INCLUSIVE ρ^0 PRODUCTION IN e^+e^- ANNIHILATION AT HIGH ENERGY

TASSO Collaboration

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We have observed ρ^0 production in e^+e^- annihilation to hadrons at high energies. The differential cross section at a centre of mass energy W, of 34 GeV, is presented. In the range $0.2 < x < 0.7$, we measure 0.33 ± 0.06 (stat.) ± 0.07 (syst.), $0.22 \pm 0.06 \pm 0.05$ and $0.22 \pm 0.02 \pm 0.05$ ρ^0/event at W = 14, 22 and 34 GeV respectively.

We report measurements of inclusive ρ^0 production in e^+e^- annihilation at average centre of mass energies, W, between 14 and 34 GeV using the TASSO detector at the electron–positron storage ring PETRA.

The detector, data taking and analysis procedures have been described in detail elsewhere [1,2]. In the measurements to be reported here, we have used information from the central tracking chambers to detect charged particles. Particle identification was not used. We have studied ρ^0 production via the $\pi^+\pi^-$ invariant mass distribution by treating all charged particles as pions. The background to ρ^0 production in this spectrum is complicated. We present two separate methods of estimating this background; by use of a Field–Feynman model for fragmentation and by explicit parametrisation of other resonance contributions in the $\pi\pi$ and $K\pi$ invariant mass spectra.

A sample of 2704, 2120 and 15634 hadronic events at W = 14, 22 and 34 GeV were selected using standard cuts: 4(5) or more charged particles with momentum component $P_{xy} > 0.1$ GeV/c transverse to the beam direction having polar angles θ satisfying $|\cos\theta| < 0.87$ for $W \leqslant 25$ GeV ($W > 25$ GeV). The sum of the charged particle momenta ΣP_i had to satisfy $\Sigma P_i > 0.265\ W$.

For this analysis, all reconstructed tracks were required to satisfy:

(a) $d_0 < 0.5$ cm, where d_0 is the distance of closest approach to the origin in the plane perpendicular to the beam direction,

(b) $z_0 < 4$ cm, where z_0 is the distance from the interaction point along the beam direction to the track at this point of closest approach in the plane perpendicular to this direction.

(c) $|\cos\theta| < 0.87$.

(d) $P_{xy} > 0.1$ GeV/c.

(e) $0.2 < P < 10.0$ GeV/c ($0.5 < P < 12.0$ GeV/c) for $W \leqslant 25$ GeV ($W > 25$ GeV), where P is the measured track momentum.

Assigning all particles the pion mass, the effective mass of all pairs of charged particles ($m_{\pi\pi}$) was calculated if they satisfied in addition:

(f) Both tracks lie in the same hemisphere of the event as defined by the sphericity axis.

(g) At least one track of the pair has $P_\perp > 0.1$ (0.2) GeV/c transverse momentum with respect to the sphericity axis for $W \leqslant 25$ GeV ($W > 25$ GeV).

Cuts (e)–(g) suppress the combinatorial background in the dipion mass spectrum by a factor of typically 2 while reducing the ρ^0 acceptance by only 15%. Furthermore, cut (a) suppresses $\pi^\pm$ from K^0 decay. The $m_{\pi^+\pi^-}$ effective mass distribution for tracks surviving these cuts is shown in fig. 1a at an average W = 34 GeV, integrated over the range $0.1 < x < 0.7$, where $x = 2E_{\pi\pi}/W$ with $E_{\pi\pi}$ being the sum of the two pion energies. A residual K^0 signal and a clear enhancement in the region of the ρ near 770 MeV are observed. For comparison, the effect of applying the identical analysis to the $m_{\pi^\pm\pi^\pm}$ effective mass distribution is shown in fig. 1b. In this case no such enhancement is observed, which indicates that the cuts do not induce an artificial signal in the ρ mass region. In fig. 1c,d we show the $m_{\pi^+\pi^-}$ distributions for W = 14 and 22 GeV integrated over the range $0.2 < x < 0.7$.

The background under the ρ^0 in the $m_{\pi^+\pi^-}$ mass spectrum has been estimated in two ways. In the first method a Monte Carlo simulation was used to provide both $m_{\pi^+\pi^-}$ and $m_{\pi^\pm\pi^\pm}$ mass spectra, with unlike sign pairs originating from the same ρ^0 removed. A generator describing $e^+e^- \to q\bar{q}$ and $e^+e^- \to q\bar{q}g$ including radiative effects together with the Field–Feynman

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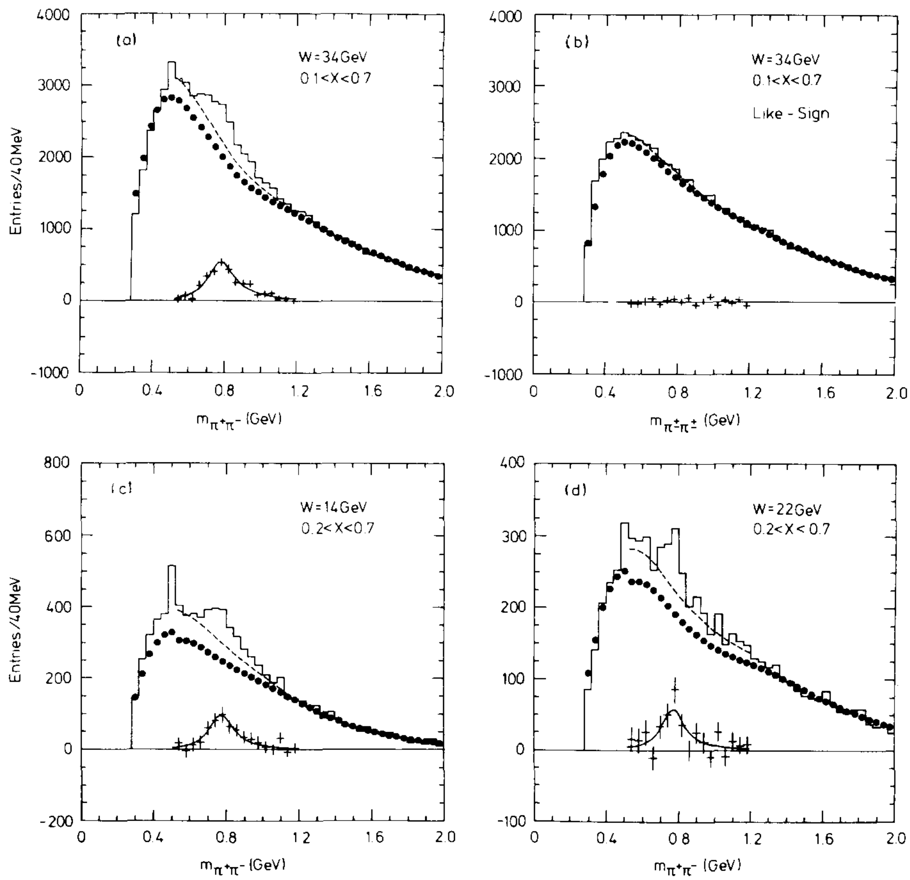

Fig. 1. The invariant mass spectra of charged particle pairs, each particle assigned the pion mass for the CM energies and x intervals indicated. Cuts are as described in the text. Fig. 1a, c, d show opposite-sign combinations, fig. 1b same-sign combinations. Solid histograms show the data, the dotted lines give the smoothed Monte Carlo background prediction and the dashed lines the Monte Carlo background plus the additional fitted background as described in the text. The points with error bars show the data after subtraction of the sum of the predicted Monte Carlo background and fitted background. The solid curves give the results of fits to a relativistic Breit–Wigner as described in the text.

model for hadronisation (including baryon production) was used to describe the process $e^+e^- \to$ hadrons [3]. Apparatus acceptance and resolution, trackfinding efficiency, multiple scattering, photon conversion and secondary interactions were included in the simulation of events observed in the detector.

In the Field–Feynman model, the production of hadrons is controlled by various parameters. The parameters a_{FF} and σ_q control the quark longitudinal momentum and the momentum perpendicular to the primary quark direction in the fragmentation process. In addition, the ratio (u : d : s) suppresses strange particle production and QCD effects are controlled in the event generator by the value of the strong coupling constant, α_s. Of particular interest in this work is the parameter $P/(P + V)$, which gives the probability that a q and $\bar{q}$ in the fragmentation process combine to form a pseudoscalar rather than a vector meson (higher spin states are not included in this model). Mass suppression effects may raise this above the value 0.25 expected from statistical weights.

The model parameters were adjusted to give good agreement with the data at W = 34 GeV, in particular in the means and rms deviations of the charged particle multiplicity distribution, momentum spectrum, momentum spectrum transverse to the sphericity axis and total charged particle energy distribution. The parameter values found were consistent with our previously published work [4].

The simulated dipion mass spectra, with the combination from pairs of pions originating from the same ρ^0 removed, were obtained by smoothing the Monte Carlo predictions in order to reduce statistical fluctuations. This also has the effect of smearing the K^0 signal. The Monte Carlo curves, normalized to the number of entries in the mass range $1.2 < m_{\pi\pi} < 3.2$ GeV separately in each x-bin, are shown in fig. 1 superimposed on the data (dotted curves). Except for a slight discrepancy in the low mass region, the like-sign combinations show very good agreement. For the unlike-sign combinations, agreement at high masses is still obtained, but some differences are apparent below the rho mass region. This region is sensitive to the fine details of the fragmentation and receives contributions from many resonance decays. Nevertheless, the simulated $m_{\pi^+\pi^-}$ distribution is expected to be approximately correct in both magnitude and shape and, when subtracted from the data, clear ρ^0 signals are obtained but some background is still present. The final fit was made to the data after subtraction of the Monte Carlo prediction using an incoherent sum of a Breit–Wigner and a linear term. The object of this procedure was to obtain the gross features of the background from the Monte Carlo calculation while ensuring that the extracted ρ^0 signal remains insensitive to plausible variation of the parameters in the Monte Carlo program.

The amount of ρ^0 production was measured by fitting the difference between the data and the Monte Carlo prediction in the mass interval $0.52 < m_{\pi\pi} < 1.2$ GeV to a relativistic P-wave Breit–Wigner [5]

$$\mathrm{BW}(m) = m m_0 \Gamma / [(m^2 - m_0^2)^2 + m_0^2 \Gamma^2] ,$$

$$\Gamma = \Gamma_0 (q/q_0)^3 [2q_0^2/(q^2 + q_0^2)] ,$$

plus an additional linear term, where m_0, Γ_0 are the ρ^0 mass and width and q is the pion momentum in the $\pi\pi$ rest frame (q_0 the value for $m = m_0$). The detector resolution was folded with the nominal ρ^0 width of 158 MeV to obtain Γ_0 which was held fixed in the fit for each energy interval (varying from 160 MeV for $E_{\rho^0} = 3$ GeV to 190 MeV for $E_{\rho^0} = 9$ GeV).

The backgrounds obtained from the sum of the Monte Carlo predictions and the fitted linear terms (dashed lines) and the difference between these backgrounds and the data (points with error bars) are shown in fig. 1. The difference spectra agree well with that expected for the ρ^0. The fitted Breit–Wigners are shown by the solid lines in fig. 1. The fitted masses are 773 ± 15, 772 ± 19 and 778 ± 7 MeV for $W = 14$, 22 and 34 GeV respectively, in good agreement with the ρ^0 mass given by the Particle Data Group [6] of 776 MeV.

In order to estimate systematic errors, this analysis was repeated using different background distributions: (a) obtained by varying the parameters of the Field–Feynman fragmentation model over a wide range ($0.28 < a_{FF} < 0.56$, $0.28 < P/(P + V) < 0.56$, $0.32 < \sigma_q < 0.36$ GeV/c); (b) obtained from the LUND [7] model for fragmentation; (c) obtained from the like-sign invariant mass spectra (which cannot provide a complete description of the unlike sign invariant mass spectra). This procedure yielded ρ^0 signals which varied by at most 20% and this variation was used as an estimate of the systematic error. Finally, the same analysis procedure was applied to the like-sign mass spectra. No spurious ρ^0 signal was measured.

A second analysis was carried out on the 34 GeV data in which a simultaneous fit was made to the $\pi^+\pi^-$ and $K^\mp\pi^\pm$ invariant mass spectra. Only cuts (a)–(e) above were applied and since particle identification was not used, particles were treated both as pions and kaons. The invariant mass spectra were assumed to be given by the corresponding like-sign spectra plus a sum of contributions from ρ^0, K^{*0}, K^0 and ω meson decay products (or reflections resulting from wrong mass assignments) and an additional linear term. The like-sign spectra were normalised to the region $1.7 < m_{\pi\pi} < 2.7$ GeV and $2.0 < m_{K\pi} < 3.0$ GeV and the fit made over the ranges $0.42 < m_{\pi\pi} < 1.40$ GeV and $0.8 < m_{K\pi} < 1.4$ GeV. Standard masses and widths folded with the apparatus resolution were used in the fit. The reflections resulting from wrong mass assignments are not strongly momentum dependent and were described by a fixed shape for each decay mode. The result of the fit to the $m_{\pi^+\pi^-}$ spectrum, integrated over the range $0.1 < x < 0.7$, is shown in fig. 2. The fitted ρ^0 contributions are in good agreement with those obtained above. Integrated over the range $0.1 < x < 0.7$, the ratio of the cross section obtained by the Field–Feynman parametrisation of the background to that obtained by this method is 1.18 ± 0.22 (statistical error only).

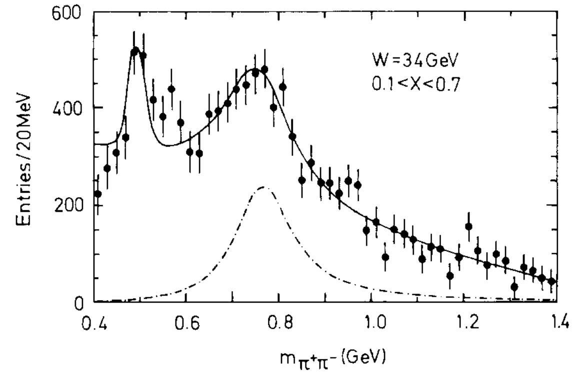

Fig. 2. The $m_{\pi^+\pi^-}$ spectrum following subtraction of the like-sign spectrum for W = 34 GeV. The solid curve shows the result of the fit and the dashed curve the ρ^0 contribution (second method described in the text).

A Monte Carlo method was used to measure the ρ^0 detection efficiency, defined by

$$\epsilon_{\rho^0}(x) = (n_r/N_r)/(n_g/N_g) ,$$

where n_g is the number of ρ^0's generated in the range x to $x + dx$ in N_g Monte Carlo events generated at the nominal centre of mass energy W, and n_r is the number of ρ^0's accepted in this interval after detector acceptance and analysis cuts in N_r Monte Carlo events, generated including radiative corrections and accepted by the detector. (The ρ^0's were assumed to be unpolarized.) At W = 34 GeV, the ρ^0 detection efficiency varies smoothly from ~40% at x = 0.1 to ~55% for $x > 0.2$. For all energies the efficiency is approximately flat in the range $0.2 < x < 0.7$ with average values of 59%, 68% and 54% at W = 14, 22 and 34 GeV respectively. For the second method described above the efficiency is ~3% higher.

The ρ^0 cross section was obtained from the measured ρ^0 signal and the total hadronic cross section

$$d\sigma(x)/dx = \sigma_{tot}[1/\epsilon_{\rho^0}(x)]\, \Delta n_0(x)/N_H \Delta x ,$$

where σ_{tot} is the total hadronic cross section [8], N_H the number of observed hadronic events and Δn_0 the number of ρ^0's obtained by integrating the fitted Breit–Wigner over the mass range $0.4 < m_{\pi\pi} < 1.2$ GeV in the range x to $x + \Delta x$.

Sufficient data were obtained at energies above 30 GeV to allow the analysis to be made in four x bins from x = 0.1 to x = 0.7. The scaled differential cross section $(s/\beta)\, d\sigma/dx$ for ρ^0 production is shown in fig. 3a. The errors shown are statistical only and do not include the 20% systematic error determined from different background calculations as detailed above or the 5% systematic uncertainty in σ_{tot}. Integration of the differential cross section gives (0.41 ± 0.04 ± 0.08) ρ^0/event in the range $0.1 < x < 0.7$. Also shown in fig. 3a is the $\pi^\pm$ cross section measured at the same energy [9]. In the range $0.1 < x < 0.4$, we measure

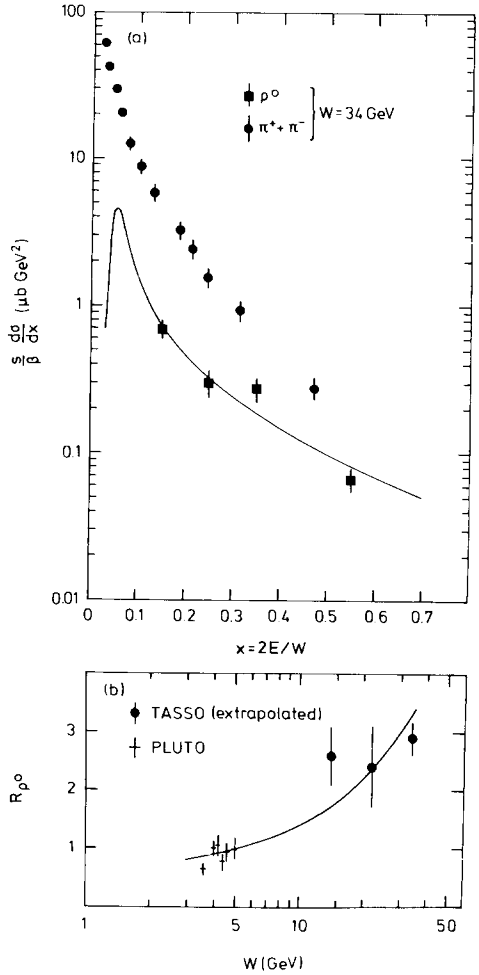

Fig. 3. (a) The scaled cross section $(s/\beta)\, d\sigma/dx$ for ρ^0 production at W = 34 GeV. Also shown is the cross section for $\pi^+ + \pi^-$ production at this energy. The smooth curve is the Field–Feynman Monte Carlo prediction for ρ^0 production assuming $P/(P + V)$ = 0.42. (b) $R(\rho^0) = \sigma(e^+e^- \to \rho^0 + \text{anything})/\sigma_{\mu\mu}$ as a function of the CM energy W (errors shown are statistical only). The curve shows a fit to the charged particle multiplicity [11] in $e^+e^- \to$ hadrons normalised to R_{ρ^0} measured at W = 5 GeV.

$\sigma(\rho^0)/\sigma(\pi^+ + \pi^-) = 0.24 \pm 0.03$ (stat.) ± 0.05 (syst.). Integration of the measured differential cross section gives $(0.22 \pm 0.02 \pm 0.05)$ ρ^0/event in the range $0.2 < x < 0.7$ at $W = 34$ GeV, in good agreement with the value obtained by analysing the mass spectrum integrated over this region as a single bin. Due to limited statistics and reduced acceptance for $x < 0.2$, the $W = 14$ and 22 GeV data have each been analysed in a single bin. At $W = 14$ (22) GeV, we measure $(0.33 \pm 0.06 \pm 0.07)$ $((0.22 \pm 0.06 \pm 0.05))$ ρ^0/event in the region $0.2 < x < 0.7$.

Within a Field–Feynman fragmentation model in which only pseudoscalar and vector mesons may be produced, the rate of ρ^0 production is mainly determined by the ratio $P/(P + V)$. From the measured rate of ρ^0 production in the range $0.2 < x < 0.7$ at $W = 34$ GeV, we deduce a value for $P/(P + V)$ of $0.42 \pm 0.08 \pm 0.15$ within this specific model [‡1]. This result is compatible with $V = P$ but also with $V = 3P$ as expected from the spin multiplicity factor $(2J + 1)$. The full curve shown in fig. 3a is the Monte Carlo prediction for ρ^0 production assuming $P/(P + V) = 0.42$ and shows good agreement with the data. The measured rates of ρ^0 production at $W = 14$ and 22 GeV in the region $0.2 < x < 0.7$ are also consistent with this value of $P/(P + V)$.

Integration of the differential cross section allows a measurement of $R_{\rho^0} = \sigma(e^+e^- \to \rho^0 + \text{anything})/\sigma_{\mu\mu}$, where $\sigma_{\mu\mu} = 4\pi\alpha^2/3s$ (s = square of CM energy W) is the cross section for muon pair production by e^+e^- annihilation. We extrapolate the measured contributions using the spectrum shape calculated by Monte Carlo to estimate R_{ρ^0}. At $W = 34$ GeV, the regions not measured, $x < 0.1$ and $x > 0.7$, contribute ~40% and ~3% of the total cross section respectively. At $W = 14$ (22) GeV, the regions $x < 0.2$ and $x > 0.7$ contribute 43 (59)% and 6 (4)% of the total cross section respectively. The results are shown in fig. 3b. The errors shown are statistical only. Also shown in fig. 3b are measurements at lower energy [10]. At $W = 34$ GeV, comparing this with the measured $\pi^\pm$ cross section [9] and setting $\rho^\pm$ production equal to ρ^0 production we conclude that approximately 30% of all charged pions come from rho-meson decay.

In conclusion, we have measured inclusive ρ^0 production at centre of mass energies $W = 14$, 22 and 34 GeV. At $W = 34$ GeV we measure $(0.41 \pm 0.04 \pm 0.08)$ ρ^0/event in the range $0.1 < x < 0.7$ from which a Monte Carlo extrapolation yields $R_{\rho^0} = 2.92 \pm 0.25$ (statistical error only). From this result, we deduce that approximately 30% of all charged pions come from rho-meson decay.

[‡1] Note that in this model, in addition to primary production, only ρ^0 production via the decays of η' is significant (12% of the total ρ^0 production).

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