MEASURING α_{QED} IN e^+e^-: AN ALTERNATIVE APPROACH*

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Abstract

We propose a method to determine the running of α_{QED} from a measurement of small angle Bhabha scattering. The method is suited to high statistics experiments at e^+e^-colliders equipped with luminometers in the appropriate angular region. A new simulation code predicting small angle Bhabha scattering is also presented.

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1 Introduction

The electroweak Standard Model $SU(2) \otimes U(1)$ contains as a constitutive part Quantum Electrodynamics (QED). The running of the electromagnetic coupling α is determined by the theory

$$\alpha(q^2) = \frac{\alpha(0)}{1 - \Delta\alpha(q^2)} \tag{1}$$

where $\alpha(0) = \alpha_0$ is the Sommerfeld fine structure constant, which has been measured to a precision of $3.7 \cdot 10^{-9}$ [1]. $\Delta\alpha(q^2)$ positive, arises from loop contributions to the photon propagator. The numerical prediction of electroweak observables involves the knowledge of $\alpha(q^2)$, usually for $q^2 \neq 0$. For instance, the knowledge of $\alpha(m_Z^2)$ is relevant for the evaluation of quantities measured by the LEP experiments. This is achieved by evolving α from q^2=0 up to the Z mass scale $q^2 = m_Z^2$. The evolution expressed by the quantity $\Delta\alpha$ receives contributions from leptons, hadrons and the gauge bosons. The hadronic contribution to the vacuum polarisation, which cannot be calculated from first principles, is estimated with the help of a dispersion integral and evaluated [2] by using total cross section measurements of $e^+e^- \to$ *hadrons* at low energies. Therefore, any evolved value $\alpha(q^2)$,particularly for $|q^2| > 4m_\pi^2$, is affected by uncertainties originating from hadronic contributions. The uncertainty on $\alpha(m_Z^2)^{-1}$ induced by these data is as small as $\pm$ 0.09 [2], nevertheless it turned out [3] that it limits the accurate prediction of electroweak quantities within the Standard Model, particularly for the prediction of the Higgs mass. While waiting for improved measurements from BEPC, VEPP-4M and DAFNE as input to the dispersion integral, intense efforts are made to improve on estimating the hadronic shift $\Delta\alpha_{had}$, as for instance [4, 5, 6, 7], and to find alternative ways of measuring α itself. Attempts have been made to measure $\alpha(q^2)$ directly using e^+e^--data at various energies, such as measuring the ratio of $e^+e^-\gamma/e^+e^-$ [8] or more directly the angular distribution of *Bhabha* scattering [9]. We propose [10] the running of α by using small angle *Bhabha* scattering. This process provides unique information on the QED coupling constant α at low *spacelike* momentum transfer $t = -|q^2|$, where $t = -\frac{1}{2}\ s\ (1 - \cos\theta)$ is related to the total invariant energy $\sqrt{s}$ and the scattering angle θ of the final state electron. The small angle region has the virtue of giving access to values of $\alpha(q^2)$ without being affected by weak contributions. The cross section can be theoretically calculated with precision at the per mille level. It is dominated by the photonic t-channel exchange and the non-QED contributions have been computed [11] and are on the order of 10^{-4}, in particular contributions from boxes with two weak bosons are safely negligible. In general, the *Bhabha*-cross section is computed from the entire set of gauge invariant amplitudes in the s- and t-channel.

The s-channel contribution gives only a negligible contribution [10]. Thus, the measurement of the angular distribution allows indeed to verify directly the running of the coupling $\alpha(t)$. Such a measurement constitutes a genuine test of QED alone. In fact, QED - as part of the electroweak theory - is valid as a consistent theory by itself, since for the applications considered here the conditions $|q^2| \ll m_W^2, m_Z^2$ are fulfilled. Furthermore, for the actual calculations $\theta \gg m_e/E_{beam}$ and $E_{beam} \gg m_e$ must be satisfied. Obviously, in order to manifest the running, the experimental precision must be adequate. This idea can be realized by high statistics experiments at e^+e^--colliders equipped with finely segmented luminometers, in particular by the LEP experiments given their large event samples, by SLC and future Linear Colliders. The relevant luminometers cover the t-range from a few GeV^2 to order 100 GeV^2. The t-dependence of the quantity $\Delta\alpha(t)$ at small values of t may be obtained using the program *alphaQED* by Jegerlehner [2]. At low energies is dominated by the contribution from the leptons, while with increasing energy also the contribution from loops due to hadrons gets relevant. The region where hadronic corrections are critical is contained in the considered t-range.

2 The Method

The experimental determination of the angular distribution of the *Bhabha* cross section requires the precise definition of a *Bhabha* event in the detector. The analysis follows closely the procedure adopted in the luminosity measurement which is described in detail, for instance in ref. [14](YR), and elaborates on the additional aspect related to the measurement of a differential quantity. To this aim the luminosity detector must have a sufficiently large angular acceptance and adequate fine segmentation. The variable t is reconstructed on an event-by-event basis.

The method to measure the running of α exploits the fact that the cross section for the process $e^+e^- \to e^+e^-$ can be conveniently decomposed into three factors :

$$\frac{d\sigma}{dt} = \frac{d\sigma^0}{dt}\left(\frac{\alpha(t)}{\alpha(0)}\right)^2 (1 + \Delta r(t)). \tag{2}$$

All three factors are predicted to a precision of 0.1 % or better. The first factor on the right hand side refers to the *Bhabha* Born cross section including soft and virtual photons according to ref. [11], which is precisely known, and accounts for the strongest dependence on t. The vacuum polarization effect in the leading photon t-channel exchange is incorporated in the running of α and gives rise to the squared factor in eq.2. The third factor $\Delta r(t)$ collects all the remaining real (in particular collinear) and virtual radiative effects not incorporated in the running of α [11, 12]. The experimental data after correction for detector effects is to be compared with eq.2.This goal is achieved by using a newly developped program based on the already existing semianalytical code NLLBHA [11, 15] called SAMBHA [10]. The two-point functions $\Pi(t) = \Delta\alpha(t)$ and $\Pi(s) = \Delta\alpha(s)$ are responsible for the running of α in the space-like and time-like regions. In the language of Feynman diagrams the effect arises from fermion loop insertions into the virtual photon lines. Anticipating the application of the proposed method to measure the t-dependence of $\alpha(t)$ to the data of a real experiment, a Monte Carlo simulation is carried out [10]. Electrons, positrons and photons are observed as clusters. Their reconstruction is based on a cluster algorithm. By applying the selection criteria the event sample is divided in clusters which areattibuted to various rings in the luminometer [10]. The hadronic contribution may be deduced by subtracting the leptonic contribution which is theoretically precisely known [10]. The extraction of the hadronic contribution is only limited by the experimental precision (see the talk of G. Abbiendi at this conference [18]). To conclude a novel experimental approach to access directly the running of α in the t-channel is proposed. It consists in analysing small angle *Bhabha* scattering. Depending on the particular angular detector coverage and on the energy of the beams, it allows to cover a sizeable range of the t-variable. The information obtained in the t-channel can be compared with the existing results of the s-channel measurements. This represents a complementary approach which is direct, transparent and based only on QED interactions and furthermore free of some of the drawbacks inherent in the s channel methods. The method outlined can be readily applied to the experiments at LEP [18] and SLC. It can also be exploited by future e^+e^- colliders as well as by existing lower energy machines. An exceedingly precise measurement of the QED running coupling $\Delta\alpha(t)$ for small values of t may be possibly envisaged with a dedicated luminometer even at low machine energies.

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References

1. D.E. Groom et.al.: Eur. Phys. J. **C15** (2000) 1
2. S. Eidelman and F. Jegerlehner: Z. Phys. **C67** (1995) 602
3. K. Hagiwara, D. Haidt, S. Matsumoto and C.S. Kim : Z.Phys. **C64** (1994) 559; Z.Phys. **C68** (1995) 353;

K. Hagiwara, D. Haidt and S. Matsumoto : Eur. Phys. J. **C2** (1998) 95

4. F. Jegerlehner: hep-ph/0308117
5. M. Davier and A. Höcker : Phys. Lett. **B435** (1998) 427;
   M. Davier, S. Eidelman, A. Höcker, Z. Zhang, Eur. Phys. J. **C27**(2003) 497-521
6. D.Karlen and H.Burkhardt, Eur. Phys. J. **C22** (2001) 39; hep-ex/0105065 (2001)
7. A.A. Pankov, N. Paver, Eur. Phys. J. **C29**(2003) 313-323
8. TOPAZ Collaboration, I. Levine et al.: Phys. Rev. Lett. **78** (1997) 424
9. L3 Collaboration : M. Acciarri *et al*, Phys. Lett. **B476** (2000) 48
10. A.B.Arbuzov, D.Haidt, C.Matteuzzi, M.Paganoni and L. Trentadue, European Physics Journal C35, 267 (2004) . hep-ph/0402211.
11. A.B. Arbuzov, V.S. Fadin, E.A. Kuraev, L.N. Lipatov, N.P. Merenkov and L. Trentadue, Nucl. Phys. **B485** (1997) 457.
12. E.A. Kuraev and V.S. Fadin, Sov. J. Nucl. Phys. **41** (1985) 466. O. Nicrosini and L. Trentadue, Phys.Lett. **B196** (1987) 551; Z. Phys. **C39** (1988) 479.
13. S.J. Brodsky, G.P. Lepage and P.B.Mackenzie, Phys. Rev. **D28** (1983) 228
14. LEP Working Group, Yellow Report CERN 96-01, Event Generators for Bhabha scattering, Convenors : S.Jadach and O.Nicrosini, p.229
15. Yellow Report CERN 96-01 : *description of NLLBHA*
16. S. Eidelman and F. Jegerlehner, Z. Phys. **C67** (1995) 585; hep-ph/9502298.
17. A. Arbuzov *et al.*, Phys. Lett. **B383** (1996) 238; hep-ph/9605239.
18. OPAL collaboration preprint 2005