Diamond-II storage ring tuning

Design to Commissioning

H. GHASEM

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Thanks to M. Apollonio, F. Bakkali-Taheri, R. Bartolini, J. Bengtsson, R. Fielder, M. Korostelev, I. Martin, T. Olsson, B. Singh, R. Walker

ARIES Workshop:
Beam Tests and Commissioning of Low Emittance Storage Rings
KIT Campus South on **18 – 20 Feb. 2019**.

Outline

- Design goals of Diamond-II
- Diamond storage ring lattice evolution
- M-H6BA lattice
  - Linear beam dynamics
  - Nonlinear beam dynamics
  - Momentum aperture and lifetime
- Commissioning simulation

Diamond II Design GOALs

Design goals for Diamond-II storage ring:

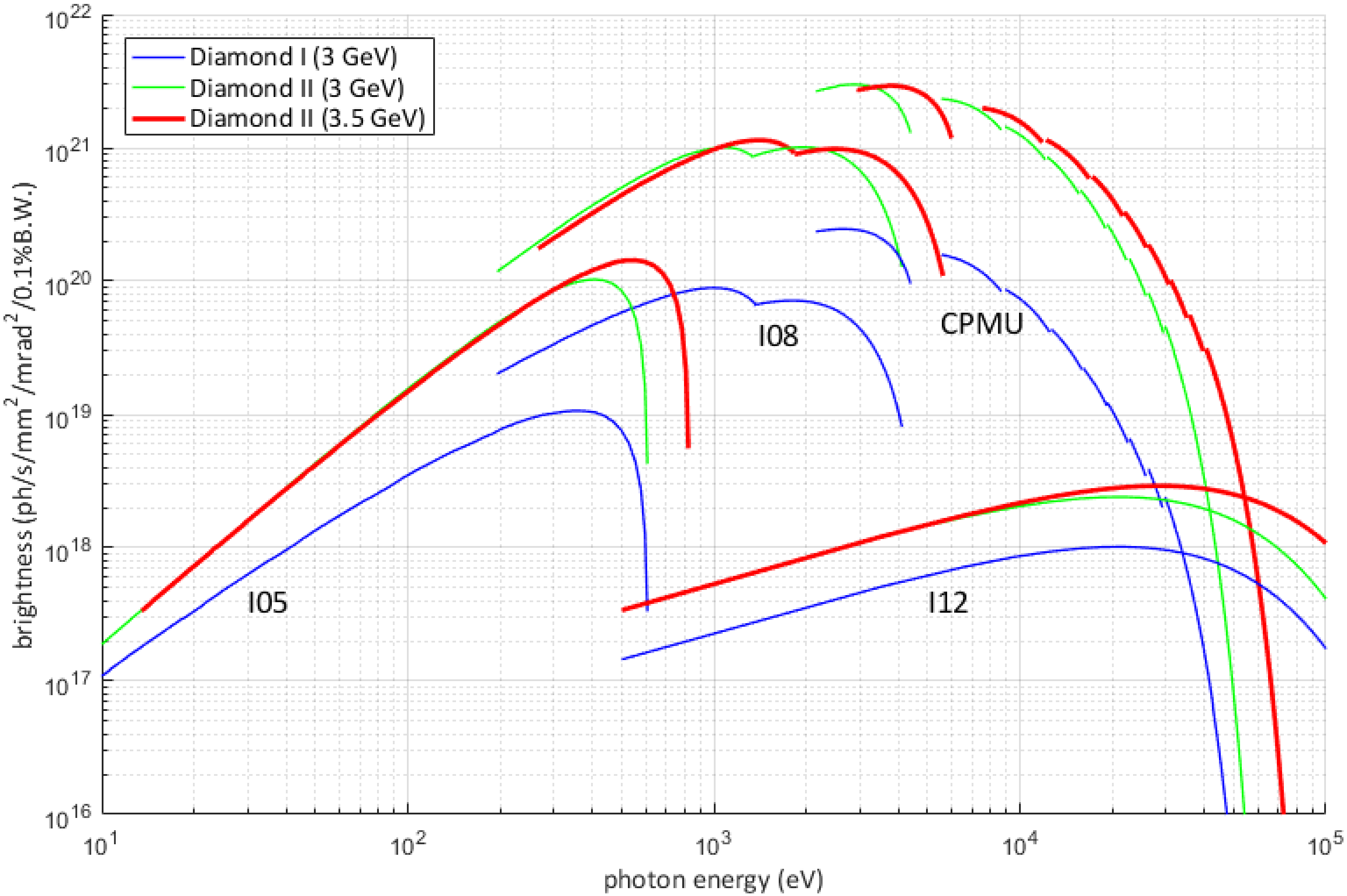
1) Improve quality of photon beams delivered to users:

- Increase spectral brightness (electron beam emittance, beam energy)
- Increase transverse coherence (electron beam matched to photons)
- Reduced source size, line-width (emittance, energy spread)
- Optimise spectral range (beam energy, ID parameters)

2) Increase number of straight sections:

- Convert bending magnet beamlines (ID / wiggler / bespoke 3-pole wiggler)
- Relocate existing IDs (I04.1 and I20-EDE)
- Space for new beamlines (up to six)
- Space for ancillary components (RF cavities, diagnostics equipment, …)

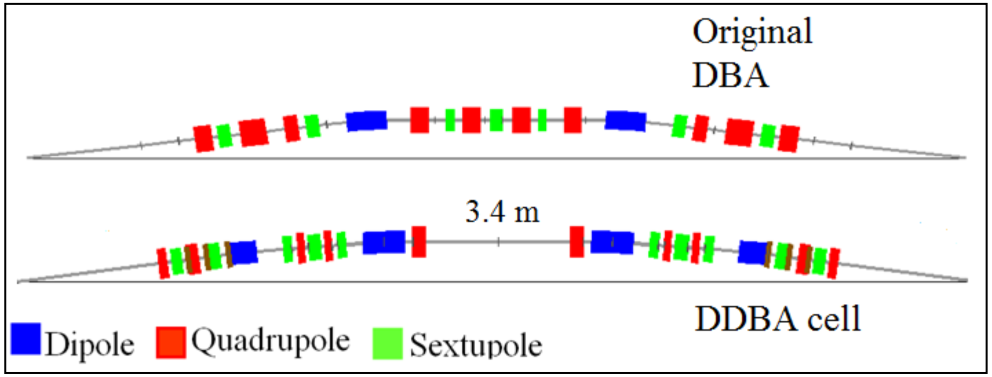
Brightness

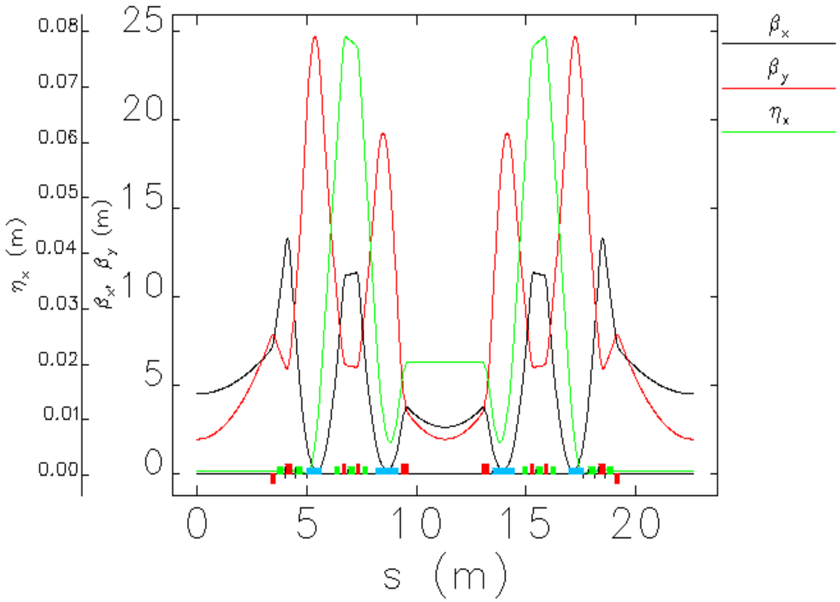


N.B. ID parameters constant for each scenario

Courtesy M. Apollonio and J. Li

Diamond Lattice Evolution



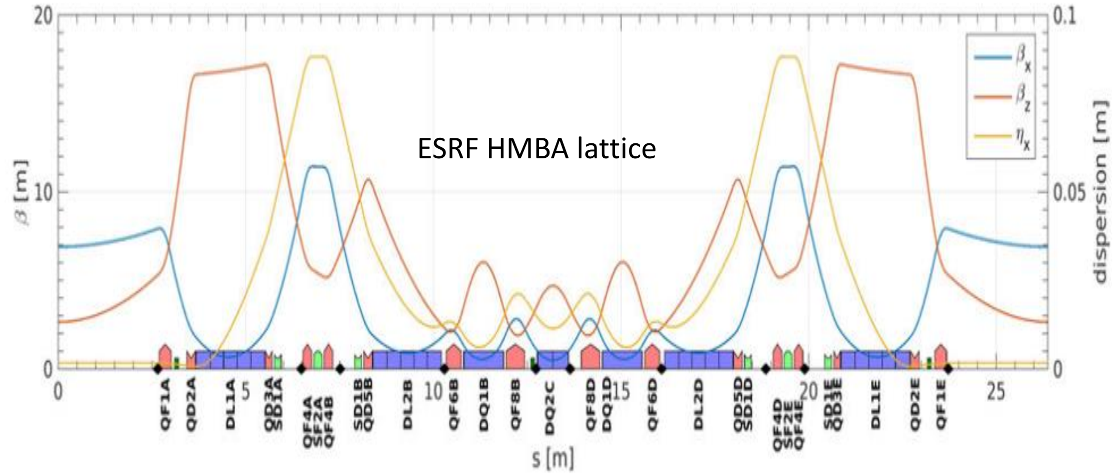


- ❑ The DDBA lattice combines the idea of doubling the capacity of the ring with the low emittance.
- ❑ The Diamond Board approved the project to replace the existing cell2 with a DDBA cell (270 pm), PRAB, 21, 050701 (20148).

Diamond Lattice Evolution

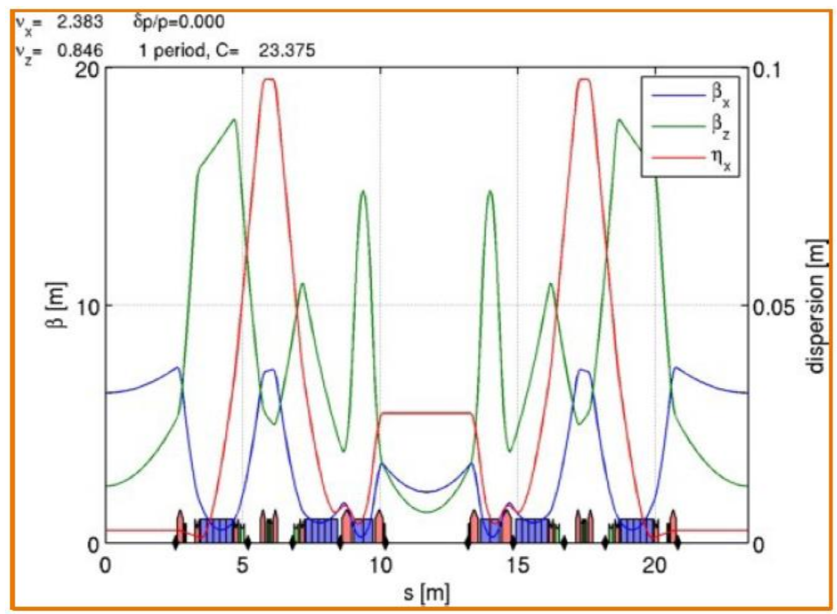
P. Raimondi, IPAC17, Denmark

- A more aggressive design has been proposed that merges the ESRF HMBA concept with the Diamond DDBA and taking the best of both.



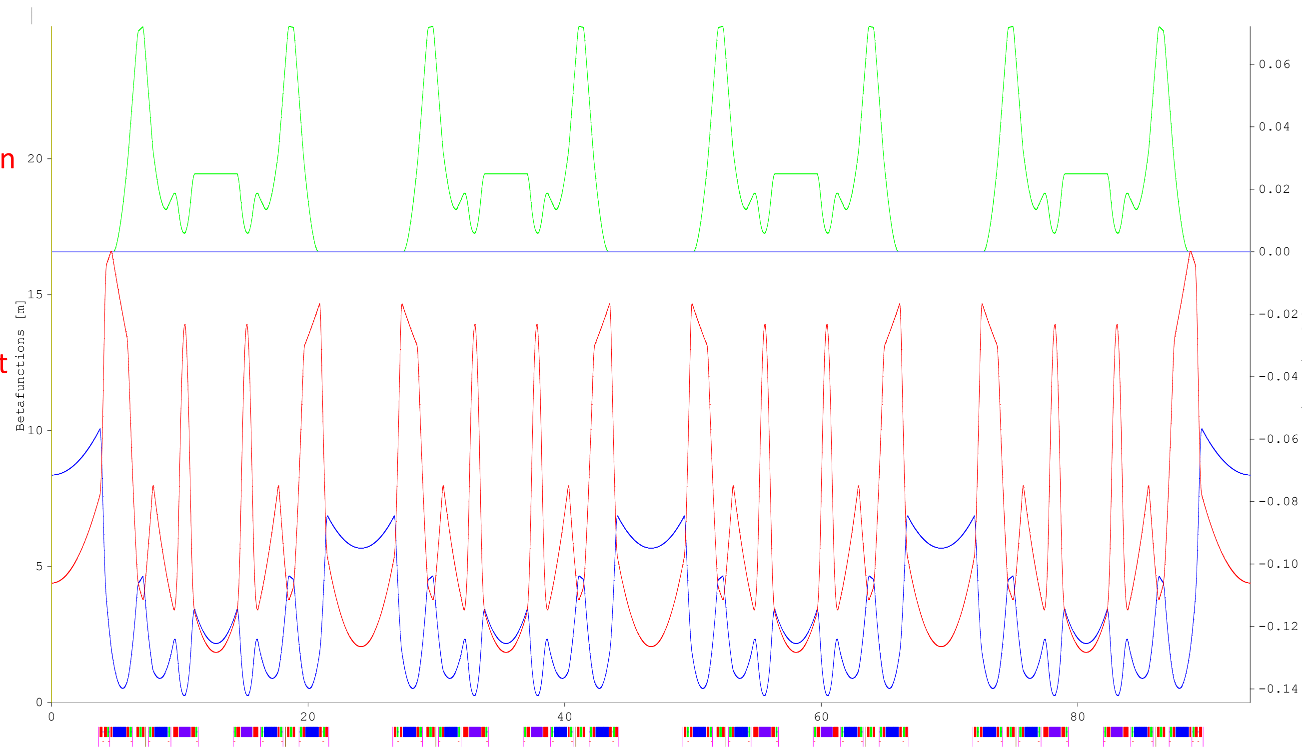
- Use the ESRF cell (7BA with longitudinal gradient dipoles) – removing the mid dipole to make it a 6BA with a straight at the center.

Modified-Hybrid 6 Bend Achromat (M-H6BA)



M-H6BA - Optical functions

- -I transformer concept
  - 3π/π H/V phase advance difference between the dispersion bump.
- Higher order achromat condition
  - set the phase advance over 2 super-period to cancel the largest possible amount of driving terms to second order (including chromatic ones)

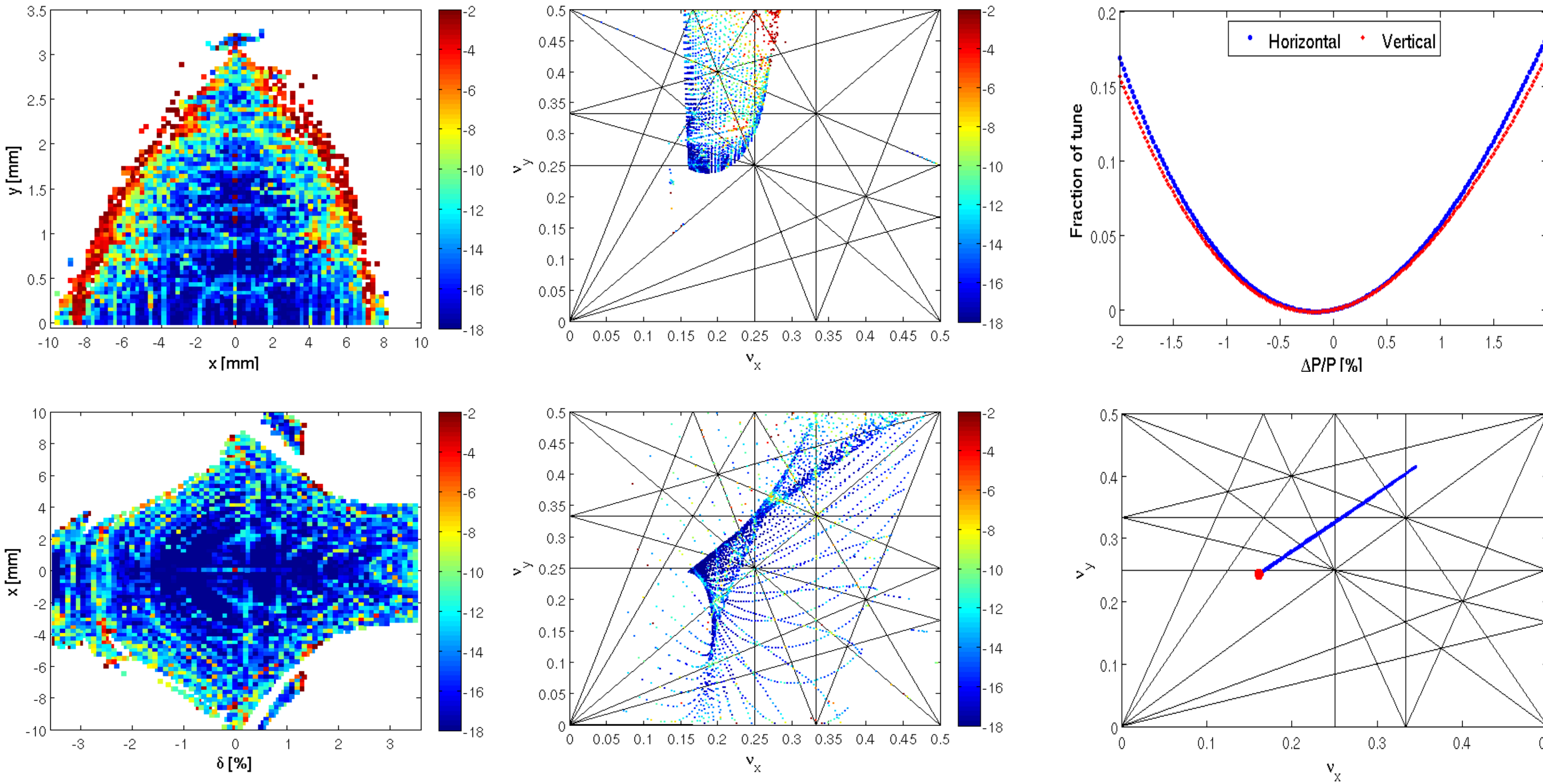


Parameters	Values
Energy [GeV]	3.5
Circumference [m]	560.388
Tune (H/V)	57. 163/20. 245
Nat. chromaticity (H/V)	-75.67/-89.59
Nat. emittance [pm]	157.3
Eff. Emittance @ MSS [pm]	227.58
Energy loss/turn [KeV]	670.318
Mom. Compaction	1.175e-04
Length of LSS/SSS/MSS	7.540/5.191/2.921

Magnets	No. in the ring	No. families-strength	No. families-length
Dipole	144 [96 LGB+48 DQ1]	2 [LGB, DQ1]	2 [1 m, 0.87 m]
Quadrupole	396	7 UC + 6 MC	5 [0.105 m, 0.15 m, 0.185 m, 0.25 m, 0.36 m]
Sextupole	288	6	2 [0.1 m and 0.14 m]
Octupole	48	1	1 [0.09 m]

M-H6BA – NLBD

- Natural chromaticity has been corrected close to zero.
- Particle tracing has been done for 2500 turns through the ring.

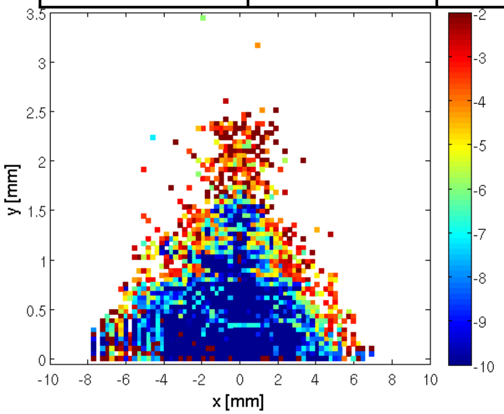


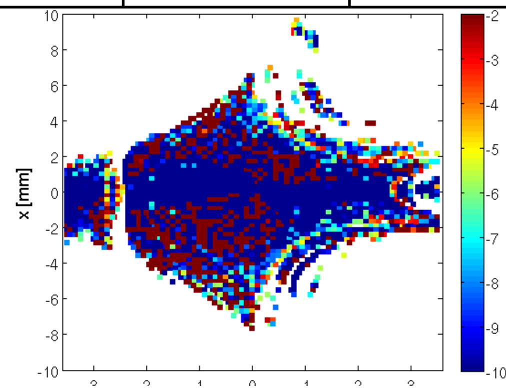
βx=8.37 m
βy=4.40 m

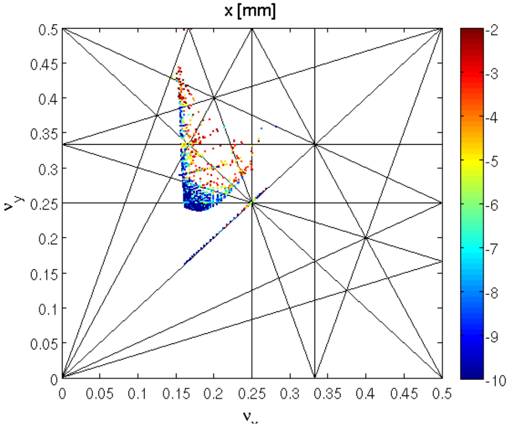
M-H6BA - NLBD

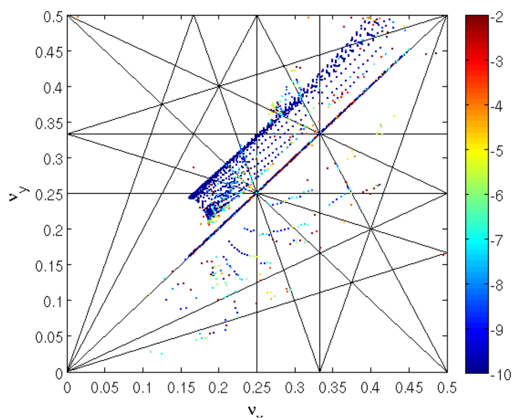
- Multipole errors + Simplified errors using Gaussian distributions.

Parameter	Δx,Δy [μm]	Roll [μrad]	Strength error	σ cut-off
Dipole	15	100	1E-3	2
Quadrupole	15	100	1E-3	2
Sextupole	15	100	1E-3	2
Octupole	15	100	1E-3	2
BPM	5	10	-	2
Girder	-	-	-	-

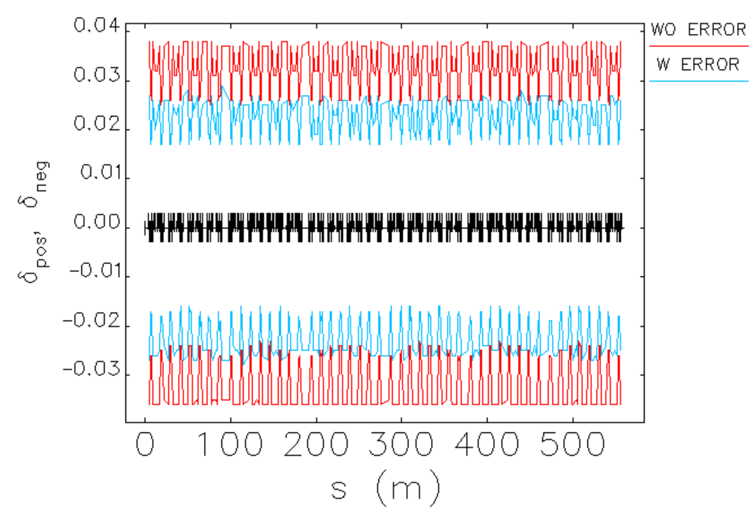








Parameters	Value
RF voltage [MV]	1.7
Harmonic number	934
RF frequency [MHz]	499.50
RF phase [Deg.]	156.7774
Beam current [mA]	300
Charge per bunch [nC]	0.62
Number of bunch	900
Vertical emittance [pm]	8
Bunche length [mm]	2.91
Energy spread	7.7575E-04
T_lifetime [h]- WO ERRORs	3
T_lifetime [h]- W ERRORs	0.8



M-H6BA – Commissioning simulation

- The simulation procedure closely follows the steps that will be performed during real commissioning.

- The procedure consists of the following major steps:

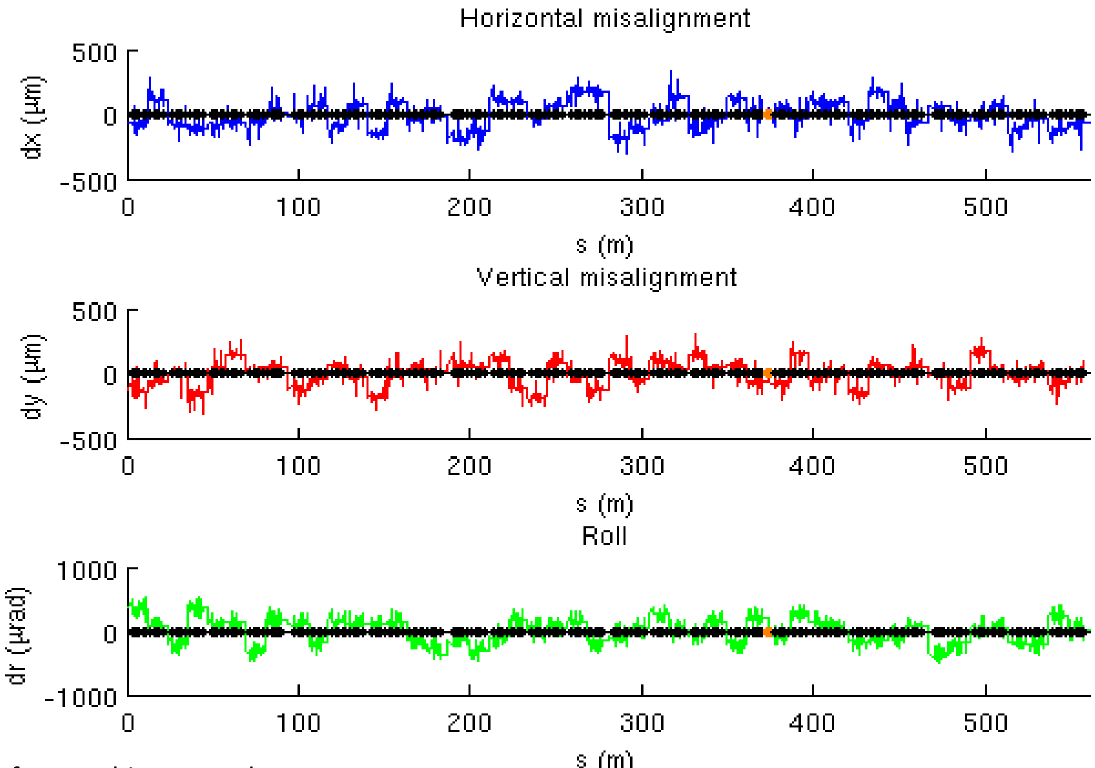
  - Generate errors for all elements using Gaussian distributions with **2σ cut off**.
  - Correct trajectory to the level that closed orbit can be found. If needed, optimize tunes.
  - Correct closed orbit
  - Correct the optics
  - Correct the vertical dispersion and coupling
  - The correction steps are based on the response matrix and SVD algorithm

- The simulation has been done for 50 seeds of machine ensembles.

Ref.:
V. Sajaev et al., IPAC2015, Richmond, VA, USA
S. M. Liuzzo et al., IPAC17, Copenhagen, Denmark
T. Hellert et al., IPAC18, Vancouver, Canada

M-H6BA – ERRORS

Parameter	Value
Girder misal. /roll [µm /µrad]	150/150
Dipole misal. / roll within girder [µm /µrad]	50/100
Quad., Sext., Oct. misal. /roll within girder [µm /µrad]	25/100
BPM misal. /roll within girder [µm /µrad]	100/100
BPM misal. /roll within girder at BBA level [µm /µrad]	5/5
Dipole/Quad./Sext./Oct. fractional strength error	1E-3

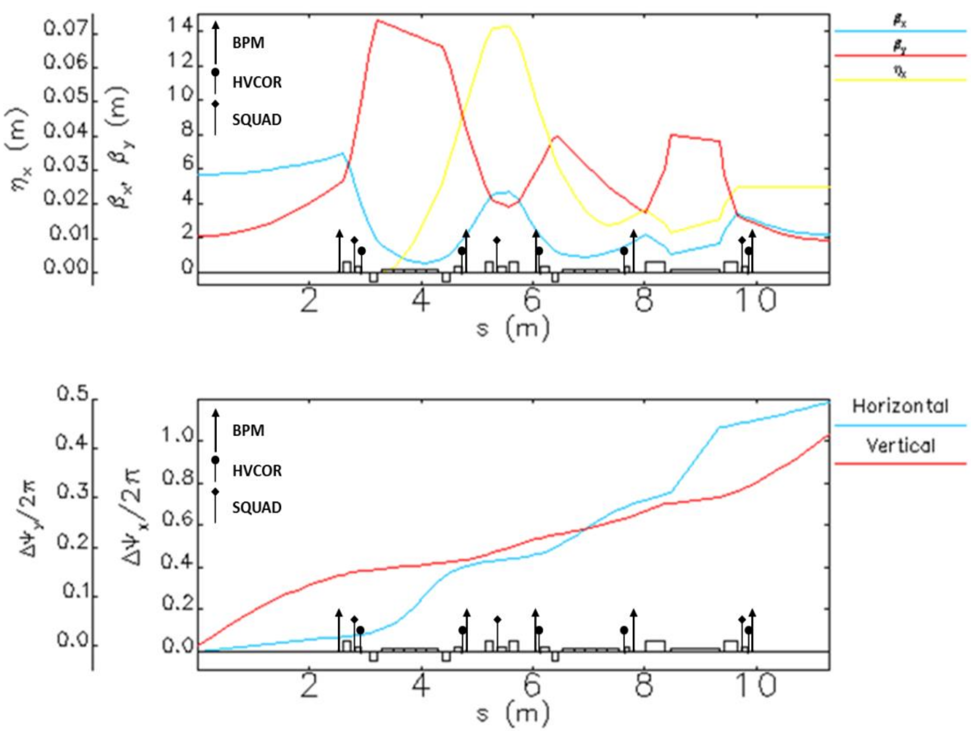


Distributed errors for an arbitrary seed

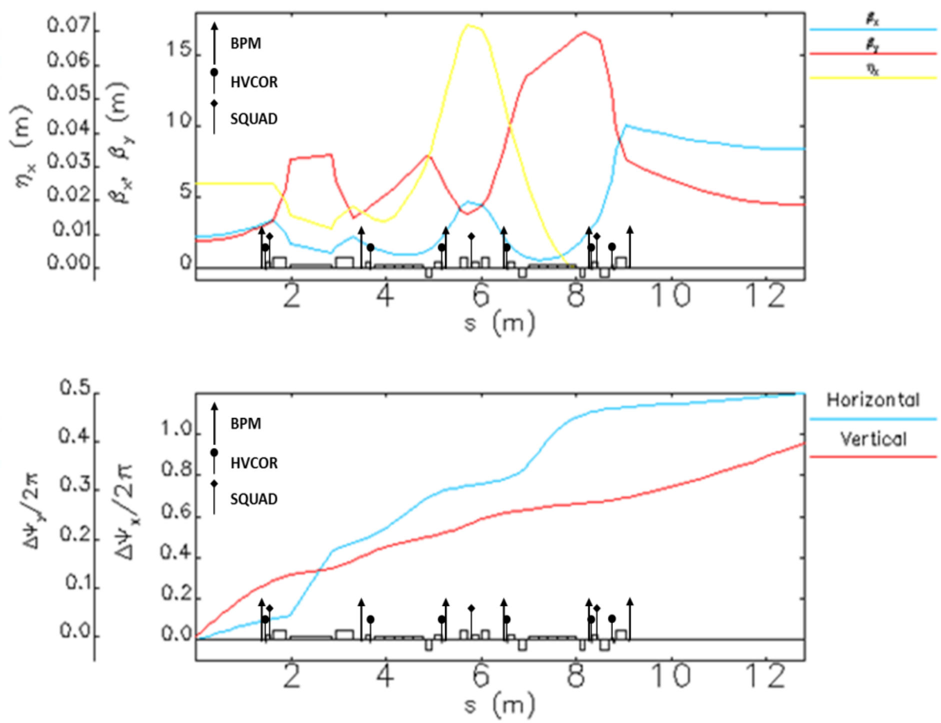
M-H6BA – CORRECTORS

- 252 HV correctors
  - 192 of HV CORs are as additional winding in the sextupoles.
  - 60 of HV CORs are as 80 mm separate magnets
- 252 BPMs
- 144 Skew quadrupole as additional windings inside the sextupoles
  - 96 @ dispersive places and 48 @ non dispersive places

Half unit cell

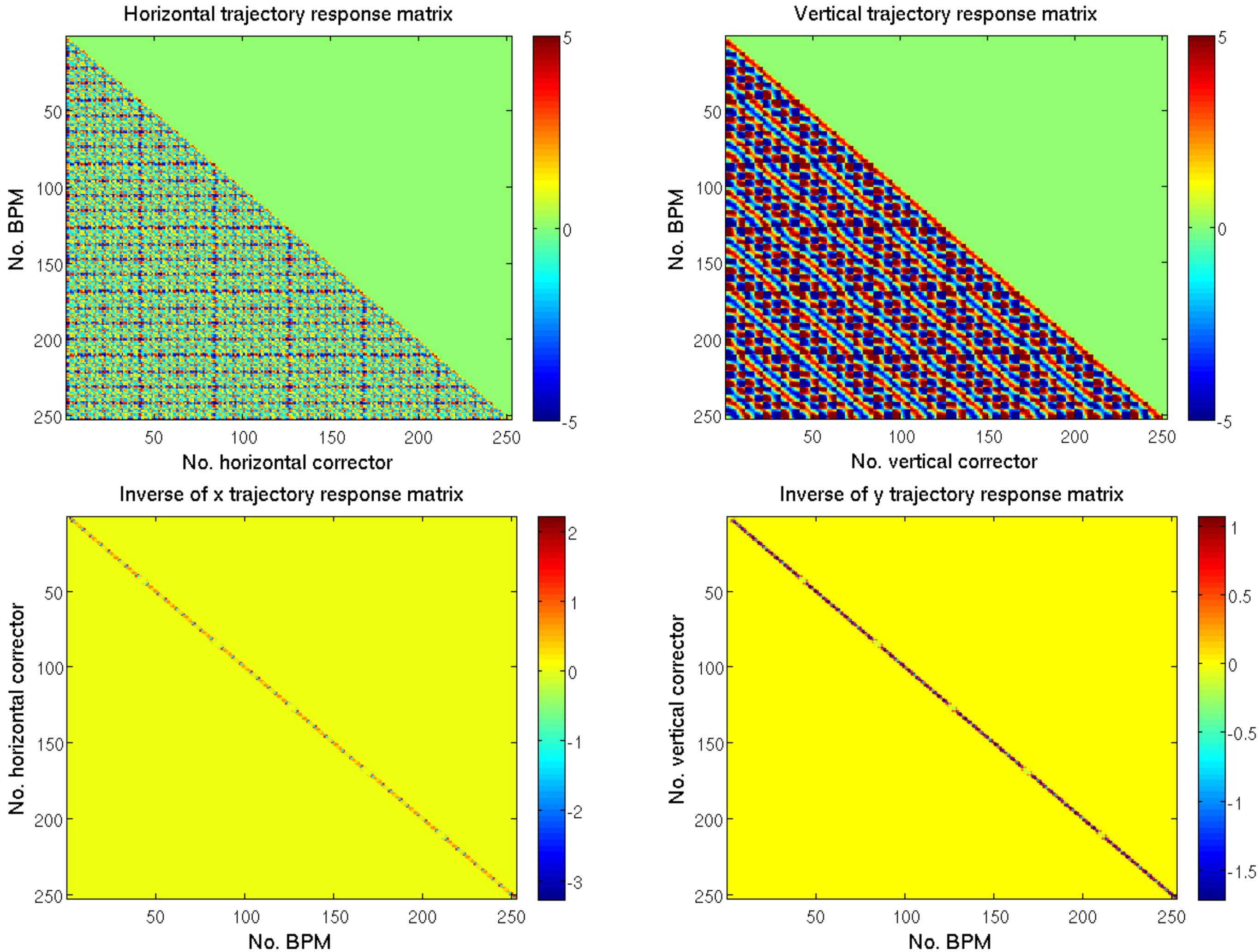


Matching section



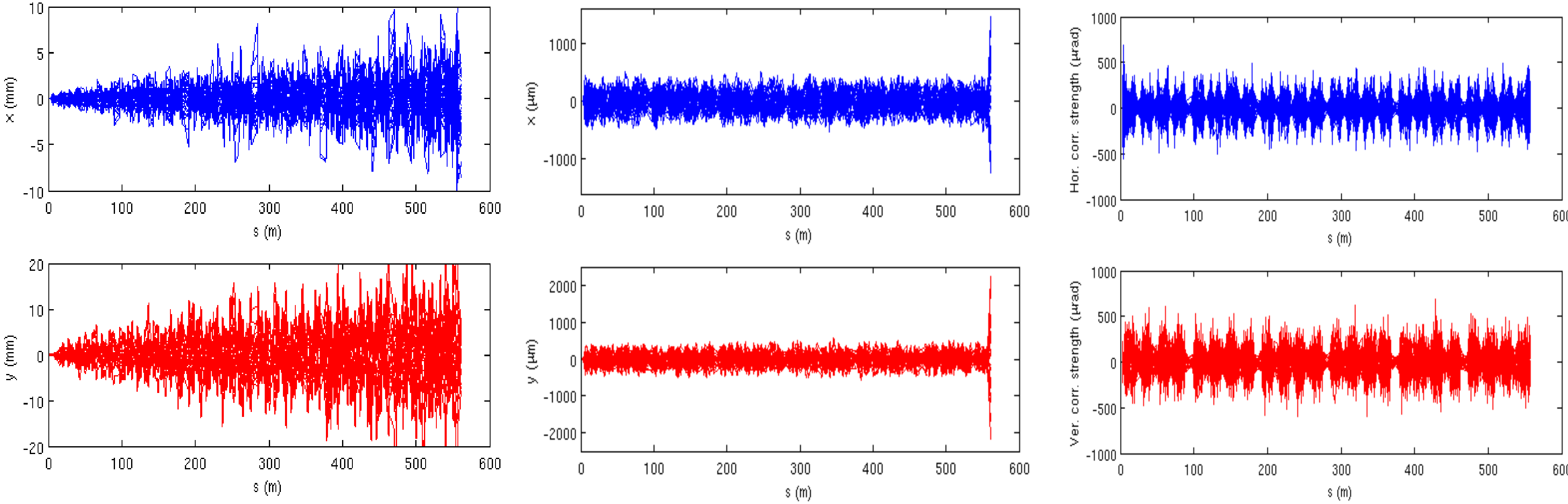
M-H6BA – TRAJECTORY correction

- Trajectory correction
- Trajectory response matrix



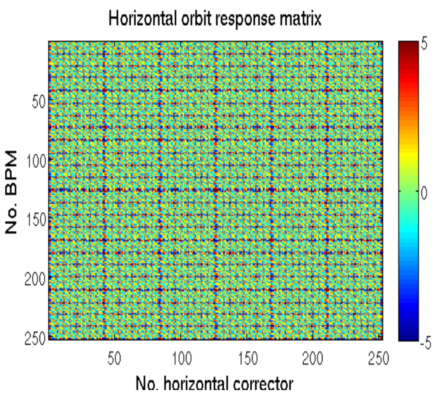
M-H6BA – TRAJECTORY correction

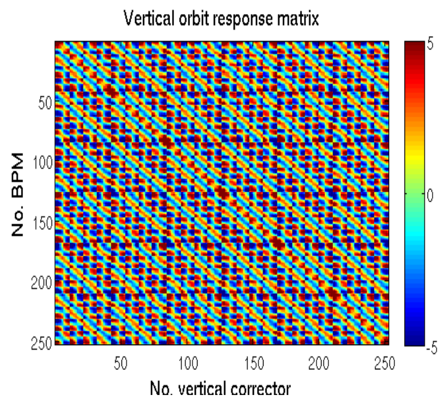
- ❑ Trajectory has been corrected to the level that closed orbit could be found.
- ❑ Sextupole magnets have been switched OFF.
- ❑ Max. corrector strength is below than 1 mrad.

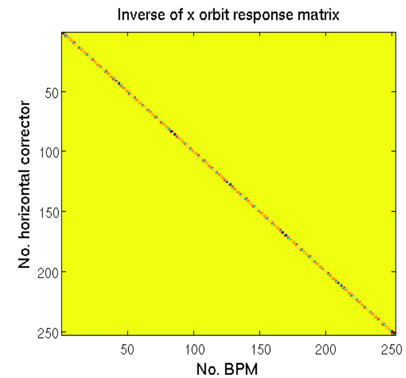


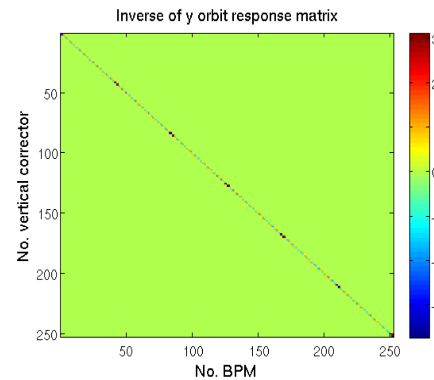
M-H6BA – ORBIT correction

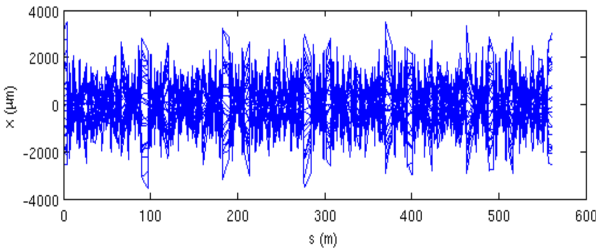
- Global closed orbit correction
- Sextupole magnets have been switched ON for the remaining correction steps.

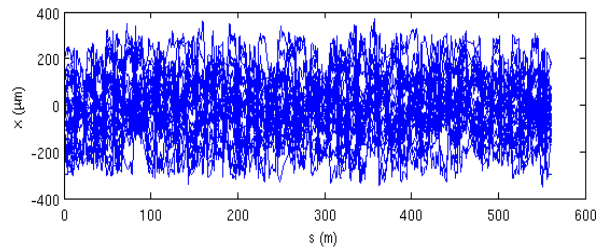


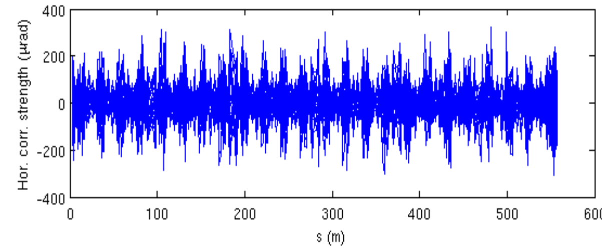


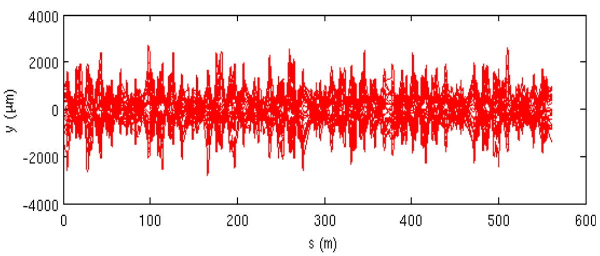


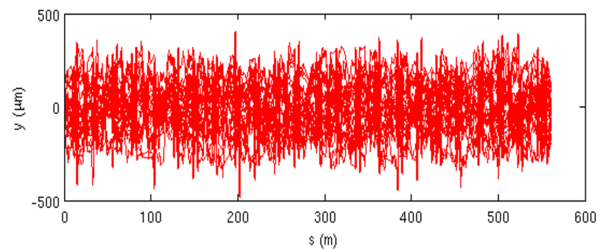


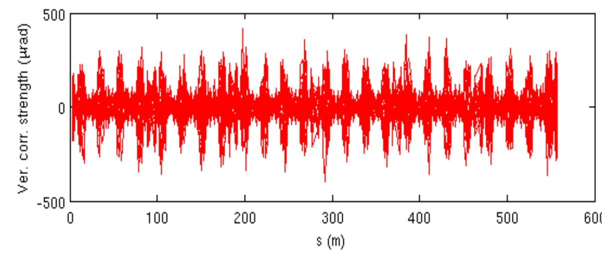










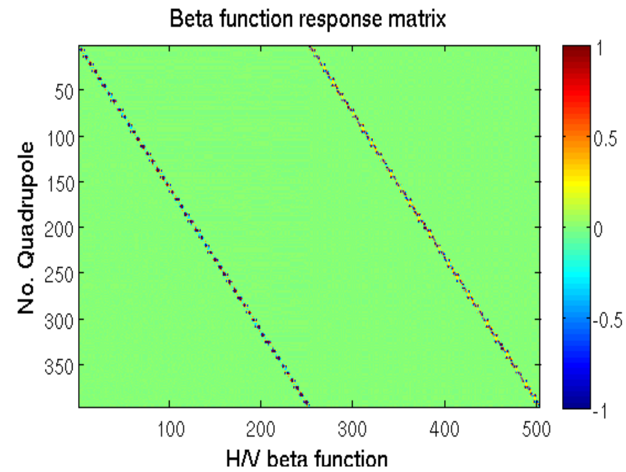


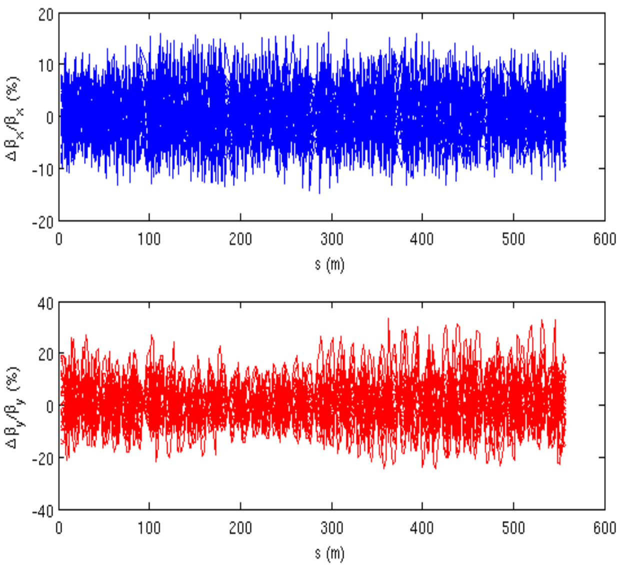
Parameter	X_rms	Y_rms
Orbit at all elements after corr. [µm]	42.45	58.46
Corrector strength [µrad]	76.47	90.02

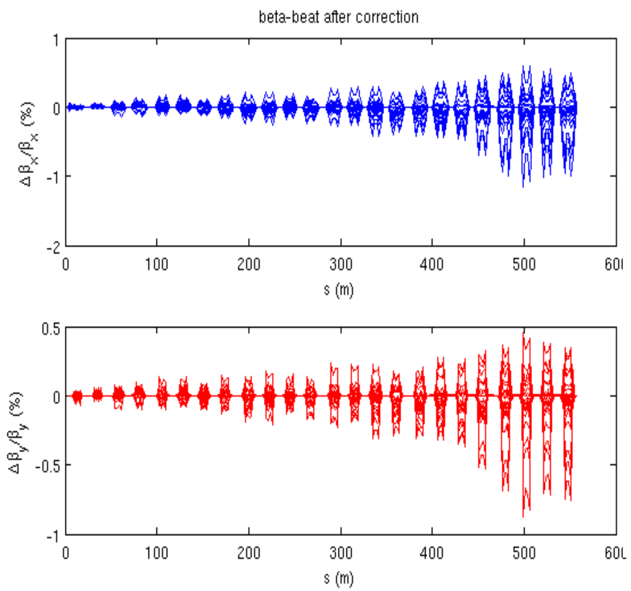
The procedure was able to correct trajectory in 94% of all cases.

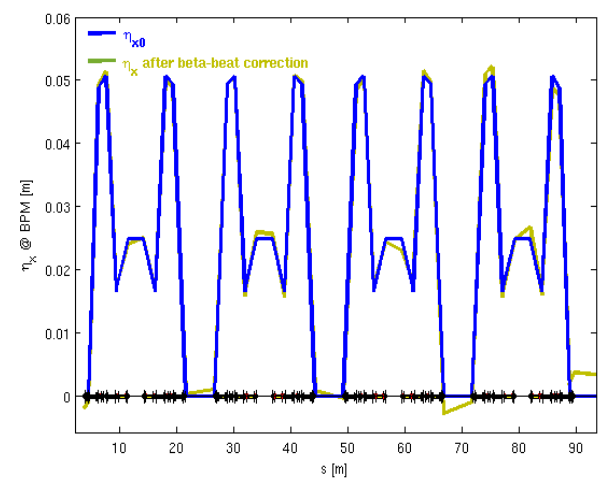
M-H6BA – OPTICS correction

- In reality, the LOCO can be used for the remaining correction steps by changing the strength of normal and skew quadrupoles.
- However, the remaining correction steps have been simulated for simplicity.
- Tune shift for an arbitrary seed: 0.0154/0.005.9
- Shift of corrected chromaticity: 0.095/0.036





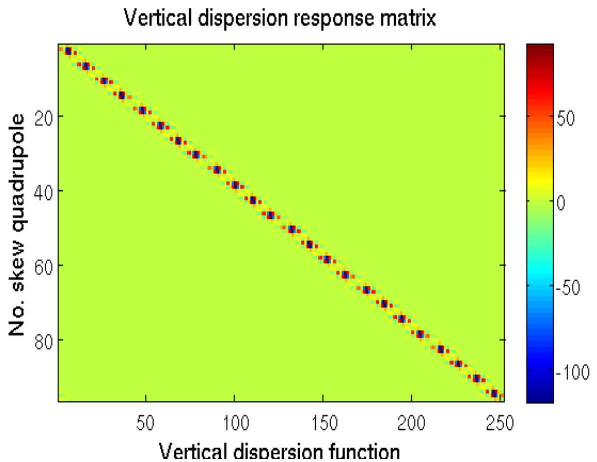


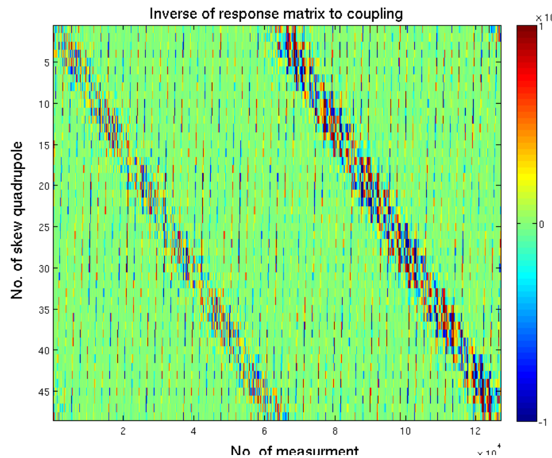


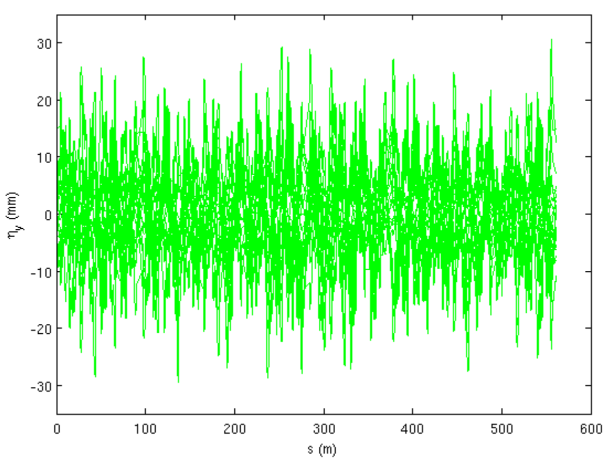
M-H6BA – V_DISPERSION & COUPLING correction

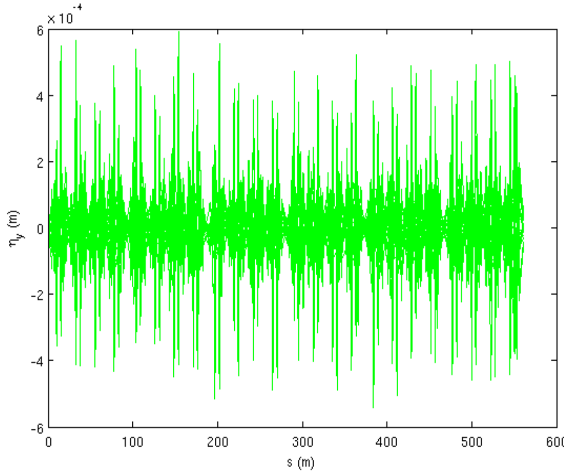
- Vertical dispersion and coupling correction
- Max. strength of skew quadrupoles is 0.36 m^{-2}.

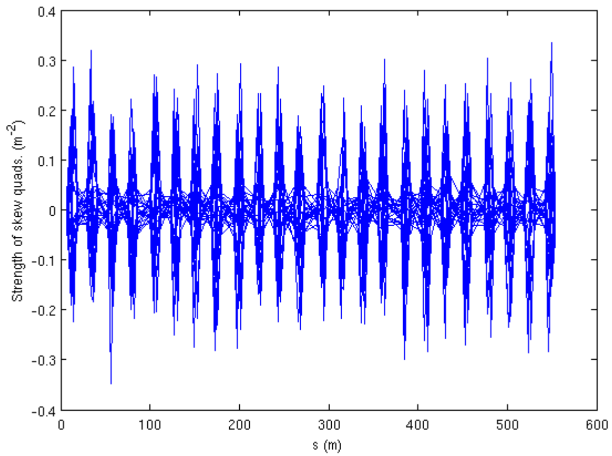
$$\begin{pmatrix} X^{HCOR} & X^{VCOR} \\ Y^{HCOR} & Y^{VCOR} \end{pmatrix}$$











M-H6BA – Summary & Conclusion

- An ultra low emittance lattice with 48 straight sections has been designed for the Diamond storage ring.
- Good dynamic aperture is obtained.
- The real momentum aperture is around +-2%. This is ongoing optimization work!
- Realistic error tolerances have been achieved.
- Commissioning simulation has been done and the results revealed that, the correction algorithm can correct the errors for 94% of the all machine ensembles.

Thank you for your attention!

We look forward to see the Diamond-II accelerators.