NEUTRAL K*(890) AND ρ^0 MESON PRODUCTION IN e^+e^- ANNIHILATION AT $\sqrt{s}$ = 29 GeV

M. DERRICK, P. KOOIJMAN, J.S. LOOS, B. MUSGRAVE, L.E. PRICE, J. SCHLERETH, K. SUGANO, J.M. WEISS [1], D.E. WOOD [2]

Argonne National Laboratory, Argonne, IL 60439, USA

P. BARINGER, D. BLOCKUS, B. BRABSON, S.W. GRAY [3], C. JUNG, H. NEAL, H. OGREN, D.R. RUST, M. VALDATA-NAPPI [4]

Indiana University, Bloomington, IN 47405, USA

C. AKERLOF, G. BONVICINI, J. CHAPMAN, D. ERREDE, N. HARNEW [5], P. KESTEN, D.I. MEYER, D. NITZ, A.A. SEIDL [2], R. THUN, T. TRINKO [2], M. WILLUTZKY

University of Michigan, Ann Arbor, MI 48109, USA

S. ABACHI, I. BELTRAMI, B.G. BYLSMA, R. DEBONTE, K.K. GAN, D. KOLTICK, F.J. LOEFFLER, E.H. LOW, R.L. McILWAIN, D.H. MILLER, C.R. NG, L.K. RANGAN, E.I. SHIBATA

Purdue University, West Lafayette, IN 47907, USA

and

B. CORK

Lawrence Berkeley Laboratory, Berkeley, CA 94720, USA

Received 21 May 1985

The production of neutral K*(890) and ρ^0 mesons was studied in e^+e^- annihilation at $\sqrt{s} = 29$ GeV using the High Resolution Spectrometer at PEP. Differential cross sections are presented as a function of the scaled energy variable z and compared to π^0 and K^0 production. The measured multiplicities are 0.84 ± 0.08 ρ^0 mesons and 0.57 ± 0.09 $K^{*0}(890)$ mesons per event for a meson momentum greater than 725 MeV/c. The ratios of vector meson to pseudoscalar meson production for (u,d), s and c quarks are compared to predictions of the Lund model.

Over the past several years, a number of models have been developed to describe the fragmentation of quarks produced in e^+e^- annihilation into observable hadrons [1–3]. In these models one of the unknowns is the probability that a quark–antiquark pair produce a vector meson as compared to its pseudoscalar partner. Although this ratio arises naturally from the

[1] Present address: SRI International, Menlo Park, CA 94025, USA.
[2] Present address: Lockheed Missiles and Space Co., Sunnyvale, CA 94086, USA.
[3] Present address: Laboratory for Nuclear Studies, Cornell University, Ithaca, NY 14853, USA.
[4] Permanent address: INFN, I 56010 Pisa, Italy.
[5] Present address: CERN, CH-1211 Geneva 23, Switzerland.

0370-2693/85/$ 03.30

cluster [2] and string [3] ideas, the results are still dependent on unknown parameters. It is thus important to measure and compare the production rates of vector and pseudoscalar mesons for all quark flavors.

We have previously reported results on D and D* production [4]; the analysis presented here extends these measurements to the $K^{*0}(890)$ and ρ^0 mesons. The results came from events collected by the High Resolution Spectrometer at the PEP storage ring. The data correspond to an integrated luminosity of 185 pb^{-1} and were taken at a center of mass energy of $\sqrt{s} = 29$ GeV.

The High Resolution Spectrometer, which has been described in detail elsewhere [5], consists of 17 layers of drift chambers surrounded by lead-scintillator shower counters, all of which are placed in a solenoidal magnetic field of 16.2 kG. The momentum resolution for charged tracks is $\sigma(p)/p = 0.005 + 0.002p$ with p in GeV/c, which translates into a two-particle mass resolution of better than 15 MeV for the momentum and mass ranges covered by these measurements.

The hadronic annihilation events were selected by the following requirements:

(a) the scalar sum of momenta of charged particles, P_{sum}, greater than 8.7 GeV, or

(b) the sum of energies in the shower counter system, E_{sum}, greater than 4.0 GeV, or

(c) the sum of E_{sum} and P_{sum} greater than 10.0 GeV, and

(d) the total number of charged particles, N_{ch}, greater than 4.

These selections yielded ~60K events. The background, primarily from two-photon annihilation, is about 10% [6].

In addition, for the subsequent analysis it was required that each charged track have more than 9 measured coordinates and a momentum greater than 200 MeV/c. This event sample has been used to determine $\rho^0 \to \pi^+\pi^-$ and $K^{*0} \to K^\pm\pi^\mp$ production rates as a function of z ($z = 2E/\sqrt{s}$ where $\sqrt{s} = 29$ GeV) by fitting the neutral two-particle effective mass spectra. Since no particle identification is used, these effective mass spectra were determined for each combination assuming first that both particles have the pion mass and secondly assigning the kaon mass to one particle and the pion mass to the other. These mass spectra contain the contribution from the ρ^0 and K^{*0}, in addition to a large combinatorial background. Other resonant states also contribute in the ρ^0 and K^{*0} mass regions, especially if incorrect mass assignment have been made or only part of a total decay has been used. In particular, the $\rho^0 \to \pi^+\pi^-$ produces an enhancement in the $K^\pm\pi^\mp$ mass spectrum in the K^{*0} mass region if one of the pions is assigned the kaon mass. The converse is also true.

To minimize this kinematic overlap between the ρ^0 and K* peaks, the helicity angle, θ^*, of each particle of the combination was required to satisfy $|\cos\theta^*| < 0.5$, where θ^* is the angle in the $\pi\pi$ or $K\pi$ center of mass between the meson and the flight direction of the $\pi\pi$ or $K\pi$ system. This particular cut is effective because of the properties of the Lorentz transformation when an incorrect mass has been assigned to a decay product which is produced isotropically in the parent rest system.

To reduce the combinatorial background, the momentum of the two-particle combination, p^{tot}, was required to be greater than 725 MeV/c and for each particle i the dot product $p^i \cdot p^{tot}$ was required to be positive. In addition, two-particle spectra of charge two were subtracted from the neutral two particle spectra. Fig. 1 shows these difference spectra for the $\pi\pi$ and $K\pi$ mass assignments for different x selections where $x = p^{tot}/p^{beam}$. The x selection in figs. 1a and 1b is $x > 0.05$ for both the $\pi\pi$ and $K\pi$ combinations. Figs. 1c and 1d show the equivalent $\pi\pi$ and $K\pi$ combinations for $x > 0.45$ respectively. Clear enhancements corresponding to ρ^0 and K^{*0} production are observed as well as a background which contains contribution from a number of other resonances.

For example, the $\pi\pi$ spectrum of fig. 1a shows (i) a shoulder at $M \sim 0.4$ coming from $\phi \to K^+K^-$ decays with the K mesons assigned the pion mass, (ii) a strong, narrow signal at 500 MeV from $K_s^0 \to \pi^+\pi^-$ decays, and (iii) a peak in the ρ^0 mass region. For the higher x selection of fig. 1c, there is an enhancement in the 1.2–1.5 GeV mass region coming from D meson decays as well as possible tensor (f^0 or K*(1420)) meson production. Similarly, the inclusive $K\pi$ spectrum of fig. 1b shows a low mass enhancement coming from K^0 decays with one particle mass assigned the kaon mass as well as a clear peak in the K*(890) mass region. The $K\pi$ spectrum of fig. 1d shows the $D^0 \to K\pi$ decay clearly as well as a possible K*(1420)/f^0 enhancement.

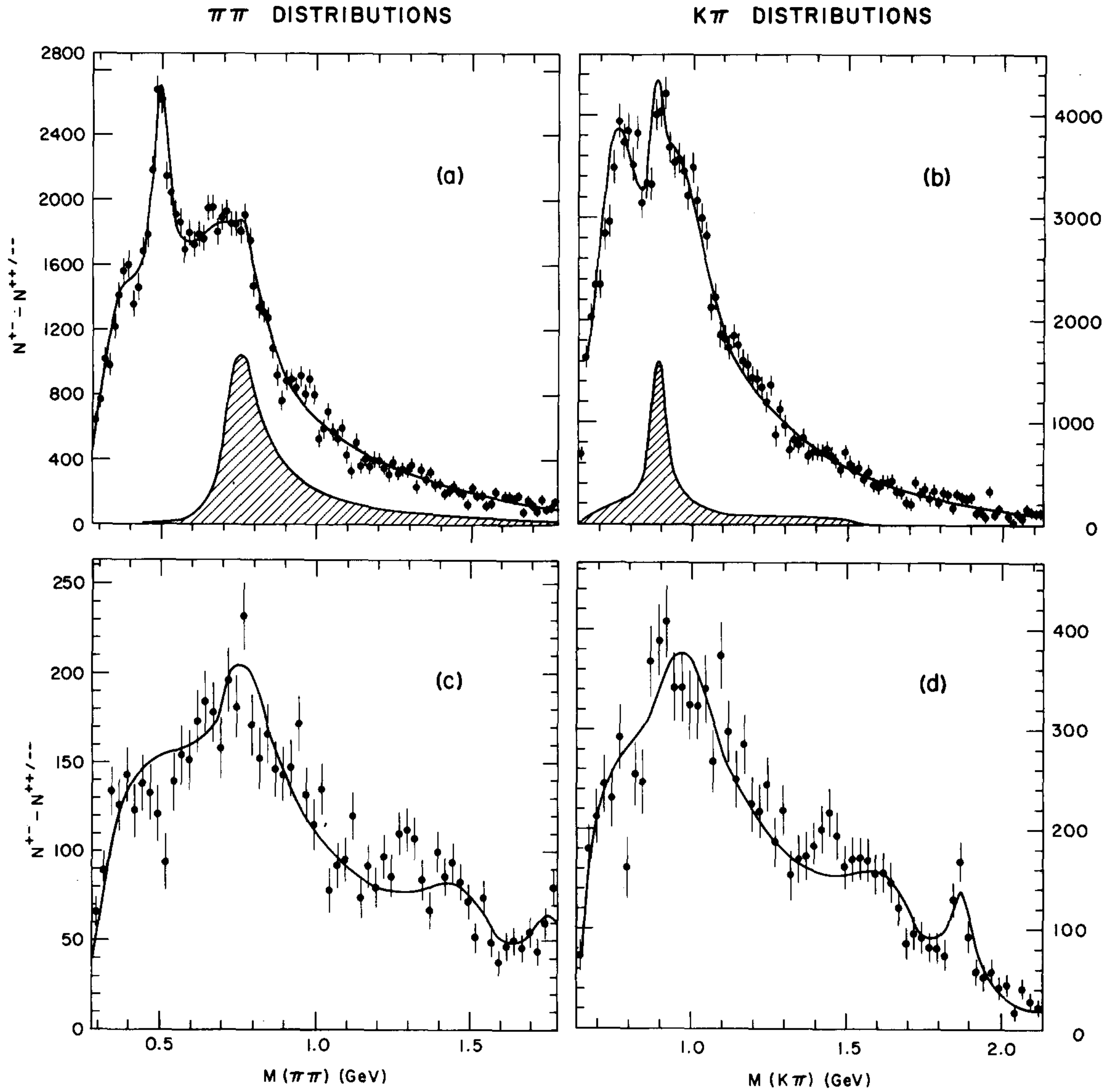

Fig. 1. Subtracted two-body effective mass spectra (charge zero minus charge two) for different x selections ($x = p^{\mathrm{tot}}/p^{\mathrm{beam}}$) together with the best fit curves. (a) $\pi^{\mp}\pi^{\pm}, x > 0.05$, (b) $K^{\pm}\pi^{\mp}, x > 0.05$, (c) $\pi^{\pm}\pi^{\mp}, x > 0.45$, (d) $K^{\pm}\pi^{\mp}, x > 0.45$. The hatched areas in (a) and (b) show the contribution from the ρ^0 and $K^{*0}(890)$, respectively.

To determine the K^{*0} and ρ^0 signals, these spectra were fitted with a shape consisting of the sum of a smooth background and resonance contributions from K^0, ρ, ω, $K^*(890)$ and D mesons. The background was parameterized as

$$F_{\mathrm{bkg}}(M) = N(M - M_{\mathrm{th}})^{\alpha} \exp[-\beta(M - M_{\mathrm{th}})] , \qquad (1)$$

where M_{th} is the relevant mass threshold for $\pi\pi$ and $K\pi$ combinations. The same value of α was used in the $\pi\pi$ and $K\pi$ spectra. The normalization constants, N, are related since the integral of the $K\pi$ background is twice the integral of the $\pi\pi$ background.

The shapes of the resonances and their acceptance in the two spectra were determined by Monte Carlo methods. The K^* and ρ input shapes were P-wave Breit–Wigner resonances with known masses and widths [7]. For the D-meson contributions from the $D^0 \to K\pi$, $K^*\pi$, $K\rho$, $Ke\nu$ and $D^\pm \to K\pi\pi$ decays were taken into account. The fits, which were performed simultaneously to the $\pi\pi$ and $K\pi$ spectra for several momentum bins, gave typical χ^2 per degree of freedom of ~1.5. The lines of fig. 1 show the fits to these particular spectra. The statistics are high: the fits of fig. 1a (1b) contains about 20K(10K) $\rho^0(K^{*0})$ mesons. The contributions of the ρ^0 and K^{*0} mesons are shown by the hatched areas in figs. 1a and 1b. The K* resonance peak sits on a background of events in which the $K^\pm$ and $\pi^\mp$ are interchanged.

The errors on the resulting cross sections $(s/\beta)\mathrm{d}\sigma/\mathrm{d}z$ are purely systematic and were determined by varying the parameters of the fits to the mass spectra. Fig. 2a shows the cross section for ρ^0 production as a function of the fractional energy variable z. The figure also shows earlier results from the JADE [‡1] and TASSO [10] collaborations which agree well with our more precise data in the overlap region. Our data extends the z range to both lower and higher values. For $x > 0.05$ our measured overall rate is $0.84 \pm 0.08\ \rho^0$ per event. This number increases to 0.95 ± 0.09 for

‡1 This group reports measurements of charged K* production [8]. The s/u value in table 1 is taken from ref. [9].

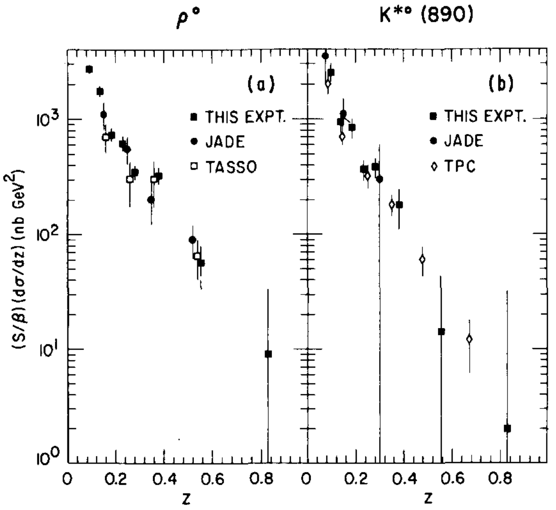

Fig. 2. Invariant cross sections for: (a) ρ^0 production compared to results from JADE (ref. [8]) and TASSO (ref. [10]), (b) K*(890) production compared to results from JADE (ref. [8]) and TPC (ref. [11]).

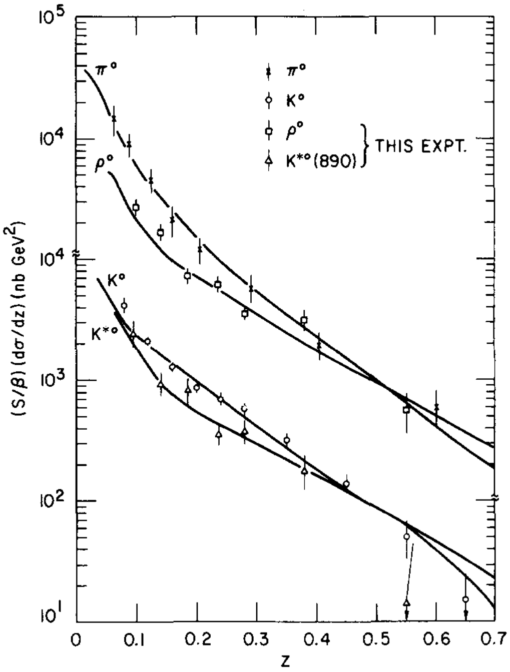

Fig. 3. Comparison of invariant cross sections for the vector and pseudoscalar mesons (π^0 data (ref. [12]), K^0 data (ref. [13]). The line shows the fit to the data using the LUND model.

the full kinematic range using the shape predicted by the Lund Monte Carlo to extrapolate to threshold. Dividing the resulting cross section of $\sigma(\rho^0) = 380 \pm 35$ pb by the point cross section for $\sqrt{s} = 27.3$ GeV, to correct for initial state radiation, gives $R(\rho^0) = 3.2 \pm 0.3$.

The scaling cross section for K*(890) production is shown in fig. 2b and compared to results from the JADE [8] and TPC [11] collaborations. The three data sets agree well. The total rate for $K^{*0}(890)$ production for $x > 0.05$ is 0.57 ± 0.09 per event. The extrapolated values are $0.63 \pm 0.10\ K^{*0}$ per event, $\sigma(K^{*0}) = 252 \pm 40$ pb and $R(K^{*0}) = 2.1 \pm 0.3$).

To investigate the implications of our measurements for the string model we compared the production rates of π^0 [12], ρ^0, K^0 [13] and $K^{*0}(890)$ in fig. 3. At low values of z, the cross sections for the pseudoscalar mesons are significantly larger than their vector meson partners due to the contributions from decays of higher mass states in the pseudoscalars. As z increases, however, the two rates become equal and there is in-

Table 1
Measurements fo Lund model parameters.

Parameter	Group			
	JADE a)	TPC b)	TASSO c,d)	HRS (this expt.)
s/u	0.27 ± 0.03 ± 0.05 e)	0.25 ± 0.02		0.34 ± 0.03
$\frac{v}{v+p}$ (u,d)	0.51 ± 0.10 ± 0.15		0.58 ± 0.08 ± 0.15	0.54 ± 0.06
$\frac{v}{v+p}$ (s)	0.70 ± 0.15 ± 0.11	0.47 ± 0.11 ± 0.09		0.66 ± 0.08
$\frac{v}{v+p}$ (c)				$1.0^{+0.2}_{-0.3}$

a) Refs. [8]. b) Ref. [11]. c) Ref. [7]. d) Using the Field–Feynman model. e) Ref. [9].

dication that the rates for vector meson production actually become larger at the highest z values. The lines in fig. 3 shows the results of the best fits to the data using the Lund Monte Carlo where the strange particle suppression expressed as the s/u ratio and the vector meson fractions $v/(v+p)$ for strange and non-strange mesons have been taken as free parameters. The predicted cross sections agree well both in shape and normalization with the data and yield values of $s/u = 0.34 \pm 0.03$, $v/(v+p)(\mathrm{u,d}) = 0.54 \pm 0.06$ and $v/(v+p)(\mathrm{s}) = 0.66 \pm 0.08$ [‡2]. With these parameters, the fit yielded an overall χ^2 per degree of freedom of 1.1. Our measurements of these parameters are in reasonable agreement with the results obtained by other groups studying vector meson production in e^+e^- annihilation at similar energies as seen in table 1.

Fig. 4 shows the measurements of the $v/(v+p)$ ratios for (u, d) and s quarks as well as c quarks as a function of the mass ratio of the vector meson to the pseudoscalar mesons [‡3]. For equal masses, a value of 3/4 is expected from spin counting and the charm quark results [4] are in accord with this expectation. The suppression of the ρ^0 and K* mesons relative to their pseudoscalar partners is explained in the string model as the result of a tunneling phenomenon. The quark spin–spin interaction spreads the wave function of the triplet meson as compared to the singlet pseudoscalar particle, thus suppressing the wave function at the origin and so the overlap with the $q\bar{q}$ pair. A variation of the p/v ratio of $\frac{1}{3}(Mv/Mp)^\gamma$ is expected.

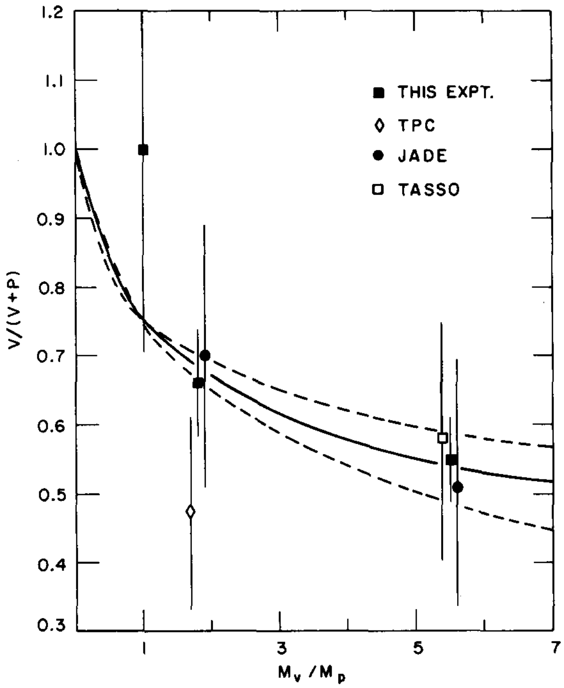

Fig. 4. The $v/(v+p)$ ratio as a function of the mass ratio Mv/Mp for charm, strange and (u, d) quarks compared to results from TPC (ref. [11]), JADE (ref. [8]), and TASSO (ref. [10]). The band shows the power-law fit discussed in the text.

‡2 In order to obtain a good fit to the K* spectrum, the K* mesons coming from D decay had to be suppressed by the ratio of the available phase space in the decay.

‡3 A similar graph has been presented by the JADE group (ref. [8]).

The lines in fig. 4, which show this parameterization with $\gamma = 0.55 \pm 0.12$, represents the data well.

Our measurements of ρ^0 and $K^{*0}(890)$ production when compared to π^0 and K^0 data show that the vector and pseudoscalar meson partners have fragmentation functions that differ significantly. By fitting these distributions, we have measured ratio of vector-to-pseudoscalar meson production with much improved precision. The results support the suggestion that the mass splitting plays a strong role in the primary quark–meson transitions.

This work was supported by the US Department of Energy. We thank W. Dunwoodie for a useful conversation. The technical staff at PEP operated the storage ring at high luminosity and so made the experiment possible.

References

[1] R.D. Field and R.P. Feynman, Nucl. Phys. B136 (1978) 1.
[2] B. Andersson, G. Gustafson, G. Ingelman and T. Sjostrand, Phys. Rep. 97 (1983) 32.
[3] B.R. Webber, Nucl. Phys. B238 (1984) 492; G. Marchesini and B.R. Webber, Nucl. Phys. B238 (1984) 1; T. Gottschalk, Nucl. Phys. B239 (1984) 349.
[4] M. Derrick et al., Phys. Rev. Lett. 53 (1984) 1971; Phys. Lett. 146B (1984) 261.
[5] D. Bender et al., Phys. Rev. D30 (1984) 515.
[6] D. Bender et al., Phys. Rev. D31 (1985) 1.
[7] Particle Data Group, Rev. Mod. Phys. 56 (1984) 1.
[8] JADE Collab., W. Bartel et al., Phys. Lett. 145B (1985) 441.
[9] JADE Collab., W. Bartel et al., Z. Phys. C20 (1983) 187.
[10] R. Brandelik et al., Phys. Lett. 101B (1981) 129.
[11] H. Aihara et al., Phys. Lett. 53 (1984) 2378; H. Yamamoto, Talk at XXth Moriond meeting (March 1985).
[12] H.J. Behrend et al., Z. Phys. C20 (1983) 207.
[13] M. Derrick et al., Particle production in e^+e^- annihilation at $\sqrt{s} = 29$ GeV, to be published.