Diamond storage ring lattice upgrade

H. GHASEM- Diamond Light Source

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

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Outline

- Design goals of Diamond-II
- Diamond storage ring lattice evolution
- M-H6BA lattice
    - Linear beam dynamics
    - Nonlinear beam dynamics
    - Momentum aperture and lifetime
    - 3rd harmonic cavity
    - Commissioning simulation
    - M-H6BA + Anti bend

Diamond II Design GOALs

Design goals for Diamond-II storage ring:

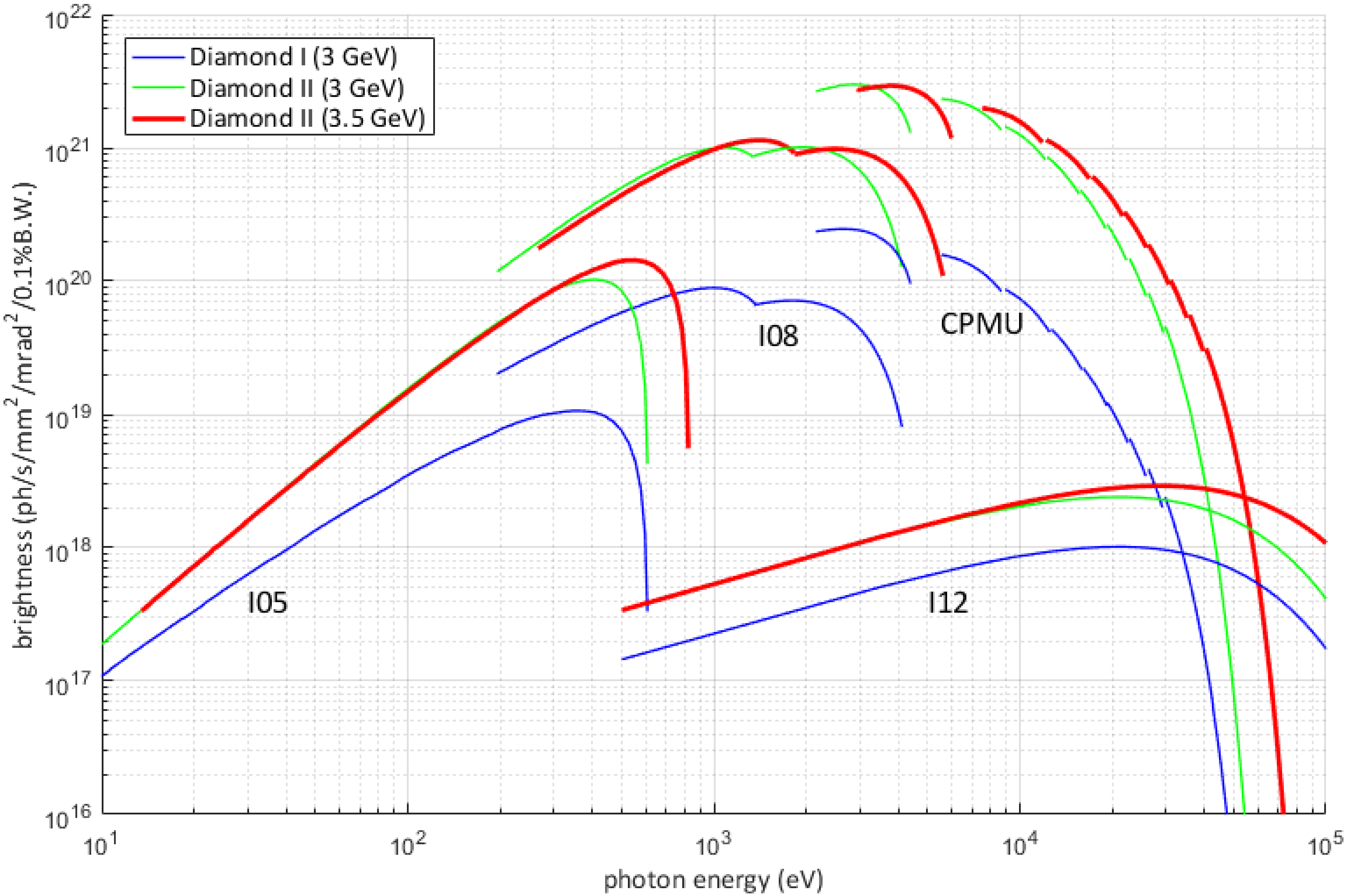
1) Improve quality of photon beams delivered to users:

- 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, …)

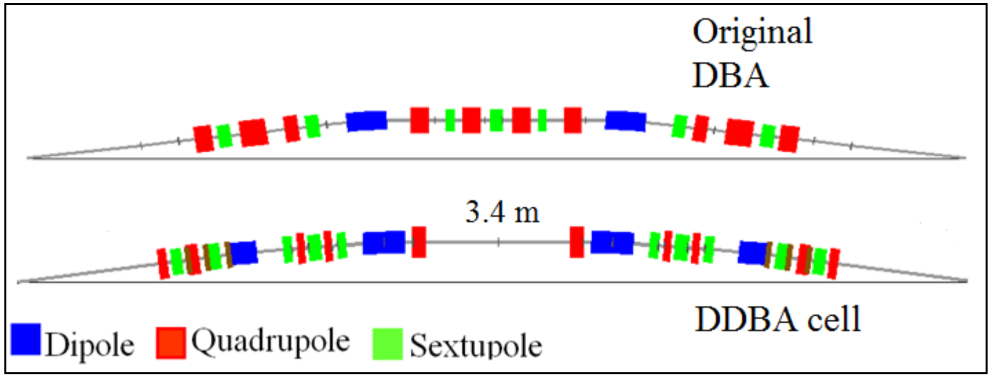
Brightness

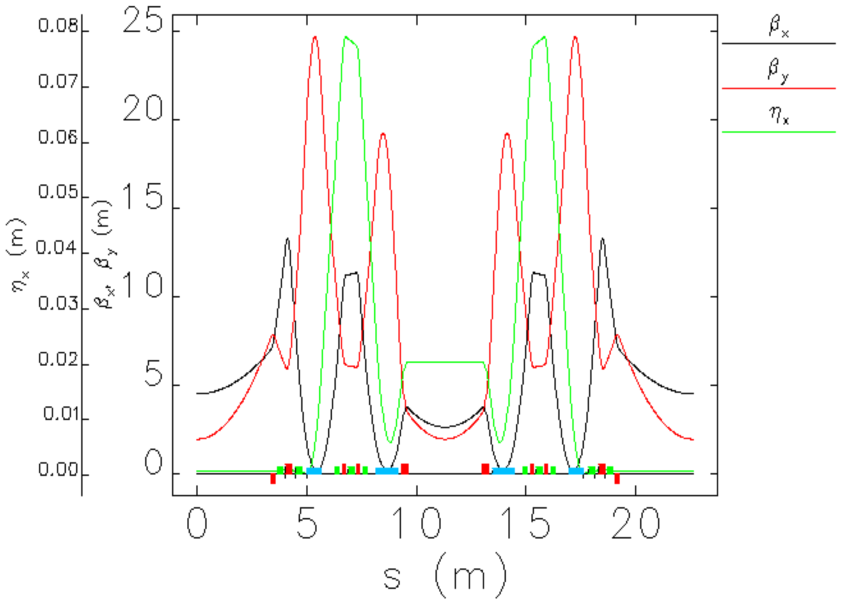


N.B. ID parameters constant for each scenario

Courtesy M. Apollonio and J. Li

Diamond Lattice Evolution



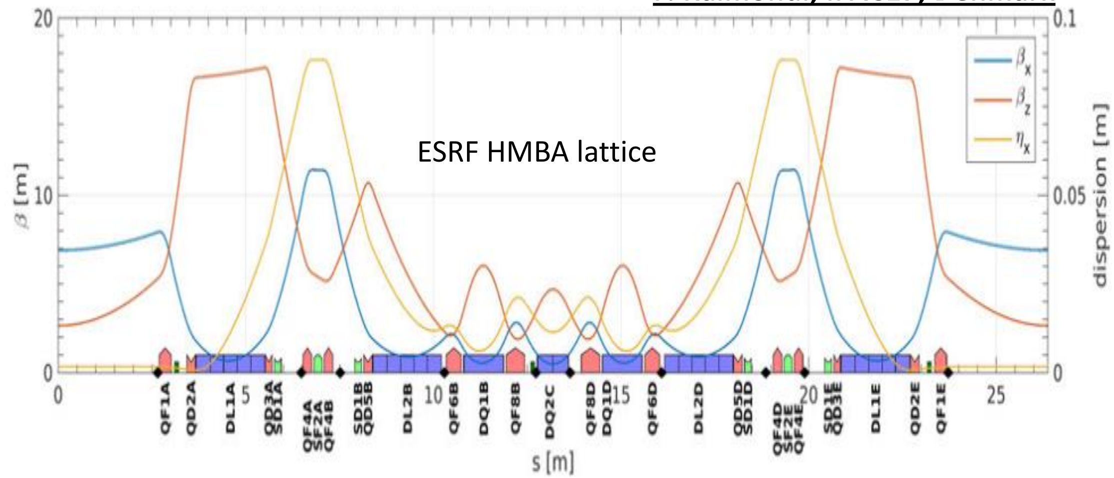


- The DDBA lattice combines the idea of doubling the capacity of the ring with the low emittance.
- The Diamond Board approved the project to replace the existing cell2 with a DDBA cell (270 pm), PRAB, 21, 050701 (20148).

Diamond Lattice Evolution

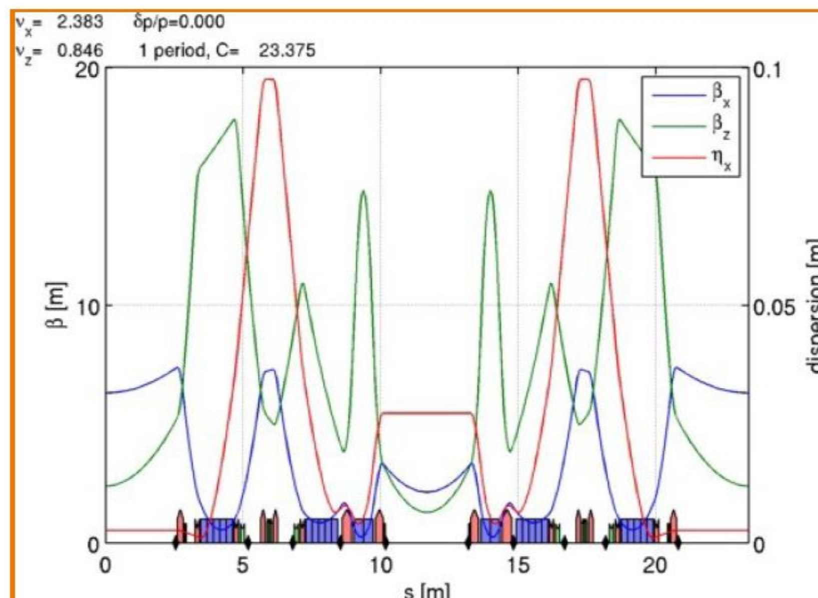
P. Raimondi, IPAC17, Denmark

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

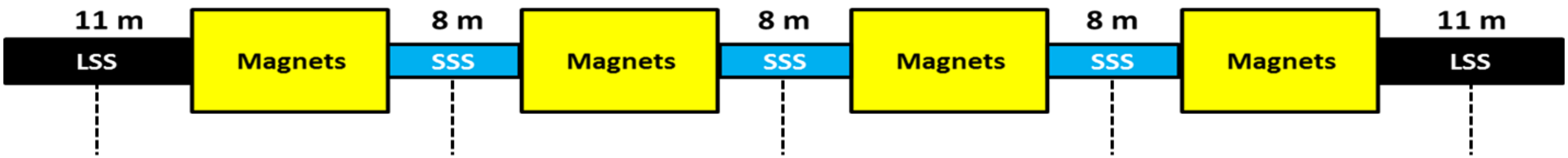


- Use the ESRF cell (7BA with longitudinal gradient dipoles) – removing the mid dipole to make it a 6BA with a straight at the center.

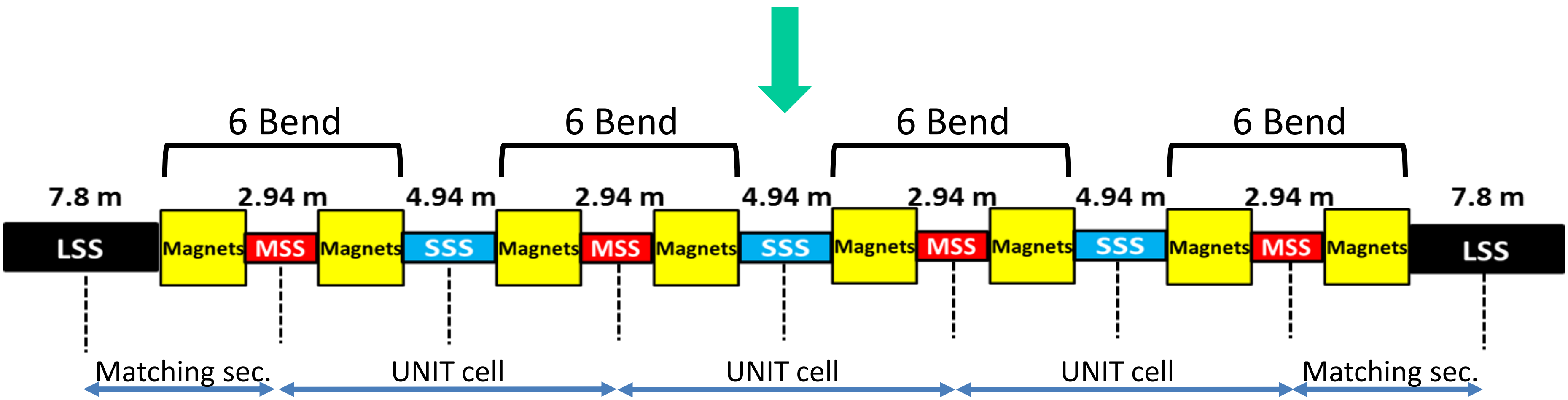
Modified-Hybrid 6 Bend Achromat (M-H6BA)



Diamond → M-H6BA



Diamond-I one super period



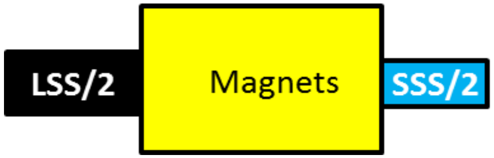
Diamond-II one super period

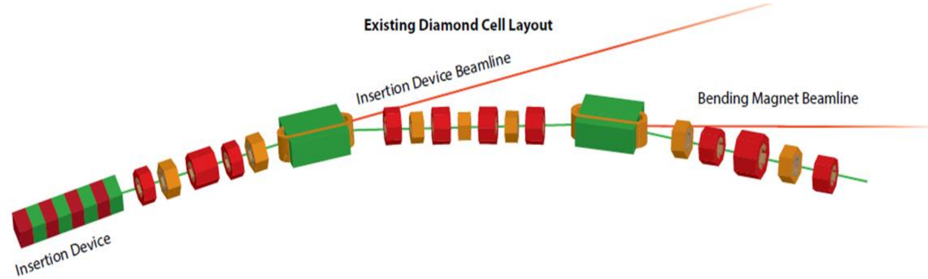
LSS: Long straight section

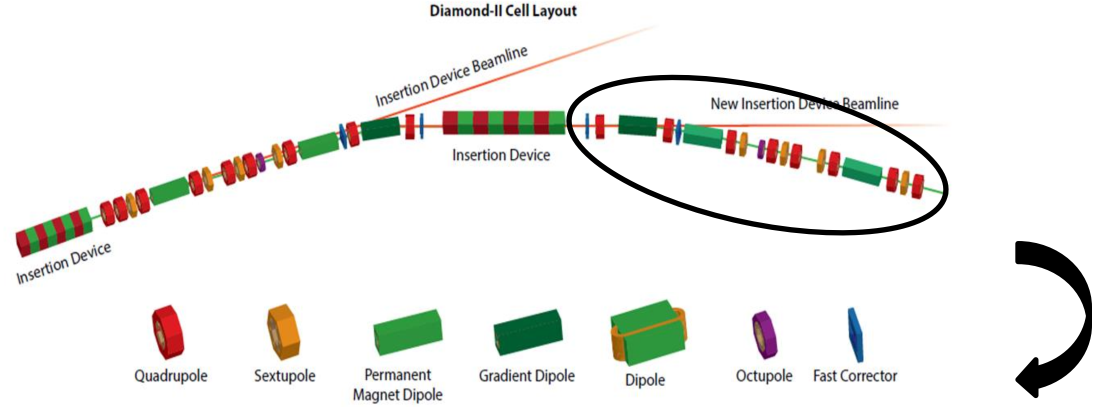
SSS: Standard straight section

MSS: Middle straight section

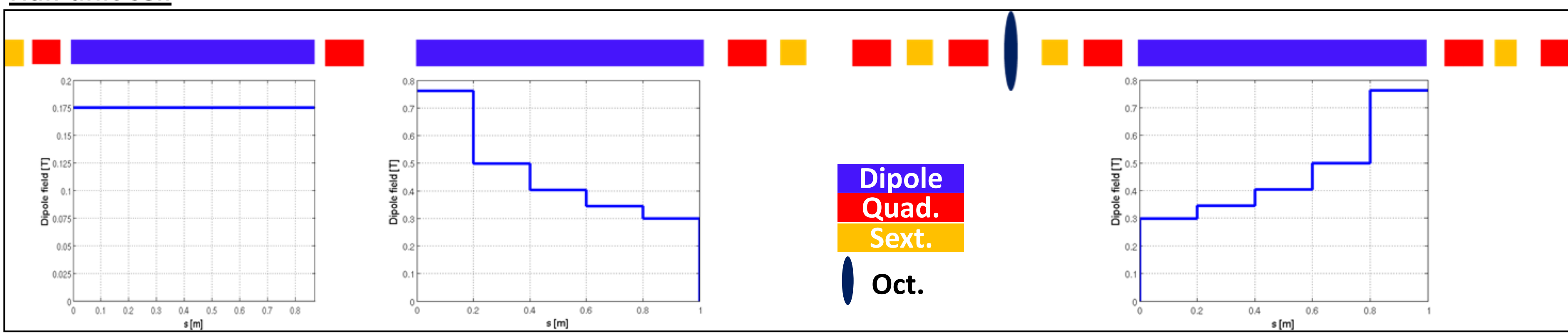
Diamond → M-H6BA



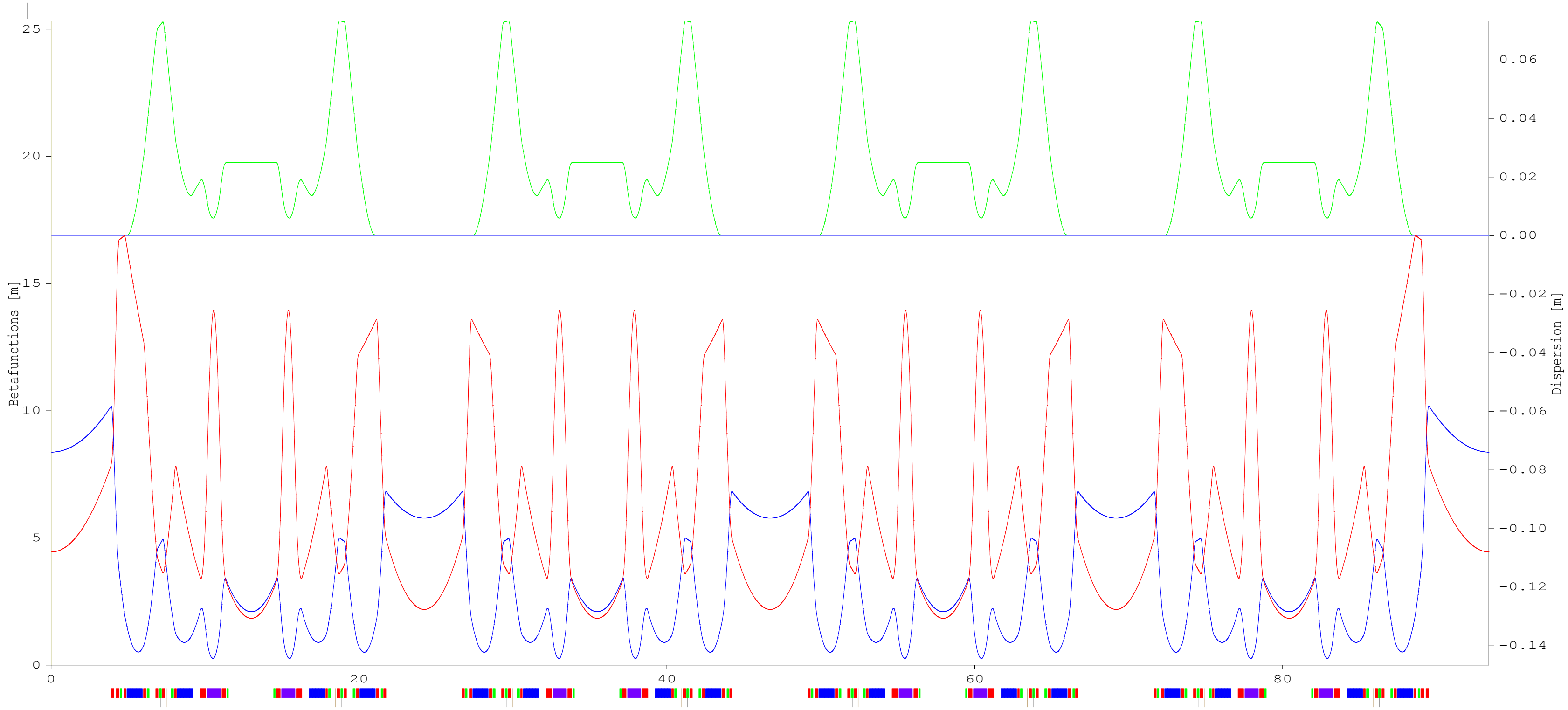




Half unit cell



M-H6BA - Optical functions



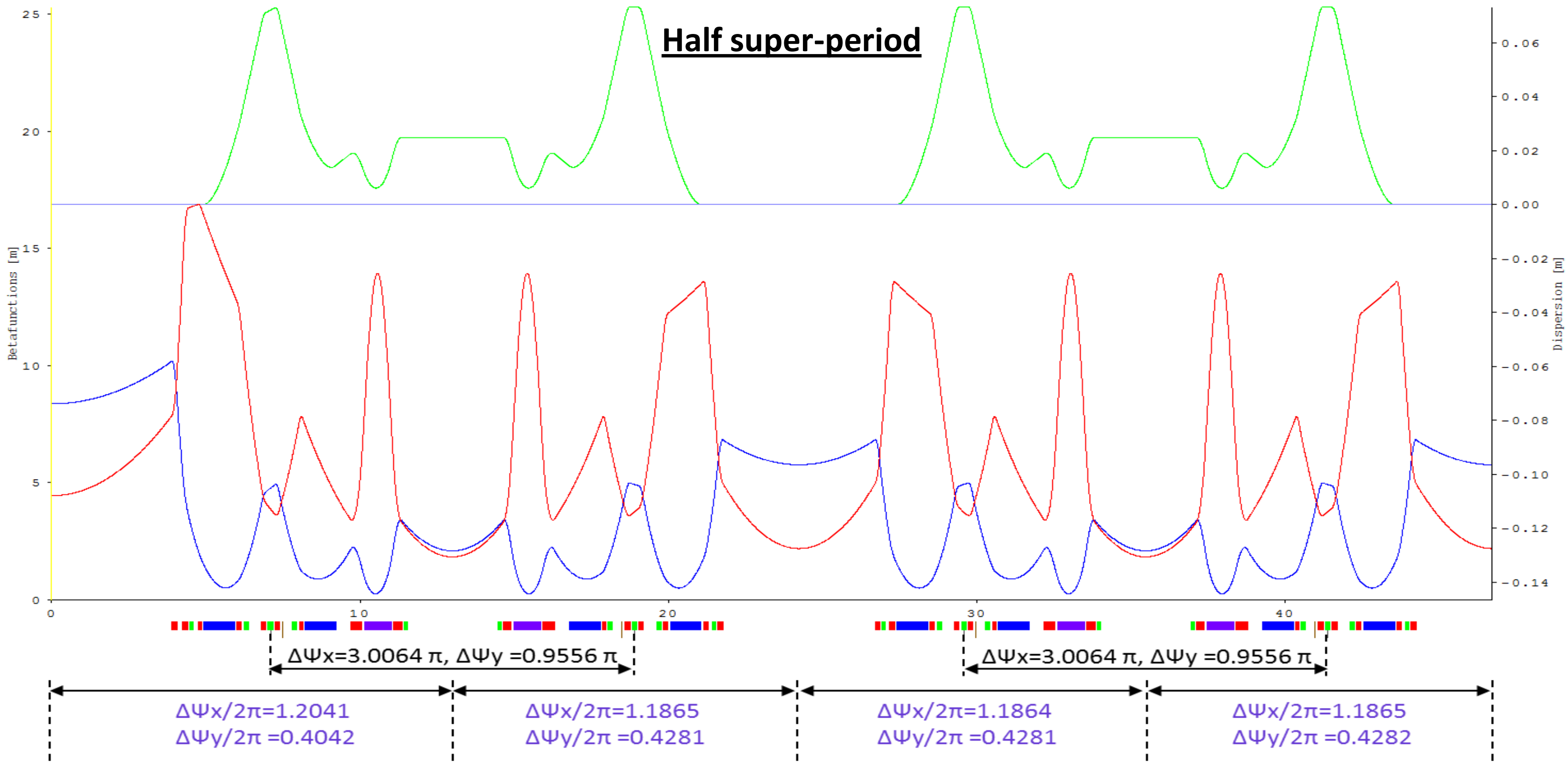
Parameters	Values
Energy [GeV]	3.5
Circumference [m]	560.388
Tune (H/V)	57. 162/20. 263
Nat. chromaticity (H/V)	-76.117/-87.670
Nat. emittance [pm]	155.5
Eff. Emittance @ MSS [pm]	227.75
Energy loss/turn [KeV]	670.318
Mom. Compaction	1.182e-04
Length of LSS/SSS/MSS	7.8/4.94/2.94

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	240	5	2 [0.1 m and 0.14 m]
Octupole	48	1	1 [0.09 m]

M-H6BA – NL Optimization

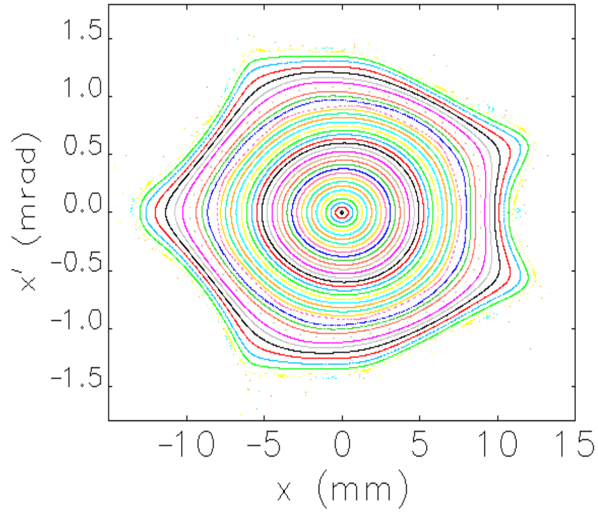
- -I transformer concept
  - 3π/π H/V phase advance difference between the dispersion bump.

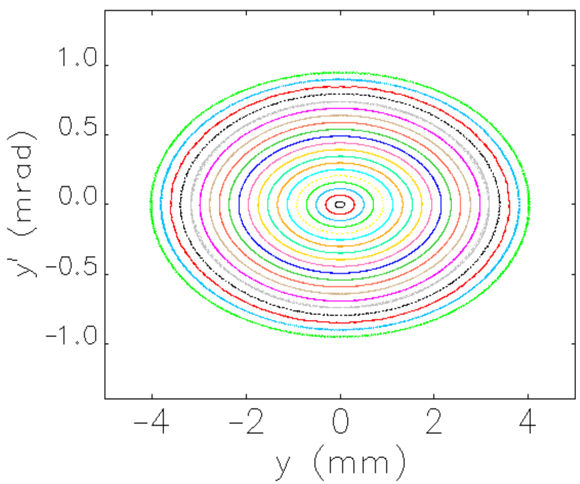
- Higher order achromat condition
  - set the phase advance over 2 super-period to cancel the largest possible amount of driving terms to second order (including chromatic ones)

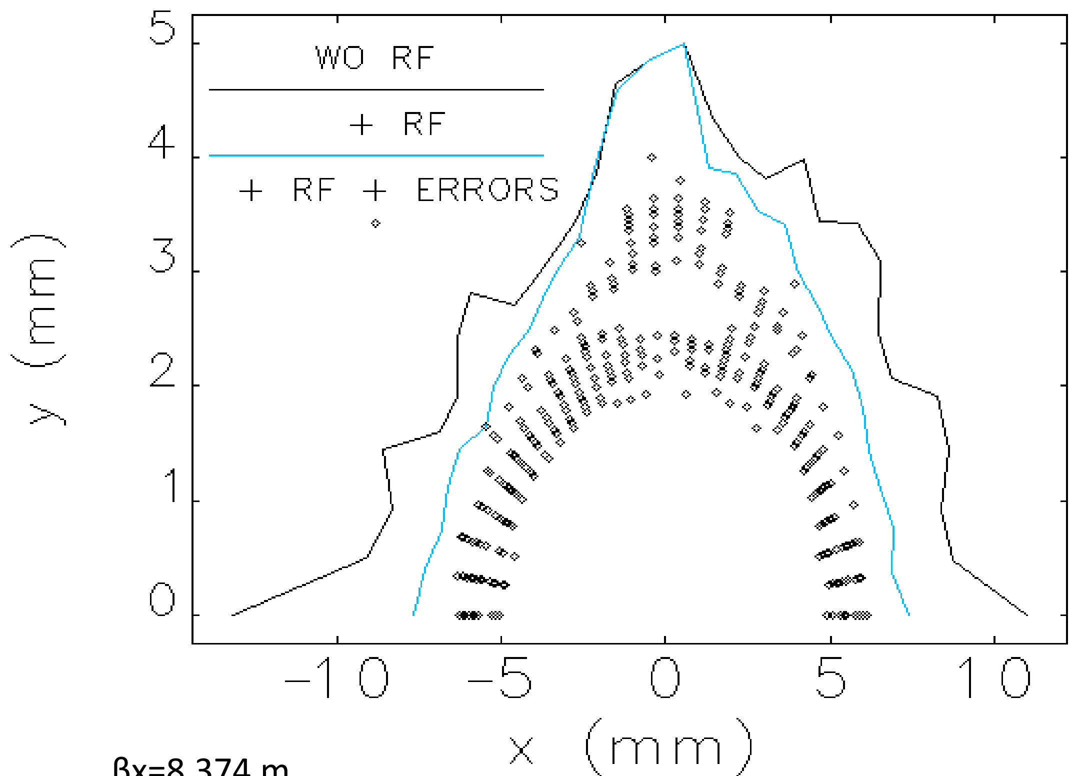


M-H6BA – NLBD – DA & Phase space

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



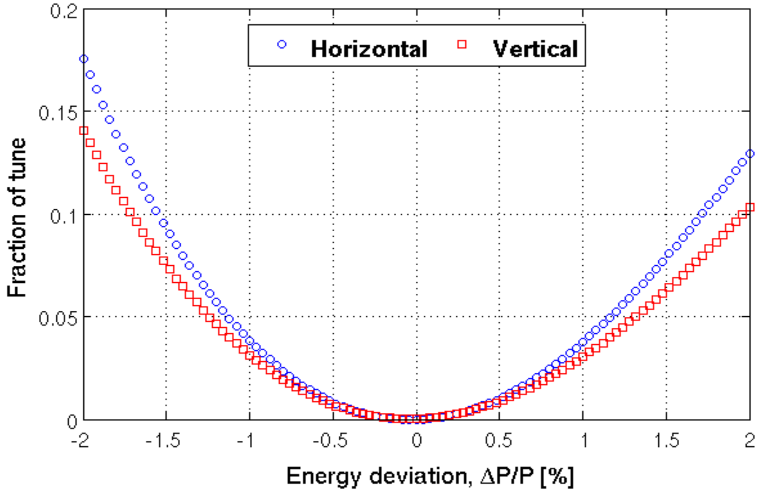


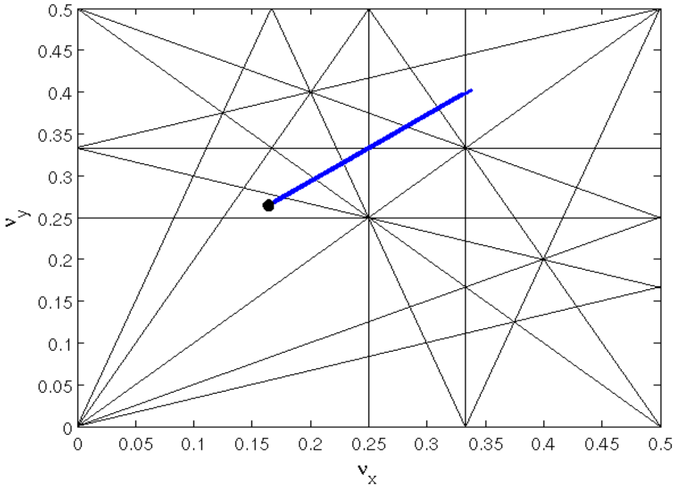


βx=8.374 m
βy=4.448 m

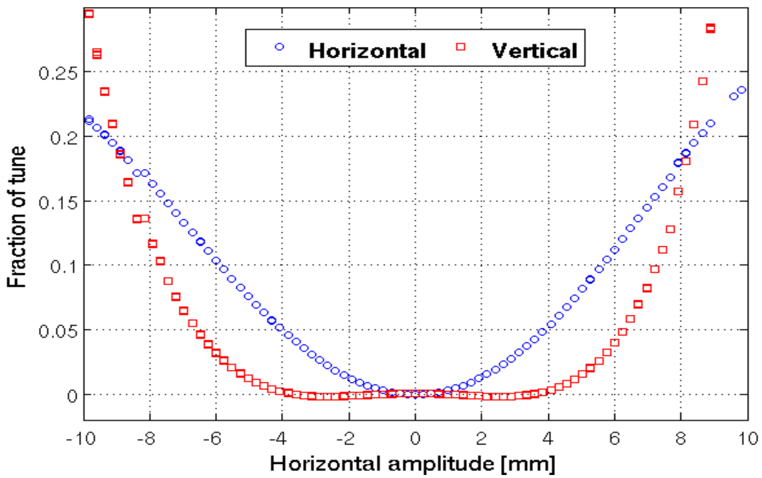
M-H6BA – NLBD – Tune vs energy & Amp.

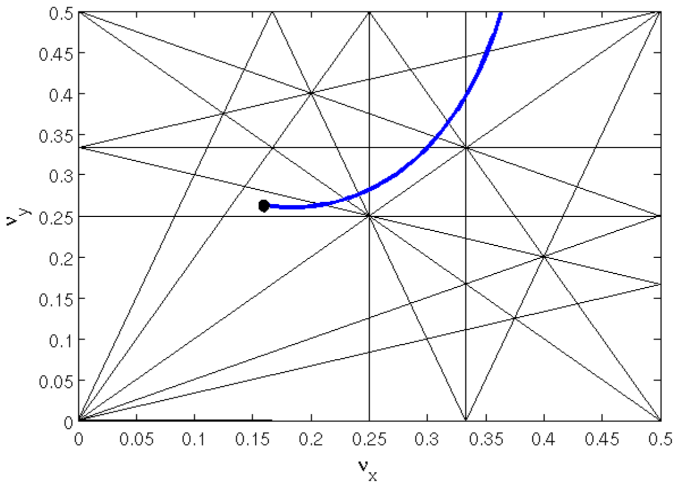
- Tune shift with energy deviation





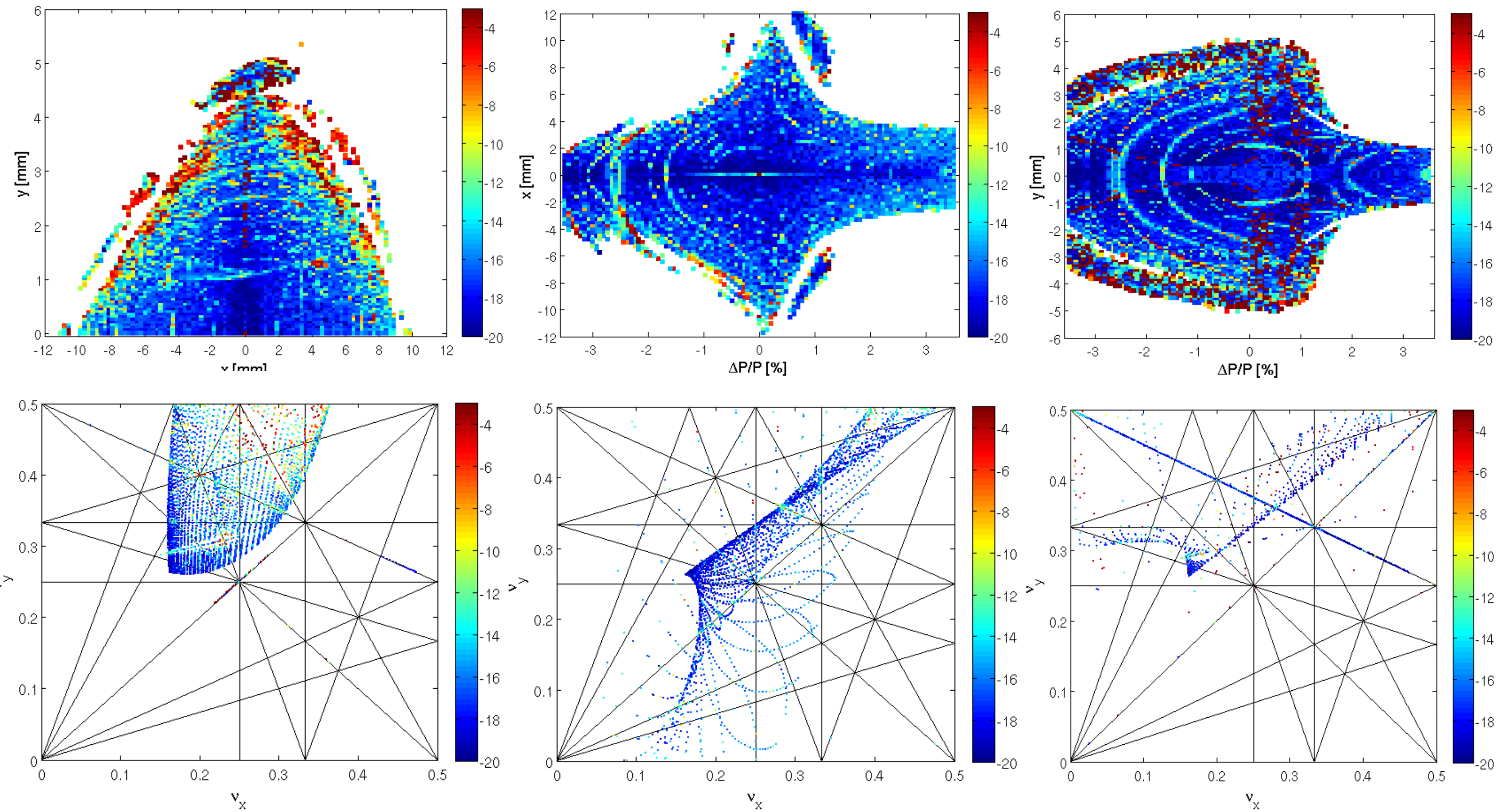
- Tune shift with horizontal amplitude





M-H6BA – NLBD - FMA

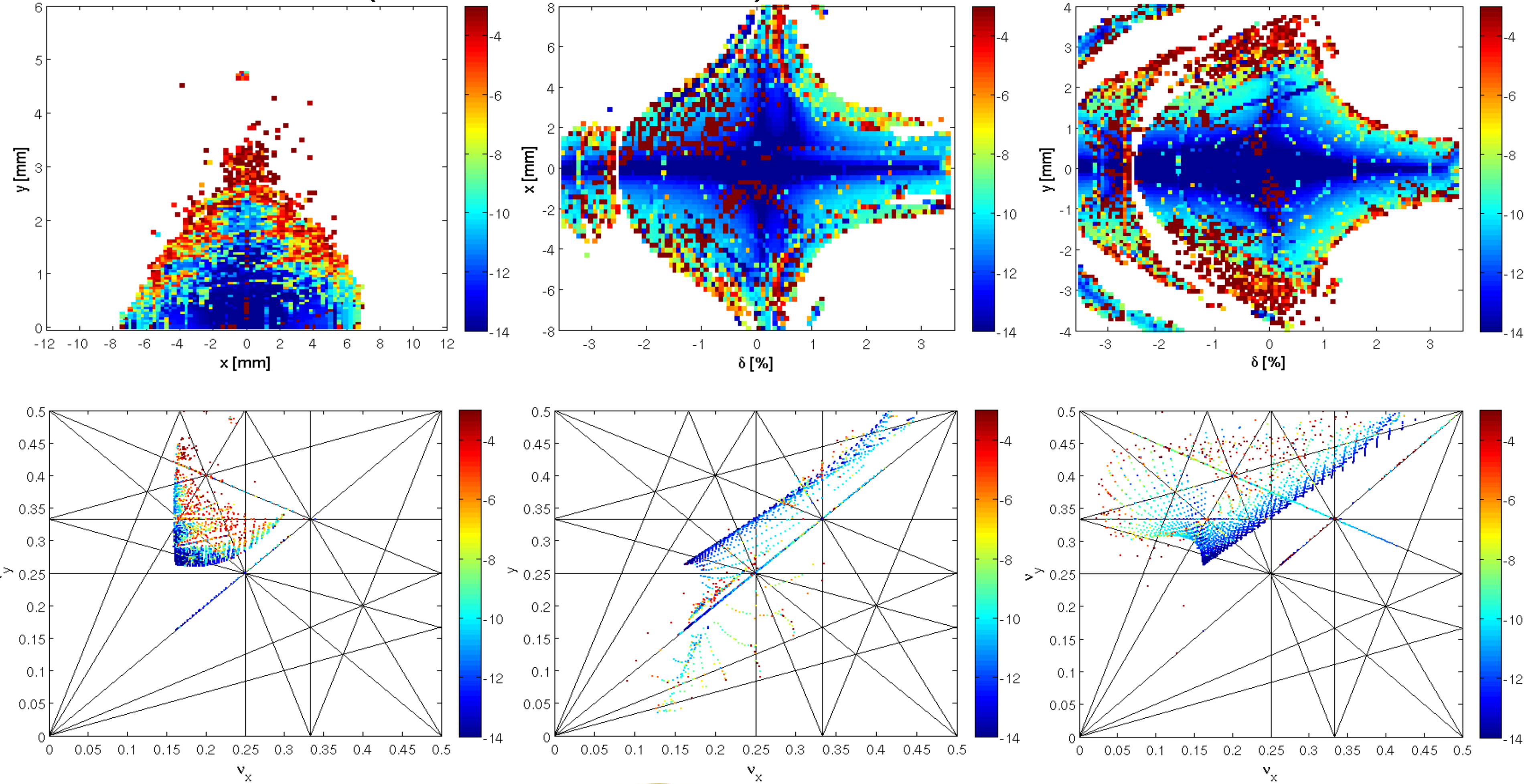
Bare lattice (±10 mm DA – 3.5% MA)



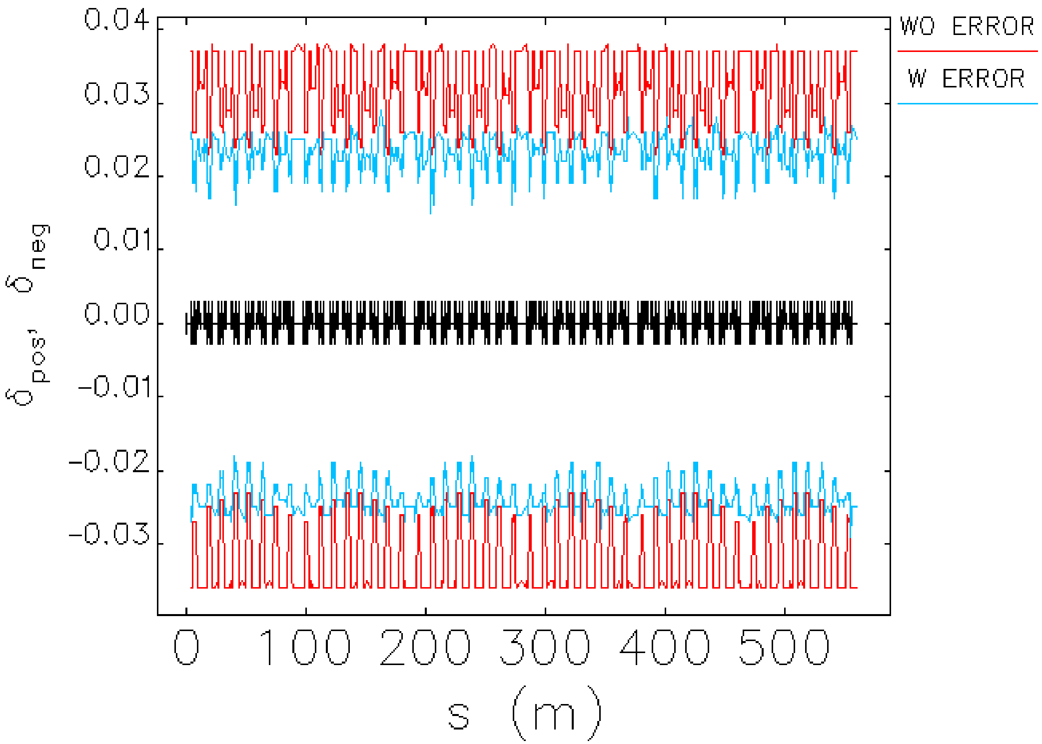
M-H6BA – NLBD - ERRORS

- Multipole errors and misalignments of magnets in the ring have been included in the simulation.
- Tune, closed orbit and natural chromaticity has been corrected.

Lattice with errors (±6 mm DA – 2.5% MA)



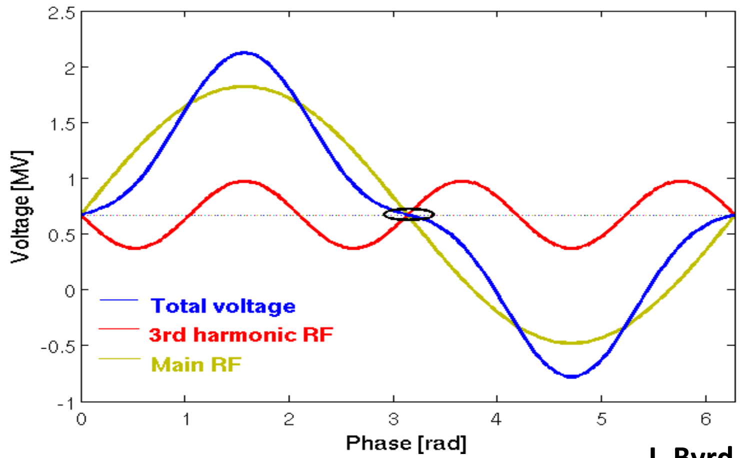
M-H6BA – Momentum aperture & T_lifetime



Parameters	Value
RF voltage [MV]	1.7
Harmonic number	934
RF frequency [MHz]	499.6648
RF phase [Deg.]	156.7774
Beam current [mA]	300
Charge per bunch [nC]	0.6
Number of bunch	934
Vertical emittance [pm]	8
Bunche length [mm]	2.923
Energy spread	7.7652E-04
T_lifetime [h]- WO ERRORs	3
T_lifetime [h]- W ERRORs	1.0

M-H6BA – 3rd harmonic cavity

- Harmonic cavity has been studied to improve the beam lifetime.
- Uniform beam loading are considered in HC (Passive mode).
- Ion clearing gap effect has not been included yet in the simulation.



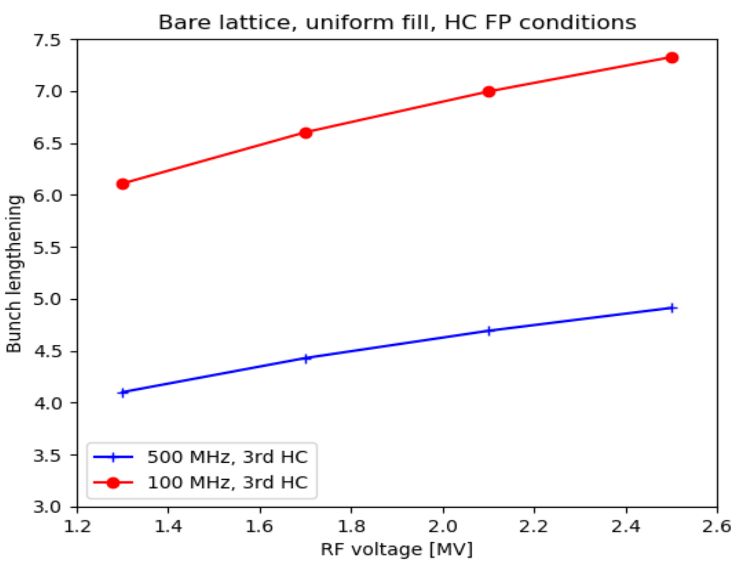
$$V = V_{RF}[\sin(\varphi+\varphi_s) + k\sin N(\varphi+\varphi_n)],$$

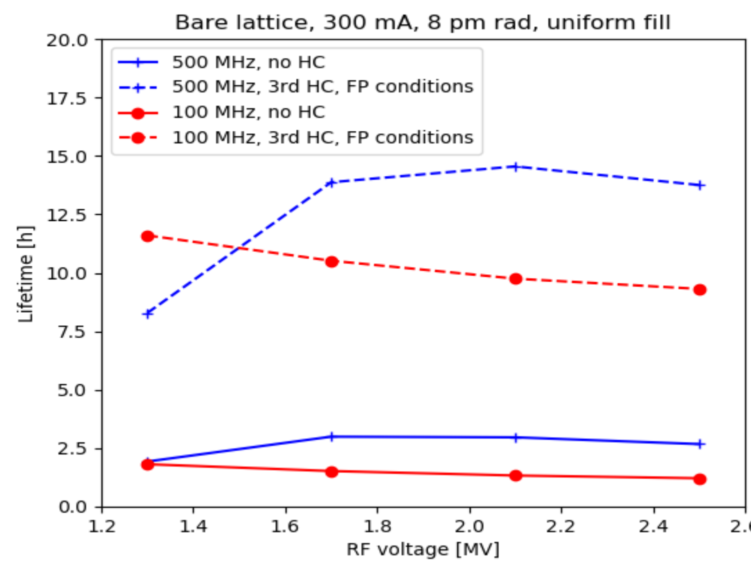
$$\varphi_s = \sin^{-1}\left[\frac{N^2}{N^2-1}\frac{U_0}{eV_{RF}}\right],$$

$$\varphi_n = \frac{1}{N}\tan^{-1}\left[-\frac{N\frac{U_0}{eV_{RF}}}{\sqrt{(N^2-1)^2 - N^4(\frac{U_0}{eV_{RF}})^2}}\right],$$

$$k = \frac{1}{N}\sqrt{1 - \frac{N^2}{N^2-1}\left(\frac{U_0}{eV_{RF}}\right)^2},$$

J. Byrd, M. Georgsson, PRSTAB, 4, 030701 (2001)





Courtesy Teresia Olsson

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 according to below Table using Gaussian distributions with **2σ cut off**.
    - Correct trajectory until closed orbit is found. If needed, optimize tunes and low-order beta function harmonics.
    - Correct closed orbit down to acceptable level.

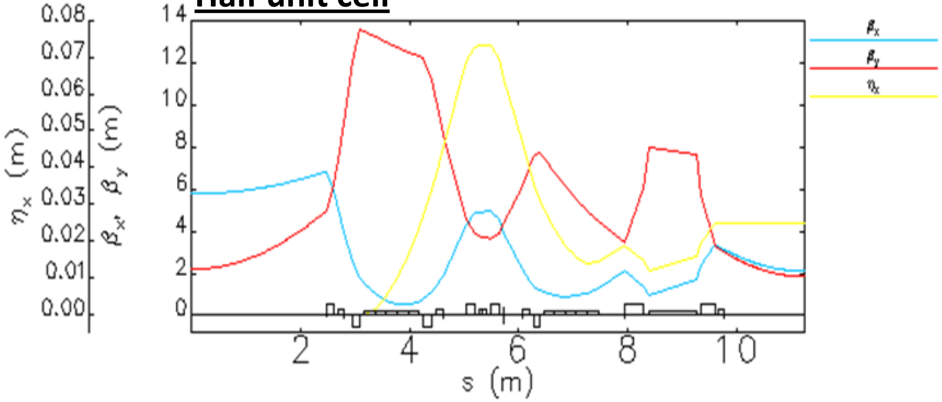
Parameters	Δx [µm]	Δy [µm]	Roll [µrad]
Girder misalignment	50	50	50
Magnets within girder	25	25	40
Dipole FSE	0.5E-3		
Quadrupole FSE	0.5E-3		
Sextupole FSE	1E-4		
Octupole	1E-4		
BPM offset	5	5	5

Ref.: V. Sajaev, M. Borland, IPAC2015, Richmond, VA, USA

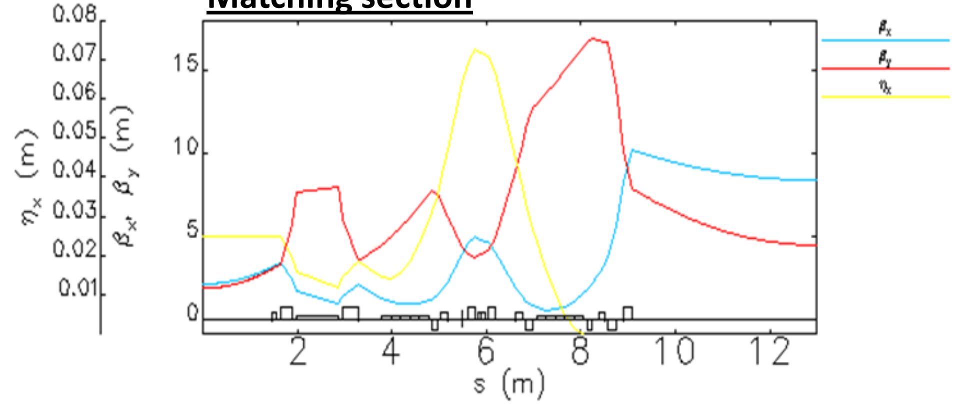
M-H6BA – Commissioning simulation

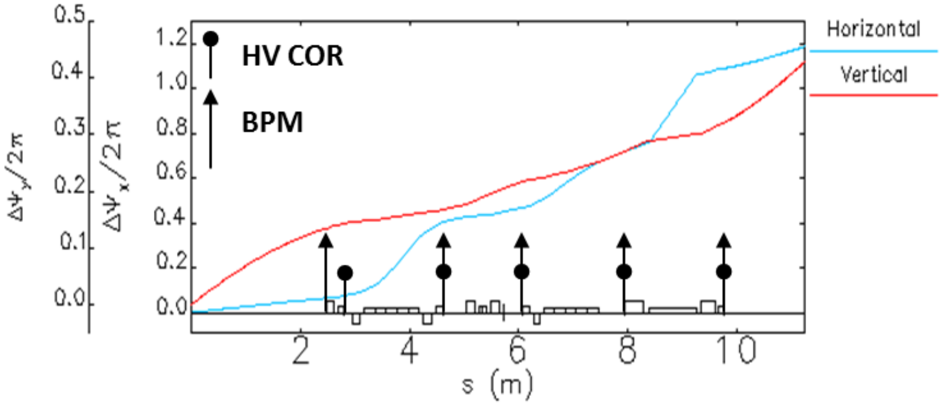
- 252 HV correctors
  - 192 of HV CORs are as additional winding in the sextupoles.
  - 60 of HV CORs are as 80 mm separate magnets
- 252 BPMs

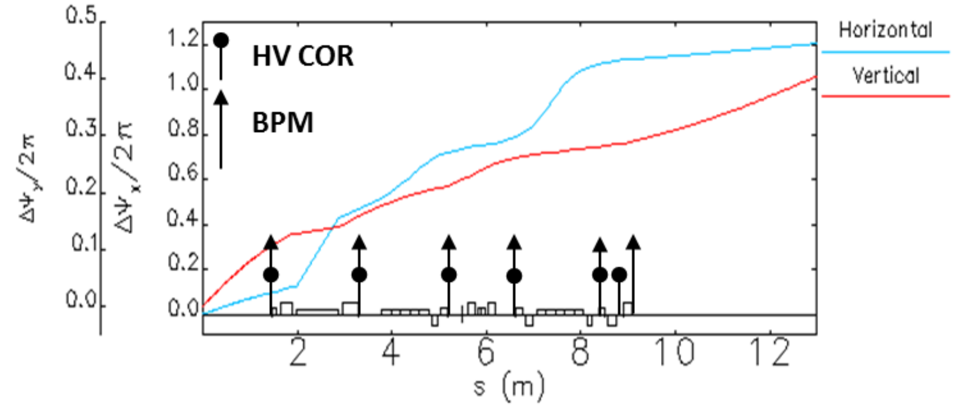
Half unit cell



Matching section



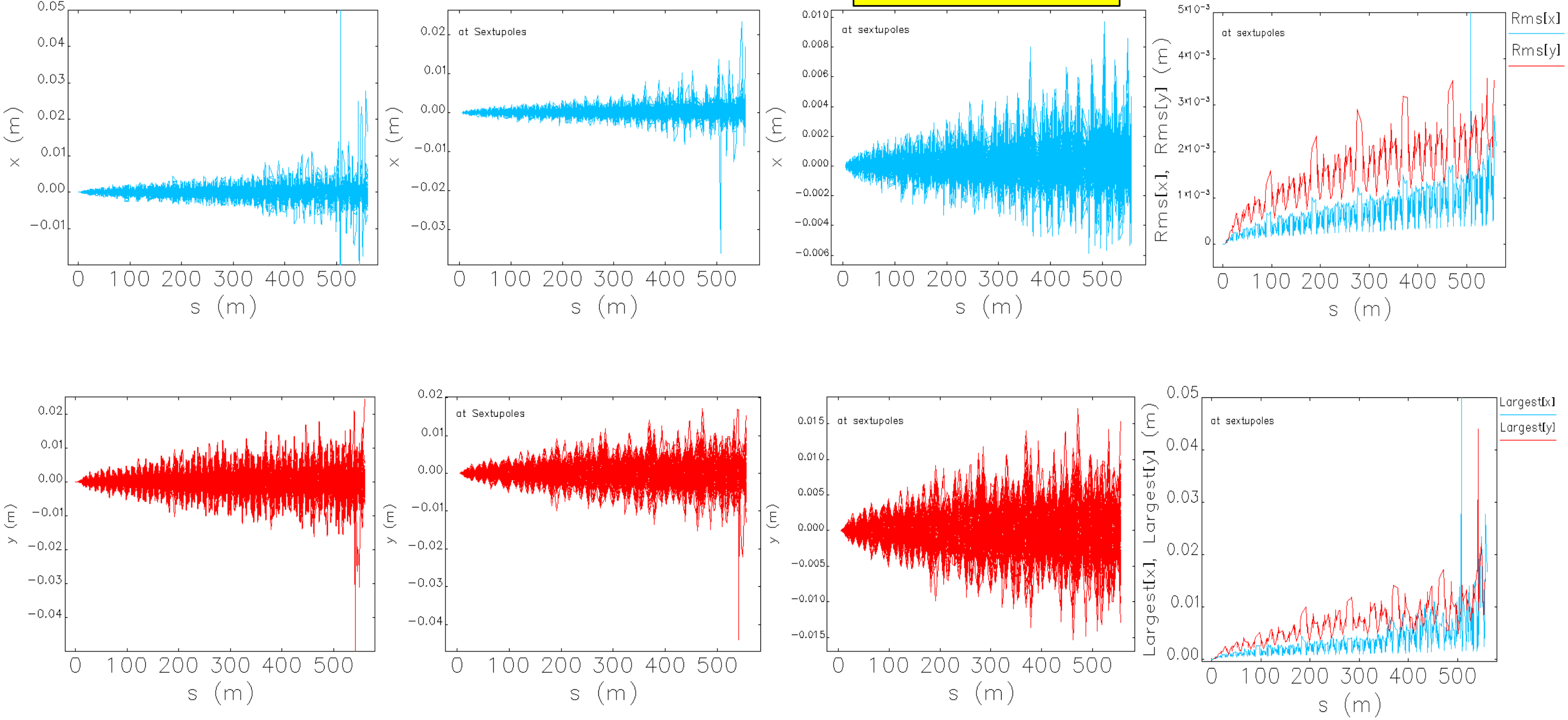




M-H6BA – Commissioning simulation

- Trajectory correction

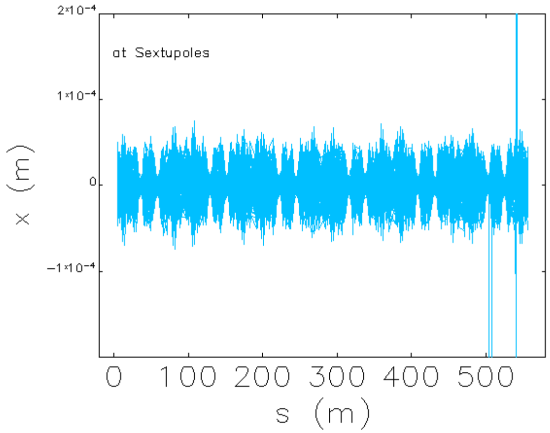
Ignoring lost seeds

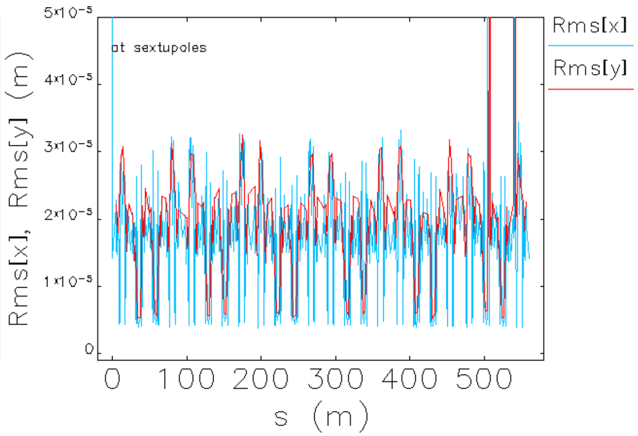


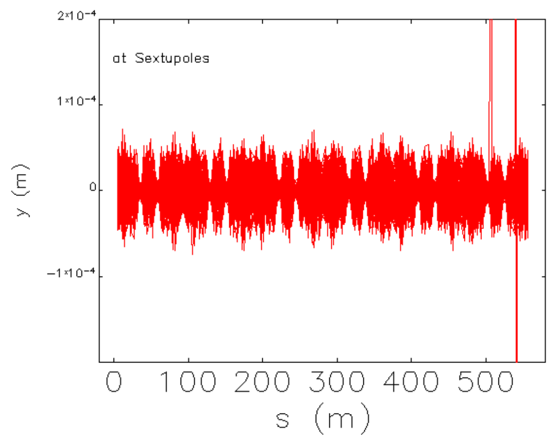
The procedure was able to correct trajectory in 97% of all cases.

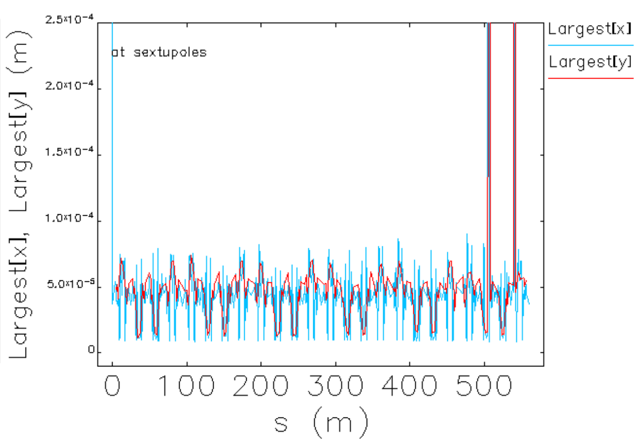
M-H6BA – Commissioning simulation

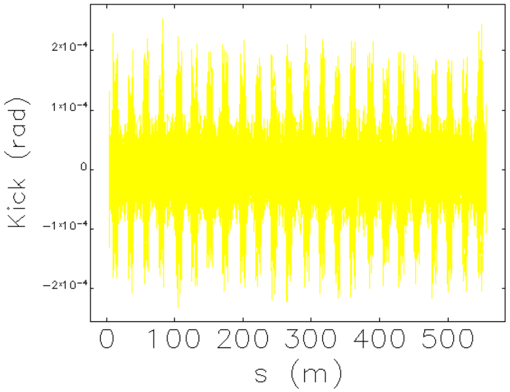
- Closed orbit is globaly corrected.
- Rms x/y value of the corrected orbit is less than 30 µm.
- Maximum strength of the correctors is less than 300 µrad.

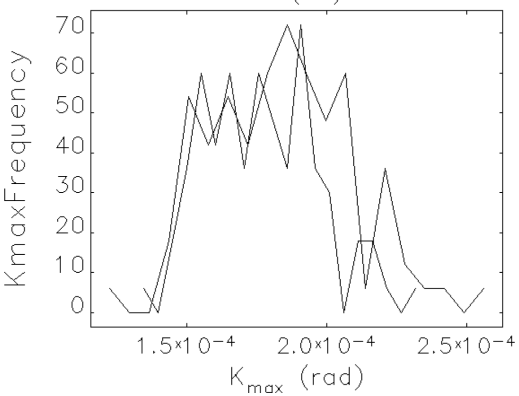


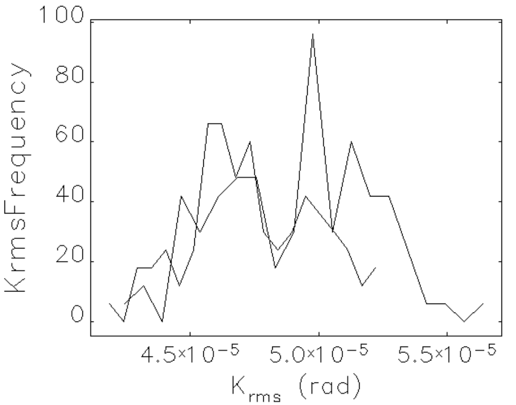






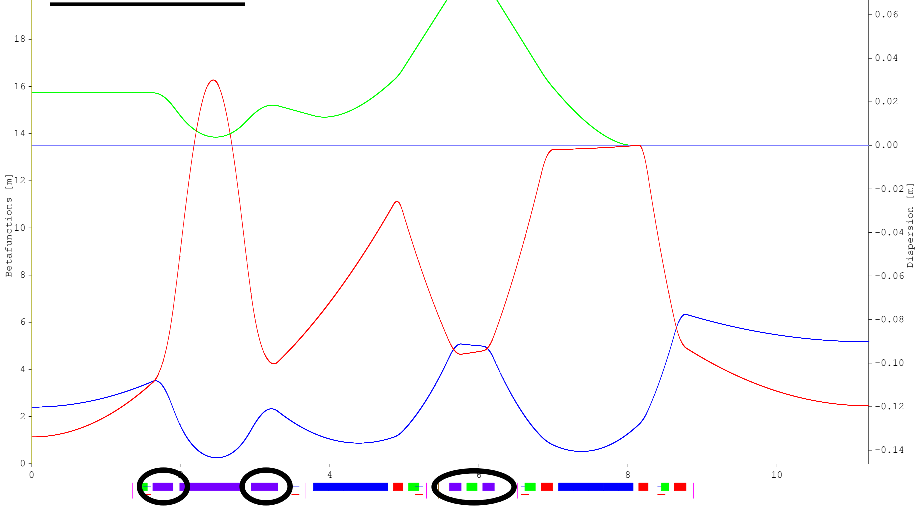




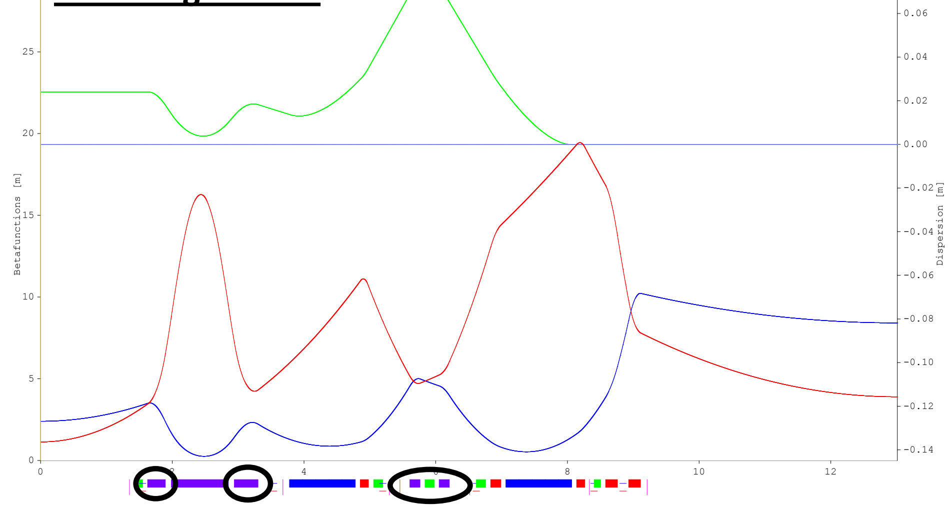


M-H6BA – Anti bend (possible future)

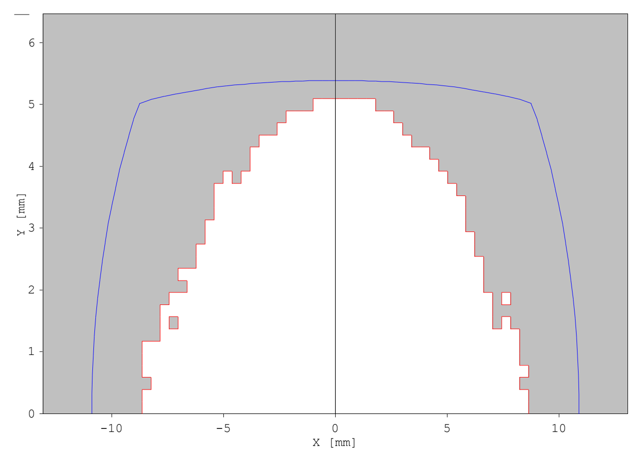
Half unit cell



Matching section



Parameters	Values
Energy [GeV]	3.5
Circumference [m]	560.436
Tune (H/V)	57. 156/20. 338
Nat. chromaticity (H/V)	-76.18/-100.299
Nat. emittance [pm]	121
Eff. Emittance @ MSS [pm]	196.7



Bends	QF4	QF6	QF8
L [m]	0.155	0.36	0.27
K [m^{-2}]	4.882	6.296	6.571
Angle [Deg.]	0.0169	0.297	0.303
Shift Δx [mm]*	-0.39	-2.3	-3

* Matching cell QF4s to be shifted by 0.36 mm and 0.5 mm respectively.

Courtesy Beni Singh

Thank you for your attention!