February 28, 1967

Supplement to SLAC Proposals No. 21 and No. 22

PROPOSAL FOR MEASUREMENTS ON THE PHOTOPRODUCTION OF π^o, η, ρ^o, ω, and ϕ MESONS AT SMALL MOMENTUM TRANSFER t AND PHOTON ENERGIES UP TO 18 GeV AND A SEARCH FOR MESONS OF OTHER MASSES. (Combination of Proposals 21 and 22).

From Stanford: D. Ritson, R. Prepost, R. Anderson, D. Gustavson, and J. Johnson
From Caltech: R.L. Walker, Gareth Jones, David Kreinick, and A.V. Tollestrup
From Northeastern: R. Weinstein, M. Gettner

We propose to join efforts for the measurement of the photoproduction processes listed in the title in a manner approximately as described in two separate proposals previously submitted, No. 22 from Stanford and Northeastern and No. 21 from Caltech. The principal change from the previous proposals would be to carry out all of the work using the 1.6 BeV/c spectrometer and to place greater emphasis on attempts to measure the photoproduction of ω and ϕ mesons. We believe that a comparison of these processes at the high energies available at SLAC will be of particular interest.

The total amount of beam time requested for these measurements is 175 hours, plus 50 hours of low energy, low rep.-rate set-up time. The original Stanford-Northeastern proposal requested 100 hours of prime time for the measurements of π^o and η photoproduction, plus 50 hours of set-up time, and this request remains unchanged. In addition, we estimate that 75 hours will be required for the measurements of ρ^o, ω and ϕ production including a small amount of time to make a search for other masses. It is estimated that these 75 hours would be distributed in the following way:

Supplement No. 2 to
Proposal No. 21/22

REQUEST FOR EXTENSION OF EXPERIMENT 21/22

by

R. Anderson	S.L.A.C.
M. Gettner	Northeastern University
D. Gustavson	S.L.A.C.
J. Johnson	S.L.A.C.
G. Jones	Cal-Tech.
D. Kreinick	Cal-Tech.
F. Murphy	Univ. of Calif. - S.B.
D. Ritson	S.L.A.C.
R. Weinstein	Northeastern University

April 9, 1968

Summary of Present Position of Experiment 21/22 - "Photoproduction of Bosons"

In runs in December and January, slightly over the allocated 200 hours were used up observing the recoil protons associated with,

$$\gamma + P \rightarrow X^{o} + P$$

where X^{o} is any boson system. A total of fifty-one "sweeps" were completed at different t values (four-momentum transfer to the proton) in the range $t = -.2(\mathrm{BeV}/c)^2$ to $t = -.9(\mathrm{BeV}/c)^2$ and with primary energies from 5.5 GeV to 17.8 GeV.

In each sweep the peak energy of the Bremsstrahlung beam, and the momenta of the protons were held fixed and the yield of protons was measured as a function of the lab angle. Figs. I to III show typical yield curves at a variety of energies and t values.

Typically in such measurements there are sharp "steps" occuring at the various particle thresholds. Cross-sections are derived from the measured heights of these "steps".

The analysis of the data from these runs is now nearly complete. We expect to be able to present preliminary results at the time of the next P.A.C. Meeting. We summarize the performance of the apparatus:

1) We were able to accept about $\sim 4.10^4$ triggers a minute and a useable count rate of $\sim 2.10^4$ counts a minute. We would expect in future runs to be able to double this rate by improving our electronics.

2) Because of the large redundancy of the data taken with our hodoscoped counter array, we were able to analyze unambiguously the internal consistency of our runs. The relative short-term stability of monitors and

electronics was better than 0.2% over a given sweep. The absolute stability was better than 2% over a two week period. This precision seems to be a result of the excellent stability of the SLAC accelerator. We believe therefore that even on an 0.1% - 0.2% level our data would only be statistically limited.

3) We took data on π^o, η^o, $(\rho + \omega)$'s, η'(?), ϕ's and other particles. We believe that the $(\rho + \omega)$'s were rather completely covered, and that the limitation to obtaining further information by this method is limited by systematics and not by statistics. The π^o running was relatively complete at lower energies, but could be considerably extended in precision at higher energies. The η^o's are only well resolved from ρ-meson production at lower energies. We should however be able to considerably improve our precision for η's at these lower energies. The main data in ϕ^o-mesons was taken in the last two days of running and could be considerably extended. We also observed clear structure due to one or more particles in the 1300-1450 MeV mass region, in these last two days of runnings.

4) The statistical accuracy associated with delineating a "step" is typically about the statistical accuracy of the points in the vicinity of the "step". For example, in the case of the ϕ-meson we observed 2% "steps" with a precision of $\sim \pm$ .4%.

5) Resolution was limited as expected almost solely by the coulomb multiple scattering of particles in the target.

6) We were able to exceed in all respects the program outlined in Exp. 21/22.

Objectives of an Extension

If an extension was granted we would wish to;

a) Extend the π^o, and η^o production measurements as far as can be done with our present techniques. (These problems are clearly of current interest and have been the subject of a number of recent theoretical investigations.)

b) To look for $\eta'(958)$ production at low energies at a number of t values.

c) To extend our ϕ^o data over a wider range and to higher precision by taking 9 hours per sweep instead of the 3 hours in our previous runs and upping the input data rate by improving our electronics by a factor 2-3.

d) To considerably extend our data in the mass range 1300-1450 MeV and to more clearly delineate the phenomena in this region.

e) To extend high precision sweeps over the high mass region from 1450 MeV to 2000 MeV.

Time Requested

We would expect that a comparable running period to that taken previously would enable us to meet many of these objectives. We are requesting time roughly as follows:

Production of π^o, η^o, X^o's	~ 60 hours
Production of ϕ's or ρ, 1300-1450's	~ 90 hours
Particles over 1450	~ 70 hours
Total	220 hours

As this experiment tends to be more duty cycle limited than beam limited, we tend to prefer running time alongside the bubble-chamber.

Priorities

We are ready to proceed with either our extension to Exp. 7 or with an extension to Exp. 21/22. Time has already been assigned to Proposal 7.

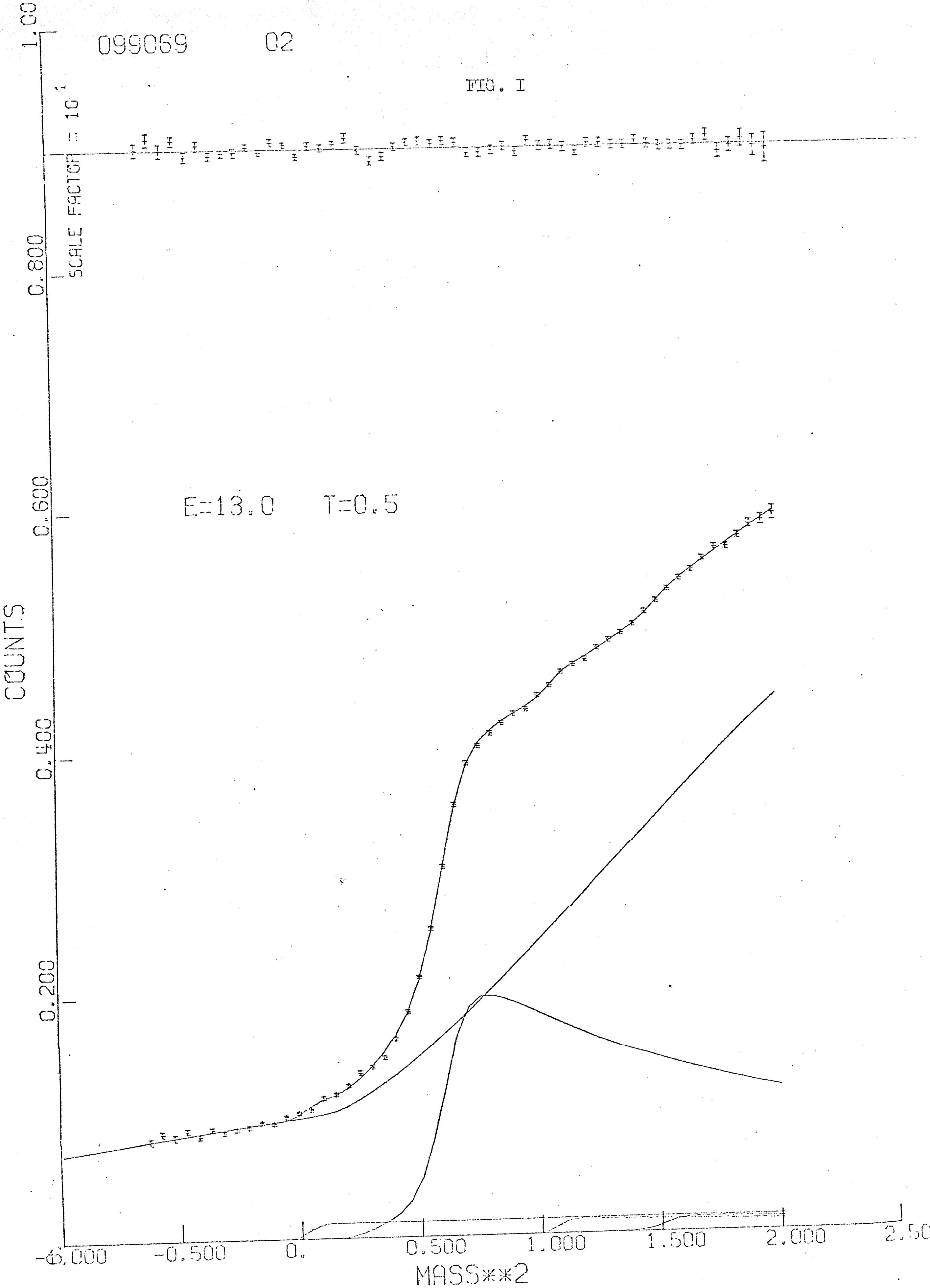
However, while making no judgements as to ultimate long term usefulness, we believe that the data of 21/22 is of more immediate interest. (Also the timing would be more convenient for the personnel involved.) If this request for an extension is accepted we would prefer to run the extension to Proposals 21/22 before the extension to Proposal 7.

FIGURES

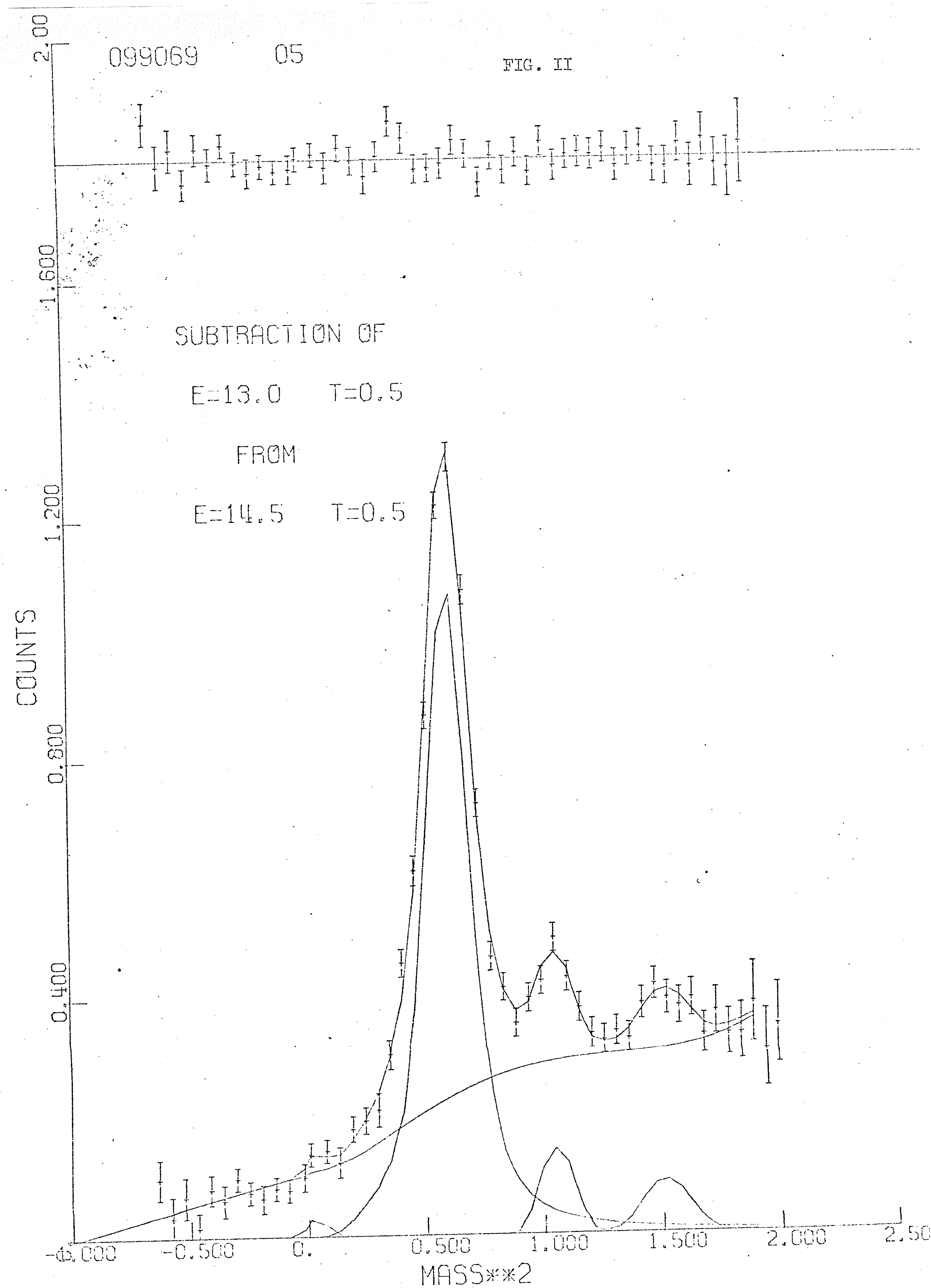
Figure 1: Yield curve for a peak Bremsstrahlung energy of 13.0 GeV, and a t value of $-0.5(\mathrm{BeV/c})^2$ versus the missing mass^2 of the unobserved boson system. The curves show the fits to the raw experimental data with the calculated contributions from π^0, $(\rho^0 + \omega^0)$, and ϕ^0 production. The top line shows the deviances from the fitted curve.

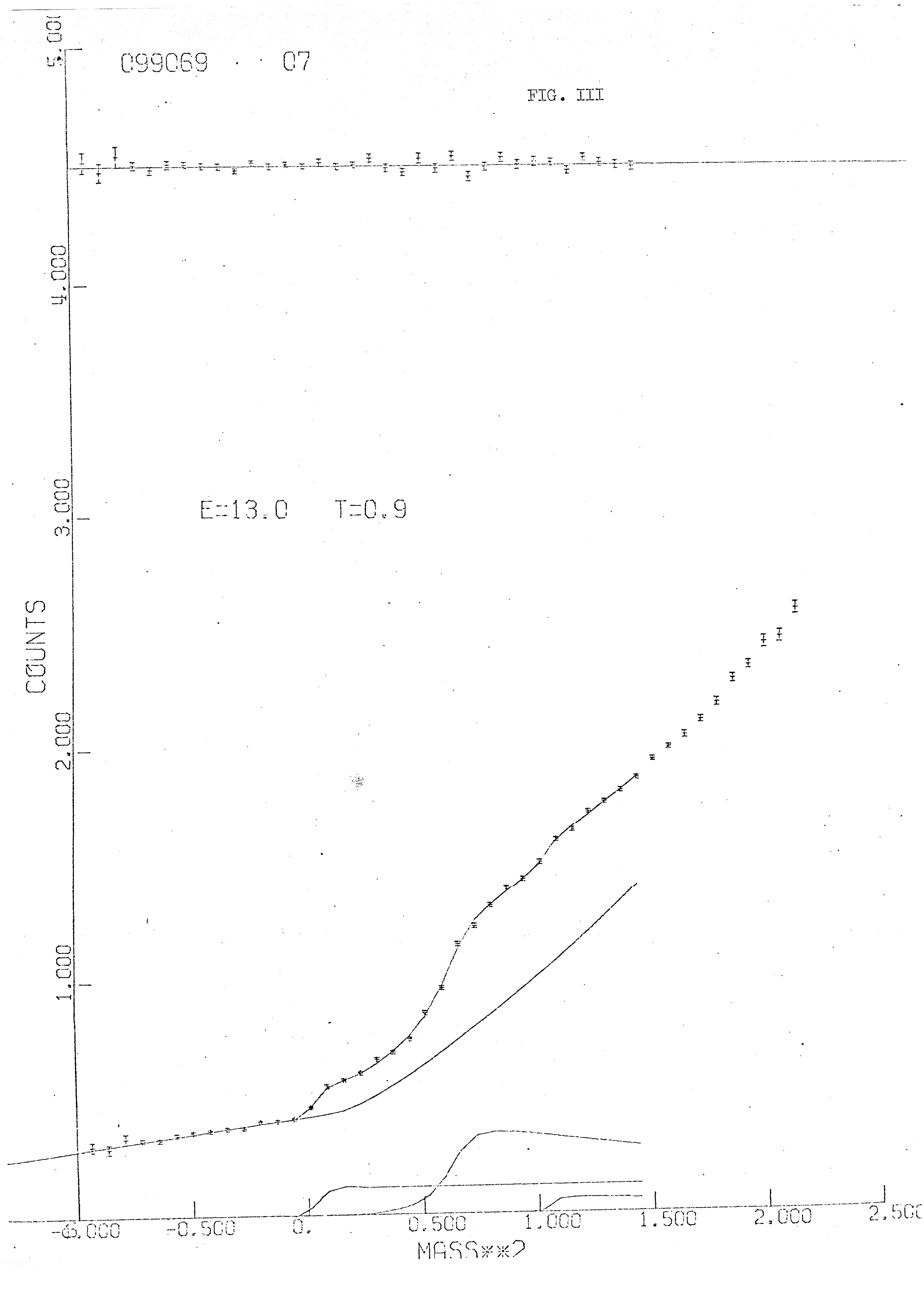
Figure 2: Is the yield curve obtained by subtracting the yields at peak energies of 14.5 GeV from the yields at 13.0 GeV and t values of $-.5(\mathrm{BeV/c})^2$. The curves show the fits to the raw experimental data with the calculated contributions from π^0, $(\rho^0 + \omega^0)$, and ϕ^0 production. The top line shows the deviances from the fitted curve. It is to be noted that the fits definitely appear to require a further resonance or resonances in the region of 1200-1400 MeV.

Figure 3: Yield curve for a peak Bremsstrahlung energy of 13.0 GeV, $t = -.9(\mathrm{BeV/c})^2$. The curves show the fits to the raw experimental data with the calculated contributions from π^0, $(\rho^0 + \omega^0)$, and ϕ^0 production. The top line shows the deviances from the fitted curve.



099069 02
FIG. I
SCALE FACTOR = 10
E=13.0 T=0.5
COUNTS
MASS**2
1.00
0.800
0.600
0.400
0.200
-1.000
-0.500
0.
0.500
1.000
1.500
2.000
2.50


099069 05
FIG. II
SUBTRACTION ØF
E=13.0 T=0.5
FRØM
E=14.5 T=0.5
COUNTS
2.00
1.600
1.200
0.800
0.400
-1.000
-0.500
0.
0.500
1.000
1.500
2.000
2.50
MASS**2



099069 · 07
FIG. III
E=13.0 T=0.9
COUNTS
5.00
4.000
3.000
2.000
1.000
-0.000
-0.500
0.
0.500
1.000
1.500
2.000
2.500
MASS**2

Supplement No. 3 to
Proposal No. 21/22

21-C

REQUEST FOR EXTENSION OF EXPERIMENT 21/22

by

R. Anderson	S.L.A.C.
D. Gustavson	S.L.A.C
J. Johnson	S.L.A.C.
F. Murphy	Univ. of Calif. - S.B.
D. Ritson	S.L.A.C.
R. Weinstein	Northeastern University
B. Wiik	S.L.A.C.

August, 1968

PROPOSAL FOR EXTENSION OF EXPERIMENT 21/22

OF FORWARD BOSON PRODUCTION TO LOW t - VALUES

INTRODUCTION

In the original Experiment 21/22 and the continuation run in July we successfully measured the forward photoproduction of π^0, η, $\rho^0(\omega)$, φ by observing the recoil proton yield as a function of missing mass in the reaction $\gamma + P \rightarrow P + X^0$. Fig. 1 shows a typical yield curve for $-t = .9\ \mathrm{GeV/c)^2}$ and a photon energy of 6.5 GeV. Data was collected on these processes at energies between 5 and 18 GeV and for t values ranging from $-.2(\mathrm{GeV/c})^2$ to $-1.4(\mathrm{GeV/c})^2$.[1,2] The ranges of t and s covered were determined in large part by the resolution of the apparatus. This resolution resulted almost solely from the multiple coulomb scattering of the protons in the target, and not from the optical properties of the spectrometer. In addition, of course, energy losses within the target set a lower limit to the detectable proton momentum.

We now propose to extend and improve these measurements by replacing the liquid target by a gaseous H_2 target pressurized to about 15 atm and cooled with a refrigerator unit. With such as arrangement we expect to be able both to reach t values as low as $-.05\ (\mathrm{GeV/c})^2$ and to reduce the amount of scatter presented to the emerging proton beam from $\sim \frac{1}{120}$ of a radiation unit to $\sim \frac{1}{400}$ of a radiation unit. While some of the cross sections may be determinable from other proposed SLAC experiments, we believe that even in those cases it is important that the t dependence be determined with one apparatus and not be composed of results from several experiments with varying normalizations.

OBJECTIVES

In our previous runs the loss of resolution at low t values led to considerable difficulties in the interpretation of our data. For instance

π^0 cross sections at 16.0 GeV could not be measured below $t = -.4\ (\text{GeV/c})^2$ despite the very high statistical precision of our data, because of confusion with the tail of the ρ-meson excitation.

The problems we wish to tackle are:

a) To harden up the existing cross sections for π^0 production, particularly at high energies and t values down to $.05\ (\text{GeV/c})^2$. In view of the dynamical zero expected for exchange of an ω-trajectory at $t = -.2\ (\text{GeV/c})^2$ it would also be interesting to obtain high energy data to complement the existing low energy data, where no such dip is observed. We would also like to obtain additional data around $t = -.5\ (\text{GeV/c})^2$ to examine with better accuracies the dip previously observed.[1,3]

b) To harden up η^0 production cross sections at energies up to ~ 10 GeV.

c) To extend the present φ cross sections down to t values of at least $t = -.1\ (\text{GeV/c})^2$. Three quantities are of obvious theoretical interest. The forward cross section (obtained by extrapolation to $t = 0$); the t dependence, and the energy dependence. We are hopeful that we can obtain the necessary information on this problem to satisfy present theoretical queries.

d) To complete ρ cross sectional measurements down to $t = -.05$. This is a high rate process and would require a modest investment of time. We believe that this would complete our present set of "ρ-ω" measurements.

ESTIMATE OF CROSS SECTIONS AND BACKGROUND

The counting rate per sec N_r integrating over the spectrometer acceptance is given by:

$$N_r = \frac{4.96}{\sin\Theta} \times \frac{d\sigma}{dt} \times \frac{dt}{d\Omega^*} \times J \times f$$

here $d\sigma/dt$ is in $\mu bs/(GeV/c)^2$ and J is the appropriate Jacobian factor. f is the photon flux in units of 10^{12} equivalent quanta/sec. The average values for f during our last series of run was about .9 for E_0 between 10 and 18 GeV decreasing to about .4 at 5 GeV/c.

In this expression the following assumptions were made:

1) Target cell 15cm long, 15atm of H_2 at about 50°K.

2) $(\Delta P/P)\ \Delta\Omega = 6.52 \times 10^{-5}$. This could be increased by perhaps a factor of two by using the full spectrometer acceptance.

We propose to measure the following cross sections

1) $\gamma + P \to \pi^0 + P$

2) $\gamma + P \to \eta + P$

3) $\gamma + P \to \rho(\omega) + P$

4) $\gamma + P \to \varphi + P$

The expected counting rates for these reactions are plotted versus t in Fig. 3. They were computed with the following assumptions for the cross sections.

1) Our[1] data and the data of M. Braunschweig, et al.[3] were used for the π^0 cross section with the assumption that $d\sigma/dt \sim s^{-2}$.

2) The η cross sections were taken from the computation by A. Dar and V.R. Weisskopf[4], based on the vector dominance theory. This computation fits the 5 BeV η data fairly well (within a factor of 1.5).

3) The ρ and φ rates were computed assuming the cross section to be of the form $d\sigma/dt = A \times e^{-Bt}$.

For ρ: $A = 90\ \mu b/(GeV/c)^2$ and $B = 8.5\ (GeV/c)^{-2}$

For φ: $A = 3\ \mu b/(GeV/c)^2$ and $B = 4.5\ (GeV/c)^2$

These values for A and B were taken from the published values by Jones, et al.[2] With the low target density, protons from double processes from within the target should be negligible. We also hope that by increasing the radius of the target and improving the collimation, we can eliminate the protons coming from interactions of the photon with the wall material of the target. However, since we have reduced the target density by a factor of 9 below the liquid target density, the room background counting rates become important.

An upper limit to the room background was obtained from the figures for no target running in our July runs. This is shown in Fig. 3, and is quite high. We hope to reduce this background by:

a) mounting the SEQ and beam dump 300-ft. downstream away from the spectrometer instead of 150-ft. downstream.

b) more careful shielding of sources of radiations.

c) reducing the amount of material the beam goes through before reaching the beam dump.

d) more careful masking between spectrometer and target.

In principle, because of the virtual elimination of double processes within the target and by careful beam layout, we might even obtain substantial improvements over our previous data runs in our signal to background ratios for π^0 production.

On the rate question we would expect to obtain a factor ~ 1.5 greater transmission of photons than in our July run by opening up the photon beam collimator slits, and we would expect, on the basis of our previous experience to be able to modify our data taking pattern to achieve a factor 1.5 to 2 greater efficiency in the use of our statistics. We therefore expect losses in data rates of at worst the order of a factor of 4.

DETECTOR SYSTEM AND TARGET

The momentum and angle of the recoil protons will be measured using the 1.6 GeV/c spectrometer. For the momentum range considered here, the protons can be uniquely identified by measuring dE/dX as well as their range. The detector system will therefore be extremely simple, consisting of 3 thin trigger counters in coincidence with an 8-channel hodoscope counter, backed up with our previous trigger counters. For $|t| \geq .2\ (\mathrm{GeV/c})^2$ we will use our previous trigger counters, which will be installed together with the low momentum counters.

The target proper is a stainless steel cylinder 5" in diameter with a 20-mil mylar window at the proton exit side. The target, pressurized to 15atm with H_2 gas, is cooled to about $50^{\circ}K$ with a refrigerator unit. The spectrometer vacuum is connected directly with the target vacuum to minimize the multiple scattering. The spectrometer can be rotated in the required angular range without breaking the vacuum. A target and counters of a similar type have been built and operated successfully for two years at the Mark III accelerator by one member of our Group (B. Wiik) while measuring recoil proton polarizations below meson threshold in proton compton scattering.

DATA TAKING PROCEDURE

The data taking procedure will be similar to that in Experiment 21/22, eg., for fixed end point energy and spectrometer momentum we will measure the excitation curve by stepping the spectrometer angle. However, since the separation between the particles is much larger at these low t values, we will not cover the range uniformly, but rather concentrate on the region around the steps. Figs. 4, 5, and 6 show the kinematics curves for end point energies of 5, 10, and 16 GeV. The experimental resolution due to multiple scattering in the target is shown in Fig. 7. For comparison the difference between the π and 2π thresholds as well as the difference between the π and η thresholds is shown for a photon energy of 10 GeV. The resolution is clearly adequate even at $t = -.05\ (\mathrm{GeV}/c)^2$ to separate the π, η, ρ, and φ. (The separation will not be entirely sufficient to separate clearly the π^0 from the non-resonant 2π production, but by considering the slopes below and above the step we expect to evaluate their contributions.)

In our early runs we used a "matrix" form of taking data where every experimental yield point was measured with each element of the hodoscope system. From data taken in this way one can obtain very extended interval consistence checks of monitor performance, electronic stability, counter efficiencies, etc. On the basis of our performance we would relax the "redundancy" of our data somewhat to obtain more data over the regions of interest.

EQUIPMENT

1.6 GeV Spectrometer.

Gas Target to be built by Group F.

Full intensity photon beam from 5 - 18 GeV (180pps).

TOTAL ESTIMATES

π^o Production - t = .05 $(GeV/c)^2$ to .5$(GeV/c)^2$, 5 to 18 GeV	70 hours
η^o Production - t = .2$(GeV/c)^2$ to .5$(GeV/c)^2$, 6 GeV and 10 GeV	35 hours
ρ^o Production - t = .05$(GeV/c)^2$, 5 to 18 GeV	25 hours
φ^o Production - t = .1$(GeV/c)^2$ to .3$(GeV/c)^2$, 5 to 18 GeV	75 hours
Set-up time and background improvement measurements	30 hours
Total	235 hours

(if possible, it would be desirable to have some opportunity to test background conditions prior to starting the main run.)

References

1) R. Anderson et al.
Phys. Rev. Letters 21, 384, 1968
and unpublished data

2) W. G. Jones et al.
Phys. Rev. Letters 21, 586, 1968
and unpublished data

3) M. Braunschweig et al.
Phys. Letters 26B, 405, (1968)

4) A. Dar and V. F. Weisskopf
Phys. Rev. Letters 21, 586, 1968

Figure Captions

Fig. 1. Yield curve for a peak Bremsstrahlung energy of 6.5 Gev, and a t value of -0 .9 (Gev/c)^2 versus the missing mass squared of the unobserved boson system. The yield curve shows breaks for π^o, η,ρ^o(ω), and φ production.

Fig. 2. Differential curve, obtained from the yield curve in Fig. 1 by subtracting points separated by one bin and plotting the result in that bin. The peaks corresponding to the π^o, η,ρ(ω), and φ are clearly seen.

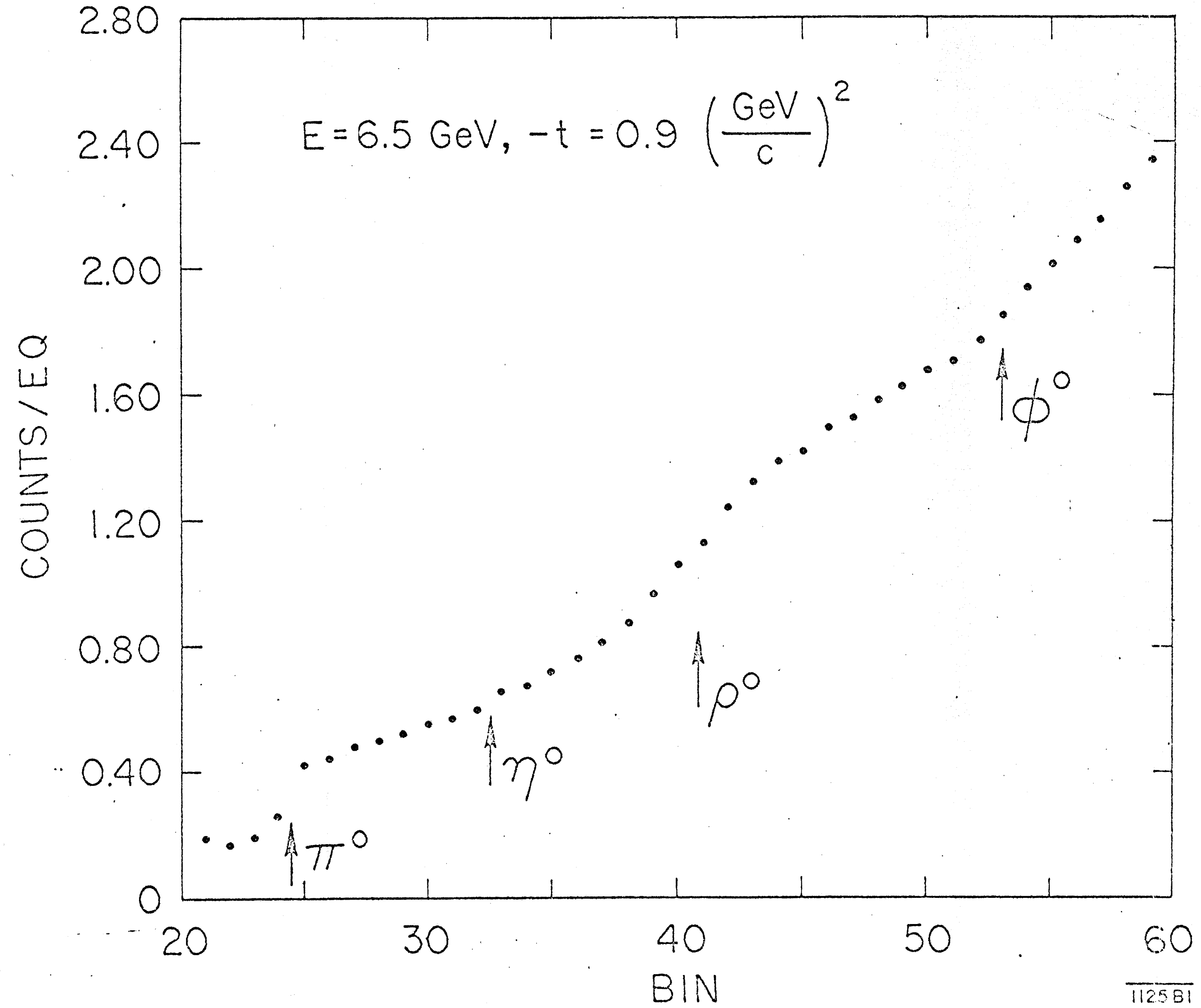
Fig.3. The expected counting rates versus the momentum transfer squared for the different reactions are shown. The points marked ☒ indicate the room background present in the July run.

Fig. 4. Kinematics for photoproduction of π^o, η, ρ(ω) and φ for a γ ray energy of 5 Gev. Plotted is the momentum of the recoil proton versus its laboratory angle. The C.M. angles are indicated on the plot.

Fig. 5. The same as Fig. 5 for k = 10 Gev.

Fig. 6. The same as Fig. 5. for k = 16 Gev.

Fig. 7. Multiple scattering in the target and windows versus momentum for a proton leaving the target at 90^o. For comparison the difference between the π and 2π thresholds as well as the difference between the π and η thresholds is shown for a photon energy of 10 Gev.



E = 6.5 GeV, −t = 0.9 (GeV/c)²
COUNTS / EQ
2.80
2.40
2.00
1.60
1.20
0.80
0.40
0
20
30
40
50
60
BIN
π°
η°
ρ°
φ°
1125B1

Fig. 1

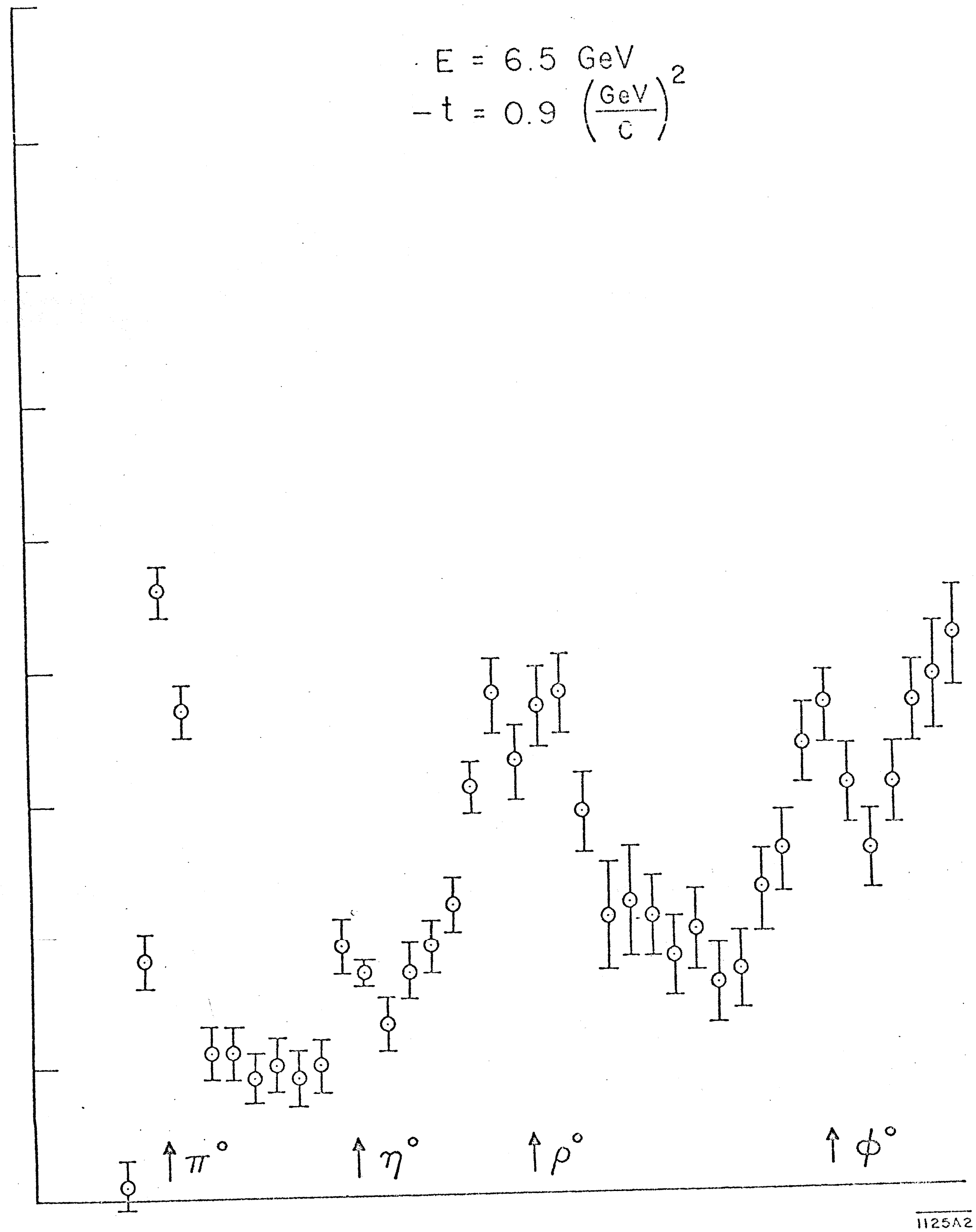


Fig. 2

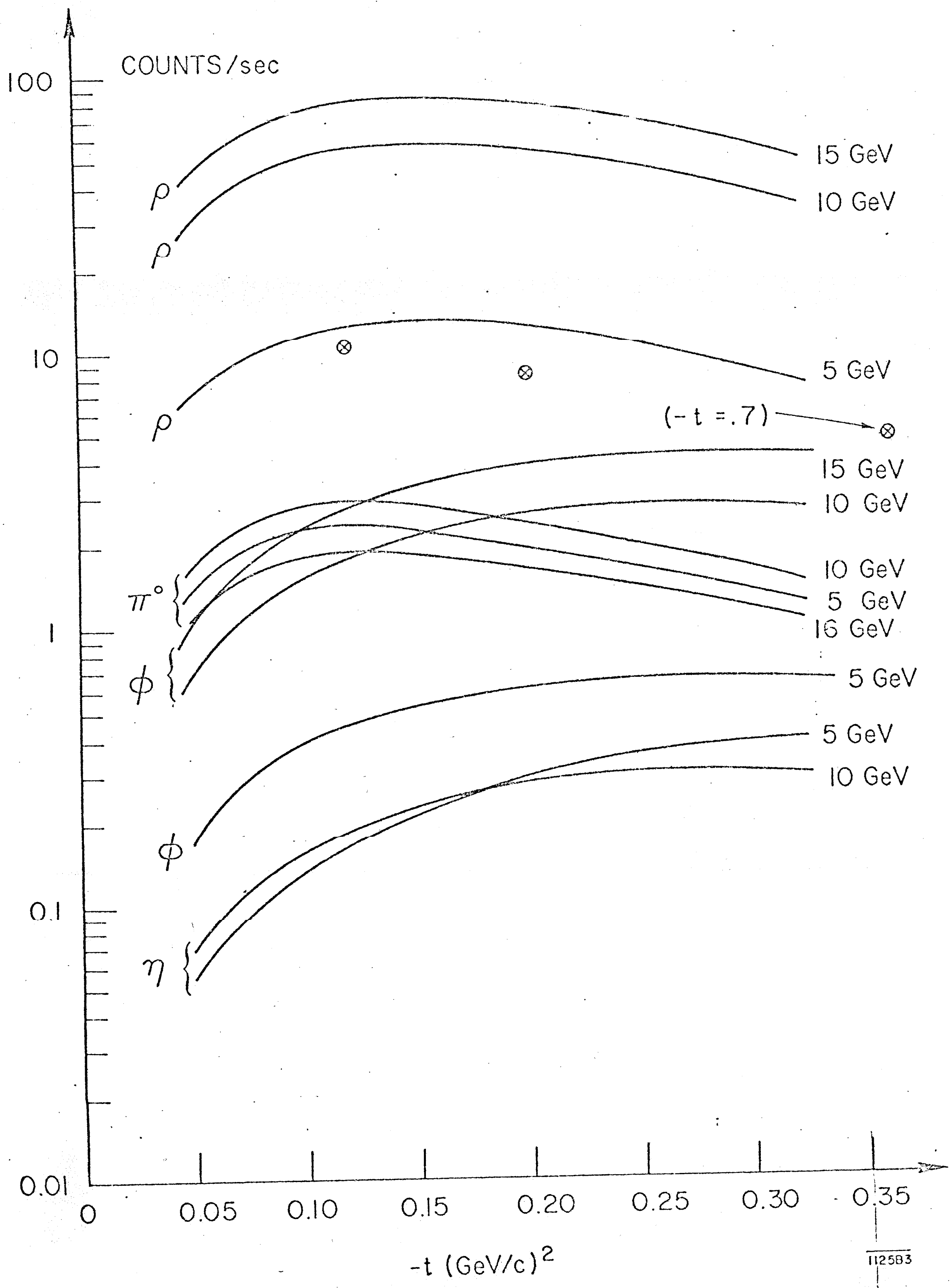

COUNTS/sec
100
10
1
0.1
0.01
ρ
15 GeV
10 GeV
5 GeV
(-t =.7)
π°
ϕ
15 GeV
10 GeV
10 GeV
5 GeV
16 GeV
5 GeV
ϕ
5 GeV
η
10 GeV
0
0.05
0.10
0.15
0.20
0.25
0.30
0.35
-t (GeV/c)^2
112583

Fig. 3

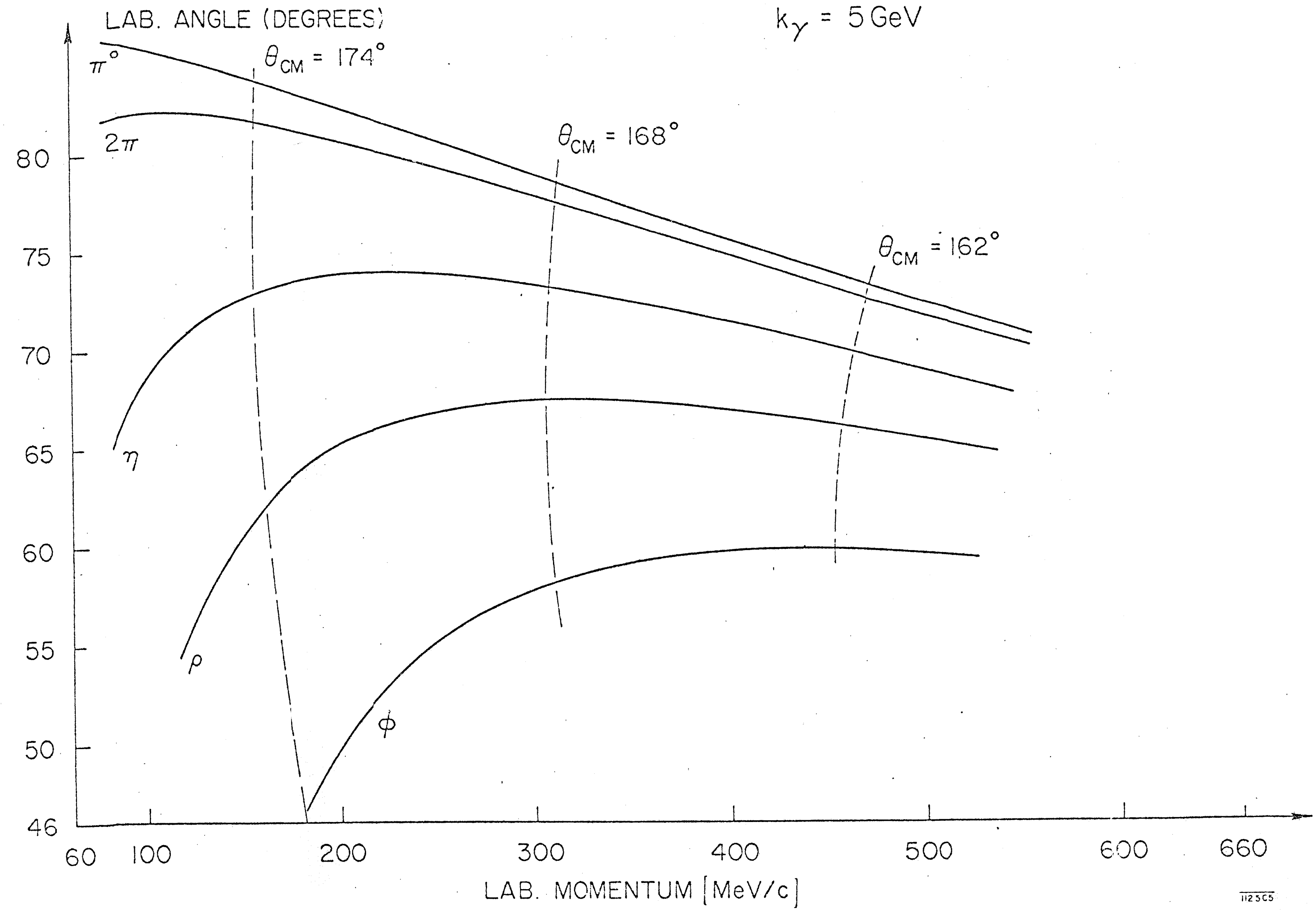

LAB. ANGLE (DEGREES)
k_γ = 5 GeV
π°
2π
η
ρ
ϕ
θ_{CM} = 174°
θ_{CM} = 168°
θ_{CM} = 162°
80
75
70
65
60
55
50
46
60
100
200
300
400
500
600
660
LAB. MOMENTUM [MeV/c]
112305

Fig. 4

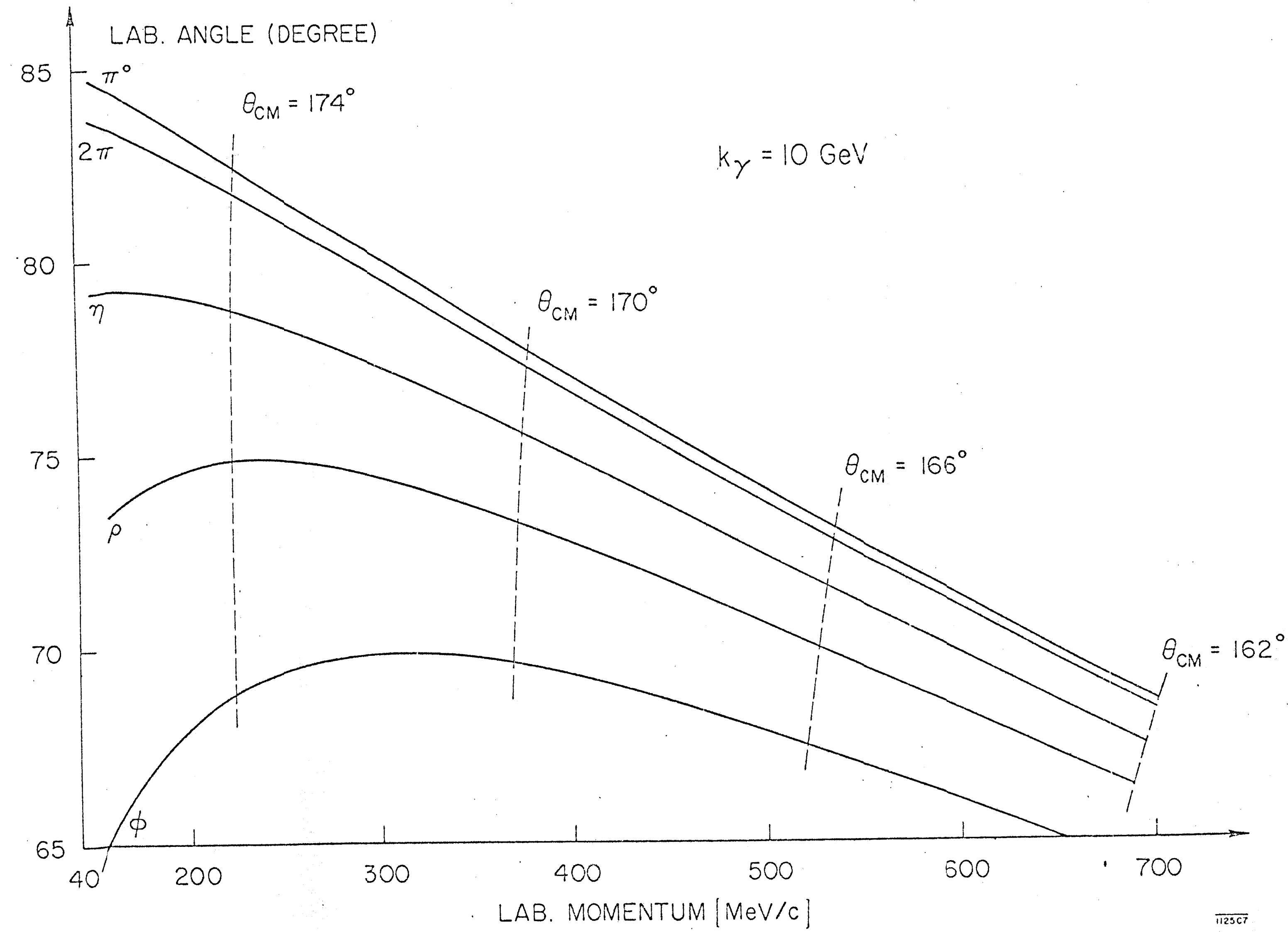

LAB. ANGLE (DEGREE)
85
80
75
70
65
40
200
300
400
500
600
700
LAB. MOMENTUM [MeV/c]
k_γ = 10 GeV
θ_{CM} = 174°
θ_{CM} = 170°
θ_{CM} = 166°
θ_{CM} = 162°
$\pi°$
2π
η
ρ
ϕ
1125C7

Fig. 5

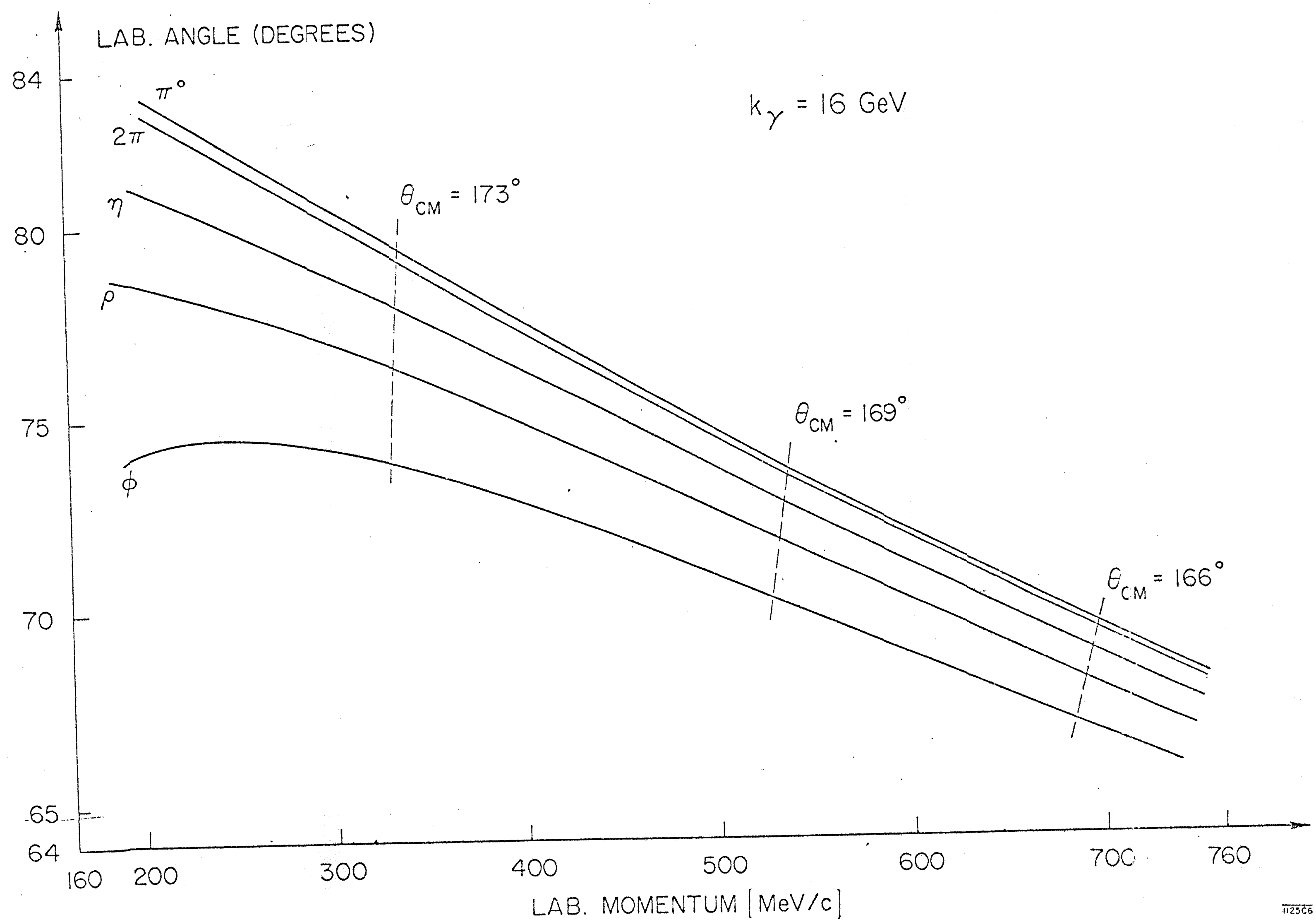

LAB. ANGLE (DEGREES)
84
80
75
70
65
64
π°
2π
η
ρ
ϕ
k_γ = 16 GeV
θ_{CM} = 173°
θ_{CM} = 169°
θ_{CM} = 166°
160
200
300
400
500
600
700
760
LAB. MOMENTUM [MeV/c]
1125C6

Fig. 6

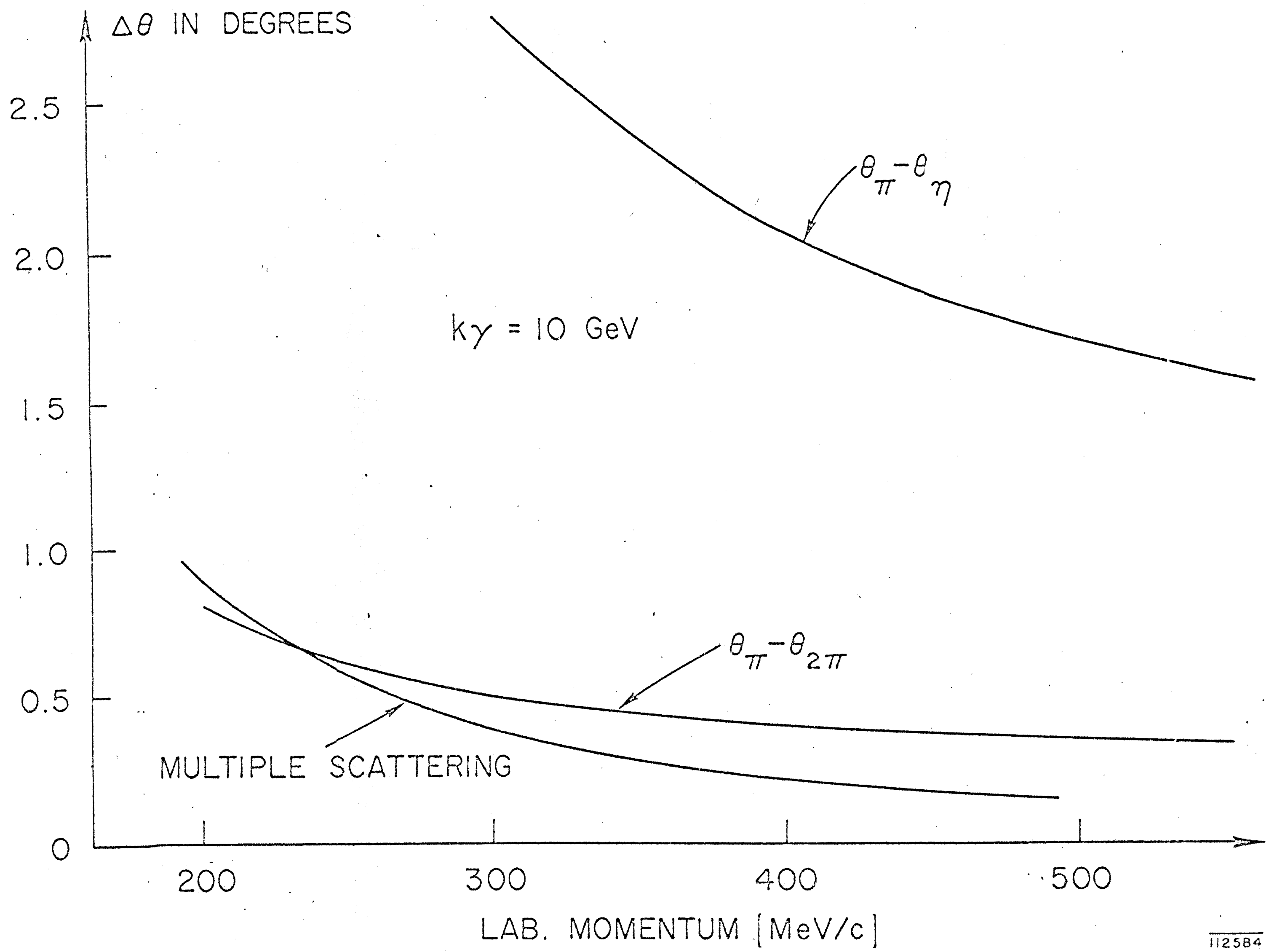

$\Delta\theta$ IN DEGREES
2.5
2.0
1.5
1.0
0.5
0
$k\gamma$ = 10 GeV
$\theta_\pi - \theta_\eta$
$\theta_\pi - \theta_{2\pi}$
MULTIPLE SCATTERING
200
300
400
500
LAB. MOMENTUM [MeV/c]
112584

Fig. 7

ESTIMATED DISTRIBUTION OF TIME TO BE DEVOTED TO ρ^{0}, ω, ϕ, AND THE MASS SEARCH

k (BeV)	t $(BeV/c)^2$	Time (hours)	Particle Studied
5	0.3	2	ρ, ω
	0.5	4	
	0.7	4	
11	0.3	2	
	0.5	4	
	0.7	4	
18	0.3	2	
	0.5	4	
	0.7	4	
11	0.3	2	ϕ
	0.5	4	
	0.7	4	
18	0.3	2	
	0.5	4	
	0.7	4	

Total for ρ, ω, ϕ = 50 hours

Mass search = 25 hours