“Comparing the Measured and Designed Performance of the Diamond Storage Ring”

I. Martin

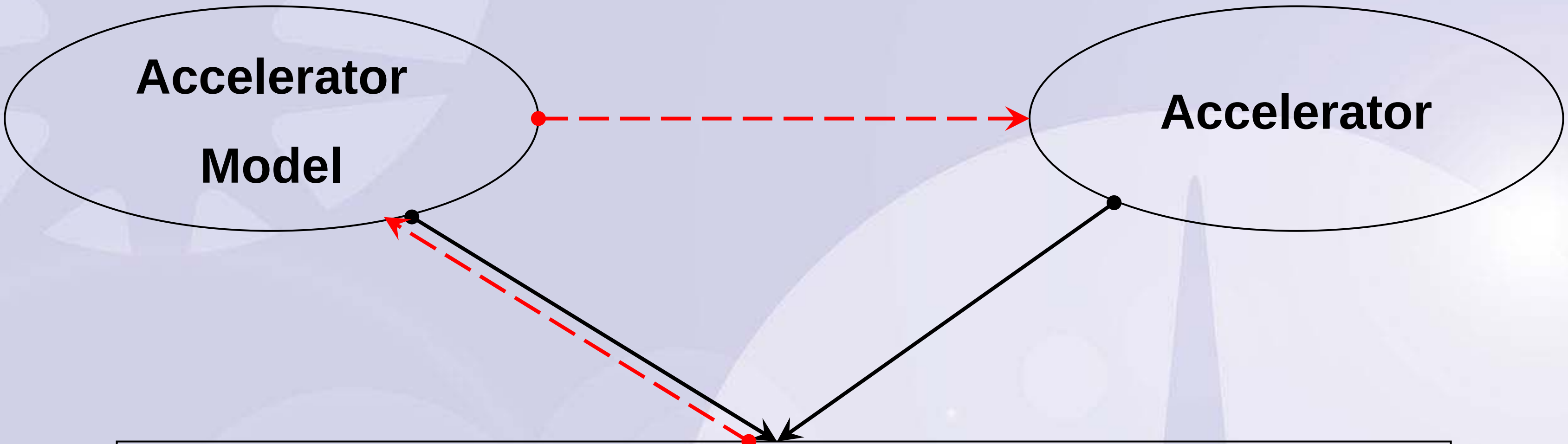
Non-Linear Beam Dynamics in Storage Rings: From Modelling to Experiment
26th to 28th May 2008

diamond

Talk Outline

1) Linear optics
   - Correction with LOCO
   - Summary of main parameters
2) Non-linear optics
   - Dynamic aperture / FMA measurement
   - Sextupole calibration method using tune-shift
   - Application to machine
3) Lifetime measurements
4) Summary

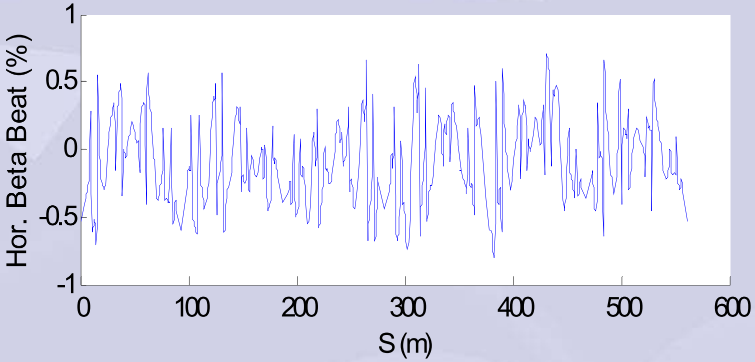
1) Linear Optics

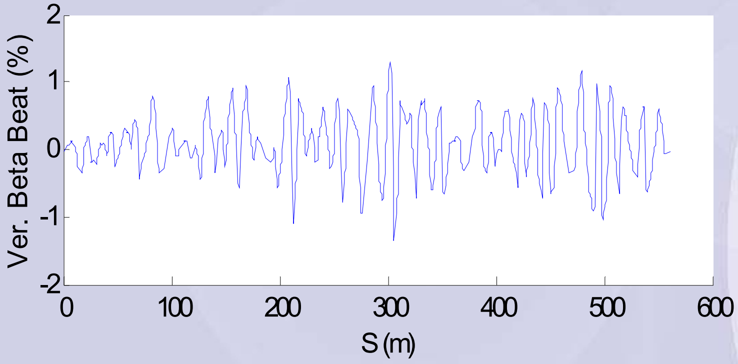


- Closed Orbit Response Matrix (LOCO)
- Detuning with amplitude (and with momentum)
- Frequency Map Analysis
- Frequency Analysis of Betatron Motion (resonant driving terms)

1) Linear Optics - LOCO

Linear-optics corrected using LOCO*





Original LOCO optimisation:

Beta beat ~40% reduced to ~1-2%
Coupling <~0.1%
Injection efficiency ~100%
Vertical dispersion ~8mm to ~0.4mm

Modified LOCO optimisation:

Beta beat ~40% reduced to ~1%
Coupling <~0.1%
Injection efficiency ~100%
Vertical dispersion ~6mm to ~0.3mm

*J. Safranek, *"Experimental Determination of Storage Ring Optics Using Orbit Response Measurements"*, Nucl. Inst. And Meth. A388, 27 (1997)

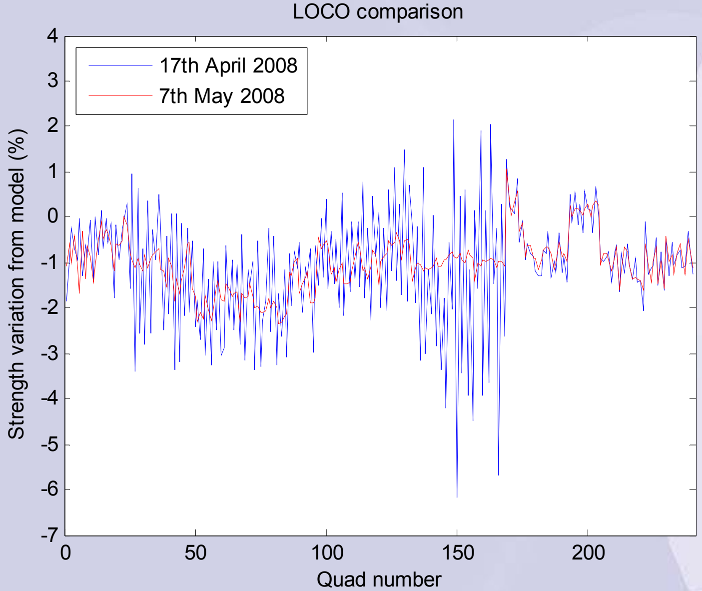
1) Linear Optics - LOCO

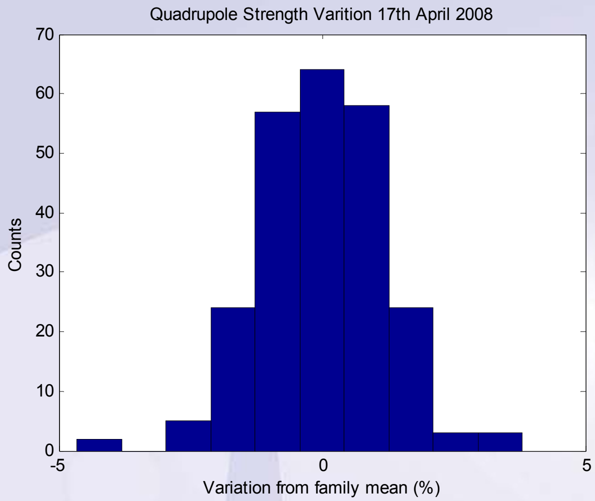
Quadrupole spread much reduced

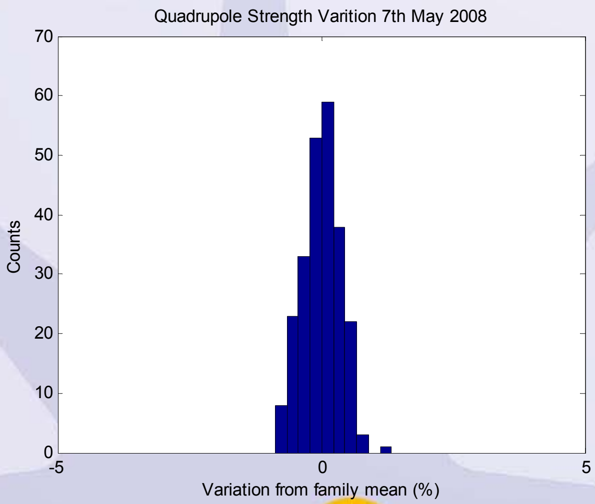
<u>NO consequent drop in performance!</u>

N.B. Quad strength slightly low:

- Calibration problem? Beam Energy?







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1) Linear Optics - Summary

	Target	Measured
Emittance	2.74 nm.rad	2.6-2.9 nm.rad
Energy Spread	0.096%	0.09% - 0.11%
Coupling	<1%	<0.1% to >3%
Tunes (x / y)	27.225 / 12.363	27.225 / 12.363
Natural Chromaticity (x / y)	-79 / -35	-68 / -28
Bunch Length (2MV)	13.5ps	~14.5ps
Bunch Length (3.3MV)	9.5ps	~10.3ps
Momentum compaction factor	1.71e-4	1.76e-4

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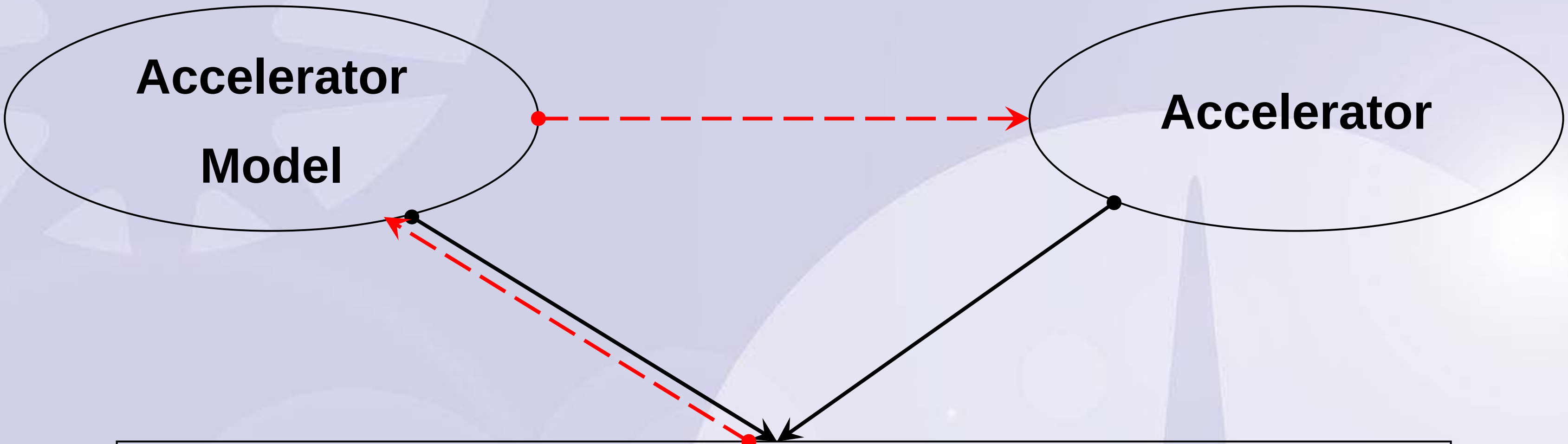
2) Non-Linear Optics



- Closed Orbit Response Matrix (LOCO)
- Detuning with amplitude (and with momentum)
- Frequency Map Analysis
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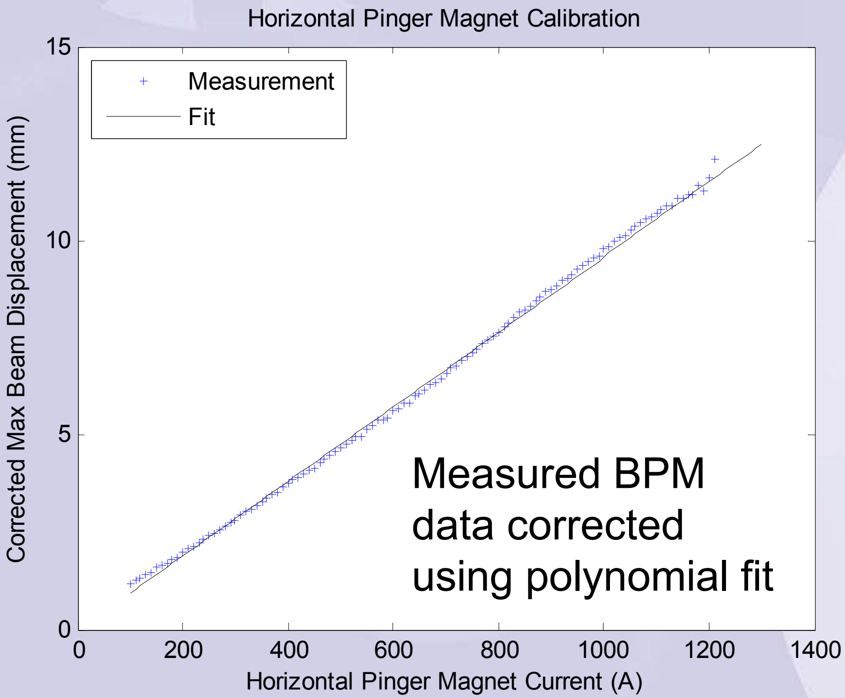
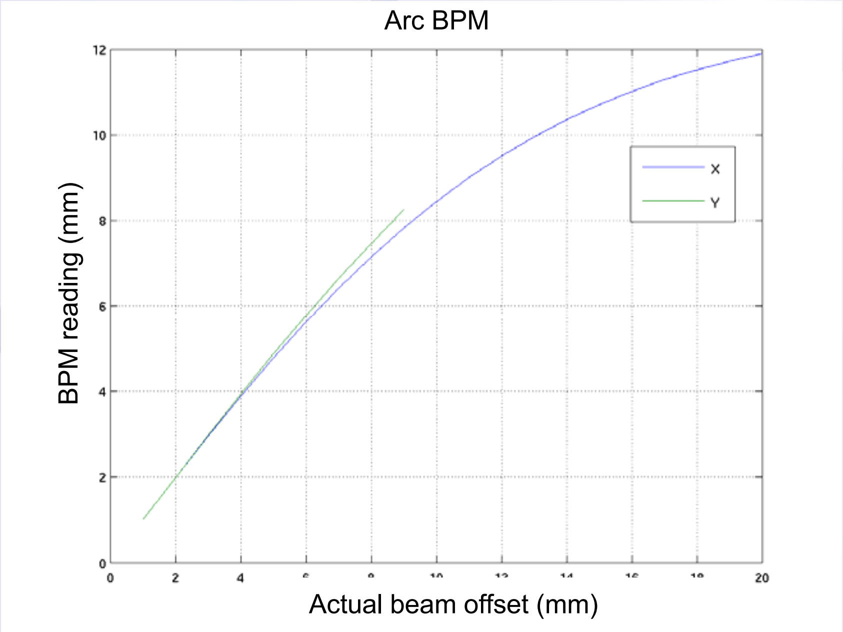
2) Non-Linear Optics - Hardware

- Non-linear beam dynamics investigated using ‘pinger’ magnets (3μs pulse)
- BPM non-linearities taken into account
- Measured BPM date scaled with beta back to centre of long straight (injection point)





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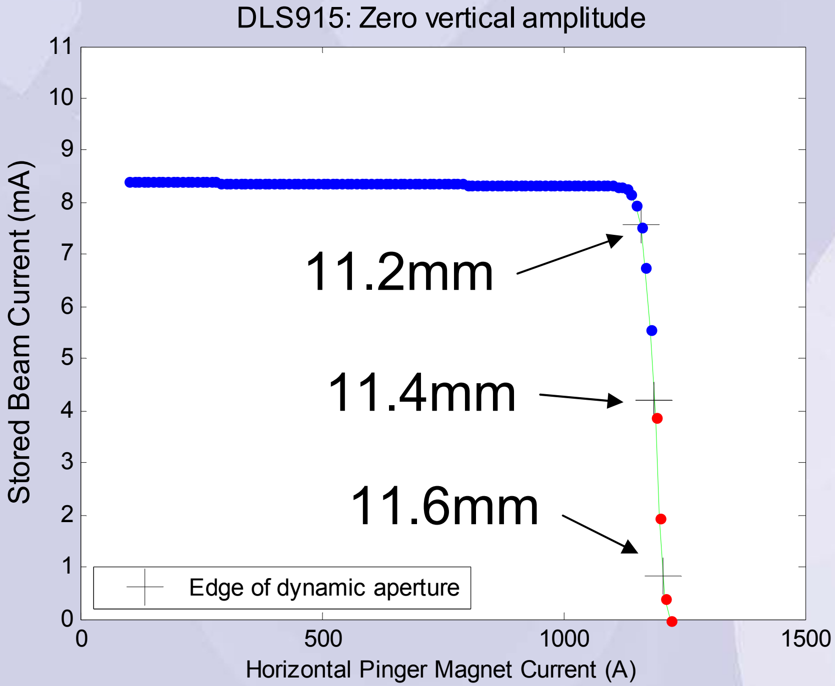
2) Non-Linear Optics – Dynamic Aperture

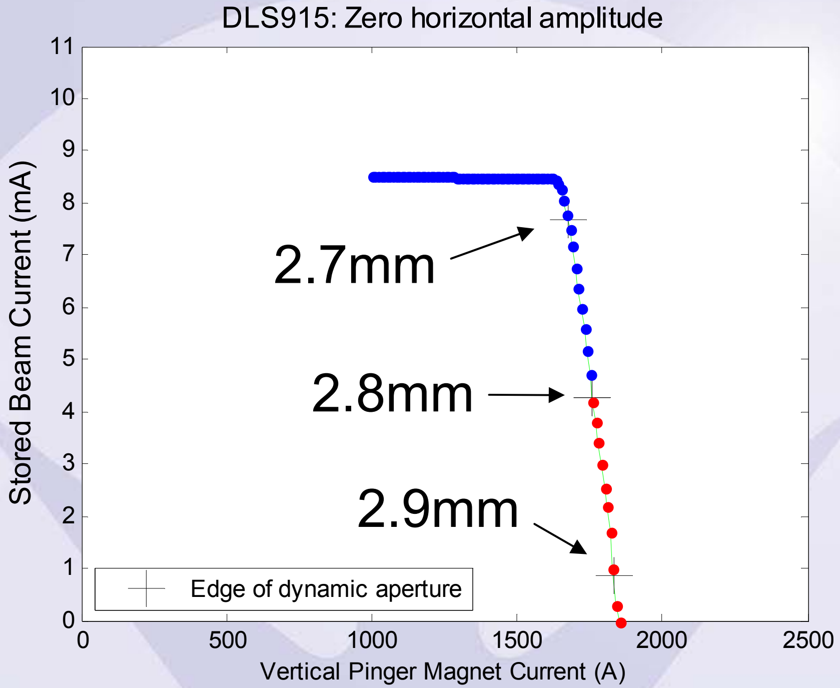
Horizontal Dynamic Aperture

(Zero vertical amplitude)



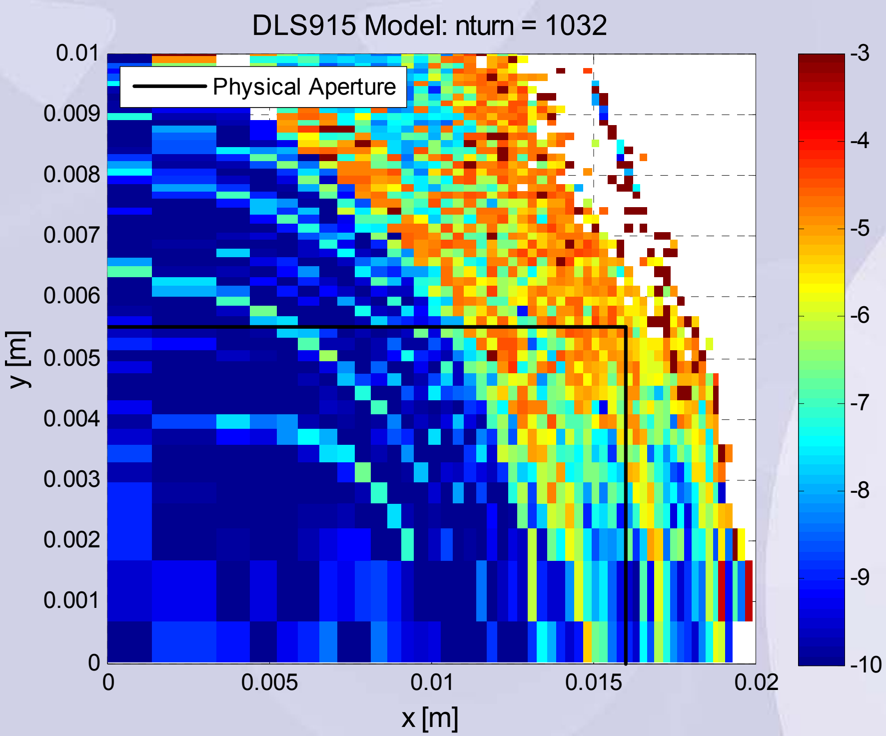
Vertical Dynamic Aperture

(Zero horizontal amplitude)

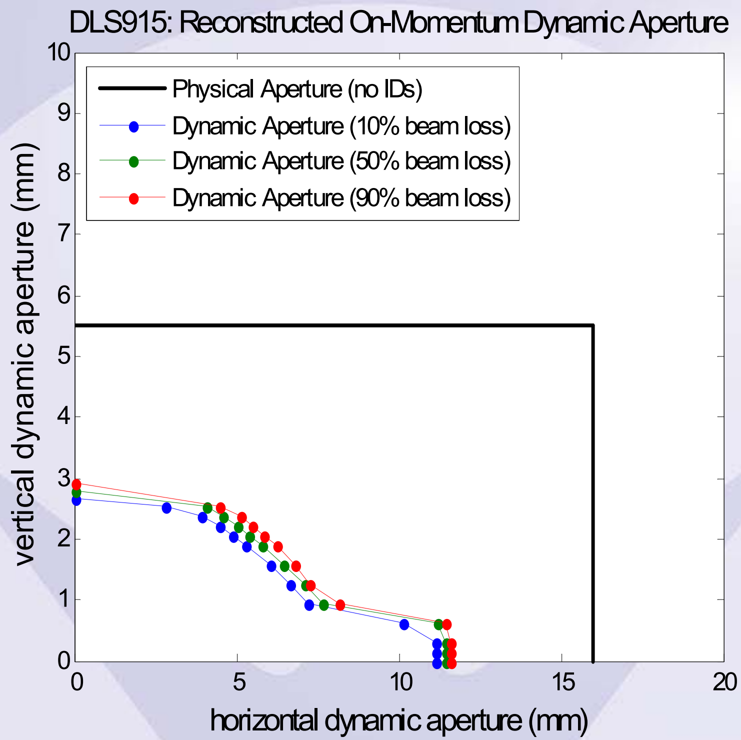


2) Non-Linear Optics – Dynamic Aperture

Model Dynamic Aperture



Measured Dynamic Aperture



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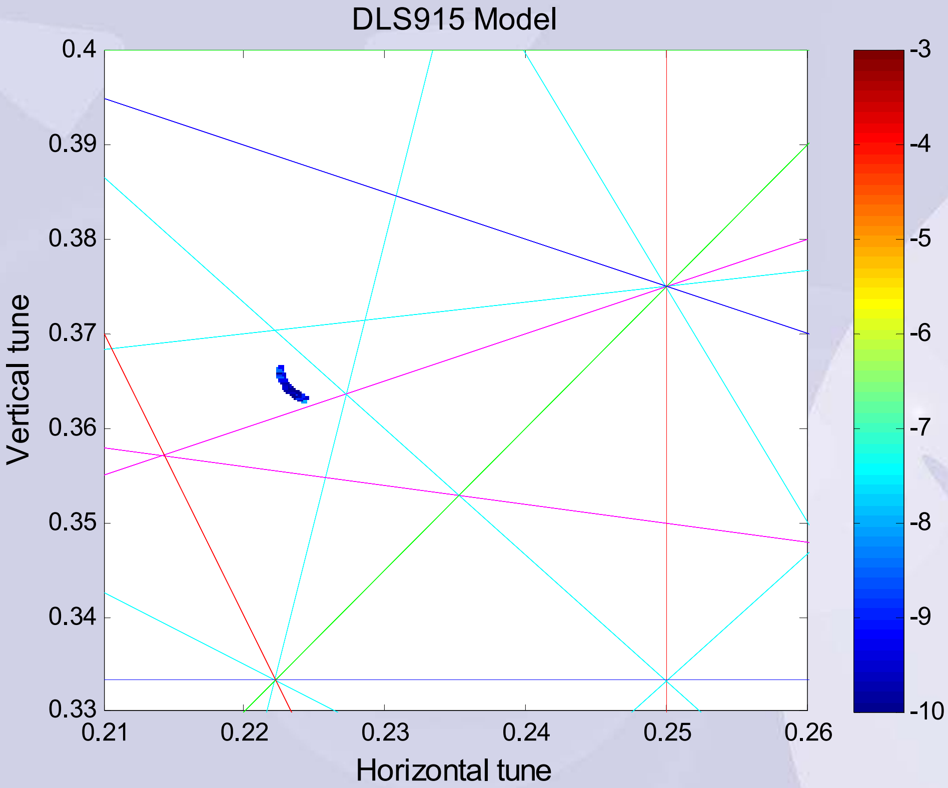
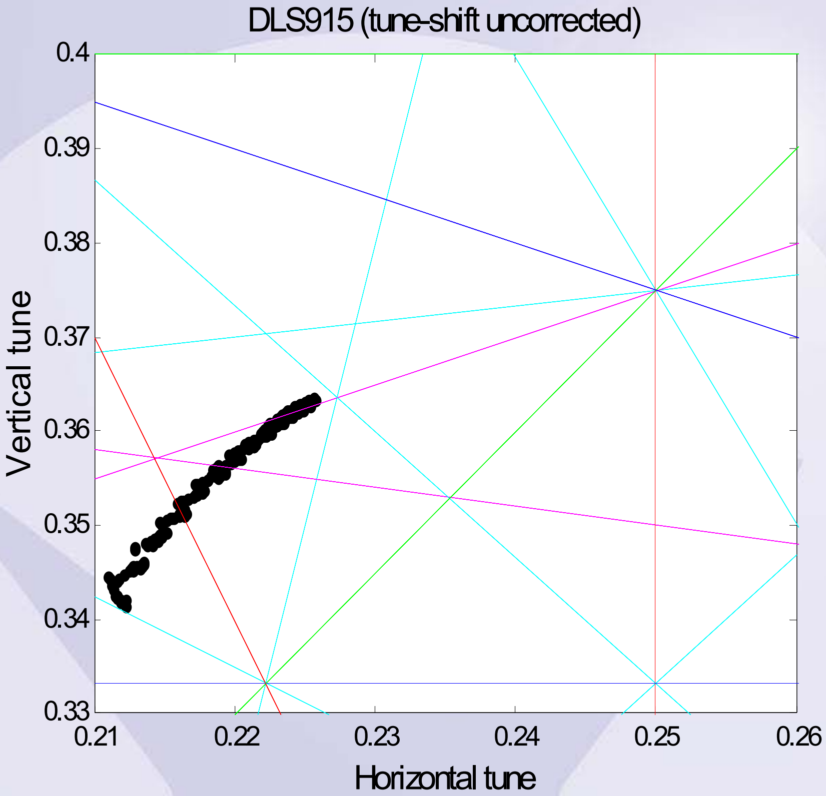
2) Non-Linear Optics – Frequency Map

Model Frequency Map



Measured Frequency Map



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Non-Linear Beam Dynamics in Storage Rings Workshop, I. Martin, 27th May 2008

2) Non-Linear Optics – Tune Shift Correction

Developed method to correct tune-shifts with amplitude:

1. Measure chromaticity and tune-shifts with amplitude
2. Build sensitivity matrix measuring the tune-shift response to sextupole strength variations (attempt to linearise problem)
3. Apply corrections to machine sextupoles
4. Iterate until convergence reached

2) Non-Linear Optics – Tune Shift Correction

Define vectors:

$$t = \left[\frac{dQ_x}{dx^2}, \frac{dQ_y}{dx^2}, \frac{dQ_x}{dy^2}, \frac{dQ_y}{dy^2}, \frac{dQ_x}{dp}, \frac{dQ_y}{dp} \right]$$

$$s = [K_{S1A}, K_{S2A}, K_{S1B}, K_{S2B}, K_{S1C}, K_{S2C}, K_{S1D}, K_{S2D}]$$

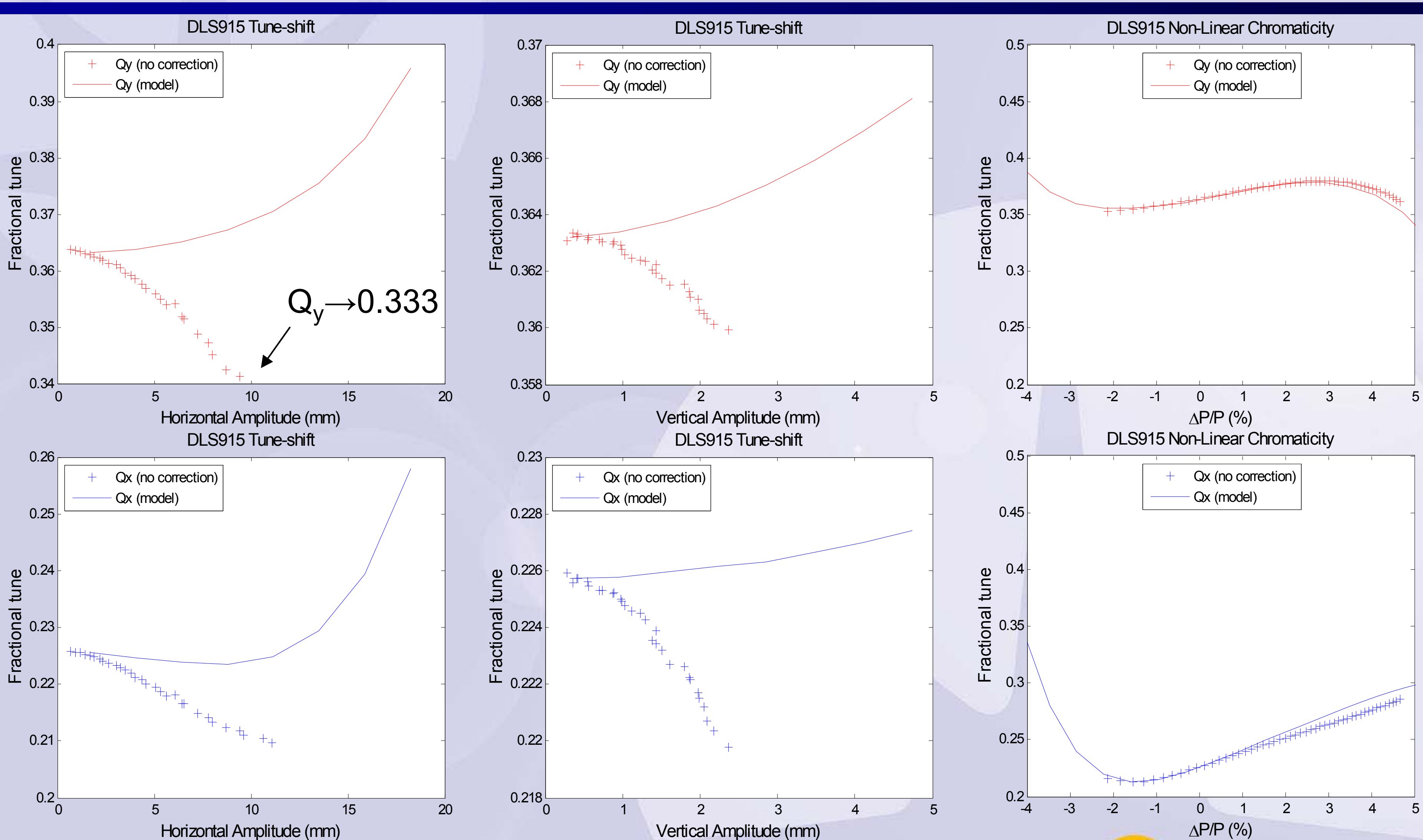
Generate linearised sensitivity matrix *R*:

$$R_{i,j} = \frac{\Delta t_i}{\Delta s_j}$$

Invert *R* and use to calculate sextupole gradient corrections

$$\Rightarrow \Delta s = R^{-1} \ \Delta t$$

2) Non-Linear Optics – Tune Shift Correction



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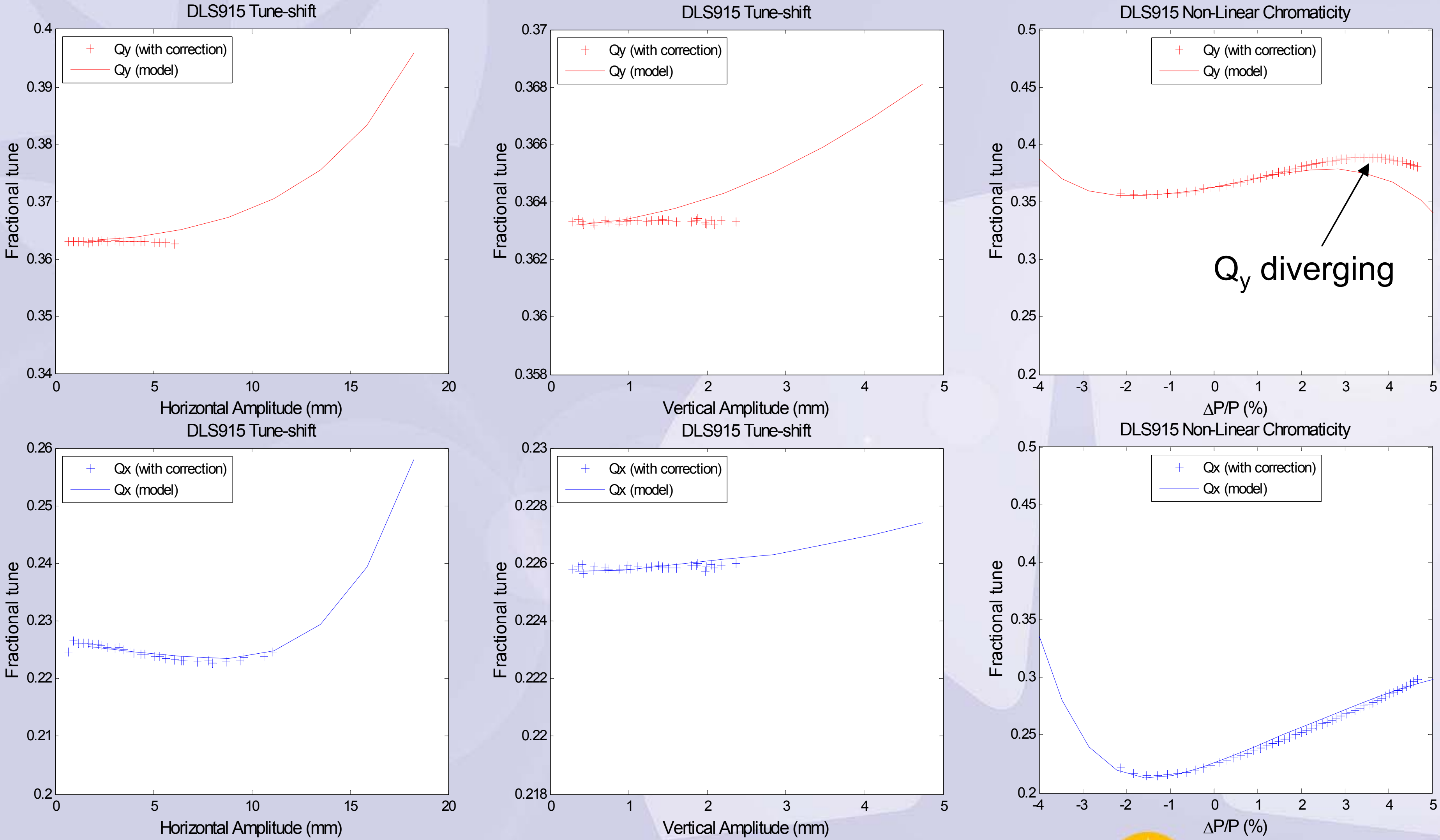

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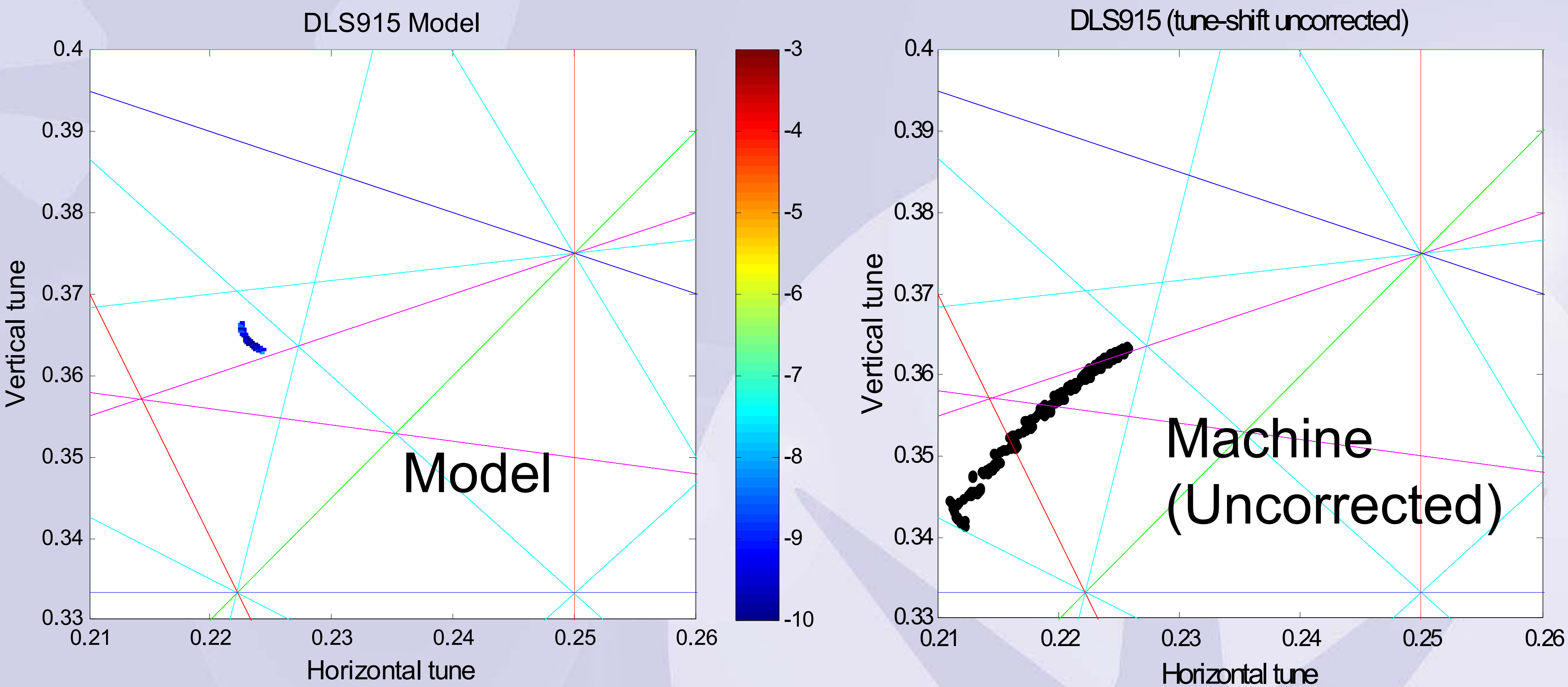

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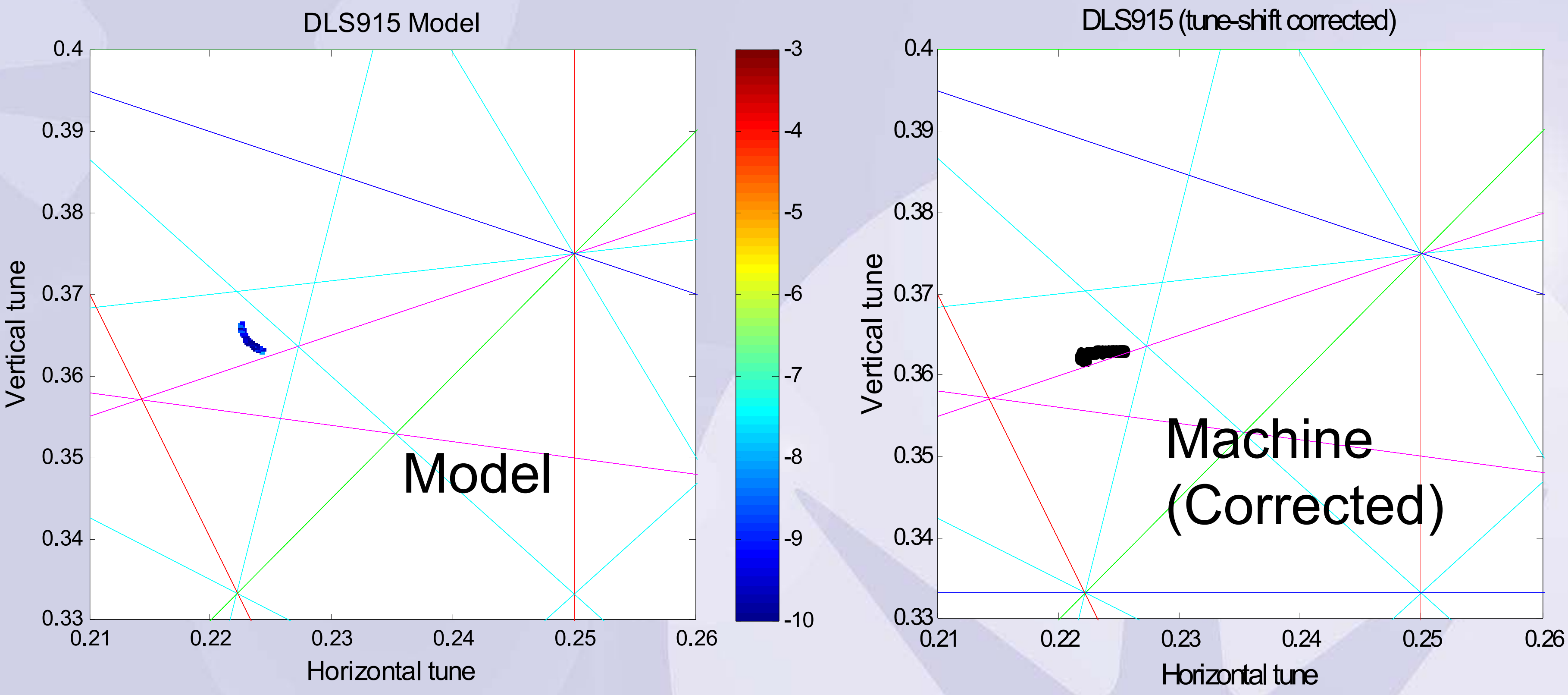
2) Non-Linear Optics – Tune Shift Correction



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2) Non-Linear Optics – Tune Shift Correction

But does it help?

A successful sextupole optimisation should:

- Give increased Touschek lifetime
- Give increased dynamic aperture
- Give information about sextupole calibration constants

Need to confirm benefits of optimisation….

2) Non-Linear Optics – Tune Shift Correction

Applied tune-shift correction procedure for 3 different starting points:

Case 1 (model):

model sextupoles

Case 2 (user):

model sextupoles with chromatic increased to give chromaticity +2/+2

Case 3 (fit):

model sextupoles scaled to make measured chromaticity match expected values from the model (chromaticity +1.6 / +0.85)

2) Non-Linear Optics – Tune Shift Correction

Initial sextupole strengths:

	CASE 1 (MODEL)	CASE 2 (USER)	CASE 3 (FIT)
S1A (m^{-3})	+18.2	+19.3 **(+6.3%)**	+18.8 **(+3.8%)**
S2A (m^{-3})	-16.8	-18.1 **(+8.0%)**	-17.6 **(+4.8%)**
S1B (m^{-3})	+10.5	+10.5 **(+0.0%)**	+10.9 **(+3.8%)**
S1C (m^{-3})	+8.5	+8.5 **(+0.0%)**	+8.8 **(+3.8%)**
S1D (m^{-3})	+6.9	+6.9 **(+0.0%)**	+7.2 **(+3.8%)**
S2B (m^{-3})	-16.6	-16.6 **(-0.0%)**	-17.3 **(+3.8%)**
S2C (m^{-3})	-10.9	-10.9 **(-0.0%)**	-11.3 **(+3.8%)**
S2D (m^{-3})	-16.8	-16.8 **(-0.0%)**	-17.4 **(+3.8%)**

CHROMATIC sextupoles in green, HARMONIC sextupoles in red

2) Non-Linear Optics – Tune Shift Correction

Final sextupole strengths:

	CASE 1 (MODEL)	CASE 2 (USER)	CASE 3 (FIT)
S1A (m^{-3})	+18.9 **(+4.0%)**	+18.8 **(+3.8%)**	+18.8 **(+3.7%)**
S2A (m^{-3})	-17.6 **(+4.8%)**	-17.5 **(+4.5%)**	-17.5 **(+4.6%)**
S1B (m^{-3})	+11.1 **(+5.3%)**	+11.1 **(+5.8%)**	+10.9 **(+4.0%)**
S1C (m^{-3})	+8.4 **(-0.4%)**	+8.7 **(+2.2%)**	+8.9 **(+5.2%)**
S1D (m^{-3})	+6.8 **(-2.2%)**	+6.7 **(-3.5%)**	+6.9 **(+0.3%)**
S2B (m^{-3})	-16.9 **(+1.4%)**	-16.7 **(+0.2%)**	-16.9 **(+1.5%)**
S2C (m^{-3})	-11.0 **(+1.2%)**	-11.3 **(+3.6%)**	-11.4 **(+4.9%)**
S2D (m^{-3})	-17.8 **(+6.0%)**	-18.2 **(+8.6%)**	-18.2 **(+8.5%)**

CHROMATIC sextupoles in green, HARMONIC sextupoles in red

2) Non-Linear Optics – Tune Shift Correction

After tune-shift correction procedure applied:

- On-momentum dynamic aperture REDUCED
- Touschek lifetime INCREASED

	USER	CASE 1	CASE 2	CASE 3
Max. Horizontal Kick (mm)	11.4	10.3	10.1	10.2
Max. Vertical Kick (mm)	2.7	2.5	2.4	2.3
Single bunch lifetime (1mA, 3MV)	4.4h	5.1h	5.3h	5.5h

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2) Non-Linear Optics - Summary

Tune-shift correction procedure shows mixed results:

- Tune shifts can be matched to model for low amplitudes
- Increased Touschek lifetime

However:

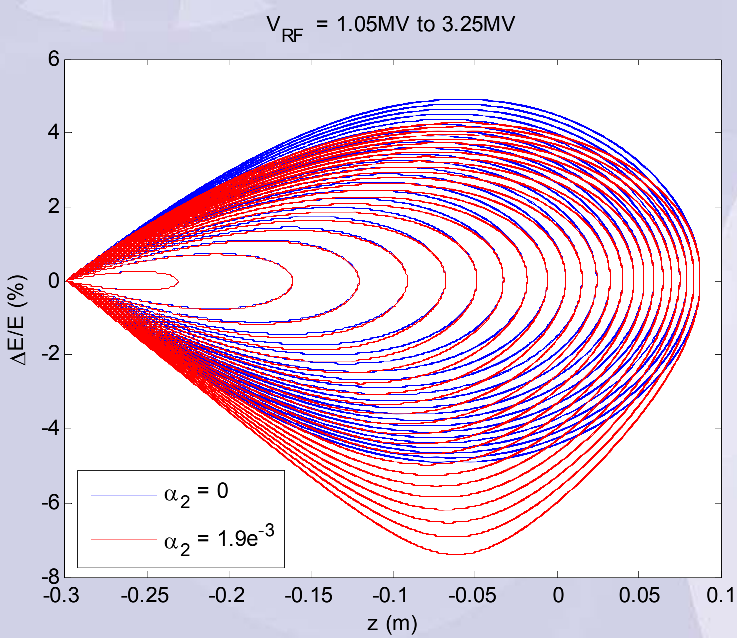
- At larger amplitudes machine and model tune-shifts still diverge
- Reduced on-momentum dynamic aperture
- Large changes required for sextupoles (unlikely from calibration)
- Not unique solution (could include higher order chromaticity in fit?)
- Difficult to measure precisely (tunes drift slightly with time / close to precision of measurement)

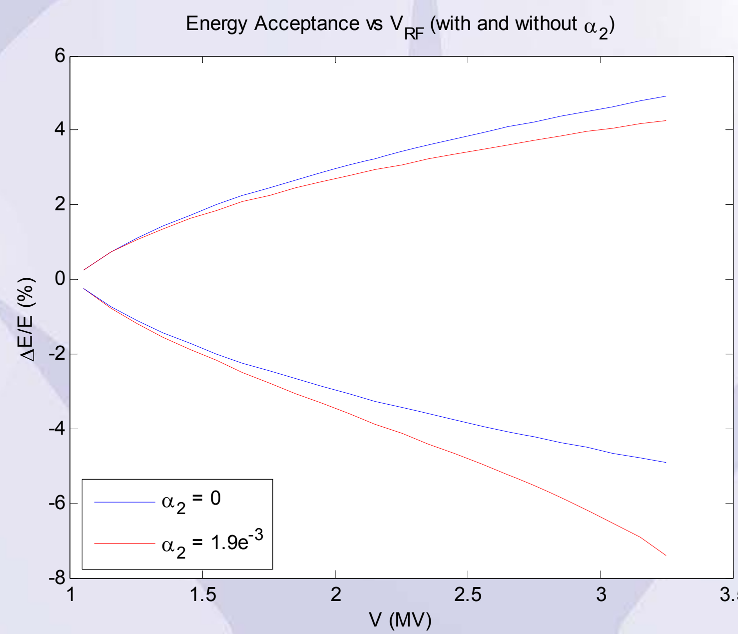
3) Lifetime

Diamond storage ring is Touschek dominated for currents > ~0.1mA

→ Single bunch lifetime is a measure of overall momentum acceptance

Note 2nd order mom. comp. factor strong (α_1=1.7×10^{-4}, α_2=1.9×10^{-3})





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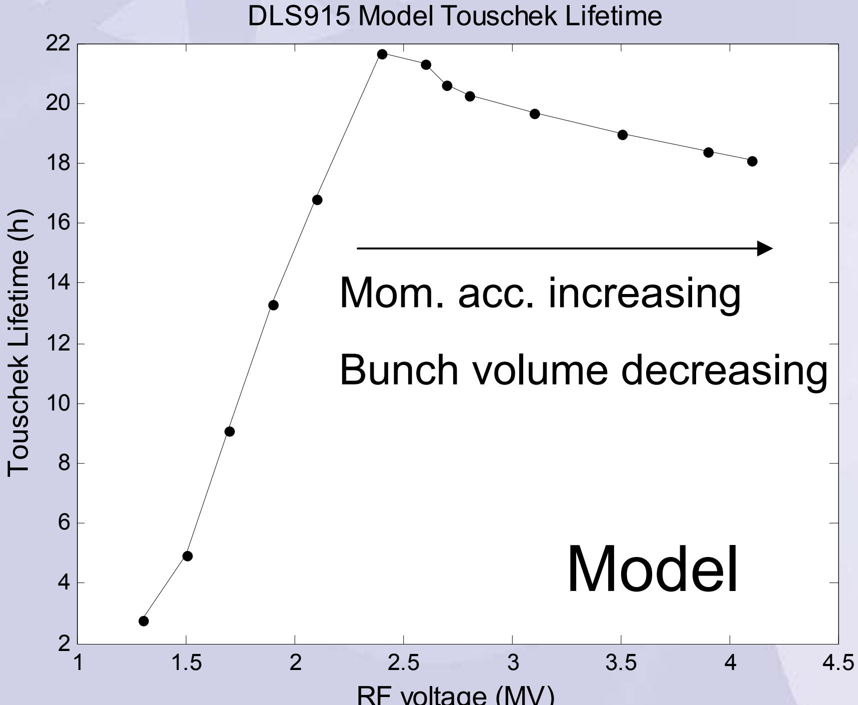
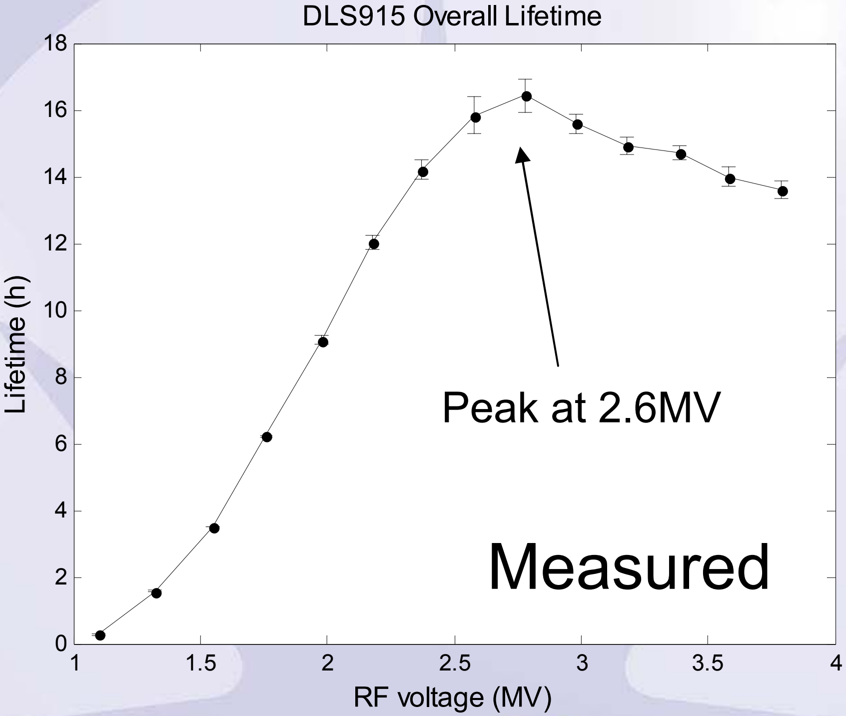
3) Lifetime

For V_{RF} below 2MV, mom. acc. is limited by RF only

For V_{RF} above 2MV, mom. acc. is limited by RF and dynamic aperture

Maximum lifetime is at 2.6MV (mom. acc. = +3.5% / -5%)





Courtesy Beni Singh

4) Summary

Linear optics:

•Generally understood (well corrected / controlled)

•Still some anomalies to be explained (bunch length, natural chromaticity)

Non-linear optics:

•Testing different methods for calibrating sextupoles

•Some success in producing desired beam dynamics, but

•Resulting sextupole strengths far from expected values

•Only the targeted beam dynamics parameters are corrected

Still some way to go…

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DLS Operations Group