The Near Future Light Source: NSLS-II

Weiming Guo
NSLS-II, Brookhaven National Laboratory
FLS, March 1, 2010

U.S. DEPARTMENT OF ENERGY

BROOKHAVEN NATIONAL LABORATORY
BROOKHAVEN SCIENCE ASSOCIATES

Outline

- **NSLS-II introduction: main parameters and the lattice**
- **The design strategy: 30 DBA, weak dipole and damping wigglers**
- **The introduction of a third chromatic sextupole**
- **Nonlinear optimization approach and criterion**

Acknowledgement:

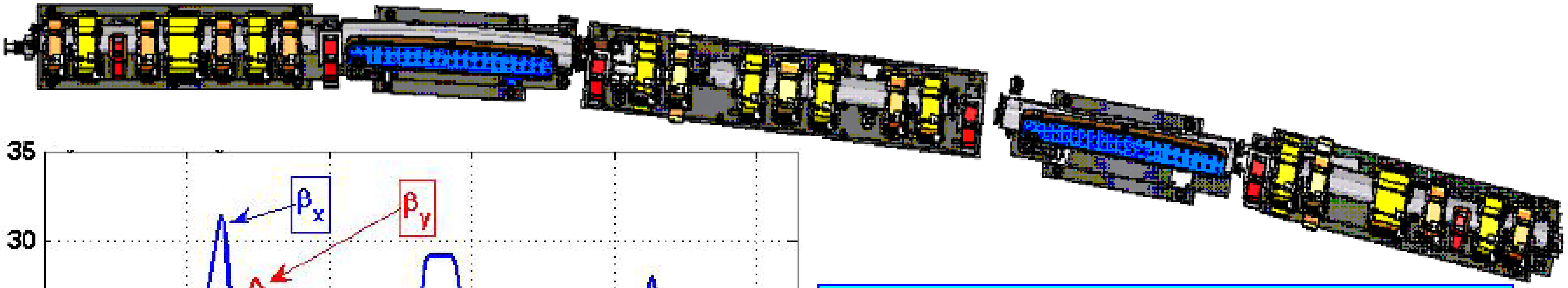
M. Borland Argonne National Laboratory

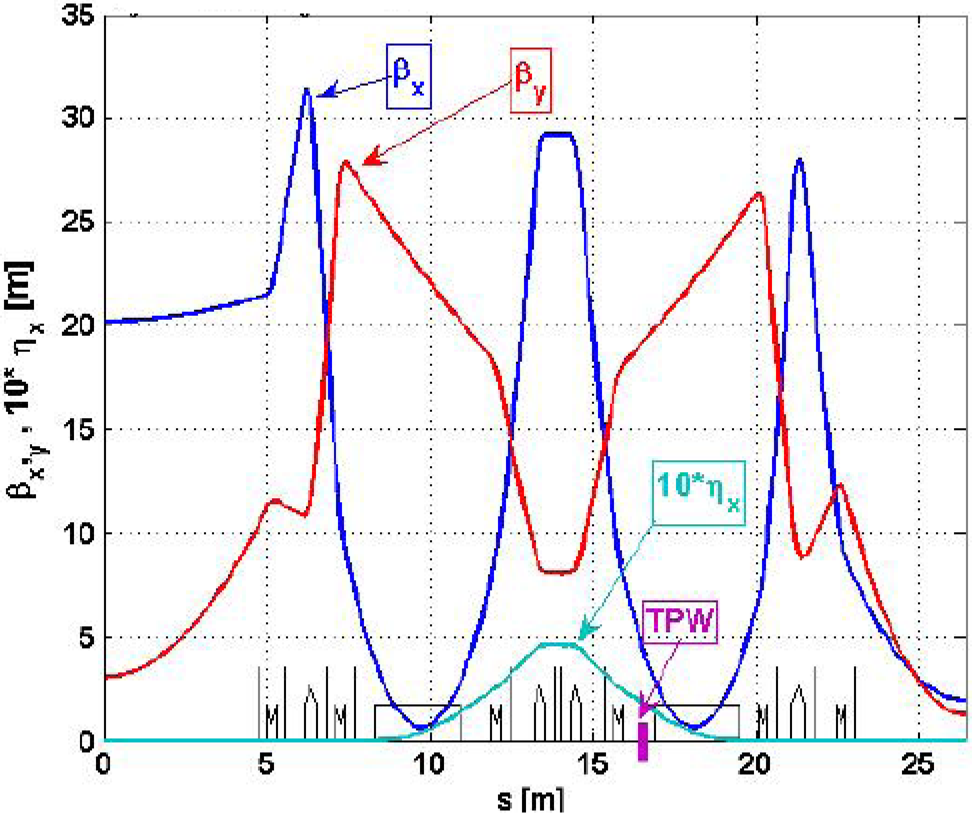
J. Bengtsson, S. Krinsky, S. Kramer, B. Nash, F. Willeke, S. Ozaki NSLS-II,BNL

NSLS-II: Main Parameters

Energy	3.0 GeV	Baseline DW:	Three 7m (1.8T)
Circumference	792 m	Energy Loss per Turn	95/225 KeV
Number of Cells	30 DBA	Energy Spread	0.05 / 0.094%
Number of Superperiods	15	Damping Time (E)	28/12 ms
Length ID Straights	6.6 & 9.3m	RF Frequency	~500 MHz
Emittance (h,v)	<1nm, 10pm	Harmonic Number	1320
Chrom. Per cell (x,y)	-3.2/-1.4	RF Bucket Height	>2.5%
Momentum Compaction	.00037	RMS Bunch Length	10 ps
Dipole Bend Radius	25m	Charge per Bunch	1.2nC
Average Current	500 mA	Top-Off Injection Freq	<1/min

Lattice Functions for One Cell





Dipole: 2, 1 ps

Quad: 10, 8 families, indep. powered

Sext: 9, 9 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

U.S. DEPARTMENT OF ENERGY

BROOKHAVEN NATIONAL LABORATORY
BROOKHAVEN SCIENCE ASSOCIATES

Some Advanced Features

- Vertical emittance has reached the diffraction limit of 1 Å
- Horizontal emittance of 1 nm is a critical number for the lattice design
- The deployment of damping wiggler and weak dipoles

The Damping Wiggler Approach

- DWs are located in the zero-dispersion straights; therefore there is no quantum excitation in the transverse planes.

- Straights are needed for damping wigglers, even though damping wigglers can also be used as radiation sources.

- IDs also reduce emittance significantly

- Weak dipole increases the circumference

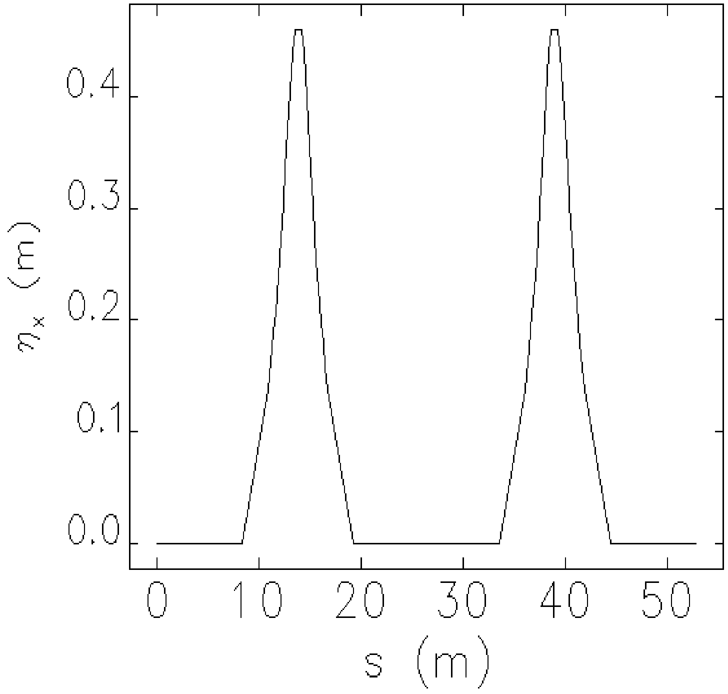
- Weak dipole contributes to the large peak beta function and large linear chromaticity

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, σ_δ=0.1%, $\beta_x \varepsilon_x \sim (\eta_x \sigma_\delta)^2$

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



Two consequences:

1. Emittance can not be further minimized by distributing dispersion to the straights
2. The number of the chromatic sextupoles is limited

Nonlinear Optimization

The sextupole **Hamiltonian**

$$M_{0\to1} e^{:S_1:} M_{1\to2} e^{:S_2:} \cdots e^{:S_n:} M_{n\to0} = A_0 e^{:V_1:} e^{:V_2:} \cdots e^{:V_n:} R_{0\to n} A_n^{-1}$$

$$= A_0 \exp(: \sum_i V_i + \frac{1}{2}\sum_{i<j} [V_i, V_j] + \cdots) R_{0\to n} A_n^{-1}$$

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

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

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

Total: 17 terms

The Chromatic Terms

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

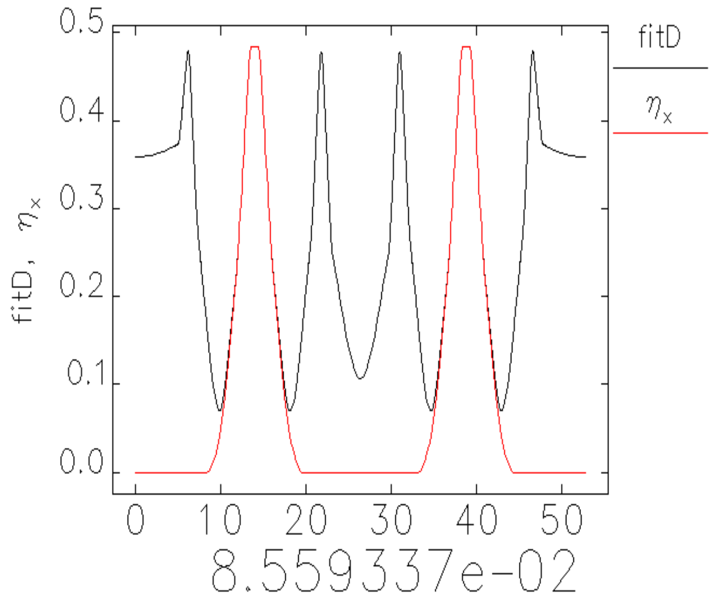
$$\Delta\xi^{(1)}{}_{x,y} = \pm\int dsK_2 D^{(1)}\beta_{x,y}$$

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

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

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

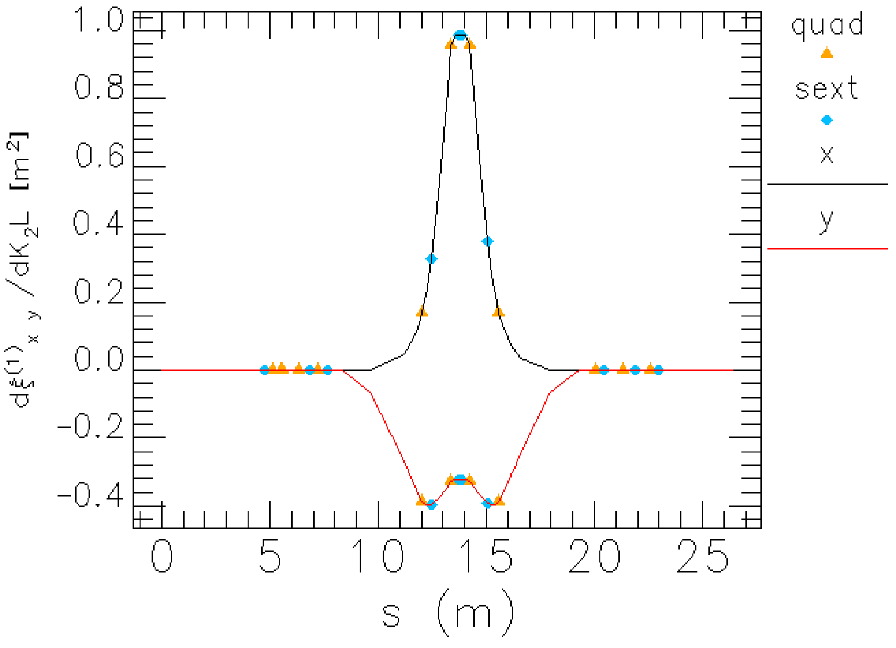
$$\frac{d\beta_y}{d\delta} = \frac{-\beta_y}{2\sin(2\pi\nu)}\int ds(K_1 - K_2 D^{(1)})\beta_y\cos(2|\Delta\Psi| - 2\pi\nu)$$



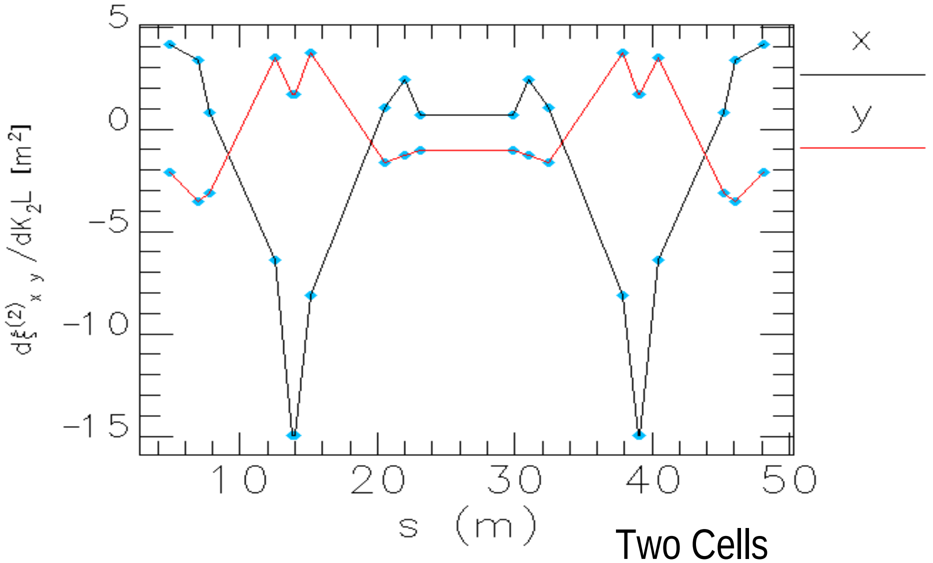
Dispersion fitting using $f(s) = C\bullet\sqrt{\beta_x(s)}$

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

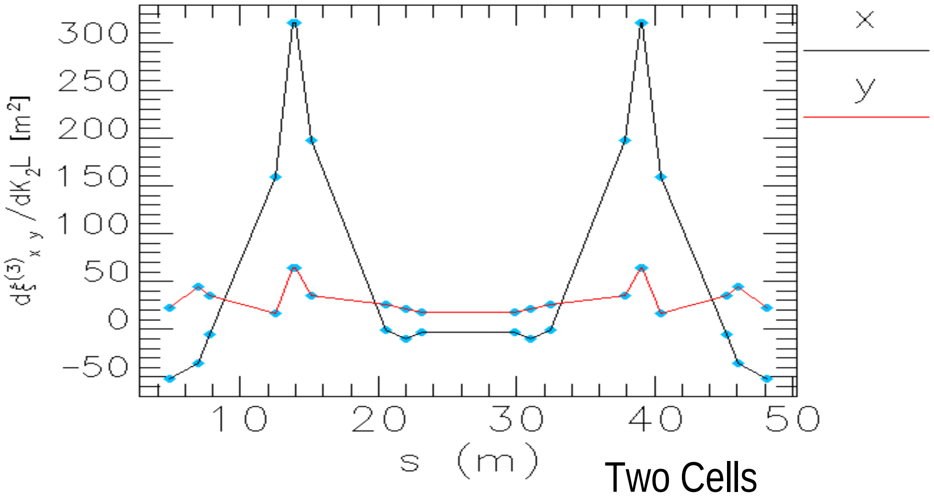
Sensitivity of Chromaticity



One Cell



Two Cells



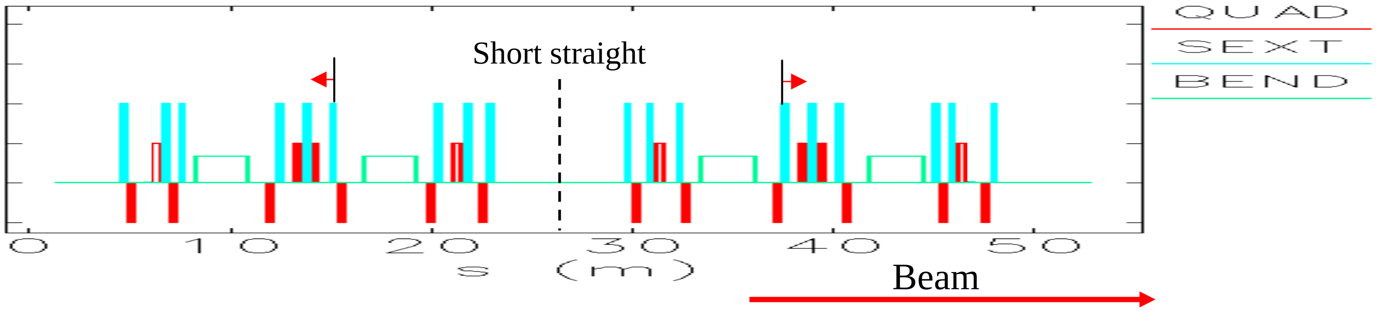
Two Cells

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

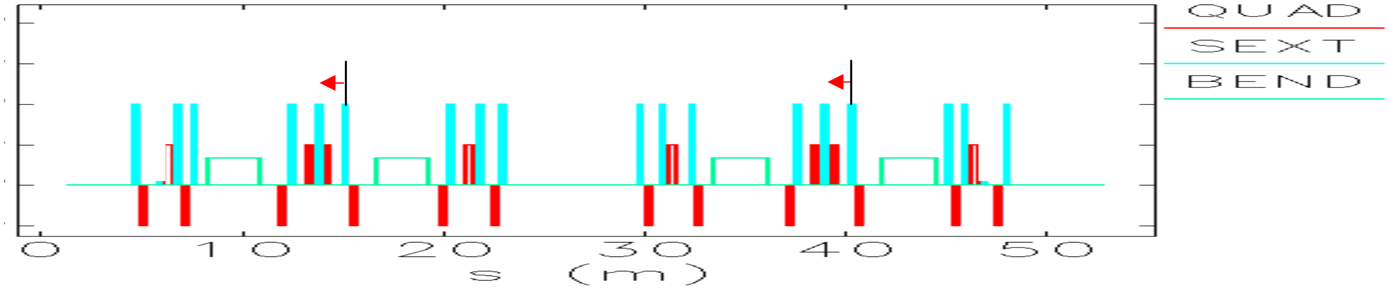
In these figures the SM1 is moved 10 cm with reflection symmetry.

Introduction of the Third Sextupole Family

Reflection Symmetry



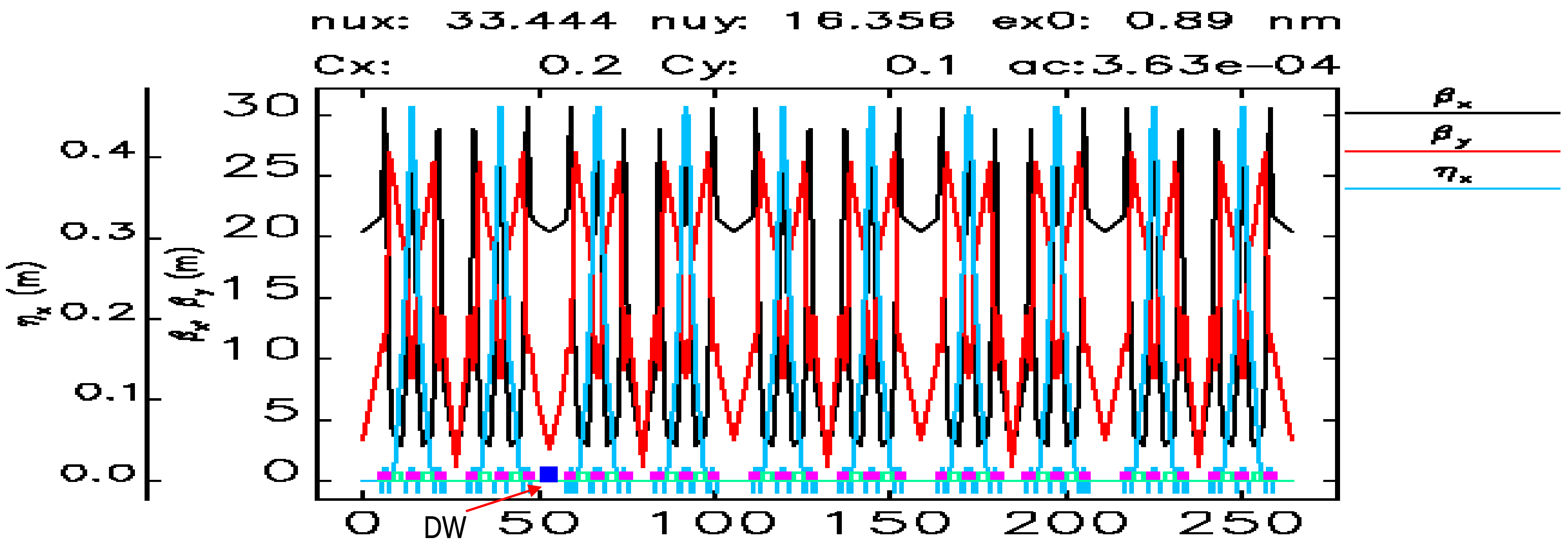
Translation Symmetry



Conclusion:

1. **The capability to correct the off-momentum closed orbit and beta functions is limited by the linear chromaticity correction.**
2. **The second and third order horizontal chromaticities are very sensitive to the location of the chromatic sextupoles.**
3. **The vertical nonlinear chromaticities are small in general, due to small vertical beta function and zero vertical dispersion .**
4. **Three chromatic sextupole families are necessary to correct the linear chromaticity ($\xi_{1,x}\xi_{1,y}$), and the 2nd order horizontal chromaticity($\xi_{2,x}$).**
5. **For NSLS-II the third sextupole family can be obtained by moving one of the degenerated sextuple by 15 cm towards the dispersion maximum.**

Dynamic Aperture Optimization with DWs

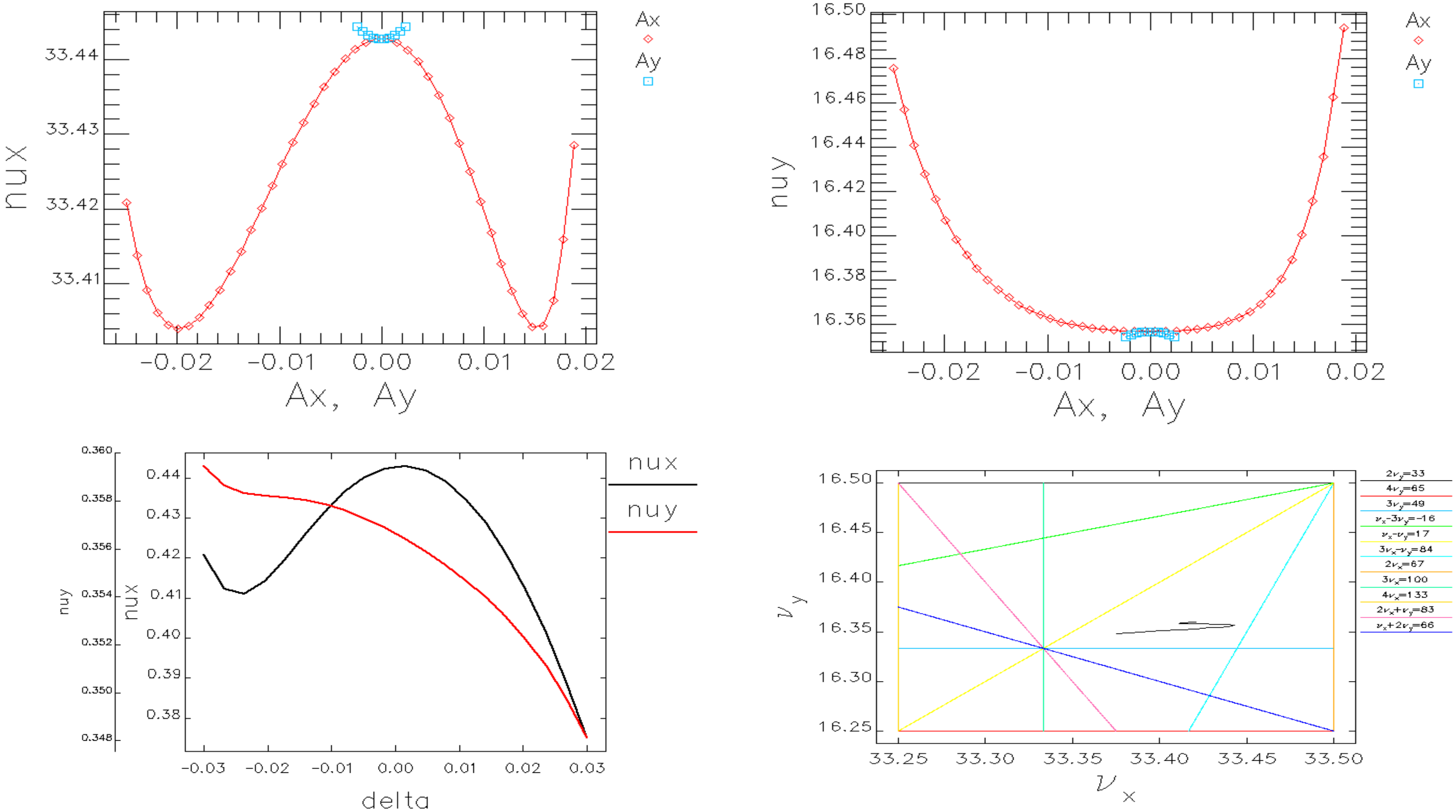


- Each Chromatic sextupole family has the same strength in 5 super-periods: 3 knobs
- Geometric sextupoles are powered independently in the DW matching section: 6+3 knobs

- Beta function

	Long St.	Short St.	DW LS
β x	20.4	1.8	20.3
β y	3.3	1.1	2.5

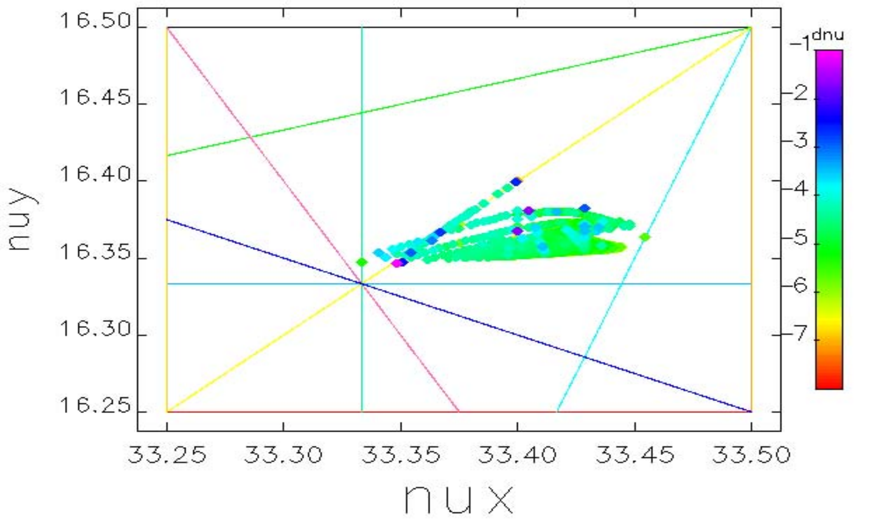
Tune variation with offsets

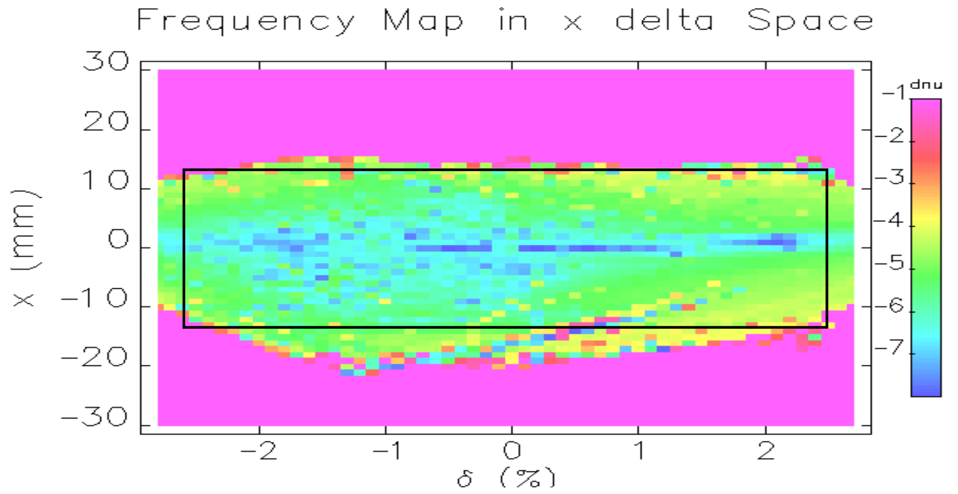


U.S. DEPARTMENT OF ENERGY

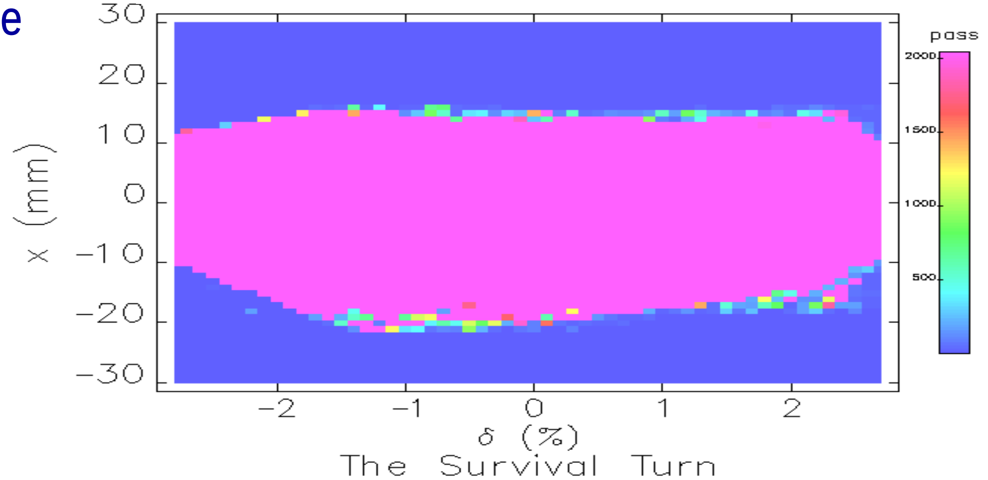
BROOKHAVEN
NATIONAL LABORATORY
BROOKHAVEN SCIENCE ASSOCIATES

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:

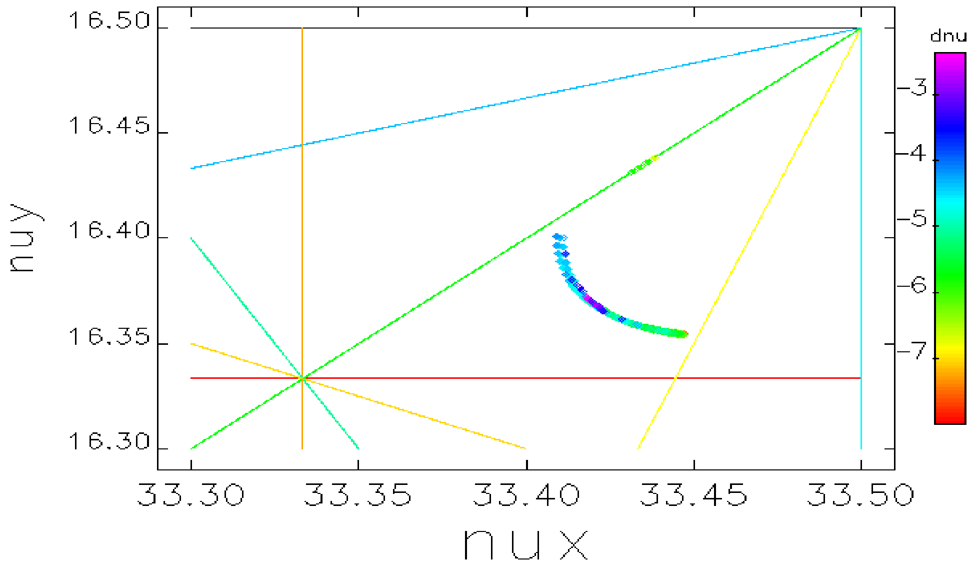
60 μm magnet to girder, 100 μm girder to girder

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



Tune footprint in the required dynamic aperture

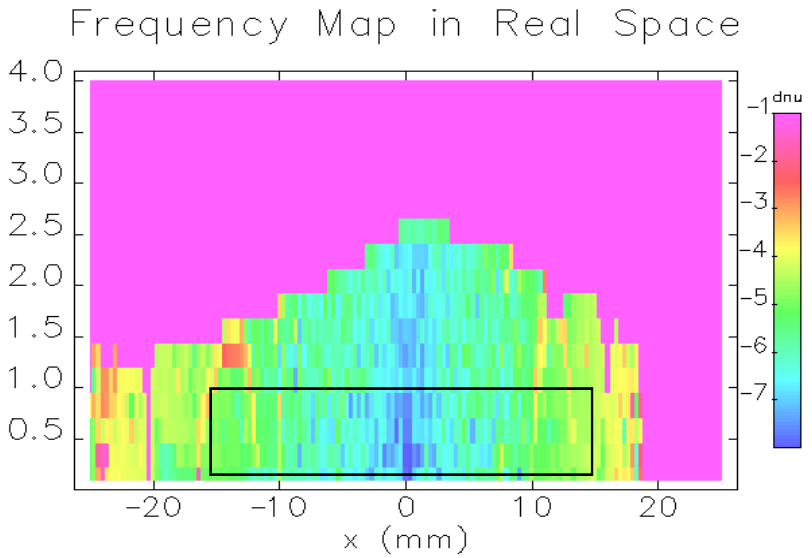
- 3 DWs
- Misalignment and magnet Error:

60 μ m magnet to girder, 100 μ m girder to girder

0.5 mr girder rotation, 0.2 mr magnet rotation

Systematic and random multipole errors

- Closed Orbit and beta beat corrected.



Color reflects tune change dnu: $1/2\log_{10}(d\nu_x^2+d\nu_y^2)$

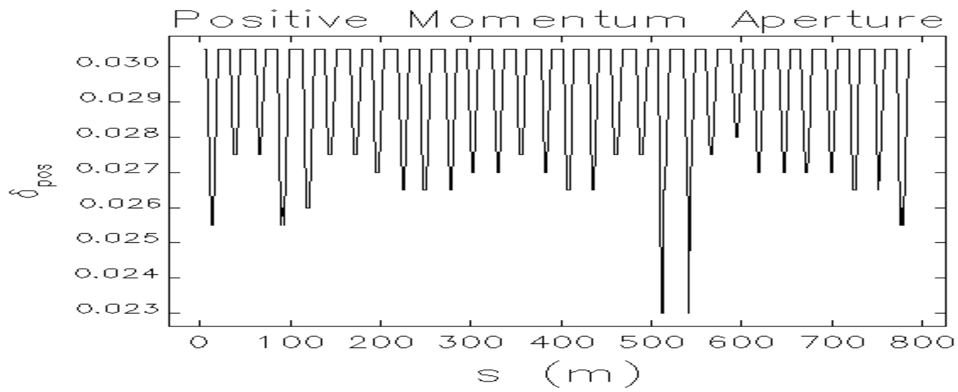
Frame:

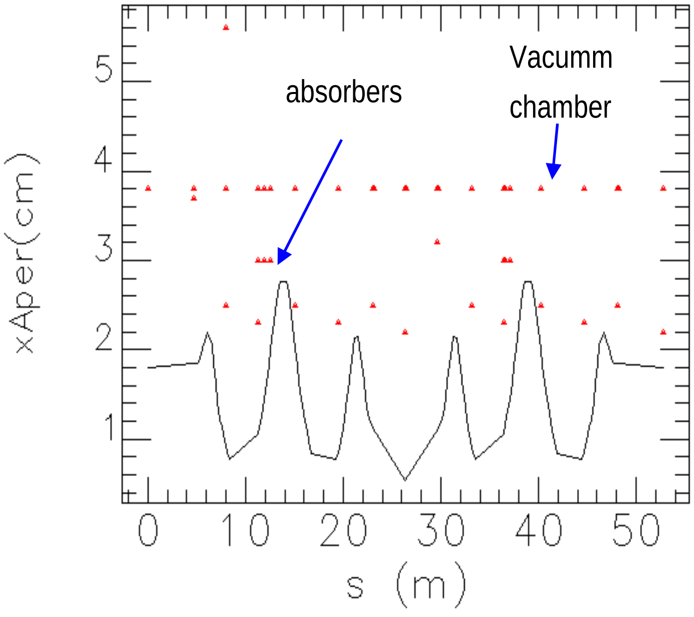
x: (-15mm,15mm)

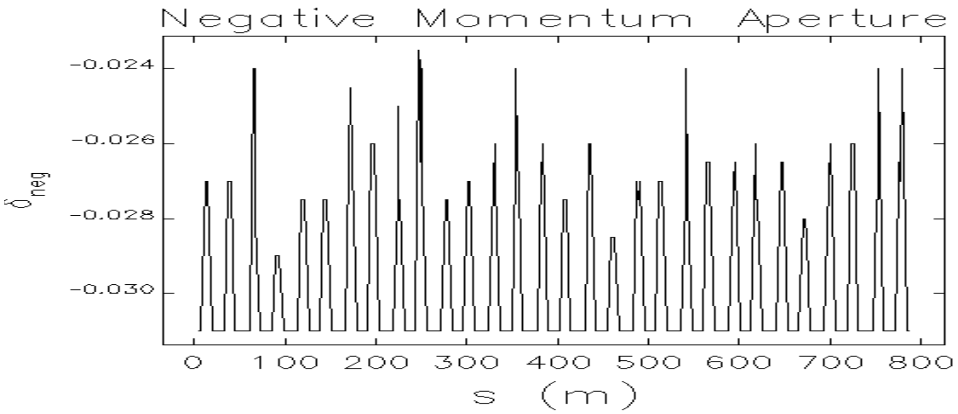
Y: (0, 1 mm)

Momentum Aperture

- The horizontal physical aperture is limited by the photon absorbers.
- The photon absorbers are placed such that particles with $\delta = \pm 3\%$ 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.

Summary

- **NSLS-II is a starting point of the future storage-ring-based light sources.**

- **For emittance <1nm, the straights must be non-dispersive; therefore the lattice has to be achromatic.**

- **A third chromatic sextupole family is needed for the nonlinear optimization of the DBA lattice. It is a knob for the minimization of the second-order horizontal chromaticity.**

- **An example is presented to demonstrate the nonlinear optimization approach for the NSLS-II.**