Dynamic Aperture with Insertion Devices

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Outline

1. Conclusions.
2. Basics.
3. Requirements.
4. Baseline.
5. Impact of Damping Wigglers & engineering tolerances.
6. Impact of insertion devices.

Conclusions

- The NSLS-II lattice is robust for the introduction of Insertion Devices. This is owing to the: symmetry, sextupole scheme (3 chromatic- and 6 geometric families), and guidelines for the engineering tolerances.
- In other words, a small tune footprint (~0.05) for the bare lattice (despite having 30 strongly focusing DBA cells), and only weak excitation of nonlinear resonances (due to tight engineering tolerances).
- To control the tune footprint of the bare lattice (w/ DWs), the nonlinear effects of the DWs (after optics correction) must be included in the sextupole optimization. This is hardly surprising, since they are an integral part of the design philosophy.
- The impact of one EPU is moderate, i.e., non-negligible. In other words, these devices will require some magnetic fine tuning to not become a limiting factor.

Model

The Hamiltonian for an insertion device is (expanded, averaged)

$$\langle H\rangle_{\lambda_u} = \frac{p_x^2 + p_y^2}{2(1+\delta)} + \frac{\langle \frac{q}{p_0} A_x^2(s)\rangle_{\lambda_u} + \langle \frac{q}{p_0} A_y^2(s)\rangle}{2(1+\delta)} + O(p_{x,y}^4)$$

The vector potential can be obtained from the magnetic field by (axial gauge)

$$A_x(s) = -\int_s B_y(z)dz, \qquad A_y(s) = \int_s B_x(z)dz, \qquad A_z(s) = 0$$

Splitting the Hamiltonian (into two integrable parts) $H = H_d + H_k$ **where**

$$H_d \equiv \frac{p_x^2 + p_y^2}{2(1+\delta)}, \qquad H_k \equiv \frac{1}{2(B\rho)^2(1+\delta)}\left[\langle\left(\int_s B_x(z)dz\right)^2\rangle_{\lambda_u} + \langle\left(\int_s B_y(z)dz\right)^2\rangle_{\lambda_u}\right]$$

The corresponding map is given by (aka a 2nd order symplectic integrator)

$$M(\Delta s) = \exp\left(:-\int_0^{\Delta s} H ds:\right) = e^{:-H\Delta s:} = e^{:-H_d\Delta s/2:} e^{:-H_k\Delta s:} e^{:-H_d\Delta s/2:} + O(\Delta s^3)$$

$$= M_d\left(\frac{\Delta s}{2}\right) M_k(\Delta s) M_d\left(\frac{\Delta s}{2}\right) + O(\Delta s^3)$$

Model cont.

In particular

$$M_{\mathrm{k}}(\Delta s)p_x = -\frac{\partial H_{\mathrm{k}}}{\partial x}\Delta s, \qquad M_{\mathrm{k}}(\Delta s)p_y = -\frac{\partial H_{\mathrm{k}}}{\partial y}\Delta s$$

The kick map M_{k} obtained from e.g. RADIA is used by Tracy-2 to compute $M(\Delta s)$.

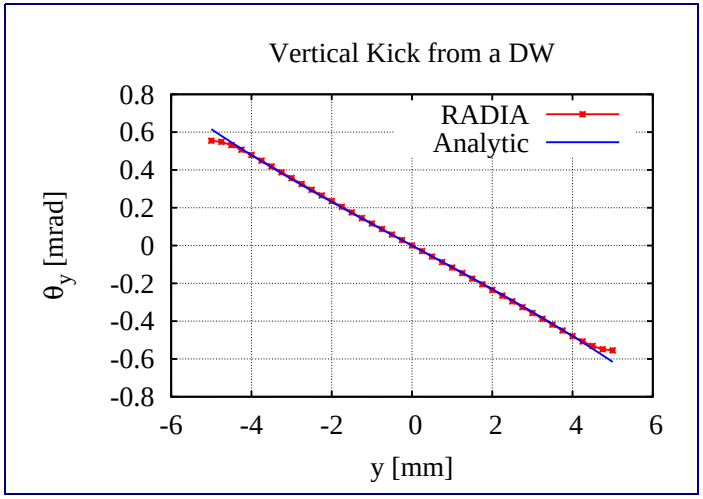
For an analytic approach (to leading order)

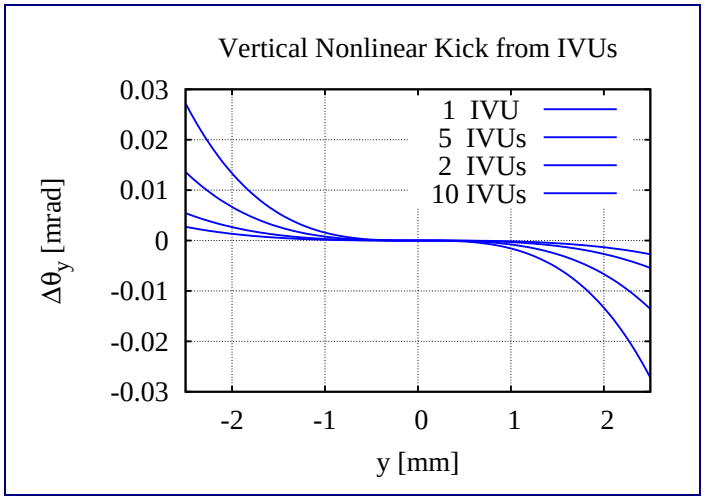
$$\frac{q}{p_0}A_x(s) = \frac{B_{\mathrm{u}}}{k_z(B\rho)}\cos(k_x x)\cosh(k_y y)\sin(k_z s), \qquad \frac{q}{p_0}A_y(s) = \frac{k_x B_{\mathrm{u}}}{k_y k_z(B\rho)}\sin(k_x x)\sinh(k_y y)\sin(k_z s)$$

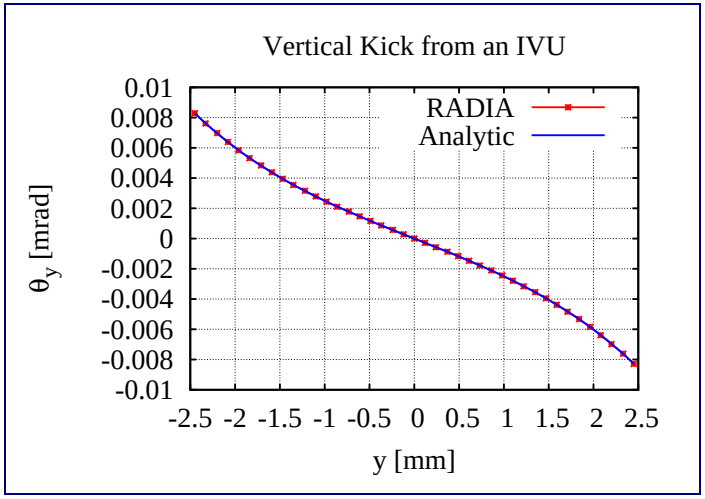
with $k_z^2 = k_y^2 - k_x^2 = (2\pi/\lambda_{\mathrm{u}})^2$. It follows that

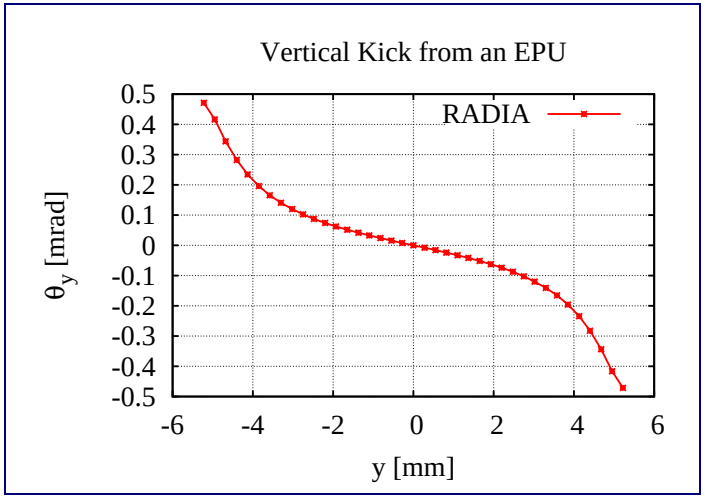
$$H_{\mathrm{k}} = \frac{B_{\mathrm{u}}^2\left(k_y^2\cos^2(k_x x)\cosh^2(k_y y) + k_x^2\sin^2(k_x x)\sinh^2(k_y y)\right)}{4k_y^2k_z^2(B\rho)^2(1+\delta)}$$

Vertical Kick from a DW and IVUs









Requirements

The requirements are:

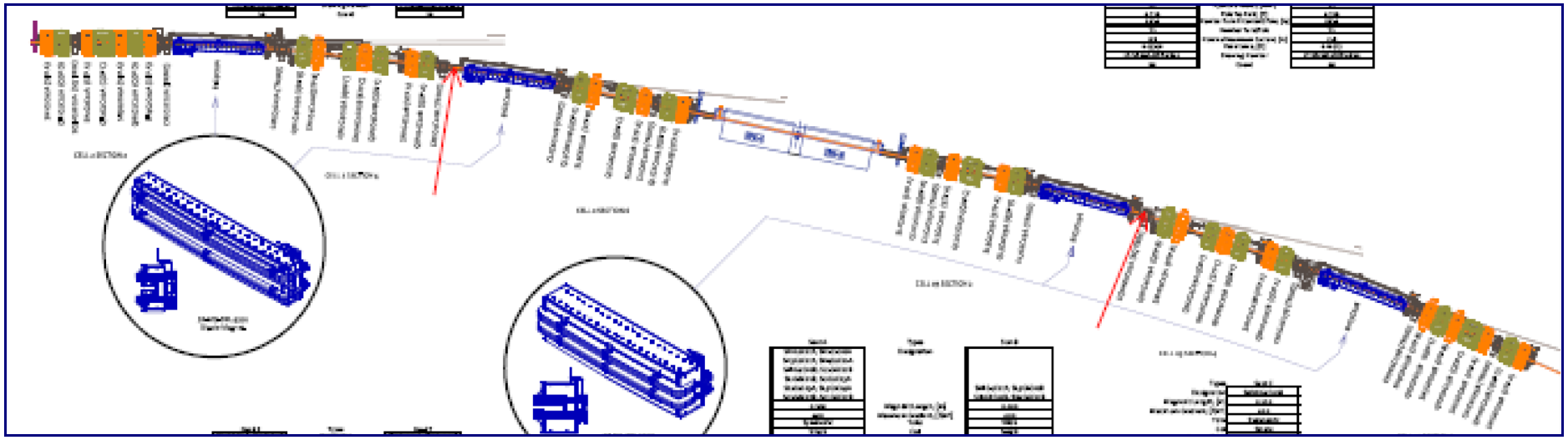
- On momentum Dynamic Aperture (DA): 11 mm (robust top-up injection),
- Off momentum Dynamic Aperture: 2.5% (Touschek life time),
- Tune footprint for the bare lattice (w/ DWs): ~0.05 (to accommodate eng. tol., IDs, etc.).

The last requirement is based on a (conservative) estimate of the tune footprint for stable beam in existing medium energy light sources, i.e., about ~0.1.

Note, due to the high number of DBA cells (30), as compared to existing medium energy synchrotron light sources, the control of the amplitude dependent tune shift per cell needs to be about 3 times better for a comparable nonlinear performance. Hence also the tight engineering tolerances.

Reference Lattice

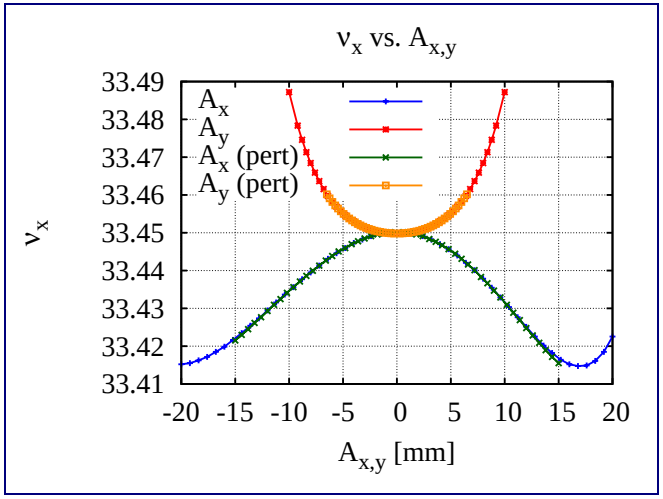
These studies are based on a lattice with 3 chromatic and 6 geometric sextupoles, i.e., with demonstrated satisfactory control of the nonlinear dynamics [2].

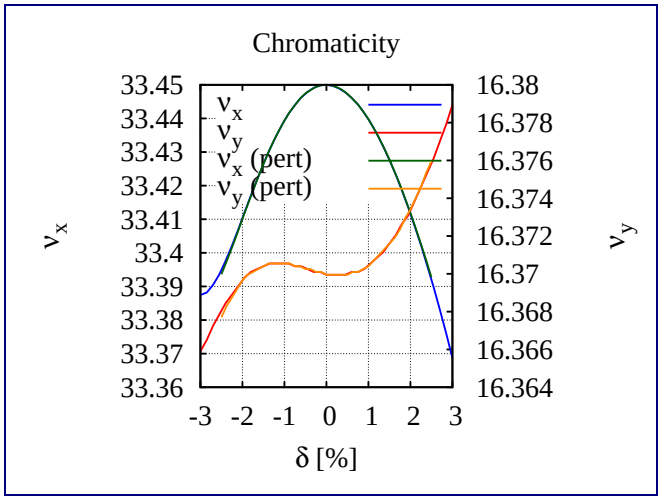


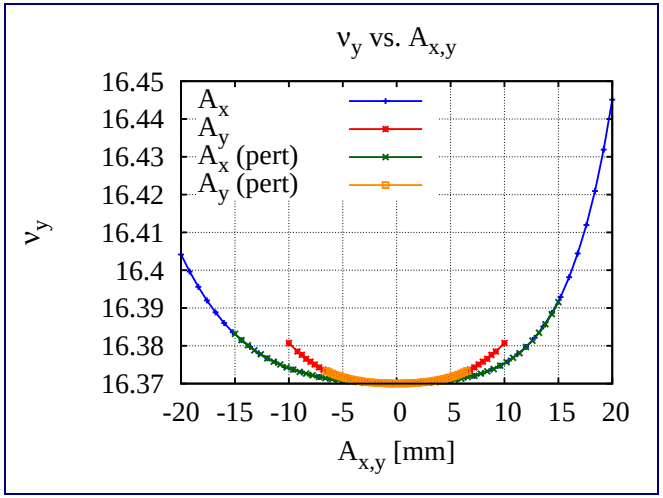
Nota bene on conventions used for the "diffusion" map:

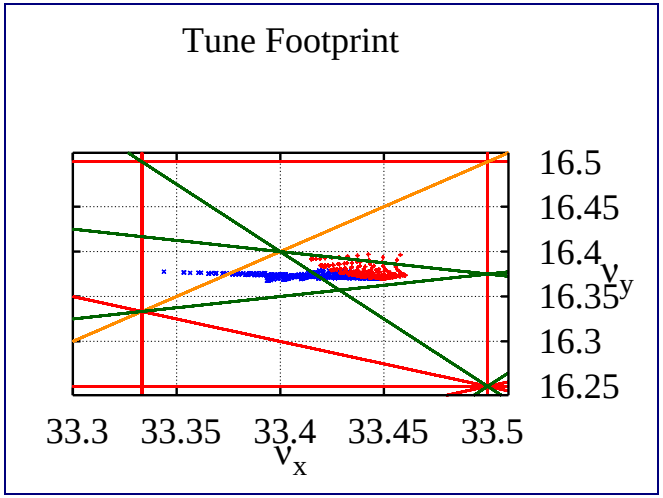
- $D = \log_{10}\left(\sqrt{(\Delta\nu_x)^2 + (\Delta\nu_y)^2}\right)$,
- **color coded, absolute scale** $[-10, -2]$.

Baseline: Tune Footprint (bare lattice)





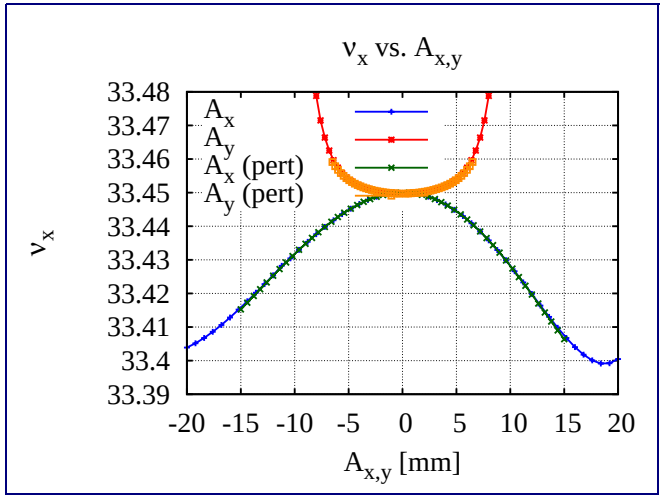


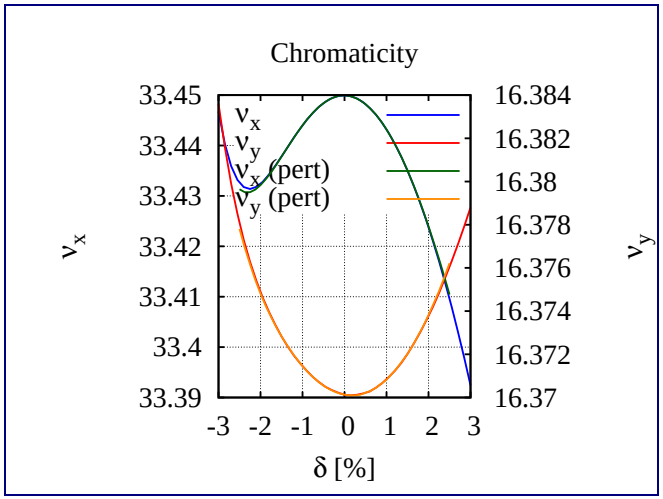


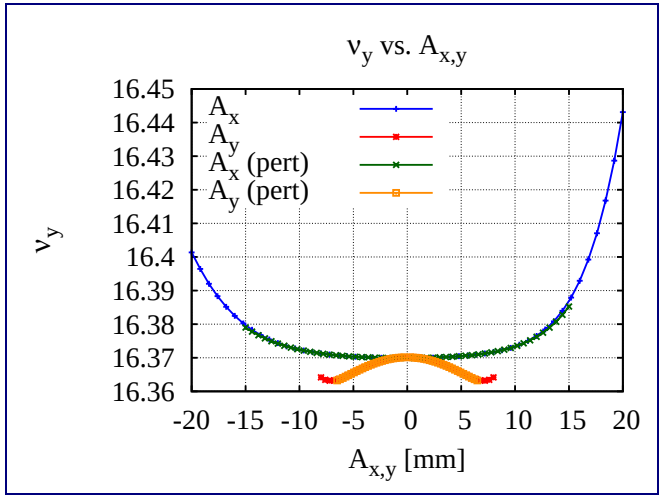
Analytic model to 6th order in the sextupole strength:

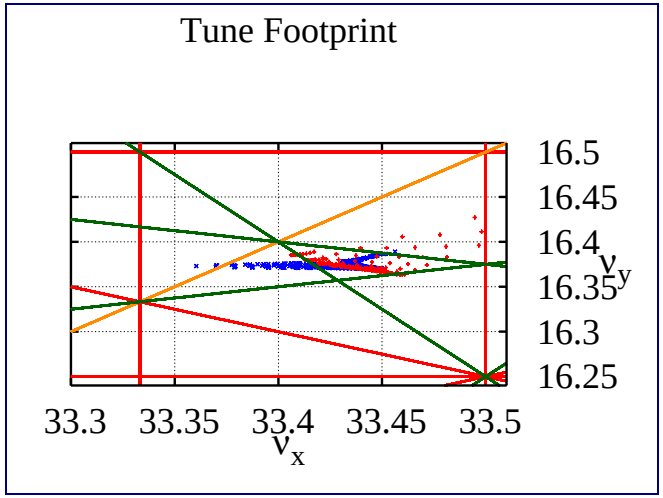
$$\bar{\nu} \equiv \bar{\nu}(\bar{\boldsymbol{J}}) + \boldsymbol{O}(\bar{\boldsymbol{J}}, \delta)^4$$

Baseline: Tune Footprint (w/ DWs)





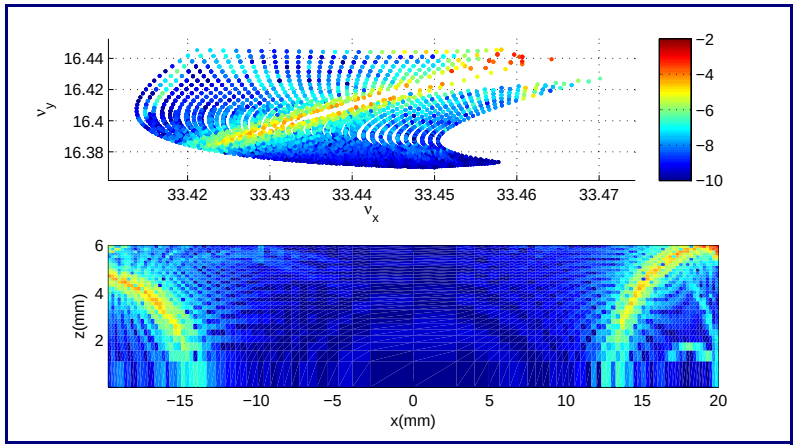


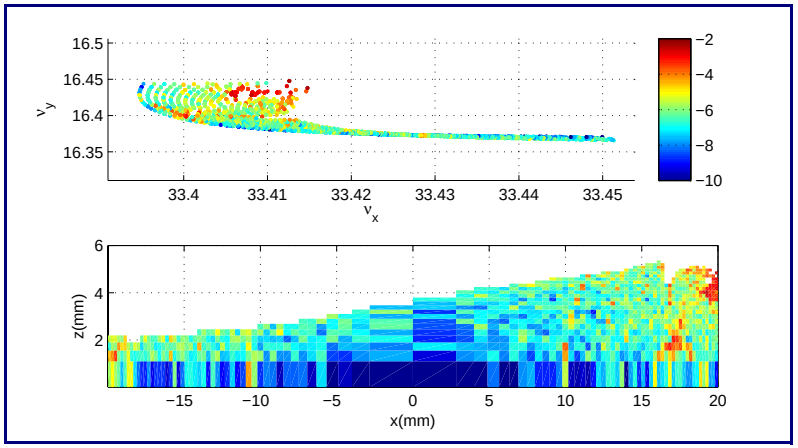


After:

- **Optics correction (local/global control of symmetry & tune).**
- **And, sextupole re-optimization (to control the DWs' contribution, $\Delta(b_3 L) \sim 0.5$).**

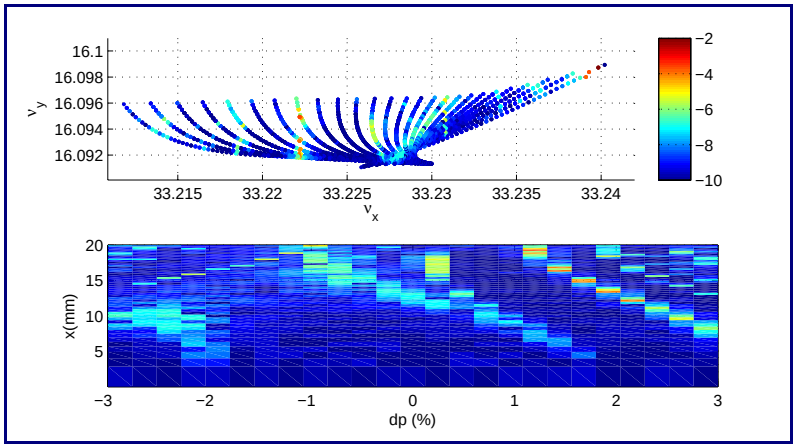
Baseline: Frequency Maps (w/wo DWs)

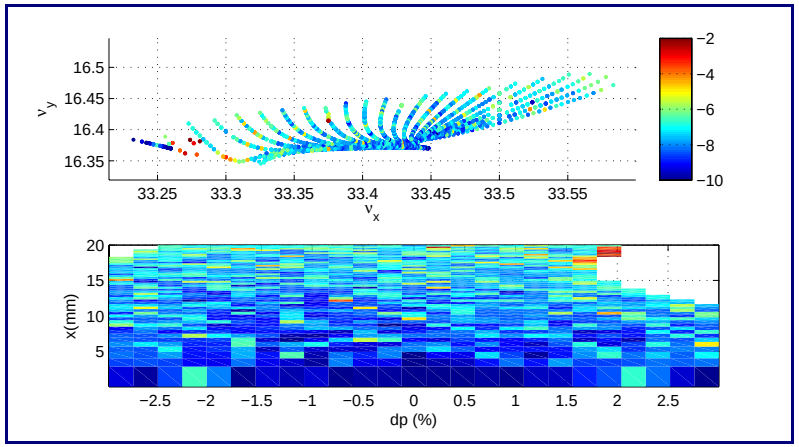




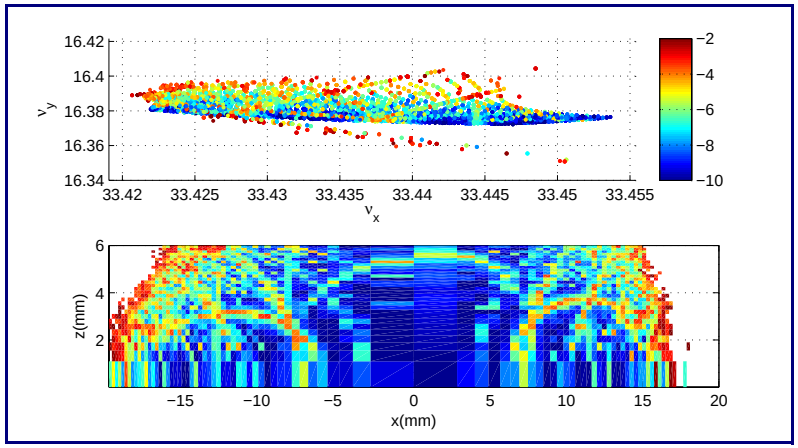
Bare lattice. (Res. is: $6\nu_x - 4\nu_y = 135$).

With DWs.

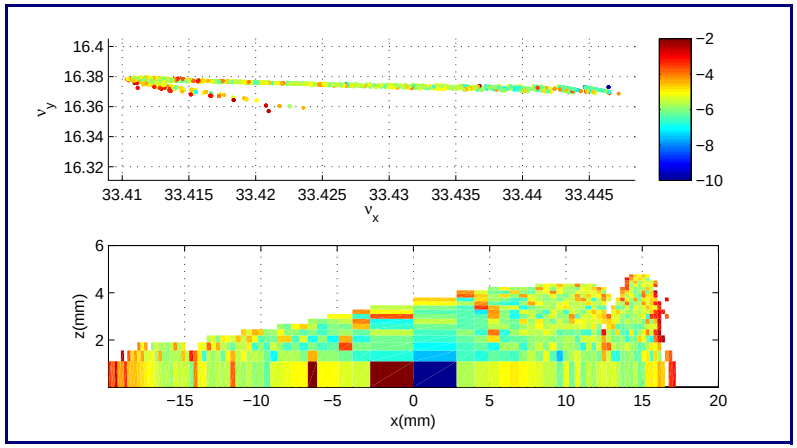




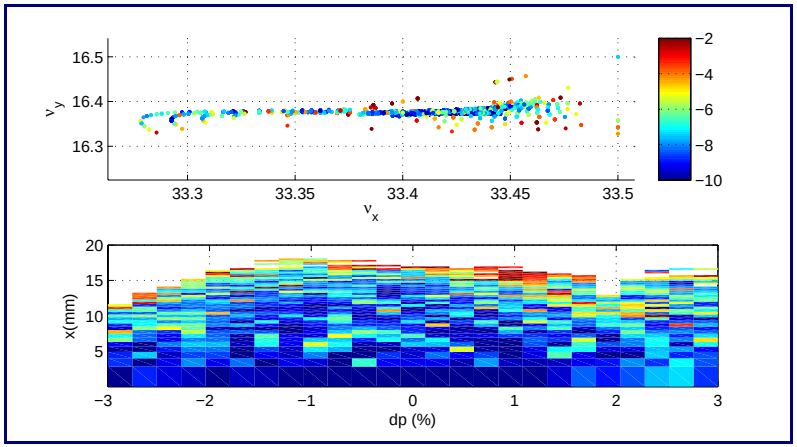
Impact of Eng. Tol. and DWs

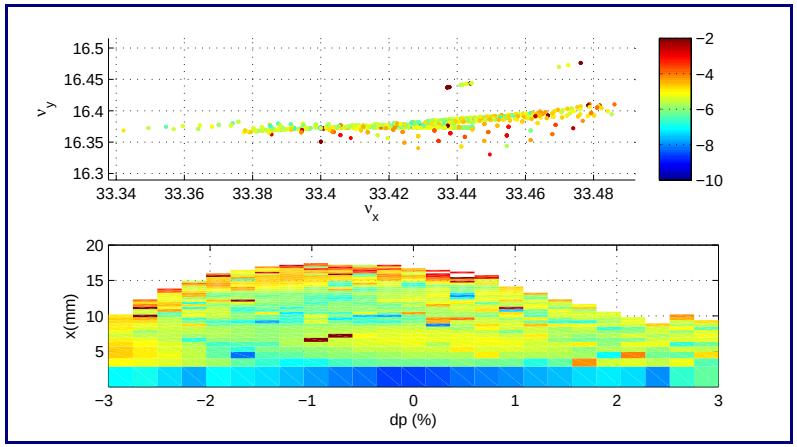


With misalign. (incl. girder correlations) and rand. and sys. multipole errors.

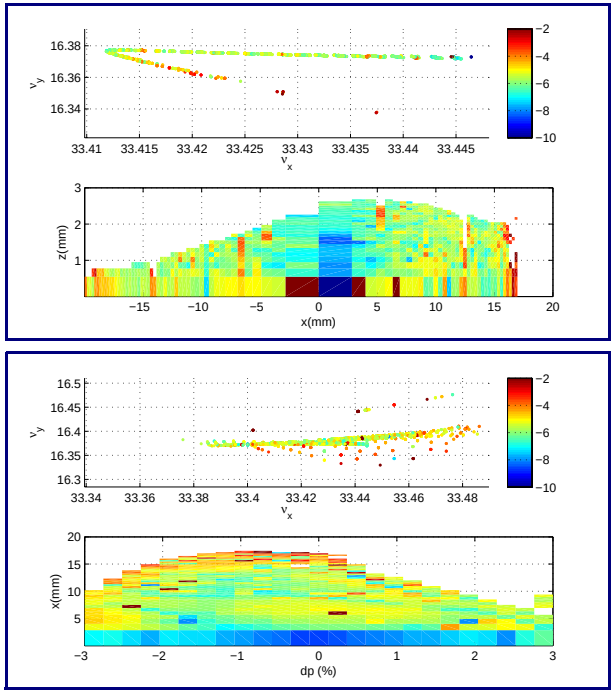


With eng. tol. and DWs.

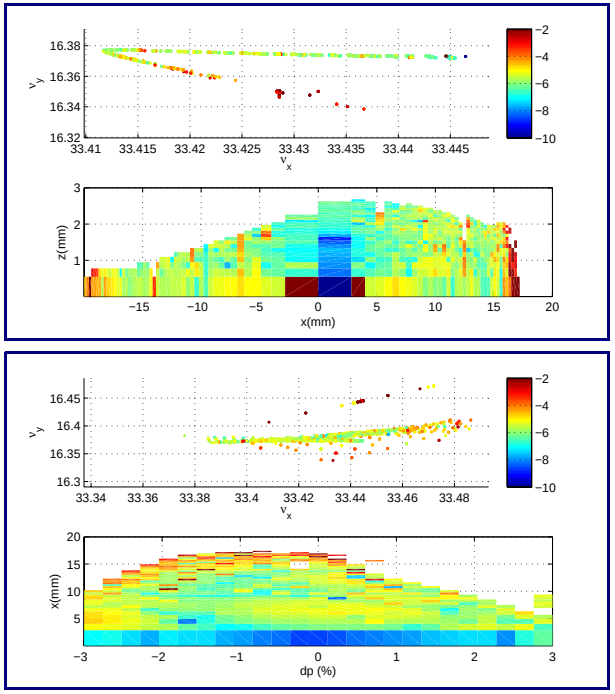




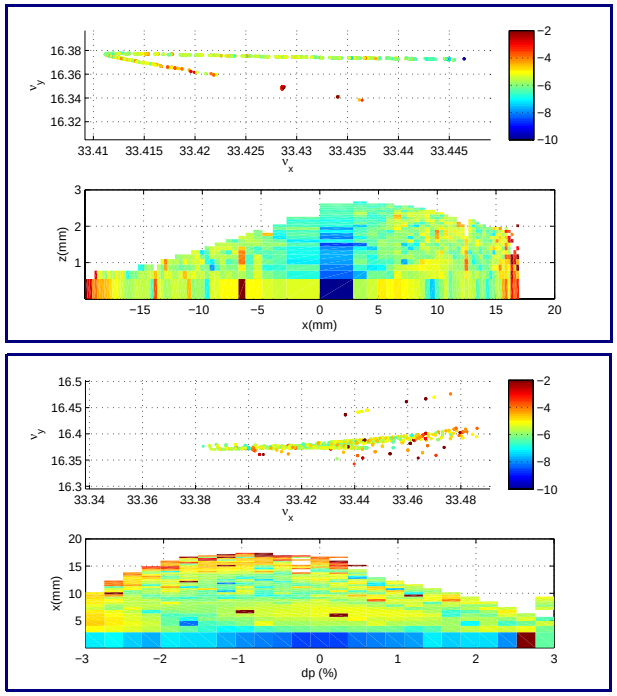
Impact of DWs, Eng. Tol, and 3, 5, or 10 IVUs



3 IVUs.

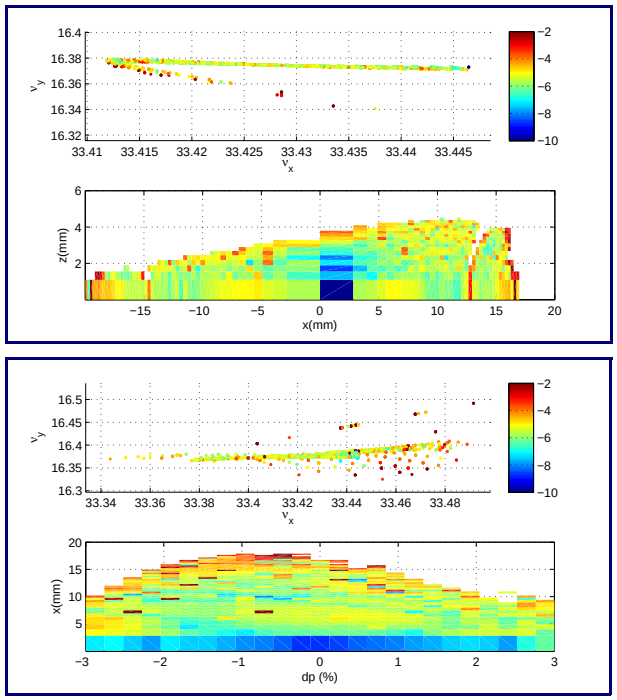


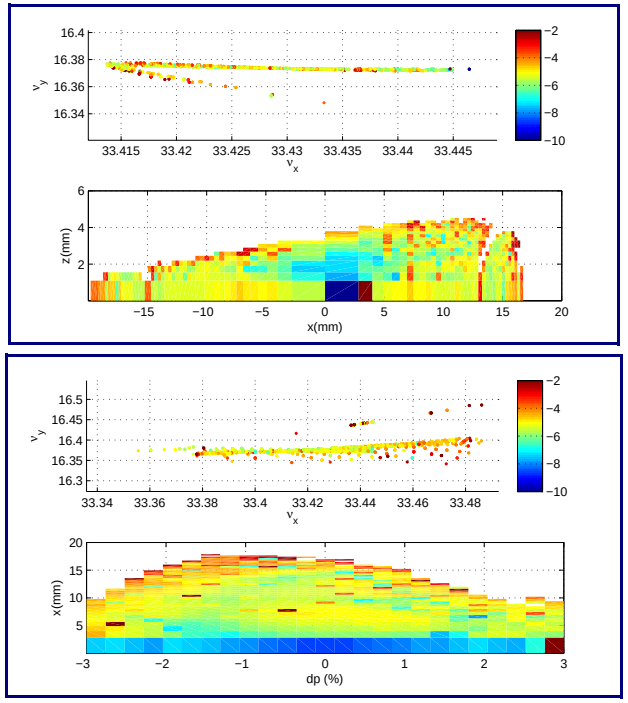
5 IVUs.

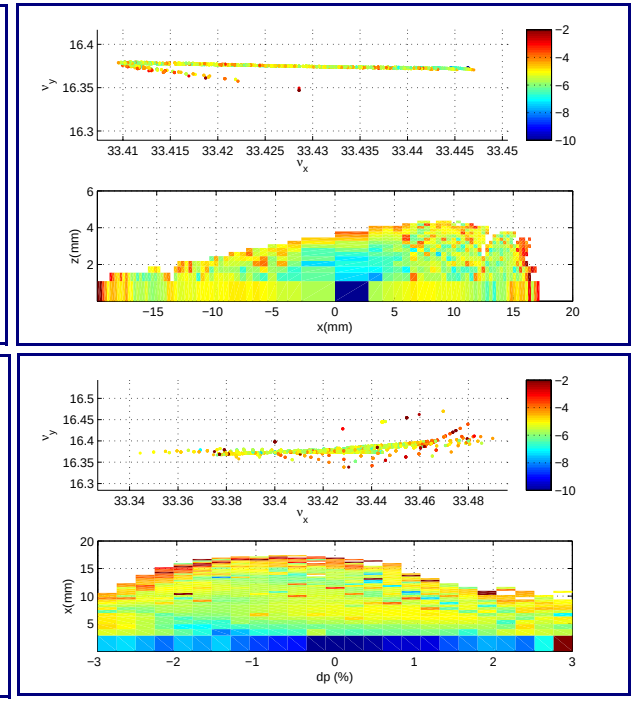


10 IVUs.

Impact of DWs, Eng. Tol., and 1 EPU







Helical mode. **Vertical linear mode.** **45° inclined mode.**

The resonance is: $5\nu_x = 167$.

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References

[1] M. Rehak, J. Skaritka, C. Spataro, C. Longo, A. Blednykh “Corrector Sextu-poles: Feasibility Study” (2008).

[2] J. Bengtsson “NSLS-II: Control of Dynamic Aperture” BNL-81770-2008-IR (2008).