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Pion-Proton Elastic Scattering at 2.00 Gev/c*

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In the course of a spark chamber experiment which studied pion-proton elastic scattering up to 5 Gev/c[1,2], we measured the π^- p elastic differential cross section at 2.01 Gev/c with high statistical accuracy (7000 elastic events) and the π^+ p elastic differential cross section at 2.02 Gev/c with moderate statistical accuracy (1400 elastic events). This momentum is of particular interest, as a resonance has recently been found in the π^- p total cross section at 2.08 Gev/c by Longo and Moyer[3] and confirmed by Diddens et al.[4] Diddens et al also found a resonance at 2.51 Gev/c in the π^+ p total cross section, so that 2.0 Gev/c lies midway between this new π^+ p resonance and the previously known π^+ p resonance[5] at 1.5 Gev/c. The data presented below show that there is a second maximum in the π^- p differential cross section at $\cos\Theta = 0.2$ (in the barycentric system). This second maximum is less pronounced in the π^+ p system. It is also shown that while the width of the π^+ p diffraction peak changes considerably in the 1.0 to 3.0 Gev/c momentum interval, no significant change in the width of the π^- p diffraction peak is observed in this interval.

The differential cross sections are given in Table I and plotted in a semilogarithmic form in Figs. 1 and 2. In the tables and graphs the errors are statistical and do not include an overall normalization error of $\pm$ 8% for π^- p and +20%-10% for π^+ p. The total elastic cross sections are 7.94 mb for π^- p and 9.1 for π^+p.

The second maximum which appears in the π^- p differential cross section, Fig. 1, is not seen at 3.0 Gev/c or above[1,2], or at 1.6 Gev/c[6] or below[7,8,9,10,11]. Unfortunately, other measurements at 2.5[8] and 2.8[12] Gev/c have insufficient accuracy to observe this second maximum. However an unpublished differential cross section measurement at about 1.85 Gev/c by Erwin and Walker[13] gives some evidence for this second maximum.

The interpretation of this second maximum as simply the second maximum in a diffraction pattern meets with several difficulties. First, if such a diffraction effect exists, one would expect it to be seen over a very large range of energies. Second, one cannot simultaneously fit the width of the first diffraction peak and the position of the second peak. If one adjusts the interaction radius to fit the position of the second maximum, it is then about 30% smaller than one would obtain by fitting the width of the main diffraction peak. Third, the model predicts additional peaks which are not seen. These would, however, probably disappear with the use of a more realistic model, e.g. one with a slightly diffuse boundary.

The $\pi^+ p$ differential cross section confirms the previous measurement and conclusions of Cook et al[14] that the $\pi^+ p$ differential cross section is larger than the $\pi^- p$ for all regions outside the diffraction peak at 2.0 Gev/c. Cook et al and Helland et al[9] showed that in the momentum region of the 1.5 Gev/c $\pi^+ p$ resonance, there is a large bump in the $\pi^+ p$ differential cross section in the backward hemisphere of the barycentric system. The comparatively larger size of the $\pi^+ p$ differential cross section outside the diffraction peak at 2.0 Gev/c may be the remains of this bump and therefore related to the 1.5 Gev/c resonance. As seen in Fig. 2, in the $\pi^+ p$ system there is evidence for a second maximum at $\cos \Theta = .2$ rising out of this background, but it is considerably less pronounced than in the π^- p case. Therefore our tentative conclusion on the basis of existing data is that the second maximum at cos Θ = .2 is the strongest in the π^- p system and is related to the 2.08 Gev/c π^- p total cross section resonance.

As another way to look for relations between the peak in the total cross section and the shape of the elastic differential cross section, we have made use of the diffraction peak parameterization used at higher energies:

$$d\sigma(\theta)/d\Omega = (d\sigma(\theta)/d\Omega)_0 \, e^{At} \qquad (1)$$

where $d\sigma(\theta)/d\Omega$ is the differential cross section in the barycentric system in mb/sr, and t is the square of the four-momentum transfer in $(\text{Gev/c})^2$. In this momentum range, and with measurements of high statistical accuracy, this simple exponential is not a very good fit, but it is a very useful way to measure the width of the diffraction peak, because the peaks are roughly exponential out to t = 0.4 $(\text{Gev/c})^2$. In Table II we have listed the values of A obtained by a least squares fit to this and other experiments for the interval $0.0 \leq t \leq 0.4$ $(\text{Gev/c})^2$. $P(\chi^2)$, the probability of obtaining a χ^2 as large as given by the fit is also listed. For comparison, it should be noted[2] that at momenta above 3 Gev/c the A's of the $\pi^\pm$ p diffraction peaks have a constant value of 7.6 to 7.9 $(\text{Gev/c})^2$. Table II shows that for the π^- p system the A values rise rather smoothly from 7.0 $(\text{Gev/c})^{-2}$ at 1.34 Gev/c to 7.9 $(\text{Gev/c})^{-2}$ at 3.15 Gev/c. That is, the π^- p diffraction peak simply narrows slightly over this momentum range. On the other hand, the A values of the π^+ p system increase from 4.0 $(\text{Gev/c})^{-2}$ at 1.12 Gev/c to a peak of about 8.2 $(\text{Gev/c})^{-2}$ at 1.5 Gev/c, then decrease to 5.0 $(\text{Gev/c})^{-2}$ and finally rise again at

2.92 Gev/c to 7.6 $(\text{Gev/c})^{-2}$ which is close to the π^- p value at that momentum. This behavior can be thought of as a considerable narrowing of the diffraction peak over the 1 to 3 Gev/c interval combined with a sudden and temporary narrowing at 1.5 Gev/c, possibly associated with the resonance at that momentum.

Finally, we point out that the high statistics in the π^- p data make evident some structure in the diffraction peak. In particular, the $0.0 \leqslant t \leqslant 0.2$ $(\text{Gev/c})^2$ interval has a steeper slope than the $0.0 \leqslant t \leqslant 0.4$ interval, $9.6 \pm .9$ as compared to $7.8 \pm .2$ $(\text{Gev/c})^{-2}$. That is, on the semilogarithmic plot there is a definite concave upward slope to the diffraction peak.

We would like to suggest that the detailed structure and energy dependence of the elastic diffraction peak parameters might prove to be a useful approach to studying properties of resonances at higher energies where the interaction is mostly inelastic.

Thus it would be particularly interesting to compare accurate π^- p diffraction data at several energies about the 2.08 Gev/c resonance to see if the diffraction peak has structure at this point analogous to the narrowing of the π^+ p diffraction peak at the 1.5 Gev/c resonance.

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Table I. Pion-proton differential cross section in barycentric system. The errors are statistical and do not include an overall normalization error of ± 8% for π^- p and + 10%, - 20% for π^+ p.

cos Θ	dσ/dΩ (mb/sr)
	π^- p Elastic scattering at 2.01 Gev/c
.935	6.04 ± .28
.925	5.28 ± .27
.915	4.74 ± .25
.905	3.92 ± .24
.890	3.16 ± .15
.870	2.54 ± .14
.850	2.13 ± .13
.83	1.86 ± .12
.81	1.45 ± .11
.79	1.02 ± .09
.77	.79 ± .08
.75	.63 ± .07
.73	.54 ± .07
.71	.35 ± .06
.69	.25 ± .05
.66	.20 ± .03
.62	.14 ± .03
.58	.06 ± .02
.54	.10 ± .02
.50	.05 ± .02
.46	.08 ± .02
.42	.11 ± .03

Table I (continued)

cos Θ	$d\sigma/d\Omega$(mb/sr)
.38	.17 ± .03
.34	.15 ± .03
.30	.18 ± .03
.26	.23 ± .03
.22	.25 ± .04
.18	.18 ± .03
.14	.23 ± .03
.10	.14 ± .03
.06	.16 ± .03
.02	.11 ± .02
-.02	.16 ± .03
-.06	.14 ± .03
-.10	.09 ± .02
-.16	.08 ± .01
-.24	.06 ± .01
-.32	.06 ± .01
-.40	.05 ± .01
-.48	.06 ± .01
-.56	.04 ± .01
-.64	.02 ± .01
-.72	.01 ± .01
-.80	.01 ± .01
-.88	.02 ± .01
-.94	.03 ± .02

Table I (continued)

	π^+ p Elastic scattering at 2.02 Gev/c
.93	6.54 ± .74
.91	4.89 ± .64
.89	3.42 ± .38
.86	3.35 ± .27
.82	2.35 ± .23
.775	1.56 ± .17
.725	1.06 ± .14
.650	.43 ± .07
.55	.29 ± .05
.45	.18 ± .04
.35	.25 ± .05
.25	.26 ± .05
.15	.32 ± .05
.5	.09 ± .03
- .5	.13 ± .04
- .15	.14 ± .04
- .25	.12 ± .04
- .35	.18 ± .04
- .45	.07 ± .03
- .55	.12 ± .04
- .65	.09 ± .04
- .75	.03 ± .03
- .85	.04 ± .03
- .93	.06 ± .05

Table I (continued)

	π^+ p Elastic scattering at 2.02 Gev/c
.93	6.54 ± .74
.91	4.89 ± .64
.89	3.42 ± .38
.86	3.35 ± .27
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- .65	.09 ± .04
- .75	.03 ± .03
- .85	.04 ± .03
- .93	.06 ± .05

Table II. Exponential fits to diffraction peaks

Incident pion laboratory momentum Gev/c	$A(\text{Gev/c})^2$	$P(\chi^2)$	Reference
	π^- p elastic scattering		
1.34	$7.5 \pm .4$	.40	a
1.48	$7.5 \pm .4$	.20	b,c
1.59	$7.1 \pm .2$	.01	d
1.85	9.3 ± 1.7	.30	e
2.01	$7.8 \pm .2$	.50	This experiment
2.5	$8.5 \pm .8$	.20	c
3.15	$7.9 \pm .3$	.02	f
	π^+ p elastic scattering		
1.12	$4.1 \pm .2$	.25	g
1.45	$7.4 \pm .6$	.30	g
1.50	$8.2 \pm .3$	.15	h
1.69	$6.4 \pm .2$	.02	g
2.00	$5.0 \pm .4$	.70	h
2.02	$5.7 \pm .4$	.40	This experiment
2.50	$6.9 \pm .5$	.02	h
2.92	$7.6 \pm .3$	.20	f

a See Reference 10; b See Reference 7; c See Reference 8; d See Reference 6; e R. C. Whitten and M. M. Block, Phys. Rev. 111, 1676 (1958); f See Reference 1; g See Reference 9; h See Reference 14.

CAPTIONS

Fig. 1 Differential cross sections in the barycentric system for π^- p elastic scattering. The errors are statistical and do not include an overall normalization error of $\pm$ 8%.

Fig. 2 Differential cross section in the barycentric system for π^+ p elastic scattering. The errors are statistical and do not include an overall normalization error of + 10%, - 20%.

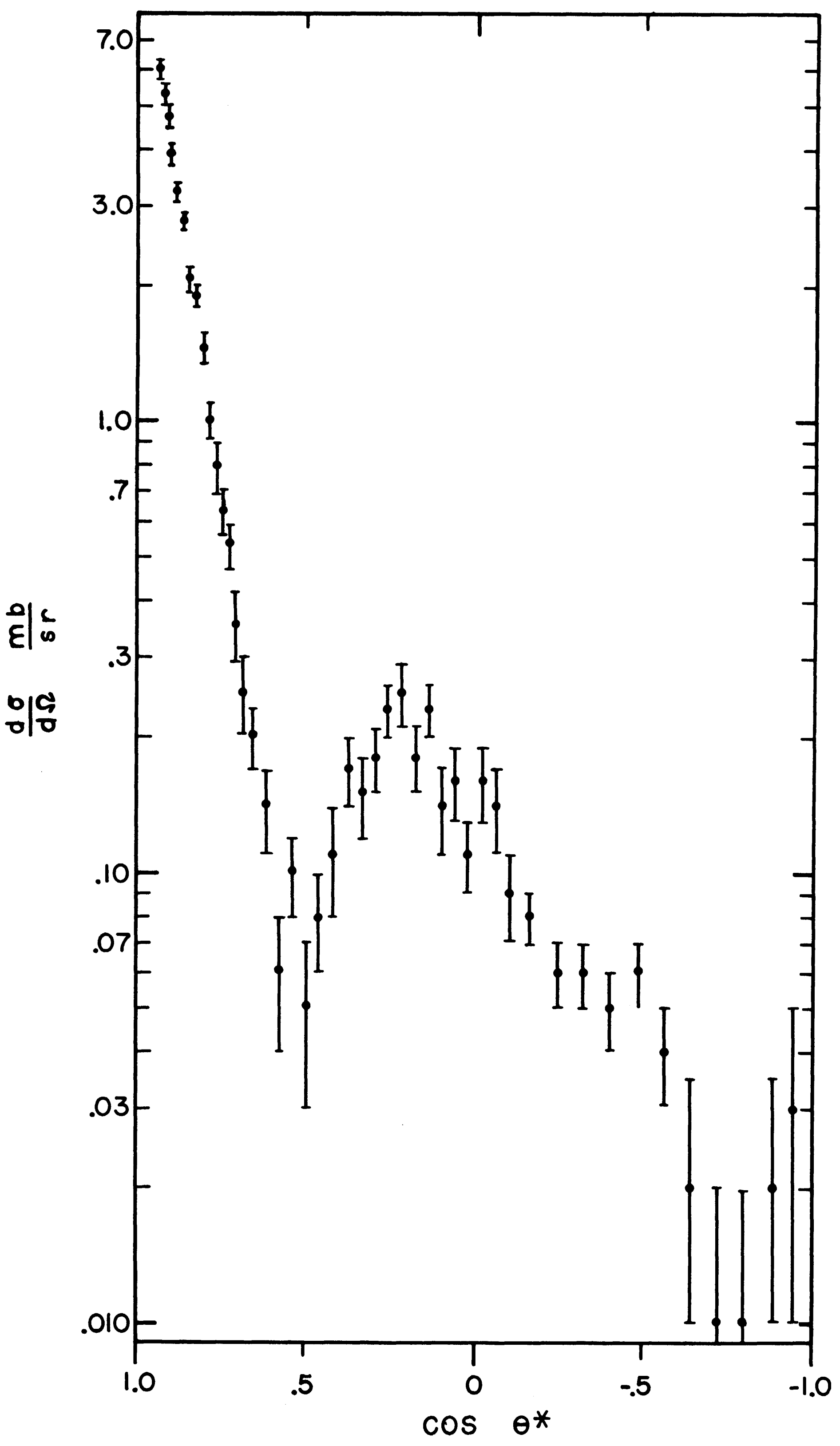

Fig. 1

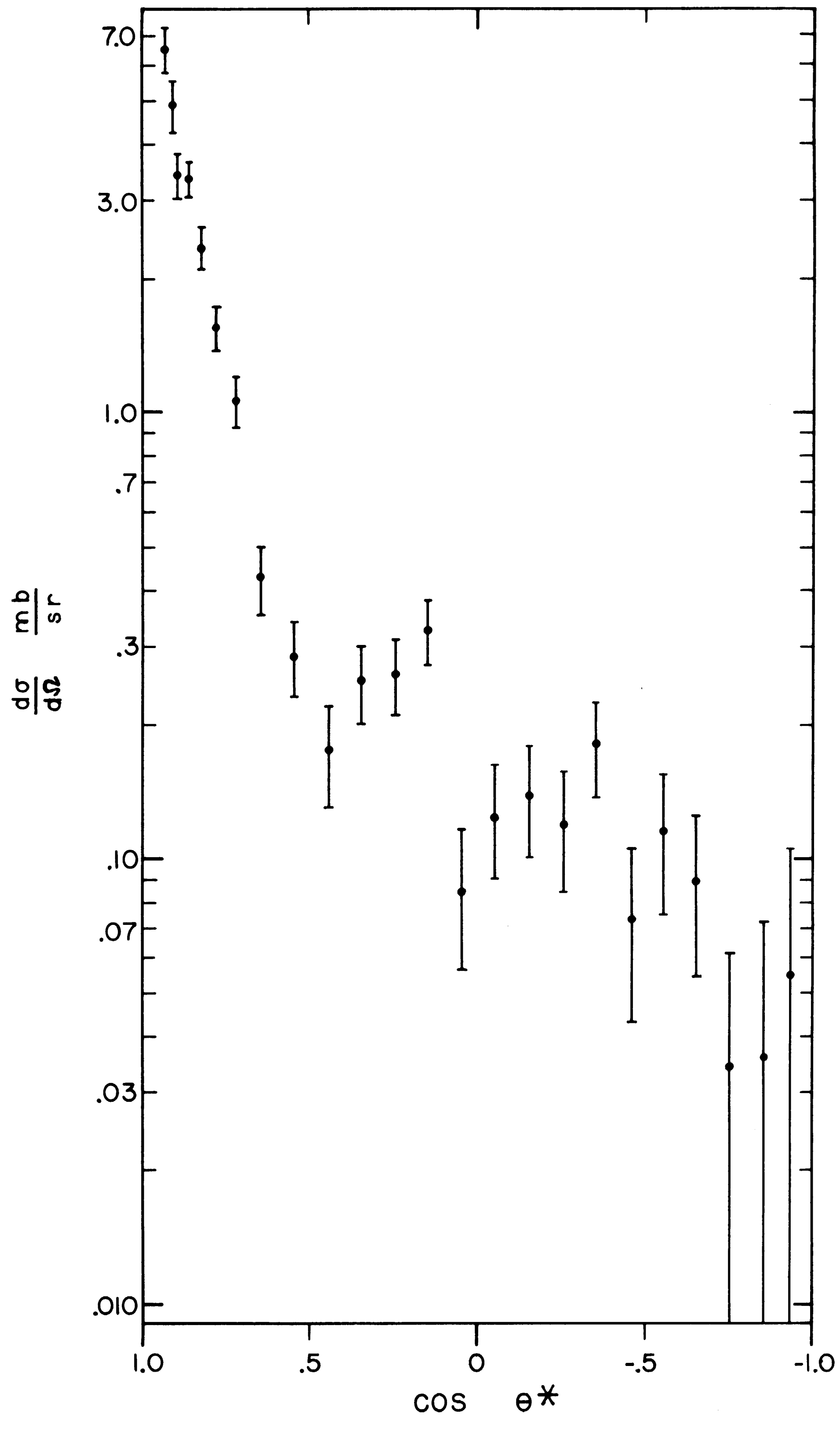

Fig. 2