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## A PROPOSED MINI BETA INSERTION FOR SPEAR\*

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### 1. Introduction

A significant gain in luminosity has been achieved by use of "mini beta insertions" implemented in several electron-positron storage rings (CESR, DORIS II, PEP, PETRA) during the last year. This concept consists of strong vertical focusing quadrupoles mounted as close as possible to the interaction point. Such an arrangement avoids the acceptance and chromaticity problems caused by an extreme focusing with the normal magnet structure. On the other hand these "mini beta quads" interfere with the particle detectors and in particular if the detector has a magnetic field one has to use additional measures to protect the quadrupole from this field. For the ARGUS detector at DORIS II with a longitudinal field of  $B = .8$  T this problem has been successfully solved by means of compensating coils surrounding the quadrupoles.

In this paper a mini beta insertion for SPEAR is suggested which is rather similar to that developed for DORIS II.<sup>1</sup> The essential element is a conventional

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iron magnet with moderate design values up to an energy of  $E = 4$  GeV. The resulting optics allow vertical amplitude functions down to  $\beta_y^* = 3$  cm at the interaction points. Compared to the present SPEAR optics, the mini beta optics is only different in the interaction regions but unchanged in the whole arcs. This is of great importance to the injection system which does'nt need any modification. The resulting gain in luminosity is calculated to be approximately a factor of four.

## 2. Luminosity

The luminosity of an electron storage ring at the space charge limit is given by the following expression for one bunch per beam:

$$L = 3.1 \times 10^{26} \frac{I^2}{f_u \epsilon_x E^2 \sqrt{k \beta_x^* \beta_y^*}}$$

with

$$I = 698.5 \frac{f_u \epsilon_x E^3 \sqrt{k} (\sqrt{\beta_x^*} + \sqrt{k \beta_y^*})}{\sqrt{\beta_y^*}} \Delta Q$$

and the emittance coupling:

$$k = \frac{\epsilon_y}{\epsilon_x}$$

The notation and units are:

$L$  = luminosity in [ $\text{cm}^{-2} \text{sec}^{-1}$ ]

$I$  = beam current in [mA]

$E$  = beam energy in [GeV]

$\epsilon_x$  = horizontal emittance at 1 GeV in [ $\pi$  mrad]

$f_u$  = revolution frequency in [Hz]

$\beta_{x,y}^*$  = beta function at the interaction point in [m]

$\Delta Q$  = beam-beam tune shift

Without the use of wigglers, the present measured luminosity of SPEAR is

$E$ [GeV]	$I$ [mA]	$L$ [ $\text{cm}^{-2} \text{sec}^{-1}$ ]
1.547	5.0	$4.5 \times 10^{20}$
1.842	9.5	$1.1 \times 10^{20}$

With the optical data

$$\beta_x^* = 1.19 \text{ m}, \quad \beta_y^* = 0.103 \text{ m}, \quad \epsilon_x = 4.94 \times 10^{-8} \text{ } \pi \text{ mrad}$$

one can derive the following average values for  $k$  and  $\Delta Q$ :

$$k = 0.11, \quad \Delta Q = 0.0261$$

Taking these numbers one gets the luminosity versus energy as shown in Fig. 1, which fits very well with the best average values achieved so far. In the new mini beta optics the emittance  $\epsilon_x$  is unchanged and the coupling  $k = \epsilon_x/\epsilon_y$  and the tune shift  $\Delta Q$  are assumed to be the same as well. Only the amplitude functions in the interaction points have the following different values:

$$\text{SPEAR Mini Beta Optics : } \beta_x^* = 0.90 \text{ m}, \quad \beta_y^* = 0.03 \text{ m}$$

The resulting luminosity is also shown in Fig. 1. It includes a correction factor due to the variation of the beta function along the bunch as figured out by G. Fischer.<sup>2</sup> Thus the mini beta insertion will increase the luminosity of SPEAR by a factor of five. This value may be somewhat too high; it is possible that the maximum tune shift  $\Delta Q$  due to beam-beam interaction will be decreased

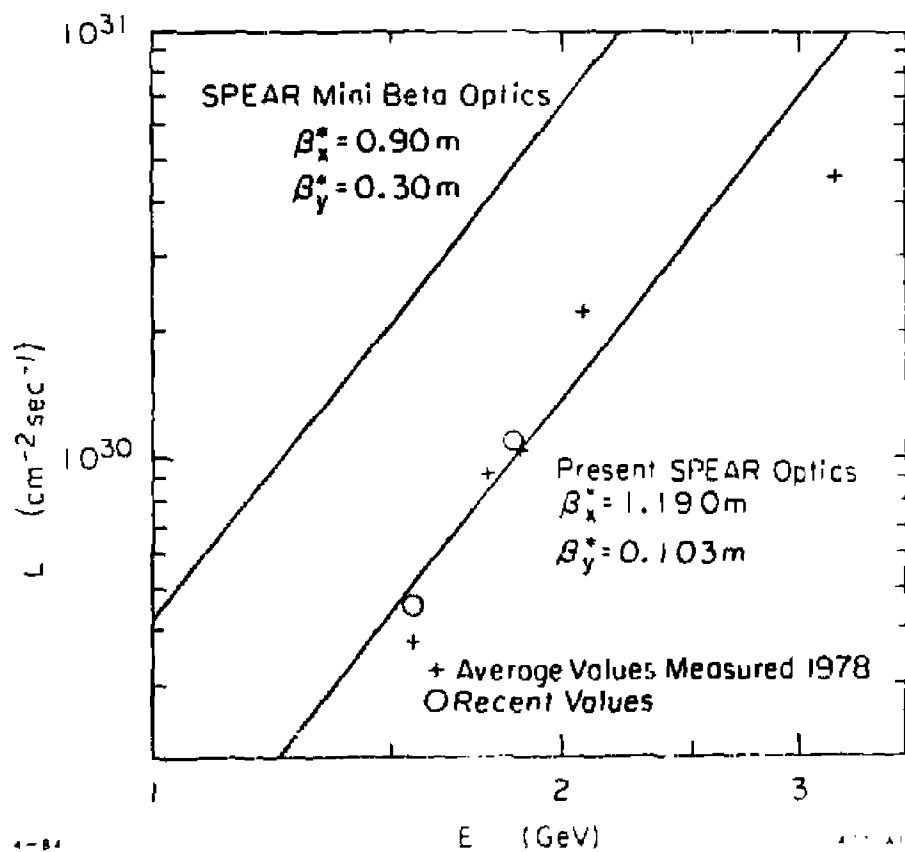


Figure 1. Luminosity of SPEAR with mini beta insertion compared to present values (without wiggler).

because of the non-negligible variation of the beta function along the bunch mentioned above. But in any case one can expect a gain factor of about four.

### 3. Lattice and Optics

In order to implement the new mini beta insertion in the SPEAR lattice, the first vertical focusing quadrupole  $Q3$  is removed and replaced by a new magnet with a significantly higher gradient. The front face of this "mini beta quadrupole"  $MBQ3$  is only 1.34 m away from the interaction point. The first horizontal focusing magnet  $Q2$  has to be moved one meter closer to the interaction point, whereas all other magnets are unchanged (see Fig. 2).

The strengths of the standard quads  $QF$  and  $QD$  are exactly the same as in the present SPEAR optics. The matching of the new mini beta insertion to the unchanged lattice of the arcs is done by varying the first six quads  $MBQ3$ ,  $Q2$ ,  $Q1$ ,  $QF1$ ,  $QD1$ , and  $QF2$ . Since all quadrupoles between the kicker magnets are unchanged, the betatron phase in this region is not changed either, and the matching of the kicker beam bump is not affected. Therefore the new mini beta optics don't require any modifications of the injection system.

The mini beta optics for SPEAR have been calculated using the computer codes "COMFORT"<sup>3</sup> and "PATRICIA".<sup>4</sup> The optics design provides a vertical beta function of  $\beta_y^* = 0.03$  m in the interaction point and the most detailed investigations have been done with this value. But several other optics with  $\beta_y^*$ -values between 0.025 and 0.05 m have also been calculated.

The following list contains the most important parameters of the 3 cm mini beta optics:

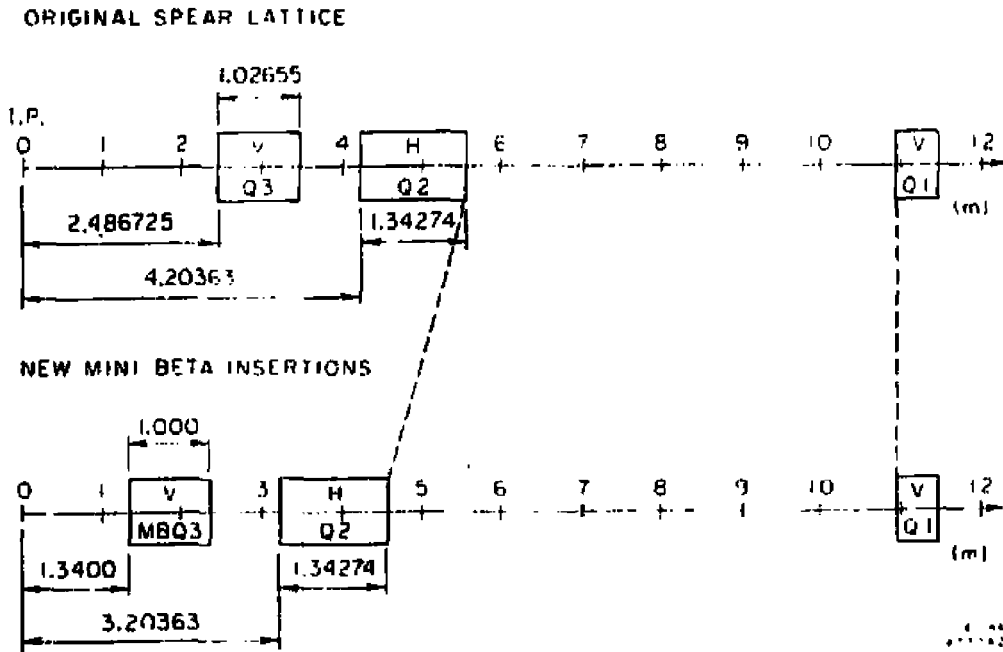


Figure 2. Comparison of the original SPEAR lattice with the proposed mini beta insertion.

Parameters	3 cm Optics	Present Optics
Beta functions at interaction point: $\beta_x^*$ [m]	0.900	1.190
$\beta_y^*$ [m]	0.030	0.103
Tune: $\nu_x$	5.2957	5.273
$\nu_y$	5.1633	5.161
Chromaticity: $\xi_x$	-12.102	- 8.95
$\xi_y$	-26.485	-15.36
Momentum compaction: $\alpha$	0.04115	0.0418
Emittance (at 1 GeV): $\epsilon_x$ [mrad]	$4.872 \times 10^{-8}$	$4.04 \times 10^{-8}$

The plots of the beta- and dispersion-functions are shown in Fig. 3; the lattice parameters, the beam-dynamics parameters and the most important integrals are listed in Tables 1-3.

#### 4. Chromaticity Compensation

The chromaticity of the 3 cm optics is—especially in the vertical plane—relatively large ( $\xi_x = -12.1$ ,  $\xi_y = -26.5$ ) for a machine of the size of SPEAR. Therefore a very effective sextupole arrangement is required, which sets the chromaticity to  $\xi_x = \xi_y = +3$  without significant reduction of the dynamic aperture. The present chromaticity compensation consists of two sextupole families, one for each plane. Using only these two families for the 3 cm mini beta optics, the off momentum particles show a strong nonlinear behavior. As plotted in Figs. 5 and 6, the vertical tune as well as the vertical beta function in the interaction point vary strongly with momentum and for values of  $\Delta p/p < -0.7\%$  the program can't even find a periodic solution. In the horizontal plane, however, there are no

SPEAR 3 CM MINIBETA OPTICS (FEB. 6, 1984)

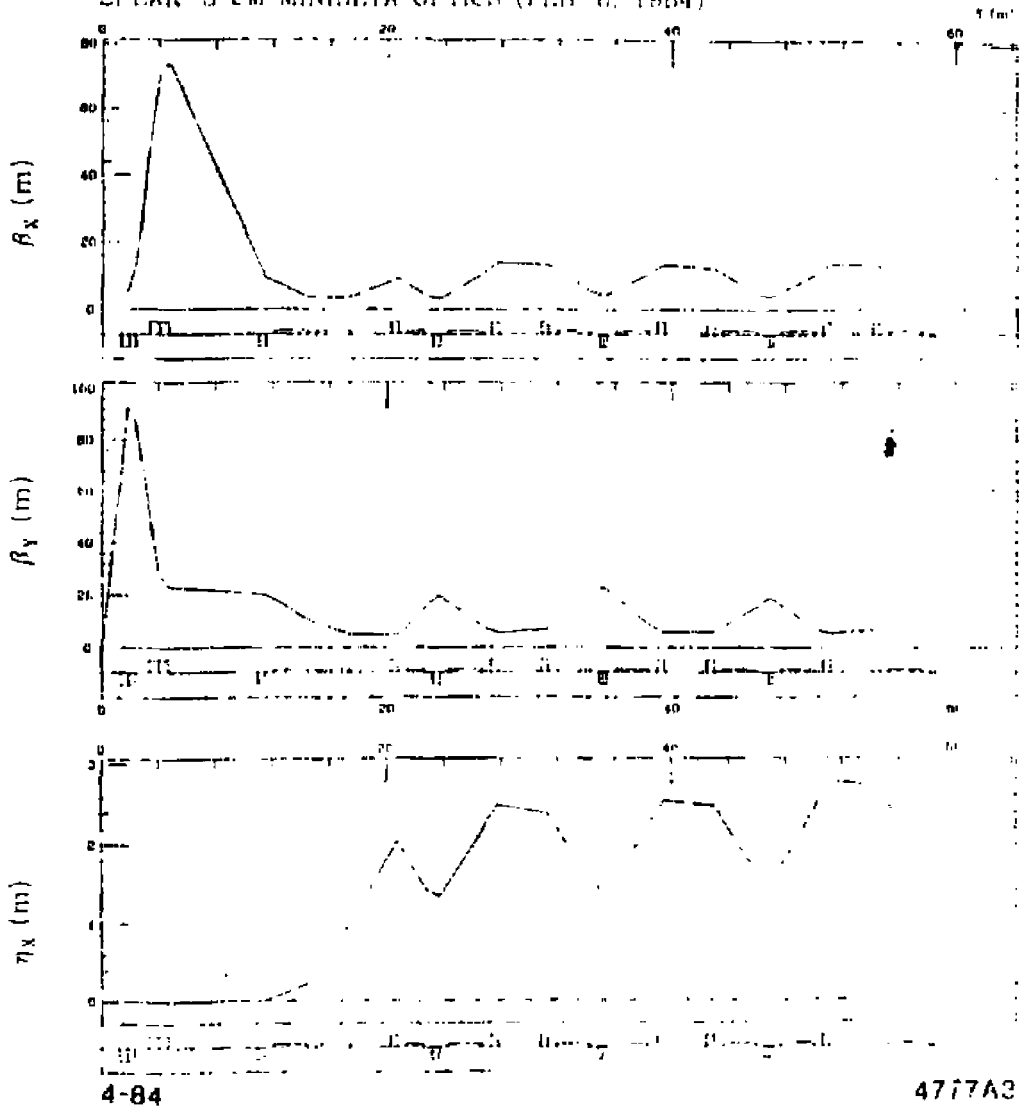


Figure 3. Amplitude and dispersion function of the 3 cm mini beta optics.

Table 1

SPREAD 3 CM NEUTRON OPTICS (FEB. 6, 1964)

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MML:jz

LATTICE-PARAMETER

UNITS: RHO=K-SH-DI, K1/H=2ISHI/2M=Z1, DM1/M=31, TORI/FI, LENO/HI, LTO/FI

NR	TPP	RHO-K-SH-DI	GRADIENT	PCRF	LEIGH	LTOF
1	STR7	0.0	0.0	0.0	0.0	0.0
2	CM	0.450000	0.0	1.34000	0.50000	1.04000
3	CM	0.450000	0.0	0.0	0.50000	2.34000
4	Q2	-0.3712100	0.0	1.00367	0.67137	4.01500
5	Q2	-0.3712100	0.0	0.0	0.67137	4.64637
6	Q1	0.1744100	0.0	0.0	0.31034	11.07809
7	Q0	-12.8152000	0.0	0.60668	2.38025	14.45402
8	Q0	-12.8152000	0.0	0.60668	2.38025	17.42097
9	QF1	0.4685300	0.0	2.81845	0.31034	20.74576
10	SP	0.0	0.0	0.30334	0.0	21.06576
11	B	-12.8152000	0.0	0.10000	1.18413	22.34967
12	SO	0.0	0.0	0.30003	0.0	22.84969
13	Q01	0.6518000	0.0	0.38000	0.51834	23.66027
14	SO	0.0	0.0	0.30334	0.0	23.97157
15	SO	-12.8152000	0.0	0.30334	2.38025	26.44314
16	SP	0.0	0.0	0.30334	0.0	26.74650
17	QF2	-0.3086600	0.0	0.30334	0.31834	27.76010
18	QF	-0.2780900	0.0	2.98166	0.51834	31.26810
19	SO	-12.8152000	0.0	0.60668	2.38025	34.24314
20	SO1	0.4500000	0.0	0.30334	0.0	34.54445
21	Q04	0.4885300	0.0	0.30334	0.25917	35.10096
22	Q04	0.4885300	0.0	0.0	0.25917	37.36813
23	SO1	0.4500000	0.0	0.30334	0.0	35.67147
24	SO	-12.8152000	0.0	0.30334	2.38025	38.34304
25	SP	0.0	0.0	0.30334	0.0	38.64640
26	QF	-0.2780900	0.0	0.30334	0.51834	39.46808
27	QF	-0.2780900	0.0	2.98166	0.91834	42.96808
28	SO	-12.8152000	0.0	0.60668	2.38025	45.91301
29	SO	0.0	0.0	0.30334	0.0	46.21635
30	Q011	0.4885300	0.0	0.30334	0.25917	46.89808
31	Q04	0.4885300	0.0	0.0	0.25917	47.06003
32	SO	0.0	0.0	0.30334	0.0	47.37137
33	SO	-12.8152000	0.0	0.30334	2.38025	50.04294
34	SP	0.0	0.0	0.30334	0.0	50.34630
35	QF	-0.2780900	0.0	0.30334	0.51834	51.16799
36	QF	-0.2780900	0.0	2.98166	0.51834	54.66798
37	SO	-12.8152000	0.0	0.60668	2.38025	57.64291
38	SO1	0.4500000	0.0	0.30334	0.0	57.94425
39	Q011	0.4885300	0.0	0.30334	0.25917	58.50076
40	SO11	0.0	0.0	0.0	0.0	58.50076

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CPU-TIME SO FAR = 21. MSEC  
CPU-TIME SO FAR = 11. MSEC

Table 2

BEAM DYNAMICS - PARALLEL												
DIPOLY D												
LAPSE OF DATA AND ILLICIT FOR MEASUREMENT IN END OF BEAM-LINE												
WACHT	RELAX	ALIAS	DEFINITE	FLUX	ORDER	RELAX	DEFINITE	FLUX	ORDER	RELAX	DEFINITE	FLUX
STW1	1	0.00002	0.0	3.91779	-0.00050	0.0	0.03001	0.0	0.51100	0.0	0.0	0.0
Q1	2	5.46176	-0.41955	9.00709	-0.00045	0.17616	42.64604	-16.33706	74.41566	0.0	0.74766	1.4470
Q1	3	11.16400	-11.14013	15.13097	-0.00007	0.18500	87.15987	75.00261	127.81972	0.0	7.18931	14.100
Q2	4	21.00000	-17.00022	35.10000	-0.00177	0.19017	27.13134	6.84350	15.43256	0.0	25.407	50.100
Q2	5	31.00000	-7.21013	55.05075	-0.00176	0.19661	22.97155	0.11057	16.16100	0.0	26.644	53.000
Q1	6	3.47371	1.40025	12.74104	-0.00016	0.21200	19.90274	3.44107	15.17605	0.0	3.0774	11.100
FB	7	1.63682	-0.40150	0.01691	0.21671	0.32206	10.42202	1.15513	1.55151	0.0	1.14301	16.100
FB	8	1.70131	-0.52116	0.22916	0.70642	0.47021	6.49137	0.60385	6.19150	0.0	0.43095	17.000
Q1	9	0.25587	1.70010	15.21950	2.00000	0.55767	6.41519	-1.05001	6.13001	0.0	0.43201	25.100
SP	10	0.20000	1.07001	16.20502	1.93005	0.56362	5.00103	2.13900	2.13900	0.0	0.50121	21.000
Q2	11	4.47176	0.56220	11.55327	1.49007	0.60100	16.18527	1.41102	16.11641	0.0	0.50715	22.000
Q2	12	5.00200	-0.07202	10.52101	1.42176	0.41104	16.11654	-1.23913	11.41601	0.0	0.50744	22.000
Q1	13	1.40500	-0.42050	0.00050	1.15706	0.85004	19.15507	2.40417	13.01913	0.0	0.50761	23.000
Q1	14	1.00000	-0.70101	10.19171	1.10000	0.66155	18.01261	2.12279	12.53279	0.0	0.50779	23.100
Q1	15	0.00002	-1.19225	16.76116	2.13650	0.70124	1.02503	1.40002	0.13500	0.0	0.49654	26.000
SP	16	11.27264	-1.91779	17.01209	2.27630	0.73504	6.26276	1.50070	7.00007	0.0	0.49157	26.000
Q2	17	14.01207	-0.05001	10.27178	2.40100	0.76500	5.10017	0.70213	6.24007	0.0	0.49300	17.000
Q2	18	11.00000	1.19000	10.20115	2.10000	0.78002	0.77000	-1.00000	0.40000	0.0	0.70013	11.000
Q1	19	5.50011	0.00025	12.05013	1.51024	0.60070	10.00070	-2.50015	12.00000	0.0	0.01274	14.000
Q1	20	0.00001	0.70003	11.50221	1.40000	0.00000	20.00000	2.00000	11.10000	0.0	0.01510	14.000
Q1	21	0.00011	-0.01005	10.00007	1.41127	0.00002	22.00007	0.00000	14.00000	0.0	0.01000	15.000
Q1	22	0.00002	-0.00011	15.00000	1.50005	-0.00021	22.05124	2.05000	13.05000	0.0	0.02111	15.000
Q1	23	0.00000	-0.00071	11.00000	1.50001	0.00002	20.30000	2.20000	15.10000	0.0	0.02319	15.000
FB	24	10.10000	-1.00000	16.90132	2.21000	0.90000	0.10000	1.20000	0.50000	0.0	0.05000	16.000
SP	25	11.00000	-1.50000	17.00000	1.10000	0.91001	7.10000	1.50000	7.00000	0.0	0.70000	15.000
Q2	26	13.10000	-1.10000	19.00000	2.10000	0.60000	5.00000	0.10000	0.00000	0.0	0.00000	17.000
Q2	27	12.10000	1.10000	18.10000	2.00000	0.50000	5.00000	-1.00000	0.00000	0.0	0.00000	17.000
Q1	28	0.00000	0.10000	11.00000	1.00000	1.00000	15.10000	-2.00000	11.00000	0.0	1.00000	11.000
Q1	29	0.40000	0.40000	11.00000	1.00000	1.00000	1.00000	-2.00000	12.00000	0.0	1.00000	11.000
Q1	30	1.00000	-0.00000	10.00000	1.00000	1.00000	1.00000	-2.00000	12.00000	0.0	1.00000	11.000
Q1	31	0.10000	-0.10000	10.00000	1.00000	1.00000	1.00000	-2.00000	12.00000	0.0	1.00000	11.000
Q1	32	0.10000	-0.10000	10.00000	1.00000	1.00000	1.00000	-2.00000	12.00000	0.0	1.00000	11.000
Q1	33	10.00000	-1.00000	10.00000	2.00000	1.00000	1.00000	-2.00000	12.00000	0.0	1.00000	11.000
SP	14	11.55211	-1.10000	10.20000	2.50000	1.10000	6.10000	1.20000	7.00000	0.0	1.10000	11.000
Q2	15	13.00000	0.00000	19.00000	2.10000	1.10000	6.00000	1.20000	7.00000	0.0	1.10000	11.000
Q2	16	13.00000	1.20000	19.00000	2.10000	1.10000	6.00000	1.20000	7.00000	0.0	1.10000	11.000
Q2	17	5.50000	0.00000	12.00000	1.20000	1.20000	10.00000	-2.00000	12.00000	0.0	1.20000	11.000
Q1	18	0.00000	0.00000	12.00000	1.20000	1.20000	10.00000	-2.00000	12.00000	0.0	1.20000	11.000
Q1	19	0.00000	0.00000	12.00000	1.20000	1.20000	10.00000	-2.00000	12.00000	0.0	1.20000	11.000
Q1	20	0.00000	0.00000	12.00000	1.20000	1.20000	10.00000	-2.00000	12.00000	0.0	1.20000	11.000
Q1	21	0.00000	0.00000	12.00000	1.20000	1.20000	10.00000	-2.00000	12.00000	0.0	1.20000	11.000
Q1	22	0.00000	0.00000	12.00000	1.20000	1.20000	10.00000	-2.00000	12.00000	0.0	1.20000	11.000
Q1	23	0.00000	0.00000	12.00000	1.20000	1.20000	10.00000	-2.00000	12.00000	0.0	1.20000	11.000
Q1	24	0.00000	0.00000	12.00000	1.20000	1.20000	10.00000	-2.00000	12.00000	0.0	1.20000	11.000
Q1	25	0.00000	0.00000	12.00000	1.20000	1.20000	10.00000	-2.00000	12.00000	0.0	1.20000	11.000
Q1	26	0.00000	0.00000	12.00000	1.20000	1.20000	10.00000	-2.00000	12.00000	0.0	1.20000	11.000
Q1	27	0.00000	0.00000	12.00000	1.20000	1.20000	10.00000	-2.00000	12.00000	0.0	1.20000	11.000
Q1	28	0.00000	0.00000	12.00000	1.20000	1.20000	10.00000	-2.00000	12.00000	0.0	1.20000	11.000
Q1	29	0.00000	0.00000	12.00000	1.20000	1.20000	10.00000	-2.00000	12.00000	0.0	1.20000	11.000
Q1	30	0.00000	0.00000	12.00000	1.20000	1.20000	10.00000	-2.00000	12.00000	0.0	1.20000	11.000
Q1	31	0.00000	0.00000	12.00000	1.20000	1.20000	10.00000	-2.00000	12.00000	0.0	1.20000	11.000
Q1	32	0.00000	0.00000	12.00000	1.20000	1.20000	10.00000	-2.00000	12.00000	0.0	1.20000	11.000
Q1	33	0.00000	0.00000	12.00000	1.20000	1.20000	10.00000	-2.00000	12.00000	0.0	1.20000	11.000
Q1	34	0.00000	0.00000	12.00000	1.20000	1.20000	10.00000	-2.00000	12.00000	0.0	1.20000	11.000
Q1	35	0.00000	0.00000	12.00000	1.20000	1.20000	10.00000	-2.00000	12.00000	0.0	1.20000	11.000
Q1	36	0.00000	0.00000	12.00000	1.20000	1.20000	10.00000	-2.00000	12.00000	0.0	1.20000	11.000
Q1	37	0.00000	0.00000	12.00000	1.20000	1.20000	10.00000	-2.00000	12.00000	0.0	1.20000	11.000
Q1	38	0.00000	0.00000	12.00000	1.20000	1.20000	10.00000	-2.00000	12.00000	0.0	1.20000	11.000
Q1	39	0.00000	0.00000	12.00000	1.20000	1.20000	10.00000	-2.00000	12.00000	0.0	1.20000	11.000
Q1	40	0.00000	0.00000	12.00000	1.20000	1.20000	10.00000	-2.00000	12.00000	0.0	1.20000	11.000

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Table 3

PARAMETERS  
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UNIT: E

DEFINITION: <FINT> = INTEGRAL OF FINT ALONG HSP SUPRIMEDDS DIVIDED BY TOTAL DIFFERENTIAL LENGTH  
CHROMATIC TERMS (SEE M.WIEDMANN DEST 16/71-18)

<K<BETA>> -0.64974010 <K<BETA1>> 0.14211001

ELECTRON STORAGE RING PARAMETERS

CIRCUMFERENCE (M) 274.83504  
REVOLUTION/FREQUENCY (MC) 1160.97271  
RF-FREQUENCY (MC) 356.87236  
HARMONIC NUMBER 280  
HORIZONTAL COMP (TOTAL) 0.0411549  
HAT.EMITTANCE(HORIZ)(MM<sup>2</sup>) 0.0487244E11RBYIGEV) ==2  
ENERGYSREAD (PERCENT) 0.0237534E11RBYIGEV)  
TRANSITION ENERGY 4.42035

RADIATION AND OTHER INTEGRALS (SEE R.H.HELM ET AL., SLAC-PUB-1193 AND M.WIEDMANN REP-142E 37-4)

<K<R>> P 0.411850-03  
<K<R<sup>2</sup>> R 0.0  
<K<R<sup>3</sup>> R 0.289500-02  
<K<R<sup>4</sup>> R 0.496000-04  
<K<R<sup>5</sup>> R 0.163470-01  
<K<R<sup>6</sup>> R 0.686000-02  
<K<R<sup>7</sup>> R 0.0

MOMENTUM (GEV/C)	1.890	1.900	1.9250	1.950	1.9750	2.000	2.250	2.500	2.750
ENERGYLOSS/TURN (MEV)	0.088	0.097	0.017	0.035	0.065	0.110	0.177	0.278	0.395
RF-PHASE (DEGREE)	12.670	0.351	9.651	10.816	11.826	12.809	13.798	14.677	15.487
RF-VOLTAGE (KVOLT)	0.488	0.848	0.181	0.186	0.314	0.495	0.742	1.065	1.479
SYNCHRO.FREQUENCY (KCI)	25.182	11.896	19.444	19.157	22.948	26.749	31.041	34.207	39.492
QUANTUMLIFETIME (HOURS)	51.325	52.134	51.710	52.803	53.472	52.377	51.807	52.185	51.172
SYNCH-DAMP-TIME (NSEC)	16.751	131.091	67.904	31.509	21.102	16.137	9.729	7.238	5.438
BET-DAMP-TIME-HOR (NSEC)	33.503	226.187	115.808	67.018	42.204	28.273	19.857	14.476	10.676
BET-DAMP-TIME-VER (NSEC)	33.503	226.187	115.808	67.018	42.204	28.273	19.857	14.476	10.676
HAT.EMITTANCE (MM<sup>2</sup>)	0.174	0.049	0.076	0.110	0.149	0.195	0.247	0.305	0.368
EMULLENGTH (CM)	3.550	3.934	3.686	3.683	3.579	3.471	3.303	3.340	3.275
ENERGYSREAD (PERCENT)	0.045	0.024	0.030	0.034	0.042	0.048	0.054	0.060	0.064

RING ACCEPTANCE IN (MM<sup>2</sup>) EPSYK<sup>2</sup>IMAX < 1000.00 LIMITED IN MAGNET SIZE AT J = 1 HALF APERTURE 1000.00 MM  
EPSYK<sup>2</sup>IMAX < 1000.00 LIMITED IN MAGNET SIZE AT J = 1 HALF APERTURE 1000.00 MM  
CPU-TIME SO FAR < 1000.00 MSEC

4-84

4777A17

such problems. Therefore it seems to be reasonable to keep the one horizontal sextupole family and to split the vertical sextupole circuit into two families.

Under ideal conditions one can compensate the undesired kick of a sextupole on an on-momentum particle with large betatron amplitudes with another sextupole of the same strength. The beta functions at the sextupoles are supposed to be equal and the betatron phase between the sextupoles has to be  $\Delta\psi = 180^\circ$ . Fortunately in the present magnet arrangement of SPEAR one can easily find two vertical sextupole groups, which almost satisfy these conditions, as sketched in Fig. 4. Because of the periodicity in the arcs, corresponding beta functions are equal and the phase advances of  $\psi_1 = 166.7^\circ$  and  $\psi_2 = 169.1^\circ$ , respectively, are very close to the ideal value.

With these three sextupole families (SF, SD SD1) a much better solution was found. The sextupole strength and other important parameters are given in the following table:

SPEAR: 3 ON-MOMENTUM ORBITES (170 A, 1984)  
WITH MULTIPOLE-STRUCTURE IN ONE HALF-SUPERPERIOD \*\*\*\*

	J	MULTIPOLE	DET(X1)	DET(Y1)	PHI(X)	PHI(Y)	ETAX(M)	SMY(M)*21
LIST OF CELL STRUCTURE								
1. MULTIPOLE AT J =	10	SF	9.270	5.610	0.565	0.561	5.960	+0.33324
2. MULTIPOLE AT J =	12	SD	1.982	15.347	0.615	0.592	1.422	+0.52799
3. MULTIPOLE AT J =	14	SD	1.639	18.043	0.444	0.600	1.177	+0.52799
4. MULTIPOLE AT J =	16	SF	11.373	6.293	0.716	0.643	2.226	+0.61521
5. MULTIPOLE AT J =	20	SD1	8.065	20.664	0.650	0.615	1.467	+0.95003
6. MULTIPOLE AT J =	23	SD1	4.927	20.359	0.785	0.623	1.495	+0.95003
7. MULTIPOLE AT J =	25	SF	11.629	7.317	0.957	0.662	2.325	+0.81125
8. MULTIPOLE AT J =	27	SD	4.471	16.619	1.070	1.051	1.600	+0.52799
9. MULTIPOLE AT J =	32	SD	4.517	16.465	1.121	1.063	1.625	+0.52799
10. MULTIPOLE AT J =	34	SF	13.567	6.357	1.173	1.110	2.653	+0.81521
11. MULTIPOLE AT J =	36	SD1	5.073	22.554	1.167	1.107	1.708	+0.95003
TOTAL NUMBER OF MULTIPOLES IN STORAGE RING:							44	3.754 4.116/4

As drawn in Figs. 5 and 6, the resulting variation of tune and vertical beta function  $\beta_y^*$  is significantly smaller than in the case of only two sextupole families over the whole range of  $\Delta p/p = \pm 1\%$ .

SPEAR: 3 CM MINIBETA OPTICS (FEB. 6, 1984)

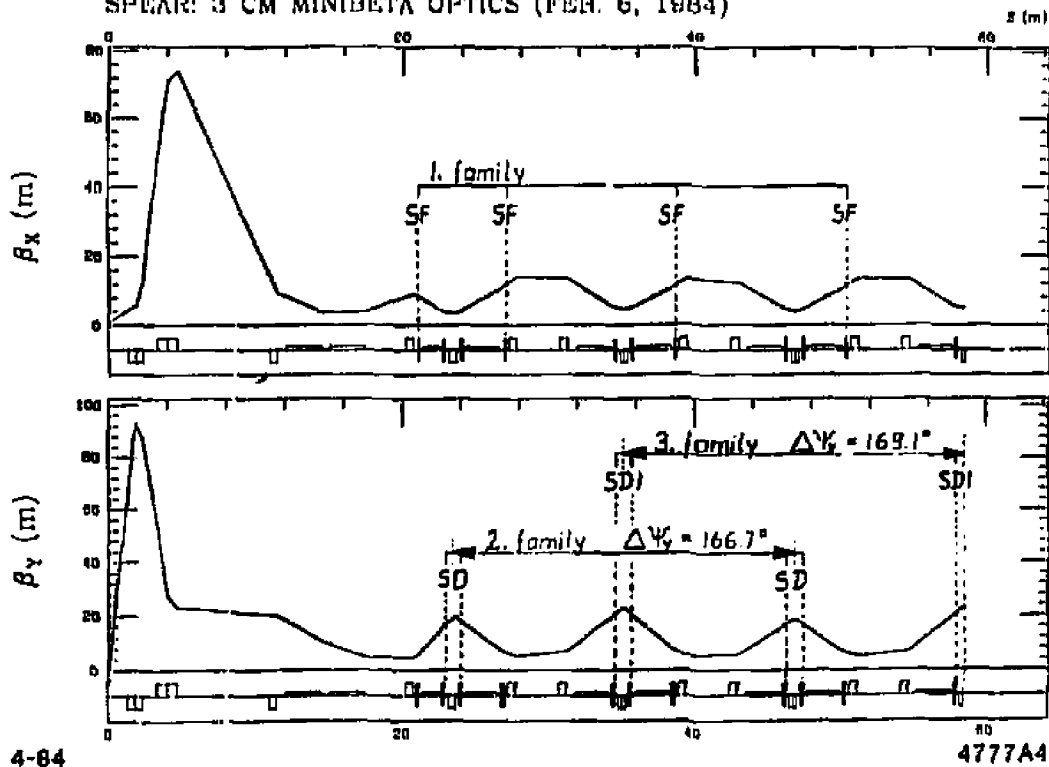
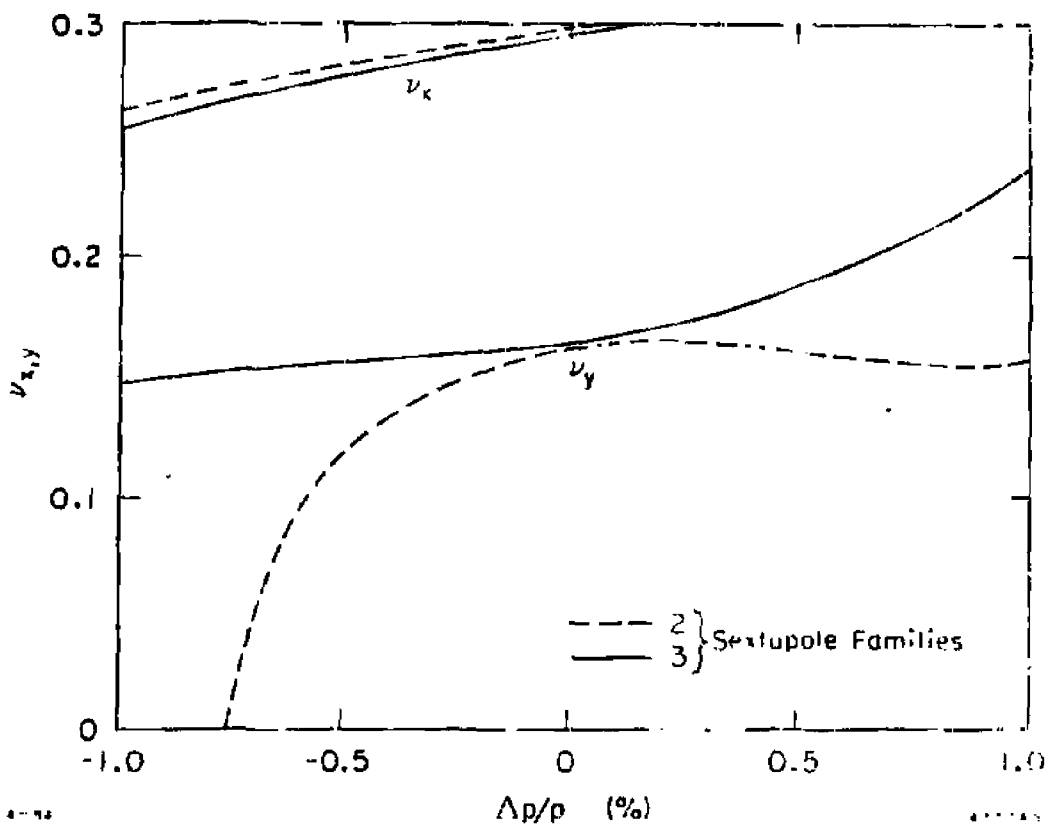


Figure 4. Three-family sextupole arrangement for mini beta optics.



**Figure 5. Tune versus momentum of the 3 cm mini beta optics with compensated chromaticity.**

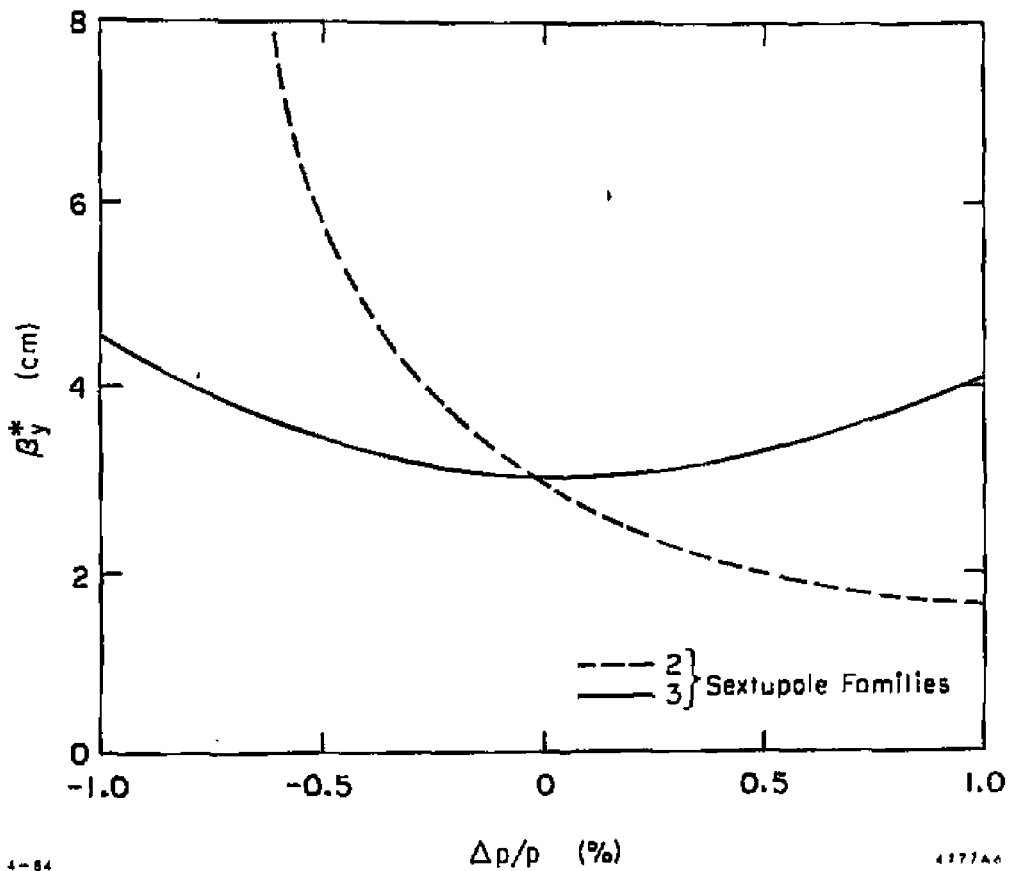


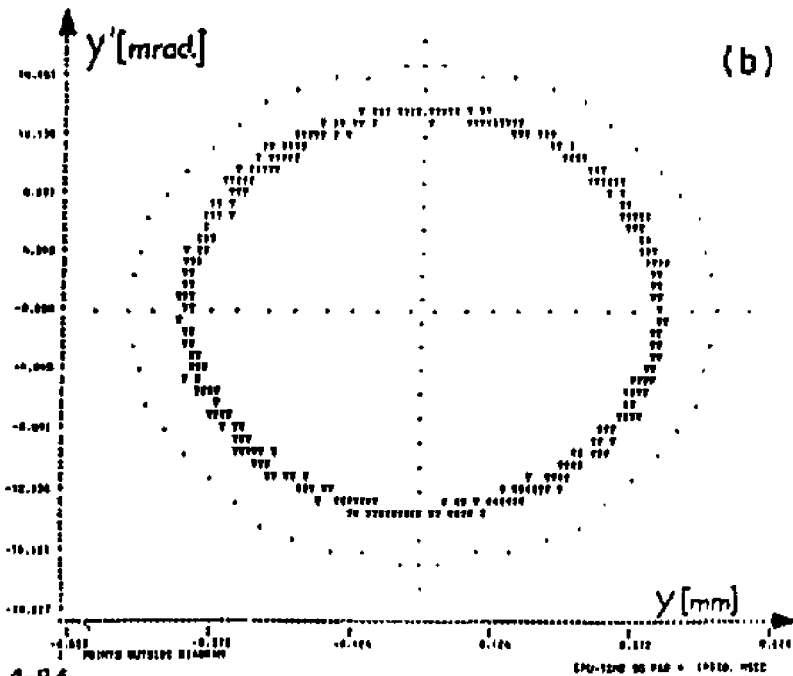
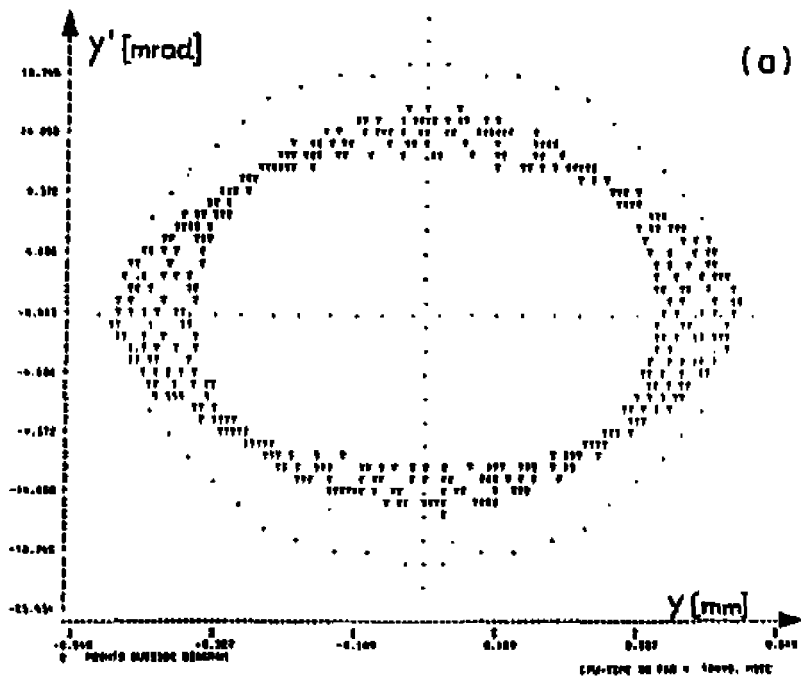
Figure 6. Vertical beta function in the interaction point versus momentum.

It is important to mention that this result has been achieved without any additional sextupole. The plot of tracked particles over 500 revolutions (Fig. 7) also shows a more stable vertical phase ellipse for the three family solution rather than for the two families. The tracking has been performed for particles with eight transverse standard deviations in both planes and six standard energy deviations including synchrotron oscillations.

### 5. Mini Beta Quadrupole and Compensation of the Detector Field

The mini beta concept requires a distance as small as possible between the interaction point and the first vertically focusing quadrupole. On the other hand, one has to consider the limitations given by the particle detector. For the SPEAR mini beta insertion a distance of 1.34 m between first quad and interaction point is chosen which seems to be the best compromise between detector and machine requirements. The magnetic length of this first vertically focusing quadrupole, the "mini beta quadrupole," is set to 1 m, which gives a quadrupole strength of  $k = 0.92 \text{ m}^{-2}$ . In order to achieve this high value, the magnet aperture should be as small as possible.

On the other hand a sufficient aperture for the beam is necessary; it should be at least  $12 \sigma$  under all conditions. The maximum energy of SPEAR is approximately  $E = 4 \text{ GeV}$ . At this energy the horizontal emittance is  $\epsilon_x = 7.80 \times 10^{-7} \text{ mrad}$  and the emittance coupling is assumed to be  $k_c = \epsilon_y/\epsilon_x = 0.2$ . The optics calculation deliver the maximum beta function in the mini beta quadrupole as  $\beta_{x\text{max}} = 13.2 \text{ m}$  and  $\beta_{y\text{max}} = 96.0 \text{ m}$  respectively. Thus the minimum required apertures in this vertically focusing magnet are:



4-84  
4777A7

Figure 7. Tracking of particles over five hundred revolutions with  
(a) two and (b) three sextupole families.

$$A_x = 12 \sqrt{\epsilon_x \beta_{zmax}} = 38.5 \text{ mm}$$

$$A_y = 12 \sqrt{k_1 \epsilon_z \beta_{ymax}} = 46.4 \text{ mm} \quad (k_1 = 0.2)$$

Therefore it seems to be reasonable to choose a pole radius of  $R = 50 \text{ mm}$  (or  $R = 3.937 \text{ in}$ ). With these values, the maximum poletip field becomes  $B_{pole} = 0.614 \text{ T}$  which is rather moderate and possible with a conventional iron magnet.

Since this magnet has to be built into the MARK III detector there are also restrictions concerning the outer dimensions. Here the limit is given by the maximum tolerable flux density in the iron yoke which is supposed not to exceed  $B = 1.5 \text{ T}$  in order to avoid saturation effects.

The final magnet design<sup>5</sup> has been done by use of the computer code "POISSON,"<sup>6</sup> which also was used to find the best pole contour with the lowest possible higher multipole fields. The iron yoke of the mini beta quadrupole is shown in Fig. 8. The magnet coils consist of conventional copper conductor with the following data (one quadrupole coil):

Number of turns :	$n = 7$
Current :	$I = 1748.2 \text{ A (at 4 GeV)}$
Current density :	$dI/dF = 12.4 \text{ A/mm}^2$
Resistance :	$R_c = 2.16 \text{ m}\Omega$
Power consumption :	$N = 8.60 \text{ kW}$

The field lines of one octant are displayed in Fig. 9. The relative field error with respect to an ideal linear quadrupole ( $B_{lin} = g x$ ) is shown in Fig. 10. These values are derived from POISSON calculations.

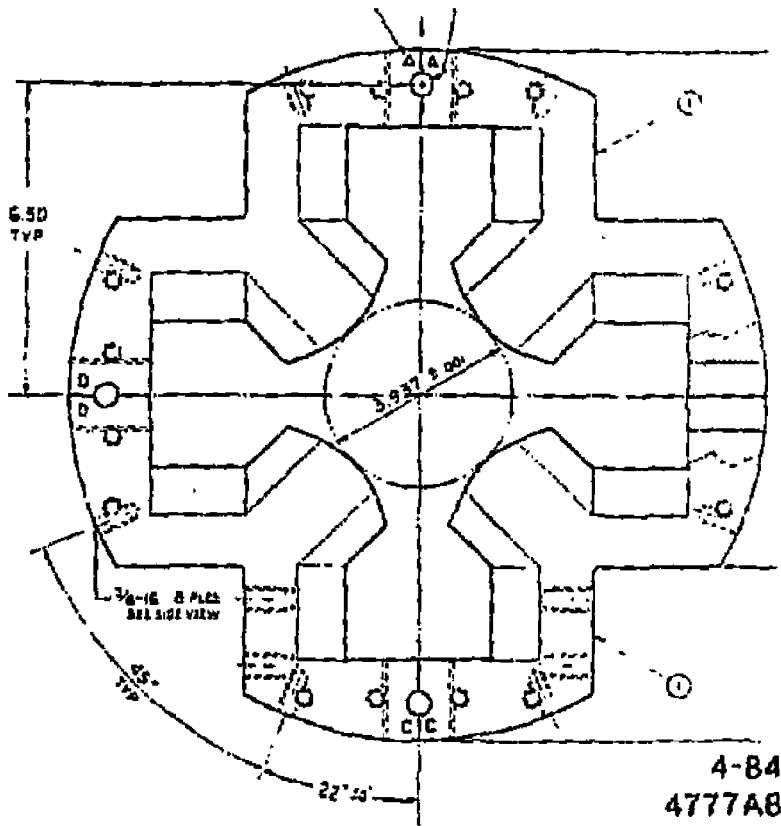


Figure 8. Iron yoke of the SPEAR mini beta quadrupole MBQ3.

QUAD FOR SPEAR MINI-BETA

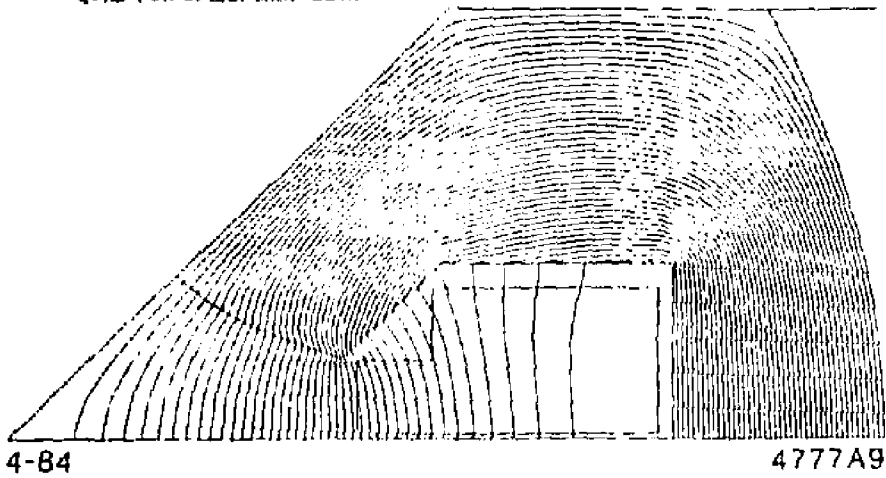


Figure 0. Field lines of one octant of the mini beta quadrupole.

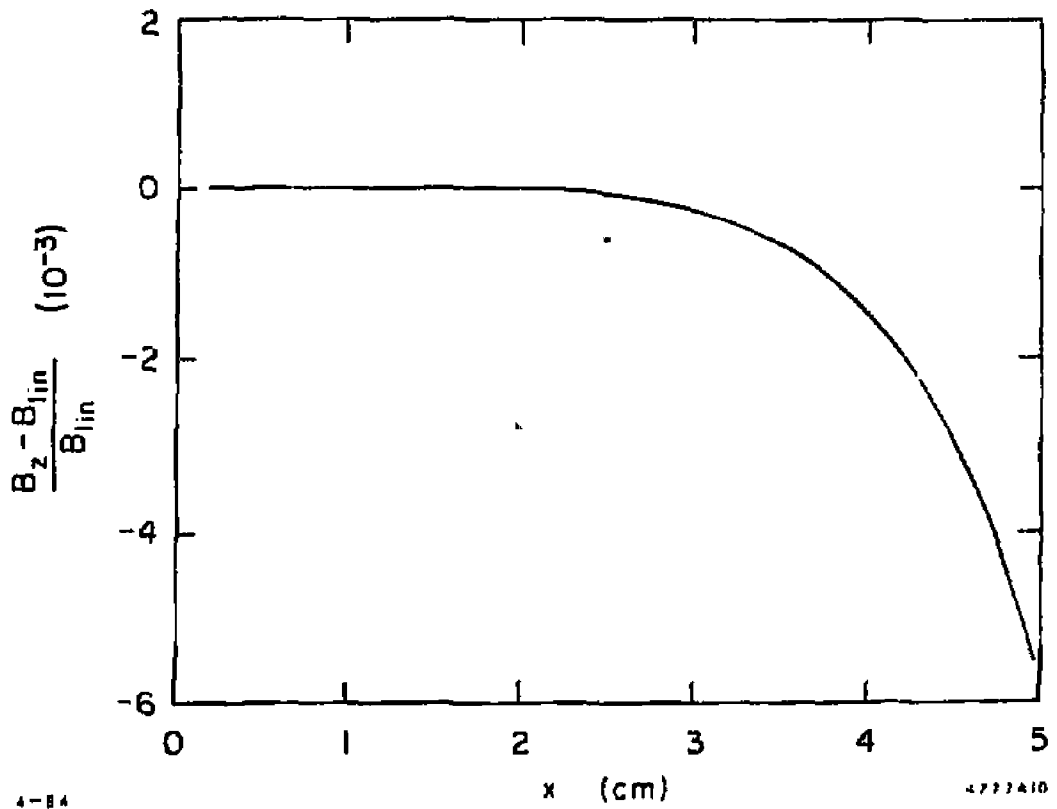


Figure 10. Relative field error of the mini beta quadrupole.

The proportions of higher multipole fields for the chosen pole contour are (four pole = 100%):

12 pole : 0.94%

20 pole : 0.24%

28 pole : 0.11%

36 pole : 0.04%

A particular problem is due to the longitudinal magnetic field of the MARK III detector with a strength of  $B_0 = 0.4$  T. Since nearly half of the mini beta quadrupole reaches into the detector, one has to surround this part by a special magnet coil which produces a longitudinal field of the same flux density, but with opposite direction, as the main detector field. An additional shielding is provided by a 19 mm thick mirror plate mounted at the front face of the quadrupole inside the detector. The entire arrangement of the mini beta quadrupole with mirror plate and surrounding "bucking" coil is sketched in Fig. 11.

The bucking coil is a conventional design with water cooled copper conductors. In order to avoid unnecessary interference with parts of the detector, the outer diameter of the coil is made as small as possible. The following list shows the most important coil data:

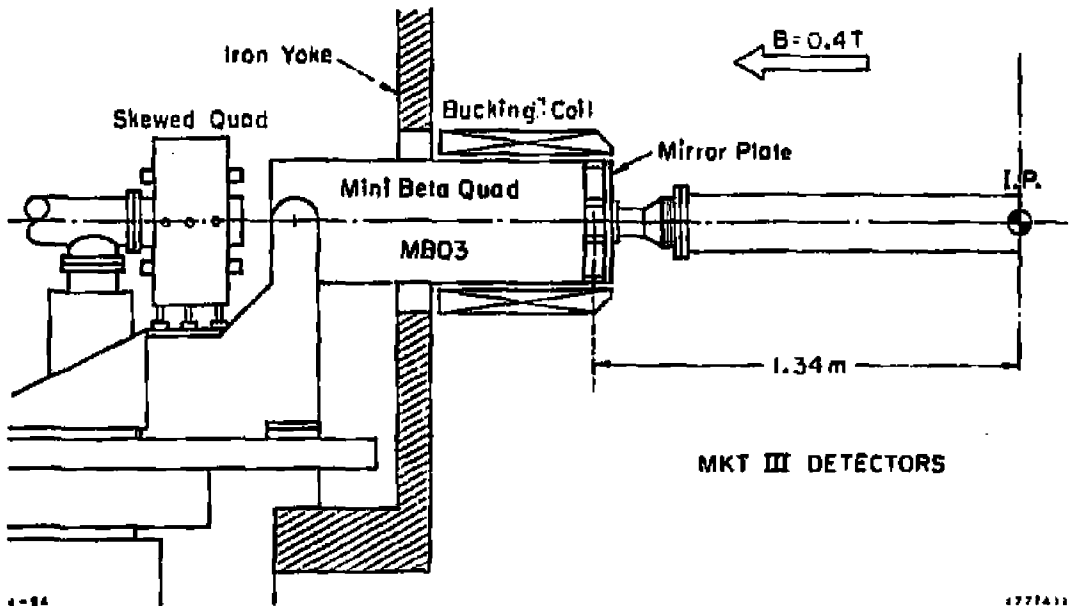
Number of turns :  $n = 101$

Current :  $I = 1782.2$  A

Current density :  $dI/dF = 12.5$  A/mm<sup>2</sup>

Resistance :  $R_{Bc} = 17.88$  m $\Omega$

Power consumption :  $N = 56.8$  kW



**Figure 11. Mini beta quadrupole mounted in the region of the MARK III detector with a longitudinal magnetic field.**

That such a compensating scheme really works has been demonstrated with the mini beta quadrupoles of DORIS II mounted in the ARGUS detector.<sup>7</sup> Because of the weaker detector field the suggested design for SPEAR is in fact even more conservative than that which worked in DORIS II. The bucking coil described in Fig. 11 is only used to keep the quadrupole iron as free as possible from the detector field, but there is still the influence of the detector field on the beam which increases the emittance coupling considerably. Unfortunately there is no space available inside the detector to install another compensating coil for this purpose. Therefore, one has to compensate the emittance coupling outside the detector by use of rotated quadrupoles.<sup>8</sup>

## 6. Optics for Dedicated Synchrotron Radiation Runs

Half of the running time of SPEAR is used as dedicated time for synchrotron radiation experiments with only one beam stored. Therefore it is necessary to demonstrate the compatibility of the new mini beta insertions with the synchrotron radiation requirements. In order to achieve a high brightness of the synchrotron light beam, the emittance has to be as small as possible. As mentioned above, the optics in the arcs is unchanged compared to the present situation and consequently the emittance is not changed either.

Another important parameter is the beam lifetime, which is supposed to be at least twenty hours. The lifetime is essentially determined by the vacuum pressure and the dynamic aperture. Since the vacuum conditions will be the same as before, the dynamic aperture is the main item to play with. As observed in SPEAR as well as in other storage rings, the lifetime can be improved by reducing the chromaticity and consequently the sextupole strength. This effect is well understood and demonstrated in various tracking calculations. The reason

is that the nonlinear magnetic fields, produced by strong sextupole magnets may reduce the dynamic aperture significantly.

Because of the beam waists in the interaction points, and the resulting large beta functions in the first quadrupoles, the main portion of the chromaticity is produced in this region. Therefore an increase of the beta functions in the interaction regions, especially in the vertical plane, will easily reduce the chromaticity. For instance, a value of  $\beta_y^* = 5$  cm will cause a vertical chromaticity of  $\xi_y = -18.7$  instead of  $\xi_x = -26.5$  for the 3 cm optics.

Unfortunately there are matching problems, if  $\beta_y^* > 6$  cm which leads to unreasonable amplitude functions in the arcs or even a lack of periodic solutions. But for the new mini beta lattice of SPEAR one can find another stable region in the  $\beta_{x,y}^*$ -diagram (Fig. 12) which gives proper matching conditions. In this region values of  $\beta_x^* = 20$  m and  $\beta_y^* = 35$  m have been chosen to calculate a particular "synchrotron radiation optics" with low chromaticity. The beta and dispersion functions of this optics are plotted in Fig. 13. As in the 3 cm mini beta optics, the quadrupole strengths in the arcs (QF and QD) are not changed. One horizontal matching quadrupole (QF1) which also acts on the dispersion is reduced by 25% compared to the luminosity optics. This results in a nonzero dispersion in the interaction point ( $\eta_x^* = 1.6$  m). A dispersion in this region is tolerable, since this optics will never be used for colliding beam runs.

The high beta synchrotron radiation optics has no waists in the interaction points and consequently the betatron phase advance in this region is very small compared to  $\Delta\psi \approx 180^\circ$  of the luminosity optics. Therefore the integer number of the tune is reduced by one in both planes. The quadrupole strengths and some important optics data of the synchrotron radiation optics, as well as the 3 cm luminosity optics are listed below:

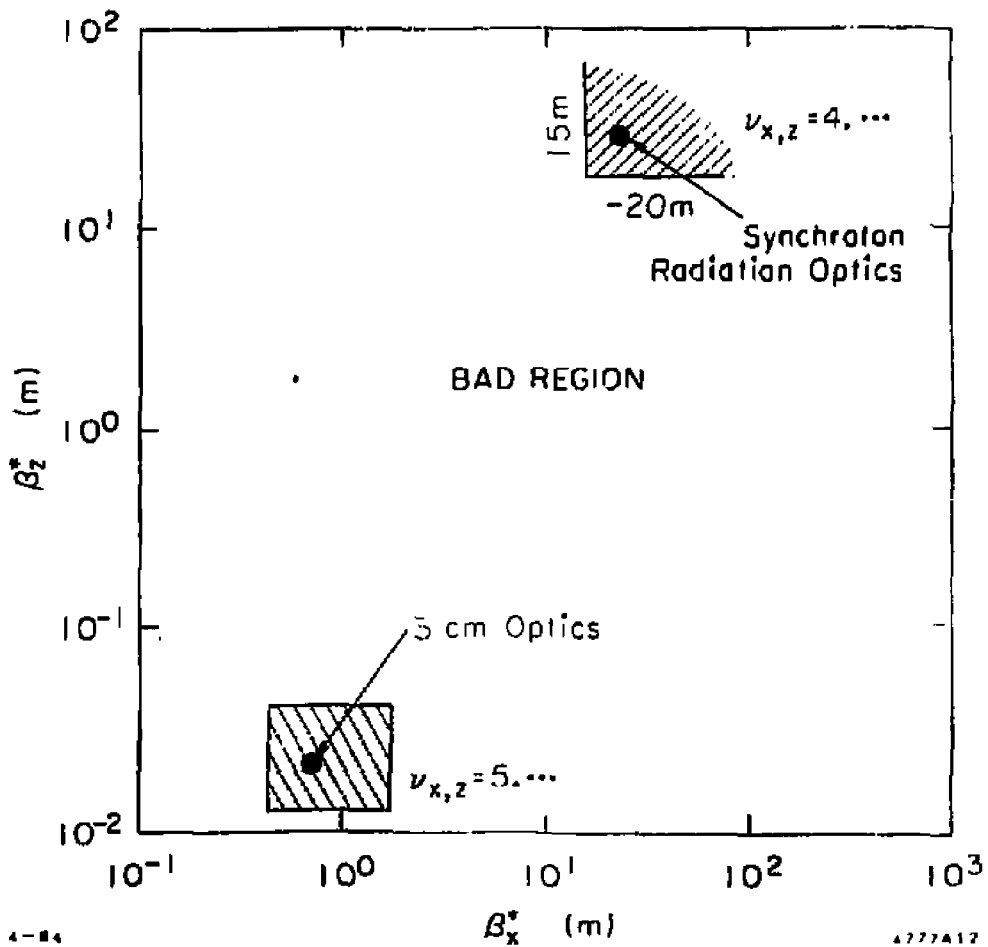
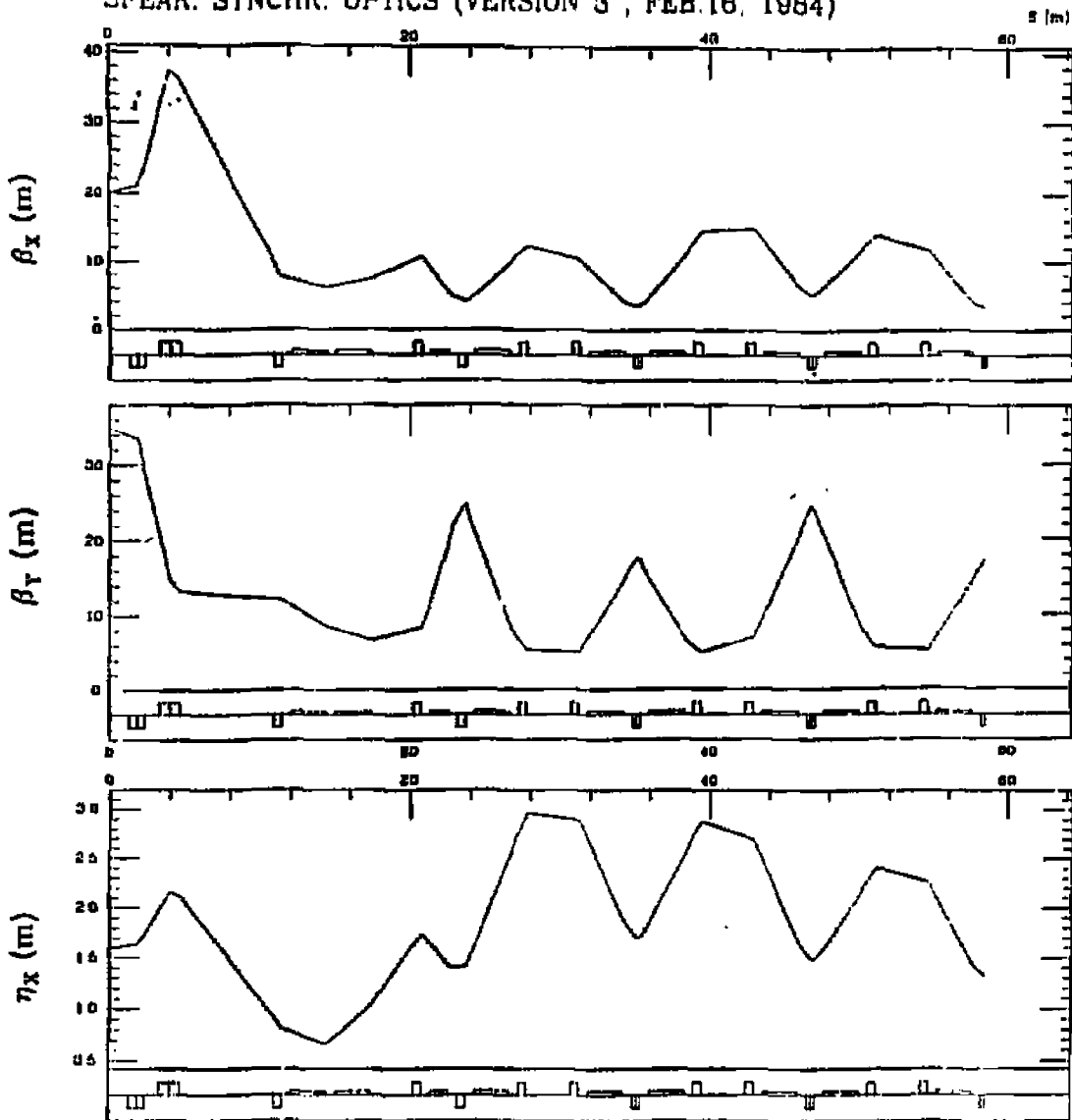


Figure 12.  $\beta_{x,y}^*$ -diagram with regions of proper matching conditions.

SPEAR: SYNCHR. OPTICS (VERSION 3 , FEB.16, 1984)



4-84

4777A13

Figure 13. Amplitude and dispersion functions of the synchrotron radiation optics.

Quads	Quadrupole strength: $k$ [ $m^{-2}$ ]	
	Mini Beta Optics	Synchrotron Radiation Optics
MBQ3	0.92048	0.17097
Q2	-0.37121	-0.17123
Q1	0.17661	0.15011
QF1	-0.06053	-0.49149
QD1	0.65148	0.58090
QF2	-0.30886	-0.31745
QD	0.48853	0.48853
QF	-0.27800	-0.27800

Parameters	Synchrotron Radiation Optics	Luminosity Optics
Tune: $\nu_x$	4.270	5.206
$\nu_y$	4.165	5.103
Chromaticity: $\xi_x$	-4.65	-12.10
$\xi_y$	-6.31	-26.49
Sextupole families:	2	3
Sextupole strength: [ $m^{-2}$ ]	SF=-0.35281	SF=-0.83321
	SD=0.25687	SD=0.50299
		SD1=0.95000

This high beta optics has the expected low chromaticity values and therefore a sufficient compensation is possible with only two sextupole families and very

low sextupole strengths. The variation of the tune with momentum is also very small and extremely linear over the whole range of  $\Delta p/p = \pm 1\%$ . Therefore this optics should have no aperture restrictions due to sextupole fields.

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