Conceptual Fast Orbit Feedback Design for PETRA III

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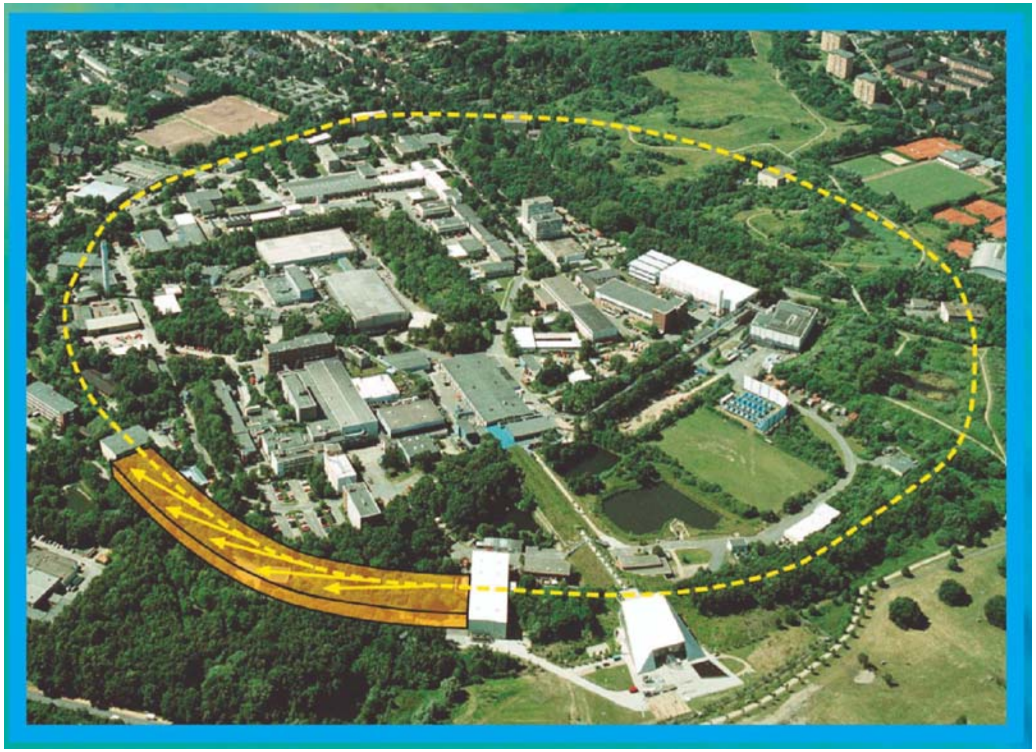
PETRA III

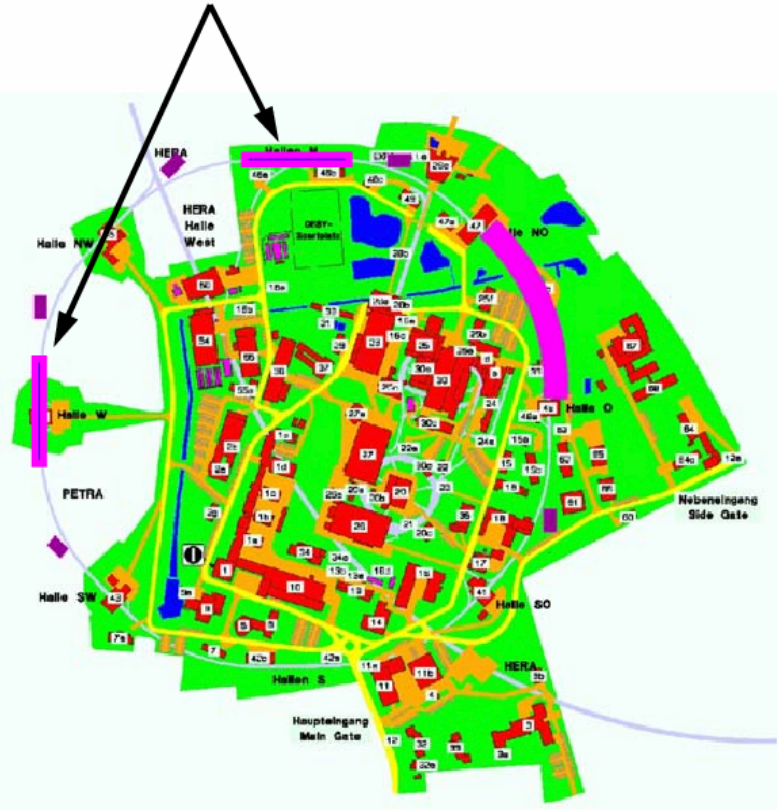


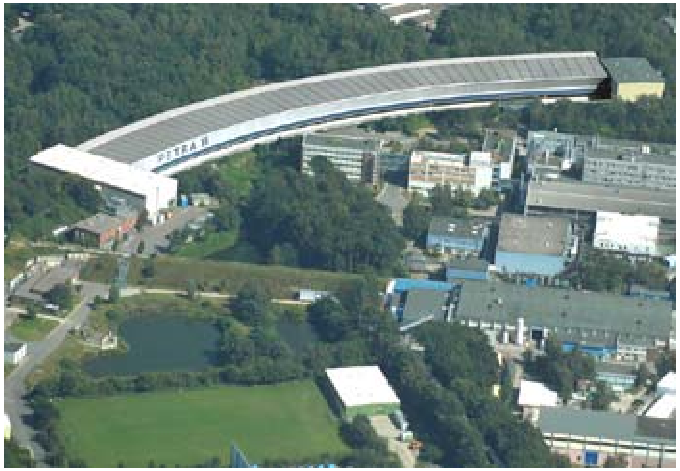
Parameters:

- Beam energy: 6 GeV
- Beam current: 100 mA
- Horz. emittance: 1 nm.rad
- No. of straight sections: 9
- undulators: 13
- undulator length: 2, 5, 10 m

Damping Wiggler Section

Damping wiggler sections





ε_x : 4 → 1nm.rad

Damping wigglers

- **B = 1.5 T**
- **λ = 0.2 m**
- **h = 0.025 m**
- **L_{tot} = 80 m (2x40m)**

Dispersion limits to achieve design emittance

	Horz. (mm)	Vert. (mm)
Wiggler section	18	5
Undulator‘s (ID‘s)	20	3
FODO arc		58
DBA	22	31

Alignment Tolerances (rms values)

Element(No.)	Δx(μm)	Δy(μm)	Δψ(mrad)	Δs(μm)	Field Error
Monitors(206)	200	200			
Quadrupoles ((281)Old Octant)	250	250	0.2	500	$\frac{\Delta K}{K} = 0.001$
Quadrupoles ((105)New Octant)	100	100	0.2	500	$\frac{\Delta K}{K} = 0.001$
Dipoles(196+18)	250	250	0.2	500	$\frac{\Delta B}{B} = 0.0005$
Sextupoles(140)	250	250	0.2	500	

Values truncated at 2σ of a Gaussian distribution

Slow Orbit Correction

Combined orbit and dispersion correction:

$$\begin{pmatrix} \alpha \vec{u} \\ (1-\alpha)\overrightarrow{D_u} \end{pmatrix} + \begin{pmatrix} \alpha R \\ (1-\alpha) S \end{pmatrix} \vec{\theta} = \vec{0}$$

u and D_u measured orbit or dispersion
R and S orbit or dispersion response matrix
α weighting factor

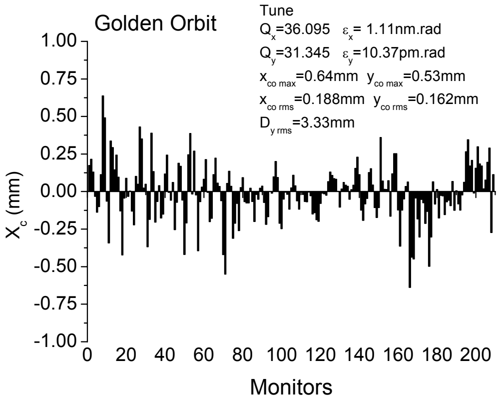
Alternative: separated orbit & dispersion correction with skew quads

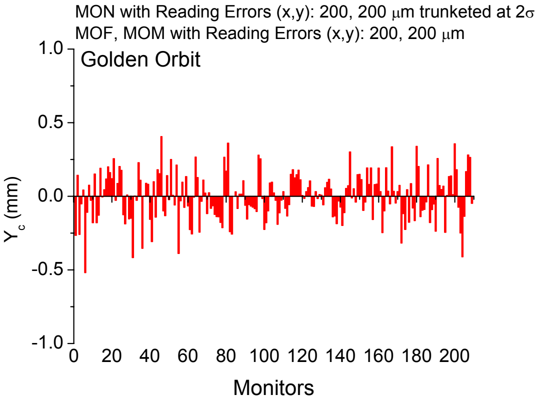
Elements for orbit correction

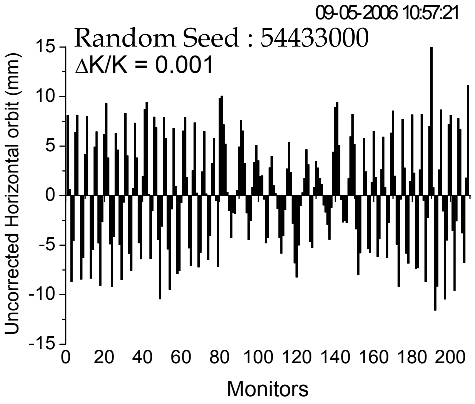
- 209 beam position monitors
- 182 horizontal correctors (resolution ≥ 16 bit)
  - 105 backleg windings on old dipoles
  - 18 backleg windings on new dipoles
  - 59 single correctors
- 189 vertical correctors (resolution ≥ 18 bit)
  - 91 additional windings on sextupoles
  - 98 single correctors

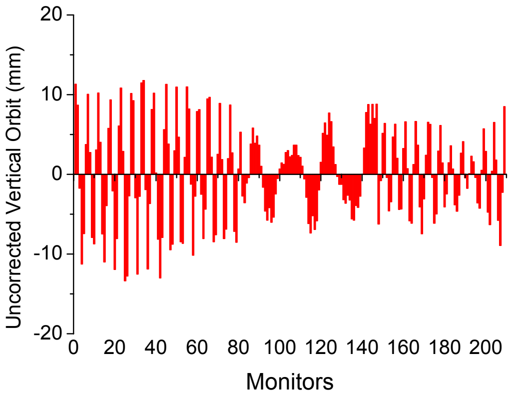
$\Theta_{max} \approx 0.5$ mrad ➔ $B*l = 100$ Gm

The intermediate golden Orbit









Vertical Dispersion Correction – Using Skew Quadrupoles

A horizontal orbit offset through a skew quadrupole will generate a deflection in the vertical plane through an angle $\Delta\theta_y = k_{1s}lx$. This will generate a vertical orbit distortion of Δy such that,

$$\Delta y_i = \frac{\sqrt{\beta_{yi}\beta_{yj}}}{2Sin(\pi Q_y)}.Cos\left(\left|\varphi_{yi}-\varphi_{yj}\right|-\pi Q_y\right)(K_{1s}lx)_j$$

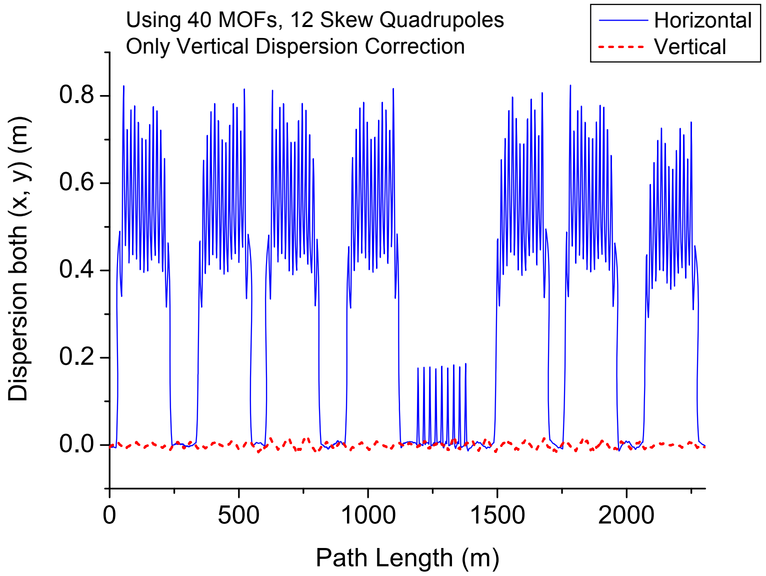
With $x = D_x \Delta P/P$ and $y = D_y \Delta P/P$, one can write the Skew Quadrupole response matrix as

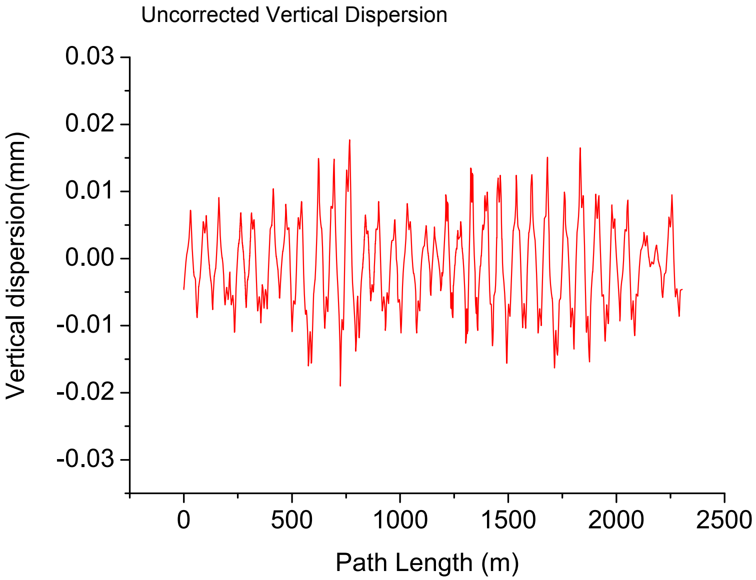
$$R_{ij} = \frac{D_{xj}\sqrt{\beta_{yi}\beta_{yj}}}{2Sin(\pi Q_y)}.Cos\left(\left|\varphi_{yi}-\varphi_{yj}\right|-\pi Q_y\right)$$

$$\Delta D_{yi} = R_{ij}(K_{1s}l)_j$$

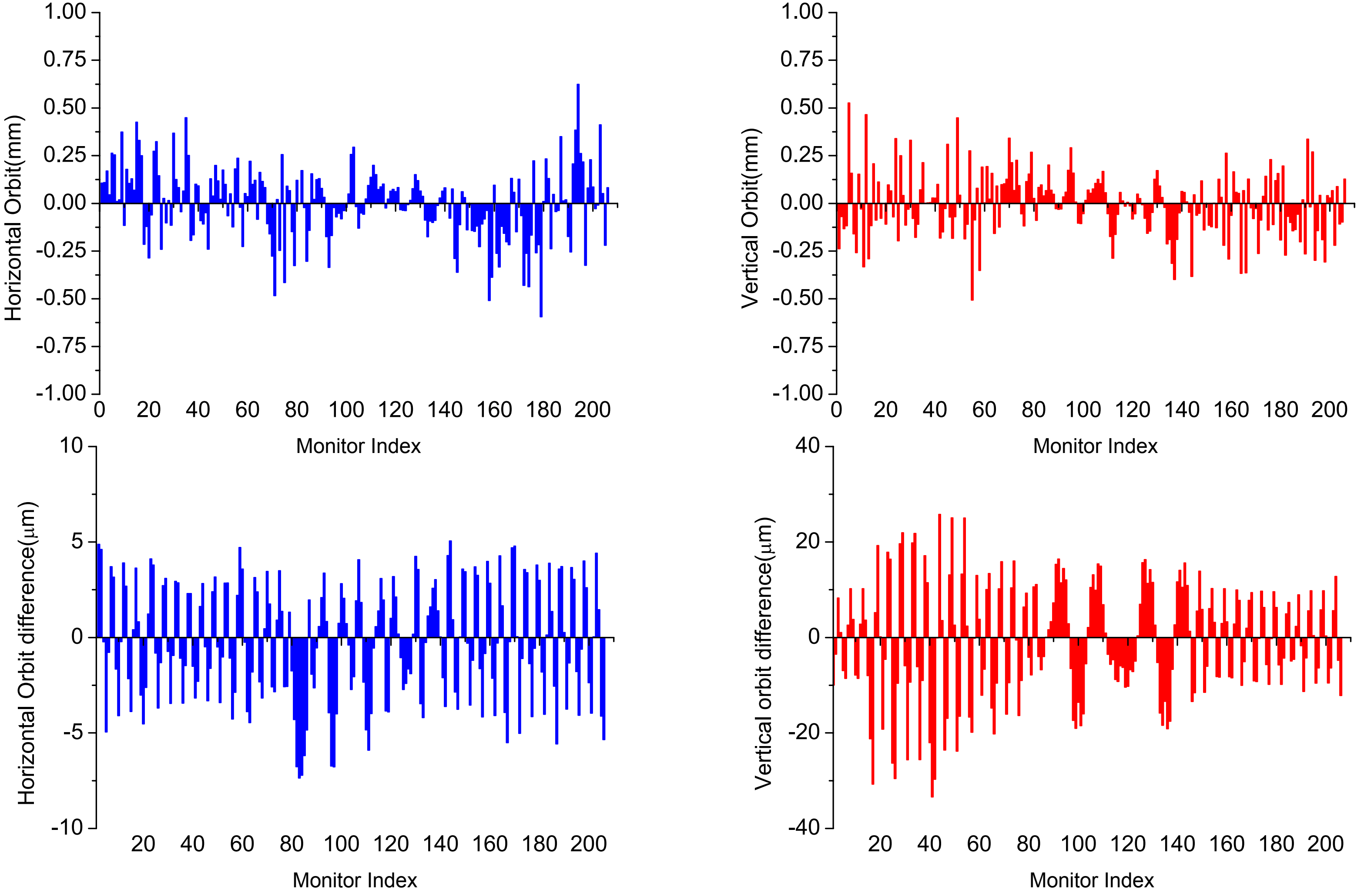
Vertical Dispersion Correction

Using: 40 Monitors and 12 skew quadrupoles

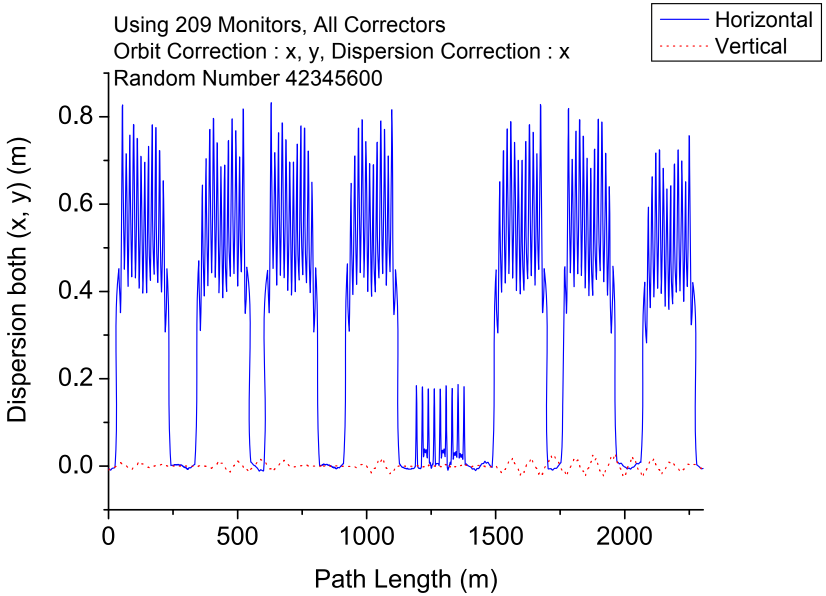


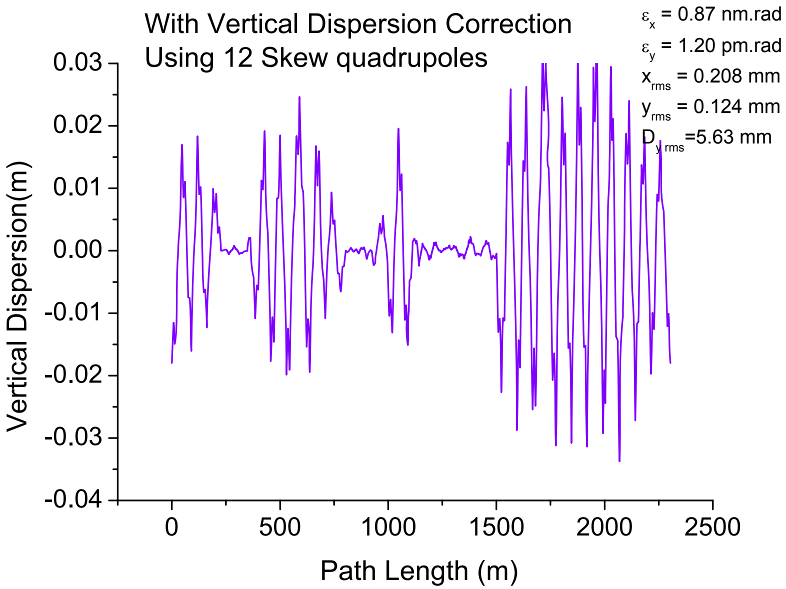


Vertical Dispersion Correction

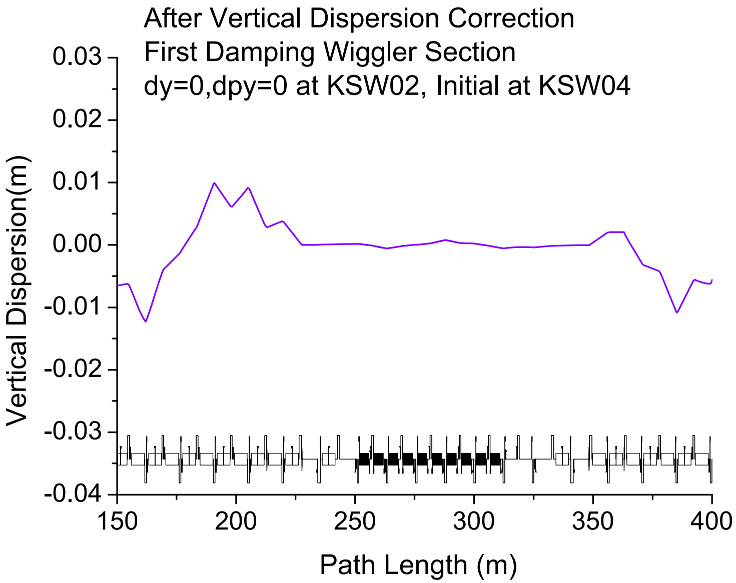


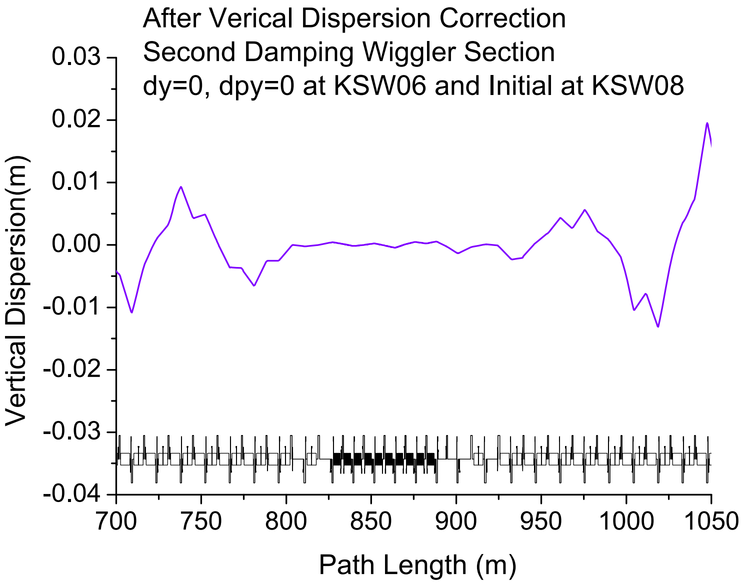
Vertical Dispersion Correction



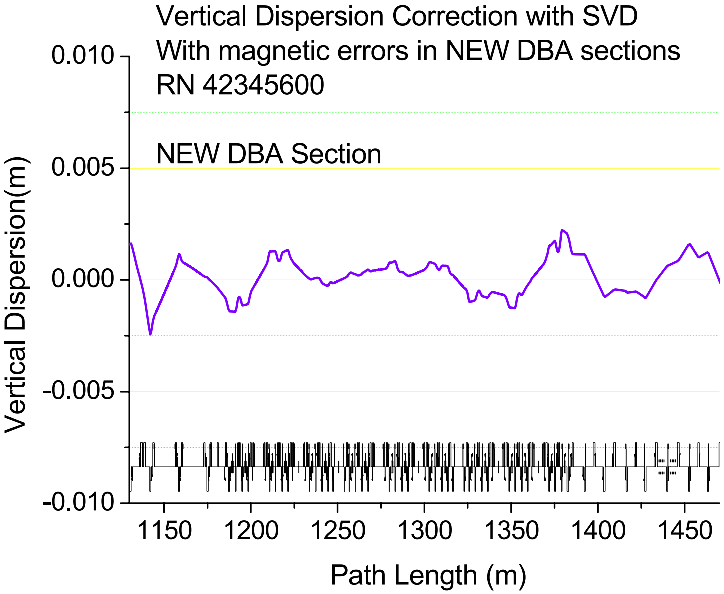


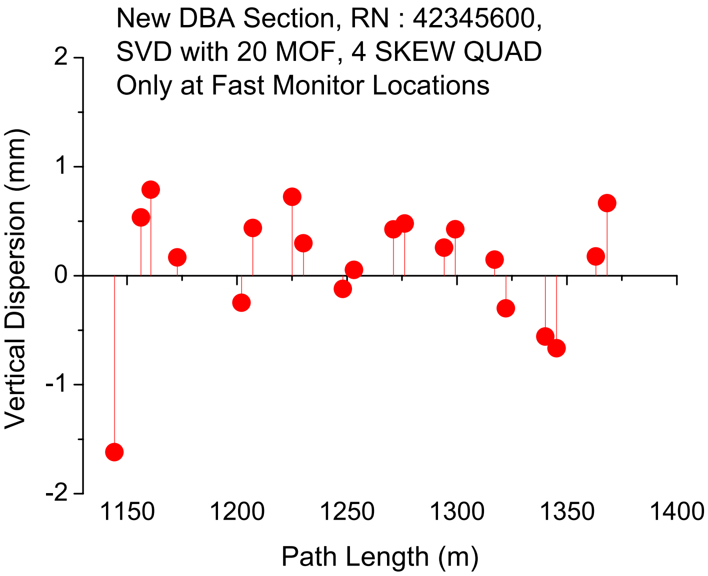
Local Vertical Dispersion Correction


After Vertical Dispersion Correction
First Damping Wiggler Section
dy=0,dpy=0 at KSW02, Initial at KSW04

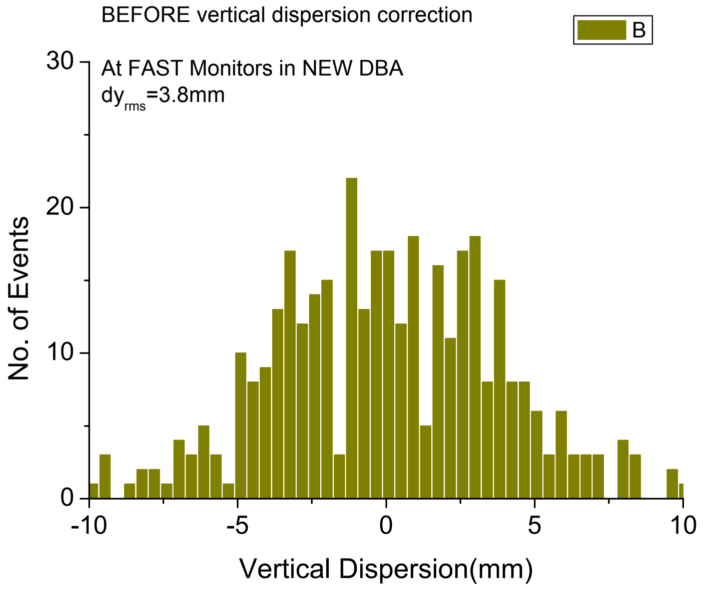

After Verical Dispersion Correction
Second Damping Wiggler Section
dy=0, dpy=0 at KSW06 and Initial at KSW08

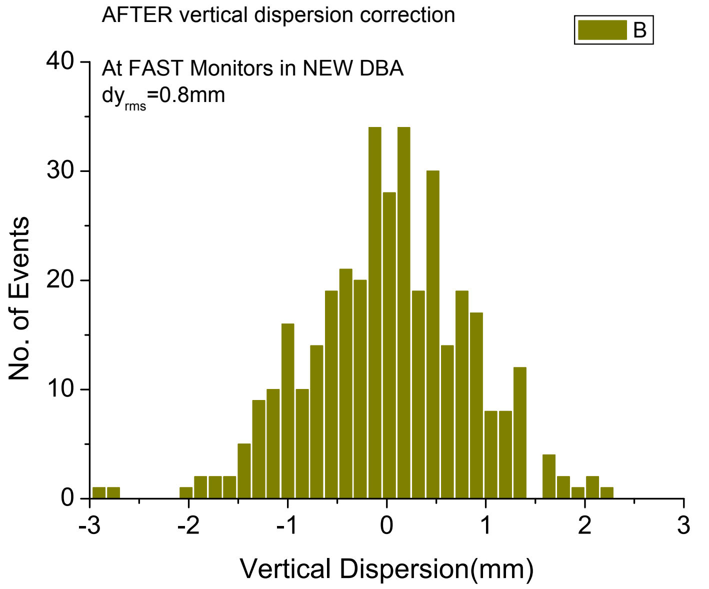
Local Vertical Dispersion Correction





Vertical Dispersion at 5m Undulator Sections





Vertical Dispersion Correction

Using Skew Quadrupole Magnets:

The emittance ratio is mostly achieved using different weights for correction scheme. Sometimes the over corrected dispersion is distorted to get the required emittance ratio. The orbit differences between before and after dispersion correction is lower (~ few μm)

So, the study shows that the dispersion correction using 12 number of skew quadrupoles is feasible and the results are with in the tolerance limits.

Orbit Stability Required

$\varepsilon_x \sim$ 1nm.rad

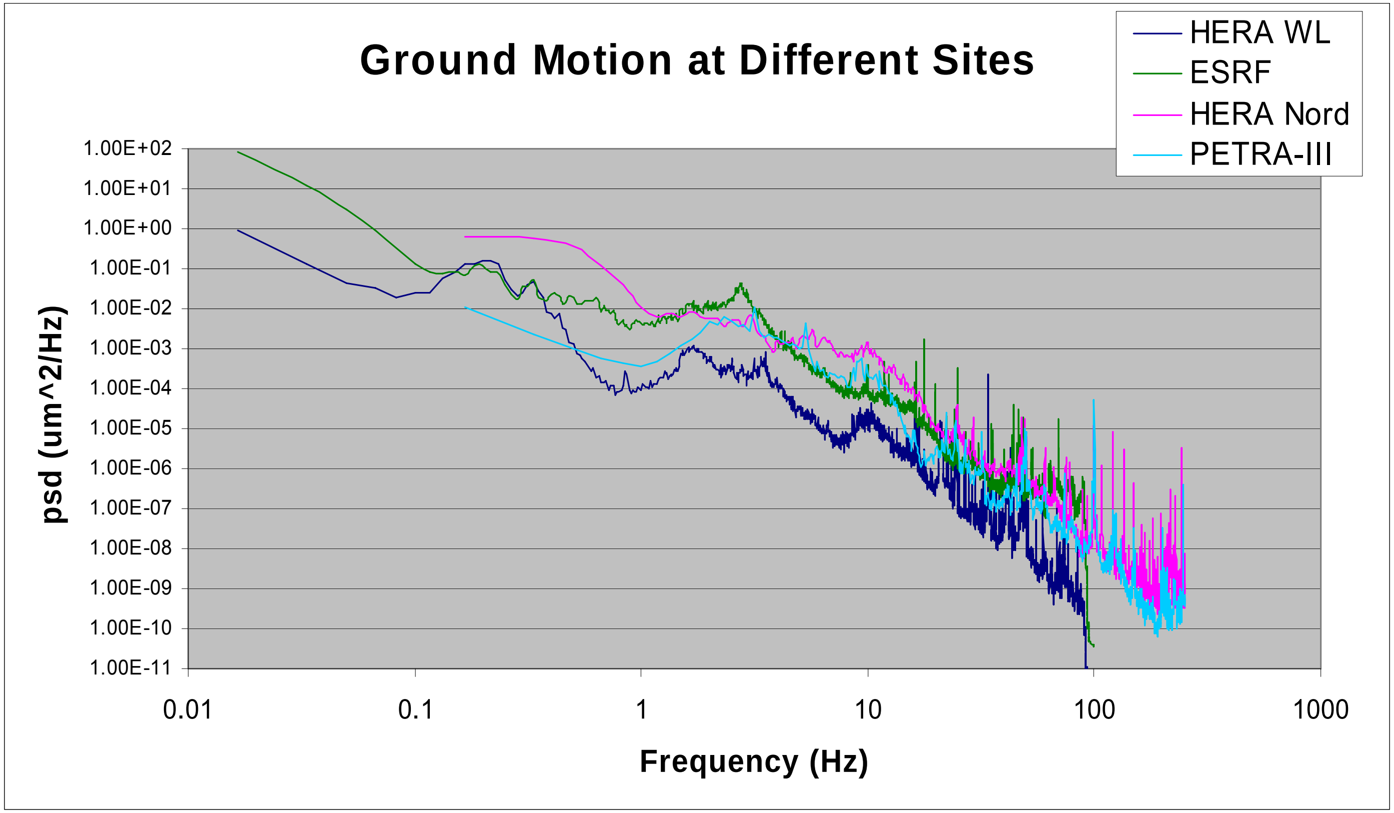
Coupling 1%

	Low β insertion			High β insertion		
	β(m)	σ(μm)	Amplification factor	β(m)	σ(μm)	Amplification factor
Horizontal	1.19	34.6	17.25	19.84	141	70.24
Vertical	4.0	6.3	34.08	2.37	4.9	26.20

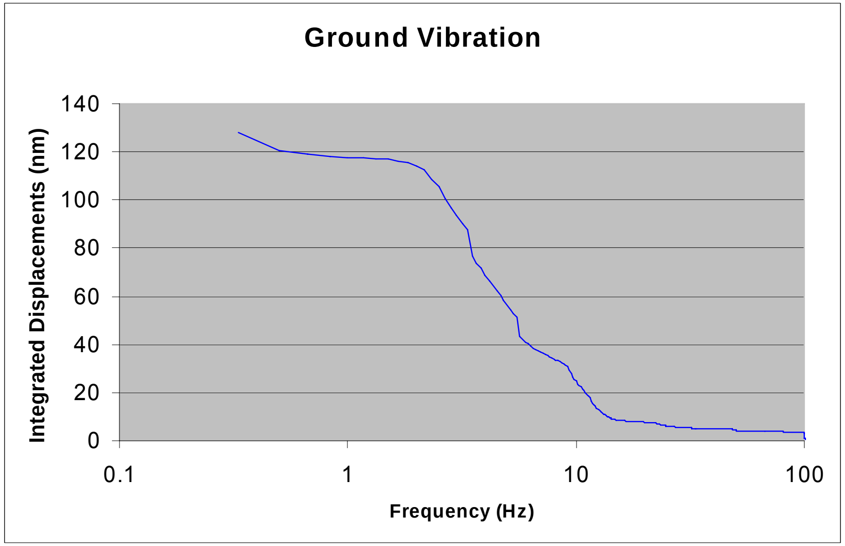
Stability requirement : 0.1* σ ⇒ Submicron orbit stability

The equivalent figure of 20% effective emittance growth corresponds to either 10% of the beam size, or 10% of its divergence, or any intermediate combination of both.

Observation of Ground Motion



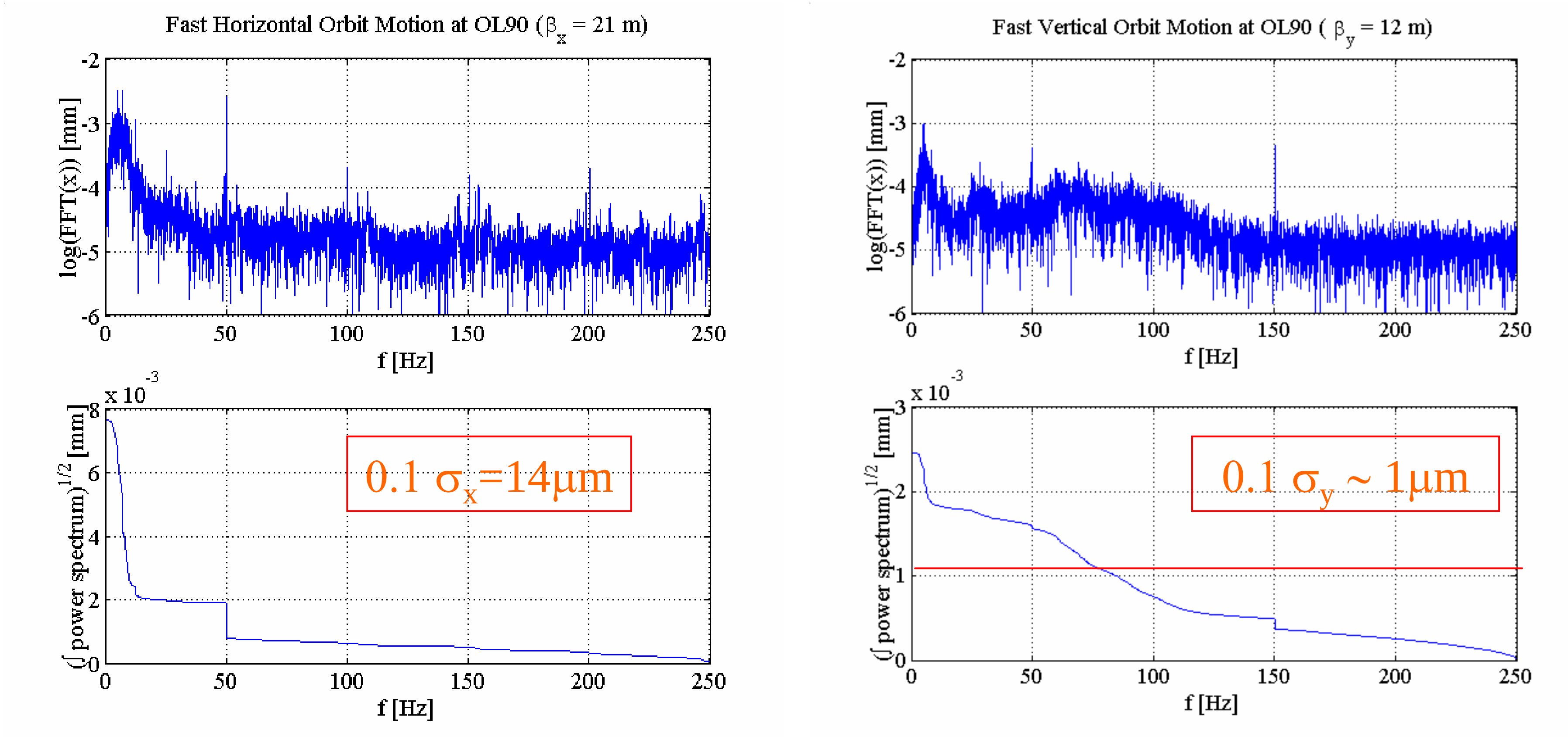
Ground Motion: Integrated rms displacement



$$Z_{rms}(f) = \sqrt{\int_{f}^{f_{\max}} S_x(f)\,df}$$

Integrated frequency range	Rms displacement(nm)	Integrated frequency range	Rms displacement(nm)
1 to 250 Hz	117.4676	0.1666 to 10 Hz	126.1172
10 to 250 Hz	116.8649	0.1666 to 20 Hz	127.9536
20 to 250 Hz	7.683232	0.1666 to 30 Hz	128.0669
30 to 250 Hz	5.445604	0.1666 to 40 Hz	128.0859
40 to 250 Hz	4.967819	0.1666 to 50 Hz	128.1156
50 to 250 Hz	4.139306	0.1666 to 60 Hz	128.123
60 to 250 Hz	3.89896	0.1666 to 250 Hz	128.1821

Fast orbit distortions in PETRA II



0.1 σ_x=14μm

0.1 σ_y ~ 1μm

Fast feedback requirements: BW ≈ 100 Hz   amplitude reduction factor ≤ 5

Elements for Fast Orbit Correction

- 41 vertical & horizontal correctors (air coils:

  $\theta_{max} \approx 5\ \mu rad \Rightarrow \mathbf{B}^* l = 1\ \mathrm{Gm}$)
  - 30 new octant
  - 11 old octant (1 per short straight & 1 at the beginning and end of each long straight section)

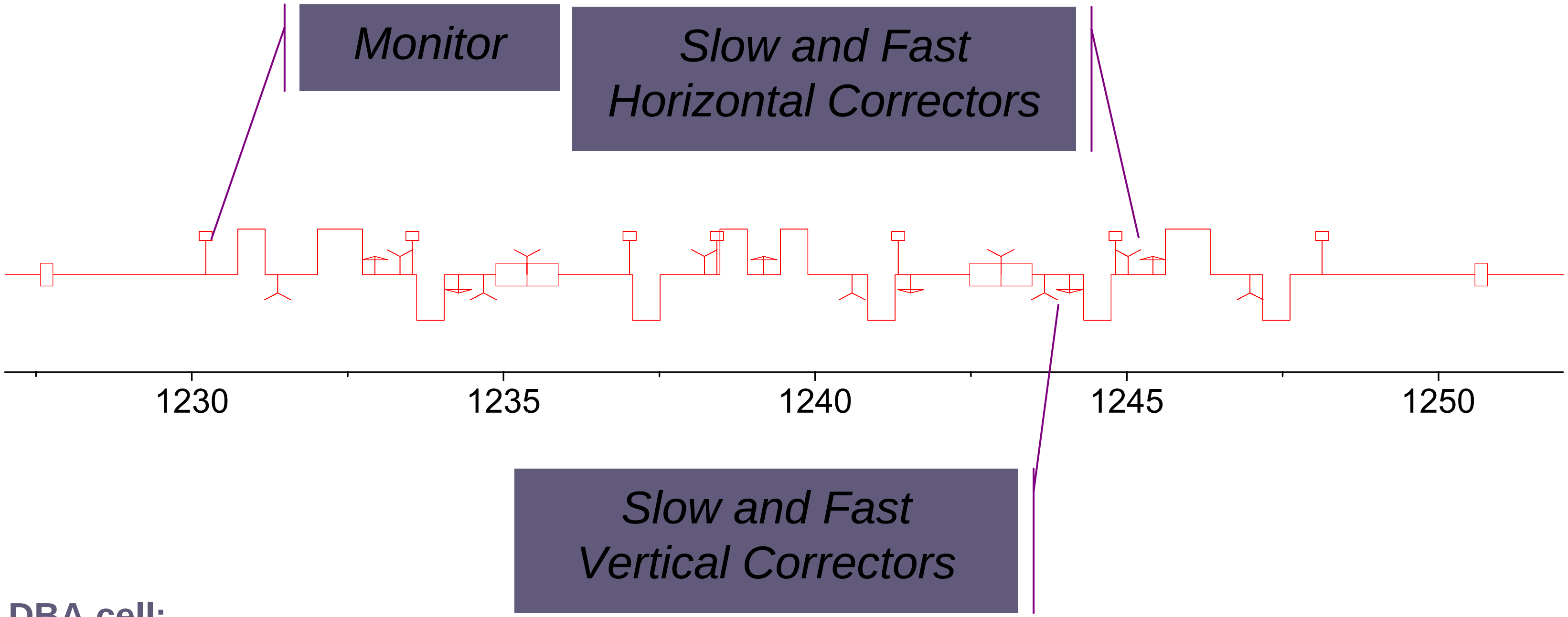
Monitors (resolution)

Monitors	#	Horz. (µm)	Vert. (µm)
Old octant	143	**10**	**10**
New octant	48	2	0.5
Next to IDs	18	2	0.2

Test of monitor-(electronic) resolution with purchased prototype.
Special supports to the monitors near to Ids.

Monitors and Correctors Layout in DBA Section

The most efficient correction is obtained when the correctors are located as near as possible to the sources generating the largest orbit deviation, i.e. the quadrupoles.



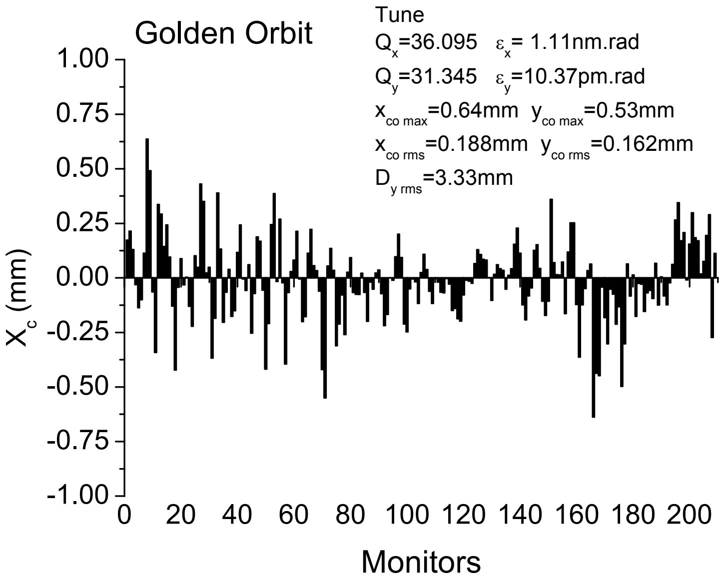
Per DBA cell:

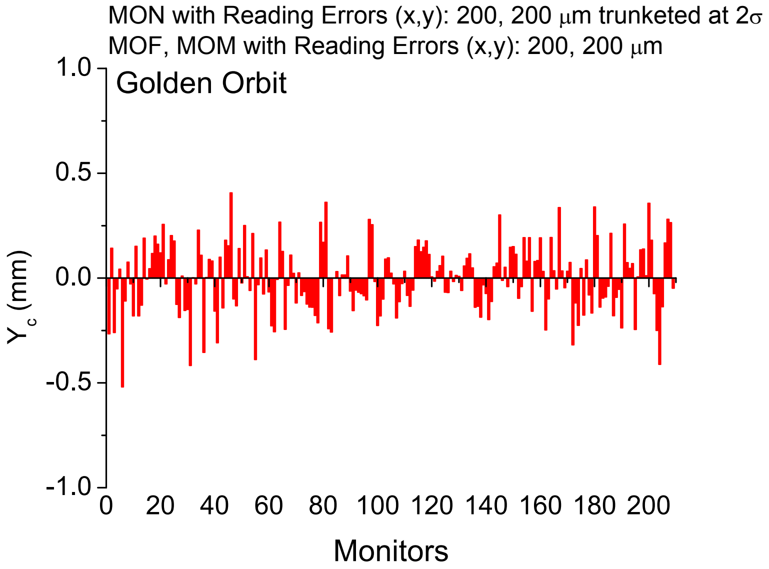
No. of Monitors : 7

No. of Horizontal Correctors : (3+2dipole) Slow; 3 Fast

No. of Vertical Correctors : 5 Slow; 3 Fast

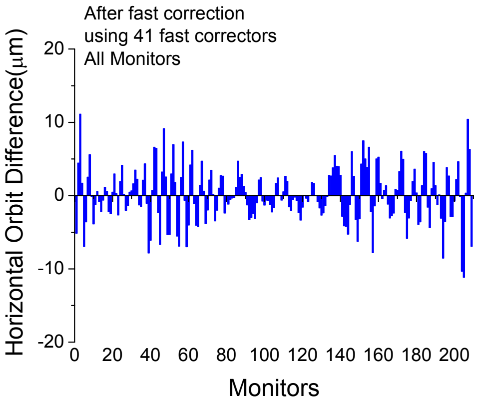
Simulation: fast orbit correction

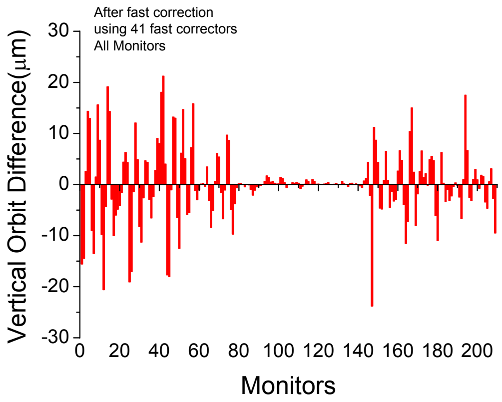


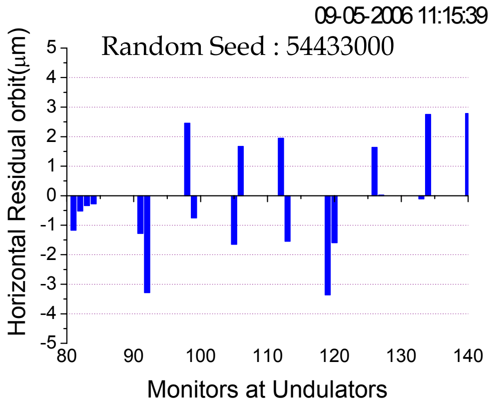


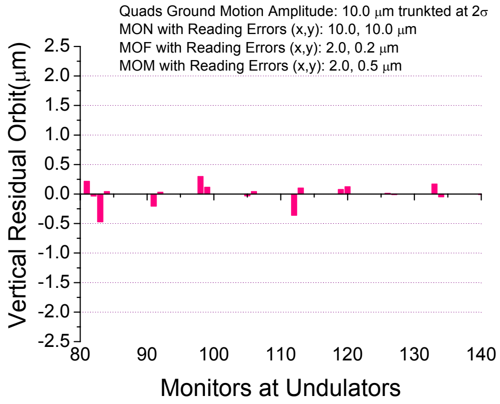
1μm misalignment was applied to all the quadrupole magnets of the PETRA III lattice. This orbit was then corrected with respect to the golden orbit. This procedure has been repeated for 5000 seeds and the position at the insertion devices and the emittances in both planes have been recorded. The orbit at the insertion devices stays within the required limits.

Simulation: Residual orbit at IDs



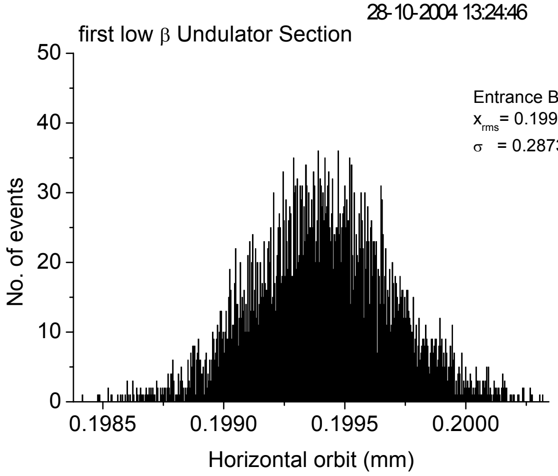


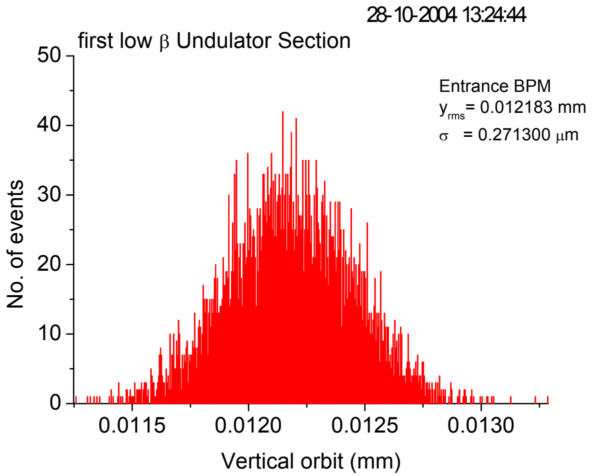


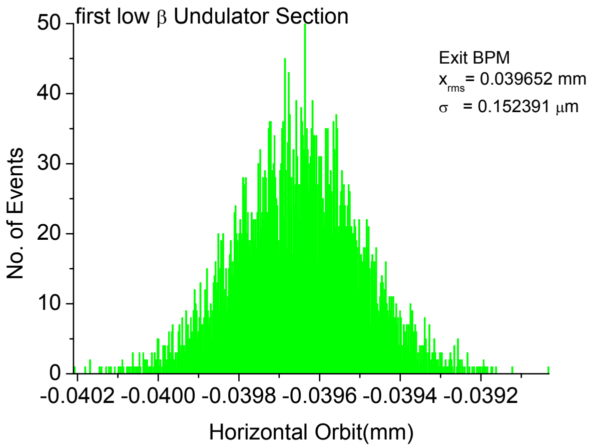


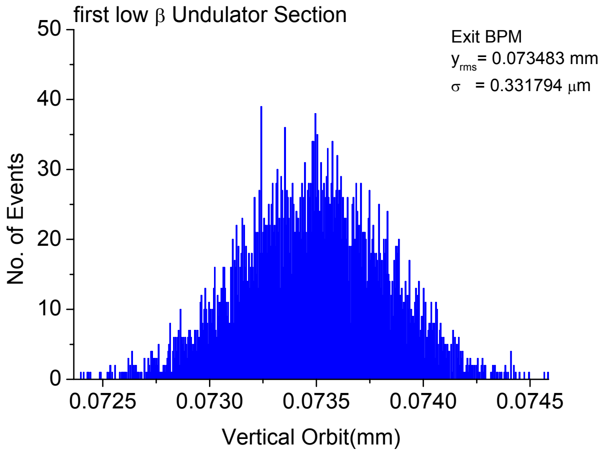
Simulation: Orbits at IDs Entry and Exit (5000 seeds)

Data shown at one ID section out of 10

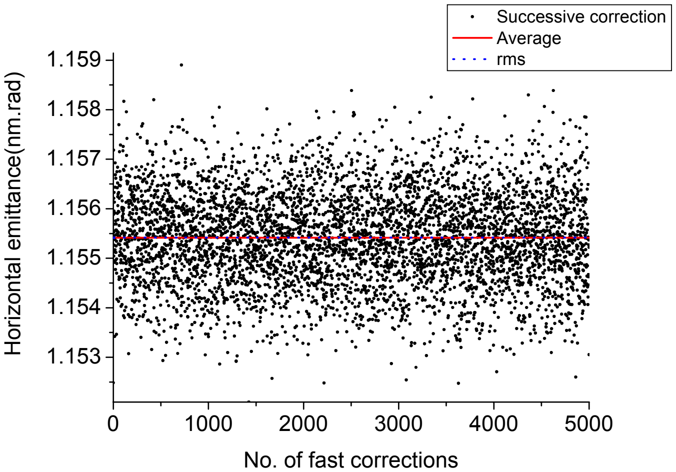


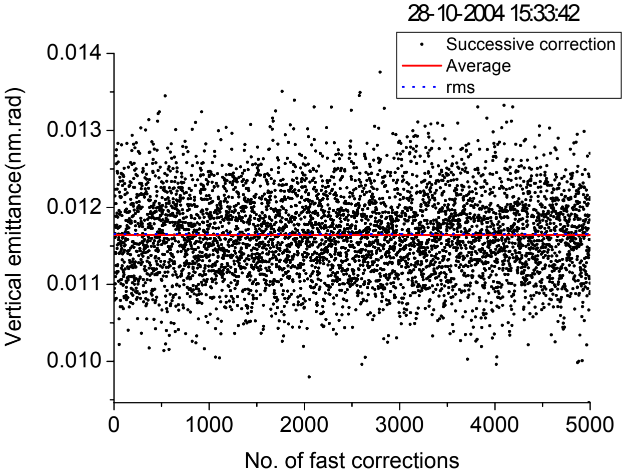


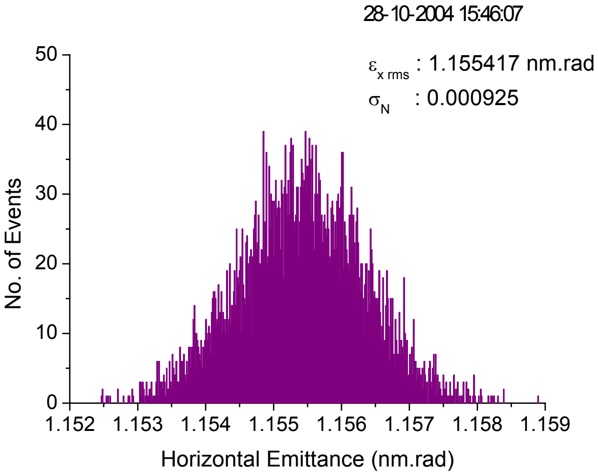


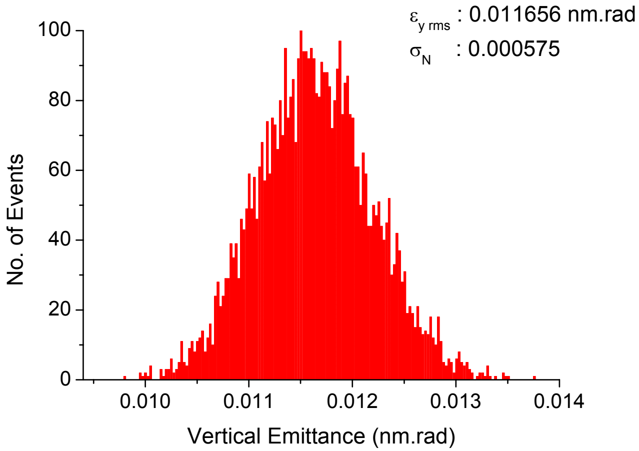


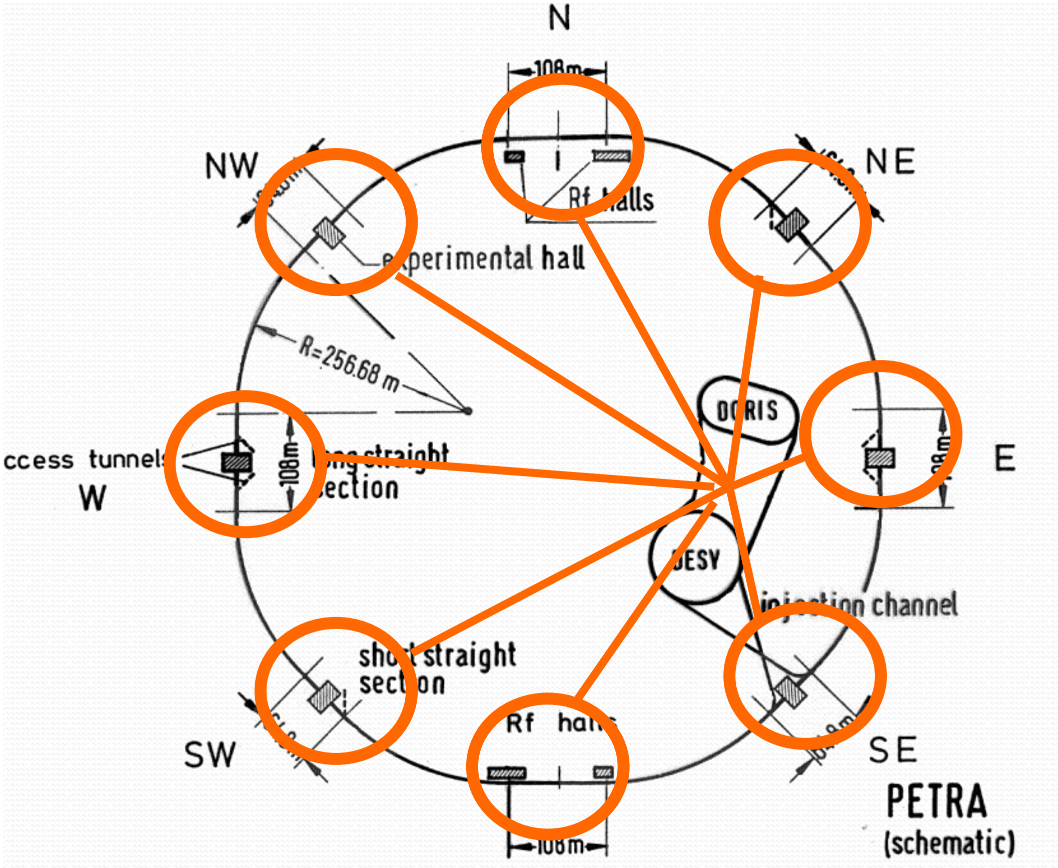
Simulation: Emittances for 5000 random seeds











Rate of orbit measurements: ≥4 kHz
Data flow on cables (fiber optics) manageable
Digital controller (SVD & PID) feasible
Power supplies: work in progress
Correctors: air coils similar to ESRF

Fast feedback systems in SRS worldwide

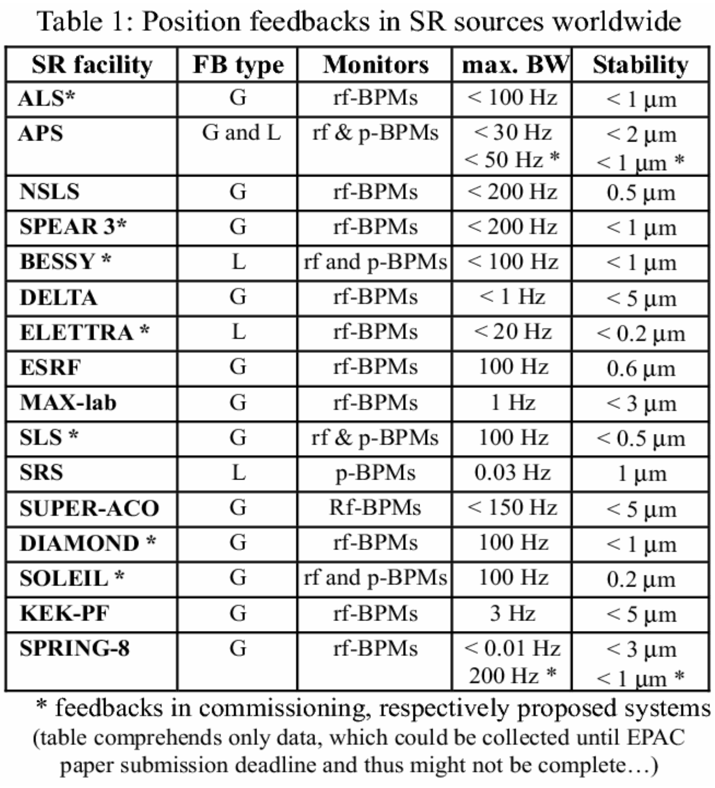


Table 1: Position feedbacks in SR sources worldwide

SR facility	FB type	Monitors	max. BW	Stability
ALS*	G	rf-BPMs	< 100 Hz	< 1 μm
APS	G and L	rf & p-BPMs	< 30 Hz < 50 Hz *	< 2 μm < 1 μm *
NSLS	G	rf-BPMs	< 200 Hz	0.5 μm
SPEAR 3*	G	rf-BPMs	< 200 Hz	< 1 μm
BESSY *	L	rf and p-BPMs	< 100 Hz	< 1 μm
DELTA	G	rf-BPMs	< 1 Hz	< 5 μm
ELETTRA *	L	rf-BPMs	< 20 Hz	< 0.2 μm
ESRF	G	rf-BPMs	100 Hz	0.6 μm
MAX-lab	G	rf-BPMs	1 Hz	< 3 μm
SLS *	G	rf & p-BPMs	100 Hz	< 0.5 μm
SRS	L	p-BPMs	0.03 Hz	1 μm
SUPER-ACO	G	Rf-BPMs	< 150 Hz	< 5 μm
DIAMOND *	G	rf-BPMs	100 Hz	< 1 μm
SOLEIL *	G	rf and p-BPMs	100 Hz	0.2 μm
KEK-PF	G	rf-BPMs	3 Hz	< 5 μm
SPRING-8	G	rf-BPMs	< 0.01 Hz 200 Hz *	< 3 μm < 1 μm *

* feedbacks in commissioning, respectively proposed systems
(table comprehends only data, which could be collected until EPAC paper submission deadline and thus might not be complete…)

V. Schlott, PSI, Villigen: ‘Global position feedback in SR sources’, Proceedings of EPAC 2002, Paris.

Long term stability: slow orbit feedback

Alignment of the machine every half a year
Temperature stability (new octant ± 0.1 °C old octant ± 1°C)
Cooling water temperature ± 0.2°C)
Establishing a new golden orbit ≥ 24 h

Monitors	#	Hor. (µm)	Ver. (µm)
Old octant	148	**20**	**20**
New octant	40	2	0.5
Next to ID	18	2	0.2*

ATL law : $\Delta x^2 = A.T.L$

$A = 4*10^{-6}$ µm²/m/s ; L = 65 m
$\Delta x = 15$ µm
➔ **T = 10 d**

Orbit stabilization

- top-up

- slow feedback: repeated orbit correction every few seconds - using all monitors and correctors via SVD algorithm
-
- fast feedback : BW few tenth of Hz up to 100 Hz

Summary

- PETRA III is an unconventional Light Source.
- Unconventional measures have to be taken to fulfill the stability requirements.
- Nevertheless use can be made of the experience gained at other light sources concerning correction procedures and hardware design.

PETRA III **Positron Storage** ring parameters

Nominal Energy	6.0 GeV
Nominal circulating current, multi-bunch	100 mA
Natural emittance	1.0 nm-rad
Natural energy spread, rms	10-4
Circumference	2304 m
Revolution time	7.685 μ s
Revolution frequency	0.130 MHz
Radio frequency	499.564 MHz
RF voltage	1.667 MV
Harmonic number	3840

Lattice type	Hybrid (FODO + DBA)
Number of periods (Full Ring)	8 Octants, 288m each
Old Octant (7/8)	FODO Cells
Per Octant, No. of FODO Cells	20
One FODO Cell Length	14.4 m
New Octant (1/8)	DBA Cells
New Octant, No. of DBA Cells	8 + 2
One DBA Cell Length	23.012m
Length available for insertion device	5.0 and 10.0 m
Mean radius	366.69298 m

In FODO Octants	
Bending field	0.1043 T
Bending length	5.378 m
Bending radius	191.7297 m
Bending magnet critical energy	2.497 keV

PETRA III **Positron Storage** ring parameters

Number of chromatic sextupoles per arc	20 (5 * 4 families)
In DBA Octants	
Bending field	0.873 T (Max.1.0T)
Bending length	1.0 m
Bending radius	22.918 m
Bending magnet critical energy	20.9 keV
Maximum quadrupole strength (QPA)	21.5 T/m
Maximum quadrupole strength (QPB)	21.5 T/m
Maximum quadrupole strength (QPC)	21.5 T/m
Injection energy	Full energy
Betatron tunes	
Horizontal	36.095
Vertical	31.345
Synchrotron tune	0.049
Maximum Beta functions	
Horizontal	41 m
Vertical	52 m
Natural emittance (without damping wigglers)	4.0 nm-rad
Emittance, with 1% coupling ratio	
Horizontal	1.0 nm-rad
Vertical	10.0 pm-rad

PETRA III **Positron Storage** ring parameters

Beta functions at insertion section centre	
a) High β_x insertion section (5m undulator)	
Horizontal	20.01 m
Vertical	2.36 m
b) Low β_x insertion section (5m undulator)	
Horizontal	1.2 m
Vertical	3.95 m
c) Other insertion section (10m undulator)	
Horizontal	20.12 m
Vertical	3.39 m
Maximum dispersion	0.825 m
Beam size and divergences at insertion symmetry point, rms	
a) High β_x insertion section	
Horizontal	142 mm, 7.1 mrad
Vertical, 1% coupling	4.9 mm, 2.1 mrad
b) Low β_x insertion section	
Horizontal	34.6 mm, 28.9 mrad
Vertical, 1% coupling	6.3 mm, 1.6 mrad
c) Other insertion section	
Horizontal	142 mm, 7.1 mrad
Vertical, 1% coupling	6.3 mm, 1.6 mrad
Momentum compaction factor	1.20*10-4
Transition gamma	28.289
Damping time	
Horizontal	17.06 ms
Vertical	16.72 ms
Longitudinal	9.84 ms