0 0 0 0 4 4 0 1 5 0 5

Invited talk presented at the ANL Summer Symposium on New Directions in Hadron Spectroscopy, Argonne, IL, July 7 - 10, 1975

LBL-4222

$\pi N \rightarrow \pi N$ AND $KN \rightarrow KN$ LOW ENERGY DATA AND PARTIAL WAVE ANALYSES RECENT RESULTS AND NEW DIRECTIONS

R. L. Kelly

July 1975

Prepared for the U. S. Energy Research and Development Administration under Contract W-7405-ENG-48

For Reference

Not to be taken from this room

LAWRENCE BERKELEY LABORATORY • UNIVERSITY OF CALIFORNIA • BERKELEY

LBL-4222

DISCLAIMER

This document was prepared as an account of work sponsored by the United States Government. While this document is believed to contain correct information, neither the United States Government nor any agency thereof, nor the Regents of the University of California, nor any of their employees, makes any warranty, express or implied, or assumes any legal responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by its trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof, or the Regents of the University of California. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof or the Regents of the University of California.

0 0 0 0 4 4 0 1 5 0 6

LBL-4222

$\pi N \to \pi N$ and $KN \to KN$ Low Energy Data and Partial Wave Analyses Recent Results and New Directions

R. L. Kelly

Lawrence Berkeley Laboratory
University of California
Berkeley, California 94720

Invited talk presented at the ANL Summer Symposium on New Directions in Hadron Spectroscopy, July 7-10, 1975.

$\pi N \to \pi N$ and $KN \to KN$ Low Energy Data and Partial Wave Analyses
Recent Results and New Directions

R. L. Kelly

Lawrence Berkeley Laboratory
University of California
Berkeley, California 94720

This review deals with $\pi N \to \pi N$ and $KN \to KN$ physics below about 3 GeV/c. I will attempt to convey the state of the art, and to point out what appear to be promising directions for future research. The situation as of about one year ago is summarized in the 1974 Review of Particle Properties[1] and in London conference talks[2,3] so I will concentrate on more recent developments. The first section of this talk contains a comprehensive survey of $\pi N \to \pi N$ data between the Δ region and 3 GeV/c. Problems associated with spin-rotation experiments are discussed in the second section, and current $\pi N \to \pi N$ partial wave analyses in the third section. Sections IV and V deal with I=1 and I=0 $KN \to KN$ analyses, respectively.

I. $\pi N \to \pi N$ Data Below 3 GeV/c

The main $\pi N \to \pi N$ differential cross section (DCS) and polarization (POL) experiments are listed in Tables I and II. These tables are by no means complete, but they do contain nearly all of the larger experiments in each part of the energy range. A few large experiments have been dropped because they are in clear disagreement with a number of others. Experiments lying wholly in the Δ region have also been omitted, and I will not discuss that region here; for information on the Δ region see particularly Refs. 5 and 6. The statistics of each experiment is indicated in the tables by a "statistical weight" which is the sum of the inverse square fractional errors for DCS data and the sum of the inverse square absolute errors for POL data. The sums are cut off at 3 GeV/c.

Although Table I indicates comparable amounts of π^+p and π^-p elastic DCS data, the π^+p data are in much better shape for purposes of partial wave analysis because they have more uniform angular coverage. Many of the π^-p data are concentrated near the backward direction, and only about one third of their statistical weight is evenly distributed in angle. Furthermore, the backward π^-p experiments are often in serious disagreement with each other, and the quoted errors on many of the data are comparable to the estimated magnitude of radiative corrections[7] which have nowhere been taken into account. (Radiative corrections to $\pi N \to \pi N$ reactions are largest for π^-p backward elastic scattering.) High precision π^+p and π^-p DCS measurements have recently been made throughout the resonance region with complete angular coverage by a Bristol-RHEL-Southampton group.[8] The first results from this group are some of their π^+p data (Hughes 72 in Table I), and when the rest of their data are available the π^-p situation should be greatly improved.

The comparison between π^+p and π^-p elastic POL data is even worse. π^+p POL has been measured in great detail by the Thresher group at RHEL (Martin 74 in Table II) and there are no comparable measurements for π^-p. The next largest experiment (Albrow 70, Albrow 72) also measured π^+p in more detail than π^-p, and the largest π^-p experiment (Hill 71) has data at only five momenta. The situation is illustrated in Fig. 1 which shows "amalgamated" polarization data at 1247, 1437, and 1790 MeV/c.[9] These data are made by fitting a surface to the world data in a ~150 MeV/c wide momentum range, interpolating the data in the central part of the range (~50 MeV/c wide) into fixed angular positions (with 3° spacing) at the central momentum, and then combining the data statistically while allowing for normalization errors, momentum calibration errors, discrepancies between experiments, interpolation errors, etc. The π^+p vs. π^-p comparisons shown in Fig. 1 are typical, as is the deterioration in the quality of the π^-p data with increasing momentum (although the quality is much better at the five momenta of Hill 71). As far as I know there is no π^-p polarization experiment presently being pursued that will remedy this situation.

CEX data is, of course, much more difficult to obtain and hence much more sparse than elastic data as is evident from the tables. In addition to the tabulated experiments there is a large experiment of the Thresher group at RHEL which has completed running and is now being analysed. Both DCS and POL data were taken at 21 momenta between 620 and 2272 MeV/c and single measurements were made at 3 more momenta.[10]

Channel	Experiment	Accelerator	Statistical Weight/1000 (Plab≤3GeV/c)	Momentum Range (MeV/c)	Number of Momenta	Experimental Technique
π^+p	Ogden 65	Saturne	53	427-777	8	Counters.
π^+p	Bowler 72	Nimrod	17	590-807	5	81-cm HBC.
π^+p	Rothschild 72	Bevatron	78	592-1628	43	Double arm counter spectrometer, $\theta=180°$.
π^+p	Hughes 72	Nimrod	393	800-1594	18	Acoustic chambers + single arm spectrometer.
π^+p	Duke 66	Nimrod	61	875-1579	12	Counters.
π^+p	Baker 70	Nimrod	18	895-1040	4	81-cm HBC.
π^+p	Baillon 74	CERN PS	101	1015-2004	3	Proportional chambers, Coulomb interference.
π^+p	Abe 74	ZGS	469	1207-2300	16	Wire chambers.
π^+p	Vavra 74	Bevatron	92	1250-2000	16	Double arm counter spectrometers, $\cos\theta\lesssim-0.6$.
π^+p	Kalmus 71	Bevatron	66	1280-1840	8	72-inch and 25-inch HBC.
π^+p	Busza 69	Nimrod	17	1720-2800	10	Optical chambers.
π^+p	Lennox 75	ZGS	14	2000-6000	38	Double arm counter spectrometer, $\cos\theta\lesssim-0.9$.
π^+p	Sidwell 71	ZGS	9	2180-5250	15	Optical Chambers.
π^+p	Coffin 67	ZGS	39	2300-4000	7	Optical chambers.
π^-p	Ogden 65	Saturne	59	490-777	7	Counters.
π^-p	Brody 71	ZGS/Bevatron	38	557-1604	35	30-inch/72-inch HBC's.
π^-p	Rothschild 72	Bevatron	24	572-1628	44	Double arm counter spectrometer, $\theta=180°$.
π^-p	Debenham 73	Nimrod	464	599-999	52	Counters, $\theta\approx180°$.
π^-p	Richards 74	Bevatron	335	600-1280	33	Double arm counter spectrometer, $\cos\theta\lesssim-0.9$.
π^-p	Baillon 74	CERN PS	174	619-1999	4	Proportional chambers, Coulomb interference.
π^-p	Duke 66	Nimrod	82	875-1579	13	Counters.
π^-p	Barber 75	Nimrod	82	996-1342	16	Counters.
π^-p	Aplin 71	Nimrod	151	1210-2940	31	Counters.
π^-p	Ott 72	Bevatron	113	1280-3000	31	Double arm counter spectrometer, $\cos\theta\lesssim-0.6$.
π^-p	Dolbeau 74	Saturne	71	1505-1739	6	180-liter HBC.
π^-p	Hill 70	ZGS	25	1700-2500	5	LMN target + counters.
π^-p	Fellinger 70	ZGS	78	1710-5530	18	Double arm counter spectrometer, $\cos\theta\gtrsim0.6$.
π^-p	Coffin 67	ZGS	21	2500-6000	6	Optical chambers.
CEX	Hauser 71	PPA	36	250-699	13	Counters.
CEX	Debenham 73	Nimrod	88	599-999	52	Counters, $\theta\approx180°$.
CEX	Chiu 67	Bevatron	16	624-1433	9	Optical chambers.
CEX	Bulos 69	Cosmotron	21	654-1247	11	Optical chambers.
CEX	Nelson 73	Bevatron	26	1030-2390	6	Optical chambers.
CEX	Kistiakowsky 72	ZGS	12	1800-6000	52	Counters, $\theta=180°$.
CEX	Sonderegger 68	CERN PS	7	2550-18200	23	Optical chambers, $\cos\theta\gtrsim0.6$.

Table I. A survey of the main $\pi N\to\pi N$ elastic and charge-exchange (CEX) differential cross section measurements below 3 GeV/c (excluding the Δ region).[4] The statistical weight is defined in the text and includes measurements at or below 3 GeV/c only.

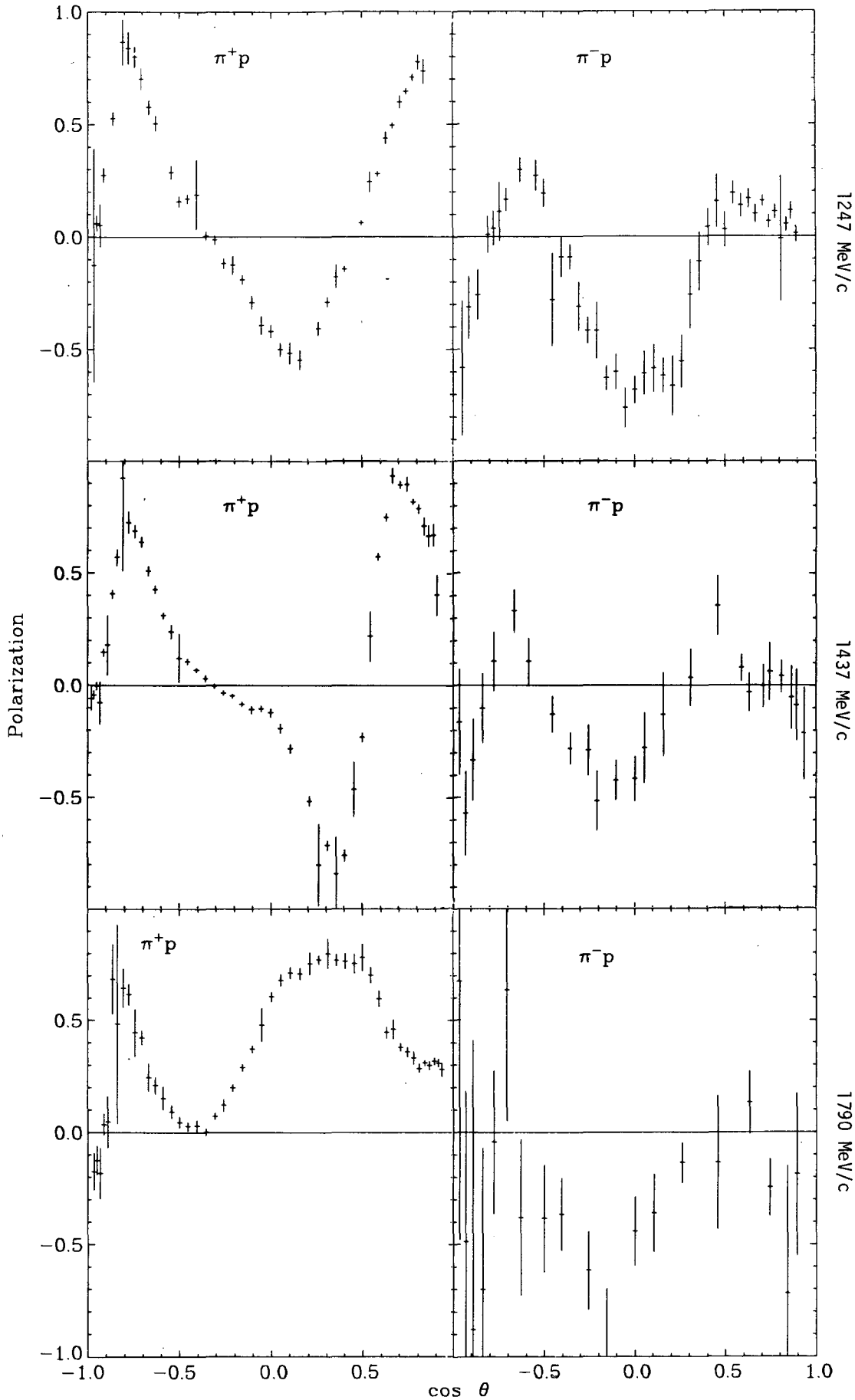


Fig. 1. Comparison of amalgamated π^+p and π^-p POL data at 1247, 1437, and 1790 MeV/c.

Channel	Experiment	Accelerator	Statistical Weight/1000 (Plab≲3GeV/c)	Momentum Range (MeV/c)	Number of Momenta	Experimental Technique
π^+p	Gorn 73	184-inch	91	356-519	4	LMN target + counters.
π^+p	Martin 74	Nimrod	2632	603-2651	68	LMN target + counters.
π^+p	Johnson 67	Bevatron	26	745-3747	15	LMN target + counters.
π^+p	Albrow 70	CERN PS	414	820-2740	24	Butanol target + counters.
π^+p	Burleson 71	ZGS	75	1600-2310	4	Ethylene glycol target + counters.
π^+p	Scheid 73	ZGS	90	2500-5150	7	LMN target + counters, $\cos\theta \gtrsim 0.4$ and $\cos\theta \lesssim -0.7$.
π^-p	Arens 68	184-inch	44	341-511	4	LMN target + counters.
π^-p	Hansroul 67	Bevatron	17	596-3260	11	LMN target + counters.
π^-p	Cox 69	Nimrod	84	643-2140	50	LMN target + counters.
π^-p	Albrow 72	CERN PS	172	865-2732	16	LMN and butanol targets + counters.
π^-p	Duke 68	Nimrod	15	875-1579	8	LMN target + counters.
π^-p	Barrelet 75	Bevatron	35	1180-1360	3	Propylene glycol target + proportional chambers, $\lvert\cos\theta\rvert \lesssim 0.4$.
π^-p	Hill 71	ZGS	356	1600-2280	5	Ethylene glycol target + counters.
π^-p	Hill 70	ZGS	20	1700-2500	5	LMN target + counters.
π^-p	Scheid 73	ZGS	8	2750-5150	5	LMN target + counters, $\lvert t\rvert \lesssim 2(\mathrm{Gev/c})^2$.
CEX	Shannon 74	Bevatron	6	1030-1790	5	Propylene glycol target + optical chambers.
CEX	Drobnis 68	ZGS	1	2070-5000	6	LMN target + counters.

Table II. A survey of the main $\pi N \to \pi N$ elastic and charge-exchange (CEX) polarization measurements below 3 GeV/c (excluding the Δ region).[4] The statistical weight is defined in the text and includes measurements at or below 3 GeV/c only.

II. $\pi N \to \pi N$ Spin Rotation Experiments

Spin rotation data in the resonance region are presently non-existant, and are sorely needed to improve the quality of partial wave analyses. In the absence of these data there are *two* continuous phase ambiguities in the $\pi N \to \pi N$ amplitudes, one of which can be resolved by spin rotation measurements. Also, there are isospin relations (equalities!) between observables which can be tested once the elastic spin rotation parameters are known. These relations could serve as a valuable consistency check between different experiments subject to systematic error (or, perhaps, could show up anomalous breaking of isospin conservation).

A technical point worth emphasising is that a spin rotation measurement is the measurement of a recoil polarization *vector* and that there is not necessarily any point in putting a lot of design effort into an attempt to measure specifically A and R rather than some other components of this vector. The components of recoil polarization to be measured should be chosen simply on considerations of optimizing the accuracy and usefulness of the results. This will primarily involve hardware considerations, but predictions of the recoil polarization from partial wave analyses can also be profitably brought into the game. This possibility is discussed in detail in Ref. 11, and more briefly below.

The utility of recoil polarization predictions is most transparently demonstrated in terms of the Wolfenstein spin rotation angle, β, defined in Fig. 2a. On recoil from a target polarized in the scattering plane, the c.m. frame polarization is rotated through an angle β and multiplied by a factor which depends only on the ordinary polarization parameter, P. The magnitude of the recoil polarization will thus be known from the results of transversley polarized target experiments, and the task of the spin rotation experiment is to measure its orientation, i.e., β. Figure 2b shows that the component of $\underline{P}_r$ perpendicular to the predicted recoil polarization is the most sensitive measure of β provided that the prediction is not too inaccurate. As a numerical example suppose the prediction is off by 30°; then the error of β as determined from a measurement of the perpendicular component is only 15% greater than what it would be for perfect alignment while the error from a determination using the parallel component would be twice as large.

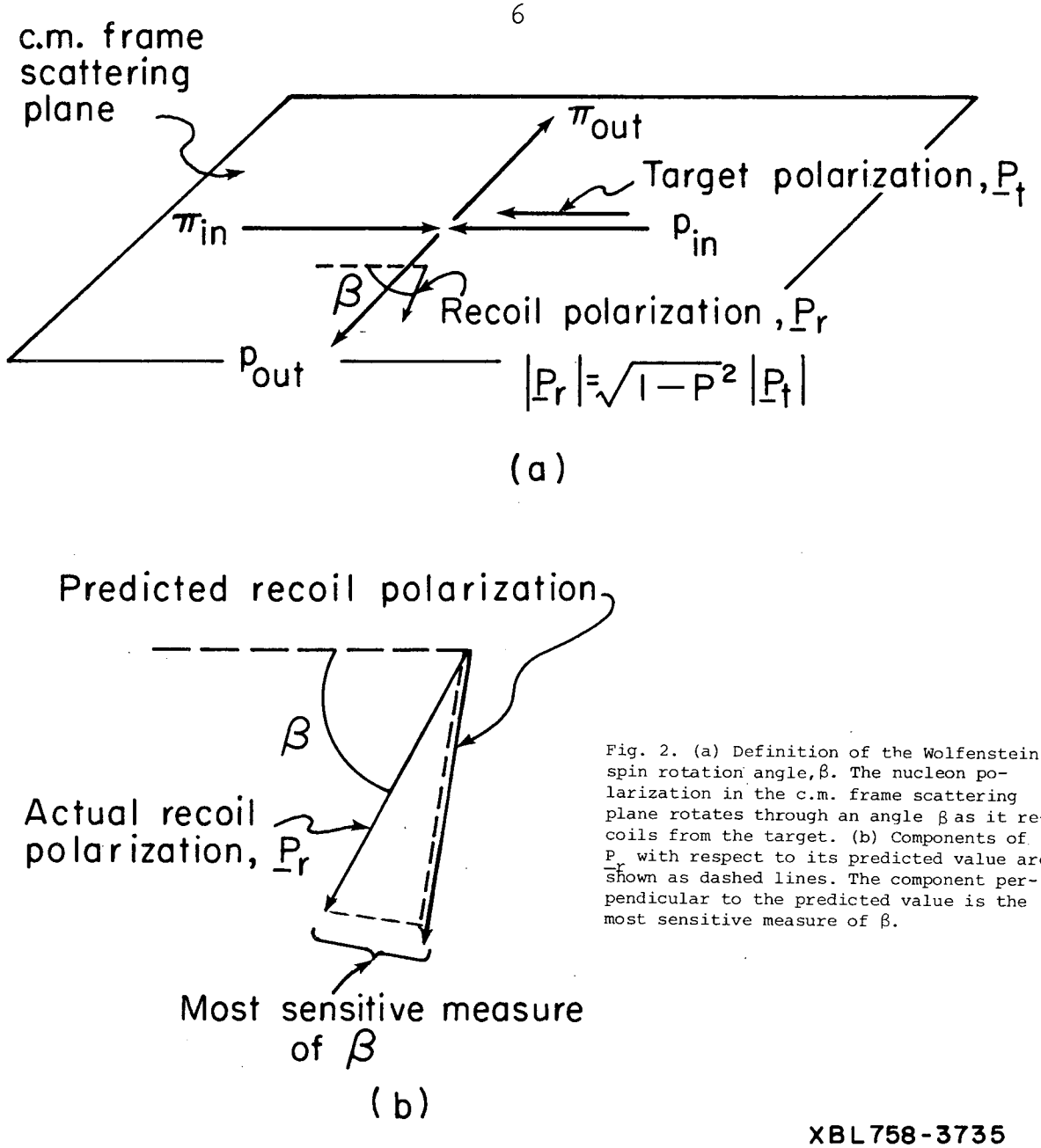


Fig. 2. (a) Definition of the Wolfenstein spin rotation angle, β. The nucleon polarization in the c.m. frame scattering plane rotates through an angle β as it recoils from the target. (b) Components of $\underline{P}_r$ with respect to its predicted value are shown as dashed lines. The component perpendicular to the predicted value is the most sensitive measure of β.

XBL758-3735

III. $\pi N \to \pi N$ Partial Wave Analyses

Although many properties of the more prominant N and Δ resonances are by now well established there remain many open questions concerning more detailed structure of the $\pi N \to \pi N$ amplitudes. The resolution of these questions will undoubtedly require improved data, as discussed in the previous sections, and also continued improvement in the methods of partial wave analysis. The four most recent comprehensive partial wave analyses are summarized in Table III. Two of these, CERN[12] and Saclay,[13] used the shortest path method to connect solutions at different energies. (Although it should be noted that the use of dispersion relations for energy continuation was pioneered by earlier CERN analyses.) The more recent analyses, Karlsruhe[14] and our own work in the CMU-LBL (CL) group, both use dispersion relations for energy continuation, and CL avoids having a cutoff in L by using a single energy parametrization based on t- and u-channel analyticity.[15] The CL analysis also uses the amalgamated DCS and POL data described earlier. It is instructive to compare the Saclay results with preliminary results of the CL

Group	Single Energy Parametrization	Energy Continuation	Status
CERN (1972)	Sum PW series to L ~ 5-6	Shortest path + some info. from partial wave DR's.	Somewhat obsolete because of new CEX data.
Saclay (1973)		Shortest path + some info. from fixed-t DR's.	Completed.
Karlsruhe (1975)		Fixed-t DR's.	In progress.
CMU-LBL (1975)	ACE	Hyperbolic DR's.	In progress.

Table III. Summary of recent πN partial wave analyses.

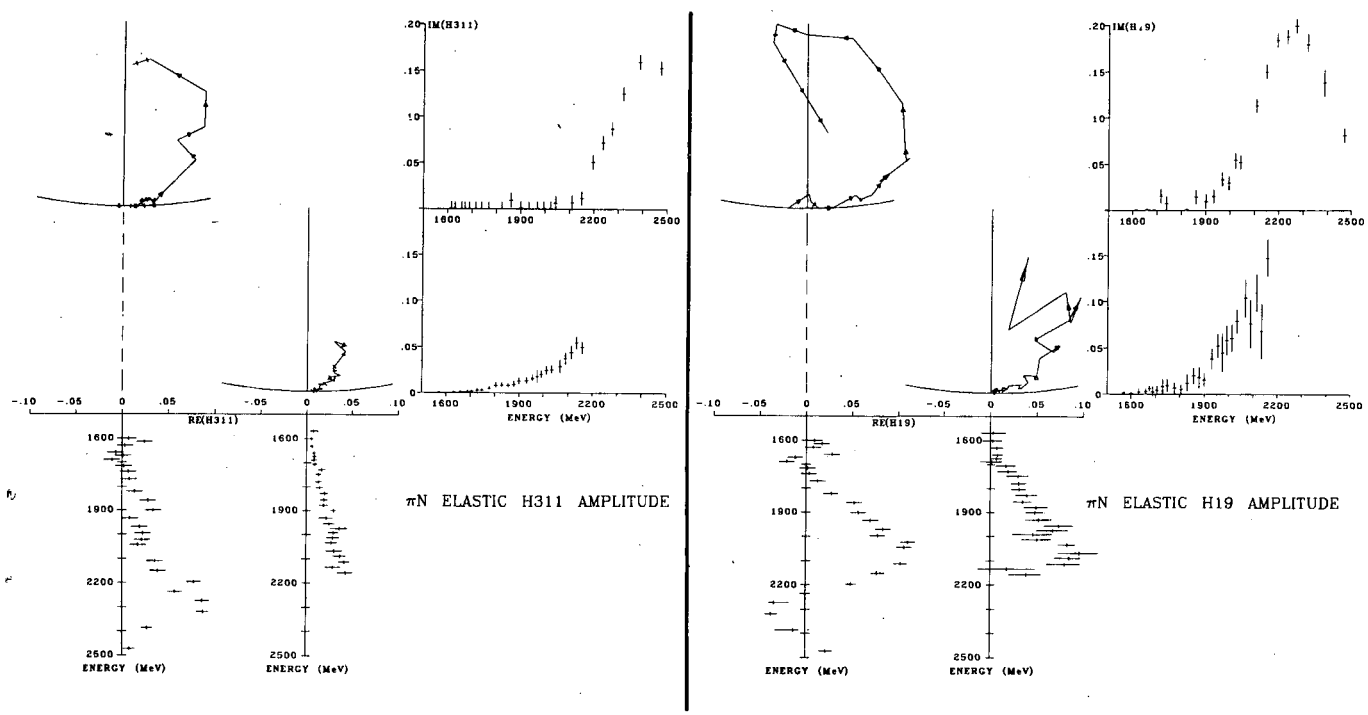
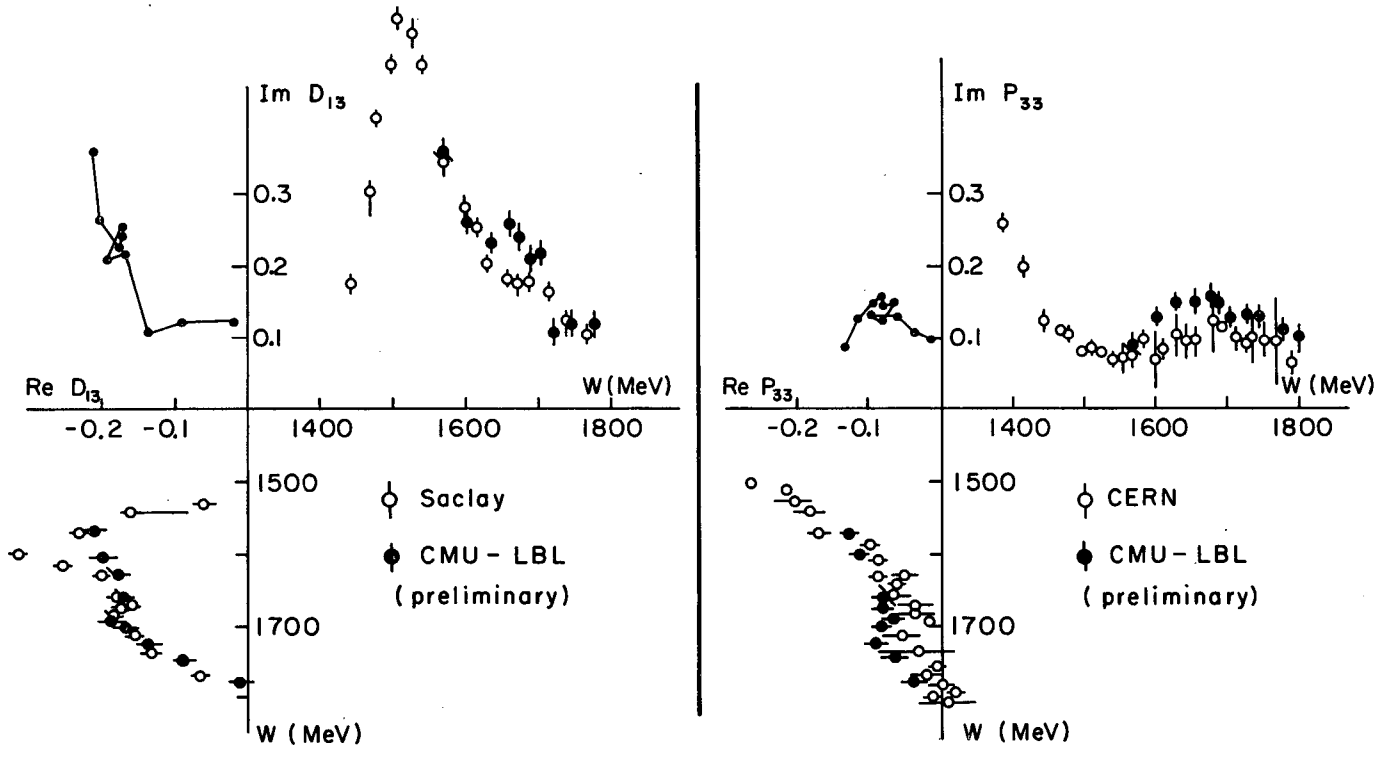


Fig. 3. Amplitudes for πN elastic scattering in the H311 and H19 partial waves. The energy dependence of each amplitude is displayed by plotting its real and imaginary parts vs. energy, in alignment with the corresponding Argand plot. In addition, arrows are plotted on the Argand plots with bases positioned at even multiples of 50 MeV and lengths of 5 MeV. Two sets of results are shown, and the energy axes are aligned for ease of comparison. The Saclay results are shown in the upper Argand plots, the preliminary CL results in the lower.



XBL758-3737

Fig. 4. Amplitudes for πN elastic scattering in the D13 (left) and P33 (right) partial waves. The plots are constructed similarly to those in Fig. 3, but the Argand plots in the insets show CL results only.

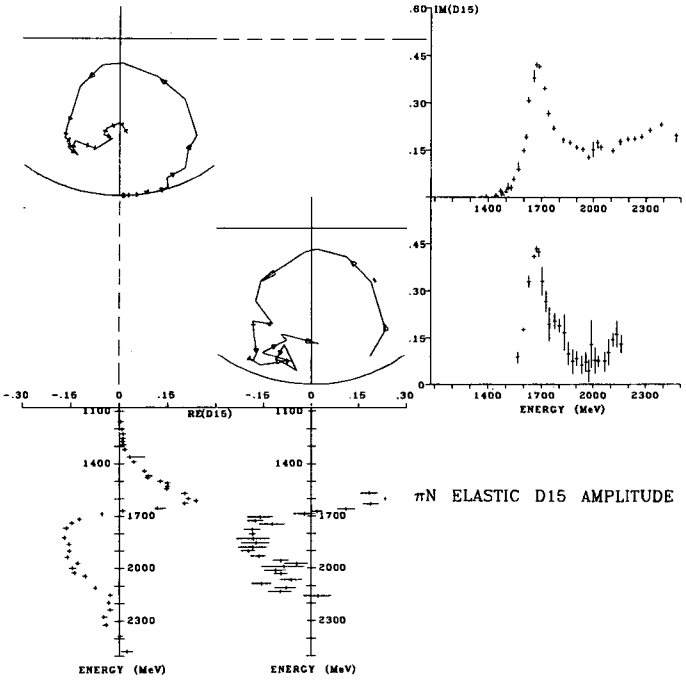


Fig. 5. Amplitude for πN elastic scattering in the D15 partial wave. See Fig. 3 caption for an explanation of the plot.

analysis. The available experimental data for the two analyses were not greatly different, but the data handling methods and methods of analysis were quite different, and the comparison shows how this can effect interesting aspects of the amplitudes. Three particular aspects of the amplitudes that I shall discuss are high partial waves, inelastic resonances, and background.

Effects of a sharp cutoff vs. ACE on the high partial waves are illustrated in Fig. 3. These are the H311 and H19 waves which contain the second recurrences of the Δ(1232) and N(939), respectively. The preliminary CL results do not yet extend into the recurrence region, but significant effects are already clear at lower energies. The CL results have generally smoother and better determined threshold behavior; note in particular the absence of any "ancestral" fluctuations in the 1700 MeV resonance region. Note also that in the CL analysis the I=3/2 wave is considerably better determined than the I=1/2 wave; this is a common occurence and is presumably due to the better quality of the π^+p data as compared to the π^-p data.

The D13(1700) and P33(1690) are shown in Fig. 4. These objects may well be bona fide resonances, having been observed in several $\pi N \to \pi N$ analyses and in other channels (particularly $\pi N \to \pi\pi N$[16]), but they are highly inelastic and it is difficult to determine their parameters with any precision. The D13(1700) was claimed as a resonance by Saclay and not by CERN and the P33(1690) by CERN (with reservations) but not by Saclay. In each case the CL amplitudes are significantly different. In connection with the D13 amplitudes it is interesting to note that the ωN threshold is at 1720 MeV, and that this has perhaps influenced the CL results.

Since we must ultimately aim at understanding the amplitudes as a whole, rather than just resonance masses and widths, it is important to determine the non-resonant "background" accurately. One of the more striking differences between the CL and Saclay analyses in this respect is shown in Fig. 5. The CL imaginary part above the D15(1670) drops to much smaller values than that of Saclay.

One hopes that as the data improve these kinds of discrepancies will go away and that partial wave analysts will converge on the correct amplitudes. To accomplish this it will be essential for the methods of analysis to keep pace with the data, and for great care to be taken in obtaining good fits in a statistically quantitative sense and in assessing the accuracy of the resulting amplitudes. It will also continue to be an extremely good thing for analyses to be done by several different groups, *using various methods*, in order to better determine the level of systematic and/or model dependent biases in the results.

IV. $K^+p \to K^+p$ Data and Analyses

I won't attempt a complete review of K^+p data, but will just mention the most recent developments. A large wire-chamber cross section experiment has been performed at the ZGS by a Maryland-ANL group in the 865 to 2125 MeV/c momentum range.[17] At lower momenta (130-775 MeV/c) there are new cross section data and a partial wave analysis from Glasgow-Bologna-Trieste.[18] The most recent polarization measurements (as well as some cross section measurements) are from the Yale-BNL group (1700-3000 MeV/c) at small $|t|$ and small $|u|$.[19] There is also a new compilation of K^+N data from CERN-HERA.[20]

The S- and P-waves from four different analyses are shown in Fig. 6. On the right are the low energy results of Birmingham-RHEL[21] (ϕ) plotted together with the CMU-LBL-ANL results[22] ($+$) at higher energy; these plots are constructed similarly to Figs. 3-5 except that the arrows here are at multiples of 100 MeV and are 20 MeV long. On the upper left are results from a Virginia-Maryland group[23] (with cross hatches every 100 MeV/c), and on the lower left the results of Martin[24] (with cross hatches at the indicated multiples of 100 MeV/c). There are a number of significant disagreements between these four analyses, one of the most interesting being that the Virginia-Maryland (VM) group claims the existence of a P13 resonance with pole position 1787-100i MeV which is not seen by the other analyses.

This disagreement on the existence of a Z_1^* around 1800 MeV is connected with the behavior of the P-waves at lower energies as illustrated in Fig. 7a. The solid curves are taken from the VM paper and show their P13 total and elastic cross sections. The dashed and dotted curves show the same quantities from the Birmingham-RHEL (BR) and CMU-LBL-ANL (CLA) analyses. Below ~1700 MeV the VM results show a strong P-wave suppression and are in order-of-magnitude disagreement with the results of the other groups. The VM Z_1^* is closely connected with the resulting rapid rise above 1700 MeV. Such strong disagreement is possible because there are no polarization data below ~1730 MeV (the vertical line in Fig. 7a), and only the P-wave combination P11+2P13 is well determined by cross section data at these low energies (and is determined to be small by the highly isotropic nature of the angular distribution). The polarization is sensitive to the P-wave combination P11-P13 and will be appreciable in the 1600-1700 MeV region according to the BR and CLA analyses, while the VM analysis predicts that it will be extremely small. This question will hopefully be clarified later this year by the Yale-BNL group who intend to measure the polarization at 650 MeV/c (1630 MeV) at the AGS.[25]

At higher energies more waves become important and the discrepancies between different analyses become more complicated. For example, cusp effects are seen in the CLA analysis in the neighborhood of the $K^*\Delta$ threshold, but are absent in other analyses. Spin rotation measurements should be very useful here as shown in Fig. 7b which compares the CLA and VM Wolfenstein angle predictions.[3]

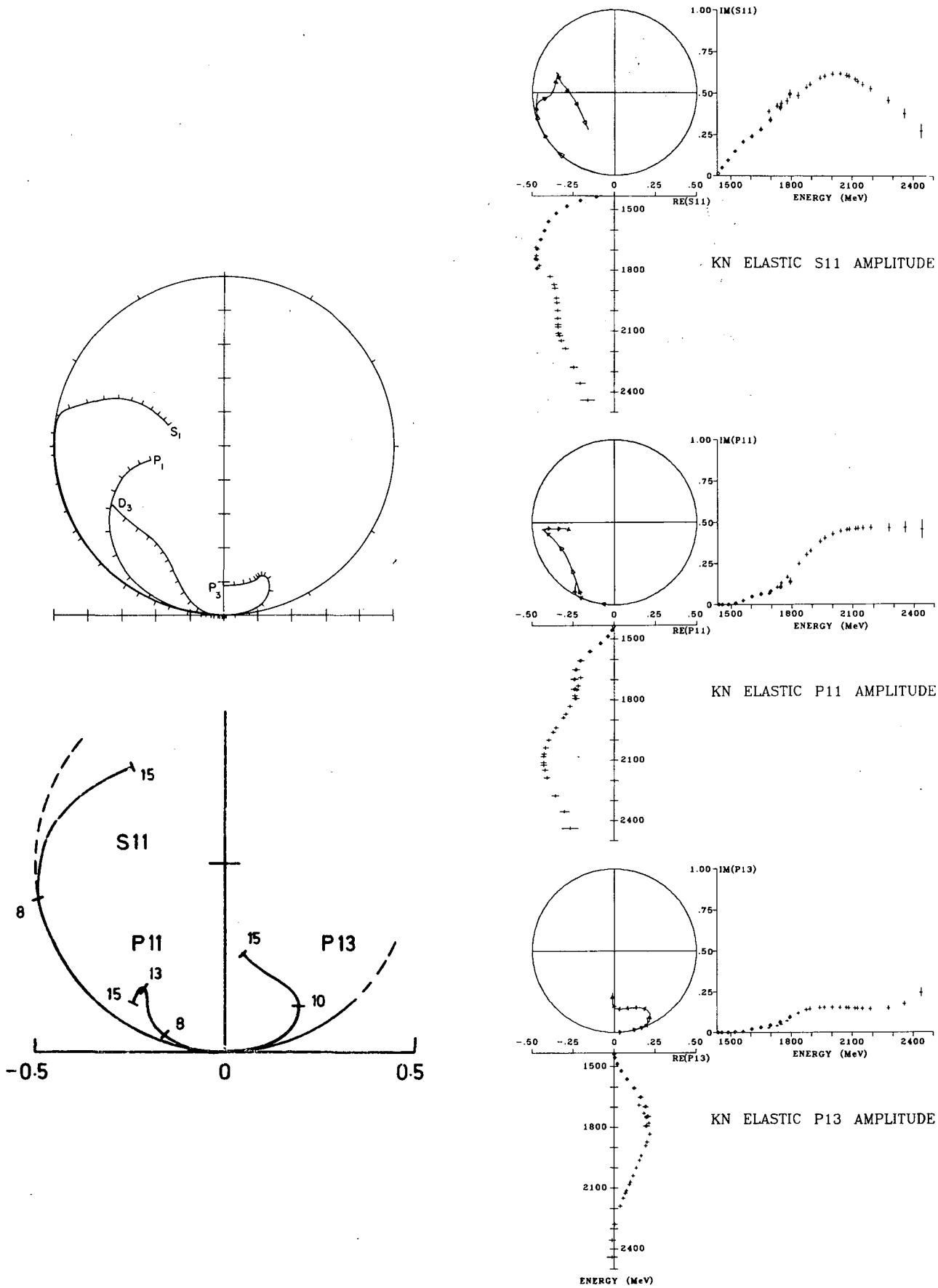


Fig. 6. $K^+p \to K^+p$ partial wave amplitudes. See text for explanation.

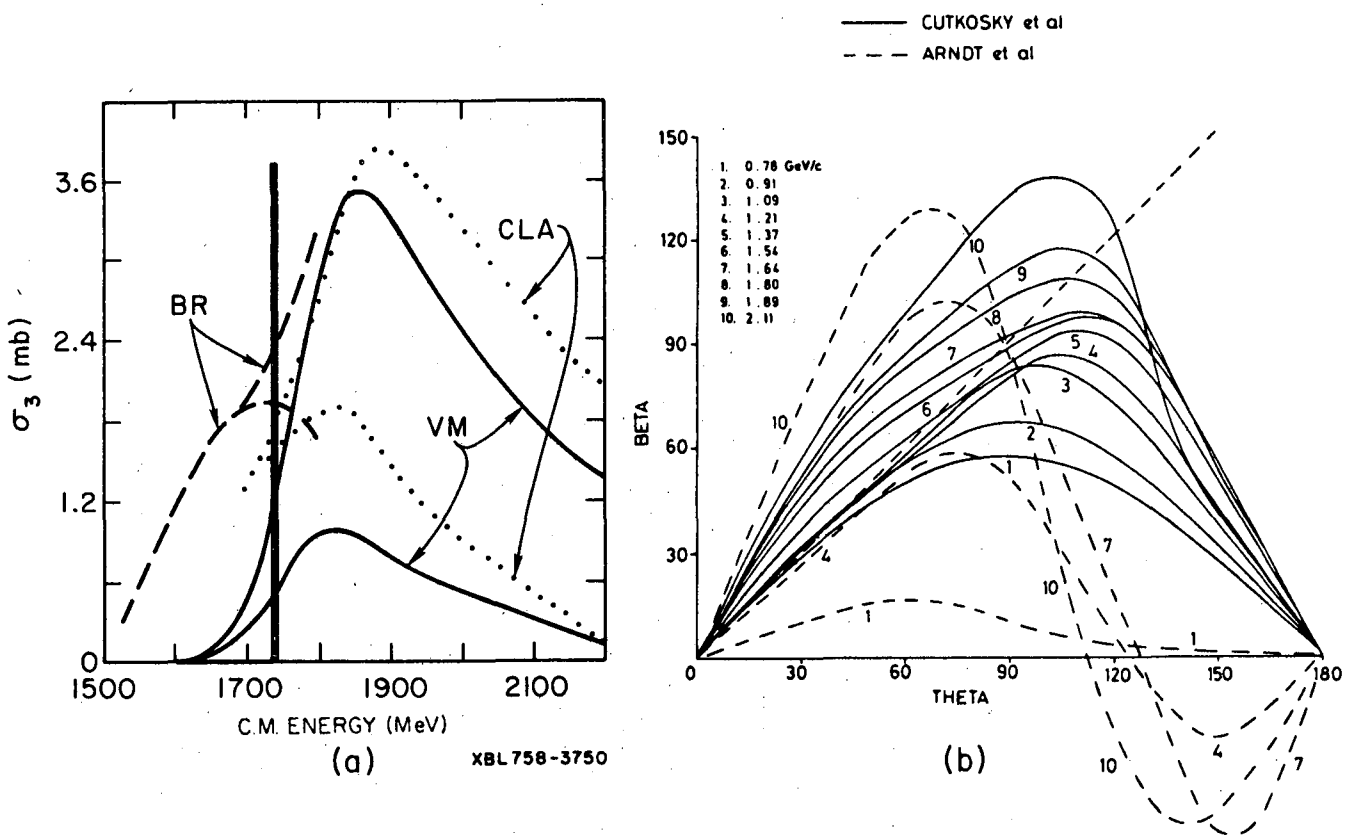


Fig. 7. (a) P13-wave total and elastic cross sections from the BR, CLA, and VM analyses. (b) Wolfenstein angle predictions from the CLA and VM analyses.

V. I=0 KN → KN Analyses and Data

The state of the art in I=0 analysis as of about one year ago is illustrated in the upper part of Fig. 8 which shows results of the Bologna-Glasgow-Rome-Trieste (BGRT) group[26] below 1500 MeV/c. Three different types of analysis were made and in each case all acceptable solutions fell into the three catagories shown in Fig. 8. Further comparisons with the single existing $K^+n \to K^0p$ polarization measurement,[27] and with recent I=0 total cross section determinations[28] indicated a preference for the class D solutions. The most likely resonance candidate was in the P01 wave at about 1740 MeV with a width of 300 MeV, but the evidence was inconclusive.

Interesting developments in the last year all go in the direction of bringing more hydrogen target data to bear on the I=0 analyses (which have relied primarily on deuterium data in the past). One possibility is to use the K^+p elastic data more directly by analysing the I=1 and I=0 channels simultaneously (rather than using fixed I=1 amplitudes in the I=0 analyses). This was done by BGRT without finding any qualitatively new solutions, and has been more recently tried by Martin whose results are quite different from those of BGRT (see Fig. 8). It is questionable whether one really gains much by such a simultaneous analysis. The only advantage over the usual fixed I=1 amplitude technique is that the K^+n data can directly influence the I=1 amplitudes, and this would be quite important if the K^+n data were at all comparable in accuracy and amount to the K^+p data. This is not the case, and in fact the BGRT simultaneous analysis found only small changes in the I=1 amplitudes. It would be interesting to try an analysis in which existing I=1 amplitudes and their errors were used as input *data* along with K^+n data in a simultaneous I=1 and I=0 fit. This technique would be considerably simpler (and cheaper) than simultaneously fitting all the K^+p and K^+n data, and until the K^+n (or K^0p) data become much more copious it should give equally accurate results.

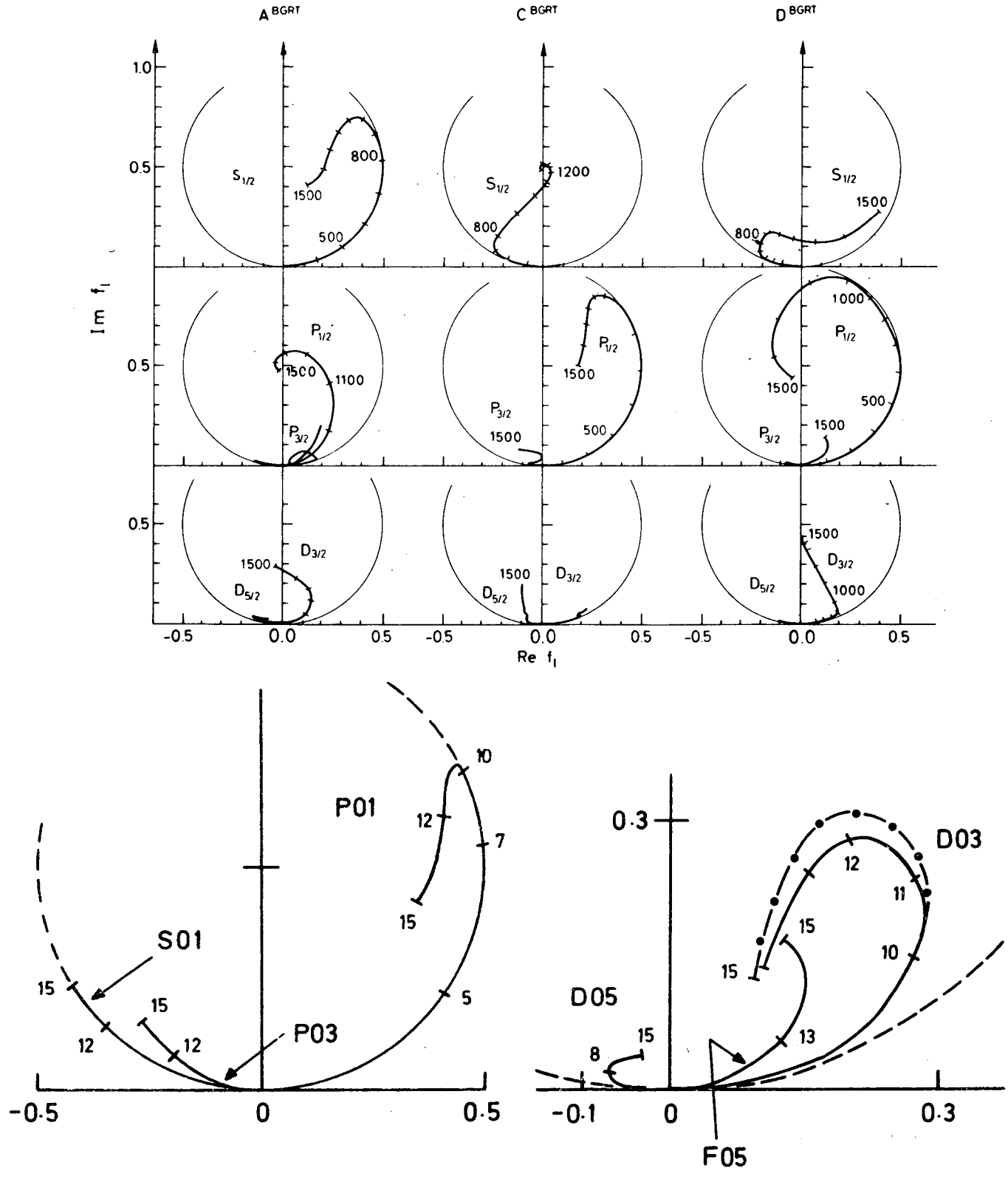


Fig. 8. I=0 KN → KN partial wave amplitudes. The BGRT results (upper) and Martin's results (lower) are shown, see text for discussion.

Another interesting development is the use of $K_L p \to K_S p$ data. The $K_L p \to K_S p$ amplitudes are superpositions of S=+1, I=1 and 0 and S=-1, I=1 amplitudes, and it was first suggested by London[29] in 1973 that this reaction would be particularly sensitive to the S=+1, I=0 ambiguities. At that time there were only a few data points, but new data have now been obtained in several bubble chamber experiments: Tel Aviv-Heidelberg (340-2160 MeV/c),[30] Bologna-Edinburgh-Glasgow-Pisa-RHEL (309-782 MeV/c),[31] and CMU-ANL (550 MeV/c).[32] These data have been compared with various combinations of amplitudes from different analyses and, though the situation is somewhat confused because of conflicting results, it appears that they are not yet of much help in sorting out the Z_0^* problem.[33] In fact, they appear to be more sensitive to Y_1^* ambiguities as shown in Fig. 9[32] where the CMU-ANL data is compared with predictions from the S=+1, I=1 amplitudes of Ref. 18, the BGRT solution D S=+1, I=0 amplitudes, and S=-1, I=1 amplitudes from the various $\bar{K}N$ analyses indicated in the figure.

The only other new data I know of that will be available in the near future is from a $K_L p \to K^+ n$ cross section experiment run at Daresbury by a Manchester group. Data have been taken between 700 and 1500 MeV/c, and are still being analysed.[39]

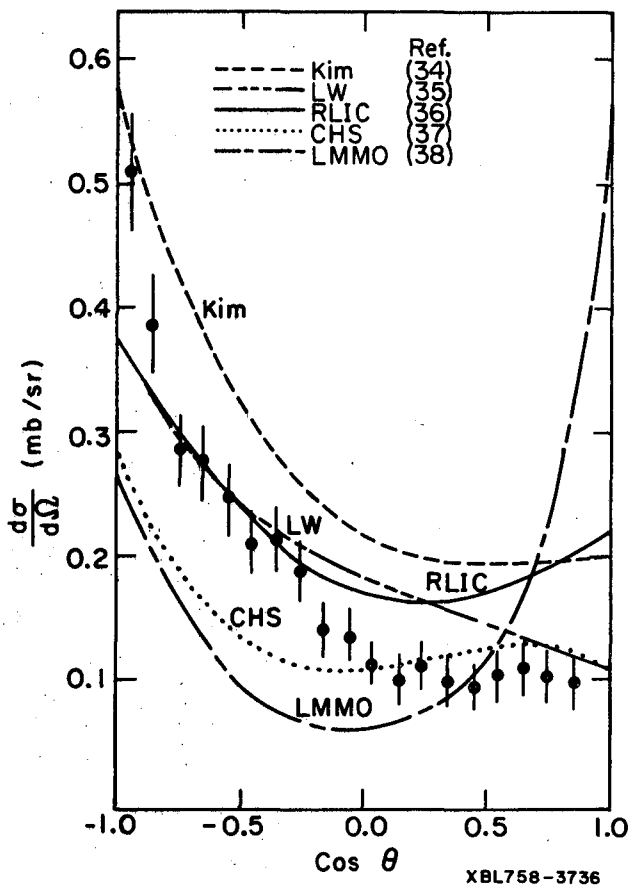


Fig. 9. Comparison of the CMU-ANL 550 MeV/c $K_L p \to K_S p$ cross section data with predictions from Ref. 18, solution D of Ref. 26, and the various $\bar{K}N$ analyses indicated.

References

1. Particle Data Group, Physics Letters 50B, No. 1 (1974).
2. P. J. Litchfield, in Proc. of the 17th Intl. Conf. on High Energy Physics, ed. J. R. Smith, London, 1974, pg. II-65.
3. R. E. Cutkosky, in Proc. of the 17th Intl. Conf. on High Energy Physics, ed. J. R. Smith, London, 1974, pg. II-54.
4. The shortened experiment names in Tables I and II consist of the first author and year of publication of the following references:

K. Abe et al., Phys. Rev. D 10, 3556 (1974).
M. G. Albrow et al., Nucl. Phys. B25, 9 (1970).
M. G. Albrow et al., Nucl. Phys. B37, 594 (1972).
P. S. Aplin et al., Nucl. Phys. B32, 253 (1971).
J. F. Arens et al., Phys. Rev. 167, 1261 (1968).
P. Baillon et al., Phys. Letters 50B, 387 (1974).
S. L. Baker et al., Nucl. Phys. B18, 29 (1970).
P. C. Barber et al., Nucl. Phys. B84, 109 (1975).
E. Barrelet, priv. comm.
M. G. Bowler et al., Nucl. Phys. B37, 133 (1972).
A. D. Brody et al., Phys. Rev. D 3, 2619 (1971).
F. Bulos et al., Phys. Rev. 187, 1827 (1969).
G. Burleson et al., Phys. Rev. Lett. 26, 338 (1971).
W. Busza et al., Phys. Rev. 180, 1339 (1969).
C. B. Chiu et al., Phys. Rev. 156, 1415 (1967).
C. T. Coffin et al., Phys. Rev. 159, 1169 (1967).
C. R. Cox et al., Phys. Rev. 184, 1453 (1969).
N. C. Debenham, Imperial College Thesis, 1973.
J. Dolbeau et al., Nucl. Phys. B78, 233 (1974).
D. D. Drobnis et al., Phys. Rev. Lett. 20, 274 (1968).
P. J. Duke et al., Phys. Rev. 149, 1077 (1966).
P. J. Duke et al., Phys. Rev. 166, 1448 (1968).
M. Fellinger et al., Phys. Rev. D 2, 1777 (1970).
W. Gorn, UCB Thesis (LBL-1320), 1973.
M. Hansroul, UCB Thesis (UCRL-17263), 1967.
M. G. Hauser et al., Phys. Letters 35B, 252 (1971).
D. Hill et al., Phys. Rev. Lett. 27, 1241 (1971).

R. E. Hill et al., Phys. Rev. D 1, 729 (1970).
C. M. Hughes, Univ. of Bristol Thesis, 1972.
C. H. Johnson, UCB Thesis (UCRL-17683), 1967.
G. E. Kalmus et al., Phys. Rev. D 4, 676 (1971).
V. Kistiakowsky et al., Phys. Rev. D 6, 1882 (1972).
A. J. Lennox et al., Phys. Rev. D 11, 1777 (1975).
J. F. Martin, RHEL Rept. RL-74-016, 1974.
J. E. Nelson et al., Phys. Letters 47B, 281 (1973).
P. M. Ogden et al., Phys. Rev. 137, B1115 (1965).
R. J. Ott et al., Phys. Letters 42B, 133 (1972).
T. J. Richards et al., Phys. Rev. D 10, 45 (1974).
R. E. Rothschild et al., Phys. Rev. D 5, 499 (1972).
J. A. Scheid et al., Phys. Rev. D 8, 1263 (1973).
S. R. Shannon et al., Phys. Rev. Lett. 33, 237 (1974).
R. A. Sidwell et al., Phys. Rev. D 3, 1523 (1971).
P. Sonderegger, priv. comm.
J. Vavra, McGill Univ. Thesis, 1974.

5. P. J. Bussey et al., Nucl. Phys. B58, 363 (1973).
6. J. R. Carter et al., Nucl. Phys. B58, 378 (1973).
7. M. R. Sogard, Phys. Rev. D 9, 1486 (1974).
8. J. Malos, private communication.
9. D. P. Hodgkinson et al., LBL-3048, 1974.
10. A. Clark, private communication.
11. R. L. Kelly et al., Phys. Rev. D 10, 2309 (1974).
12. S. Almehed and C. Lovelace, Nucl. Phys. B40, 157 (1972).
13. R. Ayed and P. Bareyre, private communication to Particle Data Group.
14. E. Pietarinen, U. Karlsruhe Rpt. TKP 15/75, June 1975.
15. R. E. Cutkosky and B. B. Deo, Phys. Rev. D 1,2547 (1970).
16. D. J. Herndon et al., Phys. Rev. D 11, 3183 (1975).
17. K. Abe et al., Phys. Rev. D 11, 1719 (1975).
18. W. Cameron et al., Nucl. Phys. B78, 93 (1974).
19. R. Patton et al., Phys. Rev. Lett. 34,975 (1975).
20. U. Casadei et al., CERN-HERA 75-1, 1975.
21. C. J. Adams et al., Nucl. Phys. B66, 36 (1973).
22. R. E. Cutkosky et al., paper in preparation.
23. R. A. Arndt et al., Phys. Rev. Lett. 33, 987 (1974).
24. B. R. Martin, RHEL Rpt. RL-75-055, 1975.
25. M. E. Zeller, private communication.
26. G. Giacomelli, Nucl. Phys. B71, 138 (1974).
27. A. K. Ray et al., Phys. Rev. 183, 1183 (1969).
28. A. S. Carroll et al., Phys. Letters 45B, 531 (1973).
29. G. W. London, Phys. Rev. D 9, 1569 (1974).
30. G. Alexander et al., Palermo Conference paper G2-18, 1975.
31. W. Cameron et al., Palermo Conference paper F2-14, 1975.
32. G. Keyes, private communication.
33. R. T. Ross, Palermo conference rapporteur talk, RHEL-Rpt. RL-75-115, 1975.
34. J. K. Kim, Phys. Rev. Lett. 27, 356 (1971).
35. W. Langbein and F. Wagner, Nucl. Phys. B47, 477 (1972).
36. A. J. Van Horn et al., Palermo conference paper F2-09, 1975.
37. R. Armenteros et al., Nucl. Phys. B14, 91 (1969).
38. A. T. Lea et al., Nucl. Phys. B56, 77 (1973).
39. J. Ellison, private communication.

0 0 0 0 4 4 0 1 5 1 3

LEGAL NOTICE

This report was prepared as an account of work sponsored by the United States Government. Neither the United States nor the United States Energy Research and Development Administration, nor any of their employees, nor any of their contractors, subcontractors, or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness or usefulness of any information, apparatus, product or process disclosed, or represents that its use would not infringe privately owned rights.

TECHNICAL INFORMATION DIVISION
LAWRENCE BERKELEY LABORATORY
UNIVERSITY OF CALIFORNIA
BERKELEY, CALIFORNIA 94720