Basic Ring Beam Dynamics

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for the Department of Energy

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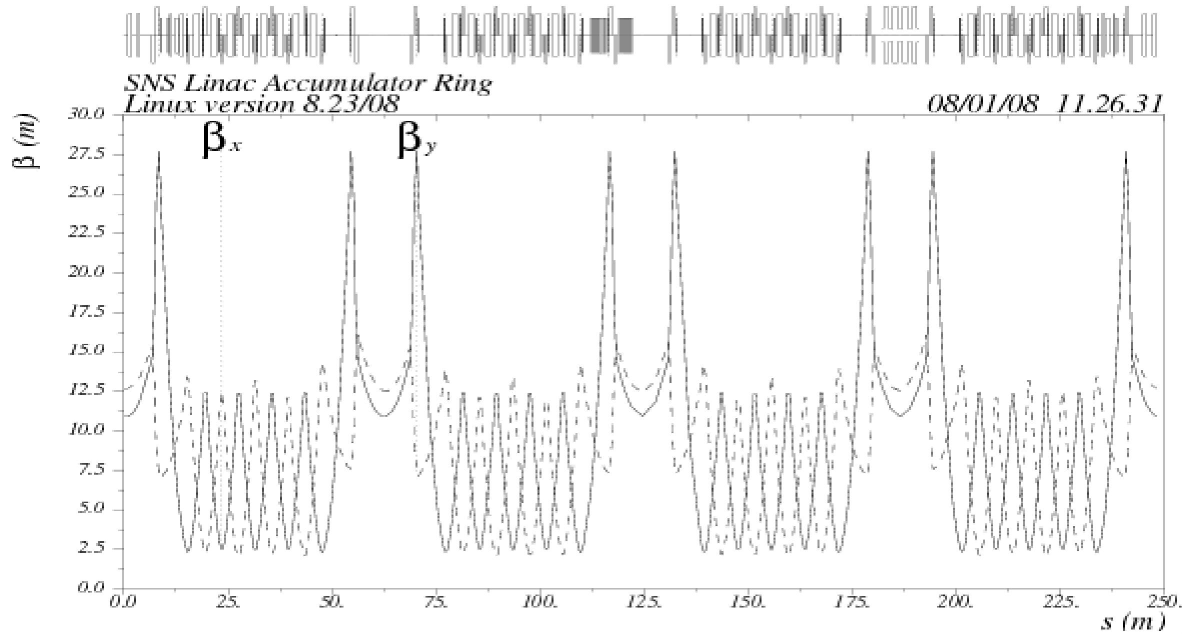
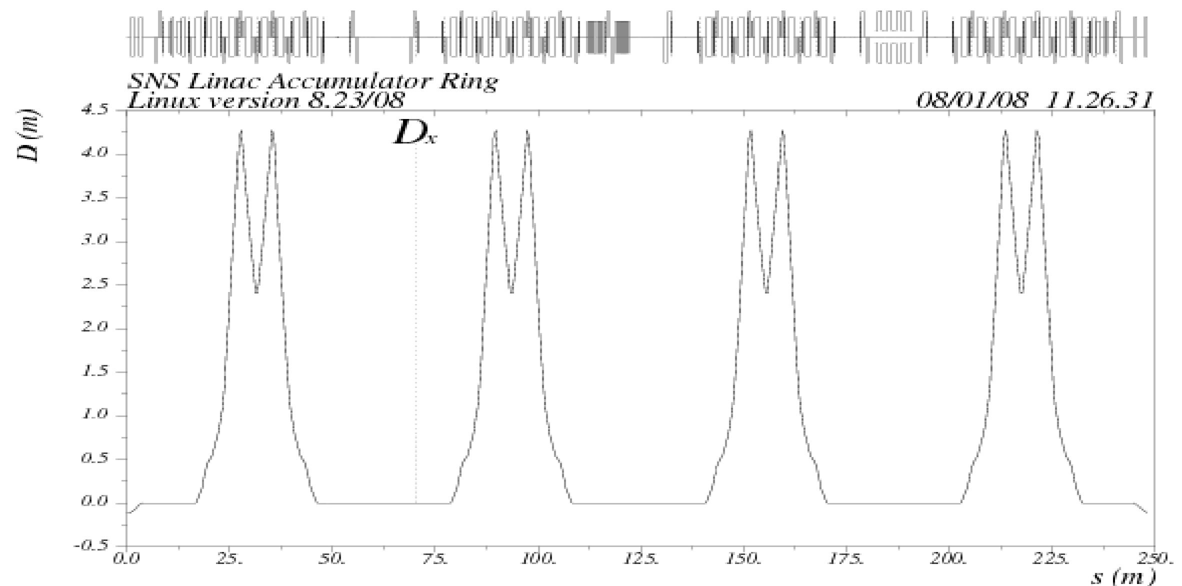
Outline

1) Brief description of ring lattice design.
2) Measurement of fundamental lattice parameters and test of linearity.
3) Identification and correction of cross-plane coupling in ring.
4) First ORBIT benchmarks of ring beam distributions.
5) Ring collimation studies.

Ring Lattice Design and Working Point

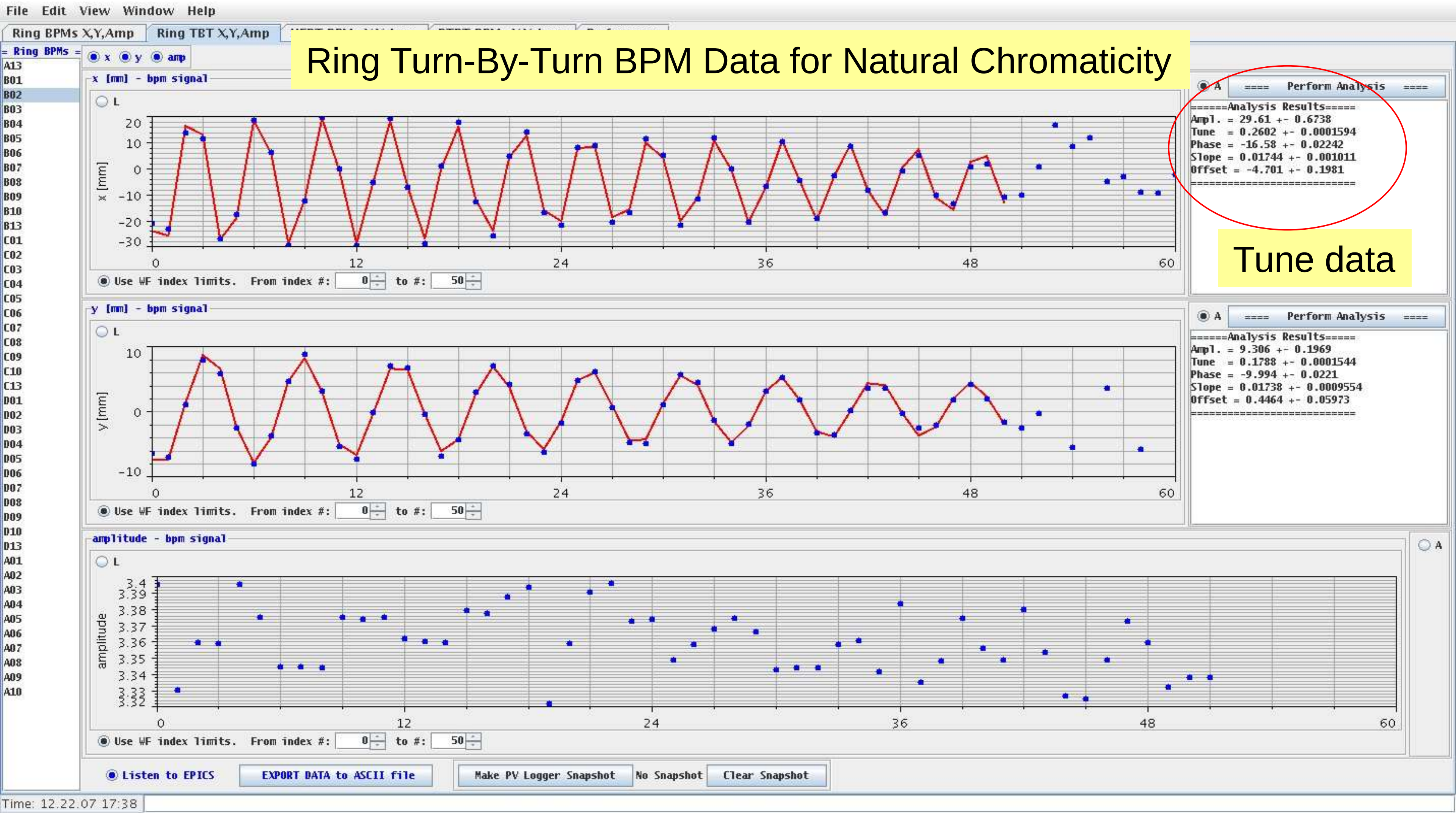
- Lattice is a 4-fold symmetric achromat.
- 6 Quadrupole power supply families (4 in arc, 2 in straight)
- Nominal working tune is (6.23, 6.20).
- Natural chromaticity is -7, -9.
- 4 sextupole families are available for chromaticity correction.





Measurement of Lattice Tune

- We routinely measure the tune using a single shot of turn-by-turn minipulse BPM data.
- Recently we have been working at tune (6.27, 6.19).



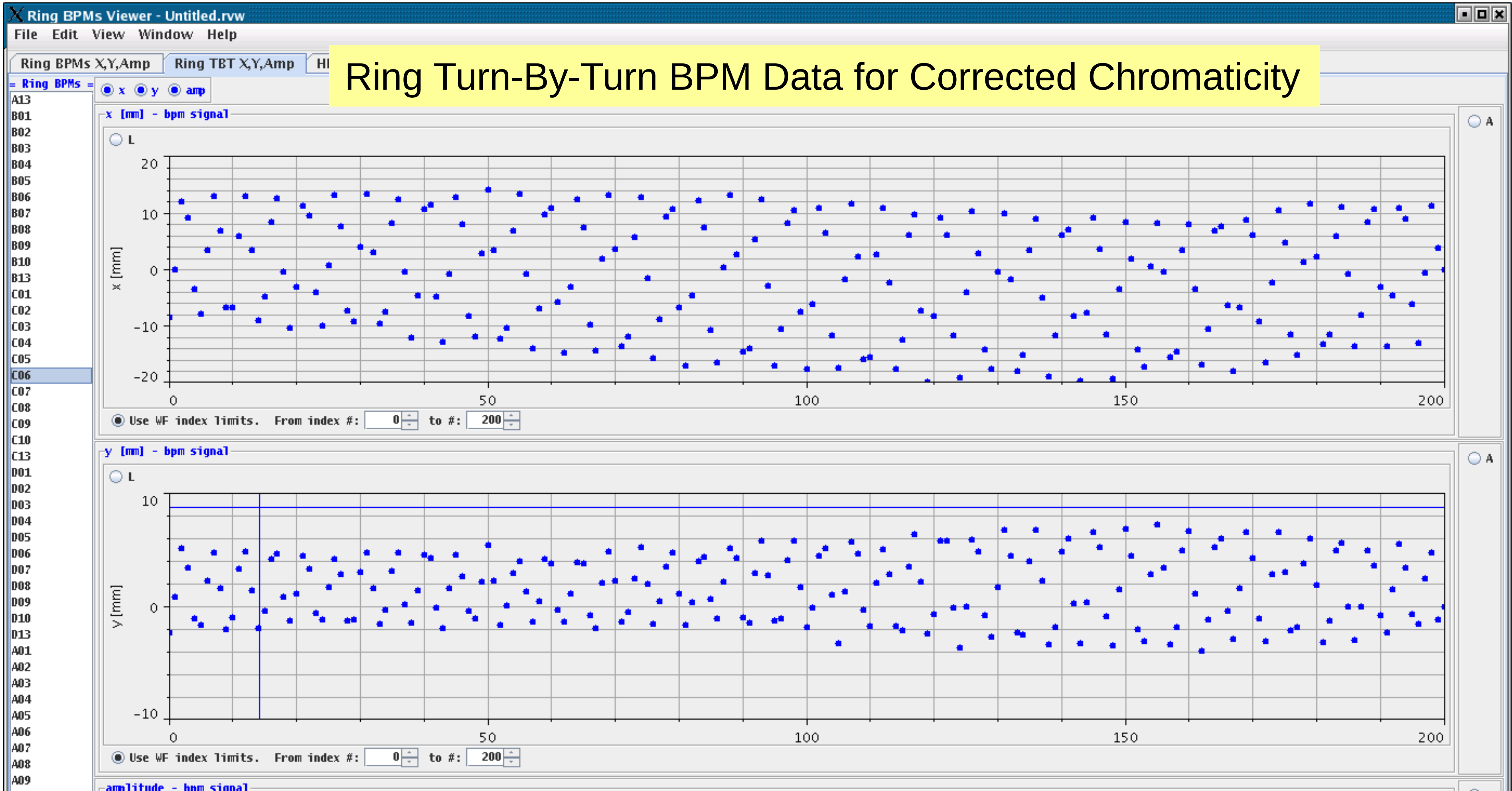
Measurement of Lattice Tune

We have measured both natural and corrected lattice chromaticity using:

$$\xi = \Delta\nu \, p_o/dp \, .$$

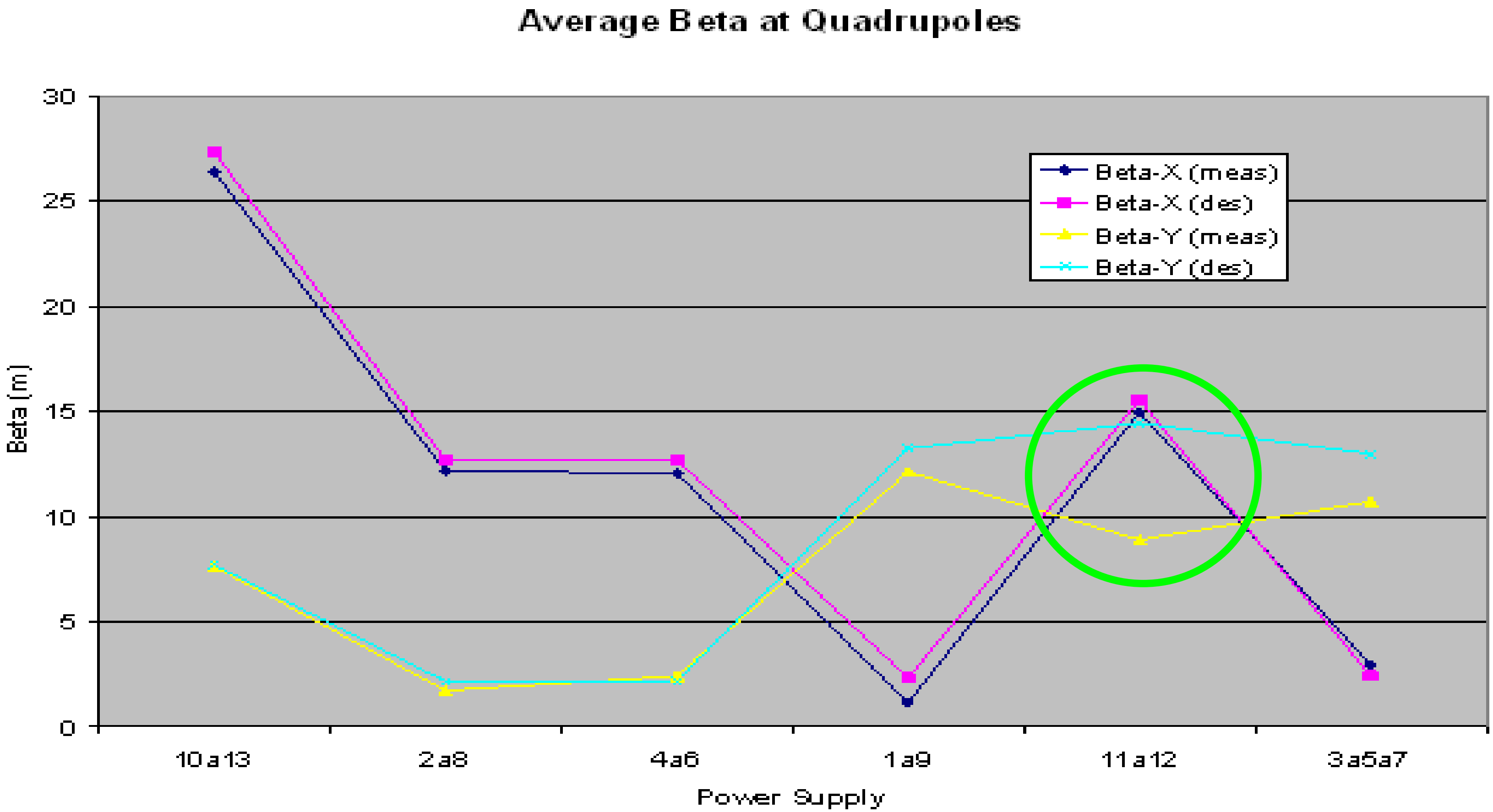
Natural chromaticity (Feb 01, 2006): $\xi x = -8$, $\xi y = -7$

Corrected chromaticity (Feb 12, 2006): $\xi x = -0.7$, $\xi y = -0.25$



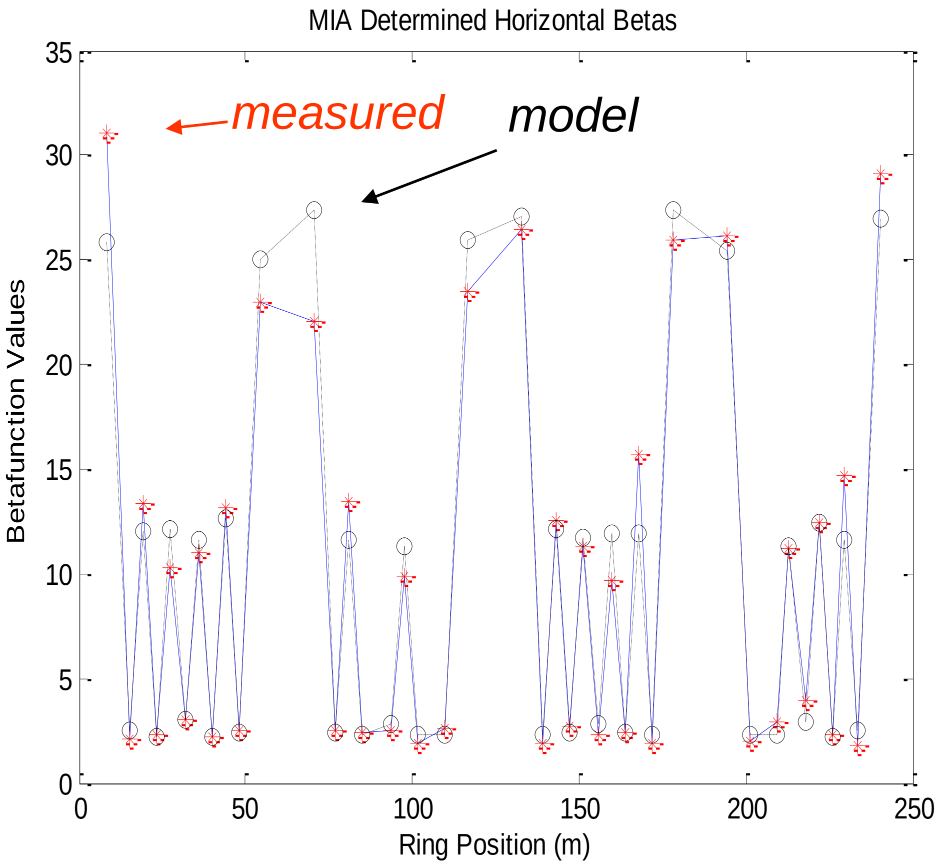
Lattice β Function Measurements – Tune Method

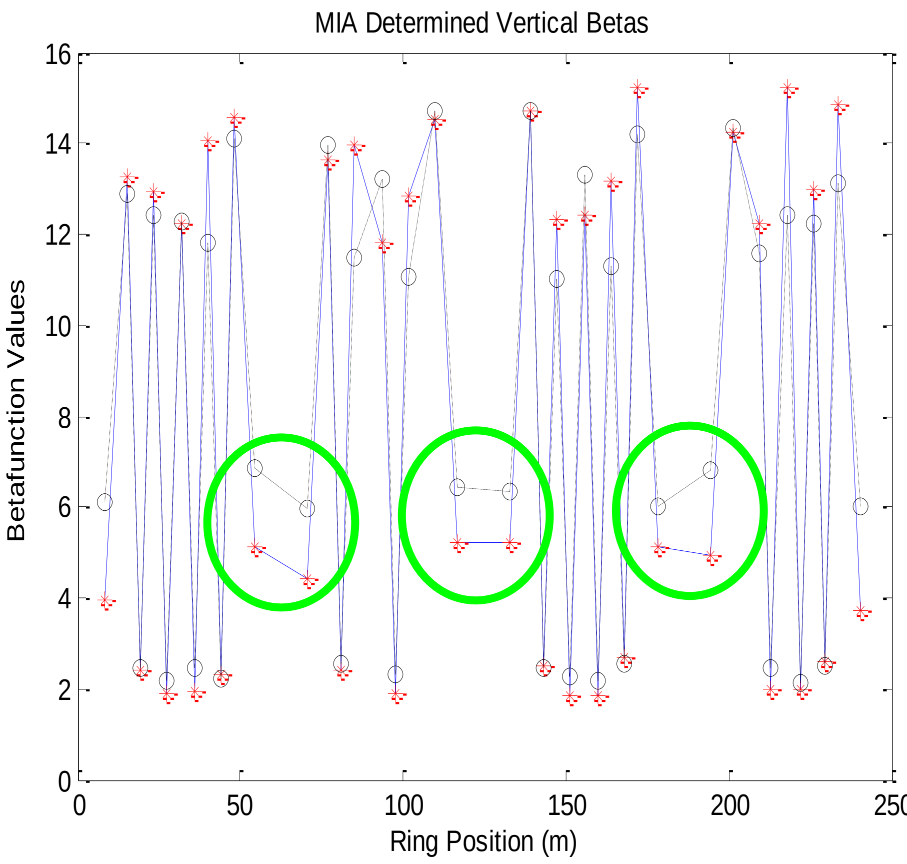
- Measured average β for each of the 6 power supply families by changing quadrupole strengths and measuring tune.
- Good agreement between measured/design was obtained, except for the straight section vertical quadrupole family.
- This has not yet been corrected. Orbit response matrix analysis is ongoing.



Lattice β Measurements – Model Independent Analysis

- Chromaticity-corrected BPM turn-by-turn data was used.
- Model Indepentent Analysis method determines β functions up to a constant scale factor.
- Again, largest discrepancies are in vertical plane in straight sections.

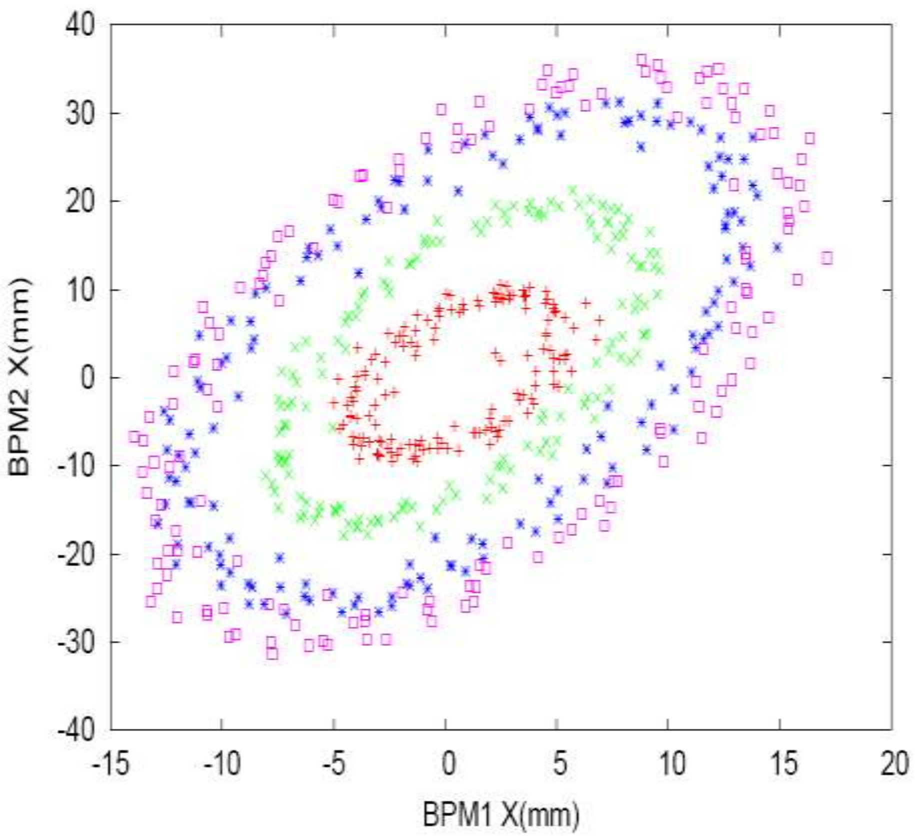




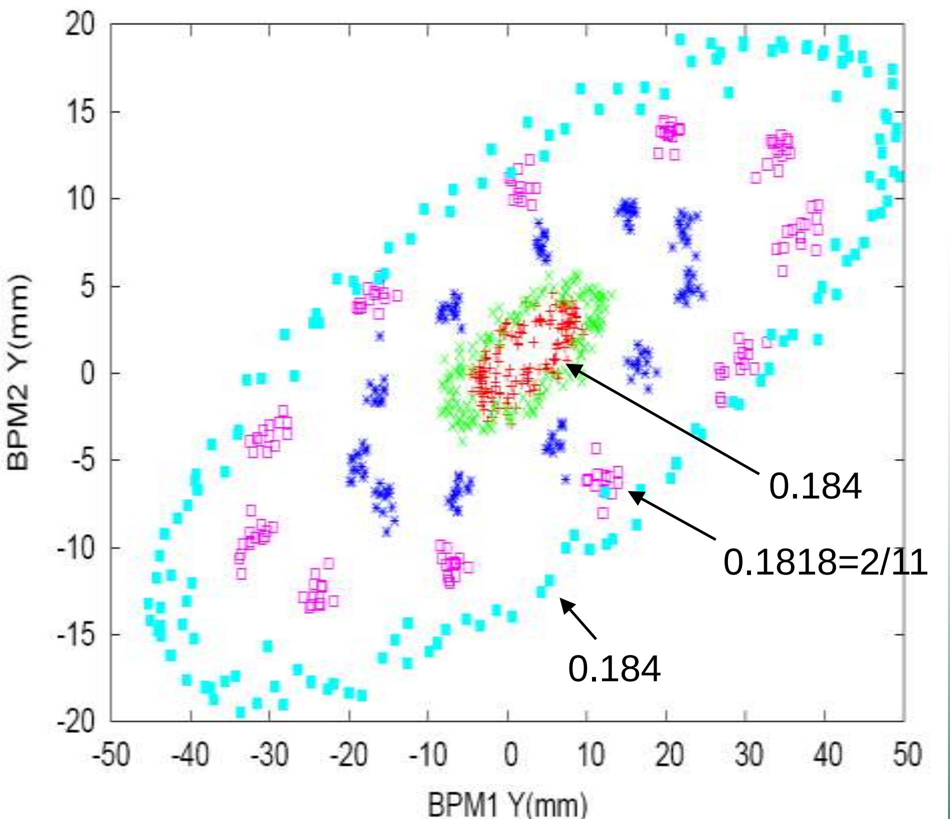
Lattice Linearity Verification

• "Poor Man's" phase space plots created from BPM turn-by-turn minipulse data.
• Minipulse amplitude is varied from a minimum to the edge of the aperture using the injection kickers.
All the way to the edge of the aperture, the lattice appears linear.

Horizontal

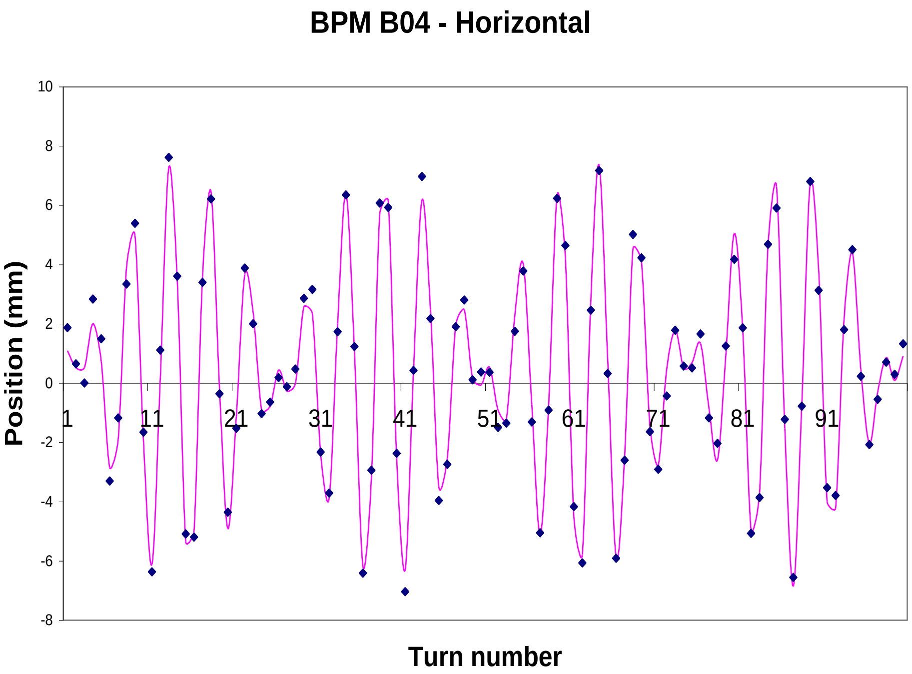


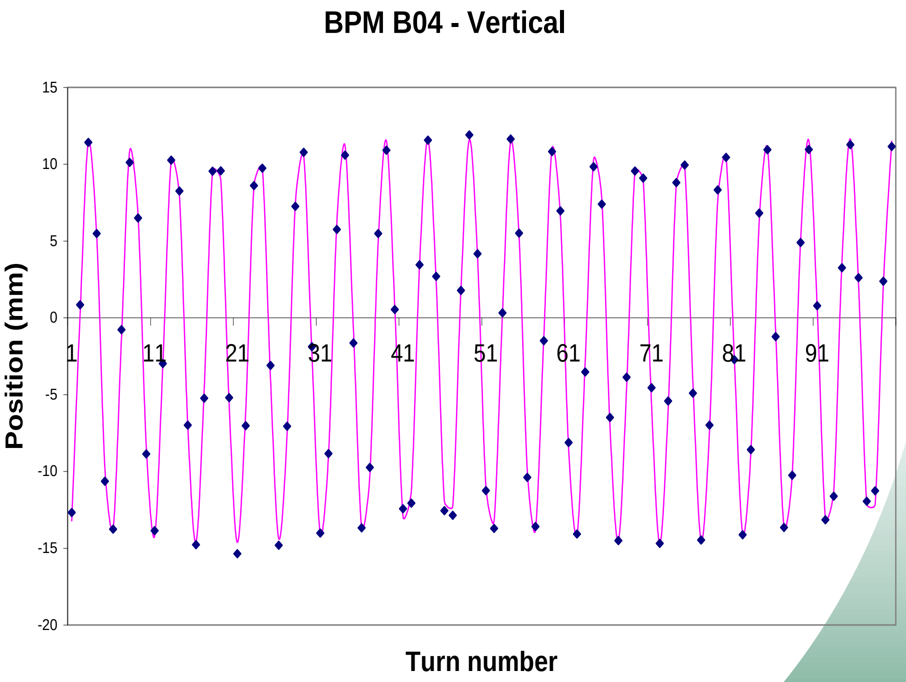
Vertical



Measurement of Transverse Coupling

- **We measure transverse coupling by injecting a single minipulse with a large vertical offset and small horizontal offset relative to the closed orbit.**





Correction of Ring Transverse Coupling

- **Following formalism of D. Sagan & D. Rubin (e.g. PRSTAB 074001 (1999))**

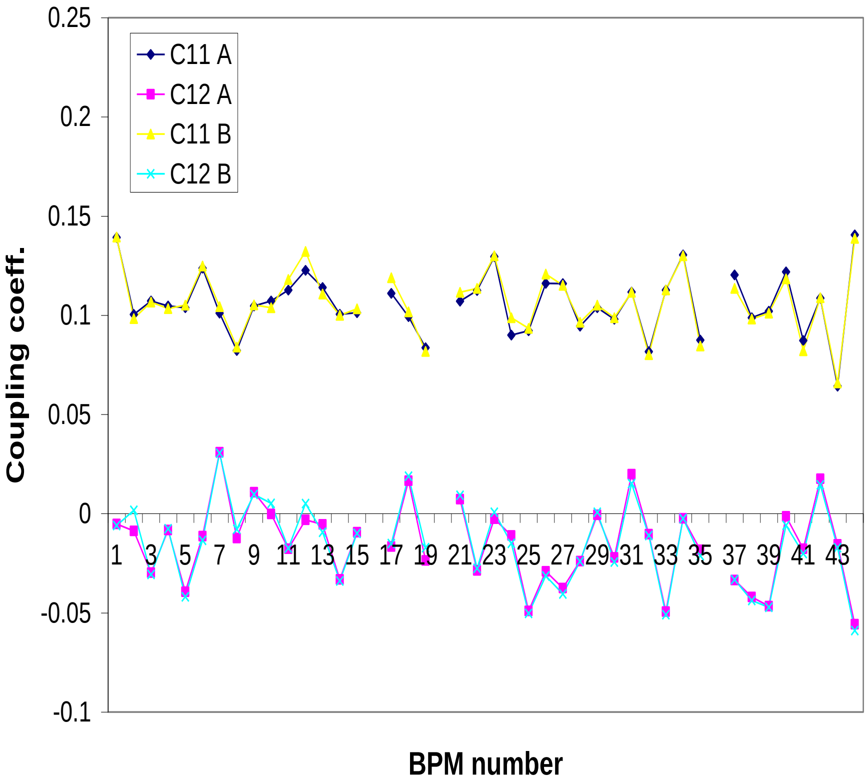
$$\begin{pmatrix} x \\ y \end{pmatrix} = \begin{pmatrix} A_x\sqrt{\beta_x}\cos\psi_x + A_y\sqrt{\beta_x}(\overline{C_{11}}\cos\psi_y - \overline{C_{12}}\sin\psi_y) \\ -A_x\sqrt{\beta_y}(\overline{C_{22}}\cos\psi_x + \overline{C_{12}}\sin\psi_x) + A_y\sqrt{\beta_y}\cos\psi_y \end{pmatrix}$$

$\psi = n\omega + \phi$

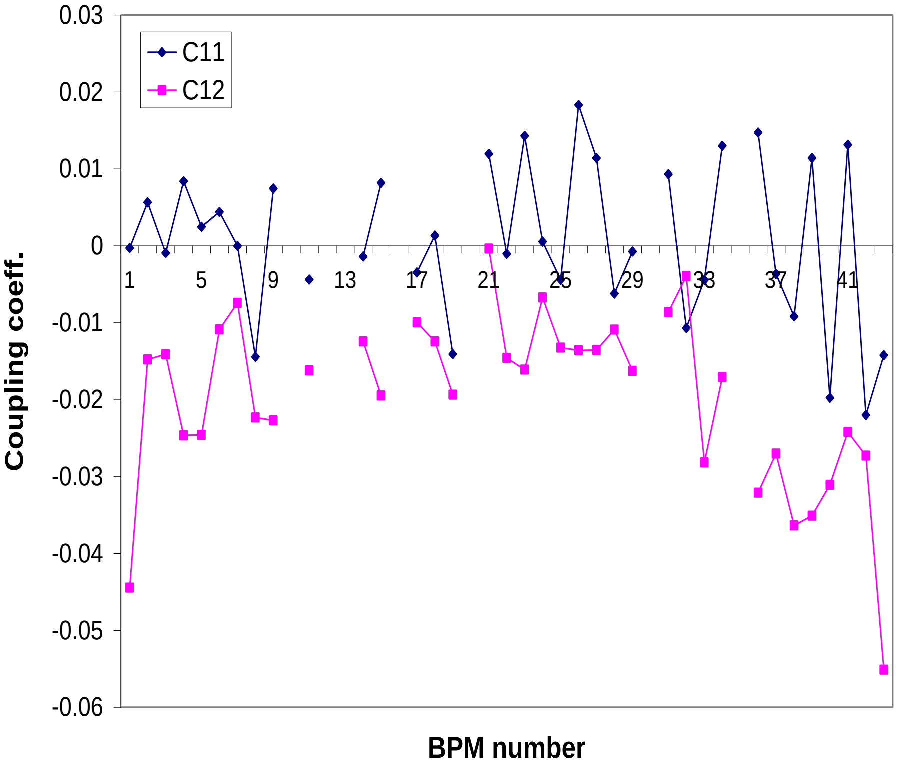
C_{11} = amount of in-phase oscillations coupled in from the vertical plane. $|C_{11}| \leq 1$.

C_{12} = amount of out-of-phase oscillations coupled in from the vertical plane. $|C_{12}| \leq 1$.

Results of Coupling Correction



Before correction

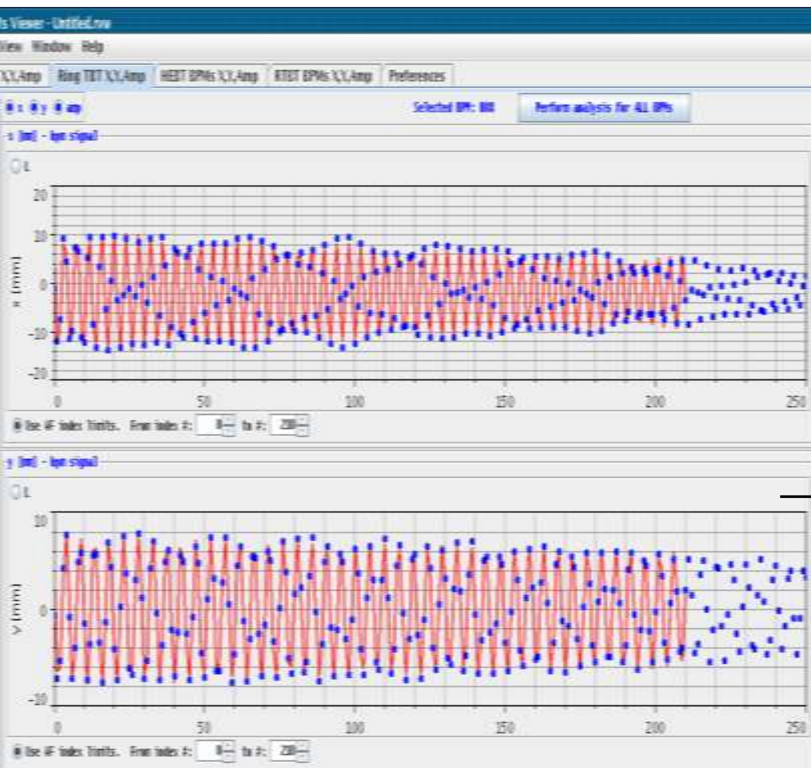


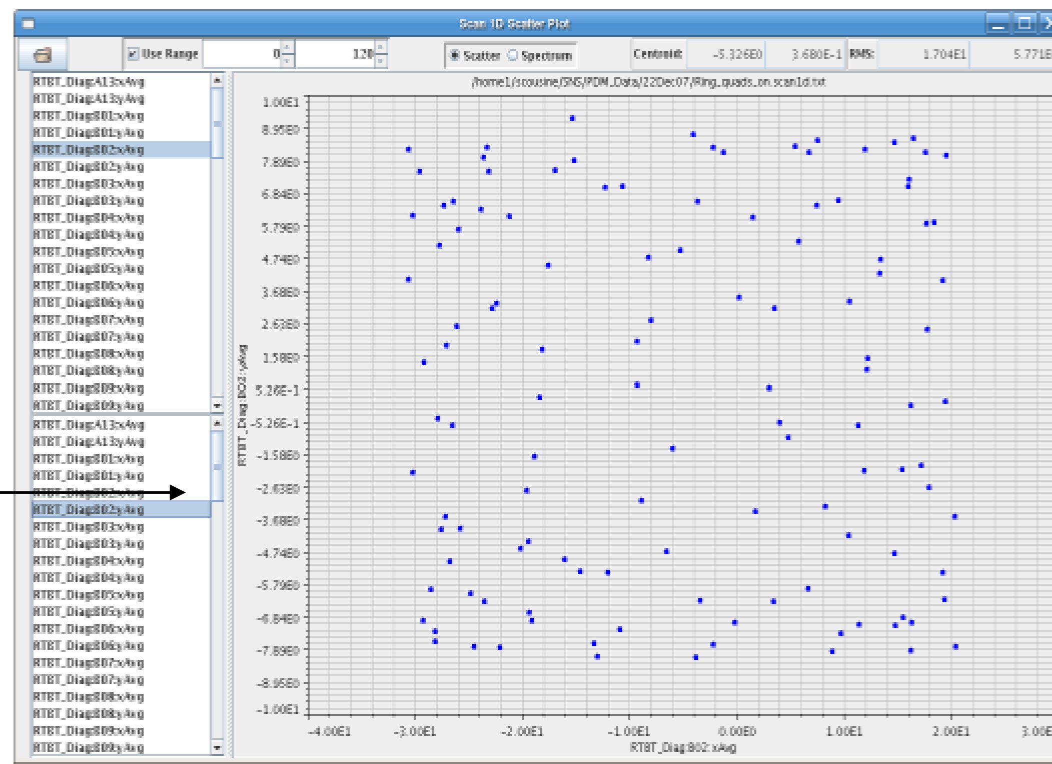
After correction
(6 vert. skew quadrupole correctors set to 4.7 A)

Residual coupling is not a problem at this time

BPM Method for Measuring Real Space Distributions

- For low intensities, in the absence of injection painting and decoherence, each minipulse in a distribution follows an identical phase space path.
- We can measure a beam distribution “all at once”, as with wire scanners or harp, or we can measure each piece separately with the BPMs and aggregate them at the end.
- In the ring, we only need 1 turn-by-turn snapshot. In the RTBT, we vary the storage time.





ORBIT Review and Status

ORBIT is a particle tracking parallel code for simulating rings and transport lines.
ORBIT has a broad range of simulation models…

- Real injection painting and distributions
- Linear and nonlinear symplectic tracking
- Transverse and longitudinal space charge – several models
- Transverse and longitudinal impedance
- Collimation and apertures
- Magnet errors
- 3D Field maps
- e-p simulations and feedback (talk by Danilov)

ORBIT was used heavily in the design of the SNS ring.
Several successful ORBIT benchmark have been conducted for other machines (PSR, CERN PSB).
We are starting to use ORBIT for SNS. Benchmarks are underway – e-p, collimation, beam distributions…

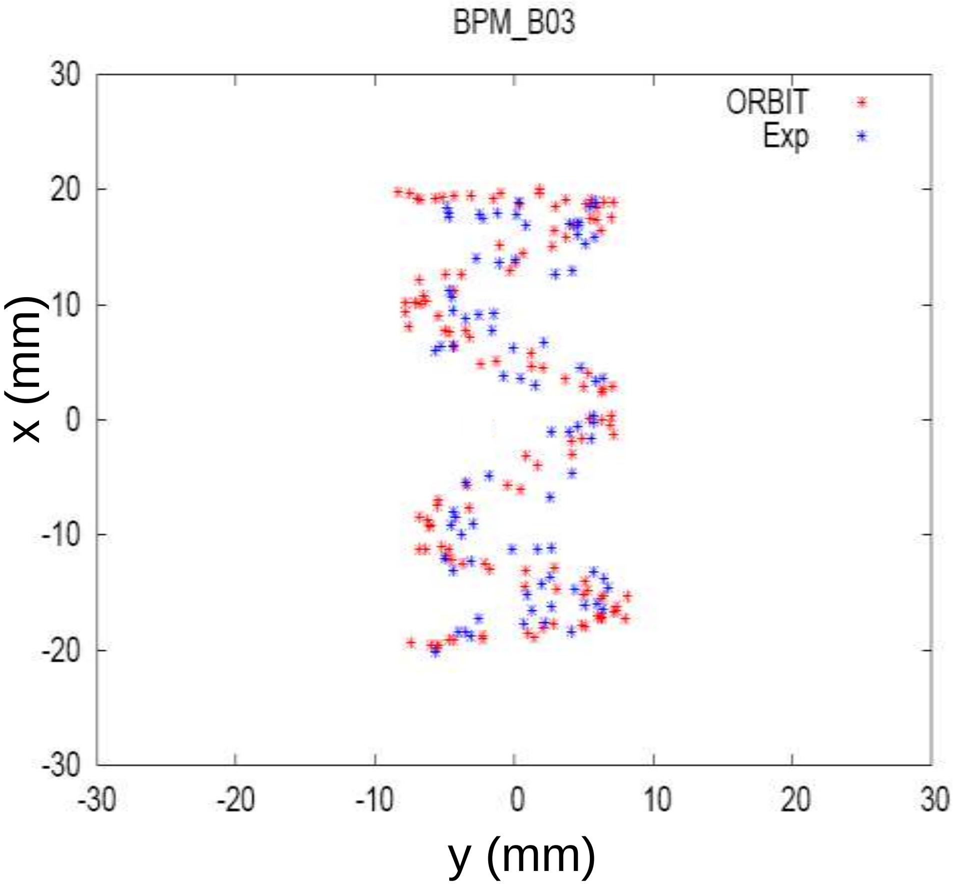
ORBIT Future:

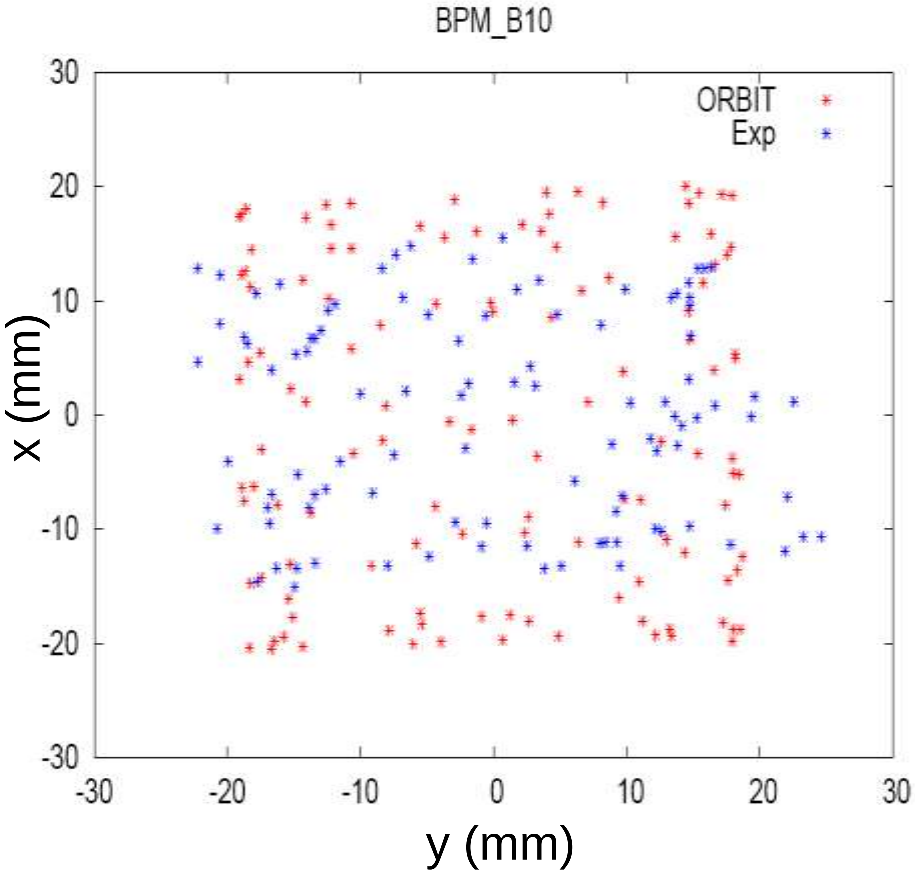
Work is underway to translate ORBIT into python language, and invoke an even more object-oriented approach.

First ORBIT Benchmarks in the Ring

- Experimental tune, injection were used. Nonlinear tracking (no chicane mults).
- To simulate experiment, we injected one mean-energy particle per turn.
- “Snake” structure seen in experiment and simulation likely due to tunes.

Benchmark Results

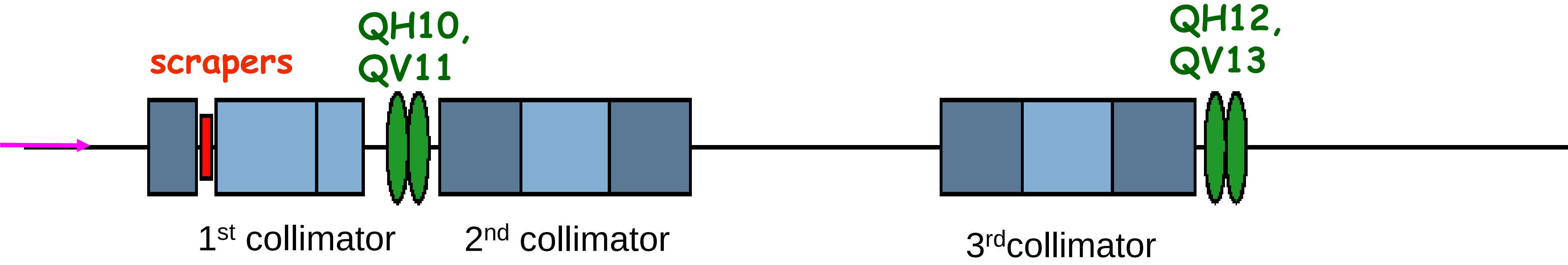


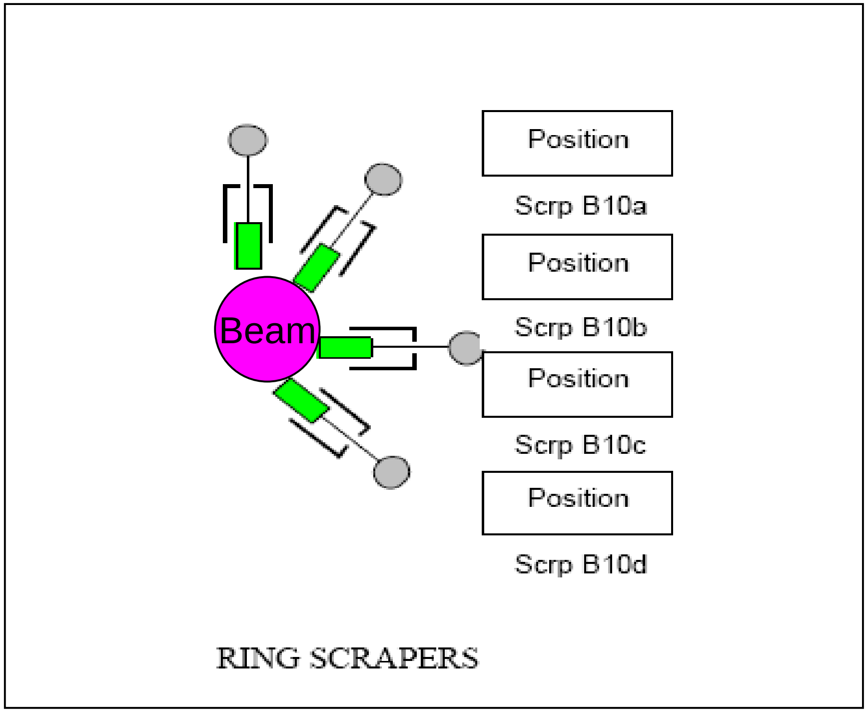


At some BPMs the agreement is great!

And at others it is not so great…

Ring Collimation Design





The ring collimators can take up to 2 kW of routine beam power, or two full 2 MW pulses.

The ring collimation system is a two-stage system with 4 scrapers and 3 large collimators.

The scrapers are used to project the beam into high emittance for high efficiency absorption in downstream collimator.

General Collimation Observations

1. The collimators perform as the limiting aperture in the machine.

2. Beam loss due to collimation inefficiency is localized to the collimation straight section and the beginning of the downstream arc.

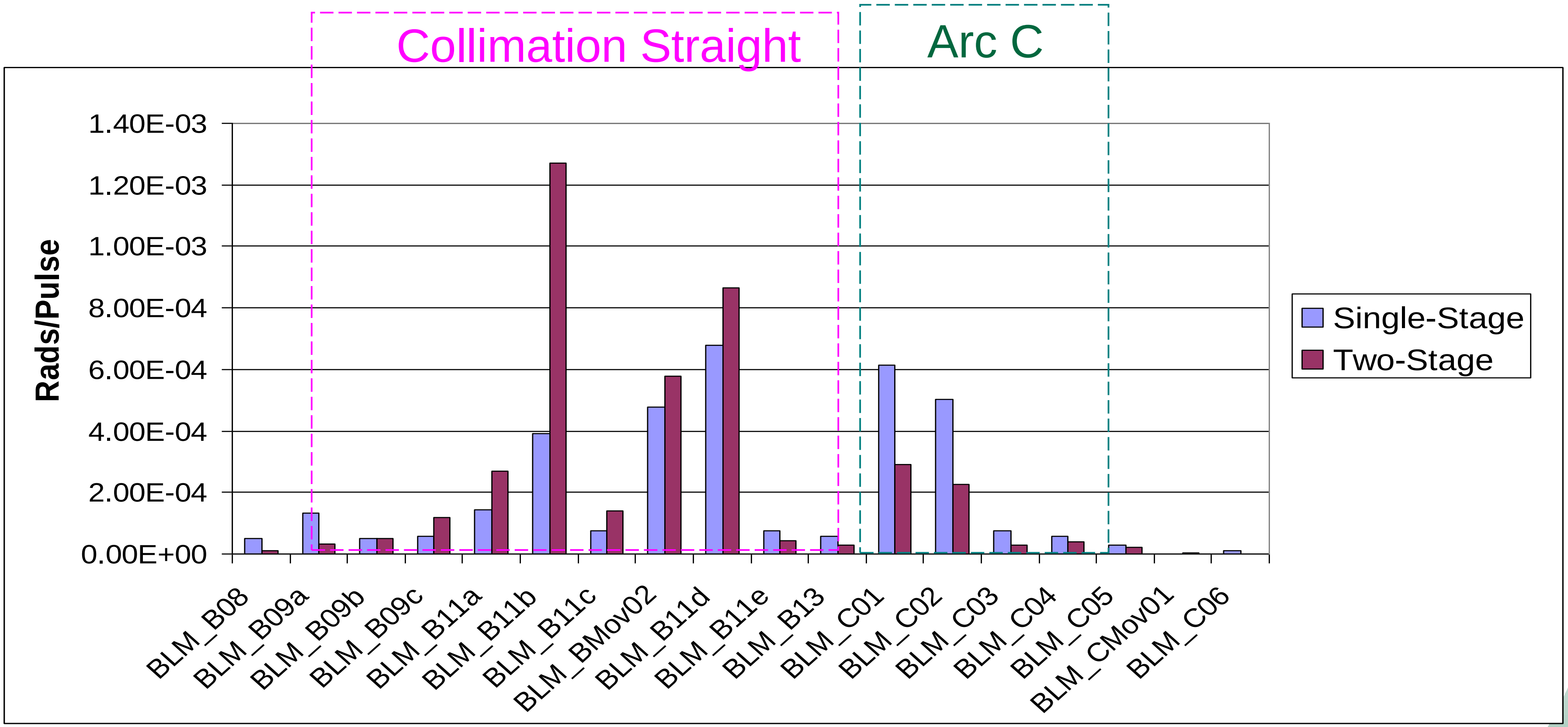
3. Areas where beam loss is higher than anticipated are:
   a) The quadrupole doublet between the primary and secondary collimators
   b) The first quadrupole and dipole in the downstream arc. This is likely due to single stage collimation inefficiency

4. ORBIT collimation benchmarks are in reasonable agreement, to within the conversion accuracy of BLM signals to Joules of beam loss (Cousineau, PAC2007).

Collimation

Collimators have been exercised in dedicated experiments (Cousineau, PAC2007).

Example experiment: Single-stage versus two-stage collimation:



Observations:
Single stage collimation (no scraping) leads to worse absorption efficiency and to larger beam loss in the downstream arc.

Summary

- We have measured the lattice parameters and found reasonable agreement with the model.
- We have measured and fixed cross-plane coupling in the ring.
- We have begun ORBIT benchmarks of ring beam distributions at low intensity.
- We have begun to characterize the collimation system peformance.