National Synchrotron Radiation Research Center

LATTICE DESIGN CONSIDERATION for TAIWAN PHOTON SOURCE (TPS) at NSRRC

Chin-Cheng Kuo

On behalf of the TPS Design Team

October 15, 2004

Facilities

1. Main Gate
2. Administration Building
3. Research Building
4. Instrumentation Building
5. Booster Building
6. Storage Ring Building
7. Utility Building
8. Guest House

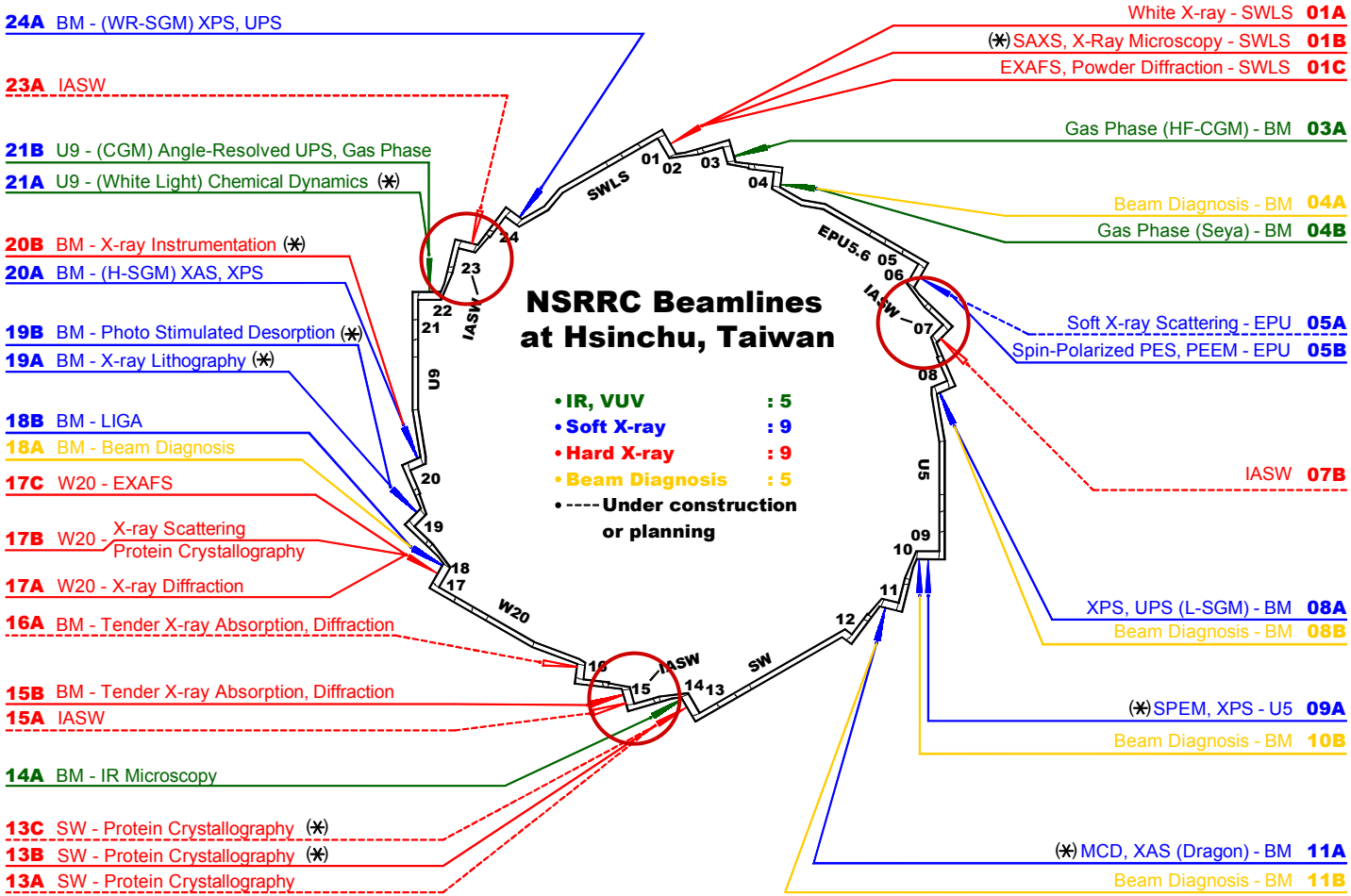
Neighboring Institutes

9. Nat'l Center for High Performance Computing
10. Nat'l Chiao Tung University

Why need a medium energy ring at NSRRC?

- A 1.5 GeV light source TLS is in operation now.
- Number of x-ray users is increasing and available photon ports are to be fully occupied.
- New research opportunities with new machine.
- July 2004, Board of Trustee gave Green Light to the 3 GeV Rings
- Forum on Low Emittance Intermediate Energy Synchrotron Light Sources, 2004, August 19~20, NSRRC.

NSRRC Beamline Map



- Insertion Devices
  EPU5.6: Elliptically Polarized Undulator (5.6 cm , 66 Periods)
  IASW: In Archomatic Superconducting Wiggler (3.5 T, 15 Poles)
  SW: Superconducting Wiggler (3.2 T, 32 Poles)
  SWLS: Superconducting Wavelength Shifter (6 T)
  U5: Undulator (5 cm, 76 Periods)
  U9: Undulator (9 cm, 48 Periods)
  W20: Wiggler (1.8 T, 27 Poles)

- (✳) : Participating Research Group
- NSRRC website: www.nsrrc.org.tw

June 2004

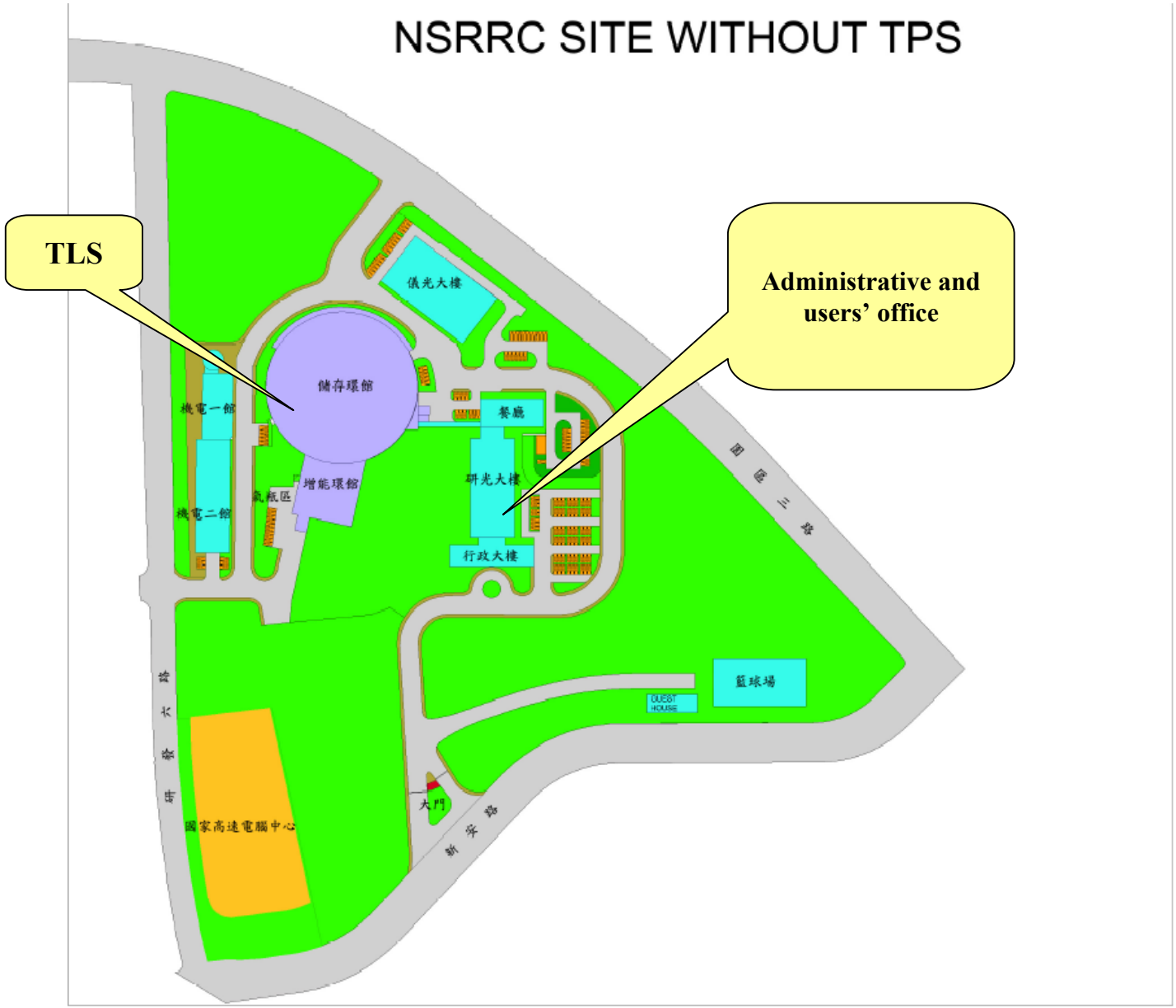
Major parameters of TLS 1.5 GeV storage ring

Lattice type	**Combined function Triple Bend Achromat (TBA)**
Operational energy	**1.5 GeV**
Circumference	**120 m**
Injection energy	**1.5 Gev**
Natural beam emittance	***25.6 nm-rad (achromat)***
Natural energy spread	***0.075%***
Momentum compaction factor	***0.00678***
Damping time	
Horizontal	***6.959 ms***
Vertical	***9.372 ms***
Longitudinal	***5.668 ms***
Betatron tunes horizontal/vertical	***7.18/4.13***
Natural chromaticities	
Horizontal	***-15.292***
Vertical	***-7.868***
Synchrotron tune (RF 800KV)	**$1.06*10^{-2}$**
Bunch length (RF 800KV)	**0.92 cm**
Radiation loss per turn (dipole)	**128 keV**
Nominal stored current (multibunch)	**200 mA**
Number of stored electrons (multibunch)	**$5*10^{11}$**

Design goals of the TPS

- **Nominal energy: 3 GeV**
- **Maximum energy: 3.3 GeV**
- **Circumference: 518.4 m**
- **Target emittance < 2 nm-rad at 3 GeV**
- **Long straights > 10 m (quad to quad)**
- **Standard straights ~ 6m**
- **Short straights ~ 3 m**
- **Energy acceptance larger than 4%**
- **Beam current > 300 mA at 3 GeV**
- **Lifetime > 10 hr**
- **Top-up injection**

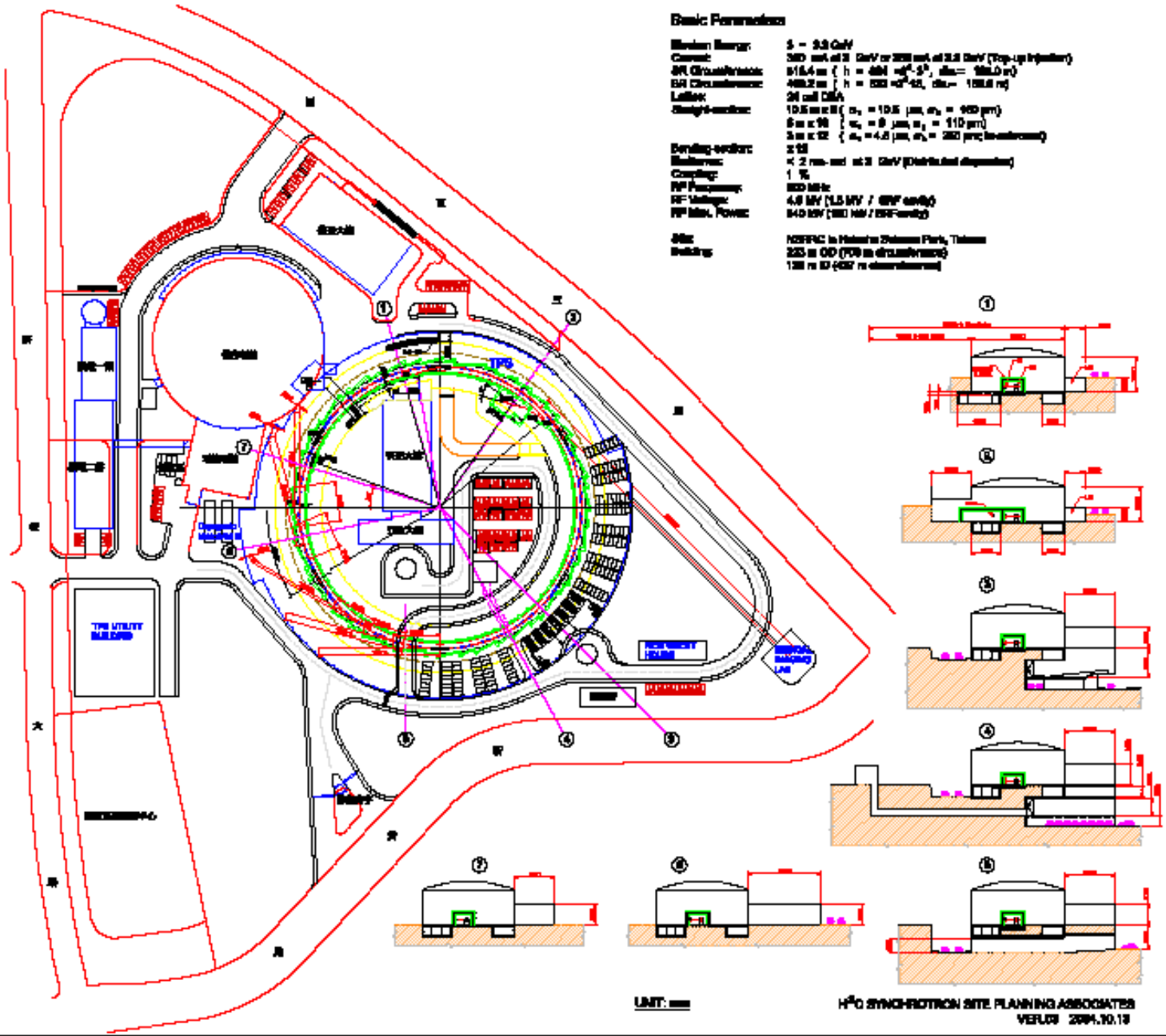
NSRRC SITE WITHOUT TPS



TAIWAN PHOTON SOURCE SITE PLAN

H^{2}C SYNCHROTRON SITE PLANNING ASSOCIATES
VER.03 2004.10.13

TAIWAN PHOTON SOURCE SITE PLAN



TPS major parameters

Type	Separated function Distributed dispersion (24P9C)	Separated function Achromat (24P9D)
Nominal energy (GeV)	3.0	3.0
Circumference (m)	518.4	518.4
Emittance (nm rad)	1.63	6.06
Number of cells	24 (DBA)	24 (DBA)
Symmetry	6	6
RF frequency (MHz)	499.654	499.654
RF voltage (MV)	3.6	3.6
Harmonic number	864	864
SR loss (dipole) per turn (MeV)	0.93796	0.93796
Straight section and length	10.5m*6+6m*18+3m*12	10.5m*6+6m*18+3m*12
Betatron Tune ν_x/ν_y	26.272/14.197	26.206/14.254
Synchrotron Tune ν_s	0.00559	0.00559

TPS major parameters (contd.)

Type	Separated function Distributed dispersion (24P9C)	Separated function achromat (24P9D)
Bunch length (mm)	2.7	2.7
Dipole field (T)/length (m)	1.3095/1	1.3095/1
Dipole gradient (T/m)	0.0	0.0
Number of dipole	48	48
Number of quadrupole	240	240
Number of sextupole	180	180
Momentum compaction	0.197E-03	0.259E-03
Natural Energy Spread σ_E	9.29e-4	9.29e-4
Damping partition Jx/Jy/Jz	0.998/1.0/2.002	0.997/1.0/2.003
Damping time $\tau_x/\tau_y/\tau_s$(ms)	11.1/11.1/5.5	11.1/11.1/5.5
Natural chromaticity $\xi x/\xi y$	-60.9/-30.1	-60.8/-26.5

Linear Lattice of the TPS

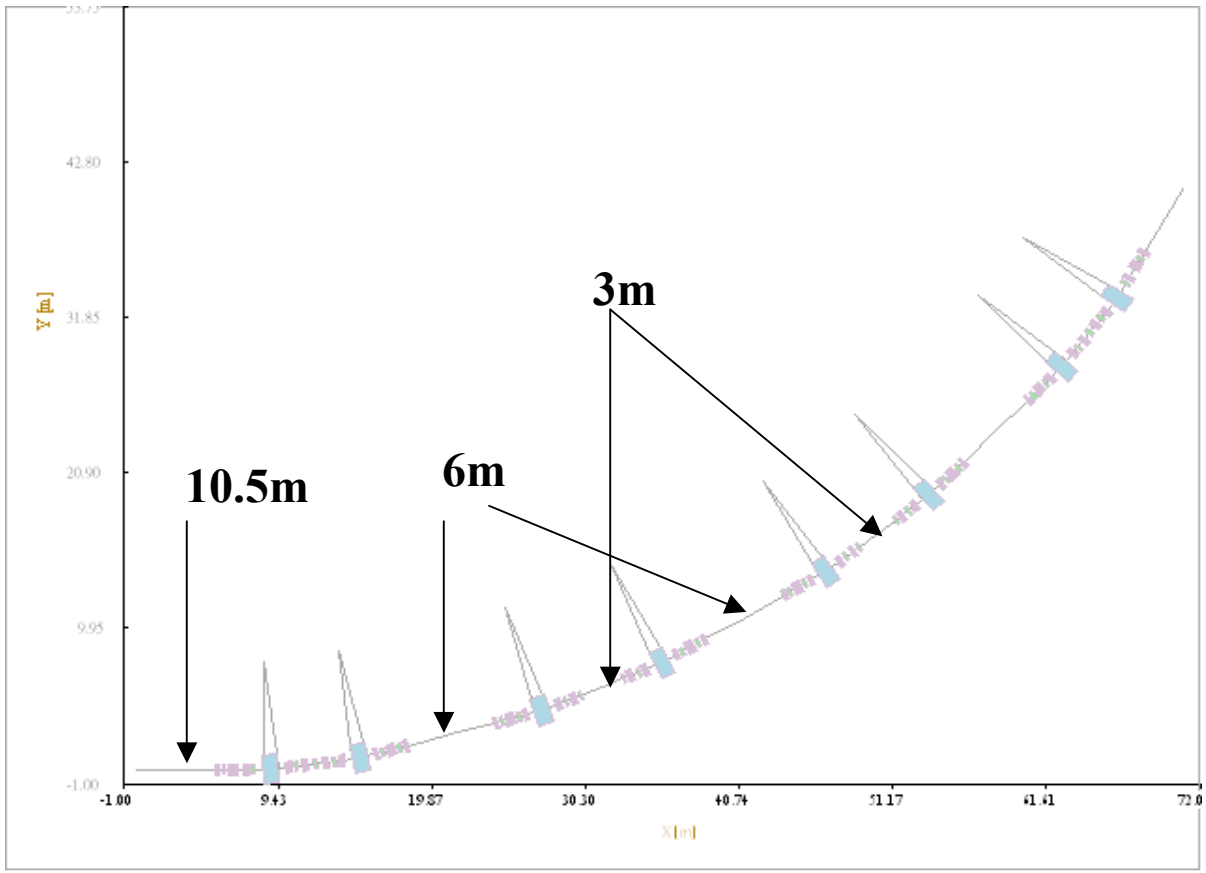
- **Long Straight: 10.5 m (Q-t-Q) X 6**
- **Standard Straight: 6 m (Q-t-Q) X 18**
- **Short Straight: 3 m (S-t-S) X 12**
- **518.4 m, 24 cells, 6-fold**
- **High β_x in long straight for injection**
- **Low $\beta_{x,y}$ in standard straight**
- **High β_x, low β_y in short straight**
- **Reasonable $\beta_{x,y}$ in the whole ring**
- **Horizontal tune between 26 and 28**
- **Vertical tune between 13 and 15**
- **Large betatron de-coupling in the arc for sextupole chromatic correction**
- **Large dispersion in arc to lower sextupole strength**
- **Reasonable distributed dispersion in straights for lowering emittance**
- **Reasonable natural chromaticities**
- **With gradient dipole, lower emittance could be obtained**

24p9c

(separated function, low emittance mode)

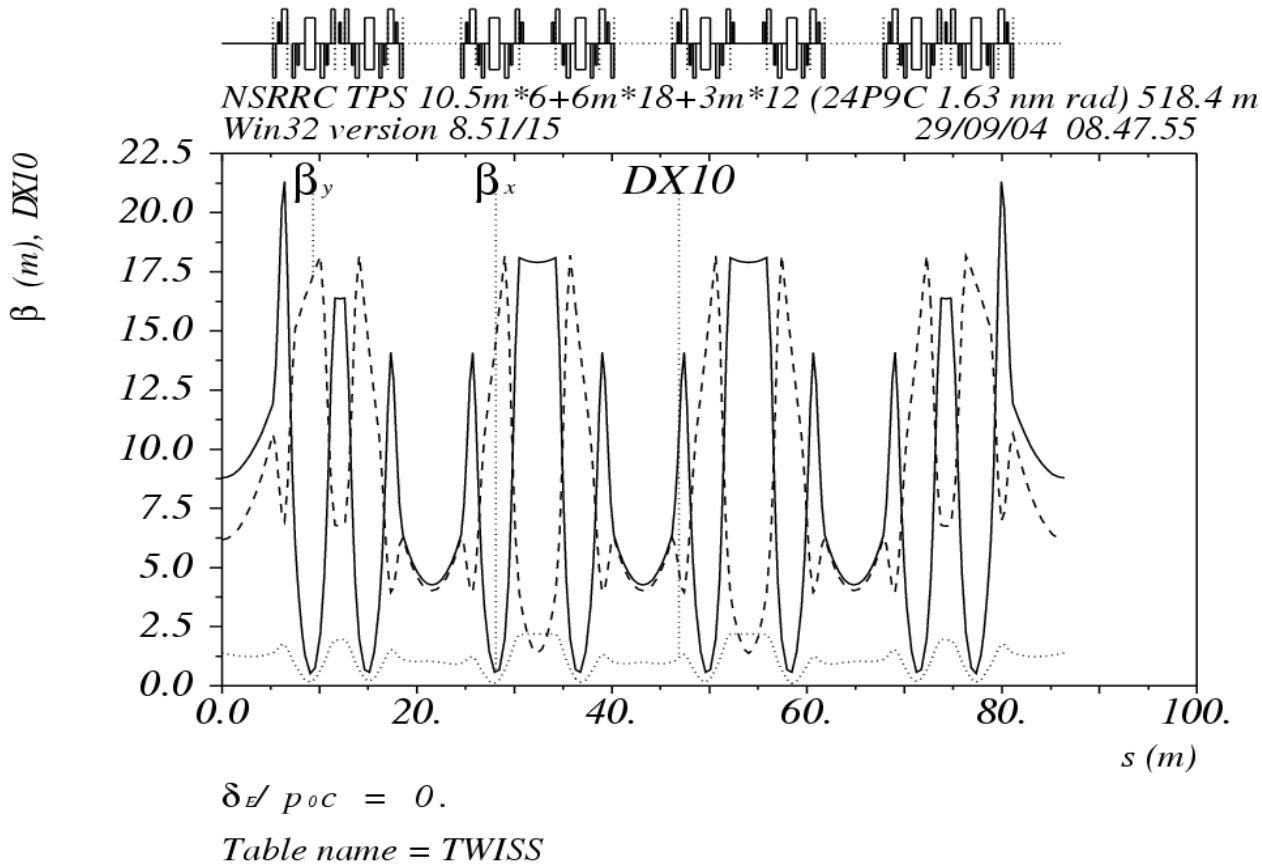
- E_x_0 = 1.63 nm rad
- 10.5m X 6, 6m X 18, 3m X 12 C=518.4m
- QL1 : QUADRUPOLE, L=0.3, K1=-1.101210896702
- QL2 : QUADRUPOLE, L=0.6, K1= 1.37113764295
- QL3 : QUADRUPOLE, L=0.3, K1=-1.167916437074
- QL4 : QUADRUPOLE, L=0.4, K1=-0.995279959753
- QL5 : QUADRUPOLE, L=0.4, K1= 1.354531601195
- QS1 : QUADRUPOLE, L=0.3, K1=-1.349130056974
- QS2 : QUADRUPOLE, L=0.6, K1= 1.486409185575
- QS3 : QUADRUPOLE, L=0.3, K1=-0.83814745919
- QS4 : QUADRUPOLE, L=0.4, K1=-1.237039602667
- QS5 : QUADRUPOLE, L=0.4, K1= 1.416248563868
- QS4A: QUADRUPOLE, L=0.4, K1=-1.513806885161
- QS5A: QUADRUPOLE, L=0.4, K1= 1.47547897779
- BEND L=1.0

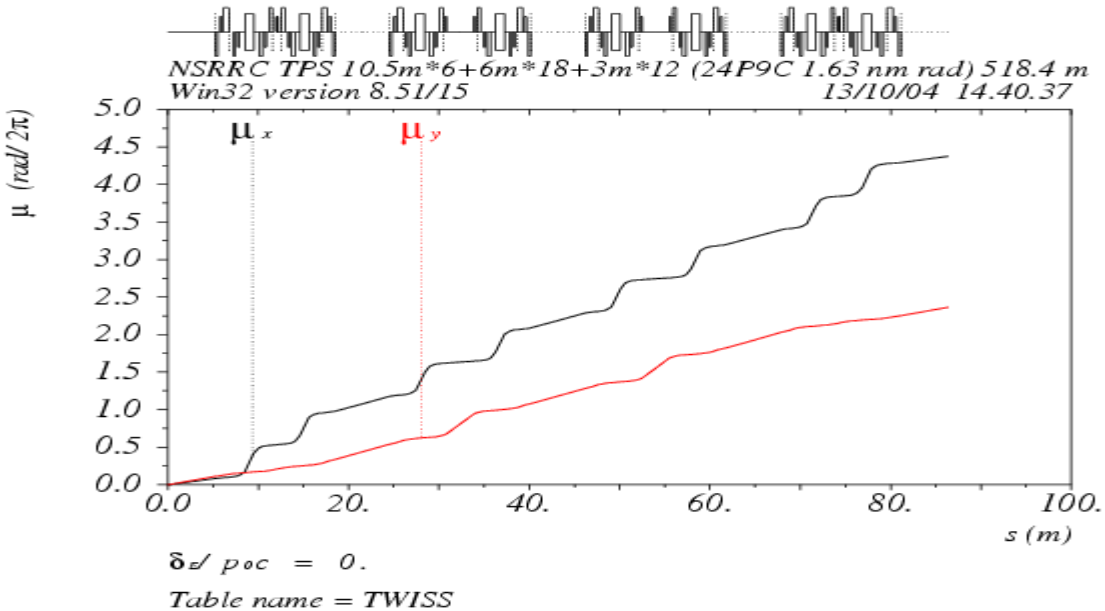
24p9c
(separated function, low emittance mode)

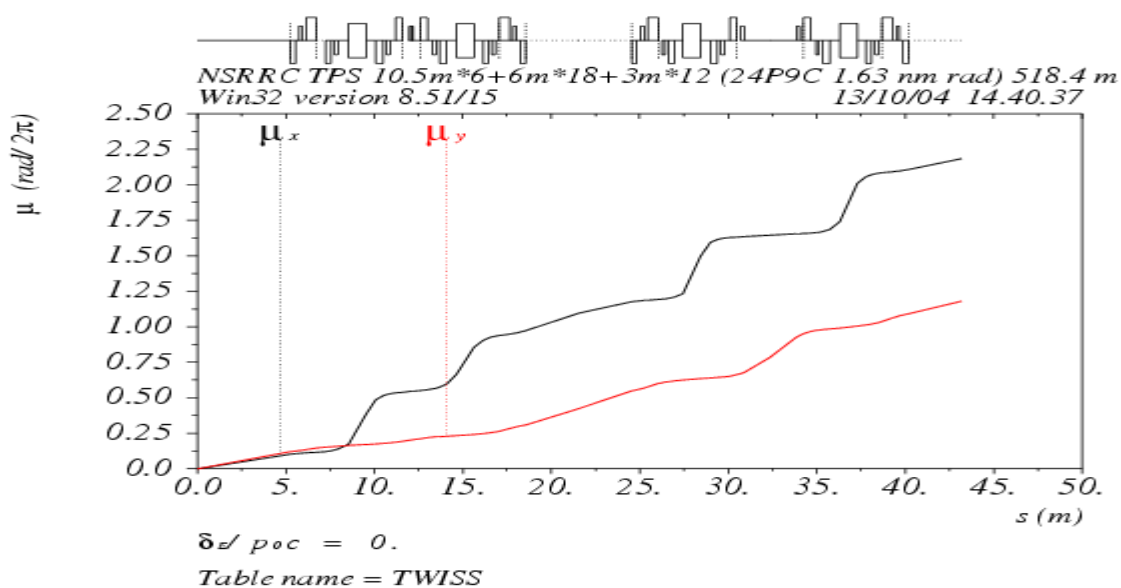


1/6 of the ring

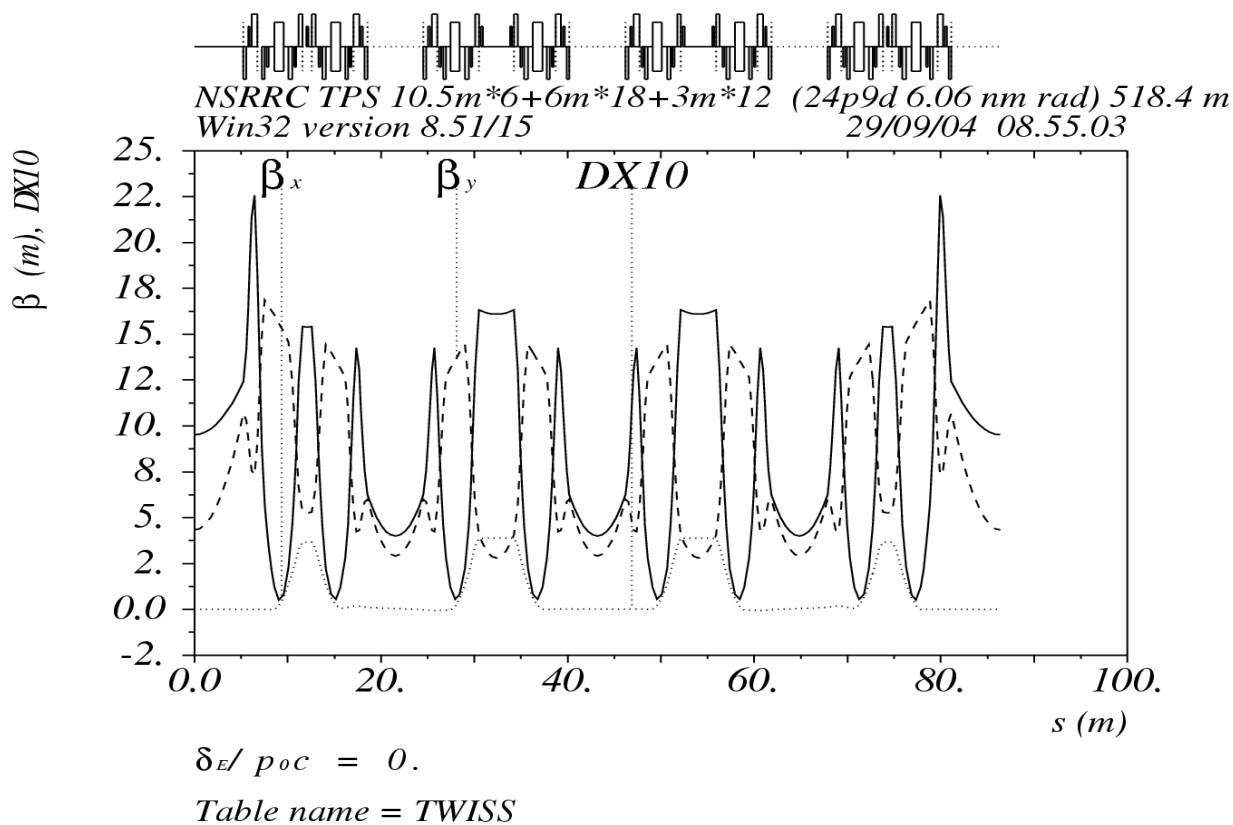
24p9c
(separated function, low emittance mode)




NSRRC TPS 10.5m*6+6m*18+3m*12 (24P9C 1.63 nm rad) 518.4 m
Win32 version 8.51/15
13/10/04 14.40.37
μ (rad/2π)
μx
μy
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
0.0
20.
40.
60.
80.
100.
s (m)
δ= poc = 0.
Table name = TWISS


NSRRC TPS 10.5m*6+6m*18+3m*12 (24P9C 1.63 nm rad) 518.4 m
Win32 version 8.51/15
13/10/04 14.40.37
μ (rad/2π)
μx
μy
2.50
2.25
2.00
1.75
1.50
1.25
1.00
0.75
0.50
0.25
0.0
0.0
5.
10.
15.
20.
25.
30.
35.
40.
45.
50.
s (m)
δ= poc = 0.
Table name = TWISS

24p9d
(separated function, achromat)

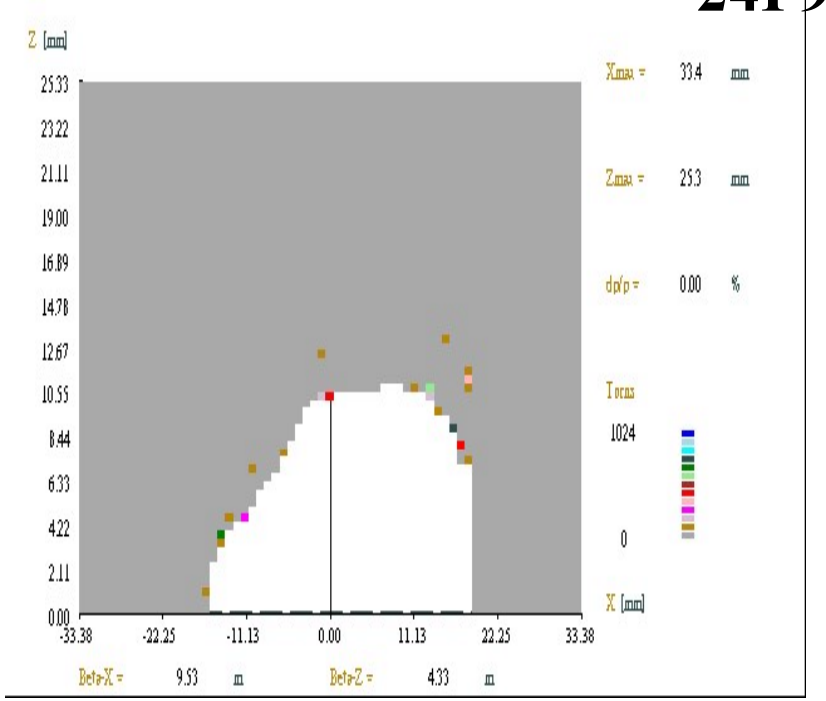


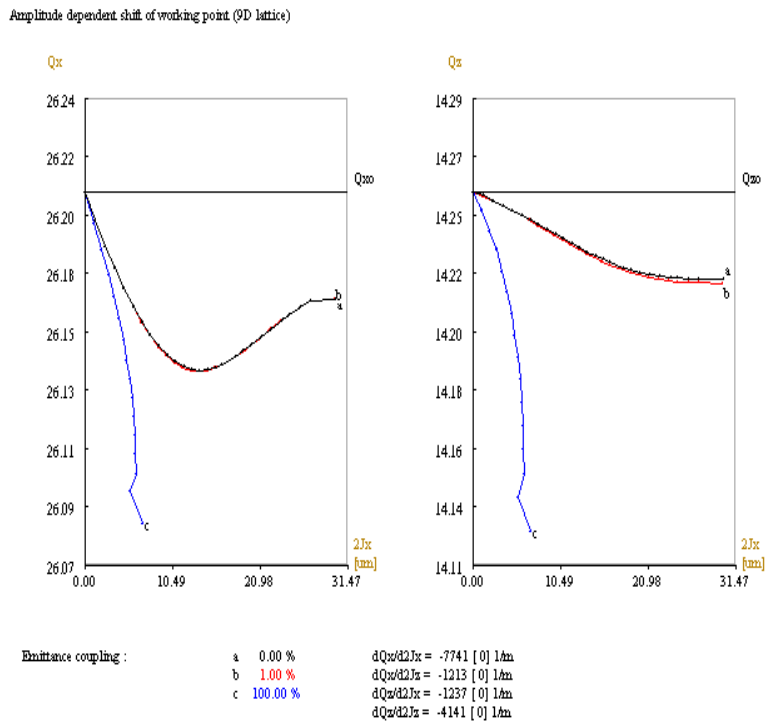
Nonlinear optimization

- Using MAD HARMON, OPA, and other codes, the sextupole configuration search is under way.
- 10 families of sextupoles are used.
- Chromacticities are corrected to zero.
- Using OPA, weighting factors such as resonance strengths, de-tuing coefficients for amplitude-dependent tune shift, second-order effects are given.
- However, still tune-shifts with amplitude are too large. Dynamic apertures are limited.
- Nonlinear momentum-dependent tune-shift shall be investigated in detail.

Dynamic aperture

24P9D

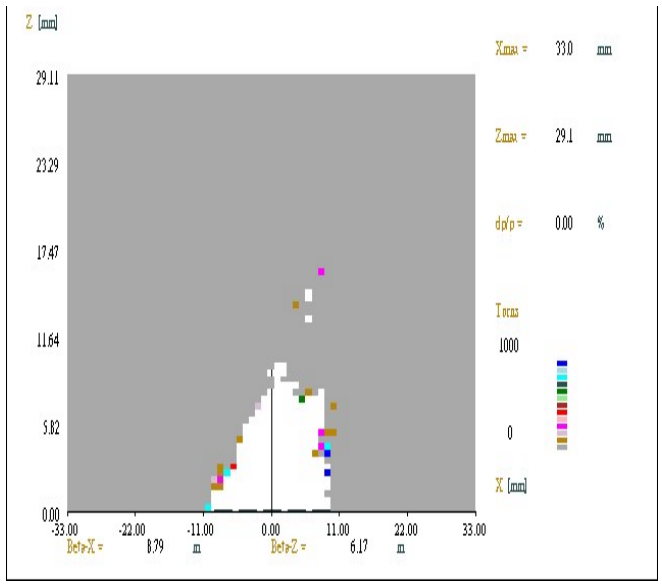




On-momentum DA
-16 mm,+19 mm in x
+/- 10 mm in y

Tune-shift with amplitude

Dynamic aperture (contd.)



24P9C
+/-10 mm in x,
+/-10 mm in y

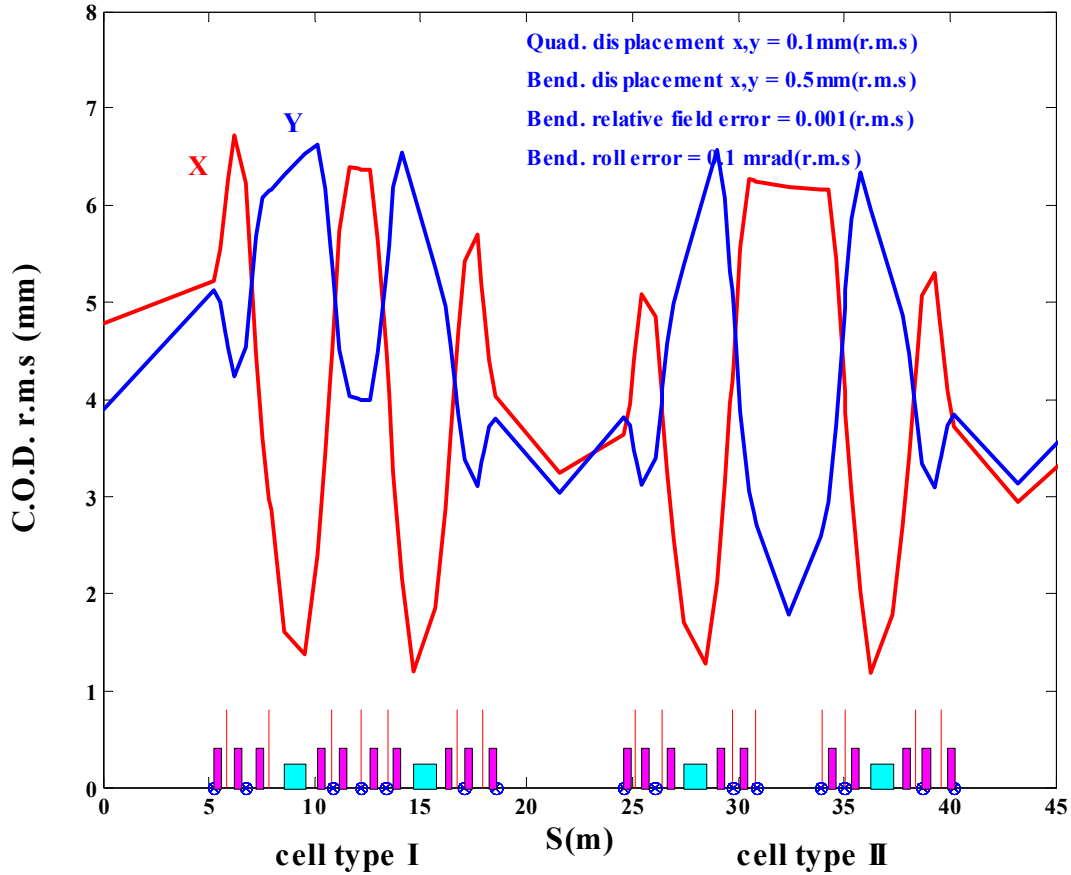
Sextupole	9D lattice	9C lattice
S1	3.365629 (m-1)	3.971841
S2	-3.664670	-5.144993
S3 (SD)	-4.197519	-5.365644
S4 (SF)	2.958521	6.338026
S5	-4.279743	-3.834290
S6	3.934426	3.356177
S7	4.101917	6.405973
S8	-4.159781	-8.473363
S9 (SD)	-1.843792	-1.414463
S10 (SF)	1.699720	1.796473

Integrated sextupole strengths

Questions to sextupole optimization

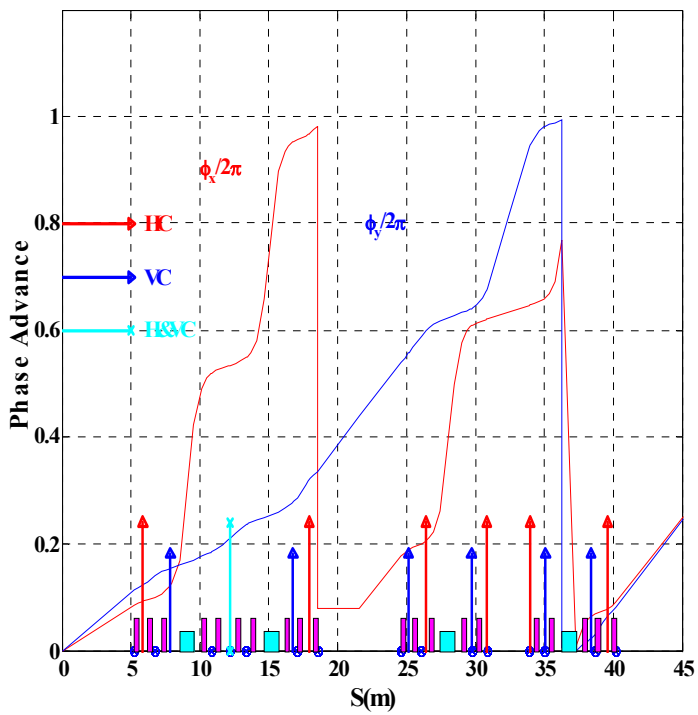
- Is it essential to have proper phase advance in sextupole to cancel geometric aberration?
- Does de-coupling of beta function play important role?
- How to decide to change another linear optics to get good sextupole optimization?
- Any rule for weighting factors in the optimization?

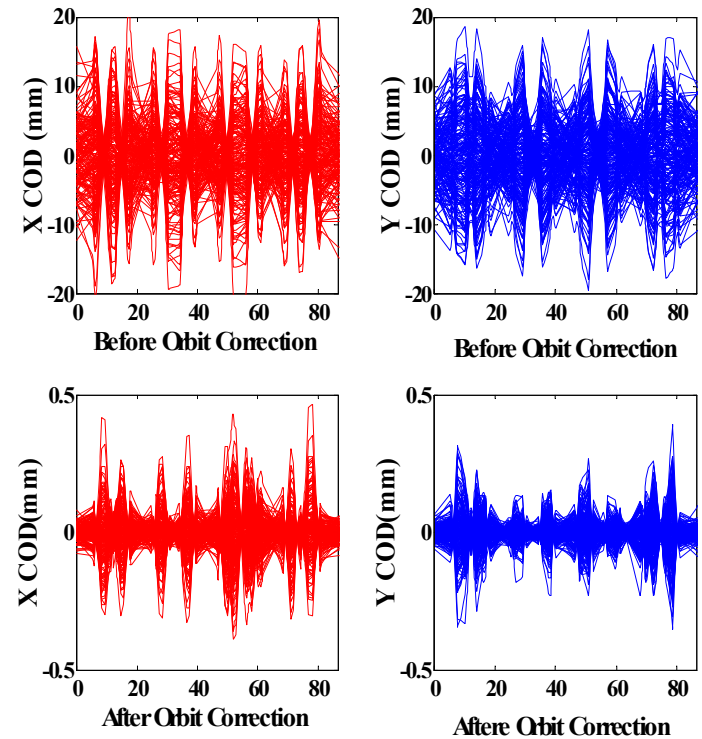
COD correction scheme



COD rms at each point due to errors (24p9c)

COD correction scheme (contd.)





Correctors and BPMs

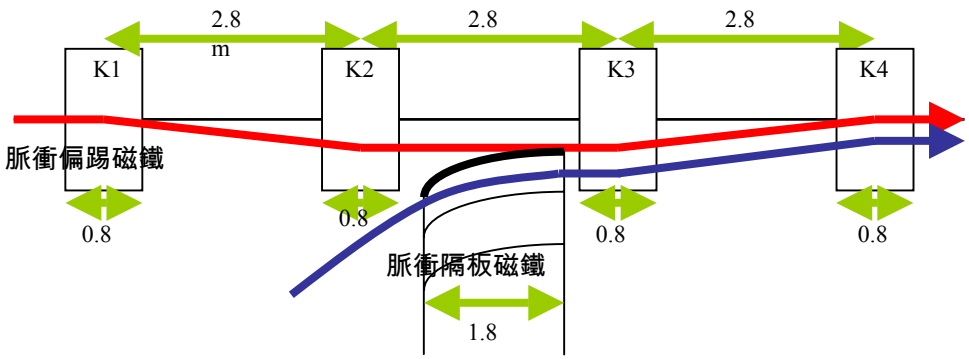
After correction

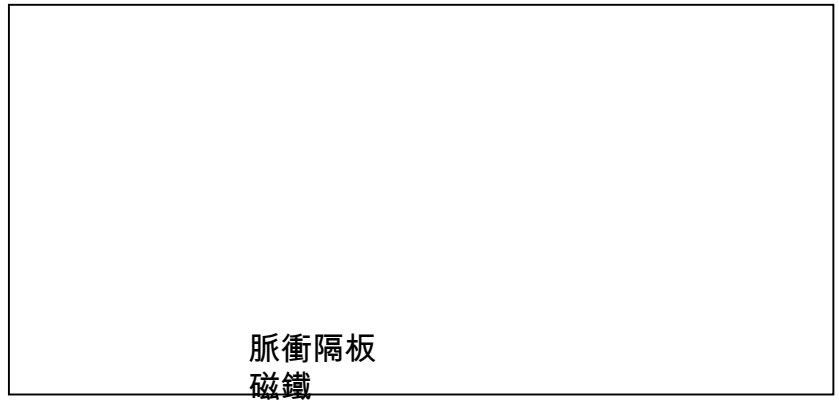
COD correction scheme (contd.)

	Correctors Used	Number of eigenvalues used	Mean of <|cor. Strength|> (mrad)	Max of <|cor. Strength|> (mrad)	Max of <|res. C.O. at BPM|> (mm)
Horizontal	(1,4,7,9,11,12,15)	84	0.0864	0.5555	0.5671
	180 C1-C15	72	0.0335	0.3178	0.3162
		84	0.0354	0.3177	0.1338
		96	0.0369	0.3342	0.0869
		180	0.0467	0.5189	5.5087E-09
Vertical	(2,4,6,8,10,13,14)	84	0.0767	0.4746	0.2589
	180 C1-C15	48	0.0263	0.1849	0.4586
		84	0.0341	0.2401	0.1656
		96	0.0357	0.2499	0.1042
		180	0.0429	0.1849	3.9313E-09

Correctors, eigenvalues in use. Corrector strengths

Injection scheme





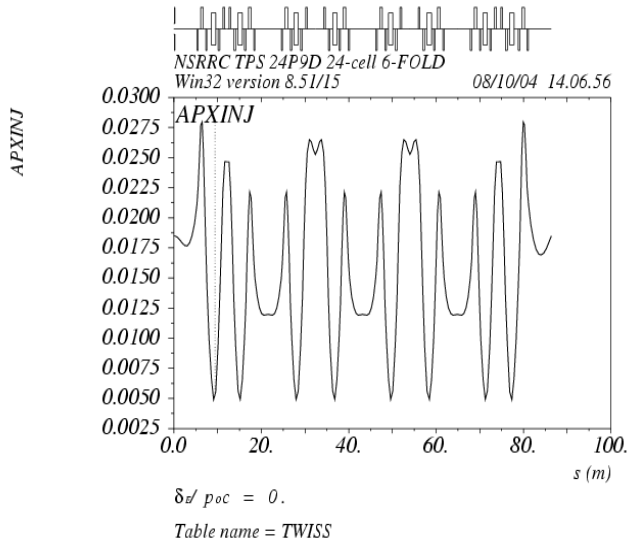
In a long straight K-t-K: 9.2m

TPS septum and kicker parameters

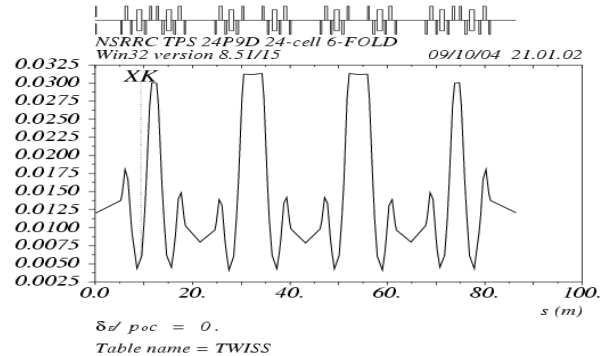
	septum	kicker
Length (m)	1.8(0.9)	0.80
Field (T)	0.97	0.073(0.146)
Bend Angle (mrad)	174.5(174.5/2)	11.65/2(11.65)

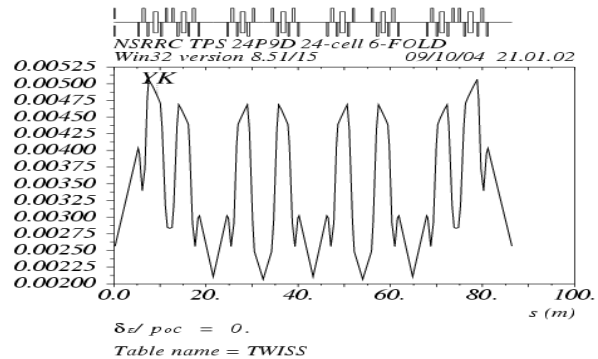
Physical Aperture Requirement

Injection requirement



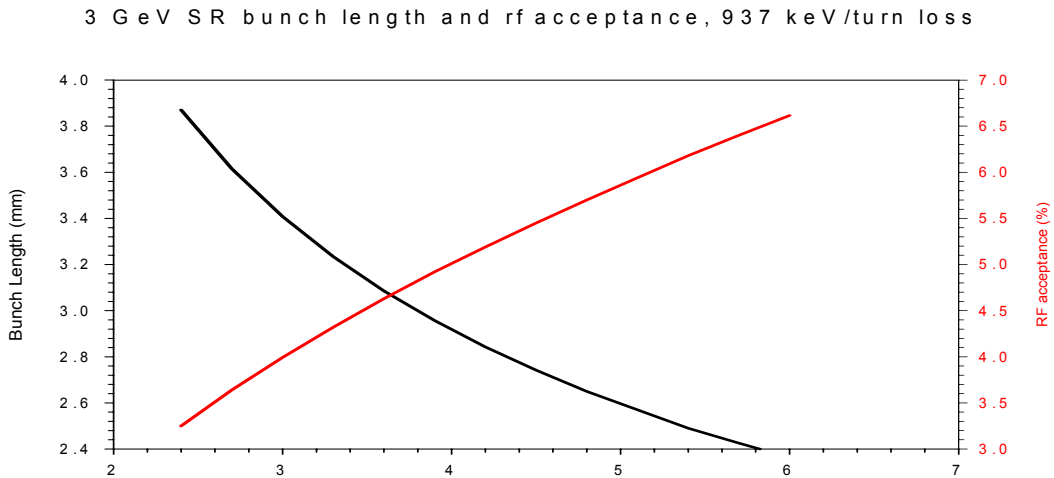
4% energy acceptance



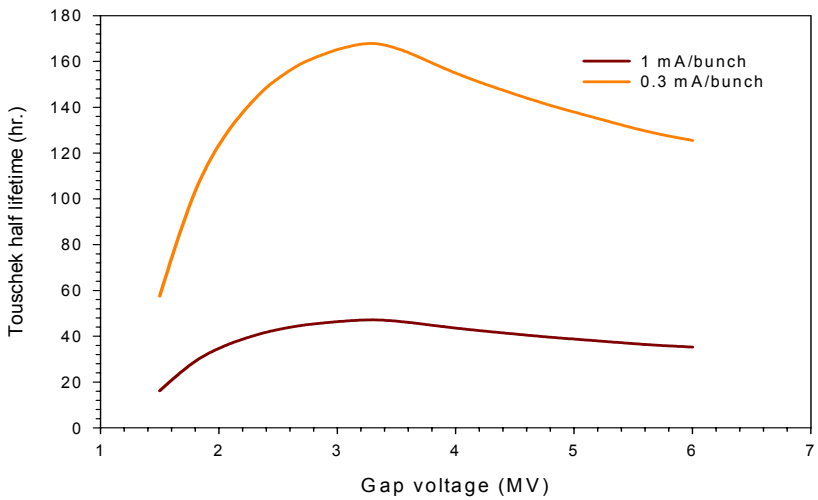


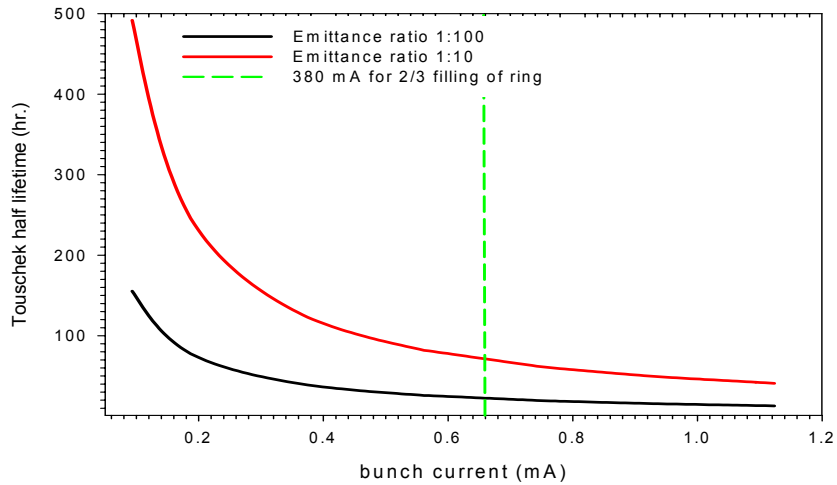
At least x: +/- 32 mm, y: +/- 6 mm BSC needed

Touschek Lifetime



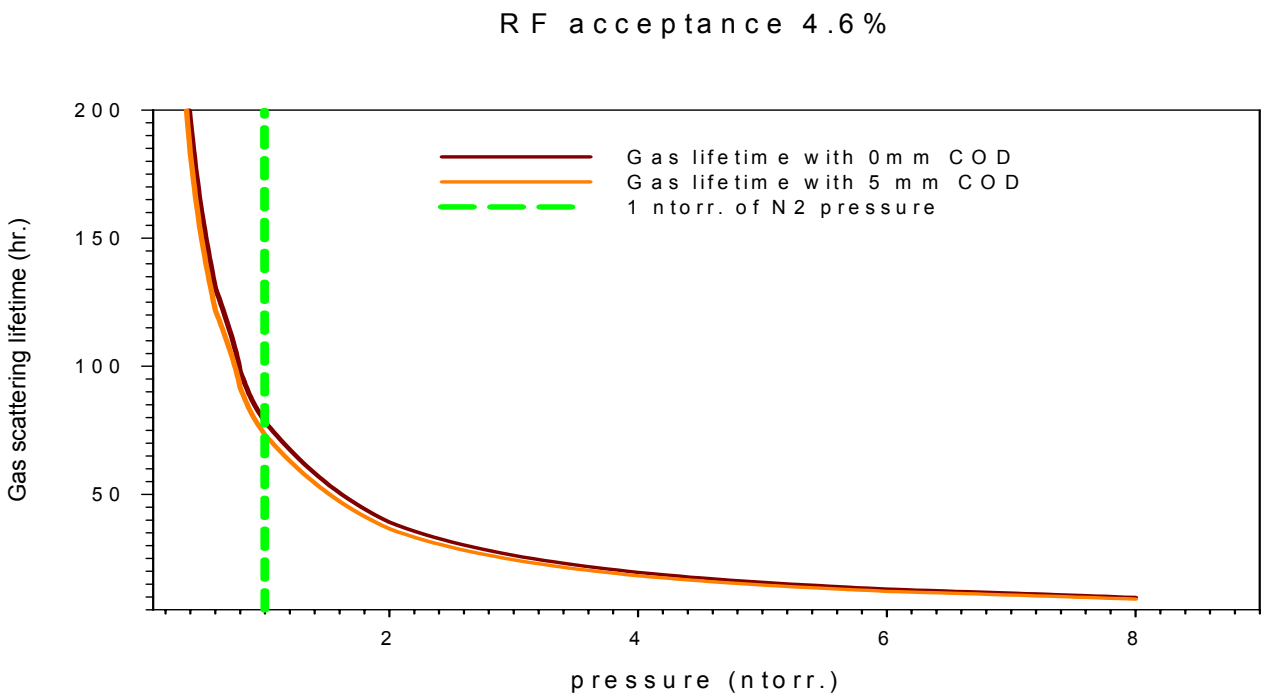
RF energy acceptance 3.6MV is chosen





Touschek lifetime calculation using ZAP,
Assuming DA=20mm for δ E=0 decreases 5mm each δ E step=1%

Gas Lifetime



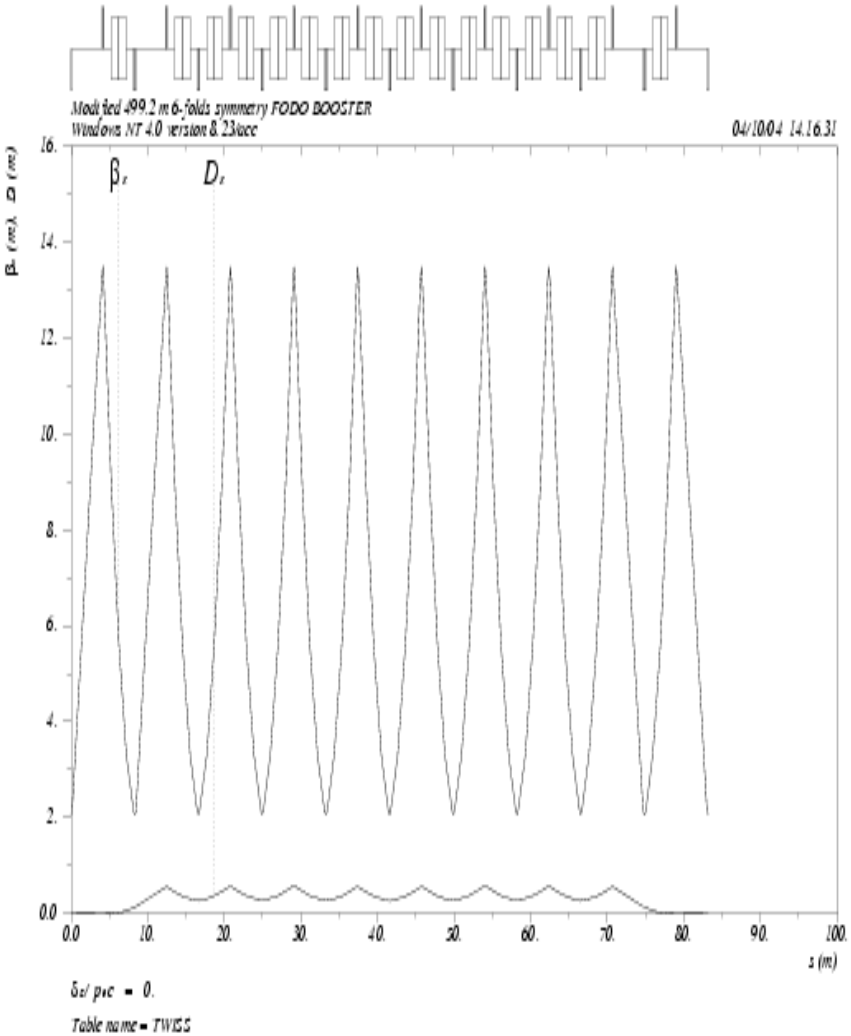
Gas lifetime due to N2 equivalent gas in different COD condition

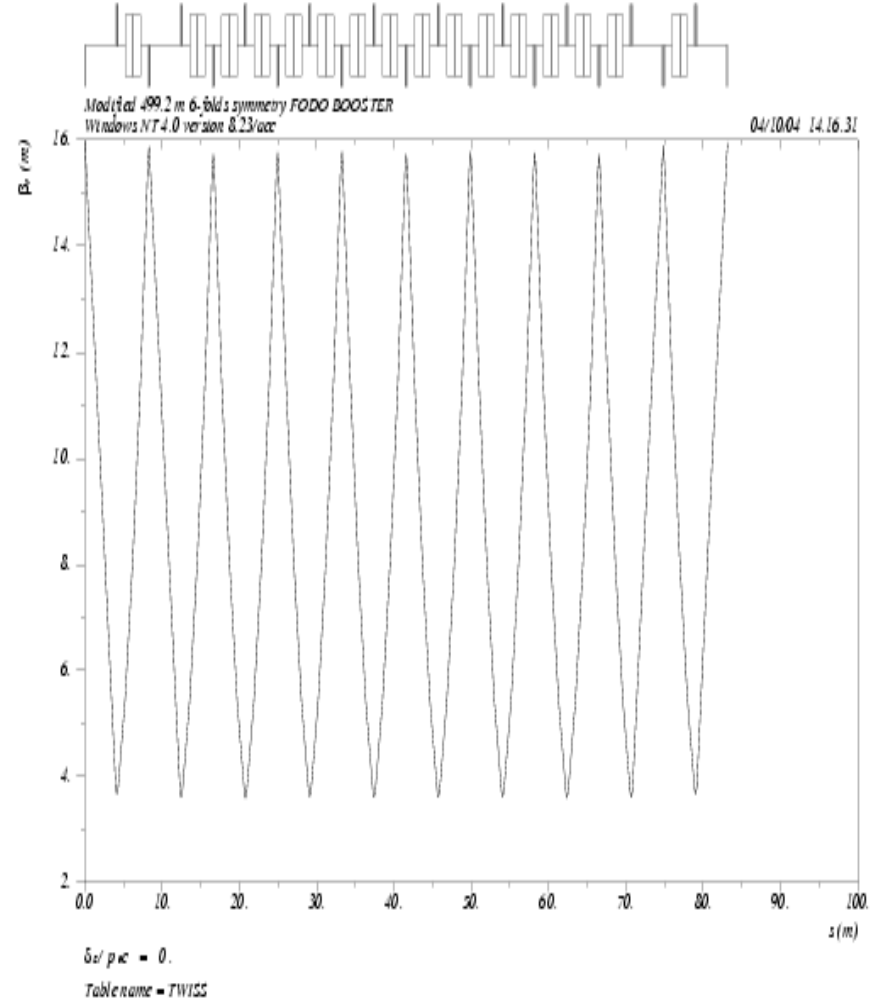
Booster Ring

- Sharing the Same Tunnel with Storage ring
- Full energy injection
- Circumference: 449.2 m
- Low emittance 11.4 nm-rad

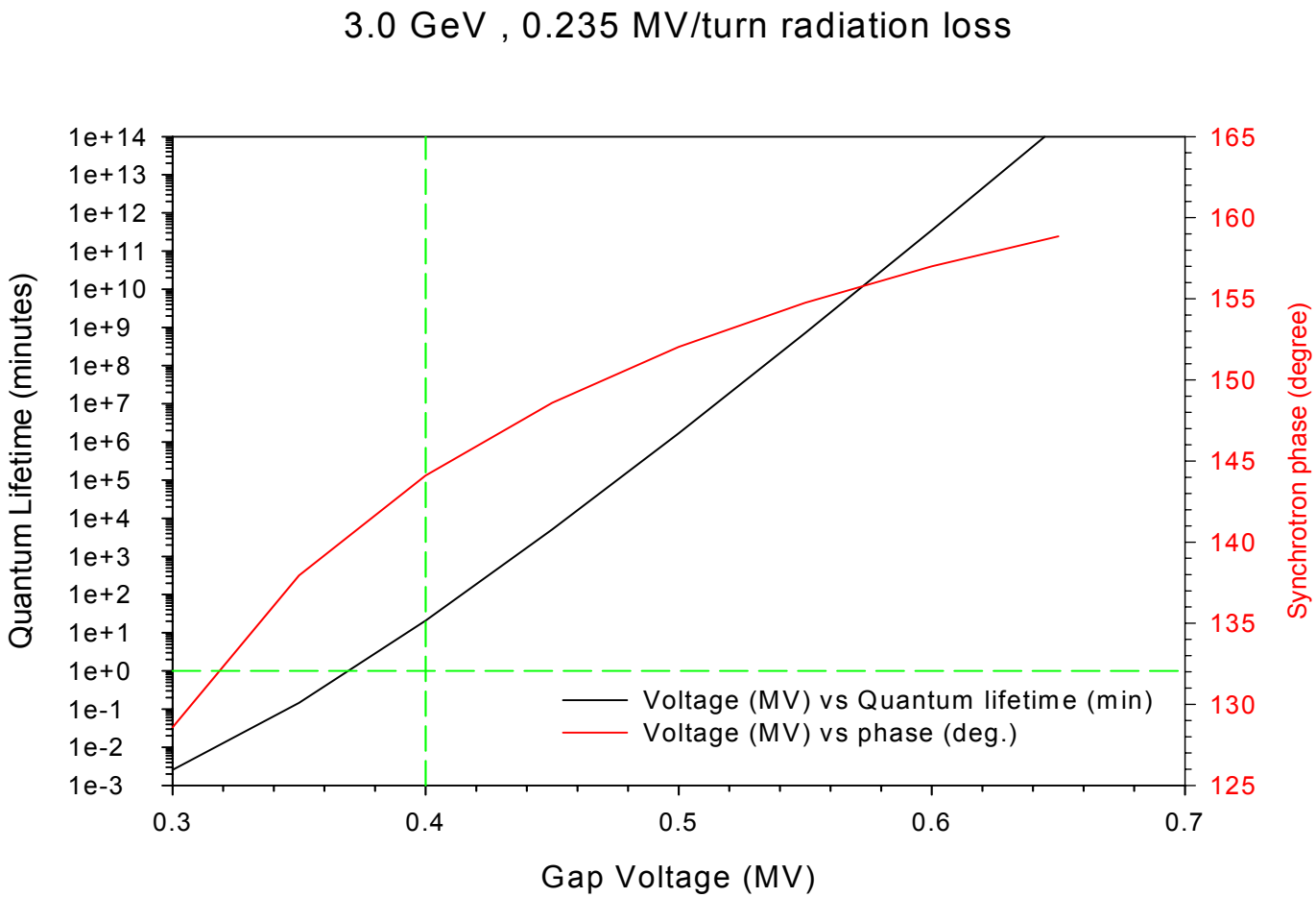
Basic parameters for a booster sharing tunnel with storage ring

Extraction energy [GeV]	3.0
Injection energy [GeV]	0.1
Circumference [m]	499.2
Super-periods	6
Tune ν_x/ν_y	17.2/11.13
Nature chromaticity (ξ_x/ξ_y)	-20.7/-15.8
Emittance @ 3GeV [nm-rad]	11.46
Damping time ($\tau_x/\tau_y/\tau_e$) [ms]	43/42.6/21.2
Damping partition ($J_x/J_y/J_e$)	0.989/1/2.01
Momentum compaction α	4.24E-3
RF frequency [MHz]	499.65
Radiation loss [keV/turn]@3GeV	234.5
Harmonic number	832


Modified 499.2 m 6-folds symmetry FODO BOOSTER
Windows NT 4.0 version 8.23/acc
04/10/04 14.16.31
βx (m), Dx (m)
βx
Dx
s (m)
δE/ p0c = 0.
Table name = TWISS

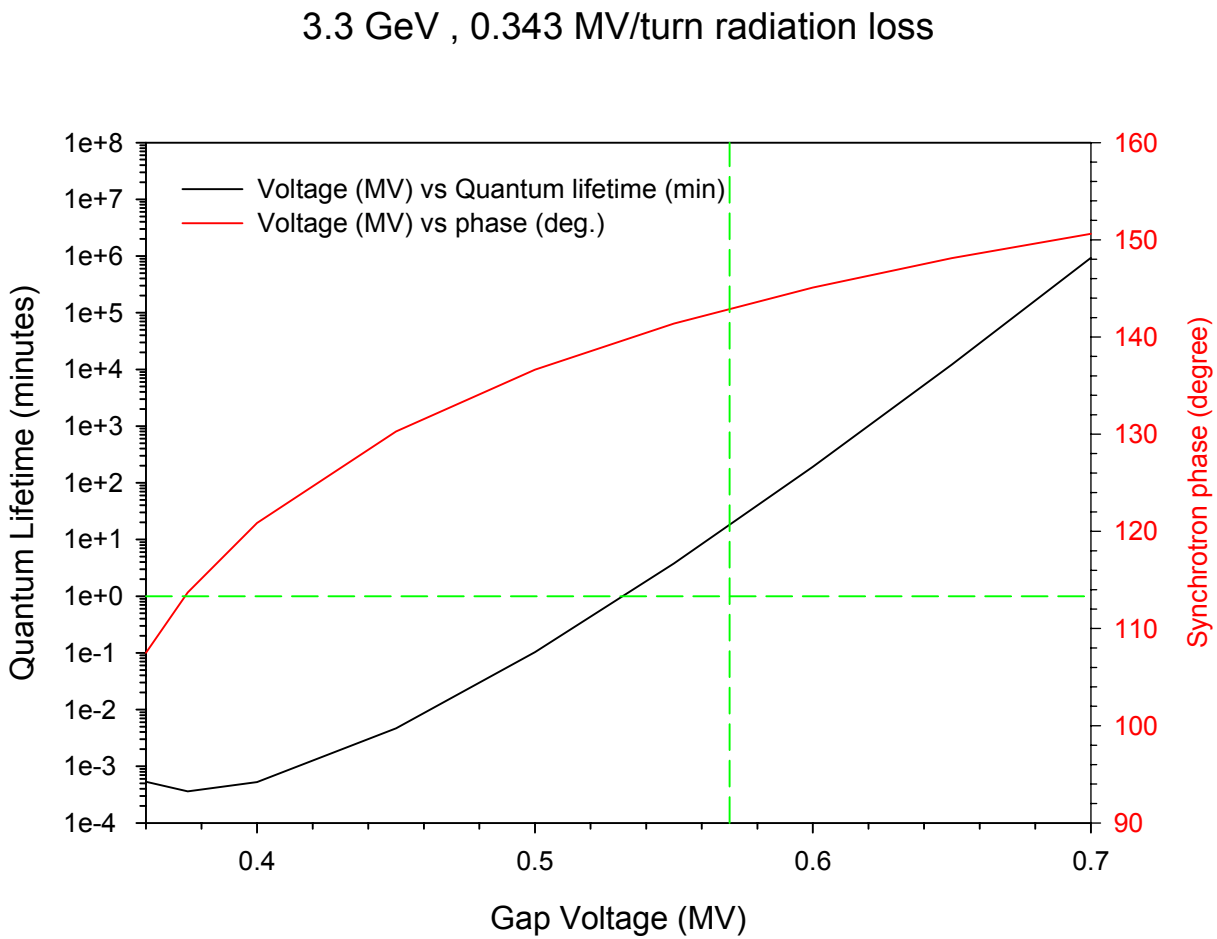

Modified 499.2 m 6-folds symmetry FODO BOOSTER
Windows NT 4.0 version 8.23/acc
04/10/04 14.16.31
βx (m)
s (m)
δE/ p0c = 0.
Table name = TWISS

Quantum lifetime at 3 GeV Booster



Quantum lifetime vs. RF gap voltage at extraction energy, 3.0 GeV.
Gap voltage larger than 0.4 MV can provide adequate quantum lifetime.

Quantum lifetime at 3.3 GeV



Quantum lifetime vs. RF gap voltage at extraction energy, 3.3 GeV. Gap voltage larger than 0.57 MV can provide adequate quantum lifetime.

Summary

- **DBA lattice structure with 24 cells, 6-fold symmetry could achieve natural emittance < 2nm-rad with a constrained circumference 518.4m and required straight lengths.**
- **Booster options are studied.**
- **Optimization of the linear lattice and nonlinear effects is in progress.**
- **Other issues such as orbit correction scheme, coupling control scheme, lifetime calculations, injection scheme… are under investigation.**

Outlook

- **Sextupole optimization tools development**
- **Phase advance analysis**
- **Energy acceptance**
- **Tracking with errors**
- **Engineering constraint analysis**
- **$$$$**