NAL PROPOSAL NO. 101

ELASTIC $\pi^+ e^-$ SCATTERING

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ABSTRACT

We propose to measure the elastic scattering of 100 GeV pions from electrons using a single arm spectrometer. The momentum transfer range which would be covered is 0.02 to 0.08 $(GeV/c)^2$. The method has sufficient consistency checks so that one would expect to obtain cross sections with typical accuracy of ± 3%. If the pion charge radius is similar to that of the proton (r = 0.81 F.), this experiment provides a measurement of the radius with an accuracy of ≃± 0.03 F.

INTRODUCTION

The importance of a reliable measurement of the electromagnetic form factor of the pion (and kaon) is evident. Present information suggests that the pionic radius is less than 1 fermi[1], although even this is not a hard fact. There is already a plan to carry out a large experiment on elastic π-e scattering at IHEP[2]. We are aware of two proposals[2] that have been made at NAL to do this experiment. However, the technique used in all three of these are similar in nature and subject to a different set of systematic errors than the method being proposed here.

DESCRIPTION OF THE EXPERIMENT

The experiment would be carried out with the high resolution, single arm spectrometer facility in Area 2. A positive beam† (3×10^6 π's and 1.5×10^7 protons per pulse),

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†A preliminary design for the 2.5 mrad beam has been given in NAL Report TM-223-2254 (March 5, 1970). We assume that the final system will have the flexibility to allow a trade-off of spot size and angular divergence at the target. With this in mind, we have taken the beam properties at the target as

$$\Delta X = \pm 1.5 \text{ mm}$$

$$\Delta Y = \pm 4.0 \text{ mm}$$

$$\Delta\psi_x = \pm 0.11 \text{ mrad}$$

$$\Delta\psi_y = \pm 0.11 \text{ mrad}$$

$$\frac{\Delta p}{p} = \pm 0.15\%$$

in which the π^+ is identified by means of a set of Cerenkov counters, will pass through a 20" hydrogen target, into the spectrometer and dump in a beam stopper after the first bend magnet. The spectrometer will collect negative secondaries over the angular range of ± 2.5 x ± 4.5 mrad with respect to the beam. A set of wire chamber hodoscopes located behind the spectrometer will measure the scattering angle ($\Delta\theta$ = ± 0.2 mrad) and the momentum ($\Delta p/p$ = ± 0.25%) of the secondary. Electrons will be distinguished from pions by the combination of a transition radiation detector and a shower counter.

The kinematic relation between the elastically scattered electron energy and angle, together with the spectrometer acceptance is shown in Fig. 1. The momentum acceptance is ~± 2%. Consequently, at each momentum setting, one is measuring a 4% bite in q^2. One would expect to take 5 to 10 such points over the q^2 range of 0.02 to 0.08 $(GeV/c)^2$.

RATES

The cross section for the coulomb scattering of an electron from a spin 0 particle is given by[3]

$$\frac{d\sigma}{d\Omega} = \frac{Z^2 r_o^2}{4} \cdot \frac{(1-\beta^2 \sin^2\frac{\theta^*}{2})}{(\beta^2\gamma)^2 \sin^2\frac{\theta^*}{2}}$$

where

r_o = 2.82 x 10^{-13} cm.

θ^* = the center of mass scattering angle

γ = E^*/m, the electron's center of mass energy to mass ratio

This may be converted into a differential laboratory cross section per unit final electron energy

$$\frac{d\sigma}{dE} = \frac{2\pi}{m(\gamma^2-1)} \frac{d\sigma}{d\Omega}$$

Using $N_\pi = 3 \times 10^6$ pions/pulse, $n_e = 2 \times 10^{24}$ electrons/cm^2 corresponding to a 20" hydrogen target, and $\Delta E = 0.04$ E for a 4% momentum acceptance, the rates shown in Table I were calculated from

$$\frac{\text{RATE}}{\text{PULSE}} = N_\pi n_e \frac{d\sigma}{dE} \Delta E \left(\frac{\Delta\phi}{2\pi}\right)$$

$$\frac{\text{RATE}}{\text{HOUR}} = 800 \frac{\text{RATE}}{\text{PULSE}}$$

BACKGROUNDS

A. Negative Pions

Using the particle yields per interaction, $\frac{dN}{d\Omega dp}$, from the 1969 Summer Study[4], we have calculated the π^- background assuming that the π^- yield from (π^+P) is the same as from (PP). The total π^- rate/pulse into the spectrometer acceptance along with the rate under the electron peak (here we've taken $\Delta\theta = \pm 0.3$ mrad) are shown in Table II. Comparison of these with the electron rate from elastic scattering, shows the pions to be ~300 times more numerous. Therefore, one would like to have a pion rejection of 10^4 or better. Simple shower counters can provide a factor of 10^2. By monitoring the shower development, one can obtain an additional order of magnitude.

Transition radiation detectors[5] have not to our knowledge been used as a mass separator in a physics experiment to date. However, this appears to be an ideal problem for this device. In the X-ray region the photon energy yield is proportional to γ of the charged particle. For a 2 GeV electron incident on a stack of 230 aluminum foils, 25μ thick, Yuan[5] has observed ~12 X-ray photons in the spectral range 6-200 KeV. Extrapolating this to 20 GeV electrons, our worst case, the number of photons in the energy interval 6 to 2000 KeV is 20; their total energy is 7 MeV. Our latest ideas for building such a gadget would place the aluminum stack upstream of the last bend magnet and detect the transition photons in a thick detector behind the magnet. At the present time, we expect to be able to obtain factors of 10^3 or more in suppressing pions. One will probably be limited by the background accidental rate in the photon detector.[††] There should be no difficulty in obtaining the required discrimination factor of 10^4 by cascading a transition radiation detector and shower counter.

[††]It is also quite practical to use synchrotron radiation to distinguish electrons. For example, a 20 GeV electron traveling through 2 meters of a 20K Gauss magnetic field emits 8 photons in the energy range 0.1 to 1.0 MeV with a total energy of 2 MeV. These could be detected upstream in a NaI crystal.

B. Electrons from π° Decay

Assuming the π° spectrum at the target is the same as π^- we have estimated the number of electrons in the spectrometer from pair production by the π° decay photons. The results are shown in Table II. The worst case occurs at low secondary momentum, where the number of background electrons will equal those from elastic scattering. However, because the spectrometer acceptance is 5 to 10 times larger than the phase space occupied by the elastic peak, one will have ample information on the behavior of the background to make a subtraction.

A second line of attack on reducing background is to install a set of veto counters upstream of the first spectrometer quadrupole. These would intercept particles emitted from the target at an angle greater than 10 mrad. Since our overall trigger rates are not too high, the veto signals would not be used in the trigger logic, but would be available for rejecting background electrons in the analysis. The total rate in the veto counters will be $\sim 2 \times 10^6$/pulse.

CONSISTENCY CHECKS

In writing this proposal, we have in mind that the experiment would be run after the initial spectrometer testing and joint experiment[6]. By this time the spectrometer and beam line characteristics would be well understood and

documented. The main parameters which must be known for the absolute cross section are:

1. The momentum calibration of the spectrometer and the beam line.

2. The momentum dispersion, so that one can define an acceptance.

Presumably, these will have been measured to an accuracy commensurate with the momentum resolution capability of the system ($\frac{\Delta P}{p} \leq \pm 0.05\%$). For a momentum acceptance of 4% this means an uncertainty in the cross section of $\leq \pm 1.3\%$.

A second important source of error in this type experiment can come from counter efficiency. For example, in attempting to get rid of negative pions it is easy to throw away 5 or 10% of the electrons. The regions which must be covered by the detectors are small. Therefore, we can afford and expect to be highly redundant in the detectors. This will enable us to keep our counter efficiencies under surveillance.

RADIATIVE CORRECTIONS

The radiative corrections for the primary interaction for this type experiment have been discussed in great detail[7]. For a 1-2% experiment the virtual and soft photon corrections will have to be re-examined to ascertain the necessity of including two photon vertices on the pion. We have made a crude estimate of the magnitude of the hard photon correction. If we restrict the electron momentum to lie within ± 0.5% of

the kinematically required value for the two body final state, the loss due to hard photon emission is ≈20%.

An additional correction will have to be made for losses from Bremsstrahlung radiation of the electron in leaving the target. For the same resolution discussed above, this loss will be ≈14%.

Both of these corrections are thought to be well understood. They depend on our knowledge of the experimental resolution as LOG $(\frac{E}{\Delta E})$ and consequently should not present a limitation in the experiment.

RUNNING TIME REQUEST

To obtain 4000 events at each of the seven q^2 values listed in Table I will require 225 hours. To allow for checking and the usual inefficiencies, we request 400 hours of running time. We will also require ~100 hours of beam time to check out the beam and spectrometer detectors.

We would be able to demonstrate feasibility (and do an initial measurement) with 100 hours of data taking time in addition to the 100 hours of check out.

APPARATUS

We expect NAL to provide the spectrometer facility and its associated beam Cerenkov detectors, spectrometer hodoscopes, and online computing facility. We require a 20" hydrogen target which should be provided by NAL. Since there are no significant special requirements on this target, we

believe that there will be a satisfactory target on hand. A beam dump, capable of handling 10^8/pulse at 100 GeV/c, will have to be set up in the 20m drift space after the first spectrometer bend magnet.

The proposers of the experiment will provide the transition radiation detectors, shower counter, and their associated electronics for the experiment. These will be tested ahead of time at the user's home laboratory.

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6. The spectrometer facility is to be constructed by a joint NAL-User Group. This group is submitting a proposal to do an initial experiment on the spectrometer in order to shake down the system.

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θ^* (DEG)	Ee (GeV)	$\frac{\Delta\phi}{2\pi}$	$\frac{d\sigma}{dEe}$ (μb/GeV)	RATE / HOUR	q^2 $(GeV/c)^2$	$\lvert F(q^2)\rvert^2$	
45	12.2	0.09	1.45	308	0.012	0.98	
60	20.9	0.12	0.44	214	0.021	0.96	Range of this Experiment
75	31.0	0.17	0.17	170	0.031	0.94	
90	41.8	0.44	0.073	260	0.042	0.92	
105	52.6	0.63	0.033	212	0.053	0.90	
120	62.7	1.0	0.016	192	0.063	0.88	
135	71.4	1.0	0.0077	106	0.071	0.86	
150	78.0	1.0	0.0030	44	0.078	0.85	
165	82.1	1.0	0.001	16	0.082	0.84	
180	83.7	1.0	2×10^{-7}	1.6×10^{-3}	0.084	0.84	

TABLE I SUMMARY OF RATES

1. Cross section and rate calculated for a point interaction.

2. $\lvert F(q^2)\rvert^2$, form factor for a mean pion radius of 0.5 fermi.

P (GeV/c)	π^+-e^- RATE (PULSE^{-1})	TOTAL π^- RATE (PULSE^{-1})	π^- RATE UNDER PEAK (PULSE^{-1})	e^- RATE UNDER PEAK (PULSE^{-1})
20	0.26	1080	86	0.19
40	0.32	880	150	0.077
60	0.24	360	83	0.010
80	0.06	40	3	2.7×10^{-5}

TABLE II BACKGROUND RATES

1. Spectrometer Momentum.
2. Expected rate from π^++e^- elastic scattering.
3. Total π^- rate into the spectrometer.
4. π^- rate under the elastic electron peak.
5. Background electron rate under the elastic peak.

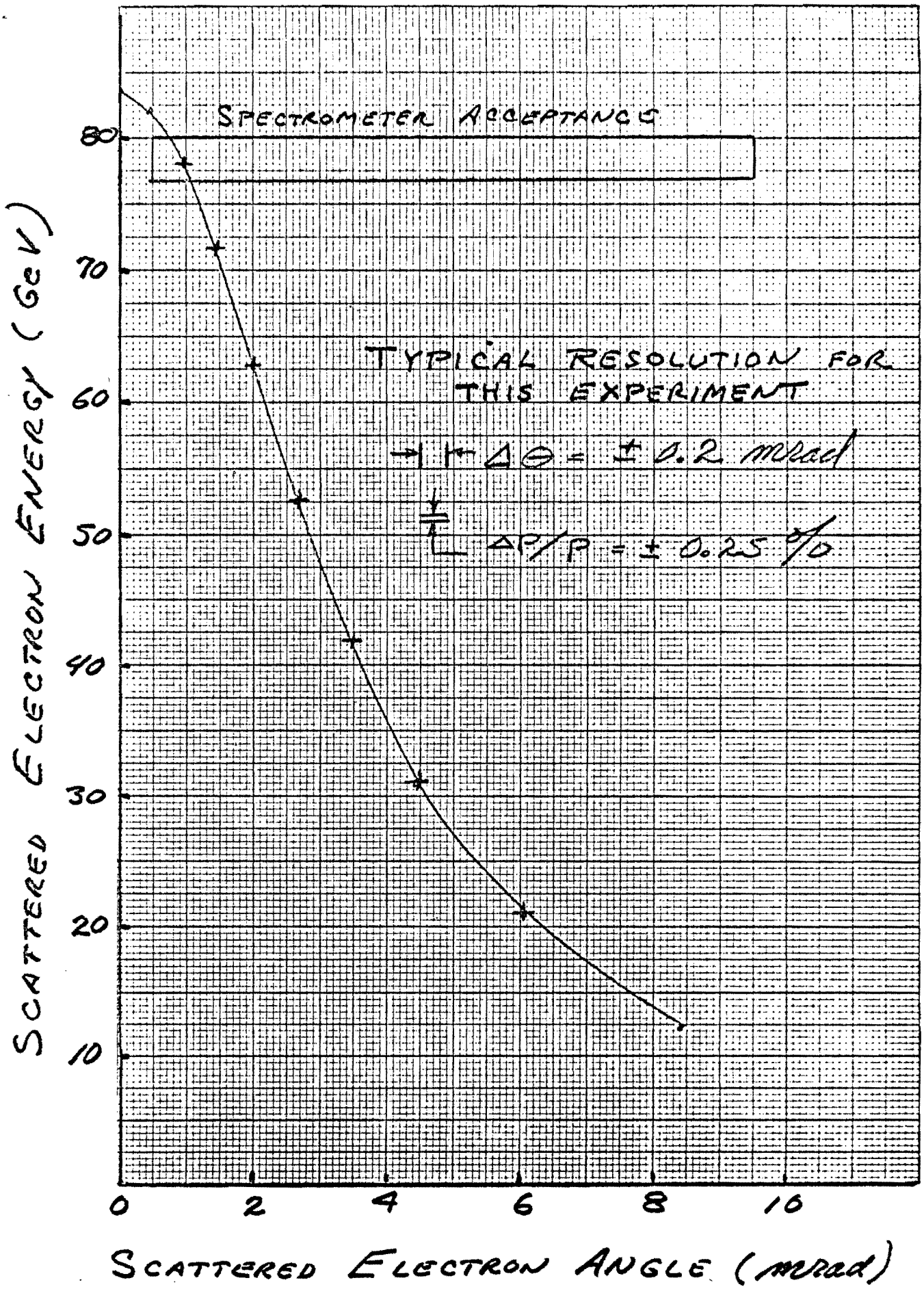

FIG. 1

K&E 10 X 10 TO ½ INCH 46 1322
7 X 10 INCHES MADE IN U.S.A.
KEUFFEL & ESSER CO.