New Physics from B-mesons

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SEPT 03

1. Introduction / Motivation
2. What new physics ?
3. Methods / analyses
4. Results from Experiment / theory
5. Conceptual issues
6. Outlook

Thanks to

T. Hurth
E. Lunghi
M. Misiak
W. Porod

1. Introduction

Physics with b-Quarks can test consistency of standard model in much detail:

CKM picture of flavour, CP-violation

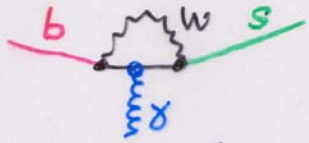
CKM-matrix elements (including their phases); unitary triangle (α, β, γ) ...

- Tree level (V_{ub}): no EW-NP loops (but hard!)
- Loops (V_{td}) : sensitive to NP

- Clear deviations from SM are possible!
- Require careful calculations and clever analyses
- Ways to handle QCD

Expect mostly from:

- "Rare" decays : FCNC decays / loops



$b \to s\gamma$ ...

- CP-violation : $|A(B \to F)|^2 = |A(\bar{B} \to \bar{F})|^2$
- Suppressed decays $B \to \tau\nu$, $B \to \mu\mu$
- Loops in "normal" decays : $B \to K\pi$

- Most tests not possible with K or even D alone
- Relationship to K (D) important

- Most results consistent within SM
- some puzzles

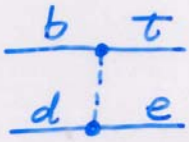
- Not yet much on B_s

2. Which new physics?

GUTs
- quark-lepton unification:
  Relations between $b \to s\gamma$ and $\tau \to \mu\gamma$, $\mu \to e\gamma$, etc.
  Relations between large ν-mixing and quark mixing
- Baryon-number-violation
  $B \to pe$, $B \to \tau p$, ...
- Structure: Extra $U(1)$'s (Z'-boson)

new scalars + leptoquarks

Suppressed decays
$B \to \mu\mu, \tau\tau, \tau e$



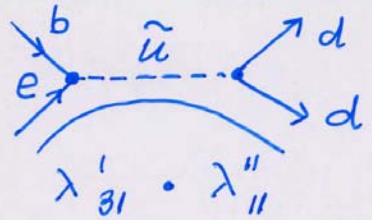
Flavour
- 4 generations
- Squark-structure in susy
  large effects in $b \to s\gamma$ etc

SM: GIM
NO FCNC at tree $\Longleftrightarrow$ New models may have large FC

Flavour problem
- links to textures, etc.

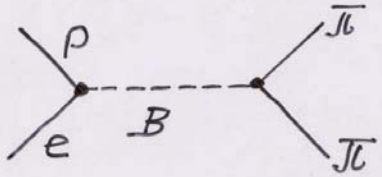
Baryon-violation in B decays

$B \to pe$:



R-parity violation

to get bound:



$$\Gamma(p \to e\pi\pi) \sim |g_{BPe}|^2$$

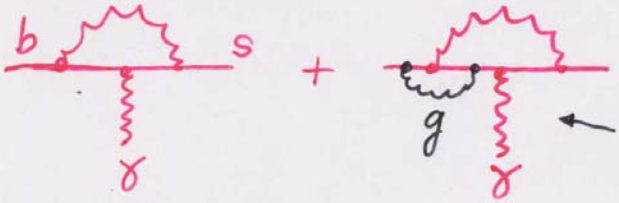
rough estimate: $BR(B \to pe) \lesssim 10^{-30}$

seems hopeless...
maybe other decays: $B \to \tau p$?

3. Methods and analyses

- Precise calculation in rare decays

$b \to s\gamma$ ($B \to X_s \gamma$ and $B \to K^* \gamma$)



$\leftarrow \alpha_s \log\left(\frac{M_W^2}{m_b^2}\right)$

$\Rightarrow$ $(\alpha_s \log)^N$ LL | $\alpha_s(\alpha_s \log)^N$ NLL | $\alpha_s^2(\log)^N$ NNLL

Effective Hamiltonian technique
sum up the logs
Uncertainties: scale dependence (of all quantities: α_s, m_c, ...

$b \to s\ell\ell$ ($B \to X_s \ell\ell$, $B \to K^{(*)}\ell\ell$)

$(\alpha_s \log)^N$ NLL | $\alpha_s(\alpha_s \log)^N$ NNLL

calculation of rates, $m_{\ell\ell}$-distribution
CP-asymmetries

lots and lots of diagrams

•• Clever observables

- time dependent CP-asymmetry

$$A(t) = \frac{\Gamma(B \to F) - \Gamma(\bar{B} \to \bar{F})}{+}(t)$$

in certain cases clean prediction

- Relations between observables

  $A(t)$ for $B \to \psi K_S$ and for $B \to \phi K_S$

- Amplitude triangles

→ May allow clearest statements

••• QCD related

- Mainly $B \to K\pi$ decays

  parametrization + estimates of QCD

  certain tools (factorization, ...)

4. Results

- perturbative calculations
- $b \to s\gamma$ up to NLL + corrections

$BR(B \to X_s\gamma)$: $(3.6 \pm 0.4)\ 10^{-4}$ T

$(3.4 \pm 0.4) \cdot 10^{-4}$ E

Nakao: LP Aug 03

This is analyzed in susy-models with off-diagonal squark masses: δm_{LL}, δm_{RR}, δm_{LR}, δm_{RL}

stringent bounds obtained, mainly LL

- $B \to K^{*0}\gamma$ 4.17 ± 0.23 10^{-5} Th (ALi)

$B \to K^{*+}\gamma$ 4.18 ± 0.32 10^{-5} $(7.2 \pm 1.1)\,10^{-5}$

$B \to K_2^{*}\gamma$ (15 ± 5) 10^{-6}

Interesting for QCD: $\dfrac{B \to K^*\gamma}{B \to X_s\gamma}$

- $b \to d\gamma$: suppressed by $\left|\dfrac{V_{td}}{V_{ts}}\right|^2$ in SM

$B \to \rho^+\gamma$ $< 2 \cdot 10^{-6}$

$B \to \rho^0\gamma$ $< 2 \cdot 10^{-6}$

$B \to \omega\gamma$ $< 10^{-6}$

Th: Similar; about factor 2 less

- $b \to s\ell\ell$ up to NNLL

(new results: Ghinkulov, Huth, Yao, Isidori; Asatryan + Greub..)

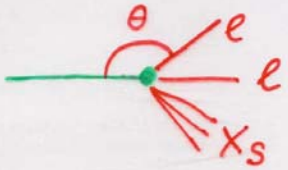
NNLL: Reduction of rate by 14%
of error by 50% (scale)

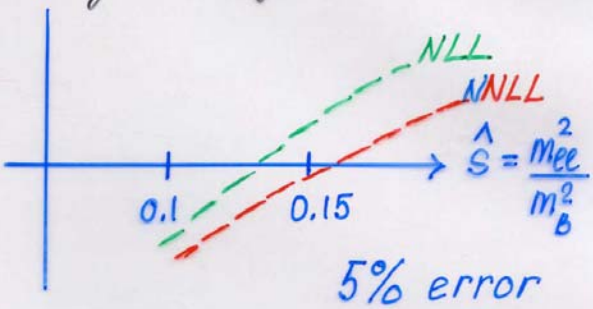
$BR(B \to X_s \ell\ell)$	$(6 \pm 1.6)\, 10^{-6}$	E
	$(1.4 \pm 0.2)\, 10^{-6}$	T *
	(cuts in $\hat{s}$!)	
$BR(B \to K e^+e^-)$	$(4\text{-}8)\, 10^{-7}$	$(3.5 \pm 2)\, 10^{-7}$
$BR(B \to K \mu^+\mu^-)$		
$BR(B \to K^* \ell\ell)$	$(5\text{-}20)\, 10^{-7}$	$(12 \pm 4)\, 10^{-7}$

- $BR(B \to K\nu\nu) < 7 \cdot 10^{-5}$ $\quad (3.8 \pm 1)\, 10^{-6}$

$BR(B \to \tau\nu) < 5 \cdot 10^{-4}$ $\quad 7 \cdot 10^{-5}$

- Forward-backward asymmetry





5% error
very sensitive

$B(B_d \to \mu\mu) < 2 \cdot 10^{-7}$ (10^{-10}) D10

$B(B_s \to \mu\mu) < 9.5 \cdot 10^{-7}$ $(4 \cdot 10^{-9})$

Interesting for new physics

large $\tan\beta$ - susy

$$\frac{BR(B_s \to \mu\mu)}{BR(B_s \to \mu\mu)_{SM}} \sim 10^{(\tan\beta/10)}$$

$m_H \approx 200\,\mathrm{GeV}$

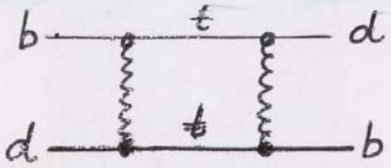
Chankowski
Stawianowsha

$$\frac{\Delta m_s}{(\Delta m_s)_{SM}} \text{ modified}$$

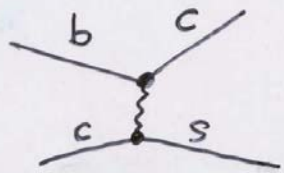
$\longrightarrow$ Correlations $BR(B_s \to \mu\mu) \leftrightarrow \Delta m_s$

time dependent asymmetries

$$A \simeq S \cdot \sin(\Delta m t) + C \cos(\Delta m t)$$



vs



$$e^{2i\underbrace{\varphi(V_{td}V_{tb}^*)}_{\beta}} \qquad e^{i\varphi(V_{cb}^* V_{cs})}$$

in $B \to J/\psi K_S (b \to \bar{c} c s)$

$S_{J/\psi} = \sin 2\beta = 0.733 \pm 0.057$ Belle + Babar

good agreement with ϵ_K, V_{ub}, Δm_B

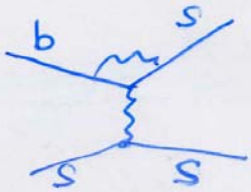
- In SM, $\varphi(V_{cb}^* V_{cs}) \simeq 0$

- other decays:

  KKK_S^0

  ϕK_S

  $\eta' K_S$



all real in SM.

$$\boxed{\text{expect } S = S_{J/\psi} \text{ for all. (+corr.)}}$$

KKK_S : (0.57 ± 0.3) BELLE

$\eta' K_S$: (0.02 ± 0.4) BuBar
(0.43 ± 0.3) Belle

ϕK_S : $-0.96 \pm .50$ Belle

$0.45 \pm .5$ BaBar

$\boxed{\text{average: } -0.15 \pm 0.33 \neq S_{J/\psi} \text{ !}}$

$\eta' K$ and ϕK pure loops => new physics possibly large:

- large $b \to sg$ vertex

  $b \to sZ'$ vertex (GUT)

  solves the problem; many models
- or experiment incorrect

$B \to J/\psi K_S$ tree level: no new physics

Rate of $B \to \eta' K$ too large for SM solved with large $b \to s$.

Direct CP-violation in $B \to X_s \gamma$

$A(B \to K^* \gamma) = (-0.5 \pm 3.7)\%$

$A(B \to X_s \gamma) = (-0.4 \pm 5)\%$

SM: 0.5%

$A(B \to X_d \gamma) \simeq -12\%$

More results:

$B \to \pi\pi$ (α)

$S = -0.4 \pm 0.25$	$S = -1.23 \pm 0.4$
$C = 0.2 \pm 0.2$	$C = -0.8 \pm 0.3$
Babar	Belle

$B \to D\pi$ ($2\beta+\gamma$)

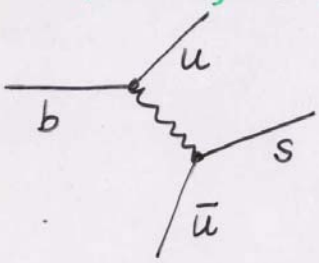
first results

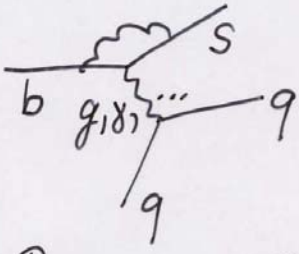
$B \to DK$ (γ)

first results

$B \to K\pi$ - puzzle

$B^+ \to K^0\pi^+,\ K^+\pi^0\ ;\ B^0 \to K^+\pi^-,\ K^0\pi^0$





tree process: T — Penguins: P, P_{EW}

$V_{ub}V_{us}^* \sim 0.001$ — $V_{tb}V_{ts}^* \sim 0.05$

Isospin (Lipkin)

$$R_L = \frac{2\Gamma(B^+ \to K^+\pi^0) + 2\Gamma(B^0 \to K^0\pi^0)}{\Gamma(B^+ \to K^0\pi^+) + \Gamma(B^0 \to K^+\pi^-)}$$

$$= 1 + O\left(\left(\frac{\text{ISO-VIOL}}{P}\right)^2\right)$$

Electroweak penguins, tree $\sim O(0.1)\cdot P$

expect $R_L \simeq 1 + O(\%)$

exp: $R_L \simeq 1.25 \pm 0.1$!

"Repair" with large $b \to s$ effects ($b \to sZ$)

- (too) large $b \to s\ell\ell$
- enhances $s \to d\nu\nu$ — $K \to \pi\nu\nu$
  also $K \to \pi ee$

Buras
Fleischer
Recksiegel
Schwab

5. Conceptual issues

- general description by effective operators
  $\frac{1}{\Lambda^2}(\bar{q}q)^2$; $\frac{1}{\Lambda^2}\bar{q}\,\sigma_{\mu\nu}F^{\mu\nu}q\,\phi$;..

Flavour structure:

SM: gauge couplings universal: GIM

Flavour symmetry $SU(3)_L \times SU(3)_{D_R} \times \cdots$

Higgs coupling matrix breaks it

$\mathcal{L}_H = \bar{Q}_L Y_D D_R H + \cdots$

Formally invariant if $Y_D \to U_L Y_D U^+_{D_R} \cdots$

All flavour violations $\sim Y_D, Y_U$

"minimal" flavour violation MFV

little deviations from SM results

Buras + Buras
D'Ambrosio et. al

Effective operators (formally) invariant:

$\sim \bar{Q}_L Y_U Y_U^+ Q_L$; $\bar{Q}_L Y_D Y_D^+ Q_L$; ....

+ extra complex couplings Hurth Lunghi Porod

$\frac{1}{\Lambda^2}(\bar{Q}\, Y_U Y_U^+ \gamma_\mu Q)(H^+ \partial^\mu H)$ etc.

- hierarchy of Y's simplifies analysis
- realized in susy models

- Can analyse data in more general way:

$$\Delta m_B = c\, e^{2i\varphi} (\Delta m_B)_{SM}$$
$$\hookrightarrow \sim (V_{tb})^2 e^{2i\beta}$$

in CKM-Fit: β, V_{tb} determined
$\sim$ two solutions

$S_{\psi K_S}$ yields $\sin 2(\varphi+\beta) \sim 0.7$

$\Rightarrow$ 2 possibilities : $c = 1$, $\varphi = 0$ SM
$c \neq 1$, $\varphi \neq 0$ disfavoured

Chiucini et.al. 0307195

6. Outlook

Relatively bright:

- Experiments give continously new and interesting results:
  $B \to X_s \gamma$, $B \to X_s \ell\ell$, $B \to \pi^0\pi^0$,
  $B \to K\pi$, $B \to DK$
  at running B-factories
- Hopes for higher Luminosities + rates (LHCB, SUPER B's); BTEV,..
- Crucial Δm_{B_s} measurement ahead
- Possibly $K \to \pi\nu\nu$
- Advanced theoretical calculations
  NNLL $B \to X_s\gamma$
- Advances in QCD (SCET)

In any case: B-physics is interesting