MEASUREMENT OF THE Z° COUPLINGS TO QUARKS
WITH THE OPAL DETECTOR AT LEP

A. JAWAHERY

Department of Physics, University of Maryland,
College Park, MD 20742, U.S.A.

Representing The OPAL Collaboration

Abstract

Based on an analysis of inclusive muons in hadronic decays of Z° detected with the OPAL detector at LEP, we present a measurement of the partial width and forward-backward asymmetry for the process Z° -> b̅b. We also report on a measurement of the partial widths for Z° q̅q and Z° -> q̅q, where q and q̅ stand for u-like and d-like quarks respectively, inferred from the measured rate for final state photon radiations in hadronic Z° decays.

1 Introduction

The recent data, from LEP and SLC have provided precision measurements of the Z° total width as well as the partial widths into lepton pairs and into hadrons. With these results the number of neutrino generations and the Z° coupling to leptons have been determined[1]. Determination of the Z° coupling to quarks provide additional test of the predictions of the standard model and an independent measurement of \sin^2 \theta_w. In particular a precision determination of the partial width for Z° -> b̅b has been proposed as an important test of the radiative corrections in the electroweak model[2]. In this article, I will report on a measurement of the partial width and the forward-backward asymmetry for the process Z° -> b̅b. The measurement is based on an analysis of inclusive muons in data recorded with the OPAL detector at LEP. We have also obtained a measurement of the Z° partial widths into u-like and into d-like quarks from a measurement of the rate for final state photon radiation in the reaction Z° -> q̅q. The data used in this analysis corresponds to 72,000 hadronic events at and around the Z° peak collected with the OPAL detector at LEP.

2 The OPAL detector

The OPAL detector has been described in detail in our recent publications[4].

Briefly, the main components are a central tracking system which consist of a jet chamber, a vertex detector, and a z-chamber positioned inside a solenoidal coil, surrounded by a time-of-flight counter array, a lead glass electromagnetic calorimeter and presampler, return yoke of the magnet instrumented with 9 layers of streamer tubes, forming the hadron calorimeter (HCAL), and the outer muon chambers. The outer muon chambers together with the hadron calorimeter form the muon identification system.

3 Event Selection and Identification of Inclusive Muons

The selection criteria for hadronic events is described in our recent publications[5]. Here we also impose several conditions on the quality and the number of charged tracks in the events, to suppress various background contributions.

Inclusive muons are identified by associating central detector tracks to track segments in the muon subdetectors. Track segments are straight lines reconstructed independently in each subdetector, from strip clusters in the HCAL layers, two dimensional hits in the muon barrel drift chambers and in the muon endcap streamer tubes. For this analysis we also require that tracks be in the angular range ∣\cos\theta∣ < 0.9.

The overall efficiency for the muon selection criteria is estimated from muon pair events, with cor-
rections applied to account for the effect of the presence of nearby hadronic activity in the multihadronic events. The overall efficiency is found to be 81.0 ± 2.5%. Hadronic contamination in the muon candidates is determined by using Monte Carlo simulated multihadronic events in the OPAL detector. We find an overall fake rate of 1.3% per track for muon candidates of momentum $p > 3.0$. The reliability of the Monte Carlo predictions for the background rate is checked by measuring the muon fake probability for pions selected using kinematically identified $K \rightarrow \nu \nu$ decays. We find a fake rate per pion of 0.9 ± 0.15% in data as compared with 0.85 ± 0.1% for Monte Carlo simulated events. We assign a systematic uncertainty of 25% to the Monte Carlo predictions of the background rate.

4 The Partial Width $T(Z^0 \rightarrow bb)$

Inclusive muons in hadronic decays of $Z^0$ originate from several sources as described in the following, (a) Semileptonic decays of $b$-hadrons where, $Z^0 \rightarrow 66$, $6 \rightarrow \nu \nu$ (b) the cascade process where $Z^0 \rightarrow 66$, followed by the decay chain, $6 \rightarrow c \rightarrow$ (c) semileptonic decays of charmed hadrons where $Z^0 \rightarrow cc$, $c \rightarrow$ and (d) hadronic fake contamination which includes muons from decays of light hadrons. Muons from $b$ quark decays are distinguished by their characteristic distributions in momentum and transverse momentum, pr, relative to the direction of the parent hadron. The hard fragmentation of the $b$ quark and its large mass gives rise to hard distributions in momentum and transverse momentum for muons. Monte Carlo simulations show that the charm and cascade decays yield considerably softer distributions in both variables.

We identify 7029 events containing a muon candidate track. In each event charged tracks are grouped into jets using the JADE jet finding algorithm\cite{1}. The thrust axis of the jet containing the muon candidate track is used as an estimate of the direction of the parent hadron. The transverse momentum, pr, of the muon candidate is then calculated with respect to this axis. In order to insure that events are well contained we require $\cos \theta_j < 0.8$.

The distribution in pr for muon candidates with momenta greater than 4.5 GeV/c is shown in Fig. 1a. This momentum cut was determined from Monte Carlo studies to suppress the contributions of the charm and cascade reactions. Fig. 1b shows the momentum distribution of the muon candidates. Overplotted in Figs. 1a and 1b are the Monte Carlo predicted distributions for the inclusive muons assuming standard model values for the partial widths for $Z^0 \rightarrow 66$ and $Z^0 \rightarrow cc$. The LUND shower Monte Carlo JETSET7.2 \cite{7} with the Peterson parametrization for the fragmentation function was used for the simulation of heavy quark events.

\begin{figure}[h]
\centering
\includegraphics[width=0.5\textwidth]{fig1.png}
\caption{(a) $PT$ distribution of muon candidates with $p > 4.5$ GeV/c. (b) Momentum distribution of muon candidates with $pr > 1.5$ GeV/c.}
\end{figure}

In order to determine the number of muons from $b$ decays we make use of the high $PT$ region, $PT > 1.0$ GeV/c where the contributions from the charm and cascade reactions are further suppressed. The fraction of the $b$ quark events is de-
using,

\[
\chi^2 \sim W \left( I_{\mu} \right) 
\]

where \( W \) is the total \( Z^0 \) hadronic width; \( I_{\mu}(i) \), \( N_B^P \), and \( \Delta T^\alpha \) are the observed number of muons, the predicted number of muons from charm decays and the number of hadronic fakes, respectively. \( N(Z^0) \) is the total number of \( Z^0 \) events, and \( i \) accounts for the muon identification efficiency, event selection and kinematic acceptances. The last term in the denominator accounts for the contribution of the cascade component, where \( B(b \rightarrow c \rightarrow f \bar{f})/B(b \rightarrow fi) \) and \( f_\mu \) is the ratio of the kinematic acceptances for muons from direct \( b \) quark decays and cascades. We use \( f_\mu = 1.05 \) as reported in reference [8] and and \( f_\mu = 0.106 \) estimated from Monte Carlo studies. The charm contribution is estimated by using the prediction of the standard model for \( \Gamma(Z^0 \rightarrow cc)/\Gamma(Z^0) \approx 0.17 \) [2] and \( < B(c \rightarrow fi) > = 0.10 \), obtained from an average of the PEP/PETRA measurements.

A free parameter of the Monte Carlo predictions is the fragmentation parameter \( \Delta \). By comparing the measured mean momentum of the muon candidates with \( PT > 1.5 \) GeV/c with that predicted by the Monte Carlo simulations we determine \( X, > 2 < P_r, > /s = 0.70 \pm 0.025 \), where \( PB \) is the mean momentum of the \( B \) hadron. This corresponds to \( = 0.0038 \) ± 0.0025.

We find, \( (r(Z^0 \rightarrow \mu\mu))/T(\mu\mu) \times B(\mu\mu) = 0.0206 \pm 0.0025 \). The errors are statistical and systematic, respectively. The systematic error accounts for the effect of uncertainties in the normalization of hadronic contamination, the predictions of the cascade and the charm components and the fragmentation parameters. The hadronic fake uncertainty is by far the largest contributor to the systematic error. Varying the charm and cascade components by 50% results in less than 3% change in the result.

In order to extract the value of the hadronic branching ratio \( B(Z^0 \rightarrow \mu\mu) = T(Z^0 \rightarrow \mu\mu) = T(Z^0 \rightarrow \mu\mu) = T(Z^0 \rightarrow \mu\mu) \) from the above measurement we need to know the average semileptonic branching ratio \( < B(b \rightarrow \mu X) > \). The current measurements are from the experiments at the \( T(45) \) and from the PEP and PETRA experiments at center of mass energies around 30 GeV. At LEP energies the composition of \( b \)-hadron may be different from those at LEP energies. This combined with a possible difference in the lifetime of the various \( b \)-hadron species could result in a different value for the average semileptonic branching ratio. However, in the absence of a direct measurement at LEP and in order to compare our results with the standard model, we use the measurement at the \( T(45) \) of \( B(b \rightarrow \tau X) = 10.2 \pm 0.2 \pm 0.7 \) [8]. This gives, \( B(Z^0 \rightarrow \mu\mu) = 0.204 \pm 0.008 \pm 0.025 \), consistent with the standard model prediction of \( B(Z^0 \rightarrow \mu\mu) = 0.217 \). Using the measured hadronic width \( T(45) = 1778 \pm 26 \) [1], we find \( r(Z^0 \rightarrow \mu\mu) = 363 \pm 47 \) MeV.

### 5 The Forward Backward Asymmetry

The angular distribution of the reaction \( e^+e^- \rightarrow \mu^+\mu^- \)

\[
d^2d\alpha/d\cos\theta \propto (1 + \cos^2\theta - 2xZ\Delta(\cos\theta)) (1)
\]

where \( \theta \) is the angle between the outgoing \( b \) quark and the incoming electron beam, and \( \Delta A^c \) gives the the forward-backward asymmetry of the reaction.

Since \( \Delta A^c \) is dependent on the center of mass energy, we restrict this analysis to the sample collected at the \( Z^0 \) peak, corresponding to 50,000 events. The off peak data is statistically too small to yield a meaningful measurement at this point. In this analysis, we use the thrust axis of the event for estimating the angle \( \theta \). The flavor of the \( b \) quark is tagged using the sign of the electric charge of the muon candidate, \( Q^0 \). In Fig. 2 is shown the distribution in \( -Q^0\cos\theta \) for the muon candidates in the kinematic region \( p > 4.5 \) GeV/c and \( p > 10 \) GeV/c, after subtraction of the background effects and correction for the \( \cos\theta \) dependence of the identification efficiency. Fitting this distribution to the equation (1) and correcting for the angular acceptance of the analysis \( |\cos\theta| < 0.8 \), gives \( i4\Delta(0) = 0.02 \pm 0.08 \).

In order to compare with the standard model predictions, the observed forward-backward \( A^c(0) \) must be corrected for the effect of, \( B^0\bar{B}^0 \) mixing. Mixing, where \( B^0 \rightarrow B^0 \) and \( B^0 \rightarrow B^- \), has the effect of reducing the true asymmetry by a factor of \( (1-2x) \), where \( x \) is the average mixing rate defined as, \( x = (B^0\bar{B}^0 \mu X)/(B^0 \rightarrow B^- \rightarrow ) \). The mixing for the \( \mu \) mesons have been measured by the CLEO and ARGUS collaborations to be \( x = 0.17 \pm 0.05 \) [9]. At LEP energies however, the
effective mixing rate is an average of mixing in the $B_d$ and $B_s$ meson. Given the large mixing in the $B_j$ system, the mixing in the $B$ mesons is expected to be maximal. By assuming a production ratio of $35\%J$, $35\%S$, $15\%S$, and $15\%J$, we expect the average mixing rate for the $b$-hadrons to be $X = 0.130$. This gives $A' = 0.027 \pm 0.11$, consistent with the standard model prediction at the $Z^0$ peak of 0.10.

Final state radiation events are identified by selecting events containing an isolated, energetic photon in the detector. The photon candidate is required to have an energy of at least 10 GeV, to have a transverse momentum $p_T$, calculated with respect to the event thrust axis, of greater than 5 GeV, and be isolated from any charged track and electromagnetic cluster within a cone of half angle 20 degrees. Cuts are also applied on the transverse profile of the photon candidates to reduce backgrounds from neutral hadrons and $\gamma\gamma$'s.

In 50,000 hadronic decays used in this analysis, we find a total of 78.0 candidate high energy, isolated photon events. The main background components are from fragmentation debris and initial state radiation. Using Monte Carlo studies we estimate a contribution of $8.0 \pm 5.0$ events from the fragmentation background and $5.1 \pm 1.4$ from initial state radiation. The remaining $61.9 \pm 10.2$ events are consistent with the predictions for the yield of final state photon radiation of $61 \pm 2.6$ events.

Using the measured yield for photons and $T_{had} = 1778 \pm 26$ MeV[1], we find $F(Z^- \rightarrow uxt) = 330 \pm 99$ MeV, and $T(Z^0 \rightarrow d \bar{d}) = 369 \pm 67$ MeV. The latter is consistent with our direct measurement of the rate for $Z^0 \rightarrow 66$.

7 References

Q. F. Couchot (LALf Orsay): What is the size of systematics on the potential width measurements to like and unlike quarks using $qgf$ final states?

A. N. Jawahery: Presently, the errors are dominated by statistics. The systematics come mainly from the background modelling (photons arising from hadronic fragmentation).