AREA 1 AS A TWO-LINE AREA

A. Maschke
National Accelerator Laboratory

R. Mischke
Princeton University

R. Morrison
University of California, Santa Barbara

F. Sciulli and A. Tollestrup
California Institute of Technology

and

J. Tenenbaum
Stanford Linear Accelerator Center

ABSTRACT

We present a possible two beam-line system for area 1 and discuss various experiments that can be done with such a system.

I. INTRODUCTION

Area 1 has certain characteristics that will make it unique when the machine turns on. These characteristics are (1) long decay distances, (2) 500-GeV protons, (3) shielding and facilities for bubble-chamber operation. We should like to discuss one possible design for the area which fully exploits these properties.

In the area design, we will aim at specific physics needs that we feel require urgent investigation in the first year of operation. We hope to show that the proposed design does, however, leave open many options for other future uses.

II. PHYSICS GOALS

In the bubble-chamber operation, the investigation of neutrino interactions in hydrogen in the energy range $10 < E_{\nu} < 100$ GeV is of prime importance. The use of H_2 as a target and the ability to investigate the details of the hadron structure promise that this tool will be of some importance in the early operation of the machine.

Of comparable interest is the question of hadron interactions up to the highest energies of the accelerator. Bubble-chamber pictures with 500-GeV protons incident provide data that could discover processes that might be visible in no other way.

For the counter and spark-chamber experiments, there are exciting and urgent questions that can be addressed early only in area 1. These include ν physics at energies above 100 GeV, muon physics in the range $100 < E_{\mu} < 300$ GeV, and p, π interactions near full machine energy.

Neutrino physics above 100 GeV promises to be extremely exciting. The intermediate boson, presently known to be more massive than 2 GeV/c^2, may be searched for up to ~15 GeV/c^2 mass. The total neutrino cross section on nucleons has been measured up to $E_{\nu} \approx 10$ GeV and rises linearly. Will it continue to rise linearly up to energies of 300 GeV, or has nature some surprises for us when we extend the energy range by a factor of 30? Deep inelastic scattering of neutrinos permits tests involving hadron structure. Scale invariance, presently tested up to about $Q^2 \approx 7$ GeV^2 can be tested up to $Q^2 \approx 300$ GeV.

The advantages of investigating these questions with neutrinos of known energy has long been recognized. The small systematic errors and small backgrounds inherent in a monochromatic neutrino beam make this a promising tool for the investigation of high-energy neutrino processes.

The study of deep inelastic electron scattering at SLAC has produced startling results. The scaling laws for the structure functions can be pursued with 300-GeV muons at NAL to values of ν 10-30 times larger than presently possible. The very important question of μ-e universality may also be investigated. To pursue these questions the experiments require muon beams of high quality and high intensity.

The use of protons at the highest possible machine energy is perhaps the most exciting tool that must be available in the early operation of the machine. Quark, heavy lepton, W searches with protons at high intensity and high energy may completely change the nature of high-energy physics.

III. AREA DESIGN

It is possible to provide both wide-band and narrow-band ν beams with a single target box by building appropriate train loads and running the experiments serially. We suggest that it is desirable to build two target boxes, side by side while still keeping the counter area adjacent to the bubble chamber. Then protons can easily be directed into either target box. This would allow the counter area to operate somewhat independently of the bubble chamber (e.g., before the bubble chamber is ready, while it is down for maintenance, and if intensity permits, simultaneously with the bubble chamber).

The design presented here keeps the bubble chamber-wide band ν line as previously conceived and moves the narrow-band ν beam to the new target box. A good μ beam is a natural part of a long π, K beam which produces monochromatic ν's. A diffracted proton beam can be easily added to the design. Since it has a very small emittance with very little transport equipment, an important beam is available to be used simultaneously with ν's and μ's.

Figure 1 shows a sketch of the experimental area. The precise linear dimensions of the drift space and shield for the bubble-chamber line require detailed study of such questions as shielding, availability of iron, optimization of bubble chamber running for low- or high-energy neutrinos, etc. For definiteness, we adopt a distance of two kilometers between the target box and bubble chamber. This distance scales the area. In adding another target box and a counter area, we place them beside the bubble-chamber line so that certain facilities can be shared.

A separate counter line to provide muon beams and special neutrino beams has been proposed previously. We should like to expand on this to demonstrate additional beam arrangements available from simple elements (quads, dipoles) placed in the target boxes. Our particular design provides a momentum-analyzed π and K beam as well as a low-emittance proton beam. The π, K beam decays down the long drift space. This results in a monochromatic neutrino beam in the forward direction as well as a clean muon beam extracted at the end of the drift space. An alternative is to transport the π's directly to the experimental area.

Figure 2 shows a drawing of a target box that will permit extraction of these beams. The proton beam hits the target at A. The protons continue through the quads and dipoles (B) where they are bent through 5 mrad and encounter a beam dump at C A small hole in this dump allows a small-emittance proton beam of 10^{-3} of the incident proton beam. The dipoles at E bend the protons through another - 5 mrad so that they emerge at 10 mrad with respect to the incident proton beam. Note that the dipoles at (B) and (E) are under the control of the 10^{-3} proton beam. The emittance of this proton beam is determined by the apertures at A and C and their separation. To obtain the desired reduction from a beam 1 mm in diameter at A, the collimator aperture at C, located about 160 feet downstream, should be about 0.5 mm in diameter. For safety reasons, the aperture at A must restrict the beam size to about 1 mm. The small emittance of this beam allows this beam to be transported a large distance at very low cost in beam-transport elements. The entire beam can be contained within an 8-in. quad located 750 meters from the target box

The septum magnet at F permits a π and K beam $100 < p < 350$ GeV to be sent through the final dipoles (G). The dipoles and septum give momentum recombination for a beam with $\Delta p/p$ up to 10%. The quads at H focus point to parallel for this momentum and accept 4 μsr solid angle. The chromatic aberrations in this system are such that the angular dispersions are about 0.1 mrad and 0.04 mrad in the two directions.

The π, K beam travels down the small-diameter vacuum pipe to a hadron absorber at the end of the decay region. The forward ν's from K decay form a monochromatic beam in the small solid-angle detector in the experimental area. Figure 3 shows the K^+ and monochromatic ν as a function of energy in the beam.

The muons from π decay form a high-quality muon beam at the end of the decay channel. Figure 4 shows the estimated total number of π's in the hadron beam assuming 400-GeV protons incident on the target, pions with $\Delta p/p = 0.10$ and $\Delta\Omega = 4$ sr for 10^{13} protons interacting in the target. Also shown is the total number of μ's from π's decaying over 1000 meters, and the total number of μ's entering an 8-in. quad located 400 meters from the end of the decay region. For $p_\mu \leq 250$ GeV/c, these forward μ's are contained within a $\Delta p/p \lesssim 0.10$. Two important features of a muon beam extracted from a momentum-analyzed π beam are (1) high ratio of useful muons/total muons, and (2) the useful muons are the highest energy muons in the beam. These are important considerations that will make for reduced halo in the μ beam.

The high-intensity π beam itself has a size at the downstream end of the decay tunnel of 9 cm $\times$ 4 cm and could be extracted down the μ channel to the experimental area.

One feature of the proton beam is the ability to get high-energy protons to the bubble chamber. Figure 5 shows the 10^{10} proton beam with a thin-target station located 1 km from the target box at an intermediate focus. A diffracted beam from this target will give 10^4 particles/pulse into the bubble chamber. Hence, during the 1 msec sensitive time of the bubble chamber, 10 protons will pass through the chamber.

IV. OTHER OPTIONS

A number of modifications to the target box have been suggested which permit other beams to be provided to the experimental areas, either through beam pipes already mentioned, or through additional beam pipes.

A. Neutron Beam

The design given above would have the π, K beam going parallel to the incident proton beam. With a slight modification it would be possible to extract a $0°$ neutron beam which would not interact with the π, K beam. By moving one of the target-box quads between the dipoles, the π, K beam could go at ~4 mrad with respect to the incident proton beam.

The neutral beam is very attractive for several reasons. It will provide the capability of going to the full energy of the machine at the earliest possible time. Even at 200 GeV this beam would be superior to the small-angle neutral beam in area 2 since it is expected that the neutron flux near the energy of the protons falls off rapidly as the production angle moves away from 0°.

One other comment is on the question of safety. If the neutral hole is 0.01 μsr, the expected neutral flux will be more than adequate. Since this solid angle is the same as that for the diffracted proton beam, even if the dipoles following the target were to trip off, only 10^{10} protons/pulse could come down the neutral beam line. A further precaution could be added by placing a section of permanent magnets in the neutral line.

B. Electron Beam

An electron beam of high intensity can also be obtained in the proposed system. The beam transport for the high-intensity π, K beam is used so that little extra equipment is used. A sweeping magnet is placed between the proton target (of low Z) and the first quadrupole. All charged particles are dumped in the iron collimator so that only neutral particles emerge through the slit. The photons in this 0-mrad neutral beam are converted to electrons in front of the first quadrupole and transported to the experimental area via the high-intensity π, K beam transport used for producing the monoenergetic neutrons. At the end of the drift space the electrons go down the muon channel. Hopefully this beam would have at least one intermediate focus for clean-up. Descriptions of this method for producing electron beams have been given in preceding summer studies. Figure 4 shows the estimated electron yields for $\Delta p/p = \pm 0.02$ and $\Delta\Omega = 4$ μsr.

V. SHIELDING

The shielding in the counter area can be completely dirt. The approximate cost of filling the counter lines to a height of 10 m along the entire 2 km is about $250 K. The π, K beam can be run up to about 400 GeV with a full earth shield.

VI. CONCLUSIONS

We conclude that the addition of another line in area 1 will provide some distinct advantages in the early operation of the accelerator up to 500 GeV. Some advantages are:

1. More important experiments can be accommodated. In particular, counter experiments up to full acceleration energy can be run.

2. Ability to share beams with the bubble chamber. For example, the 500-GeV proton beam comes quite naturally from the counter line.

3. Capability of servicing one line while the other line runs. For example, counter physics can be run while the bubble chamber, the horn, or other items in the bubble-chamber line are being repaired. Similarly, counter experiments can be

changed, or beam lines serviced while neutrino bubble-chamber experiments are run. For servicing of the target boxes themselves, this depends on the development of remote-handling equipment.

4. Ability to run bubble-chamber and counter lines during the same beam pulse. This is of prime importance in the setup stage of experiments where very few protons on the target, under real experimental conditions, are invaluable. Conversely, it provides alternative 500-GeV operation. If the machine accelerates more protons at 500 GeV than the bubble chamber can use, counter experiments could be available to receive them.

5. It provides a somewhat different approach to extracting charged beams than exists in area 2. Area 2 is in many ways experimental. The novel target-box design allows a large amount of simultaneous use which may or may not be successful. For example, the large number of bends in the beams may spray muons into other experiments which limits this simultaneous use. A different approach, which transports beams over large distances (full-range shield) with a minimum of bends might be of some use in the design of later areas.

One might argue that these features are fine but that they more logically belong in an entirely new experimental area (e.g. area 3). The proximity of the beam lines is of some importance in the present proposal. Certainly, the ability to send hadrons to the bubble chamber would be very difficult from a beam line very far away. But, in addition, it should be observed that one has indeed gained essentially all of the advantages that another experimental area would provide, but at appreciably less cost. For example, the cost of transporting the external proton beam through considerable bend is saved. The capability of sharing services in the two lines, most especially the hot-handling services of the target boxes, will provide additional saving.

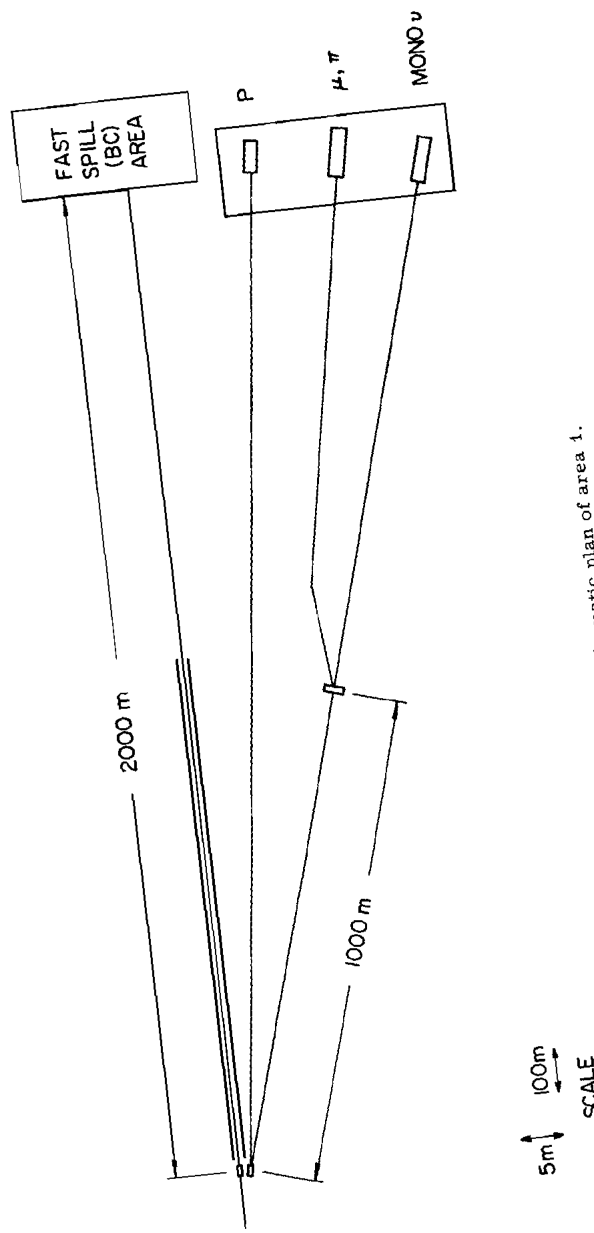

Fig. 1. Schematic plan of area 1.

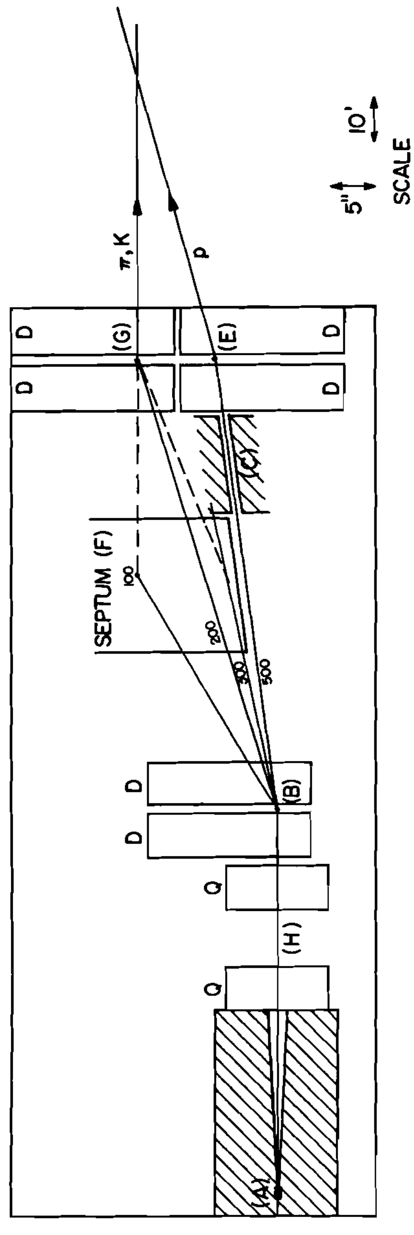

Fig. 2. Target-box concept.

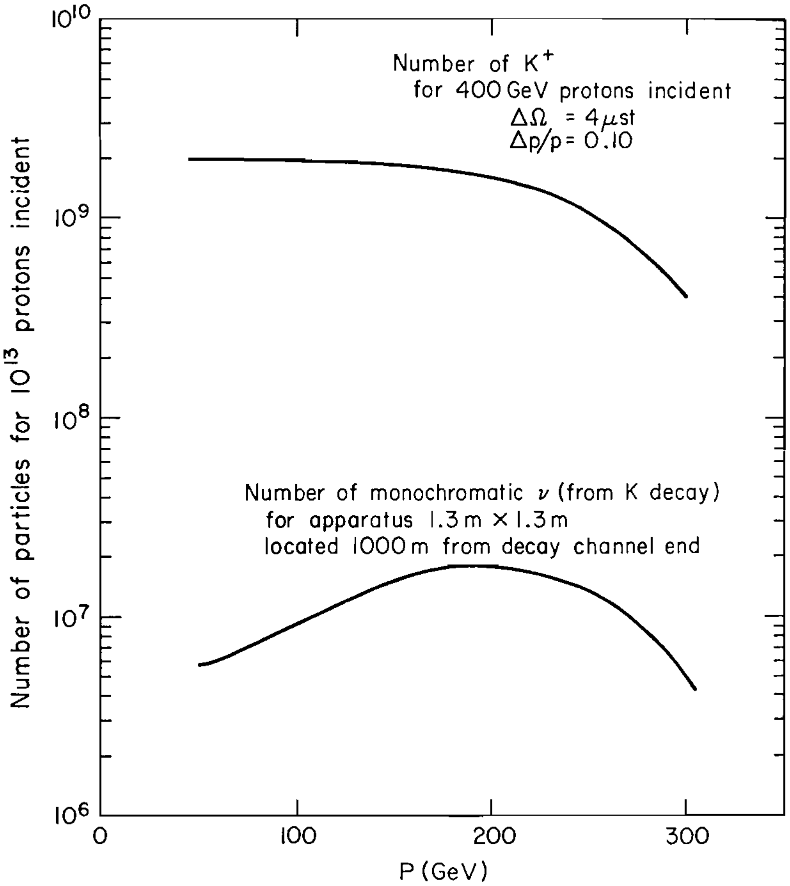

Fig. 3. Kaon and neutrino production as functions of energy.

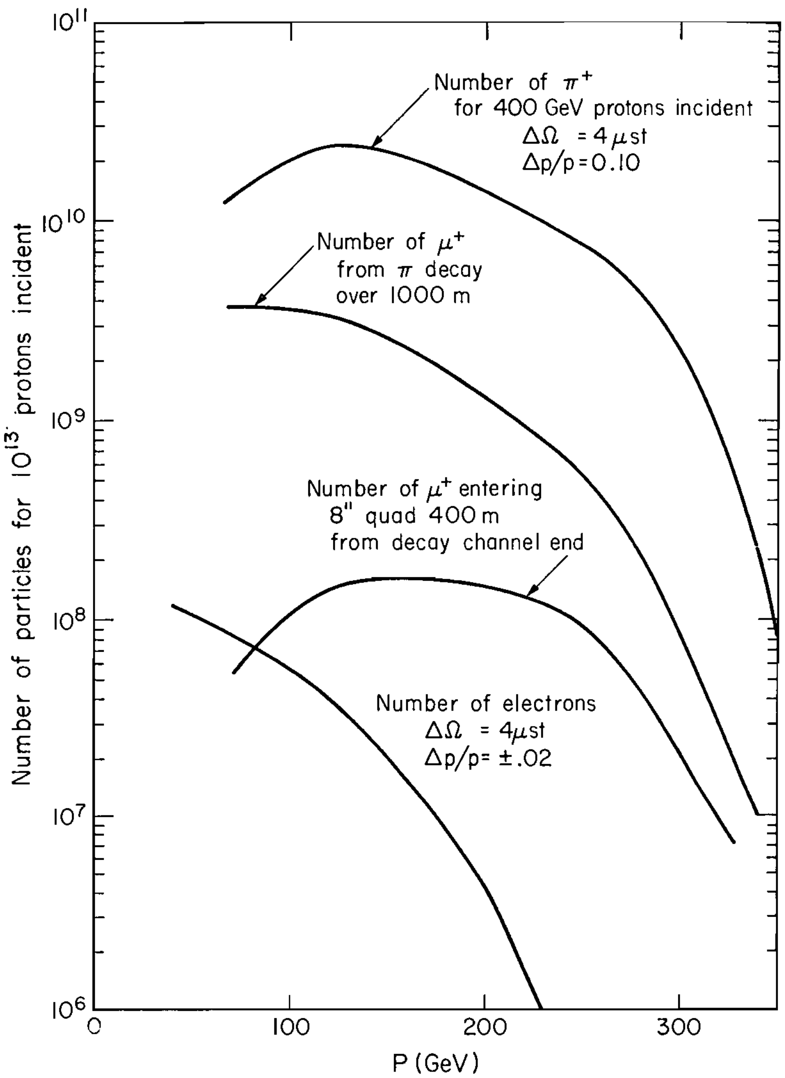

Fig. 4. Pion and muon production as functions of energy.

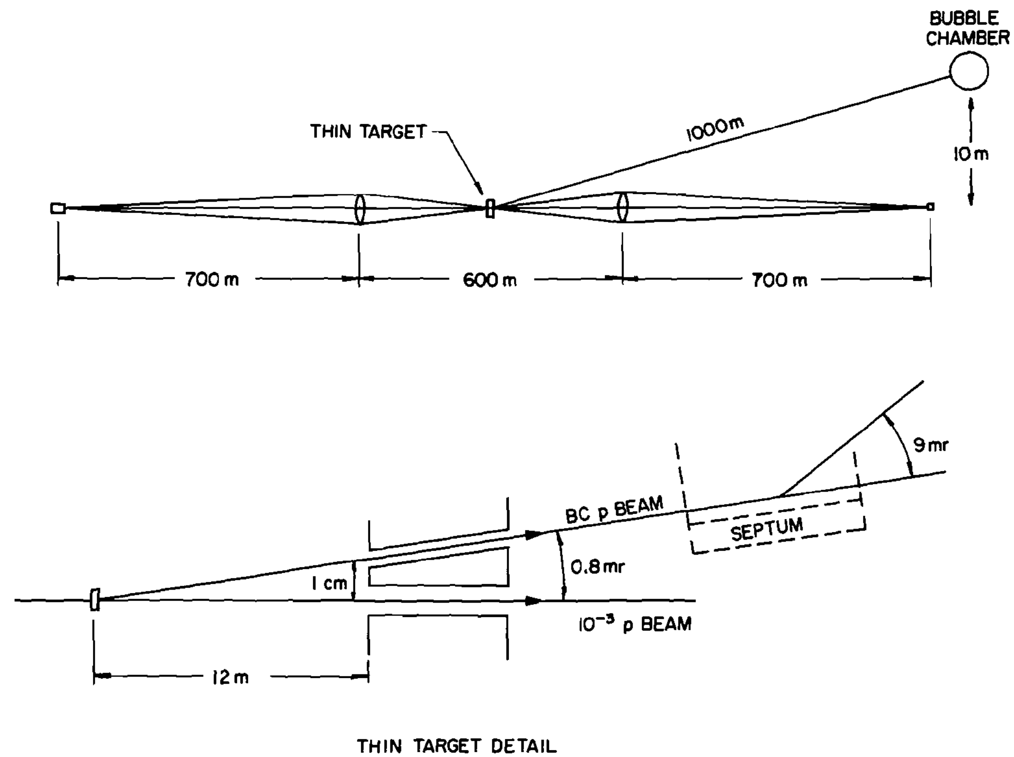

Fig. 5. Thin-target beam for the bubble chamber.