# Superb Opportunities in the Mode $b \to s\gamma$

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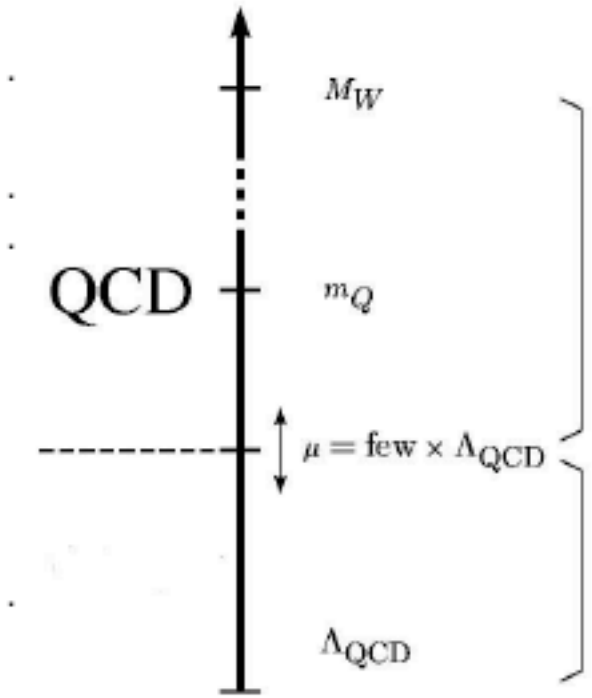
SuperB Physics Workshop, Warwick, 14.-17.4.2009

# How to separate new physics effects from hadronic uncertainities?




short-distance physics
perturbative

long-distance physics
nonperturbative

Operator product expansion: Factorization of short- and long-distance physics

- $\mu^2 \approx M_W^2$ : $C_i$: effective couplings, $< \mathcal{O}_i >$: matrix elements

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

- $\Lambda_{QCD} << m_Q = m_b$ : $1/m_b$ expansion allows for separation of effects
  $\mu^2 \approx m_b^2, m_b\Lambda_{QCD}$ $\Rightarrow$ effective theories (HQET, SCET)

- $\mu^2 \approx \Lambda_{QCD}^2$ : long-distance hadronic parameters (lattice-QCD , U-spin symmetry, QCD sum rules, chiral perturbation theory, ... )

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

## Factorization theorems: separating long- and short-distance physics

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

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

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

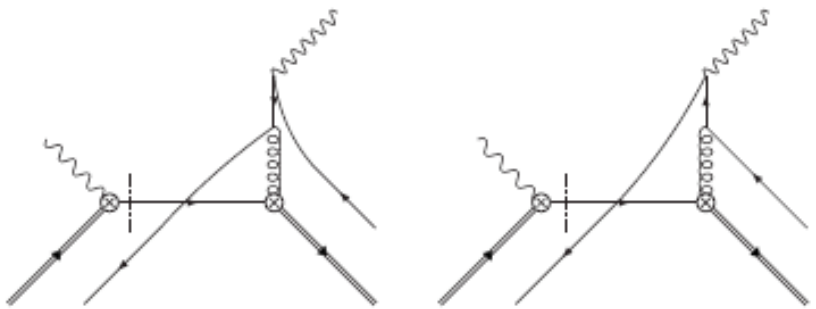
No linear term $\Lambda_{QCD}/m_b$ (perturbative contributions dominant)

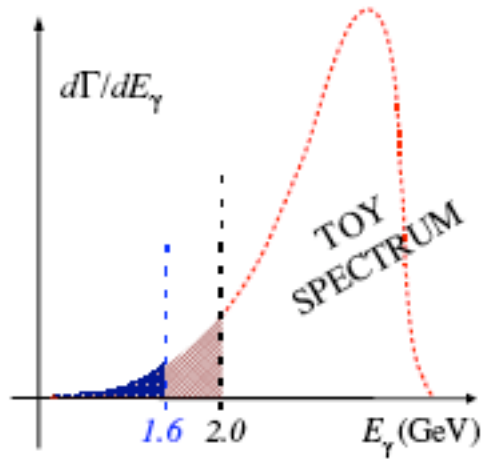
– More sensitivities to nonperturbative physics due to kinematical cuts: shape functions; multiscale OPE (SCET) with $\Delta = m_b - 2E_\gamma^0$

Becher,Neubert,hep-ph/0610067

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

Lee,Neubert,Paz,hep-ph/0609224





- QCD factorization/SCET analysis for exclusive decays with fast light particles in final state; for example $B \to K\pi$:

$$\langle \pi K | Q_i | B \rangle = F_0^{B\to\pi}\, T^{\rm I}_{K,i} * f_K \Phi_K + F_0^{B\to K}\, T^{\rm I}_{\pi,i} * f_\pi \Phi_\pi + T^{\rm II}_i * f_B \Phi_B * f_K \Phi_K * f_\pi \Phi_\pi + O(\Lambda/m_b)$$

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

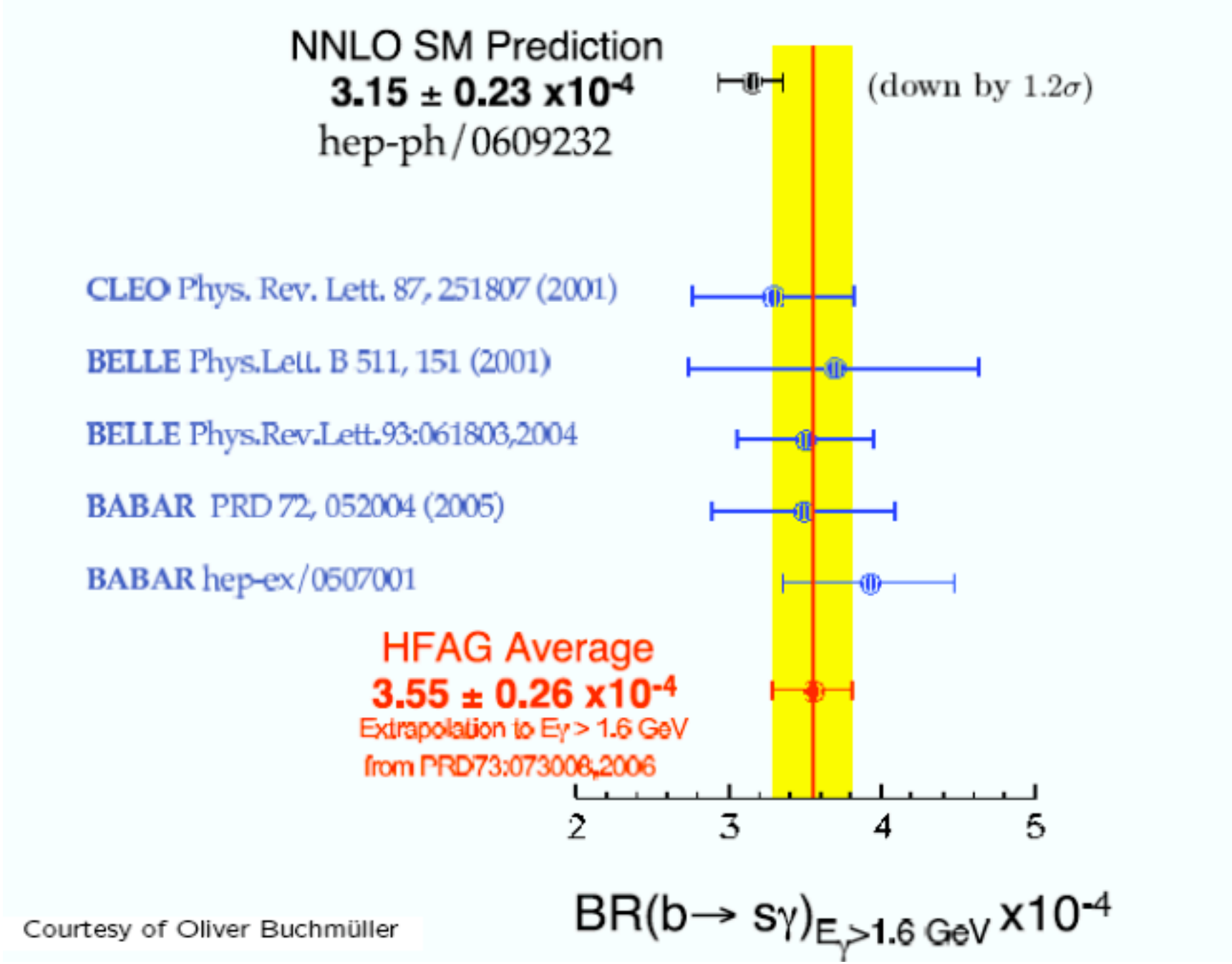
  - Relations between formfactors in large-energy limit

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

Phenomenologically highly relevant issue:

general strategy of LHCb to look at ratios of exclusive modes

- Inclusive $b \to s\gamma$ branching ratio




Courtesy of Oliver Buchmüller

- Belle $(E_0 = 1.7\text{GeV}, 605 fb^{-1}) \Rightarrow \text{BR}(1.6\text{GeV}) = (3.52 \pm 0.23 \pm 0.09) \times 10^{-4}$

HFAG

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

- New/old large-$\beta_0$ 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

- The semileptonic phase factor:

$$\mathrm{BR}_\gamma(E_0) \equiv \mathrm{BR}[B \to X_s\gamma]_{E_\gamma > E_0} = \frac{\mathrm{BR}_{c\ell\nu}}{C}\left(\frac{\Gamma[B \to X_s\gamma]_{E_\gamma > E_0}}{|V_{cb}/V_{ub}|^2\,\Gamma[B \to X_u e\bar{\nu}]}\right)$$

$$C = \left|\frac{V_{ub}}{V_{cb}}\right|^2 \frac{\Gamma[\bar{B}\to X_c e\bar{\nu}]}{\Gamma[\bar{B}\to X_u e\bar{\nu}]} = \begin{cases} 0.582 \pm 0.016, \\ 0.546^{+0.023}_{-0.033}, \end{cases}$$

1S scheme has to be updated!
Trott et al.,hep-ph/0408002
kinetic scheme
Gambino,Giordano,arXiv:0805.0271

Enhancement of $\mathrm{BR}_\gamma$ in kinematic scheme

+4.8%!? $\frac{\delta}{\delta m_c} Pert(E_0) \prec 0$, $\bar{m}_c(\bar{m}_c)_{1S} \prec \bar{m}_c(\bar{m}_c)_{kinetic}$

- Multiscale OPE: Becher,Neubert,hep-ph/0610067

| Misiak et al. | $\mathrm{BR}_\gamma$(1GeV) | $\mathrm{BR}_\gamma$(1.6GeV) |
|---|---|---|
| hep-ph/0609232 'fixed order' | $3.27\ \ 10^{-4}$ | $(3.15\pm0.23)\,10^{-4}$ |
| hep-ph/0610067 multisc. OPE | $3.27\ \ 10^{-4}$ (adapted from above) | $(2.98\pm0.26)\,10^{-4}$ |

without $-1.5\%$ of $\mathcal{O}(\alpha_s\Lambda/m_b)$
$3.05\ \ 10^{-4}$

## Ongoing discussion on cut-effects

Misiak,talk at HQL,Melbourne,arXiv:0808

- 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 $\Delta$ needed to connect the shape function and the local OPE region.

  – Using SCET, effects at the 3%-level found not by power corrections $\Lambda_{QCD}/\Delta$, 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.

$$\text{const.} + \log(\Delta/m_b) + \log^2(\Delta/m_b) + \ldots$$
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 $\mathcal{O}(\alpha_s^3)$

- 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 $\mathcal{O}_2 \Rightarrow \Gamma_{22}^{\text{brems}}/\Gamma_0 \sim 0.025$
    $\Rightarrow$ 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 $\Lambda_{QCD}/Q$ 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: $S = -0.28 \pm 0.26$
    $\Delta S = 0.02 - 0.03$ (Super B sensitivity)

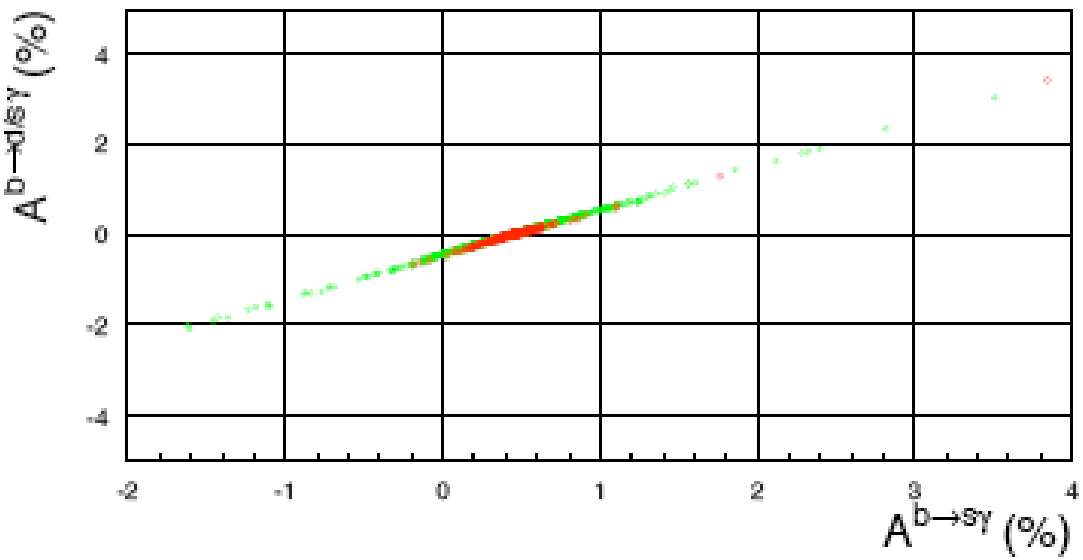
    Browder,Ciuchini,Gershon,Hazumi,Hurth,Okada,Stocchi,arXiv:0710.3799

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

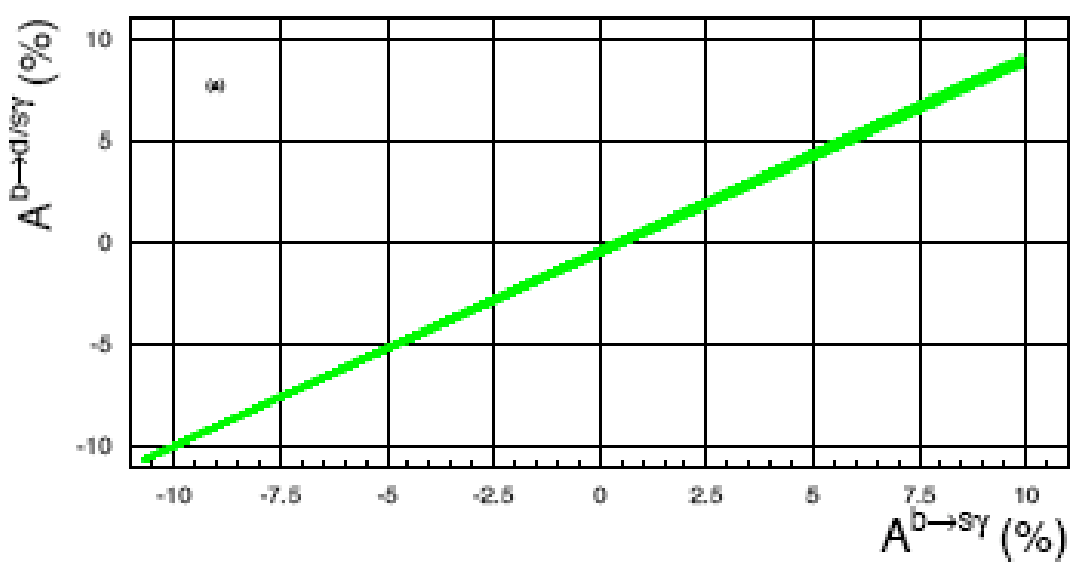
  KM mechanism CKM unitarity + U spin symmetry of matrix elements $d \leftrightarrow s$:

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

  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 $C_7^s$

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

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 $d \leftrightarrow s$:

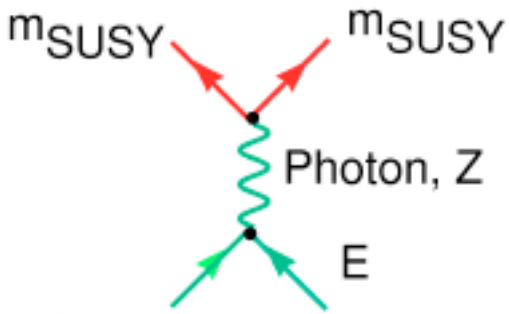
$$\Delta\Gamma_{CP}(B \to X_{s+d}\gamma) = b_{inc}\Delta_{inc}$$

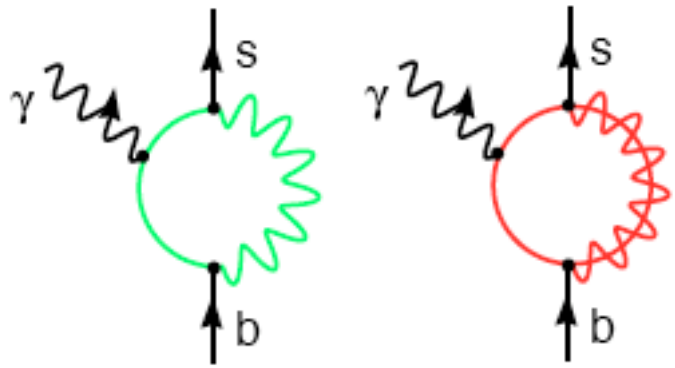
$b_{exc}$: 'relative U-spin-breaking'; $\Delta_{exc}$: 'typical size' of CP violating rate difference

$|b_{inc}| \sim m_s^2/m_b^2 \sim 5 \cdot 10^{-4}$ (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




The indirect information will be most valuable when the general nature of new physics will be identified in the direct search.

Immense potential for synergy and complementarity between high-$p_T$ and flavour physics within the search for new physics

Flavour@high-$p_T$

⇒ CERN workshop on the interplay of flavour and collider physics
Fleischer,Hurth,Mangano see http://mlm.home.cern.ch/mlm/FlavLHC.html


5 meetings between 11/2005 and 3/2007 Yellow Report

arXiv:0801.1800 [hep-ph] "Collider aspects of flavour physics at high Q"

arXiv:0801.1833 [hep-ph] "B, D and K decays"

arXiv:0801.1826 [hep-ph] "Flavour physics of leptons and dipole moments"

published in EPJC 57 (2008) 1-492

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**

Recent meeting 16.-18. of March 2009 at CERN

Next meeting 14.-16. of December 2009 at CERN

Please feel cordially invited !