Status of the Diamond Project

Richard P. Walker
on behalf of the Diamond Machine Project Team

1. **Introduction**
2. **Storage Ring Commissioning**
3. **Status and Future Plan**

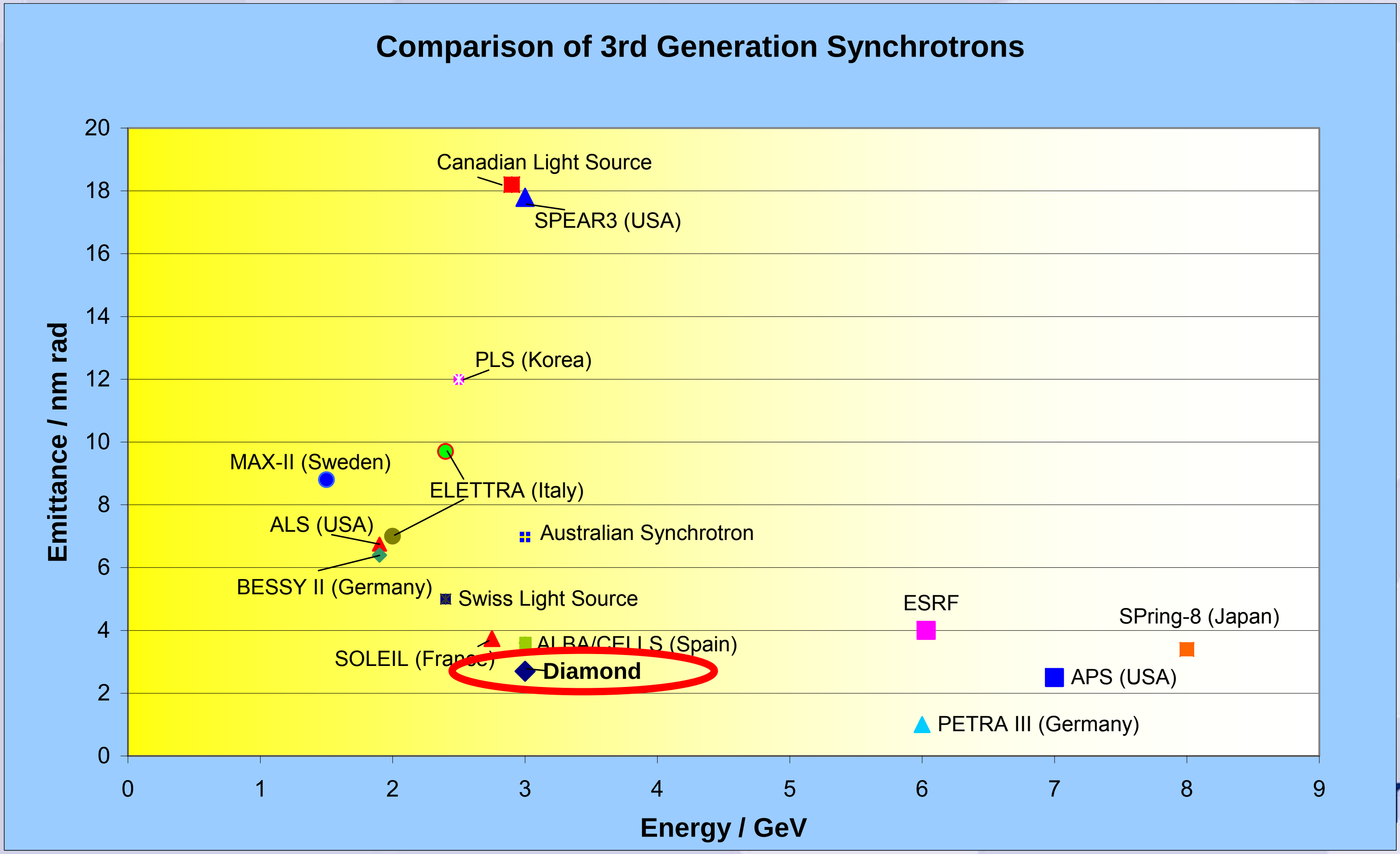
diamond

3 years ago today – January 30th 2004 !

Photo. by Angelos Gonias, DLS

Diamond is a new Medium Energy, 3rd Generation Light Source, to replace the SRS – the world's first purpose built high energy synchrotron radiation source (now 25 years old)

The largest accelerator project, and the largest scientific investment in the UK for over 30 years.



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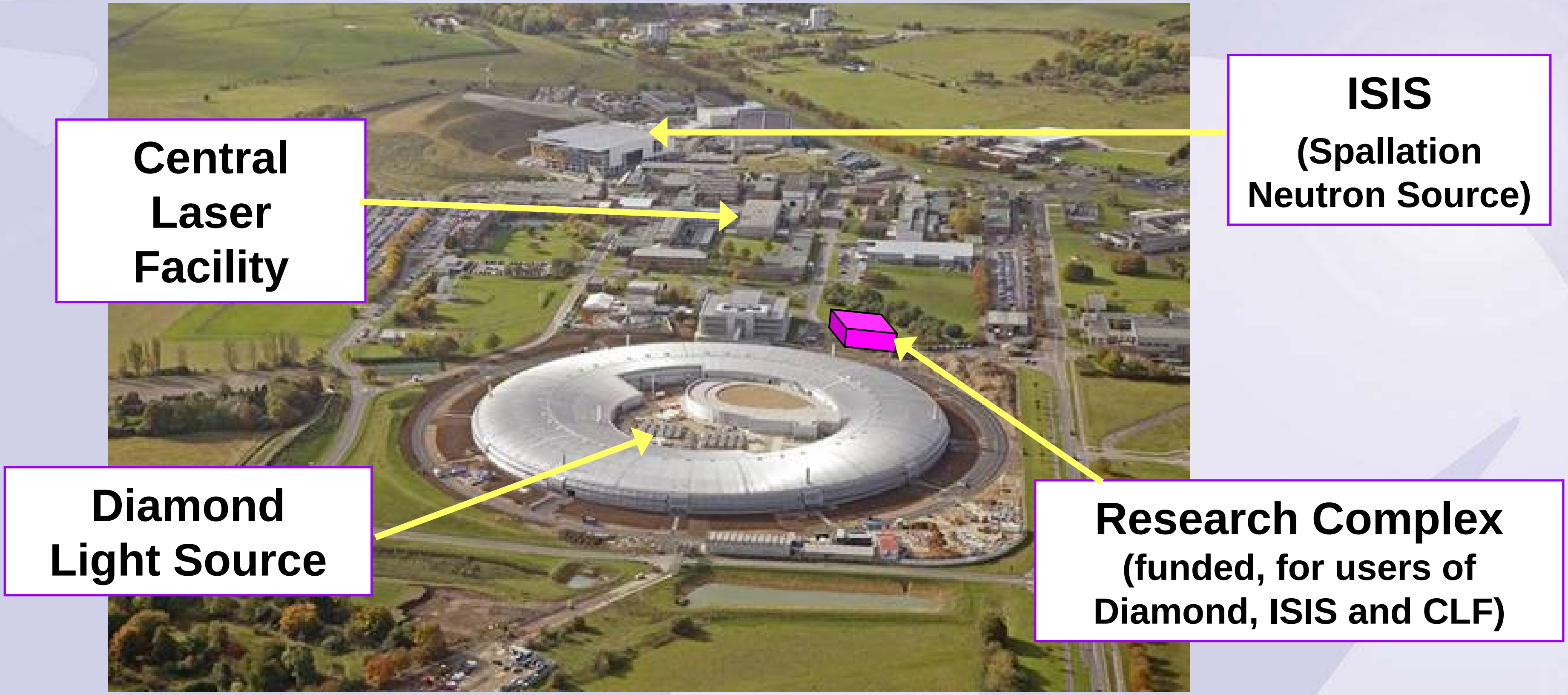
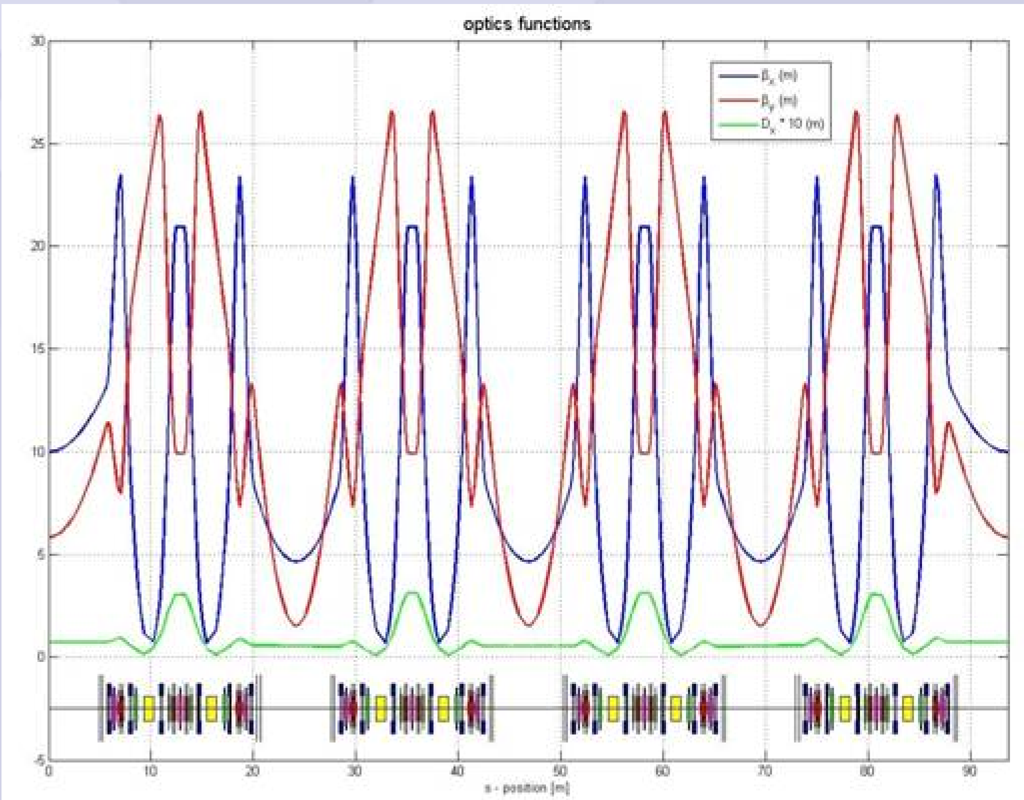
Located at the Rutherford Appleton Laboratory, Harwell Science and Innovation Campus, Oxfordshire, UK



Diamond – Main Parameters



nominal, non-zero dispersion lattice

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**

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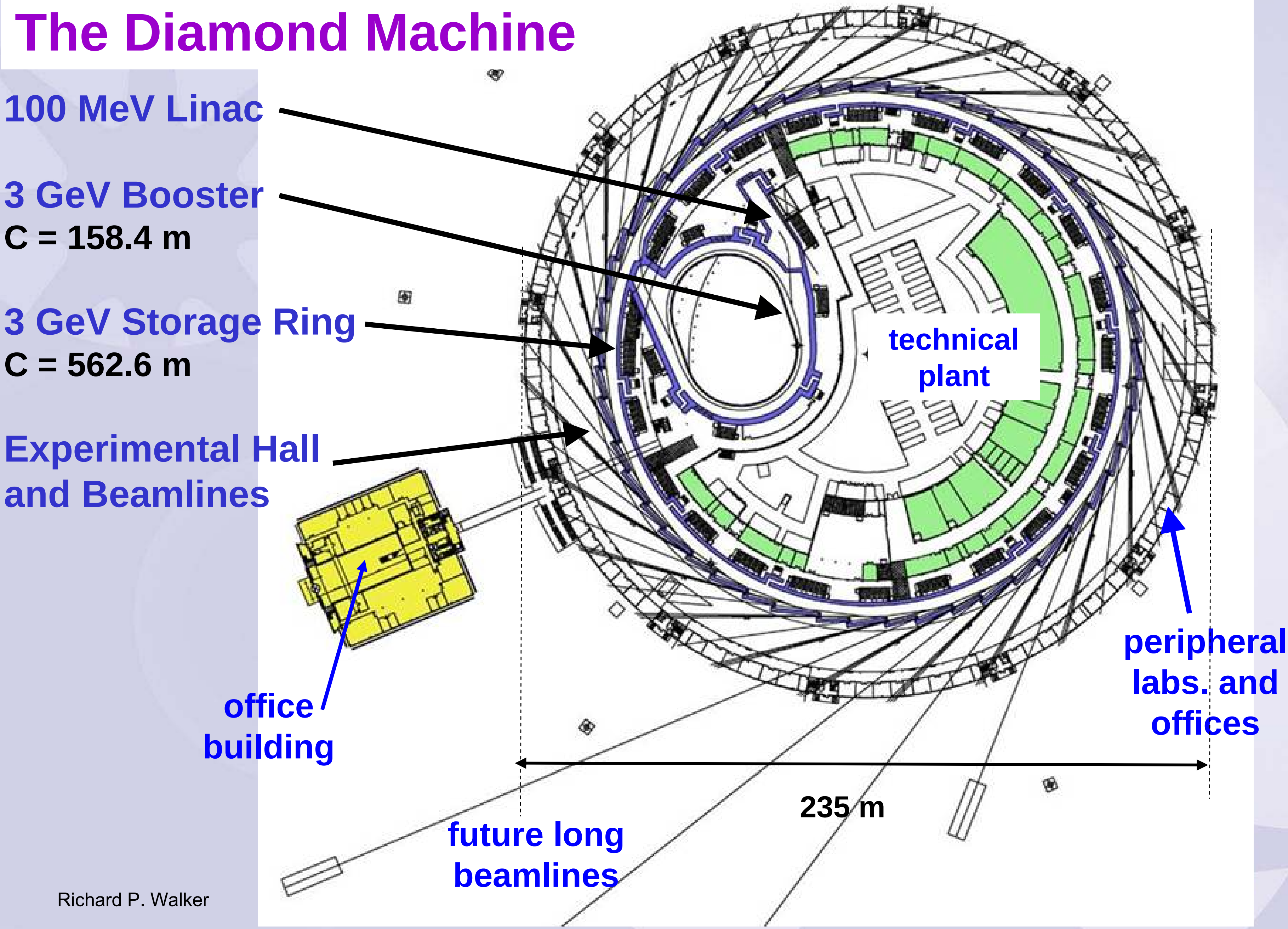
Diamond Key Dates

1993	Woolfson Review: SRS to be replaced by a new medium energy machine
1997	Feasibility Study ("Red Book") published 3 GeV, 16 cells, 345 m circumference, 14 nm rads
1998	Wellcome Trust joins as partner
Mar. '00	Decision to build Diamond at Rutherford Appleton Lab.
Oct. '00	3 GeV, 24 cells, 560 m circumference design approved
Apr. '02	Joint Venture Agreement signed (UK Govt./WellcomeTrust) Diamond Light Source Ltd. established Design Specification Report ("Green Book") completed by CCLRC
Jan. '07	Start of Operations

The Diamond Machine



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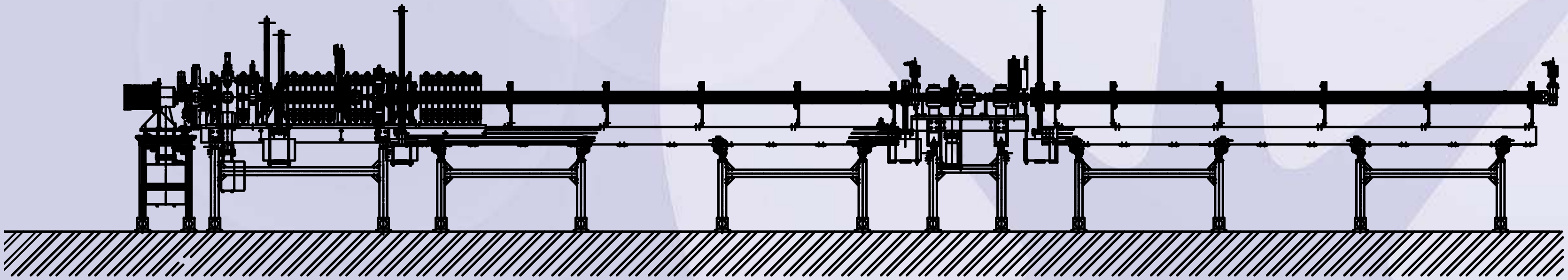
Linac

- 100 MeV Linac of the DESY S-band Linear Collider Type II design, supplied "turn-key" by Accel Instruments.

  (DLS supplied diagnostics, vacuum and control system components, and beam analysis software)

- thermionic gun; short (< 1 ns) and long pulse (0.1-1 μs) modes
- 500 MHz sub-harmonic pre-buncher, 3 GHz primary buncher, 3 GHz final buncher
- two 5.2 m constant gradient accelerating sections fed by independent klystrons



Linac Commissioning

Installation complete:	**Aug. 3rd 2005**
1st beam from gun:	**Aug. 31st 2005**
1st 100 MeV beam:	**Sep. 7th 2005**
Acceptance test complete:	**mid-Oct. 2005**

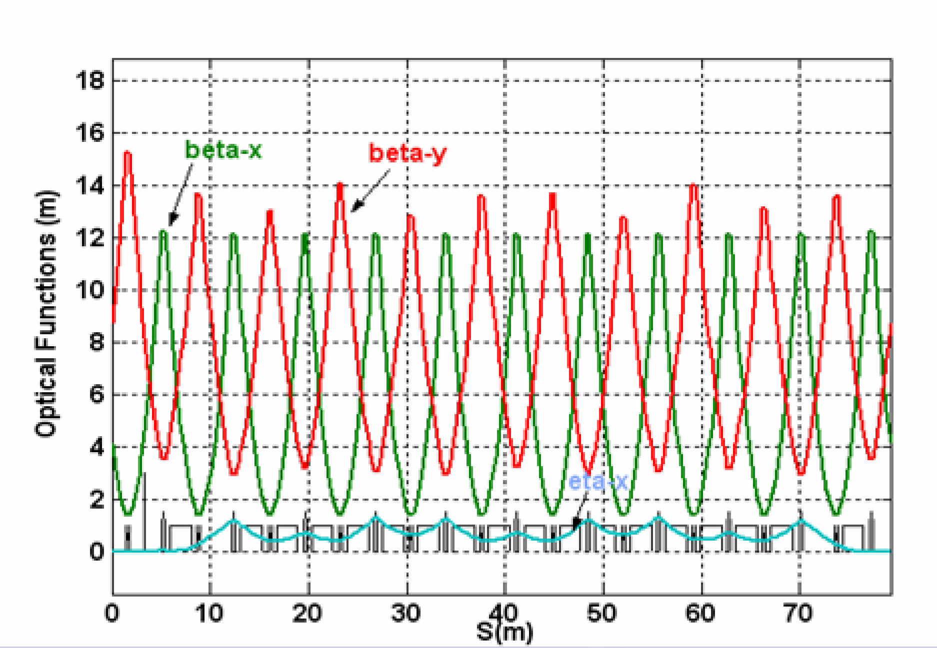
Linac Performance

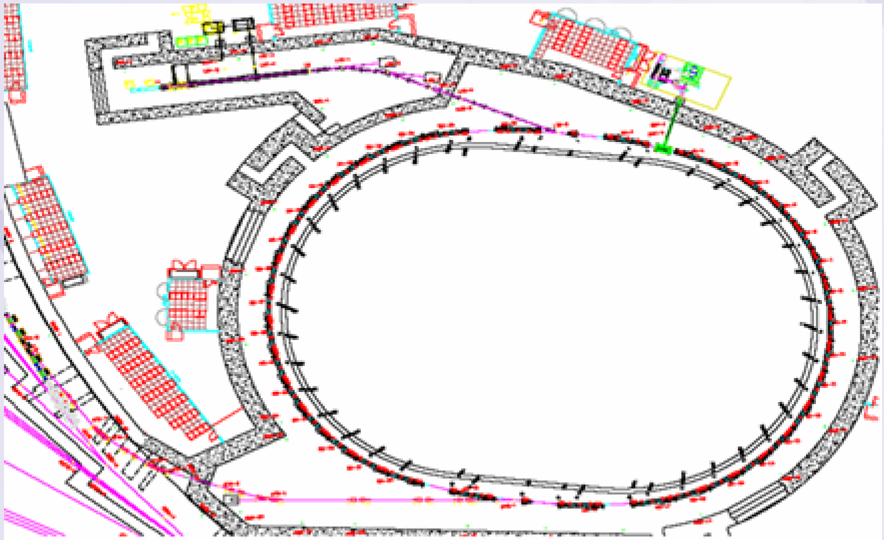
Parameter	Specification	Single bunch	Multi bunch
Energy [MeV]	> 100	103	103
x norm. emittance [π.mm.mrad]	< 50	18	16
y norm. emittance [π.mm.mrad]	< 50	27	11
Charge [nC]	> 1.5 / 3.0	2.1	4.8
Pulse width [ns]	< 1	~ 0.2 fwhm	~ 0.2 fwhm
Jitter [ps]	< 100	11	11
Energy variation [%]	< 0.25	0.05 rms, 0.21 full	0.05 rms, 0.16 full
Energy spread [%]	< 0.5	< 0.2	0.2

(Same at 1 Hz or 5 Hz)

Booster

Energy	3 GeV
Circumference	158.4 m
Emittance	141 nm rad
Repetition rate	5 Hz
Lattice	FODO, missing dipole

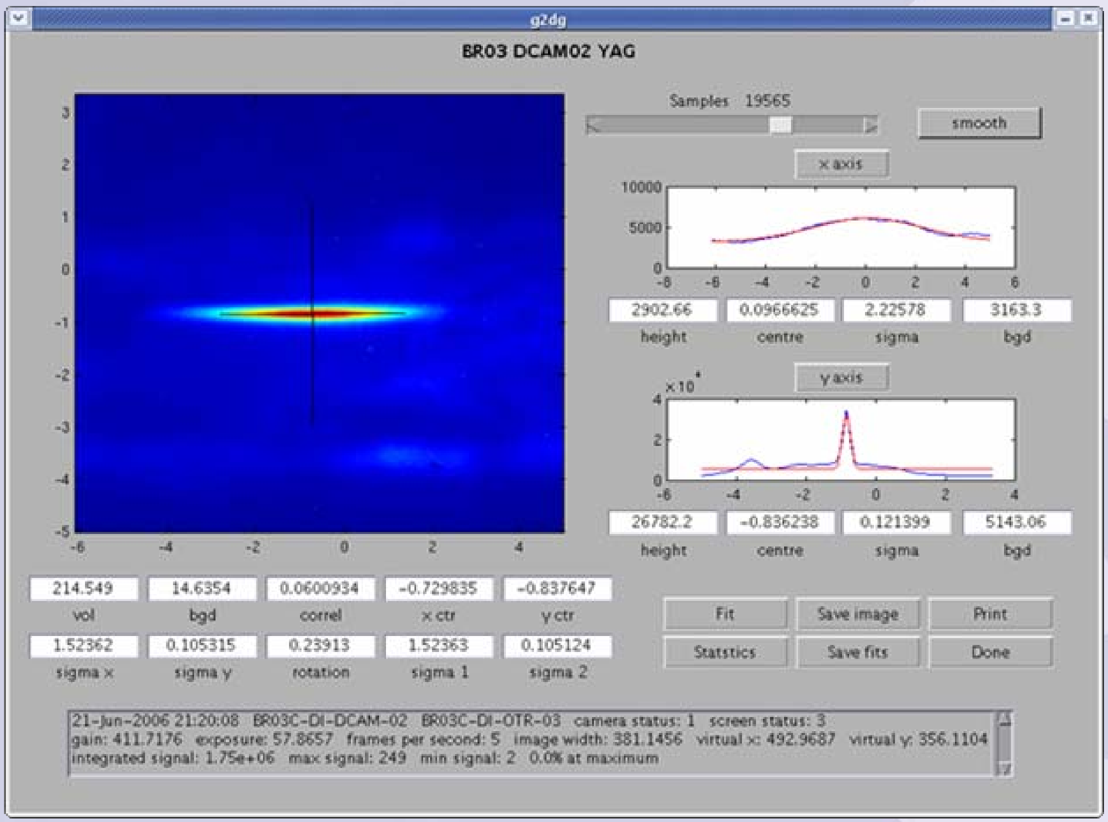




Booster Commissioning

1^{st} turn, 100 MeV:	Dec. 21^{st} 2005
Acceleration to 700 MeV:	Mar. 10^{th} 2006
Extraction at 700 MeV:	Apr. 4^{th} 2006
Acceleration and extraction at 3 GeV:	Jun. 9^{th} 2006

} limited by lack of water cooling (acceleration and extraction at 700 MeV)



Extracted beam at 3 GeV

σ_x=1.5 mm

σ_y=0.11 mm

in agreement with theory (2% coupling)

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Storage Ring Commissioning – Phase I (700 MeV)

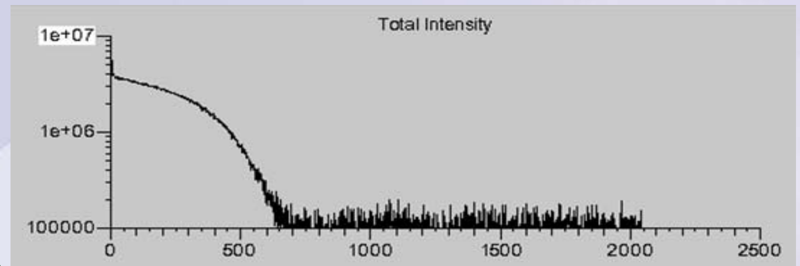
limited by lack of water cooling

May 4th 2006 - first injection in the storage ring

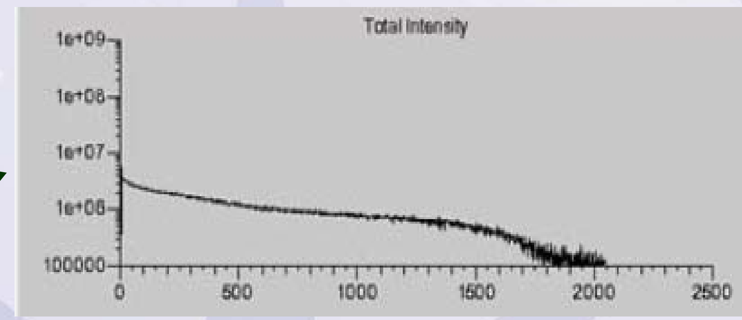
May 5th - first turn *(correctors off)*

May 6th - 4 turns

May 7th – 600 turns *(sext. off, RF off)*

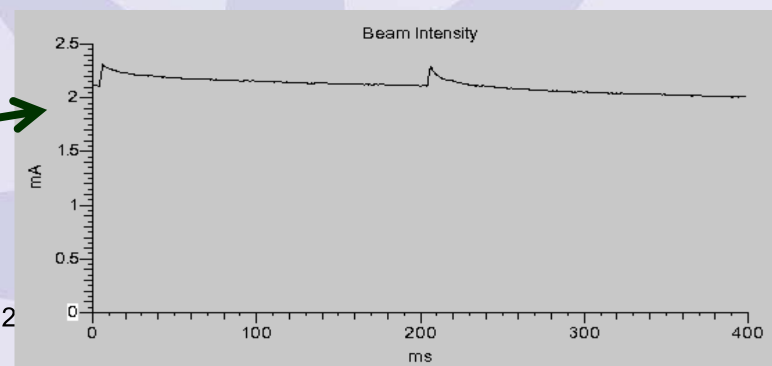


May 20th – 2000 turns *(sext. on, RF off)*



May 22nd – 0.5 mA stored beam (no accumulation)

May 30th – stacking to 2 mA

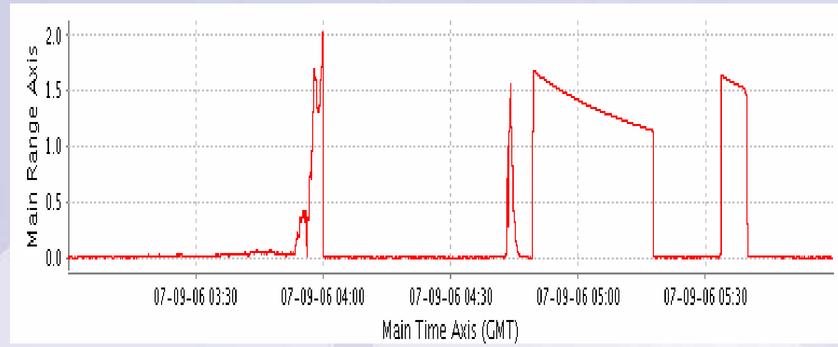


Storage Ring Commissioning – Phase II (3 GeV)

Sep. 4th 2006 – 5 turns, no correctors !

Sep. 5th – 120 turns, RF off

Sep. 6th – RF on .. 2 mA stored;
(restricted since absorber water flow interlocks not commissioned ..)



Sep. 9th – 10 mA;
(restricted since orbit interlock not commissioned ..)

Sep. 25th – 25 mA

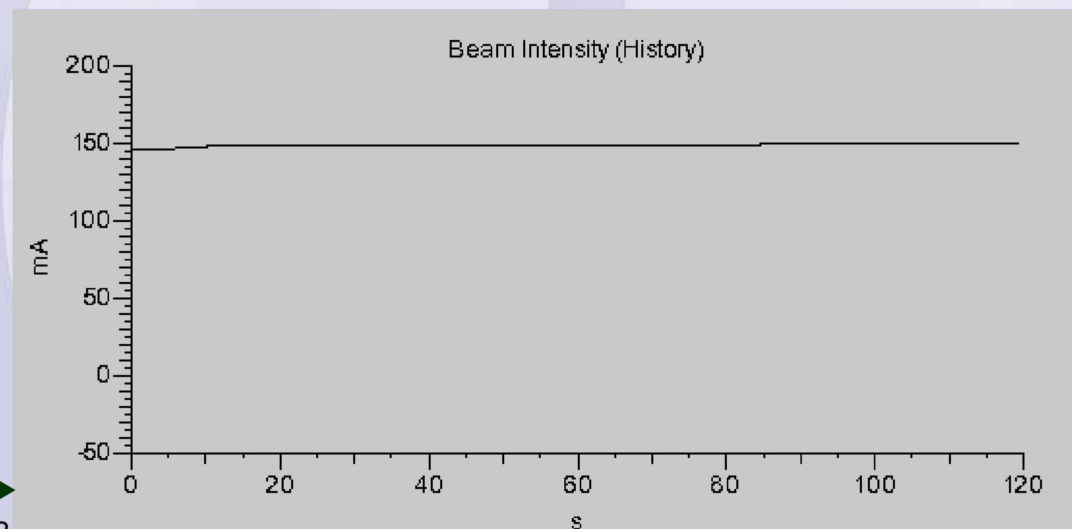
Oct. 2nd – 60 mA

Oct. 10th – 90 mA

Oct. 12th – Start of beamline commissioning

Nov. 11th – 100 mA

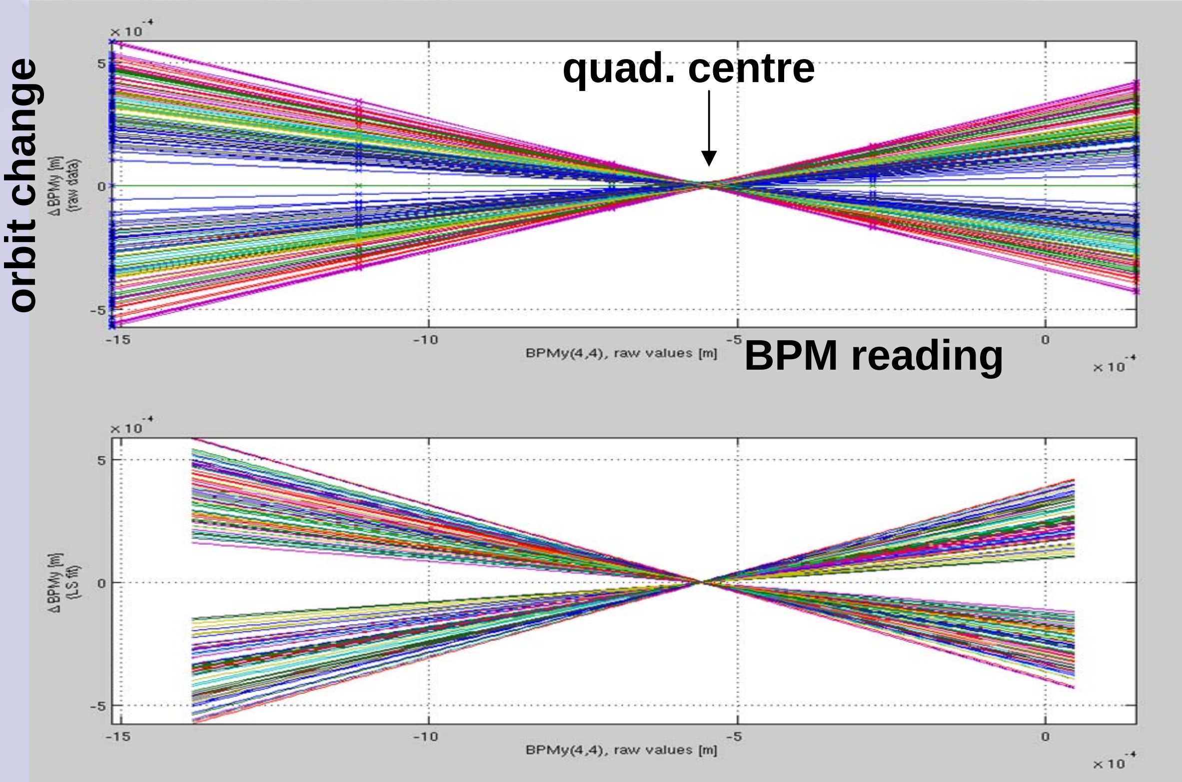
Jan. 12th 2007 – 150 mA



Closed orbit

Closed orbit initially corrected to 0.7 mm rms in both planes, then "saturated".

"Beam based alignment" carried out to determine offsets between the BPMs and quadrupole magnet centres.

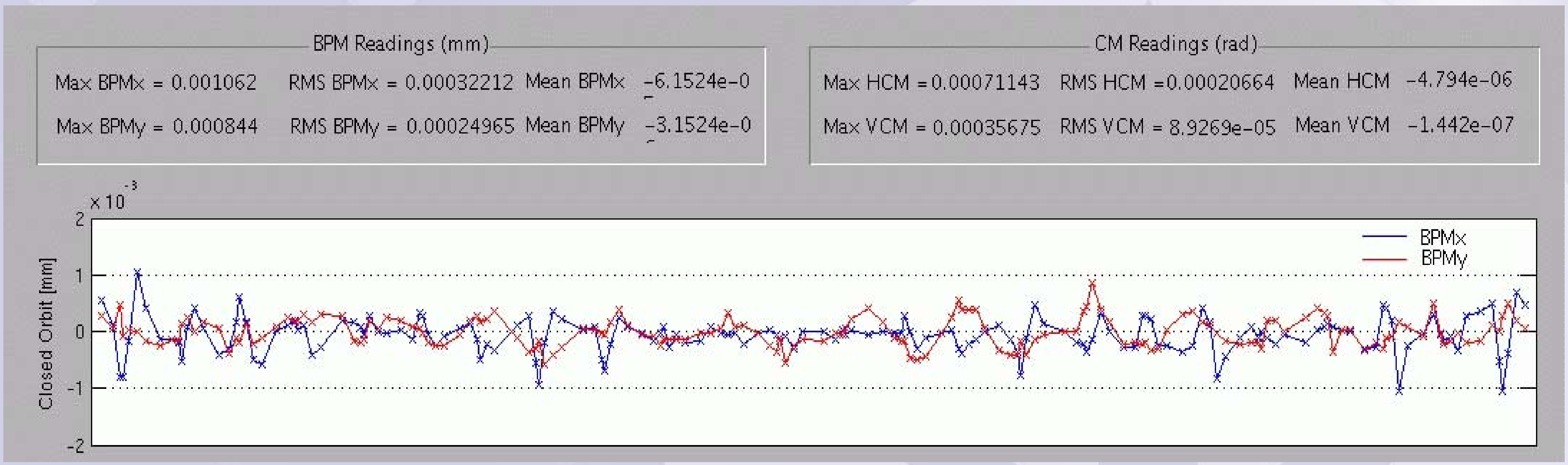


corrector is varied to find the point that the beam passes through the centre of the adjacent quadrupole

G. Portmann, et al., "An Accelerator Control Middle Layer using MATLAB", Proc. PAC 2005, p. 4009.

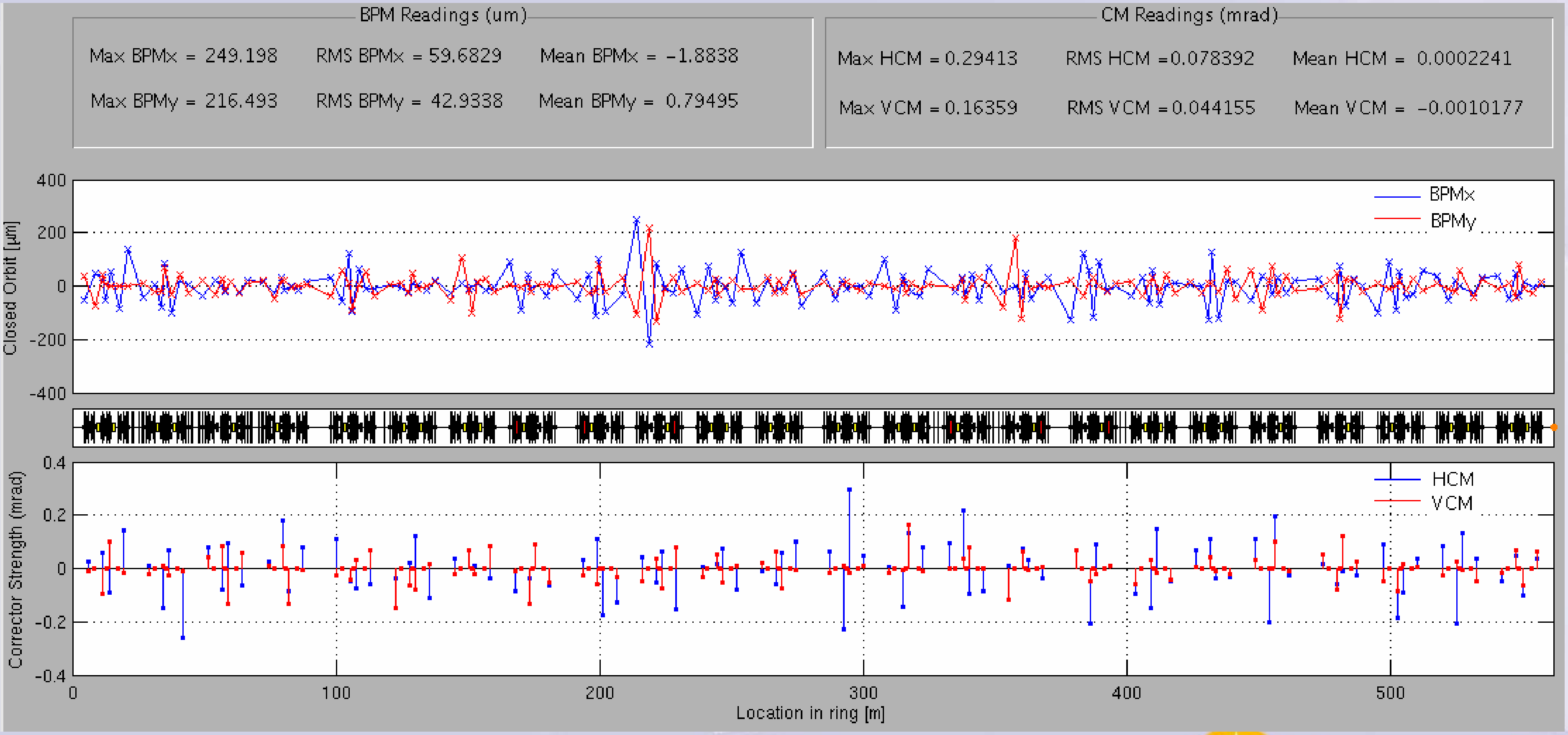
Closed orbit

After the 5th iteration, the closed orbit could be corrected to < 1 μm rms (using all correctors):



Closed orbit

With 96 correctors (168 BPMs) the closed orbit was corrected to 40-60 μm rms, with small corrector strength (<0.3 mrad H, <0.16 mrad V):



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APAC '07, Indore, Jan. 30th 2007

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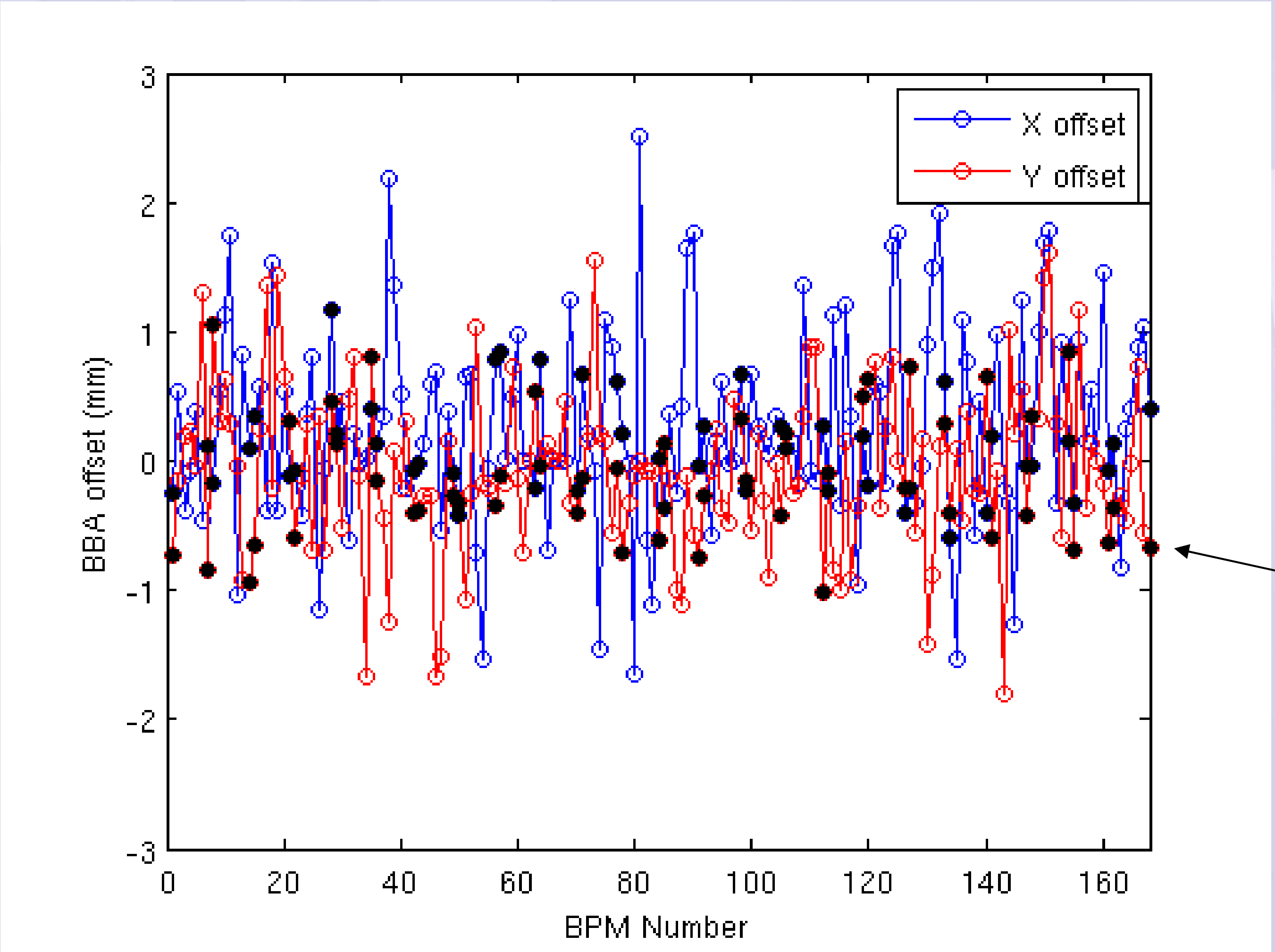
BPM-quadrupole offsets



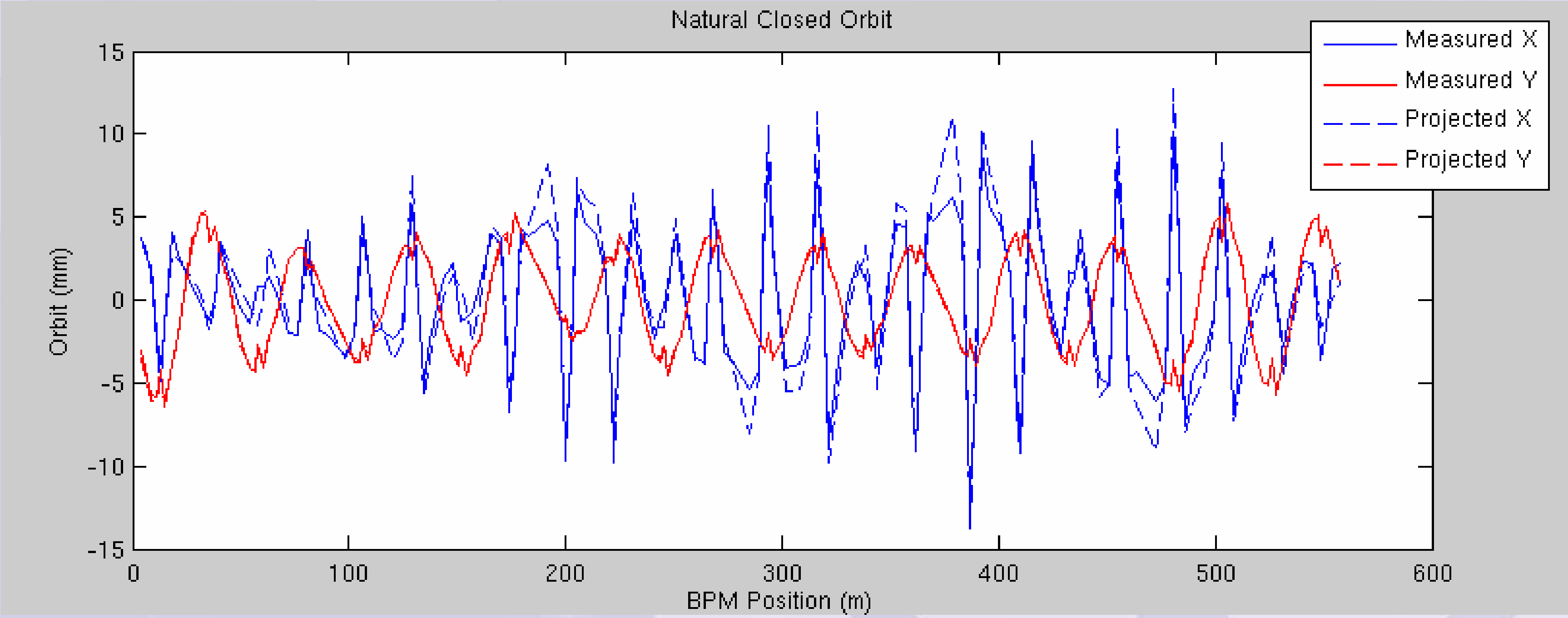
Quite large, but:

- electrical centres of the BPMs were not calibrated

- no accurate mechanical survey.

Smaller at the "primary" BPMs on either side of the IDs – mainly a calibration factor effect

“Bare orbit” – correctors off

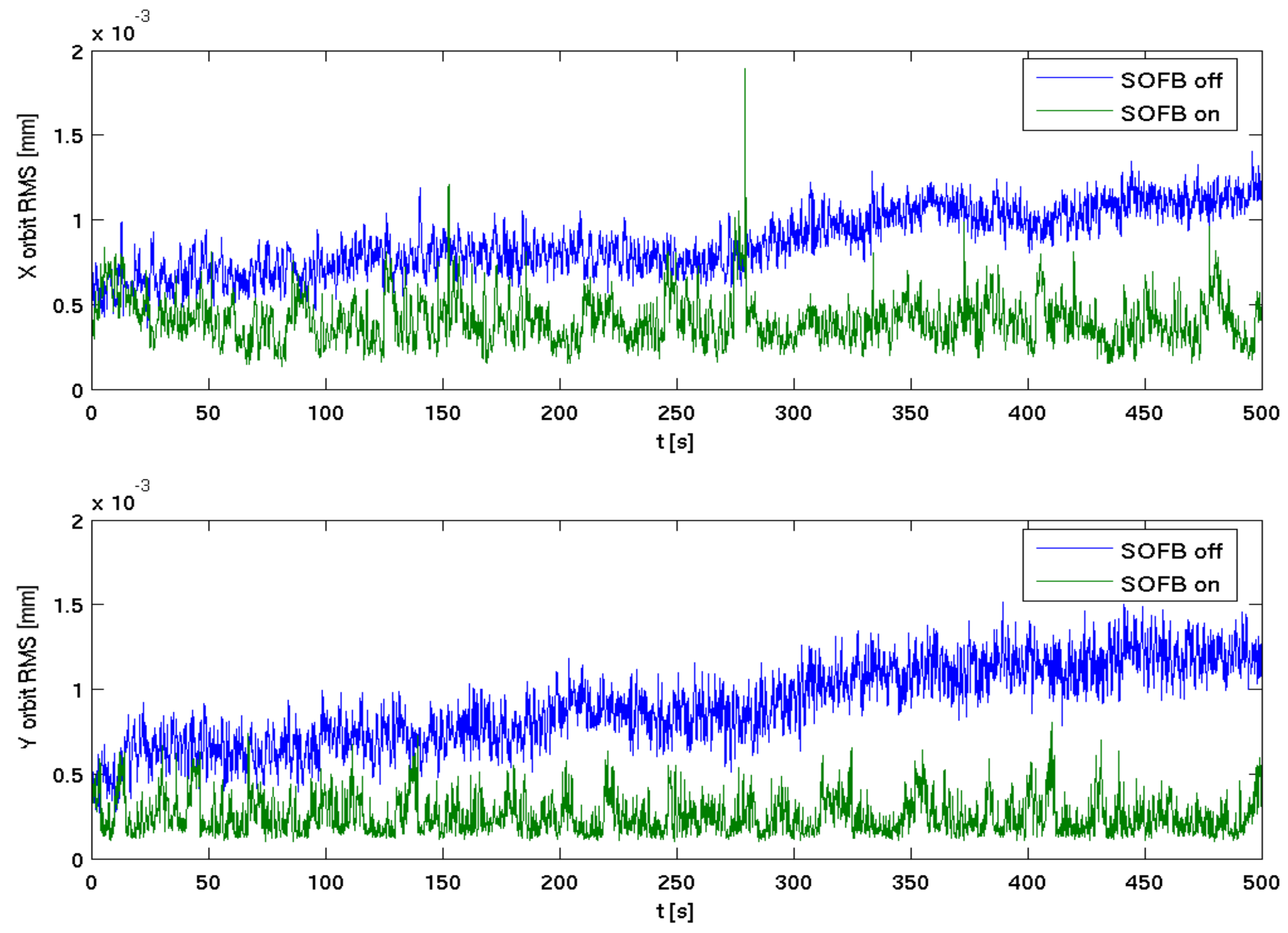


rms x = 4.8 mm, rms y = 3.1 mm

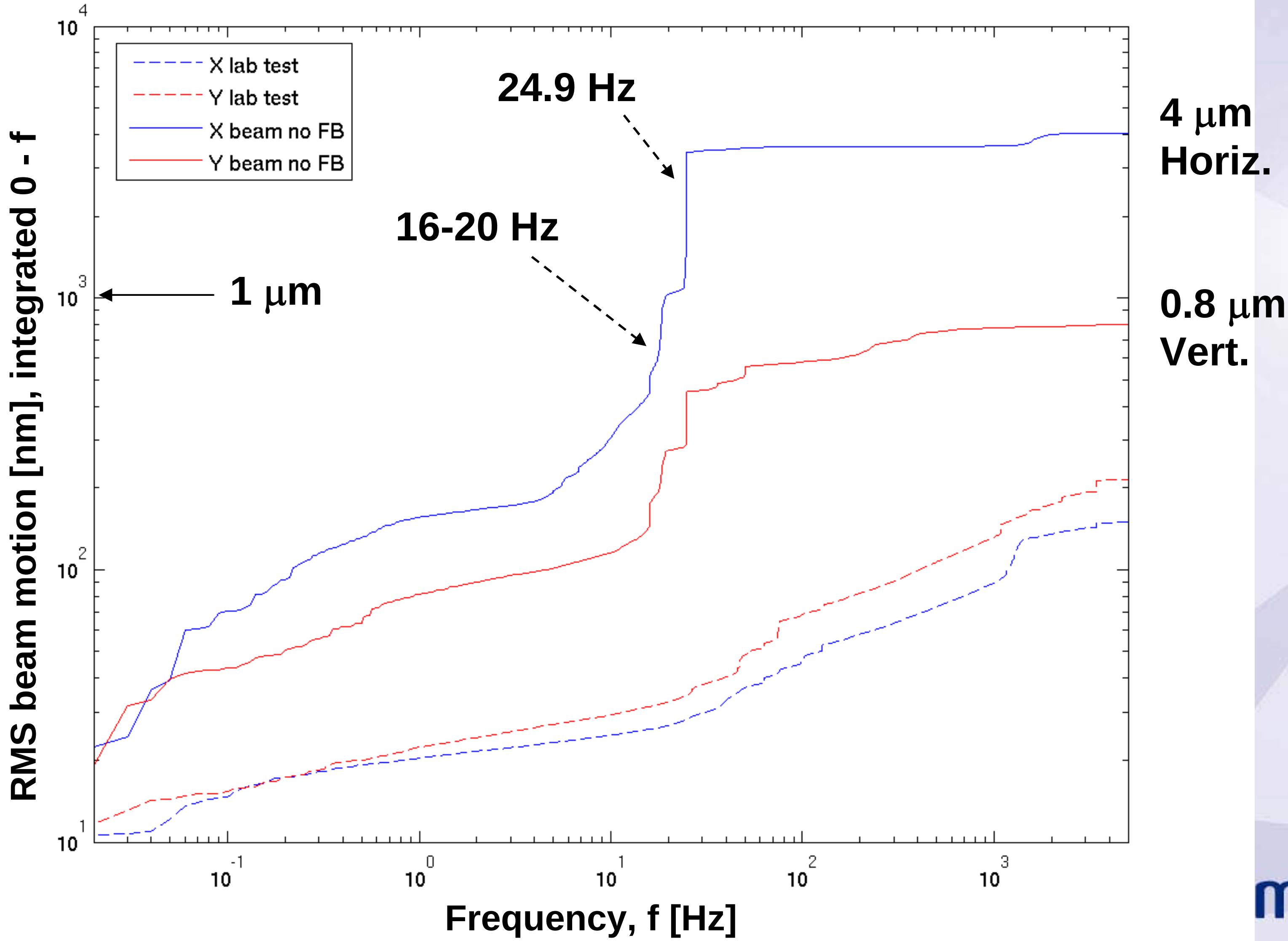
- reasonably consistent with specified 0.1 mm quadrupole positioning error

Orbit stability – long term

running from MATLAB, 0.2 Hz



Orbit stability – short term



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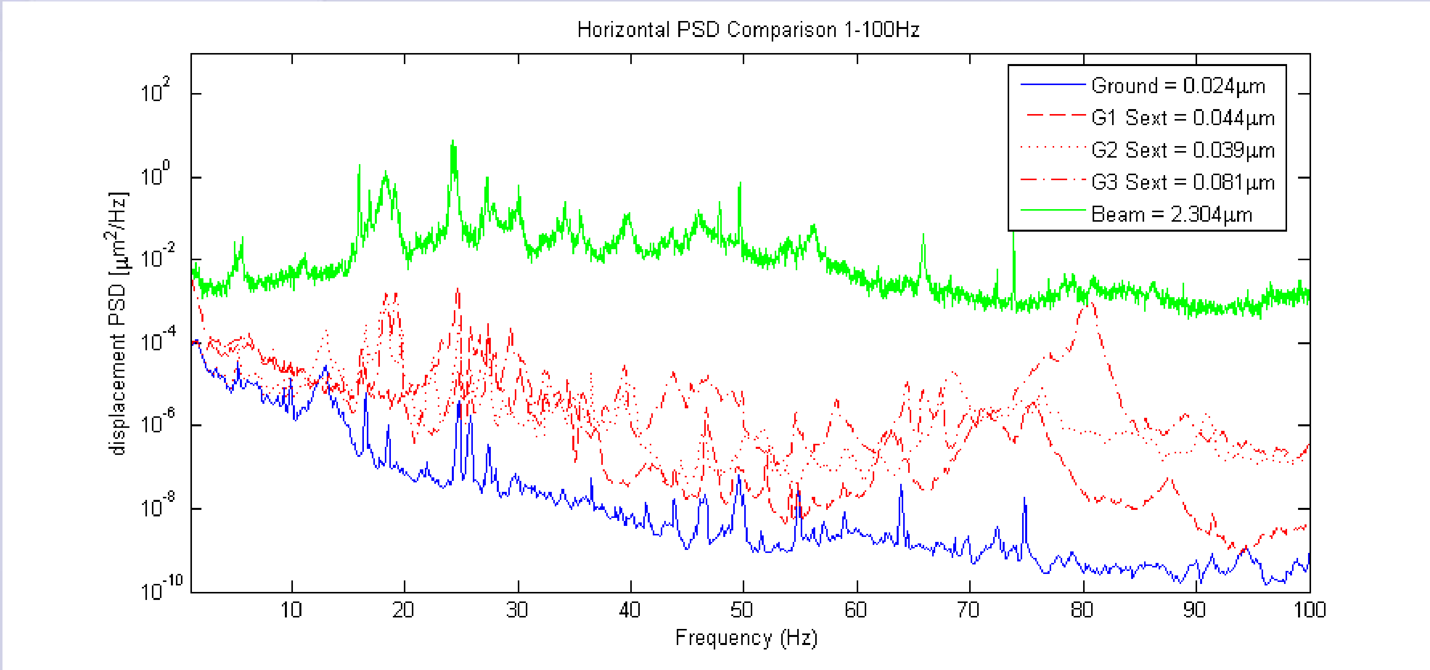
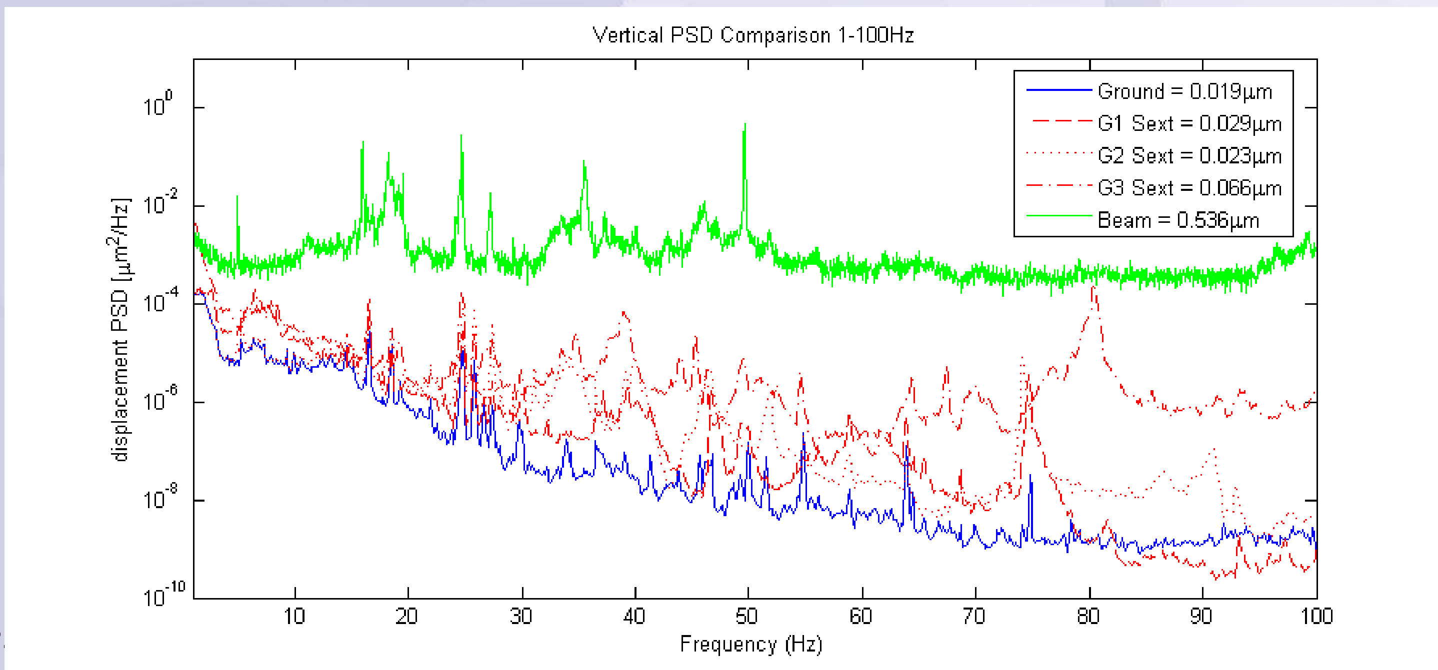
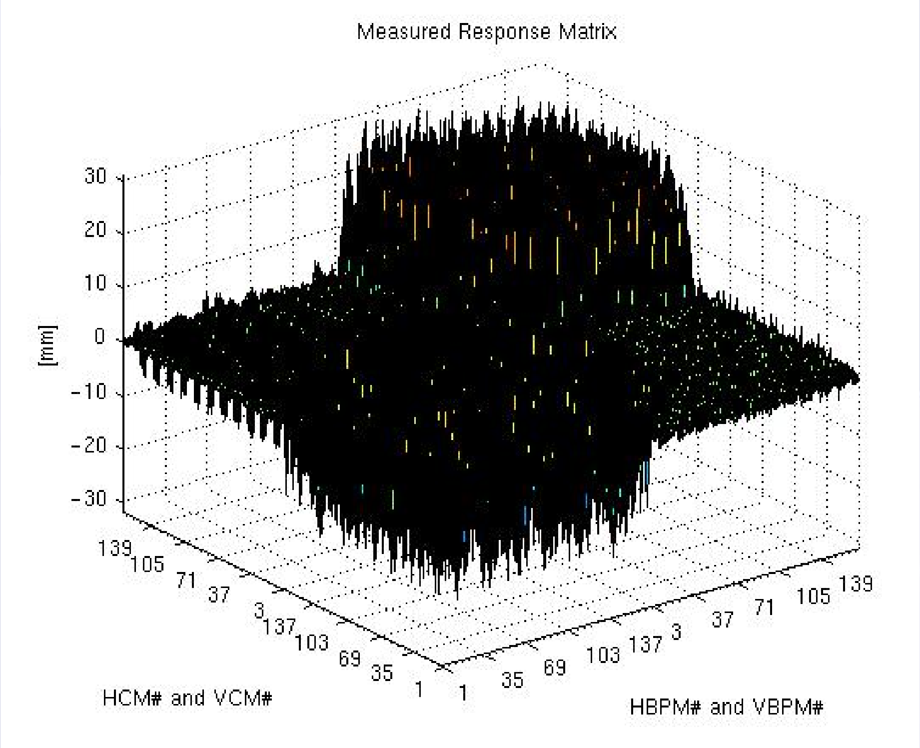
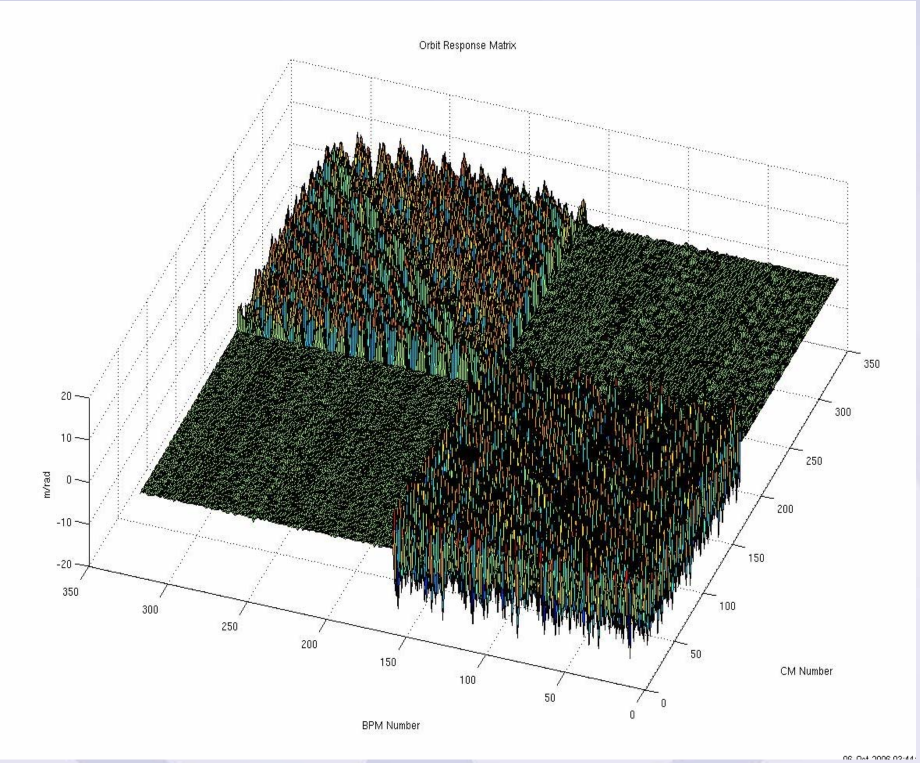

Horizontal PSD Comparison 1-100Hz
Ground = 0.024µm
G1 Sext = 0.044µm
G2 Sext = 0.039µm
G3 Sext = 0.081µm
Beam = 2.304µm
displacement PSD [µm2/Hz]
Frequency (Hz)


Vertical PSD Comparison 1-100Hz
Ground = 0.019µm
G1 Sext = 0.029µm
G2 Sext = 0.023µm
G3 Sext = 0.066µm
Beam = 0.536µm
displacement PSD [µm2/Hz]
Frequency (Hz)

Optics Analysis and Correction (using LOCO*)





Measured Response Matrices (before and after LOCO analysis)

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

J. Safranek et al., "MATLAB based LOCO", SLAC-PUB 9464, (2002).

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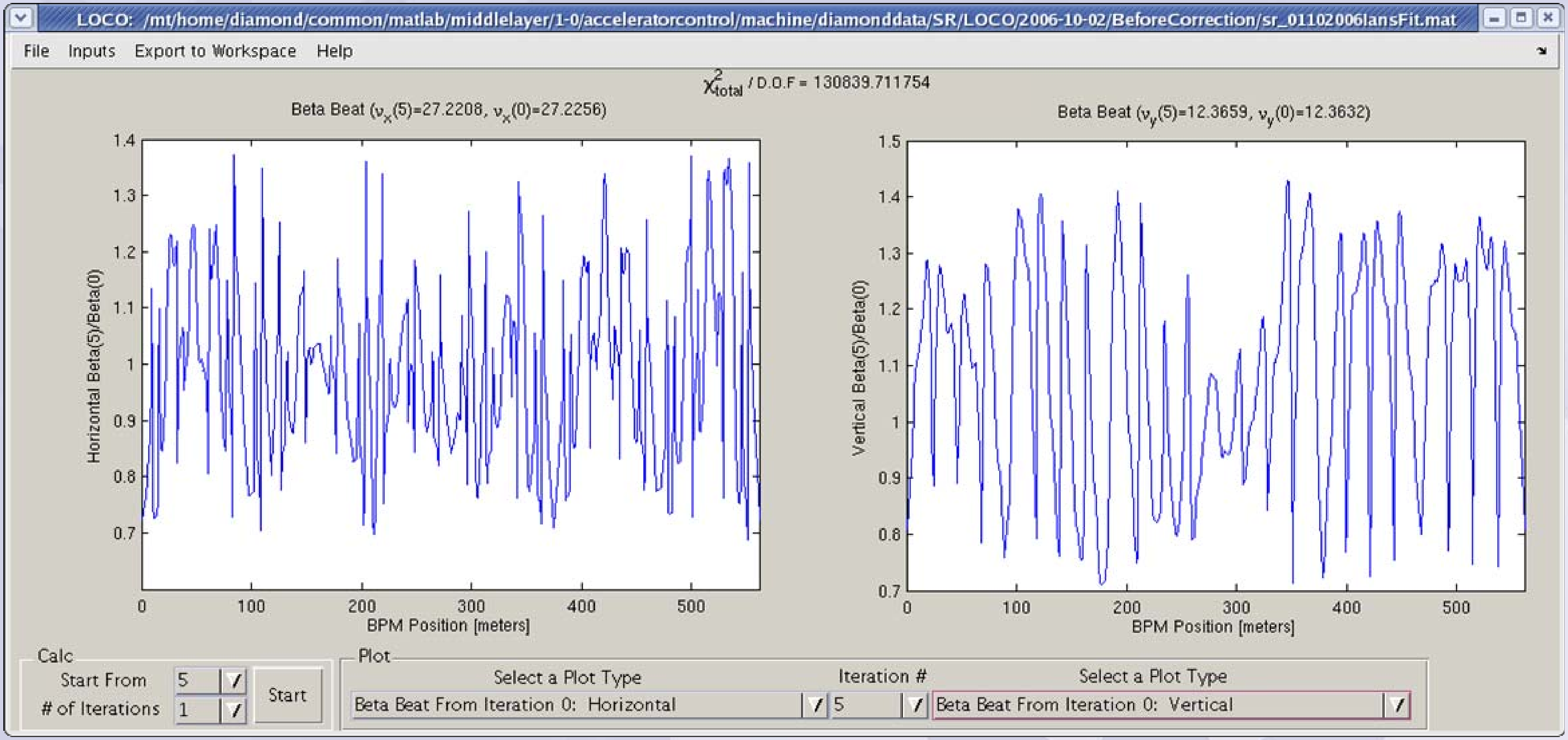
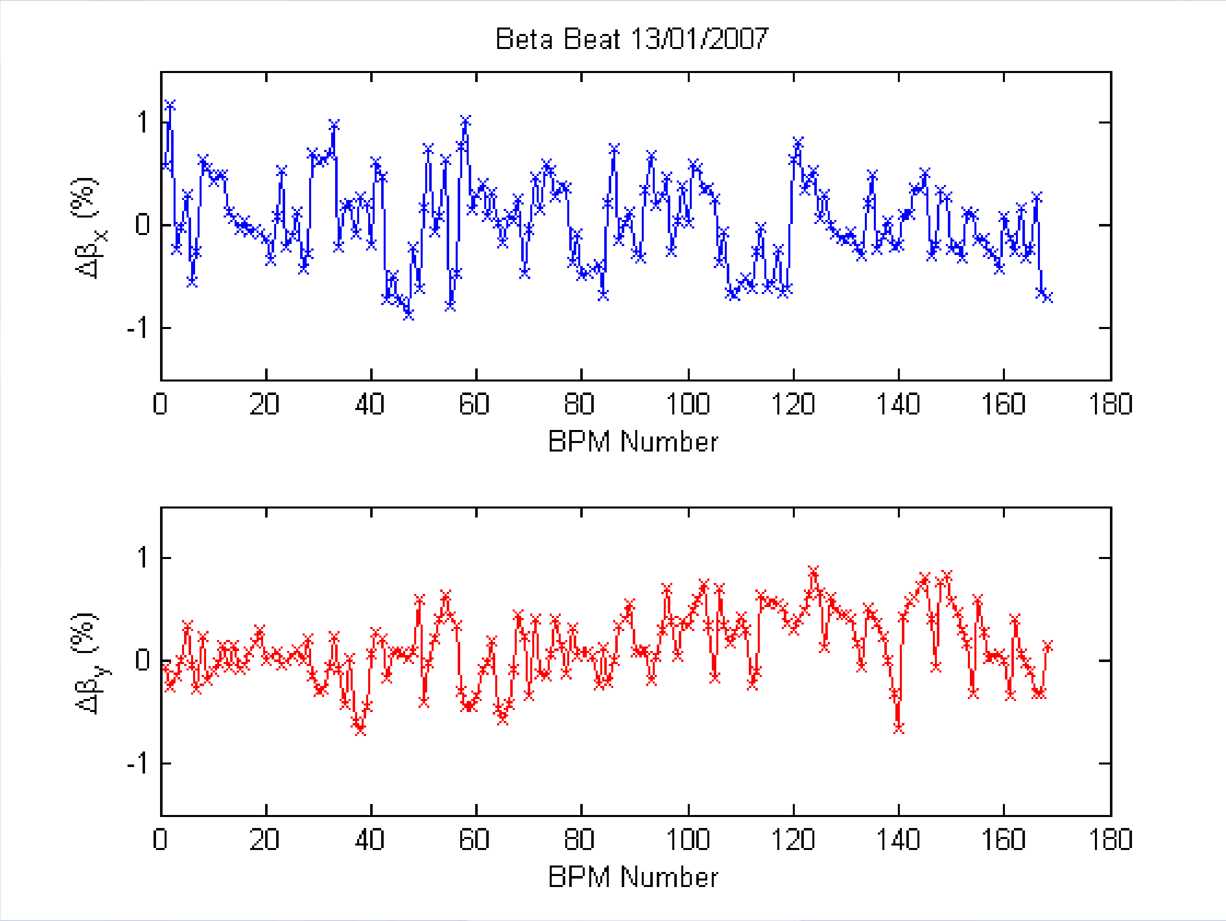
Before correction:



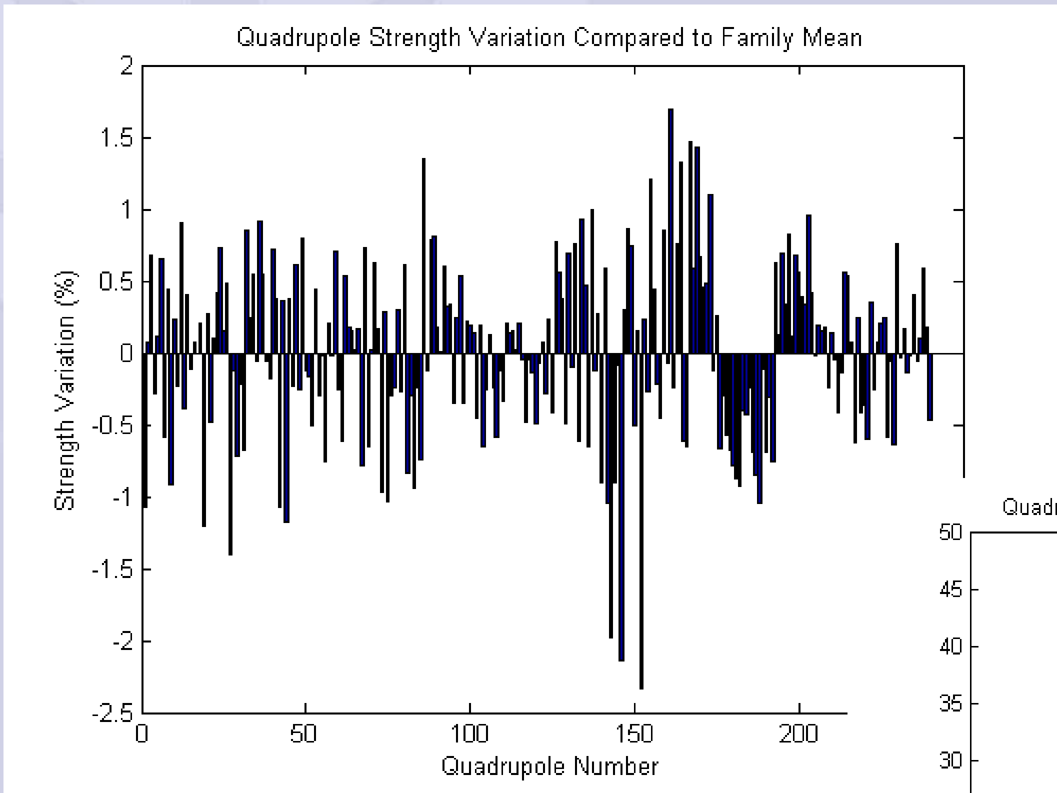
Error in β_h and β_v = ± 40 %

After correction:

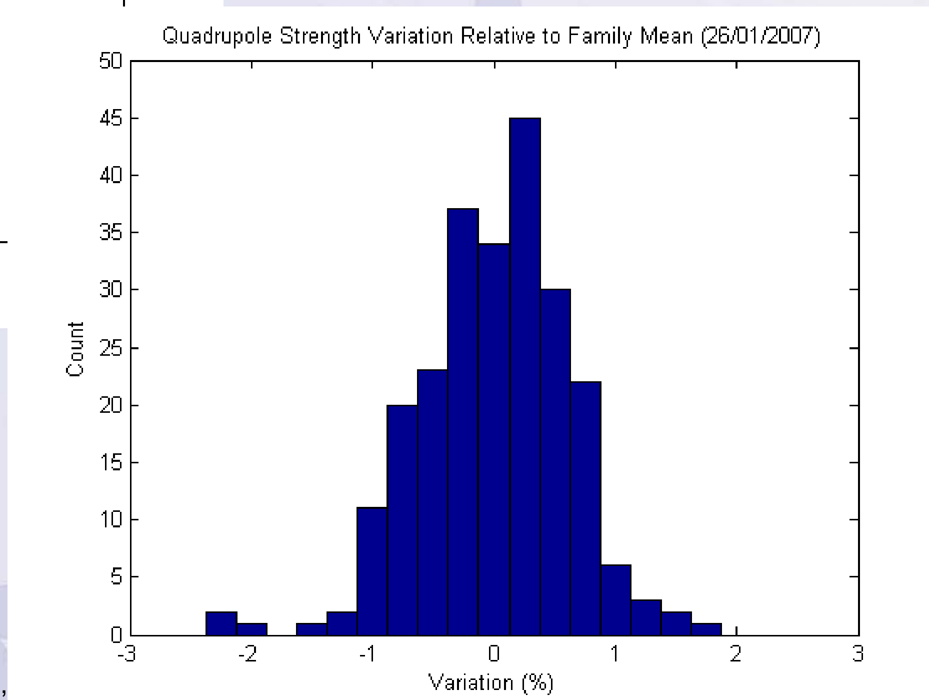


Error in β_h and β_v = ± 1 %

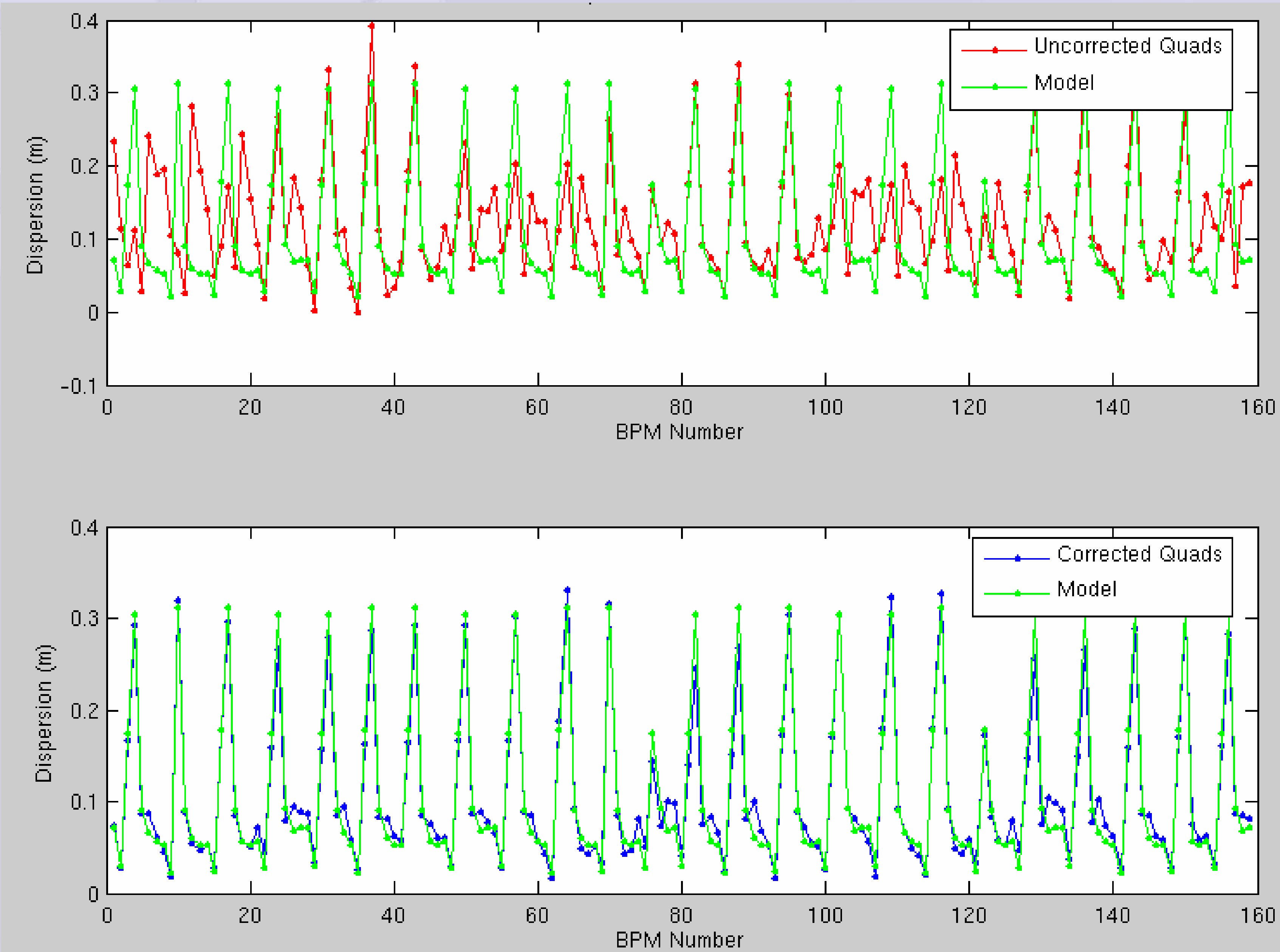
Quadrupole gradient corrections:



Up to 5 % with respect to the nominal calibration, but less than 2 % with respect to the mean for each quad. family

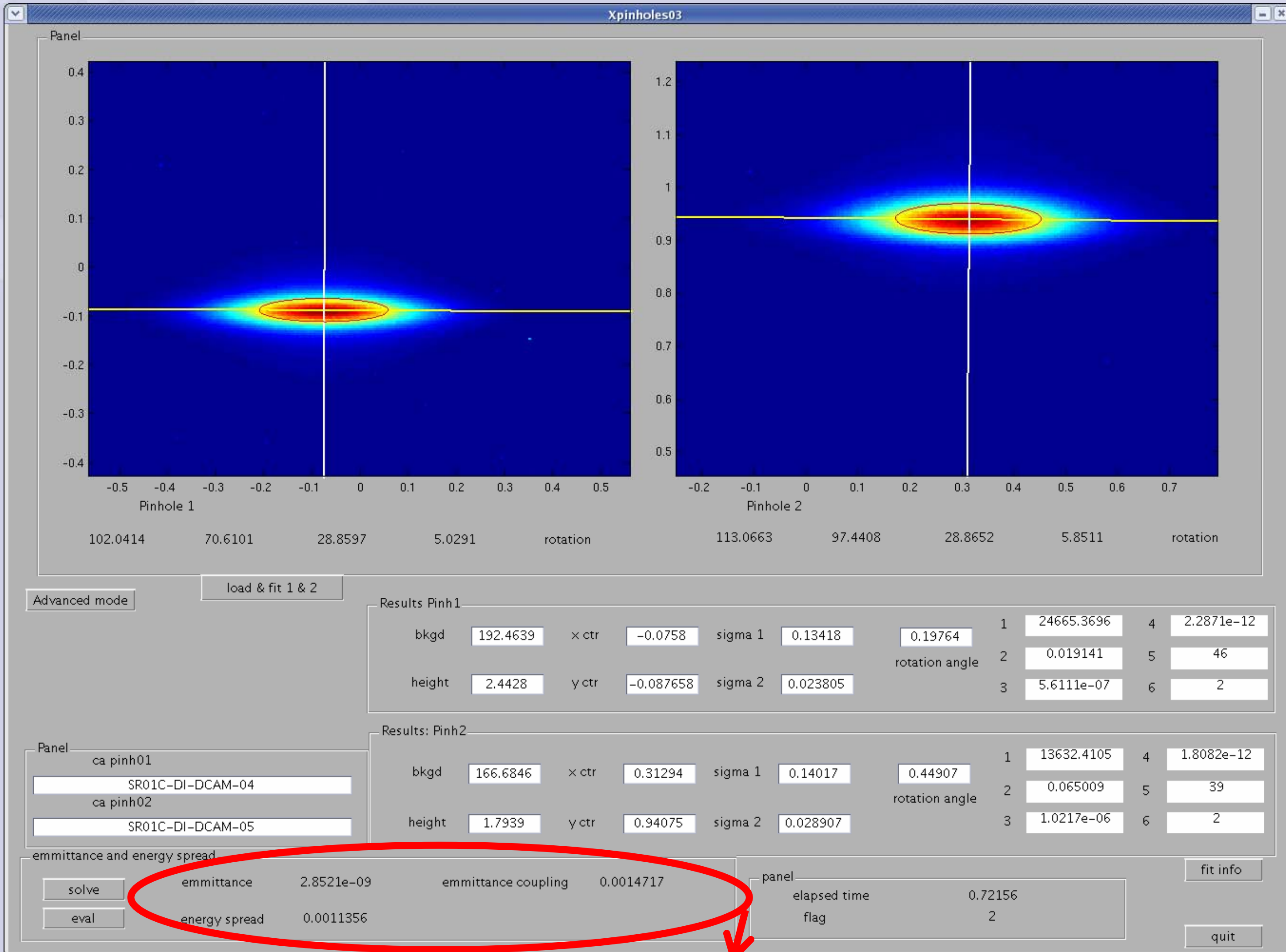


Dispersion – before and after LOCO correction



Emittance and Energy Spread

Measured using two X-ray Pinhole Cameras



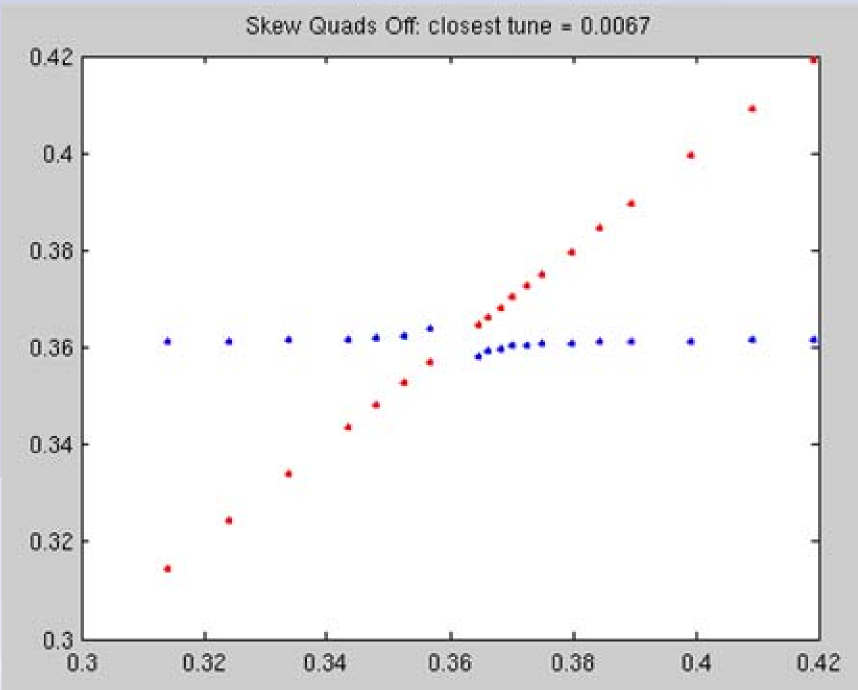
emittance 2.85 nm, energy spread 0.11%, coupling 0.15% (4.2 pm !)

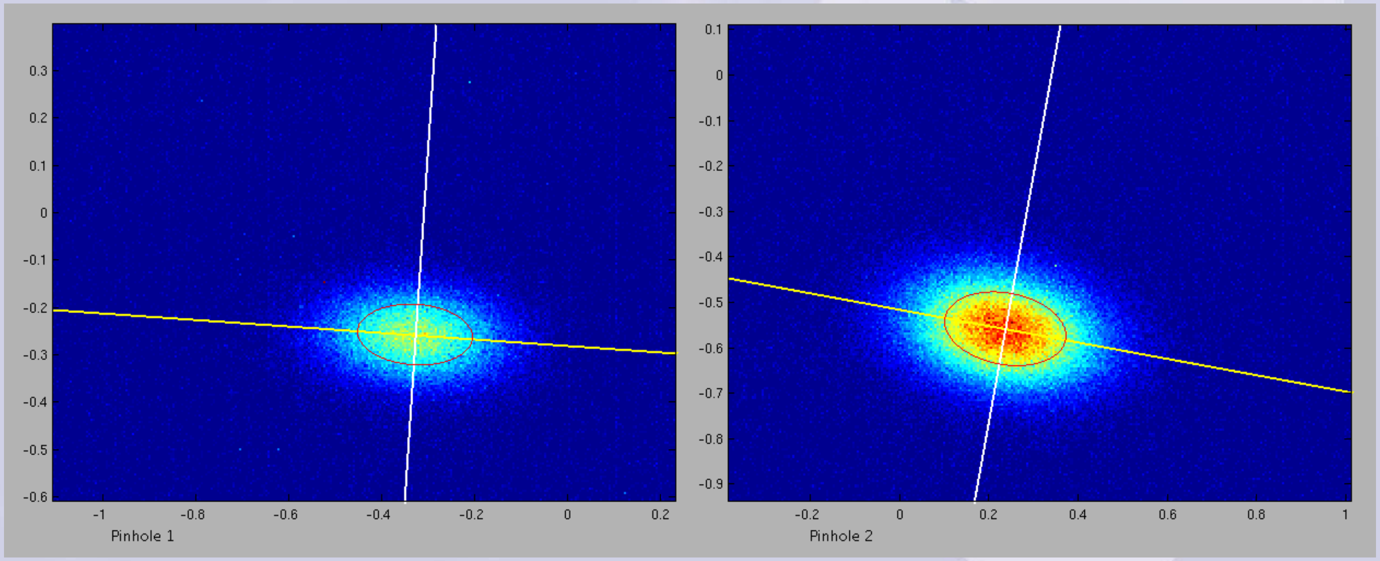
Linear coupling compensation using LOCO

Skew-quads off:

Tune separation = 0.0067

Emittance ratio from betatron coupling at nominal WP = 0.13%



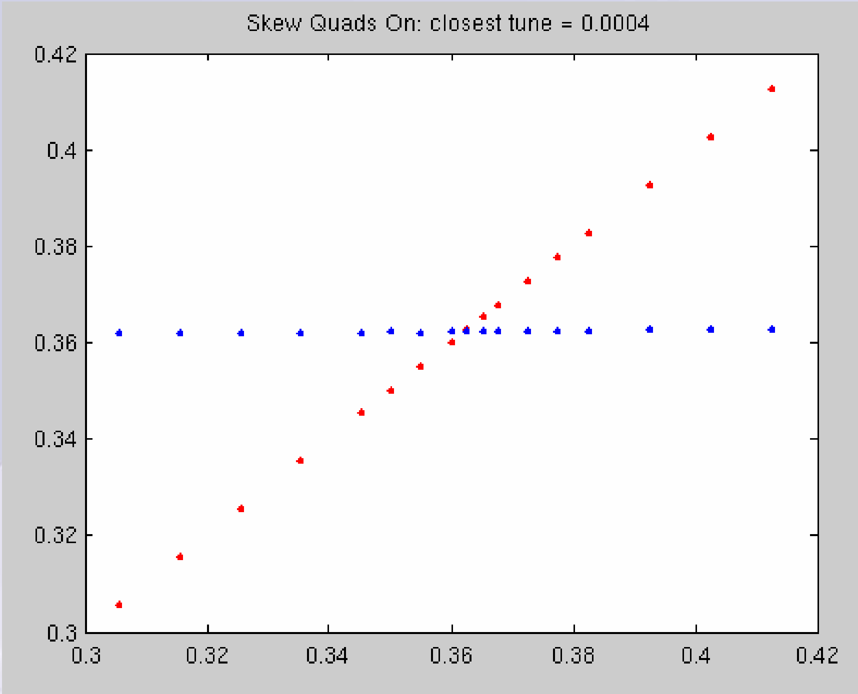


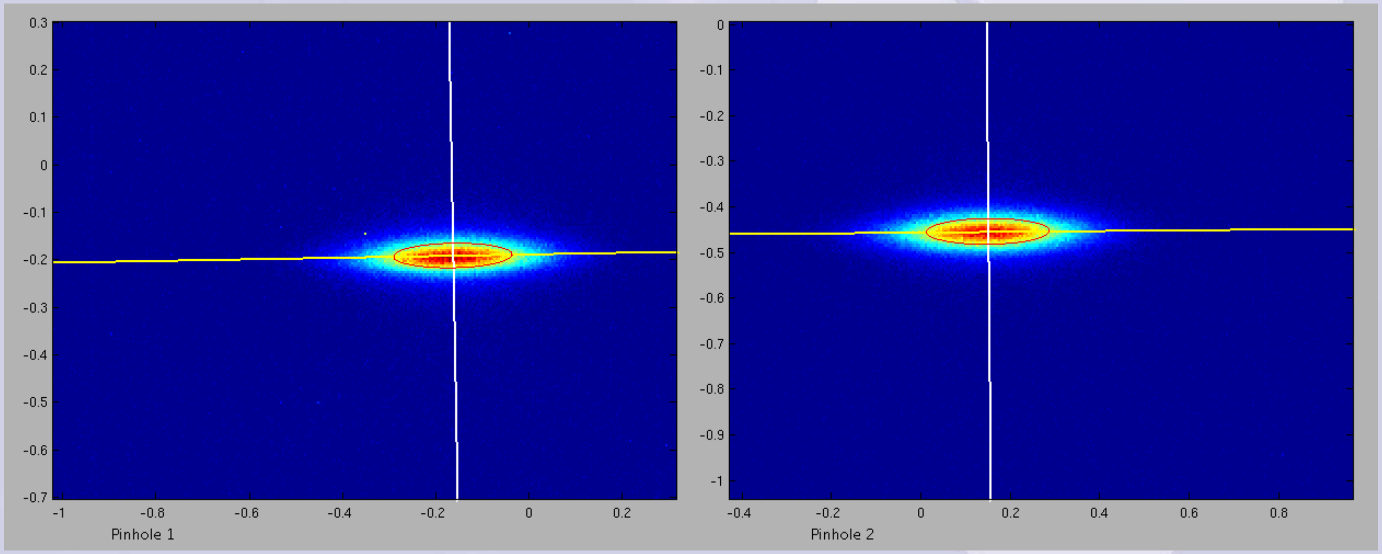
Measured emittance ratio = 1.3 %

Skew-quads on:

Tune separation = 0.0004

Emittance ratio from betatron coupling at nominal WP ~ 0%





Measured emittance ratio = 0.17 %

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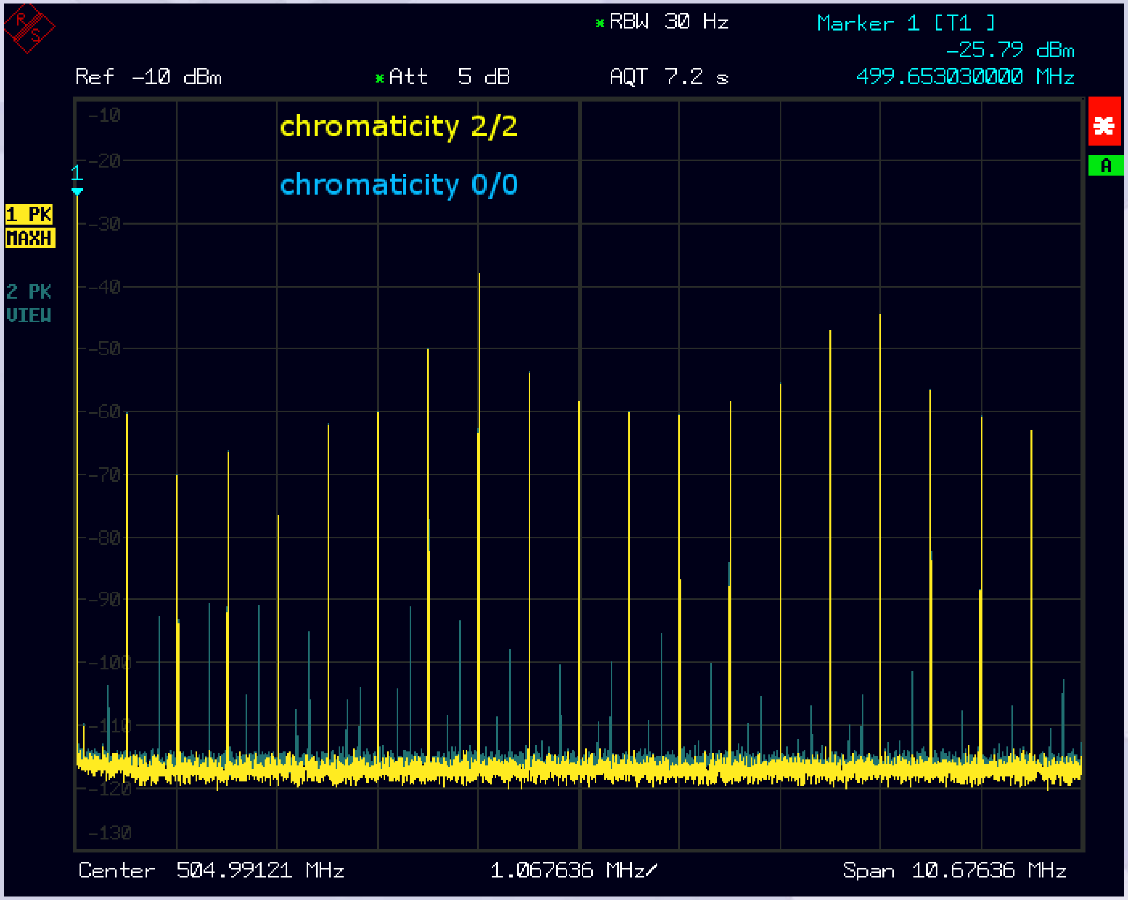
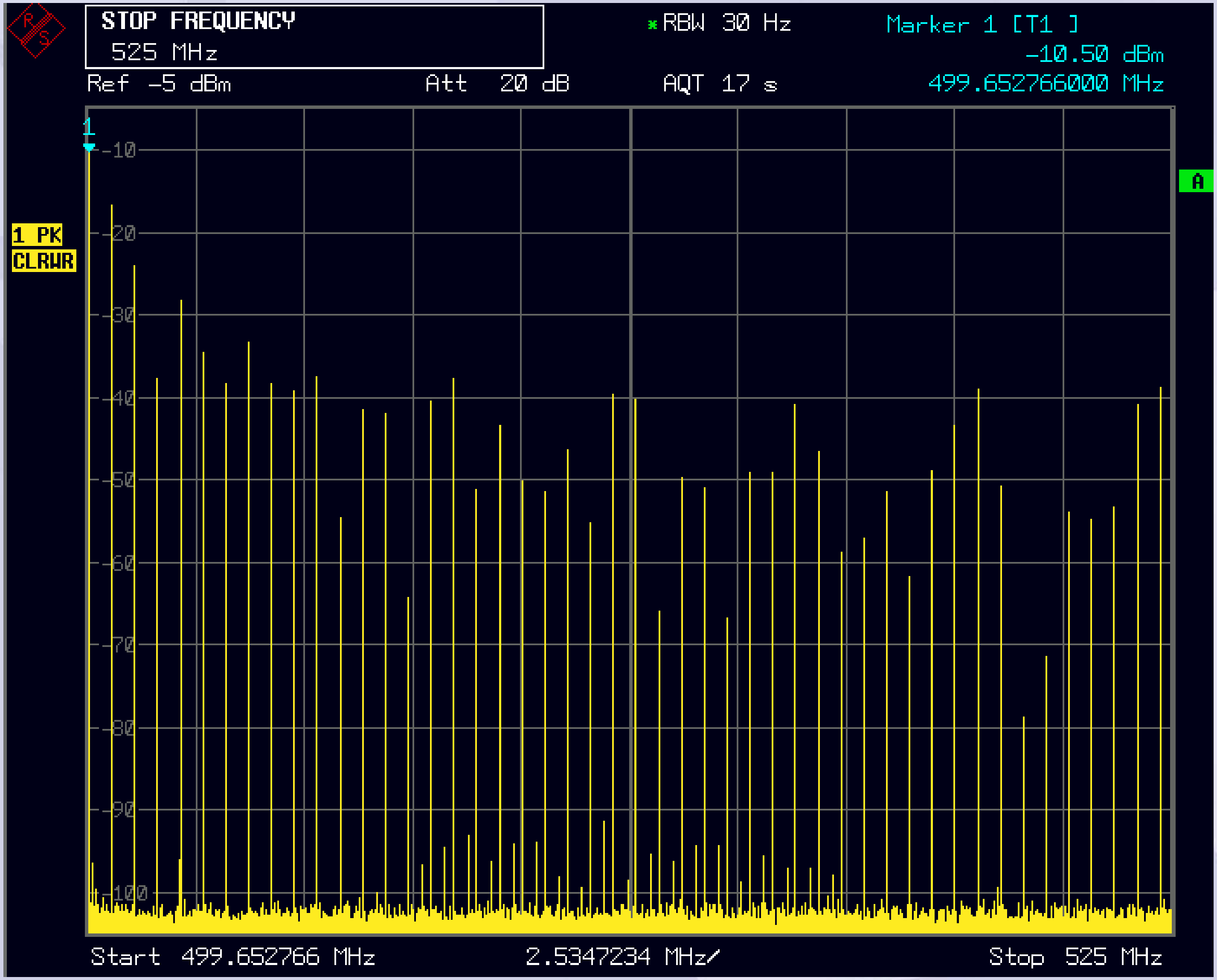
Instabilities



Vertical instability visible at 17 mA for zero chromaticity, lower than the predicted Resistive Wall Instability threshold (40 mA).

Increasing chromaticity counteracts the instability.

Beam is completely stable up to 110 mA with chromaticity ($\Delta Q/\Delta p/p$) = + 2 in both planes.



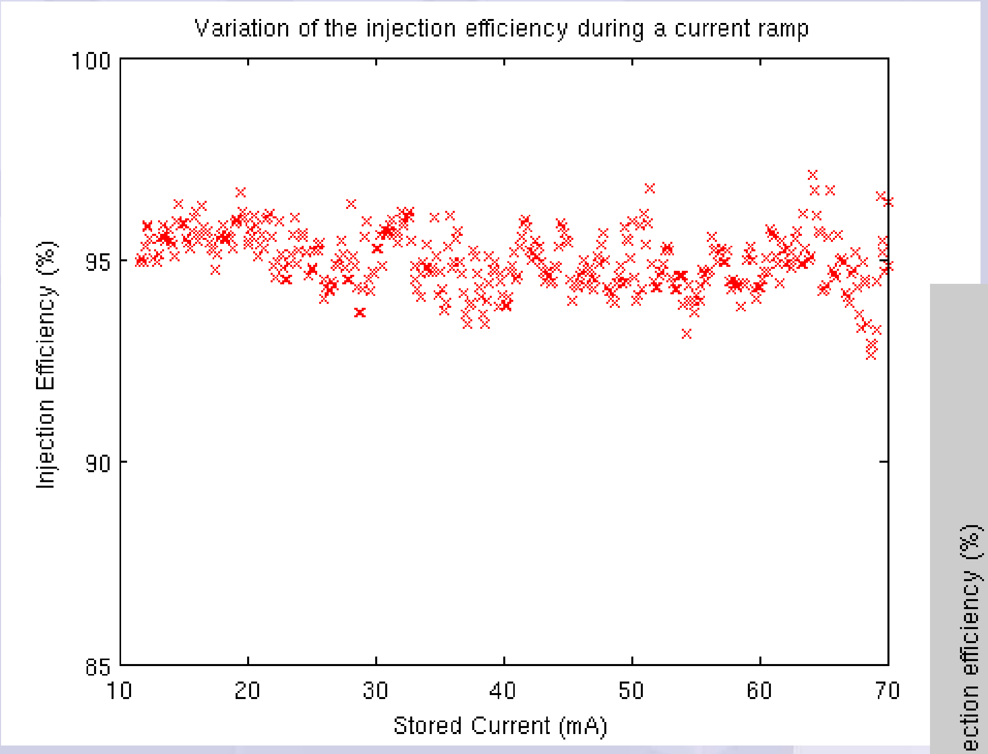
150 mA

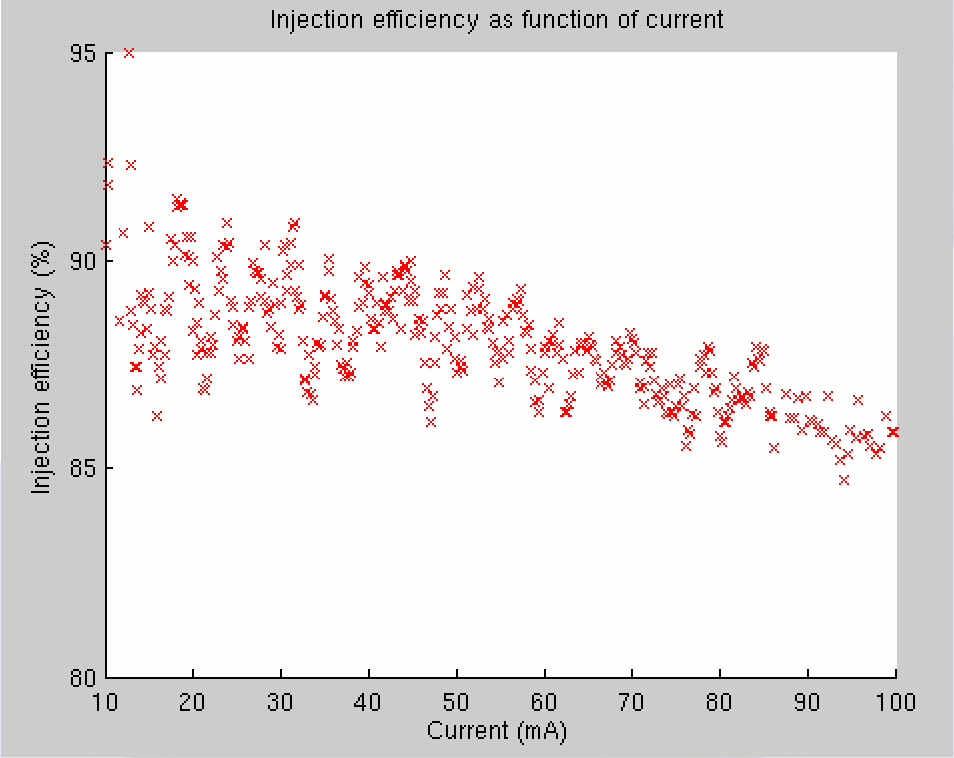
Chromaticity +2

Some evidence of ion-trapping ..

Work in progress

Injection efficiency





now being routinely monitored to determine reproducibility

Insertion Devices

IDs for the 7 Phase I beamlines and first of Phase II are all installed and commissioned

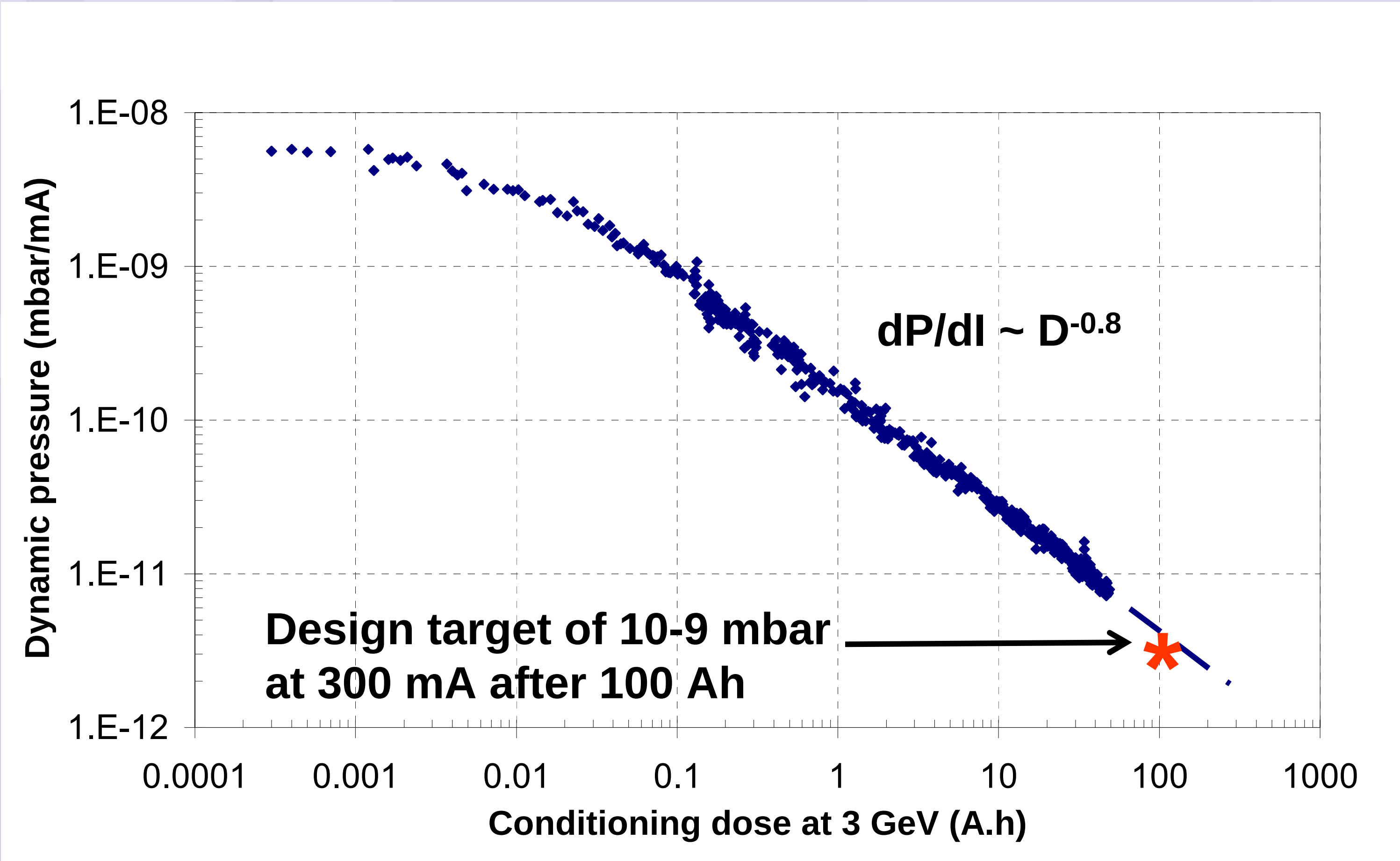
Beamline	ID	Type	Max. rms phase error (°)
I02	U23	In-vacuum	3.9
I03	U21	In-vacuum	3.1
I04	U23	In-vacuum	2.8
I06	HU64	APPLE-II	5.5
I15	SCW	3.5 T Superconducting Multipole Wiggler	-
I16	U27	In-vacuum	2.3
I18	U27	In-vacuum	2.1
I22	U25	In-vacuum	2.1

Insertion Devices Commissioning

- **Closed orbit: 20-25 μm changes in orbit (50μm for HU64) without correctors**
- **Trim coils set as a function of gap (and phase)**
- **Feed-forward keeps the residual orbit at the level of 1-2 μm.**
- **SCW can be ramped-up to 3.5 T within the beam position interlock (< 1 mm orbit change).**
- **Tunes: not measurable for in-vac ID (< 0.001); small for HU64, 0.012 for SCW**
- **No observable changes in lifetime**

All 8 IDs are operational; in-vacuum undulators down to initial minimum gap of 7 mm

Vacuum Conditioning and Beam Lifetime



Currently, after 50 Ah dP/dI = 8 10^{-12} mbar/mA

Static pressure = 4 10^{-10} mbar

RGA shows > 90% H no beam, > 80% H with beam

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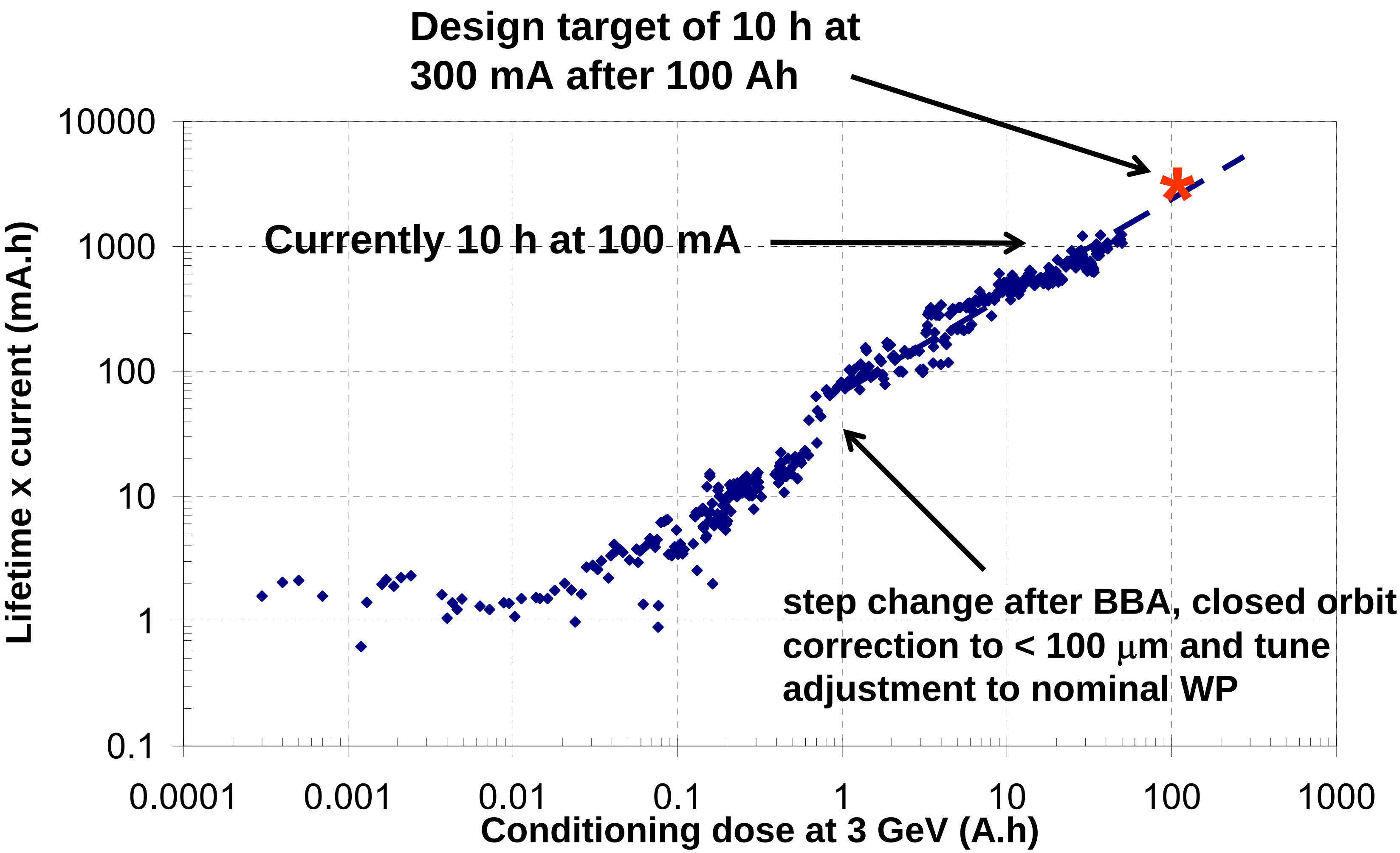
Beam Lifetime



Current Status

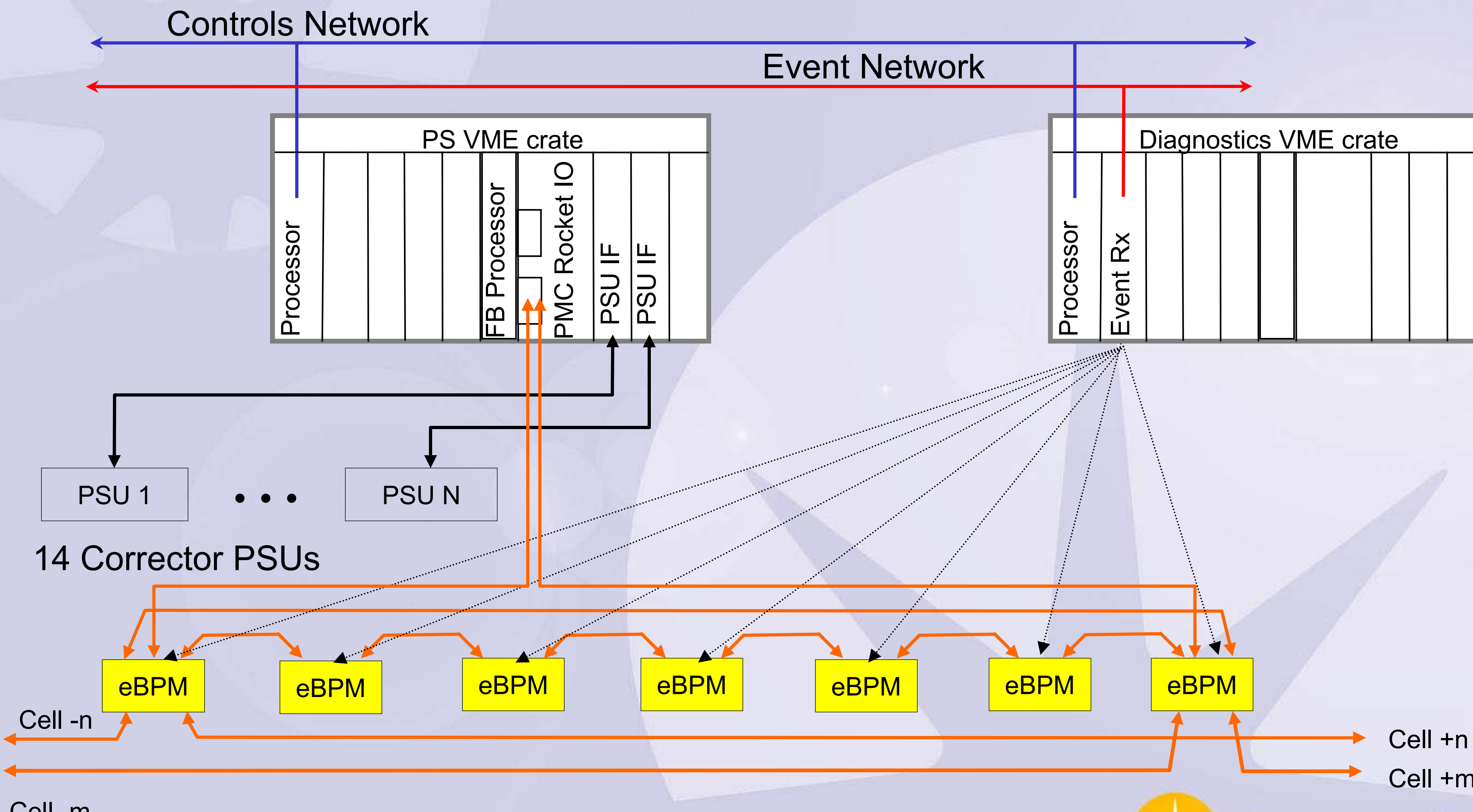
- Injection system and storage ring running reliably
- 125 mA available for user shifts; 160 mA achieved during accelerator physics shifts
- 10 h lifetime at 100 mA
- 8 Insertion devices operational
- Slow orbit feedback in operation

- Diamond is officially Operational
- "Expert users" from January to September to assist in beamline optimisation
- "Regular users" from October.

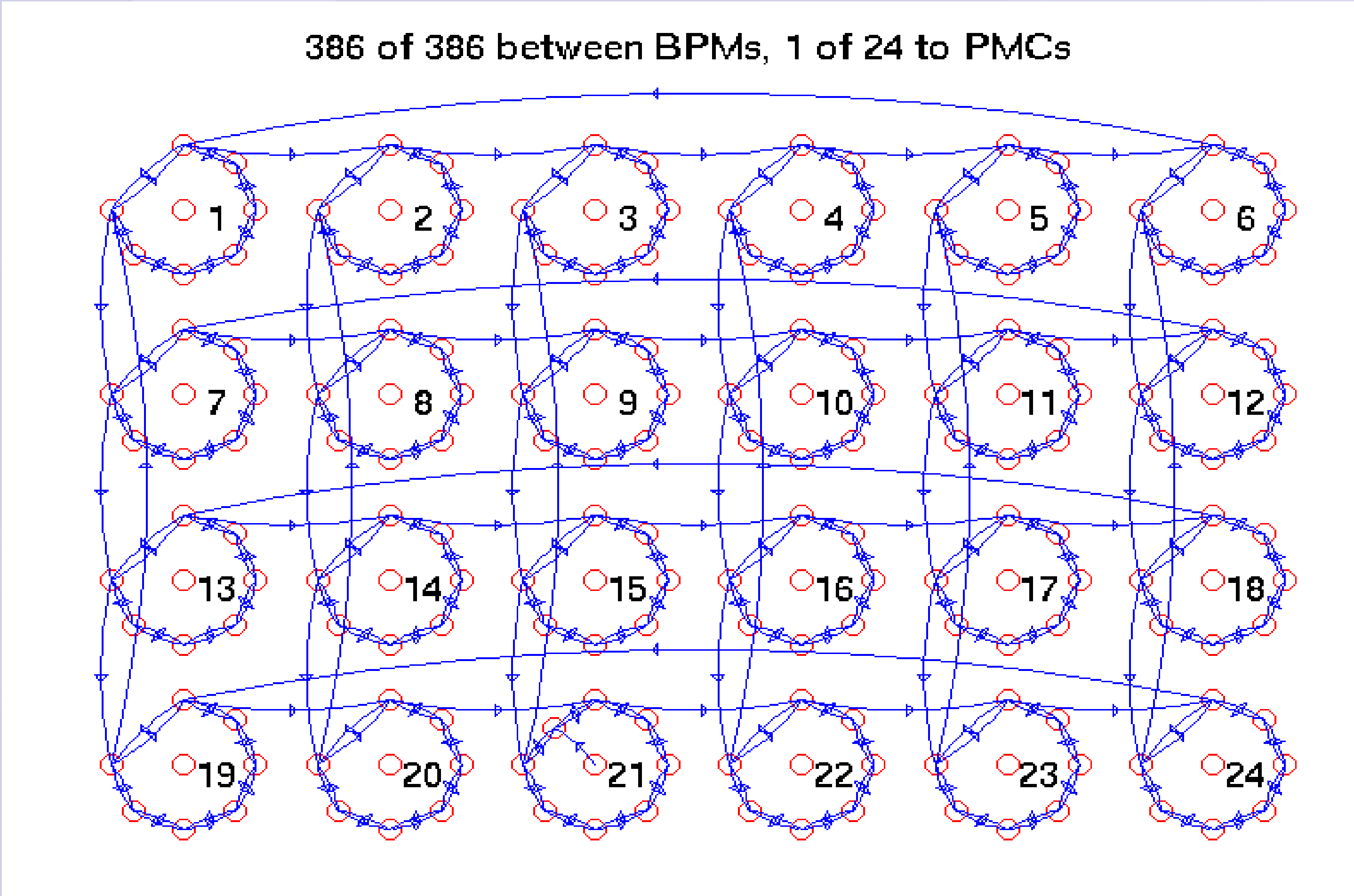
Plan for 2007

- **3000h of "User Mode"**
- **Re-installation of 2nd RF cavity, in March/April**
- **Increase current to 300 mA by end of September**
- **Install 3 Insertion Devices and 4 Front-Ends for Phase II beamlines**
- **Implement Fast Orbit Feedback in early 2007**
- **Test Transverse Multibunch Feedback in mid 2007**
- **Start to prepare top-up injection**

Fast Orbit Feedback



Global connections of FOFB



Fast Orbit Feedback Status

- **All hardware installed**
- **Communication of BPM data, at 10 kHz, is running reliably**
- **All processing software ready**
- **First loop-closure in February**

Transverse Multibunch Feedback Status

- **Kicker Striplines (SLS-type) and extra pickup buttons installed in the Diagnostics Straight**
- **All hardware (RF frontend, Libera bunch-by-bunch, power amplifiers) delivered and tested**
- **Installation and test operation of B-b-B acquisition early 2007**
- **Development of FPGA based FB algorithm (in collaboration with ESRF) underway**
- **Testing Feedback with beam by mid 2007**

Top-up Injection

A lot already done:

- **linac operates in single bunch**
- **switch mode power supplies for the booster**
- **PSS system configured for top-up**
- **timing system to fill arbitrary bunch pattern**
- **fill-pattern diagnostics**

But still a lot to do:

- **safety simulations**
- **injection with IDs closed**
- **localise beam losses**
- **radiation tests**
- **etc.**

} **aiming to complete in 2007**

Acknowledgements

- **The Diamond Commissioning Team, in particular -**

- Accelerator Physics (R. Bartolini et al.)

- Controls (M. Heron et al.)

- Commissioning and Operations (V. Kempson et al.))

- Diagnostics (G. Rehm et al.)

- RF (M. Jensen et al.)

- **G. Portmann (ALS) and J. Safranek (SSRL) for assistance with LOCO.**

Thank you for your attention.