Influence of Insertion Devices on Dynamic Aperture and Beam Lifetime

NSLS II Accelerator Systems Advisory Committee

October 8 – 9, 2007

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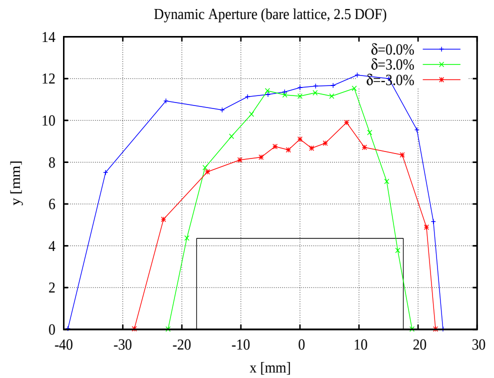
for the NSLS-II Design Team

Overview

1.0 Dynamic Aperture (DA): Analysis



Residual chromaticity (analytic model)

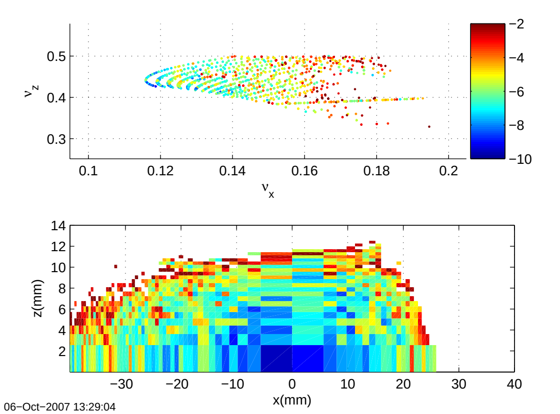
$$\nu_x(\delta) = 33.36 + 2.0\delta - 1.3\times10^{2}\delta^{2} - 3.2\times10^{2}\delta^{3} + 3.5\times10^{4}\delta^{4} - 9.7\times10^{5}\delta^{5} + \ldots,$$

$$\nu_y(\delta) = 16.28 + 1.0\delta - 7.3\times10^{1}\delta^{2} + 1.2\times10^{3}\delta^{2} - 7.2\times10^{3}\delta^{4} - 1.2\times10^{5}\delta^{5} + \ldots,$$

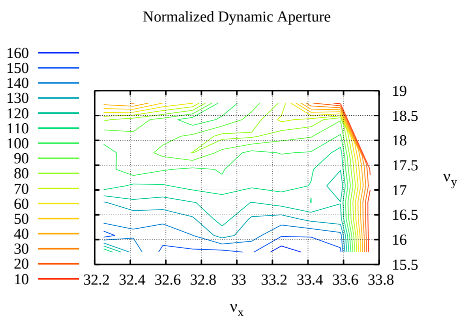
$$\nu_x(3\%) = 33.36 + 0.06 - 0.12 - 0.09 + 0.03 - 0.02 + \ldots$$

$$\nu_y(3\%) = 16.28 + 0.03 - 0.07 + 0.03 - 0.005 - 0.003 + \ldots$$

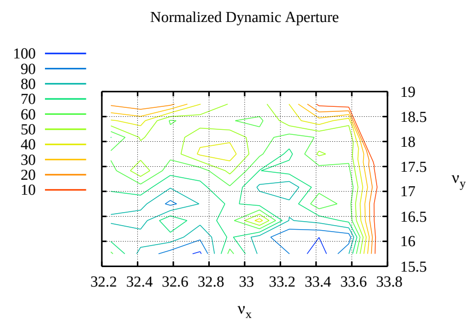
Physical aperture by injection septum and beam pipe.



Bare Lattice



With Misalignments



2.0 Control of Insertion Devices (IDs): Guidelines

The the leading order impact of a planar IDs is given by

$$\langle H \rangle_{\lambda_u} = \frac{p_x^2 + p_y^2}{2(1+\delta)} + \frac{B_u^2 y^2}{4(B\rho)^2(1+\delta)} - \frac{\pi^2 B_u^2 y^4}{3\lambda_u^2 (B\rho)^2 (1+\delta)} - \delta + O(p_{x,y})^4$$

which drive beta and phase advance beat, tune shift, nonlinear resonances, and amplitude dependent tune shift.

The propagation of the beta function in free space is: $\beta(s) = \beta_0[1 + (s/\beta_0)^2]$**.**

Therefore:

- **stay clear =>** $\beta_0 = L/2$**,**
- **control of IDs: linear optics =>** $\beta_0 = L/2\sqrt[4]{3}$**,**
- **control of IDs: nonlinear dynamics =>** $\beta_0 = L/2\sqrt[4]{5}$**.**

2.1 Symplectic Integrators: Overview

Symplectic integrators based on fit of 3D field map to analytic basis:

- generating function, implicit (G. Wüstefeld, J. Bahrdt, 1991),
- 1st order, explicit (E. Forest, K. Ohmi, 1992),
- 2nd order explicit (Y. Wu, E. Forest, D. Robin, 2001),
- generating function, explicit (G. Wüstefeld, J. Bahrdt, 2006),
- obtain vector potential by fit 3D field for elliptical geometry (C. Mitchel, A. Dragt, 2006).

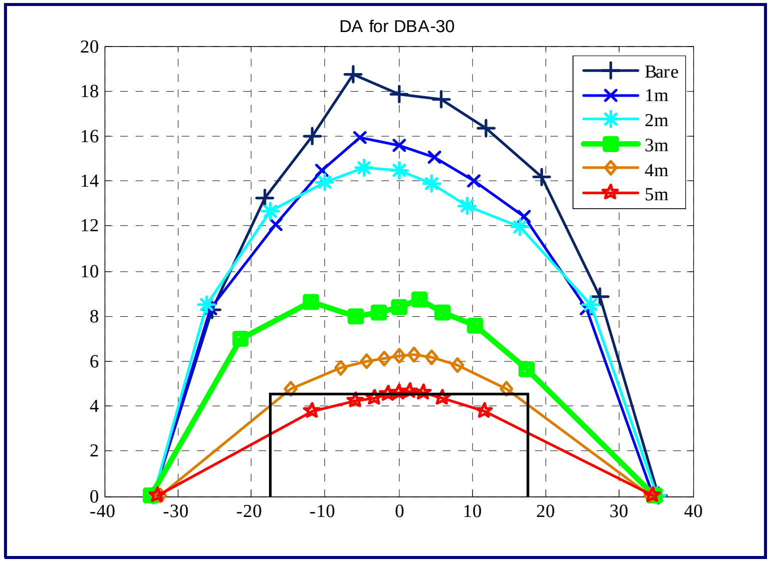
Symplectic integrators based on direct integration of 3D field maps:

- RADIA kick map (P. Elleaume, 1992),
- obtain vector potential from 3D field map (three-pole-wiggler, aperiodic, including radiation effects, J. Bengtsson, 2007).

2.2 Impact of the Length of a CPMU on the DA

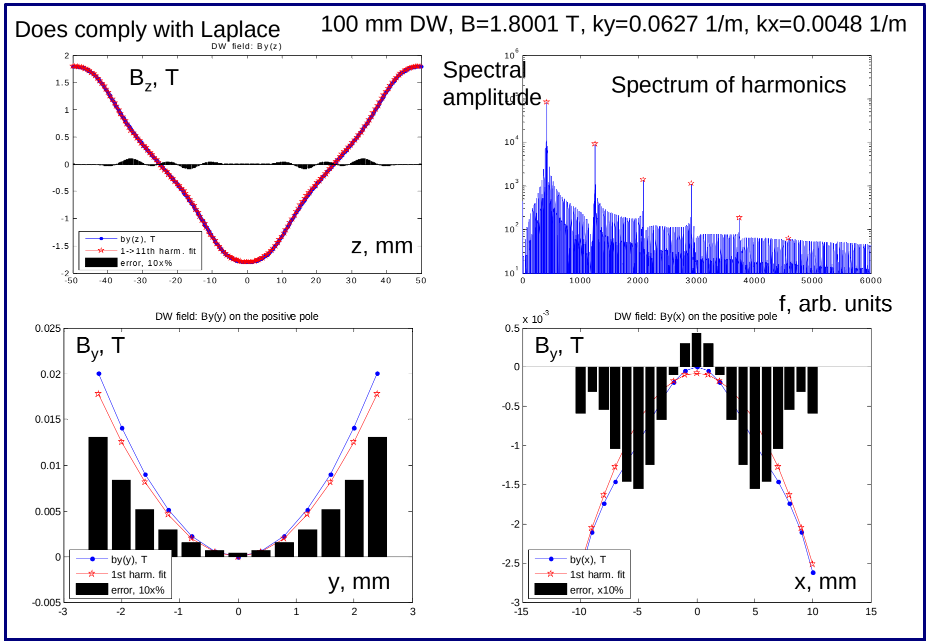
Driving Terms	Effect	Sextupole Scheme	DW (L. Strght)	CPMU (S Strght)	CPMU (L. Strght)	SCU (S. Strght)
$\lvert h_{00220} \rvert$	$\partial \nu_y / \partial J_y$	607	1,089	1,103	3,681	1,260
$\lvert h_{00310} \rvert$	$2\nu_y$	76	52	7	379	40
$\lvert h_{00400} \rvert$	$4\nu_y$	47	59	14	228	11

CDR Lattice

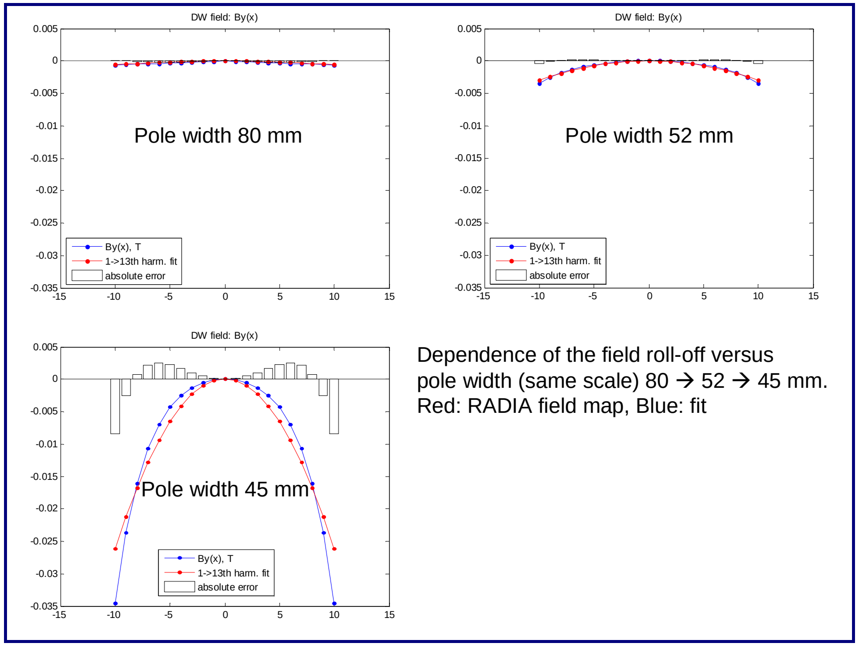


by T. Shaftan

2.3 Field Harmonics of Damping Wigglers: DW100
(with T. Shaftan and T. Tanabe)

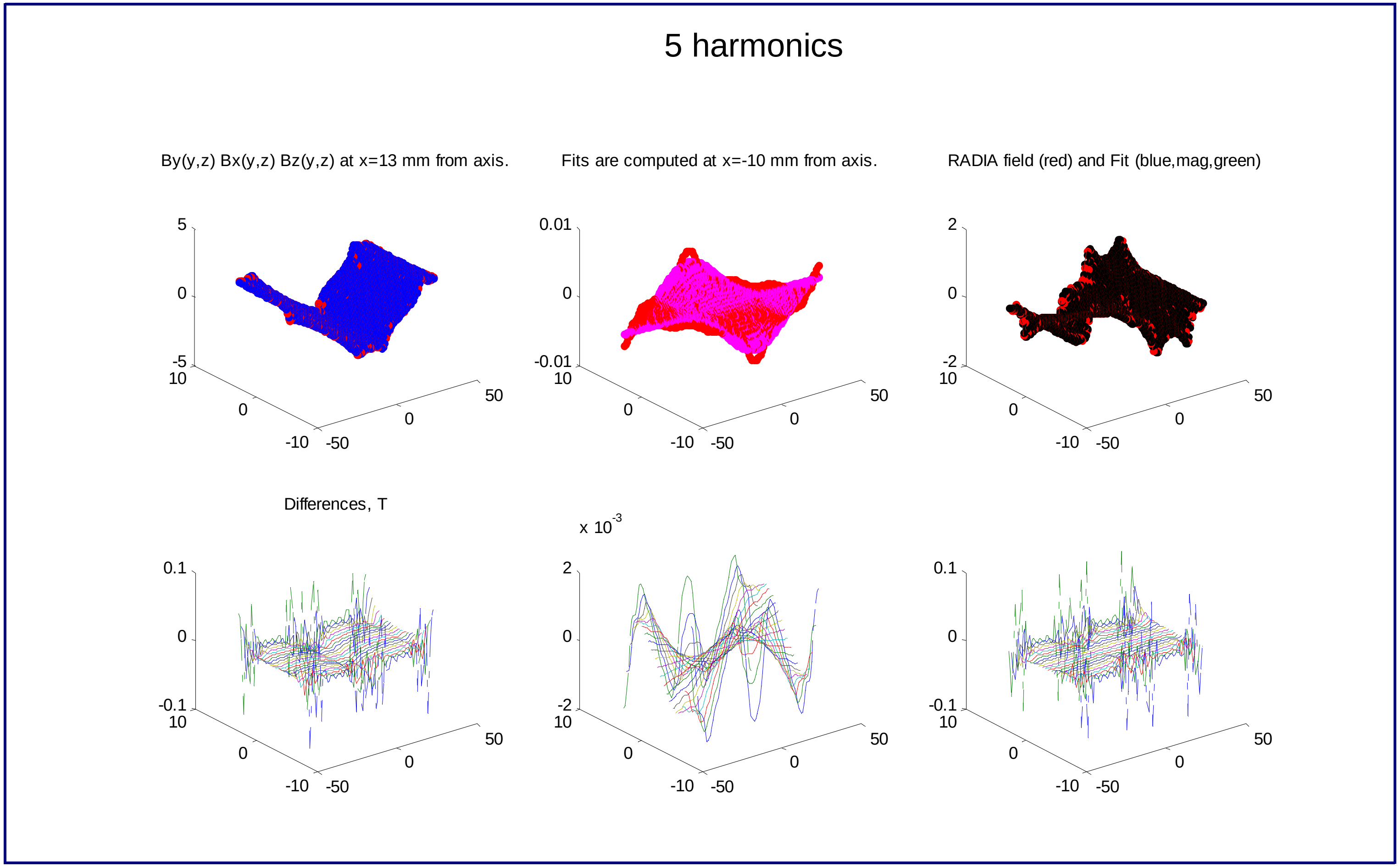


Fitted Halbach Basis from Radia Model for DW (with T. Shaftan and T. Tanabe)



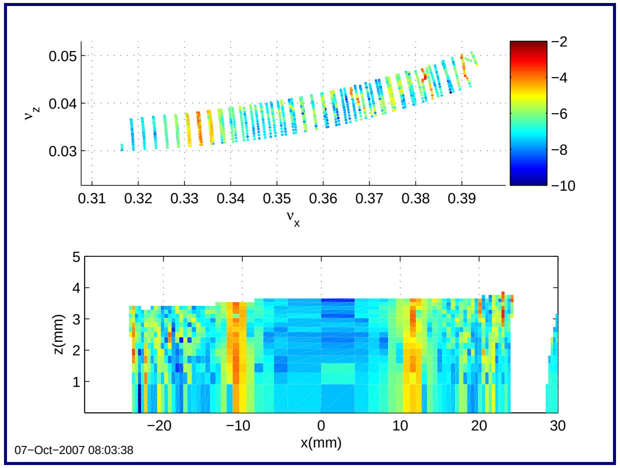
Horizontal Field Roll-Off

2.4 Field Deviations: DW100
(with T. Shaftan and T. Tanabe)

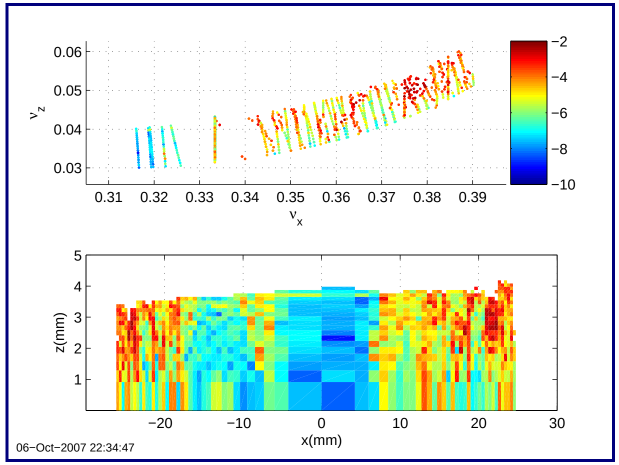


2.5 Model Validation: DW80

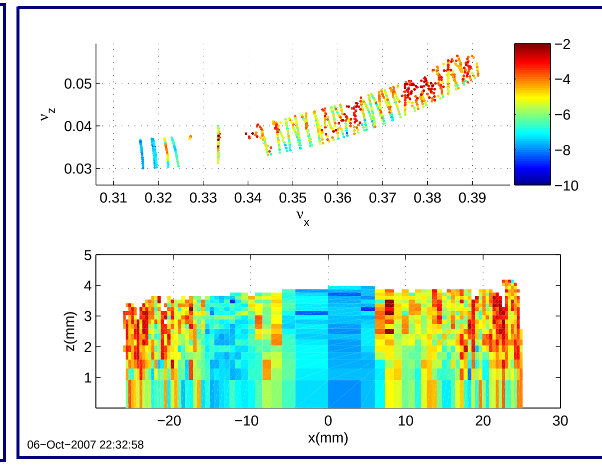
Bare Lattice



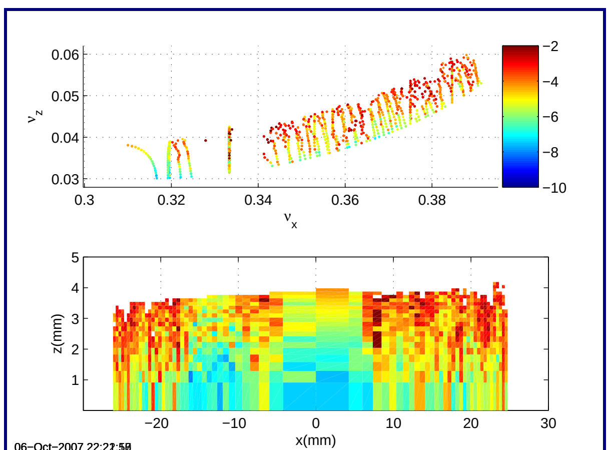
Impact of 5 Ideal Damping Wigglers



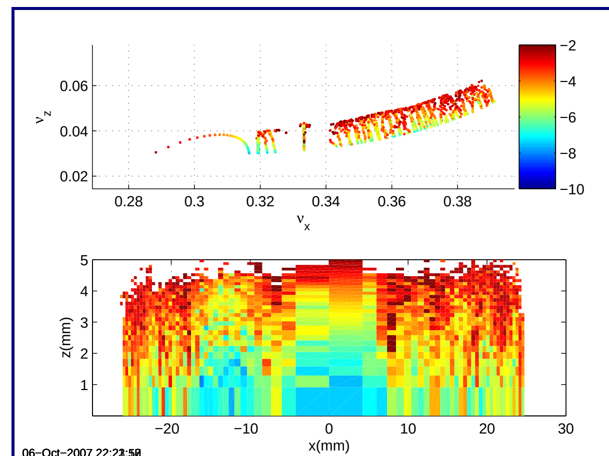
Including Harmonics up to 9th



Radia Kick Map

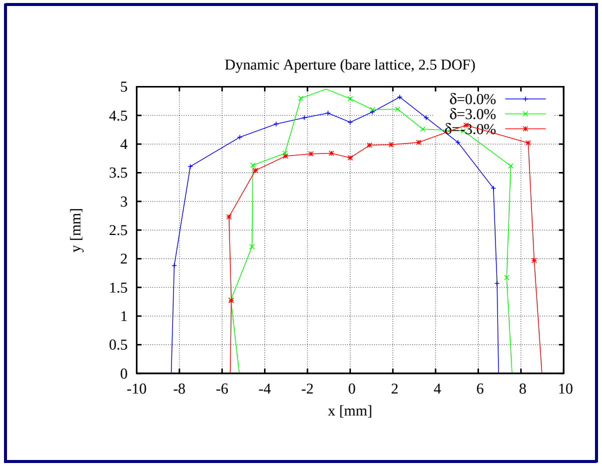


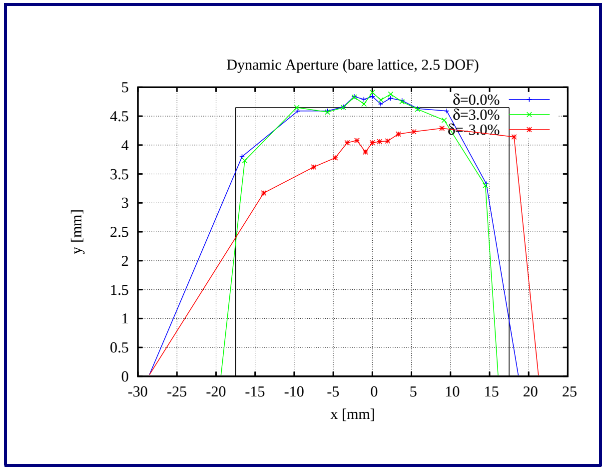
with Radia Kick Map (full gap)

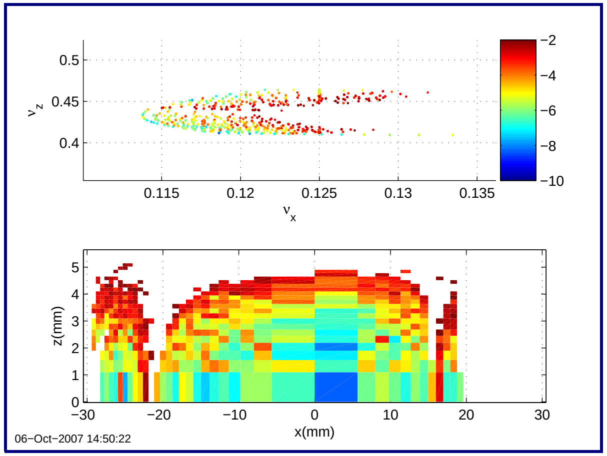


3.0 Dynamic Aperture with 3 DW90

With locally corrected optics.





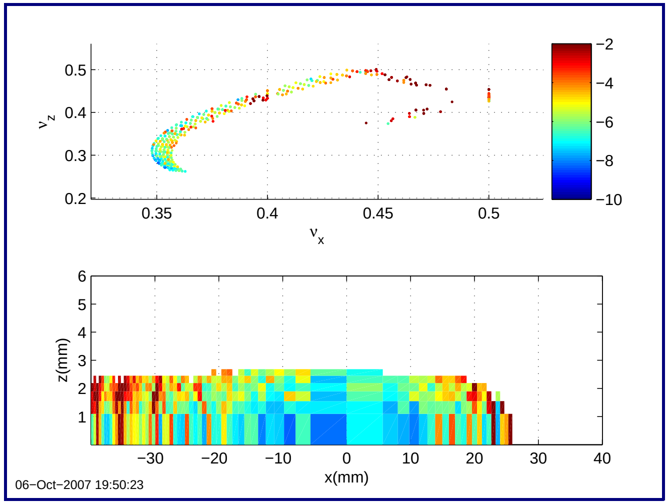


Problem: one of the quads in the matching section is significantly weaker than the other two. To fix it:

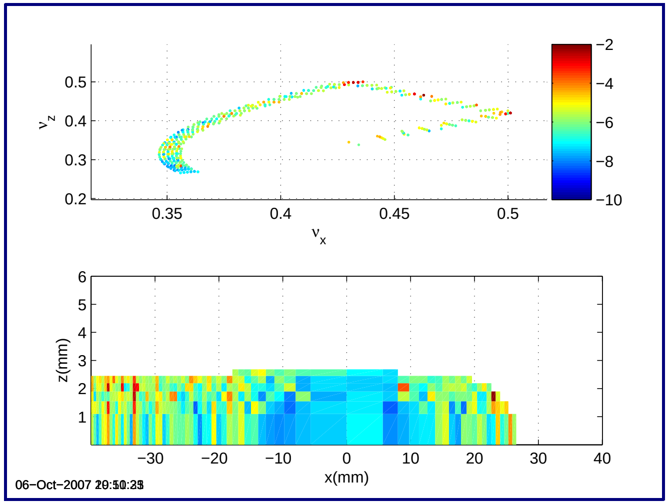
- **Correct optics by using all non-chromatic quads,**
- **and adjust working point to $\nu_{x,y} = (33.356, 16.266)$.**

3.1 Impact on the DA from CPMUs and DWs

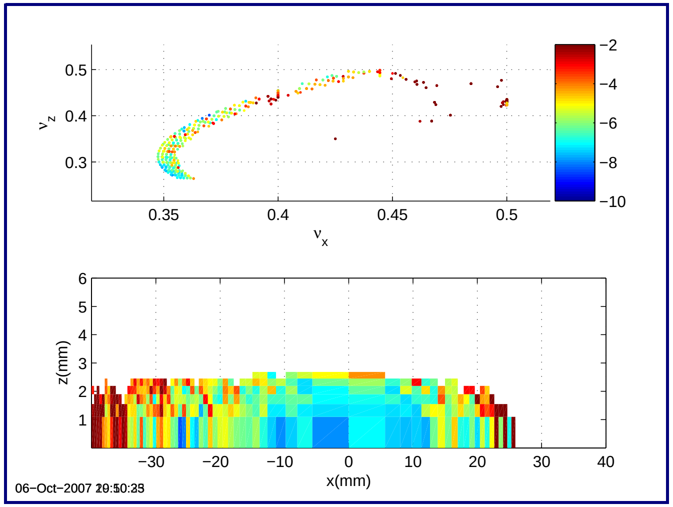
1 CPMU



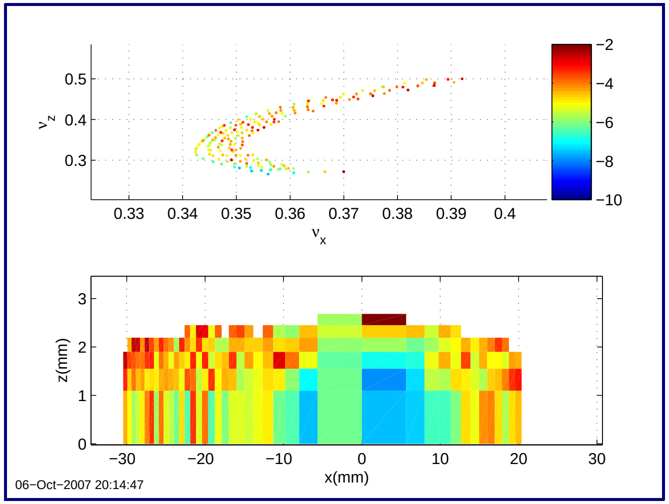
15 CPMUs



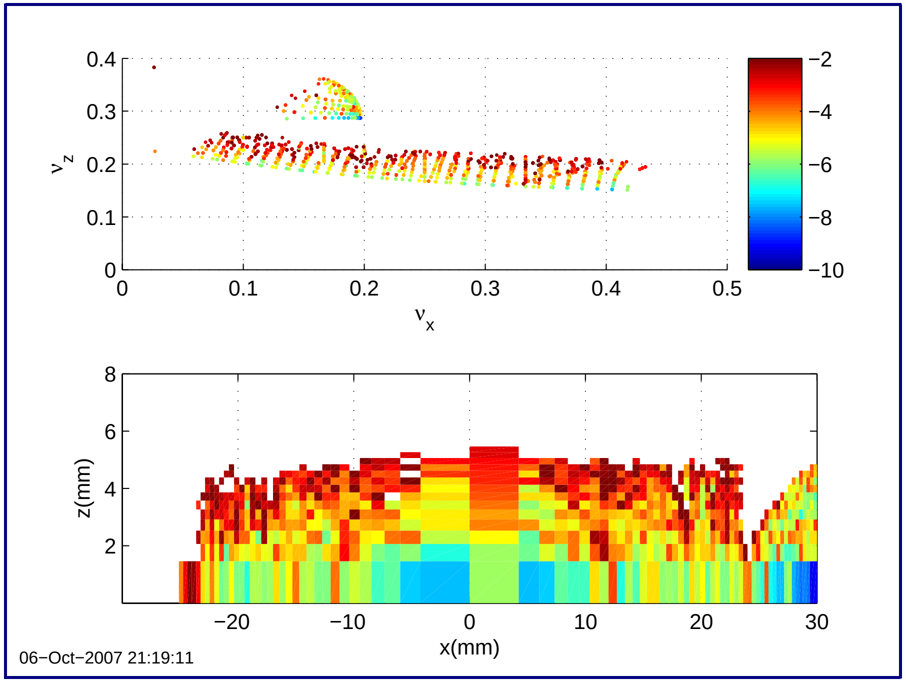
5 CPMUs



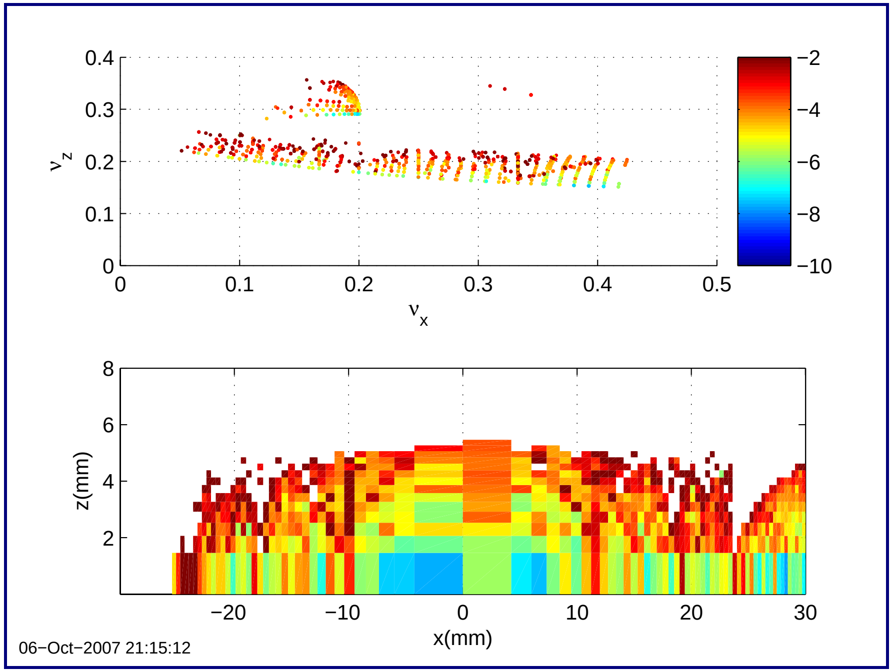
5 DWs and 15 CPMUs



3.2 Impact on the DA from EPUs



Apple-II type



HiSOR type

3.3 The Driving Terms

4.0 Design of Linear IDs: From First Principles

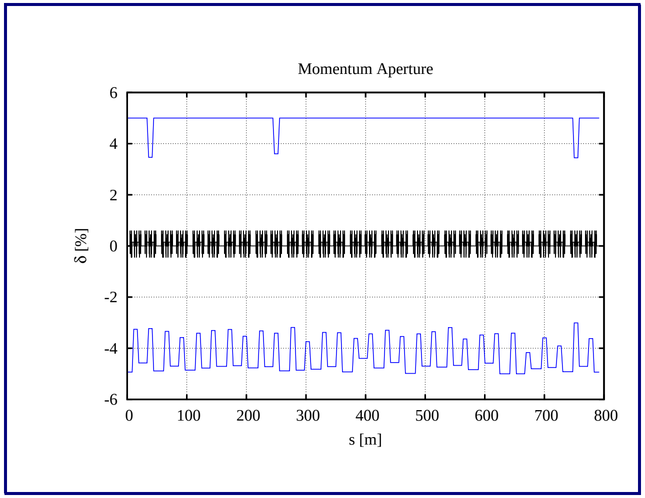
The first and second integrals are given by

$$I_1 = \int_0^L B_y(s)ds \sim x', \qquad I_2 = \int_0^L \int_0^s B_y(s')ds'ds \sim x$$

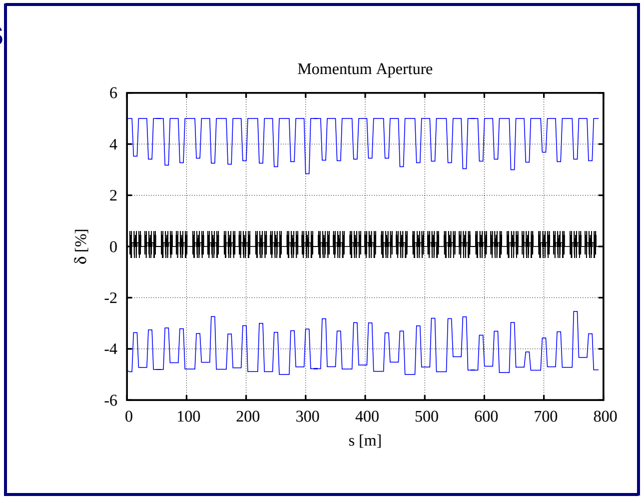
The problem is that these integrals are traditionally evaluated along a straight line rather than the path followed by the electron. In other words, while the linear and nonlinear focusing are of dynamic origin (like the coriolis force), it can be corrected locally by using L-shims between the magnets and by minimizing the relevant integral. Pioneering work has been done at the ESRF and BESSY-II.

5.0 Impact of IDs on Momentum Aperture

$\delta_{RF} = 5\%$

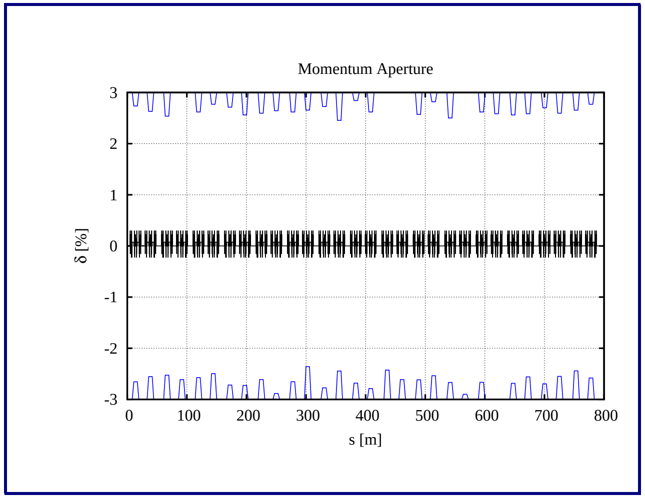


with 3 DWs

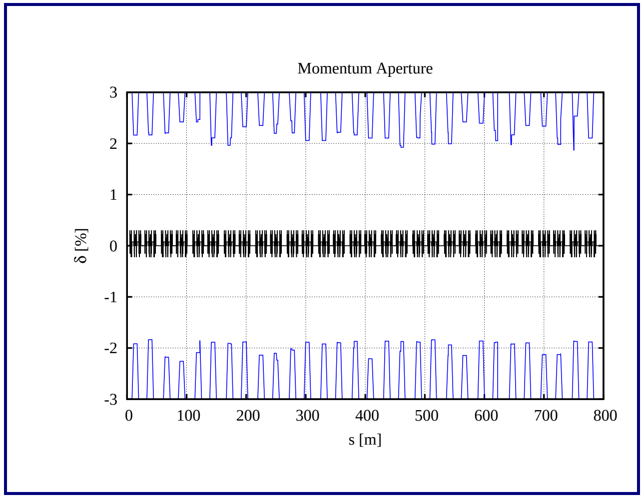


$\delta_{RF} = 3\%$

gap = 5 mm



with 15 CPMUs



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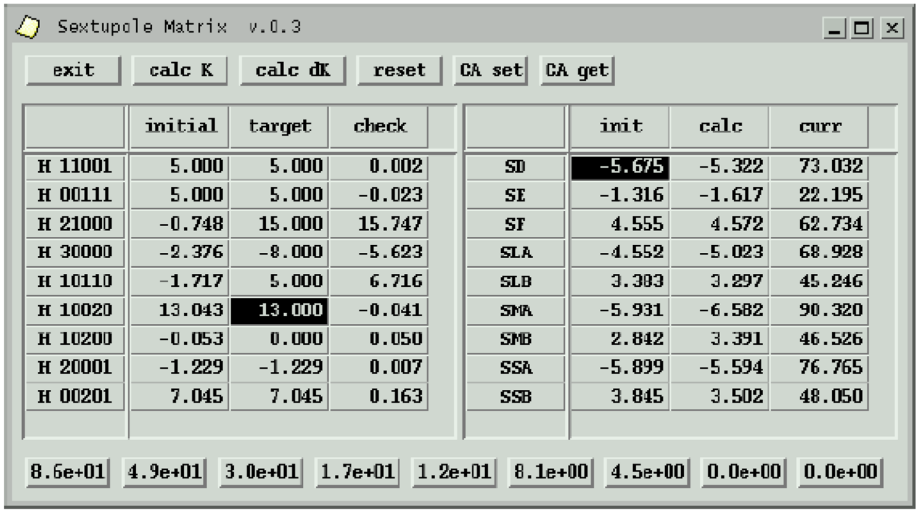
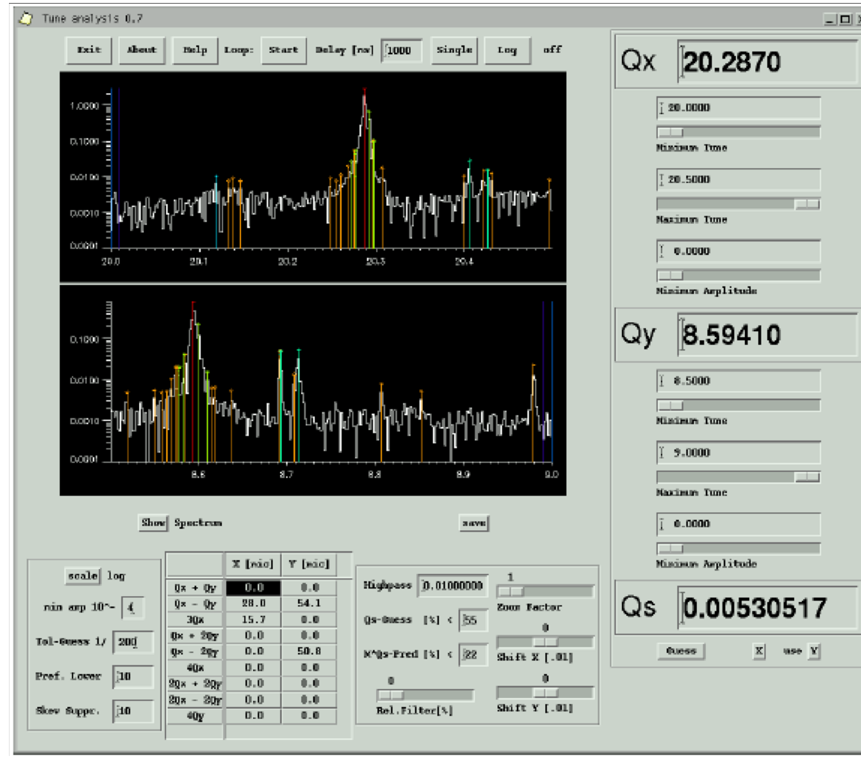
6.0 Control of the Driving Terms (SLS)



	initial	target	check		init	calc	curr
H 11001	5.000	5.000	0.002	SD	-5.675	-5.322	73.032
H 00111	5.000	5.000	-0.023	SE	-1.316	-1.617	22.195
H 21000	-0.748	15.000	15.747	SF	4.555	4.572	62.734
H 30000	-2.376	-8.000	-5.623	SLA	-4.552	-5.023	68.928
H 10110	-1.717	5.000	6.716	SLB	3.383	3.297	45.246
H 10020	13.043	13.000	-0.041	SMA	-5.931	-6.582	90.320
H 10200	-0.053	0.000	0.050	SMB	2.842	3.391	46.526
H 20001	-1.229	-1.229	0.007	SSA	-5.899	-5.594	76.765
H 00201	7.045	7.045	0.163	SSB	3.845	3.502	48.050

8.6e+01	4.9e+01	3.0e+01	1.7e+01	1.2e+01	8.1e+00	4.5e+00	0.0e+00	0.0e+00

A. Streun



- J. Bengtsson "The Sextupole Scheme for the Swiss Light Source (SLS): An Analytic Approach" SLS Note 9/97.
- Y. Luo, M. Bai, R. Calaga, J. Bengtsson, W. Fischer, N. Malitsky, F. Pilat, T. Satogata "Measurement and Correction of Third Resonance Driving Term in the RHIC" PAC07.

7.0 Conclusions

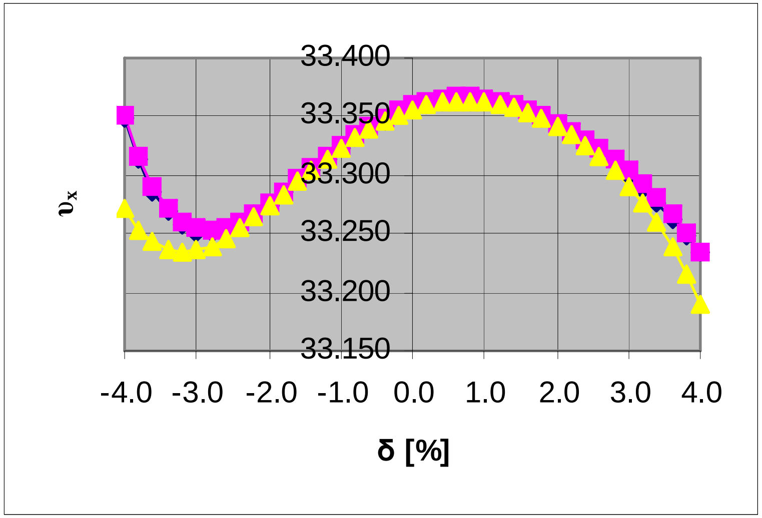
- No apparent show stoppers.
- Controlling the optics with DWs requires care. In particular, distributed (non-local) correction with the achromatic quadrupoles, and fine tuning of the working point.
- The EPUs are challenging devices that requires further study and guidelines for how to control their nonlinear effects.
- No significant advantage of HiSOR type EPUs over Apple-II devices.
- A first principles approach is to design linear devices based on the first and second integrals evaluated along the orbit, rather than straight lines, and control the nonlinear effects locally by shimming. Pioneering work has been done at the ESRF and BESSY-II.
- The driving terms can be controlled for a real accelerator with BPM turn-by-turn data and the inverted sextupole response matrix; given a sufficient number of knobs.

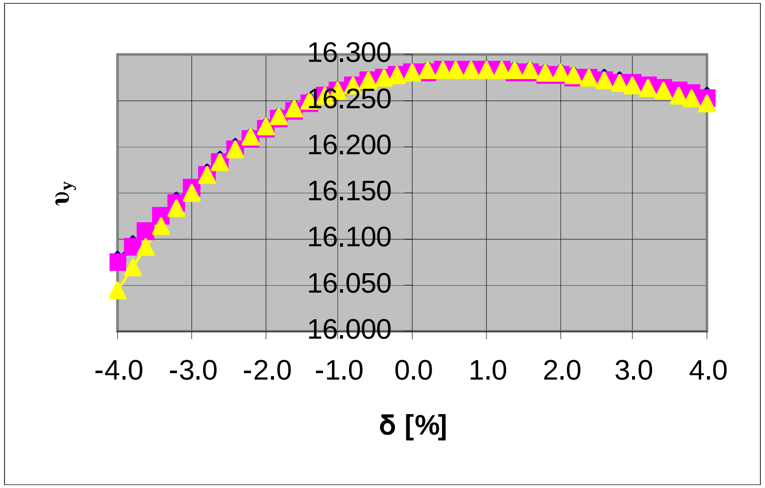
7.1 Future Work

- Need to evaluate the DA and Touschek lifetime for the new baseline lattice with a full set of insertion devices, engineering tolerances, and corrections.
- Evaluate the merits/feasibility to improve the control of the residual horizontal chromaticity by introducing octupoles/decapoles.
- Guidelines needs to be worked out for local control the nonlinear effects from EPUs, i.e., with L-shims.

Back-Up Slides

Residual Chromaticity





Order	υ_x			υ_y		
	Fit	Analytic		Fit	Analytic	
0	33.36	33.36	±5.87e-07	16.28	16.28	±1.86e-07
1	2.00E+00	2.01E+00	±5.81e-05	9.66E-01	9.95E-01	±1.85e-05
2	-1.51E+02	-1.34E+02	±2.20e-03	-8.01E+01	-7.28E+01	±6.98e-04
3	-2.55E+02	-3.23E+02	±1.37e-01	1.31E+03	1.15E+03	±4.34e-02
4	6.78E+04	3.49E+04	±1.46e+00	4.89E+03	-7.21E+03	±4.65e-01
5	-1.19E+06	-9.73E+05	±7.16e+01	-3.31E+05	-1.17E+05	±2.28e+01