Chromatic Correction of the EIC Electron Ring Lattice

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SLAC National Accelerator Laboratory

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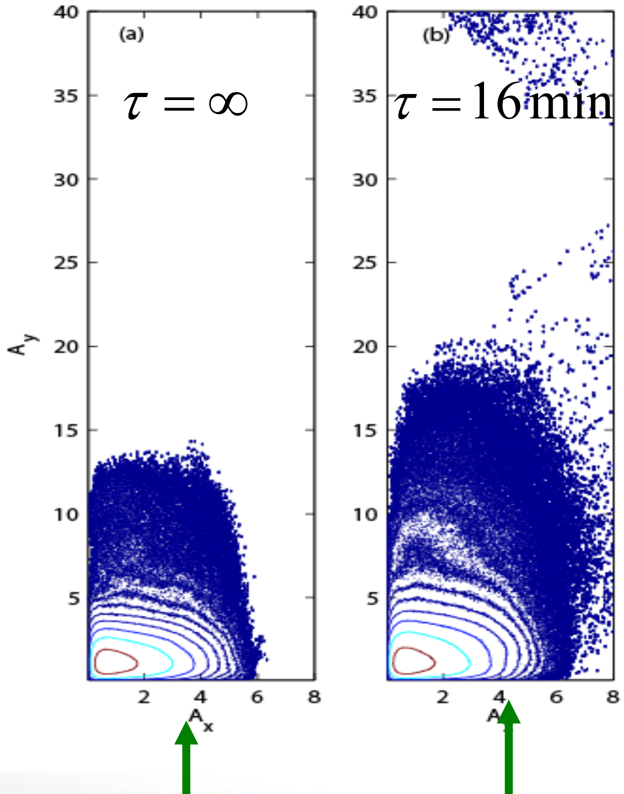
Electron-Ion Collider

BROOKHAVEN NATIONAL LABORATORY Jefferson Lab U.S. DEPARTMENT OF ENERGY Office of Science

Motivation

Beam Distributions with Beam-Beam Interaction (PEP-II)



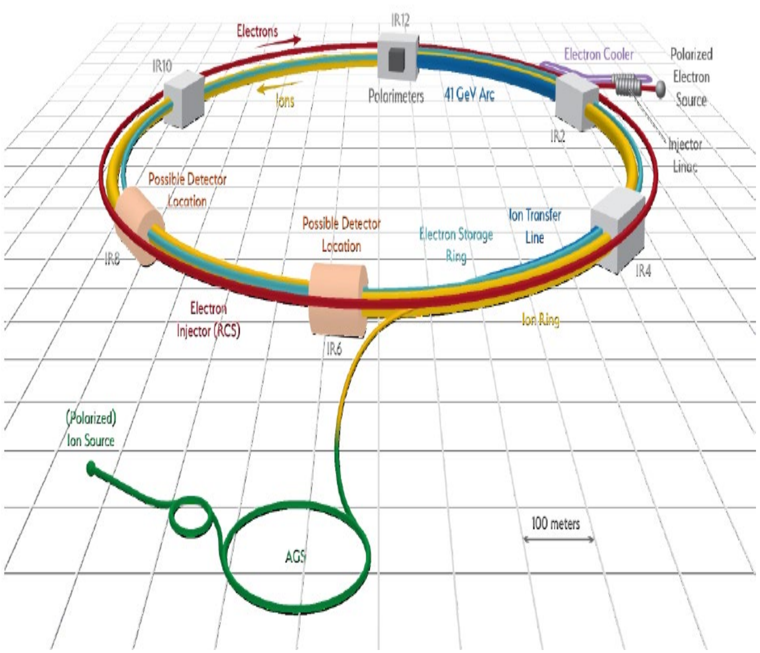
The distributions are averaged after 40,000 turns to improve the statistics.

Contours started at value of peak/sqrt(e) and spaced in e. Labels are in σ of the initial distribution.

The core distribution is not disturbed much by the nonlinearity in the ring while the tail is strongly affected.

With a linear matrix or 8th order Taylor map (ν_x^+=0.5125). Nonlinear map is important because it defines the dynamic aperture.

Electron-Ion Collider



- Design luminosity: 10^{34} $cm^{-2}s^{-1}$
- Highly polarized beams: 70%
- Hadron up to 275 GeV
- Electron up to 18 GeV
  - Electron collider ring
  - Rapid cycling synchrotron
  - Polarized electron source

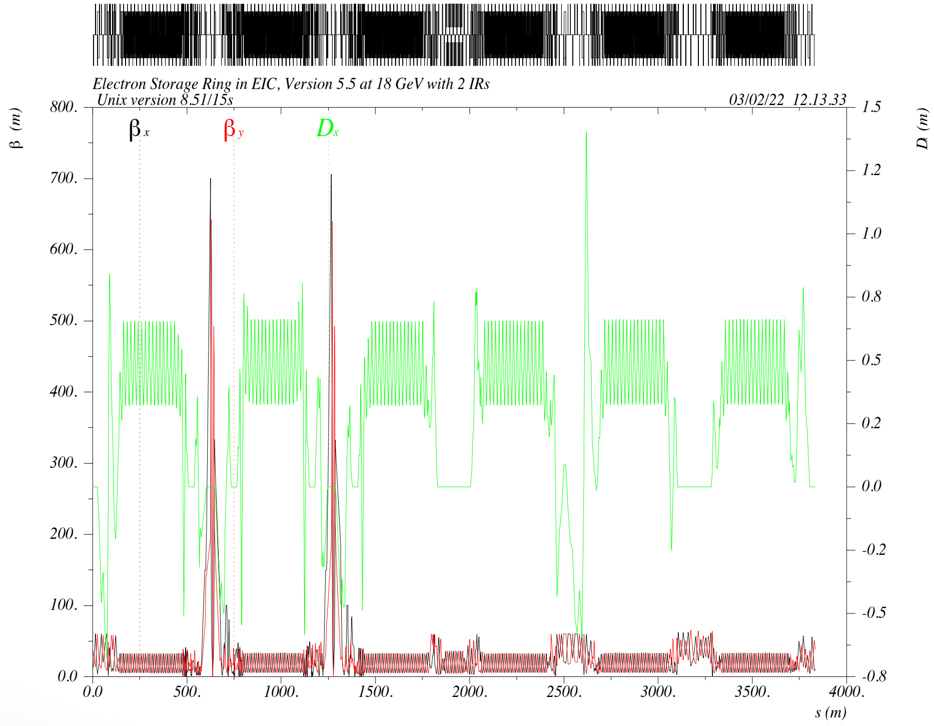
A factory that includes not only electrons but also hadrons

Main Parameters

Parameters	Units	60^0 Lattice (1IR)	90^0 Lattice (2IR)
Energy	GeV	10	18
Circumference	m	3834	
Emittance	nm	24	28
Energy spread	10^{-4}	5.5	9.8
Betatron Tunes		45.12/36.10	52.12/45.10
Chromaticity		-83/-91	-106/-110
IP betas	m	0.59/0.057	
L*	m	5.3	

- Fractional tunes are selected by the spin dynamics and beam-beam performance
- Their closeness to integer makes chromatic compensation harder

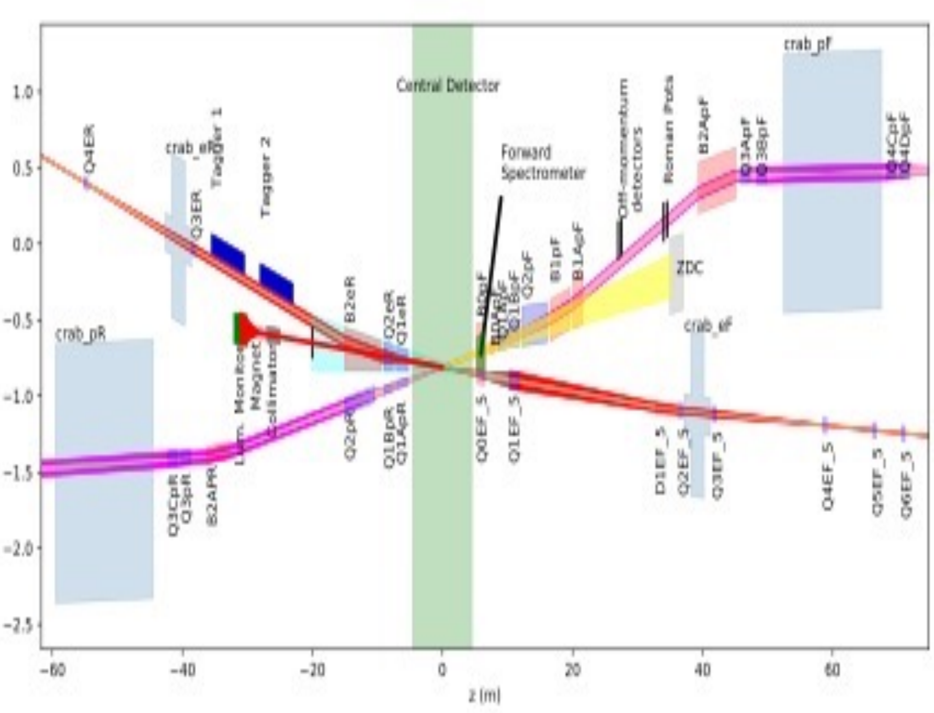
Design Optics at 18 GeV



- Fits in the RHIC tunnel along with the other rings
- 90^0 FODO cells in arcs
- On-axis injection
- One interaction region in the EIC scope
- Asymmetric interaction region

Lattice design is much more demanding because of the large energy range and the constraints

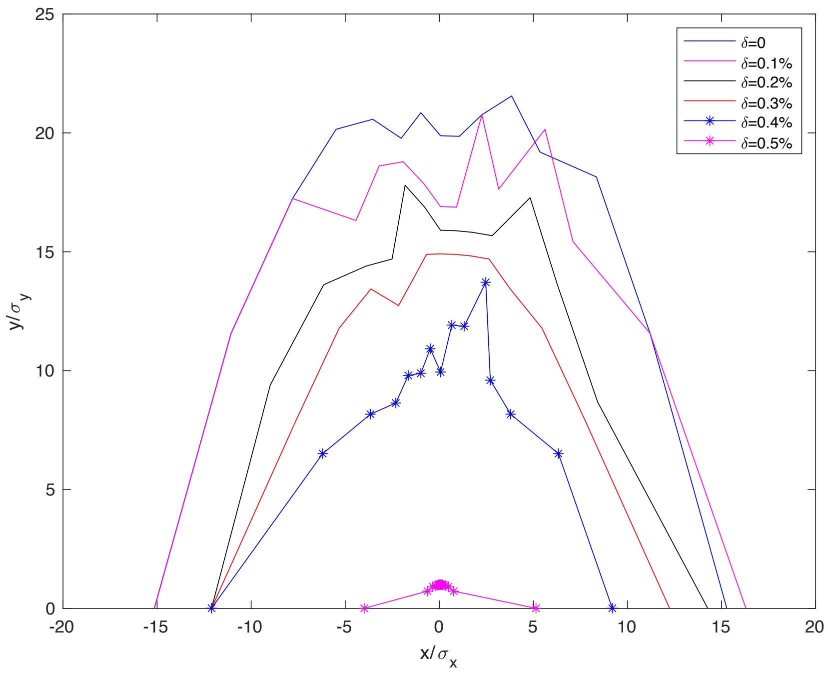
Interaction Region

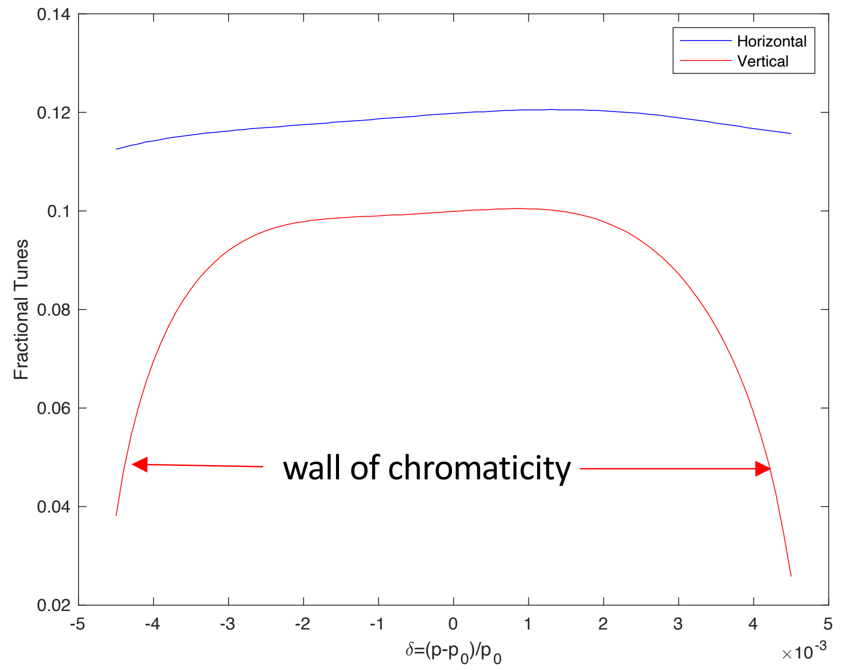


- Asymmetric
- Low-beta optics
- Crab cavity requires additional high-beta regions
- Coupled optics due to spin rotators

Interaction region is packed without space for local chromatic compensation

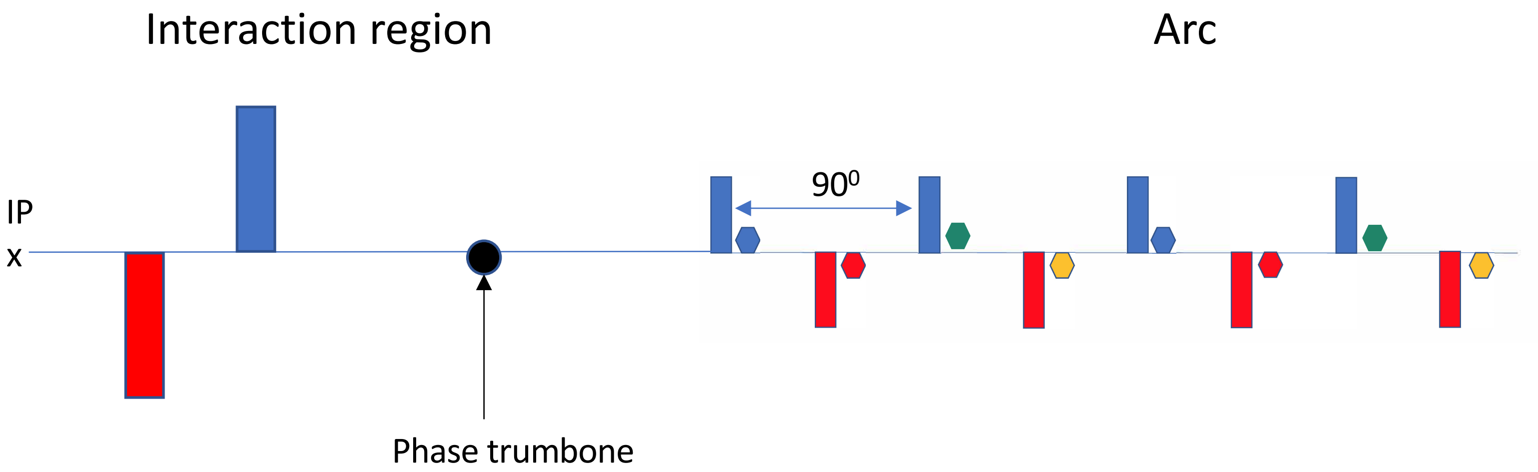
Dynamic Aperture of the 90^0 Lattice





- Use two families of sextupoles in the arcs to correct linear chromaticity to one unit
- Momentum aperture is 0.4% consistent with momentum bandwidth
- Synchrotron radiation included in tracking

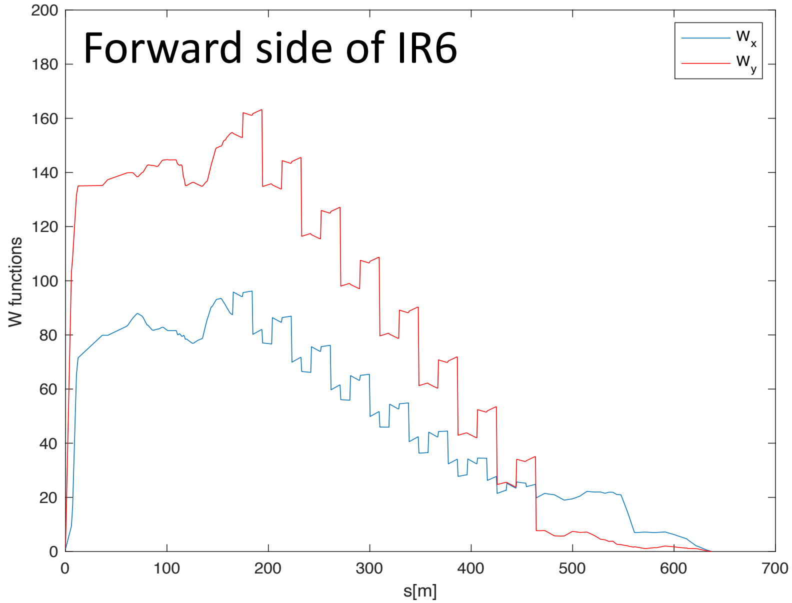
Semi-Local Chromatic Compensation Scheme

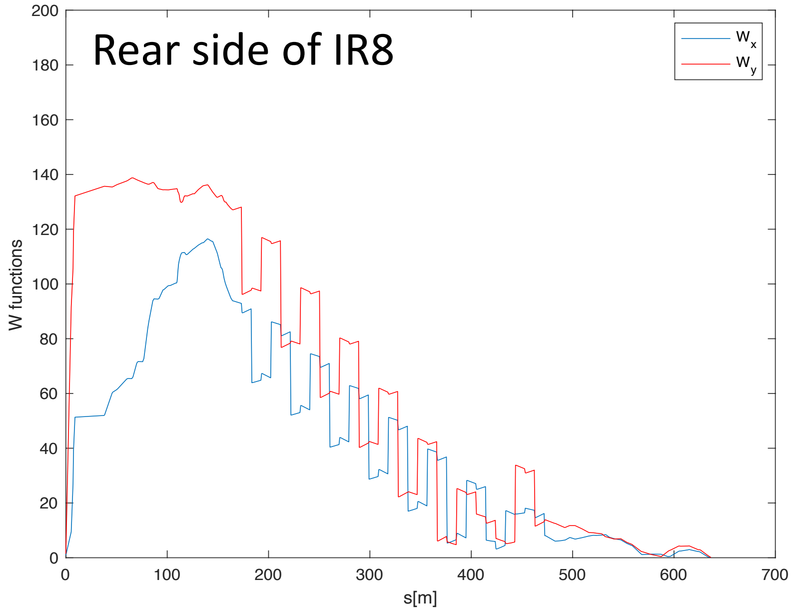


In each plane:

1) Members in the family add to the beta beating
2) The other family (same sign) cancel the beta beating but add chromaticity
3) Since all beating is in the same phase, a trombone is necessary to align the IR beating to the arc

First-Order Chromatic Matching

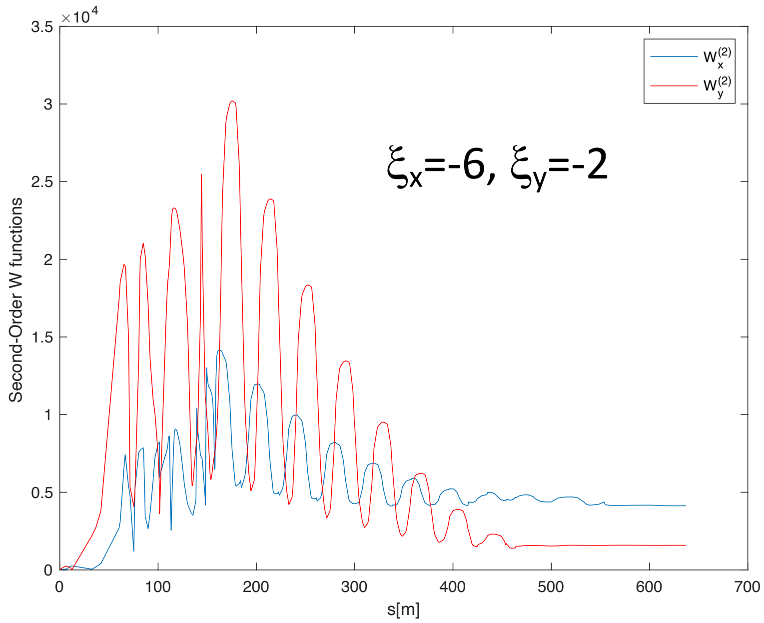




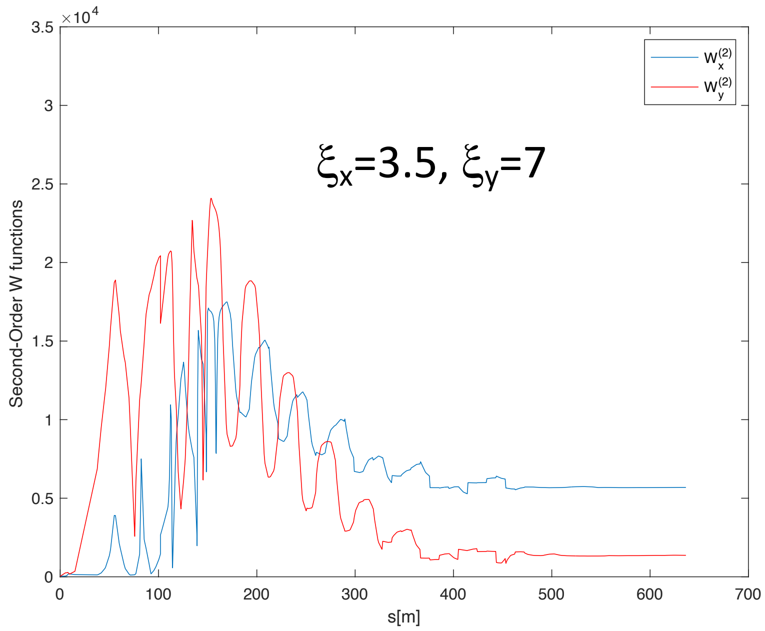
1) Four variables: strengths of two sextupole families, ν_x and ν_y
2) Four goals: β_x', α_x', β_y', α_y' setting by the periodic solution between 2IPs
3) Two local chromaticities ξ_x and ξ_y
4) Solutions are found with a downhill simplex optimizer

Second-Order Chromatic Optics

Forward side of IR6

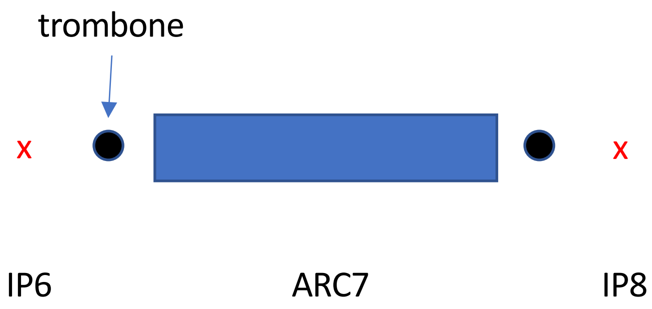


Rear side of IR8



1) Local chromaticities are knobs to control higher order chromatic bearings
2) The optimal values of the local chromaticities are obtained by tracking

Chromatic Optimization of a Periodic System



Between IP6 and IP8 are optimized as a periodic system

- Increase number of sextupole families from 4 to 8
- Keep two phase trombones
- Minimize chromatic beta beating and chromaticity up to the third-order of δ

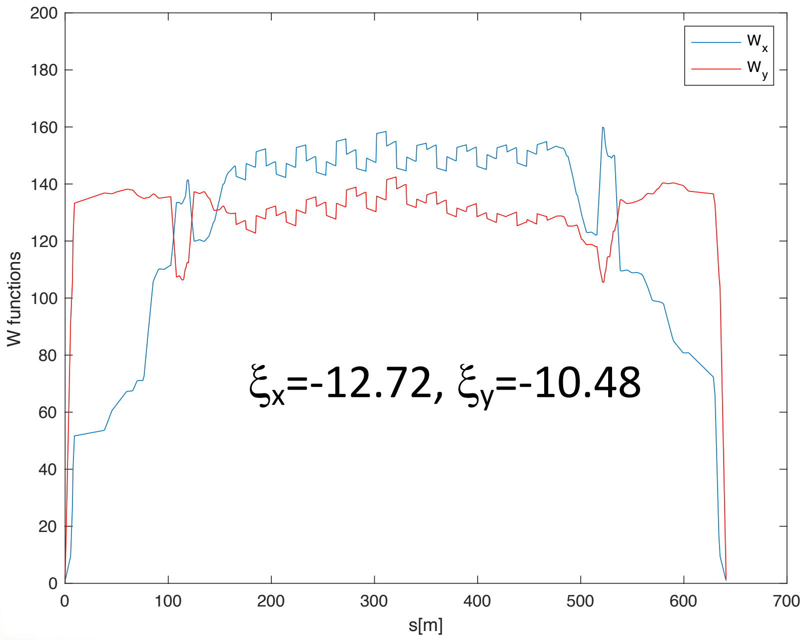
Chromatic Compensation between Two Interaction Points

TABLE III. The nonlinear chromaticities and chromatic beatings at the IPs.

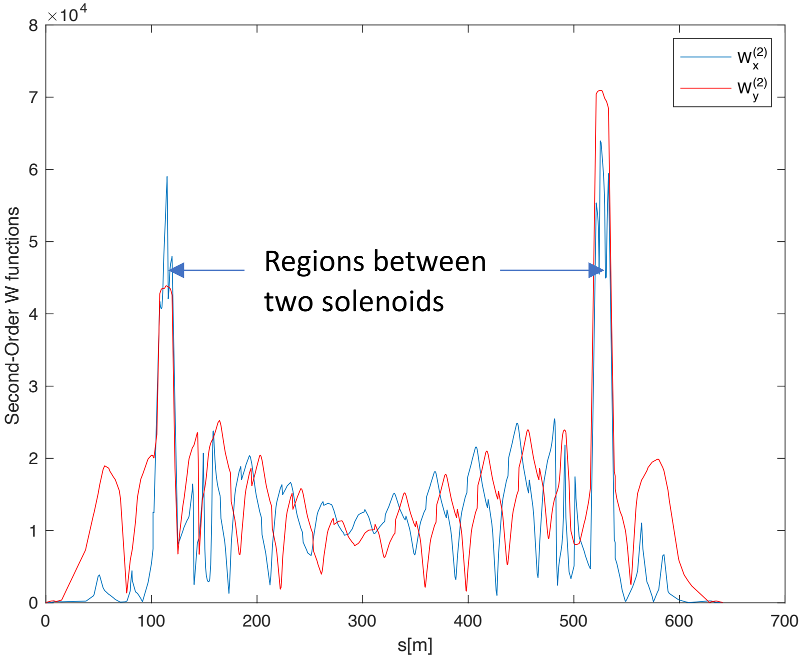
Minimized Parameters	2 Families	8 Families
$\partial\nu_{x,y}/\partial\delta$	-14.57,-16.89	$-12.72, -10.48$
$\frac{1}{2!}\partial^2\nu_{x,y}/\partial\delta^2$	$-6.37\times10^4, -6.35\times10^4$	$-9.60\times10, -1.52\times10^2$
$\frac{1}{3!}\partial^3\nu_{x,y}/\partial\delta^3$	$-2.02\times10^{11}, -2.02\times10^{11}$	$2.45\times10^4, 3.46\times10^3$
$W_{x,y}$	$8.56,\ 5.90$	$0.91, 1.44$
$W^{(2)}_{x,y}$	$1.73\times10^5, 1.69\times10^5$	$38.70, 34.39$
$W^{(3)}_{x,y}$	$5.53\times10^{11}, 5.59\times10^{11}$	$3.09\times10^4, 2.25\times10^4$

Chromatic Compensation in a Periodic System

First-Order



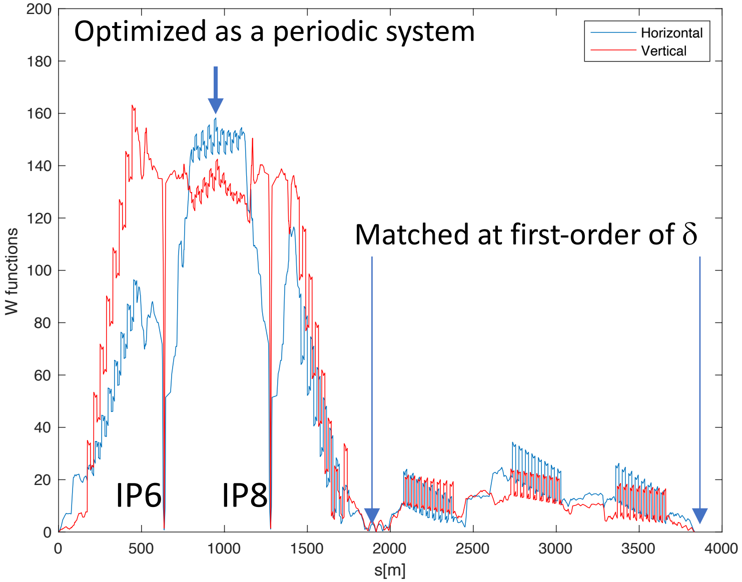
Second-Order



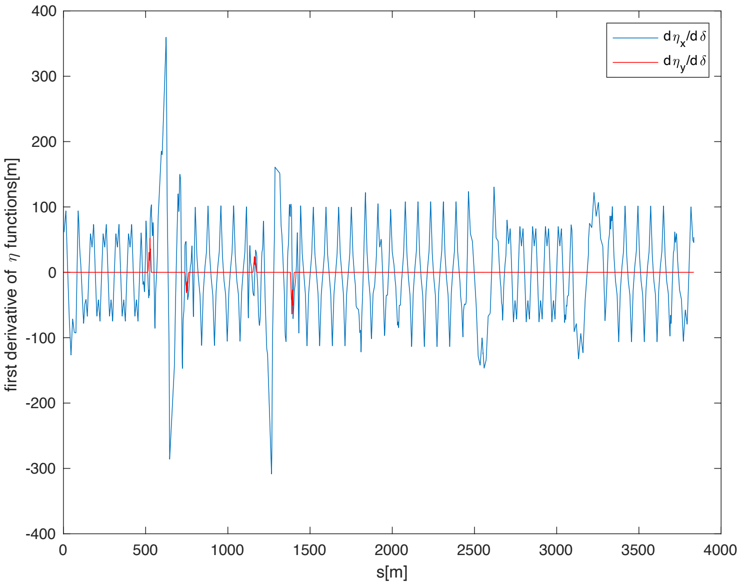
Optimized as a periodic system, cancellation between two half IRs

Chromatic Matching of the Ring

W-Functions



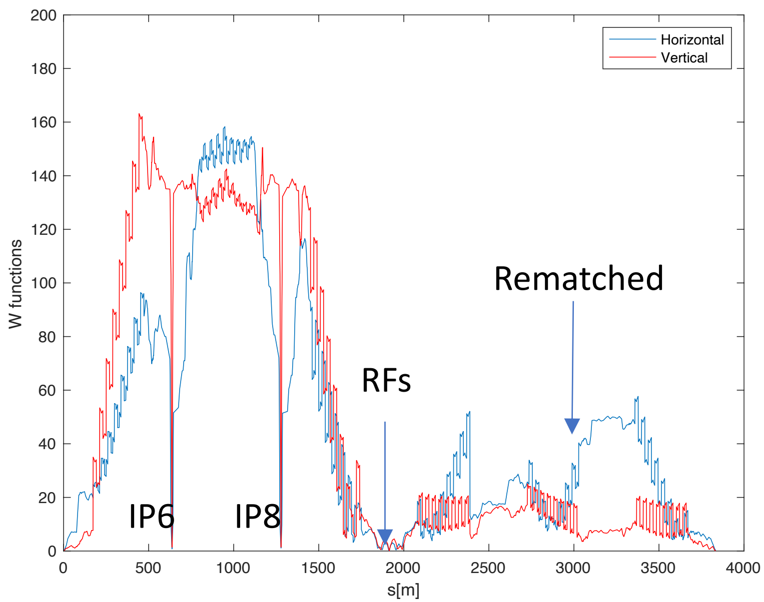
Second-Order Dispersions



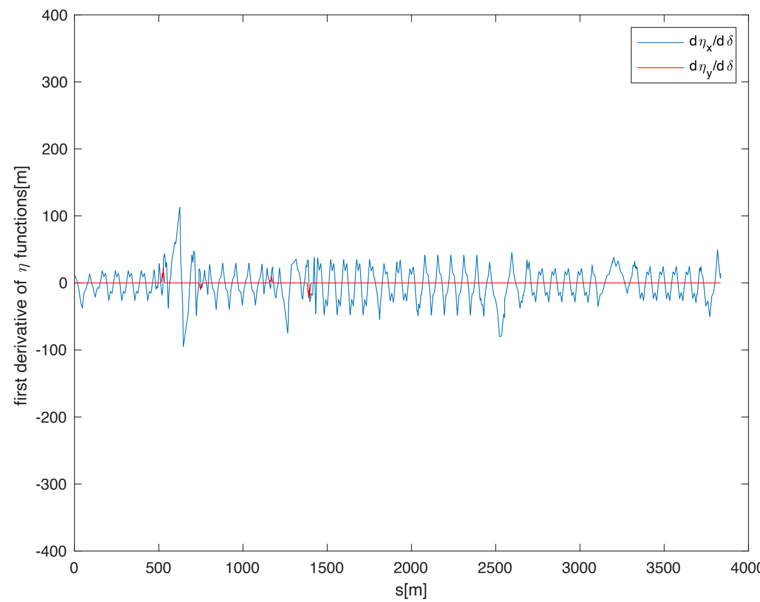
1) The second interaction region doubles the second-order dispersions
2) The paired sextupoles do not generate the second-order dispersions
3) The second-order dispersion drives the synchro-betatron resonance: $\nu_x+2\nu_s$

Correction of the Second-Order Dispersion

W-Functions

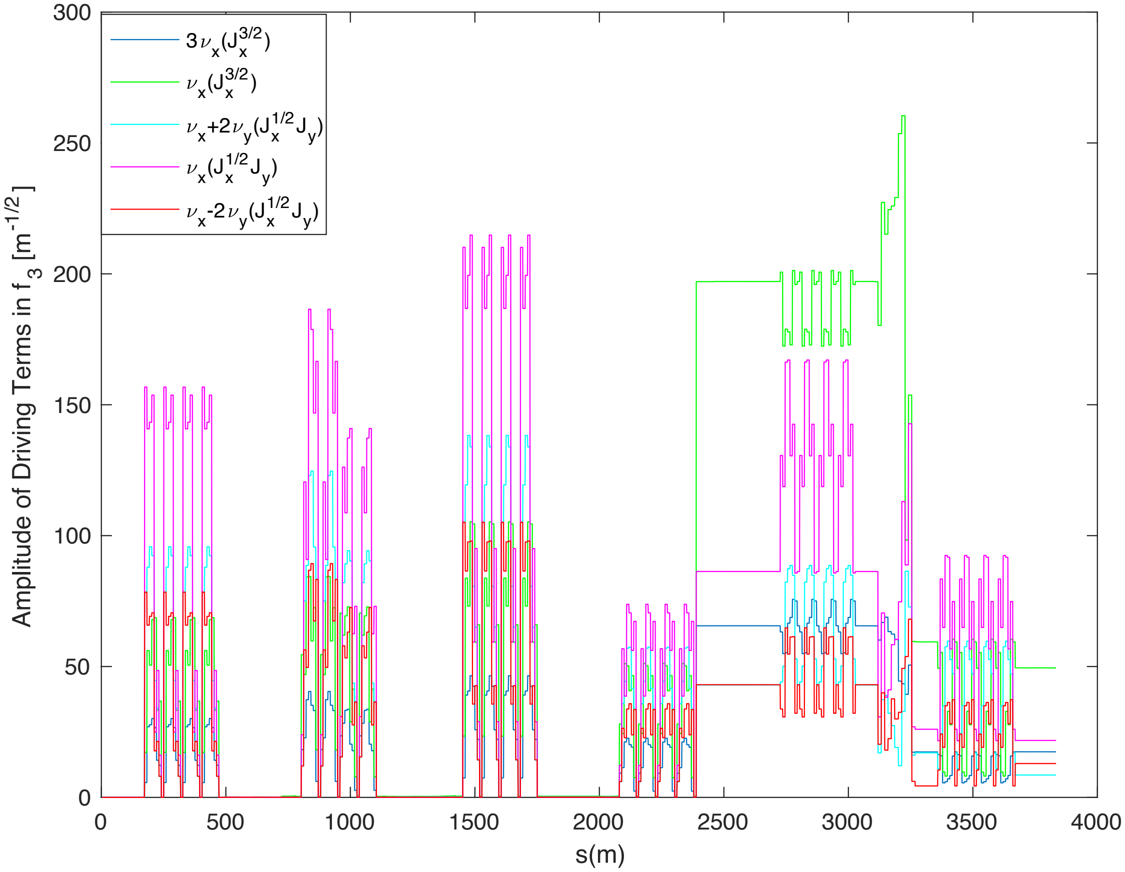


Second-Order Dispersions



The second-order dispersion is reduced significantly be two sextupoles

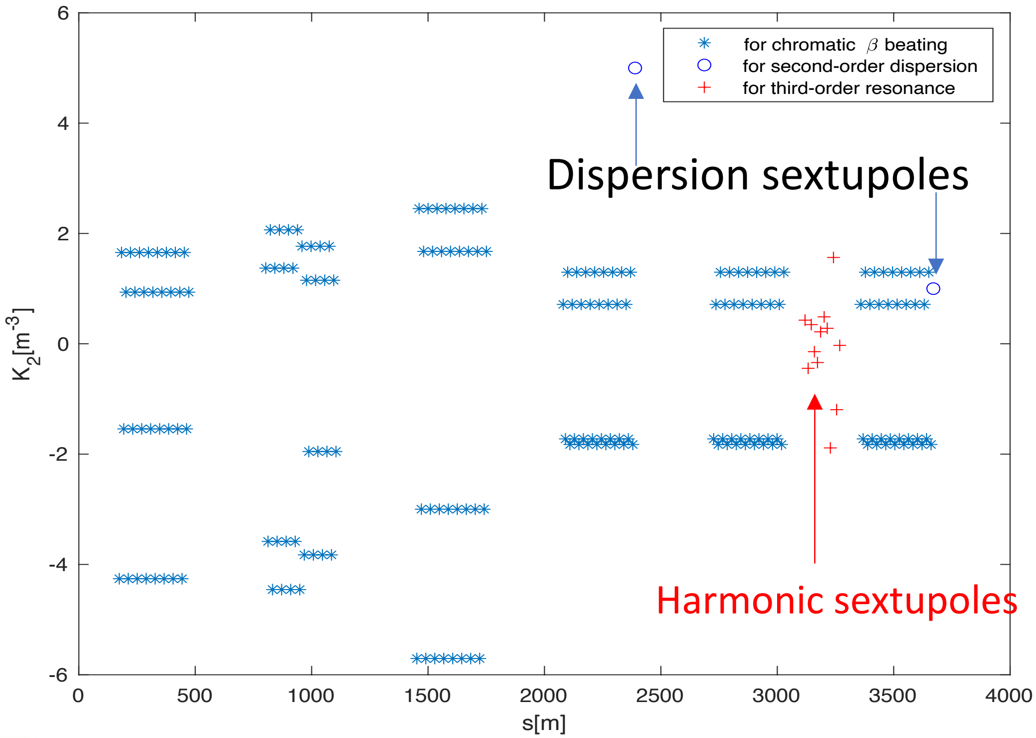
Resonance Correction



1) 12 harmonic sextupoles in IR2 used in the correction
2) 75% of the zero-out solution is optimal for dynamic aperture

Hybrid Chromatic Compensation Scheme

Sextupole Strengths

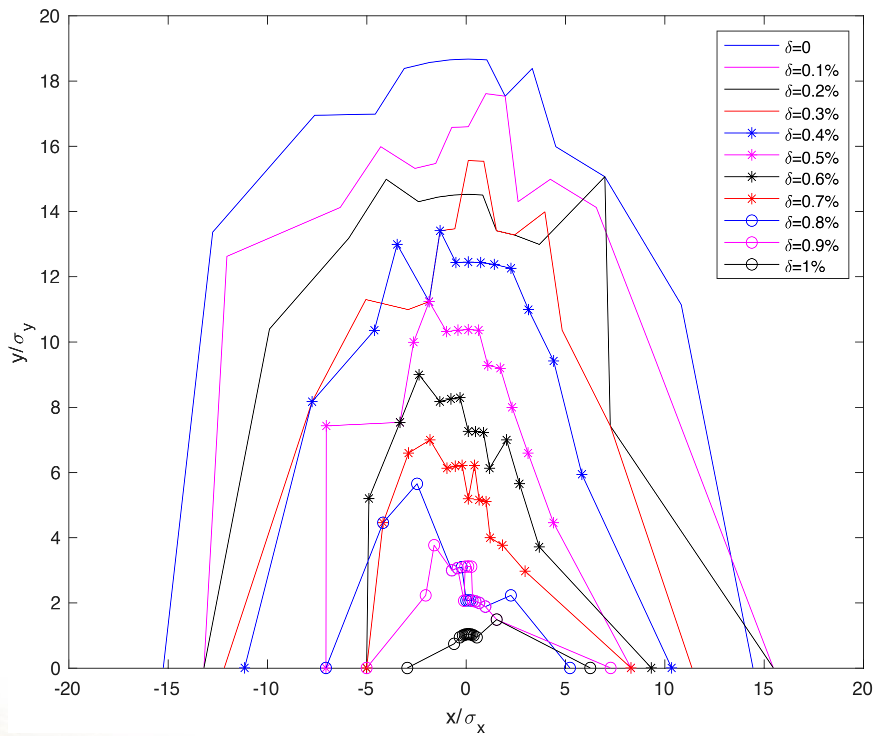


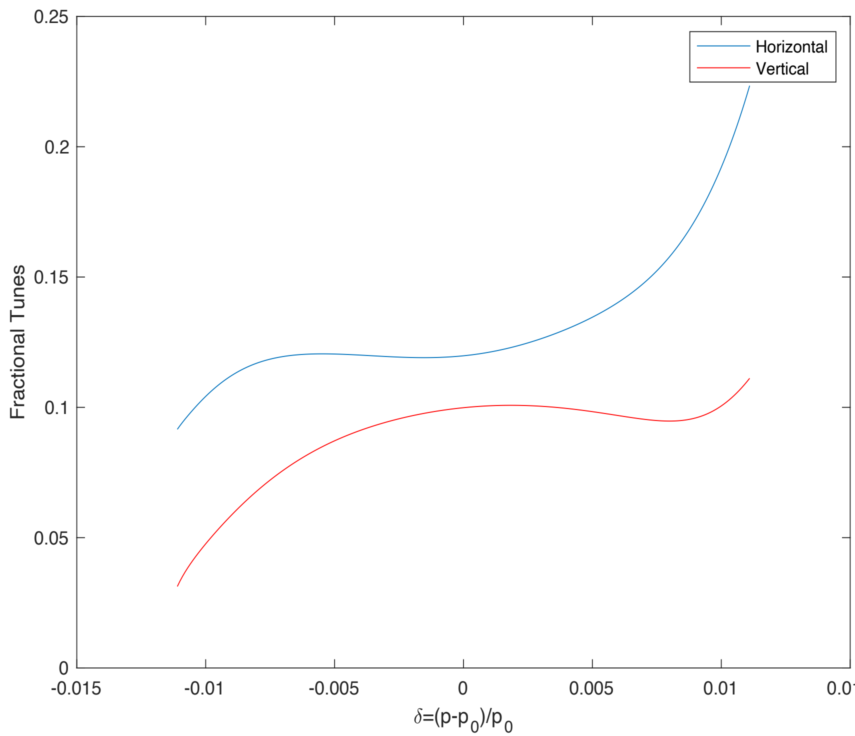
Scheme

- 20 chromatic families of sextupoles
- Eight phase trombones
- 2 sextupoles for second-order dispersion
- 12 harmonic sextupoles for the third-order resonances

1) The strongest sextupoles are in the arc 9
2) Length of sextpoles is 0.7 meter

Dynamic Aperture of the 90^0 Lattice with Two IRs





Mementum aperture is increased to 1.0%

Linear chromaticity is set one unit in both horizontal and vertical planes

Conclusion

- A new hybrid chromatic compensation scheme is developed with combination of optimization of a periodic system and semi-local correction of beamlines
- Second-order dispersion is reduced more than a factor three using two sextupoles resulting in a large momentum aperture: 1%
- For the optimization of on-momentum dynamic aperture, it is essential to reduce the third-order resonance driving terms
- The semi-local solutions are well understood and parameterized in terms of the local chromaticity. Most importantly, the scheme can be easily deployed in the online tuning and optimization of the collider

- The design criteria of dynamic aperture, namely 10 σ in all three dimensions, is achieved for the 90-degree lattices with two interaction regions

Acknowledgements

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