NSLS-II DESIGN: A NOVEL APPROACH TO LIGHT SOURCE DESIGN

Asian Particle Accelerator Conference
Indore, India

Februrary 1, 2007

Stephen Kramer for NSLS-II Design Team

THC3MA03

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NSLS-II Design Team

The NSLS-II Design Team is a large diverse group of technical people

Under the leadership of: S. Dierker, S. Ozaki, and J. Hill.

The Accelerator Systems Team was pulled together under the leadership of Satoshi Ozaki:

J. Beebe-Wang, J. Bengtsson, M. Blaskiewicz, A. Blednykh, W. Guo, R. Heese, V. N. Litvinenko, A. Luccio, Y. Luo, N. Malitsky, C. Montag, B. Nash, B. Podobedov, I. Pinayev, S. Pjerov, G. Rakowsky, J. Rose, T. Satogata, T. Shaftan, S. Sharma, N. Simos, J. Skaritka, T. Tanabe, D. Trbojevic, D. Wang, F. Wang, J. Wei, L. H. Yu, and a large number of users, technical and support staff from the NSLS and CAD Departments at Brookhaven National Lab.

Design Parameters

Beam Property	Required Goal	Challenge Goal
Beam Energy	3 GeV	3.6 GeV
Ultra low horizontal emittance	$\leq$ 1.0 nm (achromatic)	$\leq$ 0.5 nm @3 GeV
Vertical emittance diffraction limited at 12 KeV	10 pm	< 8 pm
Stored currents	500 mA	750 mA @ 3 GeV
ID straights for undulators	$\geq$21	$\geq$ 25
Electron beam stability	<1 μm	<0.3 μm
Top-off injection current stability	<1% ($\Delta t \geq 1$ min)	<0.1% ($\Delta t \geq 1$ min)

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Lattice Choices

Minimum emittance for TBA and DBA with bend angle per period $\theta_p = \frac{2\pi}{N_p}$ given by

$$\varepsilon_{METBA} = \frac{C_q \gamma^2}{4\sqrt{15}} \frac{\theta_p^3}{J_x\ 40.7}$$

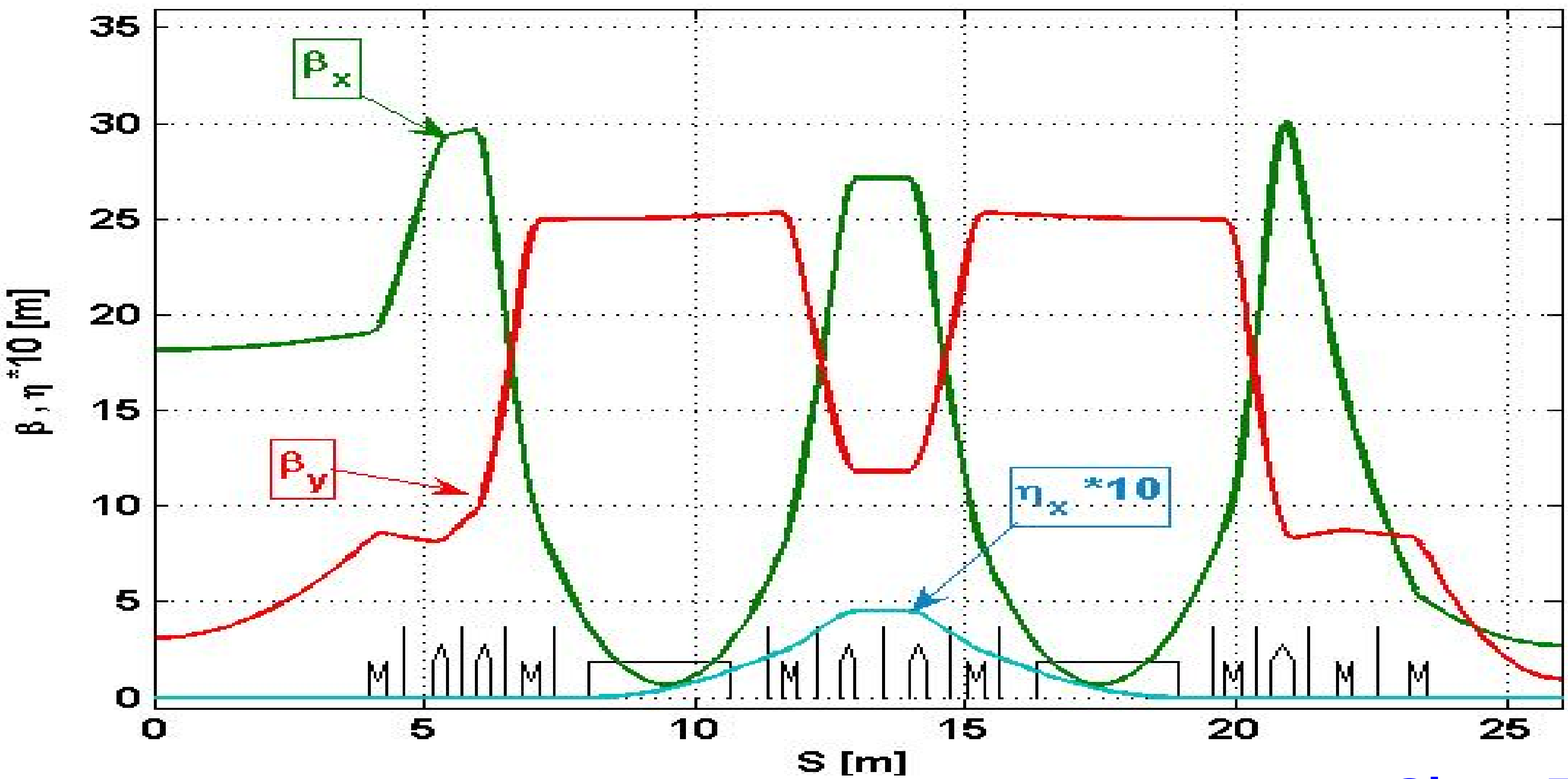
$$\varepsilon_{MEDBA} = \frac{C_q \gamma^2}{4\sqrt{15}} \frac{\theta_p^3}{J_x\ 8}$$

A 3 GeV 24 period TBA $\varepsilon_{METBA} \approx 0.38 nm$

Need $\geq$32 periods for DBA lattice

Optimized DBA-30 Lattice

Low emittance(2.05nm), large ρ_o → large η_y , small β_y in IDs, large β_x in injection ID, space for coils and correctors, tunes and beta function optimized for: reduced COAF and large DA



Long 8m ID

Short 5m ID

DBA-30 Lattice Parameters

Energy [GeV]	3
Circumference [m]	780.3
DBA Cells	30 (15x2)
Bending Radius, ρ_o [m]	25.019
Energy Loss / Turn, U_o [keV]	286.5
Momentum Compaction	0.000368
Tunes (Q_x , Q_y) / per cell	(32.35,16.28) (1.078,0.543)
Chromaticity (ξ_x , ξ_y) /per cell	(-100, -41.8) (-3.34, -1.39)
Peak Dispersion [m]	0.45
Long 8m ID (β_x, β_y) [m]	18/3.1
Short 5m ID (β_x, β_y) [m]	2.7/0.95

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Damping Wigglers for Emittance Control

Reduction of lattice emittance due to wiggler (ρ_w, L_w)

$$\frac{\varepsilon_w}{\varepsilon_o} = \frac{1+f}{1+\frac{L_w}{4\pi\rho_o}\left(\frac{\rho_o}{\rho_w}\right)^2} \approx \frac{U_o}{U_o+U_w}$$

where

$$f = \frac{2C_q\gamma^2}{3\pi^2\varepsilon_0}\frac{L_w\rho_0}{\rho_w^3}\left[\frac{K_w^2}{5\gamma^2}\langle\beta_x\rangle + \frac{\eta_0^2}{\beta_{x0}} + \beta_{x0}\eta'^2_0\right]$$

Limited by energy spread increase of the wigglers

$$\frac{\delta_W}{\delta_o} = \sqrt{\left[U_o + \frac{8U_W}{3\pi}\left(\frac{\rho_o}{\rho_W}\right)\right]\left[U_T\right]^{-1}}$$

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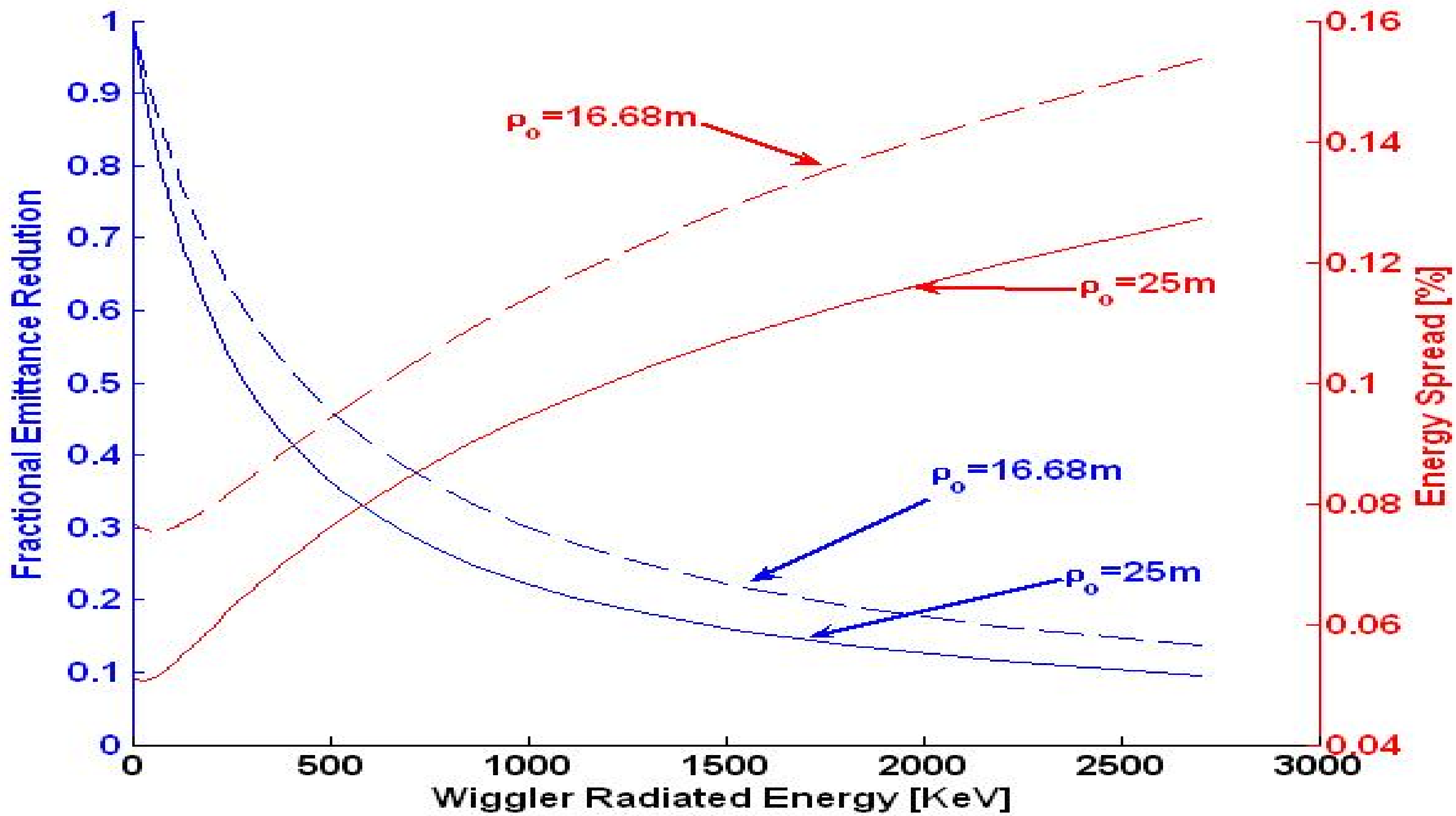
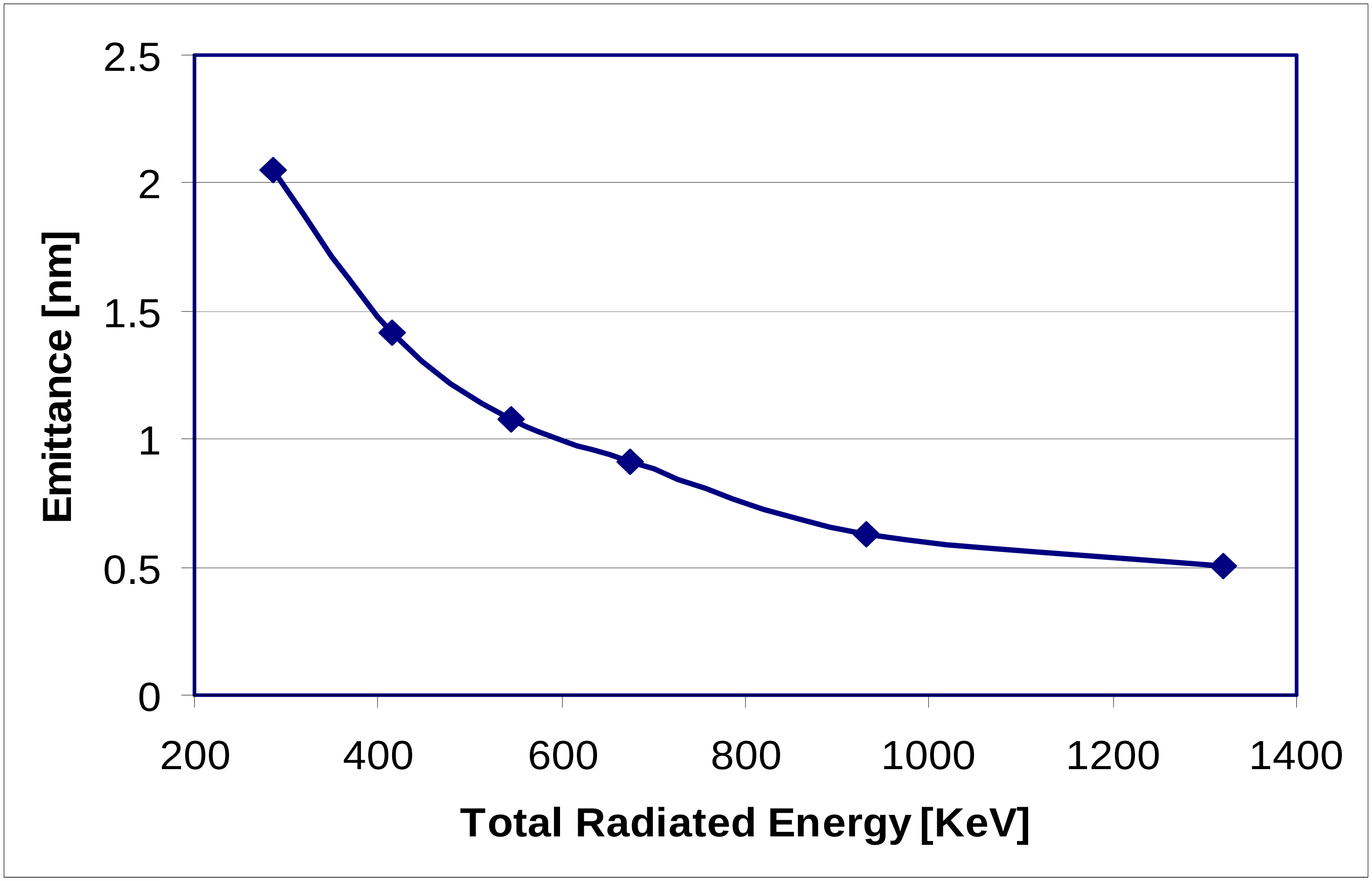
Emittance and Energy Spread vs Dipole ρ_0

Reduction of emittance limited by increase in energy spread and energy loss or available RF power (cost)



Emittance Reduction for 7m 1.8T DWs

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



Optimizing the Lower Dipole Field

Reduction of Natural Emittance to zero becomes less efficient for non-zero current due to Intra-Beam Scatter (IBS)

Total emittance is equilibrium between SR and IBS

$$\varepsilon_{x,tot} = \tau_x < H \cdot D_{\delta,SR} > + \tau_x < H \cdot D_{\delta,IBS} >$$

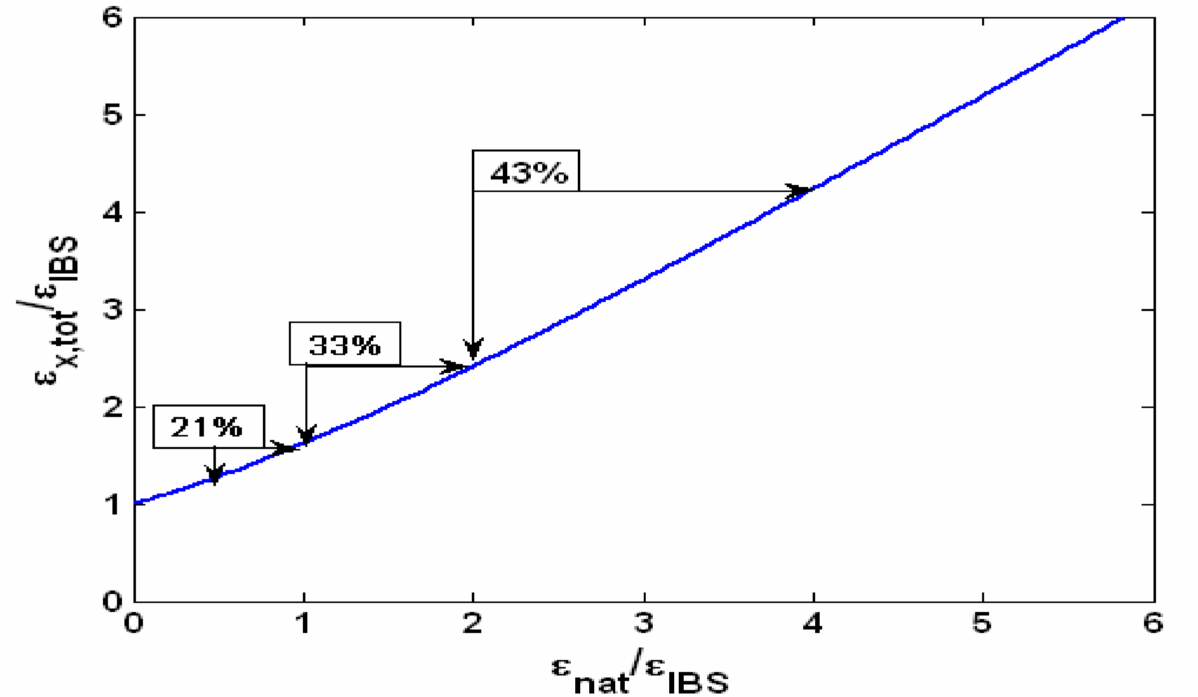
τ_x is the horizontal SR damping time, *H* the invariant dispersion amplitude $D_{\delta,SR}$ and $D_{\delta,IBS}$ are the SR and IBS energy diffusion coefficients.

Simplified solution →

$$\frac{\varepsilon_{x,tot}}{\varepsilon_{IBS}} = \left[\frac{\varepsilon_{nat}}{2\varepsilon_{IBS}} + \sqrt{\left(\frac{\varepsilon_{nat}}{2\varepsilon_{IBS}}\right)^2 + 1} \right]$$

For I=500mA in 1000 bunches in NSLS-II, ε_{IBS} ~ 0.2 – 0.25 nm

Limiting Emittance from IBS Limits



If Total Energy Loss, $U_{T,}$ is Fixed by RF Power $\varepsilon_{nat} \propto U_o \propto 1/\rho_o$

$$\varepsilon_{nat} \approx (2 to 3)\, \varepsilon_{IBS} \Rightarrow (U_o / U_T) \approx (2 to 3)(\varepsilon_{IBS} / \varepsilon_o)$$

U_T = 1 MeV and ε_{IBS} = 0.25 nm, then ρ_o ~ (20-30) m ➔ ρo = 25m NSLS-II

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Matching Optics to Undulators and Wigglers

Large DA due to careful cancellation of nonlinear driving terms

IDs will break the linear optics (Beta Function and Phase beating)

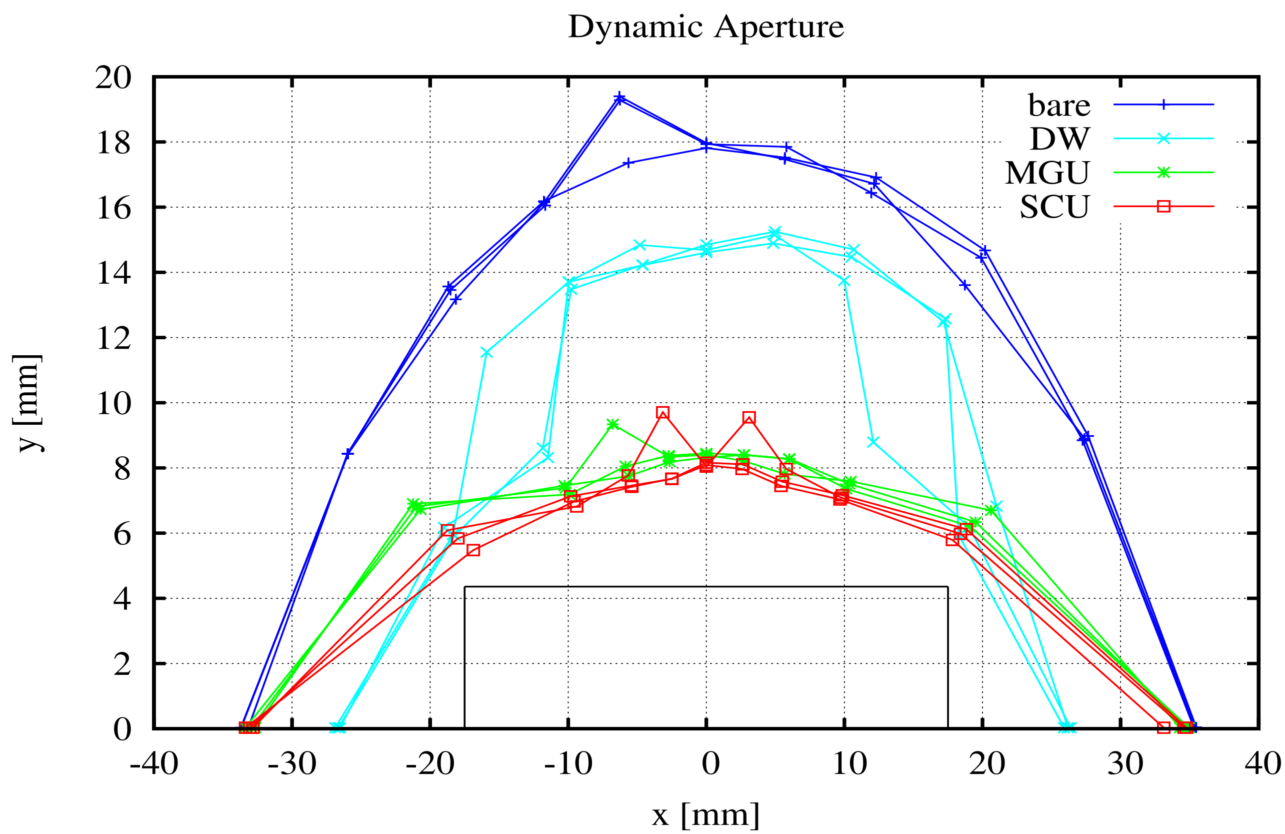
IDs will also introduce nonlinear terms, tune shift with amplitude

$$\Delta\nu_y = \frac{\langle \beta_y \rangle L_w}{8\pi\rho_w^2} \qquad \frac{d\nu_y}{dJ} = \frac{\pi \langle \beta_y^2 \rangle L_w}{4\lambda_w^2 \rho_w^2}$$

DWs have large tune and beta function distortion, need to correct 2-phases and 2- Beta functions → 4-Quadrupoles in ID straight (3-Q's?)

Short period undulators have large nonlinear tune shift, not corrected

Four Quad Correction Maintains DA



Bengtsson, NSLS-II CDR

DA with alignment errors corrected with BBA BPMs for:

5- 7m DWs(1.8T), or 15 -3m PM-MGU(19mm) or 15- 2m SCU(14mm)

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Advantage of Achromatic DBA Lattice

- **DWs and IDs will damp emittance more effectively**

  η_x ~ 1cm increases DW damped emittance by ~15%
- **No effective emittance growth due to dispersion in ID or with energy spread growth from DWs or current**

$$\varepsilon_{eff} = \varepsilon_x \sqrt{1 + \frac{(\eta_x \delta)^2}{\beta_x \varepsilon_x}}$$

- No synchro-beta coupling from IDs or Longitudinal Coupled Bunch Instability increase of effective emittance
- Higher momentum compaction, less distortion of RF buckets, also advantage of lower dipole field
- Clear separation of chromatic and geometric sextupoles

Advantages Low Field Dipole Lattice

- **Larger dispersion for reduced sextupole strength(DA)**
- **DWs and IDs will damp emittance more effectively.**
- **Smaller energy spread and larger momentum compaction factor.**
- **Lower RF power from dipoles, less heating issues.**
- **Lower critical energy from dipoles, easier to separate from ID radiation in X-ray BPMs.**
- **Lower thermal power in IDs from up-stream dipole, serious problem for SCU cryo-coolers.**
- **Dipole beams are diffraction limited <200 eV in H & V**

Disadvantages:

- Larger circumference lattice, cost risk less than technical
- No hard X-rays from dipole beams

Summary

- DBA-30 design takes novel approach to ultra-low emittance lattice
  - Damping wigglers provide evolution of emittance as users learn how to use such low emittance and high power levels
  - Damping wigglers make high flux/brilliance hard X-ray beams
  - RF power not wasted on dipole radiation
  - VUV dipole beam lines have easily handled power levels
- Further optimization of number of quadrupoles in ID straight sections should yield increased ID lengths
- Reduction of number BPM/correctors and borrowed BPMs from booster will reduce cost.