Orbit Response Matrix Analysis of ATF Optics, April-May 2008

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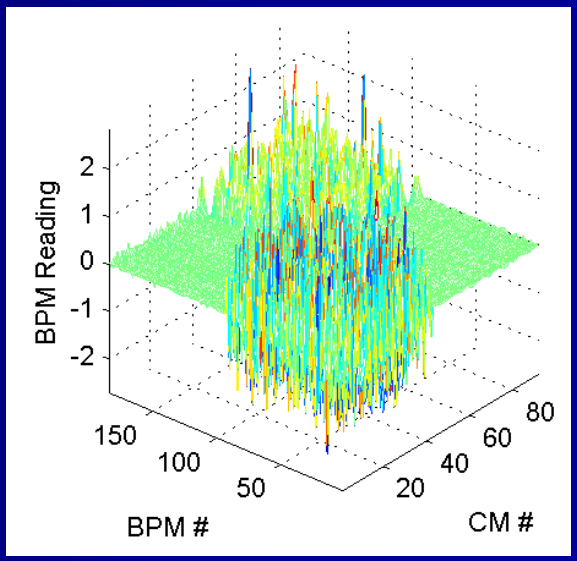
Orbit Response Matrix Analysis

- The orbit response matrix (ORM) contains the change in each BPM resulting from a change in each corrector magnet.
- The ORM is sensitive to magnet strengths, BPM gains and couplings, and corrector strengths and rotations.
- By adjusting parameters in a model to reproduce a measured ORM, we can construct a calibrated model.



Goals

- Short term:
  - To re-commence application of Orbit Response Matrix (ORM) analysis at ATF as a tool to identify optics and diagnostics errors.
  - To repeat partially successful experience from 2004 in applying ORM to reduce emittance.
- Longer term:
  - To apply ORM analysis in combination with beam-based alignment and other techniques, to achieve vertical emittance < 5 pm (2 pm..?)

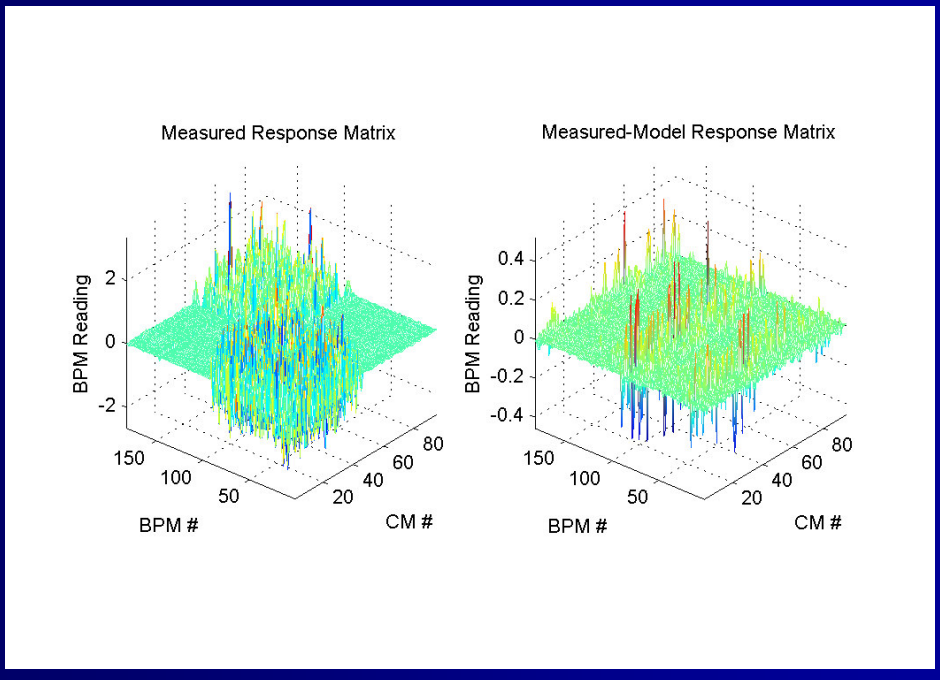
ORM analysis at ATF

- ORM analysis is used routinely at third-generation synchrotron light sources for identifying and correcting optics errors.
  - SPEAR3, ALS, Austalian Synchrotron...
- At the ATF, data collection takes up to three hours, because of the large number of orbit correctors.
  - Can we use a subset of the correctors?
- Fitting the model to the measured ORM is non-trivial, because of the large number of variables, and options for various parameters used to optimise the fit.
  - Variables: BPM gains and couplings, quad and skew quad strengths...
  - Parameters: svd tolerance, weight on dispersion data...
- Results presented here are based on data collection and machine tuning on three occasions, April – May 2008.

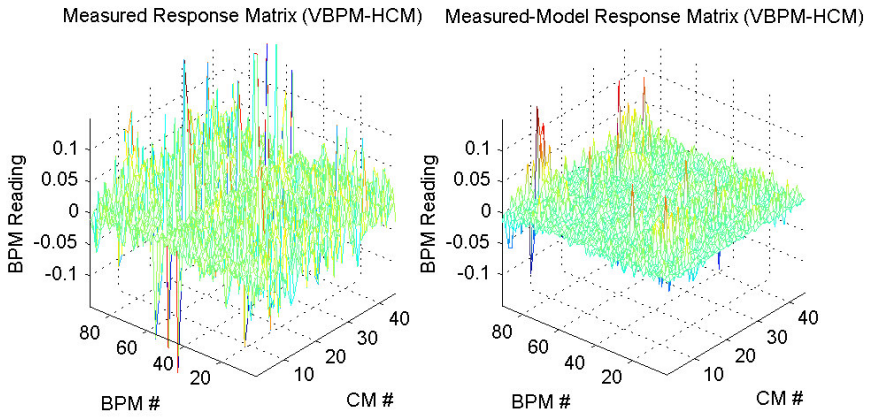
Typical procedure

1. Measure ORM and dispersion.
2. Fit a model to the measured data.
3. Determine changes to skew quadrupole strengths required to correct the coupling in the model.
4. Apply changes to skew quadrupoles in the machine.
5. Measure beam size and life time to indicate any effects on vertical emittance.
6. Measure ORM and dispersion again to characterise changes to the machine resulting from changing the skew quadrupole strengths.

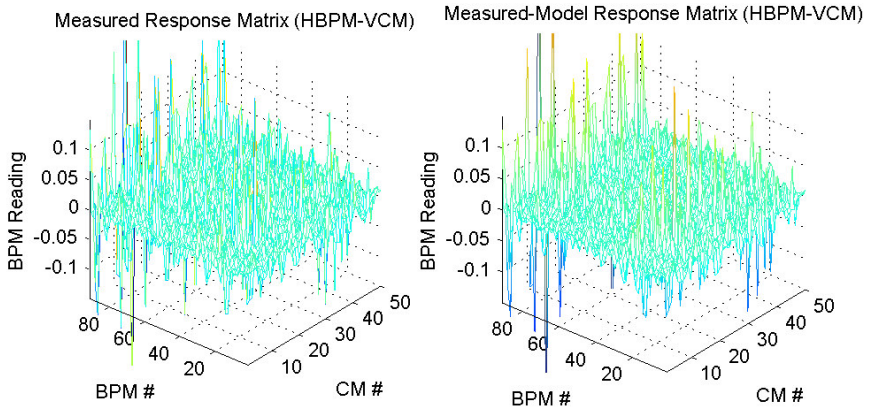
Quality of fit to ORM data: 30 May 2008



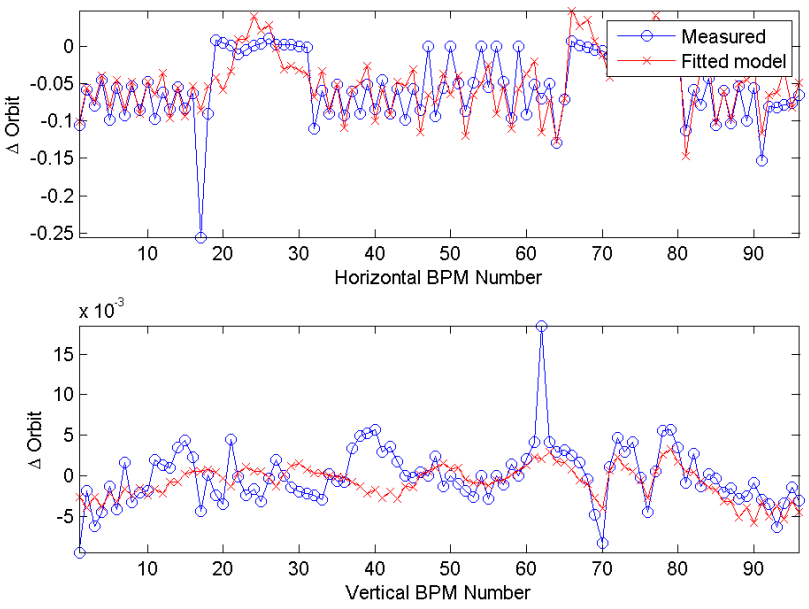
Quality of fit to ORM data: 30 May 2008



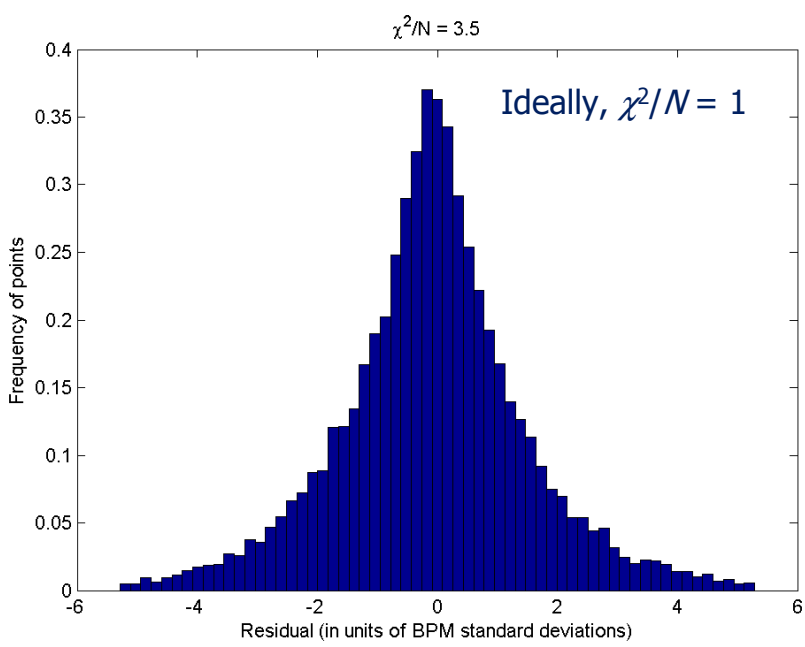
Quality of fit to ORM data: 30 May 2008



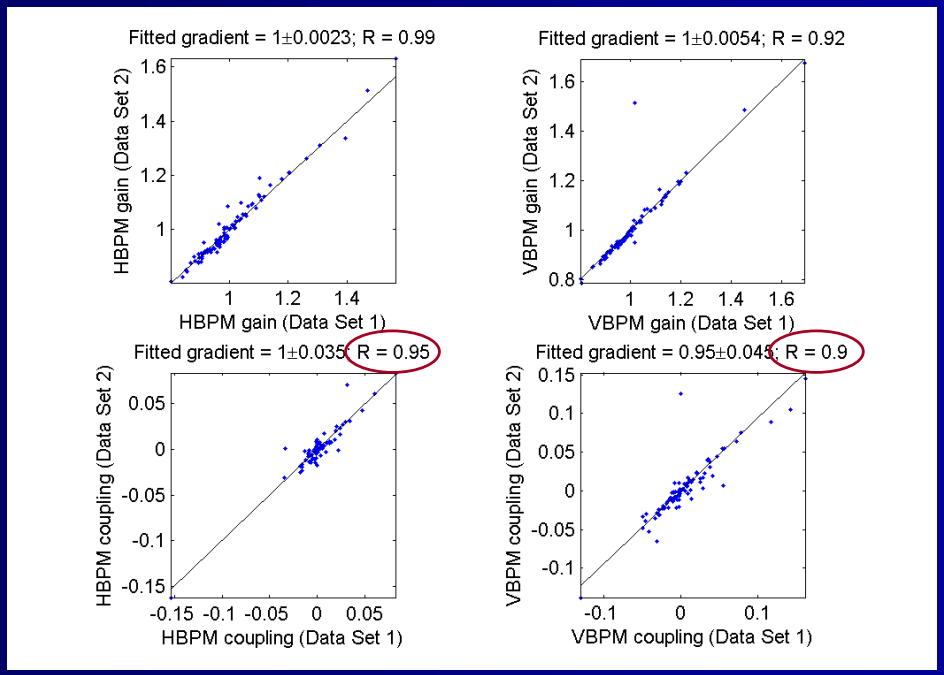
Quality of fit to dispersion: 30 May 2008



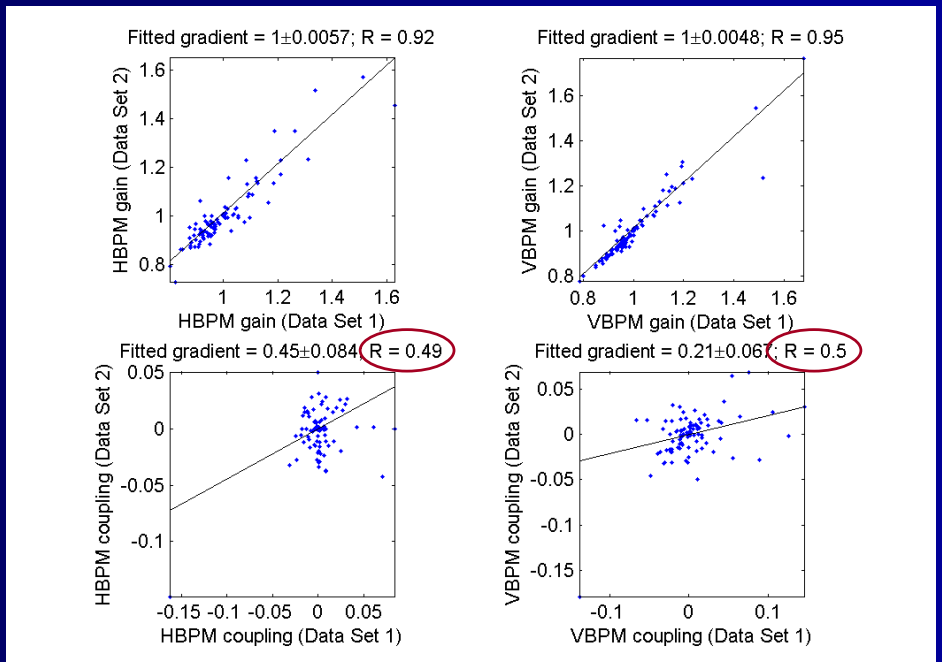
Distribution of residuals: 30 May 2008



Consistency between data sets:
(1) 16 May 2008 I, and (2) 16 May 2008 II



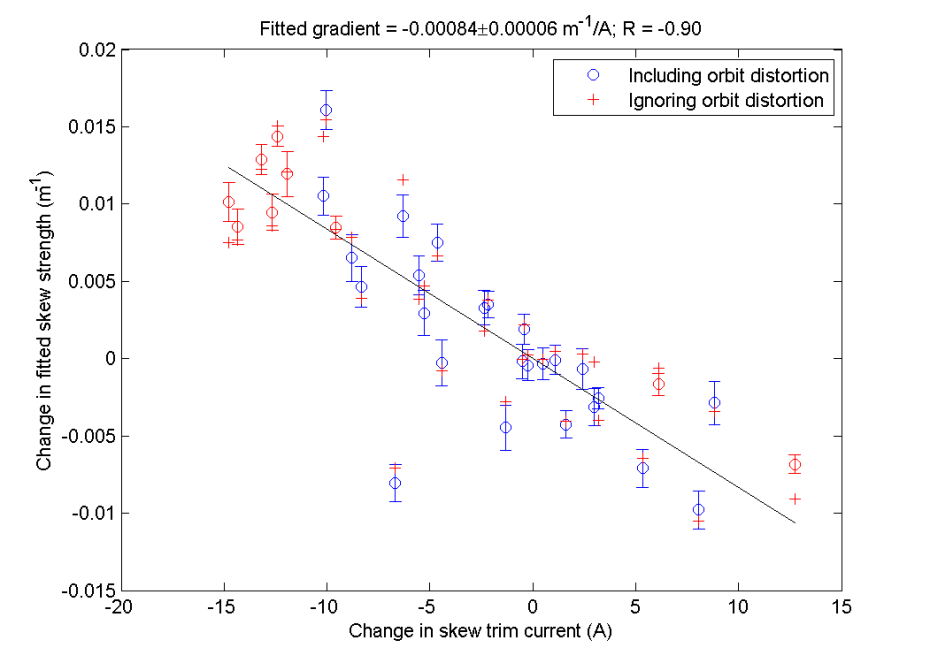
Consistency between data sets:
(1) 16 May 2008 II, and (2) 30 May 2008



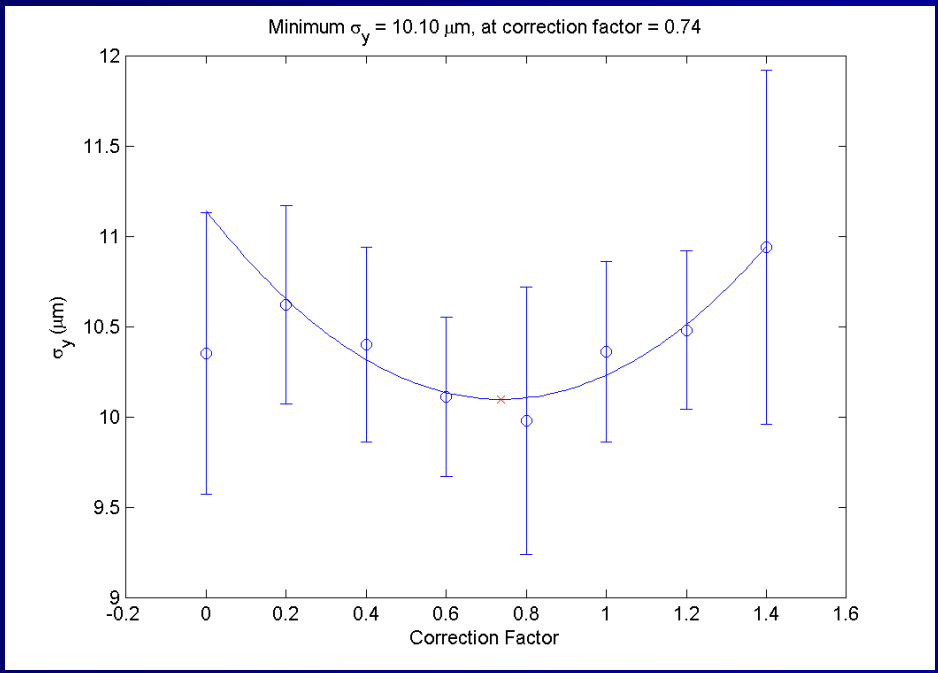
Consistency between data sets

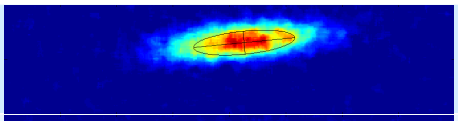
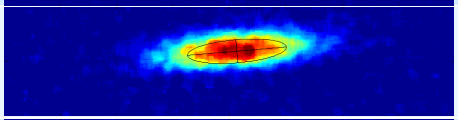
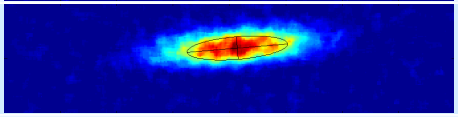
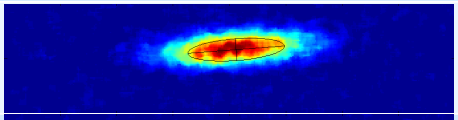
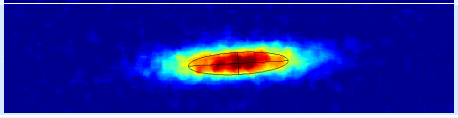
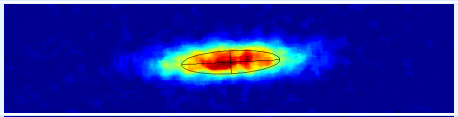
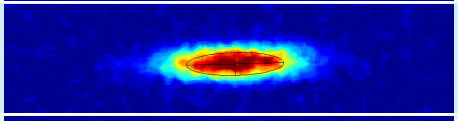
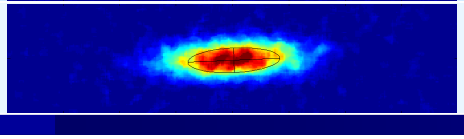
- In principle (and in an ideal world), BPM gains and couplings and corrector kicks should not change: we hope to see perfect correlation between data sets.
- Parameters fitted to the data sets each collected on 16 May show a high degree of correlation.
- Comparison between data sets from 16 May II and 30 May shows a poor correlation for BPM couplings.
- *Are the changes in BPM couplings real?*

Skew quadrupole "calibration": Data sets on 16 May 2008

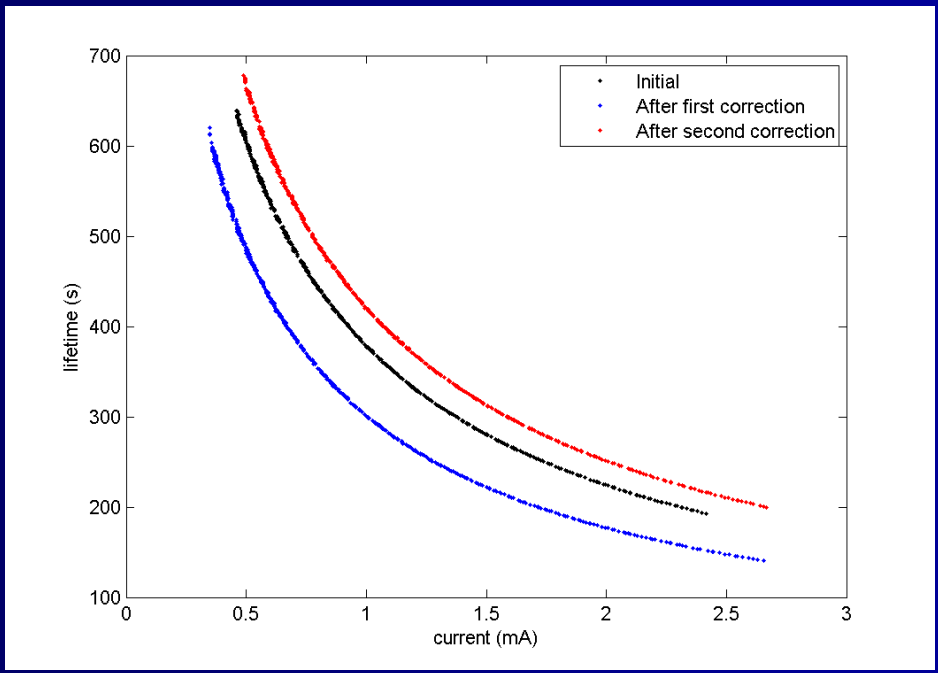


Results of a skew correction (based on 30 May 2008 data set)

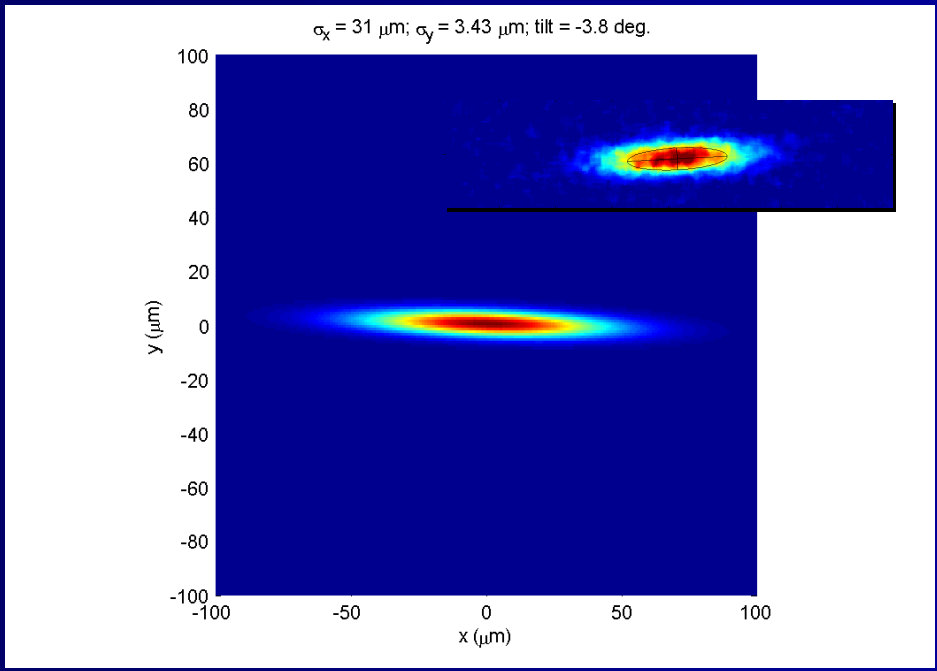


Typical XSR image	correction factor	σ_b (μm)	tilt (deg)
	0.0	10.14	5.56
	0.2	10.20	4.75
	0.4	9.96	4.69
	0.6	9.54	4.26
	0.8	9.72	3.09
	1.0	10.14	3.10
	1.2	10.02	1.37
	1.4	10.80	2.65

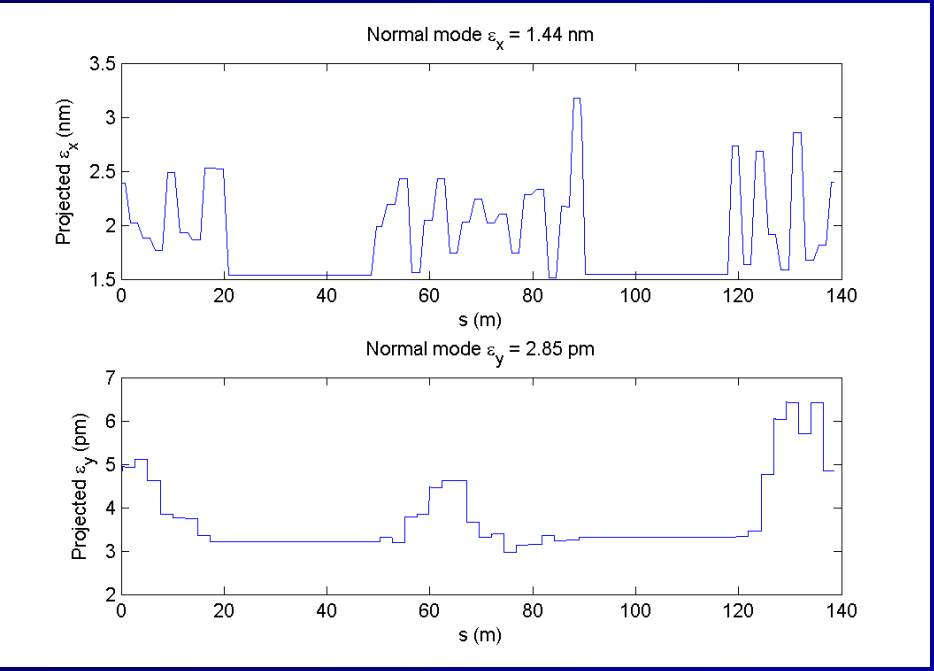
Beam lifetime measurements 30 May 2008



Beam sizes and emittances from fitted model, 30 May 2008



Projected emittance in fitted model, 30 May 2008



Conclusions…

- Good News:
  - Good correlation between applied and fitted skew quad strengths.
  - Good correlation between most parameters determined from ORM data sets two weeks apart.
- Bad News:
  - Skew correction determined from ORM has little impact on beam size.
  - Poor correlation between BPM couplings determined from ORM data sets two weeks apart: not understood.
  - Observed beam size not as small as that predicted by the fitted model.

...and questions:

- Are the skew quadrupole strengths we find from the ORM fit meaningful?
  - Correlation between applied and fitted changes suggests that the fitted strengths are significant.
- If we are finding the correct skew quadrupole strengths:
  - Why are the beam sizes in the fitted model so much smaller than those observed in the machine?
  - why does the correction have little impact on the beam size? (Collective effects..?)
- Why did the BPM couplings change so much in a two-week period?
- Why did the lifetime increase after the second coupling correction on 30 May?

Tentative explanation and proposal

- The observed behaviour of the machine may be explained if vertical dispersion from steering makes a significant contribution to the vertical emittance.
  - The fitted model does not include steering effects.
  - We can perform simulations to investigate this hypothesis.
- We may hope to achieve better results (lower vertical emittance) if we reduce the orbit distortion.
  - We need to apply beam-based alignment rigorously to determine the "optimum" steering (to the quad centres.)
- **Regular, systematic** use of BBA and ORM (and other techniques) will be needed to achieve vertical emittance <5 pm.