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STUDIES OF HADRONIC EVENT STRUCTURE IN e^+e^- COLLISIONS WITH THE L3 DETECTOR

D. DUCHESNEAU

LAPP, IN2P3-CNRS, Chemin de Bellevue, BP110, F-74941,
Annecy-le-Vieux

abstract

Results from studies of the structure of hadronic events produced in e^+e^- annihilation at LEP with the L3 detector are reviewed. Comparison of the energy dependence of various event shape variables with QCD models over a wide energy range is shown as well as measurements of inclusive charged particle distributions at different energies.

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D. DUCHESNEAU [a]
LAPP,IN2P3-CNRS, Chemin de Bellevue, BP110,
F-74941, Annecy-le-Vieux, France
E-mail: duchesne@lapp.in2p3.fr

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1 Introduction

The hadronic events produced in high energy e^+e^- annihilation are characterized by a large number of particles usually clustered in the form of jets. The structure of these events is directly related to the gluon radiation pattern occuring during the transition between the primary quarks and the hadronic final state. Two aspects of gluon radiation can then be studied from the global event shape characteristics.
The first one is the hard gluon emission from quarks. It can be investigated by studying any variable sensitive to deviations from a simple back to back jet topology, for example, the thrust variable. Because this emission depends on the strength of the strong interaction a comparison of these event shape variables with precise analytical QCD predictions provides a clean way to determine the value of the strong coupling constant α_s. Such measurements have been reported in other contributions during this conference and it will not be part of this discussion.
The second aspect that can be probed with general event characterictics concerns soft QCD phenomena such as the soft gluon interference effect which affects mostly intra-jet structure. This aspect can be studied using inclusive charged particle distributions.
At LEP the energy involved in the hadronic production is quite large. The center of mass energy available for the quark pair production has increased by a factor of 2 since the beginning, ranging from 91 GeV to 183 GeV in 1997. At these energies the hadronization corrections are quite small, and the jets of particles are well collimated allowing QCD tests over a large energy range.

[a] Representing the L3 Collaboration.

Such tests are important due to the intensive use of QCD models in most research fields, especially W pair production studies and new particle searches which are the main LEP phase 2 issues and for which QCD events are the main background. L3 has extended this energy range by using direct photon events produced in hadronic Z decays such that measurements at reduced effective center of mass energies between 30 GeV and 86 GeV were possible.
In this paper I will describe the method used by L3 to measure the global event shape variables and show comparisons with the most commonly used QCD models which are built using basic QCD principles. Then I will describe the study of charged particle multiplicity and momentum distribution before comparing them with models and calculations.

2 Event selection

The selection of hadronic events is based on the energy measured in the calorimeters. The events should have a large number of energy deposits, called calorimetric clusters, and a large visible energy to satisfy the main characteristics of the hadronic events. A more detailed description of the selection can be found in references [1,2,3]. The event samples analysed can be divided in 2 categories. First the events recorded by L3 at a mean e^+e^- center of mass energy of 91 GeV corresponding to an integrated luminosity of 142 pb^{-1}. Reduced CM energy events were obtained from the analysis of direct photons in this large sample. The second category corresponds to the high energy events collected since 1995. These high energy event samples correspond to integrated luminosities of 5 pb^{-1}, 10 pb^{-1}, 11 pb^{-1} and 52.2 pb^{-1} collected at mean center of mass energies of 133 GeV, 161 GeV, 172 GeV and 183 GeV respectively.

2.1 Low center of mass energy events

They are obtained from the sample of hadronic events recorded on the Z resonance containing an observed hard photon. When the photon is isolated and energetic it is mainly radiated early in the process through initial state radiation or through an early branching during the parton cascade. On the other hand the hadronic shower takes place over a larger time scale, so that one can effectively look at hadron production at a reduced centre of mass energy from a study of $\mathrm{q\bar{q}}\gamma$ events. The effective center of mass energy is related to the photon energy via the relation

$$\sqrt{\mathrm{s}'} = \sqrt{\mathrm{s}\left(1 - \frac{2\mathrm{E}_\gamma}{\sqrt{\mathrm{s}}}\right)} \tag{1}$$

From the analysis of 142 pb^{-1} on the Z we were able to define 6 energy ranges extending from 30 GeV to 86 GeV. The main experimental challenge was the determination of hadronic background coming from neutral hadron decays (π^o,η) faking isolated single photons. The residual contamination has been estimated by a special data based background analysis correcting the model predictions that do not correctly describe the rate of isolated neutral hadrons. Table 1 gives a summary of the statistics, selection efficiencies and purities obtained for each bin of reduced CM energy. One can observe that the purity goes from 68% to 91% while the selection efficiency goes from 27% to 41%. Event shape variables of the hadronic system are calculated after

Table 1: Summary of the $q\bar{q}\gamma$ event selection for each reduced center of mass energy interval.

$\sqrt{s'}$ (GeV)	30−50	50−60	60−70	70−80	80−84	84−86
# of events	1247	1047	1575	2938	2091	1607
selection eff.	48.3%	41.0%	35.2%	29.9%	27.4%	27.5%
purity	68.4%	78.0%	86.0%	89.0%	90.5%	87.0%

boosting the event in the center of mass frame of the hadronic system recoiling against the photon using the well measured energy and angle of the isolated photon. The variables studied here are event thrust, scaled heavy jet mass, total and wide jet broadenings.

2.2 High center of mass energy events

For the high energy samples the experimental challenges are quite different. A large fraction of the events corresponds to events with hard initial state radiation (ISR) which brings the center of mass energy of the produced hadronic system to the Z resonance region where the production rate is very high. These events are called 'return to the Z' events. In order to reduce this contamination it is necessary to apply cuts to reject hadronic events with an energetic photon seen in the detector or with a large missing momentum along the beam direction corresponding to an ISR photon lost in the beam pipe.
Above 161 GeV the main source of remaining background is due to W^+W^- decaying into 4 jets of hadrons. At 172 GeV, well above the W pair production threshold, the event sample contains about 17% of W^+W^- background. This level of contamination is quite substantial and additional cuts are therefore used. Background events from two-photon collisions ($e^+e^- \rightarrow e^+e^-+$ hadrons) amounts to about 2-3%. Table 2 summarises the final number of events and the main background content at the different energies.

Table 2: Background fractions estimated from Monte Carlo in the selected event samples.

$\sqrt{s}$	133 GeV	161 GeV	172 GeV	183 GeV
# of selected events	402	443	341	1516
$e^+e^- \to W^+W^- \to$ ffff	0.0%	4.4%	8.9%	10.9%
$e^+e^- \to e^+e^- +$ hadrons	2%	3.3%	2.8%	2.8%

3 Event shape observables

As can be seen from table 2 the final purity is not 100% and it is necessary to correct for remaining backgrounds. This is achieved by subtracting bin-by-bin the background events estimated according to the standard model cross sections and the recorded luminosity. The distributions are then corrected for detector effects, acceptance and resolution bin-by-bin comparing the detector level result with the particle level result for the same event sample. The effect of initial and final state photon radiation is also corrected bin-by-bin using the PYTHIA MC generator for the high energy events. When these corrections are applied the distributions can be compared with predictions at particle level. The comparison of the corrected distributions to the predictions of several QCD models tuned at 91 GeV has shown reasonable agreement within the statistical errors. Figure 1 shows the thrust distribution T as measured by L3

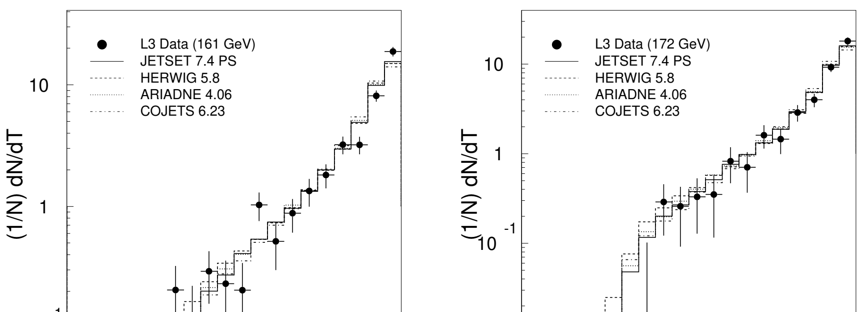

Figure 1: Corrected thrust distributions at 161 GeV and 172 GeV in comparison with QCD model predictions. The experimental errors shown are statistical only.

at 161 GeV and at 172 GeV compared to the PYTHIA, HERWIG, ARIADNE and COJETS Monte Carlo models. The agreement is satisfactory at both energies.

4 Mean event shape values

For any generic variable f which is collinear and infrared safe one can write the mean value as the sum of 2 terms:

$$\langle f \rangle = \frac{1}{\sigma_{tot}} \int f \frac{d\sigma}{df} df = R_{pert} + R_{non-pert}$$

The first term corresponds to the perturbative expansion which is proportionnal to α_s at first order and the second term includes the non perturbative contributions (hadronization and non perturbative aspects of the parton shower) and behaves like $(1/Q)^n$. We can then expect an energy dependence of the mean event shape values coming mainly from 2 sources: the logarithmic dependence of α_s and the power behaviour of the non-perturbative effects. Figures 2 a-d show the L3 measured mean values of the thrust, heavy jet mass, total and wide jet broadening as a function of the energy. There is a clear energy dependence over the full energy range which is well reproduced by the QCD models using the same parameter set tuned at 91 GeV.

5 Inclusive charged particle distributions

QCD predicts a destructive quantum mechanical interference which leads to a suppression of soft gluon emission. As a result the particle multiplicity is reduced as compared to the prediction with no coherence. To illustrate this point, figure 3 shows the mean charged particle multiplicity measured by L3 and by other experiments as a function of the e^+e^- center of mass energy. The COJETS model which has no coherence in the parton shower evolution and has an independent fragmentation predicts a much larger mean charged particle multiplicity at high energy compared to the models implementing the coherence effects. The JETSET 7.4 Matrix Element (ME) model also fails to describe the energy dependence of $< n_{ch} >$ over a wide energy range. This is a consequence of low parton multiplicity before fragmentation compared to the other models incorporating multiple gluon emission.

Suppression of soft gluon emission modifies the momentum spectra of low momentum particles. This effect is studied by looking at the $\xi_p = \ln(1/x_p)$ distribution where $x_p = p/E_{beam}$ is the scaled particle momentum. The perturbative QCD calculation predicts the ξ_p distribution to have a hump-backed shape with a peak position value proportional to the logarithm of the energy.

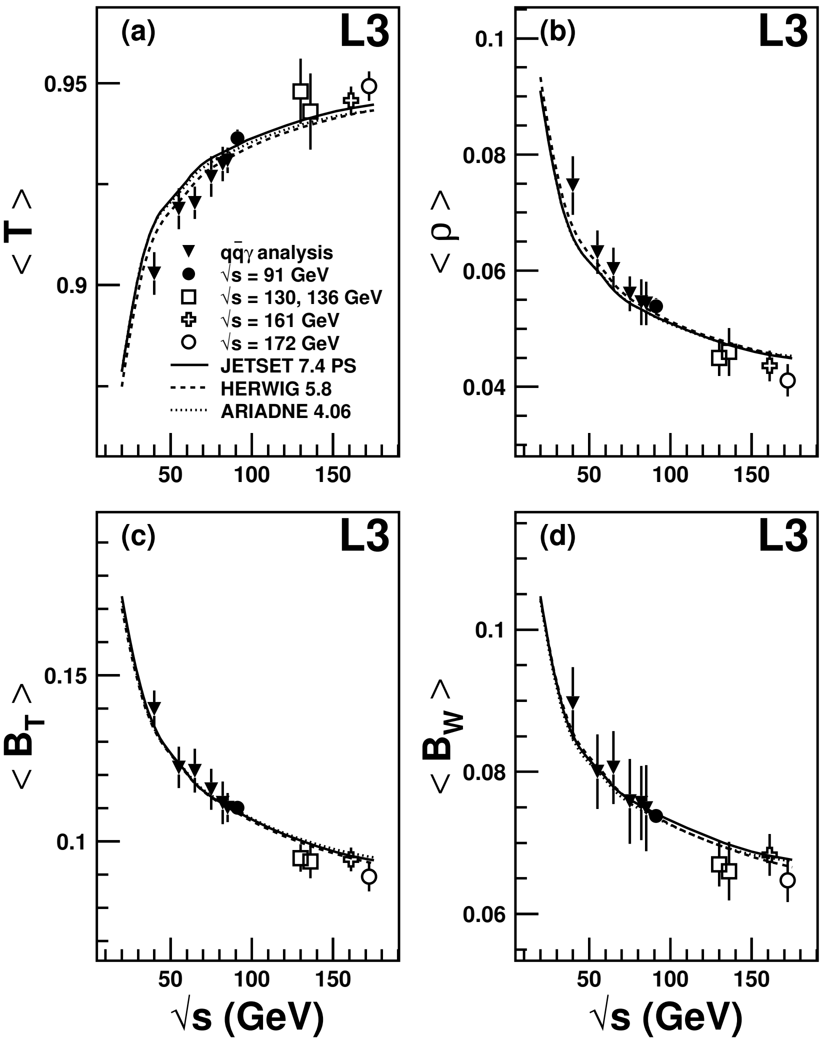

Figure 2: Distributions for the mean values of (a) thrust (T), (b) scaled heavy jet mass (ρ), (c) total jet broadening (B_T), and (d) wide jet broadening (B_W) as a function of centre-of-mass energy measured by L3. The lines correspond to the predictions of various QCD models.

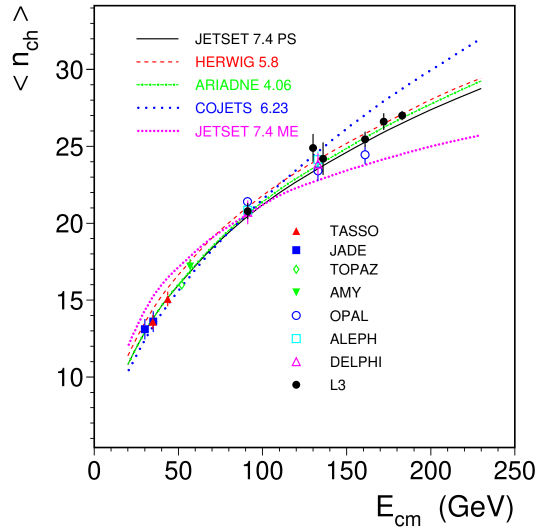

Figure 3: Distributions of mean charged particle multiplicity, $< n_{ch} >$, as a function of the centre-of-mass energy, compared to several QCD models.

The observed spectra have been corrected for detector effects, and the peak position of ξ spectra, $\xi^{\star}$, is obtained by fitting the corrected distribution to a Gaussian and a skewed Gaussian (Fong-Webber parametrisation [4]) function restricting the fit range to values of ξ where the distribution falls up to 60% of its maximum value. Figure 4a shows the preliminary ξ_p distribution measured by L3 at 183 GeV with the fitted functions. The energy evolution of the $\xi^{\star}$ measurements done at LEP at and above the Z-peak [5,6] is shown on figure 4b together with low energy data points taken from the TASSO experiment [7]. We find that the data are in good agreement with QCD predictions when computed to the next-to leading orders (Modified LLA) [8]. The fit to the DLA parametrization gives a χ^2 of 26.5 for 7 degrees of freedom corresponding to a confidence level of 4.1×10^{-4} whereas the MLLA prediction gives a fit with χ^2 of 3.9 for 7 degrees of freedom corresponding to a confidence level of 0.79.

6 Conclusions

Hadronic event characteristics have been studied in e^+e^- annihilation at effective center of mass energies from 30 GeV to 183 GeV by L3. The QCD models implementing a coherent parton shower and cluster or string fragmentation

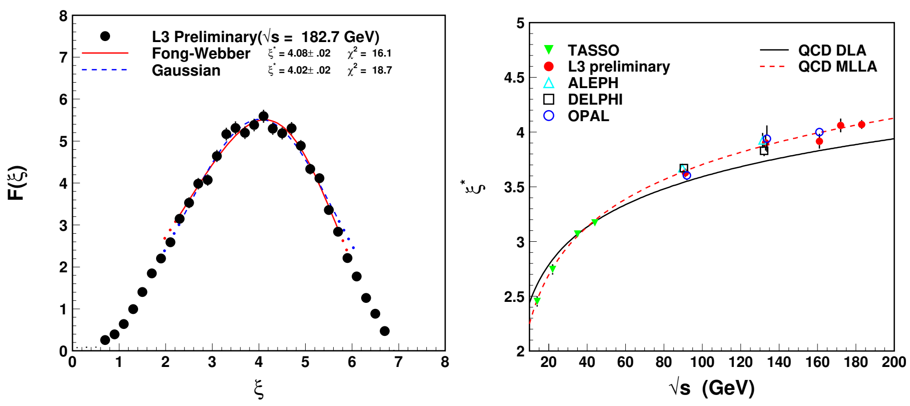

Figure 4: ξ distribution at 183 GeV and energy evolution of $\xi^\star$.

describe correctly the event shape distributions with a constant parameter set tuned at 91 GeV. These models also correctly predict the measured energy dependence of the mean values.
The inclusive charged particle distributions clearly show the suppression effect expected from soft gluon coherence phenomena.

Acknowledgments

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