THE DISADVANTAGES IN OPERATING THE NAL NEUTRINO BEAM AT LESS THAN THE FULL ACCELERATOR ENERGY

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ABSTRACT

The suggestion of producing the neutrino beam at NAL at less than the full accelerator energy has been studied. By operating the accelerator at 150 BeV and 100 BeV at a faster repetition rate, the total number of pions produced per second above 5 BeV is comparable to that produced at 200 BeV. However, the loss of higher energy pions when the accelerator is operated at the lower energies is significant. The advantages of this operation are that the muon shield becomes less expensive, and the neutrino flux below 4 BeV can be enhanced. Some of the disadvantages of this mode of operation are 1) there is a significant reduction in the neutrino flux above about 4 BeV; 2) there is a lower density of neutrino interactions per accelerator pulse (per bubble-chamber photograph); and 3) the preference of not having a flattop limits the experimental program.

It has been suggested[1] that the neutrino beam at NAL be operated at less than the full accelerator energy. Two advantages were quoted for this operation: 1) the increased repetition rate of the accelerator for lower proton energies increases the number of lower energy pions and hence neutrinos produced per second; 2) the muon shielding problem is simpler and less expensive. Since for lower proton energies the maximum muon energy is reduced, one cannot refute the second point; with the muon ionization loss being rather well known, one can conclude that a higher energy neutrino beam requires a thicker shield to stop the higher energy muon. This argument is irrelevant, however, if one's goal is to produce the highest energy neutrino possible at this accelerator.

The first quoted advantage is also misleading. The assumption that was made was that the accelerator repetition period was inversely proportional to the proton energy (e.g., for a period of T at 200 BeV, one could get a period of T/4 at 50 BeV). This assumption is wrong. The accelerator main-ring magnetic-field cycle is illustrated in Fig. 1. The components of the cycle are t_1, the time to inject the protons from the booster, t_2 and t_4, the rise and fall time respectively of the magnetic field, and t_3 the flattop. The time t_1 is proportional to the intensity of circulating protons and will, therefore, not be appreciably reduced in changing the proton energy. The slopes of the field during t_2 and t_4 are determined by the power supplies and cannot be changed; therefore, $t_2 + t_4$ is proportional to the proton energy. The flattop t_3 can vary from 0 to 1 sec. A zero flattop could be used if the entire beam went to a bubble chamber which was single pulsed. The longer flattop would accommodate counter experiments and/or a bubble chamber which was multiple pulsing. Using the values from the Design Report,[2] the energy-dependent cycle time of the accelerator can be expressed as

$$T(\mathrm{sec}) = 0.8 + 2.2\ (E/200) + \mathrm{Flattop},$$

where E is in GeV and the flattop can vary from 0 to 1 second.

Calculating the pion flux from the CKP formula[3] assuming $\theta_m = 60$ mrad and $P_\pi^{max} = E_{proton}$, and using the accelerator cycle time determined from above with a zero and one second flattop, yields the relative pion rates shown in Fig. 2. The relative pion rates for a fixed number of protons of 200 BeV, 150 BeV, 100 BeV, and 50 BeV incident on a thin target are presented. The integral pion rates above 5 BeV are comparable from the 200 BeV, 150 BeV, and 100 BeV proton beams; however, the loss at higher pion energies is dramatic.

What enhancement of the neutrino flux is obtained by operating the neutrino beam at lower proton energies? In general, as one lowers the proton energy one lowers the pion and kaon average energy. The low-energy neutrino flux (1 BeV < E_ν < 4 BeV) can therefore be enhanced by operating the accelerator at lower energies; however, to optimize the lower energy ν flux from these lower energy beams, the decay distance and shield thickness should be kept to a minimum. To have a high ν flux, therefore, the decay length and shield thickness must be changed as the proton energy is changed. This implies that either the target or the front of the muon shield be moveable. Because of the high radiation levels encountered around the target and at the face of the muon shield, considerable difficulties arise in making these portable. These problems are at present under investigation at NAL.

There are several comments that can be made concerning the operation of the accelerator at lower energies for the neutrino experiments.

1. This type of neutrino-beam operation is unacceptable for those spark-chamber neutrino experiments which demand neutrino fluxes above about 40 BeV. Therefore, spark chambers and bubble chambers probably would not be simultaneously operated in tandem and share the same neutrinos, even if they were spill length compatible.

2. To obtain the same number of neutrino interactions per day, the bubble chamber and/or optical spark chambers must take more photographs because of the increased accelerator repetition rate. This would for an equivalent experimental program result in a larger operating cost for film and for scanning and measuring machines and their staff.

3. A large advantage of this scheme lies in not having a flattop. This demand would tend to lead to: a) exclusive bubble-chamber running periods (to the distress of the counter experimenters in Areas 2 and 3); b) single-pulse operation of the bubble chamber (to the distress of the bubble-chamber strong-interaction experimenters[4]); and c) no low-intensity long-spill test beams being available for the counter experiments during the neutrino experiments.

4. Since more economical muon shields are frequently being suggested[1,5,6] and developed, the financial need to minimize this shield becomes less important.

5. When the accelerator goes to 400 BeV, would one use this scheme to reduce the proton energy to 200 BeV or less for the neutrino experiments?

In conclusion, I do not view the reduction in proton energy as an acceptable solution to the muon shielding problem. If neutrino experiments in the energy range 1 BeV $< E_\nu <$ 4 BeV are to be undertaken at NAL, then operating the accelerator at lower energies may be necessary. However, assuming that the neutrino energy region of interest at NAL is above 4 BeV, then a full range 200-BeV muon shield is a better solution because it allows the production of the highest energy neutrinos, it produces the "highest density" of neutrino interaction per accelerator pulse, it allows the bubble chamber to be multiple pulsed to obtain neutrino and strong-interaction photographs on the same accelerator cycle, it would make the bubble chamber easier to schedule with counter experiments on the same accelerator cycle, and it allows for the expansion of the accelerator to 400 BeV.

REFERENCES

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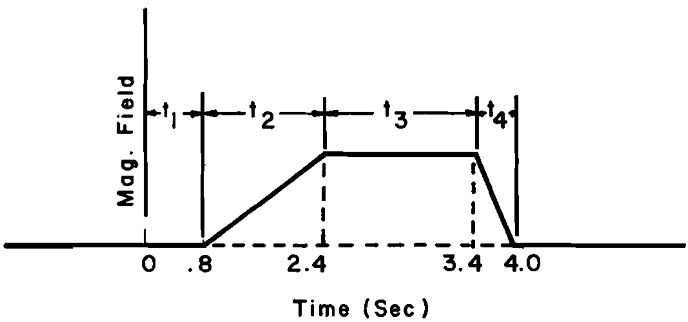

Fig. 1. Main-ring magnetic field cycle, where $0 \le t_3 \le 1.0$ sec.

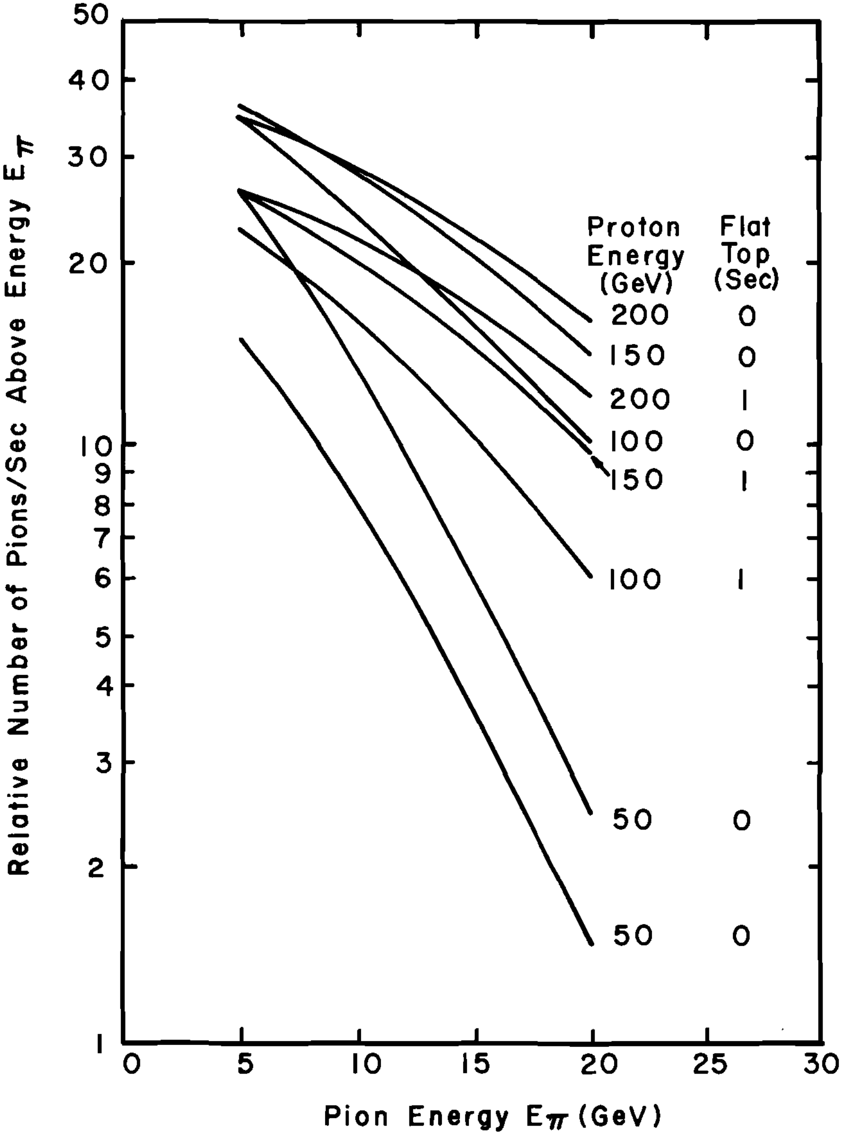

Fig. 2. Relative integral numbers of pions above the energy E_π, for the accelerator operating at 200, 150, 100, and 50 GeV, for no flat-top and a 1-sec flat-top.