Report on the

2nd nonlinear beam dynamics workshop

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Diamond Light Source Ltd
John Adams Institute, University of Oxford

ESLS XVII
DESY, 25 November 2009

2nd Nonlinear Beam Dynamics Workshop

2nd-4th November at Diamond

50 registered participants from 24 labs

US – 8	Germany – 6	Russia – 3
UK – 8	Spain – 4	Taiwan-China-Slovenia – 2
France – 7	Switzerland – 4	Armenia-Brazil-Japan-Sweden – 1

2nd Nonlinear Beam Dynamics Workshop
2nd-4th November at Diamond

Session 1: Theory and codes

Session 2: Design and optimisation

Session 3: Experiments

Session 4: Insertion devices and technology

Session 5: Low alpha lattices

Steering committee

R. Bartolini (Diamond and JAI)
D. Einfeld (ALBA)
P. Elleaume (ESRF)
S. Krinsky (NLSL-II)
P. Kuske (BESSY-II)
A. Nadji (SOLEIL and SESAME)
D. Robin (ALS)
F. Schmidt (CERN)

Thanks to Richard Walker (Diamond)

and Ken Peach (JAI)

2nd Nonlinear Beam Dynamics Workshop
2nd-4th November at Diamond

33 presentations

Nonlinear beam dynamics for

synchrotron light sources (20 talks)

colliders (3 talks)

damping rings (1 talk)

intense ion beams with space charge (2 talks)

Theory (4 talks)

Technology -> BPMs (2 talks)

Celestial mechanics (1 talk)

Motivations (I): why nonlinear beam dynamics?

Improve performance:

Dynamic aperture

Lifetime

Injection efficiency (top-up)

Beam loss understanding and control

Better understanding of dynamics enables **new operating modes**

ultra low emittance lattices, more/new IDs, low alpha lattices

… academic interest

Motivations (II): main issues (incomplete review)

Theory and Codes

symplectic integrators, exact/expanded Hamiltonians, … docs

Improve machine description

multipolar errors, wedges, fringe fields, IDs, …

Optimisation strategies

semi-analytical quantities, Tracking (4D-6D), FM, …

Measurements

DA, lifetime, apertures, losses, turn-by-turn data, …

Modelling and correct the real machine

which dynamical quantities (detuning with amplitude/momentum driving terms, FM) – agreement still far from perfect

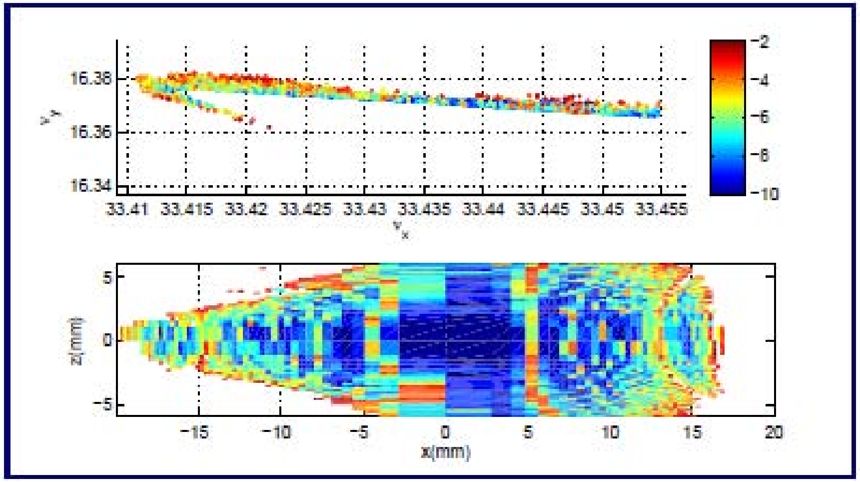
… + keep abreast of the latest development + exchange informations

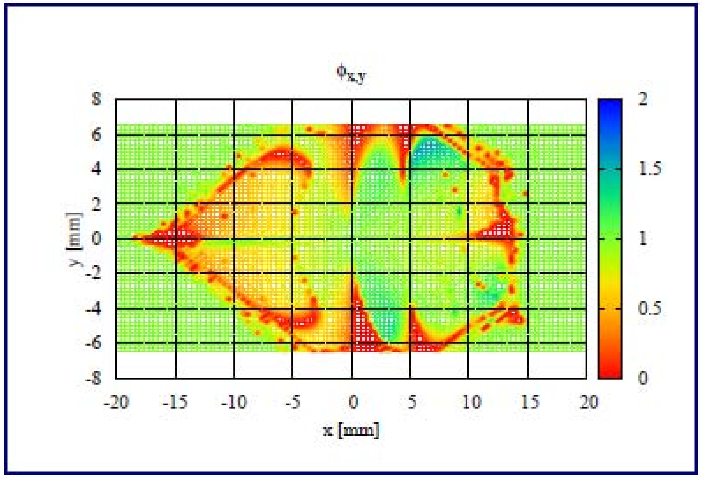
Session 1: Theory and codes

Code comparison (see Dieter's talk)

Tracking or (semi)-analytical approaches to DA?

J. Bengtsson: An analytical method to determine the Dynamic Aperture





F. Schmidt: Dynamic Aperture in large proton machines: Why we have to track!

Tracking or (semi)-analytical approaches ?

From F. Schmidt's talk:

A) Many of those techniques are presented with enthusiasm and played through for 1D toy models. Progress is promised but my observation is that "they never come back from 2d"!

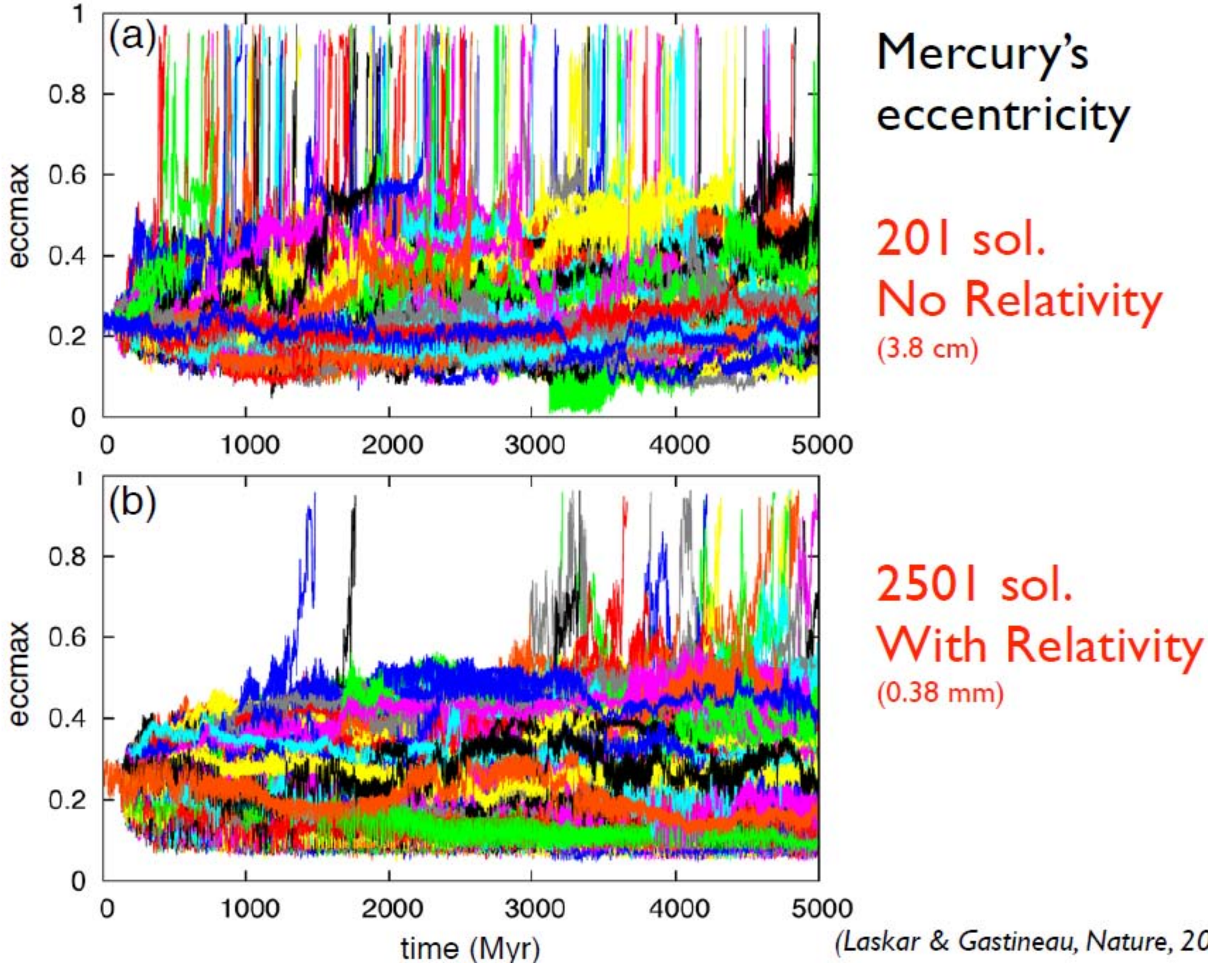
…. Difficult to extend to deal with real effect (6D, ripples, beam-beam, etc…)

D) DA studies should be left to brute force tracking! But again in the analysis of the results analytical tools can be of great help!

Numerical analysis of the Dynamic and Momentum Aperture was used in all the optimisation works presented

The availability of powerful computing resources, even if brute force tracking is not "intellectually appealing" can open new interesting research lines

Tracking for the analysis of the stability of the solar system (J. Laskar)



(Laskar & Gastineau, Nature, 2009)

Different initial conditions generate vastly different orbits

(initial condition steps 3.8 cm in Mercury's semiaxis; real uncertainty is few m)

Relativistic corrections to gravity stabilise Mercury's orbit

As a consequence of the variation of Mercury's eccentricity

collisions Earth-Mercury or Earth-Venus or Earth-Mars are possible in 3.3 Gyr

Massive simulations on massive computers

JADE

1536 Intel E5472 nodes : 12288 cores

147 Tflop/s

14th of TOP500 (nov. 2008)

Test period : August-December 2008

Session 2: Design and optimisation

M. Borland: genetic algorithms used to improve the dynamics aperture (DA) and momentum aperture (MA).

Direct optimisation based on tracking

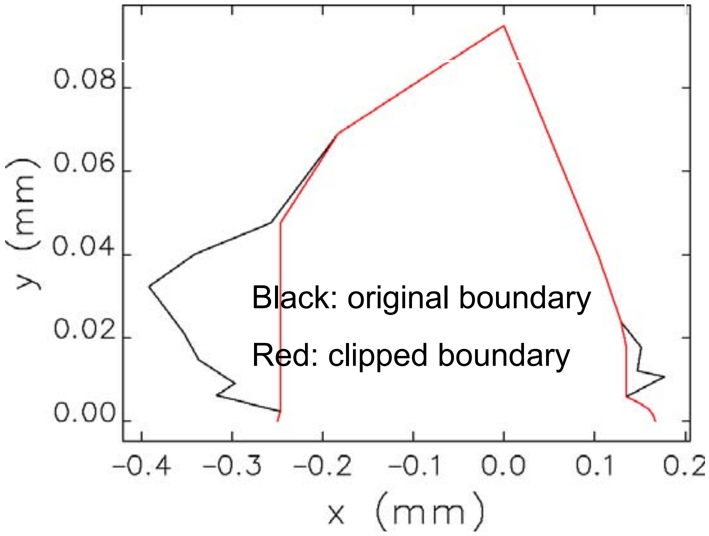
Sextupole by family or individual, symmetry can be broken

Success depends on a good penalty function:

Numerical measure of DA and MA;

proxies can be used (detuning, FM, …) but <u>it is hard to beat something derived from from tracking to obtain the DA and MA</u>;

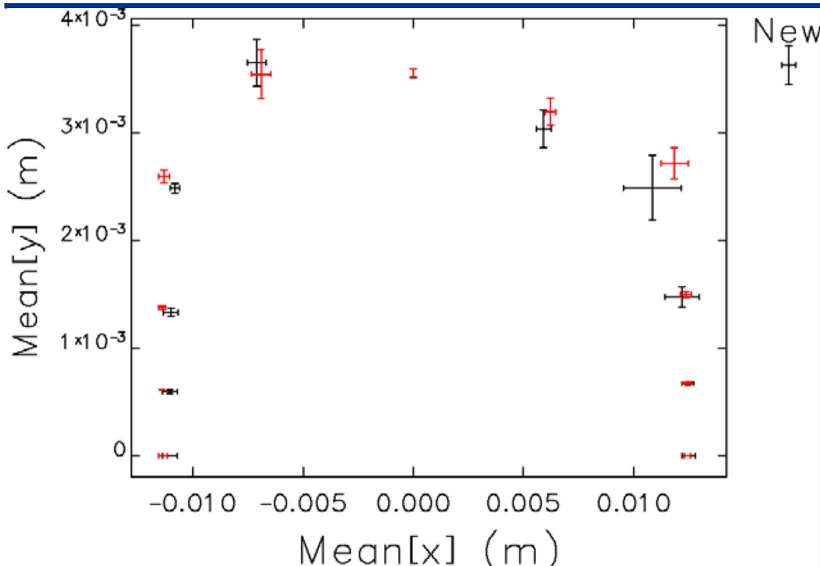
Optimisation includes errors

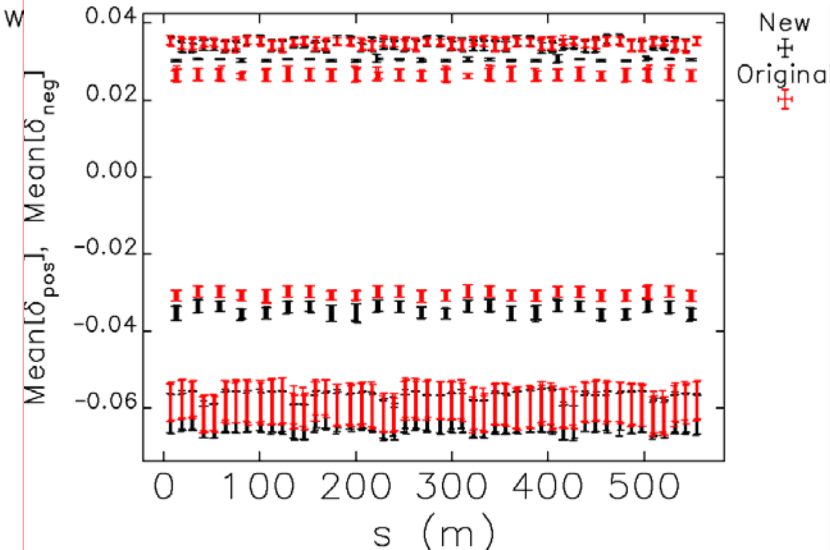


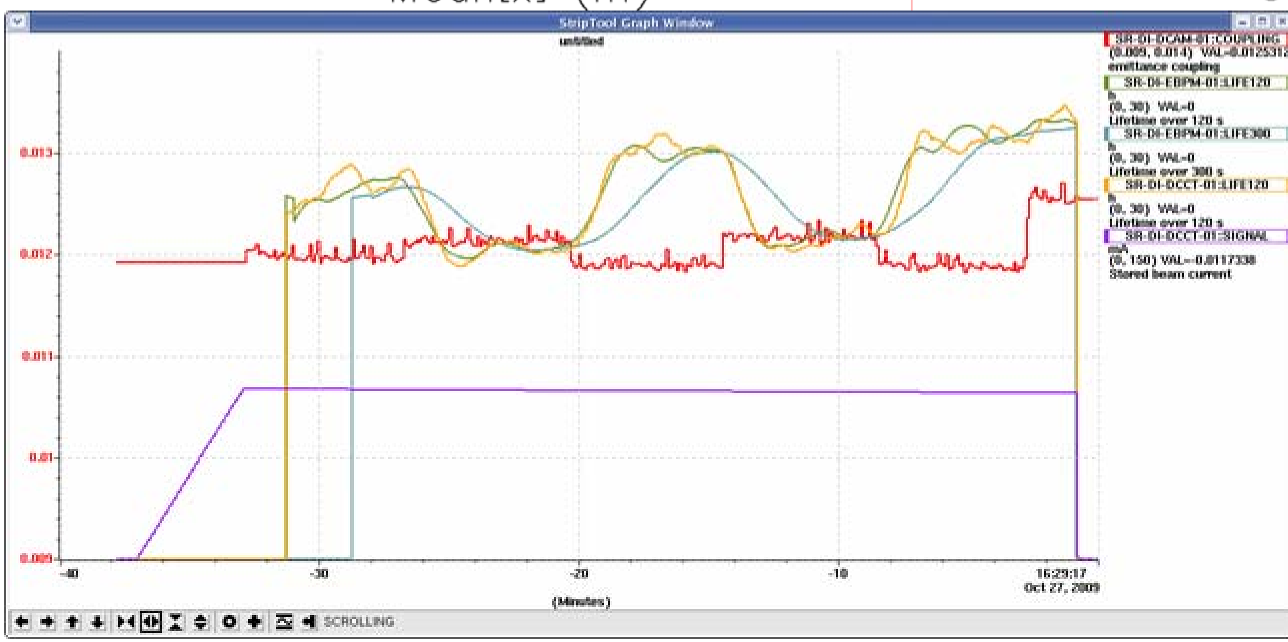
Application to APS (PAC09) reported improvement on

- nominal operation lattice → lifetime + 25%
- 24 bunches lattice (ξx ,ξy ~ 6,6) → lifetime + 25%
- hybrid (ξx ,ξy ~ 11,11) → lifetime + 10%

Application to Diamond (WIP)







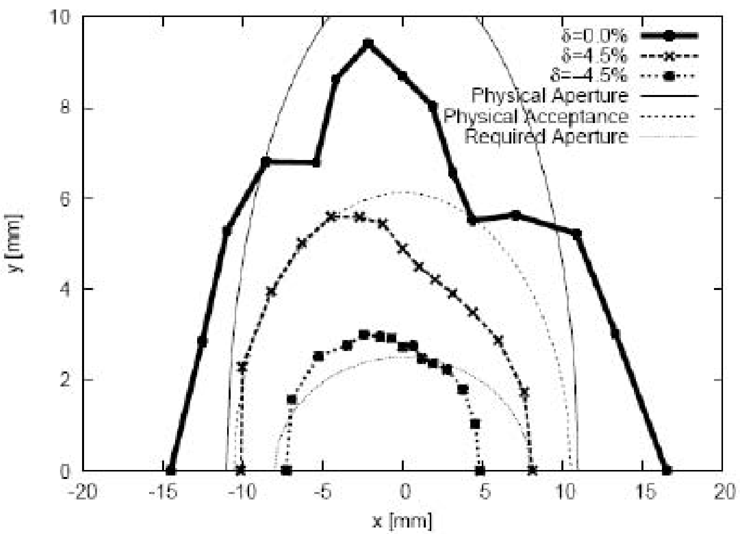
One sextupole family had to be changed by about 10%

Ultra low emittance (NLSL-II, Max-IV, Petra-III)

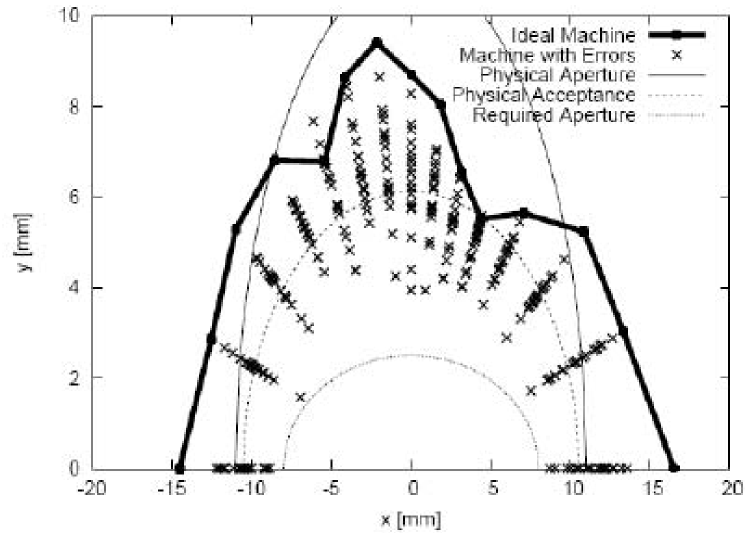
Optimisation of the design of new machines adopts a combination of tracking, FM, semi-analytical considerations

It seems adequate to produce workable solutions for NSLS-II, MAX-IV and PETRA-III

With 4 PMDW, ideal machine



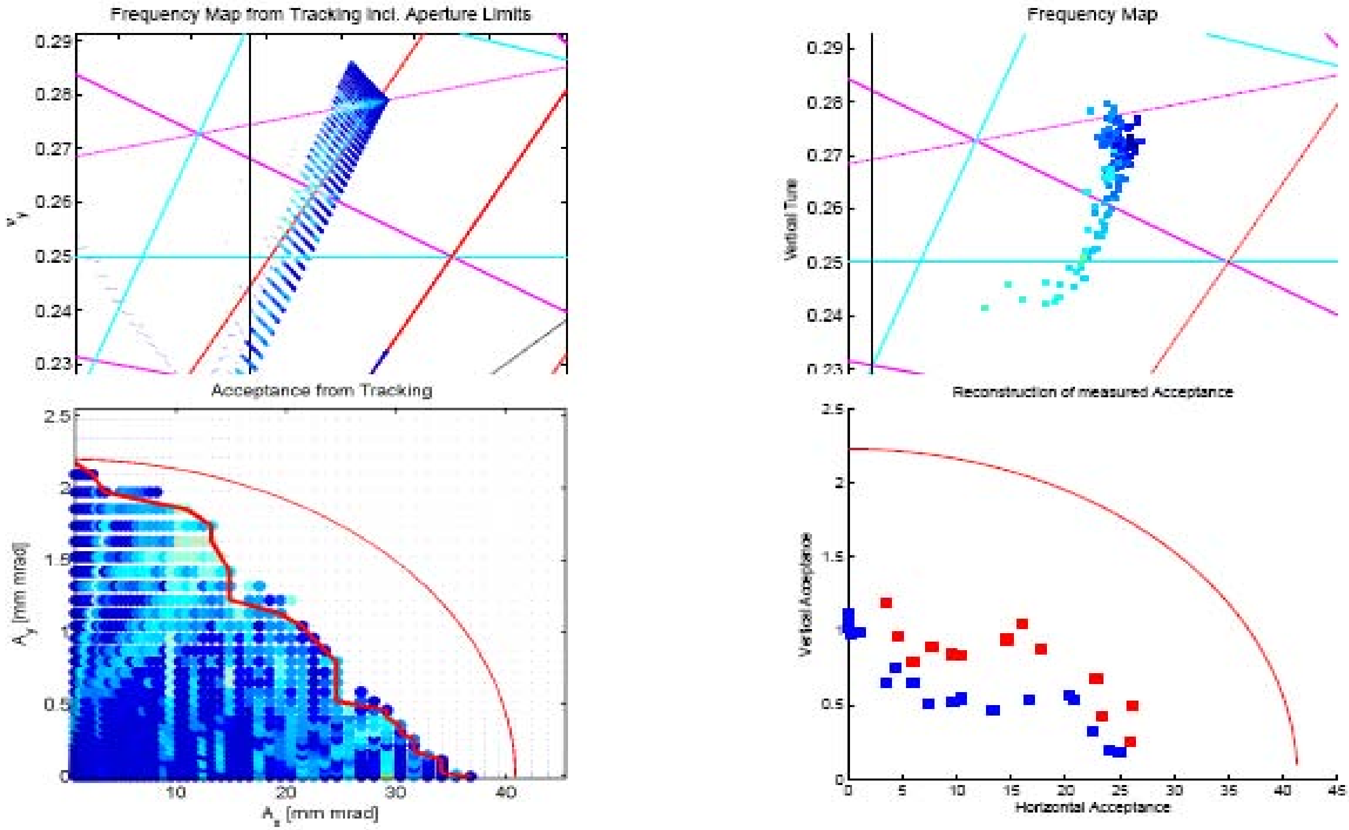
With 4 PMDW, 20 misalignment error seeds



From A. Andersson (Max-IV)

Ultra low emittance (NLSL-II, Max-IV, Petra-III)

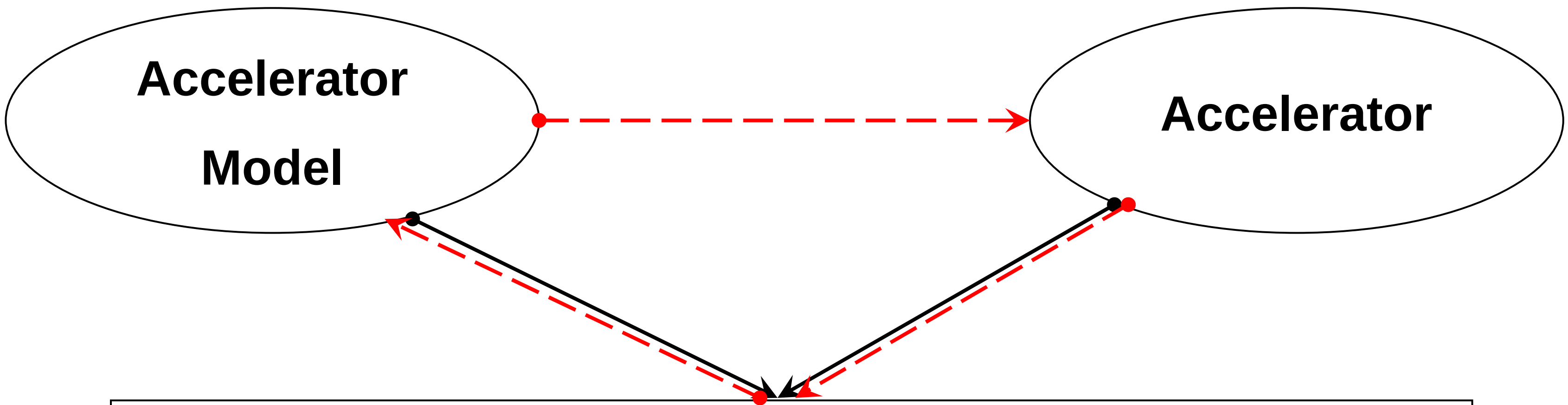
DA and FM including multipoles, wigglers and engineering apertures



from A. Kling (Petra-III)

Session 3: Experiments

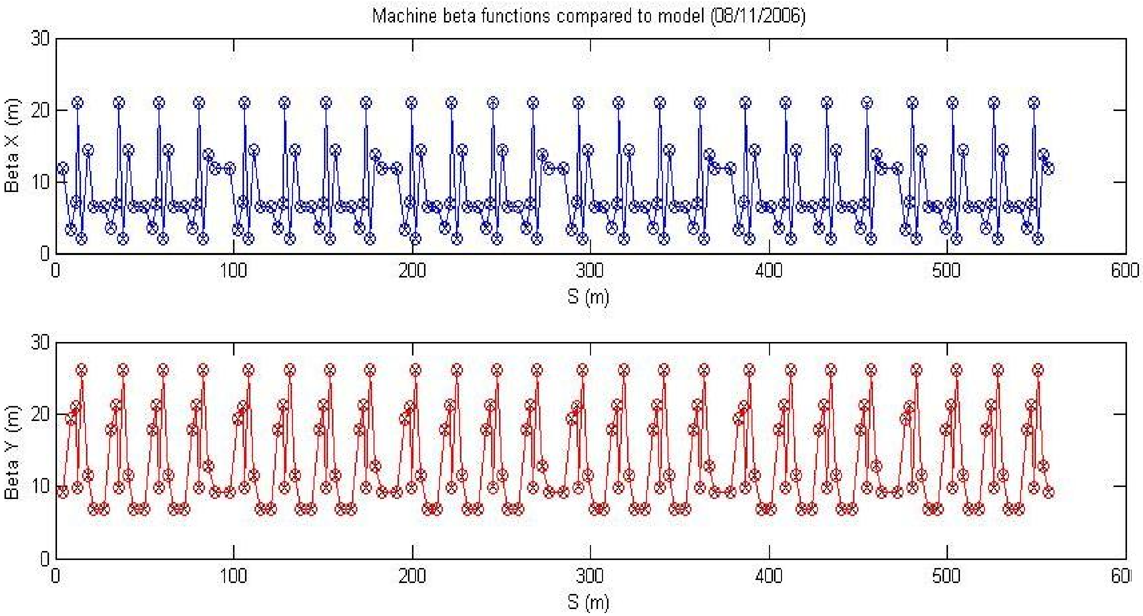
Aim: control of the nonlinear ring dynamics

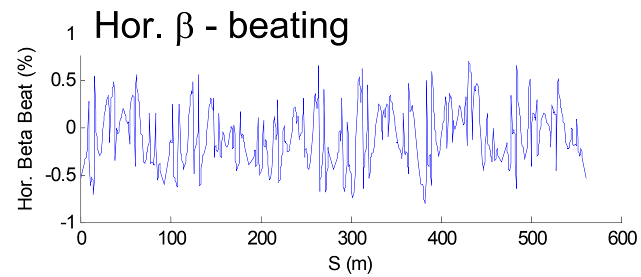


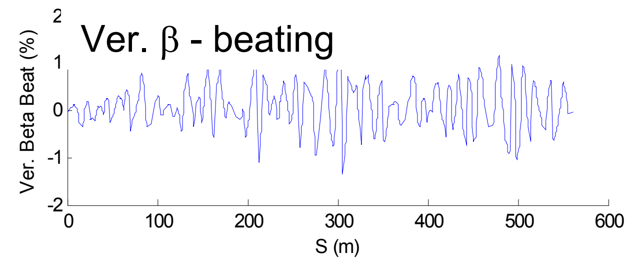
- **Closed Orbit Response Matrix (LOCO)**
- Detuning with amplitude (and with momentum)
- Apertures and Lifetime
- Frequency Map Analysis
- Frequency Analysis of Betatron Motion (resonance driving terms)

Linear optics modelling with LOCO

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

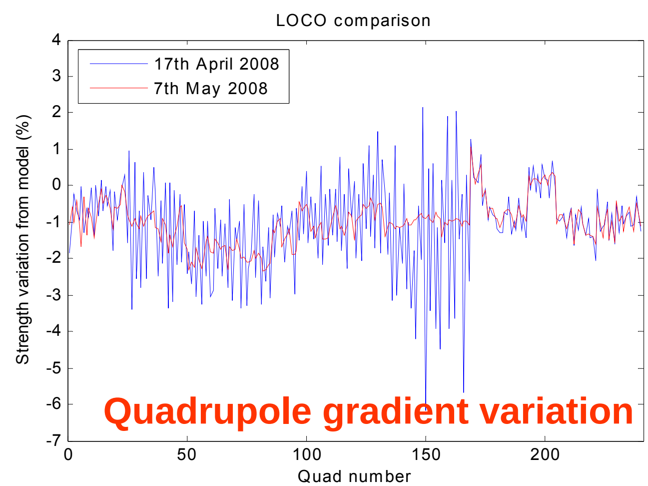






Modified version of LOCO with constraints on gradient variations **(see [ICFA Newsl, Dec'07](#))**

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

Summary of comparison model/machine for linear optics

	Model emittance	Measured emittance	β-beating (rms)	Coupling* ($\varepsilon_y / \varepsilon_x$)	Vertical emittance
ALS	6.7 nm	6.7 nm	0.5 %	0.1%	4-7 pm
APS	2.5 nm	2.5 nm	1 %	0.8%	20 pm
CLS	18 nm	17-19 nm	4.2%	0.2%	36 pm
Diamond	2.74 nm	2.6-2.9 nm	0.4 %	0.08%	2.2 pm
ESRF	4 nm	4 nm	1%	0.25%	10 pm
SLS	5.6 nm	5.4-7 nm	4.5% H; 1.3% V	0.05%	3.2 pm
SOLEIL	3.73 nm	3.70-3.75 nm	0.3 %	0.1%	4 pm
SPEAR3	9.8 nm	9.8 nm	< 1%	0.05%	5 pm
SPring8	3.4 nm	3.2-3.6 nm	1.9% H; 1.5% V	0.2%	6.4 pm

* best achieved

Modelling issues with the comparison machine-model

The most complete description of the nonlinear model is mandatory !

Exact vs expanded hamiltonian (fast computers $\rightarrow$ no need to expand anymore…)

Thick (or multi-slice) vs thin sextupoles:

- preference higher order symplectic scheme vs “many slices”
- take into account beta function variations, i.e. split only where necessary

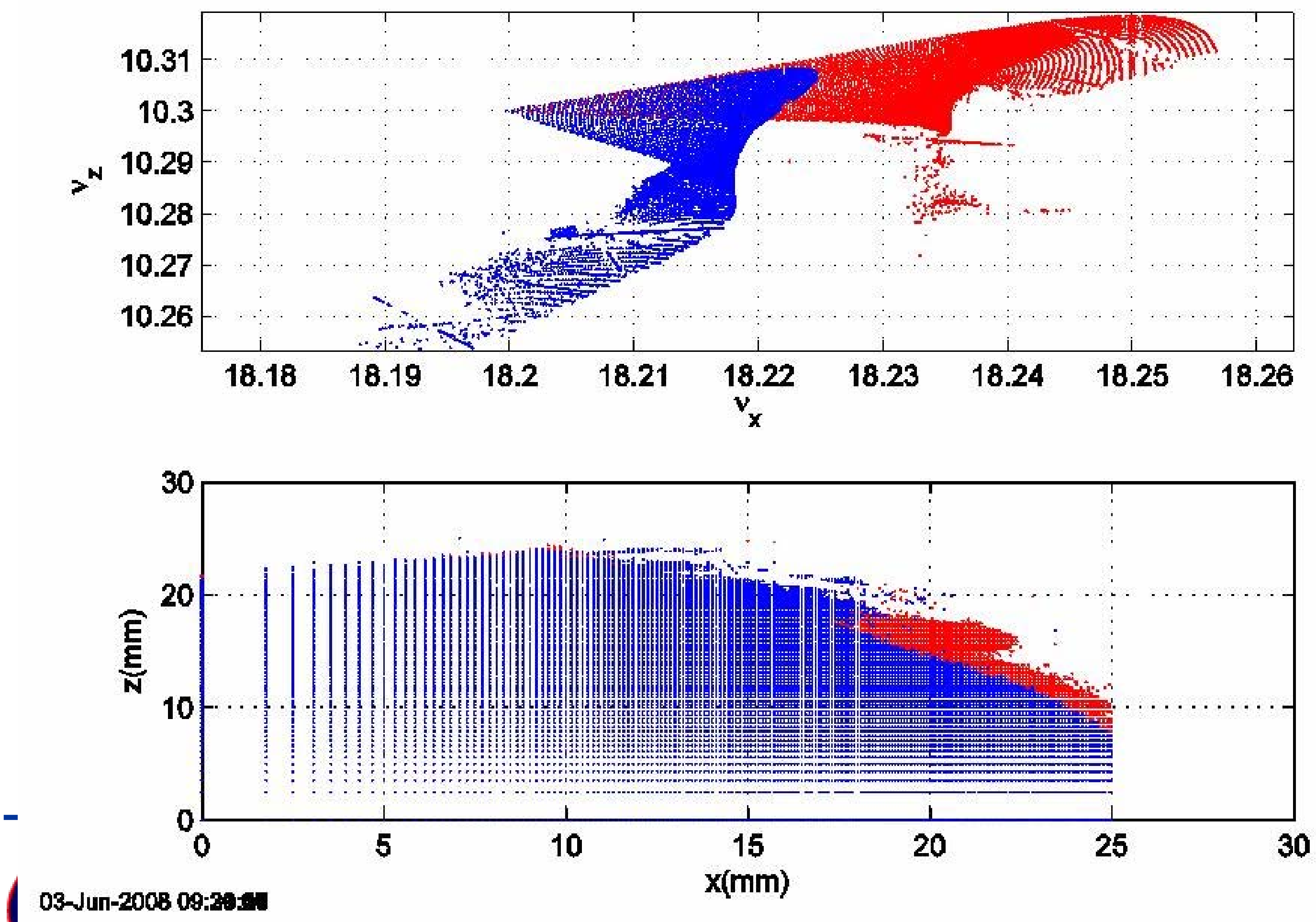
Fringe fields:

- 1st order symplectic hard edge (Forest’s book)
- 2nd order non symplectic (Brown 1975)
- symplectification of second order see PTC
- implicit integration of s dependent magnetic field (see Berg)

Higher order multipoles (mandatory! from measurements)

Modelling issues: e.g. SOLEIL FM
(L. Nadolski - A. Nadji)

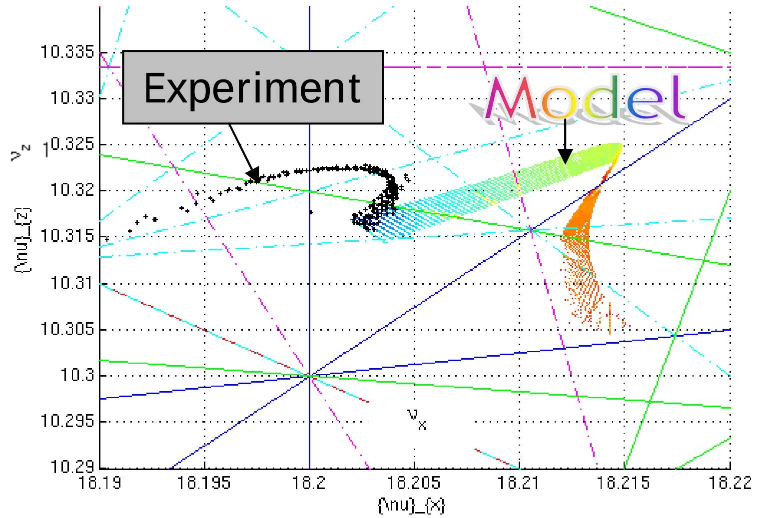
Thick sextupole magnets **Thin sextupole magnets**

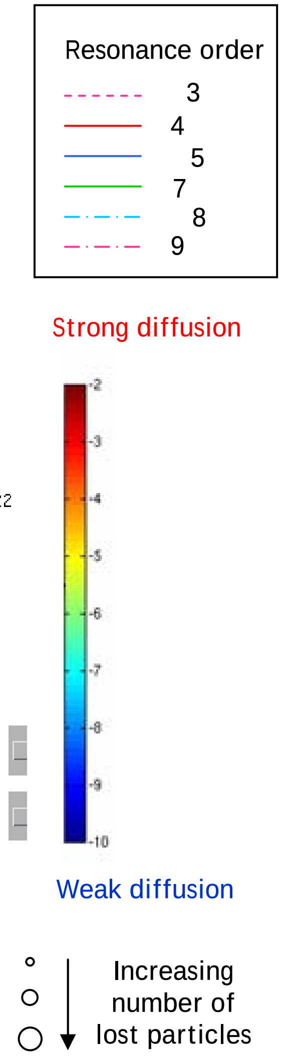


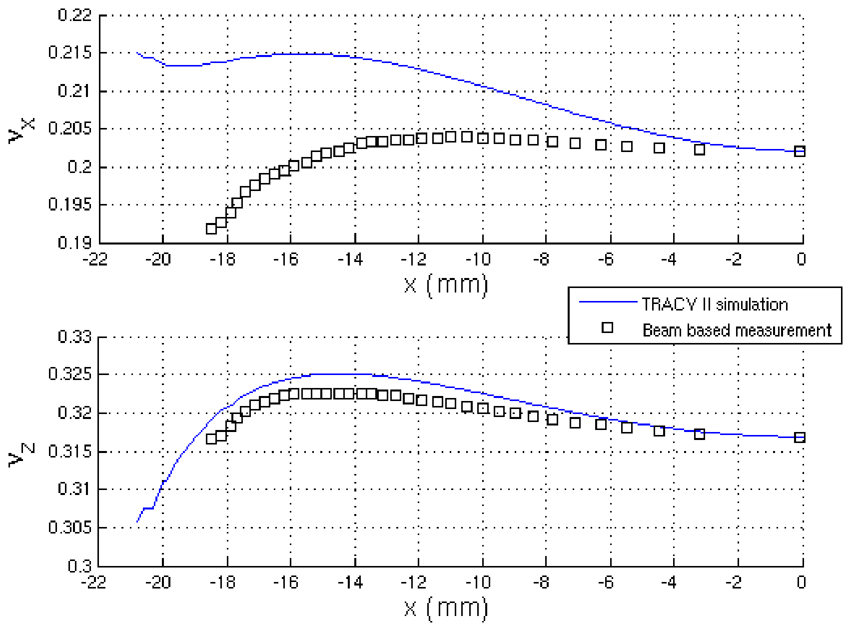
SOLEIL: comparison machine-model
On-momentum FM (L. Nadolski – A. Nadji)

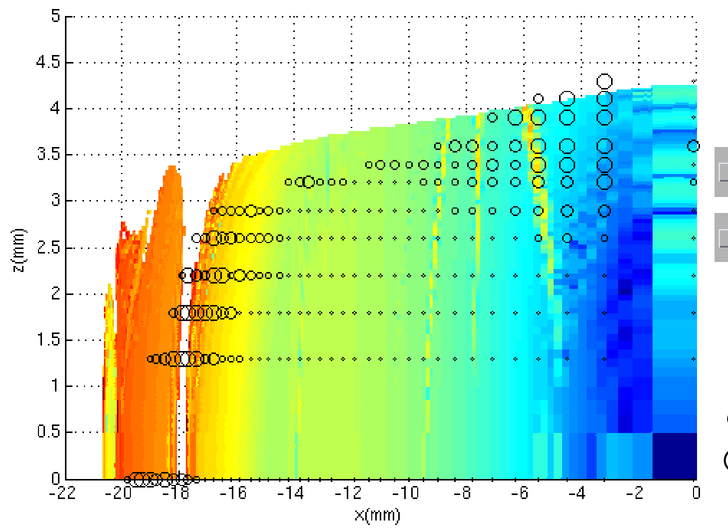
- Dynamic aperture and frequency map

Bare machine
$\nu_x = 18.202$ / $\nu_z = 10.317$
$\xi_x = 2$ / $\xi_z = 2$



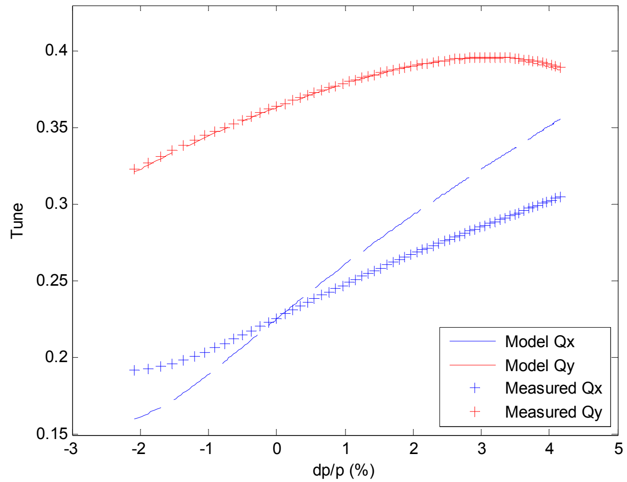


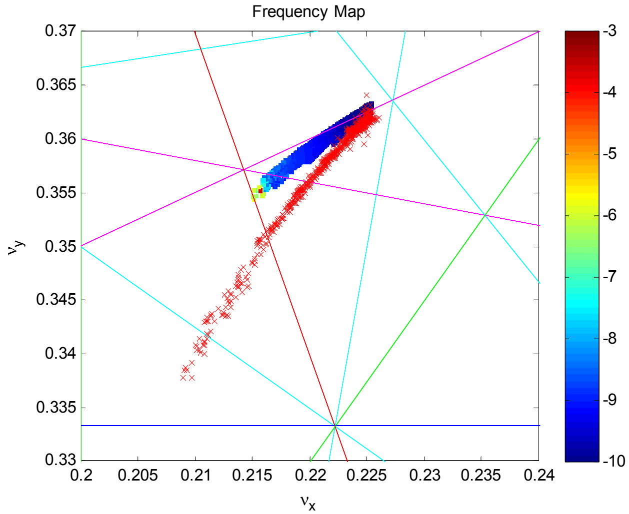




Diamond: comparison machine model tunes with dp/p and FM

Apertures investigations showed only qualitative agreement. Significant discrepancies are still under investigation





Model includes

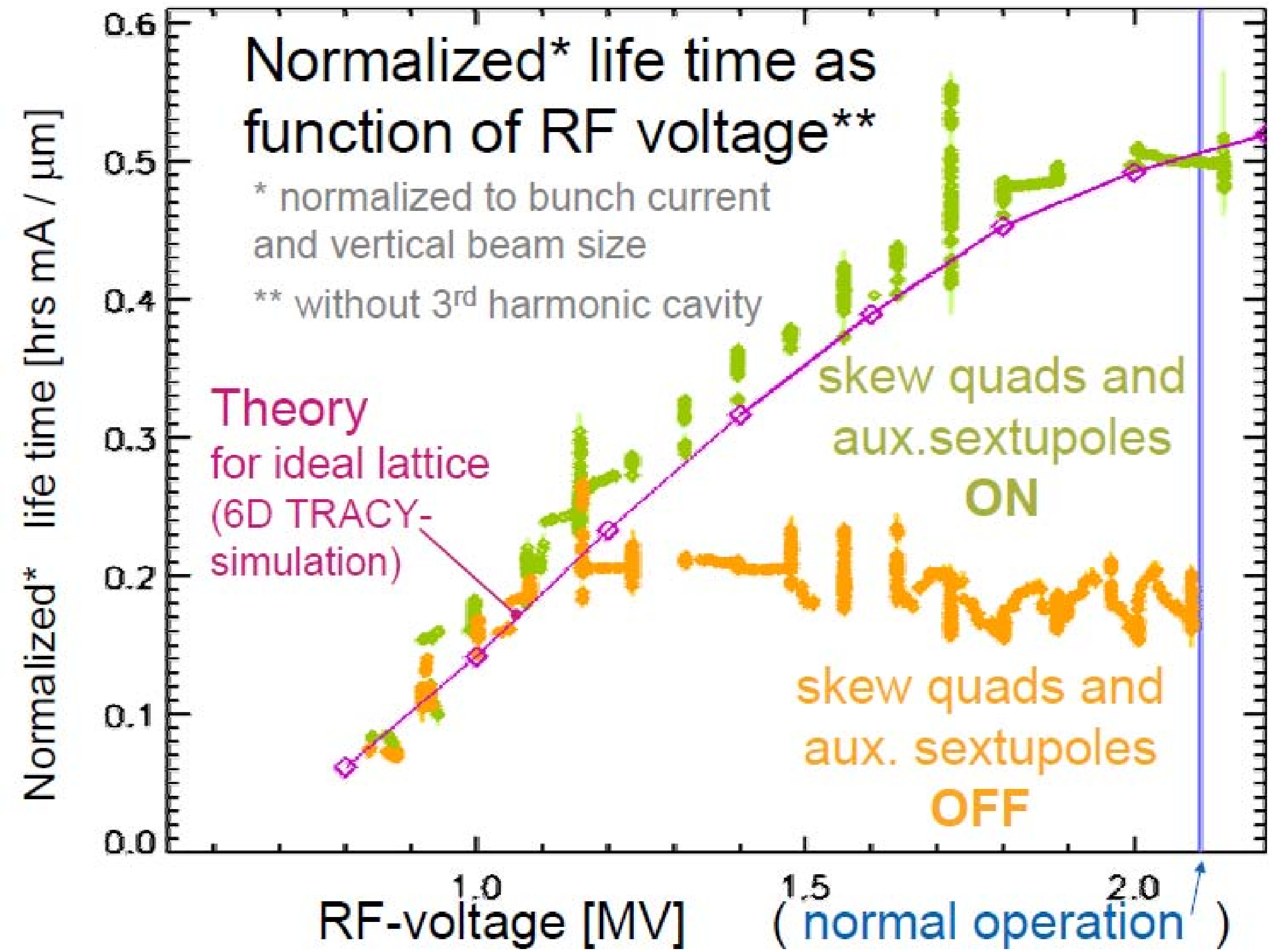
- Second order fringe fields in dipoles, fringe field in quads (as per Tracy-III):
- All multipolar error in dipole, quadrupoles and sextupoles
- BPMs nonlinearities (1D)

Main culprits to explain the disagreement:

- incomplete nonlinear model (sext. calibrations, unknown multipolar errors, fringe fields)
- BPMs frequency response; 2D description of BPMs nolinearities

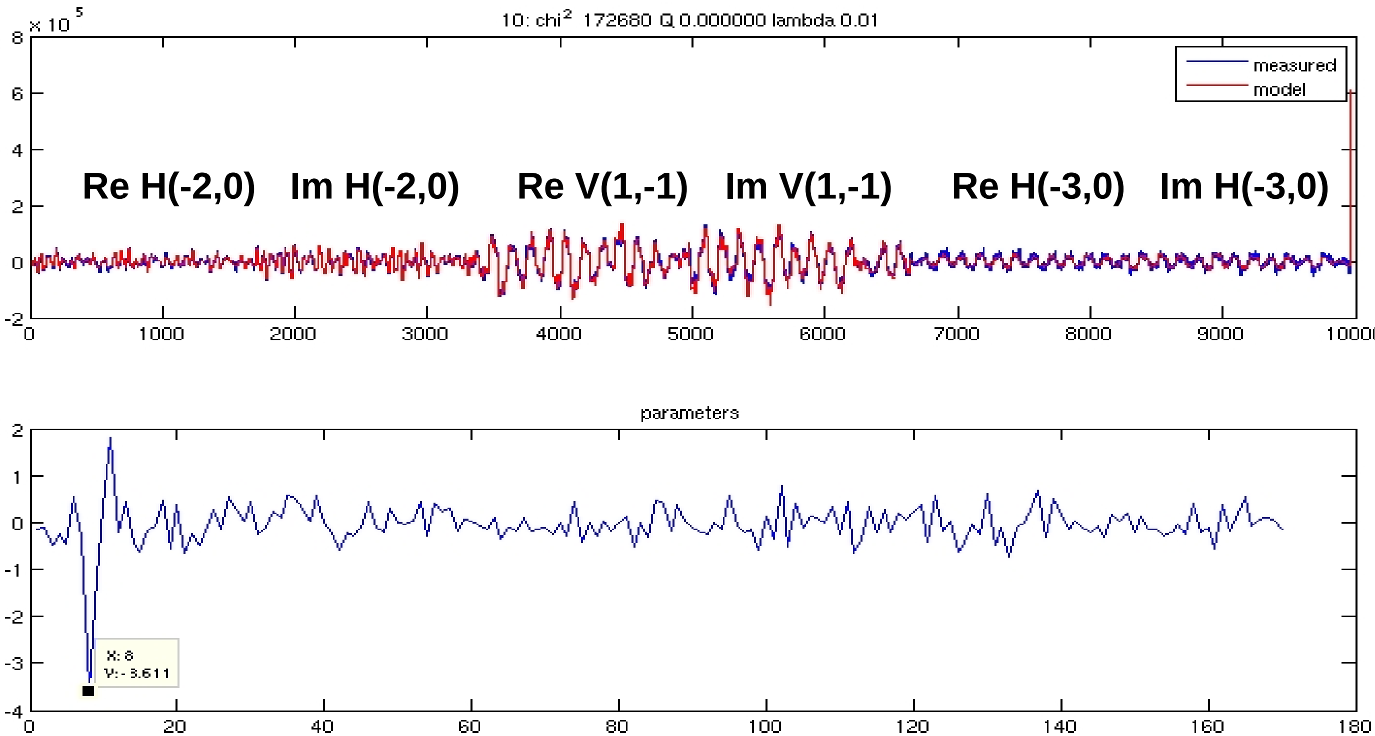
SLS: comparison machine-model lifetime vs voltage (A. Streun)

Linear coupling and 3rd order resonance correction improved significantly the agreement machine vs model;



Resonance driving terms with t-b-t data

Resonance driving terms can be used to calibrate the machine model



SOLEIL but also SLS, SSRF and others are trying to use this type of analysis

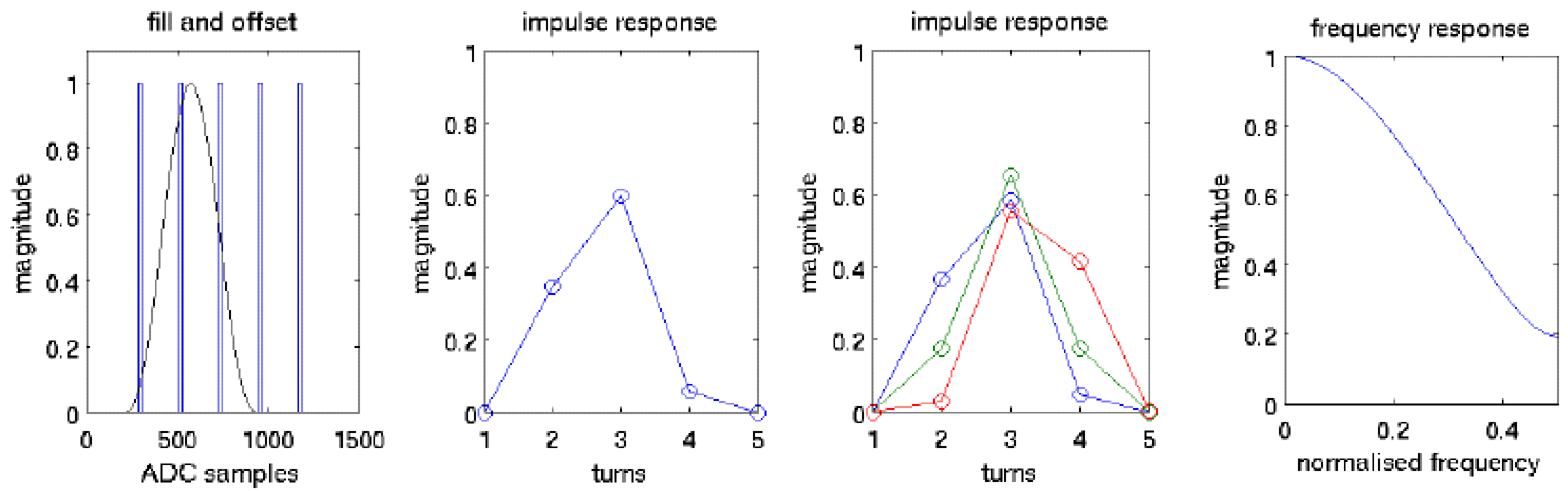
Session 4: IDs and technology

BPM requirements for turn by turn measurements

Feedback between modelling and experiments (Diamond and SOLEIL) highlighted several important issues in the functioning of Libera BPMs, which need to be take in account to get meaningful results, e.g.

time alignment of the BPMs time series

frequency response of the BPMs



talks by G. Rehm and R. Hrvatin

Session 4: IDs and technology

	Analysis of fundamental lines: Frequency map analysis, ß-function or phase advance measurements			**Analysis of higher order lines:** Driving term analysis		
	Frequency	Amplitude	Phase	Frequency	Amplitude	Phase
Turn mixing Timing errors						
BPM non-linear distortion						
Sensor tilt						
Channel cross talk						
Decoherence						
Impedance or wakefields related						

summary by P. Kuske and L. Nadolski

Session 5: low alpha lattice

Nice progress and **low alpha lattices available for users at many labs** (ANKA Bessy-II, …), recently joined by SOLEIL, Diamond and SLS. Both for THz and X-rays.

Emittance with low alpha generally larger than in nominal operation but still useable (e.g. 4.2 Diamond, 8.5 nm SOLEIL)

Longitudinal dynamics is complicated by the requirements to control higher order in the momentum compaction factor (<u>use of octupoles was discussed and seems promising</u>)

Transverse dynamics studies show that **sufficient apertures are available**, although injection efficiency is much lower than in normal operation.

Low alpha operation is limited by collective effects

Actions (I)

Comparison of codes

significant differences exists especially at large (negative) momentum still to be understood

discussion highlighted the need to clarify/document the physics contained in the codes (assumptions, approximations and limits)

benchmark of codes on specific magnetic elements

General agreement on the idea of pursuing a **campaign of measurements**

define common measurements procedures

exchange of software and people

Linked to code comparison

Actions (II)

Which measurements?

- Energy (spin dep.)
- Alpha
- dispersion
- Natural chromaticity
- Nonlinear dispersion
- Detuning with momentum
- Detuning with amplitude
- Apertures (on/off momentum and engineering apertures)
- Lifetime
- Frequency Maps (x –z and x –dp/p)
- Resonance driving terms
- Chromatic phase advance
- IDs?

Final goal is to provide a nonlinear model of the machine and be able to operate (or correct) according to the design

Set up a website with lattices and experimental data and experimental procedures

Summary (I)

Theory:

Tracking is mandatory but analytical treatment is an active area (Map and Integrators for IDs)

Design and optimisation:

Genetic algorithms seem worth pursuing (APS + DLS-preliminary results are OK). MOGA and GLASS produced interesting results at ALS. Extending this analysis to other interested light sources

A combination of semi-analytical tools, FM and tracking (6D) is adequate to optimise the most advanced design for ultra low emittance lattice

Summary (II)

Comparison machine to model:

Detuning with momentum, DA and FM progressing; still not a perfect agreement

Improve the model (more kicks or better integrators), all errors, fringe fields

Natural chromaticity: few units disagreement in V is common and not understood

Resonance driving terms experiments are progressing and adopted at different labs

Technology

Understanding of the hardware implications of t-b-t measurements on the BPMs system (and viceversa) is progressing and crucial

Summary (III)

All presentations ara availble at

http://www.diamond.ac.uk/Home/Events/Past_events/NBD_workshop.html

Alba and NSLS-II have expressed interest in hosting the next nonlinear beam dynamics workshop in about 2 years time