LONG-SPILL MUON AND NEUTRINO BEAMS IN AREA I

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ABSTRACT

A modification is described which permits the addition of slow spill muon and neutrino beams to the planned pulsed horn neutrino beam in Area I. The new beams share the decay tunnel and muon shield presently planned. The modifications to the pulsed beam operation are negligible.

INTRODUCTION

We wish to propose an amended configuration for Area I in order to accommodate long-spill neutrino and muon beams. We give particular attention to the existence of a tagged neutrino beam and show that such a facility is consistent with the simultaneous running of muon experiments from a common decay region. It is taken as a boundary condition that the design for the pulsed horn and bubble-chamber neutrino beam shall remain essentially undisturbed.

Our proposal is not intended to detail construction but only to establish feasibility. The design is not optimized from the viewpoint of beam quality; it is subjected to the constraint of saving money in tunnel construction by multiple use of the decay tunnel and muon shield as presently envisioned. The changes required are 1) establishment of a new target upstream of the neutrino horn; 2) installation of quadrupoles and dipoles for beam handling; 3) construction of a beam stop in the quadrupole area for the primary beam; 4) modification of the drift tunnel to permit installation and removal of equipment by methods similar to the Maschke railroad; 5) possible lengthening of the horn gallery with a consequent shortening of the decay tunnel. Drawings of the old and new configuations are shown in Fig. 1 for comparison.

NOMENCLATURE

The progress in previous NAL studies as well as discussions at the present session have succeeded to date in establishing three independent types of neutrino beams. We shall call them broad band, high band, and narrow band. The first results from a design criterion of maximizing the flux of all neutrinos above about 5 GeV and results in the use of a horn-type focusing device. Such a device has been well described and documented by Y. Kang and F. Nezrick,[1] and we shall not consider it further except to remark that it is likely to remain a pulsed device with a duty cycle below 10^{-4}.

The second category (high-band beams) includes a number of focusing concepts, including pulsed horns, dc or long-pulse fresnel lenses, and quadrupole optics. The object here is usually to provide a maximum neutrino flux above some lower cutoff energy (typically 40-60 GeV), and often seeks to provide a long-spill capability. The concept usually boils down to rendering parallel a beam of pions and kaons at a particular momentum. All momenta above this canonical value tend to be focused and as a consequence deliver their decay neutrinos into a smaller area than an equivalent beam of unfocused particles. The price one pays is the defocusing of momenta below the cutoff and a consequent scarcity of low-energy neutrinos. We do not concern ourselves in this report with such devices, but note that our target and quadrupoles will be completely compatible with most systems of this genre.

The third or "narrow-band" system comes from the momentum-selection system, which passes a band of pion and kaon momenta typically only 10% wide. Higher and lower momenta are absorbed, together with the external proton beam in a beam stopper preceding the decay region. This type of hadron beam is desirable, when developing a muon beam, from consideration of beam halo and when developing a tagged neutrino beam, for reasons of tagging simplicity. The technical basis for these statements will follow. We wish to point out in this section only that there exist reasons for wanting the particular system proposed. The physics motivation for a muon-beam facility and for a tagged neutrino beam are discussed in a separate document and will not be covered here.

MUON BEAMS

The general requirements for making muon beams are unfamiliar to most people, and we shall quickly review them to establish a grounds for discussion. First, and most important, is the fact that muons do not emerge from hadron interactions in fluxes even remotely adequate for beam formulation. As a consequence, we must use decaying charged pions and kaons as a muon source. Second, because pions and kaons at high energy travel very great distances before decaying, we must have a long decay region in order to harvest significant numbers of muons. Third, we note that pions with a laboratory energy E_π decay with uniform probability into muons with energy between 0.57 E_π and 1.0 E_π. Kaons decay into muons of energy 0.044 E_K to 1.0 E_K (also with equal probability per unit energy). The maximum transverse momentum available in a π - μ decay is 30 MeV/c, while 240 MeV/c is available in a K - μ decay.

As a consequence, the muon optics are better by a factor 8 for the pion decays.

The production of positive pions is about six times the production of positive kaons at high energy and about three times the production of negative pions at all energies. The lifetime of pions is about 7.5 times the lifetime of equal momentum kaons at high energy implying drift spaces of order 0.13 τ_π in order to get comparable fluxes from both sources. At 100 GeV this means a decay distance of about 300 meters.

Furthermore, once the beam of muons has been formed by letting pions and kaons decay, we must gather the muons up, momentum-select the band of interest, and eliminate the remaining pions, kaons and unwanted muons. The hadrons are removed by passing the beam through about 20 nuclear-interaction lengths of low-Z material (to minimize multiple scattering of the muons). The remaining muons are then passed through a dipole-collimator system to select the muon momentum band of interest and eliminate all other muons. Typically, the pass-band is 10% wide and the last bending magnet is used to "tag" the individual muons after the fact in the events of interest. The necessity to tag the beam muons sets an upper limit to the instantaneous beam intensity of about 10^7/sec. For this reason, a long spill is essential.

The beam diameter in a "good" muon beam is typically 4 in. × 6 in., although larger sizes are acceptable in certain classes of experiments. We propose to create a beam which is about 6 in. × 12 in. by the means explained below. As a consolation prize for letting the beam increase a factor of two in size, we will gain a simultaneous tagged-neutrino facility.

FRONT-END OPTICS

A schematic view of the front-end optics is shown in Fig. 2. We see that the beam is rendered parallel at some canonical momentum, passed through a zero-dispersion momentum-selector and sent into the decay region along the initial beam line.

We can run the muon-tagged neutrino beam only with the horn off and preferably clear out of the beam line. We will soon see why for other reasons the horn-focused beam and the present beam cannot share the area on a short-term basis, so we tentatively assume the horn to be physically out of the beam line during the muon-tagged neutrino runs. When the horn runs, the muon target is removed, the dipoles turned off, and the proton beam brought through the muon apparatus to the horn target. Change-over could take from a few hours to a few days depending upon the system used to move the horn. (We conceive of a hydraulic or crane system to move the horn. Steel locating pins and mating holes could be used for accurate relocation after initial survey and adjustment.)

BEAM STOPPER

In the narrow-band system, it is necessary to provide a proton-beam stop after the first dipole bend. We believe this is not particularly hard to do as there is a 50 m drift space between dipoles in which a massive iron beam stop could be located. The beam stop has two holes through it, one for the hadron channel and another for transporting the proton beam to the horn target. The hole along the beam axis should have a shutter to stop neutrals when the quadrupole target is in use.

The dipoles envisaged are able to translate the 100 GeV/c channel about 90 cm at the extreme point and the 200 GeV protons about half this amount. If the shield must start halfway between the two dipoles, there will be only 35 cm separation between the axis of the proton beam and the pion-kaon channel. If this makes a serious beam-stop problem, it may be necessary to use another small C-magnet to bend the protons back.

Locating a beam stop in the quadrupole area will result in high radiation and radioactivity levels. We suggest that a thick concrete wall be erected to separate the target hall into two separate areas, a quadrupole gallery and a horn gallery. Such separation has the advantage that one area can be cooling off while the other is running. Then, when changes are necessary, the beam will be off only for the time actually needed for the work rather than long enough for the entire hall to drop to acceptable radiation levels for work to commence.

DECAY TUNNEL

The presently planned decay tunnel is expected to be about five feet in diameter and five hundred meters long. When the muon-tagged neutrino beam is running, it is desirable to have a tunnel more like 8 inches in diameter, with absorbing mass everywhere else. We propose to achieve both conditions by placing gates at both ends of the tunnel, a vacuum pipe down the middle, and then flooding the tunnel with water when the muon beam is on. The water is of course pumped out and the gates opened when one desires the full five-foot tunnel for neutrino work of the wide-band type.

One scheme, proposed by A. Mann[2] to cope with the problem of installation and removal of equipment in the tunnel (say neutrino tagging counters) is to equip it with rails along the entire length so that equipment can be run into the tunnel in the same way as a train. The entrance might follow the muon beam as it is deflected away from the tunnel axis and brought to the top of the iron shield. The rail system should be sturdy enough to support loads of a few tons.

The heaviest objects now proposed for the tunnel are the dipole magnets which pitch the muon beam up from the tunnel. The muon bend angles are typically 1.6°, and the entrance ramp is therefore shallow and adapted to introducing even rather long items into the tunnel.

We summarize by restating the modifications to the tunnel, one of which is the rail scheme and the other is the water gates. These are minor problems if designed in at the start.

SHIELD AND EXPERIMENTAL AREAS

The most difficult problem in making the Area I tunnel a multi-purpose operation is the problem of compatability in layout of experiments. Whether one uses a passive iron shield or an active magnetic shield strongly influences the ultimate configuration. Rather than try to guess the outcome of the shield deliberations, we have arbitrarily based our arrangement of the Nezrick proposal as explained at the beginning of the 1969 Summer Study.[1]

We envision bending the muon beam in a dogleg fashion to bring it up to the top of the iron shield where the muon experiments could take place.

With 120 kilogauss-meters at each bend, the muon beam can be raised 3 meters in less than 100 meters. The bend starts 50 m upstream of the shield and ends 50 m downstream on top of the middle of the shield. For muon experiments less than 50 m long, no extra excavation is required beyond what is already necessary to establish the iron shield. The used muons could be ranged out in the remaining 200 m of earth shield or bent away from the neutrino area magnetically.

The neutrino area begins as soon after the iron shield as people dare to work. A number of proposals have been made, the least difficult of which would be to place the spark-chamber neutrino experiments behind the bubble chamber. This problem will have to be faced no matter what type of neutrino beam is run, as spark chambers will certainly be willing to run in the pulsed neutrino beam. Our prime concern in this report is to establish the compatability of the muon beam with almost any neutrino configuration, provided the muon area be established on or beside the neutrino shield.

D. Frisch, R. March, and others[3] have recently reopened the question of magnetic versus passive muon shields. This work is insufficiently advanced to provide a basis for a muon experimental-area design, but after such a design is clarified we can expect the muons to adapt to a compatible configuration.

CONCLUSIONS

It has been our purpose to show the feasibility of using one decay tunnel and muon shield to serve the purposes of the neutrino bubble chamber, neutrino spark chambers, a good quality tagged muon beam ($\Delta p/p \simeq 0.5\%$ or better), and a moderate quality tagged neutrino beam ($\Delta p/p \simeq 10\%$). No two of these operations are thought of as necessarily operating simultaneously (except the tagged neutrino beam and muon beam) but changeover from one to another could take only a few hours. Our prime consideration has been given to the goal of achieving muon and neutrino beams in Area I as soon as the machine comes on. Of almost equal importance has been the constraint of using the presently planned decay tunnel and muon shield in a manner compatible with the later demands of the area. We believe this design is as cheap as one can get away with and still have muon and tagged neutrino beams in Area I. Should more construction money become available, other designs (such as one proposed by L. Hand[4]) may be preferable.

REFERENCES

[1] Y. W. Kang and F. A. Nezrick, Neutrino Beam Design, National Accelerator Laboratory 1969 Summer Study Report SS-146, Vol. I.

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[4] Y. W. Kang, Muon Shielding in the Neutrino Beam, National Accelerator Laboratory 1969 Summer Study Report SS-156, Vol. I.

[5] D. Berley and L. Hand, Secondary Beam for Muons and Neutrinos for Area 1, National Accelerator Laboratory 1969 Summer Study Report SS-51, Vol. I; L. N. Hand and A. K. Mann, Neutrinos and Muons in Area 1, National Accelerator Laboratory 1969 Summer Study Report SS-50, Vol. I.

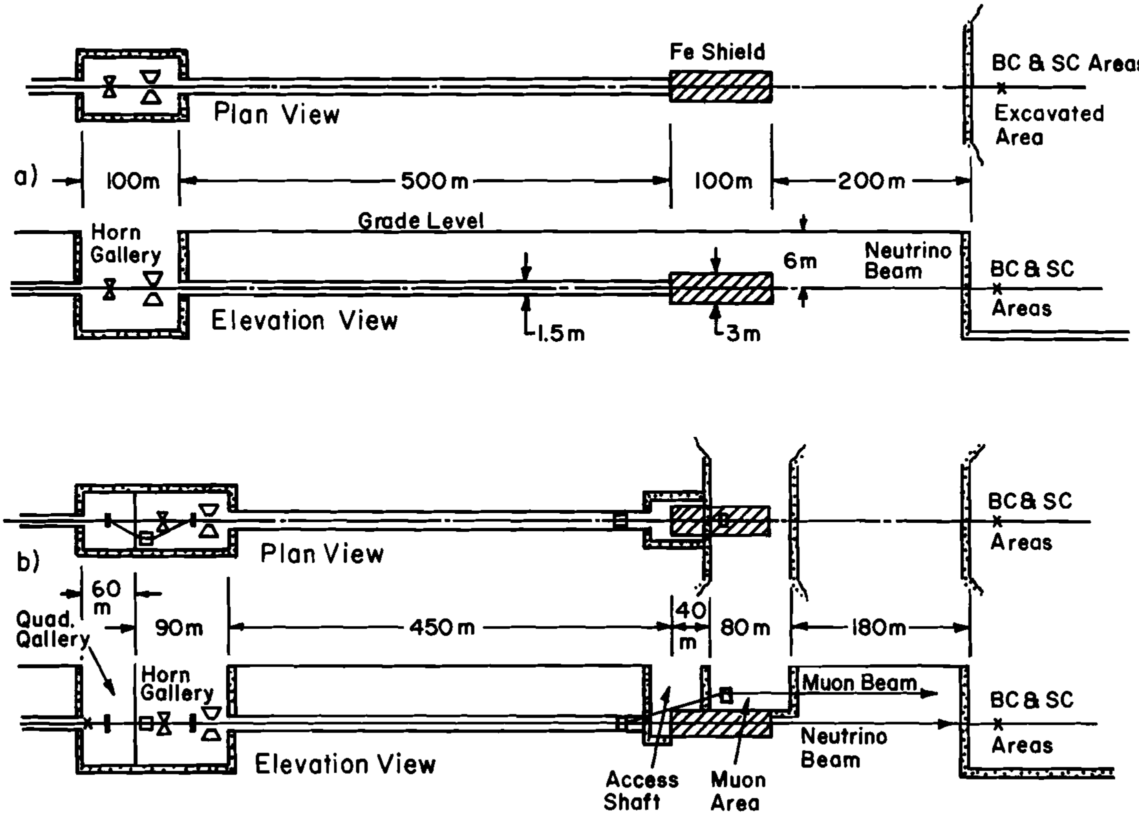

Fig. 1. Old (above) and new (below) area 1 configurations.

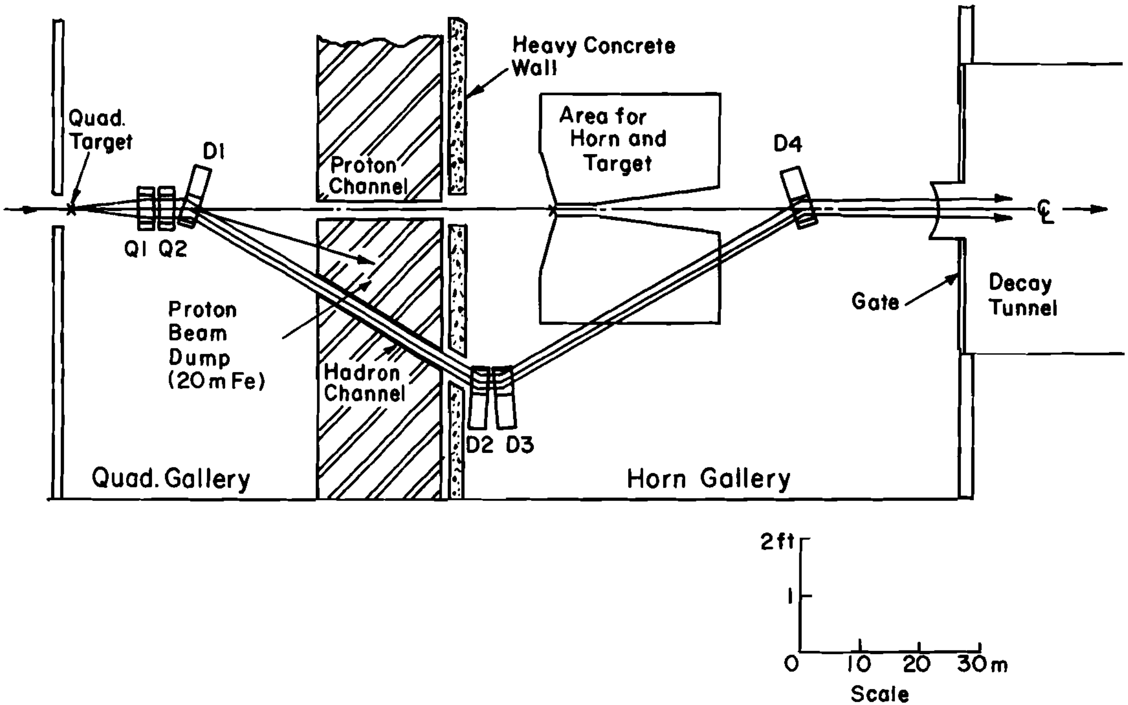

Fig. 2. Area 1 targets, horn and quad optics (dimensions are approximate).