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COMBINED FUNCTION LATTICE FOR THE AGS - RHIC BOOSTER

Booster Technical Note

No. 46

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ACCELERATOR DEVELOPMENT DEPARTMENT

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ABSTRACT

We studied the option of the combined function lattice for the AGS-Booster design. We found that THE COMBINED FUNCTION LATTICE HAS SEVERAL ADVANTAGES over the present proposed lattice:
(1) Higher superperiodicity, P=12
(2) Longer free space available L=5 m.

I) Introduction

The booster lattice is known to suffer two minor difficulties: (1) the tune of the booster is Qx=Qy=4.83 ,while the systematic fourth order resonance is located at the tune of 4.5. The Laslett tune shift due to the space charge at the injection energy of 200 MeV is of the order of 1, therefore the fourth order resonance may be important in determining the performance of the machine. (2)A longer straight section (5m) would be useful for alternative proton injection schemes and for the low frequency rf systems. In this short note we shall address these problems and study the feasibility of the combined function option for the booster design. Our goal is to design a well behaved lattice with 5m straight section with superperiodicity of 12. For a tune of 4.83, the nearest systmatic resonance is located at 4(3rd) and 6(2nd and 4th). The AGS is rather similar since its tune is 8.8 with resonances at 8(3rd) and 9(4th).

II) The Lattice

It is known that combined function magnets can usually give us longer straight sections than separated function magnets. We shall use magnets similar to the CERN-PS. The magnet is designed to contain focusing and defocusing sections in a single magnet,which can be obtained by simply shaping the pole tip of the magnets. To obtain better tuning, we shall consider the option of having quadrupoles in the lattice to obtain the HYBRID design.

The booster lattice of this discussion has the following basic properties:

```
C  = 201.78 m =1/4 of AGS
q  =   4.83
P  =  12
L  =  16.815 m in each superperiod.
B^ =   1.00506891 Tesla  @ BRHO = 16.7 Tm
Lb =   2.9 m * 3 per superperiod.
Lf =   5.0 m free space for injection for the injection
Lq =   0.2 m * 2 per superperiod.
```

With the above specification, we can set up the basic lattice structure as following.

```
             _____  quad.                      _______ ______
             I   I  I  antisymm. pt.           I     I I    I
-----------------------------*----------------------------
I____I I_____I                             I  I___I
1.45m  1.57m 1.33m  .2m
     .7575m      .6m        5m
```

Note here that we have deliberately set the peak field to be around 1 Tesla. The nominal peak field at AGS is about 1.15 T at Brho=98.1 Tm, which corresponds to 28.5 GEV kinetic energy. It is resonably to assume that the peak field of the present design of combined function magnets can do as well. In this case the length of the magnets can be reduced further, thereby the short straight section can be increased to 1 m or the long straight section can be increased to 6m. The magnet organization is similarto that of the AGS lattice design(ref1) the space between two defocusing half-dipoles or two focusing half-dipoles can be used efficiently for correction elements, such as sextupoles, correction quads.At these locations the betatron functions in both planes differ substantially.

Fig. 1 shows the betatron functions for the HYBRID lattice in two superperiods. The corresponding betatron phase advance across two superperiods is shown in Fig.2. The extraction kicker and the septum will be located in consecutive superperiod long straight sections. The phase advance from the end of the long straight section to the beginning of the next long straight section is approximately 90 degree (see Fig. 2). Fig. 3 shows the beam size assuming emittances of 50 pi mmmrad and dp/p=.5%. Table 1 list the lattice properties of the hybrid lattice with the parameter of the quadrupole gradients. Fig. 4 shows the chromatic variation for tune Qx Qy of the machine and the percentage variation for the betatron amplitudes. To compare these magnets with the AGS magnets, we also list the AGS magnet parameters. Fig.5 also plots the betatron function of the CERN-PS for comparison.

TABLE 1. HYBRID MAGNETS AND LATTICE PROPERTIES

PARAMETER	FOR BOOSTER		AGS	
GF =	3.119	T/m @Brho=16.7 Tm	4.742	T/m@Brho=98.144Tm
GD =	-3.169	T/m @Brho=16.7 Tm	-4.757	T/m@Brho=98.144Tm
BZ =	1.005	T @Brho=16.7 Tm	1.150	T @Brho=98.144Tm
QF =	12.477	T/m @Brho=16.7 Tm		
QD =	-12.677	T/m @Brho=16.7 Tm		

BETATRON FUNCTIONS OF BST — dp/p = 0.25%; Emittance = 50.000 mmmrad

POS		S(M)	NUX	NUY	BETAX(M)	BETAY(M)	XEQ(M)	2.5sigX mm	2.5sigY mm
0		0.000	0.000	0.000	9.624	9.334	1.428	25.506	21.604
1	BDL2	0.725	0.014	0.011	6.905	12.359	1.237	21.674	24.859
2	BDL2	1.450	0.033	0.019	5.960	13.254	1.201	20.264	25.743
3	S50	2.208	0.053	0.029	5.814	12.916	1.240	20.151	25.413
4	BDY	3.778	0.090	0.052	9.280	7.496	1.702	25.795	19.359
5	BFY	5.108	0.108	0.096	13.174	3.559	2.175	31.103	13.340
6	STCS	5.408	0.112	0.110	13.196	3.248	2.216	31.226	12.744
7	SEXF	5.408	0.112	0.110	13.196	3.248	2.216	31.226	12.744
8	STCS	5.708	0.116	0.125	13.231	3.004	2.256	31.362	12.256
9	BF2	5.908	0.118	0.136	12.871	2.967	2.249	30.992	12.180
10	ST	10.908	0.269	0.283	2.943	13.242	1.236	15.221	25.731
11	BD2	11.108	0.280	0.286	2.995	13.600	1.214	15.272	26.076
12	STCS	11.408	0.295	0.289	3.263	13.532	1.209	15.795	26.012
13	SEXD	11.408	0.295	0.289	3.263	13.532	1.209	15.795	26.012
14	STCS	11.708	0.309	0.293	3.600	13.478	1.204	16.426	25.960
15	BDX	13.038	0.352	0.310	7.716	9.390	1.438	23.237	21.668
16	BFX	14.608	0.375	0.347	13.350	5.766	1.734	30.172	16.979
17	S50	15.365	0.384	0.368	13.701	5.851	1.722	30.479	17.104
18	BFL2	16.090	0.392	0.387	12.768	6.727	1.641	29.369	18.340
19	BFL2	16.815	0.403	0.402	9.624	9.334	1.428	25.506	21.604

III) EXTRACTION CONSIDERATION

We observe that the phase advance between the consecutive straight sections is about 90 degree from QD to QF. It is more advantageous to have the 90 degree phase advance from QF to QF for the extraction consideration. Theregore the hybrid machine might be better to be operated at Qx=3.83. The phase advance between the extraction kicker and the extraction septum will be nearly 90 degree and the betafunction will be maximum at both of these locations. Table 2. lists the parameters relevant to these two hybrid lattices. Another advantage for the smaller tune is that the gradient of the dipoles will be slightly smaller. The aperture requirement is however increased by 3 mm in the x-plane and .5 mm in the y-plane(with the assumption of 50 pimmmrad of emittance and .25% of momentum variation). Figs. 6,7,8 and 9 show respectively the betatron amplitudes, the beam size,the chromatic variation of the machine functions and the phase advance in two superperiods.

IV) Conclusion

In conclusion, we have derived a resonably behaved combined function lattice for the Booster. We found that the basic lattice properties are good. The lattice has several interesting features, 5m long straight section can be obtained without much penalty. The machine, with some tuning quadrupoles, should be able to tuned within +- .25 easily. In Table 2 we compare the lattice parameters with those of the proposed lattice(ref. 2)

Table 2. Comparison of booster lattices

	STANDARD SEP.FN.	HYBRID COMB.FN.		AGS	CERN-PS
Circumference	1/4AGS	1/4AGS	1/4AGS		
(m)	201.78	201.78	201.78	807.12	628.3185
SUPERPERIOD	6	12	12	12	10
TUNE(Qx, Qy)	4.8	4.8	3.83	8.8	6.28
Phase/cell(deg.)	72				
Systmatic stop bands					
order 2	3,6,9	6,12	6,12	6,12	5,10
order 3	4,6,8	4,8	4,8	8	6+2/3
order 4	4+1/2,6	3,6	3,6	9	5,7+1/2
Magnet specifications					
BRHO(T-m)	16.7	16.7	16.7	98.1	81.35
dip.length(m)	2.4	2.9	2.7		4.403185
No. dipoles	36	36	36	240	100
B^@brho=16.7Tm	1.214	1.005	1.0795	1.14952	1.16
quad.length(m)	0.50375	0.2	0.2		
No. quads.	48	24	24		
quad.gradients					
QF(T/m)	9.84	12.5	10.82277		
QD(T/m)	-10.1	-12.7	-11.0504		
dipol.grad.					
BF(T/m)	0	3.12	2.705693	4.742195	4.7771
BD(T/m)	0	-3.17	-2.76262	-4.75737	-4.7771
B"/B(m^-1)	0	3.104477	2.506431	4.125370	4.118189

REFERENCES.

1) E. D. Courant, AGS lattice. private communication.

2) Y. Y. Lee, Private communication and BNL-34989 R April 1985
AGS BOOSTER CONCEPTUAL DESIGN REPORT vol. 1.

APPENDIX: SOME VARIATIONS OF THE COMBINED FUNCTION LATTICES

Figures Caption:

Fig.1 The betatron functions is plotted in the two superperiods. The dispersion function about 2.26m and the maximum beta function is about 13.7m. At the short spaces between magnets, the ratio of maximum to the minimum beta function is 2:1 and 4:1 respectively. At these locations corection elements can be used to tune the machine without inducing large coupling between the transverse planes.

Fig.2 The phase advance of the horizontal plane is plotted as a function of magnet elements. From the end of the long straight section to the begining of the next straight section is not very far away from the optimal 90 degree phase advance for the beam extraction into the AGS.

Fig.3 The beam size (2.5sigma) is calculated for the emittance of 50 pi mmmrad and dp/p=.25%.

Fig.4 The chromatic variation of the tune, betatron amplitudes(in percentage) as a function of dp/p.

Fig.5 The betatron function of the CERN-PS is shown for comparison.

Fig.6 The betatron amplitude of the HYBRID lattice at Q=3.83.

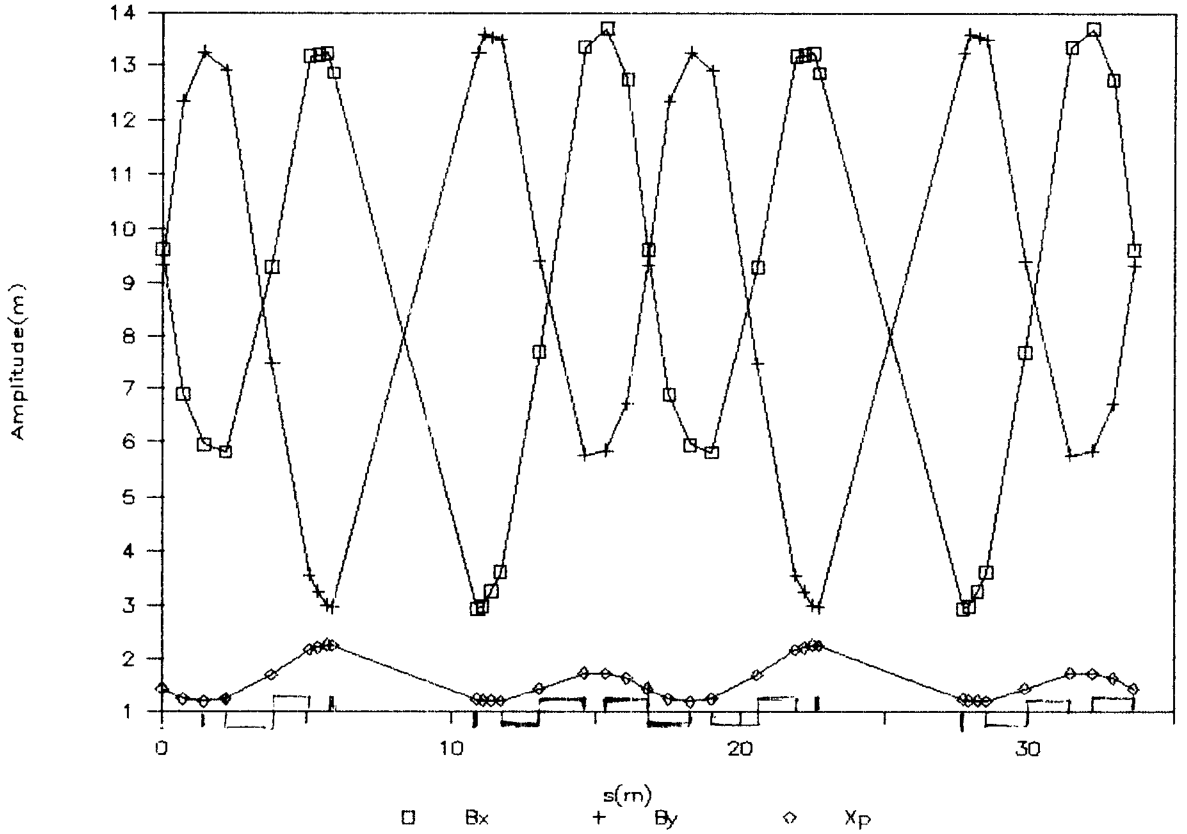
Fig.7 The beam size of Q=3.83 in mm with emittance of 50 mmmrad and dp/p=.25%.

Fig.8 The chromatic variation of the lattice with Q=3.83.

Fig.9 The phase advance of the lattice with Q=3.83 across two superperiods.

BOOSTER HYBRID LATTICE

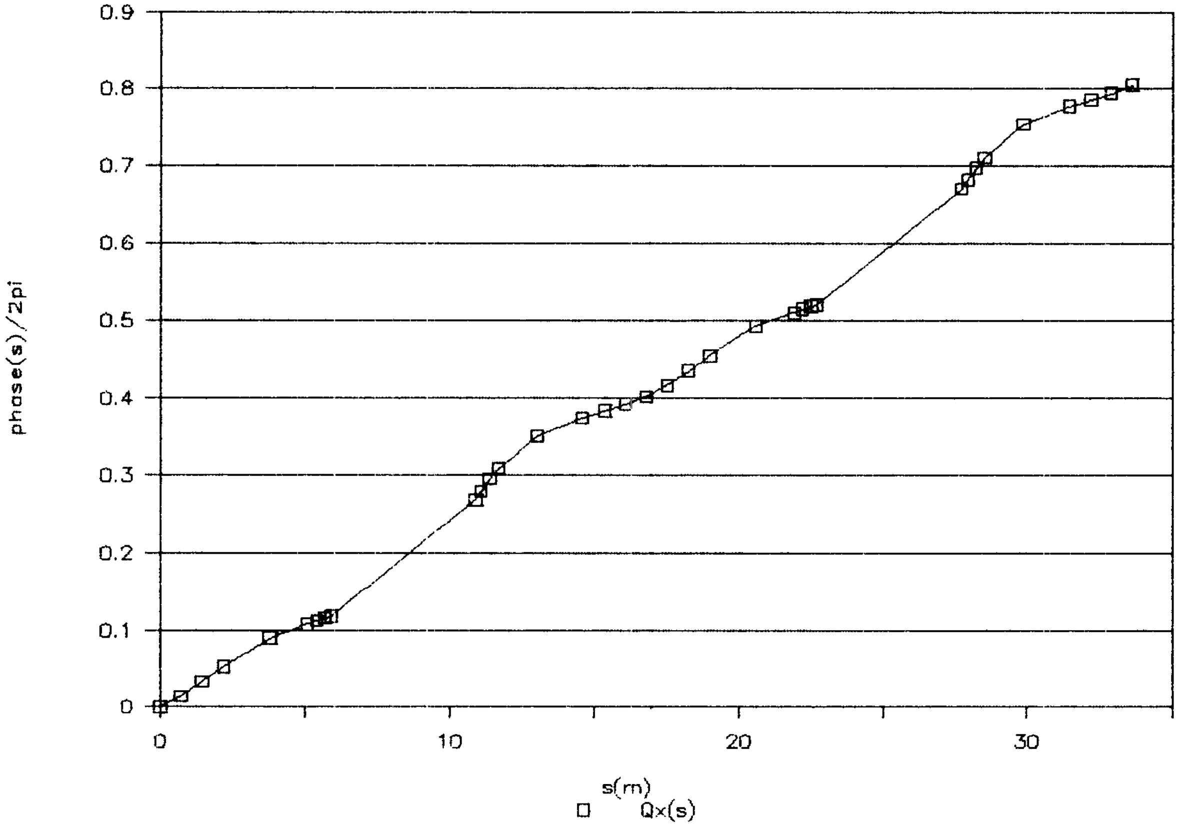
Q=4.83 P=12 ST=5m



1

BOOSTER HYBRID LATTICE

Q=4.83 P=12 ST=5m



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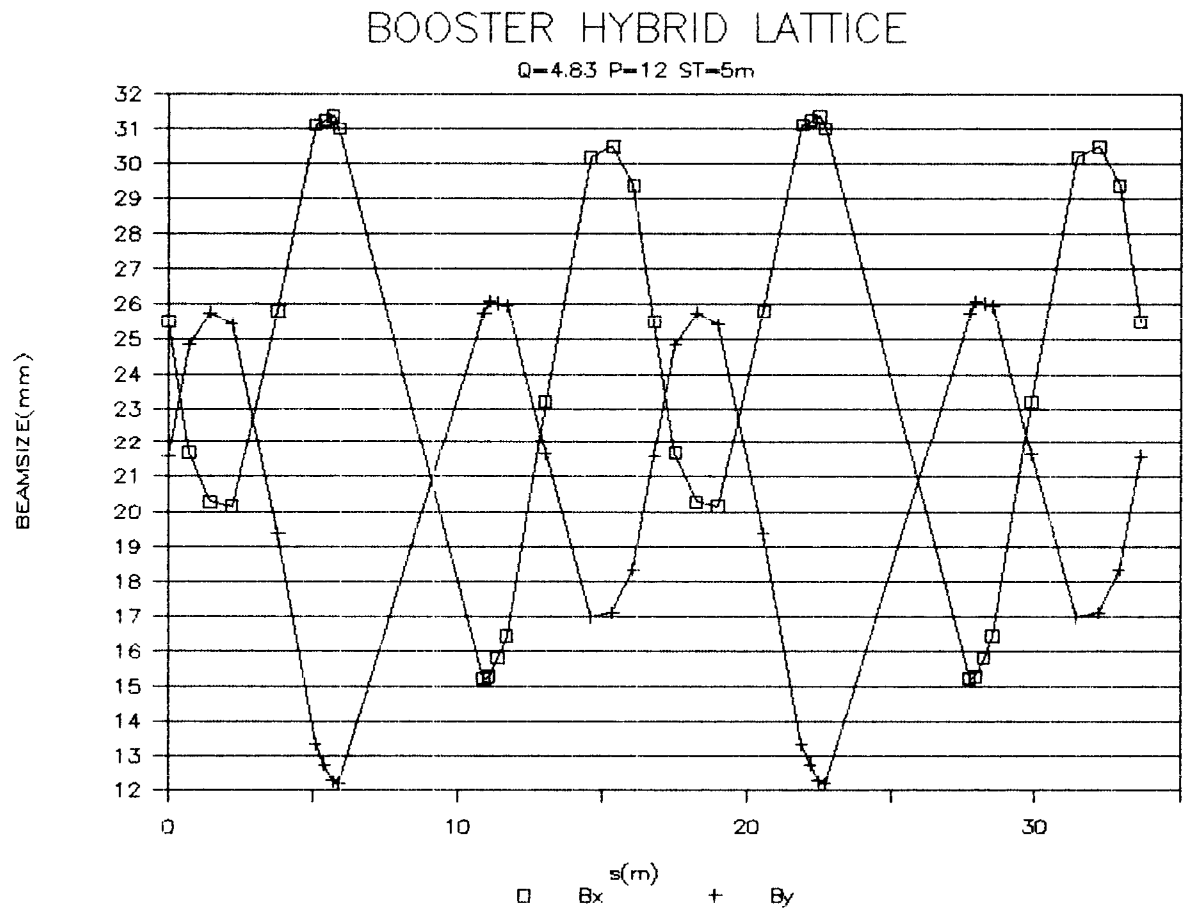
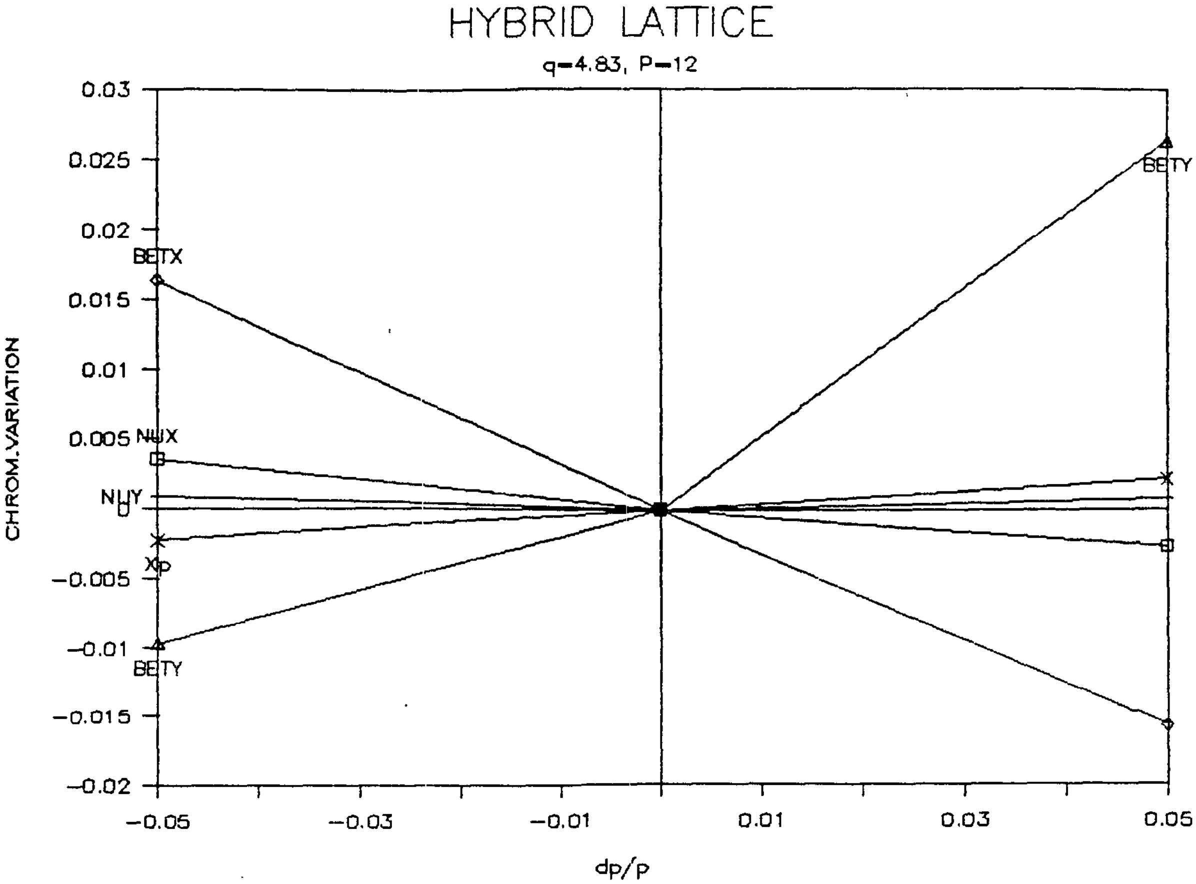
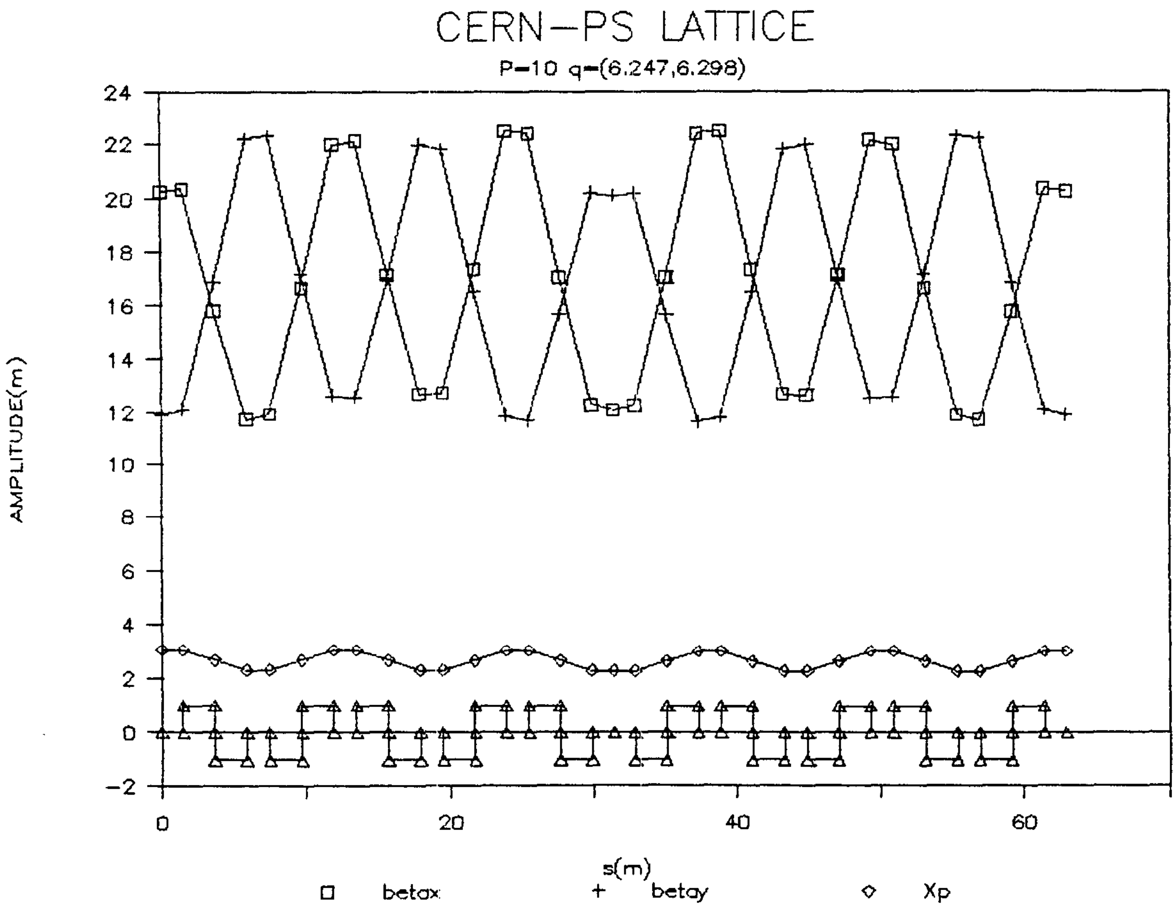


BOOSTER HYBRID LATTICE
Q=4.83 P=12 ST=5m
BEAMSIZE(mm)
32
31
30
29
28
27
26
25
24
23
22
21
20
19
18
17
16
15
14
13
12
0
10
20
30
s(m)
Bx
By

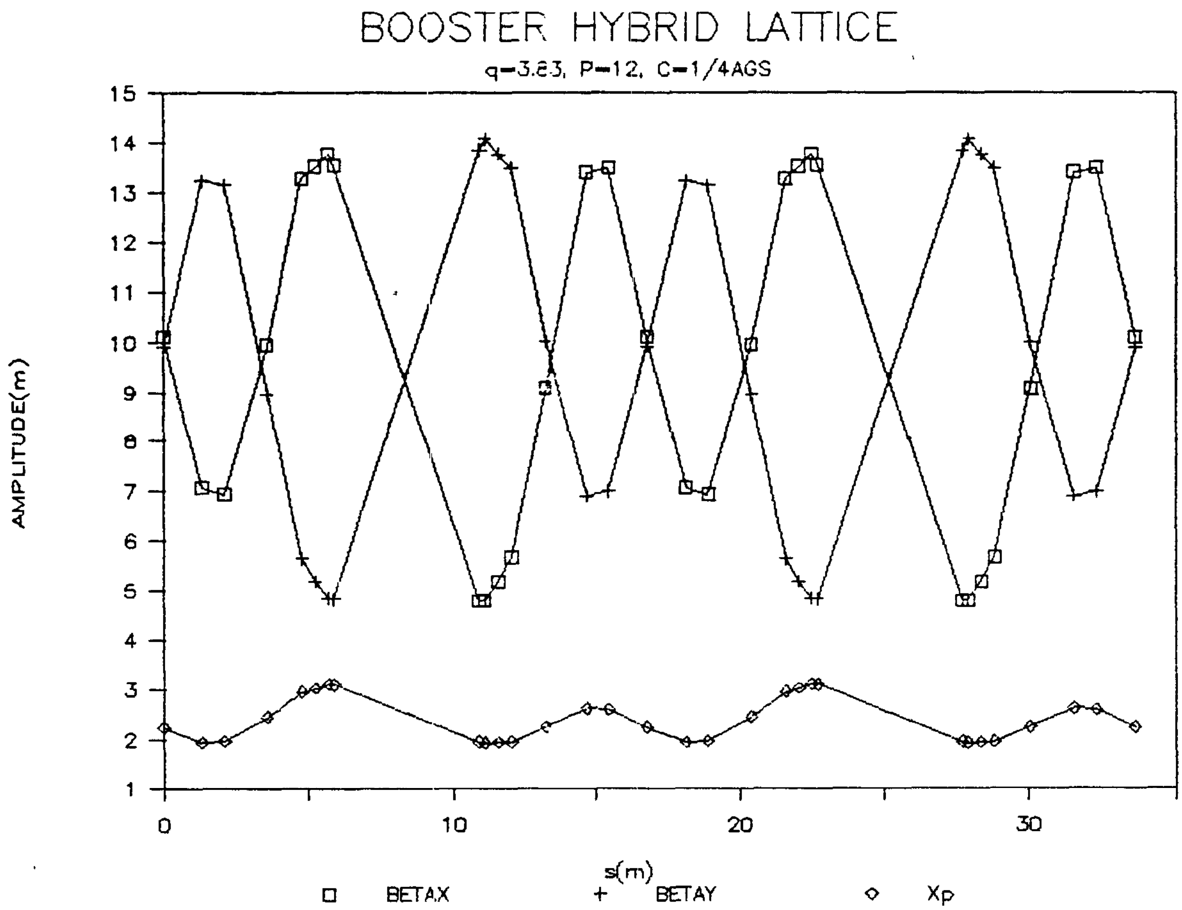
3


HYBRID LATTICE
q=4.83, P=12
CHROM.VARIATION
dp/p
BETX
BETY
NUX
NUY
Xp
0.03
0.025
0.02
0.015
0.01
0.005
0
-0.005
-0.01
-0.015
-0.02
-0.05
-0.03
-0.01
0.01
0.03
0.05

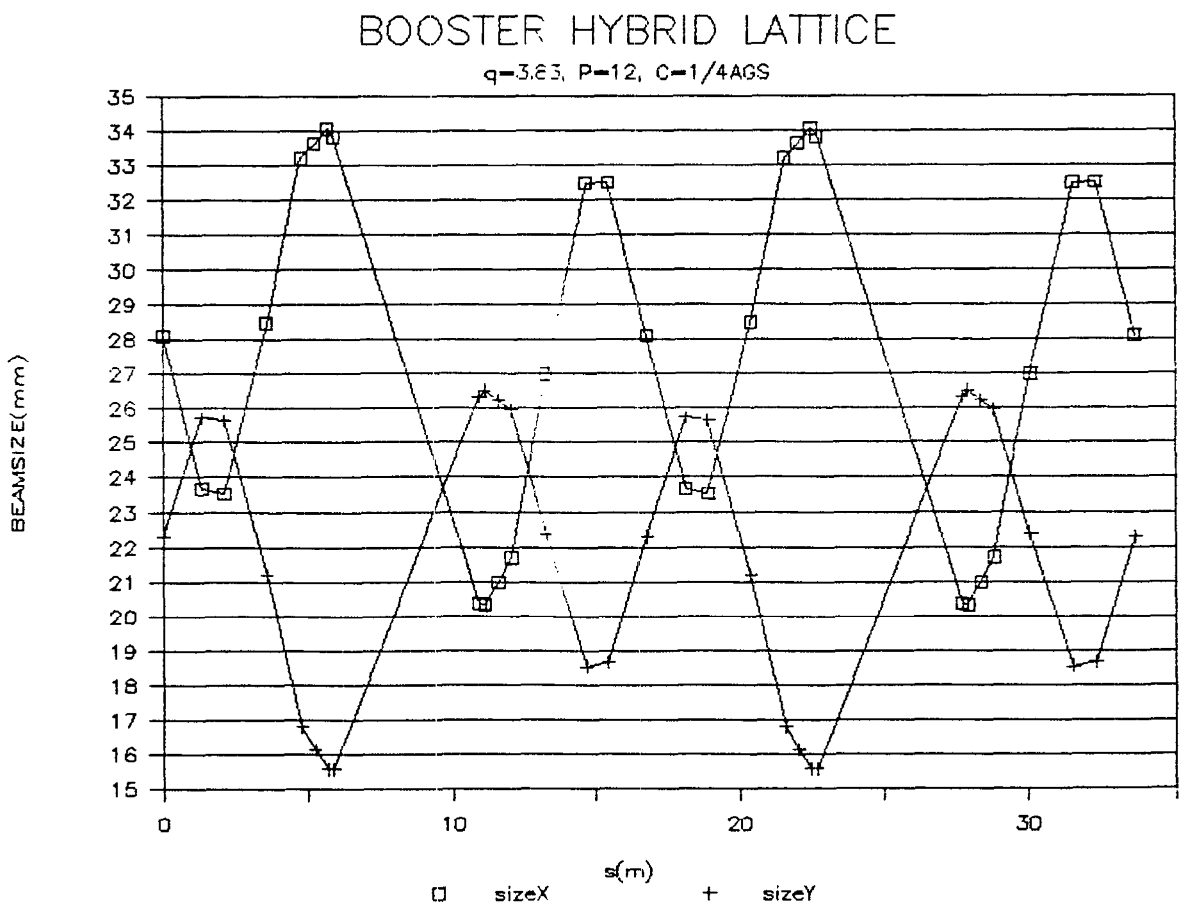
4


CERN-PS LATTICE
P=10 q=(6.247,6.298)
AMPLITUDE(m)
s(m)
betax
betay
Xp
24
22
20
18
16
14
12
10
8
6
4
2
0
-2
0
20
40
60

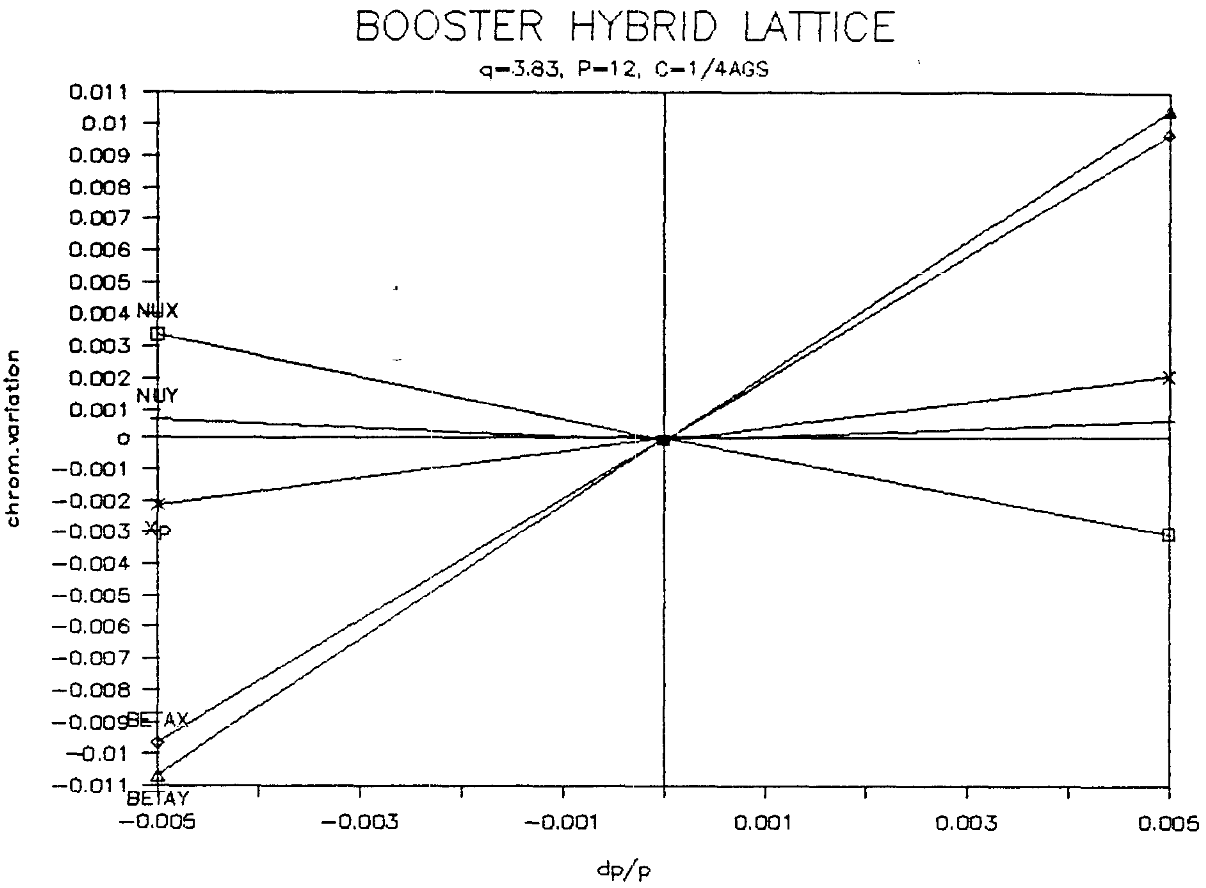
5


BOOSTER HYBRID LATTICE
q=3.83, P=12, C=1/4AGS
AMPLITUDE(m)
s(m)
BETAX
BETAY
Xp

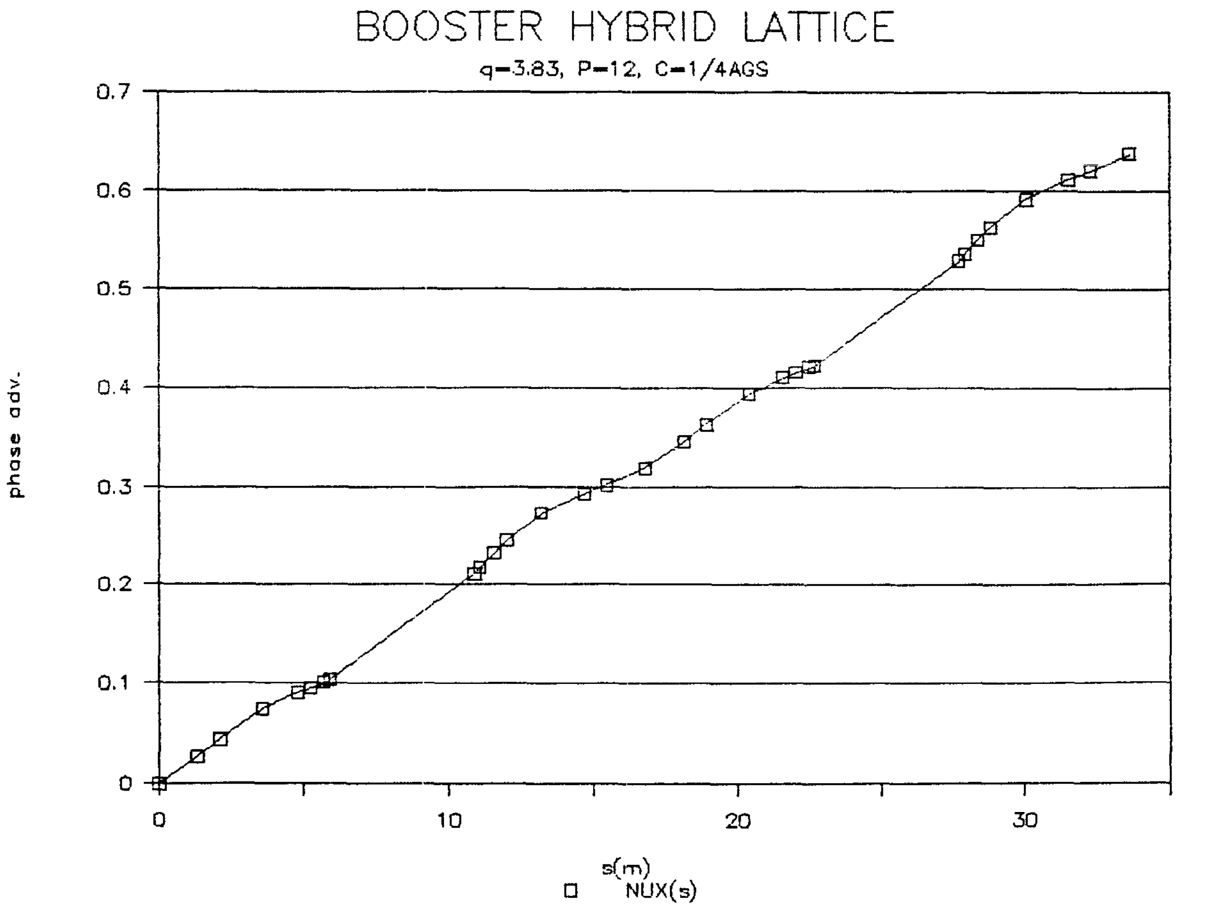
6


BOOSTER HYBRID LATTICE
q=3.83, P=12, C=1/4AGS
BEAMSIZE(mm)
s(m)
sizeX
sizeY

7


BOOSTER HYBRID LATTICE
q=3.83, P=12, C=1/4AGS
chrom. variation
dp/p
NUX
NUY
BETAX
BETAY
0.011
0.01
0.009
0.008
0.007
0.006
0.005
0.004
0.003
0.002
0.001
0
-0.001
-0.002
-0.003
-0.004
-0.005
-0.006
-0.007
-0.008
-0.009
-0.01
-0.011
-0.005
-0.003
-0.001
0.001
0.003
0.005

8


BOOSTER HYBRID LATTICE
q=3.83, P=12, C=1/4AGS
phase adv.
s(m)
NUX(s)
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
10
20
30

9

APPENDIX: Combined function Lattice for the 1/3 AGS circumference

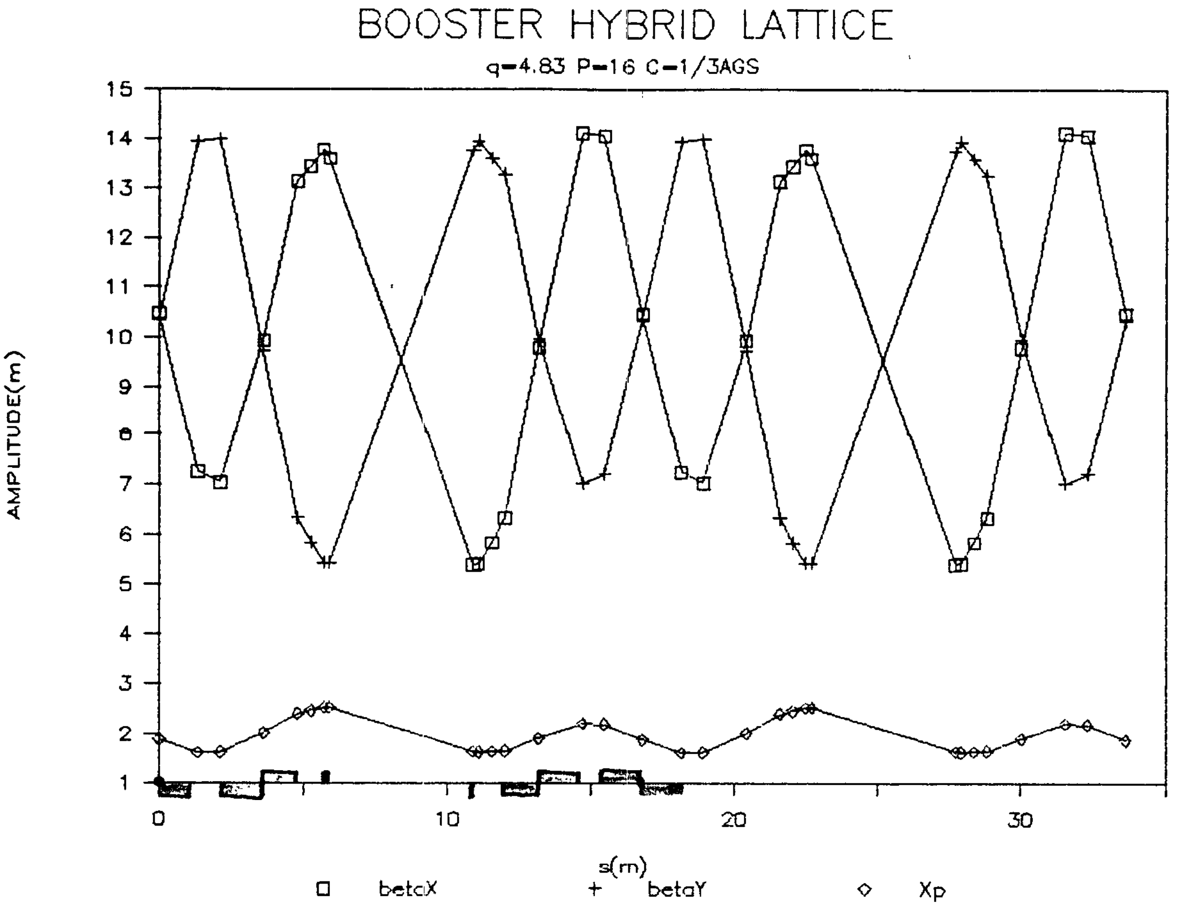
Fig.10 The betatron functions is plotted for the combined function magnets for 1/3 Circumference of AGS at the tune of 4.83 with 16 superperiodicity.

Fig.11 The beam size (in mm) is plotted for the lattice shown in Fig.10 for emittance of 50 pi mm mrad in both the horizontal and vertical plane and dp/p=.25%.

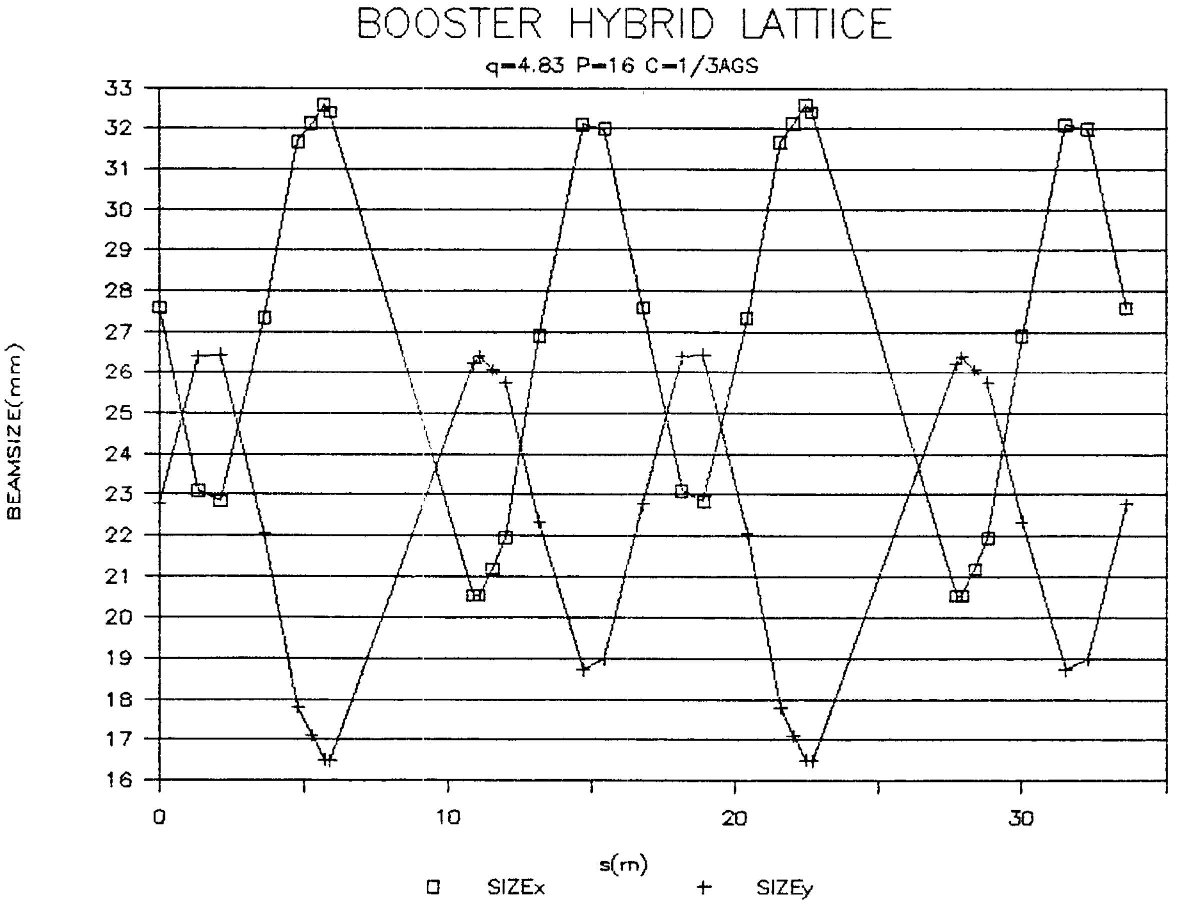
Fig.12 Chromatic properties with the sextupoles of Fig.10.

Fig.13 Phase advance acrosses two superperiods to demonstrate the extraction feasibility of the lattice of Fig.10.

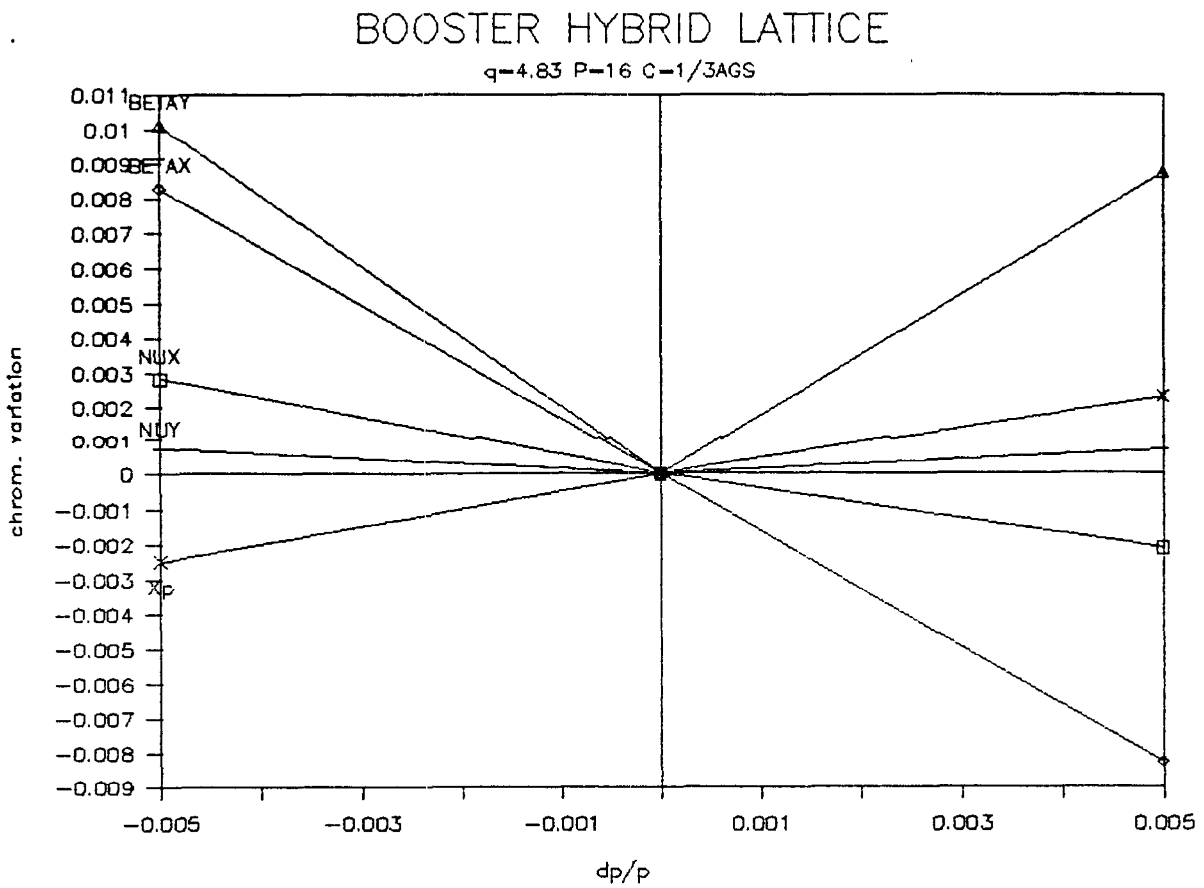
Fig.14 Tunability of the machine is demonstrated that the machine tune can be changed by 2 tuning quadrupoles at 20cm long and 5T/m at BRHO=16.7 Tm.


BOOSTER HYBRID LATTICE
q=4.83 P=16 C=1/3AGS
AMPLITUDE(m)
s(m)
betaX
betaY
Xp

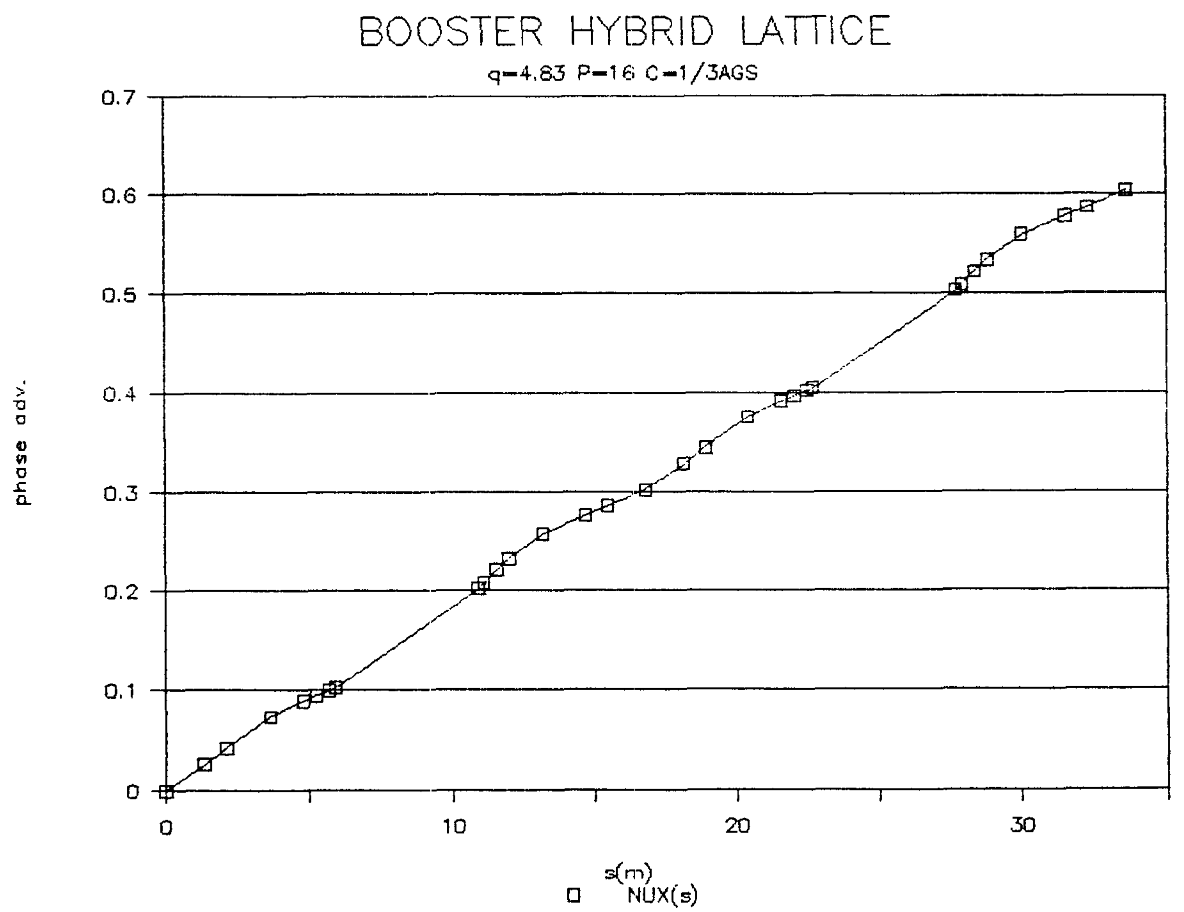
10


BOOSTER HYBRID LATTICE
q=4.83 P=16 C=1/3AGS
BEAMSIZE(mm)
s(m)
SIZEx
SIZEy

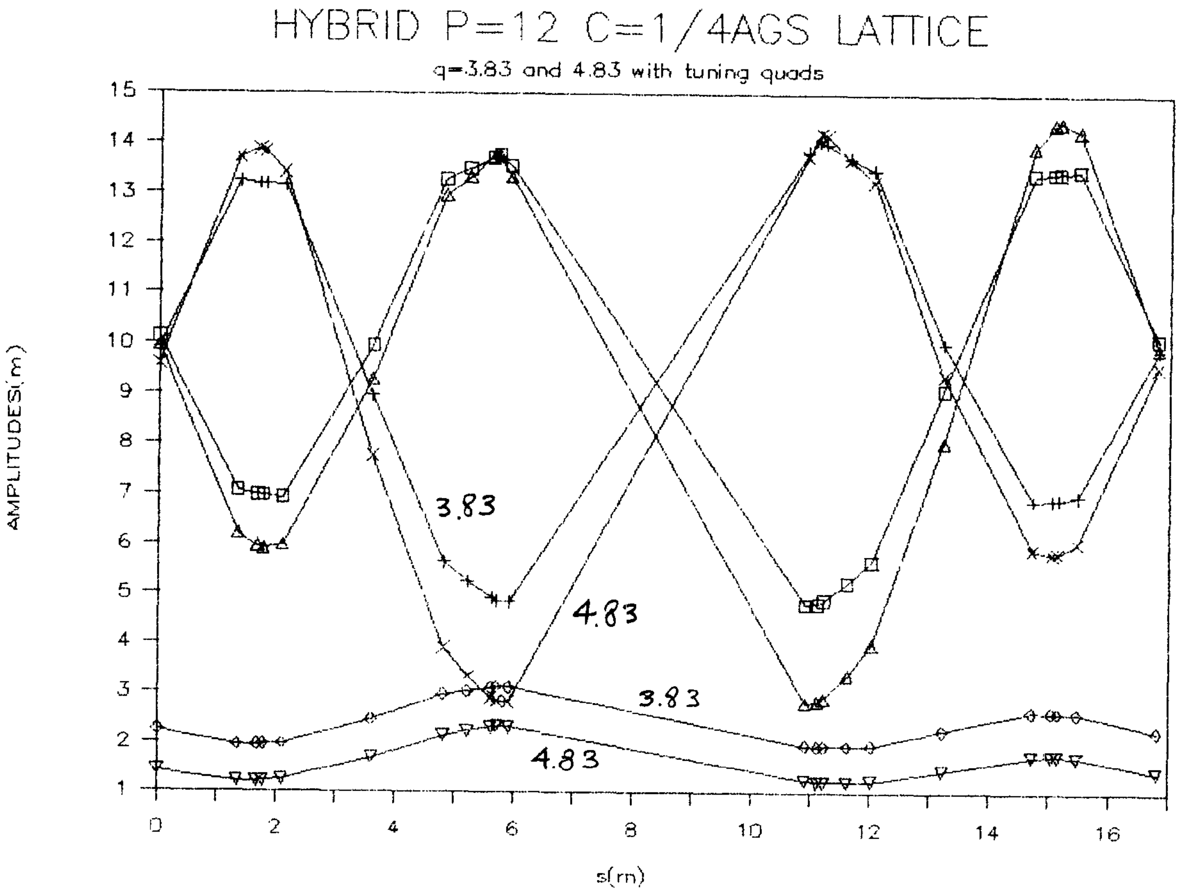
11


BOOSTER HYBRID LATTICE
q=4.83 P=16 C=1/3AGS
BETAY
BETAX
NUX
NUY
Xp
chrom. variation
dp/p
0.011
0.01
0.009
0.008
0.007
0.006
0.005
0.004
0.003
0.002
0.001
0
-0.001
-0.002
-0.003
-0.004
-0.005
-0.006
-0.007
-0.008
-0.009
-0.005
-0.003
-0.001
0.001
0.003
0.005

12


BOOSTER HYBRID LATTICE
q=4.83 P=16 C=1/3AGS
phase adv.
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
10
20
30
s(m)
NUX(s)

13


HYBRID P=12 C=1/4AGS LATTICE
q=3.83 and 4.83 with tuning quads
AMPLITUDES(m)
s(m)
3.83
4.83
3.83
4.83
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
2
4
6
8
10
12
14
16

14