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Mini-ß Insertion For The RHIC Lattice

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Abstract:

Requirement and implication of the mini-β insertion in RHIC lattice is studied. We find that (1) When the gradient is maintained at 67T/m, the free space for the experimental setup becomes ±4m at β^*=1.5m with maximum crossing angle of 3mrad at 100GeV/amu. (2) To maintain a minimum of ±5m free space for experimental setup, a higher gradient is needed. At 84.5T/m gradient, β^*=1m can be achieved. In this case, the beam size limitation is located at BC2, where 10cm coil i.d. is designed. When the machine is operating at the proton-heavy ion interaction mode, these common quadrupoles should be removed physically in order to let both beams crossing the center line at 3.5mrad. These mini-β insertion can increase the luminosity by a factor of 2~3.

I. Introduction.

The normal operation range for the RHIC collider design is constrainted by the available dynamical aperture at Q2 and Q3 in the insertion, where the β-function is high. In the norminal insertion, there are 9 quadrupoles in each side of the interaction point(IP) excited anti-symmetrically with respective to IP. When the β^*, the β value at the IP, is 3m, the maximum $\hat{\beta}$ values at Q2 and Q3 are 400m, while β^*=2m, $\hat{\beta}$ becomes 625m. Table 1 compares the beam size with the magnet coil i.d. at various operational conditions.

Table 1. Beam size vs. Coil i.d.+ in Norminal condition

	heavy ion	proton	heavy ion	proton
β^*(m)	3		2	
$\hat{\beta}$ (m)	400		625	
ε_N(μ-m)	33	20	33	20
6σ/coil i.d. (at Bρ=840 Tm)	0.42	0.21	0.52	0.26
6σ/coil i.d. (at Bρ=420 Tm)	0.59	0.29	0.73	0.37

+Coil i.d. of Q2 and Q3 are both 131mm

Based on the the tracking calculations of Dell and Parzen, we expect that β^*= 2m can be achieved at the the top energy. Therefore, the luminosity is increased by 50% in this process. Since $\hat{\beta}$ is approximately inverse proportional to β^*, $\hat{\beta}$ becomes too large when a smaller β^*<2m is requested. The only way to avoid the dynamical aperture problem in Q2 and Q3 is to resort to a MINI-β insertion. Note however that the free space available in RHIC standard insertion is ±10m. The mini-β insertion would require the experimental set up to be limited to an even smaller space or the COMMON mini-β quadrupoles should be incorporated in the detector design.

This study is intended to investigate the possible mini-β insertions. Our aim is to leave as much of space as possible for the experimental set-up while keep the ratio of (6σ/coil i.d.) to be less than 0.6 ~ 0.7 in order to maintain useful dynamical aperture. In section 2, we shall discuss the MINI-β insertion layout and find the requirement of these quadrupoles. Section 3 discusses the implication of mini-β insertions.

2. The Layout of MINI-β insertion.

To maintain the antisymmetry of the RHIC insertion, two pairs common quadrupoles, QX1 and QX2, should be placed in the interaction region between two common beam crossing dipoles, BC1, on both sides of the IP. To maximize the available free space for experimental set-up, the distance between QX2 and BC1 is set to 0.5m, which is needed for coil end of magnets. The beam line in the interaction region is arranged as following:

BC1I DX2 QX2I DX1 QX1I DXO IP DXO QX1O DX1 QX2O BC1O

2.1 B'=67 T/m as the basic assumption.

Assuming the 8 cm coil i.d. quadrupoles for QX2 and QX1, which is operating at 67 T/m norminally, we ask what is the length of the magnets to obtain $\beta^* = 1.5$m while keeping $\hat{\beta}=400m$. The result of the matching is shown in the first column of Table 2. We observe that the available free space becomes 4m for the experimental setup. Fig. 1 shows the betatron amplitudes functions (β_x,β_y,and $100 \cdot X_p$) in the insertion region. To evaluate the requirement of the dynamical aperture, we plot the ratio of the beam size(6σ) to the coil i.d. of the magnet at 100 GeV/amu and beam crossing angles in Fig. 2 and 50 GeV/amu in Fig.3. Note that the mini-β insertion configuration can only support the crossing angles up to 3 mrad at 100GeV/amu or 2 mrad at 50GeV/amu. The constraint is limited by the crossing angle of the collision species rather than the β^* at the IP. Thus to obtain maximum Luminosity, crossing angle should be kept as small as possible.

Table 2. Mini-β insertion contraint for RHIC

β^*(m)	1.5	1.5	1.0
DXO(m)	4.0468084	5.0	5.0
LQX1(m)	1.8967767	1.5	1.5
DX1(m)	1.8999972	1.5	1.5
LQX2(m)	1.6564177	1.5	1.5
βmax(m)	400.	400.	500.
GF(1/m)	0.099520	0.099520	0.099520
GD(1/m)	0.099650	0.099650	0.099650
K1I(1/m)	0.149993	0.135168	0.150904
K2I(1/m)	0.130986	0.135652	0.147122
G1I(1/m)	0.133826	0.137238	0.137711
G2I(1/m)	0.157707	0.157785	0.156988
G3I(1/m)	0.055416	0.051932	0.050933
G4I(1/m)	0.084231	0.085321	0.076361
G5I(1/m)	0.101945	0.103415	0.093903
G6I(1/m)	0.120539	0.125538	0.121913
G7I(1/m)	0.137715	0.138627	0.140795
G8I(1/m)	0.111765	0.111907	0.112740
G9I(1/m)	0.085117	0.085220	0.086562
K1O(1/m)	0.152250	0.133922	0.150941
K2O(1/m)	0.130878	0.134911	0.146960
G1O(1/m)	0.133977	0.137239	0.137679
G2O(1/m)	0.157225	0.157845	0.156421
G3O(1/m)	0.055035	0.052178	0.050841
G4O(1/m)	0.081062	0.081848	0.075912
G5O(1/m)	0.094511	0.094168	0.085706
G6O(1/m)	0.124678	0.126434	0.129953
G7O(1/m)	0.140527	0.139806	0.140081
G8O(1/m)	0.114963	0.114443	0.114472
G9O(1/m)	0.093322	0.092587	0.091758

2.2 Assumption with the available free space to be 5m.

When the maximum gradient is held with 67 T/m, we found that the available free space becomes 4 m. In order to increase the available free space to 5m, we shall decrease the length of quadrupoles to 1.5m each. The result of the beam matching is given in the column 2 of table 2 for β^*=1.5m and $\hat{\beta}$=400m. Since the dynamical aperture in this case is not limited by the quadrupoles Q2 and Q3, one can decrease further β^* to 1m, shown in the COLUMN 3 of Table 2. Note that the gradient requirement of QX1 becomes 84.5 T/m at $B\rho$=840 Tm. At β^*= 1m , the β-value at BC2 is about 350m. Thus the ratio of beam size to the magnet coil i.d. would be about 51% at BC2. We conclude that β^*=1m has almost reached the capability of the insertion. To decrease even further the β^* value, it is necessary to decrease further the available experimental free space. Fig. 4 shows the betatron functions in the insertion region for β^*=1m and $\hat{\beta}$=500m. Because of the higher gradient requirement in the present case, smaller coil i.d. of 6.3cm may be needed for QX1 and QX2. This consideration also prevent the crossing angle larger than 2mrad.

3. Implication and Hardware requirement.

The mini-β insertion in the present study requires two pairs of common quadrupoles in each of mini-β section. Because of the extra quadrupoles, the phase advance of the insertion is increased by about 0.06. To prevent the low order resonances in the collider, the tune of the machine is maintained by readjusting the rest of the accelerator. Thus it is necessary to setup the accelerator before the mini-β run. Because of the high gradient requirement for these common quadrupoles, smaller coil i.d. magnet is conceived. This limits the crossing angle configuration to be less than 2mrad at at 100 GeV/amu for heavy ion beams. For proton beam, the requirement is relaxed slightly because of smaller beam size.

We have discussed only the basic mini-β lattice without considering the effect on the dynamical aperture. Since the $\hat{\beta}$

remains the small, we expect the chromaticity would not be changed appreciably for only few mini-β insertion. The half integer stop band should be minimized by the sextupole families. Tracking calculation should be used to estabilish the available dynamical aperture. In order to optimize the configuration, these common quadrupoles should be incorporated into the detector design, where the high luminosity is required.

In conclusion, we have find some possible mini-β insertion to the present IR design. It is possible to obtain β^* value of 1m without much beam size constraint to the rest of the machine. Two pairs of common quadrupoles are needed. The available free space for the experimental instrument becomes ±5m. Because of the smaller aperture of these common quadrupoles, smaller crossing angle is required in the mini-β insertion. **At the unequal species operational mode, these common quadrupoles should be removed for beam clearence.**

Figures caption:

Fig. 1. Betatron amplitude functions(β_x,β_y,$100\cdot X_p$) are shown for the mini-β insertion region(upper graph). The lower graph shows the expanded region of matching section Q5I-Q5O. The IP is located at the center.(β^*=1.5m).

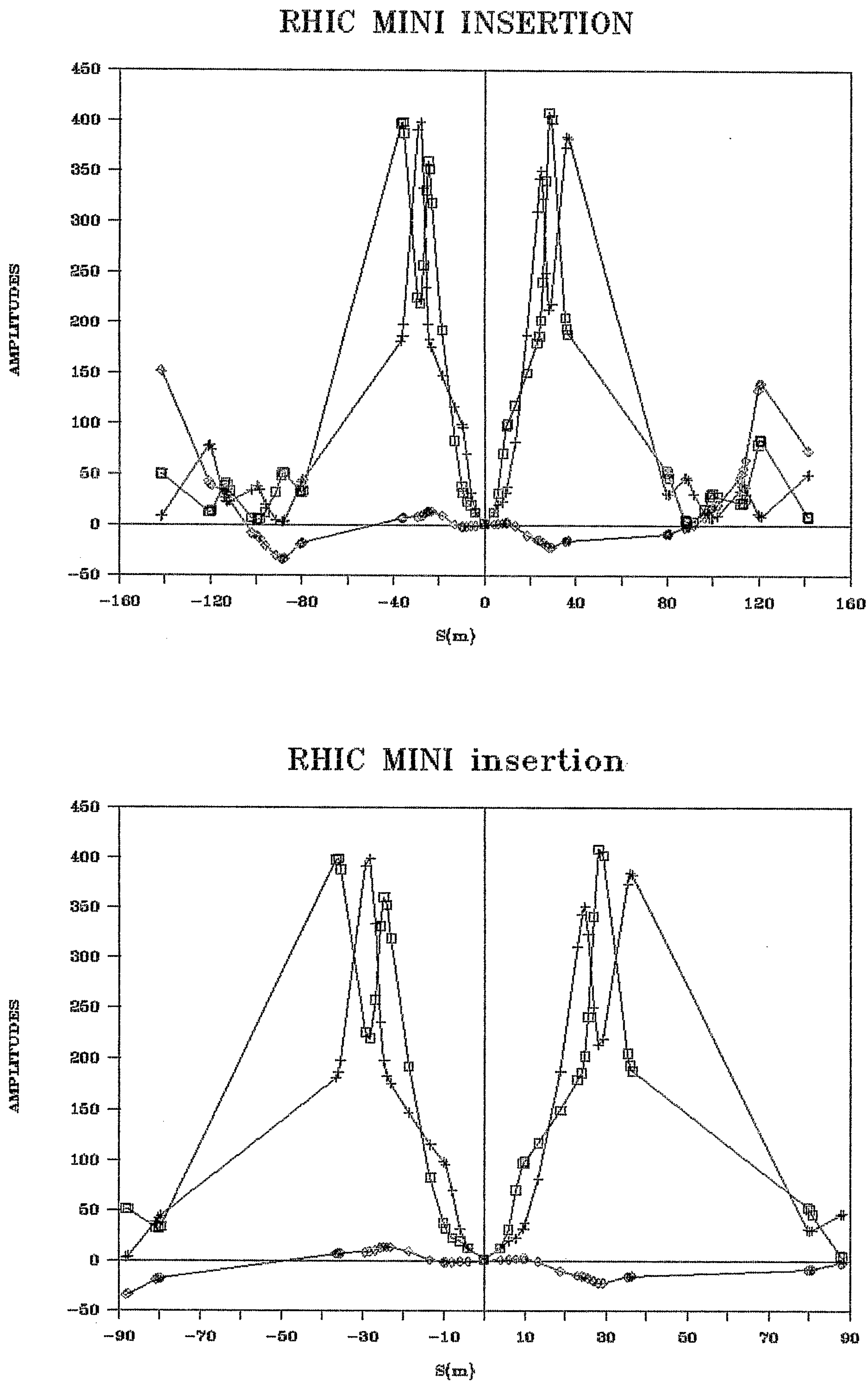
Fig. 2 The ratio of beam size to the coil i.d. is ploted in the insetion region at 100GeV/amu for the normalized emittance of 33$\mu\pi$m. At QX2, the crossing angle can not be larger than 3mrad for the 4cm coil i.d. magnet.

Fig. 3 Similar to that of Fig.2 at 50GeV/amu. Note that the crossing angle can not be larger than 2 mrad for beam stability.

Fig. 4 Betatron amplitude functions for β^*=1m and $\hat{\beta}$=500m is shown. The graph is similar to that of Fig.1 and corresponds to the parameter of column 3 in table 2.

Reference:

1. F.G. Dell and G. Parzen, private communications.

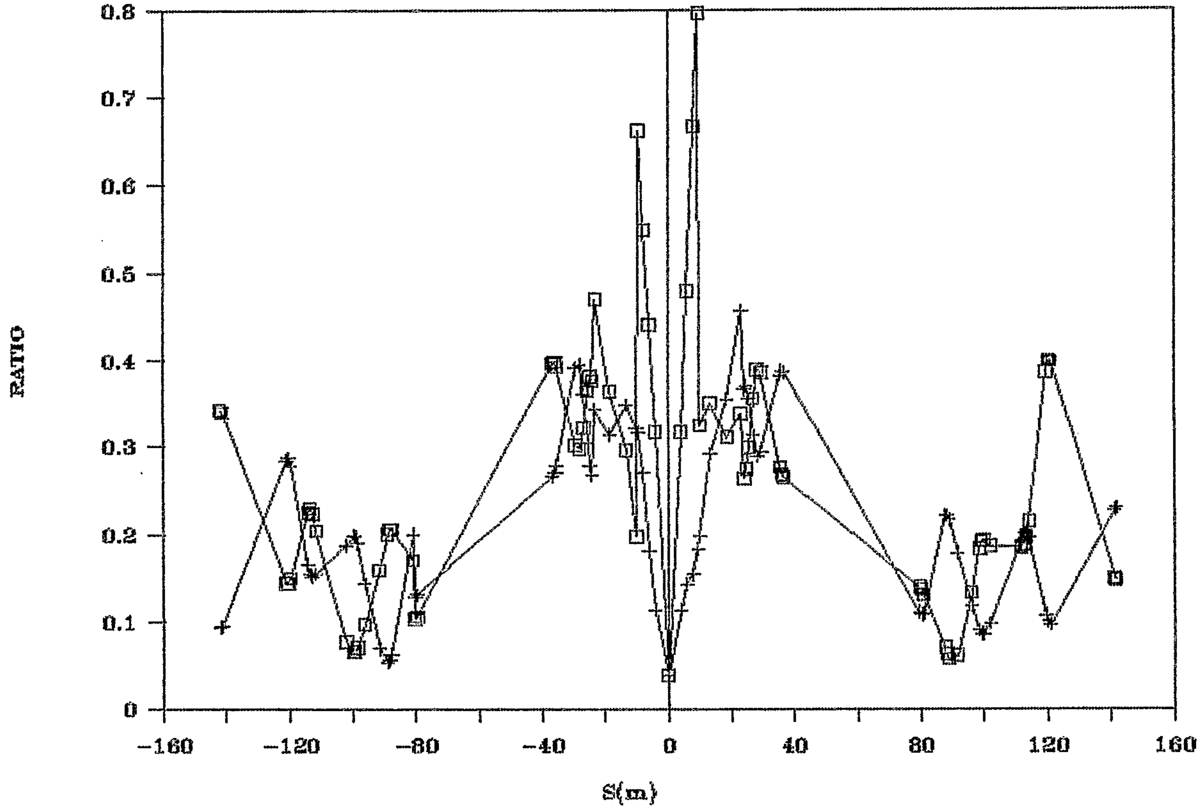


RHIC MINI INSERTION
AMPLITUDES
S(m)
RHIC MINI insertion
AMPLITUDES
S(m)

Fig. 1

RHIC MINI(BEAMSIZE/COIL ID)

@100 GeV/amu and 4mr crossing



RHIC MINI(BEAMSIZE/COIL ID)

@100 GeV/amu and 3mr crossing

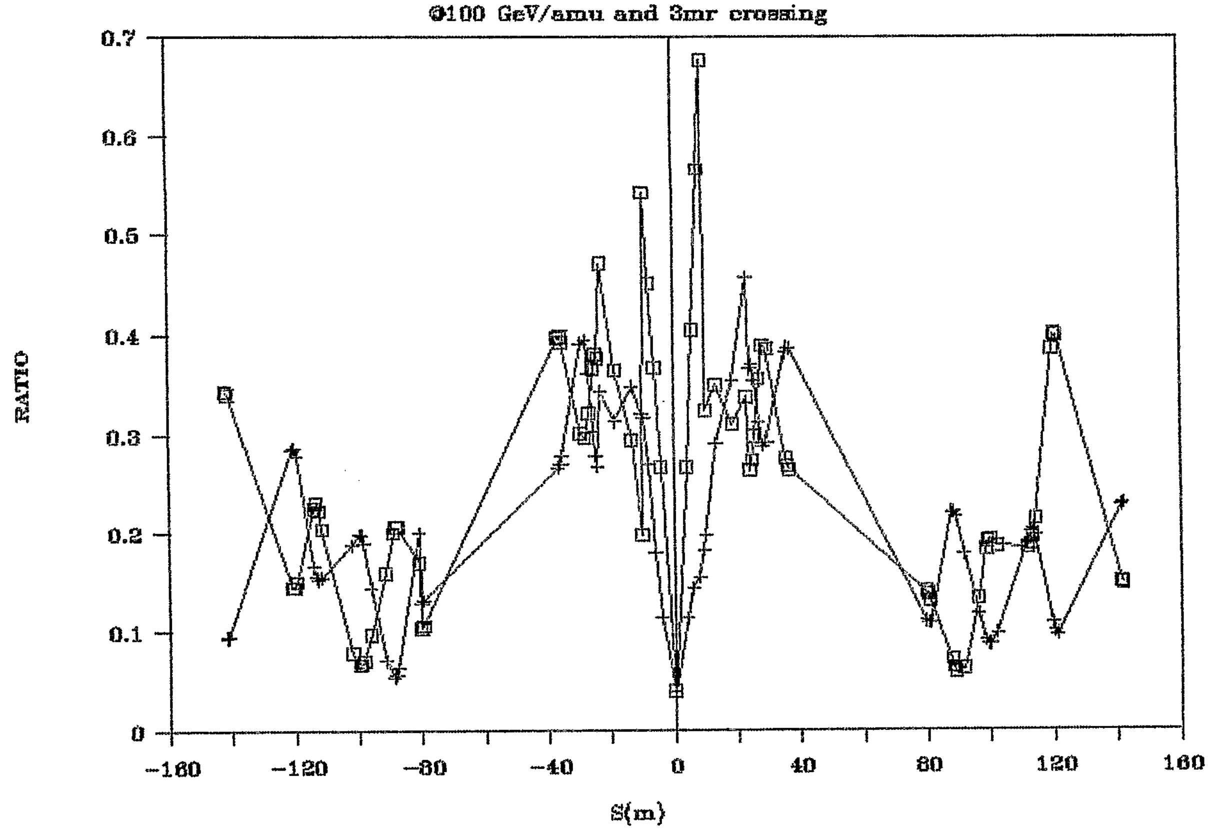
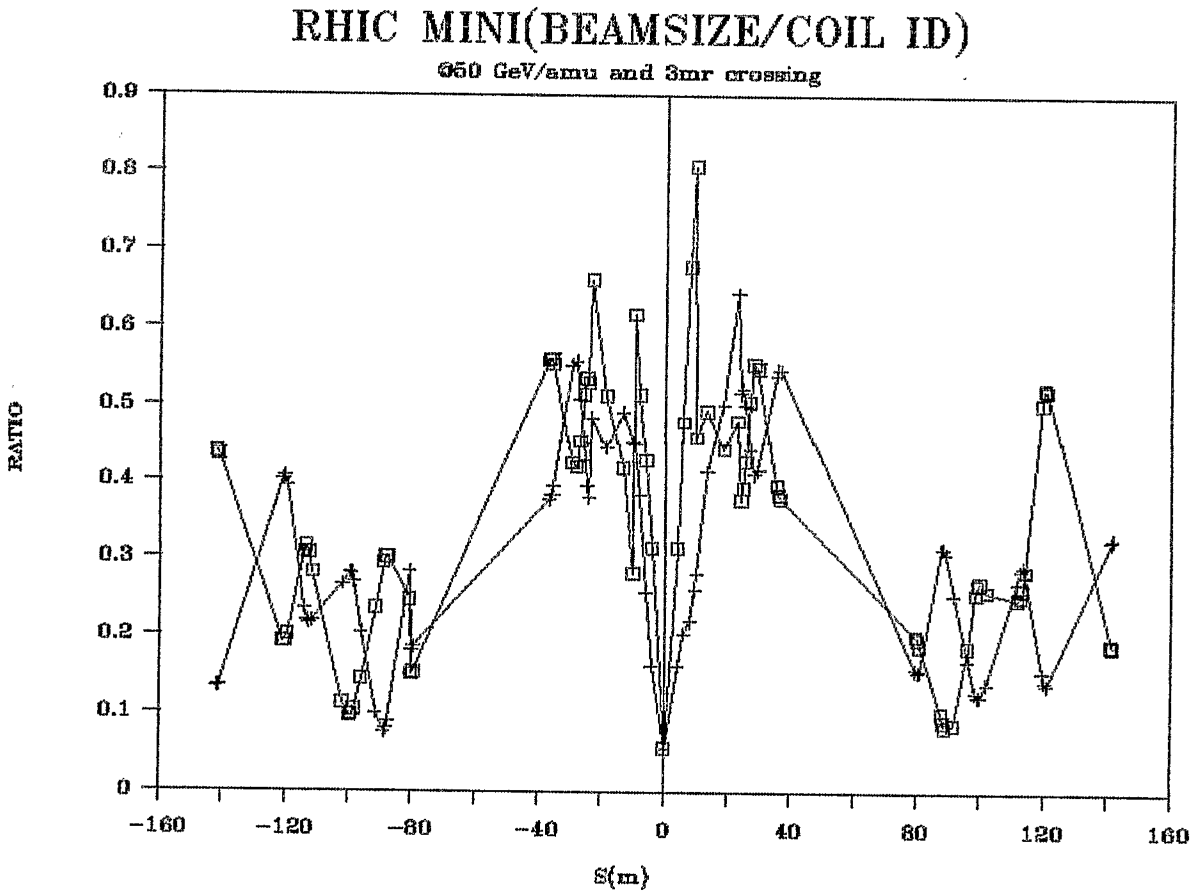


Fig. 2


RHIC MINI(BEAMSIZE/COIL ID)
@50 GeV/amu and 3mr crossing
RATIO
S(m)

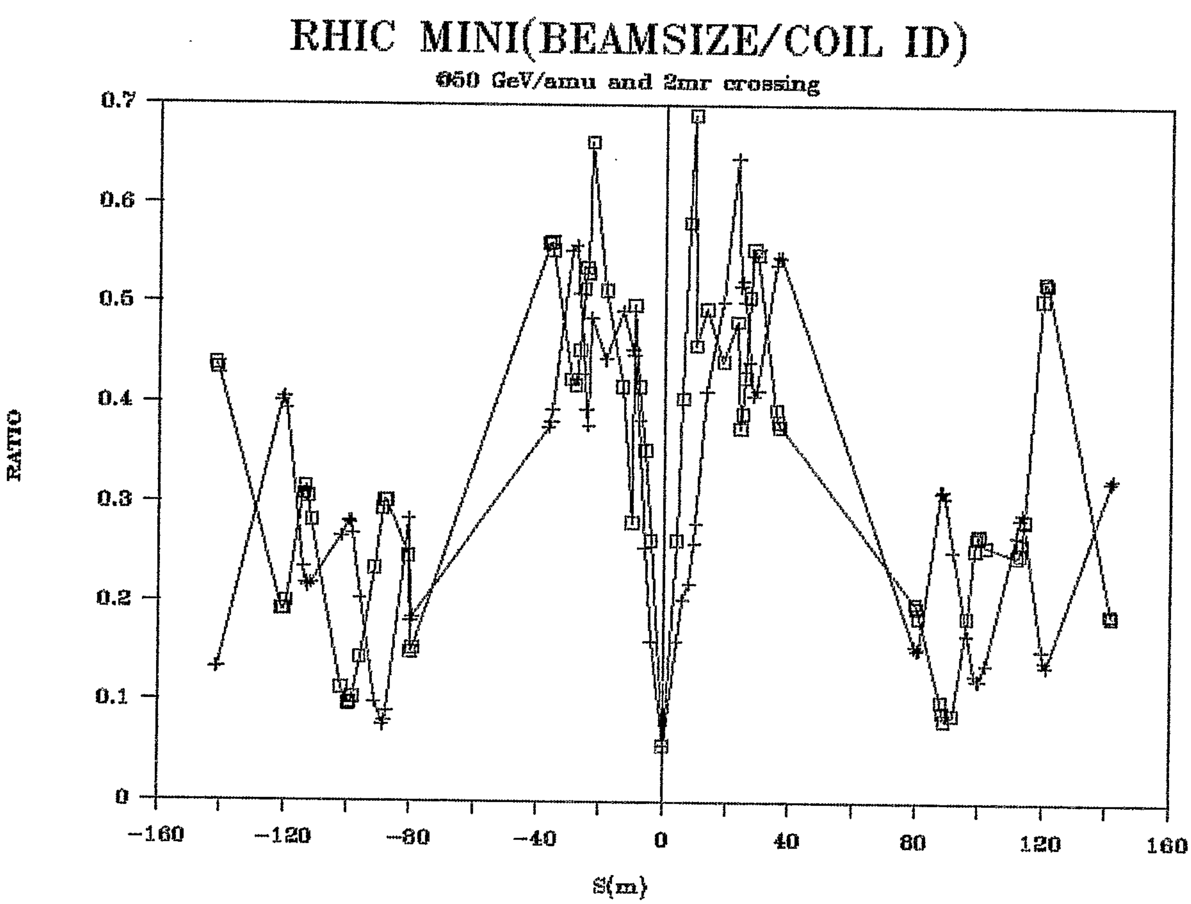
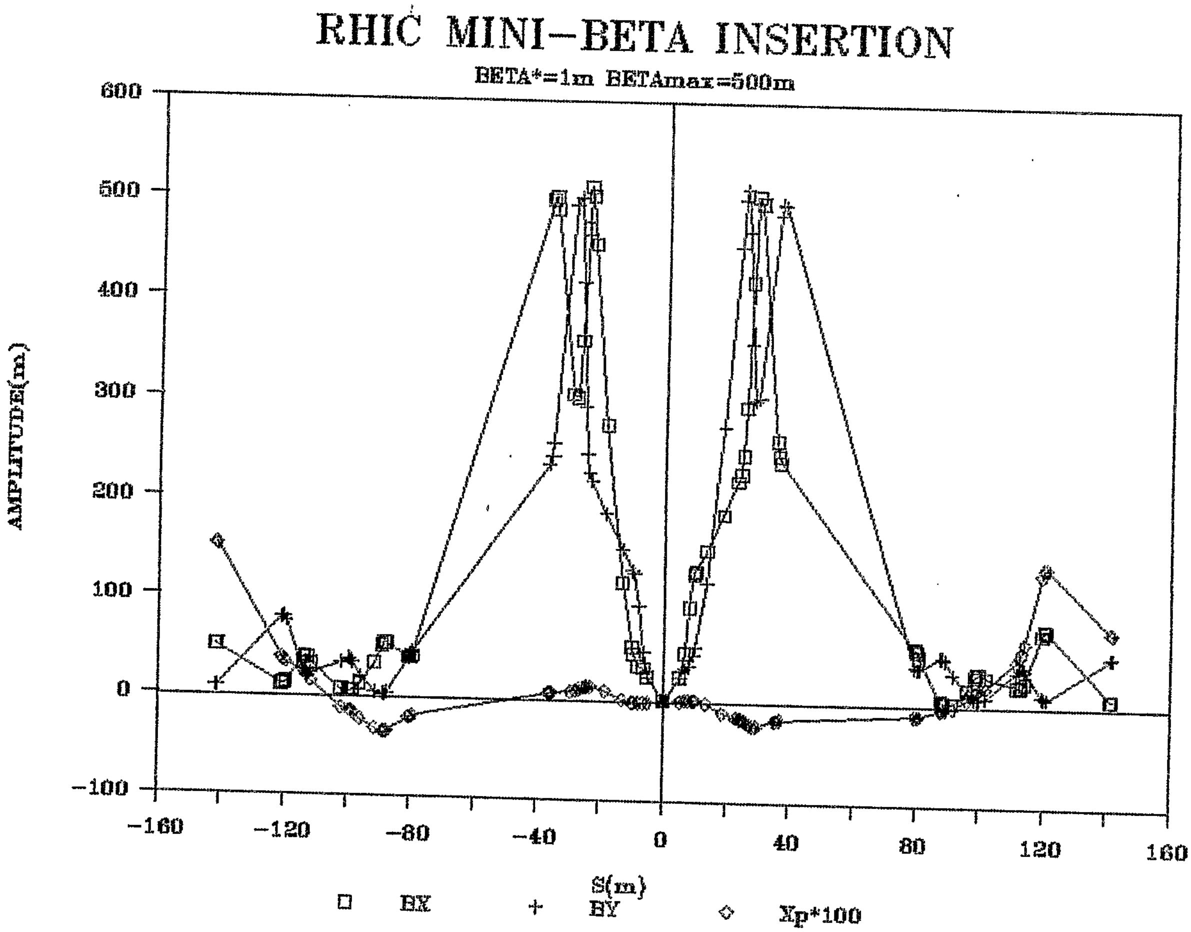

RHIC MINI(BEAMSIZE/COIL ID)
@50 GeV/amu and 2mr crossing
RATIO
S(m)

Fig. 3


RHIC MINI–BETA INSERTION
BETA*=1m BETAmax=500m
AMPLITUDE(m)
600
500
400
300
200
100
0
−100
−160
−120
−80
−40
0
40
80
120
160
S(m)
BX
BY
Xp*100

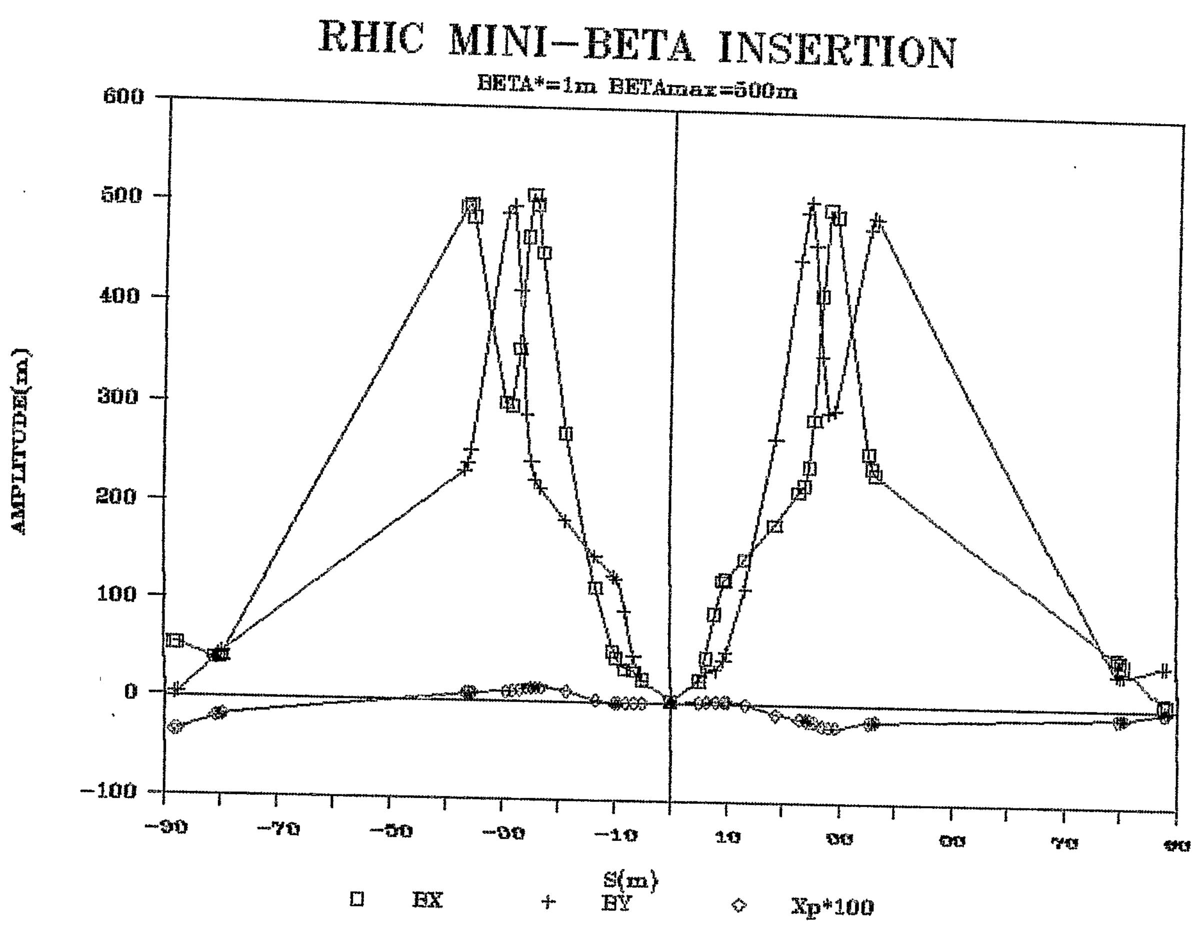

RHIC MINI–BETA INSERTION
BETA*=1m BETAmax=500m
AMPLITUDE(m)
600
500
400
300
200
100
0
−100
S(m)
BX
BY
Xp*100

Fig. 4