Neutron spectrum in Beam #6A

D. G. Ryan

September 1974

Collider Accelerator Department

Brookhaven National Laboratory

U.S. Department of Energy

DISCLAIMER

EP&S DIVISION TECHNICAL NOTE

No. 71

D.G. Ryan, W.C. Carithers[*] and P. Muhlemann[**]

September 5, 1974

NEUTRON SPECTRUM IN BEAM #6A

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 $\frac{1}{4}$" thick, interleaved with 13 iron plates $1\frac{1}{2}$" 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

---

*Department of Physics and Astronomy, University of Rochester, Rochester, N.Y.

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 $\frac{1}{2}$" x $\frac{1}{2}$" x 24" long followed by a clearing hole
$1\frac{1}{2}$" x $1\frac{1}{2}$" 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.

<u>Neutron Spectrum</u>

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

$\qquad$ C1 = 19.7 $\pm$ 1.0;

$\qquad$ C2 = 4.65 $\pm$ 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° - 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, $1/(0.92 \pm 0.04)$; and

4. Non-absorption in the calorimeter, $1/(0.95 \pm 0.02)$.

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 $\Delta\Omega = 14.8$ μsr
and 4" Pb Filter

Momentum (GeV/c)	Neutrons per GeV/c per 10^3 - 90° 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 $\underline{106}$, 189 (1973).

2. L.W. Jones et al., Phys. Letters $\underline{36B}$, 509 (1971).

3. M. Atac et al., Nucl. Instrum. Methods $\underline{106}$, 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 $\underline{7}$, 101 (1961).

6. E.W. Anderson et al., Phys. Review $\underline{19}$, 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).
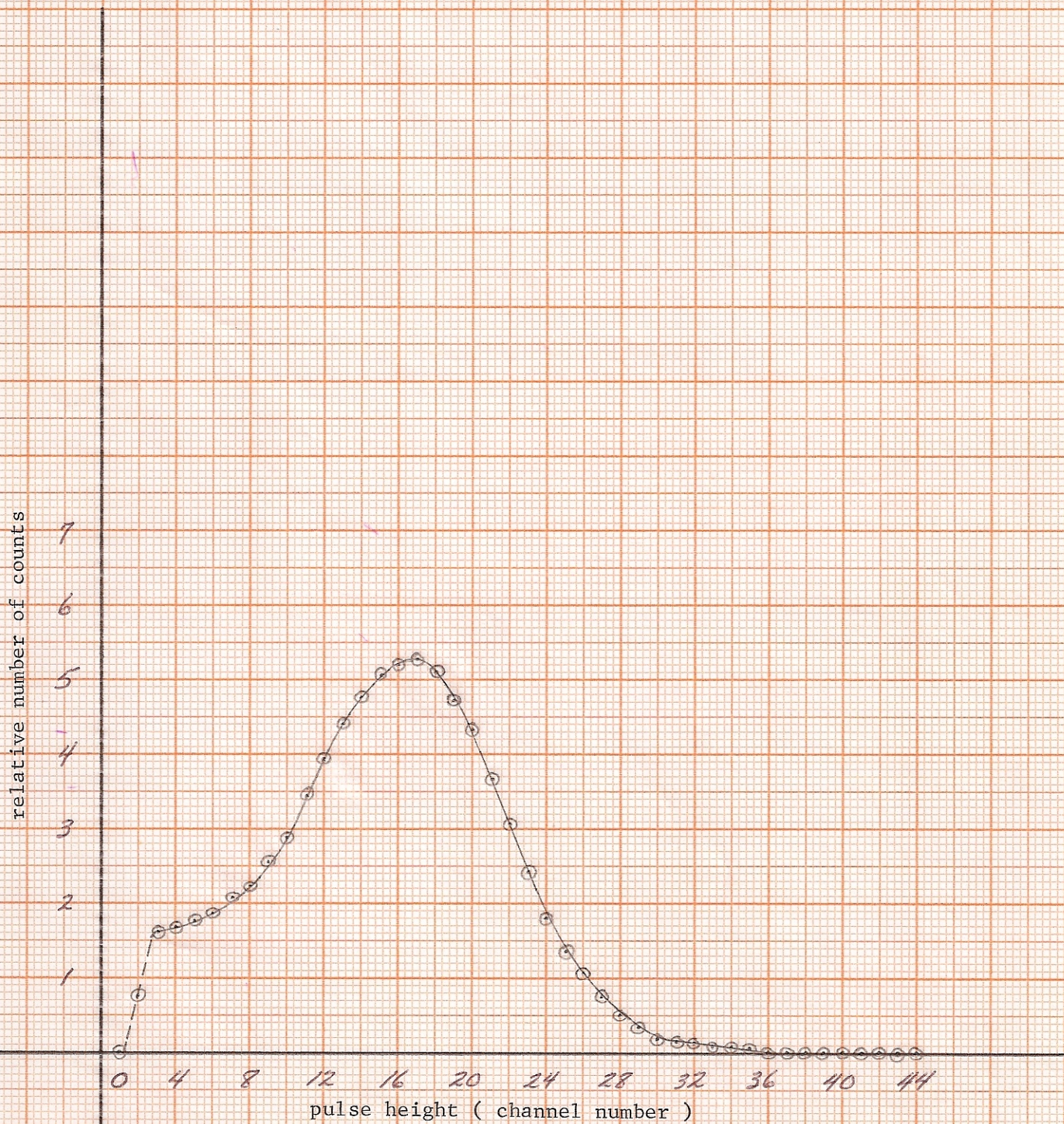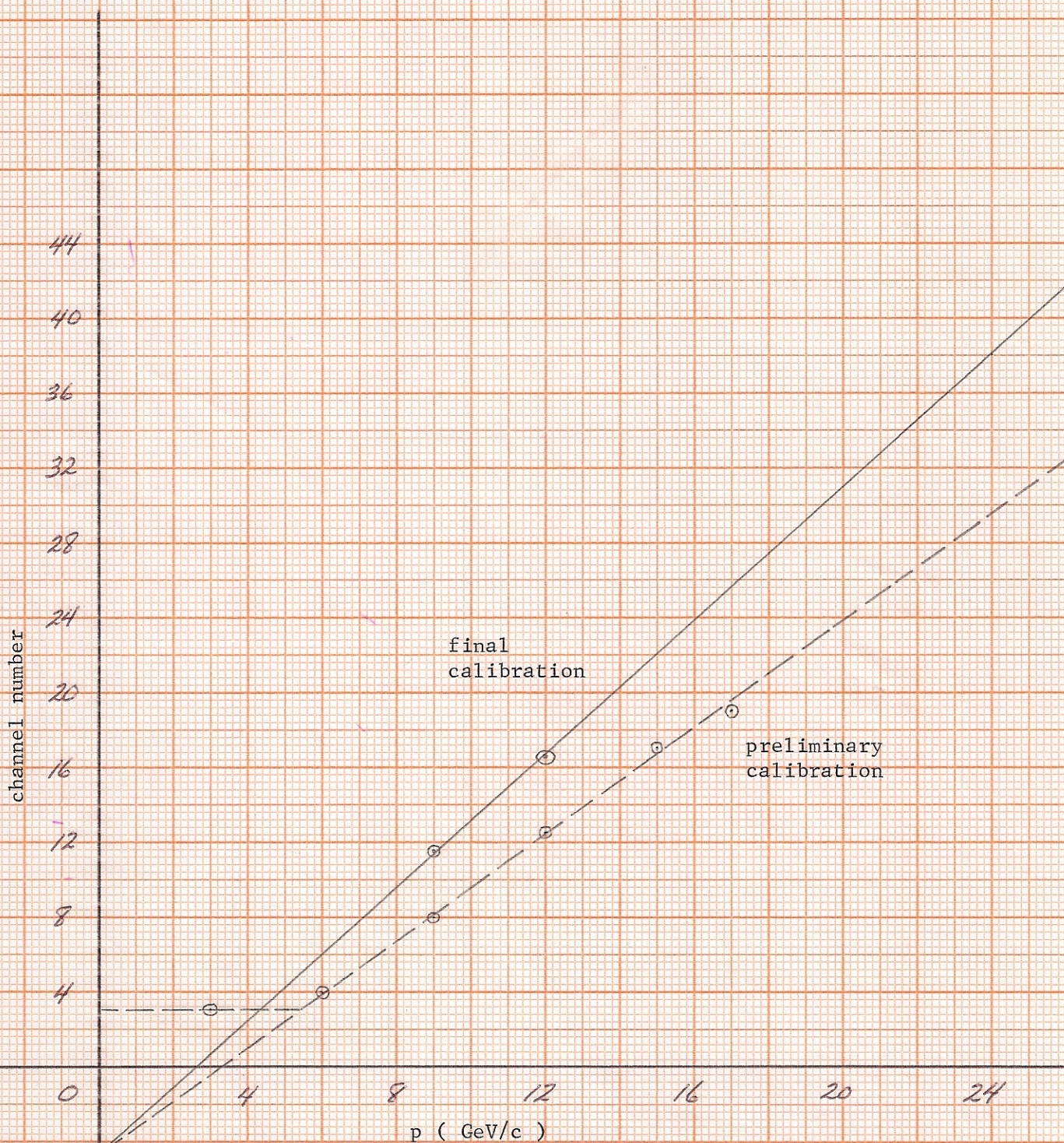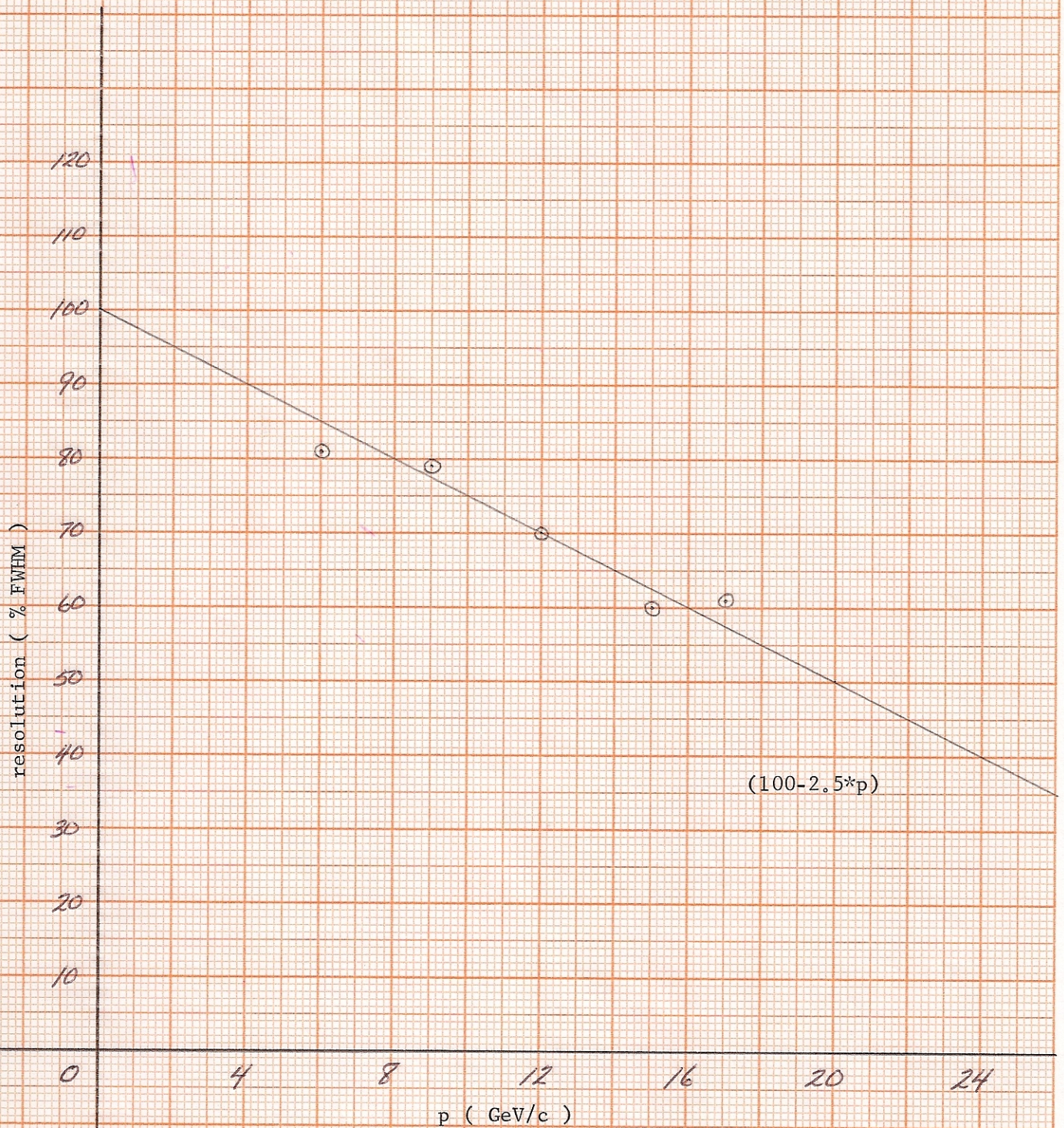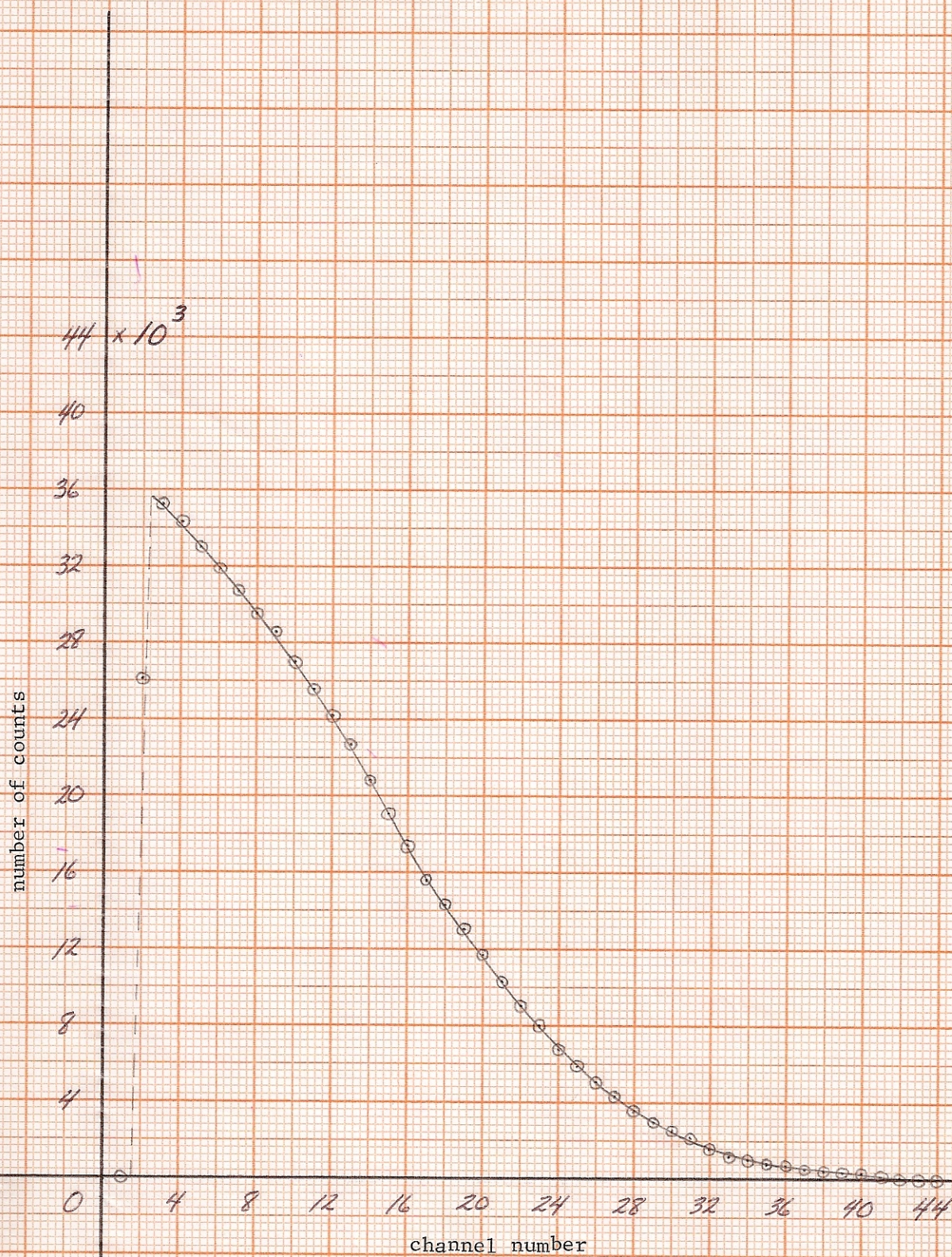
B1 Limited Distribution

Figure 1

relative number of counts

pulse height (channel number)

Calibration of calorimeter for incident protons

Figure 2

Figure 3

Resolution of calorimeter

Raw calorimeter spectrum

Figure 4

Calorimeter neutron spectra

Figure 5

neutrons per GeV/c

measured

unfolded

$\times 10^3$
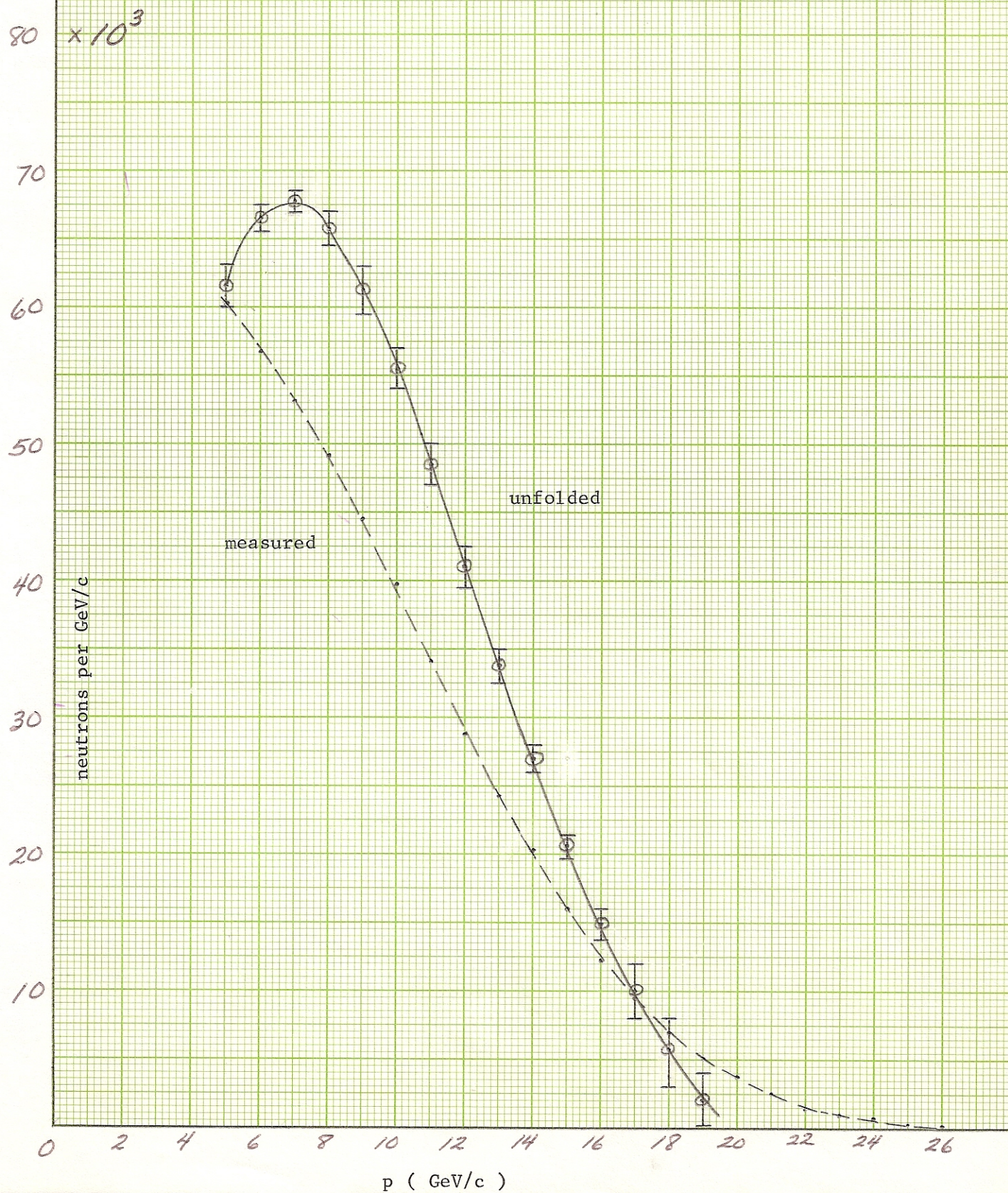
p (GeV/c)

Production spectra at 4.75°

Figure 6

present work
(neutrons)

Baker et al.
(protons)

Particles per GeV/c per steradian per circulating proton

Momentum p (GeV/c)