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Main Injector Beam to the New Muon and Meson Areas

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Main Injector Beam to the New Muon and Meson Areas

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Abstract

Measured beam parameters from the Main Injector are used to calculate the beam envelope from MI extraction to the Meson area. The primary beam is then transported to a straw-man experiment in the MP beamline. Secondary yields are also calculated for the MTest test beam.

1 The Beam Lines

In this exercise, the author assumes that no physical modification to the P1, P2, and P3 lines are made. The section from F49 to VH94 (roughly the beginning of the A0 region to the beginning of Switchyard) is modified as per “Switchyard in the Main Injector Era Technical Design Report”. Switchyard and M01 are not modified, however, all cryogenic magnets are assumed to have an EPB type aperture. The MTest beamline remains as it was for the 1999 fixed target run. The MP beamline is modified as necessary to allow transport to enclosure MP5. Note that the penetrations in the MC beamline allow for optics similar to those for MP—thus, a solution for MP is also a solution for MC.

2 Initial Beam

2.1 Vertical Beam Size

The vertical emittance and orientation is taken to be that of the circulating beam at the upstream end of element H522¹. Table 1 summarizes the measurements; table 2 scales the results to 95% and 99% beam envelope.

The vertical size of the beam is calculated by

$$y = \sqrt{(\epsilon\beta) + \left(\frac{\Sigma p}{p}\eta\right)^2} \quad (1)$$

¹This was measured by D. E. Johnson on 9 Feb 2000, as documented in the Main Injector log book. The measured η and $\dot{\eta}$ were later found to be zero. The location of the measurement was clarified by Yang on 17 March 2000.

³Private communication, Ming-Jen Yang, 8 March 2000. Yang wrote the code for this measurement.

α	1.183
β	17.59
η	0.00
$\acute{\eta}$	0.00
ϵ_N	2.40944
$\Sigma p/p$	0.19685

Table 1: Vertical values for Main Injector circulating beam at H522. The emittance quoted is the 1σ normalized emittance (units are $\pi \cdot mm \cdot mr$); $\Sigma p/p$ is the 1σ momentum spread (units are 10^{-3}).³

Parameter	1σ	95%	99%
y	0.57566	1.41007	1.74704
\acute{y}	0.05069	0.12417	0.15385
r_{43}	-0.76370	-0.76370	-0.76370

Table 2: Vertical values for Main Injector circulating beam at H522. Units for y and \acute{y} are mm and mr .

The 1σ values are calculated using the 1σ values in table 1. For the other values, the emittance is scaled as

$$-\ln(1 - f) \tag{2}$$

where f is the fraction of the beam⁴, and the momentum spread is scaled as $\sigma_f/\sigma_{0.68}$, where f is (still) the fraction of the beam.

2.2 Horizontal Beam Size

The extracted beam is modeled as a uniformly filled box in phase space. The emittance of this box is then assumed to be 99% of the beam. The 99% value is scaled as equation 2 to the 1σ value. When the 1σ values for x and \acute{x} are used as input, and the beam is traced using TURTLE⁵, the extracted beam is found to be in suprisingly good agreement with measurements.

Initially, the beam was modeled begining at the center of Q512. Table 3 summarizes the horizontal parameters for 99% emittance, lists the Twiss parameters, and scales down to 1σ for this location.

For consistency, table 4 lists the 1σ and 99% envelopes at the upstream end of H522 (the same location the vertical parameters are listed).

⁴D.A. Edwards, "An Introduction to Circular Accelerators", section 2.6.3, as found in "AIP Conference Proceedings No. 127", edited by Melvin Month, Per F. Dahl, and Margaret Dienes, 1983

⁵D.C. Carey, et al., "TURTLE with MAD Input", Fermilab-Pub-99/232.

99% Box		Twiss Parameters		1 σ	
x	1.15866	β	16.33025	x	0.38178
\acute{x}	0.07095	α	0.0	\acute{x}	0.02338
ϵ_N	10.51401	.	.	ϵ_N	1.14154

Table 3: Horizontal values for Main Injector extracted beam at Q512. Units for x and \acute{x} are mm and mr . The emittances quoted are the 99% and 1 σ normalized emittance (units are $\pi \cdot mm \cdot mr$)

Parameter	1 σ	99%
x	1.075	3.264
\acute{x}	0.057	0.173
r_{21}	0.989	0.983

Table 4: Horizontal values for Main Injector extracted beam at H522. Units for x and \acute{x} are mm and mr .

3 Results

Two types of graphs are displayed: beam envelopes and distance to beam pipe. All calculations are carried out using TRANSPORT.⁶

The beam envelopes are the “1 σ ” and the “99%” envelopes (the 1 σ envelope always lies inside the 99% envelope). For the 1 σ envelope, momentum spread is not included and the calculation is carried out to first order. For the 99% envelope, momentum spread is included and the calculation is carried out to second order. Although other reasonable envelopes and definitions may be of interest, these are the envelopes and their definitions for this paper.

The distance to the beam pipe is displayed in units of beam sigma. Specifically, what is shown is the distance from the 99% envelope to the aperture, in units of beam sigma, where the 99% envelope and beam sigma are defined as above.

3.1 MI Extraction to Switchyard

This section summarizes the results of beam transport from MI extraction to the downstream end of VH94.

The 99% beam envelope and the 1 σ envelope for Main Injector beam from extraction to VH94 is shown in Figure 1. Note that the horizontal scale is meters, beginning at MI extraction. The vertical scale is millimeters.

Figure 2 shows the distance from the 99% envelope to the beam pipe in units of beam sigma at that point. The 99% and 1 σ envelopes are defined as previously stated.

⁶D.C Carey, et al., “Third-Order TRANSPORT with MAD Input”, Fermilab-Pub-98-310.

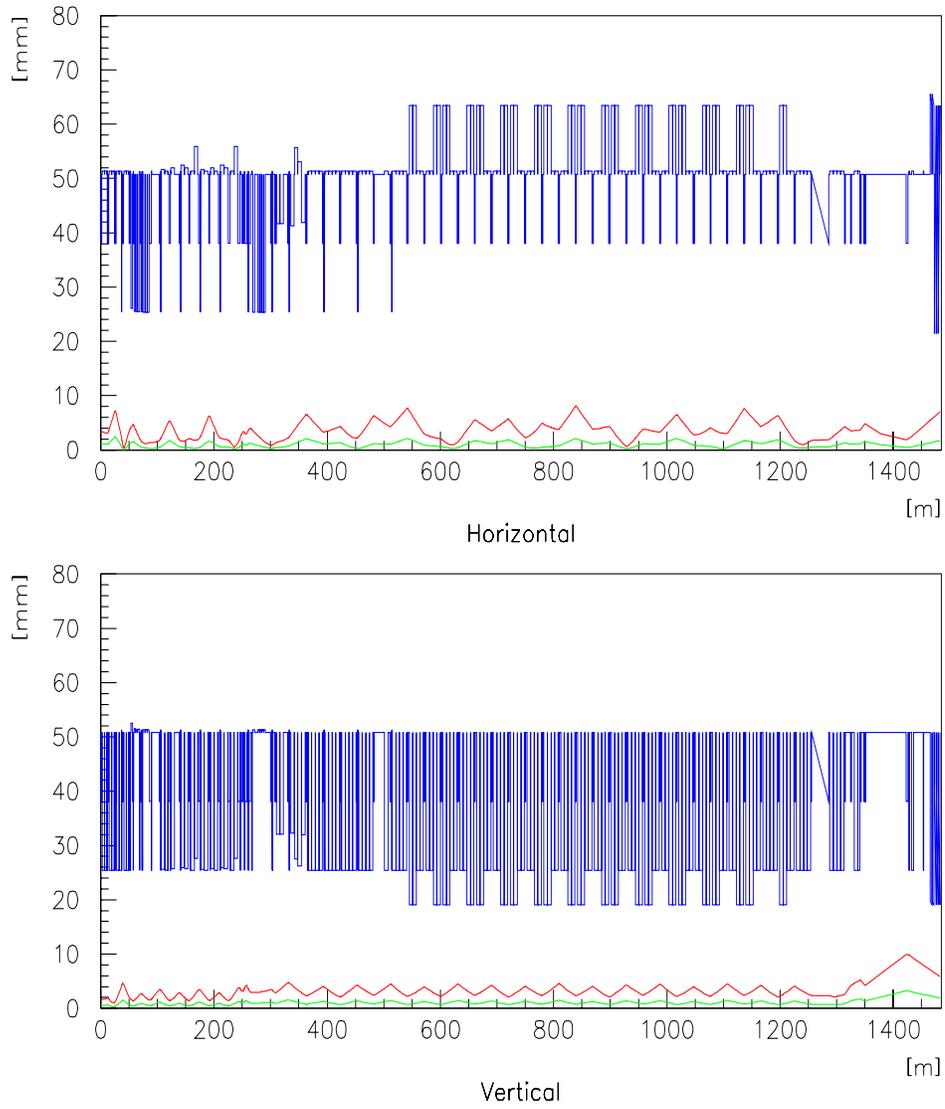


Figure 1: 99% and 1σ beam envelopes from MI extraction to VH94.

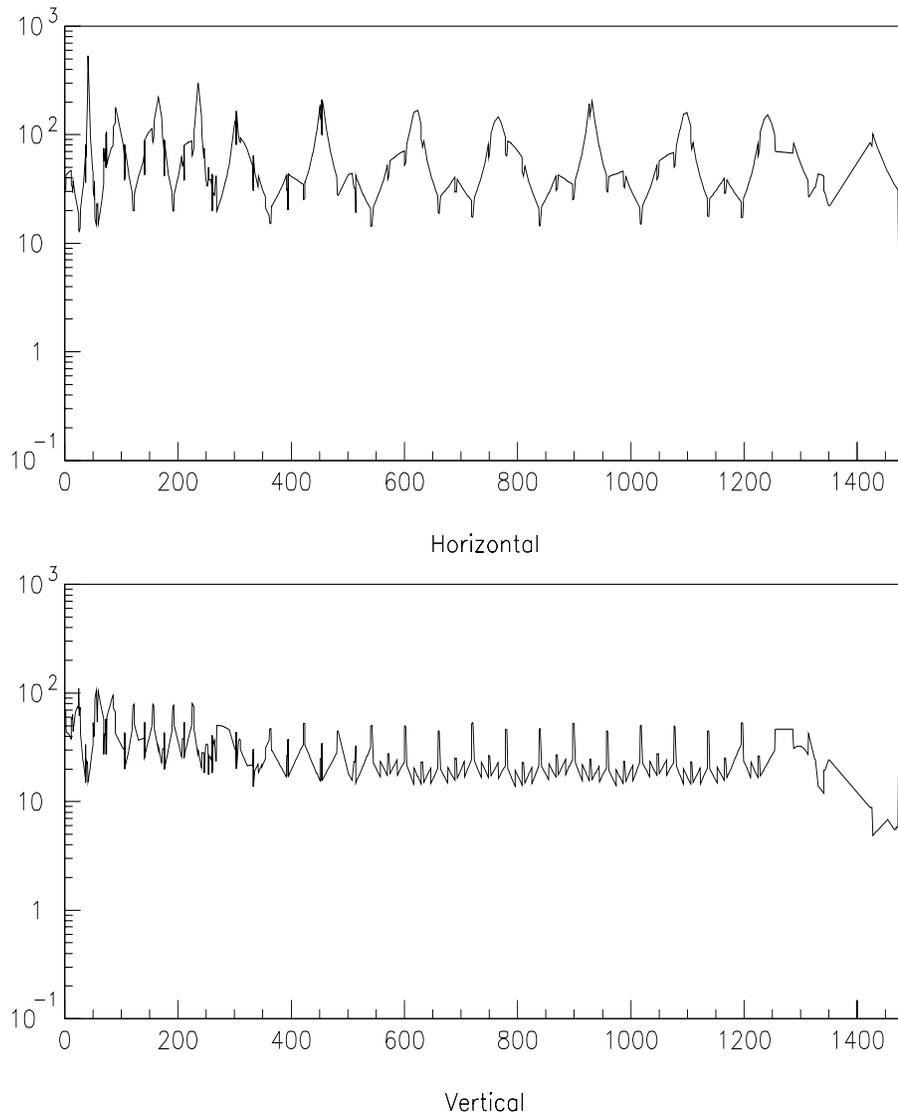


Figure 2: Distance from 99% envelope to beam pipe, from MI extraction to VH94, in units of beam sigma (σ). Note the log scale.

3.2 Switchyard to Meson

This section summarizes the results of beam transport from MI extraction to the center of the meson target train. All physical devices are the same as those currently extant in Switchyard and M01. The left-bend apertures are sized as EPBs.

The 99% beam envelope and the 1σ envelope for Main Injector beam from VH94 to the center of the meson target train is shown in Figure 3. The horizontal scale is meters, beginning at MI extraction. The vertical scale is millimeters.

Figure 4 shows the distance from the 99% envelope to the beam pipe in units of beam sigma at that point. The 99% and 1σ envelopes are defined as previously stated.

3.3 Meson Target Train to MP5

This section summarizes the results of beam transport from the center of the meson target train to the upstream end of MP5. Optics beyond this point are dependent on the experiment. One should note that the penetrations for the MC beamline are located such that the optics solution presented here works also for MC.

The 99% and 1σ envelopes are shown in Figure 5. The horizontal scale is meters, beginning at the center of the meson target train. The vertical scale is millimeters.

Figure 6 shows the distance from the 99% envelope to the beam pipe in units of beam sigma at that point. The 99% and 1σ envelopes are defined as previously stated.

3.4 Projected Particle Rates in MTest

For this exercise, the layout of the existing MTest beamline is not changed. The size of the primary beam at the target is determined using TRANSPORT. The initial size of the secondary beam is taken to be the same as the primary beam; the solid angle is chosen to be large enough to fill the first aperture.

The transmission is defined to be the number of particles at the end of the beamline divided by the number of particles at the beginning. This number is determined using TURTLE, which allows the user to specify apertures. The particles are not allowed to decay.

The production is defined as the number of particles produced at the target per incident proton. This number is calculated using the Malensek parameterization⁷.

The final rate is calculated by multiplying the transmission by the production, and accounting for particle decay. During the 1999 fixed target run, the MTest beamline typically received 5×10^{11} protons over a 40 second spill, or

⁷Malensek, A. J., "Emperical Formula for Thick Target Particle Production", FN-341 (1981)

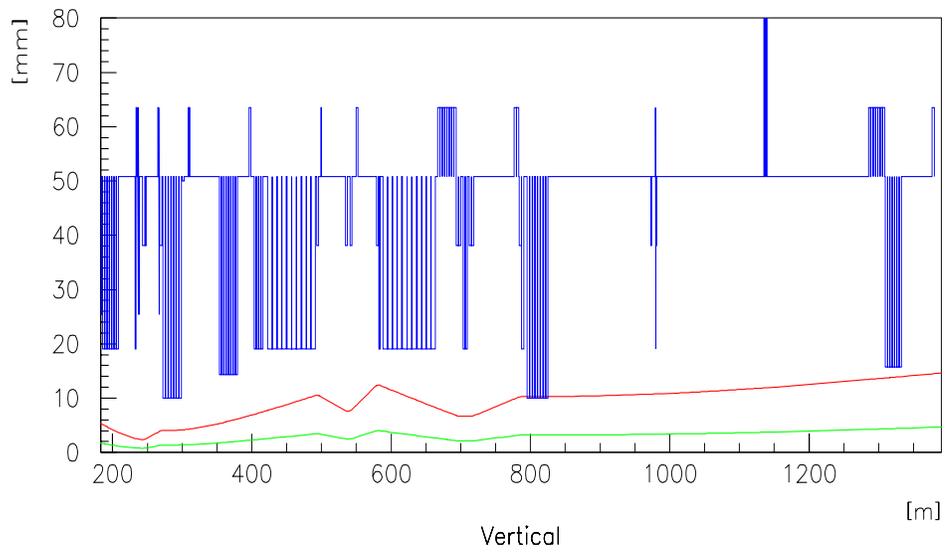
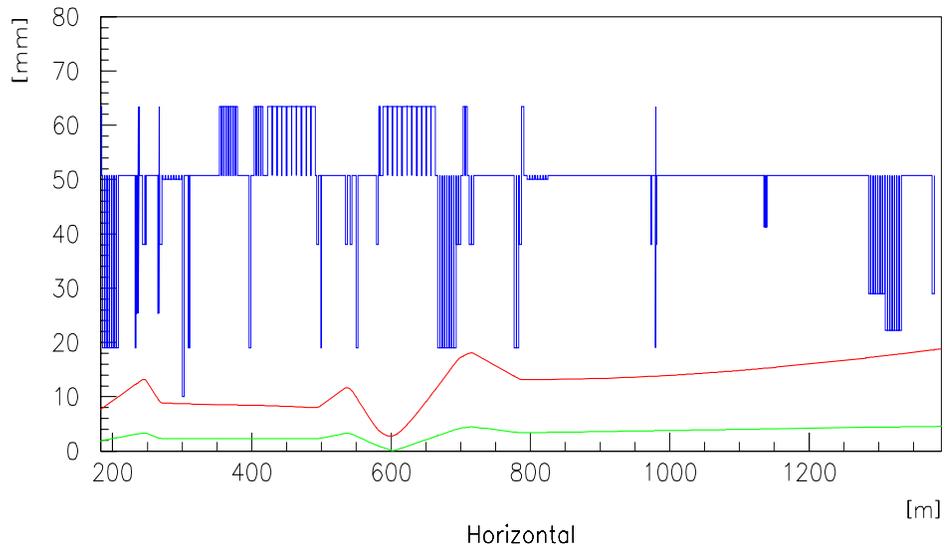
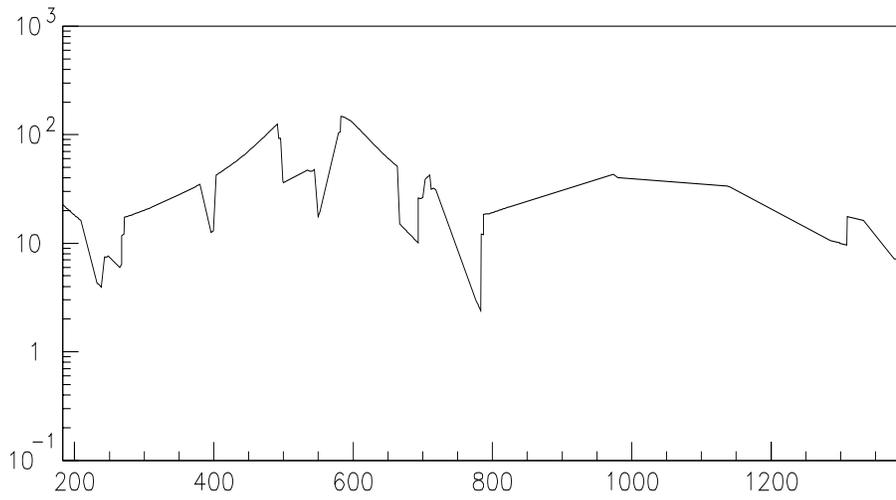
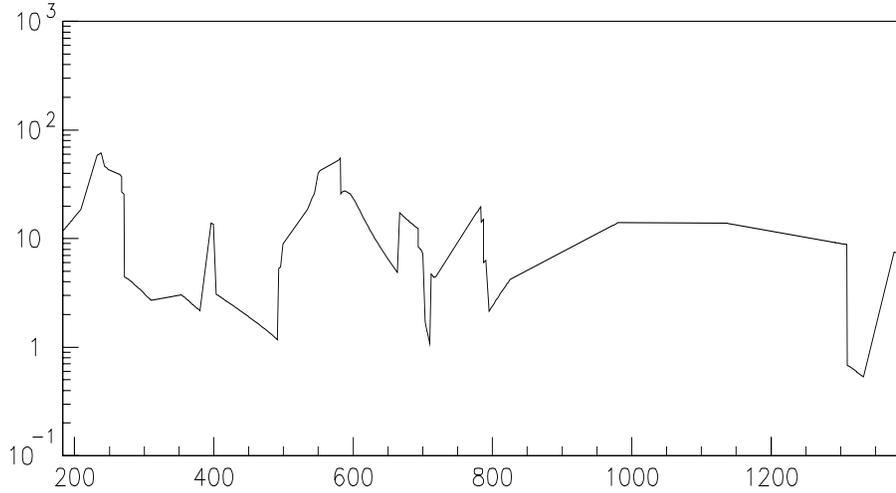


Figure 3: 99% and 1σ beam envelopes from VH94 to the center of the meson target train.



Horizontal



Vertical

Figure 4: Distance from 99% envelope to beam pipe, from VH94 to the center of the meson target train, in units of beam sigma (σ). Note the log scale.

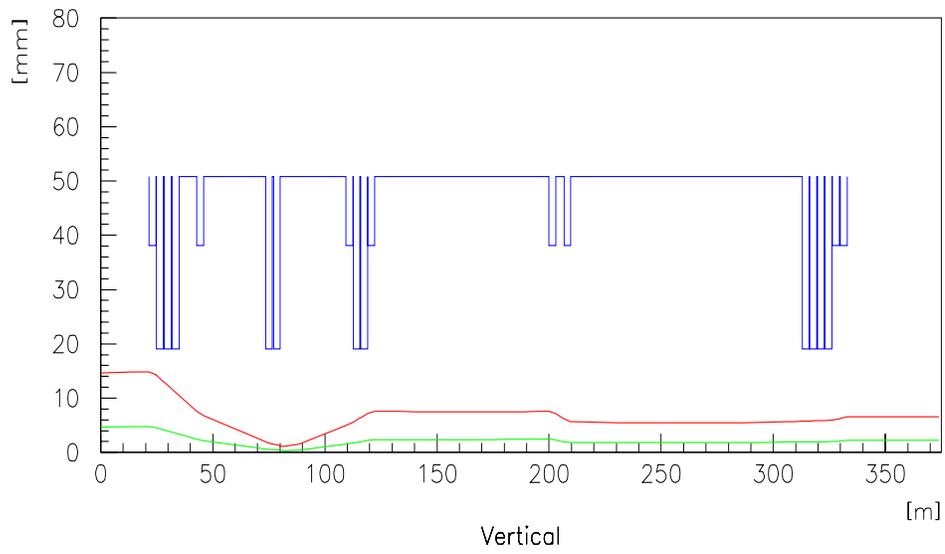
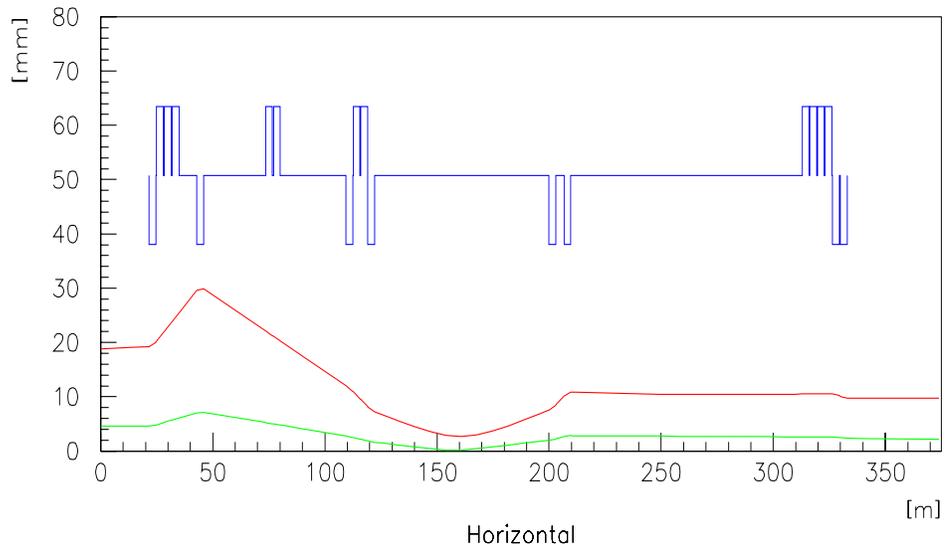
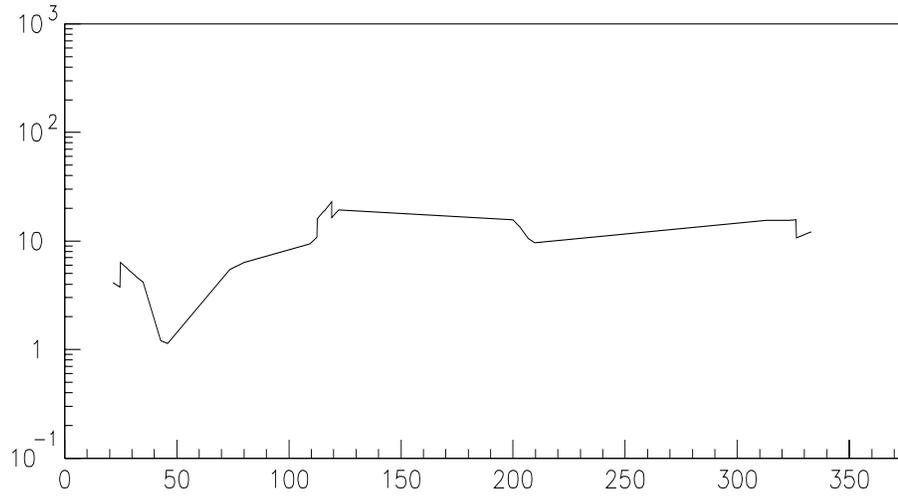
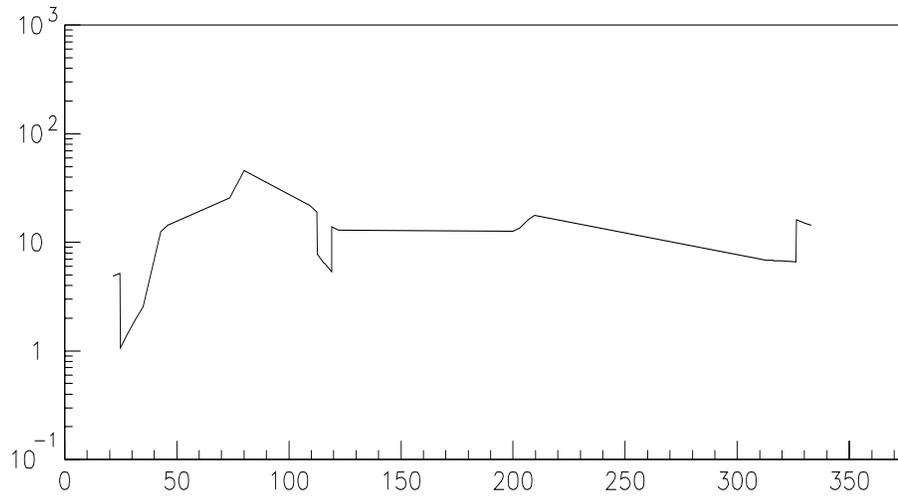


Figure 5: 99% and 1σ beam envelopes from the center of the meson target train to the MP5 pre-target region.



Horizontal



Vertical

Figure 6: Distance from 99% envelope to beam pipe, from the center of the meson target train to the MP5 pre-target region, in units of beam sigma (σ). Note the log scale.

Particle	Secondary Momentum [GeV/c]			
	100	60	30	15
$\pi+$	0.56	13.80	13.84	5.42
$\pi-$	0.08	3.85	6.03	3.79
$K+$	0.10	0.77	0.25	0.02
$K-$	0.00	0.07	0.09	0.01
$p+$	85.94	55.62	9.94	1.97
$p-$	0.00	0.02	0.18	0.26

Table 5: Particle rate in kHz, assuming 1×10^{10} protons per MI pulse, for various species and momenta, in the MTest beamline. The current MTest beamline is a zero-degree production beamline, resulting in a large proton fraction.

roughly 1×10^{10} protons per second (recall that MI flat-top is 1 second). Table 5 lists the rates for pions, kaons, and protons in the MTest beamline at four momenta; units are kHz for 1×10^{10} protons per pulse.

3.5 Switchyard to Muon

This section summarizes the results of beam transport from MI extraction to the KTeV target in NM2. All physical devices are the same as those currently extant in Switchyard, NM1, and NM2. The mu-bend apertures are sized as EPBs.

The 99% beam envelope and the 1σ envelope is shown in Figure 7. The horizontal scale is meters; the vertical scale is millimeters.

Figure 8 shows the distance from the 99% envelope to the beam pipe in units of beam sigma at that point. The 99% and 1σ envelopes are defined as previously stated.

Note that the beam is not transported cleanly through the entire line. Although this is not acceptable for high intensity running, it shows that low intensity beam may be possible.

4 Conclusion

For this study, it was assumed that the A0 region was modified as per “Switchyard in the Main Injector Era Technical Design Report”, and that the cryogenic magnets in Switchyard had EPB type gaps.

Under these assumptions, it is possible to transport 120 GeV/c protons from the Main Injector to the Meson and New Muon areas with minimal (on the order of 1%) scraping. Regarding the Meson area, this scraping occurs at the FSeps (which produce the three-way split to Meson). Regarding the New Muon area, the scraping occurs at the MuSeps, MuLams (both of which establish the Neutrino/Muon split), and the final focusing quadrupoles. Thus, multi-beam, high-intensity running to the Meson area is precluded, as is high intensity running to the New Muon area.

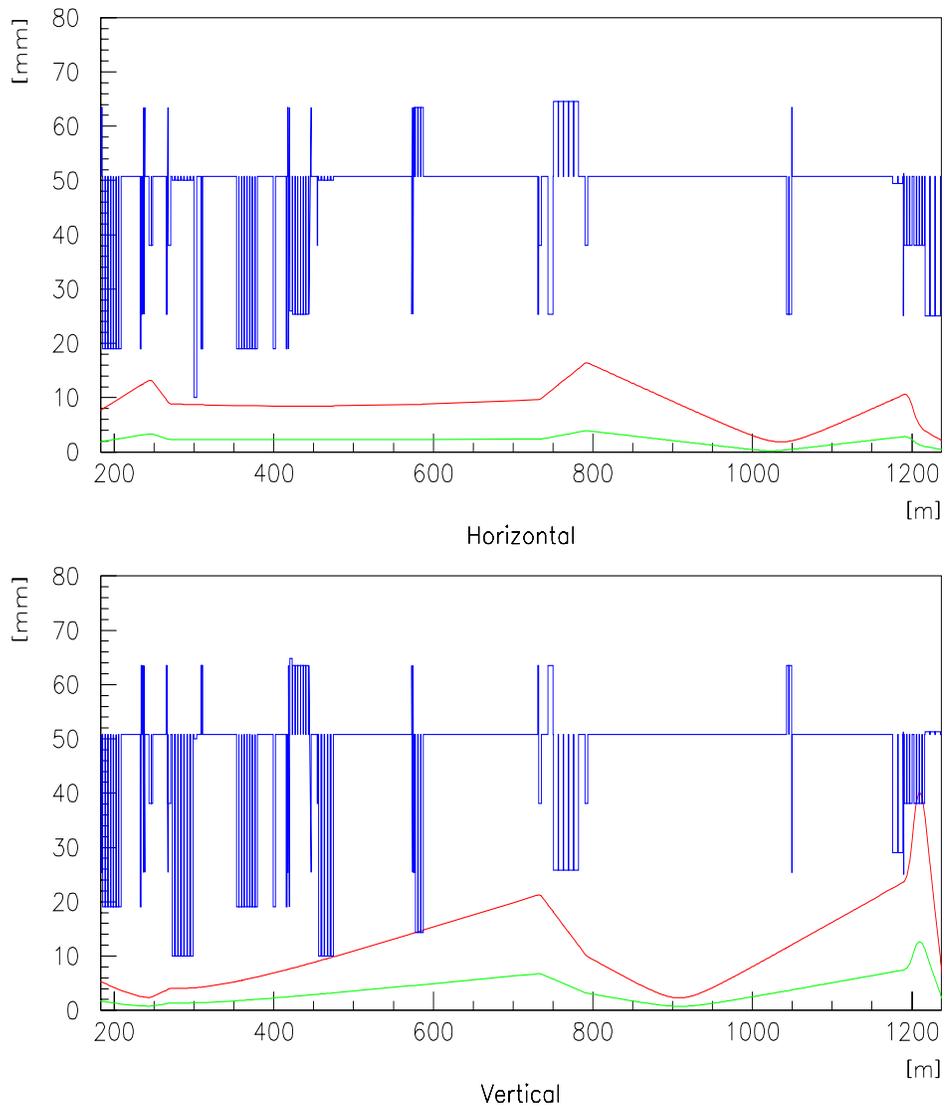


Figure 7: 99% and 1σ beam envelopes from VH94 to the present KTeV target.

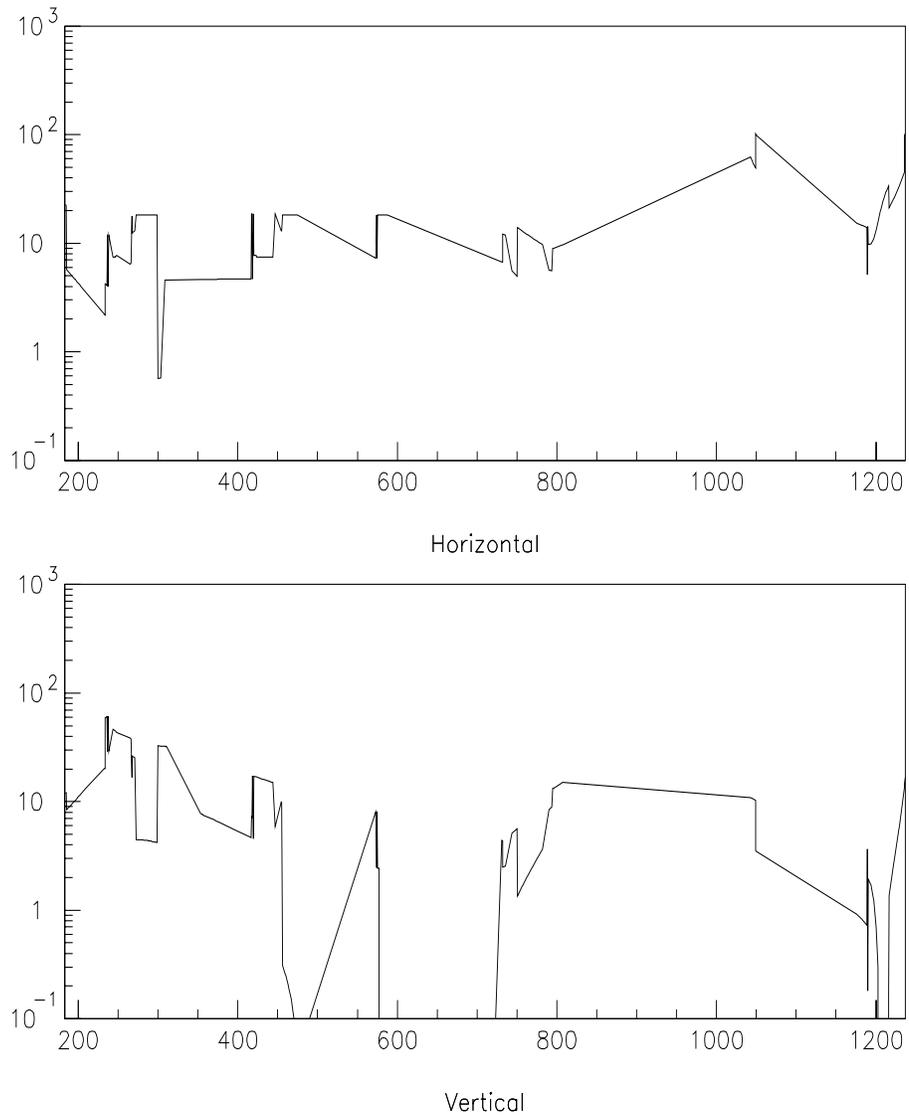


Figure 8: Distance from 99% envelope to beam pipe, from VH94 to the present KTeV target, in units of beam sigma (σ). Note the log scale.

However, single-beam to Meson is possible. In this case, the existing MTest test beam may be utilized with no modifications. Also, the MP or MC beamlines may be utilized, with minimal changes, for primary transport to experiments located in the Meson Detector Building. Finally, low intensity beam is possible to the New Muon area.

In order to transport high intensity multiple beams to the Meson area further modifications would be necessary (most likely, adding optics and relocating the three-way split). In order to transport high-intensity beam to the New Muon area, one may consider removing the MuSeps and MuLams (as there is currently no intention to send beam to the Neutrino area, this is feasible), and reconfiguring the pretarget optics.

Finally, one should recognize that because the aperture of an EPB dipole is smaller than that of a cryogenic dipole, the preceding conclusions remain valid if the cryogenic magnets are not immediately replaced with EPB dipoles. If one wishes to maintain cryogenic elements, a test beam in the Meson area could be available upon completion of the A0 reconfiguration.