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Supplement No. 2 to
SLAC Proposal No. 4-b

DATE: 26 July 1968

TO : Program Coordinator

FROM : R. E. Taylor

SUBJECT: Extension of Experiment 4b.

To date, we have used 196 hours of beam time in experiment 4b. A considerable amount of this time was spent in check out and testing. From this 196 hours, we have useful inelastic spectra at

$$\theta = 6^\circ, \ E_0 = 7, 10, 13, \text{ and } 16 \text{ GeV}$$
$$\theta = 4^\circ, \ E_0 = 7 \text{ and } 16 \text{ GeV}$$
$$\theta = 8^\circ, \ E_0 = 17 \text{ GeV.}$$

Several interesting results are evident even in this fragmentary data.

1. The dependence of the deep inelastic scattering (missing mass $W > 2$ GeV) on q^2 is much weaker than the elastic dependence. This scattering, therefore, becomes the dominant feature of the data even for moderate q^2 (~ 4 $(\text{GeV}/c)^2$).

2. The resonant structure observed is dominated by resonances at 1236, 1510, and 1688. Some evidence can be obtained for excitation of the 1920 level. The first three resonances mentioned behave roughly in the manner predicted by Walecka and Zucker (Phys. Rev. 167, 1467 (1968)). The rapid fall off of the resonances with q^2 makes observation of the resonances difficult for $q^2 \sim 3\text{-}4(\text{GeV}/c)^2$, and above. This experimental fact considerably narrows the range over which the resonances can be studied at SLAC.

We have also gained some experience in the experimental techniques necessary for reliable data taking.

1. Beam requirements seem to be more severe than other experiments. The large number of energy changes required are taking more time as the complexity of operations at SLAC increases. With many multiple beams, energy changes take much longer than anticipated, especially for low energies.

   The high resolution needed for these experiments makes it difficult to get a flat beam spill in multiple operation. Both these factors increase the calendar time necessary to get a given number of hours.

2. In the experimental running for G_E, we found that the target density changed with beam current. This has raised some doubts about the present data. We have designed better targets for our next runs. In the future, some time will have to be devoted to target tests, and in some cases, it may be necessary to restrict the current to lower values than anticipated.

3. The correcting of the data for radiative effects requires spectra at several energies at a given angle. Four energies appears to be a minimum from our experience at 6^o, and we would like to increase this number to 5 or 6, and also, extend the range of each spectrum. We also wish to spend some time checking the effects of extra radiators.

4. There are considerable numbers of positrons at high inelasticities. Each spectrum must have a companion e^+ spectrum.

5. There is evidence that a small amount of pole face scattering is occuring in the experiment. We would like to investigate the problem.

Our present program is outlinedin Table I. The main objective is a separation of the transverse and longitudinal (or W_1 and W_2) contributions to the cross section for the deep inelastic region $W > 2$ GeV. In addition, a large amount of resonance information will be collected although we will not be able to make good separations of σ_T and σ_L as it is not practical to obtain the low energies required while in multiple operation.

A third result expected will use the small angle data taken for the separation to obtain an estimate of the total photon absorption cross section to beyond 10 GeV.

At this time, we would like to request an extension of 200 hours to continue this work. With reasonable luck, this should allow completion of a large fraction of the indicated program.

In the unlikely event that the program should be completed in a shorter time than is presently scheduled, we would like to have permission to make one or two engineering runs on D_2. We plan to submit a proposal on deuterium inelastic scattering to check Bjorken's sum rules.

$$1) \quad \int_0^0 d\nu \left[W_{2p}(q^2, \nu) + W_{2n}(q^2, \nu) \right] > \tfrac{1}{2}$$

$$2) \quad \lim_{q^2 \to \infty} \int_0^\infty d\nu \left[W_{2p}(q^2, \nu) - W_{2n}(q^2, \nu) \right] > \tfrac{1}{3}$$

From our present data, we can say that the contribution of W_{2p} to the first integral appears to give a reasonable expectation that the sum rule will be satisfied.

We would like to get a rough idea of the behavior of the cross sections for Deuterium to help us construct a proposal, if there is time during the coming runs.

TABLE I

Aug. 1968	a)	Target test, pole face scattering investigations			
		θ	Spect	Eo	Purpose
	b)	6°	20	10,13.5,16,(18)	Check 6° triangle for target density effects and increase range of q^2 and ν available.
	c)	10°	20	7,10,13,16,18	higher q^2 behavior and data for separation of σ_L and σ_T (or W_1 and W_2).
Sept.	d)	1.5°	20	5,7,9,11,13,15,17,?	Precision data for finding $\sigma_T(0)$, the total photo cross section, and also for separation. Look for Roper resonance.
Oct.	e)	18° 26° 34°	8	7,10,13,16,18	higher q^2 and separation

Supplement No. 1 to Proposal 4b.

DATE: 28 October 1966

TO : Professor M. Sands

FROM : L. W. Mo and R. E. Taylor

SUBJECT: SLAC Proposal No. 4b -
The Electron-Proton Inelastic Scattering Experiment.

In reply to your letter concerning the Group A electron-proton inelastic scattering experiment, we feel that this program should be continued into the second scheduling period.

In the 100 hours of running time allotted for this experiment in the first scheduling period, we will attempt to identify as many nucleon resonances as possible and gain some understanding of the variation of cross section for different resonances with changes in the kinematic variables. Some additional time would be desirable in the second scheduling period to complete this survey measurement, and to study the problem of backgrounds due to other particles and radiative processes. We will probably take a small amount of the allotted time to measure inelastic electron spectra at large angles using the 8-BeV/c spectrometer, during the electron-proton elastic scattering runs.

We would like to begin a program to measure the form factors associated with the nucleon resonances found in the survey. As mentioned in the original proposal, this part of the program will probably involve the 8-BeV/c spectrometer too.

In view of the lack of definite information on electroproduction upon which to predict the counting rates, or even what nucleon resonances will be subject to observation, it is impossible at this time to justify a large number of accelerator hours in the second scheduling period. Some information has to be gained in the survey experiment to justify our future request of running time. We do feel that 200 hours for completion of the survey and rather complete measurement on the form factors of the 1.238-BeV isobar should be reserved in the second scheduling period, if possible, subject to change in the event that new features come to light in the first 100 hours of operation.

After the initial measurements, it should be clear what following experiment should be proposed.

LWM:RET:as
c.c. W. K. H. Panofsky

To: Program Coordinator

From: E. Bloom and R. E. Taylor
10 May 1968

PROPOSED MEASUREMENT OF THE TOTAL PHOTO ABSORPTION CROSS SECTION

During the 4b run this August, Group A proposes a measurement of the total photo absorption cross section $\sigma_{\gamma p}$ from threshold to $W_{\gamma p} \sim 5$ GeV. The measurement would be accomplished by placing the 20 GeV spectrometer at $\theta = 1.5^{\circ}$, and hence, observing low q^2 electroproduction from protons.

Using the representation given by Hand,$^{(1)}$ the cross section for inelastic scattering can be expressed (within the approximation of one photon exchange) as

$$\frac{d^2\sigma}{d\Omega dE_2} = \frac{\alpha}{4\pi^2}\,\frac{K}{q^2}\,\frac{E_2}{E_1}\left(\frac{2}{1-\epsilon}\right)(\sigma_T + \epsilon\sigma_S) = \Gamma_T\,(\sigma_T + \epsilon\sigma_S)$$

were

$$K = q_o - q^2/2M_N = \frac{W_{\gamma p}^2 - M_N^2}{2M_N}$$

and

$$\epsilon = \frac{1}{1 + 2(1 + q_o^2/q^2)\tan^2\theta/2}$$

Gauge invariance tells us that $\sigma_S \xrightarrow[q^2\to o]{} q^2\left(\frac{d^2\sigma}{dq^2}\right)_{q^2=0}$, while $\sigma_T \xrightarrow[q^2\to o]{} \sigma_{\gamma p}$. Hence, if q^2 can be made small enough, one can obtain $\sigma_{\gamma p}$ from electroproduction.

The experimental procedure used in obtaining $\sigma_{\gamma p}$ is as follows: Data are taken at a number of angles centered at 1.5°, and at several energies (c.f. fig. 1). The (radiatively corrected) data is then plotted

$(d^2\sigma/d\Omega dE_2)\ 1/\Gamma_T$ V.S. q^2 at a given $W_{\gamma p}$. If q^2 is small enough a linear dependence on q^2 will result. Linearly extrapolating to $q^2 = 0$ yields $\sigma_{\gamma p}$. A number of rough estimates can be made of how small q^2 must be to make a linear extrapolation. In these estimates, the scalar cross section, σ_S, will be neglected compared to σ_T, since $\sigma_T \gtrsim \frac{\sigma_S}{q^2}$ should be a reasonable assumption,(2) (and only a factor of 2 or 3 estimate can be expected in any case).

1) Assuming that the resonance region and the elastic scattering peak have a similar q^2 dependence,(3) we obtain the following limits.

$$\sigma_T \approx G_{Ep}^2\ \sigma_{\gamma p} = \left(\frac{1}{1 + q^2/.71}\right)^4 \sigma_{\gamma p}, \text{ or for small } q^2,$$

$$\sigma_T \xrightarrow[q^2 \to 0]{} 1 - \frac{4q^2}{.71} + \frac{4*3}{2}(q^2/.71)^2 + \dots \quad .$$

For a linear extrapolation to be valid, the second order term must be small compared to the linear term; so we require,

$$q^2 << 2/3\ .71 = .5\ (\text{GeV}/c)^2\ ,\ W_{\gamma p} \overset{\sim}{<} 2\ \text{GeV}.$$

2) Assuming ρ dominance in the region above $W_{\gamma p} = 2$ GeV,(2),(4) we obtain,

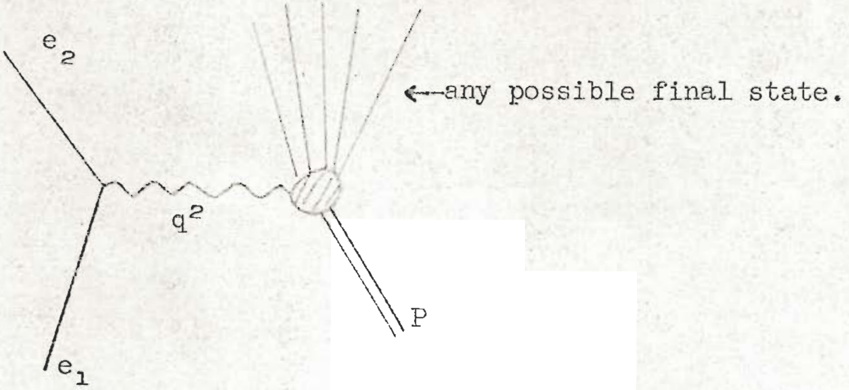
$$\sigma_T \approx \sigma_{\gamma p}\left(\frac{1}{1 + q^2/m_\rho^2}\right)^2 \Longrightarrow q^2 << 1.2\ (\text{GeV}/c)^2,\ W_{\gamma p} > 2\ \text{GeV}.$$

Note that estimates (1) and (2) are rough, and are probably only good to a factor of 2 or 3. We feel that they are "reasonable" estimates, and indeed, that (1) is probably a bit harsh.(5)

As one proceeds to small $\theta(q^2)$, the radiative tail from the elastic scattering peak gradually dominates the inelastic spectrum. One must therefore compromise, obtaining the lowest q^2 possible consistent with measuring the inelastic scattering signal. $\theta = 1.5^\circ$ appears to be such an angle. Figure 1 shows the kinematics of the experiment for this angle. As it shows, a rather large kinematic region can be covered. The percentage indications sprinkeled through the figure are estimates (in percent) of the signal due to the elastic peak tail(6), (neglecting "target" wall contaminations). We feel that the elastic peak radiative tail is known well enough,(7) so that one could extract the inelastic signal for tail contaminations $\lesssim$ 80%. Also note the indicated kinematics for e-e scattering. Clearly, e-e scattering will be no problem.

In conclusion, it should be noted that measurements at $\theta = 1.5^\circ$ are interesting in terms of the general inelastic program. Our data would greatly extend the HEPL results of Lynch et al.(8), and would provide information over a large range of $W_{\gamma p}$ in the forward angle inelastic data.

Notation:



$e_1(e_2)$ is four-momentum of incident (scattered) electron.

$q^2 = (e_1 - e_2)^2$ is the momentum transfer in electron-proton collision. P is four-momentum of target proton. (In lab $P = (0, M_p)$). We assume one photon exchange completely dominates inelastic electron scattering; hence, we define, $W_{\gamma p}$ as the C. M. energy of the γp system in the zero q^2 limit. When we refer to θ, we are speaking of the scattering angle between e_1 and e_2 in the laboratory.

References:

1) L. N. Hand, Phys. Rev. 129, 1834 (1963).

2) Private communication, S. Berman, W. Schmitt.

3) A. J. Dufner and Y. S. Tsai, SLAC-PUB-364 (1967).

4) J. D. Bjorken, Proceedings 1967 International Symposium on Electron and Photon Interaction at High Energies. Page 116.

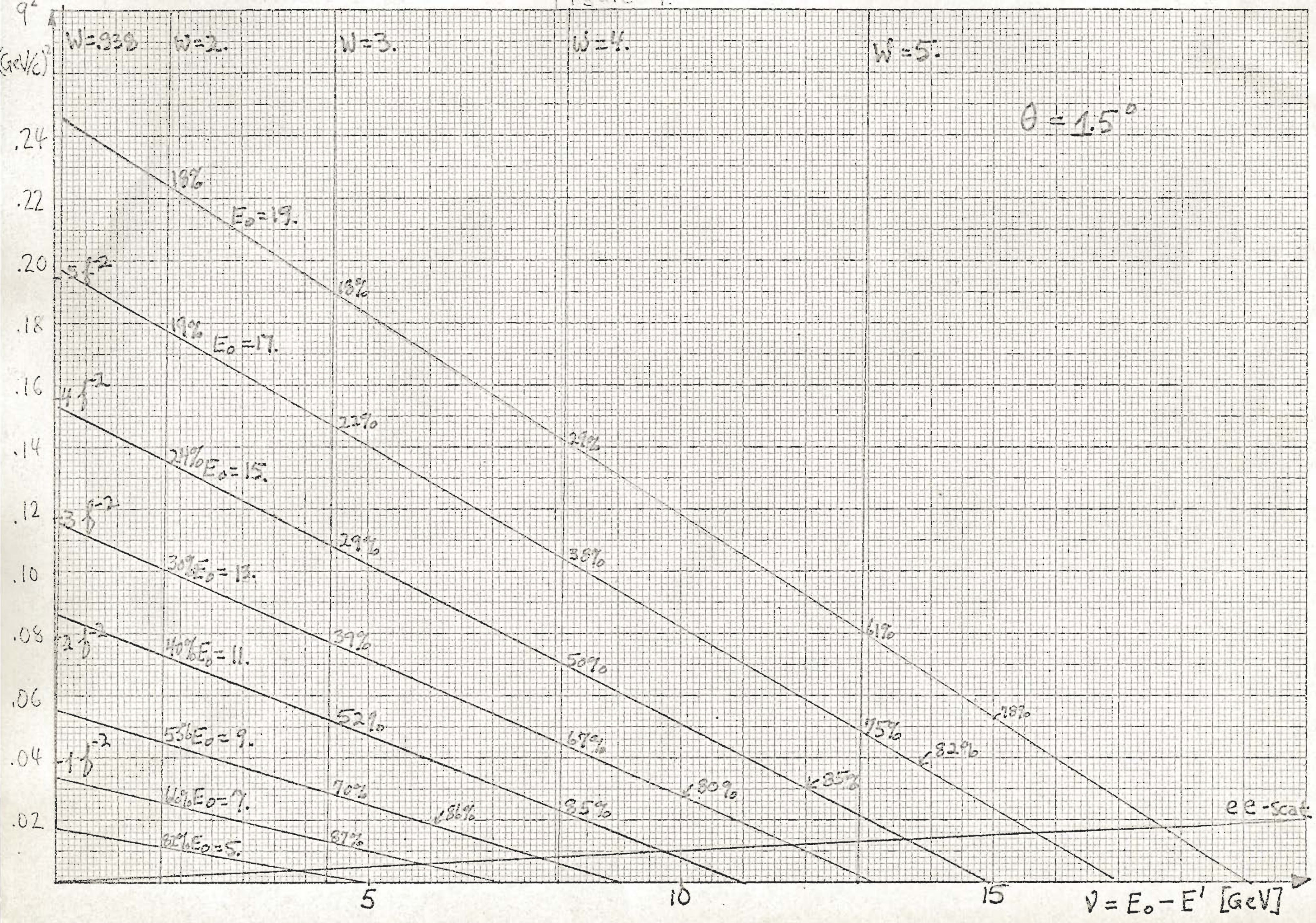
5) S. Berman or W. Schmitt might wish to comment on this point.

6) The numbers, R, are rough estimates obtained from a rather exact radiative tail calculation(7) σ_{Tail}, and a less exact inelastic cross section estimate(2) σ_{inel}. $R = \sigma_{\mathrm{Tail}}/(\sigma_{\mathrm{Tail}} + \sigma_{\mathrm{inel}}) \times 100$.

7) L. W. Mo and Y. S. Tsai, SLAC-PUB-380 (1968).

8) H. L. Lynch, J. V. Allaby and D. M. Ritson, HEPL 494 (1968).

Figure 1.


q^2
$(GeV/c)^2$
.24
.22
.20
.18
.16
.14
.12
.10
.08
.06
.04
.02
5
10
15
$\nu = E_0 - E'$ [GeV]
W=.938
W=2.
W=3.
W=4.
W=5.
$\theta = 1.5°$
18%
$E_0=19.$
18%
24%
61%
78%
19% $E_0=17.$
22%
35%
75%
82%
24% $E_0=15.$
29%
50%
85%
30% $E_0=13.$
39%
67%
80%
40% $E_0=11.$
52%
85%
53% $E_0=9.$
70%
86%
66% $E_0=7.$
87%
82% $E_0=5.$
5 f^{-2}
4 f^{-2}
3 f^{-2}
2 f^{-2}
1 f^{-2}
ee-scat.

4b. The Electron-Proton Inelastic Scattering Experiment

Summary

It was desired to conduct a survey of inelastic electron-scattering from the proton. The method of investigation consists of measuring the spectra of inelastically scattered electrons as a function of the four-momentum transfer and energy transfer to the target system. Such studies have been previously carried out at the Mark III accelerator and at the CEA. In the Stanford work[6] the (3,3) resonance was excited and studied as a function of four-momentum transfer up to about 0.79 (BeV/c). The CEA experiment(7) observed, in addition, evidence for the excitation of the 1.512-and 1.688-BeV resonances at four-momentum transfers up to about 1.97 (BeV/c); however, the measurements at the higher momentum transfers are limited by poor statistics. Because the inelastic cross section contains q^2 dependences which are similar to that of the form factors describing elastic scattering, the counting rates drop rapidly as a function of four-momentum transfer. The higher energies and intensities available at SLAC will enable both the scope and the precision of the measurements of e-p inelastic scattering to be greatly enlarged.

Received: 4 January 1966

Approved: 13 February 1966, 50 hrs parasite/100 hrs prime time

Approved: 12 August 1967, 300 hr extension