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# A TEST OF QUANTUM ELECTRODYNAMICS BY ELECTRON-ELECTRON SCATTERING*

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# A TEST OF QUANTUM ELECTRODYNAMICS BY ELECTRON-ELECTRON SCATTERING*

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We have measured the differential cross-section for electron-electron scattering at a total energy of 600 MeV in the center-of-mass system, by a colliding-beam technique using storage rings[1,2,3]. This letter reports the final analysis of the data.

The parameters and operation of the storage rings have been described[3,4,5]. The Stanford Mark III linear accelerator supplied electrons of 300 MeV, which then circulated in the rings at the same energy, in a vacuum of $10^{-8}$ torr, with a mean storage time of 30 minutes. A typical counting cycle consisted of 20 minutes of data-taking followed by 5 minutes for camera unloading, electron injection, and camera reloading. At the start of each cycle the electron beams were 30 to 60 ma.

The detection apparatus is shown in Fig. 1. The veto system provided a factor 3,000 of rejection against cosmic rays; a similar arrangement of absorbers and counters was measured to veto on less than 1% of 300 MeV electrons incident from below. The four spark chambers were triggered on the signature (5+6+7+8+9+10) - (any two of 1,2,3,or 4).

Thirty thousand photographs were obtained in 174 hours of counter-on time. For 38 of these hours the beams were displaced, either vertically or longitudinally, to provide background information. The film was scanned twice, and all but 400 events were rejected as clearly due to soft showers from spill-out electrons striking the walls of the vacuum chamber. A typical event satisfying all fiducials is shown in Fig. 1. For such events the source-point coordinates and angles of the tracks in the upper and lower chambers were measured independently. The systematic errors in angle measurement were found to be less than 1/2 degree both in the upper and the lower chambers. The fiducial length of the source region varied from 5 cm to 10 cm as a function of scattering angle. The circulating electron beams were nearly Gaussian in longitudinal distribution, with full-widths at half-maximum of 2 nanoseconds. A correction was made for the variation in source density due to the longitudinal distribution of the circulating beams.

The background for analysis was 19 events out of 400 (see Table I). The number of events per hour with source points outside transverse fiducials was the same, within statistical errors, for beams interacting or non-interacting, and for no beams in the storage rings. We conclude therefore that the principal background for analysis was cosmic-ray muons.

The observed angular distribution was compared with the Møller scattering formula[6] modified by a Feynman regulator and by a radiative correction:

$$\frac{d\sigma}{d\Omega}(\theta\ ,\ K) = \frac{r_o^2}{8}\ \left(\frac{m}{E}\right)^2 \left[\frac{s^4 + q_o^4}{q^4}\ G_K^2\ (q^2) + \frac{2s^4}{q^2 q_o^2}\ G_K(q^2)\ G_K(q_o^2) + \frac{s^4 + q^4}{q_o^4}\ G_K^2\ (q_o^2)\right]\ (1 + \delta)\quad ,$$

where

$$s^2 = 4E^2\ ,\quad q^2 = -4E^2\ \sin^2\theta/2\ ,\quad q_o^2 = -4E^2\cos^2\theta/2\ ,$$

$$G_k(a^2) = \frac{1}{1 - \frac{a^2}{K^2}}$$

, and $\delta$ is the radiative correction as calculated by Tsai[7].

Comparison of the results with the theory is shown in Table I, where the data have been grouped in 5 degree bins. In Table I, columns 2 and 3 give for each bin the total number of observed events and the background to be subtracted. Column 4 is the Møller cross section in units of $1/8\ r_o^2\ (m/E)^2$ . Column 5 is the radiative correction where the cut off energy and angle were determined by our experimental conditions (30 MeV minimum final electron energy and 10 degrees maximum for $\Delta\theta$ unless a track was within $10^\circ$ of the edge of the detection region. $\Delta\theta$ is the angle between the tracks in the upper and lower chambers.) Column 6 is a correction to the Møller cross section which includes the radiative correction as well as geometrical corrections resulting from fiducial conditions. Column 7 gives the normalized theoretically expected result for our detector if $K^{-2} = 0$.

The data were grouped in 1 degree angular bins and given a maximum likelihood analysis. All of the corrections and subtractions made in the data analysis were smaller than the statistical errors of the 400 events observed.

The maximum likelihood value of $K^{-2}$ from the data at 600 MeV(CMS) is

$K^{-2} = +\ 0.001 \pm 0.033\ F^2$ . The limit of $K^{-1}$ is

$K^{-1} < 0.18\ F = 1.8 \times 10^{-14}$ cm, $K > 1.1$ GeV/c (one standard deviation)

$K^{-1} < 0.26\ F = 2.6 \times 10^{-14}$ cm, $K > 0.76$ GeV/c (95% confidence).

A preliminary analysis of the same data[8] gave $K^{-2} = 0.030 \pm 0.032\ F^2$ , corresponding to a limit on $K^{-1}$ for real $K$ of $0.28\ F$ , $K > 0.72$ GeV/c (one standard deviation), and of $.05\ F$ for $K^{-1}$ imaginary.

The difference in the best values of $K^{-2}$ from the preliminary and final analyses comes mainly from two sources: 1) The preliminary analysis did not restrict the collinearity of the tracks in the upper and lower chambers as tightly as the final analysis did. As a result there were extra events in the preliminary analysis which were condentrated at the smaller angles. The extra events could have come from electron spill out. 2) In making the preliminary analysis the events were divided into 5 bins of 10 degrees each. By a statistical accident this choice results in a "best value" of $K^{-2}$ which is larger than for any other choice of bin size. The maximum likelihood calculation shows that the best value of $K^{-2}$ varies by less than $0.002\ F^2$ for a bin size of 3 degrees or less.

The experiment is currently being extended to 1100 MeV total energy in the center-of-mass system, with larger detector solid angle.

One should note that this experiment is sensitive to the photon propagator. It is, therefore, not in direct contradiction to the experiment of Blumenthal et al[9], which is sensitive mainly to the electron propagator.

Measurement of the anomalous gyromagnetic ratio of the muon has provided a sensitive test of quantum electrodynamics at small distances[10]. A breakdown of the theory could occur in a number of ways, but if the muon moment is analyzed using a cut off on the photon propagator of the Feynman form, the experiment[10] gives a limit $K > 0.8$ GeV (95% confidence) which is comparable in sensitivity to our result.

It is a pleasure to thank Professor W. K. H. Panofsky and the Physics Departments of Princeton and Stanford Universities for encouraging this collaborative experiment, and the engineers and technicians of our group at both universities for their great effort in construction of the storage rings and of the detection equipment.

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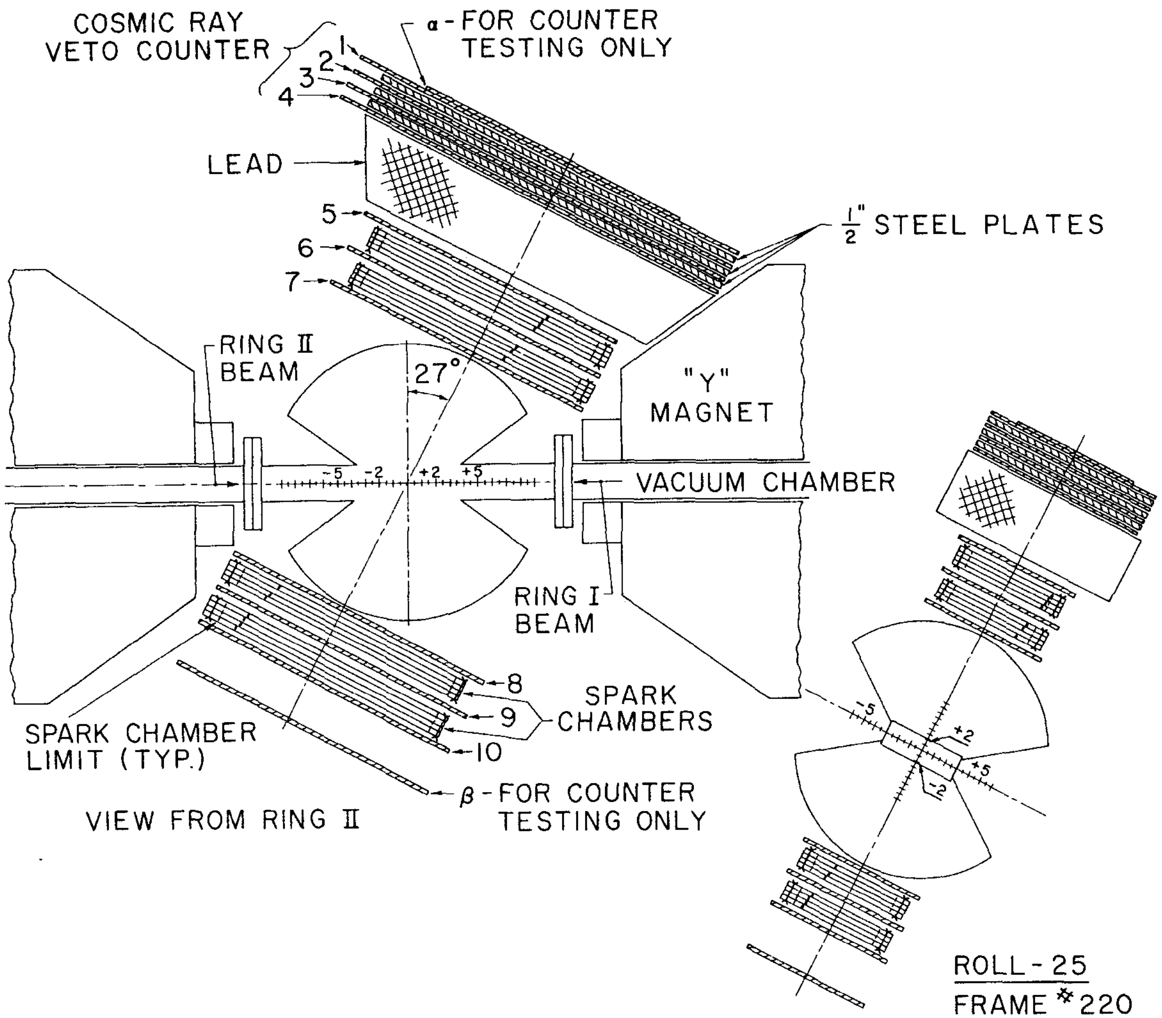
TABLE I

Comparison of the Observed Angular Distribution with that Expected from Theory if $K^{-2} = 0$.

| $\theta$ (degrees) | $N_{obs}$ | $N_{bkg}$ | $\frac{d\sigma}{d\Omega}(\theta, K^{-2}=0)$ | $-\delta(\theta)$ | $G(\theta)$ | $N_{th}(\theta, K^{-2}=0)$ |
|---|---|---|---|---|---|---|
| 40-45 | 75 | 0.6 | 120.55 | 0.057 | 0.6189 | 74.61 |
| 45-50 | 65 | 0.8 | 80.86 | 0.041 | 0.7345 | 59.39 |
| 50-55 | 36 | 1.1 | 57.36 | 0.045 | 0.8264 | 47.40 |
| 55-60 | 45 | 1.4 | 42.75 | 0.048 | 0.9024 | 38.58 |
| 60-65 | 32 | 1.8 | 33.36 | 0.051 | 0.9613 | 32.07 |
| 65-70 | 36 | 2.2 | 27.18 | 0.053 | 1.0048 | 27.31 |
| 70-75 | 29 | 2.5 | 23.09 | 0.054 | 1.0368 | 23.94 |
| 75-80 | 23 | 2.7 | 20.44 | 0.055 | 1.0563 | 21.59 |
| 80-85 | 21 | 2.9 | 18.84 | 0.055 | 1.0515 | 19.81 |
| 85-90 | 18 | 2.5 | 18.09 | 0.064 | 0.9287 | 16.80 |
| Total: | 380 | 18.5 | 442.52 | | | 361.50 |

## FIGURE CAPTION

Fig. 1 Configuration of the detection apparatus showing sparks from a real event.




SPARK CHAMBER – COUNTER GEOMETRY
WITH COLLINEAR EVENT