The present situation in the determination of $\alpha_s$

Oliver Passon
Fachbereich Physik, University of Wuppertal
Postfach 100 127, 42097 Wuppertal, Germany
E-mail: Oliver.Passon@cern.ch

This note reviews the latest measurements of $\alpha_s$ from event shapes in $e^+e^-$ annihilation at LEP1 and LEP2. A critical review of different methods to extract $\alpha_s$ is offered.

1 Introduction

Measurements of the strong coupling $\alpha_s$ serve as an important consistency test of QCD. The results presented here are based on event shape observables in $e^+e^-$ annihilation. Since QCD is the theory of (asymptotically) free quarks and gluons, hadronisation effects need to be accounted for. This is traditionally done either with phenomenological models ("monte carlo"), or with the help of QCD inspired power corrections. But we will also discuss results which indicate, that for inclusive mean values non-perturbative effects are much smaller than originally assumed.

2 The LEP QCD working group combination

The LEP QCD working group has made serious effort to set up a method for combining the $\alpha_s$ measurements of the four LEP collaborations. In the course of this work a common definition and implementation of the theoretical predictions was reached. In contrast to the electroweak working group, not the data are combined, but the combination is performed on the level of $\alpha_s$ measurements. As input the LEP collaborations provide the working group with the $\alpha_s$ fit results based on the logR matched predictions for several event shape distributions with monte carlo hadronisation corrections. The details of this procedure can be found in [1]. The averages over LEP1 and LEP2 data
Figure 1: Left: Energy dependence of the LEP combined $\alpha_s$ values. The band displays the QCD evolution of the mean value. Right: DELPHI results on $\alpha_s$ from distributions at LEP1 and LEP2 with experimentally optimised scales [6]. The inner error bar shows the statistical uncertainty, the outer one the total uncertainty.

respectively lead to:

LEP1 data: $\alpha_s(m_Z) = 0.1197 \pm 0.0049$ (tot)

LEP2 data: $\alpha_s(m_Z) = 0.1196 \pm 0.0046$ (tot)

The LEP2 data alone are more precise, since theoretical and hadronisation uncertainties reduce with increasing energy. The energy dependence of the $\alpha_s$ values at LEP1 and LEP2 is shown in Fig.1 (Left). The total error is completely dominated by the theoretical uncertainty (i.e. more than 95%). Traditionally this uncertainty was estimated by a variation of the renormalisation scale only. The exchange with theoreticians within the LEP QCD working group revealed additional sources of ambiguity, related to the so-called phase space condition. Since the NLLA calculations do not die out at the phase space boundary $y_{\text{max}}$, the replacement $L = \ln \frac{1}{y} \rightarrow L' = \frac{1}{p} \ln \left[ \frac{1}{(x_L y)^p} - \frac{1}{(x_L y_{\text{max}})^p} + 1 \right]$ was suggested, with $y$ the observable under investigation. Originally the choice $x_L = 1$ and $p = 1$ was made. But in fact other values of $x_L$ and $p$ are formally equivalent.
i.e. introduce only sub-dominant contributions. This introduces two more arbitrary parameters. The working group now considers the effect on $\alpha_s$ when changing the renormalisation scale $\mu$ ($0.5\sqrt{s} \leq \mu \leq 2\sqrt{s}$), $x_L$ ($2/3 \leq x_L \leq 3/2$) and $p$ ($p = 1, 2$). In order to avoid double counting the theoretical uncertainty is derived from an error-band method. For details of the method see [1]. Especially the $x_L$ variation leads to an increase in the theoretical uncertainty.

3 Alternative approaches

It is generally assumed that the matched $\mathcal{O}(\alpha^2_s)+$NLLA predictions represent the most complete knowledge of perturbative QCD. But one should bear in mind that the $\chi^2$ of matched fits is known to be poor which leads to strong fit-range dependence of $\alpha_s$. On top of this problems, which were known for long and seemed to be ignored by part of the community, the appearance of the above mentioned new ambiguities makes a look into alternative approaches even more pressing.

3.1 Experimentally optimised scales

One of this alternatives is provided by using fixed order calculations only. It was shown in [2], that this allows a consistent description of event shape distributions as measured with high precision at LEP1, provided that the renormalisation scale $\mu$ is treated as an additional free parameter in the fit. Hence the resulting renormalisation scales are called “experimentally optimized”. It turns out [2], that this experimentally optimised scales (EOS) correlate highly with theoretically suggested scales like the ECH [3] or PMS [4]. This result was confirmed by a study of the 4-jet rate, where the NLO calculation became available only recently [5]. Using this approach for 3-jet like event shape distributions with the DELPHI LEP2 data leads also to consistent results (see Fig.1 (Right) [6]). In all these cases a monte carlo hadronisation correction is applied.

It is a subject of controversial debate weather the EOS procedure is theoretically founded. As a matter-of-fact the scale choice for NLO calculations is in one-to-one correspondence to the choice of a renormalisation scheme. In the light of this mathematical property the scale optimisation can be viewed as the choice of a scheme which describes the data more properly than the
conventional $\overline{\text{MS}}$. The corresponding $\alpha_s$ values are then retranslated into $\overline{\text{MS}}$ to allow for a direct comparison of the results.

Theoreticians in generally do not like if one confuses “scales” and “schemes”. It is claimed that the $\overline{\text{MS}}$ scheme choice is merely conventional and that the occurrence of large logs (i.e. scales different from $\sqrt{s}$) introduces the need for resummation, i.e. the NLL approximation. This argumentation would be more convincing, if the scale dependence of NLLA calculations would actually decrease significantly, which has not been observed. Additional, the author of this lines is astonished, that a merely conventional choice (like the one for the $\overline{\text{MS}}$ scheme) is defended with so much vigor, as if it has a deeper meaning nevertheless. It should be noted, that another approach to cure the scale dependence of NLL resummation is offered by the inclusion of renormalon effects [7]. However, this approach yields smaller values for $\alpha_s$.

It may be suspected, that the refusal of the EOS method is related to its attempt to enlarge the regime of perturbative QCD (this argument applies even stronger to the RGI method, which will be reviewed later). Currently most theoreticians are more attracted by non–perturbative phenomena. The determination of $\alpha_s$ is not at the heart of current research in QCD.

3.2 Power corrections

This leads me directly to the subject of power corrections, one of the prime examples for the above mentioned new research lines. In this note the ansatz is applied to mean values of event shapes [8]. The well known result is displayed in Figure 2 (left). One gets a proper description of the energy dependence of mean values with consistent $\alpha_s$ and $\alpha_0$ values [6] (It should be noted however, that power corrections to distributions yield systematically lower values for $\alpha_s$ [9].). Seemingly power corrections provides just a different way to account for hadronisation effects, because they substitute monte carlo hadronisation corrections. But since power corrections are combined with a $\mathcal{O}(\alpha_s^2)$ calculation, this analysis tells us also something about scales and the fuzzy border line between perturbative and non–perturbative physics. Since the power corrections are given to us in the $\overline{\text{MS}}$ scheme, the perturbative part has also to be evaluated in $\overline{\text{MS}}$ (e.g. $\mu = \sqrt{s}$). But the coherent description of the data with $\mathcal{O}(\alpha_s^2)$ calculations in the $\overline{\text{MS}}$ scheme seems to be in striking contradiction to
Figure 2: Left: Fit of the $O(\alpha_s^2) +$ power correction prediction to the energy dependence of event shape means. Right: Fit of the purely perturbative RGI prediction to the same data set as in the left plot. Due to mass effects the heavy jet mass has to be modified.

our earlier claim about the need of experimentally optimised scales. The next section shows how this riddle can be solved.

3.3 Renormalisation group invariant (RGI) perturbation theory

Fig.2 (Right) [9] shows the very same data that was displayed in Fig.2 (Left). This time the data are compared to the so-called renormalisation group invariant (RGI) prediction [10], which is numerically equivalent to the effective charge scheme [3]. In fact an experimental optimisation of the scales would lead to the same curves. The hadronic data are described by the perturbative calculations only – there is neither need nor room for power corrections. The resulting $\alpha_s$ values are consistent and close to the world average [9]. It is of course no surprise that power corrections show some scale dependence, but it is perplexing that an appropriate scale can make them to vanish completely. This finding is in agreement with the results derived in the context of the renormalon resummation (see Fig. 5 and 7 in [11]).
The other – and even more important – virtues of the RGI approach (especially for a measurement of the $\beta$ function) can be found in [9].

4 Summary

The ability to describe hadronic final states with a perturbative calculation only (i.e., with one free parameter only) is surprising and its implications should be formulated with care. Certainly we do not claim, that non-perturbative effects (e.g., hadronisation) do not take place or play no role. But for the mean values of event shape distributions one of the two following statements seems to hold: either their inclusiveness makes them essentially insensitive to non-perturbative physics or for some strange reason their effects can be parameterised completely by perturbative QCD, provided a proper scheme choice. In any event it is not justified to choose the $O(\alpha_s^2)$ calculation in $\overline{\text{MS}}$ while assigning the “rest” to non-perturbative physics.

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