An Introduction to the NSLS-II Lattice

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NSLS-II
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NSLS-II: Basic Parameters

Energy	3.0 GeV	Energy Spread	0.094%
Circumference	792 m	RF Frequency	~500 MHz
Number of Cells	30 DBA	Harmonic Number	1320
Number of Superperiods	15	RF Bucket Height	>2.5%
Length ID Straights	6.6 & 9.3m	RMS Bunch Length	15ps-30ps
Emittance (h,v)	<1nm, 10pm	Average Current	500ma
Momentum Compaction	.00037	Current per Bunch	0.5ma
Dipole Bend Radius	25m	Charge per Bunch	1.2nC
Energy Loss per Turn	<2MeV	Touschek Lifetime	>3hrs
		Top-Off Injection Freq	<1/min

Recently Built 3rd Generation Light Sources

	Energy (GeV)	Emit. (nm-rad)	Circum. (m)	Num. of DBA	Current (mA)	Charge per bunch (nC)
SOLEIL	2.75	3.74	354	16	500	1.0
SSRF	3.5	3.9	432	20	300	0.6
DIAMOND	3	2.7	561.6	24	300	0.6
NSLS-II	3	1	792	30	500	1.0

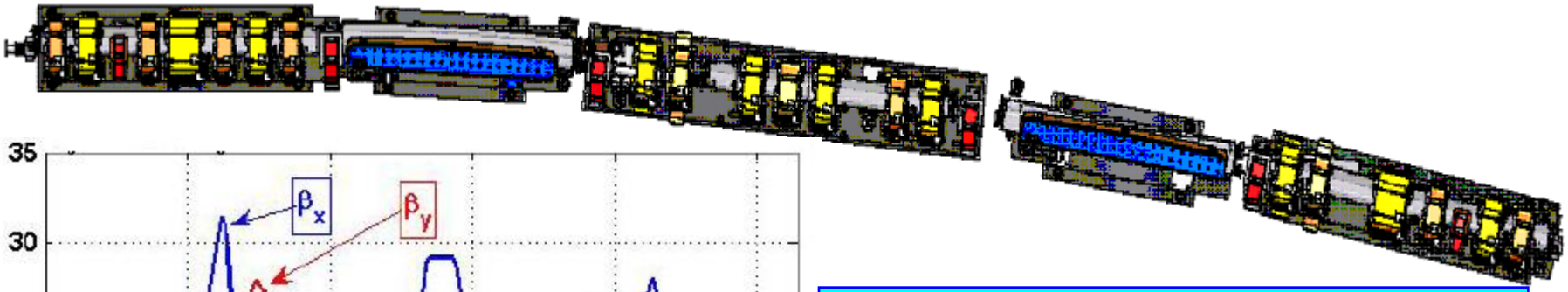
Challenges:

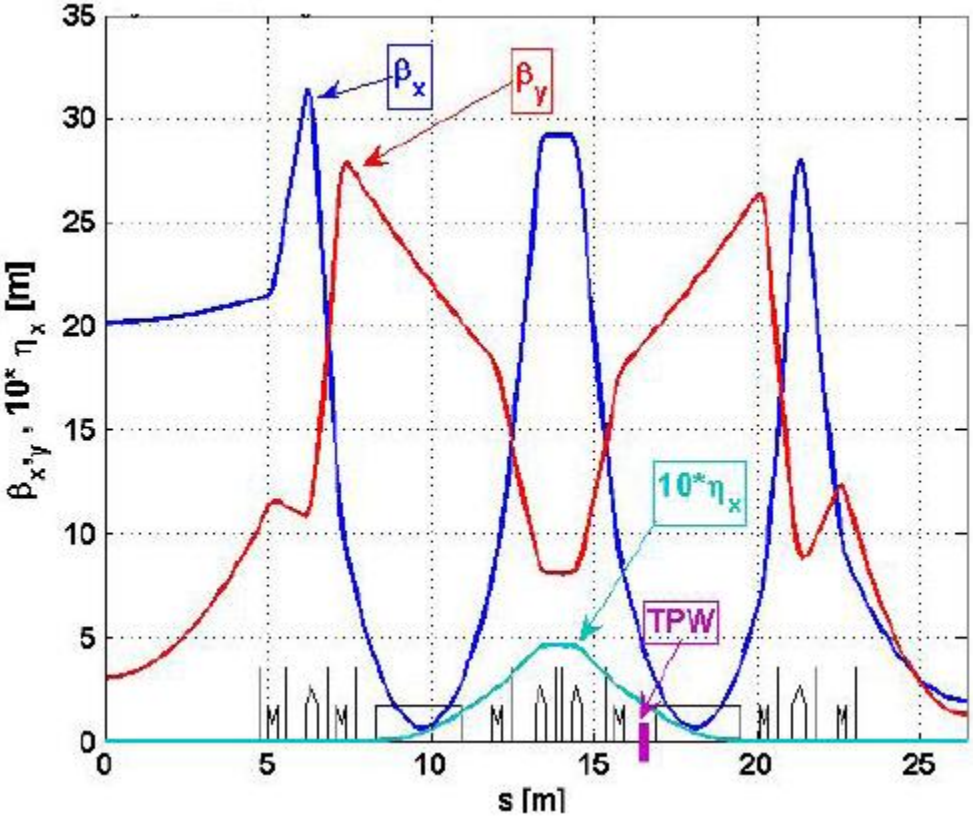
Use damping wigglers to achieve low emittance

Low emittance, low lifetime

Strict achromatic constraint, difficulty in off-momentum beam dynamics

Lattice Functions for One Cell





Dipole: 2, 1 ps

Quad: 10, 8 families, indep. powered

Sext: 10, 10 families, 1 ps for 1 family

H/V slow correctors: 6, 2 per girder

H/V Fast correctors: 3

BPMs: 6, 2 per girder

Requirements on nonlinear dynamics:

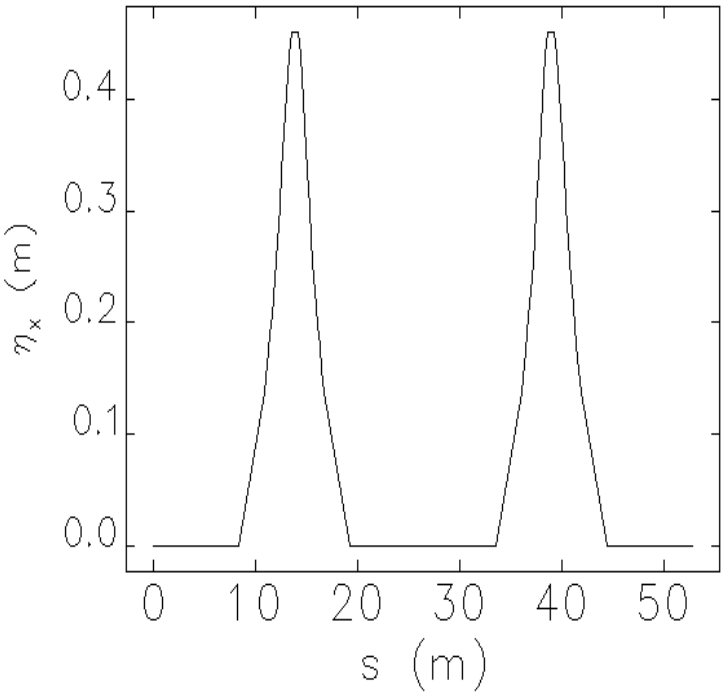
15 mm injection, +/-2.5% momentum

Why Strict Double-Bend-Achromatic Lattice

- For 1nm emittance, we need horiz dispersion <~5cm in order not to increase effective emittance of IDs

  1nm emittance. For β_x =2 m, η_x=4.5 cm, $\beta_x\varepsilon_x \sim (\eta_x\sigma_\delta)2$

- To maximize effectiveness of damping wigglers we want dispersion in straights to be small



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Nonlinear Optimization

Sextupole optimization approach

Frist order chromatic terms (5)

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

Frist order geometric terms (5)

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

Amplitude tune dependence $\frac{\partial \nu_{x,y}}{\partial J_{x,y}}$

Second and third order chromaticity

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

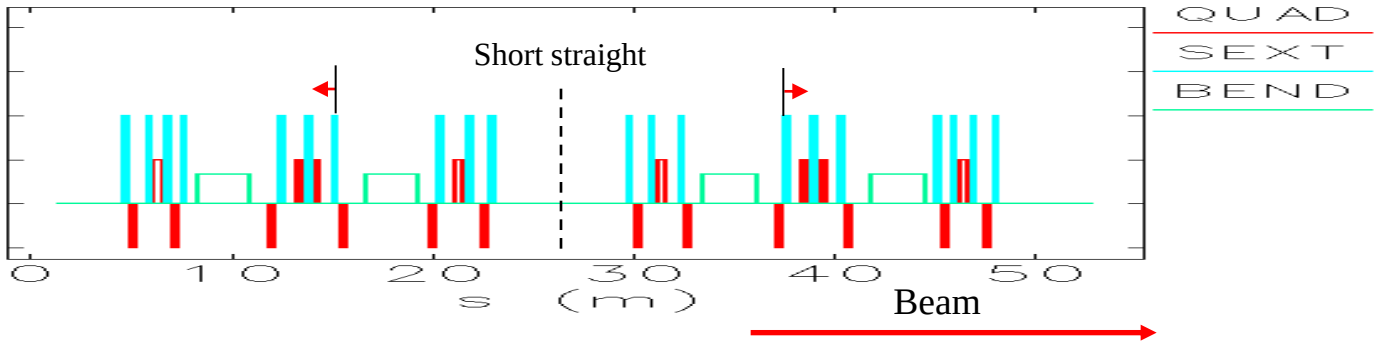
$$\xi_y^{(2)} = -\frac{1}{2}\xi_y^{(1)} - \frac{1}{8\pi}\int ds\{K_2 D^{(2)}\beta_y + [K_1 - K_2 D^{(1)}]\frac{d\beta_y}{d\delta}\}$$

Sin term and cos term:

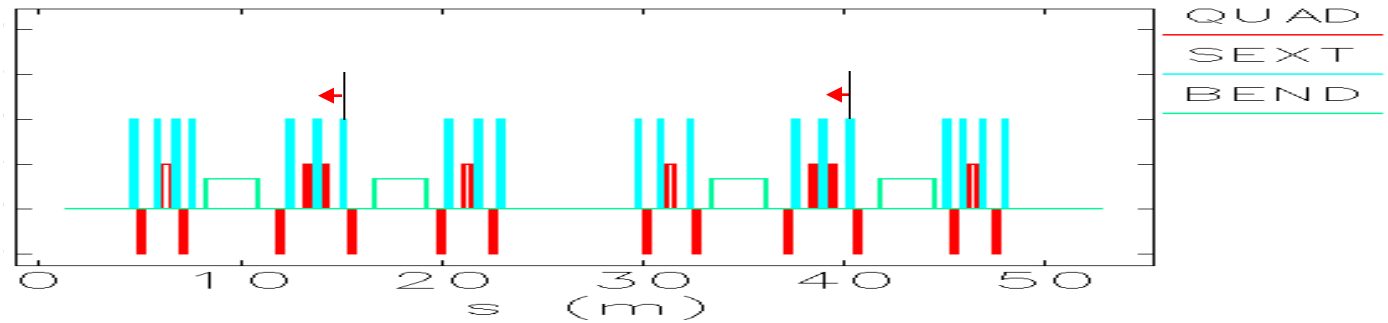
$$h_{21000} = -\frac{1}{8}\sum_{i=1}^{N}(K_2 L)\beta_{xi}^{3/2} e^{i\mu_x}$$

Reflection Symmetry and Translation Symmetry

Reflection Symmetry



Translation Symmetry



Based on mechanical constraints, it was decided to move the downstream sextupoles 15cm upstream towards the dispersion maximum maintaining translational symmetry but breaking the reflection symmetry about the insertion centers.

Effects of Adding or Moving Sextupoles

Effects: linear and nonlinear chromaticity, off-momentum beta function and closed orbit

$$\Delta\xi^{(1)}{}_{x,y} = \pm\int ds K_2 D^{(1)} \beta_{x,y}$$

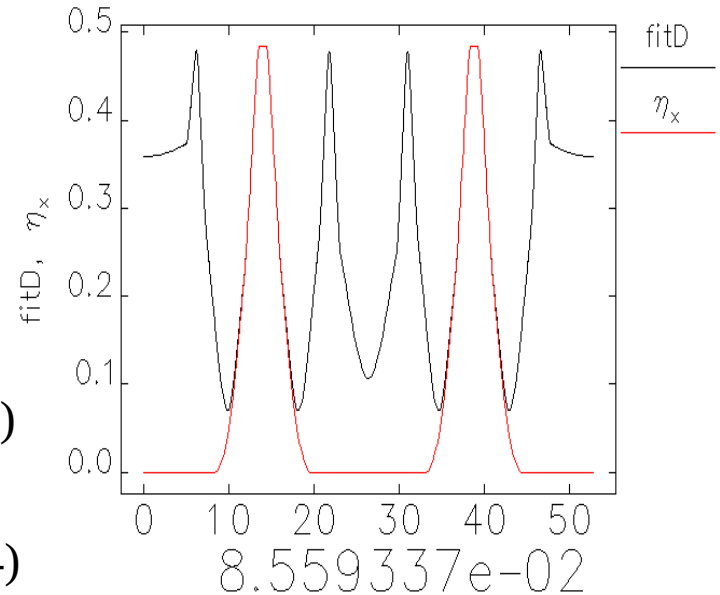
$$D^{(2)} = -D^{(1)} + \frac{\sqrt{\beta}}{2\sin(\pi\nu)}\int ds(K_1 - \frac{K_2}{2}D^{(1)})D^{(1)} \qquad (1)$$

$$\times\sqrt{\beta}\cos(|\Delta\Psi| - \pi\nu) \sim K_2 D^{(1)}\beta_x$$

$$\frac{d\beta_x}{d\delta} = \frac{\beta_x}{2\sin(2\pi\nu)}\int ds(K_1 - K_2 D^{(1)})\beta_x \cos(2|\Delta\Psi| - 2\pi\nu) \qquad (2)$$

$$\frac{d\beta_y}{d\delta} = \frac{-\beta_y}{2\sin(2\pi\nu)}\int ds(K_1 - K_2 D^{(1)})\beta_y \cos(2|\Delta\Psi| - 2\pi\nu) \qquad (3)$$

(4)



Dispersion fitting using $f(s) = C \bullet \sqrt{\beta_x(s)}$

Conclusion:

- The betatron phase advances in the dispersive region is small (x: ~ 10º, y~ 20º)
- The sextupole strength is constrained by the linear chromaticity correction
- The effects on the off-momentum closed orbit and beta functions are small

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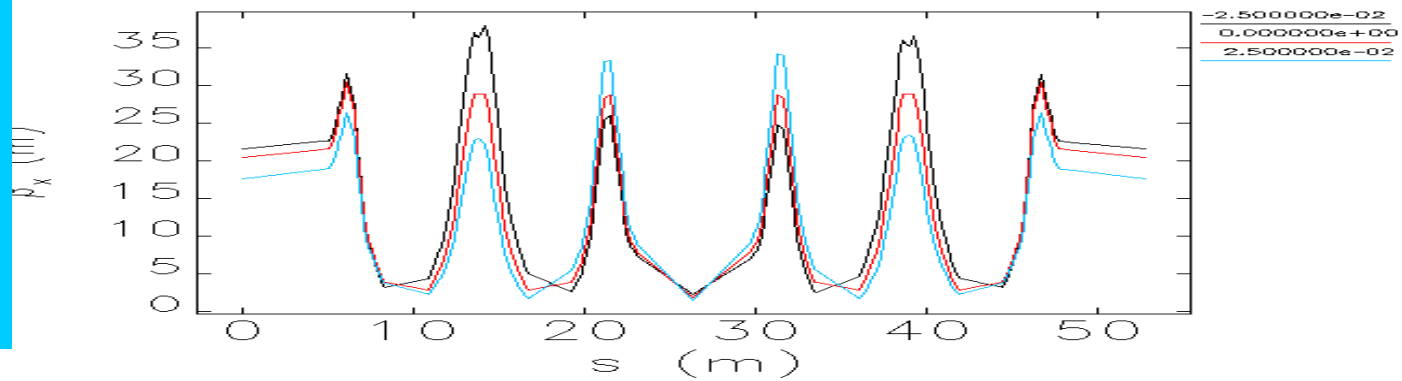
First Order Effects

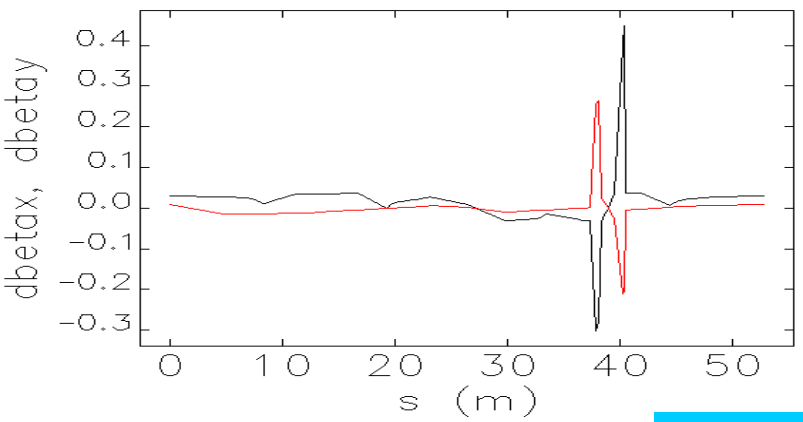
Translation symmetry

-Reflection symmetry

SM1L: -22, SM1R: -31

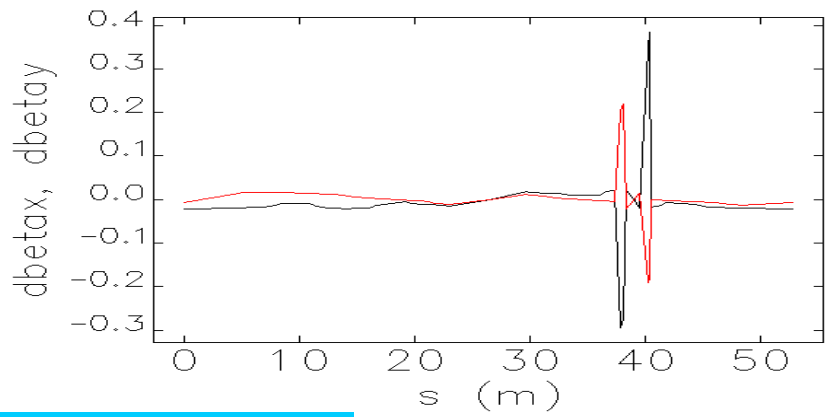
SM2: 32





Dp = -2.5%

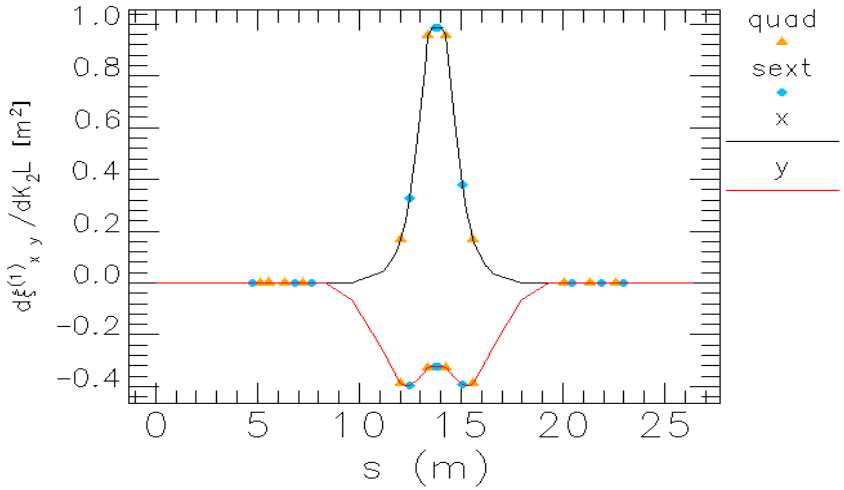
Similar results for closed orbit

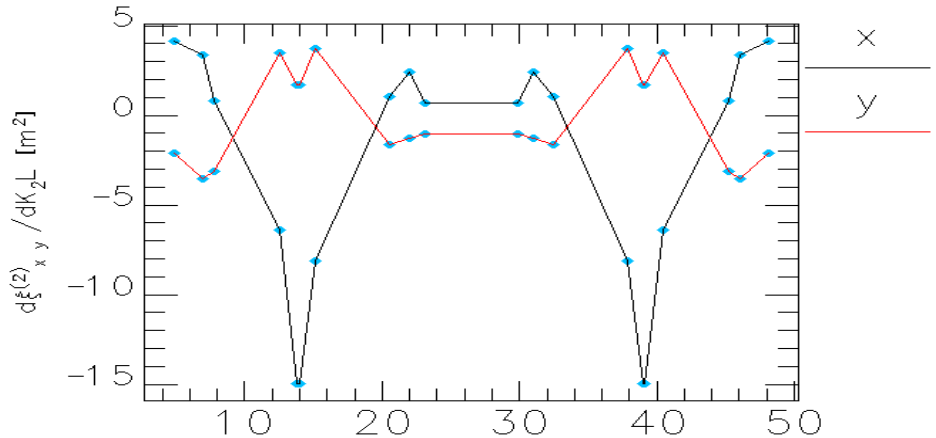


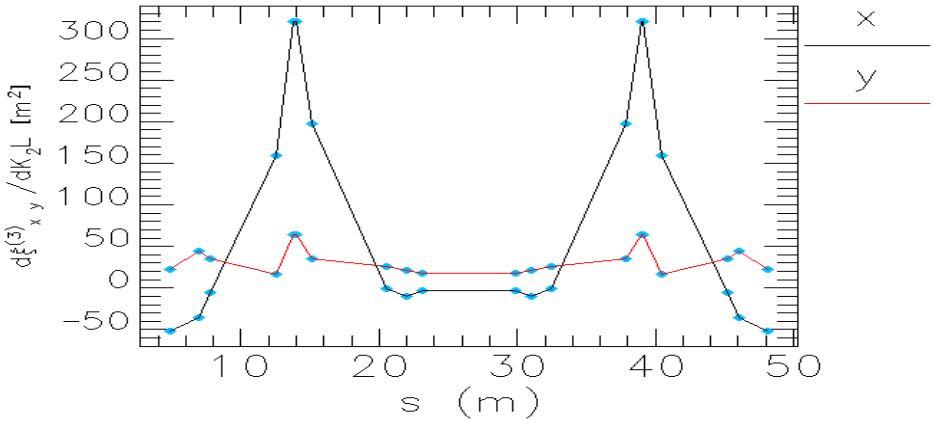
Dp = 2.5%

Conclusion: similar linear optical function for different symmetry

Sensitivity of Chromaticity



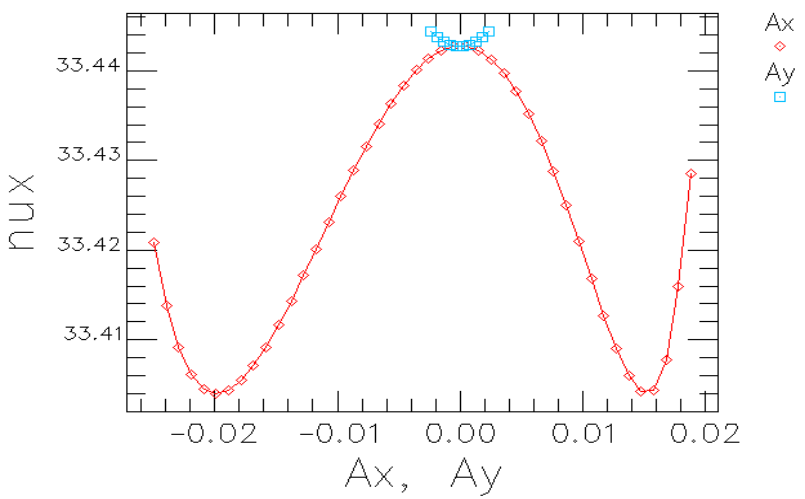


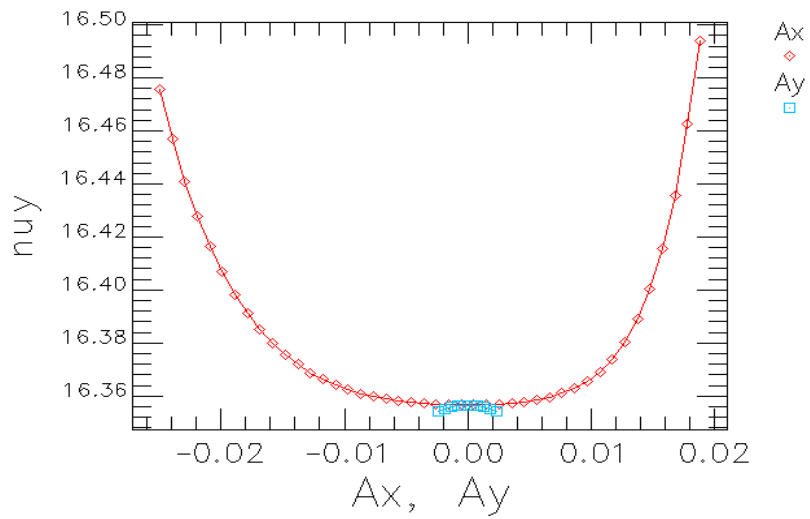


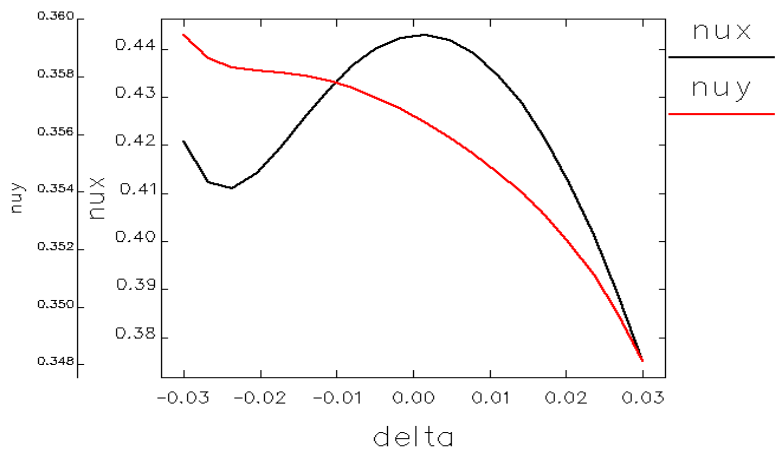
Sensitivity of the 1st (up), 2nd (upper right) and 3rd (lower right) order chromaticity per unit of sextupole strength change (ΔK2L).

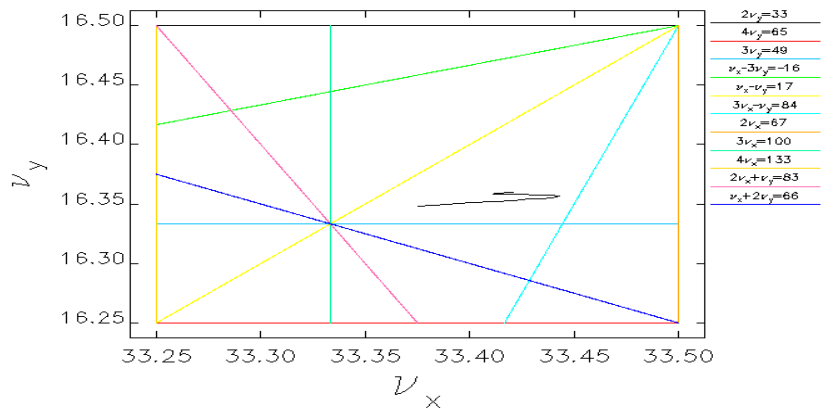
In these figures the SM1 is moved 10 cm with reflection symmetry.

Tune variation with offsets









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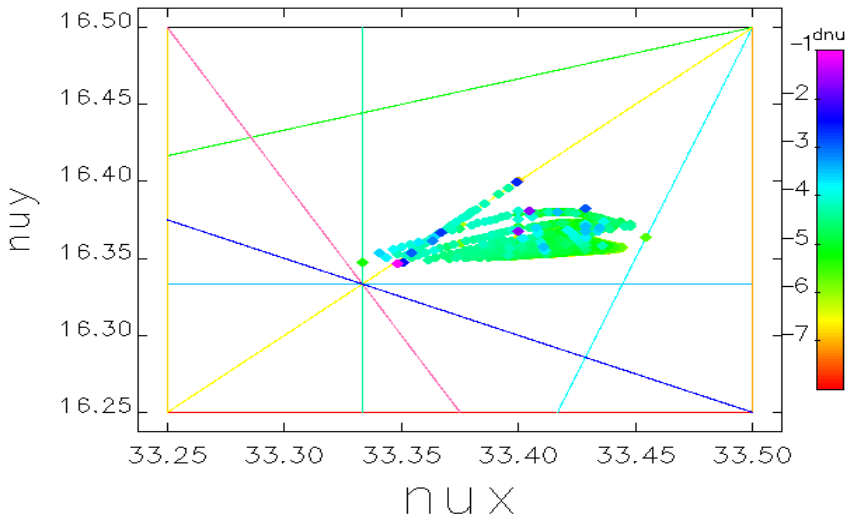
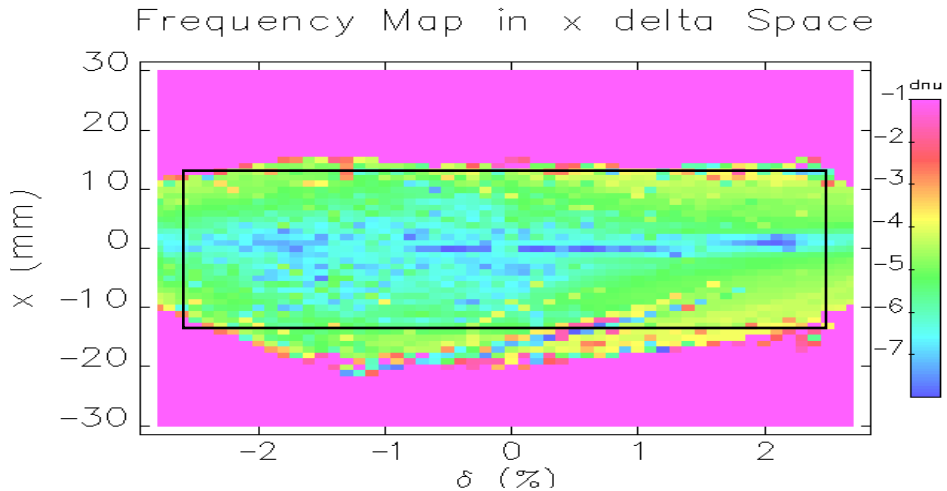
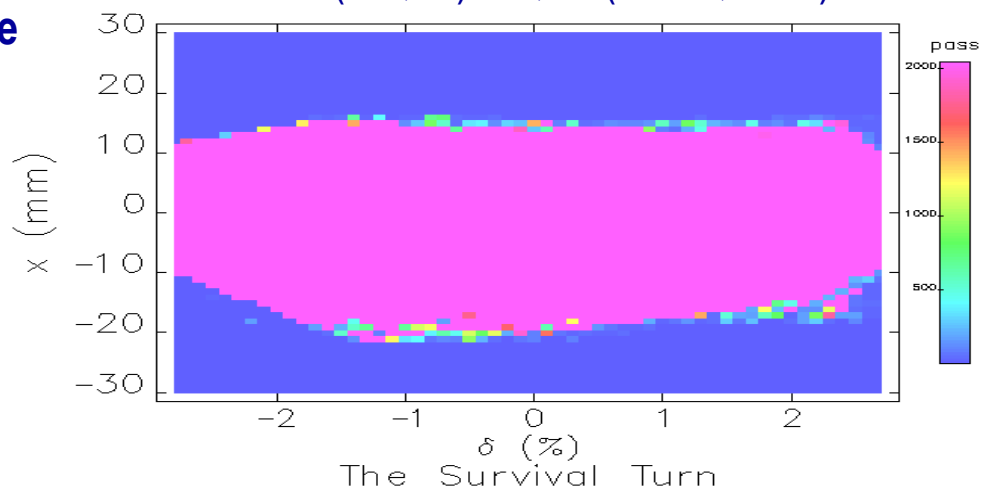
Frequency Map in (x,δ) Space





Frame: x: (-12,12)mm, δ: (-2.5%,2.5%)



Tune footprint in the required dynamic aperture

- 3 DWs
- Misalignment and magnet Error:

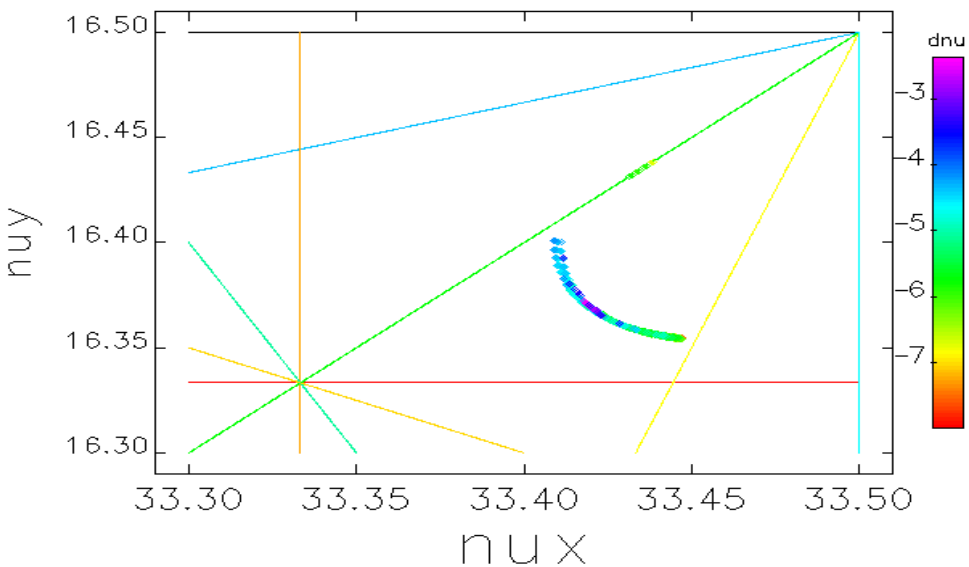
60 μm magnet to girder, 100 μm girder to girder

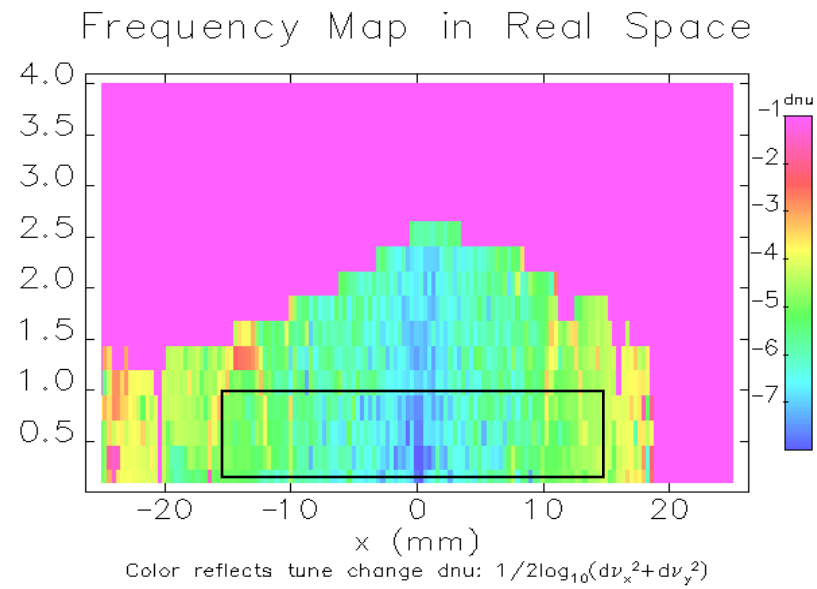
0.5 mr girder rotation, 0.2 mr magnet rotation

Systematic and random multipole errors

- Closed Orbit and beta beat corrected.

Frequency Map in (x,y) Space





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60 μm magnet to girder, 100 μm girder to girder

0.5 mr girder rotation, 0.2 mr magnet rotation

Systematic and random multipole errors

- Closed Orbit and beta beat corrected.

Frame:

x: (-15mm,15mm)

Y: (0, 1 mm)

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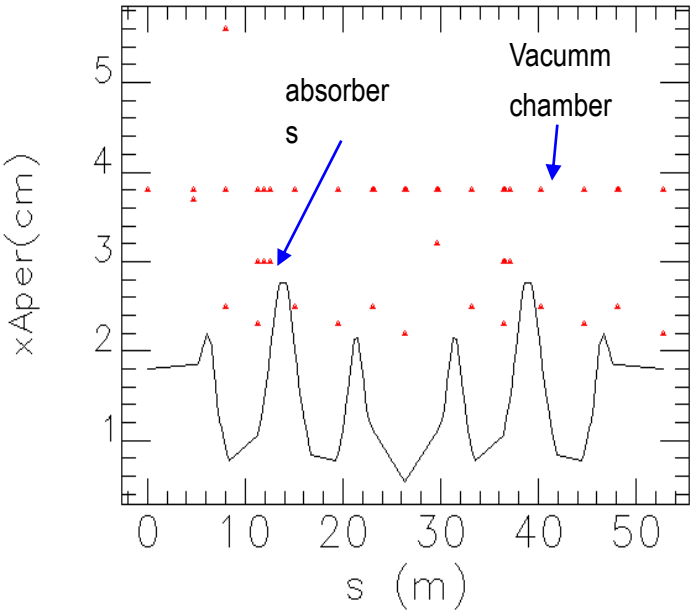
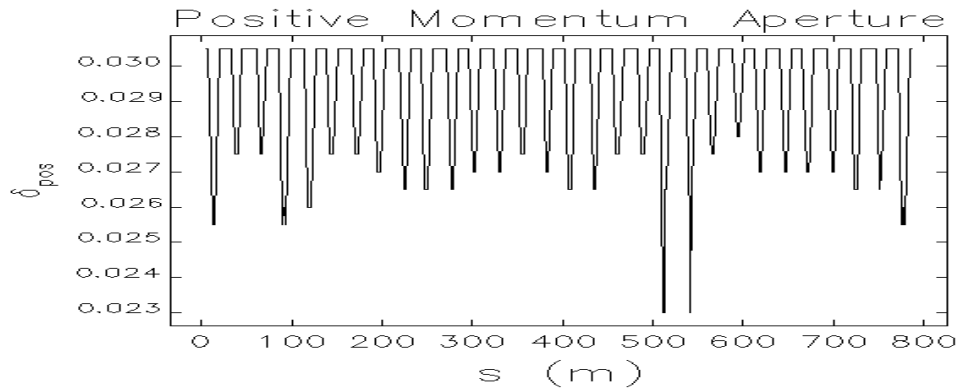
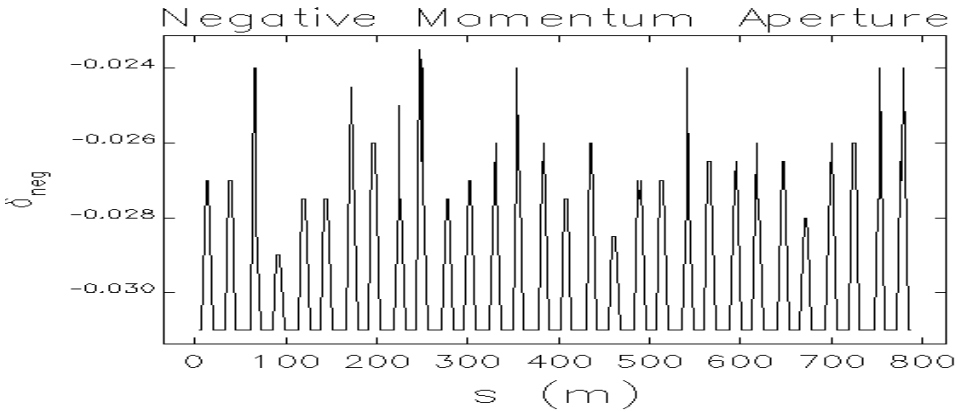
Momentum Aperture

- The horizontal physical aperture is limited by the photon absorbers.
- The photon absorbers are placed such that particles with δ=±3% are not blocked.







- Radiation damping and RF cavity are added.
- Vrf = 3.2 MV, rf bucket height is 3.1%.
- Touschek lifetime is 5 hours.

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Summary

- For emittance <1nm, we desire zero dispersion straights.
- In DBA lattice with only two sextupole families in dispersive region, it is difficult to control the second-order dispersion together with the tuneshifts-with-amplitude.
- Introducing a third-chromatic sextupole knob greatly improves controllability of these parameters.
- NSLS-II has decided to move the downstream sextupoles in the dispersive region 15 cm towards the dispersion maximum, maintaining translational symmetry
- Satisfactory nonlinear beam dynamics results have been obtained at zero linear chromaticity
- Studies at positive linear chromaticity are on-going