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Determination of the Michel Parameters ρ, ξ, and δ in τ-Lepton Decays with $\tau \to \rho\nu$ Tags

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Abstract

Using the ARGUS detector at the e^+e^- storage ring DORIS II, we have measured the Michel parameters ρ, ξ, and $\xi\delta$ for $\tau^\pm \to l^\pm\nu\bar{\nu}$ decays in τ-pair events produced at center of mass energies in the region of the Υ resonances. Using $\tau^\mp \to \rho^\mp\nu$ as spin analyzing tags, we find $\rho_e = 0.68 \pm 0.04 \pm 0.08$, $\xi_e = 1.12 \pm 0.20 \pm 0.09$, $\xi\delta_e = 0.57 \pm 0.14 \pm 0.07$, $\rho_\mu = 0.69 \pm 0.06 \pm 0.08$, $\xi_\mu = 1.25 \pm 0.27 \pm 0.14$ and $\xi\delta_\mu = 0.72 \pm 0.18 \pm 0.10$. In addition, we report the combined ARGUS results on ρ, ξ, and $\xi\delta$ using this work und previous measurements.

1 Introduction

A general ansatz to describe purely leptonic τ decays is the well-known formalism by Michel [1]. This formalism includes extensions of the Standard Model such as scalar and tensor coupling to left- or righthanded leptons. The derived differential width in the τ rest frame neglecting radiative corrections and terms proportional to m_l^2/m_τ^2 is

$$\begin{aligned} \frac{d^2\Gamma(\tau^\pm \to l^\pm\nu\bar{\nu})}{d\Omega\, dx} &= \frac{G_F^2 m_\tau^5}{192\pi^4} x^2 \cdot \left[3(1-x) + \frac{2}{3}\rho(4x-3) + 6\eta\frac{m_l}{m_\tau}\frac{1-x}{x}\right. \\ &\qquad \left.\pm P_\tau \cos\vartheta \left(\xi(1-x) + \frac{2}{3}\xi\delta(4x-3)\right)\right], \end{aligned} \tag{1}$$

where $x = 2E_l/m_\tau$ is the scaled energy of the charged lepton, P_τ the τ polarization and ϑ the angle between the polarization vector and the charged lepton momentum. Equation (1) is valid for vanishing neutrino masses. The Standard Model with a pure $V-A$ interaction predicts $\rho = 3/4$, $\eta = 0$, $\xi = 1$, and $\xi\delta = 3/4$.
Up to now, measurements of the Michel parameters ξ and $\xi\delta$ have been made by ARGUS, ALEPH, L3, SLD and CLEO [2, 3, 4]. In this paper, we present measurements of ρ, ξ, and $\xi\delta$ with a new tagging method [5] separately for electrons and muons. The results are obtained using tau pairs produced in $e^+e^- \to \tau^+\tau^- \to (\rho^\pm\nu_\tau)(l^\mp\nu_l\nu_\tau)$. The decay $\tau^\pm \to \rho^\pm\nu_\tau$ is used as a tag, i.e. for the event selection and as τ spin analyzer. They are statistically independent of previous ARGUS measurements using lepton tags [2] and a_1-meson tags in its decay into three charged pions [3].

2 Method of the Measurement

As can be seen from Eq. (1), the measurement of ξ and $\xi\delta$ requires the knowledge of the τ polarization. At DORIS energies, the average polarization of τ leptons is zero, hence no information on ξ and $\xi\delta$ can be extracted from the analysis of single τ-decays. Only ρ and η are accessible from the analysis of the momentum spectrum. However, τ-leptons are produced in pairs resulting in a spin-spin-correlation. At $\sqrt{s} = 10$ GeV, τ pairs are produced via a virtual photon and both τ spins are predominantly parallel due to the vector coupling, with only a small probability of $(1-\beta_\tau)/2 \approx m_\tau^2/s \approx 3\%$ for being antiparallel. In the analysis described here [6], we use the decay $\tau^\pm \to \rho^\pm\nu_\tau$ in order to obtain information on the τ-spin orientation. The basic method is similar to the one used in the ARGUS analysis with $\tau^\pm \to a_1^\pm\nu_\tau$ as spin analyzer [3], and is described in more detail there.

The performance of various analysis methods has been studied using a Monte Carlo simulation. Tau pair events including radiative photons were produced by the KoralB/Tauola generator [7]. These events passed the ARGUS detector simulation Simarg [8] and the reconstuction program Arg13 [9], and were finally submitted to the same selection procedure as the data, which is described in section 3 below.

The parallel orientation of the two τ spins is used to relate the spin of the tau decaying into $l^\pm\nu\bar{\nu}$ to the spin of the tau decaying into $\rho^\pm\nu_\tau$. The spin in the latter decay is related to the $\rho^\pm$ direction because of parity violation with a neutrino helicity $h_{\nu_\tau} = -1$ as supported by measurements of the sign in $\tau^\pm \to a_1^\pm \nu_\tau$ decays [3] and the modulus in $\tau^+\tau^- \to (\rho^+\bar{\nu}_\tau)(\rho^-\nu_\tau)$ events [10]. The ρ-meson can be produced in two helicity states, $h = 0$ and $h = +1$. The state with $h = 0$ dominates by a factor of $(1+\beta^*)/(1-\beta^*) = m_\tau^2/m_\rho^2 \approx 5.3$, where β^* is the velocity of the τ in the ρ rest frame. Therefore, its τ-spin ρ-momentum correlation also dominates, resulting in correlations between the momenta p_l of the lepton and p_ρ of the ρ-meson of the same tau pair event. In a Monte Carlo sample with the Standard Model value $\xi = 1$ on the lepton side and $h_{\nu_\tau} = -1$ on the ρ side, we obtain a correlation coefficent $r = \mathrm{Cov}(p_l, p_\rho)/(\sigma(p_l)\cdot\sigma(p_\rho)) = (-6.6 \pm 0.4)\%$ whereas parity conservation $(h_{\nu_\tau}\cdot\xi = 0)$ leads to $r = (-2.2 \pm 0.4)\%$ which is non-zero because of radiation in the initial e^+e^- state. A measurement of r is, therefore, a measurement of $h_{\nu_\tau}\cdot\xi$.

Additional information on ξ and $\xi\delta$ is obtained by (i) using the momentum-momentum correlations of the vectors instead of just their absolute values, and (ii) including information on the ρ-meson helicity, since the suppressed $h = +1$ state results in the opposite correlation compared to the $h = 0$ state. A discrimination between both states is possible via the decay angle for $\rho^\pm \to \pi^\pm\pi^0$, since the distributions for both helicities are different.

Maximal information on ρ, ξ, and $\xi\delta$ is obtained by a single entry maximum likelihood fit using the selected $(l^\pm\nu\bar{\nu})(\pi^\mp\pi^0\nu)$ events with all their 10 measured quantities, the e^+e^- cms energy $\sqrt{s}$, and the momentum vectors of the three observed particles, $\vec{p}(l^\mp)$, $\vec{p}(\pi^\pm)$, and $\vec{p}(\pi^0)$. The matrix element for the differential cross section $e^+e^- \to \tau^+\tau^- \to (l^\pm\nu\bar{\nu})(\pi^\mp\pi^0\nu)$ can be written as

$$|\mathcal{M}|^2 = H\,A\,[L_1 + \rho L_2 + \eta L_3] + h_{\nu_\tau} H'_\alpha C^{\alpha\beta}[\xi L'_{1\beta} + \xi\delta L'_{2\beta}], \tag{2}$$

where the first part is the spin-averaged contribution and the second part describes the $\tau^+\tau^-$-spin correlations. H and H' describe the decays $\tau^\pm \to \rho^\pm\nu$ and $\rho^\pm \to \pi^\pm\pi^0$. L_1, L_2, L_3, L'_1, and L'_2 describe $\tau^\pm \to l^\pm\nu\bar{\nu}$ decays in the most general way with zero neutrino masses. A is the spin-averaged matrix element for τ-pair production and C the spin-spin correlation matrix $(\alpha, \beta = 1\ldots4)$. $|\mathcal{M}|^2$ includes radiative corrections which are treated in a factorizable way.

The likelihood function to be maximized contains three variables $\theta = (\rho, \xi, \xi\delta)$ and $N\cdot 10$ measured quantities $m_i = (s_i, \vec{p}_i(l^\mp), \vec{p}_i(\pi^\pm), \vec{p}_i(\pi^0))$, where $i = 1\ldots N$, and N is the number of selected events,

$$L(\theta) = \prod_{i=1}^{N} L_i(\theta|m_i) = \prod_{i=1}^{N} f(m_i|\theta). \tag{3}$$

Since data were taken at different cms energies, the probability density f is taken as a function of scaled momenta $p_i/\sqrt{s}$. It is the projection of the full density $f(m,u|\theta)$ where u denotes the unobserved kinematical quantities which include neutrino momenta as well as photon momenta of initial and final state radiation. Furthermore, the observables m_i are obtained as a convolution of the true values t_i of the same kinematical quantities and the detector resolution function $\mathcal{R}$. The final density is given by

$$f(m|\theta) = \eta(m)\cdot\mathcal{N}(\theta)\int|\mathcal{M}(t,u|\theta)|^2\cdot\mathcal{P}(t,u)\cdot\mathcal{R}(m|t)\,dt\,du, \tag{4}$$

where $\mathcal{P}$ is the phase space distribution, $\eta(m)$ is the detector acceptance, and $\mathcal{N}(\theta)$ is the normalization factor given by

$$\mathcal{N}(\theta)\cdot\int\eta(m)\cdot|\mathcal{M}(t,u|\theta)|^2\cdot\mathcal{P}(t,u)\cdot\mathcal{R}(m|t)\,dt\,du\,dm = 1. \tag{5}$$

Radiative corrections including initial state radiation and internal bremsstrahlung in $\tau \to e\nu\bar{\nu}$ are included in $\mathcal{M}(t,u|\theta)$. External bremsstrahlung of the electron is included in the resolution function $\mathcal{R}(m|t)$. For the application as a likelihood function, $f(m|\theta)$ is rewritten in a more appropriate form. The factorizing radiative corrections allow to write $|\mathcal{M}(t,u|\theta)|^2 \cdot \mathcal{P}(t,u) = \sum_{j=0}^{3} \theta_j\, F_j(t,u)$ with $\theta_0 \equiv 1$. The likelihood of a single event i is then

$$L_i(\theta|m_i) = \frac{\sum\limits_{j=0}^{3} \theta_j \int F_j(t,u)\, \mathcal{R}(m_i|t)\, dt\, du}{\sum\limits_{j=0}^{3} \theta_j \int \eta(m)\, F_j(t,u)\, \mathcal{R}(m|t)\, dt\, du\, dm}, \tag{6}$$

where the acceptance factor has been omitted in the numerator since it depends only on the observed quantities m. The integration over the neutrino momenta, which are part of the unobserved quantities u, is performed to a large extent analytically, leaving only an uncertainty in the relative angular orientation of the two tau leptons. The integration over t and the remaining seven unobserved variables u is done by a Monte Carlo method in which for each event 450 kinematical configurations are tested for compatibility with the observed set of observables m_i. The seven u variables in the Monte Carlo integration are the momentum vector of the initial state photon, the τ orientation angle, and the momentum vector of the photon in $\tau \to e\nu\bar{\nu}\gamma_2$. A configuration is "successful" if the set of (m_i, t, u) is compatible with the kinematics of $e^+e^- \to \gamma_1(\pi^\pm\pi^0\nu)(l^\mp\nu\bar{\nu}\gamma_2)$ events, i.e. if the undetermined neutrino momenta can have physical values.

These 450 tries lead to n_{hit} successful matches for each event, and the distribution of n_{hit} is shown in figure 1. The high value of $\langle n_{hit}\rangle$ shows the effectiveness of the numerical integration chosen, and n_{hit} is large enough for most events to compute $L_i(\theta|m_i)$ with sufficient precision. Events with $n_{hit} < 25$ are rejected in the data selection. The good agreement between $N(n_{hit})$ for selected data and for accepted Monte Carlo events supports the validity of the assumptions used.

The integral in the denominator of Eq. (6), for each set of parameters θ, is also obtained with the help of a Monte Carlo integration which determines the four separate integrals used in the sum.

The validity of the method has been extensively tested by using Monte Carlo events as pseudo data for determining the parameter ρ, ξ, and $\xi\delta$. Even using pseudo data samples 10 times larger than the real data samples, we did not detect any significant biases in the determined parameter values.

3 Data Selection

The measurements presented here were performed with the ARGUS detector at the e^+e^--storage ring DORIS II. The detector and its trigger requirements are described elsewhere [9]. The data sample used was collected between 1983 and 1989 in the center of mass energy region of the Υ resonances. The integrated luminosity used in this analysis is 289 pb^{-1} corresponding to 265 000 τ pairs produced.

Event selection starts with requiring two oppositely charged tracks forming a vertex in the interaction region and an opening angle larger than 80° at the vertex point. Each track must have a transverse momentum above 150 MeV/c and point into the barrel region. We demand one particle to be identified as a lepton. The other track has to be accompagnied by one or two neutral clusters in its hemisphere with a minimum angle of 10° to the track. A neutral cluster is defined as energy deposition above 100 MeV in the calorimeter. No additional cluster is allowed, neither in the lepton hemisphere nor in the 10° cone around the $\pi^\pm$ candidate. In the single cluster case, accounting for photons from the π^0 decay merging into one cluster, we demand a minimum energy deposition of 1 GeV. In the two cluster case, both photons are combined to form a π^0. The two photon system must have an invariant mass within 100 MeV of the nominal π^0 mass and $\chi^2 \leq 9$ for the π^0 mass hypothesis. The lepton identification was done by a likelihood method using specific energy loss, time of flight, amount and lateral spread of energy deposition in the calorimeter and hits in the muon chambers. More details on this likelihood method are found in refs. [11, 12]. To ensure a good lepton identification, a momentum above 0.8 GeV/c for electrons and above 1.1 GeV/c for muons

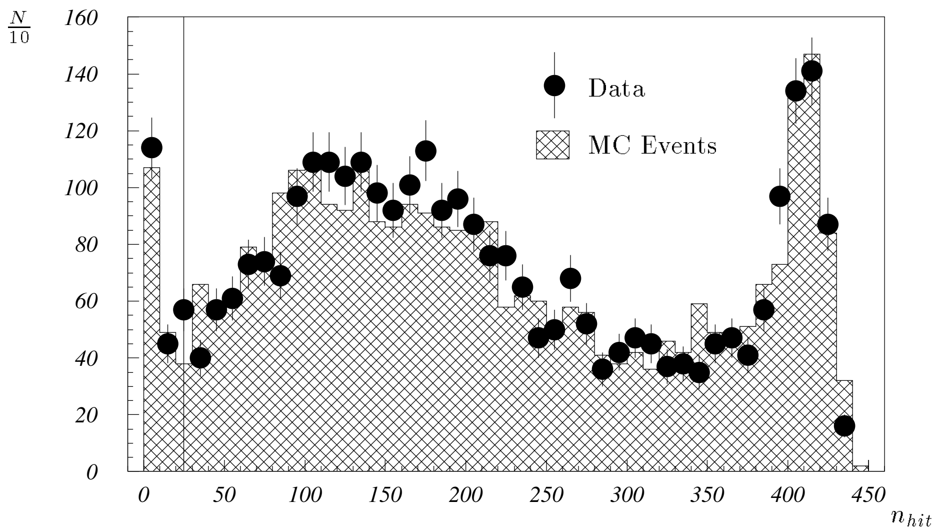

Figure 1: Number of matching $(e^{\pm}\nu\bar{\nu})(\pi^{\mp}\pi^{0}\nu)$ configurations per event. The points with error bars represent the data. The hatched histogram shows the expectation from the KoralB/Tauola Monte Carlo for the decay $(e^{\pm}\nu\bar{\nu})(\pi^{\mp}\pi^{0}\nu)$ and other contributing τ channels. The solid line marks $n_{hit} = 25$, the minimum number for selected events. Events with a hard initial state photon lead mostly to $n_{hit} < 25$.

as well as an electron or muon likelihood higher than 0.8 is required. The charged pion candidate is required to have a pion likelihood above 0.6 using specific energy loss in the drift chamber and time-of-flight [9].
To reject background, we apply the following three additional event cuts. The invariant mass $m_{\pi^{\pm}\pi^{0}}$ has to be smaller than the τ lepton mass. This cut suppresses $q\bar{q}$-events. The angle between the lepton momentum $\vec{p}_l$ and the ρ-meson momentum $\vec{p}_\rho$ is not larger than $176°$, which rejects radiative Bhabha and μ pair events. The relation $f_c \cdot (m^2_{miss}/s - f_o)^4 < p_t/\sqrt{s}$ with $f_c = 5$ and $f_o = 0.45$ for the single cluster case, and $f_c = 3$ and $f_o = 0.4$ for the two cluster case has to be fulfilled. In here, the missing mass m_{miss} uses only charged tracks and the vector sum of transverse momenta p_t uses charged and neutral particles. This cut removes $\gamma\gamma$ and radiative Bhabha events.

After these cuts, a data sample of 3176 candidates for $(e^{\pm}\nu\bar{\nu})(\pi^{\mp}\pi^{0}\nu)$ and 2099 candidates for $(\mu^{\pm}\nu\bar{\nu})(\pi^{\mp}\pi^{0}\nu)$ remains. As seen in figure 2, a good agreement for lepton momenta is found comparing data and Monte Carlo events. However, the data selection criteria do not allow to remove all background sources. The selected sample still contains 10% $(\pi^{\pm}\pi^{0}\pi^{0}\nu)(l^{\mp}\nu\bar{\nu})$ decays, 3.5% $(K^{\pm}\pi^{0}\nu)(l^{\mp}\nu\bar{\nu})$ decays, $\approx 1\%$ misidentified leptons and around 2% background from non-τ channels, as determined by Monte Carlo. Figure 3 shows the $\pi^{\pm}\pi^{0}$ invariant mass distribution with good agreement between data and Monte Carlo events. Tau decay fractions for the background estimation are taken from ref. [13].

4 Data Analysis

A first information on ξ is obtained from the p_l-p_ρ correlation coefficient. The selected data sample has $r = -(6.1 \pm 1.2)\%$ leading to $\xi = 0.89 \pm 0.27$ without background corrections. The finally used likelihood function in Eq. (6) can conveniently include background from other semihadronic τ

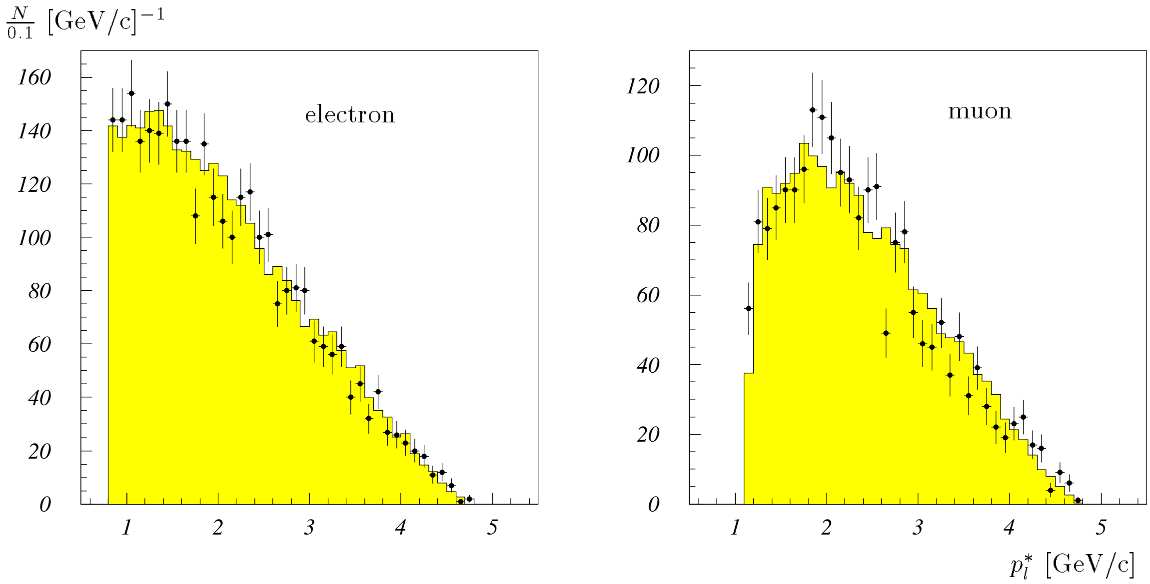

Figure 2: Spectra of scaled momentum $p_l^* = p_l \cdot 10\ \text{GeV}/\sqrt{s}$ for leptons. Data are shown as dots with error bars and accepted Monte Carlo events, generated with $\rho = 3/4$, as grey shaded area.

decays in the data sample and from lepton misidentification. The modified likelihood function is

$$L_i^* = (1 - \lambda_{a_1} - \lambda_{K^*}) \left((1 - \lambda_f) \cdot L_i + \lambda_f \cdot L_i^{fake} \right) + \lambda_{a_1} \cdot L_{i,(\pi^\pm\pi^0\pi^0)} + \lambda_{K^*} \cdot L_{i,(K^\pm\pi^0)}, \qquad (7)$$

where λ_{a_1} is the fraction of the $(\pi^\pm\pi^0\pi^0)$-tags, λ_{K^*} is the fraction of the $(K^\pm\pi^0)$-tags and λ_f considers pions misidentified as leptons. Table 1 gives the used values for λ_f, λ_{a_1}, and λ_{K^*} as determined by Monte Carlo simulation. The additional likelihood functions $L_{i,k}$ for $k = (\pi^\pm\pi^0\pi^0\nu)(l^\mp\nu\bar{\nu})$ and $(K^\pm\pi^0\nu)(l^\mp\nu\bar{\nu})$ are determined by the same technique as L_i for $(\pi^\pm\pi^0\nu)(l^\mp\nu\bar{\nu})$. L_i^{fake} is the contribution to the likelihood function for misidentified leptons. Non-τ background has not been considered in the likelihood function, because its contribution is small and is included in the systematic error studies, see Table 2.

	$(\pi^\pm\pi^0\nu)(e^\mp\nu\bar{\nu})$	$(\pi^\pm\pi^0\nu)(\mu^\mp\nu\bar{\nu})$
λ_f	$(0.8 \pm 0.2)\%$	$(1.6 \pm 0.2)\%$
λ_{a_1}	$(10.1 \pm {}^{2.8}_{0.6})\%$	$(10.5 \pm {}^{2.9}_{0.6})\%$
λ_{K^*}	$(3.7 \pm 1.0)\%$	$(3.4 \pm 1.0)\%$

Table 1: Monte Carlo determined background levels as used in the likelihood function Eq. (4). The asymmetric errors are due to the systematic deviation of ARGUS branching fractions from the world average used to calculate these factors.

The maximum likelihood fits lead to results and statistical errors for the Michel parameters as shown in Table 3 below. Figures 1 and 4 illustrate the quality of the fit and the validity of the

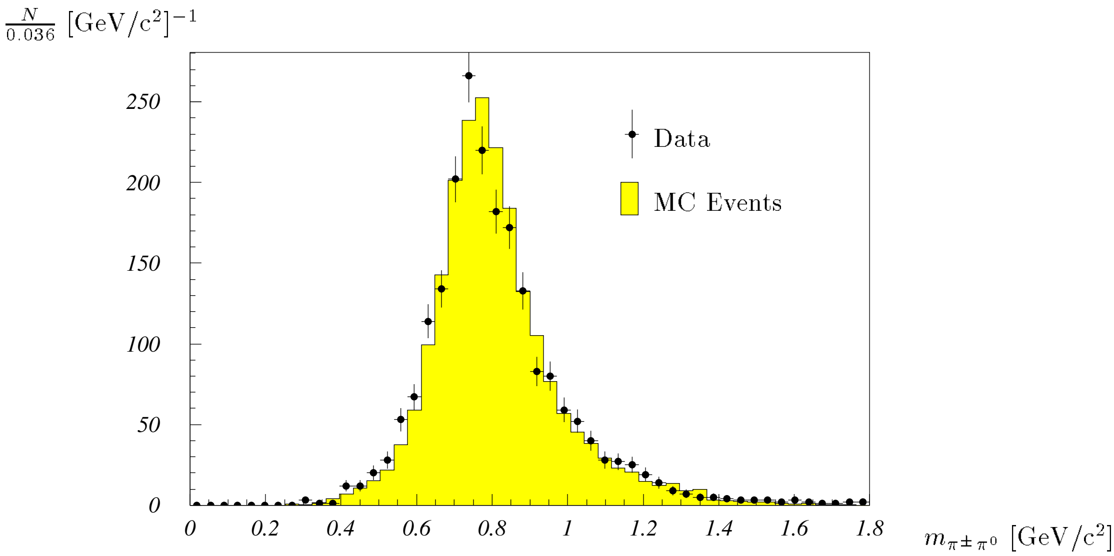

Figure 3: Invariant mass distribution $m_{\pi^\pm\pi^0}$ for the $(\pi^\pm\pi^0\bar{\nu})(\mu^\mp\nu\bar{\nu})$ signature. The Monte Carlo spectrum includes background from other tau decays.

assumptions made for the determination of the kinematical quantities used to calculate the matrix elements.

Figure 1 shows the distribution of successful tries to find a matching initial state to the observed final state comparing data and Monte Carlo events. Figure 4 shows the agreement in $-2\ln L_i^*$ for the fit to the data compared to the fit to Monte Carlo events generated with Standard Model parameters described with Eq. (7). Deviations are found at large values of $-2\cdot\ln L_i^*$ if we neglect other τ sources and misidentified leptons.

The systematic errors are summarized in Table 2 including limited Monte Carlo statistics, trigger efficiencies, branching fractions, particle identification efficiencies, lepton misidentification, the influence of background from non-τ physics and the center of mass energy dependence of the matrix element description. The total error is obtained as a quadratic sum of all errors in Table 2.

5 Results and Conclusions

The Michel parameters as found by the maximum likelihood analysis described above, and including systematic errors, are given in Table 3.

The results are in agreement with previous measurements and the Standard Model predictions. In addition, the errors are comparable to the errors of previous measurements. The results with ρ constrained to the world average of $\rho = 0.742 \pm 0.027$ [14] are very close to the unconstrained ones; they are given in Table 4 for completeness.

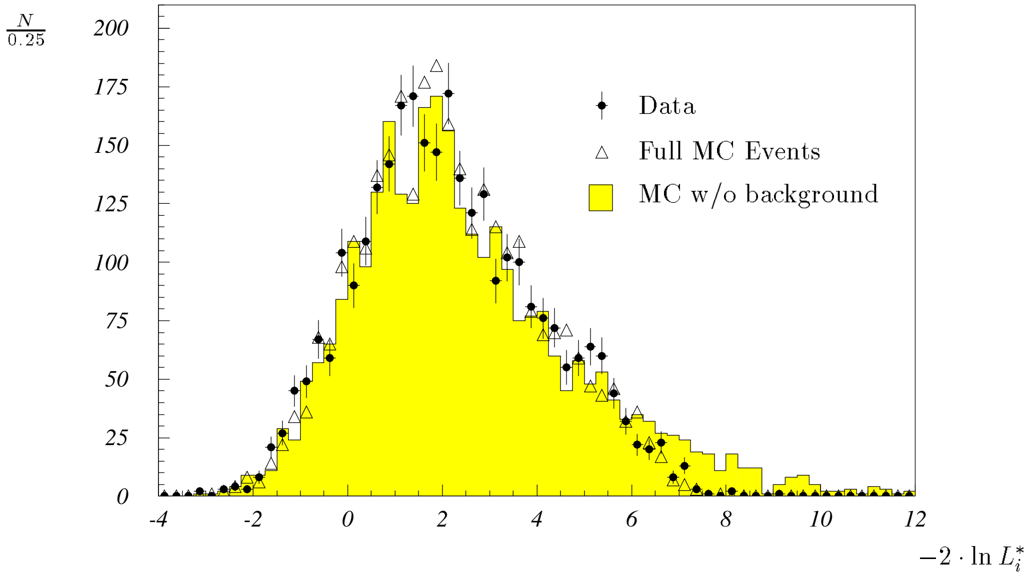

Figure 4: The contribution of single events to $-2\ln L_i^*$ for events with $n_{hit} \geq 25$. The points with error bars represent the data. The open triangles show the expectation from the KoralB/Tauola Monte Carlo for the decay $(e^{\pm}\nu\bar{\nu})(\pi^{\mp}\pi^0\nu)$ and other contributing τ channels. The shaded area are Monte Carlo events without consideration of any background from other τ decay channels or lepton misidentification.

All quoted values for ξ and $\xi\delta$ assume a τ neutrino helicity $h_{\nu_\tau} = -1$. Using the experimental average $h_{\nu_\tau} = -1.011 \pm 0.027$ [14] would not change the results.
Assuming lepton universality and combining the results of this analysis in Table 3 with previous ARGUS measurements [15] of ρ, ξ, and $\xi\delta$, we obtain

$$\begin{aligned} \rho &= 0.731 \pm 0.031 \\ \xi &= 1.03 \pm 0.11 \\ \xi\delta &= 0.63 \pm 0.09 \end{aligned}$$

where statistical and systematical errors are combined in quadrature. Correlations in the systematic errors of different measurements are taken into account. The covariance matrix is given by

	ρ	ξ	$\xi\delta$
ρ	$9.54 \cdot 10^{-4}$		
ξ	$-2.30 \cdot 10^{-5}$	$1.25 \cdot 10^{-2}$	
$\xi\delta$	$-7.88 \cdot 10^{-5}$	$1.03 \cdot 10^{-3}$	$7.84 \cdot 10^{-3}$

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References

systematic error source	$(e^{\pm}\nu\bar{\nu})(\pi^{\mp}\pi^0\nu)$			$(\mu^{\pm}\nu\bar{\nu})(\pi^{\mp}\pi^0\nu)$		
	$\Delta(\rho)$	$\Delta(\xi)$	$\Delta(\xi\delta)$	$\Delta(\rho)$	$\Delta(\xi)$	$\Delta(\xi\delta)$
Monte Carlo statistics	±0.01	±0.05	±0.03	±0.02	±0.07	±0.04
Trigger efficiency	±0.01	±0.01	±0.01	≈ 0	±0.07	±0.01
Branching fractions	$^{+0.020}_{-0.003}$	$^{+0.041}_{-0.007}$	$^{+0.024}_{-0.004}$	$^{+0.026}_{-0.004}$	$^{+0.044}_{-0.007}$	$^{+0.057}_{-0.009}$
energy dependence	±0.03	±0.02	±0.02	±0.03	±0.03	±0.02
particle identification	$^{+0.05}_{-0.06}$	±0.03	±0.03	±0.04	±0.02	±0.02
lepton misidententification	0.005	±0.01	±0.004	0.005	±0.02	±0.005
background (non τ physics)	±0.01	±0.03	±0.03	±0.01	±0.07	±0.06
total systematic error	±0.08	±0.09	±0.07	±0.08	±0.14	±0.10

Table 2: Contributions to the systematic error

	$(\pi^{\mp}\pi^0\nu)(e^{\pm}\nu\bar{\nu})$	$(\pi^{\mp}\pi^0\nu)(\mu^{\pm}\nu\bar{\nu})$	combined fit
ρ	$0.68 \pm 0.04 \pm 0.07$	$0.69 \pm 0.06 \pm 0.06$	$0.68 \pm 0.04 \pm 0.07$
ξ	$1.11 \pm 0.20 \pm 0.08$	$1.26 \pm 0.27 \pm 0.14$	$1.18 \pm 0.16 \pm 0.10$
$\xi\delta$	$0.56 \pm 0.14 \pm 0.06$	$0.73 \pm 0.18 \pm 0.10$	$0.63 \pm 0.11 \pm 0.08$

Table 3: Fitted Michel parameters

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	$(\pi^{\mp}\pi^0\nu)(e^{\pm}\nu\bar{\nu})$	$(\pi^{\mp}\pi^0\nu)(\mu^{\pm}\nu\bar{\nu})$	combined fit
ρ	0.72 ± 0.02	0.73 ± 0.02	0.72 ± 0.02
ξ	$1.12 \pm 0.20 \pm 0.09$	$1.26 \pm 0.27 \pm 0.14$	$1.18 \pm 0.16 \pm 0.10$
$\xi\delta$	$0.59 \pm 0.14 \pm 0.07$	$0.74 \pm 0.18 \pm 0.10$	$0.64 \pm 0.11 \pm 0.08$

Table 4: Fitted results with constrained ρ

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