Hadronic and Semileptonic B decays at BaBar

Fulvio Galeazzi

on behalf of the BaBar collaboration

Dipartimento di Fisica
Università and I.N.F.N. Padova
e-mail: fulvio.galeazzi@pd.infn.it

8th February 2002
Outline

• Introduction

• Semileptonic decays:
  – semileptonic branching fractions ($\mathcal{B}$) of charged and neutral $B$ mesons
  – semileptonic $B$ branching fraction and $V_{cb}$ extraction from lepton tagged decays

• Hadronic decays:
  – $\mathcal{B}(B^+ \rightarrow D^0 K^+)/\mathcal{B}(B^+ \rightarrow D^0 \pi^+)$
  – $\mathcal{B}(B^0 \rightarrow D^{*-} K^+)/\mathcal{B}(B^0 \rightarrow D^{*-} \pi^+)$
  – $B \rightarrow D^* D^*$ decays
  – $B \rightarrow D \overline{D} K$ decays

• Conclusions

Results to be updated
for upcoming conferences
(based on a data sample of 60 fb$^{-1}$)
**Introduction**

**Things in common to many analysis:**

**Integrated luminosity:** unless otherwise stated, results are based on the 1999-2000 statistics: \( \int L = (20.6_{\text{On}} + 2.5_{\text{Off}}) \text{ fb}^{-1} \)

**“Breco sample”:** sample of fully reconstructed B decays in the modes: \( B \rightarrow D^{(*)}\pi, \, D^{(*)}\rho, \, D^{(*)}a_1, \, J/\Psi K^{(*)}, \, \Psi_{(2S)} K^{(*)} \)

(B flavor is tagged)

\((\Delta E, m_{\text{ES}}) \text{ variables:} \) highly uncorrelated variables used in \( B \) mesons reconstruction, defined as:

\[
\Delta E = E_B^* - \sqrt{s}/2
\]

\[
m_{\text{ES}} = \sqrt{(\sqrt{s}/2)^2 - p_B^*}^2
\]
Semileptonic decays: $\mathcal{B}(B^\pm)/\mathcal{B}(B^0)$

- measuring this ratio is the same as:

$$\frac{\mathcal{B}(B^\pm)}{\mathcal{B}(B^0)} = \frac{\Gamma_{sl}^\pm/\Gamma_{tot}^\pm}{\Gamma_0^0/\Gamma_{tot}^0} = \frac{\Gamma_{tot}^\pm}{\Gamma_{tot}^0} = \frac{\tau_{B^\pm}}{\tau_{B^0}}$$

as the semileptonic width is expected to be the same for B mesons if the light quark does not play a major role.

- interactions of both the decaying quark and the decay products with other partons might yield to a difference in lifetimes no bigger than 10 %

- best measurement of the ratio of inclusive branching fractions is from CLEO: \( R = 0.950^{+0.117}_{-0.080} \pm 0.091 \)

**This measurement:**

- select events from the Breco sample
- measure the lepton (electron) spectrum of the other B
  - muons to be added
- correlate lepton and B charge/flavor to distinguish prompt from cascade leptons
- extrapolate to full electron spectrum
Semileptonic decays: $\mathcal{B}(B^\pm)/\mathcal{B}(B^0)$

**Event selection:**

- Breco modes (purities: $B^\pm : 84.4 \pm 0.4 \%$, $B^0 : 81.6 \pm 0.4 \%$)
- Extra selection:
  - event: $R_2 < 0.5$, $N_{trk}^{tot} - N_{trk}^{B_{reco}} \geq 1$
  - charged tracks: $p^* > 0.5 \text{ GeV}/c$, $p_{lab} > 0.5 \text{ GeV}/c$, $\theta$ in EMC angular acceptance, DoCA
  - electrons: identified by combining info from DCH, DRC, EMC

**Backgrounds:**

- $\gamma \rightarrow e^+e^-$, $\pi^0 \rightarrow e^+e^-\gamma$, $J/\Psi \rightarrow e^+e^-$
- hadron misidentification
- physics processes:
  - *right-sign* electrons: $B^+ \rightarrow X\tau^+\nu_\tau$, $\tau^+ \rightarrow e^+\nu_e\bar{\nu}_\tau$
  - *right-sign* electrons: $B^+ \rightarrow D_s^+\bar{D}$, $D_s^+ \rightarrow Xe^+\nu_e$
  - *right-sign* electrons: $B \rightarrow D\bar{D}K$
  - *wrong-sign* electrons: from opposite-sign cascade $c$ decays
- mistagged events, imperfectly reconstructed events
Semileptonic decays: $\mathcal{B}(B^+) / \mathcal{B}(B^0)$

Events are subdivided into 4 categories, for charged/neutral $B$ decays leading to right/wrong sign electrons.

**Charged $B$:**
\[
N_{\text{right}}^+ = N_{\text{prompt}}^+ \\
N_{\text{wrong}}^+ = N_{\text{secondary}}^+
\]

**Neutral $B$ ($\chi_d$ mixing parameter):**
\[
N_{\text{right}}^0 = N_{\text{prompt}}^0 (1 - \chi_d) + N_{\text{secondary}}^0 \chi_d \\
N_{\text{wrong}}^0 = N_{\text{prompt}}^0 \chi_d + N_{\text{secondary}}^0 (1 - \chi_d)
\]

**left plot:**
\[
N_{\text{prompt}}^+ = 674 \pm 34 \\
N_{\text{secondary}}^+ = 184 \pm 21
\]

**right plot:**
\[
N_{\text{prompt}}^0 = 597 \pm 38 \\
N_{\text{secondary}}^0 = 285 \pm 25
\]

Extrapolating to full spectrum:
\[
\mathcal{B}(B^+ \to Xe\nu) = (10.3 \pm 0.6 \pm 0.5) \% \\
\mathcal{B}(B^0 \to Xe\nu) = (10.4 \pm 0.8 \pm 0.5) \% \\
\mathcal{B}(B \to Xe\nu) = (10.4 \pm 0.5_{\text{stat}} \pm 0.5_{\text{sys}}) \% \\
\frac{\mathcal{B}(B^+ \to Xe\nu)}{\mathcal{B}(B^0 \to Xe\nu)} = 0.99 \pm 0.10_{\text{stat}} \pm 0.04_{\text{sys}}
\]
**Semileptonic $B$ and $V_{cb}$ measurement**

- analysis based on 4.1 fb$^{-1}$ On and 0.97 fb$^{-1}$ Off peak data
- tag semileptonic decays by means of a high momentum lepton (electron)

**Event selection:**
- event shape variable $R_2$
- $N_{ch} \geq 4$ and $N_{ch} + \frac{1}{2}N_{neu} \geq 5$

**Electron selection (signal electron):**
- only charged tracks in EMC acceptance
- $p^* > 0.5$ GeV/c
- likelihood based
- no overlap with $\gamma$ conversion, $\pi^0$ Dalitz decays or $J/\Psi$

**Tagging electron:**
- $1.4 < p^* < 2.3$ GeV/c
Semileptonic $B$ and $V_{cb}$ measurement

Form dilepton pairs of tag electrons and signal electrons and separate into same-sign and opposite-sign pairs.

Opposite-sign case: important background from the process

$$\bar{B} \to X_c e_{\text{tag}} \nu, \; X_c \to Y e_{\text{signal}}^+ \nu$$

largely eliminated by combined cut on $p^*$ and angle between electrons.

$$\cos \alpha_{oa} > -0.2$$
$$\cos \alpha_{oa} + p^* > 1$$
($\epsilon_{MC} = 54.5\%$, purity $= 95.8\%$)

Remaining background estimated from fit to $\cos \alpha_{oa}$ distribution.
Semileptonic $B$ and $V_{cb}$ measurement

After corrections for other background processes, one can derive the spectra for prompt and cascade electrons from $B$ (equal production of $B^+$ and $B^0$ is assumed):

**Prompt Electrons from B**

**Cascade Electrons**

$$\mathcal{B}(B \to Xc\nu) = (10.81 \pm 0.21 \pm 0.38) \%$$

Removing the small contribution from $V_{ub}$ one can extract$^\dagger$:

$$|V_{cb}| = 0.0411 \left( \frac{\mathcal{B}(B \to Xc\nu)}{0.105} \frac{1.55 \text{ ps}}{\tau_b} \right)^{1/2} \times (1.0 \pm 0.015_{\text{pert}} \pm 0.010_{m_b} \pm 0.012_{1/m_Q})$$

$$|V_{cb}| = 0.0408 \pm 0.0004_{\text{stat}} \pm 0.0008_{\text{sys}} \pm 0.0020_{\text{theory}}$$

CLEO: $|V_{cb}| = 0.040 \pm 0.001_{\text{exp}} \pm 0.002_{\text{theory}}$

BELLE: $|V_{cb}| = 0.0404 \pm 0.0010 \pm 0.0020$

Measurement of $\mathcal{B}(B^- \rightarrow D^0 K^-)/\mathcal{B}(B^- \rightarrow D^0 \pi^-)$

Main motivation is that $\mathcal{B}(B^- \rightarrow D^0 K^-)$ is a fundamental ingredient in some of the methods proposed to extract $\gamma$ of the CKM matrix.

- $D^0$ reconstruction:
  - reconstructed modes: $D^0 \rightarrow K^- \pi^+, K^- \pi^+ \pi^- \pi^+$
  - $D$ candidates selected in a mass window, then constrained fit is applied

- $B$ reconstruction:
  - combine a $D$ with a charged track having same charge as the kaon from $D$ decay
  - hadron is not identified: assuming one particle hypothesis, channels are separated in $\Delta E$ projection

Main background comes from:

- continuum events $\Rightarrow$ cut on event shape variables ($R_2$ and $\theta_{\text{thrust}}$)

- $B\overline{B}$ events $\Rightarrow$ estimate from MC
Measurement of $\mathcal{B}(B^- \rightarrow D^0 K^-)/\mathcal{B}(B^- \rightarrow D^0 \pi^-)$

MonteCarlo $\Delta E$ distributions

Data, before background subtraction (case $D^0 \rightarrow K\pi$)

An unbinned maximum likelihood fit is performed separately for each $D^0$ decay mode. The fit also depends on the PID information (mainly from DRC)
Measurement of $\mathcal{B}(B^{-} \rightarrow D^{0}K^{-})/\mathcal{B}(B^{-} \rightarrow D^{0}\pi^{-})$

**$D^{0} \rightarrow K\pi$**

**$D^{0} \rightarrow K\pi\pi\pi$**

Averaging over the three modes:

$$\frac{\mathcal{B}(B^{-} \rightarrow D^{0}K^{-})}{\mathcal{B}(B^{-} \rightarrow D^{0}\pi^{-})} = (8.3\pm0.6\pm0.3)\%$$

Most recent measurements:

- CLEO: $R = (5.5 \pm 1.4 \pm 0.5)\%$
- Belle: $R = (7.9 \pm 0.9 \pm 0.6)\%$

---

*Hadronic and semileptonic decays at BaBar, Aspen 2002, Fulvio Galeazzi*
Measurement of $\mathcal{B}(B^0 \rightarrow D^*-K^+)/\mathcal{B}(B^0 \rightarrow D^*-\pi^+)$

Provides a test of the factorization hypothesis, which predicts:

$$R_{K/\pi} = 7.4\%$$

K channel is Cabibbo-suppressed, hence use partial reconstruction technique to gain statistics.

- search for a soft pion charge-anticorrelated with a fast kaon/pion
- fast hadron in narrow momentum window: $2.1 \lesssim p_f \lesssim 2.4$ GeV/c
- reconstructed recoil mass should peak at the $D^0$
Measurement of $\mathcal{B}(B^0 \to D^*-K^+)/\mathcal{B}(B^0 \to D^*-\pi^+)$

**Main Backgrounds:**

- Continuum events $\implies$ rejected with cut on R2, isolation of fast track and Fisher combination
- $\pi$ misidentification $\implies$ heavily relies on DRC
- Peaking background (ex. channels with $D^{**}$, $\rho$, $K^*$) $\implies$ largely removed by cut on $p_f^*$

Upper band: $L_\pi/L_K > 1000$
Lower band: $L_K/L_\pi > 1000$

$\pi$ and $K$ efficiency and misID studied with a sample of fully reconstructed $D^{**} \to \pi^+D^0 \ D^0 \to K^-\pi^+$
Measurement of $\mathcal{B}(B^0 \to D^{*-} K^+)/\mathcal{B}(B^0 \to D^{*-} \pi^+)$

Fit to recoil mass spectrum (5 parameters)

**π channel**

**K channel**

Signal $\pi = 4170 \pm 101$ events, signal $K = 371 \pm 48$

$K$ channel crossfeed = $130 \pm 12$

$$\frac{\mathcal{B}(B^0 \to D^{*-} K^+)}{\mathcal{B}(B^0 \to D^{*-} \pi^+)} = (6.6 \pm 1.3 \pm 0.6) \%$$

in agreement with the factorization prediction.
\( B^0 \rightarrow D^{*+}D^{*-} \) decays

- can provide a measurement of \( \sin 2\beta \)
- all charge combinations selected, but \((D^{*+}D^{*-}) \rightarrow (D^+\pi^0, D^-\pi^0)\) due to high backgrounds

Event selection based on cut on \( R_2 \) and \( \cos \theta_{\text{thrust}} \)
Best \( B \) selected by using \( \Delta E \), \( m_{\text{ES}} \) and \( \chi^2_{\text{Mass}} \), where

\[
\chi^2_{\text{Mass}} = \sum_{i=D, D^*} \left( \frac{m_i - m_{i,\text{PDG}}}{\sigma_m} \right)^2
\]

\( \mathcal{B}(D^{*+}D^{*-}) = (8.3 \pm 1.6 \pm 1.2) \cdot 10^{-4} \)
$B^0 \rightarrow D^{*+}D^{*-}$ decays

Angular analysis

Decay to two vector particles contains S, P, D waves which different CP parities $\implies$ observed CP asymmetry would be diluted.

An angular analysis is required to separate CP-even and CP-odd amplitudes.
One introduces 3 amplitudes $A_0$ and $A_{//}$ (CP-even), and $A_{\perp}$ (CP-odd) and the quantity

$$R = \frac{|A_{\perp}|^2}{|A_0|^2 + |A_{//}|^2 + |A_{\perp}|^2}$$

to be determined in the transversity basis from

$$\frac{1}{\Gamma} \frac{d\Gamma}{d \cos \theta_{tr}} = \frac{3}{4} (1 - R) \sin^2 \theta_{tr} + \frac{3}{2} R \cos^2 \theta_{tr}$$
$B^0 \rightarrow D^{*+}D^{*-}$ decays

An unbinned maximum likelihood fit is performed on the events in the sideband (left) and in the signal (right) regions.

- background is expected to show a flat distribution in $\cos \theta_{tr}$, corresponding to $R = 1/3$.

![Histograms of $\cos(\theta_{tr})$ for sideband and signal regions](image)

**Fit results:**

$R^{bkg} = 0.29 \pm 0.04$ (compatible with $\frac{1}{3}$)

$R^{sig} = 0.22 \pm 0.18 \pm 0.03$ ($R^{sig} < 0.63$ at 95% c.l)
$B \to D(\ast)\overline{D}(\ast)K$ modes

- it was expected that charmed-anticharmed mesons would be produced mainly via transitions $b \to \overline{c}W$ with $W \to c\overline{s}$ hadronizing as a $D_s$

- however, $b \to c\overline{c}s$ rate estimated from $B_{SL}$ inconsistent with sum of exclusive modes

- hence, other $b \to c\overline{c}s$ processes must exist, like $B \to D\overline{D}K$, indeed observed at CLEO and ALEPH

All charge combinations are reconstructed for both $B^\pm$ and $B^0$
$B \rightarrow D^{(*)} \overline{D}^{(*)} K$ modes

- Intermediate particles $D^*$, $D$, $K_S^0$ are mass-constrained
  - $D$ modes reconstructed: $D^0 \rightarrow K^-\pi^+$, $K^-\pi^+\pi^0$, $K^-\pi^+\pi^-\pi^+$ and $D^+ \rightarrow K^-\pi^+\pi^+$
  - $D^*$ modes reconstructed: $D^{*0} \rightarrow D^0\pi^0$, $D^0\gamma$ and $D^{*+} \rightarrow D^0\pi^+$

Distributions for the sum of all the charged $B$ modes
(duplicates not removed)
$B \rightarrow D^{(*)} \overline{D}^{(*)} K$ modes

$B^{+} \rightarrow D^{*-} D^{*+} K^{+}$

$B^{0} \rightarrow D^{*-} D^{(*)0} K^{+}$

No reconstruction of $\pi^0$ or $\gamma$ from $D^{*0}$

$m_{ES}$ projections:
$D^{0}$ (up), $D^{*0}$ (down)

$\mathcal{B}(B^{+} \rightarrow D^{*-} D^{*+} K^{+}) = (3.4 \pm 1.6 \pm 0.9) \cdot 10^{-3}$ (8.2 events)

$\mathcal{B}(B^{0} \rightarrow D^{*-} D^{0} K^{+}) = (2.8 \pm 0.7 \pm 0.5) \cdot 10^{-3}$ (29.6 events)

$\mathcal{B}(B^{0} \rightarrow D^{*-} D^{*0} K^{+}) = (6.8 \pm 1.7 \pm 1.7) \cdot 10^{-3}$ (59.6 events)

---

Hadronic and semileptonic decays at BaBar, Aspen 2002, Fulvio Galeazzi
Conclusions

• Huge data set makes it possible to study a vast physics program

• Expect analysis to be updated (and completed) soon...
  – larger data sample
  – systematic error reduction