SLAC – PUB – 3780
LBL – 20280
September 1985
(T/E)

CHARGED MESON PAIR PRODUCTION IN $\gamma\gamma$ INTERACTIONS*

J. Boyer, D.L. Burke, F. Butler, G. Gidal, G.S. Abrams, D. Amidei[a], A.R. Baden, T. Barklow, A.M. Boyarski, M. Breidenbach, P. Burchat, J.M. Dorfan, G.J. Feldman, L. Gladney, M.S. Gold, G. Goldhaber, L.J. Golding[b], J. Haggerty, G. Hanson, K. Hayes, D. Herrup, R.J. Hollebeek, W.R. Innes, J.A. Jaros, I. Juricic, J.A. Kadyk, D. Karlen, S.R. Klein, A.J. Lankford, R.R. Larsen, B.W. LeClaire, M.E. Levi[c], N.S. Lockyer[d], V. Lüth, C. Matteuzzi[c], M.E. Nelson[e], R.A. Ong, M.L. Perl, B. Richter, K. Riles, M.C. Ross, P.C. Rowson, T. Schaad, H. Schellman[a], W.B. Schmidke, P.D. Sheldon, J.R. Smith, G.H. Trilling, C. de la Vaissiere[f], D.R. Wood, J.M. Yelton, and C. Zaiser

Lawrence Berkeley Laboratory and Department of Physics
University of California, Berkeley, California 94720

Stanford Linear Accelerator Center
Stanford University, Stanford, California 94305

Department of Physics
Harvard University, Cambridge, Massachusetts 02138

ABSTRACT

The cross section for the production of $\pi^+\pi^-$ or K^+K^- pairs in $\gamma\gamma$ interactions is measured for $m_{\pi\pi}$ between 1.7 and 3.5 GeV/c^2 and for two intervals of $\gamma\gamma$ center of mass scattering angle. Results are compared with predictions of a QCD model.

Submitted to Physical Review Letters

*This work was supported in part by the Department of Energy under contracts DE-AC03-76SF00098 and DE-AC03-76SF00515.

[a] Present address: U. of Chicago, Chicago, IL 60637
[b] Present address: Therma-Wave Corporation, Fremont, CA 94539
[c] Present address: CERN, CH-1211 Geneva 23, Switzerland
[d] Present address: U. of Pennsylvania, Philadelphia, PA 19104
[e] Present address: California Institute of Technology, Pasadena, CA 91125
[f] Present address: LPNHE, Univ. Pierre Marie Curie, Paris, France F-75230

Photon-photon scattering is an excellent testing ground for Quantum Chromodynamics (QCD). In a QCD model, Brodsky and Lepage[1] have calculated the cross section for the exclusive two-body processes $\gamma\gamma \to h^+h^-$ at large $\gamma\gamma$ invariant mass, $\sqrt{s}$, and fixed $\gamma\gamma$ center of mass scattering angle, θ^*. They assume that the matrix element factorizes into a hard scattering amplitude and a distribution function related to the pion form factor, whose value is taken from experiment. In particular their absolute prediction is that near 90 degrees in the gamma gamma center of mass

$$\frac{d\sigma/dt\,(\gamma\gamma\to\pi^+\pi^-)}{d\sigma/dt\,(\gamma\gamma\to\mu^+\mu^-)} \simeq \frac{4|F_\pi(s)|^2}{1-\cos^2\theta^*} \sim \frac{0.6\ \mathrm{GeV}^4}{s^2}\ .$$

Their predictions are rather insensitive to the detailed form of the distribution function.

Previous measurements[2,3] have verified the order of magnitude of the cross section predicted by this model. We have measured the differential cross sections for the production of pion and kaon pairs,

$$d\sigma(e^+e^- \to e^+e^-(\pi^+\pi^- + K^+K^-))/d\ \cos\theta^* \qquad (1)$$

for dipion masses between 1.7 and 3.5 GeV/c^2 with substantially improved statistics. We have also measured the Q^2 dependence of this cross section by studying events in which one of the outgoing beam electrons is seen in the detector. The acceptance of the detector effectively limits us to the large angle region of $|\cos\theta^*| < 0.5$. In this analysis we have used a data sample from the Mark II detector at PEP corresponding to an integrated luminosity of 230 pb^{-1} at $E_{CM} = 29$ GeV.

The Mark II detector has previously been described in detail.[4] Charged particles are tracked in multilayer cylindrical drift chambers within a 2.3 kg solenoidal magnet. The momentum resolution for tracks constrained to the vertex is

$$\Delta p / p = [(0.025)^2 + (0.01p)^2]^{1/2} \qquad (p \text{ in GeV}/c) .$$

Forty-eight scintillation counters surround the drift chamber inside the magnet coil and are used both to trigger and provide time of flight information. Since such information can only distinguish π's and K's below about 1 GeV/c, we can only measure their combined cross section. Protons can be identified below about 1.5 GeV/c. Liquid argon calorimeter modules cover about 64% of 4π sr and contain 14 radiation lengths of lead and argon. The readout strips are parallel, perpendicular and at 45 degrees to the beam axis giving an rms angular resolution of about 8 mrad in both azimuthal and dip angles. The rms energy resolution for both electrons and photons is approximately

$$\Delta E / E = 0.13/\sqrt{E} \ .$$

The detector is surrounded by four layers of steel plate absorbers and proportional tubes used to identify muons over 55% of the solid angle. A particle is identified as a muon if it traverses at least three layers of the absorber and has a range consistent with that expected for a muon. The muon system is ineffective for particles with momenta below $\approx$ 750 MeV, and so, we restrict our measurement to the region of $\sqrt{s}$ greater than 1.7 GeV/c^2. In addition, there is a small angle tagging system (SAT) that consists of three sets of four planar drift chambers and a pair of lead-scintillator electromagnetic shower counters and covers polar angles between 21 and 82 mr from the beam axis. The energy resolution of the shower counters was found to be $\sigma/E = 15.5\%/\sqrt{E}$ using Bhabha events. This system detects an outgoing electron or positron (tagged event) in $\approx$ 10% of the events of reaction (1).

The basis of the measurement is to use the liquid argon calorimeters (LA) and the muon system to efficiently reject electrons and muons arising from the QED processes $ee \rightarrow eeee$ and $ee \rightarrow ee\,\mu\mu$.

We require events to have two well-measured oppositely-charged tracks whose vertex is within 10 cm of the interaction point along the beam direction and 5 cm in radius. Their total charged energy is required to be less than 40% of E_{CM} and their net P_{T} must be $< 300\,\mathrm{MeV}/c$. Events are rejected if they contain a detected photon that deposits more than 200 MeV in the liquid argon (250 MeV in the endcaps), unless the photon is within 40 cm of the nearest charged track, or makes a low invariant mass with either charged track. A photon found within 40 cm of a charged track is assumed to be associated with it, and its energy in the LA is added to that of the charged track. These cuts isolate $\gamma\gamma$ events with a true two-prong topology. Purely QED processes are then rejected by a series of cuts requiring that both tracks be in a fiducial volume that insures good muon and electron identification. Neither track may deposit more than 60% of its energy in the liquid argon. This cut insures that the electron pair contamination is negligible ($<$ 1%). Events are also rejected if either track has enough muon chamber hits so that it is consistent with the hypothesis that it is a muon.

Efficiencies are determined by generating pion pairs, kaon pairs, and muon pairs with the Monte Carlo event generator GGDEPA[5] and the full detector simulation. The efficiencies were determined as a function of cos θ^* and $\sqrt{s}$ and were found to vary from 2% at low mass and high cos θ^* to 15% at high mass and low cos θ^*. For hadrons the efficiency must be corrected for interactions in the coil or LA that cause the the energy deposited in the LA to surpass the above electron cut. A pure sample of pions from $\psi \rightarrow \rho\pi$ decay (taken at SPEAR) was used to measure the probability that a pion will deposit more than 60% of its momentum in the LA. We find this probability to vary from 50% to 10% over the momentum range $0.2 < p < 1.5\,\mathrm{GeV}/c$. The same result is used for kaons.

Two estimates are made of the residual muon contamination. First the Monte Carlo is used to determine the probability that a muon is called a pion. For the second method we consider events having one identified pion and one identified muon. These are primarily muon pairs with one misidentified track. The small contribution of pion pairs where one pion is called a muon is subtracted using the pion pair Monte Carlo. The ratio of the number of these events to the number of detected muon pair events gives another measure of the probability that a muon is called a pion. Finally, we use the Monte Carlo to determine the detection efficiency for muon pair events, which together with the above probability and the number of detected muon pair events measures the muon contamination. The resulting corrections agree and range from 2% to 21% with associated errors approximately half those values. The contamination from $\gamma\gamma \rightarrow \bar{p}p$ is negligible[6] for the particle momenta in this analysis.

All events are treated as pion pairs. The number of observed events in each bin, $N(\cos\theta_i^*, m_{\pi\pi_j})$, varies from 62 $(0. < |\cos\theta^*| < 0.3,\ 1.7 < m_{\pi\pi} < 1.8)$ to 2 $(0.3 < |\cos\theta^*| < 0.5,\ 3.0 < m_{\pi\pi} < 3.5)$. The efficiencies and the luminosity function[7]

$$L(\sqrt{s}\,) = \left[\frac{2\alpha}{\pi} \ln \frac{E_b}{m_e}\right]^2 \frac{f\,(\sqrt{s}\,/2E_b)}{\sqrt{s}}$$

where

$$f\,(z) = (2 + z^2)^2 \ln\left(\frac{1}{z}\right) - (1 - z^2) \cdot (3 + z^2)$$

are used to determine the cross section $\sigma(\gamma\gamma \rightarrow \pi^+\pi^- + K^+K^-)$ in bins of $m_{\pi\pi}$ for two intervals of $|\cos\theta^*|$. The efficiency for each bin of $(\cos\theta_i^*, m_{\pi\pi_j})$ is taken as a weighted average of the efficiencies for pion pairs and for those kaon pairs which contribute to the same bin when treated as pions. The relative numbers of kaons and pions are calculated using the parent distributions predicted by reference (1) and its ansatz, that at fixed $\sqrt{s}$, $d\sigma(\gamma\gamma \to K^+K^-)/dt = (f_K/f_\pi)^4 d\sigma(\gamma\gamma \to \pi^+\pi^-)/dt$, with $(f_K/f_\pi)^4 = 2.0$. The weights are proportional to the luminosity function at the appropriate values of $\sqrt{s}$.

The results are shown[8] in Figure 1 compared to the absolute hard scattering predictions of reference (1) integrated over the same two intervals in $|\cos\theta^*|$. While there is good agreement above 2.1 GeV/c^2, there is a discrepancy at the lower masses, where the influence of the f (1270) is still large. Higher mass resonances as well as resonance interference with the $\pi\pi$ continuum can also contribute. In Figure 2 we replot this same data as a function of $|\cos\theta^*|$. Following reference (1), we express the ordinate as the scaling function $s^4 d\sigma/dt$. The limited statistics and angular range prevent us from checking the predicted rise with $|\cos\theta^*|$ in the mass region above 2.1 GeV/c^2.

For tagged events we project the SAT tracks back to the interaction region. A cut is made on the distance of closest approach to the beam axis. The cut is scaled according to the expected error in z to insure comparable efficiencies for small and large angle SAT tracks. Monte Carlo estimates of tagging efficiencies indicate that they vary by less than 25% over the angular range covered. Most of the tagged meson pairs have $m_{\pi\pi}$ below 2 GeV. Their Q^2 distribution, uncorrected for acceptance or efficiency, is shown in Figure 3 together with the corresponding result for identified muon pairs. The histogram is the result of a QED muon pair Monte Carlo simulation (with SAT tagging) and describes the data well. It can be seen clearly that the Q^2 distribution of hadron pairs falls off more steeply with Q^2 than that of the muon pairs, probably confirming that these events are still in the resonance region.[9] No clear predictions have yet been made for such $\gamma\gamma^*$ scattering in the model of Brodsky and Lepage.

We conclude that, at even relatively modest invariant masses between 2.1 and 3.5 GeV, the predictions of the QCD model are consistent with our observations. The statistical errors of our measurements are still relatively large, however, so detailed comparisons of the differential cross section with that expected from QCD are inconclusive.

References

(1) S.J. Brodsky and G.P. Lepage, Phys. Rev. **D24** (1981) 1808.

(2) Ch. Berger et al., Phys. Lett. **137B** (1984) 267.

(3) Results based on the first 35 pb^{-1} of this experiment have been published in J.R. Smith et al., Phys. Rev. **D30** (1984) 851.

(4) R. Schindler et al., Phys. Rev. **D24** (1981) 78; J. Jaros, in Proceedings of the International Conference on Instrumentations for Colliding Beam Physics, edited by W. Ash (SLAC Report 250, 1982), p. 29.

(5) J. R. Smith thesis, U.C. Davis (1983), unpublished.

(6) M. Althoff et al., Phys. Lett. **130B** (1983) 449. The measured limit is $\sigma(\gamma\gamma \rightarrow \overline{p}p) < 0.5$ nb for $\sqrt{s}$ above 3 GeV.

(7) S.J. Brodsky, T. Kinoshita, H. Terazawa, Phys. Rev. Lett. **25** (1970) 972; Phys. Rev. **D4** (1971) 1532.

(8) Preliminary results of this experiment have been reported at the VIth International Workshop on Photon-Photon Collisions, Granlibakken, 10-13 Sept., 1984 (World Scientific Publishing Company; R. J. Lander, ed.), and at the XVI Symposium on Multiparticle Dynamics, Kiryat-Anavim, Israel, 9-14 June 1985. The PEP 4/9 collaboration has also recently reported separate measurements of $\gamma\gamma \rightarrow \pi^+\pi^-$ and $\gamma\gamma \rightarrow K^+K^-$ at lower values of $\sqrt{s}$ (J. C. Sens, presented at Physics in Collision Conference, Autun, France, 3-5 July 1985, SLAC-PUB-3754).

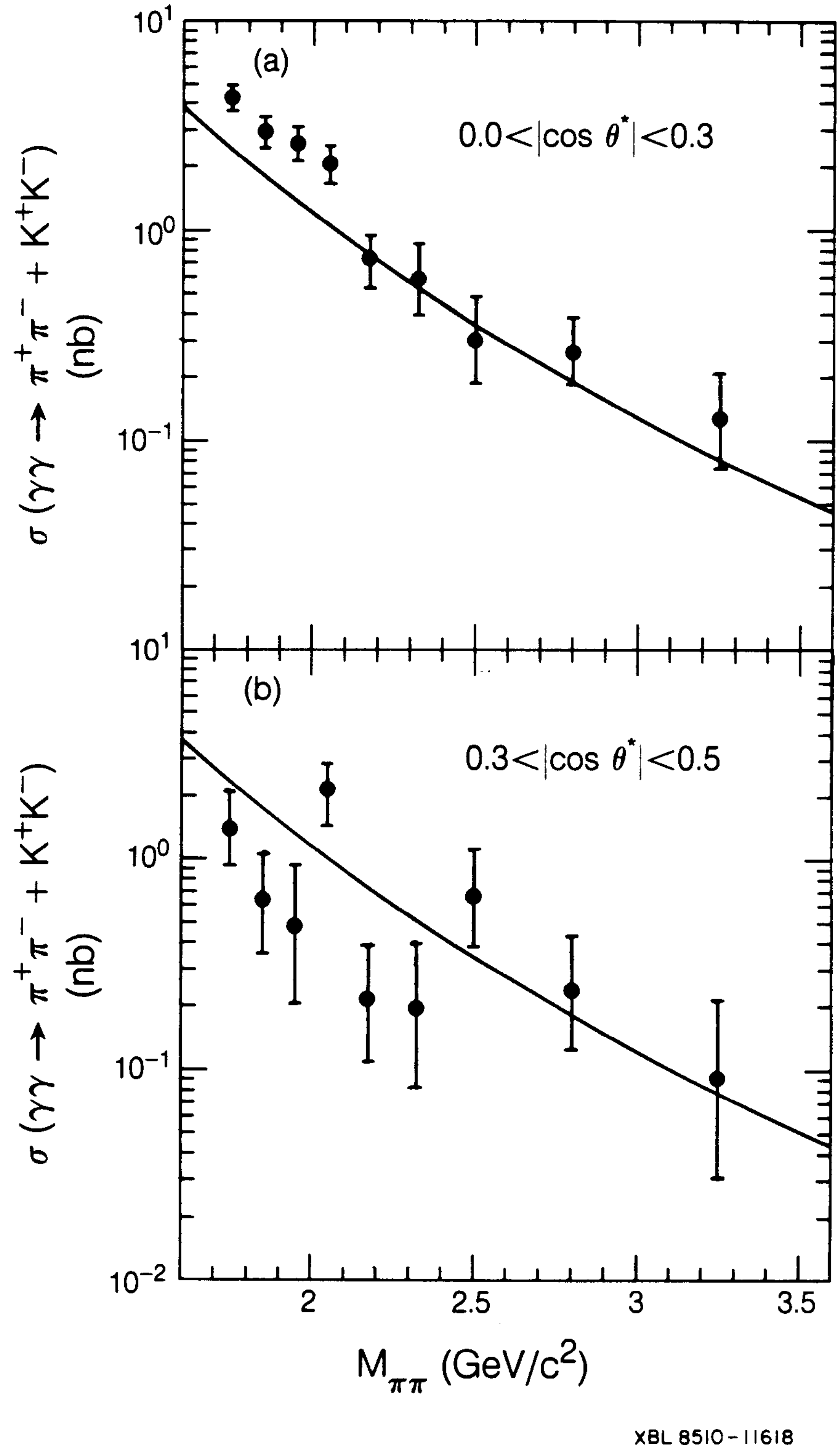
(9) Since we do not have sufficient statistics to study the angular distribution of the produced pair in each Q^2 bin, we cannot determine whether this represents a variation of the hadronic form factor with Q^2 or a change in the helicity structure of the $\gamma\gamma$ process.

Figure Captions

(1) The cross section $\sigma(\gamma\gamma \to \pi^+\pi^- + K^+K^-)$ as a function of $\pi^+\pi^-$ invariant mass for the intervals of $\gamma\gamma$ center of mass scattering angle (a) $0. < |\cos\theta^*| < 0.3$ and (b) $0.3 < |\cos\theta^*| < 0.5$. The solid curve is the absolute prediction of Reference (1). The $m_{\pi\pi}$ region above 2.1 GeV/c^2 contains 48 observed events in figure (1a) and 20 observed events in figure (1b).

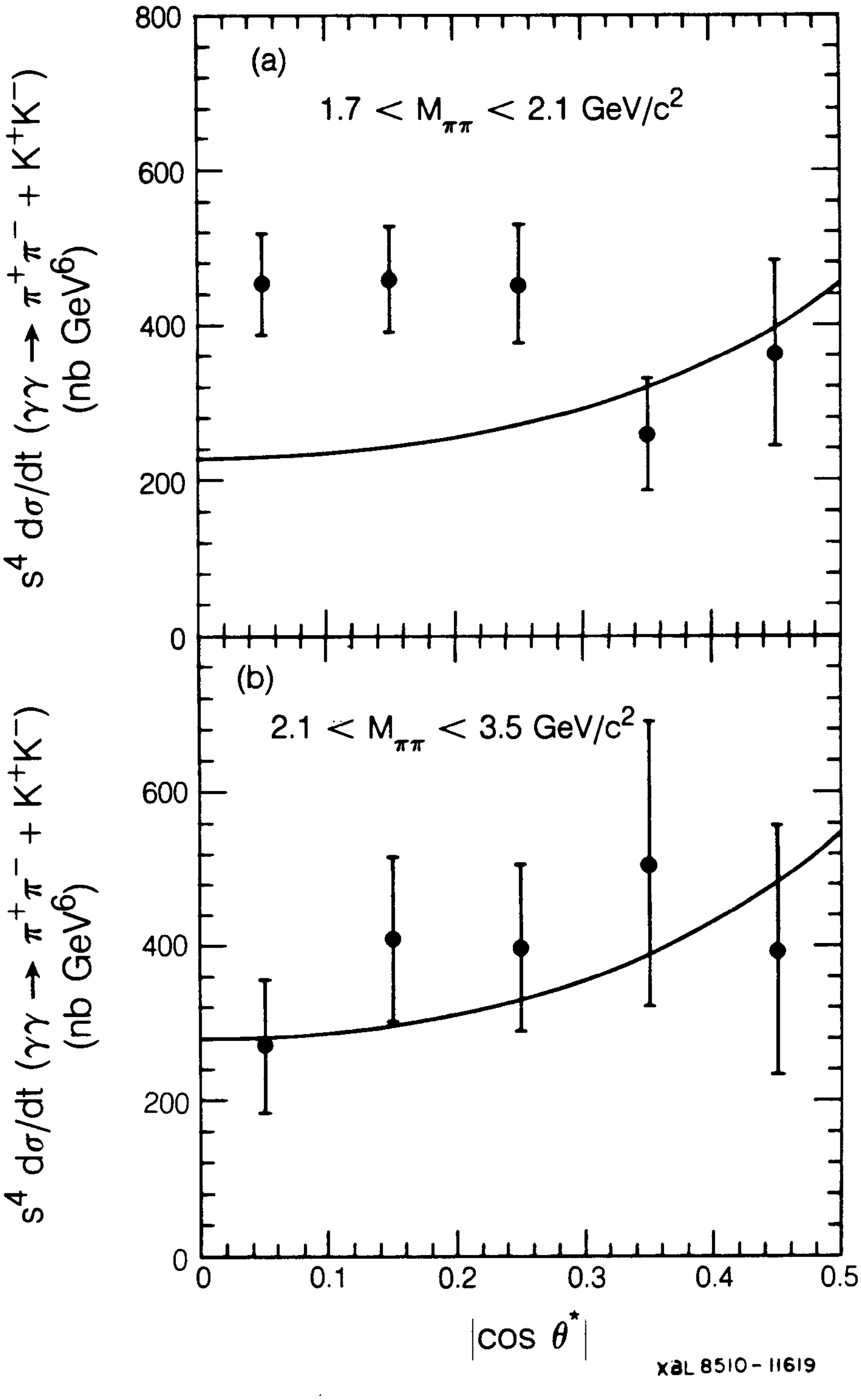
(2) The $\cos\theta^*$ dependence of the scaling function $s^4 d\sigma/dt\,(\gamma\gamma \to \pi^+\pi^- + K^+K^-)$ for (a) $1.7 < m_{\pi\pi} < 2.1$ GeV/c^2 and (b) $2.1 < m_{\pi\pi} < 3.5$ GeV/c^2.

(3) The observed Q^2 dependence of the tagged $\pi^+\pi^- + K^+K^-$ events. The observed $\mu^+\mu^-$ events together with results of a QED muon pair Monte Carlo simulation (histogram) are shown for comparison.



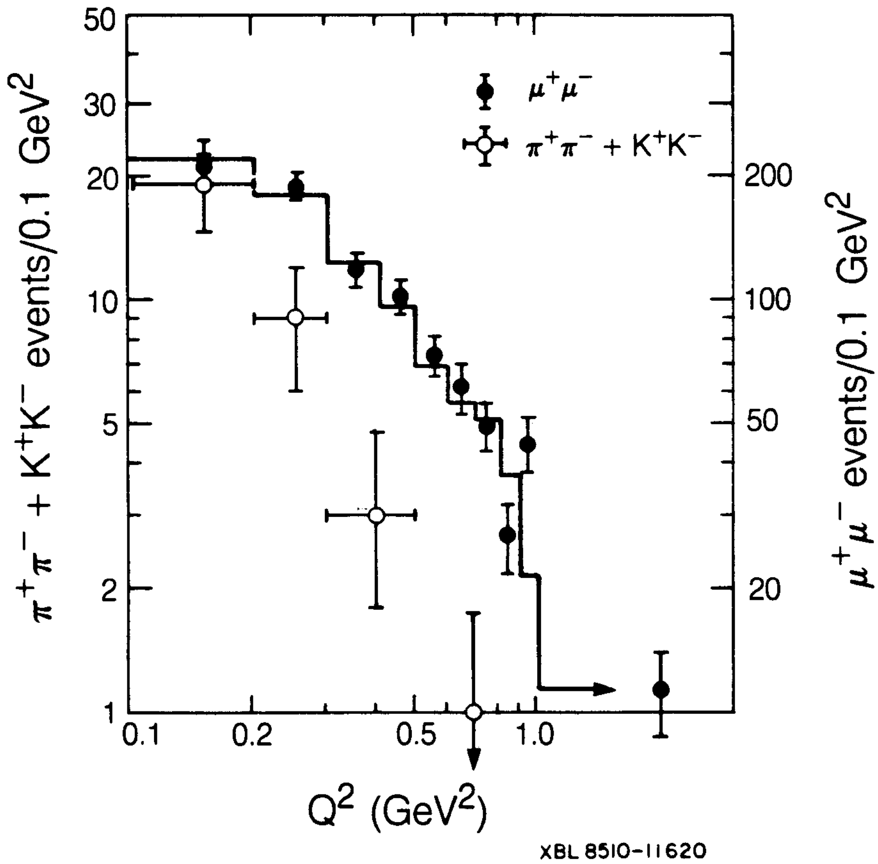
(a)
0.0<|cos θ*|<0.3
(b)
0.3<|cos θ*|<0.5
σ (γγ → π+π− + K+K−) (nb)
10^1
10^0
10^-1
10^-2
2
2.5
3
3.5
M_ππ (GeV/c²)
XBL 8510-11618

Figure 1



800
600
400
200
0
(a)
1.7 < M_ππ < 2.1 GeV/c²
s⁴ dσ/dt (γγ → π⁺π⁻ + K⁺K⁻) (nb GeV⁶)
(b)
2.1 < M_ππ < 3.5 GeV/c²
0
0.1
0.2
0.3
0.4
0.5
|cos θ*|
XBL 8510-11619

Figure 2



50
30
20
10
5
2
1
0.1
0.2
0.5
1.0
200
100
50
20
$\mu^+\mu^-$
$\pi^+\pi^- + K^+K^-$
$\pi^+\pi^- + K^+K^-$ events/0.1 GeV^2
$\mu^+\mu^-$ events/0.1 GeV^2
Q^2 (GeV^2)
XBL 8510-11620

Figure 3