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Neutral Beam Experiments at the 200 GeV Accelerator

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A significant fraction of the experimental program at all of the major proton accelerators is currently devoted to experiments using neutral beams. The majority of these are designed to study K^{o}-meson decays (inspired of course by the current interest in CP violations) and the remainder to study neutron interactions. There has been almost no experimental use of proton accelerators to produce γ beams.

It is the purpose of this note to emphasize first of all, that neutral beams are likely to play a role of comparable importance in the program of the 200 GeV accelerators. Provisions for such beams should therefore be incorporated in the design of the experimental areas. Secondly, we attempt to envision what kinds of experiments are likely to be most interesting in the first few years after turnon in order to gain some perspective as to the facilities which should be provided.

I. Neutron Scattering Experiments

A. General Discussion

One can safely predict on the basis of experiments done at existing accelerators that the following experiments will be of considerable interest at higher energies and can be performed with little or no extrapolation of present techniques.

1) n-p total cross sections measured directly with a neutron beam
2) n-p forward scattering
3) n-p backward scattering (charge-exchange).

The first two of these have recently been carried out at the AGS[1,2]; the latter is presently in the proposal stage at the AGS[3]. These experiments will be discussed below.

The Beam

All of these experiments require a well-collimated neutral beam taken off at a small angle from the production target. Such a beam poses no significant technical problems at 200 GeV provided a suitable channel is left in the muon shield to bring out the beam. The available neutron flux is entirely adequate for these experiments and beam purity is not a problem (see below).

A possible beam is shown in Fig. 1. The muon shield is $\sim$100 m. long. The solid angle subtended by the defining aperture is $\approx 5 \times 10^{-8}$ sr for a beam diameter of 2.5 cm at the exit from the shield. On the basis of previous experience at the AGS and the Bevatron it is reasonable to assume a neutron spectrum similar to the inelastic proton spectrum with a neutron flux within a factor of two of the proton flux. To predict the neutron yield we therefore use the formula Trilling developed for proton yields[4]. The resulting spectrum for the beam described is shown in Fig. 2 for takeoff angles of 0 and 2.5 mr. At 0 mr the total neutron flux between 25 GeV/c and 200 GeV/c is $\sim 5\times 10^{8}$ neutrons/(10^{12} interacting protons) for this beam. This is more than adequate for almost any conceivable experiment and generally a smaller solid angle would be used. The shape of the neutron spectrum at 2.5 mr is considerably less favorable for most experimetns than it is at 0 mr. A takeoff angle of <2 mr for the neutron beam is highly desirable. The shape of the neutron spectrum is a considerably more important factor in neutron beam experiments than it is for charged beams since one does not have the ability to physically separate out the desired momentum.

The gamma contamination in the beam is easy to reduce to negligible proportions by placing lead filters in the beam. The beam will also contain a small fraction of neutral kaons and antineutrons. The K_2^o/n ratio is likely to be <2% above 100 GeV/c and does not constitute a problem. The $\overline{n}/n$ ratio will of course be much lower still.

B. Neutron Total Cross Section Experiment

An experiment to measure total cross sections of neutrons on protons and heavier nuclei has recently been carried out at the AGS.[1] A direct measurement of the np total cross section with a neutron beam (rather than the more common pd-pp subtraction technique) has important advantages. The biggest is that the uncertainty in the deuteron screening correction (≈2 mb) is eliminated. The apparatus is shown schematically in Fig. 3. The extension of this experiment to 200 GeV is straightforward. In fact the percentage energy resolution of the neutron "calorimeter" will be considerably better at the higher energies. A 0 mr takeoff angle is very important in this experiment to improve the effective energy resolution. A much smaller beam diameter could be used for the 200 GeV experiment since the available neutron flux is several orders of magnitude larger than required. It is considerably easier to measure total cross sections for heavy nuclei with neutrons than with charged beams because problems caused by coulomb scattering do not exist. The small contamination of the beam with K° mesons is not likely to be troublesome as the calorimeter responds primarily to particles whose energies are close to the accelerator energy. The K° contamination at these energies is certainly very small.

C. n-p Diffraction Scattering

An experiment to measure differential cross sections for elastic n-p scattering in and near the diffraction peak has recently been carried out at the AGS.[2] At small t where the differential cross section for elastic scattering is relatively large the extension of this experiment to energies ~200 GeV presents no new problems. A possible experimental arrangement is shown in Fig. 4. The scattered neutron is detected in thick plate spark chambers. This gives the neutron angle with an accuracy ≈0.2 mr. The momentum and angle of the recoil proton are measured in a thin plate spark chamber spectrometer. The momentum of the incident neutron is unknown but its angle is well known because the beam is tightly collimated. This gives a 2-constraint fit to the events which provides very strong discrimination against inelastic events. It is not our purpose to give a detailed analysis of the limiting four-momentum transfers that can be studied with the simple arrangement discussed. It seems likely from past experience that the rejection of inelastics should be adequate for $t \leqslant 2.5\ (\mathrm{GeV}/c)^2$. It should be relatively easy to extend the measurements to $t \approx 4\ (\mathrm{GeV}/c)^2$ by adding a more complete shield of anti counters around the hydrogen target.

D. n-p Charge-Exchange Scattering

The study of n-p charge-exchange scattering in the 200 GeV region is of great importance to present theory.[5] Most of the experiments carried out to date have used a technique employing two successive charge-exchange scatterings.[6] The proton beam first impinges on a beryllium or deuterium target. The neutron beam thus formed is then passed through a second hydrogen target. A spectrometer with good momentum resolution then measures the flux of protons with momentum equal to that of the original proton beam. The proton flux is proportional to the square of the charge-exchange cross section. The extension of this technique to 200 GeV would require a momentum resolution $\sim .03\%$ and seems to be hopeless, particularly in view of the fact that the total charge-exchange cross section is expected to decrease rapidly with increasing energy.

A technique similar to that described for diffraction scattering seems considerably more hopeful. In this case it is necessary to detect the slow recoil neutron coming out of the target near 90° in the lab. The neutron can be detected with good efficiency ($\sim 25\%$) by means of thick scintillation counters. The requirement that the recoil neutron be detected limits the measurements to recoil neutron energies ≥ 2 MeV or four-momentum transfers $|u| \geq .004$ $(\text{BeV/c})^2$. Judging from existing low energy data[6] this is not a serious handicap.

A possible experimental arrangement is shown in Fig. 5. The momentum resolution of the proton spectrometer would be $\approx 0.2\%$. The neutron counters would be constructed with phototubes on either end. By measuring the relative timing of the pulses from either phototube it is possible to determine the neutron's position along the length of the counter to ± 1.3 cm[7]. With the dimensions shown the resolution in the measurement of the neutron angle is $\approx \pm 6$ mr which is comparable to that obtained for the recoil proton in the diffraction scattering experiment (as determined by multiple

Coulomb scattering). With care it is possible to determine the neutron momentum with an accuracy typically of 2 to 5% from its time-of-flight.

At present there is little known regarding the energy dependence of the total charge-exchange cross section. Present experimental data are relatively crude and extend only up to 8 GeV/c, thus making extrapolations to the neighborhood of 200 GeV/c purely guesswork. Again it is not our purpose here to delve deeply into questions involving data-taking rates and maximum four-momentum transfers than can be studied with the technique described. Such an attempt would be premature until experimental results are available at AGS energies to allow a more reasonable extrapolation of the cross section to 200 GeV and a better assessment of the experimental problems. The experiment would rely heavily on a complete anti shield around the hydrogen target to reject inelastic events. In principle it seems possible to provide as complete a shield as necessary to give adequate separation. In that case the maximum four-momentum transfer that can be studied will be limited by rate. The neutron flux available is more than adequate, but the requirement that the first chamber in the spectrometer not have too many accidental tracks restricts the incident neutron flux to $\sim 5\times 10^7$/sec with present techniques. This should be sufficient to allow measurements out to $u \approx 0.4(\mathrm{GeV}/c)^2$ which encompasses the region of major theoretical interest at present.

II. K^o Experiments

The situation regarding K^o experiments at the 200 GeV accelerator is considerably more problematical. First it is difficult to guess what experiments will be interesting after the accelerator is in operation. A second factor is that, unlike the neutron beam experiments, there is generally no theoretical reason for studying K^o decays with high-energy K^o beams. There may of course be significant technical advantages (or disadvantages!) to be gained at the 200 GeV accelerator. We shall therefore limit our remarks here to some general considerations regarding possible advantages.

A. Useful K^o Flux:

If we assume that the K^o/π ratios at 200 GeV are comparable to those at the AGS, the K^o flux will be in the same ratio as the π fluxes. If we assume the CKP formula we can expect about ____ ?? times greater fluxes at 200 GeV/c at 0° for the same solid angle and momentum interval. Typically in K^o experiments the beam diameter must be kept small. Since the neutral beams at the 200 GeV accelerator will generally be two or three ~~larger~~ longer, the solid angle will be $\sim$ 6 times smaller. This factor will be approximately compensated for by the larger momentum bite at 200 GeV. The useful K^o flux will therefore be ($\sim$?) greater at 200 GeV than at 30 GeV for the same diameter beam.

B. Useful Decay Rates:

Because of the greater time dilation factor the decay rate for K° beams from the 200 GeV accelerator will be ≈ 7 times smaller than at AGS energies. Again this effect is somewhat compensated for by the fact that the decay products go more strongly forward for the higher energy beams. This means that for typical experimental geometries the decay region studied will be longer by a comparable factor.

C. Event Rates

The event rate or data-taking rate will depend critically on the detailed experimental arrangement. Generally speaking if there are no spark chambers in (or very close) to the neutral beam the greater K° fluxes at the 200 GeV accelerator could give event rates ~ ____ times higher than those typical at the AGS. The requirement that no spark chambers be in the beam comes about because of the very large neutron fluxes which would most likely swamp the chambers. This requirement poses a severe limitation on experiments possible with such a beam.

D. Other Possible Advantages of the 200 GeV Accelerator for K° Experiments

There is a certain class of experiments, e.g., charge asymmetry in $K^{\circ}_{\mu 3}$ decay, where the higher average energy of the decay products would be a significant advantage. This comes about because the separation of muons from electrons and hadrons is improved when large amounts of absorber can be placed in the beam. (See for example Ref. 8 and 9).

One might also expect that in large angle neutral beams the K^o/neutron ratio will be considerably more favorable than that at the AGS. The question of whether such an advantage will be realized must await the outcome of beam surveys at the 200 GeV accelerator.

III. Other Neutral Beam Experiments

A. Experiments with γ's

Experiments with γ beams in the 200 GeV region have been discussed by Clegg, Murphy, and Tumer[10]. As is well known γ fluxes at proton accelerators are orders of magnitude less than those available from electron accelerators. The neutron fluxes in the γ beams will pose a formidable problem. It is the author's opinion that it will be a long time before γ experiments at the 200 GeV accelerator can compete usefully with those at SLAC.

B. Antineutron Experiments:

The antineutron/neutron ratio in the neutral beams at the 200 GeV accelerator will be considerably more favorable than at the AGS. Unfortunately the difficulty of distinguishing antineutrons reliably from neutrons at very high energies seems insurmountable.

IV. Discussion of Possible Neutral Beam Facility at NAL

As discussed above, there are several very interesting and feasible neutron scattering experiments that will certainly be proposed soon after the 200 GeV accelerator turns on. If provisions for it are made in the design of the muon shield it is almost trivial to provide a "zero degree" neutral beam facility. On the other hand if it is not incorporated into the early designs it most likely will be impractical until a major revision of the muon shield is made.

Basically all that is needed for the neutral beam facility (NBF) is a clear line-of-sight through the shielding to the target in the external beam. The most obvious choice for the location of the NBF is in "target station B."[11] The neutral beam would have to thread its way past the small-angle charged beams in that area. This is not a serious problem since the diameter of the neutral channel in the region where the transport magnets for the various charged beams are densely packed[11] is only several millimeters. A sweeping magnet ~ 10 meters long should be located in the neutral beam as far upstream as possible to remove charged particles (and for safety reasons). The gap spacing and pole pieces of the magnet need only be ≈2 cm.

The NBF would also serve as a simple but extremely useful parasite beam. With the sweeping magnets off high-energy proton beams of respectable intensities (See for example Fig. 2) will be available. High energy parasite beams will probably be difficult to provide in any other way, and this application alone seems sufficient to justify the facility. Total proton + neutron fluxes $\geq 10^9$/pulse will be available with most of the flux above 140 GeV. It should be possible to use these to generate very useful tertiary pion and kaon beams.

Where practical, provisions for larger angle neutral beams should be included in the initial plans for use in K° experiments. These would provide K° beams considerably better than those available at the AGS. Studies of proton and $K^{\pm}$ yields at various production angles should be made as soon as possible after turnon to provide information regarding the optimum takeoff angle for K° beams and the K°/neutron ratios that can be expected.

References and Footnotes

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9. Dorfan et al., Phys. Rev. Letters 19, 987 (1967).

10. A. B. Clegg, P. G. Murphy, and T. Tumer, ECFA Utilization Studies for a 300 GeV Proton Synchrotron, CERN/ECFA 67/16, Vol. I, p. 245.

11. National Accelerator Laboratory Design Report, January 1968, p. 14-1 ff.

Figure Captions

Figure 1. A possible location for a 0 mrad neutral beam at target station B.

Figure 2. Predicted neutron spectrum for production angles of 0 and 2.5 mrad.

Figure 3. Apparatus for total cross section measurement.

Figure 4. Apparatus for small-angle np scattering experiment.

Figure 5. Apparatus for np charge-exchange scattering experiment.

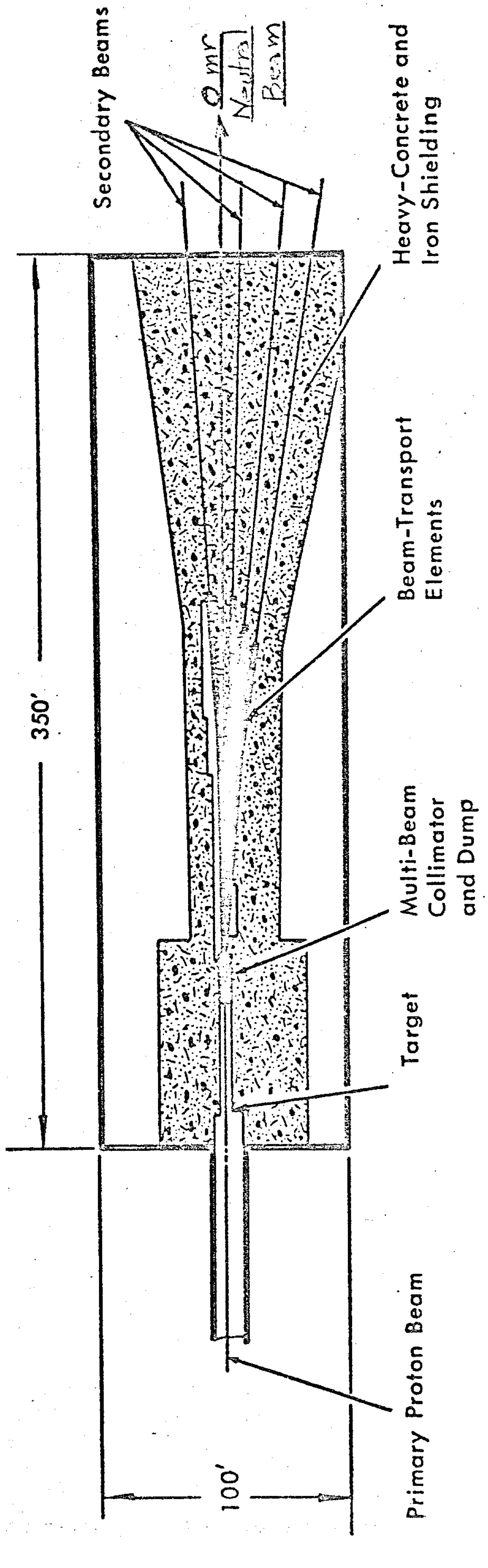

Secondary Beams
0 mr
Neutral
Beam
Heavy-Concrete and
Iron Shielding
Beam-Transport
Elements
350'
Multi-Beam
Collimator
and Dump
Target
Primary Proton Beam
100'

Figure 1

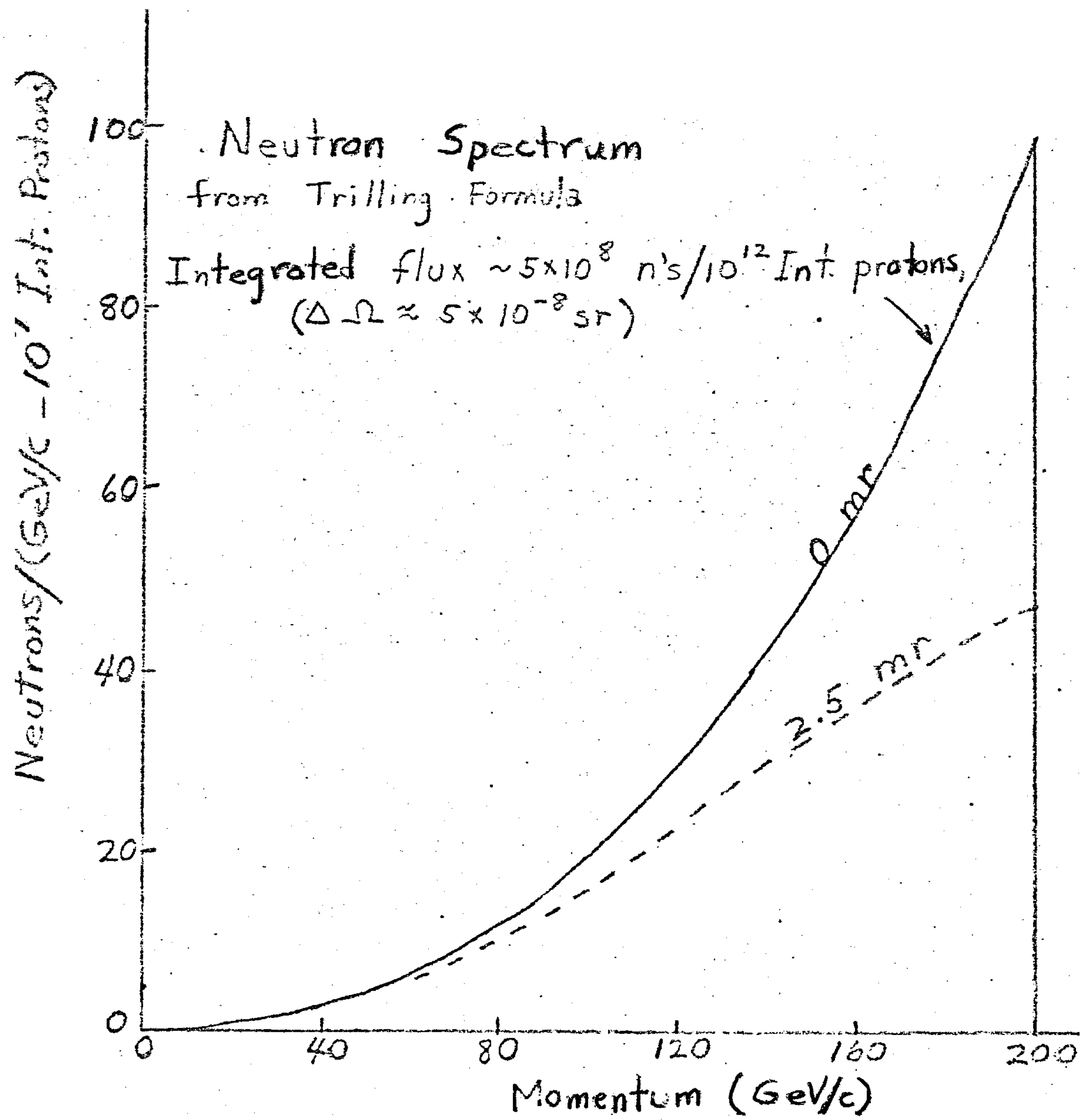
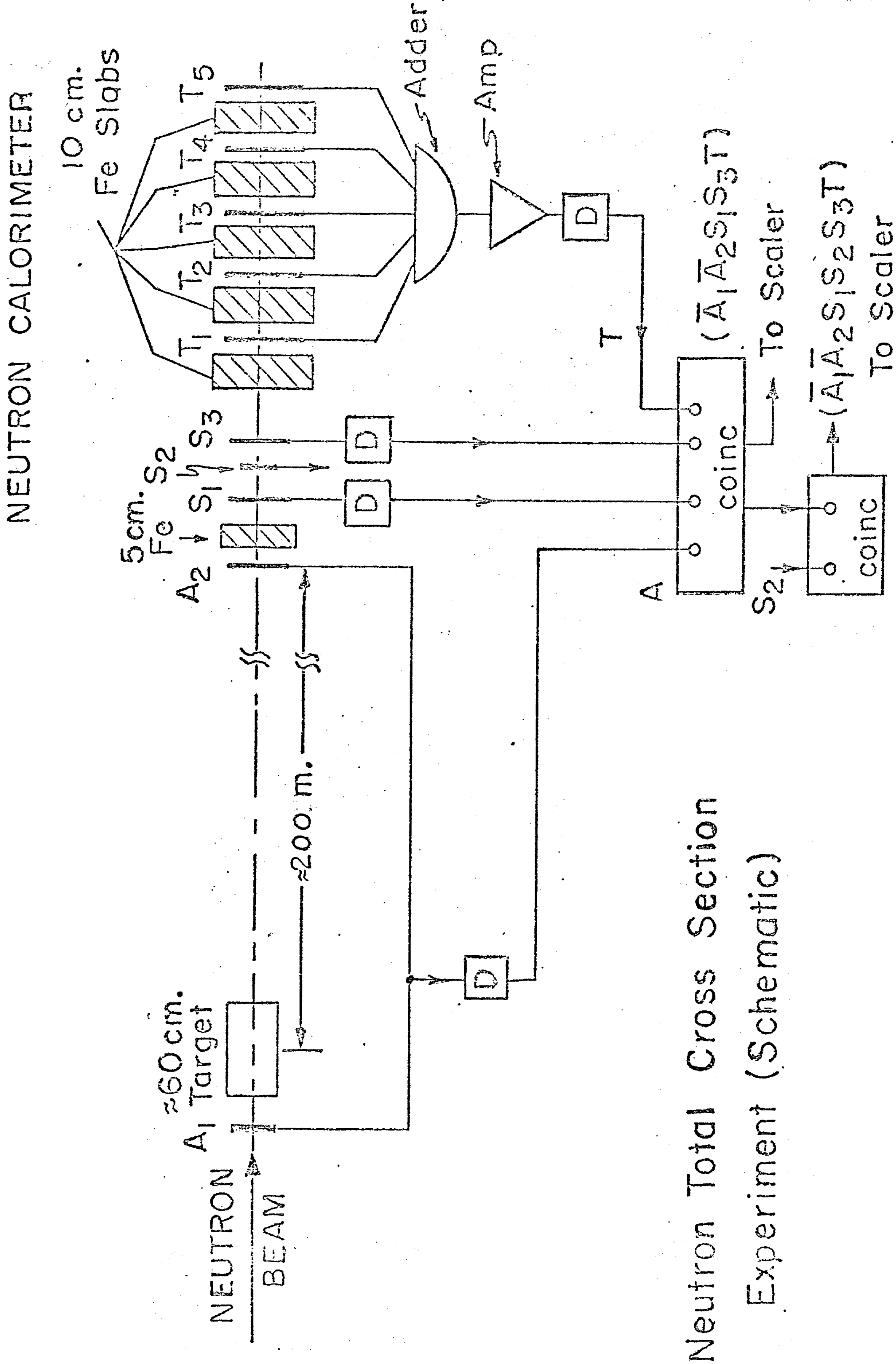
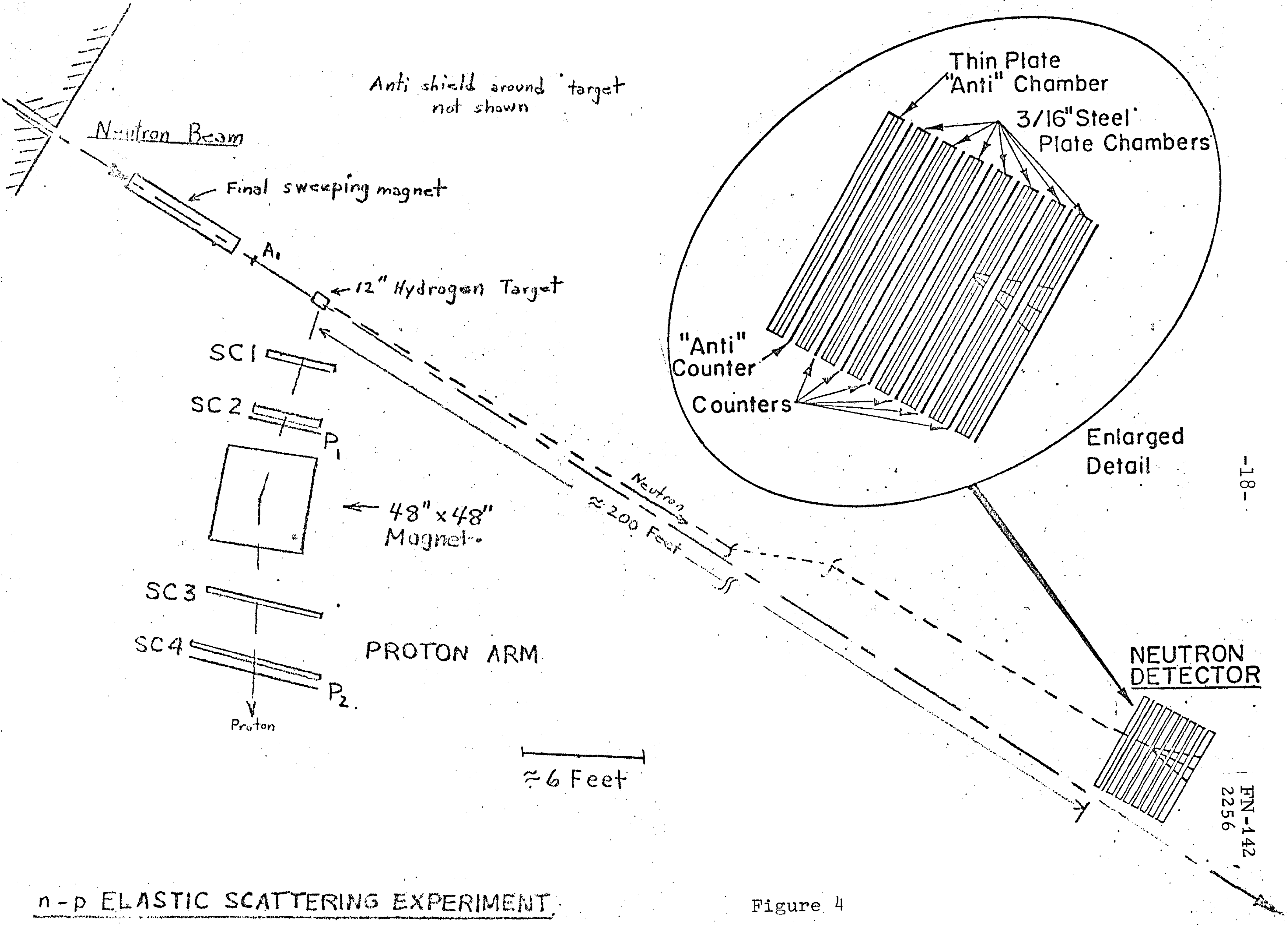

Neutron Spectrum
from Trilling Formula
Integrated flux ~5×10^8 n's/10^12 Int. protons,
(ΔΩ ≈ 5×10^-8 sr)
0 mr
2.5 mr
Neutrons/(GeV/c - 10^7 Int. Protons)
Momentum (GeV/c)
0
20
40
60
80
100
0
40
80
120
160
200

Figure 2



Neutron Total Cross Section Experiment (Schematic)

Figure 3



n-p ELASTIC SCATTERING EXPERIMENT

Figure 4

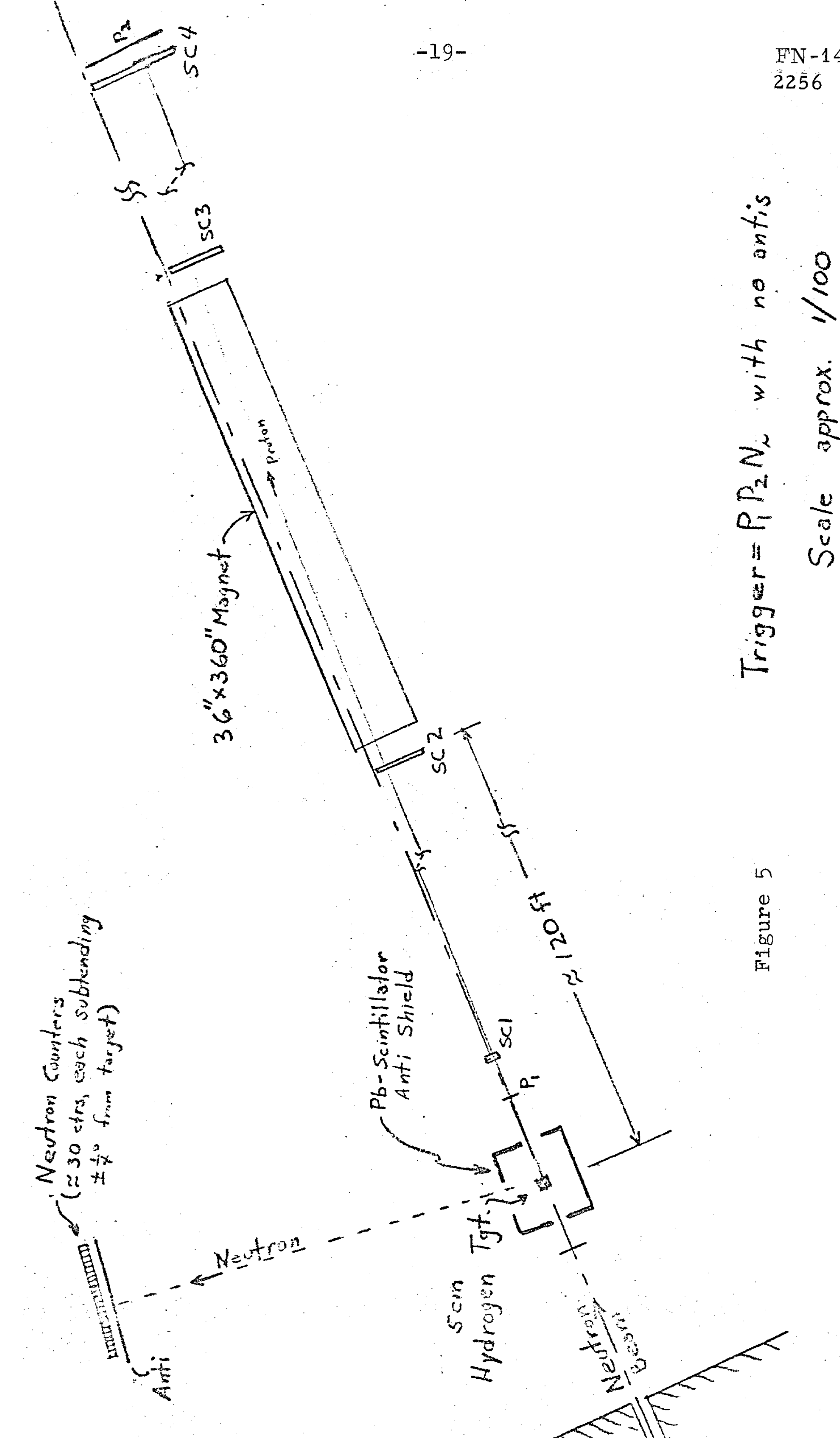

P2
SC4
SC3
36"x360" Magnet
Proton
SC2
≈ 120 ft
SC1
P1
Pb-Scintillator
Anti Shield
Neutron Counters
(≈ 30 ctrs, each subtending
±½° from target)
Neutron
Tgt.
Scin
Hydrogen
Anti
Neutron
Beam
Trigger = P1 P2 NN with no anti's
Scale approx. 1/100

Figure 5