NAL PROPOSAL No. 311

Spokesman: W.W.Neale
Neutrino Department
Fermi National Accelerator Lab.

PROPOSAL TO STUDY MULTIPARTICLE PRODUCTION IN HIGH ENERGY ANTIPROTON-PROTON INTERACTIONS WITH THE NAL 30-INCH BUBBLE CHAMBER

R.E.Ansorge, J.R.Carter, J.G.Rushbrooke and B.R.Webber
Cavendish Laboratory, Cambridge

W.W.Neale[+], L.Voyvodic, R.J.Walker and J.Whitmore
Fermi National Accelerator Laboratory

and

Z.Ming Ma, W.Morris, B.Y.Oh, D.L.Parker and G.A.Smith
Michigan State University

ABSTRACT

We propose to study multiparticle production in the interactions of 100 GeV/c antiprotons in the 30-inch hydrogen bubble chamber. We request 100,000 pictures with a Cerenkov tagged secondary beam containing roughly equal numbers of $\bar{P}$'s and π^-'s. We also plan to use the downstream wide gap spark chamber hybrid system with a few minor modifications to study neutral particle production in the forward direction.

[+]On leave of absence during 1974 from Cavendish Laboratory.

I INTRODUCTION

Antiproton-proton interactions have been studied extensively at low energies ($\lesssim$7 GeV/c). There are, however, only three $\bar{p}p$ bubble chamber exposures at a momentum higher than 10 GeV/c: 12 GeV/c, 15 GeV/c, and 32 GeV/c. From these three experiments, the main results presently available consist of topological cross sections,[1-3] a study of the 4-prong final state[1] and, most recently, a study of the neutral particle production at 15 GeV/c.[2] It is clear, therefore, that a general survey of $\bar{p}p$ interactions at high energies would be extremely valuable.

Since the beam studies that have been made to date (these studies are summarized later in this proposal) indicate that one can probably achieve ~3$\bar{p}$'s/picture, we request 100,000 pictures of a Cerenkov-tagged negative particle beam. We would propose to take a bubble chamber picture whenever we have 3 or more $\bar{p}$'s/pulse. Furthermore, we plan to use the wide gap optical spark chamber hybrid system (with a few minor modifications) in order to achieve both a better momentum determination for the forward charged particles and an increased detection efficiency for forward-going neutral anti-particles. We propose to trigger the spark chambers on the first $\bar{p}$ interaction/pulse.

Our proposed analysis will include the following topics:

1) $\bar{p}p$ total cross sections; cross sections for each final state charged multiplicity; study of the charged multiplicity distribution in terms of various multiplicity moments.

2) Inclusive strange particle production: K^{o}_{s}, Λ, $\bar{\Lambda}$.

3) Single particle inclusive distributions: p, $\pi^{\pm}$, Δ^{++}, $K^{*\pm}$ (890).

4) Neutral particle production: π^{o}, γ, ($\bar{n}$?).

5) Diffractive studies: $\bar{p}p \rightarrow p+x$.

6) Exclusive channels.

7) Two particle correlations.

While many of the above topics are similar to studies[4] already performed using pp and $\pi^{\pm}p$ interactions in the FERMILAB 30-inch chamber, $\bar{p}p$ interactions also permit the exciting possibility of observing very high energy particle-multiparticle annihilations. If one assumes that the difference between $\sigma_T(\bar{p}p)$ and $\sigma_T(pp)$ is due to the annihilation process one might expect that annihilation contributes ~10% to $\sigma_T(\bar{p}p)$ at 100 GeV/c. The annihilation process could give rise to a much higher multiplicity final state than is observed in pp collisions at similar center of mass energies; e.g., at 30 GeV/c $\sigma_{14}(pp) \sim 10^{-2}$mb while $\sigma_{14}(\bar{p}p) \sim 10^{-1}$mb. Also, the two particle correlations could be substantially different from those observed in pp collisions.

II PHYSICS INTEREST

1) Cross Sections.

Although $\sigma_T(\bar{p}p)$ has been measured in Experiment 104, it would certainly be useful to have an independent determination. We estimate that we could measure the total $\bar{p}p$ cross section with an error $\lesssim$5%. But what is more important, we will be able to determine σ_n, the cross sections for producting n charged particles in $\bar{p}p$ interactions. Figure 1 shows[2] the extent of such measure-

ments at the present time. From the σ_n there are many parameters which may be derived and which describe the multiplicity distribution. Figure 2 shows[5] $\langle n\rangle/D$, where D is the dispersion, $D^2=\langle n^2\rangle-\langle n\rangle^2$. As can be seen for $\bar{p}p$ interactions this variable has quite a different energy dependence from that observed for pp, $\pi^{\pm}p$, $K^{\pm}p$ interactions, and reaches a value ~2 at much lower energies than inother hadronic interactions. A measurement of $\langle n\rangle/D$ for $\bar{p}p$ at 100 GeV/c would be most interesting to see if $\langle n\rangle/D$ rises, remains constant at ~2, or starts to fall above 30 GeV/c.

2) Strange Particle Production

Figure 3 shows a summary [2] of the inclusive K^o_s and Λ cross sections in $\bar{p}p$ compared to pp collisions. The K^o_s cross section appears to be falling at 15 GeV/c $\bar{p}p$ and one might expect that, at 100 GeV/c, $\sigma(\bar{p}p\rightarrow K^o_s)$ has started to rise andis similar to the pp cross section. We will also determine the single particle inclusive distributions for $\bar{p}p\rightarrow K^o_s$, Λ, $\bar{\Lambda}$.

3) Single Particle Distributions

We intend to measure the inclusive rapidity and transverse momentum distributions for $\pi^{\pm}$ and for those protons with P_{lab} <1.4 GeV/c which can be identified by bubble density. These distributions may be compared to those obtained from pp and $\pi^{\pm}p$ interactions. It may also be possible to determine inclusive distributions for Δ^{++} and for $K^{*\pm}(890)$ production. One specific point of interest concerning the $\pi^{\pm}$ production is the possibility of separating the $\pi^{\pm}$ distributions into those arising from non-

annihilation and those due to the annihilation process. By removing events with identified protons, Λ, $\bar{\Lambda}$ and possibly $\bar{p}$'s (by assuming that the highest momentum negative particle is an anti-proton), one might be able to obtain $\pi^{\pm}$ inclusive distributions which are primarily due to the annihilation process.

The single particle distributions from non-annihilation may be compared to those found in 100 GeV/c pp, $\pi^{\pm}p$ for tests of factorization and to those in 15 GeV/c $\bar{p}p$ interactions to study the energy dependence of differential cross sections in both the central region and the target fragmentation regions.

To obtain increased accuracy for these distributions we plan to use the downstream wide gap optical spark chambers, with which we are quite familiary, as well as the symmetry properties available in the $\bar{p}p$ center of mass system.

4) Neutral Particle Production

We intend to study gamma conversions both in the hydrogen bubble chamber itself as well as in a lead plate converter downstream. At the present time Experiment 2B has 2.25 radiation lengths of lead placed between the 3rd and 4th spark chambers and is using this system to study both $\gamma\gamma$ and γ charged particle correlations. For this $\bar{p}p$ experiment we plan to put the lead in between the 1st and 2nd spark chamber so as to increase the solid angle acceptance for detection of gamma rays.

The study of π°-$\pi^{\pm}$ correlations in $\bar{p}p$ interactions at 15 GeV/c has shown[2,6] that the observed distribution indicates a much stronger correlation in $\bar{p}p$ than is found in pp or πp interactions at a similar beam momentum (see Figure 4). It could be that similar

differences will be observed at 100 GeV/c.

We would also like to place an interaction length of steel between the 3rd and 4th spark chambers to investigate the possibility of observing the very forward production of neutral anti-particles; e.g., $\bar{n}$, $\bar{\Lambda}$. If such a detector is feasible we might be able to measure the angular distribution (e.g., log tan θ) for such particles. Such studies are, of course, somewhat speculative and will depend upon background rates.

5) Diffraction Studies

By studying those events with an identified proton, we will be able to study the diffractive excitation of anti-protons: $\bar{p}p \rightarrow p+x$. It will be interesting to compare this process with the reaction $pp \rightarrow p+x$.

6) Exclusive Channels

With the increased accuracy obtainable by using one or two chambers of the downstream spark chamber system, we expect to be able to study $\bar{p}p$ elastic scattering in the forward direction as well as the reaction $\bar{p}p \rightarrow \bar{p}p\pi^+\pi^-$. Additional reliability in determining these four-constraint cross sections will be obtained by using the downstream neutral particle detectors as a veto against any additional neutral particles.

7) Two Particle Correlations

We plan to study two particle rapidity and azimuthal correlations and to compare them with 15 GeV/c $\bar{p}p$ and 100 GeV/c π^-p and pp interactions. Due to the lack of data from high energy $\bar{p}p$ interactions, it is impossible to predict what might be observed.

It will, however, be interesting to see if the Goldhaber effect, so prominent in low energy annihilations, is observable at FERMILAB energies.

III EXPOSURE

Assuming a 40 cm fiducial volume in the 30-inch bubble chamber and only 3$\bar{p}$'s/pulse, we request 100,000 pictures in order to obtain statistics comparable to those achieved in the earlier proton and $\pi^{\pm}$ bubble chamber runs.

IV TECHNICAL DETAILS

It is proposed to use the standard N3 beam line[7] to deliver the antiprotons to the 30-inch bubble chamber. However, instead of selecting negative particles produced directly in the target, which for 300 GeV/c incident protons would yield ~2% of antiprotons at 100 GeV/c[8], it is proposed to select negative particles in the "target halo" and thus obtain a greater proportion of antiprotons. The apparent $\bar{p}/\pi^-$ ratio could be further increased by taking bubble chamber pictures only when there are more than a given number of antiprotons in the chamber.

Particle selection is done in Enclosure 100, the layout of beam line elements being shown in Figure 5. The target between the two dipoles (T2) is used instead of the more usual target (T1). The first dipole (7B00T) is used to vary the angle of incidence of the protons on the target enabling the production angle to be varied between 0 and 7.5 mr. The second dipole (3B00T) is used to deflect charged secondaries so that most of them hit the beam

dump and are absorbed. Particles passing through the hole in the beam dump will be well outside the angular acceptance of the beam line and will be absorbed at various places downstream.

Strange particle decay products will also be deflected if they are produced before the end of 3B00T. Beyond 3B00T the two important decay processes giving rise to 100 GeV/c negatives are

$$K^{o}_{s} \rightarrow \pi^{-} + \pi^{+}$$

$$\bar{\Lambda}^{o} \rightarrow \bar{p} + \pi^{+}$$

The pions are produced at angles up to 2 mr, and the antiprotons at angles up to 1 mr and hence appear to originate closer to the center of the target. Using a vertical vernier bending magnet in Enclosure 101 the beam may be deflected so that different parts of the "halo" pass through the aperture of the vertical collimator in Enclosure 103.

Detailed calculations (see Appendix I) indicate that with 10^{11} protons incident on the target it should be possible to obtain ~10 $\bar{p}$/pulse with a $\bar{p}/\pi^{-}$ ratio of about 30%. However, because the $\bar{\Lambda}^{o}$ spectrum is not well known and because there may be unforeseen sources of background, it is important that tests be done at an early date to check the predictions.

APPENDIX I

ESTIMATE OF PARTICLE FLUXES

Several bubble chamber experiments have yielded measurements of the cross section for $\bar{\Lambda}^\circ$ production in p-p collisions[4]. Above 50 GeV/c the cross section for $\bar{\Lambda}^\circ$ production appears to be about one-half of that for $\bar{p}$ production. It is assumed that to a good approximation the detailed spectra have the same shape.

Since 100 GeV/c $\bar{p}$ are produced by $\bar{\Lambda}^\circ$ with momenta between 107 and 132 GeV/c, the flux of $\bar{p}$ arising from $\bar{\Lambda}^\circ$ decay may be estimated if the $\bar{\Lambda}^\circ$ flux is known. It is known that ~64% of $\bar{\Lambda}^\circ$ decay into $\bar{p}$ and since ~60% decay after the second dipole (3B00T) then it can be estimated that the intensity of the $\bar{p}$ from $\bar{\Lambda}^\circ$ decay will be ~8-10% of the intensity of directly produced $\bar{p}$.

Assuming that the cross sections for K^o_s production are the arithmetic mean of the K^+ and K^- cross sections then at a production angle of 3.6 mr it can be calculated that there would be 12 π^- from K^o_s decay for every $\bar{p}$ from $\bar{\Lambda}^\circ$ decay.

The π^- are spread over a larger area than the $\bar{p}$ at the defining collimators in Enclosure 103. Further, the beam dump removes several π^- that would otherwise get to the collimators. A detailed calculation including these effects indicates that $\gtrsim$10% of the $\bar{p}$ can be selected and a $\bar{p}/\pi^-$ ratio of ~0.3 obtained. Thus, the "halo" $\bar{p}$ beam should have an intensity $\gtrsim$1% of the directly produced beam, so that with 10^{11} incident protons at least 10 $\bar{p}$ should arrive at the bubble chamber.

REFERENCES

[1] I.Borecka et al, Nuovo Cimento 5A, 19 (1971)

[2] F.T.Dao, J.Lach, J.Whitmore, NAL-Pub-73/80, 73/81-EXP (1973)

[3] G.A.Akopdjanov et al, CERN/D.Ph.II/PHYS 74-4 (1974)

[4] For a summary of the results obtained from the "bare" FERMILAB 30-inch bubble chamber experiments, see J.Whitmore, NAL-Pub-73/70 (1973)

[5] F.T.Dao, J.Lach, J.Whitmore, Phys. Letters 45B, 513 (1973)

[6] F.T.Dao and J.Whitmore, Phys. Letters 46B, 252 (1973)

[7] J.Lach and S.Pruss, "Hadron Beams in The Neutrino Area", FERMILAB Internal Report TM-285 (1971)

[8] W.F.Baker et al, NAL-Pub-74/13-EXP (1974)

FIGURE CAPTIONS

Figure 1 $\bar{p}p$ Topological Cross Sections As A Function of The Incident Laboratory Momentum.

Figure 2 Plot of $\langle n \rangle / D$ Versus Laboratory Momentum. Broken Lines Are Drawn Through Data of Same Initial States.

Figure 3. Inclusive Cross Sections For K^{o}_{s} And Λ Production. The Solid Curves Represent Data From pp Collisions.

Figure 4 Average Number of π°'s as a Function of Negative Particle Multiplicity. The α's Are Obtained by Fitting The Data to $\langle \pi^{\circ} \rangle = \alpha n_{-} + \beta$

Figure 5 Schematic Layout of Elements in The N3/5 Beam Line in The Vicinity of The Target.

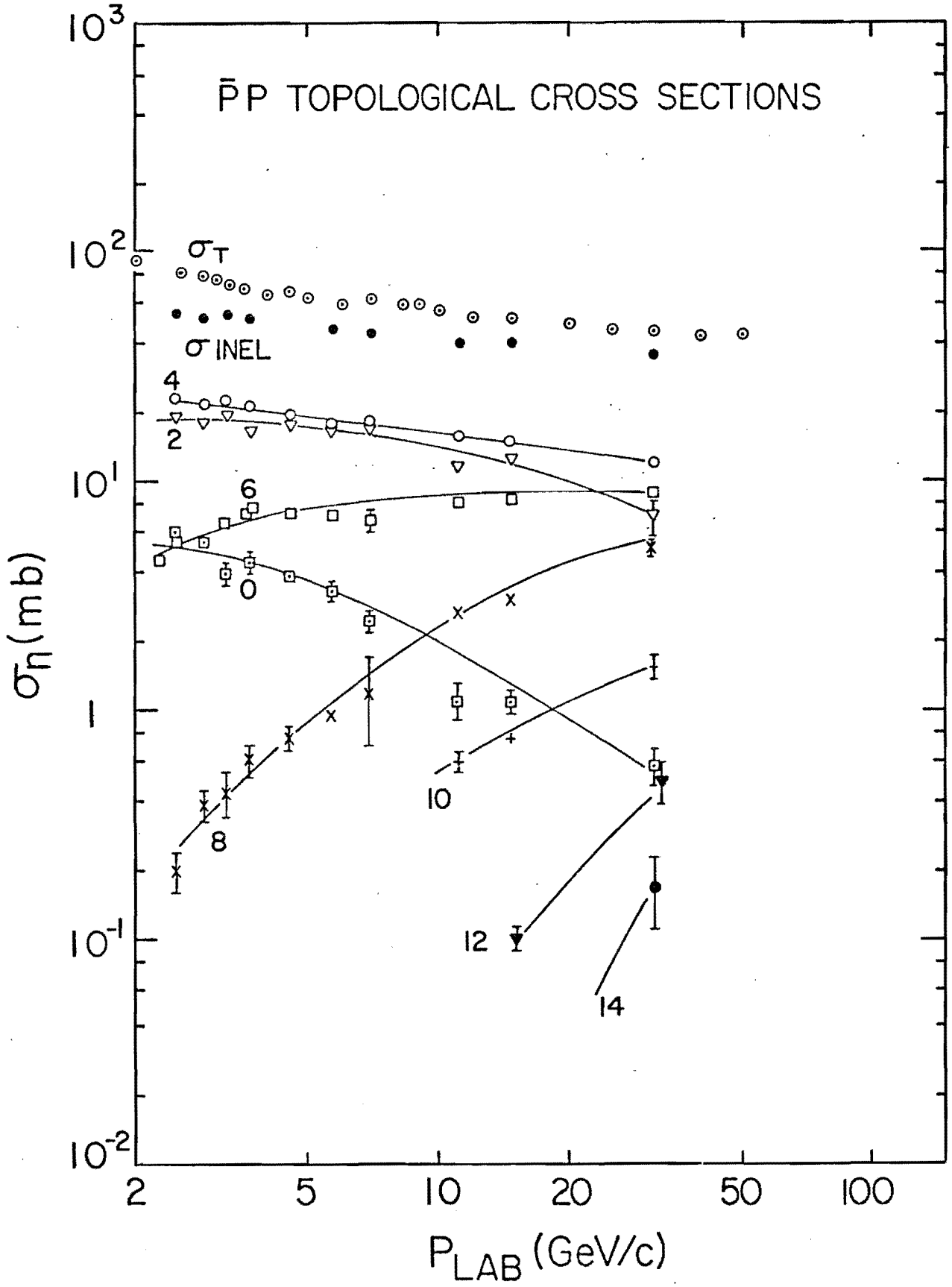
P̄P TOPOLOGICAL CROSS SECTIONS
σT
σ INEL
4
2
6
0
8
10
12
14
σn (mb)
PLAB (GeV/c)
10^3
10^2
10^1
1
10^-1
10^-2
2
5
10
20
50
100

Fig. 1

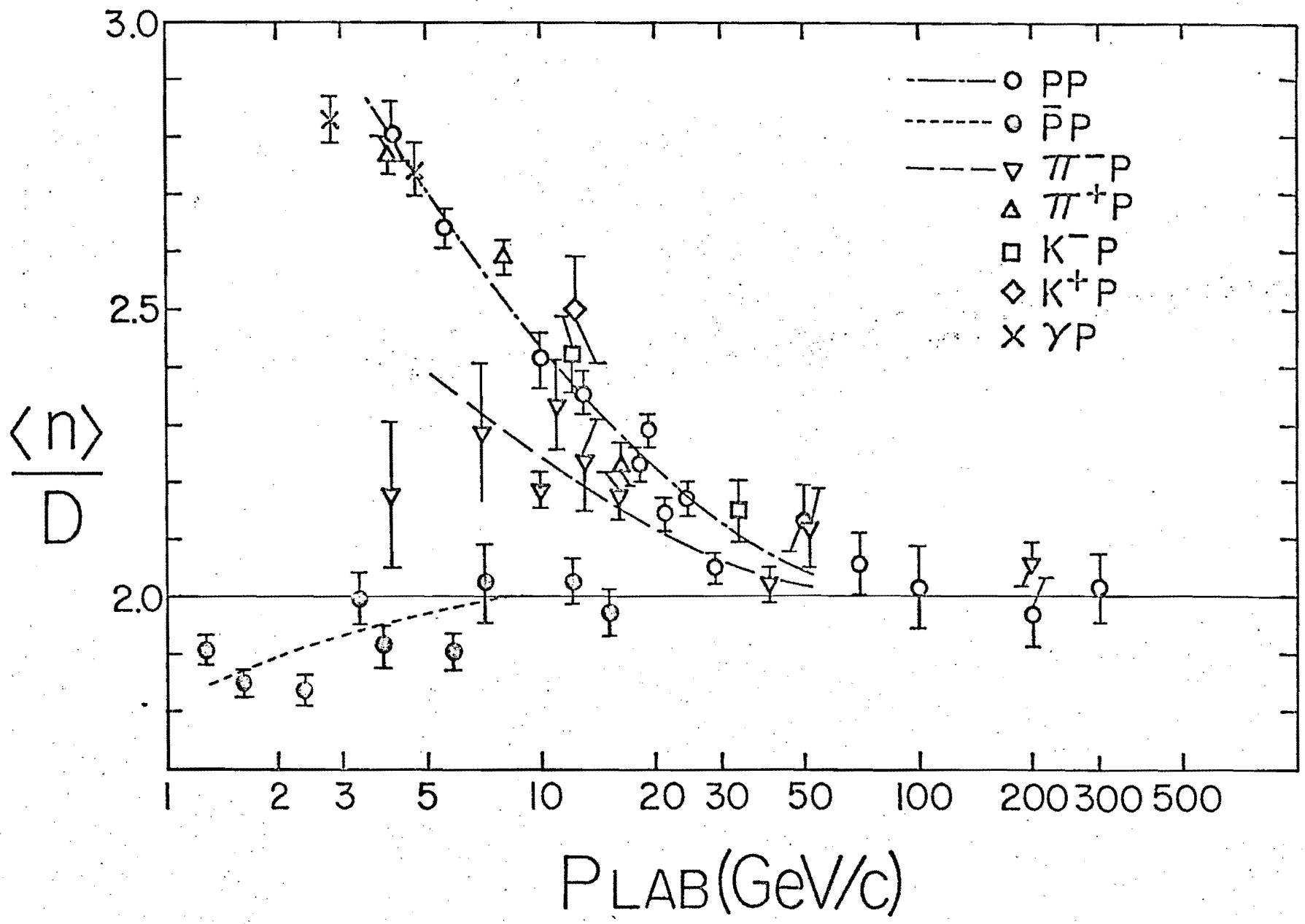
3.0
2.5
2.0
⟨n⟩/D
1
2
3
5
10
20
30
50
100
200
300
500
PLAB(GeV/c)
PP
P̄P
π⁻P
π⁺P
K⁻P
K⁺P
γP

Fig. 2

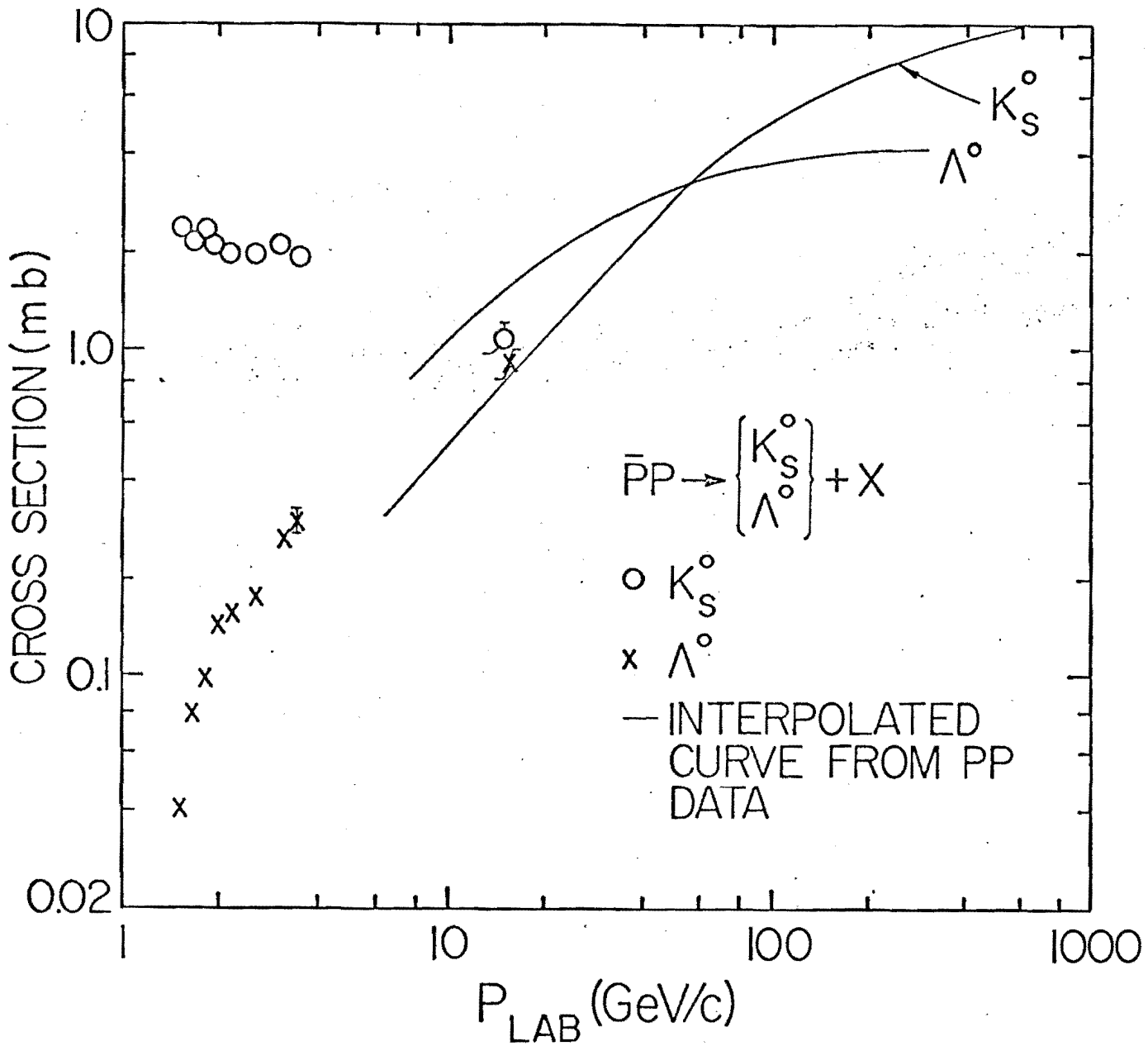
10
1.0
0.1
0.02
CROSS SECTION (mb)
1
10
100
1000
P_{LAB} (GeV/c)
K_S^0
Λ^0
$\bar{P}P \rightarrow \left\{ \begin{matrix} K_S^0 \\ \Lambda^0 \end{matrix} \right\} + X$
o K_S^0
x Λ^0
— INTERPOLATED CURVE FROM PP DATA

Fig. 3

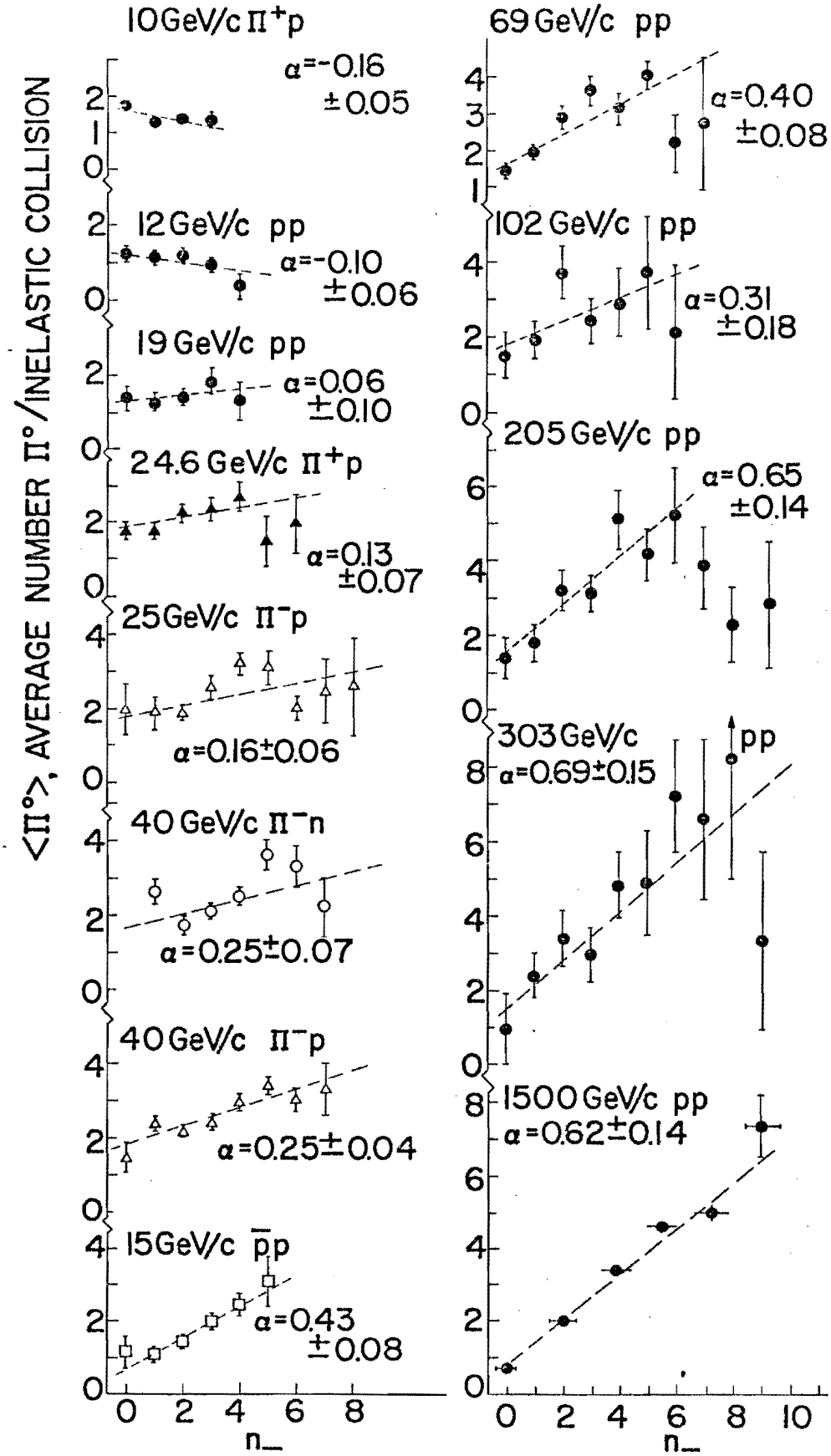
10 GeV/c π⁺p
α=-0.16 ±0.05
12 GeV/c pp
α=-0.10 ±0.06
19 GeV/c pp
α=0.06 ±0.10
24.6 GeV/c π⁺p
α=0.13 ±0.07
25 GeV/c π⁻p
α=0.16±0.06
40 GeV/c π⁻n
α=0.25±0.07
40 GeV/c π⁻p
α=0.25±0.04
15 GeV/c p̄p
α=0.43 ±0.08
69 GeV/c pp
α=0.40 ±0.08
102 GeV/c pp
α=0.31 ±0.18
205 GeV/c pp
α=0.65 ±0.14
303 GeV/c pp
α=0.69±0.15
1500 GeV/c pp
α=0.62±0.14
<⟨π°⟩, AVERAGE NUMBER π°/INELASTIC COLLISION
n₋

Fig. ~~75~~ 4

K+E 10 X 10 TO ½ INCH 46 1320
7 X 10 INCHES MADE IN U.S.A.
KEUFFEL & ESSER CO.

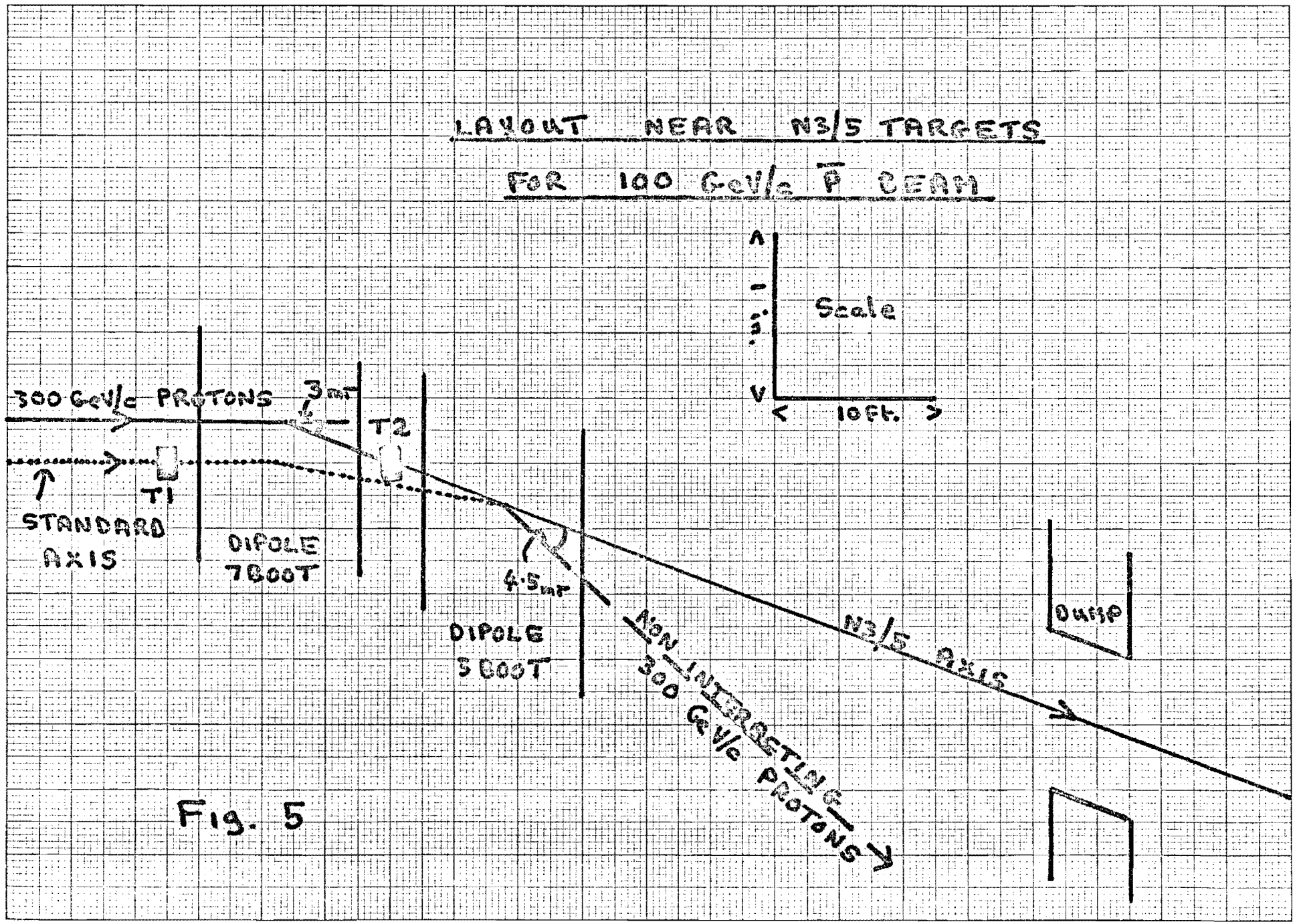

Fig. 5