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MEASUREMENT OF THE KAON FORM FACTOR

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SUMMARY

We propose an experiment to measure elastic kaon scattering from electrons at a beam energy of 250 GeV. This measurement will provide the first experimental value for the charge radius of the kaon. The anticipated error on the determination of the radius is 0.03 Fermi.

The experiment can be performed by the present E216 spectrometer in the M1 beam line. A drift chamber system will be added to improve the spectrometer resolution and minor modifications of the trigger hodoscope and shower counter geometry will be required.

The experimental design incorporates our experience in performing π–e elastic scattering at 50 GeV/c at Serpukhov and at 100 GeV/c in E216 at Fermilab (data taking completed on October 1, 1975). The analysis of the E216 results is well underway and we anticipate that a definitive value for the pion radius will soon be obtained (anticipated error ± 0.03 F).

All apparatus is designed with the goal of measuring a 1% absolute cross section. To cleanly identify elastic events and reject background, the angles and momenta of both the scattered K and e are measured. Proportional chambers and drift chambers upstream and downstream of the hydrogen target measure angles to high accuracy. Two 8-24-72 analysis magnets are used, followed by a set of six 0.5 x 1.5 m^2 spark chambers, to determine momenta. A lead glass shower counter hodoscope provides electron shower identification. In the trigger there is only one veto counter used which is sensitive to target interactions. It helps to suppress non K-e background and its effect on K-e elastic events is small and well understood.

A time request for 200 hours of testing and 600 hours for data taking is made in the proposal. Our continued interest in pion form factor measurements at energies much higher than 100 GeV is indicated in an Appendix.

I. INTRODUCTION

We propose a measurement of the elastic kaon-electron scattering cross section at an energy of 250 GeV. The data from this experiment will allow a direct measurement of the electromagnetic form factor of the kaon to the maximum four momentum transfer of $q^2_{max} = 0.13\ (GeV/c)^2$.

This form factor will give the first experimental value for the electromagnetic radius of the kaon. The anticipated error on the determination of the radius is 0.03 F.

The measurement will be carried out with the E216 spectrometer, modified by the addition of a drift chamber system to improve its spatial resolution (see Fig. 1). The spectrometer consists of three blocks of coordinate detectors. The first block has two stations of proportional chambers and two drift chamber packages which measure the trajectory of the particle incident on the liquid hydrogen target to an angular precision of at least 0.01 mrad. The second block, between the target and the analysis magnets, consists of three proportional chamber stations and two drift chamber packages. These detectors will measure the scattering angles of both the kaon and electron to an accuracy of better than 0.03 mrad. The third block, behind the analysis magnets, is composed of six magnetostrictive wire spark chambers. These chambers record the trajectories of the particles after the magnets and thus determine their momenta. The angular resolution of the third block is about 0.08 mrad. The rest of the spectrometer includes scintillation counters, a sixth proportional chamber station between the magnets, a trigger hodoscope of scintillation counters which requires two particles in the third block, and a lead glass shower counter array which is used to identify electrons both for the fast trigger and in off-line analysis.

The experimental design is determined by our previous π-e experience, both in E216 and at Serpukhov.[1] To cleanly identify elastic events and reject background, it is necessary to measure the angles and momenta of both scattered particles. This information provides a four-constraint fit for every event: coplanarity, opening angle, transverse momentum balance, and total momentum. Since the form factors are dependent on the shape of the differential cross sections, we have designed an apparatus which has essentially flat (and nearly 100%) geometric acceptance across the entire q^2 range of interest.

The apertures of all chambers in the spectrometer were chosen so that the beam would go through their active areas with the analysis magnets on and off, allowing for precise calibration of the spectrometer at all times. Finally, significant corrections to the overall spectrometer efficiency are avoided by requirements in the beam signature that the incident particles are well separated in time.

II. PHYSICS INTEREST

A study of matter using the well understood electrodynamic laws has played a fundamental role in physics. In particular, the concept of the extended structure of elementary particles resulted from electron scattering experiments in which deviations from point scattering behavior were measured. In order to explain the experimental data on nucleon electromagnetic structure, the existence of the vector mesons was postulated.[2] The vector mesons, ρ, ω, and ϕ, which play a significant role in elementary particle physics were subsequently detected. Since their spin and parity are the same as the photon's, they are used to describe the coupling of the hadrons to the electromagnetic interaction in the vector dominance model.[3] In this model, the charge radius of the pion is calculated to be 0.63 F. Similarly, vector dominance predicts the kaon radius to be 0.58 F.[4]

Simple vector dominance relies on the nearest singularity (e.g., the ρ pole for the pion form factor) for calculation of these results. However it is not clear that the nearest singularity controls the entire range of virtual photon effective masses up to $q^2 = 0$. Moreover, vector dominance meets with difficulty in attempting to describe the nucleon form factor in the spacelike region. In contrast to its successes in the timelike region (as observed in colliding beam experiments[5]) this model does not correctly predict the charge radius of the proton or the q^2 dependence of the nucleon form factors. Precise values of the kaon and pion form factors are the most direct tests of this model.

Knowledge of the ratio of the pion radius to that of the kaon is a further sensitive test. Vector dominance predicts a ratio $(r_\pi / r_K)^2 = (0.63/0.58)^2 = 1.18$. This ratio is also a test for other models which attempt to describe the pion and kaon charge structures. For example, quark models have been constructed which predict a ratio of about 1.[6]

In contrast to the pion form factor, where electroproduction experiments[7] have extracted (in a model dependent way) form factors consistent with vector dominance, this method is impractical for the kaon form factor. The position of the K meson pole is far from the physical region because of its large mass and hence its contribution to the photoproduction amplitude is diminished. Other singularities however, such as the K^* pole, give important contributions in the physical region making this a very dangerous method for attempting to determine the K meson form factors. A direct measurement of the form factors in Ke scattering is the only experimentally feasible technique.

The first measurement of the K meson charge radius is a unique experiment which can only be done at Fermilab.

III. EXPERIMENTAL SETUP: DESIGN CONSIDERATIONS AND PERFORMANCE

The experimental setup is shown in Fig. 1. It is essentially the E216 setup with drift chambers added for improved resolution. A differential Cerenkov counter for kaon identification is placed in the beam and minor changes have been made in the trigger hodoscope and shower counter to correspond to the kaon elastic scattering kinematics.

The principal design features are dictated by: (1) an absolute cross section measurement to a precision of 1% and (2) an acceptable trigger rate.

1. Beam Logic

A beam particle signature requires a B_0, B_1, B_2 scintillation counter coincidence with the differential and threshold Cerenkov counters. High efficiency for track finding is achieved by additional beam logic conditions which produce a clean environment for the operation of the spectrometer. A scintillation counter pulse amplitude is used to veto two or more particles in one r.f. bucket. An additional two-particle beam veto is derived from the proportional wire chambers in front of the hydrogen target. The beam and trigger logic is designed ("effective kill") to reduce the number of events with an extra beam track within the detector memory times to a minimum and to allow tagging those that remain as a separate class of events with a separate beam normalization. This procedure approaches "zero beam intensity" conditions and allows highly efficient chamber operation at high data rates. However, the usable beam is reduced by an amount that depends upon time structure of the beam as extracted. Usable beam (including effects of deadtime after each trigger) was 40% in our 100 GeV run and 50% in our 200 GeV test. These runs had effective kill times of 1.7 microseconds.

2. Beam Flux

A 250 GeV/c K^-/π^- yield ratio of 0.04 for 400 GeV/c protons can be estimated from published yield studies.[8] The ratio drops to 0.032 at our hydrogen target because of decay. For a total beam flux of 500,000 per spill, 16,000 will be kaons. Our recent experience indicates that a one microsecond kill is satisfactory. The useful kaon flux becomes 8,000 per spill for a 70% duty factor.

3. Liquid Hydrogen Target

The hydrogen target has been constructed along the lines of the Dubna design for the Serpukhov experiment with thin, flat, pressure-equalized end windows on the liquid flask. It is 50 cm long and 12.5 cm in diameter. The target length is thus accurately known as is its density from vapor pressure measurements. The vacuum windows are well removed from the liquid hydrogen and are distinguished geometrically from the liquid hydrogen as a scattering source. A 10 cm diameter bubble shield inside the flask prevents bubbles from passing through the interaction volume.

4. Trigger Rate

The trigger consists of the beam signal defined above together with at least two particles through the last two proportional wire chamber stations, two particles through the trigger hodoscope, and the presence of an electron in the shower counters indicated by a pulse amplitude safely above threshold for K-e elastic scattering. Furthermore, the hole counter A5 with a brass converter is used to veto hadronic backgrounds. The brass converter also removes K-e associated delta ray electrons from this veto. E216 studies indicate that inefficiencies and biases are exceedingly small with this loose trigger.

With 8,000 kaons per pulse, trigger rates as high as 10×10^{-4} triggers per incident kaon will be acceptable and pose no limitation of the data rate.

In E216, the 100 GeV/c pion trigger rate was 1.4×10^{-4} and the test with 200 GeV/c pions gave a trigger rate of 2.6×10^{-4}. We expect a trigger rate of roughly 3×10^{-4} for 250 GeV/c kaons.

5. Geometric Acceptance

For 250 GeV/c K-e elastic scattering the spectrometer has flat and close to 100% geometric acceptance for the simultaneous detection of the kaon and the electron over the momentum transfer region:

$$0.03 \leq q^2 \leq 0.13 \ (\text{GeV/c})^2 .$$

Figure 2 shows the geometric acceptance achieved for our 100 GeV run. It will be similar at 250 GeV for the kaon q^2 range above.

6. Spectrometer Resolution -- Background Rejection

Our experience with π-e scattering indicates a background that increases with energy. If we define background to be the number before cuts of non-elastic two prong events under the elastic π-e peak for a given kinematic variable, we find a background to signal ratio of 0.20 at 50 GeV/c (Serpukhov), 0.60 at 100 GeV/c (E216), and 1.50 for the 200 GeV/c test. This increase can be qualitatively understood through the shrinkage of the forward strong interaction cone and the increase in charged particle multiplicity.

The background at 100 GeV/c after cuts (or after fitting the π-e elastic hypothesis) is about 1%. In view of the rise in background with energy, we might extrapolate to an average kaon background at 250 GeV/c of as much as 10% after cuts, a serious problem for accurate measurement of the cross section, especially for high q^2.

We intend, however, to improve our spectrometer resolution with drift chambers and expect to gain an order of magnitude in rejection of background.

We can illustrate this improvement in terms of the average transverse momentum imbalance for elastic events $\overline{\Delta p_{\perp}}$, a quantity determined largely by the resolution of the measured scattering angles. The spatial resolution of our proportional wire chambers is 0.5 mm which provides a 0.10 mr resolution for the reconstructed space angle. The measured average momentum imbalance for 100 GeV/c π-e events is 10 MeV/c and at 200 GeV/c is 18 MeV/c. These results are consistent with the above angular resolution if the multiple scattering contribution is taken into account. We predict a momentum imbalance of 22 MeV/c for 250 GeV/c kaons.

With drift chambers in the first and second blocks of the spectrometer, we expect to achieve spatial resolution of 0.1 mm, resolution of scattering angles of 0.03 mr (including multiple scattering in the 50 cm liquid hydrogen target), and hence transverse momentum imbalance resolution of 7 MeV/c. With an improvement from 22 to 7 MeV/c we can expect an order of magnitude improvement in background rejection.

The momentum resolution of the spectrometer is limited by the angular resolution of the third block spark chambers, which is about 0.05 mr (in the plane of bend). This corresponds to $\Delta p = 0.4$ GeV/c for particles at a typical value of half the incident energy. This uncertainty is smaller than the spread of the incident beam, 2.5 GeV/c, and smaller than the typical radiative momentum loss.

7. Radiative Corrections

Radiative corrections to the π-e data have been calculated by Bardin and Michelmacher.[9] The corrections vary from 6% at low q^2 to about 15% at high q^2. Because of the dependence of the corrections on experimental conditions, it is not useful to express them in analytic form. A Monte Carlo program was written for their calculation and was used for the Serpukhov and E216 experiments. It is being modified for the K-e calculation at 250 GeV/c.

IV. REQUEST FOR RUNNING TIME

In order to measure the kaon radius to an accuracy of 0.03 F we require 10,000 K-e elastic events. This requirement is based on the following three items: (1) the goal for the systematic error on the determination of the absolute cross section is 1%, (2) the energy of the primary particles is 250 GeV, and (3) the events have a range of energy of the scattered electron between 30 and 128 GeV.

In order to obtain 10,000 K-e elastic events we require 500 hours of actual data taking. This estimate of 500 hours depends on:

1) Cross Section: 3.2 μbarn.

   This represents the integrated cross section between electron energies of 30 GeV and 128 GeV and assumes vector dominance for the kaon form factor.

2) Beam Rate: 8000 useful K's per spill and 360 spills/hour.

   This estimate is based on a K^-/π^- production ratio of 0.04 and

500,000 beam particles per spill. It accounts for a 50% loss of beam due to the requirement that incident particles be well separated in time.

3) Target: 50 cm of liquid hydrogen.

Our specific request for running time can be summarized as follows:

1)	Checkout Time This category represents beam tuning and checkout of new and modified pieces of apparatus which include drift chambers, hodoscope, and shower counter.	200 hours
2)	Data Collection Time We apply a factor of 1.20 to the number of 500 hours quoted above to account for empty target runs (10%), beam runs (5%), and spectrometer efficiency.	600 hours
	Total:	800 hours

This estimate of 800 hours of beam time does not take into account accelerator inefficiency.

All of the apparatus used in E216 will be required. The PREP equipment now assigned to the experiment (including the portacamp and the spark chamber gas purifying cart) would be needed for the K - e experiment. The differential Cerenkov counters at present in the M1 East beam line would be needed. Additional apparatus is to be provided:

A. By Fermilab:

1. Drift chamber readout system	$18000
2. Drift chamber high voltage supplies and distribution boxes	$10000
3. Drift chamber low voltage supplies	$ 1000
4. Air conditioning for drift chambers	$ 3000

B. By the experimenters:

1. Drift chambers for blocks I and II (see Appendix A)	exist
2. Amplifiers and gas system for drift chambers	exist
3. Fermilab Physics Department contribution to new apparatus (drift chamber stands, cabling, gases are examples)	$11000

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APPENDIX A: DRIFT CHAMBERS

The drift chamber system to be added to the spectrometer consists of four modular packages. Each package consists of four X and four Y planes which gives a total of 32 drift chamber planes to be added to the system. The chambers have a total of 144 sense wires; each sense wire in the second block will have two digitizer channels assigned to it to allow for multiple hits on one wire. The drift chambers, their amplifiers, and the gas system were constructed at JINR, Dubna and are now at Fermilab. A 288 channel digitizing readout system is to be supplied by Fermilab.

The chambers are constructed according to a working CERN design (Charpak & Sauli).[10] The drift cell size is 21 mm which gives a maximum drift time of less than 500 nanoseconds. Neighboring planes of drift chambers are staggered to avoid left-right ambiguities. Drift chambers made with epoxy molding give good reproducibility of the gaps. The mechanical accuracy of the chamber details and spacing of the signal wires is about 10 microns. The working gas mixture is 67.2% of argon, 30.3% of isobutane, and 2.5% of methane.

APPENDIX B: PION FORM FACTOR

We have measured the pion radius in our E216 run at 100 GeV/c. The physics in the shape of the form factor is exceedingly interesting. A threshold energy for significant results is 250 GeV/c. While we are quite interested in obtaining simultaneous pion data during the kaon run if it does not interfere with the kaon data taking, we feel that the present spectrometer is useful to 350 GeV/c if the M1 beam line is upgraded. We are studying the possibility of pion form factor measurements at highest energies and intend to submit at a future date a proposal to carry out significant measurements on the shape of the pion form factor.

B_0, B_1, B_2, A_H, A_5, SeSp — Scintillation Counters
All PWC Stations = 2X planes, 2Y planes
All DC Stations = 4X planes, 4Y planes
(R) = Rotated chamber(s)
(Transverse Dimensions are not to scale)

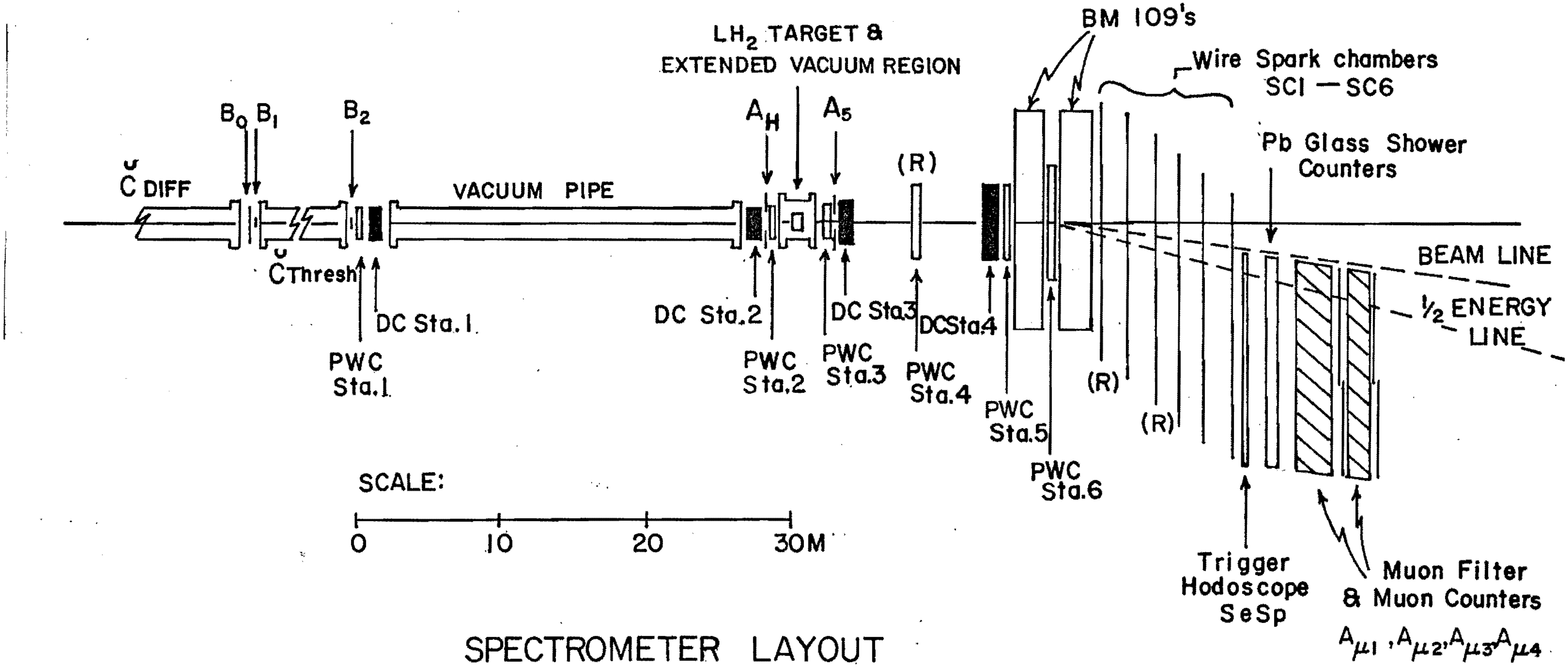

Figure 1

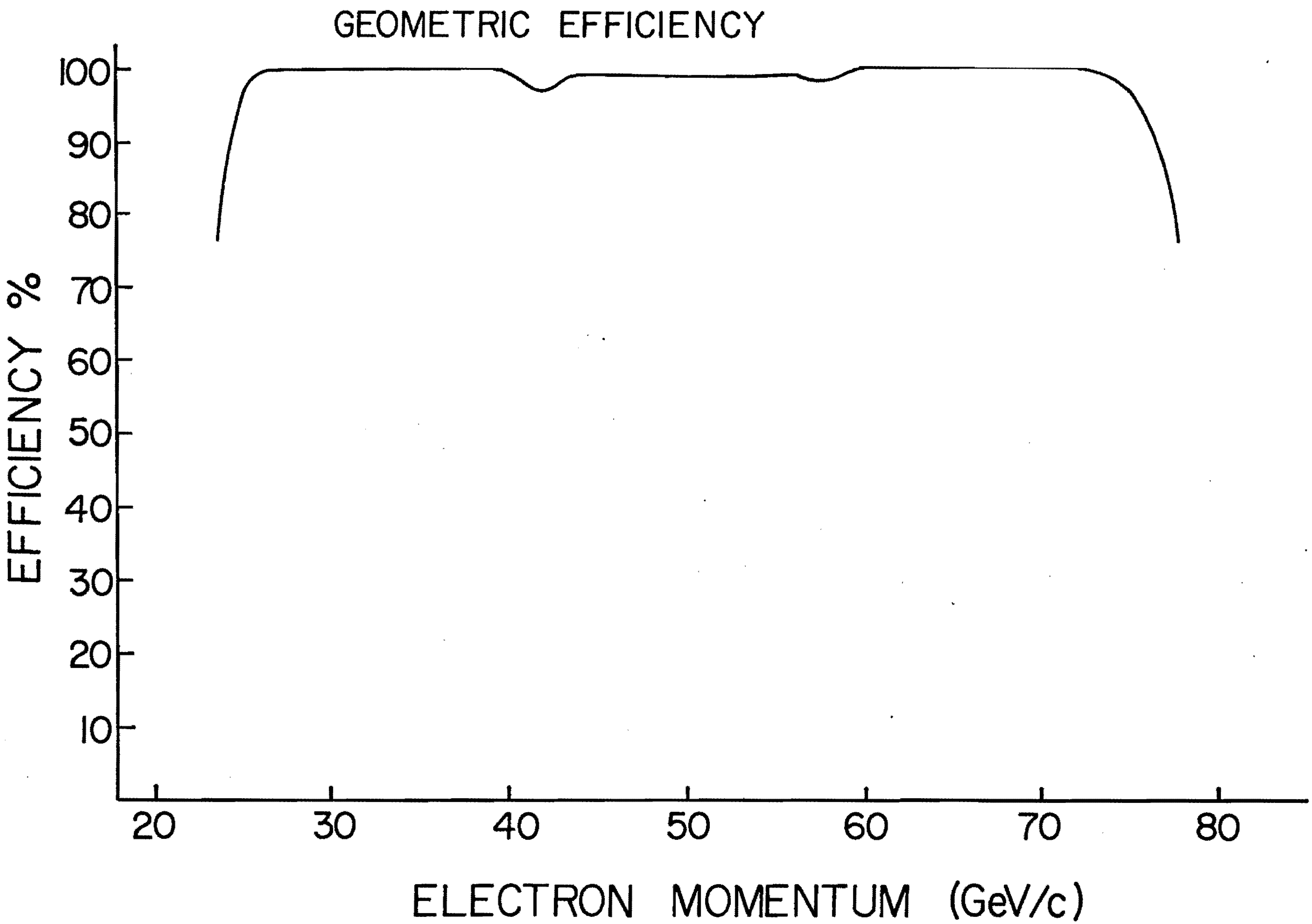
GEOMETRIC EFFICIENCY
EFFICIENCY %
100
90
80
70
60
50
40
30
20
10
20
30
40
50
60
70
80
ELECTRON MOMENTUM (GeV/c)

Figure 2