Coupling studies at Diamond

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Outline

• Assumptions and numerical studies

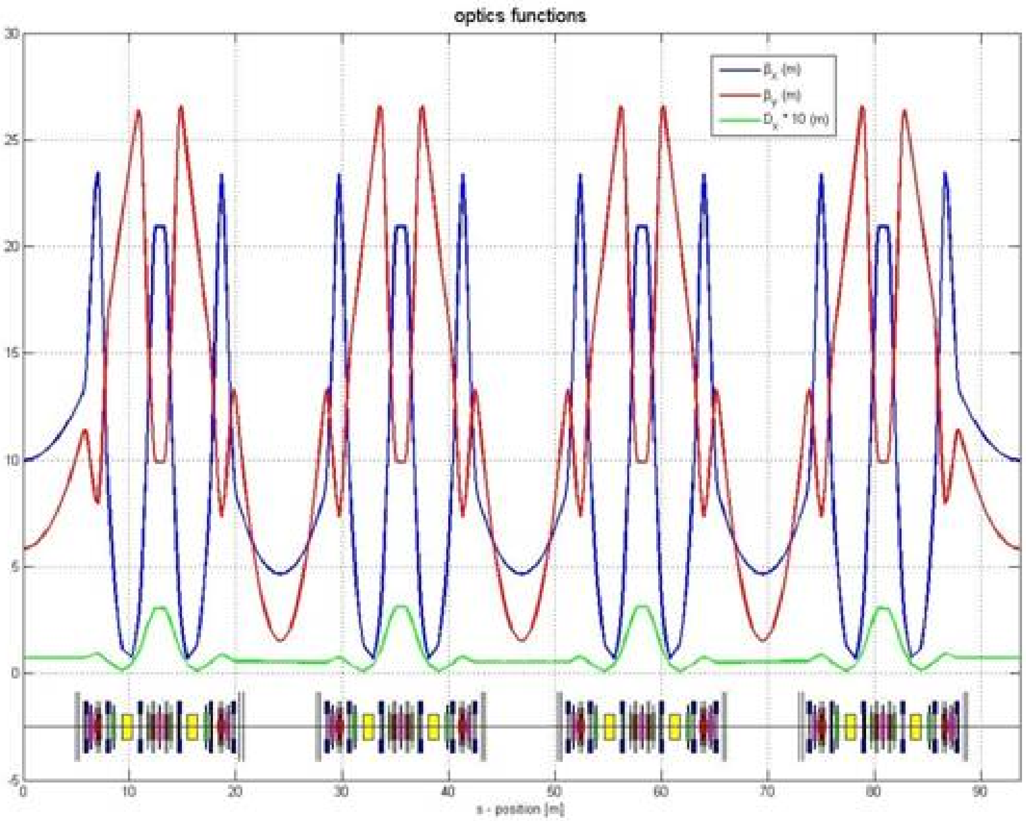
• Experiments

LOCO
turn-by-turn coupling correction

• Measurements issues

• Conclusion

Diamond storage ring main parameters
non-zero dispersion lattice



48 Dipoles; 240 Quadrupoles; 168 Sextupoles (+ H and V orbit correctors + 96 Skew Quadrupoles);
3 SC RF cavities; 168 BPMs

Quads + Sexts have independent power supplies

Energy	**3 GeV**
Circumference	**561.6 m**
No. cells	**24**
Symmetry	**6**
Straight sections	**6 x 8m, 18 x 5m**
Insertion devices	**4 x 8m, 18 x 5m**
Beam current	**300 mA (500 mA)**
Emittance (h, v)	**2.7, 0.03 nm rad**
Lifetime	**> 10 h**
Min. ID gap	**7 mm (5 mm)**
Beam size (h, v)	**123, 6.4 μm**
Beam divergence (h, v) ***(at centre of 5 m ID)***	**24, 4.2 μrad**
Beam size (h, v)	**178, 12.6 μm**
Beam divergence (h, v) ***(at centre of 8 m ID)***	**16, 2.2 μrad**

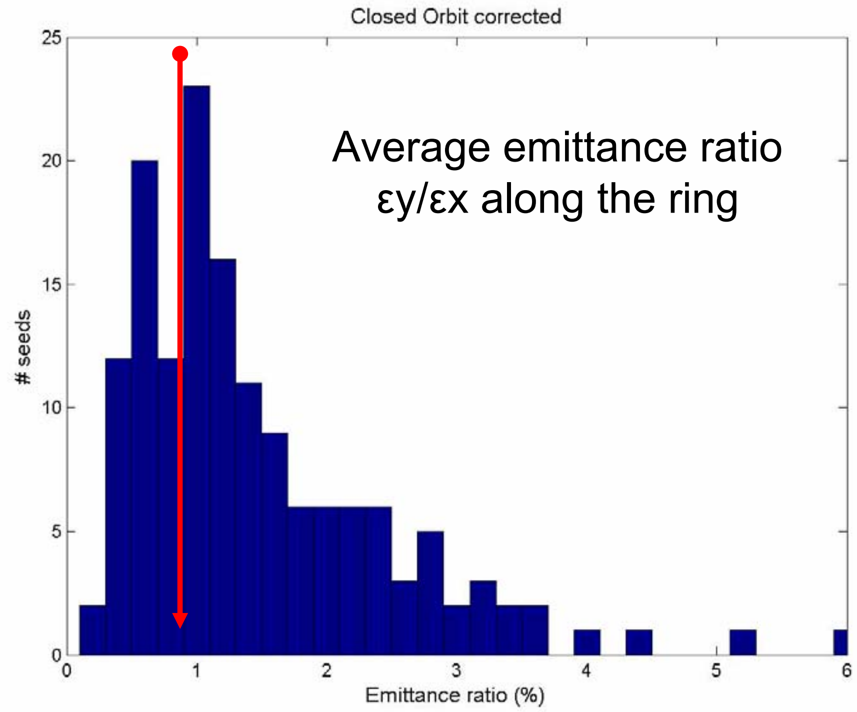
Numerical studies of linear coupling: sensitivity to machine errors

Quadrupole transverse displacement	0.1 mm
Sextupole transverse displacement	0.1 mm
Dipole transverse displacement	0.05 mm
Dipole longitudinal displacement	0.05 mm
Dipole Field Errors	0.1 %
Quadrupole roll errors	0.2 mrad
Dipole roll error	0.2 mrad
BPM transverse displacement	0.05 mm
BPM reading	0.5 μm

After orbit correction – 150 seeds

Horizontal C.O. r.m.s. (m)	$1.0\cdot10^{-4}$
Vertical C.O. r.m.s (m)	$1.1\cdot10^{-4}$
Average Linear Coupling (%)	1.5
r.m.s. Linear Coupling (%)	1.0

Coupling dominated by V misalignment of sextupoles (> 60 % of total)



Measured K = 0.9% with skew quadurpoles off

Numerical correction with crossed orbit response matrix

1) Crossed orbit response matrix

2) Simultaneous minimisation of vertical dispersion

	1)	2)
Horizontal C.O. r.m.s. (mm)	0.10	0.10
Vertical C.O. r.m.s. (mm)	0.11	0.11
Average Linear Coupling χ (%)	0.10	0.03
r.m.s. Linear Coupling (%)	0.11	0.07
r.m.s. H corrector str. (mrad)	0.32	0.32
r.m.s. V corrector str. (mrad)	0.27	0.27
r.m.s. Skew Quad str. (m^{-1})	0.02	0.02

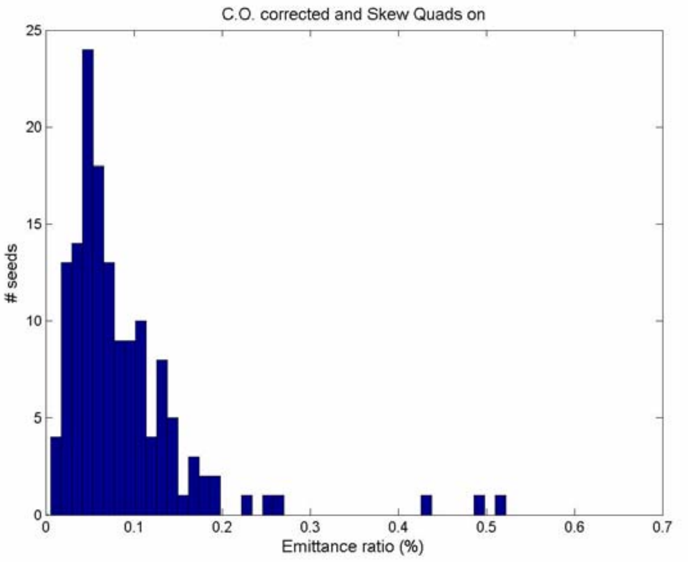
Linear coupling can be reduced

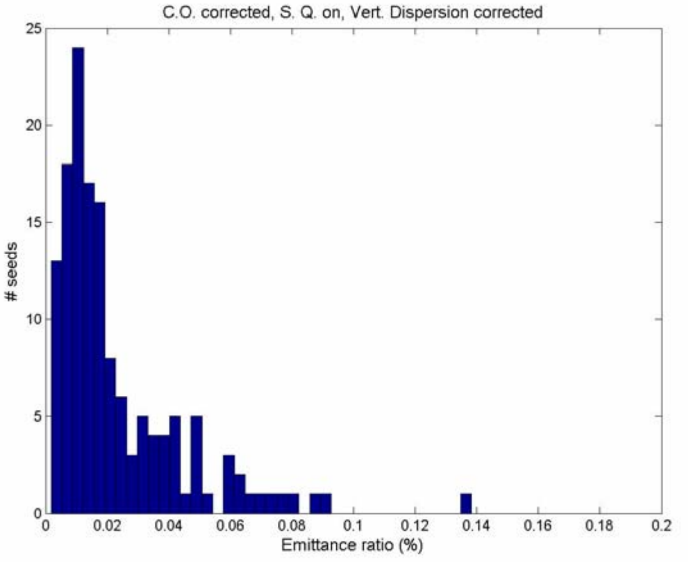
(…on the computer)

to the limit set by the radiation opening angle:

V emittance ~0.6 pm corresponding to K ~ 0.02%

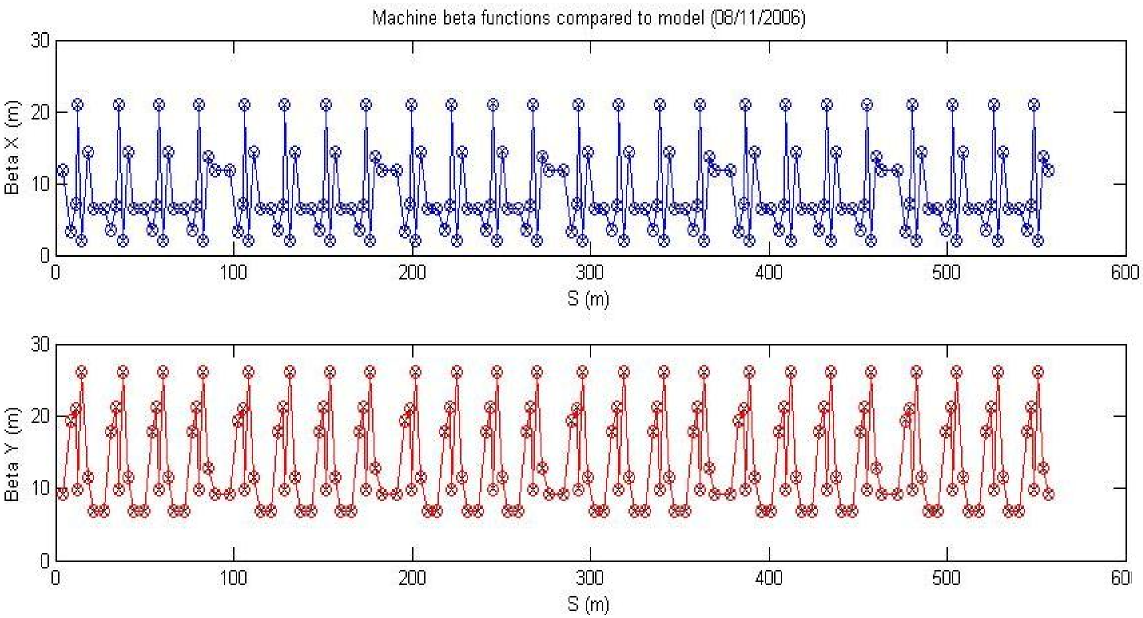
(BETA_LNS code)

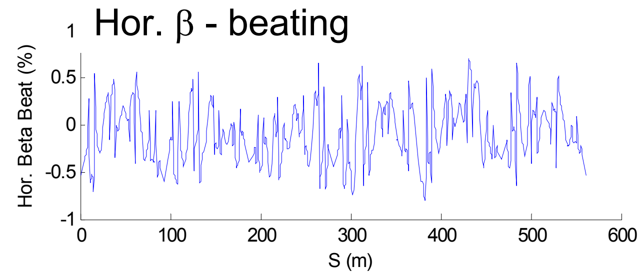


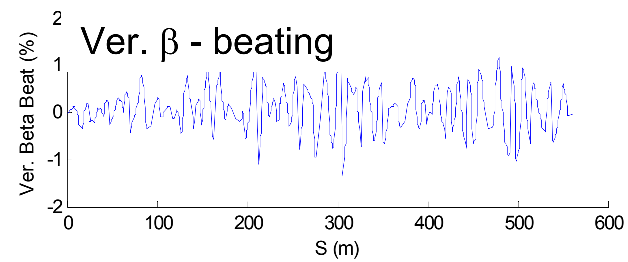


Linear optics modelling with LOCO

Linear Optics from Closed Orbit response matrix – J. Safranek et al.



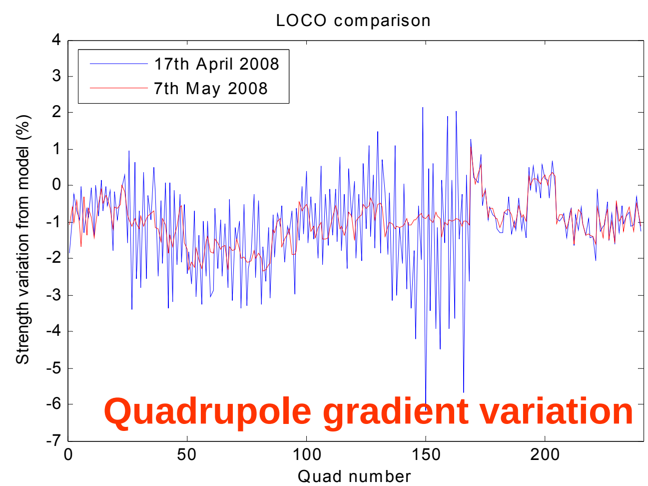




Modified version of LOCO with constraints on gradient variations **(see [ICFA Newsl, Dec'07](#))**

β - beating reduced to 0.4% rms

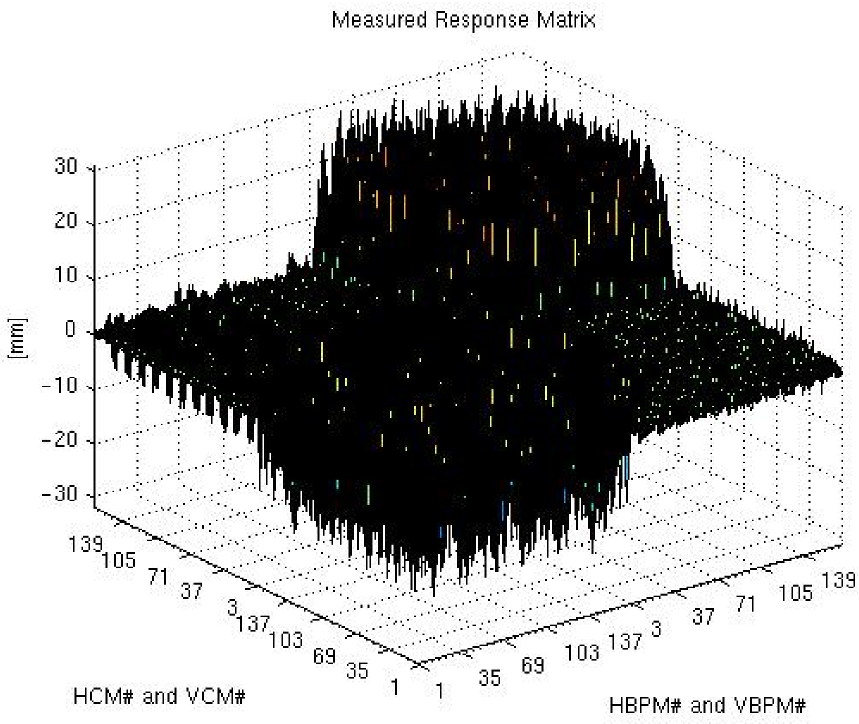
Quadrupole variation reduced to 2%
Results compatible with mag. meas. and calibration

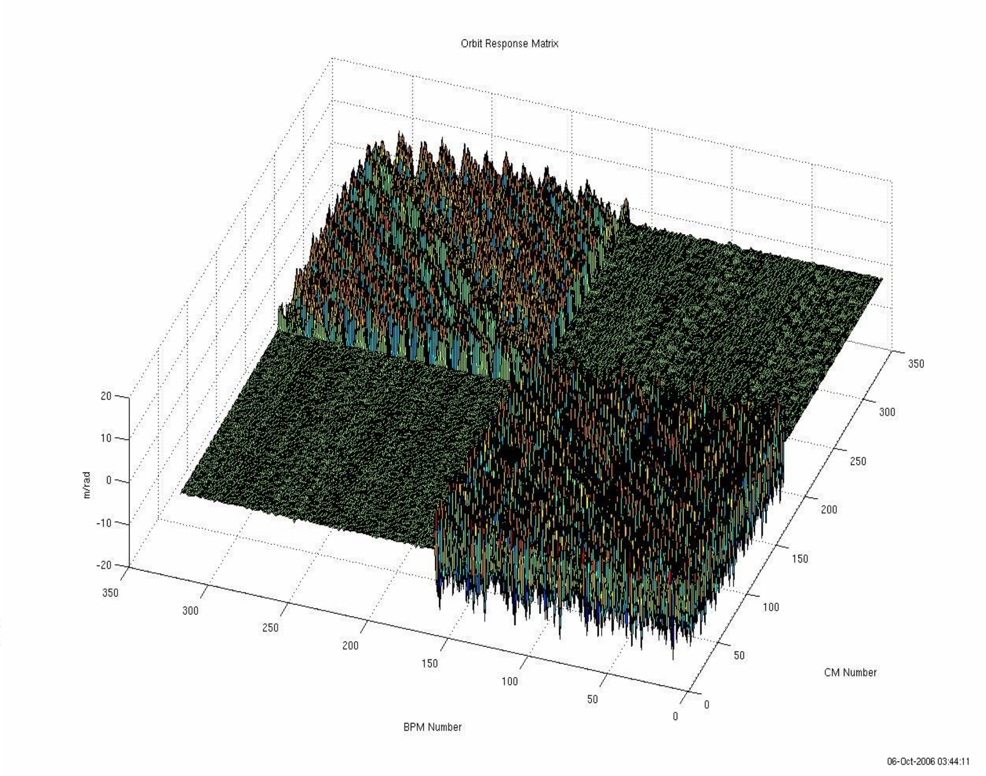


LOCO allowed remarkable progress with the correct implementation of the linear optics

Measured RM (before and after LOCO analysis)

Quadrupoles and skew quadrupoles can be simultaneously fit in order for the measured response matrix to reproduce the model orbit response matrix

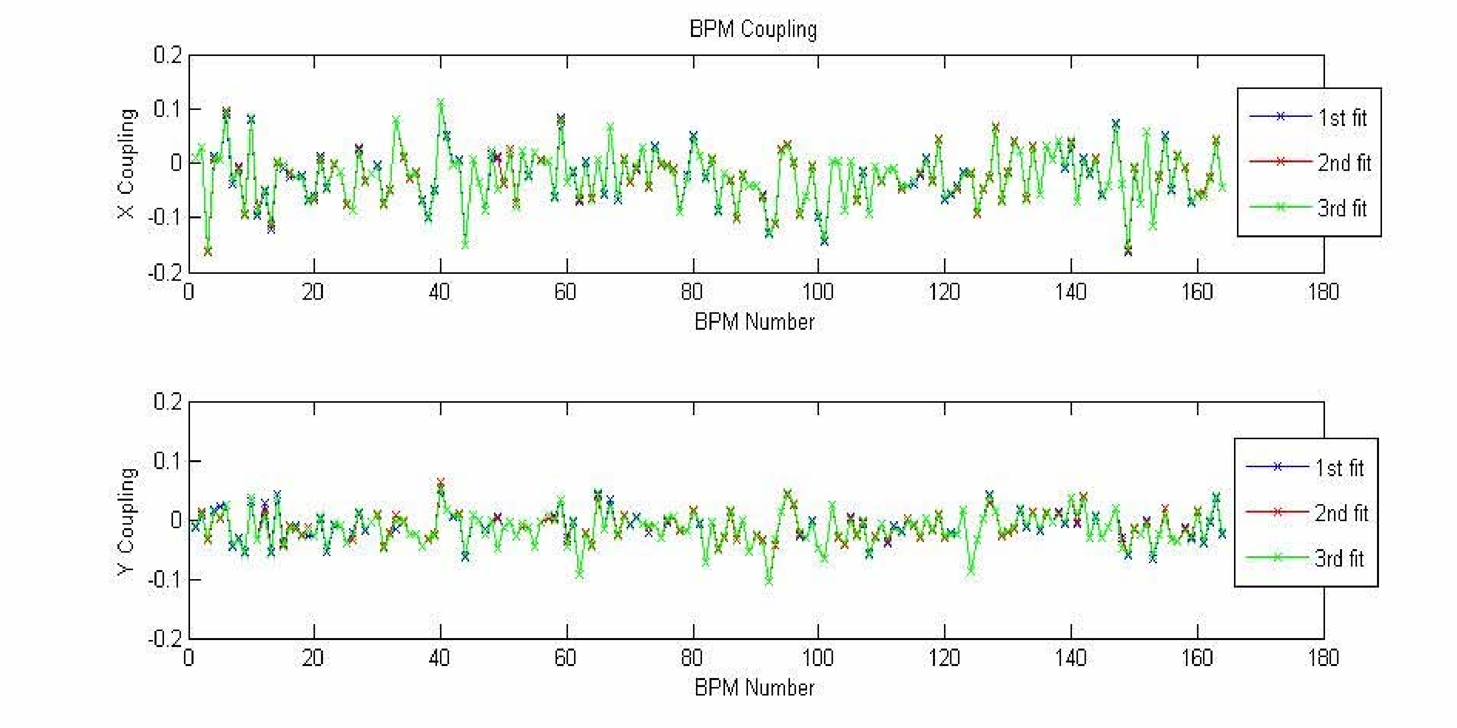




BPMs coupling

LOCO fits also the BPM gain and coupling

BPM coupling includes mechanical rotation and electronics cross talk



These data are well reproducible over months

Measured emittances

Coupling without skew quadrupoles off K = 0.9%

(at the pinhole location; numerical simulation gave an average emittance coupling 1.5% ± 1.0 %)

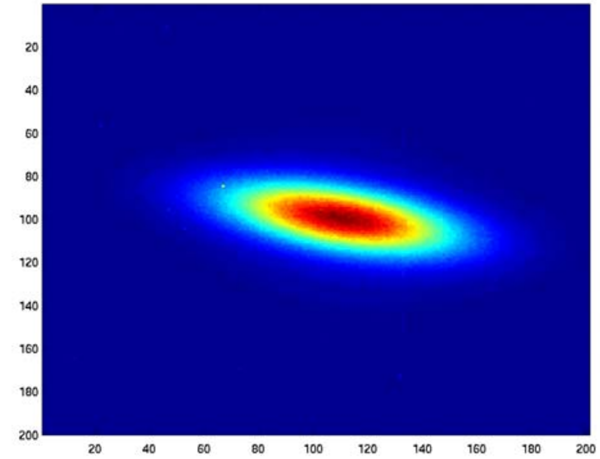
Emittance [2.78 - 2.74] (2.75) nm

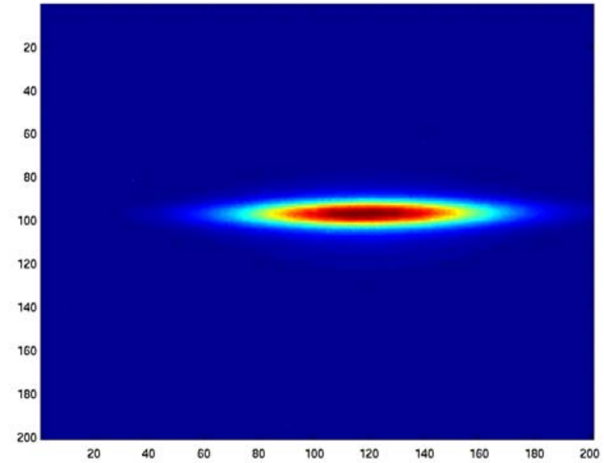
Energy spread [1.1e-3 - 1.0-e3] (1.0e-3)

After coupling correction with LOCO (2*3 iterations)

V beam size at source point 6 µm

Emittance coupling 0.08% → **V emittance 2.2 pm**



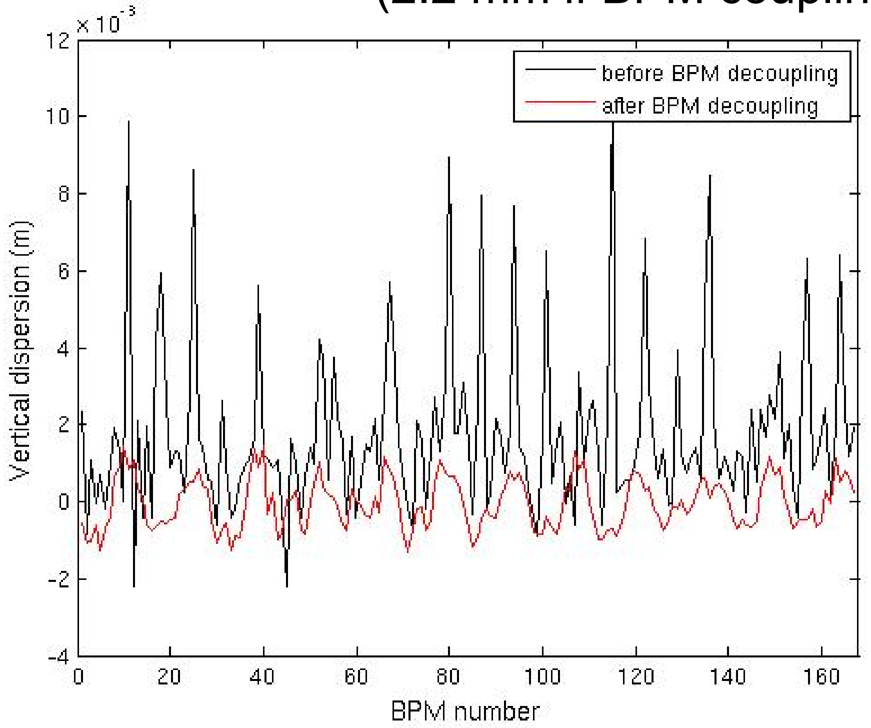


Residual vertical dispersion

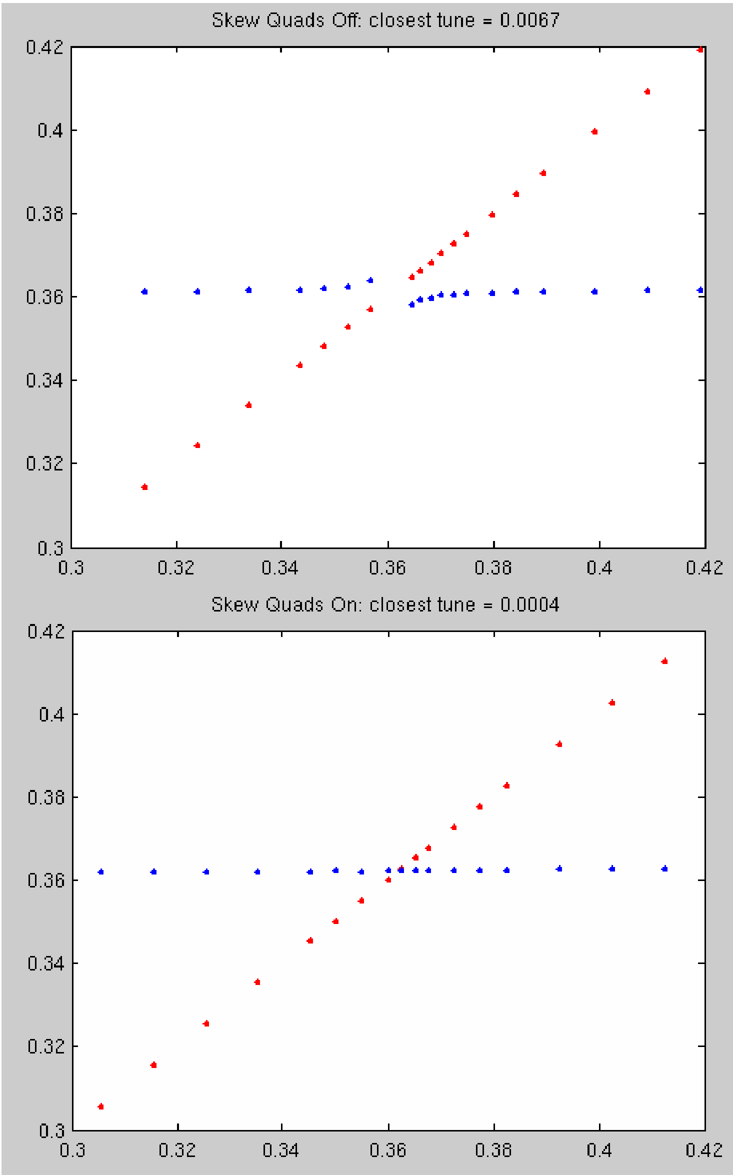
Without skew quadrupoles off r.m.s. Dy = 14 mm

After LOCO correction r.m.s. Dy = 700 μm

(2.2 mm if BPM coupling is not corrected)



Betatron coupling measurement: closest tune approach



The linear betatron coupling (χ) is given by

$$\chi = \frac{\left(c/\Delta\right)^2}{1/2 + \left(c/\Delta\right)^2}$$

C is the minimum separation of the betatron tunes at the resonance is crossed

Δ is the distance of the betatron tunes at the nominal working point

In this particular example

	betatron coupling	emittance coupling
before	0.47 %	1.3%
after	0.002 %	0.15%

Linear coupling with turn-by-turn measurements

All BPMs have turn-by-turn capabilities

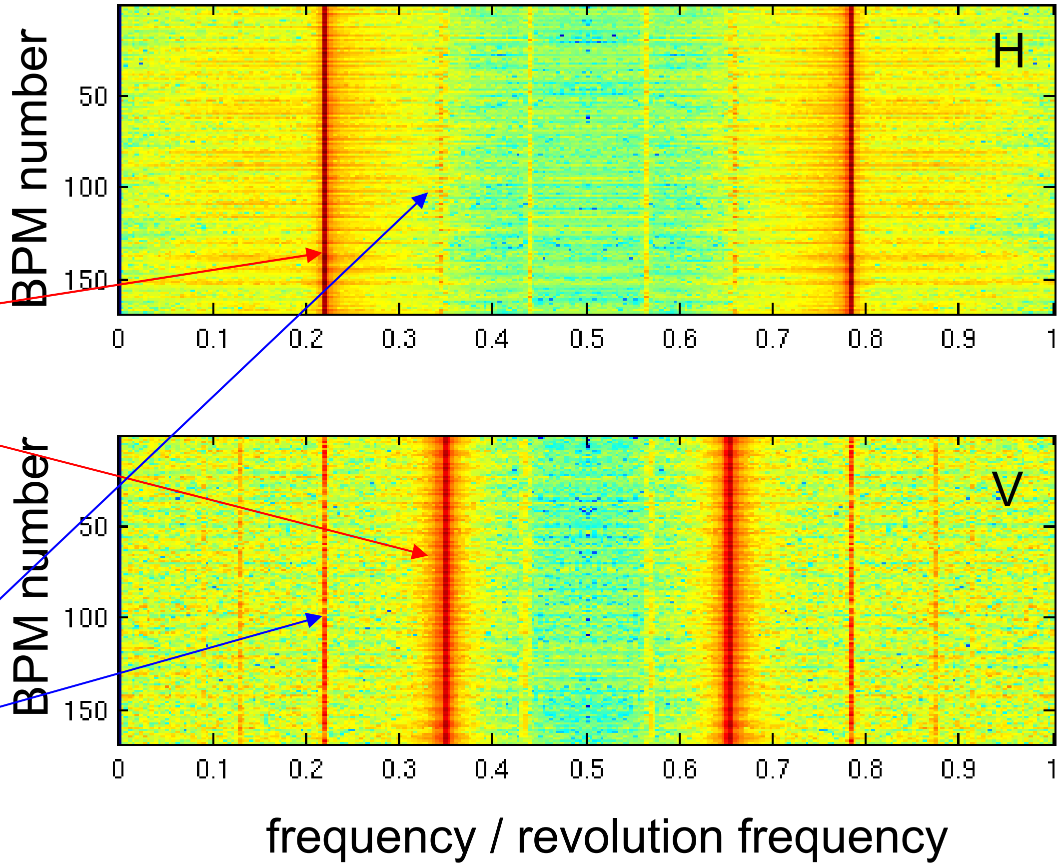
- excite the beam diagonally
- measure tbt data at all BPMs
- colour plots of the FFT

Q_X = 0.22 H tune in H

Q_y = 0.36 V tune in V

All the other important lines are linear combination of the tunes Q_x and Q_y

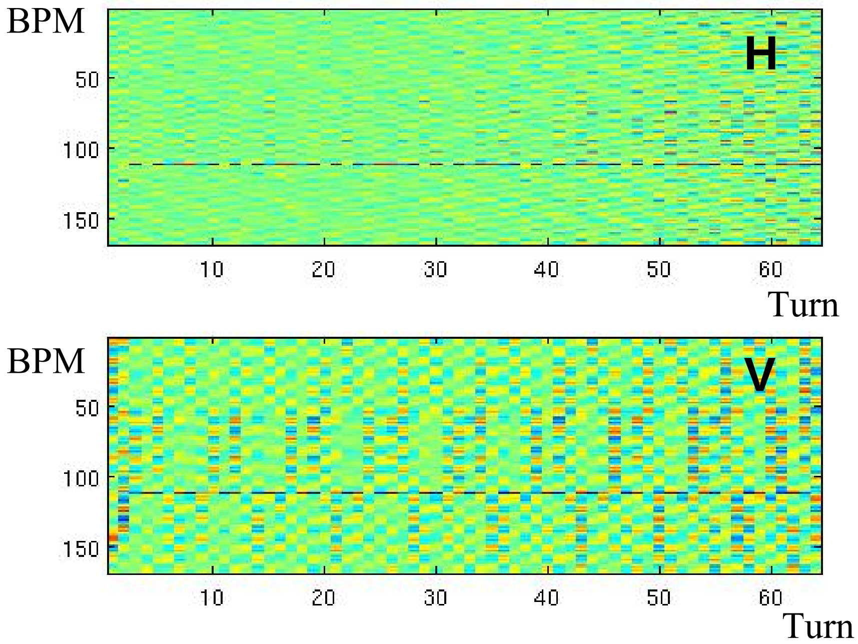
m Q_x + n Q_y



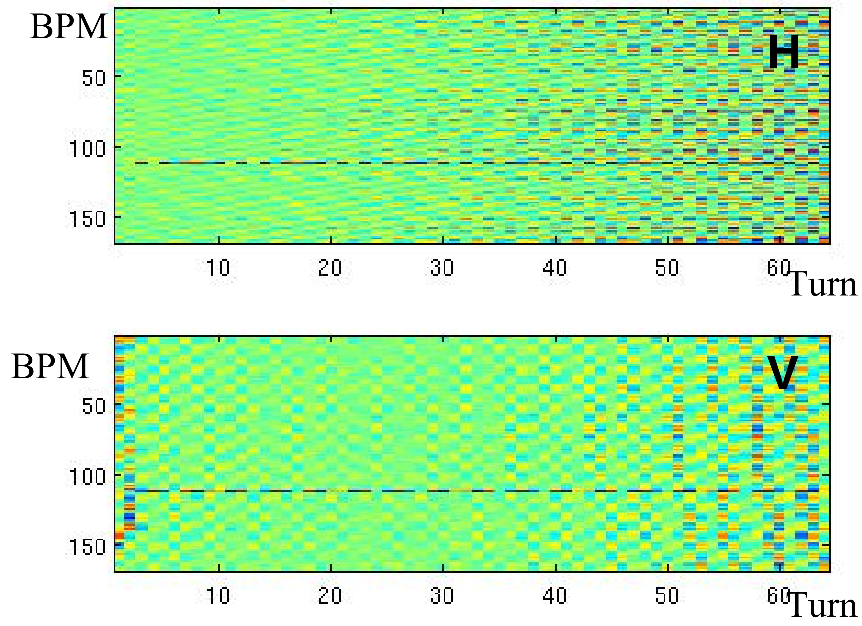
Detection of skew quadrupole variation (WIP)

To test the method we powered two skew quadrupoles and let the fit algorithm find them

X_model(turn; bpm) - X_machine(turn; bpm)



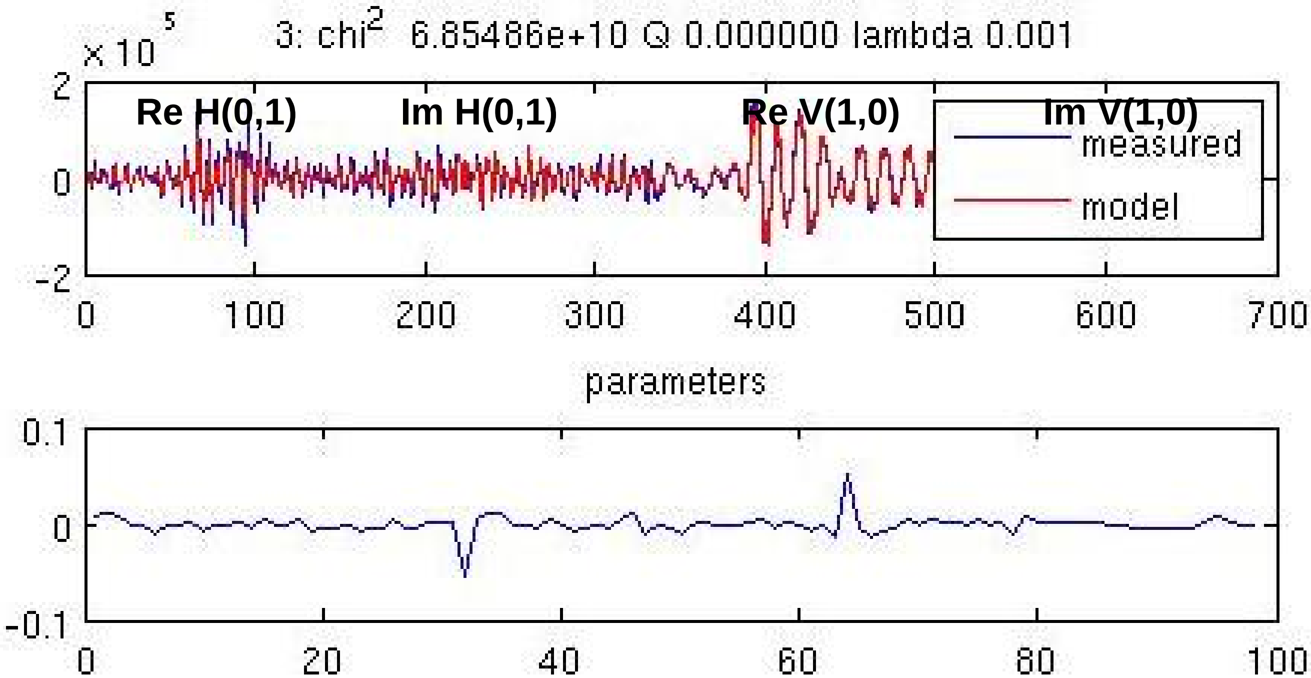
Machine model difference before the skew quadrupole fit



Machine model difference after the skew quadrupole fit

Skew quadrupoles fit (WIP)

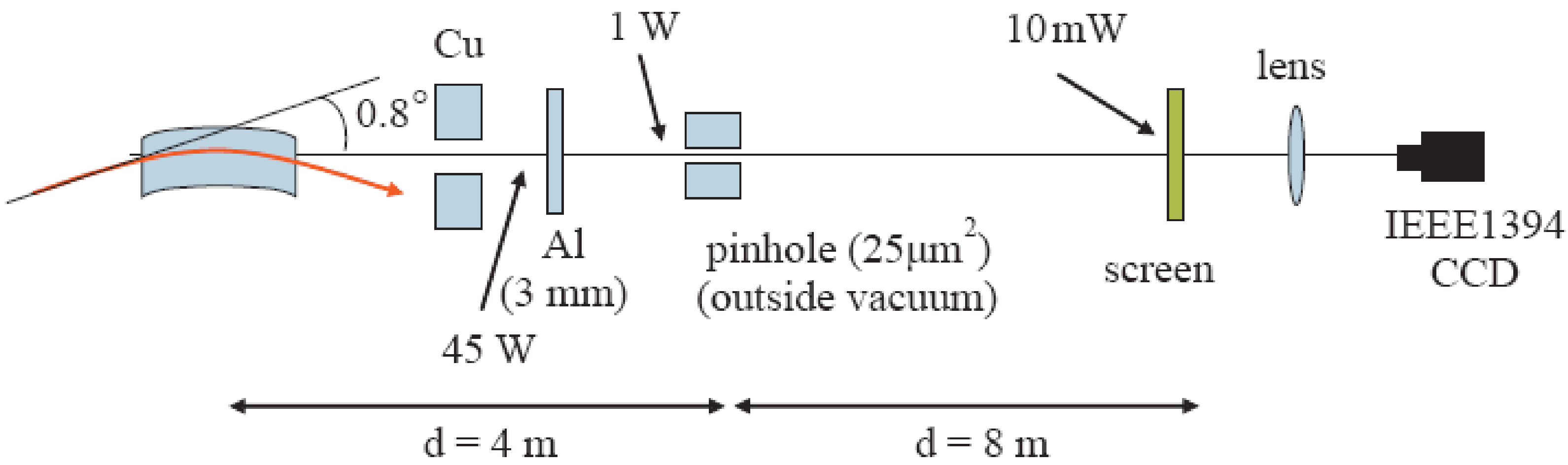
The spectral lines analysed were H(0,1) and V(1,0): these are proportional to the sum and difference coupling resonance driving terms ($Q_x \pm Q_y$)



This method has the potential to make a **fast betatron (local) coupling correction** (ping + fit + correct ~ 1 minute). Comparison with LOCO coupling corrections are ongoing.

Emittance and coupling measurements (I)

Measurements of emittance, energy spread and coupling are made with two **X-rays pinhole cameras** which take the synchrotron radiation from the two dipoles in cell 1



Emittance and emittance coupling are measured indirectly from

measurement of beam spot at the camera

point spread function of the system (→ beam size at the camera)

magnification of the optics (→ beam size at the source point)

electron beam optics functions at the source point (→ emittance)

Emittance and coupling measurements (II)

The point spread function (PSF) is the spot size measured for a zero emittance electron beam. Its computation requires

compute diffraction contributions (Fresnel diffraction+spectrum dependence)

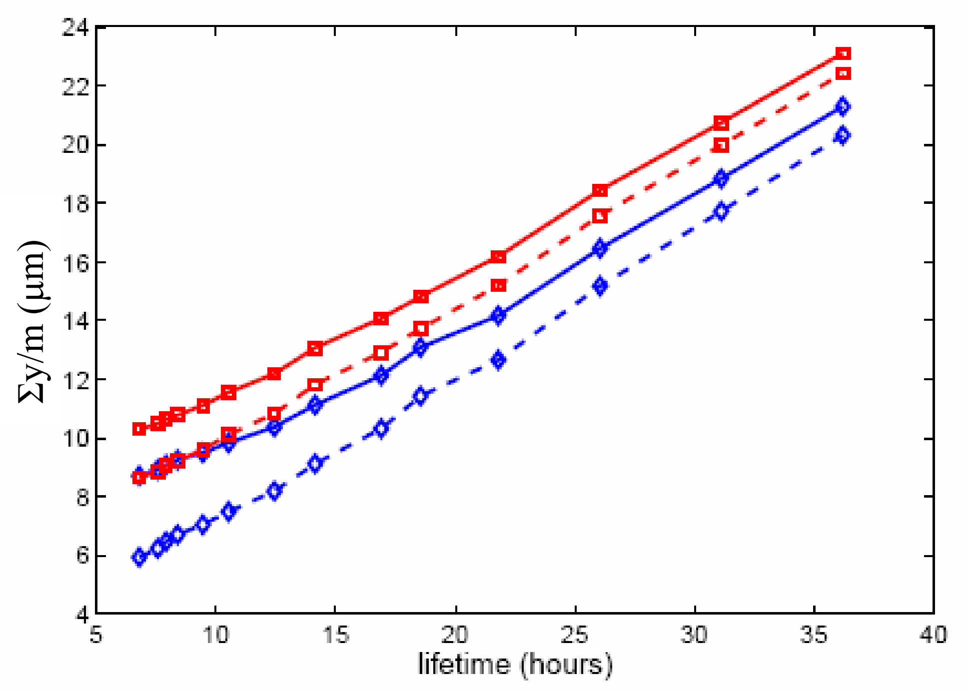
deconvolution of beam size (assuming Gaussian distributions)

$$\Sigma^2 = S^2 + S^2_{pinhole} + S^2_{camera}$$

Experimental tests were based on the simultaneous computation of the beam lifetime (Touschek dominated) and the vertical beam size σ_y with/without the deconvolution procedure

Data with the deconvolution (open diamonds) provide the expected linear relation

The vertical beam size is varied scanning the skew quads



Emittance and coupling measurements (III)

The optics functions at the source point can be either inferred from LOCO or measured directly

measure dispersion at the source point

added source point as a BPM in the LOCO procedure to make sure the optics function at the source point (~5 degrees inside the bending magnet) are correct.

Difference with interpolation with the model was not significant (good linear model)

The resolution of our system is below 3 μm which is adequate to measure a 6 μm V beam size.

(C. Thomas et al. submitted to PRSTAB)

Conclusions and future work

Conclusions:

Careful alignment and independent power supplies in all quadrupoles have allowed a very good control of the linear optics

Sufficient provision for independently powered skew quads have allows good coupling correction

With LOCO a V emittance of 2.2 pm has been achieved

Effect of IDs on coupling is negligible (see I. Martin's talk)

Future work:

Can we correct the linear coupling better than LOCO? No (..not yet)

Is sextupole BBA and realignment necessary to achieve lower V emittance?

(…zero push from users... but damping rings and B-factories are interested)