NSLS-II Lattice Design Strategies

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Acknowledgement:

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Outline

1. Introduction to the linear lattice
2. Linear lattice grid
3. Nonlinear requirements: injection and Touschek scattering
4. Minimum needed sextupole families
5. Required physical aperture
6. Effects of the multipole field errors

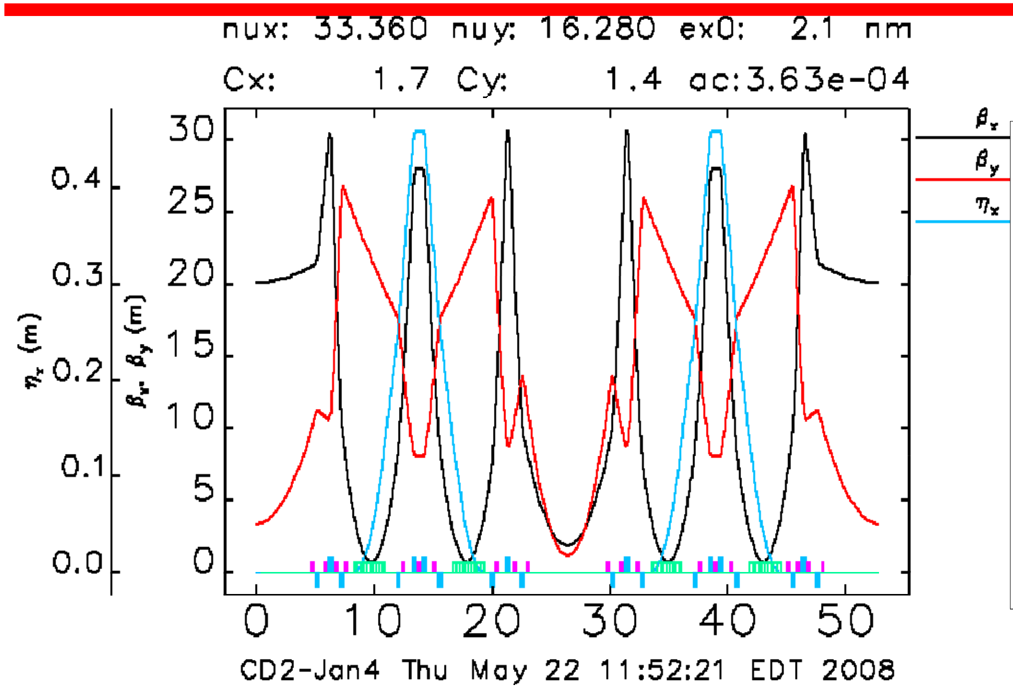
Method:

Simulation using Elegant

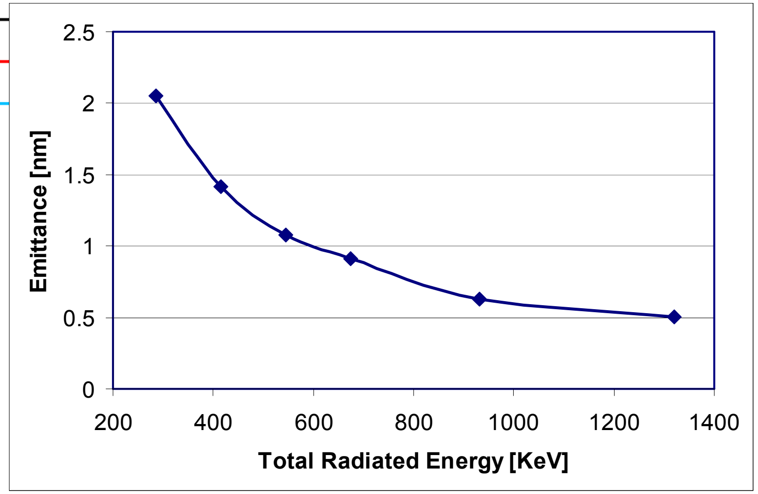
Main Design Parameters

Beam Energy	3 GeV
Circumference	792 m
Circulating current	500 mA
Total number of buckets	1320
Lifetime	3 hours
Electron beam stability size	10% beam
Top-off injection current stability	<1%
ID straights for undulators	>21
Straight length	9.3/6.6 m

Magnets and lattice



Natural emittance with 0, 1, 2, 3, 5 and 8 DWs added



Courtesy of S. Kramer

Quad. Family: 8, 10 magnets per cell

Sext. Family: 9, 10 magnets per cell

Chromaticity per cell: -3.4/-1.4

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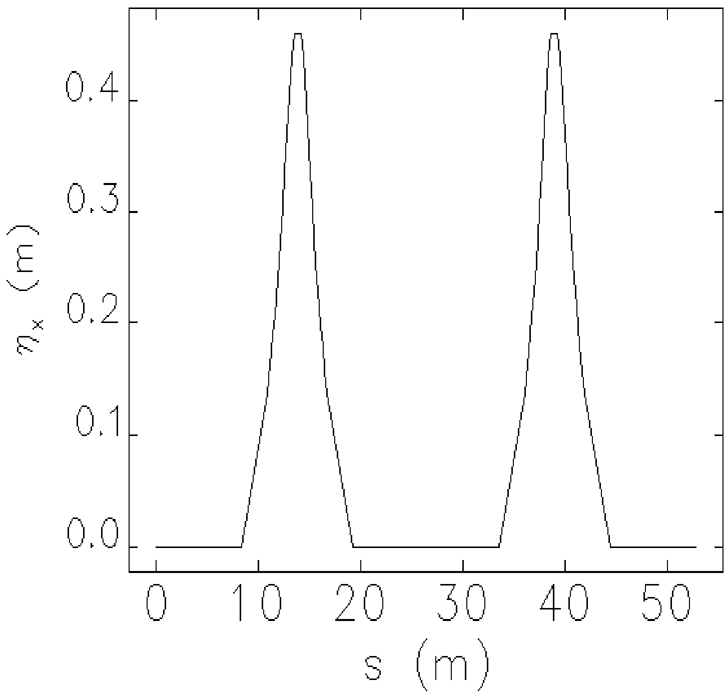
Linear Lattice design approaches

1. Large bending radius enhances the effect of the damping wigglers

$$B = 0.4T, \rho = 25m, \begin{cases} D_x = \rho(1-\cos\theta) \\ D_x' = \sin\theta \end{cases}$$

2. Strict double-bend-acromat



Two reasons NSLS-II is sensitive to the residual dispersion:

- 1nm emittance. For β_x =2 m, η_x=4.5 cm, $\beta_x\varepsilon_x \sim (\eta_x\sigma_\delta)^2$
- Damping wiggler has quantumn excitation effect

Tunability: An Ensemble of Stable Solutions

Tune scan: ν_x~ 33, n_v~ 16

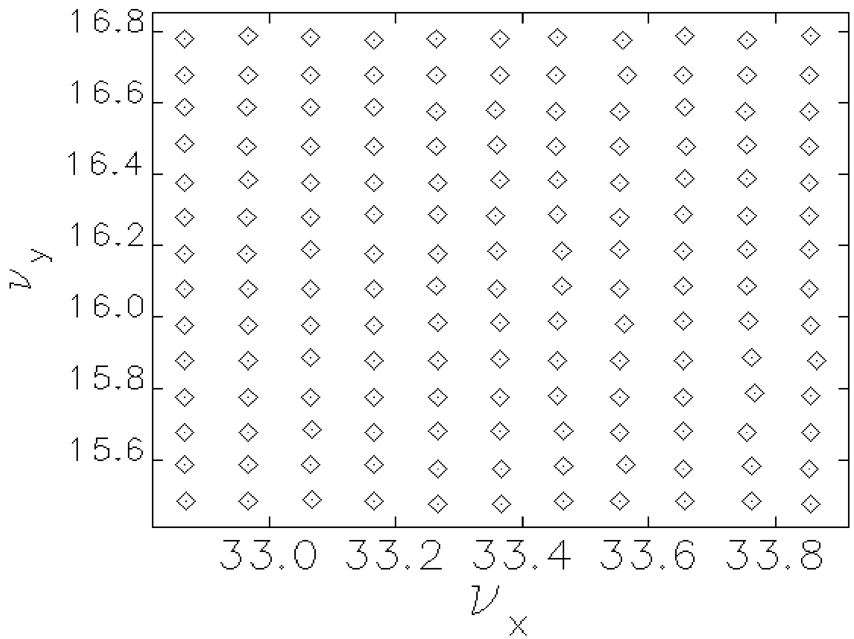
$$\nu_x \pm 0.5$$

$$\nu_y \pm 0.5$$

$\Delta\nu_x / \nu_x = \pm$ **1.5% in horizontal**

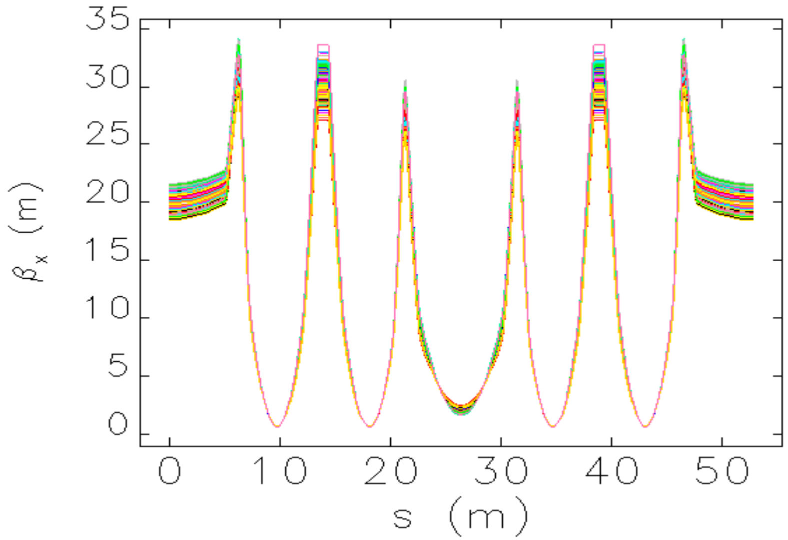
$\Delta\nu_y / \nu_y = \pm$ **3% in vertical**

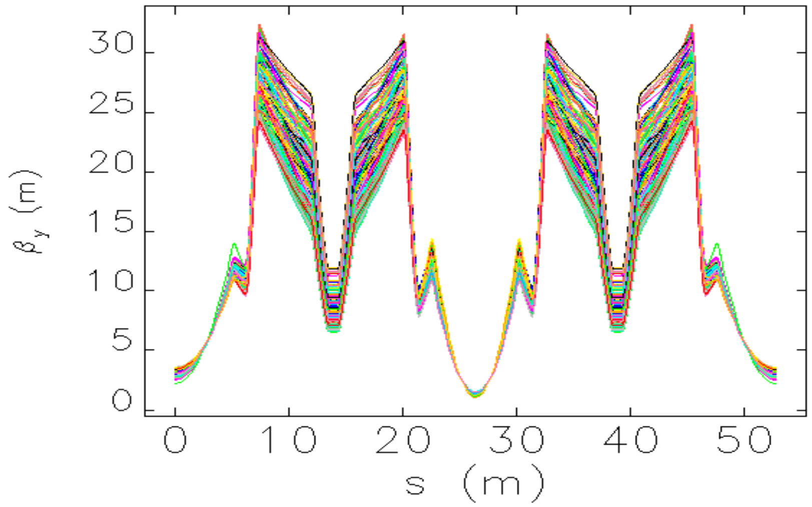
◊=Stable solution found by the Elegant optimizer

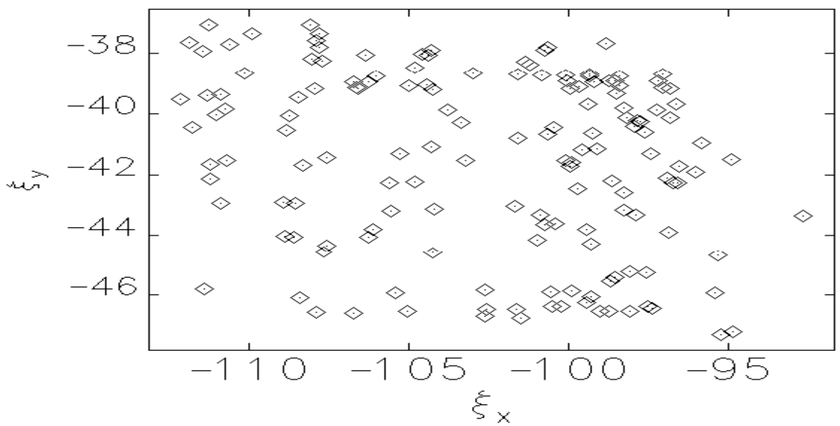


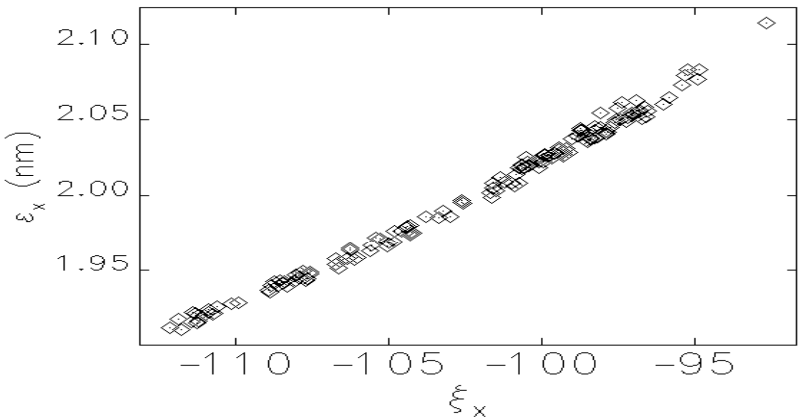
- **Each solution meets the requirements on the emittance, symmetry, chromatic conditions, beta functions, and chromaticity**
- **This ensemble of solutions is used as input for the dynamic aperture optimization**

Lattice Functions of the Solutions

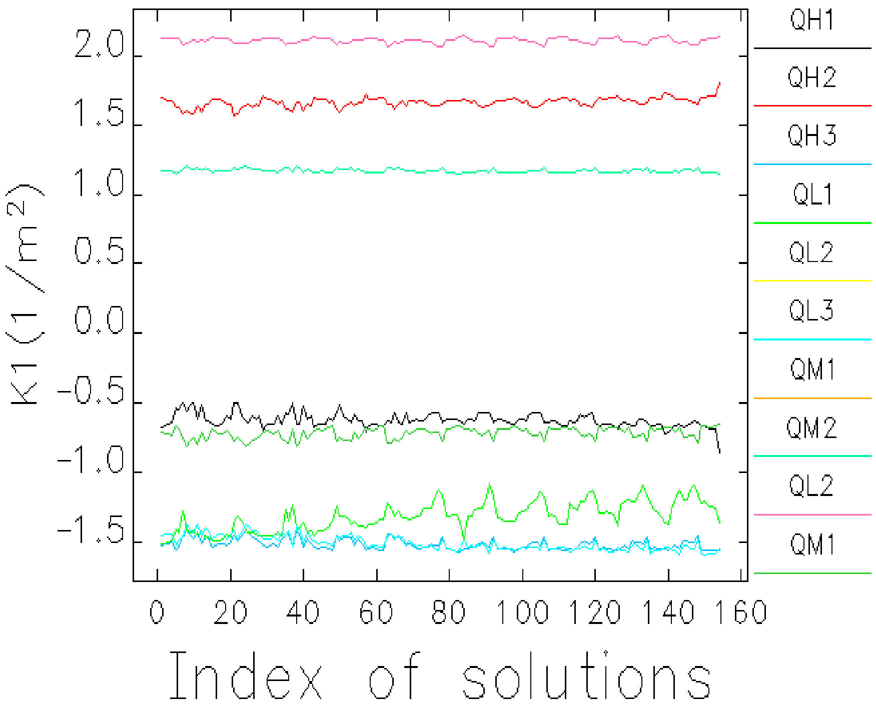








Quadrupole Strength Variation Range

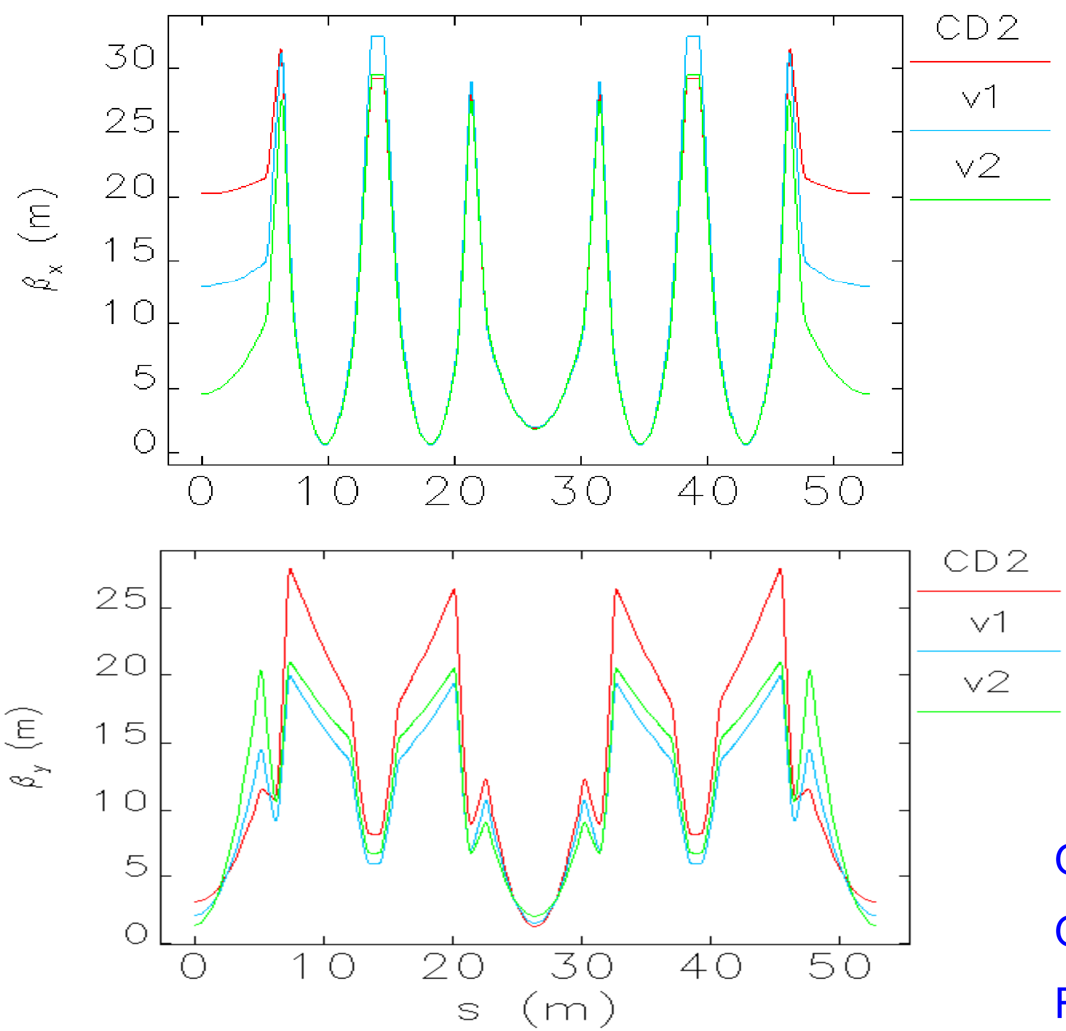


Quad	min	max	ave	$\frac{sig}{ave.}$ (%)	$\frac{\max.-\min.}{2*ave.}$ (%)
QH1	-0.861	-0.500	-0.625	7.8	28.9
QH2	1.572	1.800	1.662	2.0	6.9
QH3	-1.570	-1.423	-1.520	2.5	4.8
QL1	-1.513	-1.086	-1.320	7.8	16.2
QL2	2.066	2.150	2.112	0.9	2.0
QL3	-1.597	-1.374	-1.511	3.5	7.4
QM1	-0.814	-0.657	-0.717	5.7	10.9
QM2	1.150	1.199	1.169	1.1	2.1

Variation of K1 ($1/m^2$)

Conclusion: Although we are tuning in a large range, the relative change of the quadrupole Strength is <30%. This allows us to use weaker power supplies for certain quadrupoles.

K1 Margin for the Customization of β_x



Quad	ave	$\frac{v1-ave.}{ave.}$ %	$\frac{v2-ave.}{ave.}$ %
QH1	-0.625	103.06	146.55
QH2	1.662	17.58	26.35
QH3	-1.520	7.19	15.15
QL1	-1.320	7.52	11.26
QL2	2.112	1.23	1.56
QL3	-1.511	1.31	1.38
QM1	-0.717	6.32	7.54
QM2	1.169	1.22	1.44

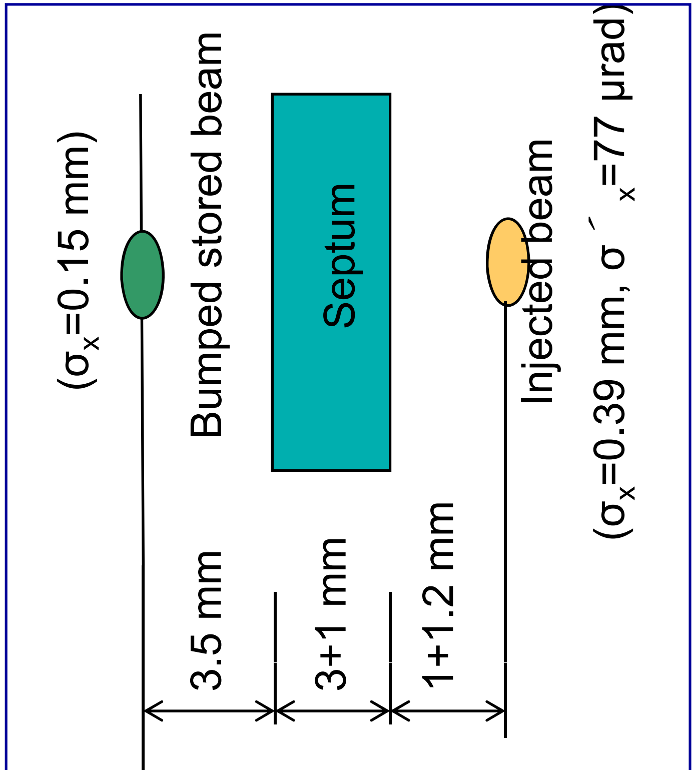
Variation of K1 ($1/m^2$)

QH2,QL2: K1<2.2, 37% margin

QM1: K1<1.3, ~ 25% margin

Rest: K1<2, ~25% margin

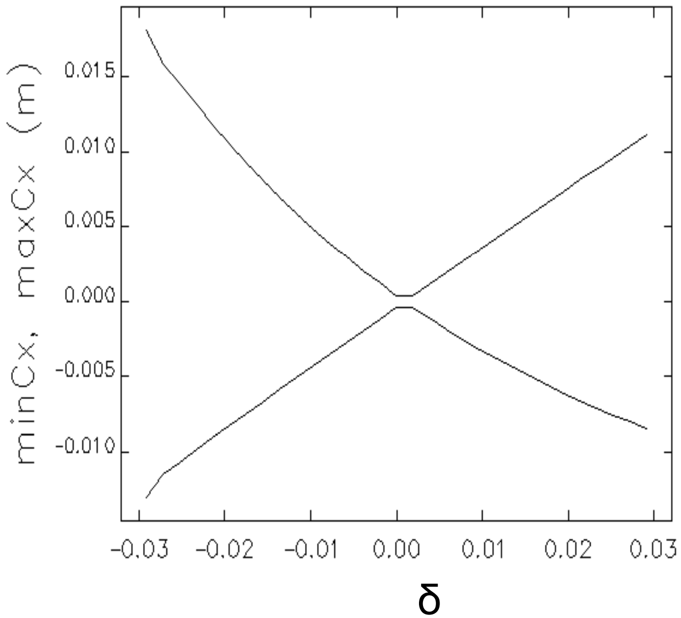
Nonlinear Design Goal



Courtesy of I. Pinayev

1. **Sufficient dynamic aperture (>11mm) for injection**

On momentum particle



Minimum required dynamic aperture

2. **Sufficient dynamic aperture to keep Touschek scattered particles with δ= ±2.5%**

Off momentum particle

Source of the nonlinearity

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 order chromaticity

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

Number of chromatic sextupole families

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

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

$$= -D^{(1)} + \frac{\sqrt{\beta}}{2\sin(\pi\nu)} \int ds K_1 D^{(1)} \sqrt{\beta} \cos(|\Delta\Psi| - \pi\nu) - c \times \Delta\xi_x^{(1)}$$

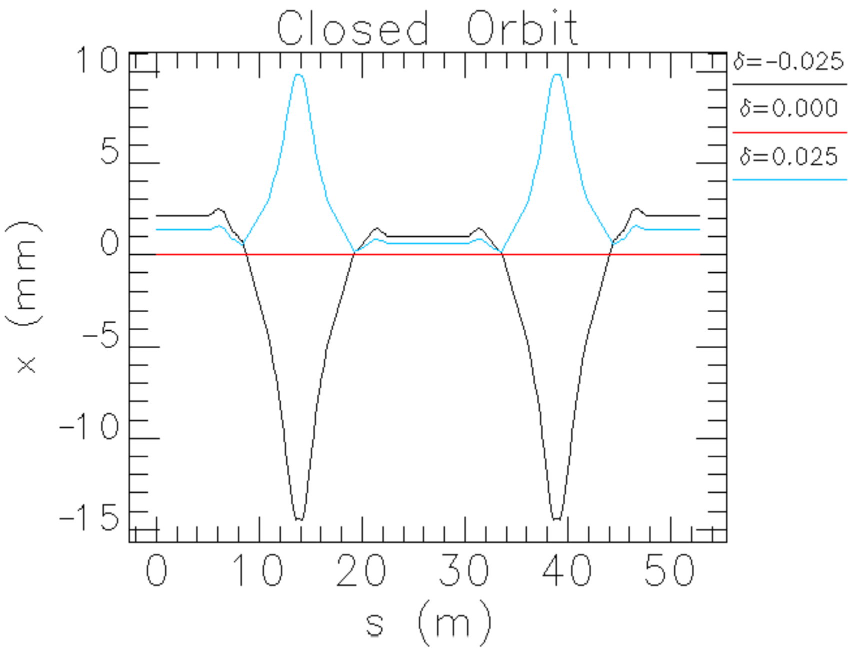
$$\frac{d\beta_x}{d\delta} = \frac{\beta_x}{2\sin(2\pi\nu)} \int ds (K_1 - K_2 D^{(1)}) \beta_x \cos(2|\Delta\Psi| - 2\pi\nu)$$

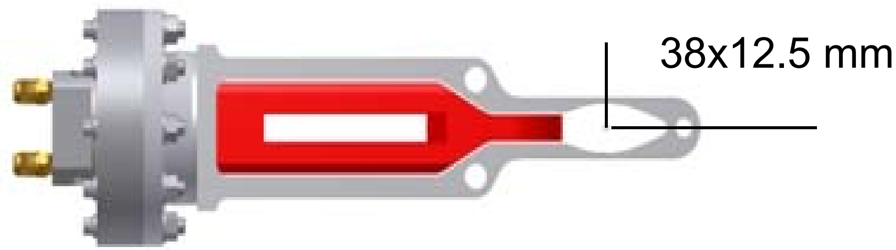
$$\frac{d\beta_y}{d\delta} = \frac{-\beta_y}{2\sin(2\pi\nu)} \int ds (K_1 - K_2 D^{(1)}) \beta_y \cos(2|\Delta\Psi| - 2\pi\nu)$$

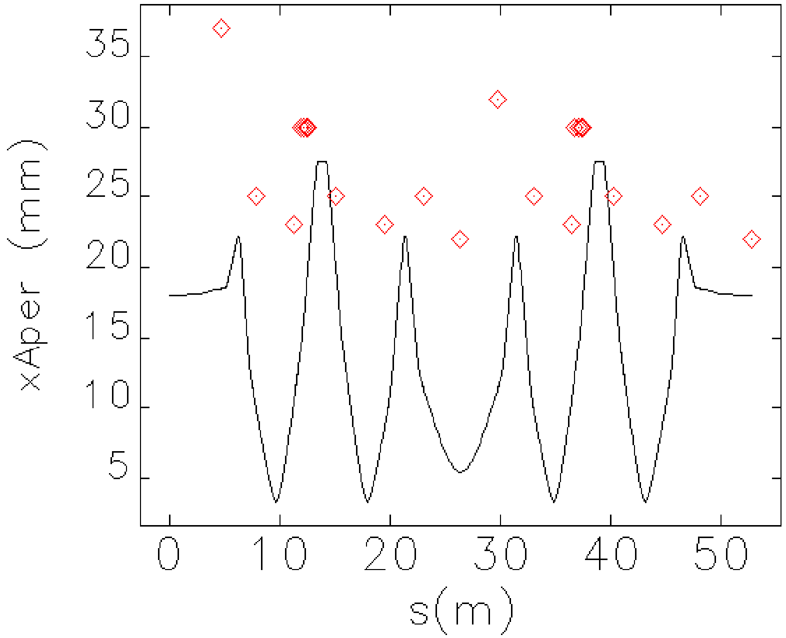
Conclusion:

Because the betatron phase advance in the dispersive region is small (x: ~ 10^{o}, y~ 20^{o}), the five chromatic terms have only two degree of freedom. → 7~8 sextupole families

Stay-clear aperture

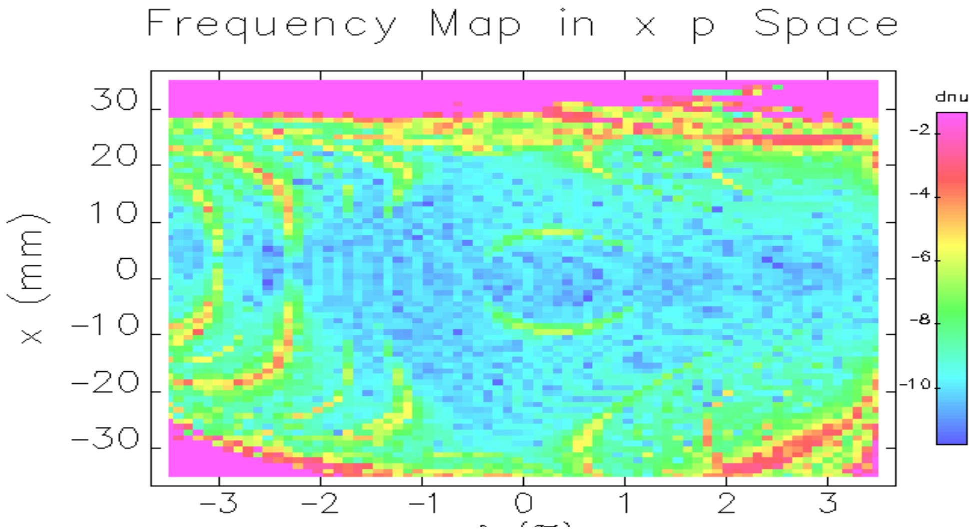






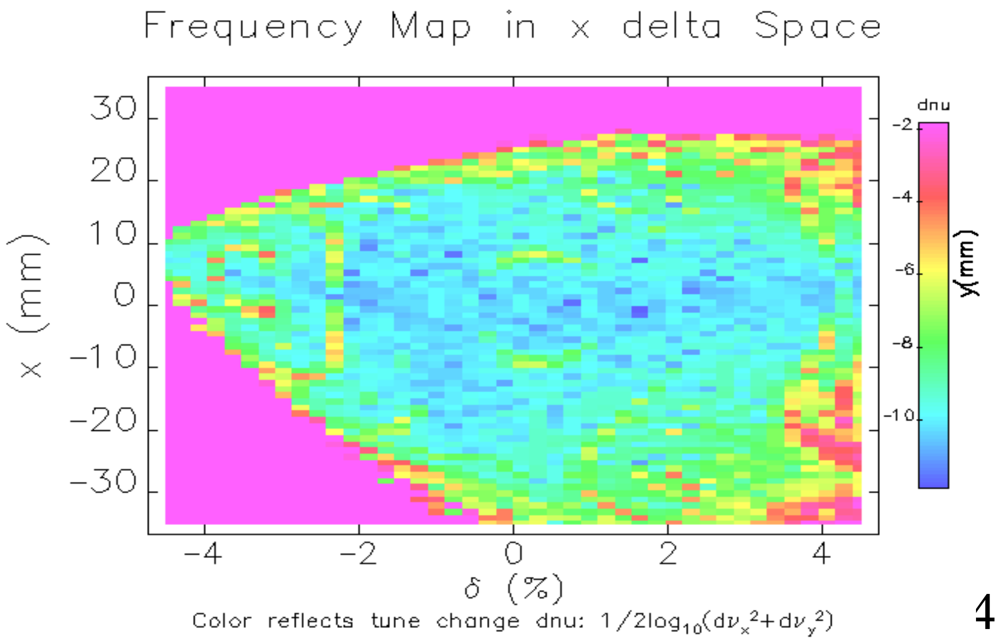
$$x_{c.o.}(s)+x_{c.o.}(s_0)\sqrt{\beta(s)/\beta(s_0)}$$

Dynamic Aperture with Multipole Error

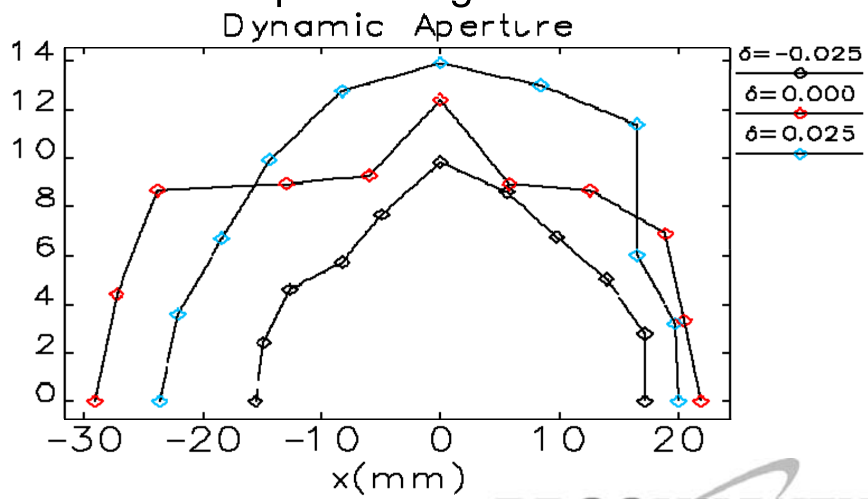


The Feb.-08 multipole components at 25 mm

Magnet Type	Magnet Aperture (mm)	Multipole Order	Relative Strength (x10^{-4})
Quad	66	6	1
Quad	66	10	3
Sext	68	9	1
Sext	68	15	2



DA collapse at negative momentum



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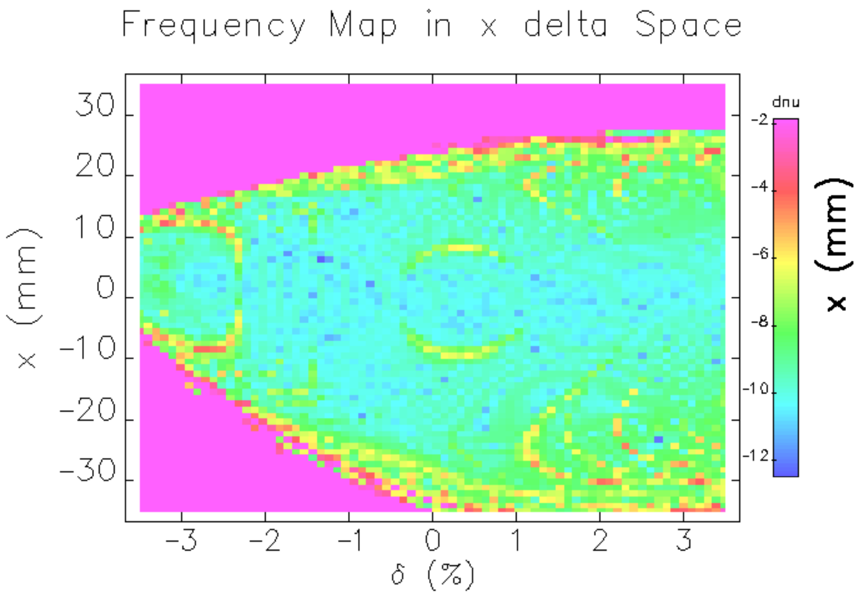
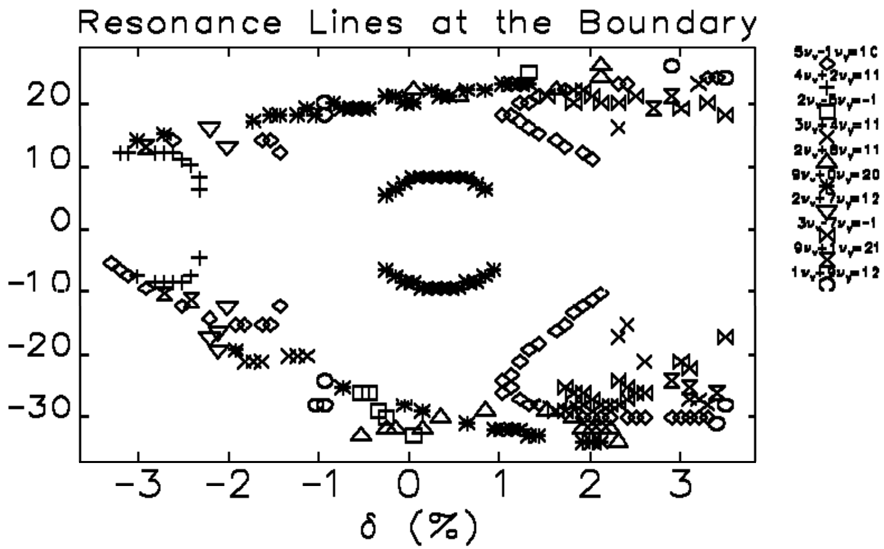
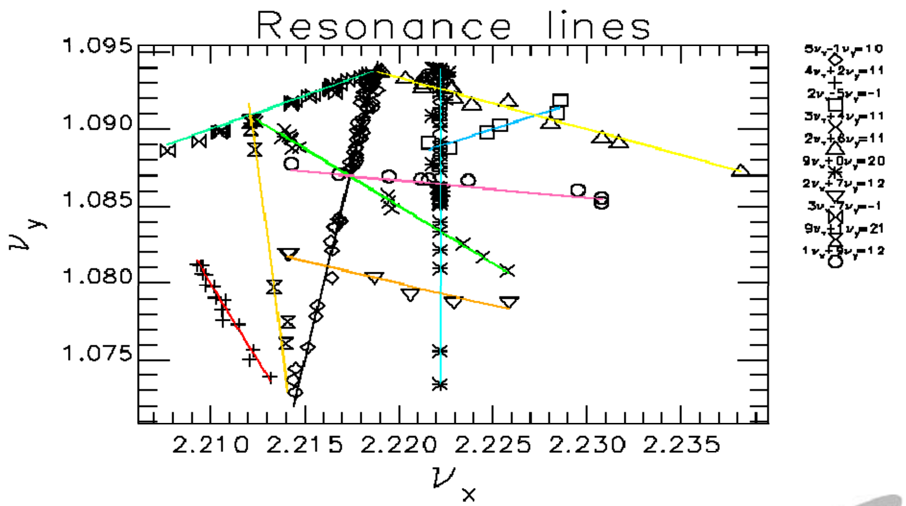
Effects of Multipoles



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

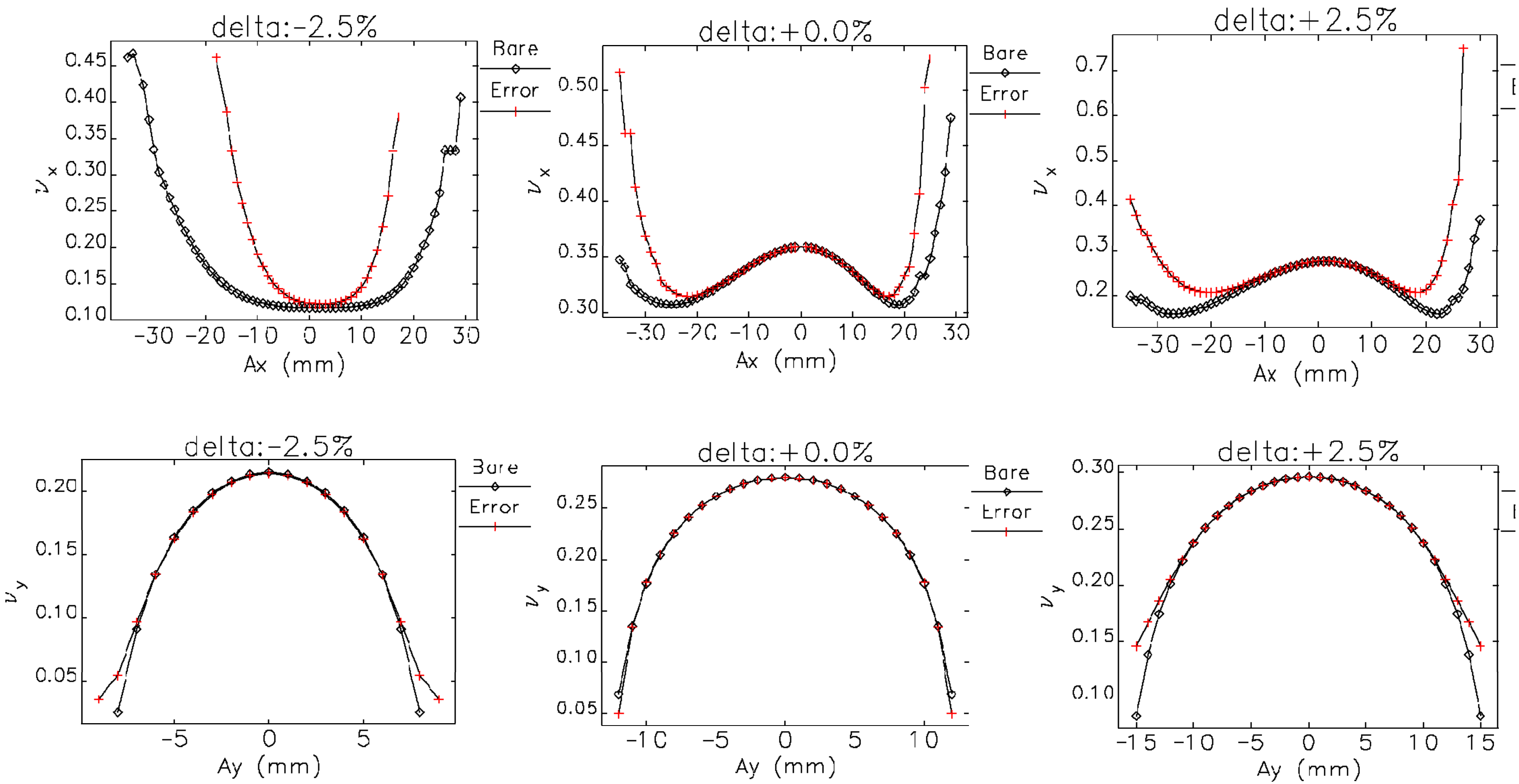




Conclusion:

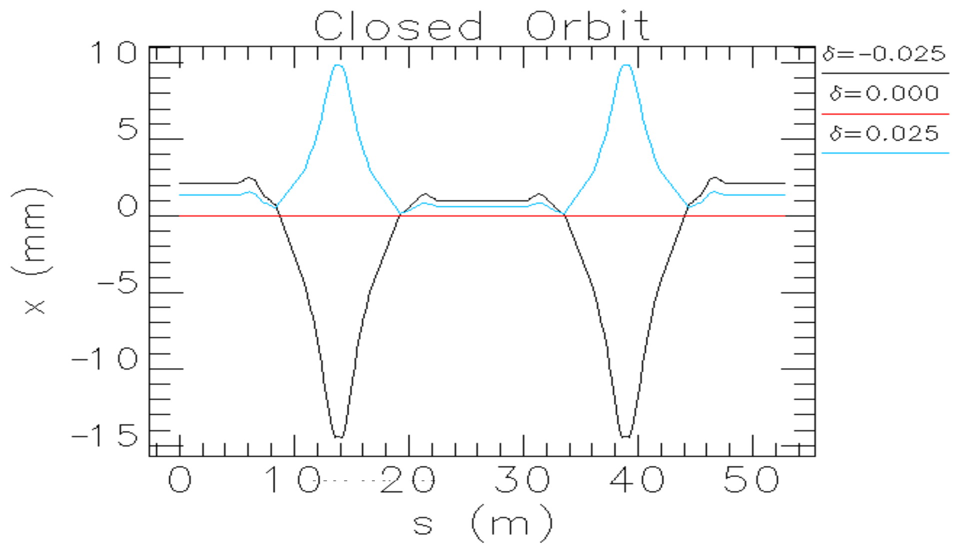
introducing systematic multipole errors doesn't add resonance lines.

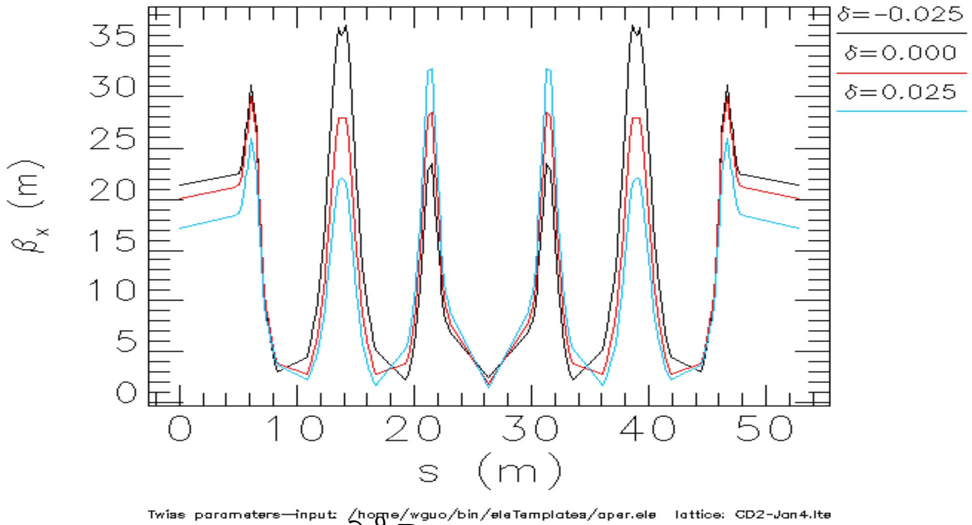
Amplitude Tune Dependence

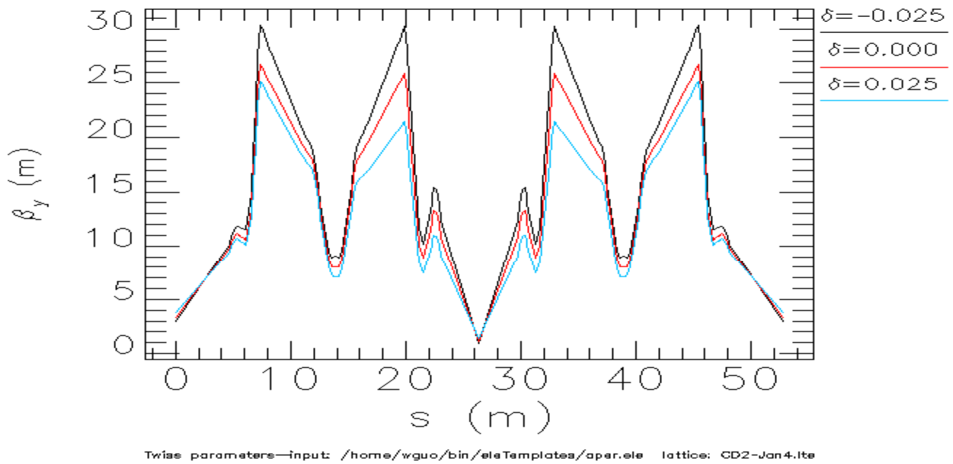


Conclusion: Multipole terms changes the tunes at large amplitude dramatically, and makes the stable area smaller.

Why Negative Momentum?







$$H_{10} = -\frac{1}{B\rho}\frac{1}{10!}\frac{\partial^9 B_y}{\partial x^9}(x^{10} - 45x^8y^2 + ...),$$

$$x = x_{c.o.} + x_\beta$$

$$\nu_{10} = \frac{1}{2\pi}\frac{\partial}{\partial J_x} < H_{10} >$$

$$= -\frac{1}{2\pi}\frac{1}{B\rho}\frac{1}{10!}\frac{\partial^9 B_y}{\partial x^9}\times$$

$$\sum_{k=1}^{5} kC_{10}^{2k} x_{c.o.}^{10-2k}(2\beta)^k < \cos^{2k}\varphi > J_x^{k-1},$$

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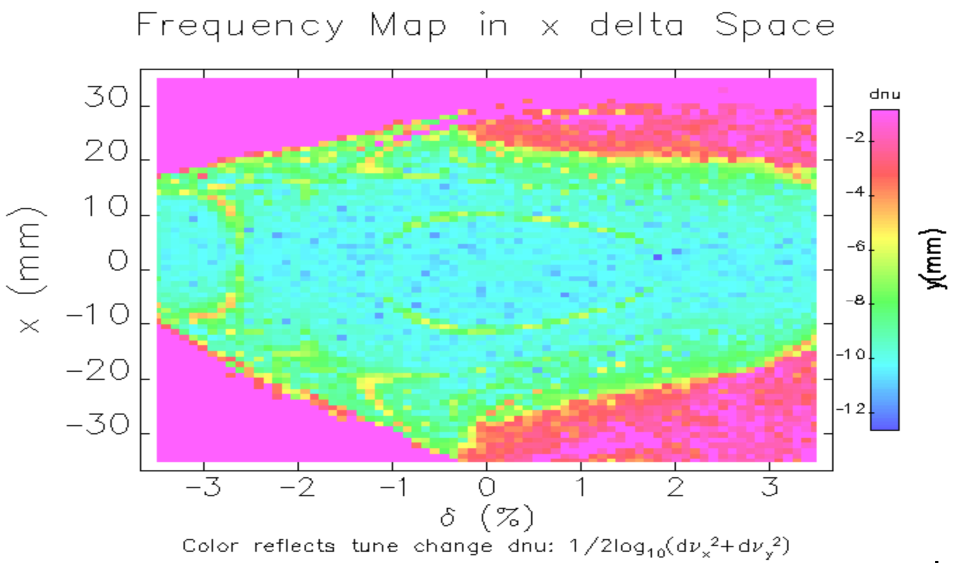
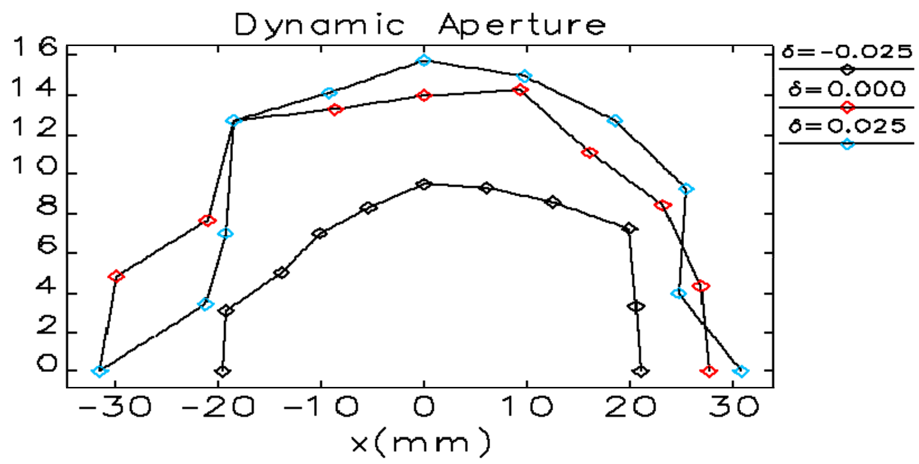
New Specifications





Multipole components of high precision magnets (25 mm)

Magnet Type	Magnet Aperture (mm)	Multipole Order	Relative Strength (x10^{-4})
Quad	90	6	1
Quad	90	10	0.5
Quad	90	14	0.1
Sext	76	9	0.5
Sext	76	15	0.5
Sext	76	21	0.5

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Summary

- Linear lattice is designed to enhance the effects of the damping wigglers
- A grid of stable solutions is used to determine the power supply specifications; and for nonlinear optimization
- Nonlinear design goal to provide sufficient dynamic aperture for injection and Touschek scattered particles up to δ=2.5%
- There are 8 sextupole families in the lattice, one more might be added.
- The physical aperture is conservatively retained.
- The reduction of the dynamic aperture due to multipole errors is shown to be the momentum related tune shift with amplitude.
- Further optimization of the dynamic aperture is proceeding.