Selected Charm and Tau Results from ARGUS

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Abstract. In the area of charm physics, first evidence for Ω_C production in e^+e^-annihilation has been obtained in the channel $\Xi^- K^- \pi^+ \pi^+$, leading to a mass determination of $(2719 \pm 7 \pm 2.5)$ MeV/c^2. A preliminary study of 1-1 prong tau decays provides measurements of the Michel parameters ρ and ξ. A detailed analysis of a sample of $\tau^- \rightarrow \pi^- \pi^0 \nu_\tau$ leads to a high precision determination of the branching ratio, a test of CVC and a confirmation of the spin alignment of the ρ. Finally, a pseudomass technique employing 3-prong tau decays yields a value of $(1976 \pm 3 \pm 1)$ MeV/c^2 for the tau mass, in agreement, but somewhat lower than, the original DELCO result.

**A DESY-Dortmund-Erlangen-Hamburg-Heidelberg-IPP Canada-Karlsruhe-Ljubljana-Lund-ITEP Moscow Collaboration.*

Observation of the Ω_C in e^+e^- Annihilation (U.Becker) [1]. A search for the Ω_C baryon, containing a single charm and two strange quarks, has been made in the decay channel $\Xi^- K^- \pi^+ \pi^+$. Previously, WA62 reported [2] a cluster of three events in this mode at a mass of (2740 ± 20) Mev/c^2. The data sample, corresponding to an integrated luminosity of 389 pb^{-1}, was obtained at the energy of the $\Upsilon(4S)$ and in the nearby continuum. The Ξ^- were reconstructed from $\Lambda\pi^-$ combinations lying within ± 12 MeV/c^2 of the nominal Ξ^- mass, with no vertex restriction on the pion. The Λ hyperons were identified from $p\pi^-$ combinations forming a secondary vertex separated by more than 4 cm from the primary vertex and lying within ± 12 MeV/c^2 of the nominal Λ mass.

Leading particles from the charm quark fragmentation typically carry a large fraction of the available momentum. Therefore, candidates were required to have a scaled momentum, $x_p = p/\sqrt{E_{beam}^2 - m^2}$, greater than 0.4. In addition, the decay products from the Ω_C tend to lie in the same hemisphere as the parent charm quark. Using the plane perpendicular to the thrust axis to divide events into two halves, the Ξ^- was required to have an opening angle of less than 45° with respect to the axis pointing into the selected hemisphere. Monte Carlo simulations show that 60% of the signal is retained by this cut, while the background is reduced by a factor of four.

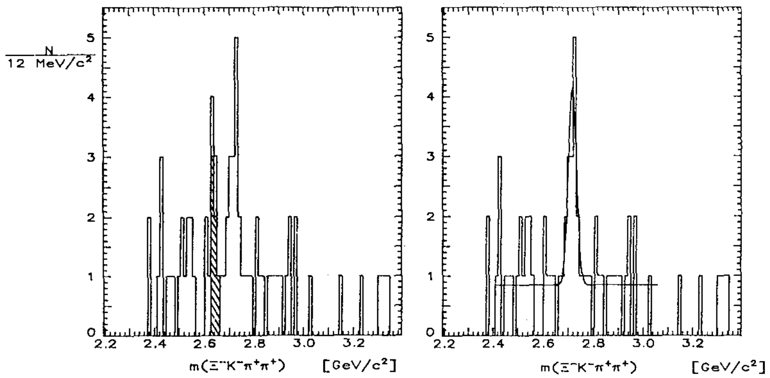

Figure 1. Invariant $\Xi^- K^- \pi^+ \pi^+$ mass spectrum after cuts described in the text, with (a) Ξ_C^0 reflection indicated by the hatched area, and (b) fit to data after reflection subtraction.

Two peaks are visible around 2.7 GeV/c^2 in the resulting invariant mass distribution for $\Xi^- K^- \pi^+ \pi^+$ (Figure 1a). Reflections from the decay $\Xi_C \to \Xi^- \pi^- \pi^+ \pi^+$, where the π^- is misidentified as a K^-, are known to produce the excess just above 2.6 GeV/c^2. This has been confirmed by both Monte Carlo studies and directly from the data. If a ± 22 MeV/c^2 region around the Ξ_C peak in the $\Xi^- \pi^- \pi^+ \pi^+$ channel is selected and subjected to the same cuts as applied in the Ω_C analysis, the narrow hatched region in Figure 1a is obtained. After subtraction of the reflection contribution, the final mass distribution (Figure 1b) exhibits a peak of 11.5 ± 4.3 events at a fitted mass of $(2719 \pm 7 \pm 2.5)$ MeV/c^2. The free width, $\sigma = (16.6 \pm 6.3)$ MeV/c^2, is also in good agreement with Monte

Carlo prediction. The signal corresponds to about a 4 standard deviation excess over background. Relaxing the x_p cut, the product of cross section times branching ratio for this channel is determined to be $(2.4 \pm 0.9 \pm 0.3)$ pb at 10 GeV.

Extraction of Michel Parameters in Tau Decays (K.Strahl). A study of tau-pair decays in a 1-1 topology:

$$e^+e^- \longrightarrow \tau^+\tau^- \longrightarrow e^-\overline{\nu}_e\nu_\tau$$
$$\hookrightarrow \mu^+\nu_\mu\overline{\nu}_\tau$$

has been used to study the Michel parameters ρ and ξ in tau decays. The data sample for this analysis corresponds to an integrated luminosity of 333 pb^{-1} containing about 336000 tau pairs. Events were selected by requiring exactly two charged accolinear ($\cos\theta_{1,2} > -0.9997$) tracks with zero net charge, and a polar angle θ restricted to the barrel region of the detector ($|\cos\theta_{1,2}| < 0.7$). Electrons were required to have momentum above 0.4 GeV/c; muons were restricted to lie above 1.3 GeV/c. Both were required to have particle identification likelihoods exceeding 80% for the appropriate hypothesis. The primary cut against bhabha events was a requirement that the square of the missing mass in the event exceed 4 GeV^2/c^4. The final sample consisted of 3457.3 ± 60.9 events, after subtraction of small QED and tau-pair backgrounds. Acceptances have been determined by Monte Carlo simulation, including detailed studies of trigger efficiencies. The exclusive one-prong branching ratios obtained are $\text{Br}_e = (17.9 \pm 0.6 \pm 0.7)\%$ and $\text{Br}_\mu = (17.5 \pm 0.6 \pm 0.7)\%$, assuming the expected ratio $\text{Br}_e/\text{Br}_\mu = 0.973$.

The Michel parameter ρ can be extracted from global fits to the lepton momentum spectra. Following the method of our previous measurement [3] with 1-3 prong tau-pair events, the new sample yields preliminary values of $\rho = 0.78 \pm 0.05$ and 0.72 ± 0.08 from electrons and muons respectively, assuming $\eta = 0$. These results are independent of the older study and have comparable statistical precision. The asymmetry parameter ξ can be determined through the spin alignment of the electromagnetically produced tau pairs. In particular, ξ modifies the lepton momentum spectrum for different angles θ between the tau spin direction and the lepton momentum. Thus, for the likely topologies of a pair of fast or a pair of slow leptons where $\cos\theta$ corresponds to -1 and $+1$ respectively, one might expect different ℓ^- spectra for a fast or slow tagging ℓ^+. For the actual study, a χ^2 was constructed in bins of electron and muon momentum, and the accolinearity angle. The preliminary result of the fit was a value $|\xi| = 0.90 \pm 0.13$, ruling out $\xi = 0$ at the 3.8σ level. Systematic uncertainties are still under investigation.

Study of the Decay $\tau^- \to \rho^-\nu_\tau$ (B.Spaan) [4]. One of the leading problems in our understanding of the tau lepton is the discrepancy between the topological one-prong branching ratio and the sum of the measured exclusive branching ratios for channels with one charged particle in the final state. One possible explanation is a common systematic error created by the strong correlation among existing measurements. The largest contributing exclusive channel is the decay $\tau^- \to \pi^-\pi^0\nu_\tau$, with a nominal branching ratio of $22.7 \pm 0.8\%$ [5]. ARGUS has performed a new study of this channel by selecting tau-pair events of the form:

$$e^+e^- \longrightarrow \tau^+\tau^- \longrightarrow \pi^-\pi^0\nu_\tau$$
$$\hookrightarrow \pi^+\pi^0\bar{\nu}_\tau$$

a method which has the virtue of being almost completely independent of other tau decay branching ratios. The event sample for this analysis corresponds to an integrated luminosity of 264 pb^{-1} containing about 262000 tau pairs.

Events were selected by requiring exactly two charged tracks with zero net charge, and a polar angle θ restricted to the barrel region of the detector ($|\cos\theta_{1,2}| < 0.75$). Energy clusters in the calorimeter of more than 80 MeV with no associated track were accepted as photon candidates. Either 2, 3 or 4 clusters were allowed per event, to allow for the merging of photon energy deposition in the case of high energy π^0's. The fraction of single-cluster π^0's rises sharply above 1 Gev/c^2, to reach a value in excess of 70% above 3 GeV/c^2. The characteristic 1-1 topology of the charged particles in tau-pair events was selected by requiring $\cos(\vec{p}_1, \vec{p}_2) < -0.5$. Photons within a cone of 60° around a charged track were assigned to a specific τ decay candidate. For each $\pi^\pm\pi^0$ candidate, either 1 or 2 photons were allowed. If only one photon was found in a given hemisphere it was required to have an energy greater than 1 GeV/c^2. This merged cluster was then treated as a π^0 for further analysis. The two-photon system of one hemisphere was required to have an invariant mass within ± 100 MeV/c^2 of the nominal π^0 mass [6] and yield a $\chi^2 < 9$ when kinematically constrained to the π^0 mass.

The pion mass was assumed for both charged tracks, ignoring available dE/dx and time-of-flight information. The $\pi^\pm\pi^0$ system in each hemisphere was required to have an invariant mass less that 1.8 GeV/c^2. The final selected sample consisted of 1249 events. The background from multihadron, two-photon and bhabha sources were determined to be small, totaling 32 ± 7 events. Contamination from tau-pair events can be divided into two classes, where (1) neither τ decays into $\pi^-\pi^0\nu_\tau$ (33.1 ± 7.5 events) or (2) only one. The latter cannot be calculated without knowing the branching ratio for $\tau^- \to \pi^-\pi^0\nu_\tau$, hence requiring that $\mathrm{Br}_\rho = \mathrm{Br}(\tau^- \to \pi^-\pi^0\nu_\tau)$ be extracted instead from:

$$\mathrm{N}_{\tau\tau} \cdot \left[\epsilon_{\rho\rho}\mathrm{Br}_\rho{}^2 + 2 \cdot \mathrm{Br}_\rho \cdot \Sigma\left(\epsilon_{\rho i}\mathrm{Br}_i\right)\right] = \mathrm{N}_{\mathrm{corr}}\,,$$

where the Br_i are the branching ratios for "background" τ decays, $\mathrm{N}_{\mathrm{corr}} = 1183.9 \pm 10.4$ is the number of selected events after background subtraction, $\mathrm{N}_{\tau\tau} = 261500 \pm 5420$ is the number of τ pairs produced, $\epsilon_{\rho\rho}$ is the efficiency for selecting a tau-pair event where both τ's decays into $\pi^\pm\pi^0$, and $\epsilon_{\rho i}$ is the efficiency for selecting events where one tau decays into $\pi^-\pi^0\nu_\tau$ and the other into the "background" decay channel i. The efficiency calculation includes the influence of the trigger as well as the effect of fake photons, produced both by noise in the electromagnetic calorimeter and by split-offs from the shower cluster associated with the charged track. The efficiency $\epsilon_{\rho\rho}$ has been determined to be (6.68 ± 0.24)%, leading to a value of $(22.6 \pm 0.4 \pm 0.9)$% for $\mathrm{Br}(\tau^- \to \pi^-\pi^0\nu_\tau)$.

For further studies not requiring absolute normalization, the data sample has been enlarged by selecting 1-3 topology events of the form:

$$e^+e^- \longrightarrow \tau^+\tau^- \longrightarrow \pi^-\pi^-\pi^+\nu_\tau$$
$$\hookrightarrow \pi^+\pi^0\overline{\nu}_\tau$$

Events were selected with exactly four charged tracks, with the characteristic 1-versus-3 topology ensured by requiring $\cos(\vec{p}_1, \vec{p}_i) < 0$, $(i = 2,3,4)$ and $\cos(\vec{p}_1, \sum_{i=2}^{4} \vec{p}_i) < -0.5$, where $\vec{p}_1$ denotes the momentum of the charged particle on the 1-prong side and the $\vec{p}_i (i = 2, 3, 4)$ are the particle momenta on the 3-prong side. The π^0 reconstruction requirements were analogous to those used for the 1-1 prong selection. In addition, the invariant mass of the $\pi^-\pi^0$ and the $\pi^-\pi^+\pi^+$ systems were both required to be less than 1.8 GeV/c^2. This selection enlarged the $\tau^- \to \pi^-\pi^0\nu_\tau$ sample by 1772 events, of which 155 ± 41 are attributed to background from non-τ events.

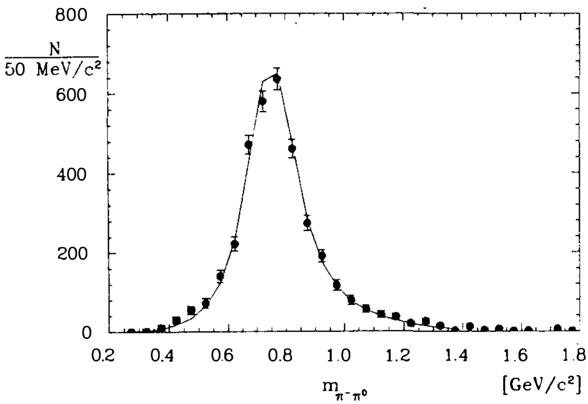

Figure 2. Background subtracted mass spectrum for $\tau^- \to \pi^-\pi^0\nu_\tau$ showing fitted expectation from the CVC prediction folded with detector acceptance.

Using the combined sample, a test has been made of the CVC prediction [6] for the $\pi^-\pi^0$ mass spectrum:

$$\frac{d\Gamma(q^2)}{dq} = \frac{G_F^2}{16\pi^2 m_\tau^3} q(m_\tau^2 - q^2)^2(m_\tau^2 + 2q^2)v_1(q^2)$$

where $v_1(q^2)$ denotes the spectral function obtained from the $I = 1$ component of the cross section for $e^+e^- \to \pi^+\pi^-$ and $q^2 = m^2_{\pi^-\pi^0}$. Following the prescription of Kühn and Santamaria [7], the CVC prediction, convoluted with acceptance effects, was fit to the data over the region of $0.28 \leq m_{\pi^-\pi^0} \leq 1.4$ GeV/c^2 using only the normalization as a free parameter. The background corrected $m_{\pi^-\pi^0}$ spectrum is shown together with the CVC prediction in Figure 2. The agreement is excellent with a χ^2 of 22.5 for 22 degrees of freedom.

In the case that the tau decays at rest, the coupling is left-handed (L) for the ρ in a helicity state $H_\rho = 0$ and right-handed (R) for $H_\rho = -1$. The expected angular distribution for the pions in the ρ rest frame relative to ρ flight direction is:

$$\frac{dN}{d\cos\vartheta} \sim \frac{L}{R}\cos^2\vartheta + \sin^2\vartheta = 1 + b_\tau \cos^2\vartheta$$

where $b_\tau = (m_\tau^2 - m_\rho^2)/m_\rho^2$. If the tau is in motion, the direction of the ρ in the tau rest frame is no longer known. However, the angular distribution is still of the form $1+b\cos^2\theta$, but with $b_{MC} = 0.57 \pm 0.01$ as predicted by Monte Carlo calculation [7]. The observed distribution is shown in Figure 3, along with a fit result which yields $b_{meas} = 0.57 \pm 0.12$. This value is in excellent agreement with our Monte Carlo expectation for a vector-like coupling, corresponding to b_τ in the interval $2.3 < b_\tau < 10$ (95% CL), or a ratio of left-handed to right-handed coupling $x_L = L/(L+R) = (b_\tau + 1)/(b_\tau + 2)$ lying between $0.77 < x_L < 0.92$ (95% CL). Note that $x_L = 0.5$ is expected if the coupling is independent of the tau's handedness. Since $x_L = 1$ and $x_L = 0$ correspond to $|H_\rho| = 0$ and $|H_\rho| = 1$ respectively, the experimental bounds on x_L show that neither of the ρ helicity states is exclusively populated. Assuming $m_{\nu_\tau} = 0$ the only possible spin states for the neutrino are 1/2 and 3/2; the latter possibility is excluded by this measurement, since it requires the ρ to be in a pure $H_\rho = -1$ state.

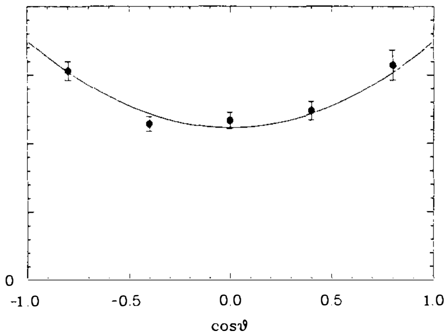

Figure 3. Angular distribution of the pions in the ρ rest frame with respect to the observed ρ direction of flight with the result of the fit described in the text. The vertical scale is arbitrary.

New Determination of the Tau Mass (B.Spaan). Another possible problem in tau decays is the more than two sigma discrepancy between the average values for the electronic branching ratio (Br_e) which are directly measured versus derived from the tau lifetime. One possible resolution of this difficulty would be a slight shift in the accepted tau mass, which is largely based on a single measurement by DELCO [8] of the tau-pair cross section near threshold. Another technique which is sensitive to the tau mass has been proposed by B.Spaan and A.Golutvin at ARGUS. For a boosted decay $\tau^- \to a_1^- \nu_\tau$ the a_1 and tau tend to be moving in the same direction, i.e. $\cos\theta_{a_1,\tau} \simeq 1$. The tau mass is simply given by $m_\tau^2 = E_\tau^2 - p_\tau^2$ where, except for radiative events, $E_\tau = E_{beam}$. Assuming $\cos\theta_{a_1,\tau} = 1$, the tau momentum is $p_\tau = p_{a_1} \pm p_\nu$. Choosing the positive solution produces a sharp threshold, in part due to the better resolution for small 3 pion energies. Finally, assuming a zero mass for the tau neutrino, $p_\nu = E_\tau - E_{a_1}$. Thus, it is possible to calculate on an event-by-event basis a tau pseudomass, m_τ^*, using the known beam energy and the measured momenta of the charged pions from the a_1^- decay:

$$m_\tau^* = 2(E_{a_1} - p_{a_1})(E_\tau - E_{a_1}) + m_{a_1}^2$$

The pseudomass spectrum has a sharp cutoff on the high mass side, which is linearly related to the tau mass, as illustrated in Figure 4. A standard 1-3 prong selection procedure yields an sample containing 10959 $\tau^- \to a_1^- \nu_\tau$ decays.

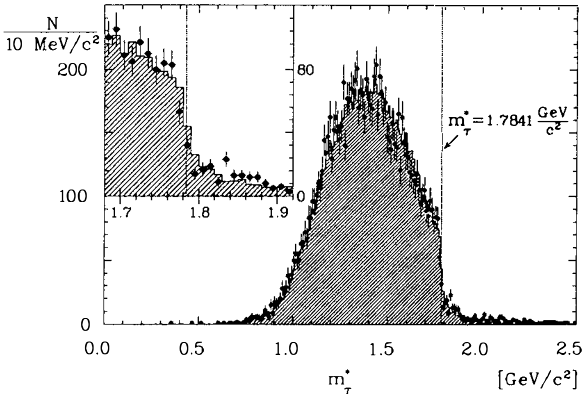

Figure 4. Pseudomass distribution from $\tau^- \to \pi^-\pi^-\pi^+\nu_\tau$ showing data (points with error bars) and Monte Carlo simulation including backgrounds (shaded histogram).

The shape of the threshold has been determined by Monte Carlo simulation, including all effects of detector resolution and acceptance, and the beam energy spread. The region from 1.7 to 1.85 GeV/c in the simulation was used to fix the parameters α_i in a threshold model of the form:

$$\frac{dN}{dm_\tau^*} \sim \alpha_1[1 + \alpha_2 \cdot m_\tau^* \cdot \tanh(\alpha_3(m_\tau^* - \alpha_4))]$$

for a nominal tau mass of 1.7841 GeV/c^2. The fit to the data shifted the threshold by allowed for small changes $+\Delta m$ in m_τ^*, corresponding to a correction to the nominal tau mass of $-\Delta m$. In addition to the signal channel, the principal sources of background in the sample were multihadron annihilation events and tau decays in the mode $\tau^- \to \pi^-\pi^-\pi^+\pi^0\nu_\tau$. The $q\bar{q}$ component is small and exhibits a smooth behaviour in the threshold region. The threshold in the four-body tau decay contribution is shifted below the region of sensitivity. The fit to the pseudomass distribution in the data (Figure 5) included free normalization for the signal and the two background sources. A preliminary result for the tau mass of $(1776.0 \pm 3.2 \pm 1.2)$ MeV/c^2 is thereby determined, representing a shift of -8 ± 4.5 MeV/c^2 with respect to the PDG value [5]. The systematic errors include contributions from uncertainties in the absolute beam energy, the assumption of zero neutrino mass and the absolute momentum scale of the experiment. This result is in a direction to marginally improve the agreement between Br_e and the tau lifetime. The lower tau mass also results in a revised upper limit for the tau neutrino of 31 MeV/c^2 (95% CL).

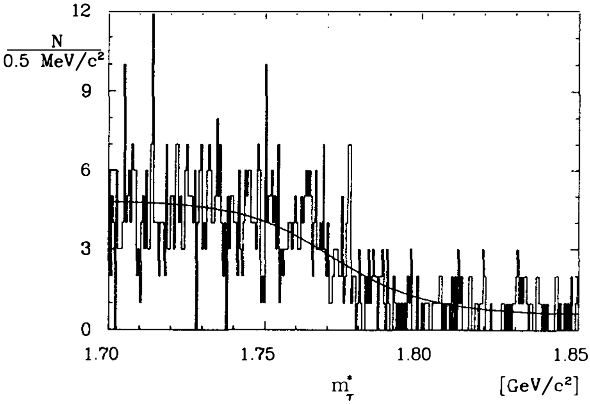

Figure 5. Detailed view of pseudomass distribution from $\tau^- \rightarrow \pi^-\pi^-\pi^+\nu_\tau$ with fit to threshold for tau mass.

References

[1] H.Albrecht *et al.* (ARGUS), "First Evidence for the Production of the Charmed Doubly-Strange Baryon Ω_C in e^+e^- Annihilation", in preparation.
[2] S.Biagi *et al.* (WA62), Z.Phys. **C28** (1985) 175.
[3] H.Albrecht *et al.* (ARGUS), Phys.Lett. **246B** (1990) 278.
[4] H.Albrecht *et al.* (ARGUS), "Measurement of the Decay $\tau^- \rightarrow \rho^-\nu_\tau$", in preparation.
[5] Particle Data Group, Phys.Lett. **239B** (1990) 1.
[6] Y.S.Tsai, Phys.Rev. **D4** (1971) 2821.
[7] J.H.Kühn and A.Santamaria, Z.Phys. **C48** (1990) 445.
[8] W.Bacino *et al.* (DELCO), Phys.Rev.Lett. **41** (1978) 13.