Title
NOTES ON THE 60| SEPARATED K BEAMS

Author
Stork, Donald H.

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Donald H. Stork

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September 26, 1956

Donald H. Stork

During the month of June, 1956, a series of nuclear emulsion stacks and test plates were exposed to positive and negative K mesons at several relatively high momenta, produced at 60° to the 6.2 Bev proton beam at the Bevatron. The purpose was twofold: (1) to determine the flux of K mesons produced at 60° in order to compare with other angles and to be able to make an optimum choice for future K beams, (2) to study a particular scheme for separation of π's and K's. In addition, several nuclear emulsion stacks were exposed for the purpose of K-meson research.

Much of the initial design was done by O. R. Price and the modifications for the higher K energy was carried out by Joseph Lanutti.

I. The Physical Setup.

A sketch of the setup is shown in Figure 1.

A. Target. The target mechanism was the drop-string target at the West-tangent-tank-upstream-top-lock position. The target shaft and target arm were both in the down-stream position and the target at a nominal 601" radius. The target was copper in the shape of a 60° parallelogram, 1 1/2" long, 1/2" radially, and 3/8" vertically. A 1/8" x 1/8" x 3/8" polyethylene lip was used. The plunging clipper was not used. There is evidence that, in spite of extensive foretesting, the target arrival position dropped about 1/8" during the initial phases of the run. The target timing was adjusted and set with the aid of a counter telescope looking at the target.

B. Separation Scheme. A brute force method was used in which the

Be degrader was immediately followed by the C magnet in order to achieve spacial seperation before the beam had spread to an excessively large area because of Coulomb multiple scattering. The refinement of a second quadrupole lens was considered, but was discarded as unnecessary for nuclear emulsion exposures.

The choice of parameters for the system was determined only by compromising a number of contradictory requirements. In practise the procedure was as follows. The C magnet was run at maximum field for maximum seperation, with the field direction such as to permit a momentum focus. A maximum momentum spread at the stack position was then chosen; this choice fixed (for a given degrader thickness) the momentum bite to be accepted at the defining slit at the degrader.

The first analyzing magnet was set up for maximum angular deflection, 32°. The slit width and distance form analyzing magnet to slit were determined by the desired momentum bite and by the requirement that the momentum bite accepted by determined primarily by the slit width rather than horizontal image size.

Finally the spatial beam size for the π's and K's were studied as a function of degrader thickness and a satisfactory thickness found that permitted the full desired momentum bit and an adequate π-K spatial seperation.

C. Optics. Having fixed the above requirements for seperation, we set the following requirements for the focusing scheme: First, the vertical and horizontal images were to be smaller than the multiple scattering spread at the stack position - - that is, the spatial beam dimensions were to be determined primarily by the multiple scattering in the degrader. Second, at the degrader the horizontal image size was to be comparable to the slit size. Third, the vertical image size at the degrader was to be small enough so that good collimation could be achieved and a narrow C magnet gap used. The C magnet pole-tip-shim gap at entrance was 3 1/2 inches and was flared (stepwise) to 6 inches at the exit end.

The relationships between the individual quadrupoles were then adjusted to give maximum flux. Maximum flux was obtained by maximizing the quantity $\Delta\Omega/M_H$, subject to the condition that the image requirements be met. $\Delta\Omega$ is the effective quadrupole aperture and M_H is the horizontal magnification. The latter appears since for a fixed horizontal image size (one of the requirements above) the target length (and thus the K yield) is determined by M_H. In summary, the total K flux through the system was determined by $\Delta\Omega/M_H$, and the momentum bite. The intensity at the stack was determined by the total flux and the multiple scattering spread.

The results of maximizing $\Delta\Omega/M_H$ were that the first quadrupole was to be turned off, the second quadrupole converging vertically, and the third quadrupole converging horizontally. Schematic diagrams of the focusing are shown in Figures 2 and 3 with the deflections in the bending magnets straightened out. The double arrows labeled "MS" indicate the multiple scattering spread.

It is seen that vertically there is a target image at the slit (degrader position). The C magnet is vertically converging and the stack is near the "exit pupil" of the system. Horizontally, the C magnet is diverging and the target image is situated at the stack position.

II. Quadrupole Lens Currents.

Parametric quadrupole lens equations were plotted for the general cases of interest. The focusing could then be traced through the three lens system by reading from the plots. Conditions for the desired image positions were determined by successive approximation. In this fashion the quantity $\Delta\Omega/M_H$ (Section ID) was maximized and the final quadrupole currents determined. The results are given in Table I. The effective field lengths used for the 8" and 16" quadrupoles were 10" and 18" respectively. The results of wire trajectory measurements are also shown in Table I and the agreement indicates that the chosen equivalent lengths were quite satisfactory. We found also that we could scale accurately from one momentum to another using the Magnet Testing Group's magnetization curve for an 8" quadrupole (Eng. Note 4902-02 MT-2 Oct. 3, 1955, page 518).

III. 60 Inch Analysing Magnet Currents.

Prior to the run wire trajectory measurements were made to determine the current required for a 32° deflection in the 60 inch analyzing magnet for momenta 525 and 725 Mev/c. The results are shown in Table II. In addition, during the run, test plates imbedded in aluminum were exposed at the slit for three magnet currents. The momentum in each case was then determined from the measured range of protons in aluminum. These results are also shown in Table II.

IV. Current Corrections Required Because of Bevatron FringeField.

Since negative protons were too few in number to calibrate the momentum for the K^- exposures, Bevatron fringe field measurements were made throughout the magnet system by Mr. Pete Watson. His results are shown in Figure 5.

Dr. Steven White's group used these measurements to determine the change in magnet currents required for the separated K⁻ beam exposure. Their results are shown in Table III.

V. Miscellaneous Parameters.

Separated K beams of two momenta were used. The first was produced at 525 Mev/C and degraded to 480 Mev/C. Several parameters pertaining to these two beams are shown in Table IV.

VI. Vertical and Horizontal Focusing from Test Plates.

The vertical distribution at the slit was determined for pions and protons at several momenta by means of test plates. The results for protons at 525 Mev/C are shown in Figure 6. The curves shown in Figure 6 are the expected results for protons, K-mesons, and pions computed from the focusing properties and the multiple scattering in the thin window and air path.

The horizontal distribution for a given momentum at the slit cannot be directly determined, but this distribution and the momentum dispersion determine the momentum distribution at any given point. The calculated integral momentum flux curve for 525 Mev/C is shown in Figure 7, together with the experimental points determined by the proton integral range curve in aluminum. Fairly good agreement is found.

VII. Pion and Proton Fluxes at the Slit.

Test plate exposures were made at several momenta for both positive and negative beams. The pion flux was determined by counting minimum ionization tracks in the beam direction. The proton flux was determined by counting tracks in the beam direction with apparent ionization near that expected for protons. In the latter count an effort was made to exclude alpha particles, but deuterons may have been included in the count.

In each case the flux was integrated in the vertical direction and the results are shown in Table V, where the fluxes are given in number per horizontal centimeter per 10^{10} beam protons as indicated by the induction electrode integrater.

VIII. Reproducibility of Fluxes.

An examination of the time variation of the flux at 725 and 525 Mev/C indicates a serious drop in flux between the first and last parts of the run. The new induction electrodes had just been installed prior to this run, but calibration against the East induction electrodes showed no change before and after our drop in flux. However, Kerth and Van Rossum were running K^+ from the 5^o target during the same period and experienced the same drop in apparent flux. No satisfactory explanation has been found for this variation. Therefore, caution must be exercized in comparing the yields at 60^o to other K beams.

A summary of the fluxes after the drop in apparent yield is given in Table VI.

IX. Variation of π^+ and π^- Fluxes with Momentum.

In addition to the data obtained from test plates, information concerning pion fluxes was obtained form counter data collected during an investigation of the beam structures behind the C magnet. The results are given in Table VII.

Although the agreement between counters and test plates is rather poor, it can be seen that the pion flux falls off markedly as the momentum is increased and that the π^+/π^- flux ratio is approximately two.

X. K Flux and Background in the Separated Beams.

Preliminatry data are available from three stacks exposed to separated K beams:

A. 525-420 Mev/C, K^+ (Price, Ticho). (The two momenta are the momenta at production and the momentum entering the stack). The exposure was 4×10^{13} beam protons. The K^+ flux is approximately three per millimeter in each 600 micron emulsion and the directional minimum background is about five per K^+. Background confusable with the K's is negligible.

B. 525-420 Mev/C, K^- (White, Gilbert, Violet). The exposure was 8×10^{13} beam protons. Approximately one K^- per centimeter has been found. The directional minimum track backgound is about 200 per K^-. A large improvement (compared to exposures at 90°) in the background of tracks confusable with K^- has been achieved. This improvement results in a scanning rate increase of nearly an order of magnitude.

*C. 720-480 Mev/C, K^+ (Lanutti, Goldhaber). The exposure was 5×10^{13} protons. Approximately 25 K^+ per centimeter have been found. The directional minimum track background is approximately one per K^+ Background confusable with the K's is negligible.

From the results of the above positive K exposures the flux of K^+ at the slit and at the target has been calculated. The correction for decay in flight has been made and the degrader attenuation cross section has been taken to be nuclear area. The results are shown in Table VIII.

The discussion of Section VIII on the reproducibility of fluxes must be kept in mind before comparison is made between the fluxes given in Table VIII and fluxes obtained in other K-beam setups. The above stack exposures were made after the drop in apparent yield by a factor of 2.4.

* See ADDENDUM - Page 9

The approximate flux ratios derived at the slit may be summarized as follows:

$$\frac{K^+725}{K^+525} = 3 \qquad \frac{\pi^+725}{\pi^+525} = 0.7$$

at 725 Mev/C, $\pi^+/K^+ = 60$

at 252 Mev/C, $K^+/K^- = 60$, $\pi^+/\pi^- = 2$

$\pi^+/K^+ = 240$, $\pi^-/K^- = 7000$

The improvement provided by the separation method is thus a factor of about 50 in the π to K ratio for each exposure.

XI. Comparison with the 90° Beam.

The discussion of Section VIII on the reproducibility of fluxes must be kept in mind before comparison is made between the fluxes given in Table VIII and fluxes obtained in other K-beam setups. The above stack exposures were made after the unexplained drop in apparent yield of a factor of 2.4.

The Crawford-Stevenson setup at 90° gave for a 1/2 inch copper target 5 K^+ per horizontal centimeter per 10^{10} beam protons at the unseparated K image point for a momentum of 385 Mev/C. This yield is thus comparable to the fluxes at the slit position in the 60° set-up.

Tracing the 90° yield back to the target we find that the cross section for 385 Mev/C K^+ at 90° is about the same as the cross section of 725 Mev/C K^+ at 60° and is slightly larger than the cross section for 525 Mev/C K^+ at 60°. (The figures in the last row of Table VIII are proportional to the cross section, $d^2\sigma/d\Omega/dE$).

We can compare these results with the pahse calculations of Dr. Lynn Stevenson. These phase space calculations predict roughly (Fermi motion was neglected) an increase in cross section of a factor of about two from 90° to 60° for the momenta considered. If we had used the higher apparent yields in the first part of the 60° run (see Section VIII), the experimental 60° cross sections would have agreed well with the phase space predictions.

XII. Further Information.

The stacks exposed during the 60° K beam run are listed with the conditions of exposure in Table IX. Further information will therefore be available when the results of the scanning of these stacks is received.

ADDENDUM

EXPOSURE OF PHOTOGRAPHIC EMULSIONS TO A 480-Mev/c SEPARATED POSITIVE K-MESON BEAM

Gerson Goldhaber and Joseph E. Lannutti

In line with our program of studying the interactions of K mesons in photographic emulsion, we, in conjunction with Donald Stork, have designed and used a system for obtaining a beam of positive K mesons with a much reduced light meson contamination and with an energy higher than that previously studied. The system employs focusing coils, two magnets, and a beryllium degrader. Particles produced by 6.2-Bev protons on a drop-string copper target are accepted by the system if emitted at an angle of 58° and with a momentum of 725 ± 23 Mev/c. After passing through the energy degrader the K mesons have been reduced to a momentum of 480 ± 33 Mev/c; they are focused on an emulsion stack.* Preliminary study of a stack indicates that we have obtained an average K-meson flux of approximately 400 K's/cm^2 for 4.7×10^{13} protons on the target. The ratio of K mesons to light mesons and electrons is roughly unity at beam center.

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*Exposure carried out jointly with Warren W. Chupp and Sulamith Goldhaber.

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Table I. Quadrupole Currents in Amperes.

	525 Mev/C		725 Mev/C	
	Calculated	Wire Trajectory	Calculated	Wire Trajectory
Quadrupole 1	0	0	0	0
Quadrupole 2	99.5	101.5	138	139.6
Quadrupole 3	158.0	158.3	222	223

Table II. 60" Analysing Magnet Currents (32° deflection)

Method	Current in amperes	Momentum in Mev/C
Wire trajectory	390.8	525.0
Wire trajectory	438.2	725.0
Proton Range	312.4	417.5
Proton Range	390.8	524.5
Proton Range	416.4	716

Table III. Adjustment of Magnet Currents to take Fringe Field into Account

	Current for K^+ beam	Current for K^- beam	Momentum
60" Magnet	390.8 amp	397.8 amp	525 Mev/C
C Magnet	144.0 amp	142.5 amp	420 Mev/C

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Table IV. Miscellaneous Parameters

Initial Momentum	525 Mev/C	720 Mev/C
Final Momentum	420 Mev/C	480 Mev/C
Be Degrader Thickness	28 gm/cm^2	82 gm/cm^2
π-K Central Trajectory Separation at Stack	5 inches	6 inches
K rms radial multiple coulomb scattering spread at stack	1.5 inches	2.0 inches
(dP/dx)/P at slit	0.0276 in^{-1}	0.0256 in^{-1}
Slit Width, inches	2.0 inches	2.0 inches
Slit Width, Mev/C	31 Mev/C	37 Mev/C
x*	30 inches	35 inches
Y*	5 inches	6 inches
α*	24°	20°
β*	28°	24°
$1^{-t/\tau}$, target to slit	0.254	0.375
$1^{-t/\tau}$, target to stack	0.151	0.237

* See Figure 1

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Table V. Proton and Pion Fluxes at Slit from Test Plates; and Daily Variation

Date	Charge	Momentum	Protons per cm per 10^{10}	Pions per cm per 10^{10}	Protons per pion
6/20	+	725	7,300 11,500 9,500	1200 1300	6 9
	+	525	9,700 6,100 8,000	1600 1800	6 3.4
6/22	-	525		800	
6/23	+	420	4,500		4.2
	+	476	4,600		6.7
	-	420		600	
6/24	+	525	3,100		
6/25	+	525	3,500		
6/26	+	525	1,600		
6/27	+ -	525 525	4,200	 600	
6/29	+	725	3,700	400	9

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Table VI. Summary of Table V for conditions after 6/22
Multiply by 2.4 for conditions before 6/22.

Charge	Momentum	Protons per cm per 10^{10}	Pions per cm per 10^{10}	Protons per pion
+	420	4500	1100	4.1
+	476	4600	700	6.7
+	525	3600	680	5.3
+	725	4000	480	---
-	420	---	600	---
-	525	---	700	---

Table VII. Relative Pion Flux at Slit

(Normalized to 476 Mev/C $\pi+$); and $\pi+/\pi^-$.

	π^+		$\pi-$		$\pi+/\pi-$	
Momentum	Counters	Test Plates	Counters	Test Plates	Counters	Test Plates
420	3.2	1.5	1.35	0.86	2.4	1.7
476	1.0	1.0	0.35	--	2.9	---
525	---	0.97	---	1.00	1.7*	1.0
580	0.46	--	---	--	---	---
725	---	0.68	---	--	---	---

* Ratio determined with Be degrader in place.

Table VIII. K^+ Flux Inferred from Stacks in Separated Beams
(assuming geometric cross section in Be for K attenuation).

	Initial-Final Momentum	525-420 Mev/C	720 - 480
At Stack	Number $K/in^2/10^{10}$	0.81	0.68
	Number $K/10^{10}$	5.7	8.6
At Slit (degrader)	Number $K/10^{10}$ (through slit)	14	42
	Number $K/cm/10^{10}$	2.8	8.2
	Number $K/(Mev/C)/10^{10}$	0.46	1.1
At Target	Number $K/(Mev/C)/ster/cm\ Cu/10^{10}$	380	620
	Number $K/Mev/ster/cm\ Cu/10^{10}$	522	750

Table IX. Nuclear Emulsion Stacks exposed to the 60° $K^{\pm}$ beams 6/23-6/30

	Charge	Momentum	Exposure	Approximate Stack Dimensions, inches	Exposure for
	-	420	10^{12}	1 x 3 x 9	Birge, Kerth
Unseperated	+	476	10^{12}	1 x 3 x 9	Birge, Kerth
(slit position)	+	660	10^{12}	1 1/2 x 3 x 8	MIT, Harvard, Johns Hopkins (Ritson, Pevsner et al)
	+	420	4×10^{13}	1 1/2 x 3 x 8	MIT, Harvard, Johns Hopkins (Ritson Pevsner, et al)
	+	420	4×10^{13}	3 x 4 x 8	UCLA (Price, Ticho)
Separated	+	420	4×10^{13}	3 x 4 x 8	Wisconsin (Fry, Swami, et al)
	-	420	8×10^{13}	6 x 6 x 12	White, Gilbert,, Violet (Livermore)
	+	480	5×10^{13}	3 x 4 x 7	Lenutti, Goldhaber

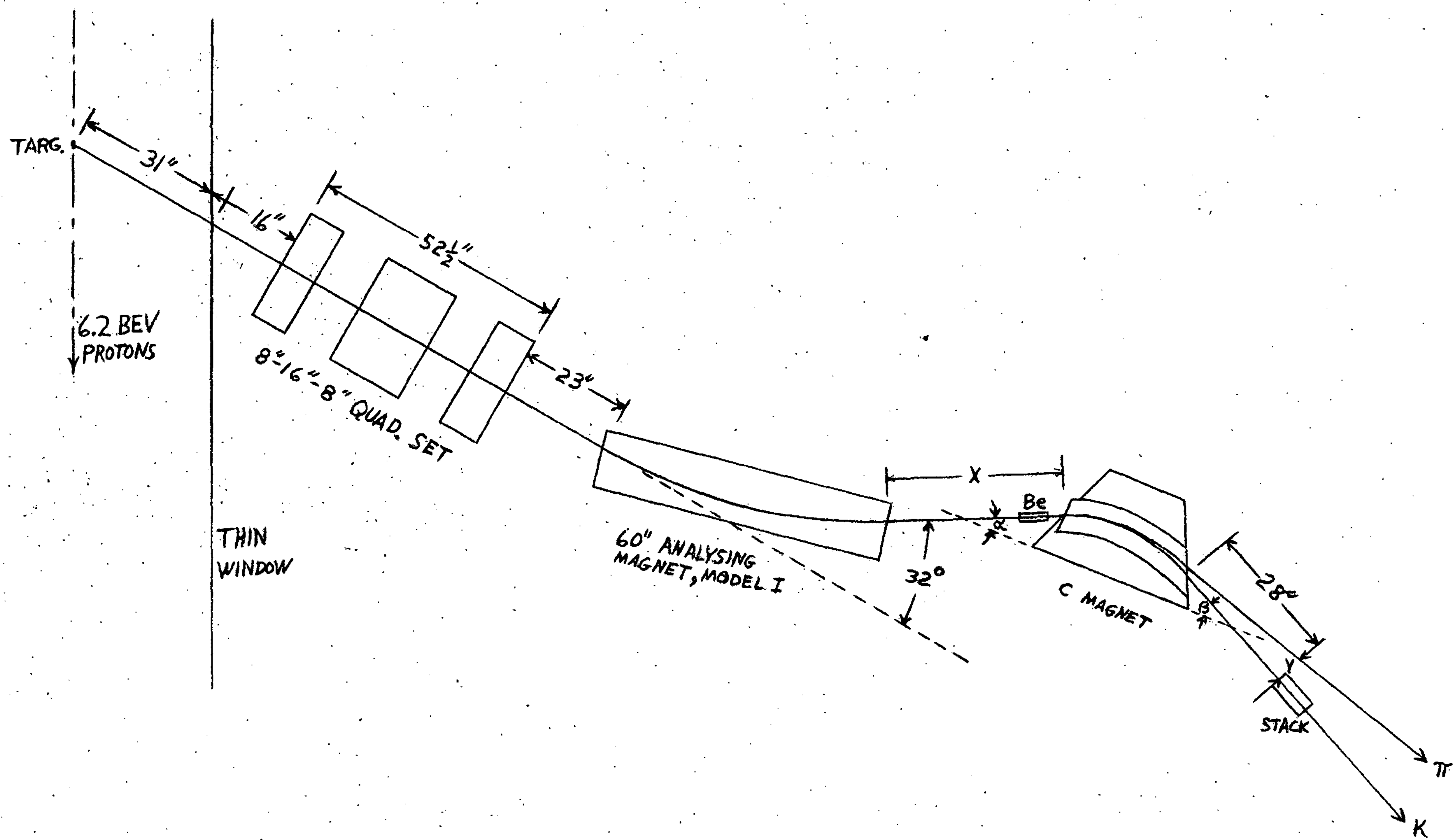
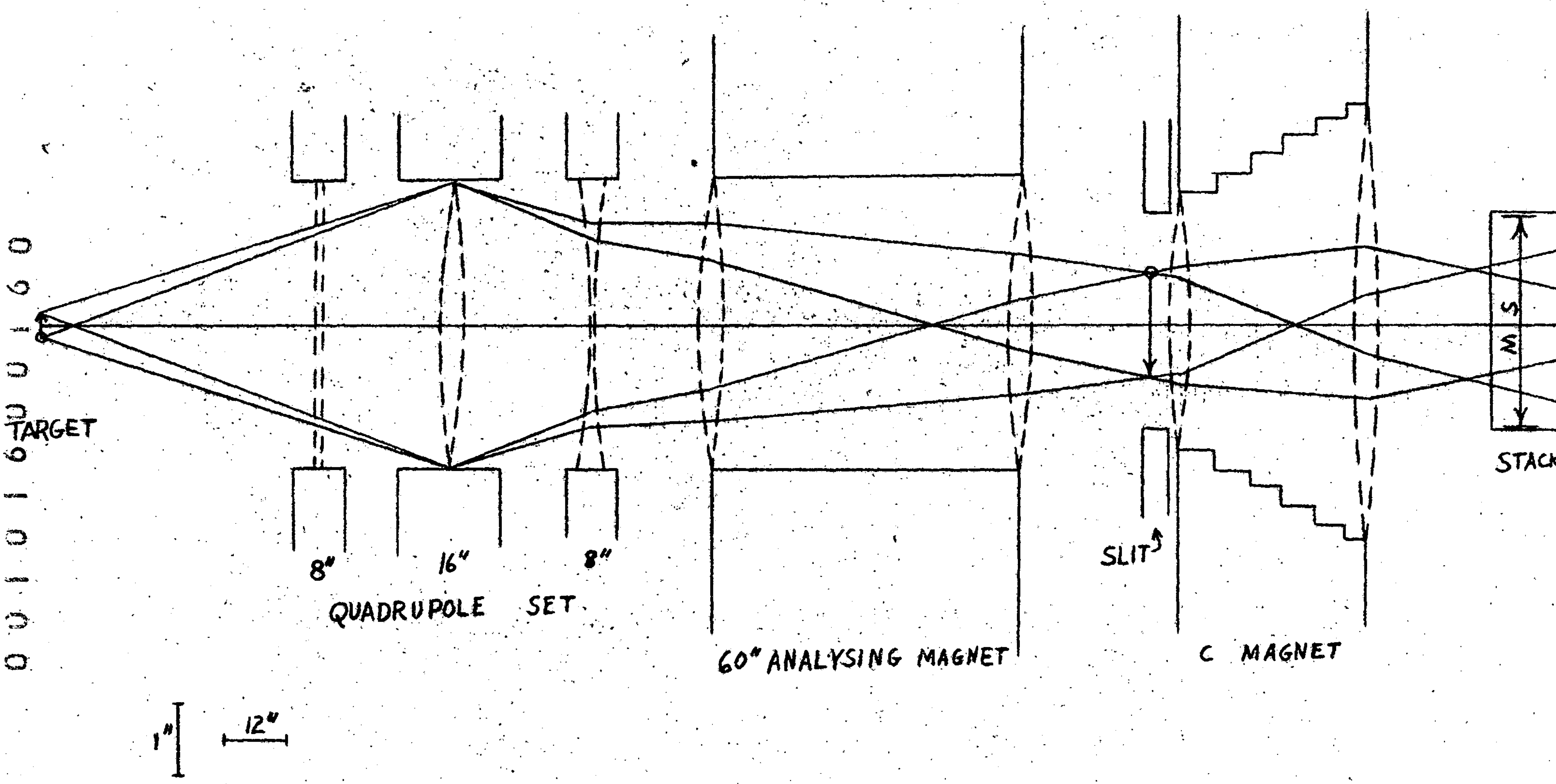


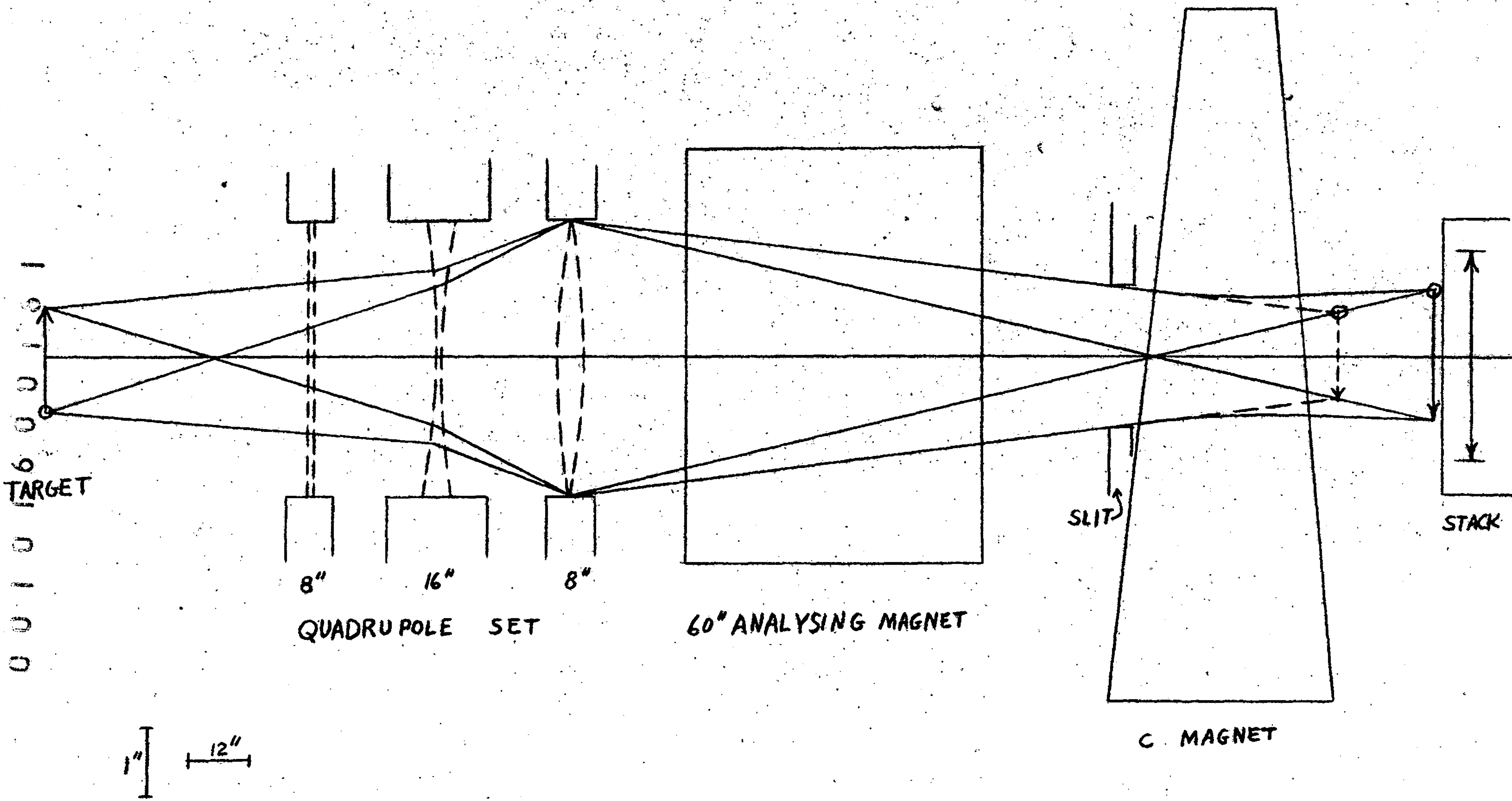
FIGURE 1: EXPERIMENTAL ARRANGEMENT, 60° $K^{\pm}$-BEAMS

FIGURE 2



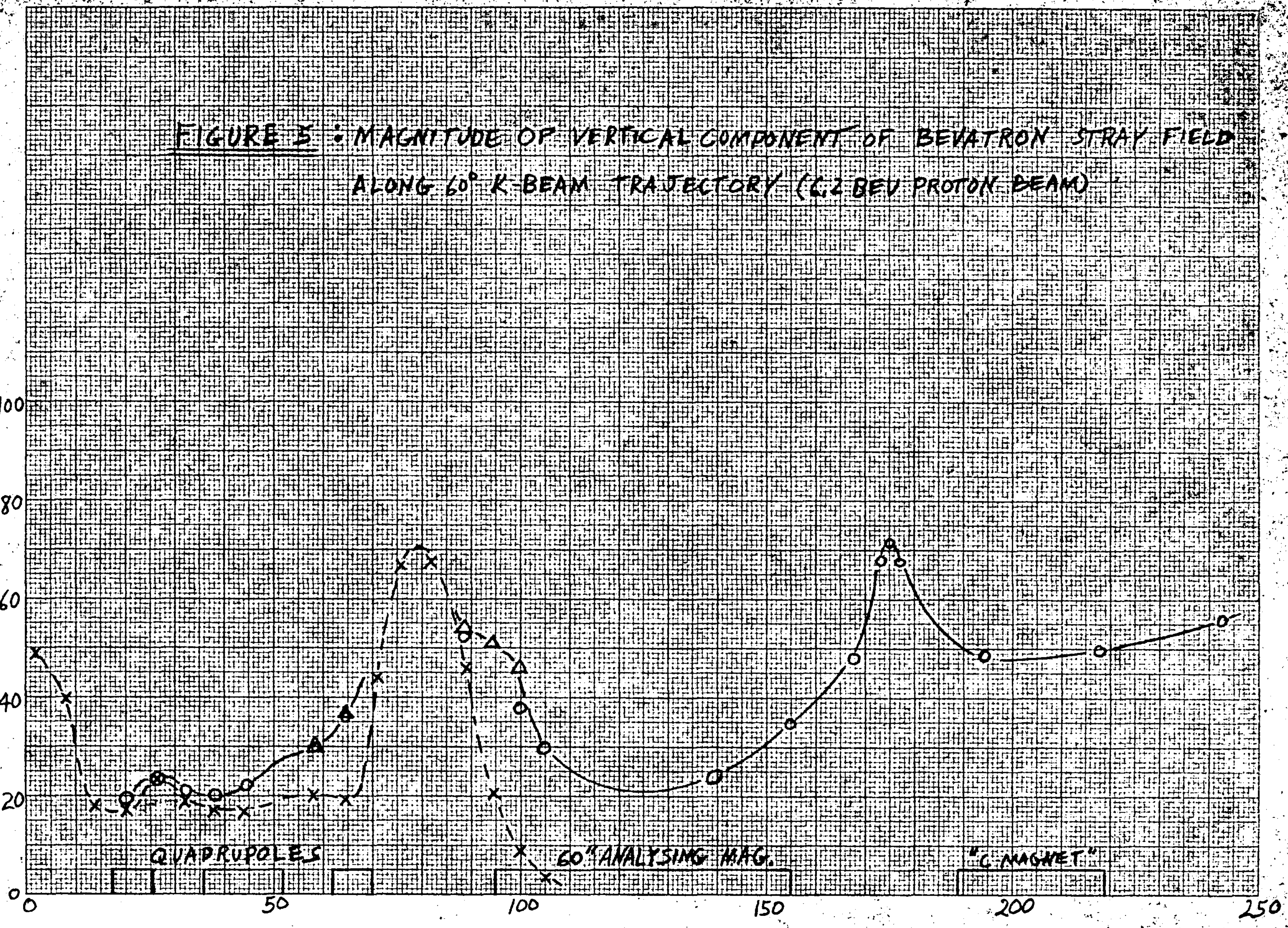
FOCUSING IN THE VERTICAL PLANE

FIGURE 3



FOCUSING IN THE HORIZONTAL PLANE

FIGURE 3 : MAGNITUDE OF VERTICAL COMPONENT OF BEVATRON STRAY FIELD ALONG 60° K-BEAM TRAJECTORY (6.2 BEV PROTON BEAM)



0 0 1 6 2

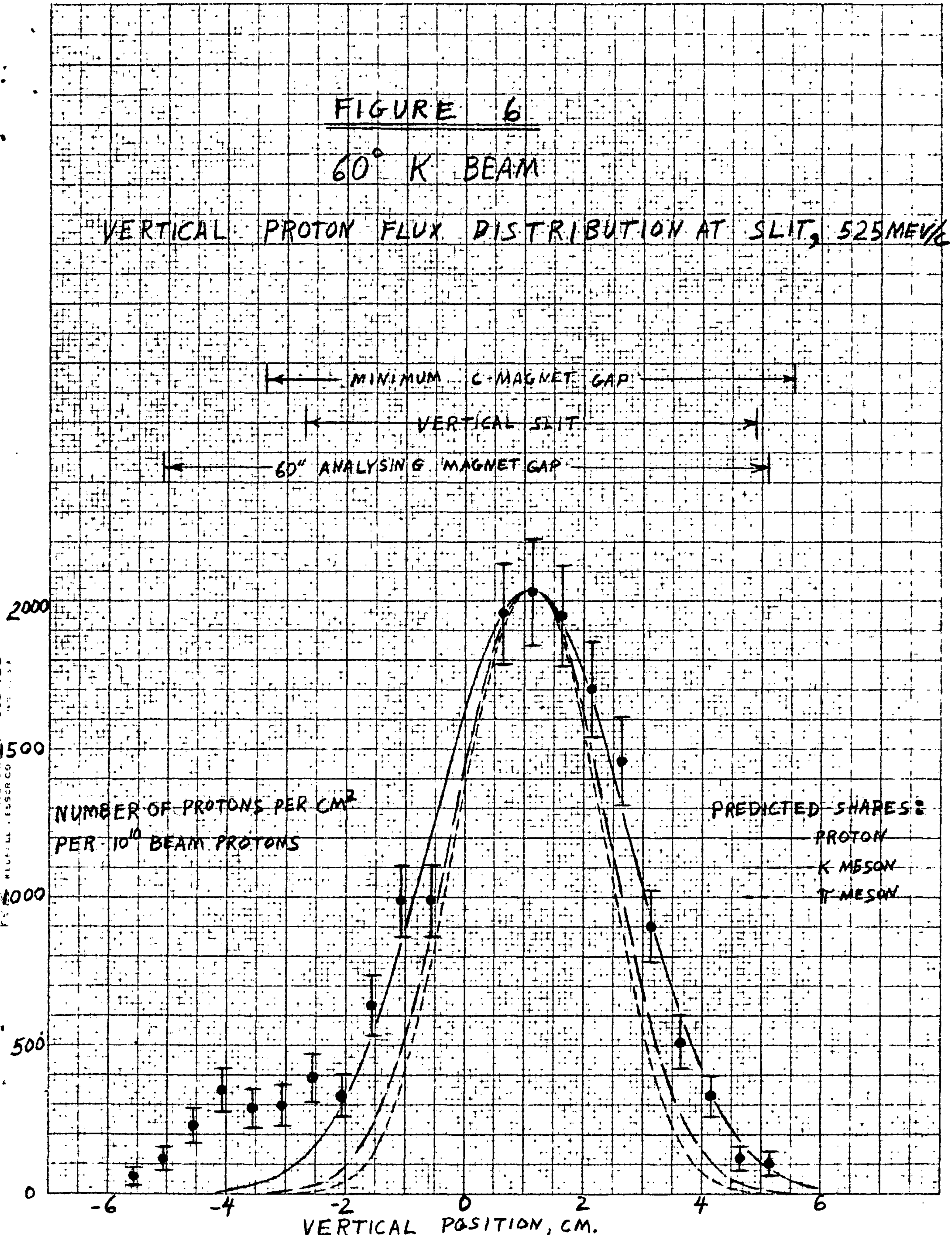


FIGURE 6
60° K BEAM
VERTICAL PROTON FLUX DISTRIBUTION AT SLIT, 525 MEV/c
MINIMUM C MAGNET GAP
VERTICAL SLIT
60" ANALYSING MAGNET GAP
NUMBER OF PROTONS PER CM²
PER 10¹⁰ BEAM PROTONS
PREDICTED SHAPES:
PROTON
K MESON
π MESON
2000
1500
1000
500
0
-6
-4
-2
0
2
4
6
VERTICAL POSITION, CM.

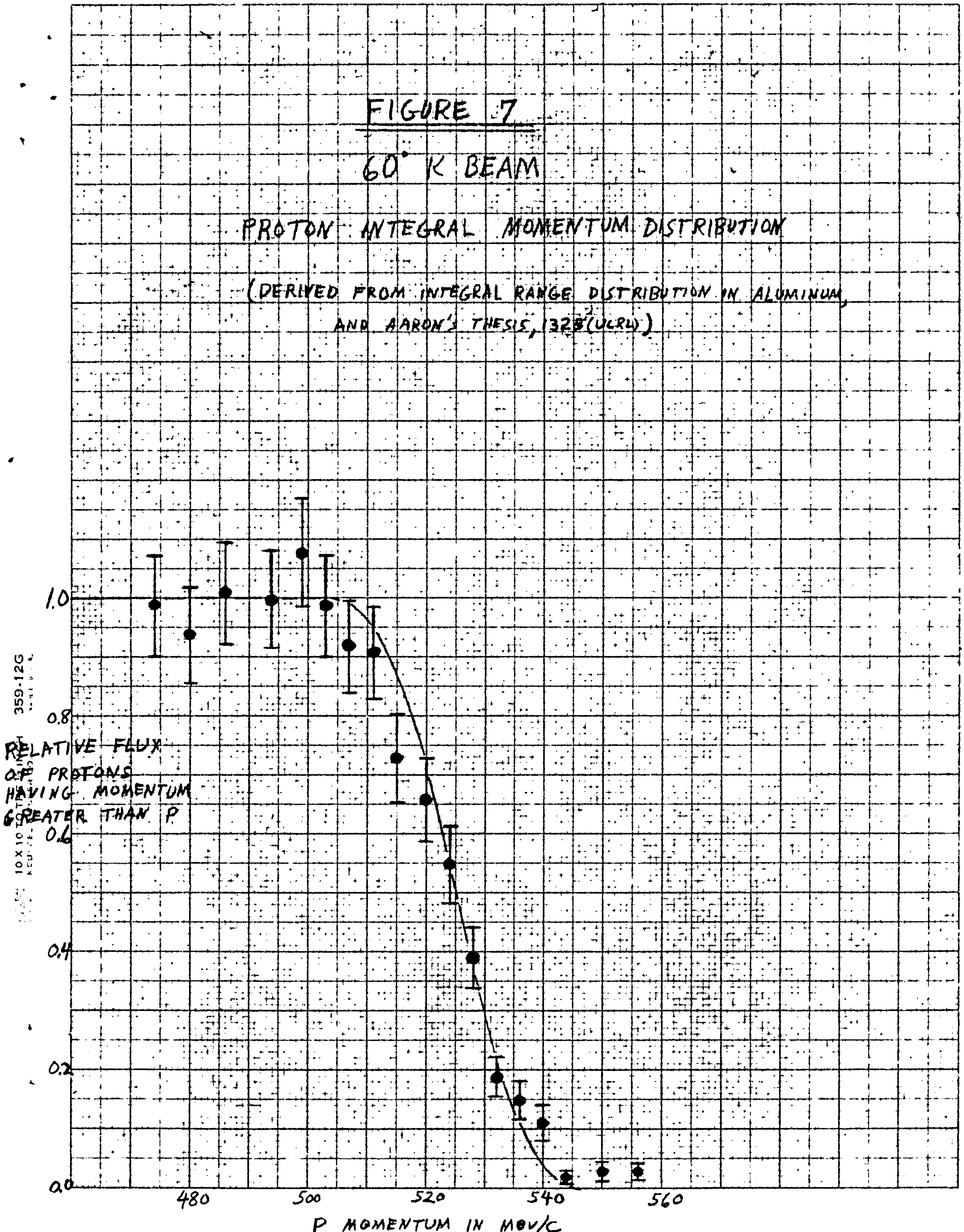


FIGURE 7

60° K BEAM

PROTON INTEGRAL MOMENTUM DISTRIBUTION

(DERIVED FROM INTEGRAL RANGE DISTRIBUTION IN ALUMINUM, AND AARON'S THESIS, 1325 (UCRL))