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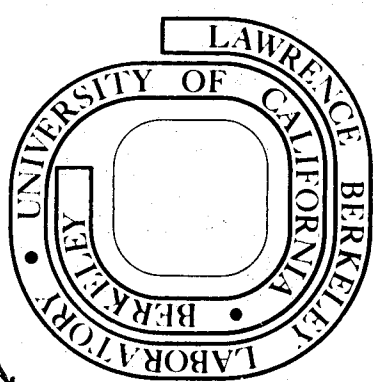

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STUDY OF THE REACTION $\pi^- p \to \pi^0 n$ BETWEEN 1.0 AND 2.4 GeV/c*

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ABSTRACT

The differential cross section for the reaction $\pi^- p \to n\pi^0$ has been measured with high statistics at six incident-beam momenta between 1.0 and 2.4 GeV/c. The results are compared with predictions of recent phase shift analyses and forward dispersion relations.

While $\pi^\pm p$ elastic scattering has been studied extensively at low and intermediate energies ($\lesssim$ 3 GeV),[1] the charge-exchange reaction

$$\pi^- p \to n\pi^0 \ (\pi^0 \to 2\gamma) \qquad (1)$$

has received comparatively little attention,[2-7] primarily because of the additional complexities of detecting and measuring final states involving neutral particles. For example, in the beam momentum region of 1.5-2.5 GeV/c there have been only two experiments[3,5] which measured differential cross-sections, yielding inconsistent results. Accurate data from this reaction are needed to obtain a unique set of phase shifts for pion-nucleon scattering in this energy region.

We have performed an experiment at the Berkeley Bevatron to study reaction (1) at beam momenta of 1.03 GeV/c and 1.59 to 2.39 GeV/c

in steps of 0.20 GeV/c. Approximately half the data have been analyzed, yielding between 3500 and 8000 charge-exchange events at each momentum. The reaction was identified from the γ-ray information only, using a detector consisting of thin lead-plate optical spark chambers and lead-scintillator shower counters. A salient feature of the experiment was the high γ-ray detection efficiency over more than 90% of the entire 4π sr solid angle. As a result of this high efficiency, our charge-exchange data sample had a very low ($< 5\%$) background from other neutral final states. Preliminary results have been reported elsewhere.[8,9]

Figure 1 shows the arrangement of the spark chambers and the scintillation counters surrounding the target. Detailed descriptions of the apparatus and its characteristics may be found in Ref. 9. The π^- beam with a momentum bite of $\pm 1\%$ was focused onto a liquid hydrogen target 20 cm long by 10 cm in diameter. A set of scintillation-counter hodoscopes defined the beam direction to within $\pm 0.2°$ (rms). The target was surrounded by anti-coincidence counters A_1 and A_2 which vetoed any interaction that produced charged particles. Beam counters $M_1M_2M_3$ and anti-coincidence counters A_1A_2 defined a neutral final state trigger by the logical combination $M_1M_2M_3\bar{A}_1\bar{A}_2$. A threshold Cerenkov counter monitored the beam contamination of μ^- and e^-. The γ-ray detector consisted of a large cubical array of lead-plate optical spark chambers surrounding the target and covering five sides of a cube, with the sixth side (beam entrance face) being almost completely covered by γ (shower) counters constructed of lead-scintillator sandwiches (G_i in Fig. 1). This geometry results in an

approximately 3.7π sr solid angle for detection of γ-rays. The downstream chamber was approximately 8 radiation lengths thick and the four side chambers were each approximately 7 radiation lengths thick. Each chamber plate was about 0.14 radiation lengths thick. This thin-plate construction ensured a low-energy γ-ray detection threshold of about 10 MeV and a high average detection probability of 93 ± 1% per γ-ray for the change-exchange events.[10]

A description of the data analysis procedures is given in Ref. 9, where preliminary differential cross section estimates were obtained from only the events with two visible showers in the chambers. Here we also include the 1-shower events (~ 15% of the π^0 data sample). From the 2-shower sample, the angular distribution of the γ-γ bisector direction in the π^-p c.m. system was determined for events with γ-γ opening angles near the kinematic minimum opening angle (where the distribution is strongly peaked).[11] The observed 1-shower events are mainly from reaction (1), where the missing photon escaped through the upstream hole of the detector. Thus the 1-shower events provide essential information for the differential cross section near the backward direction. At each beam momentum the angular distribution of the shower direction from the 1-shower events was combined with the 2-shower bisector distribution, and the combined distribution was corrected by a Monte Carlo calculation to yield the true π^0 production angular distribution.[12] The resulting π^0 distribution, when used as input to the Monte Carlo calculation, reproduced both 1- and 2-shower distributions separately as well as their sum.

The $\pi^- p \to \pi^0 n$ differential cross sections are plotted in Fig. 2 and the total cross sections are listed in Table I. At each momentum the differential cross section was fit to a Legendre polynomial series. However in the extreme backward direction, even with the 1-shower events, the data were inadequate and could not be properly corrected by the Monte Carlo calculation. To define this region, previously published values of $d\sigma/d\Omega$ (180°) were used in the fit and are listed in Table I.[2,4,5,7] This significantly reduced the errors on the Legendre coefficients and the correlations between them, but had very little effect on the shape of the fitted angular distribution outside of the extreme backward region. The order of the fit selected was unambiguously determined by picking the lowest even order that gave a reasonable confidence level to the fit. Results are given in Table I (b). The full correlation matrices for the errors have been omitted due to space limitations but are available upon request.

Since the charge-exchange differential cross section is a sensitive test of π-N phase shift parametrizations,[1] we have also plotted recent phase shift predictions[13,14] in Fig. 2. While the comparison with the data at 1030 MeV/c is fair, the agreement at higher momenta is poor. In particular, the disagreement with Almehed and Lovelace[13] is quite severe at 1790 and 1990 MeV/c.

Finally, by extrapolating the Legendre polynomial fits to $\cos\theta = +1.0$, we obtained the forward cross sections which are listed in Table I(a)

and are plotted in Fig. 3. For comparison, we also show in Fig. 3 results from previous experiments and predictions from two different dispersion-relation calculations by (a) Höhler and Strauss,[15] also tabulated in Table I, and (b) Carter and Carter.[16] At 1030 MeV/c (not shown in Fig. 3), both predictions are very similar and agree with our result listed in Table I; however at the higher momenta our results are significantly lower than the Höhler-Strauss predictions but agree very well with those of Carter-Carter, which are based on a doubly-subtracted dispersion relation approach.[16] Our results are also systematically lower than those from Refs. 5 and 6. The disagreement with Ref. 5 is not one of normalization since our total $\pi^- p \to \pi^0 n$ cross sections agree very well.

We wish to thank Dr. Sherwood Parker and Dr. Charles Rey for their efforts in building the excellent spark chambers, and the Bevatron crew for providing smooth beam conditions. We also thank R. Hogrefe, E. Epstein, T. Daly, M. R. Long, and the group of scanners for their tireless efforts.

FOOTNOTES

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

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[1]Reviews of pion-nucleon interactions can be found in: a) C. Lovelace, in Proceedings of XVIth International Conference on High Energy Physics, Chicago-Batavia, Illinois, Sept. 6-13, 1972 (NAL, Batavia, 1972), Vol. 3, p. 73 (referred to as the Batavia Conference in subsequent references); b) R. G. Moorhouse, Ann. Rev. Nucl. Sci. 19, 301 (1969).

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[7]V. Kistiakowsky et al., Phys. Rev. D 6, 1882 (1972).

[8]J. Nelson et al., Lawrence Berkeley Laboratory Report LBL-1027, paper No. 628 submitted to the Batavia Conference (1972). These preliminary results of the differential cross sections were based on the 2-shower data sample only.

[9]J. E. Nelson (Ph. D. thesis), Lawrence Berkeley Laboratory Report LBL-1019 (1972) (unpublished).

[10]The average detection probability for multi-π^0 final states was 89±1% per γ-ray, averaged over all γ-ray energies and production lab angles.

[11]Specifically, the opening-angle cut at each momentum was chosen by Monte Carlo calculation to retain 80% of the 2-shower $n\pi^0$ events.

[12]A description of the (straightforward) extension of the Monte Carlo program described in Ref. 9 to incorporate the 1-shower data will be given in a future publication, along with a complete summary of the entire experiment.

[13]S. Almehed and C. Lovelace, Nucl. Phys. B40, 157 (1972).

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Figure Captions

Fig. 1. Layout of the apparatus about the hydrogen target. G_{1-4} are lead-scintillator sandwich counters. $A_{1,2}$ are charged-particle veto counters. $M_{2,3}$ are part of the beam telescope M_1 M_2 M_3. M_1 (not shown) is 5 feet upstream from M_2.

Fig. 2. $\pi^- p \to \pi^0 n$ differential cross-section results. The solid (dashed) curves are phase shift analysis predictions of Almehed and Lovelace[13] (Ayed et al.[14]), evaluated at the momenta listed in the legends.

Fig. 3. $d\sigma/d\Omega_{cms}(0°)$ for $\pi^- p \to \pi^0 n$. The solid (dashed) curves are dispersion-relation predictions by Höhler and Strauss[15] (Carter and Carter[16]).

Table I. Cross sections and Legendre coefficients for $\pi^- p \to n\pi^0$

a. Cross Sections

P_π-(MeV/c)	1030	1590	1790	1990	2190	2390
σ_{tot}(mb)	7.05±0.26	2.03 ±0.10	1.40 ±0.06	1.07 ±0.05	0.77 ±0.04	0.60 ±0.03
$\frac{d\sigma}{d\Omega}(0^\circ)$(mb/sr)	2.90±0.13	0.31 ±0.03	0.53 ±0.04	0.44 ±0.04	0.36 ±0.03	0.16 ±0.03
$\frac{d\sigma}{d\Omega}(0^\circ)$(mb/sr)[a]	2.83	0.44	0.68	0.64	0.41	0.19
$\frac{d\sigma}{d\Omega}(180^\circ)$(mb/sr)[b]	0.20±0.05	0.220±0.025	0.105±0.005	0.048±0.005	0.045±0.005	0.073±0.005

b. Legendre Coefficients: $\frac{d\sigma}{d\Omega}(\cos\theta) = \sum_j C_j P_j(\cos\theta)$ (μb/sr)

C_0	561±7	162±2	111±2	85±2	61±1	48±1
C_1	-50±17	34±4	70±3	62±3	47±2	37±2
C_2	916±19	59±6	57±5	54±5	40±3	44±3
C_3	451±21	115±7	139±6	80±5	46±4	24±4
C_4	181±21	99±7	145±6	135±6	92±4	58±4
C_5	958±20	-9±7	50±7	56±6	60±4	33±4
C_6	-113±22	-41±8	-8±6	3±6	22±4	15±4
C_7		-105±8	-47±7	-35±6	-10±4	-37±4
C_8		-3±8	11±7	7±7	-5±4	-27±5
C_9				33±7	13±5	-6±5
C_{10}				-40±7	-10±5	-30±5
C_{11}						-9±5
C_{12}						7±6
No. of data points	89	94	89	76	73	67
Confidence level	0.32	0.02	0.84	0.90	0.66	0.20
No. of experimental events	8000	6000	5000	4000	4000	3500

[a]Dispersion relation prediction from Ref. 15.

[b]Values taken from Refs. 7, 2, 4, and 5.

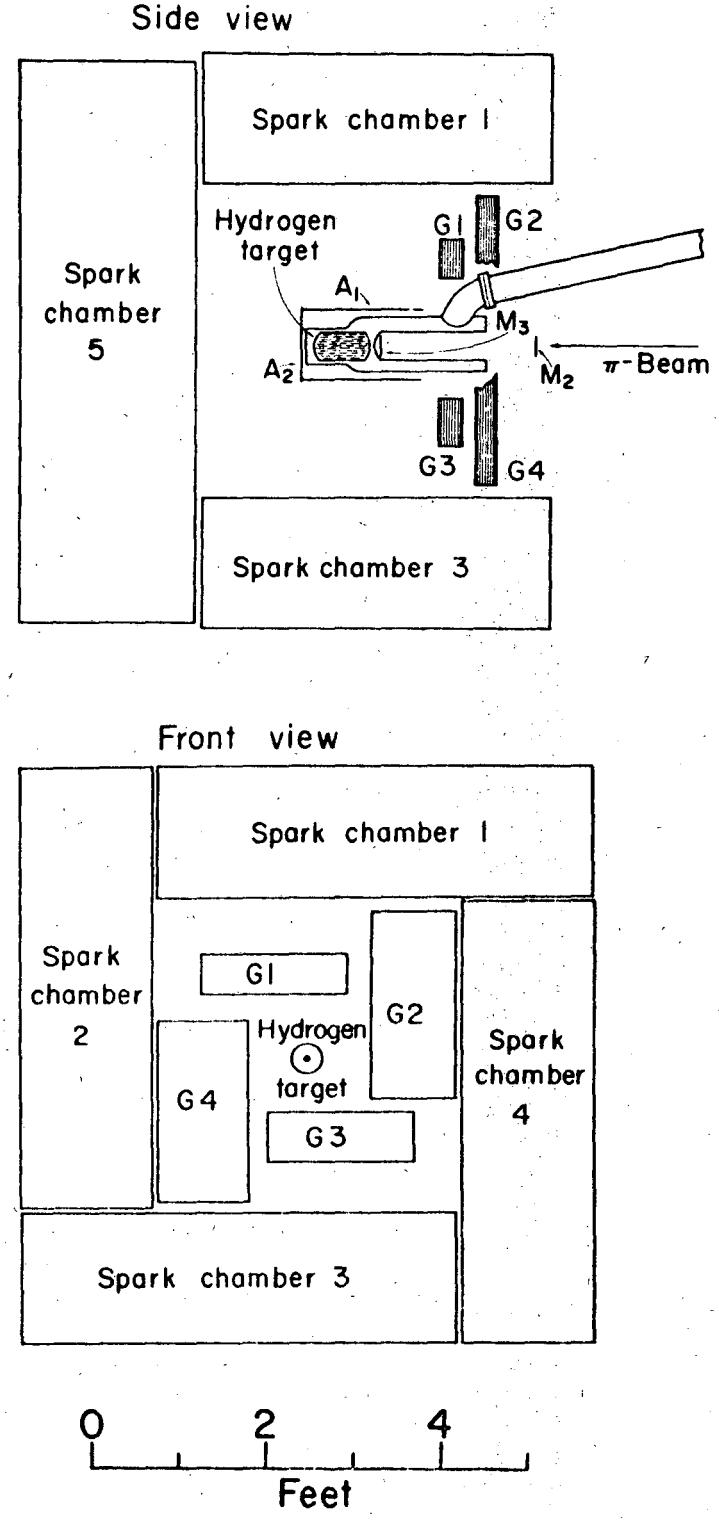
Side view
Spark chamber 1
Spark chamber 5
Hydrogen target
G1
G2
A1
M3
A2
M2
π-Beam
G3
G4
Spark chamber 3
Front view
Spark chamber 1
Spark chamber 2
G1
G2
Hydrogen target
G4
G3
Spark chamber 4
Spark chamber 3
0
2
4
Feet
XBL 735-340B

Fig. 1

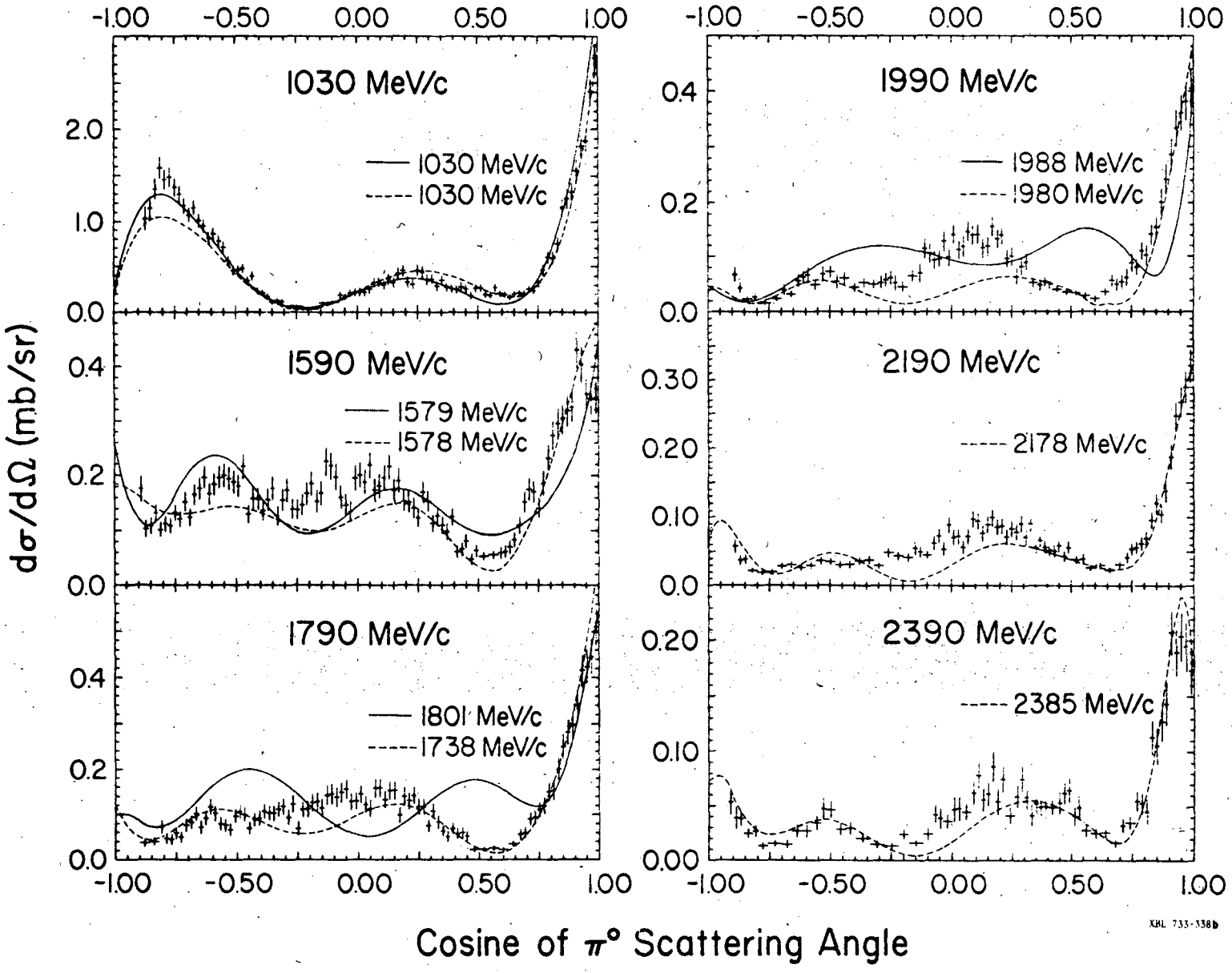
1030 MeV/c
1030 MeV/c
1030 MeV/c
1590 MeV/c
1579 MeV/c
1578 MeV/c
1790 MeV/c
1801 MeV/c
1738 MeV/c
1990 MeV/c
1988 MeV/c
1980 MeV/c
2190 MeV/c
2178 MeV/c
2390 MeV/c
2385 MeV/c
dσ/dΩ (mb/sr)
Cosine of π° Scattering Angle
XBL 733-338b

Fig. 2

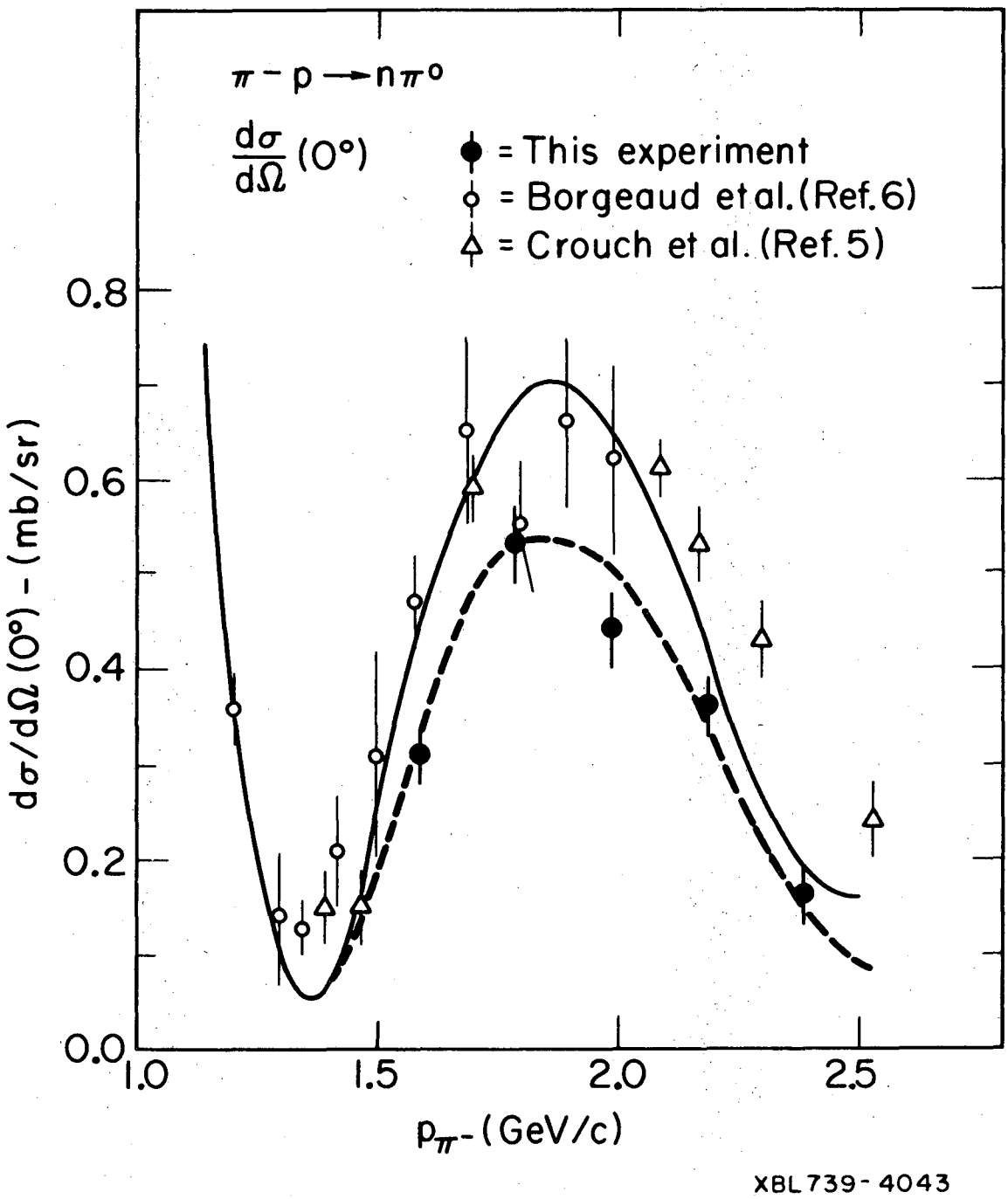
π⁻ p → n π°
dσ/dΩ (0°)
● = This experiment
○ = Borgeaud et al. (Ref. 6)
△ = Crouch et al. (Ref. 5)
dσ/dΩ (0°) - (mb/sr)
0.0
0.2
0.4
0.6
0.8
1.0
1.5
2.0
2.5
p_π⁻ (GeV/c)
XBL739-4043

Fig. 3

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