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A Measurement of the Production of Low Energy Pions at Large Angles from the AGS Proton Beam

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Introduction

As a preliminary step in the design of a proposed, very low energy pion and muon beam at the AGS, we have measured the production by 28 GeV protons of positive pions with momenta of 90 to 208 MeV/c at large production angles.

The only previously published data on large angle production of low energy pions from 28 GeV protons are in a survey by Fitch et al[1] in 1962. This work included measurements of pions produced at 45° and 90° lab. angle from an internal thin Be target in the AGS. Since the target for the presently proposed beams would be the existing 3 in. long iridium target at the B station in the AGS slow external beam, the results of Fitch are not directly applicable. For thick external targets of heavy nuclei, the only available data are from the measurements of Berley et al,[2] of the production of pions below 200 MeV/c at forward angles up to 30° from 17 GeV incident protons.

Our measurements, therefore, were made in order to design beams compatible with the existing B station target. The production targets for this experiment were located at the B' station in the B5, 28 GeV slow extracted beam. The most significant measurements were made with an iridium target, 0.100 in. in diameter, similar to the existing B station target.

Apparatus and Technique

The measurements rely on the signature of a π-μ decay from a positive pion stopping in a thin plastic scintillator. Figure 1 is a drawing of the apparatus and a simplified block diagram of the electronics. A π^+ produced in the target passes through 1/4 in. thick scintillation counters, 1, 2 and 3, and stops in the 1/16 in. thick counter, 4. Counter 5, located behind 4, is in anticoincidence. Seven brass moderators, ranging from 1/8 in. to 1 7/8 in. thick, can be remotely inserted between counters 2 and 3 in order to select the momenta of pions stopping in counter 4, a range of momenta from 91 to 208 MeV/c at production. In order to reduce background, counters 3 and 4 have upper as well as lower thresholds, so that there is a window in the pulse heights that are accepted. The window in 3 selects a narrow band of large pulses for a pion on its way to stopping in 4. A $1234\bar{5}$ coincidence signifies a stopping particle. If the stopping particle is a π^+, the μ^+ decay will usually not escape from 4. The signal from a stopping pion starts a time-to-amplitude converter (TAC). A subsequent pulse in 4 from the decay muon stops the TAC. The output pulses of the TAC are recorded by a multichannel pulse height recorder (PHA). A typical time spectrum, shown in Fig. 2, is consistent with the 26 ns lifetime of the pion after subtraction of a 10% background of accidentals.

The entire apparatus is mounted on a plate that pivots on a point directly below the production target. This plate is motor driven, so that the production angle can be remotely varied. Because of a large magnet immediately downstream of the production target, it was only possible to go to 66^o in the forward direction. The three production angles measured were 66^o, 90^o, and 135^o. Production targets were mounted on a wheel so that they also could be remotely changed.

The flux of incident protons was measured by an ionization chamber, which was, in turn, calibrated at higher proton intensities by a secondary emission chamber. Since the emittance of the 28 GeV proton beam at B' target station is much larger than the emittance at B, many of the protons that register in the secondary emission chamber and ion chamber are not incident on the 0.100 in. diameter target. To determine the targeting efficiency for this target, the horizontal and vertical profiles of the proton beam at B' were measured by activating a grid of 1 mm diameter aluminum wires, which were exposed to the beam for 8 hours and counted in proportional counters. The measured targeting efficiency for the iridium target is 16.8%. For the other target used, a 1/2 in. x 1/2 in. x 3 in. piece of hevimet (tungsten), a targeting efficiency of 100% was assumed.

The data for each point consist of the number of counts accumulated in the PHA after subtraction of a background determined by the shape of the spectrum, for an ionization chamber count corresponding to 2×10^{10} incident protons. The π^+ production per proton incident on the target is given by the equation,

$$dN_{\pi+}/dpd\Omega = (N_{\pi+}/N_p)\cdot e^{b/\lambda_c}\, e^{t_1/\tau_\pi}/(t_4\cdot(\tfrac{dp}{dx})_{p_o}\cdot f_t\cdot f_c\cdot\Omega_4)$$

where $N_{\pi+}$ is the number of observed counts after background subtraction,

N_p is the number of incident protons (= 2×10^{10}),

e^{t_1/τ_π} is a correction for early μ^+ that miss the gate,

t_4 is the thickness of #4 in gm/cm^2 (= 0.177 gm/cm^2),

$(\frac{dp}{dx})_{p_o}$ is the momentum loss/(gm/cm^2) in scintillator at the production momentum, p_o,

f_t is the targeting efficiency (= 0.168 for Ir target),

f_c is the capture efficiency, i.e. the fraction of μ^+ that do not escape 4 (= 0.60),

e^{b/λ_c} is the correction for nuclear interactions of pions in the brass moderator of thickness b gm/cm^2.

In the analysis, λ_c was taken as a constant independent of π^+ energy. A value of λ_c = 105 gm/cm^2 was chosen as representative of the available data at higher momenta where the effect is significant.

Ω_4 is the effective solid angle subtended by 4. A Monte Carlo study indicates that this solid angle is not much influenced by Coulomb scattering in the brass plate and in the upstream counters, because the number of pions that scatter out of #4 are balanced by the number that scatter in.

Results and Discussion

Pion production for the Ir target, which is similar in material, thickness and length to the present B station target, is plotted in Fig. 3. The errors shown are statistical only. The tungsten (hevimet) target was included in the experiment to see if a wider target, by providing an opportunity for more cascade development, might effect an improvement in π^+ yield. Results from this target are shown in Fig. 4. The effect is the opposite of what might have been expected. Even allowing for the fact that the tungsten target has a smaller fraction of an interaction length, the wider target seems to have the effect of absorbing some of the produced pions.

The measurements in this experiment are, of course, only for positive pions. However, the results of Fitch et al are compatible with the assumption that, for multiple pion production at this high proton energy, an almost equal number of negative pions are produced.

The results of this experiment can be applied directly to predict the number of muons that would emerge from the SREL channel operating at a pion momentum of 200 MeV/c. At the 66° production angle, the SREL channel would produce a total of 7.1×10^7 muons per 10^{12} protons incident on the target. The momentum distribution of these muons would be in two peaks corresponding to forward and backward angle decay in the channel. The backward peak, in the momentum range 100-150 MeV/c, would contain 3×10^7 muons. An experiment with a target area of 25 cm^2 would stop 2×10^5 per gm/cm^2 of these muons.

Since it is difficult to extrapolate the data of Fig. 3 to zero momentum, estimates of surface muons from the target itself, i.e. decays from stopped pions, are not possible. It is, however, possible to estimate the surface μ^+ production in a relatively thick secondary target in the vicinity of the primary target. For example, a 5 mm thick brass target subtending 1 sr with respect to the primary target would produce 10^5 surface μ^+ at the end of the proposed surface beam channel.

We wish to thank Mr. J. Shill for a quick and accurate design of a rotating mechanism for our apparatus. We also thank Dr. J. Cumming of BNL for his invaluable help with the measurement of the beam profile.

[1] V.L. Fitch et al, Phys. Rev. 126, 1849 (1962).

[2] D. Berley et al, Proceedings of the 1973 Particle Accelerator Conference, IEEE Trans. Nucl. Sci. 997-1001 (1973).

[3] C. Chedester et al, Phys. Rev. 82, 958 (1952).
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A. Pevsner et al, Phys. Rev. 100, 1419 (1955).

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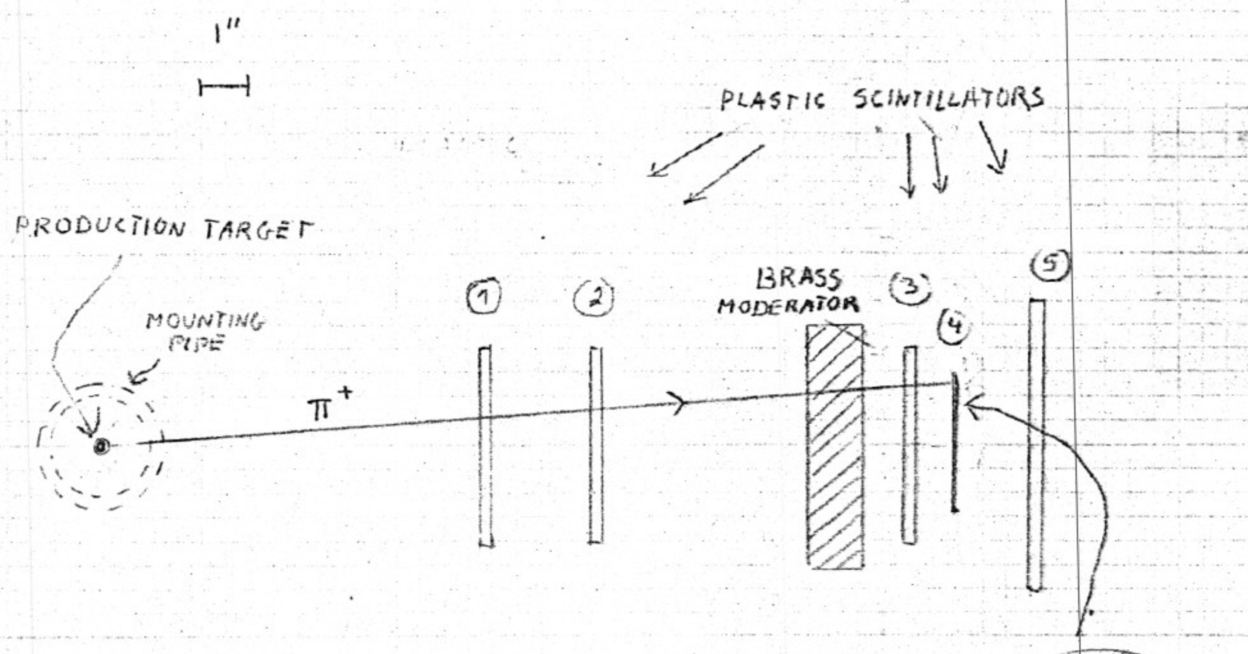
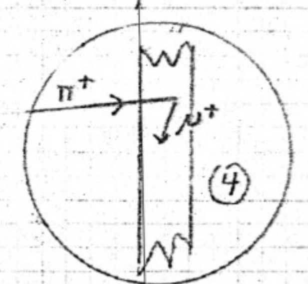
FIGURE 1 LAYOUT OF EXPERIMENT

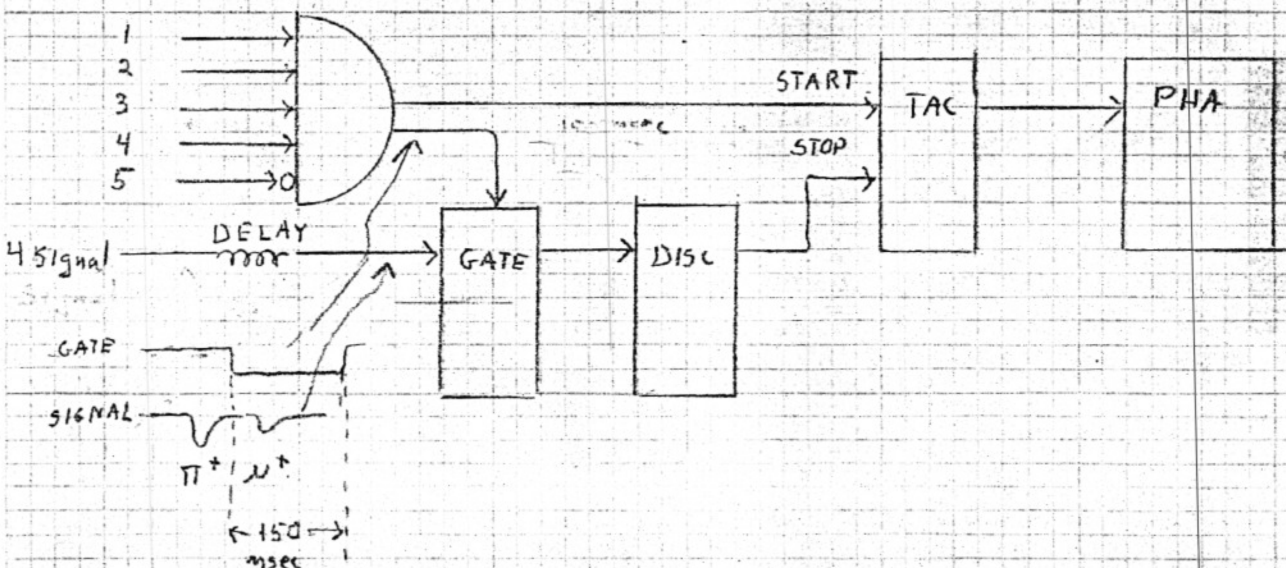




Counter Dimensions

1, 2, 3 : 3 3/4" × 3 3/4" × 1/4"
4 : 3" × 3" × 1/16"
5 : 6" × 6" × 1/4"

ELECTRONICS



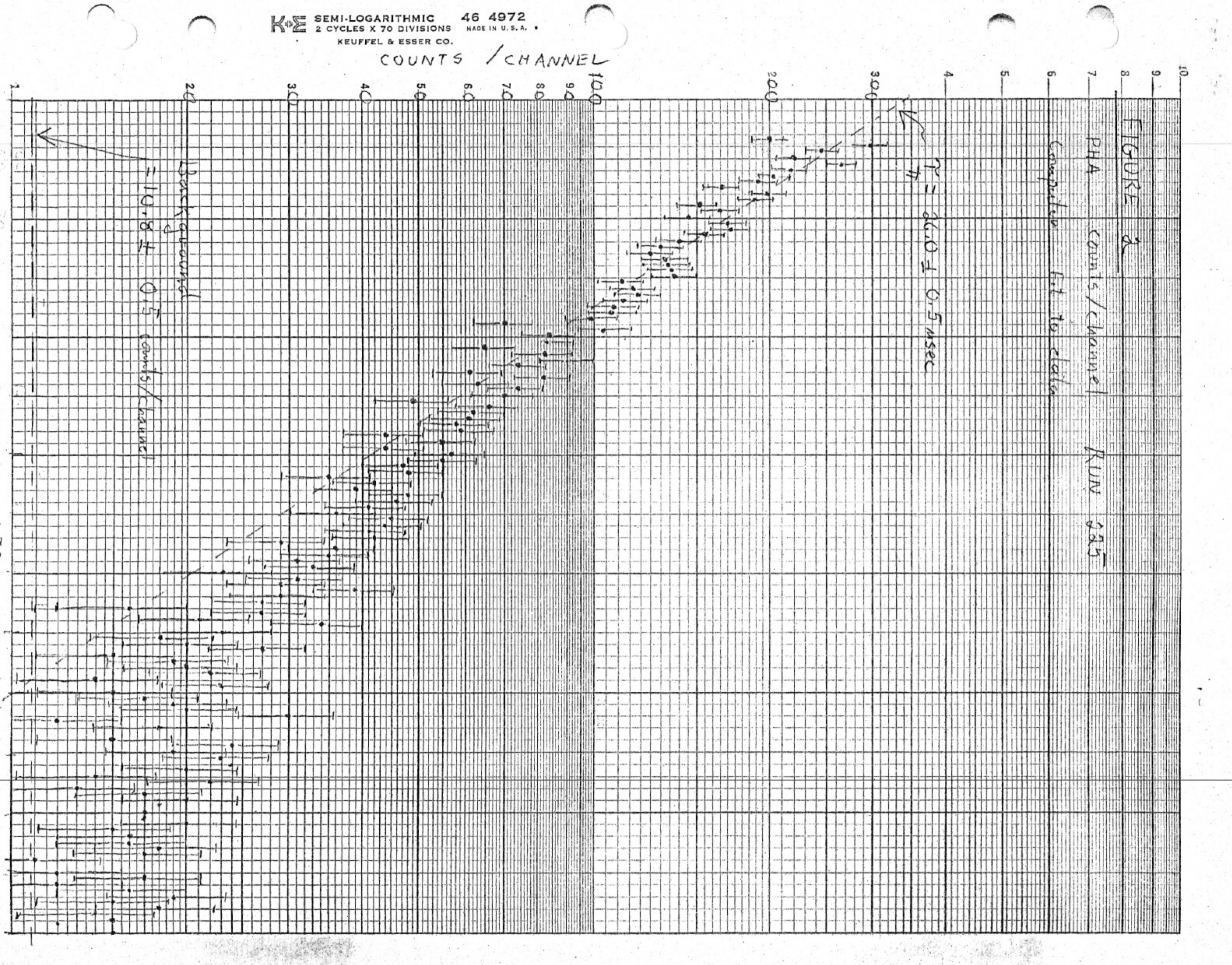
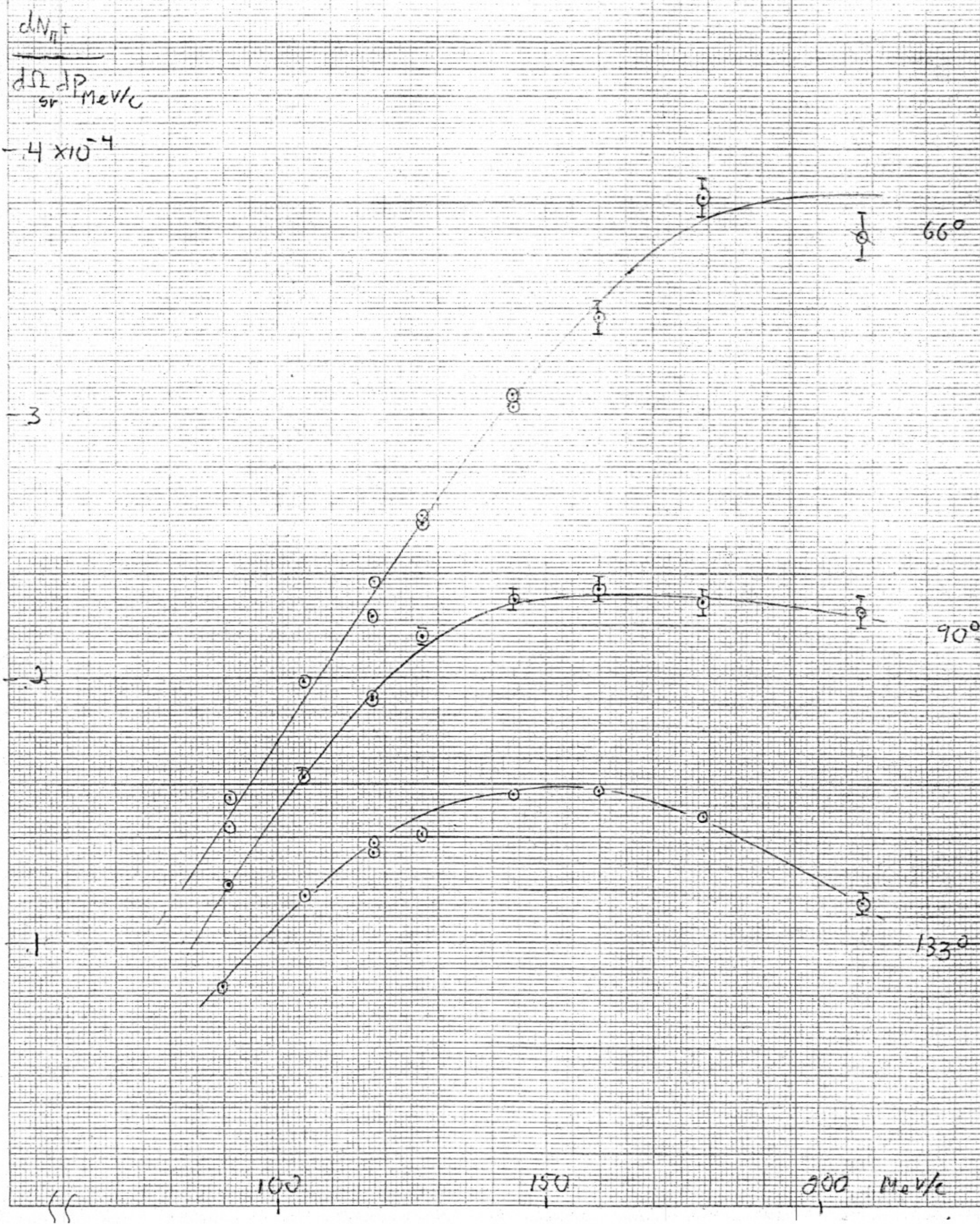

K+E SEMI-LOGARITHMIC 46 4972
2 CYCLES X 70 DIVISIONS MADE IN U.S.A.
KEUFFEL & ESSER CO.
COUNTS /CHANNEL
20
30
40
50
60
70
80
90
100
200
300
PHA counts/channel RUN 335
Computer fit to data
τ = 26.0 ± 0.5 μsec
Background = 10.87 ± 0.5 counts/channel

FIGURE 2

π^+ Production per proton incident on a 3" long 0.1" dia Iridium target



π^+ Production per proton incident on a

1/2" x 1/2" x 3" Heavimet Target