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Introduction

During the running of an experiment (AGS #620) in neutral beam #6A derived from the G10 internal target, over 10^8 triggers were accumulated. Although the main purpose of the experiment was to study coherent and Coulomb production of $K^{*o}(890)$ on nuclei, a substantial amount of data was obtained on the production of $p\pi^-$ pairs by incident neutrons. To aid in the analysis of the latter data, the neutron spectrum was measured using a sampling total absorption counter or calorimeter of the type described by Engler et al.[1]

Calorimeter

The calorimeter consisted of 14 scintillator planes, 36"w x 22"h x ¼" thick, interleaved with 13 iron plates 1½" thick. Light from the first, third, fifth, seventh, ninth, eleventh, and thirteenth scintillators was summed optically and viewed by one photomultiplier tube. Light from the other seven scintillators was similarly summed and viewed by a second phototube. This calorimeter has been used in two previous AGS experiments to detect neutrons[2,3] and is described in some detail by McCorriston.[4]

For the present measurement, both phototubes of the calorimeter were plateaued using minimum ionizing muons in the East Test Beam. A coincidence was then formed between the two tubes, and this was used to gate a linear

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signal obtained by passively adding the two dynode signals. The linear gate had a fixed dead time of 14 μsec and incorporated an amplifier-stretcher whose output was directed to a pulse height analyzer.

Calibration

To calibrate the calorimeter, its respons to protons of various momenta in the East Test Beam was obtained. Figure 1 shows a typical pulse height spectrum for 15 GeV/c protons. Note that each channel represents the sum of eight adjacent pulse height analyzer channels. The spectrum peaks in channel 17 and has a FWHM = 60%. This procedure was repeated for several proton momenta, and Figure 2 shows a plot of the peak pulse height versus momentum for both a preliminary and the final calibration. This curve shows that the calorimeter response is proportional to proton momentum and there is an electronic threshold at about 4 GeV/c. Figure 3 shows the observed resolution as a function of momentum. Values of resolution in good agreement with those predicted from the curves in Ref. 1 are obtained. Also shown in Figure 3 is the expression for resolution $R = 100 - 2.5\,p$ which is later used to parameterize the resolution as a function of momentum.

Spectrum Measurement

Before measuring the neutron spectrum in beam #6A, the neutron flux was reduced from $\sim 10^7$/pulse to $\sim 3 \times 10^3$/pulse in order to avoid dead-time and pile-up in the linear gate. This was accomplished by inserting an additional collimator in the beam and reducing the intensity targeted at G10 to 2×10^{10} protons/pulse. The additional collimator was made of Pb and had a defining hole ½" x ½" x 24" long followed by a clearing hole 1½" x 1½" x 36" long. The effective solid angle of this combination was 0.188 μsr which reduced the normal solid angle of 14.8 μsr by a factor of 79. Using the trigger of Experiment #620 with a 1/32" Pb target, the measured flux reduction with this collimator was 73 ± 3.

In Figure 4, we show the raw calorimeter spectrum obtained for 293 AGS pulses. This data corresponds to 6.67×10^3 90° monitor counts or 3.29×10^5 30° - monitor counts. Using the calibration of Figure 2, the pulse height spectrum was converted to a raw momentum spectrum and this is shown as the dashed curve in Figure 5.

Neutron Spectrum

To derive the neutron spectrum from the measured pulse-height spectrum of the calorimeter, the instrumental resolution has to be unfolded. Let K(x,p) be the probability that a neutron with momentum p produces a pulse height x at the output of the calorimeter. A typical response function for 15 GeV/c protons (or neutrons) is shown in Figure 1. Note that this response function must be normalized such that $\int_0^\infty K(x,p)dx = 1$. If a spectrum of neutrons N(p) is present, then for those that interact in the calorimeter the pulse height spectrum produced is given by

$$A(x) = \int_0^{p_{max}} K(x,p)\; N(p)\; dp$$

In this expression A(x) is measured, K(x,p) is known and, therefore, N(p) can be extracted although the procedure can be mathematically intricate.

Here, a somewhat different procedure is adopted. First, normalized response functions at 1 GeV/c intervals from 1 to 25 GeV/c (25.8 GeV/c is the maximum possible neutron momentum in this beam) are computed using the measured response at 15 GeV/c from Figure 1 together with the calibration of Figure 2, and the parameterization of resolution shown in Figure 3. Next, a trial function is used for N(p) and its parameters and normalization are varied until the sum $\sum_{p=1}^{25} K(x,p)\; N(p)$ produces a best fit to A(x). Several functional forms were tried for N(p), and none produced a better fit than:

N(p) = CNORM * (C1-p) * p ** 2 * EXP (-p/C2)

where CNORM = 490.6

C1 = 19.7 ± 1.0;

C2 = 4.65 ± 0.35.

This fit gave a X^2/d.f. = 0.8, and the errors shown for C1 and C2 correspond to a X^2/d.f. increase of unity. Figure 5 shows this unfolded neutron spectrum N(p). The errors shown for the various points correspond to the maximum variation of C1 and C2.

The intensity of neutrons in beam #6A, which has a solid angle of 14.8 μsr and a 4" Pb filter, per 10^3 90^0 - monitor counts is obtained from the above data after applying the following corrections:

1. Collimator ratio, 73 ± 3;
2. Contamination of charged particles, 0.97 ± 0.01;
3. Linear gate dead time, 1/(0.92 ± 0.04); and
4. Non-absorption in the calorimeter, 1/(0.95 ± 0.02).

The final spectrum is given in Table I where the integrated intensity from 5 - 19 GeV/c is 7.1×10^6 neutrons/10^3 90°-monitor counts.

To compare with other data, the neutron flux must be referred to the number of targeted protons at G10. For this we used 10^3 90°- monitor counts $\equiv 10^{12}$ targeted protons (known only to $\sim$ 20% accuracy). Allowance for neutron attenuation in the 4" Pb filter was made using an average n - Pb total cross section of 3.15 barns.(4) Note that only 35% of the neutrons survive the filter. The resulting neutron flux per steradian per 10^{12} circulating protons is shown in Figure 6 together with the proton data of Baker et al.(5) at the same angle from an aluminum target. The two spectra agree quite well except for the somewhat flatter momentum dependence of the neutron data. This same trend is also indicated relative to the hydrogen data of Anderson et al.(6) No comparison can be made with the neutron data of Engler et al.(7) as they do not extend to large enough angles.

TABLE I

Neutron Spectrum in Beam #6A with $\Delta\Omega = 14.8\ \mu sr$
and 4" Pb Filter

Momentum (GeV/c)	Neutrons per GeV/c per 10^3 - 90^0 Mon.
5	75×10^4
6	81
7	82
8	80
9	74
10	67
11	59
12	50
13	41
14	33
15	25
16	18
17	12
18	6.8
19	2.5

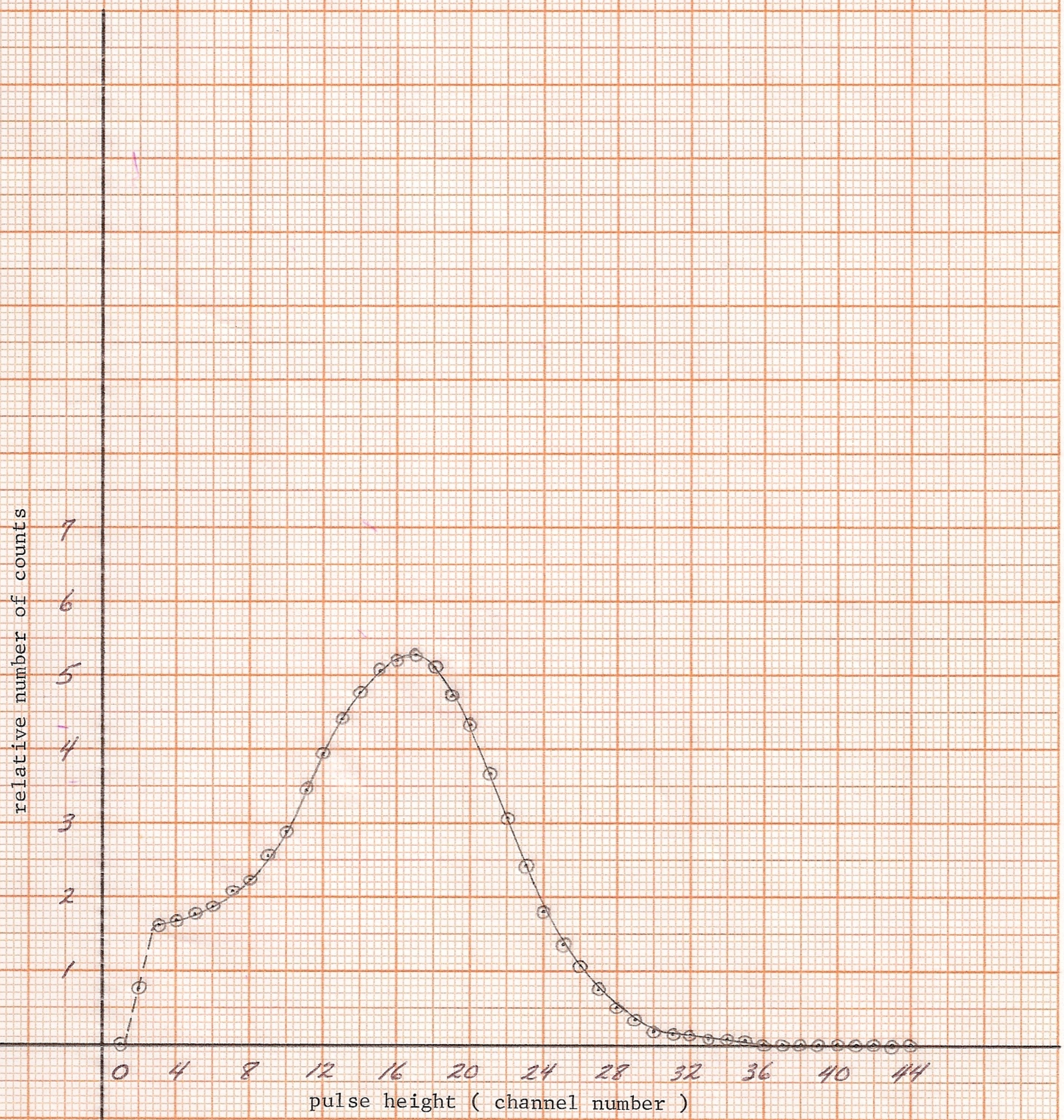
References

1. J. Engler et al., Nucl. Instrum. Methods 106, 189 (1973).
2. L.W. Jones et al., Phys. Letters 36B, 509 (1971).
3. M. Atac et al., Nucl. Instrum. Methods 106, 389 (1973).
4. T.P. McCorriston, Jr., Report No. UM-HE 72-11, Dept. of Physics, Univ. of Michigan, Ann Arbor, Michigan (1972).
5. W.F. Baker et al., Phys. Rev. Letters 7, 101 (1961).
6. E.W. Anderson et al., Phys. Review 19, 198 (1967).
7. J. Engler et al., CERN Report, "Measurement of Inclusive Neutron Spectra from p-Be up to 24 GeV/c Incident Momentum", May (1973).

B1 Limited Distribution

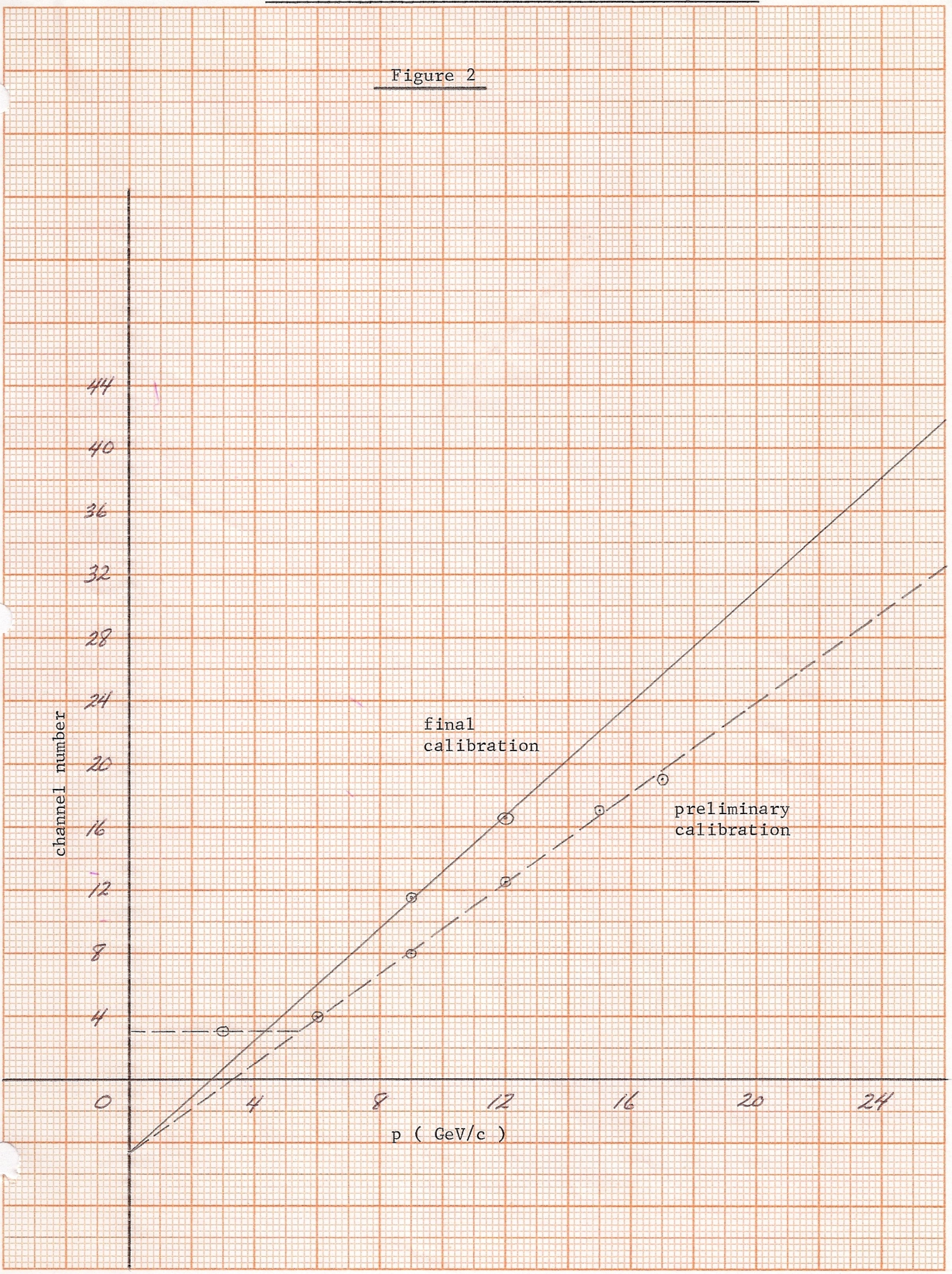
Calorimeter Response at 15 GeV/c

Figure 1



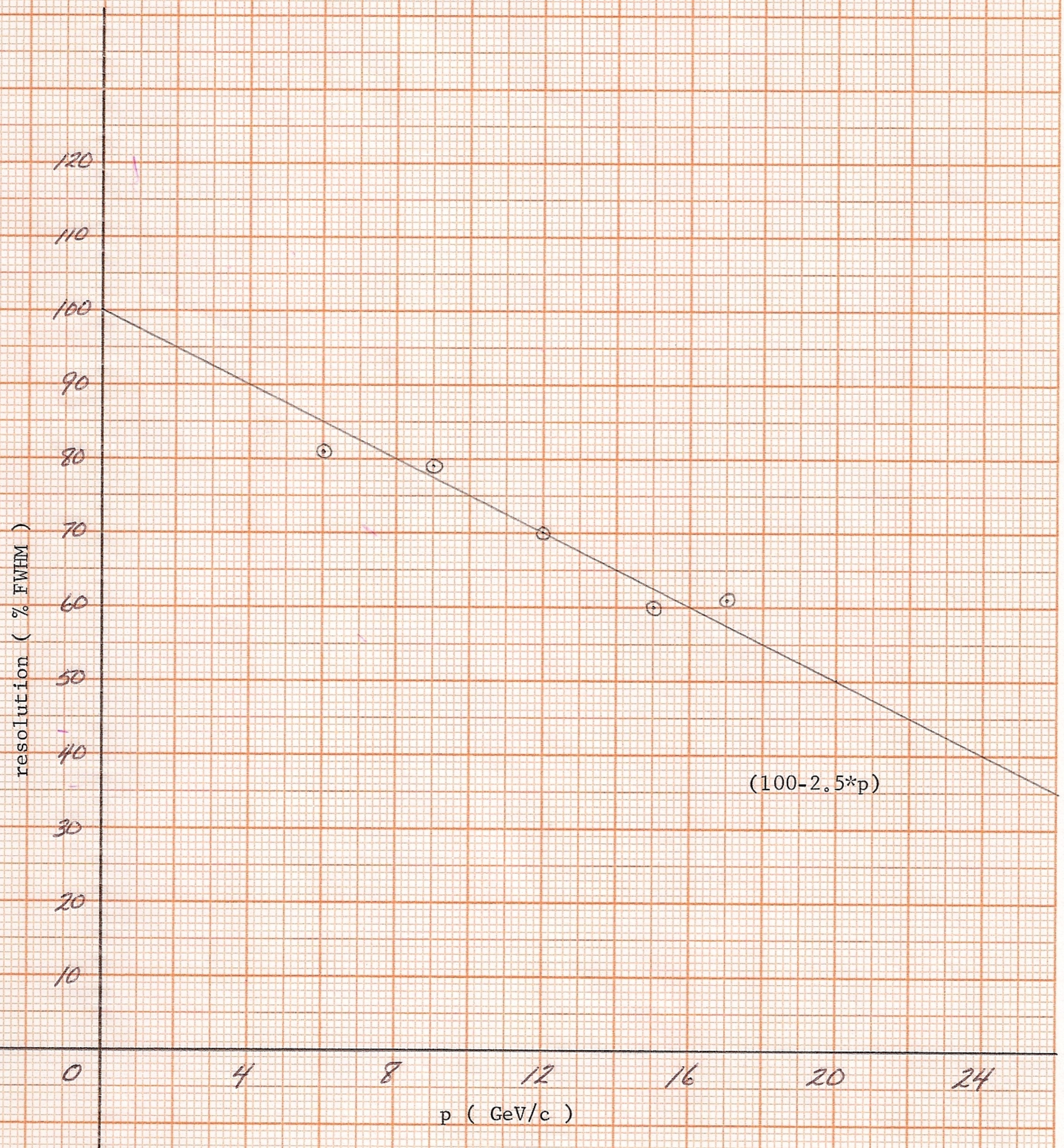
Calibration of calorimeter for incident protons

Figure 2



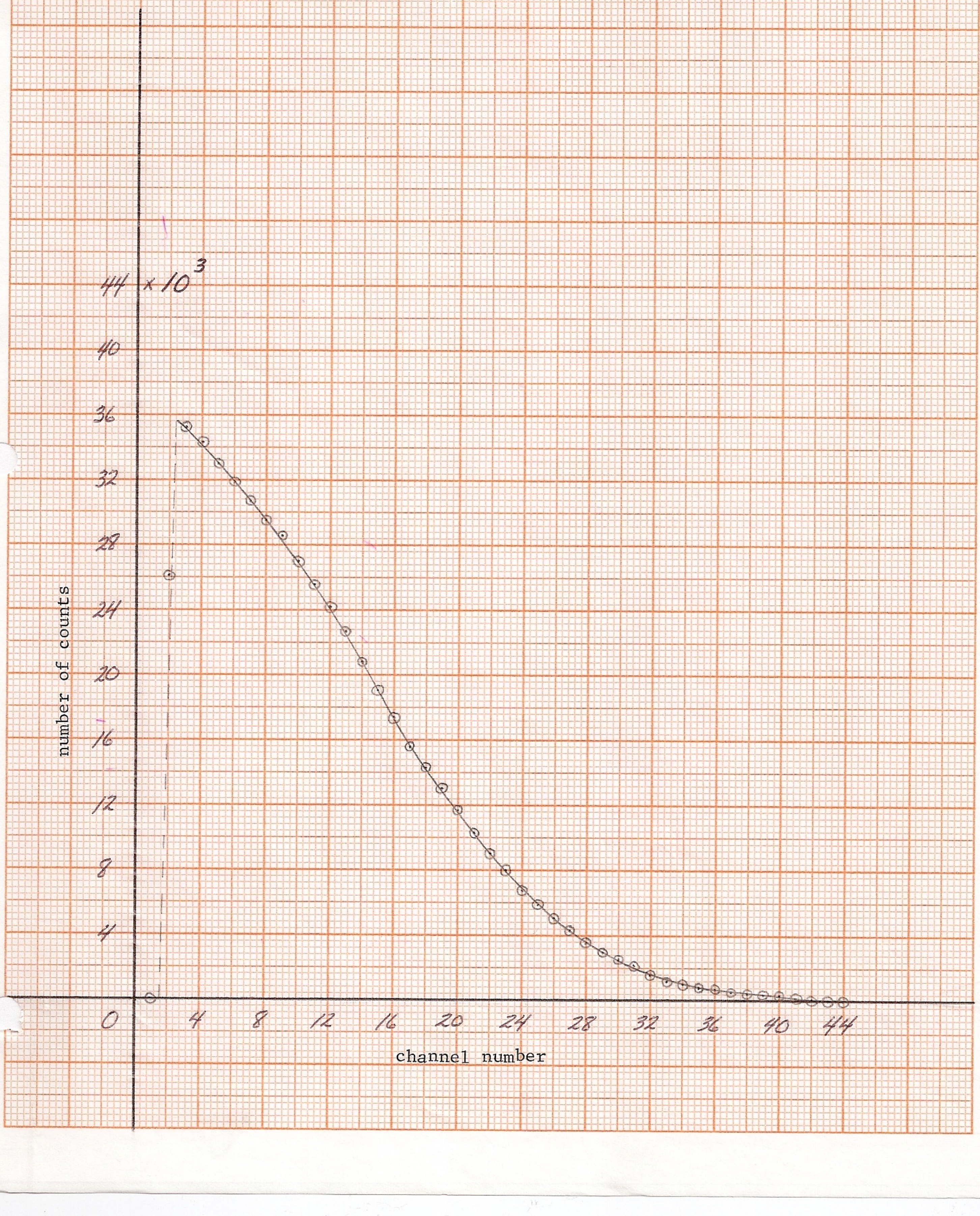
Resolution of calorimeter

Figure 3

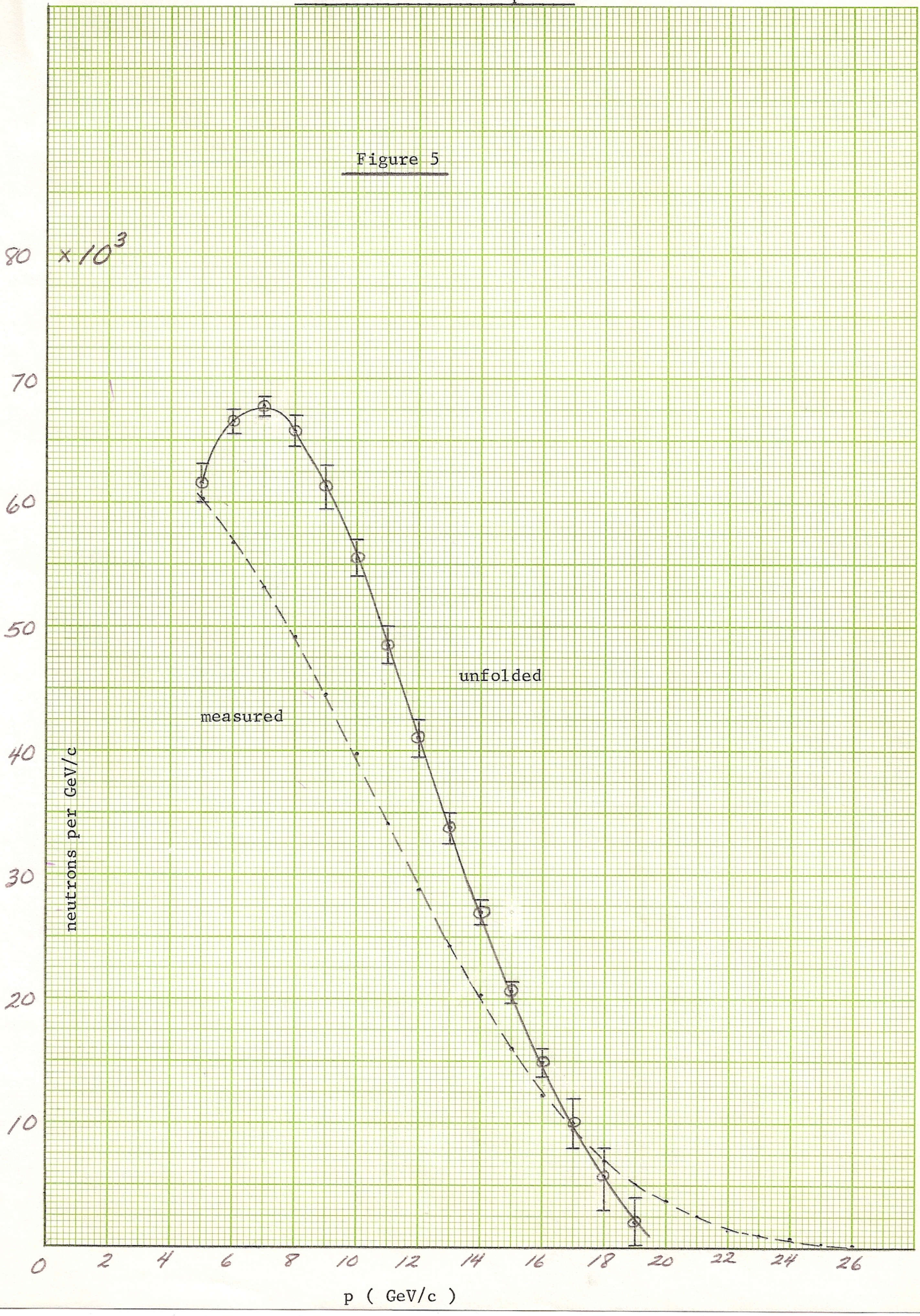


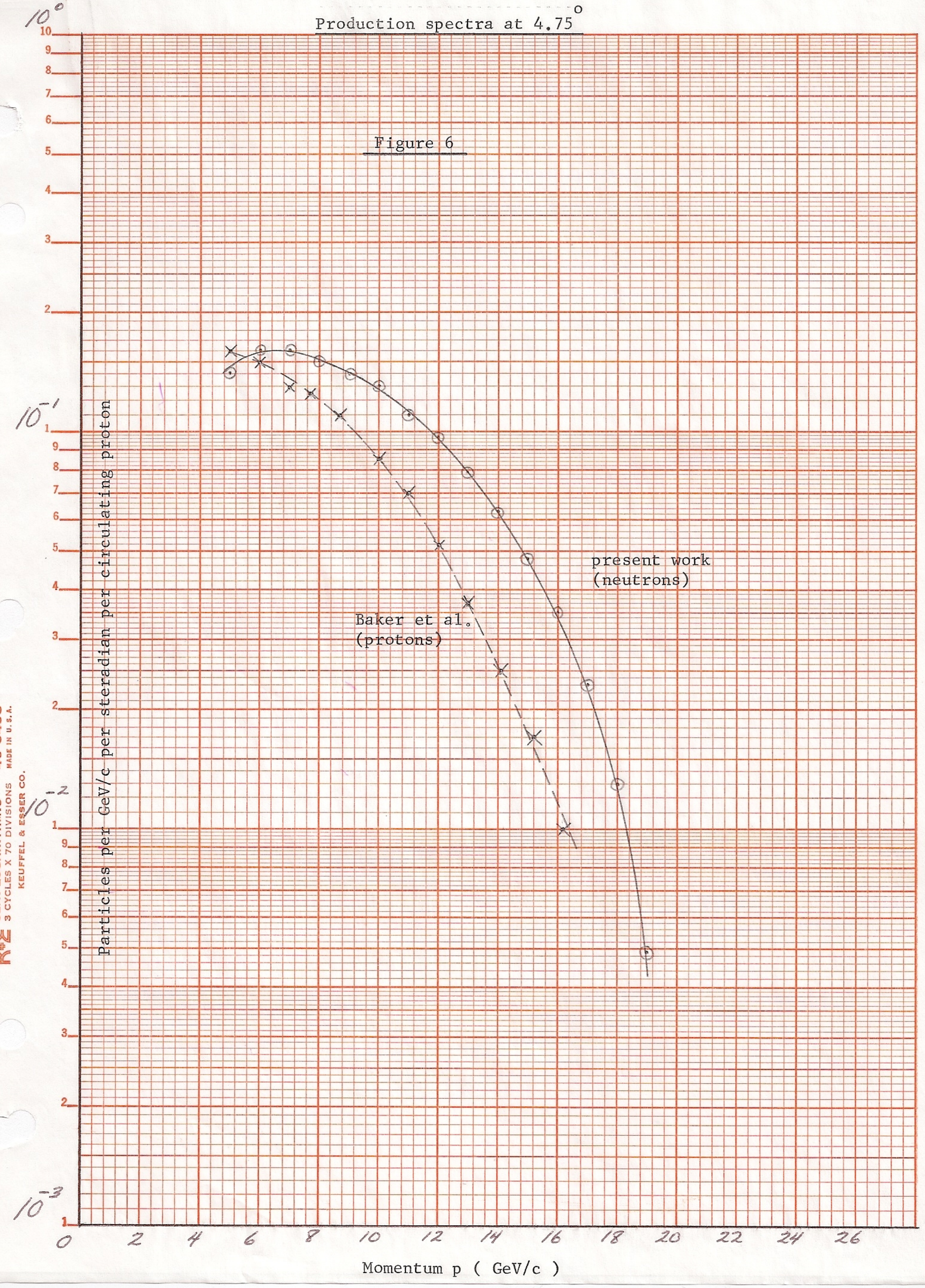
Raw calorimeter spectrum

Figure 4



Calorimeter neutron spectra





Production spectra at 4.75°
Figure 6
Particles per GeV/c per steradian per circulating proton
present work
(neutrons)
Baker et al.
(protons)
Momentum p (GeV/c)