SLAC Proposal No. 22

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COMPARISON OF η° AND π° PHOTOPRODUCTION

I INTRODUCTION

II CROSS-SECTION ESTIMATES

III BACKGROUNDS

IV RESOLUTION REQUIREMENTS

V EXPERIMENTAL METHOD

VI CONCLUSIONS

VII SUMMARY OF REQUIREMENTS

VIII REFERENCES AND APPENDICES

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SLAC PROPOSAL NO. 22

(Comparison of η^o and π^o Photoproduction)

I - INTRODUCTION

In our Proposal No. 7, (approved in February, 1966) we discussed a broad range of photoproduction processes that we intended to make exploratory measurements on, including

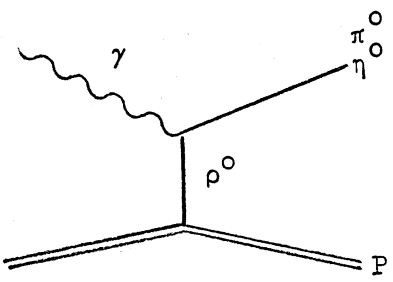
$$\gamma + p \rightarrow \pi^o + p \qquad \text{---(1)}$$

In view of the success of Prepost and Anderson[1] in measuring the processes

$$\begin{aligned} &\gamma + p \rightarrow \eta^o + p \\ \text{and} \quad &\gamma + D \rightarrow \eta^o + D \end{aligned} \qquad \text{---(2)}$$

by running excitation curves at the HEPL 1-GeV linac and detecting the angle and energy of the recoiling proton or deuteron we would propose to make additional measurements to measure simultaneously <u>both</u> the production of η^o's and π^o's from hydrogen and possibly deuterium with the same techniques on the 100" spectrometer at S.L.A.C. Such measurements are equivalent to measuring the production of η^o's and π^o's at very forward angles. Good data do not exist on these reactions above energies of $\sim$ 1.5 GeV, and these reactions can only be explored with considerable difficulty by other techniques such as bubble-chambers. The comparison of the production cross-sections is of course of considerable theoretical interest. For instance if the production of π^o and η^o proceded predominantly

by "ρ^o exchange",



the ratio $\pi^o:\eta^o$ would be predicted on the quark model[2] to be 120:70 (or approximately 2:1).

We would, of course, be interested in exploring whether ρ^o's, ω^o's and φ^o's (or $[\rho^o$'s + ω^o's$]$ and φ^o's) could also be separated by measuring production excitation curves. It is clear from C.E.A. and Hamburg results that ρ^o production should be easily measured. However, it is not clear whether in view of the predicted ratios of production $\rho^o:\omega^o:\varphi^o$ of 9:1:2 that it is easy to detect φ^o's. It is also not clear how competitive the spectrometer measurements will ultimately prove to be with bubble-chamber, spark chamber, or streamer chamber measurements.

We append to the discussion graphs of the kinematics for these processes (Figs. 2 and 3). The kinematics are unusual in that one is working in the so-called "Jacobian" region. In this region the main limitation is set by the angular discrimination and not the precision of measurements of the momentum or primary energy. The kinematics permit one to explore a considerable amount of the region in which a boson is produced in the "forward peak".

It is possible to determine an "excitation" curve by a) holding the angle and secondary energy constant, varying the maximum photon energy and measuring the yield of protons (or deuterons), b) holding

the angle and primary energy constant, and varying the secondary energy and c) holding the primary and secondary energy constant, and varying the angle. a) is of course the traditional method although we have in the past also used c) to explore excitation curves. It is likely that method b) or c) would be the most economical in time.

An excitation curve to detect the π^o and η^o cross-sections would require about 15 points with 2% precision, and if extended to the φ^o mass about 40 points. The time required for such a measurement using the technique of changing the primary energy would be typically ~ 2 hours and using the technique of changing the recoil angle might be reduced to about one hour. One such curve only gives one cross-section and accordingly a grid of 5 angular values at five energies would require about 50 hours of data taking and about 50 hours of checks and empty target backgrounds. We would estimate accordingly that a preliminary experiment to this depth would require an additional time of about 100 hours over and above the previous request. As is usual the backgrounds will be serious and will limit the range over which data can be meaningfully obtained with such techniques. At proton momenta corresponding to small values of four momenta transfer, the background will originate from recoil protons via secondary electrons which make small angle coulomb scatters in the target. At larger four momentum transfers the background will arise from protons re-scattering in the target. Rough estimates have been made of these backgrounds. They will undoubtedly limit the energy range accesssible to measurements. The cross-sections appear to be dropping sharply as a function of energy whereas the predicted backgrounds remain roughly constant. Accordingly measurements will become impractical at some primary energy possibly of the order 10 GeV.

II - CROSS-SECTION ESTIMATES

We have proposed to measure the following cross-sections by experiments taking "excitation curves" of the recoil target particle.

$$\gamma + p \rightarrow \pi^o + p \qquad ---(1)$$

$$\gamma + p \rightarrow \eta^o + p \qquad ---(2)$$

$$\gamma + p \rightarrow \rho^o + p \qquad ---(3)$$

and $$\gamma + p \rightarrow \text{vector meson} + p \qquad ---(4)$$

to the extent that the cross-sections are sufficiently large.

For estimates of reaction 1), the best estimates of expected cross-sections can be made from the most recent DESY data [3.] on π^o production at forward angles. The data are reasonably well fit at forward angles by

$$\frac{d\sigma}{dt} = \left(\frac{k}{M}\right)^{2\left[\alpha(t)-1\right]} T(t) \qquad ---(5)$$

where k is the laboratory photon energy, M the recoil target mass, $\alpha(t)$ is the regge formalism parameter, and $T(t)$ is a form factor which depends upon t only. t is the usual 4 momentum transfer squared. A best fit to the DESY data gives $\alpha(t) = 0.4 \pm 0.08 + (1.0 \pm 0.33)\ t$ with t in $(GeV/c)^2$. This fit comes from fitting the DESY results at 2.0 GeV and 3.0 GeV. We note that the value of $\alpha(t)$ is very similar to that of the ρ^o trajectory, $\alpha(t) = (0.57 \pm 0.01) + (0.91 \pm 0.06)\ t$ given by Höhler[4.]. It would, of course, be very desirable to further check this assignment at higher energies. Information about the form factor $T(t)$ also comes from considerable DESY data on the reaction: $\gamma + p \rightarrow \pi^+ + n$[5.].

Although the π^+ cross-sections themselves are different, the t dependence seems to be the same as $\gamma + p \rightarrow \pi^o + p$. The 3.0 GeV DESY data for $\gamma + p \rightarrow \pi^o + p$ gives $d\sigma/dt \sim 3\mu b/(GeV/c)^2$ for $t = 0.1\ (GeV/c)^2$ and $d\sigma/dt \sim 1.2\mu b/(GeV/c)^2$ for $t = 0.3\ (GeV/c)^2$. It is possible from this data combined with Equ. 5 to estimate cross-sections at higher energies and various value of t.

In particular, for $t = 0.25\ (GeV/c)^2$ which is approximately the smallest value of t we would consider studying (due to multiple scattering resolution factors) we estimate:

k	$d\sigma/d\Omega^*$	(Expected value normalized to the cross-section for π^o production at 2 GeV)
2 GeV	1.0	
5 GeV	1/1.6	
10 GeV	1/2.60	
15 GeV	1/3.40	
20 GeV	1/4.10	

(Note that $d\sigma/d\Omega^*$ has been tabulated, not $d\sigma/dt$. $d\sigma/d\Omega^*$ as actually measured by DESY at 2.0 GeV and for $t \sim 0.2\ (GeV/c)^2$ is $\sim 1.2\mu b/sr$.)

The yield is given by:

N(yield per unit time) = (beam per unit time)·

(radiator thickness in radiation lengths)·

$f(k_o, k)\ d\sigma/d\Omega^*\ J\ \Delta p/p\ \Delta\Omega\ \rho\ N\ \sigma\ \ell$

where $N\ \sigma\ \ell$ - target thickness in protons per cm^2. $f(k_o, k)$ Bremsstrahlung Function (probability for electron of energy k_o to radiate photon of energy k in the interval dk about k, per radiation length multiplied by k).

J - Jacobian which converts from ($\Delta\Omega^*$, $\Delta k/k$) to ($\Delta\Omega$, $\Delta p/p$)

$\Delta\Omega\,\ell$ for the 1.6 GeV/c spectrometer - 30 msr inches

$\Delta p/p$ for the 1.6 GeV/c spectrometer - $\pm$ 4%

for π^o production with t ~ 0.2 - 0.3 at 10 GeV the Jacobian factor is ~ 2. Assuming a $d\sigma/d\Omega^*$ of 1μb/sr and a SLAC beam of 10^{11} electrons/pulse incident upon a 0.01 radiator, the yield per second at 360 cycles per second would be 74 protons/sec.

We would thus expect that for 10 GeV π^o production, the counting rates will be on the order of ~ 20 counts/sec from this reaction alone over the whole spectrometer acceptance. Resolution considerations determine that only 3 or 4 channels will have a clean separation of one pion and two pion invariant masses. The 1.6 GeV spectrometer has a 30 channel counter array which may be oriented in the "P, θ" plane for optimum resolution for the reaction under consideration. For the "good channels" then we would expect ~ 2 counts/sec at 10 GeV from $\gamma + p \rightarrow \pi^o + p$.

As discussed in the introduction to this proposal, the cross-section for $\gamma + p \rightarrow \eta^o + p$ should be roughly down by a factor of 2 from $\gamma + p \rightarrow \pi^o + p$ for the same photon energy and momentum transfer. Experimentally, however, the problem of measuring η^o production is significantly different in that the η^o mass is well above the 2 pion production threshold. Thus the η^o yield can only be measured by subtracting the background produced by non-resonant 2 pion production. The background estimates are contained in the next Section III. For reaction (3), $\gamma + p \rightarrow \rho^o + p$, the expected cross-sections are extrapolated from the CEA data on the basis that the ρ^o is diffraction produced at the momentum transfers accessible to measurement by our techniques. In the region t $\geq$ 0.25 $(GeV/c)^2$ $d\sigma/d\Omega^*$, the differential cross-section in the CM system, will range from 10μb/sr at t = 0.25 $(GeV/c)^2$ to ~ 2μb/sr at t = 0.40 $(GeV/c)^2$.

The CEA and Hamburg results lead us to expect that the backgrounds from non-resonant processes will be of the order of 20% only. Due to the large width of the ρ^o peak one will be forced to make "end point" subtractions by taking data below and above the ρ^o threshold. The expected counting rates are $\geq$ 20 counts/sec over the full spectrometer aperture for t values out to t = 0.40 $(GeV/c)^2$.

III - BACKGROUNDS

A) Backgrounds from Double Processes Within the Target

In an experiment that measures the proton yield at some fixed angle and energy produced by a Bremsstrahlung beam, backgrounds will arise from a variety of sources. In a measurement, made at a fixed angle and fixed secondary momentum for scattered protons, the counting rate arising from the production of bosons of "mass" μ will be proportional to the value of $\frac{d\sigma_\mu}{dt}$ at k_μ, the photon energy that produced the boson.

The counting rate $C(E_o)$ at some primary energy E_o is,

$$C(E_o) \propto \sum\left(\frac{d\sigma_\mu}{dt}\right) + \text{Background}$$

where the summation is over all possible values of produced masses μ up to μ_{max} consistent with $k_{\mu_{max}} \leq E_o$.

Part of the background arises from photoproduced protons that are rescattered in the target. However such protons, prior to scattering, have higher initial energies and thus have larger t values at production. As the cross-section for production decreases sharply for higher t values the numbers of such protons will be small and the background should be a few percent only.

Background protons also arise from small angle coulomb scattering on protons of pair produced electrons. The expression for $C(E_o)$ can be shown to be,

$$C(E_o) \propto \sum_\mu\left(\frac{d\sigma_\mu}{dt}\right) + \left\{\frac{56\pi}{9}\frac{\mu^2_{max}}{\left(t+\mu^2_{max}\right)} \cdot \frac{m_e^2 k_o^2}{t^3} F^2(t) \sum r_e^2 \cos\theta_p\right\}$$

Where k_o is the primary energy of the electrons that elastically scatter protons into the spectrometer acceptance. X is the number of radiation lengths to the center of the target, m_e is the mass of the electron, r_e is the classical radius of the electron, and F(t) the proton form factor for elastic electron scattering. θ_p is the recoil angle of the proton. At an E_o of 10 GeV, and a t of .25 GeV^2/c^2, this background is comparable to the backgrounds arising from multi-pion production.

B) Non-Resonant Multi-Pion Backgrounds

From CEA and DESY data at 5.0 GeV, $\sigma_{2\pi_{total}} - \sigma_{2\pi_{\rho^o}} \cong 5\mu b$ and this appears to be independent of energy. This information can be used to estimate the recoil proton flux coming from non-resonant 2π production.

$$\text{Approximating:} \quad \left.\frac{d\sigma}{d\Omega^* dM}\right|_k \cong \left.\frac{\sigma_{2\pi \text{ non-res}}}{4\pi\ \Delta M}\right|_k$$

where $d\sigma/d\Omega^* dM$ is the CM differential cross-section per steradian per invariant mass interval ΔM, for non-resonant 2 pion production at photon energy k. $\Delta M = (M_{max} - M_{min})$ where $M_{min} = 2m_\pi$ and $M_{max} = (S + m_p^2 - 2S^{\frac{1}{2}}m_p)^{\frac{1}{2}}$ where S is the square of the total CM energy and m_p is the proton mass. This situation holds if there is no forward peaking of the non-resonant production. Since we would expect some forward peaking due to a form factor, we would guess that the forward peaking will be no sharper than that for $\gamma + p \rightarrow \pi^o + p$ and $\gamma + p \rightarrow \pi^+ + N$ at 5 GeV, giving $d\sigma/d\Omega^* dM \cong 10\ \frac{\sigma_{2\pi \text{ non-res}}}{4\pi\ \Delta M}$ for the angular range probed in this experiment. This should be a very conservative assumption. Then $d\sigma/d\Omega^* dM \cong 2\mu b/sr$ at 5 GeV using the CEA, DESY data.

Then at a given end point energy k_o (but still below the threshold for ρ^o production) the contribution from 2π production will be proportional to:

$$\sum_{k_{2\pi\,\text{threshold}}}^{k_o} \frac{kdN}{dk} \int_{M_{min}}^{M_{max}} \frac{d\sigma}{d\Omega^* dM} \, dM \left(\frac{\Delta k}{k}\right)$$

where $k_{2\pi\ \text{thresh}}$ is the threshold photon energy for producing protons of momentum p and angle θ from the reaction $\gamma + p \rightarrow 2\pi + p$. dM is the effective mass interval accepted by the spectrometer when set at a momentum p and angle θ. $\left(kdN/dk\right)$ is the Bremsstrahlung function.

Evaluating this expression for the case of the spectrometer set to look at the η^o mass with 10 GeV photons ($p = 500$ MeV/c, $\theta_p = 72.5^o$), one finds that $N_{2\pi}$ is proportional to $\sim 0.5\mu b/sr \left(kdN/dk\right)^p \Delta\Omega^*$. While for comparison the π^o yield for the same momentum and angle setting of the spectrometer is:

$$N_{\pi o} \sim 0.16\mu b/sr \frac{kdN}{dk} \Delta\Omega^* \sim 2\, N_{\eta o}$$

over the full 8% $\Delta p/p$ of the spectrometer. Thus this simple estimate shows that the η^o signal will be on top of a non-resonant background due to 2π production $\sim {}^{.5}/_{.08} \cong 6$ times larger than the η^o signal itself.

Table I gives our estimated backgrounds both from non-resonant and double processes and the cross-sections for η^o production for various values of the primary energy (for the spectrometer kinematically set to measure recoil protons from η^o production produced by the tip of the Bremsstrahlung spectrum).

TABLE I

Units are $\mu b/(GeV/c)^2$

	k_{η^o}	$d\sigma/dt_{\pi^o}$	$d\sigma/dt_{\eta^o}$	Effective $d\sigma/dt$ (elastic) from Electron Scattering	"Non-resonant" 2π Production $d\sigma/dt_{2\pi}$	Total	Ratio $\left(\frac{d\sigma/dt_{\eta^o}}{\text{Total}}\right)$
t=0.25	5	2.0	0.29	.268	1.74	4.3	0.068
	10	0.61	0.090	1.06	0.54	2.3	0.039
	15	0.31	0.044	2.42	0.26	3.0	0.015
	20	0.19	0.028	4.30	0.17	4.7	0.006
t=0.50	5	0.51	0.098	0.043	0.59	1.24	0.078
	10	0.11	0.021	0.173	0.126	0.43	0.049
	15	0.046	0.0084	0.390	0.050	0.50	0.017
	20	0.024	0.0046	0.693	0.028	0.75	0.006

Fig. 1 gives the ratio of signal to background predicted for η^o production. It will be noted that if this figure is correct, that measurements can be made up to above 10 GeV primary energies and become increasingly difficult at higher energies.

The ρ^o signal of course is expected to be 2 - 5 times larger than the π^o signal in the t region of small angles that we are interested in. Thus the subtractions can be no worse for ρ^o mass and it should be considerably easier to measure. In the worse case we anticipate that the ρ^o signal will be approximately equal to the non-resonant background.

IV - RESOLUTION REQUIREMENTS

Errors in resolution arise from the following sources:

(1) The momentum resolution of the spectrometer.

(2) The angular resolution of the spectrometer.

(3) Angular inaccuracies produced by the "multiple" scattering of a particle energing from the target.

(4) The energy spread of the primary electron beam.

The major source of imprecision in defining the kinematics can be shown to be due to source (3), the angular inaccuracy resulting from multiple scattering, the other errors introducing much smaller imprecision.

V - EXPERIMENTAL METHOD

The method followed for measuring single cross-sections will be identical to that followed by Prepost and Anderson to measure η^o production,

$$\gamma + p \rightarrow \eta^o + p$$
$$\gamma + D \rightarrow \eta^o + D$$

where the recoil proton or deuteron is detected with a spectrometer. Since this is a two body final state process, the momentum and angle determine the process kinematically. By changing the end point energy of the photon beam, with the spectrometer momentum and angle fixed, an excitation curve of yield versus the peak photon energy (or accelerator electron energy) is obtained. For processes with distinct masses a step will occur at the appropriate threshold energy, and a plateau will occur for increased end point energies until another process is reached. Fig. 8 shows an example of such an excitation curve obtained at Mark III in measuring $d\sigma/d\Omega$ for $\gamma + p \rightarrow p + \eta^o$ for a γ-ray energy of 860 MeV. The main curve in Fig. 8 is the yield obtained in the backing counters which accept the full aperture of the spectrometer. The insert shows the excitation curve in the region of the η^o step utilizing the "ladder counters" which are narrow counters dividing up the acceptance of the backing counters. The ladder counters are placed at a "ladder angle" θ_{lad} to maximize the rate of change in the ladder counters as the end point passes through the threshold for η^o production. This corresponds to aligning the ladder along the kinematics for the process being measured. In Fig. 8 steps are seen for π^o production, and η^o production.

The experimental problem can be broken into two parts, (1) to identify the protons and measure their yield accurately, (2) to resolve the steps due to the various particles. Consideration of (2) determines the proton momenta at which the spectrometer can be run successfully.

Figs. 2 and 3 show the kinematics for the production of various mass particles for γ-ray energies of 5 and 10 GeV/c. In the region, of interest around 500 MeV/c, all the lack of resolution in differentiating between various processes is in the angular resolution. In this region the angular resolution is determined by the multiple scattering and not by the ultimate resolution of the spectrometer. This is shown in Figs. 4, 5, and 6. In these graphs the angular resolution necessary to resolve π's from 2π's 2π's from η^o's and η^o's from ρ^o's is plotted. Also plotted is the experimental angular resolution in detecting protons (dashed curves) of the spectrometer for two hydrogen targets, determined only by the multiple scattering in the targets. The poorer one is for the target presently being built at SLAC and the better one is for a smaller target made of mylar with all mylar windows. At higher energies for the same momentum the margin of resolution required to separate π's from 2π's gets poorer. At 20 GeV with the good target we would expect to separate π's from the 2π threshold above 800 MeV/c, at 10 GeV only above 500 MeV/c. At 5 GeV γ-ray energies we can separate π's from the 2π threshold for momenta above 300 MeV/c using either target. At all energies we can separate η's from the 2π threshold.

Therefore, we are interested in detecting protons from 300 MeV/c up to perhaps 1000 MeV/c and for laboratory angles varying from 60° to 80°. At low momenta where backgrounds may be worse, we may have to resort to time of flight methods as we did at Mark III where we detected

η's associated with a coherent deuteron recoil. There the deuteron flux was about 1/100 of the proton flux in the spectrometer. In this case one needs a rejection ratio of 10^4 against protons for a 1% background. At Mark III we found we could achieve this with one counter and the time of flight system. We are building a similar system for use with the 1.6 GeV/c spectrometer at SLAC. A variable frequency transmitter is being constructed with a frequency range of 10 to 20 MC. The voltage signal from the beam chopper plates is being sent the full length of the accelerator to be used as a time marking signal in the counting room. Fig. 7 shows the time of flight for various particles through the spectrometer. Also shown is how the pattern repeats with the transmitter run at 10 MC and at 15 MC. For example, at 10 MC we can separate protons from relativistic particles above 450 MeV/c while with the transmitter at 15 MC we can separate protons from relativistic particles below 500 MeV/c. Thus by varying the frequency of the beam chopper we can arrange the repetition patterns indicated in Fig. 7 so protons in the momentum range of interest can be separated from any given other particle.

At low momenta, identification of the protons is simplified by the proton's large dE/dx and short well determined range. Above 600 MeV/c descrimination on the basis of dE/dx and range becomes less clean, and the identification will rely more on the time of flight separation.

VI - CONCLUSIONS

The 1.6 GeV/c spectrometer is ideally suited for the detection of the recoil protons for processes of the type:

$$\gamma + P \rightarrow \text{meson} + p$$

$$\text{or} \quad \gamma + D \rightarrow \text{meson} + D$$

for small values of the invariant momentum transfer squared, $0.1 \leq t \leq 0.50$. This corresponds to the proton recoiling in the lab with 300 to 1000 MeV/c momentum. Depending on the γ-ray energy this corresponds to the meson being produced in the lab at angles varying between 1° to 10°. For many processes for these small values of t it may be much easier to measure the process by detecting the recoil proton rather than the decay products of the meson. The chief limitations in measuring the above processes by means of detecting the recoil proton come from the angular resolution that can be obtained (limited by the multiple scattering in the target) and the subtractions necessary to separate the processes.

At these values of t measurement of π° production should be easy for γ-ray energies below about 10 GeV. Above 10 GeV due to multiple scattering in the target it will become more difficult. η° production will probably also be relatively easy below 10 GeV. Above 10 GeV due to backgrounds it will become increasingly hard (this is based on our predicted cross-sections). ρ's should be easy at all energies. To measure ω°'s and φ°'s could be difficult if the predicted ratio of the cross-sections of $\rho:\varphi:\omega$ of 9:2:1 holds up at high energies. Protons

of the momenta involved should be easy to identify with the 1.6 GeV/c spectrometer using dE/dx, range, and time of flight methods.

We have accordingly requested one hundred hours of prime running time, of which the major fraction would be used at machine energies below 10 GeV to measure η^{o} and π^{o} production.

VII - SUMMARY OF REQUIREMENTS FOR η^o, π^o COMPARISON

Requested Prime Time

100 hours at 360 ppsec, 10^{11} epp. The 100 hours running would be split with about 60 hours below 10 GeV primary energy, and 40 hours in the range of primary energy 10 - 18 GeV.

Set-up Time

10 pulses per sec below 10 GeV. ~ 50 hours required time.

Special Requirements

Chopper operation on the beam.

Apparatus

1.5 GeV/c spectrometer plus associated equipment.

VIII - REFERENCES

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2) Dalitz, "Les Houches Notes", Table 3, p. 157, Summer 1965.

3) M. Braunschweig, D. Husman, K. Lubelsmeyer, and D. Schmitz, "Single Photoproduction of Neutral π - Mesons on Hydrogen at Small Angles between 1.3 and 3 GeV", Universität Bonn, Physikalisches Institut Technical Report 1-014, July 1966.

4) G. Höhler et. at., Phys. Lett. 20, 79 (1966).

5) G. Buschhorn, et. al., "Photoproduction of Single Positive Pions between 1.2 GeV and 3.0 GeV", DESY Report 66/22, September 1966.

FIGURE CAPTIONS

1) Ratio of the η° production "signal" or recoil protons relative to the background protons plotted as a function of the primary energy k in GeV.

2) Kinematics for photoproduction of various mass mesons for a γ-ray energy of 5 GeV. Plotted is the momentum of the recoil proton vs its laboratory angle. Center of mass angles are indicated on the curves.

3) Kinematics for photoproduction of mesons for a γ-ray energy of 10 GeV.

4) Angular resolution: Plotted are the angular resolutions to separate π's from 2π's, η's from 2π's and ρ's from η's for a peak γ-ray energy, k = 5 GeV, as a function of the momentum of the spectrometer. Also plotted is the resolution of the spectrometer as determined by multiple scattering in two hydrogen targets. $\theta = \frac{15}{p\beta}\sqrt{\frac{1}{100}}$ gives the multiple scattering for the present target being built for End-Station A. $\theta = \frac{15}{p\beta}\sqrt{\frac{1}{225}}$ gives the multiple scattering for a mylar target. Above 300 MeV/c both targets allow resolution between all four processes discussed.

5) The same as Fig. 4 for k = 10 GeV.

6) The same as Fig. 4 for k = 20 GeV.

7) Time of flight through the 1.6 GeV/c spectrometer for various particles as a function of momentum. Using the chopped beam this pattern repeats in time. The pattern is shown for running the beam chopper at 15 MC and 10 MC.

8) A yield curve obtained at Mark III obtained by detecting the proton at a fixed angle and momentum and stepping the energy of the accelerator. Steps due to π^0 and η^0 production are clearly visible. The insert shows that the data obtained with the ladder counters in the region of the η^0 step with backgrounds subtracted. The arrow marked η^0 is the predicted threshold for η^0 production.

K&E 10 X 10 TO ½ INCH 46 1320
7 X 10 INCHES MADE IN U.S.A.
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FIG. 1

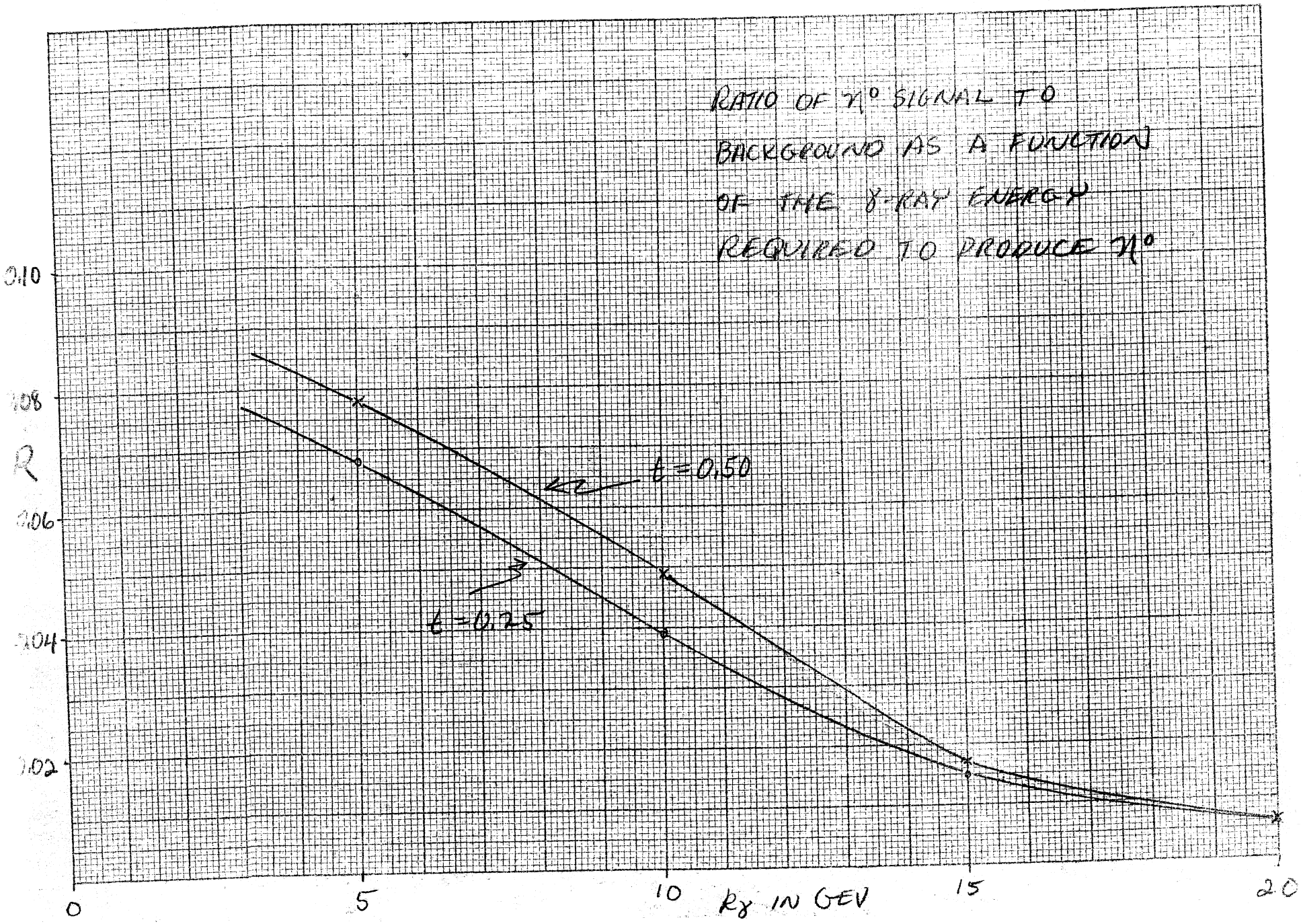
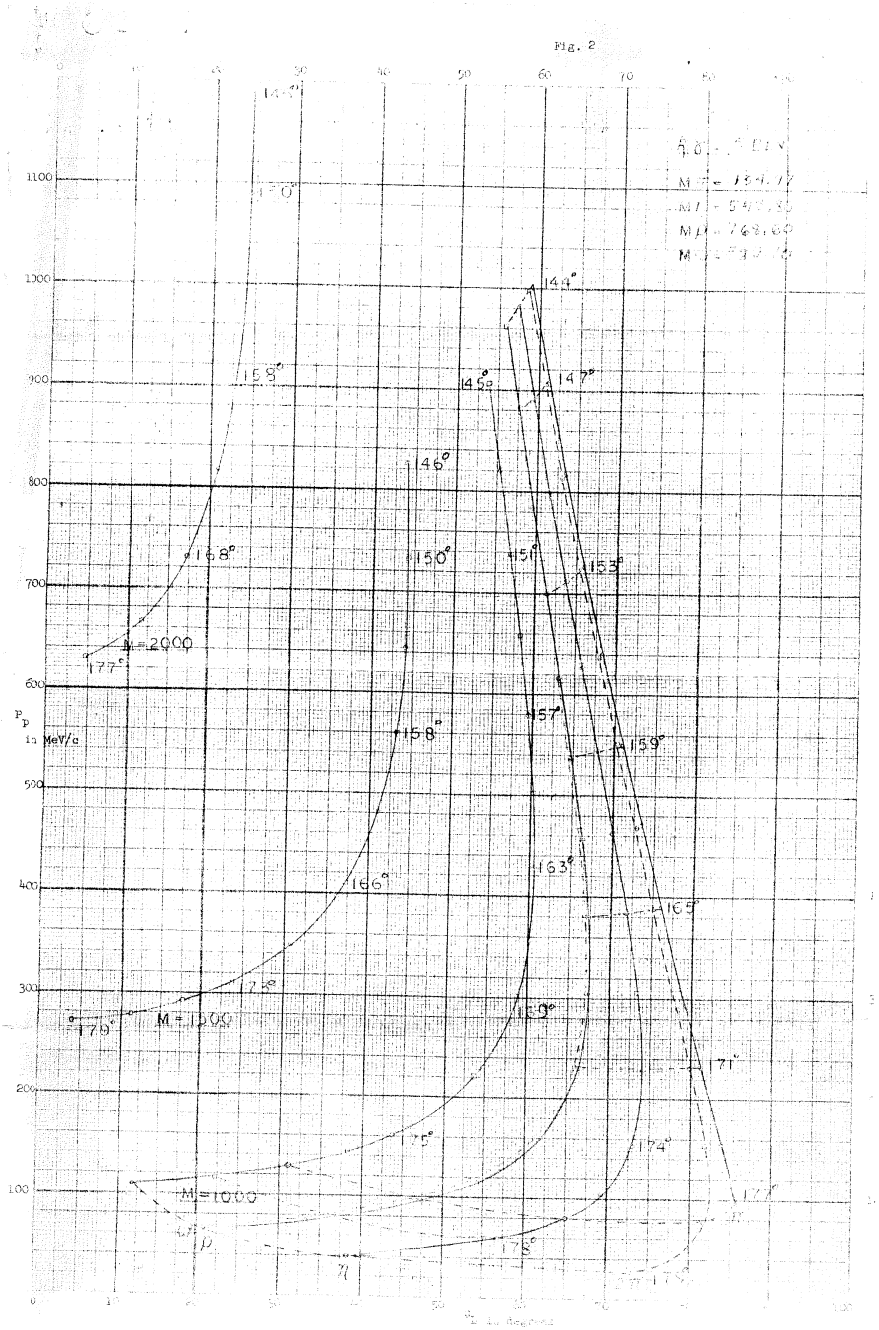


Fig. 2



P_p in MeV/c
θ_p in degrees
M=2000
M=1000
M=1000
144°
145°
146°
147°
150°
151°
153°
157°
158°
159°
163°
165°
166°
168°
169°
171°
174°
175°
177°
178°
179°

Fig. 3

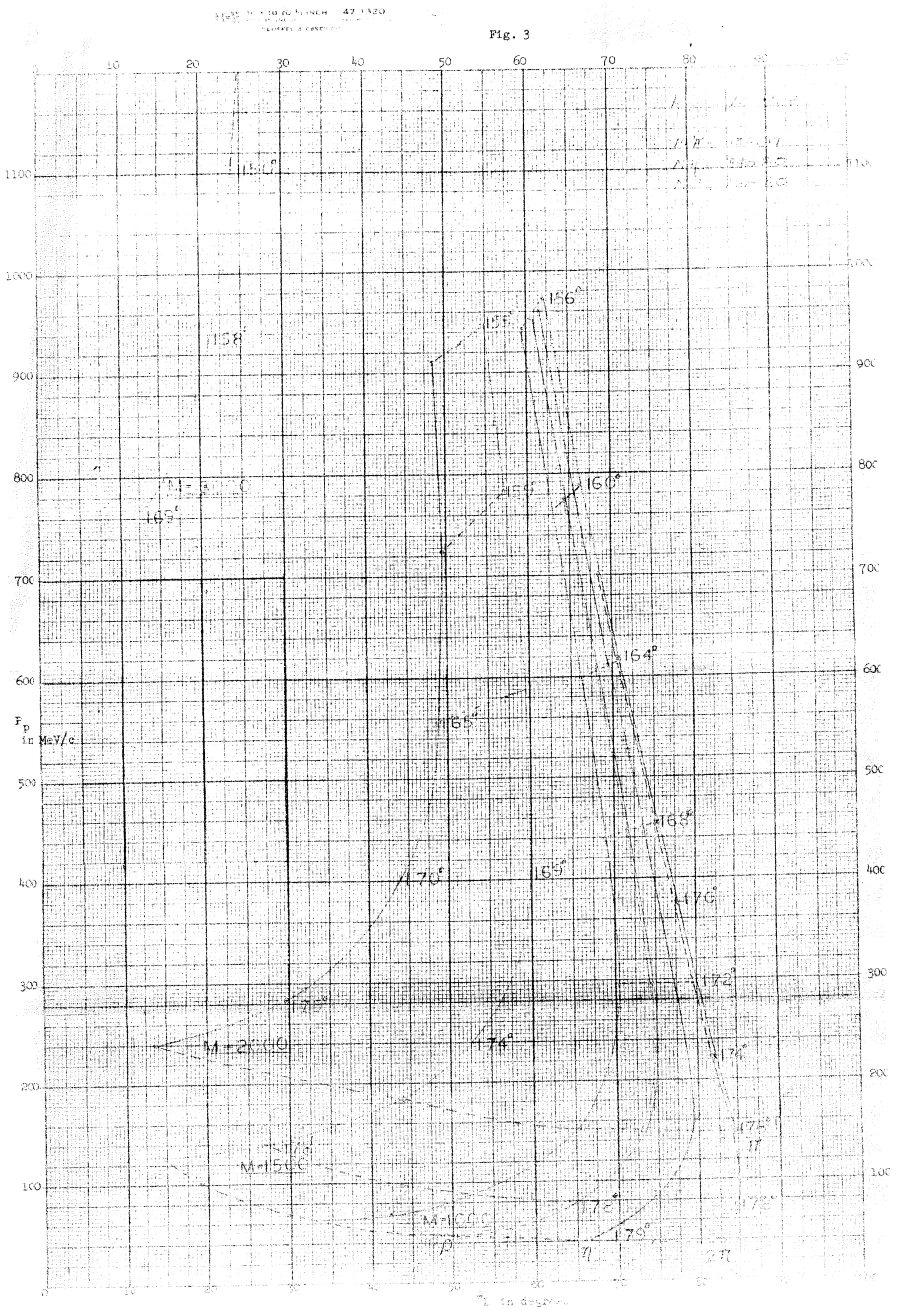
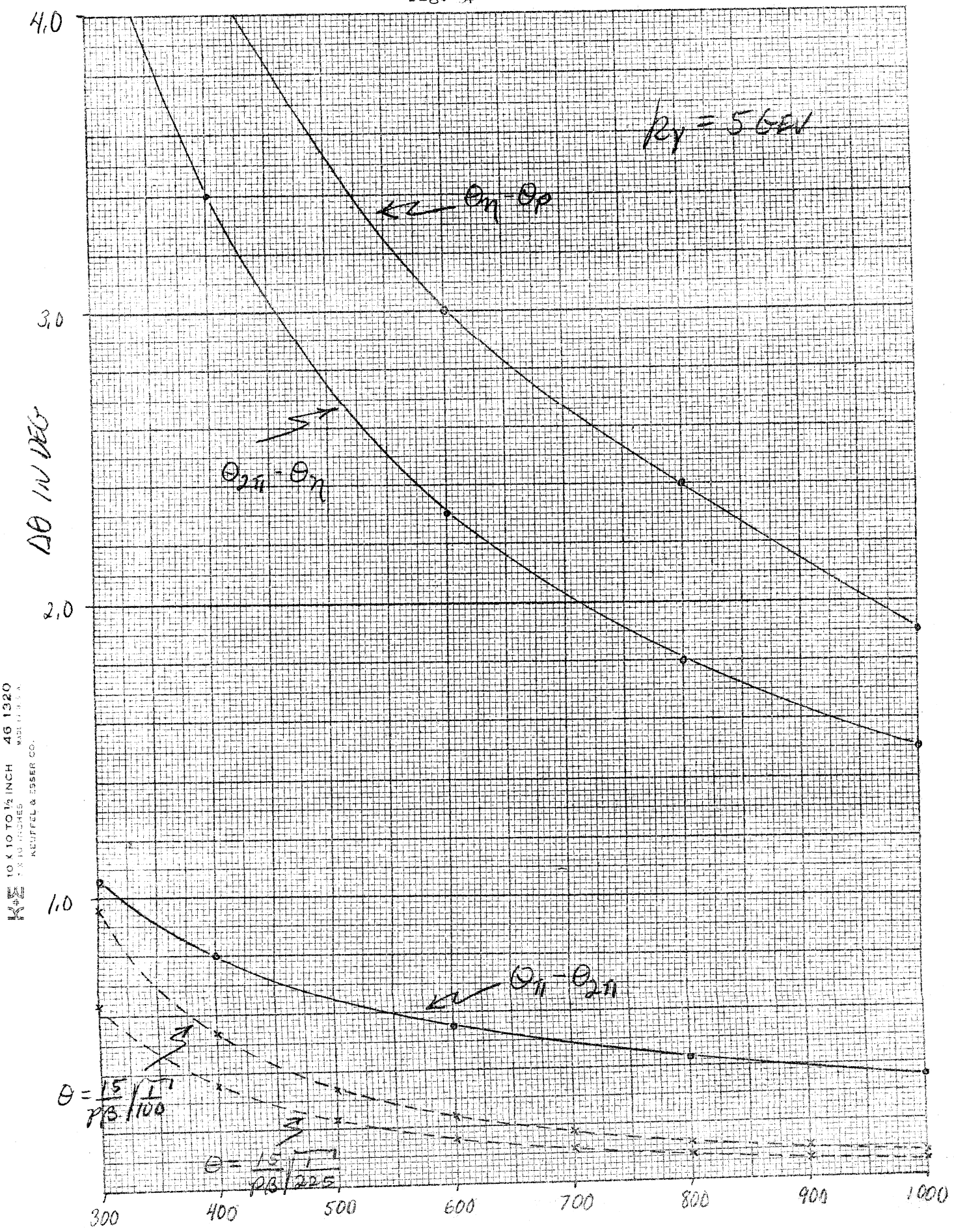


Fig. 4



KE 10 X 10 TO ½ INCH 46 1320
7 X 10 INCHES MADE IN U.S.A.
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Fig. 5

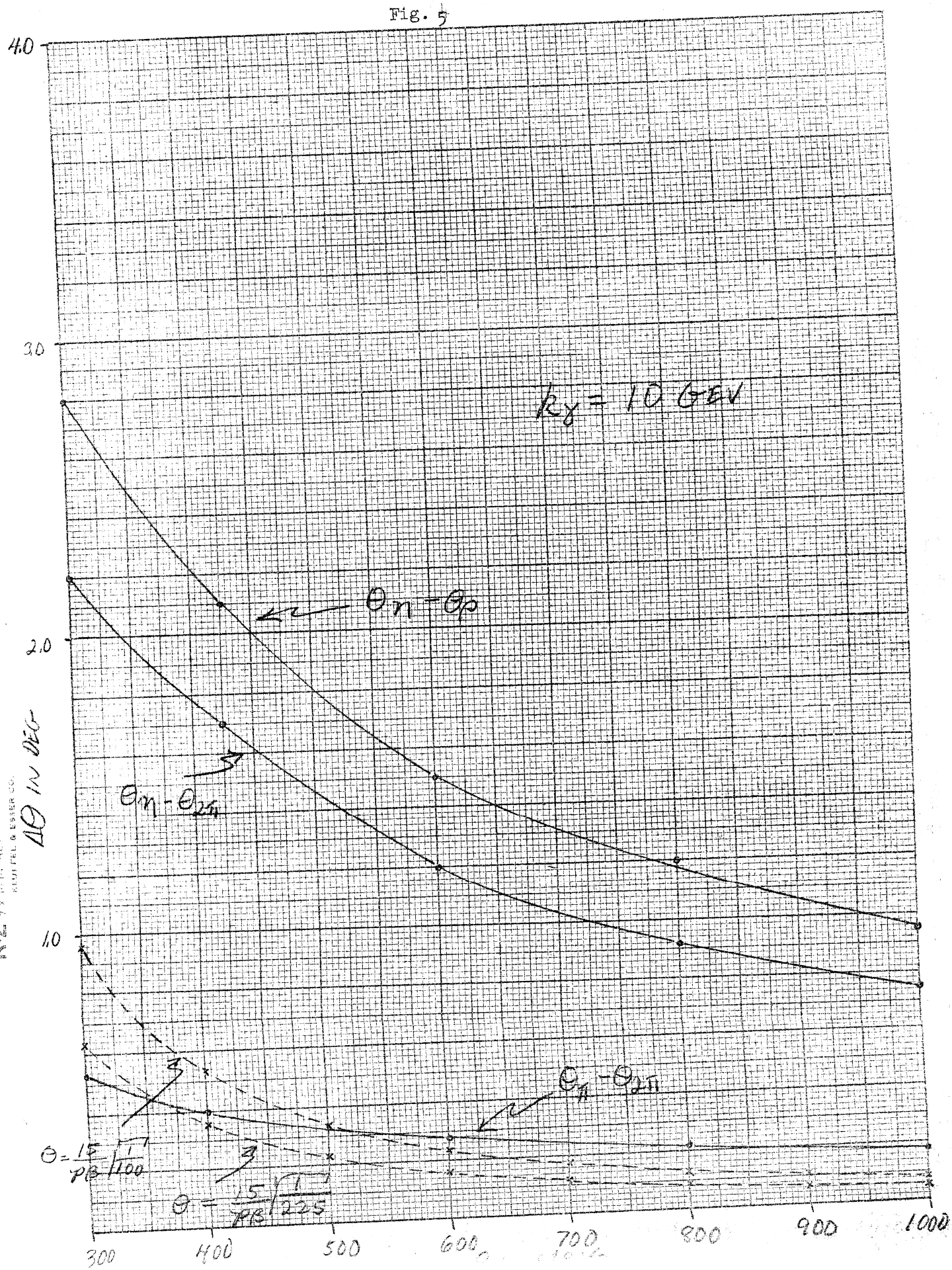
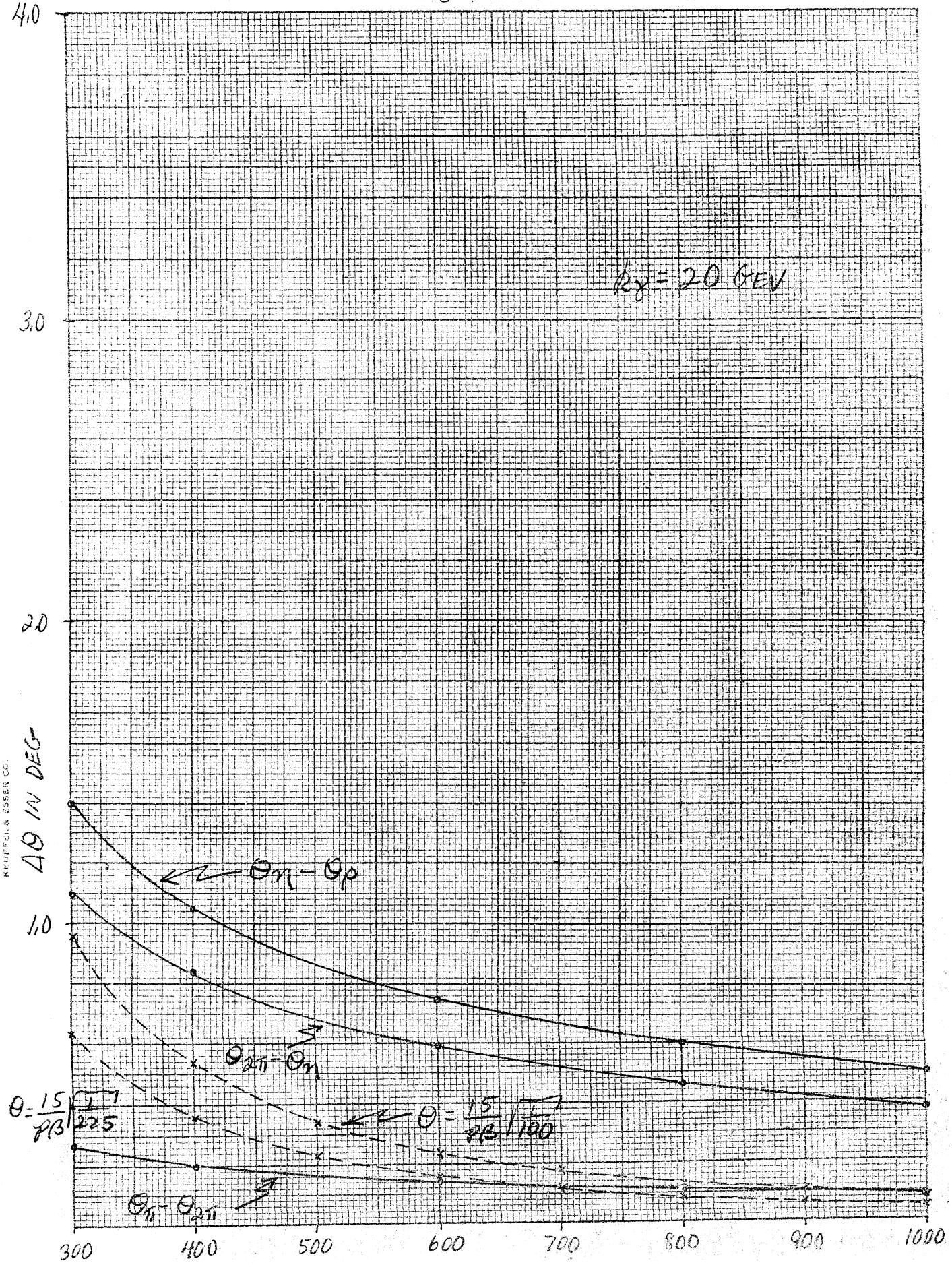

4.0
3.0
2.0
1.0
$k_\gamma = 10$ GEV
$\theta_n - \theta_p$
$\theta_n - \theta_{2\pi}$
$\theta_\pi - \theta_{2\pi}$
$\Delta\theta$ in Deg
$\theta = \frac{15}{p\beta}\sqrt{\frac{1}{100}}$
$\theta = \frac{15}{p\beta}\sqrt{\frac{1}{225}}$
300
400
500
600
700
800
900
1000

Fig. 6


4.0
3.0
2.0
1.0
$\Delta\theta$ IN DEG
$E_\gamma = 20$ GEV
$\theta_n - \theta_p$
$\theta_{2\pi} - \theta_n$
$\theta = \frac{15}{\beta B}\sqrt{\frac{1}{225}}$
$\theta = \frac{15}{\beta B}\sqrt{\frac{1}{100}}$
$\theta_\pi - \theta_{2\pi}$
300
400
500
600
700
800
900
1000

K+E 10 X 10 TO ½ INCH 46 1322
7 X 10 INCHES
KEUFFEL & ESSER CO.

FIG. 7

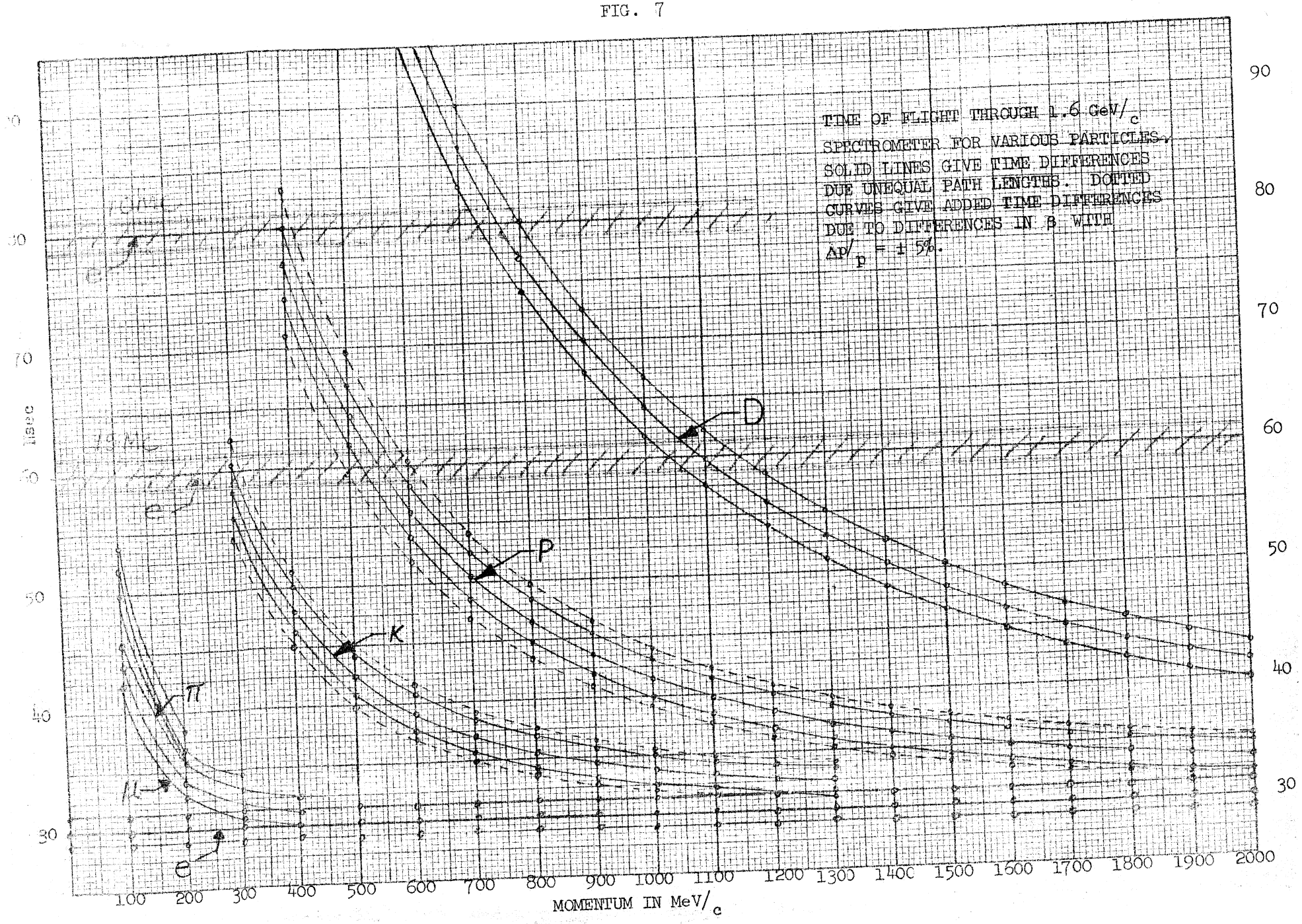
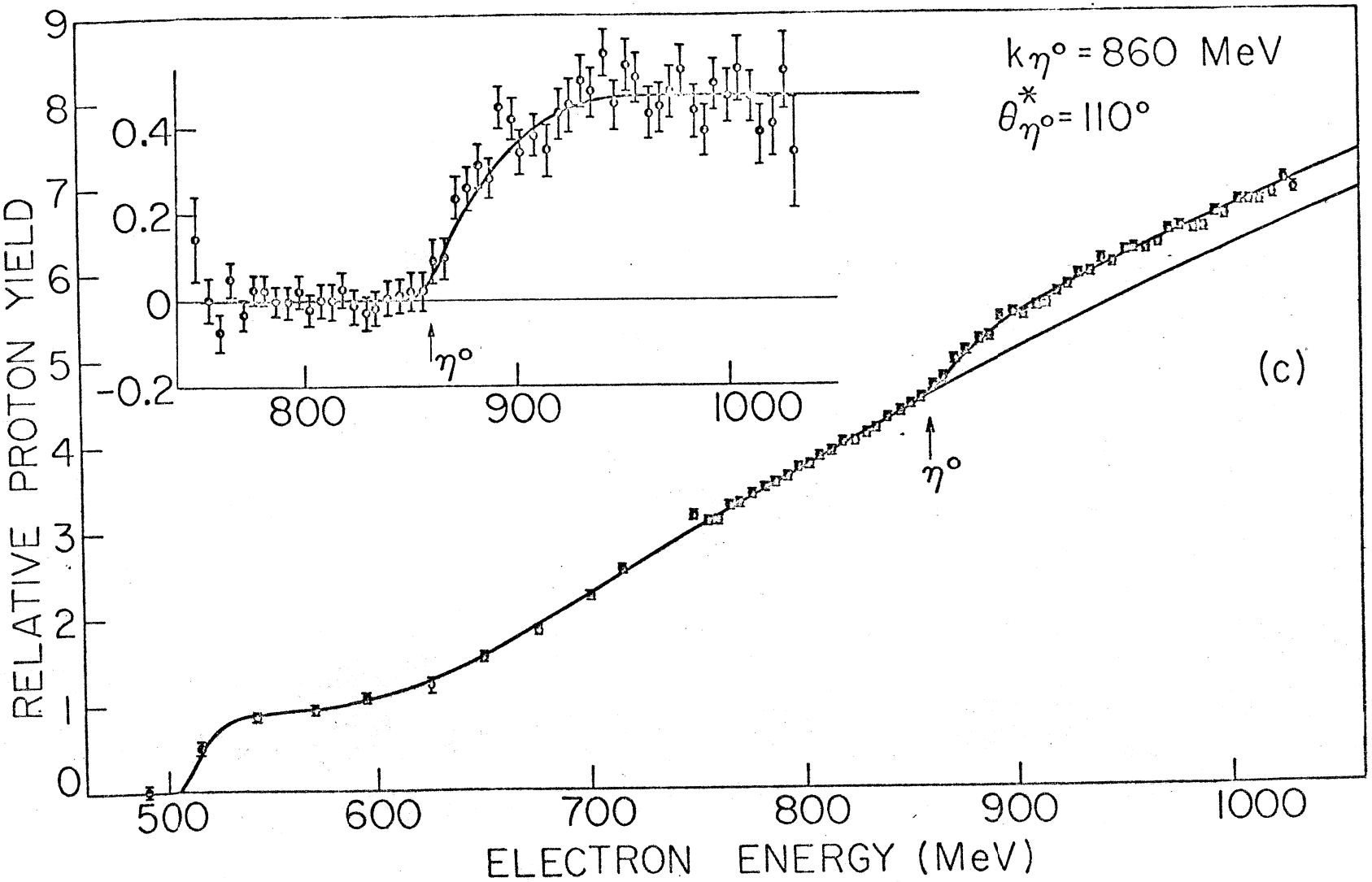


Fig. 8


RELATIVE PROTON YIELD
ELECTRON ENERGY (MeV)
kη° = 860 MeV
θ*η° = 110°
η°
(c)
0.4
0.2
0
-0.2
800
900
1000
500
600
700
800
900
1000
0
1
2
3
4
5
6
7
8
9