PRODUCTION OF η MESONS IN e^+e^- ANNIHILATIONS AT $\sqrt{s}=29$ GeV

HRS Collaboration

S. ABACHI, C. AKERLOF, P. BARINGER, D. BLOCKUS, B. BRABSON, J.-M. BROM, B.G. BYLSMA, J. CHAPMAN, B. CORK, R. DeBONTE, M. DERRICK, D. ERREDE, C. JUNG [1], M.T. KEN, D. KOLTICK, P. KOOIJMAN, J.S. LOOS [2], E.H. LOW, R.L. McILWAIN, D.I. MEYER, D.H. MILLER, B. MUSGRAVE, H. NEAL, C.R. NG, D. NITZ, H. OGREN, H.W. PAIK, L.E. PRICE, J. REPOND, D.R. RUST, E.I. SHIBATA, K. SUGANO, R. THUN and R. TSCHIRHART

Argonne National Laboratory, Argonne, IL 60439, USA
Indiana University, Bloomington, IN 47405, USA
University of Michigan, Ann Arbor, MI 48109, USA
Purdue University, West Lafayette, IN 47907, USA
Lawrence Berkeley Laboratory, Berkeley, CA 94720, USA

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Data from e^+e^- annihilations at 29 GeV have been used to measure the production cross section and fragmentation function of η mesons. The signal is observed in the $\eta\to\gamma\gamma$ decay channel. The fragmentation for $p_\eta > 1.5$ GeV/c agrees well with the prediction of the Lund model, whereas the prediction of the Webber model lies above the data. The mean multiplicity is measured to be $\langle n_\eta \rangle = 0.58 \pm 0.10$ η mesons per hadronic event, of which 0.51 represents the direct production of η and η' mesons in the fragmentation chain.

The annihilation of e^+e^- into hadrons is well understood in the context of the quark–parton model and QCD. In this picture, the e^+e^- annihilates to form a virtual photon or Z^0, that subsequently emits a quark–antiquark pair, which is sometimes accompanied by one or more gluons. These partons then fragment to form hadrons which, in turn, may decay to give the particles observed in the detector. The fragmentation process is less well understood theoretically, but has been reasonably parametrized by Monte Carlo models. One of the most successful models, in recent years, has been the Lund string fragmentation model [1]. This model contains decay branching ratios of many mesons and baryons including, in particular, the states containing heavy quarks. There are, in addition, other arbitrary parameters such as the vector-to-pseudoscalar ratio and the diquark-to-quark ratios that must be extracted by comparing the model predictions to measurements of hadron production. At present the Lund model gives a reasonable parametrization of the fragmentation process and can account for most of the known data [2].

In this paper, we present new measurements of η-meson production in e^+e^- annihilation at 29 GeV. These data agree well with the expectation that the η mesons come predominantly from direct production of the pseudoscalar mesons, η and η' in the fragmentation chain. By comparison, the π mesons come predominantly from decays of higher mass states, with only a small contribution from the direct production, and so are less sensitive to the initial parton–hadron transitions.

The data sample on which this paper is based, was collected over a period of five years by the High Resolution Spectrometer (HRS) at the PEP e^+e^- storage ring at a center-of-mass energy $\sqrt{s}=29$ GeV, and corresponds to an integrated luminosity of 300 pb^{-1}.

The HRS detector [3] consisted of a solenoidal

[1] Present address: Stanford Linear Accelerator Center, Stanford, CA 94305, USA

[2] Present address: Bell Laboratories, Naperville, IL 60566, USA.

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magnet of 4.5 m diameter with a central field of 1.6 T, and which contained 17 layers of drift chambers. The magnetic field volume also contained 40 barrel shower counter modules with alternate layers of lead and scintillator, each subtending an angle of 9° in azimuth. the modules were segmented in depth into a $3X_0$ and an $8X_0$ section with a single layer of 14 proportional wires separating the two regions [4]. The energy resolution of the shower counters was $\sigma_E E = 16\%/\sqrt{E}$ (E in GeV). The z position, along the beam axis, was determined by current division in the PWC layer to an accuracy of $\sigma(z) = 2.5$ cm. The forward and backward regions were covered by endcap shower counters.

Hadronic annihilation events were selected by requiring a total visible energy of 10 GeV and a minimum of five charged tracks reconstructed in the detector.

The η meson decays predominantly into neutral particles, and for the present analysis, we use the decay mode $\eta \to \gamma\gamma$. To detect the photons from the η decay, only the barrel shower counter system was used because of its superior position and energy resolution. The algorithm for extracting photons from the shower counter information is as follows:

– All PWC wires with a pulse height above threshold were scanned to create clusters of contiguous wires in azimuth. In this clustering, gaps of up to three wires were allowed, however, no cluster was allowed to have two or more gaps.

– Inside these clusters, a scan was made to ensure consistent z positions on all wires. It this was not the case, the cluster was split into two or more subclusters in each of which the z information was consistent.

– From previous measurements of radiative Bhabha scattering, it was determined that photon/electron clusters typically have fewer than seven PWC wires, so any cluster with ten or more wires was split into two, at the wire with the lowest pulse height, regardless of the z information.

– All charged tracks in the event were extrapolated to the PWC plane of the shower counter, and clusters with consistent azimuthal angles and z positions were associated with the charged tracks.

– If only one cluster inhabited a module, the energy of that module was associated with that cluster. If more clusters appeared in one module, the energy was shared equally between all clusters, with the exception of clusters associated with tracks, which were given the mean energy deposition for a minimum-ionizing particle of 200 MeV. The remaining energy of the module was then distributed equally among the non-track clusters.

– All clusters not associated with tracks were then

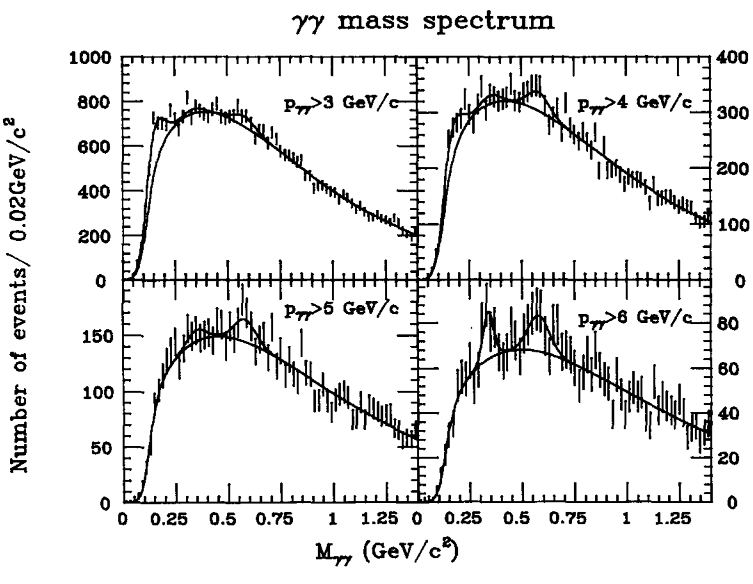

Fig. 1. Photon–photon mass spectra for (a) $p_{\gamma\gamma} > 3$ GeV/c, (b) $p_{\gamma\gamma} > 4$ GeV/c, and (c) $p_{\gamma\gamma} > 5$ GeV/c, (d) $p_{\gamma\gamma} > 6$ GeV/c. Lines are results of the fits discussed in the text.

considered as photon candidates.

For the final analysis, only those photons which did not share a shower counter module with any other photons and which had at least 250 MeV of energy were used.

In fig. 1 we show representative $\gamma\gamma$ mass spectra where it is required that the opening angle of the photon pair by less than 90°. Fig. 1a shows the spectrum for $p(\gamma\gamma) > 3$ GeV/c, and figs. 1b, 1c and 1d show the equivalent spectra for $p > 4$ GeV/c, $p > 5$ GeV/c, and $p > 6$ GeV/c. Clear enhancements are seen at $M(\gamma\gamma) \cong 550$ MeV corresponding to the η meson. In fig. 1d an additional enhancement is seen at ~ 370 MeV. This enhancement is due to the $K^0_s \to \pi^0\pi^0$ decay where each π^0 is detected as a single photon cluster, due to the small opening angle in the $\pi^0 \to \gamma\gamma$ decay.

To measure the η signal, the $\gamma\gamma$ mass spectra were fit to a smooth background, with gaussian contributions at the η, π^0, and $K^0(\gamma\gamma)$ masses. The widths of the resonance contributions were left as free parameters in the fit. The lines in fig. 1 show the results of the fits. This procedure was repreated for many momentum bins, and table 1 gives the number of signal events as a function of $Z(=E_\eta/E_{beam})$. The errors include both a statistical and a systematic contribution. The systematic errors, which dominate for values of $Z < 0.5$ were determined by varying the parameters in the fits to the $\gamma\gamma$ mass spectra.

The acceptance was determined using a Monte Carlo simulation. Events were generated with the Lund Monte Carlo generator and passed through a simulation of the detector. The resulting events were then analysed in the same way as the data, to extract the number of detected η mesons. Table 1 shows the rsulting acceptances, including a BR$(\eta\to\gamma\gamma)$ of 39%. The systematic error on the acceptance, estimated by examination of the various contributing factors, is 15%, independent of Z. This error is not included in the cross section given in table 1. Integrating the dis-

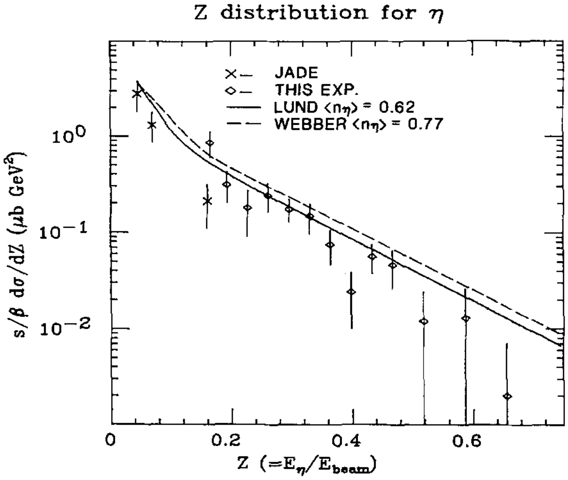

Fig. 2. Scaling cross section for η-meson production as a function of the scaled energy Z. ◇ : this experiment. ×: JADE data. Errors do not include a 15% systematic uncertainty in the normalization. The full (dashed) line is the prediction of the Lund (Webber) model.

Table 1

Number of events, detection efficiency, and scaling cross section for η-meson production.

Z	Number of events	Acceptance $\varepsilon\cdot$BR$(\eta\to\gamma\gamma)$ (%)	$(s/\beta)\, d\sigma/dZ$ (μb GeV^2)
0.160	97±30	0.95	0.85 ±0.26
0.193	45±15	1.15	0.31 ±0.11
0.227	30±15	1.35	0.18 ±0.09
0.261	49±16	1.65	0.24 ±0.08
0.296	42±11	1.95	0.172±0.045
0.330	44±15	2.40	0.146±0.050
0.364	26± 9	2.75	0.075±0.029
0.398	10± 6	3.30	0.025±0.014
0.433	26± 9	3.70	0.056±0.019
0.467	25±11	4.30	0.046±0.020
0.518	16±16	5.05	0.012±0.012
0.587	20±20	6.15	0.013±0.013
0.656	4±10	7.20	0.002±0.005

tribution we find $N_\eta(p>1.5\ \mathrm{GeV}/c)=0.20\pm0.03\pm0.03$ per event.

Fig. 2 shows the scaling cross section, $(s/\beta)\ d\sigma/dZ$, for η mesons, as a function of Z. Here we use a radiatively corrected value of $\sqrt{s}=28.3$ GeV. Also shown in fig. 2 are the data from the JADE experiment [5] at PETRA. Where the data overlap, there is good agreement.

The full line of fig. 2 is the prediction of the Lund model (V.5.3) which has been modified to take into account the recent measurements [6] of the charm meson decay branching ratios[#1]. There is generally good agreement between the data and the model, both in shape and in normalization. The best fit to the data in the range $0.160\leqslant Z\leqslant 0.467$, using the shape predicted by the Lund model after incorporating the new charm decay rates [6] [#1], yields a multiplicity per event $\langle n_\eta\rangle=0.58\pm0.08$, to be compared to the predicted number of $\langle n_\eta\rangle_{\mathrm{Lund}}=0.62$. The latter value contains a direct η production of 0.33 per event, plus 0.22 η's coming from the decay of the η′(958) meson. In addition, there is a small contribution of 0.07 η's per event resulting from charm decay. If the fit is extended to the full measured Z range, the mean multiplicity drops to $\langle n_\eta\rangle=0.52\pm0.08$, and yields a significantly poorer χ^2, possibly indicating that the Lund fragmentation is somewhat harder than suggested by the data. We have reported a similar result in studies of other resonances [7].

The dashed line of fig. 2 shows the prediction of the Webber cluster model [8] after changing the charm decay to agree with the new data [6] [#1]. In this model, heavier particles are suppressed relative to lighter particles by the smaller phase space available in the cluster decay. It is clear from the dashed line that this model overestimates the η production and, in fact, the predicted multiplicity is $\langle n_\eta\rangle=0.77$. We have investigated the source of this discrepancy by fitting all of the data of fig. 2 to the sum of the direct η, the η's from η′ decay and the charm contribution; the latter was fixed, whereas the direct η and η′ contributions were allowed to vary in the fit. The resulting mean multiplicity was $\langle n_\eta\rangle=0.55\pm0.13$. However, the fit reduced the direct η contribution by 0.6 from that given by the model. The η′ contribution was unchanged within errors. We conclude that the Webber model significantly overestimates the direct η production.

By contrast, there is much less sensitivity of the Lund model to these three contributions, and within reasonable variations, the mean multiplicity is stable to ±0.05. The fit becomes unacceptable when the charm contribution is raised above 0.15 η/event.

These studies show that the Lund model gives a better representation of the data and our best estimate for the overall multiplicity is $\langle n_\eta\rangle=0.58\pm0.10$ per event. Since the contributions from η′ and charm decay are relatively small, the data can be taken as establishing the primordial production of pseudoscalar mesons in the fragmentation chain.

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[#1] The inclusive $\mathrm{Br}(D^0\to\eta+X)$ was decreased from 12% to 1% and $\mathrm{BR}(D^+\to\eta+X)$ was decreased from 4% to 1%. The unknown $\mathrm{BR}(D_s^+\to\eta+X)$ was varied in the range from 12% to 50%. The curve in fig. 2 corresponds to $\mathrm{BR}(D_s^+\to\eta+X)=35\%$.

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