Accelerator Physics Issues for the Taiwan Photon Source (TPS)

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NSRRC

On behalf of TPS accelerator physics team

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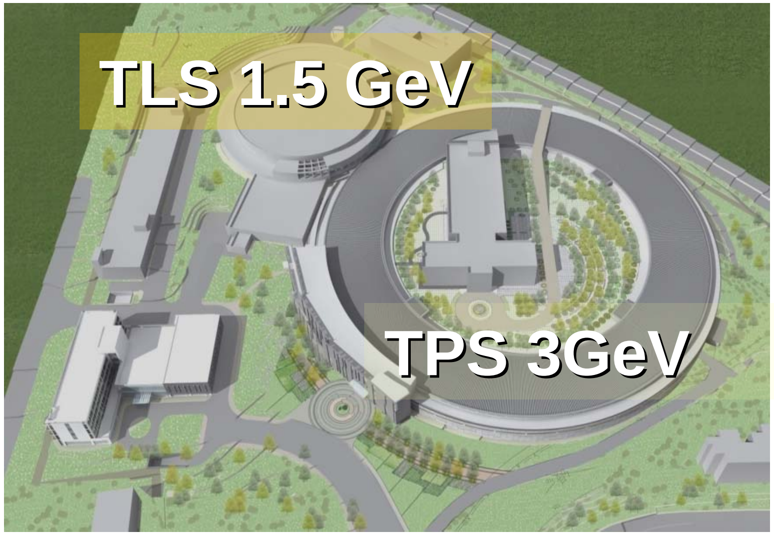
IPAC10
The 1st International Particle Accelerator Conference
Kyoto, Japan / May 23-28, 2010

NSRRC in Hsinchu Science Park, Taiwan before Feb. 2010

1.5 GeV Taiwan Light Source since 1993

Taiwan Photon Source (TPS) Project at NSRRC



Parameters	TLS	TPS
Electron Energy	1.5 GeV	**3.0 GeV**
Beam Current	360 mA	**400 mA**
Circ. (Str. Ring)	120 m	**518.4 m**
Circ. (Booster)	72 m	**496.8 m**
SR Lattice	6-cell TBA	**24-cell DBA**
Emittance	25 nm-rad	**1.6 nm-rad**

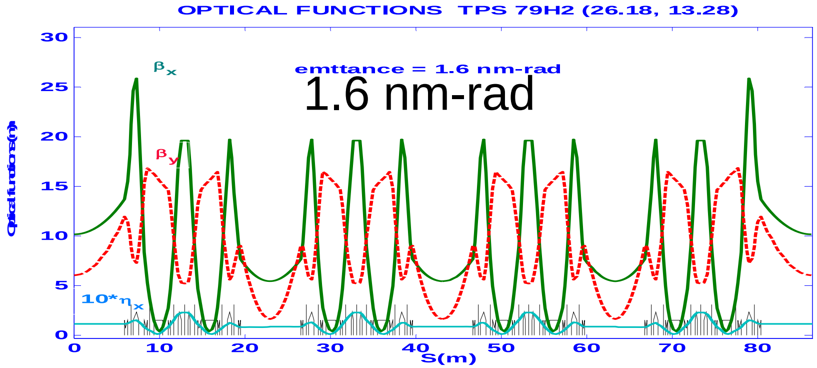
TPS Project milestone

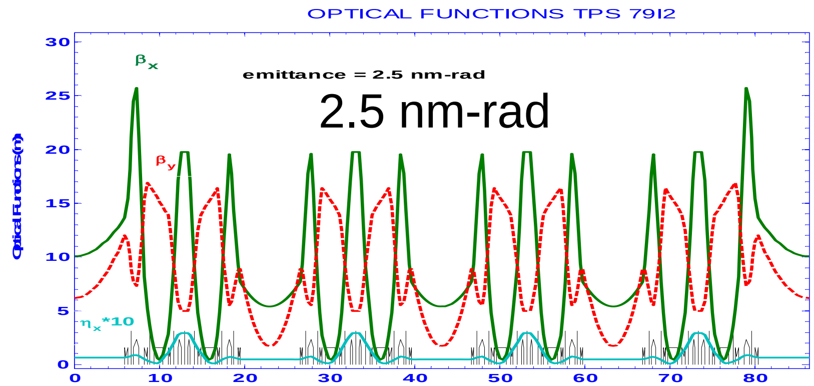
2004 Feasibility study
2006 Project proposed
2007 Budget approval
2010 Groundbreaking
2014 User operations

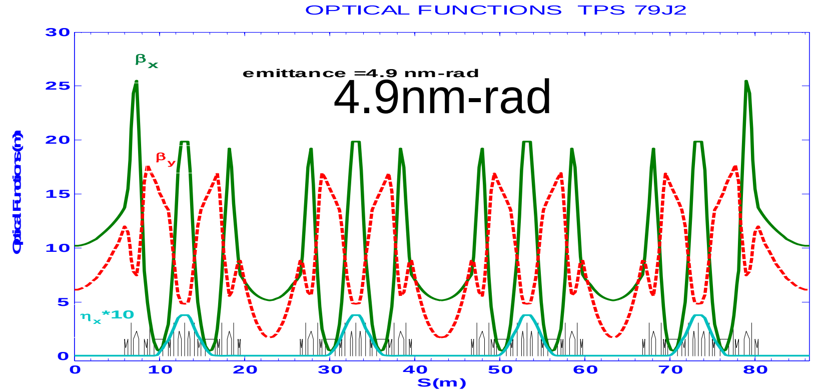
Outline

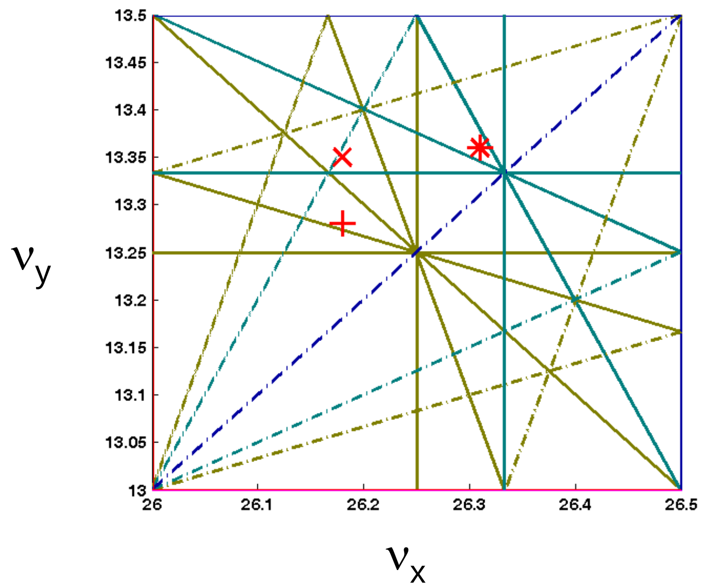
- **Linear lattice**
- **Nonlinear optimization**
- **Orbit correction**
- **coupling control**
- **ID effect**
- **Touschek lifetime**
- **Impedance and instabilities**
- **Alternative lattices**
- **Summary**

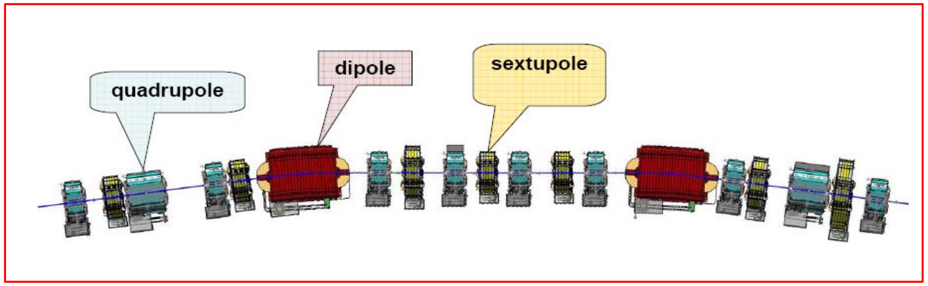
TPS Storage Ring Lattice Functions







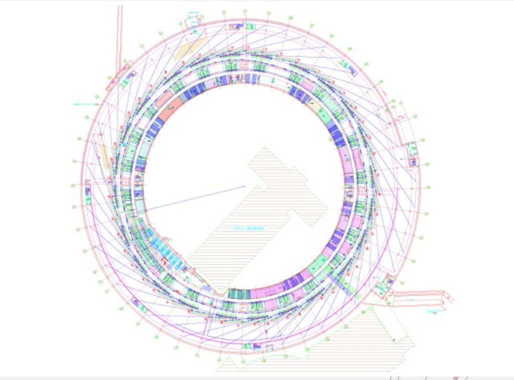


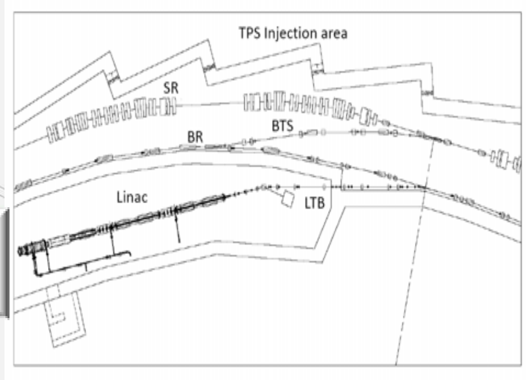


24 DBA cells

Major Parameters of TPS Storage Ring

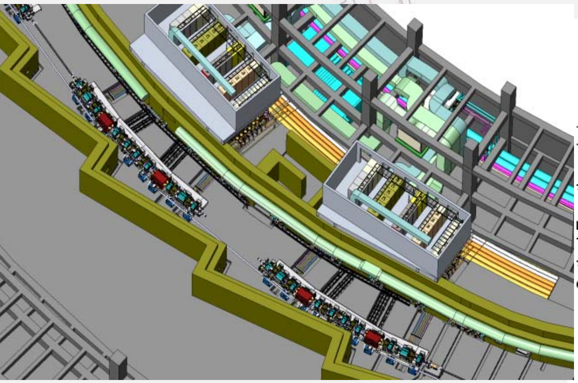
Circumference C (m)	518.4
Energy E (GeV)	3.0
Beam current (mA)	400
Natural emittance ε_{x0} (nm-rad)	1.6
Straight sections (m)	12 (x6) + 7 (x18)
Radiofrequency (MHz)	499.654
Harmonic number h	864
RF voltage (MV)	3.5
Energy loss per turn (dipole) (MeV)	0.85269
Betatron tune ν_x/ν_y	26.18 /13.28
Momentum compaction (α_1, α_2)	2.4×10^{-4}, 2.1×10^{-3}
Natural energy spread σ_E	8.86×10^{-4}
Damping time $\tau_x/\tau_y/\tau_s$ (ms)	12.20 / 12.17 / 6.08
Natural chromaticity ξ_x/ξ_y	-75 / -26
Synchrotron tune ν_s	0.00609
Bunch length (mm) σ_l	2.86

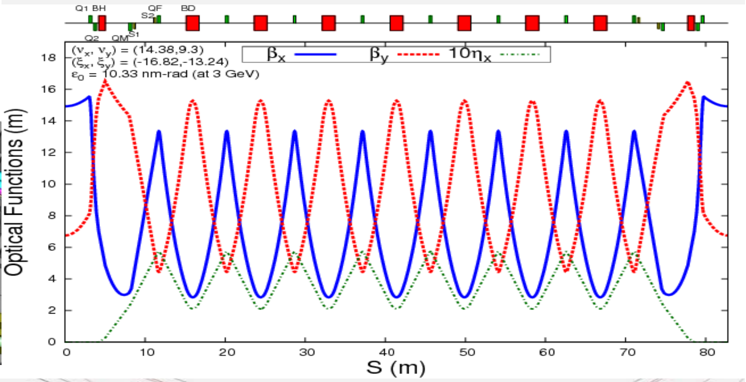


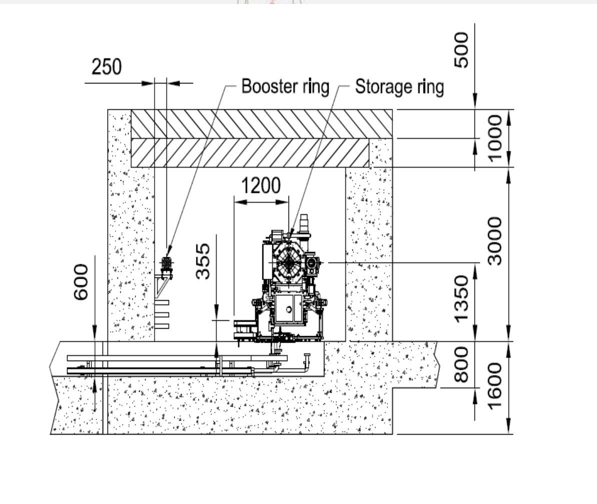


TPS injector parameters

Linac energy : 150 MeV
Booster energy: 3 GeV
Booster circumference: 496.8 m
Lattice structure: Modified FODO
Booster emittance: 10 nm-rad
Repetition rate: 3 Hz
RF: 500 MHz



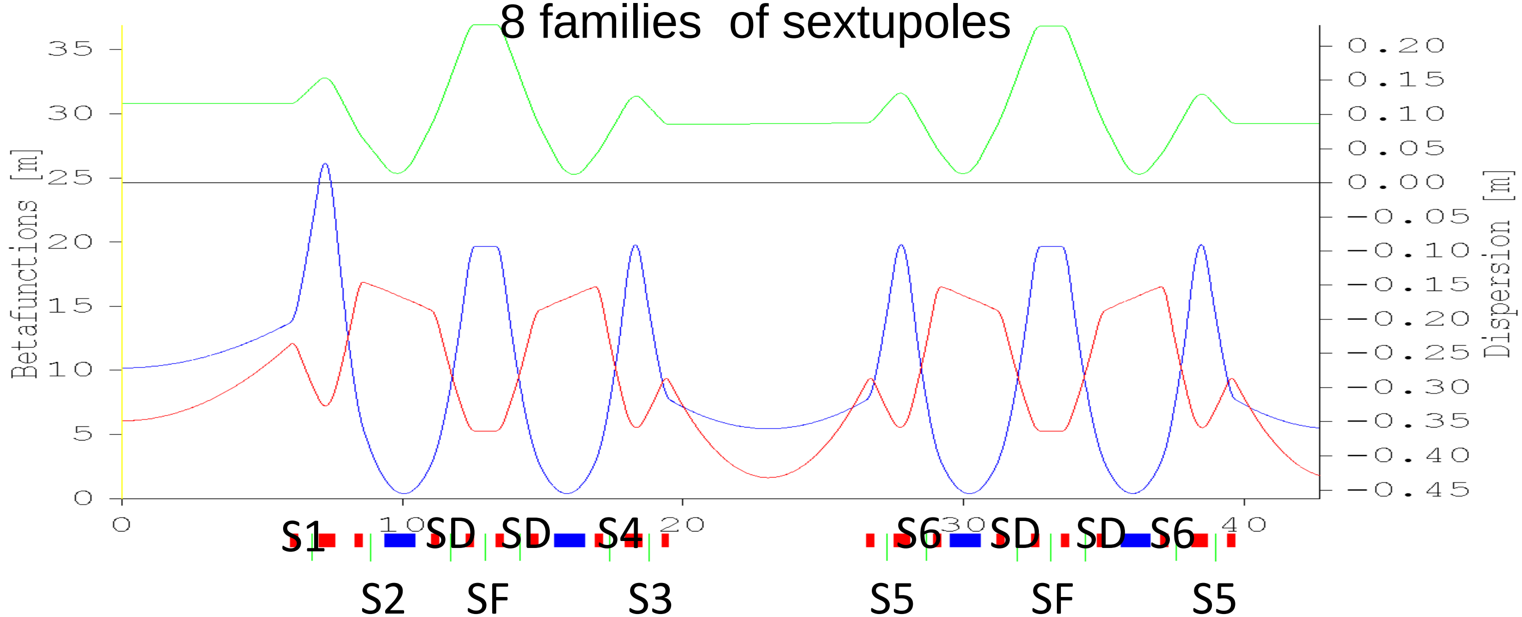




TPS Sextupole Scheme

- 8 sextupole families to minimize the first 12 driving terms in the single resonance approach .
- The locations are appropriately chosen and the strengths are optimized using OPA and BETA .
- An iterative process between linear lattice and nonlinear optimization is repeated until reach acceptable design.

8 families of sextupoles



OPA08

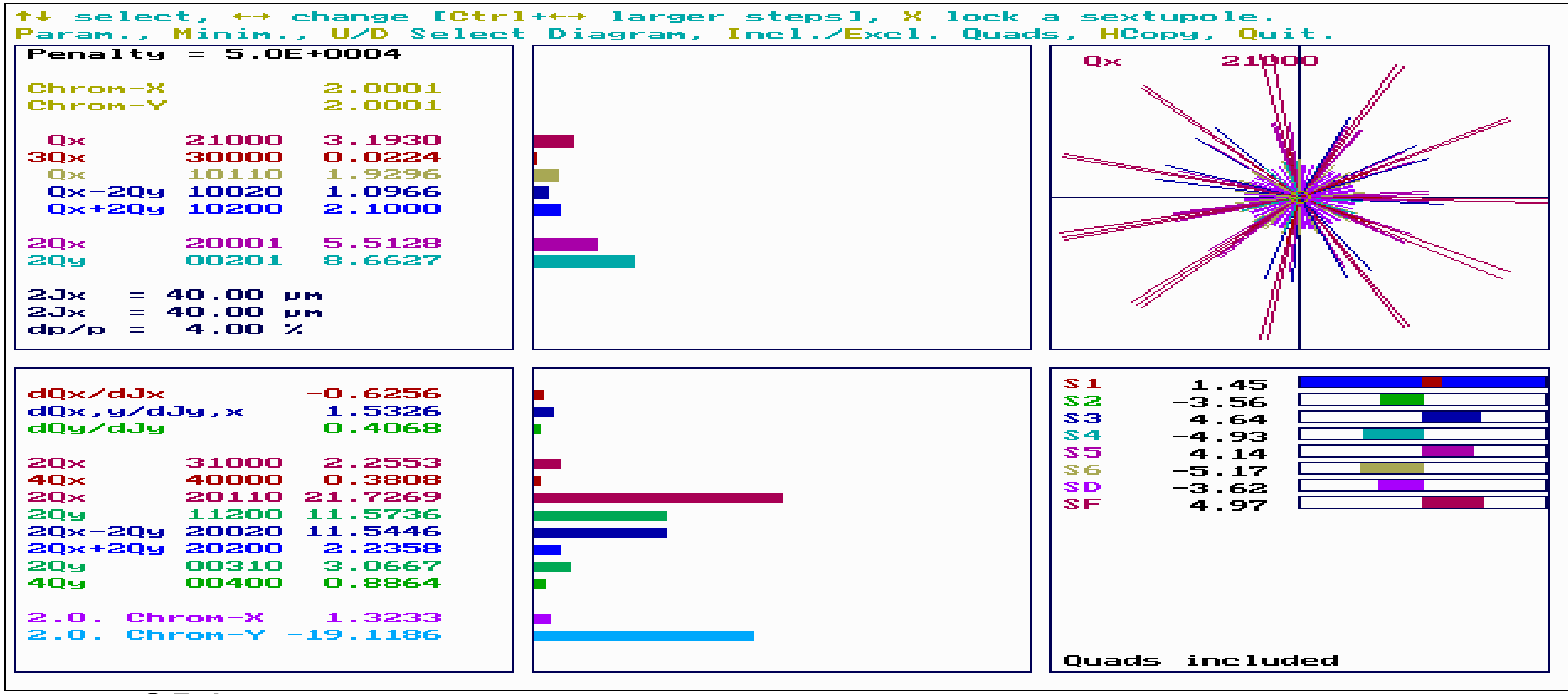
Minimization of driving terms

$$h_{jklmp} \propto \sum_{n}^{Nsxt} (b_3 L)_n \beta_{xn}^{\frac{j+k}{2}} \beta_{yn}^{\frac{l+m}{2}} \eta_n^p e^{i[(j-k)\varphi_{xn} + (l-m)\varphi_{yn}]} - [\sum_{n}^{Nquad} (b_2 L)_n \beta_{xn}^{\frac{j+k}{2}} \beta_{yn}^{\frac{l+m}{2}} e^{i[(j-k)\varphi_{xn} + (l-m)\varphi_{yn}]}]_{p \neq 0}$$

$$\begin{aligned} f = {} & p_1 |h_{21000}(Q_x)|^2 + p_2 |h_{10110}(Q_x)|^2 \\ & + p_3 |h_{30000}(3Q_x)|^2 \\ & + p_4 |h_{10020}(Q_x + 2Q_y)|^2 + p_5 |h_{10200}(Q_x - 2Q_y)|^2 \\ & + p_6 |dQ_x / dJ_x|^2 + p_7 |dQ_x / dJ_y|^2 \\ & + p_8 |dQ_y / dJ_y|^2 \\ & + p_9 |h_{11001}(\xi_x)|^2 + p_{10} |h_{00111}(\xi_y)|^2 \\ & + p_{11} |h_{20001}(2Q_x(\delta))|^2 + p_{12} |h_{00201}(2Q_y(\delta))|^2 \end{aligned}$$

4 Chromatic terms
5 Geometry terms
3 Amplitude dependent terms

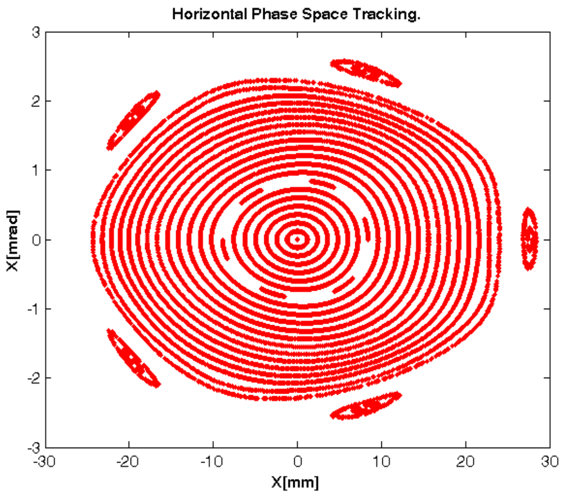
Nonlinear Optimization with Sextupoles

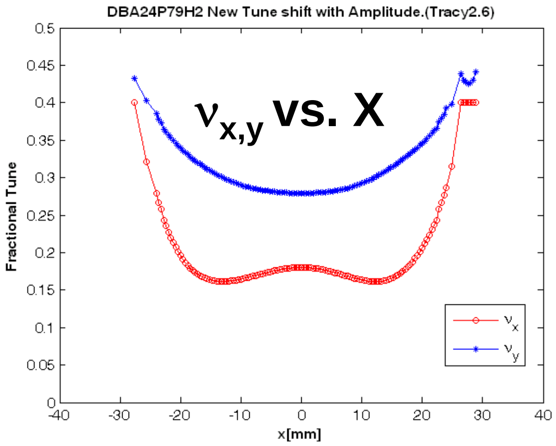


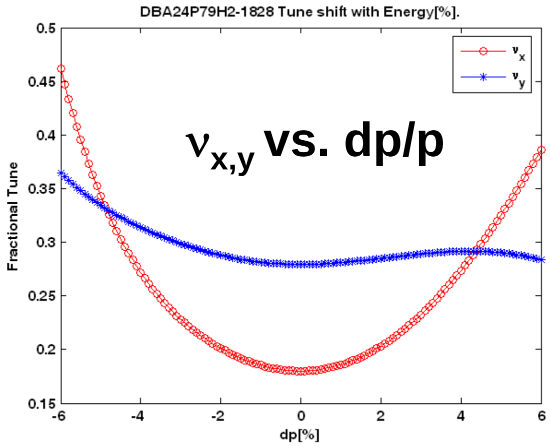
OPA

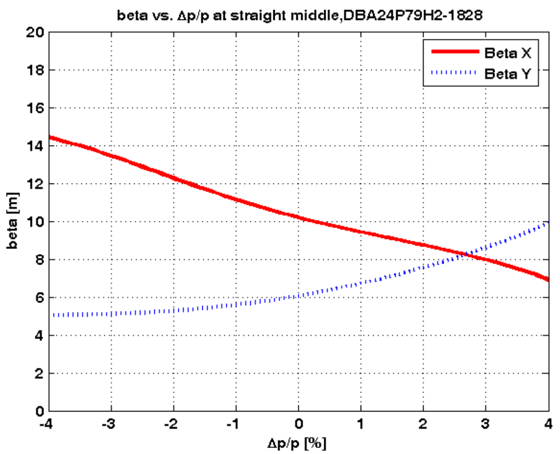
8 families of sextupoles for nonlinear optimization. Chromaticity of +5 in both planes are still with acceptable dynamic aperture and energy acceptance.

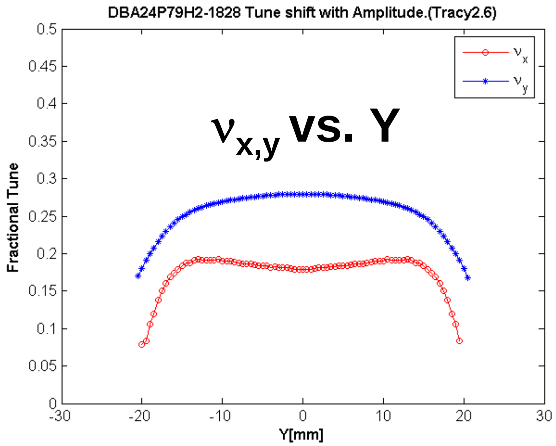
Phase Space
Betatron Function vs Energy
Tune Shifts vs. Amplitude and Energy
Dynamic Aperture

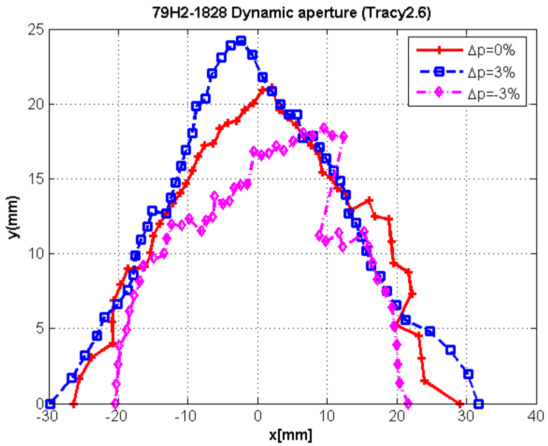






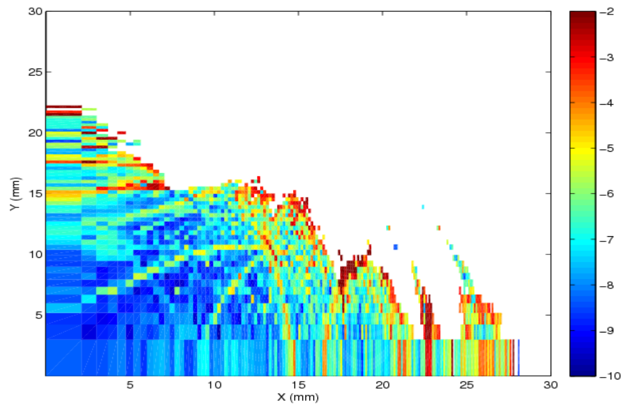


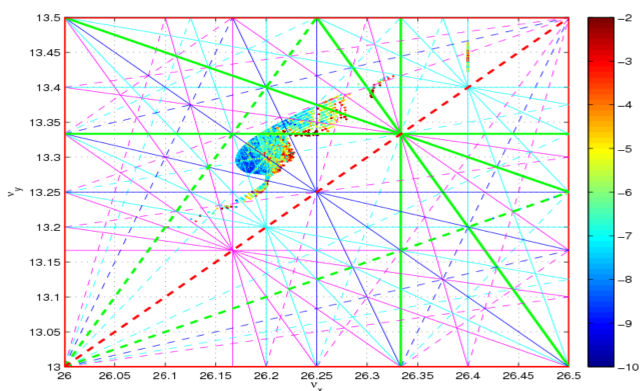




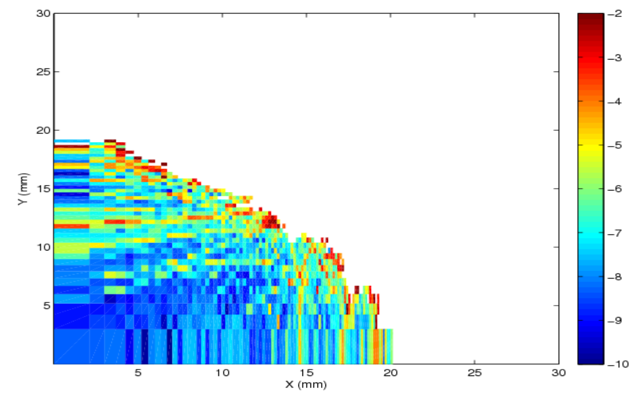
Dynamic Aperture and Frequency Map Analysis

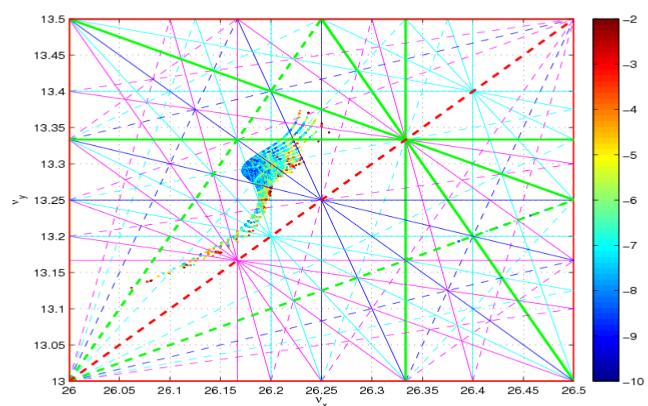
Without multipole errors





With multipole errors

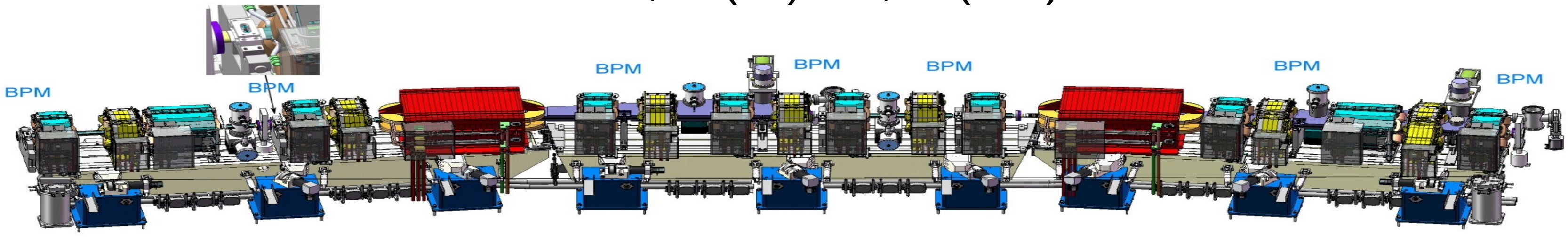




Tune diffusion rate D= $\log_{10}((\Delta\nu_x)^2+(\Delta\nu_y)^2)^{1/2}$ for tune difference between the first 512 turns and second 512 turns

COD Correction Scheme

168 BPM, 72(96) HC, 96(120) VC



Error Source (rms) 3 sigma truncated	
Girder displacement x, y (mm)	0.1
Girder roll θ (mrad)	0.1
Quad and sext displacement x,y w.r.t. girder (mm)	0.03
Dipole displacement x,y (mm)	0.5
Dipole roll θ (mrad)	0.1
Dipole field error (10^{-3})	1
BPMs displacement x, y (mm)	0.1

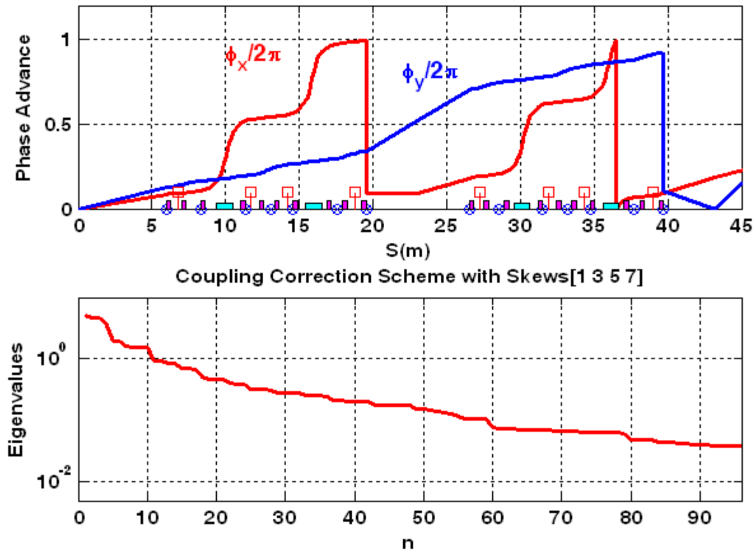
7 BPM each cell
3 HC(+1) and 4 VC(+1) each cell for SVD but all (7) sextupoles are with HC and VC.

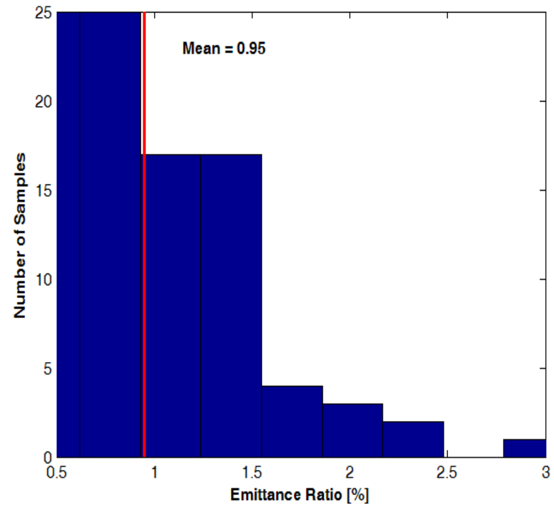
COD due to Errors:
Horizontal: 3.8 mm rms
Vertical : 2.2 mm rms

After correction:
Horizontal: 0.08 mm rms
Vertical : 0.06 mm rms

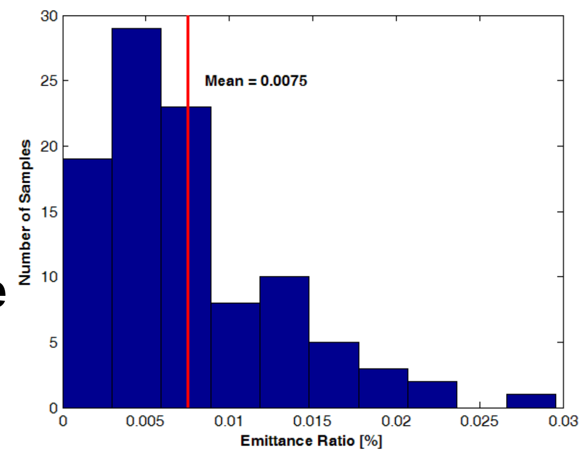
Real-time orbit feedback systems using 48 h/v fast correctors keep beam orbit in sub-micron range

Coupling Correction





Coupling ratio
Before
correction
100 machines



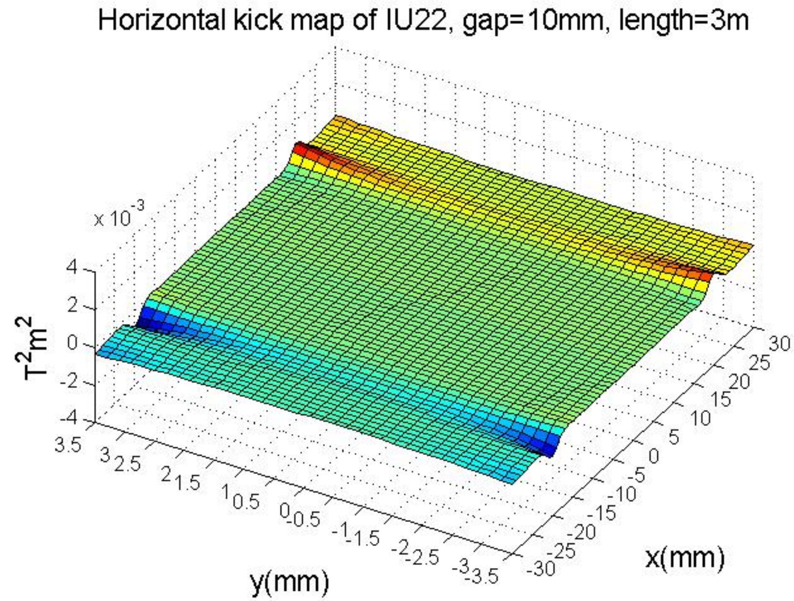
Coupling ratio
After correction

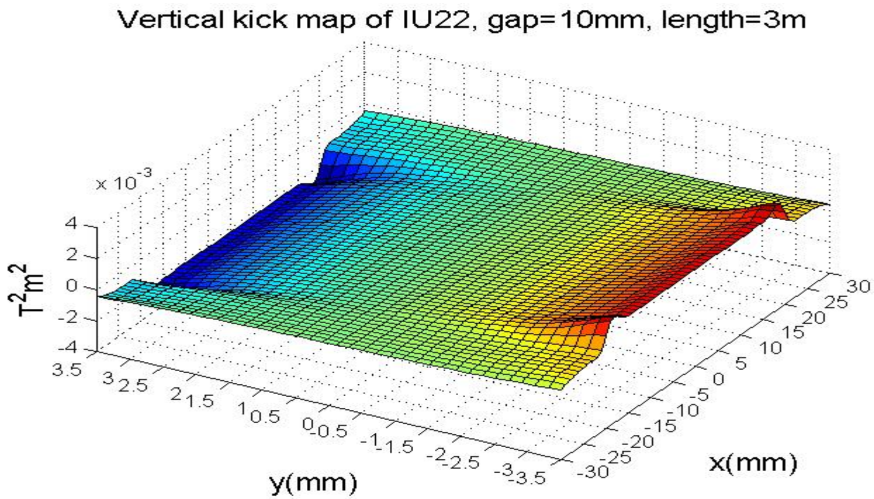
- **Using cross-plane response matrix and SVD method to correct both betatron coupling and vertical dispersion with a set of skew quadrupoles.**
- **With 96 skew quads, <1% emittance ratio can be achieved.**

ID Effects

- IDs will change optical functions, emittance, tune, energy spread, etc, and have been well studied.
- Using kick map form ID model (RADIA), we perform dynamic aperture tracking using Tracy-2.
- Multipole errors and chamber limitation are included in the simulation.
- First phase IDs are studied.
- Acceptable dynamic aperture tracking results are shown.
- After optics and tune re-matching, longer Tosuchek lifetime is obtained.

In-vacuum Undulator IU22





IU22:

- period length = 22 mm
- Number of period =139
- Total length = 3.0 m
- Peak field

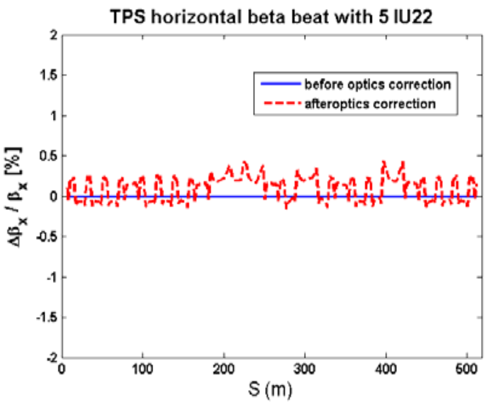
  B_y=0.84 T for 7 mm gap

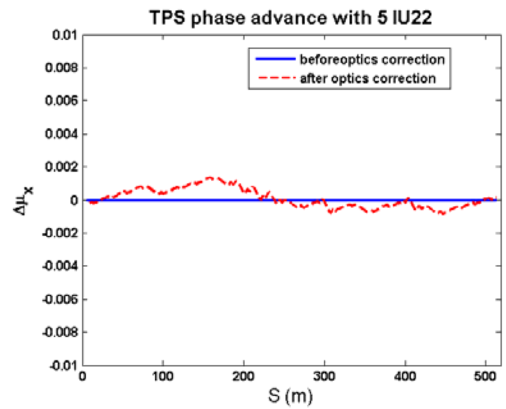
  B_y=0.5 T for 10 mm gap

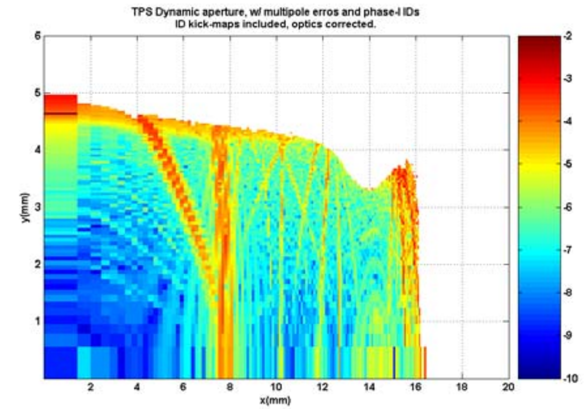
Optics Correction with ID (IU22)

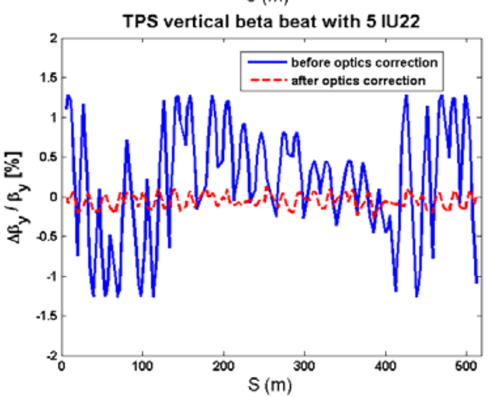
IU22 (length=2m X 2 + 3m X3, gap=7mm)

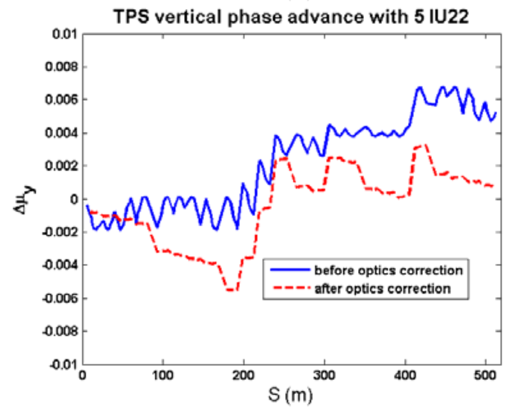
SVD algorithm– restore lattice functions and phase advance and working point using all (240) quadrupoles

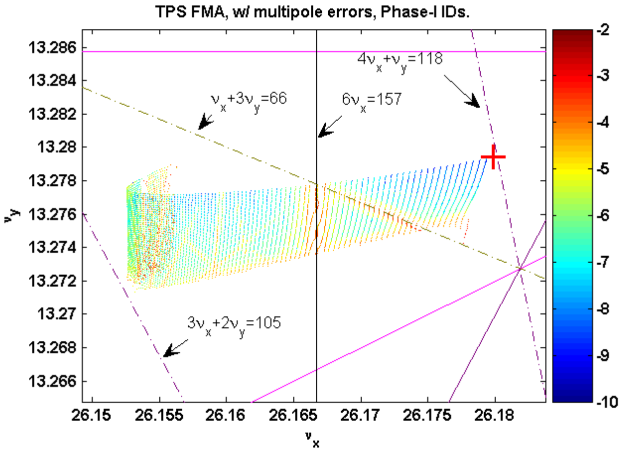




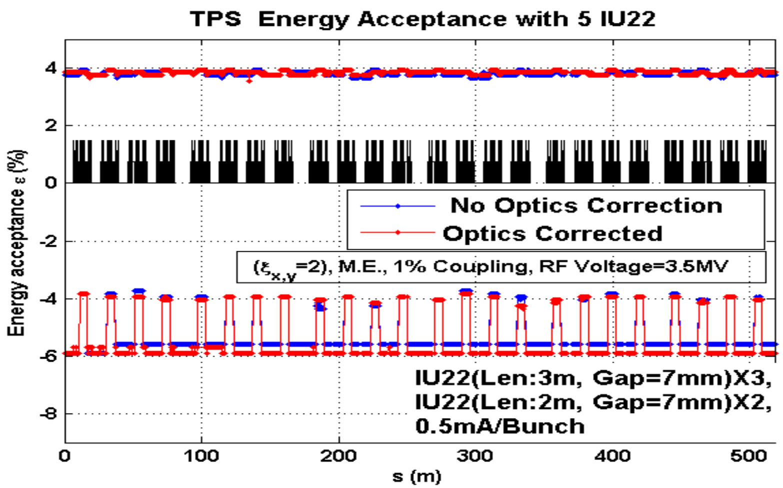


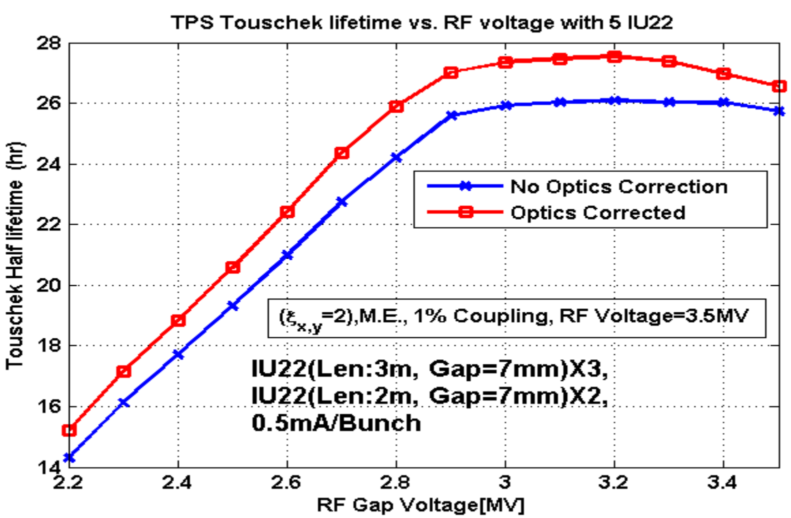






Touschek Lifetime with 5 IU22





Bruck formula

$$\frac{1}{\tau_{T_{1/2}}} = \left(\frac{r_e^2 c N}{8\pi\gamma^3 \sigma_l}\right) \cdot \frac{1}{L}\int_0^L \frac{C\left[\left(\frac{\varepsilon_{acc}(s)}{\gamma\sigma_x'(s)}\right)^2\right]}{\sigma_x(s)\sigma_z(s)\sigma_x'(s)\varepsilon_{acc}^2(s)} ds$$

$$C(\varsigma) = -1.5e^{-\varsigma} + \frac{\varsigma}{2}\int_\varsigma^\infty \frac{\ln u}{u} e^{-u} du + 0.5(3\varsigma - \varsigma\ln\varsigma + 2)\int_\varsigma^\infty \frac{e^{-u}}{u} du$$

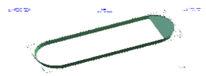
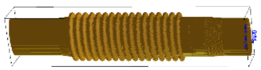
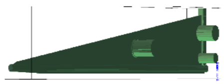
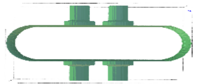
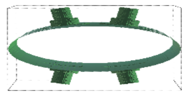
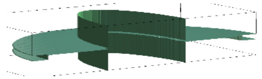
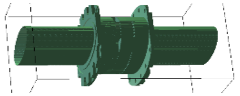
Tracy-II 6-D tracking
- 5 IU22 gap 7 mm
- Multipole field errors
- 1% coupling
- Chromaticity=2
- Kick maps
- optics corrected

WEPEA059

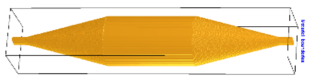
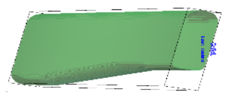
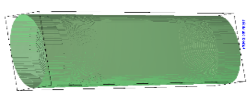
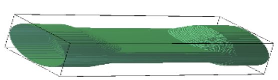
Impedance Budget

Numerical code GdfidL is used to simulate 3D geometry of each element.
Total longitudinal Impedance $|Z_{||}/n|$ =0.37 ohm

TUPD057

Components		$\|Z_{\|\|}/n\|, \Omega$	$k_{\|\|}, V/pC$	$k_x, V/pC/m$	$k_y, V/pC/m$	Estimated number of components
Σ Absorbers (injection section)		$9.27 \cdot 10^{-6}$	$1.36 \cdot 10^{-3}$	$4.79 \cdot 10^{-2}$	$4.99 \cdot 10^{-11}$	1
Σ Absorbers (straight sections)		$3.62 \cdot 10^{-5}$	$6.42 \cdot 10^{-3}$	$1.78 \cdot 10^{-1}$	$6.71 \cdot 10^{-11}$	24
Bellows (straight sections)		$3.14 \cdot 10^{-4}$	$6.12 \cdot 10^{-2}$	$7.53 \cdot 10^{-3}$	$1.99 \cdot 10^{-1}$	144
Bending chamber		$1.04 \cdot 10^{-5}$	$2.75 \cdot 10^{-3}$	$8.70 \cdot 10^{-2}$	$1.35 \cdot 10^{-3}$	48
Primary BPM (long straight sections)		$1.72 \cdot 10^{-4}$	$6.39 \cdot 10^{-2}$	$1.26 \cdot 10^{-5}$	$1.95 \cdot 10^{-6}$	48
Standard BPM (achromatic sections)		$8.50 \cdot 10^{-5}$	$3.35 \cdot 10^{-2}$	$1.24 \cdot 10^{-3}$	$9.00 \cdot 10^{-4}$	168
Flange (straight sections)		$3.57 \cdot 10^{-4}$	$5.82 \cdot 10^{-2}$	$2.57 \cdot 10^{-4}$	$3.15 \cdot 10^{-4}$	168
Gate valve (comb type, straight sections)		$5.99 \cdot 10^{-5}$	$1.34 \cdot 10^{-2}$	$4.66 \cdot 10^{-2}$	$1.11 \cdot 10^{-2}$	56

Impedance Budget (continued)

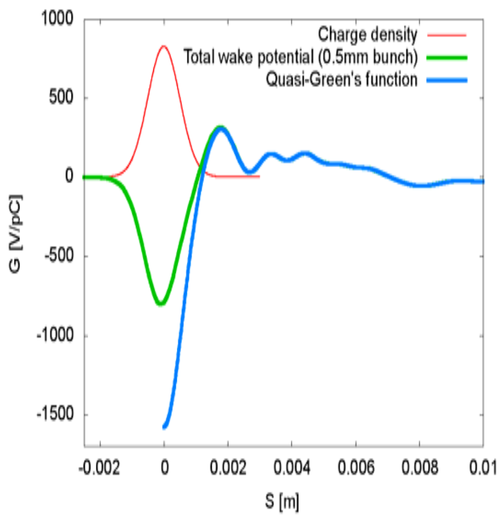
Components		$\|Z_{\|\|}/n\|$, Ω	$k_{\|\|}$, V/pC	k_x, V/pC/m	k_y, V/pC/m	Estimated number of components
Pumping slots chamber (straight sections)		$1.36 \cdot 10^{-5}$	$1.17 \cdot 10^{-3}$	$2.53 \cdot 10^{-10}$	$1.37 \cdot 10^{-11}$	96
SRF Cavity (500 MHz)		$4.44 \cdot 10^{-2}$	$4.10 \cdot 10^{-1}$	$2.26 \cdot 10^{-4}$	$1.81 \cdot 10^{-5}$	4
SRF Cavity Tapers		$1.09 \cdot 10^{-2}$	4.84	$2.03 \cdot 10^{-3}$	$2.08 \cdot 10^{-1}$	2
Taper (injection section)		$2.57 \cdot 10^{-6}$	$7.15 \cdot 10^{-5}$	$3.59 \cdot 10^{-2}$	$8.17 \cdot 10^{-9}$	1
Taper (straight sections, gap 20mm)		$5.46 \cdot 10^{-4}$	$7.82 \cdot 10^{-2}$	$2.65 \cdot 10^{-2}$	$1.87 \cdot 10^{-1}$	24
ID Taper (straight sections, gap 10mm)		$2.43 \cdot 10^{-3}$	$3.25 \cdot 10^{-1}$	$2.23 \cdot 10^{-4}$	$3.35 \cdot 10^{-1}$	4
Resistive wall		$1.84 \cdot 10^{-2}$	TBD			
Total:		$3.74 \cdot 10^{-1}$	$4.29 \cdot 10^{1}$			987

TUPD057

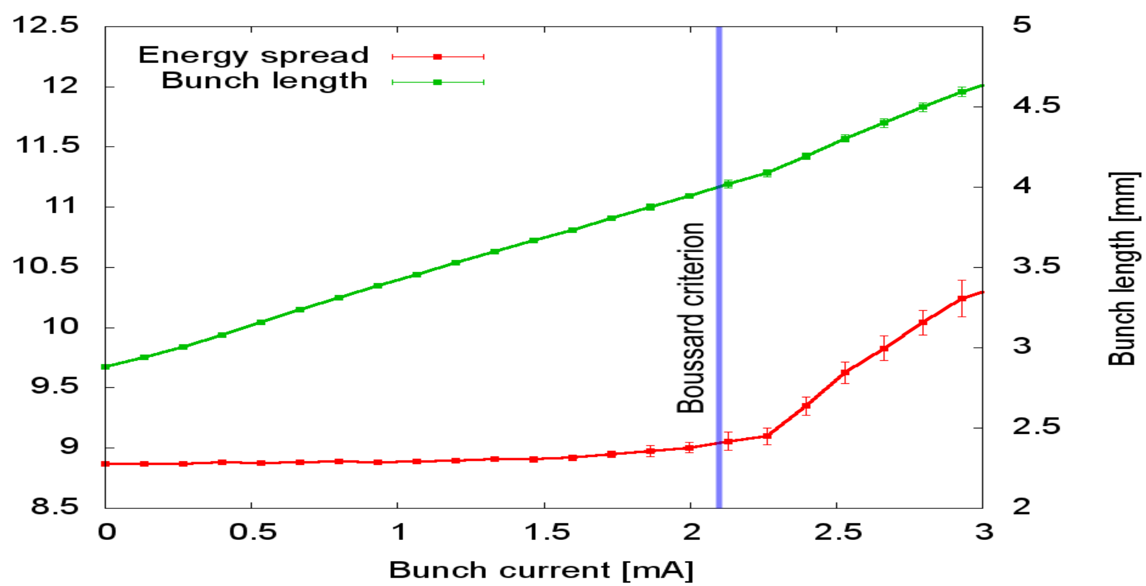
Instability Summary

- **SC RF cavities will not cause coupled-bunch instability in nominal operation.**
- **Resistive wall impedance will cause transverse coupled-bunch instability. To stabilize the beam higher chromaticity is needed. But we require a damping feedback system.**
- **Wake potentials for all the components of the TPS storage ring have been simulated with 3.0mm and 0.5mm bunch length.**
- **Impedance budget has been estimated, around 0.37ohm.**
- **Total quasi-Green's function of the ring has been obtained and used for collective effects simulations in tracking code.**
- **Longitudinal microwave instability and CSR instability have been studied. The threshold currents is higher than nominal operational bunch current.**
- **Active transverse feedback system is required for stable operation.**

Microwave Instabilities
3.0 mm bunch



Total longitudinal wake potential from a 0.5mm bunch and calculated quasi-Green's function for ELEGANT input.



Numerical result obtained with ELEGANT for 10,000 particles after 20,000 turns (CSR considered)

Boussard criterion:

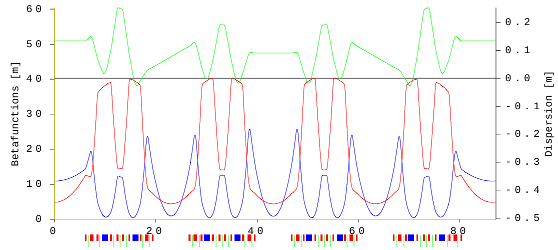
$$I_{th} = \frac{\sqrt{2\pi}\alpha_c (E/e)\,\sigma_s}{R\left|Z/n\right|_{eff}}\left(\frac{\sigma_E}{E}\right)^2$$

$$\left|\frac{Z}{n}\right|_{eff} = \left|\frac{Z}{n}\right|\left(\frac{\sigma_s}{b}\right)^{1.68}$$

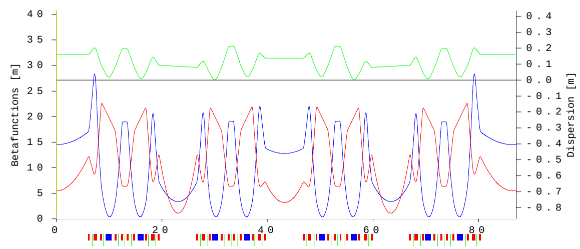
TUPD058

Alternative Lattice Configurations

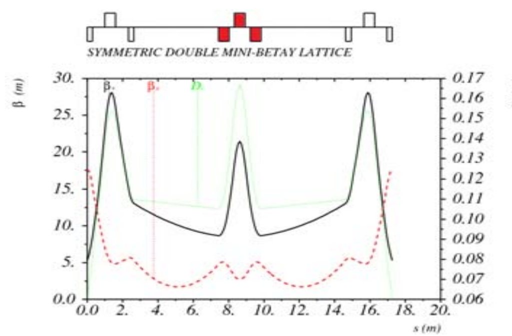
- Low α short bunch -- reduce 1st –order α so that bunch length can be reduced by a factor of 5 (a few ps).
- High/low β_x in the straight -- provide tuning flexibility for optimizing photon beam properties for the experiments.
- Double mini- β_y in the long straight – accommodate two mini-gap insertion devices in a long straight.

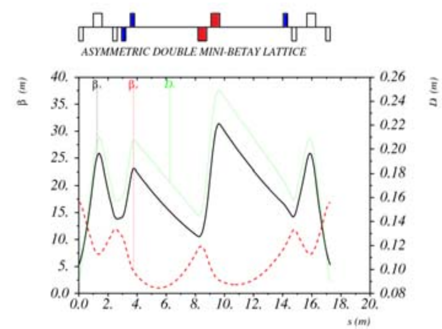


α_1 = 7.3e-6
ε_x= 2.8 nm-rad.



ε_x= 1.6 nm-rad





THPE030

Summary

- **TPS Linear and nonlinear beam dynamics issues are investigated.**
- **Optimization procedures for dynamic aperture and momentum acceptance are emphasized.**
- **Impedance simulations are carried out and instabilities are studied and possible cures are proposed.**
- **Acceptable design is achieved and construction is going on.**
- **Alternative lattices for specified purposes are also studied.**

Thank you for your attention!