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SMR/1270-3

SCHOOL ON SYNCHROTRON RADIATION

6 November - 8 December 2000

Miramare - Trieste, Italy

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Storage Ring Design with Beam Optics Program

Chitrlada Settakorn
Stanford University
CA - USA

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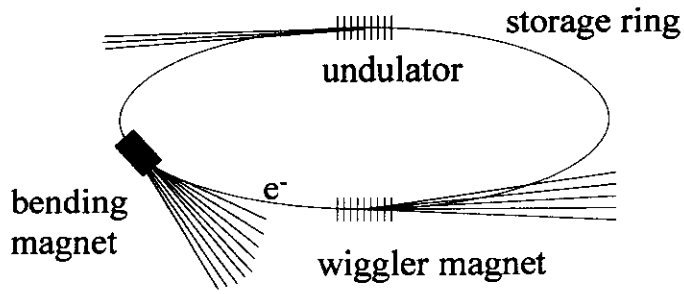
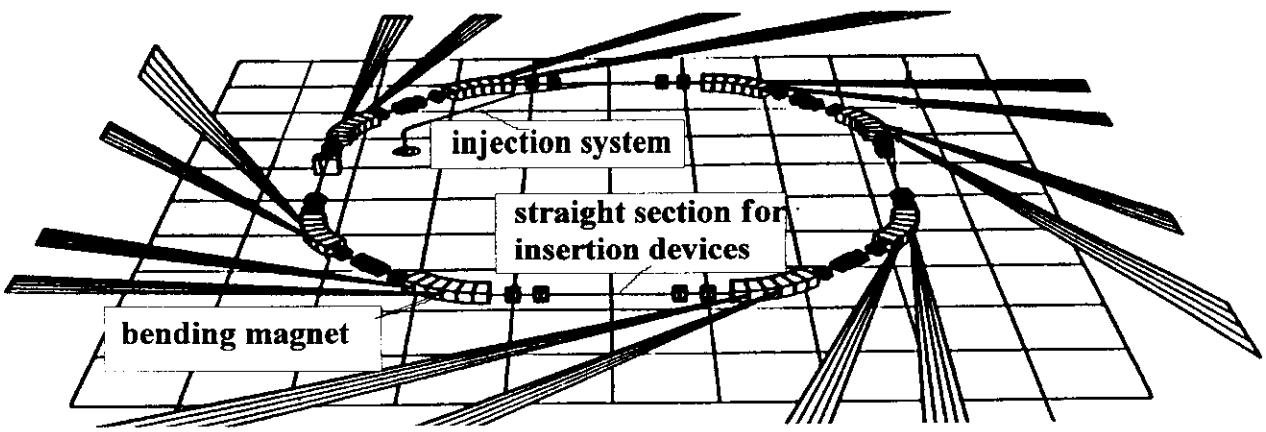
November 13- 16, 2000

ICTP, Trieste, Italy

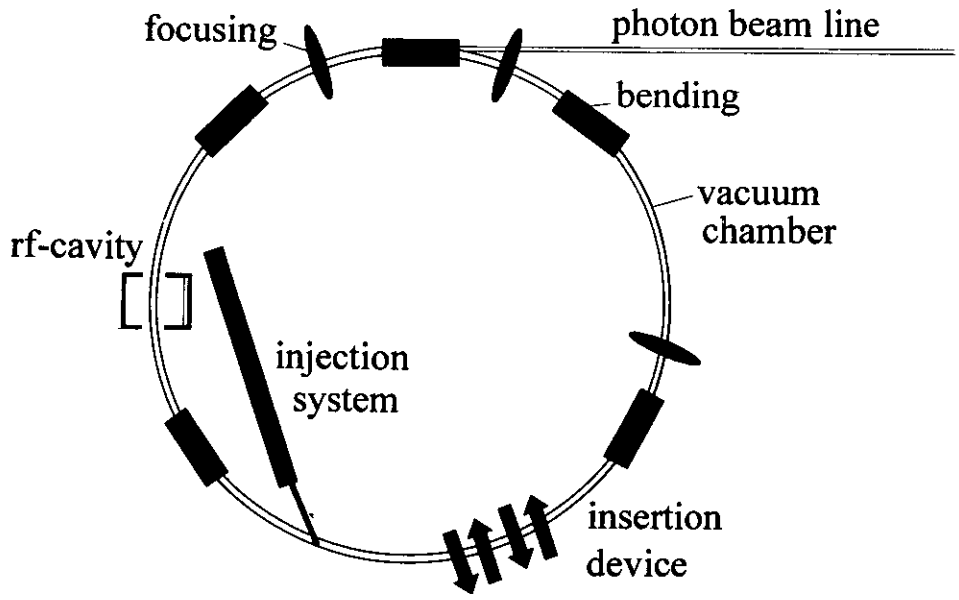
Storage Ring and Synchrotron Radiation

Highly relativistic electrons are stored in a circular path. To keep the electron circulate in the ring, dipole magnets are used to guide the electron to a circular trajectory. Transverse acceleration from the magnetic forces causes the electron to radiate. Insertion devices (undulators, wiggler magnets, and wavelength shifters) are often added to the straight section to generate radiation which specific characteristics.





Storage Ring components



Injection system: provides electrons to the storage source

Bending magnets: keep electron beams on a closed path and be synchrotron radiation source

Quadrupole magnets: focus electron beam

RF-cavity: compensate energy loss to synchrotron radiation

Vacuum chamber: eliminating scattering on gas atom, to be able to store electrons for long period of time.

Bending magnet

A bending magnet of B Tesla and length l (m) deflects a charged particle beam with a bending angle φ given by

$$\varphi = \frac{l}{\rho} = \frac{eB}{cp} \quad \text{or in practical unit} \quad \varphi = 0.3\frac{B(\mathrm{T})l(\mathrm{m})}{E(\mathrm{GeV})},$$

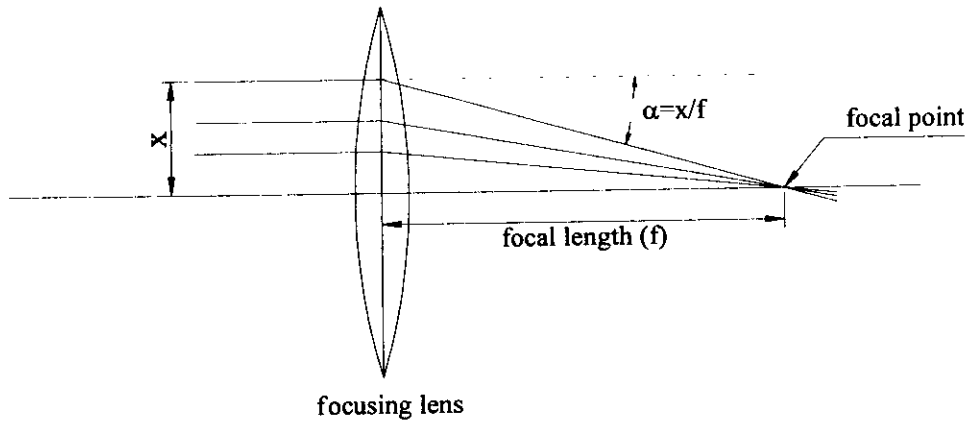
where E is the particle energy.

Example:

For a bending magnet of 1 Tesla, 1 m long and a particle energy of 3 GeV, the deflecting angle is 0.1 rad.

Bending magnets are distributed along the beam path. With appropriate deflection angles, the beam therefore travels in a close orbit(total deflection angle of 360 degree, 2π).

Beam focusing from quadrupole magnets



Quadrupole magnets act in particle beam optics like lenses in light optics.

Deflection angle to the focal point $\alpha = x/f = klx$, where k is the quadrupole strength given by

$$k(m^{-2}) = 0.3\frac{g(T/m)}{cp(GeV)}$$

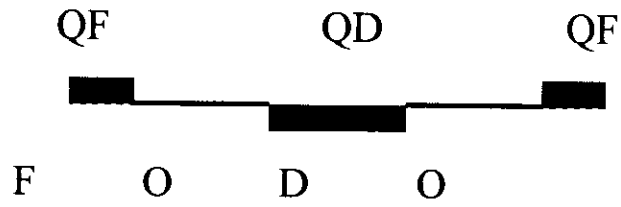
The focal length of the quadrupole is $1/f = kl$ where l is the length of the quadrupole

Magnet Lattice or Lattice

The arrangement of magnets (bending, quadrupole,sextrupole magnets) along the beam path is called magnet lattice or lattice. Most of storage ring consists of a repetitive sequence is called *periodic magnet lattice.*

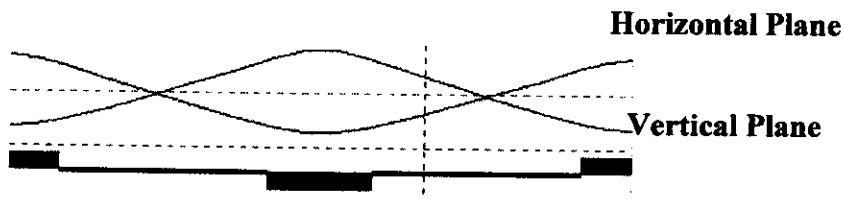
FODO lattice

Equidistant sequence of focusing and defocusing quadrupole

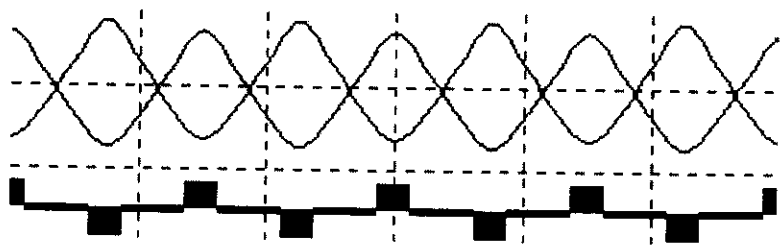


A quadrupole is called focusing if it focus the particle beam in the horizontal plane. The opposite is true for the vertical plane.

A focusing quadrupole in the horizontal plane is defocusing in the vertical plane and vice versa.

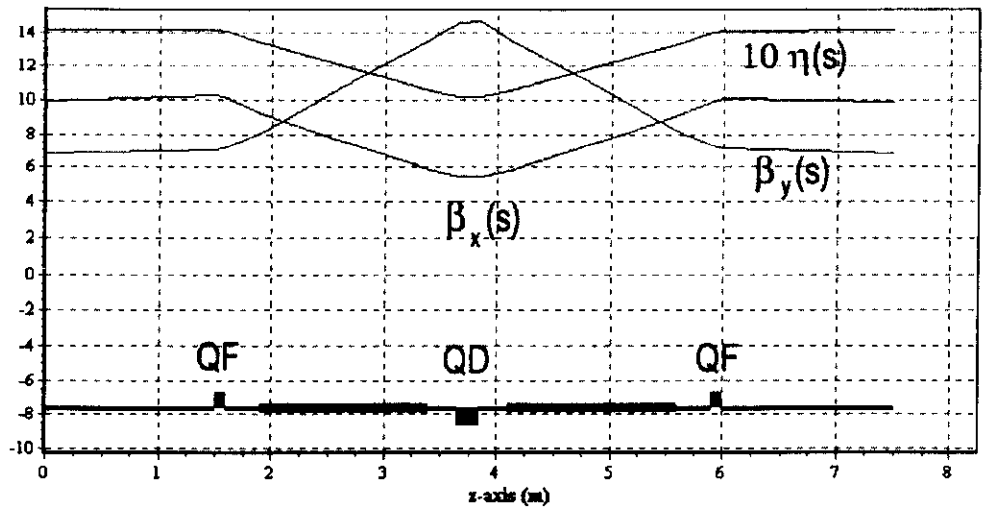


Sequence of FODO cells:



- Periodic cells can be used to construct arbitrary long transport lines.
- To make a ring, insert bending magnets between quadrupoles.

Example of FODO lattice modified to provide magnet free straight sections:



Beam Emittance:

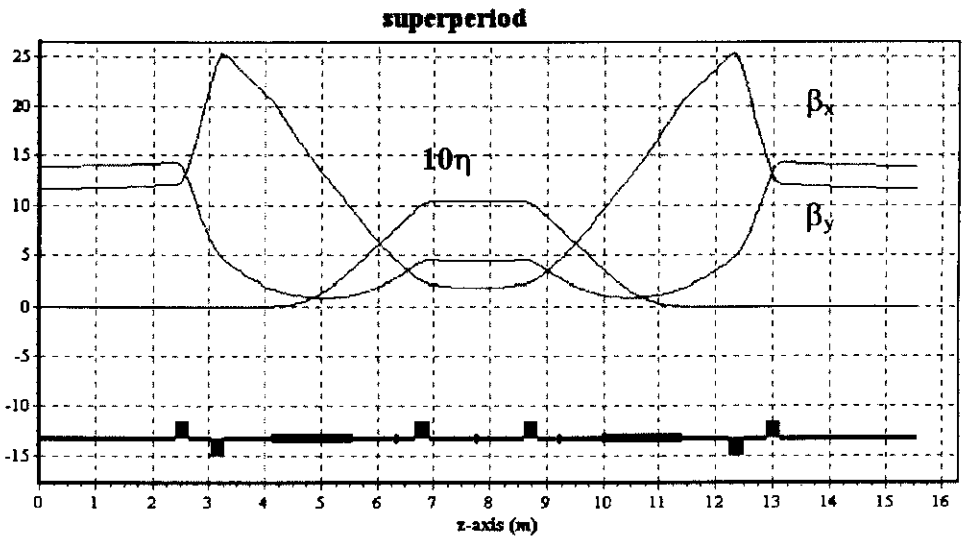
$$\varepsilon_{FODO} \approx 100x\ 10^{-13}\ E^2\ \varphi^3$$

E: beam energy(GEV)

φ: deflection angle per bending magnet(degree)

Double Bend Achromat (DBA) lattice

DBA lattice provides dispersion free straight section.



DBA lattice of LNLS, Campinas, Brazil

Beam Emittance :

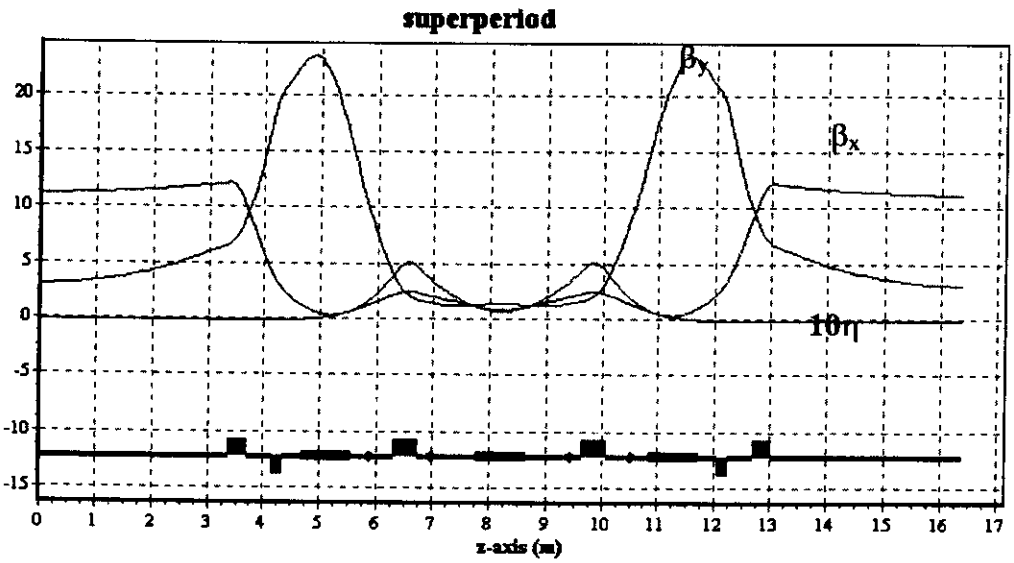
$$\varepsilon_{DBA} \approx 5x\ 10^{-13}\ E^{2}\ \varphi^{3}$$

E: beam energy(GEV)

φ: deflection angle per bending magnet(degree)

Triple Bend Achromat (TBA) lattice

TBA lattice can be used to reduce the ring circumference. Used usually for smaller, low energy rings.



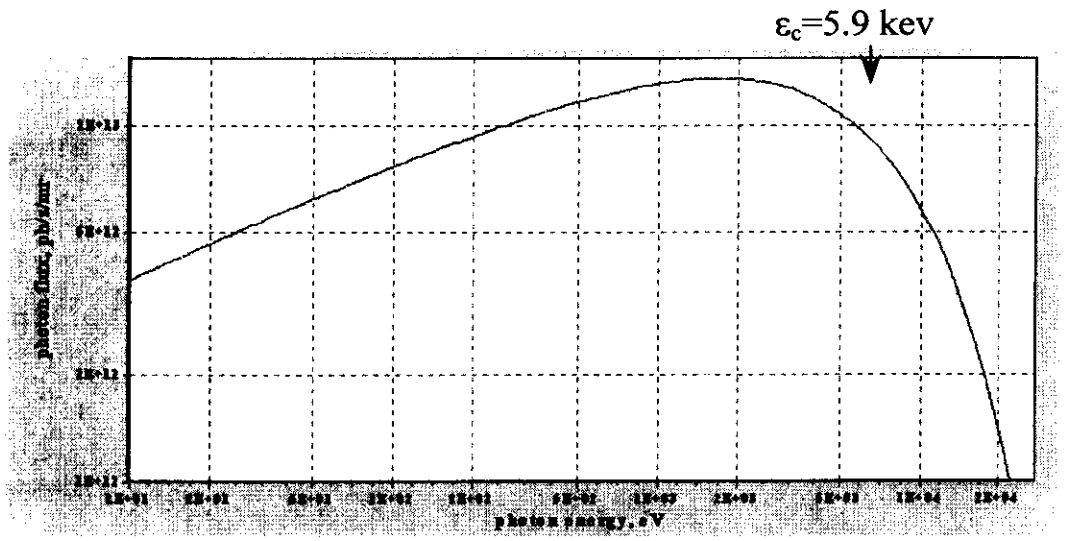
TBA lattice of ALS, California, USA

Beam Energy and Critical Photon energy

The synchrotron radiation spectrum from bending magnets is determined by the particle energy and the magnetic field strength. The useful spectrum extends from low photon energy up to a few times of the critical energy.

Critical photon energy of synchrotron radiation from bending magnet,

$$\varepsilon_c\,(\text{keV}) = 0.665E^2(\text{GeV}^2)B(\text{T}).$$



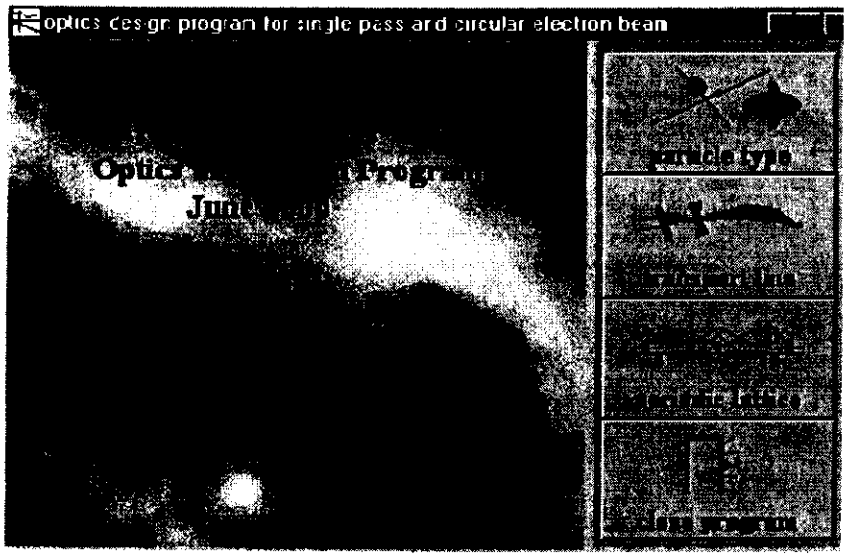
Synchrotron radiation from a 1 Tesla bending magnet and a 3 GeV beam.

The desired maximum photon energy and the bending field strength determine the required particle energy.

Storage Ring Design using Particle Beam 2000

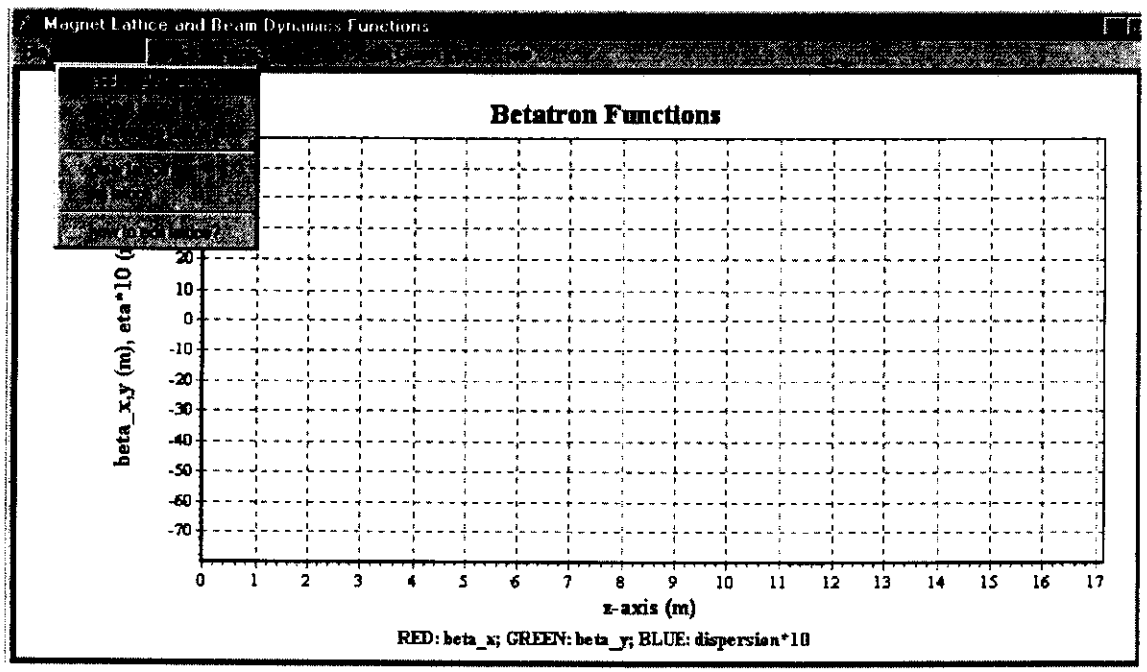
Optics and Design Program

(The program is available to download at http://coherent.stanford.edu/He-Web/PC-programs.html)

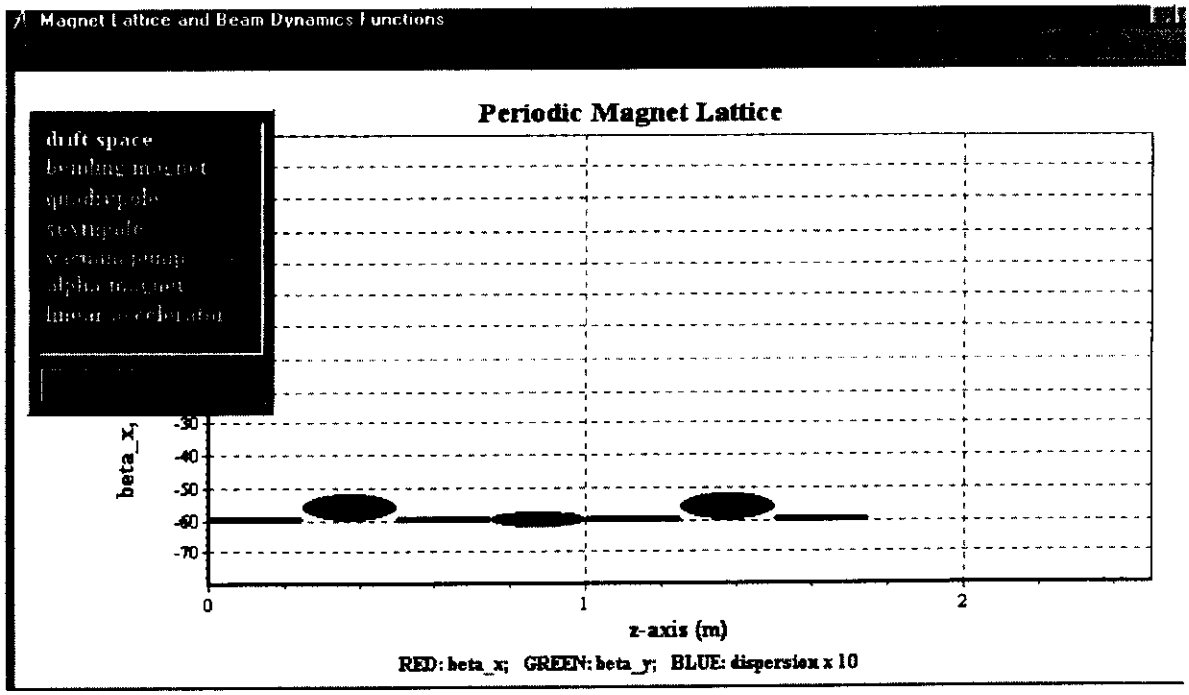


for periodic lattice design

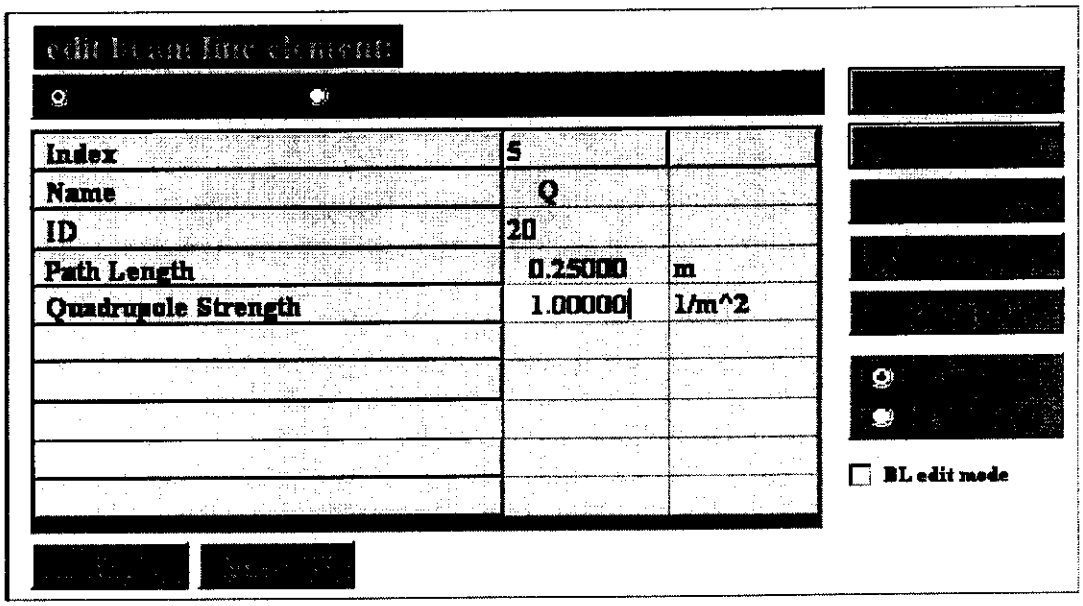
- Start by creating a new lattice.



- Add elements to compose a lattice. Once completed, click done.

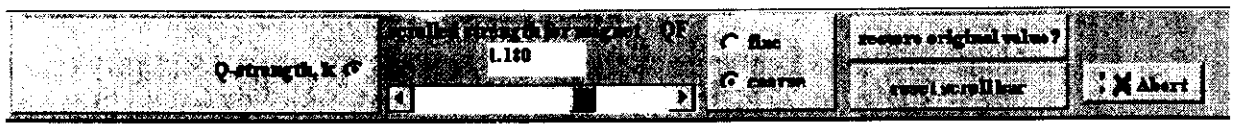


- Edit properties of each element e.g. length, quadrupole strength, curvature of dipole magnets, etc.

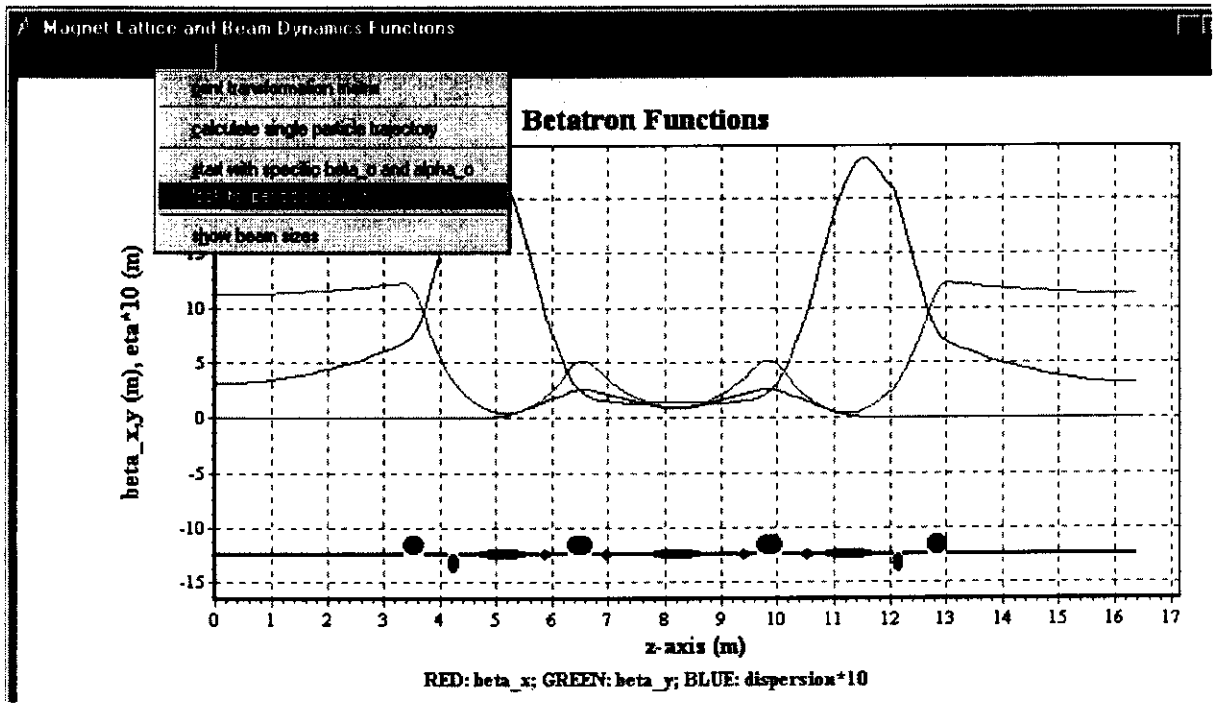


- Select the Beam Line Edit Mode (BL edit mode), for editing several elements at once.

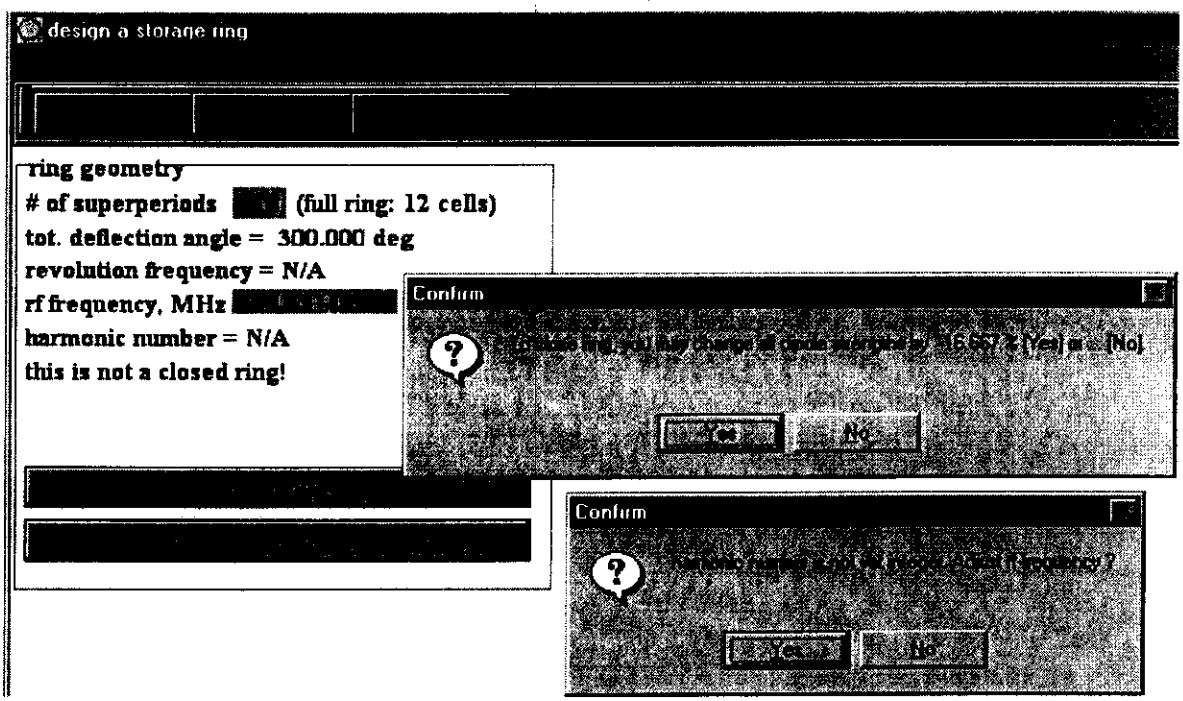
- A special feature for the quadrupole magnet editing is **scroll quad**, in which the quadrupole strength can be adjusted using a scroll bar. This scroll quad will become handy for optimizing the lattice and the quadrupole doublet design exercise.



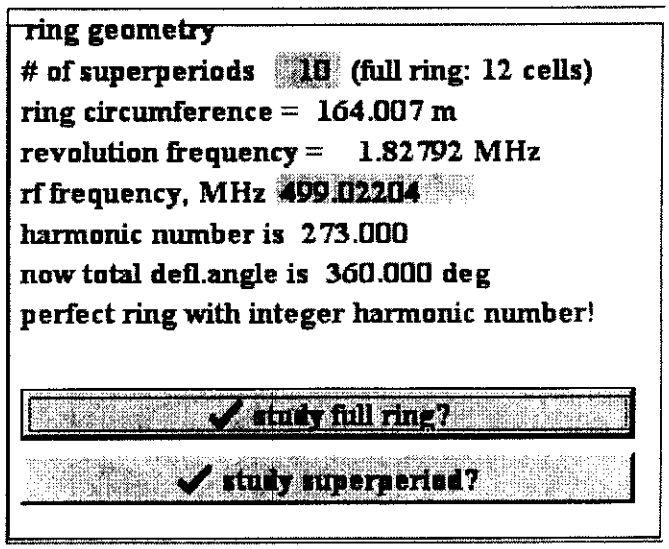
- To obtain a periodic solution for the lattice, select **look for periodic solution** under the **optics** menu.
- If exist, the periodic solution of β_x (red), β_y (blue) and dispersion(η) function (green) will be displayed.



- Select **ring design** to compose a ring from the periodic lattice.



- To get a completed circular path, it is required a total bending angle of 360 degree. The RF frequency should be an integer multiple of the revolution frequency for the beam to gain energy from the RF-cavity. (this integer multiple is called harmonic number)



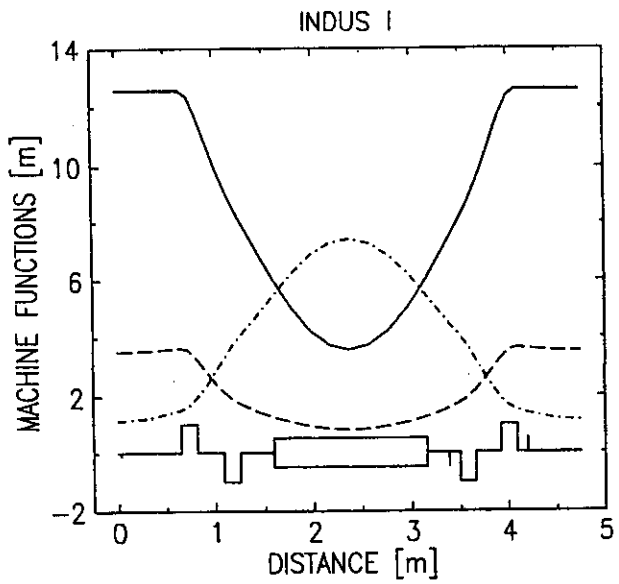
- Selecting **beam parameters** under the **beam optics** menu will show the ring parameters. **Resonance diagram** can also be viewed under this menu.
- Parameter lists can be chosen under the **lists** menu.
- More features in the ring design are tracking, rf-cavity, vacuum system and beam lifetime.

Storage Ring Lattices

(from Synchrotron Light Source Data Book, J. Murphy)

More lattices can be found at http://www.nsls.bnl.gov/AccPhys/hlights/dbook/MAD/Mad.Menu.html .

56

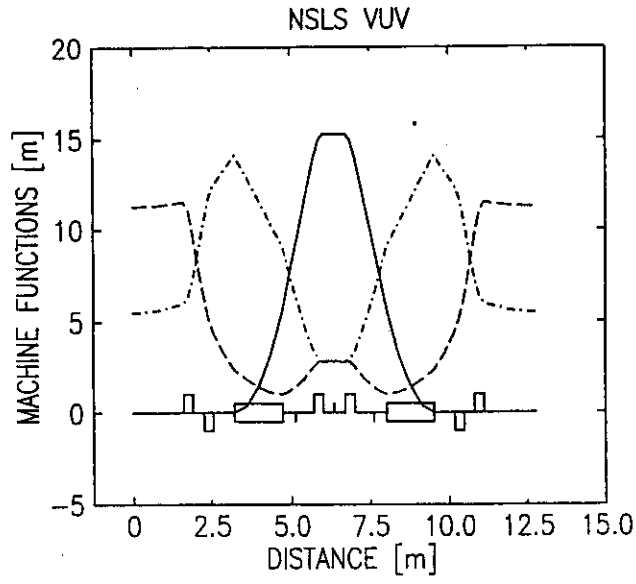


E=	.450	α=	.146E+00	——	$10\eta_x$
N_s=	4	ε=	.733E−07	- - -	β_x
				·····	β_y
ν_x=	1.880	ξ_x=	−1.32	f_{rf}=	31.6
ν_y=	1.220	ξ_y=	−2.96	V_{rf}=	25.0

57

```
TITLE,"INDUS-1"
!DATA COURTSEY OF G.K. SAHOO AT CAT, 2/96
D1:DRIFT,L=0.6524
D2:DRIFT,L=0.264
D3:DRIFT,L=0.337
D4:DRIFT,L=0.227
D5:DRIFT,L=0.11
D6:DRIFT,L=0.5424
Q1:QUADRUPOLE,L=0.166,K1=4.468250
Q2:QUADRUPOLE,L=0.166,K1=-2.062026
MAG:SBEND,L=1.5708,ANGLE=1.5708,K1=-0.5
S1:SEXTUPOLE,L=0,K2=0
S2:SEXTUPOLE,L=0,K2=0
RING:LINE=(D1,Q1,D2,Q2,D3,MAG,D4,S2,D5,Q2,D2,Q1,&
D5,S1,D6 )
USE,RING,SUPER=4
PRINT,#S/E
TWISS
STOP
```

84

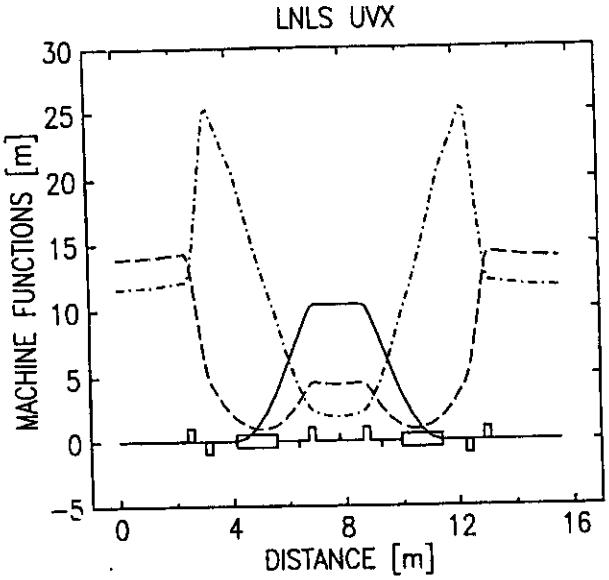


E=	.800	α=	.235E−01	——	$10\eta_x$
N_s=	4	ε=	.155E−06	- - -	β_x
				·····	β_y
ν_x=	3.140	ξ_x=	−3.59	f_{rf}=	52.9
ν_y=	1.260	ξ_y=	−4.87	V_{rf}=	80.0

85

```
TITLE, "NSLS VUV RING"
!   DATA COURTESY OF S. KRAMER 2/96
Q1   :QUADRUPOLE,L=.3,K1=1.844759
Q2   :QUADRUPOLE,L=.3,K1=-1.176509
Q3   :QUADRUPOLE,L=.3,K1=1.8797615
BD   :SBEND,L=1.5,K1=-.026784185,ANGLE=TWOPI/8.,&
E1=PI/8.,E2=PI/8.
SF   :SEXTUPOLE,L=0.,K2=0.
SD   :SEXTUPOLE,L=0.,K2=0.
D1   :DRIFT,L=1.628
D2   :DRIFT,L=.35
D3   :DRIFT,L=.65
D4   :DRIFT,L=.41
D5   :DRIFT,L=.59
HSUP  :LINE=(D1,Q1,D2,Q2,D3,BD,D4,SD,D5,Q3,D2,SF)
USE,HSUP,SYMM,SUPER=4
PRINT,#S/E
TWISS
STOP
```

94



E= 1.150 α= .831E−02 —— $10\eta_x$ --- β ..... β^x_y

N_s= 6 ϵ= .672E−07

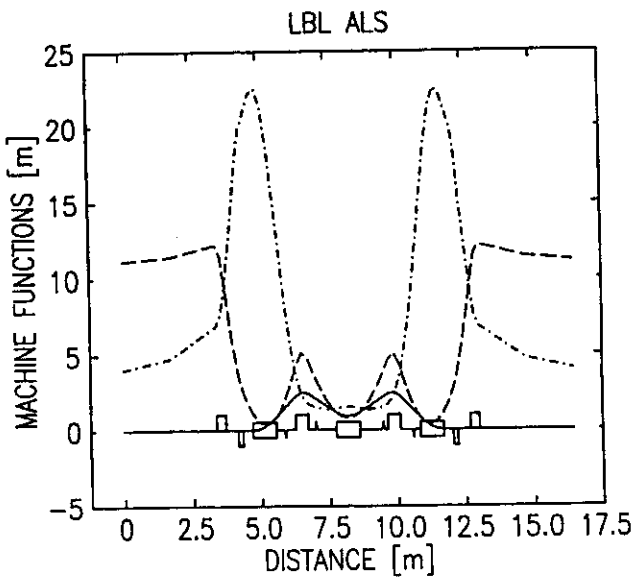
ν_x= 5.270 ξ_x= −13.99 f_{rf}= 476.0

ν_y= 2.170 ξ_y= 19.91 V_{rf}= 500.0

95

```
TITLE, "LNLS UVX - MODO NORMAL"
!DATA COURTESY OF L. LIU, 3/96
D1:DRIFT,L=2.39867
D2:DRIFT,L=.39
D3:DRIFT,L=.84
D4:DRIFT,L=.715
D5:DRIFT,L=.31
D6:DRIFT,L=.782
BD:SBEND,L=1.432,ANGLE=PI/6.0,K1=0.0,E1=PI/12.0,&
E2=PI/12.0,TILT=0.0,K2=0.0,H1=0.0,H2=0.0,&
HGAP=0.0,FINT=.5
QF:QUADRUPOLE,L=.25,K1=2.7265
QD:QUADRUPOLE,L=.25,K1=-2.497497
QFC:QUADRUPOLE,L=.25,K1=2.1132645
SF:SEXTUPOLE,L=.05,K2=0.
SD:SEXTUPOLE,L=.1,K2=0.
HSUP:LINE=(D1,QF,D2,QD,D3,BD,D4,SD,D5,QFC,D6,SF)
USE,HSUP,SYMM,SUPER=6
PRINT,#S/E
TWISS
STOP
```

98



E= 1.500 α= .160E−02 —— $10\eta_x$ --- β ..... β^x_y

N_s= 12 ϵ= .337E−08

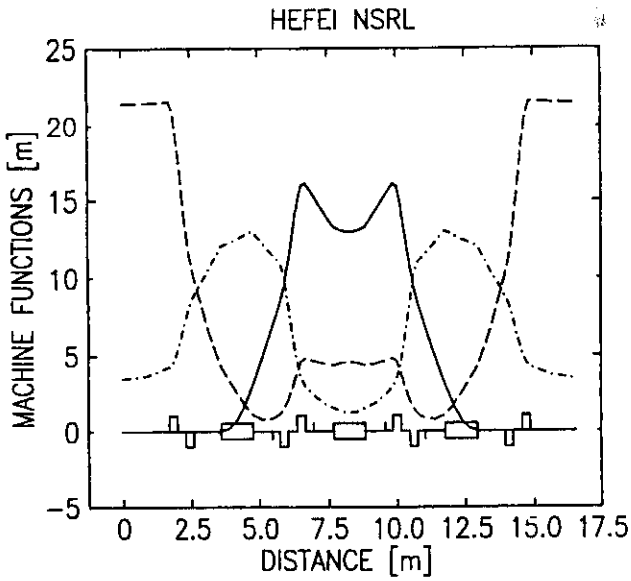
ν_x= 14.281 ξ_x= −24.58 f_{rf}= 499.7

ν_y= 8.199 ξ_y= −27.69 V_{rf}= 1000.0

99

```
TITLE, ALS
!DATA COURTESY OF D. ROBIN, 2/96
L1:DRIFT,L=3.3786950
L2:DRIFT,L=0.4345000
L3:DRIFT,L=0.3486980
LSDA:DRIFT,L=0.2156993
LSDB:DRIFT,L=0.3245
LSFA:DRIFT,L=0.1245
LSFB:DRIFT,L=0.6906981
SF:SEXTUPOLE,L=.203,K2=0
SD:SEXTUPOLE,L=.203,K2=0
QF:QUADRUPOLE,L=0.1720,K1=2.23695543
QD:QUADRUPOLE,L=0.0935,K1=-2.2542799
QF1:QUADRUPOLE,L=0.2240,K1=2.8883478
BTHETA:=PI*10.0/180
BEDGE:=PI*3.0/180
BK:=-0.8100
BU:SBEND,L=0.43257,ANGLE=BTHETA/2,E1=BEDGE,K1=BK
BD:SBEND,L=0.43257,ANGLE=BTHETA/2,E2=BEDGE,K1=BK
SDD:LINE=(LSDA,SD,LSDB)
SFF:LINE=(LSFA,SF,LSFB)
SPRU:LINE=(L1,QF,QF,L2,QD,QD,L3,BU,BD,SDD,QF1,
QF1,SFF,BU)
SPRD:LINE=(BD,SFF,QF1,QF1,SDD,BU,BD,L3,QD,QD,L2,QF,
QF,L1)
SPR:LINE=(SPRU,SPRD)
RING:LINE=(12*SPR)
USE,RING
PRINT
TWISS
STOP
```

80



E= .800 α= .480E−01 —— $10\eta_x$ --- β_x ..... β_y

N_s= 4 ϵ= .137E−06

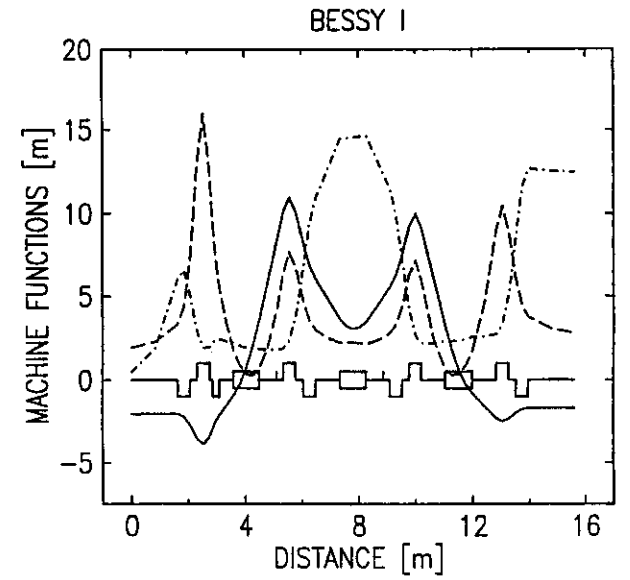
ν_x= 3.580 ξ_x= −6.21 f_{rf}= 204.0

ν_y= 2.580 ξ_y= −6.19 V_{rf}= 80.0

81

```
TITLE, "NSRL NSRLS"
!DATA COURTESY OF N. LIU AT NSRL, 3/96
Q1   : QUADRUPOLE, L=.3,  K1=1.569180
Q2   : QUADRUPOLE, L=.3,  K1=-0.955667
Q3   : QUADRUPOLE, L=.3,  K1=-2.267100
Q4   : QUADRUPOLE, L=.3,  K1=3.070800
Q5   : QUADRUPOLE, L=.3,  K1=3.070800
Q6   : QUADRUPOLE, L=.3,  K1=-2.267100
Q7   : QUADRUPOLE, L=.3,  K1=-0.955667
Q8   : QUADRUPOLE, L=.3,  K1=1.569180
B    : SBEND,L=1.1635,ANGLE=TWOPI/12.,&
E1=PI/12.,E2=PI/12.
SF   : SEXTUPOLE, L=0., K2=1.46
SD   : SEXTUPOLE, L=0., K2=1.5
DL   : DRIFT, L=1.6811
DQ   : DRIFT, L= .32
DBQ  : DRIFT, L=1.
DSB  : DRIFT, L= .72
DQS  : DRIFT, L= .28
HSUP : LINE= (DL,Q1,DQ,Q2,DBQ,B,DSB,SD,DQS,&
Q3,DQ,Q4,DQS,SF,DSB,B,DSB,SF,DQS,Q5,DQ,Q6,&
DQS,SD,DSB,B,DBQ,Q7,DQ,Q8,DL)
RING:LINE(HSUP,-HSUP,HSUP,-HSUP)
USE,RING
PRINT,#S/E
TWISS
STOP
```

76



E= .800 α= .166E−01 —— $10\eta_x$ --- β_x ..... β_y

N_s= −2 ϵ= .558E−07

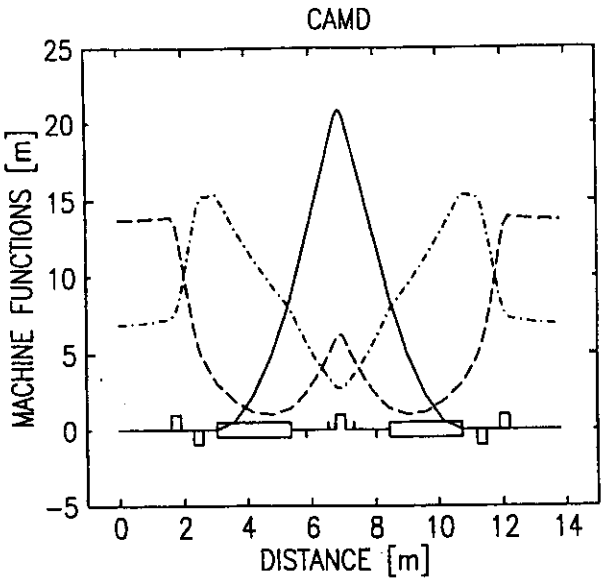
ν_x= 5.553 ξ_x= −13.47 f_{rf}= 499.7

ν_y= 3.254 ξ_y= −8.53 V_{rf}= 200.0

77

```
TITLE, "BESSY-I WAVELENGTH SHIFTER OPTICS"
!DATA COURTESY OF G. WUSTEFELD, 3/96
BEAM, PARTICLE=ELECTRON, ENERGY=0.8, RADIATE
RHO   = 1.783809
AN    = 15*PI/180
D1 :DRIFT, L= 1.634
D2 :DRIFT, L= 0.250
D3 :DRIFT, L= 0.835
D4 :DRIFT, L= 0.475
D5 :DRIFT, L= 0.110
D6 :DRIFT, L= 1.634
D7 :DRIFT, L= 0.600
D8 :DRIFT, L= 0.235
Q1 :QUAD, L= 0.44, K1=-1.888
Q2 :QUAD, L= 0.44, K1= 3.033
Q3 :QUAD, L= 0.44, K1= 3.260
Q4 :QUAD, L= 0.44, K1=-1.525
Q1T :QUAD, L= 0.44, K1=-3.363
Q2T :QUAD, L= 0.44, K1= 4.562
Q3T :QUAD, L= 0.25, K1=-2.874
S1 :MULTI, K2L= 0
S2 :MULTI, K2L= 0
HB :SBEND, L= 2*AN*RHO, ANGLE= 2*AN,E1=AN,E2=AN
RF :RFCAV, L= 0.0, VOLT=-0.2, HARMON=104
DUB :LINE= (D3,Q2,D2,Q1,D1)
TRI :LINE= (D6,Q1T,D2,Q2T,D5,Q3T,D4)
AC1 :LINE= (D7,S1,D8,Q3,D2,Q4,D3)
AC2 :LINE= (D7,S2,D8,Q4,D2,Q3,D3)
ACH :LINE= (HB,AC1,HB,AC2,HB)
BE4 :LINE= (TRI,ACH,DUB)
BE2 :LINE= (BE4,-BE4)
BE1 :LINE= (BE2,BE2,RF)
USE, BE1, SUPER= 1
PRINT,#S/E
```

100



E= 1.500 α= .332E−01 —— $10\eta_x$

N_s= 4 ϵ= .342E−06 --- β_x ..... β_y

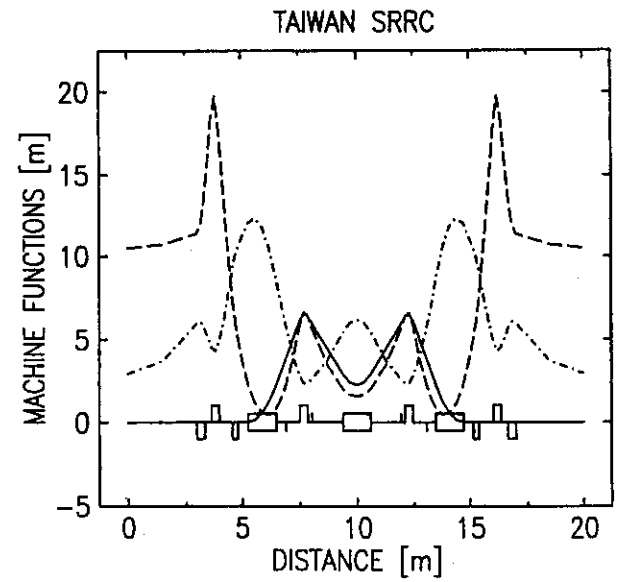
ν_x= 3.260 ξ_x= −4.54 f_{rf}= 499.7

ν_y= 1.168 ξ_y= −3.79 V_{rf}= 350.0

101

```
TITLE, "LSU CAMD"
!DATA COURTESY OF H. BLUEM & B. CRAFT, 3/96
BEAM,PARTICLE=ELECTRON,ENERGY=1.5
D1      :DRIFT, L=1.6
D1X     :DRIFT, L=1.35
D2      :DRIFT, L=0.4
D3      :DRIFT, L=0.45
D4      :DRIFT, L=0.4
D5      :DRIFT, L=0.6
D6      :DRIFT, L=0.2
QF      :QUAD,  L=0.3,  K1= +1.909478
QD      :QUAD,  L=0.3,  K1= -1.466674
QA      :QUAD,  L=0.15, K1= +2.682152
SD      :SEXT,  L=0.1,  K2=-25.31921
SF      :SEXT,  L=0.1,  K2=+17.34186
RF      :RFCAVITY,VOLT=0.35,HARMON=92,SHUNT=10,&
TFILL=10,L=0.5
BEND    :RBEND, L=2.3,ANGLE=TWOPI/8
HAFSUP :LINE=(D1,QF,D2,QD,D3,BEND,D4,SD,&
D5,SF,D6,QA)
HAFSUPX  :LINE=(D1X,QF,D2,QD,D3,BEND,D4,&
SD,D5,SF,D6,QA)
SUP     :LINE=(-HAFSUP,HAFSUP)
RING    :LINE=(-HAFSUPX,RF,HAFSUPX,3*SUP)
USE,RING
TWISS,SAVE
BMPM,SINGLE=T,SYNRAD=T
STOP
```

96



E= 1.300 α= .678E−02 —— $10\eta_x$

N_s= 6 ϵ= .194E−07 --- β_x ..... β_y

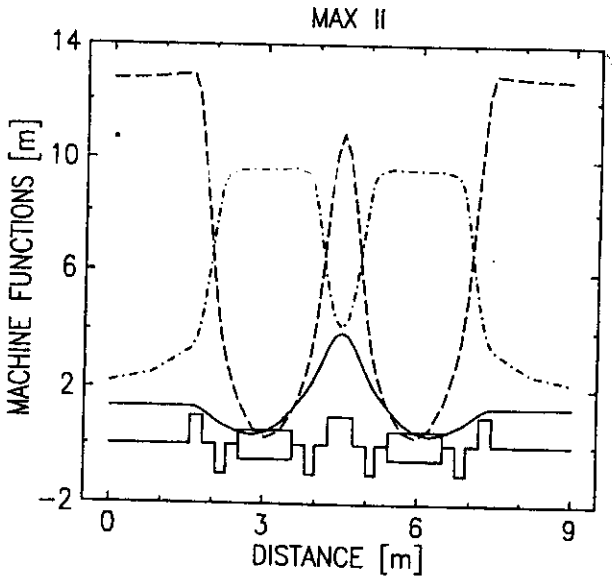
ν_x= 7.180 ξ_x= −15.67 f_{rf}= 499.7

ν_y= 4.130 ξ_y= −7.61 V_{rf}= 800.0

97

```
TITLE, "TAIWAN SRRC"
!DATA COURTESY OF C.C. KUO, 3/96
D1  :DRIFT, L=3.
D2  :DRIFT, L=0.3
D3  :DRIFT, L=0.595
D4  :DRIFT, L=0.435
D5  :DRIFT, L=0.42
D6  :DRIFT, L=0.6
D7  :DRIFT,L=0.2
D8  :DRIFT,L=1.33
Q1  :QUAD, L=0.35,K1=-1.50815
Q2  :QUAD, L=0.35,K1=2.87048
Q3  :QUAD, L=0.24,K1=-1.15592
Q4  :QUAD, L=0.35,K1=2.73087
BD :SBEND, L=1.22,ANGLE=TWOPI/18.,K1=-0.37,&
E1= PI/18.,E2=PI/18.,HGAP= 0.,FINT=0.5
SD  :SEXTUPOLE, L=0.,K2=0
SF :SEXTUPOLE, L=0.,K2=0
SECTION  :LINE=(D1,Q1,D2,Q2,D3,Q3,D4,BD,D5,SD,&
D6,Q4,D7,SF,D8,BD,&
D8,SF,D7,Q4,D6,SD,D5,BD,D4,Q3,D3,Q2,D2,Q1,D1)
RING  :LINE=(6*SECTION)
USE,RING
PRINT,#S/E
TWISS
STOP
```

102



E= 1.500 α= .405E−02 —— $10\eta_x$ ---- β_x ..... β_y

N_s= 10 ε= .873E−08

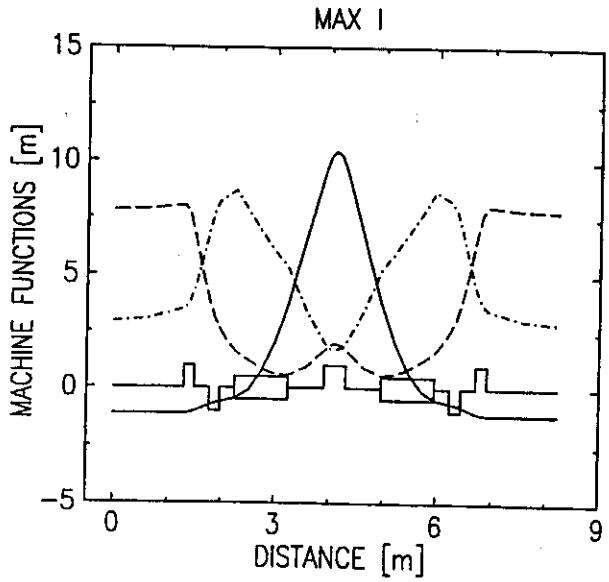
ν_x= 9.221 ξ_x= −27.49 f_{rf}= 499.8

ν_y= 3.262 ξ_y= −10.48 V_{rf}= 800.0

103

```
TITLE,"MAX II"
!DATA COURTESY OF L.J. LINDGREN, 2/96
D1:  DRIFT,L=1.5685
Q1:  QUADRUPOLE,L=0.25,K1=4.18216
D2:  DRIFT,L=0.2515
Q2:  QUADRUPOLE,L=0.2,K1=-3.97668
D3:  DRIFT,L=0.25
MAG:     SBEND,L=1.0470,ANGLE=0.31416,&
         E1=0.15708,E2=0.15708
Q4:  QUADRUPOLE,L=0.18,K1=-3.97668
Q5:  QUADRUPOLE,L=0.25000,K1=4.18216
HMAX2:  LINE=(D1,Q1,D2,Q2,D3,MAG,D2,Q4,D2,Q5)
MAX2:    LINE=(HMAX2,-HMAX2)
USE,MAX2,SUPER=10
PRINT,#S/E
TWISS
STOP
```

62



E= .550 α= .198E−01 —— $10\eta_x$ ---- β_x ..... β_y

N_s= 4 ε= .796E−07

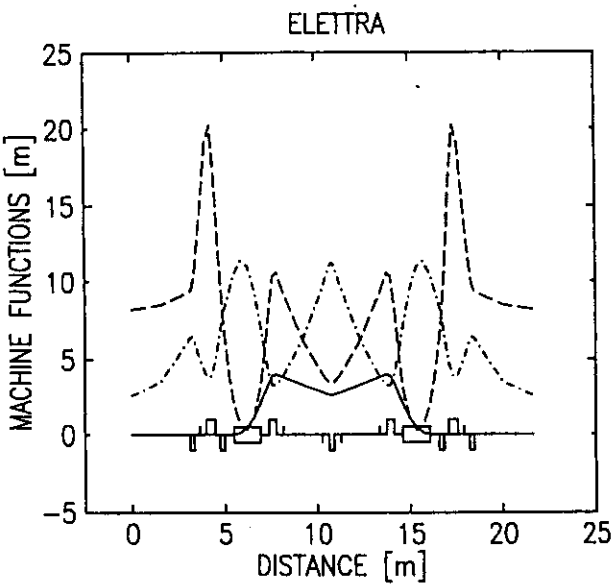
ν_x= 3.152 ξ_x= −4.07 f_{rf}= 501.8

ν_y= 1.323 ξ_y= −4.66 V_{rf}= 200.0

63

```
TITLE, "MAX I"
!DATA COURTESY OF M. ERIKSSON AT LUND, 2/96
Q1    :QUADRUPOLE, L=.2, K1=4.42
Q2    :QUADRUPOLE,L=.2,K1=-3.14
Q3    :QUADRUPOLE,L=.2,K1=4.35
BD    :SBEND,L=1.,ANGLE=TWOPI/8.,&
      E1=PI/8.,E2=PI/8.
SF    :MULTIPOLE,K2L=0.
SD    :MULTIPOLE,K2L=0.
D1    :DRIFT,L=1.3
D2    :DRIFT,L=.275
D3    :DRIFT,L=.657
HSUP   :LINE=(D1,Q1,D2,Q2,D2,BD,D3,Q3)
USE,HSUP,SYMM,SUPER=4
PRINT,#S/E
TWISS
STOP
```

108



E= 2.000 α= .161E−02 —— $10\eta_x$ --- β ..... β^x_y

N_s= 12 ϵ= .701E−08

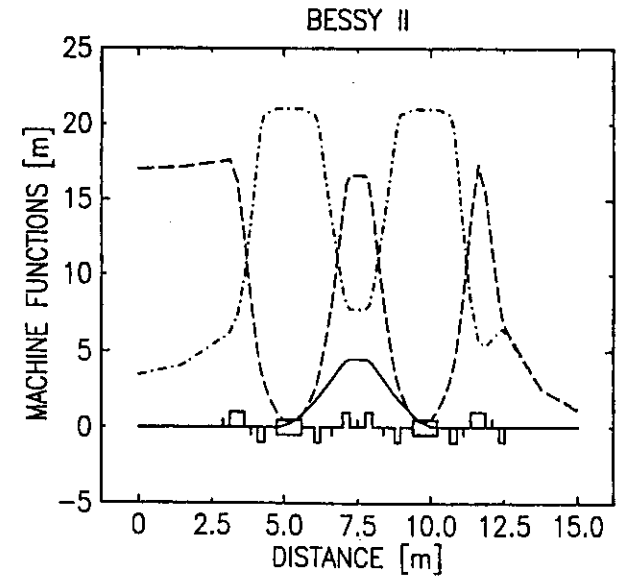
ν_x= 14.294 ξ_x= −40.92 f_{rf}= 499.7

ν_y= 8.201 ξ_y= −13.95 V_{rf}= 1800.0

109

```
TITLE, "ELETTRA 2 GEV, SINCOTRONE TRIESTE"
! DATA COURTESY OF E. KARANTZOULIS, 3/96
Q1    :QUADRUPOLE, L=.26 , K1=-1.952436
Q2    :QUADRUPOLE, L=.498, K1= 2.235991
Q3    :QUADRUPOLE, L=.26,  K1=-1.277189
Q4    :QUADRUPOLE, L=.409, K1= 2.227470
Q5    :QUADRUPOLE, L=.13,  K1=-1.4
BD    :SBEND,L=1.456,ANGLE=.261799,K1=-.430418,&
E1=PI/24.,E2=PI/24.
D1    :DRIFT,L=3.116
D2    :DRIFT,L= .281
D3    :DRIFT,L= .34
D4    :DRIFT,L= .251
D5    :DRIFT,L= .507
D6    :DRIFT,L= .4725
D7    :DRIFT,L= .3755
D8    :DRIFT,L=2.074
D9    :DRIFT,L= .37
S1    :MULTIPOLE,K2L= 2.2
SF    :MULTIPOLE,K2L= 8.406257
SD    :MULTIPOLE,K2L=-7.223313
HSUP  :LINE=(D1,Q1,D2,S1,D3,Q2,D4,Q3,D5, &
       BD,D6,Q4,D7,SF,D8,SD,D9,Q5)
FSUP  :LINE=(HSUP,-HSUP)
RING  :LINE=(12*FSUP)
USE,RING
PRINT,#S/E
TWISS
STOP
```

106



E= 1.700 α= .732E−03 —— $10\eta_x$ --- β ..... β^x_y

N_s= −8 ϵ= .516E−08

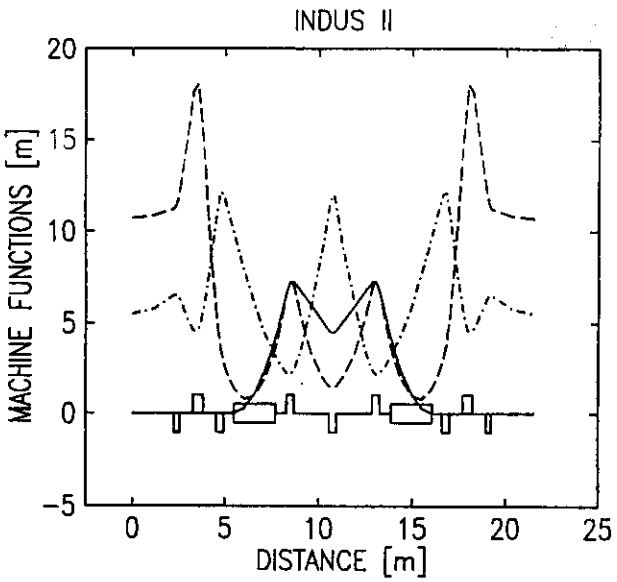
ν_x= 17.825 ξ_x= −52.66 f_{rf}= 499.7

ν_y= 6.724 ξ_y= −26.70 V_{rf}= 2000.0

107

```
TITLE,"BESSY-II"
!DATA COURTESY OF G. WUSTEFELD, 3/96
BEAM, PARTICLE=ELECTRON, ENERGY= 1.7 , RADIATE
RHO   := 4.35448
LENGTH := RHO*PI/16
ANGLE  := PI/16
Q1: QUAD, L= 0.50, K1= 1.4050
Q2: QUAD, L= 0.25, K1=-2.0149
Q3: QUAD, L= 0.20, K1=-1.8975
Q4: QUAD, L= 0.25, K1= 2.4519
Q5: QUAD, L= 0.25, K1=-2.4632
Q6: QUAD, L= 0.50, K1= 2.6208
Q7: QUAD, L= 0.20, K1=-2.6
D1: DRIFT, L= 2.886    D5: DRIFT, L= 0.387
D2: DRIFT, L= 0.233    D6: DRIFT, L= 0.368
D3: DRIFT, L= 0.42     D7: DRIFT, L= 0.265
D4: DRIFT, L= 0.42     D8: DRIFT, L= 2.453
BB:SBEND,L=LENGTH,ANGLE=ANGLE,&
E1=ANGLE/2.,E2=ANGLE/2.
RF :RFCAV, L= 0.0, VOLT=-2.0, HARMON=400
S1: MULTI, K2L=0    S4: MULTI, K2L=0
S2: MULTI, K2L=0    S5: MULTI, K2L=0
S3: MULTI, K2L=0    S6: MULTI, K2L=0
DUB : LINE = (D1, S1, D2, Q1, D2, S2, D2, Q2, D3)
TRI : LINE = (D3, Q5, D2, S6 ,D2, Q6, D2, S5, D2, Q7 ,D8)
ACH : LINE = (BB, D4, Q3, D5, S3, D6, Q4, D7, S4)
HAF : LINE = (DUB,ACH,-ACH,TRI)
CEL : LINE = (-HAF,HAF)
BE2 : LINE = (8*CEL,RF)
USE, BE2 ,SUPER=1
PRINT,#S/E
TWISS
STOP
```

110



E= 2.000 α= .516E−02 —— $10\eta_x$

N_s= 8 ϵ= .441E−07 ---- β_y ..... β^x

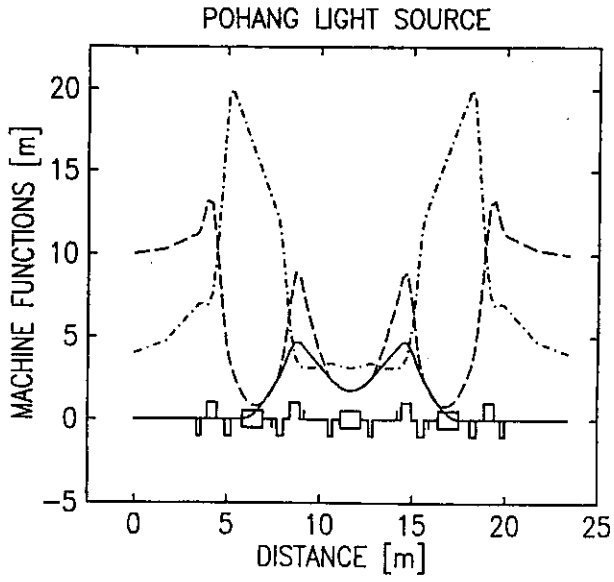
ν_x= 9.197 ξ_x= −16.22 f_{rf}= 189.7

ν_y= 5.201 ξ_y= −8.91 V_{rf}= 1500.0

111

```
TITLE,"INDUS-2"
!DATA COURTSEY OF G.K. SAHOO AT CAT, 2/96
D1:DRIFT,L=2.28
D2:DRIFT,L=0.35
D3:DRIFT,L=0.55
D4:DRIFT,L=0.6
D5:DRIFT,L=1.2079011
Q1:QUADRUPOLE,L=0.3,K1=-0.9
Q2:QUADRUPOLE,L=0.55,K1=1.400256
Q3:QUADRUPOLE,L=0.4,K1=-1.39194
Q4:QUADRUPOLE,L=0.4,K1=1.875615
Q5:QUADRUPOLE,L=0.2,K1=-1.45
MAG:SBEND,L=2.17948,ANGLE=0.39269908,E1=0.19634954,
E2=0.19634954
S1:SEXTUPOLE,L=0,K2=0
S2:SEXTUPOLE,L=0,K2=0
S3:SEXTUPOLE,L=0,K2=0
S4:SEXTUPOLE,L=0,K2=0
HALF:LINE=(D1,Q1,D2,S1,D2,Q2,D2,S2,D2,Q3,D3,MAG,D4,&
Q4,D2,S3,D5,S4,D2,Q5)
RING:LINE=(HALF,-HALF)
USE,RING,SUPER=8
PRINT,#S/E
TWISS
STOP
```

112



E= 2.000 α= .181E−02 —— $10\eta_x$

N_s= 12 ϵ= .121E−07 ---- β_y ..... β^x

ν_x= 14.280 ξ_x= −23.36 f_{rf}= 500.1

ν_y= 8.180 ξ_y= −18.17 V_{rf}= 1800.0

113

```
TITLE,"POHANG LIGHT SOURCE (PLS)"
! DATA COURTESY OF MOOHYUN YOON AT PLS (2/96)
Q1    :QUADRUPOLE,L=.24, K1=-0.64177618
Q2    :QUADRUPOLE,L=.53, K1=1.51772681
Q3    :QUADRUPOLE,L=.35,K1=-1.69278925
Q4    :QUADRUPOLE,L=.35,K1=-1.45439552
Q5    :QUADRUPOLE,L=.53,K1=1.81955515
Q6    :QUADRUPOLE,L=.24,K1=-0.794745539
BD    :SBEND,L=1.1,ANGLE=.174532924,E1=0.087266462,&
E2=0.087266462
SF    :MULTIPOLE,K2L=0.
SD    :MULTIPOLE,K2L=0.
D1    :DRIFT,L=3.4
D2    :DRIFT,L=.32
D3    :DRIFT,L=.42
D4    :DRIFT,L=.6
D5    :DRIFT,L=.5
D6    :DRIFT,L=.25
D7    :DRIFT,L=.34
D8    :DRIFT,L=1.3
FSUP  :LINE=(D1,Q1,D2,Q2,D3,Q3,D4,BD,D5,SD,D6,&
        Q4,D7,Q5,D6,SF,D8,Q6,D3,BD,D3,Q6,D8,&
SF,D6,Q5,D7,Q4,D6,SD,D5,BD,D4,Q3,D3,Q2,D2,Q1,D1)
RING  :LINE=(12*FSUP)
USE,RING
PRINT,#S/E
TWISS
STOP
```

SASEME

```
ASSIGN,PRINT=ERG.DAT

! driftlengths:
DL : DRIFT,L=3.00
DW : DRIFT,L=1.25
D1 : DRIFT,L=0.25
D2 : DRIFT,L=0.50
D3 : DRIFT,L=0.80
D4 : DRIFT,L=1.00
D5 : DRIFT,L=0.20
D6 : DRIFT,L=0.366

! quadrupoles:
Q1 : QUADR,L=0.44,K1= 1.08277
Q2 : QUADR,L=0.44,K1= -0.72544
Q1W: QUADR,L=0.44,K1= 1.30499
Q2W: QUADR,L=0.44,K1= -0.93862
Q3W: QUADR,L=0.25,K1= 2.92330
Q4W: QUADR,L=0.25,K1= -4.59568
Q5 : QUADR,L=0.44,K1= 1.75786

! dipole:
BB : RBEND,L=0.934,ANGLE=0.5236

! sextupoles:
S1 : SEXTU,L=0.2,K2= -5.1
S2 : SEXTU,L=0.2,K2=  3.6

! full achromat:
ACH:LINE=(BB,D2,S1,D3,S2,D6,Q5,D6,S2,D3,S1,D2,BB)

! half of long straight:
DDL:LINE=(D3,Q2,D2,Q1,DL)

! half of wiggler straight:
DDW:LINE=(DW,Q4W,D1,Q3W,D4,Q1W,D2,Q2W,D3)

! one out of three unit cells:
PA3:LINE=(DDW,ACH,DDL,-DDL,-ACH,-DDW)

USE,PA3,SUPER=3

PRINT,FULL
TWISS,SAVE,TAPE
STOP
```