SS-130
2251

A PROPOSAL FOR A TWO-TARGET NEUTRINO FACILITY FOR EXPERIMENTAL-AREA E1, PROVIDING HIGH- AND LOW-ENERGY NEUTRINOS AND MUONS

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ABSTRACT

We present an argument for a two-target facility for experimental-area E1. Although we have not optimized the parameters of the beam configuration, we believe that the number and importance of the potential advantages of this idea are such as to warrant it being thoroughly explored. Among the advantages which we see arising from the concept are the following: flexibility of neutrino physics capability, optimization of neutrino flux, specificity of neutrino beam spectrum, efficient transformation to 400-GeV operation, and possible overall cost savings on the entire experimental facility.

1. A TWO-TARGET NEUTRINO AREA

The configuration of experimental-area E1, which services the proposed 25-foot bubble chamber, is primarily determined by neutrino-beam requirements. We shall also contemplate in this area a spark-chamber experimental area in-line with the bubble chamber and probably, although not necessarily, downstream of the bubble chamber. We should like to present a brief for a two-target facility for this area. One is always at risk in presenting a proposal with many ramifications, in that some potential advantages may be lost sight of in a morass of technical discussion of one or only a few of its aspects. We should, therefore, like to summarize at the outset what we believe some of the possible advantages of the basic idea of two targets might be, with the stress on the point that the two-target suggestion is the primary idea rather than specific dimensions, shield materials, or beam components.

The beam described in SS-146 was adduced, we believe, primarily to serve as a standard of comparison rather than to be enshrined as the design of choice. We shall, accordingly, make reference to this beam which is sketched in Fig. 1. The beam represents a compromise of various sorts. It emphasizes the mid-range of energies, 5 GeV $\lesssim E_\nu \lesssim$ 40 GeV, considers the entire beam configuration as fixed in its dimensions, the only change being made in going to 400-GeV operation is that 200 meters of earth shielding is replaced with iron. It appears to be the tacit assumption that all neutrino experiments would essentially use the same configuration although some tuning of the horn focusing system could certainly be contemplated. Nevertheless, the beam of Fig. 1 is a wide-band system in a larger sense than we would suggest. What we have done is essentially to relax some of the self-imposed constraints on the design of SS-146.

II. POTENTIAL ADVANTAGES OF THE TWO-TARGET SYSTEM

A. Flexibility of NAL Neutrino Physics Capability

At a high-energy accelerator like NAL, one might think to optimize the neutrino facility for energies uniquely accessible at NAL. This was the approach of SS-146 with the emphasis being on the region $E_\nu > 5$ GeV rather than the highest energy region, $E_\nu > 40$ GeV. On the other hand, Block,[1] Palmer,[2] and others[3] have pointed out that an important class of neutrino experiments, principally the study of form factors, can only be done with low-energy neutrinos, $E_\nu \lesssim$ 1-3 GeV. The two-target concept provides NAL with the capability of providing beams optimized for low energies, medium energies, and high energies.

B. Optimization of Neutrino Flux per Running Unit

Since the expense of running the accelerator, the beam components, and the bubble chamber is an important design consideration, it is desirable to optimize the number of neutrino interactions (or flux) per proton in the machine. We shall see that the total number of neutrinos per proton is at least equal to the flux of SS-146 and it may even be improved by the proposed mode of operation. We have specified "running unit" so as to be able to speak either of neutrino flux per proton or neutrino flux per second. Since one of our proposals is to achieve at least some of the low-energy neutrino running by cycling the accelerator only to 70 GeV or 100 GeV, one possible mode of operation would permit the repetition rate to be increased so as clearly to enhance the total neutrino flux per second, as suggested in B. 1-68-82 of the 1968 Summer Study Volumes.

C. Specificity of Neutrino Experiments

With our suggested mode of operation, the neutrino experiments would be somewhat separated on the basis of energy, i.e., it would not be the case that essentially the same spectrum would be used for all experiments. In SS-146 some mention of the possible advantages of hardening the beam were discussed, but the only mechanism for effecting this was the tuning of the focusing elements. With the two-target concept, one has available for change not only the focusing elements (including the possible switch from horn focusing for low-energy beams to quadrupole focusing for high-energy beams), but the decay length and the shield length as well. The use of a quadrupole focusing system for high energy facilitates the hardening of the neutrino beam with no loss of high-energy flux. The specificity of the neutrino spectrum is a decided convenience for low-energy experiments where the bookkeeping of high-energy events serves only to clutter things up. For high-energy experiments the specificity or hardening of the spectrum is more of an imperative since it is the case, for many experiments of interest (e.g., the W search experiments discussed in SS-123), that the cross section for the reaction of interest increases with neutrino energy much more rapidly than does the background implying improved signal-to-noise as the spectrum is hardened.

D. Optimization for 400-GeV Operation

It has been the thought of many people at the summer study that it would be folly indeed to fix the dimensions of the neutrino area without careful consideration of the proposed 400-GeV operation. It would seem to be highly desirable to be able to provide drift spaces for 400-GeV operation at least of the order of 1 kilometer because of the necessity for longer shields and the higher gamma of the parent pions and kaons. For example, Fig. 21 of SS-146 indicates a 50% increase in the flux of neutrinos of energy > 100 GeV in going from 600 meters to 1000 m of drift space. The fact that the K/π ratio is not known and may be dropping with meson energy, as the Serpukhov results seem to indicate, may make pions more important for high-energy neutrino beams than has been thought up until now. This development emphasizes the need for long drift spaces. The two-target concept was primarily motivated by the desirability of reserving an upstream target location for 400-GeV running.

E. Possible Use of Quadrupole Beam Elements

It is generally conceded that the horn is the most desirable wide-band focusing element for low-energy neutrino beams. The focusing advantage of the horn decreases with increasing neutrino energy since the Cocconi angle of interest is itself shrinking in size. Effectively, a horn does not "see" the highest energy particles. We contemplate the use of a horn focusing system in connection with the downstream target for low- and medium-energy neutrinos ($E \lesssim 40$ GeV). We now consider the possibility of using a quadrupole lens system after the upstream target for high-energy neutrinos.

A first and obvious consideration is that the channel elements for the high-energy beam may serve as transport elements for targeting the proton beam at the low-energy target station. The arrangement is shown in Fig. 2. A disadvantage of a quadrupole channel when only a single neutrino production target station is used is that it cuts off the low-energy flux, which requires a wider angular range to include the characteristic angle of production. Once the low-energy region is separately taken care of, this is no longer an objection. In fact, the possibility of cutting out the lower energy events by selectively tuning the channel, as indicated in the tuning curve of Fig. 3, may be an advantage in that the high rate of background from low-energy neutrinos is eliminated from the high-energy experiments, as mentioned above.

F. Cost Considerations: Shielding, Capital Investment and Maintenance

The smaller cross section of the quad channel (4-inch or 8-inch vacuum pipe, assuming 4-inch or 8-inch quads) also helps the shielding problem by making possible a tunnel of smaller lateral dimensions. The concrete shielding needed to reduce earth irradiation to acceptable levels is annular in shape and, accordingly, the volume goes directly as the radius of the tunnel. The useful tunnel width is the vacuum pipe through the quads, whether this is four or eight inches. The actual tunnel width would depend on whether one chose to handle the magnets in the tunnel or to provide access shafts to each magnet. The problem of evacuating the drift space region is obviously much simplified for a smaller tunnel. In general, the lateral dimensions of a horn focusing system are significantly larger than those of a quad system.

The use of a horn-focusing device only for low- and medium-energy neutrinos should make the design of the horn easier and the cost of construction somewhat less. The quads presently contemplated should be fairly standard in cost and not excessive in number. The problem of maintenance should be substantially easier for the quad system since the coils are the only active elements and are out of the main beam. The problem of maintaining the horn system, on the other hand, is likely to be a severe one which is reduced in our mode of operation by being restricted to low- and medium-energy running.

G. DC Operation

One should contemplate spark-chamber experiments in the neutrino area and, while there is a question as to whether spark-chamber experiments might or might not survive in pulsed beams, it is clear that certain experiments are better with dc or long spill beams. Possible design for dc focusing devices, such as the Fresnel lens of Frisch and Kang[4] and a proposal from Palmer[5] have been made. In our suggested mode of operation, such dc devices could certainly be incorporated but the dc feature is clearly served in the high-energy regime by the quadrupole system. Since by far the major part of the proposed spark-chamber experimentation has been concerned with high-energy neutrinos, this appears to serve the desired end without precluding incorporation of any of the newly proposed devices. The beam line is thus compatible, for high energies, with both bubble chamber and spark-chamber operation (although, of course, not necessarily simultaneously).

H. Possible Utilization of the Area for Other Beams

At present, the E1 area is the only one projected for a 0° production beam. The use of a quadrupole front end would be compatible with matching to other beams. E. J. N. Wilson has shown in the CERN/ECFA 300-GeV Study[6] that, with a proper choice of quadrupoles, 80% of the Cocconi angle of produced particles at any reasonably high momentum can be captured into a parallel beam. This yields of the order of 10^9 π^+ per pulse for a 1% momentum bite at 100 GeV/c, for 10^{13} protons incident at 200 GeV/c. Matching this front end to the decay channel and determining the final total width and neutrino energy spectrum will require more detailed studies using particle-ray traces and typical experimental-area configurations. This will be pursued further.

The upstream target could be used to provide a rf-separated high-energy secondary beam, since it is far enough from the bubble chamber to provide the space needed for this facility. Likewise, the use of the high-energy quadrupole system would permit the transport of protons to a downstream target much closer to the bubble chamber and hence might permit a low-energy hadron beam targeted close to the chamber. Perhaps a hyperon beam might be facilitated in this way.

More to the point at this time, it is attractive to consider the usefulness of using the same front end as the front end of an intense muon beam by adding 160 kG-m of bending magnets between the front end and the muon channel for 100 GeV/c muons. It is well to note that for muons, unlike neutrinos, the available decay distance is the distance from the target even when there is a bending magnet in the system, since the desired muons produced between the target and the dipoles are bent into the channel.

Another possible muon beam which should be considered is one utilizing the upstream target and the neutrino high-energy beam drift space as the drift space for the muon beam. One would have to bend and then filter the muon beam as shown in Fig. 26. The advantages of this would be three-fold. First, the extra expense might be less. Second, it might be possible to utilize the muon bend as part of the bubble-chamber muon shielding and run muon experiments and neutrino experiments simultaneously (assuming spill incompatibilities can be overcome). Third, the suggested "tagged neutrino" feature might be facilitated.

Apart from the obvious efficient usage of protons in being able to run various beams off the same target station simultaneously, the number of required target stations is reduced for the whole experimental area. If we can, for example, provide a muon beam and an rf-separated hadron beam in area 1, then the cost of the components must be shared among all the facilities rather than be regarded as constituting only an expensive neutrino area.

SPECIFIC PROPOSALS

In summary, we propose a dual facility in area 1 as indicated in Fig. 2. In addition to an upstream target providing a long decay space appropriate for high-energy neutrinos, there is a downstream horn target together with appropriate decay space and shield thickness to optimize the low-energy neutrino flux into the chamber.

The shield thickness may be reduced from 300 meters either by going to a dense material like uranium and building a full range shield for 200 or 400 GeV/c muons, or by extracting the proton beam at an energy at or below that determined by the maximum muon ranging capability of a thinner shield. By building the shield starting from downstream and near the bubble chamber the solid angle for the lowest energy neutrinos is improved. The shield can be incremented on the upstream end when the energy of the incident proton beam is increased beyond the limit of the existing shield. This reduces the decay space, but, provided the final decay space length is adequate, nothing is lost by having the longer space for lower energies. Opting for low-energy neutrinos only at turn-on in the absence of a 200-BeV uranium full-range shield may be an undesirable restriction, but it is not inconsistent with the schedule of the chamber. Low-energy neutrino experiments may be done in hydrogen, and it is to be expected that the first fillings of the chamber will be with hydrogen until some experience is gained. This low-energy beam is described in a separate paper (SS-139).

Figure 4 indicates several possibilities for the shield configuration. The shield is broken into "filters" so as to enhance its overall efficiency. The major handling difficulties of a Uranium shield are obviated by absorbing the hadronic cascade separately.

REFERENCES

[1] M. M. Block, Neutrino Physics, National Accelerator Laboratory 1968 Summer Study Report B.1-68-42, Vol. I, p. 215.

[2] R. B. Palmer, Form Factor Determination in Neutrino Interactions, National Accelerator Laboratory 1969 Summer Study Report SS-85, Vol. IV.

[3] D. Jovanovic and M. M. Block, Recoil Proton Polarization Measurement in $\nu + \binom{n}{p} \rightarrow \bar{\mu} + p$, National Accelerator Laboratory 1969 Summer Study Report SS-127, Vol. IV.

[4]D. H. Frisch and Y. W. Kang, DC Horn For Very High Energy Spark-Chamber Neutrino Experiments, National Accelerator Laboratory 1969 Summer Study Report SS-160, Vol. 1.

[5]R. B. Palmer, The Design of Long Pulse Monopole Focusing Elements, National Accelerator Laboratory 1969 Summer Study Report SS-70, Vol. 1.

[6]E. J. N. Wilson, CERN/ECFA 67/16, Vol. I, p. 256.

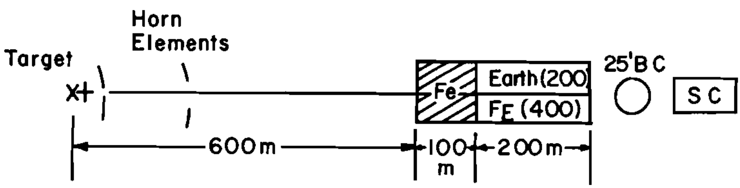
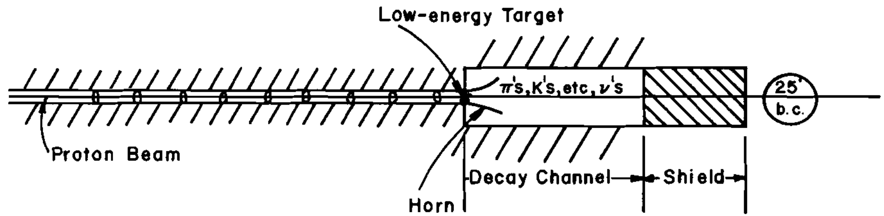
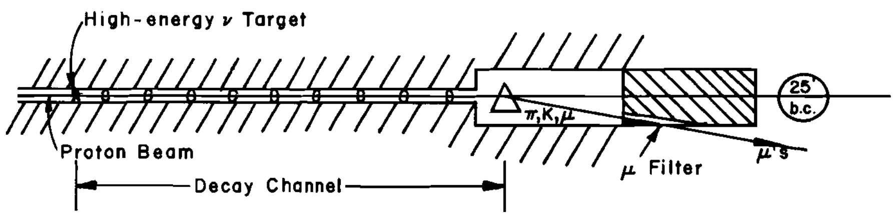


Fig. 1. Broad-band neutrino beam setup as proposed in SS-146.



(a) Low-energy Neutrino Facility



(b) High-energy Neutrino Facility with Muon-Beam

Fig. 2. Alternative neutrino beam arrangements.

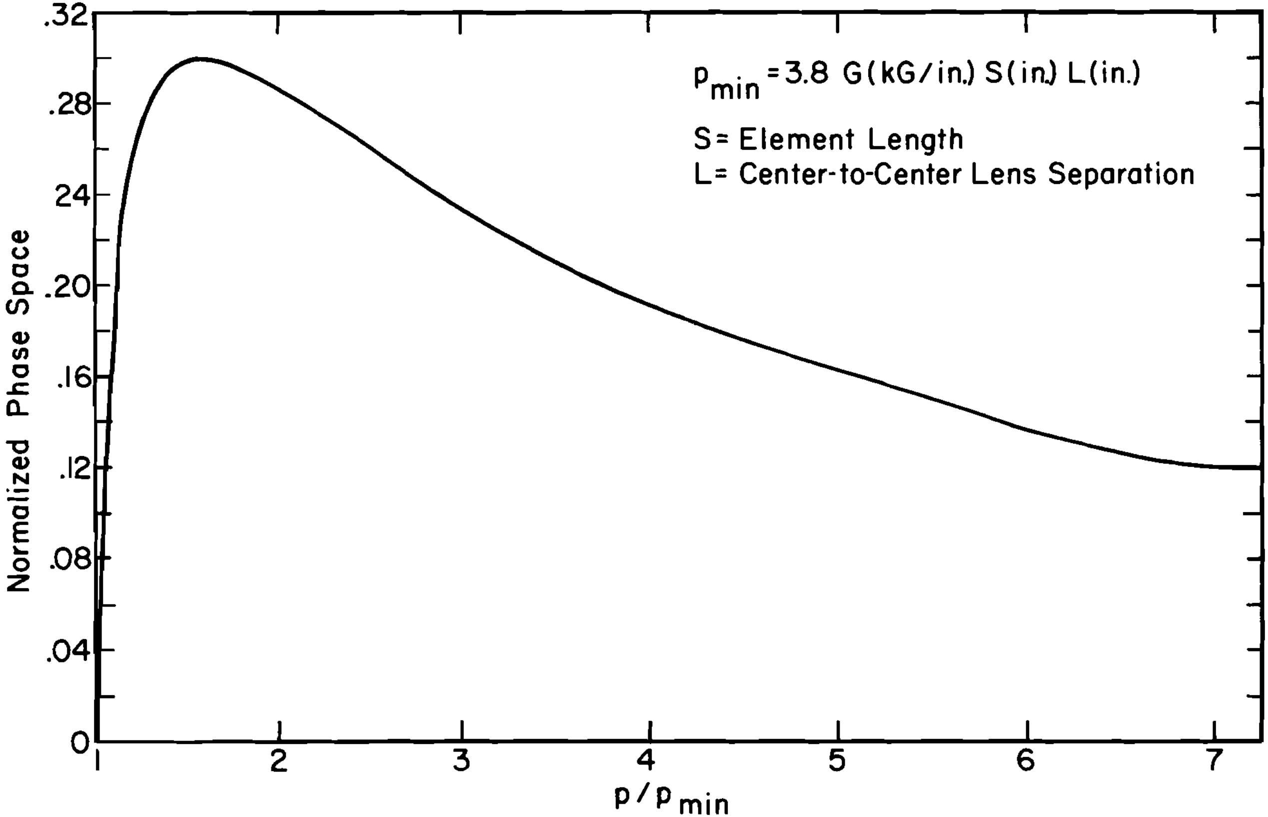


Fig. 3. Phase space for FODO focusing channel.

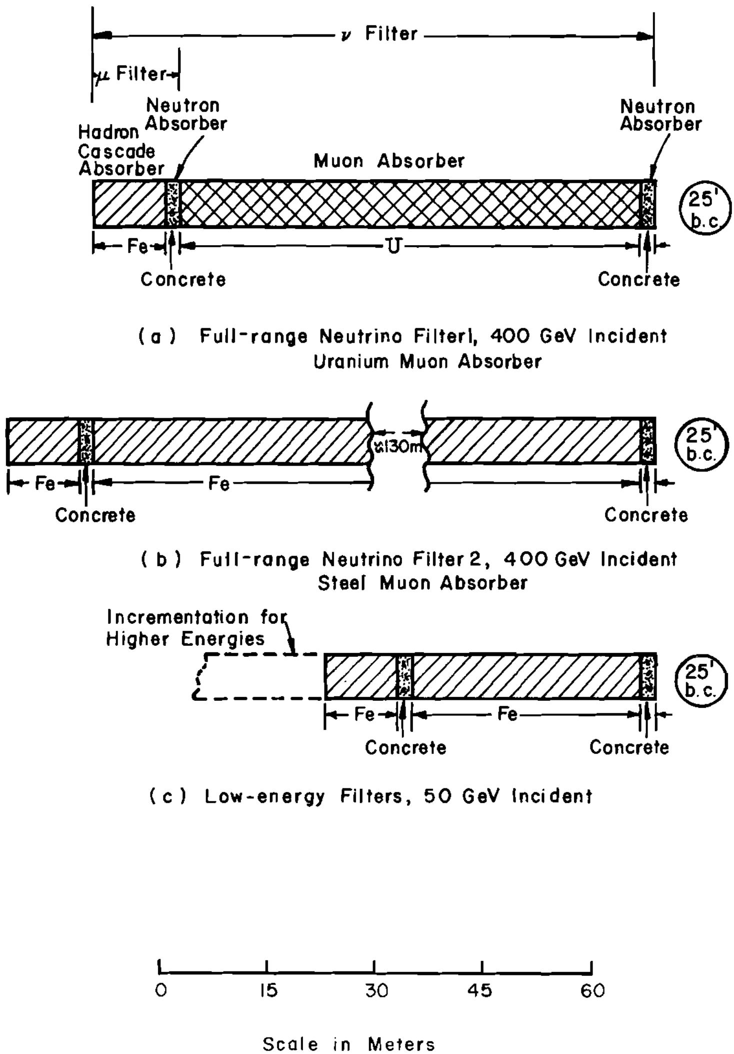


Fig. 4. Neutrino filters for 400 GeV and for 50 GeV.