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Searching for Quantum LOVE at the **A**ustralian **S**ynchrotron Light Source

Eugene Tan

On behalf of Rohan Dowd

Overview

- Motivation
- Lattice, Alignment and orbit correction
- LOCO method and Coupling minimisation
- Measurements
- Alternate skew configuration simulations
- Conclusions

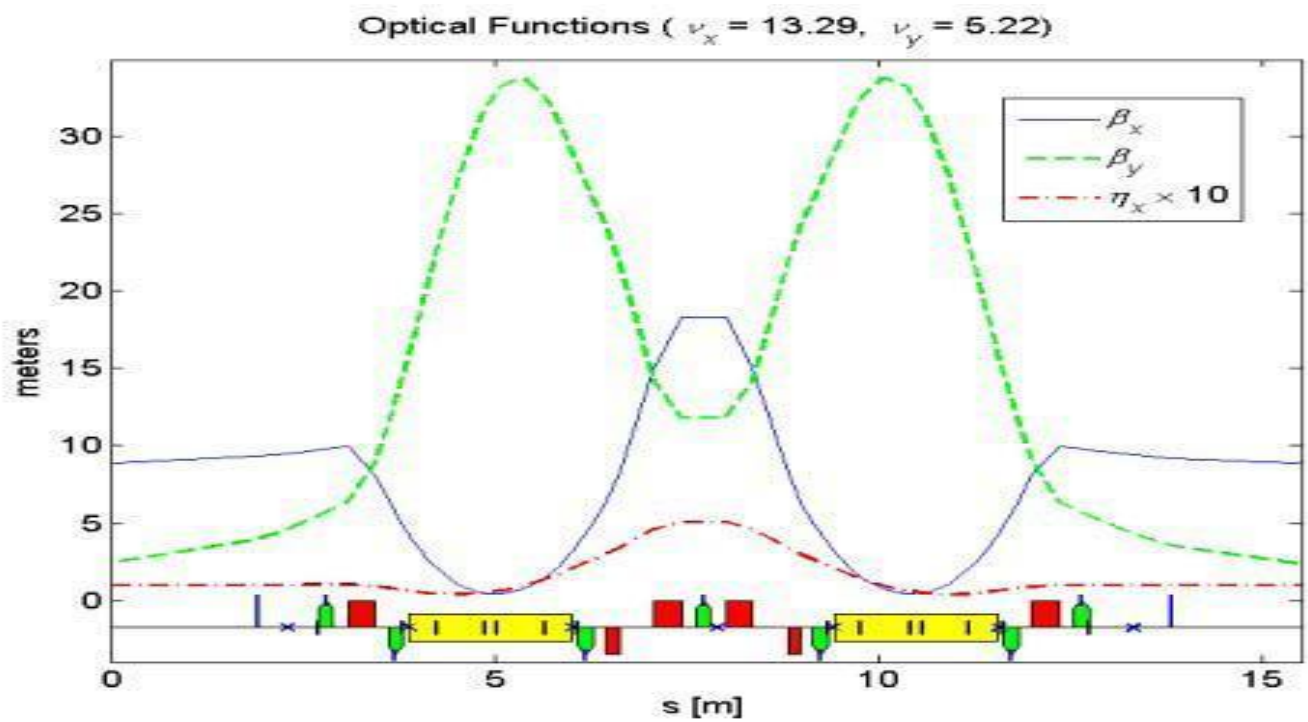
Motivation

- As a light source, coupling manipulation was used "artificially" increase the lifetime by increasing coupling.
- Uncorrected coupling at ASLS was very small → how low can we go?
- Is Quantum LOVE (Limit Of Vertical Emittance) within our grasp?
- ASLS is now part of the ACAS (MOU with CLIC on damping ring work).
- Light source storage rings can be good test beds of techniques and technology – but it must benefit photon beam users also.

Lattice overview

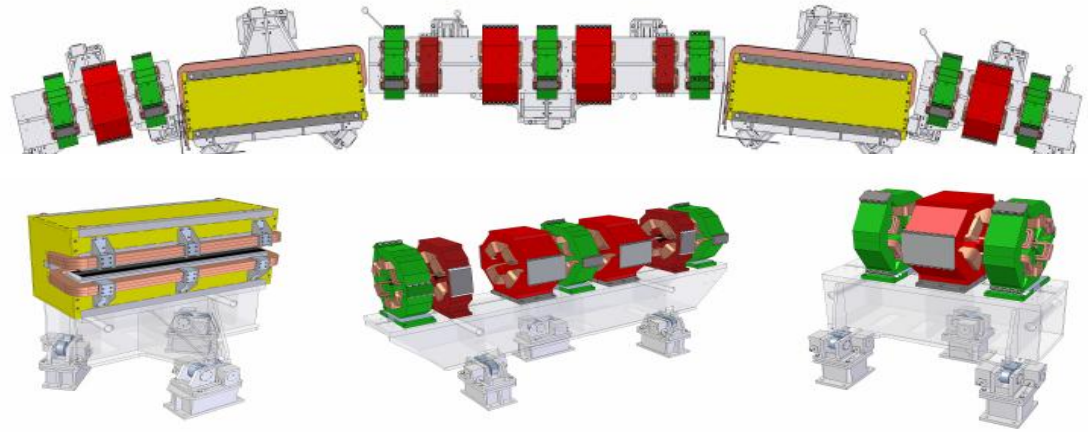
Energy	3 GeV
Circumference	216 m
Current	200 mA
Momentum Compaction	0.002
ε_x (nominal)	10.4 nm·rad

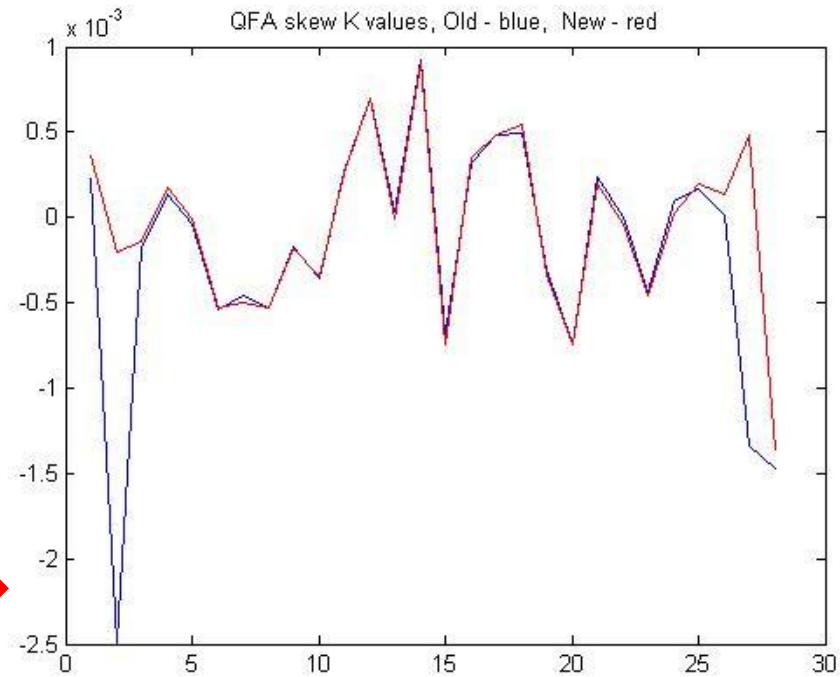
- Corrector and skew quad coils on sextupoles.
- Horizontal emittance reduced with dispersion in straights.



Alignment

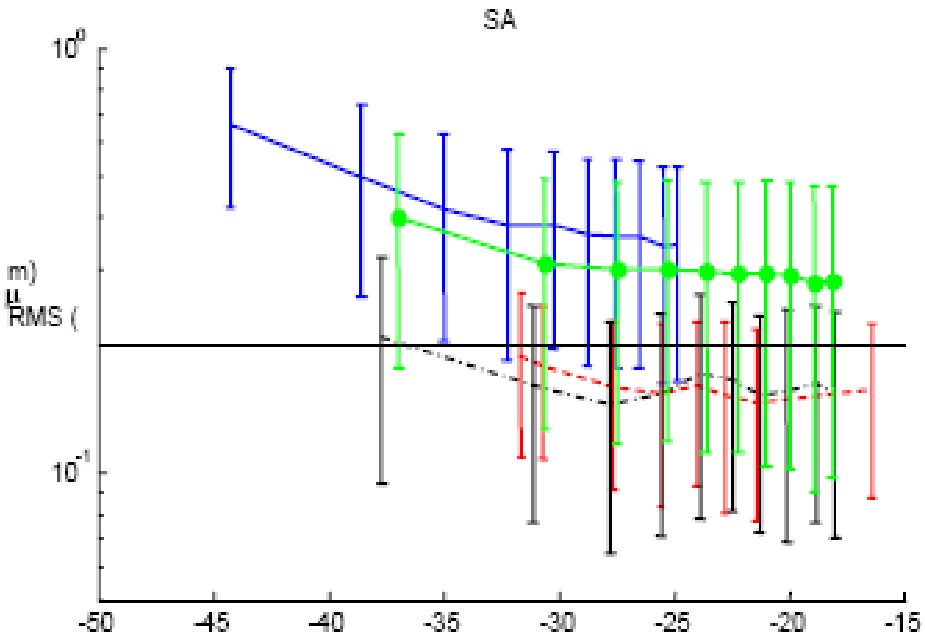
- Vertical alignment error:
  - 26 µm Quadrupoles,
  - 18 µm Dipoles
- Intrinsic Fiducial and assembly error:
  - 16 µm (Quad)
  - 6 µm (Dipole)
- Full ring realignment: ~yearly.
- 'natural' emittance coupling has changed each alignment, not always for the better!
  - 2008 – 0.1%
  - 2009 – 0.06%
  - 2010 (Feb.) – 0.18%
  - 2010(Sep.) – 0.29%

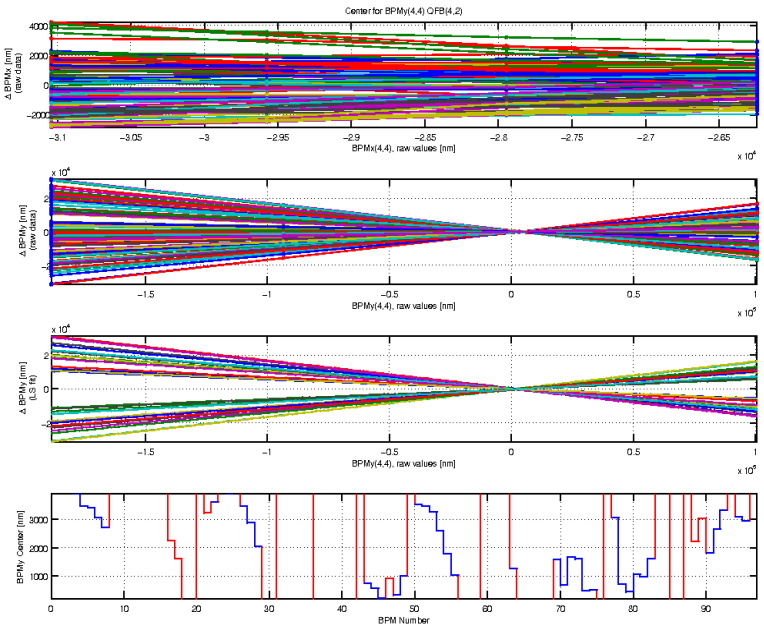




BPM resolution and Beam Based Alignment

- Libera BPM electronics
- BPM resolution ~0.1 um (rms)
- Resolution of BBA is ~10 um.
- BPM mechanical alignment resolution <20 um
- RMS orbit deviation typically: <20 µm Horizontal, <10 Vertical





LOCO (Linear Optics from Closed Orbits)

- Adjusts the linear parameters in the model to fit real machine data.
- Data used: corrector orbit response and dispersion response.
- Model response – Measured machine response = Error
- Minimise error by adjusting a set of model parameters.
- Fit Parameters normally include:
  - **BPM/Corrector gains and coupling**
  - **Corrector gains and coupling**
  - **Quadrupole strengths**
  - **Skew Quadrupole strengths**

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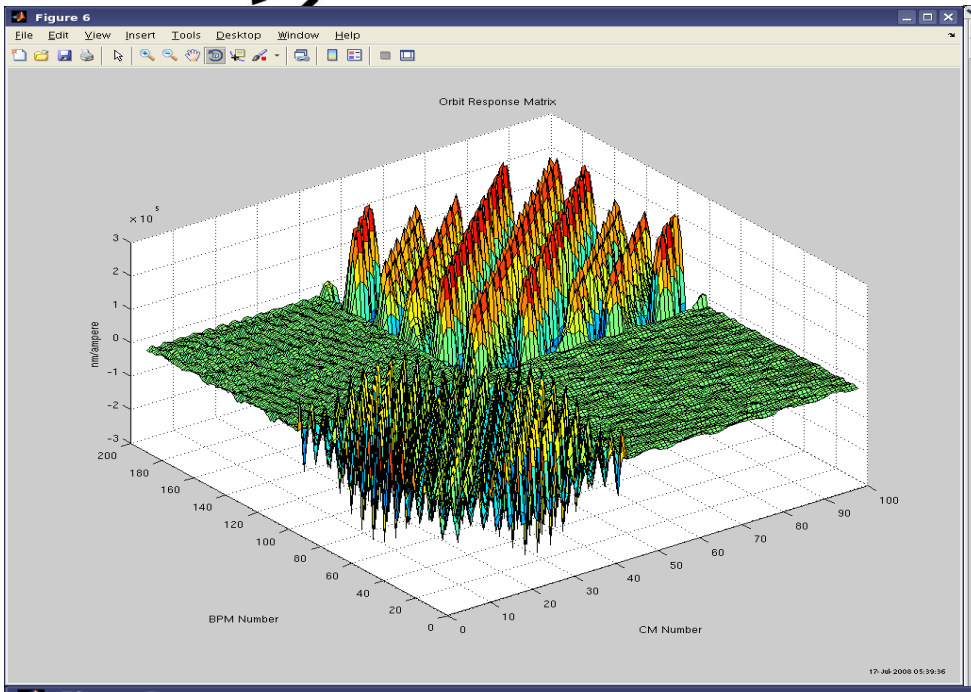
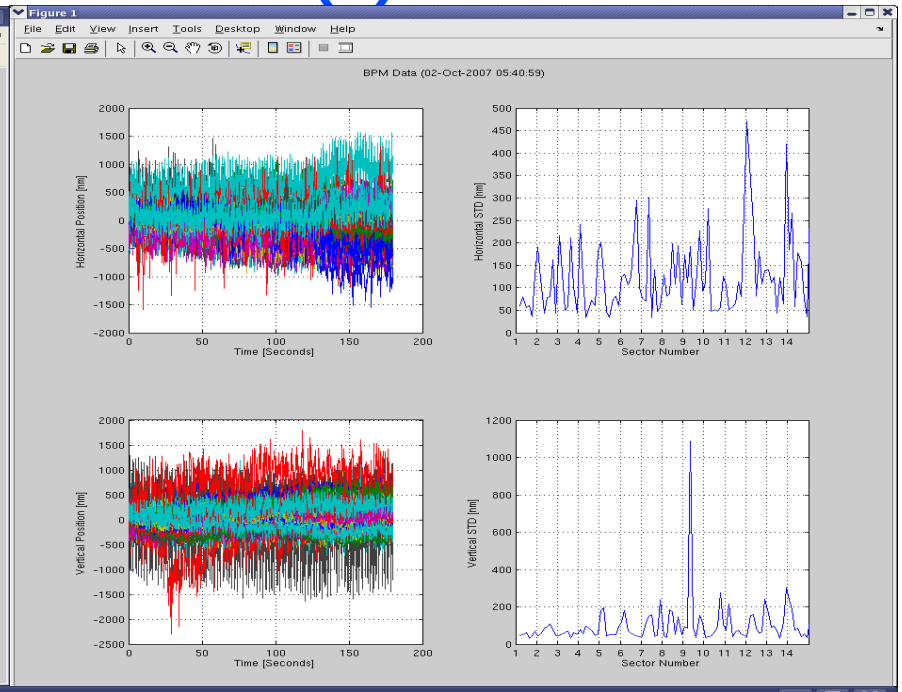
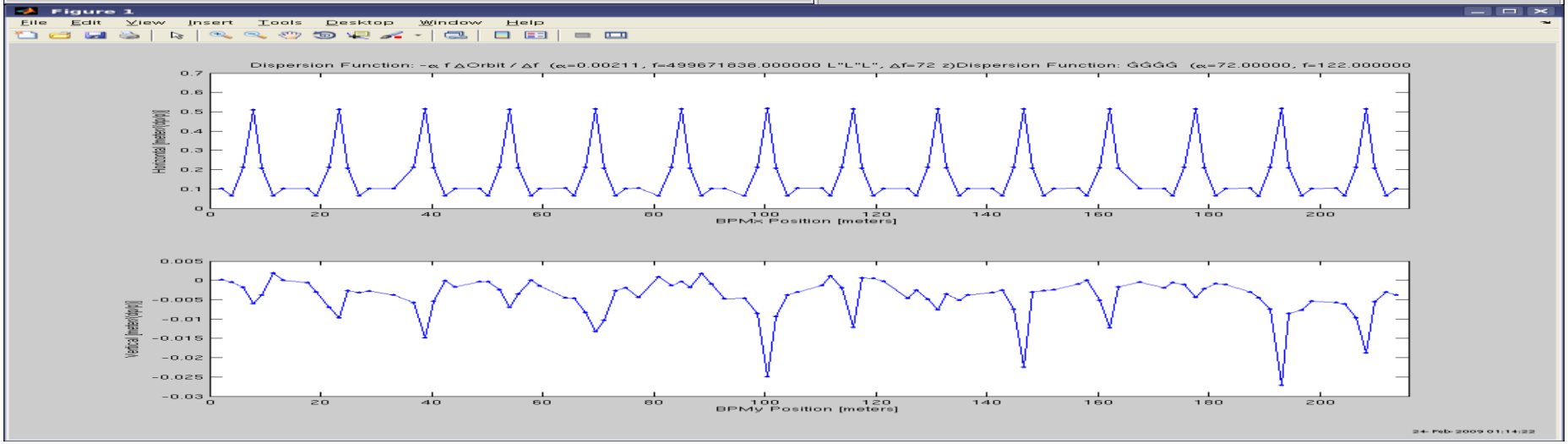
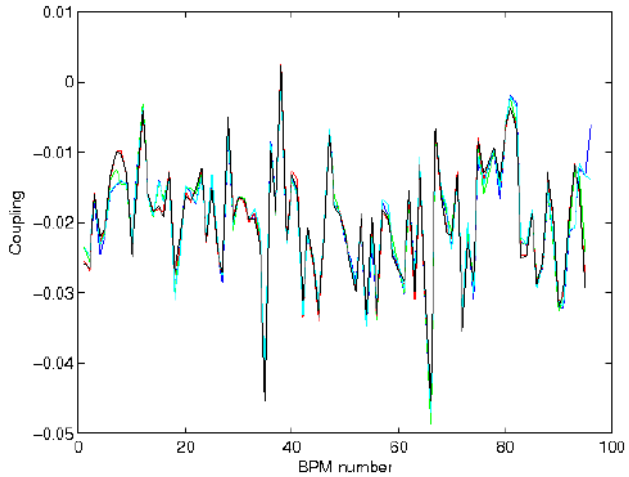


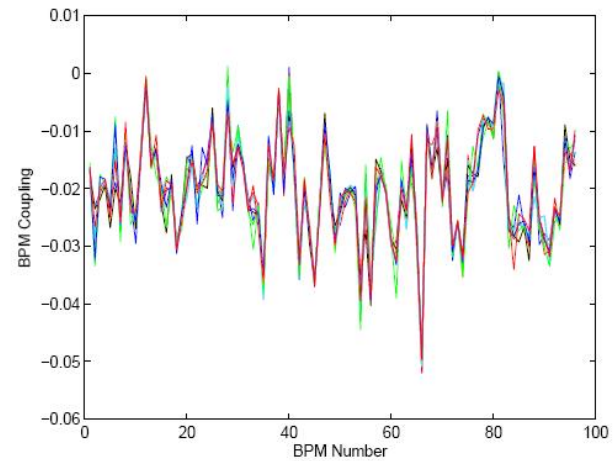


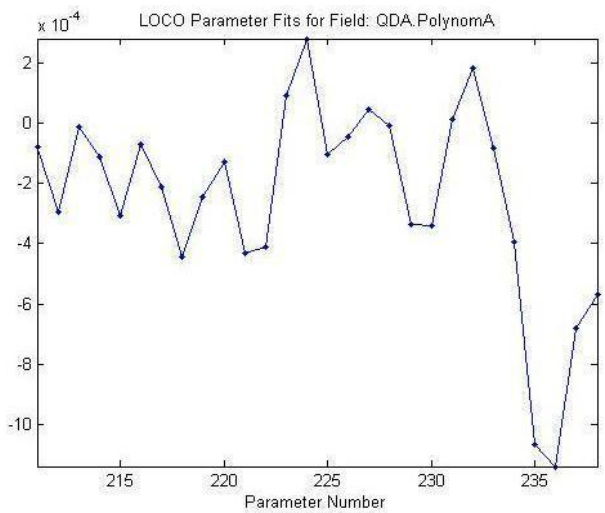


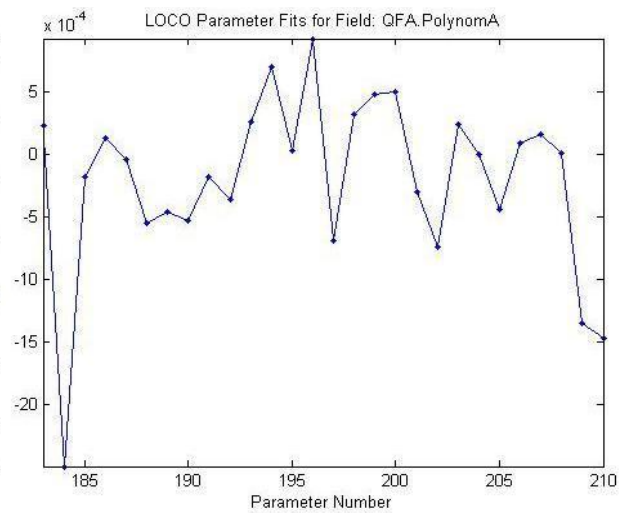
LOCO - Outputs

- BPM Gains
- BPM couplings
- Skew components
- Quad Strengths
- Corrector gains/tilts
- Full Calibrated model









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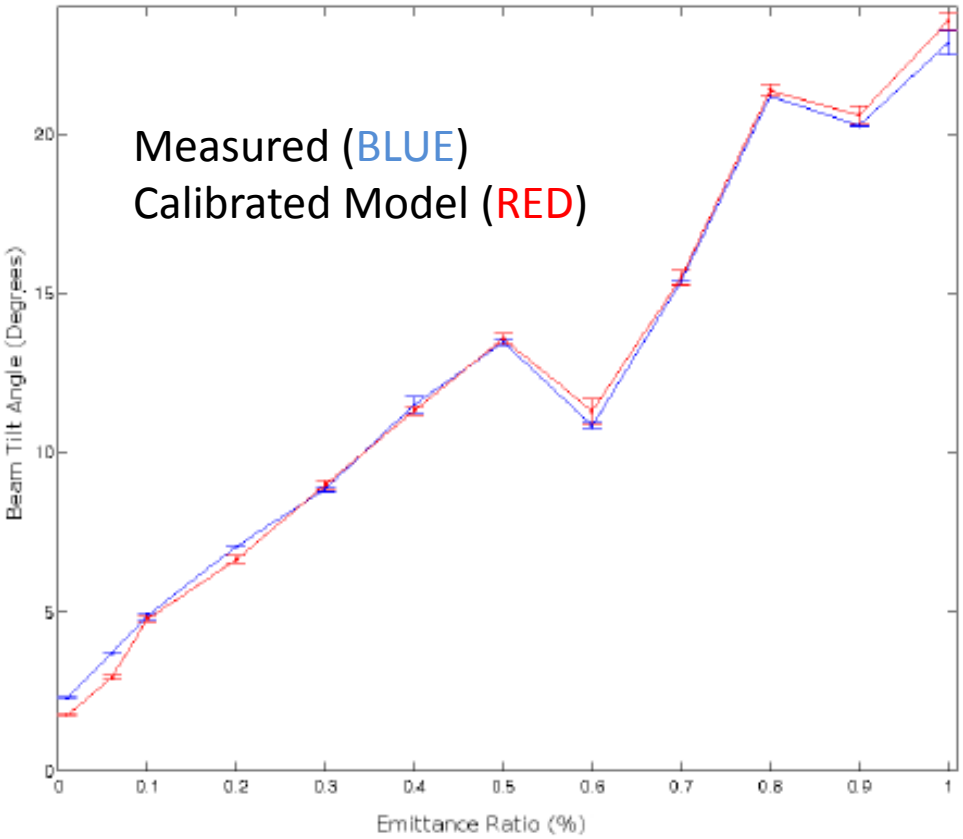
Emittance Coupling minimisation

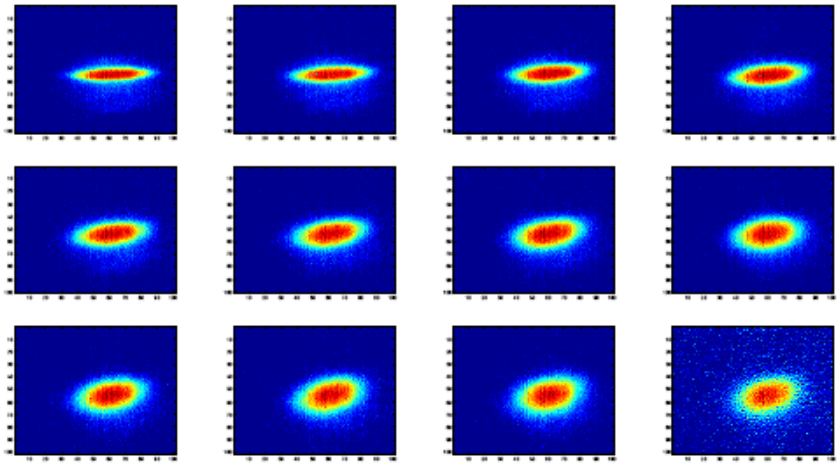
- Emittance coupling calculated from LOCO Calibrated model (using beam envelope calculation from particle tracking).
- Minimisation algorithm used to adjust skew quads to achieve arbitrary emittance ratios.

Set Coupling	LOCO Measured Coupling	Calculated ε_y (pm)
0.0%	0.009%	0.9
0.1%	0.12%	12.2
0.2%	0.23%	23.5
0.3%	0.33%	33.7
0.4%	0.43%	43.9
0.5%	0.54%	55.1
0.6%	0.64%	65.3
0.7%	0.74%	75.5
0.8%	0.84%	85.7
0.9%	0.92%	93.8
1.0%	1.04%	106.1

Model Check - Local Beam tilt

Compare local beam tilt at the X-ray Pinhole source against calibrated model prediction to cross-check the results of the calibrated model.





2D fit to pinhole image used to extract tilt angle. A camera tilt offset of 1.06 degrees has been subtracted

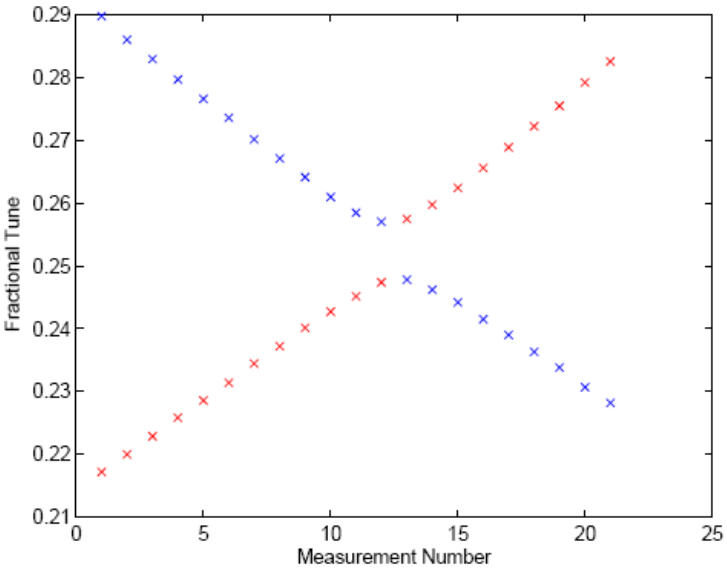
Tune Crossing

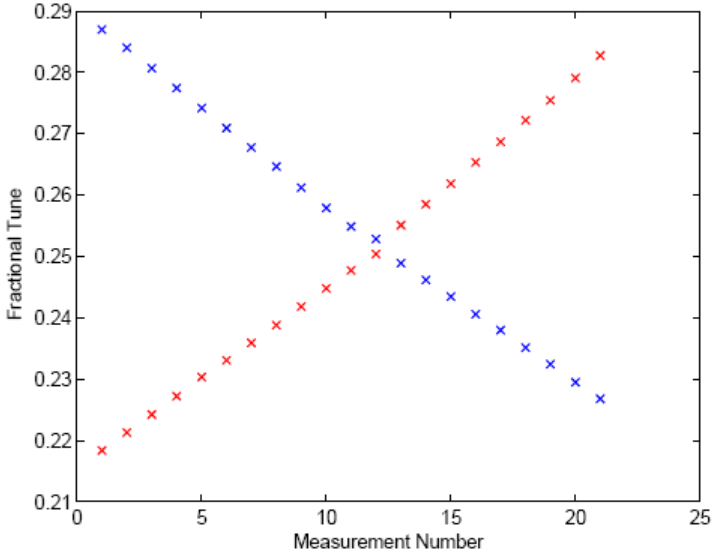
- Separation of Horizontal and Vertical tunes when brought to difference resonance will indicate the level of betatron coupling:

$$g = \frac{(|C|/\Delta)^2}{(|C|/\Delta)^2 + 2}$$

- Be careful about Chromaticity!

Model Total coupling	Measured Separation	Measured β Coupling
0.011%	0.0008± .0002	0.006 ± .003%
0.074%	0.0024± .0002	0.053± .007%
0.125%	0.0034± .0002	0.105± .010%
0.223%	0.0046± .0002	0.193± .013%
0.406%	0.0066± .0002	0.396± .018%
0.748%	0.0091± .0002	0.750± .021%
0.905%	0.0097± .0002	0.852± .026%





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Model Comparison with tune crossing results

Calculated ε_y from model should agree with measured betatron coupling plus the vertical dispersion results.

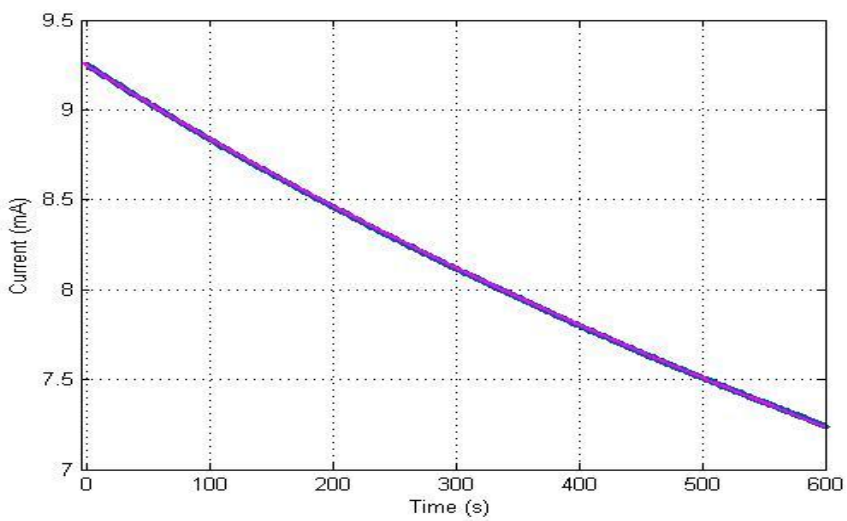
Model ε_y (pm)	ε_y from measured η_y (pm)	ε_y from Betatron Coupling (pm)	Total (pm)	Difference (model – measured)
1.05 ± 0.03	0.73 ± 0.03	0.59 ± 0.30	1.32 ± 0.30	0.27 ± 0.30
7.55 ± 0.23	1.73 ± 0.07	5.41 ± 0.71	7.14 ± 0.71	0.41 ± 0.75
12.75 ± 0.38	2.14 ± 0.09	1071 ± 1.02	12.85 ± 1.02	0.10 ± 1.09
22.75 ± 0.68	2.04 ± 0.08	19.69 ± 1.33	21.72 ± 1.33	1 03 ± 1.49
41.41 ± 1.24	1.73 ± 0.07	40.39 ± 1.84	42.23 ± 1.84	0.82 ± 2.22
76.30 ± 2.23	2.96 ± 0.12	76.50 ± 2.14	78.64 ± 2.14	2.34 ± 3.09
92.31 ± 2.77	2.24 ± 0.09	86.90 ± 2.65	89.55 ± 2.65	2.76 ± 3.83

Tousheck Lifetime vs RF

- By taking single bunch lifetime over extended period the Tousheck component of the lifetime can be extracted.

$$\frac{1}{\tau} = \frac{N r_e^2 c}{8\pi\sigma_z\gamma^2}\left\langle \frac{D(\varepsilon)}{\delta_{\max}^3\sigma_x\sigma_y}\right\rangle, \varepsilon = \left(\frac{\delta_{\max}\beta_x}{\gamma\sigma_x}\right),$$

$$D(\varepsilon) = \sqrt{\varepsilon}\left(-\frac{3}{2}e^{-\varepsilon} + \frac{\varepsilon}{2}\int_\varepsilon^\infty \frac{e^{-u}\ln(u)}{u}du + \frac{1}{2}(3\varepsilon - \varepsilon\ln(\varepsilon) + 2)\int_\varepsilon^\infty \frac{e^{-u}}{u}du\right)$$



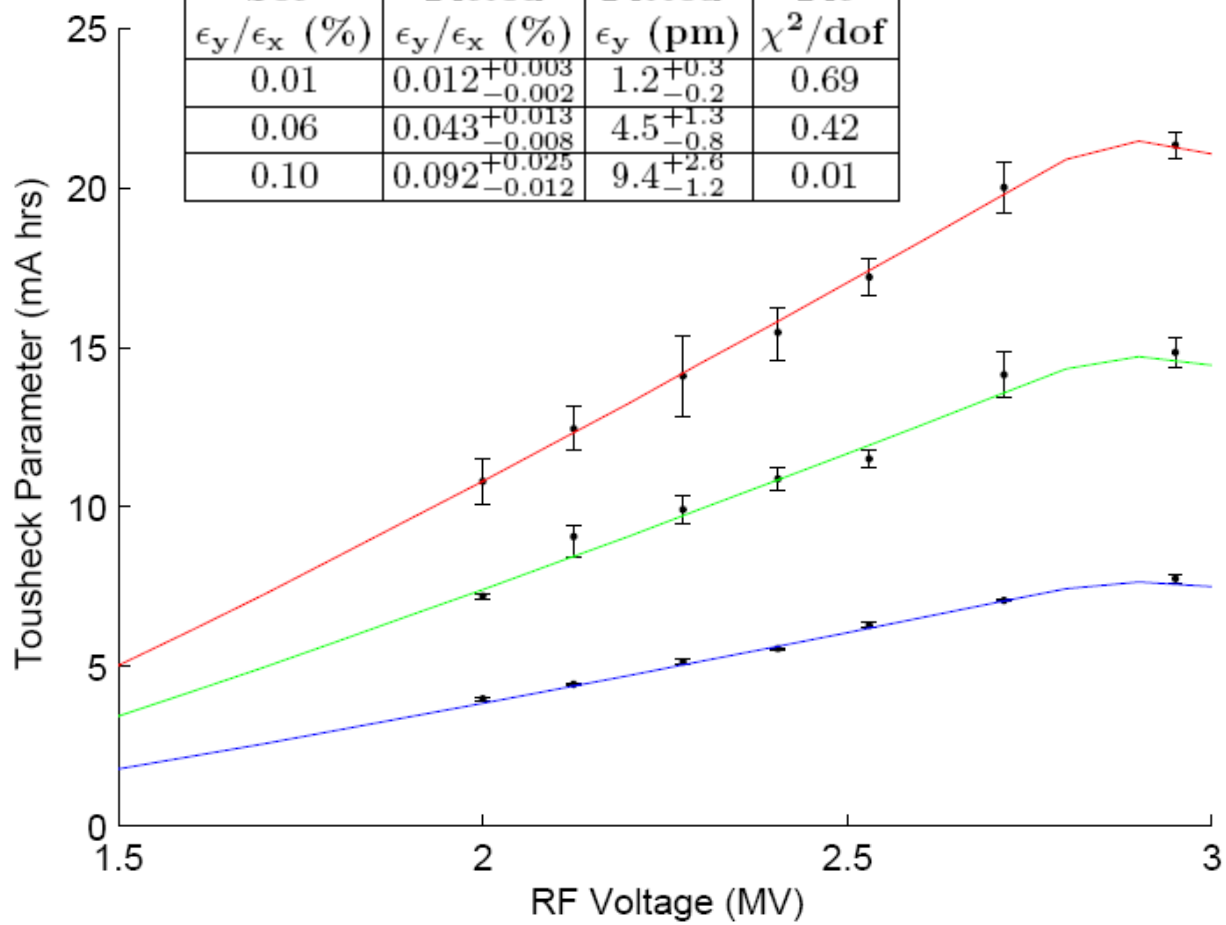
$$\frac{di}{dt} = -\frac{i}{a} - \frac{i^2}{b}$$

$$i(t) = \frac{i_0 b e^{-\frac{1}{a}}}{b + i_0 a(1 - e^{-\frac{1}{a}})}$$

Tousheck Lifetime vs RF

- Tousheck component will change with RF voltage.
- Measurements taken at 3 settings – 0.01% (min), 0.06%(uncorrected) and 0.1% emittance coupling.
- 2.1% energy acceptance (measured)
- Curve fit by varying $\varepsilon_y/\varepsilon_x$, other values fixed.
- Blue curve fit corresponds to $\varepsilon_y = 1.24 \pm 0.3$ pm

Set ϵ_y/ϵ_x (%)	Fitted ϵ_y/ϵ_x (%)	Fitted ϵ_y (pm)	Fit χ^2/dof
0.01	$0.012^{+0.003}_{-0.002}$	$1.2^{+0.3}_{-0.2}$	0.69
0.06	$0.043^{+0.013}_{-0.008}$	$4.5^{+1.3}_{-0.8}$	0.42
0.10	$0.092^{+0.025}_{-0.012}$	$9.4^{+2.6}_{-1.2}$	0.01

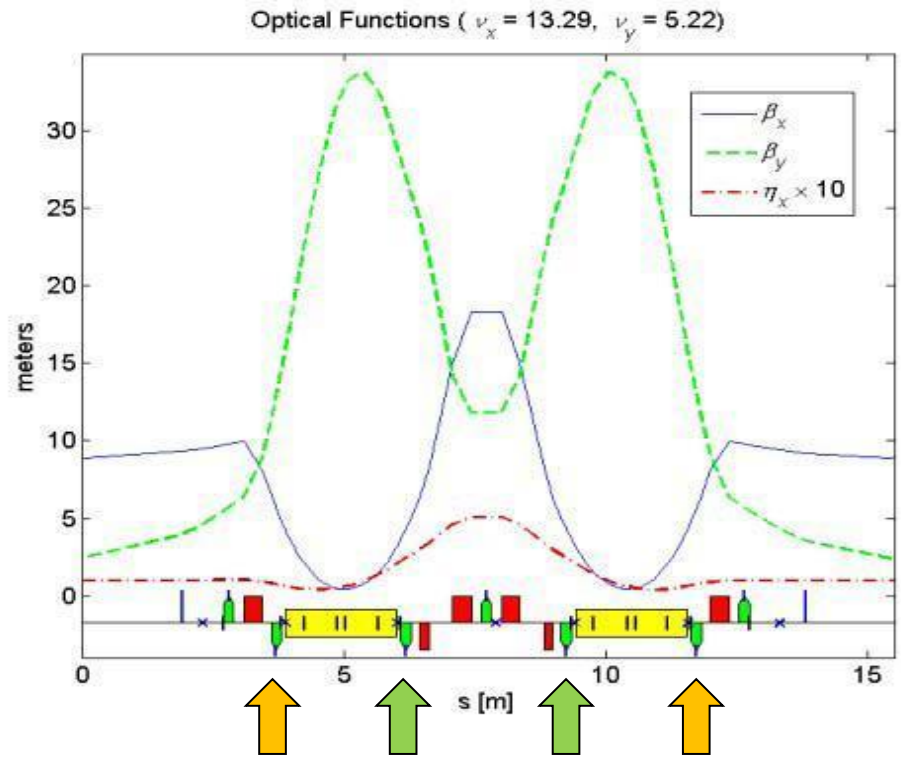


Alternate skew quad configurations

Simulations of different skew configurations have been performed to find optimal configuration .

Note: Measured ε_y > simulated ε_y (~x1.6)

Skew Config.	Simulated Minimised coupling	Simulated Dispersion (mm)
Nominal 28 skews	0.00696% (0.7pm)	2.49
56 skews	0.00291% (0.3 pm)	1.02
28 even	0.00674% (0.7pm)	1.51
28 odd	0.00571% (0.6pm)	1.32



Currently powered.

Not powered.

Conclusions

- Low uncorrected coupling achieved by good mechanical and beam based alignment.
- LOCO is an effective tool for coupling measurements and manipulations.
- The more skew quadrupoles, the better possible correction as coupling can be cancelled locally. Skew quads in dispersion regions are important to control the dispersion.
- Tune crossing and Tousheck Lifetime Analysis indications give: $\varepsilon_y \sim 1.2 \pm 0.3$ pm
- Improvements possible with mechanical re-alignment and/or changes to the skew quadrupole configuration.

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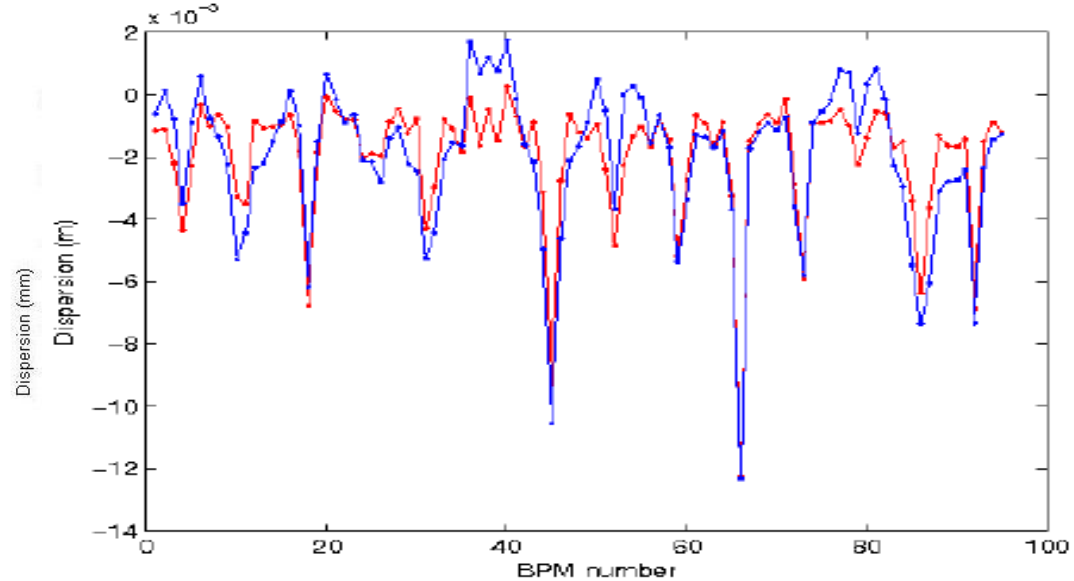
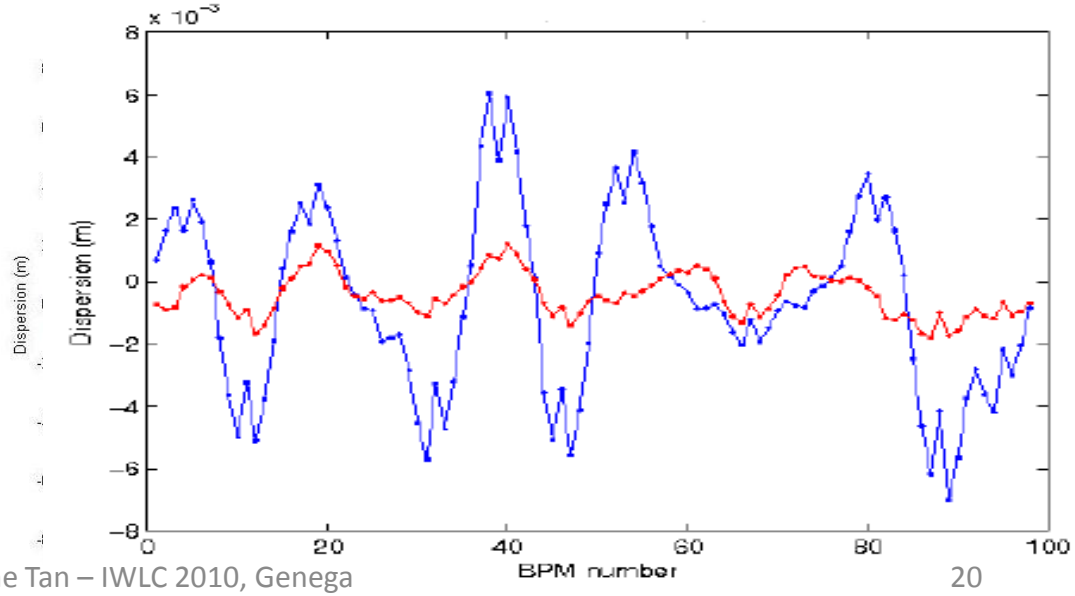
Thank You

Additional Slides

Model Check – Dispersion Minimisation

- Same method used to minimise vertical dispersion only
- Clear reduction found in dispersion, but linear coupling increases.
- εy/εx ~ 0.9%
- Vertical dispersion reduced from 3.4mm to 0.9mm (rms)





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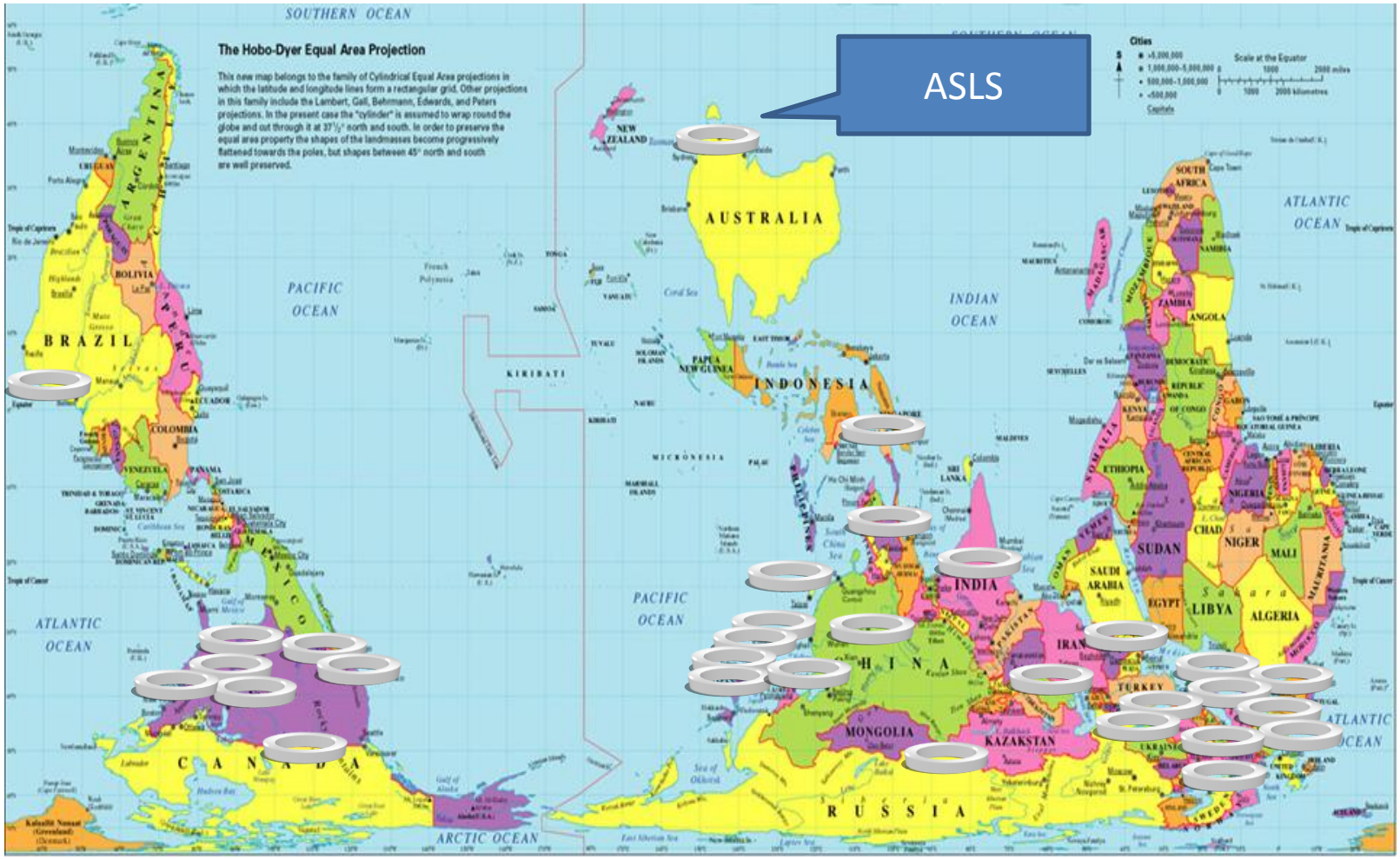
Where are we?



Storage Ring Overview

Operations:

- Operational since April 2007
- 9 beamlines
- 1000+ users
- 5000+ hr user beamtime per year

Machine:

- 3 GeV storage ring
- Full energy injection
- 200 mA
- 35 hr lifetime
- f_{RF} =500 MHz
- Circ. 216 m
- f_{rev} =1.39 MHz
- Harmonic # 360