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n-p ELASTIC SCATTERING NEAR 1400 MeV cm ENERGY

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π^-p Elastic Scattering near 1400 MeV cm Energy

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I. Introduction

It is likely that no subject in particle physics has received more intensive study than the pion-nucleon scattering. A great quantity of data has been collected and analysed in recent years.[1,2] Nevertheless and paradoxically perhaps, there are still unresolved difficulties and lack of general agreement of published data with various results of phase shift analyses. Certainly some of the inconsistencies among the various conclusions result from differences in search methodologies, insensitivity of the elastic scattering differential cross sections to mostly inelastic partial waves and other inadequacies of the analytical techniques. Data on inelastic channel cross sections and production angular distributions should provide valuable subsidiary or corroborative information to help choose among the possible parameters. Such analysis, based on results from the present experiment have already been published[3] and further work at other incident pion energy is in progress. There is also some possibility, not to be completely disregarded, if previous history is to be a guide, of unknown inaccuracies resulting from unsuspected or incompletely understood error sources. Most data of reasonable statistical validity have come from experiments using counter techniques. Bubble chamber data suffer from inaccuracies also but their sources are rather different in character so that results using this technique are useful to supplement as well as complement those data which have served as input for phase shift analyses. It therefore seems worthwhile to present our results in the $\pi^- p$ elastic scattering at energies spanning the region of the $P_{11}(1470)$ resonance.

II. Data Collection, Processing and Analysis

The Saclay 180-liter (80 cm) liquid hydrogen bubble chamber was exposed to pions at incident momenta, as subsequently determined from measurements of the photographs, of 415 ± 25 MeV/c, 499 ± 18 MeV/c, 552 ± 14 MeV/c, 590 ± 30 MeV/c, 670 ± 15 MeV/c and 750 ± 20 MeV/c. (The results at 499 and 552 MeV/c are from an early run and have already been published.[3] Methods of correction discussed here do not apply to those data.) The upper and lower limits represent restrictions on acceptability of events. Within these imposed "cuts" the momentum distributions are roughly Gaussian in shape, with the quoted central values. Measurements of the film were made, both at the Lawrence Berkeley Laboratory and the Oxford University Nuclear Physics Department with image-plane digitisers having a setting accuracy of about 7μ on the film. Geometrical reconstruction and kinematical analysis to identify elastic scatters were made with three view recontruction and minimising programs of the TVGP-SQUAW type. Consistency with observed bubble density was required in all cases. In ambiguous situations, the 4c elastic fit was always chosen rather than the 1c fit to the inelastic hypotheses, $n\pi^+\pi^-$ or $p\pi^-\pi^0$. The resulting sample of events, after further imposition of restrictions on acceptable entrance angle and position within the chamber volume, and with greater than 2 % confidence level, is essentially free of contamination. Although unmeasured, we may expect, especially at the lower momenta, a significant contamination of the incident beam with electrons and muons. Lacking measurement of that component of the beam it is not possible to determine total cross sections, so only angular distributions are presented here.

A second scan of one-fifth of the film revealed serious biases against observation of forward scatters and, to a lesser extent, backward scatters of the pion. Forward scattering presents the particular problem of configurations with invisible recoil proton and undetectable angle between incident and outgoing pion so that there exists a class of unobservable, or invisible, events. These cannot be corrected for by measurement of scanning efficiency by the standard two-scan coincidence method. Rather, we seek some geometrical variable whose distribution can be inferred from well established principles of symmetry or kinematics that suitably demonstrates this partial invisibility by severe departure from the expected distribution. Such a variable, used in our analysis, is the azimuthal angle of the scattering plane measured with respect to an axis specified for each event by the cross-product of the incident momentum vector and a vector parallel to the plane of the top glass of the bubble chamber. The distribution in azimuth must be uniform. Departures from uniformity were observed at all energies for events with very forward scattering, those with c.m. scattering angle θ , such that $\cos\theta \geq 0.8$. At the lowest energy, this bias was present in events with $\cos\theta \geq 0.6$. In addition, backward scatters, those with $\cos\theta \leq -0.9$ also gave evidence of restricted visibility. Some examples of biased distributions, plotted as histograms of number of events in particular intervals of $\cos\theta$, are shown in Fig. 1 . These, and indeed all, show significantly fewer than average numbers of events in the intervals $0 \leq \phi \leq 18°$ and $162° \leq \phi \leq 180°$. Those most severely affected also show this lack of events, compared to the average, for azimuthal angles $18° \leq \phi \leq 36°$ and $144° \leq \phi \leq 162°$. Corrections were applied to the number of events in a histogram of ten "bins" provided the fit to a uniform distribution had a $\chi^2 > 10$. Those events in the lowest bin, provided it was within the limits above, were removed and the χ^2 recalculated; if the resultant χ^2 was the greater than 9, all events in the next bin were removed. This process was continued until either a χ^2 less than the number of bins was obtained, or all candidates for exclusion, that is only those with $0° \leq \phi \leq 36°$ and $144° \leq \phi \leq 180°$, were removed. The remaining number of events was then multiplied by the appropriate factor to bring the corrected total into consistency with the average number of events in the unbiased bins of the histogram. After this correction for invisibility, a further correction for scanning efficiency was applied, of amount determined by comparison of observed numbers in unbiased intervals of azimuth in the two independent scans.

III. Results

Following the procedures outlined above, there resulted the scattering angular distributions shown in Figs. 2-6. Both the originally observed and corrected values are shown. Rather than attempting an independent analysis to determine yet another set of phase shift solutions, we simply show the comparison of these results with those that result from the most recent and exhaustive analysis program of the CERN group[2]. The theoretical curves are normalised to the number of events in the interval $-0.9 < \cos\theta < 0.8$; χ^2 values are given in Table I. As might be expected, qualitatively no surprises are present. In fact, the fits at all momenta other than 415 MeV/c are quite satisfactory except in the forward direction. The lowest energy data are not fit well. Given the observational difficulties, it is likely the data, even as corrected, still are not quite valid. Future input of these data into phase shift searching programs should be restricted to events with $-0.9 < \cos\theta < 0.8$ to include that portion of the angular distributions to which we attach greatest confidence. It is perhaps well to point out to other practitioners that their favored solutions are comparably satisfactory representations of these new results.

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2. The most recent published elastic phase shift analysis is that of S. Almehed and C. Lovelace, Nucl. Phys. B40, 157 (1972). Earlier work is reviewed in D. J. Herndon, A. Barbaro-Galtieri and A. H. Rosenfeld, UCRL-20030 πN (unpublished).

3. D. H. Saxon, J. H. Mulvey and W. Chinowsky, Phys. Rev. D 2, 1790 (1970).

TABLE I.

Goodness of fits (χ^2) of experimental angular distributions to phase shift analyses solutions of Almehed and Lovelace.[2]

Pπ (MeV/c)	χ^2
415	70.0
499	29.9
552	12.8
590	13.7
670	37.8
751	27.8

FIGURE CAPTIONS

Fig. 1. Azimuthal angular distributions for backward and forward c.m. scattering angles θ. Φ is the angle between the scattering plane and a direction specified by the cross product of the incident pion momentum vector and a vector perpendicular to the camera axes.

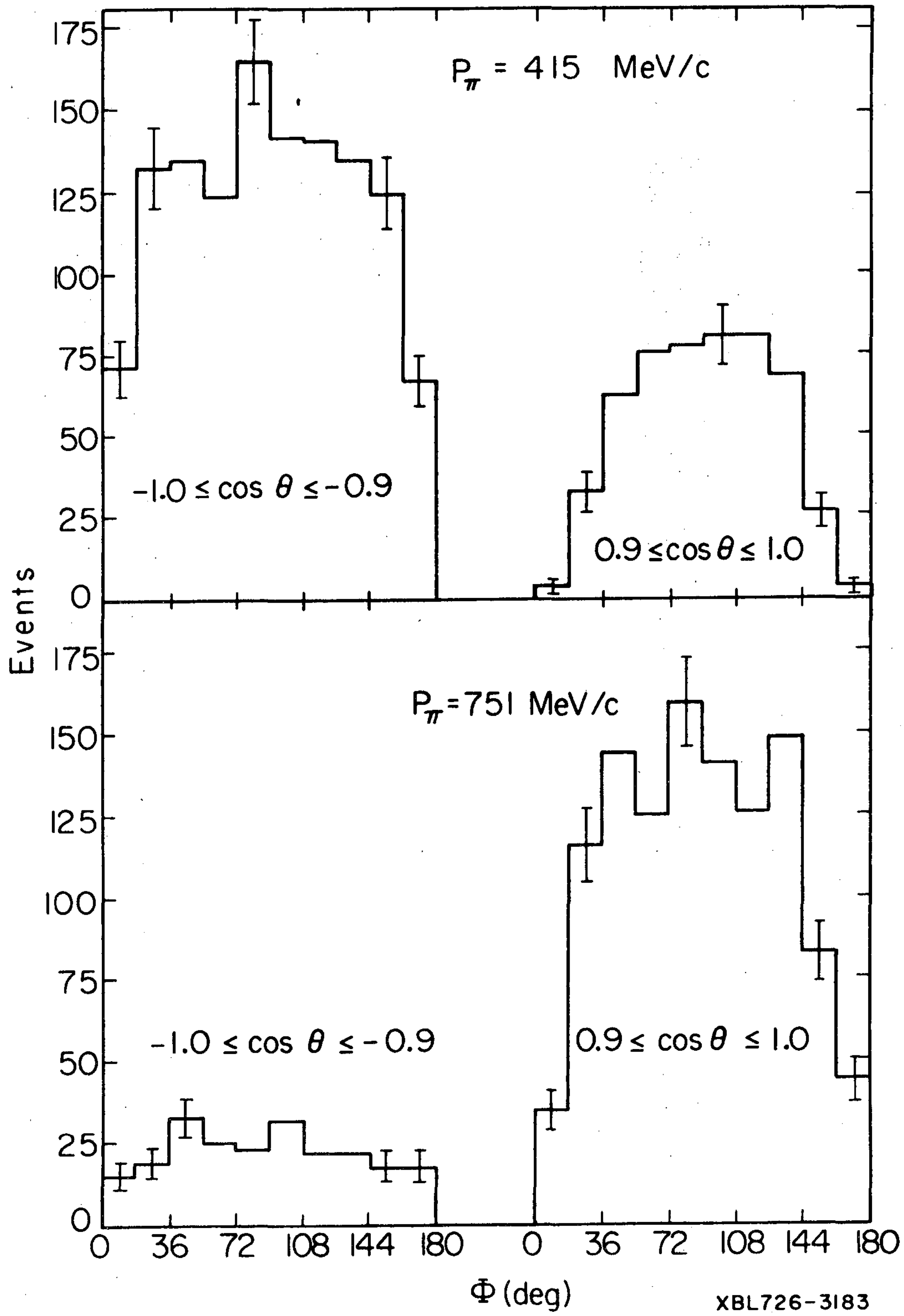
Fig. 2. Elastic scattering angular distribution for 415 MeV/c incident momentum. Both observed and corrected (see text) numbers of events are given. The smooth curve shows the results of the phase shift analysis of the CERN group.[2]

Fig. 3. Elastic scattering angular distribution for 590 MeV/c incident momentum. Both observed and corrected (see text) numbers of events are given. The smooth curve shows the results of the phase shift analysis of the CERN group.[2]

Fig. 4. Elastic scttering angular distribution for 670 MeV/c incident momentum. Both observed and corrected (see text) numbers of events are given. The smooth curve shows the results of the phase shift analysis of the CERN group.[2]

Fig. 5. Elastic scattering angular distribution for 751 MeV/c incident momentum. Both observed and corrected (see text) numbers of events are given. The smooth curve shows the results of the phase shift analysis of the CERN group.[2]

Fig. 6. Previously published[(3)] elastic scattering angular distributions for 499 MeV/c and 552 MeV/c incident pions.



175
150
125
100
75
50
25
0
Events
P_π = 415 MeV/c
$-1.0 \le \cos\theta \le -0.9$
$0.9 \le \cos\theta \le 1.0$
P_π = 751 MeV/c
0 36 72 108 144 180
Φ (deg)
XBL726-3183

Fig. 1

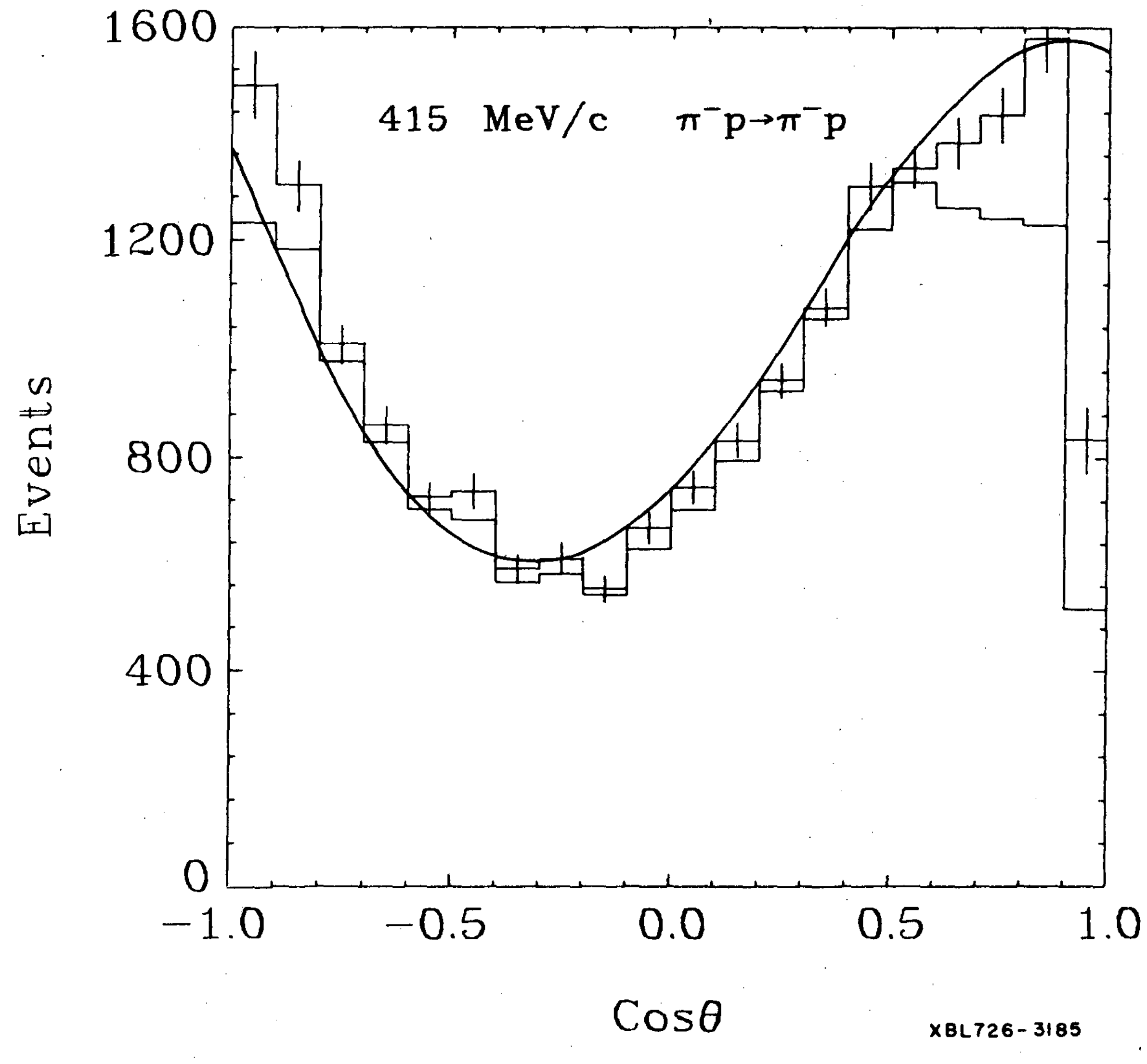
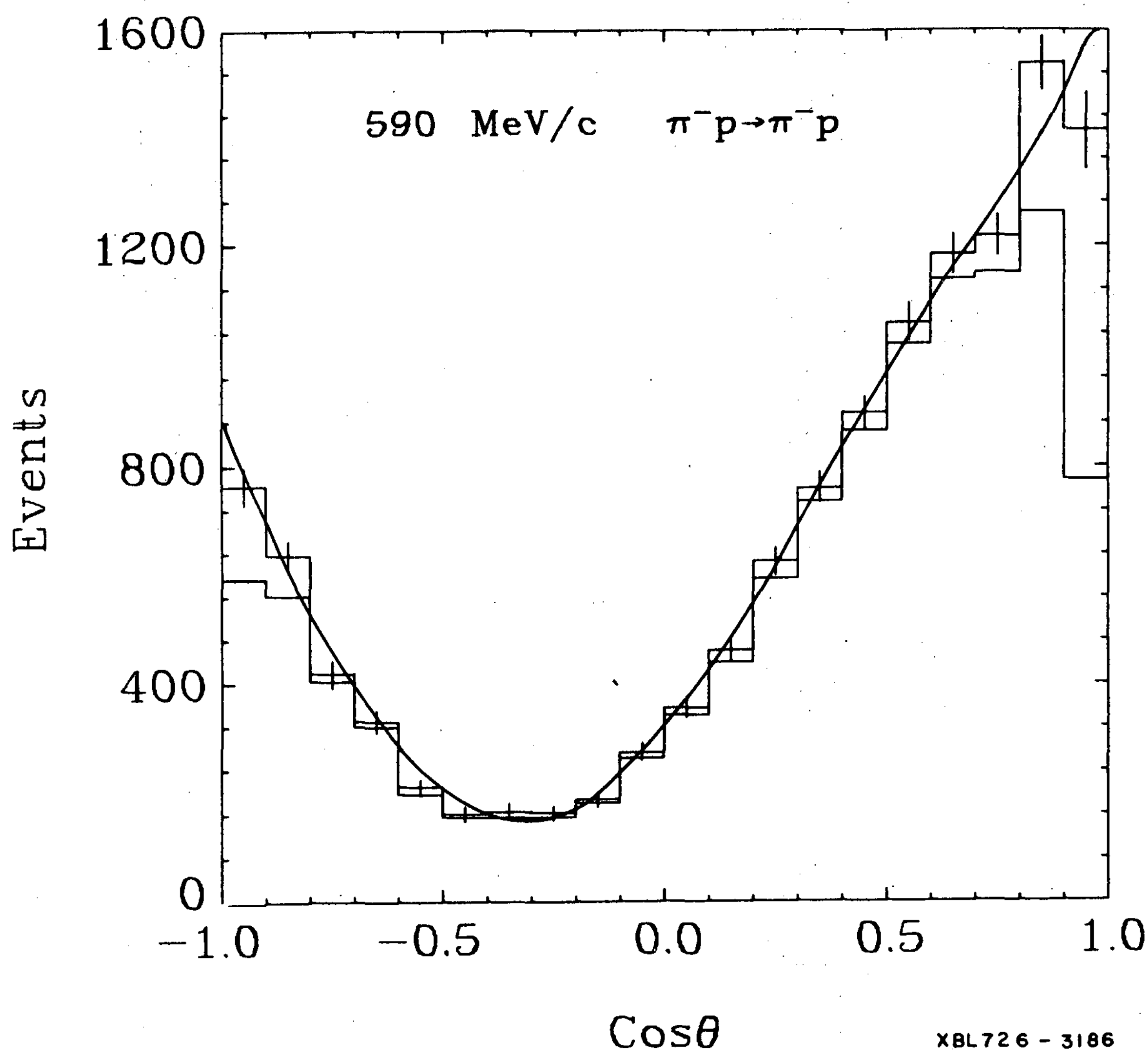

1600
1200
800
400
0
Events
415 MeV/c π⁻p→π⁻p
-1.0
-0.5
0.0
0.5
1.0
Cosθ
XBL726-3185

Fig. 2



590 MeV/c π⁻p→π⁻p
1600
1200
800
400
0
Events
−1.0
−0.5
0.0
0.5
1.0
Cosθ
XBL726 - 3186

Fig. 3

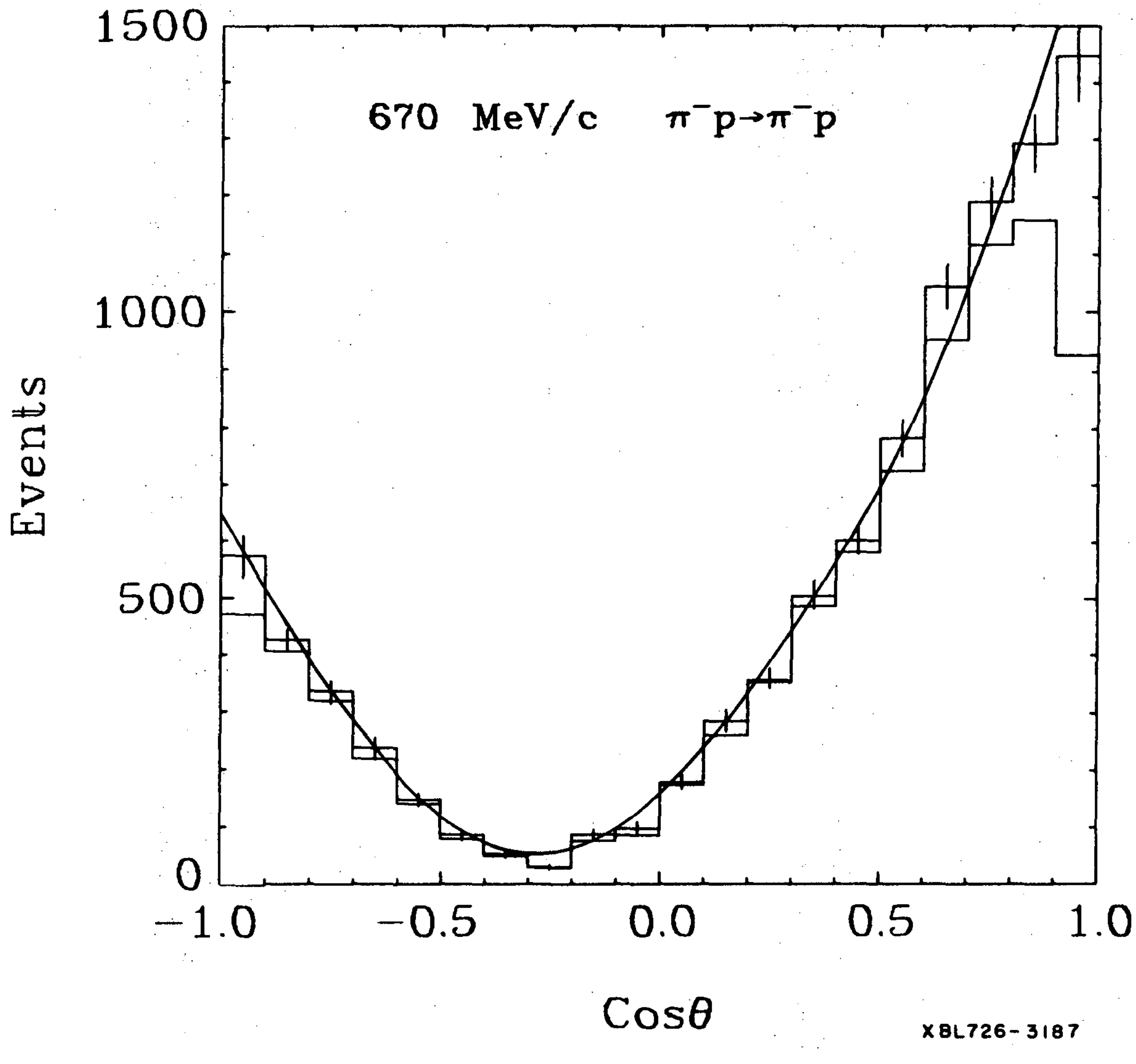

1500
1000
500
0
Events
670 MeV/c π⁻p→π⁻p
−1.0
−0.5
0.0
0.5
1.0
Cosθ
XBL726-3187

Fig. 4

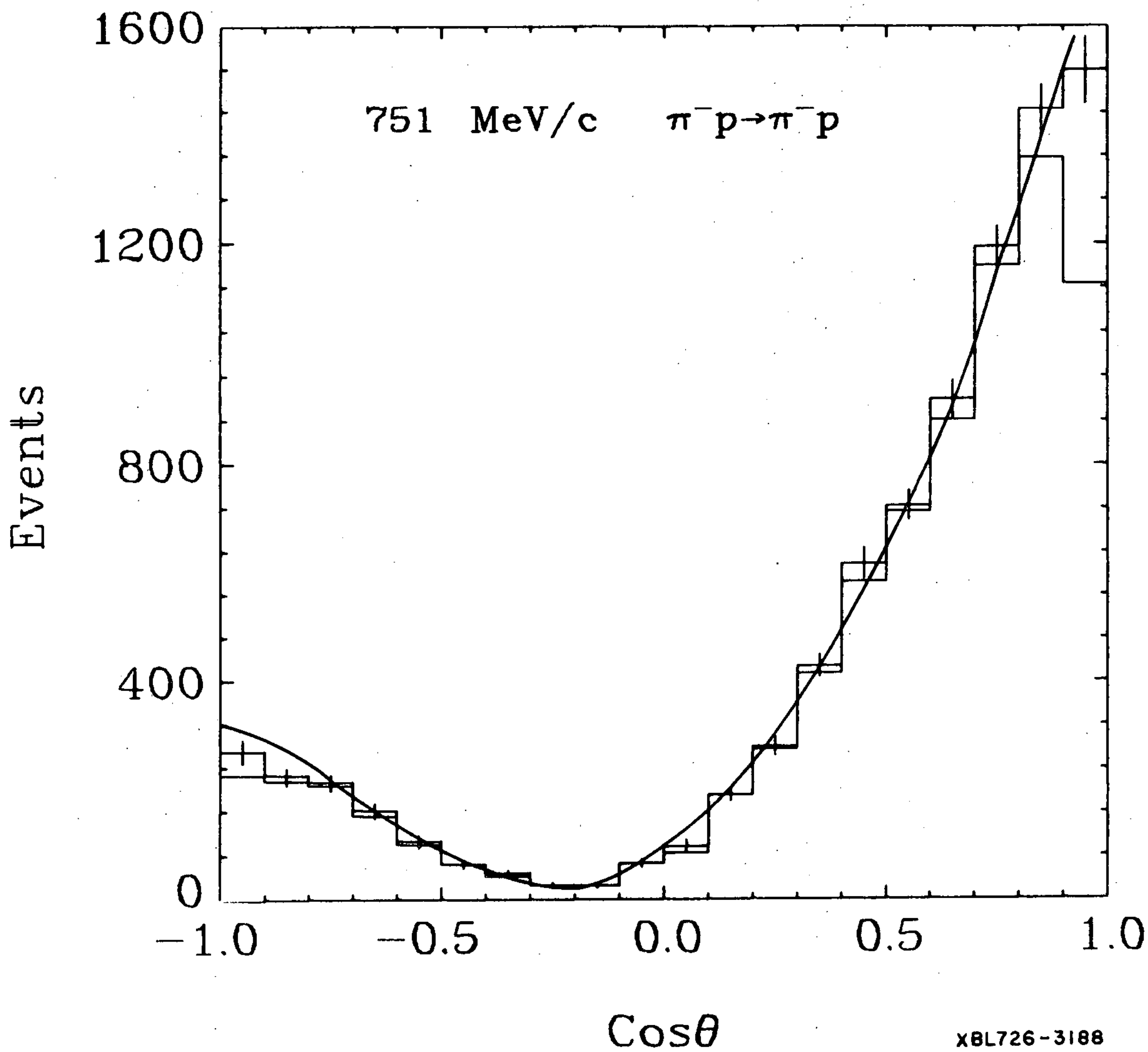
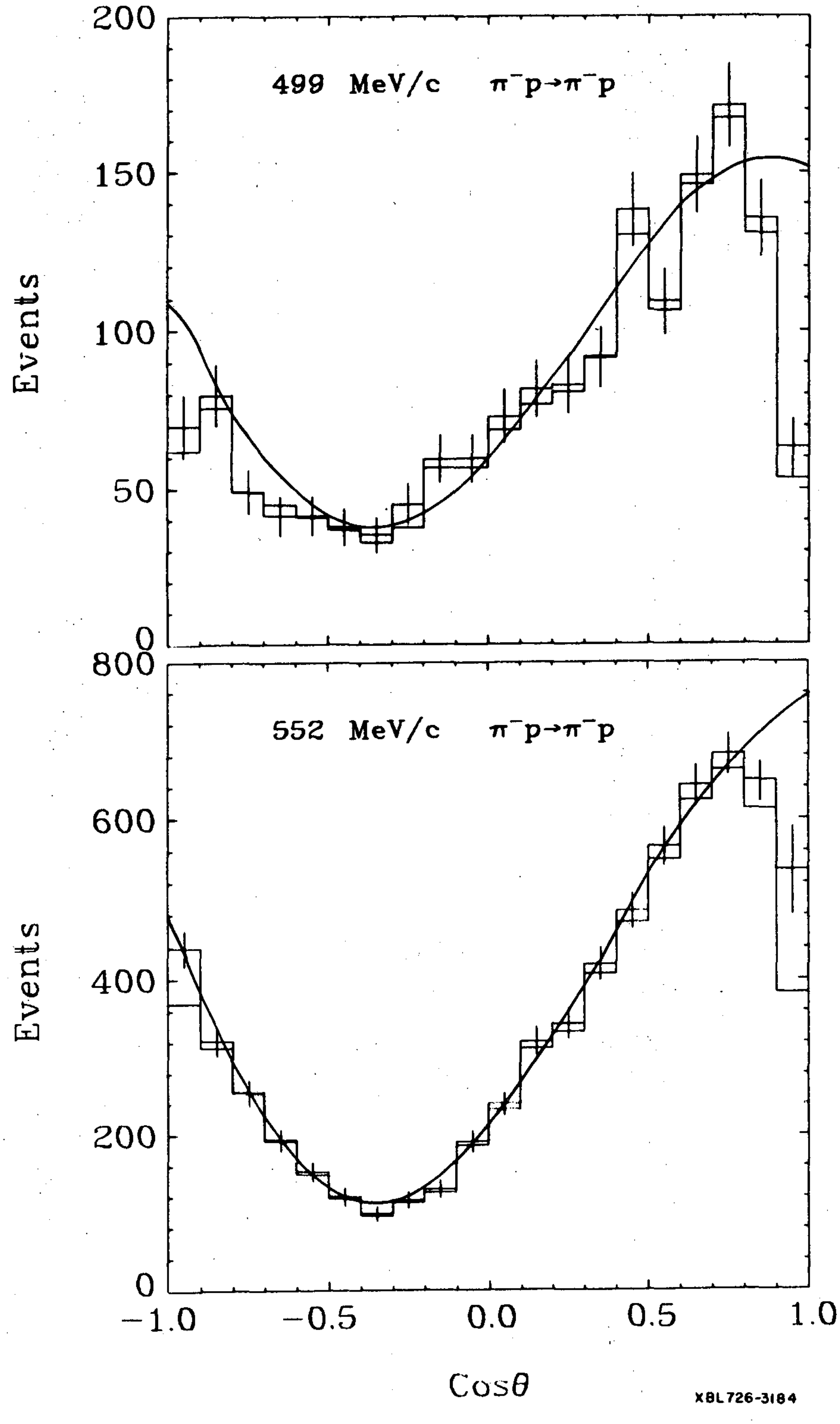

1600
1200
800
400
0
Events
751 MeV/c π⁻p→π⁻p
−1.0
−0.5
0.0
0.5
1.0
Cosθ
XBL726-3188

Fig. 5



499 MeV/c π⁻p→π⁻p
552 MeV/c π⁻p→π⁻p
Events
Events
200
150
100
50
0
800
600
400
200
0
−1.0
−0.5
0.0
0.5
1.0
Cosθ
XBL726-3184

Fig. 6

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