# TESTING FACTORIZATION IN b-DECAYS

GUDRUN HILLER, SLAC

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outline:
- Why
- factorization concept
- status
- new ways
- conclusion

# theory issues in b-physics

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

In the SM the correct effective theory up to $\sim 1\,TeV$ ; could be probed by rare FCNC decays $b \to s\gamma$, $b \to s\ell^+\ell^-$, $b \to s q\bar{q}$

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

"QCD BGD" limits potential of **precision tests**

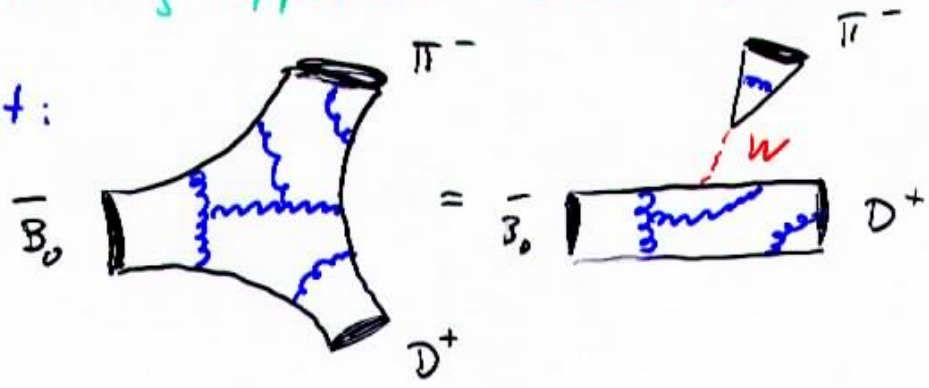
(+) many modes, many observables, many facilities

# factorization in Hadronic 2-body decays

naive factorization: A = (decay constant) × (form factor)

working hypothesis BSW '87

concept:




cut along W

color transparency: justification for some decays

Bjorken, Politzer Wise, Dugan Grinstein

e.g. $\bar{B}_0 \to D^+ \pi^-$

must fail for e.g. $\bar{B}_0 \to \pi^+ D^-$

no general theory for all 2-body decays

classifications: color allowed, color suppressed, heavy-light, ...

QCD based theories (color transparency) BBNS, KLS, Bauer et al

differ in power counting

test where (naive) factorization holds

and where corrections arise

▲ B decay data

■ prediction from τ-data

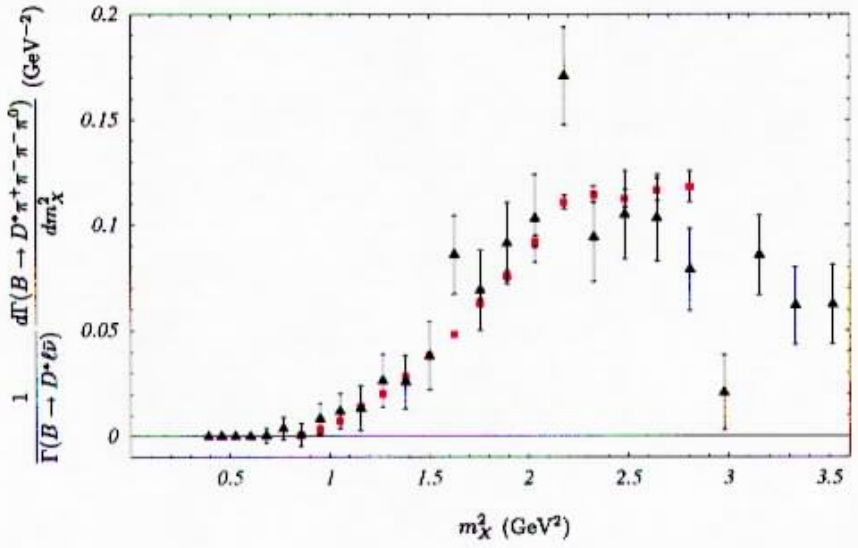



FIG. 1. $d\Gamma(B \to D^*\pi^+\pi^-\pi^-\pi^0)/dm_X^2$, where $m_X$ is the $\pi^+\pi^-\pi^-\pi^0$ invariant mass, normalized to the semileptonic width $\Gamma(B \to D^*\ell\bar{\nu})$. The triangles are the $B$ decay data, and the squares are our predictions using the $\tau$ data. There is an additional 9% uncertainty in the $B$ decay data from the overall normalization.

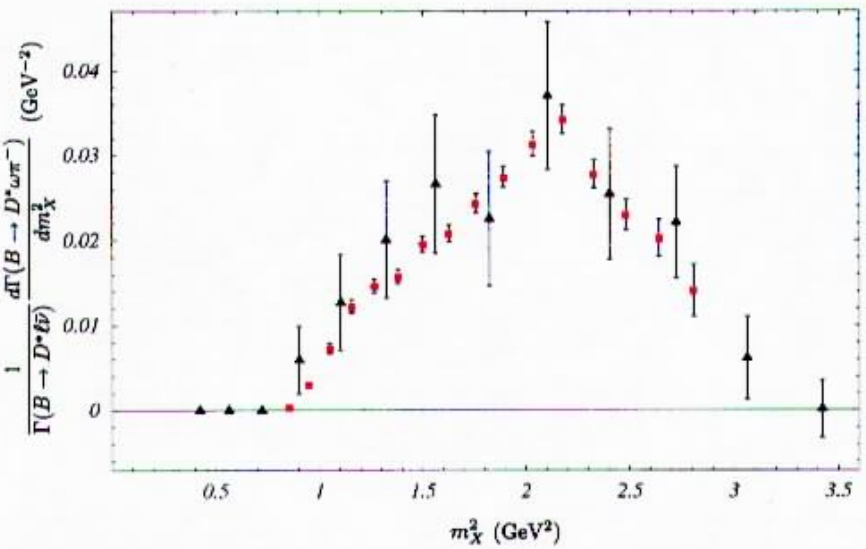



FIG. 2. $d\Gamma(B \to D^*\omega\pi)/dm_X^2$, where $m_X$ is the $\omega\pi^-$ invariant mass, normalized to the semileptonic width $\Gamma(B \to D^*\ell\bar{\nu})$. The triangles are the $B$ decay data, and the squares are our predictions using the $\tau$ data. There is an additional 9% uncertainty in the $B$ decay data from the overall normalization.

from Ligeti, Luke, Wise PLB 507, 142

# color allowed decays

tree level dominated / SM dominates

- $\bar{B}_0 \to D^{(*)+} (\pi, S, a_1)^-$ color transparency
  factorization ok $|a_1| = 1.1 \pm 0.1$
- $\bar{B}_0 \to D^{(*)+} X^-$ $X = 4\pi, \omega\pi$ Ligeti, Luke, Wise hep-ph/0103020
  CT if X fast $\frac{E_X}{m_X} >> 1$ → FIG
  → expect corrections for growing $m_X$ ( not in $1/N_c$ )
  "decay constant" from $\tau$-data
- no CT $A(\bar{B}_0 \to \pi^+ D^-_{(s)}) \sim V_{ub} F^{B\to\pi}_{(s)}(m^2_{D_{(s)}}) f_{D(s)}$
  $Br(\bar{B}_0 \to \pi^+ D_s^-) < 1.1 \cdot 10^{-4}$ 90% C.L. Belle 2001
  ok with factorization
- heavy-heavy $B \to D^{(*)} D_s^{(*)}$ no CT
  factorization holds within errors Luo Rosner hep-ph/0101089
  including penguins Kim et al, hep-ph/0108004
  dominant error: $f_{D_s} = 280 \pm 48$ MeV Cleo '98
  from $D_s \to \ell\nu$

factorization concept rules => improve precision to study corrections OR suppress factorizable contributions =>

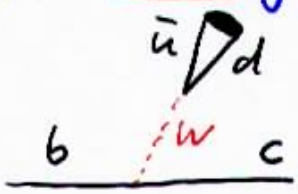
# exploring factorization with designer mesons

Diehl, G.H. hep-ph/0105194

Choose final state mesons whose

coupling to W is suppressed
either spin > 1 or decay constant is
e.g. isospin suppressed

- amplitudes in naive factorization are tiny or zero




$= 0$

$Br(\bar{B}_0 \to D^+ a_2^-)_{\text{naive}} = 0$

- power correction escape suppression

## EXAMPLES:

| $X$ | $a_0$ | $b_1$ | $\pi$ | $a_2$ | $a_0$ | $\pi_2$ | $\rho_3$ | $\pi$ | $a_4$ | $\chi_{c0}$ | $\chi_{c2}$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| $m_X$ [MeV] | 985 | 1230 | 1300 | 1318 | 1474 | 1670 | 1691 | 1801 | 2014 | 3415 | 3556 |
| $J^{PC}$ | $0^{++}$ | $1^{+-}$ | $0^{-+}$ | $2^{++}$ | $0^{++}$ | $2^{-+}$ | $3^{--}$ | $0^{-+}$ | $4^{++}$ | $0^{++}$ | $2^{++}$ |

| $X$ | $K_0^*$ | $K_2^*$ | $K_2$ | $K_3^*$ | $K_2$ | $K_4^*$ | $D_2^*$ | $D_{sJ}$ |
|---|---|---|---|---|---|---|---|---|
| $m_X$ [MeV] | 1412 | 1426 | 1773 | 1776 | 1816 | 2045 | 2459 | 2573 |
| $J^P$ | $0^+$ | $2^+$ | $2^-$ | $3^-$ | $2^-$ | $4^+$ | $2^+$ | $(2^+)$ |

scalars $\langle S(q)|\bar{q}\gamma^\nu q'|0\rangle = -i f_S q^\nu$

for $q'=q$ $f_S = 0$ by charge conjugation

$\Rightarrow$ $f_{\chi_{c0}} = 0$ ; $f_{a_0^\pm}, f_{b_1^\pm} \sim (m_u - m_d)$

($1^+$ single charm meson $D_{J=1}(j=3/2)$ with $f_{D_{J=1}}^{(\frac{3}{2})} = 0$ in heavy quark limit Oliver et al, hep-ph/9607300)

$f_{a_0} = 0.7 - 2.5$ MeV
$f_{K_0^*} = 33 - 46$ MeV
} Narison '89, Maltman hep-ph/9906267

$f_{\pi(1300)} = 0.5 - 7.2$ MeV Volkov and Weiss '97, Elias et al '97

measure decay constants of $a_0, \pi(1300), K_0^*, b_1$ in $\tau$-decays

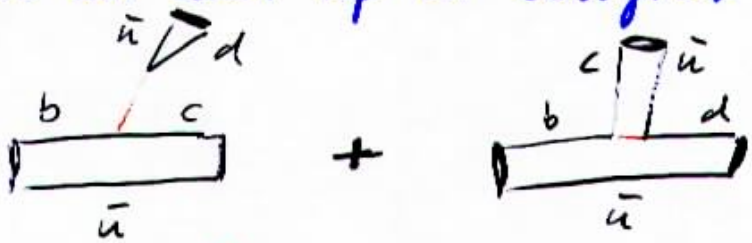
| $f_x$ [MeV] | $a_0(980)$ | $a_0(1450)$ | $\pi(1300)$ | $K_0^*(1430)$ |
|---|---|---|---|---|
| | 1.1 | 0.7 | 7.2 | 42 |
| $Br(\tau \to X \nu_\tau)$ | $3.8 \cdot 10^{-6}$ | $3.7 \cdot 10^{-7}$ | $7.3 \cdot 10^{-5}$ | $7.7 \cdot 10^{-5}$ |

CLEO: $Br(\tau \to \pi(1300)\nu_\tau) < 10^{-4}$

# flavor selection criteria → designer modes

spectator should not end up in designer

$B^- \to D^0 a_0^-$




suppressed

unsuppressed
(FF's are not anomalous Chernyak hep-ph/0102217)

$B^- \to a_0^0 a_0^-$ suppressed

- (+) many modes $B_0, B^+, B_s, \Lambda_b$ decays
- (+) many final states, cover wide range of masses
- (+) many topologies
  - color allowed decays
    - heavy – light
    - light – heavy
    - heavy – heavy
    - light – light
  - color suppressed decays
    - light – heavy
    - charmonium
    - light – light
  - baryons

color allowed

| example decay | factorizing contribution | | | annihilation | | |
|---|---|---|---|---|---|---|
| | quark level | tree | peng. | topology | tree | peng. |
| heavy-light: $\bar{B}^0 \to D^+ a_0^-$ | $\bar{d}b \to \bar{d}(c\bar{u}d)$ | $\lambda^2$ | | a | $\lambda^2$ | |
| $\to D^+ K_0^{*-}$ | $\to \bar{d}(c\bar{u}s)$ | $\lambda^3$ | | | | |
| $\bar{B}_s \to D_s^+ a_0^-$ | $\bar{s}b \to \bar{s}(c\bar{u}d)$ | $\lambda^2$ | | | | |
| light-heavy: $\bar{B}^0 \to \pi^- D_{sJ}^-$ | $\bar{d}b \to \bar{d}(u\bar{c}s)$ | $\lambda^3$ | | | | |
| $B^- \to \pi^0 D_2^{*-}$ | $\bar{u}b \to \bar{u}(u\bar{c}d)$ | $\lambda^4$ | | a | $\lambda^4$ | |
| $\to \eta D_2^{*-}$ | $\to \bar{u}(u\bar{c}d)$ | $\lambda^4$ | | a, c | $\lambda^4$ | |
| $\to \pi^0 D_{sJ}^-$ | $\to \bar{u}(u\bar{c}s)$ | $\lambda^3$ | | | | |
| $\to \eta D_{sJ}^-$ | $\to \bar{u}(u\bar{c}s)$ | $\lambda^3$ | | a, c | $\lambda^3$ | |
| $\bar{B}_s \to K^+ D_2^{*-}$ | $\bar{s}b \to \bar{s}(u\bar{c}d)$ | $\lambda^4$ | | | | |
| heavy-heavy: $\bar{B}^0 \to D^+ D_{sJ}^-$ | $\bar{d}b \to \bar{d}(c\bar{c}s)$ | $\lambda^2$ | $\lambda^2$ | a | | $\lambda^2$ |
| $B^- \to D^0 D_2^{*-}$ | $\bar{u}b \to \bar{u}(c\bar{c}d)$ | $\lambda^3$ | $\lambda^3$ | a | $\lambda^3$ | $\lambda^3$ |
| $\to D^0 D_{sJ}^-$ | $\to \bar{u}(c\bar{c}s)$ | $\lambda^2$ | $\lambda^2$ | a | $\lambda^4$ | $\lambda^2$ |
| $\bar{B}_s \to D_s^+ D_2^{*-}$ | $\bar{s}b \to \bar{s}(c\bar{c}d)$ | $\lambda^3$ | $\lambda^3$ | a | | $\lambda^3$ |
| light-light: $\bar{B}^0 \to \pi^+ K_2^{*-}$ | $\bar{d}b \to \bar{d}(u\bar{u}s)$ | $\lambda^4$ | $\lambda^2$ | a | | $\lambda^2$ |
| $B^- \to \pi^- \bar{K}_2^{*0}$ | $\bar{u}b \to \bar{u}(d\bar{d}s)$ | | $\lambda^2$ | a | $\lambda^4$ | $\lambda^2$ |
| $\to K^- K_2^{*0}$ | $\to \bar{u}(s\bar{s}d)$ | | $\lambda^3$ | a | $\lambda^3$ | $\lambda^3$ |
| $\bar{B}_s \to K^- a_2^-$ | $\bar{s}b \to \bar{s}(u\bar{u}d)$ | $\lambda^3$ | $\lambda^3$ | a | | $\lambda^3$ |

color transparency

Table 2: Color allowed decay modes $B \to YX$ satisfying the criteria specified in the text. $X$ is the meson emitted from the weak decay vertex. Any meson can be replaced by another with the same flavor structure and isospin, e.g, $D$ by $D^*$, $\pi$ by $\rho$, and the meson $X$ by an appropriate candidate from Table 1. The second column gives the quark composition of the final state, with the quarks originating from the $b$ decay enclosed in brackets. In the third and fourth columns we give the power of the Wolfenstein parameter $\lambda$ in the decay amplitude for tree level $W$ exchange and penguin operators, respectively. Annihilation contributions are listed with their topology as shown in Fig. 5 and the power of the Wolfenstein parameter for tree level and penguin operators.

hep-ph/0105194

color suppressed

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

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.

hep-ph/0105194

baryons

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

Table 4: Flavor structure of the decay modes of the $\Lambda_b$ and the $\Omega_b$ 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 fourth columns give the power of the Wolfenstein parameter $\lambda$ 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

- color suppressed into charmonium BELLE-CONF-0138

$$Br(B^+ \to \chi_{c0} K^+) = \left(8.0^{+2.7}_{-2.4} \pm 1.0 \pm 1.1\right) \cdot 10^{-4}$$

$$R = \frac{Br(B^+ \to \chi_{c0} K^+)}{Br(B^+ \to J/\psi K^+)} = 0.77^{+0.27}_{-0.23} \pm 0.11$$

O(1) violation of naive factorization $R_{naive} = 0$

[large single charm $Br(\bar{B}_0 \to D_0^{(*)} \pi^0)$ (CLEO, BELLE)
isospin analysis in $B \to D\pi$ Xing hep-ph/0107257, Neubert Petrov hep-ph/0108103

- light - light

$Br(B^+ \to (K_X(1400) \to K^+\pi^-)\pi^+) = \left(12.7^{+3.5+1.8+2.9}_{-3.4-1.8-5.8}\right) \cdot 10^{-6}$ BELLE hep-ex/0107051

$Br(B^+ \to K_0^{*} \pi^+) = (15.5 \pm 3.4 \pm 1.8) \cdot 10^{-6}$ BABAR hep-ex/0109007

| $K_X$ | $K_0^*$ | $K_2^*$ | $K^*(1410)$ |
|---|---|---|---|
| $Br(K_X \to K\pi)$ | 93% | 50% | 7% |

$Br_{naive}(B^+ \to K_2^* \pi^+) = 0$

$$Br(B^+ \to K \pi^+) = \begin{cases} 13.7^{+5.7+1.9}_{-4.8-1.8} \cdot 10^{-6} & \text{BELLE} \\ 18.2^{+3.3}_{-3.0} \pm 2.0 \cdot 10^{-6} & \text{BABAR} \end{cases}$$

$K, K_X$ comparable!

large contributions from scalar penguins $(\bar{q} L b)(\bar{s} R q)$

chirally enhanced for $K \sim \frac{2m_K^2}{m_b m_s}$ and $K_0^* \sim \frac{2m_{K_0^*}^2}{m_b m_s}$

compensate for $\frac{f_{K_0^*}}{f_K} \sim \frac{1}{4}$ suppression

$\to K_X \hat{=} K_0^*$ consistent with factorization Chernyak hep-ph/0102217, Diehl G.H. hep-ph/0105194

Exiting: measure $K_2^*$

Quantitatively: color allowed $B \to D^{(*)} X$ decays

$X = a_0, a_2, b_1, \pi(1300), \pi_2, 3_3$ and $K_0^*, K_2^*$

Diehl G.H. '01

$I=1$ generically $Br(B \to D^{(*)} (\pi, 3, a_1)) \sim 10^{-3}$

$\sim 10\%$ corrections to factorization $1/N_c^2$ ; $\frac{1}{m_b}$

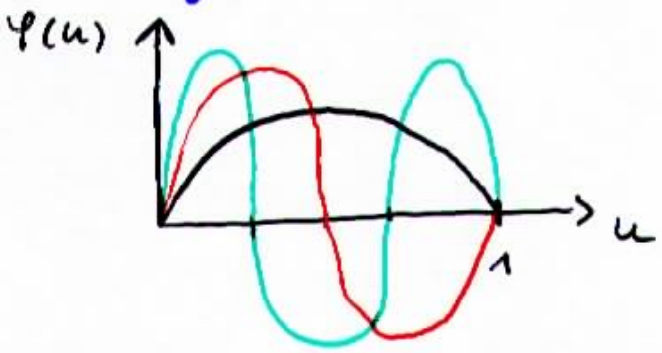
$\to Br(B \to D^{(*)} X) \sim 10^{-5} - 10^{-6}$

calculate branching ratios in QCD factorization (BBNS)

$$\langle D^+ X^- | \mathcal{H}_{eff} | B \rangle \sim a_1(\mu) f_X + \underbrace{\frac{\alpha_s(\mu)}{4\pi} C_2(\mu) \frac{C_F}{N_c} \int_0^1 du\, F(u)\, \varphi(u,\mu)}_{\text{from hard gluon exchange}}$$

in naive factorization: if $f_X = 0$ $\to$ amplitude vanishes

decay constant $f_X = \int_0^1 du\, \varphi(u)$ normalization $f_X \cong 0 \not\Rightarrow \varphi \cong 0$




$\pi, \pi(1300), \pi_2, 3_3$ : $\varphi(u) = \varphi(1-u)$

$a_0, a_2, b_1, K_0^*, K_2^*$ : $\varphi(u) = -\varphi(1-u)$

} up to isospin breaking

Estimate leading coefficients in Gegenbauer expansion from Fock state normalization similar to $\pi$

| 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 $\mu$. 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.

hep-ph/0105194

**Comments:**

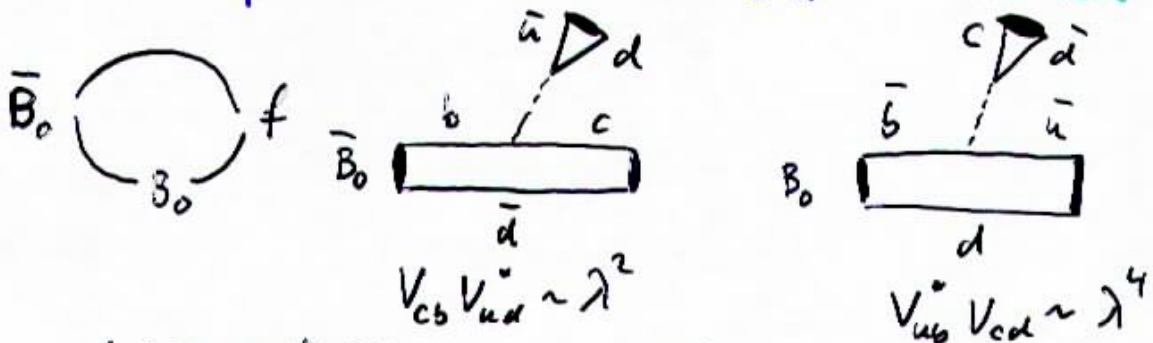
- similar Br's for $B_s \to D_s X$
- enhancement over naive factorization
- large scale dependence
- large strong phases
- Br's are much smaller than "non-designer" modes e.g. $B \to D\pi$

**current dominant uncertainties:**

- decay constants → measure in $\tau$-decays
- distribution amplitudes $\varphi$ → measure in $\gamma\gamma^*$ collision in $e^+e^- \to e^+e^- X$ for $a_0, a_2, \pi(1300), \pi_2$ similar to analysis for $\pi, \eta, \eta'$ CLEO '97

**measure strong phases as a byproduct from $2\beta+\gamma$**

time dependence a la $B \to D^{\pm}\pi^{\mp}$ Dunietz et al




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

Diehl, G.H. '01 hep-ph/0105213

- clean extraction of $2\beta+\gamma$ and strong phases
- statistically competetive to $B \to D\pi$ (small ~1% asymmetry)
- resolve ambiguity

# conclusions

- factorization in color allowed decays with CT
  $B \to D^{(*)} (\pi, \rho, a_1)$ and $B \to D^{(*)} (4\pi, \omega\pi)$
  and in $B \to D D_s$ works within errors
  → decrease error on $f_{D_s}$
  → analyze helicity structure in $B \to 1^- 1^-$ decays
  → await belle data
- power counting is controversial among QCD based theories → need to know size, and where they appear
- tests of factorization with modes where the factorizable contribution is suppressed
  → isolate power corrections
  similar to measure pure annihilation decays:
  $B_0 \to K^+ K^-$, $B_s \to \pi^+ \pi^-$, $B_s \to \pi^0 \pi^0$, $\not{B} \to$ baryon baryon
  → improve knowledge on non-perturbative input
  measure decay constants, distribution amplitudes
- "designer" final states and modes might be useful to study CPX $B \to a_0 \pi$ Laplace Shelkov hep-ph/0105252

  $Br(B^0 \to a_0^+(980)\pi^-) < 11.5 \cdot 10^{-6}$ 90% C.L. BaBar hep-ex/0107075