SLAC Proposal No. 23

BACKWARD Π^0 PHOTOPRODUCTION

B. Gittelman SLAC

G

A. Minten SLAC

H

B. Wiik HEPL

Stanford University

Stanford, California

January 16, 1967

INTRODUCTION

A class of high energy interactions which are being treated with peripheral models are those involving large t and small u. Several recent experiments on elastic pion-proton scattering around 180° have shown the cross sections to have interesting structure. At 180° for laboratory energies of 2 to 5 BeV(1), there are a number of bumps and dips in the cross sections of both $\pi^+ + p$ and $\pi^- + p$. Data on the angular distribution at 4, 6.5, and 8(2) show a narrow backward peak whose width decreases with increasing energy. An explanation of this data has been given by Barger and Cline(3). Their model consists of an amplitude for the direct channel which is a sum of Breit Wigner amplitudes over the known $Y = 1$ resonances plus an amplitude for the exchange of a Fermion-Regge pole. At intermediate energies (2 to 4 BeV) the interference between the direct and cross channel are needed to match the data. At higher energies (4 to 8 BeV), the exchange term begins to dominate. For 180° scattering, where u remains approximately equal to zero, the theoretical cross section falls smoothly as $s^{2\alpha(u)-1}$. The theoretical angular distributions at high energies show characteristic "Regge behavior" and track the data reasonably well.

We expect similar structure in photo-pion production and would like to compare it with the elastic pion scattering data(4). Very little is known about the coupling of γNN^* for N^* mass above 1688 MeV and one immediate result of such a comparison will be information on the γNN^* vertex for higher energy resonances. We would also like to trace out the s and u dependence of the cross section up to 15 or 20 BeV where the process should be completely dominated by "Fermion exchange". There are two pertinent photoproduction experiments one might do.

$$\gamma + p \rightarrow \begin{array}{l} p + \pi^0 \\ N + \pi^+ \end{array}$$

Both reactions are interesting and both should be measured, since they will provide complimentary isotopic spin information. We are proposing to measure the cross section for π^0 photoproduction for incident photon energies 2 to 20 BeV and center of mass production angles typically 150° to 180° (we will cover the range in u of 0 to $-1(\text{BeV}/c)^2$. We want to cover this region in a thorough manner. For $\theta_{cm} = 180$, we will obtain the differential angular cross section as a function of photon energy over the full range. At low energies we will take data in sufficiently fine steps to define the "resonance" region. At high energies we will probably be able to take coarser steps. We will also take an angular distribution at a number of photon energies in an angular range which is consistent with the amount of available running time and how rapidly the cross section falls as θ_{cm} moves away from 180°. The experiment has been designed to cover angles out to $u = -1(\text{BeV}/c)^2$.

As discussed later under backgrounds, if we do this experiment, we will also measure the magnitude of backward ρ^0 and η^0 production since these processes will contribute protons into our detectors unless we discriminate against them carefully. We plan to locate these resonances to avoid contamination of our data. At the same time, we will have obtained cross sections which are entirely unknown at this time.

EXPERIMENTAL TECHNIQUE

Kinematics

Photoproduction of neutral pions at center of mass angle of 180° appears in the laboratory as a forward proton at zero degrees and a backward moving pion. At high energies ($s \gg M^2$), the momentum of the backward pion is almost $1/2M_p$. Momentum conservation then requires that the forward moving proton have a momentum of 450 MeV/c above the beam energy. The kinematic region in which the proton momentum is above the momentum in the incident beam is a convenient region in which to work since there are no known processes which can produce pions, muons, or electrons of this momentum. This means that we avoid having to turn down the incident beam and discriminate electronically against processes which are known to be many orders of magnitude greater. This method may be extended into a finite angular range around 0°. The pion coming out at 90° in the laboratory carries momentum M_p. In this case the proton momentum is $P_p = (K^2 + M_p^2)^{1/2} \simeq K$ at laboratory angle $\theta_p \simeq \frac{M_p}{K}$ and $u \simeq -M_p^2$. Later in the proposal, we refer to this range of θ_p and P_p as the background free kinematic region (BFKR). By this we mean, the region is accessible only to protons. In Fig. 1 and 2, we have plotted the kinematic curves in the P_L-P_T plane for monochromatic photon energies of 10 and 20 GeV.

Description of the Experiment

We plan to perform the experiment in End Station A, using the 20 BeV

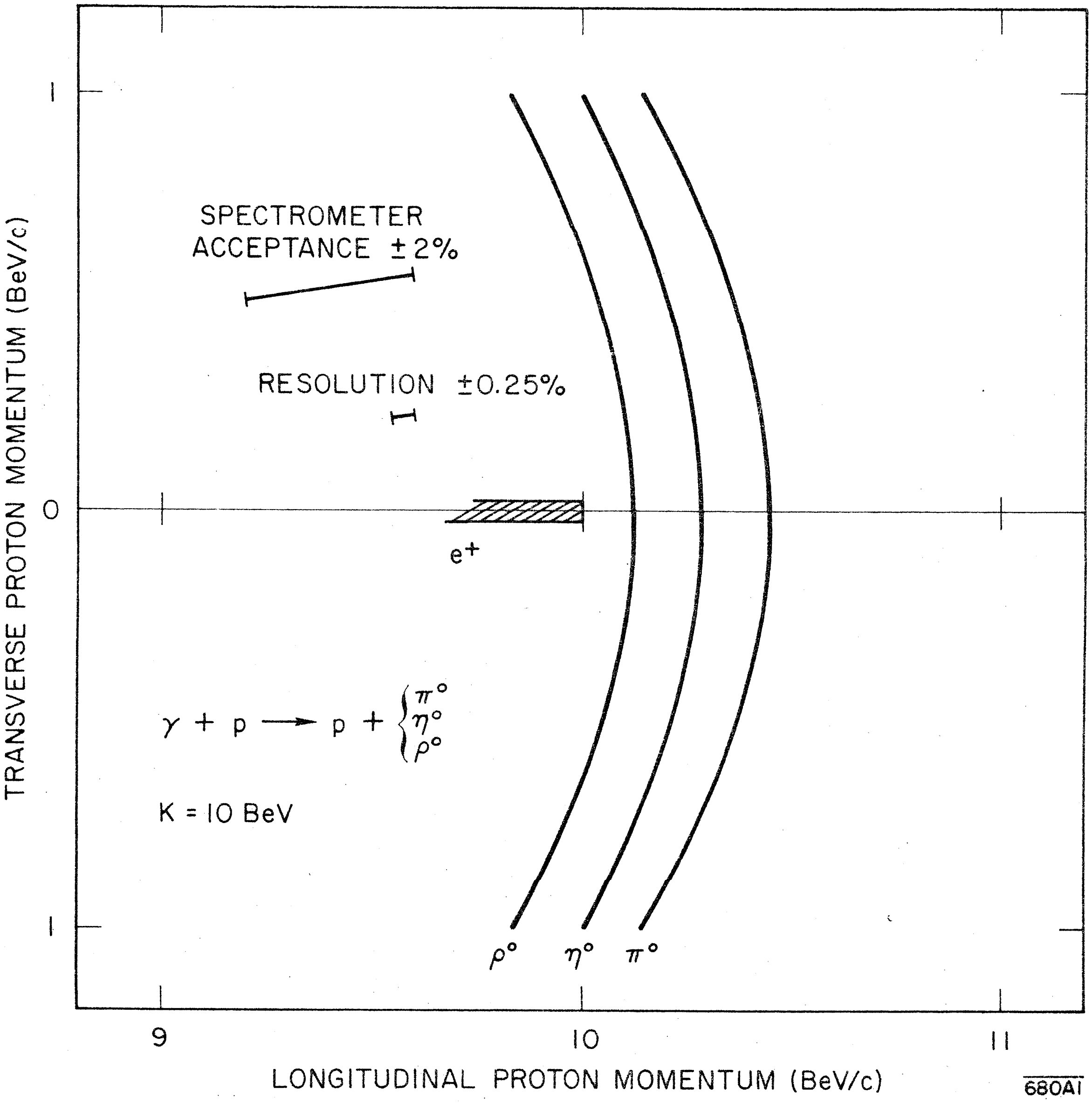


FIG. 1--KINEMATIC PLOT FOR $\gamma + p \longrightarrow p + \begin{Bmatrix} \pi^\circ \\ \eta^\circ \\ \rho^\circ \end{Bmatrix}$,
PHOTON ENERGY 10 BeV.

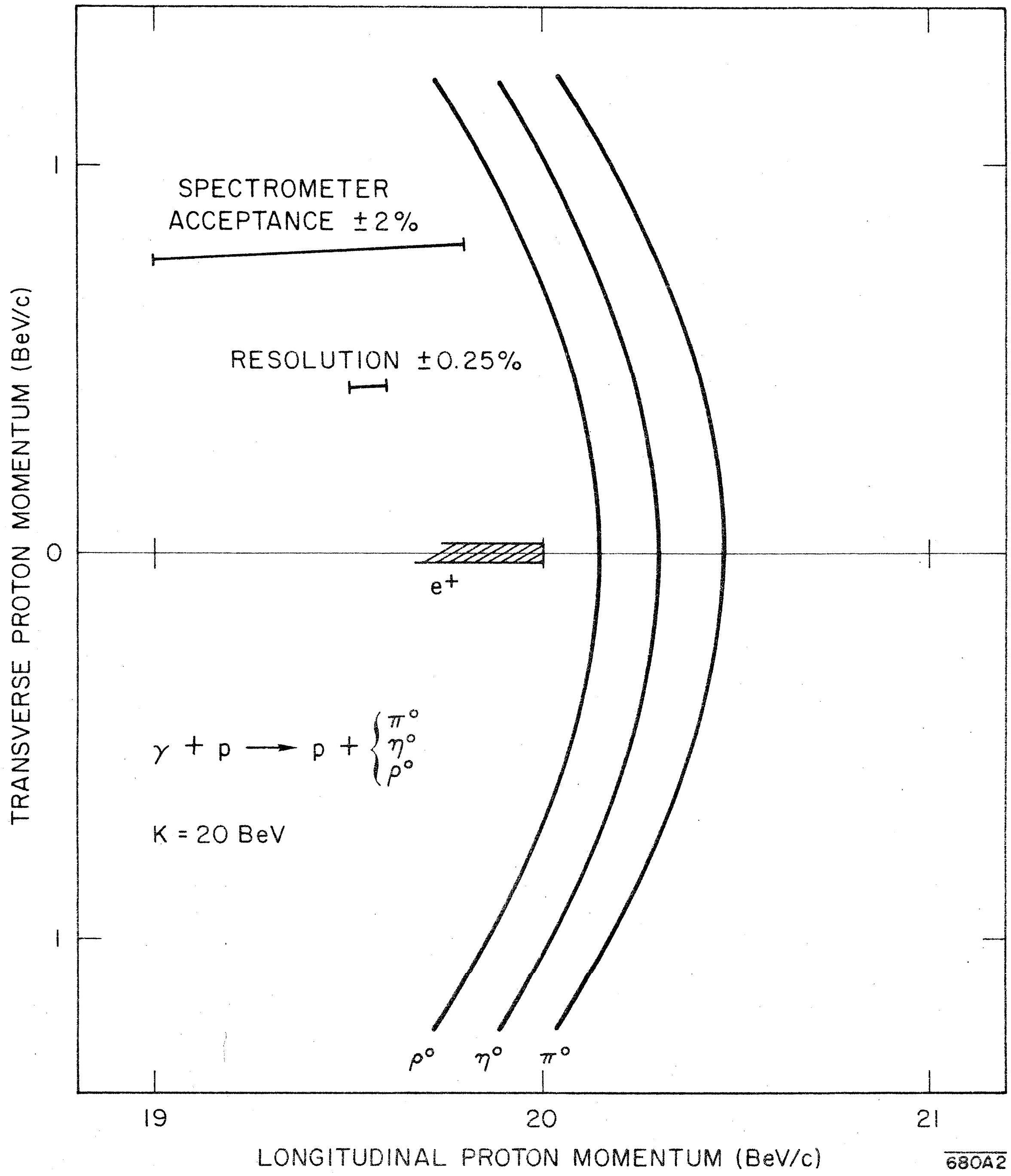


FIG. 2--KINEMATIC PLOT FOR $\gamma + p \longrightarrow p + \begin{Bmatrix} \pi^\circ \\ \eta^\circ \\ \rho^\circ \end{Bmatrix}$, PHOTON ENERGY 20 BeV.

spectrometer at zero degrees. After passing thru the hydrogen target, the photon beam will be buried in the first quadrupole magnet. The radiator, target, and detector will be the same (in design or fact) as used for other photoproduction experiments on the 20 BeV spectrometer. With the spectrometer at zero degrees, we have additional background problems from two sources:

a) shower positrons from the dissipation of the photon beam in the spectrometer.

b) positrons from asymmetric pairs of maximum momentum k produced in the target.

The first background arises in a similar way in the asymmetric muon pair experiment (proposal no. 14) and it is believed that the spectrometer itself will be sufficient to eliminate the background in this case. The cross sections we will be measuring are more than 10^2 times larger than in the muon pair experiment.

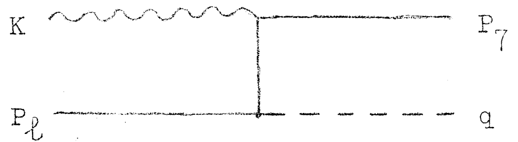
The second problem is solved in principle by the fact that the protons are separated by 450 MeV/c from the positrons. However, the positrons are more abundant than the protons. For example, we expect $\simeq 2 \times 10^5$ positrons per pulse into the spectrometer with momentum between 0.95 K and K. In order to control the spill of these positrons, we will use the dispersion of the first half of the spectrometer ($\frac{\Delta y}{\Delta P}$ = 5.5 cm/GeV/c at 20 GeV/c) and remove the electrons by collimation. It is even possible to put 3 radiation lengths of lead into the collimator. Only 1 in 10^6 electrons will pass thru the lead without losing at least 1% in energy. Corrections to the data for absorption of protons will be less than 10%, and the angular resolution from multiple scattering will be degraded by only ± 1.5 mrad. Since the expected width of the proton peak at 20 BeV is ± 20 mrad, we will not require better angular angular resolution.

Rate for π^0 Photoproduction

We have estimated the π^0 photoproduction cross section two different ways.

a. Elementary particle exchange with final state absorption--

A straight forward calculation of the single Feynman diagram



gives a center of mass cross section near 180° of

$$\left.\frac{d\sigma}{d\Omega}\right)_{CM} \simeq \frac{1}{4}\left(\frac{e^2}{4\pi M_p}\right)\left(\frac{g^2}{4\pi M_p}\right)\frac{[1+\kappa/2]^2}{1+\left(\frac{\omega}{M_p}\right)^2(\theta)^2}$$

Here e^2 and g^2 are the electro-magnetic and pion-nucleon coupling constants, M_p is the proton mass, κ is the proton anomalous moment G factor ($\kappa = 1.79$), and ω is the center of mass final proton energy. θ is the angle between the final proton and the photon in the center of mass.

This cross section has nothing to do with the facts of life. According to local lore, one must throw in a factor of 100 for final state absorption. The final state absorption will also sharpen the backward peak so that a "realistic" cross section estimate would be

$$\left.\frac{d\sigma}{d\Omega}\right)_{CM} = \frac{0.3 \times 10^{-30}}{\left(1 + \left(\frac{\omega}{M_p}\right)^2 \theta^2\right)^N} \quad \frac{cm^2}{sterad}$$

where N is a number between 2 and 5 depending on what one assumes for an interaction length.

b. Comparison with π-p elastic scattering.

The experimental center of mass elastic π^-p differential cross section at 180° ($\theta = 0$, for definition above) may be crudely fitted by

$$\left.\frac{d\sigma}{d\Omega}\right)_{CM} \simeq \frac{230 \times 10^{-30}}{\left(\frac{E_{LAB}}{M_p}\right)^{3/2} \left(1 + \left(\frac{\omega}{M_p}\right)^2 \theta^2\right)^4}$$

Here we have used the data of Kormanyos(1) and Frisken(2), averaging over-all of the structure to obtain a simple energy dependence. The angular distribution comes from the data of Brody(2) at 6 BeV.

If we make the blind assertion that the photo production cross sections should be lower by a factor of 140 (i.e., a factor of α for an electromagnetic vertex), then we end up with

$$\left.\frac{d\sigma}{d\Omega}\right)_{CM} = \frac{1.64 \times 10^{-30}}{\left(\frac{E_{lab}}{M_p}\right)^{3/2} \left(1 + \left(\frac{\omega}{M_p}\right)^2 \theta^2\right)^4} \quad \frac{cm^2}{STER}$$

For $\theta = 0$, the two estimates agree at 3 BeV. At 10 BeV, the second estimate is about a factor of 6 smaller. Since we believe the second estimate to be more meaningful, we will use it to evaluate our expected rates. In Figure 3, we have plotted the rates for several energies and

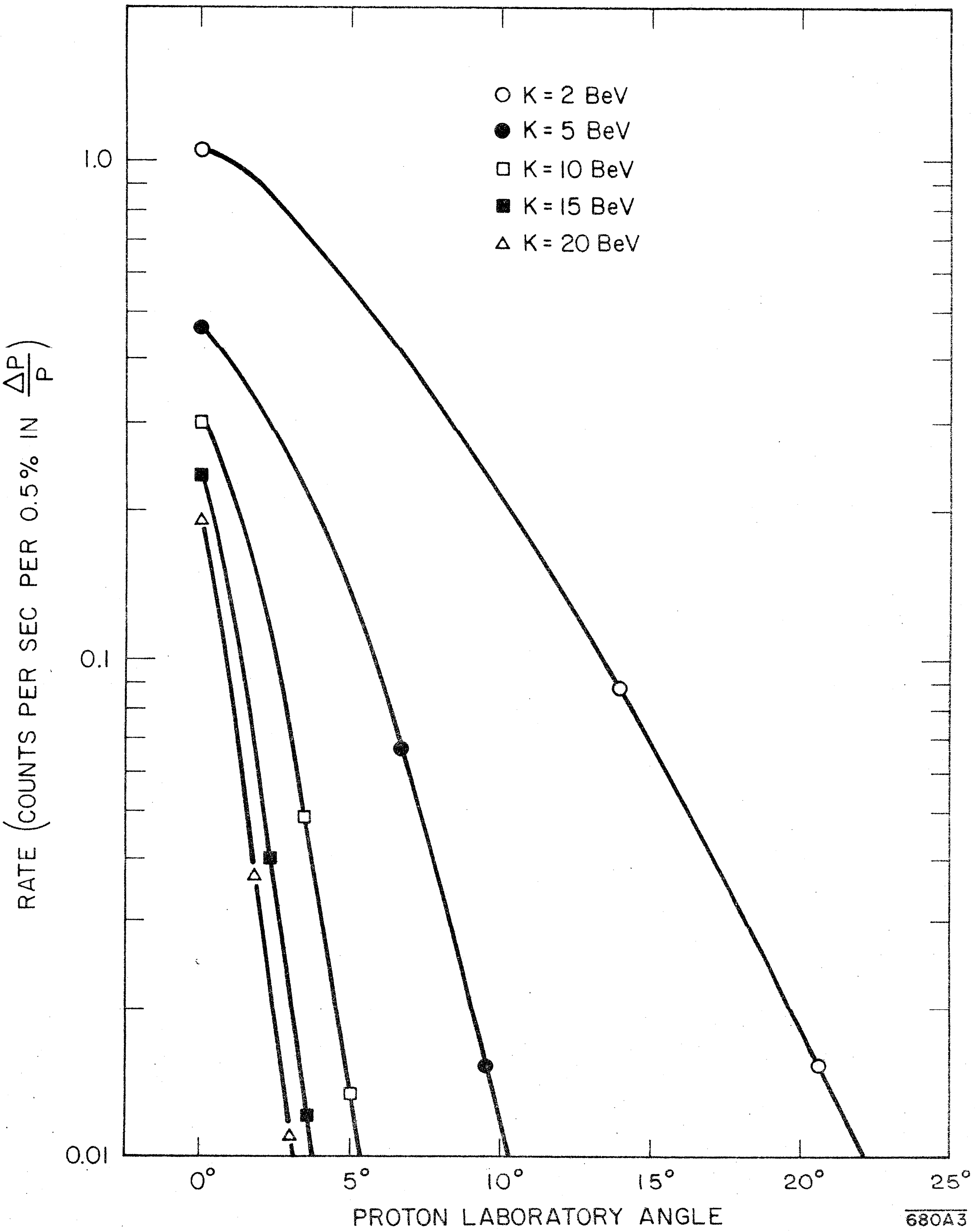


FIG. 3 -- ESTIMATE OF COUNTING RATES

angles. Here we have used the following parameters.

a-Number of electrons/pulse = 10^{11}

b-Radiator thickness - 0.03 radiation lengths.

c-Hydrogen target thickness - 10 inches

d-Spectrometer angular acceptance 10^{-4} sterad.

e-For the purpose of this proposal we have assumed 1/2 of the photons produced in the radiator will pass through the collimator. This number is based on a 5 mm high photon beam at the target at 20 BeV.

BACKGROUNDS

Identification of Protons

In the kinematic region in which we will be taking data we do not expect to see particles other than protons except possibly from scattering inside the spectrometer. However, since the fluxes of pions of nearby momentum can be expected to be 10^2 times larger (and the positron flux will be 10^5 times), it is necessary to provide adequate particle identification to prevent possible contamination of our signal. We intend to use a large differential gas Cerenkov counter for this purpose.

High Energy Protons from Other Processes

The other processes which can contribute high energy protons into the BFKR are

1. Proton Compton Effect
2. η^o meson production

3. ρ^{o} meson production

4. Non-resonant multiple pion production.

The first three are characterized by the backward emission of a particle of a definite (reasonably definite) rest mass. With a sufficiently high resolution system, each of these processes show up as a step in the excitation curve and its cross section may be measured by the size of the step. In order to resolve the steps the difference in momentum of the protons coming from processes, 1 thru 3 must be greater than the rise of the tip of the bremsstrahlung curve folded with the spectrometer resolution. For purposes of the proposal, we will take this overall resolution to be 0.5% of the spectrometer momentum. For a photon energy K, the momentum of the forward proton varies with the mass, μ, of the associated particle approximately as $P_{\text{proton}} \simeq P_o - \frac{1}{2M_p}\mu^2$ where M_p is the proton mass, and

$$P_o \simeq \frac{K(1 + M_p/K)}{(1 + M_p/2K)}$$

The momentum separation between Compton and π^o photoproduction is only 10 MeV/c. Consequently, we will not be able to distinguish these processes on the proton kinematics. Here we must rely on the factor α in the cross section because of an extra electro-magnetic vertex to argue that the Compton effect will not provide a significant background.

The separation between π^o production and η^o production is 115 MeV/c. This is greater than the 0.5% resolution even at the maximum energy. The separation for ρ production is 250 MeV/c or 1.2% at the maximum energy. The amount of difficulty in distinguishing these three processes and the final error in the individual cross sections above 10 BeV will depend to a large extent on the relative magnitude of the cross sections.

The non-resonant multiple pion production produces a ramp instead of a step in the excitation spectrum because the mass of the final state pion system is not unique. The slope at the top of the excitation spectrum may be used to measure the amount of non-resonant background and by extrapolating to the step at single pion threshold, we may obtain the single pion cross section. We have made a crude estimate of the amount of non-resonant production one might expect and calculated the slope of the ramp in order to see whether the above extrapolation is practical. Our conclusions are--

a-If the non-resonant multiple pion production cross section is of the same order of magnitude as the single pion cross section because we kinematically reject practically all of the phase space available to the two pion system, the total contamination will be only a few percent.

b-If the non-resonant backward production cross section were 100 times the single pion cross section, the extrapolation procedure will work.

c-Our ability to obtain cross sections for η^o and ρ^o production will depend on the magnitude of non-resonant 2-pion production.

ESTIMATE OF REQUIRED RUNNING TIME

In Table 1 below, we have tabulated our estimate of the time required to obtain various data. The times are calculated from the rates given in Figure 3. For each data point, we have added 15 minutes to allow for the

TABLE I

Experimental Aims		Time Required (hours)	
		Sub-total	Total
1. To obtain the energy dependence of the $\theta^* = 180^\circ$ cross section			56
a.			
a. Take 30 points between 2 and 8 BeV with a statistical accuracy of ± 3% per 0.5% in $\Delta P/P$		24	
b. Take 24 points between 8 and 20 BeV with the same accuracy		32	
2. Angular distribution for 6 photon energies to trace at the variation up to $u \simeq -1$ BeV^2. We plan on 8 points per curve.			69
Energy	Statistical Accuracy		
	$\theta = 0 \rightarrow \theta_{MAX}$		
2	± 3% to ± 10%	8	
5	± 3% to ± 10%	10	
8	± 3% to ± 10%	13	
12	± 5% to ± 15%	12	
16	± 5% to ± 15%	14	
20	± 7% to ± 20%	12	
3. Measuring η^0 and ρ^0 cross sections for 5 energies to a statistical accuracy of 5% (data taking time is calculated assuming $\sigma_\eta = \sigma_\rho = \sigma_\pi$)			20
4. To measure the shape of the bremsstrahlung curve folded with the spectrometer resolution at 4 machine energies.			23
5. To check data reproducibility (asking for 25% of the above time)			40
6. To set up on the machine			10
GRAND TOTAL			218

changing of machine energy, spectrometer momentum, etc. In addition, we request 50 hours for setup time and checking data reproducibility.

SUMMARY OF EQUIPMENT AND LINEAC REQUIREMENTS

A. Running time - 220 hours of machine operation at 360 cycles- (We would also expect to have 20 to 40 hours of parasite time at almost arbitrary beam current and energy.)

B. Beam Requirements-

  a. Current - 10" EPP (time estimates were based on 3.6×10^{13} electrons/sec).

  b. Beam energy spread - Variable from ± 0.2% below 10 BeV to ± 0.1% at 20 BeV.

  c. Beam Phase Space - Beam diameter at the radiator should be $\lesssim 3$ mm with an angular divergence of less than 5×10^{-4}.

  d. Beam pulse duration 1 to 2 μsec.

C. Equipment Requirements - 20 BeV spectrometer, hodoscopes, Cerenkov counter, liquid hydrogen target, photon radiator and collimator system, ion chamber and quantameter for beam monitoring.

We could be ready to do this experiment by September 1967.

REFERENCES

1. S. W. Kormanyos, A. D. Krisch, J. R. O'Fallon, K. Roddick, and L. G. Ratner, PRL 16, 709 (1966). A. I. Alikhanov, et.al., Phys. Letters 19, 345 (1965).

   P. M. Ogden, et. al., Phys. Rev. 137, B 1115 (1965).

   H. H. Atkinson, et. al., Proc. Royal Soc. A., 289, 449 (1966).

   J. A. Helland, et. al., Phys. Rev. 134, B 1062 (1964).

   F. E. James, et. al., Phys. Letters 19, 72 (1965).

2. W. R. Frisken, et. al., PRL 15, 313 (1965).

   H. Brody, et. al., PRL 16, 828, 968 (E) (1966).

3. V. Barger and D. Cline, Phys. Letters 22, 666 (1966).

   V. Barger and D. Cline, Phys. Rev. Letters 16, 913, (1966).

4. Pion photoproduction differs from elastic scattering in two respects.
   a. In π^+p scattering the direct channel is pure I = 3/2, even though the cross channel is a sum of I = 1/2 and I = 3/2. In π^-p scattering the cross channel is pure I = 3/2 and the direct channel is an admixture. For photo-production, both the cross channel and the direct channel are admixture of I = 1/2 and I = 3/2. We consider this a distinct disadvantage since one would prefer to deal with pure states whenever possible.
   b. For elastic scattering at 180°, the spin flip amplitude vanishes because of angular momentum conservation For photoproduction, the non-spin flip amplitude vanishes for the same reason. This means that we are dealing with the same number of amplitudes, but different ones.

Supplement No. 1
to SLAC Proposal No. 23

ADDENDUM TO PROPOSAL NO. 23 - BACKWARD π^0 PHOTOPRODUCTION

In writing the proposal for the backward π^0 photoproduction experiment, we seemed to have overlooked the fact that it is customary to present running time requirements on the basis of 180 cycle operation rather 360 cycles. Professor Sands has requested that we retabulate our running time on the basis of 180 cycles. (See attached table).

We are aware that 385 hours is an unusually large request considering present SLAC operation. We have briefly considered what parts of the program might be eliminated in a first experiment in order to reduce the time requirement to 200 hours. It should be mentioned that since we are not limited by dead times, a doubling of the accelerator beam intensity (to 2×10^{11} E.P.P in the required energy range of ±0.1%) would permit us to carry through the program in 220 hours. Although we have not decided on definite abridgments, a possibility might be

a - Reduce the number of points between 8 and 20 BeV at $\theta^* = 180^\circ$ from 24 to 6 (time saved 43.5 hours).

b - Take angular distributions at 3 energies rather than 6 (time saved 63 hours).

c.- Eliminate making the special runs at low energies to measure η and ρ production where the spectrometer momentum acceptance is not large enough to include these (40 hours). The virtue of doing this will only be apparent when we find out how easy (or difficult) it will be to extract these cross sections.

3/10/67

d - Presumably data reproducibility time should be reduced to 40 hours (time saved 20 hours).

Putting these together we have eliminated 166 hours and reduced the program to 220 hours.

TABLE I

Experimental Aim	Time Required (Hours)	
	Data Taking Time	Total (including changing energy, spectrometer, etc.)
1. To obtain the energy dependence of the $\theta^* = 180^\circ$ cross section		
a. Take 30 points between 2 and 8 BeV with statistical accuracy of ± 3% per 0.5% in $\frac{\Delta p}{p}$.	33	40.5
b. Take 24 points between 8 and 20 BeV.	52	58
2. Angular distribution for 6 photon to trace out the variation up to $u = -1$ BeV^2. We plan on 8 points per curve		
Energy		
2	12	
5	16	
8	22	
12	20	
16	24	
20	20	
		126
3. Measuring η^o and ρ^o cross sections at 5 energies to a statistical accuracy of 5% (data taking time c calculated assuming $\sigma_\eta = \sigma_\rho = \sigma_\pi$)		40
4. To measure the shape of the bremsstrahlung curve folded with the spectrometer resolution at 4 machine energies.	32.8	39
5. To check data reproducibility (20% of the above time)		60
6. Set up time (checking counters, rates, beam monitors, etc.).		20
GRAND TOTAL		383.5

Supplement No. 2
to SLAC Proposal No. 23

DATE: 3 May 1967

TO : Matt Sands

FROM : Bernie Gittelman

SUBJECT: Proposal No. 23.

The following SLAC physicists would like to join us in carrying out the Backward π^0 Photoproduction experiment (Proposal No. 23).

R. Anderson
J. Litt
D. Yount

Please add their names to the proposal.

BG:as
c.c. J. Ballam
W.K.H.Panofsky
R. Anderson
J. Litt
A. Minten
B. Wiik
D. Yount

MS 5/3/67

23 June 1967
Supplement No. 3
to Proposal No. 23

BACKWARD π^0 PHOTOPRODUCTION

We have been asked to reevaluate our use of running time under the following assumptions:

1. The backward π^0 photoproduction cross section is given by α/π times the $\pi^- + p$ elastic cross section.
2. The SLAC linear accelerator can provide an electron beam at 180 cps with the following properties:

Beam Energy (BeV)	Beam Energy Spread $(\frac{\Delta E}{E})$	Beam Intensity $(\frac{\text{Electrons}}{\text{Pulse}})$
2	±0.005	5×10^{10}
5	±0.004	13 x
10	±0.003	22 x
20	±0.002	35 x

3. The time required to change machine energy is 0.5 hours.

In our proposal, we assumed the cross sections to be a factor of α smaller than the mean of the $\pi^- p$ and $\pi^+ p$ elastic cross sections. The new assumption requires us to reduce our rates by a factor of six. This will force us to reduce the scope of the present experiment. Our present choice would be to limit the experiment to the study of the s-dependence of the cross sections at 180°. A practical goal would be

a- Between 2 and 8 BeV, obtain the 180° cross sections at 20 points to an accuracy of ±10%. This would permit us to measure the S-dependent structure with an accuracy which is comparable to what has been done in pion-nucleon scattering.

b- Between 8 and 20 BeV, we would obtain the 180° cross section every 2 BeV to an accuracy of ± 10 to 15%. If one assumes that there is no structure coming from S-channel resonances, this will be sufficient to establish the general s-dependence at high energy.

In order to decide how long to run at a particular point we must make some additional assumptions about backgrounds from ρ production and non-resonant 2-pion production. In our proposal we took:

a) The ρ-production cross section is equal to the π^0 cross section.

b) The non-resonant 2-pion production is given by an extrapolation of the DESY bubble chamber data.

c) At 10 BeV, we will maintain 0.5% resolution on the Bremsstrahlung spectrum.

If we stick with these assumptions, an excitation curve at 10 BeV will look like figure 1. The π^0 cross section may be extracted from this curve with 10% accuracy. The entire momentum range from ρ threshold to the end of the π^0 spectrum (10.128 to 10.438 BeV/c) is taken with one setting of the spectrometer. To calculate the ordinant scale, we use the following formula for the rate--

$$R = n_p \left[t\ f\ N_e \frac{\Delta K}{K} \right] \frac{d\sigma}{d\Omega}_{cm} \frac{\partial \cos \theta_{cm}}{\partial \cos \theta_{lab}} \Delta\Omega_{lab}$$

n_p	Target Thickness, 10^{24} cm^{-2}
t	Radiator thickness, 0.03 R.L.
f	fraction of photon beam coming through the collimator, $f = 0.25$
N_e	Number of beam electrons
$\frac{\Delta K}{K}$	Fraction of photons having the correct momentum to give protons in a 0.5% momentum bin, $\Delta K/K \simeq \Delta P/P = 5 \times 10^{-3}$.
$\frac{d\sigma}{d\Omega}_{cm}$	Photoproduction cross section. $\frac{d\sigma}{d\Omega}_{cm} = 4 \times 10^{-30} \times \frac{1}{137 \times \pi}$ cm^2/ster.

$$\frac{\partial \cos \theta_{cm}}{\partial \cos \theta_{lab}} \simeq \frac{2K}{M_P} = 20$$

$$\Delta\Omega_{lab} = 10^{-4} \text{ Sterad.}$$

Multiplying the above numbers gives

$$R = 0.7 \times 10^{-15} N_e$$

To accumulate 300 events requires

$$N_e = \frac{300}{0.7 \times 10^{-15}} = 4.3 \times 10^{17} \text{ electrons}$$

At 10 BeV the lineac can deliver 1.5 x 10^{11} electrons per pulse in an energy band $\Delta E/E = \pm 0.002$. At 180 cps the required time is

$$T = \frac{4.3 \times 10^{17}}{1.5 \times 10^{11} \times 180 \times 3600} = 4.4 \text{ hours}$$

To scale the above calculation to different energies, we note the following requirements on resolution...

a- At low energy (for example 2 BeV), the ρ and π^0 threshold are sufficiently separated that we do not need to worry about resolving the separate processes. It would be useful to keep the resolution sufficiently sharp so that we see the edge of the proton spectrum and the flat region simultaneously in the spectrometer. Good resolution will also reduce the background from non-resonant 2-pion production. We would try to hold the rise on the edge of the spectrum to 1.5%.

b- At very high energy we have to push the resolution in order to clearly define π^0 production. We will aim for $\Delta P/P \simeq 0.25 - 0.3\%$.

Table I summarizes a set of beam parameters. The height of the photon beam and the energy spread in the electron beam will determine the resolution.

In order to decide how long to run at each energy we look at the amount of non-resonant 2-pion background we can expect. In our note on this background we took the very conservative point of view that the proton is isotropic in the center of mass. This is probably too conservative, but if we stick to it we will require 300 counts in each 0.5% momentum bin in order to extract a 10% cross section. In Table 2 we list the expected counting rates and the running time required to accumulate the 300 events. The average time per point is about 4 hours. Adding in 0.5 hours for changing beam energy and perhaps 1 hour for empty target runs brings the total time per point to 5.5 hours. To do the 26 points will require about 143 hours. Adding in time for monitor calibrations, data reproducing runs, etc. will use up our 220 hours.

Beam Energy (BeV)	Desired Resolution (percent)	$\Delta E/E$ of Beam (percent)	Beam Current (x 10^{11} EPP)	Height of Photon Beam (cm)	Fraction Useable Photons, f
2	1.5	±0.5	0.5	3	0.16
5	1	±0.35	1.2	1	0.24
10	0.5	±0.2	1.5	0.5	0.25
15	0.4	±0.15	1.6	0.5	0.37
20	0.25-0.3	±0.1	1.7	0.5	0.5

TABLE I

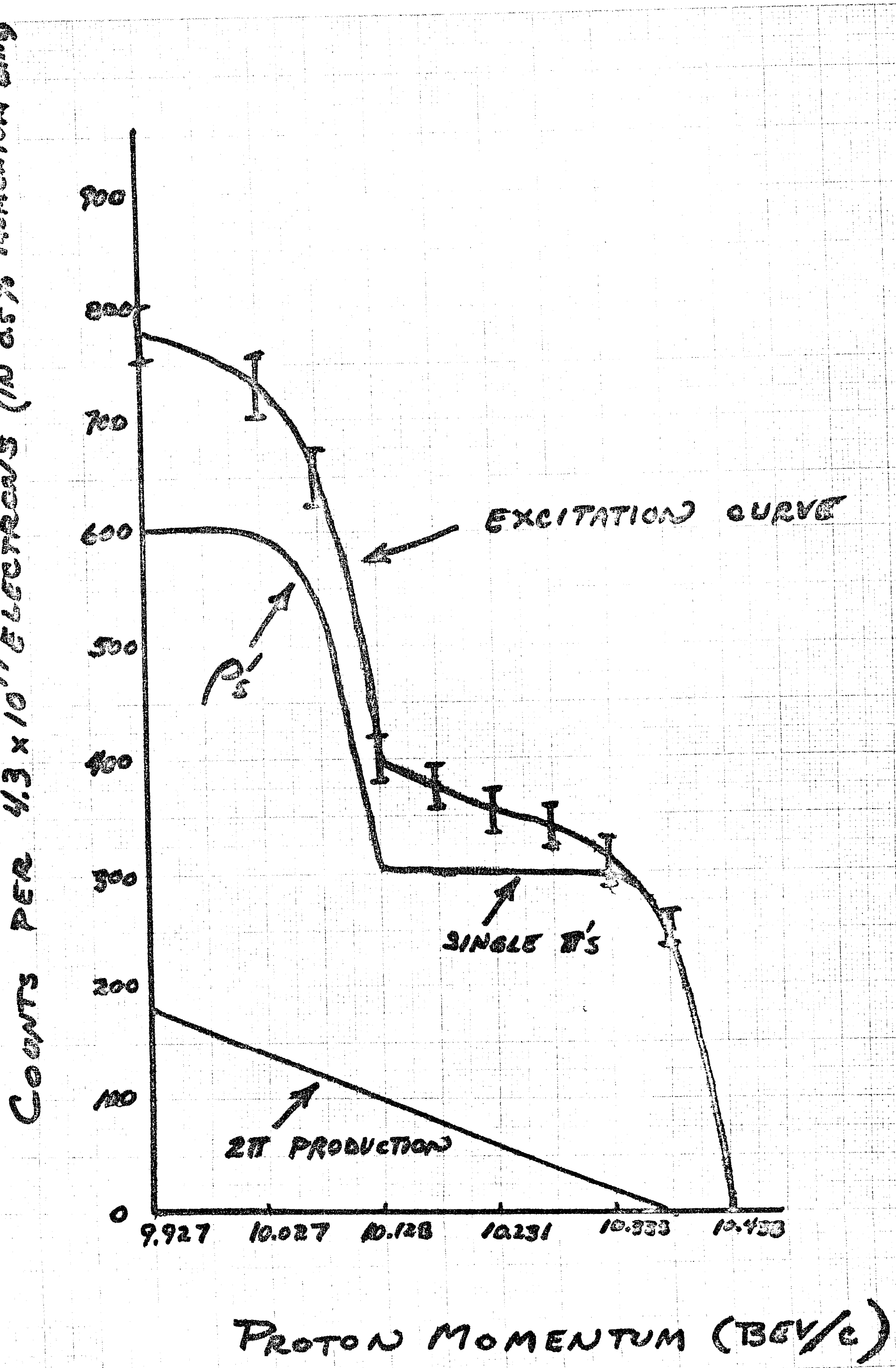
TABLE 2

Beam Energy	Beam Current $\times 10^{11}$ EPP	f	$\left(\frac{d\sigma}{d\Omega}\right)_{cm}$ $\times 10^{-33}\mathrm{cm}^2$/ster	$\frac{\partial \cos \theta_{cm}}{\partial \cos \theta_{lab}}$	Rate $\times 10^{-5}$/ Pulse	Time for 300 events in $\Delta P/P = .5\%$ (Hours)
2	0.5	0.16	100	7.5	9.0	5.2
5	1.2	0.24	26	13.6	15.3	3.1
10	1.5	0.25	9.3	24	12.5	3.7
15	1.6	0.37	5.1	36	16.4	2.8
20	1.7	0.50	3.3	46	19.5	2.4

$$R = n_P [t\ f\ N_e \frac{\Delta K}{K}] \left(\frac{\partial\sigma}{\partial\Omega}\right)_{cm} \left(\frac{\partial \cos \theta_{cm}}{\partial \cos \theta_{lab}}\right) \Delta\Omega_{lab}$$

$$R = 10^{24}\ [.03\ f\ N_e \cdot 5 \times 10^{-3}] \left(\frac{\partial\sigma}{\partial\Omega}\right)_{cm} \left(\frac{\partial \cos \theta_{cm}}{\partial \cos \theta_{lab}}\right) (10^{-4})$$

$$R = 0.15 \times 10^{17}\ f\ Ne \left(\frac{\partial\sigma}{\partial\Omega}\right)_{cm} \left(\frac{\partial \cos \theta_{cm}}{\partial \cos \theta_{lab}}\right)$$


COUNTS PER 4.3 x 10^17 ELECTRONS (IN 0.5% MOMENTUM BINS)
900
800
700
600
500
400
300
200
100
0
EXCITATION CURVE
P'_s
SINGLE π'S
2π PRODUCTION
9.927
10.027
10.128
10.231
10.333
10.438
PROTON MOMENTUM (BEV/C)