AN EXPERIMENTAL INVESTIGATION OF RADIATIVE INTERFERENCE *

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The DELPHI collaboration has published an investigation of the effects of interference between initial state and final state radiation in the process $e^+e^-\to\mu^+\mu^-$, by studying the forward–backward asymmetry as a function of the acoplanarity angle between the muons.

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1. Introduction

The interference between initial state and final state radiation has been analysed using $e^+e^-\to\mu^+\mu^-$data collected by the DELPHI experiment [1] at LEP. In these proceedings a summary of the analysis is given. Further information can be found in [2–5] and [6].

2. Theoretical predictions

The predicted correction to the forward-backward asymmetry, $A_{\rm FB}$, due to radiative interference is defined as

$$\delta A_{\rm FB}^{\rm int} = A_{\rm FB}|_{\rm with\ interference} - A_{\rm FB}|_{\rm without\ interference}.$$

This correction is only calculated at $\mathcal{O}(\alpha)$ in QED. At $\sqrt{s}\sim M_Z$, for loose cuts on the phase space available to photons, $\delta A_{\rm FB}^{\rm int}$ is predicted to be smaller than 10^{-4}. The size of the correction can be enhanced by placing direct or indirect cuts on the phase space available to photons. The magnitude of the correction is predicted to depend on the width of the Z^0 resonance, Γ_Z.

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A space–time picture of the $e^+e^-\to\mu^+\mu^-$ reaction suggests why this is the case [2].

To make predictions which could be compared to measurements the event generator KORALZ [7] was used. It was found that studying A_{FB} as a function of the acoplanarity angle, ϕ_{acop}[1], between the muons was particularly sensitive to the presence of radiative interference. Figure 1 shows the prediction of KORALZ for A_{FB} as a function of ϕ_{acop} with and without $\mathcal{O}(\alpha)$ radiative interference. The rise at low ϕ_{acop} in the predictions is an artefact of a soft photon cut-off in the event generator: only events which contain a photon of energy have $\phi_{acop}\neq 0$. The sensitivity of the predictions to the soft photon cut-off was investigated by increasing the cut to $0.0050\sqrt{s}/2$. It was found that the predictions were relatively insensitive for $\phi_{acop}\geq 0.63°$.

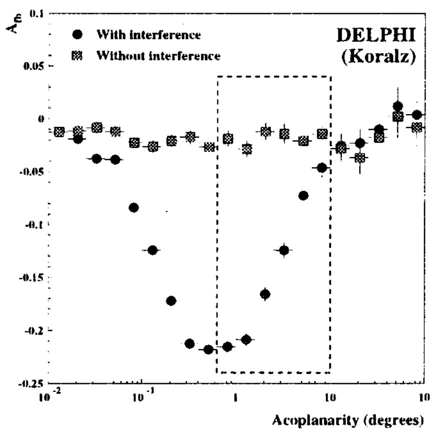

Fig. 1. Predictions for A_{FB} as a function of ϕ_{acop} with and without radiative interference.

3. Experimental procedure

Topological and kinematic cuts together with muon identification criteria were used to select a sample of $e^+e^-\to\mu^+\mu^-$ events from the data collected by the DELPHI experiment between 1992 and 94 in the polar angle acceptance, $|\cos\theta| \leq 0.94$. Events with $0.63°<\phi_{acop}<10.0°$were used to investigate radiative interference. The A_{FB} of these events was predicted to be sensitive to the interference, and the $\mathcal{O}(\alpha)$ predictions of KORALZ were not particularly sensitive to the soft photon cut-off in this interval. This

[1] $\phi_{acop}=\ |180°\text{-}\ |\phi_i - \phi_j||$, where $\phi_{i,j}$ are the azimuthal angles of two particles in spherical polar coordinates, with the axis of the coordinate system in the direction of the incoming e^-.

sample contained 7753 events from $\sim 100,000$ $e^+e^-\to\mu^+\mu^-$ events in total. The A_{FB} for the events was calculated by counting the number of events in the forward and backward scattering hemispheres, with respect to the direction of the incident e^-. A correction was applied for the efficiency of the detector. Events in which both muons were measured to have the same electric charge were rejected from the analysis. The measured asymmetry was corrected for background from misidentified $e^+e^-\to\tau^+\tau^-$ events and cosmic ray muons. The angular resolution of the detector was simulated by smearing the azimuthal angle of events generated by KORALZ. Systematic uncertainties from angular mismeasurement, charge misassignment and backgrounds were evaluated.

4. Comparisons

Three comparisons were made between the predictions of KORALZ including $\mathcal{O}(\alpha)$ radiative interference and the data. The first to show that the data was incompatible with the hypothesis that there was no radiative interference, the second to extract a value of Γ_Z and the third to estimate the size of higher order radiative interference corrections. In the first two comparisons the predictions of KORALZ included $\mathcal{O}(\alpha)$ non-interference corrections (*i.e.* pure initial and final state corrections) and $\mathcal{O}(\alpha)$ interference corrections. In the third comparison the full non-interference corrections of KORALZ were included.

The theoretical predictions, for $\Gamma_Z = 2.497$ GeV, with radiative interference and without were compared to the data for six bins of acoplanarity in the interval $0.63° < \phi_{\text{acop}} < 10.0°$ using χ^2 tests. Taking into account the sources of systematic error, without radiative interference the χ^2 was never smaller than 108 for 6 degrees of freedom. With radiative interference the χ^2 was never larger than 3.6 (6 d.o.f). The data was therefore incompatible with the hypothesis that there was no radiative interference, see figure 2. The agreeement between the $\mathcal{O}(\alpha)$ predictions and the data is particularly striking. Comparisons which included only initial or only final state radiation were also incompatible with the data.

Rather than fixing a value of Γ_Z as above, a χ^2 fit to Γ_Z gave

$$\Gamma_Z = 2.50 \pm 0.21(\text{stat.}) \pm 0.06(\text{syst.}),$$

assuming that the combined interference and non-interference higher order corrections could be neglected.

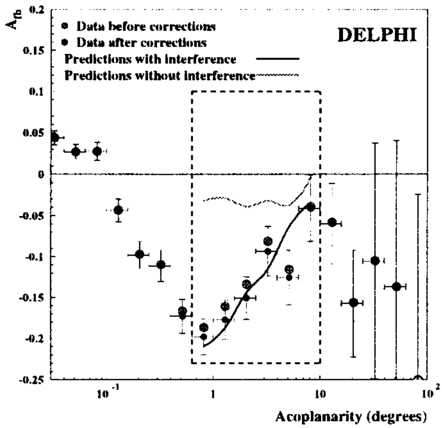

Fig. 2. $A_{\rm FB}$ as a function of $\phi_{\rm acop}$ with and without radiative interference compared to the data before and after corrections for backgrounds.

An estimate of the size of the higher order radiative interference corrections, was made. Theoretical predictions were made by adding the $\mathcal{O}(\alpha)$ radiative interference corrections to the predictions of KORALZ with all available non-interference QED corrections included, taking $\Gamma_Z = 2.497$ GeV. These were compared to the data. Attributing the difference between the predictions and the data shown in figure 3 to higher order interference corrections gave the ratio of higher order interference correction to those at $\mathcal{O}(\alpha)$. This ratio was consistent with being constant over the interval

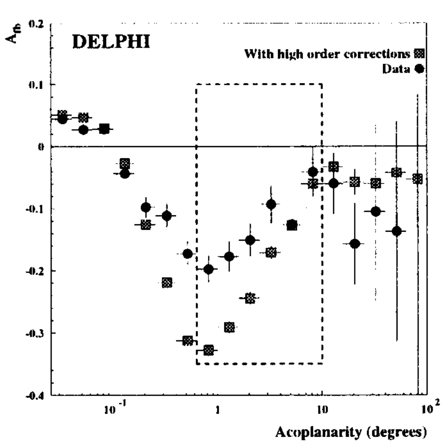

Fig. 3. $A_{\rm FB}$ in data compared to the predictions of KORALZ including higher order corrections as discussed in the text.

$0.63^\circ < \phi_{\rm acop} < 10.0^\circ$, with a value of

$$\left|\frac{\delta A_{\rm FB}^{\rm int}|_{\rm h.o.}}{\delta A_{\rm FB}^{\rm int}|_{\mathcal{O}(\alpha)}}\right| = 0.64 \pm 0.08({\rm stat.}) \pm 0.02({\rm syst.}).$$

5. Conclusions

The investigation presented here shows that the data is consistent with the $\mathcal{O}(\alpha)$ predictions of radiative interference. The possibility that there is no interference between initial and final state radiation is ruled out. The data was used to make a measurement of Γ_Z largely independent of traditional lineshape measurements which are used to constrain the Standard Model, presented elsewhere in these proceedings. The size of higher order interference corrections was also estimated assuming a fixed value of Γ_Z.

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