Coupling Correction at the Australian Synchrotron

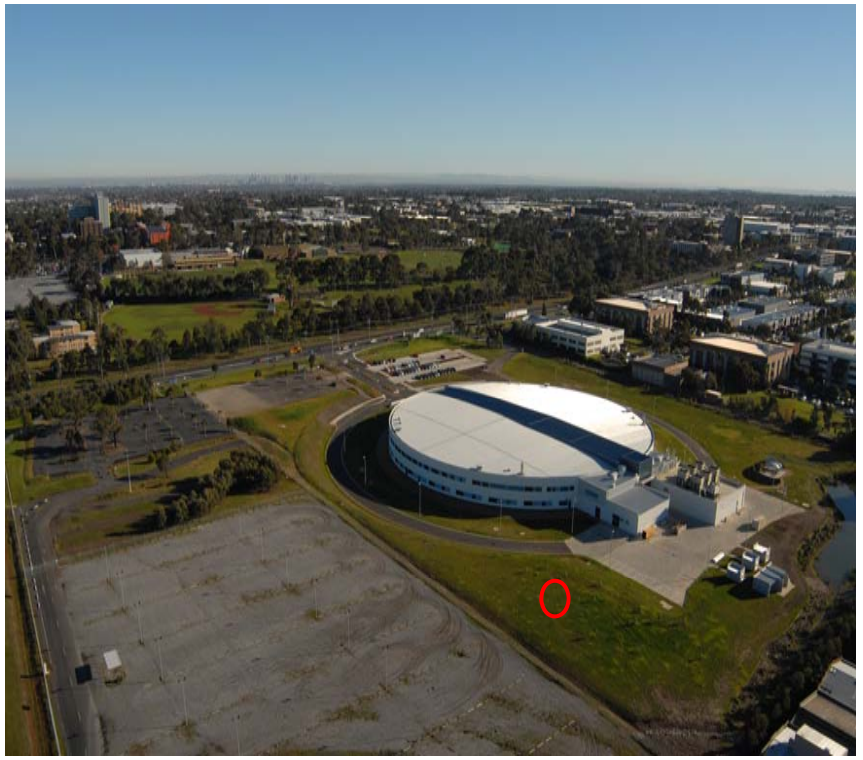
Rohan Dowd
Australian Synchrotron

Outline

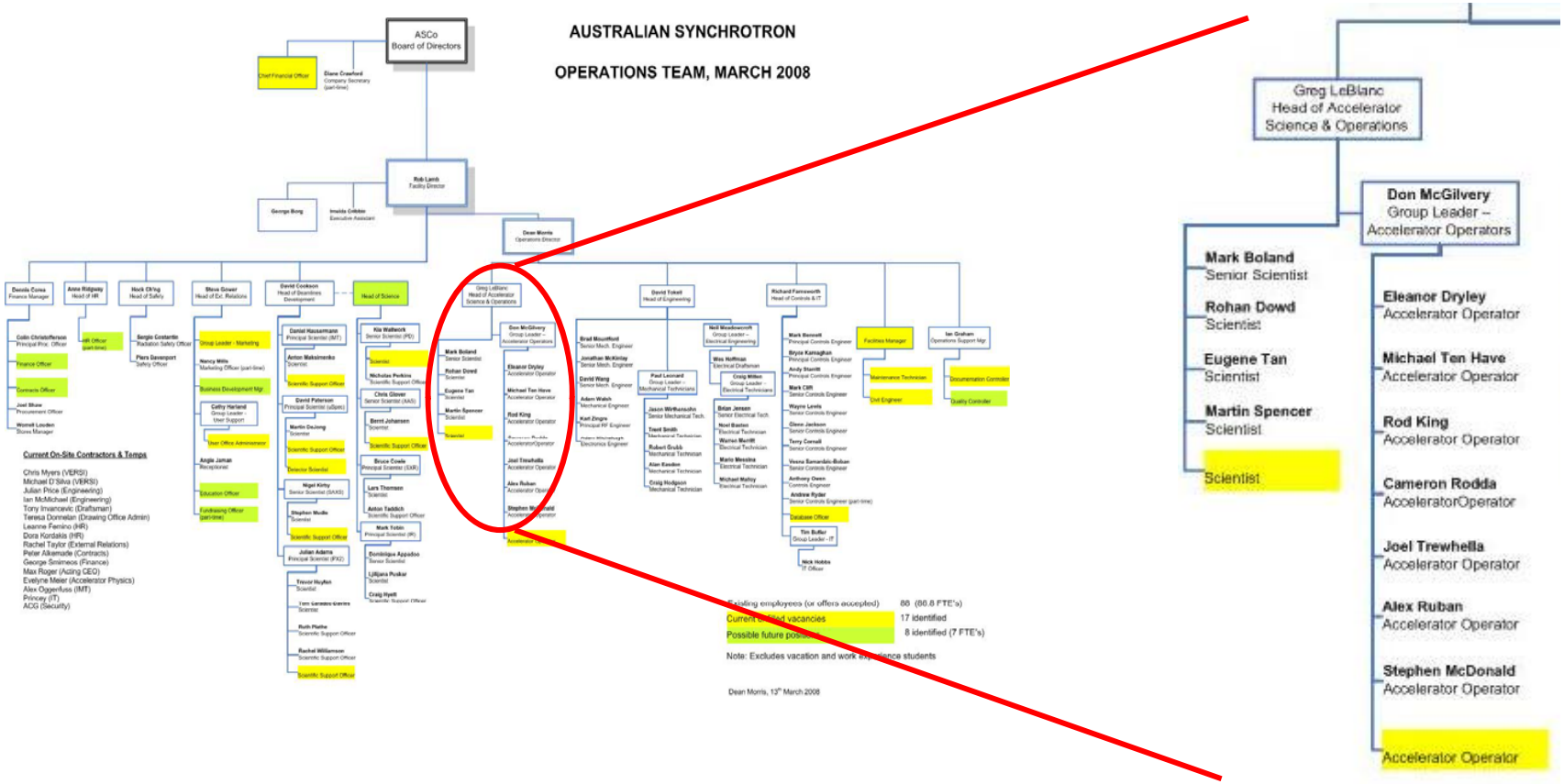
- Overview of AS Facility
- Storage ring Lattice and Optics
- LOCO Method at AS
- Optics Corrections with LOCO
- Coupling control and emittance tuning results with LOCO
- Planned improvements

Our Facility

- First Light Source Facility in Australia
- 3rd Generation Light source
- 3 GeV electron storage ring, with linac and booster synchrotron.
- Currently 9 beamlines
- Room for 30+ beamlines
- Construction started: Mid-2004,
- Injector commissioning: Early 2006.
- First Light: 14 July 2006.
- User Operations Started: April 2007



Organisation

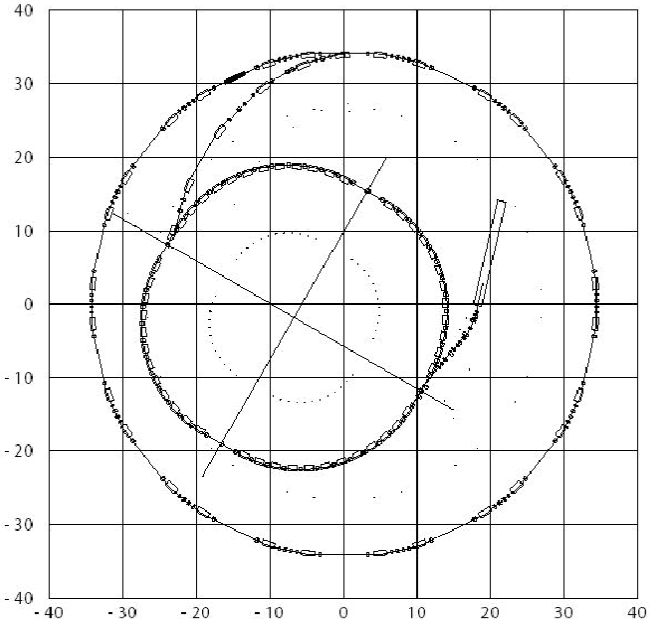


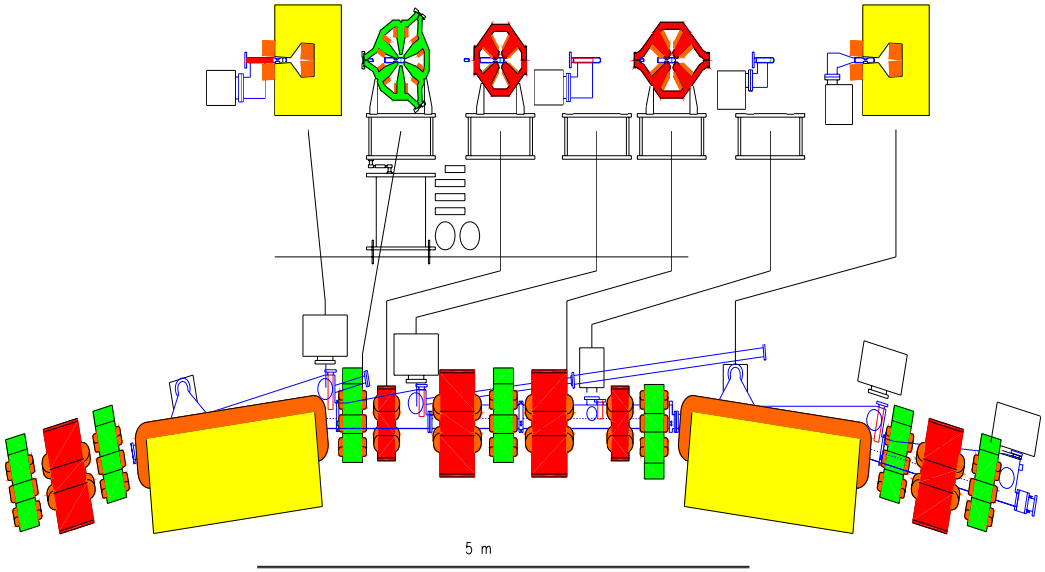
•Currently ~ 100 staff total

•Limited in-house development capability. Extensive use of contractors for large projects

Storage ring overview

- Double bend achromat
- 14 Unit cells
- Combined function dipoles
- Corrector and skew quad coils on sextupoles (SDAs).
- Horizontal emittance varied with dispersion.
- Individual magnet strength control

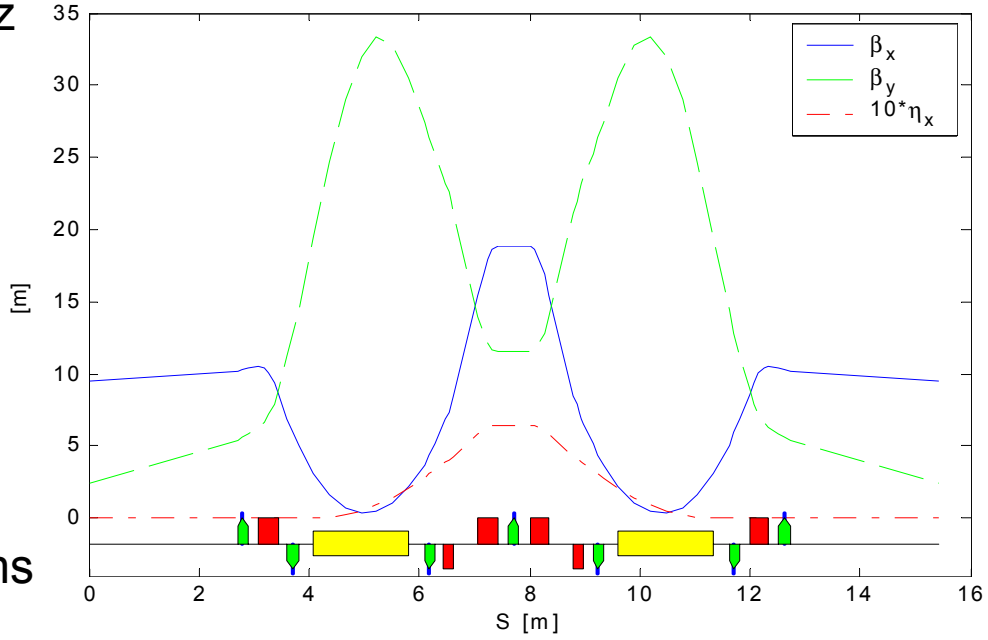




Lattice overview

Storage Ring Parameters

Energy	3 GeV
Circumference	216 m
RF Frequency	499.654 MHz
Harmonic Number	360
Peak RF Voltage	3.0 MV
Current	200 mA
Critical Photon Energy	7.8 keV
Betatron Tune (h/v)	13.3/5.2
Momentum Compaction	0.002
Natural Chromaticity (h/v)	-28/-27
Radiation Damping (h/v/l)	3.4/4.6/2.8 ms
Energy Spread	0.1 %
Radiation Loss Per Turn	932 keV
Horizontal Emittance	7-16 nm·rad



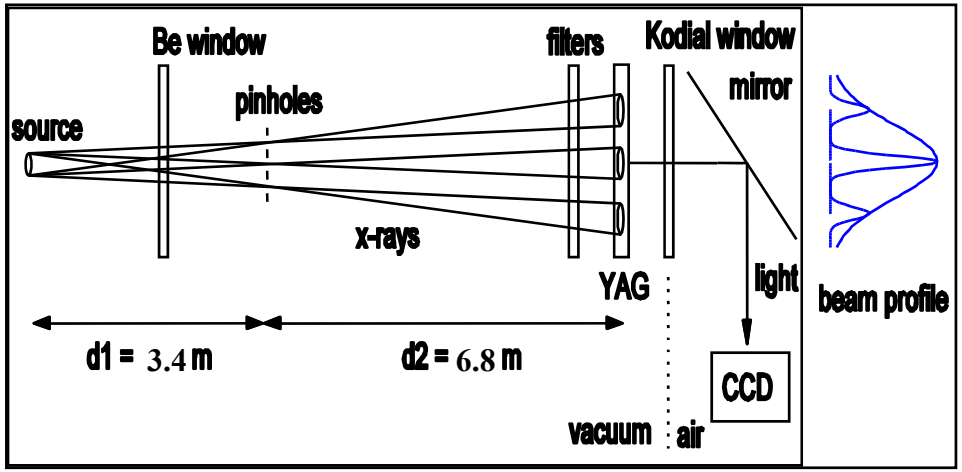
Beam Diagnostics

•X-ray and optical diagnostic beamlines

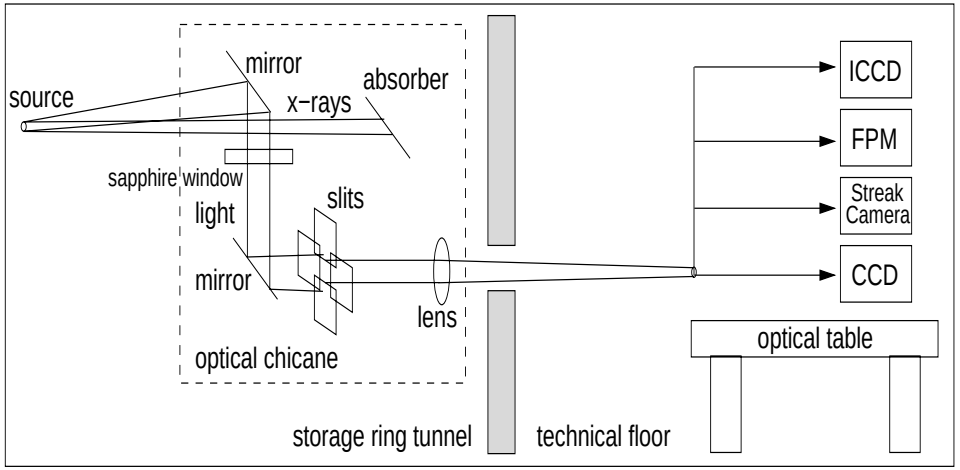
•X-ray pinhole used for emittance measurements, but has inherent resolution limits

•Diagnostic straight with, kickers, scrapers, striplines, DCCT.

•98 BPMs (micron resolution). Beam based alignment conducted regularly.



X-ray Diagnostic Beamline



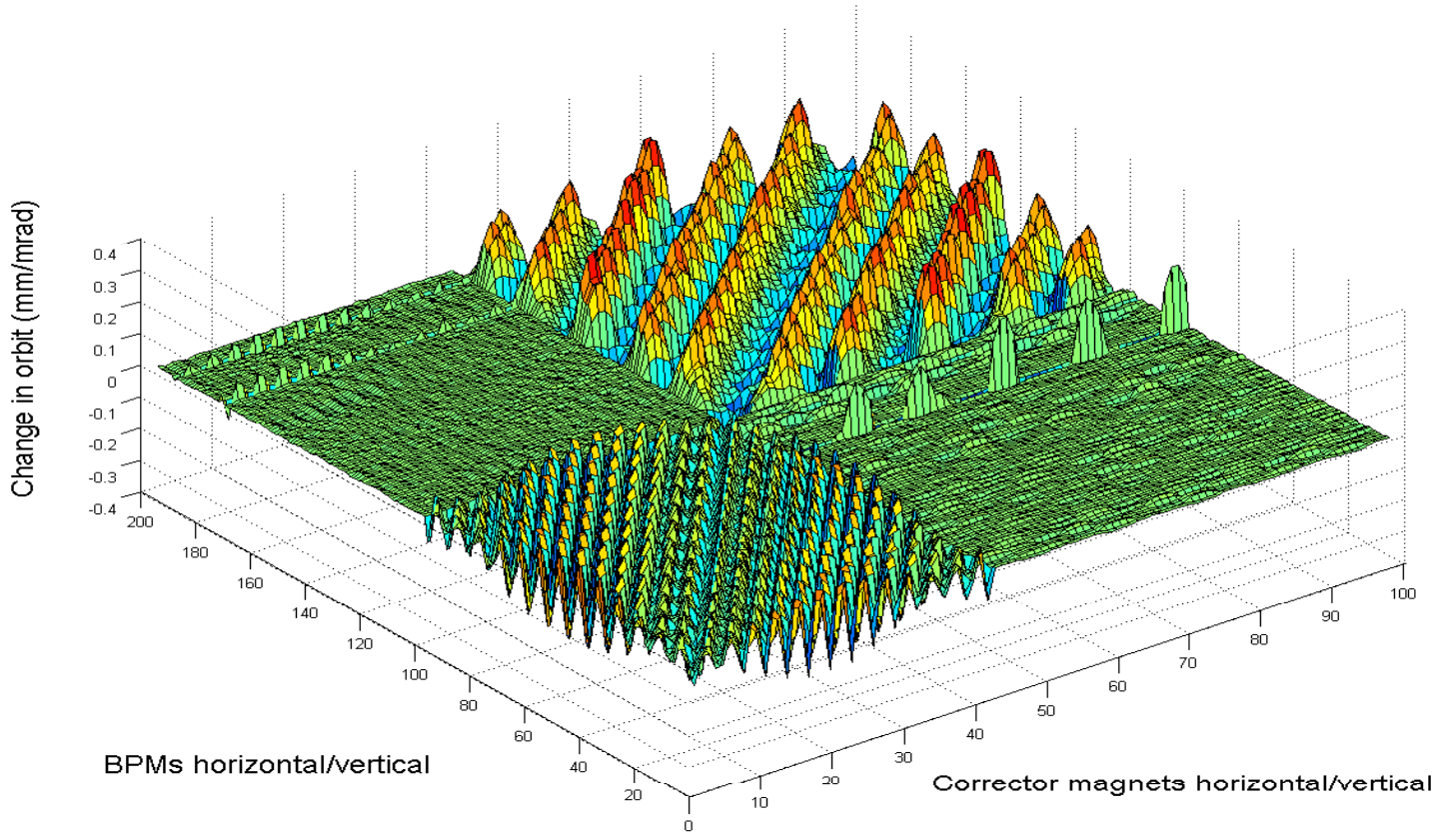
Optical Diagnostic Beamline

LOCO method

- LOCO – Linear Optics from Closed Orbits.
- Adjusts the linear optics (no sextupoles) in the model to fit the real machine data
- Model response matrix – Machine response matrix = Error
- Minimise by adjusting the model ‘fit parameters’

Response Matrix

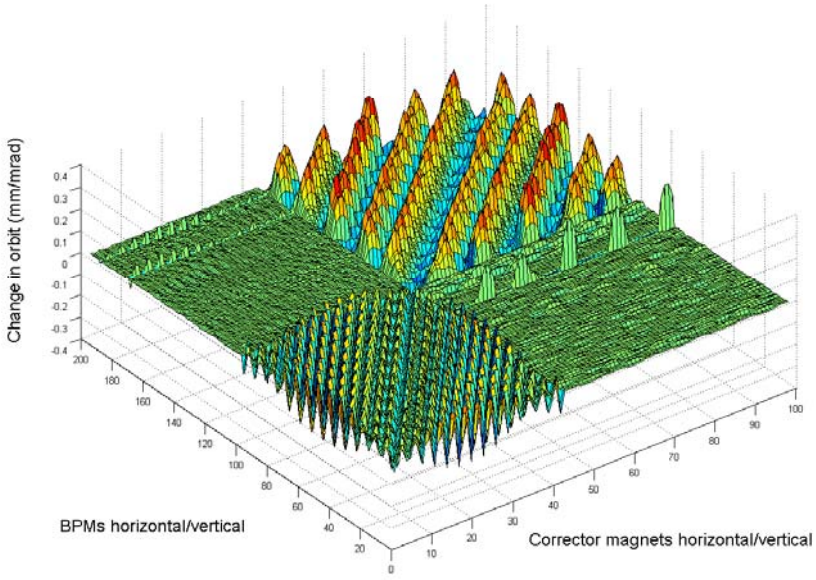
- Used for orbit and optics corrections
- Gives the orbit change at each BPM for a given kick at each corrector

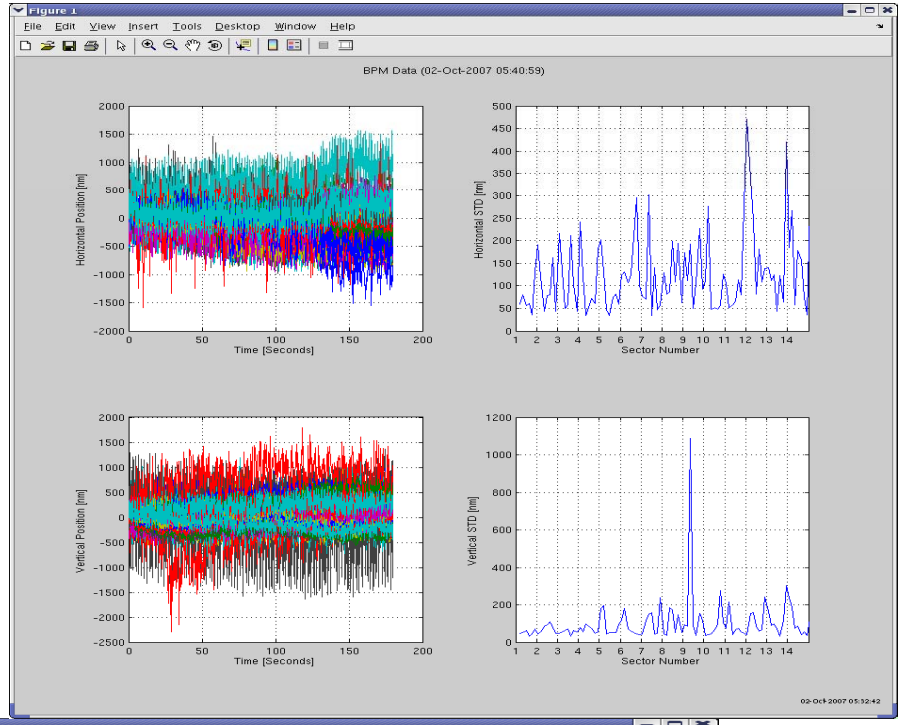


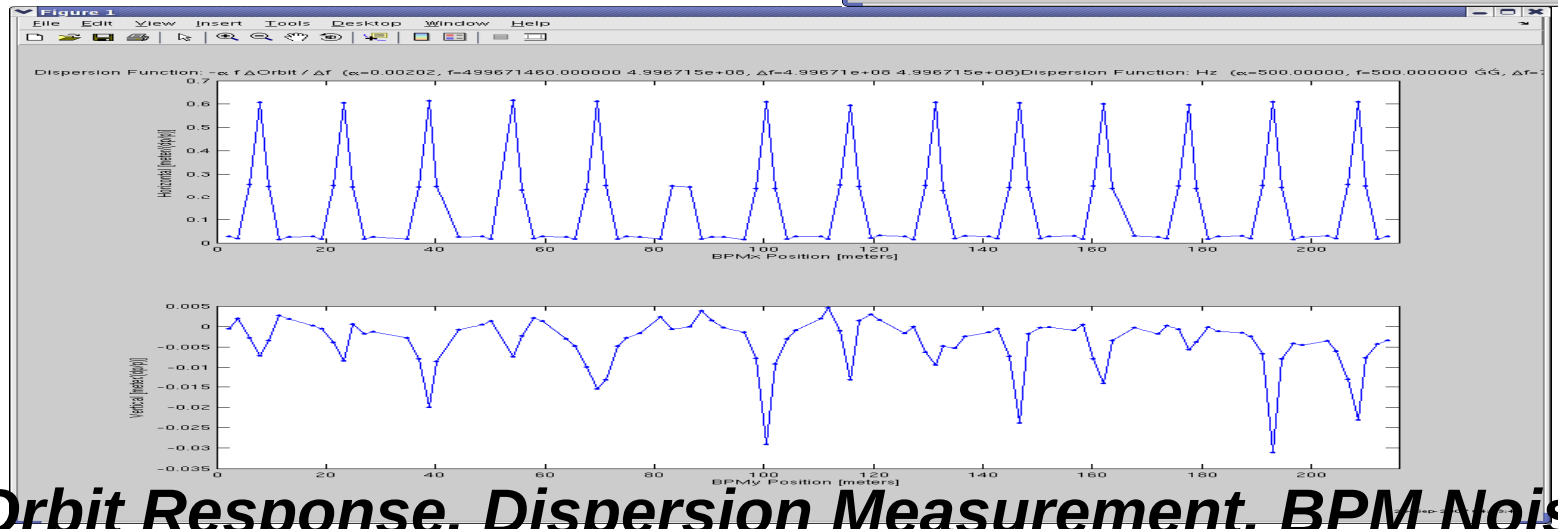
LOCO fit parameters

- Normally include
  - **BPM/Corrector gains and rolls**
  - **Quadrupole strengths**
  - **Skew Quadrupole strengths**
- Also can include:
  - Insertion device Kx/Ky
  - Dipole focusing
  - Misalignments x/y/z of any component
  - Rotations of any component.
  - Anything else you can think of…

LOCO inputs

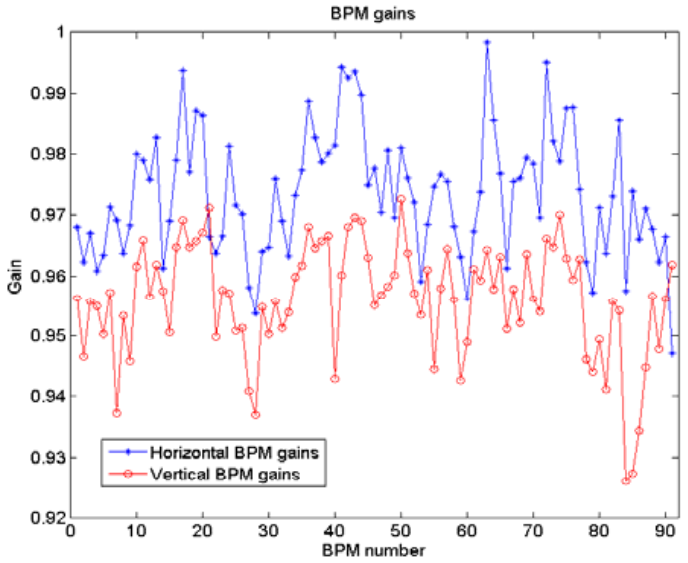


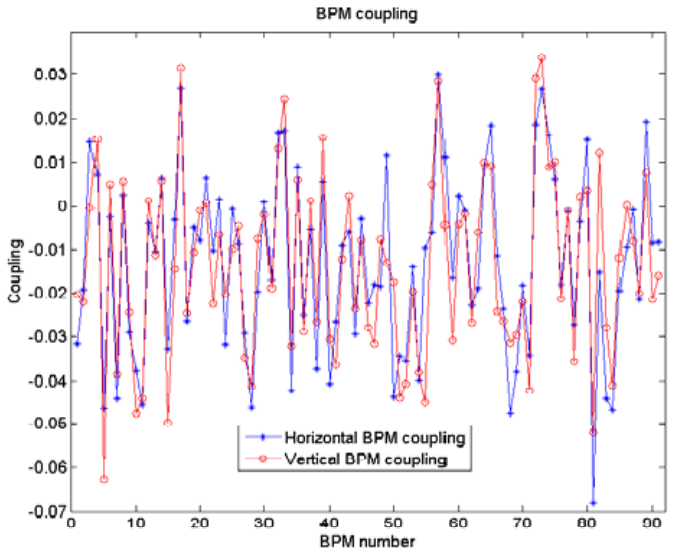


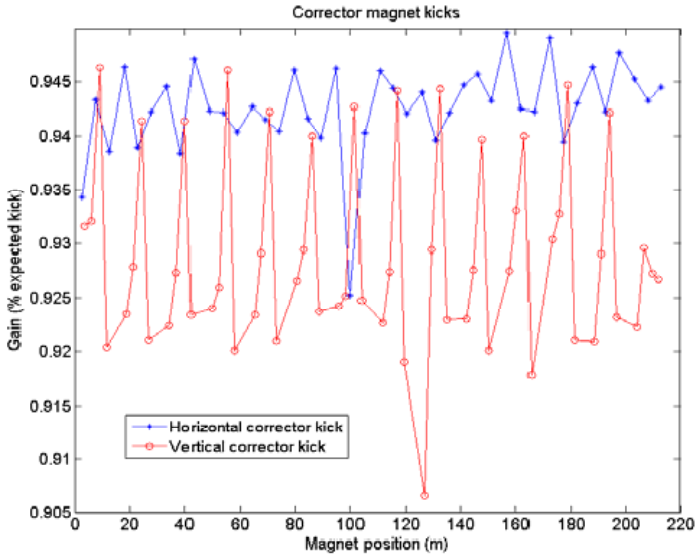


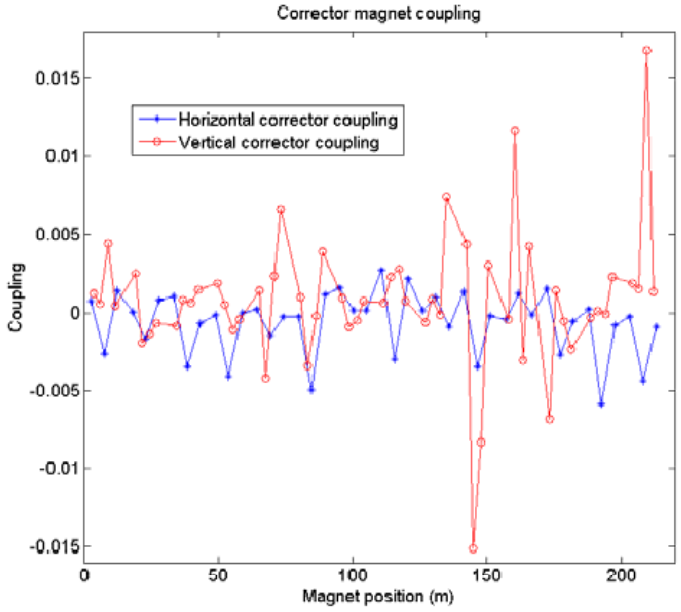
Orbit Response, Dispersion Measurement, BPM Noise

LOCO Outputs - gains and coupling





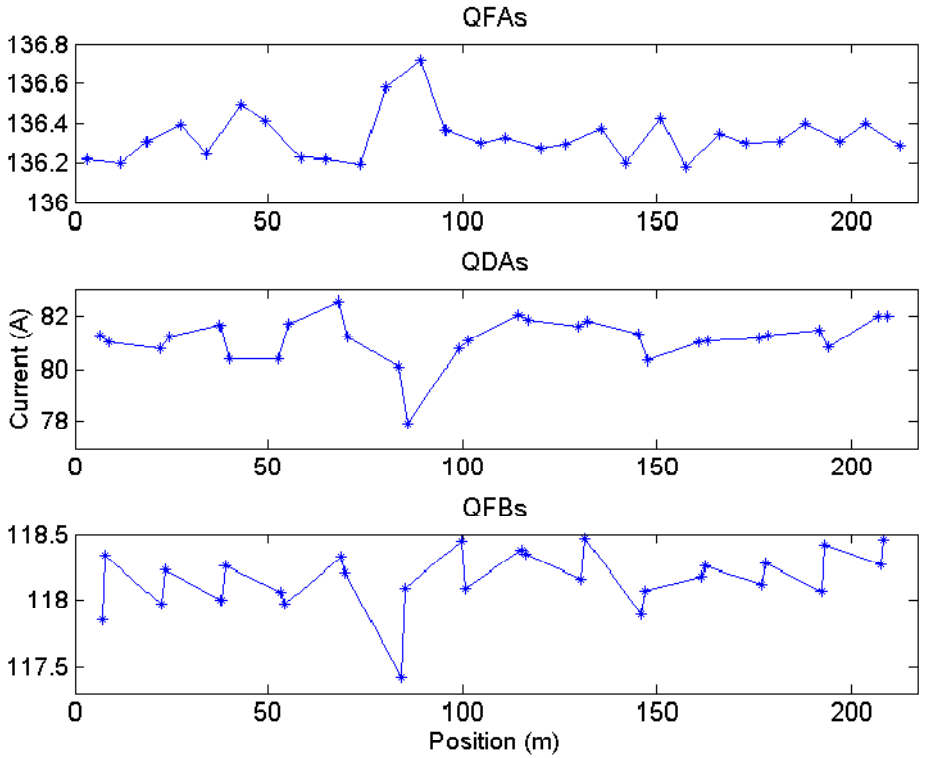




LOCO Outputs – Quadrupole Strengths

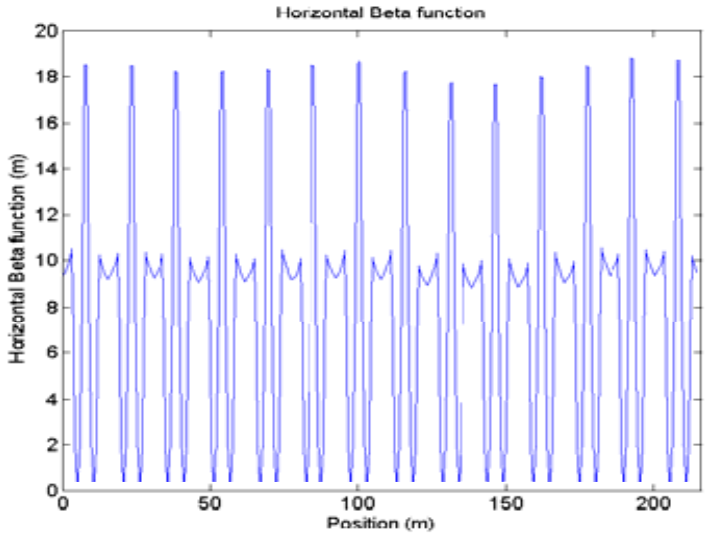
•Quadrupole strength changes used to fit the model to the machine can be inverted and then applied back to the machine in order to correct the machine for differences in quadrupole gains

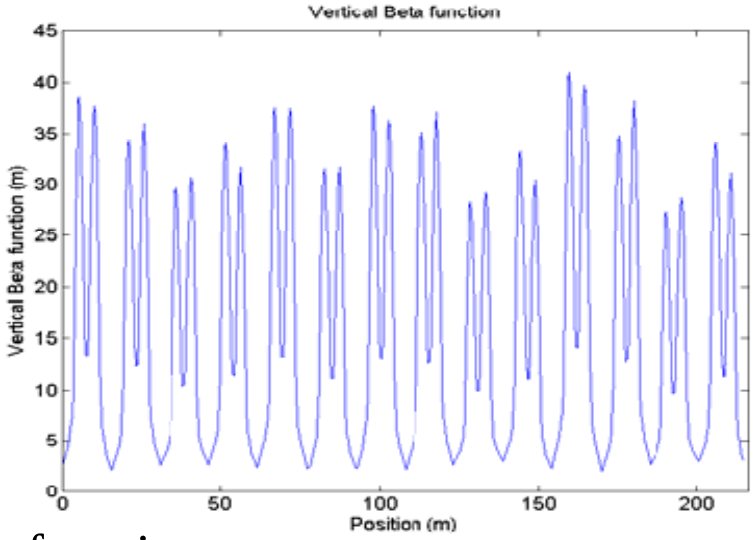
•This can smooth out the beta functions of the machine.



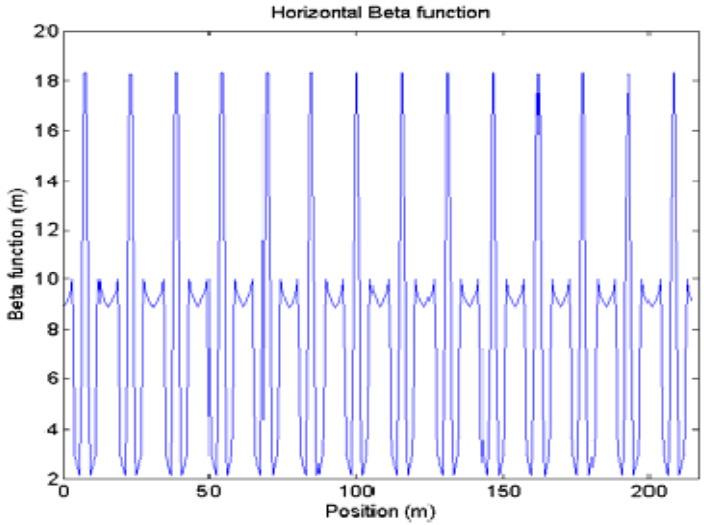
LOCO Optics Corrections – Quadrupole errors

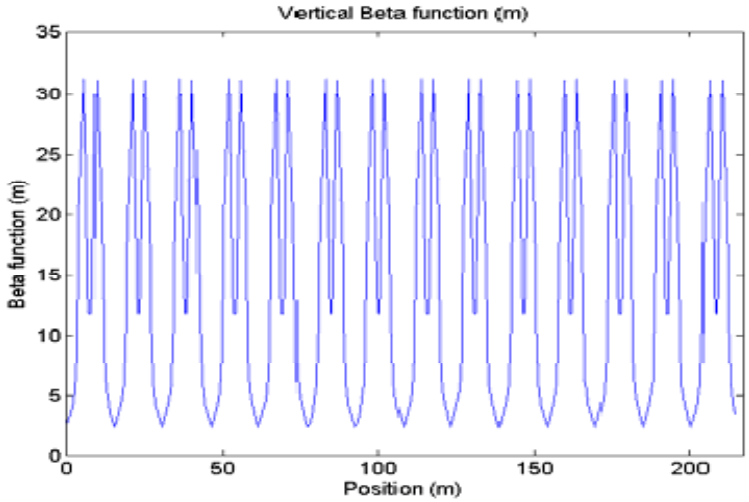
Uncorrected beta functions





Corrected beta functions

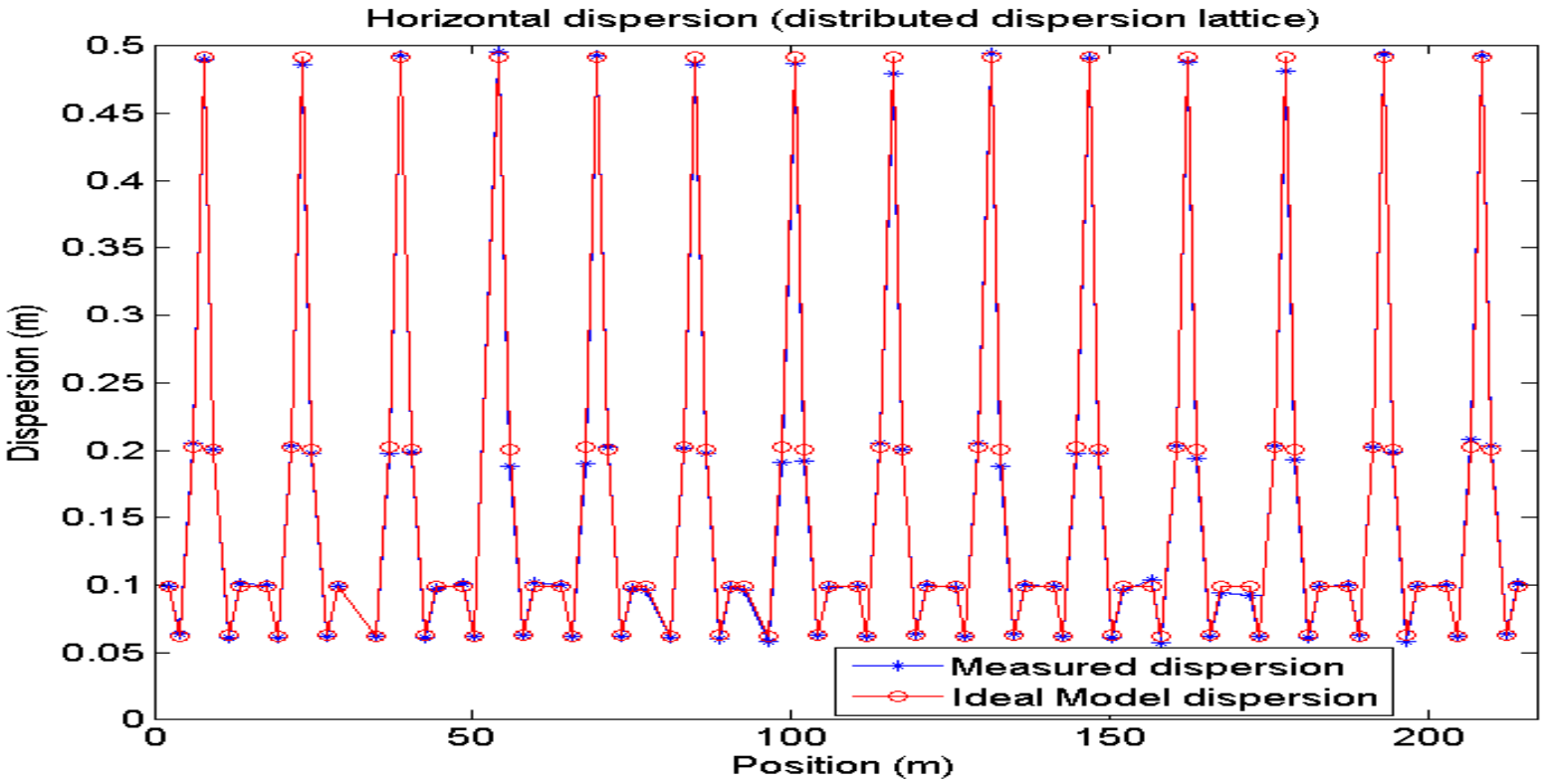




LOCO Optics Corrections

• Check the accuracy of the calibrated model by comparing Dispersion measurement against the model

•Beta functions also be checked against the calibrated model



Dispersion Modes

•We can allow dispersion to leak into the straights to reduce our emittance

•Calibrated model used to adjust the optics

•Current User mode is 0.1m dispersion.

•Emittance confirmed with X-ray pinhole measurements

X-ray pinhole measurements using calibrated model source point parameters

Dispersion [m]	**Measured Horizontal Emittance [nm]**	**Measured Vertical Emittance[pm]**	**Measured Emittance Coupling [%]**
0	19	21	0.11
0.1	14	14	0.10
0.24	10	7	0.07

LOCO emittance coupling

- Coupling of the lattice is measured by including ‘ghost’ skew quadrupoles into the model and allowing LOCO to adjust their strength.

- Model (with ghost skew quadrupoles) is calibrated to the machine. Fit parameters are:
  - BPM gains and rotations
  - Corrector gains and rotations
  - Quadrupole strengths
  - ‘Ghost’ Skew quadrupole components strengths in all quadrupole and sextupoles

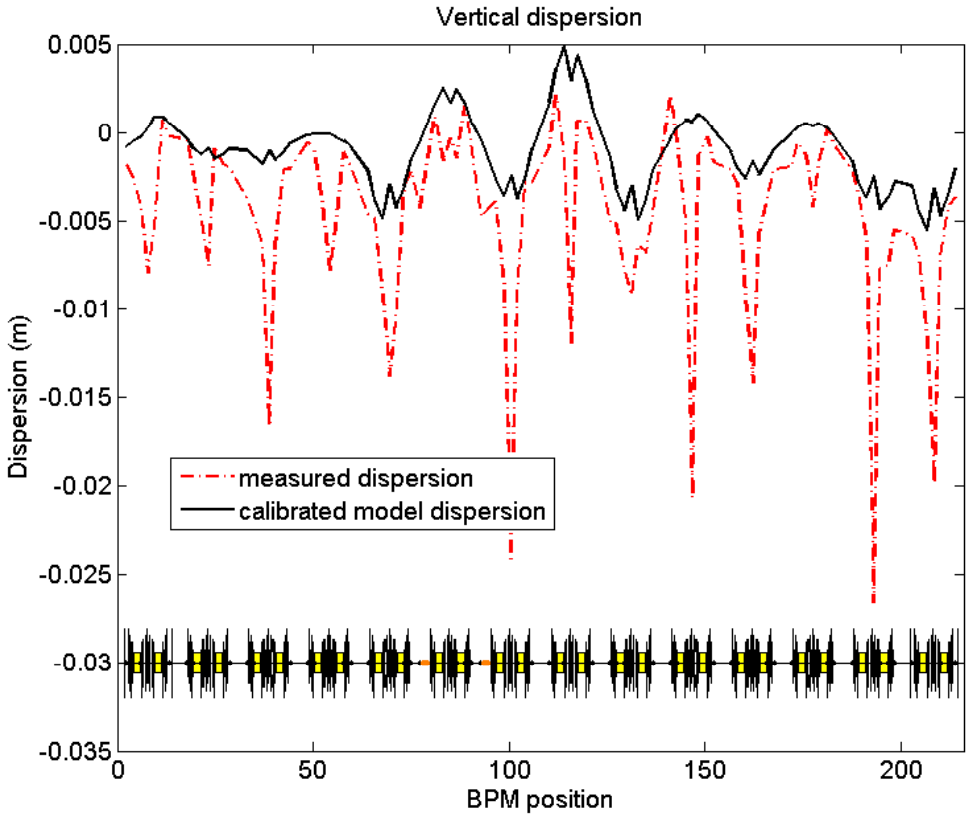
- Coupling of lattice is calculated using AT function ‘calccoupling’ (beam envelope calculation).

- Result (with Natural ring coupling) = 13.4 pm.rads

Vertical Dispersion Contribution

- Measured vertical dispersion dominated by BPM coupling.
- Used calibrated model with BPM rotations set to zero to extract the vertical dispersion.
- Emittance contribution can then be calculated

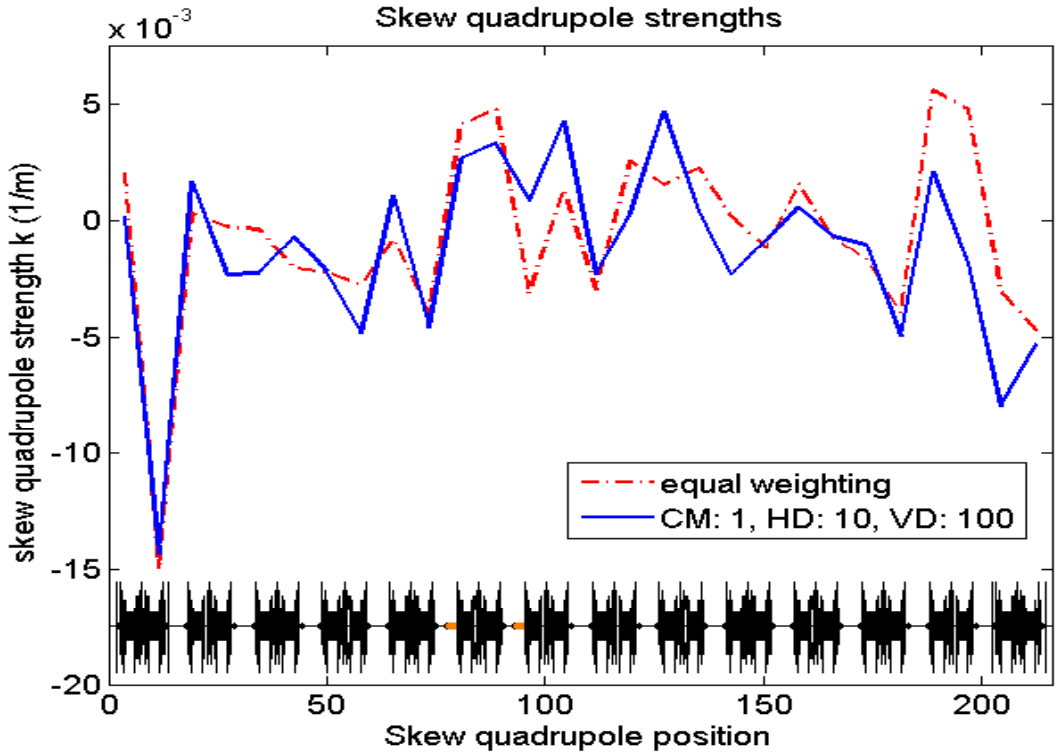
$$\varepsilon_y = \frac{C_q \gamma^2}{j_y} \frac{\left\langle H_y / \rho^3 \right\rangle_s}{\left\langle 1/\rho^2 \right\rangle_s}$$



Result = 1.2 pm.rads

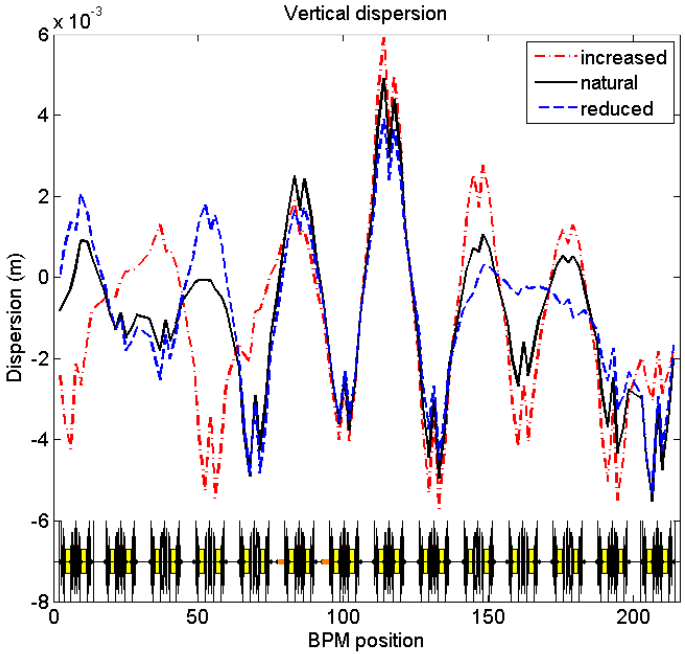
Coupling Adjustment

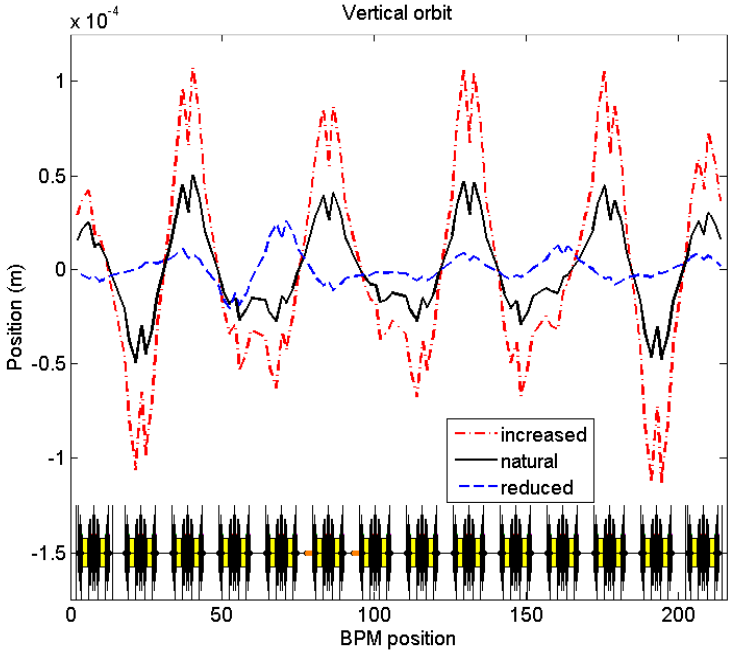
- Fit skew quadrupole components in the model only where there are real skew quadrupole magnets in our machine.
- Obtain strengths of skew quadrupoles used to calibrate model.
- Measure lifetime, Adjust LOCO weightings for Resp. matrix, Horizontal and vertical dispersion for lowest (Touscheck dominated) lifetime – should be lowest emittance.



Coupling Adjustment Measurements

- Three configurations used:
  - Natural Coupling: Skew quads set to zero
  - Reduced Coupling: Skew quads set to the negative of the LOCO fit results
  - Increased Coupling: Skew quads set to the positive of the LOCO fit results





- Vertical Dispersion remains mainly unchanged – skew quads are in low dispersion areas.
- Vertical orbit change from horizontal kick shows significant effect.

Coupling Adjustment measurements

Method	Increased Coupling (1%)	Natural Coupling (0.1%)	Reduced Coupling (0.01%)
X-ray pinhole	68μm (23 pm??)	58μm 14 pm	52μm (9 pm??)
Lifetime Measurement	12.0 ± 0.05 hours	6.16 ± 0.05 hours	2.45 ± 0.05 hours (6.3 decrease in ε)
Beam envelope calc	89.5 pm	13.4 pm	1.2 pm
Other Methods			
Tune crossing measurement	3.2%	0.32%	0.02%
Vertical dispersion calc	1.55 pm	1.20 pm	1.18 pm
Transverse coupling calc	0.62% (86.8 pm)	0.15% (21 pm)	0.012% (1.68 pm)
Sum (dispersion + coupling)	88.3 pm	22.2 pm	2.86 pm

- Lifetime measurements indicate a factor 6.3 reduction in emittance.
- Tune crossing measurement may have some accuracy problems.
- If the model is accurate then we may well be achieving very small emittances.

Planned Improvements

- Investigate skew quadrupole repositioning. All sextupoles have skew quad windings, only one family has power supplies (28/98) .
- Interferometric measurement of the emittance on the optical diagnostic beamline may yield more accurate results than X-ray pinhole.
- Refinement of LOCO correction technique.
- Turn-by-turn BPM analysis may be also used to calculate quadrupole strengths (phase advance), may be used to independently check the model

Conclusion

- Our calibrated model indicates we can currently achieve a vertical emittance of ~ 2-3 pm.rad
- More work need to be done to confirm the accuracy of the model.
- Coupling control may be enhanced by repositioning skew quads.
- The Accelerator Physics team at the Australian Synchrotron are keen to work on this topic and eager to share our experiences with the ILC

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