Theoretical review of b-physics @GigaZ

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outline

- theory issues in b-physics
- GigaZ, (super) B-factories, hadron machines
- polarized Λ_b-decays @GigaZ
- designer mesons @super-babar
- brain storming

SM: standard model
NP: new physics
FCNC: flavor changing neutral currents

theory issues in b-physics

Is the CKM description of CP✗ correct or are there other sources of CP✗ ?

Is the SM the correct effective theory up to ~ 1 TeV, could be probed by FCNC, rare decays $b \to s\gamma$, $b \to s\, \ell^+ \ell^-$

Is our understanding of non-perturbative QCD good enough to answer these questions?

"QCD BGD" limits potential

no true separation

$\to$ need whole picture for $\boxed{\text{precision test}}$

+ many modes, many observables, many facilities

be selective

b-facilities

	time scale	b's	e^+e^-	# B-$\bar{B}$/year
B-factories BaBar, Belle, Cleo	now	B_0, B_+	+	10^7
RUN II DØ, CDF	just started	all $B_s, \Lambda_b \ldots$	—	
BTEV LHC-B	~2006	all	—	$10^{12} - 10^{13}$ but $S/N \sim 5 \cdot 10^{-3}$
Giga Z ($2 \cdot 10^9$ Z's/yr)		all	+	$6 \cdot 10^8$
($2 \cdot 10^{10}$ Z's/yr)				$6 \cdot 10^9$
superbabar $\mathcal{L} \sim 10^{36} cm^{-2} s^{-1}$		B_0, B_+ $\Upsilon(4S)$	+	10^{10} 1 day superbab ≙ 1 yr pep II

b @ GigaZ

literature: Ali et al, Hawkings, Willocq, Mönig, TDR, orange book

"classic" b-physics observables Δm_s, $B \to J/\psi K \to \sin 2\beta$ at most competetive, hardly an advantage

advantages of GigaZ:

- initial state flavor tag by direction (with polarized e^+e^- beams)
- all b-flavored hadrons in clean e^+e^- envir.
- large boost
- b's are polarized
- can do much more than b-physics
-

designer observables for Giga Z

- b-polarization
- direct CP-asymmetries
  e.g. in rare decays $b \to s\gamma$, $s\,e^+e^-$
- inclusive measurements
- "missing energy" modes
  $b \to s \nu \bar{\nu}$, $B \to \tau \nu$

↳ also discussed/interesting for super babar
see J. Alexander BCP4 talk

- rare $Z \to b\bar{s} + \bar{b}s$ decays

  $Br|_{SM}(Z \to b\bar{s} + \bar{b}s) \simeq 1.4 \cdot 10^{-8}$

  $Br\,(\qquad) < 10^{-3}$ L3

  $Br\,(\qquad) < 5 \cdot 10^{-7}$

  from $Br(b \to s e^+ e^-)$ bound Buchalla, Hiller, [redacted] Isidori '01 polarized Λ_b decays at the Z

G.H., A.Kagan

b-polarization in $Z \to b\bar{b}$: $P_b = -0.94$ for $\sin^2\theta_W = 0.23$

$b \to \Lambda_b (udb)$ HQET: depolarization small

$$P_{\Lambda b}^{HQET} = -(0.69 \pm 0.06)$$ A.Falk, M.Peskin

measured at LEP (Aleph, OPAL, Delphi) from $\Lambda_b \to \Lambda_c \ell \nu X$ decays

OPAL : $\boxed{P_{\Lambda b} = -0.56^{+0.20}_{-0.13} \pm 0.09}$

can be done much better at GigaZ

$\sim 10^3$ more events.

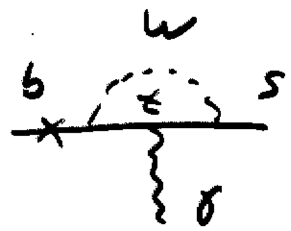
use $P_{\Lambda b}$ as input $\Rightarrow$

GigaZ is high luminosity source of polarized Λ_b's

$2 \cdot 10^9$ Z/year $\sim$ few 10^7 Λ_b's

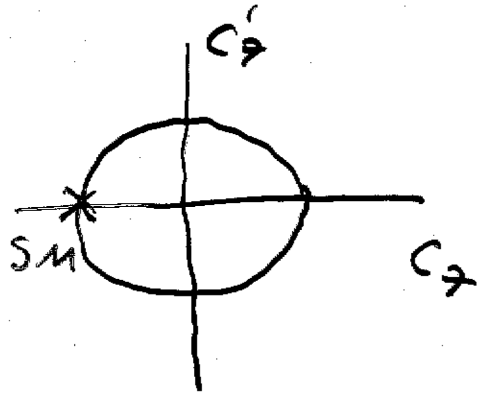
$2 \cdot 10^{10}$ Z/year $\sim$ few 10^8 Λ_b's probing for flipped helicity in $b \to s \gamma$

rare decay : easily affected by NP
change effective couplings (Wilson coefficients)
or new operators



SM $\quad b_R \to s_L \gamma_L \quad \Rightarrow C_7$

flipped $\quad b_L \to s_R \gamma_R \quad \Rightarrow C_7'$



data $\quad Br(B \to X_s \gamma) \sim |C_7|^2 + |C_7'|^2$

$$\boxed{C_7'|_{SM} = \frac{m_s}{m_b} C_7|_{SM}}$$

C_7' sizeable in L-R symmetric models or SUSY with flavor non-universal breaking

$\to$ SM prefers γ back-to-back b spin
at Giga Z we know the direction of b-spin
Λ_b-spin

$\Rightarrow$ angular asymmetry $(\vec{p}_\gamma, \Lambda_b\text{-spin})$
in $\Lambda_b \to \Lambda \gamma$ decays
probes $\quad r = \left| \frac{C_7'}{C_7} \right|$

how well can we do this?

$Br(\Lambda_b \to \Lambda_\gamma)|_{SM} \sim |F(0)|^2 |C_7|_{SM}|^2 \sim (3-10)\cdot 10^{-5}$

strong form factor dependence

asymmetry $\boxed{A = \frac{P_{\Lambda_b}}{2} \frac{1-r^2}{1+r^2}}$ form factor dependence drops out! clean!

$r = \frac{\text{flipped / NP}}{SM}$ couplings ; $r_{SM} \approx \frac{m_s}{m_b} = 4\%$

Do better with CP average (un-tagged)

CP conservation : $A = \bar{A}$

$\Rightarrow \boxed{\frac{A+\bar{A}}{2} \quad \text{double statistics}}$

if CPX : in SM : CKM ~ very small $\lesssim 1\%$

in general : $|A-\bar{A}| \leq 2 P_{\Lambda_b} \underbrace{\frac{Br - \bar{B}r}{Br + \bar{B}r}}_{\text{direct CP asymmetry}}$

<u>but</u>: even in the presence of non-SM CPX

⊕ the CP-averaged asymmetry is a function of the CP-even part of r

even more:

spin analyze final state $\Lambda \to p\pi^-$ $\sim 64\%$

define another asymmetry A' between Λ-spin and photon

$$\boxed{A' = -\frac{\alpha}{2}\,\frac{1-r^2}{1+r^2}}$$

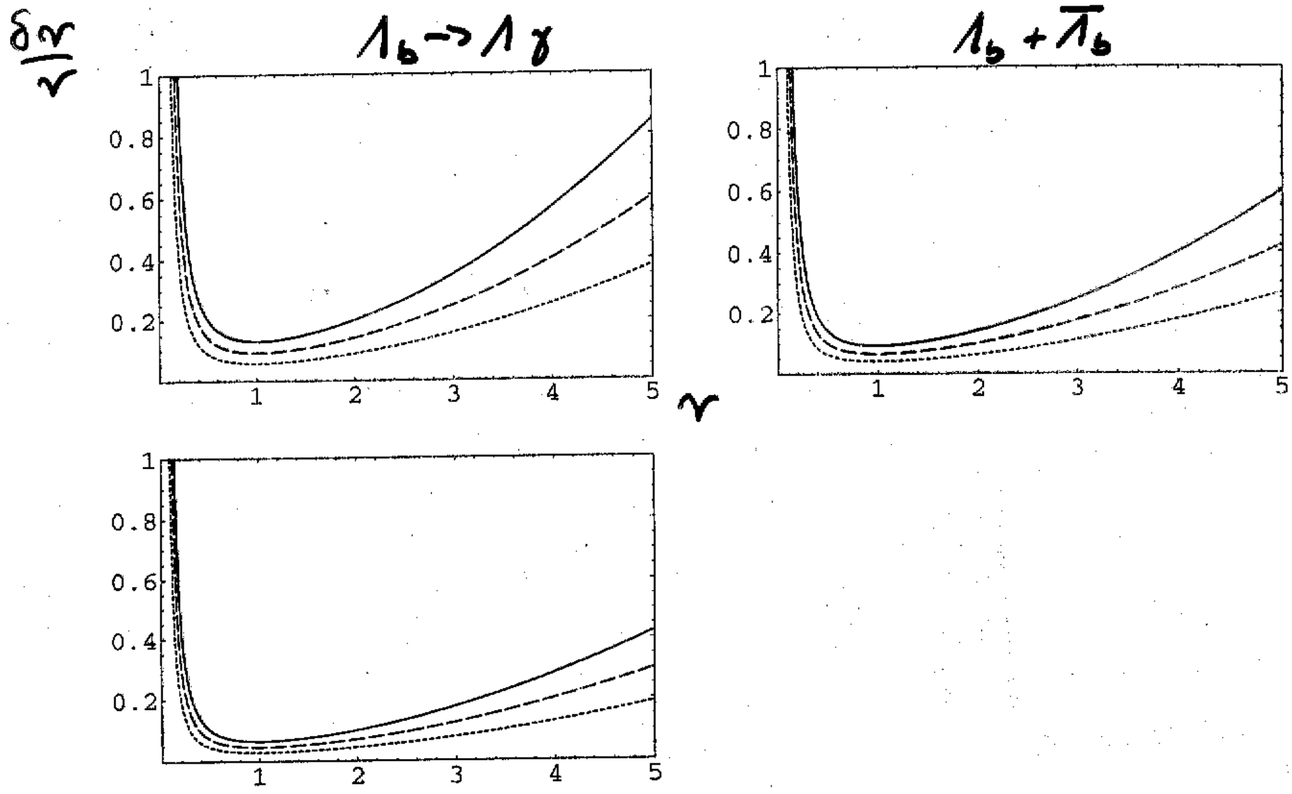
$\alpha = 0.642 \pm 0.013$ Λ decay parameter

A' does not require polarized Λ_b's ; originally discussed by Mannel / Recksiegel / we disagree in equation (G.H., Kagan)

⊕ increase statistics (+ CP) : x 4

⊕ consistency check for initial state polarization: r_extracted should agree
if not, e.g. P_{Λ_b} (input) from $b \to c\ell\nu$ has right handed currents

Sensitivity study



$Br(\Lambda_b \to \Lambda\gamma) \approx 7.5 \cdot 10^{-5}$ thanks to

reconstruction efficiencies (Su Dong)

0.5 for Λ

0.9 for γ

—— $2 \cdot 10^9$

- - - $4 \cdot 10^9$ Z's

...... 10^{10}

5-sigma ranges

#(Z's)	$\Lambda_b \to \Lambda\gamma$	$\Lambda_b, \bar{\Lambda}_b$ A, A'
$2 \cdot 10^9$	$0.5 < r < 2.0$	$0.3 < r < 3.3$
$4 \cdot 10^9$	$0.38 < r < 2.6$	$0.25 < r < 4.0$
10^{10}	$0.23 < r < 4.3$	$0.16 < r < 6.2$

$Br(\Lambda_b \to \Lambda\gamma) \approx 7.5 \cdot 10^{-5}$

Λ reconstruction eff : 0.5

γ reconstruction eff : 0.9

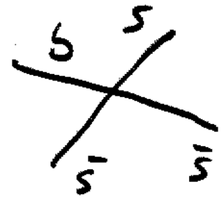
probing for NP in $\Lambda_b \to \Lambda \phi$ decays @ Z

G.H., A. Kag.

similar study than $\Lambda_b \to \Lambda \gamma$ decays

$\Lambda_b \to \Lambda \phi$ is a rare, loop induced decay:

penguin - 4-fermi operator



ϕ: ⊕ $I=0$ QCD penguins contribute => Br large $\sim 10^{-5}$

⊕ 1^- no chiral enhancement $\langle 0 | O_6^F | \phi \rangle = 0$

(potentially large corr. to factorization)

many operators, probe specific combination

$C_7 \to a_3 + a_4 + a_5 - \frac{1}{2}(a_7 + a_9 + a_{10})$

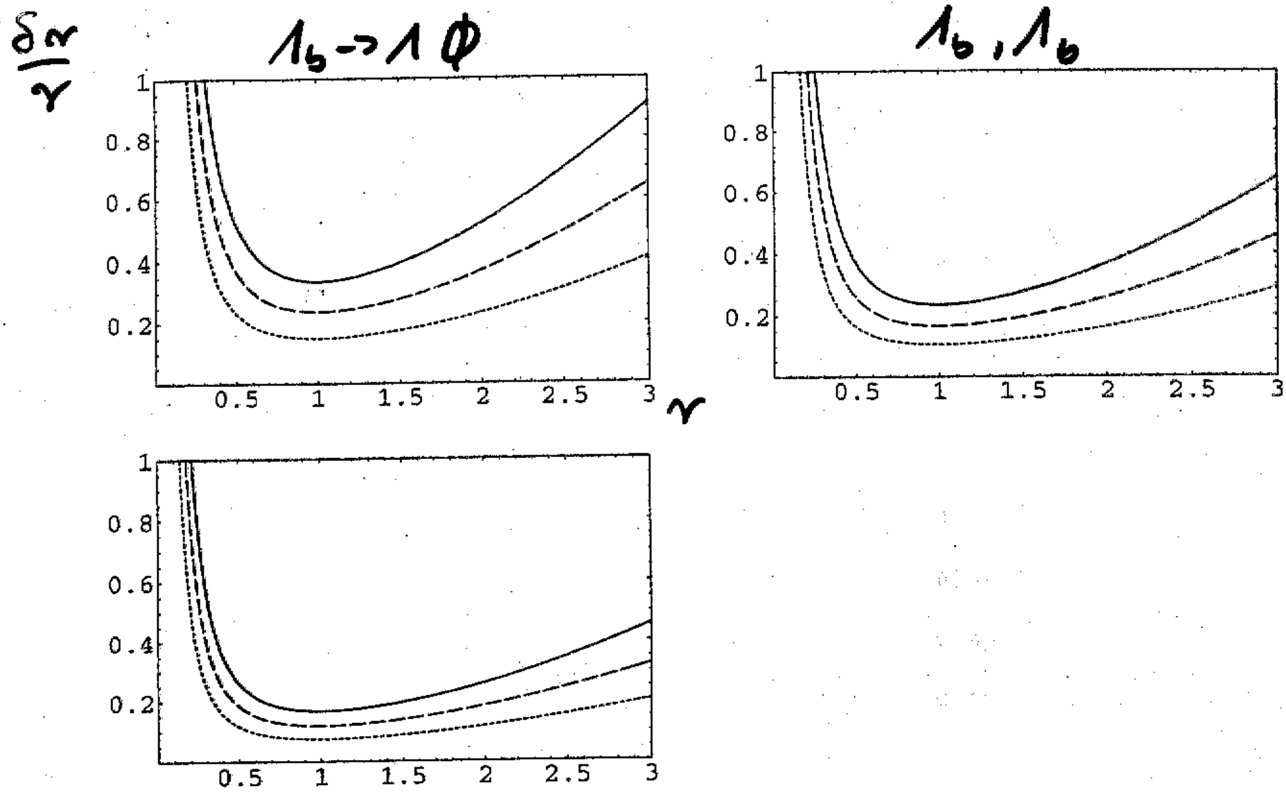
$\Lambda\phi$ is theoretically less clean than $\Lambda\gamma$, but IMPORTANT: only way to probe helicity of 4-quark penguin operators

- factorization assumption
- more form factors than $\Lambda\gamma$: (only one)
  $\Lambda_b \to \Lambda\phi$: 6 form factors

⊕ symmetries in large energy limit: only 2 form factors F_1, F_2 and

$$\boxed{\frac{F_2}{F_1} = -\frac{m_\Lambda}{2E_\Lambda} \sim -\frac{m_\Lambda}{m_{\Lambda b}}}$$

Sensitivity study



$Br(\Lambda_b \to \Lambda \phi) \approx 3.0 \cdot 10^{-5}$

reconstruction efficiencies:

$\phi \to KK$: $\sim 0.9 \cdot 0.4$

Λ : 0.5

program for polarized Λ_b decays at Giga Z

semileptonic $\Lambda_b \to \Lambda_c \, \ell \, \nu_\ell$

$\Lambda_b \to p \, \ell \, \nu_\ell$

rare
radiative,
semileptonic

$\Lambda_b \to \Lambda \, \gamma$

$\Lambda_b \to \Lambda \, \ell^+ \ell^-$

$\Lambda_b \to \Lambda \, \nu \, \bar{\nu}$

hadronic $\Lambda_b \to \Lambda \, \phi$

$\Lambda_b \to n \, D_2^{*0}$ factorization test

$\vdots$

inclusive e.g. $\Lambda_b \to X_s \gamma$?

super babar : asymmetric e^+e^- @ $\Upsilon(4S)$ $\sim 10^{10}$ b/year
with $\mathcal{L} \sim 10^{36}\ cm^{-2}\,s^{-1}$

<u>ideas</u> : Talks by Bigi, Ligeti, Alexander, Falk (on V_{ub})
on the web
workshop "beyond 10^{34}"

suggestions :
- precision measurements of rare decays
  $b \to s\gamma$, $b \to d\gamma$, $b \to s\nu\bar{\nu}$
  $B \to \tau\nu$
- "α" from $B \to \pi\pi$, $\rho\pi$
- "$2\beta+\gamma$" from $B \to D\pi$
  (<u>$B \to DM$ $\to$ late</u>)
-
-

colar allowed

example	factorizing contribution			annihilation		
	quark level	tree	peng.	topology	tree	peng.
$\bar B_0 \to D^+ a_0^-$	$\bar d b \to \bar d(c\bar u d)$	λ^2		a	λ^2	
$\to D^+ K_0^{*-}$	$\to \bar d(c\bar u s)$	λ^3				
$\bar B_s \to D_s^+ a_0^-$	$\bar s b \to \bar s(c\bar u d)$	λ^2				
$\bar B_0 \to \pi^+ D_{sJ}^-$	$\bar d b \to \bar d(u\bar c s)$	λ^3				
	$\bar u b \to \bar u(u\bar c d)$	λ^4		a	λ^4	
	$\to \bar u(u\bar c d)$	λ^4		a, c	λ^4	
	$\to \bar u(u\bar c s)$	λ^3				
	$\to \bar u(u\bar c s)$	λ^3		a, c	λ^3	
$\bar B_s \to K^+ D_2^{*-}$	$\bar s b \to \bar s(u\bar c d)$	λ^4				
$\bar B_0 \to D^+ D_{sJ}^-$	$\bar d b \to \bar d(c\bar c s)$	λ^2	λ^2	a		λ^2
	$\bar u b \to \bar u(c\bar c d)$	λ^3	λ^3	a	λ^3	λ^3
	$\to \bar u(c\bar c s)$	λ^2	λ^2	a	λ^4	λ^2
	$\bar s b \to \bar s(c\bar c d)$	λ^3	λ^3	a		λ^3
$\bar B_0 \to \pi^+ K_2^{*-}$	$\bar d b \to \bar d(u\bar u s)$	λ^4	λ^2	a		λ^2
	$\bar u b \to \bar u(d\bar d s)$		λ^2	a	λ^4	λ^2
	$\to \bar u(s\bar s d)$		λ^3	a	λ^3	λ^3
$\bar B_s \to K^+ a_2^-$	$\bar s b \to \bar s(u\bar u d)$	λ^3	λ^3	a		λ^3

ay modes $B \to YX$ satisfying the criteria specified in the text. . the weak decay vertex. Any meson can be replaced by another re and isospin, e.g, D by D^*, π by ρ, and the meson X by an Table 1. The second column gives the quark composition of the originating from the b decay enclosed in brackets. In the third ie power of the Wolfenstein parameter λ in the decay amplitude

hep-ph/0105194

color suppressed

example decay	factorizing contribution			annihilation		
	quark level	tree	peng.	topology	tree	peng.
$\bar{B}^0 \to \pi^0 D_2^{*0}$	$\bar{d}b \to \bar{d}(d\bar{u}c)$	λ^2		a	λ^2	
$\to \eta\, D_2^{*0}$	$\to \bar{d}(d\bar{u}c)$	λ^2		a, c	λ^2	
$B^- \to K^- D_2^{*0}$	$\bar{u}b \to \bar{u}(s\bar{u}c)$	λ^3				
$\bar{B}_s \to K^0 D_2^{*0}$	$\bar{s}b \to \bar{s}(d\bar{u}c)$	λ^2				
$\to \eta\, D_2^{*0}$	$\to \bar{s}(s\bar{u}c)$	λ^3		a, c	λ^3	
$\bar{B}^0 \to \bar{K}^0 \chi_{c0}$	$\bar{d}b \to \bar{d}(s\bar{c}c)$	λ^2	λ^2	b		λ^2
$\to \pi^0 \chi_{c0}$	$\to \bar{d}(d\bar{c}c)$	λ^3	λ^3	b	λ^3	λ^3
$\to \eta\, \chi_{c0}$	$\to \bar{d}(d\bar{c}c)$	λ^3	λ^3	b, c	λ^3	λ^3
$B^- \to K^- \chi_{c0}$	$\bar{u}b \to \bar{u}(s\bar{c}c)$	λ^2	λ^2	b	λ^4	λ^2
$\to \pi^- \chi_{c0}$	$\to \bar{u}(d\bar{c}c)$	λ^3	λ^3	b	λ^3	λ^3
$\bar{B}_s \to \eta\, \chi_{c0}$	$\bar{s}b \to \bar{s}(s\bar{c}c)$	λ^2	λ^2	b, c	λ^2	λ^2
$\to K^0 \chi_{c0}$	$\to \bar{s}(d\bar{c}c)$	λ^3	λ^3	b		λ^3
$\bar{B}_s \to K^0\, a_2^0$	$\bar{s}b \to \bar{s}(d\bar{u}u)$	λ^3	λ^3	a		λ^3
$\to \eta\, a_2^0$	$\to \bar{s}(s\bar{u}u)$	λ^4	λ^2	a, c	λ^4	λ^2

Table 3: As Table 2 but for decays where the tree level contribution is color suppressed. We remark that the decay $\bar{B}_s \to K^0\, a_2^0$ has a color allowed penguin contribution.

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baryons

example decays		factorizing contribution			pseudo-annihilation	
		quark level	tree	peng.	tree	peng.
$\Lambda_b \to$	$n D_2^{*0}$	$udb \to ud(c\bar{u}d)$	λ^2		λ^2	
$\to \Lambda_c K_0^{*-}$, ΛD_2^{*0}		$\to ud(c\bar{u}s)$	λ^3		λ^3	
$\to p\, D_{sJ}^-$		$\to ud(u\bar{c}s)$	λ^3			
$\to \Lambda_c D_{sJ}^-$, $\Lambda \chi_{c0}$		$\to ud(c\bar{c}s)$	λ^2	λ^2	λ^4	λ^2
$\to$	$n\, \chi_{c0}$	$\to ud(c\bar{c}d)$	λ^3	λ^3	λ^3	λ^3
$\Omega_b \to \Omega_c a_0^-$, $\Xi^- D_2^{*0}$		$ssb \to ss(c\bar{u}d)$	λ^2			
$\to$	$\Omega\, D_2^{*0}$	$\to ss(c\bar{u}s)$	λ^3			
$\to$	$\Omega\, D_2^{*0}$	$\to ss(u\bar{c}s)$	λ^3			
$\to \Xi^0 D_2^{*-}$, $\Xi^- D_2^{*0}$		$\to ss(u\bar{c}d)$	λ^4			
$\to$	$\Omega\, \chi_{c0}$	$\to ss(c\bar{c}s)$	λ^2	λ^2		λ^2
$\to \Omega_c D_2^{*-}$, $\Xi^- \chi_{c0}$		$\to ss(c\bar{c}d)$	λ^3	λ^3		λ^3
$\to$	$\Omega\, a_2^0$	$\to ss(u\bar{u}s)$	λ^4	λ^2		
$\to$	$\Xi^- a_2^0$	$\to ss(u\bar{u}d)$	λ^3	λ^3		λ^3

Table 4: Flavor structure of the decay modes of the Λ_b and the Ω_b for which the emitted meson must originate from the weak current. The mesons can be replaced by others from Table 1 with the same flavor structure. The second column gives the quark composition of the final state, with the three quarks originating from the electroweak vertex enclosed in brackets. The third and forth columns give the power of the Wolfenstein parameter λ in the decay amplitude for W exchange and penguin operators, respectively, and the corresponding information for pseudo-annihilation contributions is given in the last two columns.

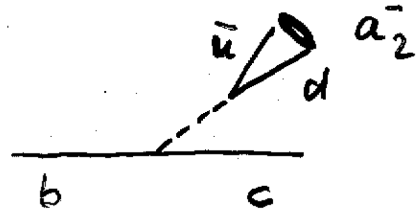
hep-ph/0105194

designer mesons @ super babar

factorization and CPX studies: M. Diehl, G.H. hep-ph/0105194 hep-ph/0105213
S. Laplace, V. Shelkov hep-ph/0105252

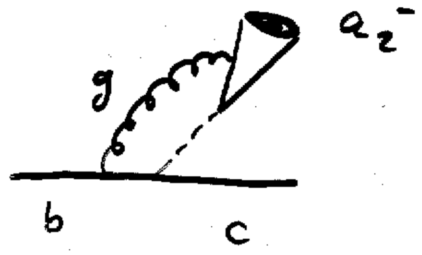
Coupling to W is suppressed
either spin > 1 or decay constant is e.g. isospin suppressed
examples: $a_0, a_2, K_2^*, b_1, \pi(1300), \ldots$

⊕ amplitudes in <u>naive</u> factorization are tiny or zero



$\simeq 0$

power corrections escape suppression



⊕ many modes, $B_{0,u}$, (B_s, Λ_b,)...

⊕ many "designer" final states, cover wide range of masses

⇒ explore factorization breaking as a function of m_X^2

"color transparency vs $1/N_c$" Weinstein, Ligeti, Luke, Wise

decay mode	naive factorization	QCD factorization	
		$\mu = m_b$	$\mu = m_b/2$
$\bar{B}^0 \to D^+ a_0(980)$	$1.1 \cdot 10^{-6}$	$2.0 \cdot 10^{-6}$	$4.0 \cdot 10^{-6}$
$\bar{B}^0 \to D^+ a_0(1450)$	$8.6 \cdot 10^{-8}$	$5.8 \cdot 10^{-7}$	$2.1 \cdot 10^{-6}$
$\bar{B}^0 \to D^+ b_1,\ D^+ a_2$	0	$3.5 \cdot 10^{-7}$	$1.7 \cdot 10^{-6}$
$\bar{B}^0 \to D^+ \pi(1300)$	$9.1 \cdot 10^{-6}$	$9.3 \cdot 10^{-6}$	$9.6 \cdot 10^{-6}$
$\bar{B}^0 \to D^+ \pi_2,\ D^+ \rho_3$	0	$1.4 \cdot 10^{-9}$	$8.1 \cdot 10^{-9}$
$\bar{B}^0 \to D^+ K_0^*(1430)$	$2.0 \cdot 10^{-5}$	$2.0 \cdot 10^{-5}$	$2.1 \cdot 10^{-5}$
$\bar{B}^0 \to D^+ K_2^*$	0	$1.9 \cdot 10^{-8}$	$9.2 \cdot 10^{-8}$
$\bar{B}^0 \to D^{*+} a_0(980)$	$1.0 \cdot 10^{-6}$	$1.8 \cdot 10^{-6}$	$3.7 \cdot 10^{-6}$
$\bar{B}^0 \to D^{*+} a_0(1450)$	$7.9 \cdot 10^{-8}$	$5.2 \cdot 10^{-7}$	$1.9 \cdot 10^{-6}$
$\bar{B}^0 \to D^{*+} b_1,\ D^{*+} a_2$	0	$2.9 \cdot 10^{-7}$	$1.5 \cdot 10^{-6}$
$\bar{B}^0 \to D^{*+} \pi(1300)$	$8.3 \cdot 10^{-6}$	$8.4 \cdot 10^{-6}$	$8.4 \cdot 10^{-6}$
$\bar{B}^0 \to D^{*+} \pi_2,\ D^{*+} \rho_3$	0	$5.7 \cdot 10^{-10}$	$3.2 \cdot 10^{-9}$
$\bar{B}^0 \to D^{*+} K_0^*(1430)$	$1.8 \cdot 10^{-5}$	$1.9 \cdot 10^{-5}$	$1.9 \cdot 10^{-5}$
$\bar{B}^0 \to D^{*+} K_2^*$	0	$1.5 \cdot 10^{-8}$	$7.7 \cdot 10^{-8}$

Table 6: Branching ratios for various decay modes obtained in QCD factorization for two choices of the renormalization scale μ. For comparison we also give the branching ratios in the naive factorization approach. We recall that we have set $f_{b_1} = 0$ for lack of better knowledge.

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designer modes in QCD factorization

[redacted] Beneke, Buchalla, Neubert, Sachrajda

- enhancement over naive factorization
- large scale dependence
- large strong phases
- much smaller than "non"-designer mode e.g. $Br(\bar{B}_0 \to D^+\pi^-) \sim 10^{-3}$

experimental program requires [thanks to Stefan Spanier for input]

- high luminosity
- good PID, π^0, γ
- angular analysis (a_0 vs a_2, K_0^* vs K_2)

INCLUDES:
- measurement of decay constants from τ-decay of a_0, $\pi(1300)$, K_0^*, b_1

	$a_0(980)$	$a_0(1450)$	$\pi(1300)$	$K_0^*(1430)$
theory f_X [MeV]	1.1	0.7	7.2	42
$Br(\tau \to X \nu_\tau)$	$3.8 \cdot 10^{-6}$	$3.7 \cdot 10^{-7}$	$7.3 \cdot 10^{-5}$	$7.7 \cdot 10^{-5}$

Cleo $Br(\tau \to \pi(1300)\nu) < 10^{-4}$

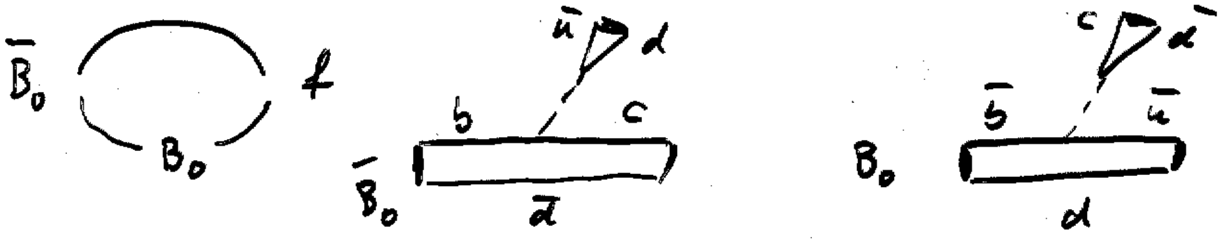
- measurement of distribution amplitudes of a_0, a_2, $\pi(1300)$, π_2 from $\gamma\gamma^*$ collisions $e^+e^- \to e^+e^- X$ similar to Cleo analysis for π, η, η'

Clean extraction of $2\beta+\gamma$ from $\bar{B} \to D^{(*)} M^{+}$

hep-ph/0105213

$M = a_0, a_2, \pi(1300), \ldots$ designer meson $I = 1$

$2\beta+\gamma$ from time dependence in $\bar{B} \to D^{\pm}(\pi^{\mp}, \rho^{\mp}, a_1^{\mp})$ Duniets et al



$V_{cb} V_{ud}^{*} \sim \lambda^2$ $\qquad$ $V_{ub}^{*} V_{cd} \sim \lambda^4$

<u>problem</u> : $Br(\bar{B} \to D^{+}\pi^{-}) \sim 10^{-3}$; $Br(B \to D^{+}\pi^{-}) \sim 10^{-6}$

$\Rightarrow$ $\sin(2\beta+\gamma)$ from small $O(1\%)$ asymmetry

$\oplus$ $\bar{B} \to D^{\pm} a_0$:

$$\frac{A(B_0 \to D^{+} a_0^{-})}{A(\bar{B}_0 \to D^{+} a_0^{-})} \simeq \frac{f_D}{f_{a_0}} \cdot \frac{\lambda^4}{\lambda^2} \sim O(1) \;!$$

$Br(\bar{B} \to D^{(*)} M^{-}) \sim 10^{-6}$ $\Leftrightarrow$ few % factoriz. breaking in $B \to D\pi$

- statistically competitive
- complementary
- method allows extraction of <u>strong</u> phases, which differ among the mesons M and are LARGE
- resolve ambiguity

brain storming

- designer mesons @ Giga Z ?
- Giga Z or 10 * Giga Z + good PID
  vs super babar ?

- detailed study of $B \to \tau \nu$, $b \to s \nu \bar{\nu}$
  inclusive decays
  some observables in rare B-decays are theoretically very clean
- inclusive $\Lambda_b \to X_s \gamma$?

$$Br(\Lambda_b \to X_s \gamma) \simeq \frac{1}{|F(0)|^2} Br(\Lambda_b \to \Lambda \gamma) \sim \text{few } 10^{-4}$$

- super babar: how asymmetric ?

- b-physics has UNIQUE observables to explore flavor / CP violation complementary to direct searches