Study of the structure of hadronic events at LEP with L3

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Global event shape variables and charged particle spectra are studied from hadronic collected by the L3 detector corresponding to hadronic center of mass energies between 30 and 189 GeV. Strong coupling constant (α_s) and active number of flavours (N_f) are determined from the event shapes to be: $\alpha_s(M_Z) = 0.1220 \pm 0.0015(\text{exp}) \pm 0.0060(\text{theo})$, and $N_f = 4.4 \pm 1.0(\text{exp}) \pm 2.0(\text{theo})$ respectively. The energy evolution of the moments of the event shapes have been fitted to a combination of $\mathcal{O}({\alpha_s}^2)$ calculations and power law parametrization of the non-perturbative part, and the universality of the power law behaviour is observed.

1. Introduction

Clean initial state in e^+e^- annihilation offers an ideal set-up to study hadronic interactions. Over the last 10 years, LEP provided good running conditions over a wide range of center of mass energy.

Hadronic event topologies are characterised by hard gluon radiations. These different jet topologies appear differently in the distributions of the collinear and infrared safe global event shape variables, like thrust (T), heavy jet mass (ρ), total and wide jet broadening (B_T and B_W), C-parameter. Energy evolution of the mean values of the event shapes, charged particle multiplicity, peak position of the momenta spectra are compared with the analytical calculations and QCD parton shower models.

Resummed analytical calculations of the global shape variables provide expansion in terms of strong coupling constant (α_s) upto leading and next to leading order. This together with fixed order calculations upto second order are used to determine α_s from the event shape distributions [1]. Following some recent theoretical calculations, the non-perturbative contributions to *first* and *second moments* of these variables can be parametrised by power law like terms. This allows a model independent determination of α_s, and can also be used to test the universality of effective coupling constant (α_{eff}) below a fixed infrared cut off scale.

*On behalf of the L3 collaboration.

2. Event Samples

For this analysis, three event samples collected by the L3 detector have been used:

1. at $\sqrt{s} = M_Z$ from hadronic decays at the Z resonance. Since the cross-section is large, this channel can be isolated with high efficiency (98%), and high purity (99%) [1].
2. at $\sqrt{s} < M_Z$ from events with isolated energetic photon in hadronic decays of Z. After removing the photon, the event is boosted to the rest frame of the remaining hadronic system with an effective reduced center of mass energy of $\sqrt{s'} = \sqrt{s\left(1 - \frac{2E_\gamma}{\sqrt{s}}\right)}$. A neural network is used for π^o/η rejection, and the hadronic system is studied at $\sqrt{s'} = 30-50, 50-60, 60-70, 70-80, 80-84, 84-86$ GeV with efficiency of $50-30\%$, and purity of $70-90\%$ [2].
3. at $\sqrt{s} > M_Z$ from LEP II data at $\sqrt{s} = 130, 136, 161, 172, 183, 189$ GeV. The events from radiative return to the Z are removed by tagging energetic photon observed in the detector, or cutting on parallel energy imbalance if the photon escapes down the beam pipe. Above WW (ZZ) threshold, balanced high multiplicity events compatible with 4 jet WW (ZZ) topology are also removed. True high energy events are identified with efficiency of $90-80\%$, and purity of $80-84\%$ [3].

3. Event structures

Hadronic event structures have been studied in terms of the global event shapes, jet rates and charged particle spectra. The background subtracted data have been corrected for the detector acceptance and resolution effects, as well as for initial and final state radiations [4].

3.1. Shape variables

The energy evolutions of the mean values of the event shape variables are well described by the QCD parton shower models. As as example, figure 1 shows the mean values of wide jet broadening compared to different QCD models: JETSET, HERWIG, ARIADNE and COJETS, tuned at the Z-peak [4].

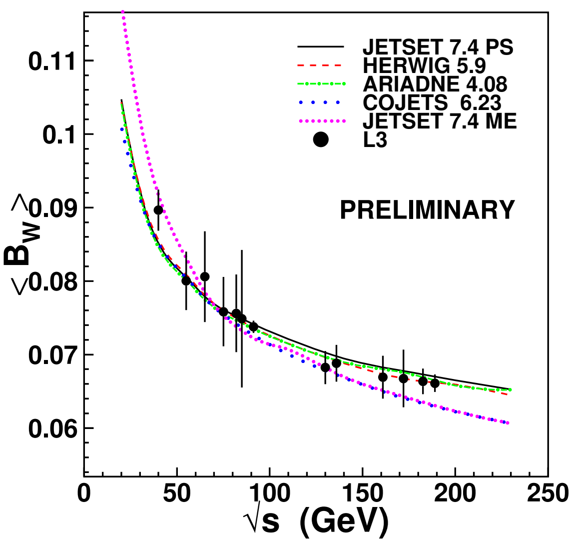

Figure 1. *Energy evolution of mean values of wide jet broadening compared to QCD models.*

3.2. Charged particle spectra

The energy evolution of the mean multiplicity agrees with the coherent QCD parton shower models (figure 2). COJETS (with incoherent PS and independent fragmentation) predicts higher multiplicity at high energies, while fixed order Matrix Element implementation in JETSET cannot describe the energy evolution.

Beyond the leading logarithmic behaviour, destructive interference between the soft gluons emitted within a jet, reduces the phase space

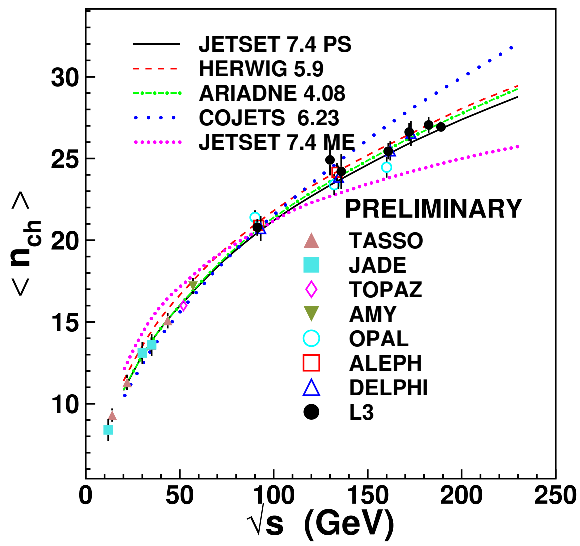

Figure 2. *Energy evolution of mean charged particle multiplicity compared to QCD models.*

available for further parton emission to an angular ordered region. This dynamical suppression of the momenta in the infrared region leads to energy and emission angle ordering of the successive parton radiations, causing a dip in the parton momenta spectra for small values. We studied the inclusive momenta in terms of the variable $\xi = -\ln(\frac{2|\vec{p}|}{\sqrt{s}})$ [5] (where $\vec{p}$ is the momenta). The energy evolution of the measured peak position ($\xi^\star$) (figure 3), is well described by infrared sensitive modified leading logarithmic approximation.

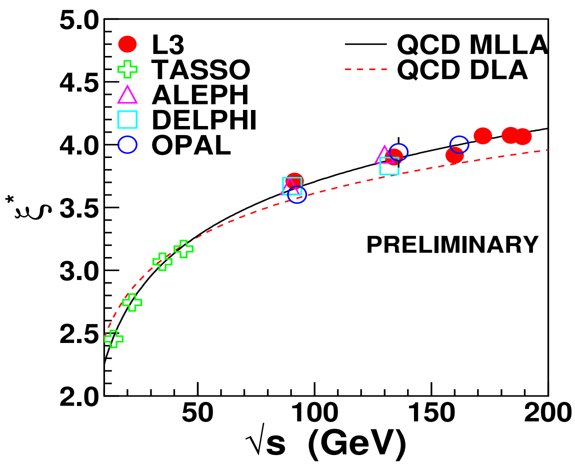

Figure 3. *Energy evolution of $\xi^\star$ compared to QCD predictions.*

4. Determination of α_s

Strong coupling constant is extracted independently from the several event shape variables (eg., y = 1-T, ρ, B_T, B_W and C), and then unweighted average of the different estimates is taken.

4.1. Model dependent determination

Complete analytical calculations upto second order exist for the five variables [6]: $\int_0^y \frac{1}{\sigma}\frac{d\sigma}{dy} = \overline{\alpha}_s A(y) + \overline{\alpha}_s{}^2\left[B(y) + 2\pi\beta_\circ \ln(\mu^2/s)A(y)\right]$, with A and B being known numbers [7], and μ being the renormalization scale. Analytical results for resummation to all orders of leading logarithmic $(\sum(\alpha_s L^2)^n)$ and next to leading logarithmic $(\sum(\alpha_s{}^n L^{2n-1}))$ terms (where $L = \ln(1/y)$) also exist. While the former describes well the data in the multi-jet region, it fails in the 2 jet region, and by combining the two approaches, the data have been fitted over the entire range. The hadronization effects are folded in using the JETSET PS Monte Carlo. α_s thus extracted [1] at each center of mass energy, from 1-T, ρ, B_T and B_W, gives a good fit to the QCD evolution (figure 4) with:

$$\alpha_s(M_Z) = 0.1220 \pm 0.0015(\mathrm{exp}) \pm 0.0060(\mathrm{theo}).$$

The slope of the energy evolution of α_s has been fitted as free parameter along with α_s, leading to the number of active flavours: $N_f = 4.4 \pm 1.0(\mathrm{exp}) \pm 2.0(\mathrm{theo})$.

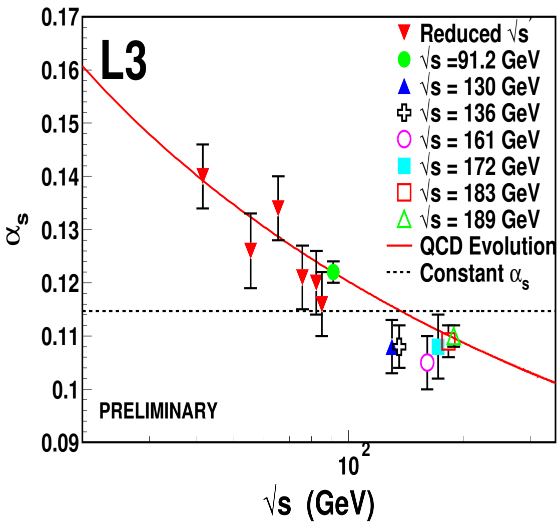

Figure 4. *Running of α_s as determined from four event shapes at different center of mass energies.*

4.2. Model independent determination

Assuming the soft gluon emission is controlled by an effective $\alpha_{\rm eff}$, different from α_s below an infrared matching scale (μ_I), the non-perturbative contributions to the moments of the event shape variables can be parametrised as [8]: $\langle V\rangle = \langle V\rangle_{PT} + c_V * \mathcal{P}$, where second order calculations are used for the perturbative part, and c_V is a shape dependent parameter. The "shift" given by $\mathcal{P}$ is supposed to have a universal form $\propto \alpha_0/Q$, where $\alpha_0(\mu_I) = \frac{1}{\mu_I}\int_0^{\mu_I} dq\alpha_{\rm eff}(q)$, accounts for contributions below $\mu_I(= 2$ GeV). For the broadening variables, the non-perturbative corrections involve additional "logarithmic skew" given by an extra multiplicative factor to $\mathcal{P}$.

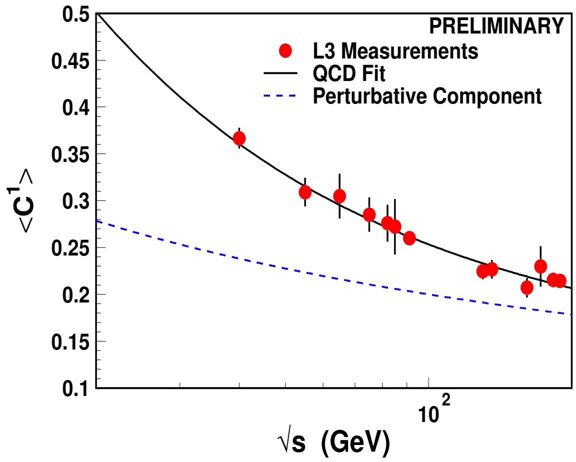

Figure 5. *Fit to energy evolution of the first moment of C-parameter.*

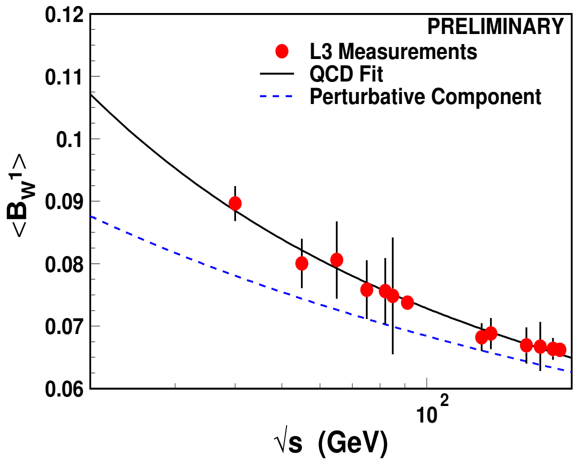

Figure 6. *Fit to energy evolution of the first moment of total jet broadening.*

The fit to the first moment of *five* event shapes from L3 data [10] at 30-189 GeV with correlated systematic errors are in agreement with the predicted universality of the power law behaviour within 10% accuracy. The five estimates of α_s values can be combined to get an overall α_s from the power law fit: $\alpha_s(M_Z) = 0.1106 \pm 0.0036(\text{exp}) \pm 0.0040(\text{theo})$. As examples, fit to C-parameter and B_W are shown in figures 5, 6.

The prediction for the power law corrections to the second moments can be written as [9]: $\langle V^2 \rangle = \langle V^2_{\text{pert}} \rangle + 2\langle V_{\text{pert}} \rangle \cdot c_V \mathcal{P} + \mathcal{O}\left(\frac{1}{Q^2}\right)$. Using α_0 and α_s from the corresponding fits to the first moments, the fit to the *second moment* show that the contributions of the $\mathcal{O}(\frac{1}{Q^2})$ term are sizable. Fits to (1-T) and ρ_H are shown in figures 7, 8.

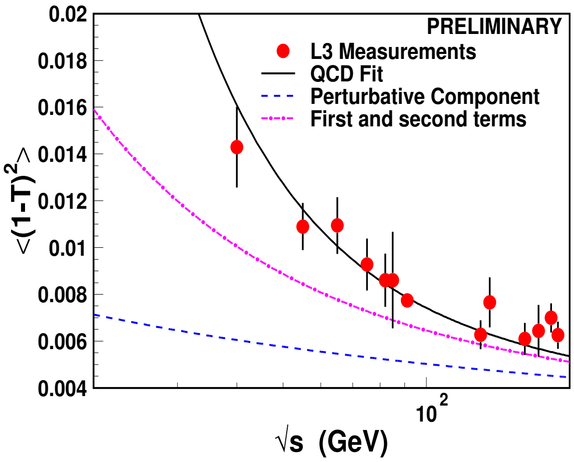

Figure 7. *Fit to energy evolution of the second moment of (1-thrust).*

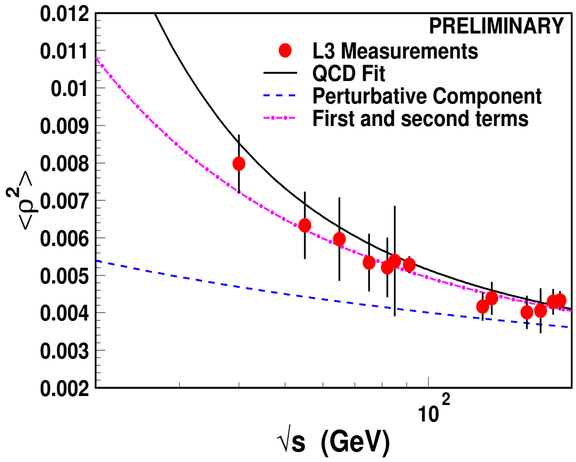

Figure 8. *Fit to energy evolution of the second moment of heavy jet mass.*

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