UCRL-9279 Rev.

UNIVERSITY OF CALIFORNIA

Ernest O. Lawrence

Radiation Laboratory

BERKELEY, CALIFORNIA

For Publication in Physical Review Letters UCRL-9279 Rev.

UNIVERSITY OF CALIFORNIA
Lawrence Radiation Laboratory
Berkeley, California

Contract No. W-7405-eng-48

PHOTOPRODUCTION OF CHARGED MESONS FROM DEUTERIUM AND THE π^-/π^+ RATIO

William P. Swanson, Duane C. Gates, Thomas L. Jenkins, and Robert W. Kenney

September 1, 1960

PHOTOPRODUCTION OF CHARGED MESONS FROM DEUTERIUM AND THE π^-/π^+ RATIO

William P. Swanson, Duane C. Gates, Thomas L. Jenkins, and Robert W. Kenney

Lawrence Radiation Laboratory
University of California
Berkeley, California

September 1, 1960

We have used a 4-in.-diameter deuterium bubble chamber at the Lawrence Radiation Laboratory electron synchrotron to observe the reactions

$$\gamma + d \rightarrow \pi^- + 2p \qquad (1)$$

and

$$\gamma + d \rightarrow \pi^+ + 2n \text{ (followed by } \pi^+ \rightarrow \mu^+ + \nu) \qquad (2)$$

in the interval between threshold and 194 Mev photon energy (lab).[1] In Reaction (1), sufficient final-state information was obtained to determine the kinematical parameters required to calculate the final-state Coulomb effects. By correcting the observed ratio $R_d = (\sigma_{\gamma d \rightarrow \pi^-}) / (\sigma_{\gamma d \rightarrow \pi^+})$ to account for the final-state Coulomb interactions, we obtained values of the ratio $R = (\sigma_{\gamma n \rightarrow \pi^-}) / (\sigma_{\gamma p \rightarrow \pi^+})$, (see Table I) which involves the reaction of principal interest:

$$\gamma + n \rightarrow \pi^- + p . \qquad (3)$$

Very basic theoretical assumptions[2] lead to the conclusion that R is 1.28 at threshold, independent of the details of the meson-nucleon interaction, if nucleon recoil is included and final-state Coulomb effects are excluded. Ball[3] has recently estimated $R = 1.28\,(1 - 0.14\,\Lambda)$, where Λ is a parameter, measured in units of $e = 1/\sqrt{137}$, arising from the photon—

three-pion interaction. Low-energy positive and neutral photopion production and neutral pion decay data are not inconsistent with a value of Λ as large as unity, but small values for Λ are not excluded. Our data are consistent with a value $\Lambda = +1.1$.

The question of general agreement among several measured threshold pion parameters[4,5,6] requires knowledge of R, and a value near that predicted is required for agreement. Several groups[7,8,9] have investigated Reactions (1) and (2) near threshold, and have determined that the ratio R_d lies in the range 1.3 to 2.1, before Coulomb corrections are made. However, their knowledge of the final-state parameters was generally insufficient to allow a detailed correction.

Baldin[4] has employed the impulse approximation to calculate the corrections needed to account for the Coulomb interactions between all final-state particles in Reaction (1); no correction is necessary in Reaction (2). We have uniquely determined the kinematical parameters required for the Baldin corrections in the energy range $152 \lesssim k \lesssim 175$ Mev.

The experimental arrangement is shown in Fig. 1.[10] In an auxiliary experiment, a pair spectrometer was used to determine both the peak energy and the spectrum of the hardened bremsstrahlung beam incident on the bubble chamber. All together, 1,300 analyzable π^- events and 450 $\pi^+ \rightarrow \mu^+$ events were found. After the multipronged events were located, each was measured and the angles and lengths of the tracks were calculated. By means of energy-momentum conservation laws we were able to determine completely any π^- event in which three prongs were visible and those events in which only two prongs were visible but both prongs stopped in the chamber. The background of single-prong heavy-particle events was about one per picture. The occasional scattering of a photoproton by a deuteron was distinguished from Reaction (1) on the basis of kinematics, ionization, or location of the vertex.

Reaction (2) was identified by the characteristic range of the muon (1.004 ± 0.053 cm in the bubble chamber), and in 27% of the cases by the electron decay of the muon as well. Because of the requirement for identification of the π^+, the π^+ and π^- energies accepted for the calculation of R were limited to energies (lab) of 3 to 9 Mev. A total of 299 π^+ (out of 450 observed) and 369 π^- events satisfying all criteria was found within these energy limits. Corrections were made for the efficiency of observing the events by means of a Monte Carlo calculation on an IBM 704. An additional 9.5% correction was applied to the π^- data to account for scanning efficiency and for events missed because both recoil protons were invisibly short or too short to be measured satisfactorily. For consistency in the evaluation of the ratio R_d, two-body kinematics were used to determine k in both reactions, because they were necessary in Reaction (2).

Using the impulse approximation, Baldin[4] has calculated the spin-flip part of the cross section for π^- production from deuterium as

$$\frac{\partial^2\sigma}{\partial p \partial q} = A(p, q) \; |K^{(-)}|^2 ,$$

where the final-state Coulomb interactions are ignored in obtaining the values for A(p, q). Near threshold, the no-spin-flip term is negligible. The quantities p and q are, respectively, half the vector difference and the vector mean of the momenta (lab) of the recoiling nucleons, and $|K^{(-)}|^2$ is the square of the matrix element for Reaction (3). By using exact Coulomb wave functions, values of $A^c(p, q)$ are also obtained to replace A(p, q) when p-p final-state Coulomb effects are included. From Baldin's tabulated values we have applied a correction by weighting each event by the ratio $A(p, q) / A^c (p, q)$. The average value of the correction is $+5.49\%$.

The π-p final-state Coulomb correction (average value = - 14.6%) was estimated for each pion momentum (lab) $\vec{p}_\pi$ by dividing the number of events of pion momentum $\vec{p}_\pi$ by Baldin's expression

$$1 + \frac{2\pi e^2}{|\vec{p}_\pi - \vec{q}/M|} \quad .$$

This correction is roughly independent of photon energy, for a given pion momentum and direction. After both the p-p and π-p corrections were made, the combined average Coulomb correction was -8.6% .

Before Coulomb correction, the average ratio was $R_d = 1.38 \pm 0.12$; after Coulomb corrections, the average ratio was $R = 1.27 \pm 0.11$.

The pions included had an average kinetic energy (lab) of 6.15 Mev and angle 90 deg, corresponding to the photon energy (lab) of 162 Mev and c.m. pion angle 120 deg, in the two-body $(\gamma + p \rightarrow \pi^+ + n)$ center of mass. However, these spectator photon energies range from 152 Mev at forward pion angles to 175 Mev in the backward direction.

The data, broken down into three bins roughly according to spectator photon energy, are presented in Table I. The points show the expected increasing trend with photon lab energy and pion c.m. angle. After Coulomb correction, the two points at higher energy are in agreement, within statistics, with the dispersion relations and with previous experiments in this range corrected for final-state Coulomb interactions. The point at lowest energy is below the theoretical value by two standard deviations. This may reflect the influence of the parameter Λ. If so, this value of R corresponds to a value $\Lambda = +1.1$.

A typical distribution of photon energies contributing to the bins of Table I is presented in Fig. 2. As may be seen, the distribution is peaked at its spectator energy, but also has a high-energy tail which makes an important contribution. The distribution is in qualitative agreement with calculations made by Beneventano et al.,[9] and justifies the use of two-body kinematics in determining the photon energy for ratios determined in this manner.

The guidance and support of Prof. A.C. Helmholz throughout this work is gratefully acknowledged; as is the collaboration of Drs. J.D. Anderson and C.A. McDonald in early phases of the experimental work. The authors express their appreciation to Prof. L.W. Alvarez and his group for the use of the bubble chamber and extend their thanks to Mr. Rudin M. Johnson and the synchrotron crew. Many stimulating discussions were held with Prof. G.F. Chew and Dr. M.J. Moravcsik.

Table I.

σ^-/σ^+ as a function of photon energy and meson angle

Bins	Spectator photon energy (Mev)[a]	θ^* pion c.m. angle, (deg)	σ^-/σ^+ Before (R_d) Coulomb correction	After (R) Coulomb correction
I	152-158	0-90	1.22 ± 0.16	1.08 ± 0.14
II	158-165	90-140	1.36 ± 0.19	1.27 ± 0.18
III	165-175	135-180	1.54 ± 0.21	1.44 ± 0.20

[a]The spectator photon energy (lab) and pion angle θ^* (lab) are from ($\gamma + p \rightarrow \pi^+ + n$) two-body kinematics.

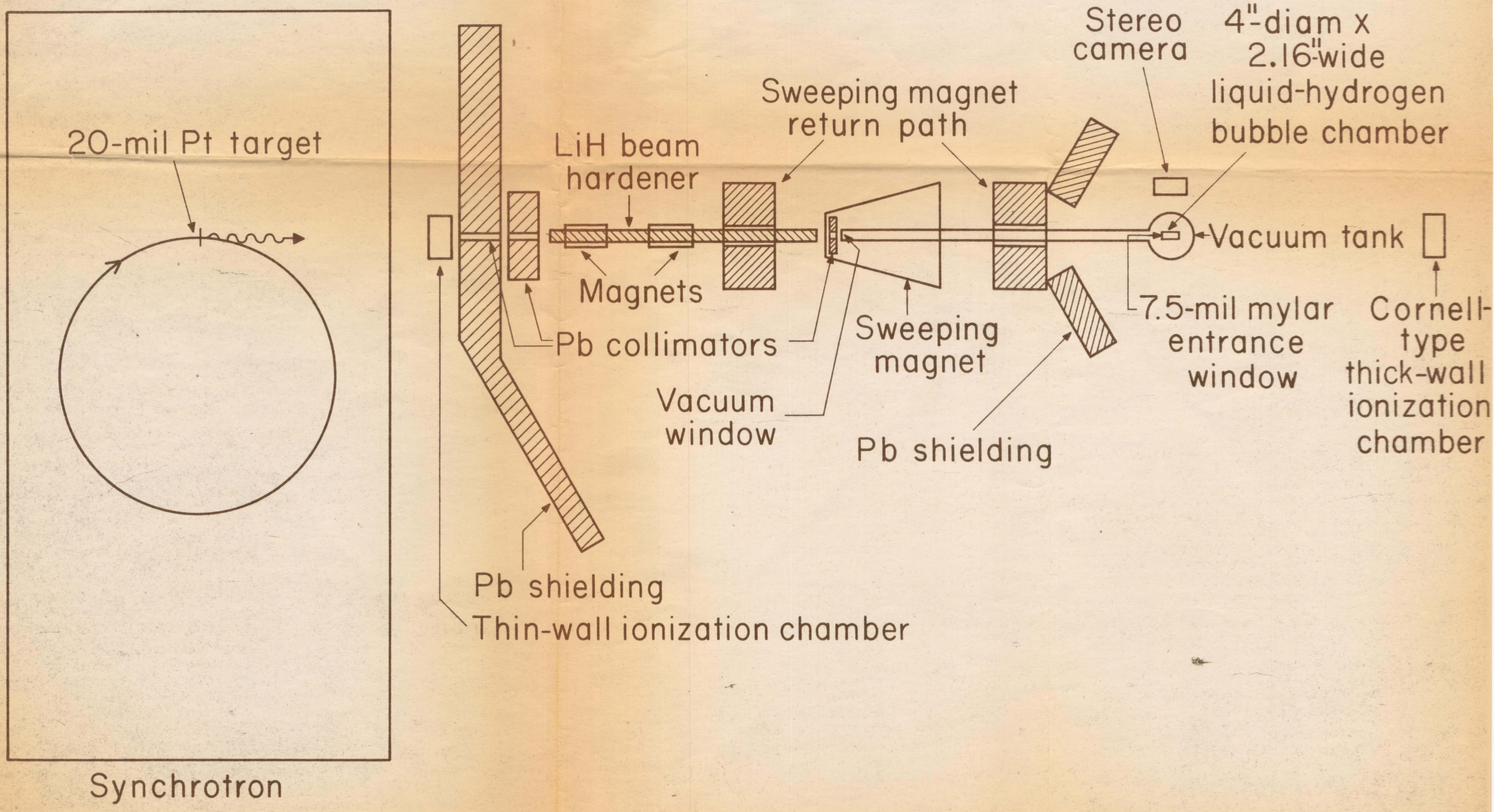
REFERENCES

1. William P. Swanson, John D. Anderson, Duane C. Gates, Thomas L. Jenkins, and Robert W. Kenney, Bull. Am. Phys. Soc., Ser. II, 5, 237 (1960).
2. G.F. Chew, M.L. Goldberger, F.E. Low, and Y. Nambu, Phys. Rev. 106, 1345 (1957).
3. James S. Ball, "The Application of the Mandelstam Representation to Photoproduction of Pions from Nucleons," UCRL-9172, April 1960.
4. A. Baldin, Nuovo cimento 8, 569 (1958).
5. M. Cini, R. Gatto, E. L. Goldwasser, and M. Ruderman, Nuovo cimento 10 1, 243 (1958).
6. J. Hamilton and W.S. Woolcock, Phys. Rev. 118, 291 (1960).
7. Dorothy Carlson-Lee, Bull. Am. Phys. Soc., Ser II, 3, 334 (1958).
8. W.R. Hogg and E.H. Bellamy, Proc. Phys. Soc. 72, 895 (1958).
9. M. Beneventano, G. Bernardini, G. Stoppini, and L. Tau, Nuovo cimento 10, 1109 (1958).
10. Duane C. Gates, Robert W. Kenney, Donald A. McPherson, and William P. Swanson, "Operation of Hydrogen Bubble Chambers in High-Energy Photon Beams," Rev. Sci. Instr. 31, 565 (1960).

FIGURE LEGENDS

Fig. 1. Schematic diagram of setup.

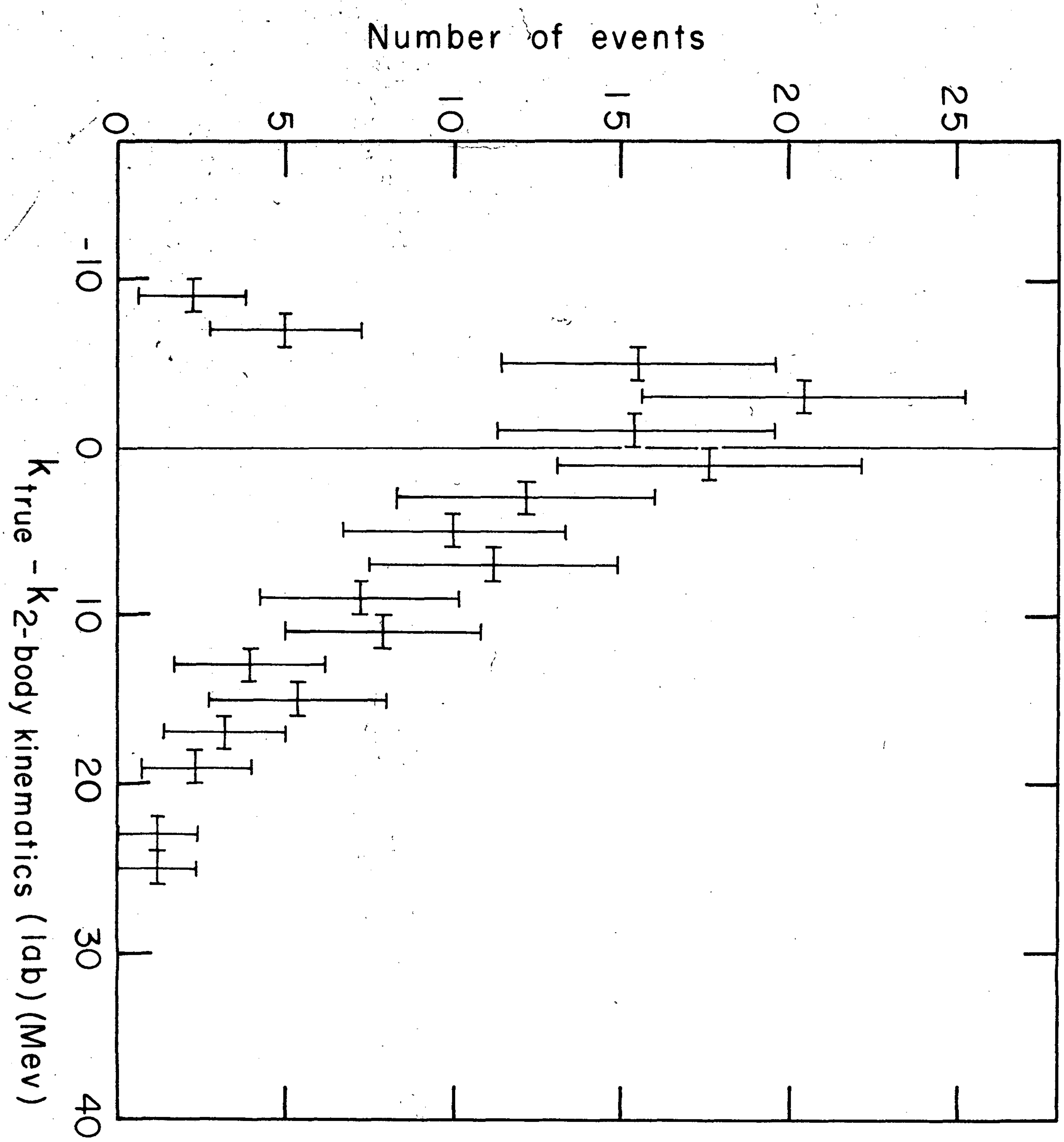
Fig. 2. Laboratory-system photon energy distribution for the negative photopion events of Bin II, Table I. The abscissa is obtained by subtracting the spectator photon energy (obtained from two-body kinematics) from the true photon energy for each event. The two-body kinematics gave a lab photon energy in the range 158 to 165 Mev and a c.m. pion angle $\theta^* = 90$ to 140 deg for events in this bin.



20-mil Pt target
Synchrotron
Pb shielding
Thin-wall ionization chamber
Pb collimators
LiH beam hardener
Magnets
Sweeping magnet return path
Vacuum window
Sweeping magnet
Pb shielding
Stereo camera
4"-diam x 2.16"-wide liquid-hydrogen bubble chamber
Vacuum tank
7.5-mil mylar entrance window
Cornell-type thick-wall ionization chamber

Fig. 1

58155-3



Number of events
0
5
10
15
20
25
-10
0
10
20
30
40
$k_{true} - k_{2\text{-body kinematics}}$ (lab) (Mev)