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Kloster Banz
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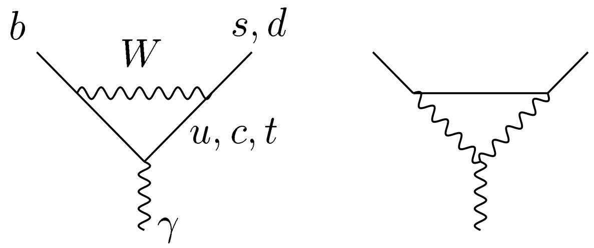
Radiative Corrections to Radiative B Decays:

Exclusive $B \to V\gamma$ at NLO

S. Bosch, G.B.

Introduction



- $b \to s\gamma$, $b \to d\gamma$ probe flavour physics at loop level

$$B(B \to X_s\gamma) = (3.23 \pm 0.42) \cdot 10^{-4}$$

(CLEO, ALEPH, BELLE, BABAR)

$$B(B^0 \to K^{*0}\gamma) = (4.44 \pm 0.35) \cdot 10^{-5}$$

$$B(B^\pm \to K^{*\pm}\gamma) = (3.82 \pm 0.47) \cdot 10^{-5}$$

$$B(B^0 \to \rho^0\gamma) < 1.4 \cdot 10^{-6}$$

$$B(B^\pm \to \rho^\pm\gamma) < 2.3 \cdot 10^{-6}$$

(CLEO, BELLE, BABAR)

- inclusive $b \to s\gamma$: HQE, perturbative QCD (NLO)
  Adel, Yao; Chetyrkin, Misiak, Münz; Greub, Hurth, Wyler

exclusive $B \to V\gamma$

experiment: easier, theory: harder

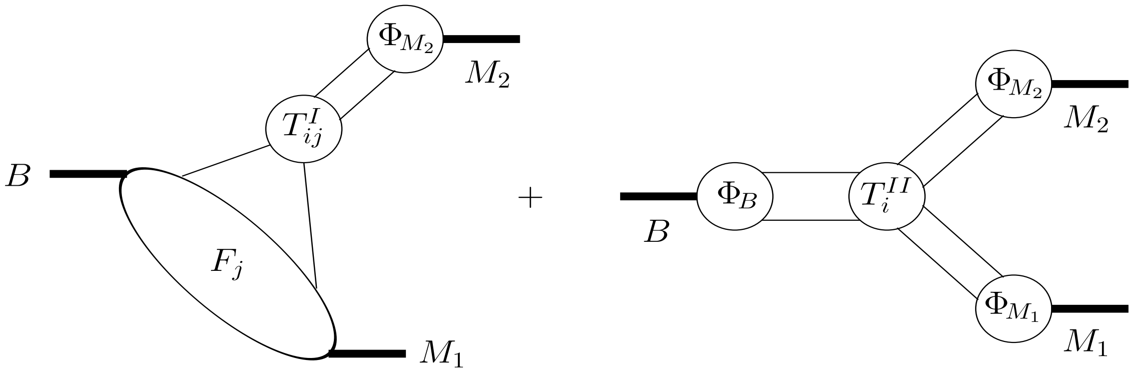
- test case for theory of exclusive hadronic B decay
- probing $b \to d\gamma$ via $B \to \rho\gamma$

Exclusive Nonleptonic B Decays in QCD

$B \to D\pi$, $B \to \pi\pi$, $B \to \pi K$

Stech et al.; Bjorken; Szczepaniak et al.; Dugan, Grinstein

problem:matrix elements $\langle Q_i \rangle$: $\langle \pi\pi | (\bar{u}b)_{V-A} (\bar{d}u)_{V-A} | B \rangle$



Politzer, Wise
Beneke, G.B., Neubert, Sachrajda
Bauer, Fleming, Pirjol, Stewart

- $\Lambda_{QCD}/m_b \ll 1 \to$ power counting $\to$ leading power

- light-cone dynamics
  $\langle \pi(p) | u(0) \bar{d}(z) | 0 \rangle = \frac{i f_\pi}{4} \gamma_5 \not{p} \int_0^1 dx \; e^{ixpz} \; \Phi_\pi(x)$

- colour transparency

- short-distance $\leftrightarrow$ long-distance (soft, collinear) separation: factorization formula

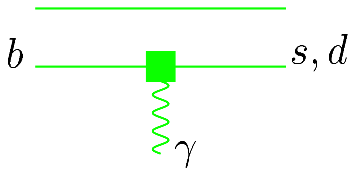
$B \to V\gamma$: Overview

Beneke, Feldmann, Seidel
Bosch, G.B.
Ali, Parkhomenko

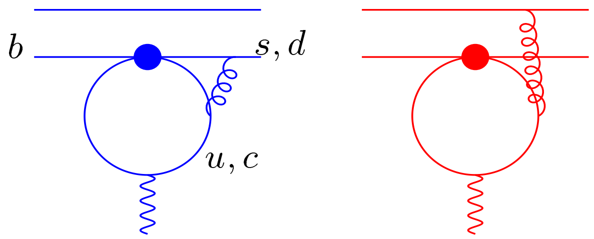
$$\mathcal{H}_{eff} = \frac{G_F}{\sqrt{2}} \sum_{p=u,c} V^*_{ps} V_{pb} \left[C_1 Q_1^p + C_2 Q_2^p + \sum_{i=3,\ldots,8} C_i Q_i \right]$$

$$Q_1^p = (\bar{s}p)_{V-A} (\bar{p}b)_{V-A} \qquad Q_7 = \tfrac{e}{8\pi^2} m_b \, \bar{s}\sigma^{\mu\nu}(1+\gamma_5) b \, F_{\mu\nu}$$

factorization formula:



$$\langle V\gamma | Q_7 | B \rangle \sim F(B \to V)$$

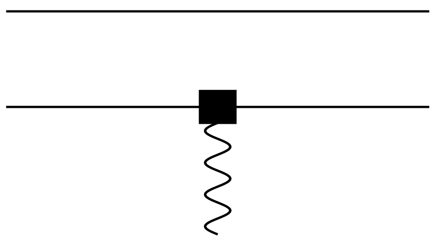


$$\langle V\gamma | Q_1^c | B \rangle = F(B \to V) \cdot T^I(\frac{m_c}{m_b}) \; +$$

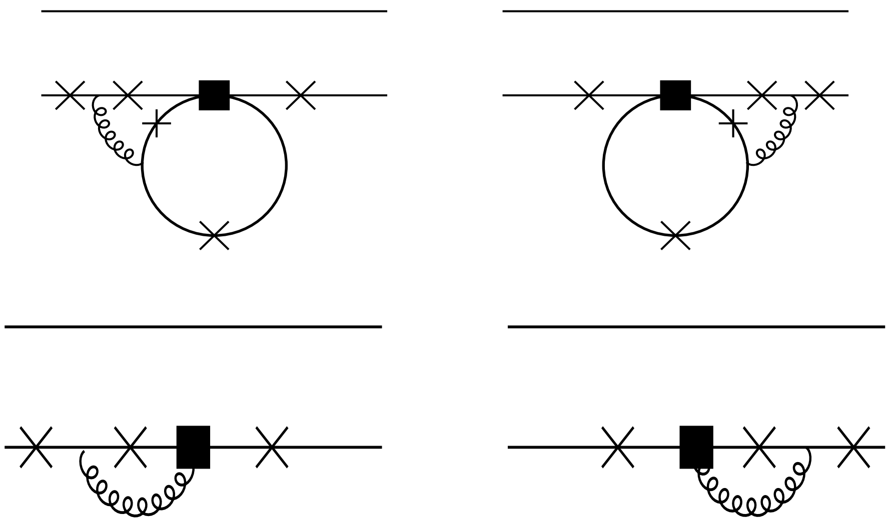
$$+ \int_0^1 d\xi \, dv \;\, T^{II}(\xi, v, \frac{m_c}{m_b}) \;\, \Phi_B(\xi) \, \Phi_V(v)$$

Leading-Power Contributions

T^I, $\mathcal{O}(\alpha_s^0)$

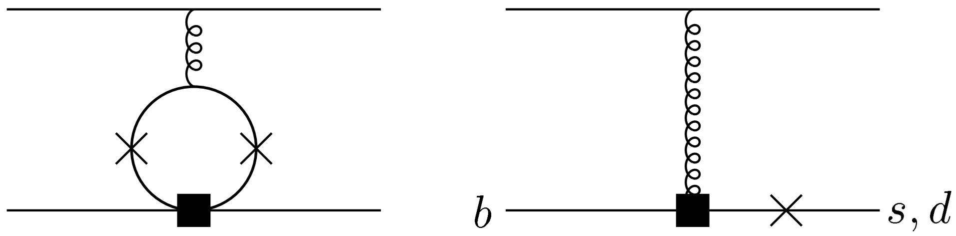


T^I, $\mathcal{O}(\alpha_s)$



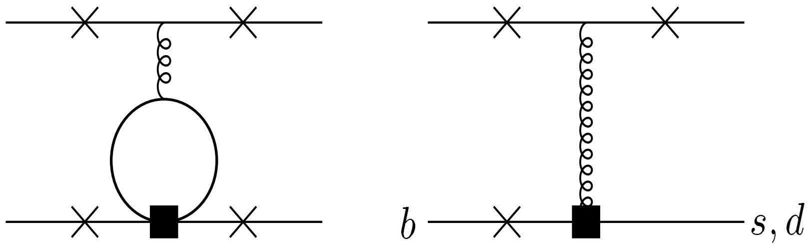
Greub, Hurth, Wyler
Buras, Czarnecki, Misiak, Urban

T^{II}, $\mathcal{O}(\alpha_s)$

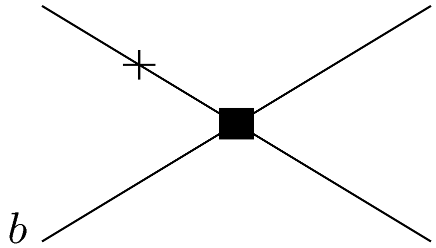


Beneke, Feldmann, Seidel; Bosch, G.B.
Ali, Parkhomenko

Subleading-Power Contributions



weak annihilation

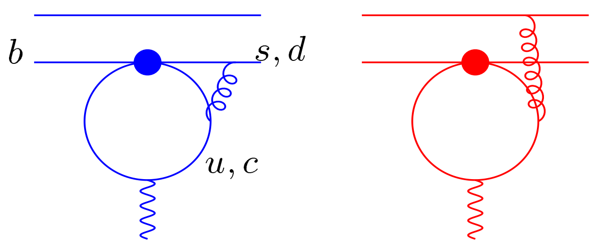


Grinstein, Pirjol
Ali, Handoko, London
Bosch, G.B.

- power suppression $\sim \Lambda/m_b$
- calculable
- sizeable effect from $Q_{1,2}$ in $B \to \rho\gamma$
  isospin breaking
- isospin breaking in $B^0 \to K^{*0}\gamma \leftrightarrow B^\pm \to K^{*\pm}\gamma$
  from Q_6 ($\sim$ 10%)

Kagan, Neubert

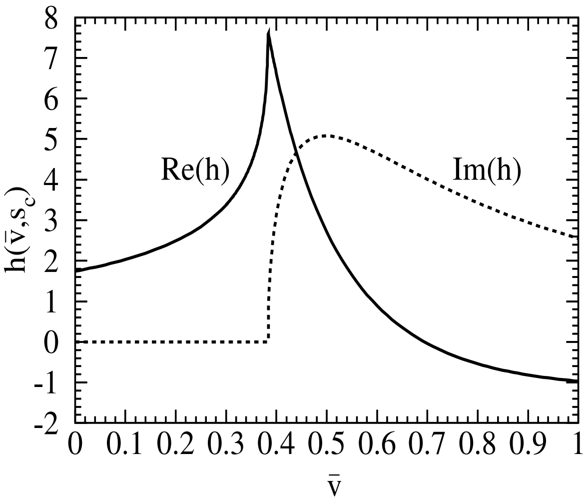
Up- and Charm-Quark Loops



- leading-power, short-distance effect, $\mathcal{O}(\alpha_s)$
- long-distance contributions power suppressed $\sim (\Lambda/m_Q)^n$

$$\langle Q_1^p \rangle^{II} \sim \alpha_s \int_0^1 dv\, h(\bar{v}, s_p)\, \Phi_V(v)$$

$$p = u, c \qquad s_p = m_p^2/m_b^2 \qquad \bar{v} \equiv 1 - v$$



power counting for soft gluon $\bar{v} \sim \Lambda/m_b \ll 1$:

$$d\bar{v}\, \bar{v}\, h(\bar{v}, s_p) \sim (\Lambda/m_b)^2 \cdot h(\Lambda/m_b, s_p)$$

charm: $\dfrac{\Lambda^2}{m_b^2} \cdot \dfrac{1}{s_c} = \dfrac{\Lambda^2}{m_c^2}$ ($B \to X_s\gamma$: *Voloshin*)

up: $\dfrac{\Lambda^2}{m_b^2} \cdot \dfrac{1}{\bar{v}} = \dfrac{\Lambda}{m_b}$ ($B \to X_{s,d}\gamma$: *G.B., Isidori, Rey*)

Table 1: Summary of input parameters.

CKM parameters and coupling constants					
V_{us}	V_{cb}	$\lvert V_{ub}/V_{cb}\rvert$	$\Lambda^{(5)}_{\overline{MS}}$	α	G_F
0.22	0.041	0.085 ± 0.025	225 MeV	1/137	$1.166 \times 10^{-5}\mathrm{GeV}^{-2}$

Parameters related to the B mesons				
m_B	f_B	λ_B	τ_{B^+}	τ_{B^0}
5.28 GeV	180 MeV	(350 ± 150) MeV	1.65 ps	1.56 ps

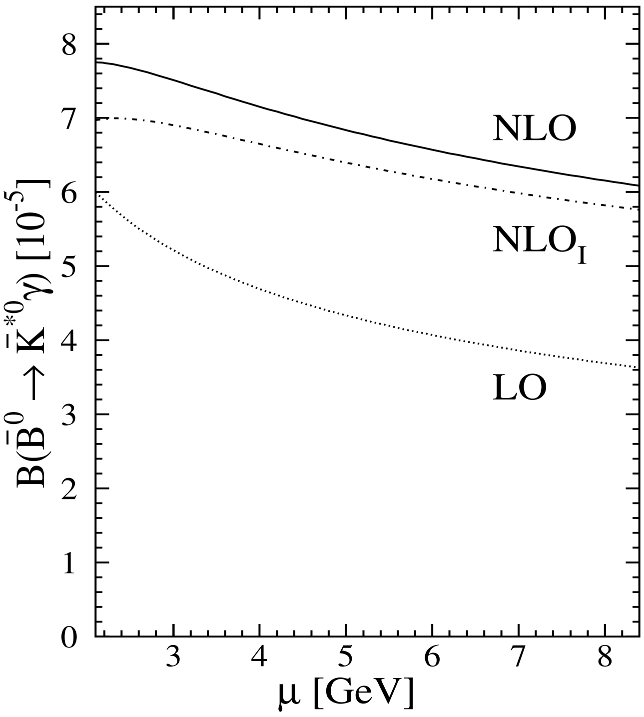
Parameters related to the K^* meson (*Ball, Braun*)					
F_{K^*}	$f^{\perp}_{K^*}$	m_{K^*}	$\alpha_1^{K^*}$	$\alpha_2^{K^*}$	f_{K^*}
0.38 ± 0.06	185 MeV	894 MeV	0.2	0.04	230 MeV

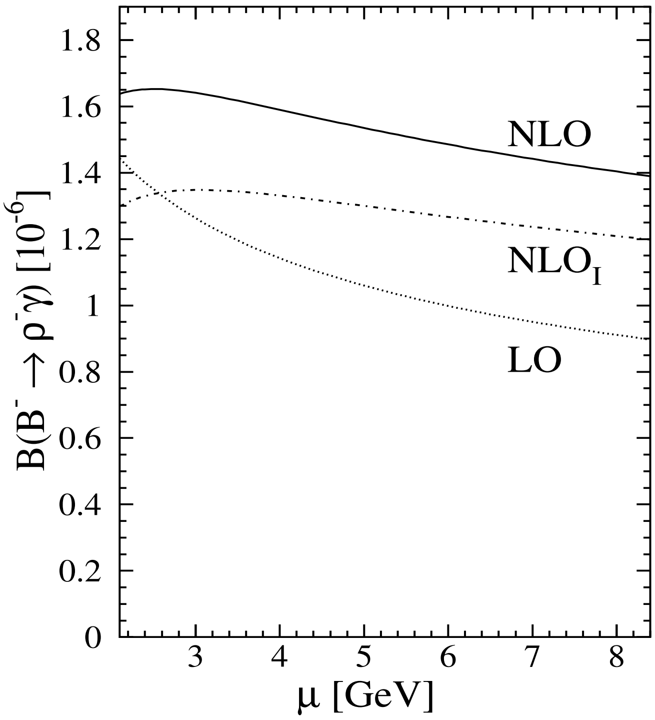
Parameters related to the ρ meson (*Ball, Braun*)					
F_{ρ}	$f^{\perp}_{\rho}$	m_{ρ}	α_1^{ρ}	α_2^{ρ}	f_{ρ}
0.29 ± 0.04	160 MeV	770 MeV	0	0.2	200 MeV

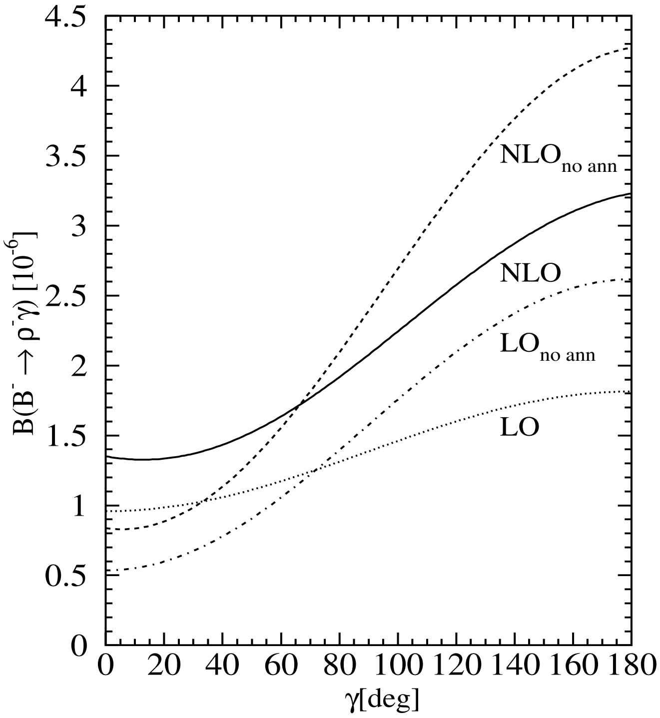
Quark and W-boson masses			
$m_b(m_b)$	$m_c(m_b)$	$m_{t,\mathrm{pole}}$	M_W
4.2 GeV	(1.3 ± 0.2) GeV	174 GeV	80.4 GeV

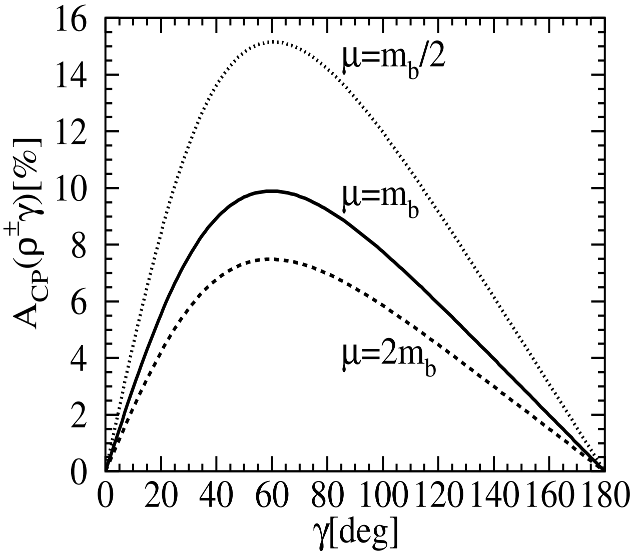
Table 2: Predictions for branching ratios and CP asymmetries with the errors from the individual input uncertainties.

	$B(\bar{B}^0 \to \bar{K}^{*0}\gamma)[10^{-5}]$	$B(B^- \to \rho^-\gamma)[10^{-6}]$	$\mathcal{A}_{CP}(\rho^{\pm}\gamma)[\%]$
central	7.09	1.58	9.89
F_{K^*}	$+2.32/-1.99$	–	–
F_{ρ}	–	$+0.42/-0.37$	$+0.12/-0.13$
μ	$+0.67/-1.00$	$+0.07/-0.19$	$+5.25/-2.40$
λ_B	$+0.38/-0.15$	$+0.26/-0.09$	$+0.35/-0.28$
m_c	$+0.38/-0.43$	$+0.12/-0.12$	$+1.40/-1.52$
$\lvert V_{ub}/V_{cb}\rvert$	$+0.05/-0.05$	$+0.15/-0.13$	$+3.48/-3.30$









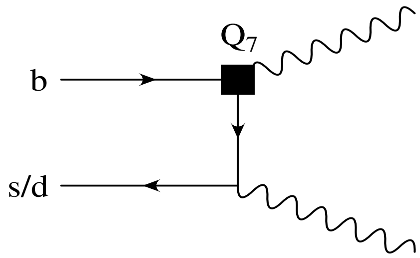
$$B(\bar{B}^0 \to \bar{K}^{*0}\gamma)/10^{-5} = 7.1 \pm 2.5 \qquad (4.44 \pm 0.35)$$

$$B(B^- \to \rho^-\gamma)/10^{-6} = 1.6 \pm 0.6 \qquad < 2.3$$

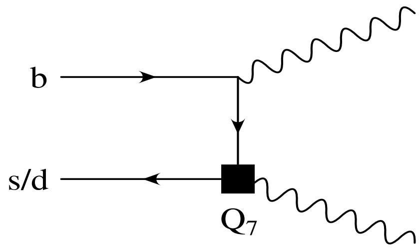
Factorization for $B \to \gamma\gamma$

Bosch, G.B.

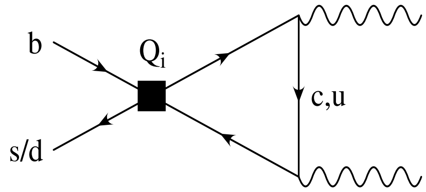
leading



Λ/m_b suppressed



Λ/m_b suppressed, calculable



$$B(\bar{B}_s \to \gamma\gamma) \sim 1.2 \cdot 10^{-6} \qquad (< 1.48 \cdot 10^{-4} \quad \textit{L3})$$

$$B(B_d \to \gamma\gamma) \sim 3 \cdot 10^{-8} \qquad (< 1.7 \cdot 10^{-6} \quad \textit{BABAR})$$

other application: $B \to K^* l^+ l^-$

Beneke, Feldmann, Seidel

Conclusions

- model independent framework for $B \to V\gamma$
  $m_b \gg \Lambda$: factorization formula

- exclusive $B \to V\gamma$ at NLO in QCD

- strong phases at $\mathcal{O}(\alpha_s)$

- charm- and up-quark loops: $\mathcal{O}(\alpha_s)$, leading in Λ/m_b
  short-distance effect

- long distance: $\mathcal{O}(\Lambda/m_b)$

- weak annihilation: $\mathcal{O}(\Lambda/m_b)$, but calculable

- limitation: form factors

- important observable: $B(B \to \rho\gamma)/B(B \to K^*\gamma)$

- further application of HQL: $B \to \gamma\gamma$, $B \to K^* l^+ l^-$