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Low-Mass Electron-Pair Anomaly in 17-GeV/c π^-p Collisions

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Inclusive e^+e^- production in 17-GeV/c π^-p collisions has been measured. An excess of e^+e^- pairs over those from known sources for $0.1 \leq m_{ee} \leq 0.6$ GeV and $x < 0.5$ was found. No evidence is found for enhancements in specific final states involving electrons and photons or charged particles. The photon multiplicity associated with these pairs is measured.

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Recently there have been reports of both low-mass $\mu^+\mu^-$ [1-3] and e^+e^- [4,5] production above what is expected from known meson decays. Dilepton production is one explanation for the anomalous single-lepton to pion ratios at low p_T.[6] However, the experimental situation regarding the existence of anomalous e/π ratios is still unsettled. We report here the first observation of e^+e^- pairs in which associated photons, as well as charged particles, are measured. The experiment was performed with a hydrogen target in the multiparticle spectrometer at the Brookhaven National Laboratory alternating-gradient synchrotron. Charged particles were observed over most of the full solid angle.[7] Electron identification was made by two Li-foil transition-radiation detectors (TRD)[8] within the magnet and two lead-scintillator shower detectors (SD)[9] outside the magnet. The back SD subtended $\pm 15°$ around the beam axis and detected e^+ and e^- above 2.5 GeV/c, as well as most produced photons above 0.5 GeV. The side SD, centered at 35°, detected e^+ between 0.8 and 1.8 GeV/c.

Two triggers were collected. Each required correlated hits in both TRD's and back SD for an e^-. Trigger PAIRA required an e^+, also in the back SD, and favored Feynmann $x > 0.45$ for the pair. Trigger PAIRB required an e^+ in the side SD; it required $x > 0.2$ and had maximum acceptance near $x = 0.4$. The pair mass acceptance was essentially flat below 1 GeV; the p_T acceptance was uniform at high x and gently falling with p_T below $x = 0.5$.

The analysis program selected good electrons by stringent cuts on TRD pulse heights and comparison of SD energy with momentum. Hadron rejections for e^-, PAIRA e^+, and PAIRB e^+ were greater than 3000, 3000, and 100, respectively. In order to survive as a direct pair, the trigger e^+ and e^- had to satisfy tight vertex cuts with the beam and produced charged particles. Each member of a direct pair was fitted to a γ hypothesis with all oppositely charged tracks. A trigger e^+ or e^- satisfying this fit with any nontrigger electron was removed from the sample. Surviving direct pairs were divided into two categories: If the pair could be constrained to a γ-fit hypothesis it was defined as low mass. If not, it was called high mass. The demarcation between these categories was about 0.1 GeV. For pair masses above 0.2 GeV there was negligible probability for the event to be in the low-mass sample. The low-mass sample contains a residual contamination from external γ conversions within 10 cm of the production point. Further details on the experiment, calibrations, and analysis are given elsewhere.[10]

The resulting mass distributions above 0.2 GeV are shown in Fig. 1. We expect contributions from three classes of sources: direct decays ρ, ω

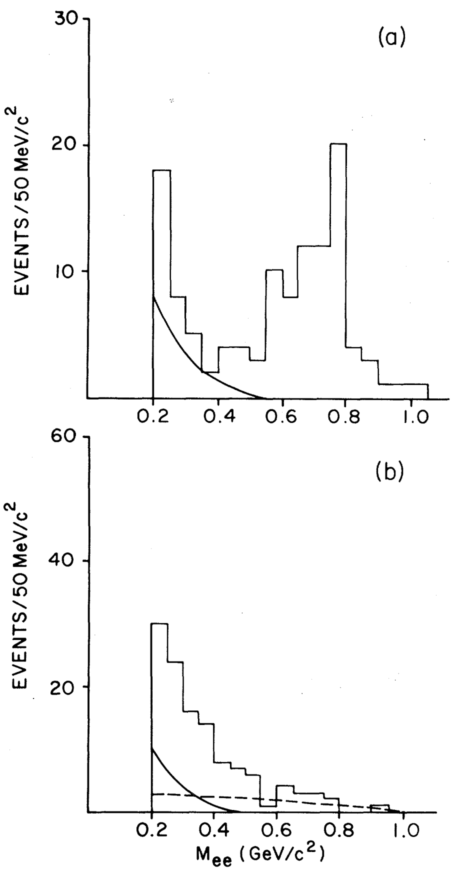

FIG. 1. Electron pair mass distributions for (a) PAIRA and (b) PAIRB. The contributions from $\eta \to \gamma e^+e^-$ and $\omega \to \pi^0 e^+e^-$ are shown as the solid line. Hadron background is indicated by the dashed line.

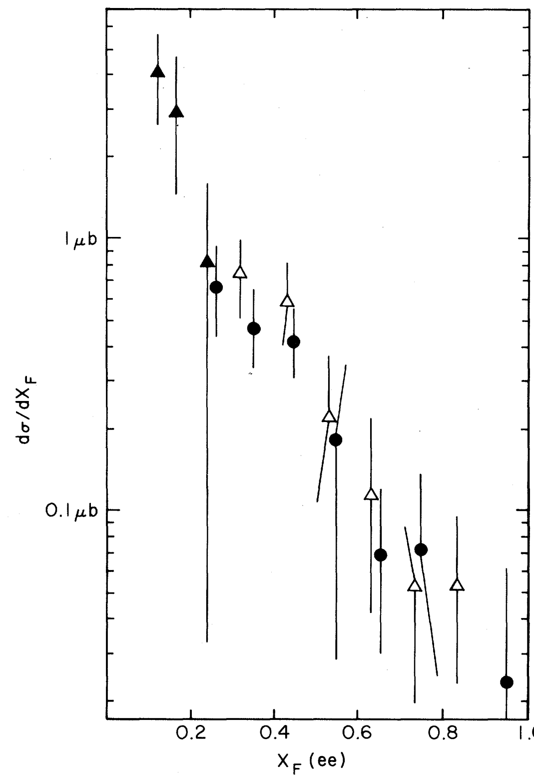

FIG. 2. Feynman x distribution of anomalous electron and muon pairs. Circles, data from this experiment; solid triangles, electron data from Ref. 4; open triangles, muon pair data from Ref. 3. Electron pairs have been weighted by the factor discussed in the text.

$\to e^+e^-$, internal conversion decays $\eta \to \gamma e^+e^-$ and $\omega \to \pi^0 e^+e^-$, and background events simulating direct electron pairs.

The direct decay contribution is clearly evident in the PAIRA sample but is absent in PAIRB. Fits to the PAIRA data with use of an average radiative energy loss for electrons reproduce the data well and yield 54 ± 8 direct decay events for this trigger. A calculation with use of known inclusive ρ and ω cross sections[11] and branching ratios[12] predicts 60 ± 10 PAIRA ρ and ω direct decays. The same calculation predicts 10 ± 2 events for PAIRB, in agreement with our observation.

Pairs from internal conversion decays have been determined from our direct decay signal and the measured inclusive and semi-inclusive production of η, ω, and ρ in π^--p collisions.[13] These cross sections, together with our calculated acceptances, known internal conversion probabilities,[14] and pair mass distributions,[13] allow the computation of the ratio of pairs from internal conversions in any mass interval to the direct signal. This source of pairs is indicated in Fig. 1. An independent estimate of the internal conversion pairs was made from our observed mass distribution of γe^+e^- in both low- and high-mass samples. A photon was defined as a localized energy deposit in the SD, of energy >0.5 GeV, away from the extrapolated hit position of any charged track. Here the $\eta \to \gamma e^+e^-$ signal may be evaluated directly. This estimate gives 11 ± 4 and <24 (95% confidence level) internal conversion events in the PAIRA and PAIRB samples, respectively, compared with 22 ± 8 and 22 ± 8 found from the ratio to the direct signal.

The only appreciable backgrounds are due to hadron leakage into the electron sample and pairs of true electrons from different γ's. Both were evaluated with use of data from this experiment. The hadron background for PAIRB is shown in Fig. 1 and is negligible for PAIRA. Two-photon backgrounds were 4 ± 1 for PAIRB and 1.0 ± 0.3

for PAIRA.

After known sources and backgrounds of electron pairs are removed, there remains an unexplained excess of events at low x and $m_{ee} \leq 0.6$ GeV. Integrating over p_T we find $d\sigma/dx = (3.9 \pm 1.4\ \mu\text{b}) \exp[-(5.5 \pm 0.7)x]$. The p_T dependence of all pairs with $0.2 < m_{ee} < 0.6$ GeV and $x < 0.5$ is well represented by $dN/dp_T^2 \sim \exp[-(5.7 \pm 2.2)p_T^2]$. Our observed shape in p_T^2 is similar to the expectation for e^-e^+ from η and ω internal conversions. This low-mass anomaly is similar to that observed in other e^-e^+ (Refs. 4 and 5) and $\mu^+\mu^-$ (Refs. 1–3) experiments. Figure 2 shows the x distribution of the anomalous pairs in the mass interval $0.2 < m_{ee} < 0.6$ GeV, together with other results at a similar energy.[3,4] Here electron pairs have been weighted by the kinematic factor $(1+2z^2)(1-4z^2)^{1/2}$, where $z = m_\mu/m_{\text{pair}}$, to allow direct comparison of electron and muon pairs. A fit to the three data sets (with e^+e^- weighted as $\mu^+\mu^-$) is given by $d\sigma/dx \approx (5.5 \pm 2.1\ \mu\text{b}) \exp[-(6.0 \pm 0.9)x]$.

It has recently been suggested[15] that the origin of anomalous low-mass lepton pairs is the internal conversion decay of a $J^P = 0^-$ partial wave produced in hadron collisions with a broad mass enhancement centered at 0.4 GeV. Such a mechanism implies that anomalous pairs are accompanied by a photon. Using the back SD, we have measured the associated photon multiplicity in events with a direct e^-e^+ pair. Our Monte Carlo calculation indicates that 81% of the γ's from $\pi^0 \to \gamma e^+e^-$ triggers would be detected, whereas for $\eta \to \gamma e^+e^-$ our efficiency is 79%. These efficiencies are insensitive to variation in the parent mesons' mass, x, or p_T distributions. The $J^P = 0^-$ source proposed[15] should yield observable γ's with efficiency similar to those from π^0 and η internal conversion. Figure 3 shows the associated photon multiplicity for three kinematic regions of the pair. We find that in the low-mass event sample for which at least one γ always exists, the fraction, f_0, of events with zero photons is 0.214 ± 0.010, consistent with our detection efficiency. For $0.1 < m_{ee} < 0.6$ GeV and $x < 0.5$ (dominantly the anomalous pairs), f_0 is 0.304 ± 0.035. When the events in the anomalous region due to η and ω internal conversions are subtracted, we obtain $f_0 = 0.359 \pm 0.042$. The fraction f_0 for the anomaly after subtraction is different from that for the low-mass sample by 3.4 standard deviations. Associated charged-particle multiplicities are similar for the two distributions; thus we expect that the associated π^0 production would be similar.

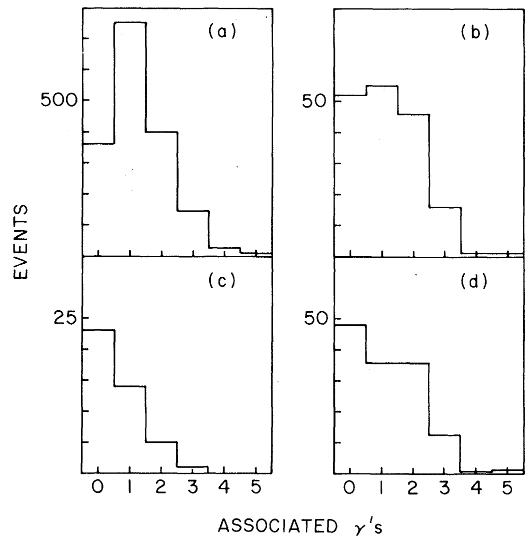

FIG. 3. Associated γ multiplicity distributions (for γ energies above 0.5 GeV). (a) Low mass, $x < 0.5$ (mainly π^0 Dalitz decay). (b) $0.1 < m_{ee} < 0.6$ GeV, $x < 0.5$ (mainly anomaly). (c) $0.6 < m_{ee} < 0.9$ GeV, $x > 0.7$ (mainly ρ, ω direct decay). (d) events from (b) after η and ω internal conversion contribution subtraction.

We conclude that the anomalous pairs are unexplained by such a γe^+e^- source.

We have searched for the existence of radiative decay modes of various states which might explain the anomalous pairs. For this study, we have selected events with $0.1 < m_{ee} < 0.6$ GeV and $x < 0.5$. Many effective-mass combinations have been examined including γe^+e^-, $\pi^0 e^+e^-$, $\pi^\pm e^+e^-$, $\pi^+\pi^- e^+e^-$, $\pi^\pm\pi^0 e^+e^-$, and $\pi^+\pi^-\pi^0 e^+e^-$. No significant structure is observed in any such channel. It has been suggested[16] that radiative decays of tensor mesons may produce the anomalous pairs. We see no enhancements in $\rho^0 e^+e^-$, $\rho^\pm e^+e^-$, or ωe^+e^- and conclude that less than 7% of the anomaly can be attributed to any of these decays.

The anomalous e^+e^- pairs seen in this experiment are an obvious contributor to the single-e/π ratio at low p_T. Assuming that the anomalous pair production of Fig. 2 is symmetric about $x = 0$, we compute that these pairs contribute about 2×10^{-4} to the e/π^+ ratio in $\pi^- p$ collisions at $x = 0$ and $p_T = 0.5$ GeV/c. This calculation agrees well with the result of an experiment[17] with the same mass cutoff imposed; it is somewhat larger than the result of a second experiment[18] with no mass cutoff. We find it plausible that the pairs observed in this experiment are the dominant source of single direct electrons at low p_T.

If the anomalous e^+e^- pair signal observed here were to be extrapolated to zero mass with the usual internal conversion mass distribution,[14] it would predict a large direct γ/π^0 ratio. We estimate $\gamma/\pi^0 = 0.15$ for $x = 0.3$, integrated over all p_T. Available data on direct photons in similar reactions in this energy range[19] suggest $\gamma/\pi^0 < 0.15$. Direct observation of internal conversion of hadronic bremsstrahlung[20] in $\pi^- p$ collisions demonstrates that this source is negligible in the kinematic range of this experiment.

In conclusion, we find evidence for anomalous electron pair production, for $m_{ee} < 0.6$ GeV. These pairs are not accompanied by an excess of photons and do not appear to be caused by specific particle decays such as $0^- \to \gamma e^+ e^-$ or $2^+ \to 1^- e^+ e^-$. Anomalous pair production is strongly central (x near 0). It is larger than expected from the Drell-Yan mechanism by a factor of about 10; it is in qualitative agreement with models based upon the annihilation of wee quarks produced in hadronic collisions.[21]

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