NSLS-II Lattice Development:

Reduced Horizontal Beta Function in Long Straights

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U.S. DEPARTMENT OF ENERGY

BROOKHAVEN NATIONAL LABORATORY

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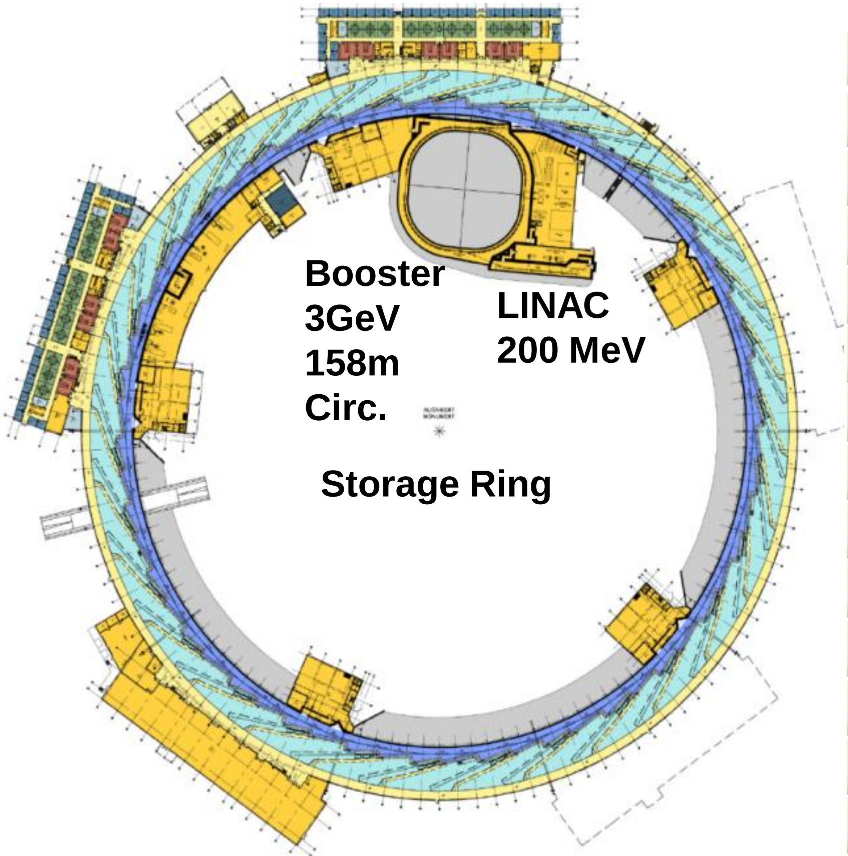
Outline

- Overview of NSLS-II
- The storage ring lattice considerations
  - Physics design and parameters (linear)
  - Dynamic aperture optimization (nonlinear)
- Lattice development with lower horizontal beta function in long straights
  - Motivation
  - Linear lattice solutions
  - Nonlinear dynamic aperture optimization
- Summary

NSLS-II Main Parameters

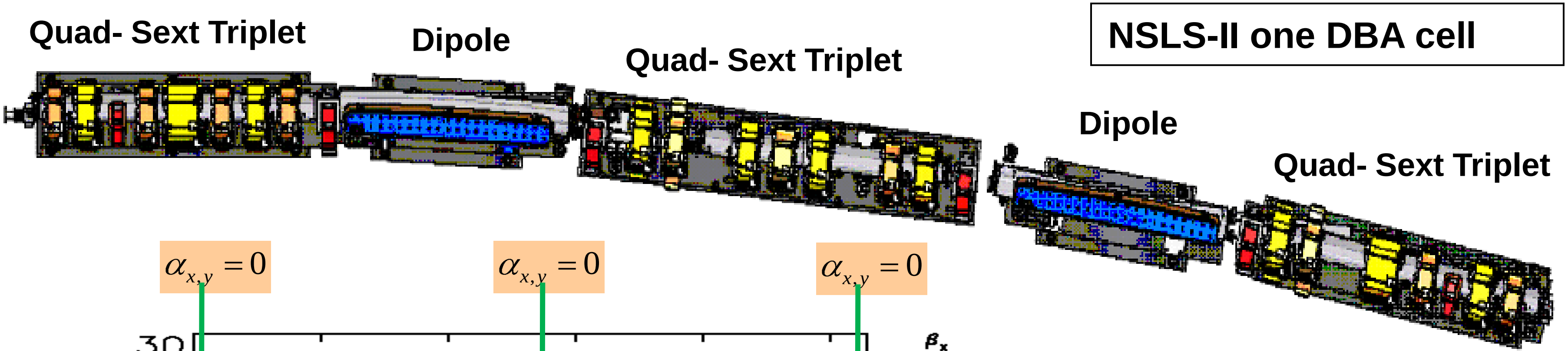


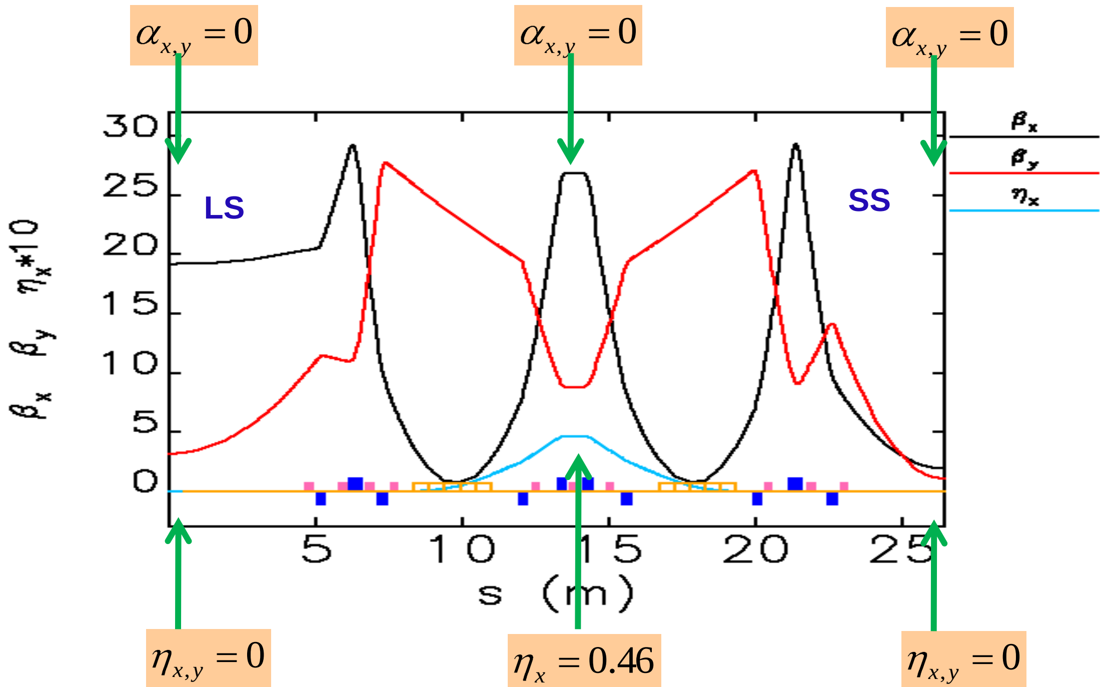
Characteristics	Value
Energy [GeV]	3
Total current (mA)	500
Circumference [m]	792
Number of DBA cells	30
βx/βy [m] in 15 9.3m long straights	19.0/3.0
βx/βy [m] in 15 6.6m short straights	2.0/1.0
Horizontal emittance of bare lattice [nm-rad]	2.0
Horizontal emittance with three 7m 1.8T DW [nm-rad]	1.0
Vertical emittance [nm-rad]	0.008
Momentum Compaction	0.00037
Bunch length, RMS [ps]	15-30
Energy spread, RMS	0.094%
RF Frequency [MHz]	500
RF acceptance (%)	3
Harmonic number	1320
Number of bunches at 80% fill	1040
Touschek Lifetime [hrs]	>3

Average spectral brightnetss: 10^{21} ph.mm^{-2} mrad^{-2} s^{-1} (0.1%BW)$^{-1}$

Spectral flux density :10^{15} ph.s^{-1} (0.1%BW)$^{-1}$

Design of Baseline Lattice





- Working point : (33.15, 16.27)
- Natural emittance : 2.0nm
- Natural chromaticity : ~ (-110, -45)

Straight	LS	SS	LS w DW
β_x (m)	19.2	1.9	19.1
β_y (m)	3.2	1.1	2.5

- **Linear Knobs**
  - **3QHs(in LS) + 2QMs (in arc) + 3QLs (in SS) = 8 Quad families**

Requirements on Dynamic Aperture

- **Injection** produces particles with initial displacement about 11 mm. Therefore, calculated solutions should provide on-momentum dynamic aperture of >15mm (including IDs and errors)

- **Touschek lifetime** limits the beam lifetime. The Touschek lifetime can be >3hrs with our goal of achieving a calculated energy acceptance of +/-2.5% for scattering at low dispersion and +/- 2.0% for scattering at high dispersion.

$$\frac{1}{\tau_{touschek}} = \frac{r_e^2 cq}{8\pi e \gamma^3 \sigma_s} \cdot \frac{1}{C} \cdot \oint_C \frac{F((\delta_{acc}(s)/\gamma \sigma_{x'}(s))^2)}{\sigma_x(s)\sigma_{x'}(s)\sigma_y(s)\delta_{acc}^2(s)} ds,$$

Nonlinear Constraints and Knobs

- Nonlinear Constraints for Sextupole Optimization
  - First Order Chromatic Terms (5)

$$h_{11001} \to \xi_x^{(1)}$$
$$h_{00111} \to \xi_y^{(1)}$$
$$h_{20001} \to \frac{d\beta_x}{d\delta}$$
$$h_{00201} \to \frac{d\beta_y}{d\delta}$$
$$h_{10002} \to D^{(2)}$$

  - First Order Geometric Terms (5)

$$h_{21000} \to \nu_x$$
$$h_{30000} \to 3\nu_x$$
$$h_{10110} \to \nu_x$$
$$h_{10020} \to \nu_x - 2\nu_y$$
$$h_{10200} \to \nu_x + 2\nu_y$$

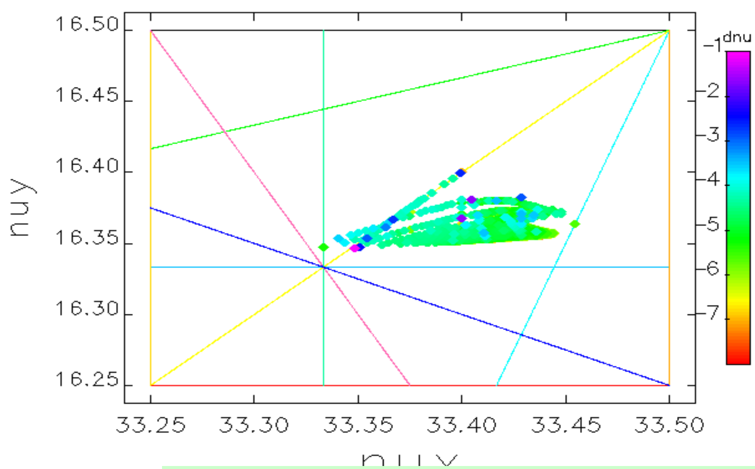
  - Amplitude tune dependence $\frac{d\upsilon_{x,y}}{dJ_{x,y}}$
  - Second order chromaticity

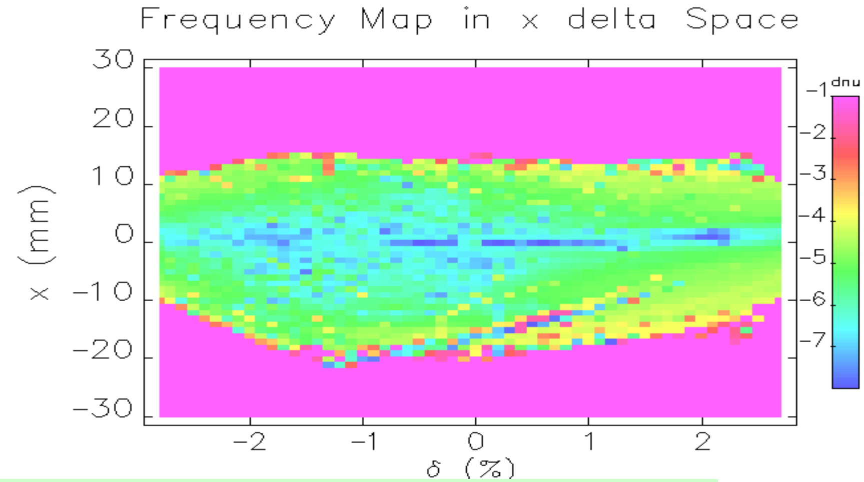
$$\xi_x^{(2)} = -\frac{1}{2}\xi_x^{(1)} + \frac{1}{8\pi}\int ds\{K_2 D^{(2)}\beta_x - [K_1 - K_2 D^{(1)}]\frac{d\beta_x}{d\delta}\}$$
$$\xi_y^{(2)} = -\frac{1}{2}\xi_y^{(1)} - \frac{1}{8\pi}\int ds\{K_2 D^{(2)}\beta_y + [K_1 - K_2 D^{(1)}]\frac{d\beta_y}{d\delta}\}$$

- Nonlinear Knobs

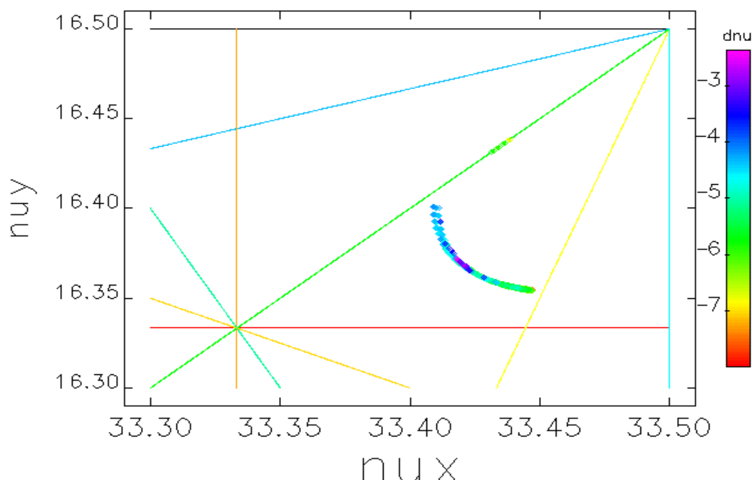
3 chromatic sextupoles + 6 geometric sextupoles = 9 sextupoles families / DBA cell

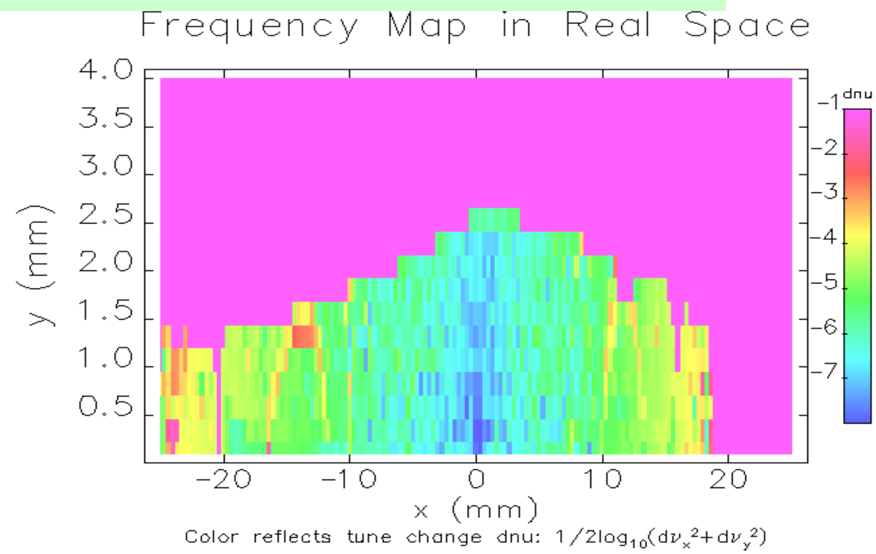
Frequency Map in (x, δ) and (x,y) Phase Space





Current baseline lattice solution with chromaticities of (+2,+2) has been found in simulations. It has sufficient dynamic aperture for good injection efficiency, and provides Touschek lifetime > 3 hours.





Courtesy of W.Guo

Lattice Development

- Motivation : Increase the brightness of IDs by reducing the horizontal beam size in the long straights

- Requirements :
  - maintain 3-fold symmetry of the lattice
  - maintain baseline lattice beta functions in the short straight
  - maintain baseline lattice properties, such as emittance and natural chromaticity

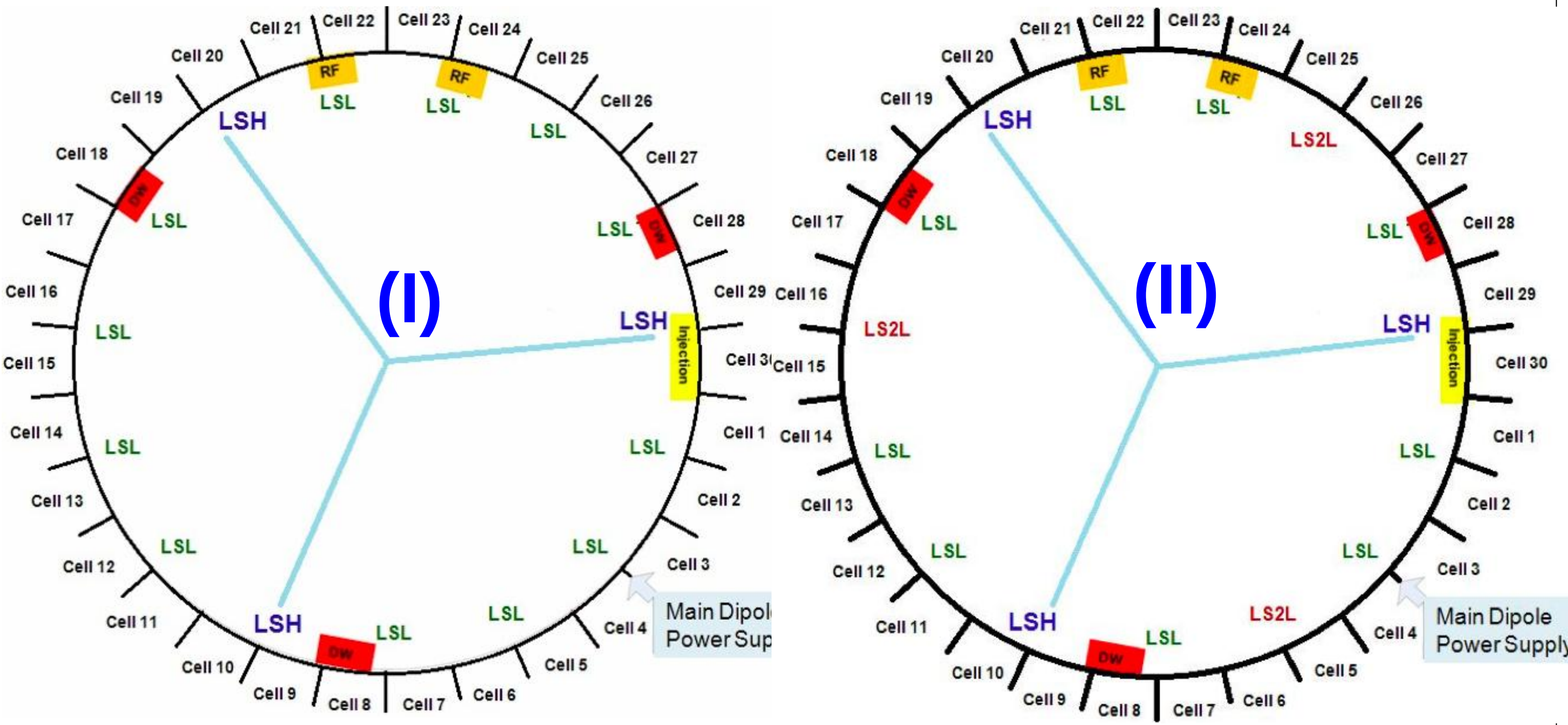
- Approach : lower the horizontal beta function in the long straights

  (I) using the existing quadrupoles
  - No more quads are needed

  (II) adding additional quadrupoles at the center of long straights
  - Two source points are produced in one long straight

Lattice Layout for Two Approaches

Lattice with 3-fold symmetry



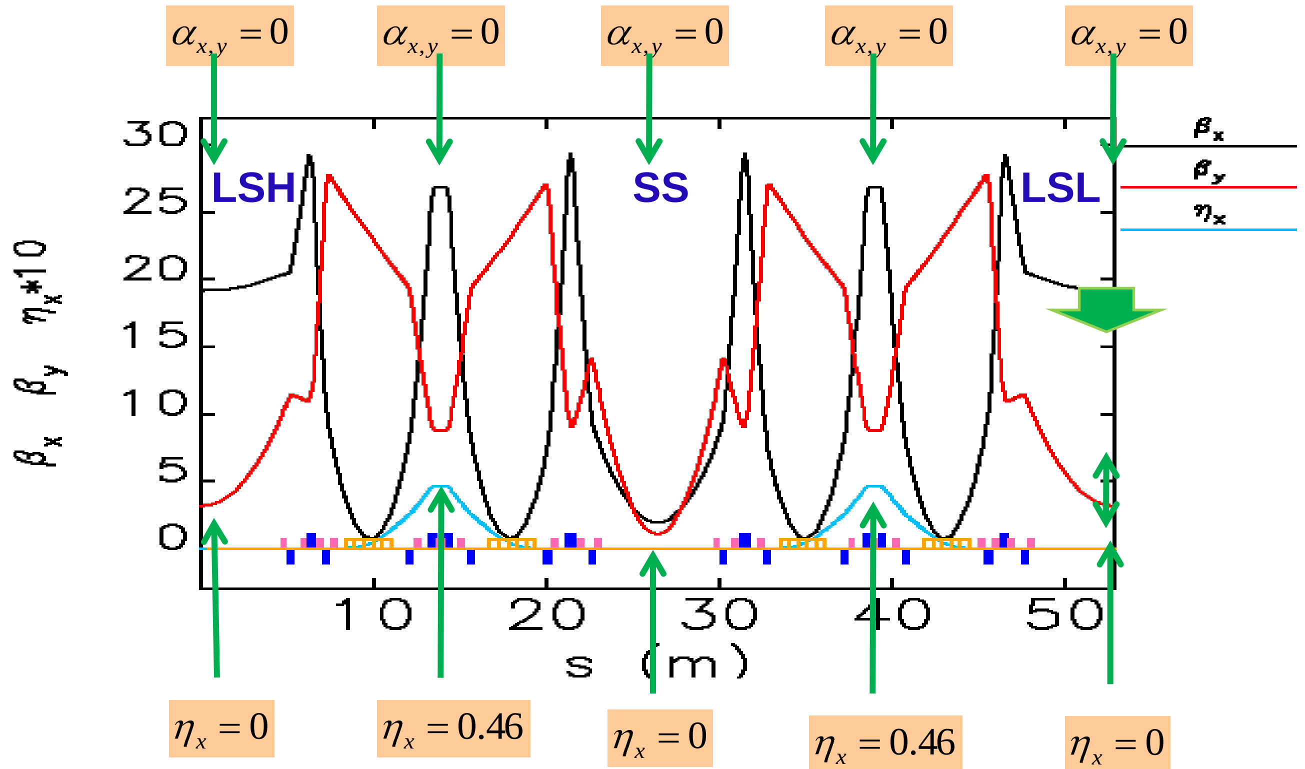
Injection	
RF	DW

LSH: long straight with high horizontal beta function

LSL: long straight with low horizontal beta function

LS2L: long straight with two low horizontal beta functions

Approach (I) : Linear Optimization



LSH: long straight with high horizontal beta function

LSL: long straight with low horizontal beta function

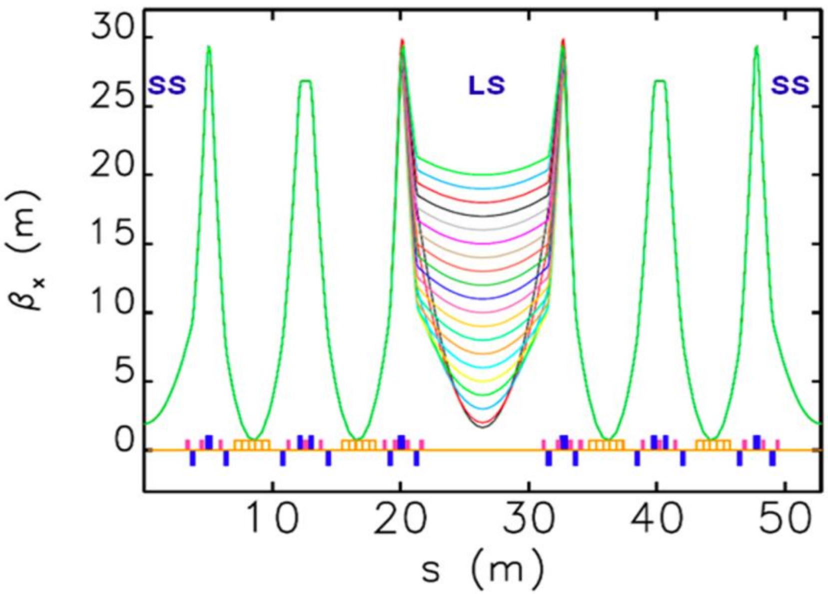
SS : short straight

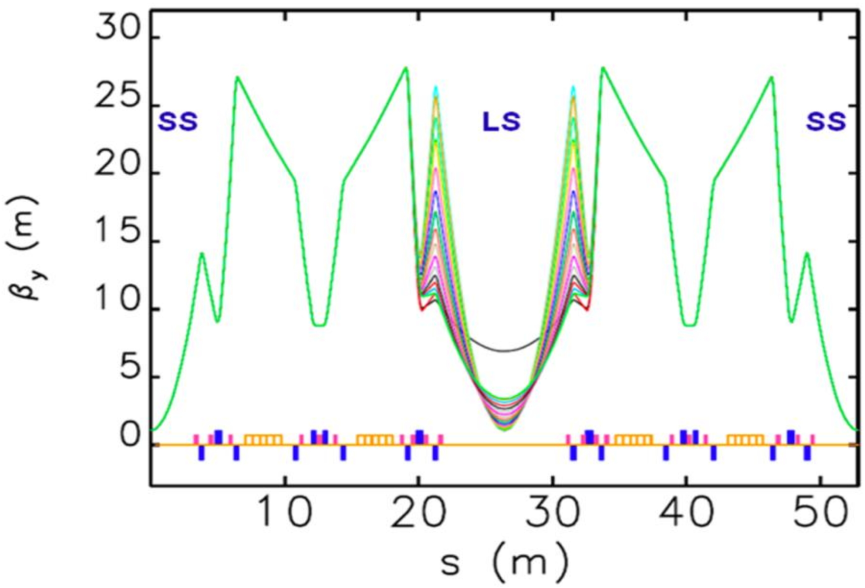
- Natural emittance : 2.0nm
- Natural chromaticity : ~ (-110, -45)
- Similar lattice function in the LSHs and SS

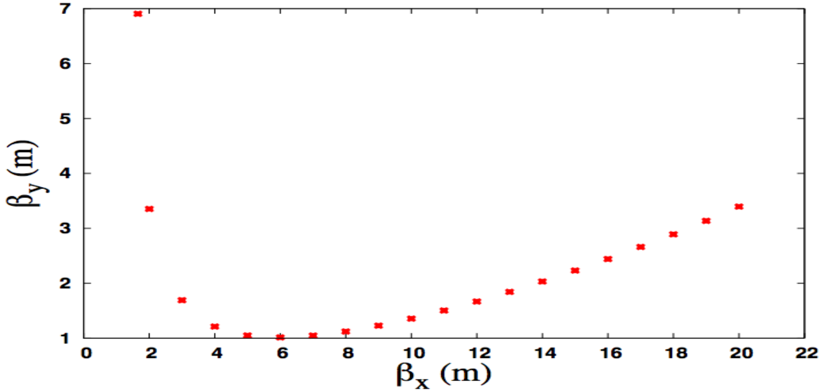
- **Linear Knobs**
  - 3QHs(LSH) + 2QMs + 3QLs + 3QHNEWs (LSL) = 11 Quad families

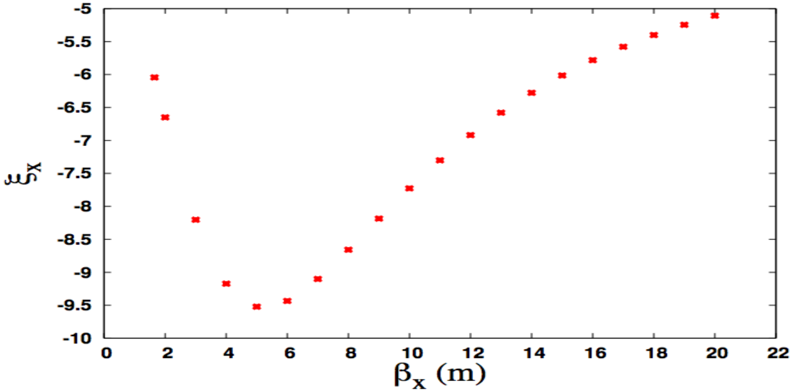
Local Lattice Functions Studies Results

Method: locally change the 3 QH families to scan the horizontal beta function at the center of long straight with 1m unit step







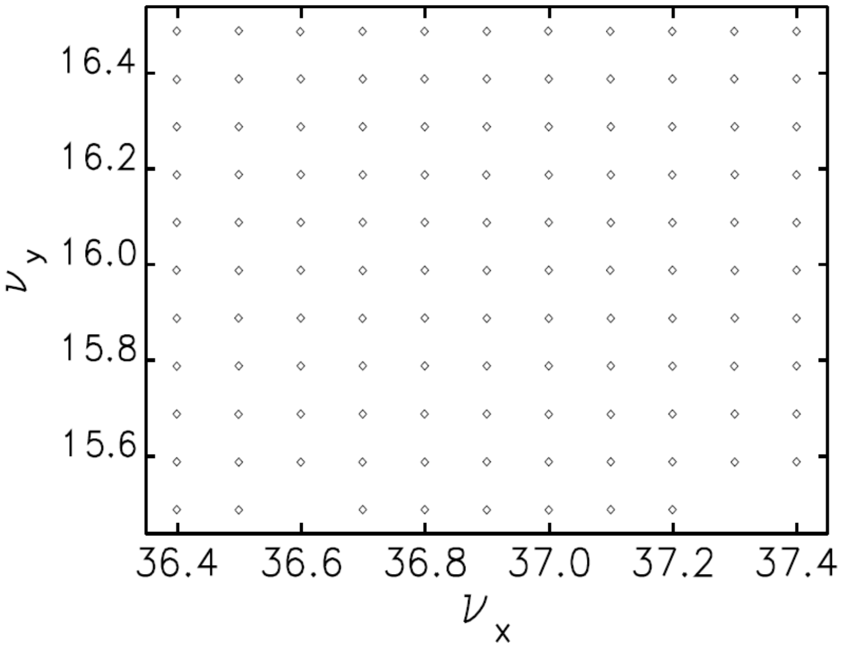


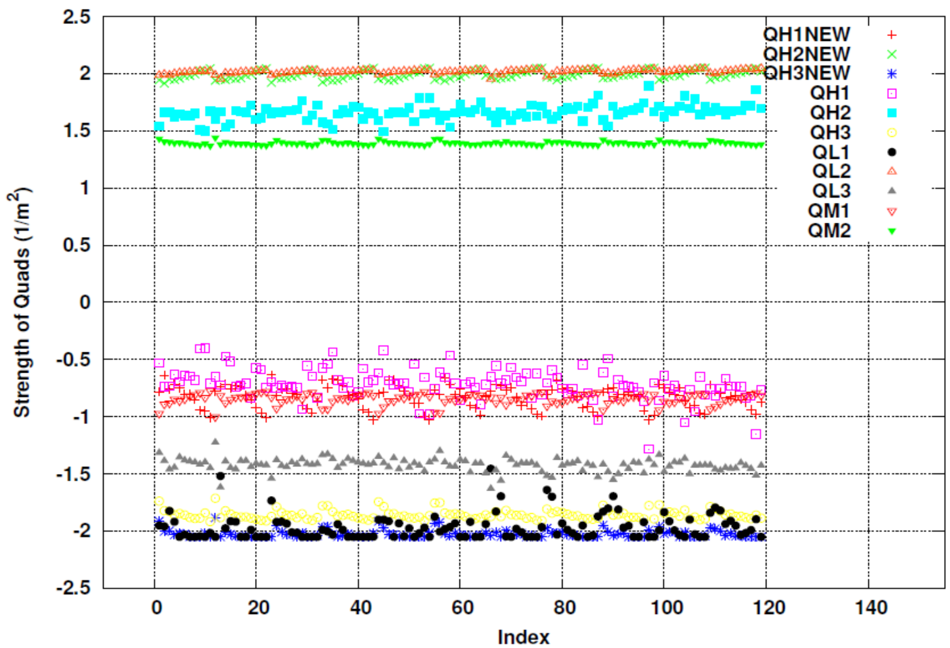
Linear Lattice Tunability

- Tune scan for the 3-fold symmetric high-low horizontal beta function lattice
- All 11 quad families are used
- $\nu_x \sim 37$ and $\nu_y \sim 16$

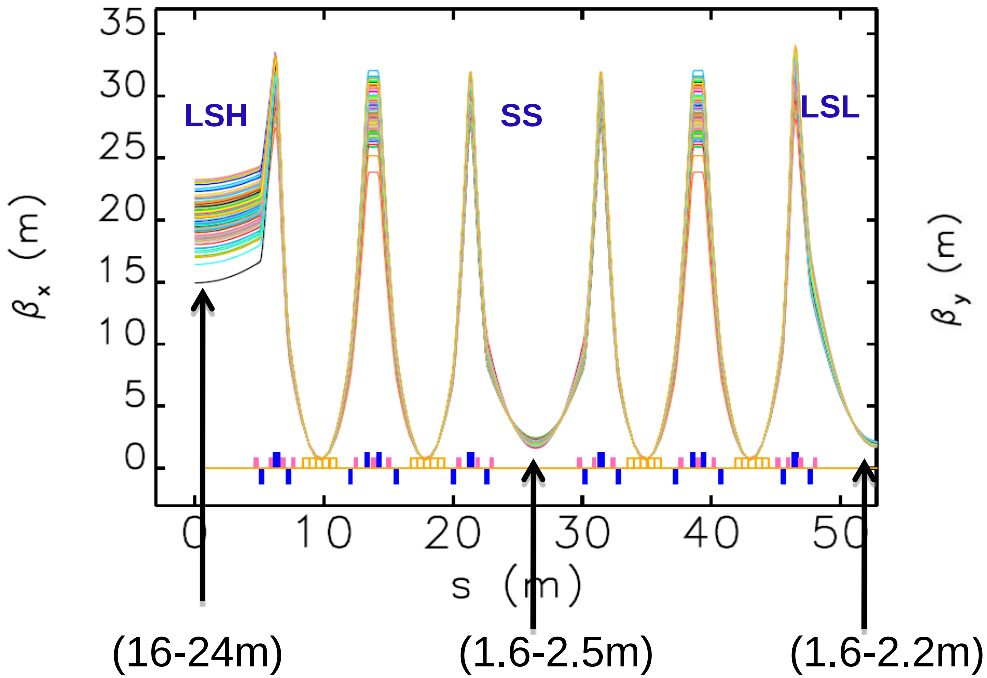
$\nu_x = 36.40 \rightarrow 37.40$ $\nu_y = 15.49 \rightarrow 16.49$

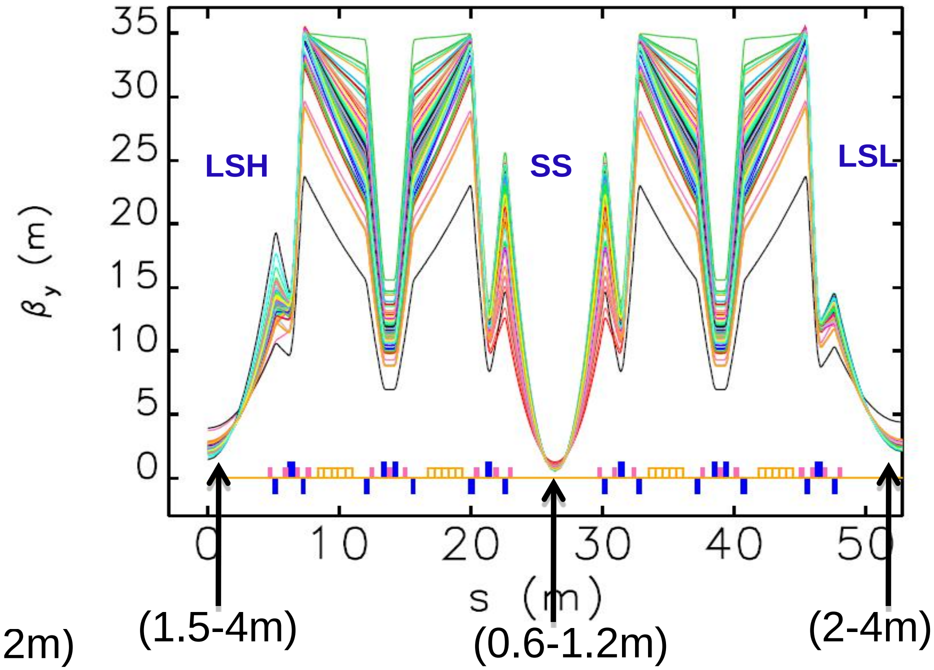
- Quads Strength $\frac{B'}{B\rho} \le 2.1(1/m^2)$

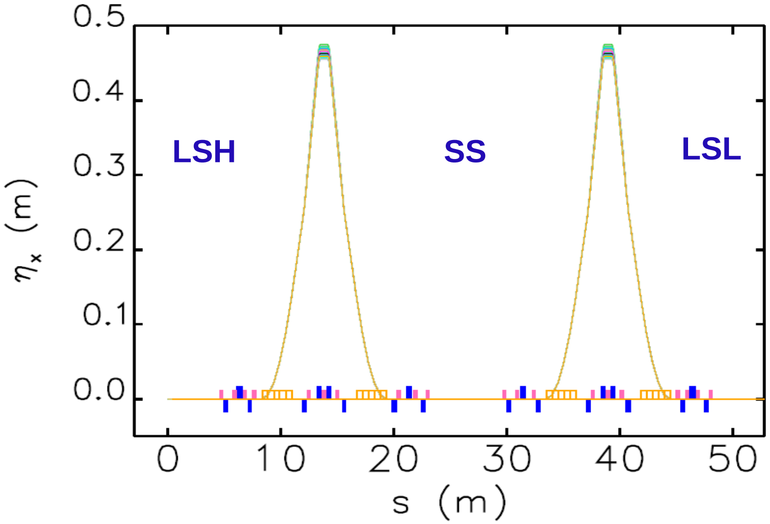


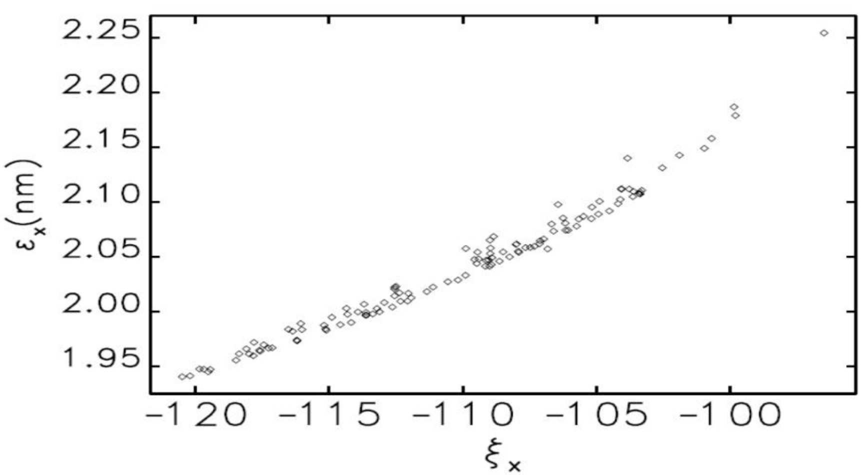


Ensemble of Lattice Functions



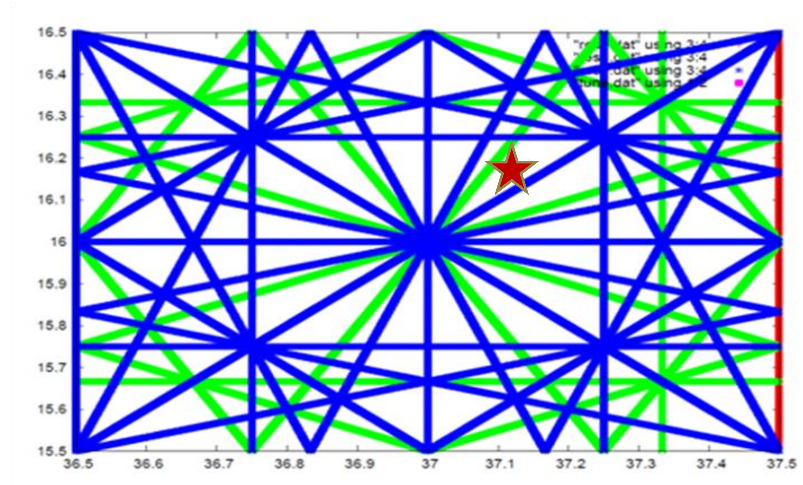


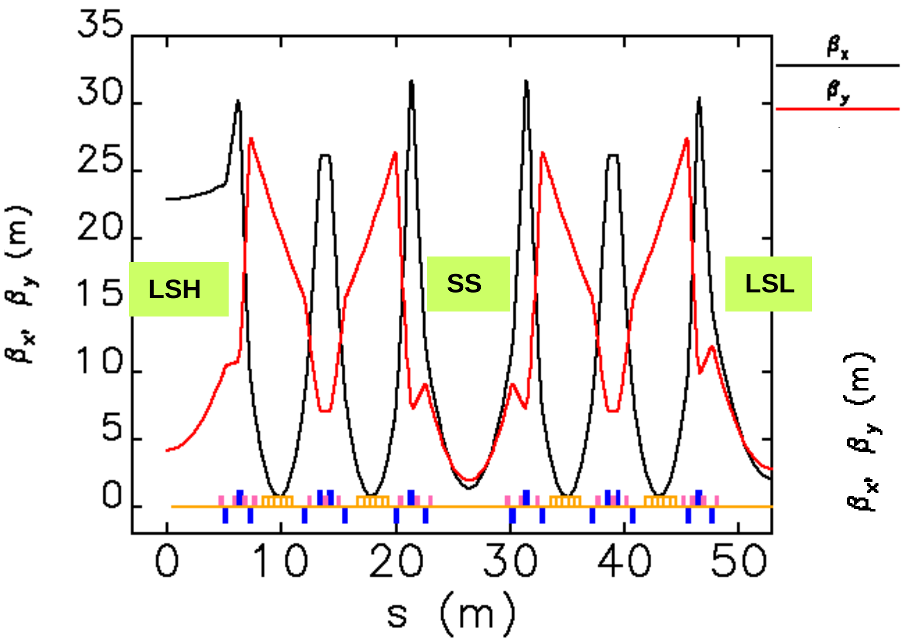




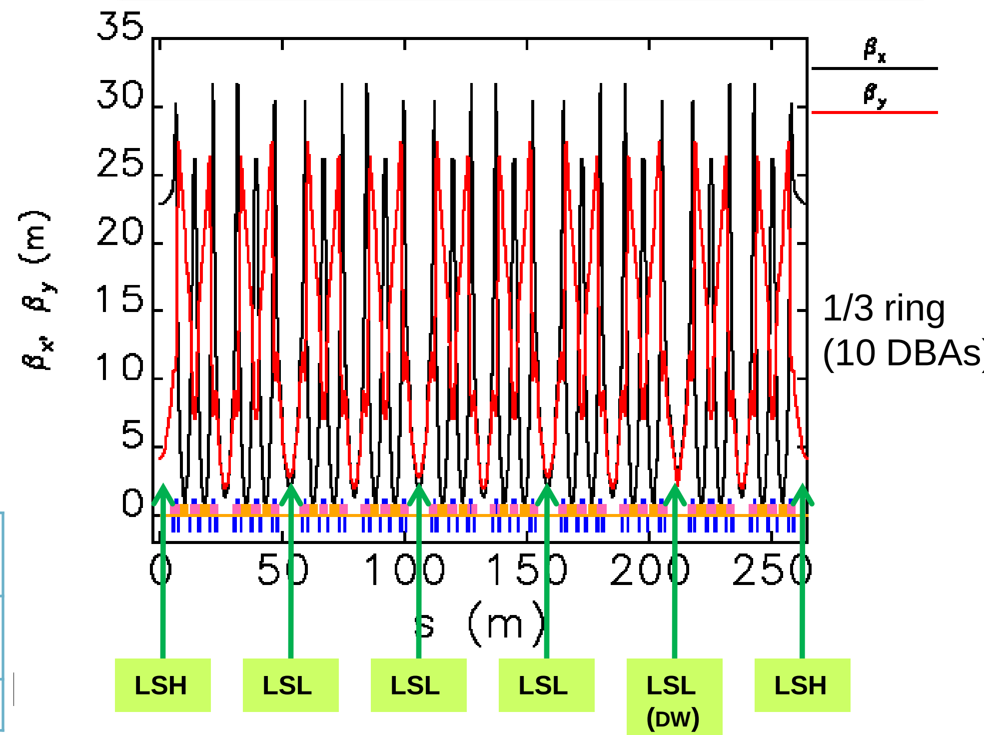
One Linear Solution

- Linear Optics
  - tune : 37.18,16.22
  - natural chromaticity : (-107, -40)
  - natural emittance : 2.1 nm-rad
  - emittance (w 3 DW) : 0.9 nm-rad

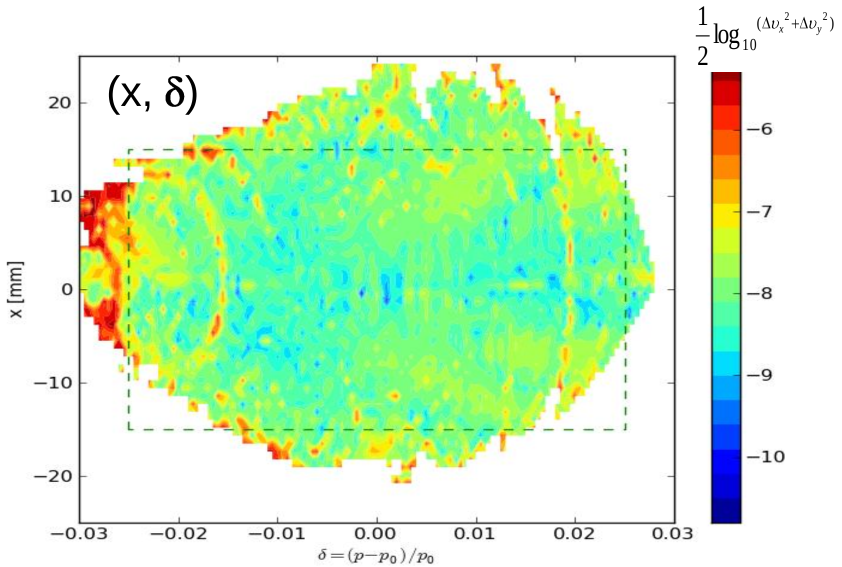


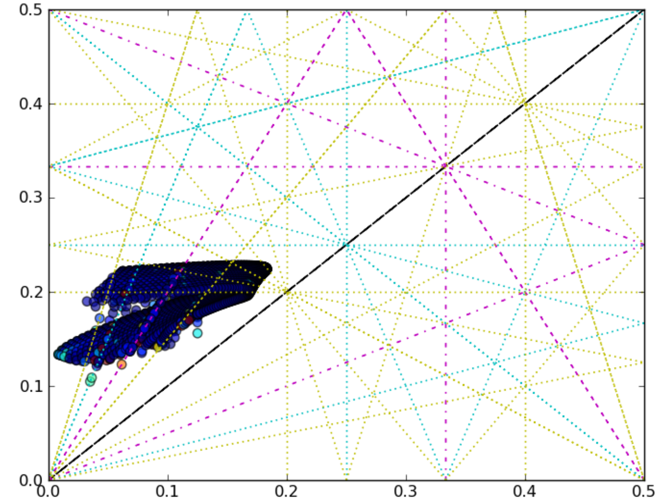


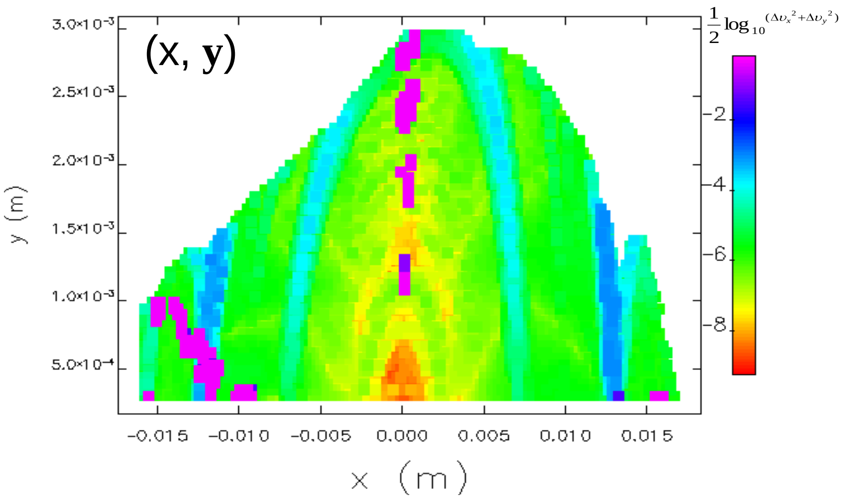
Straights	LSH	SS	LSL	LSL (DW)
β_x (m)	22.85	1.39	2.13	2.16
β_y (m)	4.20	1.98	2.86	2.21

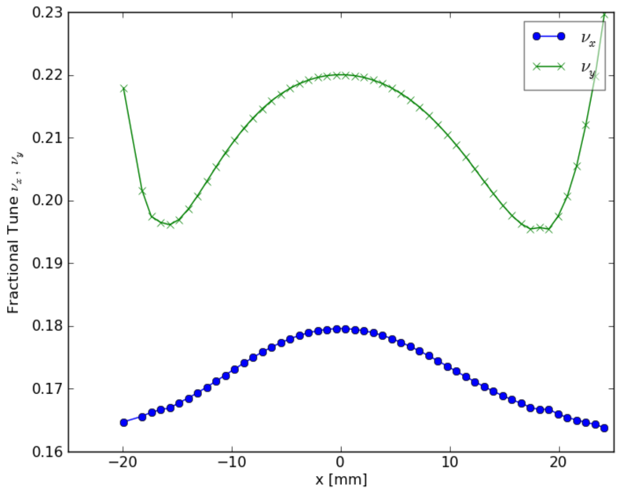


Frequency Map and Tune Footprint in (x,δ) and (x,y)



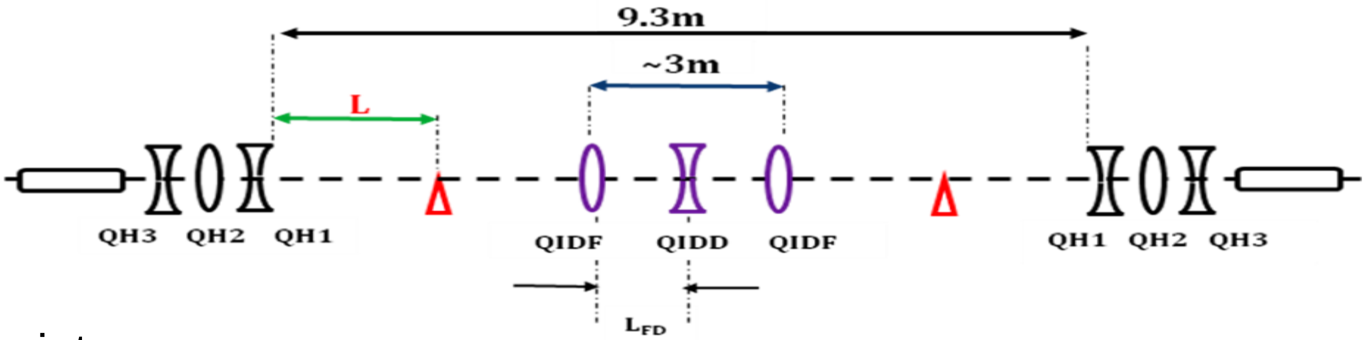






Approach (II) : Linear Optimization

- Schematic Drawing of the long straight with additional quads. at the center

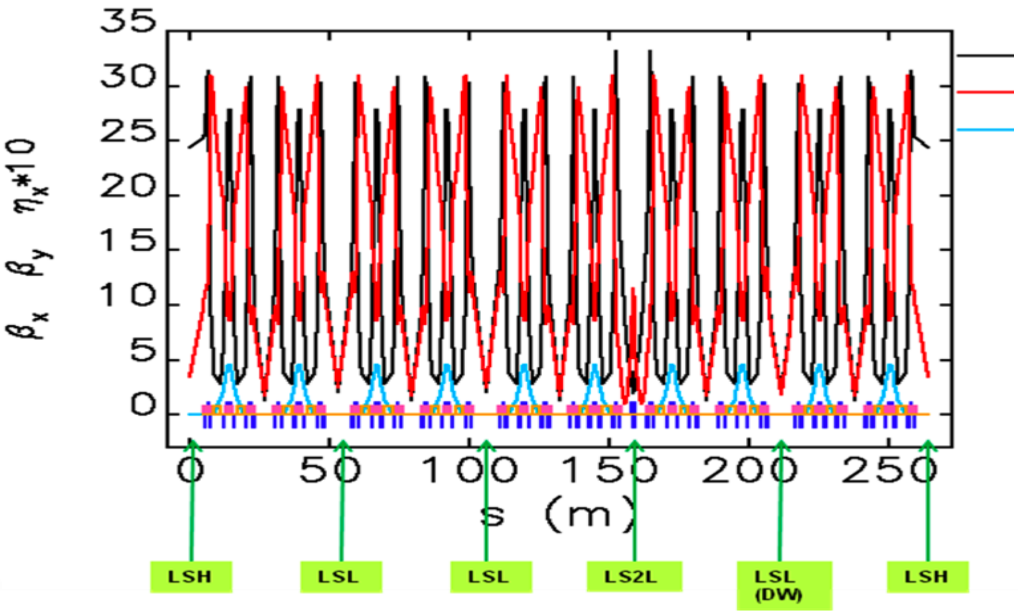


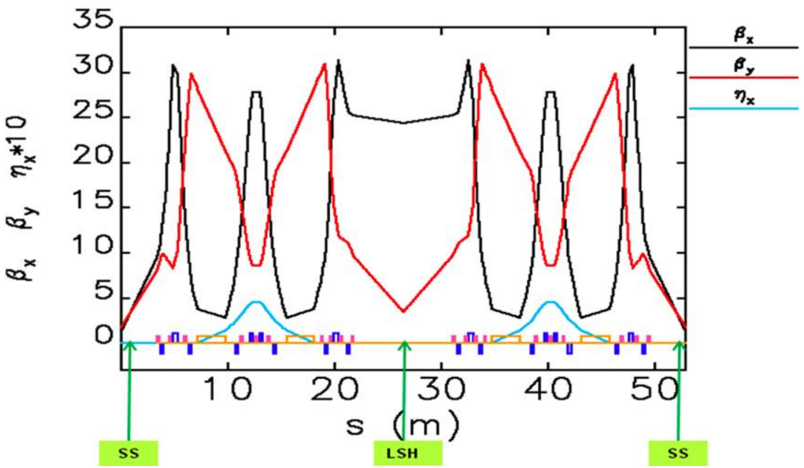
- Constraints
  - mirror symmetric condition at the centers of straights and arcs
  - achromatic with zero dispersion in all straights
  - designed linear functions at the centers of straights
  - proper maximum dispersion at the center of arc to facilitate chromaticity correction
  - lattice properties: natural emittance ~ 2nm and natural chromaticity ~ (-110 / -45)
  - practical maximum strength of quads $B'_{\max} = 22(T/m)$
  - mirror symmetry of the vertical beta function at the center of insertion devices
  - $\beta_y \sim 1.5$ m for an optimum vertical gap of ~3 m long IDs
  - small β_x as much as possible for optimum brightness

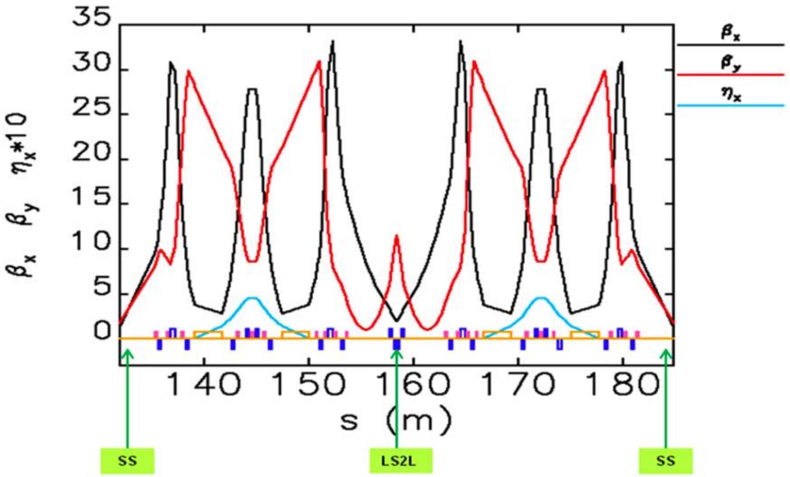
- Linear Knobs
  - 11 Quad families + 3 QHIDNEWs + QIDF + QIDD + L_{FD} = 17

One Linear Solution

- Linear Optics
  - tune : 37.16,17.22
  - natural emittance : 2.0 nm-rad
  - natural chromaticity : (-112, -47)
  - emittance (w 3 DW) : 0.87 nm-rad

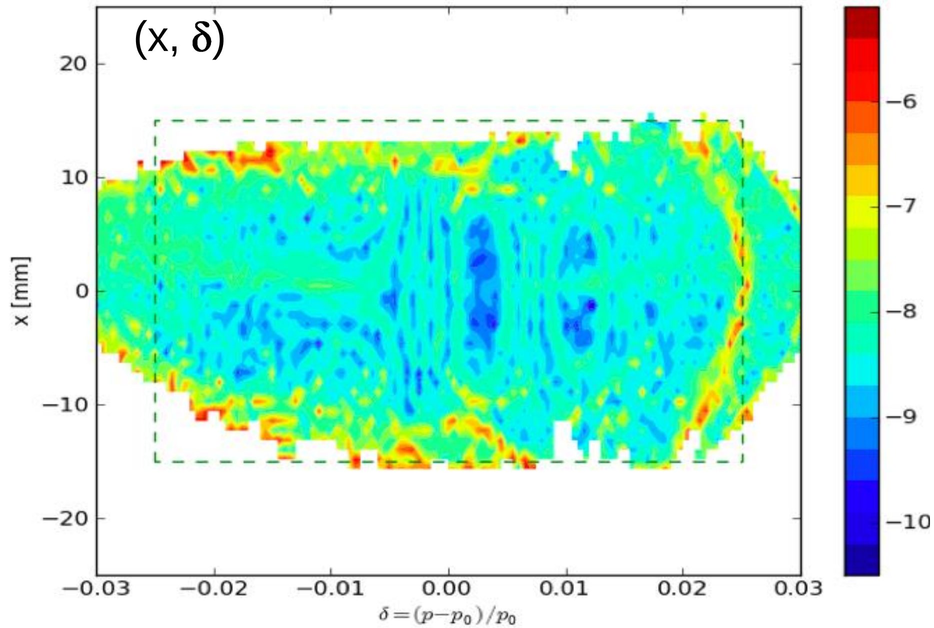


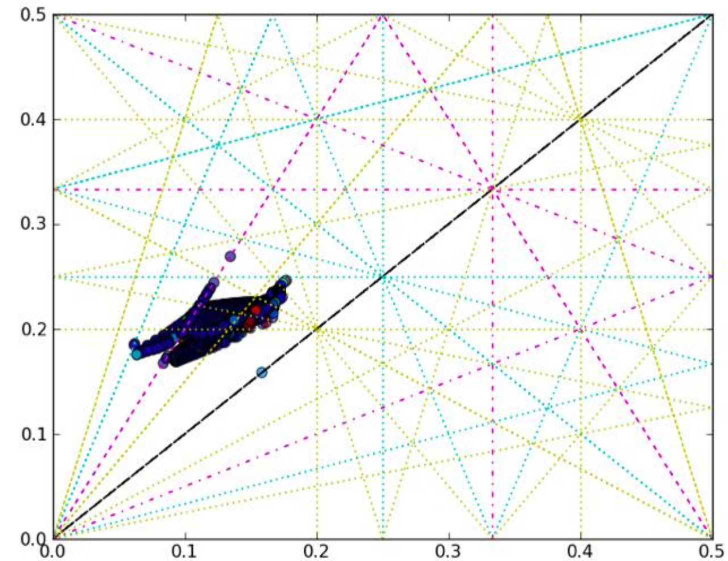


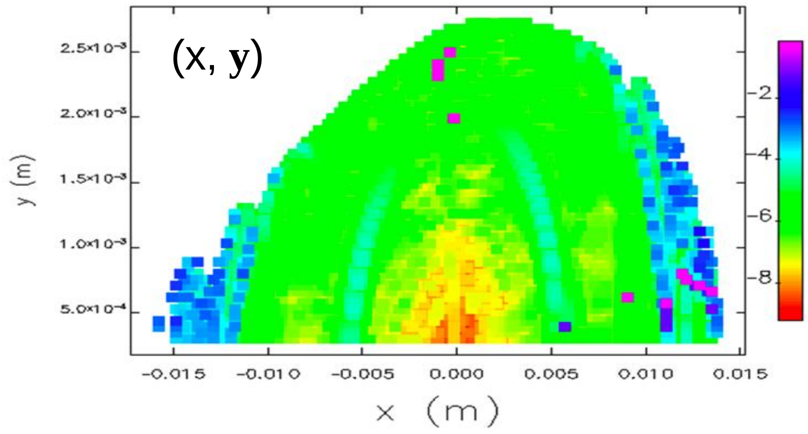


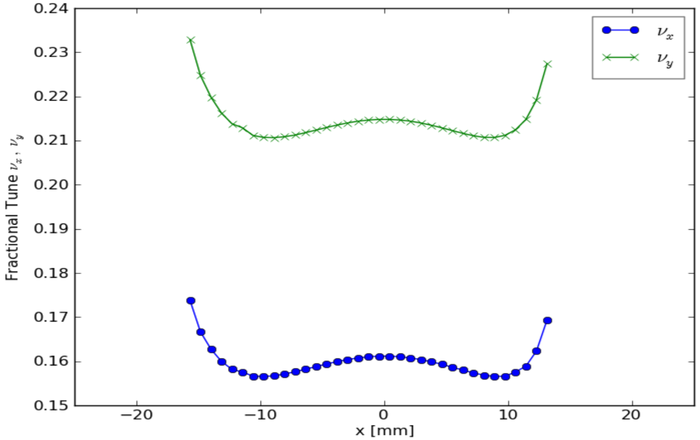
Straights	LSH	SS	LSL	LS2L	LSL (DW)
β_x (m)	23.65	1.33	2.02	8.49	2.07
β_y (m)	3.53	1.72	2.47	1.02	1.91

Frequency Map and Tune Footprint in (x,δ) and (x,y)









Summary

- NSLS-II is a 3 GeV third-generation synchrotron light source with low emittance < 1nm and high current electron beam at 500 mA

- The baseline storage ring has 30 DBA cells with alternate long and short straights. Damping wigglers help lower the horizontal emittance down to sub-nm-rad. 3 chromatic and 6 geometric sextuples families are used to optimize the dynamic aperture for good injection efficiency and >3 hrTouschek lifetime.

- Lattice developments are performed to to reduce horizontal photon source size by reducing the horizontal beta function in 12 long straights. This can be accomplished by

  (i) using the existing quads

  (ii) introducing additional quads at the center of the long straights.

Both of the two approaches show the possibilities of stable linear solutions and good dynamic apertures for enough injection efficiency and adequate Touschek lifetime.

Acknoledgement

- All NSLS-II project colleagues
- Accelerator Physics Group: S.Krinsky (group leader) , A.Blednykh, J.Bengtsson, G.Bassi, W.Cheng, J.Choi, W.Guo, P.Ilinski, S.Kramer, Y.Li, I.Pinayer, L.Yu, L.Yang,

Thank You for your attention !

back up

Accelerator Overview

- 2 dipoles per DBA cell with 0.4 T normal bending field at 3 GeV and 25 m bending radius, radiated eneregy 288keV/turn
- 8 quad families (10 quad magnets) individually powered per cell (allow dispersion to be corrected cell-by-cell for any dipole variations), maximum gradient <22 T/m, quad field transverse alignment = 30 μm
- 3 chromatic sextupoles and 6 geometric sextupoles per cell, powered in 2x9 families per pentant
- S.C. RF : 2x500MHz Cavities (4.0MV), 2 x 300kW klystron amplifier, 1 passive 1.5GHz landau cavity: 1MV field @+ 90 degree for bunch lengthening.
- Damping wigglers: B=1.8T, λ=100mm, 15mm vertical magnetic gap, radiation energy loss per DW 129 keV
- 3-pole wigglers as wave length shifter next to soft dipoles (1 in baseline, more in early operation), 28 mm vertical magnetic gap (for the current users of hard X-ray bending magnets at NSLS)
- Insertion devices: 4 IVU (2x3m, λ=20mm, 5mm vertical gap; 1x 3m, λ=22mm, 7mm vertical gap; 1 x 1.5m, λ=21mm, 5.5mm vertical gap), 2 EPUs (2x 2m, λ= 49mm, 11.5mm vertical gap)
- BPM system with 0.1-0.2 μm resolution and stability
- Injection Straight with 4-kicker closed bump for Top-off injection
- 200MeV Linac and 3GeV Booster
- 6 project beamlines, and space for at least 58 beamlines

Design of the NSLS-II Storage Ring Lattice

- Physics design:
  - double bend achromat (DBA)
    - achromatic arc
    - provide large number of dispersion free insertion straights
  - optimal bend radius (25 m, B=0.4Tesla)
    - reduce both emittance and energy spread
    - enhance the effectiveness of damping wigglers
  - damping wigglers
    - increase emittance damping
    - need small β_y in the damping wiggler to minimize the tune shift due to both linear and nonlinear effect of wigglers
  - quadrupoles (8 families per cell)
    - optic functions, tune, phase advance
    - beam-based alignment, correction of the linear optics
  - sextupoles (9 families per cell)
    - enough dynamic aperture for beam performance: good injection efficiancy and adequate Touschek lifetime

Prepare for each individual possible questions

Control of the Nonlinear Dynamics

In the nonlinear case, the (symplectic[3]) one-turn (functional) map can be (formally) represented by a Lie series [7]

$$\mathcal{M} \equiv \mathcal{A}^{-1} e^{:h(\bar{x}):} \mathcal{R} \mathcal{A} \tag{6}$$

where $\mathcal{A}$, $\mathcal{R}$ and $:h:$ are (functional) operators[4], and the Lie derivative $:h(\bar{x}):$ of a function $f(\bar{x})$ of the phase-space variables is defined by the Poisson bracket

$$:h:f(\bar{x}) \equiv \sum_{i=1}^{n} \frac{\partial h}{\partial x_i}\frac{\partial f}{\partial p_{xi}} - \frac{\partial f}{\partial x_i}\frac{\partial h}{\partial p_{xi}}, \tag{7}$$

The *generator* h is a power series in the phase-space variables

$$h = \sum_{j,k,l,m,n} h_{jklmn} J_x^{(j+k)/2} J_y^{(l+m)/2} \delta^n e^{i[(j-k)\phi_x + (l-m)\phi_y]} + \text{c.c.}, \tag{8}$$

and, to 1st order in the sextupole strength, the *driving terms* h_{jklmn} are [3]

$$h_{jklmn} \sim \sum_{a=1}^{N} (b_3 L)_a \beta_{x,a}^{(j+k)/2} \beta_{y,a}^{(l+m)/2} \eta_{x,a}^{n} e^{i[(j-k)\mu_{x,j\to k} + (l-m)\mu_{y,l\to m}]} + \text{c.c.} \tag{9}$$

Higher order terms are generated by cross terms, i.e., commutators, of these. The driving terms to 2nd order in sextupole strength (and leading order in momentum dependence) are summarized in Tab. 2. Note, the resonance terms have additional momentum dependant terms that have not been listed[1].

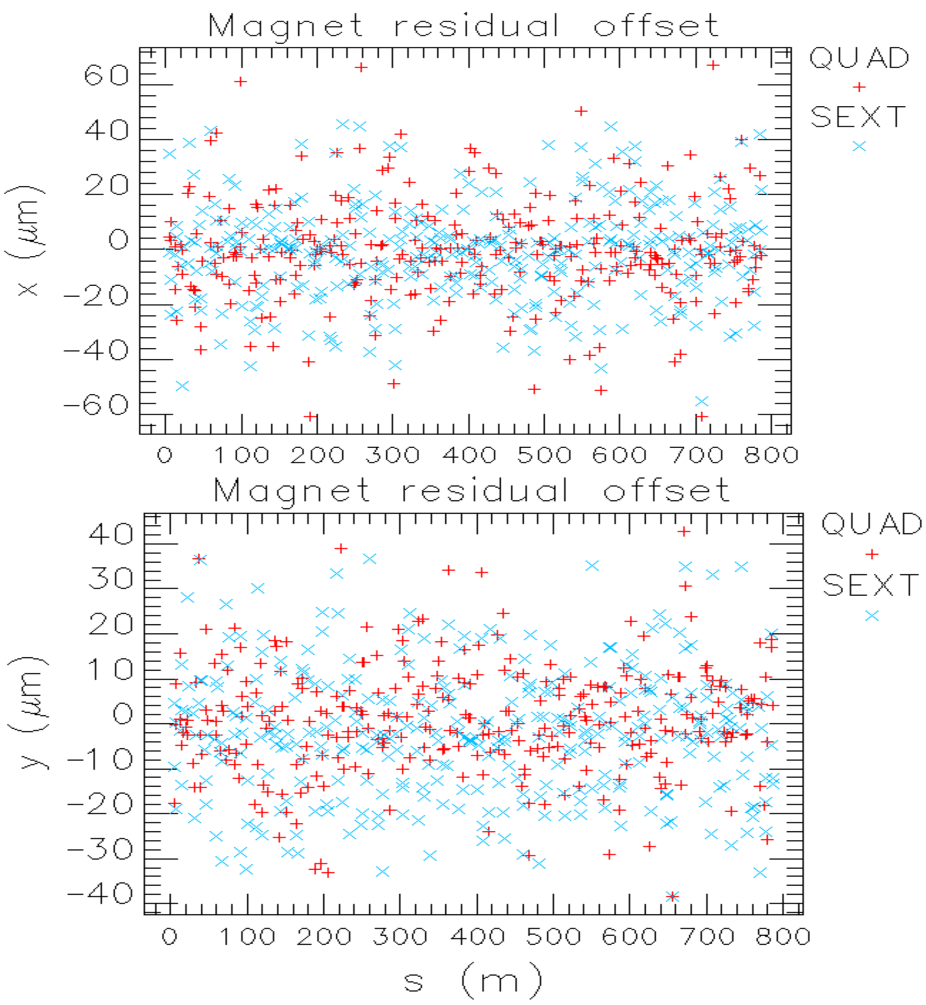
1st Order	h_{10001}	h_{20001}	h_{00201}	h_{10110}	h_{21000}	h_{30000}	h_{10200}	h_{10020}
Effect	$d\eta_x/d\delta$	$d\beta_x/d\delta$	$d\beta_y/d\delta$	ν_x	ν_x	$3\nu_x$	$\nu_x+2\nu_y$	$\nu_x-2\nu_y$
2nd Order	h_{31000}	h_{00310}	h_{20110}	h_{11200}	h_{40000}	h_{00400}	h_{20200}	h_{20020}
Effect	$2\nu_x$	$2\nu_y$	$2\nu_x$	$2\nu_y$	$4\nu_x$	$4\nu_y$	$2\nu_x+2\nu_y$	$2\nu_x-2\nu_y$

TABLE 2. Driving Terms to 2nd Order in the Sextupole Strength.

J.Bengtsson, NSLS-II Tech Note

Misalignment Errors

- Misalignment tolerance specifications:
  - 100 μm girder to girder
  - 30 μm magnet to girder
  - 0.5 mm in the beam direction
  - 0.5 mr for the girder roll
  - 0.2 mr for the magnet roll
- Correction:
  - Closed orbit can be corrected using beam-based Alignment like algorithm. Each cell has 6 correctors and 6 BPMs. Beam is centered at the BPMs.
- Residual offset of magnets
  - Quadrupoles : •σ_x = 19 μm
    •σ_y = 12 μm
  - Sextupoles : •σ_x = 17 μm
    •σ_y = 14 μm



Courtesy of W.Guo

Physical Aperture from Insertion Devices

Name	U20	U22(IXS)	EU49	U21(SRX)	DW-1.8T	3PW
Type	IVU	IVU	EPU	IVU	PMW	PMW
Photon energy range	Hard x-ray (1.9-20keV)	Hard x-ray (9.1keV)	Soft x-ray (250eV-7keV)	Hard x-ray (1.9-20keV)	Broad band (<10eV-100keV)	Broad band (<10eV-100keV)
Type of straight section	Short	Long	Short (canted)	Short (canted)	Long (in-line)	near 2nd Dipole
Period length (mm)	20	22	49	21	100	-
Length (m) & Number of Devices	3.0 x 2	3.0	2.0 x 2	1.5	3. 5 x 6	0.25
Number of periods	148	135	36 x 2	69	34 x 2	0.5
Magnetic gap (mm)	5	7.0	11.5	5.5	15.0	28
Peak magnetic field strength B (T)	1.03	0.78	0.57(Heli) 0.94 (Lin) 0.72(vlin) 0.41 (45°)	0.9	1.80	1.14
Keff	1.81	1.52	2.6(Heli) 4.3 (Lin) 3.2(vlin) 1.8 (45°)	1.79	18.0	-
hν fundamental, eV	1620	1802	230 (Heli) 180 (Lin) 285(vlin) 400 (45°)	1570		
hν critical, keV					10.7	6.8
Total power (kW)	8.0	4.7	8.8	3.6	64.5	0.32

Courtesy of T. Tanabe

Local Lattice Functions Studies

- Purpose : explore the possible beta functions in the long straights

- Method : locally change the 3 QHNEW families to scan the horizontal beta function at the center of long straight with 1m unit step

- Constrains :
  - both horizontal and vertical beta function in the beginning of long straight are fixed to be matched to the ring
  - lattice is symmetric at the center of the long straight with $(\alpha_x = \alpha_y = 0)$
  - horizontal beta function at the center of long straight is scanned from 1m to 20m

- Results:
  - the ensemble of horizontal beta functions
  - the ensemble of vertical beta functions
  - dependence of the vertical beta function on the value of the horizontal beta function at the center of the long straight
  - natural horizontal chromaticity per 2 DBA cells vs. the horizontal beta function at the center of the long straight

Basic Features

Energy [GeV]	3
Circumference [m]	792
Number of DBA cells	30
Number of 9.3 m straights	15
Beta-functions in the center of the 9.3 m straights: β_x, β_y [m]	21, 3.0
Number of 6.6 m straights	15
Beta-functions in the center of the 6.6 m straights: β_x, β_y [m]	2.0, 1.0
Number of dipoles	60
Number of quadrupoles	300
Number of sextupoles	300
Circulating current at 3 GeV, multi-bunch [mA]	500
Radio frequency [MHz]	499.68
Harmonic number	1320
Number of bunches at 80% fill	1040
Nominal bending field at 3 GeV [T]	0.4
Dipole critical energy at 3 GeV [keV]	2.4
Total Bending magnet radiation energy loss [keV]	286.4
Radiation energy loss per damping wiggler [keV]	129.3
Vertical emittance [nm-rad]	0.008
Horizontal emittance of bare lattice [nm-rad]	2.0
Horizontal emittance with three 7 m 1.8 T damping wigglers [nm-rad]	1.0
Horizontal emittance with eight 7 m 1.8 T damping wigglers [nm-rad]	0.6
Momentum compaction factor	3.7×10^{-4}
Bunch length, RMS, natural [mm, ps]	2.9, 10
Energy spread, RMS	0.05 –0.1%

Characteristics	Value
Energy [GeV]	3
Circumference [m]	792
Number of DBA cells	30
Number of 9.3m long straights and βx,βy [m] in the center	15 ; 21,3.0
Number of 6.6m short straights and βx,βy [m] in the center	15 ; 2.0,1.0
Number of dipoles, quadrupoles and sextupoles	60,300,270
Circulating current at 3 GeV, multi-bunch [mA]	500
Radio frequency [MHz]	499.68
Harmonic number	1320
Number of bunches at 80% fill	1040
Nominal bending field at 3 GeV [T]	0.4
Total Bending magnet radiation energy loss [keV]	286.4
Radiation energy loss per damping wiggler [keV]	129.3
Vertical emittance [nm-rad]	0.008
Horizontal emittance of bare lattice [nm-rad]	2.0
Horizontal emittance with three 7m 1.8T DW [nm-rad]	1.0
Horizontal emittance with eight 7m 1.8T DW [nm-rad]	0.6
Bunch length, RMS, natural [mm,ps]	2.9, 10
Energy spread, RMS	0.05-0.1%

Knobs for Dynamic Aperture Optimization

- Knobs for lattice sections without DW :
  - 11 quadrupoles for choosing working point (tunes) and linear lattice properties
  - 15 sextupoles for optimizing nonlinear driving terms
    - 6 sextupoles in the high dispersion range, four of them for chromatic correction, and two is for momentum dependence of linear optics correction
    - 9 sextupoles in the dispersion free long and short straights for tune shift with amplitude and resonances correction

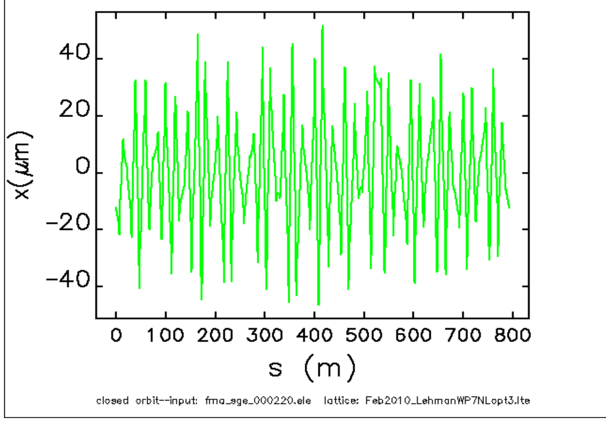
- Knobs for lattice sections with DW section :
  - 3 quadrupoles for local matching of beta function and phase advance
  - 6 sextupoles in the DW straight for tune shift with amplitude and resonances correction

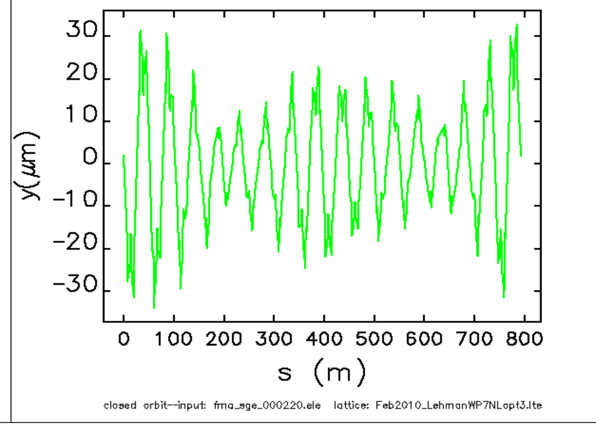
- Total
  - 14 quadrupoles for choosing and optimizing linear lattice, including working point, linear lattice properties
  - 21 sextupoles for optimizing nonlinearity, including chromaticity, amplitude dependent tune shift and nonlinear resonance terms

Dynamic Aperture Considerations

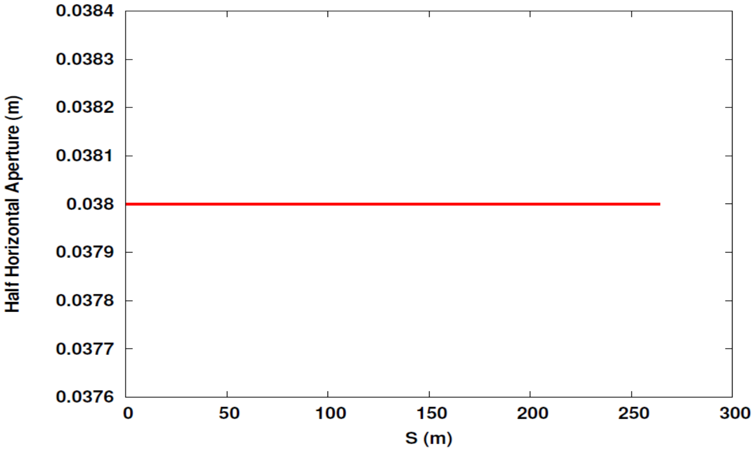
- Inclusion of misalignment errors
  - $\sigma_{x,y}$ = 0.3 μm offset for quads
  - $\sigma_{x,y}$ = 30 μm offset for sexts
  - σ_r = 0.5 mr magnet roll for both quads and sexts

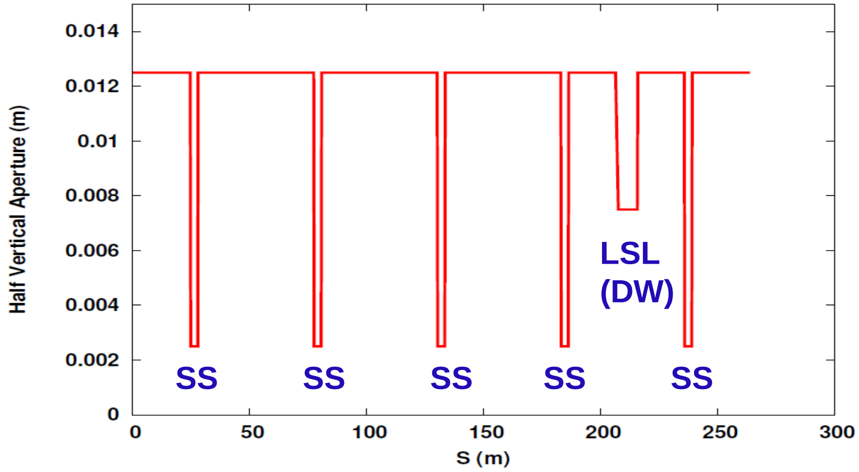
Close Orbit with Errors





- Physical apertures from insertion devices (1/3 of the ring)





Brightness of Undulator Radiation

H.Wiedemann: " *Particle Accelerator Physics II* ", second Edition

Brightness

$$\boxed{\mathrm{B} = \frac{\dot{N}_{ph}}{4\pi\sigma_{t,x}\sigma_{t,x'}\sigma_{t,y}\sigma_{t,y'}(d\omega/\omega)}}$$

Transverse beam size at a s distance from the waist

$$\sigma_{x,y}^{2} = \sigma_{x,y}^{*2} + \sigma_{x',y'}^{*2} \cdot s^{2}$$

$\sigma^{*}_{x,y}$ $\sigma^{*}_{x',y'}$ beam size and divergence at the waist

Average beam size along the undulator length L

$$\left\langle \sigma_{x,y}^{2} \right\rangle = \sigma_{x,y}^{*2} + \sigma_{x',y'}^{*2} \cdot L^{2}/12$$

Beam size from the oblique observation angle

$$\sigma_{oa}^{2} = \theta^{2} L^{2}/36$$

Beam size from the ransverse motion in the undulater field

$$\sigma_{uf}^{2} = a^{2} = (\lambda_{p} K/(2\pi\gamma))^{2}$$

Diffraction limited beam size

$$\sigma_{r}^{2} = \lambda L/(2\cdot 4\pi^{2}) \qquad \sigma_{r'}^{2} = \lambda/2L$$

Brightness of Undulator Radiation (cont.)

Total effective beam size

$$\boxed{\begin{aligned} &\sigma_{t,x}^2 = \underline{\sigma_r^2} + \underline{\sigma_x^{*2} + \sigma_{x'}^{*2} L^2/12} + \underline{\theta^2 L^2/36} + \underline{(\lambda_p K/(2\pi\gamma))^2} \\ &\sigma_{t,y}^2 = \underline{\sigma_r^2} + \underline{\sigma_y^{*2} + \sigma_{y'}^{*2} L^2/12} + \underline{\psi^2 L^2/36} \\ &\sigma_{t,x',y'}^2 = \underline{\sigma_{r'}^2} + \sigma_{x',y'}^{*2} \end{aligned}}$$

Maximum brightness is achieved by minimizing ($\sigma_{t,x}\sigma_{t,x'}\sigma_{t,y}\sigma_{t,y'}$)

Ideally assume no transverse coupling and dispersion free for an undulator, the minimization is reduced to minimize each individual beam size term

For example $$\boxed{\sigma_{t,x}^2 \propto \sigma_x^{*2} + \sigma_{x'}^{*2} L^2/12}$$

$$\sigma_x^{*2} = \varepsilon_x \cdot \beta_x^* \qquad \sigma_{x'}^{*2} = \varepsilon_x / \beta_x^{*2}$$

Therefore

$$\beta_x^* = \frac{L}{2\sqrt{3}}$$

Control of the Nonlinear Dynamics

- "Sextupole-dominated lattices of modern low-emittance synchrotron light sources are intrinsically non-linear and do not allow the traditional approach of designing a linear lattice and later retrofitting it with the appropriate number of sextupole families. Instead, nonlinear aspects of the lattice must be addressed from the very beginning of the lattice design through continuous iterations of both linear and nonlinear elements." ----------- *NSLS-II Preliminary Design Report*

- Linear Control for modest strong chromatic and geometric sextupoles
  - natural horizontal chromaticity per cell $\xi_x \sim 3.5$
  - peak dispersion $\eta_x > 0.3$ m

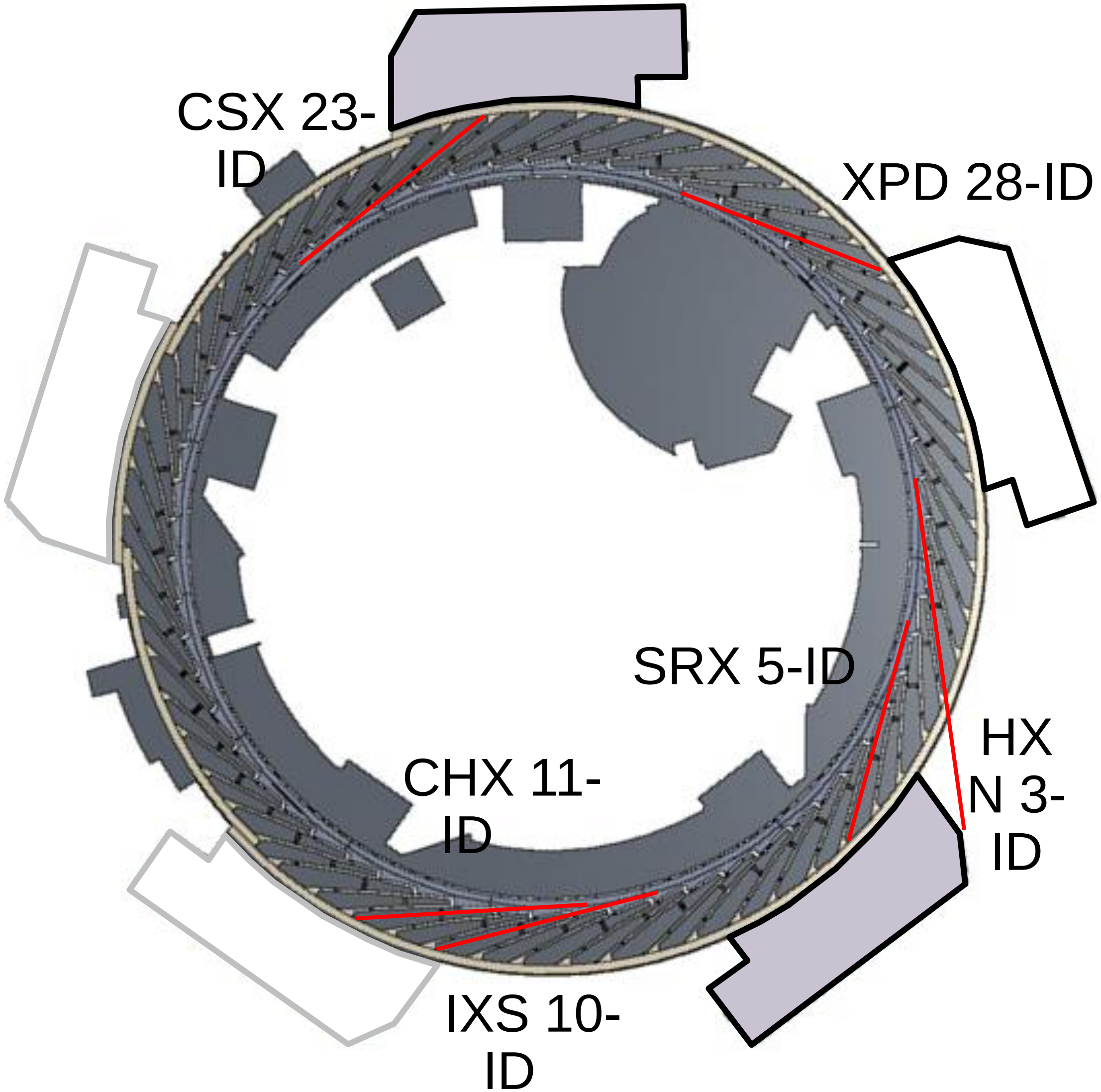
$$\xi_{x,y}^{(1)} = \mp \frac{1}{4\pi}\sum_{k=1}^{N}\left[(b_2 L)_k - 2(b_3 L)_k \eta_{x,k}\right]\bar{\beta}_{x,y,k},$$

- Nonlinear Control for nonlinear driving terms (J.Bengtsson, NSLS-II Tech Note)
  - Depend on the first order sextupole strength

$$\xi_{x,y}^{(1)} = \mp \frac{1}{4\pi}\sum_{k=1}^{N}\left[(b_2 L)_k - 2(b_3 L)_k \eta_{x,k}\right]\bar{\beta}_{x,y,k},$$

    - 2 terms drive the linear chromaticities
    - 3 terms drive the momentum dependence of the linear optics: 2nd order dispersion and beta beat
    - 5 terms drive the first order geometric resonance: $\upsilon_x, 3\upsilon_x, \upsilon_x - 2\upsilon_y, \upsilon_x + 2\upsilon_y$
  - Depend on the second order sextupole strength
    - 3 terms drive amplitude dependent tune shift $d\upsilon_x/dJ_x,\ d\upsilon_x/dJ_y,\ d\upsilon_y/dJ_x$
    -

Six Beamlines in Construction Project



- Inelastic X-ray Scattering (IXS)
- Hard X-ray Nanoprobe (HXN)
- Coherent Hard X-ray Scattering (CHX)
- Coherent Soft X-ray Scattering & Polarization (CSX)
- Sub-micron Resolution X-ray Spectroscopy (SRX)
- X-ray Powder Diffraction (XPD)

<u>Note</u>: Beamline locations have been finalized for the six project beamlines

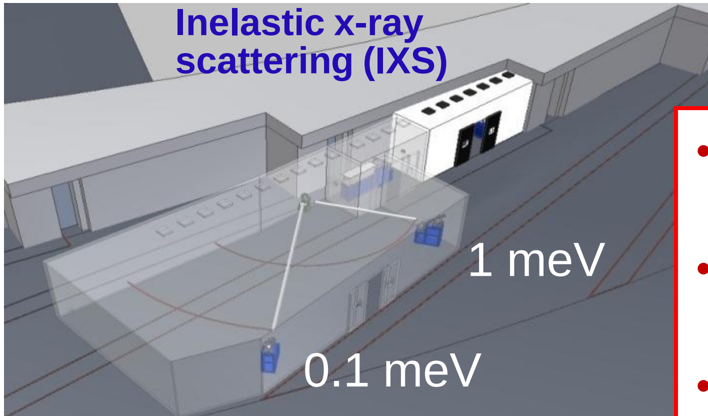
Misalignment Tolerance

- Misalignment tolerance specifications:
  - 100 μm girder to girder
  - 0.5 mm in the beam direction
  - 0.2 mr for the magnet roll
  - 30 μm magnet to girder
  - 0.5 mr for the girder roll
- Effects of misalignment errors

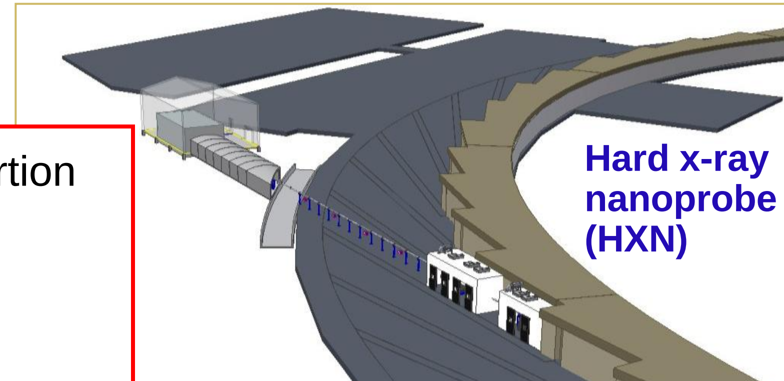
Misalignment Error	Beta Beat (%) $\Delta\beta x/\beta x$, $\Delta\beta y/\beta y$	Dispersion in LS (mm) x, y
Longitudinal shift 0.5 mm	1.5, 0.5	1.8, ~0
Girder to girder Δr=0.1 mm	0.5, 0.2	1.1, 0.7
Magnet to girder Δr=30 μm	1.5, 0.5	2.7, 1.3
Girder roll $\Delta\theta$=500 μr	0.006, 0.003	~0, 2.2
Magnet roll $\Delta\theta$=200 μr	0.03, 0.01	~0, 1.3

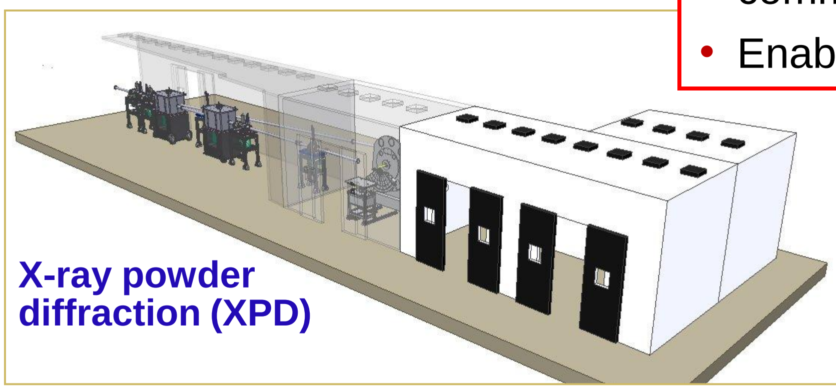
- Beam-based alignment can correct the closed orbit

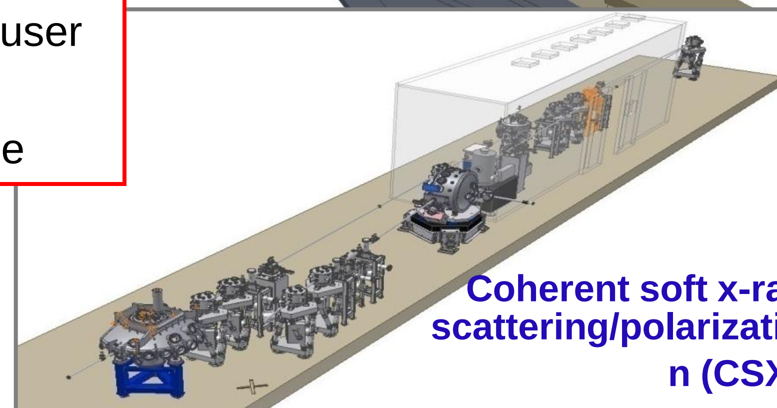
Six Project Beamlines

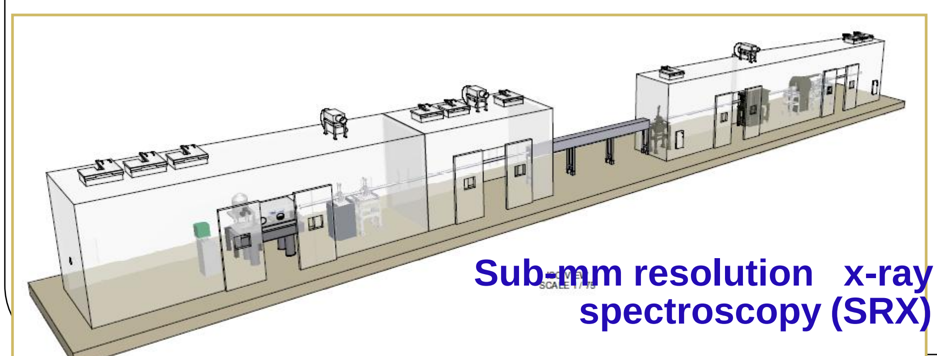


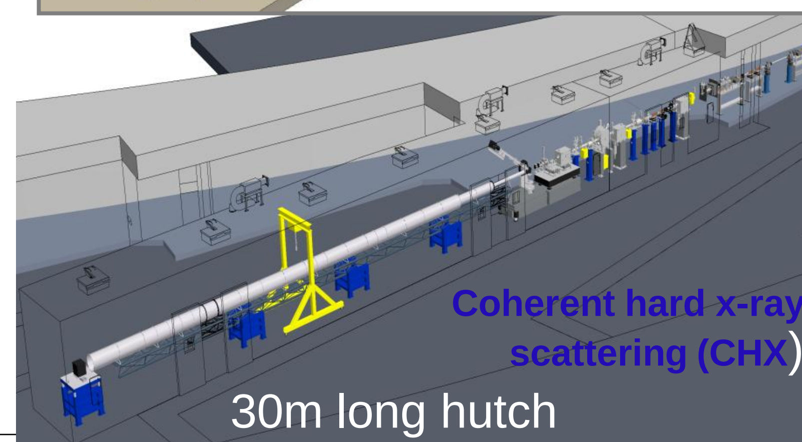
- Initial suite of insertion device beamlines
- World-leading characteristics
- Meet the needs of user community
- Enable new science





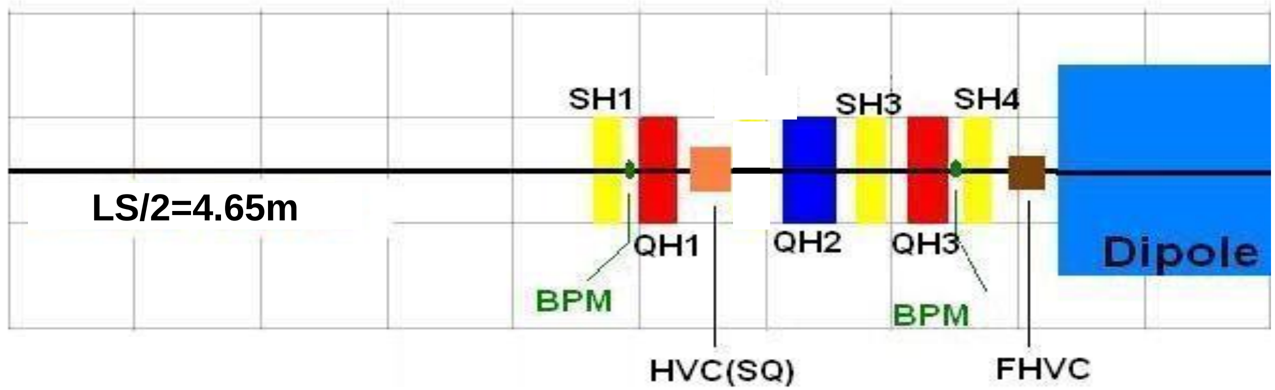




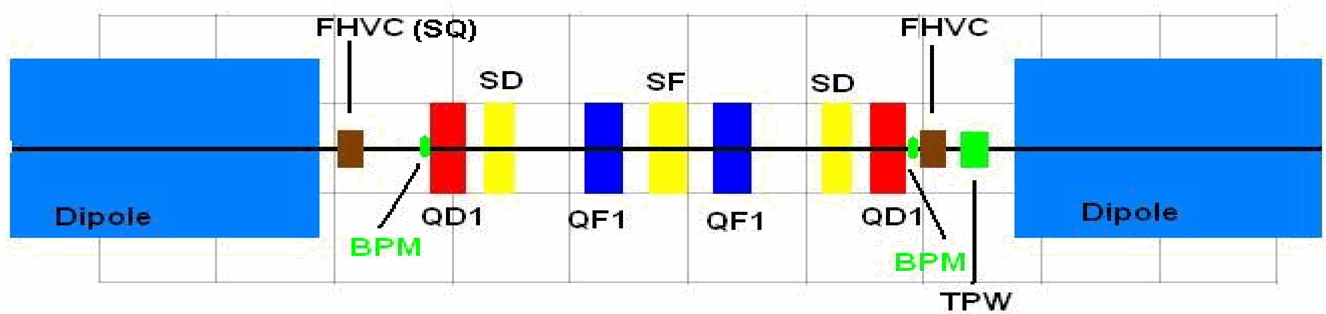


Magnets Layout

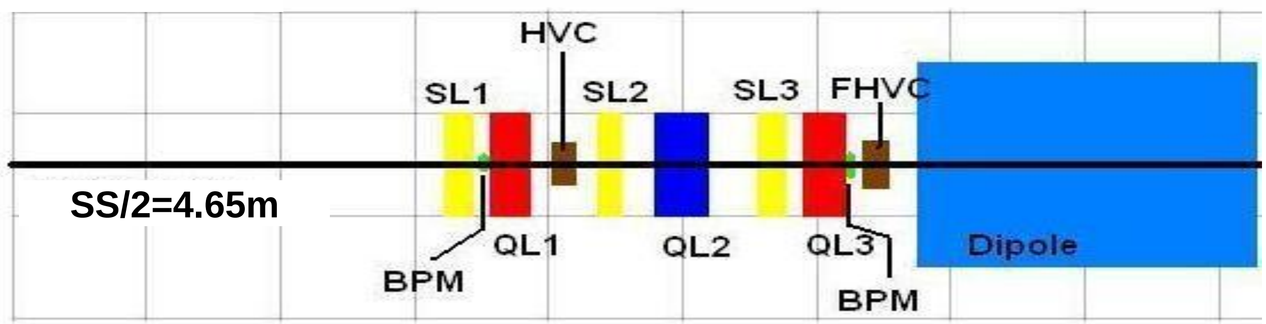
- Layout for half of a long straight



- Layout for dispersion section



- Layout for half of a short straight



Ensemble of Lattice Properties