NSLS-II &
Philosophy of the Ring Design with Sub-Nanometer Horizontal Emittance

Particle Accelerator Conference
Albuquerque

June 25, 2007

S. Ozaki, J. Bengtsson, S. Kramer, S. Krinsky, V. Litvinenko

and the NSLS-II Design Team

MOOAAB01

BROOKHAVEN SCIENCE ASSOCIATES

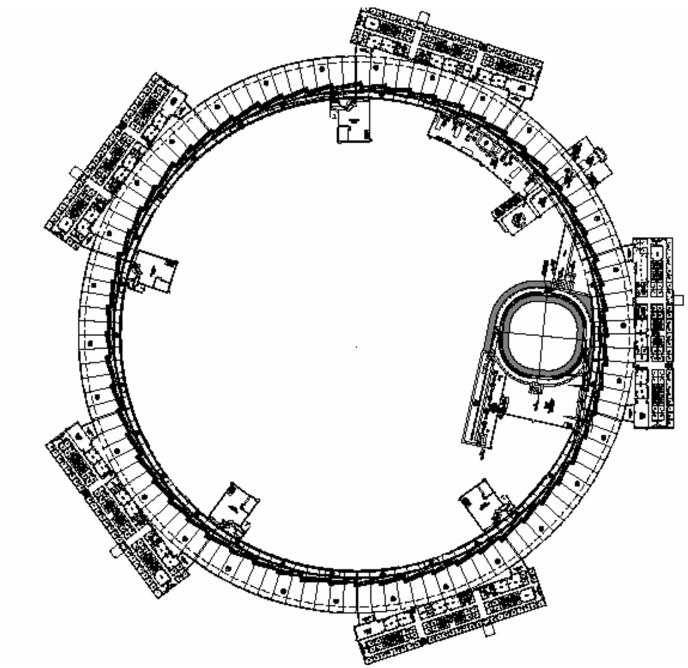
The basic mission requirements of the NSLS-II

- To develop a x-ray sources providing research capability with:
  - 1 nm spatial resolution and
  - 0.1 meV energy resolution
  - with single atom sensitivity.

- Requirements for the NSLS-II facility:
  - State-of-the-art optical system
  - Ultra-high brightness and stable synchrotron radiation.
  - Spectrum coverage ranging from far IR to 10~20 keV x-rays

- Requirements for the accelerator complex:
  - Ultra-small horizontal emittance ε_x <1.0 nm•rad (achromatic),
  - Vertical emittance ε_y: ~0.007 nm•rad, diffraction limited
  - Diffraction limited vertical emittance at 12KeV,
  - Beam stability ~10% of beam size or better (≤3μm)
  - Stored current (i_o) > 500 mA ±1% with top-off injection, and
  - More than 24 straight section >5m, for IDs,

NSLS-II Concept



NSLS-II Machine Concept

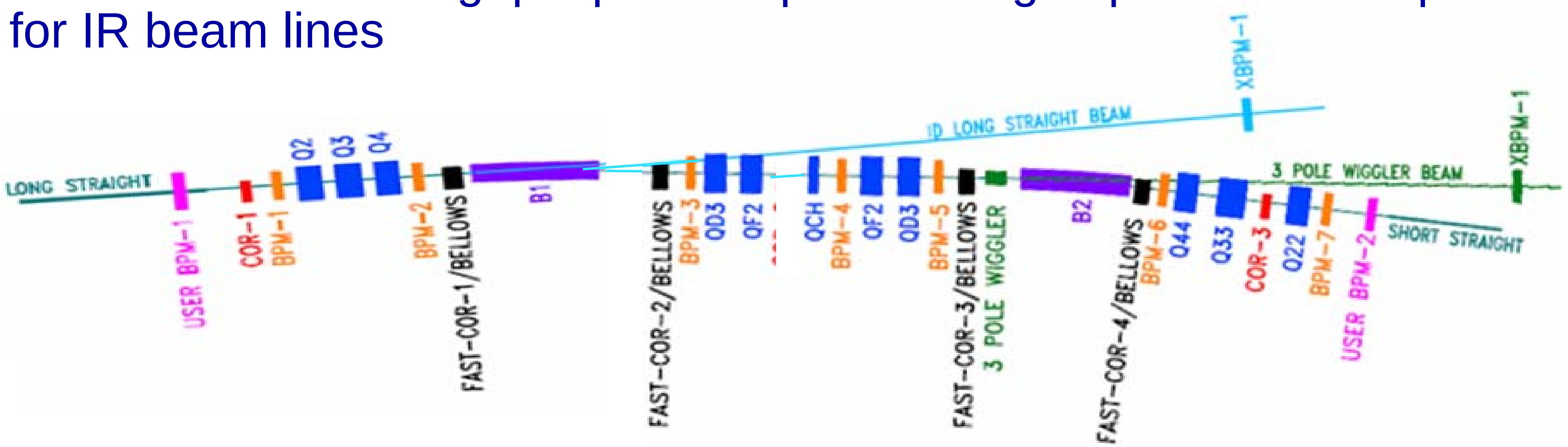
- New 3 GeV Electron Storage Ring
- Large Circumference (791.5 m), H = 1320
- Low Emittance Booster (~158m, H=264)
- High Stored Current (500 mA $\pm$1%)
- Top-Off Injection
- Superconducting RF (500 MHz)
- DBA30 Lattice (15 fold symmetry)
- 15 long and 15 short straights with Hi-Lo β
- Ultra-Low Emittance (<1 nm)
- Damping Wigglers (21m) (full built-out – 56 m)
- Large Dipole Bend Radius (25 m)
- Provision for IR Source (3 pair of Wide Gap D)
- Three-pole wiggler x-ray sources

Technical Challenges

- Sub-nanometer horizontal emittance for ultra-bright x-ray beams.
- Lattice design:: dynamic aperture, energy acceptance
- Source stability:: vibrations, thermal issues, feedback
- Insertion Device: CPMUs, EPUs, SCUs(?) and their impact to dynamics of beam

Key Aspects of the NSLS-II Storage Ring Lattice

- DBA lattice with small natural emittance.
- Damping wigglers in achromatic straights for emittance control,
  - A novel for a light source ring but commonly used in HEP accelerators
- Use of soft-bend dipoles to enhance the effectiveness of damping wigglers,
- Introduction of 3-Pole-Wiggler just upstream of the second dipole of a cell to provide high quality hard x-ray beams.
- Introduction of wide-gap dipoles to provide large aperture beam ports for IR beam lines



4S 6S 3S

Lattice Choices

Theoretical minimum emittance for double bend (DBA) and triple bend (TBA) achromatic lattices for a given number of cells (*M*),

$$\varepsilon_{MEDBA} = \frac{\gamma^2}{M^3}(0.77\, pm - radians)$$

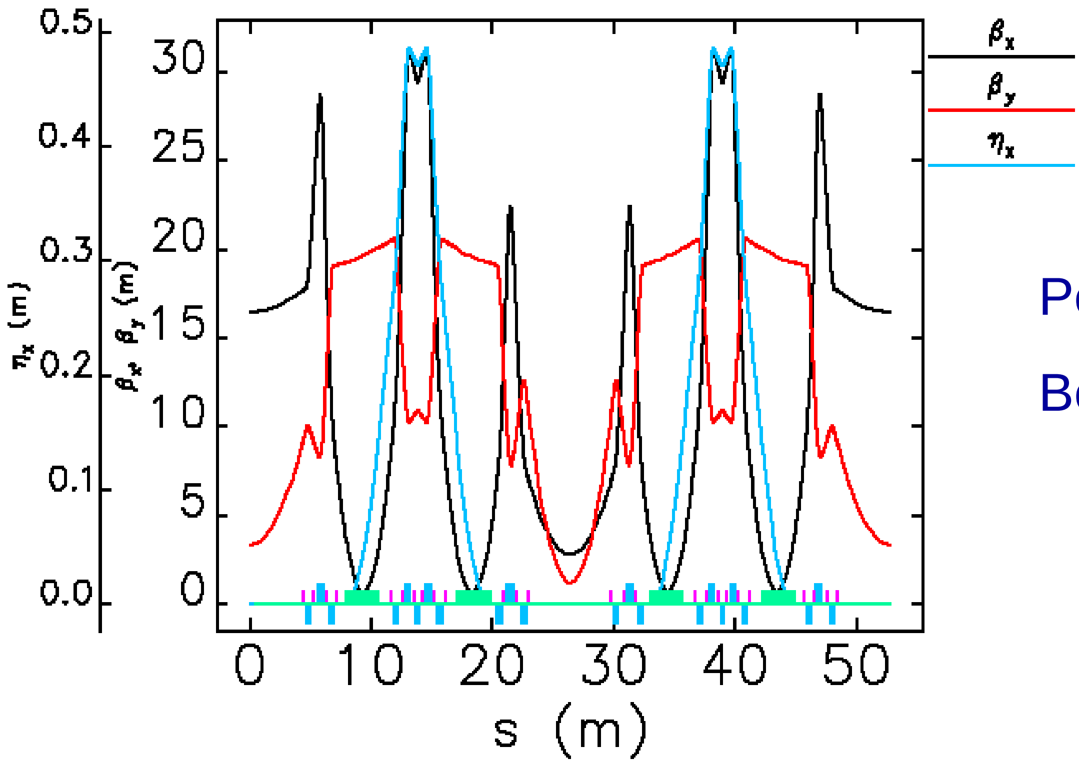
$$\varepsilon_{METBA} = \frac{\gamma^2}{M^3}(0.151\, pm - radians)$$

DBA30, instead of TBA24, was chosen for a large number of achromatic ID straights for damping wigglers

Our lattice design guidelines were:

- minimize horizontal chromaticity per cell,
- maximize peak dispersion, horizontal and vertical dynamic acceptance, horizontal DA (top-off injection), and momentum aperture (Touschek lifetime),
- control nonlinear effects by sextupole correction (10 families) and parameter choice in ID straights

Lattice Functions For One Superperiod



Peak Dispersion: 0.489 m

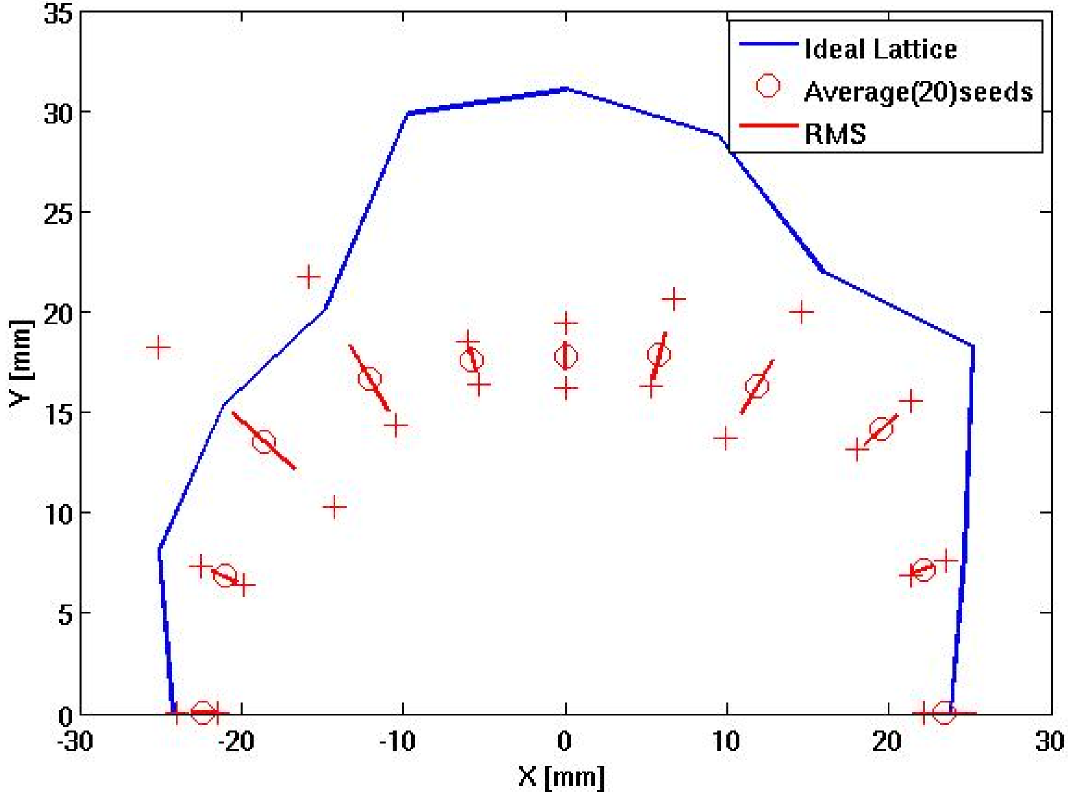
Beta-Functions:

- 8.6m ID Straight
  (βx, βy) 18/3.8 m
- 6.6m ID Straight
  (βx, β y) 1.9/2.1 m

Twiss parameters for one superperiod
of the DBA-30 lattice

Lattice Dynamic Aperture (DA)

The DA simulation from 20 randomly seeded sets:
alignment tolerances and synchrotron oscillations are included



DA is sufficiently robust for the high current operation, complex insertion devices, and top-off injection

Damping Wigglers for Emittance Control

- Damping wigglers in the dispersion free straight sections enhance the damping of the lattice without significantly increasing the quantum excitation
- This is a novel approach for a light source but is a well established technology for HEP accelerators and colliders.
- The equilibrium values for the energy spread and the emittance depend not only on the wiggler radiation energy loss but also on the dipole energy loss
- The horizontal emittance ε_{nat} relative to the bare lattice emittance ε_o

$$\frac{\varepsilon_{nat}}{\varepsilon_0} \approx \frac{U_0}{U_0 + U_w}$$

where U_w is the energy radiated by the wigglers and
U_o is bare lattice emittance (7.17 [MeV] / ρ_o [m])

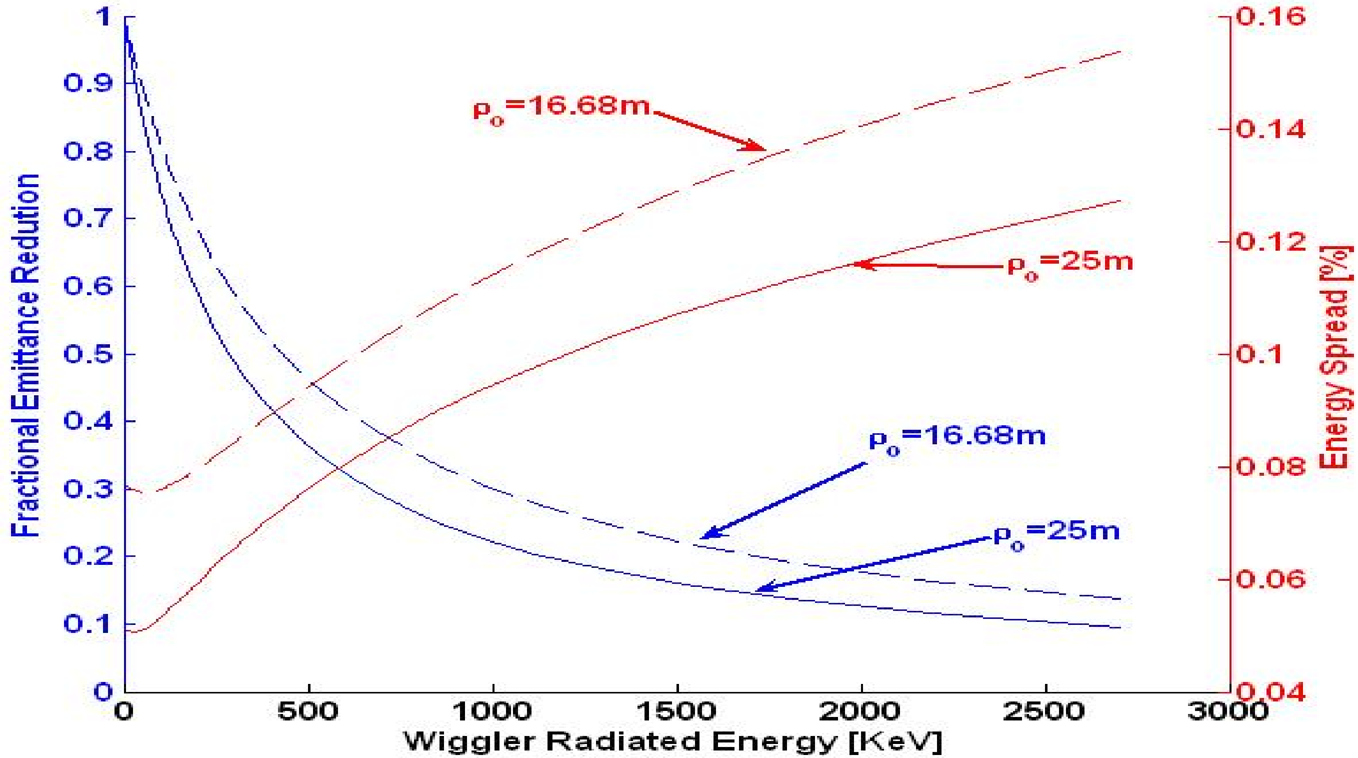
- Namely, effectiveness of damping wigglers is enhanced by reducing U_0, i.e., increasing the dipole bending radius ρ (a soft bend)

Office of Science
U.S. DEPARTMENT OF ENERGY

BROOKHAVEN NATIONAL LABORATORY
BROOKHAVEN SCIENCE ASSOCIATES

Emittance and Energy Spread vs. Dipole ρ_o

As one increases the damping wigglers, reduction of emittance is limited by increase in energy spread and energy loss (or available RF pow



21 56 DW Length (m)

Optimizing the Lower Dipole Field

Effectiveness of larger dipole bending radius in reducing the natural emittance diminishes when the energy diffusion coefficient due to Intra-Beam Scatter (IBS) become comparable with that from synchrotron radiation (SR)

Namely, total emittance is equilibrium between SR and IBS

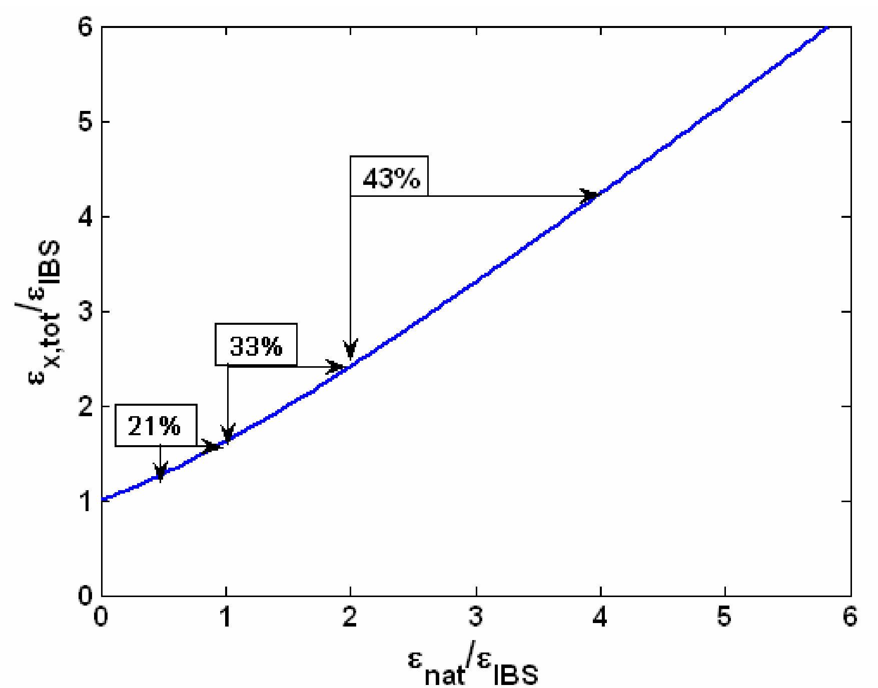
$$\varepsilon_{x,tot} = \tau_x < H \cdot D_{\delta,SR} > + \tau_x < H \cdot D_{\delta,IBS} >$$

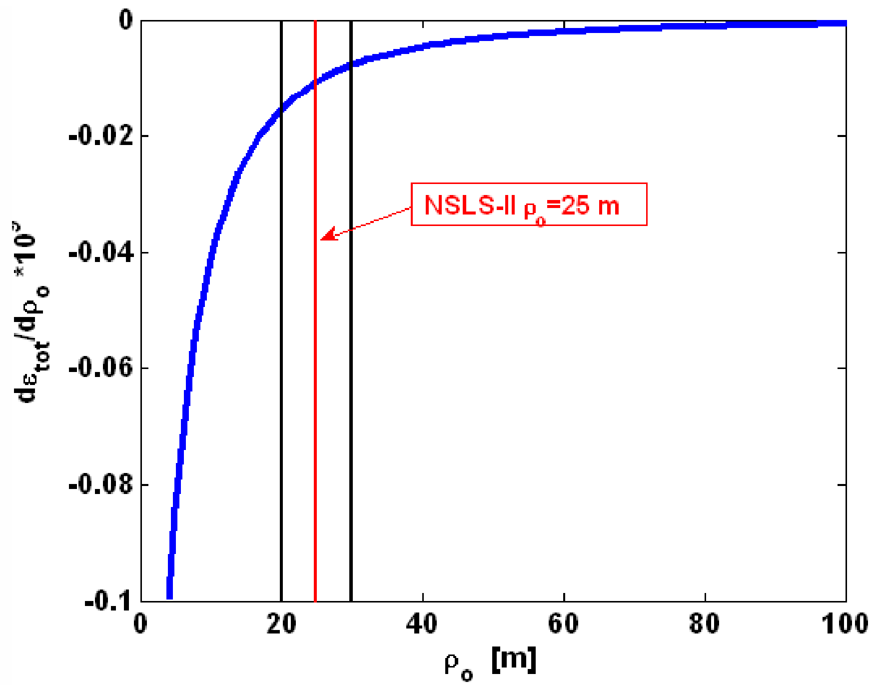
Where τ_x: the horizontal SR damping time
H: the invariant dispersion amplitude
$D_{\delta,SR}$ and $D_{\delta,IBS}$: the SR and IBS energy diffusion coefficients

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

Limiting Emittance from IBS Effect





The change of total emittance with IBS growth for 500mA ring current per unit of change of the dipole bend radius. The optimum range is shown, with the NSLS-II value

Summary

- Optimized design of the NSLS-II storage ring, based on well proven DBA configuration, has a robust DA with low natural emittance
- Combination of damping wigglers and dipoles with a large bending radius provides sub-nm•rad horizontal emittance for ultra-high brightness x-ray beams
- Damping wigglers also make high flux/brilliance hard x-ray beams
- Expected performance meet stringent requirement for the highly demanding performance
- A wide range of wavelength, from far IR to hard x-ray beams, will be provided to a wide spectrum of research program
- Further optimization of lattice and beam stability in progress in preparation of the CD-2 review

- List of NSLS-II poster presentations by our Accelerator Design Team

NSLS-II Posters Presented at this PAC

MOPAS102	“Design of Beam Transfer Line for the NSLS-II”	N. Tsoupas, *et al*
TUPMS072	“Longitudinal Beam Parameter Tolerances of NSLS II”	W-M. Guo, *et al*
TUPMS073	“Dispersion Tolerance of NSLS II”	W-M. Guo, *et al*
TUPMS074	“Collective Effects in the NSLS-II Storage Ring”	S. Krinsky, *et al*
TUPMS077	“Injection Simulations for NSLS-II Storage Ring”	I. Pinayev, *et al*
TUPMS083	“Design Considerations of the NSLS-II Injection Linac”	J. Rose, et al
TUPMS083	“Conceptual design of the NSLS-II Injection System”	T. Shaftan, *et al*
TUPMS086	“Insertion Devices R&Ds for NSLS-II"	T. Tanabe, *et al*
WEPMS091	“Conceptual Design of the NSLS-II RF System”	J. Rose, *et al*
FRPMS099	“The Poincare Map, Lie Generator, Dynamic Aperture, and nonlinear Chromaticity for the Double Bend Achromat”	J. Bengtsson,
FRPMS102	“Preliminary Impedance Budget for the NSLS-II Storage Ring”	A. Blednykh, *et al*
FRPMS103	“Coupling Impedance of the CESR-B RF Cavities for the NSLS-II Storage Ring”	A. Blednykh, et al
FRPMS104	“Coupling Impedance of the Vacuum Chambers for the NSLS-II Storage Ring”	A. Blednykh, *et al*
FRPMS113	“Touschek Lifetime Calculations and Simulations for NSLS-II”	C. Montag, *et al*