



HAL
open science

Search for CP violation in the decay $Z \rightarrow \tau^+ \tau^-$

D. Buskalic, D. Casper, I. de Bonis, D. Decamp, P. Ghez, C. Goy, J.P. Lees,
M.N. Minard, P. Odier, B. Pietrzyk, et al.

► **To cite this version:**

D. Buskalic, D. Casper, I. de Bonis, D. Decamp, P. Ghez, et al.. Search for CP violation in the decay $Z \rightarrow \tau^+ \tau^-$. Physics Letters B, 1995, 346, pp.371-378. in2p3-00003643

HAL Id: in2p3-00003643

<https://hal.in2p3.fr/in2p3-00003643>

Submitted on 18 May 1999

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

Search for \mathcal{CP} violation in the decay $Z \rightarrow \tau^+ \tau^-$

The ALEPH Collaboration

Abstract

Data collected by ALEPH in the years 1990, 1991 and 1992 have been used to update a previous search for \mathcal{CP} violation in the decay of the Z into $\tau^+ \tau^-$. The measurement of the weak dipole form factor of the τ lepton has been performed by studying correlations between the τ leptons. No signal of \mathcal{CP} violation was found. The weak dipole form factor is found to be $\tilde{d}_\tau = (+0.15 \pm 0.58_{stat} \pm 0.38_{sys}) 10^{-17} e \cdot \text{cm}$, obtained with 19628 identified $\tau^+ \tau^-$ events. This gives an upper limit on the weak dipole form factor of $|\tilde{d}_\tau| < 1.5 \cdot 10^{-17} e \cdot \text{cm}$ at the 95% confidence level.

(Submitted to Physics Letters B)

The ALEPH Collaboration

D. Buskalic, 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), IN²P³-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 Autònoma de Barcelona, 08193 Bellaterra (Barcelona), Spain⁷

D. Creanza, M. de Palma, A. Farilla, G. Iaselli, G. Maggi, 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 China⁸

G. Bonvicini, P. Comas, P. Coyle, H. Drevermann, A. Engelhardt, R.W. Forty, M. Frank, G. Ganis, C. Gay,³ M. Girone, R. Hagelberg, J. Harvey, R. Jacobsen, B. Jost, J. Knobloch, I. Lehraus, M. Maggi, C. Markou, E.B. Martin, P. Mato, H. Meinhard, A. Minten, R. Miquel, P. Palazzi, J.R. Pater, P. Perrodo, J.-F. Puztaszeri, F. Ranjard, L. Rolandi, D. Schlatter, M. Schmelling, W. Tejessy, I.R. Tomalin, R. Veenhof, A. Venturi, H. Wachsmuth, W. Wiedenmann, W. Witzeling, J. Wotschack

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

Z. Ajaltouni, M. Bardadin-Otwinowska, 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. Proriot, J.-M. Rossignol, F. Saadi

Laboratoire de Physique Corpusculaire, Université Blaise Pascal, IN²P³-CNRS, Clermont-Ferrand, 63177 Aubière, France

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

Niels Bohr Institute, 2100 Copenhagen, Denmark⁹

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

Nuclear Research Center Demokritos (NRCD), Athens, Greece

A. Blondel, 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, IN²P³-CNRS, 91128 Palaiseau Cedex, France

D.J. Candlin, M.I. Parsons, E. Veitch

Department of Physics, University of Edinburgh, Edinburgh EH9 3JZ, United Kingdom¹⁰

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, S. Salomone

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

P. Colrain, I. ten Have,⁶ I.G. Knowles, J.G. Lynch, W. Maitland, W.T. Morton, C. Raine, P. Reeves, J.M. Scarr, K. Smith, M.G. Smith, A.S. Thompson, S. Thorn, R.M. Turnbull

Department of Physics and Astronomy, University of Glasgow, Glasgow G12 8QQ, United Kingdom¹⁰

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, M. Wunsch

Institut für Hochenergiephysik, Universität Heidelberg, 69120 Heidelberg, Fed. Rep. of Germany¹⁶

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

Department of Physics, Imperial College, London SW7 2BZ, United Kingdom¹⁰

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

Institut für Experimentalphysik, Universität Innsbruck, 6020 Innsbruck, Austria¹⁸

C.K. Bowdery, T.J. Brodbeck, A.J. Finch, F. Foster, G. Hughes, D. Jackson, N.R. Keemer, M. Nuttall, A. Patel, T. Sloan, S.W. Snow, E.P. Whelan

Department of Physics, University of Lancaster, Lancaster LA1 4YB, United Kingdom¹⁰

A. Galla, A.M. Greene, K. Kleinknecht, J. Raab, B. Renk, H.-G. Sander, H. Schmidt, S.M. Walther, R. Wanke, B. Wolf

Institut für Physik, Universität Mainz, 55099 Mainz, Fed. Rep. of Germany¹⁶

A.M. Bencheikh, C. Benchouk, A. Bonissent, D. Calvet, J. Carr, C. Diaconu, F. Etienne, D. Nicod, P. Payre, L. Roos, D. Rousseau, M. Talby

Centre de Physique des Particules, Faculté des Sciences de Luminy, IN²P³-CNRS, 13288 Marseille, France

I. Abt, S. Adlung, R. Assmann, C. Bauer, W. Blum, D. Brown, P. Cattaneo,²³ B. Dehning, H. Dietl, F. Dydak,²¹ A.W. Halley, K. Jakobs, H. Kroha, J. Lauber, G. Lütjens, G. Lutz, W. Männer, H.-G. Moser, R. Richter, J. Schröder, A.S. Schwarz, R. Settles, H. Seywerd, U. Stierlin,² U. Stiegler, R. St. Denis, G. Wolf

Max-Planck-Institut für Physik, Werner-Heisenberg-Institut, 80805 München, Fed. Rep. of Germany¹⁶

R. Alemany, J. Boucrot, O. Callot, A. Cordier, F. Courault, M. Davier, L. DufLOT, J.-F. Grivaz, Ph. Heusse, M. Jacquet, P. Janot, 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, IN²P³-CNRS, 91405 Orsay Cedex, France

D. Abbaneo, G. Bagliesi, G. Batignani, S. Bettarini, U. Bottigli, C. Bozzi, G. Calderini, M. Carpinelli, M.A. Ciocci, V. Ciulli, R. Dell'Orso, I. Ferrante, F. Fidecaro, 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, J.A. Strong

Department of Physics, Royal Holloway & Bedford New College, University of London, Surrey TW20 OEX, United Kingdom¹⁰

V. Bertin, D.R. Botterill, R.W. Clift, 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 0QX, United Kingdom¹⁰

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, A.M. Litke, G. Taylor, J. Wear

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

A. Beddall, C.N. Booth, C. Boswell, S. Cartwright, F. Combley, I. Dawson, A. Koksai, 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, U. Schäfer, L. Smolik

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

L. Bosisio, R. Della Marina, G. Giannini, B. Gobbo, L. Pitis, F. Ragusa²⁰

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

H. Kim, J. Rothberg, S. Wasserbaech

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

S.R. Armstrong, L. Bellantoni, J.S. Conway,²⁴ 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. Scott, V. Sharma, J.D. Turk, A.M. Walsh, F.V. Weber,¹ T. Wildish, Sau Lan Wu, X. Wu, J.M. Yamartino, M. Zheng, G. Zoernig

*Department of Physics, University of Wisconsin, Madison, WI 53706, USA*¹¹

¹Now at CERN, 1211 Geneva 23, Switzerland.

²Deceased.

³Now at Harvard University, Cambridge, MA 02138, U.S.A.

⁴Also Istituto di Fisica Generale, Università di Torino, Torino, Italy.

⁵Also Istituto di Cosmo-Geofisica del C.N.R., Torino, Italy.

⁶Now at TSM Business School, Enschede, The Netherlands.

⁷Supported by CICYT, Spain.

⁸Supported by the National Science Foundation of China.

⁹Supported by the Danish Natural Science Research Council.

¹⁰Supported by the UK Science and Engineering Research Council.

¹¹Supported by the US Department of Energy, contract DE-AC02-76ER00881.

¹²On leave from Universitat Autònoma de Barcelona, Barcelona, Spain.

¹³Supported by the US Department of Energy, contract DE-FG05-92ER40742.

¹⁴Supported by the US Department of Energy, contract DE-FC05-85ER250000.

¹⁵Permanent address: Universitat de Barcelona, 08208 Barcelona, Spain.

¹⁶Supported by the Bundesministerium für Forschung und Technologie, Fed. Rep. of Germany.

¹⁷Supported by the Direction des Sciences de la Matière, C.E.A.

¹⁸Supported by Fonds zur Förderung der wissenschaftlichen Forschung, Austria.

¹⁹Permanent address: Kangnung National University, Kangnung, Korea.

²⁰Now at Dipartimento di Fisica, Università di Milano, Milano, Italy.

²¹Also at CERN, 1211 Geneva 23, Switzerland.

²²Supported by the US Department of Energy, grant DE-FG03-92ER40689.

²³Now at Università di Pavia, Pavia, Italy.

²⁴Now at Rutgers University, Piscataway, NJ 08854, USA.

²⁵Partially supported by Colciencias, Colombia.

²⁶Also at Istituto di Matematica e Fisica, Università di Sassari, Sassari, Italy.

1 Introduction

The decay of the Z boson into $\tau^+\tau^-$ is an appropriate process to search for signals of \mathcal{CP} violation caused by new interactions. Since in the Standard Model \mathcal{CP} violation occurs only in the couplings of the charged current as described in the CKM scheme, \mathcal{CP} odd contributions to the reaction $Z \rightarrow \tau^+\tau^-$ are at most of the order of 10^{-7} [1] compared to the electroweak amplitude at the Born level. On the other hand extensions of the Standard Model, such as models with leptoquarks or with extended Higgs sectors, but also left–right symmetric or supersymmetric interactions can generate \mathcal{CP} violating effects at the $Z\tau\tau$ vertex[2]. The parametrization of these contributions by the weak dipole form factor of the τ lepton at the Z resonance gives a model independent description of the on–shell amplitude, which in this case consists of the coherent sum of the electroweak amplitude and an amplitude proportional to the weak dipole form factor \tilde{d}_τ .

An indirect limit on the weak dipole form factor can be derived from the measurement of the Z partial width Γ_τ , since there would be an additional contribution from the weak dipole form factor $\Delta\Gamma_\tau \approx |\tilde{d}_\tau|^2 m_Z^2 / (24\pi)$ [1]. From the comparison of the value measured at LEP, $\Gamma_\tau = (84.26 \pm 0.34) \text{ MeV}$ [3], and the theoretical prediction of the Standard Model, $\Gamma_\tau^{SM} = (83.7 \pm 0.4) \text{ MeV}$ [4], one obtains an indirect upper limit on the weak dipole form factor of $|\tilde{d}_\tau| < 2.3 \cdot 10^{-17} e \cdot \text{cm}$ (95 % *c.l.*). However, if there are new physics effects, there may also be \mathcal{CP} even contributions to the partial width, which can cancel partially the contribution from \tilde{d}_τ .

In order to measure the dipole form factor directly from \mathcal{CP} odd correlations between the τ leptons, we use the following \mathcal{CP} odd tensor observables[5, 6]:

$$\hat{T}_{ij} = (\hat{p}_+ - \hat{p}_-)_i \cdot \frac{(\hat{p}_+ \times \hat{p}_-)_j}{|\hat{p}_+ \times \hat{p}_-|} + (i \leftrightarrow j) \quad i, j = 1, 2, 3 \quad (1)$$

\hat{p}_+ (\hat{p}_-) denotes the normalized momentum vector of one of the decay particles of the τ^+ (τ^-), i, j are cartesian coordinate indices. The relation between the observable and the dipole form factor \tilde{d}_τ is given by[5, 6]:

$$\langle \hat{T}_{ij} \rangle_{AB} = \frac{m_Z}{e} \cdot \tilde{d}_\tau \cdot \hat{c}_{AB} \cdot s_{ij} \quad (2)$$

A and B are the decay modes of τ^- and τ^+ , respectively. The constants \hat{c}_{AB} describe the sensitivity of the angular distributions of the decay particles used to build \hat{T} to the spin states of the τ leptons. Therefore these constants depend in magnitude and sign explicitly on the decay mode of τ^- and τ^+ . This analysis uses the major τ decay modes $e\nu\nu$, $\mu\nu\nu$, $\pi\nu$, $\rho\nu$, and $a_1\nu$, with $a_1 \rightarrow \pi\pi^+\pi^-$ and $a_1 \rightarrow \pi 2\pi^0$. This results in 18 different classes, the three classes $a_1 - a_1$ are not used due to low statistics and high backgrounds. The matrix $s_{ij} = \text{diag}(-\frac{1}{6}, -\frac{1}{6}, \frac{1}{3})$ is a diagonal matrix representing the tensor polarisation of the Z boson in the coordinate system in which the z axis is determined by the direction of the incident positron beam. As can be seen from the matrix s_{ij} , \hat{T}_{33} is the most sensitive component and will give the largest signal if $\tilde{d}_\tau \neq 0$. Since in addition the three diagonal elements are strongly correlated due to the fact that the trace of \hat{T} must be zero and since the systematic checks are easier to perform for \hat{T}_{33} , only \hat{T}_{33} is used in this analysis.

The analysis described in this paper improves upon and supersedes the result published by the ALEPH Collaboration ($|\tilde{d}_\tau| < 3.7 \cdot 10^{-17} e \cdot \text{cm}$ at the 95 % *c.l.*)[7]. This is due to a better selection, yielding about 30 % more acceptance, the inclusion of the τ decays into a_1 and a doubling of the collected data. A limit on the weak dipole form factor of the τ has also been published by the OPAL Collaboration ($|\tilde{d}_\tau| < 7.0 \cdot 10^{-17} e \cdot \text{cm}$ at the 95 % *c.l.*)[8].

2 ALEPH Detector and Event selection

The ALEPH detector is described in detail elsewhere[9]. The main components used to measure the energies and the momenta are the electromagnetic calorimeter (ECAL) and the tracking devices, namely the vertex detector (VDET), the inner tracking chamber (ITC) and the time projection chamber (TPC). The particle identification relies on the dE/dx measurement in the TPC, on the ECAL, on the hadronic calorimeter (HCAL) and the muon chambers.

This analysis employs data collected by ALEPH in the years 1990, 1991 and 1992, corresponding to 57000 produced τ pairs. The event selection is based on a method developed for the analysis of the τ polarisation[10], and which is therein referred to as the neural net method. This includes particle identification and the cuts applied to classify the τ decays as well as to reject the background from non- τ events. In contrast to the polarisation analysis, events with both τ leptons decaying into electrons are

Event class	Selection-efficiency	Background fractions from	
		τ events	other processes
e-e	36.4 ± 0.6	2.8 ± 0.3	3.6 ± 1.2
e- μ	67.9 ± 0.4	3.2 ± 0.2	1.0 ± 0.3
e- π	39.3 ± 0.5	9.9 ± 0.5	0.3 ± 0.3
e- ρ	33.3 ± 0.4	7.4 ± 0.4	0.2 ± 0.2
e- $\pi\pi^+\pi^-$	41.7 ± 0.7	5.5 ± 0.5	0.2 ± 0.2
e- $\pi 2\pi^0$	25.2 ± 0.6	26.8 ± 1.0	0.4 ± 0.3
μ - μ	60.3 ± 0.6	3.2 ± 0.2	2.5 ± 0.7
μ - π	55.5 ± 0.5	8.9 ± 0.4	0.3 ± 0.2
μ - ρ	42.3 ± 0.4	7.2 ± 0.3	< 0.1
μ - $\pi\pi^+\pi^-$	50.4 ± 0.7	5.1 ± 0.4	0.3 ± 0.3
μ - $\pi 2\pi^0$	32.8 ± 0.6	27.9 ± 0.9	0.3 ± 0.3
π - π	47.1 ± 1.0	14.3 ± 0.9	1.0 ± 0.7
π - ρ	36.4 ± 0.5	13.6 ± 0.5	0.2 ± 0.2
π - $\pi\pi^+\pi^-$	42.8 ± 0.8	13.7 ± 0.8	0.2 ± 0.2
π - $\pi 2\pi^0$	27.6 ± 0.7	32.3 ± 1.2	0.5 ± 0.5
ρ - ρ	28.3 ± 0.4	12.4 ± 0.6	0.2 ± 0.2
ρ - $\pi\pi^+\pi^-$	30.9 ± 0.5	10.8 ± 0.4	0.3 ± 0.2
ρ - $\pi 2\pi^0$	22.2 ± 0.5	30.3 ± 0.9	< 0.1

Table 1: *Efficiencies and background with statistical errors for the event classes used in the analysis. All numbers are given in percent.*

retained and the decay of the a_1 into $\pi 2\pi^0$ is included. Event classes involving the latter decays can be used safely despite the large background and the uncertainty in the description of the multipion decays of the τ , because the sensitivity of these classes comes mainly from the lepton, π or ρ in the opposite hemisphere. The decay $a_1 \rightarrow \pi 2\pi^0$ is identified by cutting on the reconstructed masses of the a_1 , of the intermediate ρ and of the reconstructed π^0 's. In the case of two-electron events, severe cuts on the energy and $\cos\theta_{T_{hrust}}$ are applied to reduce background from Bhabha events as much as possible, because these events could fake a \mathcal{CP} violating effect due to bremsstrahlung in the detector material and to the forward-backward asymmetry of the t-channel distribution. The resulting efficiencies and the background fractions for all classes are listed in table 1.

3 Data analysis

The constants \hat{c}_{AB} are determined channel by channel using a Monte Carlo generator for the process $Z \rightarrow \tau^+\tau^-$ with \mathcal{CP} violating couplings[11]. The \hat{c}_{AB} 's can be determined from the generated distributions with known \vec{d}_τ using relation (2). Since there are 18 different classes, which all have to be treated separately, several million events must be generated. Therefore, in order to save computing time a simplified detector simulation was used. Kinematic cuts were implemented at generator level, whereas acceptance variations in the kinematic variables were taken care of by a weighting procedure based on acceptances for single event hemispheres. These weights have been determined from the Monte Carlo including the full detector simulation. To test the effects of the detector resolution, events with the full detector simulation were generated for three classes. It was found that the differences between the constants \hat{c}_{AB} computed that way and using the simplified detector simulation were negligible.

Misidentification of τ decay modes and background events change the value of the constants \hat{c}_{AB} in the various event classes. This is considered computing effective values by making the sum of the \hat{c}_{AB} of the event class and the contributing background channels weighted by their relative fraction. The uncertainties on the \hat{c}_{AB} of the background channels due to the cuts applied to reject that background were estimated from the effects of the cuts on the \hat{c}_{AB} of the event classes, where the cuts have been implemented in the Monte Carlo. These uncertainties resulted in an additional error on the effective sensitivities.

For the τ decays into ρ or a_1 mesons one can either use the reconstructed total momentum vector of the ρ or a_1 to build \hat{T}_{33} , or the momentum vector of a single pion from the decay, which is the charged pion in the case of the ρ and the pion with unique charge in the case of the a_1 . It was pointed out in [12]

Event class	Number of events	\hat{c}_{AB}	\tilde{d}_τ	$\Delta\tilde{d}_\tau^{stat}$	$\Delta\tilde{d}_\tau^{sys}$	$\Delta\tilde{d}_\tau^c$	$\Delta\tilde{d}_\tau^{Ecal}$
e-e	668	+0.59	+5.1	4.2	1.5	0.6	—
e- μ	2449	+0.72	-3.5	2.0	1.1	0.3	—
e- π	1101	-0.89	-0.5	2.3	1.1	< 0.1	—
e- ρ	1801	+0.36	+1.5	4.7	2.6	0.3	—
e- $\pi\pi^+\pi^-$	804	+0.49	-0.9	5.2	2.2	0.2	—
e- $\pi 2\pi^0$	560	+0.44	+2.5	6.9	1.9	0.7	—
μ - μ	1260	+0.90	+2.2	2.2	0.4	0.2	—
μ - π	1463	-0.57	-5.8	3.3	0.6	0.7	—
μ - ρ	2291	+0.39	+3.8	3.8	0.4	0.6	—
μ - $\pi\pi^+\pi^-$	937	+0.49	-3.9	4.8	1.1	0.3	—
μ - $\pi 2\pi^0$	730	+0.63	+0.9	4.3	0.6	0.2	—
π - π	479	-1.88	-1.4	1.7	0.2	0.1	—
π - ρ	1352	-1.53	± 0.0	1.2	0.2	< 0.1	0.4
π - $\pi\pi^+\pi^-$	564	-1.54	+1.3	1.9	0.4	0.2	—
π - $\pi 2\pi^0$	467	-1.45	+1.1	2.2	0.4	0.2	1.1
ρ - ρ	1100	-0.95	+1.9	2.1	0.6	0.2	0.6
ρ - $\pi\pi^+\pi^-$	889	-0.70	+6.2	3.4	1.1	1.6	0.8
ρ - $\pi 2\pi^0$	713	-0.72	-2.7	3.7	1.3	0.6	2.2

Table 2: The dipole form factors and the errors (in units of $10^{-17} e \cdot \text{cm}$) and the constants \hat{c}_{AB} for the event classes used in the analysis. The specification of the errors is given in the text.

that the sensitivity in the classes with a leptonic decay on the other side will be higher if a single pion is taken to build \hat{T}_{33} , whereas for a hadronic decay it is better to use the momentum of the ρ or a_1 meson. The resulting values of the \hat{c}_{AB} 's are shown in table 2.

Even though all steps of the selection are built to be \mathcal{C} and \mathcal{P} blind, the \mathcal{CP} invariance of the selection was checked. Further checks concern the radiation of photons, which affects the measurement of the momenta, and the event reconstruction from the subdetectors used in the analysis.

In order to avoid any systematic uncertainty from possible misalignments of the tracking devices a method is applied which ensures that the determination of \tilde{d}_τ is not affected by a possible shift in \hat{T}_{33} due to uncertainties in the track measurement. From equation (2) it follows that the influence of a systematic shift in \hat{T}_{33} on \tilde{d}_τ depends on the value of \hat{c}_{AB} . The measured \tilde{d}_{AB} for each individual class can be written as the sum of the physical dipole form factor \tilde{d}_τ and a part originating from a detector shift $\Delta\hat{T}$, as discussed in [7]:

$$\tilde{d}_{AB} = \tilde{d}_\tau + 3 \frac{\Delta\hat{T}}{\hat{c}_{AB}}$$

The shift can be eliminated in the combined result $\tilde{d} = \Sigma \lambda_{AB} \tilde{d}_{AB}$ if the constraint $\Sigma \frac{\lambda_{AB}}{\hat{c}_{AB}} = 0$ is imposed. The λ_{AB} are then determined by minimising the square of the error on \tilde{d}_τ with the two constraints $\Sigma \lambda_{AB} = 1$ and $\Sigma \frac{\lambda_{AB}}{\hat{c}_{AB}} = 0$. It can be noted that compared to the combined result of all classes with no constraint, this solution has practically the same statistical precision; this is due to the fact that the constants \hat{c}_{AB} have different signs. The result is:

$$\tilde{d}_\tau = (+0.15 \pm 0.58_{stat}) 10^{-17} e \cdot \text{cm} \quad \text{and} \quad \Delta\hat{T} = +0.004 \pm 0.008$$

The ECAL, used for the reconstruction of π^0 's, enters the measurement only in a few classes. Therefore a shift from the ECAL cannot be eliminated with the above method. To test it, an event mixing method is used. The observable \hat{T}_{33} is built from combinations of ρ 's and a_1 's, respectively, originating from different events and having an acollinearity between the charged pions greater than 170° for the ρ and 160° for the a_1 . Detector effects are then still visible in the mean value $\langle \hat{T}_{33} \rangle$, but a shift due to a true \mathcal{CP} violation will vanish. In all these cases no systematic effect was found, and the statistical errors of the methods are used as systematic uncertainties on $\langle \hat{T}_{33} \rangle$.

4 Results and Conclusion

Using the data collected in the years 1990, 1991 and 1992 no signal of \mathcal{CP} violation was found. Table 2 shows the results for \tilde{d}_τ in the individual classes with the following errors:

- $\Delta\tilde{d}_\tau^{stat}$: statistical error of the data.
- $\Delta\tilde{d}_\tau^{sys}$: systematic error, resulting from the checks concerning the \mathcal{CP} invariance of the selection and the radiation of photons. The contribution of $\Delta\hat{T}$ is not propagated, because it is negligible and cancels out in the combined result of all classes.
- $\Delta\tilde{d}_\tau^c$: error from the combined errors of the constants \hat{c}_{AB} .
- $\Delta\tilde{d}_\tau^{ECAL}$: error originating from the uncertainty of the event mixing.

Correlations in the systematic errors between the classes have been taken into account for the combination of the individual measurements. The result obtained with 19628 identified $\tau^+\tau^-$ events considering the τ decay modes $e\nu\nu$, $\mu\nu\nu$, $\pi\nu$, $\rho\nu$ and $a_1\nu$ is:

$$\tilde{d}_\tau = (+0.15 \pm 0.58_{stat} \pm 0.38_{sys}) 10^{-17} e \cdot \text{cm}$$
$$|\tilde{d}_\tau| < 1.5 \cdot 10^{-17} e \cdot \text{cm} \quad (95\% \text{ c.l.})$$

Acknowledgements

We wish to thank our colleagues from the accelerator division for the operation of LEP. We are indebted to the engineers and technicians in all our institutions for their contribution to the good performance of ALEPH. Those of us from non – member states thank CERN for its hospitality.

References

- [1] W. Bernreuther, U. Löw, J. P. Ma, O. Nachtmann, Z. Phys. C 43, 117(1989)
- [2] W. Bernreuther, T. Schröder, T. N. Pham, Phys. Lett. B 279, 389(1992)
S. M. Barr, A. Masiero, Phys. Rev. Lett. 187B, 187(1987)
A. Barroso, J. Maalampi, Phys. Lett. 187B, 85(1987)
W. Bernreuther in *Proceedings of the LP-HEP91 conference* edited by S. Hegarty, K. Potter, E. Quercigh, World Scientific, Singapore, 211(1992)
R. N. Mohapatra in *CP Violation — Advanced Series on Directions in High Energy Physics Vol. 3* edited by C. Jarlskog, World Scientific, Singapore, 1989
J. C. Pati, A. Salam, Phys. Rev. D 10, 275(1975)
R. N. Mohapatra, J. C. Pati, Phys. Rev. D 11, 566, 2558(1975)
G. Ecker, W. Grimus, H. Neufeld, Nucl. Phys. B 247, 70(1984)
- [3] D. Schaile, Rapporteur talk given at the 27th International Conference on High Energy Physics, Glasgow, Scotland, 20 – 27 Jul. 1994
- [4] W. Hollik in *Proceedings of the XVI International Symposium on Lepton and Photon Interactions, Ithaca, 1993*, edited by P. Drell and D. Rubin, AIP, New York, 352(1994)
- [5] W. Bernreuther, O. Nachtmann, Phys. Rev. Lett. 63, 2787(1989)
- [6] W. Bernreuther, G. W. Botz, O. Nachtmann, P. Overmann, Z. Phys. C 52, 567(1991)
- [7] D. Buskulic et al., ALEPH Collaboration, Phys. Lett. B 297, 459(1992)
- [8] P. D. Acton et al., OPAL Collaboration, Phys. Lett. B 281, 405(1992)
- [9] D. Decamp et al., ALEPH Collaboration, Nucl. Inst. and Meth. A 294, 121(1990)
- [10] D. Buskulic et al., ALEPH Collaboration, Z. Phys. C 59, 369(1993)
- [11] Program written by W. Bernreuther, P. Overmann, private communication
- [12] W. Bernreuther, O. Nachtmann, P. Overmann, Phys. Rev. D 48, 78(1993)