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September 24, 1962

ANGULAR DISTRIBUTIONS IN $\pi^{\pm}$-p ELASTIC SCATTERING IN THE RANGE 500 TO 1600 MeV*

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Angular distributions for pions elastically scattered from protons were measured at the Berkeley Bevatron in November and December of 1961. The laboratory kinetic energies of the pions selected for the measurements were: 533, 581, 698, 873, and 990 MeV for π^+ and π^-, and 1311 and 1555 MeV for π^+.

The differential cross sections were measured at as many as 20 angles simultaneously for each energy. The corrected data are listed in Tables I through VII, along with the cosine of the pion scattering angle in the center-of-mass system. These tables include the dispersion relations point at $\cos\theta^* = 1.0$.

The data were least-squares-fitted with a curve having an equation of the form

$$\frac{d\sigma}{d\Omega^*}(\theta^*) = \sum_{n=0}^{N} a_n \cos^n \theta^*, \qquad (1)$$

where θ^* is the angle in the center-of-mass at which the pion is scattered. The results from the π^--p measurements are in essential agreement with those obtained by Wood et al.,[1] the main difference being that absolute normalizations, and hence total elastic cross sections, were obtained in the present experiment. In addition, the energies of these measurements are slightly lower than Wood's; however, this does not prohibit comparison of the two experiments.

The data points and the fitted curves are shown in Figs. 1 and 2. Attention should be directed to the backward peak and subsequent sharp drop-off of the cross section at 180 deg in the $\pi^- - p$ scattering in the vicinity of the 900-MeV peak, and also to the sharp rise of the cross sections near 180 deg in the $\pi^+ - p$ scattering in the vicinity of the 1350-MeV peak.

The values of the coefficients a_n in Eq. (1) are listed in Tables VIII and IX, and are plotted as a function of energy in Figs. 3 and 4. The curves of Fig. 4 include data from many experiments in addition to this one.[1,2] At 900 MeV ($\pi^- - p$) the small value of a_6 suggests that there is little scattering from partial-wave states with total angular momentum $J = 7/2$ or higher. The large value of a_5 may indicate that a superposition of $F_{5/2}$ and $D_{5/2}$ partial waves is prominent in the scattering at this energy. One possible explanation is that the $F_{5/2}$ enhancement comes from an elastic resonance in the isotopic-spin $T = 1/2$ state, consistent with the Regge-pole formalism,[3] and the $D_{5/2}$ partial-wave state may be enhanced by inelastic processes in the $T = 3/2$ state.

At 600 MeV ($\pi^- - p$) the values of the coefficients do not seem to indicate the prominence of any single partial-wave state. The similarity of the differential-cross-section curves at 533 and 581 MeV, except for the larger value of the forward diffraction peak at the higher energy, may indicate that the 600-MeV peak is due to inelastic processes rather than an elastic resonance.

At 1350 MeV ($\pi^+ - p$) the small value of a_7 suggests that there is little scattering from partial-wave states with $J = 9/2$ or larger. The large value of a_6 may indicate that $F_{7/2}$ scattering is prominent (although $G_{7/2}$ scattering could give the same results). The $F_{7/2}$ assignment is consistent with the Regge-pole formalism.[3]

The total elastic cross sections, obtained by integrating under the fitted curves, are listed in Table X.

The details of the experiment and data processing will be discussed in a forthcoming article.

FOOTNOTES AND REFERENCES

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Table I. Differential-cross-section data and errors in standard deviations for T_π = 533 MeV.

$\cos\theta^*$	$\frac{d\sigma(\theta^*)}{d\Omega^*}$	
	π^+-p	π^--p
1.000	4.800 ± 0.648	4.700 ± 0.418
0.547	2.389 ± 0.064	1.972 ± 0.057
0.446	1.906 ± 0.074	1.506 ± 0.067
0.363	1.482 ± 0.074	1.294 ± 0.085
0.259	1.202 ± 0.075	1.034 ± 0.083
0.155	0.793 ± 0.122	0.757 ± 0.110
-0.062	0.348 ± 0.031	0.386 ± 0.029
-0.173	0.156 ± 0.023	0.175 ± 0.023
-0.276	0.071 ± 0.020	0.159 ± 0.019
-0.445	0.054 ± 0.019	0.222 ± 0.021
-0.551	0.060 ± 0.018	0.386 ± 0.021
-0.675	0.090 ± 0.021	0.622 ± 0.029
-0.768	0.142 ± 0.022	0.887 ± 0.038
-0.836	0.217 ± 0.029	1.045 ± 0.048
-0.885	0.157 ± 0.035	1.399 ± 0.065
-0.925	0.145 ± 0.035	1.490 ± 0.078

Table II. Differential-cross-section data and errors in standard deviations for T_π = 581 MeV.

Cos θ^*	$\frac{d\sigma(\theta^*)}{d\Omega^*}$	
	π^+-p	π^--p
1.000	3.470 ± 0.742	6.640 ± 0.387
0.613	2.163 ± 0.056	2.851 ± 0.080
0.533	2.032 ± 0.054	2.613 ± 0.077
0.429	1.512 ± 0.071	1.882 ± 0.093
0.345	1.019 ± 0.082	1.346 ± 0.135
0.239	0.807 ± 0.091	0.915 ± 0.151
0.135	0.589 ± 0.131	0.745 ± 0.174
-0.083	0.259 ± 0.022	0.280 ± 0.031
-0.193	0.086 ± 0.019	0.057 ± 0.027
-0.295	0.020 ± 0.019	0.095 ± 0.026
-0.461	0.046 ± 0.018	0.213 ± 0.028
-0.565	0.090 ± 0.017	0.429 ± 0.029
-0.686	0.127 ± 0.018	0.693 ± 0.037
-0.776	0.156 ± 0.019	0.913 ± 0.046
-0.842	0.113 ± 0.022	1.107 ± 0.056
-0.890	0.153 ± 0.023	1.402 ± 0.067
-0.928	0.079 ± 0.028	1.530 ± 0.092

Table III. Differential-cross-section data and errors in standard deviations for T_π = 698 MeV.

$\cos\theta^*$	$\frac{d\sigma(\theta^*)}{d\Omega^*}$	
	π^+-p	π^--p
1.000	2.250 ± 0.542	6.390 ± 0.351
0.664	1.426 ± 0.050	2.163 ± 0.068
0.583	1.221 ± 0.044	1.829 ± 0.059
0.499	1.041 ± 0.046	1.634 ± 0.062
0.391	0.694 ± 0.048	1.187 ± 0.073
0.303	0.607 ± 0.049	0.803 ± 0.075
0.195	0.375 ± 0.050	0.592 ± 0.076
0.089	0.156 ± 0.072	0.422 ± 0.108
-0.129	0.130 ± 0.026	0.192 ± 0.035
-0.237	0.113 ± 0.021	0.222 ± 0.026
-0.336	0.115 ± 0.023	0.333 ± 0.029
-0.497	0.208 ± 0.025	0.667 ± 0.037
-0.596	0.264 ± 0.022	0.762 ± 0.037
-0.710	0.267 ± 0.023	0.877 ± 0.040
-0.794	0.272 ± 0.027	0.922 ± 0.046
-0.855	0.195 ± 0.032	0.798 ± 0.050
-0.899	0.239 ± 0.035	0.807 ± 0.056
-0.934	0.186 ± 0.045	0.731 ± 0.073

Table IV. Differential-cross-section data and errors in standard deviations for T_π = 873 MeV.

1. Cos θ^*	$\frac{d\sigma(\theta^*)}{d\Omega^*}$	
	π^+-p	π^--p
1.000	3.800 ± 0.453	16.680 ± 0.702
0.709	2.339 ± 0.081	2.806 ± 0.077
0.627	1.788 ± 0.072	1.405 ± 0.053
0.540	1.549 ± 0.065	0.617 ± 0.041
0.450	1.279 ± 0.066	0.328 ± 0.050
0.336	0.854 ± 0.103	0.264 ± 0.080
0.246	0.551 ± 0.103	0.261 ± 0.083
0.134	0.278 ± 0.090	0.327 ± 0.077
0.027	0.254 ± 0.116	0.287 ± 0.064
-0.190	0.141 ± 0.039	0.441 ± 0.037
-0.295	0.095 ± 0.041	0.726 ± 0.038
-0.391	0.172 ± 0.042	1.035 ± 0.045
-0.542	0.265 ± 0.046	1.813 ± 0.061
-0.635	0.397 ± 0.047	2.350 ± 0.062
-0.740	0.385 ± 0.045	2.403 ± 0.070
-0.816	0.447 ± 0.053	2.547 ± 0.080
-0.871	0.413 ± 0.063	2.136 ± 0.087
-0.910	0.575 ± 0.069	2.106 ± 0.091
-0.942	0.853 ± 0.100	1.602 ± 0.105

Table V. Differential-cross-section data and errors in standard deviations for T_π = 990 MeV.

Cos θ^*	$\frac{d\sigma(\theta^*)}{d\Omega^*}$	
	π^+-p	π^--p
1.000	4.780 ± 0.410	14.530 ± 0.632
0.770	2.934 ± 0.090	3.685 ± 0.090
0.690	2.470 ± 0.079	2.073 ± 0.065
0.604	1.838 ± 0.070	1.012 ± 0.047
0.513	1.518 ± 0.061	0.413 ± 0.032
0.420	1.265 ± 0.078	0.173 ± 0.050
0.303	0.777 ± 0.092	0.142 ± 0.039
0.210	0.407 ± 0.086	0.159 ± 0.037
0.097	0.268 ± 0.085	0.280 ± 0.038
-0.011	0.238 ± 0.146	0.278 ± 0.049
-0.226	0.247 ± 0.046	0.393 ± 0.042
-0.329	0.423 ± 0.043	0.425 ± 0.038
-0.422	0.502 ± 0.046	0.568 ± 0.040
-0.568	0.485 ± 0.052	0.978 ± 0.051
-0.657	0.532 ± 0.041	1.151 ± 0.047
-0.756	0.495 ± 0.047	1.429 ± 0.056
-0.828	0.596 ± 0.049	1.316 ± 0.061
-0.880	0.688 ± 0.065	1.304 ± 0.069
-0.917	1.068 ± 0.078	1.066 ± 0.070
-0.946	1.308 ± 0.124	0.914 ± 0.095

Table VI. Differential-cross-section data and errors in standard deviations for T_π = 1311 MeV.

Cos θ^*	$\frac{d\sigma(\theta^*)}{d\Omega^*}$, π^+-p
1.000	14.030 ± 0.818
0.730	1.796 ± 0.081
0.640	0.879 ± 0.063
0.543	0.512 ± 0.053
0.443	0.254 ± 0.056
0.342	0.466 ± 0.091
0.218	0.405 ± 0.097
0.121	0.190 ± 0.090
0.006	0.362 ± 0.076
-0.101	0.386 ± 0.075
-0.310	1.182 ± 0.065
-0.407	1.355 ± 0.068
-0.494	1.288 ± 0.076
-0.627	1.091 ± 0.076
-0.705	0.917 ± 0.065
-0.793	0.702 ± 0.071
-0.855	0.757 ± 0.085
-0.899	1.162 ± 0.102
-0.930	1.504 ± 0.131
-0.955	1.927 ± 0.180

Table VII. Differential-cross-section data and errors in standard deviations for T_π = 1555 MeV.

$\cos(\theta^*)$	$\frac{d\sigma(\theta^*)}{d\Omega^*}$, π^+-p
1.000	11.180 ± 0.776
0.832	3.537 ± 0.120
0.702	1.155 ± 0.071
0.603	0.458 ± 0.056
0.500	0.302 ± 0.062
0.394	0.395 ± 0.073
0.289	0.464 ± 0.075
0.161	0.382 ± 0.076
0.063	0.337 ± 0.074
-0.053	0.257 ± 0.071
-0.160	0.260 ± 0.070
-0.363	0.496 ± 0.061
-0.456	0.582 ± 0.065
-0.537	0.419 ± 0.067
-0.662	0.266 ± 0.073
-0.734	0.178 ± 0.079
-0.814	0.005 ± 0.033
-0.870	0.085 ± 0.076
-0.910	0.098 ± 0.124
-0.938	0.152 ± 0.177
-0.960	0.679 ± 0.195

Table VIII. Coefficients of powers of cos θ^* (π^+-p).

Coefficients	Pion kinetic energy in lab system (MeV)						
	533	581	698	873	990	1311	1555
a_0	0.436±0.017	0.336±0.026	0.173±0.014	0.190±0.053	0.184±0.046	0.337±0.052	0.308±0.031
a_1	2.042±0.070	1.745±0.121	0.692±0.049	1.108±0.213	0.528±0.175	-1.266±0.290	0.467±0.175
a_2	2.869±0.101	2.678±0.139	1.960±0.092	3.004±0.621	4.583±0.508	5.272±0.626	1.642±0.397
a_3	0.250±0.250	-0.051±0.377	0.432±0.141	-0.931±1.688	0.920±1.335	-1.235±2.248	-6.322±1.326
a_4	-0.868±0.239	-1.303±0.369	-0.940±0.174	-2.221±1.820	-6.515±1.430	-17.364±1.970	-7.837±1.286
a_5	--	--	--	4.475±3.939	3.604±2.998	10.548±5.072	16.012±2.990
a_6	--	--	--	1.482±1.387	5.237±1.111	20.410±1.764	12.252±1.140
a_7	--	--	--	-3.300±2.611	-3.682±1.978	-2.614±3.415	-4.971±2.068

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Table IX. Coefficients of powers of cos θ^* (π^--p)

Coefficients	Pion kinetic energy in lab system (MeV)				
	533	581	698	873	990
a_0	0.431±0.028	0.372±0.043	0.243±0.028	0.291±0.046	0.293±0.018
a_1	1.682±0.120	2.188±0.248	1.157±0.102	-0.377±0.152	-0.259±0.063
a_2	2.240±0.216	4.034±0.523	4.431±0.354	1.594±0.591	-0.949±0.247
a_3	-1.001±0.591	-1.031±1.121	-1.917±0.463	-6.755±0.786	-3.157±0.343
a_4	0.554±0.361	-1.887±2.040	-5.201±1.118	4.698±1.878	8.118±0.810
a_5	0.784±0.594	1.223±0.979	3.597±0.464	15.551±0.986	10.365±0.431
a_6	---	1.745±1.688	4.014±0.881	2.473±1.649	-0.162±0.735

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Table X. Total elastic cross sections with errors.

Energy (MeV)	Total elastic cross section π^+-p	Total elastic cross section π^--p
533	15.32±0.47	16.20±0.50
581	12.17±0.57	19.96±0.54
698	8.02±0.22	15.75±0.28
873	12.05±0.45	26.58±0.61
990	14.54±0.31	19.82±0.24
1311	19.31±0.61	---
1555	13.04±0.28	---

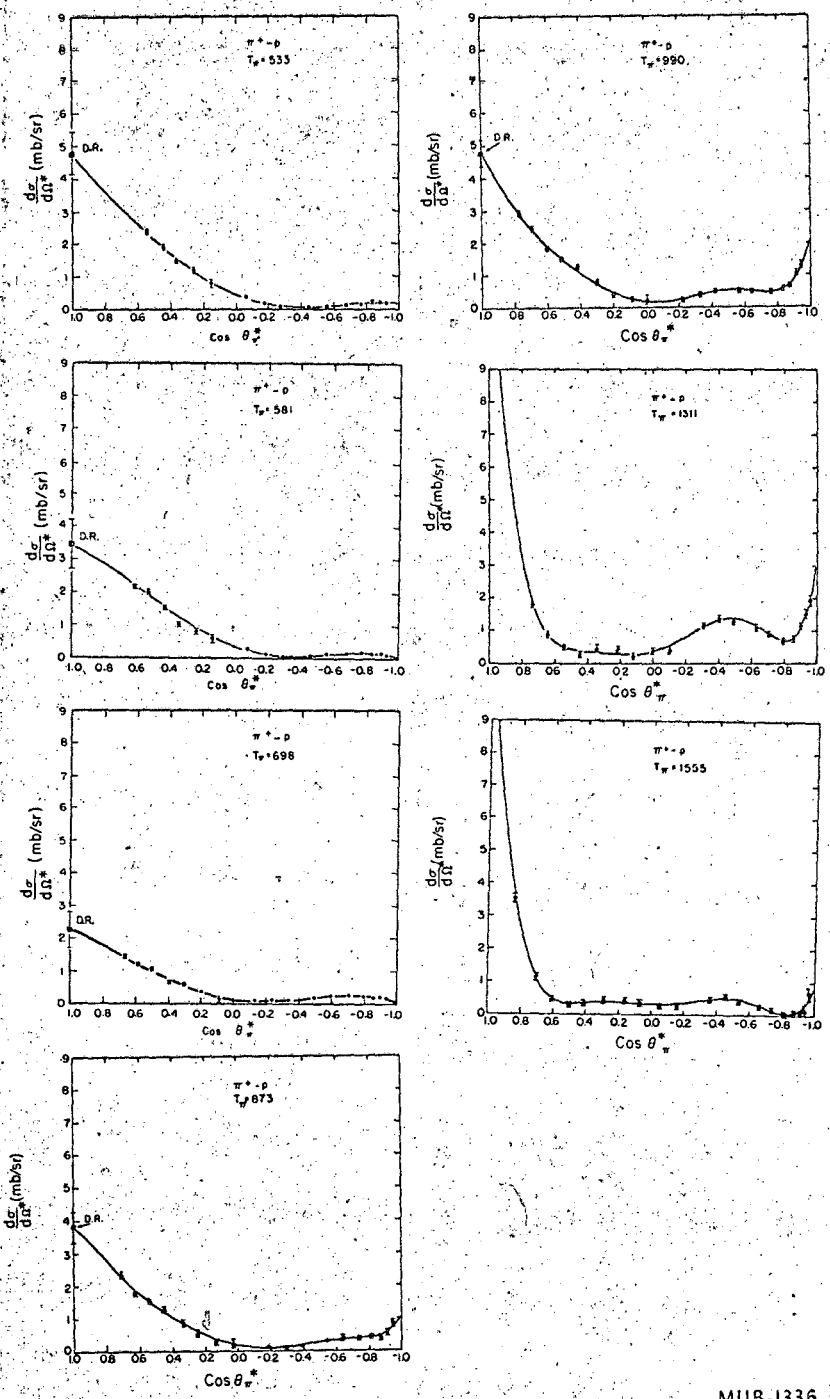
FIGURE CAPTIONS

Fig. 1. Differential cross sections for π^+-p plotted vs cosine of pion scattering angle in center-of-mass system.

Fig. 2. Differential cross sections for π^--p plotted vs cosine of pion scattering angle in center-of-mass system.

Fig. 3. Coefficients a_n for π^+-p plotted vs incident pion laboratory kinetic energy.

Fig. 4. Coefficients a_n for π^--p plotted vs incident pion laboratory kinetic energy.



MUB-1336

Fig. 1

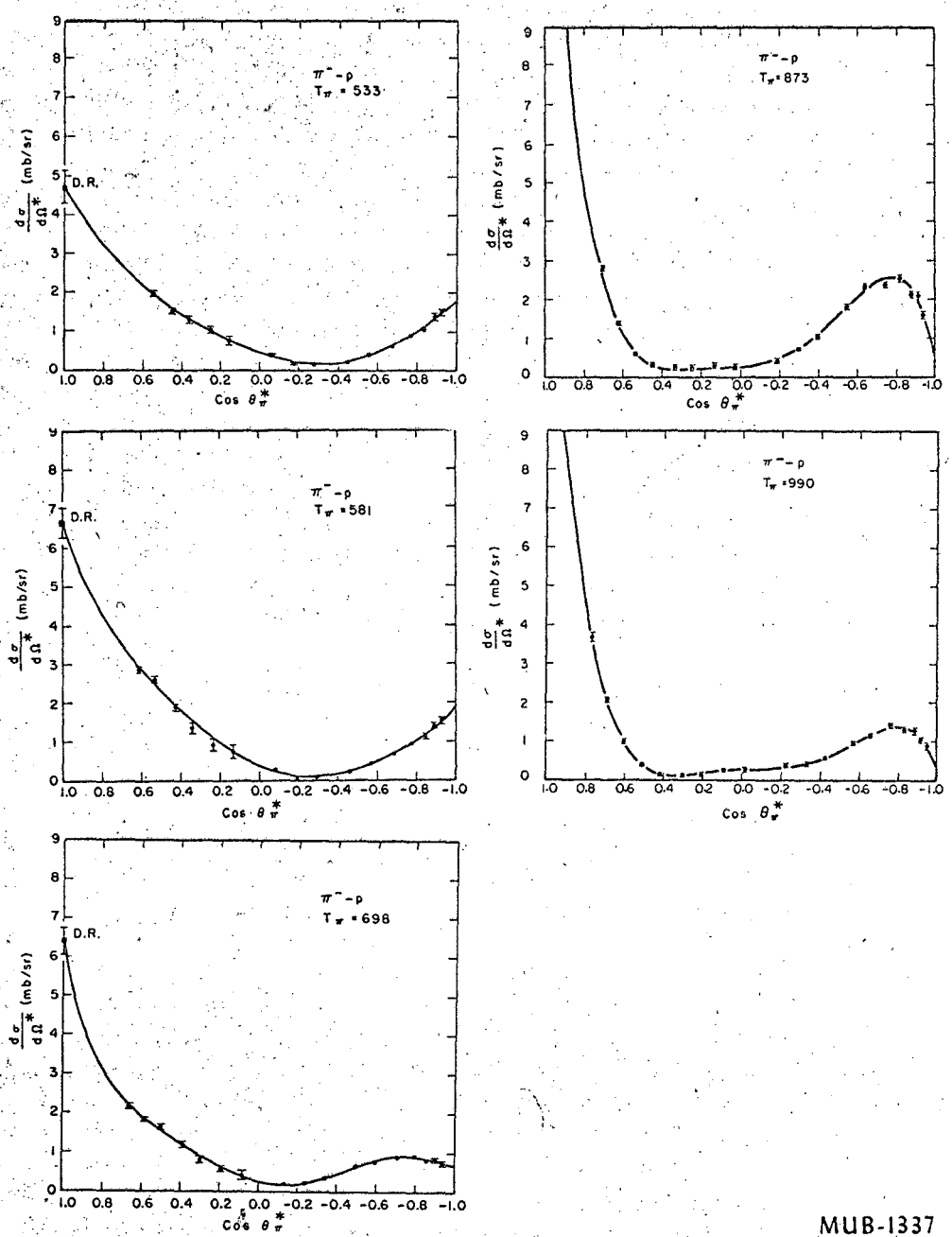


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Fig. 2

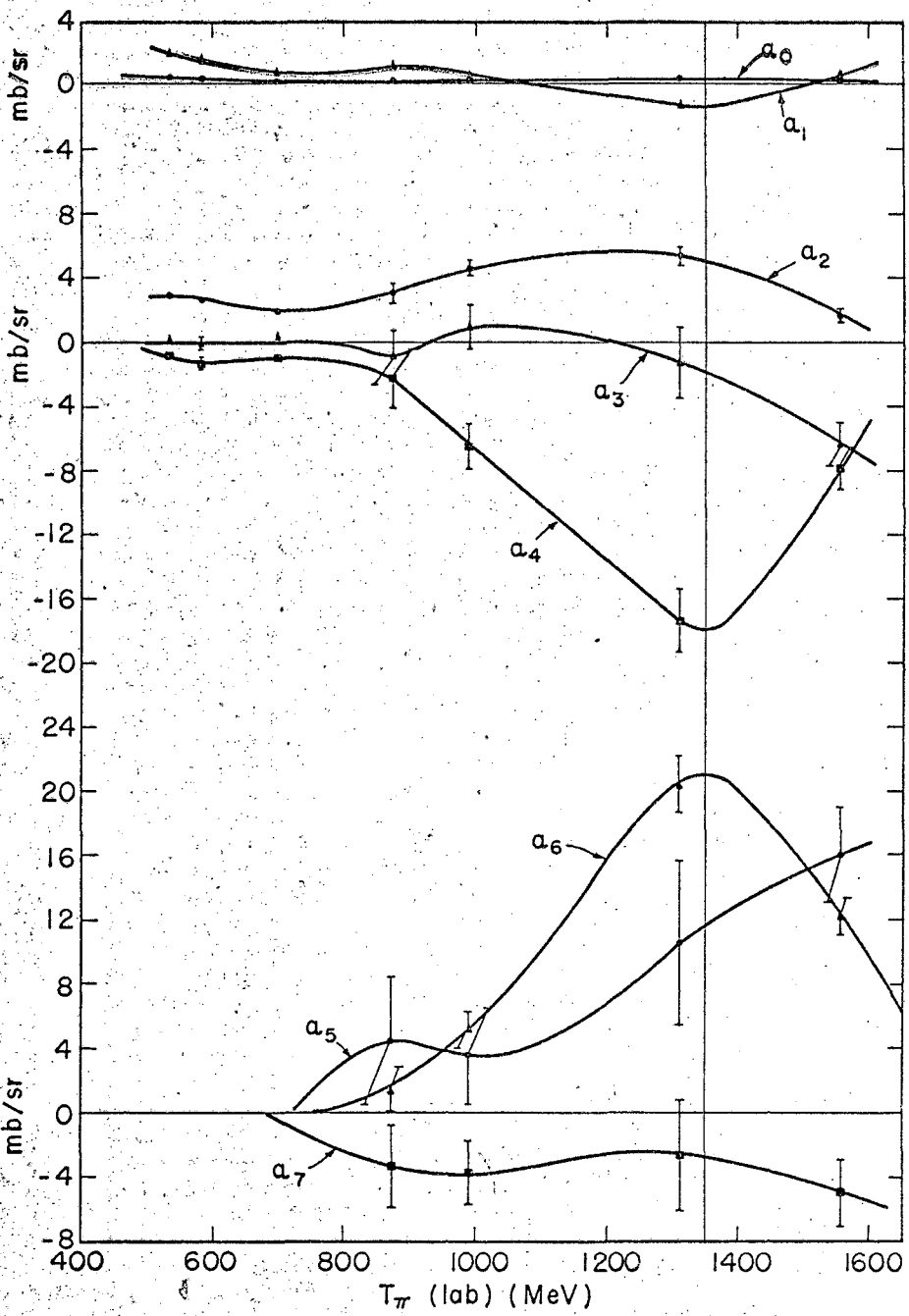

Fig. 3

MUB-1197

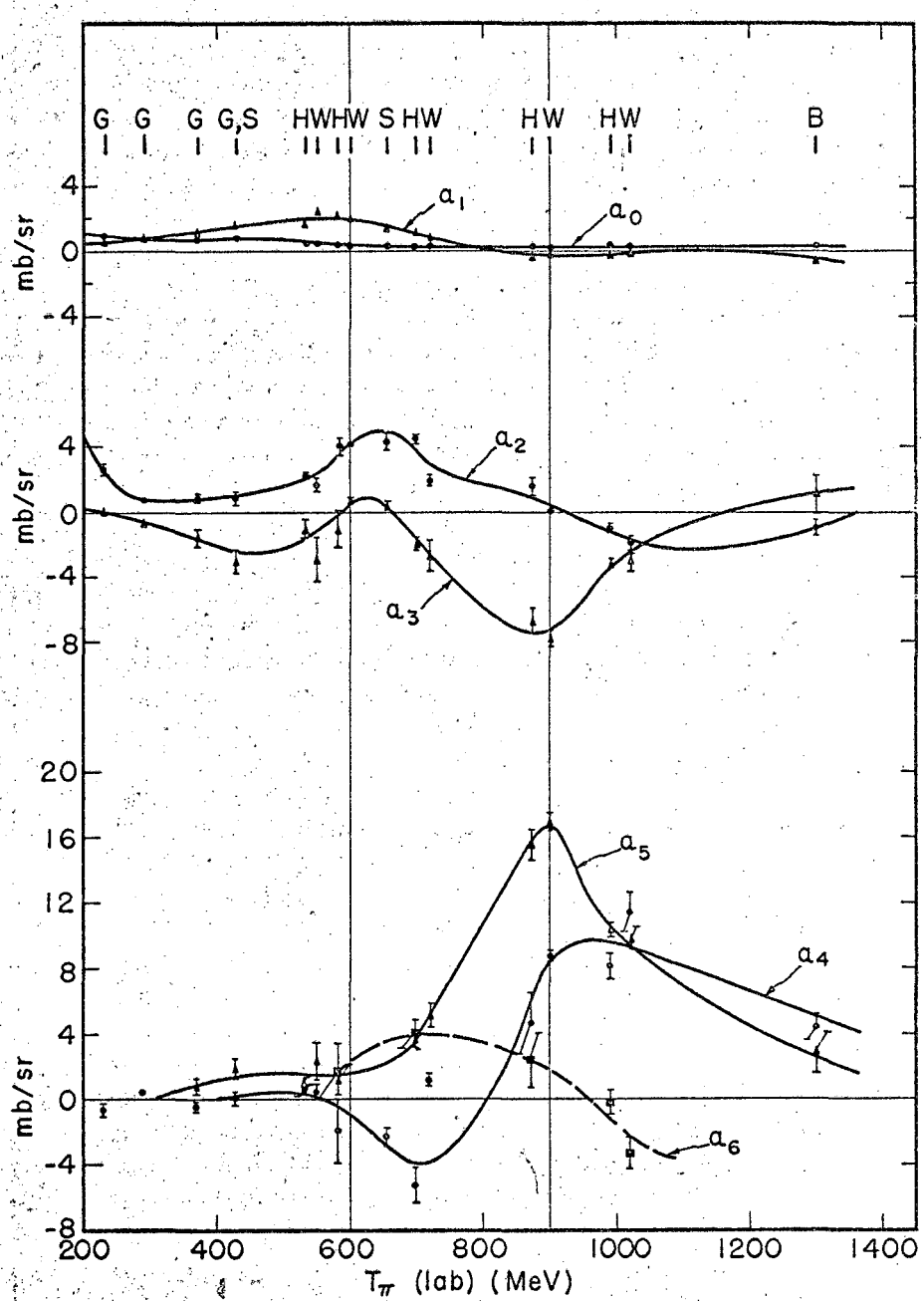

Fig. 4

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