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OBSERVATION OF A SPIN-PARITY 4^+ $K^*(2090)$[†]

D. Aston, W. Dunwoodie, S. Durkin, T. Fieguth, A. Honma[¶],
D. Hutchinson, W. B. Johnson, P. Kunz, T. Lasinski[††],
D. W. G. S. Leith, L. Levinson, W. T. Meyer[§], B. N. Ratcliff,
R. Richter[¶], S. Shapiro, R. Stroynowski[Π], S. Suzuki[**],
S. Williams.

Stanford Linear Accelerator Center, Stanford University,
Stanford, California 94305

R. Carnegie, P. Estabrooks, R. J. Hemingway, A. McPherson,
G. Oakham, J. Va'Vra[ΠΠ].

Carleton University, Ottawa, Ontario, Canada K1S 5B6

R. McKee[‡]

National Research Council, Ottawa, Canada K1A 0R6

ABSTRACT

High statistics data for the reaction $K^-p \rightarrow K^-\pi^+n$ at 11 GeV/c have been obtained in the LASS spectrometer at SLAC. A spherical harmonic moment analysis of the $K\pi$ angular distribution displays evidence for a new K^* state at 2086 MeV/c^2 with the spin-parity assignment, $J^P = 4^+$.

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[††] Present Address: NASA, Ames Research Center, Mountain View, California 94040.

[‡] Present Address: Los Alamos Scientific Lab., Los Alamos, NM87545.

[§] Present Address: Iowa State University, Ames, Iowa 50011.

[¶] Present Address: CERN, 1211 Geneva 23, Switzerland.

[**] On leave from Nagoya University, Nagoya, Japan.

[Π] Present Address: California Institute of Technology, Pasadena, California, 91125.

[ΠΠ] Present Address: Stanford Linear Accelerator Center, Stanford University, Stanford, California, 94305.

We present results from a high statistics study of the reaction:

$$K^- p \rightarrow K^- \pi^+ n \qquad (1)$$

at 11 GeV/c using the LASS spectrometer at SLAC. This reaction has been an important source of information on the production of strange, natural spin-parity mesons for many years. In particular, the three lowest mass K^* states (the spin-parity 1^- $K^*(892)$. the 2^+ $K^*(1430)$, and the 3^- $K^*(1780)$) have been clearly observed in this channel and are now rather well understood[1]. However, at higher mass the increasingly inelastic nature of $K\pi$ scattering, coupled with limitations in experimental acceptance and sensitivity, has prevented any clear observation of the continuation of the L-excitation ladder predicted by the quark model. In this paper, we present evidence for a new spin-four K^* state based on a spherical harmonic analysis of the $K\pi$ scattering angular distribution in reaction (1).

This experiment used the LASS spectrometer facility shown schematically in Fig. 1. LASS is built around two large magnets and a variety of charged particle detectors, including 86 spark chamber and proportional wire chamber planes. The first magnet is a superconducting solenoid with a 23 kg. field parallel to the beam direction. This is followed by a 30 kg-m dipole magnet with a vertical field. The solenoid is effective in measuring the interaction products which have large production angles and relatively low momenta. High energy particles close to the beam line are not well measured in the solenoid, but pass through the dipole spectrometer for measurement there. The trigger for this experiment required two or more charged particles to exit the target, and was defined by requiring two or more hits outside a 3.2 cm. square beam hole in the full-aperture proportional chamber 54 cm. downstream of the target.

The data sample for the $K^-\pi^+n$ final state was extracted from the data tapes before analysis by requiring less than four hits in the combination of proportional chambers which surrounded the target. After event reconstruction, candidates for reaction (1) were chosen from the two-prong charge-zero events by requiring the missing mass of the recoil system to be less than 1.1 GeV/c^2, yielding a sample of 104,000 events in the invariant $K\pi$ mass region below 2.7 GeV/c^2 with $|t'| < 1.0$ GeV^2/c^2. The $K^-\pi^+$ mass distribution of Fig. 2 shows prominent $K^*(892)$ and $K^*(1430)$ peaks. However, there is little clear evidence for states at higher mass in the invariant mass projection alone. This is consistent with results from earlier experiments in the charge-zero $K\pi$ channels[2-5], where the structure interpreted as the $K^*(1780)$ has been clearly observed only in certain regions of the $K\pi$ center of mass decay angle.

Fig. 3 is a computer generated three-dimensional projection invariant $K\pi$ mass distribution, $M(K\pi)$, versus the cosine of the t-channel kaon scattering angle in the $K\pi$ center of mass, $\cos\theta_J$. The $K^*(892)$ stands out clearly as a ridge at low mass, while spikes at both forward and backward scattering angles indicate the $K^*(1430)$. There is a clear bump at forward angles between 1700 and 1800 MeV/c^2 on top of a ridge extending to higher mass. This ridge becomes progressively steeper as M(Kπ) increases and is most simply interpreted as Kπ diffractive scattering. It falls as the mass increases due to a fixed angle cut generated by the two prong trigger. In the central part of the decay angular distribution, there is a complex ridge structure in the mass region above 1500 MeV/c^2 which peaks at a cos θ_J of ≈ − .5 at about 1800 MeV/c^2. This structure is indicative of the 3^- $K^*(1780)$. At still higher M(Kπ), this ridge tends toward small, positive cos θ_J. This complicated interference structure implies the existence of overlapping waves of high spin in the mass region above 1800 MeV/c^2, and leads us to a study of the spherical harmonic moments of the data in this region.

Data from reaction (1) involve charge exchange in the t-channel and are dominated by pion exchange at small values of momentum transfer [6]. To emphasize the pion exchange component, we select events with $|t'| < .2$ GeV^2/c^2. Restrictive cuts were then applied to remove the small competing backgrounds from $\bar{K}^o n$, $K^- p$ elastic, and $K^- p \pi^o$ final states, while the missing mass was constrained to lie between .45 and 1.1 GeV/c^2, leaving 51,000 events for analysis in the Kπ mass region between .7 and 2.3 GeV/c^2. With these cuts, the estimated background from other reactions is 3%.

The geometrical acceptance of the LASS spectrometer covers most of the total (4π) solid angle. In the case of reaction (1). the two prong trigger modifies the basic geometrical acceptance by limiting the observation of very forward and backward decays both for very low and very high invariant $K\pi$ masses. The acceptance of the apparatus was calculated by a Monte Carlo program which included geometrical effects, measured chamber resolutions and efficiencies, and particle decay and absorption, as well as the physics event selection criteria which were applied to the data. Using this acceptance, the observed $K\pi$ angular distributions were fitted to an expansion of spherical harmonics.

Fig. 4 shows the acceptance corrected t-channel $M = 0$ moments for the data as a function of $K\pi$ mass. These results were obtained from fits using $M \leq 2$ and $L \leq L_{max} \leq 8$, where L_{max} was the minimum L required to fit the data in each mass region (see Fig. 4). Tests with higher moments were performed in each mass region, and did not alter the quality of the fit. However, the acceptance introduced correlations which substantially increased the error bars on all of the moments if unnecessary higher moments were included. Therefore, the moments Y_{90} and Y_{100}, which are shown in Fig. 4, were taken from a separate fit which included moments up to $L \leq 10$, $M \leq 2$.

The $K^*(892)$ and $K^*(1430)$ resonances are apparent as bumps in the Y_{20} and Y_{40} moments, together with clear interference patterns in the odd L moments, Y_{10} and Y_{30}. At higher mass, there is a peak in Y_{60} near 1800 MeV/c^2 indicating the $J^P = 3^-$ $K^*(1780)$. At still higher mass, the moments with $L = 7, 8$ show significant structure and are inconsistent with zero (confidence level $<< 10^{-4}$), while moments with larger L remain consistent with zero (confidence level = .16), providing strong evidence for a significant G wave. In particular, there are bumps at about 2080 MeV/c^2 in both the Y_{60} and Y_{80} moments, and a rapid variation in the Y_{70} moment which reflects interference between waves of even and odd opin. This structure is most simply attributed to a G wave resonance, presumably the next leading K^* resonance, with $J^P = 4^+$, expected from the quark model. A G wave resonance would give rise to the structures in the even L moments, and could also interfere with a more slowly varying F wave to produce the observed structure in Y_{70}.

The complexity of the high mass region makes a determination of the mass and width of this state rather difficult. The simplest approach is to assume that the G wave turn on is dominated by resonance production, and to fit the Y_{80} moment to a relativistic Breit-Wigner form,[1] giving:

$$M_G = 2074 \pm 29 \text{ MeV/c}^2$$

$$\Gamma_G = 140 \pm 91 \text{ MeV/c}^2$$

The quality of the fit is excellent (χ^2/NDF = 1.8/3) as shown by the dotted line in Fig. 4. However, in this method the data are insufficient to deal adequately with possible non-resonant contributions to the G wave.

In a second approach, which uses more of the available infor-

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[1] We parametrize the width as

$$\Gamma = \Gamma_o \left(\frac{q}{q_o}\right)^{2\ell+1} \frac{D_\ell(q_o R)}{D_\ell(q\ R)}$$

where q is the momentum in the Kπ center of mass, q_o is q evaluated at the resonance mass, R is fixed at 1 fm, and $D_\ell(qR)$ is the "penetration factor" defined by Blatt and Weisskopf[7].

mation, a simple mass dependent amplitude analysis using the high L moments, Y_{60}, Y_{70}, and Y_{80} was performed. Some uncertainties still remain due to the unknown nature of possible underlying states and the tail of the $K^*(1780)$. In the fit below, we have parameterized the D, F, and G wave backgrounds as simple polynomials in $M(K\pi)$, and the leading F and G waves states as relativistic Breit-Wigner amplitudes. The mass and width of the leading 3^- resonance were fixed on the basis of a separate study of the leading edge of the Y_{60} moment.[2] A fully correlated fit, which is shown by the solid line in Fig. 4, gives good agreement to the data ($\chi^2/\mathrm{NDF} = 14.4/13$), with parameter values of

$$M_G = 2092 \pm 21 \text{ MeV}/c^2 \quad ,$$
$$\Gamma_G = 205^{+70}_{-55} \text{ MeV}/c^2 \quad ,$$

where the errors are purely statistical.[3] The significance of the observed spin-four state using this model is 4.6 standard deviations.

In conclusion, we have presented evidence for a new $J^P = 4^+$ resonance at 2086 MeV/c^2, with a width of about 180 MeV/c^2. It is most naturally interpreted as the strange member of the SU(3)

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[2] This fit gives $M(K^*(1780)) = 1786 \pm 15$ MeV/c^2, and $\Gamma(K^*(1780) = 225 \pm 60$ MeV/c^2). The width of the $K^*(1780)$ remains poorly understood, presumably because it is inelastic and lies in a complicated region with several interfering waves[1].

[3] Reasonable changes in forms, the $K^*(1780)$ width, etc., are sufficient to change the parameters by a significant fraction of the quoted error bars. Therefore, it seems prudent to consider the systematic errors to be as large as the statistical.

nonet which contains the h(2040) meson.

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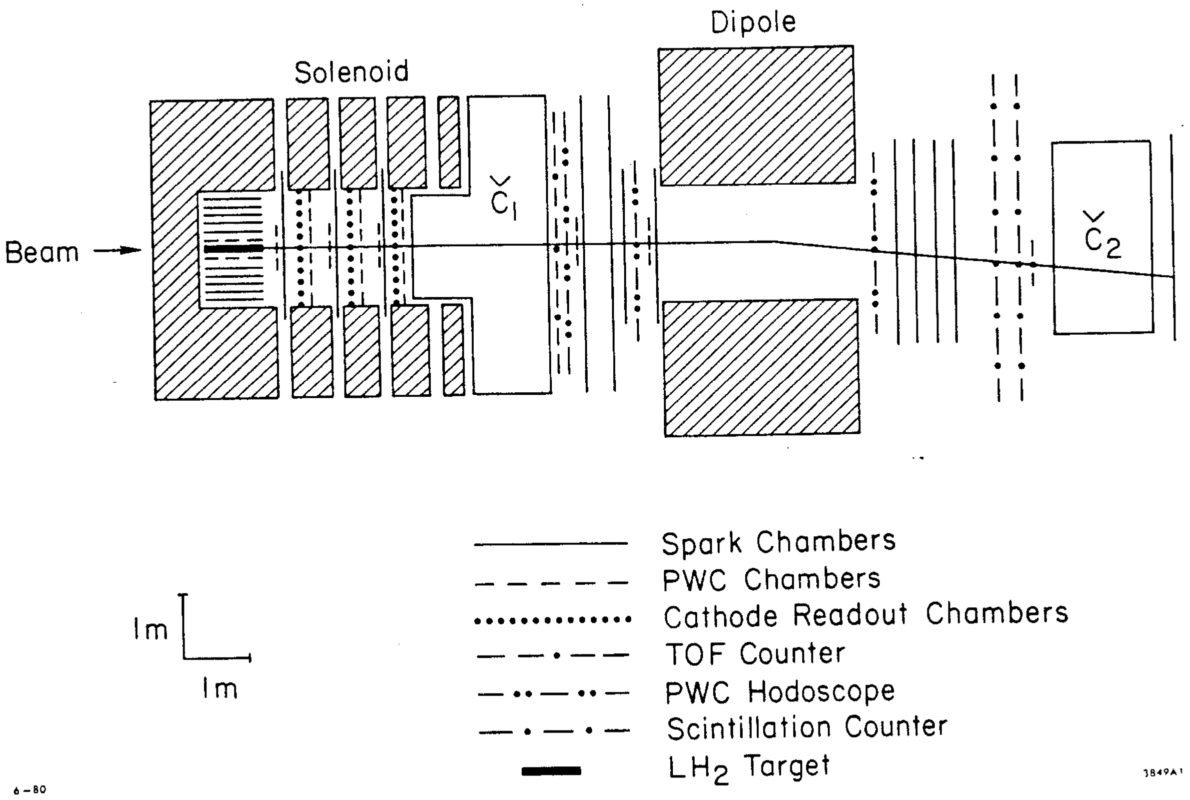
REFERENCES

1. See, for example, "Review of Particle Properties," Particle Data Group, Rev. Mod. Phys. 52II (1980) and references therein.
2. G. W. Brandenburg et al., Phys. Lett. 60B (1976) 478.
3. A. Firestone et al., Phys. Lett. 36B (1971) 513.
4. H. Grassler et al., Nucl. Phys. 125 (1977) 189.
5. S. U. Chung et al., Phys. Rev. Lett. 40 (1978) 355.
6. P. Estabrooks et al., Nucl. Phys. 133B (1978) 490.
7. J. Blatt and V. Weisskopf, Theoretical Nuclear Physics, Wiley, New York (1952) 333.

FIGURE CAPTIONS

1. Plan view of the LASS spectrometer.
2. Invariant $K^-\pi^+$ mass distribution for the observed data sample with $|t'| < 1.0$ GeV^2/c^2.
3. Three dimensional projection of M(Kπ) versus cos θ_J. The height of the surface above the plane is proportional to the number of events per bin.
4. The acceptance-corrected unnormalized t-channel moments of the $K^-\pi^+$ angular distribution for $|t'| < .2$ GeV^2/c^2. The curves represent the fits described in the text.


Dipole
Solenoid
Beam
Č1
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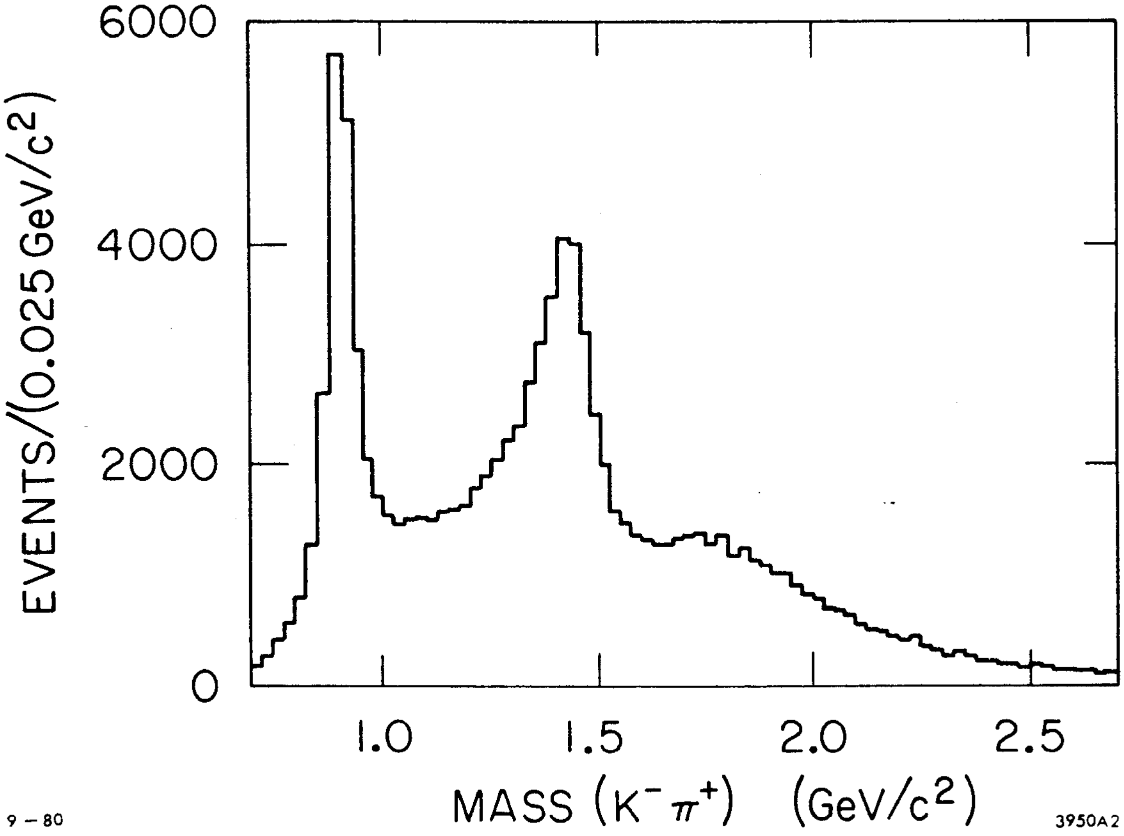
Spark Chambers
PWC Chambers
Cathode Readout Chambers
TOF Counter
PWC Hodoscope
Scintillation Counter
LH2 Target
1m
1m
6-80
3849A1

Fig. 1



EVENTS/(0.025 GeV/c²)
6000
4000
2000
0
1.0
1.5
2.0
2.5
MASS (K⁻π⁺) (GeV/c²)
9 – 80
3950A2

Fig. 2

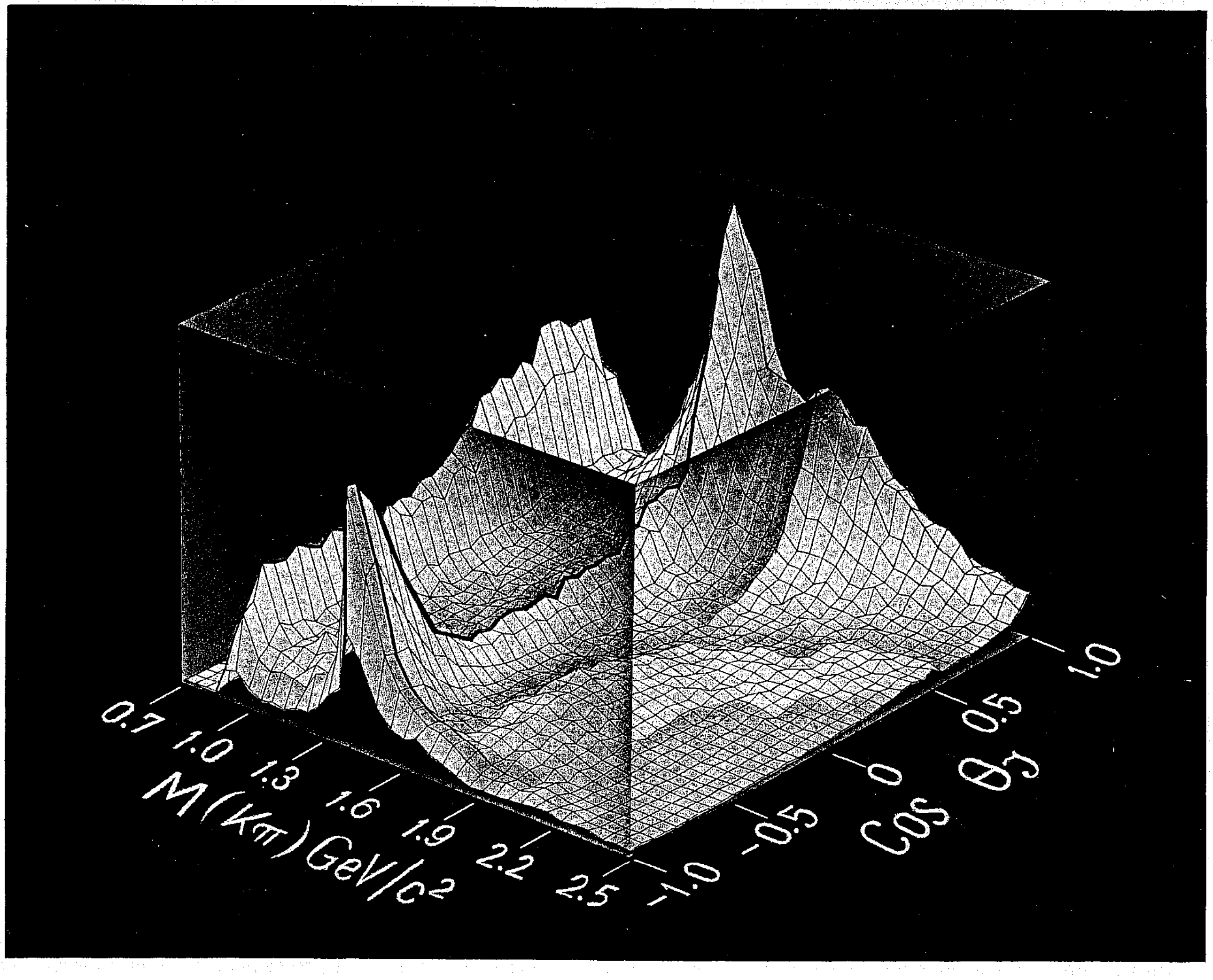
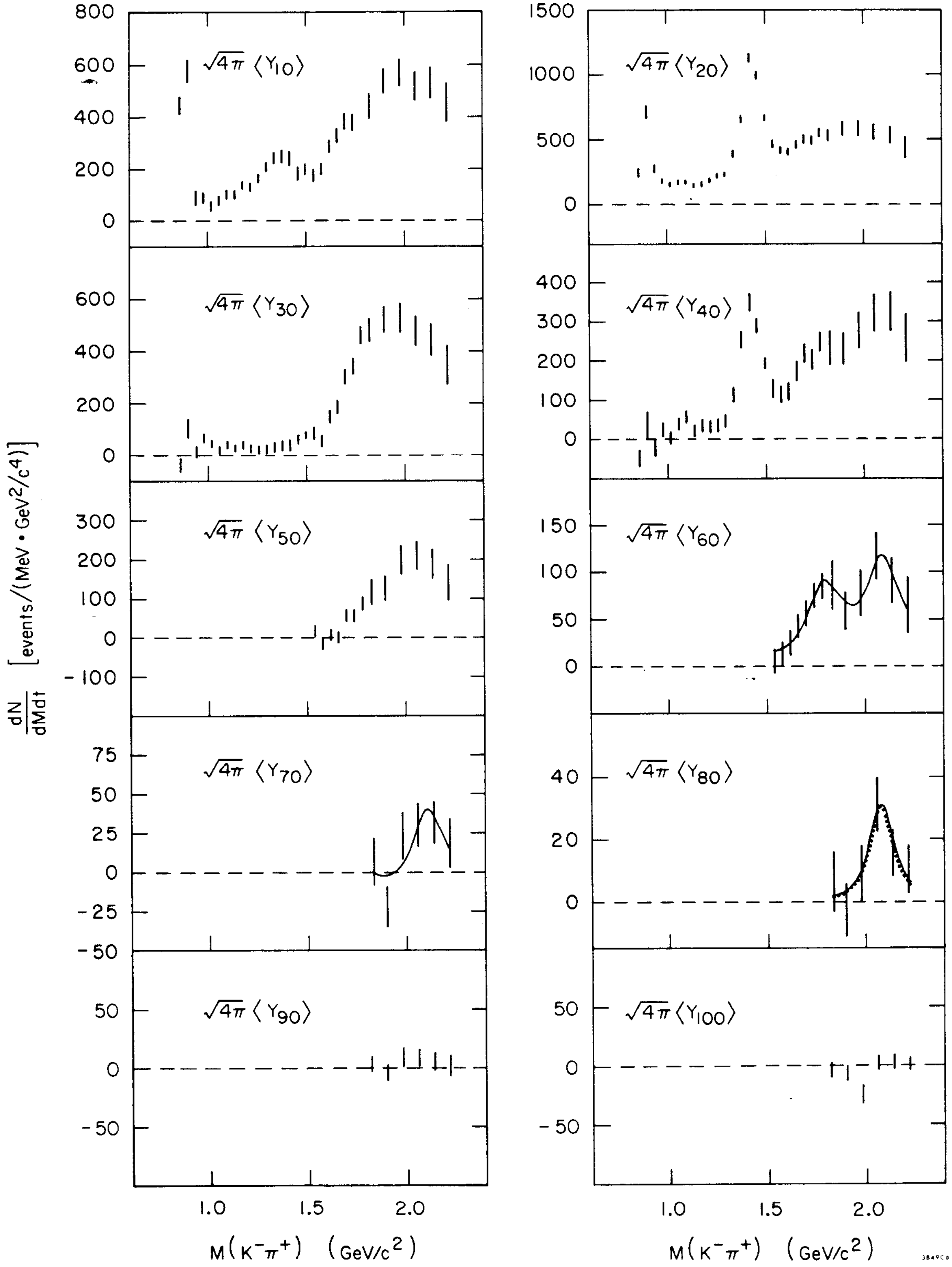


Fig. 3



$\sqrt{4\pi}\langle Y_{10}\rangle$
$\sqrt{4\pi}\langle Y_{20}\rangle$
$\sqrt{4\pi}\langle Y_{30}\rangle$
$\sqrt{4\pi}\langle Y_{40}\rangle$
$\sqrt{4\pi}\langle Y_{50}\rangle$
$\sqrt{4\pi}\langle Y_{60}\rangle$
$\sqrt{4\pi}\langle Y_{70}\rangle$
$\sqrt{4\pi}\langle Y_{80}\rangle$
$\sqrt{4\pi}\langle Y_{90}\rangle$
$\sqrt{4\pi}\langle Y_{100}\rangle$
$\frac{dN}{dMdt}$ [events/(MeV • GeV^2/c^4)]
800
600
400
200
0
1500
1000
500
300
100
-100
150
50
75
25
-25
-50
40
20
1.0
1.5
2.0
$M(K^-\pi^+)$ (GeV/c^2)
3849C6

Fig. 4