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FLAVOUR IN THE ERA OF THE LHC
Final Plenary Meeting, CERN, March 2007

- Introduction
- $B \to M_1 M_2$, NNLO, QED
- $B \to M$, LCSR, Lattice
- Outlook

Introduction

$$B \to \pi\pi,\ B \to \pi K,\ B \to K^* l^+ l^-,\ B \to \rho\gamma,\ B - \bar{B}$$

$$\Lambda_{QCD}$$

quark flavours $\quad b,\ c,\ s,\ d,\ u$

$$m_b$$

top, $W^\pm$, Z

$$\Lambda_{EW}$$

$$\tilde{q},\ \chi,\ \ldots$$

$$\Lambda_{NP}$$

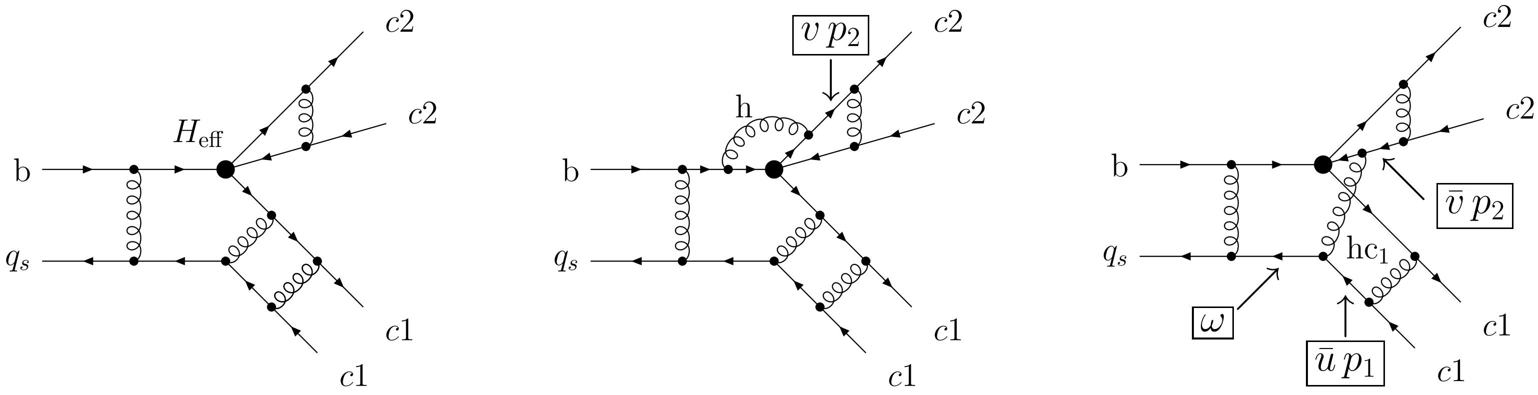
Nov 05	Photos	E. Barberio
	Nonleptonic B_s Decays	P. Colangelo
Feb 06	B meson form factors from SR and kaon DA	R. Zwicky
	User's guide to lattice QCD	S. Dürr
	Hadronic uncertainties in 2-body B decays	T. Feldmann
	NLO hard spectator scattering in QCDF	S. Jäger
	QED corrections in hadronic B decays	E. Baracchini
	News on Photos MC: systematic errors	Z. Was
May 06	$B \to VV$ decays can be useful	M. Beneke
	$\Lambda_b \to \Lambda V$	E. Conte
Oct 06	$B_{s,d} \to KK$ using QCDF and flavour symm.	S. Descotes
	Higher-order QCD corr. in excl. B decays	G. Bell
	Charm resonances in $b \to sll$	A. Khodjamirian

Yellow Report

- Overview
- Charmless two-body B decays *Feldmann*
  - Factorization
  - NNLO in α_s *Bell, Beneke, Jäger*
  - QED effects *Baracchini, Isidori*
- LCSR *Ball, Zwicky*
  - DA, $B \to M$ form factors
- Lattice QCD *Dürr*
  - f_M, form factors, bag parameters, systematics

Charmless B Decays

$$\langle M_1 M_2 | Q | B \rangle =$$
$$F^{BM_1} \int dv \, T^{\rm I}(v) \varphi_{M_2}(v) + \int d\omega \, du \, dv \, T^{\rm II}(u,v,\omega) \varphi_B(\omega) \varphi_{M_1}(u) \varphi_{M_2}(v)$$



hard $\sim m_b^2$

hard-collinear $\sim \Lambda m_b$

	heavy	soft	coll$_1$	coll$_2$
heavy	–	heavy	hard	hard
soft	heavy	soft	hard-coll$_1$	hard-coll$_2$
coll$_1$	hard	hard-coll$_1$	coll$_1$	hard
coll$_2$	hard	hard-coll$_2$	hard	coll$_2$

SCET: factorization proofs, scale separation, log summation

Input: F^{BM}, $\varphi_M(u)$ $(\alpha_1, \alpha_2, \ldots)$, $\lambda_B^{-1} = \int_0^\infty \frac{d\omega}{\omega}\varphi_B(\omega)$

$$
\begin{aligned}
a_1(\pi\pi) &= 0.975^{+0.034}_{-0.072} + (0.009^{+0.024}_{-0.051})i \\
a_2(\pi\pi) &= 0.184 - [0.153 + 0.077i]_{NLO,I} + [? - 0.042i]_{NNLO,I} \\
&\quad + \left\{[0.122]_{NLO,II} + [0.050 + 0.053i]_{NNLO,II} + [0.071]_{\mathrm{tw3}}\right\} \\
&= 0.275^{+0.228}_{-0.135} + (-0.066^{+0.115}_{-0.081})i
\end{aligned}
$$

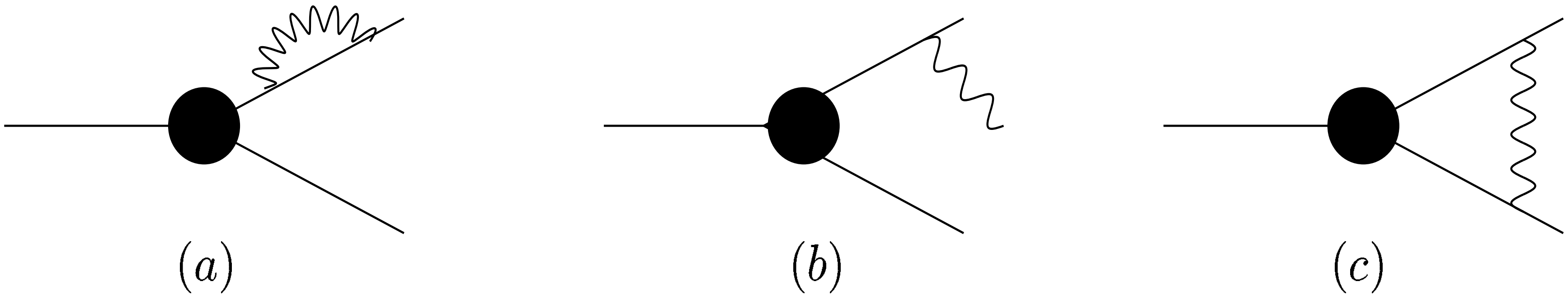
NLO, I *BBNS*

$NNLO, I$ *Bell* Im: done, Re: under way

$NNLO, II$ *Beneke, Jäger; Kivel; Pilipp*

NNLO important: a) numerically; b) to test validity of pert. theory

QED Corrections



Cirigliano et al.

$$\Gamma^{incl}(E) = \Gamma(B \to P_1 P_2 + \gamma)|_{E_\gamma < E} \equiv \Gamma^{(0)}_{12}(\mu) G_{12}(E,\mu)$$

$$G_{+-} = 1 - \frac{2\alpha}{\pi}\left[\left(2l - 1 - \ln(1-\delta^2)\right)\ln\frac{M_B}{2E} + 2l + \frac{\pi^2}{6} + \mathcal{O}(1)\right]$$

$$l = \ln\frac{2M_B}{m_1+m_2} \qquad \delta = \frac{m_1-m_2}{m_1+m_2}$$

$$B \to \pi\pi,\ \pi K, \qquad |G_{12} - 1| \lesssim 5\%$$

Baracchini, Isidori

PHOTOS

Ball, Zwicky

light-cone distribution amplitudes (DA)

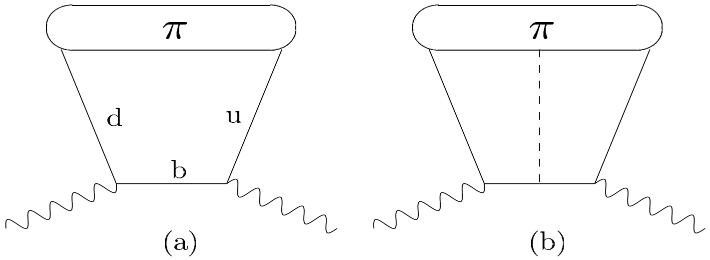
expansion in Gegenbauer polynomials

$$\varphi_M(u,\mu) = 6u(1-u)\left[1+\sum_{n=1}^{\infty}\alpha_n^M(\mu)C_n^{3/2}(2u-1)\right]f_M$$ truncate: $n=1,2$

f_M: $M=\pi,\ K;\ V^{\parallel},\ V^{\perp},\ \ V=\rho,\ K^*,\ \omega,\ \varphi$ exp./SR

Gegenbauer coefficients (at $\mu = 1\,\mathrm{GeV}$)

$$\alpha_1^\pi = 0 \quad \alpha_1^K = 0.06\pm 0.03 \quad \alpha_2^\pi = 0.27\pm 0.08 \quad \alpha_2^K/\alpha_2^\pi = 1.05\pm 0.15$$



form factors, LCSR: $0 \leq q^2 \lesssim 14\,\mathrm{GeV}^2$

$$F^{BM}(q^2) = \frac{r_1}{1-q^2/M_1^2} + \frac{r_2}{1-q^2/M_2^2} \qquad \textit{BK/BZ}$$

$$F_+^{B\pi}(0) = 0.258 \pm 0.031$$

$B \to V\gamma$: form factor $T_1^V(0)$

$$\xi = \frac{T_1^{K^*}(0)}{T_1^\rho(0)} = 1.17 \pm 0.09$$

$T_1^{K^*}(0) = 0.31 \pm 0.04$ (LCSR)

$T_1^{K^*}(0) = 0.28 \pm 0.02$ ($B \to K^*\gamma$ rate + QCDF)

Lattice QCD

Dürr

decay constants: f_π, f_K, f_{D_s}; f_B test method $\longrightarrow$ predict f_{B_s} $(B_s \to \mu^+\mu^-)$

form factors: at $q^2 = 0$ (extrapolation !) $F_+^{B\pi}(0) \approx 0.25 \pm 0.04$

bag parameters (SM + BSM operators)

systematics:

- fix input: $(\Lambda_{QCD}, m_{ud}, m_s, m_c, m_b)$ from $(M_p, M_\pi, M_K, M_D, M_B)$
- renormalization
- extrapolation: $T \to 0$, $a \to 0$, $V \to \infty$, $m_{ud} \to m_{ud}^{phys}$, $m_b \to m_b^{phys}$

$f_+^{K\to\pi}(0) = 0.960(5)(7)$	$N_f = 0$	— /clov	no	Romel-Orsay
$f_+^{K\to\pi}(0) = 0.952(6)$	$N_f = 2$	clov/clov	no	JLQCD
$f_+^{K\to\pi}(0) = 0.968(9)(6)$	$N_f = 2$	dom/dom	no	RBC
$f_+^{K\to\pi}(0) = 0.9680(16)$	$N_f = 2+1$	dom/dom	no	UKQCD/RBC
$f_+^{K\to\pi}(0) = 0.962(6)(9)$	$N_f = 2+1$	stag/clov	no	FNAL/MILC/+
$f_+^{D\to\pi}(0) = 0.64(3)(6)$	$N_f = 2+1$	stag/stag	no	FNAL/MILC/+
$f_+^{D\to K}(0) = 0.73(3)(7)$	$N_f = 2+1$	stag/stag	no	FNAL/MILC/+
$f_+^{B\to\pi}(0) = 0.23(2)(3)$	$N_f = 2+1$	stag/stag	no	FNAL/MILC/+
$f_+^{B\to\pi}(0) = 0.27(2)(4)$	$N_f = 2+1$	stag/stag	yes	HPQCD
$\mathcal{F}^{B\to D}(1) = 1.074(18)(16)$	$N_f = 2+1$	stag/stag	no	FNAL/MILC/+

	Lat'06	Lat'07	2-3 yrs.	5-10 yrs.
f_{D_s}, f_{B_s}	10	7	5	3-4
f_D, f_B	11	7-8	5	4
$f_B\sqrt{B_B}$	17	8-13	4-5	3-4
ξ	–	4	3	1-2
$(B, D) \to (K, \pi)\ell\nu$	11	8	6	4
$B \to (D, D^*)\ell\nu$	4	3	2	1

Percent errors. (MILC Collab.)

The $B \to \pi\ell\nu$ form factor is taken at $q^2 = 16\text{GeV}^2$.

- ≤ 1 stable hadron per initial/final state
- valence quarks in connected graphs
- momenta $\ll 2\pi/a$

difficult: $F^{B\to\rho}$

use $\Delta B(B \to \rho l\nu)/B(B \to \rho\gamma)$

Outlook

many tools to handle QCD in B decays:

- flavour symmetries ($SU(2)$, $SU(3)$)
- experimental input (semileptonic decays, variety of channels)
  ratios ($|V_{td}|/|V_{ts}|$, A_{CP})
- factorization, SCET ($m_b \gg \Lambda_{QCD}$)
- LCSR
- lattice QCD
- combinations of the above

BACKUP SLIDES

$10^5\, B(B^0 \to K^{*0}\gamma) = 4.01 \pm 0.20$ *Cleo, Belle, Babar; HFAG*

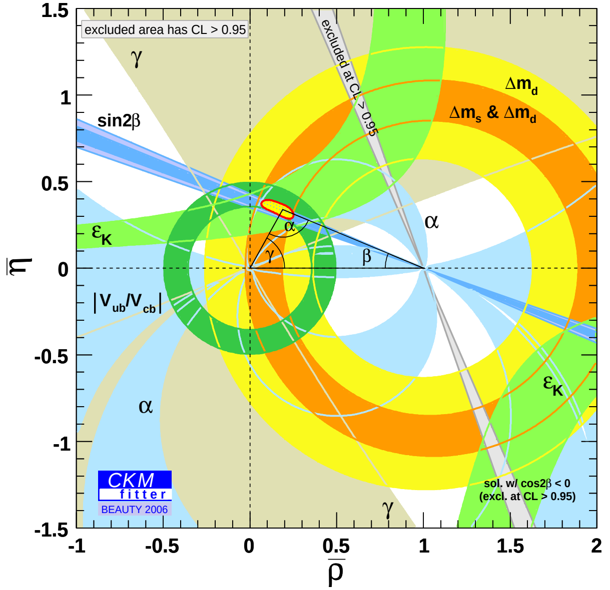
$B(B^0 \to K^{*0}\gamma) = (7 \pm 2) \cdot 10^{-5}$ for $F_{K^*} = 0.38 \pm 0.06$ (LCSR)

extract F_{K^*} from $B^0 \to K^{*0}\gamma$:

$$F_{K^*} = -0.025^{+0.007}_{-0.016} + 0.150^{+0.010}_{-0.002}\, \sqrt{10^5\, B(B^0 \to K^{*0}\gamma)}$$

$\to F_{K^*} = 0.28 \pm 0.02$ *Bosch, G.B.*

LCSR (new): $F_{K^*} = 0.31 \pm 0.04$ *Ball, Zwicky*



$$\xi \equiv \frac{F_{K^*}}{F_\rho} = 1.17 \pm 0.09$$

Ball, Zwicky

$$R_0 \equiv \frac{B(B^0 \to \rho^0 \gamma)}{B(B^0 \to K^{*0} \gamma)} = 0.0227 \pm 0.0049$$

Cleo, Belle, Babar; HFAG

$$\left|\frac{V_{td}}{V_{ts}}\right| = 1.4\,\xi\,\sqrt{R_0} = 0.246 \pm 0.019(\xi) \pm 0.027(\mathrm{exp})$$

Bosch, G.B.

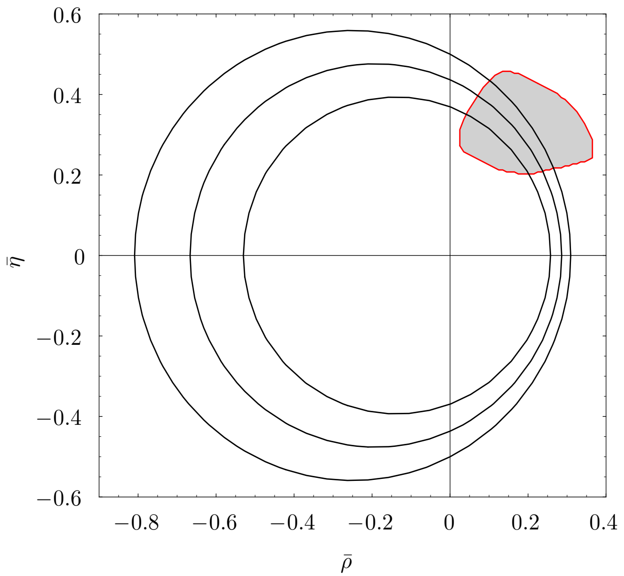
$$\left|\frac{V_{td}}{V_{ts}}\right|_{CKM} = 0.216 \pm 0.029$$

$$\left|\frac{V_{td}}{V_{ts}}\right|_{CDF,\Delta M_s} = 0.206^{+0.008}_{-0.006}(\mathrm{th}) \pm 0.0007(\mathrm{exp})$$

Applications $B \to \rho\gamma$, $B \to \rho l\nu$

Bosch, G.B.

$$\frac{\Delta B(B\to\rho l\nu)}{B(B\to\rho\gamma)} \sim \left|\frac{V_{ub}}{V_{td}}\right|^2$$



SCET relations:

$B \to \rho l\nu$ helicity form factors $H_\pm$, H_0

$\frac{H_-(q^2)}{F_\rho(0)}$ clean for small q^2

$\cos\vartheta \approx 1$