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FORM-FACTOR EXPERIMENTS

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The form factors of unstable particles like the K and π can be directly determined by scattering off an electron target.[1] Unfortunately the only practical target is the electrons found in matter bound to atomic nuclei. Beams of electrons are far from being practical targets. (The charge density of electrons in liquid hydrogen is 6×10^3 C/cm^3; if a velocity like c is used, then one would need a current of 2×10^{14} amp/cm^2 to be equivalent to 1 cm of hydrogen.)

The form factors can be measured indirectly using $\pi^{\pm}$ scattering from[2] He and using electroproduction of pions.[3] The results are sensitive to the details of the analysis. Various experimental results are given with the references. Theoretically if one used a ρ-dominance model for the π one would expect $r_{\pi} = 0.63$ Fermi.[4] Similarly a K^* dominance for the K would give $r_K = 0.53$ Fermi.

T. Toohig describes an experiment to measure the pion form factor at a 200-GeV accelerator.[5] The experiment is straightforward and has ample cross section. However, I believe that nuclear backgrounds would cause troubles and that additional experimental constraints are needed to insure that most of the incoming energy is accounted for in the outgoing π and electron. Toohig had a target 1 meter long or about a quarter of an interaction length, hence scattered pions have ~ 15% chance of interacting. The bremsstrahlung loss of the electron in the target was several GeV on the average. For these reasons a thinner target would be required, and in fact a study of the systematics would require measurements with several target thicknesses. A target of 10 cm would still give many thousand events per day.

Additions to Toohig's experiment should include:

1. A shower counter at 0° to account for bremsstrahlung in the target.

2. Instead of the electron shower spark chamber a total absorption counter should be mounted. Another shower counter should be used to detect the synchrotron radiation as a positive identification of an electron. Even a lead glass counter at 100 GeV should have a resolution of three percent (full width at half maximum).[6]

3. The lower energy pion should be put through spark chambers and Cerenkov counters to identify as much as possible the particle type.

4. One should remove electrons from the incident beam by either lead at a secondary focus or by going through enough magnetic field that electrons lose enough energy by synchrotron radiation to be lost in the final momentum analysis. We do not want e-e scattering events. Strong interactions which need suppression are multiple pion production where a π^- and π^0 get most of the energy and the π^0 decays so as to give

most of the energy to one electron. For example,

$$\begin{array}{l}\pi^- + p \rightarrow \rho^- + p \\ \qquad\qquad\ \ \llcorner\!\!\rightarrow \pi^0 + \pi^- \rightarrow e^+ + e^- + \gamma + \pi^- \quad .\end{array}$$

One will try to suppress such reactions by anticoincidence around the target, requiring energy conservation, and correct correlated angles. Hopefully the requirement of only two negative particles in the final state will allow a large suppression of multipion reactions. An extrapolation of the ρ^- cross section indicates that it will not be an important background. One should design the experiment so that kinematically forbidden events can be seen, i.e., electrons greater than the maximum. This will allow an estimate of the background.

The form factor of the kaon will be a much harder experiment. The flux of kaons at high energy is expected to be about 1/100th that of the pions. Because of the higher mass of the kaon the maximum momentum transfer is much lower.

$$t_{max} \simeq \frac{-2mE_K}{1 + \dfrac{m_K^2}{2mE_K}} \quad ,$$

where m = electron mass, E_K = incident K energy and m_K = kaon mass. At 150 GeV t_{max} is $- 0.056\ (\text{GeV}/c)^2$. If we approximate the form factor by

$$F^2 = 1 + 1/3 \langle r_K \rangle^2 \, t_{max} \quad ,$$

and assume the $\langle r_K \rangle^2$ is given by $6/m_{K^*}^2$ (analogous to the $6/m_\rho^2$ for the pion) then F = 0.86 for 150 GeV K's. Therefore, we are trying to measure a 14% effect. The following is a first approximation to what an experiment might look like.[7] In the region where $M_K^2 > 2mE_K$ the electron receives the least energy, the opposite of Toohig's experiment where $2mE_K > M_\pi^2$. If we work over a range of t from maximum to 1/2 max then E_K varies from 94 to 132 GeV and E_e varies from 56 to 28 GeV. The angles involved for a momentum transfer 1/2 of maximum are 1 mrad for the K and 4 mrad for the electron. Figure 1 shows the expected cross sections from a form factor of 1 and for the $<r^2>$ given above. If we use a pion beam of intensity 10^7 and a 10 cm hydrogen target then we can expect in the interval from 28 - 56 GeV about

$$N = (4 \times 10^{23}) (10^{-30}) 10^5 K/sec = 4 \times 10^{-2} \text{ event/sec.}$$

We need at least 4×10^4 events or 10^6 sec of running time to get enough statistics and even more to understand background and systematic errors.

A sketch of a possible experimental layout is shown in Fig. 2. Four magnets each with 3.5 m of length are needed. Three of these need gaps like 10 cm and widths like 50 cm. The first can be considerably smaller. The magnets are used to disperse the beam but still keep an approximately parallel beam. The parallel beam is needed so that differential Cerenkov counters can be used to identify the outgoing K's. The angles involved for the K's are less than 1 mrad and the K beam covers a rectangular region 40 cm wide and 5 cm in height.

These Cerenkov counters will need careful design. Preliminary estimates are that counters similar to DISC counters could be used to identify the outgoing particles as K's, rejecting pions strongly. Wire spark chambers are used to measure particle trajectories. A lead glass hodoscope measures the electron energy to 5%. A septum magnet is used to dispose of the main beam. Threshold or DISC counters would tag the incoming beam.

This is a hard experiment and would not be attempted until after several rounds of experiments had measured the pion form factor well.

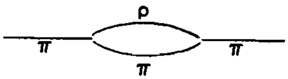
FOOTNOTES AND REFERENCES

[1] Thoughts about the details of such experiments were inspired by a talk given by S. Drell at Aspen. Direct experiments: Crawford et al., Phys. Rev. 117, 1119 (1960) and Cassels, Ph.D. thesis, Department of Physics, Princeton University (1965) ($R_\pi < 3$ Fermi).

[2] M.. M. Sternheim and R. Hofstadter, Nuovo Cimento 38, 1854 (1965); G. West, Phys. Rev. 162, 1677 (1967); Block et al., Phys. Rev. 169, 1074 (1968) (1.1 ± 0.8 Fermi); M. E. Nordberg and K. F. Kinsey, Phys. Rev. Letters 20, 692 (1966) ($R_\pi < 2$ Fermi); K. Crowe, A. Fainberg, J. Miller and A. Parsons, Lawrence Radiation Laboratory UCRL-18473 ($R_\pi = 3.0 \pm 0.4$ Fermi).

[3] C. W. Akerlof, W. W. Ash, K. Berkelman and C. A. Lichtenstein, Phys. Rev. Letters 16, 147 (1966) (0.80 ± 0.10 Fermi); Mistretta et al., Phys. Rev. Letters 20, 1523 (1968) (0.86 ± 0.14 Fermi); Akerlof et al., Phys. Rev. 163, 1482 (1967).

[4] From a diagram:



[5] T. Toohig, Lawrence Radiation Laboratory UCRL-16830, Vol. I, p. 144.

[6] D. Luckey, Proceedings of the International Symposium on Electron and Photon Interactions at High Energies, Hamburg 1965, Vol. II, p. 397.

[7] This work did not have the benefit of public exposure at Aspen since it was only completed at the end of the summer.

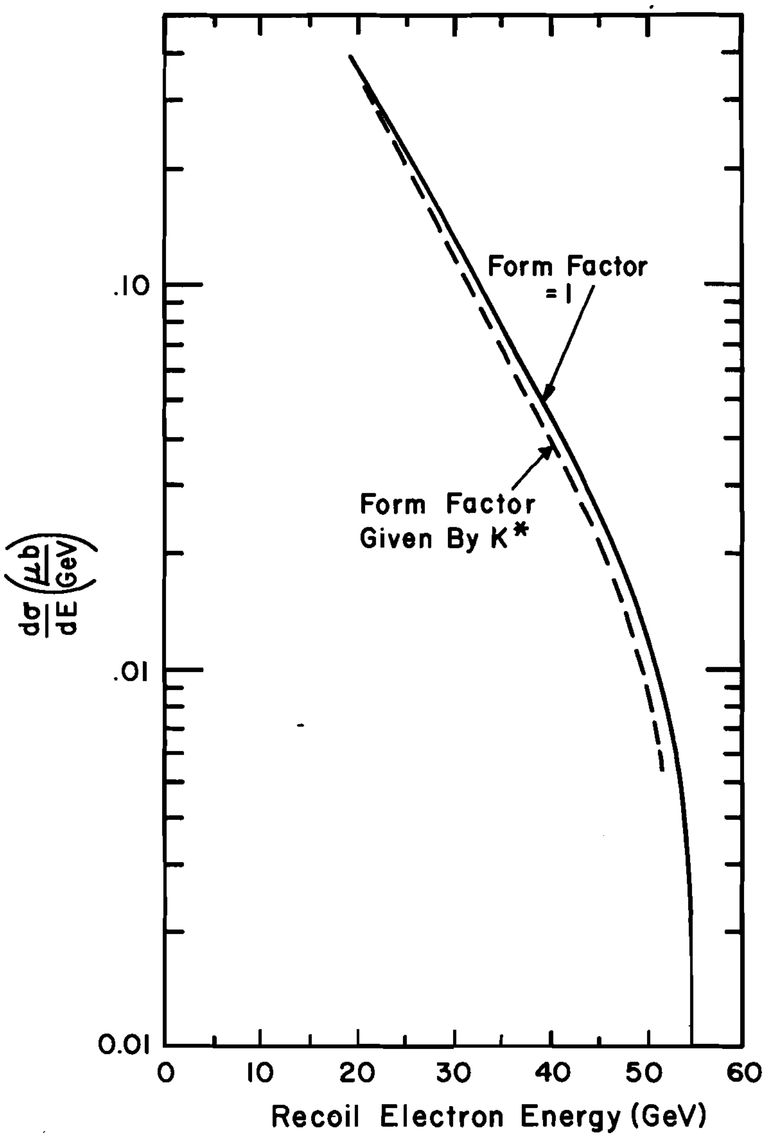


Fig. 1. Expected cross sections for kaon-electron scattering.

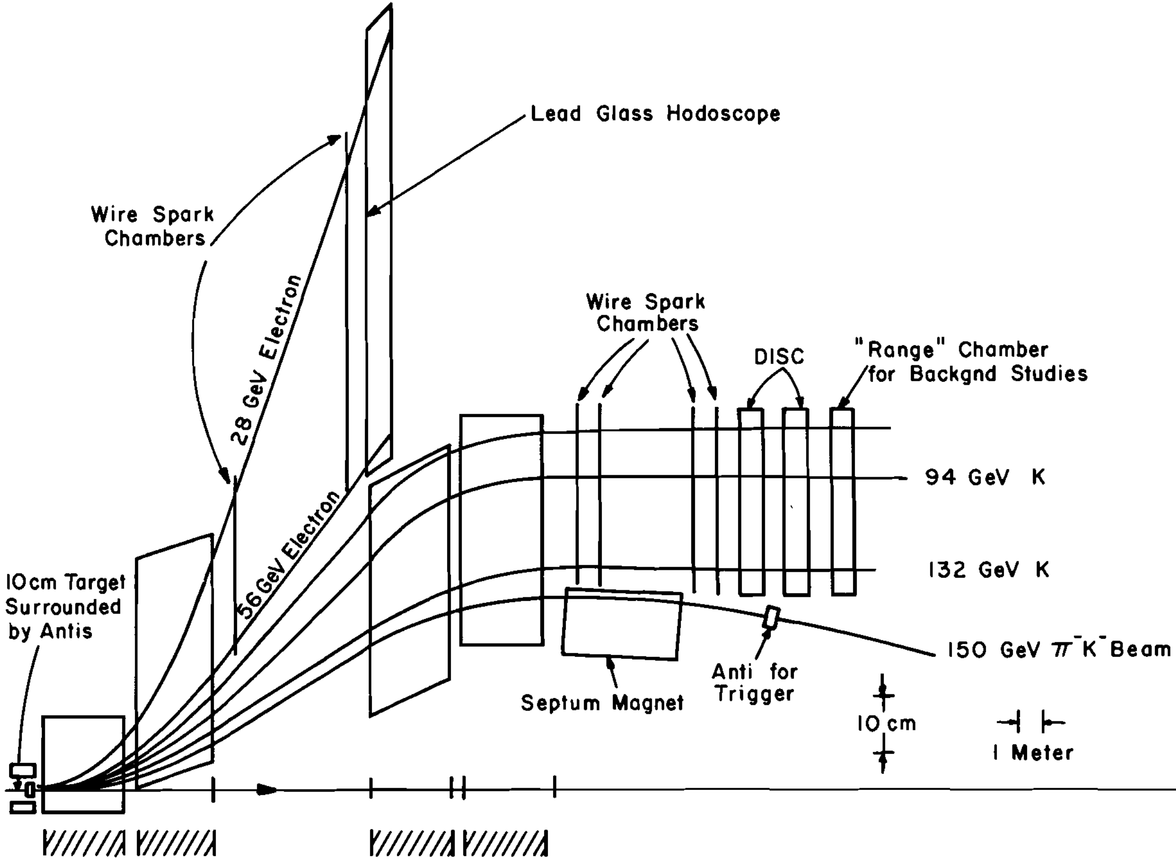


Fig. 2. Experimental arrangement for kaon-electron scattering.