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FOCUSING DEVICES FOR A NEUTRINO BEAM AT NAL

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ABSTRACT

Three focusing systems for a neutrino beam are described and compared. The dc "fish" system is found to give fluxes at least a factor of two less than the two "horn" systems. In the first of these horn systems, currents, power requirements, and stress levels are all much lower than in the second, more conventional design. The first system could operate at only 200 volts using solid-state switching; good focusing would be provided over a 2.5 msec spill and greater reliability should be possible.

A neutrino beam consists of 1) a target from which pions and kaons emerge, 2) a focusing system that focuses these particles into the forward direction, 3) a tunnel down which these particles pass and decay into neutrinos and muons and, finally, 4) a shield that stops the muons and allows the neutrinos to pass on into the chamber.

I shall consider here focusing devices that have been designed to focus all momenta of primary particles and thus give a "wide-band" neutrino beam. The systems were optimized and fluxes calculated on certain assumptions that will follow. The general conclusions, however, are almost certainly independent of the details of these assumptions.

The assumptions are:

1. decay length 600 m, shield length 300 m, tunnel diameter 1 m,
2. machine energy 500 GeV, π and K spectra from Hagedorn-Ranft formula,
3. focusing system to be located in the first 60 meters of the decay path,
4. target to be shorter than 1 meter, but thin enough to allow all π's and K's to leave without absorption, and
5. the detector has a radius of 1.35 meters.

The systems that I have considered are:

1. a horn[1] system as designed at NAL,
2. a horn system as designed by Palmer,[2] and
3. a fish system.[3]

The first two systems are pulsed devices that could not be employed for spills much longer than 2.5 msec. The last system, however, is a dc system and could be used with a long spill for counter work. The last two systems are designed to focus all primary momenta equally, whereas, the first was optimized somewhat better for the lower momentum primary particles. The detailed procedures used to optimize the designs will not be discussed further.

The general physical dimensions of the three systems are illustrated in Fig. 1. Note that the vertical scale is different from the horizontal and that the devices are really long and thin. The horn systems consist of axially symmetric current sheets down which the current flows and through which the particles pass, first entering the field region and then leaving it (see Fig. 2). The fish system consists of a series of flat strip conductors arranged like fins about the axis (see Fig. 3). The particles pass between these fins and experience the approximately circular field that exists between the plates. Parameters of the systems are given in Table I. In Fig. 4, I show the neutrino fluxes calculated[4] from pion decay only for the three systems, with no allowance for absorption of particles in passing through the horns or for hitting the fins of the fish. I note

1. The NAL-horn and Palmer-horn systems have similar performance, the NAL design being better at 12 GeV and the Palmer design better at high energies.

2. The fish design is in every respect worse than the horn designs. This arises because of the technical unfeasibility of building a smaller fish to be placed as near the target as the horn systems are placed.

In Fig. 5, I show the neutrino fluxes when absorption is taken into account. Comparison with Fig. 4 shows that both horn systems have absorption of the order of 20%, but the fish has absorption of 40%. The larger absorption in the fish arises primarily because the rays are not deflected strictly back towards the axis but, in fact, are deflected sideways into the fins. The effect is not reduced by increasing the number of fins and can only be reduced by increasing the distance between the target and the first fish.

I note that the dc fish gives, at the peak, neutrino fluxes approximately a factor of 1/2 those obtained with the horn systems. It would be desirable to compare these performance figures with a suitably designed wide-band quadrupole system. This has not yet been done under comparable conditions. Indications are that the quadrupole system is no better than the fish system and possibly worse by another factor of 2.

I conclude that a practical fish system is not as good as a well-designed horn system. I should then consider whether a horn system could be constructed to give 1) a long pulse and 2) great reliability. It was with these points in mind that the Palmer design was optimized. It would be proposed to provide the current, which is less than half that in conventional designs, from a 200 volt (instead of 20 kV) condenser bank employing silicon-controlled rectifiers (instead of ignitrons to switch the current on and crowbar it after a 1/3 cycle. The specifications would then be

Condenser bank - capacity ≈ 2 F
voltage ≈ 200 V
current = 125,000 A
time constant = 2.4 msec

The pulse is shown in Fig. 6. The useful beam-time is approximately 2.5 msec. The temperature reached in the horns is less than those experienced in the present CERN and BNL horns, and the forces on the conductors are less than one-fifth of those in the existing horns.

As a result of these 1) low voltages, 2) solid-state switching, and 3) low forces, it is believed that such a horn system would have a life of tens of millions of pulses.

The cost of the system has been estimated as follows:

Condenser bank	$ 30,000
SCR switching	5,000
Charging supply	10,000
Horns	55,000
	$100,000

I conclude that a suitable horn system can be built that will give good focusing, 2.5 msec useful time, high reliability, and that it can be built for a reasonable cost.

REFERENCES

[1] A. Asner and C. Iselin, Layout of the New CERN Neutrino Beam, CERN Yellow Report 66-24, 1966.

[2] R. B. Palmer, Proceedings of Informal Conference on Experimental Neutrino Physics, CERN Yellow Report 65-32, 1965, p. 141.

[3] R. B. Palmer, The Design of Long Pulse Monopole Focusing Elements, National Accelerator Laboratory 1969 Summer Study Report SS-70, Vol. I, p. 383.

[4] These calculations were made at NAL using the NAL neutrino flux program. Perfect focusing calculations for conventional horns were performed at BNL and NAL and agreed to within 15%.

Table I. Parameters of Focusing Systems Considered.

1) NAL Horn

Element #	1	2
Current	300,000 amps	400,000 amps
Outer Radius	50 cm	50 cm
Minimum Radius	0.5 cm	6 cm
Thickness	~ 2 mm	2 mm
Inductance	3.0 μH	0.6 μH
Stored Energy	135 kJ	27 kJ

The total energy required, including cable loss, is ~ 217 kJ.

2) Palmer Horn System

Element #	1	2	3
Current	125,000 amps	125,000 amps	125,000 amps
Outer Radius	12 cm	25 cm	50 cm
Minimum Radius	0.75 cm	1.5 cm	3 cm
Thickness	2 mm	2 mm	2 mm
Inductance	1.0 μH	1.0 μH	1.0 μH
Stored Energy	8.5 kJ	8.5 kJ	8.5 kJ

The total energy required, including cable loss, is ~ 36.5 kJ.

3) Fish System

Element #	1	2
Total Current	150,000 amps	150,000 amps
No. of Plates	30	30
Plate Thickness	1.33 mm	2 mm
Current per Plate	5000 A	5000 A
Field	1.4 kG	0.7 kG
Temperature Maximum	500° C	300° C
Power	0.36 MW	0.18 MW

Total power 0.54 MW; total voltage drop 108 V.

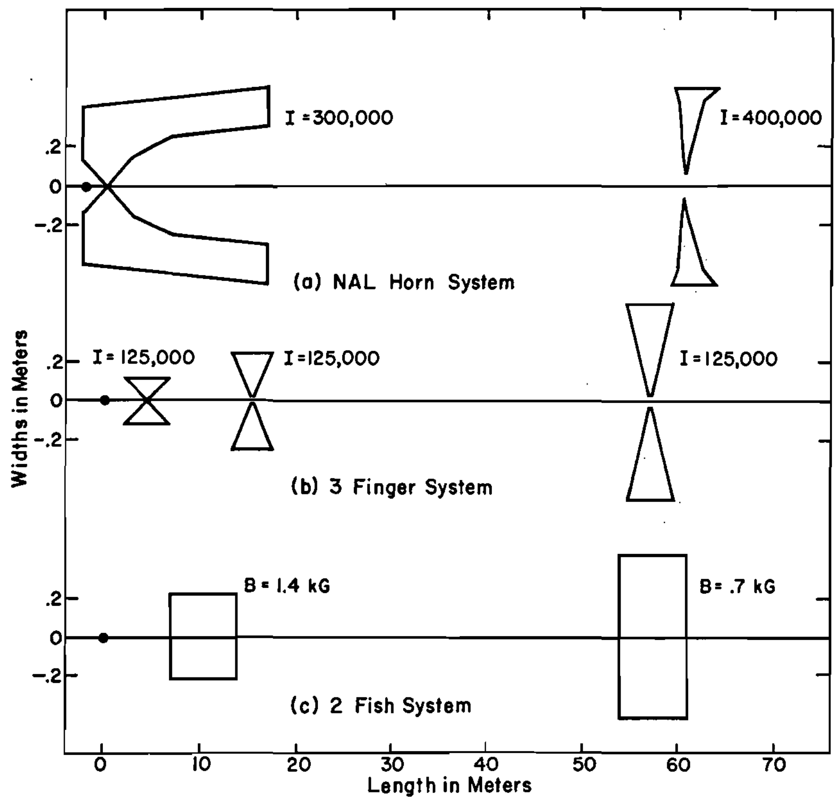

Fig. 1. Dimensions of focusing systems considered.

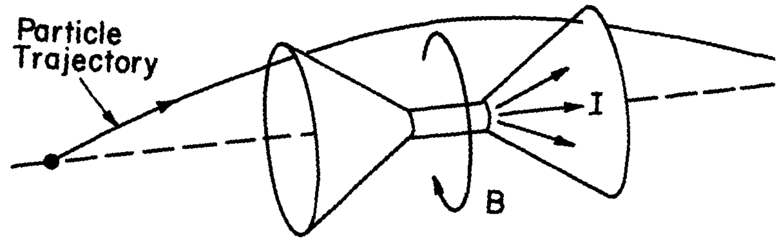

Fig. 2. Principle of horn focusing.

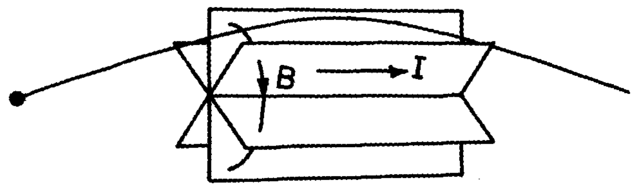

Fig. 3. Principle of fish focusing.

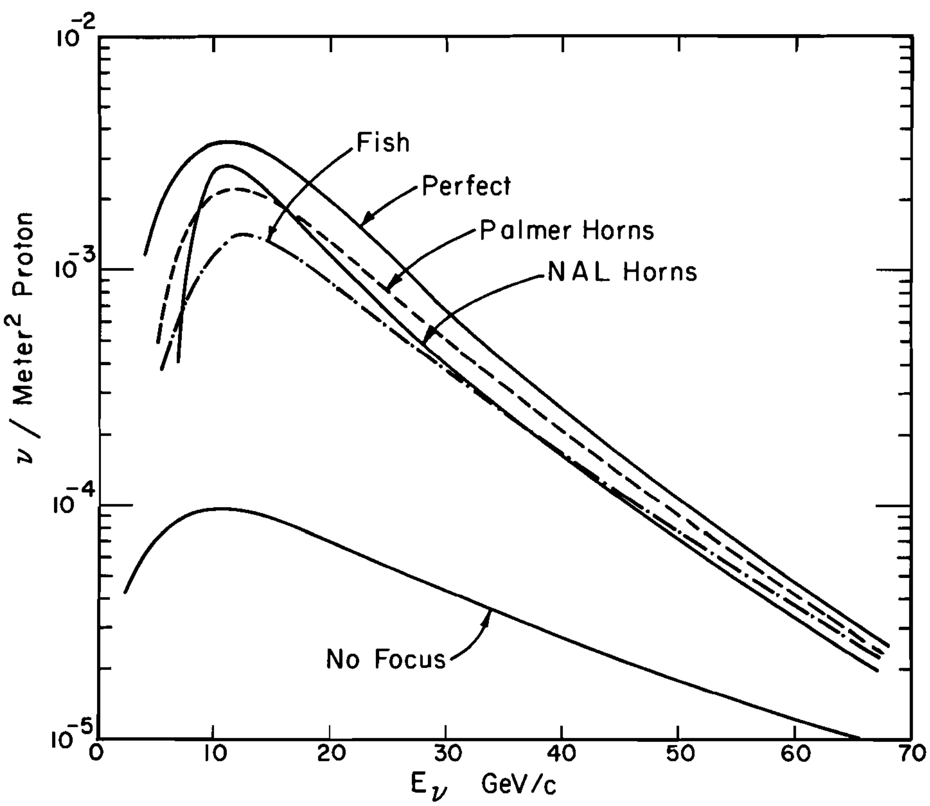

Fig. 4. Neutrino fluxes with no absorption of particles in the focusing system.

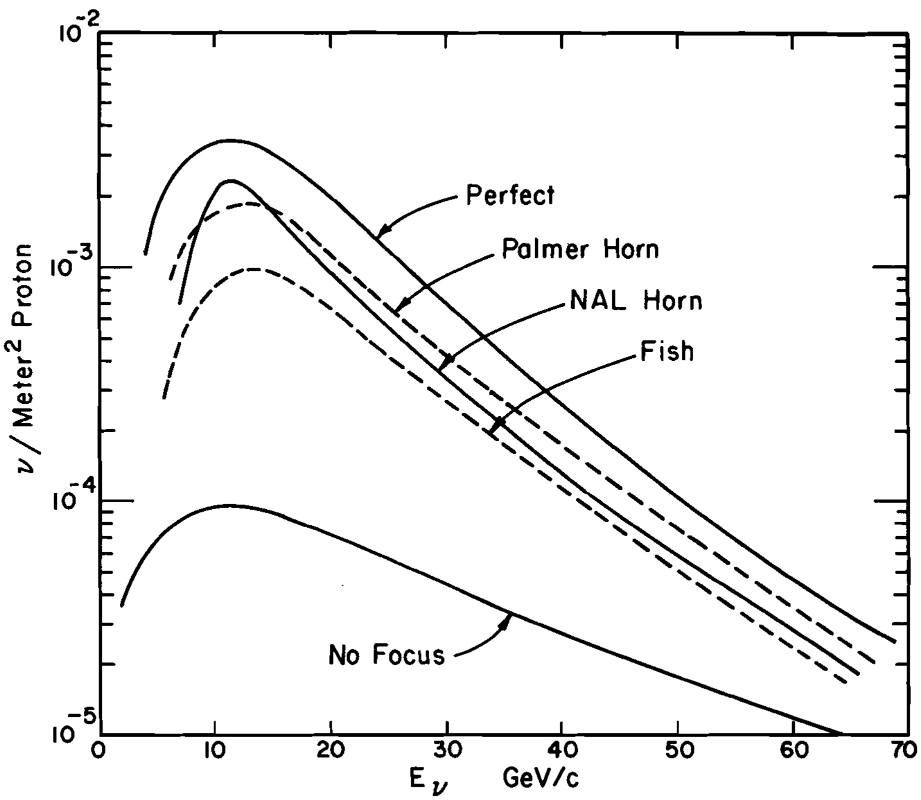

Fig. 5. Neutrino fluxes with absorption of particles in the focusing system.

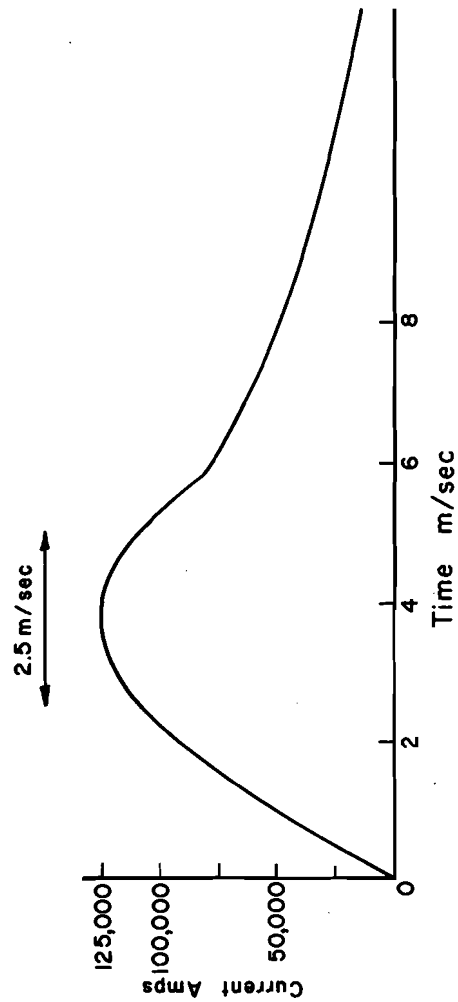

Fig. 6. Horn current pulse shape.