Pion - Proton Scattering with Enrico Fermi in the 1950s

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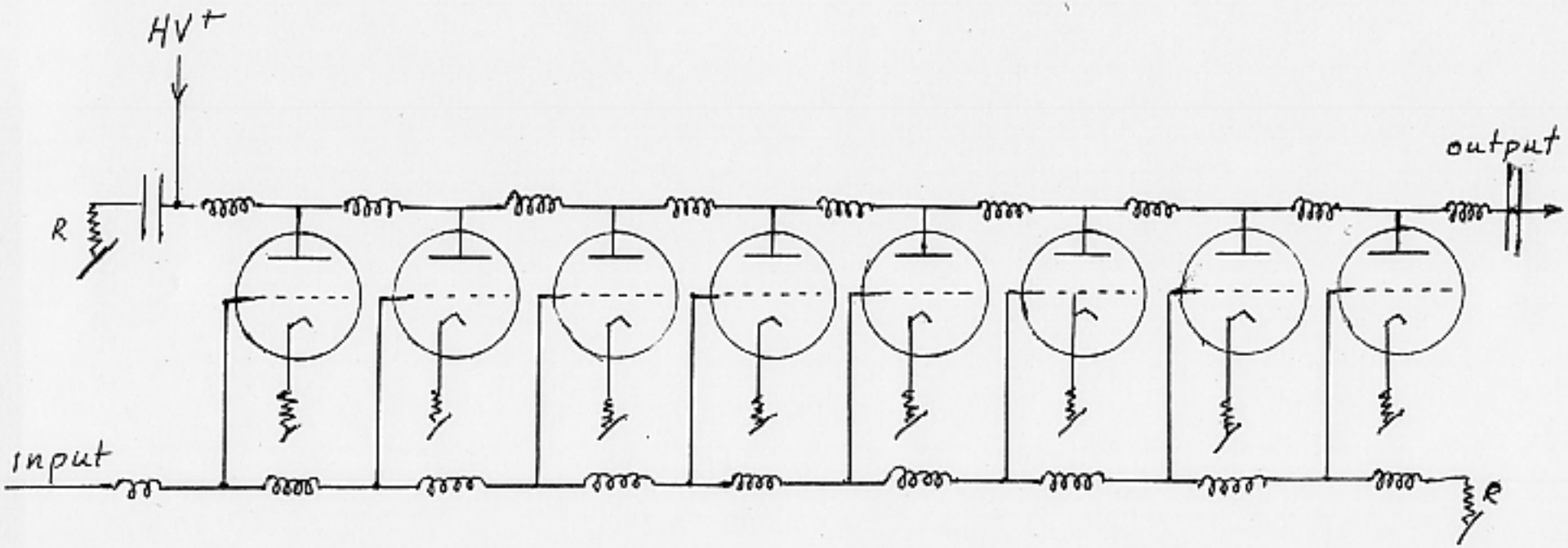
Argonne National Laboratory
Dec. 4, 2002



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Background

1935	Yukawa
1940	μ mesons
1943	not Yukawa particle
1947	π mesons (Lattes, Powell)
1951	450 MeV Chicago Synchrocyclotron
1951 - 1954	Pion appears to be the Yukawa particle

1951	Lee Teng - "Regenerative" extraction
1955 (?)	Al Crewe - Liverpool to Chicago

Fermi to Martin (1950):

"Young man - you are doing the most exciting thing in the world.
May I join you?"

Pion - Proton Scattering Group:

E. Fermi, H. Anderson, D. Nagle, R. Martin, G.Yodh, M. Glicksman
(A. Lundby, E. Long, L. Slattery)

Pion Energies

π^+	π^-	
78 MeV		
110 MeV	120 MeV	First Fermi - Metropolis
135 MeV	144 Mev	Phase Shifts
	169 MeV	
Resonance →	194 MeV	
	210 MeV	

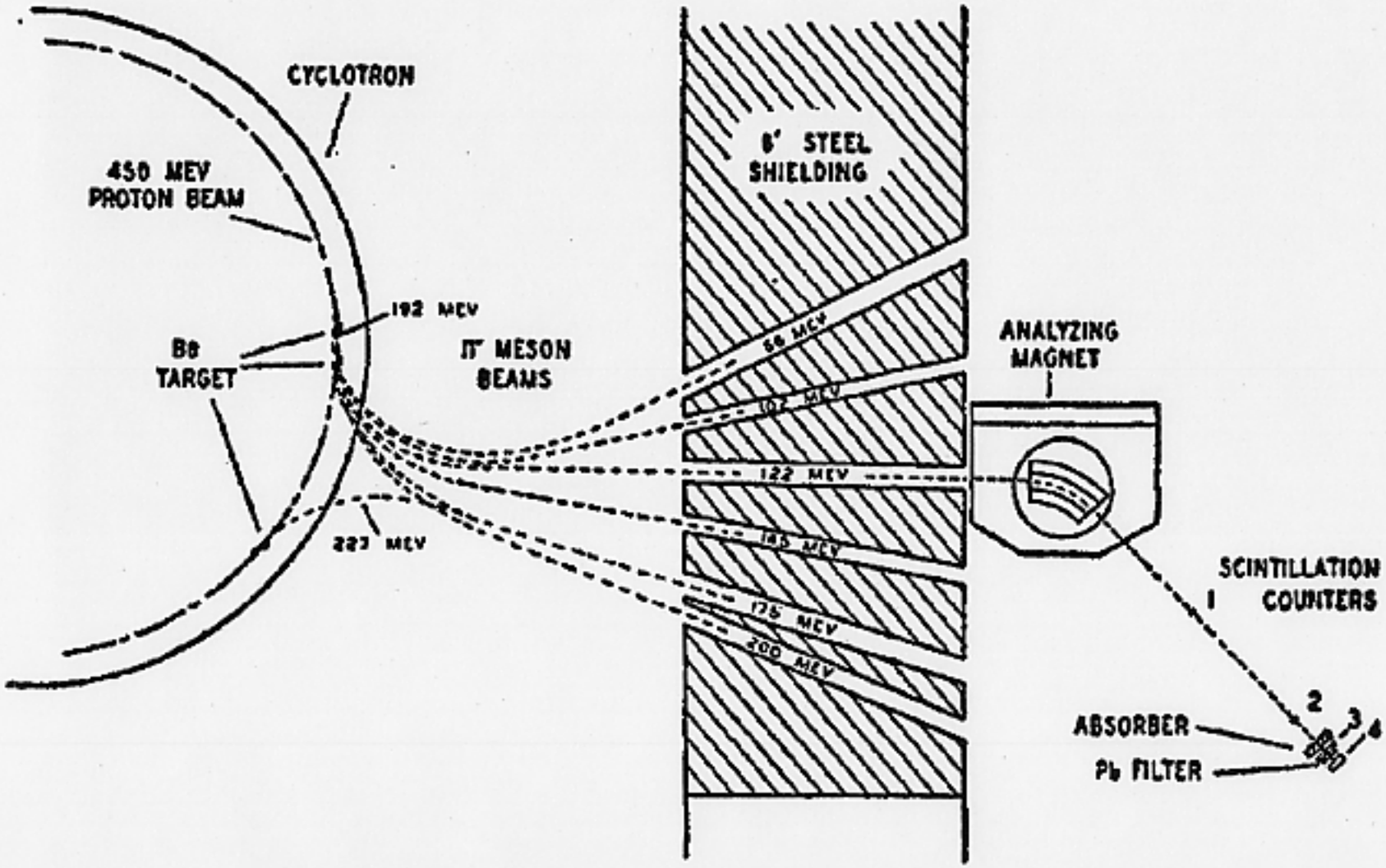
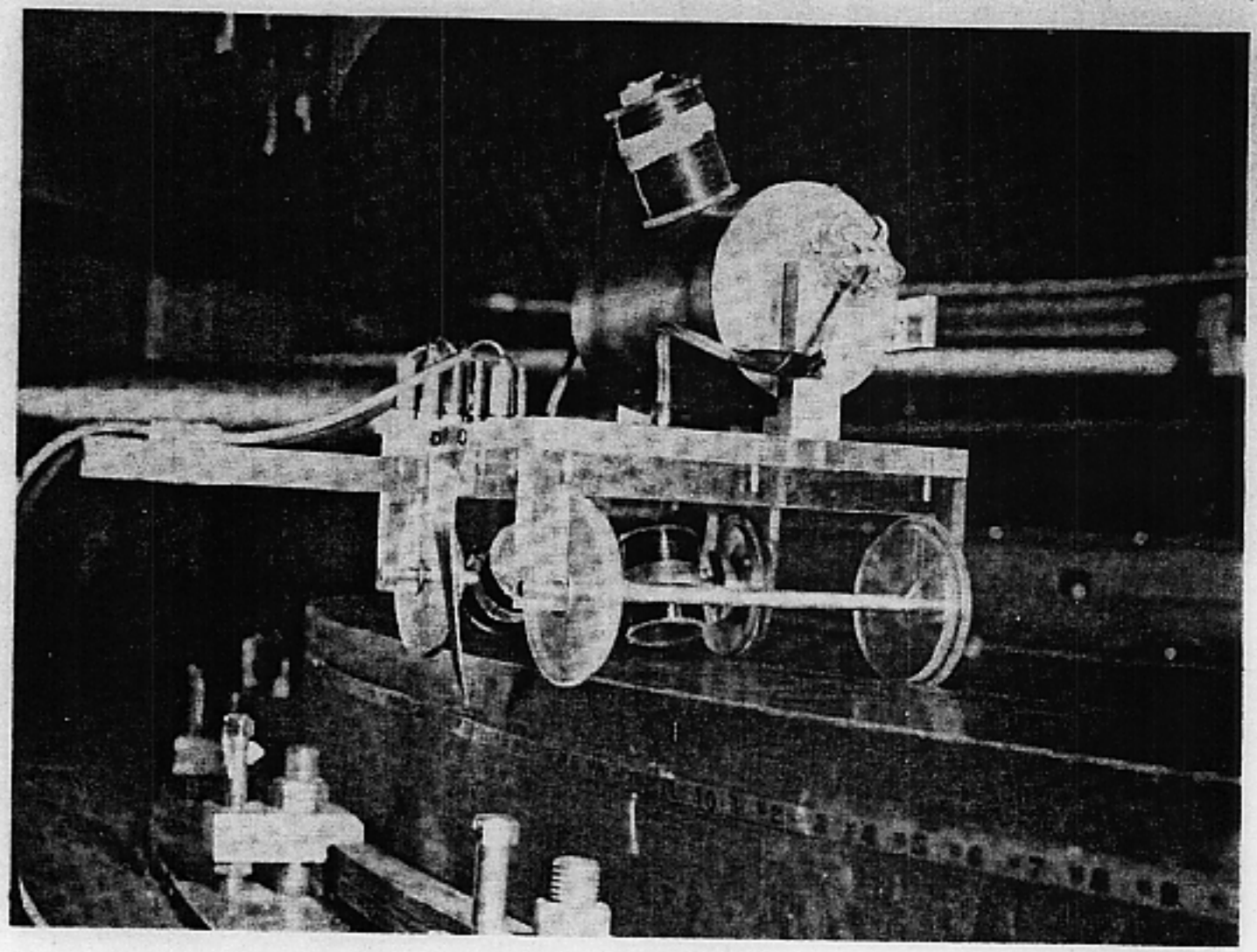
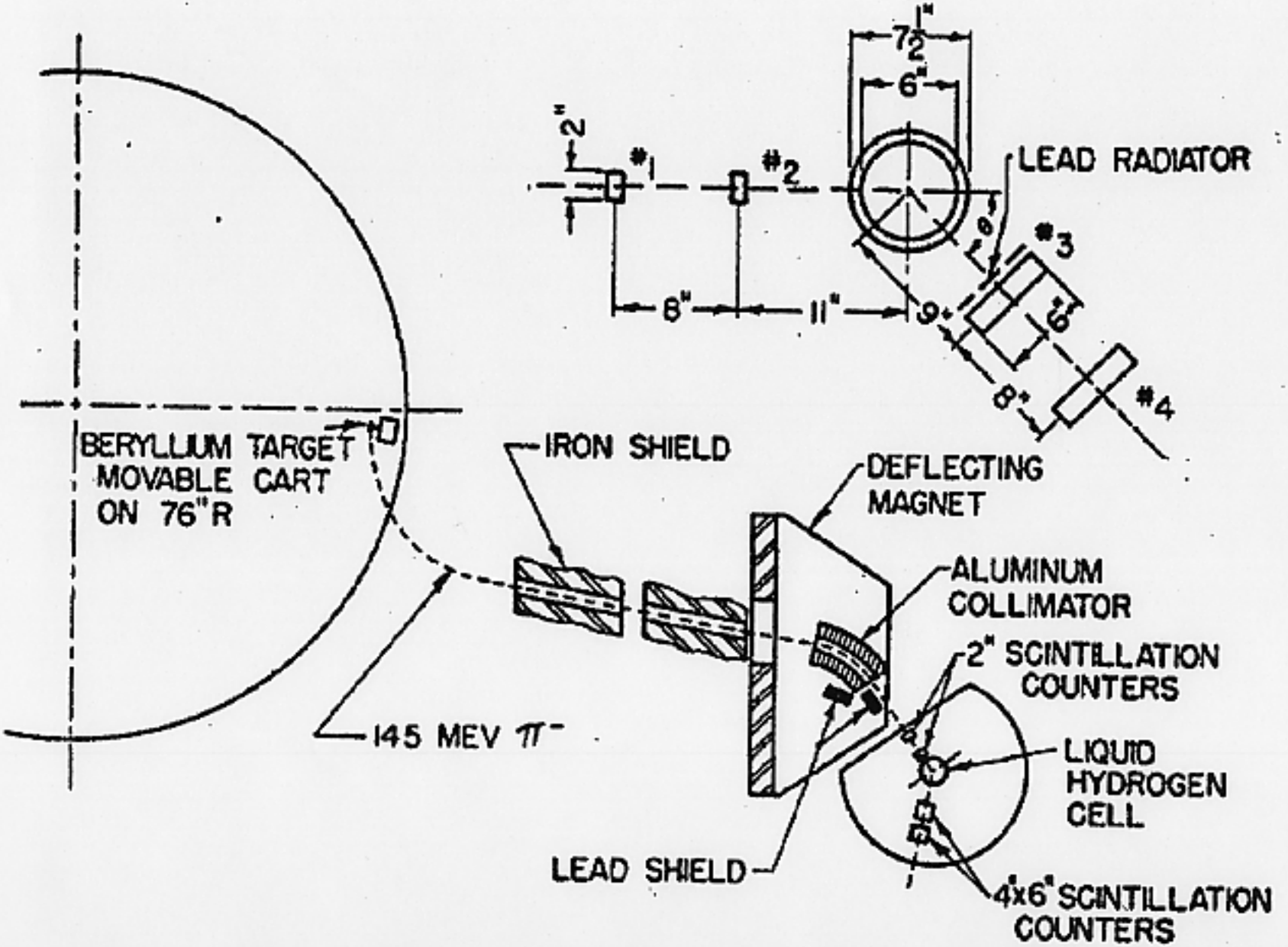


FIG. 1. Experimental arrangement.



Fermi's Streetcar



General experimental arrangement. In the inset the details of the scattering geometry are given.

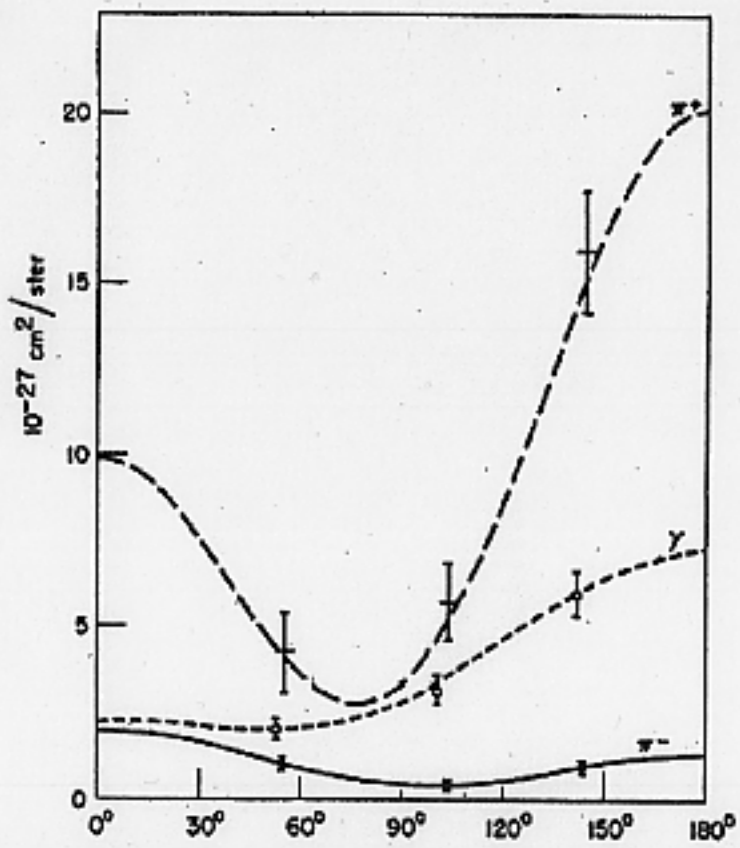


FIG. 9. Computed and observed cross sections at 120 Mev.

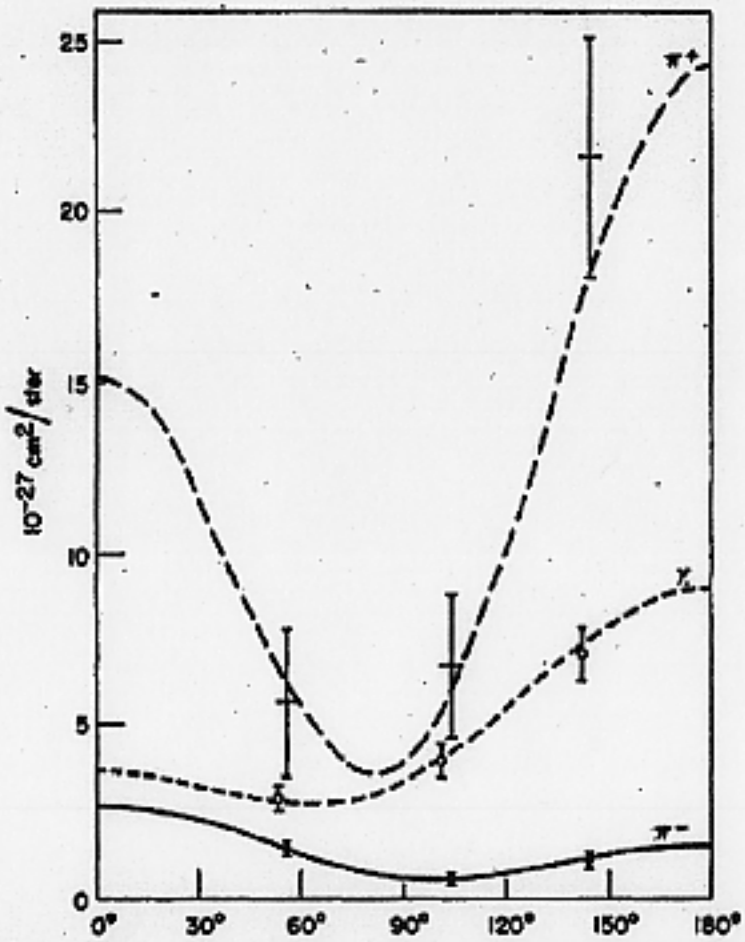
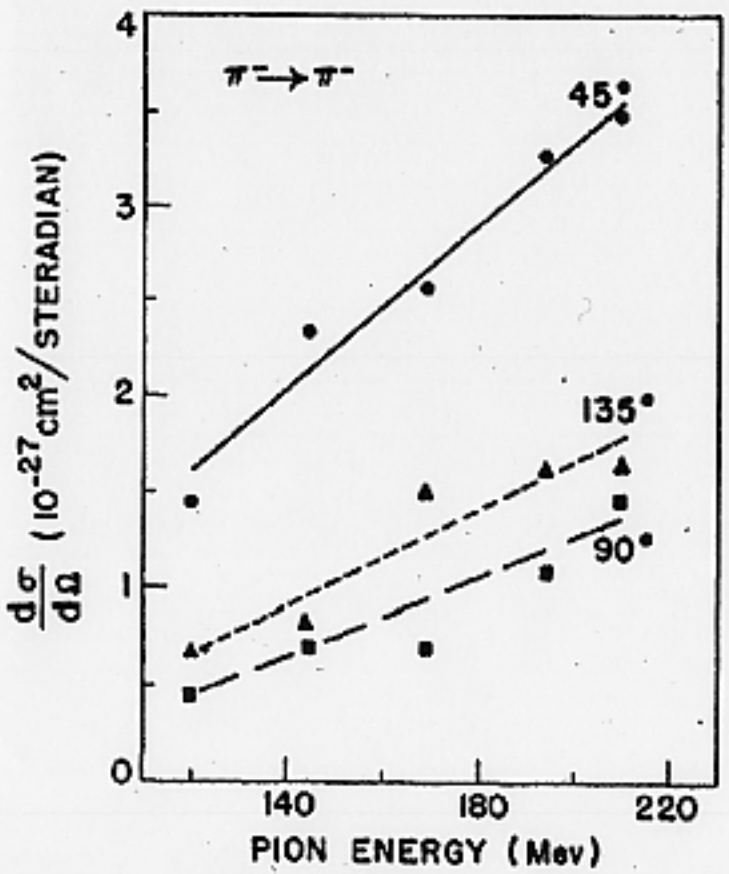
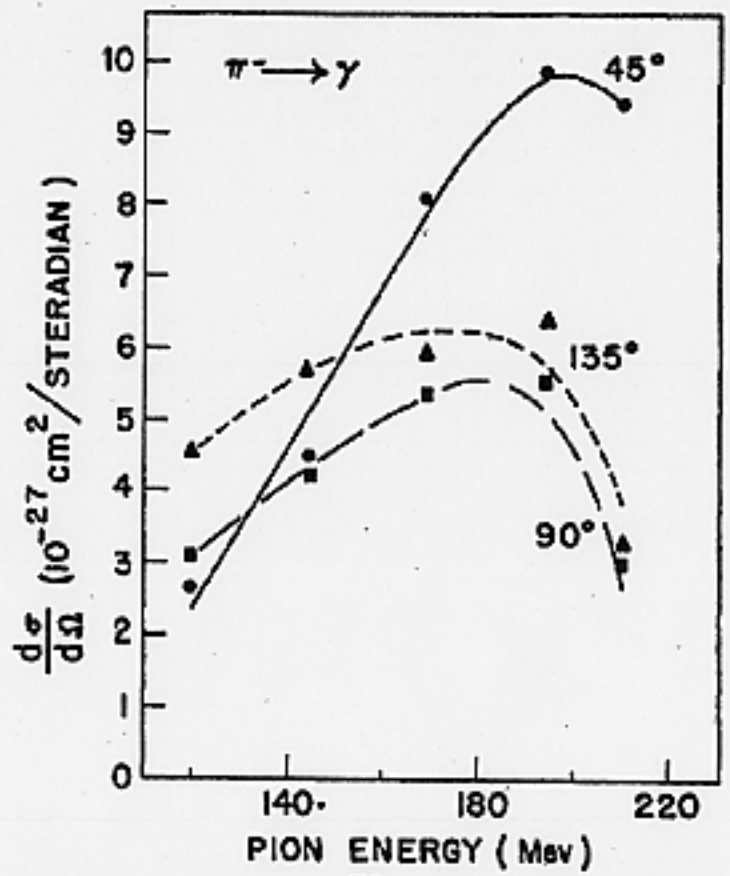


FIG. 10. Computed and observed cross sections at 135 Mev.

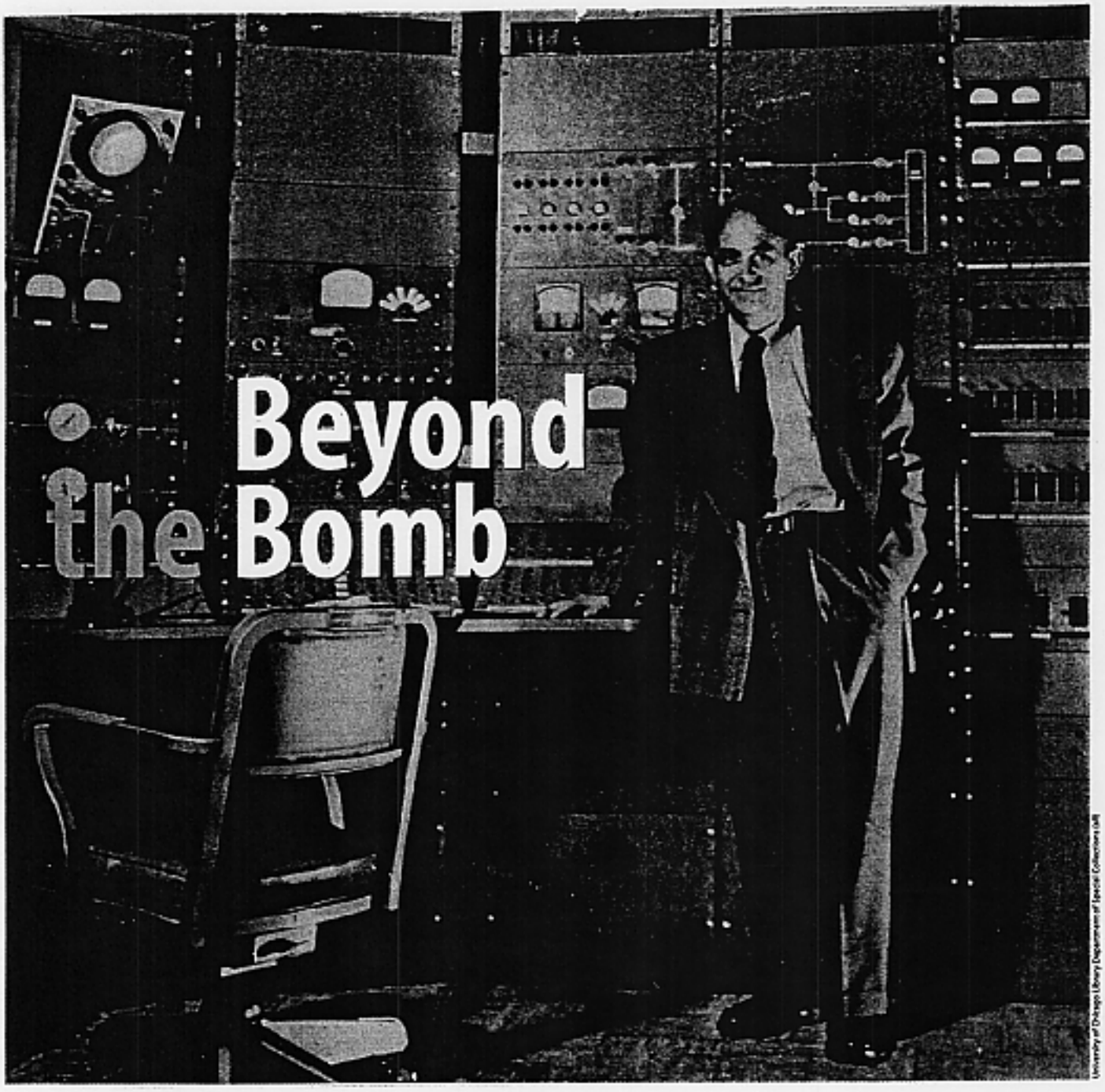


(a)



(b)

FIG. 1. Differential cross sections in the laboratory system for negative pions on hydrogen as functions of the primary pion energy. (a) Elastic scattering. The three curves correspond to laboratory scattering angles 45°, 90°, and 135°. The curves are graphical interpolations of the data. (b) Cross sections for photon production at the same angles.



University of Chicago Library Department of Special Collections (left)

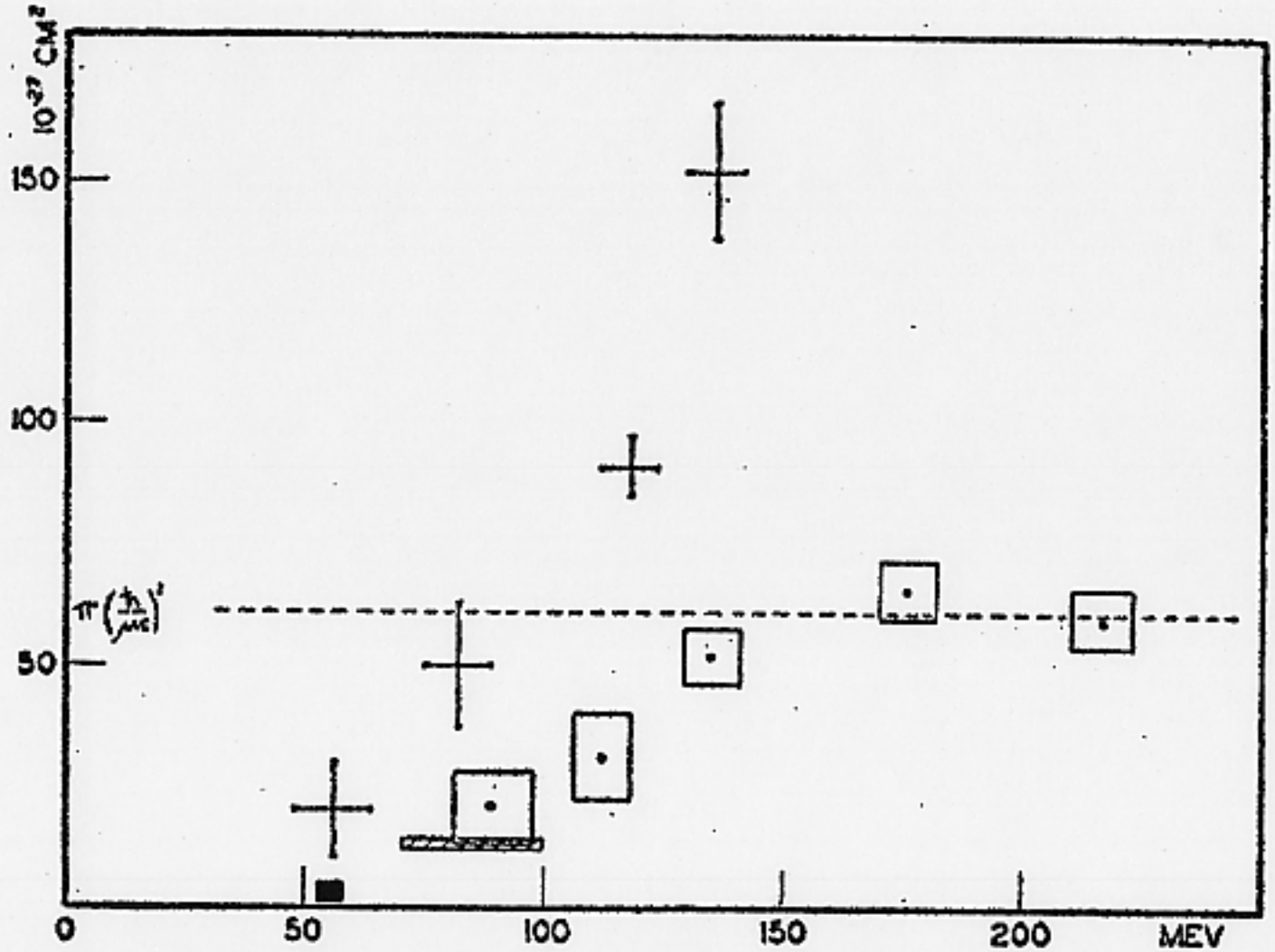


FIG. 1. Total cross sections of negative pions in hydrogen (sides of the rectangle represent the error) and positive pions in hydrogen (arms of the cross represent the error). The cross-hatched rectangle is the Columbia result. The black square is the Brookhaven result and does not include the charge exchange contribution.

the differential scattering cross sections are:

$$\frac{d\sigma(+)}{d\Omega}=\left|\frac{1}{2ik}A+\frac{1}{2ik}B\cos\theta\right|^2+\left|\frac{1}{2ik}C\sin\theta\right|^2 \tag{2}$$

$$=a_++b_+\cos\theta+c_+\cos^2\theta, \tag{2a}$$

$$\frac{d\sigma(-)}{d\Omega}=\frac{1}{9}\left|\frac{1}{2ik}X+\frac{1}{2ik}Y\cos\theta\right|^2+\frac{1}{9}\left|\frac{1}{2ik}Z\sin\theta\right|^2 \tag{3}$$

$$=a_-+b_-\cos\theta+c_-\cos^2\theta, \tag{3a}$$

$$\frac{d\sigma(0)}{d\Omega}=\frac{2}{9}\left|\frac{1}{2ik}P+\frac{1}{2ik}Q\cos\theta\right|^2+\frac{2}{9}\left|\frac{1}{2ik}R\sin\theta\right|^2 \tag{4}$$

$$=a_0+b_0\cos\theta+c_0\cos^2\theta, \tag{4a}$$

where k is the wave number in the c.m. system.

$$A=\exp(2i\alpha_{\frac{1}{2}}^0)-1,$$
$$B=2\exp(2i\alpha_{\frac{1}{2}}^1)+\exp(2i\alpha_{\frac{3}{2}}^1)-3,$$
$$C=\exp(2i\alpha_{\frac{3}{2}}^1)-\exp(2i\alpha_{\frac{1}{2}}^1),$$
$$X=A+2\exp(2i\beta_{\frac{1}{2}}^0)-2,$$
$$Y=B+4\exp(2i\beta_{\frac{1}{2}}^1)+2\exp(2i\beta_{\frac{3}{2}}^1)-6,$$
$$Z=C+2\exp(2i\beta_{\frac{3}{2}}^1)-2\exp(2i\beta_{\frac{1}{2}}^1),$$
$$P=\tfrac{3}{2}A-\tfrac{1}{2}X,$$
$$Q=\tfrac{3}{2}B-\tfrac{1}{2}Y,$$
$$R=\tfrac{3}{2}C-\tfrac{1}{2}Z.$$

Note: $T=\frac{3}{2}$ phase shifts are α_J^L; $T=\frac{1}{2}$ phase shifts are β_J^L.

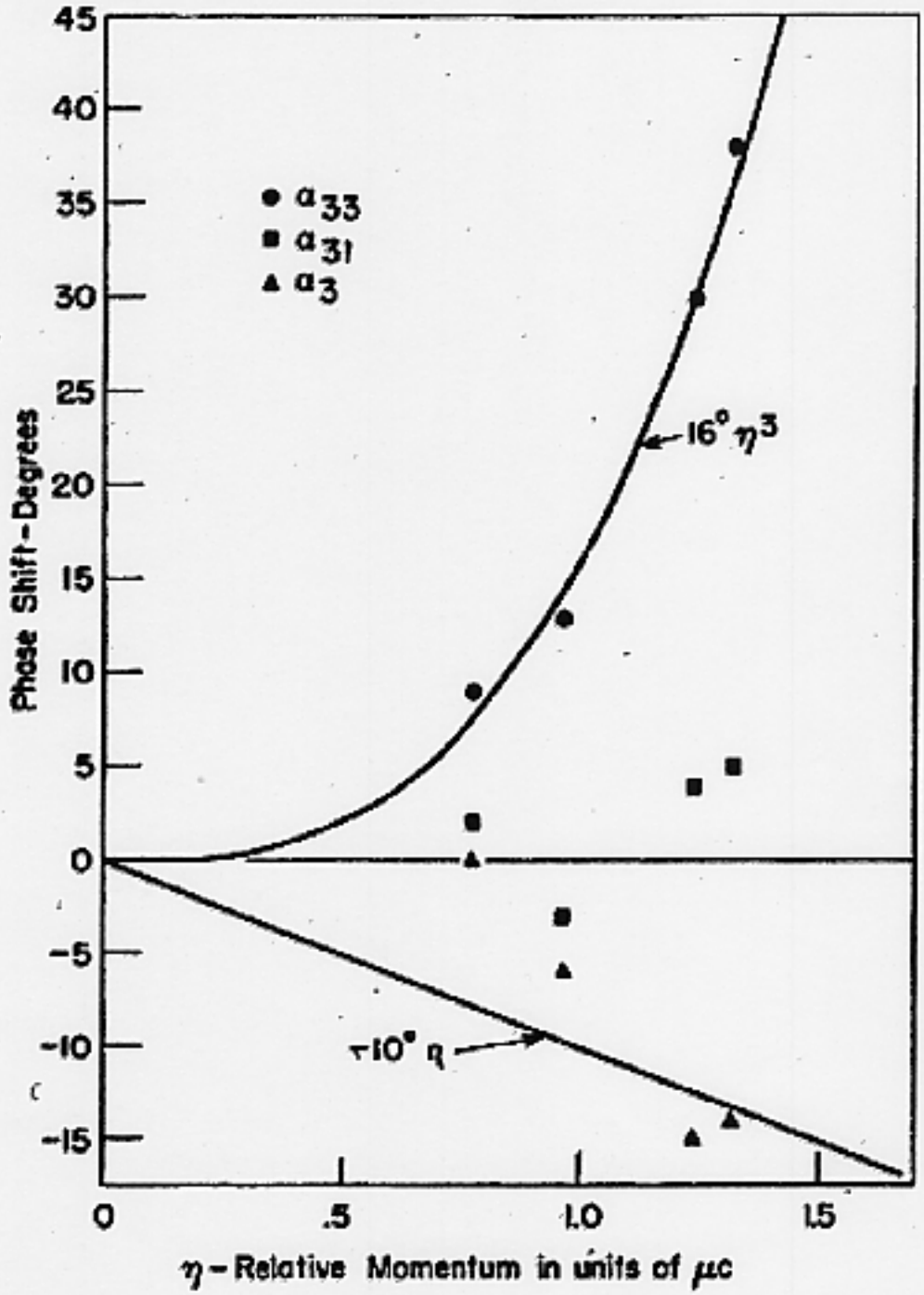


FIG. 11. Phase shifts plotted *versus* relative momentum.

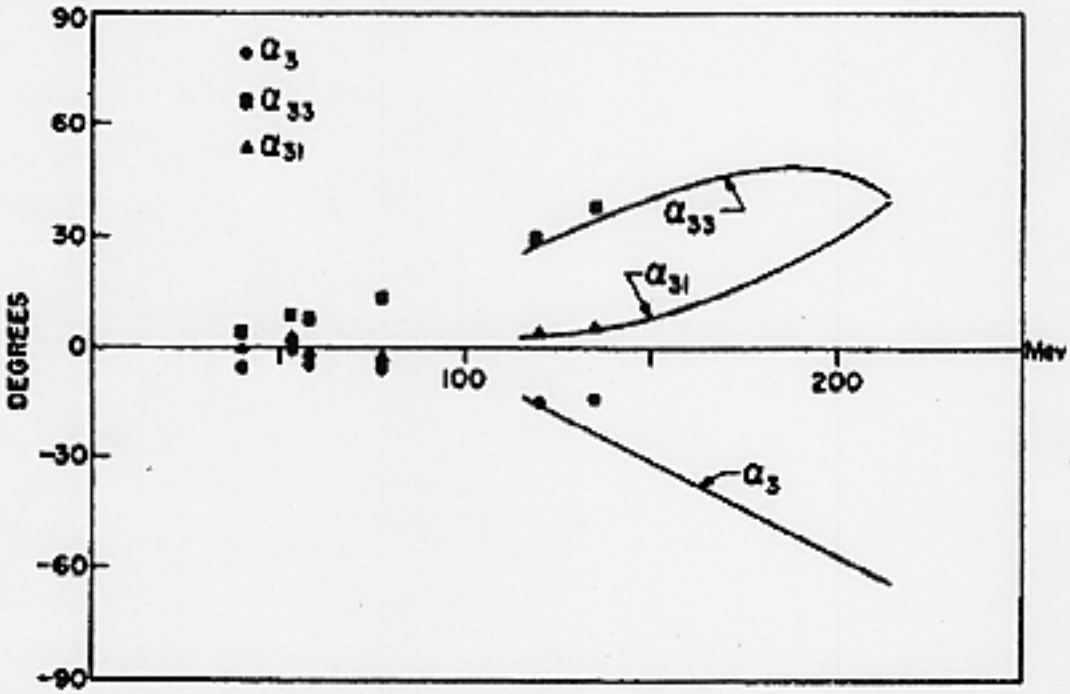


FIG. 1. Phase shifts of the states of isotopic spin $\frac{3}{2}$ plotted *versus* the energy of the primary pion for solution 1. For comparison, values of the same phase shifts at lower energies are also plotted.

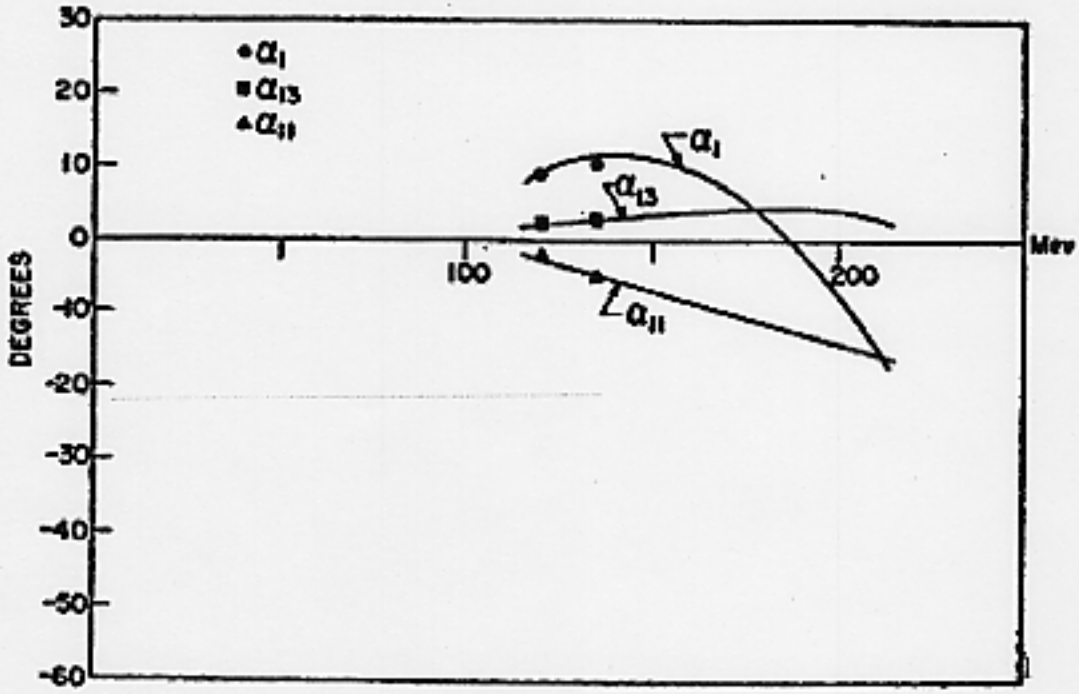


FIG. 2. Phase shifts of the states of isotopic spin $\frac{1}{2}$ plotted *versus* the energy of the primary pion for solution 1. Values previously obtained at 120 and 135 Mev are also plotted.

Phase Shift Debate (1953)

Bethe: Field theory demands resonant state.

Fermi: Maybe so - but you can't ignore a phase shift solution that fits the data until you have other equally good solutions.

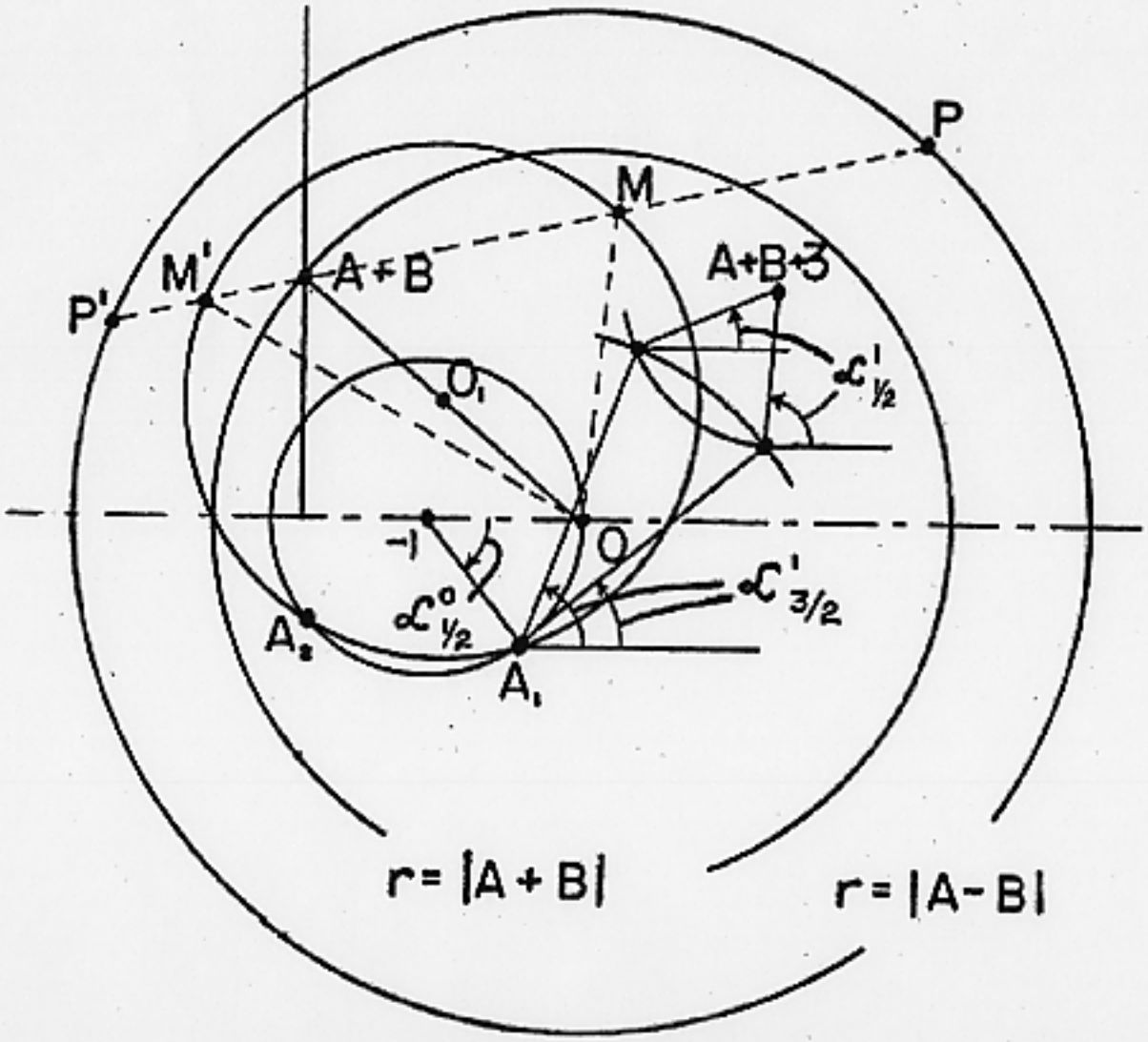


FIG. 1. Graph for Fermi's 135-Mev π^+ scattering.

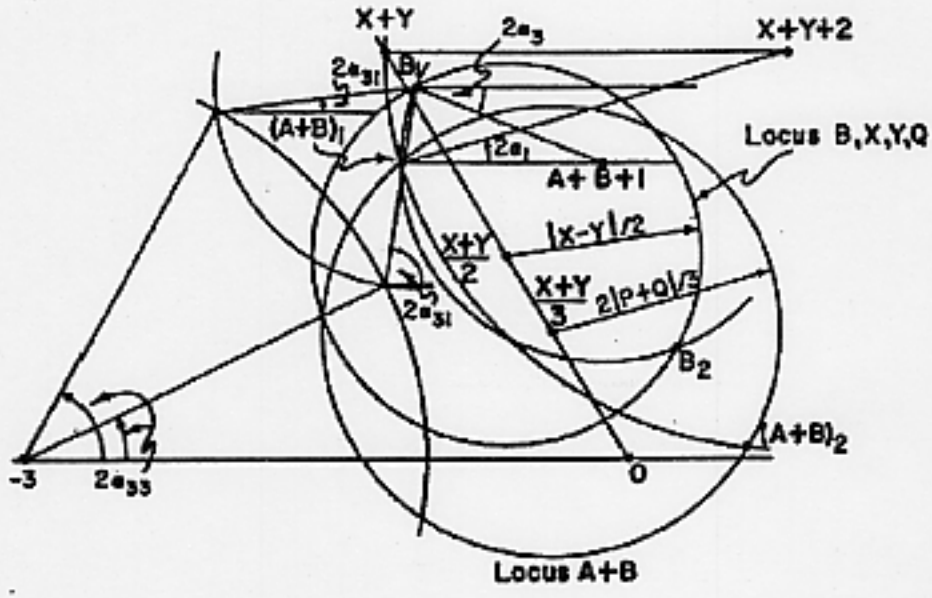


FIG. 1. Phase shift solution at 125 Mev by the goemetrical method of Ashkin and Vosko.

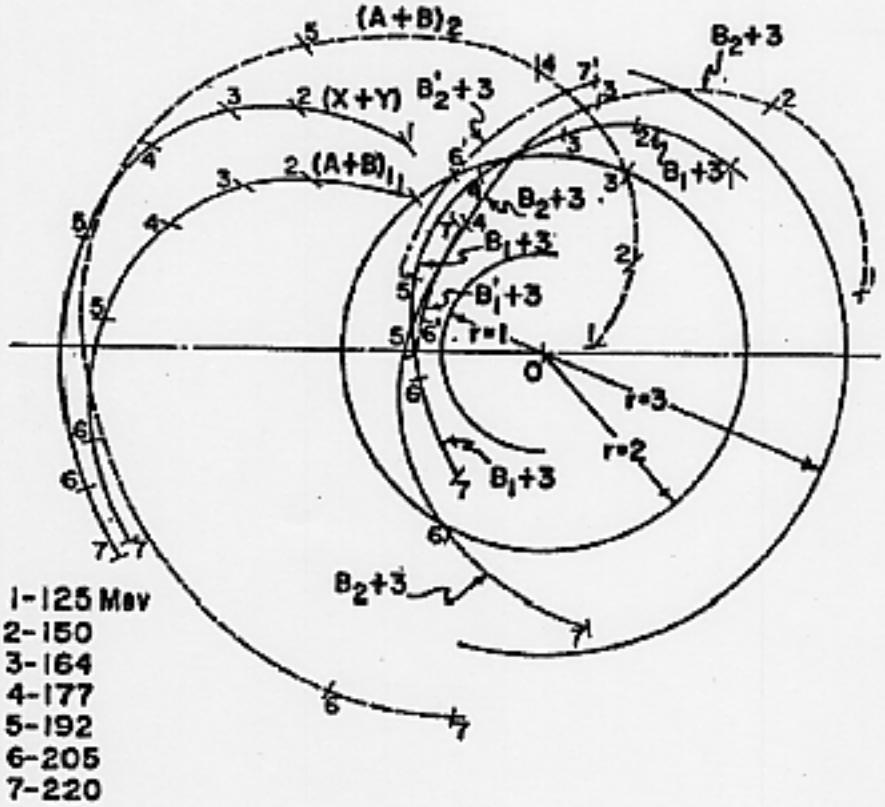


FIG. 2. Pertinent points of the geometrical solutions at different energies for an interpolation of the negative pion-proton scattering data.

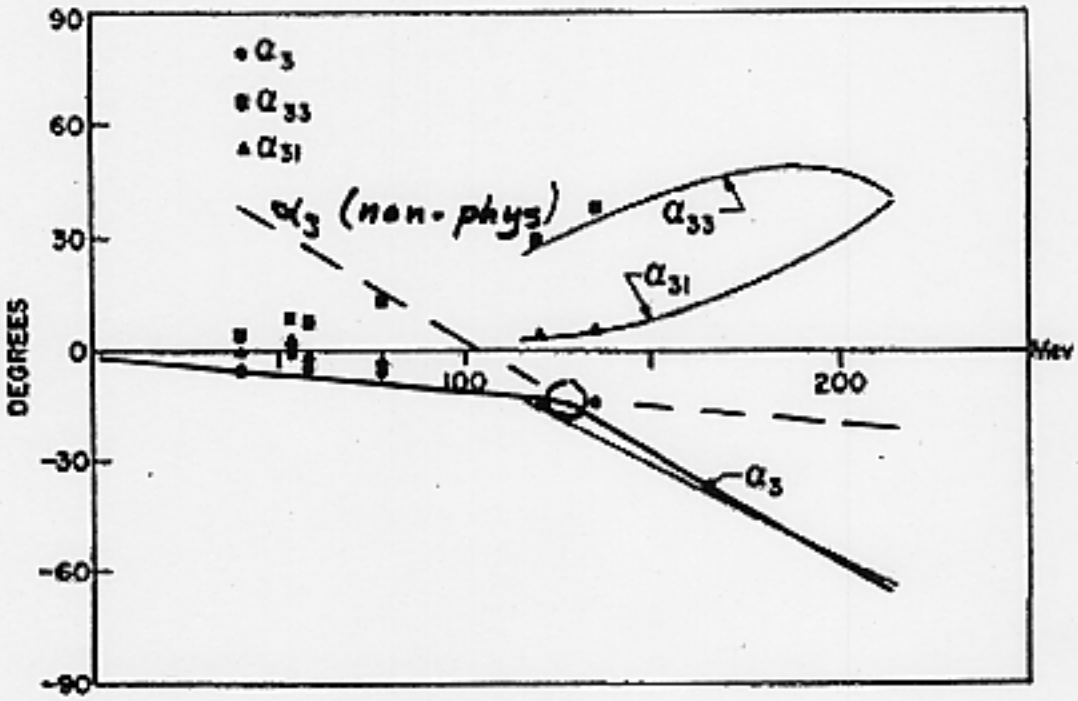


FIG. 1. Phase shifts of the states of isotopic spin $\frac{3}{2}$ plotted *versus* the energy of the primary pion for solution 1. For comparison, values of the same phase shifts at lower energies are also plotted.

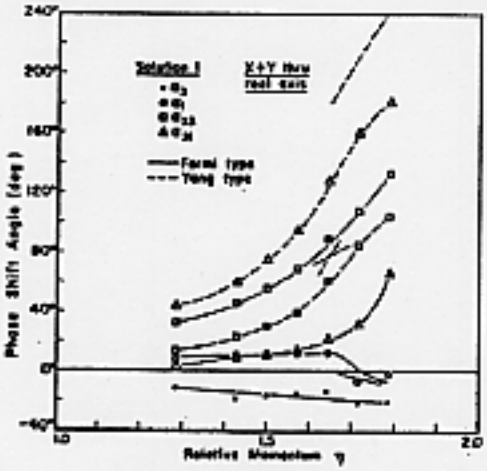


FIG. 5. Phase-shift solution 1.

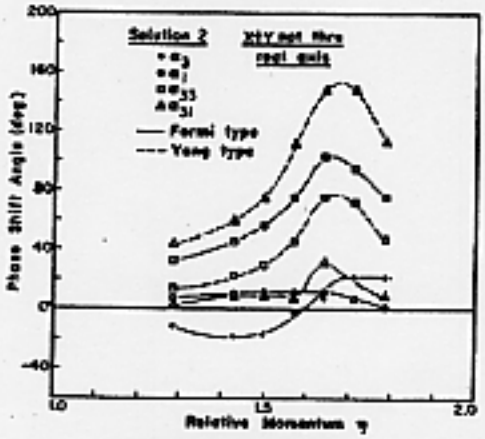


FIG. 6. Phase-shift solution 2.

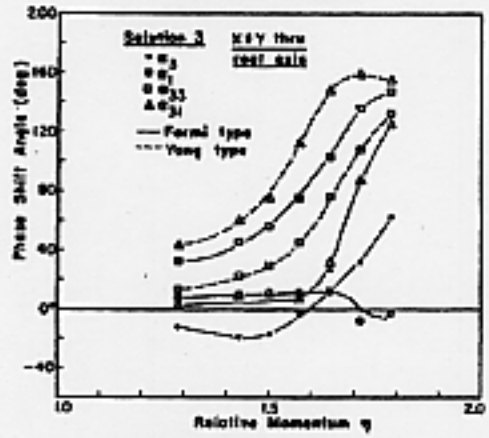


FIG. 7. Phase-shift solution 3.

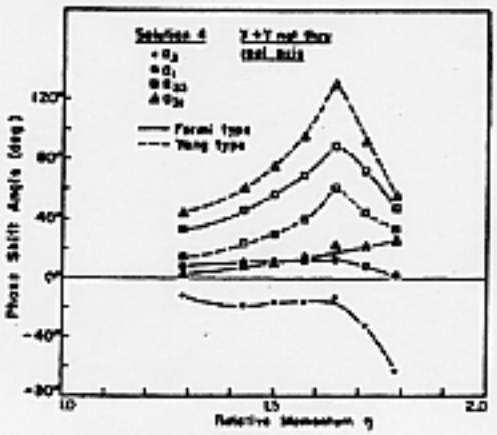


FIG. 8. Phase-shift solution 4.

- **Phase Shift Analysis of the Scattering of Negative Pions by Hydrogen**
  E. Fermi, N. Metropolis, and E. F. Alei
  pp. 1581-1585 [View Page Images or PDF (860 kB) [Order Document]]

- **Pion-Hydrogen Phase Shift Analysis between 120 and 317 Mev**
  F. d. Hoffmann, N. Metropolis, E. F. Alei, and H. A. Bethe
  pp. 1586-1605 [View Page Images or PDF (3591 kB) [Order Document]]

- **Phase-Shift Analysis of the Scattering of Negative Pions on Hydrogen**
  R. L. Martin
  pp. 1606-1611 [View Page Images or PDF (1002 kB) [Order Document]]

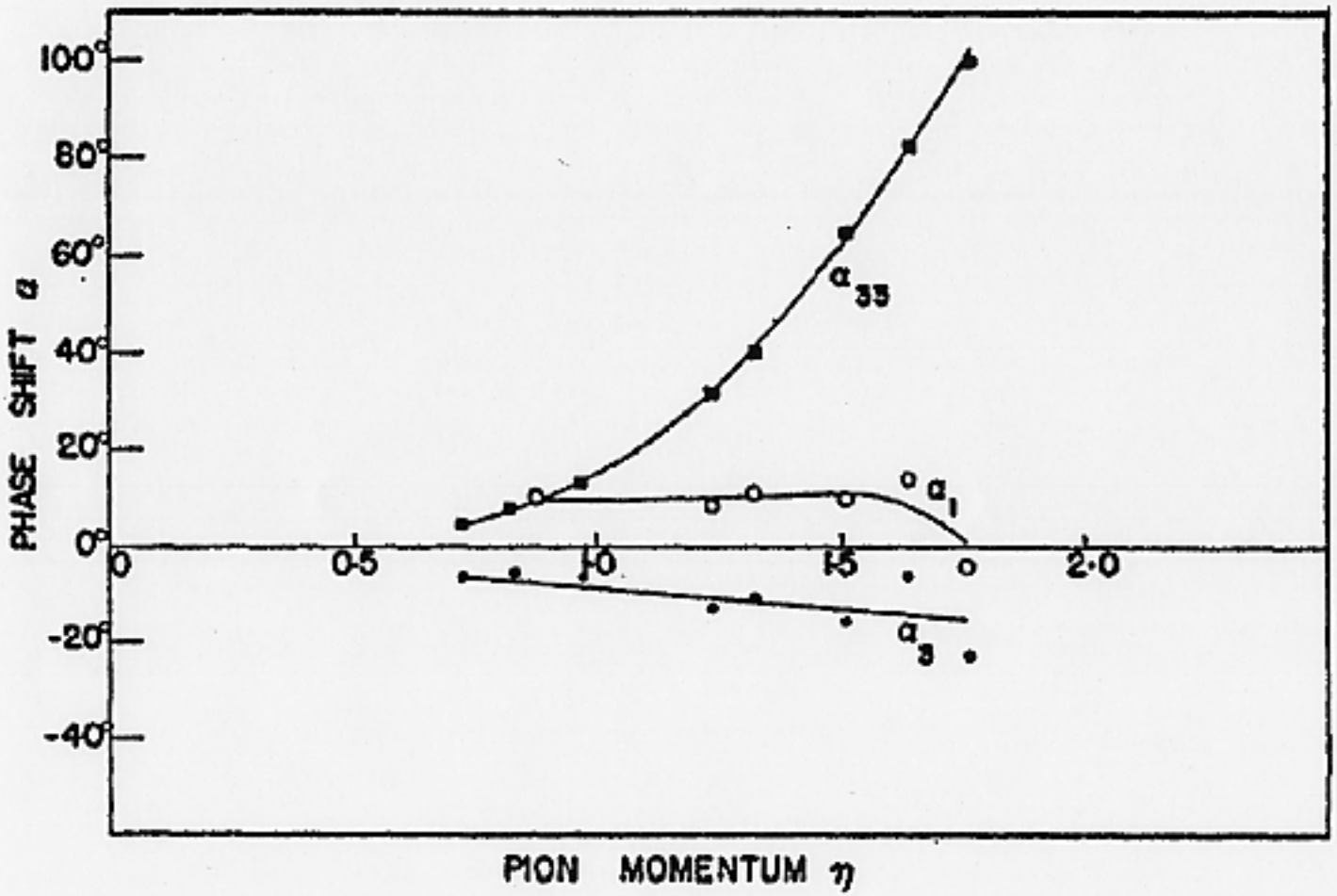


FIG. 6. A possible set of phase shifts obtained by setting $\alpha_{31}=\alpha_1=\alpha_{11}=0$, plotted *versus* pion momentum in the barycentric system. The values plotted for $\eta<1.0$ are the solutions of Bodansky Sachs, and Steinberger, references 4 and 26 (58 and 65 Mev) Orear, Lord, and Weaver [Phys. Rev. **93**, 575 (1954)] (45 Mev) and from AFMN, reference 5 (78 Mev).

Comparison of Phase Shifts for α_3 and α_{33} for selected solutions

E MeV →	120	144	169	194	217
α_3					
BD	-12°	-13°	-4°	-13°	-20°
MG	-13°	-12°	-15°	-12°	-23°
RM	-10°	-12°	-16°	-19°	-22°
α_{33}					
BD	30°	46°	64°	90°	107°
MG	32°	46°	65°	78°	100°
RM	28°	40°	56°	88°	120°

a) BD is Bethe-de Hoffmann, Track 1

b) MG is Glicksman

c) RM is Martin, solution 1, Fermi type

Phase Shift Debate (1953)

Bethe: Field theory demands resonant state.

Fermi: Maybe so - but you can't ignore a phase shift solution that fits the data until you have other equally good solutions.

Martin: $(\alpha_{13} = \alpha_{11} = 0)$ Many solutions, several of them representing resonant states.

Glicksman: $(\alpha_{31} = \alpha_{13} = \alpha_{11} = 0)$ Perfectly good resonant solution.

Bethe, de Hoffmann: Many solutions with all six S and P phase shifts, choice on physics grounds appears resonant.