Study of Multi-Bend Achromat Lattices for the HALS Diffraction-Limited Storage Ring

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Outline

- Introduction
- Locally symmetric MBA lattice &
  8BA and 6BA lattice design for the HALS
- MBA lattice with interleaved dispersion bumps &
  7BA lattice design for the HALS
- Conclusion

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From HLS to HALS

- HLS (Hefei Light Source):
  - A second-generation synchrotron source in China
  - Beam emittance: ~160 nm·rad @ 800 MeV
  - Operated in 1991
- HLS-II (upgrade of HLS):
  - Beam emittance: ~40 nm·rad @ 800 MeV
  - 6 straight sections for insertion devices
  - Upgrade successfully finished in 2014
- HALS (Hefei Advanced Light Source) :
  - A green-field soft X-ray and VUV diffraction-limited storage ring
  - Beam energy: 2.4 GeV
  - Beam emittance: < 50 pm·rad
  - The pre-research project has been supported by the Chinese Academy of Sciences and the local government.

To develop other MBA lattice concepts

- The hybrid multi-bend achromat (MBA) concept has been widely used in designing diffraction-limited storage rings, which can promise very large dynamic aperture (DA). But it is hard to achieve large dynamic momentum aperture (MA) for the HALS with ten-picometer-order emittance when using the hybrid MBA concept, because the number of knobs (i.e. families of sextupole) is limited in the concept.
- Can we develop other MBA lattice concepts to achieve good performance for both on- and off-momentum nonlinear dynamics?
  - in which the nonlinear cancellation can be done within one cell as in the hybrid MBA,
  - but there are more families of sextupoles in each cell than the hybrid MBA, which can be employed to control tune shift with momentum, tune shift with amplitude and high-order resonance driving terms.
- Good on- and off-momentum nonlinear dynamics performance could provide longer beam lifetime and more options for beam injection, such as longitudinal injection.

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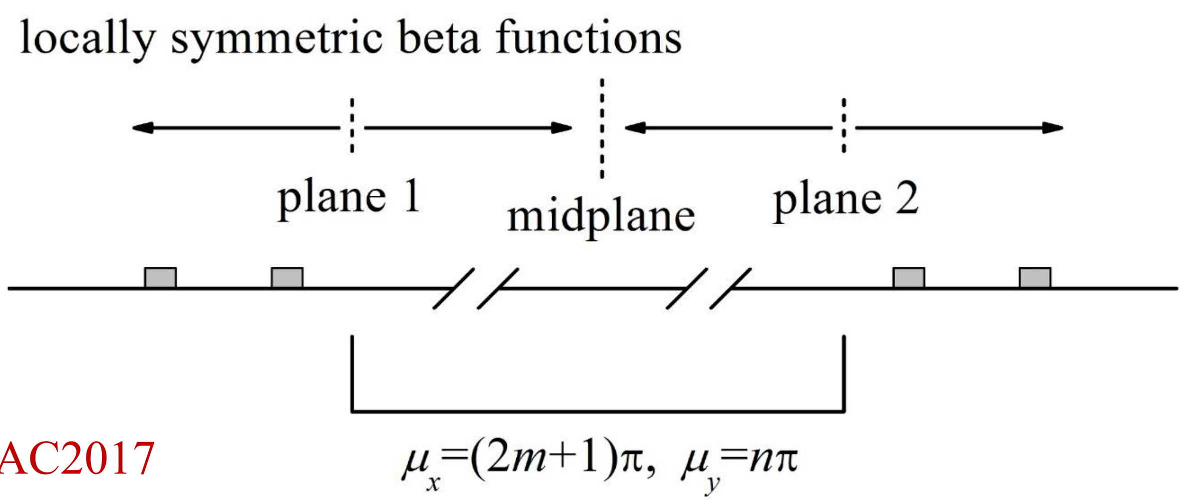
Locally symmetric MBA lattice concept

- The first MBA lattice concept — locally symmetric MBA lattice:
  - The horizontal and vertical beta functions of each lattice cell are made to be locally symmetric about two mirror planes.
  - The horizontal and vertical phase advances between the two mirror planes satisfy: $\mu_x = (2m+1)\pi$, $\mu_y = n\pi$, where m & n are integers.
  - Normal sextupoles are also placed locally symmetric about the two mirror planes so that many nonlinear effects can be cancelled out within one cell. There can be placed many families of sextupoles (i.e. many knobs) in this lattice.



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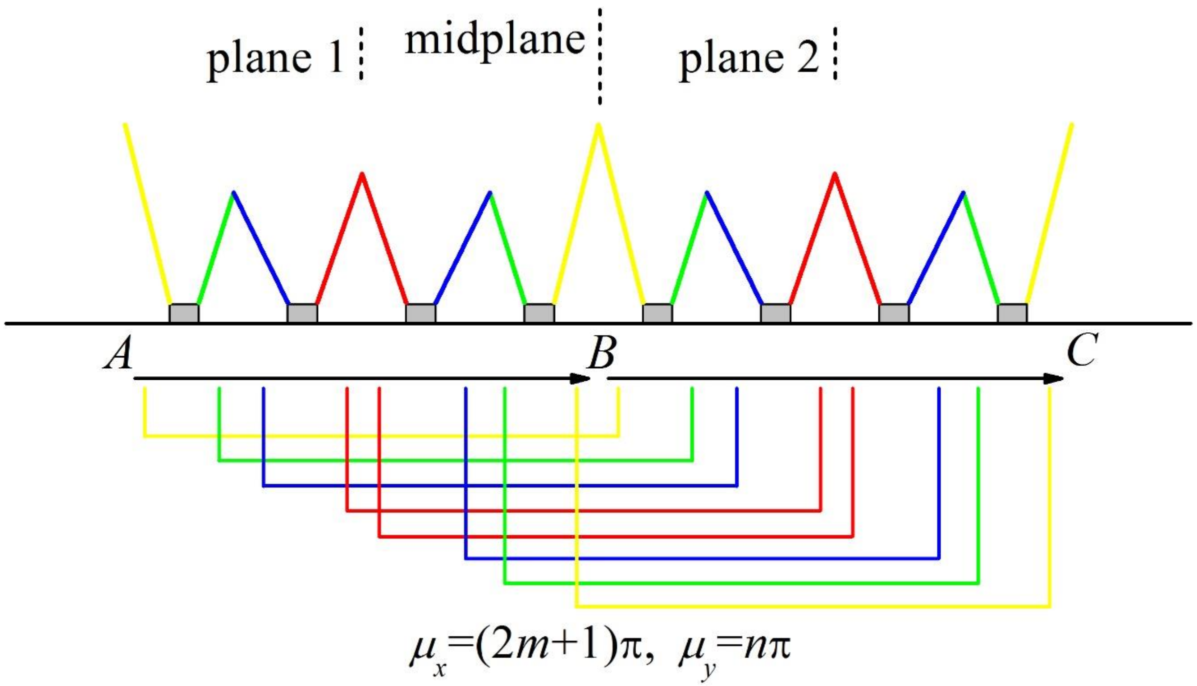
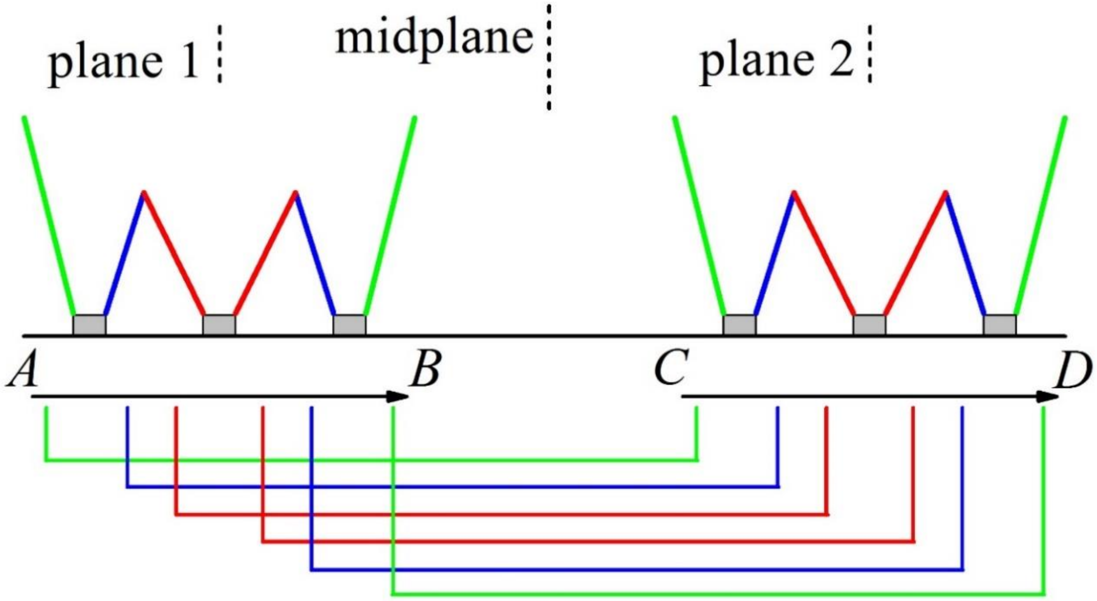
Locally symmetric MBA of the first kind

- According to the position of the midplane of a lattice cell, locally symmetric MBA lattices can be classified into two kinds:
  - In the usual representation of a lattice cell, the midplane is at the middle of the arc section. The locally symmetric MBA under such a representation is called the locally symmetric MBA of the first kind.



Locally symmetric MBA of the second kind

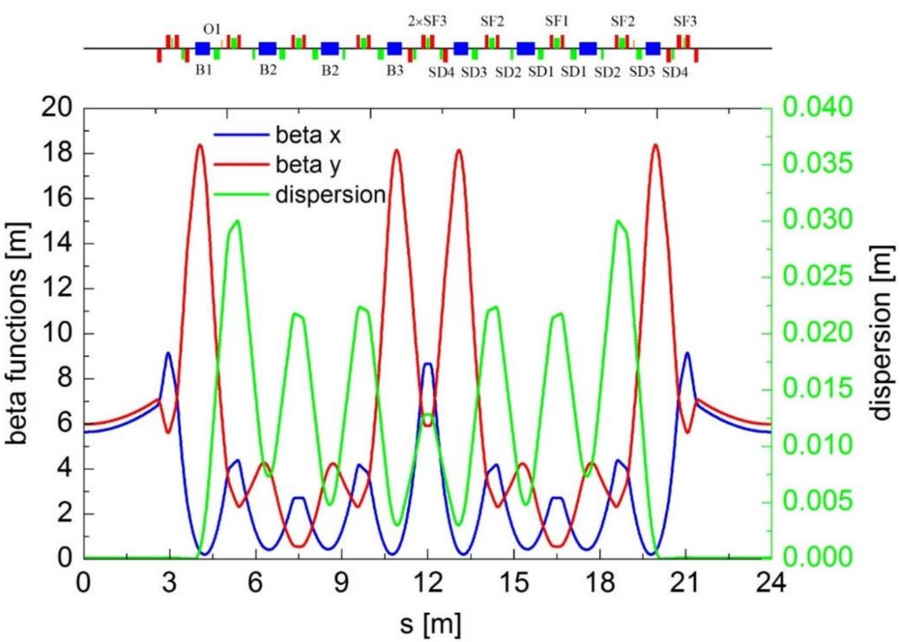
- In an unusual representation of a lattice cell, the midplane is at the middle of the long straight section. The locally symmetric MBA under such a representation is called the locally symmetric MBA of the second kind.



$\mu_x = (2m+1)\pi, \ \mu_y = n\pi$

8BA lattice for HALS

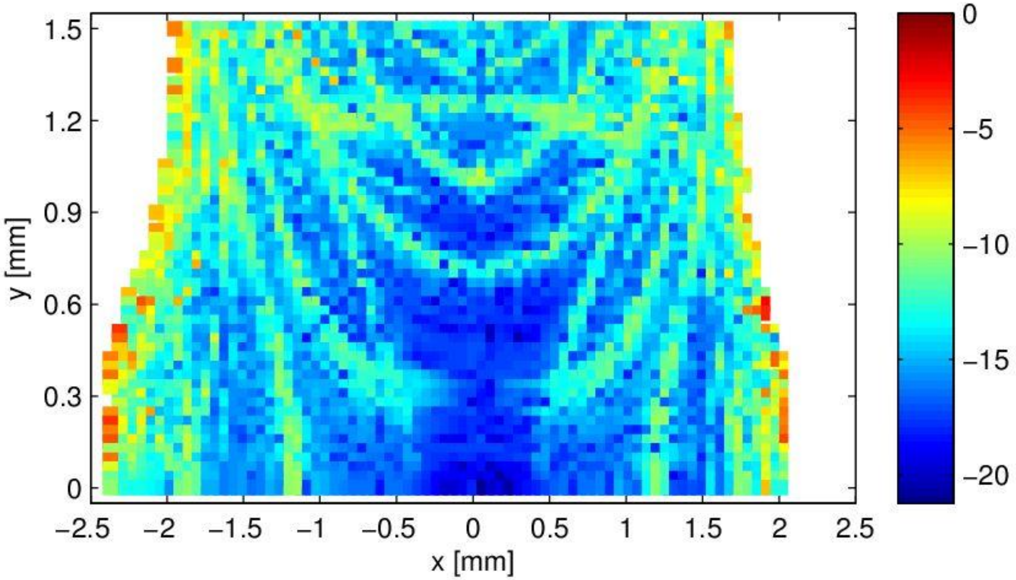
- Lattice design
  - 8BA: locally symmetric MBA of the first kind.
  - The left mirror plane is at the middle between the 2nd and the 3rd bends. Two mirror planes are separated by –I transformation.
  - 7 families of sextupoles and 1 family of octupole.
  - Natural emittance: 35.8 pm·rad.

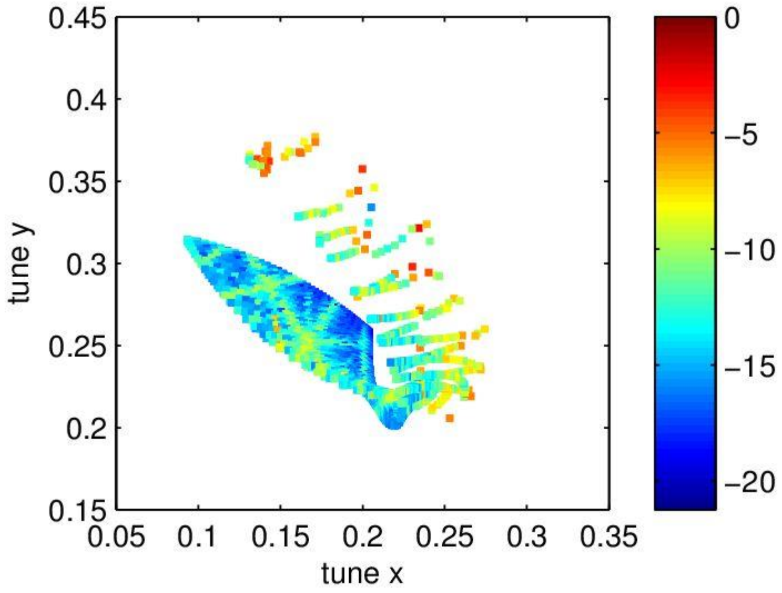


Parameters	Values
Energy	2.4 GeV
Circumference	576 m
Number of cells	24
Natural emittance	35.8 pm·rad
Transverse tunes	76.205, 27.258
Natural chromaticities	-136, -116
Momentum compaction factor	5.96×10^{-5}
Length of long straights	5.1 m
Beta functions at long straights	5.632, 5.977 m

8BA lattice for HALS

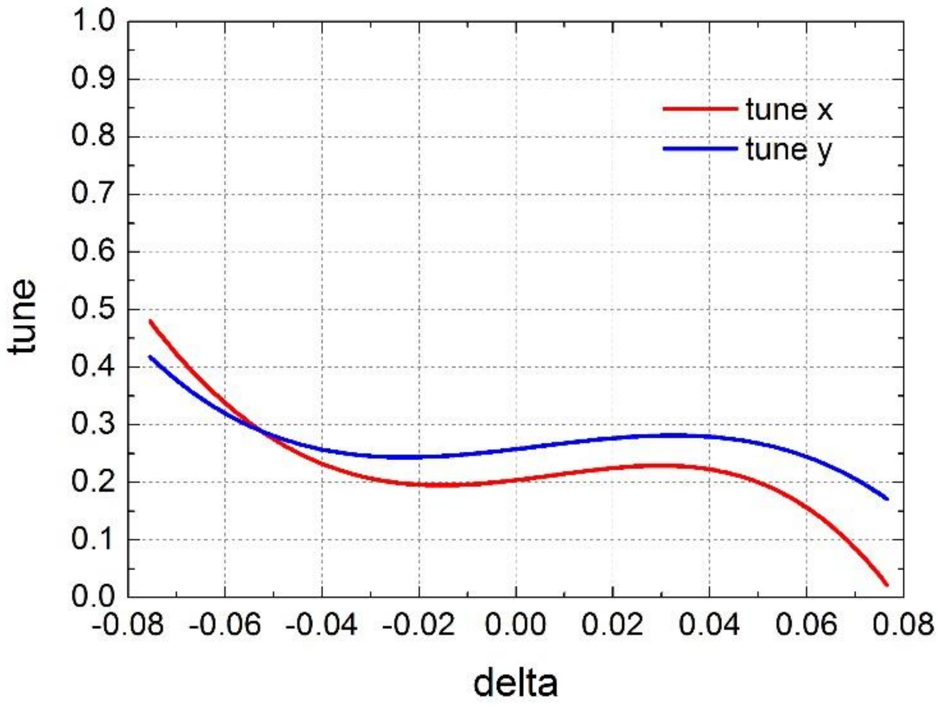
- Nonlinear dynamics optimization [solution 1]:
  - DA: about 150 sigma.
  - The amplitude dependent tunes are well controlled in a small tune region.

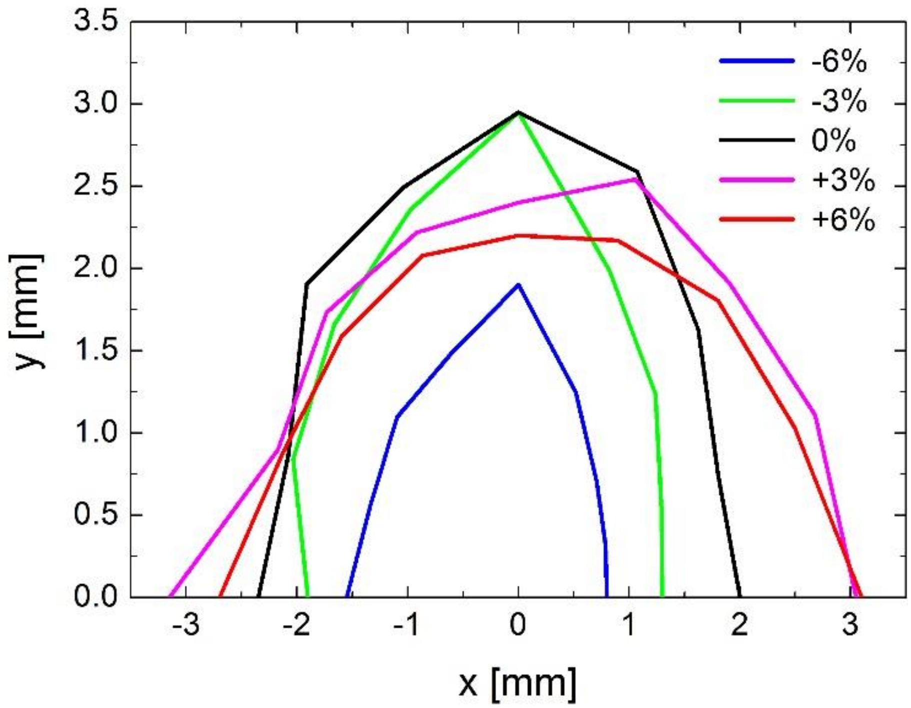




8BA lattice for HALS

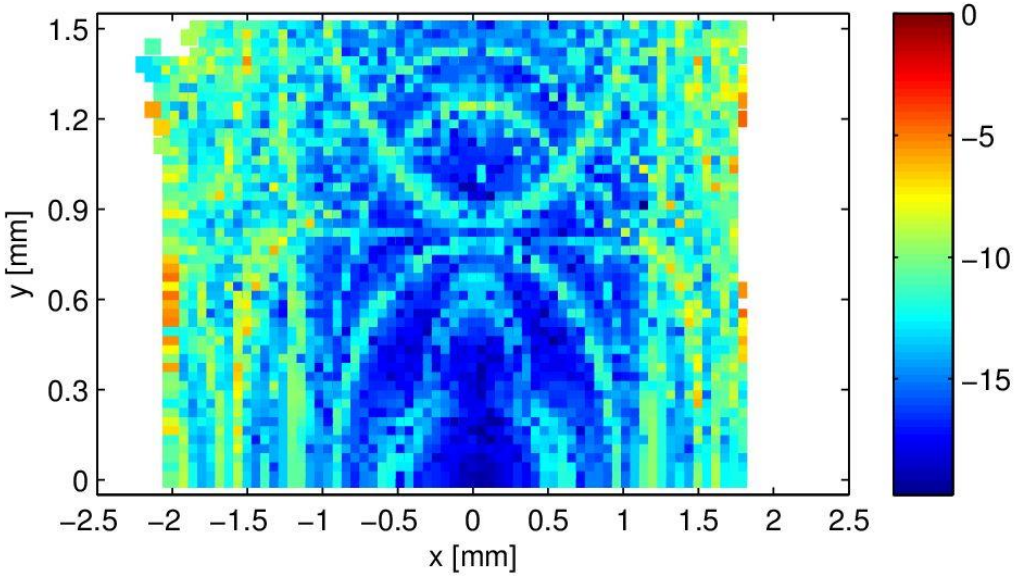
- Dynamic MA @ long straight section: > 7%.
- The off-momentum DAs are not reduced much compared to the on-momentum DA.

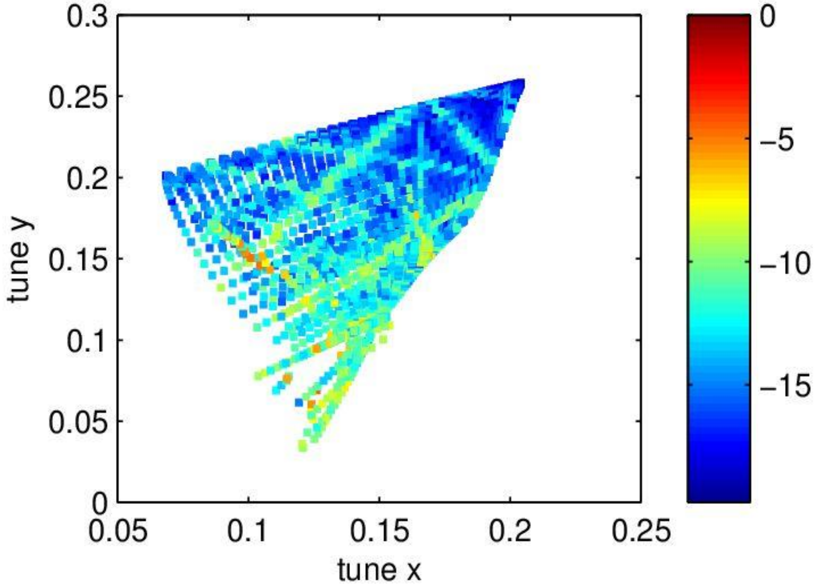




8BA lattice for HALS

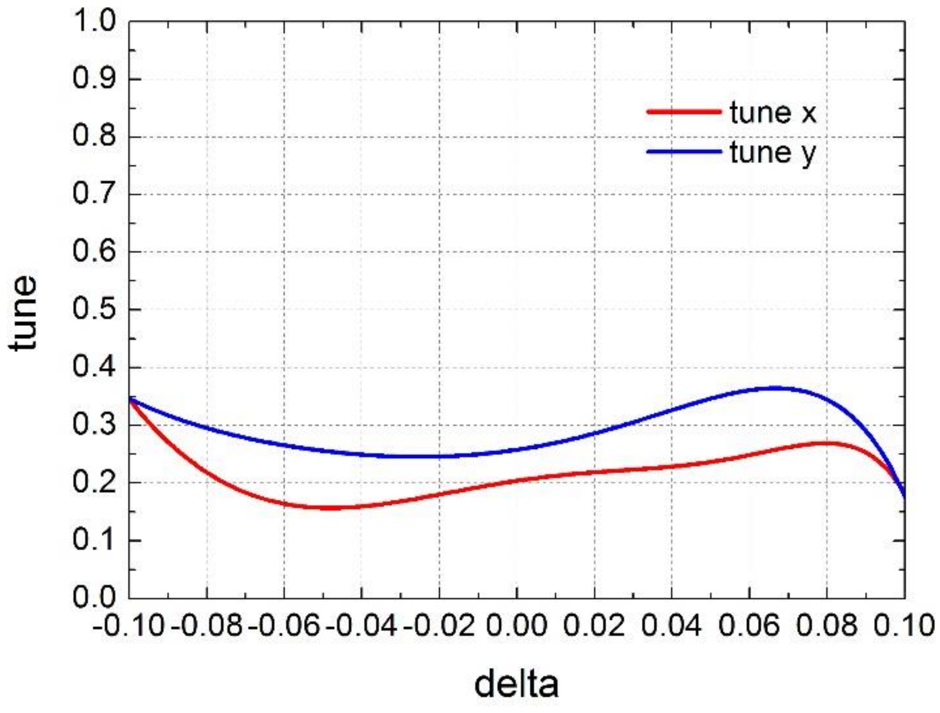
- Nonlinear dynamics optimization [solution 2]:
  - DA: about 130 sigma (it is smaller than that of solution 1, but is also good).

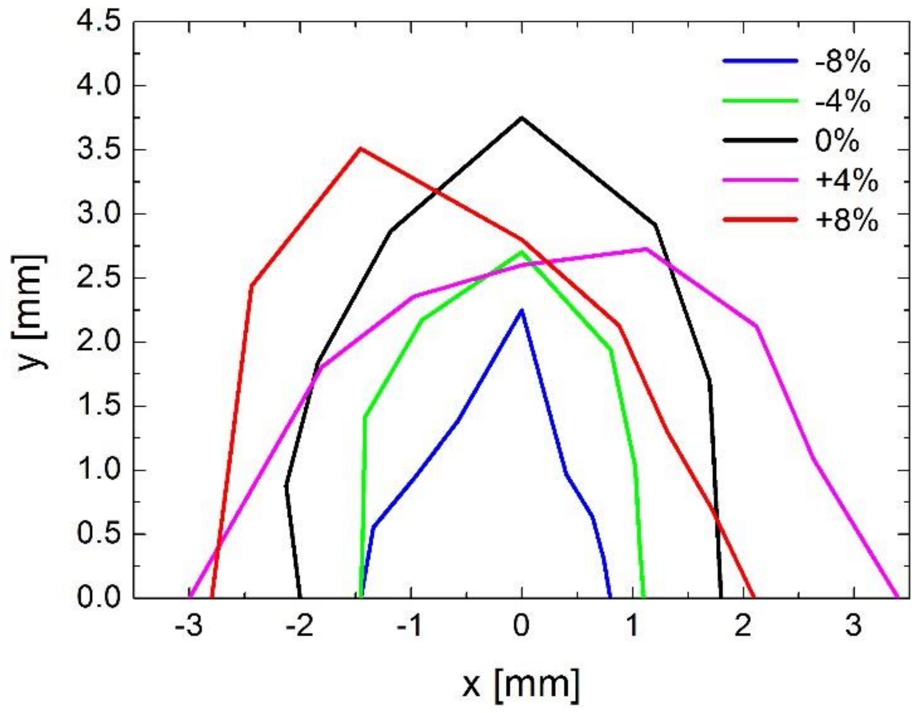




8BA lattice for HALS

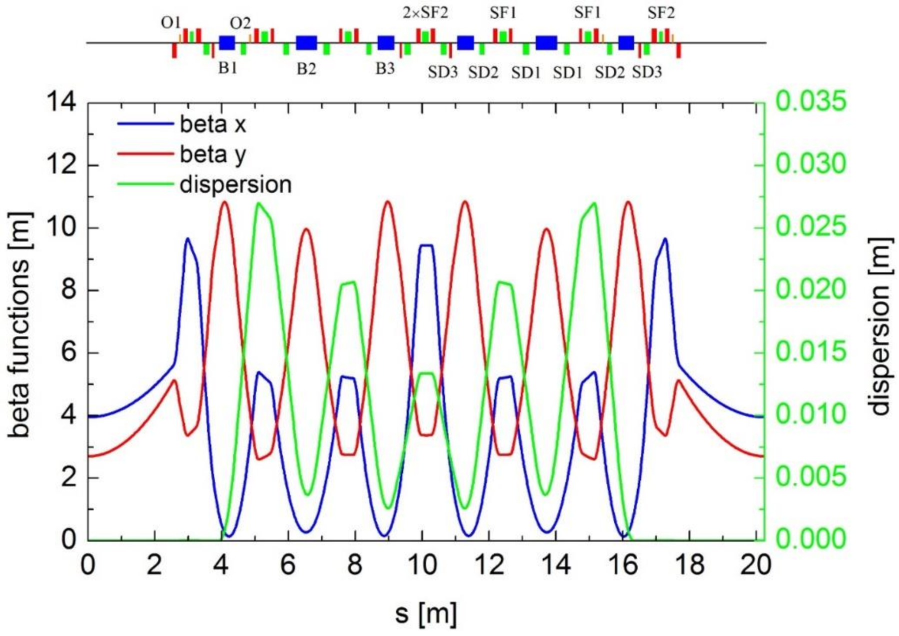
- Dynamic MA @ long straight section: > 10% !
- Off-momentum DAs are also good.





6BA lattice for HALS

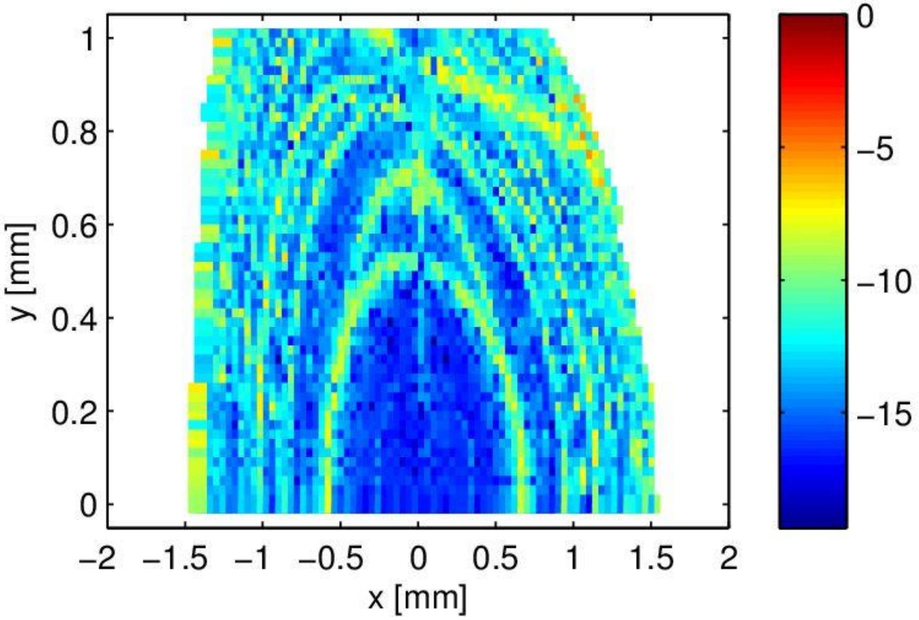
- Lattice design
  - 6BA: locally symmetric MBA of the second kind.
  - The two mirror planes are at the middle of the 2nd and the 5th bends, respectively, which are separated by –I transformation.
  - 5 families of sextupoles and 2 families of octupoles.
  - Natural emittance: 26.5 pm·rad.

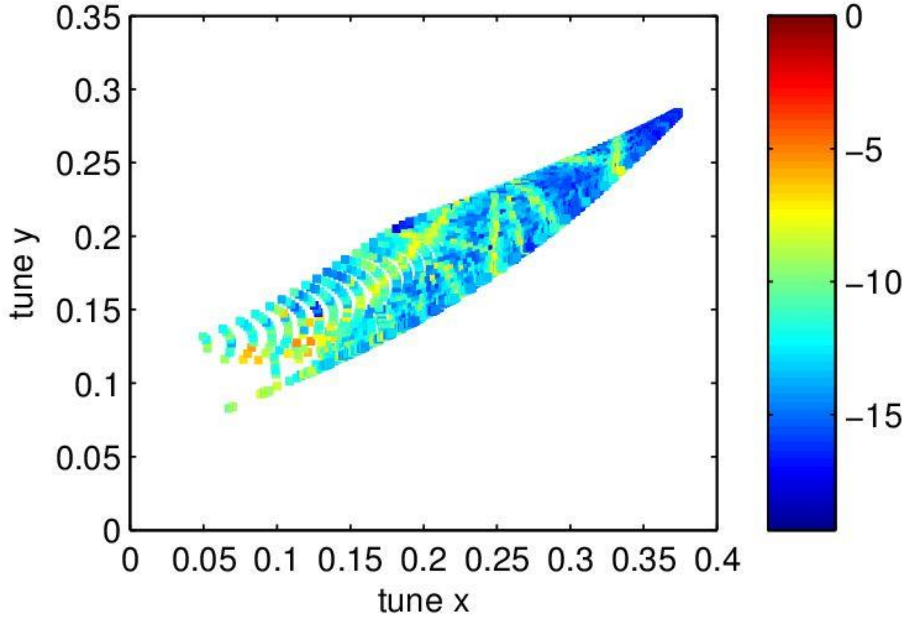


Parameters	Values
Energy	2.4 GeV
Circumference	648 m
Number of cells	32
Natural emittance	26.5 pm·rad
Transverse tunes	88.374, 23.284
Natural chromaticities	-204, -100
Momentum compaction factor	3.42×10^{-5}
Length of long straights	5.1 m
Beta functions at long straights	3.904, 2.761 m

6BA lattice for HALS

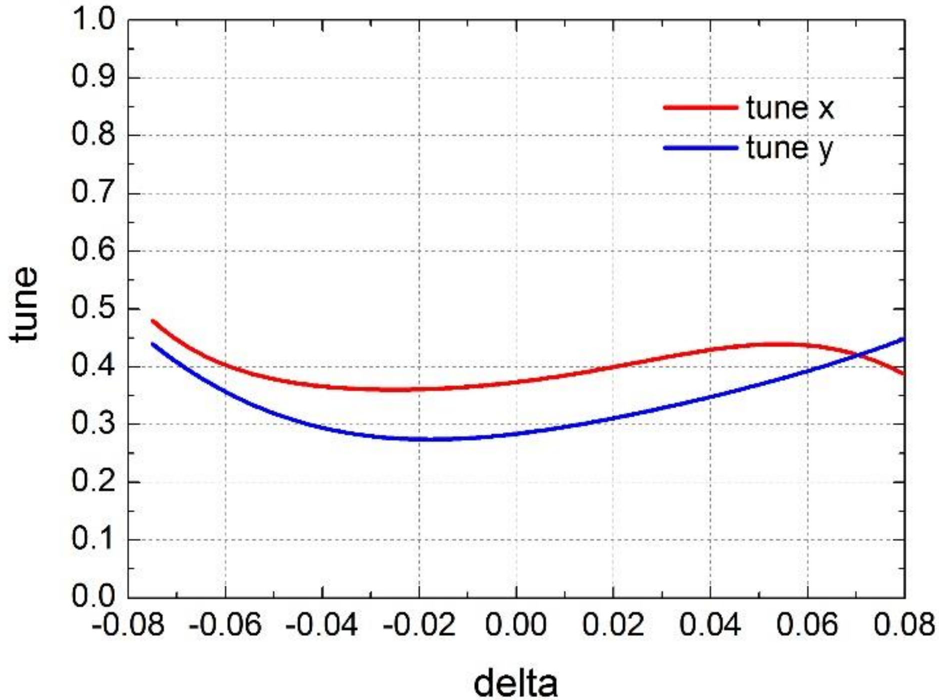
- Nonlinear dynamics optimization:
  - DA: about 150 sigma.

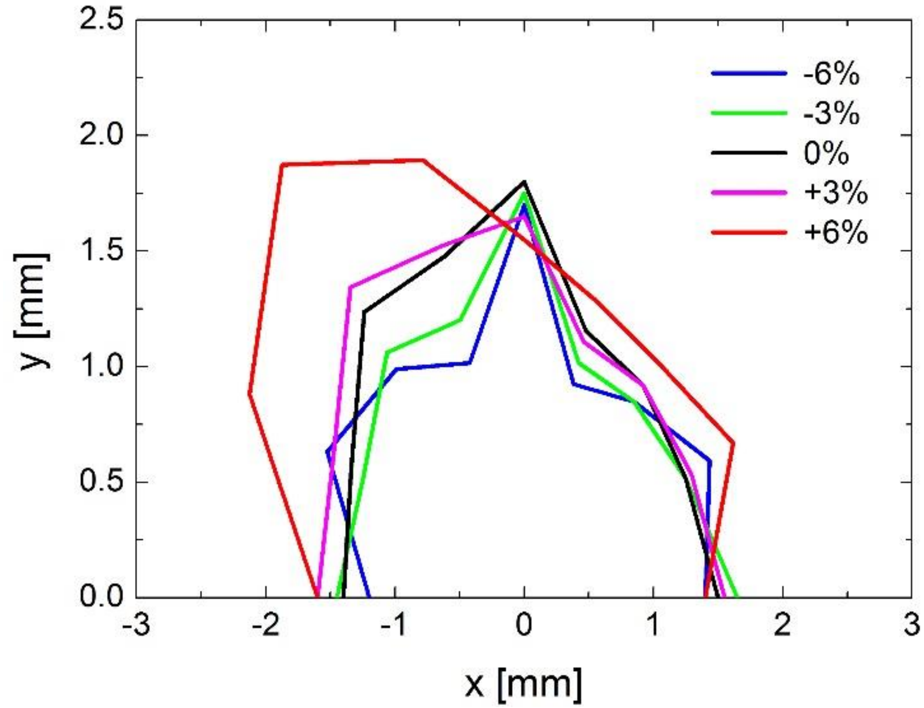




6BA lattice for HALS

- Dynamic MA @ long straight section: > 7%;
- The off-momentum DAs are almost not reduced compared to the on-momentum DA.





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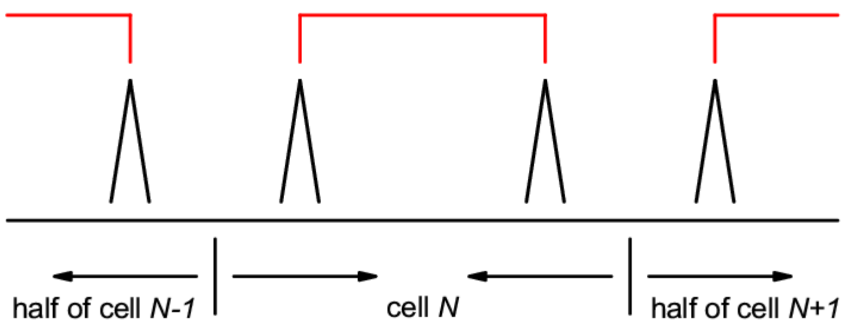
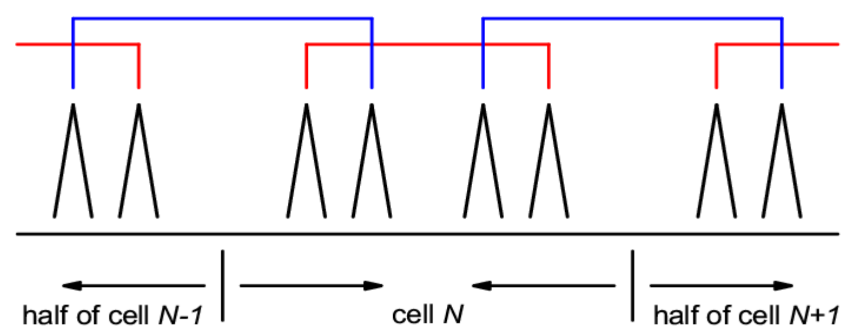
MBA lattice with interleaved dispersion bumps

- The second MBA lattice concept — MBA lattice with interleaved dispersion bumps:
  - To reduce the strengths of sextupoles.
  - Two pairs of interleaved dispersion bumps are created in each cell, and the two bumps of each pair are separated by –I transformation so that most of nonlinear effects can be cancelled out within one cell.
  - Compared to the hybrid MBA proposed by ESRF EBS, more knobs (i.e. families of sextupoles) can be used in this new MBA.



MBA with one pair of dispersion bumps



MBA with interleaved dispersion bumps

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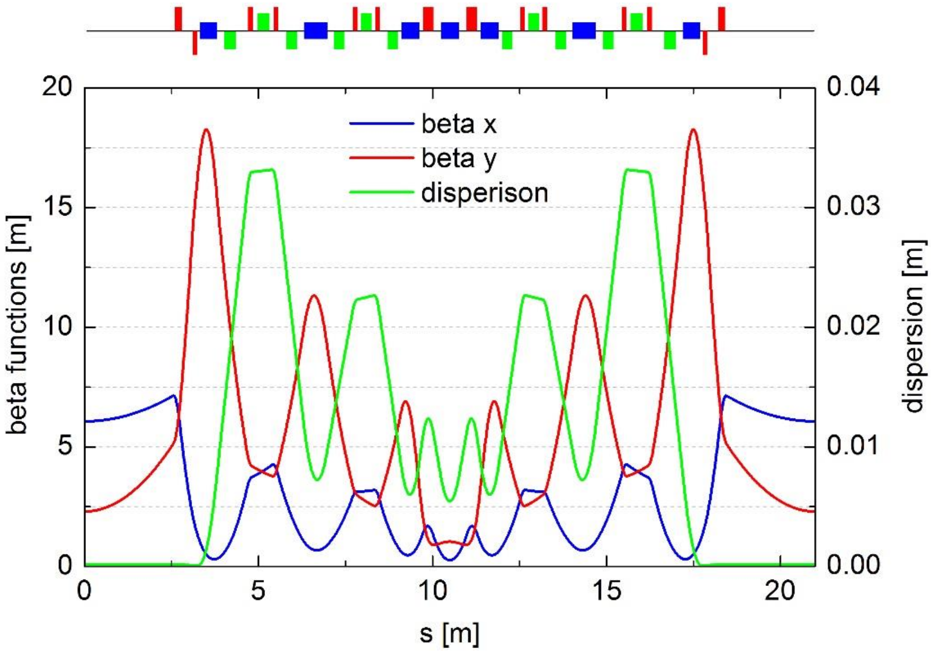
7BA lattice for HALS

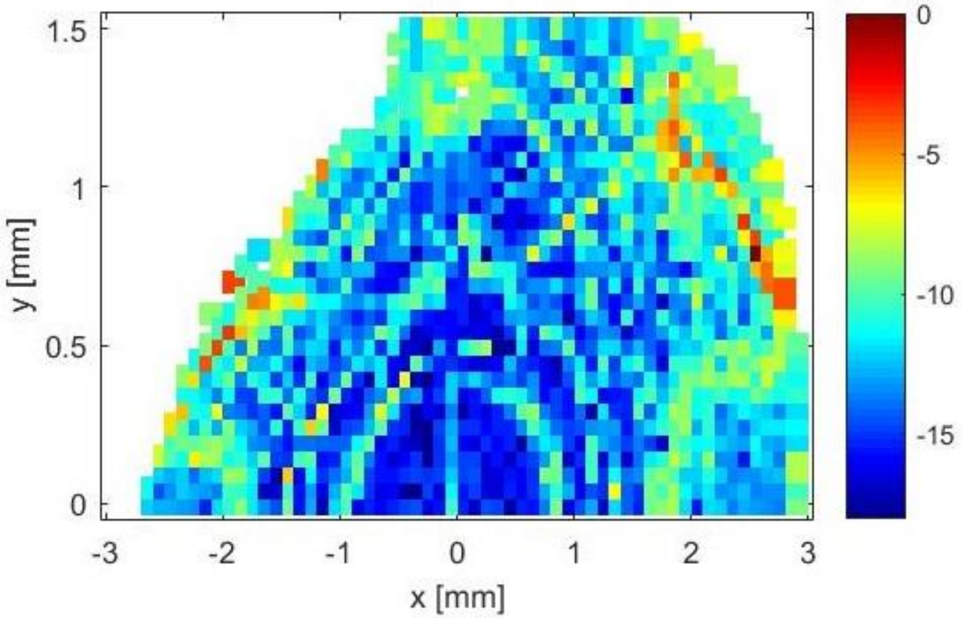
- Lattice design
  - Two pairs of dispersion bumps are created, and each pair is separated by -I transformation.
  - Six families of sextupoles are employed, three in each pair of bumps.
  - The natural emittance is 32.1 pm·rad.

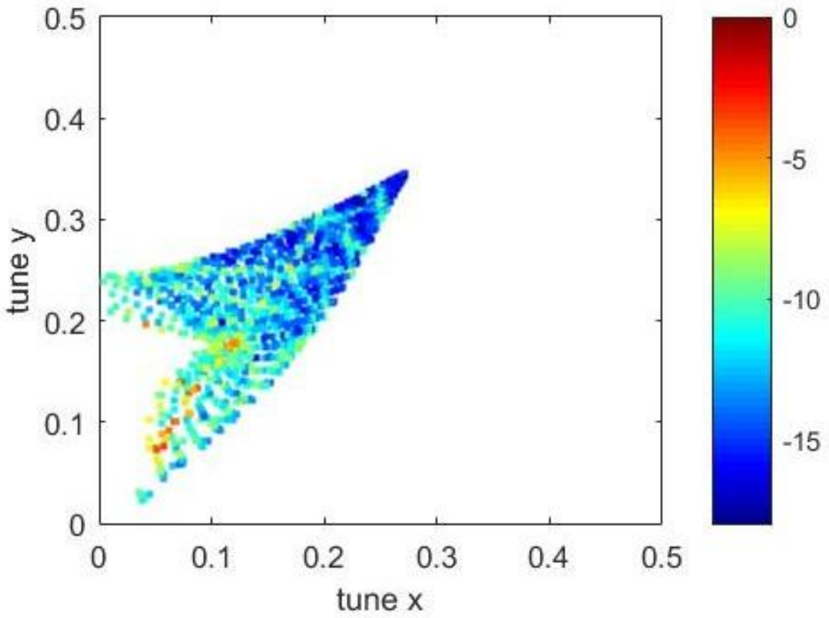


Parameters	Values
Energy	2.4 GeV
Circumference	672 m
Number of cells	32
Natural emittance	32.1 pm·rad
Transverse tunes	78.273, 29.345
Natural chromaticities	-103, -117
Momentum compaction factor	5.75×10^{-5}
Length of long straights	5.1 m
Beta functions at long straights	6.068, 2.299 m

7BA lattice for HALS

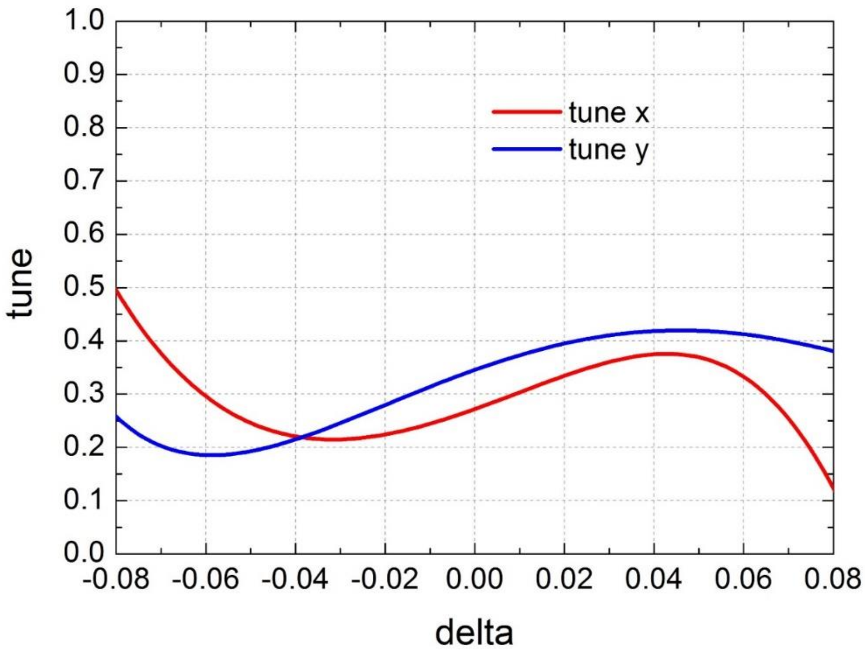
- Nonlinear dynamics optimization
  - The strengths of sextupoles: < 4000 T/m^2.
  - DA: about 200 sigma.

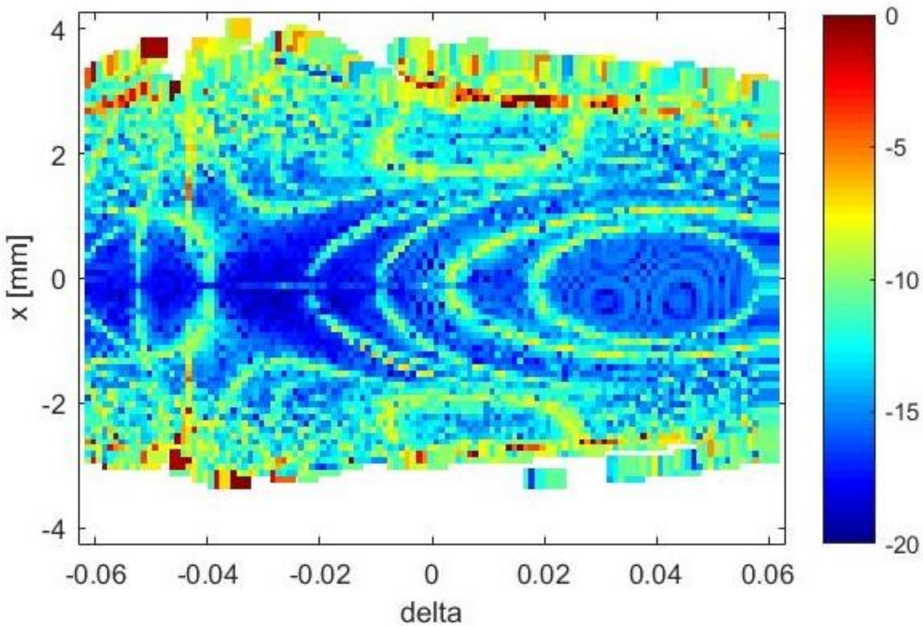




7BA lattice for HALS

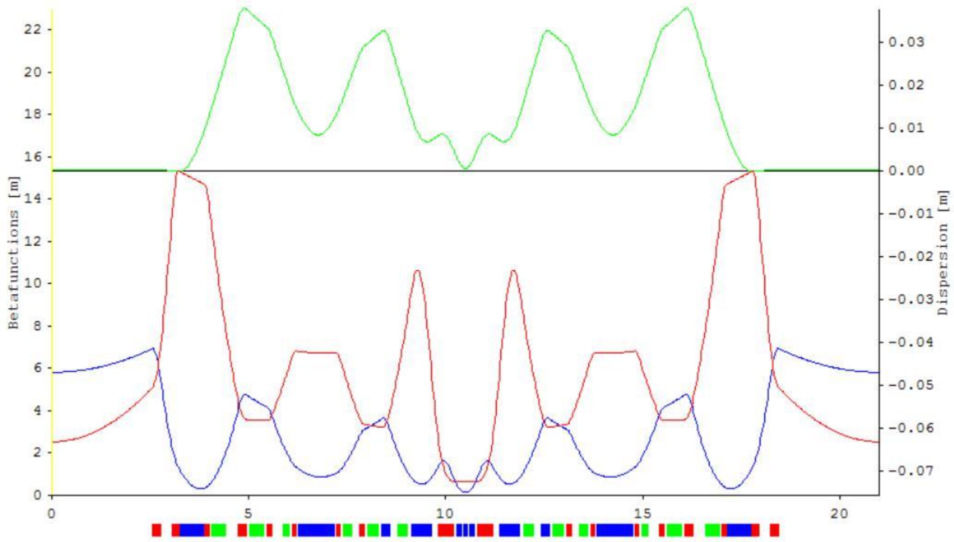
- Dynamic MA @ long straight sections: about 8%.
- Off-momentum DAs: all horizontal DAs are large.





Lower-emittance 7BA lattice for HALS

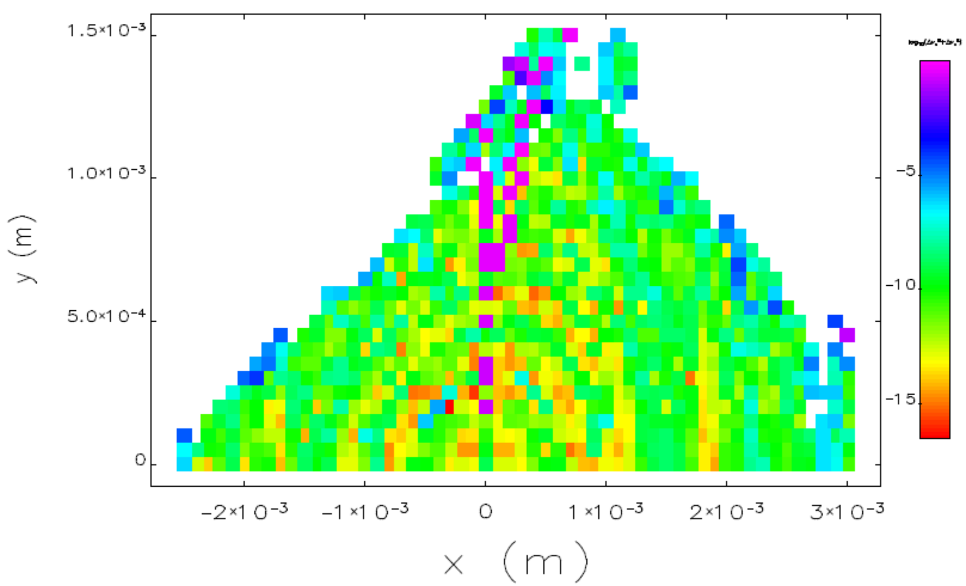
- Lattice design:
  - Longitudinal gradient bends (2 famlies) and reverse bends (1 family) are employed.
  - Superbends (2 T) are used as bend radiation sources for beam lines.
  - Natural emittance: 23 pm·rad.

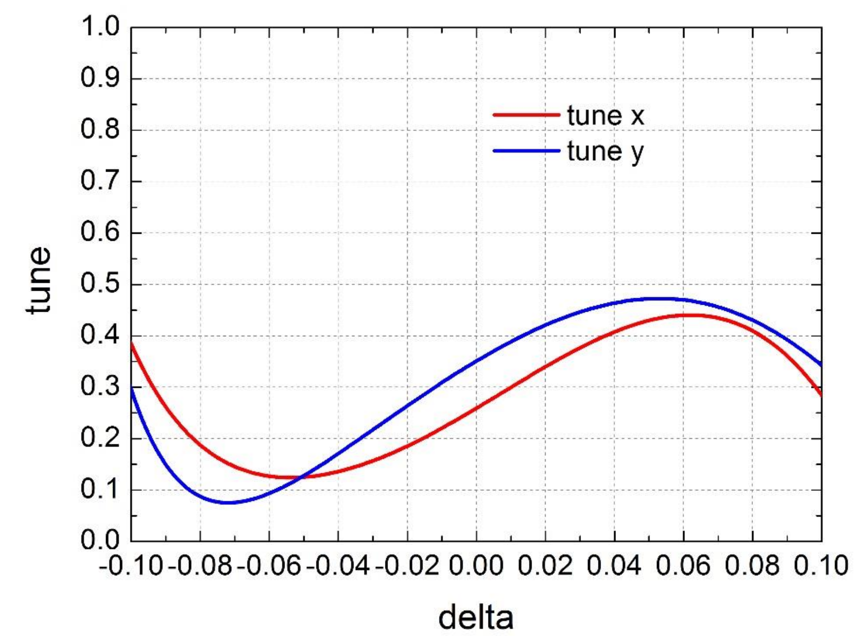


Parameters	Values
Energy	2.4 GeV
Circumference	672 m
Number of cells	32
Natural emittance	23.0 pm·rad
Transverse tunes	78.273, 29.345
Natural chromaticities	-108, -126
Momentum compaction factor	4.50×10^{-5}
Length of long straights	5.1 m
Beta functions at long straights	5.816, 2.531 m

Lower-emittance 7BA lattice for HALS

- Nonlinear dynamics optimization
  - 6 families of sextupoles & chromaticities corrected to (4, 4).
  - The strengths of sextupoles: < 4000 T/m^2.
  - Dynamic MA: > 10%.
  - Further nonlinear optimization is being studied.





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Conclusion

- The HALS will be a soft X-ray and VUV diffraction-limited storage ring with ten-picometer-order emittance.
- The HALS lattice has been studied using our two MBA concepts, and good enough DA, dynamic MA and off-momentum DAs have been achieved, which can provide long beam lifetime and promise the implementation of longitudinal injection scheme for the HALS.
- Our two MBA lattice concepts follow the same philosophy: nonlinear cancellation within one cell & many knobs.
- There is a lot of work to do in the HALS physics study in the future.