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POSSIBLE LAYOUTS FOR A MUON-LONG SPILL NEUTRINO (μ-ν_L) BEAM

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ABSTRACT

Possible locations and layouts for a muon and long-spill neutrino beam were studied. If a high-momentum long-spill separated beam for counter and spark-chamber experiments is planned for beam 1 it is advantageous to install the muon-neutrino beam as a branch of beam 1 to share the experimental area with the separated beam. Otherwise it would be simpler to install the muon-neutrino beam on beam 3.

POSSIBILITY 1

We can use the 15 mrad high-flux beam from T2. The π^+ flux is estimated to be 9×10^8 per pulse at 50 GeV (communication from J. Sanford). In Yamanouchi's beam (1968 Summer Study, Vol. II, p. 1) the number of 50 GeV π^+ for entrance system 1 is

$$\underbrace{5 \times 10^{12}}_{\substack{\text{protons on} \\ \text{target}}} \times \underbrace{1/3}_{\substack{\text{fraction of} \\ \text{protons} \\ \text{interacting}}} \times \underbrace{10\% \times 50}_{\substack{\text{momentum} \\ \text{spread of} \\ \pi^+ \text{ in GeV/c}}} \times \underbrace{0.96 \times 10^{-3}}_{\substack{\pi^+ \text{ yield per} \\ \text{GeV/c per} \\ \text{interacting p}}} = 8 \times 10^9$$

This number of π^+ will yield 1.34×10^8 μ in a momentum spread of $\Delta p/p = \pm 5\%$. Straightforward scaling gives

$$\frac{9 \times 10^8}{8 \times 10^9} \times 1.34 \times 10^8 = 1.5 \times 10^7 \ \mu$$

per pulse if Yamanouchi's muon channel were tied on to the 15 mrad high-flux beam from T2. Two things should be pointed out:

1. The Yamanouchi decay length is only 200 m long. It should be possible to lengthen the decay path and increase the μ flux by, say, a factor of 2.

2. Even with the lengthened decay path it is doubtful that the neutrino yield is much more than 10^8-10^9 per pulse which indicates that this beam is useless as a long-spill ν beam (ν_L beam).*

*The subscripts L, S refer to long, short spills.

POSSIBILITY 2

We can use T3 to design a proper high-flux μ-ν_L beam. The production target should be about 2 interaction lengths long, namely about 1 m for Be or 0.4 m for Cu. We shall take hadrons produced at 0° angle. Immediately after the target there will be a quadrupole matching section perhaps 100 m in length. This matching section has yet to be designed. Following the matching section, we have, say, a 600-m long decay channel. The quadrupoles in the decay channel can have the following properties, as an example. (The detailed beam design will be given in a separate report.)

Lattice: FODO
Cell length: 60 m (10 FODO cells)
Total number of quadrupoles: 20 (10 F and 10 D)
Quadrupole length: 1 m
Quadrupole field gradient: 67 kG/m
Max. beam diameter: ~ 20 cm (8 inch)
Max. beam divergence: ~ 1 mrad
Low momentum cut-off: ~ 30 GeV/c
Quadrupole aperture: 8-inch diameter
Quadrupole field on pole tip: 6.7 kG
Quadrupole outer dimension: 20-inch diameter

The construction could be a 600 m long 8-inch diameter vacuum pipe buried in earth shielding, pumped from both ends to a reasonable vacuum (1 mm Hg is adequate). Twenty manholes will be placed along the pipe at 30 m intervals for installing the quadrupoles. Upstream of the decay channel there should be a 100-m long, 1-m diameter vault to house the target and the matching quadrupole section. Downstream of the decay channel there should be a bending magnet (say, picture-frame type) with an aperture 8 in. × 8 in., energized to about 20 kG by an NI $\approx 4 \times 10^5$ amp-turn. The overall dimensions of the magnet would be about 40 in. (wide) × 20 in. (high). To bend 100 GeV/c muons 30 mrad we need a $B\ell$ = 100 kGm, so this 20 kG bending magnet will have to be about 5-m long.

Following the bending magnet there should be an iron hadron filter 1 m^2 in cross section and 20-m long with an 8 in. diameter Be channel for the μ beam set at 30 mrad angle. It should be pointed out that although the μ beam has a diameter of only 8 in., since the decaying hadron beam in the channel has a maximum divergence of about 1 mrad, neutrinos from decays at the beginning of the 600 m channel will give a ν beam radius of 1 mrad × 600 m = 0.6 m or a diameter of 1.2 m.

It was pointed out by A. Maschke that to do other experiments in experimental area E3 the μ-ν_L* target could be removed and the matching and decay quadrupole sections could then transport the primary proton beam 700 m to the hadron filter which could be modified into or replaced by a primary target station for other experiments in E3. The entire arrangement is shown diagramatically in Fig. 1.

It is difficult to estimate the fluxes without detailed calculation. But educated guesses give for 50% of accelerator beam on target a μ flux at 100 GeV/c, with $\Delta p/p = \pm 5\%$, of about 5×10^9 per pulse, and a total ν flux of about 10^{11} per pulse.

POSSIBILITY 3

We can consider installing the beam described in Fig. 1 in or along the ν-tunnel of beam 1 leading to the bubble chamber (BC), deflecting the μ beam into the counter-spark chamber (C-SC) experimental area E1 provided for a branch of the high-momentum rf-separated hadron beam. In that case, when the BC is taking ν pictures from the "horn" ν beam, C-SC experiments using the rf-separated beam can be performed in E1; and when the BC is taking hadron pictures from the rf-separated beam, muon and counter neutrino experiments can be performed in E1 using the μ-ν_L beam.

To install the μ-ν_L beam in the "horn" ν-tunnel has many disadvantages:

1. The time required to interchange the "horn" system and the quadrupole system is necessarily long. Design of the tunnel to enable this interchange by remote handling (because of the extremely high radiation level) will lead to complicated and unreliable mechanical devices and will greatly add to the cost of the tunnel.

2. It is not clear how the quadrupoles and the beam pipe shown in Fig. 1 can be put in and taken out of the 5 ft × 5 ft ν-tunnel easily.

3. Even if the vacuum beam pipe and quadrupoles are somehow put in the 5 ft × 5 ft tunnel, the lack of shielding immediately outside the 8 in. diameter beam pipe will produce undesirable "halos" around the μ beam, which especially at high fluxes, may be detrimental to μ experiments. It has been suggested that one can flood the tunnel with water for "halo shielding." This clearly is unattractive.

4. With the μ-ν_L beam in the tunnel, the ν_L beam will be along the same line as the short-spill ν beam (ν_S beam) for the BC. This implies that the C-SC unit using ν_L beam will have to be located in line with the BC (and perhaps other C-SC units) using the ν_S beam. Although this is physically possible, it means that detector unit(s) downstream will receive a beam of poorer quality than if the detector were pushed up immediately against the shield. Such a linear array of detectors may also cause spatial and operational interferences.

For these reasons it is more attractive, and also perhaps more economical, to install the μ-ν_L beam permanently as a separate beam alongside the "horn" ν beam (ν_S beam). The layout of the three beams--ν_S beam (ν), μ-ν_L beam (μ), and the separated hadron beam (σ)--is then as shown in Fig. 2. The ν beam and the μ beam are on the same level, 15 feet below grade, inclined at 20 mrad to each other, and have exactly the optimal designs for each beam without any compromise. The 200-GeV primary p beam is switched 20 mrad from target T1ν for the ν beam to target T1μ for the μ beam by a fast (a few msec rise/fall time) switching magnet at the point A. This magnet could have parameters:

Length: 7 m
Field: 20 kG
Aperture: 2 cm (high) $\times$ 10 cm (wide)
Outer dimension: 15 cm (high) $\times$ 35 cm (wide)
Construction: Thin laminated steel core with stranded coil.

The μ beam will be pitched up after the hadron filter F into the experimental area E1 above grade. (If this pitching section is overly expensive, it may be better to pitch the entire μ beam at a very shallow angle upward.)

The separated hadron beam (σ beam) as conceived will be above grade. The primary proton beam will be bent upward by a switching magnet at B onto target T1σ for the σ beam. The rf separators in the σ beam will be capable of pulsed operation to give a short beam pulse σ_S to the BC, or CW operation to give a long beam spill σ_L, to C-SC experiments in E1. The switching of the σ beam between the BC and E1 will be accomplished by a fast switching magnet at point C.

Several features of the three-beam operation are of interest:

1. The three beams may all be operated during the same accelerator pulse but they will never be operated at the same time; i.e., they will only be operated sequentially. This distinguishes them from, say, targets T2 and T3, which are operated at the same time during a pulse and must share the primary beam by means of a beam splitter. The one primary beam coming down beam 1 will be sequentially switched between the three targets T1ν, T1μ, and T1σ.

2. Compared to Possibility 2 of installing the μ-ν_L beam at target T3, this scheme saves the cost of the experimental area E1 which will be shared between the μ-ν_L beam and the separated hadron beam. In addition, by installing the μ-ν_L beam as part of beam 1 we make use of utility runs which have already been provided, and save the long utility runs to beam 3. Both the experimental area and the utility runs are high-cost items. The cost saving is considerable and may amount to about \$10 million.

3. Because of the pulsed "horn" the ν beam can provide only short beam pulses. On the other hand there is no point in ever operating the μ beam for short pulses. The σ beam should be capable of either long or short operations. We have, thus, the following table where D signifies operation of C at a low or zero comment:

	Long	Short	Intensity
ν beam		A	high
μ beam	B		high
σ beam	D	C	low

During an accelerator pulse it makes sense to operate only one long spill (with two long spills they have to share the available flat-top length and each will have only half of the duty factor). Hence we can, for example, operate the three beams during an accelerator pulse in the following modes:

Mode 1	A (short)	B (long)	C (short)
	↑	↑	↑
	ν_S for BC	μ-ν_L for C-SC	σ_S for BC
Mode 2	A (short)	D (long)	C (short)
	↑	↑	↑
	ν_S for BC	σ_L C-SC	σ_S for BC

For either mode the BC will take two pictures, one ν picture and one hadron picture. For Mode 1, muon-neutrino C-SC experiments will be run in E1, and for Mode 2 hadron C-SC experiments will be run in E1. In Mode 1, since both the A (short) and the B (long) beam spills require high intensity they will have to share the total primary p flux available. Of course, if the BC can triple-pulse we may even operate in

Mode 3	A (short)	D (long)	C (short)	D (long)	C (short)
	↑	↑	↑	↑	↑
	ν_S for BC	σ_L for C-SC	σ_S for BC	σ_L for C-SC	σ_S for BC

4. It is obvious, now that the μ-ν_L beam is installed permanently and separate from the ν_S-beam tunnel, that all the disadvantages mentioned above of installing the μ-ν_L beam in the same 5 ft $\times$ 5 ft ν_S tunnel cease to exist. For example we can check that the empty 5 ft $\times$ 5 ft ν tunnel is sufficiently separated from the μ beam so as not to cause "halos."

5. Because the three beams are operated sequentially in time there is no background interference between experiments operating in these beams.

6. The Maschke proposal is still valid: target T1μ can be removed and the primary p beam can be transported down the μ beam to the hadron filter. The hadron filter can then be modified to or replaced by a target station for C-SC hadron experiments in E1 just as target station T2 is used for experiments in E2. In the remote event that no BC is ever made available to NAL the existence of the μ beam operated as proton transport makes beam 1 as versatile and useful as beams 2 and 3.

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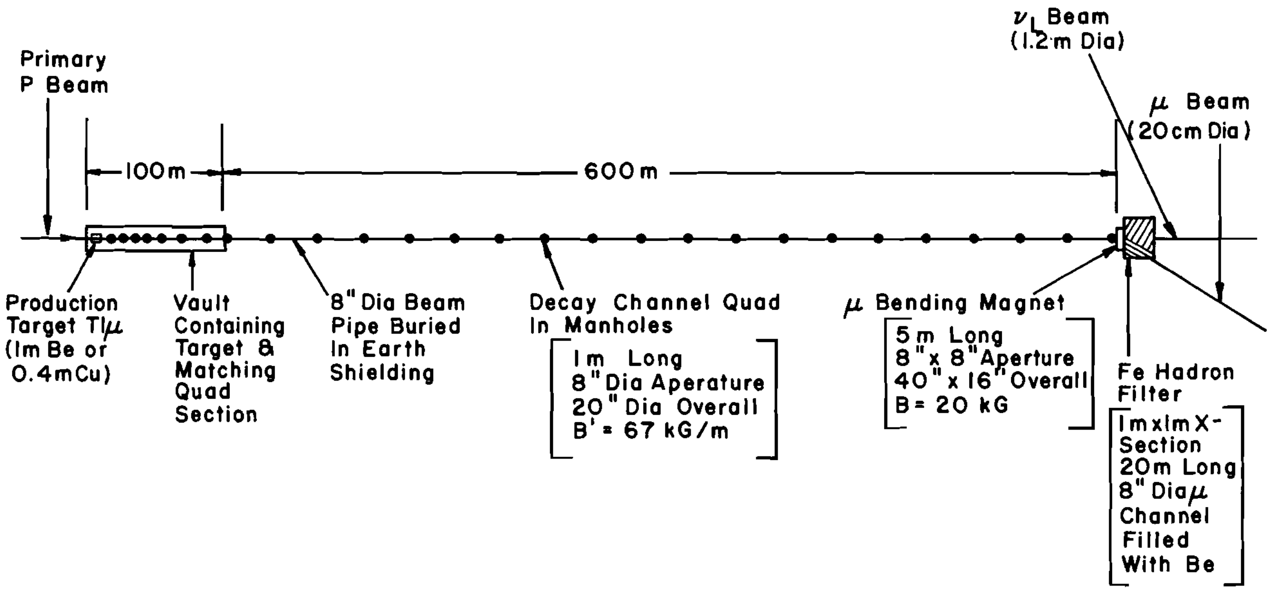

Fig. 1. Combined muon and neutrino beams.

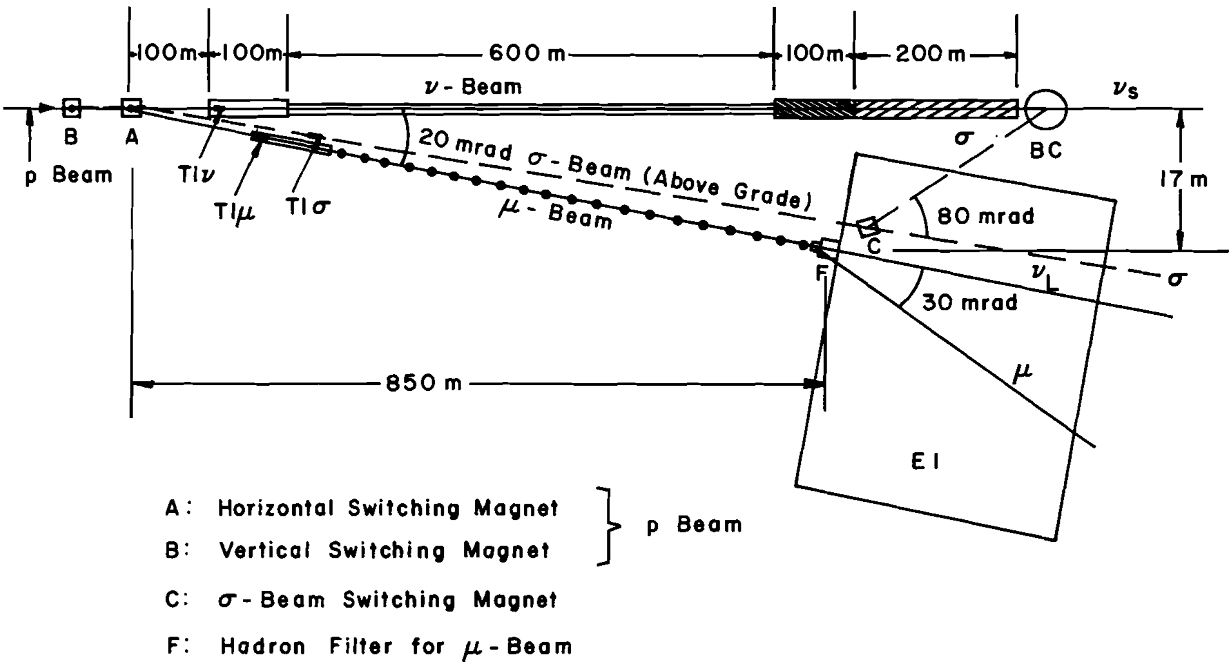

Fig. 2. Combination of muon, neutrino and (strongly interacting particle) beams. Longitudinal and transverse distances not to same scale.