MEASUREMENT OF THE POLARIZATION OF RECOIL PROTONS FROM e-p SCATTERING AT 950 MeV

J. C. Bizot, J. M. Buon, J. Lefrançois, J. Perez y Jorba, and Ph. Roy
Laboratoire de l'Accélérateur Linéaire, École Normale Supérieure, Orsay (Seine et Oise), France
(Received 7 October 1963)

It has been, for years, a common procedure to analyze e-p elastic scattering in terms of two form factors, according to the Rosenbluth formula.[1] So far, all the experiments performed have shown good agreement with this analysis.

Theoretically, the Rosenbluth formula has been established on the basis of the one-photon exchange hypothesis, but it has been shown by Gourdin and Martin[2] that a Rosenbluth shape for the cross sections is not a sufficient criterion to eliminate the possibility of many-photon exchange.

To investigate this point, it is, in principle, better to design experiments sensitive directly to the amplitude of the two-photon exchange term and not to an expression where the one-photon term dominates, as is the case for the usual scattering experiments. Already, there have been some preliminary measurements by Browman and Pine[3] of a possible difference between e^+p and e^-p scattering in the same conditions of energy and angle. This difference would be directly proportional to the real part of the amplitude of the two-photon exchange term if the two-photon diagram is the second dominant diagram in the process.

In the same way, polarization of the recoil proton is also a phenomenon which would reveal the existence of more than one-photon exchange in the elastic scattering. Here, the magnitude of the effect should be proportional to the imaginary part of the amplitude of the two-photon exchange term.

950-MeV electrons were scattered in a liquid hydrogen target, the useful length of which was 4 cm. The mean angle of the detected protons was 40.3° (~90° c.m.) corresponding to a transfer $q^2 = 16\ \mathrm{F}^{-2}$. The cross-sectional width of the proton source (2.8 cm) was defined by brass slits located at the target itself. The protons went through a brass slit 4 cm wide in the horizontal plane and two 20-cm diameter quadrupole lenses (Fig. 1) and were momentum analyzed by a 2.50-m uniform field magnet where they were bent through 42°. Multiple scattering was reduced by a helium bag.

The polarization of the protons was then analyzed by letting them scatter in a carbon block where they were slowed down from around 300 MeV to 170 MeV. The precision of the polarization measurement was then in a large part governed by the precision on the measurement of the scattering angle.

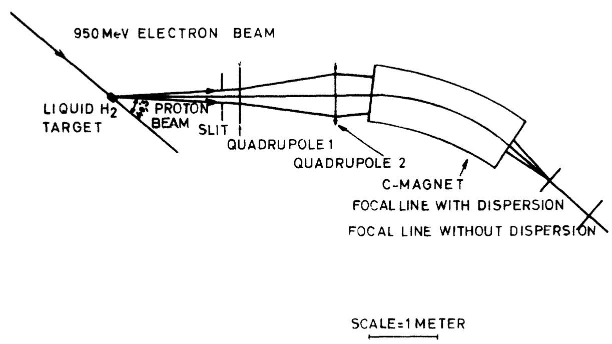

FIG. 1. Experimental setup: optics.

The directions of the incoming and of the outgoing proton were accurately determined by a set of four spark chambers (Fig. 2).

The first three chambers are identical. Each of them is a 6-gap chamber with aluminum plates 15 cm × 15 cm × 1 mm separated by 5-mm gaps. The fourth chamber is a 70-cm × 70-cm chamber with nine 1-cm gaps. The entrance plate is a 8-mm Cu plate, the other ones are either 3-mm Cu or 3-mm Al. The fourth chamber therefore allowed range measurements to be performed on the

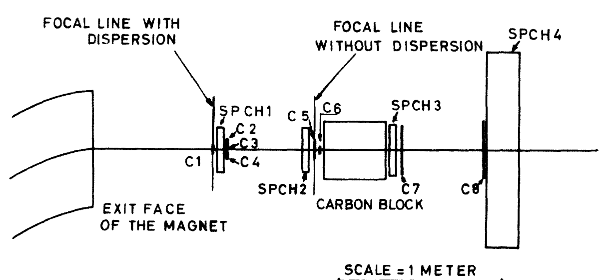

FIG. 2. Experimental setup: polarimeter. c = scintillators, SPCH = spark chambers.

scattered protons. The eight views (two for each chamber) were sent on the same picture of a camera by an assembly of 15 mirrors.

Besides the direction of the incoming proton, the first two chambers gave two important data. The second chamber was located at the focal line of the optics and therefore gave the energy of the proton. The first one was located at the focal line with dispersion, which allows for the fact that the energy of the proton varies with scattering angle. Therefore, one obtains on this line the same spectrum one would obtain on the usual focal line if there were no variation of proton energy with scattering angle or alternatively if one were using very narrow defining slits at the entrance of the first quadrupole. Another advantage of the system was that the magnification at this point was extremely small, ~0.10, a fact which again improved our resolution. So this was the line of best resolution, which was used to separate the elastic protons from the inelastic ones, as we will see. Then the proton entered a 20-cm long carbon block. The last two chambers gave the direction of the outgoing proton.

A system of scintillation counters was used to define the beam and trigger the chambers. $C1$ was a 2-cm wide scintillator located on the focal line with dispersion and meant to cut off the inelastic protons (Fig. 3). $C2$, $C3$, and $C4$ were three small scintillation counters 3 mm wide situated immediately behind $C1$. $C3$ corresponded to the top of the elastic peak, $C2$ and $C4$ to the slopes. Any shift in the beam was in this way immediately detected. $C6$ defined a 2.5-cm beam on the carbon block. $C8$ was an 18-cm diameter anticoincidence counter eliminating the direct and small scattering events. The sequence used to trigger the chambers was then $C1+C5+C6+C7-C8$.

As the ordinary elastic e^-p scattering experiments are very well analyzed with the one-photon terms only, one can think that the two-photon terms are not very important. This experiment was then meant to reveal rather small effects, that is, to obtain an over-all experimental error on the measured number as small as possible. It is thought that a final absolute error less than 2.5% will be obtained. Of these 2.5%, 1.5 to 2% will be statistics and one hopes to keep the accidental asymmetries under a 1.5% level. In order to do so, before and after each run, the chambers were aligned to 0.1 mm, temperature was controlled continuously during runs and corrections were applied. The spectra of pulses in scintillators were also constantly registered. The events were scanned by measuring the position of the trace as it intersected a given gap. This position scanning in the first two chambers and in the last two gave, respectively, the direction of the incoming and outgoing trajectories. At the same time, but only as a check, the angle of the trace in the chamber was recorded.

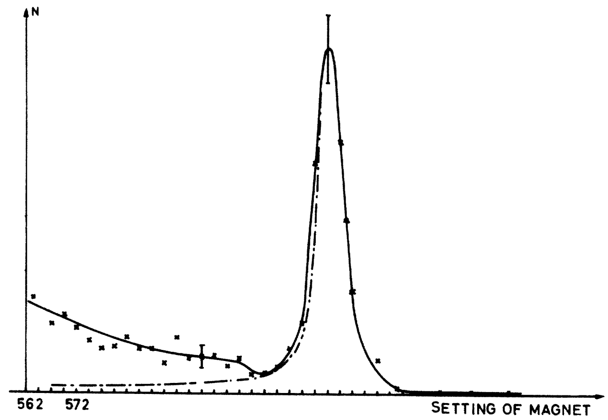

FIG. 3. Spectrum of protons in a small scintillator counter. The solid curve represents the experimental data. The dash-dot curve represents the calculated radiative tail.

The events were detected at any azimuthal angle φ, and the data were put in an IBM 650 where they were analyzed through a maximum likelihood method. Several restrictions and tests were included in the program in order to avoid creating accidental asymmetries.

(1) Accidental asymmetries could be generated if, to a detected event, that is an event outside the anticoincidence, one may associate events with the same incident trace, scattering point, and scattering polar angle θ, but different scattering azimuthal angle φ which fall into the anticoincidence. In this case, the program assigns to the detected event a weight taking into account only the detectable events in this situation. That is called a cone test.

(2) In the same way, there are detected events giving a coincidence in $C7$ but such that associated events with the same incident trace, scattering point, scattering polar angle θ, but different scattering azimuthal angle φ fall outside $C7$. Again the program gives to these detected events a weight which takes this effect into account.

This is another cone test.

(3) A third cone test is applied to events entering the big chamber, and therefore detected, but where the corresponding cone intersects the circle limiting the inside of the chamber.

(4) The amount of inelasticity in the scattering in carbon is measured through knowledge of the proton incident energy, of the location of the scattering point in the block and of the proton energy at the output of the carbon block deduced from its range in the large chamber.

(5) It is very important to separate the protons produced by elastic scattering from the protons obtained through inelastic events, that is, from the protons of single-π^0 electro- or photoproduction, and from the protons of Compton effect. In particular, it is known that the photoproduction protons are about 40% polarized in this range of energy and angle.[4]

The threshold for the photoproduction protons is about 13 MeV below the elastic peak. Figure 3 shows that the radiative tail follows quite closely the spectrum in the valley just above the π^0 threshold. One can evaluate the number of π^0 protons to be less than 0.001 in the channel which was used and the upper limit on the effect on polarization is even less.

The Compton proton polarization is unknown. Recent results show that the Compton cross section is of the order of 0.02 times the π^0 cross section up to 820 MeV. We have assumed an upper limit 0.05 for this ratio. Then one finds an upper limit of 0.003 for the contribution of Compton protons to the protons detected.

The program gives also histograms of various relevant parameters for the analyzed events. In this way, one can perform the necessary selections.

The various histograms are as follows:

(1) Scattering angle into carbon (Fig. 4). Scattering angles between 8° and 30° are used.

(2) Minimum distance between incoming and outgoing proton trajectories. This is a test of the coplanarity of the p-C scattering. Only distances less than 15 mm were allowed.

(3) Amount of energy lost in carbon scattering (Fig. 5). This shows that among the accepted events there are very few scattered from the 15-MeV carbon level or from higher excitation levels.

(4) Angular differences between a direction (either incoming or outgoing) measured by position scanning as defined above and the same direction as measured by its trace in one single chamber.

(5) Energy of the proton while undergoing the carbon scattering.

(6) Various quantities relevant to the cone tests.

Of the order of 20 000 pictures out of a total of 70 000 have been scanned. As a check, the horizontal transverse component of the polarization, as measured by an asymmetry in the vertical plane, is also obtained from the program. It should be zero if parity-conservation in electromagnetic interactions is valid. The result for the polarization is

$$P = 0.038 \pm 0.038.$$

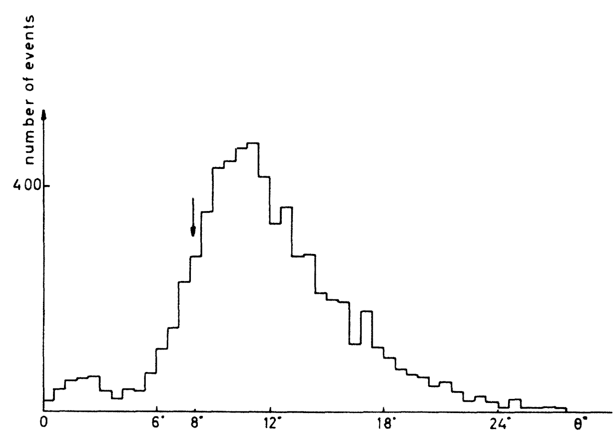

FIG. 4. Histogram of the number of events as a function of the scattering angle θ in carbon. The arrow represents the lower limit of θ for accepted events.

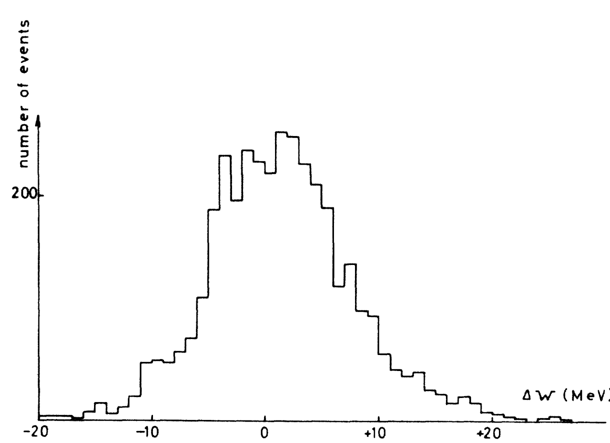

FIG. 5. Histogram of the "amount of inelasticity" Δw in carbon scattering.

Horizontal polarization (asymmetry in the vertical plane) gives

$$P' = -0.014 \pm 0.031.$$

The errors given here are purely statistical. There are still corrections we have not yet applied, but they are certainly smaller than our present statistical errors. It is interesting to note here that theoretical calculations by Guérin and Picketty[5] indicate a very weak polarization P of the order of 0.003.

We thank Professor Blanc Lapierre for extending to us the facilities of the laboratory. We are gratly indebted to Dr. J. K. Walker for his invaluable collaboration to the first stages of the experiment. We express our gratitude to Dr. Milman for his help in the setting up of the experiment. We are grateful to Mr. Round and his collaborators for building the experimental equipment, to Mr. Boutouyrie and the magnet group, to Mr. Alon and the electronics group, to Mr. Burnod and Mr. Verlon and the machine crew. We acknowledge the help during the runs of Mr. Delcourt and Mr. Bounin, Mr. Frêrejacque, Mr. N'Guyen, and Mr. Riskalla. Finally, we wish to thank Mr. Jeanjean and Mr. Ortega for their valuable collaboration.

---

[1]For a review, see L. N. Hand, D. Miller, and Richard Wilson, Rev. Mod. Phys. 35, 335 (1963). Small-angle scattering has also recently been measured by J. R. Dunning, Jr., K. W. Chen, N. F. Ramsey, J. R. Rees, W. Shlaer, J. K. Walker, and Richard Wilson, Phys. Rev. Letters 10, 500 (1963).

[2]M. Gourdin and A. Martin (to be published).

[3]A. Browman and J. Pine, Proceedings of the International Conference on Nucleon Structure, Stanford, California, 24-27 June 1963 (unpublished).

[4]C. Mencuccini, R. Querzoli, and G. Salvini, Proceedings of the Aix-en-Provence Conference on Elementary Particles, 1961 (C.E.N. Saclay, France, 1961), Vol. 1, p. 17.

[5]F. Guerin and C. A. Picketty (to be published).

INTERMEDIATE BOSON PAIR PRODUCTION AS A MEANS FOR DETERMINING ITS MAGNETIC MOMENT*

S. M. Berman and Y. S. Tsai

Stanford Linear Accelerator Center, Stanford University, Stanford, California

(Received 14 October 1963)

It has been proposed that the weak interactions are mediated by a vector particle (W).[1] In addition to its weak interactions, the charged W can interact with the electromagnetic field through its charge, magnetic moment, and quadrupole moment. Lee and Yang,[2] and Lee[3] have examined the electrodynamics of a vector boson which has no strong interaction and have shown that a kind of renormalizable theory can be constructed in which the boson has arbitrary magnetic moment and, to lowest order in the fine structure constant, no anomalous quadrupole moment.[4] In this note we show that, under the assumption of zero anomalous quadrupole moment, the reaction

$$\gamma + p \to W^+ + W^- + p \tag{1}$$

has a cross section which is very sensitive to the magnetic moment, and, therefore, an investigation of this process may serve as a means for its determination.

The coherent process

$$\gamma + Z \to W^- + W^+ + Z \tag{2}$$

is also calculated. However, in the range of photon energies and W masses considered here,

$$E_\gamma < 20 \text{ BeV}, \quad 0.8 < m_W < 2.0 \text{ BeV},$$

this coherent process is generally much smaller than the incoherent process (1). This is because even the minimum momentum transfer q_m, which for an infinitely heavy target has the value $q_m = 2m_W^2/E_\gamma$, is large compared to the inverse nuclear radius.

To lowest order in the fine-structure constant α, the Feynman diagrams for pair production are shown in Fig. 1. The form of coupling be-

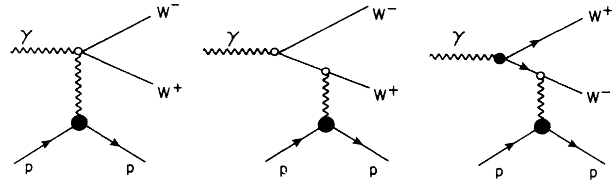

FIG. 1. Feynman diagrams for W-pair production.