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Charged particle multiplicity in e^+e^- interactions at $\sqrt{s} = 130$ GeV

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Abstract

From the data collected by DELPHI at LEP in autumn 1995, the multiplicity of charged particles at a hadronic energy of 130 GeV has been measured to be $\langle n_{\mathrm{ch}} \rangle = 23.84 \pm 0.51(\mathrm{stat}) \pm 0.52(\mathrm{syst})$. When compared to lower energy data, the value measured is consistent with the evolution predicted by QCD with corrections at next-to-leading order, for a value $\alpha_s(130\,\mathrm{GeV}) = 0.105 \pm 0.003(\mathrm{stat}) \pm 0.008(\mathrm{syst})$.

1. Introduction

The average charged particle multiplicity is one of the basic observables characterizing hadronic final

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[1] On leave of absence from IHEP Serpukhov.

states. It has been extensively studied both theoretically and experimentally, and many predictions exist for its evolution with energy (see for example [1,2]).

The data collected recently in the 1995 third period of data taking at LEP (P3) are at the highest centre of mass energies in e^+e^- interactions, up to 140 GeV. In this letter, the data recorded using the DELPHI detector [3,4] were used to compute the average multiplicity at 130 GeV. The result was compared with the predictions from QCD at next-to-leading order.

2. Event selection

Hadronic events were selected among the data collected by DELPHI during 1995 at centre of mass energies of 130, 136 and 140 GeV with an integrated luminosity of 2.85, 2.98 and 0.04 pb^{-1} respectively. It was required that the multiplicity for charged particles (with momentum, p, above 400 MeV/c, angle with respect to the beam direction, θ, between 20 and 160 degrees, a track length of at least 30 cm in the TPC and consistent with coming from the interaction point) was larger than seven, and that the total energy of the charged particles exceeded $0.12 \times E_{\text{cm}}$. The data sample fulfilling the hadronic criteria contained 1506 events. Charged particles were used in the analysis if they had $p > 100$ MeV/c, a relative error on the momentum measurement $\Delta p/p < 1$, $20° < \theta < 160°$, a track length of at least 30 cm in the TPC and a distance of closest approach to the primary vertex smaller than 3 cm in the plane perpendicular to the beam axis, and 6 cm along the beam axis.

The cross section is dominated by radiative $q\bar{q}\gamma$ events; the initial state photons are generally aligned along the beam, and they are not detected. In order to compute the hadronic centre of mass energy, the following procedure was used. The charged particles were clustered in jets by means of the $k_\perp$ (or Durham) jet algorithm [5]. In this algorithm, a jet resolution variable y_{ij} is defined for all pairs of particles:

$$y_{ij} = \frac{2 \cdot \min(E_i^2, E_j^2) \cdot (1 - \cos\alpha_{ij})}{E_{\text{vis}}^2}, \qquad (1)$$

where α_{ij} is the angle between the two particles, E_i is the energy of the i-th particle, and E_{vis} is the sum of all charged particle energies in the event. The particle pair with the smallest y_{ij} is replaced by a pseudoparticle with four-momentum equal to the sum of the four-momenta of particles i and j. The procedure is iterated, and the pseudoparticles are treated as normal particles; at the end, the remaining (pseudo)particles are the jets. In the present study, all charged particles were clustered until two jets were left in the event. To each of the jets and to the missing photon a calculated energy was assigned as derived from the jet directions, assuming massless kinematics. The photon was assumed to be collinear to the beam axis. The spectrum of the calculated energies in Fig. 1 was obtained. The full width at half maximum of the peak corresponding to the radiative return to the Z is about 10 GeV.

The influence of the detector on the analysis was studied with the full DELPHI simulation program, DELSIM [4]. Events were generated with the JETSET 7.3/PYTHIA Parton Shower (PS) Monte Carlo program [6] with parameters tuned by DELPHI [7]. The particles were followed through the detailed geometry of DELPHI giving simulated digitizations in each detector. These data were processed with the same reconstruction and analysis programs as the real data. Simulations based on JETSET 7.4 PS with default parameters were also used.

3. Analysis and results

Events with reconstructed hadronic centre of mass energy ($\sqrt{s'}$) between 122 and 136 GeV were used to compute the multiplicity at 130 GeV (they will be referred to as "high energy events" in what follows). They were compared to events between 83.2 and 99.2 GeV, corresponding to the radiative return to the Z (they will be referred to as "Z events" in what follows). A total of 346 high energy events and 567 Z events were selected.

The distribution of $\xi_E = -\ln(2E/\sqrt{s'})$ for the charged particles, corrected via simulation for the effect of the initial state radiation and for detector effects, is shown in Fig. 2 for high energy and Z events (taken from the radiative return). In the calculation of the energies E, all particles were assumed to have the pion mass. By comparing the distributions related to the two energies, there is no evidence of scaling violations at small ξ_E (large momentum). The difference in multiplicity is due to the soft particles. It was ver-

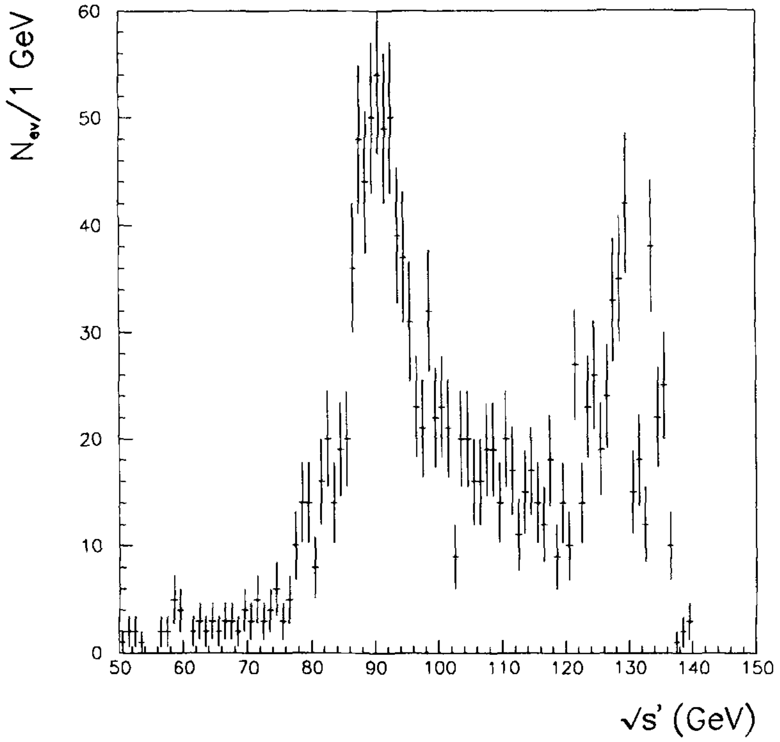

Fig. 1. Distribution of the reconstructed hadronic energy. The two peaks around 130 and 136 GeV correspond to two different energies of operation of LEP.

ified by means of the simulation that the depletion in $b\bar{b}$ pairs, due to the different branching fraction into $b\bar{b}$ pairs in the continuum with respect to the Z pole, can mask the effect of the scaling violations (predicted by QCD), since the momentum spectrum of charged particles in b fragmentation is softer than in light quarks [8]. According to the simulation, the effect would only be marginally visible within the present statistics anyway.

The average multiplicity of charged particles with $p > 0.1$ GeV/c measured in the high energy events is 21.29 ± 0.37(stat), to be compared to 18.98 ± 0.25(stat) for the Z events. The dispersions of the multiplicity distributions are 6.93 ± 0.26 and 6.06 ± 0.18 respectively. By assuming, as verified by simulation, that the correction factors from the measured data are the same for high energy and Z events, one can correct the observed values by rescaling the measurements at the Z peak. The average multiplicity at the Z is 20.92 ± 0.24 [9] and the dispersion is 6.49 ± 0.20 [10]; the corrected mean charge multiplicity for the high energy events ($\langle n_{\mathrm{ch}} \rangle$) is thus 23.47 ± 0.51(stat) ± 0.27(syst$_{\mathrm{l}}$), and the dispersion (D) is 7.42 ± 0.36(stat) ± 0.24(syst$_{\mathrm{l}}$), where the systematic error (syst$_{\mathrm{l}}$) accounts for the propagation of the error on the measurement at LEP1. The above values include the products of the decays of particles with lifetime $\tau < 10^{-9}$ s, in particular K^0_S and Λ.

The above values need to be corrected for the fact that one is integrating over hadronic energies from 122 to 136 GeV. This correction was estimated by comparing the multiplicity and the dispersion obtained using JETSET PS at 130 GeV with the average value between 122 and 136 GeV from the energy spectrum in Fig. 1. It amounts to 0.05 and 0.02 for $\langle n_{\mathrm{ch}} \rangle$ and D respectively. These corrections were added in quadrature to the systematic error. Another correction was applied to account for possible biases introduced by the procedure used for the calculation of the reconstructed hadronic centre of mass energy. The method overestimates $\sqrt{s'}$ (and thus gives too low a result for the average multiplicity) when both the incident elec-

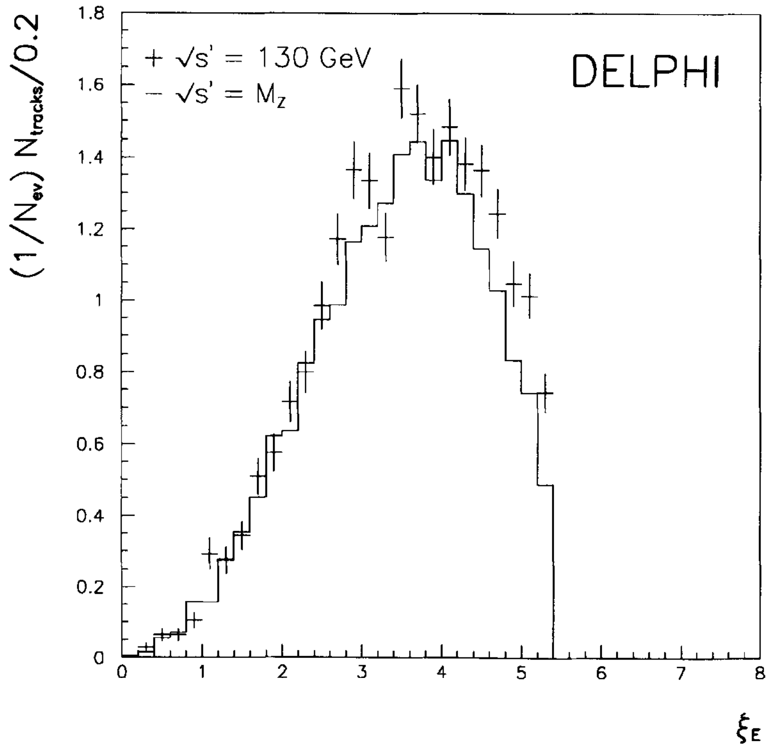

Fig. 2. ξ_E distribution of high energy events compared to Z events.

tron and positron radiate a sizeable amount of energy. The effect of this bias was estimated by means of the simulation; 0.32 units had to be added to the average multiplicity and 0.11 units to the dispersion in order to correct for it. These corrections were also added in quadrature to the systematic error.

In order to investigate possible sources of error due to the correction procedure, the average multiplicity was also computed by integrating the distributions of rapidity, $y = \frac{1}{2} \ln \frac{E-p_{\parallel}}{E+p_{\parallel}}$, with respect to the thrust axis and of ξ_E, both corrected bin by bin using the simulation (in this case the correction factors were computed independently for high energy and Z events). In the calculation of the energies, all particles were again assumed to have the pion mass. The ξ_E distribution was integrated up to a value of 5.4, and the extrapolation to the region above this cut was based on the simulation. The multiplicity obtained for Z events was found to be consistent with the world average measured at the Z peak. The multiplicity of high energy events, including the above corrections, was found to be 23.73 and 24.14 respectively from the y and ξ_E distribution, consistent with the value, 23.84, obtained from the average observed multiplicity. The maximum shift with respect to that value was added in quadrature to the systematic error.

Finally, for the centre of mass energy of 130 GeV, the values

$$\langle n_{\mathrm{ch}} \rangle = 23.84 \pm 0.51(\mathrm{stat}) \pm 0.52(\mathrm{syst}), \qquad (2)$$

$$D = 7.55 \pm 0.36(\mathrm{stat}) \pm 0.26(\mathrm{syst}) \qquad (3)$$

were obtained for the average charge multiplicity and for the dispersion.

The ratio of the dispersion to the average multiplicity as measured at 130 GeV (0.317 ± 0.032 (stat)) is consistent with the ratio of the world averages measured at the Z^0 (0.310 ± 0.010); this is compatible with the KNO scaling [11].

The value of the average charged particle multiplicity at 130 GeV is displayed in Fig. 3 and compared with lower energy points from TASSO [12], HRS [13], AMY [14], DELPHI in $q\bar{q}\gamma$ events at the Z^0 [15] and with the average from LEP experiments [9].

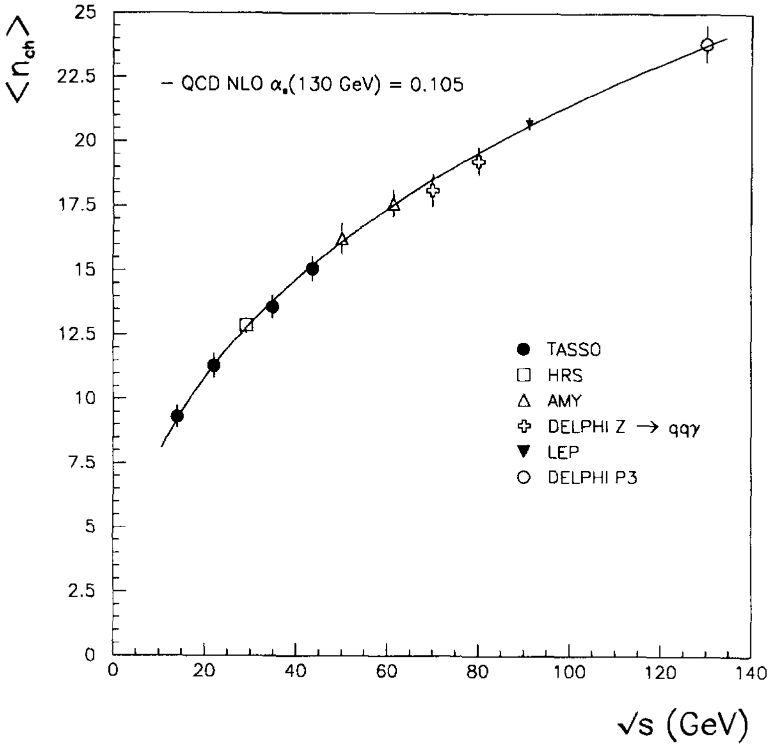

Fig. 3. Measured multiplicity at 130 GeV, compared with lower energy measurements and with a fit to a prediction from QCD in next-to-leading order.

This last value has been lowered by 0.20, to account for the different proportion of $b\bar{b}$ and $c\bar{c}$ events at the Z^0 with respect to the continuum e^+e^-. To the statistical errors on the charge multiplicities in $q\bar{q}\gamma$ events at the Z^0 [15], a systematic error assumed to be ±0.50 has been added in quadrature.

The QCD prediction for charge multiplicity has been computed as a function of α_s including the resummation of leading (LLA) and next-to-leading (NLLA) corrections [2]:

$$n_{\mathrm{ch}}(\sqrt{s}) = a\alpha_s(\sqrt{s})^b \times e^{c/\sqrt{\alpha_s(\sqrt{s})}}\left[1 + O(\sqrt{\alpha_s(\sqrt{s})})\right], \tag{4}$$

where s is the squared centre of mass energy and a is a parameter (not calculable from perturbation theory) whose value has been fitted from the data. The constants $b = 0.49$ and $c = 2.27$ are predicted by the theory [2] and $\alpha_s(\sqrt{s})$ is the strong coupling constant. In order to consider the effect of the higher order corrections to Eq. (4), a parameter d was introduced [15] in the form:

$$n_{\mathrm{ch}}(\sqrt{s}) = a\alpha_s(\sqrt{s})^b \times e^{c/\sqrt{\alpha_s(\sqrt{s})}}\left[1 + d \cdot \sqrt{\alpha_s(\sqrt{s})}\right]. \tag{5}$$

A fit to data using Eq. (5), with α_s(130 GeV) (being expressed at next-to-leading order), a and d as free parameters, is shown in Fig. 3. The results of the fit are $a = 0.057 \pm 0.006$, $d = 0.43 \pm 0.35$, and $\alpha_s(130\ \mathrm{GeV}) = 0.105 \pm 0.003(\mathrm{stat}) \pm 0.008(\mathrm{syst})$, where the systematic error was calculated as in [15].

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References

[1] DELPHI Coll., P. Abreu et al., Z. Phys. C 50 (1991) 185 and references therein.

[2] B.R. Webber, Phys. Lett. B 143 (1984) 501 and references therein.

[3] DELPHI Coll., P. Abreu et al., Nucl. Instr. Meth. A 303 (1991) 233.

[4] DELPHI Coll., P. Abreu et al., "Performance of the DELPHI Detector", CERN-PPE/95-194, to be published in Nucl. Instr. Meth.

[5] S. Bethke et al., Nucl. Phys. B 370 (1992) 310.

[6] T. Sjöstrand, Comp. Phys. Comm. 82 (1994) 74.

[7] K. Hamacher and M. Weierstall, "Tuning and Test of Fragmentation Models Based on Identified Particles and Precision Event Shape Data", Contributed paper eps0548 to the EPS-HEP Conference, Bruxelles 1995 (DELPHI Note 95-80).

[8] DELPHI Coll., P. Abreu et al., Phys. Lett. B 347 (1995) 447.

[9] A. De Angelis, "Light Quark Hadrons in Hadronic Z Decays", CERN-PPE/95-135 (1995), to be published in the Proceedings of the EPS-HEP Conference, Bruxelles 1995.

[10] OPAL Coll., P.D. Acton et al., Z. Phys. C 53 (1991) 539.

[11] Z. Koba et al., Nucl. Phys. B 40 (1972) 317.

[12] TASSO Coll., W. Braunschweig et al., Z. Phys. C 45 (1989) 193.

[13] HRS Coll., M. Derrick et al., Phys. Rev. D 34 (1987) 3304.

[14] AMY Coll., H. Zheng et al., Phys. Rev. D 42 (1990) 737.

[15] DELPHI Coll., P. Abreu et al., "Energy Dependence of the Differences between the Quark and Gluon Jet Fragmentation", CERN-PPE/95-164 (1995), submitted to Z. Phys. C.