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Nuclear and Particle Physics Proceedings 270–272 (2016) 103–107
www.elsevier.com/locate/nppp

α_s from the updated ALEPH data for hadronic τ decays

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Abstract

We extract the strong coupling $\alpha_s(m_\tau^2)$ from the recently updated ALEPH non-strange spectral functions obtained from hadronic τ decays. We apply a self-consistent analysis method, first tested in the analysis of OPAL data, to extract $\alpha_s(m_\tau^2)$ and non-perturbative contributions. The analysis yields $\alpha_s^{\rm FO}(m_\tau^2) = 0.296 \pm 0.010$, using Fixed Order Perturbation Theory (FOPT), and $\alpha_s^{\rm CI}(m_\tau^2) = 0.310 \pm 0.014$, using Contour Improved Perturbation Theory (CIPT). The weighted average of these results with those previously obtained from OPAL data give $\alpha_s^{\rm FO}(m_\tau^2) = 0.303 \pm 0.009$ and $\alpha_s^{\rm CI}(m_\tau^2) = 0.319 \pm 0.012$, which gives, after evolution to the Z boson mass scale, $\alpha_s^{\rm FO}(m_Z^2) = 0.1165 \pm 0.0012$ and $\alpha_s^{\rm CI}(m_Z^2) = 0.1185 \pm 0.0015$, respectively. We observe that non-perturbative effects limit the accuracy with which α_s can be extracted from τ decay data.

Keywords: α_s, τ decays, duality violations

1. Introduction

The extraction of α_s from hadronic τ decays represents an important test of the evolution of the strong coupling as predicted by the QCD β-function. At and around the τ mass, $m_\tau \approx 1.78$ GeV, perturbative QCD can still be used, but realistic analyses must include the contribution from non-perturbative effects. The standard framework to describe hadronic τ decays is to organize the QCD description in an operator product expansion (OPE) where, apart from the perturbative contribution and quark-mass corrections, the QCD condensates intervene [1].

Observables such as R_τ,

$$R_\tau = \frac{\Gamma\left[\tau^- \to \nu_\tau \text{hadrons}(\gamma)\right]}{\Gamma\left[\tau^- \to \nu_\tau e^- \bar{\nu}_e(\gamma)\right]}, \qquad (1)$$

can be written as weighted integrals over the experimentally accessible QCD spectral functions. The spectral functions have been determined at LEP by the ALEPH [2] and OPAL collaborations [3]. In the specific case of R_τ, the weight function is that determined by τ-decay kinematics and the integral runs over the total energy of the hadronic system in the final state, s, from zero to m_τ^2. Since the OPE description is not valid at low-energies the evaluation of the theoretical counterpart is performed exploiting the analytical properties of the QCD correlators. One writes then a finite-energy sum rule (FESR) where the theoretical counterpart of the observable is obtained from an integral along a complex circle of fixed radius $|s| = m_\tau^2$. In fact, any analytic weight function gives rise to a valid sum rule, and it has become customary to exploit this freedom in order to analyse several FESRs simultaneously. This type of combined analysis allows for the extraction of α_s as well as non-perturbative contributions.

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http://dx.doi.org/10.1016/j.nuclphysbps.2016.02.022

The computation, in 2008, of the NNNLO term, $O(\alpha_s^4)$, of the perturbative expansion of the QCD correlators [4] triggered several reanalyses of α_s from τ decays [5–8]. In the process, it was discovered that the correlation matrices of the then publicly available spectral functions from the ALEPH collaboration had a missing contribution from the unfolding procedure [9]. (It was for this reason that we restricted our attention to OPAL data in the analyses of Refs. [7, 8].) Recently, a new analysis of the ALEPH data became available, employing a new unfolding method, which corrects for this problem in the correlation matrices [10, 11]. The ALEPH spectral functions have smaller errors than OPAL's and have the potential to constrain the theoretical description better. The new set of ALEPH spectral functions motivates the present reanalysis.

On the theoretical side, two different aspects have received attention recently. The first one regards the use of the renormalization group in improving the perturbative series. There are several prescriptions as to how one should set the renormalization scale. The most commonly used are Contour Improved Perturbation Theory (CIPT) [12] and Fixed Order Perturbation Theory (FOPT) [13]. Different prescriptions lead to different results with the available terms of the perturbative expansion, and therefore to different values of α_s. This discrepancy remains one of the largest sources of uncertainty in α_s extractions from τ decays. Strong evidence in favour of the FOPT prescription has been given in Refs. [14, 15] but the issue is still under debate. Here, we chose to perform our analysis using both prescriptions and hence quote two values of α_s.

The second point that has been studied recently is the description of non-perturbative effects. Since the work of Ref. [5] it is known that the OPE parameters obtained in some of the recent analyses are inconsistent. With these parameters one cannot account properly for the experimental results when s_0, the upper limit of the integration in the FESR, is lowered below m_τ^2. A strategy that allows for a self-consistent analysis is the inclusion of Duality Violation (DV) effects in the theoretical description. It is well known that in the vicinity of the Minkowski axis the OPE alone cannot account for all non-perturbative effects. In the past, in the description of R_τ, this contribution was systematically ignored due to the fortuitous double zero of the weight function at the Minkowski axis. In the same spirit, combined analyses of several FESRs were restricted to the so-called *pinched moments*, i.e., moments that have a zero at the the Minkowski axis. Until recently, DVs were not tackled directly and their contribution to final results and errors were not systematically assessed.

Recent progress in modeling the DV contribution [17–21] has allowed for analyses that include them explicitly in the FESRs. In Refs. [7] a new analysis method taking into account DVs explicitly was presented. This led to a determination of α_s from OPAL data in a self-consistent way, together with the OPE contribution and DV parameters [8]. In a recent work, we applied the same analysis method to the updated version of the ALEPH non-strange spectral functions [22].

In the remainder we discuss the main results of Ref. [22].

2. Analysis framework

For the sake of self-consistency, here we make a brief review of the framework of our analysis. The details can be found in the original publications Refs. [7, 8, 22].

Fits performed in our analysis are based on FESRs of the following form [1, 16]

$$\begin{aligned} I^{(w)}_{V/A}(s_0) &\equiv \int_0^{s_0} \frac{ds}{s_0}\, w(s)\, \rho^{(1+0)}_{V/A}(s) \\ &= -\frac{1}{2\pi i}\oint_{|s|=s_0} \frac{ds}{s_0}\, w(s)\, \Pi^{(1+0)}_{V/A}(s)\,, \end{aligned} \quad (2)$$

where the weight-functions $w(s)$ are polynomials in s, and $\Pi^{(1+0)}_{V/A}(s)$ is given by

$$\begin{aligned} & i\int d^4x\, e^{iqx}\, \langle 0|T\left\{J_\mu(x)J^\dagger_\nu(0)\right\}|0\rangle \\ &= \left(q_\mu q_\nu - q^2 g_{\mu\nu}\right)\Pi^{(1+0)}(s) + q^2 g_{\mu\nu}\Pi^{(0)}(s)\,, \end{aligned} \quad (3)$$

with $s = q^2 = -Q^2$, and J_μ one of the non-strange V or A currents $\bar{u}\gamma_\mu d$ or $\bar{u}\gamma_\mu\gamma_5 d$. The superscripts (0) and (1) refer to spin. In the sum rule Eq. (2), $\rho^{(1+0)}_{V/A}$ is the experimentally accessible spectral function. We construct FESRs at several values of $s_0 \leq m_\tau^2$ for a given weight function.

The correlators $\Pi^{(1+0)}_{V/A}(s)$ can be decomposed exactly into three parts

$$\Pi^{(1+0)}(s) = \Pi^{(1+0)}_{\rm pert}(s) + \Pi^{(1+0)}_{\rm OPE}(s) + \Pi^{(1+0)}_{\rm DV}(s), \quad (4)$$

where "pert" denotes perturbative, "OPE" refers to OPE corrections of dimension larger than zero (including quark-mass corrections), and "DV" denotes the DV contributions to $\Pi^{(1+0)}(s)$.

It is convenient to write the perturbative contribution in terms of the physical Adler function [13, 14], that satisfies a homogeneous renormalization group equation. When treating the contour integration, one must adopt a prescription for the renormalization scale. As discussed