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Recent b physics results from DELPHI

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Recent b physics results from the DELPHI collaboration are presented, including the branching fraction to B_u^+, the b fragmentation function, the production of orbitally exited B states, the determination of $|V_{cb}|$ using exclusive decays, determination of non-perturbative Operator Product Expansion parameters and the value of Δm_d and the limit on Δm_s from $B^0 - \bar{B}^0$ mixing.

1. INTRODUCTION

The DELPHI detector was dismantled in 2000 together with the three other LEP experiments, yet a considerable number of analysis related to b physics are still being worked on in the DELPHI collaboration, with new results to be published.

The results presented here can be divided into two categories; those related to the production of the B hadrons at LEP, and those striving to measure the parameters of the Cabibbo-Kobayashi-Maskawa (CKM) mixing matrix. New results related to the former are measurement of b branching fractions, b fragmentation function and production rates of excited B states. On topics related to the CKM matrix, there are a new measurement of $|V_{cb}|$ using exclusive decays, work done to measure Operator Product Expansion (OPE) parameters using statistical moments of the lepton energy spectrum and the hadron mass spectrum in semileptonic B decays, the determination of Δm_d from $B_d^0 - \bar{B}_d^0$ oscillations and searches for $B_s^0 - \bar{B}_s^0$ oscillations.

2. B HADRON PRODUCTION

2.1. Branching fractions

To measure the branching fractions of b quarks into charged and neutral b-hadrons, the charge of the weakly decaying b hadron in each event is reconstructed as a weighted sum of the individual particle charges using a dedicated Neural Net, as described in [1]. Using simulated DELPHI-data, the expected distributions for the charge estimator Q_B are obtained for positively and negatively charged, and neutral, b-hadrons. To measure the branching fractions, these expected distributions are fitted to the distribution observed in data (Figure 1), resulting in charged branching fraction of $f^+ = (42.09 \pm 0.82(\text{stat}) \pm 0.89(\text{syst}))\%$. When contributions

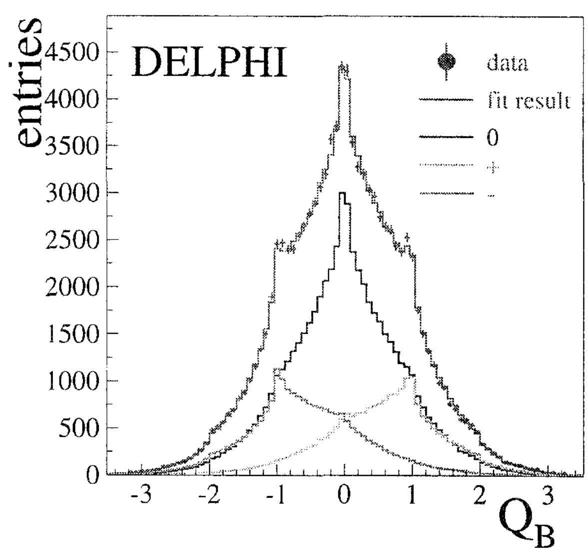

Figure 1. The weak b-hadron decay vertex charge Q_B for the data (points with error bars) with the result of the fit superimposed (solid histogram). The shapes for neutral, negatively charged and positively charged b-hadrons from the simulation are also shown.

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from charged baryons $\bar{\Xi}_b^+$, $\bar{\Omega}_b^+$ are subtracted, the branching fraction to B^+ mesons is found to be $f_{B_u^+} = (40.99 \pm 0.82(\text{stat}) \pm 1.11(\text{syst}))\%$, which is the single most precise measurement of a specific b-hadron branching fraction, and comparable to the accuracy achieved by combining all other information available on b-hadron production fractions.

2.2. Fragmentation function

There are three variables that are of interest when studying the fragmentation function, z, x_B^{prim} and x_B^{weak}, defined as

$$z = \frac{(E + p_{||})_B}{(E + p)_b} \tag{1}$$

and

$$x_B^{\text{prim(weak)}} = \frac{2E_{B^{\text{prim(weak)}}}}{\sqrt{s}}. \tag{2}$$

The distributions of each of the three variables are reconstructed using a Neural Network[2]. Assuming that the reconstructed distribution $g(v_{rec})$ is convoluted from the true distribution $f(v)$ with a response function $R(v_{rec}, v)$, and that there is an additional contribution from background $b(v_{rec})$,

$$g(v_{rec}) = \int R(v_{rec}, v) f(v)\, dv + b(v_{rec}), \tag{3}$$

unfolding is performed to obtain the true distribution. The unfolded distributions for the three variables are depicted in Figure 2. The shapes of the measured distributions differ significantly from the distributions used in simulation. The mean values of the unfolded distributions and their uncertainties are tabulated in Table 1.

Table 1
The means of unfolded distributions in x_B^{prim}, x_B^{weak} and z. The first uncertainty is statistical and the second systematical.

	Mean
$f(x_B^{\text{prim}})$	$0.7346 \pm 0.0008 \pm 0.0055$
$f(x_B^{\text{weak}})$	$0.7153 \pm 0.0007 ^{+0.0049}_{-0.0052}$
$f(z)$	$0.8872 \pm 0.0012 \pm 0.0054$

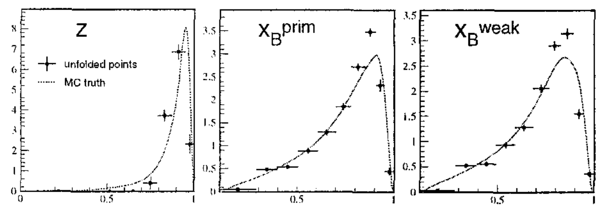

Figure 2. The result of unfolding z, x_B^{prim} and x_B^{weak} from real data. The point represent the unfolding results and the overlayed histograms show the input Monte Carlo distributions. The errors are statistical only.

2.3. Excited states

When measuring the production rates of orbitally excited B states, good control of the background is essential. Two different approaches have been taken, one maximizing the efficiency and the other the purity of the event selection[3]. In the high efficiency case, the background is measured using a signal-depleted sample and performing a simultaneous fit to signal enriched and signal depleted samples. The channels that are considered are $\bar{B}_u^{**} \to \bar{B}_d^0 \pi^-$ and $\bar{B}_d^{**} \to B^- \pi^+$. In the high purity approach the shape of the background is taken from simulation, while the normalization is left free when performing the fit. The high purity approach is based on identification of the π mesons produced in the decay.

The high efficiency approach gives for the narrow state

$$\frac{\sigma(B_{u,d}^{**}) \cdot BR(B_{u,d}^{**} \to B^{(*)}\pi)}{\sigma_b} = (12.2 \pm 1.4 \pm 1.8)\%$$

and the corresponding number obtained from the high purity approach is

$$\frac{\sigma(B_{u,d}^{**}) \cdot BR(B_{u,d}^{**} \to B^{(*)}\pi)}{\sigma_b} = (14.3 \pm 1.4 \pm 1.8)\%.$$

The narrow B_s^{**} production rate was measured to be

$$\frac{\sigma(B_s^{**}) \cdot BR(B_s^{**} \to B^{(*)}\pi)}{\sigma_b} = (1.0 \pm 0.2 \pm 0.03)\%.$$

3. CKM MATRIX ELEMENTS

3.1. V_{cb} using $\bar{B}_d^0 \to D^{*+}\ell^-\bar{\nu}_\ell$

The differential partial width of decay $\bar{B}_d^0 \to D^{*+}\ell^-\bar{\nu}_\ell$ is

$$\frac{d\Gamma}{dw} = \frac{G_F^2|V_{cb}|^2}{48\pi^3}\mathcal{K}(w)\mathcal{F}_{D^*}^2(w), \quad (4)$$

where

$$w = \frac{m_{D^{*+}}^2 + m_{\bar{B}_d^0}^2 - q^2}{2m_{\bar{B}_d^0}m_{D^{*+}}} \text{ and } q^2 = (p_{\bar{B}_d^0} - p_{D^{*+}})^2.$$

In order to measure this partial width and extract the value of V_{cb}, decays $D^0 \to K^-\pi^+$, $D^0 \to K^-\pi^+\pi^+\pi^-$ and $D^0 \to K^-\pi^+(\pi^0)$ are reconstructed[4]. Signal events are selected based on the reconstructed D^0 mass $m(D^0)$ and the mass difference $\delta m = m(D^0\pi^+) - m(D^0)$. Performing

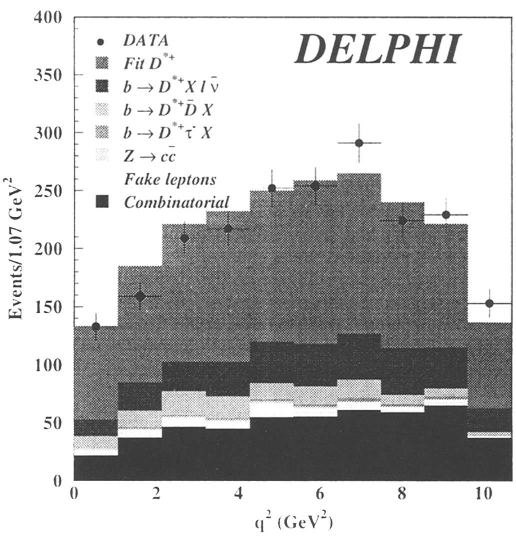

Figure 3. Fit on real data events. Only events selected within the δm mass interval corresponding to the D^{*+} signal are shown.

a simultaneous fit to several distributions, including the q^2 distribution (Figure 3), allows the evaluation of the signal and background contributions in the selected sample, resulting in

$$\mathcal{F}_{D^*}(1)|V_{cb}| = 0.0392 \pm 0.0018 \pm 0.0022,$$

$$\rho_{A_1}^2 = 1.32 \pm 0.15 \pm 0.33 \text{ and}$$

$$\mathrm{BR}(\bar{B}_d^0 \to D^{*+}\ell^-\bar{\nu}_\ell) = (5.90 \pm 0.22 \pm 0.48)\%.$$

Combined with the inclusive measurement of $|V_{cb}|$ by DELPHI collaboration[5] and using $\mathcal{F}_{D^*}(1) = 0.91 \pm 0.04$, $|V_{cb}|$ is measured to be

$$|V_{cb}| = 0.0414 \pm 0.0012 \pm 0.0021 \pm 0.0018(\text{theory}).$$

3.2. OPE parameters

The theoretical uncertainty on the exctraction of $|V_{cb}|$ is significant compared to the statistical accuracy. The uncertainty is due to uncertainties in the modelling of semileptonic b decays, and can be reduced through determination of parameters used in the models, m_b, m_c, μ_π^2 (or λ_1, $\bar{\Lambda}$). The values of these parameters can be measured from the hadronic mass spectrum and the lepton energy spectrum in $B \to X_c\ell\bar{\nu}$ decays. The DELPHI collaboration has measured the first three statistical moments of these two spectra [6,7]. Using expressions relating the values of the moments to the parameters of the model, a common intersection in multi-parameter space (Figure 4) is found, with the values tabulated in Table 2[8].

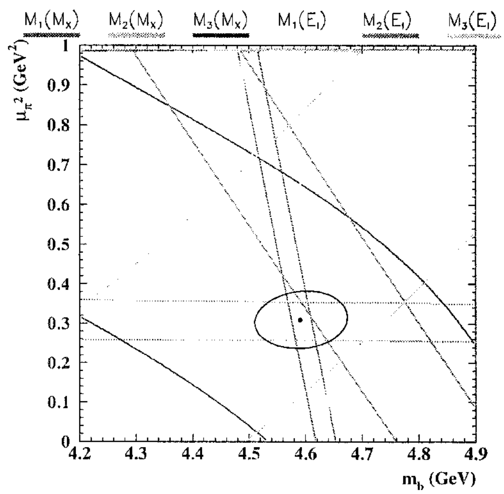

Figure 4. Intersection of the bands defined by the measured moments projected on m_b-μ_π^2 plane.

Table 2
The parameter values corresponding to the intersection of bands defined by the moments.

Fit Param.	Fit Val	Fit Uncert.	Syst. Uncert.	
$m_b(1\ \mathrm{GeV})$	4.59	±0.08	±0.01	GeV
$m_c(1\ \mathrm{GeV})$	1.13	±0.13	±0.03	GeV
$\mu_\pi^2(1\ \mathrm{GeV})$	0.31	±0.07	±0.02	GeV^2
ρ_D^3	0.05	±0.04	±0.01	GeV^3

3.3. $B^0 - \bar{B}^0$ mixing

The $B_q^0 - \bar{B}_q^0$ mass difference Δm_q ($q = d, s$) is related to the CKM matrix elements,

$$\Delta m_q = |V_{tq}|^2 |V_{tb}|^2 m_{B_q} m_t^2 f_{B_q}^2 B_{B_q} \eta_B \frac{G_F^2}{6\pi^2} F(\frac{m_t^2}{m_W^2}) \quad (5)$$

Even though Δm_d is sufficient to constrain the unitarity triangle, the ratio of the two mass differences would be more valuable, as some of the uncertainties cancel,

$$\frac{\Delta m_d}{\Delta m_s} = \frac{m_{B_d} f_{B_d}^2 B_{B_d} \eta_{B_d}}{m_{B_s} f_{B_s}^2 B_{B_s} \eta_{B_s}} \frac{|V_{td}|^2}{|V_{ts}|^2}. \quad (6)$$

The value of Δm_d has been measured to be

$$\Delta m_d = (0.531 \pm 0.025 \pm 0.007)\mathrm{ps}^{-1}[9].$$

As B_s mesons are not produced at B-factories, it is important to extract all possible information on Δm_s from DELPHI and other LEP experiments. For the measurement of Δm_s DELPHI has several approaches. The most powerful approach is the one profitting from high transverse momentum leptons for identifying the charge of the decaying b-hadron[10]. Also the reconstruction of a D_s meson in connection with a lepton[10] has a good resolution, but it suffers from low statistics. The third approach uses inclusively reconstructed vertices without high transverse momentum leptons[9], where the statistics is very large, but the charge identification is not as pure as in the other cases. When the results of all three approaches are combined, a limit of $\Delta m_s > 8.5\,\mathrm{ps}^{-1}$ is obtained with a sensitivity of 12.0 ps^{-1} at 95 % confidence level[11].

4. CONCLUSIONS

There are still several B physics topics actively studied in DELPHI. Some of the work is improvement of earlier results, such as the measurement of production rates of orbitally excited B states, the determination of $|V_{cb}|$ and the measurement of Δm_s from $B^0 - \bar{B}^0$ oscillations. There are also new studies, like the measurement of B_u^+ branching fraction and the b fragmentation function, and the determination of the OPE parameters. Some of the results presented are still preliminary, with final results expected to be published soon.

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