EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

CERN-PPE/95-44
5 April 1995

The Forward-Backward Asymmetry for Charm Quarks at the Z Pole

*The ALEPH Collaboration**

Abstract

From 1.4 million hadronic Z decays collected by the ALEPH detector at LEP, an enriched sample of $Z \rightarrow c\bar{c}$ events is extracted by requiring the presence of a high momentum $D^{*\pm}$. The charm quark forward-backward charge asymmetry at the Z pole is measured to be $A_{FB}^{0,c} = (8.0 \pm 2.4)\%$ corresponding to an effective electroweak mixing angle of $\sin^2\theta_W^{\text{eff}} = 0.2302 \pm 0.0054$.

(Submitted to Physics Letters B)

* See next pages for the list of authors

The ALEPH Collaboration

D. Buskulic, D. Casper, I. De Bonis, D. Decamp, P. Ghez, C. Goy, J.-P. Lees, M.-N. Minard, P. Odier, B. Pietrzyk

Laboratoire de Physique des Particules (LAPP), IN^2P^3-CNRS, 74019 Annecy-le-Vieux Cedex, France

F. Ariztizabal, M. Chmeissani, J.M. Crespo, I. Efthymiopoulos, E. Fernandez, M. Fernandez-Bosman, V. Gaitan, Ll. Garrido,[15] M. Martinez, S. Orteu, A. Pacheco, C. Padilla, F. Palla, A. Pascual, J.A. Perlas, F. Sanchez, F. Teubert

Institut de Fisica d'Altes Energies, Universitat Autonoma de Barcelona, 08193 Bellaterra (Barcelona), Spain[7]

D. Creanza, M. de Palma, A. Farilla, M. Girone, G. Iaselli, G. Maggi,[3] N. Marinelli, S. Natali, S. Nuzzo, A. Ranieri, G. Raso, F. Romano, F. Ruggieri, G. Selvaggi, L. Silvestris, P. Tempesta, G. Zito

Dipartimento di Fisica, INFN Sezione di Bari, 70126 Bari, Italy

X. Huang, J. Lin, Q. Ouyang, T. Wang, Y. Xie, R. Xu, S. Xue, J. Zhang, L. Zhang, W. Zhao

Institute of High-Energy Physics, Academia Sinica, Beijing, The People's Republic of China[8]

G. Bonvicini, M. Cattaneo, P. Comas, P. Coyle, H. Drevermann, A. Engelhardt, R.W. Forty, M. Frank, R. Hagelberg, J. Harvey, R. Jacobsen,[24] P. Janot, B. Jost, J. Knobloch, I. Lehraus, M. Maggi, C. Markou,[23] E.B. Martin, P. Mato, H. Meinhard, A. Minten, R. Miquel, T. Oest, P. Palazzi, J.R. Pater, J.-F. Pusztaszeri, F. Ranjard, P. Rensing, L. Rolandi, D. Schlatter, M. Schmelling, O. Schneider, W. Tejessy, I.R. Tomalin, A. Venturi, H. Wachsmuth, W. Wiedenmann, T. Wildish, W. Witzeling, J. Wotschack

European Laboratory for Particle Physics (CERN), 1211 Geneva 23, Switzerland

Z. Ajaltouni, M. Bardadin-Otwinowska,[2] A. Barres, C. Boyer, A. Falvard, P. Gay, C. Guicheney, P. Henrard, J. Jousset, B. Michel, S. Monteil, J-C. Montret, D. Pallin, P. Perret, F. Podlyski, J. Proriol, J.-M. Rossignol, F. Saadi

Laboratoire de Physique Corpusculaire, Université Blaise Pascal, IN^2P^3-CNRS, Clermont-Ferrand, 63177 Aubière, France

T. Fearnley, J.B. Hansen, J.D. Hansen, J.R. Hansen, P.H. Hansen, B.S. Nilsson

Niels Bohr Institute, 2100 Copenhagen, Denmark[9]

A. Kyriakis, E. Simopoulou, I. Siotis, A. Vayaki, K. Zachariadou

Nuclear Research Center Demokritos (NRCD), Athens, Greece

A. Blondel,[21] G. Bonneaud, J.C. Brient, P. Bourdon, L. Passalacqua, A. Rougé, M. Rumpf, R. Tanaka, A. Valassi, M. Verderi, H. Videau

Laboratoire de Physique Nucléaire et des Hautes Energies, Ecole Polytechnique, IN^2P^3-CNRS, 91128 Palaiseau Cedex, France

D.J. Candlin, M.I. Parsons

Department of Physics, University of Edinburgh, Edinburgh EH9 3JZ, United Kingdom[10]

E. Focardi, G. Parrini

Dipartimento di Fisica, Università di Firenze, INFN Sezione di Firenze, 50125 Firenze, Italy

M. Corden, M. Delfino,[12] C. Georgiopoulos, D.E. Jaffe

Supercomputer Computations Research Institute, Florida State University, Tallahassee, FL 32306-4052, USA [13,14]

A. Antonelli, G. Bencivenni, G. Bologna,[4] F. Bossi, P. Campana, G. Capon, F. Cerutti, V. Chiarella, G. Felici, P. Laurelli, G. Mannocchi,[5] F. Murtas, G.P. Murtas, M. Pepe-Altarelli

Laboratori Nazionali dell'INFN (LNF-INFN), 00044 Frascati, Italy

S.J. Dorris, A.W. Halley, I. ten Have,[6] I.G. Knowles, J.G. Lynch, W.T. Morton, V. O'Shea, C. Raine, P. Reeves, J.M. Scarr, K. Smith, M.G. Smith, A.S. Thompson, F. Thomson, S. Thorn, R.M. Turnbull

Department of Physics and Astronomy, University of Glasgow, Glasgow G12 8QQ,United Kingdom[10]

U. Becker, O. Braun, C. Geweniger, G. Graefe, P. Hanke, V. Hepp, E.E. Kluge, A. Putzer, B. Rensch, M. Schmidt, J. Sommer, H. Stenzel, K. Tittel, S. Werner, M. Wunsch

Institut für Hochenergiephysik, Universität Heidelberg, 69120 Heidelberg, Fed. Rep. of Germany[16]

R. Beuselinck, D.M. Binnie, W. Cameron, D.J. Colling, P.J. Dornan, N. Konstantinidis, L. Moneta, A. Moutoussi, J. Nash, G. San Martin, J.K. Sedgbeer, A.M. Stacey

Department of Physics, Imperial College, London SW7 2BZ, United Kingdom[10]

G. Dissertori, P. Girtler, E. Kneringer, D. Kuhn, G. Rudolph

Institut für Experimentalphysik, Universität Innsbruck, 6020 Innsbruck, Austria[18]

C.K. Bowdery, T.J. Brodbeck, P. Colrain, G. Crawford, A.J. Finch, F. Foster, G. Hughes, T. Sloan, E.P. Whelan, M.I. Williams

Department of Physics, University of Lancaster, Lancaster LA1 4YB, United Kingdom[10]

A. Galla, A.M. Greene, K. Kleinknecht, G. Quast, J. Raab, B. Renk, H.-G. Sander, R. Wanke, C. Zeitnitz

Institut für Physik, Universität Mainz, 55099 Mainz, Fed. Rep. of Germany[16]

J.J. Aubert, A.M. Bencheikh, C. Benchouk, A. Bonissent,[21] G. Bujosa, D. Calvet, J. Carr, C. Diaconu, F. Etienne, M. Thulasidas, D. Nicod, P. Payre, D. Rousseau, M. Talby

Centre de Physique des Particules, Faculté des Sciences de Luminy, IN^2P^3-CNRS, 13288 Marseille, France

I. Abt, R. Assmann, C. Bauer, W. Blum, D. Brown,[24] H. Dietl, F. Dydak,[21] C. Gotzhein, K. Jakobs, H. Kroha, G. Lütjens, G. Lutz, W. Männer, H.-G. Moser, R. Richter, A. Rosado-Schlosser, R. Settles, H. Seywerd, U. Stierlin,[2] R. St. Denis, G. Wolf

Max-Planck-Institut für Physik, Werner-Heisenberg-Institut, 80805 München, Fed. Rep. of Germany[16]

R. Alemany, J. Boucrot, O. Callot, A. Cordier, F. Courault, M. Davier, L. Duflot, J.-F. Grivaz, Ph. Heusse, M. Jacquet, D.W. Kim,[19] F. Le Diberder, J. Lefrançois, A.-M. Lutz, G. Musolino, I. Nikolic, H.J. Park, I.C. Park, M.-H. Schune, S. Simion, J.-J. Veillet, I. Videau

Laboratoire de l'Accélérateur Linéaire, Université de Paris-Sud, IN^2P^3-CNRS, 91405 Orsay Cedex, France

D. Abbaneo, P. Azzurri, G. Bagliesi, G. Batignani, S. Bettarini, C. Bozzi, G. Calderini, M. Carpinelli, M.A. Ciocci, V. Ciulli, R. Dell'Orso, R. Fantechi, I. Ferrante, L. Foà,[1] F. Forti, A. Giassi, M.A. Giorgi, A. Gregorio, F. Ligabue, A. Lusiani, P.S. Marrocchesi, A. Messineo, G. Rizzo, G. Sanguinetti, A. Sciabà, P. Spagnolo, J. Steinberger, R. Tenchini, G. Tonelli,[26] G. Triggiani, C. Vannini, P.G. Verdini, J. Walsh

Dipartimento di Fisica dell'Università, INFN Sezione di Pisa, e Scuola Normale Superiore, 56010 Pisa, Italy

A.P. Betteridge, G.A. Blair, L.M. Bryant, Y. Gao, M.G. Green, D.L. Johnson, T. Medcalf, Ll.M. Mir, P. Perrodo, J.A. Strong

Department of Physics, Royal Holloway & Bedford New College, University of London, Surrey TW20 OEX, United Kingdom[10]

V. Bertin, D.R. Botterill, R.W. Clifft, T.R. Edgecock, S. Haywood, M. Edwards, P. Maley, P.R. Norton, J.C. Thompson

Particle Physics Dept., Rutherford Appleton Laboratory, Chilton, Didcot, Oxon OX11 OQX, United Kingdom[10]

B. Bloch-Devaux, P. Colas, H. Duarte, S. Emery, W. Kozanecki, E. Lançon, M.C. Lemaire, E. Locci, B. Marx, P. Perez, J. Rander, J.-F. Renardy, A. Rosowsky, A. Roussarie, J.-P. Schuller, J. Schwindling, D. Si Mohand, A. Trabelsi, B. Vallage

CEA, DAPNIA/Service de Physique des Particules, CE-Saclay, 91191 Gif-sur-Yvette Cedex, France[17]

R.P. Johnson, H.Y. Kim, A.M. Litke, M.A. McNeil, G. Taylor

Institute for Particle Physics, University of California at Santa Cruz, Santa Cruz, CA 95064, USA[22]

A. Beddall, C.N. Booth, R. Boswell, S. Cartwright, F. Combley, I. Dawson, A. Koksal, M. Letho, W.M. Newton, C. Rankin, L.F. Thompson

Department of Physics, University of Sheffield, Sheffield S3 7RH, United Kingdom[10]

A. Böhrer, S. Brandt, G. Cowan, E. Feigl, C. Grupen, G. Lutters, J. Minguet-Rodriguez, F. Rivera,[25] P. Saraiva, L. Smolik, F. Stephan

Fachbereich Physik, Universität Siegen, 57068 Siegen, Fed. Rep. of Germany[16]

L. Bosisio, R. Della Marina, G. Ganis, G. Giannini, B. Gobbo, L. Pitis, F. Ragusa[20]

Dipartimento di Fisica, Università di Trieste e INFN Sezione di Trieste, 34127 Trieste, Italy

J. Rothberg, S. Wasserbaech

Experimental Elementary Particle Physics, University of Washington, WA 98195 Seattle, U.S.A.

S.R. Armstrong, L. Bellantoni, P. Elmer, Z. Feng, D.P.S. Ferguson, Y.S. Gao, S. González, J. Grahl, J.L. Harton, O.J. Hayes, H. Hu, P.A. McNamara III, J.M. Nachtman, W. Orejudos, Y.B. Pan, Y. Saadi, M. Schmitt, I.J. Scott, V. Sharma, J.D. Turk, A.M. Walsh, F.V. Weber,[1] Sau Lan Wu, X. Wu, J.M. Yamartino, M. Zheng, G. Zobernig

Department of Physics, University of Wisconsin, Madison, WI 53706, USA[11]

[1]Now at CERN, 1211 Geneva 23, Switzerland.
[2]Deceased.
[3]Now at Dipartimento di Fisica, Università di Lecce, 73100 Lecce, Italy.
[4]Also Istituto di Fisica Generale, Università di Torino, Torino, Italy.
[5]Also Istituto di Cosmo-Geofisica del C.N.R., Torino, Italy.
[6]Now at TSM Business School, Enschede, The Netherlands.
[7]Supported by CICYT, Spain.
[8]Supported by the National Science Foundation of China.
[9]Supported by the Danish Natural Science Research Council.
[10]Supported by the UK Particle Physics and Astronomy Research Council.
[11]Supported by the US Department of Energy, contract DE-AC02-76ER00881.
[12]On leave from Universitat Autonoma de Barcelona, Barcelona, Spain.
[13]Supported by the US Department of Energy, contract DE-FG05-92ER40742.
[14]Supported by the US Department of Energy, contract DE-FC05-85ER250000.
[15]Permanent address: Universitat de Barcelona, 08208 Barcelona, Spain.
[16]Supported by the Bundesministerium für Forschung und Technologie, Fed. Rep. of Germany.
[17]Supported by the Direction des Sciences de la Matière, C.E.A.
[18]Supported by Fonds zur Förderung der wissenschaftlichen Forschung, Austria.
[19]Permanent address: Kangnung National University, Kangnung, Korea.
[20]Now at Dipartimento di Fisica, Università di Milano, Milano, Italy.
[21]Also at CERN, 1211 Geneva 23, Switzerland.
[22]Supported by the US Department of Energy, grant DE-FG03-92ER40689.
[23]Now at University of Athens, 157-71 Athens, Greece.
[24]Now at Lawrence Berkeley Laboratory, Berkeley, CA 94720, USA.
[25]Partially supported by Colciencias, Colombia.
[26]Also at Istituto di Matematica e Fisica, Università di Sassari, Sassari, Italy.

1 Introduction

The existence of both vector and axial contributions to the coupling of the Z boson to fermions leads to the prediction of a forward-backward charge asymmetry (denoted A^f_{FB}) in the production of fermion pairs $\bar{f}f$. In the Standard Model, the differential cross-section, expressed as a function of the angle θ between the outgoing fermion and the incoming electron directions, is :

$$\frac{\mathrm{d}\sigma}{\mathrm{d}\cos\theta} \propto (1+\cos^2\theta + \frac{8}{3}\cdot A^f_{FB}\cdot\cos\theta) \quad .$$

At the Z pole, for unpolarized e^+e^- beams, the asymmetry term in the Born approximation is related to the effective couplings through the expression :

$$A^{0,f}_{FB} = \frac{3}{4}\frac{2\mathrm{g_{Ve}g_{Ae}}}{(\mathrm{g^2_{Ve}}+\mathrm{g^2_{Ae}})}\frac{2\mathrm{g_{Vf}g_{Af}}}{(\mathrm{g^2_{Vf}}+\mathrm{g^2_{Af}})} \quad . \qquad (1)$$

Therefore, the measurement of the forward-backward asymmetry for each produced fermion type constitutes an important test of the Standard Model. In this paper, a measurement of the asymmetry in charm quark production and the corresponding electroweak mixing angle $\sin^2\theta^{\mathrm{eff}}_W$ is described.

Decays of the Z into $\mathrm{D}^{*\pm}$ mesons produced in the $\mathrm{Z}\to\mathrm{q\bar{q}}$ process are used to tag charm and beauty quarks. Essentially all charmed mesons are expected to be produced either directly from the hadronization of charm quarks in the process $\mathrm{Z}\to\mathrm{c\bar{c}}$ or from the decay of b hadrons produced in $\mathrm{Z}\to\mathrm{b\bar{b}}$ events, with approximately equal rates. The selection of high momentum $\mathrm{D}^{*\pm}$ candidates removes a large amount of background events and enriches the charmed-meson sample to a purity of about 80% in $\mathrm{D}^{*\pm}$'s originating from the $\mathrm{Z}\to\mathrm{c\bar{c}}$ process.

The decay channel $\mathrm{D}^{*+}\to\mathrm{D}^0\pi^+$ (the π^+ being labeled π^+_s hereafter) is used to select D^{*+}'s. Three D^0 decay channels have been considered (charge-conjugate modes are implied throughout this paper):

$$\begin{array}{ll} (i) & \mathrm{D}^0\to K^-\pi^+\,; \\ (ii) & \mathrm{D}^0\to \mathrm{K}^-\pi^+\pi^+\pi^-\,; \\ (iii) & \mathrm{D}^0\to \mathrm{K}^-\pi^+\pi^0\,. \end{array}$$

This paper is an update of Ref. [1], with statistics increased by more than a factor of 3 to 1.4 million hadronic Z's collected by the ALEPH detector [2] from 1991 to 1993. Center-of-mass energies within 1 GeV of the Z peak were used with an average of 91.24 GeV. The channel (iii) is selected differently, the π^0 not being directly used in the D^0 reconstruction. The D^0's containing a soft π^0 originating mainly from a ρ^+ decay are tagged in a way which makes use of the kinematics of this decay. This new selection increases the number of selected $\mathrm{D}^0\to\mathrm{K}^-\pi^+\pi^0$ by a factor of 2.

2 Selection of the D^{*+} Decays

Hadronic Z's are selected as described in [1]. The channels $D^{*+} \to \pi_s^+ K^- \pi^+$ and $D^{*+} \to \pi_s^+ K^- \pi^+ \pi^+ \pi^-$ are reconstructed as follows. The invariant mass of a system combining 2 tracks ($D^0 \to K^- \pi^+$) or 4 tracks ($D^0 \to K^- \pi^+ \pi^+ \pi^-$) with relevant mass assignments is required to be within 30 MeV/c^2 of the D^0 mass. This is equivalent to roughly 2 standard deviations of the invariant mass resolution. A low momentum pion ($P_{\pi_s^+} < 4.2$ GeV/c) is added to the system and a D^{*+} candidate is kept if $\Delta M = M_{\pi_s^+ D^0} - M_{D^0}$ satisfies $143.5\ \mathrm{MeV/c^2} < \Delta M < 147.5\ \mathrm{MeV/c^2}$. A cut $X_E = E_{D^{*+}}/E_{beam}$ greater than 0.5 is imposed to enrich the sample in charm events against b decays and other backgrounds.

The scalar nature of the D^0 is exploited in order to remove a large fraction of the remaining background by requiring $|\cos\theta^*| \leq 0.8$, where θ^* is the angle between the K track ($D^0 \to K^- \pi^+$ case) or the sphericity axis of the four decay products ($D^0 \to K^- \pi^+ \pi^+ \pi^-$ case) and the D^0 direction, in the D^0 rest frame.

The background behaviour is reproduced by selecting fake D^0 candidates in a mass range above the D^0 mass from 2.00 GeV/c^2 to 2.26 GeV/c^2, which pass the other selection criteria. For the $D^{*+} \to \pi_s^+ K^- \pi^+$ channel, the background mass-difference spectrum is normalized to the data upper side spectrum ($\Delta M > 160$ MeV/c^2), giving an estimate of the number of background events in the selected ΔM region (Fig. 1). In the $D^{*+} \to \pi_s^+ K^- \pi^+ \pi^+ \pi^-$ channel, the experimental spectrum has an additional contribution due to a K^-/π^- inversion in the D^0 or coming from partially reconstructed $D^0 \to K^- \pi^+ \pi^+ \pi^-$, where one of the four D^0 tracks is taken from the combinatorial background. This additional contribution gives a tail in the upper side of the mass-difference spectrum and forms a broad enhancement in the region of the D^* peak, leading to a double counting of events containing a D^* . These partially reconstructed events allow a correct estimation of the quark direction, just as well as fully reconstructed $D^0 \to K^- \pi^+ \pi^+ \pi^-$ contribution. The number of background events for this channel is derived from a fit of the experimental spectrum (fig. 2) with two contributions, one for the D^* signal and the second for the pure combinatorial background, the shape of these two contributions being given by the Monte-Carlo simulation. Finally, for each event, only the candidate with the mass closest to the D^0 mass is kept. This further selection criterion reduces the signal sample by $(18 \pm 1)\%$. The selection leads to samples containing 1022 ± 33 $D^{*+} \to \pi_s^+ K^- \pi^+$ and 2035 ± 68 $D^{*+} \to \pi_s^+ K^- \pi^+ \pi^+ \pi^-$.

The D^0's from $D^{*+} \to \pi_s^+ K^- \pi^+ \pi^0$ are not fully reconstructed. Leaving out the π^0, the D^0 is selected by requiring a $K\pi$ invariant mass in the range from 1.5 GeV/c^2 to 1.7 GeV/c^2, populated mainly by the $D^0 \to K^- \rho^+$ contribution to the $D^0 \to K^- \pi^+ \pi^0$ channel, with the π^0 emitted backward with respect to the ρ flight direction. The selection is the same as that of $D^{*+} \to \pi_s^+ K^- \pi^+$ channel, except that the X_E cut is lowered to 0.42 and the range for ΔM is enlarged to the interval $141\ \mathrm{MeV/c^2} < \Delta M < 152\ \mathrm{MeV/c^2}$, to take into account the 4-momentum carried by the π^0. The mass-difference distribution is shown in Fig. 3. The contribution from background events in the selected signal region is evaluated in the same way as for the $D^{*+} \to \pi_s^+ K^- \pi^+$ channel, from fake D^0 candidates in a mass window above the D^0 mass. This selection leads to a sample containing 2439 ± 73 $D^{*+} \to \pi_s^+ K^- \pi^+ \pi^0$. Table 1 summarizes the statistics of the three samples available for the asymmetry measurement.

channel	candidates	D^* signal
$D^{*+} \to \pi_s^+ K^- \pi^+$	1068	1022 ± 33
$D^{*+} \to \pi_s^+ K^- \pi^+ \pi^+ \pi^-$	3542	2035 ± 68
$D^{*+} \to \pi_s^+ K^- \pi^+ \pi^0$	3940	2439 ± 73

Table 1: Summary table for the three channels used in the asymmetry measurement. The error is the sum in quadrature of the statistical error and the systematic error coming from the background estimation.

3 Forward-Backward Asymmetry Measurement

The thrust axis is used to define the production angle θ_{thrust} of the $q\overline{q}$ pair with respect to the e^- beam axis. It is computed using both charged and neutral particles and oriented according to the reconstructed D^* direction. The charge Q of the D^* gives the charm quark sign and the cosine of the c-quark production angle is estimated by $\cos\theta = Q \times cos\theta_{thrust}$. The charm quark asymmetry is extracted from the observed angular distributions by means of an unbinned maximum likelihood fit. For each decay mode, the angular distribution includes three contributions: charm, beauty and background, each of them being of the form:

$$(1 + \cos^2\theta + \frac{8}{3} \cdot A_{FB} \cdot \cos\theta) \quad .$$

The function is calculated for each D^{*+} candidate, taking into account the asymmetry and the proportion of each physical source to the sample. The distributions from the three samples are considered simultaneously, the sum of the log-likelihood functions being maximized to obtain the best estimate of the only unknown parameter A_{FB}^c. The fraction of D^{*+} in each sample is deduced from the mass difference spectrum (see sect. 2), and the relative abundance of charm and beauty in the D^* signal is taken from the Monte Carlo with the relative probability for a D^* to originate from a beauty rather than a charm quark set to the measured value $\frac{P_{b \to D^{*\pm}}}{P_{c \to D^{*\pm}}} = 0.87^{+0.15}_{-0.13}$[1]. This charm purity, which depends basically on the X_E cut, is found to be the same in each of the three samples and equal to $(79 \pm 3)\%$. The proportions of each kind of event in the samples are deduced from these fraction numbers.

The background in the signal region is purely combinatorial and in these events the asymmetry is expected to be very small. An experimental background asymmetry is extracted from the D^0 side-band samples. The side-bands include also partially reconstructed charm decays giving a small positive asymmetry. The measured background asymmetry $A_{FB}^{back} = (1.45 \pm 0.91_{(stat)})\%$ is compatible with these expectations, and is used in the fit with an error of 100% of its value included in the systematic errors.

Background normalization	0.22 %
Background asymmetry	0.93 %
b,c relative contribution	0.07 %
b asymmetry	0.29 %
χ_{mix}	0.16 %
$\chi_{\bar{c}s}$	0.08 %
$\sum_{syst}$	1.02 %

Table 2: Sources of systematic errors on the measured asymmetry.

The beauty asymmetry is diluted by $B^0 - \bar{B}^0$ mixing, and by $\bar{c}$ originating from $b \rightarrow cW, W \rightarrow \bar{c}s$. The effective b asymmetry can be expressed as the true b asymmetry corrected by two dilution factors depending on parameters χ_{mix} and $\chi_{\bar{c}s}$:

$$A_{FB}^{b,eff} = A_{FB}^{b} \cdot (1 - 2\chi_{mix}) \cdot (1 - 2\chi_{\bar{c}s}).$$

The ALEPH measurement from semileptonic b-decays, corrected from $B^0 - \bar{B}^0$ mixing: $A_{FB}^{\mathrm{b}} = (8.1 \pm 1.7)\%$ [3], was used to fix the b quark asymmetry in the analysis. In the $\mathrm{D}^{*\pm}$ sample, the contributions from B_s^0 and beauty baryons are small, leading to a χ_{mix} different from that for semileptonic b-decays. To evaluate χ_{mix} in the $\mathrm{D}^{*\pm}$ sample, the World average value $\chi_d = 0.183 \pm 0.017$ [5] is used and a value $\chi_s > 0.4$ is derived from the ALEPH [6] and OPAL [7] limits on B_s oscillations. The mixing value in the analysed sample is then deduced to be $\chi_{mix} = 0.16 \pm 0.04$, The b hadrons fractions in $b \rightarrow \mathrm{D}^{*\pm}$ decays being given by the Monte-carlo simulation.

The decay $b \rightarrow cW, W \rightarrow \bar{c}s$ has an expected rate of about 14% [8], and produces three types of final states :

$$\begin{array}{ll} (a) & b \rightarrow (c\bar{c})X\,; \\ (b) & b \rightarrow D_s^{(*)}X\,; \\ (c) & b \rightarrow D^{(*)}X\,; \end{array}$$

where the X states do not contain the $\bar{c}$ from the decay $W \rightarrow \bar{c}s$. Only decays of type (c) produce D^* states with the wrong sign. The rate of charged D^*'s in type (c) decays was evaluated to be $(25 \pm 25)\%$; this assumes $(50 \pm 50)\%$ vector meson production, half on it in charged states. Using CLEO and ARGUS measurements for decays (a) and (b) [9], an estimate of $\chi_{\bar{c}s} = 0.025 \pm 0.025$ is obtained.

The simultaneous fit yields:

$$A_{FB}^{c} = (6.99 \pm 2.05(\mathrm{stat.}) \pm 1.02(\mathrm{syst.}))\%$$

The contributions to systematics are listed in table 2. The dominant error is due to the background. A change of +1% in the input beauty asymmetry A_{FB}^{b} would result in a change of -0.17% on A_{FB}^{c}.

	correction
$\sqrt(s) \neq M_Z$	– 0.0023
QED initial state	+ 0.0104
QED final state	+ 0.0001
QCD final state	+ 0.0023
γ exchange and interference	– 0.0007

Table 3: Corrections to the measured c-quark asymmetry.

Figure 4 shows the combined angular distribution after background subtraction and acceptance corrections, together with the result of the fit. Corrections summarized in table 3 are applied to the measurement to extract the pole asymmetry. The first correction arises from the fact that the average centre-of-mass energy is slightly above the Z pole. The main correction comes from QED initial state contribution which lowers the available energy, leading to an effect of opposite sign. QED final state radiation, γ exchange and γZ interference give negligible corrections to the asymmetry. No systematic error was assign to the corrections, which have been calculated using the MIZA program [10] where QCD final state correction is estimated from [11], giving:

$$A_{FB}^{0,c} = (8.0 \pm 2.4)\%$$

Finally, expressing the effective couplings as a function of $\sin^2\theta_W^{\rm eff}$ ($\equiv \frac{1}{4}(1 - {\rm g_{Ve}}/{\rm g_{Ae}})$[14]) , including appropriate c-quark vertex corrections from the Standard Model [10], leads to:

$$\sin^2\theta_W^{\rm eff} = 0.2302 \pm 0.0054.$$

4 Conclusion

A sample of 5496 D* of which 80% originate from Z $\rightarrow$ c$\bar{\rm c}$ events has been used to measure the forward-backward asymmetry in charm quark production. The asymmetry is found to be $A_{FB}^{0,c} = (8.0 \pm 2.4)\%$, which is in agreement with results obtained from D* samples by DELPHI [12] and OPAL [13]. The effective electroweak mixing angle resulting from this measurement $\sin^2\theta_W^{\rm eff} = 0.2302 \pm 0.0054$ is in good agreement with the various determinations of this quantity performed at LEP [14].

5 Acknowledgements

We wish to thank our colleagues from the accelerator divisions for the successful operation of LEP. We are grateful to the engineers and technicians in all our institutions for their contribution towards ALEPH's success. Those of us from non-member countries also thank CERN for its hospitality.

References

[1] D. Buskulic *et al.* (ALEPH Collab.), Z. Phys. C. 62 (1994) 1.

[2] D. Buskulic *et al.* (ALEPH Collab.), 'Performance of the ALEPH detector at LEP' CERN-PPE/94-170 (1994) (submitted to Nucl. Instr. Meth. A);
D. Decamp *et al.* (ALEPH Collab.), Nucl. Instr. Meth. A294 (1990) 121.

[3] D. Buskulic *et al.* (ALEPH Collab.), Z. Phys. C. 62 (1994) 179.

[4] J. Bartelt *et al.* (CLEO Collab.), Phys. Rev. Lett. 71 (1993) 1680.
H. Albrecht *et al.* (ARGUS Collab.), Z. Phys. C 55 (1992) 357.

[5] R. Forty, 'CP violation and $B\bar{B}$ mixing', talk given at the 27th International Conference on High Energy Physics, Glasgow (1994).

[6] D. Buskulic *et al.* (ALEPH Collab.), Phys. Lett B 322 (1994) 441.

[7] R. Akers *et al.* (OPAL Collab.), 'A Study of B Meson Oscillations Using Dilepton Events', CERN-PPE/95-12 (submitted to Z. Phys. C).

[8] J.P. Leveille, 'B decays' CLNS 51/505 (1981).

[9] H. Albrecht *et al.* (ARGUS Collab.), Z. Phys. C 54 (1992) 1;
D. Bortoletto *et al.* (CLEO Collab.), Phys Rev. D 45 (1992) 21;
H. Albrecht *et al.* (ARGUS Collab.), Phys. Lett. B 277 (1992) 209;
R. Balest *et al.* (CLEO Collab.), CLNS 94/1315 (1994) (submitted to Phys. Rev. D);
T.E. Browder, K. Honscheid and S. Playfer, 'A review of hadronic and rare B Decays' in 'B Decays', 2nd edition, edited by S Stone, World Scientific.

[10] M. Martinez *et al.*, Z. Phys. C 49 (1991) 645.

[11] G. Altarelli and B. Lampe, Nucl. Phys. B 391 (1993) 3.

[12] P. Abreu *et al.* (DELPHI Collab.), 'Measurement of the Forward-Backward Asymmetry of Charm and Bottom Quarks at the Z Pole using $D^{*\pm}$ Mesons', CERN-PPE/94-193 (submitted to Z. Phys. C).

[13] R. Akers *et al.* (OPAL Collab.), 'A Measurement of the Forward-Backward Asymmetry of $e^+e^- \to c\bar{c}$ and $e^+e^- \to b\bar{b}$ at Center of Mass Energies and near the Z^0 Peak using $D^{*\pm}$ Mesons', Z. Phys. C. 60 (1993) 601.

[14] The LEP Collaborations ALEPH, DELPHI, L3, OPAL and the LEP Electroweak Working Group 'Combined Preliminary Data on Z Parameters from the LEP experiments and Constraints on the Standard Model', CERN-PPE/94-187 (1994).

Figure Captions

Fig. 1. Mass-difference distribution, for $X_E(\mathrm{K}\pi\pi_s) > 0.5$. The $\mathrm{K}\pi$ mass is required to be between 1.8345 and 1.8945 GeV/c^2. The background, estimated from the upper side-band, is shown. The arrows indicate the selection cuts.

Fig. 2. Mass-difference distribution, for $X_E(\mathrm{K}\pi\pi\pi\pi_s) > 0.5$. The $\mathrm{K}\pi\pi\pi$ mass is required to be between 1.8345 and 1.8945 GeV/c^2 and all D^0 candidates are kept. The pure combinatorial background, estimated as described in the text, is shown. The arrows indicate the selection cuts.

Fig. 3. Mass-difference distribution for the channel $\mathrm{D}^0 \to \mathrm{K}^-\pi^+\pi^0$, with $X_E(\mathrm{K}\pi\pi_s) >$ 0.42. The $\mathrm{K}\pi$ mass is required to be between 1.5 and 1.7 GeV/c^2. The background, estimated from the side band, is shown. The signal shape predicted by Monte-Carlo is added, demonstrating that the background size is correctly estimated by the upper side-band normalization. The arrows indicate the selection cuts.

Fig. 4. Distribution of the signed cosine angle of the thrust axis. The distribution is corrected for acceptance; the combinatorial background and beauty contributions are subtracted. A function (solid line) corresponding to the fitted charm asymmetry is superimposed.

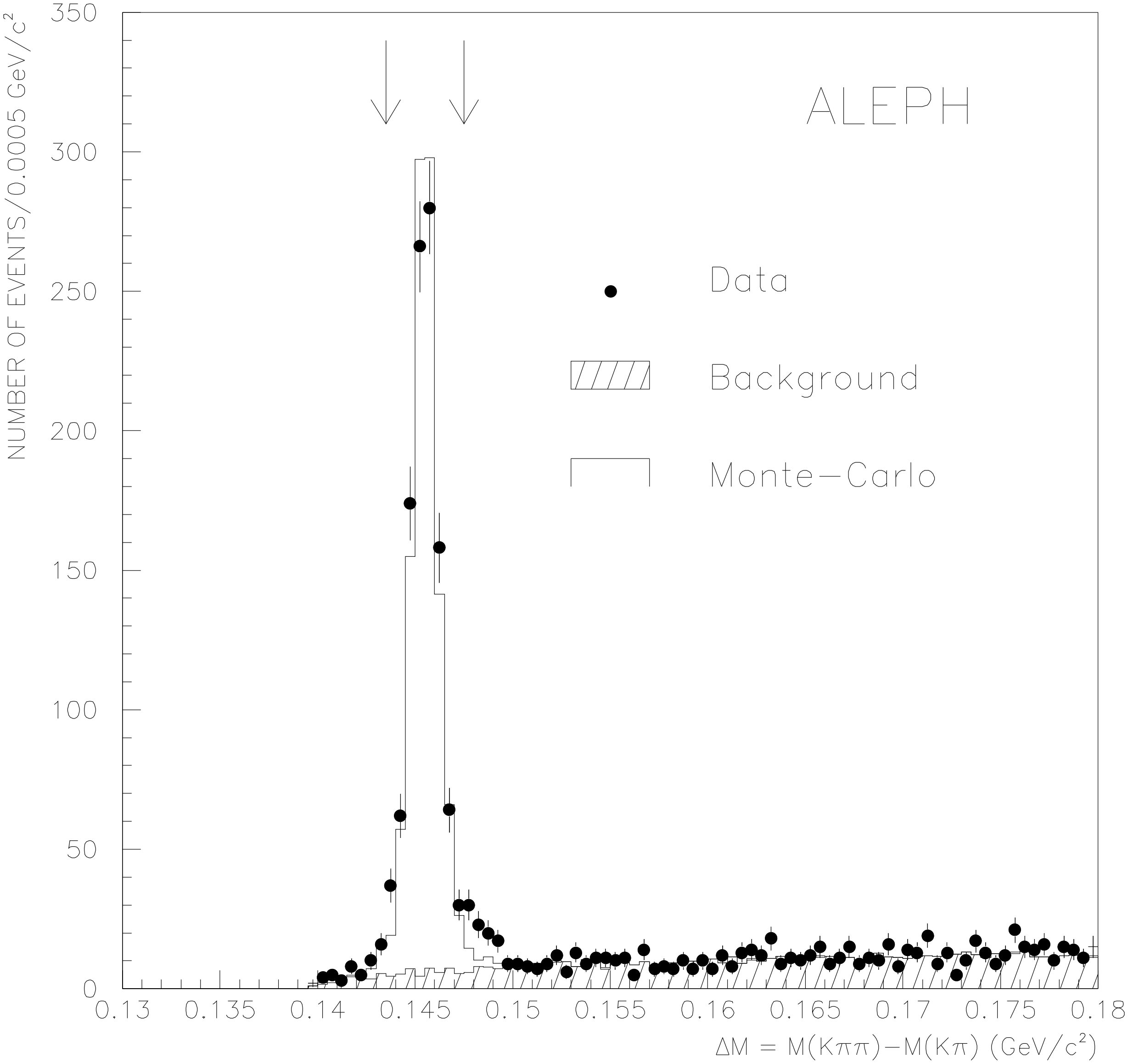
ALEPH
Data
Background
Monte-Carlo
NUMBER OF EVENTS/0.0005 GeV/c²
ΔM = M(Kππ)−M(Kπ) (GeV/c²)
0
50
100
150
200
250
300
350
0.13
0.135
0.14
0.145
0.15
0.155
0.16
0.165
0.17
0.175
0.18

Fig. 1

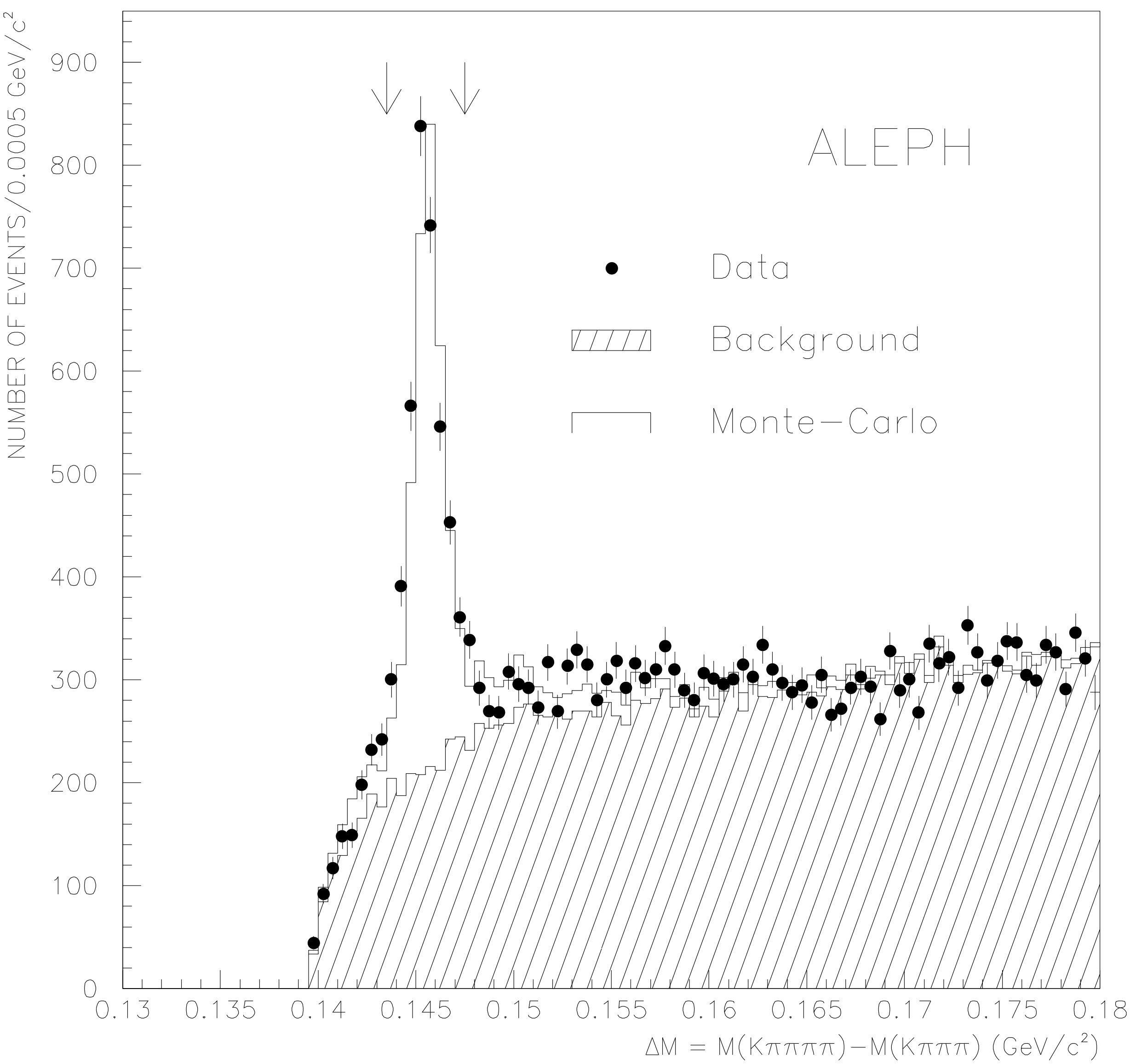
NUMBER OF EVENTS/0.0005 GeV/c^2
900
800
700
600
500
400
300
200
100
0
0.13
0.135
0.14
0.145
0.15
0.155
0.16
0.165
0.17
0.175
0.18
ΔM = M(Kππππ)−M(Kπππ) (GeV/c^2)
ALEPH
Data
Background
Monte−Carlo

Fig. 2

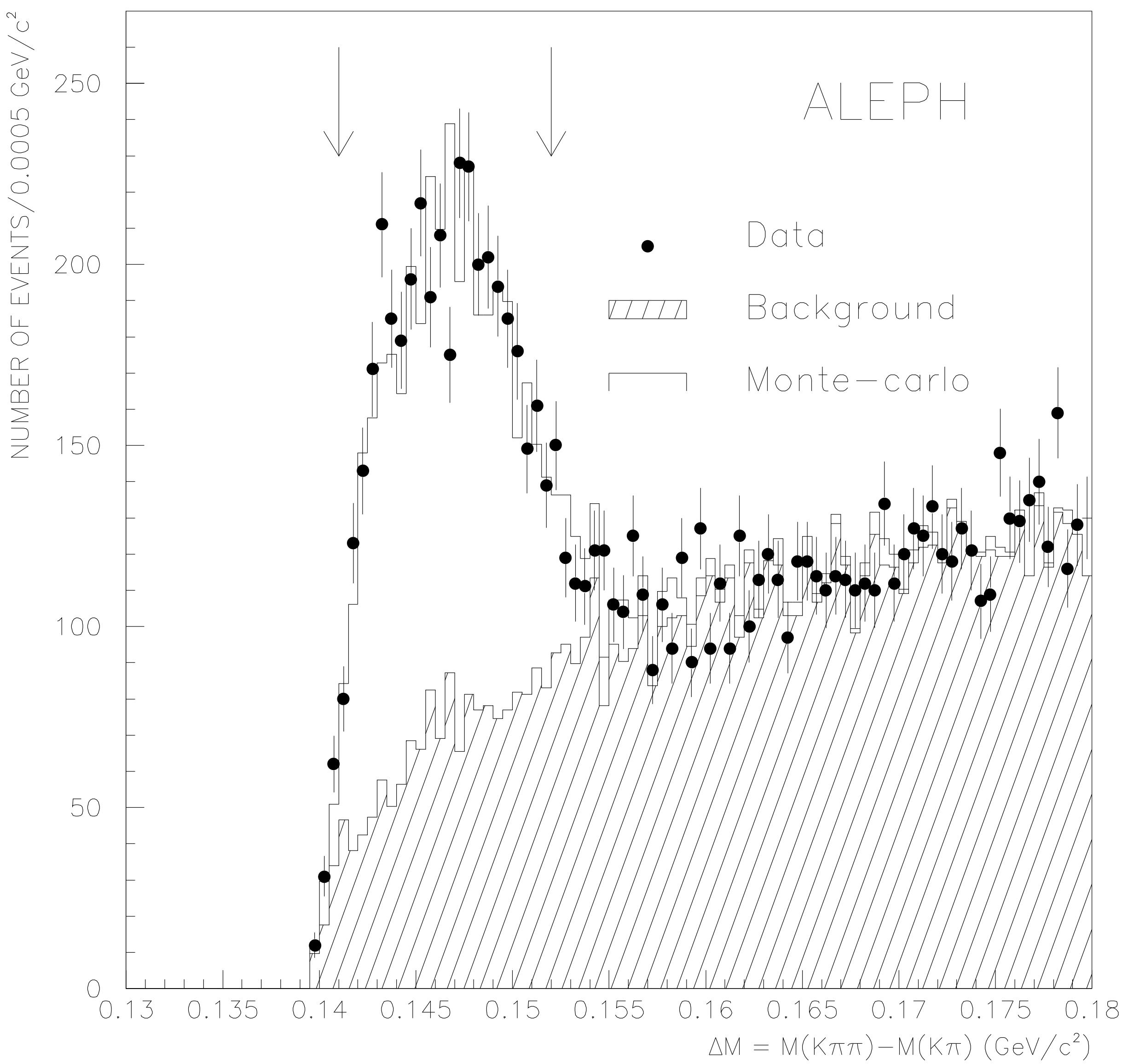
ALEPH
Data
Background
Monte-carlo
NUMBER OF EVENTS/0.0005 GeV/c²
ΔM = M(Kππ)−M(Kπ) (GeV/c²)
0
50
100
150
200
250
0.13
0.135
0.14
0.145
0.15
0.155
0.16
0.165
0.17
0.175
0.18

Fig. 3

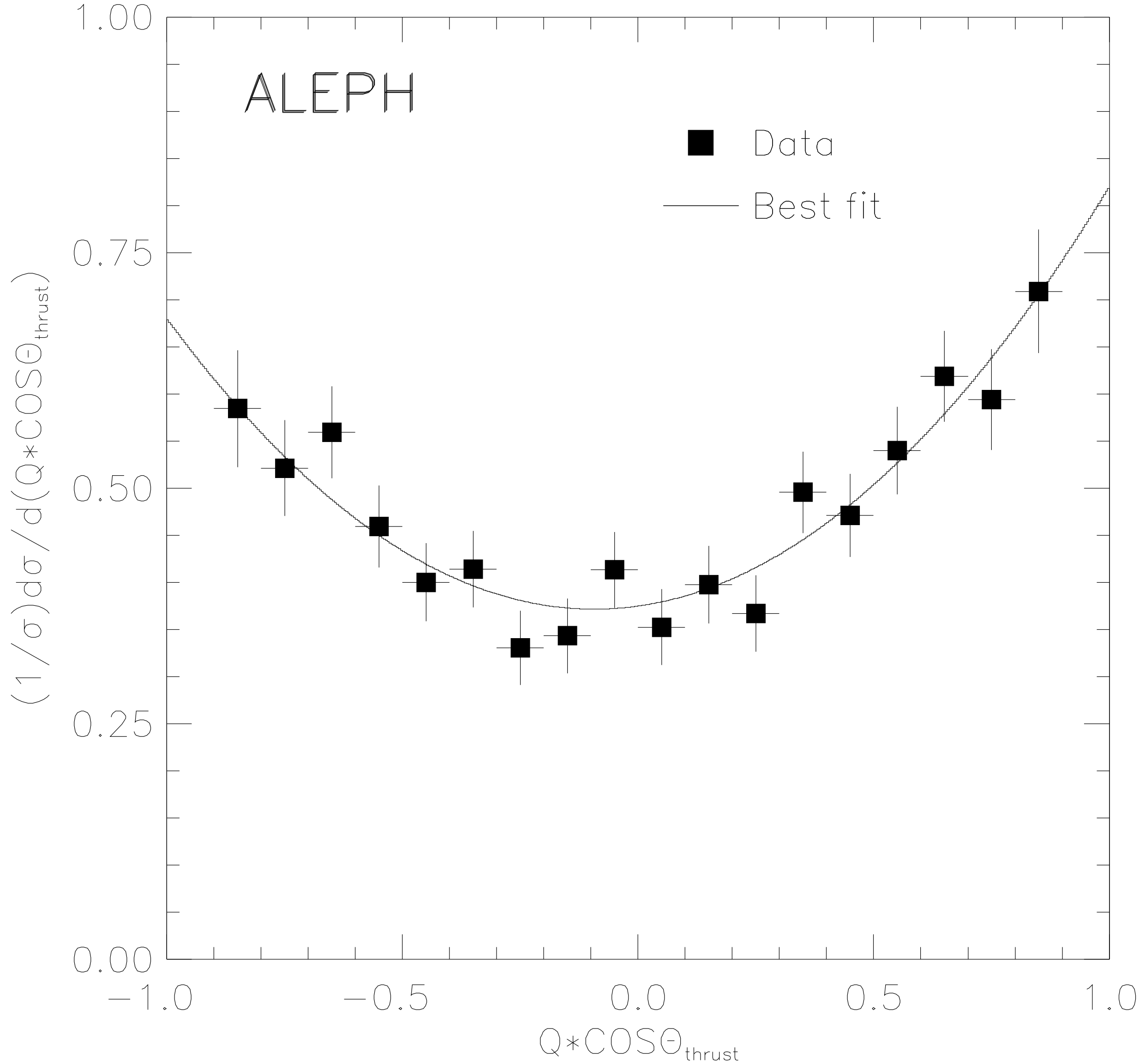
ALEPH
Data
Best fit
1.00
0.75
0.50
0.25
0.00
−1.0
−0.5
0.0
0.5
1.0
(1/σ)dσ/d(Q∗COSΘthrust)
Q∗COSΘthrust

Fig. 4