Update on emittance coupling studies at the Australian Synchrotron

Rohan Dowd
Senior Accelerator Physicist, Australian Synchrotron, ANSTO

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Overview

- Observations on multipole magnet alignment

- Further investigation of results near quantum limit

- Ongoing work

Motivation for Beam Based Magnet Alignment at AS

- Seeking to eliminate coupling from all sources in the ring
- Coupling terms in multipole magnets rise from quadrupole rolls and sextupole vertical offsets.

- Ring re-alignment based entirely on laser tracker sometimes made coupling worse
  - Alignment survey positioning doesn’t tell you what is happening at the magnetic centre.

- The beam is very similar to a vibrating wire. It samples the magnetic fields along the curved beam path.

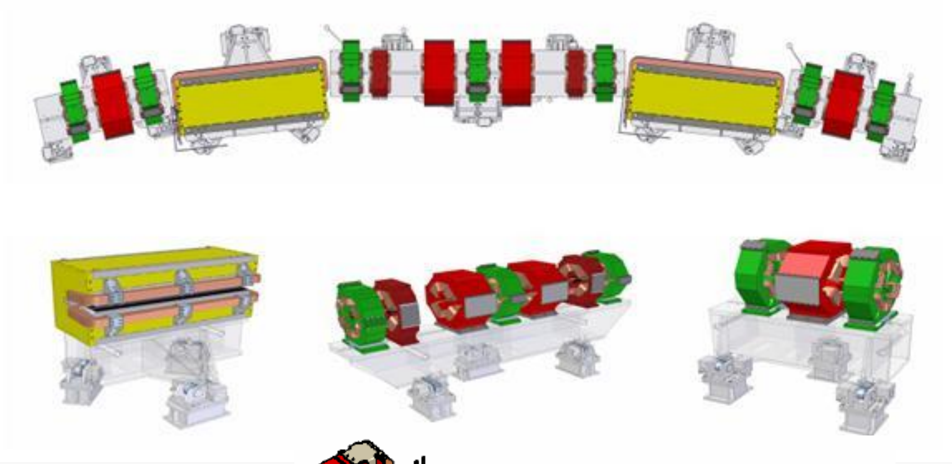
- Beam orbit response matrix analysis should allow you to find the alignment errors by picking out the effects of offset fields.

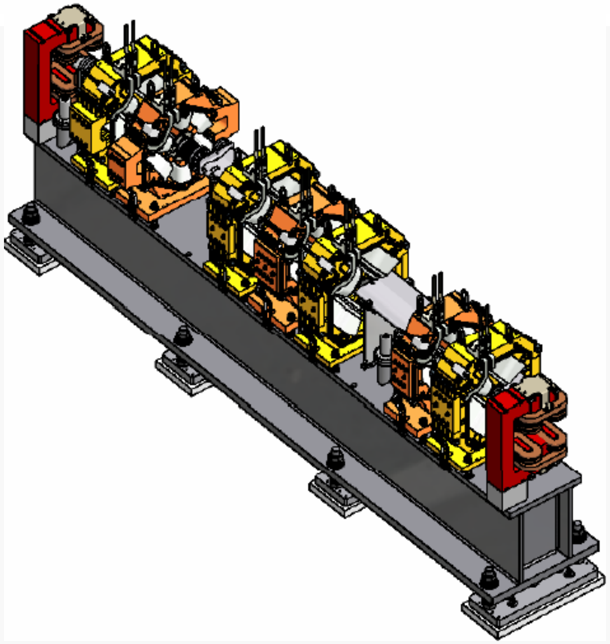
Mechanical alignment Methods - Examples

- AS uses laser tracker and magnet fiducials. Magnet to magnet resolution ~ 25-50 micron (but magnetic centre somewhat uncertain).

- NSLS II employs a vibrating wire measurement. Resolution of finding magnetic centre is 5-10 micron. Locked onto girder then installed. Overall magnet to magnet positioning claimed < 30 micron (15-20?),

- What about Beam based Alignment?



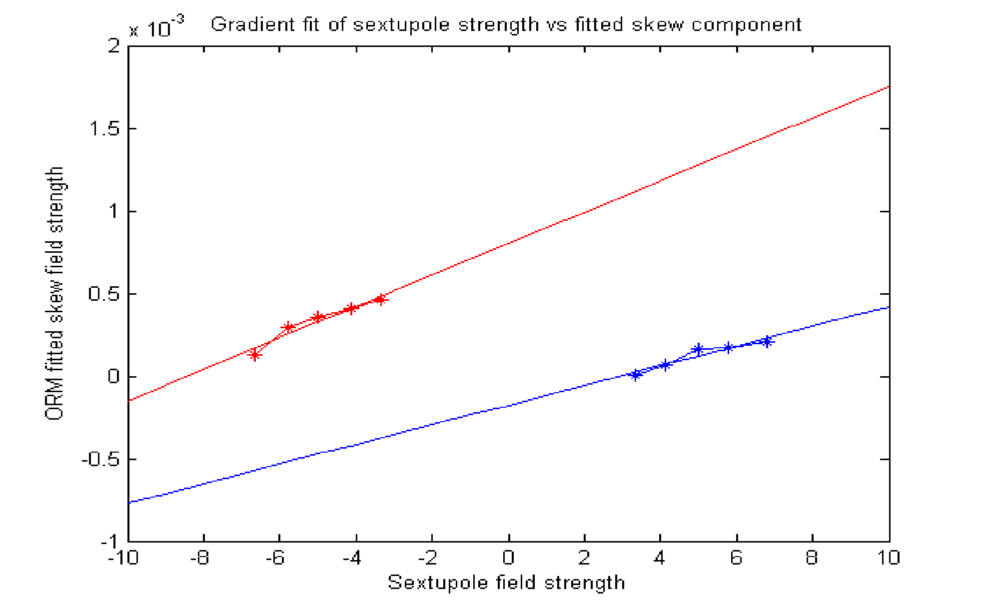


Multipole offset measurements

•Shunt each sextupole magnet family to different strengths and take a response matrix at each point

•Perform LOCO analysis and fit quadrupole and skew quadrupole terms to each sextupole

•Gradient of quad/skew quad field vs main field gives the offset.



Accuracy Assessment

Applied BPM Offset	Measure Mean Beam Offset	Difference from zero
+125	234.6 ± 10.6	128.7 ± 18.8
+75	167.7 ± 16.5	61.8 ± 22.6
0	105.9 ± 15.5	0
-75	33.1 ± 17.8	-72.8 ± 23.6
-125	-16.1 ± 21.6	-122 ± 26.6

Magnet	Original Offset (µm)	Applied Shim (µm)	New Offset (µm)	Delta offset (µm)
Sector 9 SFB	-108.4 ± 44.6	150	-249.3 ± 7.2	-140.9 ± 45.2
Sector 11 SFB	-56.7 ± 10.0	100	-120.4 ± 56.0	-63.4 ± 57.4
Sector 9 SDA	-14.6 ± 9.9	100	-118.3 ± 8.3	-103.7 ± 14.1

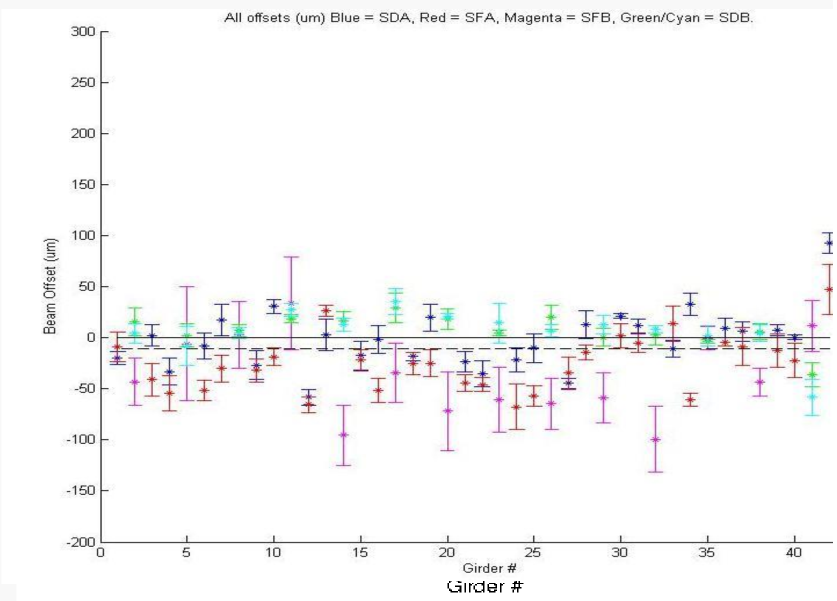
Cross checks show that amplitude of offset is correct and individual magnets can be adjusted accurately.

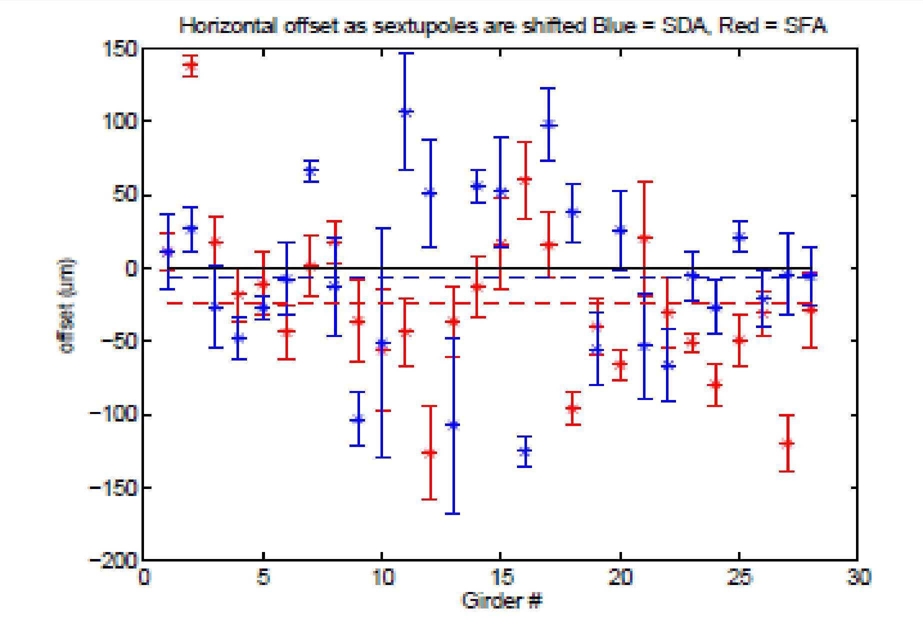
Multipole offset measurements

• We were lucky with the vertical offset, most sextupoles were too low and therefore we could shim them individually.

•Have no way of mechanically shifting magnets horizontally

•Average vertical offset reduced to <15 um.





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Quadrupole rolls

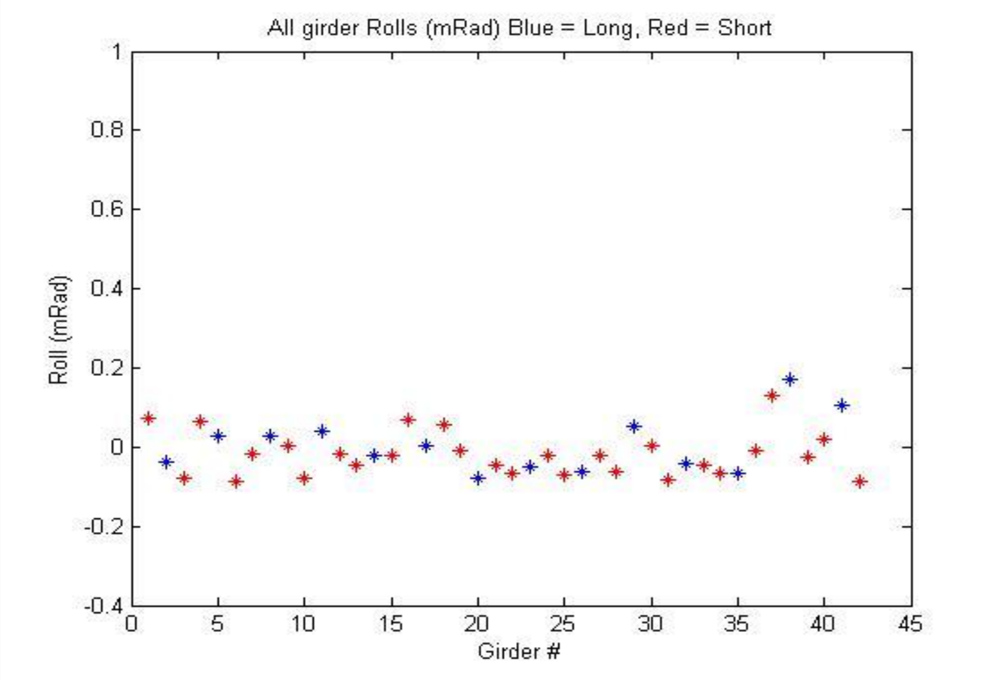
•Turn off Sextupoles and perform LOCO analyis of quadrupoles.

• Unable to roll individual magnets, so whole girder is rolled.

•Roll Girders by the amount indicated in the LOCO analysis and re-measure.

•Method was found to be accurate to ±0.05 mRad. Mechanical precision of setting the girders ±0.1 mRad. Rolls now reduced to < 0.2 mRad.

•May be compensating for other magnet misalignments



Girder roll (mRad) progression over several alignment iterations

Beam based alignment summary

- Sextupole horizontal and vertical offsets can be measured with the beam to a accuracy of 10-50 microns depending on the magnet position. The larger inaccuracies may be reduced with more development of the technique. Comparable with vibrating wire method but much less effort and **in-situ**.

- Quadrupole rolls can be measured to 0.05 mrad and corrected down to 0.1 mrad (or less, if girder supports allow and multiple iterative).

- LOCO analysis tends to ‘smear’ out effects across multiple magnets depending on BPM density. Need to take care when analysing and separate shunted magnets by appropriate distance. .

- We hoped to get better results from single magnet shunts, but preliminary investigations did not yield clear results above noise.

Vertical emittance minimisation method recap

- Measure orbit response matrix and dispersion. Analyse with LOCO, fit skew quad components to every multipole in the ring.

- Use LOCO calibrated lattice to calculate equilibrium beam envelope in AT, using Ohmi method (K.Ohmi et al. Phys.Rev.E. Vol.49. (1994)). Calculate Vertical emittance from this. This calculation takes vertical dispersion into account.

- Feed calculated emittance into minimisation algorithm which adjusts the skew quadrupole currents in the model to minimise it (or set it to an **arbitrary** value) by adjusting betatron coupling and vertical dispersion simultaneously.

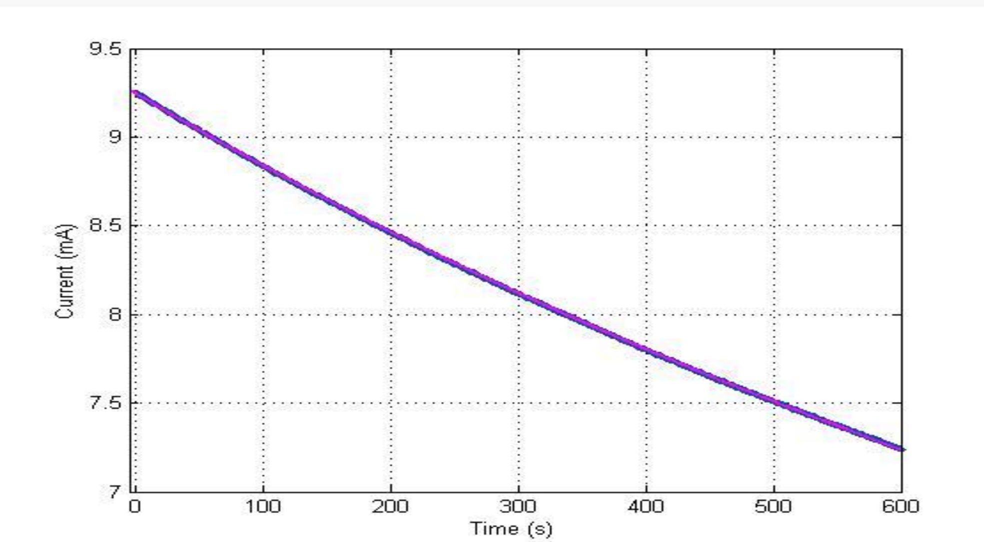
- Apply skew quadrupole settings onto machine and re-do LOCO analysis. Calculate vertical emittance from calibrated lattice. (iterate if necessary)

- Calculated emittance incorporates coupling and vertical dispersion effects only, not radiation opening angle.

Touschek Lifetime Fitting

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

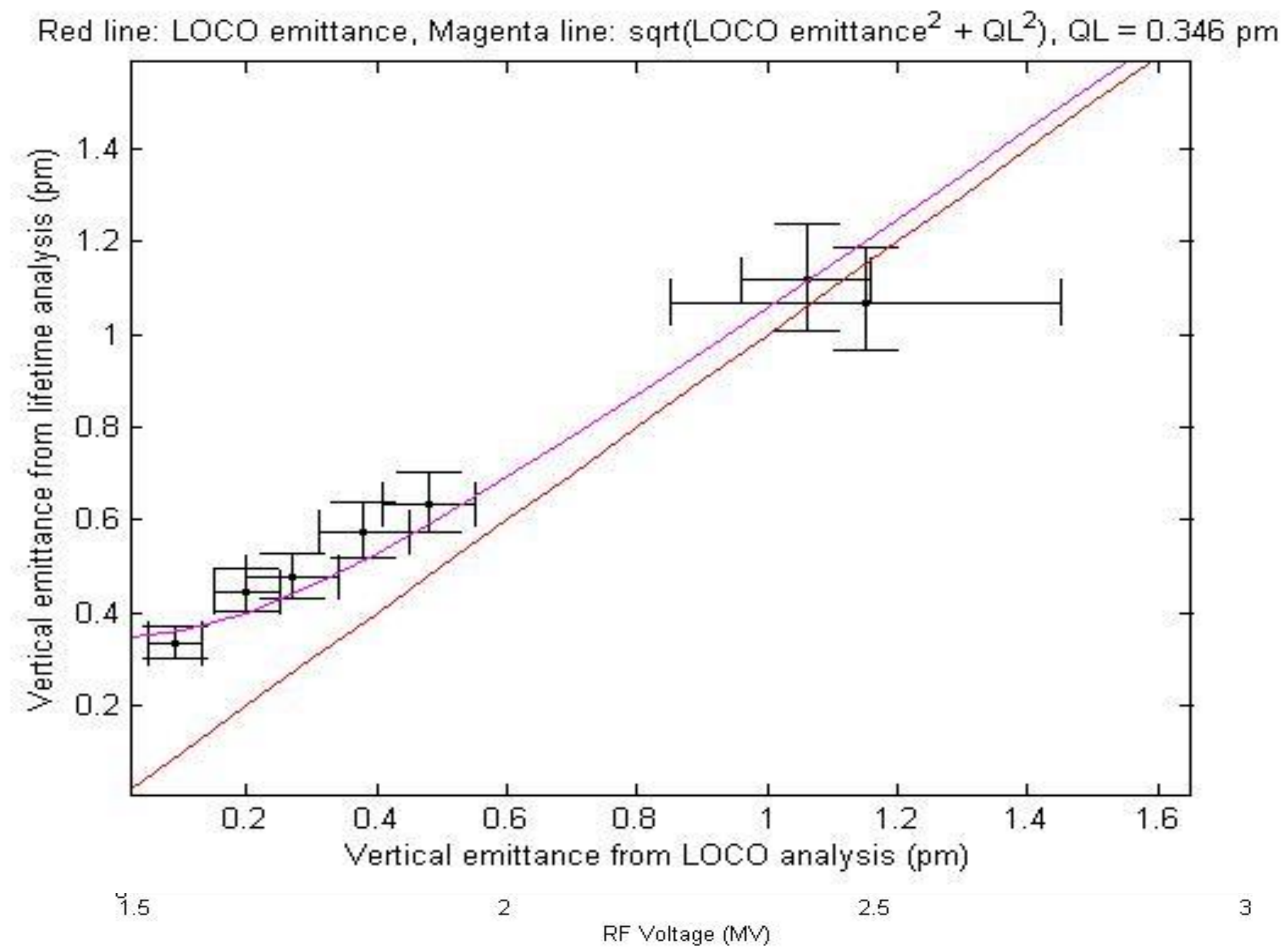
$$\frac{1}{T} = \left\langle \frac{r_p^2 c \beta_x N_p}{8\pi\beta\gamma^3\sigma_{x\beta}\sigma_{y\beta}\sigma_z\widetilde{\sigma}_x} \int_{\tau_m}^{\infty} \left((2+\frac{1}{\tau})^2 (\frac{\tau/\tau_m}{1+\tau} - 1) + 1 - \frac{\sqrt{1+\tau}}{\sqrt{\tau/\tau_m}} - \frac{1}{2\tau}(4+\frac{1}{\tau}) ln(\frac{\tau/\tau_m}{1+\tau}) \right) e^{(-\frac{\tau\epsilon_m}{\tau_m})} \frac{d\tau}{\sqrt{1+\tau}} \right\rangle$$



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

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

Touschek Lifetime Analysis - Previous results



The problem.

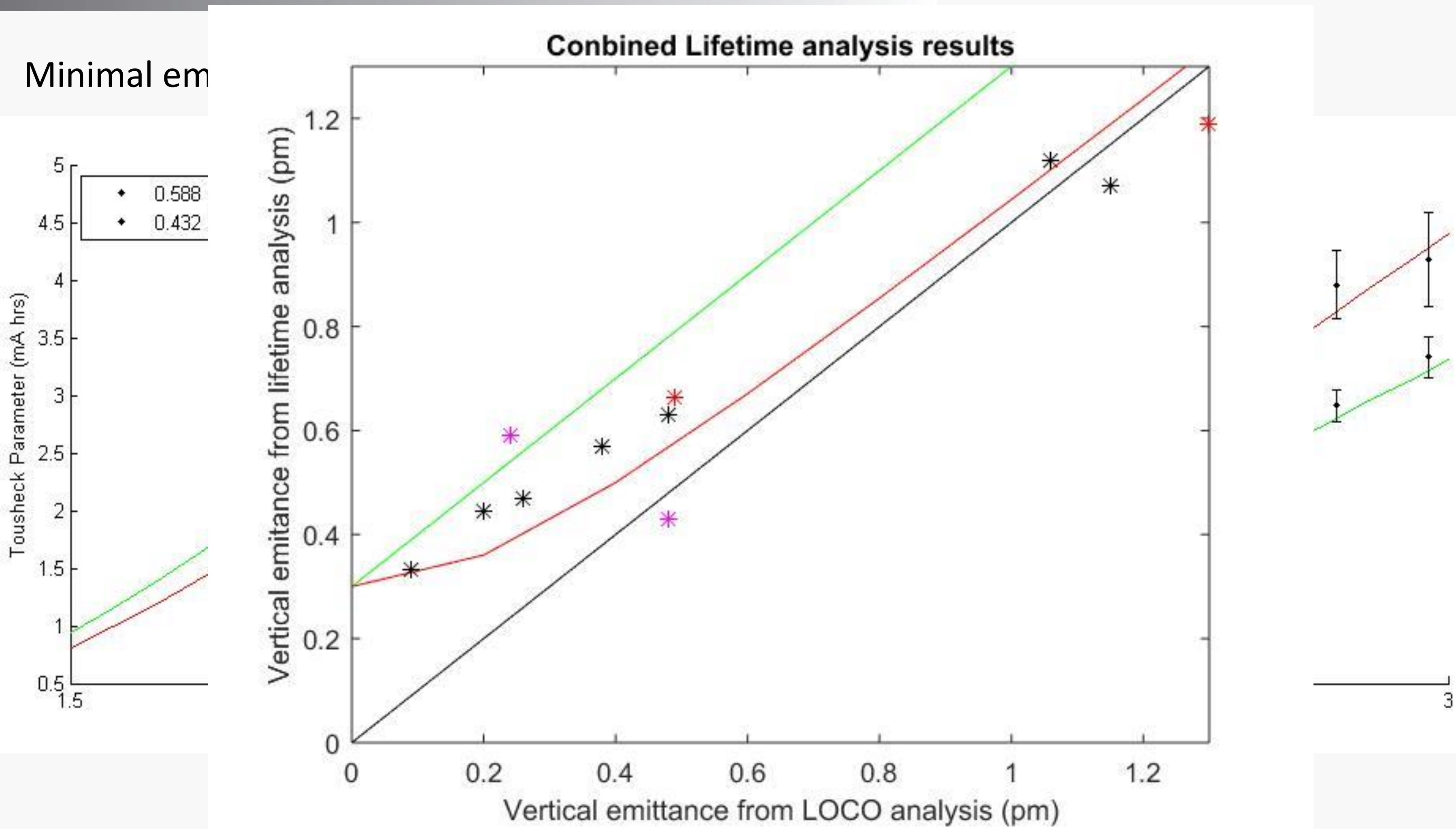
- Emittances are normally added linearly however the data best follows a quadratic line

- How should the quantum limit be added?
  - It is a reduction in the rate of radiation damping as the emittance approaches zero – so should it really add in the normal way?
  - Add appropriate term to radiation diffusion matrix in Ohmi calculation?

- Is this pattern just a quirk of the data I collected? Will more data show something different?

Results with difference lattice configurations.

Minimal em



Need more results but similar pattern is emerging.

Ongoing work

- Decrease uncertainty in multipole offset measurments.
- Investigation of alternate methods for beam based alignment of multipoles without full LOCO analysis.

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- Need to incorporate opening angle into Ohmi envelope calculation equation to see how it behaves near this limit.

- More investigation into alternative lattices needed to confirm pattern.