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Event Shapes and Power Corrections in e^+e^- Annihilations

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Hadronic final states in e^+e^- annihilations at centre-of-mass energies from 14 GeV up to 189 GeV are studied in order to test recent predictions for power corrections to the mean values as well as the distributions of event shape variables.

1. Introduction

When studying observables in the process $e^+e^- \rightarrow$ Hadrons, it is found that the perturbative QCD predictions have to be complemented by non-perturbative corrections of the form $1/Q^p$, where Q is the centre-of-mass energy E_{CM}, and the power p depends on the particular observable. For fully inclusive observables such as the total cross section $p = 4$, however, for less inclusive ones such as event shape variables the power is much smaller, typically $p = 1$. So for those observables non-perturbative effects can be sizeable, e.g., at LEP1 energies corrections of 5-10% are found. Since these variables are extensively used for α_s determinations, non-perturbative effects have to be well understood. Until recently they have been determined from QCD-inspired Monte Carlo (MC) models of hadronization, however, this method leads to model dependence and thus limitations in the precision of the α_s measurements. The new approach of power law corrections to event shapes, pioneered by Dokshitzer and Webber [1], could lead to improvements in this respect.

The event shape variables studied are Thrust, C-parameter, Heavy Jet Mass and Total and Wide Jet Broadening. These are infrared and collinear safe variables, and perturbative predictions are known up to second order in α_s, as well as the resummations of leading and next-to-leading logarithms to all orders.

The results presented in the following are mostly based on the study of Ref. [2], where data from e^+e^- annihilations at $E_{CM} = 14$ GeV up to 161 GeV have been analyzed. In addition, some preliminary results from the LEP2 runs up to 189 GeV have been employed.

2. Power Corrections

Power corrections are supposed to have their origin in infrared divergences (renormalons) in the perturbative expansions when the overall energy scale Q approaches the Landau pole Λ. The first approaches were based on the assumption of the existence of a universal non-singular behaviour of an effective strong coupling at small scales, parametrized by a non-perturbative parameter

$$\alpha_0(\mu_I) = \frac{1}{\mu_I}\int_0^{\mu_I} dk\ \alpha_s(k)\ , \qquad (1)$$

with $\Lambda \ll \mu_I \ll Q$, which separates the perturbative from the non-perturbative region, $\mu_I = 2$ GeV, typically. $\alpha_0(\mu_I)$ is assumed to be universal.

2.1. Mean Values

Using the Ansatz described above, the following prediction is obtained for the mean value of an event shape variable f :

$$\langle f \rangle = \langle f \rangle^{pert} + \langle f \rangle^{pow}\ , \qquad (2)$$

where $\langle f \rangle^{pert}$ is the full second order prediction of the form

$$\alpha_s(\mu^2)A_f + {\alpha_s}^2(\mu^2)\left[B_f + A_f b_0 \ln\frac{\mu^2}{s}\right]\ . \qquad (3)$$

Here μ^2 is the renormalization scale, $s = E^2_{CM}$, and $b_0 = (33 - 2n_f)/(12\pi)$, n_f being the number of active flavours.

The power correction term is given by $\langle f \rangle^{pow} = a_f \mathcal{P}$, where a_f is 2 for Thrust, 1 for Heavy Jet Mass and 3π in case of the C-parameter. $\mathcal{P}$ is a universal function of the form $\mathcal{P} \approx \mathcal{M}\, \mu_I\, \alpha_0(\mu_I)/Q$ (up to a constant and corrections of order α_s and $\alpha_s{}^2$). The *Milan factor* $\mathcal{M} \approx 1.8$ [3] takes into account two-loop effects. Recently it has been found [4] that in the case of the Jet Broadening variable the power correction is of a more complicated type compared to above, namely of the form $1/(Q\sqrt{\alpha_s(Q)})$.

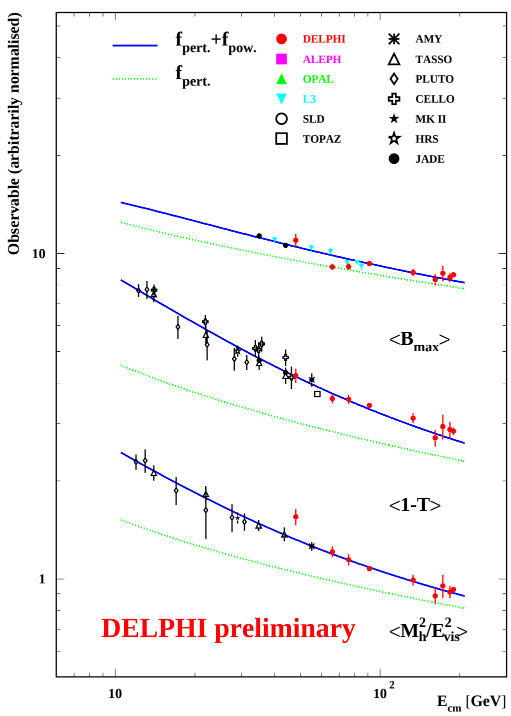

Figure 1. Mean values of event shape variables as a function of the centre-of-mass energy.

DELPHI [5] have measured mean values for Thrust, Wide Jet Broadening and Heavy Jet Mass from the LEP1 and LEP2 data and combined their results with measurements from low energy e^+e^- experiments in order to extract $\alpha_s(M_Z)$ and α_0 from a fit of the power law Ansatz to these data. The fits are displayed in Fig. 1. Very good fits are obtained with $\alpha_s(M_Z)$ between 0.118 and 0.120, and $\alpha_0(2\text{GeV})$ between 0.40 and 0.55. Similar results have been found in the analysis of Ref. [4].

2.2. Distributions

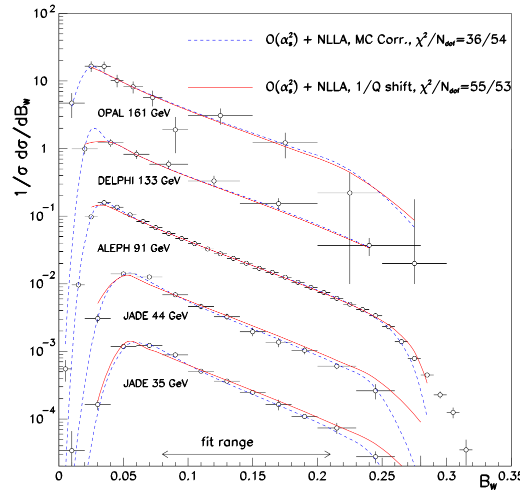

Figure 2. Fits to distributions of the Wide Jet Broadening at several centre-of-mass energies.

For distributions of event shape observables it has been shown [6] that the non-perturbative corrections lead to a shift in the distribution, i.e,

$$\frac{1}{\sigma_{tot}} \frac{d\sigma(f)^{corr}}{df} = \frac{1}{\sigma_{tot}} \frac{d\sigma(f - \Delta f)^{pert}}{df} \qquad (4)$$

where in the cases of Thrust, Heavy Jet Mass and C-parameter the shift Δf is given by exactly the same terms as the correction for the mean values, i.e., $\Delta f = a_f \mathcal{P}$. An improved calculation [4] for the Jet Broadening variable has shown that in this case the distribution is not only shifted, but also squeezed, since the shift is of the form $\Delta B \propto \mathcal{P} \ln(1/B)$. The perturbative distribution is obtained from a matching of the full next-to-leading order prediction to the resummation of all leading and next-to-leading logarithms $\ln f$. Theoretical uncertainties on the α_s and α_0 determinations are estimated from variations of the renormalization scale and the scheme applied for matching the fixed order and resummed calculations. Central values are given for $\mu^2 = s$. In Fig. 2 the fits to the Wide Jet Broadening are displayed, for various centre-of-mass energies. Good fits are obtained for the power law Ansatz as well as for the more traditional approach of hadronization corrections from MC models. Similar fits to

Thrust and Heavy Jet Mass work well at high energies, however, some deviations are found at very small energies. There probably the limit of applicability of the power law approach is reached. Furthermore, mass effects could play a role there.

In Fig. 3 a summary of the results can be found. A combination of the results gives $\alpha_s(M_Z) = 0.1082 \pm 0.0021$, $\alpha_0(2\text{GeV}) = 0.504 \pm 0.042$. For α_0 universality is found at the level of 20%. The value of the strong coupling results to be lower than the one obtained from a similar fit when using MC models for the hadronization corrections, namely $\alpha_s(M_Z) = 0.1232 \pm 0.0040$. This difference has still to be understood.

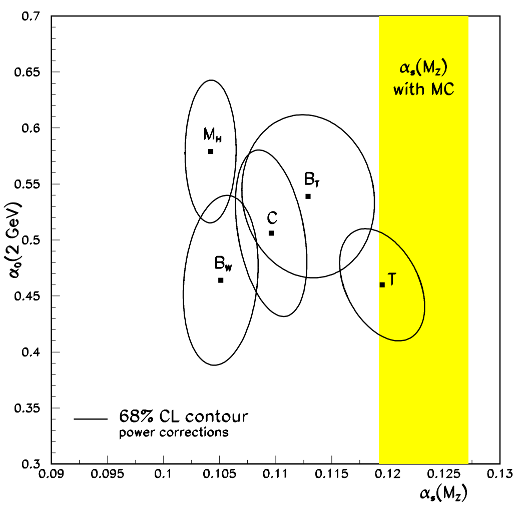

Figure 3. Summary of the power law fits to distributions of event shapes.

3. Non-Perturbative Shape Functions

Recently it has been shown [7] that all leading power corrections of the type $1/(fQ)$, f being the event shape variable, can be resummed when folding the perturbative distribution with a non-perturbative *shape function*. The form of the shape function depends on the observable, and new non-perturbative parameters are introduced. Fits have been tried for Thrust and Heavy Jet Mass. For the former a good fit quality for a large energy range is obtained, and $\alpha_s(M_Z)$ values close to the world average are found. However, in case of the latter no satisfactory fits could be achieved. This should be followed up in the future analyses.

4. Conclusions

Significant progress has been made in the understanding of power corrections to event shape variables in e^+e^- annihilations. Universality of the non-perturbative parameter α_0 is observed at the level of 20%. Some open questions remain such as the difference of α_s values obtained with power laws and MC corrections. Also the effects of quark or hadron masses should be studied. Power law predictions for other variables such as the differential two-jet rate as well as the energy-energy correlations are awaited for.

A new approach based on non-perturbative shape functions looks very promising, but some further investigations are required.

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