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SELECTED TOPICS ON PRECISION ELECTROWEAK TESTS FROM ALEPH

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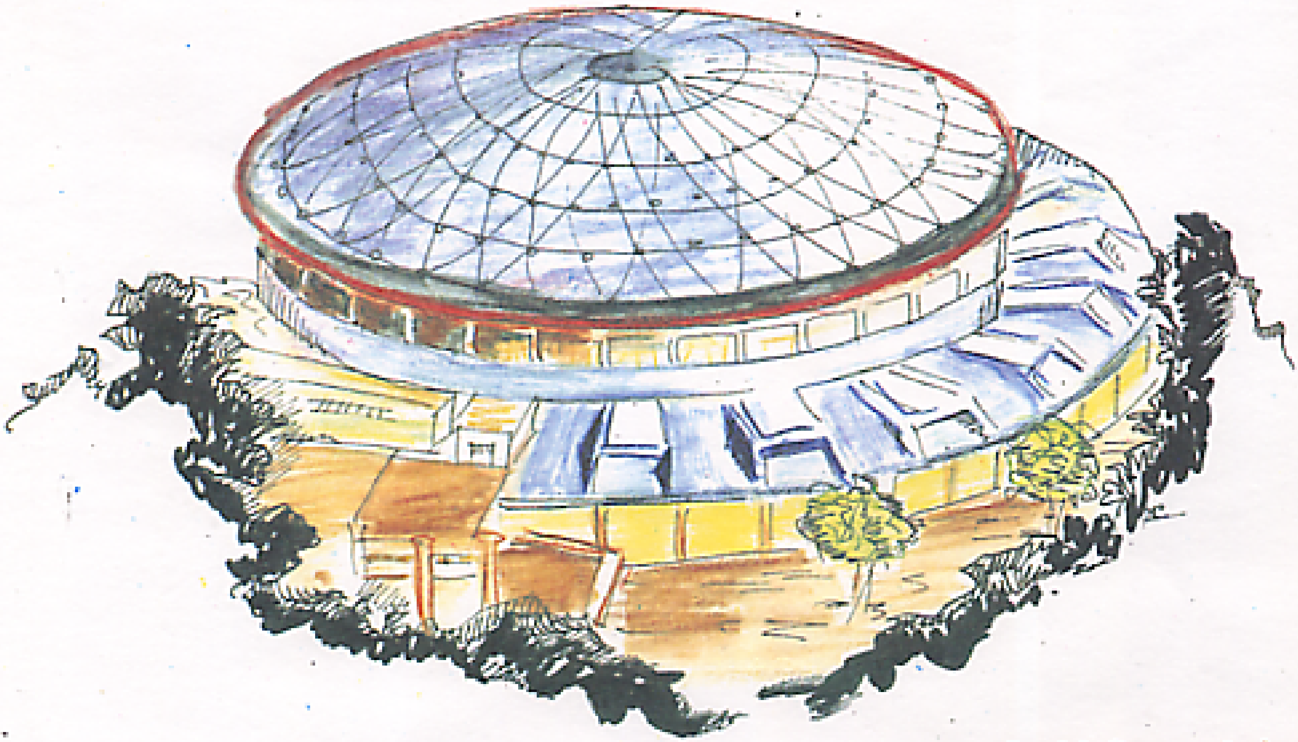

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SELECTED TOPICS ON PRECISION ELECTROWEAK TESTS FROM ALEPH

M. Pepe Altarelli
INFN – Laboratori Nazionali di Frascati, P.O. Box 13, I–00044 Frascati (Roma) Italy

Abstract

Some precision electroweak measurements from ALEPH are reviewed where a significant progress can still be realized. In particular improved measurements of the Z hadronic peak cross-section are obtained by exploiting the better accuracy of the second generation luminosity calorimeters. A new powerful method of analysis of the $b\bar{b}$ forward-backward asymmetry which relies on the so-called jet-charge technique is also presented.

1 Introduction

LEP1 is entering now a last phase where the basic electroweak measurements will reach their utmost precision.

$\mathrm{M_Z}$ and Γ_Z are extracted by a scan of the Z resonance, i.e. by measuring the cross-sections $e^+e^- \rightarrow f\bar{f}$ for hadronic ($q\bar{q}$) and leptonic ($\ell^+\ell^-$) final states as a function of $\sqrt{s} \sim \mathrm{M_Z}$. In 1993 a scan of the resonance was performed, which should allow to bring the error on Γ_Z from ± 7 MeV down to about ± 3 MeV.

The hadronic cross-section, the ratio R_l of the hadronic and leptonic partial widths and the asymmetries are measured at the peak. Exploiting the improved accuracy in the luminosity determination provided by the new silicon-tungsten luminosity calorimeter (SICAL), ALEPH[1] has considerably improved the precision on the absolute cross-section. A similar accuracy will be obtained by the OPAL collaboration in the near future.

The $b\bar{b}$ forward-backward asymmetry already provides one of the most powerful determinations of $\sin^2\theta_W^{eff}$. A new analysis has been developed by ALEPH[2] and DELPHI[3] to measure $A_{FB}(b\bar{b})$ using the lifetime-tag and the jet-charge method. This method leads to a precision on $\sin^2\theta_W^{eff}$ comparable or better than that of other techniques, by taking full advantage of the large statistics accumulated at the peak.

2 Absolute luminosity and hadronic peak cross section.

The knowledge of the absolute luminosity is essential for the measurement of the hadronic peak cross-section σ^0_{had}. Experimentally the cross-section is given by

$$\sigma^{exp}_{had} = \frac{N^{obs}_{had}}{\epsilon_{had} L}$$

where N^{obs}_{had} is the number of observed $e^+e^- \rightarrow q\bar{q}$ events, ϵ_{had} is the hadron selection efficiency and L is the integrated luminosity collected by the experiment.

A particularly important result from LEP has been the determination of the number of neutrino species N_ν. By making use of the equations

$$\sigma^0_{had} = \frac{12\pi\Gamma_e\Gamma_{had}}{\mathrm{M}_z^2\Gamma_z^2}$$

and

$$\Gamma_\mathrm{Z} = 3\Gamma_e + \Gamma_{had} + N_\nu\Gamma_\nu$$

where Γ_e, Γ_{had} and Γ_ν are the partial widths of the Z into electrons, hadrons and neutrinos respectively, the following expression can be derived:

$$N_\nu = \frac{\sqrt{\frac{12\pi R_{had}}{\sigma^0_{had} \mathrm{M}_z^2}} - R_{had} - 3}{\frac{\Gamma_\nu}{\Gamma_l}} .$$

This equation can be used to extract the number of neutrinos using the experimental measurements for R_{had} and σ^0_{had} and assuming the Standard Model value for the ratio $\frac{\Gamma_\nu}{\Gamma_l} = 1.992 \pm 0.003$. The error on N_ν is now dominated (via σ^0_{had}) by the systematic error on the absolute luminosity. In particular from the previous formula one derives that $\Delta N_\nu \sim 8\frac{\Delta L}{L}$.

The luminosity is measured by counting small angle Bhabha scattering events and dividing by the theoretical cross-section σ_{ref} : $L = \frac{N_{Bhabha}}{\sigma_{ref}}$. In fact at small scattering angles Bhabha scattering is dominated by γ exchange in the t-channel, while contributions from Z exchange interference terms are small ($\sim 0.2\%$ to $\sim 1\%$ of the Born cross-section depending on the angular acceptance of the luminosity monitor). The Bhabha reference cross-section is calculated using the Monte-Carlo program BHLUMI[5]. The theoretical uncertainty associated to this Monte-Carlo generator is ~ 0.25 to 0.3% (again depending on the angular acceptance of the calorimeter) and is common to all four LEP experiments.

Since the Bhabha cross-section falls rapidly down with increasing scattering angle ($\frac{d\sigma}{d\Omega} \sim \frac{1}{\theta^4}$) it is crucial to accurately define the experimental acceptance in the region of the smallest scattering angle. A detector subtending smaller angles must have an improved precision in the knowledge of the internal radius in order to maintain the same systematic uncertainty in the acceptance.

The SICAL calorimeter was installed in ALEPH in September 1992 with the goal of measuring the luminosity with an experimental precision better than 0.2%.

The detector consists of two homogeneous cylindrical sampling calorimeters which surround the beam-pipe at about ± 250 cm from the interaction point. The calorimeters subtend an angular region between 24 and 58 mrad. They consist of 12 tungsten layers alternated with 12 silicon crystals layers each having 16 radial and 32 azimuthal divisions. Successive layers are staggered in order to avoid aligned cracks.

The precision of the detector mechanics is such that the 70 mm internal radius r_{min} defining the acceptance is known with an uncertainty Δr_{min} of only 18 μm.

This results in an error on the luminosity given approximately by

$$\frac{\Delta L}{L} = 2\frac{\Delta r_{min}}{r_{min}}\frac{1}{1-(\frac{r_{min}}{r_{max}})^2} \sim 6\,10^{-4}.$$

In addition to the improved mechanical precision with respect to the previous luminosity calorimeter, the SICAL is also more dense, thus allowing a better position measurement and shower containment due to the smaller size of the electromagnetic shower.

In order to separate the Bhabha candidates from possible backgrounds the selection requires at least one reconstructed cluster in each endcap (A and B), with an energy $\geq$ 20 GeV. The sum of their energies must be $\geq$ 55 GeV. The acoplanarity of the two clusters, i.e. the difference between their azimuthal angles $\delta\phi$, is required to be between 150^0 and 210^0.

Radial fiducial cuts are used to precisely define the acceptance of the measured Bhabha cross-section. In order to reduce the sensitivity to possible beam offsets two fiducial cuts are employed: a "tight cut" selection (within radial pads 4 to 12) is applied to one cluster and a "loose cut" (pad 2 to 15) to the opposite cluster. The fiducial role alternates from one event to the next.

In order to determine whether a cluster near the boundary is within the fiducial region, the event is required to pass an energy asymmetry cut:

$$\frac{E_{in} - E_{out}}{E_{in} + E_{out}} > 0$$

where E_{in} is the energy inside a radial padwidth within the fiducial region and E_{out} is the energy in the radial padwidth outside.

The background to the Bhabha selection is small and it is originating from two sources:

- a machine related background due to accidental coincidences of off-momentum beam particles yielding a contamination of $\sim 8.5\,10^{-4}$ of the Bhabha rate
- t-channel production of two hard photons producing a $1.5\,10^{-4}$ contamination of the selection.

The total experimental systematics is 0.15 % and should be improved to 0.1 % for the 1993 analysis through better temperature control.

Using all the data accumulated until 1992 we obtain

$$\sigma^0_{had} = (41.60 \pm 0.16)\ \text{nb}\,.$$

The corresponding number of light neutrino species is $N_\nu = 2.983 \pm 0.034$.

The contribution of the improved SICAL luminosity precision is such that after two months of running in '92 the error on σ^0_{had} is the same as obtained by the four LEP experiments combined. The total error of 0.38 % in the cross-section is now dominated by the uncertainty of 0.25 % in the theoretical cross-section.

3 Asymmetries. $b\bar{b}$ forward-backward asymmetry.

From the measurements of the various asymmetries at the Z different values of the effective electroweak mixing parameter $\sin^2\theta_W^{eff}$ can be extracted allowing independent tests of the Standard Model. The asymmetries are defined as follows:

- $A^f_{FB} = \frac{\sigma_F - \sigma_B}{\sigma_F + \sigma_B}$,
  where σ_F is the cross-section for finding a fermion in the forward hemisphere, i.e. along the initial e^- direction.

- $A^\tau_{POL} = \frac{\sigma(\tau_L) - \sigma_(\tau_R)}{\sigma(\tau_L) + \sigma_(\tau_R)}$,
  where $\sigma(\tau_L)$ and $\sigma_(\tau_L)$ are the cross-sections for production of a τ with left and right-handed helicity , respectively.

- $A_{LR}(e^+e^- \to X) = \frac{\sigma_L - \sigma_R}{\sigma_L + \sigma_R}\frac{1}{P}$.
  A longitudinal polarization P for the e^- beam is needed in this case. σ_L and σ_R are the cross-sections for $e^-_{LR} + e^+ \to X$ where X can be any channel. In particular the experiment can be done in a completely inclusive way.

Introducing the ratio $x_f = \frac{g_v}{g_a} = 1 - 4|Q_f|\sin^2\theta_W^{eff}$ where g_v and g_a are the vector and axial vector coupling constants of the neutral current to fermion f and Q_f is the fermion charge and defining $\mathcal{A}_f = \frac{2x_f}{1+x_f^2}$, the asymmetries can be expressed as $A^f_{FB} = \frac{3}{4}\mathcal{A}_e\mathcal{A}_f, \quad A^\tau_{POL} = \mathcal{A}_\tau, \quad A_{LR} = P\mathcal{A}_e.$

The difference in the dependence of the asymmetries on the parameter $\mathcal{A}$ has a strong impact on the sensitivity to $\sin^2\theta_W^{eff}$:

$$\delta(\sin^2\theta_W^{eff}) \simeq \frac{1}{8}\delta A^\tau_{POL} \simeq \frac{1}{8P}\delta A_{LR} \simeq \frac{1}{2}\delta A^l_{FB} \simeq \frac{1}{6}\delta A^b_{FB}.$$

In particular, since $\mathcal{A}_b$ is large(~ 0.93) compared to $\mathcal{A}_e$ (~ 0.08) the $b\bar{b}$ forward-backward asymmetry is larger than the lepton ones, leading to an increased sensitivity to $\sin^2\theta_W^{eff}$.

The "classical" method of measuring $A_{FB}(b\bar{b})$ is based upon the identification of electrons or muons from b semileptonic decays with large p and p_T with respect to the parent jet direction. The b direction is defined by the thrust axis, while its charge is inferred from the lepton charge. Due to the effect of $B^0 - \bar{B}^0$ mixing, the true asymmetry is diluted with respect to the measured one :

$$A_{FB}(b\bar{b}) = \frac{A_{FB}^{obs}(b\bar{b})}{(1-2\chi)}$$

where χ represents the mixing parameter. The purity of the selected events is $\sim 70 \div 80\%$ with efficiencies of $\sim 10 \div 12\%$ including branching ratios.

A new method to measure $A_{FB}(b\bar{b})$ has been introduced by the ALEPH[2] and DELPHI[3] collaborations. It relies on a lifetime tag to detect the presence of a b quark in at least one hemisphere using the vertex detector information. The typical efficiency obtained by Aleph is $\sim 55\%$ with a purity of $\sim 90\%$, numbers which are far superior to the ones obtained with the lepton tag.

The charge of the parent quark is reconstructed using the "jet-charge" technique, i.e. from a weighted charge summation:

$$Q = \frac{\sum_{i=1}^{n} q_i |p_i^l|^k}{\sum_{i=1}^{n} |p_i^l|^k}.$$

q_i and p_i^l are the charge and longitudinal momentum of track i with respect to the thrust axis, and k is an empirical weighting power. Thanks to the extremely large efficiency of the vertex tag, the severe dilution of the primary $b - \bar{b}$ charge from the jet-charge method remains tolerable.

The mean forward-backward charge asymmetry, i.e. the difference between reconstructed hemisphere charges in the forward and backward detector hemispheres:

$$Q_{FB} = Q_F - Q_B$$

can be related to $A_{FB}(b\bar{b})$:

$$Q_{FB} = C\delta_b A_{FB}(b\bar{b}).$$

C is an acceptance factor and δ_b is the b charge separation, i.e. twice the reconstructed charge of a b quark hemisphere.

In order to evaluate the electroweak component from the measured mean charge asymmetry it is necessary to establish the degree of charge dilution involved in the method by measuring δ_b. This can be done either by Monte Carlo (as in the DELPHI analysis) or by using the data (as done by ALEPH). It is clear that an experimental determination of the charge separation allows to reduce considerably the systematic error, by constraining the uncertainty due to the depencence on fragmentation models.

ALEPH has measured δ_b from data using two different methods. The first one uses high p, p_t leptons to tag a b in one hemisphere whilst measuring the jet charge in the opposite one. This approach leads to a 5% measurement of δ_b including the mixing correction which has to be applied to the lepton. The second method makes use of the opposite signs of the quark charges in opposite hemispheres. δ_b is then extracted from the difference between the width of the Q_{FB} and $Q = Q_F - Q_B$ distributions. This second method yealds a 4% measurement of δ_b which is independent from the previous result and fully consistent with it.

The ALEPH result for $A_{FB}(b\bar{b})$ based on the 1992 data sample using the jet-charge method is:

$$A_{FB}(b\bar{b}) = (10.9 \pm 1.2_{stat} \pm 0.5_{syst})\%$$

This can be compared to the lepton measurement[4] which is based upon a larger statistics (1990-1992):

$$A_{FB}(b\bar{b}) = (8.1 \pm 1.0_{stat} \pm 0.3_{syst})\%$$

As one can see the two analyses already give comparable precision. If all four LEP experiments will measure $A_{FB}(b\bar{b})$ with the jet-charge technique the improvement will be important.

At present the error is in both cases dominated by its statistical component but also the systematic error is statistically dependent. For example the dominant systematics on $A_{FB}(b\bar{b})$ with the jet-charge is that due to the charge separation measurement from the data which can be reduced by an increase in statistics. Part of the systematic uncertainty in the high p, p_t lepton analysis comes from mixing which also depends on statistics. On the other hand an increase in the accumulated data will also improve the A^l_{FB} measurement.

If we for example assume that each LEP experiment collects $60pb^{-1}$ in 1994, then the error on $\sin^2\theta_W^{eff}$ from asymmetries at LEP will drop from ±0.0006 to about ±0.0004.

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