A G4BEAMLINE simulation of the Meson Test Beam

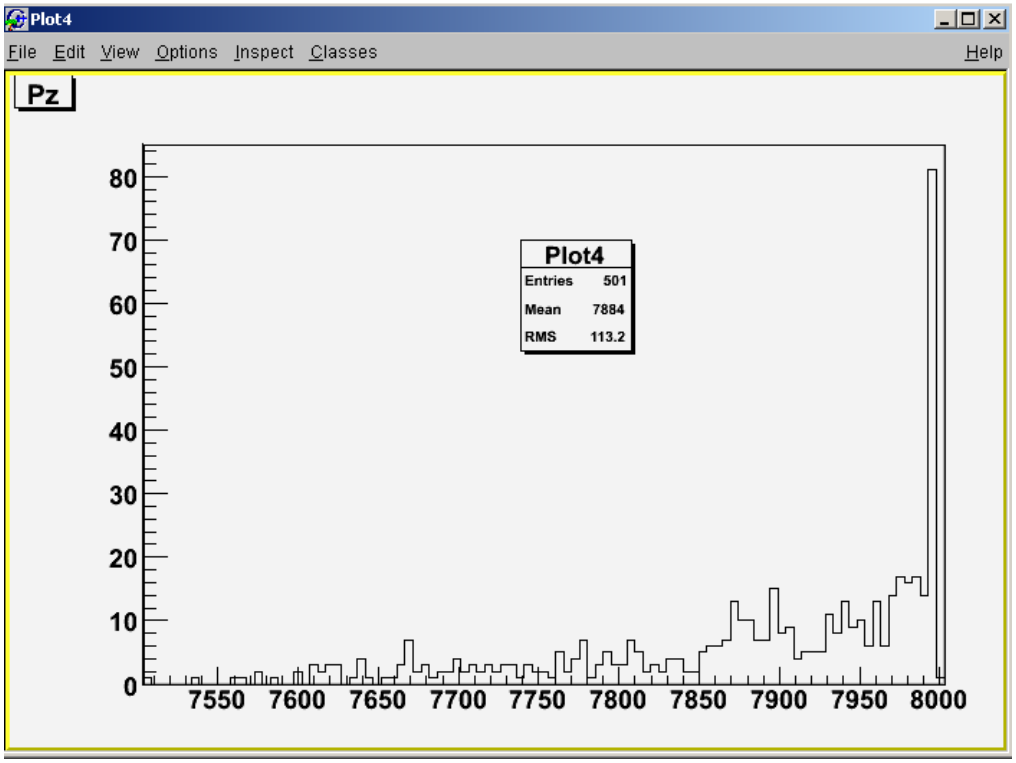
Tim Rinn

I. Introduction

G4Beamline is a powerful simulation tool developed by Tom Roberts. This program, using simple and straightforward commands allows one to create a fairly complex simulation of a beamline. The Basis of G4beamline lies within Geant4 which is an exceptionally complex and powerful simulation tool. G4beamline allows one to create simpler input files, to execute complex simulations.

The G4beamline software is available to download from Muons Inc. at (**g4beamline**.muonsinc.com/). Along with this software comes a Historoot program. Which allows one to take the data output files created by g4beamline, and create graphical representations of the data. However, in order to use the Historoot function one must download Root version 5.16.00.

.



Histogram 1, using Historoot program

With the Historoot program one can make graphs comparing different variables (X, Y, Z, Px, Py, Pz, T, PDGID, Event Id, Track Id, Parent Id, Weight) In this Histogram a one variable view was selected. Along the x axis are the different momentums in the z-direction (down the beamline) and the y axis is the number of particles that had such momentum

II. Beamline simulations

The first thing I did with g4beamline was to use the beam sheet to create a basic frame of the Meson Test Beam upstream end. I took the information to base my placements off of the Beam Sheet, which explained the placements of the magnets, as well as the angles of curvature. (Beam sheet attached in appendix 2.) This simulation served as a test, to see what one could do using G4Beamline.

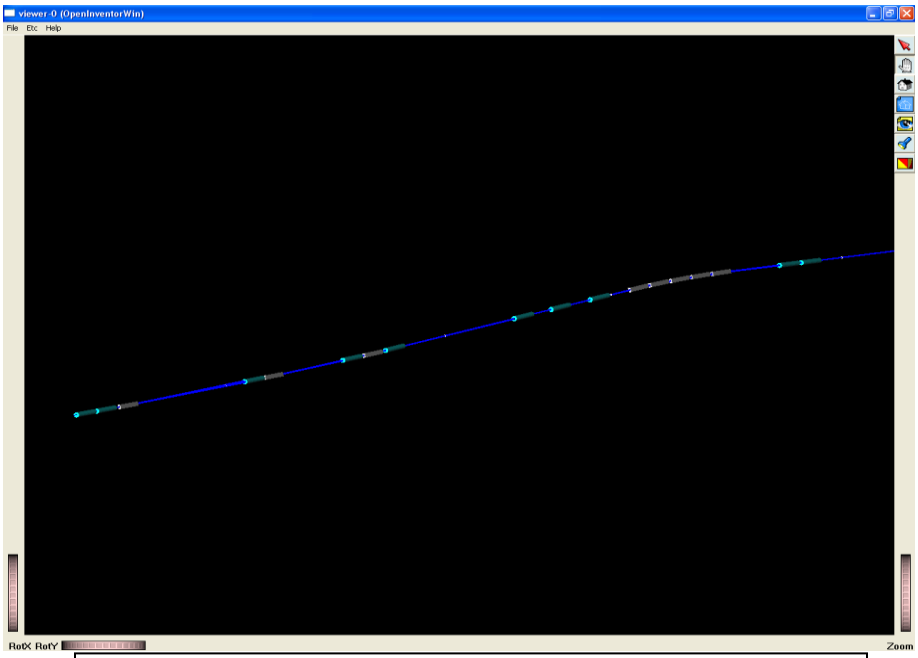


Figure 1, Vertical view of the beamline upstream to the right and downstream to the left. Using the provided Open inventor viewer in conjunction with G4beamline

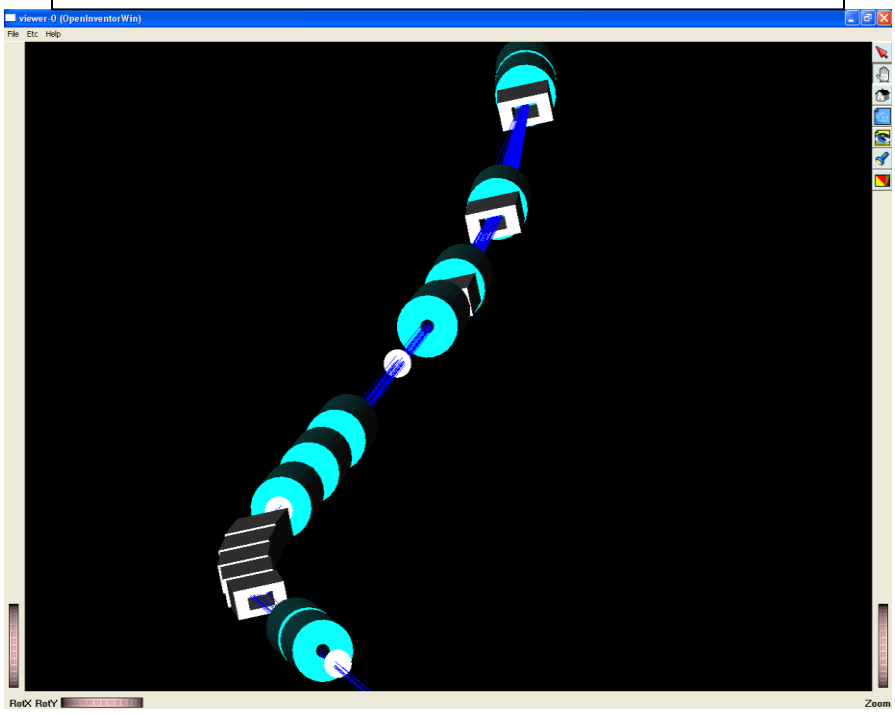


Figure 2, Downstream view of the beamline

The next step was to retune the beamline to 120GeV proton beam and add a 30 cm long block of aluminum, which replicates the target that exists in MTest. This allows us to accurately predict the types of particles that would arrive to experiments taking place at MTest.

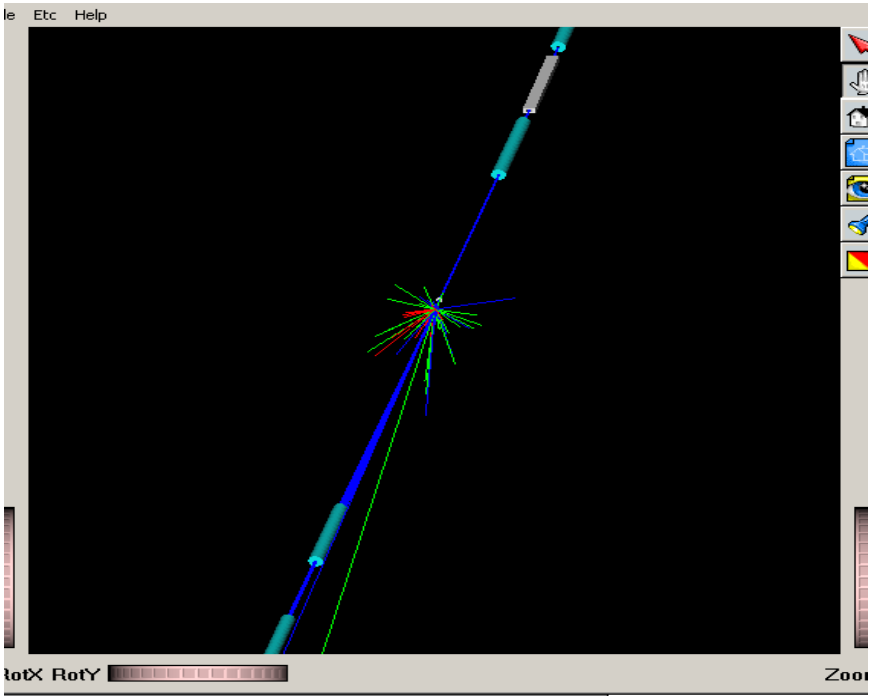


Figure 3, View of beamline, upstream towards the top of the image and downstream towards the bottom left. Beam collides into aluminum block causing shower of particles.

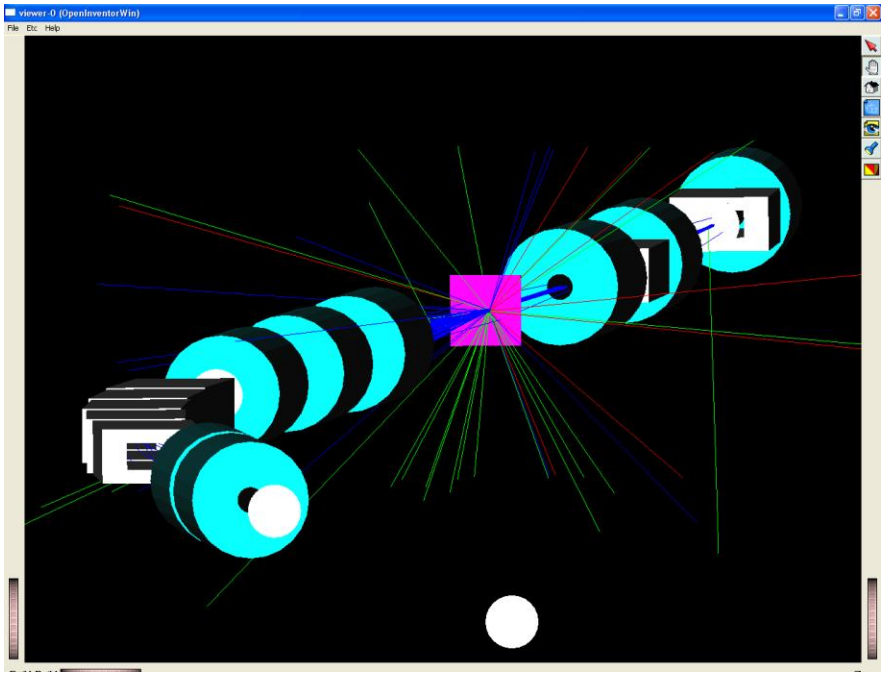


Figure 4, downstream view of the shower of particles.

III. Simulating the T953 Setup

As an example of the versatility of G4Beamline, the next step that was undertaken was to create a simulation of a recently performed experiment in an attempt to compare data and to determine which particles would make it through a total of 60cms of iron and lead. This also allowed the comparison of the results generated with the simulation to the actual results observed in MTest (Input file in appendix 3)

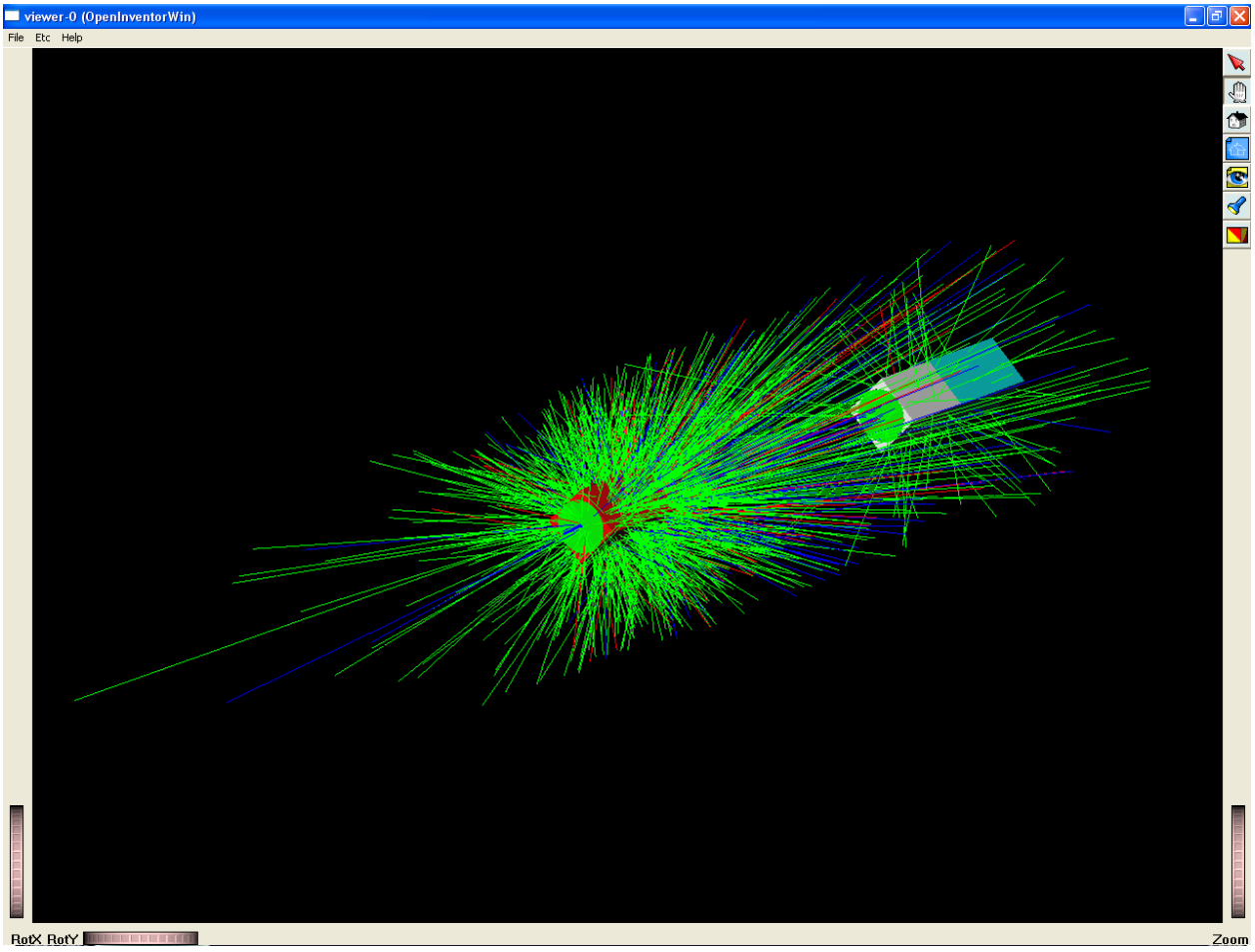


Figure 5, 120 GeV beam collides into a series of lead and iron blocks. To determine how it would work as a muon filter. Upstream is to the left and downstream is to the right. As one can tell the shower is much denser at the upstream end in comparison to the downstream end.

IV. Determining the appropriate thickness of lead to produce an E+ filter

This study was done to determine the amount of lead at the focal point of the beamline that would maximize the π+ to electron ratio without completely destroying the beam. Different input files were created for the different energy levels as well as lead thicknesses. Each file was set to run for 10,000 events, and the results were recorded as root files.

G4Beamline results for 10,000 events generated in each case

Energy	Length of lead (mm)	π+ MT5FP2 detector	π+ MT6FP detector	e+ MT5FP2 detector	e+ MT6FP detector	Ratio π+ to e+
1Gev	0	1340	710	9990	9990	0.07
1Gev	0.5	29	15	137	129	0.12
1Gev	1	17	8	46	43	0.19
1Gev	2	10	5	7	6	0.83
1Gev	5	7	2	1	5	0.4
2Gev	0	3560	2440	9990	9990	0.24
2Gev	0.5	268	200	513	486	0.41
2Gev	1	120	88	176	158	0.56
2Gev	2	63	46	34	27	1.71
2Gev	5	9	5	2	1	2.5
4Gev	0	6030	5030	9990	9990	0.5
4Gev	0.5	1423	1198	1676	1585	0.75
4Gev	1	793	671	615	548	1.22
4Gev	2	370	308	135	110	2.8
4Gev	5	128	109	5	2	55
8Gev	0	7840	7100	9980	9960	0.71
8Gev	0.5	3999	3636	3702	3564	1.02
8Gev	1	2700	2440	1850	1680	1.45
8Gev	2	1740	1570	501	410	3.83
8Gev	5	657	601	15	10	60

As this table shows, the more lead in the beamline the better the π+ vs. Electron ratio is. However this table also shows us that in the low energy beams, 1, 2 GeV practically any amount of lead significantly cuts back on the beam transmission. While for 4 and 8 GeV a larger amount of lead is usable, up to 5mm. on an 8 GeV beam, with 5mm of lead inserted we get 60 times as many π+ than electrons but the number of π+ particles in the beam is scaled down by a factor of 17. A similar study was done with aluminum however the results showed that the aluminum made no difference in the ratio of π+ to e+.

Appendix 1

Input File For an 1 GeV π+ beam with 1mm of Lead

```
#
#       MTest.in  TTR  23-Jan-2008
#
#       Using information from beam sheet
#
#       Lengths are mm; momentum is MeV/c, density is gm/cm^3
#
physics QGSP

#
#        Beam is protons at 1 GeV, spatial width of 1 mm, momentum bite of .5%
#

param histoFile=1GevPi+1

beam gaussian particle=pi+ meanMomentum=1000 beamZ=36000. \
        sigmaX=1.0 sigmaY=1.0 sigmaXp=0.0001 sigmaYp=0.0001 \
        nEvents=10000000 firstEvent=1 lastEvent=10000


#-------------------------------------------------------
#       Detector

virtualdetector MT4TGT radius=75
place MT4TGT z=36030.060
#-------------------------------------------------------
#  MT4Q1 quadrupole:

genericquad MT4Q1 ironLength=3048 fieldLength=3048 apertureRadius=36.5 ironRadius=165 \
        gradient=0 maxStep=1 ironColor=0,1,1 kill=1
place MT4Q1 z=40850.86
#-------------------------------------------------------
#  MT4W1 dipole:

genericbend MT4W1 fieldWidth=139.7 fieldHeight=76.2\
        fieldLength=3048 ironWidth=279.4 ironHeight=152.4 \
```

```
        ironLength=3048 By=.0083125 kill=1 ironColor=1,1,1
place MT4W1 z=44230.61
#-------------------------------------------------------
cornerarc z=44230.61 angle=-.458366
#-------------------------------------------------------
virtualdetector MT5TGT2 radius=75
place MT5TGT2 z=46000.00
#-------------------------------------------------------
#       Detector

virtualdetector MT5TGT radius=36.5
place MT5TGT z=56000.00
#-------------------------------------------------------
#  MT4Q2 quadrupole:

genericquad MT4Q2 ironLength=3048 fieldLength=3048 apertureRadius=36.5 ironRadius=165 \
        gradient=-.1131625 maxStep=1 ironColor=0,1,1 kill=1
place MT4Q2 z=57771.26
#-------------------------------------------------------
#  MT4W2 dipole:

genericbend MT4W2 fieldWidth=139.7 fieldHeight=76.2\
        fieldLength=3048 ironWidth=279.4 ironHeight=152.4 \
        ironLength=3048 By=.0090625 kill=1 ironColor=1,1,1
place MT4W2 z=61460.61
#-------------------------------------------------------
cornerarc z=61460.61 angle=-.458366

#-------------------------------------------------------
#  MT4Q3 quadrupole:

genericquad MT4Q3 ironLength=3048 fieldLength=3048 apertureRadius=36.5 ironRadius=165 \
        gradient=.1131625 maxStep=1 ironColor=0,1,1 kill=1
place MT4Q3 z=65164.81

#-------------------------------------------------------
#       Detector

virtualdetector MT4FP radius=75
place MT4FP z=73928.735

#-------------------------------------------------------
#               BOX

box Lead material=Pb height=200 width=200 length=1 color=0,0,1
place Lead z=74465.310
```

```
#-------------------------------------------------------

#  MT4Q4 quadrupole:

genericquad MT4Q4 ironLength=3048 fieldLength=3048 apertureRadius=36.5 ironRadius=165 \
        gradient=.038075 maxStep=1 ironColor=0,1,1 kill=1
place MT4Q4 z=87520.11

#-------------------------------------------------------
#         MT4CH2

#-------------------------------------------------------
#  MT4Q5 quadrupole:

genericquad MT4Q5 ironLength=3048 fieldLength=3048 apertureRadius=36.5 ironRadius=165 \
gradient=-.056825 maxStep=1 ironColor=0,1,1 kill=1
place MT4Q5 z=93920.91

#-------------------------------------------------------
#  MT4Q6 quadrupole:

genericquad MT4Q6 ironLength=3048 fieldLength=3048 apertureRadius=36.5 ironRadius=165 \
        gradient=.0607075 maxStep=1 ironColor=0,1,1 kill=1
place MT4Q6 z=100686.51

#-------------------------------------------------------
#         MT5FP1         Detector

virtualdetector MT5FP1 radius=75
place MT5FP1 z=102747.085

#-------------------------------------------------------
#         MT5E1 Dipole:

genericbend MT5E1 fieldWidth=139.7 fieldHeight=76.2\
        fieldLength=3048 ironWidth=279.4 ironHeight=152.4 \
        ironLength=3048 By=-.009828125 kill=1 ironColor=1,1,1

place MT5E1 z=107570.31

#-------------------------------------------------------
cornerarc z=107570.31 angle=.509989

#-------------------------------------------------------
```

```
#       Mt5E2

genericbend MT5E2 fieldWidth=139.7 fieldHeight=76.2\
        fieldLength=3048 ironWidth=279.4 ironHeight=152.4 \
        ironLength=3048 By=-.009828125 kill=1 ironColor=1,1,1
place MT5E2 z=111101.31

#-------------------------------------------------------
cornerarc z=111101.31 angle=.509989

#-------------------------------------------------------
#       Mt5E3

genericbend MT5E3 fieldWidth=139.7 fieldHeight=76.2\
        fieldLength=3048 ironWidth=279.4 ironHeight=152.4 \
        ironLength=3048 By=-.009828125 kill=1 ironColor=1,1,1
place MT5E3 z=114632.31
#-------------------------------------------------------
cornerarc z=114632.31 angle=.509989

#-------------------------------------------------------
#       MT5E4

genericbend MT5E4 fieldWidth=139.7 fieldHeight=76.2\
        fieldLength=3048 ironWidth=279.4 ironHeight=152.4 \
        ironLength=3048 By=-.009828125 kill=1 ironColor=1,1,1
place MT5E4 z=118163.31
#-------------------------------------------------------
cornerarc z=118163.31 angle=.509989

#-------------------------------------------------------
#       MT5E5

genericbend MT5E5 fieldWidth=139.7 fieldHeight=76.2\
        fieldLength=3048 ironWidth=279.4 ironHeight=152.4 \
        ironLength=3048 By=-.009828125 kill=1 ironColor=1,1,1
place MT5E5 z=121694.31
#-------------------------------------------------------
cornerarc z=121694.31 angle=.509989

#-------------------------------------------------------
#  MT5Q1 quadrupole:

genericquad MT5Q1 ironLength=3048 fieldLength=3048 apertureRadius=36.5 ironRadius=165 \
        gradient=.0159592735 maxStep=1 ironColor=0,1,1 kill=1
```

```
place MT5Q1 z=133119.31
#------------------------------------------------------
#  MT5Q2 quadrupole:

genericquad MT5Q2 ironLength=3048 fieldLength=3048 apertureRadius=36.5 ironRadius=165 \
        gradient=-.0319185469 maxStep=1 ironColor=0,1,1 kill=1
place MT5Q2 z=136776.91
#------------------------------------------------------
#         MT5FP2         Detector

virtualdetector MT5FP2 radius=75
place MT5FP2 z=142133.285
#------------------------------------------------------
#         MT6FP          Detector

virtualdetector MT6FP radius=75
place MT6FP z=180266.220
#------------------------------------------------------
#
#  See what happens
#
trackcuts killSecondaries=1
```

Appendix 2

Beam Sheet

1 "MAD" Version: 8.23/08 Run: 15/12/06 15.26.44
Survey. SURVEY line: ALIGN range: #S/#E
symm: F super: 1 page 1

pos. no.	E L E M E N T element name	S E Q U E N C E occ. no.	sum(L) [m]	arc [m]	I I	P O S I T I O N S x [m]	y [m]	z [m]	I I	A N G L E S theta [rad]	phi [rad]	psi [rad]
begin	ALIGN	1	0.000000	0.000000		10.783600	227.159030	226.436500		0.062550	-0.000565	0.000000
begin	MT3STUB	1	0.000000	0.000000		10.783600	227.159030	226.436500		0.062550	-0.000565	0.000000
1	WALL2	1	0.000000	0.000000		10.783600	227.159030	226.436500		0.062550	-0.000565	0.000000
2	D25	1	2.207423	2.207423		10.921584	227.157783	228.639605		0.062550	-0.000565	0.000000
3	D26	1	2.329343	2.329343		10.929205	227.157714	228.761287		0.062550	-0.000565	0.000000
4	MT3PWC	1	2.451263	2.451263		10.936826	227.157645	228.882968		0.062550	-0.000565	0.000000
5	D26A	1	3.005135	3.005135		10.971449	227.157332	229.435758		0.062550	-0.000565	0.000000
6	MT3CON	1	3.062285	3.062285		10.975021	227.157300	229.492796		0.062550	-0.000565	0.000000
7	D27	1	3.624260	3.624260		11.010150	227.156982	230.053672		0.062550	-0.000565	0.000000
8	MT3SW	1	6.672260	6.672260		11.200678	227.155260	233.095711		0.062550	-0.000565	0.000000
9	D28	1	7.162785	7.162785		11.231340	227.154983	233.585276		0.062550	-0.000565	0.000000
10	MT3BS	1	9.964735	9.964735		11.406488	227.153400	236.381746		0.062550	-0.000565	0.000000
11	DS1	1	10.421935	10.421935		11.435067	227.153142	236.838052		0.062550	-0.000565	0.000000
12	MT3Q3	1	13.469935	13.469935		11.625595	227.151419	239.880091		0.062550	-0.000565	0.000000
13	DS1	2	13.927135	13.927135		11.654174	227.151161	240.336397		0.062550	-0.000565	0.000000
14	MT3Q4	1	16.975135	16.975135		11.844702	227.149439	243.378435		0.062550	-0.000565	0.000000
15	DS1	3	17.432335	17.432335		11.873281	227.149181	243.834741		0.062550	-0.000565	0.000000
16	MT3CN2	1	17.765710	17.765710		11.894121	227.148992	244.167464		0.062550	-0.000565	0.000000
17	MT3W	1	20.813710	20.813715		12.094534	227.147270	247.208868		0.069050	-0.000565	0.000004
18	D31	1	21.461410	21.461415		12.139222	227.146904	247.855024		0.069050	-0.000565	0.000004
19	MT3U1	1	24.509410	24.509416		12.349520	227.147550	250.895761		0.069050	0.000989	0.000004
20	D32	1	27.862210	27.862216		12.580846	227.150864	254.240569		0.069050	0.000989	0.000004
21	D32	2	31.215010	31.215016		12.812173	227.154178	257.585378		0.069050	0.000989	0.000004
22	MT3U2	1	34.263010	34.263016		13.022470	227.159559	260.626110		0.069050	0.002542	0.000004
23	D33A	1	35.512690	35.512696		13.108691	227.162736	261.872808		0.069050	0.002542	0.000004
24	MT4PWC	1	35.634610	35.634616		13.117103	227.163045	261.994437		0.069050	0.002542	0.000004
25	D33AA	1	36.060060	36.060066		13.146457	227.164127	262.418872		0.069050	0.002542	0.000004
end	MT3STUB	1	36.060060	36.060066		13.146457	227.164127	262.418872		0.069050	0.002542	0.000004
begin	MTSECOND	1	36.060060	36.060066		13.146457	227.164127	262.418872		0.069050	0.002542	0.000004
begin	FWD1	1	36.060060	36.060066		13.146457	227.164127	262.418872		0.069050	0.002542	0.000004
26	MT4TGT	1	36.060060	36.060066		13.146457	227.164127	262.418872		0.069050	0.002542	0.000004
27	MTD1	1	37.193260	37.193266		13.224642	227.167008	263.549368		0.069050	0.002542	0.000004
28	MTABS	1	39.022060	39.022066		13.350820	227.171656	265.373804		0.069050	0.002542	0.000004
29	DS	1	39.326860	39.326866		13.371850	227.172431	265.677876		0.069050	0.002542	0.000004
30	MT4Q1	1	42.374860	42.374866		13.582146	227.180179	268.718603		0.069050	0.002542	0.000004
31	MTD	1	42.706610	42.706616		13.605035	227.181023	269.049562		0.069050	0.002542	0.000004
32	MT4W1	1	45.754610	45.754624		13.827493	227.188771	272.089423		0.077050	0.002542	-0.000017
33	DS	2	46.059410	46.059424		13.850955	227.189545	272.393318		0.077050	0.002542	-0.000017
34	DEPB	1	49.107410	49.107424		14.085570	227.197293	275.432265		0.077050	0.002542	-0.000017
35	DEPB	2	52.155410	52.155424		14.320185	227.205041	278.471212		0.077050	0.002542	-0.000017
36	MTBCOL	1	52.155410	52.155424		14.320185	227.205041	278.471212		0.077050	0.002542	-0.000017
37	MTBABS	1	56.155410	56.155424		14.628080	227.215209	282.459331		0.077050	0.002542	-0.000017
38	DD2	1	56.247260	56.247274		14.635150	227.215442	282.550909		0.077050	0.002542	-0.000017
39	MT4Q2	1	59.295260	59.295274		14.869765	227.223190	285.589856		0.077050	0.002542	-0.000017
40	DS	3	59.600060	59.600074		14.893227	227.223965	285.893750		0.077050	0.002542	-0.000017
41	DS	4	59.904860	59.904874		14.916688	227.224740	286.197645		0.077050	0.002542	-0.000017
42	DS2	1	59.936610	59.936624		14.919132	227.224821	286.229301		0.077050	0.002542	-0.000017

1 "MAD" Version: 8.23/08 Run: 15/12/06 15.26.44
Survey. SURVEY line: ALIGN range: #S/#E
symm: F super: 1 page 2

pos. no.	E L E M E N T element name	S E Q U E N C E occ. no.	sum(L) [m]	arc [m]	I I	P O S I T I O N S x [m]	y [m]	z [m]	I I	A N G L E S theta [rad]	phi [rad]	psi [rad]
43	MT4W2	1	62.984610	62.984632		15.165901	227.232568	289.267285		0.085050	0.002542	-0.000037
44	DE2	1	63.031210	63.031232		15.169860	227.232687	289.313717		0.085050	0.002542	-0.000037
45	DS	5	63.336010	63.336032		15.195752	227.233461	289.617414		0.085050	0.002542	-0.000037
46	DS	6	63.640810	63.640832		15.221644	227.234236	289.921111		0.085050	0.002542	-0.000037
47	MT4Q3	1	66.688810	66.688832		15.480563	227.241983	292.958084		0.085050	0.002542	-0.000037
48	DS	7	66.993610	66.993632		15.506455	227.242758	293.261781		0.085050	0.002542	-0.000037
49	DS3	1	67.050760	67.050782		15.511310	227.242903	293.318725		0.085050	0.002542	-0.000037
50	DT	1	67.177760	67.177782		15.522098	227.243226	293.445265		0.085050	0.002542	-0.000037
51	MT4CV1	1	68.677760	68.677782		15.649519	227.247039	294.939839		0.085050	0.002542	-0.000037
52	DS	8	68.982560	68.982582		15.675411	227.247813	295.243536		0.085050	0.002542	-0.000037
53	DS	9	69.287360	69.287382		15.701303	227.248588	295.547233		0.085050	0.002542	-0.000037

54	MT4VT	1	70.049360	70.049382	15.766032	227.250525	296.306476	0.085050	0.002542	-0.000037
55	DEPHB	1	71.090710	71.090732	15.854492	227.253172	297.344059	0.085050	0.002542	-0.000037
56	DOGLEG1	1	73.526910	73.526932	16.061441	227.259364	299.771445	0.085050	0.002542	-0.000037
57	DEPBB	1	73.855710	73.855732	16.089372	227.260200	300.099056	0.085050	0.002542	-0.000037
58	DFPM	1	73.928735	73.928757	16.095575	227.260385	300.171817	0.085050	0.002542	-0.000037
59	MT4FP	1	74.087485	74.087507	16.109060	227.260789	300.329992	0.085050	0.002542	-0.000037
60	DFPM	2	74.160510	74.160532	16.115263	227.260975	300.402753	0.085050	0.002542	-0.000037
61	DS	10	74.465310	74.465332	16.141155	227.261749	300.706450	0.085050	0.002542	-0.000037
62	MT4CH1	1	75.215310	75.215332	16.204866	227.263656	301.453737	0.085050	0.002542	-0.000037
63	MT4CYM	1	75.215310	75.215332	16.204866	227.263656	301.453737	0.085050	0.002542	-0.000037
end	FWD1	1	75.215310	75.215332	16.204866	227.263656	301.453737	0.085050	0.002542	-0.000037
begin	STGT1	1	75.215310	75.215332	16.204866	227.263656	301.453737	0.085050	0.002542	-0.000037
64	MT4CH1	2	75.965310	75.965332	16.268576	227.265562	302.201024	0.085050	0.002542	-0.000037
65	DEPB	3	79.013310	79.013332	16.527496	227.273309	305.237997	0.085050	0.002542	-0.000037
66	DOGLEG1	2	81.449510	81.449532	16.734444	227.279501	307.665383	0.085050	0.002542	-0.000037
67	DEPB1	1	84.346050	84.346072	16.980497	227.286864	310.551444	0.085050	0.002542	-0.000037
68	MT4HT	1	85.108050	85.108072	17.045227	227.288800	311.310687	0.085050	0.002542	-0.000037
69	DT1	1	85.386510	85.386532	17.068881	227.289508	311.588140	0.085050	0.002542	-0.000037
70	DS	11	85.691310	85.691332	17.094773	227.290283	311.891837	0.085050	0.002542	-0.000037
71	DS	12	85.996110	85.996132	17.120665	227.291058	312.195534	0.085050	0.002542	-0.000037
72	MT4Q4	1	89.044110	89.044132	17.379585	227.298805	315.232507	0.085050	0.002542	-0.000037
73	DS	13	89.348910	89.348932	17.405477	227.299580	315.536205	0.085050	0.002542	-0.000037
74	DS5	1	89.414950	89.414972	17.411086	227.299747	315.602006	0.085050	0.002542	-0.000037
75	MT4CH2	1	90.914950	90.914972	17.538507	227.303560	317.096579	0.085050	0.002542	-0.000037
76	DEPB2	1	92.396910	92.396932	17.664396	227.307327	318.573178	0.085050	0.002542	-0.000037
77	MT4Q5	1	95.444910	95.444932	17.923315	227.315074	321.610150	0.085050	0.002542	-0.000037
78	DE5	1	95.510950	95.510972	17.928925	227.315242	321.675952	0.085050	0.002542	-0.000037
79	DS	14	95.815750	95.815772	17.954817	227.316017	321.979649	0.085050	0.002542	-0.000037
80	MT4CV2	1	97.315750	97.315772	18.082238	227.319829	323.474222	0.085050	0.002542	-0.000037
81	DEPB3	1	98.857710	98.857732	18.213223	227.323748	325.010604	0.085050	0.002542	-0.000037
82	DS	15	99.162510	99.162532	18.239115	227.324523	325.314301	0.085050	0.002542	-0.000037
83	MT4Q6	1	102.210510	102.210532	18.498034	227.332270	328.351274	0.085050	0.002542	-0.000037
84	DS	16	102.515310	102.515332	18.523926	227.333045	328.654971	0.085050	0.002542	-0.000037
85	DFPM	3	102.588335	102.588357	18.530130	227.333231	328.727732	0.085050	0.002542	-0.000037
86	MT5FP1	1	102.747085	102.747107	18.543615	227.333634	328.885908	0.085050	0.002542	-0.000037
87	DFPM	4	102.820110	102.820132	18.549818	227.333820	328.958669	0.085050	0.002542	-0.000037

pos. no.	ELEMENT name	SEQUENCE occ. no.	sum(L) [m]	arc [m]	I I	POSITIONS x [m]	y [m]	z [m]	I I	ANGLES theta [rad]	phi [rad]	psi [rad]
88	D22	1	103.582110	103.582132		18.614548	227.335757	329.717912		0.085050	0.002542	-0.000037
89	MT5SC	1	103.886910	103.886932		18.640440	227.336531	330.021609		0.085050	0.002542	-0.000037
90	DS	17	104.191710	104.191732		18.666332	227.337306	330.325306		0.085050	0.002542	-0.000037
91	MT5CON	1	104.191710	104.191732		18.666332	227.337306	330.325306		0.085050	0.002542	-0.000037
92	DS	18	104.496510	104.496532		18.692224	227.338081	330.629004		0.085050	0.002542	-0.000037
93	DS	19	104.801310	104.801332		18.718116	227.338856	330.932701		0.085050	0.002542	-0.000037
94	MT5VT1	1	105.563310	105.563332		18.782846	227.340792	331.691944		0.085050	0.002542	-0.000037
end	STGT1	1	105.563310	105.563332		18.782846	227.340792	331.691944		0.085050	0.002542	-0.000037
begin	MT5STRIN	1	105.563310	105.563332		18.782846	227.340792	331.691944		0.085050	0.002542	-0.000037
95	DEST1	1	106.046310	106.046332		18.823875	227.342020	332.173197		0.085050	0.002542	-0.000037
96	MT5E1	1	109.094310	109.094342		19.069275	227.349768	335.211292		0.076149	0.002542	-0.000014
97	DEST	1	109.577310	109.577342		19.106019	227.350995	335.692891		0.076149	0.002542	-0.000014
98	MT5E2	1	112.625310	112.625352		19.324366	227.358743	338.733050		0.067247	0.002542	0.000008
99	DEST	2	113.108310	113.108352		19.356822	227.359971	339.214957		0.067247	0.002542	0.000008
100	MT5E3	1	116.156310	116.156362		19.548098	227.367719	342.256939		0.058345	0.002542	0.000031
101	DEST	3	116.639310	116.639362		19.576263	227.368947	342.739116		0.058345	0.002542	0.000031
102	MT5E4	1	119.687310	119.687372		19.740454	227.376694	345.782680		0.049444	0.002541	0.000054
103	DEST	4	120.170310	120.170372		19.764325	227.377921	346.265089		0.049444	0.002541	0.000054
104	MT5E5	1	123.218310	123.218383		19.901418	227.385667	349.309994		0.040542	0.002541	0.000076
105	PM	1	123.218310	123.218383		19.901418	227.385667	349.309994		0.040542	0.002541	0.000076
106	DEST	5	123.701310	123.701383		19.920994	227.386894	349.792596		0.040542	0.002541	0.000076
end	MT5STRIN	1	123.701310	123.701383		19.920994	227.386894	349.792596		0.040542	0.002541	0.000076
107	DMV	1	125.701310	125.701383		20.002057	227.391976	351.790946		0.040542	0.002541	0.000076
108	D2C	1	131.595310	131.595383		20.240947	227.406952	357.680084		0.040542	0.002541	0.000076
109	MT5Q1	1	134.643310	134.643383		20.364486	227.414696	360.725569		0.040542	0.002541	0.000076
110	DS	20	134.948110	134.948183		20.376840	227.415471	361.030118		0.040542	0.002541	0.000076
111	DS	21	135.252910	135.252983		20.389194	227.416245	361.334666		0.040542	0.002541	0.000076
112	MT5Q2	1	138.300910	138.300983		20.512733	227.423990	364.380152		0.040542	0.002541	0.000076
113	DS	22	138.605710	138.605783		20.525087	227.424764	364.684700		0.040542	0.002541	0.000076
114	DS3	2	138.662860	138.662933		20.527403	227.424909	364.741803		0.040542	0.002541	0.000076
115	DT2	1	139.183560	139.183633		20.548508	227.426232	365.262074		0.040542	0.002541	0.000076
116	MT5VT2	1	139.945560	139.945633		20.579392	227.428169	366.023445		0.040542	0.002541	0.000076
117	DS	23	140.250360	140.250433		20.591746	227.428943	366.327994		0.040542	0.002541	0.000076
118	DT3	1	140.834710	140.834783		20.615431	227.430428	366.911861		0.040542	0.002541	0.000076
119	MT5HT2	1	141.596710	141.596783		20.646315	227.432364	367.673233		0.040542	0.002541	0.000076
120	DS	24	141.901510	141.901583		20.658669	227.433138	367.977781		0.040542	0.002541	0.000076
121	DFPM	5	141.974535	141.974608		20.661629	227.433324	368.050746		0.040542	0.002541	0.000076

122	MT5FP2	1	142.133285	142.133358	20.668063	227.433727	368.209365	0.040542	0.002541	0.000076
123	DFPM	6	142.206310	142.206383	20.671023	227.433913	368.282330	0.040542	0.002541	0.000076
124	DC	1	146.423860	146.423933	20.841965	227.444629	372.496401	0.040542	0.002541	0.000076
125	MT5CV1	1	158.615860	158.615933	21.336121	227.475607	384.678343	0.040542	0.002541	0.000076
126	DS4	1	161.015045	161.015118	21.433363	227.481703	387.075549	0.040542	0.002541	0.000076
127	MT5CV2	1	176.255045	176.255118	22.051057	227.520426	402.302976	0.040542	0.002541	0.000076
128	OFFSET	1	179.475645	179.475718	22.181592	227.528609	405.520919	0.040542	0.002541	0.000076
end	MTSECOND	1	179.475645	179.475718	22.181592	227.528609	405.520919	0.040542	0.002541	0.000076
begin	NEWMT6	1	179.475645	179.475718	22.181592	227.528609	405.520919	0.040542	0.002541	0.000076
129	MT6S1BEG	1	179.475645	179.475718	22.181592	227.528609	405.520919	0.040542	0.002541	0.000076

pos. no.	E L E M E N T element name	occ. no.	S E Q U E N C E sum(L) [m]	arc [m]	I I	P O S I T I O N S x [m]	y [m]	z [m]	I I	A N G L E S theta [rad]	phi [rad]	psi [rad]
130	D58	1	179.802670	179.802743		22.194847	227.529440	405.847675		0.040542	0.002541	0.000076
131	DS	25	180.107470	180.107543		22.207201	227.530215	406.152223		0.040542	0.002541	0.000076
132	MT6FP	1	180.266220	180.266293		22.213635	227.530618	406.310842		0.040542	0.002541	0.000076
133	DS	26	180.571020	180.571093		22.225989	227.531393	406.615391		0.040542	0.002541	0.000076
134	MT6WC1	1	180.571020	180.571093		22.225989	227.531393	406.615391		0.040542	0.002541	0.000076
135	DS	27	180.875820	180.875893		22.238343	227.532167	406.919939		0.040542	0.002541	0.000076
136	MT6SC	1	180.875820	180.875893		22.238343	227.532167	406.919939		0.040542	0.002541	0.000076
137	D59	1	185.447820	185.447893		22.423651	227.543784	411.488168		0.040542	0.002541	0.000076
138	MT6D1	1	192.838421	192.838494		22.723201	227.562563	418.872672		0.040542	0.002541	0.000076
139	MT1374C	1	192.838421	192.838494		22.723201	227.562563	418.872672		0.040542	0.002541	0.000076
140	MT6D2	1	213.068121	213.068194		23.543134	227.613964	439.085683		0.040542	0.002541	0.000076
141	MT1440C	1	213.068121	213.068194		23.543134	227.613964	439.085683		0.040542	0.002541	0.000076
end	NEWMT6	1	213.068121	213.068194		23.543134	227.613964	439.085683		0.040542	0.002541	0.000076
end	ALIGN	1	213.068121	213.068194		23.543134	227.613964	439.085683		0.040542	0.002541	0.000076

total length = 213.068121 arc length = 213.068194

error(x) = 0.127595E+02 error(y) = 0.454934E+00 error(z) = 0.212649E+03

error(theta) = -0.220076E-01 error(phi) = 0.310587E-02 error(psi) = 0.761278E-04

Appendix 3

T953 Setup Input File
8 GeV Muons

```
physics QGSP


param histoFile=LeadBricks36

#       list particles

#------------------------------------------------------------------------
beam gaussian particle=mu+ meanMomentum=8000 beamZ=1 \
        sigmaX=40.0 sigmaY=40.0 sigmaXp=0.001 sigmaYp=0.001 \
        nEvents=10000000 firstEvent=1 lastEvent=10000
#------------------------------------------------------------------------
#       Detector

virtualdetector S0 radius=50 color=0,1,0

place S0 z=49
#------------------------------------------------------------------------

#------------------------------------------------------------------------
#       Iron Brick 1

box Iron_block1 width=200.0 height=200.0 length=400 material=Fe color=1,0,0

#place Iron_block1 z=300
#------------------------------------------------------------------------
#       Detector

virtualdetector S1 radius=50 color=0,1,0

place S1 z=501
#------------------------------------------------------------------------
#       Detector

virtualdetector S2 radius=50 color=0,1,0

place S2 z=1999
#------------------------------------------------------------------------
#       Iron Brick 2

box Iron_block2 width=200.0 height=200.0 length=300 material=Fe color=1,5,1
```

```
place Iron_block2 z=2150

#-------------------------------------------------------------------------

#         Lead Brick 1

box Lead_Brick1 width=200 height=200 length=400 material=Pb color=0,1,1

place Lead_Brick1 z=2500

#-------------------------------------------------------------------------
#         Detector

virtualdetector S3 radius=50 color=0,1,0

place S3 z=2701
#-------------------------------------------------------------------------
trackcuts killSecondaries=0
```