MAX-PLANCK-INSTITUT FÜR PHYSIK

WERNER-HEISENBERG-INSTITUT

MPI-PhE/99-09
August 1999

Power corrections to e^+e^- event shape variables

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POWER CORRECTIONS TO e^+e^- EVENT SHAPE VARIABLES

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Event-shape variables measured in the energy range from 14 GeV to 161 GeV are re-analyzed under the aspect of non-perturbative power corrections. Phenomenological parameters of 1/Q corrections are determined and results of the strong coupling constant are compared to standard method measurements based on Monte Carlo corrections for hadronization.

[a]Contibution to the Proceedings of the *XXXIV*th Rencontres de Moriond, QCD and Hadronic Interactions, Les Arcs (France), March 20-27 1999

1 Power Corrections

Non-perturbative effects in hadronic observables of e^+e^- annihilation are in general suppressed by powers of $1/Q$. These effects are small in inclusive quantities like the total cross section. In event-shape distributions, however, the power of $1/Q$ terms is equal to one, and hadronization corrections are relatively large (5 - 10 % at $Q = M_Z$). Corrections for hadronization are usually derived from Monte Carlo generators and applied to perturbative predictions, in order to extract the value of the strong coupling constant, α_s. Here a comparative study is presented, in which α_s is determined both with analytical power corrections and with Monte Carlo corrections. The aim is to test models of power corrections and to evaluate possible improvements for measurements of α_s.

Since power corrections scale with 1/Q, it is important to include data sets at largely different $Q = \sqrt{s}$. Measurements of the event-shape variables thrust, heavy jet mass, c-parameter, wide and total jet broadening have been carried out by the collaborations ALEPH, AMY, DELPHI, HRS, JADE, L3, MARKII, OPAL, SLD, TASSO and TOPAZ [1], in the range from 14 GeV to 161 GeV.

2 Measurement of α_s with Monte Carlo corrections

Basic ingredients for measurements of α_s are perturbative calculations to second order, which are matched to calculations resumming leading and next-to-leading logarithms to all orders in α_s. Two matching schemes are used here, the Log(R)- and the R-matching scheme. Results are quoted as the average using these two schemes.

The perturbative prediction is then corrected for hadronization with a transition matrix, which describe the probability for an event with an event-shape value in bin i of the partonic distribution to have an entry in bin j of the hadronic distribution. The transition matrix is derived from the generators PYTHIA, HERWIG and ARIADNE, for each energy separately. Main parameters of all generators are tuned to LEP data at $Q = M_Z$. The value of the coupling constant is extracted by fitting the corrected predictions to the distributions. Experimental systematic uncertainties, where available, are added in quadrature to the statistical errors, the sum is included in the fit. In order to fit distributions at different energies, the energy evolution of the coupling constant in three-loop approximation has been used. Examples of distributions and fits are shown in Fig. 1.

Main systematic uncertainties are of perturbative nature and related to the choice of the renormalization scale μ, which is set to Q in the nominal case. The scale is varied in the range $-1 \leq \ln(\mu^2/s) \leq 1$ and the change in values of α_s is taken as error. The hadronization uncertainty is estimated by replacing the nominal corrections obtained with PYTHIA by alternative corrections obtained with either HERWIG or ARIADNE. Results for all variables are given in Table 1. In general perturbative uncertainties dominate over hadronization errors. An exception

Table 1: Results of simultaneous fits to event-shape distributions at different energies, using Monte Carlo corrections for hadronization.

variable	$\alpha_s(M_Z)$	experimental error	perturbative error	hadronization error	χ^2/N_{dof}
T	0.1260	$\pm$ 0.0002	$\pm$ 0.0024	$\pm$ 0.0012	259/210
M_H	0.1201	$\pm$ 0.0004	$\pm$ 0.0022	$\pm$ 0.0043	306/125
C	0.1216	$\pm$ 0.0002	$\pm$ 0.0045	$\pm$ 0.0010	49/74
B_W	0.1191	$\pm$ 0.0005	$\pm$ 0.0051	$\pm$ 0.0004	36/54
B_T	0.1221	$\pm$ 0.0004	$\pm$ 0.0079	$\pm$ 0.0007	54/62

is found for the heavy jet mass, which is subject to large non-perturbative errors. Furthermore,

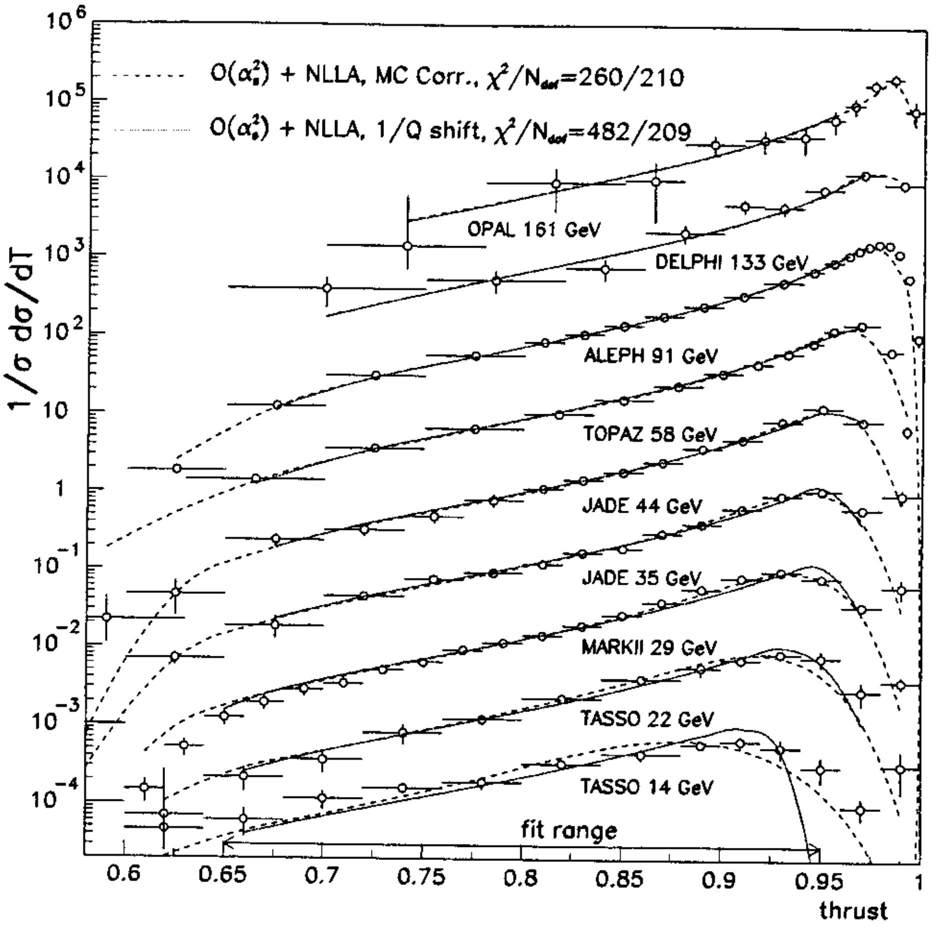

Figure 1: Distributions of thrust at various centre-of-mass energies. The dashed line is the result of a fit using Monte Carlo corrections, the full line the fit result with power corrections.

the bad quality of the fit result indicates a bad description at the perturbative level, most problematic and dominating the total χ^2 are the fits at lower energy below 44 GeV.

3 Measurement of α_s with power corrections

Power corrections in the spirit of Ref.[2] are related to infrared divergences of the perturbative expansion at low scales. Analytical calculations introduce one additional phenomenological parameter α_0

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

which measures effectively the strength of the coupling up to an infrared matching scale μ_I of the order of a few GeV. The parameter α_0 is expected to be universal and is to be determined by experiment.

In event-shape distributions the effect of power corrections is to shift the perturbative spectra

$$\frac{1}{\sigma}\frac{d\sigma(x)}{dx}^{corrected} = \frac{1}{\sigma}\frac{d\sigma(x-\Delta x)}{dx}^{pert} \ , \Delta x = a_x\mathcal{P}$$

with

$$\mathcal{P} = \frac{4C_F}{\pi^2}\mathcal{M}\frac{\mu_I}{Q}\left[\alpha_0(\mu_I) - \alpha_s(Q) - \frac{\beta_0}{2\pi}\left(\ln\frac{Q}{\mu_I} + \frac{K}{\beta_0} + 1\right)\alpha_s^2(Q)\right] \ ,$$

where

$$\mathcal{M} = 1 + \frac{2.437C_A - 0.052n_f}{\beta_0} \ , \ K = C_A\left(\frac{67}{18} - \frac{\pi^2}{6}\right) - \frac{5}{9}nf$$

and

$$a_T = 2 \ , \ a_{MH} = 1 \ , \ a_C = 3\pi \ .$$

The concept of a constant shift applies not to jet broadenings[3], where the shift is B-dependent and should be operated on the radiator $R(B) = \frac{1}{\sigma}\int_0^B \frac{d\sigma}{dB}db = R^{pert}\left(B - \frac{1}{2}\mathcal{P}D(B)\right)$. For the wide jet broadening the B-dependent shift reads as follows

$$D_{BW} = \ln\frac{1}{B_W} + \eta_0 - 2 - \rho(\mathcal{R}') + \chi(\mathcal{R}') + \psi(1+\mathcal{R}') - \psi(1)$$

where

$$\mathcal{R}' = 2C_F\frac{\alpha_s(B_W Q)}{\pi}(\ln\frac{1}{B_W} - \frac{3}{4}) \ , \ \eta_0 = -0.6137056$$

and

$$\rho(x) = \int_0^1 dz\left(\frac{1+z}{2z\lambda(x)}\right)^{-x}\ln z(1+z) \ , \ \chi(x) = \frac{2}{x}\left([\lambda(x)]^x - 1\right)$$

with

$$[\lambda(x)]^{-x} = \int_0^1 dz\left(\frac{1+z}{2z}\right)^{-x} .$$

Formulae for the total jet broadening are given in [3]. Fit results of α_s and α_0 with power corrections are given in Table 2. Non-perturbative systematic uncertainties are estimated by

Table 2: Results of simultaneous fits of α_s and $\alpha_0(2\text{ GeV})$ to distributions at different energies, using power corrections .

variable	$\alpha_s(M_Z)$	exp. error	perturbative error	non-perturbative error	χ^2/N_{dof}
T	0.1195	± 0.0003	± 0.0024	± 0.0007	482/209
M_H	0.1042	± 0.0008	± 0.0010	± 0.0008	436/124
C	0.1096	± 0.0006	± 0.0020	± 0.0004	55/73
B_W	0.1051	± 0.0008	± 0.0020	± 0.0002	55/53
B_T	0.1129	± 0.0004	± 0.0038	± 0.0005	53/61
variable	$\alpha_0(2\text{ GeV})$	exp. error	perturbative error	non-perturbative error	correl.
T	0.460	± 0.003	± 0.018	± 0.027	-39 %
M_H	0.579	± 0.011	± 0.007	± 0.040	2 %
C	0.506	± 0.007	± 0.035	± 0.034	-35 %
B_W	0.464	± 0.002	± 0.035	± 0.036	17 %
B_T	0.539	± 0.009	± 0.014	± 0.045	-8 %

varying the infrared matching scale in the range 1 GeV $\leq \mu_I \leq$ 3 GeV and by probing missing higher order corrections to the Milan factor $\mathcal{M} \to \mathcal{M} \pm \mathcal{O}(\alpha_s/\pi)$. It appears that the central values of $\alpha_s(M_Z)$ are much smaller than with Monte Carlo corrections, in particular in the case of M_H and B_W, also the spread of values is increased. Both perturbative and non-perturbative errors are reduced, the former one is scaling with the absolute value of α_s. The measurements of α_s and α_0 are not independent, the statistical correlation is typically -60 % to -80 %. The total correlation is modified by systematic effects and given in Table 2. The universality of α_0 is verified at the level of 20 %, the total error being of the order of 10 %.

4 Conclusion

The results of measurements of $\alpha_s(M_Z)$ and α_0 using power corrections are compared in Fig. 2 to the combined value of α_s obtained with the standard method based on Monte Carlo corrections. Combined values of α_s and α_0 are obtained by weighting individual measurements proportional

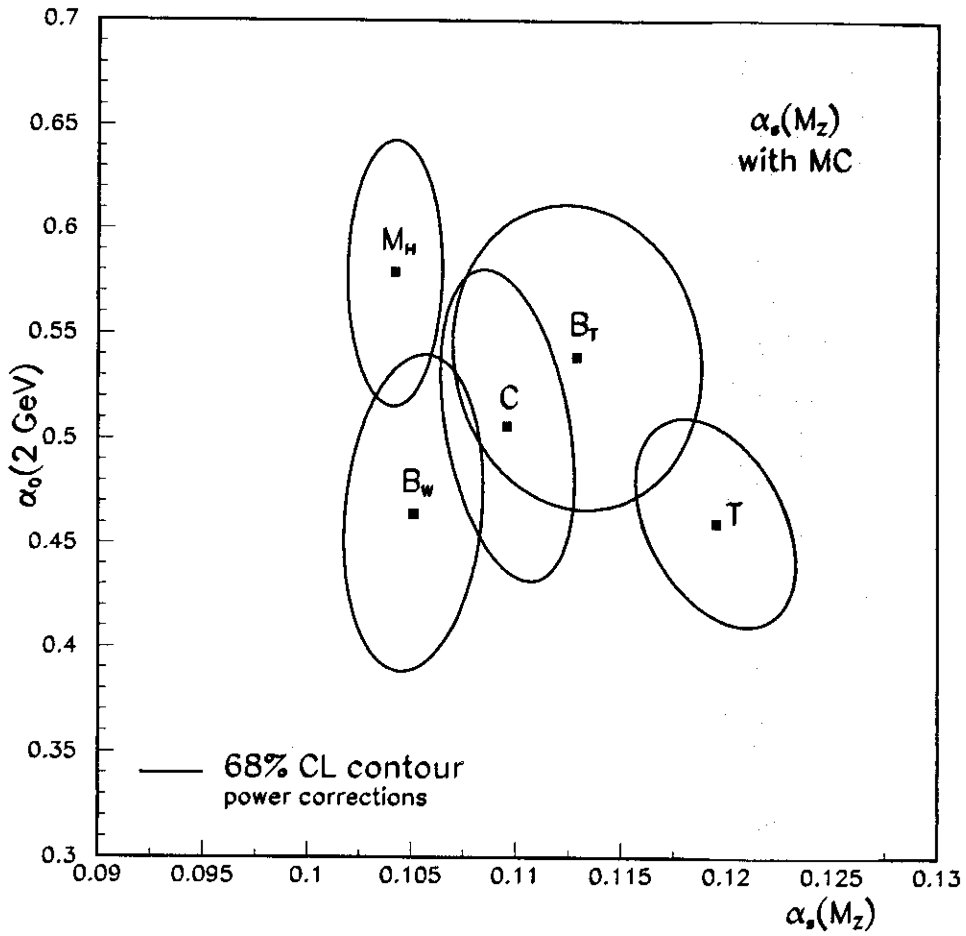

Figure 2: Confidence contour levels of simultaneous measurements of α_s and α_0 compared to the combined measurement of α_s using Monte Carlo corrections.

to the inverse square of their respective total errors.

MC corrections	power corrections	
$\alpha_s(M_Z)$	$\alpha_s(M_Z)$	$\alpha_0(2\ \mathrm{GeV})$
0.1232 ± 0.0040	0.1082 ± 0.0021	0.504 ± 0.042

The average of α_s with power corrections should be taken with care, since the individual results using different variables are incompatible with each other, in particular the case of the heavy jet mass needs to be further investigated. There is also a rather large discrepancy in α_s between power corrections and Monte Carlo corrections. This discrepancy could to some extend be explained by quark mass effect, which are neglected in the power correction approach. The expected size of mass effects at $Q = M_Z$ is 1 %, but scaling with m_b^2/s, and should be taken into account at lower energies. In the case of the heavy jet mass also final state hadron masses may contribute to the low fitted value of α_s.

The non-perturbative parameter α_0 is found to be universal within 20 % , twice the total error of α_0. A considerable reduction of the spread of values is reached with the new calculations for jet broadenings.

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