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Four-jet final state production in e+e- collisions at centre-of-mass energies ranging from 130 to 184 GeV

R. BARATE

Manoj THULASIDAS
Singapore Management University, manojt@smu.edu.sg

LABORATOIRE EUROPEEN POUR LA PHYSIQUE DES PARTICULES (CERN)

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The ALEPH Collaboration*)

Abstract

The four jet topology is analysed in the ALEPH data taken between November 1995 and October 1997, at centre-of-mass energies ranging from 130 to 184 GeV. While an unexpected accumulation of events with a dijet mass sum around 105 GeV/c^2 had been observed during the first run in 1995 at 130/136 GeV, corresponding to an integrated luminosity of 5.7 pb^{-1}, no significant differences between data and standard model prediction is seen, either in the high energy runs (81.1 pb^{-1} taken at centre-of-mass energies from 161 to 184 GeV) or in the 7.1 pb^{-1} recorded during a new short run at 130/136 GeV in 1997. We have found no other explanation for the earlier reported "four jet anomaly" than a statistical fluctuation.

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*) See next pages for the list of authors

The ALEPH Collaboration

R. Barate, D. Buskulic, D. Decamp, P. Ghez, C. Goy, J.-P. Lees, A. Lucotte, M.-N. Minard, J.-Y. Nief, B. Pietrzyk

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

G. Boix, M.P. Casado, M. Chmeissani, J.M. Crespo, M. Delfino, E. Fernandez, M. Fernandez-Bosman, Ll. Garrido,[15] E. Graugès, A. Juste, M. Martinez, G. Merino, R. Miquel, Ll.M. Mir, P. Morawitz, I.C. Park, A. Pascual, J.A. Perlas, I. Riu, F. Sanchez

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

A. Colaleo, D. Creanza, M. de Palma, G. Gelao, G. Iaselli, G. Maggi, M. Maggi, S. Nuzzo, A. Ranieri, G. Raso, F. Ruggieri, G. Selvaggi, L. Silvestris, P. Tempesta, A. Tricomi,[3] 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]

D. Abbaneo, R. Alemany, U. Becker, P. Bright-Thomas, D. Casper, M. Cattaneo, F. Cerutti, V. Ciulli, G. Dissertori, H. Drevermann, R.W. Forty, M. Frank, F. Gianotti, R. Hagelberg, J.B. Hansen, J. Harvey, P. Janot, B. Jost, I. Lehraus, P. Mato, A. Minten, L. Moneta,[22] A. Pacheco, J.-F. Pusztaszeri,[20] F. Ranjard, L. Rolandi, D. Rousseau, D. Schlatter, M. Schmitt, O. Schneider, W. Tejessy, F. Teubert, I.R. Tomalin, M. Vreeswijk, H. Wachsmuth, A. Wagner[1]

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

Z. Ajaltouni, F. Badaud G. Chazelle, O. Deschamps, A. Falvard, C. Ferdi, P. Gay, C. Guicheney, P. Henrard, J. Jousset, B. Michel, S. Monteil, J-C. Montret, D. Pallin, P. Perret, F. Podlyski, J. Proriol, P. Rosnet

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

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

Niels Bohr Institute, 2100 Copenhagen, Denmark[9]

G. Daskalakis, A. Kyriakis, C. Markou, E. Simopoulou, A. Vayaki

Nuclear Research Center Demokritos (NRCD), Athens, Greece

A. Blondel, J.-C. Brient, F. Machefert, A. Rougé, M. Rumpf, A. Valassi,[6] H. Videau

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

T. Boccali, E. Focardi, G. Parrini, K. Zachariadou

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

R. Cavanaugh, M. Corden, C. Georgiopoulos, T. Huehn, 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, V. Chiarella, G. Felici, P. Laurelli, G. Mannocchi,[5] F. Murtas, G.P. Murtas, L. Passalacqua, M. Pepe-Altarelli

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

L. Curtis, S.J. Dorris, A.W. Halley, J.G. Lynch, P. Negus, V. O'Shea, C. Raine, J.M. Scarr, K. Smith, P. Teixeira-Dias, A.S. Thompson, E. Thomson, F. Thomson, J. Ward

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

O. Buchmüller, S. Dhamotharan, C. Geweniger, G. Graefe, P. Hanke, G. Hansper, V. Hepp, E.E. Kluge, A. Putzer, J. Sommer, 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, P.J. Dornan, M. Girone, S. Goodsir, E.B. Martin, N. Marinelli, A. Moutoussi, J. Nash, J.K. Sedgbeer, P. Spagnolo, M.D. Williams

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

V.M. Ghete, P. Girtler, E. Kneringer, D. Kuhn, G. Rudolph

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

A.P. Betteridge, C.K. Bowdery, P.G. Buck, P. Colrain, G. Crawford, A.J. Finch, F. Foster, G. Hughes, R.W.L. Jones, E.P. Whelan, M.I. Williams

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

I. Giehl, C. Hoffmann, K. Jakobs, K. Kleinknecht, G. Quast, B. Renk, E. Rohne, H.-G. Sander, P. van Gemmeren, C. Zeitnitz

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

J.J. Aubert, C. Benchouk, A. Bonissent, G. Bujosa, J. Carr, P. Coyle, A. Ealet, D. Fouchez, O. Leroy, F. Motsch, P. Payre, M. Talby, A. Sadouki, M. Thulasidas, A. Tilquin, K. Trabelsi

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

M. Aleppo, M. Antonelli, F. Ragusa

Dipartimento di Fisica, Università di Milano e INFN Sezione di Milano, 20133 Milano, Italy.

R. Berlich, W. Blum, V. Büscher, H. Dietl, G. Ganis, C. Gotzhein, H. Kroha, G. Lütjens, G. Lutz, C. Mannert, W. Männer, H.-G. Moser, R. Richter, A. Rosado-Schlosser, S. Schael, R. Settles, H. Seywerd, H. Stenzel, W. Wiedenmann, G. Wolf

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

J. Boucrot, O. Callot,[12] S. Chen, M. Davier, L. Duflot, J.-F. Grivaz, Ph. Heusse, A. Höcker, A. Jacholkowska, M.M. Kado, D.W. Kim,[2] F. Le Diberder, J. Lefrançois, A.-M. Lutz, M.-H. Schune, L. Serin, E. Tournefier, J.-J. Veillet, I. Videau, D. Zerwas

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

P. Azzurri, G. Bagliesi,[12] S. Bettarini, C. Bozzi, G. Calderini, R. Dell'Orso, R. Fantechi, I. Ferrante, A. Giassi, A. Gregorio, F. Ligabue, A. Lusiani, P.S. Marrocchesi, A. Messineo, F. Palla, G. Rizzo, G. Sanguinetti, A. Sciabà, G. Sguazzoni, J. Steinberger, R. Tenchini, C. Vannini, A. Venturi, P.G. Verdini

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

G.A. Blair, L.M. Bryant, J.T. Chambers, J. Coles, M.G. Green, T. Medcalf, P. Perrodo, J.A. Strong, J.H. von Wimmersperg-Toeller

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

D.R. Botterill, R.W. Clifft, T.R. Edgecock, S. Haywood, P. Maley, P.R. Norton, J.C. Thompson, A.E. Wright

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

B. Bloch-Devaux, P. Colas, B. Fabbro, G. Faïf, E. Lançon, M.-C. Lemaire, E. Locci, P. Perez, H. Przysiezniak, J. Rander, J.-F. Renardy, A. Rosowsky, A. Roussarie, A. Trabelsi, B. Vallage

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

S.N. Black, J.H. Dann, H.Y. Kim, N. Konstantinidis, A.M. Litke, M.A. McNeil, G. Taylor

Institute for Particle Physics, University of California at Santa Cruz, Santa Cruz, CA 95064, USA[19]

C.N. Booth, C.A.J. Brew, S. Cartwright, F. Combley, M.S. Kelly, M. Lehto, J. Reeve, L.F. Thompson
Department of Physics, University of Sheffield, Sheffield S3 7RH, United Kingdom[10]

K. Affholderbach, A. Böhrer, S. Brandt, G. Cowan, J. Foss, C. Grupen, L. Smolik, F. Stephan
Fachbereich Physik, Universität Siegen, 57068 Siegen, Fed. Rep. of Germany[16]

M. Apollonio, L. Bosisio, R. Della Marina, G. Giannini, B. Gobbo, G. Musolino
Dipartimento di Fisica, Università di Trieste e INFN Sezione di Trieste, 34127 Trieste, Italy

J. Putz, J. Rothberg, S. Wasserbaech, R.W. Williams
Experimental Elementary Particle Physics, University of Washington, WA 98195 Seattle, U.S.A.

S.R. Armstrong, E. Charles, P. Elmer, D.P.S. Ferguson, Y. Gao, S. González, T.C. Greening, O.J. Hayes, H. Hu, S. Jin, P.A. McNamara III, J.M. Nachtman,[21] J. Nielsen, W. Orejudos, Y.B. Pan, Y. Saadi, I.J. Scott, J. Walsh, Sau Lan Wu, X. Wu, J.M. Yamartino, G. Zobernig
Department of Physics, University of Wisconsin, Madison, WI 53706, USA[11]

[1]Now at Schweizerischer Bankverein, Basel, Switzerland.
[2]Permanent address: Kangnung National University, Kangnung, Korea.
[3]Also at Dipartimento di Fisica, INFN Sezione di Catania, Catania, Italy.
[4]Also Istituto di Fisica Generale, Università di Torino, Torino, Italy.
[5]Also Istituto di Cosmo-Geofisica del C.N.R., Torino, Italy.
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[9]Supported by the Danish Natural Science Research Council.
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[11]Supported by the US Department of Energy, grant DE-FG0295-ER40896.
[12]Also at CERN, 1211 Geneva 23,Switzerland.
[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 Bildung, Wissenschaft, 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]Supported by the US Department of Energy, grant DE-FG03-92ER40689.
[20]Now at School of Operations Research and Industrial Engireering, Cornell University, Ithaca, NY 14853-3801, U.S.A.
[21]Now at University of California at Los Angeles (UCLA), Los Angeles, CA 90024, U.S.A.
[22]Now at University of Geneva, 1211 Geneva 4, Switzerland.

1 Introduction

With the data recorded by ALEPH in November 1995 at centre-of-mass energies of 130 and 136 GeV, corresponding to an integrated luminosity of 5.7 pb^{-1}, 16 events were selected in the four-jet topology while 7.4 events were expected from standard model processes. The events were found to present an unexpected accumulation in the dijet mass sum spectrum around 105 GeV/c^2 [1]: nine events were selected with a dijet mass sum in a mass interval corresponding to $\pm 2\sigma$ of the detector resolution, for the jet pairing with the smallest mass difference, while 0.7 were expected from standard model processes. These events were characterized in addition by unusual parton dynamics and jet charges, and by a large dijet charge separation. The significance of these observations was reinforced by three events selected (with 1.0 expected) with the dijet mass sum in the same mass window when the jet pairing with the second smallest mass difference was considered instead. The dijet mass difference distribution of these 12 events was found not to be compatible with pair production of equal mass particles.

Thorough systematic studies were carried out in Ref. [1] to check whether these anomalies could be due to an underestimation of the cross-section for any of the standard processes, or could be an artifact of the selection, the jet momentum rescaling procedure, the detector geometry or unexpected detector effects. Complementary studies were performed during the following years within a LEP working group created for the purpose of investigating possible systematic differences in detector response and analysis methods among the four experiments. Their results are summarized in Ref. [2]. No systematic bias was found in either the analysis or the events themselves.

The corresponding distributions of the dijet mass sum for the jet combination with the smallest and second smallest mass difference, of the smallest jet charge, of the dijet charge separation and of the QCD matrix element squared are shown in Figs. 1a, 2a, 3a, 4a and 5a. These distributions are obtained with a selection, adopted prior to any other data taking, almost identical to that described in Ref. [1]. The only difference is that no use is made of the JADE algorithm when the Durham one fails. All cuts and the rescaling procedure were unchanged. The current selection is simpler and allowed an easier comparison between experiments to be made [2]. The observations and the conclusions of Ref. [1], which stressed the need for further statistics to decide whether the various anomalies were due to a conspiracy of statistical fluctuations or pointed to some kind of new physics, remained unchanged after this simplification. The observations and the conclusions of this letter, in which further data are investigated, remain identical if the original selection is used instead.

2 Analysis of higher energy data

The same four jet analysis was repeated in 1996 and 1997 with data collected at centre-of-mass energies ranging from 161 to 184 GeV, corresponding altogether to an integrated luminosity of 81.1 pb^{-1}. At these higher energies, a new selection cut was included to reduce the contribution of the $e^+e^- \to W^+W^-$ process. A good compromise between selection efficiency (as determined with simulated $hA \to b\bar{b}b\bar{b}$) and W^+W^- rejection was achieved by requiring that, for the three jet pairings ordered by increasing dijet mass difference, the dijet mass sum differ from twice the W mass

- by at least 10 GeV/c^2 for the first combination, if the dijet mass difference is smaller than 15 GeV/c^2;
- by at least 10 GeV/c^2 for the second combination, if the dijet mass difference is smaller than 30 GeV/c^2;
- by at least 5 GeV/c^2 for the third combination, if the dijet mass difference is smaller than 60 GeV/c^2.

The last cut is only useful at 161 GeV and is therefore not applied at the higher energies.

A total of 116 events was observed, with 103 expected from standard model processes. The distribution of the dijet mass sum is shown in Fig. 6a. (Here, and in the following unless otherwise specified, "dijet mass sum" stands for the jet pair combination with the smallest dijet mass difference.) The origin of the binning of this distribution is defined by the 12 peak events of the 1995 data, and the bin width corresponds to approximately twice the detector resolution at these centre-of-mass energies, *i.e.*, 4.8 GeV/c^2. This distribution presents no significant deviations with respect to the theoretical prediction. In the $\pm 2\sigma$ window around 105 GeV/c^2, 15 events are observed with 9.3 events expected. The slight excess observed is entirely due to the 161/172 GeV data: eight events out of a total of 21 were selected in this window, with 2.3 expected. The agreement is perfect in the 183 GeV data (seven events selected with 7.0 expected). The distribution of the dijet mass sum for the jet pair combination with the second smallest dijet mass difference is shown in Fig. 6b. It is also seen to be in agreement with the expectation.

The smallest jet charge and the dijet charge separation of these events were found to be compatible with the standard model expectation. This is, in particular, true for the 161/172 GeV data in which the excess in the 105 GeV/c^2 mass window is not supported by a deviation in either of these two quantities. The charge estimators are shown in Fig. 7 as a function of the dijet mass sum. While six out of the nine events observed in 1995 with their dijet mass sum around 105 GeV/c^2 had their smallest jet charge in excess of 0.12 or their dijet charge separation in excess of 0.60, these fractions become 8% and 16%, respectively, for the higher energy data, in agreement with expectation. Both criteria were simultaneously satisfied by five of the 1995 peak events, but only by 3% of the events selected at higher energies.

The distribution of the QCD matrix element squared, which quantifies the parton dynamics, was also found to be in agreement with the standard model prediction. It is, however, not a very discriminating variable at these energies, due in particular to the presence of the $e^+e^- \to W^+W^-$ process, more copiously produced than $q\bar{q}$ events in the four jet topology.

3 Result of the new run at 130/136 GeV

Following the ALEPH observation in 1995, the other three LEP Collaborations, DELPHI, L3 and OPAL, developed selection procedures [3] very similar to that of ALEPH. Their measured four jet rate during the 1995 run at 130/136 GeV was also high, although compatible within statistics with standard predictions: a total of seven events with a dijet mass sum around 105 GeV/c^2 was reported with 2.9 events expected, while no excess was observed [2] in the data collected at 161/172 GeV (about 20 pb^{-1} per experiment). The origin of the effect at 130 and 136 GeV, new physics or statistical fluctuation, therefore remained open.

A new short run at these centre-of-mass energies was thus scheduled at LEP to settle the problem. With an integrated luminosity of 7.1 pb^{-1}, collected during one week in October 1997, equally shared between 130 and 136 GeV, a total of eight events was observed in ALEPH after the four jet selection, with 9.2 expected from standard model processes. In the dijet mass sum window around 105 GeV/c^2, the only event observed is in agreement with the 0.9 events predicted. The corresponding dijet mass sum, charge and QCD matrix element squared distributions are shown in Figs. 1b, 2b, 3b, 4b and 5b. No events were found in this run with both a smallest jet charge in excess of 0.12 and a charge separation larger than 0.60.

All 1997 data were processed with an improved reconstruction program compared to the version used in previous years and incorporating in particular an upgraded tracking algorithm. Although the former version was shown in Ref. [1] not to create, with Z peak data, either spurious accumulations in dijet mass spectra, or fictitious deviations in charge or matrix element squared distributions, the 1995 (at 130/136 GeV) and 1996 (at 161/172 GeV) data have all been reprocessed with this new track reconstruction. The total numbers of events selected were 14 and 22, respectively, instead of the 16 and 21 originally found. At 130/136 GeV, 11 out of the original 12 events were found again in the dijet mass sum window around 105 GeV/c^2, of which seven in the first jet pair combination, and four in the second. The same eight events as in the original processing were found in this window at 161/172 GeV. The deviations seen in the charge and QCD matrix element squared distributions were still observed.

4 Conclusion

In this letter, the result of further investigations of the unexpected accumulation of events observed [1] in the four jet final state, at centre-of-mass energies of 130 and 136 GeV, has been presented. In the analysis of larger statistics at higher centre-of-mass energies and of a dedicated run at the original energies, the anomaly does not reappear.

We find no other explanation for the earlier reported effects than a statistical fluctuation.

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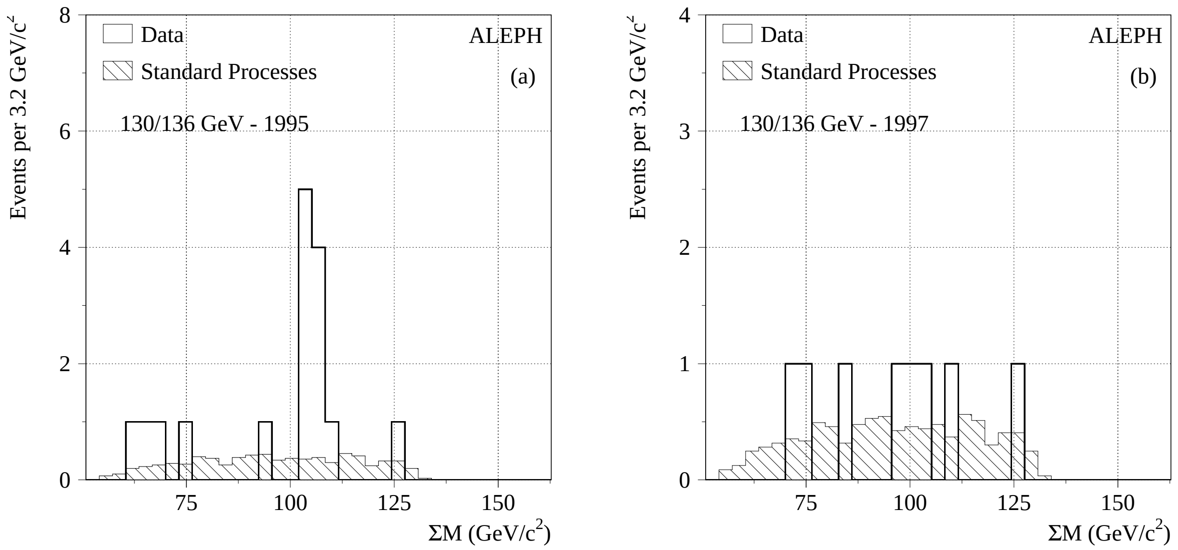

Figure 1: Distributions of the dijet mass sum for the jet pair combination with the smallest dijet mass difference in the data taken at centre-of-mass energies of 130/136 GeV (a) in 1995, and (b) in 1997.

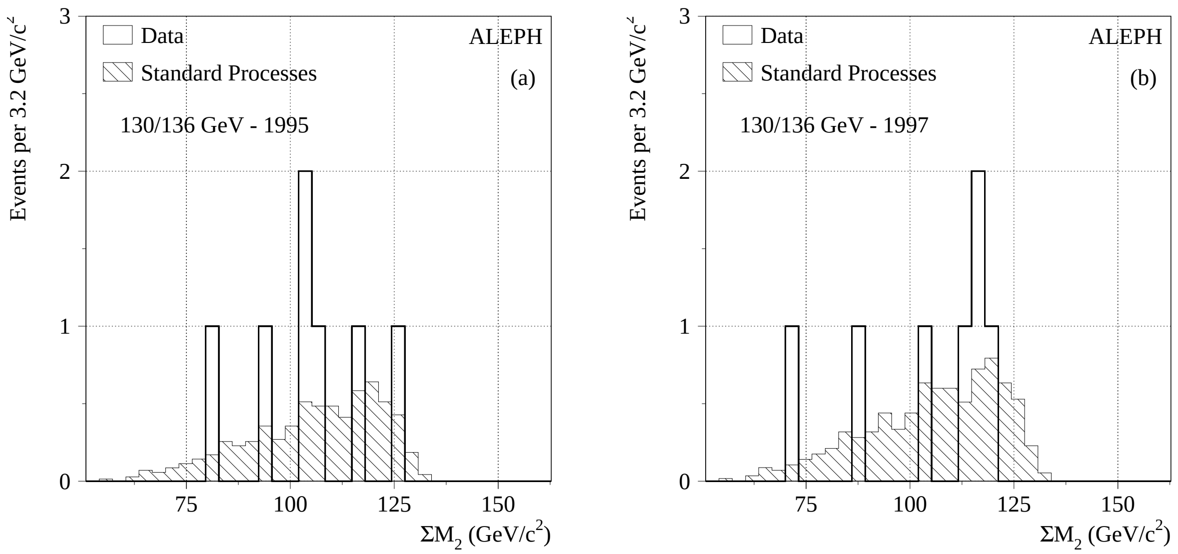

Figure 2: Distributions of the dijet mass sum for the jet pair combination with the second smallest dijet mass difference in the data taken at centre-of-mass energies of 130/136 GeV (a) in 1995, and (b) in 1997.

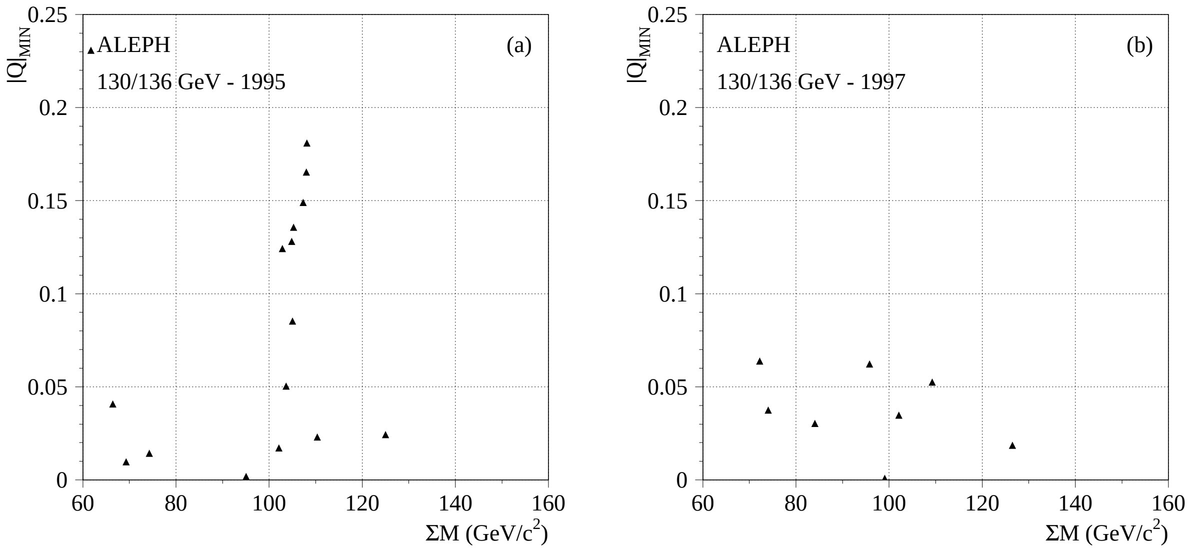

Figure 3: Distributions of the smallest jet charge *vs* the dijet mass sum in the data taken at centre-of-mass energies of 130/136 GeV (a) in 1995, and (b) in 1997.

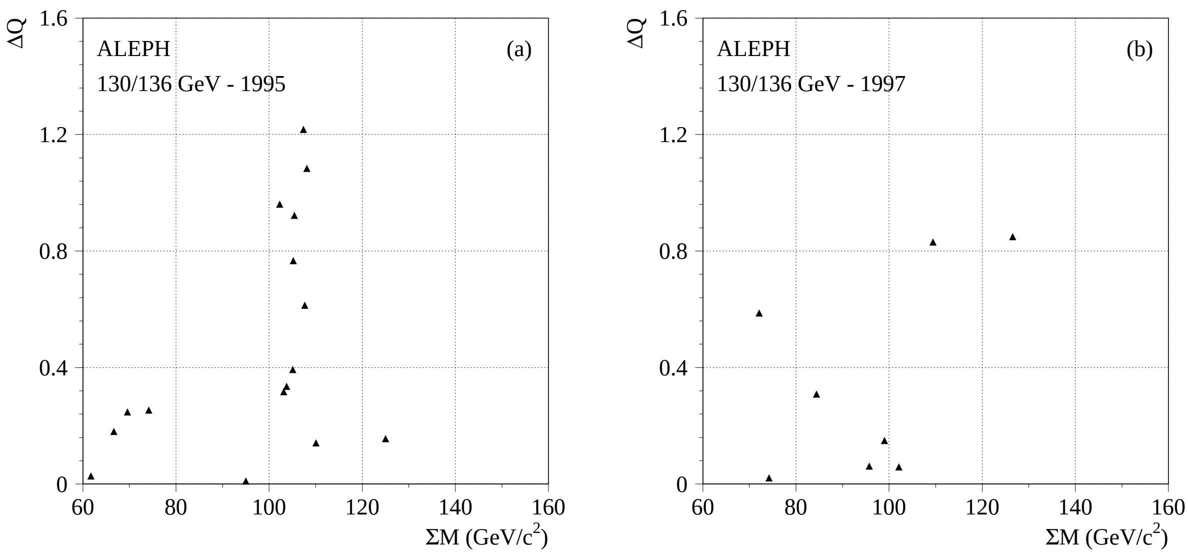

Figure 4: Distributions of the dijet charge separation for the jet pair combination with the smallest dijet mass difference *vs* the dijet mass sum in the data taken at centre-of-mass energies of 130/136 GeV (a) in 1995, and (b) in 1997.

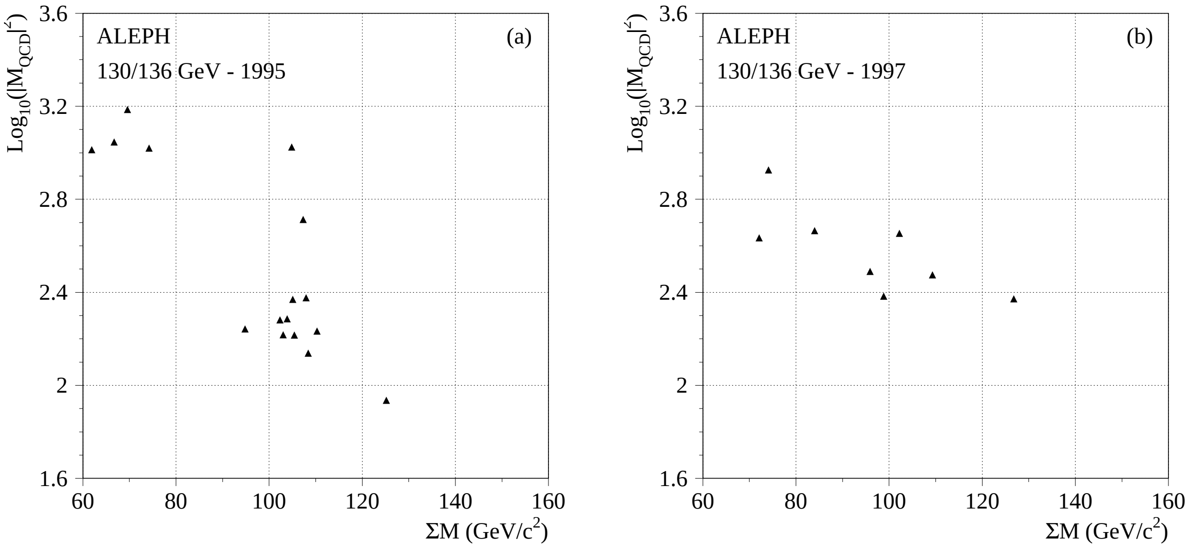

Figure 5: Distributions of the QCD matrix element squared, for the parton ordering leading to the highest value, *vs* the dijet mass sum in the data taken at centre-of-mass energies of 130/136 GeV (a) in 1995, and (b) in 1997.

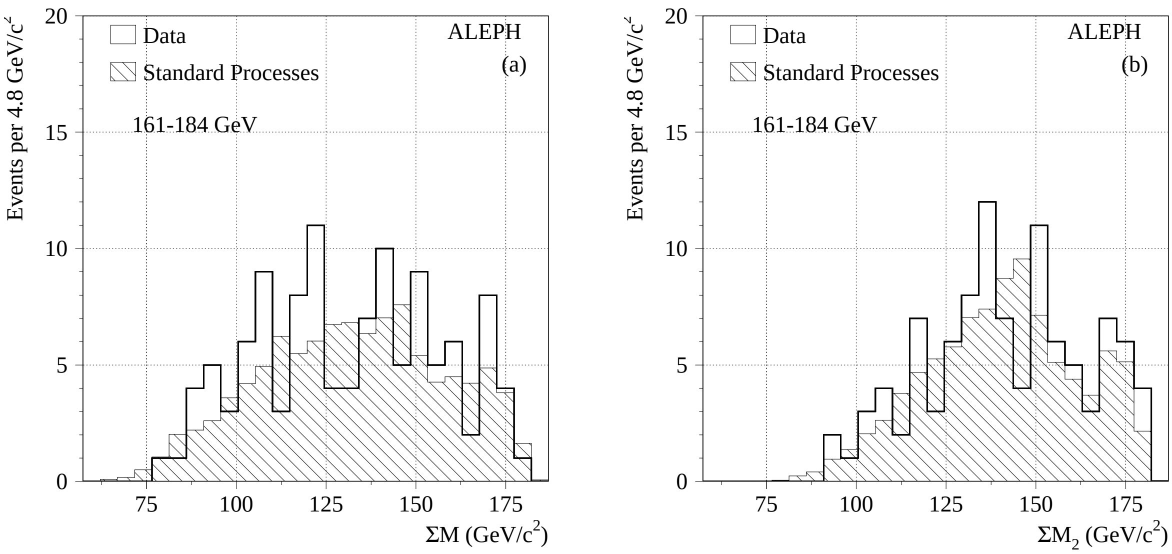

Figure 6: Distributions of the dijet mass sum for the jet pair combination with the (a) smallest and (b) second smallest dijet mass difference in the ALEPH data taken in 1996-1997 at centre-of-mass energies from 161 to 184 GeV.

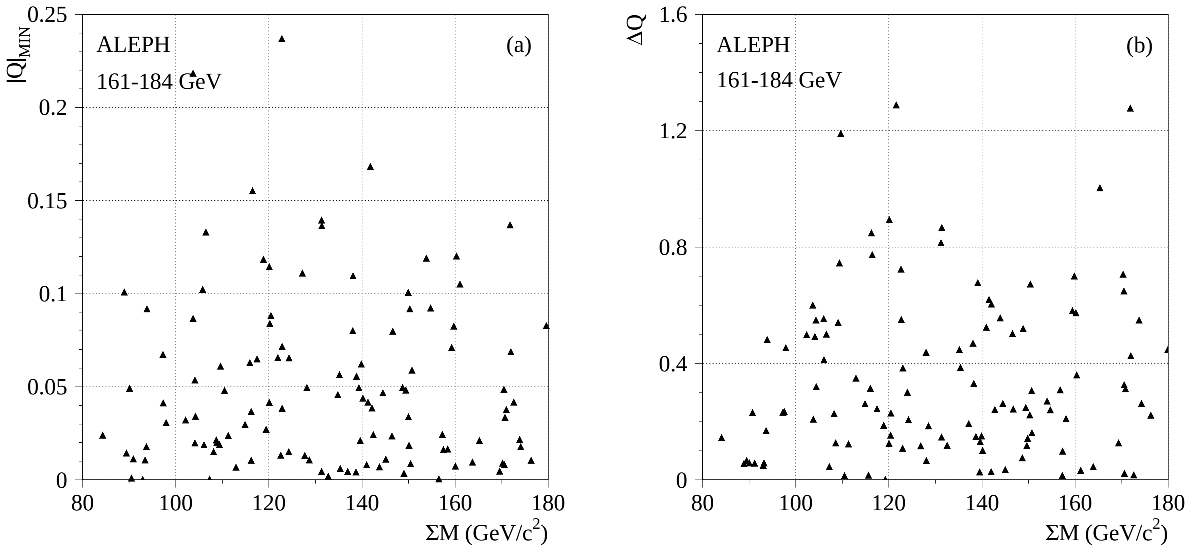

Figure 7: Distributions of the smallest jet charge (a) and of the dijet charge separation for the jet pair combination with the smallest dijet mass difference (b) *vs* the dijet mass sum in the ALEPH data taken in 1996-1997 at centre-of-mass energies from 161 to 184 GeV.