E-136
7/11/80

PROPOSAL FOR
MEASUREMENT OF THE ELASTIC ELECTRON-PROTON CROSS SECTION AT LARGE MOMENTUM TRANSFER

Submitted by

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ABSTRACT

We propose to measure the absolute value of the cross-section for electron-proton scattering at three values of momentum transfer $Q^2 = 12.1$, 23.6 and 37.3 $(\mathrm{GeV}/c)^2$ with good statistical precision ($\sim$ 50 events at the highest Q^2), using the high intensity SLED and non-SLED beams and the facilities of End Station A. This data on an important and fundamental scattering process at large Q^2 will be compared with recent QCD calculations and, in conjunction with data from other experiments, will provide important information on the strong coupling constant as $\alpha_s(Q^2)$ and on the scaling behavior of quark-quark interactions. We request 1044 hours of data-taking time (180 pps, 100% efficiency), including background running and consistency checks. In addition, we will require one month of low rate (10 pps) running for checkout. Elastic events will be detected, using a coincidence measurement between the 8 GeV and the 20 GeV spectrometers. The major items of equipment required are: an upgrade of the A-bend to transport 30 GeV beams; a VAX computer for the Counting House; a set of proportional wire chambers for the 8 GeV spectrometer (if an existing set is not available on loan). We expect to be ready for checkout in the fall of 1981.

E-136

THE AMERICAN UNIVERSITY
WASHINGTON, DISTRICT OF COLUMBIA 20016

College of Arts and Sciences
DEPARTMENT OF PHYSICS

April 8, 1981

G. E. Fischer
EPAC Secretary
Stanford Linear Accelerator Center
P.O. Box 4349
Stanford, CA 94305

Dear Gerry:

Here is a copy of our "Proposal for a measurement of elastic electron-proton cross section at large momentum transfer", SLAC Experiment E136, which was reviewed by the EPAC and the Deputy Director at their last meeting September 4-5, 1980. As your letter of 12 September indicated, the Deputy Director and the committee were strongly supportive of our proposal, but the financial situation at that time would not allow them to make a decision to recommend full approval of our project. We were deferred with encouragement until the financial future of the laboratory was better understood.

It is my understanding from conversations with the Director that the present budget situation will allow End Station A to be reopened for high energy experimentation in FY1982, and that he intends to do so. With that statement and assuming that the present financial situation holds, it appears that the conditions for full approval of E136 are at hand.

We hereby resubmit our proposal for consideration at the upcoming EPAC meeting on May 15.

Sincerely,

Raymond G. Arnold

Raymond G. Arnold

RGA/wh
Enclosure

STANFORD UNIVERSITY

STANFORD LINEAR ACCELERATOR CENTER

Mail Address
SLAC, P. O. Box 4349
Stanford, California 94305

September 12, 1980

Prof. R. G. Arnold
Department of Physics
The American University
Washington, DC 20061

Dear Ray:

This brief note is to inform you formally of action taken by the SLAC Deputy Director regarding your "Proposal for a measurement of the elastic electron-proton cross section at large momentum transfer". The decision, taken upon the recommendation of the Experimental Program Advisory Committee at their meeting of September 4-5, 1980,was to defer the decision until such time at which there will be a better understanding of the FY82 budget prospects.

It may be of use to know that the Committee and Deputy Director were strongly supportive of your proposal on the basis of physics considerations but felt it necessary to exercise prudent caution by not at this time committing the laboratory to reopen ESA in FY82 due to budget considerations.

During the Committee's deliberations there was a fair amount of discussion regarding your proposed run plan. In particular, the merits of investing so much running time to the highest q^2 data point - a point which requires "sledded operation" with an upgraded beam switchyard. Some members felt that the point $q^2 \simeq 23.6\ (\mathrm{GeV}/c)^2$, if sufficiently well determined might yield results precise enough to distinguish between models. These comments are relevant should it become possible and/or wise to combine your data taking with that of experiment E-137 which was approved "in principle" at this meeting.

You are therefore encouraged to remain in close contact with the laboratory in the early part of the coming calendar year and will probably be asked to resubmit your proposal when the financial future of the laboratory becomes better understood.

Very sincerely yours,

G. E. Fischer
EPAC Secretary

cc: A. Abashian, NSF Washington
D. Berley, DOE Washington
J. Ballam/R. Mozley
J. Cronin, EPAC Chairman
S. Drell
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R. E. Taylor

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I. INTRODUCTION AND SUMMARY

When the original SLAC e-p elastic scattering measurements were performed ten years ago,(1) the form factor of the nucleon was, in some sense, an experimental curiosity to be compared to the empirical dipole law. With the coming of age of quantum chromodynamics, elastic eN scattering should attain its rightful place as a fundamental process amenable to serious theoretical calculation. Previous high-Q^2 measurements(1,2) have been limited by running time rather than by serious backgrounds. Furthermore, the increased energy available from SLED provides both an increased range in Q^2 over which measurements can be made, and, for a given value of Q^2, a larger cross-section. We therefore feel that it is now appropriate to perform an experiment devoted to the measurement of the elastic e-p cross-section at high Q^2.

A naive QCD argument predicts that the magnetic form factor of the proton $G_{Mp}(Q^2)$ should be given by

$$Q^4 G_{Mp}(Q^2) \propto \alpha_s^2(Q^2), \tag{1}$$

where Q^2 is the absolute value of the mass of the exchanged virtual photon and $\alpha_s(Q^2)$ is the strong coupling constant. As can be seen from Fig. 1, the existing measurements of G_{Mp} for $Q^2 > 5\ (\mathrm{GeV/c})^2$ are consistent with the predicted Q^{-4} scaling behavior (for comparison, note the Q^2 and $1/Q^2$ curves of Fig. 1). However, within the statistics of the present data, no evidence is seen for the expected logarithmic dependence of α_s upon Q^2. In the following paragraphs, we hope to demonstrate that it is important to QCD to search for deviations from the simple Q^{-4} behavior in order to obtain information on the behavior of the strong coupling constant $\alpha_s(Q^2)$. However, we must first admit to some of the limitations of the quantitative interpretation of the proposed measurements.

A correct perturbative QCD calculation for the magnetic form factor of the nucleon gives(3)

$$G_M(Q^2) = \frac{32\pi^2}{9} \frac{\alpha_s(Q^2)}{Q^4} \sum_{n,m} b_{nm} \left(\ln \frac{Q^2}{\Lambda^2} \right)^{-\gamma_n - \gamma_m} \left[1 + 0 \left(\alpha_s(Q^2), \frac{m^2}{Q^2} \right) \right] \qquad (2)$$

Here Λ^2 is the unknown QCD scale parameter, defined by

$$\alpha_s(Q^2) = \frac{4\pi}{\beta \ln(Q^2/\Lambda^2)}$$

$$\beta = 11 - 2n_f$$

$$n_f = \text{number of flavors}$$

The γ_n are known anomalous dimensions, and the b_{nm} are unknown constants determined by the hadronic wave function. They can be evaluated for a given parameterization of the hadronic wave function. Thus, the quantitative behavior of $\alpha_s(Q^2)$ is obscured by the Q^2 dependence of the coefficients of the model-dependent b_{nm}. However, we will argue below that these effects are expected to be, at best, comparable to the statistical precision of our proposed measurements.

The calculation is also subject to mass terms $O(m^2/Q^2)$ and higher order in α_s terms $O(\alpha_s(Q^2))$. The mass terms can be well minimized by measurements at sufficiently high Q^2. The higher order terms in α_s are calculable (at least to next-to-leading order) but as yet uncalculated. These terms are important not only for their direct effect upon G_M, but also for relating the scale parameter Λ^2 to those of other processes.

While one is left with theoretical uncertainties in attempting a quantitative analysis of the proposed measurements, this situation is hardly unique to elastic scattering. Within the context of QCD, e-p elastic scattering remains a fundamental process. When compared to other processes available for study, it possesses a number of advantageous features as a theoretical testing ground. We list, in brief, the following arguments for the importance of the measurements, and will elaborate on each point in subsequent paragraphs.

(1) It is important to see some effect of the running coupling constant, or at least to set stringent limits on its size, in order to obtain even a crude estimation of the scale parameter Λ^2.

(2) In contrast to inelastic lepton-nucleon scattering, higher-order twist terms in exclusive processes can reasonably be expected to be small.

(3) In contrast to inelastic lepton-nucleon scattering, the magnetic form factor is a leading-order QCD amplitude, as evidenced by its proportionality to α_s^2. At the same time, the presence of the purely QED electron-photon vertex results in significant computational advantages over hadron-induced reactions.

(4) The proposed measurements go to higher Q^2 values than other exclusive reactions, and provide a large span in Q^2 from a single experiment.

1. At present, there are no completely unambiguous quantitative measurements of the scale parameter Λ from any process. For this reason, it is important to obtain even qualitative information from as many different processes as possible. We note, for

example, that, in inelastic lepton-nucleon scattering, difficulties with higher twist terms (see below) prevent a reliable quantitative interpretation of scaling violation data. Nonetheless, the existence of these data has contributed significantly to the development of QCD. Just as it was important to obtain data on inelastic scaling violation, it is important to obtain data on the elastic form factor beyond the simple Q^{-4} behavior.

The interpretation of the results of the proposed experiment clearly will depend upon the results themselves. We consider the three possible outcomes of the experiment:

a. $d(Q^4G_{Mp})/dQ^2 > 0$: This result is contrary to all QCD expectations and would be of great significance.

b. $d(Q^4G_{Mp})/dQ^2$ consistent with zero: The simplest interpretation of this result would be that Λ is small. Since the effect of the model-dependent terms b_{nm} of Eq. (2) would correspondingly also be small, one should be able to place an upper limit on the value of Λ. Comparing the statistical errors of the proposed experiment with the QCD calculation of Ref. 3 (see Fig. 1), one can see that this would be a significant, even if fuzzy, limit.

c. $d(Q^4G_{Mp})/dQ^2 < 0$: In this case it is important to try to assess the effect of the model-dependent terms b_{nm}. In Ref. 3, G_{Mp} was calculated to first order in α_s, using two relatively extreme ansatzes for the form of the hadronic wave function (allowing an arbitrary normalization). The value of Λ^2 used was larger than is consistent with present data, which also amplifies the model-dependent effects. The results of the two cases, when normalized to the same value at $Q^2 = 10\ (\mathrm{GeV/c})^2$, gave values at $Q^2 = 40\ (\mathrm{GeV/c})^2$ which differed by an amount comparable to our proposed statistical error. The major theoretical uncertainty would then lie in the higher order in α terms. Here we can only emphasize that these terms are calculable, and hope that the measurement would stimulate progress on the theoretical front.

2. The QCD interpretation of scaling violation data in inelastic lepton-nucleon scattering is clouded by the presence of higher-order twist terms, which are not directly calculable from perturbative QCD. These are higher-order terms in $1/Q^2$, the most dominant of which are due to coherent effects between quarks of the nucleon. For these terms, the $1/Q^2$ suppression is offset by a kinematic enhancement at large x.(4) No such enhancement is expected for elastic scattering.(3) Note also that, for inelastic scattering, coherent effects can occur between valence quarks. For elastic scattering, the valence quarks are already scattered coherently, thus requiring any further coherent effects to involve virtual gluons or sea quarks.

Since sea quarks are created in pairs, and both must scatter coherently, the suppression factor for sea quarks is $1/Q^4$ rather than $1/Q^2$.

It has been shown(5) that (for purposes of demonstration) the inelastic scaling violation data could be explained entirely by higher-order twist terms. If these terms are neglected, one obtains values for the scaling parameter Λ^2 which appear to be considerably higher than those indicated by other measurements (including the presently existing elastic e-p data), indicating that higher-order twist terms are important. Thus, the relative absence of such terms in elastic scattering is significant.

3. In elastic scattering, the leading-order scaling behavior is determined by QCD, whereas, in inelastic lepton-nucleon scattering, the leading-order behavior is determined by QED, and it is only the violation of scaling which is determined by QCD. Thus, even the Q^4 behavior of the elastic form factor directly tests the scale invariance of the quark-quark scattering amplitude, as well as the elementary scaling of the quark and gluon propagators.

In common with inelastic lepton-nucleon scattering, the presence of the simple QED electron-photon vertex offers significant computational advantages over purely hadronic processes. For example, the QCD calculation of elastic e-p scattering involves only four leading Born terms, whereas elastic p-p scattering has more than 10^6 such terms.(3)

4. Experimentally, the proposed experiment covers a Q^2 range large in comparison with other SLAC data. It is of interest to compare the range of the proposed experiment with that of large-angle hadronic exclusive experiments, of which the most extensive data exist for p-p elastic scattering. Here, data at 90° in cm extend out to $s \sim 40$ GeV^2, or $|t| \sim 20$ GeV^2. If one were to plot $s^{10}\, d\sigma/dt$ vs. $|t|$ for this data, one would obtain a plot similar to our Fig. 1, in which $|t|$ is directly comparable to Q^2. Thus, good measurements of e-p scattering out to $Q^2 \sim 40$ (GeV/c)^2, which we consider to be practical, would provide a significantly greater lever arm for testing scaling behavior than do the p-p data.

The availability of high Q^2 data is also important in eliminating effects of mass terms. From inspection of Fig. 1, it can be seen that a Q^2 cut at 10 GeV^2 to eliminate mass terms is not overly conservative. Because the present data for $Q^2 > 20$ GeV^2 have very poor statistical precision, the use of a more conservative cut (say 15 GeV^2) would make even large deviations impossible to discern from the present data.

We note that the full Q^2 range can be covered by a single experiment, thus minimizing systematic errors. We also note that, because G_{Mp} is a function only of Q^2, logistics problems in handling the data are minimized. For example, the use of a Q^2 cut to eliminate mass terms does not introduce gaps or weighting problems in the coverage of other variables.

We propose to measure the elastic e-p scattering cross-section for values of $Q^2 = 12.1$, 23.6, and 37.3 $(GeV/c)^2$, using the End-Station-A 8 GeV and 20 GeV spectrometers in coincidence. Assuming a value of $Q^4 G_{Mp}/\mu_p = 0.4$ $(GeV/c)^4$. the measurement at the highest value of Q^2 would result in ∿ 50 events, corresponding to 7% statistical error in the value of G_{Mp}. The proposed statistical errors of the three points are shown in Fig. 1, illustrating the extended Q^2 range and, more importantly, the improved statistics obtained for $Q^2 > 20$ $(GeV/c)^2$. Because of the large Q^2 and the low cross sections involved in the measurement, the high energy and beam intensity of SLAC make it uniquely suited for this experiment.

Our reasons for choosing these kinematic set points and the assumptions we made to estimate the counting rates are explained in Section II. The experimental plan, the run time budget, expected backgrounds, and the performance of beams, spectrometers, and other hardware are also described in Section II. The detailed lists of requirements for SLAC resources are given in Section III.

II. THE EXPERIMENT

A. Goals, Limitations, Set Points

The goal of the experiment is a high quality absolute measurement of the e-p elastic cross-section to the highest Q^2 possible, using the SLED beam and the spectrometers of End Station A (ESA). The points selected and relative running times allocated have been chosen to optimize the determination of the slope of $Q^4 G_{Mp}/\mu_p$ between adjacent points.

To establish the optimum kinematic set points and running times, we have used the following criteria and experimental limitations:

(a) At the highest Q^2 point in the region of 40 $(GeV/c)^2$, we want at least 50 good events above background. This gives a measurement of $Q^4 G_{Mp}/\mu_p$ with ± 7% statistical errors.

(b) We want at least two other points with smaller errors at lower Q^2 values to determine the slope, with the lowest Q^2 point anchored around $Q^2 = 10\ (\mathrm{GeV/c})^2$ where previous high quality data exist.

(c) The SLED and non-SLED maximum beam parameters delivered through ± 0.5% slits to ESA are assumed to be:

	E (GeV)	Peak Current (mA)	Pulse Width (ns)	e^-/Pulse
SLED	29	150	150	1.41×10^{11}
Non-SLED	22	50	1500	4.23×10^{11}

(d) The scattered electrons are detected in the 8 GeV spectrometer, and the counting rate is maximized by running this spectrometer at 8.4 GeV/c, which is the highest momentum for which the gas Cerenkov counter can be used for electron identification.

(e) The recoil protons will be detected in the 20 GeV spectrometer with a maximum momentum of 21.5 GeV/c and a maximum angle of 20 degrees.

(f) To estimate cross-sections, we use $Q^4 G_{Mp}/\mu_p = 0.4\ (\mathrm{GeV/c})^4$.

(g) Sufficient running time will be required to measure a 10% empty target background.

For electron detection in the three End-Station-A spectrometers, the 8 GeV spectrometer run at (or near) its maximum momentum provides the highest statistics measurement of the cross-section for a given value of Q^2. The traditional combination of lead-glass pre-radiator, shower counter, and Cerenkov counter should provide adequate electron identification. However, the combination of high beam intensity, poor SLED duty cycle, and long target required by the experiment would produce intolerably high rates in the scintillation counter hodoscopes previously used in the spectrometer. To gain more redundancy in the track reconstruction capability of the spectrometer, we propose to replace the hodoscopes with proportional or drift chambers. The improved tracking ability would also be useful in ensuring that the detected particles originate from the target.

While we believe that the 8 GeV spectrometer alone will be sufficient to measure the high Q^2 elastic cross-section, the overlap of the 20 GeV spectrometer acceptance detecting protons is approximately 70% of the 8 GeV electron acceptance near $Q^2 = 40$ $(\mathrm{GeV}/c)^2$. Hence, relatively modest backgrounds in the single-arm measurement could result in a situation where the cleaner coincidence measurement gives superior results. In view of the large running time required by the experiment, we believe it prudent to ensure a quality measurement by placing both spectrometers in coincidence (as has previously been done in experiments E-101, E114, and E-121). Single-arm data from the 8 GeV spectrometer would still be accumulated so that, if the single-arm measurements give superior results, the coincidence data need not be used.

With the above factors in mind, we have chosen the kinematic set points at $Q^2 = 12.1$, 23.6, 37.3 $(\mathrm{GeV}/c)^2$. The energies, angles, and cross-sections are given in Table I. The run time budget is given in Table II. The projected error bars on $Q^4 G_{Mp}/\mu_p$ are plotted in Fig. 1. The particular considerations at each point are as follows:

<u>$Q^2 = 12.1$</u> This is the high-rate, low-Q^2 anchor point which we use for various internal consistency checks and as a cross-comparison with previous measurements. We have chosen this point to allow both a single- and double-arm measurement (the limiting element is the 20 GeV maximum angle of 20 degrees). The running time allows a 3.4% statistical error on the double-arm cross-section (1.7% error on G_{Mp}) with 900 events. This error is less than the expected overall systematic error, and can be achieved in quite reasonable running time.

$Q^2 = 23.6$ This point provides a nearly optimum lever arm in Q^2 for comparison with the $Q^2 = 12$ $(\mathrm{GeV}/c)^2$ point. It also corresponds to the maximum energy which can be run with a non-SLED beam, allowing a factor of 3 increase in total beam and a factor of 10 improvement in duty cycle. The use of both SLED and non-SLED beams at this point allows a cross-calibration check for rate effects due to the poorer duty cycle of the SLED beam. We estimate approximately 138 double-arm events in 120 hours, which yields a ± 4.3% measurement of $Q^4 G_{Mp}/\mu_p$.

$Q^2 = 37.3$ This point represents a compromise between the optimum lever arm for comparison with the $Q^2 = 23.6$ $(\mathrm{GeV}/c)^2$ point (~ 35 $(\mathrm{GeV}/c)^2$) and the maximum attainable Q^2 (39 $(\mathrm{GeV}/c)^2$ for the double-arm and 40 $(\mathrm{GeV}/c)^2$ for the single-arm measurement). For this point the beam energy is 28.5 GeV, somewhat below its absolute maximum energy. Over the course of the experiment this should result in a higher overall efficiency than would running at the absolute maximum energy.

In addition to empty target running, we have budgeted 55 hours for various kinds of calibration runs and consistency checks. These include running with a short target to check radiative corrections and solid angles, several measurements of the spectrometer acceptances using scattered electrons in the region of relatively flat cross-section in the deep inelastic, and rate tests using various beam intensities.

B. Beam and Target

1. Beam

The beam requirements for this experiment are listed in Tables I and II. Most of the running will use a SLED beam at a single energy of 28.5 GeV, with some SLED and non-SLED running at several lower energies. To deliver the high-energy SLED beam to ESA will require that the A-bend be upgraded to 30 GeV. This can be accomplished by adding two more existing bending magnets. A detailed plan for this modification has been worked out by the SLAC staff.

The beam parameter of primary interest to us (aside from the energy) is the average current delivered to ESA. For purposes of estimating running times, we have assumed nominal SLED beam parameters of 150 mA peak current and 150 ns pulse width through ± 0.5% slits, which corresponds to 1.4×10^{11} electrons/pulse into ESA.

In addition to the requested hours for actual data taking, we need at least one month (calendar time) of low rate (10 pps) checkout running for setting up the two spectrometers. For checkout we would prefer primarily non-SLED running.

2. Target and Scattering Chamber

The target assembly we request is a variation on the now-standard ESA target arrangement. We need two cells filled with liquid hydrogen, one long cell (60 cm), and one half-length cell (30 cm). In addition, we need three empty target cells: a long and a short cell with thick end-caps, and a long cell with thin end-caps. The exact cell dimensions are still under consideration, but they would be similar to the 57 cm cell used in E-121.

The only new feature beyond the cell designs used in previous experiments is that we will mount some Pb or W shielding on the target assembly to shield the target end caps from view in the 8 GeV spectrometer. At scattering angles around 20 degrees, the end caps can be geometrically completely shadowed by such shields, which should eliminate the end cap background from the electron spectrometer.

In addition to the empty and full cells, we need a solid target, which can double as a Zn/S screen, and a hole (no target) position.

The scattering chamber must be arranged to allow scattered electrons to be detected at angles from 15° to 30° in the 8 GeV spectrometer, while recoil protons must be detected at 8° to 20°. The spectrometers will both be moved during the running. The exact arrangement of bellows, He bags, windows, etc., is still under consideration.

C. Detectors and Rates

1. Detectors

a. 8 GeV Spectrometer Detectors

The 8 GeV spectrometer will be equipped with a combination of gas Cerenkov counter and lead-glass shower counters for triggering and particle identification, proportional wire chambers for momentum and angle determination, and scintillation counters for triggering during setup. The arrangement of detectors is shown in Fig. 2.

The 8 GeV Cerenkov counter is used in the long configuration, in which its length is increased to 2.5 meters by connecting it to the vacuum pipe of the spectrometer extending to Q83. In this configuration it was used successfully in E-114 and E-80 with N2 gas at 350 mm pressure, equivalent to an 8.37 GeV/c pion threshold.

Electrons will be detected in the pre-radiator, consisting of 6 lead-glass blocks 4 radiation lengths thick and the total absorption counter of 4 lead-glass blocks already built for the 8 GeV spectrometer. These were used in E-130. We very conservatively estimate a factor of 25 in hadron rejection from the lead glass and another factor of 20 from the gas Cerenkov counter, giving an acceptance of only 0.2% for hadrons. In addition, any real π^- must be produced with another pion and will then be outside our elastic missing mass limits.

To determine the angle and momentum of the particle, we plan on using a minimum of four modules of PWC's, two with x, y, and 45^o wire planes, and two or three with only x and y planes positioned between the Cerenkov and shower counters. The spacial resolution of a few millimeters allows the full resolution of the 8 GeV spectrometer to be exploited. We expect approximately two hits/chamber-plane to be recorded per event with a 50 ns trigger. However, even at the high rate of 5 hits/chamber-plane/event, the probability of reconstructing a track using these random noise hits and the constraints of the 8 GeV optics is only a few parts in 10^5 for a four-module system.

The E-130 Group has built and used a set of PWC's which satisfy our requirements and which will fit into the 8 GeV hut. If these are available, using them would be the most economical way to instrument the spectrometer. If not, we propose to have built a set of four PWC modules, two with vertical, horizontal, and 45° wires, and two with only vertical and horizontal wires. We will instrument the wires to match the 8 GeV acceptance. This region would vary between 70 cm and 100 cm long and 18 cm and 40 cm high. With 2 mm wire spacing, there will be a total of about 3500 instrumented wires. This would become a permanent facility for the 8 GeV spectrometer. We are also investigating alternate methods, such as the use of drift chambers, to see if they are more cost effective.

b. 20 GeV Spectrometer Detectors

The 20 GeV spectrometer will be equipped with the same set of detectors as in E-133. This consists of a Cerenkov counter (to reject pions), three trigger counters, five planes of PWC's and shower counters. The electron detection equipment will be used to calibrate the spectrometer.

2. Rates

In discussing counting rates in the detectors, one must distinguish between "real" particle rates (due to particles of the correct momentum coming up the spectrometer) from soft (primarily electromagnetic) room background, which leaks through the shielding. In this experiment, "real" particle rates are negligible compared to background "singles" rates. Potential backgrounds due to "real" particles are discussed in Section D.

Our estimate of singles rates in the detectors is based on direct experience from E-133, E-121, E-101, E-87, and E-114 at incident energies of 20 GeV and angle and momentum settings similar to this experiment. The rates from these experiments agree when renormalized for target length and type and scattering angle. The rates used below have been normalized to a 150 ns long, 150 mA peak current SLED beam. Compared to non-SLED running, this is three times the peak current, one third the average current, and one tenth the spill length. The rates below are for a 50 cm long hydrogen target.

a. 8 GeV Spectrometer Rates

The singles rates in scintillation detectors range from 20/spill at the very front end of the hut to 5/spill at the p focal plane to 3/spill at the rear end of the hut. These rates are too high to be usable, so the trigger will use signals from only the Cerenkov counter, pre-radiator, and shower counter. The counting rate in the Cerenkov counter is expected to be ∿ 0.5/spill. Rates in the shower counter and the pre-radiator will be lower. All the shower counter data we have immediately available reflect the "real" particle rates in the spectrometers; therefore, we do not have information on the singles rates in the shower counter. However, we note that experiment E-4 used the 8 GeV spectrometer to measure an elastic cross-section only twice as large as that of our highest Q^2 point. Their experiment used a shower counter and the momentum and the theta scintillator hodoscopes. The superior electron identification and track reconstruction of our experiment should easily compensate for our lower cross-section and higher instantaneous rates.

Based on measurements with the 20 GeV proportional wire chambers, we estimate the counting rate for the PWC's of the 8 GeV to be about the same as scintillation counters. The factor of 10 loss in time resolution of PWC's compared to scintillators is more than made up for by the accuracy in spacial measurement and redundancy in the number of positions at which the track is measured.

b. 20 GeV Spectrometer Rates

Singles rates will be about 0.5/spill in scintillation counters. This is comparable to the instantaneous rate during previous measurements.

D. Physics Backgrounds

Because the spectrometers are set for elastic scattering, and because of their small (± 2%) momentum acceptance, several limitations are placed on the kinematics of potential background processes. In particular:

(i) The phase space for single pion production, in which the electron is detected in the 8 GeV spectrometer and either the pion or the proton is detected in the 20 GeV spectrometer, is severely limited.

(ii) The missing mass resolution of the 8 GeV spectrometer alone is sufficient to resolve single pion production from elastic scattering.

(iii) While the missing mass resolution of the 20 GeV spectrometer is not sufficient to resolve elastic scattering from single pion photoproduction, it is sufficient to resolve single pion electroproduction for which the electron is sufficiently energetic to reach the 8 GeV spectrometer acceptance.

Before embarking on a detailed discussion of the particle rates in the spectrometers, we first list the points we are attempting to establish:

(i) Sources of electrons in the 8 GeV spectrometer are small, compared to the elastic cross-section.

(ii) The pion-to-electron ratio in the 8 GeV spectrometer is sufficiently small that electron identification is reliable.

(iii) "Real" particle rates in both spectrometers are sufficiently small that the coincidence between the two spectrometers is reliable.

To estimate "real" particle rates other than electrons, we may replace electroproduction with an equivalent radiator ($\sim 4.5\%$), which we combine with half the radiation length of the target ($\frac{1}{2} \times 6\%$), and treat all particles as coming from photoproduction. Because the spectrometers are set for elastic kinematics, we may confine our attention to quasi-two-body photoproduction reactions. These may be estimated from the large-angle photoproduction data of Anderson et al.(7) for photon energies between 4 and 6 GeV. An s^{-7} cross-section dependence predicted by parton models (and verified in Ref. 7 between 4 and 6 GeV) is then used to extrapolate to our energies. For Compton scattering, we use the data of Shupe et al.(8) and an s^{-6} dependence.

Although it is somewhat disconcerting that the energy extrapolation covers $5\frac{1}{2}$ orders of magnitude in cross-section, the results at least are not alarming. In particular, the calculations indicate that the cross-sections for most photoproduction reactions are comparable to that for elastic scattering, while the cross-section for Compton scattering is expected to be an order of magnitude smaller.

The most serious potential source of electrons in the 8 GeV spectrometer is from inelastic electron scattering in the end-caps of the target. Here the Fermi motion in the complex nuclei can smear the kinematics to allow inelastic electrons in the elastic kinematic region. For this reason, we propose to place "collars" on the target ends to shield the end-caps from the spectrometer acceptance.

One might also expect electrons from the photon reactions $\gamma p \rightarrow \gamma p$ and $\gamma p \rightarrow \pi^o p$, in which the final state photons are converted to e^+e^- pairs. Either reaction is suppressed by 3 to 4 orders of magnitude by the conversion probability and the requirement that the electron carry the full energy of the pair. The π^o reaction is further suppressed by the requirement that a single photon carry the full energy of the π^o. Thus, the final electron rate from these two reactions is roughly 5 orders of magnitude below that for elastic scattering.

The principal photoproduction reaction giving particles in the 8 GeV spectrometer is $\gamma p \rightarrow \pi^- \Delta^{++}$. If our estimates of the cross-section are correct, the pion rejection of the pre-radiator and the shower counter (∿ 25) should be adequate. The Cerenkov counter should provide an additional factor of ∿ 25 in pion rejection. Furthermore, as has already been mentioned, the spectrometer has adequate missing mass resolution to reject these events, and the probability of the 20 GeV spectrometer also detecting the proton from the Δ^{++} decay is extremely small.

The 20 GeV spectrometer will detect photoproduced single pions and kaons as well as the recoil proton from a variety of reactions, with the result that the real particle rate should be roughly 1 order of magnitude higher than that for elastic scattering. Clearly, this rate would not provide a source of accidental coincidences with the 8 GeV spectrometer.

III. REQUIREMENTS

A. Beam

- 1044 hours of mostly SLED running at 180 pps, 100% efficiency, 1.4×10^{11} electrons/pulse through ± 0.5% slits into End Station A (see Table II). The primary requirement is to maximize the average beam current.
- Upgrade A-bend to transport 30 GeV beams to End Station A.
- One month (calendar time) of low rate (10 pps) checkout time, preferably mostly non-SLED running.

B. Target and Scattering Chamber

- Standard End Station A target assembly with five cells:

  60 cm LH2
  60 cm empty, thick end-caps
  60 cm empty, thin end-caps
  30 cm LH2
  30 cm empty, thick end-caps

  and

  Al-Zn/S solid target
  no target position

- Scattering chamber with targets visible at 8° to 20° in the 20 GeV spectrometer and 15° to 30° in the 8 GeV spectrometer.

C. Spectrometers

- 8 GeV: Assembled, surveyed, movable 15° to 30°, equipped to detect electrons with:

  Cerenkov counter in extended mode*
  10 planes of PWC's (3500 wires)**
  lead-glass pre-radiator and total absorption shower counters*
  scintillation trigger counters*

*Existing

**May be available on loan from the Yale Group

- 20 GeV: Assembled, surveyed, movable 8° to 20°, equipped to detect protons (and electrons for calibrations) with:

  Cerenkov counter*
  5 planes of PWC's*
  3 scintillation trigger counters*
  lead-glass pre-radiator and total absorption shower counters*

D. Electronics and Computers

The normal complement of fast logic for a double arm experiment (similar to E-101 and E-121) will be requested from HEEP (exact details are still under consideration). We also request that the previously existing configuration of VAX computer be reinstalled in the Counting House. The downstream leg of LSI/11 beam steering system will be used to maintain the beam on target.

E. Date

We expect to be ready to begin checkout in the fall of 1981.

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*Existing

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TABLE I

KINEMATICS AND CROSS SECTIONS

Q^2 (GeV/c)^2	E_i (GeV)	θ_e (deg)	E_f (GeV)	θ_p (deg)	p_p (GeV/c)	$\frac{d\sigma}{d\Omega}$(a) (cm^2/sr)
12.1	14.0	19.5	7.54	20.0	7.33	1.16×10^{-36}
23.6	21.0	21.0	8.44	13.0	13.4	2.83×10^{-38}
37.3	28.5	22.5	8.60	9.10	20.8	2.01×10^{-39}

(a) $Q^4 G_{Mp}/\mu_p = 0.4$ (GeV/c)^4

TABLE II

COUNTING RATES*

			Counts/Hr		Total Counts		Hours	
Q^2	Beam	TGT Length (cm)	Single Arm	Double Arm	Single Arm	Double Arm	TGT Full	TGT mT
12.1	normal	60	290	26	4670	420	16	3
12.1	normal	30	150	30	2400	480	16	3
23.6	SLED	60	2.0	0.67	155	50	76	23
	normal	60	6.2	2.0	271	88	44	13
37.3	SLED	60	0.12	0.084	72	50	595	200
							747	242
						Data Time =	989	
Solid Angle Measurements		60					20	
		30					5	
Consistency Checks		60					30	
						Calibration =	55	
							TOTAL =	1044

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*See following page for assumptions.

TABLE II (cont'd.)

COUNTING RATES

Assumptions

Beam:

SLED - 150 mA peak, 150 ns width into ± 0.5% slits
1.41×10^{11} electrons/pulse into End Station A

Non-SLED - 50 mA peak, 1500 ns width into ± 0.5% slits
4.22×10^{11} electrons/pulse into End Station A

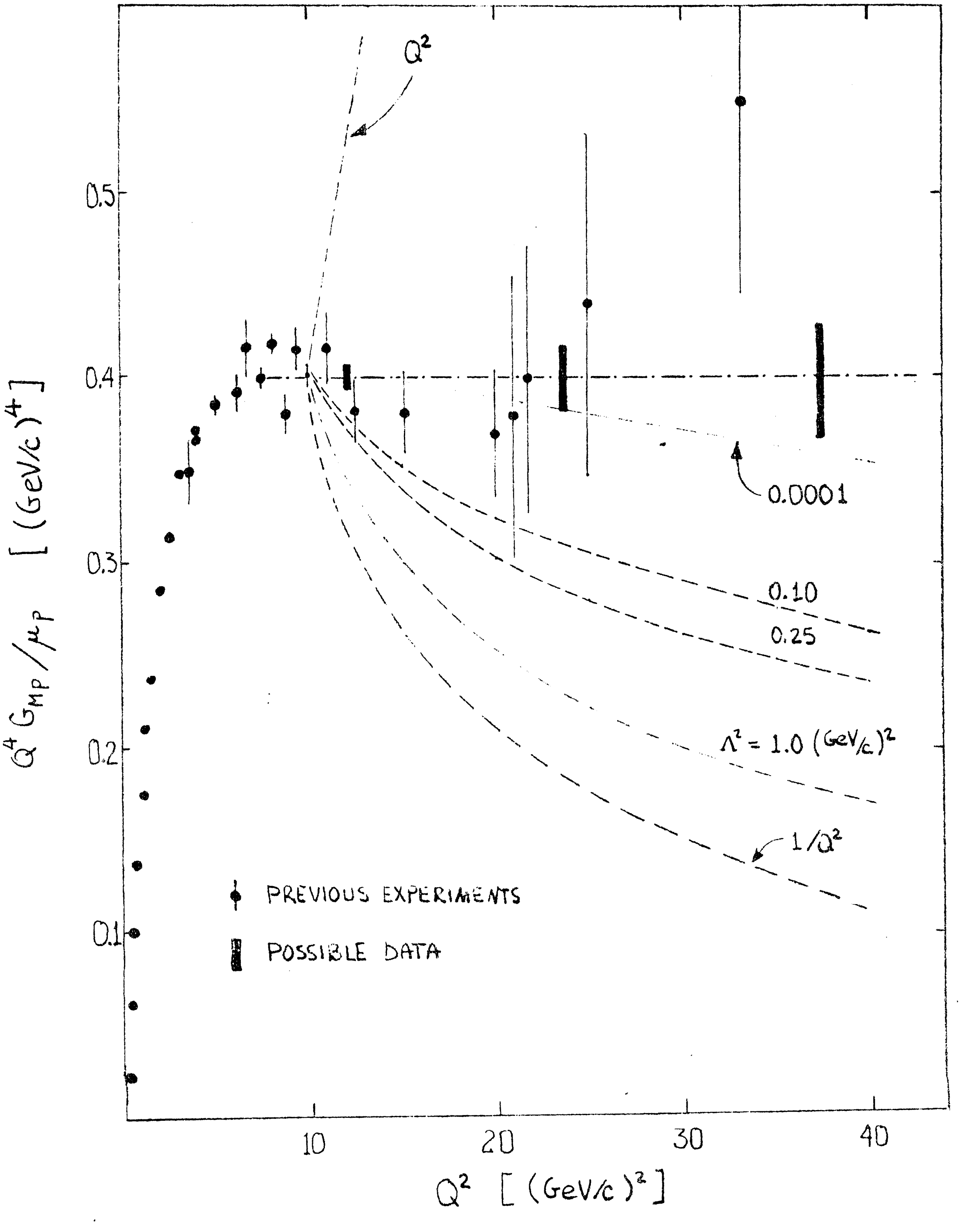
Target: LH2 length = $20/\sin\theta_e$ (cm)

Spectrometers: (Acceptance) x (radiative correction) from Monte Carlo with reconstructed electron missing mass cut at $0.6 < M_x^2 < 1.1$ $(\mathrm{GeV}/c^2)^2$

Cross Sections: Rosenbluth form with $Q^4 G_{Mp}/\mu_p = 0.4$ $(\mathrm{GeV}/c)^4$

FIGURE CAPTIONS

1. $Q^4 G_{Mp}/\mu_p$ versus Q^2. The experimental data are from Refs. 1 and 2. The curves labeled Q^2 and $1/Q^2$ indicate the effect of one more or less power of Q^2. The curves labeled with the scale parameter Λ^2 are a QCD calculation from Ref. 3. The statistical error bars of the proposed experiment are also indicated.
2. The detector arrangement in the 8 GeV spectrometer used to detect the scattered electrons.



Q^2
0.0001
0.10
0.25
$\Lambda^2 = 1.0\ (GeV/c)^2$
$1/Q^2$
PREVIOUS EXPERIMENTS
POSSIBLE DATA
0.5
0.4
0.3
0.2
0.1
$Q^4 G_{Mp}/\mu_p\ [(GeV/c)^4]$
10
20
30
40
$Q^2\ [(GeV/c)^2]$

Figure 1

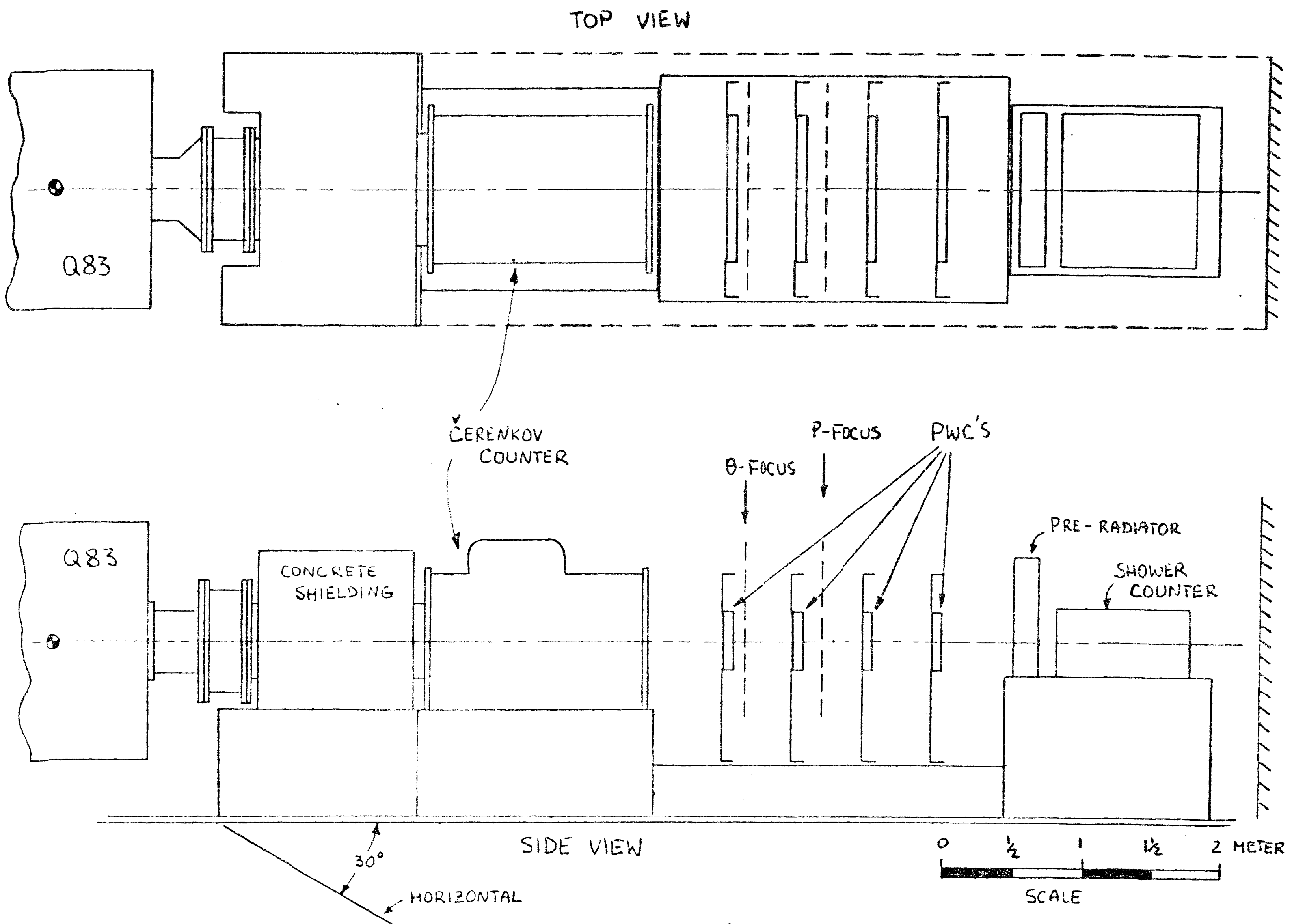

TOP VIEW
Q83
ČERENKOV COUNTER
θ-FOCUS
P-FOCUS
PWC'S
PRE-RADIATOR
SHOWER COUNTER
Q83
CONCRETE SHIELDING
SIDE VIEW
30°
HORIZONTAL
0
½
1
1½
2 METER
SCALE

Figure 2