MASTER

COO-1195-96

COST PRICE

FIG. 3.09 MN. 65

RECEIVED BY DTIC SEP 6 1967

REPORT ON THE RECENT BEAM SURVEY OF THE INTERMEDIATE
ENERGY MESON BEAM IN THE PROTON AREA AT THE ZGS

W. V. Hassenzahl, C. Mencuccini[†], E. Beier,
R. Edwards, D. Herzo, L. J. Koester, A. Wattenberg

Department of Physics, University of Illinois
Urbana, Illinois

June, 1967

Technical Report 160

Department of Physics, University of Illinois
Urbana, Illinois

* Work supported in part by the United State Atomic Energy
Commission Contract AT(11-1)1195 - X.

[†] Present address: Comitato Nazionale Energia Nucleare
Laboratori Nazionali di Frascati, Rome, Italy

LEGAL NOTICE

This report was prepared as an account of Government sponsored work. Neither the United States, nor the Commission, nor any person acting on behalf of the Commission:
A. Makes any warranty or representation, expressed or implied, with respect to the accuracy, completeness, or usefulness of the information contained in this report, or that the use of any information, apparatus, method, or process disclosed in this report may not infringe privately owned rights; or
B. Assume any liability with respect to the use of, or for damages resulting from the use of any information, apparatus, method, or process disclosed in this report.
As used in the above, "person acting on behalf of the Commission" includes any employee or contractor of the Commission, or employee of such contractor, to the extent that such employee or contractor of the Commission, or employee of such contractor prepared, disseminates, or provides access to, any information pursuant to his employment or contract with the Commission, or his employment with such contractor.

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

Key

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency Thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

Summary

The primary purpose of the beam survey performed in February, 1967, was to determine the K^+ and π^+ fluxes to be expected in future experiments in this beam. The fluxes obtained with a $\pm 1\%$ momentum bite may be found in Tables 4 and 5.

The effect of target thickness on total production is shown in Figures 12 and 13. The extrapolation to 0 thickness is used in calculating cross sections. Observed production cross sections are quite similar to those of Novey et.al. The π^+ , K^+ , p and $\bar{p}$ production cross sections from Be, Cu, Ta is used to find the relative production as a function of A. Deviations from the $A^{2/3}$ law are as large as a factor of 1.6.

Description of Beam

The meson beam used in experiment E-36 at the Zero Gradient Synchrotron at the Argonne National Laboratory is shown in Figure 1. It consisted of four bending magnets, six quadrupole magnets, one differential Cerenkov counter, and one threshold Cerenkov counter. Protons extracted from the Z.G.S. are focused onto a target placed either 10" upstream of the first element of the meson beam, XBF1, for 2° production; or at the intersection of the proton beam and the axis of the two quadrupoles XQF11 and XQF12 for 13° production. Studies of 2° production were made

Figure 1. : Beam layout

with the first two bending magnets on, each deflecting the 3.5 GeV particles by 5.5° . Production at 13° was obtained by turning off the first two bending magnets. Both target positions are shown in Figure 1.

The first two quadrupole magnets limit the solid angle to a maximum of $.5 \times 10^{-3}$ steradian, and focus the beam at the center of the momentum slit. The second pair of quadrupole magnets focus the beam to be parallel, or slightly converging, for the differential Cerenkov counter.

Momentum Slit

The momentum slit is made of brass plates of various thicknesses which are screwed together and may be readily adjusted. Figures 2, 3, and 4 show details of the construction and positioning of the slit. The lengths and thicknesses of the pieces labeled in Figure 2 are listed in Table 1. The minimum width of the slit was .25" and it was shaped to accept about 50% of the particles off momentum by $\pm 1\%$. The taper was shaped in order to obtain a symmetric momentum bite.

The tapered slit may be moved along the beam. In its farthest downstream position the quadrupoles XQF11 and XQF12 are able to focus 6.5 GeV/c particles at the center of the slit. This was the reason for arranging three "boxes" one inside the other.

Figure 2. Top view of steel shielding and momentum slit.

Figure 3. Detail of the momentum slit as it was during E-36 and the Beam survey. Note that the centerline of the brass box is both displaced and tilted with respect to the beam line. This misalignment is due to difficulties in positioning the outer steel box. It is corrected by adding more brass on the beam right, and shaping the 1/8" inserts to fit the envelope of $\pm 1\%$ rays properly.

DO NOT SCALE

BEAM $\leftarrow$

BEAM DIRECTION $\rightarrow$

$\leftarrow$ OF BRASS BOXES

DISTANCE FROM CENTER OF COPPER TARGET

Figure 4

Figure 4.a. Detail of the attachment of
the brass inserts to the brass
box

Figure 4.b. Typical 1/8" brass insert

TABLE 1

-11-

Lengths and thicknesses of the pieces in the momentum slit. The position of each piece is shown explicitly in figure 3. The minimum slit width, $1/4"$, corresponds to $\Delta p/p \approx \pm 1\%$.

Piece	Length 36" Section Downstream	Thickness	
BR 1	15.52"	1/8"	
2	17.28"	1/8"	
3	25.38"	1/8"	
4	31.20"	1/8"	
5	36.00"	1/8"	
6	36.00"	1"	tapped
7	36.00"	1/2"	
BL 1	8.22"	1/8"	
2	14.28"	1/8"	
3	18.48"	1/8"	
4	22.68"	1/8"	
5	27.24"	1/8"	
6	36.00"	1"	shaped and tapped
18" Section Upstream			
BR A	3.48"	1/8"	
B	9.42"	1/8"	
C	15.42"	1/8"	
D	18.00"	1"	tapped
E	18.00"	1/2"	
BL A	4.56"	1/8"	
B	10.86"	1/8"	
C	17.58"	1/8"	
D	18.00"	1/8"	
E	18.00"	1"	tapped

The outer steel box has inner dimensions 8"x8"x126". After construction all joints and screwholes in this box were sealed with epoxy so that the slit can be filled with He gas. The inner steel box fits snugly in the outer box. Its inner dimensions are 6"x 6" x 60".

The brass box is made in two sections, with inner dimensions 4" x 4" x 18" and 4" x 4" x 36". 1/4-20 capscrews are used to attach the brass inserts to this box. The details of the attachment are shown in Figure 4. The momentum slit was modified after the completion of E-36. Figure 5 shows the slit as it is now set up. The sizes of the new inserts may be found in Table 2.

Contamination, Multiple Scattering and Absorption

The combination of threshold and differential Cerenkov counters provides a π rejection ratio greater than 10^5 . Since the ratio $\frac{K}{\pi} \approx .01$ the π contamination of the K beam is less than 10^{-3} . The differential Cerenkov counter is better than 95% efficient in detection of K's which have an angular divergence less than 7 milliradians.

There is some μ and e contamination in both the π and K flux. The μ contamination in the K flux is mainly from K decays downstream of XBF12. At the present time the exact magnitude of this contamination is not known; however, a crude estimate of the maximum possible contamination due to μ mesons is 0.7% for the K flux and 2.5% for the π flux.

Figure 5 Detail of the modified momentum slit. The slit was changed so that the $1/8$ " brass inserts are parallel to the beam line. This was accomplished by using tapered pieces. The tapered pieces in the 36" (18") section are .490 (.420) at the thick end and .400 (.425) at the narrow end.

DO NOT SCALE

BEAM $\downarrow$

BEAM DIRECTION $\rightarrow$

$\downarrow$ OF BRASS BOXES

TABLE 2

Lengths and thicknesses of pieces in the momentum slit as in Figure 5. This is how the slit is now set up. The minimum slit width, $3/8"$, corresponds to a $\Delta p/p \approx 1.5\%$. Note the $1/2"$ tapered pieces for the 36" section are $.490"$ at the thick end and $.410"$ at the thin end.

Piece	Length 36" Section Downstream	Thickness	
BR 1	14.8"	$1/8"$	
2	22.8"	$1/8"$	
3	28.3"	$1/8"$	
4	33.6"	$1/8"$	
5	36.0"	1"	tapped
6	36.0"	$1/16"$	
7	36.0"	$1/2"$	tapered
BL 1	12.3"	$1/8"$	
2	16.9"	$1/8"$	
3	21.7"	$1/8"$	
4	26.2"	$1/8"$	
5	30.2"	$1/8"$	
6	36.0"	$1/2"$	tapered and tapped
7	36.0"	$1/4"$	
	18" Section Upstream		
BR A	4.2"	$1/8"$	
B	10.4"	$1/8"$	
C	17.2"	$1/8"$	
D	18.0"	1"	tapped
E	18.0"	$1/2"$	tapered
BL A	5.8"	$1/8"$	
B	11.8"	$1/8"$	
C	18.0"	$1/8"$	
D	18.0"	$1/16"$	
E	18.0"	$1/2"$	
F	18.0"	$1/2"$	tapered and tapped

The total amount of material in the beam is about 19.3 g/cm^2 amounting to a total of about $1/4$ of an interaction length. This material will give a transmission of $e^{-.25} \approx .78$ for π^+ , p , $\bar{p}$, K^- . Because the K^+N total cross section is smaller, fewer K^+ s will be removed. The transmission for K^+ is about $e^{-.2} \approx .82$. Table 3 shows the thickness in g/cm^2 of various substances and the part of beam in which they arise.

Table 3. Thicknesses of the various materials in the beam.

Material	Thickness (g/cm^2)	Position along beam
CO_2	10.6	Differential Cerenkov Counter
Al	5.3	Cerenkov Counter Windows
Freon	2.2	Threshold Cerenkov Counter
Scintillation Plastic	1.0	Counters B1, B2
He	.2	As shown in Fig. 1
Mylar	.1	Windows on He bag and vacuum tank
Air	1.0	All Other places

A large part of the material in the beam is in the two Cerenkov counters. The Coulomb multiple scattering angle for this material is $\theta \approx 3 \times 10^{-3}$ rad. Since the second pair of quadrupoles focus the beam to be parallel, or slightly converging, the Coulomb multiple scattering in the Cerenkov counters determines the phase

space of the beam beyond the fourth bending magnet. The two pictures shown in Fig. 6 were taken with a scintillation camera about 100" behind the last quadrupole. The picture at the top was taken before the Cerenkov Counters were put in the beam. The picture at the bottom was taken after they had been positioned and filled with gas. All other beam parameters, fields in bending and quadrupole magnets, etc. were optimized to give the smallest beam in each case.

Figures 7, 8, 9, 10 show some of the calculated particle trajectories neglecting multiple scattering mentioned above. The 0 line on each of these figures is the nominal beam line with the deflection of the bending magnets removed, i.e., it is the path of a particle produced at the center of the target at 2° to the proton line and having a momentum of exactly 3.5 GeV/c.

Production from various targets

Using 4" x 4" beam defining counters at approximately 1240" and 1300" from a $1/2"$ x $1/2"$ x 2" Cu target one obtains the particle fluxes per 10^{11} extracted protons from 2° production shown in Table 4. The fluxes for 13° production are given in Table 5. The scaling factor to a 5" Cu target is about 1.6.

During E-36 two lead collimators were used to clean up the beam by removing particles with large divergence. The first collimator was placed in front of XQF11, the second between XQF13 and XQF14. The two lead collimators also reduce the acceptance solid angle of the beam by a factor of 2.1, from $.5 \times 10^{-3}$ steradian to

Figure 6

- Figure 6.a. Scintillation camera picture of the beam 100" downstream of XQF16 before the Cerenkov counters were placed in the beam. Quadrupoles XQF13 and XQF14 were tuned for the smallest beam at this point.
- Figure 6.b. Scintillation camera picture of the beam 100" downstream of XQF16 after the Cerenkov counters were placed in the beam and filled with gas.

Q14 - 63.0
IN FRONT OF VACUUM
TANK

BL

15 pulses

Figure 7. Typical vertical trajectories through the magnet system for particles with momentum 3.5 GeV/c. Multiple coulomb scattering is neglected.

Figure 8. Typical horizontal trajectories through the magnet system for particles with 3.5 GeV/c. Multiple coulomb scattering is neglected.

Figure 9. Typical horizontal trajectories through the magnet system for particles with 3.535 GeV/c. Multiple coulomb scattering is neglected.

Figure 10. Typical horizontal trajectories through the magnet system for particles with 3.605 GeV/c. Multiple coulomb scattering is neglected.

$.24 \times 10^{-3}$ steradian. We observed a factor of 2.3 reduction in the π mesons and a factor of 1.8 reduction in the K mesons.

We believe this difference is due to the different sensitivity of the differential Cerenkov counter to the divergence of the incident K mesons. Thus when the collimators were removed K mesons with large divergence were included in the beam, some of these did not trigger the differential Cerenkov counter. π mesons were detected by both the threshold Cerenkov counter and the outer ring of the differential Cerenkov counter. Neither is as sensitive to particle divergence as the inner ring of the differential Cerenkov counter which is used to detect K mesons.

Table 4. Measured flux per 10^8 extracted protons using 2° production from a $2'' \times 1/2'' \times 1/2''$ Cu target. About 75% of the primary proton beam hits the target. The secondary beam was defined by two $4'' \times 4''$ scintillation counters placed 1240" and 1300" from the target. Both lead collimators were removed.

Momentum (GeV/c)	π^+	π^-	K^+	K^-	p	$\bar{p}$
2.5	43	27	.650	.140	51	-
3.5	80	36	1.600	.270	70	.037
4.5	83	34	2.500	.290	130	.033

Study of Production as a Function of Target Thickness

Production of secondaries, π 's, K's, etc. is not directly proportional to the length of the target. The smaller production per unit length from thicker targets is easily understood in terms of the attenuation of the primary and secondary beam.

If we assume that the number of protons decreases exponentially along the target, $N_p = N_0 e^{-x/\lambda}$, and that the cross sections for interactions between the produced particles and the target nuclei is the same as for incident protons and the target nuclei then the number of particles produced in a target of length L is:

$$N_1(L) = C \int_0^L N_0 e^{-x/\lambda} \cdot e^{-(L-x)/\lambda} \cdot dx = CN_0 L e^{-L/\lambda}$$

This simple example corresponds to a target with a cross sectional area much larger than the proton beam as shown in Figure 14-a.

Table 7 contains the π^+ and K^+ flux and flux per unit length. The fluxes are plotted in Figures 11 and 12 and the flux per unit length in Figure 13. The straight solid line plotted in Figure 13 is the function $N_1(L)/L$. We see that the slope of the straight line $\lambda = 4.9'' = \lambda_p$ is certainly too large to fit the experimental data. However other data show that 4.9'' is the correct interaction length for π^+ .

Figure 11. Production of K^+ mesons as a function of target length.

Figure 12. Production of π^+ mesons as a function of target length.

Figure 13. Production of π^+ and K^+ mesons per unit length of target as a function of target length. The dashed line is put in by hand to connect the data points.

Table 5. Measured flux per 10^8 extracted protons using 13° production from a $2" \times 1/2" \times 1/2"$ Cu target. About 75% of the primary protons hit the target. The secondary beam was defined by two $4" \times 4"$ scintillation counters placed 1190" and 1250" from the target. Both lead collimators were removed.

Momentum (GeV/c)	π^+	π^-	K^+	K^-	p	$\bar{p}$
2.5	10.3	9.2	.42	.056	17.2	-
3.5	9.9	5.8	.57	.050	25	.010
4.5	3.9	2.1	.33	.018	18	.003

To compare 2° and 13° production, the π^+ fluxes and the K^+/π^+ , $K^+/\pi^+ + p$, K^-/π^- , and p/π^+ ratios are listed in Table 6 at 3.5 GeV/c.

$$\frac{\pi^+(2^\circ)}{\pi^+(13^\circ)} \approx 8.0 \qquad \frac{\pi^-(2^\circ)}{\pi^-(13^\circ)} \approx 6.2$$

$$\frac{K^+(2^\circ)}{K^+(13^\circ)} \approx 2.7 \qquad \frac{K^-(2^\circ)}{K^-(13^\circ)} \approx 5.5$$

Table 6. Comparison of 2° and 13° beam using a $2"$ Cu target.

Prod. Angle	Momentum = 3.5 GeV/c					
	$\pi^+/10^8$ Protons	$\pi^-/10^8$ Protons	K^+/π^+	$K^+/\pi^+ + p$	K^-/π^-	p/π^+
2°	80	36	.025	.013	.009	.89
13°	9.9	5.8	.075	.011	.011	2.5

Since the production data was for 2° it may be useful to investigate the effect of some small fraction of the π 's leaving the target before having a chance to interact.

Table 7. Observed π^+ and K^+ fluxes per 10^{11} extracted protons as a function of target length. Two $4" \times 4"$ beam defining counters were used at 1240" and 1300" from the target. Both lead collimators were removed. The cross section of each target is $1/2" \times 1/2"$.

Thickness Cu	$\pi^+/10^{11}$ protons	$\pi^+/10^{11}$ protons /in. Cu	$K^+/10^{11}$ proton	$K^+/10^{11}$ protons /in. Cu	K^+/π^+
$1/2"$	2.38×10^5	4.77×10^5	4.56×10^3	9.10×10^3	1.9×10^{-2}
$2"$	7.00×10^5	3.50×10^5	14.8×10^3	7.4×10^3	2.1×10^{-2}
$3-3/4"$	10.0×10^5	2.66×10^5	21.9×10^3	5.8×10^3	2.2×10^{-2}

We will make the calculation for a general angle θ , and for the case $L \cdot \tan(\theta) < W$ as shown in Figure 14.b. Clearly the only change from the previous example will be that some of the secondaries travel a shorter distance in the target. The integral in this case is slightly more complicated but not difficult.

$$N_2(L) = \frac{N(L)}{L} = \frac{C}{L} \frac{1}{\int_0^W dy} \left\{ \int_0^L N_0 e^{-x/\lambda} \cdot \left[\int_0^{(L-x)\tan\theta} e^{-y/\lambda \sin\theta} dy + \int_{(L-x)\sin\theta}^W e^{-(L-x)/(\lambda \cos\theta)} dy \right] dx \right\}$$

Figure 14

Figure 14.a. Relationship of target and primary beam corresponding to $N_1(\theta)$ in the text. The target is larger than the primary proton beam.

Figure 14.b. Relationship of target and primary beam corresponding to $N_2(\theta)$. Target is smaller than the primary beam so that some particles leave the side of the target.

$$\approx C N_0 \left\{ e^{-L/\lambda} + \frac{\lambda \sin \theta}{W \cdot L} (\lambda - L e^{-L/\lambda}) - \frac{(\lambda^2 + L/2)}{W L} \sin \theta e^{-L/\lambda} \right\}$$

Table 8 is a comparison of $N_1(L)$ and the experimental 2° production.

Table 8. Comparison of the calculated and observed production from copper targets of various lengths. The calculated values of production per unit length, N_1 and N_2 , are compared to the measured production per unit length. Note this value is obtained by taking the total production at one-half inch and dividing by one-half inch, etc.

Thickness Cu	$N_1(0^\circ)$ ($e^{-x/\lambda}$)	$N_2(2^\circ)$	$N_2(13^\circ)$
1/2"	.903	.903	.903
2"	.665	.668	$\approx .715$
3-3/4"	.465	.484	$\approx .61$

The difference between $N_1(2^\circ)$ and $N_2(2^\circ)$ is much smaller than those observed and cannot explain the differences observed at 2° , refer to Figures 11, 12, and 13. A possible explanation⁹ for the larger than expected production from thicker targets is that some of the π 's observed are created by other secondaries of higher

energy, or possibly are produced by decays of other particles in a "halo" about the target.

Observed Cross Sections

The following cross sections were observed for 2° production when both lead collimators were removed, and a counter much larger than the beam was placed in front of XBF12:

$$\frac{d^2\sigma(\pi^+)}{d\Omega dp} = 314 \text{ mb} / (\text{BeV/c} \times \text{s.r.} \times \text{Cu nucleus})$$

$$\frac{d^2\sigma(K^+)}{d\Omega dp} = 14 \text{ mb} / (\text{BeV/c} \times \text{s.r.} \times \text{Cu nucleus})$$

The fluxes used to calculate these cross sections were corrected for target length and for interactions along the beam path. The results are in complete agreement with those observed by Novey et al.

Relative Production of Particles from Various Target Elements

The production of the various particles, as a function of the atomic number of the target nucleus can be put in the parametric form.

$$N(A) = F \cdot A^\alpha \quad (F \text{ is independent of } A)$$

If most of the production occurs at the surface of the nucleus then we expect that α will be $2/3$.

From a plot of the number of particles produced per unit incident flux, per unit number of target nuclei, it is possible to obtain α :

$$N(A_1) = F \cdot A_1^\alpha$$

$$\text{also } N(A_2) = F \cdot A_2^\alpha$$

dividing

$$\frac{N(A_1)}{N(A_2)} = \frac{A_1^\alpha}{A_2^\alpha}$$

or

$$\alpha = \frac{\log(N(A_1)) - \log(N(A_2))}{\log(A_1) - \log(A_2)}$$

Table 9 contains the 2° production data, where production is the observed flux corrected for decays and interactions, i.e. it is the number of π mesons, K mesons, protons or antiprotons produced at the target. The production is normalized to 10^{11} protons extracted and to 10^{23} nuclei/cm². The error in any given number, e.g. π^+ from Cu may be as large as 10%. Errors in the relative measurements of π^+ on Cu and π^+ on Be however, will be due either to the statistical error, or to the possible error in positioning the target. We estimate this latter error to be less than 2%. Statistical errors on all fluxes are less than 2%, except for antiprotons where the error is about 4%.

Figure 15. Production of π mesons, K mesons, p and $\bar{p}$ per 10^{23} nuclei/cm², per 10^{11} incident protons from Be, Cu, and Ta are used to find a law of the form $\sigma \propto C A^\alpha$ where C and α may be different for different particles. Momentum = 2.5 GeV/c

Figure 16. Production of π mesons, K mesons, p and $\bar{p}$ per 10^{23} nuclei/cm², per 10^{11} incident protons from Be, Cu, and Ta are used to find a law of the form $\sigma \propto C A^\alpha$ where C and α may be different for different particles. Momentum = 3.5 GeV/c

Figure 17. Production of π mesons, K mesons, p and $\bar{p}$ per 10^{23} nuclei/cm², per 10^{11} incident protons from Be, Cu, and Ta are used to find a law of the form $\sigma \propto C A^a$ where C and a may be different for different particles. Momentum = 4.5 GeV/c

Table 9. 2* Production at the target per 10^8 extracted protons per 10^{23} nuclei/cm². To obtain this data the fluxes were corrected for decay in flight, and interactions along the beam. $\Delta\Omega = .18$ milliradians $\Delta p/p = \pm 1\%$.

Momentum (GeV/c)	Element	P a r t i c l e					
		π^+	π^-	P	$\bar{P}$	K^+	K^-
2.5	Ta	71	44.0	30		4.15	.810
2.5	Cu	40	25	14.1		2.0	.440
2.5	Be	14	8.5	3.8		.57	.135
3.5	Ta	118	54	63	.031	6.3	.940
3.5	Cu	70	31	35	.019	3.2	.540
3.5	Be	29	12	92	.007	1.0	.186
4.5	Ta	117	50	117	.026	6.8	.780
4.5	Cu	70	29	67	.017	3.9	.470
4.5	Be	29	12	23	.007	1.3	.185

Figures 15, 16 and 17 are taken from Table 9. The values of α obtained from these figures are tabulated in Table 10:

Table 10. Values of α for the various momenta and particles. These values were obtained from Figures 15, 16 and 17.

Momentum (GeV/c)	α					
	π^+	π^-	P	$\bar{P}$	K^+	K^-
2.5	.530	.525	.678	-	.636	.601
3.5	.476	.508	.663	.510	.615	.540
4.5	.474	.488	.550	.455	.564	.482

The $A^{2/3}$ model does not hold. We plan to investigate this further using an impulse approximation model.

It is interesting to ask which element is the most effective as a target Be, Cu, or Ta. From Table 11 we see that if the length is fixed at 4", and small angle production is used then we find Copper is the best material for a target.

Table 11. Relative production of K^+ from various nuclei.
The relative production R is defined by
 $R = \text{Production density} \exp(-X/\lambda) / \text{At.wt.}$

Material	Density gm/cm ²	At wt	$-X/\lambda$ e 4" target	K^+ production at 3.5 GeV/c from Table 9	relative K^+ production from 4"
Be	1.84	9	.719	186	22
Cu	8.9	63.5	.427	540	32
Ta	16.6	181	.333	940	29