Submitted to Physical Review Letters

LBL-300
Preprint c.2

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AEC Contract No. W-7405-eng-48

A STUDY OF THE DECAY $\Lambda(1520) \rightarrow \Sigma(1385)\pi$*

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The decay $\Lambda(1520) \rightarrow \Sigma(1385)\pi$ has been studied in an energy-independent partial wave analysis of the reaction $K^-p \rightarrow \Lambda\pi^+\pi^-$ in the momentum range 300 to 470 MeV/c. The $\Lambda\pi^+\pi^-$ final state of the $\Lambda(1520)$ is found to be overwhelmingly $\Sigma(1385)\pi$. The width for this decay mode is $\Gamma = 1.66 \pm 0.24$ MeV. Combining this result with one recently reported for another member of the $J^P = 3/2^-$ multiplet, $\Lambda(1690)$, we obtain for the singlet-octet mixing angle $|\theta| = (75 \pm 10)°$. This is in sharp disagreement with the value $\theta = (-25 \pm 6)°$ derived from the rates for the two-body decays of the $J^P = 3/2^-$ states. Thus, some modification of the usual SU(3) description of these states needs to be made.

The decay

$$\Lambda(1520) \rightarrow \Sigma(1385)\pi \qquad (1)$$

is forbidden in SU(3) if the $\Lambda(1520)$ is an unmixed SU(3) singlet. Several experiments have shown evidence for this decay.[1,2] Mixing between the $\Lambda(1520)$ and the corresponding $3/2^-$ octet member, $\Lambda(1690)$, has been used to explain the decay. The singlet-octet mixing angle can be derived from the rate for reaction (1) and the rate for

$$\Lambda(1690) \rightarrow \Sigma(1385)\pi. \qquad (2)$$

Previous estimates for these decay rates[1,3] yielded a lower limit for

the magnitude of the mixing angle of $(21 \pm 5)°$.[1] Mixing of this amount was also obtained from the Gell-Mann-Okubo mass relation[4] and from the two-body decays of these states to $\bar{K}N$ and $\Sigma\pi$.[5] Thus, the rates for (1) and (2) were considered to be excellent confirmation for the multiplet assignments and the simple hypothesis of singlet-octet mixing.[5]

In this paper we present the results of a detailed analysis of the formation reaction $K^-p \rightarrow \Lambda(1520) \rightarrow \Lambda\pi^+\pi^-$. We have used an isobar model for the analysis of the three-body final state. The model, as formulated by Deler and Valladas for $\pi N \rightarrow \pi\pi N$, has been modified for $\Lambda\pi\pi$ and extended to incorporate knowledge of the Λ polarization coming from its decay.[6] We obtain a decay rate for (1) of 1.66 ± 0.24 MeV, which is more than twice as large as the previous measurement[1] of 0.67 ± 0.17 MeV. In addition, in making SU(3) comparisons, our calculation of the phase space ratio between reactions (1) and (2) disagrees by a factor of 3 with that of Ref. 1. Finally, a recent isobar analysis[7] of reaction (2) has yielded a decay rate an order of magnitude lower than the previous upper limit.[3] Using these new values there is an overall disagreement by about a factor of 70 with the description of reactions (1) and (2) based upon mixing between the generally accepted $3/2^-$ singlet and octet states.

<u>Data</u>. — An exposure of 11 events per μb in the Berkeley 25-in. hydrogen bubble chamber has yielded about 9000 events of the type $K^-p \rightarrow \Lambda\pi^+\pi^-$ with K^- momenta between 300 and 470 MeV/c.[8] We first present a semiquantitative discussion of the structure in the data.

The momentum dependence of the partial cross section (Fig. 1) is dominated by the $\Lambda(1520)$ near 400 MeV/c, but a substantial non-resonant background exists beyond the resonance. A visual interpolation of the background to 395 MeV/c would suggest that 80 - 90% of the cross section at resonance comes from the resonance itself. (The background shown as crosses results from the analysis discussed later.) The question then arises of how much of this resonance contribution proceeds through the quasi-two-body reaction (1). Information about this is given in the Dalitz plot, mass distributions and the production and decay angular distributions.

The Dalitz plot at the resonant energy (390-400 MeV/c) and its projections are shown in Fig. 2. Enhancements at the high $\Lambda\pi$ invariant masses indicate the presence of $\Sigma(1385)$ (actually centered outside the kinematically allowed region). There is increased density at low $\pi\pi$ mass, indicating constructive interference between $\Sigma(1385)^-$ and $\Sigma(1385)^+$.

The constructive interference between $\Sigma(1385)^-$ and $\Sigma(1385)^+$ indicates dominance of symmetric I = 0 production. Further information on the isospin composition is given from a separate analysis of the $\Lambda\pi^0\pi^0$ channel from the same exposure. At all momenta the $\Lambda\pi^0\pi^0$ cross section is approximately half that of $\Lambda\pi^+\pi^-$. This ratio is consistent with pure I = 0 production. We thus conclude that the reaction proceeds dominantly through I = 0. A more sensitive measure of the presence of I = 1 contributions comes from the charge asymmetry of the Dalitz plot, $(N^- - N^+)/(N^- + N^+)$, where N^- is the number of events with a $\Lambda\pi^-$ mass larger than a $\Lambda\pi^+$ mass. This asymmetry, shown as a function of incident momentum in Fig. 3d, arises from a difference between the $\Sigma(1385)^-$ and $\Sigma(1385)^+$ masses[9] and from I = 0 and I = 1 interference. An I = 1 amplitude about 10% as large as the resonant I = 0 amplitude is sufficient to explain the observed structure. Thus the I = 1 contribution to the partial cross section is of the order of a few percent.

Figures 3a-c show the Legendre polynomial coefficients for the Λ angular distribution and polarization as a function of incident K^- momentum. Here the large A_2/A_0 coefficient with a maximum in the vicinity of the resonance is consistent with the reaction (1) interpretation. However, the large structure in A_1/A_0 and the appreciable B_1/A_0 polarization coefficient shows that even-parity states are also present in significant amounts. The dots are from the partial wave analysis discussed next.[8]

Analysis. — We now describe the results of the complete analysis of the $\Lambda\pi^+\pi^-$ reaction by means of an isobar model. The data between 350 and 470 MeV/c was divided into nine bins in incident K^- momentum. The data in each bin was fitted independently by a maximum likelihood fit using up to 17 partial waves chosen to describe the data. These include S, P1, P3, and D3 partial waves for the incoming state (in two isospin states) and four types of isobars: (a) "Y^*," a $\Lambda\pi$ system resonating as $\Sigma(1385)$; (b) "$\Lambda\pi$," a $\Lambda\pi$ system in a relative S wave; (c) "σ," an S-wave $\pi\pi$ system, and (d) "ρ," a P-wave $\pi\pi$ system.[9] Many of these amplitudes were found to be zero within errors for most of the momentum intervals and so were discarded. In this manner, by successive elimination and remaximization, satisfactory solutions at all nine momenta were found using only six of the amplitudes. Argand plots of these six amplitudes are shown in Fig. 4. Here we have chosen the arbitrary phase inherent in a reaction process to be fixed by the dominant Y^*DS03 resonant Breit-Wigner form.[10] The energy dependence of this form will be discussed later.

The amplitudes imply that reaction (1) described by the Y^*DS03 amplitude contributes 90% of the cross section at resonance. The S-wave dipion in the DP03 state is also fed by the $\Lambda(1520)$ resonance, but to a much smaller degree. The other amplitudes which are fed by nonresonant incident states give magnitudes which are plausible from angular-momentum barrier considerations. The small Y^*DS13 amplitude along with the $\Sigma(1385)^+ - \Sigma(1385)^-$ mass difference is sufficient to explain the asymmetry in the Dalitz plot (Fig. 3d).

The overall magnitude of the waves is fixed to agree with the measured partial cross section (Fig. 1). The relative amounts of each wave, however, have been freely chosen by the fit. Thus, it is of interest to compare the magnitude of the Y^*DS03 with that expected for a Breit-Wigner resonance with appropriate centrifugal barriers for all channels fed by the resonance. The Breit-Wigner form used includes D-wave barriers (with radius of interaction 1 fermi) for the $\overline{K}N$ and $\Sigma\pi$ partial widths. The partial width for reaction (1) contains only an effective phase space factor since the reaction proceeds through a final S state. The effective phase space depends linearly on the relative momentum of the $\Sigma(1385)\pi$ system. The effective relative momentum of the $\Sigma(1385)$ was determined by averaging the momentum over the P-wave Breit-Wigner shape with a width of 40 MeV. The curve in Fig. 4 corresponds to the resulting Breit-Wigner form, and the good agreement with the energy-independent points confirms the momentum dependence of the form.

<u>Results and Discussion.</u> — Defining a branching fraction $R = [\Lambda(1520) \to \Sigma(1385)\pi]/[\Lambda(1520) \to \text{all } \Lambda\pi\pi]$, each of the five momentum intervals centered on the $\Lambda(1520)$ resonance (intervals 3-7) yields a value > 0.95. The overall value is $R = 0.97^{+0.03}_{-0.10}$, where the error is estimated by altering some of the input parameters of the model[9] and by studying the sensitivity of R to the inclusion of different sets of amplitudes consistent with a reasonable energy continuity. This

result is in strong disagreement with the value $R = 0.39 \pm 0.10$ quoted from the production experiment.[11] Using the world average values[12] for the $\Lambda(1520)$ total width and branching fraction into $\Lambda\pi\pi$, we obtain $\Gamma = 1.66 \pm 0.24$ MeV for reaction (1).

We wish to compare this partial width at resonance for reaction (1) with that for reaction (2). An upper limit for the width for reaction (2) was obtained from a reported enhancement in the $\Lambda\pi^+\pi^-$ cross section.[3] However, a more recent experiment with increased statistics found no structure in the $\Lambda(1690)$ region. An isobar model fit to the recent data found an amplitude at resonance of -0.06 ± 0.03 (Refs. 7 and 13) which yields a partial width of $1.0^{+2.4}_{-0.9}$ MeV.

The mixing angle between the singlet and octet members is related to the coupling constants for decays (1) and (2) by

$$\tan\theta = G_{1520}/G_{1690}\,.$$

The measured partial widths are related to the coupling constants by

$$\Gamma = G^2 \int |M(Y^*DS03)|^2 d\rho,$$

where $M(Y^*DS03)$ is the matrix element for the decay, given by the isobar model;[6,8] and the integral is over the three-body phase space. The ratio of this integral at 1520 MeV and 1690 MeV is 9.5.[14] Using this ratio, our measurement of the decay rate, and a mixing angle of 25°, we would predict the partial width for reaction (2) to be some 70 MeV; rather than the measured value of 1 MeV. Thus the interpretation of <u>simple</u> singlet-octet mixing is now in gross disagreement with the observed rates for (1) and (2). Alternatively we can calculate $|\theta|$ from the observed rates. In this case $|\theta| = (75 \pm 10)°$ instead of $(25 \pm 6)°$. A possible explanation of this discrepancy may involve mixing of these states with another octet as predicted by the quark model.[15]

Footnotes and References

*Work done under the auspices of the U. S. Atomic Energy Commission.

1. E. Burkhardt et al., Nucl. Phys. B27, 64 (1971).

2. Shu-bon Chan et al., Hyperon Resonances-70, F. C. Fowler, Ed. (Moore Publishing Co., Durham, North Carolina, 1970), p. 79. Also D. Cline et al., presented to the 14th Int. Conf. on High Energy Physics at Vienna, paper 922 (1968).

3. J. H. Bartley et al., Phys. Rev. Lett. 21, 111 (1968).

4. In addition to the Λ(1690), other members of the $3/2^-$ octet are assumed to be N(1520), Σ(1670), and Ξ(1815).

5. R. Levi-Setti, in Proceedings of the Lund Int. Conf. on Elementary Particles, p. 339 (Berlingskas Boktryckeriet, Lund, 1969). The mixing angle was recently recalculated to be $\theta = (-25 + 6)°$ by D. E. Plane et al., Nucl. Phys. B22, 93 (1970).

6. B. Deler and G. Valladas, Nuovo Cimento 45A, 559 (1966); D. Morgan and G. Shaw, Phys. Rev. 2D, 520 (1970).

7. J. Prevost et al., Partial Wave Analysis of $\bar{K}N \rightarrow \Sigma(1385)\pi$ between 0.6 and 1.2 GeV/c (CERN-Heidelberg-Saclay Collaboration), presented at the Amsterdam Int. Conf. on Elementary Particles (June 30-July 6, 1971).

8. Details about the data as well as the analysis will be presented in a longer paper. See T. S. Mast, Ph. D. thesis, Lawrence Berkeley Laboratory Report LBL 301 (1971).

9. For the Σ(1385) we have used $M^+ = 1384$ MeV, $M^- = 1388$ MeV, and $\Gamma = 40$ MeV. For the S-wave Λπ system we have used the parameters obtained by Martin and Sakitt, Phys. Rev. 183, 1352 (1969). The parametrization of the ππ phase shifts for "σ" and "ρ" waves have been taken from D. Morgan, Phys. Rev. 166, 1731 (1968).

10. The notation here is LL' I2J, where L and L' refer to the orbital angular momentum for the incoming K^-p system and the outgoing quasi-two-body system (Y^* or σ) respectively, I is the isotopic spin of the $\Lambda\pi^+\pi^-$ system, J is the total angular momentum of the $\Lambda\pi^+\pi^-$ system. For L' only S and P waves were used.

11. The experiment of Ref. 1 has many fewer events (206 events) than the present experiment and has the additional problem of extracting the Λ(1520) signal from the $\Lambda\pi^+\pi^-\pi^0$ final states. They divide the data into three mass intervals centered on the Λ(1520). The data in the central interval (with about 15% background) agrees with ours and yields a branching fraction consistent with ours. The data in the side intervals (with about 30% background) yield lower branching fractions and contribute to their low overall value.

12. Particle Data Group, Reviews of Modern Physics 43, S1(1971); $\Gamma(1520) = 16 \pm 2$ MeV, Γ(1520) branching fraction into $\Lambda\pi\pi = 9.6 \pm 0.6\%$, branching fraction of Σ(1385) branching fraction into $\Lambda\pi = 90 \pm 3\%$.

13. The estimate of the range of uncertainty on the amplitude is from a private communication from R. Barloutaud.

14. The formula used in Ref. 1 (Eq. 12) to calculate an effective integral of the matrix element squared, by calculating an average Σ(1385) momentum, uses an incorrect normalization for the Σ(1385) Breit-Wigner. The normalization should not depend on the particular kinematic region being weighted.

15. See, for example, R. H. Dalitz, in Symmetries and Quark Models, R. Chand, Ed. (Gordon and Breach, New York 1970); also, D. Faiman and A. W. Hendry, Phys. Rev. 173, 1720 (1968).

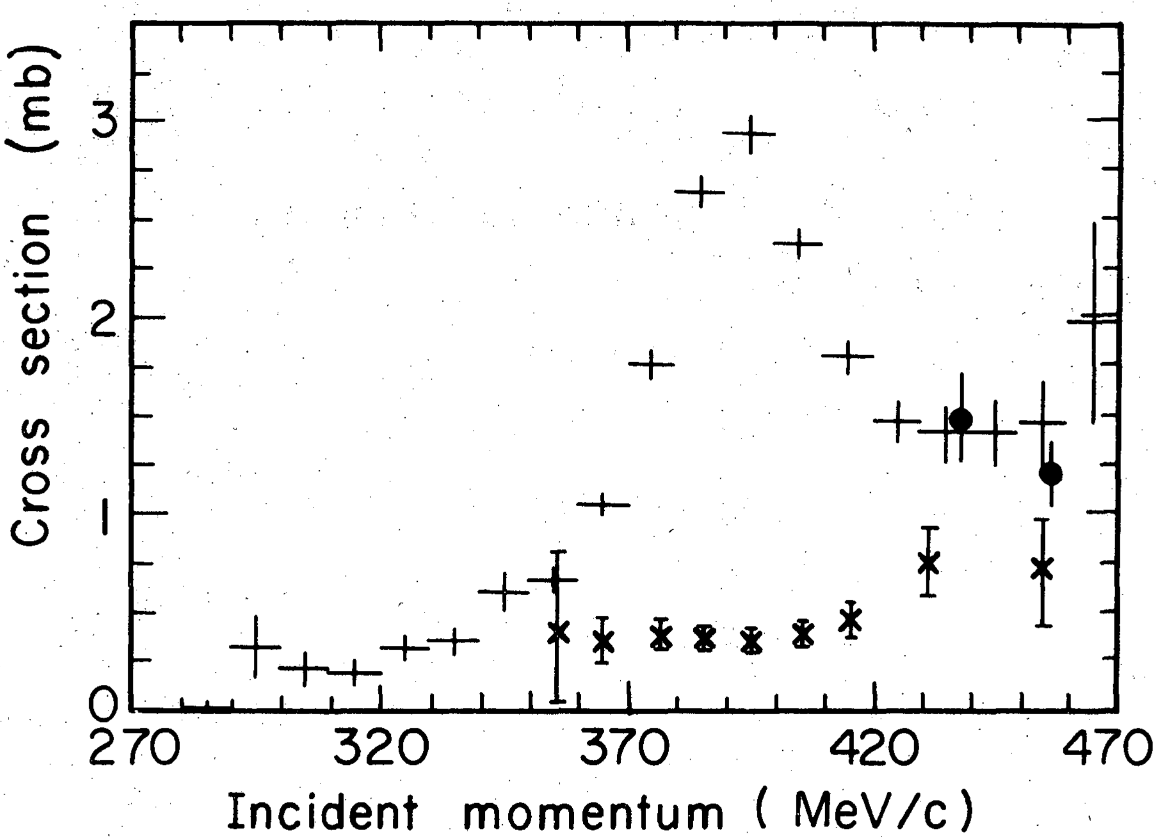
Figure Captions

Fig. 1. Cross section for $K^- p \rightarrow \Lambda\pi^+\pi^-$ as a function of incident K^- momentum. The $\nmid$ represent the background to the $\Lambda(1520)$ resonance, obtained through the partial wave analysis discussed in the text. The dotted data is from Armenteros et al., Nucl. Phys. B21, 15-75 (1970).

Fig. 2. Dalitz plot and projections for events in the momentum interval 390-400 MeV/c. The curves result from the partial wave analysis discussed in the text. The symbols $\vdash\!\ast\!\dashv$ in (c) indicate the $\Sigma(1385)$ bands.

Fig. 3. Legendre polynomial coefficients for the Λ angular distribution (a, b) and polarization (c), and charge asymmetry of the Dalitz plot (d), as a function of incident momentum. The dots are results from the partial wave analyses.

Fig. 4. Partial wave amplitudes with statistical errors resulting from the fits discussed in the text. The numbers 1 through 9 indicate successive incident K^- momentum intervals (same as in Fig. 3). The curve on the Y^*DS03 partial wave is explained in the text.



XBL7110-4528

Fig. 1

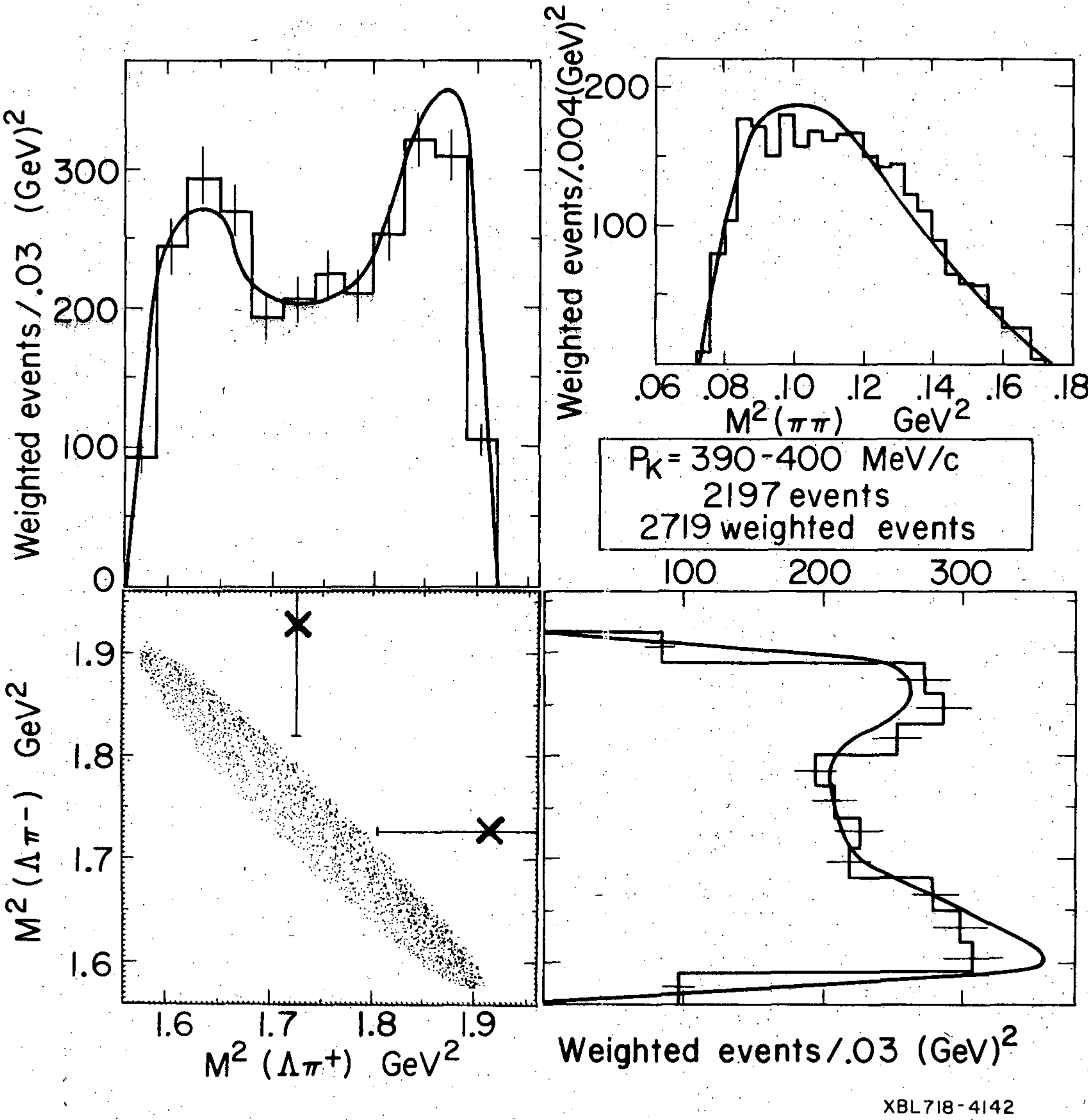
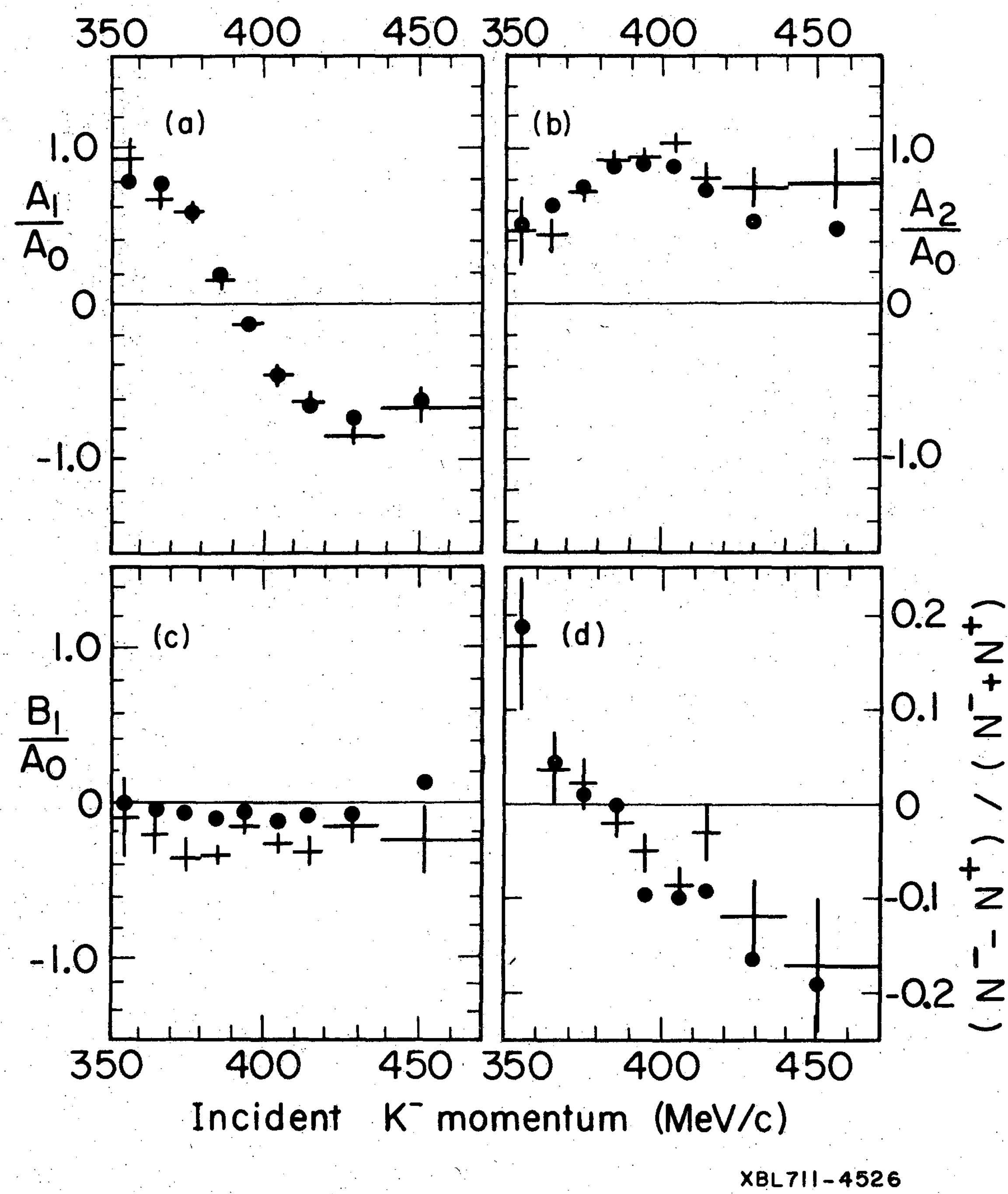

Weighted events/.03 (GeV)^2
0
100
200
300
Weighted events/.004(GeV)^2
100
200
.06 .08 .10 .12 .14 .16 .18
M^2 ($\pi\pi$) GeV^2
P_K = 390-400 MeV/c
2197 events
2719 weighted events
100 200 300
M^2 ($\Lambda\pi$-) GeV^2
1.6
1.7
1.8
1.9
1.6 1.7 1.8 1.9
M^2 ($\Lambda\pi$+) GeV^2
Weighted events/.03 (GeV)^2
XBL718-4142

Fig. 2



350
400
450
(a)
(b)
(c)
(d)
1.0
0
-1.0
0.2
0.1
-0.1
-0.2
A1/A0
A2/A0
B1/A0
(N⁻−N⁺)/(N⁻+N⁺)
Incident K⁻ momentum (MeV/c)
XBL711-4526

Fig. 3

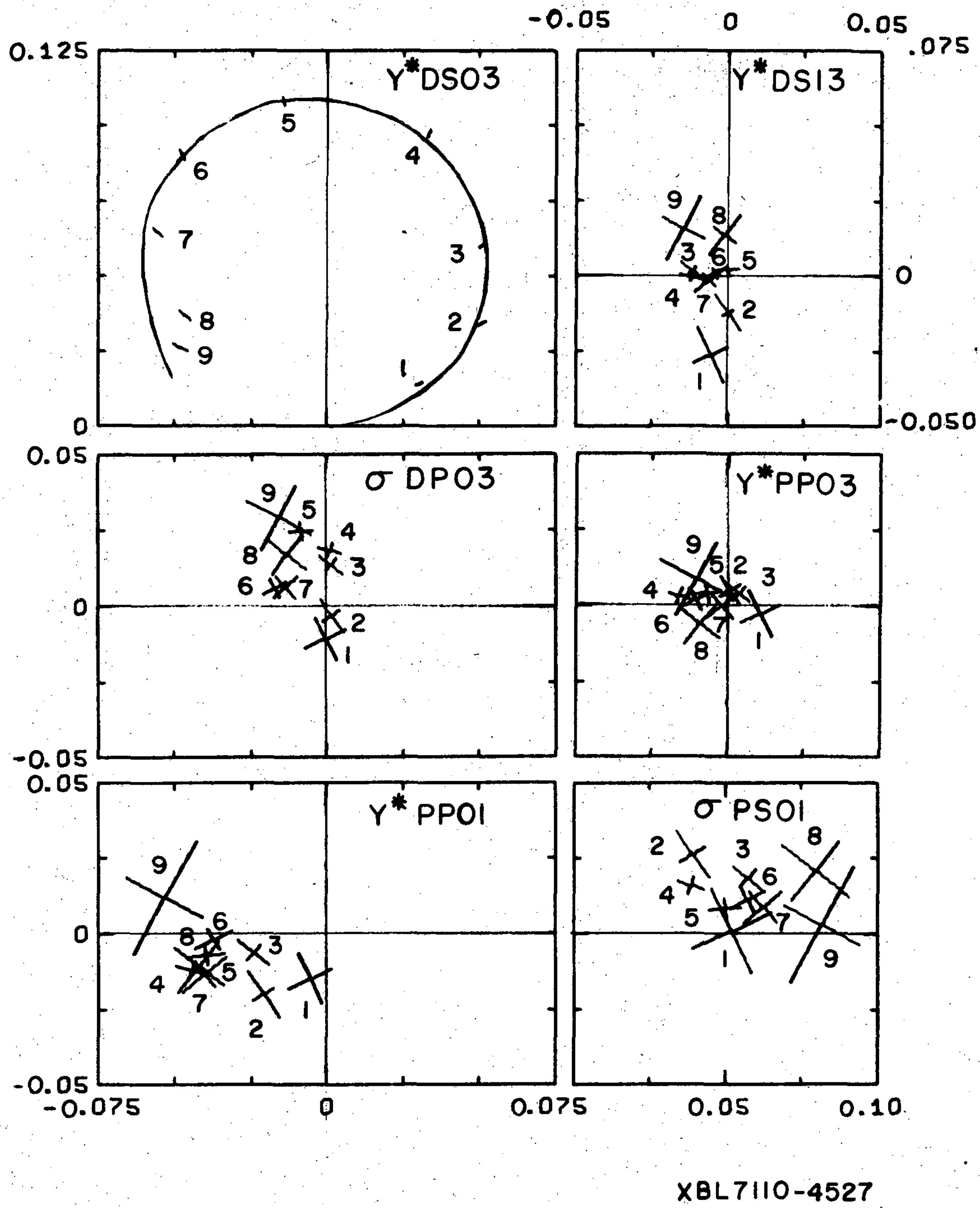

Y*DS03
Y*DS13
σ DP03
Y*PP03
Y*PP01
σ PS01
0.125
0
0.05
-0.05
-0.075
0
0.075
0.05
0.10
-0.05
0.05
.075
-0.050
XBL7110-4527

Fig. 4

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