A MEASUREMENT OF THE KAON CHARGE RADIUS

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We have measured the negative kaon electromagnetic form factor in the space-like q^2 range $0.015 - 0.10$ (GeV/c)² by the direct scattering of 250 GeV kaons from electrons at the CERN SPS. We find the kaon mean square charge radius $\langle r_K^2 \rangle = 0.34 \pm 0.05$ fm². From data collected simultaneously for π^+ scattering we find the difference between the charged pion and kaon mean square radii (which is less sensitive to systematic errors): $\langle r_\pi^2 \rangle - \langle r_K^2 \rangle = 0.10 \pm 0.045$ fm².

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The low energy behaviour of meson form factors is predicted in a number of theories and leads to estimates of meson charge radii: it is generally expected that the radius of the charged kaon is smaller than that of the pion due to the presence of the heavier strange quark. Experimentally the pion radius is relatively well known since the electromagnetic form factor F_π is well measured for both space-like and time-like q^2 . By comparison the behaviour of the kaon form factor is poorly constrained due to the absence of electroproduction data, the relatively high threshold ($q^2 = 4m_K^2$) for e^+e^- annihilation and uncertainty in the isoscalar contribution. We have previously reported a result for the pion radius from a high statistics measurement of pion electron scattering at 300 GeV [1] [2]. Here we report a similar measurement of kaon electron scattering, for which we used a 250 GeV/c beam to maximise the kaon flux, and simultaneously collected πe events. Previous data on this reaction are restricted to a single measurement [3] [4] and resulted in a kaon radius considerably lower than expected from an extrapolation of time-like data [5].

The differential cross-section for meson electron scattering is given to lowest order in α by

$$d\sigma/dq^2 = |F|^2 \cdot d\sigma/dq^2_{\text{point}} \sim |F|^2 q^4 \cdot (1 - q^2/q_{\text{max}}^2)$$

where q_{max}^2 for 250 GeV/c kaons is $0.13(\text{GeV}/c)^2$. The charge radius is given by the slope of the form factor at zero q^2 :

$$\langle r^2 \rangle = -6 \cdot dF/dq^2 |_{q^2=0}$$

Our experimental method was very similar to the 300 GeV πe measurement; in particular the elastic event kinematics were determined from the measured scatter angles alone. Charged particle momenta and shower energies were used loosely to reject background and provided a high degree of redundancy.

The apparatus (which is shown in Fig.1 and described in detail in [2]) consisted of the FRAMM forward spectrometer with a target and vertex detectors constructed specially for the πe and $K e$ measurements. The SPS H4 beam

consisted mainly of pions (97%) with 3% of kaons which were tagged by a differential Cerenkov counter (CEDAR).

A clean incident beam definition included requirements of single counts in the hodoscopes S_h, S_v , low pulse height in S2, a time separation from S1 and a beam halo veto V1. The event trigger was based on the signature of two scattered particles detected by pulse height in counters M1 and M2 and by the hodoscopes L_h and L_v . Veto counters surrounding and downstream of the target rejected hadronic events and a telescope of counters (BS1-3) rejected unscattered beam. A very loose electron signature was required from the front part of at least one shower detector. A scintillator (SEV) in the first magnet aperture vetoed electrons of less than 1 GeV.

Although pion events were recorded, the accepted pion flux was electronically reduced by a factor two, and the counter S3 (which was 99.86% efficient) was required in the pion trigger. The total incident beam rate was high, with typically $3 \cdot 10^6$ particles counted by the final beam counter per machine burst of 2 seconds. Final trigger rates were $3 \cdot 10^{-4}$ per incident kaon and $6 \cdot 10^{-5}$ per incident pion. The full data sample contained approximately $1.6 \cdot 10^6$ pion and $4 \cdot 10^5$ kaon triggers.

The multiwire chambers in the vertex region were used to determine the coordinates of the event vertex and the scatter angles. The majority of events were hadronic scatters, which were mostly rejected after MWPC reconstruction by their high multiplicity or poor co-planarity. An additional rejection of high multiplicity events was made from the integrated signals in counters M1 and M2. Remaining events were required to satisfy cuts on the longitudinal vertex coordinate (± 30 cm from the target centre) and on the projection of the scattered tracks into a fiducial window at the entrance to the spectrometer.

After reconstruction of tracks and showers in the spectrometer events were rejected on the the following criteria:

- more than two cleanly reconstructed tracks.

- the presence of a positively charged track.
- candidate electron shower energy less than 50% of its measured momentum.

The distribution of scatter angles, θ_K vs θ_e , for the final sample of kaon events is shown in Fig.2, and is peaked along the elastic kinematic curve. Each event was assigned a value of q^2 corresponding to the nearest point on this curve, and the distance above it ($D\theta$) was taken as a measure of elasticity. The Ke signal was counted within cuts of $|D\theta| < 0.16$ mr. Subtractions were made for the following sources of background:

a) At low q^2 a contamination of πe events was present due to misidentification ($\sim 0.1\%$) by the CEDAR counter. Above $q^2 = 0.05 (\text{GeV}/c)^2$ the angle coordinates of πe and Ke scattering are well separated and the πe events can be clearly seen in Fig.2(a). The beam contamination ($4.3 \pm 0.5\%$) was measured by fitting Ke and πe peaks to the observed $D\theta$ distribution.

b) A small correction was necessary for the presence of muons (0.3% of the kaon beam) generated by kaon decay downstream of the CEDAR.

c) The residual background in each q^2 bin was estimated from the event rate at $D\theta > 0.3$ mr. These events were mainly hadronic (at low q^2) with a contribution from poorly reconstructed kaon decays above $q^2 = 0.07 (\text{GeV}/c)^2$.

Corrections for inefficiencies in the trigger and event reconstruction were similar to those described in [2], and are summarised in Table 1. The majority of corrections to the data were a slow function of q^2 and were similar for our three data sets: $\pi e(300\text{GeV})$, $\pi e(250\text{GeV})$, $\text{Ke}(250\text{GeV})$. However, the form factor results obtained from the 250GeV pion data lie below the 300GeV data at all q^2 . A pole fit to the 250GeV pion data, $|F_\pi|^2 = n/(1+q^2 \cdot r^2/6)^2$ gives:

$$\langle r^2_\pi \rangle = 0.444 \pm 0.023 \text{ fm}^2, \quad n = 0.970 \pm 0.008 (\text{stat}) \pm 0.01 (\text{syst})$$

The measured pion radius is in good agreement with the pole result at 300GeV, $\langle r^2_\pi \rangle = 0.43 \pm 0.01 \text{ fm}^2$, but the overall normalisation of the 250GeV result is 3% low. The response of the trigger counters and our off-line

cuts are well calibrated. However, there is evidence from data taken with an incident beam trigger for a small rate dependence of the trigger logic. Since this effect is independent of q^2 we have renormalised both pion and kaon data by 3%. Our final values for $|F_K|^2$ as a function of q^2 are given in Table 2 and Fig. 3.

A pole fit to the kaon data yields:

$$\langle r_K^2 \rangle = 0.40 \pm 0.11 \text{ fm}^2, \quad n = 1.02 \pm 0.03(\text{stat}) \pm 0.01(\text{syst}).$$

Our best estimate of $\langle r_K^2 \rangle$ is given by constraining n to 1.0 within the estimated systematic error of 1%:

$$\langle r_K^2 \rangle = 0.34 \pm 0.05 \text{ fm}^2 \quad \text{with a } \chi^2 \text{ probability of 50\%}.$$

The corresponding root mean square radius is $\langle r_K^2 \rangle^{1/2} = 0.58 \pm 0.04 \text{ fm}$. These results are insensitive to the functional form assumed for F_K , for example the choice of a dipole rather than a pole fit. A linear fit to the ratio:

$$|F_K|^2 / |F_\pi|^2 = 1 + q^2 \cdot (\langle r_\pi^2 \rangle - \langle r_K^2 \rangle) / 3,$$

which should be free of common systematic errors, gives:

$$\langle r_\pi^2 \rangle - \langle r_K^2 \rangle = 0.10 \pm 0.045 \text{ fm}^2 \quad \text{with a } \chi^2 \text{ probability of 50\%}.$$

In Table 3 we have collected some direct, indirect and theoretically based values for the kaon charge radius. By comparison with the previous measurement of Dally et al [3] our result is higher by nearly one standard deviation. It is however slightly lower than the timelike extrapolation of Blatnik, Stahov and Lang [5] and a recent evaluation by Micelmacher et al based on kaon decay to four leptons [6].

TABLE 1

Summary of corrections (in percent) applied to the data. The error column gives the estimated contribution to uncertainty in normalisation of the data.

<u>Source</u>	<u>%Corrn</u>	<u>Error</u>	
Beam muon contamination	0.30	± 0.05	
Beam pion contamination	4.3	± 0.5	
Target electron density	-	± 0.25	
Kaon absorption	4.5	± 0.3	
Kaon decay	1.1	± 0.2	
<u>Trigger losses:</u>			
Multiplicity definition	3.4-4.3	± 0.2	
BS veto loss	0.20	± 0.06	
Electron signature	3.5-1.0	± 0.5	
SEV veto loss	1.8-0.6	± 0.2	
Vetoing by δ -rays	2.4	± 0.3	
Veto from beam halo	4.0	± 0.5	
<u>Reconstruction losses</u>			
Beam track reconstruction	4.3	± 0.02	
Downstream MWPC inefficiency	1.3	± 0.3	
M1,M2 pulse height cut	4.0	± 0.1	
Longitudinal vertex cut	0.7-3.3	± 0.3	
Spectrometer cuts	1.9	± 0.2	

πe background	6.0-0.0	± 0.05	($q^2=0.015-0.07$)
μe background	0.3-0.0	-	($q^2=0.015-0.04$)
hadronic + decay background	0.3-1.0 ($q^2=0.07$)	- 10% ($q^2=0.1$)	
Radiative correction:	2.0-3.2	± 0.5	
Geometric acceptance: 50% at $q^2=0.018$ - 100% above $q^2=0.023$.			

TABLE 2

Form factor results. $|F_K|^2$ is given with statistical errors only: the estimated overall normalisation is uncertain to $\pm 1\%$. The ratio $|F_K|^2/|F_\pi|^2$ is assumed free of systematic uncertainty.

q^2 (GeV/c) ²	$ F_K ^2$	$ F_K ^2/ F_\pi ^2$
0.0175	0.965 ± 0.024	1.048 ± 0.027
0.0225	0.900 ± 0.024	0.968 ± 0.027
0.0275	0.973 ± 0.031	1.069 ± 0.036
0.0325	0.962 ± 0.037	1.066 ± 0.044
0.0375	0.918 ± 0.043	1.068 ± 0.052
0.0425	0.890 ± 0.049	1.026 ± 0.058
0.0475	0.877 ± 0.055	1.039 ± 0.066
0.0525	0.813 ± 0.060	0.977 ± 0.073
0.0575	0.880 ± 0.071	1.11 ± 0.09
0.0625	0.938 ± 0.084	1.19 ± 0.11
0.0675	0.742 ± 0.088	0.95 ± 0.11
0.0725	0.732 ± 0.095	1.02 ± 0.13
0.0775	0.72 ± 0.12	0.94 ± 0.16
0.0850	0.73 ± 0.10	0.96 ± 0.13
0.0950	0.80 ± 0.14	1.09 ± 0.20

TABLE 3

Experimental and theoretical values for the kaon charge radius.

Source	$\langle r_K^2 \rangle (\text{fm}^2)$	$\langle r_\pi^2 \rangle - \langle r_K^2 \rangle (\text{fm}^2)$
This experiment	0.34 ± 0.05	0.10 ± 0.045
Dally et al [3] [4] K-e scattering	0.28 ± 0.05	0.16 ± 0.06
Blatnik et al [5] timelike extrapolation	0.385 ± 0.046	
Micelmacher et al [6] $K_{\ell 4}$ decay	0.45 ± 0.09	
Gasser & Leutwyler [7] chiral perturbation theory	0.38 ± 0.03	
Godfrey & Isgur [8] quark potential model	0.35	
L. Cosmai et al [9] A.C.D.	0.45	

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Figure Captions

Fig. 1 Schematic diagram of the apparatus

The target was a 28cm long vessel of liquid hydrogen with 50 cm vacuum tubes at each end. The detectors were, in the BEAM region: small hodoscopes (S_h, S_v), S1, S2 and V1 (veto). MWPC stacks 1,2. In the VERTEX region: multiplicity counters M1, M2 and hodoscopes L_h, L_v . S3 had a circular hole comparable to the beam dimensions. TV, V2-5 were veto counters, faced with Lead and Aluminium. MWPC stacks: 3,4,5. SPECTROMETER: 4 magnets and drift chamber stacks. FS, SD1, SD5 were lead scintillator shower detectors. SD2, SD3 SD4 were lead glass arrays. Front SD sections were 4 radiation lengths, rear sections 20 radiation lengths with 3.5 cm lateral granularity. BS was a beam veto telescope of 3 counters. Incident Kaons were tagged by a CEDAR Cerenkov counter 37m upstream of the target.

Fig. 2 (a) Scatter plot of the measured angles θ_K vs θ_e . Events below the elastic line are mainly radiative and those clustered along a line in the upper left of the plot are pion electron scatters.
(b) $D\theta$ distribution with cuts indicated.

Fig. 3 The measured kaon form factor squared. The line corresponds to the pole fit with $\langle r^2 \rangle = 0.34 \text{ fm}^2$.

Fig 1

Fig 2(a)

Fig 2(b)

Fig 3