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ELECTRON TRIPLET PRODUCTION IN HYDROGEN

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INTRODUCTION

In 1933, Perrin[1] suggested that an electron pair can be formed in the Coulomb field of an electron by a photon whose energy is greater than 4 mc^2. The final state is a "triplet" of electrons; the momentum taken up by the parent electron in the production process allows it to be observed under suitable conditions. The parent electron is defined as the recoil electron, i. e., the less energetic of the negatrons. This electromagnetic process, similar to electron-pair production in the nuclear Coulomb field, has been studied by several observers,[2] and the experiment reported here extends these measurements to the highest available energy from the 340-Mev Berkeley synchrotron.

The total cross section for triplet production has been calculated in various approximations by Wheeler and Lamb[3], Watson[4], Borsellino[5], Nemirovsky[6], and Votruba[7]. Joseph and Rohrlich[8] have reviewed the present state of the theory and have included an extensive bibliography. There are no available calculations of either the momentum (for $P_R > mc$) or angular distributions of the recoil electron. However, Jost, Luttinger, and Slotnick[9] have worked out similar distributions for the recoiling proton in the case of ordinary electron-pair production in hydrogen. Our recoil distributions are in qualitative agreement with this work and our total cross-section data are consistent with the calculations of Watson.[4]

EXPERIMENTAL ARRANGEMENT

The experimental arrangement is shown in Fig. 1. A 4-inch hydrogen bubble chamber was situated in the synchrotron bremsstrahlung beam. The beam was collimated to 1/8 inch diameter 57 inches from the 20-mil Pt internal target and then passed through a 6-foot LiH beam hardener. The function of the LiH was to absorb selectively the very-low-energy photons in the bremsstrahlung spectrum and therefore to reduce the number of background Compton recoils in the bubble chamber. The photon beam was then recollimated, cleared of charged particles by a 10-kilogauss magnetic field, and finally passed into the bubble chamber through a 7.5-mil mylar window. A 10-kilogauss pulsed magnetic field was applied to the bubble chamber by Helmholtz coils, which were placed directly outside the chamber volume and were powered by a condenser bank and thyratron switching circuit.

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ANALYSIS OF DATA

Preliminary scanning of the film was done on a stereoscopic viewer. Frames that contained excessive background or were otherwise obscured were omitted from the analysis. By reconstruction of the geometry of the events from stereoscopic photographs, the angles of the triplet fragments were determined and their momenta found from their ranges or curvatures in the magnetic field. Recoil electrons with momenta greater than about 0.1 Mev/c left detectable tracks in the bubble chamber. A total of 1105 triplets and 177 pairs was analyzed. Measurements are being continued on the pair events.

The photon spectrum incident on the bubble chamber was calculated by using the Bethe-Heitler bremsstrahlung spectrum for lead,[10] corrected for absorption of the beam due to pair and triplet production and the Compton and photoelectric effects in the LiH beam hardener.

RESULTS AND DISCUSSION

Figure 2 shows the ratio ϕ_t (apparent)/ϕ_p (apparent) for various photon energy intervals, where ϕ_t (apparent) and ϕ_p (apparent) are the cross sections for events identified as triplets, and for events which appear to be pairs, respectively. Therefore ϕ_p (apparent) accounts for all real pairs as well as for those triplets which are indistinguishable from pairs in this experiment. It is seen that the relative number of triplets with visible recoil momenta decreases with increasing photon energy. This is in qualitative agreement with the results of Jost, Luttinger, and Slotnick[9] for recoiling protons. Also shown is Watson's curve of $(\phi_t(k)/\phi_p(k))$ vs k, where $\phi_t(k)$ and $\phi_p(k)$ are the true unscreened triplet and pair cross sections, respectively.[4] A comparison gives an approximate indication of the detection efficiency of the bubble chamber.

The preliminary values for $(\phi_t + \phi_p)$ and ϕ_t (apparent) were normalized by assuming the values for $(\phi_t + \phi_p)$ at low energy (below 150 Mev) to have the same k-dependence as twice the Bethe-Heitler unscreened pair-production cross section.[11] The constant term in the Bethe-Heitler formula was adjusted to fit the experimental point for $(\phi_t + \phi_p)$ of Anderson et al. at 319 Mev,[12] after this value had been corrected to give the unscreened cross section. Experimental values for ϕ_t were then obtained by subtracting the Bethe-Heitler unscreened pair cross section[11] from the normalized values of $(\phi_t + \phi_p)$. The uncertainties shown in Fig. 3 are standard statistical counting errors due principally to the small statistical sample of electron pairs used, and include neither the uncertainty in the photon spectrum nor the error in normalization.

At this stage of the experiment, the data are in satisfactory agreement with the unscreened triplet calculations of Watson.[4] Additional scanning for electron pairs is in progress in order to reduce the over-all uncertainty in the measured total triplet cross section. Further running with the bubble chamber will be undertaken in order to decrease the statistical errors. An improved photon-monitoring system will be employed which will remove the dependence of the absolute values of the cross sections upon subsidiary experimental values for $\phi_t(k) + \phi_p(k)$. In order to check the proposed monitoring system, plans have been made to measure the total absorption of high-energy photons in a long liquid hydrogen target by a transmission-type experiment. By subtraction of the Klein-Nishina[13] and photomeson[14] cross sections from the transmission cross section, a value for $\phi_t(k) + \phi_p(k)$ will be obtained for comparison.

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Distributions in momentum and angle of the recoil electron are shown in Figs. 4 and 5. There is no theory predicting these electron distributions for the momentum range of this experiment, but the data are in qualitative agreement with the Jost, Luttinger, and Slotnick distributions for proton recoil in ordinary pair production in hydrogen.[9] The relative shapes of both curves are insensitive to photon energy so that in both cases data for all photon energies have been included on one curve. In the region above $P_R = 0.5$ Mev/c, the differential cross section is proportional to $P_R^{-1.76 \pm 0.20}$, where P_R is the recoil electron momentum. The differential cross section in Fig. 5 passes through a maximum near 55° and falls to a small value at 90°. The recoil angle θ_R kinematically cannot be larger than $\pi/2$ and the events with larger angles are probably due to scattering of the recoil electron very close to the origin of the triplet event.

ACKNOWLEDGMENTS

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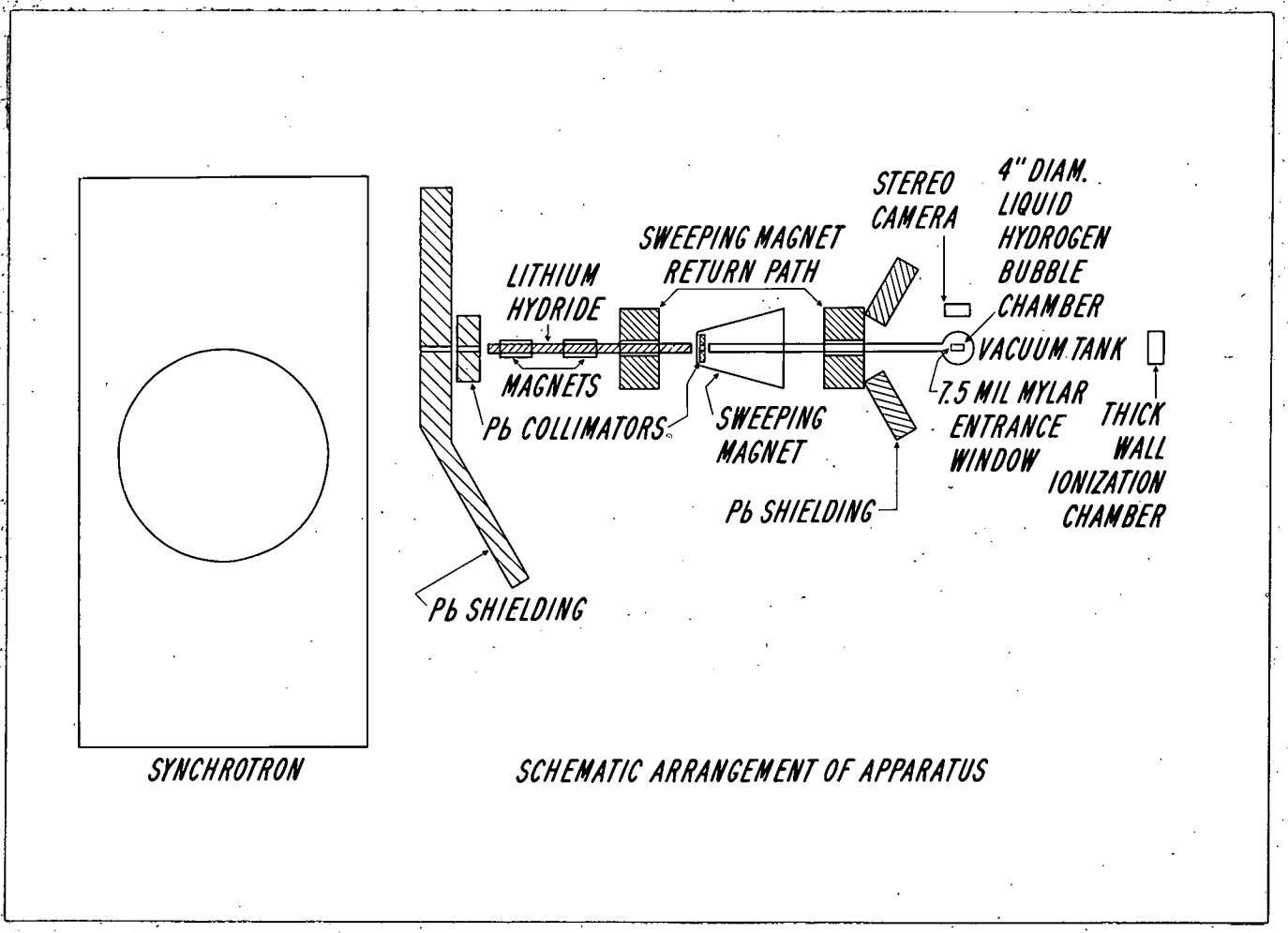


Fig. 1. Experimental arrangement.

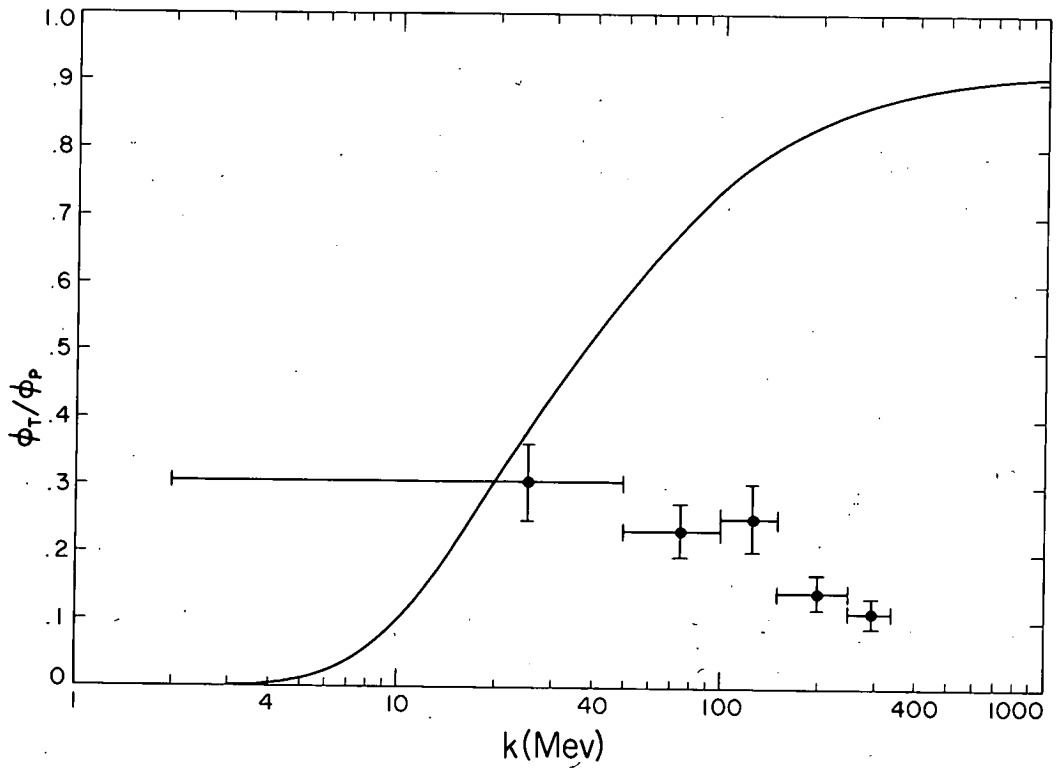


Fig. 2. Apparent triplet-to-pair ratio vs photon energy. The theoretical curve is that by Watson.[4] The experimental points depart markedly from theory because triplet events with too short a recoil to be seen occur more frequently with increasing photon energy.

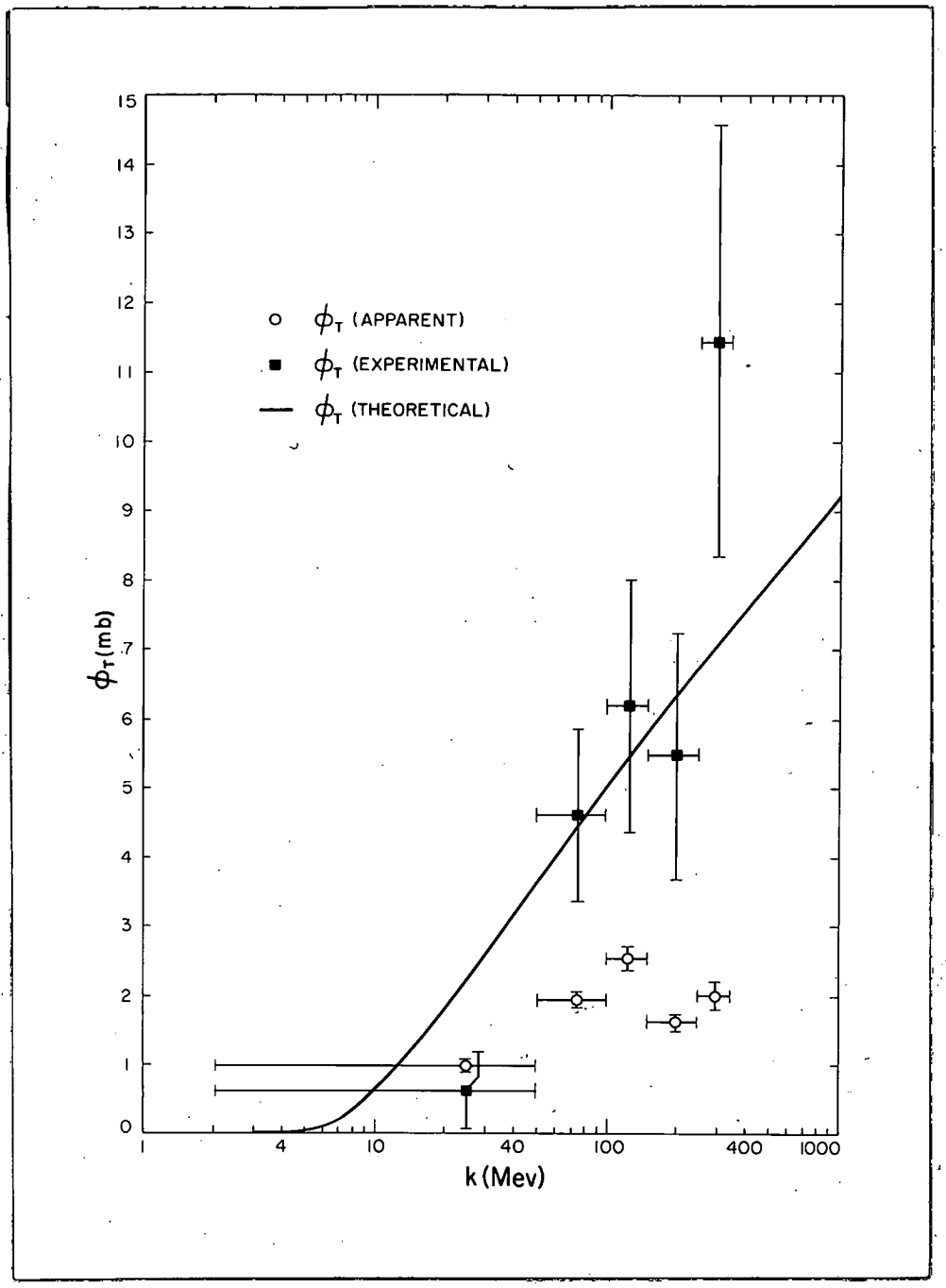
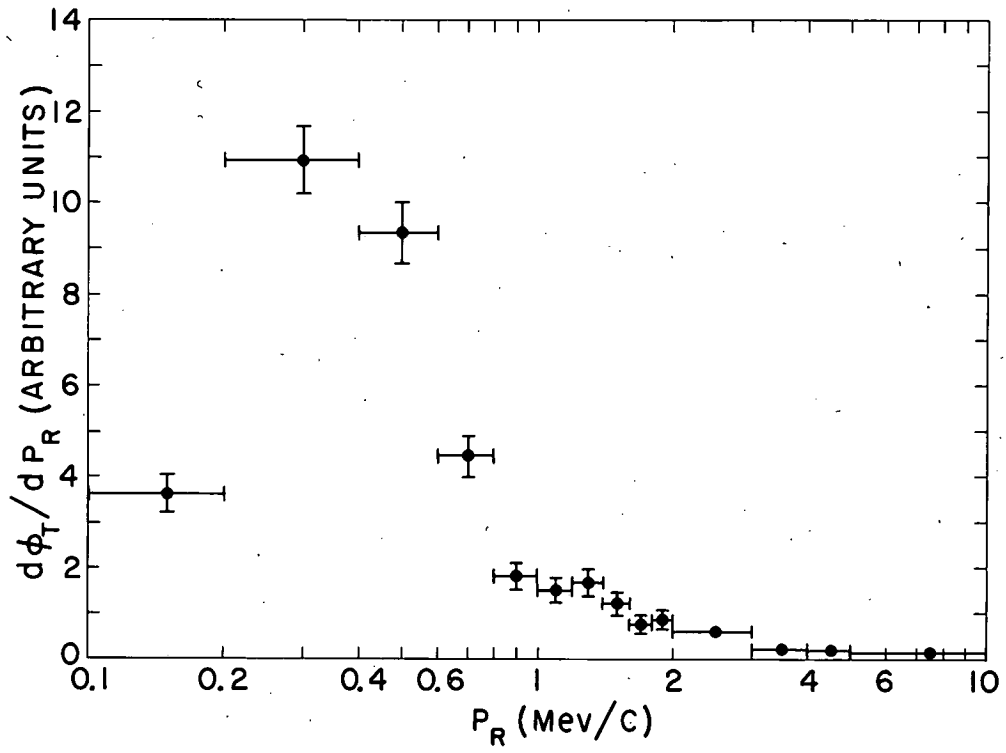


Fig. 3. Triplet-production cross section ϕ_t as a function of photon energy k. The apparent cross section is only for events with recoils of sufficient energy to be seen in the bubble chamber. The experimental cross section is the measured total cross section for pair and triplet production with the theoretical Bethe-Heitler[11] unscreened pair production cross section subtracted. The theoretical curve is Watson's curve[4] for $\phi_t(k)/\phi_p(k)$ multiplied by the theoretical Bethe-Heitler[11] unscreened pair production cross section.

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Fig. 4. Momentum distribution of the recoil electron for $20 < k < 340$ Mev. The recoil electron is defined to be the negatron of smaller momentum.

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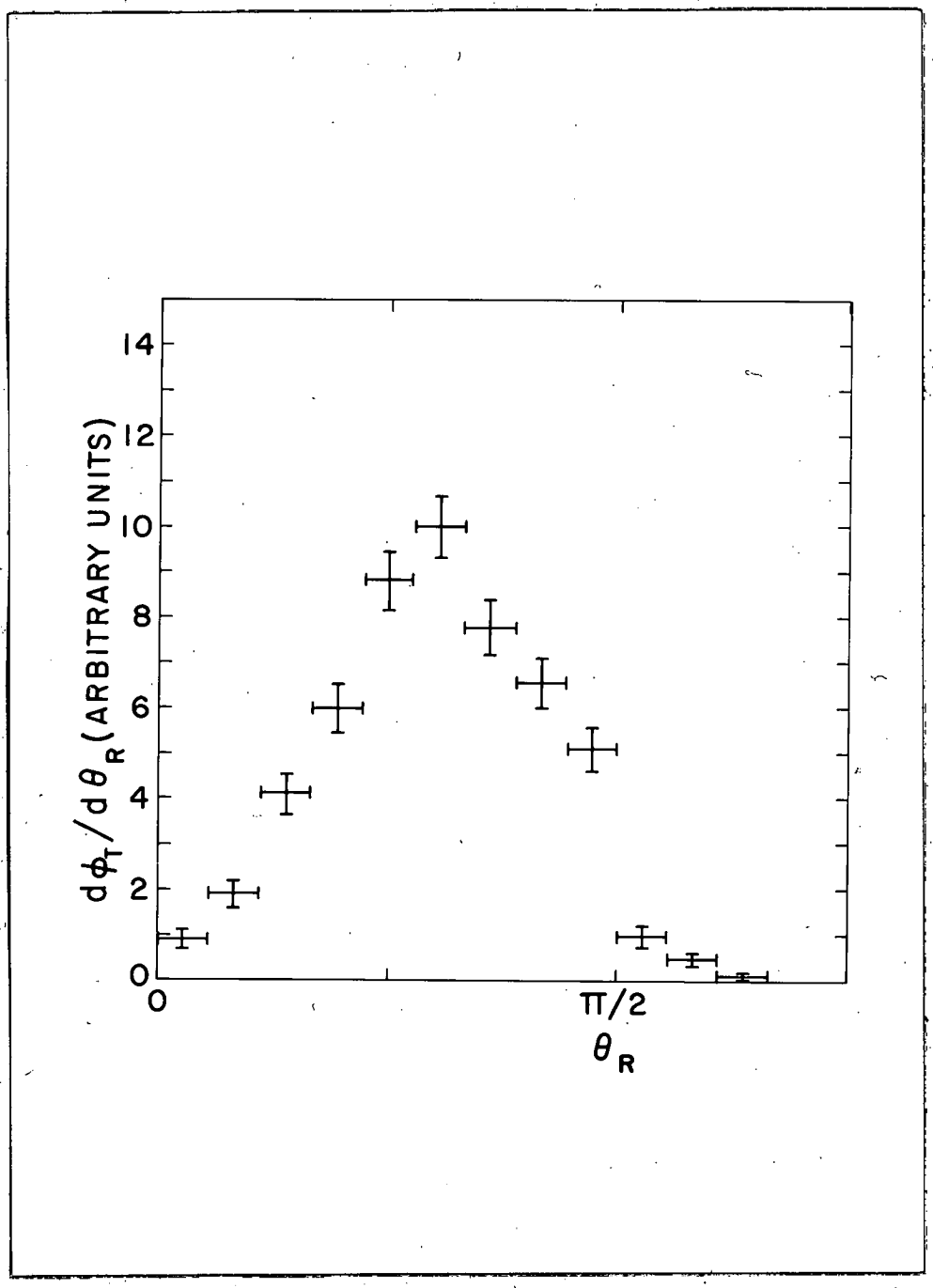


Fig. 5. Distribution in angle of the recoil electron for all events. Events with $\theta_R > \pi/2$ are due to scatterings too near the origin to be observed.

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