Robust Design and Control of the Nonlinear Dynamics for BESSY-III

Work-in-Progress

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for the BESSY-III CDR-Project Team

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Overview:

1. Requirements: *Straw Man*.
2. Control of Linear Optics – *Bare Lattice*:
   a) *Higher-Order-Achromat* (HOA)
      (SLS, NSLS-II, MAX IV, SLS 2, DIAMOND-II, BESSY-III)
   b) Driving Terms.
   c) Tune Footprint.
3. Control of Nonlinear Dynamics – *Real Lattice*:
   (incl. the impact of Engineering Tolerances: magnet mechanical mis-alignments & magnetic multipole errors [random & systematic])
   a) Control of Orbit.
   b) Control of Linear Optics (LOCO).
   c) Frequency Maps.
   d) On & Off-Momentum Dynamic Aperture (DA).

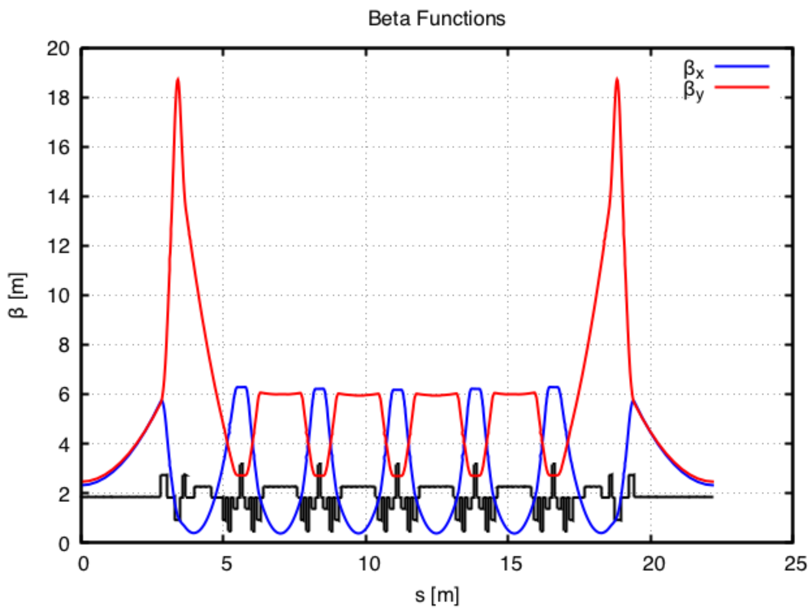
Requirements: *Straw Man*

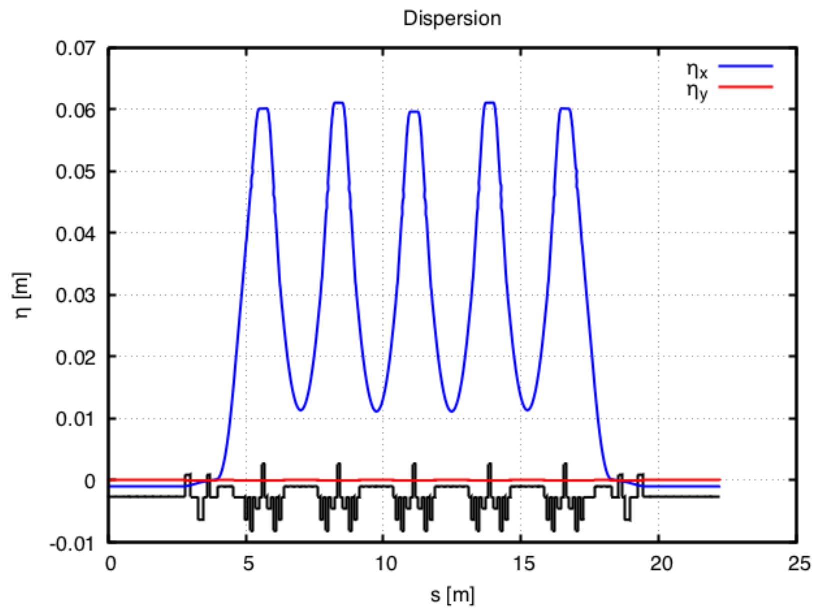
This conference:

- P. Goslawski *BESSY III & MLS II - Status Of The Development Of The New Photon Science Facility In Berlin*.
- B. Kuske *Towards Deterministic Design of MBA-Lattices*.

Beam Lines	
Circumference [m]	~300
Beam Energy [GeV]	2.5
ε_x [pm·rad]	~100
σ_s [mm]	2.5
σ_δ	~1e-3
$\beta_{x,y}$ [m]	[~2.0, ~2.0]
Beam Dynamics	
On-Momentum $A_{x,y}$ DA [mm]	[~2.0, ~1.5]
Off-Momentum δ DA [%]	2.0+
α_c	~1e-4
Beam Lifetime [hrs]	~1.0

Control of Linear Optics





Circc. = 356 m.

ε_x = 151 pm·rad.

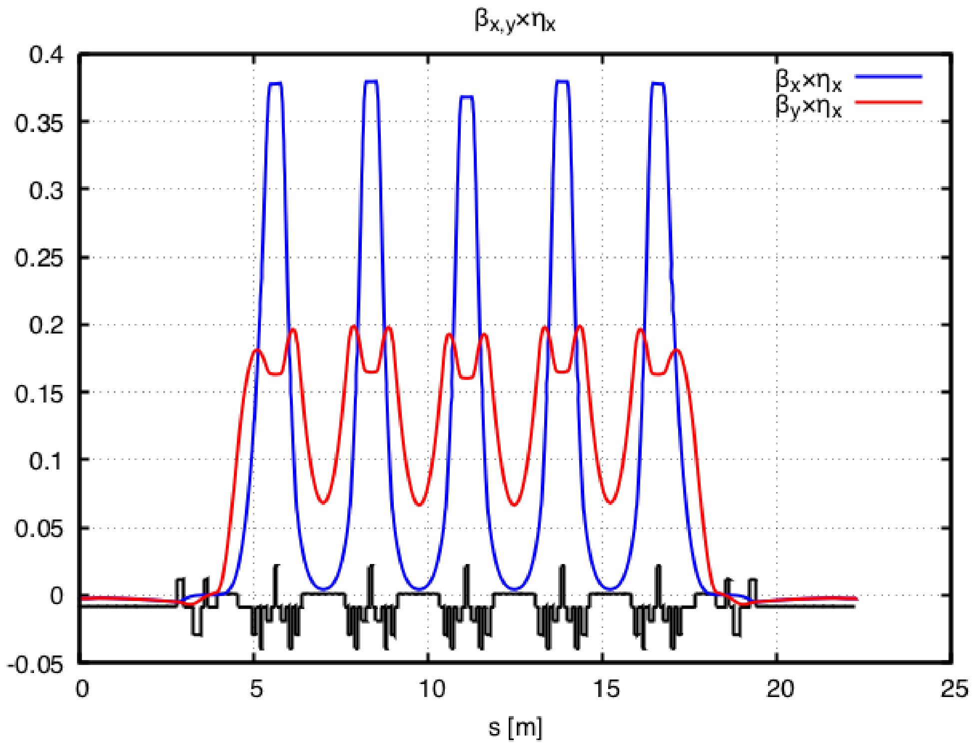
α_c = 1.1e-4.

ν_{cell} = [0.40, 0.10].

ν_{sp} = [2.72, 0.76].

ξ_{sp} = [-4.9, -3.1].

Control of Linear Chromaticity



$$\xi_x^{(1)} = -\frac{1}{4\pi}\sum_{i=1}^{N}\left[(b_2L)_i - 2(b_3L)_i\eta_{xi}^{(1)}\right]\beta_{xi}\,,$$

$$\xi_y^{(1)} = \frac{1}{4\pi}\sum_{i=1}^{N}\left[(b_2L)_i - 2(b_3L)_i\eta_{xi}^{(1)}\right]\beta_{yi}$$

- Two Sextupole Families [SF, SD].
- Good separation between ditto.

Sextupole Schemes:

- *-I Transformer*: introduce sextupole pairs separated by n · π phase advance in both planes.
- *Higher-Order-Achromat*: introduce a unit cell, repeat it four or more times to generate a super period, and adjust the total phase advance to n · 2π in both planes.
  (K. Brown *A Second-Order Magnetic Optical Achromat* PAC 1979)

The first approach is standard practice for collider design; and has been generalised by introducing a dispersion bump. However, because the non-linear effects only cancel on-momentum, it tends to yield inferior momentum aperture vs. a HOA; due to systematically driven off-momentum terms: h_{11001} & h_{00111}.

$$M = \begin{bmatrix} \cos(\mu+\xi\delta) & \beta\sin(\mu+\xi\delta) \\ -\dfrac{\sin(\mu+\xi\delta)}{\beta_x} & \cos(\mu+\xi\delta) \end{bmatrix} \rightarrow \begin{bmatrix} -1 & -\beta\xi\delta \\ \dfrac{\xi\delta}{\beta} & -1 \end{bmatrix} + (\delta^2)$$

$$\mathcal{M}_{\text{cell}} = \mathcal{A}^{-1}\mathcal{R}e^{:h:}\mathcal{A}$$

$$\begin{aligned} \mathcal{M} &= \mathcal{M}_{\text{cell}}\mathcal{M}_{\text{cell}}\cdots\mathcal{M}_{\text{cell}} \\ &= \mathcal{A}^{-1}e^{:\mathcal{R}h:}e^{:\mathcal{R}^2h:}\cdots e^{:\mathcal{R}^nh:}\mathcal{R}^n\mathcal{A} \\ &= \mathcal{A}^{-1}e^{:\mathcal{R}h+\mathcal{R}^2h+\cdots+\mathcal{R}^nh+\cdots:}\mathcal{R}^n\mathcal{A} \end{aligned}$$

$$(\mathcal{R}+\mathcal{R}^2+\cdots+\mathcal{R}^n)h = \mathcal{R}\sum_{k=0}^{n-1}\mathcal{R}^k\,h = \mathcal{R}\frac{I-\mathcal{R}^n}{I-\mathcal{R}} = 0$$

- J. Bengtsson *The Sextupole Scheme for the Swiss Light Source (SLS): An Analytic Approach* SLS Tech Note 9/97 (1997).

ν_{cell} = [0.40, 0.10].
ν_{sp} = [2.72, 0.76].

$$h_{20001} = h^*_{02001} = \frac{1}{8}\sum_{i=1}^{N}\left[(b_2L)_i - 2(b_3L)_i\eta^{(1)}_{xi}\right]\beta_{xi}e^{i2\mu_{xi}} + O\left(\delta^2\right),$$

$$h_{00201} = h^*_{00021} = -\frac{1}{8}\sum_{i=1}^{N}\left[(b_2L)_i - 2(b_3L)_i\eta^{(1)}_{xi}\right]\beta_{yi}e^{i2\mu_{yi}} + O\left(\delta^2\right),$$

$$h_{10002} = h^*_{01002} = \frac{1}{2}\sum_{i=1}^{N}\left[(b_2L)_i - (b_3L)_i\eta^{(1)}_{xi}\right]\eta^{(1)}_{xi}\sqrt{\beta_{xi}}e^{i\mu_{xi}} + O\left(\delta^3\right)$$

$$h_{21000} = h^*_{12000} = -\frac{1}{8}\sum_{i=1}^{N}(b_{3i}L)\,\beta^{3/2}_{xi}e^{i\mu_{xi}},$$

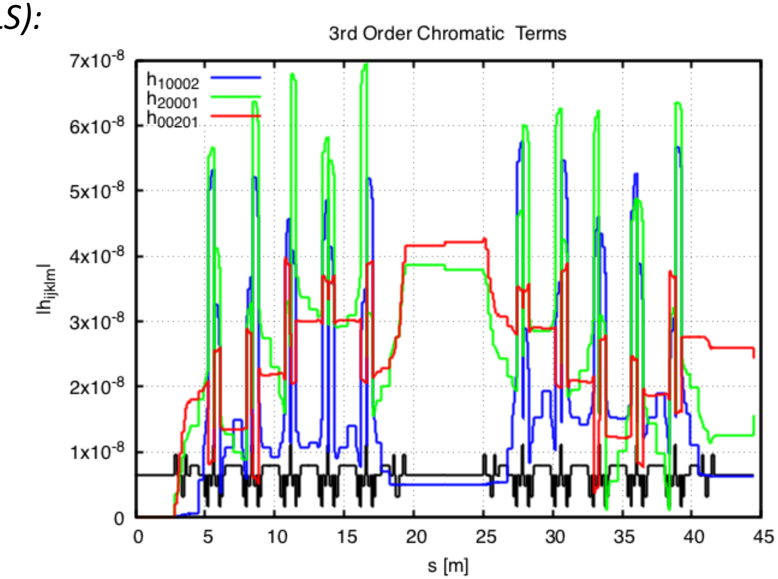
$$h_{30000} = h^*_{03000} = -\frac{1}{24}\sum_{i=1}^{N}(b_{3i}L)\,\beta^{3/2}_{xi}e^{i3\mu_{xi}},$$

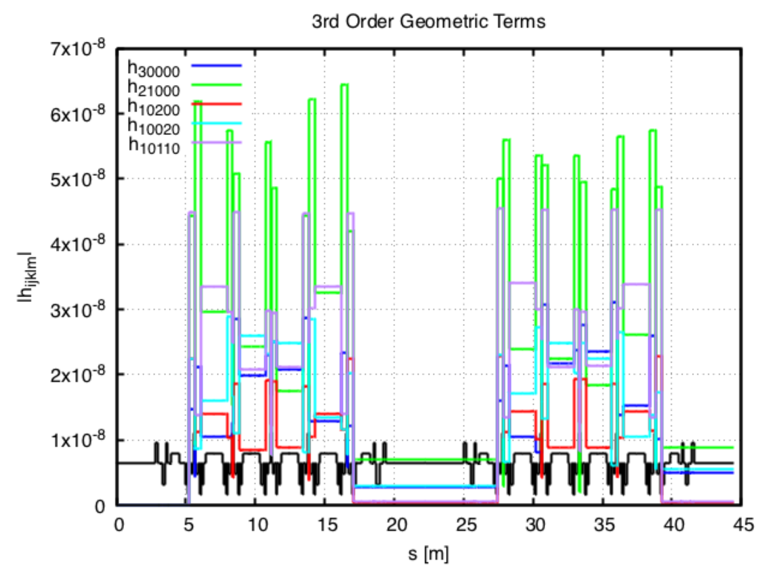
$$h_{10110} = h^*_{01110} = \frac{1}{4}\sum_{i=1}^{N}(b_{3i}L)\,\beta^{1/2}_{xi}\beta_{yi}e^{i\mu_{xi}},$$

$$h_{10020} = h^*_{01200} = \frac{1}{8}\sum_{i=1}^{N}(b_{3i}L)\,\beta^{1/2}_{xi}\beta_{yi}e^{i(\mu_{xi}-2\mu_{yi})},$$

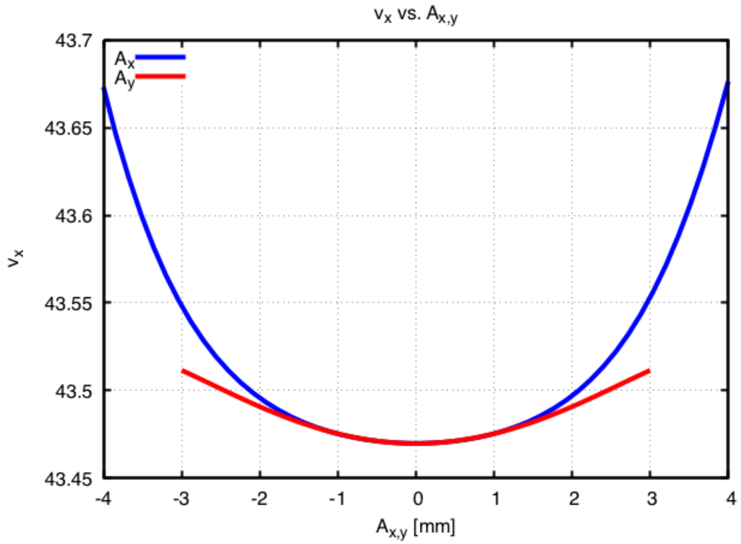
$$h_{10200} = h^*_{01020} = \frac{1}{8}\sum_{i=1}^{N}(b_{3i}L)\,\beta^{1/2}_{xi}\beta_{yi}e^{i(\mu_{xi}+2\mu_{yi})}$$

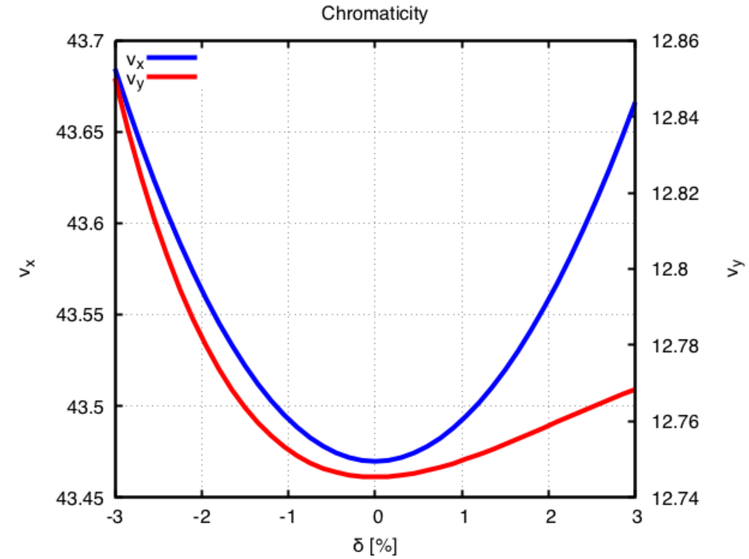
- Chromatic terms (3) cancelled over two super periods.
- Geometric terms (5) cancelled over one super period.

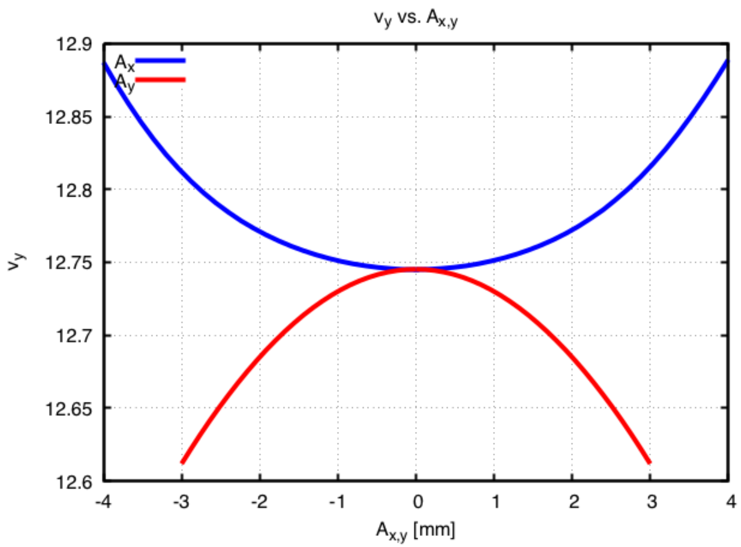




Control of Tune Footprint





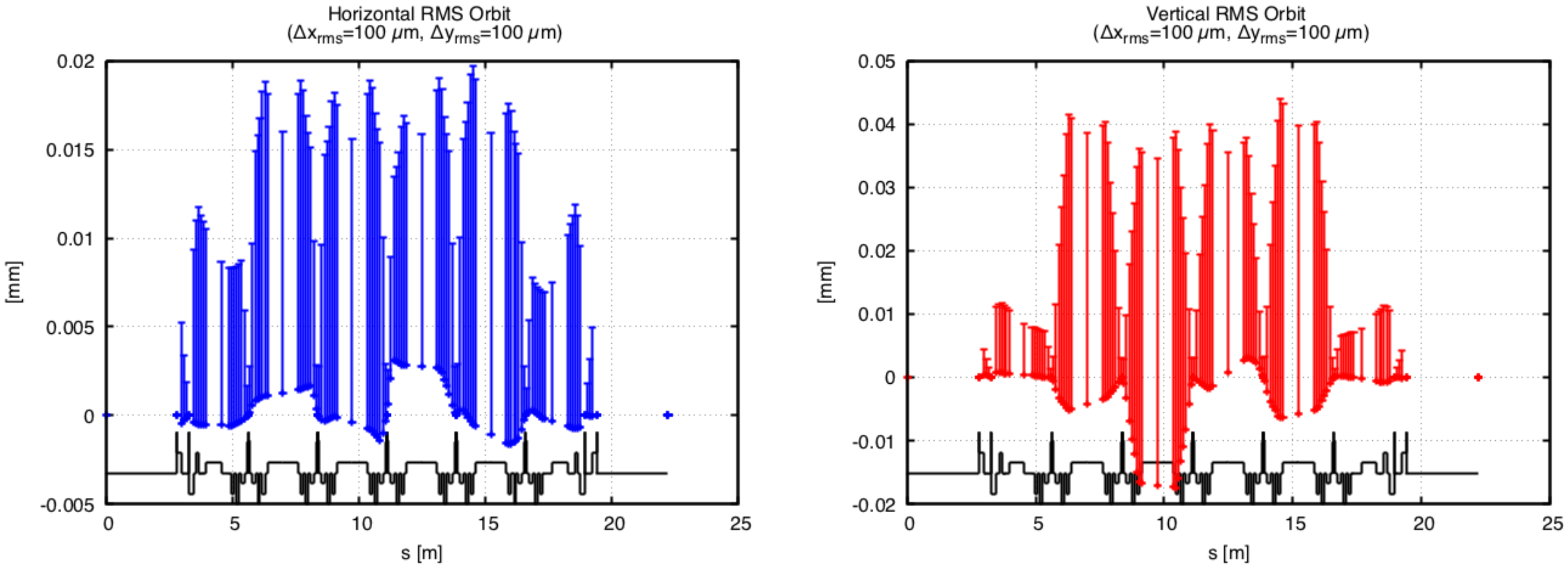


Tune Confinement:

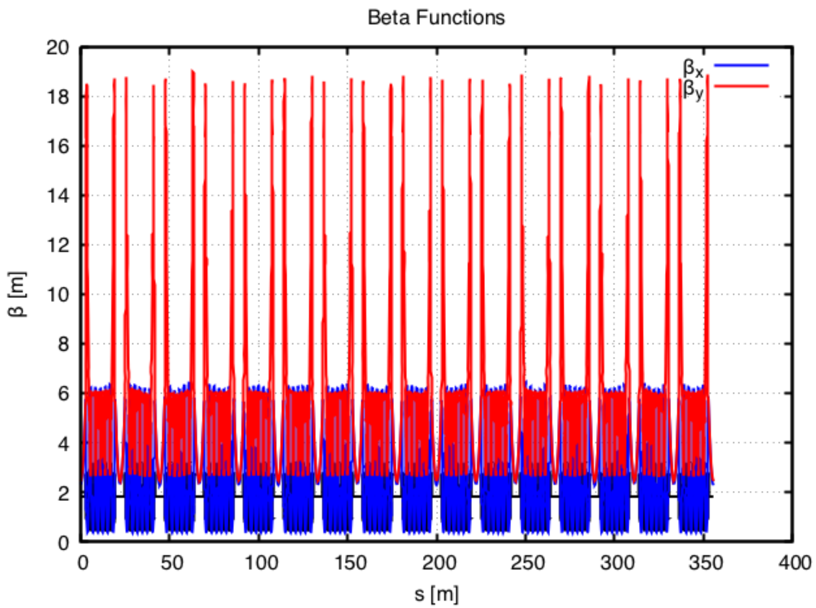
- Two Sextupole Families [SF, SD].
- $\Delta\nu = 0.1$ *benchmark*.
- A ~ [3.0, 2.5] mm.
- δ ~ 2.0 %.

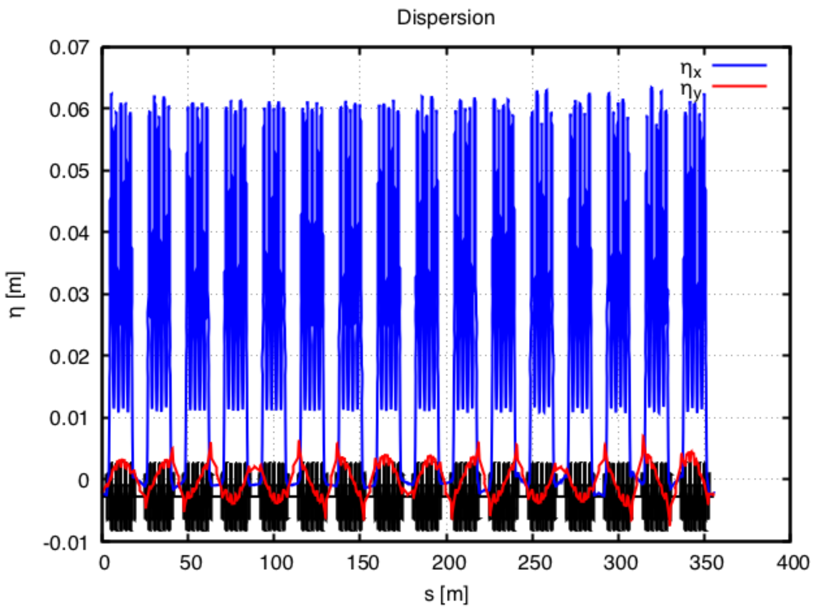
J. Bengtsson NSLS-II: *Control of Dynamic Aperture* BNL-81770-2008-IR (2008).

Control of Orbit



- 9 × 9 BPMs & Hor/Ver Orbit Trims.
- Average & rms orbit for 100 seeds.

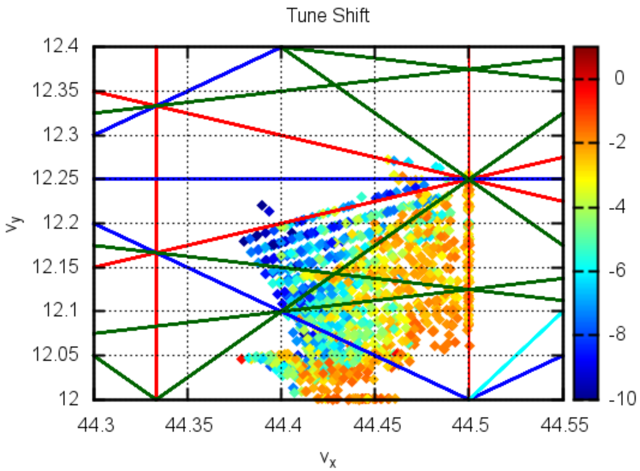




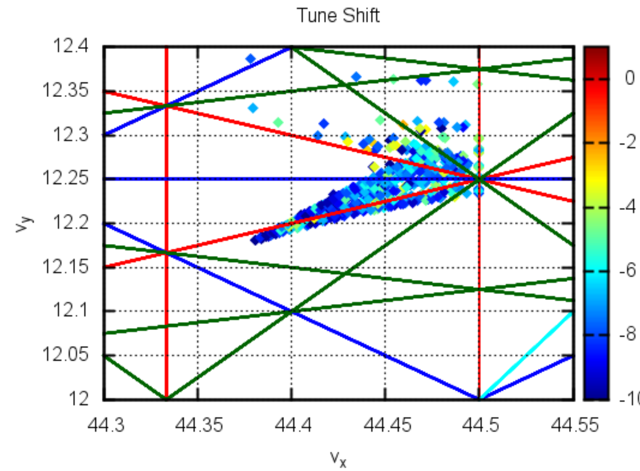
- Magnet mechanical mis-alignments & magnetic multipole errors (random & systematic).
- Closed orbit correction.
- Correction of linear optics by LOCO (*linear optics from closed orbits*).

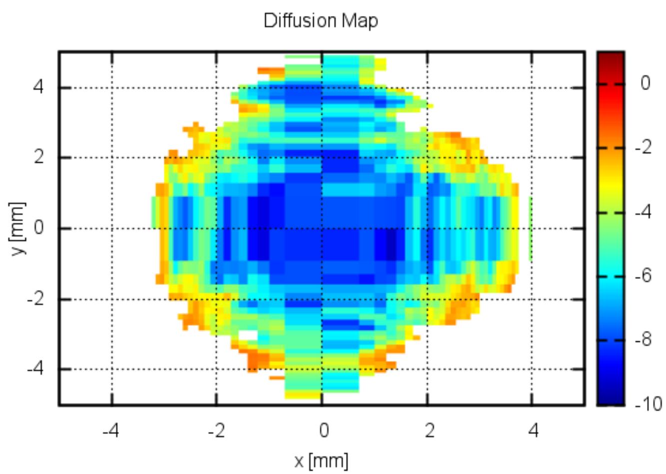
Frequency Map

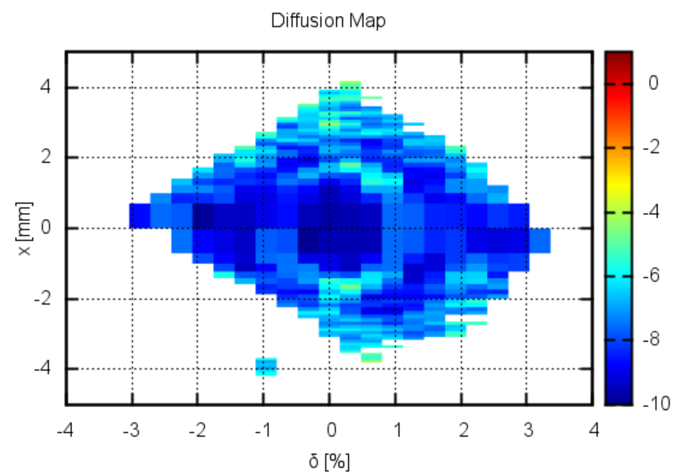
$\bar{\nu}(x, y)$



$\bar{\nu}(x, \delta)$

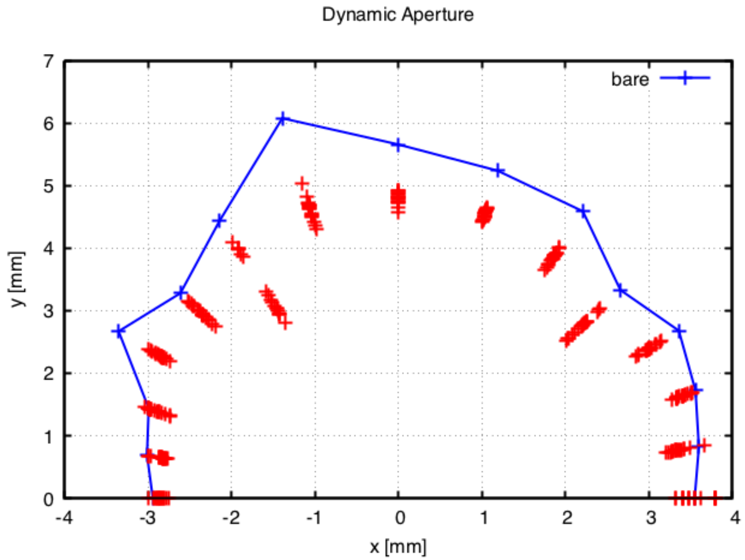


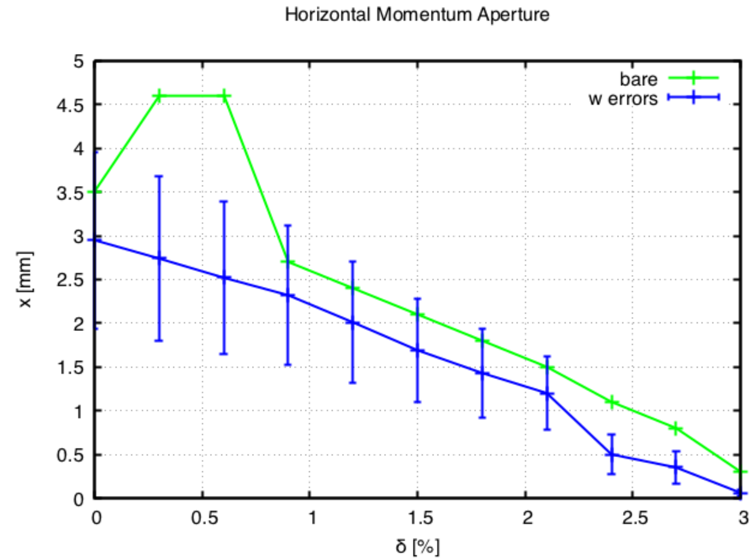


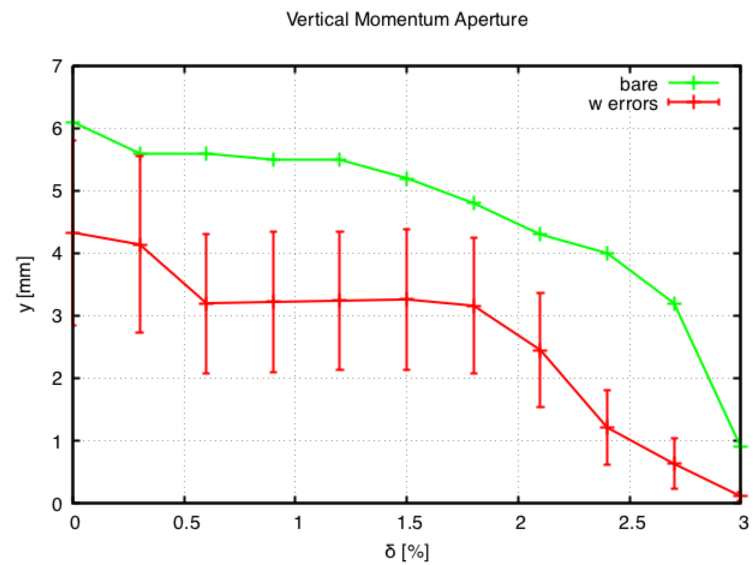


Working point not (yet) optimised.

HZB Helmholtz Zentrum Berlin







- β = [2.3, 2.5] m.
- For 20 seeds.
- A ~ [3.0, 4.0] mm.
- δ ~ 2.5 %.

Q.E.D. (*quod erat demonstrandum*).

- Convergence on a robust design reference lattice – based on a *Higher-Order-Achromat* with only two sextupole families [SF, SD] (so far) and the *Tune Confinement Approach* – has been achieved for BESSY-III.
- Presumably, control of the off-momentum tune footprint can be improved by introducing two chromatic octupole families.
- After which the trade-off between $\varepsilon_x \leftrightarrow \left[A_x, A_y, \tau_{\mathrm{Tou}}\right]$ can be made.