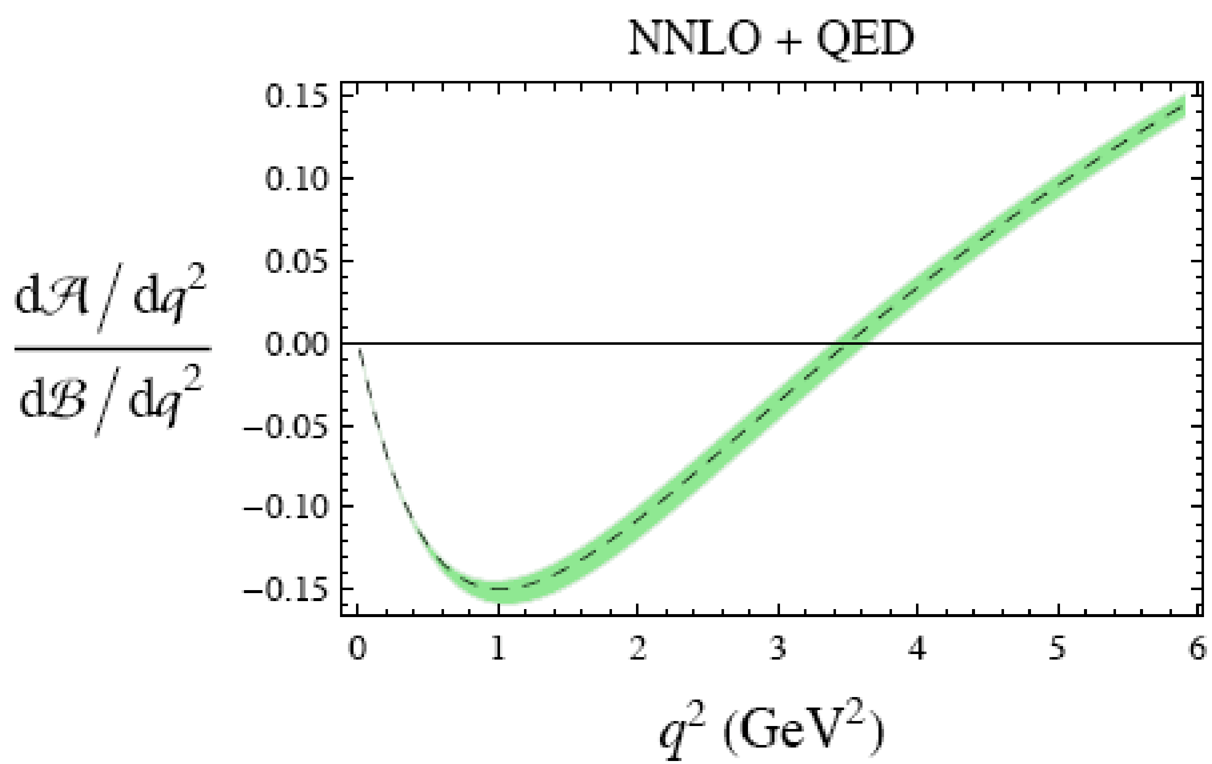
due to $\mathcal{A}_{LO} \sim \alpha_s\mathcal{A}_{NLO}$, $\mathcal{A}_{LO}^{em} \sim \alpha_s\mathcal{A}_{NLO}^{em}$ $\qquad \alpha_s\mathcal{A}_{NNNLO} \ll \mathcal{A}_{NNLO}$

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

- Zero of the forward-backward asymmetry q_0^2:

$$(q_0^2)_{\mu\mu} = \Big[3.50 \pm 0.10_{\rm scale} \pm 0.002_{m_t} \pm 0.04_{m_c,C} \pm 0.05_{m_b} \pm 0.03_{\alpha_s(M_Z)} \pm 0.001_{\lambda_1} \pm 0.01_{\lambda_2}\Big]\,{\rm GeV}^2 = (3.50 \pm 0.12)\,{\rm GeV}^2$$

$$(q_0^2)_{ee} = \Big[3.38 \pm 0.09_{\rm scale} \pm 0.002_{m_t} \pm 0.04_{m_c,C} \pm 0.04_{m_b} \pm 0.03_{\alpha_s(M_Z)} \pm 0.002_{\lambda_1} \pm 0.01_{\lambda_2}\Big]\,{\rm GeV}^2 = (3.38 \pm 0.11)\,{\rm GeV}^2$$



- Branching ratio for $1GeV < q^2 < 6GeV$ (low-q^2 region):

$$\mathcal{B}_{\mu\mu} = \Big[1.59 \pm 0.08_{\rm scale} \pm 0.06_{m_t} \pm 0.024_{C,m_c} \pm 0.015_{m_b} \pm 0.02_{\alpha_s(M_Z)} \pm 0.015_{\rm CKM} \pm 0.026_{{\rm BR}_{sl}}\Big] \times 10^{-6} = (1.59 \pm 0.11) \times 10^{-6}$$

not updated, from hep-ph/0512066

We find only a -1.3% shift in our new analysis.

Experiment: $$\mathcal{B}(\bar{B} \to X_s \ell^+ \ell^-)_{\rm low} = \begin{cases} \left(1.493 \pm 0.504^{+0.411}_{-0.321}\right) \times 10^{-6} & ({\rm Belle}) \\ (1.8 \pm 0.7 \pm 0.5) \times 10^{-6} & ({\rm BaBar}) \\ (1.60 \pm 0.50) \times 10^{-6} & ({\rm Average}) \end{cases}$$

- Branching ratio for $q^2 > 14.4GeV$ (high-q^2 region):

$$\mathcal{B}^{\rm high}_{\mu\mu} = 2.40 \times 10^{-7} \Big(1 + \left[{}^{+0.01}_{-0.02}\right]_{\mu_0} + \left[{}^{+0.14}_{-0.06}\right]_{\mu_b} \pm 0.02_{m_t} + \left[{}^{+0.006}_{-0.003}\right]_{C,m_c} \pm 0.05_{m_b} + \left[{}^{+0.0002}_{-0.001}\right]_{\alpha_s} \pm 0.002_{\rm CKM} \pm 0.02_{{\rm BR}_{sl}} \pm 0.05_{\lambda_2} \pm 0.19_{\rho_1} \pm 0.14_{f_s} \pm 0.02_{f_u}\Big) = 2.40 \times 10^{-7} \left(1^{+0.29}_{-0.26}\right)$$

Experiment: $$\mathcal{B}(\bar{B} \to X_s \ell^+ \ell^-)_{\rm high} = \begin{cases} \left(0.418 \pm 0.117^{+0.061}_{-0.068}\right) \times 10^{-6} & ({\rm Belle}) \\ \left(0.5 \pm 0.25^{+0.08}_{-0.07}\right) \times 10^{-6} & ({\rm BaBar}) \\ (0.44 \pm 0.12) \times 10^{-6} & ({\rm Average}) \end{cases}$$

- Again additional subtleties $\Rightarrow$ additional uncertainties
  - Locally: breakdown of OPE in Λ_{QCD}/m_b in the high-s (q^2) endpoint
    Partonic contribution vanishes in the limit $s \to 1$, while the $1/m_b^2$ corrections in $R(s)$ tend towards a nonzero value.

    Theoretically: s-quark propagator in the correlator of OPE:

    $$S_s(k) = \frac{\not{k} + i \not{D}}{k^2 + 2ik \cdot D - \not{D}\not{D} + i\varepsilon} \, .$$

    Endpoint region of the q^2 spectrum in $\bar{B} \to X_s l^+ l^-$ different from endpoint region of the photon spectrum of $\bar{B} \to X_s \gamma$:
    $q^2 \approx m_b^2 \approx M_B^2 \Rightarrow k \sim \Lambda, \quad k^2 \sim \Lambda^2$ $\Rightarrow$ complete breakdown of OPE
    no partial all-orders resummation possible, shape-function irrelevant
    Buchalla,Isidori

    Practically: for integrated high-s (q^2) spectrum one finds an effective expansion ($s_{\rm min} \approx 0.6$): Ghinculov,Hurth,Isidori,Yao hep-ph/0312128

    $$\int_{s_{\rm min}}^1 ds \; R(s) = \left[1 - \frac{1.6\lambda_2}{m_b^2(1-\sqrt{s_{\rm min}})^2} + \frac{1.8\rho_1 + 1.7 f_1}{m_b^3(1-\sqrt{s_{\rm min}})^3} \right] \times \int_{s_{\rm min}}^1 ds \;\; R(s)|_{m_b \to \infty}$$

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

Numerical results Huber, Hurth, Lunghi

$$\begin{aligned}
\mathcal{R}(s_0)^{\rm high}_{\mu\mu} &= 2.29 \times 10^{-3}\Big(1 \pm 0.04_{\rm scale} \pm 0.02_{m_t} \pm 0.01_{C,m_c} \pm 0.006_{m_b} \pm 0.005_{\alpha_s} \pm 0.09_{\rm CKM} \\
&\quad \pm 0.003_{\lambda_2} \pm 0.05_{\rho_1} \pm 0.03_{f_u^0+f_s} \pm 0.05_{f_u^0-f_s}\Big) \\
&= 2.29 \times 10^{-3}(1 \pm 0.13)
\end{aligned}$$

- Hadronic invariant-mass cut is imposed in order to eliminate the background like $b \to c\,(\to se^+\nu)e^-\bar{\nu} = b \to se^+e^- +$ missing energy
  - Babar,Belle: $m_X < 1.8$ or $2.0 GeV$
  - high-q^2 region not affected by this cut
  - kinematics: X_s is jetlike and $m_X^2 \leq m_b \Lambda_{QCD}$ $\Rightarrow$ shape function region
  - SCET analysis: universality of jet and shape functions found:
    the 10-30% reduction of the dilepton mass spectrum can be accurately computed using the $\bar{B} \to X_s\gamma$ shape function
    (5% additional uncertainty due to subleading shape functions)
    Lee,Stewart, hep-ph/0511334;
    Lee,Ligeti,Stewart,Tackmann, hep-ph/0512191

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

Some remarks:

- Model-independent analysis of $b \to s\ell^+\ell^-$ and $b \to s\gamma$:

  * Global fit to the Wilson coefficients C_7, C_9, C_{10}
  $\Rightarrow$ Determines magnitude + sign of these coefficients

  * In MFV the sign of C_7 is already fixed by $b \to s\ell^+\ell^-$ data

- Experimental issues in $b \to s\ell^+\ell^-$:

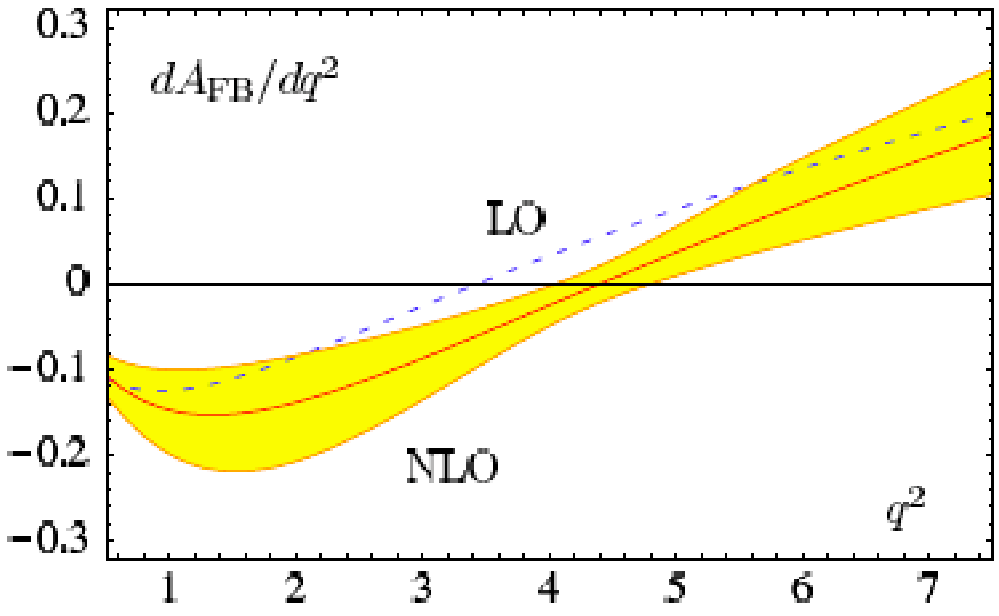
  * End of Babar and Belle (1/ab) 15% accuracy possible
  * LHCb: only semi-inclusive analysis possible without the π_0 modes

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

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

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

Focus on ratios of exclusive modes like FBA in $B \to K^* \ell^+ \ell^-$



- At LO the zero depends on the short-distance Wilson coefficients only because the formfactor dependence cancels out:

$$q_0^2 = q_0^2(C_7, C_9), \quad q_0^2 = (3.4 + 0.6 - 0.5) GeV^2 \quad \text{(LO)}$$

- NLO contribution calculated within QCD factorization approach leads to a large shift: Beneke,Feldmann,Seidel,hep-ph/0412400

$$q_0^2 = (4.39 + 0.38 - 0.35) GeV^2 \quad \text{(NLO)}$$

- Issue of power corrections ($1/m_b$) !

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: $10 fb^{-1} \to 100 fb^{-1}$

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.

Exclusive Zero:

Theoretical error: $9\% + O(\Lambda/m_b)$ uncertainty

Experimental error at SLHC: 2.1% Libby

Inclusive Zero:

Theoretical error: $O(5\%)$

Experimental error at SFF: $4-6\%$ arXiv:0710.3799[hep-ph]

5 meetings between 11/2005 and 3/2007, Yellow Report to appear

see http://mlm.home.cern.ch/mlm/FlavLHC.html **This week !!**

Goals of the workshop

- to outline and document a programme for flavour physics for the next decade,
- to discuss new experimental proposals in flavour physics,
- to address the complementarity and synergy between the LHC and the flavour factories in our search for new physics.

Follow-up workshop:

Working Group on the Interplay Between Collider and Flavour Physics

The working group addresses the complementarity and synergy between the LHC and the flavour factories within the new physics search. New collaborations on this topic were triggered by the two recent CERN workshop series Flavour in the Era of the LHC and CP Studies and Non–Standard Higgs Physics at the border line of collider and flavour physics and experiment and theory. This follow–up working group wants to provide a continuous framework for such collaborations and trigger new research work in this direction. Regular meetings at CERN (well–connected by VRVS) are planned in the near future.

https://twiki.cern.ch/twiki/bin/view/Main/ColliderAndFlavour

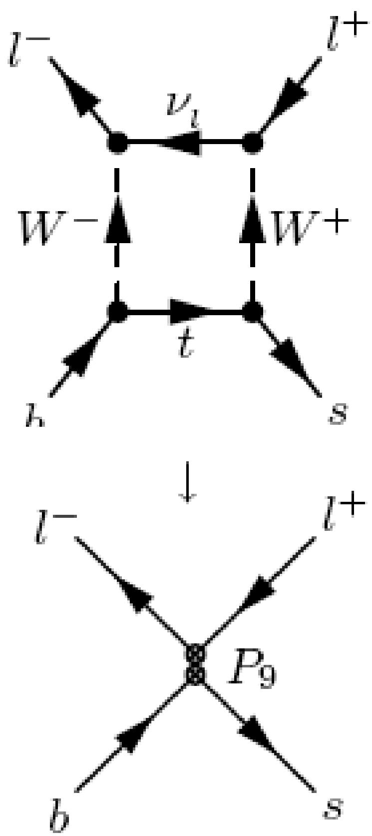
Kick-off meeting 3.-4.December 2007 at CERN

http://indico.cern.ch/conferenceDisplay.py?confId=22180

Extra

Effective Lagrangean

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



C_i: Wilson Coefficients

scale dependent effective couplings, process independent

$C_i(\mu_W)$ obtained by matching on full theory

$C_i(\mu_b)$ obtained by solving perturbatively

the RGE $\quad \mu \frac{d}{d\mu}\vec{C}(\mu) = \hat{\gamma}^T(\mu)\, \vec{C}(\mu)$

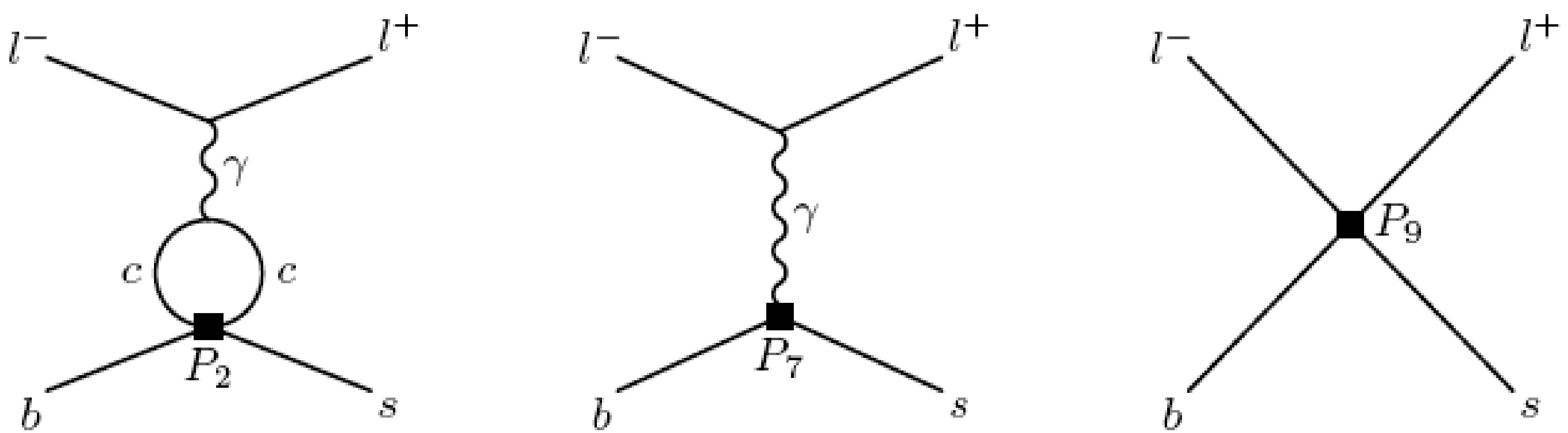
$\vec{C}(\mu_b) = \hat{R}\, \vec{C}(\mu_W)$

Effective Operators

$$P_1 = (\bar{s}_L\gamma_\mu T^a c_L)(\bar{c}_L\gamma^\mu T^a b_L), \quad P_4 = (\bar{s}_L\gamma_\mu T^a b_L)\sum_q(\bar{q}\gamma^\mu T^a q),$$
$$P_2 = (\bar{s}_L\gamma_\mu c_L)(\bar{c}_L\gamma^\mu b_L), \quad P_5 = (\bar{s}_L\gamma_\mu\gamma_\nu\gamma_\sigma b_L)\sum_q(\bar{q}\gamma^\mu\gamma^\nu\gamma^\sigma q),$$
$$P_3 = (\bar{s}_L\gamma_\mu b_L)\sum_q(\bar{q}\gamma^\mu q), \quad P_6 = (\bar{s}_L\gamma_\mu\gamma_\nu\gamma_\sigma T^a b_L)\sum_q(\bar{q}\gamma^\mu\gamma^\nu\gamma^\sigma T^a q),$$

$$P_7 = \frac{e}{16\pi^2} m_b(\bar{s}_L\sigma^{\mu\nu} b_R)F_{\mu\nu}, \quad P_9 = (\bar{s}_L\gamma_\mu b_L)\sum_l(\bar{l}\gamma^\mu l),$$
$$P_8 = \frac{g}{16\pi^2} m_b(\bar{s}_L\sigma^{\mu\nu} T^a b_R)G^a_{\mu\nu}, \quad P_{10} = (\bar{s}_L\gamma_\mu b_L)\sum_l(\bar{l}\gamma^\mu\gamma_5 l),$$

$$P_{3Q} = (\bar{s}_L\gamma_\mu b_L)\sum_q Q_q(\bar{q}\gamma^\mu q),$$
$$P_{4Q} = (\bar{s}_L\gamma_\mu T^a b_L)\sum_q Q_q(\bar{q}\gamma^\mu T^a q),$$
$$P_{5Q} = (\bar{s}_L\gamma_\mu\gamma_\nu\gamma_\sigma b_L)\sum_q Q_q(\bar{q}\gamma^\mu\gamma^\nu\gamma^\sigma q),$$
$$P_{6Q} = (\bar{s}_L\gamma_\mu\gamma_\nu\gamma_\sigma T^a b_L)\sum_q Q_q(\bar{q}\gamma^\mu\gamma^\nu\gamma^\sigma T^a q),$$
$$P_b = \frac{1}{12}\left[(\bar{s}_L\gamma_\mu\gamma_\nu\gamma_\sigma b_L)(\bar{b}\gamma^\mu\gamma^\nu\gamma^\sigma b) - 4(\bar{s}_L\gamma_\mu b_L)(\bar{b}\gamma^\mu b)\right]$$



Input parameters

$\alpha_s(M_z) = 0.1189 \pm 0.0010$ [38]	$m_e = 0.51099892$ 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
$\lvert V_{ts}V_{tb}/V_{cb}\rvert^2 = 0.962 \pm 0.002$ [39]	$m_c(m_c) = (1.224 \pm 0.017 \pm 0.054)$ GeV [40]
$\lvert V_{ts}V_{tb}/V_{ub}\rvert^2 = (1.28 \pm 0.12) \times 10^2$ [39]	$m_b^{1S} = (4.68 \pm 0.03)$ GeV [29]
$BR(B \to X_c e\bar{\nu})_{\rm exp} = 0.1061 \pm 0.0017$ [41]	$m_{t,\rm pole} = (170.9 \pm 1.8)$ GeV [42]
$M_Z = 91.1876$ GeV	$m_B = 5.2794$ GeV
$M_W = 80.426$ GeV	$C = 0.58 \pm 0.01$ [29]
$\lambda_2^{\rm eff} = (0.12 \pm 0.02)$ GeV^2	$\rho_1 = (0.06 \pm 0.06)$ GeV^3 [29]
$\lambda_1^{\rm eff} = (-0.243 \pm 0.055)$ GeV^2 [40]	$f_u^0 + f_s = (0 \pm 0.2)$ GeV^3 [24]
$f_u^0 - f_s = (0 \pm 0.04)$ GeV^3 [24]	$f_u^\pm = (0 \pm 0.4)$ GeV^3 [24]

Extra Extra

- Mixing-induced CP asymmetries in $b \to s\gamma$ transitions
  - General folklore: within the SM are small, $O(m_s/m_b)$

$$\mathcal{O}_{7L} \equiv \frac{e}{16\pi^2} m_b \, \bar{s}\sigma_{\mu\nu} P_R \, b F^{\mu\nu} \quad \mathcal{O}_{7R} \equiv \frac{e}{16\pi^2} m_{s/d} \, \bar{s}\sigma_{\mu\nu} P_L \, b F^{\mu\nu} \; .$$

Mainly: $\bar{B} \to X_s \gamma_L$ and $B \to X_s \gamma_R$ $\Rightarrow$ almost no interference in the SM

  - But: within the inclusive case the assumption of a two-body decay is made, the argument does not apply to $b \to s\gamma gluon$
    Corrections of order $O(\alpha_s)$, mainly due operator $\mathcal{O}_2$ $\Rightarrow \Gamma_{22}^{\rm brems}/\Gamma_0 \sim 0.025$
    $\Rightarrow$ 11% right-handed contamination
    Grinstein,Grossman,Ligeti,Pirjol, hep-ph/0412019
  - QCD sum rule estimate of the time-dependent CP asymmetry in $B^0 \to K^{*0}\gamma$ including long-distance contributions due to soft-gluon emission from quark loops versus dimensional estimate of the nonlocal SCET operator series:
    Ball,Zwicky,hep-ph/0609037 $\leftrightarrow$ Grinstein,Pirjol,hep-ph/0510104

$$S = -0.022 \pm 0.015^{+0}_{-0.01}, \; S^{sgluon} = -0.005 \pm 0.01 \leftrightarrow |S^{sgluon}| \approx 0.06$$

Note: Expansion parameter is Λ_{QCD}/Q where Q is the kinetic energy of the hadronic part. There is no contribution at leading order. Therefore, the effect is expected to be larger for larger invariant hadronic mass, thus, the K^* mode has to have the smallest effect, below the 'average' 10%

Experiment: $S = -0.28 \pm 0.26$

- Untagged direct CP asymmetries in $b \to s/d$ transitions

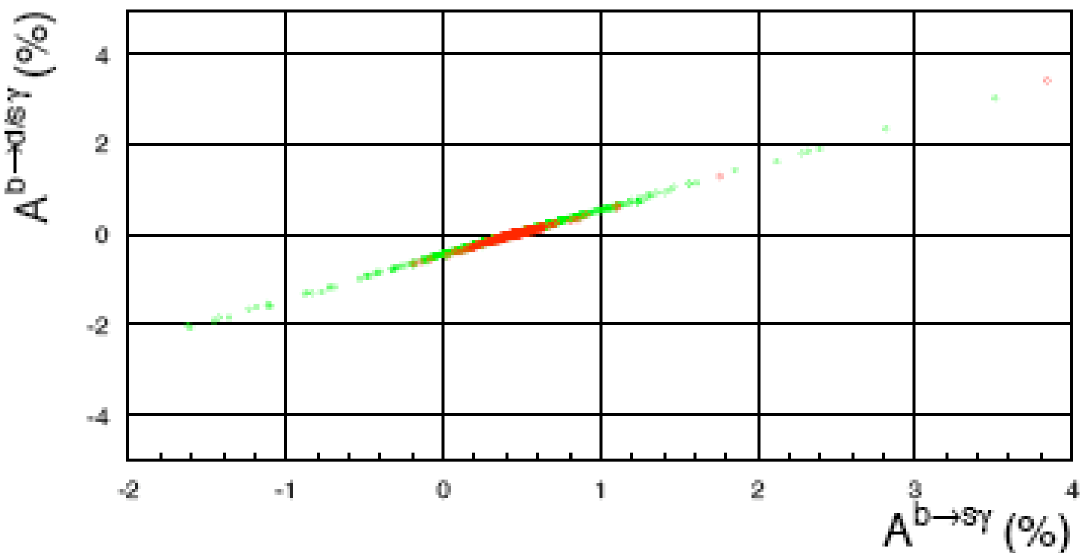
  KM mechanism CKM unitarity + U spin symmetry of matrix elements $d \leftrightarrow s$:

$$|\Delta BR_{CP}(B \to X_s\gamma) + \Delta BR_{CP}(B \to X_d\gamma)| \sim 1 \cdot 10^{-9} \approx 0$$

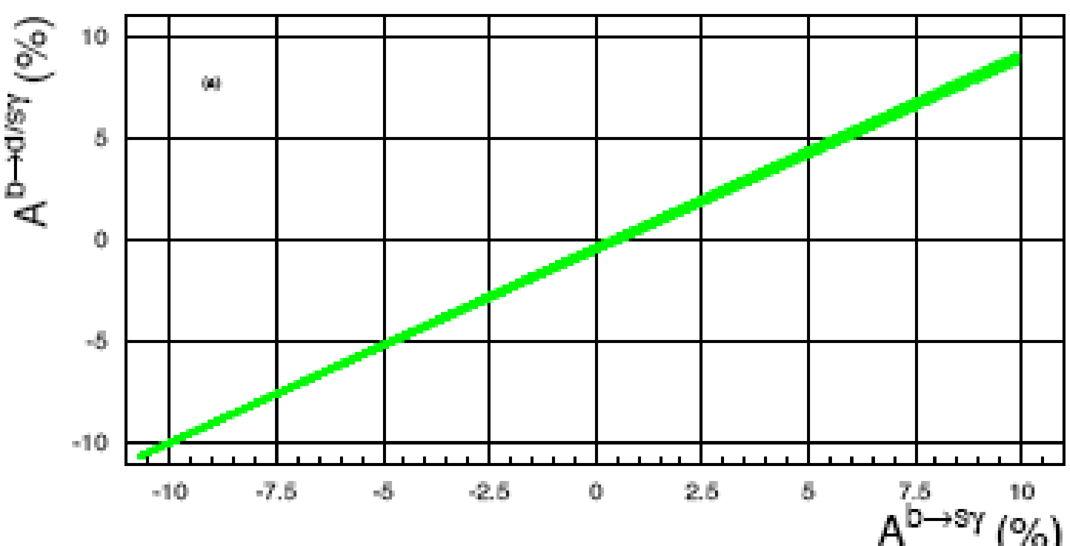
  Clean test, whether new CP phases are active or not

  Hurth,Mannel,hep-ph/0109041; Hurth,Lunghi,Porod,hep-ph/0312260

  Experiment: (Super-) B-factories ±3% (±0.3%) precision possible



MFV with (flavourblind) phases



Model-independent analysis C_7^s;

Null test: Untagged CP asymmetries in $b \to (s+d)$ transitions Hurth, Mannel

$$\Delta\Gamma_{CP}(B \to X_{s+d}\gamma) = \Gamma(\bar{B} \to X_{s+d}\gamma) - \Gamma(B \to X_{\bar{s}+\bar{d}}\gamma)$$

KM mechanism CKM unitarity

$\Rightarrow\ J = \mathrm{Im}(\lambda_u^{(s)}\lambda_c^{(s)*}) = (-1)\ \mathrm{Im}(\lambda_u^{(d)}\lambda_c^{(d)*})$

+ U spin symmetry of matrix elements $d \leftrightarrow s$:

$$\Delta\Gamma_{CP}(B \to X_{s+d}\gamma) = b_{inc}\Delta_{inc}$$

b_{exc}: 'relative U-spin-breaking'; Δ_{exc}: 'typical size' of CP violating rate difference

$|b_{inc}| \sim m_s^2/m_b^2 \sim 5 \cdot 10^{-4}$ (also in $1/m_b^2$ and in $1/m_c^2$ corrections)

$$|\Delta\mathcal{B}_{CP}(B \to X_{s+d}\gamma)| \sim 1 \cdot 10^{-9} \approx 0$$

Very clean test, whether new CP phases are active or not

Experiment: (Super-) B factory $\pm 3\%$ ($\pm 0.4\%$) precision possible

Analysis in MFV (upper bound 4%) and in uMSSM (10%) Hurth,Lunghi,Porod