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PRODUCTION OF $4\pi^{\pm}$ and $6\pi^{\pm}$ BY e^+e^- ANNIHILATION BETWEEN 2.4 GeV and 7.4 GeV*

B. Jean-Marie[†††], G. S. Abrams, A. M. Boyarski,
M. Breidenbach, F. Bulos, W. Chinowsky, G. J. Feldman,
C. E. Friedberg, D. Fryberger, G. Goldhaber, G. Hanson,
D. L. Hartill,[‡] J. A. Kadyk, R. R. Larsen, A. M. Litke, D. Lüke,[†]
B. A. Lulu, V. Lüth, H. L. Lynch, C. C. Morehouse,
J. M. Paterson, M. L. Perl, F. M. Pierre,[‡] T. P. Pun,
P. Rapidis, B. Richter,[‡] B. Sadoulet, R. F. Schwitters, W. Tanenbaum,
G. H. Trilling, F. Vannucci,[††] J. S. Whitaker,
F. C. Winkelmann,[‡‡] and J. E. Wiss

Stanford Linear Accelerator Center
Stanford University, Stanford, California 94305

and

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

ABSTRACT

The cross sections for e^+e^- annihilation into $4\pi^{\pm}$ and $6\pi^{\pm}$ are presented for center-of-mass energies between 2.4 and 7.4 GeV; they are found to decrease rapidly with energy. Around 3.0 GeV, the $4\pi^{\pm}$ final state is dominated by $\rho\pi\pi$ and $f\pi\pi$.

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†Fellow of Deutsche Forschungsgemeinschaft

††Permanent address Institut de Physique Nucléaire, Orsay, France

‡Permanent address Centre d'Études Nucléaires de Saclay, France

§Alfred P. Sloan Fellowship, permanent address, Cornell University, Ithaca, New York.

†††Present address Laboratoire de l'Accélérateur Linéaire, Orsay, France.

‡‡Present address Carleton University, Ottawa, Canada

‖Present address CERN, Geneva, Switzerland

The study of the energy dependence of exclusive channels is a way to investigate hadron production in e^+e^- annihilation. Most theoretical models predict that the cross section for a given exclusive channel should decrease rapidly with energy (as s^{-2}, s^{-3} for example). While the number of channels increases with energy their sum, the total hadronic cross section σ_{hadron}, should decrease as s^{-1}. This leads to a constant ratio $R = (\sigma_{hadron}/\sigma_{\mu\mu})$. Since the discovery at SPEAR[1] of the step in R near 4 GeV, it has become even more interesting to check if the increase in R is reflected in any exclusive channels.

This study has been made using the data collected by the SLAC/LBL Magnetic Detector at SPEAR[2] at center-of-mass energies ranging from 2.4 to 7.4 GeV. In this experiment only events which have no more than one neutral particle can be fully reconstructed. Although various channels such as $\pi\pi KK$ or $8\pi^{\pm}$ have been observed, only the $4\pi^{\pm}$ and $6\pi^{\pm}$ charged pion final states exhibit measureable signals over the whole energy range. The events produced in a given channel $n\pi^{\pm}$ can be identified if all n tracks (4C-events) or n-1 tracks (1C-events) are detected. In both cases one cut on the missing momentum and another on the missing mass squared are sufficient to select the events. The cuts are set according to the momentum resolution, which varies with the momentum and the magnetic field setting. At 3.0 GeV, the 4C-events are defined by a missing momentum compatible with zero ($P_{miss} < 0.100$ GeV/c) and a missing mass squared compatible with zero ($-0.03 < MSQ < +0.03$ $(GeV/c^2)^2$. For the 1C-events the conditions are: $P_{miss} > 0.200$ GeV/c and

$-0.06 < MSQ < +\ 0.08\ (GeV/c^2)^2$.

In addition we applied cuts, defined in Ref. (3), on the vertex position (± 2 standard deviations), and on the angle between any pair of particles ($\gtrsim 10^o$). Particles striking any of the six internal support posts are treated as missing particles, and the event is correspondingly demoted to a lower constraint class. Besides the increase of statistics, the use of the 1C-events reduces the systematic errors due to the post losses; the losses amount to 25% of the $4\pi^{\pm}$ and 31% of the $6\pi^{\pm}$. The main background to the $4\pi^{\pm}$ events comes from the radiative process $e^+e^- \rightarrow e^+e^-\gamma \rightarrow e^+e^-(e^+e^-)$, where the photon converts in the vacuum pipe or the scintillation counter around the beam pipe. In most cases these events are rejected by the 10° cut already mentioned. The remaining background events are eliminated by requiring that no large shower pulse be associated with a particle of momentum greater than half the beam energy. This cut reduces the number of real events by about 4%. However, since the ratio $\sigma(e^+e^- \rightarrow 4\pi^{\pm}) / \sigma(e^+e^- \rightarrow e^+e^-)$ decreases between 2.4 GeV and 7.4 GeV by about a factor of 100, the 1C-events, which are more sensitive to contamination than the 4C-events, were not used above 4.0 GeV. This procedure was also necessary in order to avoid a possible contamination from the channel $\pi^+\pi^-K^+K^-$. Due to the momentum resolution, one constraint is not sufficient to separate the $\pi^+\pi^-K^+K^-$ from the $4\pi^{\pm}$ events above 4.0 GeV. Even among the 4C-events, those having relatively high kaon momentum could be accepted as $4\pi^{\pm}$. The residual contamination of $\pi^+\pi^-K^+K^-$ events is not expected to be large since $\sigma(\pi^+\pi^-K^+K^-)/\ \sigma(4\pi^{\pm}) \sim 1/4$ at 3.0 GeV and only a fraction of such events are misidentified.

Conversely the channel $\pi^+\pi^-\pi^+\pi^-K^+K^-$ does not contaminate the $6\pi^{\pm}$ channel, and the 1C-events were used at all energies. At 3.8 GeV and 3.9 GeV the events produced by the radiative process $e^+e^- \rightarrow \gamma e^+e^- \rightarrow \gamma\psi'$ followed by the transition $\psi' \rightarrow \pi\pi\mu\mu$ were removed. Above 3.9 GeV, the cut on the missing momentum completely eliminated them.

All the cuts we have described were included in a Monte Carlo program simulating the multipion production according to Lorentz invariant phase-space. Although there is good agreement with the observed momentum and angular distributions, the error on the efficiencies has been increased by 10% to cover our ignorance of the real production mechanism.

The e^+e^- pairs produced at large angles by the well known Bhabha scattering were used to determine the luminosity. The error, estimated at 5%, is dominated by systematics. The cross sections are displayed in Figure 1 a-b, along with previous data from Orsay[4] and Frascati.[5-7] In order to increase the statistical significance of the measurement some data points have been grouped together. Both cross sections decrease faster than s^{-1}: Using the data above 3.0 GeV, a fit of the form $\sigma = A\, s^{-B}$ gives $B = 2.8 \pm 0.5$ and $B = 2.3 \pm 0.6$ for the $4\pi^{\pm}$ and $6\pi^{\pm}$ channels, respectively. The $6\pi^{\pm}$ cross section appears to be consistently larger than the $4\pi^{\pm}$ cross section. In both cases no dramatic change occurs between 3.8 GeV and 4.8 GeV, where the total cross section shows structure.[1]

Only at the lowest energies do we have enough events to investigate resonances within the multipion final state. It has been

shown[3] that the $4\pi^{\pm}$ and $6\pi^{\pm}$ events observed among $\psi(3095)$ decays are not direct hadronic decays, but proceed via an intermediate photon. Thus we may merge such data with data taken at 3.0 GeV. Figure 2a-b shows the invariant mass distributions $M_{\pi^+\pi^-}$, and Fig. 3 shows a scatter plot of the invariant mass of one pion pair vs. the invariant mass of the remaining pion pair for $4\pi^{\pm}$ events. A ρ signal is clearly seen in both $4\pi^{\pm}$ and $6\pi^{\pm}$ as well as an f signal in the $4\pi^{\pm}$. A fit[8] of the 4π spectrum to two uncorrelated Breit-Wigner distributions indicates that the data are compatible with production entirely via $\rho\pi\pi$ or $f\pi\pi$ with a ratio $\rho\pi\pi/f\pi\pi = 1.9 \pm 0.5$. However, this result gives only a crude estimate because neither a possible ρf correlation, nor interference between modes has been taken into account.

Analysis of the Frascati data has indicated that most of the $4\pi^{\pm}$ events at 1.6 GeV were produced via $\rho\epsilon$[9]. Such a signal is non-existent or very small in our higher energy data, as seen in Fig. 3.

References

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5. M. Grilli et al., Nuovo Cimento 13A, 593 (1973).
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8. The depopulation observed around 0.500 GeV/c^2 in Fig. 2a and Fig. 3 is due to a cut which eliminates the events $K_s^o K\pi$ which contaminate the 4C-events at the ψ energy.

9. F. Ceradini et al., Phys, Lett. 43B, 341 (1973).

Figure Captions

1. Cross sections for e^+e^- annihilation into (a) $4\pi^{\pm}$ and (b) $6\pi^{\pm}$ as a function of center-of-mass energy. The results from earlier experiments were taken from Refs. 4-7.

2. $\pi^+\pi^-$ invariant mass distributions for (a) $4\pi^{\pm}$ and (b) $6\pi^{\pm}$ final states. The solid lines show fits to the data using uncorrelated Breit-Wigner distributions for the indicated resonances plus uncorrelated pions. The dashed lines show invariant phase space.

3. Invariant mass $M_1(\pi^+\pi^-)$ vs. the mass of the remaining pair $M_2(\pi^+\pi^-)$ for the $4\pi^{\pm}$ channel. The events are the same as those in Fig. 2a and are ordered such that $M_1 \geq M_2$ (two combinations per event).

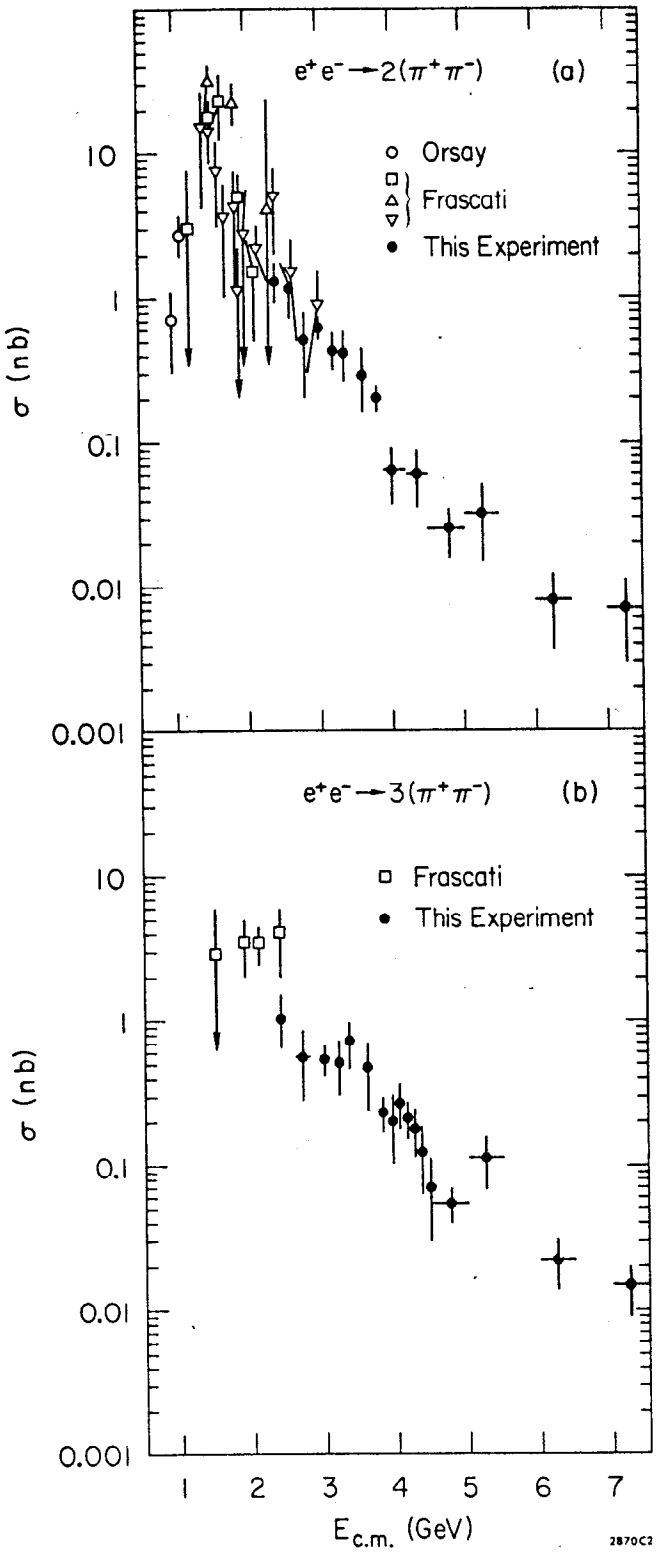
e⁺e⁻ → 2(π⁺π⁻)
(a)
Orsay
Frascati
This Experiment
σ (nb)
10
1
0.1
0.01
0.001
e⁺e⁻ → 3(π⁺π⁻)
(b)
Frascati
This Experiment
σ (nb)
10
1
0.1
0.01
0.001
1
2
3
4
5
6
7
E c.m. (GeV)
2870C2

Fig. 1

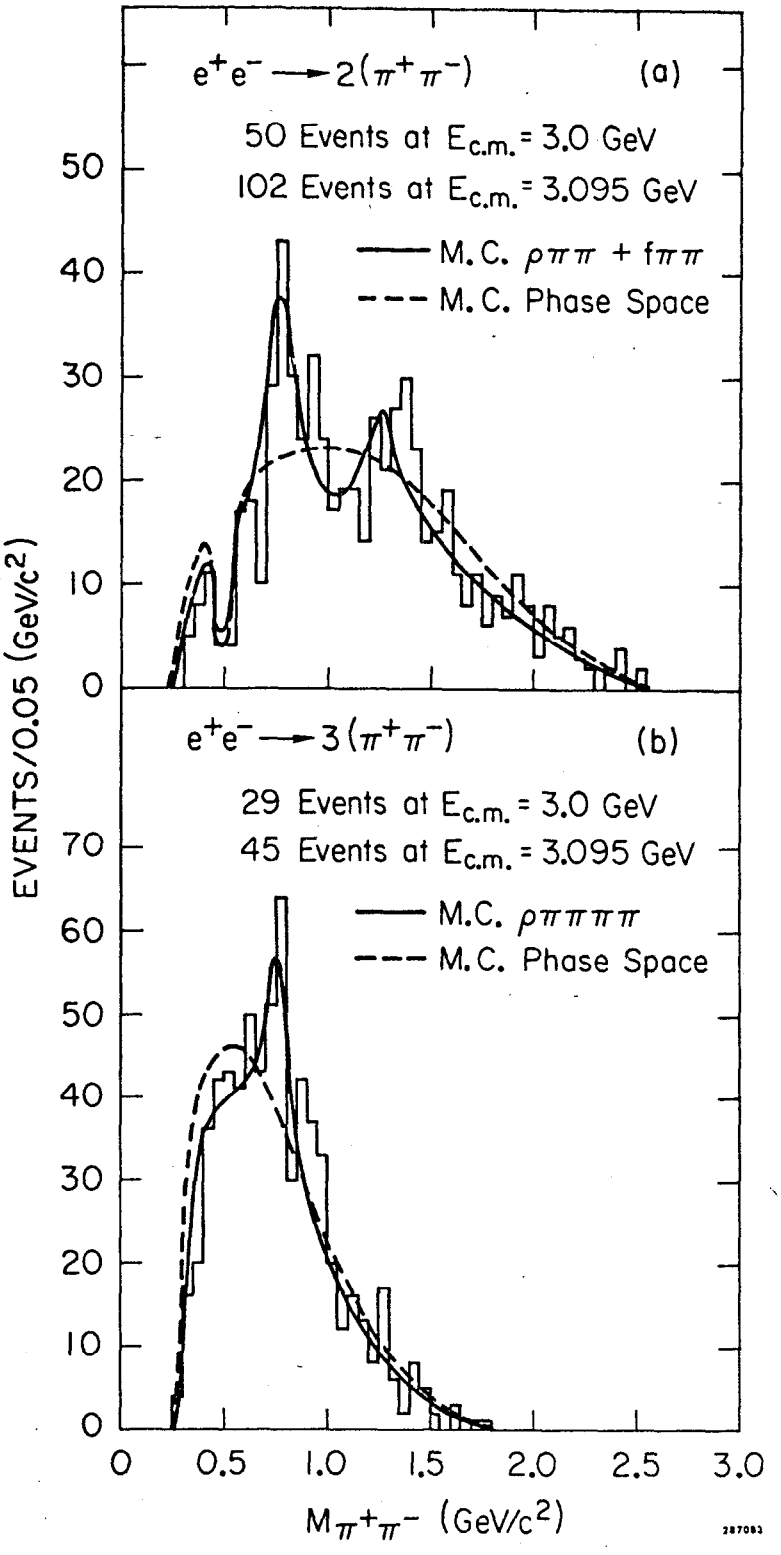
$e^+e^- \rightarrow 2(\pi^+\pi^-)$
(a)
50 Events at $E_{c.m.}$ = 3.0 GeV
102 Events at $E_{c.m.}$ = 3.095 GeV
M.C. $\rho\pi\pi$ + $f\pi\pi$
M.C. Phase Space
$e^+e^- \rightarrow 3(\pi^+\pi^-)$
(b)
29 Events at $E_{c.m.}$ = 3.0 GeV
45 Events at $E_{c.m.}$ = 3.095 GeV
M.C. $\rho\pi\pi\pi\pi$
M.C. Phase Space
EVENTS/0.05 (GeV/c^2)
$M_{\pi^+\pi^-}$ (GeV/c^2)

Fig. 2

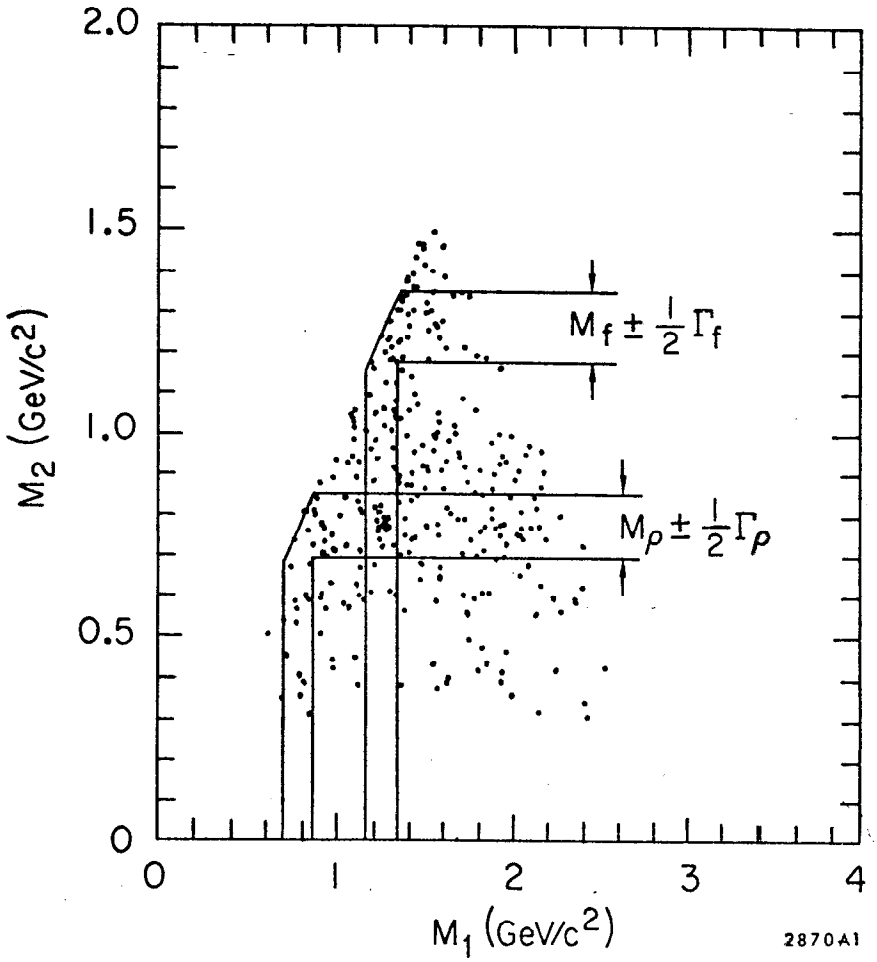
2.0
1.5
1.0
0.5
0
M_2 (GeV/c^2)
$M_f \pm \frac{1}{2}\Gamma_f$
$M_\rho \pm \frac{1}{2}\Gamma_\rho$
0
1
2
3
4
M_1 (GeV/c^2)
2870A1

Fig. 3