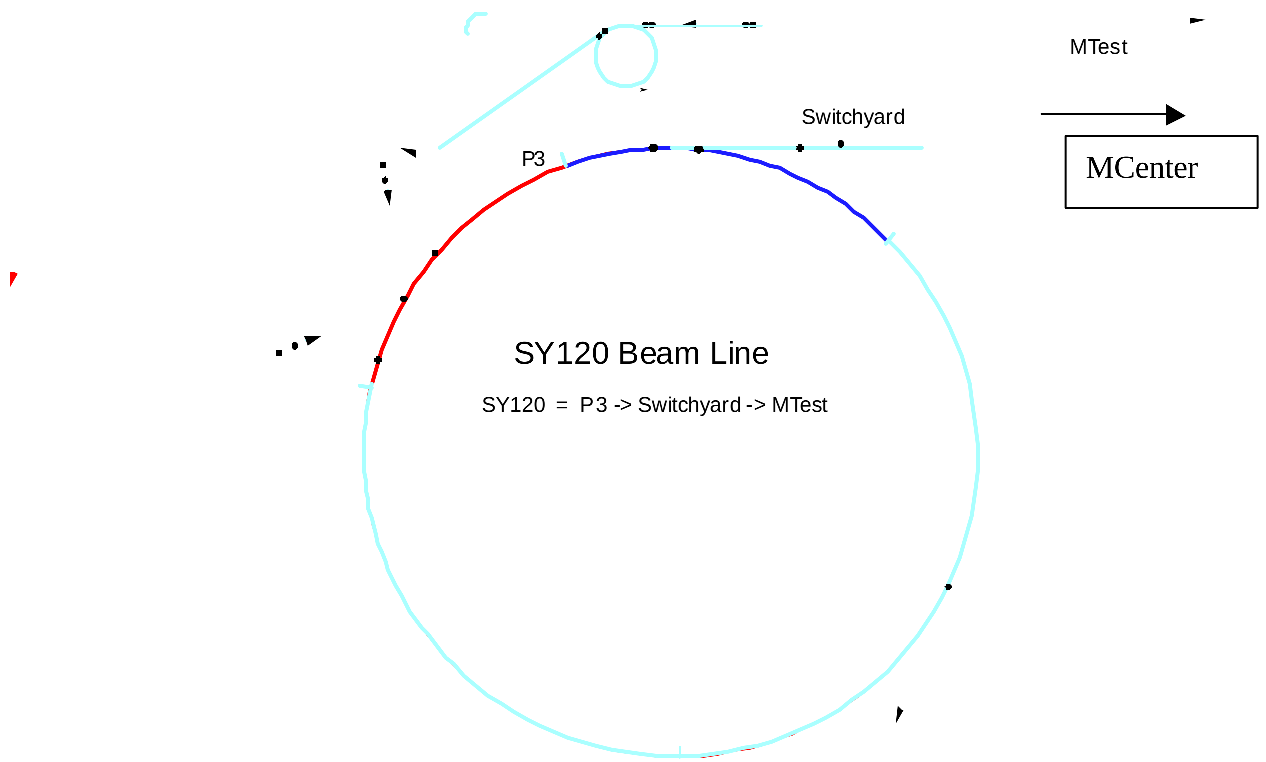
Addendum to the SY 120 Shielding Assessment to add the MCenter branch to the beam line



C. Brown, D. Jensen, October 6, 2003

Addendum to the SY 120 Shielding Assessment to include the MCenter branch of the beam line in the Meson Laboratory

1. Introduction

The MCenter beam line shown schematically on the cover of this document serves to provide a secondary beam of $\pi^{\pm}$,$K^{\pm}$, and $p^{\pm}$ particles to the MIPP(FNAL-E907) experiment located in the MC7 area of the Meson Lab. The secondary beam momenta will range from 5GeV/c to 90GeV/c. This is known as the ‘pion’ mode of operation. Later on, the secondary beam line will be reconfigured to transport a low intensity beam of 120GeV/c protons to interact with the MINOS target. This mode of operation, known as the ‘proton’ mode will occur later in the experiment and a separate shielding assessment will be filed at the appropriate time.

The documents being presented examine the shielding in the secondary beam line located in M05 and MC6 areas as well as the experimental hall in MC7. The MCenter primary 120 GeV proton beam line starts in the M01 enclosure, proceeds through the M02, M03, M04, and M05 enclosures, and is targeted and absorbed at the upstream end of the MC6 enclosure. The MCenter primary beam line is a very simple proton beam transport that contains only two dipole bends (in M01 and M05) and only two quad doublets (in M02 and M05). The intensity of the beam can be reduced to the low intensities requested by the E907 group by adjusting the Meson Lab triple split in enclosure F1 to direct excess beam to the Meson Target Train Beam Absorber. Appendix MC-1, the MCenter beam sheet, lists all the components in longitudinal order.

The 120 GeV primary beam creates a secondary beam of hadrons, the ‘pion beam’, which is transported by a short secondary beam line in MC6 to the E907 experiment in enclosure MC7. Appendix MC-7, the MCenter secondary beam sheet, lists all the components of the secondary beam line up to the E907 target in longitudinal order. This shielding assessment addresses the primary beam line from M01 to MC6 in Section 2 below, the secondary beam line in MC6 in Section 3 below, and the E907 experimental area in MC7, in Section 4 below.

2. MCenter Primary Proton Beam Line, M01 – MC6

The primary beam line is evaluated for an intensity of 2e12 120 GeV protons per 2.9 second Main Injector cycle. Appendix MC-2 lists the shielding requirements for this intensity as determined by the Cossairt requirements and the Fermilab Radiological Standards.

The longitudinal and transverse shielding was examined and the results are displayed in the shielding spreadsheets in Appendix MC-3 and Appendix MC-4. The shielding is sufficient to protect against a continuous loss of 2e12 120 GeV protons per 2.9 second Main Injector cycle or a single pulse accident of 3e13 120 GeV protons at all points in the beam line up to and including the momentum collimator in MC6. The shielding is sufficient to protect against a continuous loss of 2e5 90 GeV (or less) hadrons in the secondary beam beyond the momentum collimator in enclosure MC6 and in enclosure MC7 (or a single pulse accident of 4e6 hadrons in these secondary beam regions), see below.

For Experiment E907, the first user of this beam, the proton beam will be targeted on a 20 cm long copper target in MC6. Jim Kilmer has designed this target to withstand a continuous beam intensity of 2e12 every 2.9 seconds. A MARS simulation of the target location shielding in MC6 was made. The results are found in Appendix MC-5 and are based on an integrated intensity of 2e16 protons per year, twice the maximum integrated beam that E907 intends to record. The groundwater limits are not exceeded.

The labyrinths and penetrations into the MCenter beam line are examined in Appendix MC-6. The shielding around the labyrinths and penetrations is sufficient for an intensity of 2e12 120 GeV protons per 2.9 second Main Injector cycle. The two penetrations in MC6 which would otherwise fail penetrate through to the MWest/M05 primary beam enclosure which is interlocked whenever the MCenter beam is enabled.

Air activation is adequately covered in the 'Air Activation' section of the main SY120 SA. Note that the M05 and MC6 enclosure ventilation is configured to ensure that any air activation from the MC6 target and beam absorbers is carried upstream through M05 before being vented into a fenced radiation area above the M05 enclosure.

Muon production from the M01 beam absorber is covered in the SY120 SA. Muon production from the beam absorber in the MC6 enclosure has been modeled using MARS; see the discussion of the MC7 E907 experimental area muon rates in section 4 below.

The only major residual radiation problems will occur at the M01 beam absorber, the MC6 copper target, the first few MC6 magnets, and the MC6 beam absorbers. The residual rates expected for the E907 running are shown in Appendix MC-5. These can easily be controlled using standard Beams Division operating procedures.

Three integrating radiation detectors located on the roof of the shielding pile in MC6 (the area with the least shielding) are used to protect against the inadvertent transport of more than 2e12 120 GeV protons per pulse to MC6 (or more than a single one-pulse accident of 3e13 protons).

The integrated beam transmitted down the MCenter beam line will be monitored by the Beam Budget Monitor recording the incident proton intensity on the MC6IC ion chamber.

Conclusion: the shielding of the MCenter 120 GeV primary proton beam line from enclosure M01 to MC6 in the Meson Lab is adequate to protect against the accidental loss of 2e12 120 GeV protons per 2.9 second Main Injector acceleration cycle.

3. MCenter Secondary Hadron Beam Line in MC6

A short secondary beam line has been constructed in the MC6 enclosure. The elements of this beam line are listed in the beam sheet, Appendix MC-7. The beam line elements are shown in Figure 1. Figure 2 shows a cut view of the beam line and Figure 3 shows the beam optics.

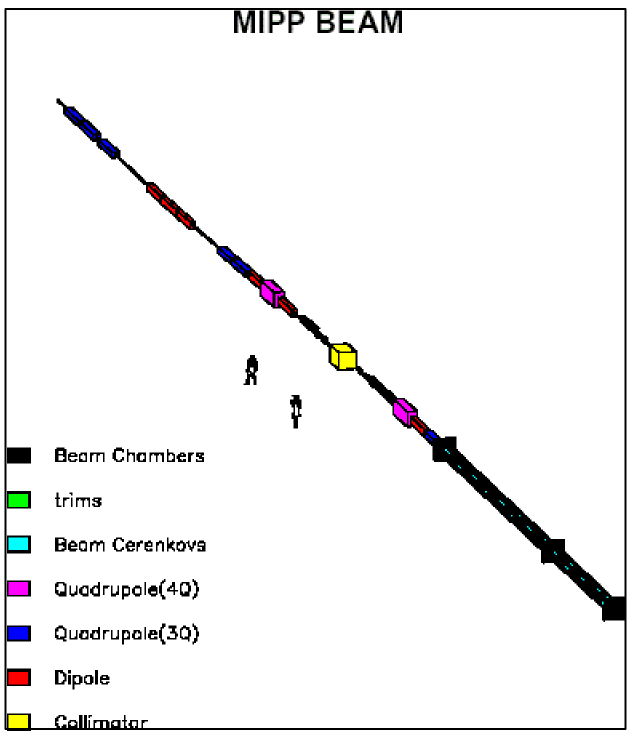


Figure 1 MIPP secondary beam line elements

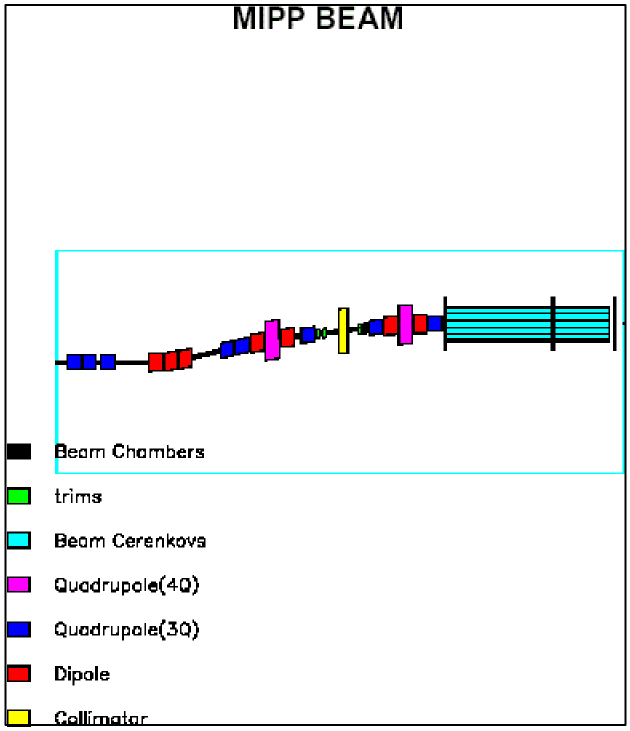


Figure 2 Side view of MIPP secondary beamline

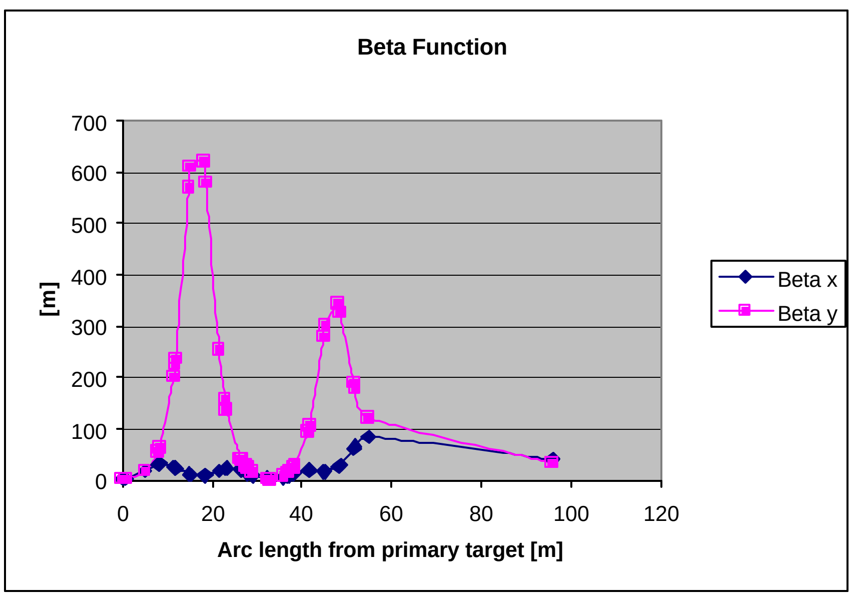


Figure 3 Beta functions in the horizontal (x) and vertical (y) directions for the beam line. The beam is brought to a focus in both planes at the momentum selection collimator placed at 33m downstream of the primary target (0m). The beam is focused again at the secondary (experiment) target at 95.95m. The vertical dispersion is designed to be large at the collimator and the beam is designed to have low divergence at the beam cerenkov counters.

The E907 experiment has requested a number of different secondary hadron beam conditions. They are detailed in Appendix MC-8. To summarize, they wish to take a total of about 1e16 120 GeV protons onto their primary beam target in MC6 with an average intensity of about 1e10 protons per spill.

Note, the run condition table specified by the E907 experimenters in Appendix MC-8 includes 'proton mode' runs wherein they wish to transport 125,000 120 GeV protons/pulse, without a primary target in MC6, directly to their secondary target in MC7. The 'proton mode' running will not occur until at least one year after data taking has begun for E907. The experience obtained running the MC6 section of the beam in a secondary 'pion' beam configuration will be invaluable in determining the safest configuration for the primary beam 'proton mode'. Therefore this assessment explicitly DOES NOT include running the MC6 beam line in the 120 GeV primary beam 'proton mode'.

In the secondary 'pion beam' mode, the primary beam is targeted at the upstream end of the MC6 enclosure and a secondary pion beam of energies from +90 to –90 GeV will be transported through MC6 to the E907 experiment in MC7. This is the mode that this shielding assessment will address. For one of the 'pion mode' conditions, namely –90 GeV negative pions, they will request a primary beam intensity of 2e11 protons/pulse. This is because the K^- and antiproton yields are lowest at -90GeV/c and a larger primary proton intensity is required to get adequate fluxes of these minority particles in the secondary beam. Despite this lower maximum intensity request, we have installed interlocks, and have shielded the area, to address an intensity of 2e12 per pulse. The secondary intensity in MC7 will be limited by radiation detectors (in MC7) to 2e5 hadrons per pulse, the maximum intensity that the E907 detector can withstand, see below.

In 'pion mode' the secondary beam line in MC6 will be limited to an energy setting of 90 GeV or below with an interlocked current upper limit on the MC6D1 EPB dipole string. The momentum collimator in MC6, MC6CY, has been physically modified to limit its maximum vertical opening to 1.0 inch, i.e. –0.5 to +0.5 inches. When the MC6D1 current string is set to transport 90 GeV secondary particles, 120 GeV uninteracted protons from the primary beam hit the collimator at least 1.0 inches above the center of the momentum collimator. The tight collimation just downstream of the primary target combined with the fact that the four dipoles in the MC6D string are all in series make it impossible to mis-steer the primary beam through the collimator opening. MARS simulations have shown that there are no uninteracted particles (for a MARS run with 100,000 primary protons) that traverse the MC6 beam line into MC7. At other 'pion mode' settings, the uninteracted protons are intercepted either higher on the momentum collimator or on elements of the beam line upstream of the momentum collimator. For a schematic view of the trajectories of the uninteracted primary 120 GeV protons see Appendix MC-5.

In 'pion mode' the maximum intensity of primary protons (plus secondary hadrons) will be limited in MC6 by radiation detectors to less than 2e12. The maximum intensity transmitted by the secondary beam line through to MC7 will be limited to the equivalent of 200,000 120 GeV protons/pulse by radiation detectors. A single pulse accident of 3e13 protons per pulse (20 times more intensity) from the Main Injector is not a problem since the maximum 2.9 sec. pulse rate assumed (1200 pulses per hour) means the D.C. rate dominates the shielding calculations.

The shielding of the MCenter secondary beam line in enclosure MC6 is configured to handle primary proton beam intensities up to 2e12 120 GeV protons every 2.9 seconds from the primary target location to the momentum collimator location. This is necessary since the uninteracted primary beam interacts at different places in MC6 depending on the energy setting of the secondary beam line. Appendix MC-5 includes a schematic of the region of the secondary beam where the uninteracted 120 GeV primary protons are absorbed by the magnetic elements and the absorbers. MARS calculations show that the radiation fields expected outside the MC6 enclosure are greatest on the roof of the enclosure and hence that is where the radiation detectors are placed to limit the beam intensity, see Appendix MC-5. Appendix MC-3 and Appendix MC-4 also show that the longitudinal and transverse shielding in these regions meets the Cossairt criteria.

The only labyrinth into the MC6 shielding in the Meson Detector Building is the entrance gate on the west side of the shielding pile as listed in Appendix MC-6.

Air activation issues in MC6 are addressed in section 2 above.

Ground Water and Muon production from the primary beam in MC6 is addressed in section 2 above.

The only active shielding controls are the three Radiation Detectors located on the roof of the MC6 enclosure. These detectors will monitor the DC dose rates in the MC6 enclosure and will be adjusted to limit the hadron flux to 2e12 per 2.9 seconds.

Thus the MC6 secondary beam line can be safely operated with incident proton intensities up to 2e12 protons per 2.9 seconds at secondary beam energies of 90 GeV or below.

4. MC7, the Secondary Hadron Beam Enclosure and E907 Experiment

MIPP (E907) EXPERIMENTAL HALL SHIELDING ASSESSMENT - D. A. JENSEN

This document addresses the radiation shielding needs for MC7 and the portacamps for the MIPP experiment (E907). The area to be addressed is MC7 (where the experiment is located); the portacamps adjacent to MC8 where the experimenters will work during shifts, and the secondary beam stop just downstream of MC7. The muon plumes extending downstream of this area will be addressed. The running conditions addressed are those for secondary running. The layout of the beam lines and experiment are detailed in drawing 3907-500-ME-397560 below.

The MIPP Experiment

MIPP will run in the Meson Center beam line, using a maximum of 2×10^{11} 120 GeV protons per spill to produce a secondary beam of charged π's and K's. The π's and K's will impinge on a secondary target – the scattering on the secondary target being the focus of the experiment. The secondary momenta will be ±5, ±10, ±15, ±25, ±50, ±70 and ±90 GeV/c. The maximum intensity at which the experiment will run will be 1.25×10^5 secondaries per one second spill (every 2.9 seconds or longer). In this document, it will be assumed that the secondary beam will be limited to intensities below 2.0×10^5 secondaries per spill so as not to overly constrain the experiment.

The secondary beam is absorbed entirely on the calorimeter at the downstream end of the E907 spectrometer. The secondary beam is designed to be less than 1 cm in diameter and to have a divergence of less than 0.5 mr. At the downstream end of the experiment, the divergence is increased due to multiple scattering in the 0.14 radiation lengths of material in the E907 spectrometer upstream of the calorimeter. At 5 GeV/c, the multiple scattering adds about 1 mr. to the beam divergence. The beam size at the calorimeter thus grows to about 2 cm (rms). This implies that at the low momentum setting, the secondary beam must hit the calorimeters at least 5 cm from the edge (see discussion below).

The secondary beam flux is limited by the experiment; the detectors cannot accept a higher flux. The primary beam shielding assessment is dealt with above. The secondary beam intensity will be monitored using a Chipmunk radiation monitor that will be placed near the upstream face of the first Cerenkov counter immediately next to the secondary beam entering MC7. This detector will be in the halo of both the secondary beam and the detector elements in the beam at this location. It must be calibrated and appropriate trip settings established as a part of the initial commissioning of the beam. This protection will also serve to protect against an accident condition of for example the full MI beam being delivered to the MIPP primary target. That would be 4E13 as opposed to the nominal of 2E12 or 20 times more beam. If the chipmunk responds within 5 spills and the beam is then held off for one hour, the fast pulse accident dose would not exceed the hourly limit.

The MIPP experiment layout is shown in Figure 4 below.

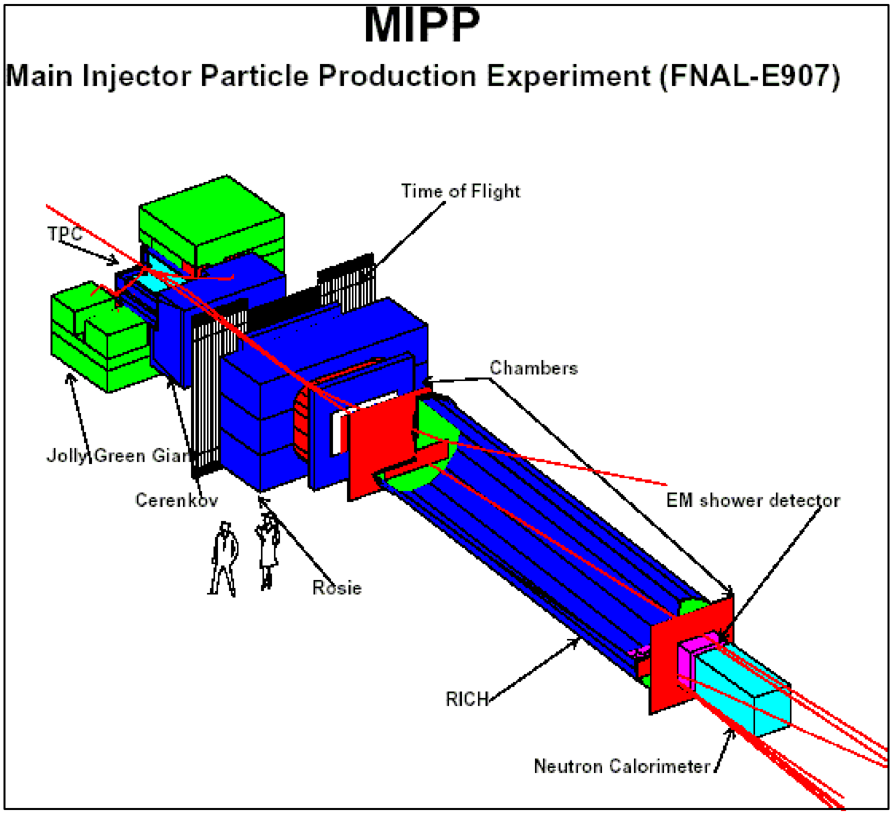


Figure 4 Schematic of the MIPP apparatus. The beam Cerenkov counters are not shown.

The experiment, situated in MC7, consists of a secondary beam line containing beam transport pipes and a set of Cerenkov counters. The target upon which the secondary beam impinges is located just inside the JGG spectrometer magnet. Then follows a Cerenkov counter, a time-of-flight scintillator wall and the ROSIE spectrometer magnet. Wire chambers are interspersed among these elements. Downstream of ROSIE and the wire chambers is a Ring Imaging Cerenkov Counter. Finally there is a calorimeter – the only massive (along the beam) device. The space from the secondary target through the calorimeter is tightly packed with apparatus.

There are two sources of radiation in MC7: the secondary beam, and muons from the upstream primary and secondary beam lines. The methodology used to analyze the radiation due to the hadron beam is outlined in section 4.1a below. Muons from upstream are tracked through the apparatus; the track densities are then used to calculate dose rates in section 4.2a below.

DOSE RATES AND ALLOWED LIMITS FOR HADRONS

The hadron-induced radiation may come from beam losses along the beam line, from beam interacting in the apparatus, or from the secondary beam dump. The methodology for dealing with beam losses and the beam dump are discussed in section 4.1a below.

Dose due to the Secondary beam

Note that the absorption of the beam by the target and the resulting reduction in secondary beam intensity is not included in this discussion. These rates are 'target out' rates and are thus more conservative.

The dose in the secondary beam line, using 25000 mip tracks/cm2 equals one mrem, indicates that the dose in the beam (assuming a 1 sq cm beam) is 5 mrem/spill or 5*1200 = 6000 mr/hr. Clearly it is necessary that access to the beam itself be excluded. Exclusion from the beam is assured by having the experimental enclosure interlocked when beam is enabled. It is also necessary that the secondary beam be dumped either in the experimental hadron calorimeter or in the downstream beam dump and is thus not allowed to exit the downstream end of the MC7 enclosure.

The worst case for a beam induced radiation accident is that of the highest energy secondary beam hitting an 'optimal size steel log' that someone has left inadvertently in the beam line. The radiation generated is proportional to energy and flux, but for MIPP, the flux is held constant at 125K particles per spill (as noted above, calculations here assume 200 K particles per spill), so only the energy is variable. Since the dose rate increases with increasing energy, if the highest energy running (90 GeV/c) leads to acceptable radiation fields, the lower energy running will also be acceptable. Using the methodology discussed in section 4.1a below, the dose rate outside the MC7 building due to total beam loss would be 0.6 mr/hr. This assumes 1200 spills per hour. As this is well below the 100 mrem/hr allowed in a fenced area, no constraints need to be added to the experimental layout.

Secondary Target

The secondary target is located inside the JGG. The yoke to the right and left inside the JGG is 42 inch thick iron, more than adequate transverse shielding.

Calorimeters

There are two calorimeters at the downstream end of the apparatus, an electromagnetic calorimeter (EM) and a hadronic calorimeter. The length of these objects is 0.35 and 9.7 interaction lengths respectively. The transverse dimensions are 152.4 and 100 cm square respectively. The hadron calorimeter will completely absorb the hadron component of the secondary beam if the beam impinges inside the edges of the hadron calorimeter. The methodology of section 4.1a below is used, noting that for the EM calorimeter the material is Pb instead of Fe, so that the interaction length is 1.47 times shorter.

There are two cases, radiation out the top and bottom, and radiation out the sides. Consider first the case of radiation out the top or bottom. Assume that the entire beam is absorbed in the hadron calorimeter. Following the method of 4.1a below, the radiation out the top or bottom of the calorimeter is less than 10 micro-rem/hour – negligible on the scale of the 100 mrem limit for a fenced area.

The case of radiation out the sides of the calorimeter is more complex because the beam sweeps across the calorimeter system as a function of secondary beam momentum. At 5 GeV/c, the secondary beam, about 47 cm off axis, hits the EM calorimeter about 3 cm inside the Hadron Calorimeter. This is far enough into the calorimeter that the beam is absorbed, but not far enough into the calorimeter horizontally to provide any self-shielding. This assumes that the spectrometer magnets are at their nominal settings. If the spectrometer magnet currents are limited to within $\pm$10%, then in the worst case, the secondary beam of 5GeV/c misses both calorimeters and a 10 GeV/c beam can hit about 12 cm inside the edge of the Hadron Calorimeter. There is essentially no self-shielding of the calorimeter and the dose rate outside the enclosure is about 0.14 mrem/hour for 125 K secondary beam (0.23 mrem/hr for 200 K secondary beam). Again, this is not a problem for the fenced area. More seriously, if the spectrometer magnets are set far from nominal – for example if the JGG is on but ROSIE is off – the secondary beam misses not only the calorimeter but also the beam dump. This is clearly unacceptable and is prevented by interlocked limits on the two analysis magnet currents. An analysis of where the beams of different momenta hit the calorimeter and beam dump is given in Appendix MC-9.

Beam Stop

There is a beam stop downstream of MC7. This is the beam stop installed by E871, HyperCP. It is detailed in Drawing 9206.200-MD-328885. The beam stop consists of a set of steel blocks 96 inches wide by 74 inches high by 120.49 inches deep. The block is offset 18 inches beam left with respect to the nominal beam line and is 117.25 inches above the nominal floor level. (Beam height for MIPP is approximately 82 inches) If the secondary beam is scattered by the EM calorimeter, this beam stop will absorb the remaining secondary beam. If the beam is unscattered as it hits the beam stop, there is the possibility of some of the secondary beam penetrating cracks in the beam dump support and not being fully absorbed. It is therefore required that the secondary beam impact the EM calorimeter inside its edges by at least 5 cm. This requirement means that the relative currents in the spectrometers be either both zero or that the magnet set points are interlocked to be within 10% of nominal.

Dose Rates and Allowed Limits for Muons

The muon flux is assumed to come exclusively from upstream of MC7. This muon flux has been calculated using MARS. The muons are tracked through the experiment to the portacamps using the experiment Monte-Carlo program. The results for muons in the portacamps are discussed in 4.1b below. The muon fluxes are well below the limits imposed for continuous occupancy.

The main muon fluxes are in plumes above and below the experiment. The secondary beam is generated vertically from the primary beam and the bending magnets associated with the control of the secondary beam therefore bend vertically. These lobes are either into the ground/Mbottom or are well above the height of the portacamps at that distance from the experiment.

MIPP EXPERIMENTAL HALL ACTION ITEMS

Install a Chipmunk near the upstream face of the first Cerenkov and the secondary beam line in MC7. This Chipmunk will be calibrated during the first engineering test runs of the beam line to trip the beam if the secondary intensity exceeds 200 K particles/second.

The spectrometer magnets must have monitoring installed to assure that the polarities are opposite and that the currents are nominal to within +/- 10%.

With the current specifications and design of the spectrometer, the secondary beam momentum must be constrained to be at or above 5 GeV/c. This requirement is imposed because at lower momenta, the secondary beam may be dumped near the edge of the hadron calorimeter in such a way that the self-shielding is not adequate to keep dose rates outside the beam enclosure below 0.05 mrem/hr. It would be possible to remove this constraint with a modest adjustment of the spectrometer magnetic field(s) at the experimenter's discretion.

4.1a

Appendix A – Beam induced radiation outside the enclosure

The Experimental Halls Methodology assumes a loss can occur anywhere along a beam. The maximum shower intensity in the transverse direction occurs when the beam impacts a chunk of steel 90cm long and 30cm diameter. This worst case "steel log" is assumed in the calculation. The Methodology places the "steel log" at various points along the secondary beam, and the dose rate (DR) outside the Experimental Hall due to the resulting shower is calculated. The formula for calculating the dose rate is :

$$DR\ (mrem/pulse) = I * (1x10^{-3}) * (1x10^{-2}) * \{(E/1000)^{0.8}\} * \{(0.5/D_{air})^{2}\} * 10^{-Rs/1.0} * 10^{-Rc/2.6}$$

where

I is the beam intensity per pulse (pulse=1sec)
E is the beam energy in GeV
$1x10^{-3}$ is the number of shower particles per cm^3 on the surface of the "steel log"
$1x10^{-2}$ is the conversion from shower particle density to mrem
D_{air} is the amount of air between the loss point and the measurement point, in feet
R_S is the amount of shielding steel, as above, in feet
R_C is the amount of shielding concrete, as above, in feet

The dose rates are specified in mrem/pulse and mrem/hour. 1200 pulses per hour are assumed. For normal (DC) running, areas outside the Experimental Hall where there is unrestrained access must have dose rates less than 0.05 mrem per hour

While using the worst-case "steel log" may not seem realistic or reflect the make-up of the detector elements, this method does assist in identifying areas in and around enclosures where monitoring is needed, and where precautions must be taken to prevent such a worst case from happening.

Note that for large objects placed in the beam line (for example, calorimeters), the radiation that they generate is calculated using the same equation. For these large objects, material outside the 15 cm radius (nominally 6 inches) is counted as self shielding and is included in, for example, the Rs reduction factor. For lead, the Rs reduction factor, scaled by the ratio of the interaction length of lead to that of steel is used making lead 1.47 times as effective per foot as steel.

4.1b

Appendix B – Estimation of muon induced radiation in the MIPP Portakamps

Mikhail Kostin, Holger Meyer, Rajendran Raja

22-August-2003

We have estimated the yield of muons in the MIPP experimental hall due to decay of particles produced by the MIPP secondary beams at beam momenta of –90,-50, -5, 5,50 and 90 GeV/c. The program MARS was used to track particles through the MIPP beamline. The tracking included particle interaction of hadrons as well as electromagnetic particles due to the secondary particles produced in the MIPP primary Copper target

(20cm long) as well as those produced by the uninteracted primary proton beam. In order to obtain large enough statistics, the pions and kaons thus produced were forced to decay to muons and each such muon given an appropriate decay weight. The MARS simulation run was for 100,000 primary protons on target. The muons thus produced were tracked to the plane of the MIPP secondary target close to the TPC. These muons were then input into the Geant simulation of the MIPP experimental apparatus. This simulation has realistic field maps for the MIPP magnets the Jolly Green Giant and Rosie as well as realistic descriptions of the MIPP apparatus (TPC, Chambers, Cerenkov, RICH and Calorimeters). We have also added a realistic description of the beam dump (concrete and steel) for this simulation. Figure 5 shows the MIPP apparatus as described in Geant used for this simulation.

Figure 6 shows the tracks of muons as tracked through the apparatus in Geant. The muons shown are for a negative secondary beam momentum of 90 GeV/c. Figure 7 shows the x and y positions (x is horizontal and y vertical in the MIPP co-ordinate system. Positive z , out of the plane of the paper is the direction of the beam) of all the muons that intersect the z plane of the entrance of the portakamp. The muons in this plot are unweighted . Since the weights are approximately evenly distributed with respect to position, this plot is typical of the distribution of the muons. The portakamp is defined as a box whose cross section has dimensions 370cm X 500cm in x and y. The center of this box is located at –720., 0.0 in x and y. The portakamp is located at 90.7 meters downstream of the center of the Jolly Green Giant. Table 1 gives the muon statistics in the portakamp as a function of the beam momentum and the expected proton intensities. Even if we run MIPP with a slow spill of 1 second duration every 3 second, the radiation induced by muons is seen to be negligible. It should be pointed out that current scenario is promising MIPP one second slow spill every 60 seconds, which is a factor of 20 less intense. We thus conclude that the muon induced radiation is not a problem in MIPP with the current beam design and running scenario.

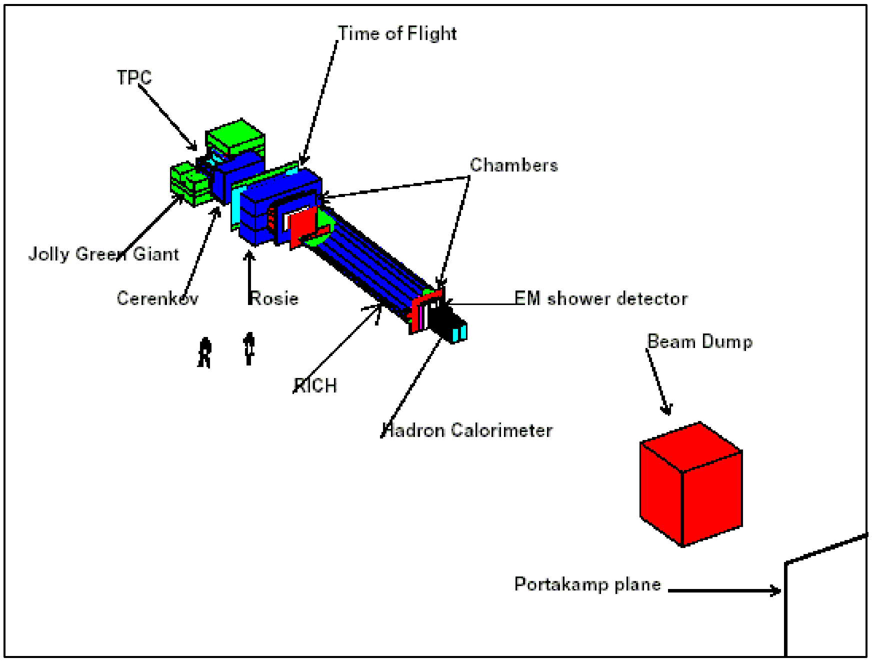


Figure 5 Geant simulation of MIPP apparatus. Beam dump and portakamp position are shown.

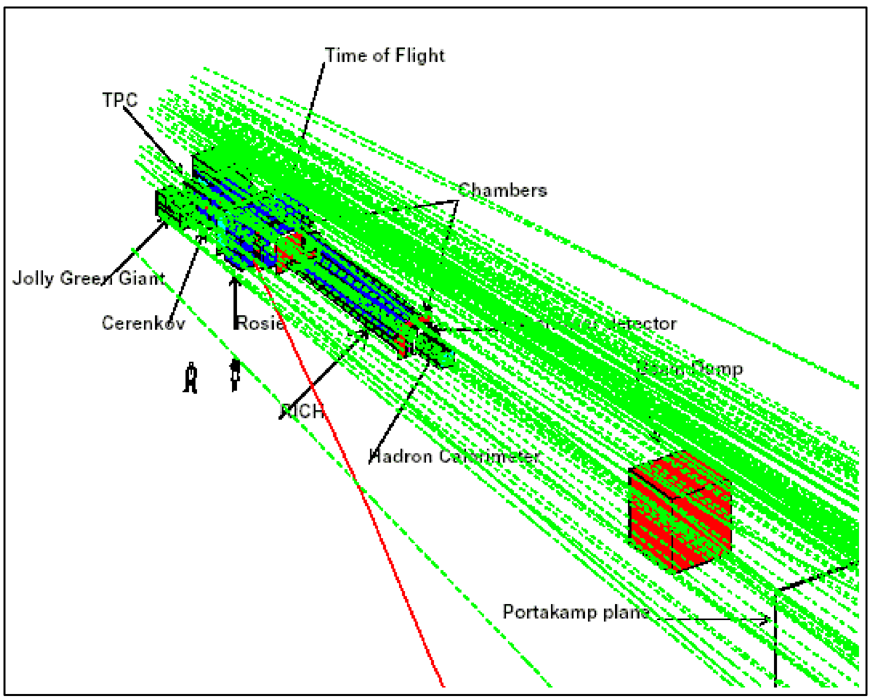


Figure 6 Geant simulation of muons produced by 90 GeV/c negative beam. Both positive and negative muons are tracked. Red track is an electron from muon decay.

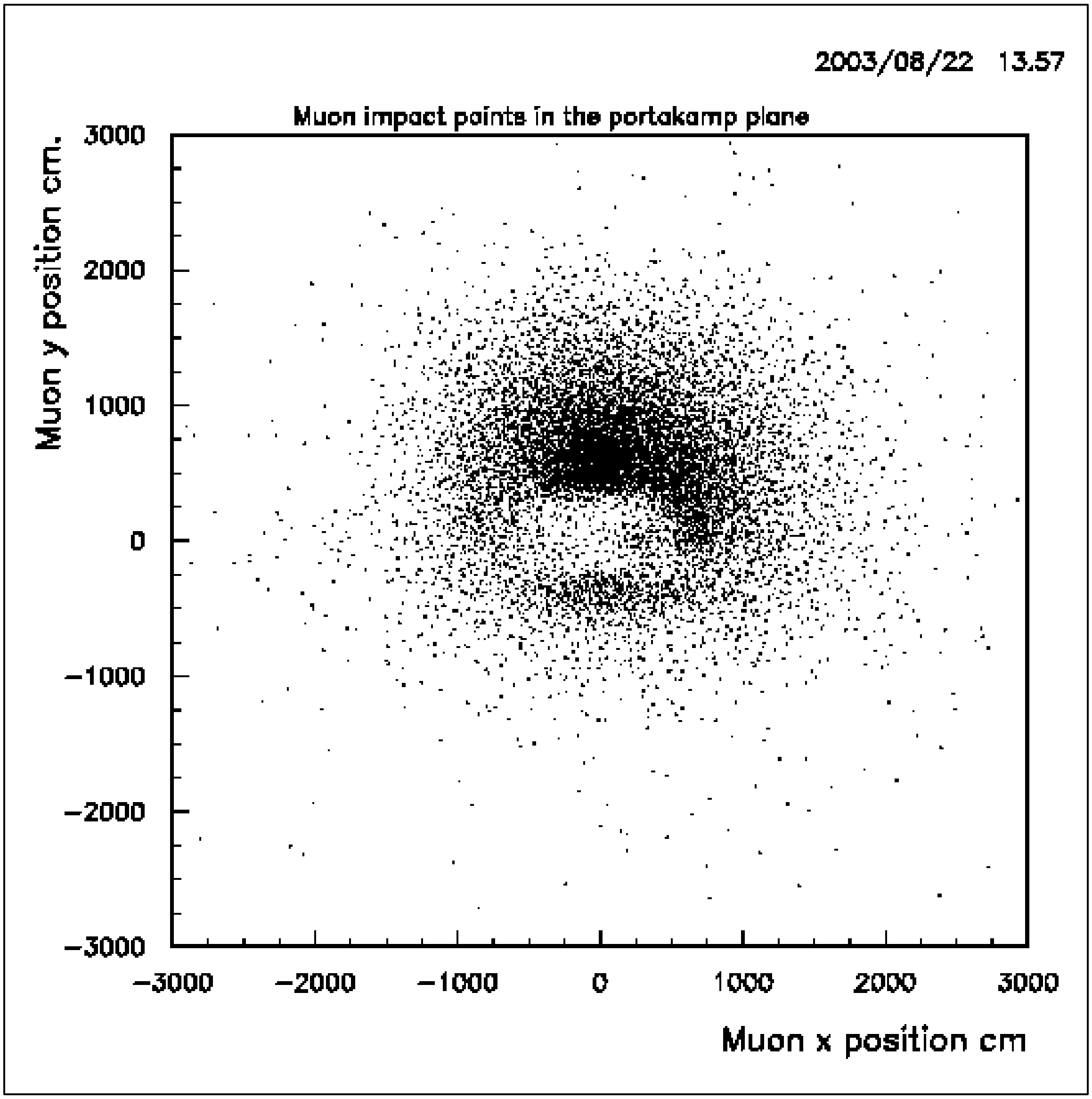


Figure 7 Muon Impact points in the portakamp plane (50 GeV/c negative beam)

Table 1: Muons entering the portakamp as a function of secondary beam momentum and intensity. One beam spill every 3 seconds is used to calculate the dose in the portakamp.

Beam Momentum GeV/c	Proton Intensity */spill*	*Muons in Portakamp /spill*	*Radiation Mrem /hour*	*Average Muon Momentum in portkamp GeV/c*
5	9.66E+09	8.01E+04	2.02E-02	4.84
50	5.76E+08	8.81E+03	2.22E-03	6.38
90	2.67E+08	7.98E+03	2.01E-03	5.73
-5	1.49E+10	1.26E+05	3.19E-02	5.41
-50	5.73E+09	3.91E+04	9.88E-03	5.09
-90	7.62E+10	4.23E+05	1.07E-01	5.41

5. Appendices:

Appendix MC-1: MCenter Beam Sheet
http://ppd.fnal.gov/experiments/e907/Beam/mipp_primary_beam_sheet.htm

Appendix MC-2: Cossairt requirements
http://home.fnal.gov/~chuckb/MC02.xls

Appendix MC-3: MCenter Longitudinal Shielding Spreadsheet
http://home.fnal.gov/~chuckb/MC03.xls

Appendix MC-4: MCenter Transverse Shielding Spreadsheet
http://home.fnal.gov/~chuckb/MC04.xls

Appendix MC-5: MARS calculations by Mikhail Kostin:
http://ppd.fnal.gov/experiments/e907/Beam/sas.pdf

Appendix MC-6: MCenter Labyrinth and Penetration Spreadsheet
http://home.fnal.gov/~chuckb/MC06.xls

Appendix MC-7: MCenter Secondary Beam Sheet
http://ppd.fnal.gov/experiments/e907/Beam/mipp_beam_sheet_8.htm

Appendix MC-8: MIPP run conditions
http://ppd.fnal.gov/experiments/e907/Beam/MIPP beam needs.pdf

Appendix MC-9:MIPP Beam dump analysis
http://ppd.fnal.gov/experiments/e907/Beam/beam_dump.htm

6. Drawings:

MC-D1 Schematic layout of the MCenter primary beam line, M01-MC6
MC-D2 MCenter secondary beam line in MC5, MC6 and MC7, and E907
MC-D3 MC7 beam dump

(note: these drawings are included in the 3-ring binder Master Copy of this Shielding Assessment Addendum)