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COMPARISON OF ELECTRON-PROTON AND POSITRON-PROTON ELASTIC SCATTERING AT FOUR-MOMENTUM TRANSFERS UP TO 5.0 $(\mathrm{GeV}/c)^2$ *

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(Received 31 May 1968)

Measurements of the ratio (R) of positron-proton and electron-proton elastic-scattering cross sections have been made, with the square of the four-momentum transfer (q^2) equal to 0.20, 0.69, 0.73, 1.54, 2.44, 3.27, 3.79, and 5.00 $(\mathrm{GeV}/c)^2$. The measurements, after radiative corrections, are consistent with $R=1$, with standard errors ranging from ±0.016 to ±0.123. The results give limits for the size of the two-photon effects.

Electron elastic-scattering experiments to date have been interpreted using the Rosenbluth formula based on the single-photon-exchange model. A measurement of R is a test of this model because a deviation of R from 1 is an indication of the size of the real part of the two-photon-exchange amplitude.[1] Because the interference between the single-photon amplitude and the two-photon amplitude occurs with opposite sign for electrons and positrons, one may write $R \approx 1+4 \times \mathrm{Re}B/A$, where $\mathrm{Re}B/A$ is the ratio of the real part of the two-photon amplitude ($\mathrm{Re}B$) to the single-photon amplitude (A). Earlier measurements of R by other experimenters[2] for the most part gave $R\approx 1$. Past theoretical estimates[3,4] either make no definite prediction as to the size of $|R-1|$, or predict it to be $\lesssim 0.02$. A summary of previous investigations of R has recently been given by Pine.[5]

Results.—The ratio R was measured for the laboratory scattering-angle regions $12.5° \leq \theta \leq 35.0°$ and $2.6° \leq \theta \leq 15.0°$ with incident electron (and positron) energies of 4.0 and 10.0 GeV, respectively. The high-q^2 data extend to higher q^2 than earlier experiments, and the moderate-q^2 data include measurements at smaller angles than previously explored.

The results are displayed in Table I, and a comparison with previous measurements is given in Fig. 1. In the table, R is the corrected experimental ratio with its uncertainty. The uncertainty in R is the square root of the sum of the squares of the statistical uncertainty and the estimated uncertainty due to systematic errors, both of which are given in the table. The systematic error is dominated by the beam monitor uncertainty.

The difference in radiative corrections for e^+ and e^- scattering was calculated using the results of Meister and Yennie,[6] with exponentation. The column labeled "Rad Corr" is the net correction to R from radiative effects. No uncertainty is assigned to the radiative corrections. The column labeled "$\mathrm{Re}B/A$" in the table gives the 95% confidence limits for the quantity $\mathrm{Re}B/A$ defined earlier.

As can be seen in the table, all the elastic data are consistent with $R=1$. This result is in agreement with estimates by Drell, Ruderman, and others,[3] and supports the one-photon approximation over an enlarged kinematical region.

The inelastic measurements in the table, labeled "$N^*(1238)$," give R for all scattered events in which the missing mass of the final-state particles other than the recoiling electron lay between 1110 and 1370 MeV. About 70% of the cross section leads to $N^*(1238)$ production. The remainder of the scattering in this region can be

Table I. The final radiatively corrected ratios (R) of this experiment are shown together with the statistical and systematic errors. The ratios of the real part of the two-photon amplitude (ReB) to the single-photon amplitude (A) are included.

ELASTIC SCATTERING DATA

Scattering Angle θ (deg.)	Incident Energy E_0 (GeV)	q^2 $(\mathrm{GeV}/c)^2$	$R = \frac{\sigma^+}{\sigma^-}$	Statistical Error	Systematic Error	Rad. Corr.	Limits on ReB/A Lower	Limits on ReB/A Upper
12.5	4.00	.689	0.986 ± .016	± .006	± .015	-.006	-.012	.005
20.0	4.00	1.54	1.003 ± .022	± .016	± .015	-.015	-.010	.010
27.5	4.00	2.44	1.040 ± .043	± .041	± .013	-.028	-.012	.032
35.0	4.00	3.27	1.111 ± .123	± .122	± .018	-.045	-.034	.090
2.60	10.0	.204	1.010 ± .020	± .013	± .015	-.001	-.008	.013
5.00	10.0	.731	0.965 ± .045	± .043	± .013	-.002	-.032	.014
12.5	10.0	3.79	1.024 ± .034	± .032	± .011	-.014	-.011	.024
15.0	10.0	5.00	1.038 ± .059	± .057	± .015	-.020	-.020	.039
	INELASTIC DATA: REGION OF N*(1238)							
2.60	E_0 = 10.0 GeV		1.015 ± .020	± .012	± .016	0.000	-.007	.014
5.00	E_0 = 10.0 GeV		1.007 ± .048	± .045	± .017	0.000	-.022	.026

attributed to nonresonant pion production and to the radiative tail for elastic scattering. No radiative corrections were made to these cross sections. For these data R is again consistent with 1.

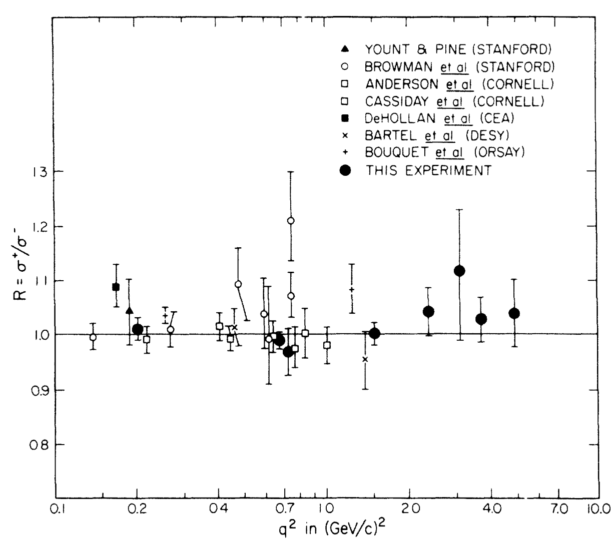

FIG. 1. The ratios R (from Ref. 2) of positron-proton to electron-proton elastic-scattering cross sections are shown plotted against four-momentum transfer squared (q^2). The new results from this experiment are shown as solid points.

Experimental method.—The positron and electron beams were made by passing an electron beam, with energy about 5.5 GeV, into a 2.2-in.-thick water-cooled copper radiator positioned one-third of the way along the Stanford Linear Accelerator Center (SLAC) accelerator. The low-energy electrons or positrons emerging from this radiator were accelerated to form the beams for the experiment.[7] In this way for each data point the positron and electron beams were similar with regard to transverse phase space, energy spectrum, and intensity. This technique was important in minimizing the effects of possible systematic errors.

The full energy spread of the beams varied from 0.5 to 1.0%. To increase intensity, the 1.0% width was used for most of the data. The average intensity varied from 6×10^9 $e^\pm$/sec to 4×10^{11} $e^\pm$/sec. The incident beam direction was maintained to better than ±0.1 mrad.

The beam charge was measured with a toroid current transformer[8] and a Faraday cup.[9] Two thin-foil secondary-emission monitors were also used. The ratio of positron to electron charge measured by the toroid differed from the ratio measured by the Faraday cup by up to 1.5%. Comparisons with the secondary-emission monitors indicated that the Faraday cup was more likely to be in error than was the toroid. Various arguments tend to support this conclusion, but the discrepancy is not fully understood. As a consequence, the toroid was used as the standard for determining beam charge and a systematic error in R equal to the observed disagreement between Faraday cup and toroid was assigned for each datum point.

The SLAC 8-GeV/c magnetic spectrometer was used to analyze particles scattered from a 27-cm-diam vertical cylinder of liquid hydrogen. For the small angles (2.6° and 5.0°), the SLAC 20-GeV/c spectrometer was used with a 7-cm-diam target. The solid-angle acceptances into these systems were approximately 0.8 and 0.06 msr, respectively.

The detection systems of both the 8-GeV/c spectrometer[10] and the 20-GeV/c spectrometer[11] have been described in earlier papers. Both systems contained momentum (p) and angle (θ) scintillation-counter hodoscopes and a lead-Lucite total-absorption shower counter for π-e discrimination. The energy loss (dE/dX) in a counter positioned after 0.5 radiation lengths of lead was also used to improve π-e discrimination for the data at 35°. Pion contamination was reduced to less than 1% by requiring the pulse heights in the shower and dE/dX counters to be greater than certain minima.

R was determined from the number of counts in a standard area in the background-subtracted p-θ hodoscope plane which contained the elastic peak. The background subtractions were approximately 2% and had negligible effects upon the values of R. Corrections were made for small variations in incident energy and scattering angle as well as for electronic and computer losses.

We want to thank R. A. Early, H. W. Kendall, P. N. Kirk, S. C. Loken, and L. W. Mo; and also E. Taylor and other members of the spectrometer group, for their contributions to the experiment. We are expecially grateful to the operating staff of the SLAC accelerator, particularly to Roger Miller, for providing the positron beam.

*Work supported in part by the U. S. Atomic Energy Commission.

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