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$\alpha(m_Z^2)$ AND THE STANDARD MODEL FITS *

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The importance of $\alpha(m_Z^2)$ for the Standard Model fits is discussed. It is shown that the error of $\alpha(m_Z^2)$ ultimately limits the Standard Model interpretation of the $\sin^2\theta_{\rm eff}^{\rm lept}$ measurements. Possibilities for improvements are being discussed.

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The value of the QED fine structure constant α is running (Fig. 1a) as a function of $\sqrt{q^2}$, reaching at the scale of m_Z^2 the value of $\frac{1}{128.89\pm0.09}$ [1, 2].

$$\alpha(s) = \frac{\alpha(0)}{1+\Pi_{\gamma\gamma}(s)} \qquad \Delta\alpha(s) = -\Pi_{\gamma\gamma}(s)$$

The contribution of leptonic loops to the running is calculated with almost infinite precision. The quark-loop contribution is calculated from the $R_{\rm had}$, the QED cross-section of the process $e^+e^- \to$ hadrons normalized to the QED cross-section for muon-pair production using a dispersion integral:

$$\mathrm{Re}\,\Pi_{\gamma\gamma}(s) = \frac{\alpha\, s}{3\pi}\ P\int_{4m_\pi^2}^{\infty} \frac{R_{\rm had}(s')}{s'(s'-s)}ds'$$

A summary of recent evaluations of the hadronic contribution $\Delta\alpha_{\rm had}$ to the running of α is given in Fig. 1b. In this paper the value $\alpha = \frac{1}{128.89\pm0.09}$ is used, corresponding to $\Delta\alpha_{\rm had} = 0.0280 \pm 0.0007$ [1, 2].

$\alpha(m_Z^2)$ is, together with G_F and m_Z, one of three input parameters of the Standard Model. Its value influences the determination of electroweak corrections depending on m_t and m_H. Fig. 2a compares the LEP/SLD measurements of $\sin^2\theta_{\rm eff}^{\rm lept}$ and LEP measurements of $\Gamma_{\rm lepton}$ with the Standard

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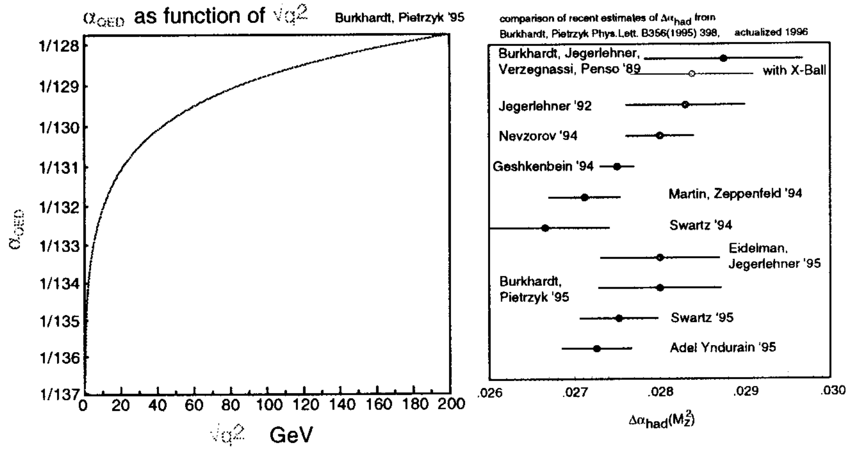
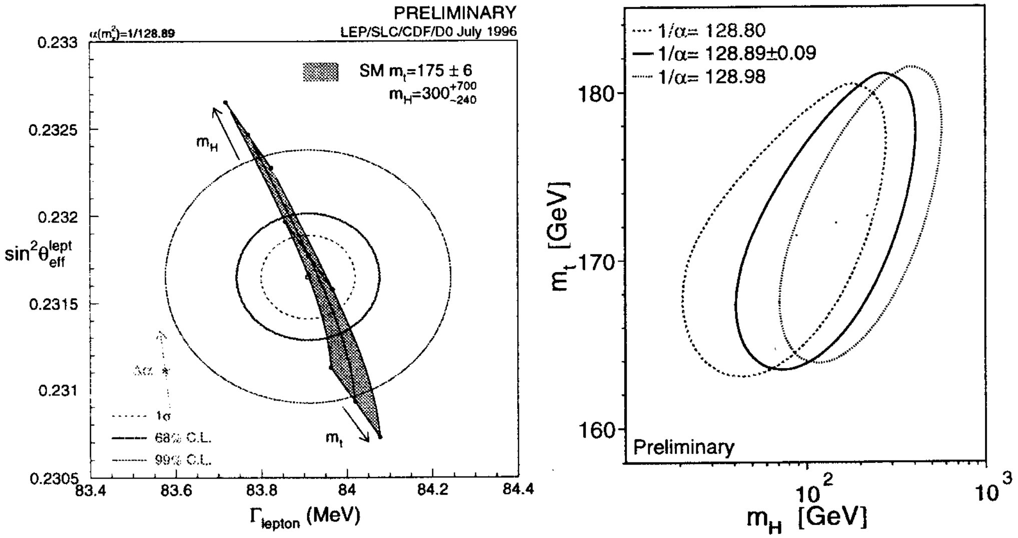


(a) (b)

Fig. 1. (a) The running of α. (b) Summary of recent evaluations of hadronic contribution $\Delta\alpha_{\rm had}$ to the running of α. See ref. [1] for references to different evaluations and also [3, 4].

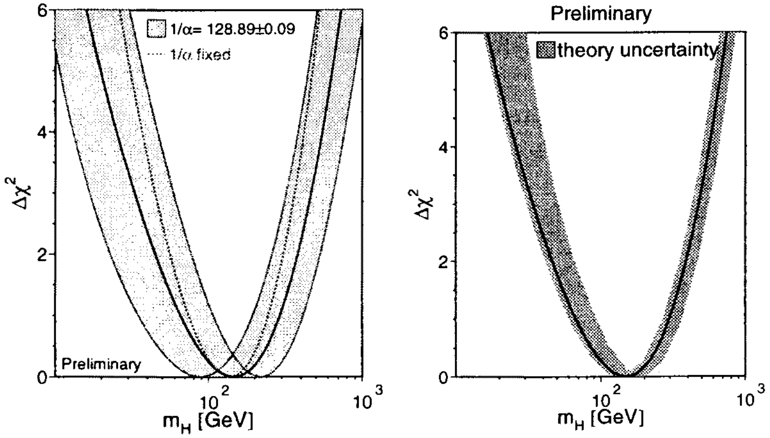


(a) (b)

Fig. 2. (a)The LEP/SLD measurements of $\sin^2\theta_{\rm eff}^{\rm lept}$ and the LEP measurements of $\Gamma_{\rm lepton}$ compared with the Standard Model prediction. The star shows the prediction if among the electroweak radiative corrections only the vacuum polarization is included. (b) The results of the Standard Model fit of m_t and m_H with three different values of $\alpha(m_Z^2)$.

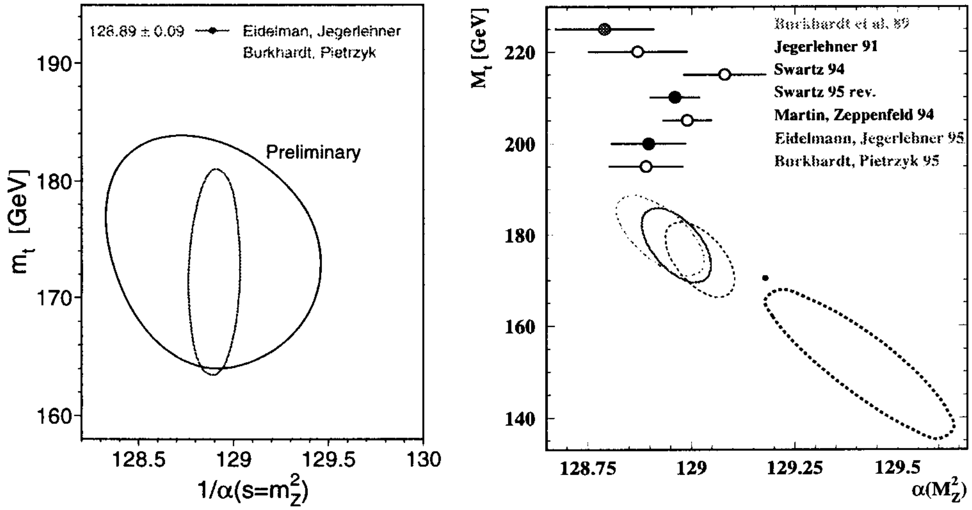
Model prediction. The star shows the prediction if among the electroweak radiative corrections only the vacuum polarization is included (the running of α). The corresponding arrow shows variation of this prediction if $\alpha(m_Z^2)$ changes by one standard deviation. This variation gives an additional uncertainty to the Standard Model prediction shown in the figure. The existence of electroweak corrections is clearly proven; they were used in previous years to fit the top mass within the Standard Model. Currently, the Higgs mass can be fitted using the experimentally measured value of the top mass [5], as can be seen in Fig. 2a. However, the experimental error on $\sin^2\theta_{\mathrm{eff}}^{\mathrm{lept}}$ is the same as the variation of the Standard Model prediction of $\sin^2\theta_{\mathrm{eff}}^{\mathrm{lept}}$ with the error of α seen as an arrow in Fig. 2a. In the future the Standard Model interpretation of improved measurements of $\sin^2\theta_{\mathrm{eff}}^{\mathrm{lept}}$ would be limited if the error of $\alpha(m_Z^2)$ were not reduced.

Results of the Standard Model fit of m_t and m_H made with α and $\alpha \pm$ its error are shown in Fig. 2b. Constraining the fit with the measured top mass of 175 ± 6 [5] one can obtain the $\Delta\chi^2$ distribution of the Standard Model fit of m_H shown in Fig. 3a. The shaded region in the figure shows the variation of the $\Delta\chi^2$ distribution when the input parameter to the fit α changes by $\pm$ its error. This variation is larger than the variation with the theoretical error of the calculation of the Higgs contribution to the electroweak corrections shown in Fig. 3b [6]. In the standard fits made



(a) (b)

Fig. 3. (a) The shaded region shows variation of the $\Delta\chi^2$ distribution of the Standard Model fit of m_H with the input value of $\alpha \pm$ its error. The dashed line shows the result of the fit with α fixed. (b) The shaded region shows the theoretical error of the m_H fit.



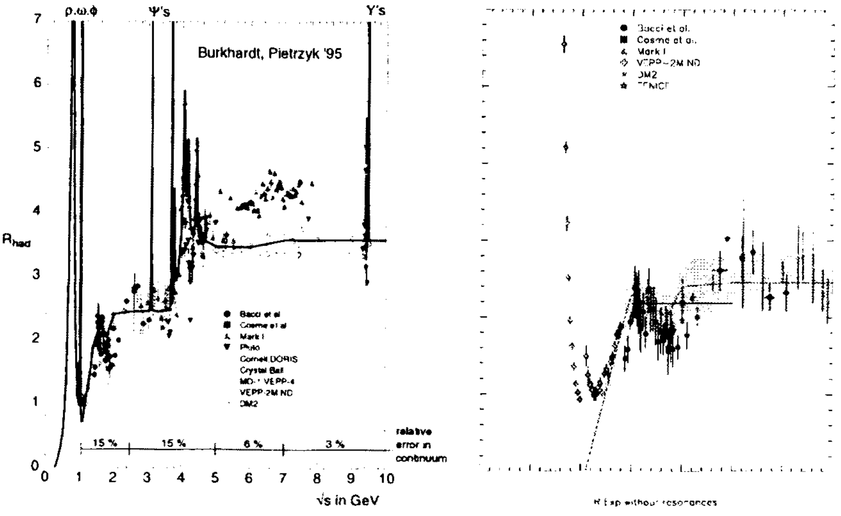
(a) (b)

Fig. 4. Results of the Standard Model fit of m_t *vs.* α with and without constraint on α for (a) 1996 data and (b) 1994 data.

by the LEP Electroweak Working Group [6], represented by solid lines in Fig. 3a and b, the error of α is included in the fitting procedure. The dashed curve in Fig. 3a shows the result of the fit with α fixed, showing the maximum improvement of the fit with infinite precision of determination of the $\alpha(m_Z^2)$.

Fig. 4a shows the results of the Standard Model fits of m_t *vs.* α with and without constraint on $\alpha(m_Z^2)$ using 1996 data. The constrained-fit results confirm the unconstrained fit with a better precision. This was not the case with the data from previous years, mostly because of the difference between the measured value of R_b and the Standard Model prediction (Fig. 4b).

The error of $\alpha(m_Z^2)$ comes from the errors of $R_{\rm had}$ measurement, which are presented in Fig. 5a for different c.m.s energies. The shaded region and the numbers in the lower part of the plot show the experimental uncertainty of the continuum measurement. The largest error of 15% comes from the continuum measurement between c.m.s. energies of 1 and 5 GeV. The region up to 3.5 GeV is shown in more detail in Fig. 5b. The old pioneering e^+e^- measurements made at Orsay, Frascati and SLAC are often contradictory. The radiative corrections were not applied or either applied only approximately. Different topologies were measured in different experiments. There was no agreement on the properties of resonant structures seen in this region.



(a) (b)

Fig. 5. (a) R_{had} for different c.m.s energies. The shaded region and the numbers in the lower part of the plot show the experimental uncertainty of the continuum measurement. (b) The c.m.s. energy region below 3.5 GeV in more detail.

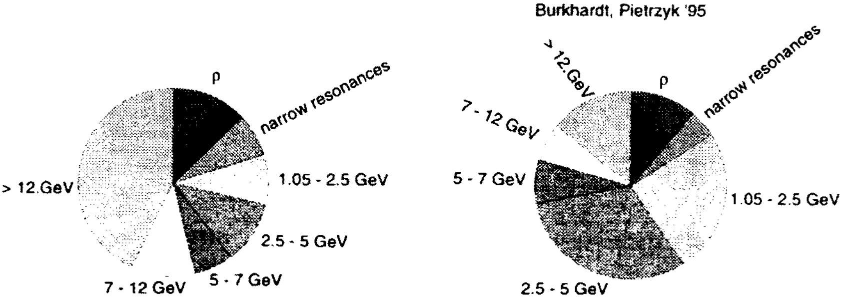


Fig. 6. Different contributions to the value (left) and error (right) of $\Delta\alpha_{\text{had}}$.

The contribution of R_{had} (measured in different c.m.s. energy regions) to the value of $\Delta\alpha_{\text{had}}$ is shown in Fig. 6 as well as the contribution to its error. It can be seen in Fig. 6 that the continuum between 1 and 5 GeV contributes more than half of the error.

Therefore it is important to remeasure the R_{had} in the e^+e^- annihilations at the c.m.s. energies between 1 and 5 GeV. It is not very probable that these measurements could be made at CERN PS, at Cornel or at DESY. They could be made at BEPC in Beijing, which recently has been upgraded, increasing its luminosity by a factor of 1.5–2. However, the present BES detector measures the luminosity with a precision of 10% and the detector efficiency is known with 15% efficiency [7].

New measurements of $R_{\rm had}$ in the c.m.s. region of 0.5 to 1.5 GeV are being made at VEPP-2M in Novosibirsk. In the future, measurements in this energy region will come from ϕ factories at DAΦNE Frascati and in Novosibirsk. They will improve the precision of α needed for the g-2 measurement at Brookhaven [8] and luminosity measurements at CERN [1, 9]. They will make, however, only a limited improvement on the precision of $\alpha(m_Z^2)$ (see Fig. 6).

In conclusion

- the error of $\alpha(m_Z^2)$ ultimately limits the Standard Model interpretation of the $\sin^2\theta_{\rm eff}^{\rm lept}$ measurements;
- a very small improvement will be possible in the near future;
- measurements of $R_{\rm had}$ in Beijing in the c.m.s. energy region of 1 to 5 GeV could substantially reduce the error, providing improvements in the luminosity measurement and determination of the detector efficiency;
- ϕ factories will reduce the error of luminosity measurements at LEP and interpretation of the g-2 experiment.

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