MEASUREMENTS OF $\alpha_s$ FROM HADRONIC EVENT SHAPES IN $e^+e^-$ ANNIHILATION

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New studies of hadronic event shape observables in $e^+e^-$ collisions between 13 and 183 GeV CM energy have enabled the running of $\alpha_s$ to be confirmed and the validity of non-perturbative power-law corrections to be investigated. A more precise value of $\alpha_s(M_Z)$ with reduced theoretical errors has been reported from fitting 18 oriented event shape distributions measured in one experiment at the Z.

1 Running of $\alpha_s(Q)$ and Power Corrections

Most experimental measurements of $\alpha_s$ are limited in precision by theoretical errors arising from missing higher order terms and uncertainties in the hadronisation corrections which are normally derived from the phenomenological Monte Carlo models. Recently, improved perturbative QCD predictions for the event shape observables, C-parameter and the Jet Broadenings $B_W$, $B_T$, have become available to add to those already produced for Thrust ($T$) and Heavy Jet Mass ($M^2_H$).

Leading non-perturbative (1/Q, where $Q = \sqrt{s}$) power corrections have also been calculated for these observables. They are based on an effective strong coupling, $\alpha_0(\mu_I)$, at an infra-red matching scale, $\mu_I$ (usually set to 2 GeV). This coupling is expected to be approximately universal but must be derived from experiment. Once evaluated, power corrected distributions can be compared directly with experiment leaving the Monte Carlo models for detector corrections only. Recently, a 2-loop analysis of these 1/Q power corrections has been performed for Thrust rescaling the original prediction by a so-called 'Milan' factor ($M$) which has been shown to apply equally to the other aforementioned observables.

The power corrections basically shift the perturbative predictions for the differential spectra of each observable linearly in $\alpha_0$ although additional logarithmic terms are thought to be required for the jet broadenings.

In a contribution to this conference, ALEPH fit the power corrected perturbative predictions in the 3-jet regions of the 1-T, C, $M^2_H$ and $B_W$ distributions to the measurements at 5 values of $\sqrt{s}$ from 91.2 to 183 GeV. The perturbative predictions are $O(\alpha_s^2)$ with $\ln(R)$ (or R) matched NLL terms. The perturbative renormalisation scale parameter, $x_\mu (= \mu/\sqrt{s})$, is set to 1. They extract simultaneously values for $\alpha_0(\mu_I)$ and $\alpha_s(M_Z)$ from each observable. The fits are reasonably satisfactory except to the $B_W$ distributions where the results are far from those obtained for the other observables with either matching scheme. The bad quality of these fits disfavours the concept of a logarithmically enhanced shift. DELPHI and a JADE group, who also include data from higher energies, fit instead to the means of event shape distributions simultaneously at all $\sqrt{s}$ values. In this case, only the $O(\alpha_s^2)$ terms can be used for the perturbative contribution. OPAL presented a similar analysis applied also to the second and third moments of the 1-T and C distributions. In this case, the power corrections are suppressed by $(\mu_I/Q)^n$ where $n = 2$ or 3. Using Monte Carlo models, they show that the power corrections for the higher moments are small above $Q = M_Z$ and also a low value of $x_\mu$ is required to obtain consistent values of $\alpha_s$ from them. They fit simultaneously to the first three moments in the data for each observable at 91.2, 133, 161 and 172 GeV. When correlations are taken into account, the fits are not stable if $x_\mu = 1$ indicating that higher order perturbative terms are large. Thus, $x_\mu$ is allowed to vary as well and is found to be highly correlated to $\alpha_0(\mu_I)$. As expected, the results are insensitive to the power terms in the higher moments which are therefore set to zero.

Table 1 compares the values of $\alpha_0(\mu_I)$ and $\alpha_s(M_Z)$ obtained from each experiment. The latter values are renormalised to $M_Z$ assuming compatibility with QCD; they are in good agreement except for the OPAL(2) result where $x_\mu$ is kept fixed. Theory systematics dominate and are typically evaluated from varying $x_\mu$ from 0.25 to 4.0.

Table 1: Values of $\alpha_s(M_Z)$ and $\alpha_0(\mu_I)$ as obtained from the fits. $\dagger$ Results from C and (1-T) are consistent; $\ddagger$ values are compatible only at 30% level.

| Expt | $\alpha_s(M_Z)$ | $\alpha_0(\mu_I)$ | $x_\mu$ |
|------|-----------------|--------------------|--------|
| ALEPH | 0.1168±0.0048 | 0.451±0.065$\dagger$ | 1.0 |
| DELPHI | 0.1176±0.0057 | 0.494±0.009 (T) | 1.0 |
| | 0.1172±0.0037 | 0.558±0.025 (C) |
| JADE | 0.1188$^{+0.0044}_{-0.0034}$ | 0.325 - 0.616$\ddagger$ | 1.0 |
| OPAL(1) | 0.1143±0.0088 | 0.322 (T) | 0.038 |
| | 0.1158±0.0107 | 0.249 (C) | 0.052 |
| OPAL(2) | 0.141 | as above | 1.0 |
and $\mu_T$ between 1 and 3 GeV.

All the LEP experiments have tested the running of $\alpha_s(Q)$ using event shape observables. L3 have fitted resummed $O(\alpha_s^2)$ predictions of $T$, $M^2_H$, $B_W$ and $B_T$ to measured distributions. In this case, the predictions are corrected to the hadron level by Monte Carlo models. Values of $\alpha_s(Q)$ are determined at 11 $\sqrt{s}$ energy points between 30 and 183 GeV using events with isolated photons to extend the energy range below the $Z$. The 3-loop QCD running $\alpha_s$ curve gives an excellent fit $\chi^2$ from which $\alpha_s(M_Z) = 0.1216 \pm 0.0017 \pm 0.0058$. The most precise and comprehensive test was submitted by a JADE group as described earlier incorporating data from other PETRA, TRISTAN, LEP and the SLD experiments. The 2-loop power corrected $O(\alpha_s^2)$ predictions for the mean values of 5 event shape observables as a function of $\sqrt{s}$ are fitted individually to the data over a CM energy range from 13 to 172 GeV. Fig. 1 show the best fits to the heavy jet mass and wide jet broadening observables. As seen by ALEPH, the fits to the jet broadenings have poor $\chi^2$s. The values of $\alpha_s$ found are averaged with those from the other 3 observables, $\langle 1-T \rangle$, $\langle B_T \rangle$, $\langle C \rangle$, to give the results quoted in Table 1. It was pointed out at the conference that the power correction terms provided for the jet broadenings (where fits are generally poor) are incorrect and need to be revised. This may improve the level of consistency found.

2 Precise determination of $\alpha_s(M_Z)$ from oriented event shapes

The DELPHI Collaboration reported a new precise determination of $\alpha_s(M_Z)$ from a high statistics study of 1.4 million re-processed hadronic events at the $Z$. Eighteen event shape distributions were measured as a function of the polar angle of the thrust axis. The corresponding $O(\alpha_s^2)$ QCD predictions were corrected to the hadron level using Monte Carlo models and fitted to the data in defined ranges individually chosen for each observable to avoid regions where these corrections are greater than 40% and the acceptance less than 80%. In addition, the range was adjusted until the value of $\alpha_s$ obtained was stable.

With the renormalisation scale fixed to $x_\mu = 1$ a large scatter is observed in the 18 fitted values of $\alpha_s$ found. This arises mainly from missing higher order perturbative QCD contributions (resummed terms are not available for many of the observables used). This procedure was repeated using the experimentally-optimised-scale (EOS) procedure where $x_\mu$ is allowed to vary with $\alpha_s$ in a 2-parameter fit to each observable. An impressive reduction in the scatter is achieved although the values of $x_\mu$ required vary considerably between 0.0033 for $T$ to 6.33 for $D^2_{\text{Geneva}}$. Such an improvement was not observed.

Figure 1: Energy dependence of $\langle M^2_H \rangle$ and $\langle B_W \rangle$; the dashed line is the perturbative prediction only.
Table 2: Weighted values of $\alpha_s(M_Z)$ obtained from 18 event shape distributions in the DELPHI experiment using various choices of renormalisation scales. † 4 fits fail to converge and correlation with experimentally optimised procedure is poor.

| Scale choice | $\alpha_s(M_Z)$ | $\chi^2$/dof | $x_\mu$ range |
|--------------|-----------------|--------------|---------------|
| Optimised    | 0.1164±0.0025   | 7.3/16       | 0.0033 - 6.33 |
| fixed        | 0.1243±0.0080   | 40/15        | 1.0           |
| ECH          | 0.1148±0.0038   | 18/16        | -             |
| PMS          | 0.1147±0.0040   | 21/16        | -             |
| BLM          | 0.1168±0.0053   | 24/13†       | -             |

in a similar analysis by the SLD experiment. Although this analysis was based on only 50,000 events, it would appear that statistics do not account for the discrepancy since the total errors are largely dominated by theory and hadronisation uncertainties in both experiments. It is likely that the choice of fit ranges are crucial since $x_\mu$ and $\alpha_s$ are correlated in the EOS procedure. Three alternative theoretically motivated schemes to determine values of $x_\mu$ for each observable were tried by DELPHI all of which reduce the scatter observed with the fixed $x_\mu$ but are not so successful as the EOS procedure. Table 2 shows the results using the the ECH scheme, the PMS scheme and the BLM scheme compared with the EOS and fixed procedures.

The DELPHI submission to the conference also includes further studies of selected observables where resummed NLL terms to combine with the $\mathcal{O}(\alpha_s^2)$ predictions are available. Fits are made to the data selecting regions of the shape distributions which are: (a) restricted to the 2-jet region where pure NLLA should apply and (b) to the 2+3 jet region using the full theory. The renormalisation scale, $x_\mu$, is set to 1. Acceptable fits are obtained to the data but in general the fits using the EOS procedure without resummed terms are superior over a wider range of the distributions.

In conclusion, although apparently successful, the EOS procedure remains a controversial and somewhat unsatisfactory method of producing a precise measurement of $\alpha_s$. A better method may be to constrict the analysis to observables for which resummed and power-law predictions are available. A proper solution to the missing higher orders and other non-perturbative effects is still highly desirable.

References

1. S. Catani and B.R. Webber, hep-ph/9801350.
2. Yu.L. Dokshitzer et al., hep-ph/9801324.
3. Yu.L. Dokshitzer and B.R. Webber, Phys. Lett. B 404, 321 (1997).
4. Yu.L. Dokshitzer et al., Nucl. Phys. B 511, 396 (1998).
5. Yu.L. Dokshitzer et al., hep-ph/9802381.
6. ALEPH Collaboration, Contribution to ICHEP98 Ref. 940.
7. DELPHI Collaboration, Contribution to ICHEP98 Ref. 137.
8. P.A Movilla Fernandez et al., PITHA 98/21 and contribution to ICHEP98 Ref. 646.
9. OPAL Collaboration, Contribution to ICHEP98 Ref. 305.
10. L3 Collaboration, Contribution to ICHEP98 Ref. 536.
11. Yu.L. Dokshitzer, private communication.
12. DELPHI Collaboration, Contribution to ICHEP98 Ref. 142.
13. S. Bethke, Z. Phys. C 43, 331 (1989).
14. P.N. Burrows et al., Phys. Lett. B 382, 157 (1996).
15. G. Grunberg, Phys. Rev. D 29, 2315 (1984).
16. P.M. Stevenson, Phys. Rev. D 23, 2916 (1981).
17. S.J. Brodsky, G.P. LePage and P.B. MacKenzie, Phys. Rev. D 28, 228 (1983).