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H- and heavy ion injection lines for the Booster

R. C. Gupta

September 1987

Collider Accelerator Department

Brookhaven National Laboratory

U.S. Department of Energy

USDOE Office of Science (SC)

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H^- AND HEAVY ION INJECTION LINES FOR THE BOOSTER

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R.C. GUPTA, R. DAMM, Y.Y. LEE AND W.T. WENG

SEPTEMBER 17, 1987

ACCELERATOR DEVELOPMENT DEPARTMENT

Brookhaven National Laboratory

Upton, N.Y. 11973

H^- and Heavy Ion Injection Lines for the Booster

R.C. Gupta, R. Damm, Y.Y. Lee and W.T. Weng

In this note we describe the layout and beam optics of the new design of the heavy ion and H^- injection lines for the AGS booster. The earlier design and general reqirements for these beam lines have been described in reference 1 and reference 2. The major design changes come due to the fact that now the heavy ions will be injected in the straight section C3 instead of A3. In the earlier plan the heavy ion line would have gone through the old 50 Mev Linac staging area. In the new plan we propose to use the existing tunnel for the 200 MeV H^- line from the LINAC to the AGS. The heavy ions will enter in it from the AGS tunnel. The overall layout of the two injection lines is shown in Fig 1. The layout near the booster area is shown in more detail in Fig 2. The positions of various dipoles, quadrupoles and other elements is also shown in this figure. As shown in Fig 2, there will be a common tunnel for both lines in the intermediate area of the booster and the 200 Mev H^- line to the AGS. The optics has been designed in such a way that the two beam lines produces a 10 feet long component free section in the intermediate tunnel. This space will be used for a concrete wall which would provide a radiation shielding between the booster and the linac. The minimum separation between the two lines at any place will be about 3 feet.

The H^- line will always remain at the booster elevation, which is 75 feet above the sea level. The heavy ion line, however, has to go through different elevations during its course from the 69 degree bend (located in the old south west experiment area of the AGS) to the injection point in the booster. The elevation of this line at the 69 degree bend point is 85 feet, in the AGS tunnel will be 76.18 feet, in the present 200 MeV H^- line tunnel will be 78 feet and after the last dipole in the intermediate tunnel will be 75 feet. Fig 2a shows the beam line elevations from HITL to all the way into the Booster. A small tilt in various horizontal bends will provide the required vertical bend to pitch the line up or down at the above

mentioned locations. In the following two sections, these two lines will be described in little more detail.

The H^- Injection Line

The proposed H^- injection line to the booster will use the first five quadrupoles of the present H^- injection line for the AGS. A kicker magnet, imparting a 7.5 degree deflection, will be installed in the present line to guide the H^- beam towards the new injection line. The new beam line will have four dipoles, each 1.3 meter long and giving a deflection of 31.5413 degrees with a field strength of 9.1 kG. Richard Thomas has computed the loss due to electromagnetic stripping in these magnets (Please see reference 3). The loss is about 0.01%, which can be tolerated here. We cluster the first three dipoles quite close to each other and put the last one far away. There are two quads between the last two dipoles which have been put very close to the either dipoles to create a component free 10 feet long section for radiation shielding. There are six quadrupoles between the last dipole of this line and the first magnet of the booster ring. These six quads will be used to experimentally determine the phase ellipse parameters of the beam at the injection point to achieve the highest intensity of the accelerated protons. In the final design described in this note, the phase space ellipses and the dispersion functions of the injected beam are matched to the lattice parameters of the booster lattice at the injection point. The H^- ions will enter in the booster through the displaced yoke of the dipole magnet MDC5. The injection line has been designed so that the injected H^- beam at the stripper foil comes parallel to the circulating proton beam and has a separation of 2" form it. The actual position of the stripper foil and the injection point can be changed later to empirically determine the best injection and operation parameters.

The position of various dipoles and quadrupoles in this beam line, in both booster and AGS coordinates, is given in Fig 3. The input to the computer program MAD, which has been used in the final design of this line, is given in Fig 4. The input file also gives the

value of length and strength of all elements used in this line. The final optics of this beam line can be seen in Fig 5 where we have plotted the variations in the lattice functions (BETAX, BETAY and XP). We use the beam ellipse parameters of the 200 MeV beam just after the last LINAC tank (Tank T9) to design the rest of the beam line. The beam size at any point remains well within the 4" aperture of the quadrupoles. The MAD output giving the lattice functions of the injected beam in the H^- injection line is given in Fig 6.

The Heavy Ion Injection Line

In this note we describe a part of the heavy ion injection line. However, this is the most crucial part in designing beam optics since this part does the matching of the dispersion function (and also its derivative) and provides a 10 feet long component free section for the radiation shielding. In fact, had we not found a solution fulfilling these requirements, we would have to continue with the older design where the beam was injected in the straight section A3. The beam line in question is from the tunnel of the present 200 MeV H^- line (to AGS) to the injection point in the booster. This beam line is shown in Fig 2.

This beam line has three dipople magnets and one electrostatic septum. Each magnet has a length of 0.9 meter and gives a deflection of 40 degrees. The first two magnets (HIDA and HIDB) bends the beam in clockwise direction and the last (HIDC) in counter clockwise direction. The magnets, HIDB and HIDC, are tilted by 6.31228 degrees to produce the 3 feet downward pitching. The electrostatic septum is 3.2 meter long and gives a deflection of 20.6329 degrees in the counter clockwise direction.

The position of various dipoles and quadrupoles in the heavy ion beam line, in both booster and AGS coordinates, is given in Fig 7. The input to the computer program MAD, which has been used in the final design of this line, is given in Fig 8. The input file also gives the value of length and strength of all elements used in this

line. The final optics of this beam line can be seen in Fig 9 where we have plotted the variations in the lattice functions (BETAX, BETAY, XP and YP). The beam size at any point remains well within the 4" aperture of the quadrupoles. The MAD output giving the lattice functions of the injected beam in this injection line is given in Fig 10.

In the design described in this note, the phase space ellipses and the horizontal dispersion function (together with its derivative) of the injected beam are matched to the lattice parameters of the booster lattice at the injection point. The vertical dispersion function, however, could not be matched completely and it comes out to be about 0.4 meter at the injection point. In these calculations we have used the MAD version 4.03. This version does not deal with the electrostatic septum. Now the higher version of this program are available in the laboratory and they will be used in future computations to describe the optics of the electrostatic septum correctly. In the present run we assumed that the electrostatic septum behaves the same way as the magnetic septum for giving the change in XP and the change in the XP' due to it will be twice as that of the magnetic element. In any case, the eight quadrupoles between the magnets HIDB and HIDC, should be sufficient to produce any solution in the vicinity of the one we are presenting in this note.

References

1. R.C. Gupta, S.Y. Lee, Y.Y. Lee, X.F. Zhao, "Beam Transfer Lines for the AGS Booster", 1987 Particle Accelerator Conference, Washington D.C.

2. R.C. Gupta and Y.Y. Lee, "The Heavy Ion Injection Line for the AGS Booster", Booster Tech Note No. 7.

3. R. Thomas, "H^- Stripping in the Booster Protron Injection Line", Booster Tech Note No. 79.

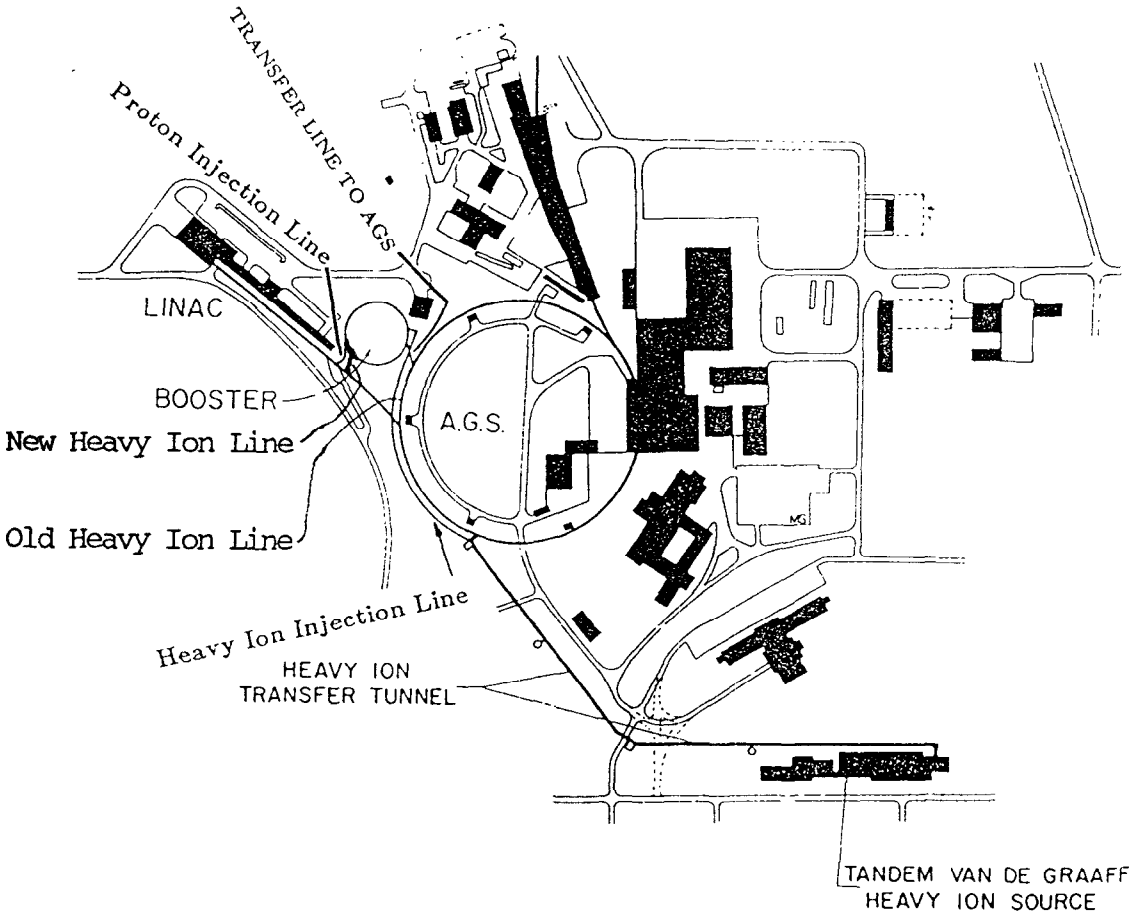

Fig 1. Layout of the complete heavy ion and proton injection lines.

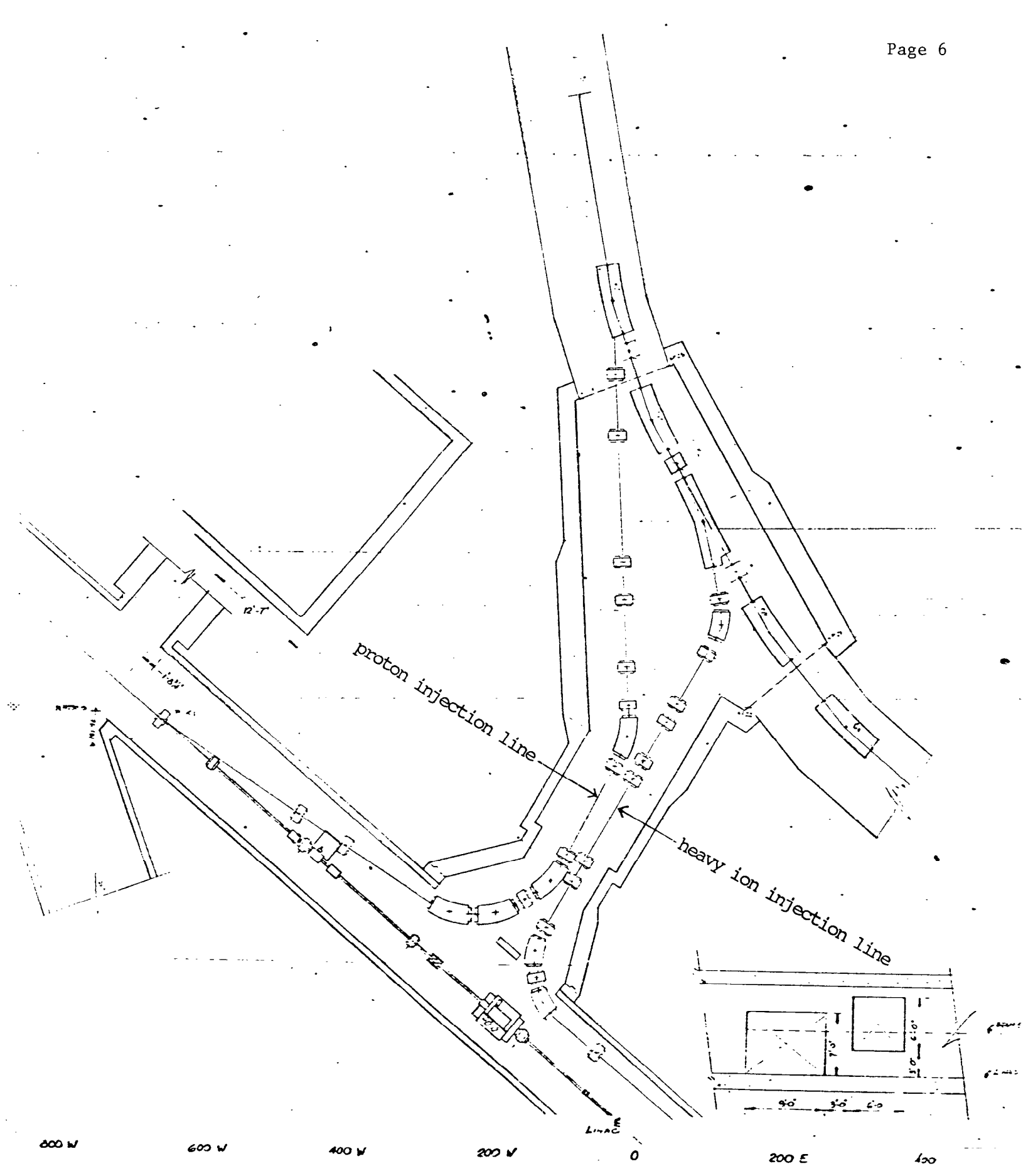

Fig 2. Detail layout of the injection lines near the Booster.

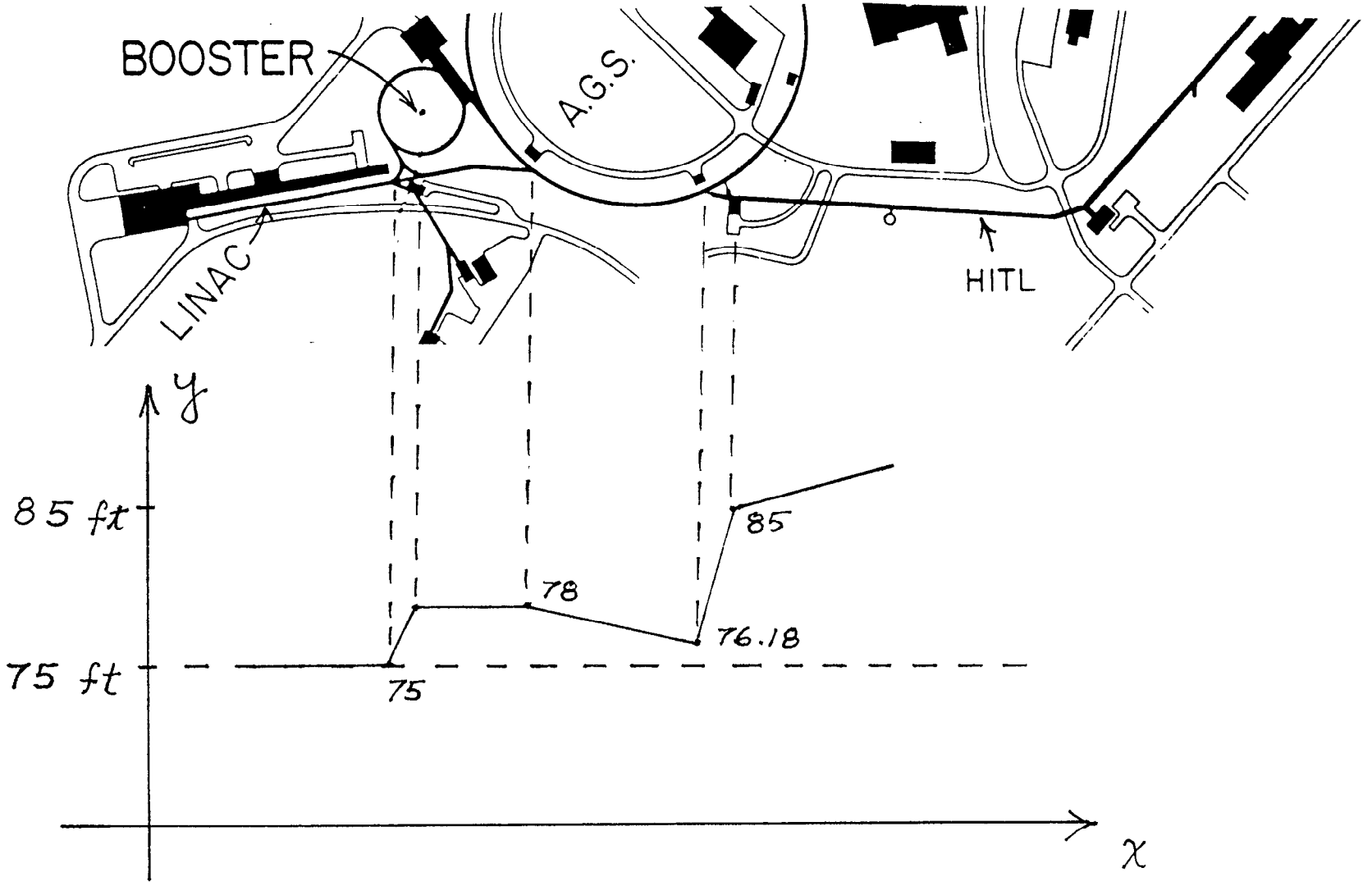

Fig. 2a. Beam Line Elevation in the Heavy Ion Injection Line.

ELEMENT		Xbst(m)	Ybst(m)	Eags(")	Nags(")
BEGIN	PIK1	-46.1260	-23.7550	-667.104	14524.124
1	PIK1	-45.9980	-23.8551	-662.064	14520.183
2	PIK1	-45.8637	-23.9467	-656.776	14516.578
3	PIQF1	-41.2199	-26.8938	-473.952	14400.549
4	PIQF1	-41.0933	-26.9742	-468.966	14397.385
5	PIQF1	-40.9666	-27.0546	-463.980	14394.220
6	PIQD1	-39.6157	-27.9119	-410.794	14360.466
7	PIQD1	-39.4891	-27.9923	-405.808	14357.302
8	PIQD1	-39.3624	-28.0727	-400.822	14354.137
9	PIDL	-36.4073	-29.9481	-284.480	14280.300
10	PIDL	-35.8178	-30.2170	-261.270	14269.715
11	PIDL	-35.1774	-30.3155	-236.056	14265.836
12	PIDL	-34.8774	-30.3200	-224.247	14265.658
13	PIDL	-34.2343	-30.2408	-198.928	14268.778
14	PIDL	-33.6370	-29.9897	-175.411	14278.662
15	PIQD2	-33.3790	-29.8366	-165.253	14284.689
16	PIQD2	-33.2500	-29.7601	-160.174	14287.702
17	PIQD2	-33.1210	-29.6836	-155.096	14290.716
18	PIDL	-32.8630	-29.5305	-144.938	14296.742
19	PIDL	-32.3563	-29.1265	-124.992	14312.646
20	PIDL	-31.9786	-28.6001	-110.120	14333.372
21	PIQF3	-31.8388	-28.3347	-104.615	14343.821
22	PIQF3	-31.7689	-28.2020	-101.863	14349.047
23	PIQF3	-31.6990	-28.0693	-99.111	14354.271
24	PIQD3	-30.2435	-25.3061	-41.810	14463.056
25	PIQD3	-30.1736	-25.1734	-39.058	14468.280
26	PIQD3	-30.1037	-25.0407	-36.305	14473.506
27	PIDL	-29.9639	-24.7753	-30.801	14483.956
28	PIDL	-29.7434	-24.1660	-22.121	14507.943
29	PIDL	-29.6969	-23.5197	-20.288	14533.388
30	PIQF4	-29.7166	-23.2204	-21.063	14545.173
31	PIQF4	-29.7264	-23.0707	-21.451	14551.065
32	PIQF4	-29.7362	-22.9210	-21.838	14556.958
33	PIQD4	-29.8019	-21.9232	-24.423	14596.244
34	PIQD4	-29.8117	-21.7735	-24.810	14602.137
35	PIQD4	-29.8216	-21.6238	-25.198	14608.029
36	PIQF5	-29.9529	-19.6281	-30.367	14686.600
37	PIQF5	-29.9627	-19.4784	-30.754	14692.492
38	PIQF5	-29.9726	-19.3288	-31.142	14698.385
39	PIQD5	-30.0382	-18.3309	-33.726	14737.670
40	PIQD5	-30.0480	-18.1813	-34.114	14743.563
41	PIQD5	-30.0579	-18.0316	-34.502	14749.456
42	PIQF6	-30.3205	-14.0402	-44.839	14906.597
43	PIQF6	-30.3303	-13.8905	-45.227	14912.489
44	PIQF6	-30.3402	-13.7409	-45.614	14918.382
45	PIQD6	-30.4583	-11.9447	-50.266	14989.096
46	PIQD6	-30.4682	-11.7951	-50.654	14994.988
47	PIQD6	-30.4780	-11.6454	-51.042	15000.881
BEG 49	MDC5	-30.5987	-9.8103	-55.794	15073.126
END 50	MDC5	-30.8095	-8.1526	-64.094	15138.391
51	MQFC5	-30.9957	-7.1701	-71.425	15177.072
MID 52	MQFC5	-31.0423	-6.9245	-73.258	15186.743

Fig 3. The positions of all elements in the proton injection line.

```
TITLE!
                                        NEW PROTON INJECTION LINE
!
! DATE AND TIME: 14/05/87      09.57.23
!
PILO1:     DRIFT,L=1.98120000000
PILO2:     DRIFT,L=2.97180000000
PILO3:     DRIFT,L=3.27660000000
PILO4:     DRIFT,L=3.50520000000
PILO5:     DRIFT,L=3.51790000000
PILO6:     DRIFT,L=1.69160000000
PILL:      DRIFT,L=3.12300000000
PILB:      DRIFT,L=0.300000000000
PIL1:      DRIFT,L=5.50000000000
PIL2:      DRIFT,L=1.60000000000
PIL3:      DRIFT,L=3.50000000000
PIL41:     DRIFT,L=1.00000000000
PIL42:     DRIFT,L=2.00000000000
PIL43:     DRIFT,L=1.00000000000
PIL44:     DRIFT,L=4.00000000000
PIL5:      DRIFT,L=1.80000000000
PIL6:      DRIFT,L=1.03900000000
PIL7:      DRIFT,L=0.300000000000
PILM:      DRIFT,L=0.800000000000
PILQ:      DRIFT,L=0.300000000000
MLC5O:     DRIFT,L=1.00000000000
PIQFO1:    QUADRUPO,L=0.152400000000,K1=1.24320751965
PIQFO2:    QUADRUPO,L=0.152400000000,K1=0.977547149089
PIQDO1:    QUADRUPO,L=0.152400000000,K1=-1.20668120508
PIQDO2:    QUADRUPO,L=0.152400000000,K1=-0.904393748845
PIQDO3:    QUADRUPO,L=0.152400000000,K1=-0.678966509956
PIQF1:     QUADRUPO,L=0.150000000000,K1=1.10757531455
PIQD1:     QUADRUPO,L=0.150000000000,K1=-0.829563275212
PIQF2:     QUADRUPO,L=0.150000000000,K1=0.950431935974
PIQD2:     QUADRUPO,L=0.150000000000,K1=-0.719638783317
PIQF3:     QUADRUPO,L=0.150000000000,K1=0.938201139475
PIQD3:     QUADRUPO,L=0.150000000000,K1=-1.24815510170
PIQF4:     QUADRUPO,L=0.150000000000,K1=1.00186627857
PIQD4:     QUADRUPO,L=0.150000000000,K1=-0.994898265284
PIQF5:     QUADRUPO,L=0.150000000000,K1=1.04066058544
PIQD5:     QUADRUPO,L=0.150000000000,K1=-1.11294657227
PIQF6:     QUADRUPO,L=0.150000000000,K1=1.39221315431
PIQD6:     QUADRUPO,L=0.150000000000,K1=-1.64087278457
MQFC5:     QUADRUPO,L=0.250000000000,K1=0.554569000000
PIK1:      SBEND,L=0.162560000000,ANGLE=-0.654500000000E-01
PIDL:      SBEND,L=0.650000000000,ANGLE=-0.275249500000
MDC5:      SBEND,L=1.67210000000,ANGLE=-0.121610000000,E1=1.32758000000
LINAC:     LINE=(PILO1,2*PIQDO1,PILO2,2*PIQFO1,PILO3,2*PIQDO2,PILO4,2*&
           PIQFO2,PILO5,2*PIQDO3,PILO6)
LTOBND:    LINE=(2*PIK1,PIL1,2*PIQF1,PIL2,2*PIQD1,PIL3)
LBND:      LINE=(2*PIDL,PILB,2*PIDL,PILB,2*PIQD2,PILB,2*PIDL,PILB,2*&
           PIQF3,PILL,2*PIQD3,PILB,2*PIDL)
LTOBST:    LINE=(PIL7,2*PIQF4,PIL41,2*PIQD4,PIL42,2*PIQF5,PIL43,2*PIQD5
           ,PIL44,2*PIQF6)
LQD:       LINE=(PIL5,2*PIQD6,PIL6)
LBST:      LINE=(PILM,MDC5,MLC5O,MQFC5)
LSURVEY:   LINE=(LTOBND,LBND,LTOBST,LQD,LBST)
LMATCH:    LINE=(LINAC,LTOBND,LBND,LTOBST,LQD,LBST)
USE,LSURVEY
PRINT,#S/E

SURVEY,Z0=-46.126,X0=-23.755,THETA=-0.69641
USE,LMATCH
PRINT,#S/E
TWISS,BETX=6.508,ALFX=1.998,BETY=3.68,ALFY=-0.964
STOP
```

Fig 4. The input to MAD for the proton injection line.

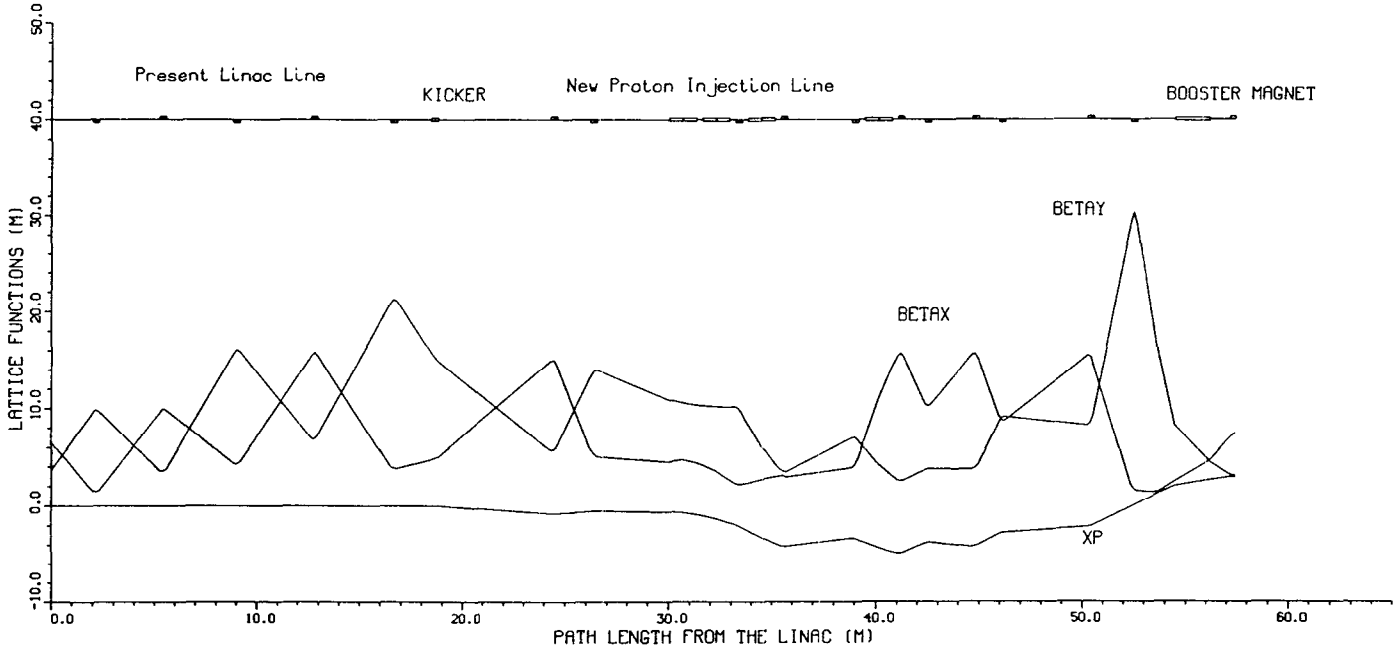

Fig 5. The optics of the proton injection line.

NEW PROTON INJECTION LINE — MAD VERSION: 4.03 — RUN: 26/08/87 15.49.29

TWISS PARAMETERS FOR BEAM LINE "LMATCH" — DELTA(P)/P = 0.000000 — SYMM = F — PAGE 1

POS. NO.	ELEMENT NAME	OCC. NO.	DIST [M]	I I	HORIZONTAL BETAX [M]	ALFAX	MUX [2PI]	X(CO) [MM]	X'(CO) [MRAD]	DX [M]	DX'	I I	VERTICAL BETAY [M]	ALFAY	MUY [2PI]	Y(CO) [MM]	Y'(CO) [MRAD]	DY [M]	DY'
BEGIN	LMATCH	1	0.000		6.508	1.998	0.000	0.00	0.000	0.000	0.000		3.680	-0.964	0.000	0.00	0.000	0.000	0.000
1	PIL01	1	1.981		1.602	0.478	0.105	0.00	0.000	0.000	0.000		9.558	-2.003	0.054	0.00	0.000	0.000	0.000
2	PIQD01	1	2.134		1.517	0.086	0.121	0.00	0.000	0.000	0.000		9.903	-0.245	0.057	0.00	0.000	0.000	0.000
3	PIQD01	2	2.286		1.548	-0.296	0.137	0.00	0.000	0.000	0.000		9.704	1.540	0.059	0.00	0.000	0.000	0.000
4	PIL02	1	5.258		9.514	-2.384	0.278	0.00	0.000	0.000	0.000		3.619	0.507	0.143	0.00	0.000	0.000	0.000
5	PIQF01	1	5.410		9.970	-0.585	0.280	0.00	0.000	0.000	0.000		3.575	-0.216	0.150	0.00	0.000	0.000	0.000
6	PIQF01	2	5.563		9.863	1.282	0.283	0.00	0.000	0.000	0.000		3.753	-0.964	0.156	0.00	0.000	0.000	0.000
7	PIL03	1	8.839		4.341	0.404	0.366	0.00	0.000	0.000	0.000		15.595	-2.649	0.227	0.00	0.000	0.000	0.000
8	PIQD02	1	8.992		4.314	-0.227	0.372	0.00	0.000	0.000	0.000		16.078	-0.497	0.228	0.00	0.000	0.000	0.000
9	PIQD02	2	9.144		4.482	-0.878	0.377	0.00	0.000	0.000	0.000		15.893	1.697	0.230	0.00	0.000	0.000	0.000
10	PIL04	1	12.649		15.487	-2.262	0.446	0.00	0.000	0.000	0.000		6.994	0.841	0.284	0.00	0.000	0.000	0.000
11	PIQF02	1	12.802		15.826	0.053	0.448	0.00	0.000	0.000	0.000		6.900	-0.216	0.287	0.00	0.000	0.000	0.000
12	PIQF02	2	12.954		15.455	2.363	0.449	0.00	0.000	0.000	0.000		7.128	-1.293	0.291	0.00	0.000	0.000	0.000
13	PIL05	1	16.472		4.101	0.864	0.522	0.00	0.000	0.000	0.000		20.859	-2.611	0.337	0.00	0.000	0.000	0.000
14	PIQD03	1	16.624		3.909	0.397	0.528	0.00	0.000	0.000	0.000		21.328	-0.450	0.338	0.00	0.000	0.000	0.000
15	PIQD03	2	16.777		3.856	-0.044	0.535	0.00	0.000	0.000	0.000		21.130	1.740	0.339	0.00	0.000	0.000	0.000
16	PIL06	1	18.468		4.749	-0.484	0.599	0.00	0.000	0.000	0.000		15.789	1.417	0.354	0.00	0.000	0.000	0.000
17	PIK1	1	18.631		4.893	-0.397	0.605	0.00	0.000	-0.005	-0.065		15.334	1.388	0.356	0.00	0.000	0.000	0.000
18	PIK1	2	18.793		5.007	-0.304	0.610	0.00	0.000	-0.021	-0.131		14.888	1.356	0.358	0.00	0.000	0.000	0.000
19	PIL1	1	24.293		14.944	-1.503	0.720	0.00	0.000	-0.739	-0.131		5.742	0.307	0.459	0.00	0.000	0.000	0.000
20	PIQF1	1	24.443		15.023	0.981	0.721	0.00	0.000	-0.749	-0.007		5.797	-0.676	0.463	0.00	0.000	0.000	0.000
21	PIQF1	2	24.593		14.366	3.368	0.723	0.00	0.000	-0.741	0.117		6.155	-1.728	0.467	0.00	0.000	0.000	0.000
22	PIL2	1	26.193		5.789	1.993	0.751	0.00	0.000	-0.553	0.117		13.342	-2.764	0.495	0.00	0.000	0.000	0.000
23	PIQD1	1	26.343		5.311	1.208	0.755	0.00	0.000	-0.541	0.050		13.928	-1.118	0.497	0.00	0.000	0.000	0.000
24	PIQD1	2	26.493		5.055	0.514	0.760	0.00	0.000	-0.538	-0.018		14.004	0.611	0.499	0.00	0.000	0.000	0.000
25	PIL3	1	29.993		4.520	-0.361	0.891	0.00	0.000	-0.600	-0.018		10.926	0.268	0.544	0.00	0.000	0.000	0.000
26	PIDL	1	30.643		4.735	0.038	0.913	0.00	0.000	-0.677	-0.220		10.619	0.204	0.554	0.00	0.000	0.000	0.000
27	PIDL	2	31.293		4.426	0.426	0.935	0.00	0.000	-0.882	-0.405		10.394	0.141	0.564	0.00	0.000	0.000	0.000
28	PILB	1	31.593		4.194	0.346	0.946	0.00	0.000	-1.003	-0.405		10.319	0.111	0.569	0.00	0.000	0.000	0.000
29	PIDL	3	32.243		3.566	0.595	0.973	0.00	0.000	-1.314	-0.548		10.216	0.047	0.579	0.00	0.000	0.000	0.000
30	PIDL	4	32.893		2.725	0.667	1.006	0.00	0.000	-1.704	-0.646		10.196	-0.016	0.589	0.00	0.000	0.000	0.000
31	PILB	2	33.193		2.372	0.508	1.025	0.00	0.000	-1.898	-0.646		10.214	-0.046	0.593	0.00	0.000	0.000	0.000
32	PIQD2	1	33.343		2.268	0.186	1.035	0.00	0.000	-2.011	-0.857		10.066	1.032	0.596	0.00	0.000	0.000	0.000
33	PIQD2	2	33.493		2.259	-0.125	1.045	0.00	0.000	-2.156	-1.082		9.602	2.043	0.598	0.00	0.000	0.000	0.000
34	PILB	3	33.793		2.375	-0.260	1.066	0.00	0.000	-2.480	-1.082		8.425	1.881	0.604	0.00	0.000	0.000	0.000
35	PIDL	5	34.443		2.706	-0.236	1.107	0.00	0.000	-3.170	-1.027		6.207	1.531	0.618	0.00	0.000	0.000	0.000
36	PIDL	6	35.093		2.958	-0.143	1.143	0.00	0.000	-3.799	-0.895		4.444	1.181	0.638	0.00	0.000	0.000	0.000
37	PILB	4	35.393		3.075	-0.246	1.159	0.00	0.000	-4.068	-0.895		3.784	1.019	0.649	0.00	0.000	0.000	0.000
38	PIQF3	1	35.543		3.091	0.140	1.167	0.00	0.000	-4.159	-0.316		3.566	0.441	0.656	0.00	0.000	0.000	0.000
39	PIQF3	2	35.693		2.992	0.514	1.175	0.00	0.000	-4.162	0.271		3.516	-0.101	0.663	0.00	0.000	0.000	0.000
40	PILL	1	38.816		3.902	-0.805	1.358	0.00	0.000	-3.316	0.271		6.946	-0.998	0.771	0.00	0.000	0.000	0.000
41	PIQD3	1	38.966		4.268	-1.660	1.364	0.00	0.000	-3.322	-0.349		7.053	0.292	0.775	0.00	0.000	0.000	0.000
42	PIQD3	2	39.116		4.917	-2.703	1.369	0.00	0.000	-3.421	-0.979		6.775	1.549	0.778	0.00	0.000	0.000	0.000
43	PILB	5	39.416		6.690	-3.210	1.378	0.00	0.000	-3.715	-0.979		5.891	1.398	0.786	0.00	0.000	0.000	0.000
44	PIDL	7	40.066		10.857	-3.038	1.390	0.00	0.000	-4.292	-0.786		4.285	1.072	0.806	0.00	0.000	0.000	0.000
45	PIDL	8	40.716		14.195	-1.968	1.398	0.00	0.000	-4.724	-0.534		3.103	0.746	0.835	0.00	0.000	0.000	0.000
46	PIL7	1	41.016		15.407	-2.071	1.401	0.00	0.000	-4.884	-0.534		2.700	0.596	0.852	0.00	0.000	0.000	0.000
47	PIQF4	1	41.166		15.682	0.251	1.403	0.00	0.000	-4.909	0.203		2.592	0.134	0.861	0.00	0.000	0.000	0.000
48	PIQF4	2	41.316		15.259	2.552	1.404	0.00	0.000	-4.823	0.936		2.619	-0.315	0.870	0.00	0.000	0.000	0.000
49	PIL41	1	42.316		10.648	2.059	1.417	0.00	0.000	-3.888	0.936		3.668	-0.735	0.922	0.00	0.000	0.000	0.000
50	PIQD4	1	42.466		10.272	0.465	1.419	0.00	0.000	-3.790	0.384		3.813	-0.225	0.928	0.00	0.000	0.000	0.000
51	PIQD4	2	42.616		10.365	-1.088	1.421	0.00	0.000	-3.778	-0.200		3.801	0.305	0.935	0.00	0.000	0.000	0.000
52	PIL42	1	44.616		15.561	-1.510	1.446	0.00	0.000	-4.178	-0.200		3.730	-0.270	1.024	0.00	0.000	0.000	0.000
53	PIQF5	1	44.766		15.650	0.920	1.448	0.00	0.000	-4.159	0.452		3.907	-0.918	1.030	0.00	0.000	0.000	0.000
54	PIQF5	2	44.916		15.018	3.265	1.450	0.00	0.000	-4.043	1.093		4.290	-1.653	1.036	0.00	0.000	0.000	0.000
55	PIL43	1	45.916		9.264	2.489	1.463	0.00	0.000	-2.950	1.093		8.465	-2.522	1.062	0.00	0.000	0.000	0.000
56	PIQD5	1	46.066		8.756	0.924	1.466	0.00	0.000	-2.822	0.613		9.018	-1.136	1.065	0.00	0.000	0.000	0.000
57	PIQD5	2	46.216		8.700	-0.548	1.468	0.00	0.000	-2.765	0.147		9.135	0.364	1.068	0.00	0.000	0.000	0.000
58	PIL44	1	50.216		15.479	-1.146	1.524	0.00	0.000	-2.176	0.147		8.209	-0.132	1.144	0.00	0.000	0.000	0.000
59	PIQF6	1	50.366		15.339	2.068	1.526	0.00	0.000	-2.120	0.597		8.512	-1.910	1.147	0.00	0.000	0.000	0.000
60	PIQF6	2	50.516		14.264	5.026	1.528	0.00	0.000	-1.998	1.028		9.379	-3.929	1.150	0.00	0.000	0.000	0.000
61	PIL5	1	52.316		2.135	1.712	1.580	0.00	0.000	-0.147	1.028		29.203	-7.084	1.167	0.00	0.000	0.000	0.000
62	PIQD6	1	52.466		1.730	1.018	1.593	0.00	0.000	0.005	1.011		30.250	0.188	1.168	0.00	0.000	0.000	0.000
63	PIQD6	2	52.616		1.509	0.477	1.608	0.00	0.000	0.158	1.031		29.093	7.433	1.169	0.00	0.000	0.000	0.000
64	PIL6	1	53.655		1.396	-0.368	1.735	0.00	0.000	1.229	1.031		15.734	5.424	1.178	0.00	0.000	0.000	0.000
65	PILM	1	54.455		2.506	-1.019	1.805	0.00	0.000	2.053	1.031		8.293	3.877	1.188	0.00	0.000	0.000	0.000
66	MDC5	1	56.128		4.613	-0.969	1.887	0.00	0.000	2.652	0.286		4.498	0.823	1.232	0.00	0.000	0.000	0.000
67	MLC50	1	57.128		6.971	-1.389	1.915	0.00	0.000	2.938	0.286		3.225	0.450	1.274	0.00	0.000	0.000	0.000
68	MQFC5	1	57.378		7.436	-0.452	1.921	0.00	0.000	2.959	-0.124		3.131	-0.071	1.287	0.00	0.000	0.000	0.000
END	LMATCH	1	57.378		7.436	-0.452	1.921	0.00	0.000	2.959	-0.124		3.131	-0.071	1.287	0.00	0.000	0.000	0.000

TOTAL LENGTH =	57.377520	MUX =	1.920560	MUY =	1.286676
		MUX' =	-1.096794	MUY' =	-1.259697
		BETAX(MAX) =	15.826435	BETAY(MAX) =	30.250089
		DX(MAX) =	4.908799	DY(MAX) =	0.000000

Fig 6. The MAD output for the proton injection line.

ELEMENT	Xbst(m)	Ybst(m)	Eags(")	Nags(")	Height(")
MID MQFC3	-28.2486	-14.7906	36.730	14877.055	0.000
1 MQFC3	-28.1209	-15.0055	41.760	14868.594	0.000
2 HIKICK	-27.9676	-15.2633	47.795	14858.441	0.000
3 HIKICK	-27.2778	-16.7046	74.950	14801.697	0.000
4 HIKICK	-26.8574	-18.2462	91.504	14741.008	0.000
5 HIQDG	-26.6820	-19.2307	98.407	14702.247	0.000
6 HIQDG	-26.6557	-19.3783	99.443	14696.434	0.000
7 HIQDG	-26.6294	-19.5260	100.478	14690.619	0.000
8 HIDC	-26.5768	-19.8214	102.549	14678.991	0.000
9 HIDC	-26.5756	-20.2690	102.598	14661.367	0.337
10 HIDC	-26.7266	-20.6898	96.650	14644.803	1.306
11 HIQFD	-26.9740	-21.1229	86.912	14627.752	2.697
12 HIQFD	-27.0482	-21.2528	83.991	14622.637	3.114
13 HIQFD	-27.1224	-21.3827	81.070	14617.521	3.531
14 HIQDF	-27.9633	-22.8553	47.962	14559.547	8.262
15 HIQDF	-28.0375	-22.9852	45.041	14554.432	8.679
16 HIQDF	-28.1117	-23.1151	42.119	14549.316	9.096
17 HIQFC	-28.3096	-23.4616	34.329	14535.675	10.209
18 HIQFC	-28.3838	-23.5915	31.408	14530.560	10.627
19 HIQFC	-28.4580	-23.7215	28.487	14525.444	11.044
20 HIQDE	-29.1011	-24.8475	3.169	14481.111	14.661
21 HIQDE	-29.1753	-24.9775	0.247	14475.996	15.078
22 HIQDE	-29.2495	-25.1074	-2.674	14470.881	15.496
23 HIQFB	-29.4473	-25.4539	-10.464	14457.239	16.609
24 HIQFB	-29.5215	-25.5838	-13.385	14452.124	17.026
25 HIQFB	-29.5957	-25.7137	-16.307	14447.009	17.443
26 HIQDD	-31.0798	-28.3123	-74.732	14344.702	25.791
27 HIQDD	-31.1540	-28.4423	-77.654	14339.586	26.208
28 HIQDD	-31.2282	-28.5722	-80.575	14334.471	26.625
29 HIQFA	-31.4755	-29.0053	-90.313	14317.420	28.016
30 HIQFA	-31.5497	-29.1352	-93.234	14312.305	28.434
31 HIQFA	-31.6239	-29.2652	-96.155	14307.189	28.851
32 HIQDC	-32.3659	-30.5645	-125.368	14256.035	33.025
33 HIQDC	-32.4401	-30.6944	-128.289	14250.920	33.442
34 HIQDC	-32.5143	-30.8243	-131.211	14245.805	33.860
35 HIDB	-32.6627	-31.0842	-137.053	14235.574	34.694
36 HIDB	-32.8138	-31.5049	-143.001	14219.010	35.663
37 HIDB	-32.8125	-31.9526	-142.952	14201.386	36.000
38 HIQDB	-32.7599	-32.2479	-140.881	14189.758	36.000
39 HIQDB	-32.7336	-32.3956	-139.846	14183.943	36.000
40 HIQDB	-32.7073	-32.5433	-138.810	14178.130	36.000
41 HIDA	-32.6547	-32.8386	-136.739	14166.502	36.000
42 HIDA	-32.5009	-33.2591	-130.682	14149.948	36.000
43 HIDA	-32.2125	-33.6015	-119.329	14136.465	36.000
44 HIQDA	-30.6782	-34.8845	-58.923	14085.956	36.000
MID 45 HIQDA	-30.5631	-34.9807	-54.393	14082.168	36.000

Fig 7. The positions of elements in the heavy ion injection line.

```
                    NEW HEAVY ION INJECTION LINE
!
! DATE AND TIME: 25/08/87      11.57.14
!
! BOOSTER RING ELEMENTS
!
MQFC3:     QUADRUPO,L=0.250000000000,K1=0.554569000000
MDR:       DRIFT,L=0.300000000000
HIKICK:     SBEND,L=1.60000000000,ANGLE=-0.180056000000
!
!  HEAVY ION LINE ELEMENTS
!
! DRIFT SPACES
!
HILA:        DRIFT,L=2.00000000000
HILB:        DRIFT,L=0.300000000000
HILC:        DRIFT,L=0.300000000000
HILD:        DRIFT,L=0.300000000000
HILE:        DRIFT,L=1.50000000000
HILF:       DRIFT,L=0.500000000000
HILG:        DRIFT,L=3.00000000000
HILH:       DRIFT,L=0.400000000000
HILI:        DRIFT,L=1.30000000000
HILJ:       DRIFT,L=0.400000000000
HILK:        DRIFT,L=1.70000000000
HILL:        DRIFT,L=0.500000000000
HILM:        DRIFT,L=0.300000000000
HILN:        DRIFT,L=1.00000000000
!
! DIPOLE MAGNETS
!
HIDC:       SBEND,L=0.450000000000,ANGLE=-0.349065850000,TILT=&
          0.110170000000
HIDB:       SBEND,L=0.450000000000,ANGLE=0.349065850000,TILT=&
          0.110170000000
HIDA:       SBEND,L=0.450000000000,ANGLE=0.349065850000,TILT=&
          0.000000000000E+00
! QUADRUPOLE MAGNETS - FOCUSING AND DEFOCUSING
!
HIQFA:       QUADRUPO,L=0.150000000000,K1=3.01531400678
HIQFB:       QUADRUPO,L=0.150000000000,K1=2.97376034875
HIQFC:       QUADRUPO,L=0.150000000000,K1=3.49999999916
HIQFD:       QUADRUPO,L=0.150000000000,K1=1.98711700012
!
HIQDA:       QUADRUPO,L=0.150000000000,K1=-1.08624681663
HIQDB:       QUADRUPO,L=0.150000000000,K1=0.000000000000E+00
HIQDC:       QUADRUPO,L=0.150000000000,K1=-2.00000000079
HIQDD:       QUADRUPO,L=0.150000000000,K1=-2.96600878394
HIQDE:       QUADRUPO,L=0.150000000000,K1=-3.19999999262
HIQDF:       QUADRUPO,L=0.150000000000,K1=-2.00000000988
HIQDG:       QUADRUPO,L=0.150000000000,K1=-1.46334111601
!
! DEFINITION OF THE BEAM LINES
!
HIBST: LINE=(2*HIDC,HILM,2*HIQDG,HILN,2*HIKICK,MDR,MQFC3)
HINTER: LINE = (HILD,2*HIQDC,HILE,2*HIQFA,HILF,2*HIQDD,HILG,&
        2*HIQFB,HILH,2*HIQDE,HILI,2*HIQFC,HILJ,2*HIQDF,HILK, &
        2*HIQFD,HILL)
HILINC: LINE = (HIQDA,HILA,2*HIDA,HILB,2*HIQDB,HILC,2*HIDB)
HILINE : LINE = (HILINC,HINTER,HIBST)
!
USE,HILINE
PRINT,#S/E
TWISS,BETX=3.875,BETY=12.322,ALFX=3.191,ALFY=.401
SURVEY,X0=-34.980697,Z0=-30.563126,THETA0=2.445183
STOP
```

Fig 8. The input to MAD for the heavy ion injection line.

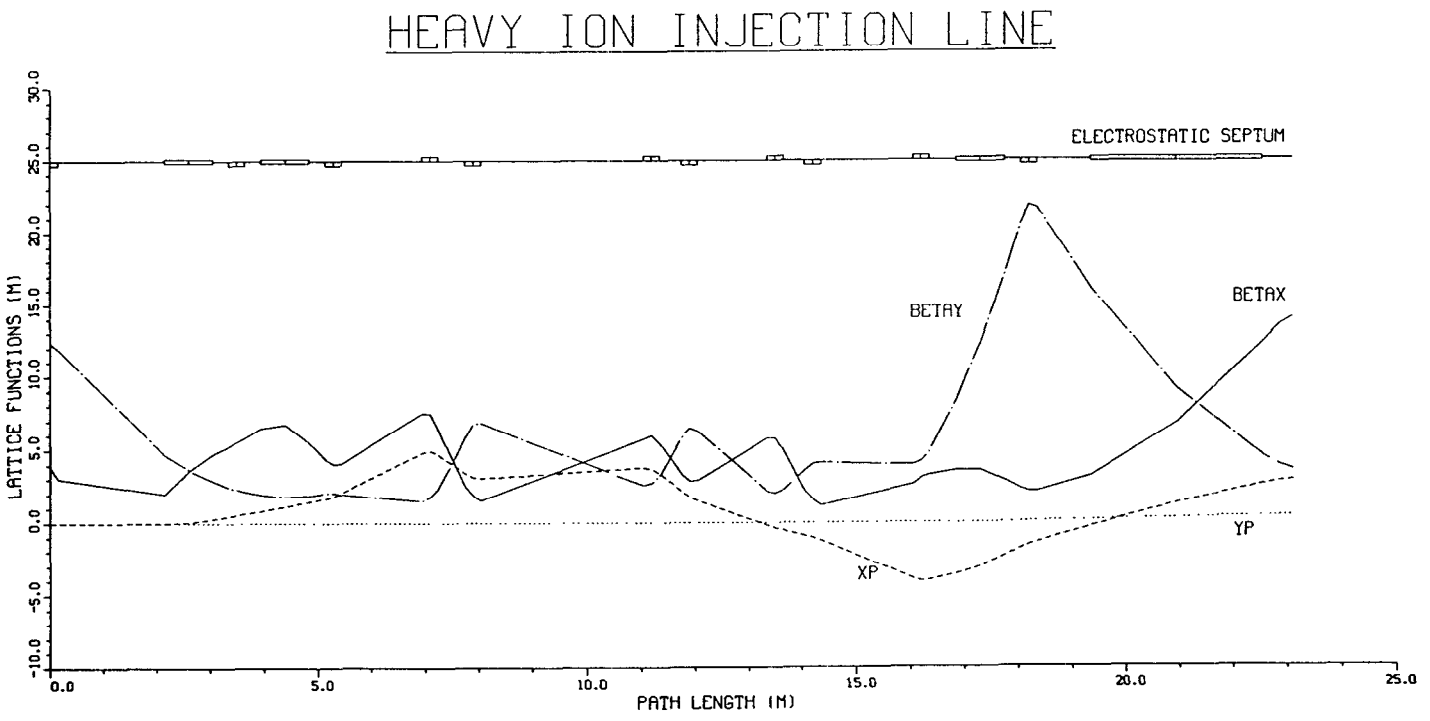

Fig 9. The optics of the heavy ion injection line.

NEW HEAVY ION INJECTION LINE — MAD VERSION: 4.03 — RUN: 25/08/87 17.21.19

TWISS PARAMETERS FOR BEAM LINE "HILINE" — DELTA(P)/P = 0.000000 — SYMM = F — PAGE 1

POS. NO.	ELEMENT NAME	SEQUENCE OCC. NO.	DIST [M]	I	HORIZONTAL BETAX [M]	ALFAX	MUX [2PI]	X(CO) [MM]	X'(CO) [MRAD]	DX [M]	DX'	I	VERTICAL BETAY [M]	ALFAY	MUY [2PI]	Y(CO) [MM]	Y'(CO) [MRAD]	DY [M]	DY'
BEGIN	HILINE	1	0.000		3.875	3.191	0.000	0.00	0.000	0.000	0.000		12.322	0.401	0.000	0.00	0.000	0.000	0.000
1	HIQDA	1	0.150		3.063	2.267	0.007	0.00	0.000	0.000	0.000		11.907	2.343	0.002	0.00	0.000	0.000	0.000
2	HILA	1	2.150		2.012	-1.741	0.358	0.00	0.000	0.000	0.000		4.716	1.253	0.045	0.00	0.000	0.000	0.000
3	HIDA	1	2.600		3.608	-1.662	0.384	0.00	0.000	0.078	0.342		3.698	1.008	0.062	0.00	0.000	0.000	0.000
4	HIDA	2	3.050		4.767	-0.806	0.401	0.00	0.000	0.302	0.643		2.902	0.762	0.084	0.00	0.000	0.000	0.000
5	HILB	1	3.350		5.281	-0.910	0.410	0.00	0.000	0.494	0.643		2.493	0.599	0.102	0.00	0.000	0.000	0.000
6	HIQDB	1	3.500		5.562	-0.962	0.415	0.00	0.000	0.591	0.643		2.326	0.517	0.112	0.00	0.000	0.000	0.000
7	HIQDB	2	3.650		5.858	-1.014	0.419	0.00	0.000	0.687	0.643		2.183	0.435	0.122	0.00	0.000	0.000	0.000
8	HILC	1	3.950		6.497	-1.117	0.427	0.00	0.000	0.880	0.643		1.971	0.272	0.145	0.00	0.000	0.000	0.000
9	HIDB	1	4.400		6.740	0.599	0.437	0.00	0.000	1.188	0.714		1.834	0.033	0.184	0.00	0.000	0.002	0.008
10	HIDB	2	4.850		5.504	2.038	0.449	0.00	0.000	1.510	0.700		1.912	-0.207	0.222	0.00	0.000	0.006	0.006
11	HILD	1	5.150		4.365	1.757	0.459	0.00	0.000	1.720	0.700		2.086	-0.371	0.246	0.00	0.000	0.008	0.006
12	HIQDC	1	5.300		4.043	0.424	0.464	0.00	0.000	1.864	1.235		2.113	0.190	0.257	0.00	0.000	0.008	0.004
13	HIQDC	2	5.450		4.103	-0.832	0.470	0.00	0.000	2.093	1.826		1.975	0.717	0.269	0.00	0.000	0.009	0.001
14	HILE	1	6.950		7.526	-1.450	0.514	0.00	0.000	4.833	1.826		1.549	-0.433	0.433	0.00	0.000	0.011	0.001
15	HIQFA	1	7.100		7.452	1.935	0.517	0.00	0.000	4.940	-0.396		1.810	-1.346	0.447	0.00	0.000	0.011	0.006
16	HIQFA	2	7.250		6.417	4.807	0.520	0.00	0.000	4.715	-2.592		2.394	-2.633	0.459	0.00	0.000	0.013	0.012
17	HILF	1	7.750		2.549	2.929	0.540	0.00	0.000	3.419	-2.592		5.855	-4.289	0.480	0.00	0.000	0.018	0.012
18	HIQDD	1	7.900		1.891	1.554	0.551	0.00	0.000	3.140	-1.141		6.776	-1.714	0.484	0.00	0.000	0.020	0.003
19	HIQDD	2	8.050		1.574	0.604	0.565	0.00	0.000	3.073	0.233		6.838	1.309	0.488	0.00	0.000	0.019	-0.006
20	HILG	1	11.050		5.752	-1.996	0.828	0.00	0.000	3.773	0.233		2.557	0.119	0.615	0.00	0.000	0.003	-0.006
21	HIQFB	1	11.200		5.967	0.593	0.832	0.00	0.000	3.682	-1.439		2.703	-1.119	0.624	0.00	0.000	0.002	-0.005
22	HIQFB	2	11.350		5.411	3.028	0.836	0.00	0.000	3.346	-3.015		3.258	-2.663	0.632	0.00	0.000	0.001	-0.004
23	HILH	1	11.750		3.290	2.276	0.851	0.00	0.000	2.140	-3.015		5.787	-3.657	0.647	0.00	0.000	0.000	-0.004
24	HIQDE	1	11.900		2.859	0.660	0.859	0.00	0.000	1.760	-2.084		6.480	-0.852	0.651	0.00	0.000	-0.001	-0.004
25	HIQDE	2	12.050		2.874	-0.761	0.867	0.00	0.000	1.507	-1.305		6.274	2.193	0.655	0.00	0.000	-0.001	-0.003
26	HILI	1	13.350		5.780	-1.474	0.919	0.00	0.000	-0.190	-1.305		2.137	0.989	0.712	0.00	0.000	-0.005	-0.003
27	HIQFC	1	13.500		5.768	1.551	0.923	0.00	0.000	-0.375	-1.156		2.018	-0.179	0.724	0.00	0.000	-0.006	-0.006
28	HIQFC	2	13.650		4.897	4.101	0.927	0.00	0.000	-0.532	-0.916		2.249	-1.404	0.735	0.00	0.000	-0.007	-0.009
29	HILJ	1	14.050		2.199	2.646	0.947	0.00	0.000	-0.898	-0.916		3.584	-1.933	0.758	0.00	0.000	-0.011	-0.009
30	HIQDF	1	14.200		1.564	1.645	0.960	0.00	0.000	-1.057	-1.208		4.017	-0.910	0.764	0.00	0.000	-0.012	-0.006
31	HIQDF	2	14.350		1.181	0.946	0.978	0.00	0.000	-1.263	-1.555		4.114	0.273	0.770	0.00	0.000	-0.013	-0.002
32	HILK	1	16.050		2.600	-1.781	1.267	0.00	0.000	-3.907	-1.555		3.940	-0.171	0.839	0.00	0.000	-0.016	-0.002
33	HIQFD	1	16.200		3.040	-1.105	1.275	0.00	0.000	-4.051	-0.365		4.177	-1.436	0.845	0.00	0.000	-0.017	-0.007
34	HIQFD	2	16.350		3.244	-0.235	1.283	0.00	0.000	-4.015	0.842		4.827	-2.962	0.851	0.00	0.000	-0.019	-0.013
35	HILL	1	16.850		3.560	-0.397	1.306	0.00	0.000	-3.594	0.842		8.296	-3.975	0.863	0.00	0.000	-0.025	-0.013
36	HIDC	1	17.300		3.541	0.437	1.326	0.00	0.000	-3.086	1.395		12.267	-4.847	0.870	0.00	0.000	-0.016	0.049
37	HIDC	2	17.750		2.835	1.069	1.348	0.00	0.000	-2.364	1.781		17.011	-5.691	0.875	0.00	0.000	0.016	0.091
38	HILM	1	18.050		2.261	0.842	1.367	0.00	0.000	-1.830	1.781		20.603	-6.280	0.878	0.00	0.000	0.043	0.091
39	HIQDG	1	18.200		2.095	0.275	1.378	0.00	0.000	-1.591	1.406		21.818	-1.735	0.879	0.00	0.000	0.056	0.080
40	HIQDG	2	18.350		2.092	-0.255	1.390	0.00	0.000	-1.406	1.078		21.621	3.036	0.880	0.00	0.000	0.067	0.067
41	HILN	1	19.350		3.112	-0.764	1.454	0.00	0.000	-0.327	1.078		16.022	2.563	0.889	0.00	0.000	0.134	0.067
42	HIKICK	1	20.950		6.693	-1.450	1.511	0.00	0.000	1.251	0.888		9.030	1.807	0.910	0.00	0.000	0.241	0.067
43	HIKICK	2	22.550		12.194	-1.950	1.539	0.00	0.000	2.501	0.670		4.456	1.051	0.950	0.00	0.000	0.347	0.067
44	MDR	1	22.850		13.400	-2.069	1.542	0.00	0.000	2.702	0.670		3.868	0.910	0.962	0.00	0.000	0.367	0.067
45	MQFC3	1	23.100		13.976	-0.208	1.545	0.00	0.000	2.821	0.286		3.568	0.304	0.973	0.00	0.000	0.391	0.119
END	HILINE	1	23.100		13.976	-0.208	1.545	0.00	0.000	2.821	0.286		3.568	0.304	0.973	0.00	0.000	0.391	0.119

TOTAL LENGTH =	23.100000	MUX =	1.545331	MUY =	0.972635
		MUX' =	-1.484247	MUY' =	-0.240087
		BETAX(MAX) =	13.975695	BETAY(MAX) =	21.818147
		DX(MAX) =	4.940429	DY(MAX) =	0.390587

Fig 10. The MAD output for the heavy ion injection line.