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LEPTON FORWARD-BACKWARD ASYMMETRIES

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Abstract

Results of Forward-Backward Aysmmetries with Leptons measured at Z^0 energies are presented. Details of the analysis by the DELPHI Collaboration are given together with the most recent values of the peak Aymmetries for electrons, muons and taus obtained by ALEPH, DELPHI, L3 and OPAL Collaborations at LEP.

INTRODUCTION

In view of recent improvements in the determination of the beam energies at LEP[1], The four LEP experiments were performing combined lineshape and asymmetry analysis of their 1990 and 1991 data samples. Complete results of these analysis have been presented at this conference[2].

In this report I will concentrate on the analysis of the Forward-Backward Leptonic asymmetries measured by the DELPHI Collaboration. I will describe the selection of electrons, muons and taus final states together with the flavor independent analysis. All numbers given in this paper are preliminary.

In 1990 and 1991, data taking was organized such as about 2/3 of the data was collected at a centre-of-mass energy, $\sqrt{s}$, equal to the Z^0 mass. The remaining data was collected during several "energy scan" at about seven different center-of-mass energies on the Z^0 resonance peak. During these two years, DELPHI collected about 450,000 Z^0 events.

Results of the Forward-Backward leptonic asymmetries measured with the DELPHI dectector[3] during 1990 data taking have already been published[4]. In 1991, the statistics was more than twice the 1990 one with an improved detector (in particular, the use of a silicon microvertex[5]) and better understanding of the detector which make the overall uncertainty on the measured leptonic asymmetries about a factor 2 smaller.

The Forward-Backward asymmetry, A_{FB}, can be estimated by two different methods :

1. from the ratio

$$A_{FB} = \frac{\sigma_F - \sigma_B}{\sigma_F + \sigma_B} \qquad (1)$$

   ("counting method"), where σ_F and σ_B are the cross sections in forward and backward hemispheres respectively after extrapolation to the full angular acceptance.

2. from a likelihood fit of the differential cross-section

$$\frac{d\sigma}{dcos\theta} = 1 + cos^2\theta + \frac{8}{3} A_{FB} cos\theta \qquad (2)$$

   where the last term gives the Forward-Backward asymmetry.

Although the likelihood method gives in principle better precision, different systematics contribute to these measurements and both methods were used for muon and tau final states. For electrons, the t-channel (and interference channel) contribution has to be subtracted and only the counting method was applied.

SELECTION OF ELECTRONS

The electron Forward-Backward asymmetry $A^e_{FB}(s)$ was measured in the barrel region only because of large t-channel contribution. Two independent analysis were performed. The first one, similar to the 1990 one[4], requires two back to back energy clusters in the Barrel electromagnetic detector (HPC) together with less than 4 charged tracks in the barrel tracking system which is based on the vertex detector (VD), the inner detector (ID), the time projection chamber (TPC) and the outer detector (OD).

In a second analysis, two independent selection criteria were applied which make it possible to compute selection efficiencies with high precision. The first set of cuts is based on the VD and the HPC only asking for more than two opposite tracks (and less than 4) in the VD and two electromagnetic clusters in the HPC. The second set of cuts relies on the barrel tracking system without making use of the VD together with energy deposition in the barrel hadron calorimeter (HCAL) compatible with that of electrons and hit distribution in the OD matching the OD electron hypothesis. Events were retained for which the polar angle of both electrons are in the range $44^\circ < \theta < 136^\circ$ and the acollinearity between the two electrons is smaller than 10°.

The global selection efficiency and trigger efficiency amount to $(97.1 \pm 0.2)\%$ and $(99.6 \pm 0.2)\%$ respectively.

The main backgroud comes from the reaction $e^+e^- \rightarrow \tau^+\tau^-$ (1.1% *at* $\sqrt{s} = M_Z$) and two photon events with electron pair final state (1.5% *at* $\sqrt{s} = M_Z$). The background coming from hadron final states was found to be negligible.

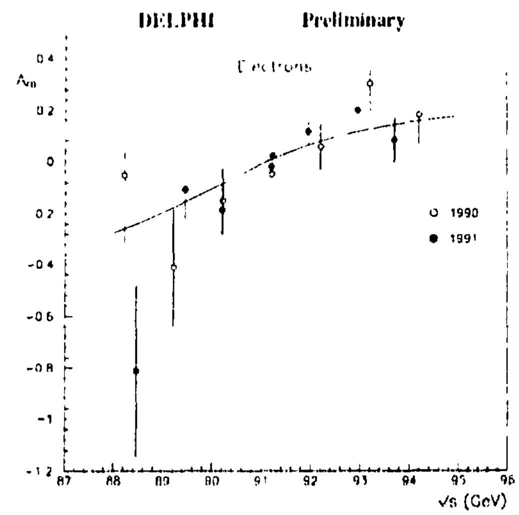

Figure 1. Electron Forward-Backward asymmetry as function of $\sqrt{s}$

As in 1990, the charge was determined from the tracking system and from the difference of the azimuthal position of the impact point on the HPC when the first method failed. The contribution to the systematic uncertainty from charge determination amount to $\delta A_{syst} = \pm 0.002$.

Figure 1 shows the measured values of A^e_{FB} for each energy point in 1990 (empty circle) and in 1991 (full circle) together with the result of the global electroweak fit which will be discussed later.

SELECTION OF MUONS

The analysis procedure for the selection of $e^+e^- \rightarrow \mu^+\mu^-$ candidates was very similar to that of 1990[1]. The polar-angle range was further extended to $10^\circ < \theta < 170^\circ$ and extensive use of the vertex detector was made to allow better background rejection. Tracks were retained if their momentum was greater than 15 GeV and acolinearity less than 10^o.

It was required that each particle was identified as a muon by either the electromagnetic calorimeter or the hadron calorimeter or the muon chambers both in the barrel and forward regions. For the muon chambers, identification was based on the association of the position of the muon chambers hits with those expected from the extrapolation of the tracks. For the hadronic and electromagnetic calorimeters, it was required that the energy deposited was consistent with that expected for a minimum ionising particle.

The identification efficiency of each of the sub-detectors was estimated as a function of θ. The overall muon identification efficiency was found to be 97.4%. The sign of the electric charge was obtained from track momentum determination. The uncertainty from charge misidentification was found to be negligible. The resulting sample contained 11465 events.

The cosmic background was further reduced in 1991 by the use of time of flight detector (TOF) and OD timing informations. the remaining background amount to 0.2%. The main background comes from $\tau^+\tau^-$ final state (2.6%) and was computed using KORALZ Monte-Carlo and subtracted.

The muon Forward backward asymmetry was computed with both counting and likelihood methods. The two methods give compatible results. The overall systematic uncertainty was then estimated to be $\delta A^{\mu}_{syst} = \pm 0.003$. The values obtained with likelihood method are shown on Figure 2 together with the result of the global electroweak fit (solid line). On Figure 3 the region near $\sqrt{s} = M_Z$ has been enlarged and preliminary value for the ongoing 1992 data taking has been added. Two peak points are reported for 1991 data taking because of different machine condition resulting in different center-of-mass energy.

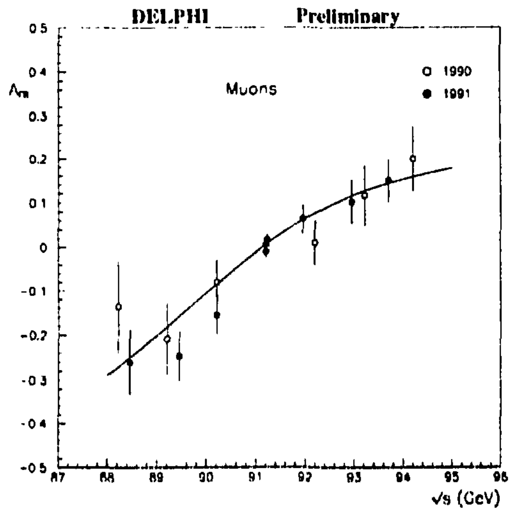

Figure 2. Muon Forward-Backward asymmetry as function of $\sqrt{s}$

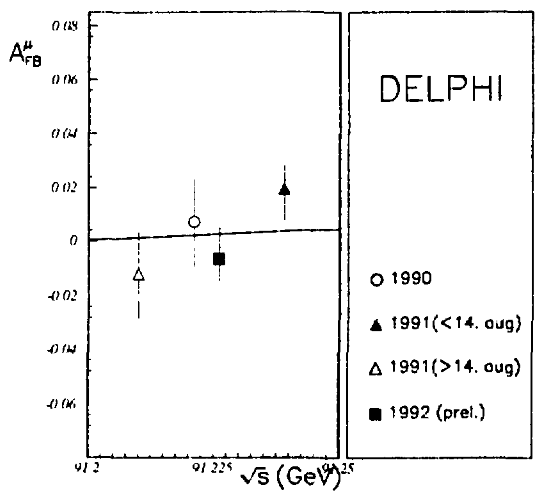

Figure 3. Muon Forward-Backward asymmetry near $\sqrt{s} = M_Z$

SELECTION OF TAUS

The selection of $e^+e^- \to \tau^+\tau^-$ events consisted of a combination of topological cuts based on the charged particle tracking and cuts using electromagnetic calorimetry in order to separate the $\tau^+\tau^-$ signal from the different backgrounds.

The background from hadronic events was minimized by demanding a maximum of 6 charged particles, one of which had to be isolated in angle from all the other charged particles in the event by at least 160^o and be in the polar angle range $25^o < \theta < 155^o$. The rejection of leptonic Z^0 decays was done asking for the "radial" electromagnetic energy, $E_{rad} = \sqrt{E_1^2 + E_2^2}$ to be smaller than E_{beam} for rejecting $e^+e^- \to e^+e^-(\gamma)$ events and and the radial momentum, $P_{rad} = \sqrt{P_1^2 + P_2^2}$ be smaller than P_{Beam} for rejecting $e^+e^- \to \mu^+\mu^-(\gamma)$ events. The remaining resonant background amounts to $(1.9 \pm 0.4)\%$.

In order to minimize the contamination of events from two photon reactions ($e^+e^- \to e^+e^- f^+ f^-$), it was required that the total visible energy be greater than 8 GeV and that the missing transverse momentum with respect to the beam direction be greater than 0.4 GeV. The remaining cross section for two photon processes was calculated to be (4.2 ± 0.9) pb in the acceptance.

The selection efficiency was determined from simulated data produced with KORALZ Monte-Carlo to be $(81.6 \pm 0.7)\%$ in the acceptance region and the trigger efficiency was found to be $(99.9 \pm 0.1)\%$.

To calculate A_{FB}, one has to be able to reconstruct the $\tau^+\tau^-$ pair production direction and the charges. Thrust axis is used for the direction. For the charge determination, the sign of the total charge in each hemisphere is used. The systematic uncertainty from charge determination is estimitated to be $\delta A = 0.001A$.

Because of its t-channel contribution, the high QED asymmetry of the $e^+e^- \to e^+e^-$ background had to be taken into account. It introduced a shift $\Delta A_{FB} \approx 0.9\delta$ (δ is the relative amount of t-channel bhabhas in the sample) which was subtracted.

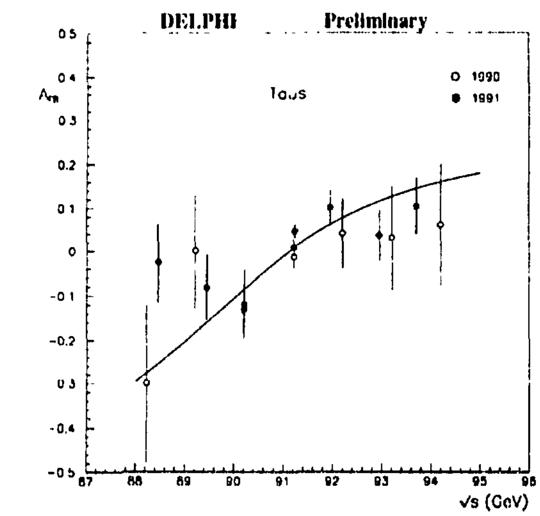

Figure 4. Tau Forward-Backward asymmetry as function of $\sqrt{s}$

The tau Forward-Backward asymmetry was computed with both counting and likelihood methods. The two methods give compatible results. The values obtained with the maximum likelihood method are shown on Figure 4 together with the result of the global electroweak fit. The overall systematic error is $\Delta A_{FB} = 0.015 A_{FB} \oplus \frac{0.0013}{\sigma(nb)}$.

FLAVOR INDEPENDENT ANALYSIS

In this analysis, the leptonic decays $Z^0 \to l^+l^-$ where $l = e, \mu, \tau$) were selected without trying to separate the three flavors. This approch allows a very efficient selection of leptonic events since no tight cuts are needed to separate the different leptonic channels. In addition, since leptonic channels are the main background one to another, the total background is smaller than in the flavor dependent analysis.

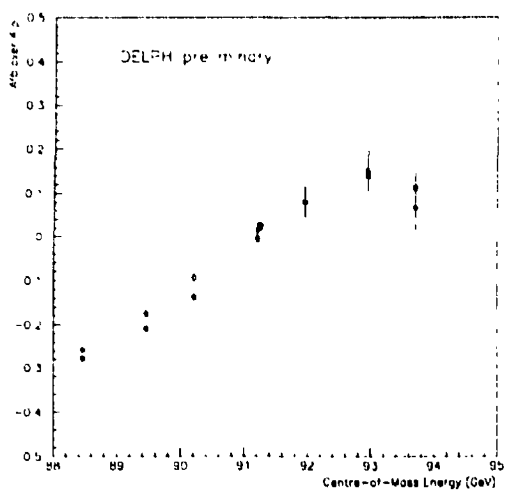

Figure 5. Flavor independent Forward-Backward asymmetry as function of $\sqrt{s}$

The event selection was based on the tracking system only. Its takes advantage of the low multiplicity, back-to-back topology and high visible momentum of the leptonic final states. It was restricted to the barrel region ($43^\circ < \theta < 137^\circ$) and the event acolinearity was required to be less than 20°.

The remaining hadronic and two-photon backgrounds were computed using Monte-Carlo to be $(0.3 \pm 0.2)\%$ and (7 ± 1) pb respectively.

To avoid systematic errors associated with track superposition and bad charge determination in τ decays, only 1-1 topology events with oppositively-charged particles were retained. A total of 18172 events were selected in the 1991 data sample. The asymmetry was computed by the counting method. In Figure 5, the measured flavor independent asymmetry is plotted as function of the centre-of-mass energy (open circles) together with the average of the 3 independent leptonic asymmetries (stars). The values agree very well.

DETERMINATION OF PEAK ASYMMETRIES

The four LEP experiments agreed on a common set of electroweak parameters to extract from their data and to compare. The Forward-Backward leptonic peak asymmetries, $A_{FB}^{0,l}$ are of these parameters together with the mass of the Z^0, the width, the peak cross-section and the ratios of the leptonic partial width and the hadronic width, R^l. These parameters are obtained from a combined fit to the hadronic cross-section and leptonic cross-sections and asymmetries as function of the center-of-mass energy. The DELPHI Collaboration makes use of a program called ZFITTER[7] to do these fits. At first, a 9 parameters fit is performed to extract the leptonic asymmetries separately for electron, muons and taus. The combined 1990 and 1991 analysis gives :

$$A_{FB}^{0,e} = 0.013 \pm 0.013$$
$$A_{FB}^{0,\mu} = 0.015 \pm 0.008$$
$$A_{FB}^{0,\tau} = 0.033 \pm 0.010$$

The values are positive as expected in the electroweak theory and agree well with the lepton universality hypothesis. Therefore assuming universality, one can performe a 5 parameters fit and extract the leptonic Forward-Backward peak asymmetry, $A_{FB}^{0,l}$ to :

$$A_{FB}^{0,l} = 0.0202 \pm 0.0059$$

which show a 4 standard deviation positive Forward-Backward Leptonic peak asymmetry in agreement with the standard model prediction.

The leptonic Forward-Backward peak asymmetry being defined as :

$$A_{FB}^{0,l} = \frac{3\frac{g_v^2}{g_a^2}}{(1 + \frac{g_v^2}{g_a^2})^2} \qquad (3)$$

one can derive a value of the electroweak mixing angle from the asymmetry alone using the relation :

$$\frac{g_v^2}{g_a^2} = (1 - 4\sin^2\theta_W^{eff}(M_Z))^2$$

Table 1. Lepton Peak Asymmetries

	$A_{FB}^{0,e}$	$A_{FB}^{0,\mu}$	$A_{FB}^{0,\tau}$
ALEPH	0.014 ± 0.009	0.007 ± 0.007	0.027 ± 0.008
DELPHI	0.013 ± 0.013	0.015 ± 0.008	0.033 ± 0.010
L3	0.017 ± 0.014	0.031 ± 0.010	0.028 ± 0.016
OPAL	-0.002 ± 0.012	0.005 ± 0.008	0.016 ± 0.008

One obtains for the effective electroweak mixing angle :

$$\sin^2 \theta_W^{eff}(M_Z) = 0.2294 \pm 0.0031$$

which happens to be, according to recent calculations[8], numerically equal to the $\overline{MS}$ scheme value $\sin^2 \theta_W^{\overline{MS}}(M_Z)$. This measurement agrees very well with other LEP and $p\bar{p}$ as well as low energy measurements.

Table 2. Leptonic Peak Asymmetry

Exp.	$A_{FB}^{0,l}$
ALEPH	0.0154 ± 0.0048
DELPHI	0.0202 ± 0.0059
L3	0.0264 ± 0.0074
OPAL	0.0076 ± 0.0048
Average	0.0163 ± 0.0037

CONCLUSION

The LEP Collaborations have performed precise measurements of the Forward Backward leptonic peak asymmetries. The values obtained for electrons, muons and taus final states by the 4 experiments are given in table 1. All measurements are in good agreement and reached similar precision.

A more sensitive measurement is obtained mixing the three leptonic flavors. The values obtained by the 4 LEP Collaborations together with the weighted average are reported in table 2. The four measurements are in very good agreement. The uncertainty being still dominated by statistics, these measurements will profit very soon from the foreseen future increase of LEP luminosity.

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