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New measurement of the charged particle multiplicity of weakly decay B hadrons with the DELPHI detector at LEP

Preliminary

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Abstract

A sample of events enriched in b quarks was selected in the data collected in 1994 with the DELPHI detector at LEP. The charged particle multiplicity of weakly decaying B hadrons was precisely measured using the particles in the hemisphere opposite the one containing the tagged b quark. The result is given as a function of the b purity and using two different b tagging methods.

The difference between the number of tracks with positive and negative lifetime sign impact parameter is used to estimate the charged multiplicity, which is found to be:

$$n_B = 4.96 \pm 0.03 \pm 0.05.$$

A second measurement was done, counting the number of charged tracks coming from a reconstructed secondary vertex, giving a consistent result with the first analysis.

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1 Introduction

An important parameter needed in electroweak measurements concerning the b quark is the charged track multiplicity of weakly decaying B-hadrons, n_B. Measurements of the charged particle multiplicities of B hadron decays have been performed previously by CLEO [1], ARGUS [2], OPAL [3] and DELPHI [4]. The first two results apply to equally mixed samples of B_d^0 and B^+ mesons, whereas the others concern samples of B hadrons containing all weakly decaying B particles as obtained in the fragmentation of a b-quark jet at high energy.

In 1994 a large sample of Z decays has been collected by the DELPHI experiment with a new Vertex Detector [5] capable of measuring the three space coordinates, thus improving considerably the b-tagging performance. In addition, a major improvement of the reconstruction program has greatly enhanced the tracking efficiency. The improved b purity allows a better measurement of n_B. Two methods were used, one based on the sign of the track impact parameters and the other based on reconstructed secondary vertices.

The value of n_B is extracted by comparing real data and simulation, and the dominant systematic errors are computed.

2 The DELPHI Detector

The DELPHI detector and its performances have been described in detail in ref.[6, 7]. Here only the new Vertex Detector (VD) [5], that is the most relevant detector used in this analysis, will be described.

The VD is the innermost detector in DELPHI. It is located between the LEP beam pipe and the Inner Detector. To increase the performance of the detector in tracking and especially in the identification of B hadrons, in 1994 the DELPHI microvertex detector [8] was upgraded to provide a three-dimensional readout [5]. It consists of three concentric layers of silicon microstrip detectors at radii of 6.3, 9 and 11 cm from the beam line, called respectively closer, inner and outer layer. The microstrip detectors of the closer and outer layers provide hits in the $R\Phi$ and the Rz-plane [2], while for the inner layer only the $R\Phi$ coordinate is measured. For polar angles of $44° \leq \theta \leq 136°$ a track crosses all the three silicon layers of the VD. The closer layer covers the polar region between 25° and 155°.

The measured intrinsic resolution is about 8 μm for the $R\Phi$ measurement while for z it depends on the incident polar angle of the track, and goes from about 10 μm for tracks perpendicular to the modules to 20 μm for tracks with a polar angle of 25°. For charged tracks with hits in all three $R\Phi$ VD layers, the impact parameter resolution is $\sigma^2_{R\Phi} = (61/p\sin^{3/2}\theta)^2 + 20^2\mu m^2$ while for tracks with hits in both the Rz layers is $\sigma^2_z = (67/p\sin^{5/2}\theta)^2 + 33^2\mu m^2$.

3 Event Selection and Simulation

The same event selection as in ref.[9] was applied to this analysis. Briefly, charged particles were accepted with a polar angle between 20° and 160°, a track length larger than 30 cm, an impact parameter in the $R\Phi$ plane less than 2.5 cm and less that 10 cm in z and a

[2]In the DELPHI coordinate system z is along the beam line, Φ is the azimuthal angle in the xy plane and θ is the polar angle w.r.t. to the z axis.

momentum larger than 200 MeV/c. Neutral particles were accepted if the energy was larger than 700 MeV in the HPC [6, 7] and 400 MeV in the FEMC[6, 7]. Events were selected if there were at least 6 charged particles and if the energy of the charged particles was larger that 15% of the center of mass energy. About 1400000 Z events were selected in the 1994 data sample.

The events in the simulation were generated by the JETSET 7.3 parton shower (PS) Monte Carlo program [10] tuned for the DELPHI data.

A good description in the simulation behaviour of the data concerning the impact parameter and the b-tagging variables for $udsc$-quark events is very important in this analysis. For this reason a fine tuning of the $R\Phi$ and z impact parameter resolutions has been developed and applied [11]. This leads to a detailed understanding of the detector behaviour.

4 Analysis and results

4.1 The b-tagging

Two different b-tagging algorithms have been used in this analysis. The first method originally proposed by ALEPH [12] and then developed inside DELPHI [13] uses two variables only, namely the projections of the impact parameter, in the $R\Phi$ plane and along the z direction [14]. The tagging variable P_H^+ is the probability for the hypotesis that, in a given hemisphere, the tracks with positive impact parameter all come from the primary vertex.

The second method is a further development and combines other variables defined for the jets that have reconstructed secondary vertices. Similarly to before, the hemisphere is tagged as containing a b quark if the discriminating variable $y < y_0$, where y_0 defines the efficiency and purity of the sample. This method is described in detail in [9]. The secondary vertices are accepted if $L/\sigma_L \geq 4$ where L is the distance from the primary vertex and σ_L is its error, which happens in about 55% of the hemispheres with b-quarks. This second method therefore can only tag those hemispheres.

A search for secondary vertices is performed in the first method as well, but only to improve the determination of the B-hadron flight direction. Whenever a secondary vertex is reconstructed, the jet direction is recomputed as the direction from the primary vertex to the secondary vertex. The sign of the impact parameter is then redefined with respect to the new direction [14]. In the other cases the direction of the jet is given by the jet clustering algorithm used.

4.2 The impact parameter analysis

Events are divided in two hemispheres using the plane perpendicular to the thrust axis. Long living neutral particles like K^0 and Λ are reconstructed and their decay products are excluded from this analysis.

Since the VD is the detector that dominates the impact parameter resolution, only tracks with VD information are used. In particular, both for the probability computation and for the secondary vertex reconstruction, tracks are accepted if they have at least one $R\Phi$ vertex detector hit or at least one Rz detector hit [14]. Events are accepted if most of the tracks are inside the acceptance of the VD, i.e. if $|\cos\theta_{thrust}| < 0.65$.

In order to reduce hemisphere-hemisphere correlations in the tagging efficiency for b-quarks, a separate primary vertex is computed for each hemisphere.

In the hemisphere opposite to the one identified as b-quark the quantity:

$$N_{+-} = \sum IP^{+} - \sum IP^{-}$$

has been measured, where $\sum IP^{+}$ is the number of tracks in the hemisphere with a positive impact parameter and $\sum IP^{-}$ is the number of tracks with negative impact parameter. The sign of the impact parameter is defined with respect to the jet direction. It is positive if the point on the jet axis corresponding to the closest approach of the track to the jet axis is downstream of the primary vertex following the jet direction, and it is negative if it is upstream. The same sign is thus assigned to both the $R\Phi$ and z impact parameters. In figure 1 the mean value of N_{+-} is plotted for simulated events as a function of the tagging variable y for the three different quark favours, while in figure 2 the same quantity is plotted for the data collected in 1994. The corresponding distribution obtained in the simulation has been superimposed as an histogram.

Selecting events with a purity greater than 99% using the first b-tagging method (i.e. for $P_H^{+} \leq 10^{-10}$) the value for N_{+-} is:

$$N_{+-} = 3.194 \pm 0.019$$

and it is

$$N_{+-}^{MC} = 3.167 \pm 0.011$$

in the simulation.

A similar result is obtained when using as a b-tagging variable the quantity y defined in section 4.1 and again selecting events with a purity greater than 99% (i.e. for $y > 3.$):

$$N_{+-} = 3.197 \pm 0.015$$

and it is

$$N_{+-}^{MC} = 3.177 \pm 0.011$$

in the simulation.

If N_0^{MC} is the generated value in the simulation, the value of n_B in the data is determined from N_{+-} by the following equation:

$$n_B = N_0^{MC} + (N_{+-} - N_{+-}^{MC}) \times \frac{\Delta N_0^{MC}}{\Delta N_{+-}^{MC}} \qquad (1)$$

In the simulation $N_0^{MC} = 4.927$. The coefficients of eq.1 have been determined by varying the generated multiplicity in the simulation by $\Delta N_0^{MC} = \pm 10\%$, giving $\Delta N_{+-}^{MC} = 0.297$. The error on this quantity is included as a systematic error.

The value obtained is:

$$n_B = 4.96 \pm 0.03(stat).$$

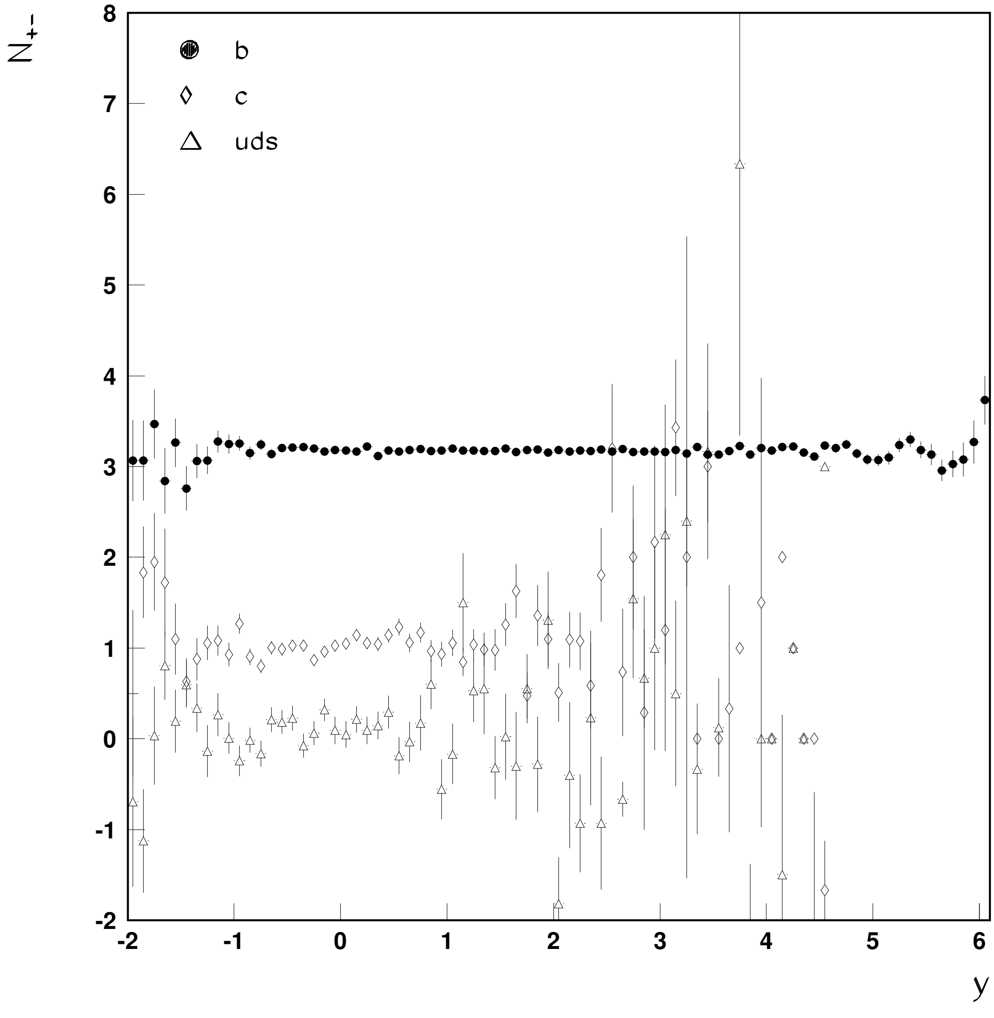

Figure 1: *The value of N_{+-} is shown for the different quark flavors as a function of the tagging variable y, i.e. for increasing b purity in the selected sample of events.*

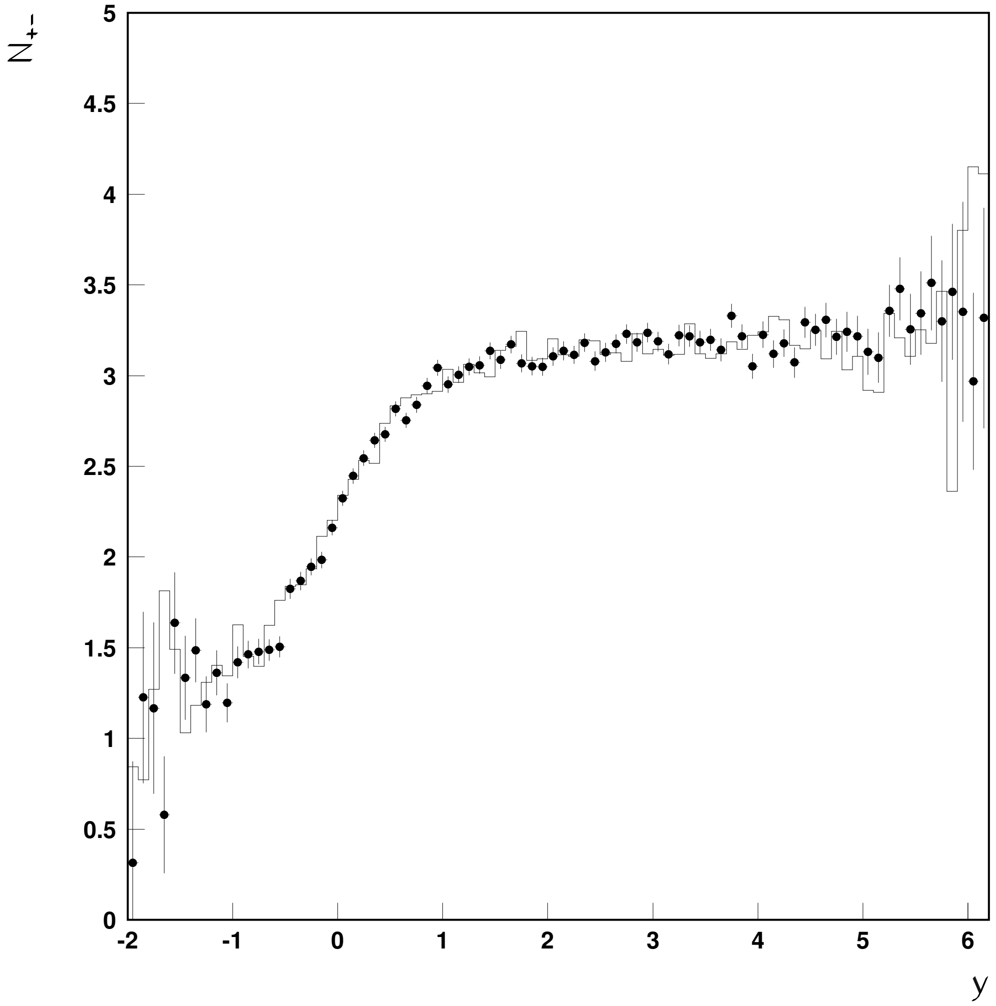

Figure 2: *The value of N_{+-} is shown for the data taken in 1994 (full points). Superimposed as an histogram is the simulation.*

4.3 Systematic uncertainties of impact parameter analysis

The systematic errors can come from two different sources: detector effects and modelling of the B hadron production and decays. This analysis is connected to the measurement of R_b [9], and the evaluation of the systematic uncertainties have been done following the recommendation of ref.[15] and the work done in [9].

The following contributions were studied:

Impact parameter sign assignment. In the method used, the definition of the sign of the impact parameter is crucial. The sign is defined with respect to the jet direction as explained in the previous section. As said in section 4.1 the jet direction is defined by the direction from the primary to the secondary vertex whenever a secondary vertex is reconstructed. It has been demonstrated that such a definition improves the b-tagging performance [14]. The analysis has been repeated by computing the sign of the impact parameter using for the jet direction the one defined by the jet clustering algorithm used in the program (JADE with $y_{min} = 0.01$). The measured value of N_{+-} is different w.r.t the previous one, but remains in agreement with the value obtained in the simulation:

$$N_{+-} = 2.87 \pm 0.01,$$
$$N_{+-}^{MC} = 2.85 \pm 0.02.$$

Detector resolution effects. To estimate the effects of the detector resolution, two different tests have been done. First the simulation has been rerun with a tuning [11] that describes the data worse than the default one (about 4% relative difference in the light and charm quark efficiencies). Secondly the calibration file for the data has been used to analyse simulated events. This second test is preferred for the charm background estimation since the charm carry lifetime and has a non zero charged decay multiplicity (see figure 1).

Tracking Efficiency. The ratio between the number of tracks in data and in simulation used in the analysis in an anti-b-tagged sample is measured to be 0.995. In order to compute the systematic error due to tracking efficiency, the track reconstruction efficiency in simulation has been varied by an amount corresponding to two times the residual of the data- Monte Carlo difference.

Hemisphere correlation. The influence of the hemisphere correlation on the analysis can be studied doing the measurement with a single fitted primary vertex per event. The result is:

$$N_{+-} = 3.207 \pm 0.017,$$
$$N_{+-}^{MC} = 3.198 \pm 0.01.$$

The average b lifetime was varied as recommended by [15] around its central value.

The gluon splitting rates into $b\bar{b}$ and into $c\bar{c}$ final states were varied as recommended by [15].

The average multiplicity in the simulation was varied by 10% to verify the linearity of the measurement.

The branching ratio of D mesons into Kaons was varied by 15%. This is the largest error, coming from uncertainties in charm hadron decay properties, for the measurement of R_b [9].

All studied systematic errors are summarized in table 1.

Source of systematics	Range	$\Delta n_B \times 10^{-2}$
Detector resolution		± 2.6
Tracking efficiency		± 2.5
Sign assignment		± 1.4
Hemisphere correlations		± 1.6
Gluon splitting $g \to b\bar{b}$	$(0.31 \pm 0.11)\%$[1]	± 0.4
Gluon splitting $g \to c\bar{c}$	$(2.38 \pm 0.48)\%$[1]	± 0.4
$BR(D \to K^0 X)$	0.46 ± 0.06	± 1.1
B lifetime	1.55 ± 0.05 ps	± 1.9
Linearity	$\pm 10\%$	± 3.0
Total		± 5.4

Table 1: Systematic errors on the measurement of n_B with the impact parameter method.

4.4 Secondary Vertex Analysis

The other method used to estimate the charged track multiplicity is to count the tracks that are fitted at a secondary vertex. A secondary vertex is reconstructed requiring at least two tracks with VD hits and asking a $\chi^2 \leq 4$. It is accepted if $L/\sigma_L > 4$, where L is the distance from the primary vertex and σ_L is its error. The tracks that are excluded by the secondary vertex fit but pass close to the estimated flight direction of the B hadron and far from the primary vertex are included in the secondary vertex. This takes into account the cases were a D meson decays far away from the B decay vertex, thus having the decay tracks far away from it. Since a secondary vertex is reconstructed with at least two tracks, the value of the multiplicity will be biased towards higher values.

Consistent results have been found and real data and simulation agree also for this method. Plotting the number of tracks retained at the secondary vertex N_{sec} as a function of the b-tagging variable (i.e. for increasing purity), as shown in figure 3, the following results have been obtained when selecting events with a b purity greater than 98% (i.e. $y \geq 1$):

$$N_{sec} = 4.57 \pm 0.01,$$
$$N_{sec}^{MC} = 4.59 \pm 0.01.$$

Similar results have been found whenever one primary vertex per event has been fitted, and using a different b-tagging method.

If N_0^{MC} is the generated value in the simulation, the value of n_B is determined as in the previous method:

$$n_B = N_0^{MC} + (N_{sec} - N_{sec}^{MC}) \times \frac{\Delta N_0^{MC}}{\Delta N_{sec}^{MC}}. \tag{2}$$

The same systematic errors considered in the first analysis have been evaluated and are listed in table 2.

The value of n_B obtained with this method is:

$$n_B = 4.91 \pm 0.03 \pm 0.07.$$

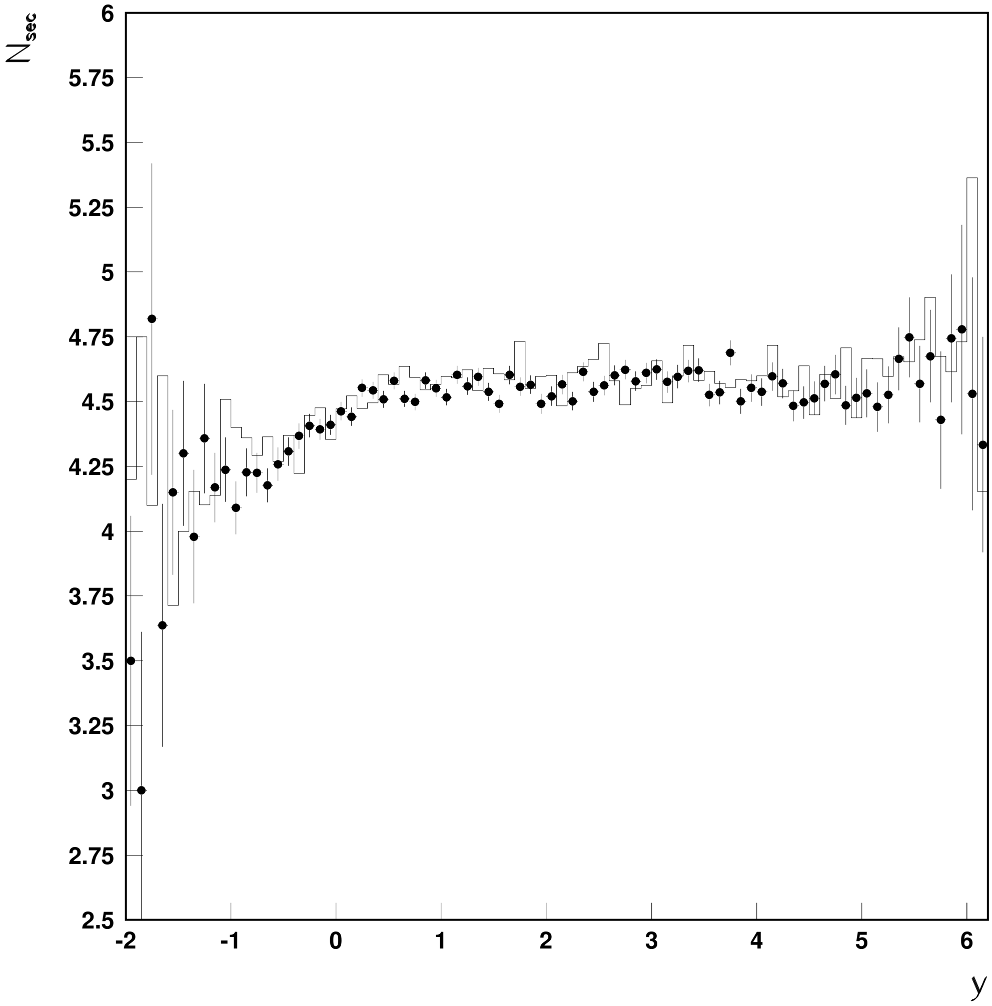

Figure 3: *The value of N_{sec} is shown for the data taken in 1994 (full points). Superimposed as an histogram is the simulation.*

Source of systematics	Range	$\Delta n_B \times 10^{-2}$
Detector resolution		± 1.9
Tracking efficiency		± 0.6
Hemisphere correlations		± 2.8
Gluon splitting $g \to b\bar{b}$	$(0.31 \pm 0.11)\%^1$	± 0.1
Gluon splitting $g \to c\bar{c}$	$(2.38 \pm 0.48)\%^1$	± 0.1
$BR(D \to K^0 X)$	0.46 ± 0.06	± 5.3
B lifetime	1.55 ± 0.05 ps	± 0.3
Linearity	$\pm 10\%$	± 3.5
Total		± 7.2

Table 2: Systematic errors on the measurement of n_B with the secondary vertex method.

4.5 Summary

The average charged decay multiplicity of weakly decaying B hadrons produced in a b-quark jet at the Z pole energy has been measured by counting the difference between the tracks with positive and negative impact parameters in a hemisphere to be:

$$n_B = 4.96 \pm 0.03(stat.) \pm 0.05(syst.).$$

This value has been obtained with K^0 and Λ decay products excluded.

A second method that counts the tracks pointing to a secondary vertex gives a consistent result.

The measurement is in agreement with the OPAL [3] and DELPHI [4] results, ($n_B = 5.03 \pm 0.04 \pm 0.49$, and $n_B = 5.20 \pm 0.04 \pm 0.38$ respectively) obtained in similar condition, after excluding K^0 and Λ decay products and, for the DELPHI number, after excluding as well the contribution of $B^{**} \to \pi^{\pm} B$ of 0.16 ± 0.03, but is by far more accurate.

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