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Variations in the Wide Band and Narrow Band Beams for NuMI

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This note describes two studies that have been done on variations of the reference beams[1,2]. The first suggests a method to reduce the low-energy tail of the narrow band beam (NBB); the second addresses possibilities for minimizing the far/near variations in the spectra for the wide band beam (WBB). Both of these are studied with NUADA (Long Baseline) and are meant to give guidance for GEANT calculations that would be able to answer whether the suggested ideas are in fact improvements, once all the complex processes are included.

Figure 1 shows the results when the momentum selecting collimator is offset from the central ray for the 45 GeV/c NBB beam. The acceptance is changed so that the aperture on the high momentum side remains fixed while the low momentum edge is moved inward, thus creating an asymmetric slit. Three different plots indicate the trade off between total muon neutrino events and the spectrum shape. The NBB study is done using the nominal 45 GeV/c tune. The apertures (the central ray is at X = 0.0) for the three cases are:

"nominal" = (a)	-3.6 cm to +3.6 cm	500 Total NuMu Events
"2/3" = (b)	-3.6 cm to +1.2 cm	400 Total NuMu Events
"1/2" = (c)	-3.6 cm to +0.0 cm	300 Total NuMu Events

For the wide band beam study, a quadrupole transport system is added to the decay pipe $r = 1$ meter, following the nominal 3-horn beam. The motivation for having a series of quadrupoles in the decay region is to reduce the spatial size of the beam, particularly at the downstream end. With the 1 meter radius decay pipe, it is possible that wide angle decays will enter the Near Detector (radius of 0.25 meters), but miss the Far Detector. Putting in quadrupoles having an aperture that is comparable or less than the Near Detector size, should improve the variation in the far/near ratio.

A FODO channel with identical quadrupoles is used to make an approximate 180° phase advance from the end of the horns to the primary proton dump. Matching the horn beam into the FODO is accomplished by running the first quadrupole at half value. The phase advance per cell is given by the expression,

$$\cos \mu = 1 - \frac{1}{2} \left(\frac{3glL}{p} \right)^2$$

μ = phase advance per cell (degrees)

g = quadrupole gradient(kG / cm)

l = quadrupole length(meter)

L = center - to - center distance between quadrupoles(meter)

p = momenta(GeV / c)

The acceptance of a FODO channel varies as a function of phase advance per cell, however, it reaches a broad maximum at 76.5° . The following choices are made-- (i) 60° phase advance per cell, (ii) 1 meter long quadrupoles, and (iii) $L=125$ meters. The total decay space of 800 meters is divided between 50 meters for the horns in the target hall and 750 meters for the decay pipe. Three 60° cells make up the 180° , and the six magnets are equally spaced, giving $L=125$ meters. Rearranging the above equation to calculate the gradient and substituting the quantities,

$$g\left(\frac{\text{kG}}{\text{cm}}\right) = \frac{p}{3lL} \sqrt{2(1 - \cos \mu)} = \frac{p(\text{GeV} / c)}{375}$$

The flux at the far detector is the same for tunes of 10 GeV/c and 20 GeV/c. It drops by 3% for $p=30$ GeV/c and 9% for 40 GeV/c. Tuning the FODO for 10 GeV/c gives a gradient of 2.66667 kG/meter in each of the quadrupoles, except the first one which is half that value for matching purposes. NUADA was then used to obtain the event rates (flux to NuMu events is the same as TM-1951) for quad half-apertures ranging from 4 to 20 inches. The results are shown in Figure 2. Figure 3 shows the (far flux)/(near flux) comparison for the 10 GeV/c tune with 16 inch (half-aperture) quads which retains about 85% of the events. Clearly the FODO is only having an effect at high energy and does not have the improvement of the "hadronic hose" that was recently presented by Jim Hylen [3]. The "hadronic hose" is a 2 mm (diameter) current carrying wire, centered on the optic axis and running the length of the decay pipe.

GEANT should be run with various collimator settings to explore the NBB tail versus event rate. However for the WBB, it's more appropriate that GEANT studies focus on the "hadronic hose", since there is less variation in the far/near ratio with it compared to the FODO. For reference, a NUADA input file is included for the combined three-horn/FODO WBB. The location of the near detector is 500 meters downstream of the beam absorber ($Z=1300$ meters).

References

- [1] A. J. Malensek, "Neutrino Beams Using the Main Injector." (Batavia, IL.: Fermilab Internal Report TM-1951, 1995).
- [2] D. A. Crane et al., "Status Report: Technical Design of Neutrino Beams for the Main Injector (NuMI)." (Batavia, IL.: Fermilab Internal Report TM-1946, 1995).
- [3] J. E. Hylen, "NuMI Beam Update", presented at the Workshop on Fixed Target Physics at the Main Injector, Fermilab, May 1-4, 1997.

Input NUADA File

THREE-HORN BEAM WITH FODO IN DECAY PIPE (NEAR DETECTOR)

TARGET 12

-1.60 1.56 .002 .000 .74

TUNNEL

-2.0 2.00 3.00 12.0 40.0 44.0 45.0 800.

0.16 0.16 0.26 0.26 0.52 0.52 1. 1.

D 800.

SHIELD 490.

RECE 10.

CURRENTS

+.17 +.17 +.17

HORN 1

-.01 0.00 1.60 1.63 1.64

.10 .029 .010 .010 .10

.005 .002 .002 .005

HORN 2

7.89 7.90 10.4 10.43 10.44

.250 .160 .020 .020 .25

.005 .002 .002 .005

HORN 3

41.09 41.1 43.6 43.63 43.64

.50 .235 .040 .040 .50

.005 .002 .002 .005

QUAD 1

50. 1. -0.5419 0.4064

QUAD 2

175.0 1. +1.0837 0.4064

QUAD 3

300.0 1. -1.0837 0.4064

QUAD 4

425.0 1. +1.0837 0.4064

QUAD 5

550.0 1. -1.0837 0.4064

QUAD 6

675.0 1. +1.0837 0.4064

CHAMBER 1

0.25

SPECTRUM 120.

A+

00.0 120.00 3. 0. .060 .0001 4

PFLUX 3.7E20

SUPPRESS

PION 1.

INTEG 0.

KAON

ADD

EMUL 1.

STOP

Figure 1

Figure 2

Figure 3