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DIRECT MEASUREMENT OF THE NEGATIVE KAON FORM FACTOR*

E. B. Dally[(a)], J. M. Hauptman, J. Kubic, D. H. Stork, and A. B. Watson

Physics Department, University of California, Los Angeles, California 90024

and

Z. Guzik, T. S. Nigmanov, V. D. Riabtsov, E. N. Tsyganov, and A. S. Vodopianov

Joint Institute for Nuclear Research, Dubna, U.S.S.R.

and

A. Beretvas[(b)], A. Grigorian[(c)], J. C. Tompkins[(d)], T. E. Toohig,

and A. A. Wehmann

Fermi National Accelerator Laboratory, Batavia, Illinois 60510

and

J. A. Poirier, C. A. Rey[(e)], and J. T. Volk[(f)]

Physics Department, University of Notre Dame, Notre Dame, Indiana 46556

and

P. D. Rapp[(g)], and P. F. Shepard

Physics Department, University of Pittsburgh, Pittsburgh, Pennsylvania 15620

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ABSTRACT

The electromagnetic form factor of the negative kaon has been measured by direct scattering of 250 GeV/c kaons from the stationary electrons of a liquid hydrogen target. The deviation of the measured elastic scattering cross section from the point cross section may be characterized by a root-mean-square kaon radius of $\langle r_{K^-}^2 \rangle^{\frac{1}{2}} = 0.53 \pm .05F$.

A first measurement of the negative kaon electromagnetic form factor has been obtained by elastically scattering 250 GeV/c kaons from electrons in a liquid hydrogen target. The departure of the elastic scattering cross section from the point (pt) cross section is given by

$$d\sigma/dq^2 = (d\sigma/dq^2)_{pt} \cdot |F_K(q^2)|^2$$

where $F_K(q^2)$ is the kaon form factor. The maximum kinematically allowed recoil electron energy is 128 GeV, corresponding to $q^2 = 0.131$ $(\mathrm{GeV}/c)^2$. The beam kaon and the scattered kaon and electron were detected with a high resolution single arm spectrometer. Geometric efficiency was high (84% to 100%) for electron energies from 36 to 116 GeV and in this paper we present data on the kaon form factor over the corresponding momentum transfer interval $0.037 \leq q^2 \leq 0.119$ $(\mathrm{GeV}/c)^2$.

Elastic scatters were recorded by the apparatus illustrated in Figure 1. The incident beam kaon and the scattered kaon and electron were tracked by both proportional wire chamber (PWC) stations and by drift chamber (DC) stations. Both chamber types were used in track finding and event reconstruction to provide the high redundancy required for good efficiency. With PWC calibration an overall drift chamber resolution of approximately 100 μm was achieved and made possible good discrimination against the copious strong interaction background. The momentum of the scattered kaon and of the electron were determined by two magnets with a total field integral of 70.35 kg-m followed by three PWC stations. Located behind the last PWC station was a lead-glass shower counter system 21 radiation lengths in thickness which was used in the trigger and in the final background determination.

An event trigger was determined by stringent beam requirements and a loose two-particle requirement. The beam logic was

$$\mathrm{BEAM} = C_D \cdot B_0 \cdot B_1 \cdot B_2 \cdot \overline{B_{2TWO}} \cdot \overline{AH} \cdot \mathrm{KILL} \cdot SP \cdot \overline{DP} \cdot DCD$$

C_D represents the differential Cerenkov counter signal requirement (100 feet of helium at ∿ 13 PSI provided unambiguous identification of the 2 per cent kaons in the beam). B_0, B_1, and B_2 represent beam scintillation counter signals. B_{2TWO} is an additional signal from the counter B_2 with the discrimination level set to twice minimum ionization. A beam halo counter AH defined the transverse dimensions of the beam. KILL required that no other beam particle preceded the event within 500 ns nor followed it within 60 ns. The beam PWC's provided a single particle requirement SP and discriminated against double particles DP. Similar requirements were formed by the beam drift chambers in the logic decision DCD. For a two second beam spill, the typical number of beam kaons was 18,000 (out of 10^6 beam particles). Of these about 6,000 satisfied the clean beam trigger requirement. The event trigger was

$$\mathrm{EVENT} = \mathrm{BEAM} \cdot \overline{A_5} \cdot TP \cdot C$$

where A_5 was a scintillation counter with a circular hole 10.16 cm in diameter which vetoed some of the strong interaction events (a small correction was required for elastic kaon-electron events vetoed due to radiative photons and delta rays striking the A_5 scintillator). TP required that there were at least two particles in PWC stations 5 and 6. Requirement C was that some combination of the five lead-glass shower counter sections produced a pulse consistent with an electron from an elastic kaon-electron scatter. The trigger rate was about 10^{-3} per incident kaon or ten per spill. Less than one per cent of these were elastic scatters.

Events were reconstructed by finding and fitting horizontal and vertical track projections and then matching these projections with rotated PWC's in stations 4, 7 or 8. Pairs of secondary tracks having a common target origin with an incident beam track were taken to be candidates for elastic scattering. The target vacuum windows were 1 meter from either end of the liquid hydrogen flask allowing clean identification of events originating in the target flask. The inefficiency in the event finding procedures was estimated from detailed studies of the analysis programs and by Monte Carlo calculations using real chamber efficiencies.

Events were tested for energy and momentum conservation in the elastic scattering process by means of a chi-square fit. In this fit it was assumed that an undetected photon was produced in the electron's direction either by radiation accompanying the elastic scatter or by electron bremsstrahlung in the target or spectrometer material. Events were selected to have chi square less than 30 and to have radiated photon energy less than 12 GeV. Losses due to the chi-square and photon-energy cuts were determined by Monte Carlo calculations.

The electron energies measured in the lead-glass shower counter system had a resolution function with typical standard deviation of 3.1%. A cut was made requiring the pulse height to be greater than 80% of that expected from the momentum measurement of the electron. The small hadronic background which survived various cuts was determined by extrapolating the measured hadronic background pulse height distribution under the electron peak.

Table I lists the corrections applied to the data. The resulting form factor is shown as a function of q^2 in Table II and in Figure 2. The errors shown are the combined statistical and systematic errors.

A fit to the data in Table II with the pole form $|F_K(q^2)|^2 = (1 + q^2\langle r_K^2\rangle/6)^{-2}$ with the full error matrix gives for the square of the kaon radius $\langle r_K^2\rangle = 0.28 \pm 0.05\ F^2$; or $\langle r_K^2\rangle^{1/2} = 0.53 \pm 0.05F$. The error is dominated by the statistics of the data sample and the fit is negligibly different if the off-diagonal elements of the error matrix are neglected. A fit using a dipole form $|F_K(q^2)|^2 = (1 + q^2\langle r_K^2\rangle/12)^{-4}$ gives negligible difference. The result was also found to be insensitive to change in the cuts in the radiated photon energy, in the chi square, and in the geometry. The result may be compared to $\langle r_\pi^2\rangle = 0.31 \pm 0.04\ F^2$ (or $\langle r_\pi^2\rangle^{1/2} = 0.56 \pm 0.04F$) for the pion[2].

An accurate theoretical prediction has not been produced, but it is of interest to compare our result for the electromagnetic form factor with the Chou-Yang model in which the kaon hadronic form factor is extracted from hadronic scattering data. The model gives[3] $\langle r_K^2\rangle^{1/2} = 0.54 \pm 0.14F$. Greenberg et al.[4] suggest a relativistically valid quark model inequality which relates the ratio of strange (m_s) to non-strange (m_n) quark masses to the ratio of electromagnetic radii for neutral and charged kaons. Combining the recently measured[5] neutral kaon radius $\langle r_{K^0}^2\rangle = -0.054 \pm 0.026\ F^2$ with the present charged kaon radius measurement, we find $m_s/m_n \geq 1.39 \pm 0.28$.

In conclusion, our best determination of the negative kaon radius is $\langle r_K^2\rangle^{1/2} = 0.53 \pm 0.05$ as obtained from the fit to the directly measured form factor constrained to unity at zero momentum transfer.

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FOOTNOTES

[a]Now at Varian Associates, Hansen Way, Palo Alto, CA 94306.

[b]Now at Rutgers University, Piscataway, NJ 08854.

[c]Now at Hughes Aircraft Co., Culver City, CA 90230.

[d]High Energy Physics Laboratory, Stanford University, Stanford, CA 94305.

[e]Now at Intersonics, Inc., Northbrook, IL. 60062.

[f]Now at Ohio State University, Columbus, OH 43210.

[g]Now at Fermi National Accelerator Laboratory, Batavia, IL 60510.

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TABLE I. Corrections to the data

Effect	% correction
q^2-independent corrections	
Beam momentum cut	0.5 ± 0.1
e, μ, π, $\bar{p}$ contaminations	0.1 ± 0.2
Primary K decay	1.5 ± 0.1
Primary K attenuation	2.9 ± 0.1
Target electron density	0.0 ± 0.3
Secondary K attenuation	4.1 ± 0.1
δ rays in A5	0.4 ± 0.1
Trigger inefficiencies	0.2 ± 0.2
Range of q^2-dependent corrections	
Geometric inefficiency	(0.0-13.1) ± (0.0-0.4)
Radiative corrections (Ref. 1)	(4.1-10.5) ± (0.2-0.3)
Secondary K decay	(1.4-2.1) ± (0.1-0.1)
Hadronic background	(0.0-1.7) ± (0.0-1.2)
Track finding inefficiency	(2.7-4.0) ± (0.5-0.6)
External bremsstrahlung	(13.9-25.6) ± (0.2-0.3)

TABLE II. Events, measured cross section, and form factor versus q^2

$q^2\,(\mathrm{GeV/c})^2$	Number of Events	Events after correction	$d\sigma/dq^2$ $\mu b(\mathrm{GeV/c})^2$	$\lvert F_K \rvert^2$
0.0409	728	1020	100.6 ± 3.3	0.93 ± 0.03
0.0491	459	625	61.7 ± 2.7	0.90 ± 0.04
0.0572	295	407	40.2 ± 2.3	0.89 ± 0.05
0.0654	190	267	26.2 ± 1.8	0.85 ± 0.06
0.0736	120	171	16.7 ± 1.5	0.79 ± 0.07
0.0818	94	137	13.2 ± 1.3	0.90 ± 0.09
0.0899	48	70	6.8 ± 1.0	0.67 ± 0.10
0.0981	37	55	5.2 ± 0.9	0.77 ± 0.13
0.1063	23	36	3.3 ± 0.7	0.76 ± 0.16
0.1145	15	26	2.2 ± 0.6	0.90 ± 0.23

FIGURE CAPTIONS

Figure 1. Arrangement of the spectrometer apparatus.

While transverse dimensions are not to scale, they are magnified approximately a factor of 10 over longitudinal dimensions. B_0, B_1, B_2, A_H, and A_5 are scintillation counters. Each PWC station has four planes. Stations 1 - 6 have transverse readout coordinate pairs with station 4 rotated to 45°. Stations 7 and 8 each have two x planes and two planes rotated to ± 29°. The four drift chamber stations have four x planes and four y planes each. Helium bags between drift chamber and PWC stations are not shown.

Figure 2. Kaon form factor.

The pole fit, constrained to a value of one at $q^2 = 0$, is shown as the solid curve. An unnormalized fit yielding $\langle r_K^2 \rangle^{1/2} = 0.65 \pm 0.15$F is shown as the dashed curve. The error bar at $q^2 = 0$ corresponds to the uncertainty in the normalization (1.07 ± 0.09) in the latter fit at $q^2 = 0$.

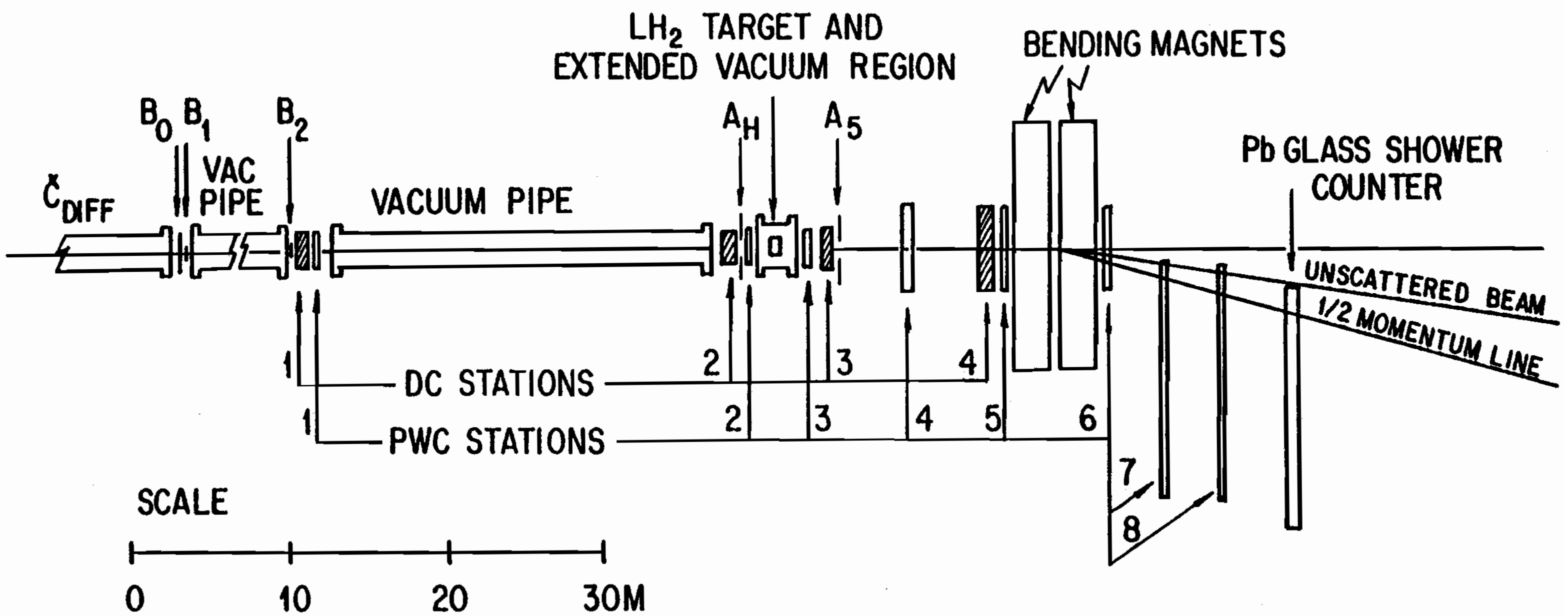
LH2 TARGET AND
EXTENDED VACUUM REGION
BENDING MAGNETS
B0 B1
VAC
PIPE
B2
AH
A5
ČDIFF
VACUUM PIPE
Pb GLASS SHOWER
COUNTER
UNSCATTERED BEAM
1/2 MOMENTUM LINE
1
DC STATIONS
2
3
4
1
PWC STATIONS
2
3
4
5
6
7
8
SCALE
0
10
20
30M

FIGURE 1

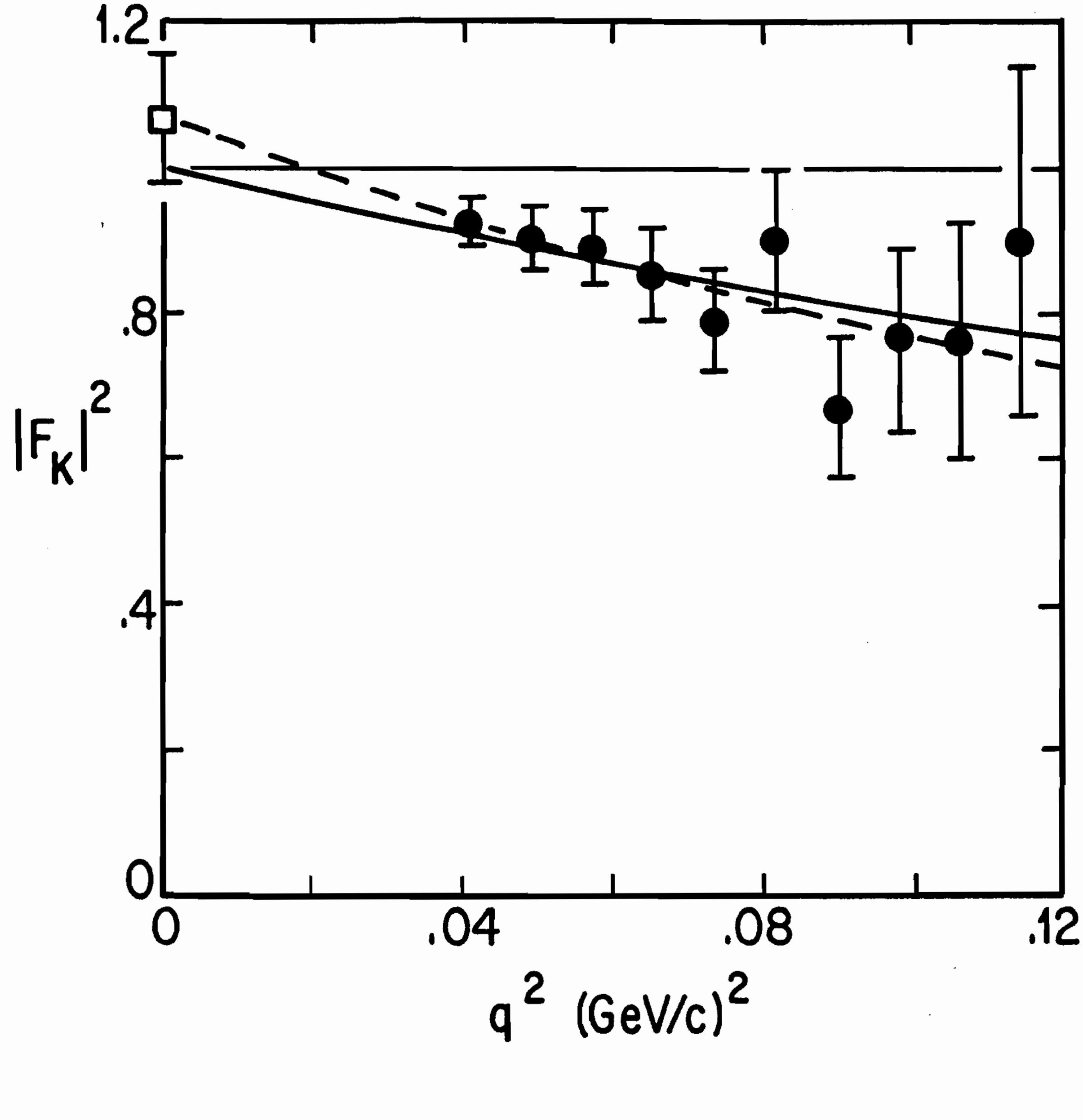

FIGURE 2