



Optics Design for a Storage Ring Based Electron Cooler for Cooling at High Energies

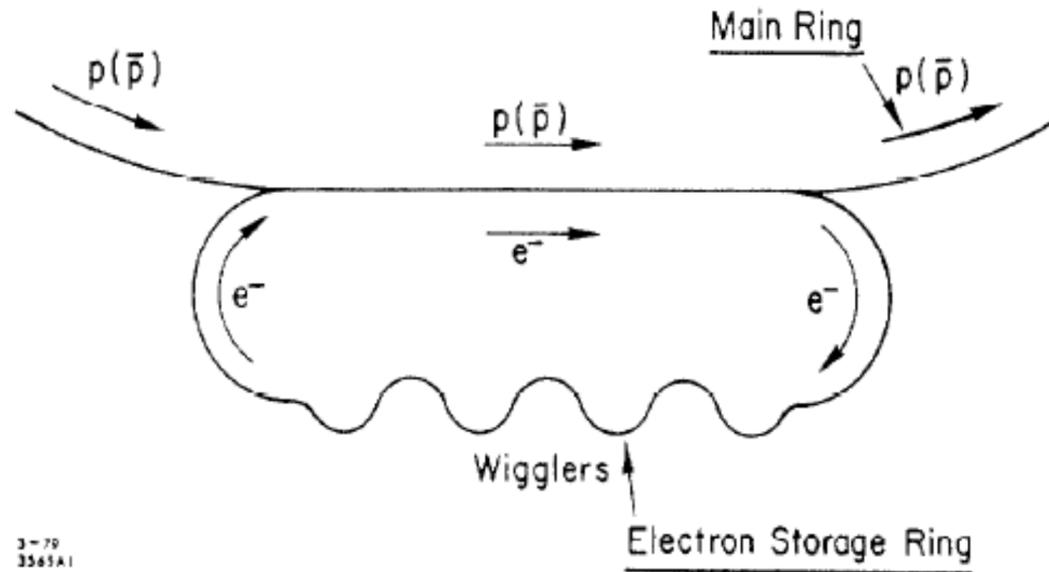
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Cool 25, Stoneybrook, October 26-31, 2025

HIGH ENERGY ELECTRON COOLING TO IMPROVE THE LUMINOSITY AND LIFETIME IN COLLIDING BEAM MACHINES*

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3-79
3545A1

Sergei Seletskiy: Development of Storage Ring Electron Cooler for High Energy Applications, this conference, Tuesday

Emittance

- The emittance results from the equilibrium of
 - Quantum excitation in dipoles
 - IBS excitation where the dispersion is not zero
 - Beam-beam scattering excitation in the cooling section
 - And the radiation damping
- The program GETRAD calculates the emittances by iteration

$$\epsilon_{new} = \frac{(\lambda_{rad} + \lambda_{IBS}(\epsilon_{old}) + \lambda_{BBS}(\epsilon_{old}))}{\lambda_{damping}}$$

- All three excitations are dominated by the H-function

$$H = \frac{D^2}{\beta} + 2\alpha DD' + \beta D'^2$$

Chromaticity

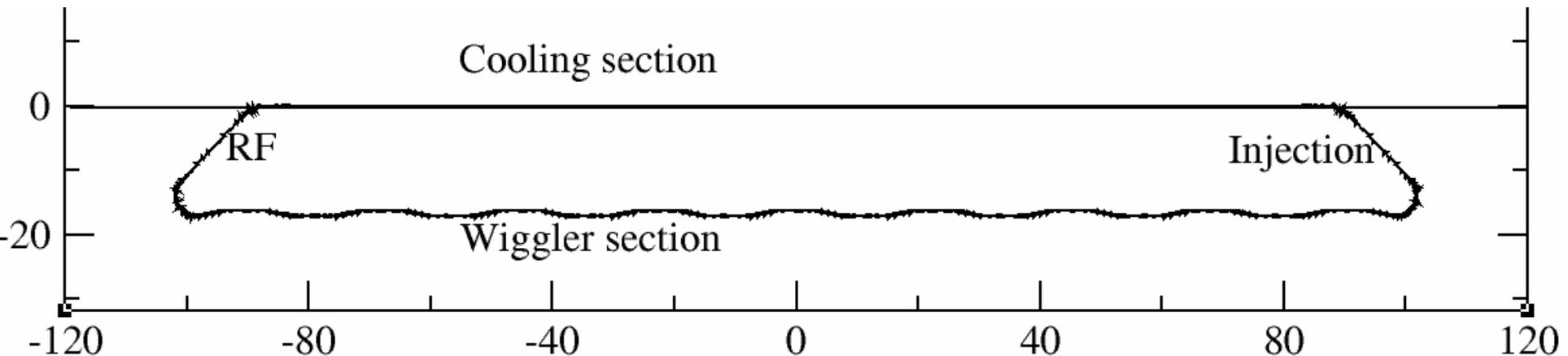
- For chromaticity correction a large dispersion and a difference in the beta functions is necessary
- This requirement contradicts the requirement for a low emittance
- This talk is about finding a compromise between the two

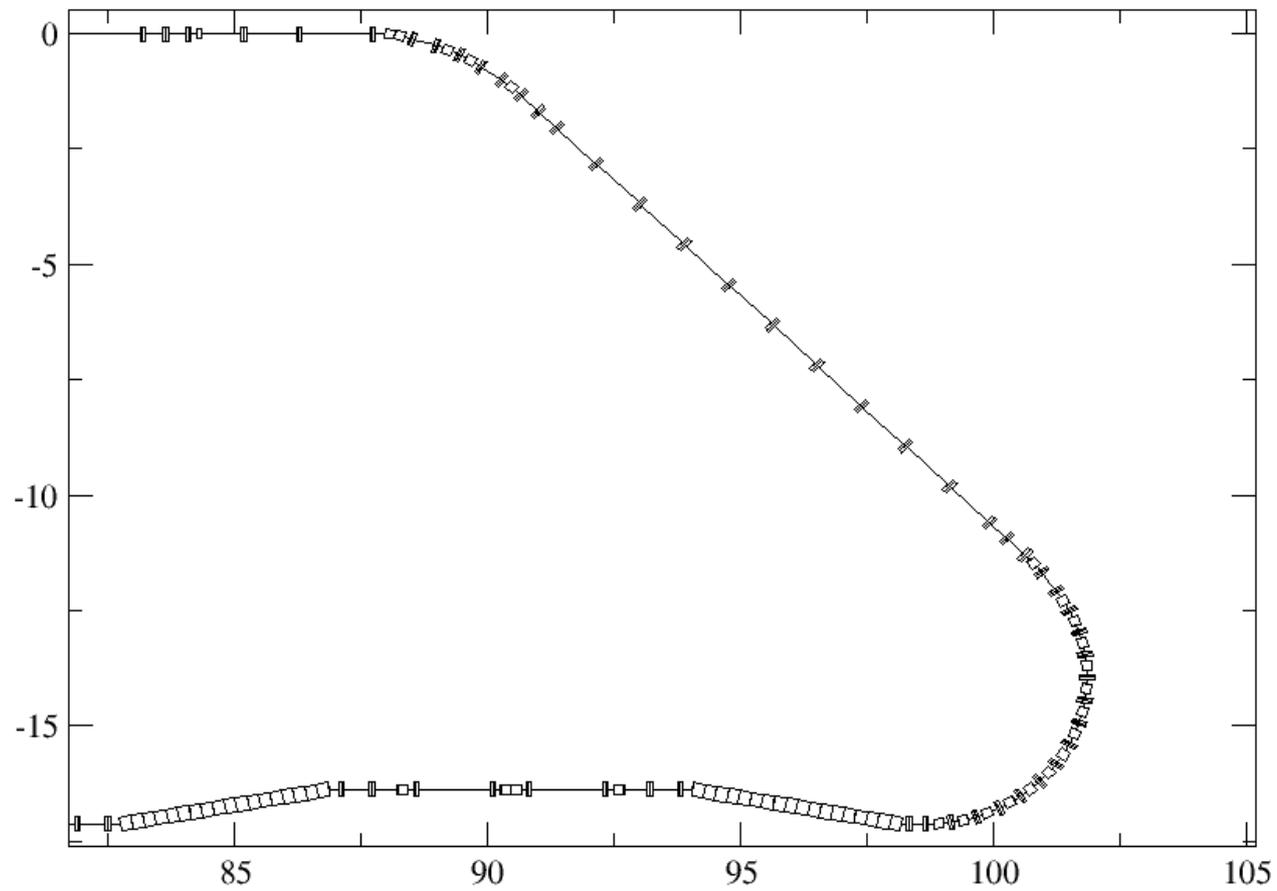
EIC geometry constraints

- The available length between ion quadrupoles is 176.58 m
- The RF frequency is 98.6 Mhz
- We want the ratio of the ion and electron harmonic numbers to be an integer
- The circumference can be 255 m, 426 m or 576 m

Foot print

- The trapezoidal shape allows the wiggler section to be longer than the cooling section
- The straight sections inside the arcs are used for RF and injection



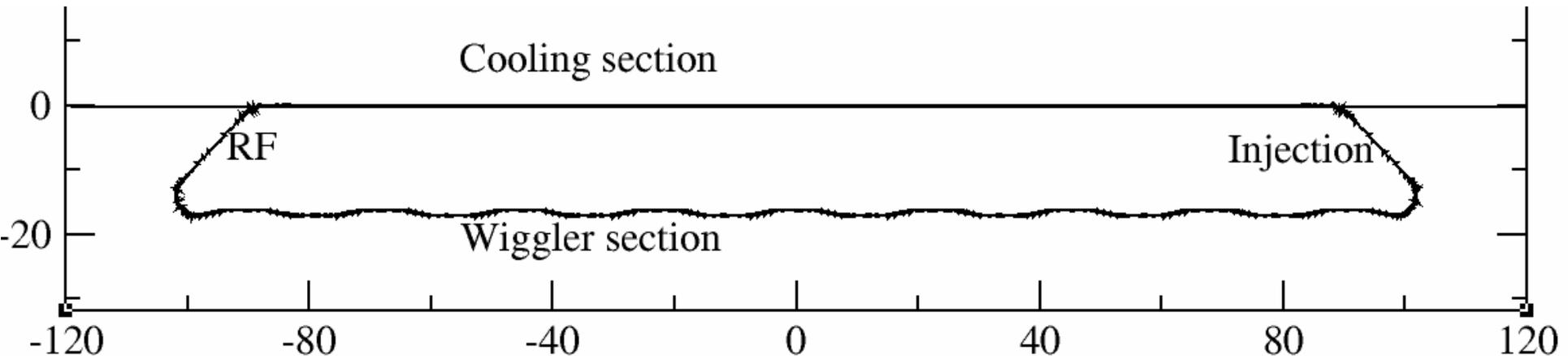


| | |
|-------------------------------|--------------|
| Energy | 149.259 MeV |
| Gamma | 293.093 |
| Number of bunches | 140 |
| Number of electrons per bunch | 1.3e11 |
| Charge per bunch | 21 nC |
| Average current | 2 A |
| Tunes | 60.18 / 8.18 |
| Nat Chromaticity | -140 / -114 |
| Geometric Emittance | 7.8 / 7.8 nm |
| Relative momentum spread | 9.7e-4 |

| | |
|-----------------------------|-----------------|
| Bunch length | 6 cm |
| Momentum compaction | -1.43e-3 |
| Damping times | 6.3 / 6.7 ms |
| Radiation power per wiggler | 674 W |
| | |
| Cooling section length | 170 m |
| Cooling section betas | 180 / 160 m |
| Cooling section dispersion | 1 m |
| Cooling times | 2 / 4 / 3 Hours |

Foot print

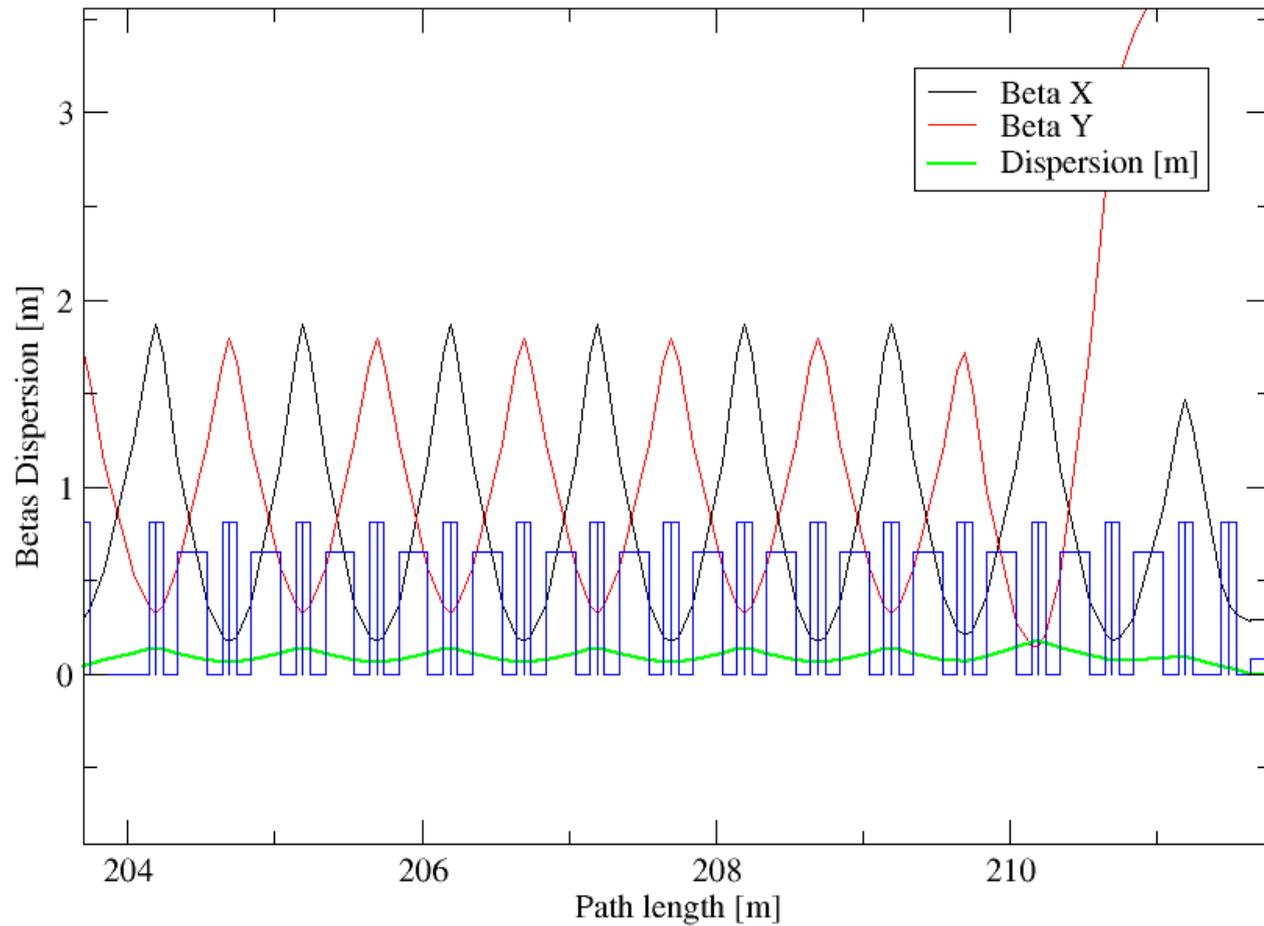
- The arcs are tiny compared to the rest of the machine
- The sextupoles for chromaticity correction are instead located in the wiggler section



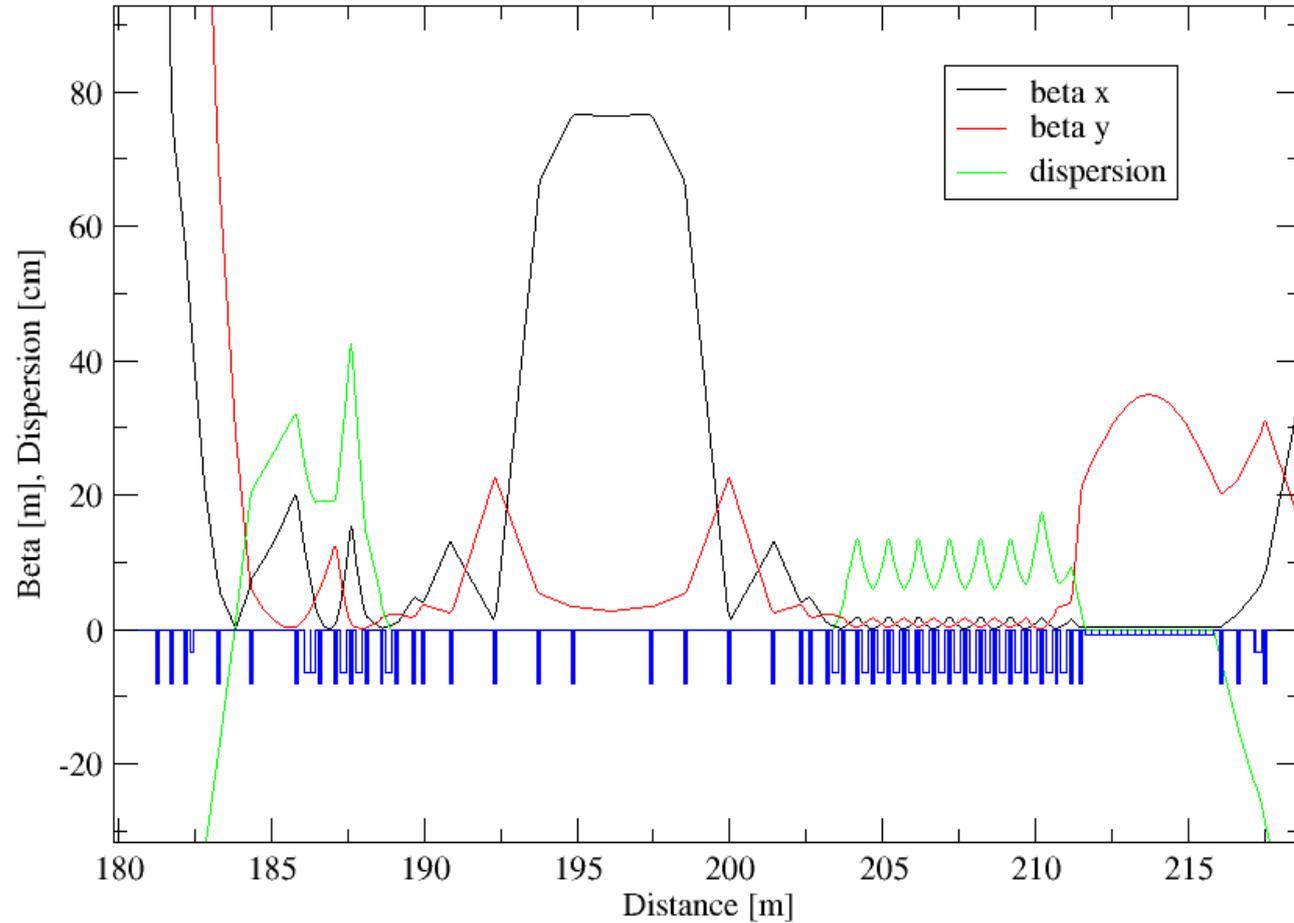
ARC

- The arc has a FODO lattice
- A low emittance is achieved with 20 dipoles per arc. Dipole length is 20 cm.
- A DBA lattice does not give a better emittance
 - Less contribution from the dipoles
 - More contribution from IBS

Arc



Arc



Wigglers

- [R.P. Walker, “Wigglers”, DOI: 10.5170/CERN-1995-006.807]

$$B_y = B_0 \cosh(k_x x) \cosh(k_y y) \sin(k_z z)$$

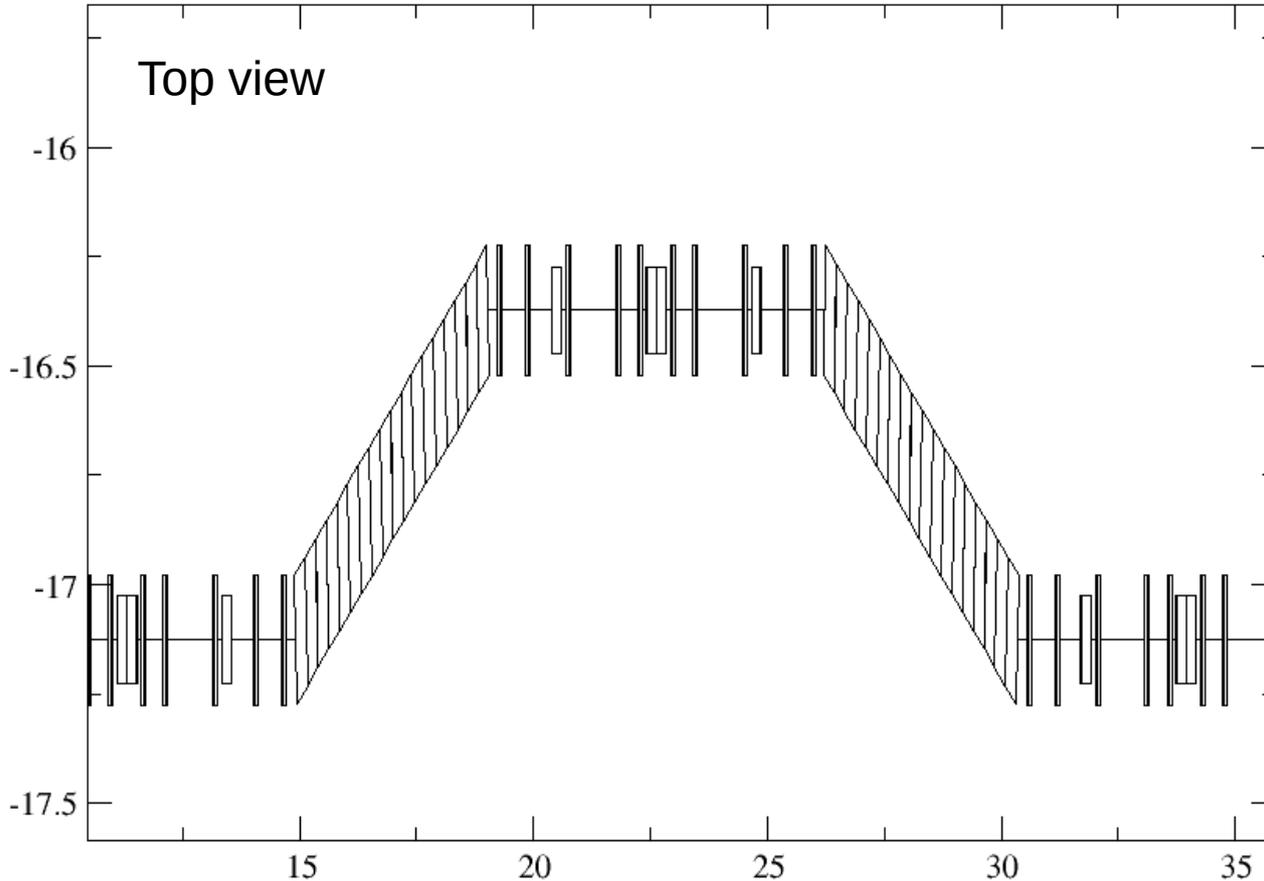
$$B_x = B_0 \frac{k_x}{k_y} \sinh(k_x x) \sinh(k_y y) \sin(k_z z)$$

$$B_z = B_0 \frac{k_z}{k_y} \cosh(k_x x) \sinh(k_y y) \cos(k_z z)$$

$$k_y^2 = k_z^2 - k_x^2$$

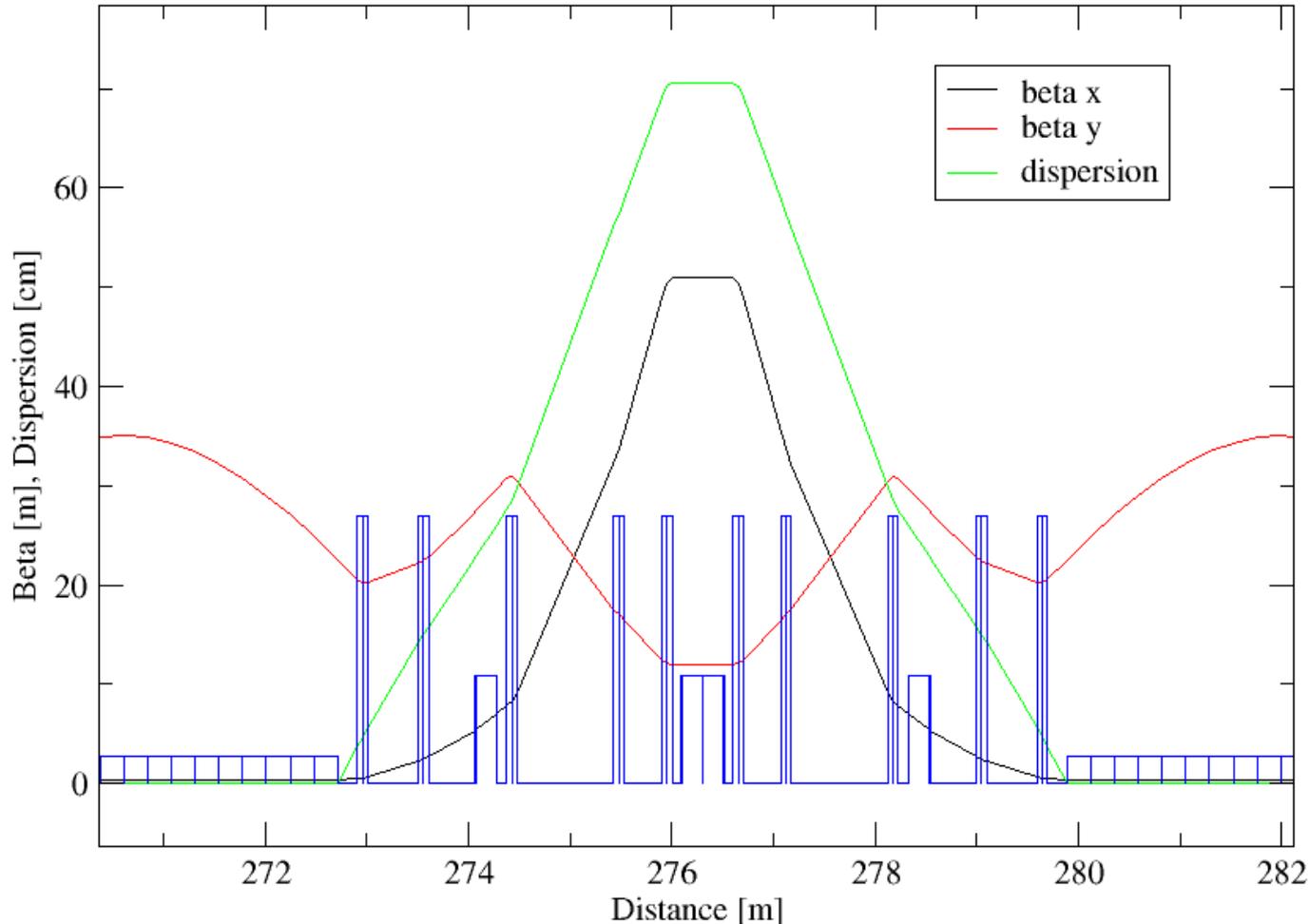
- We chose a very small k_y
 - the wiggler is focusing in the horizontal direction
 - the horizontal chromaticity is corrected by the sextupole component of the field.

Injection into the wiggler under an angle



- The wigglers don't have half strength cells at the ends. Instead the beam is injected into the wiggler under an angle of 10.37 degrees
- After $\frac{1}{2}$ wiggler period the beam is bend back onto the wiggler axis.
- 18 wigglers
- 2.385 Tesla peak field
- Wiggler period 23.28 cm
- Full gap 2 cm
- 18 periods per wiggler
- Total length 4.19 m
- Radiation per wiggler 674 W

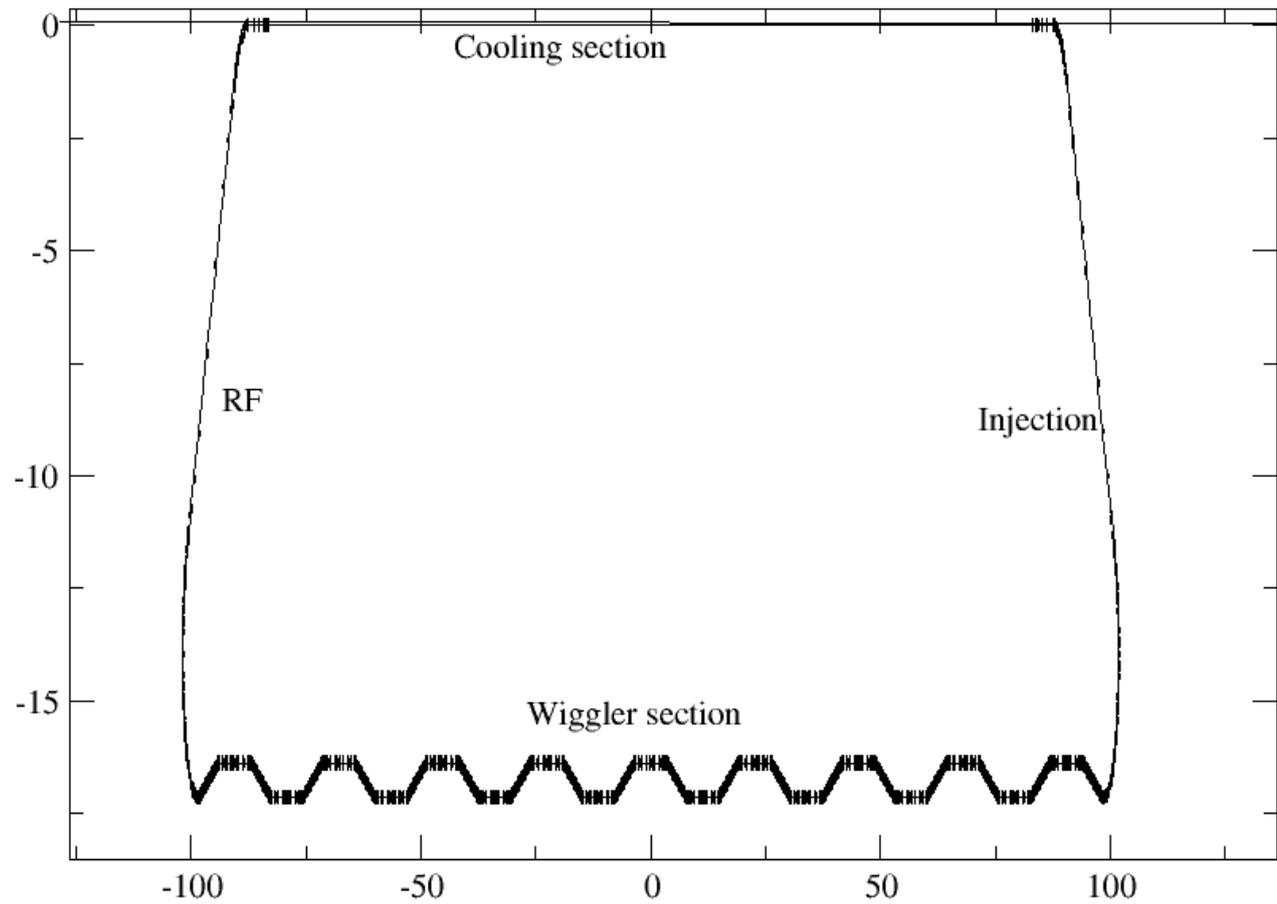
Optics between wigglers



H is constant outside dipoles

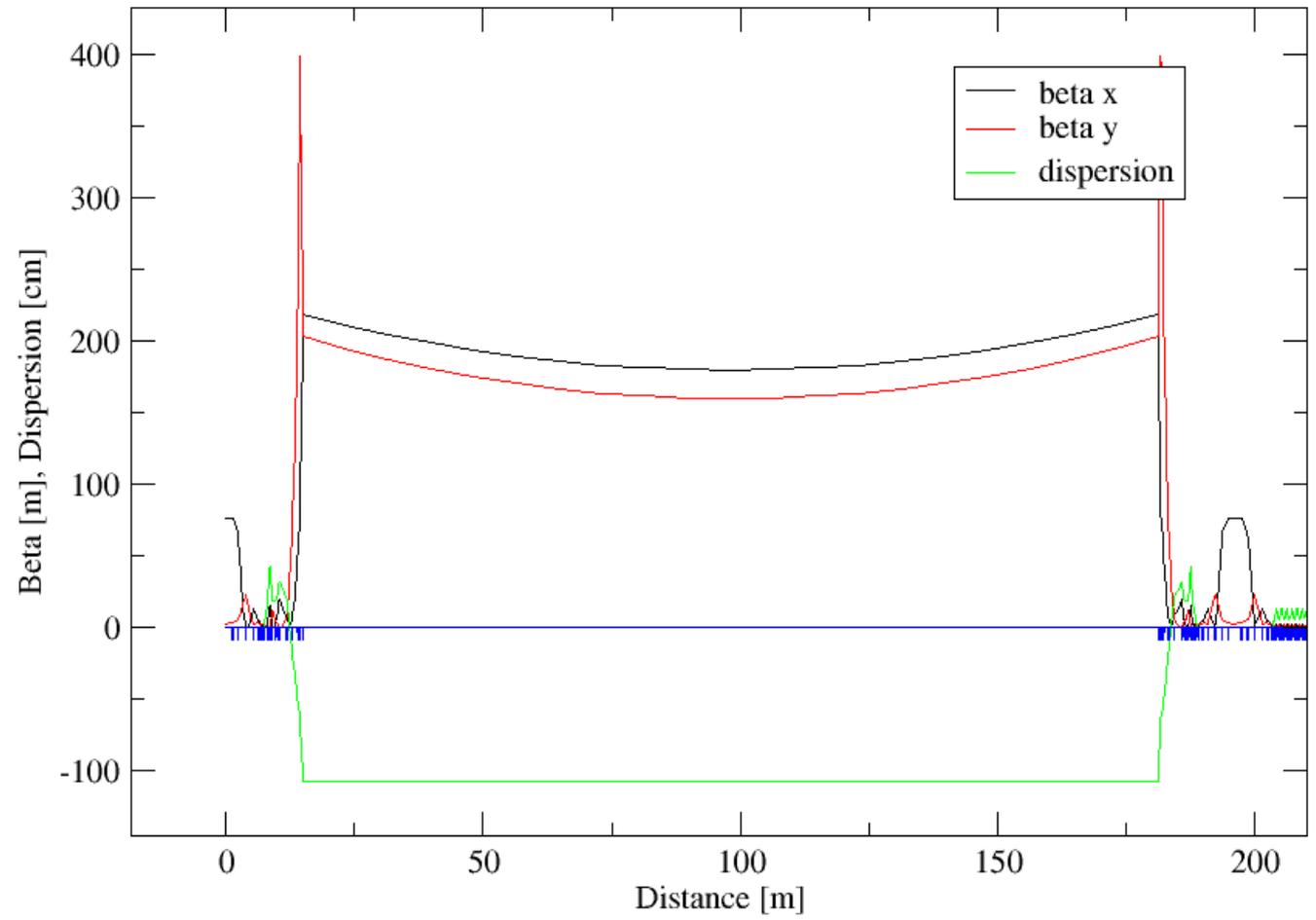
$$H = \frac{D^2}{\beta} + 2\alpha DD' + \beta D'^2$$

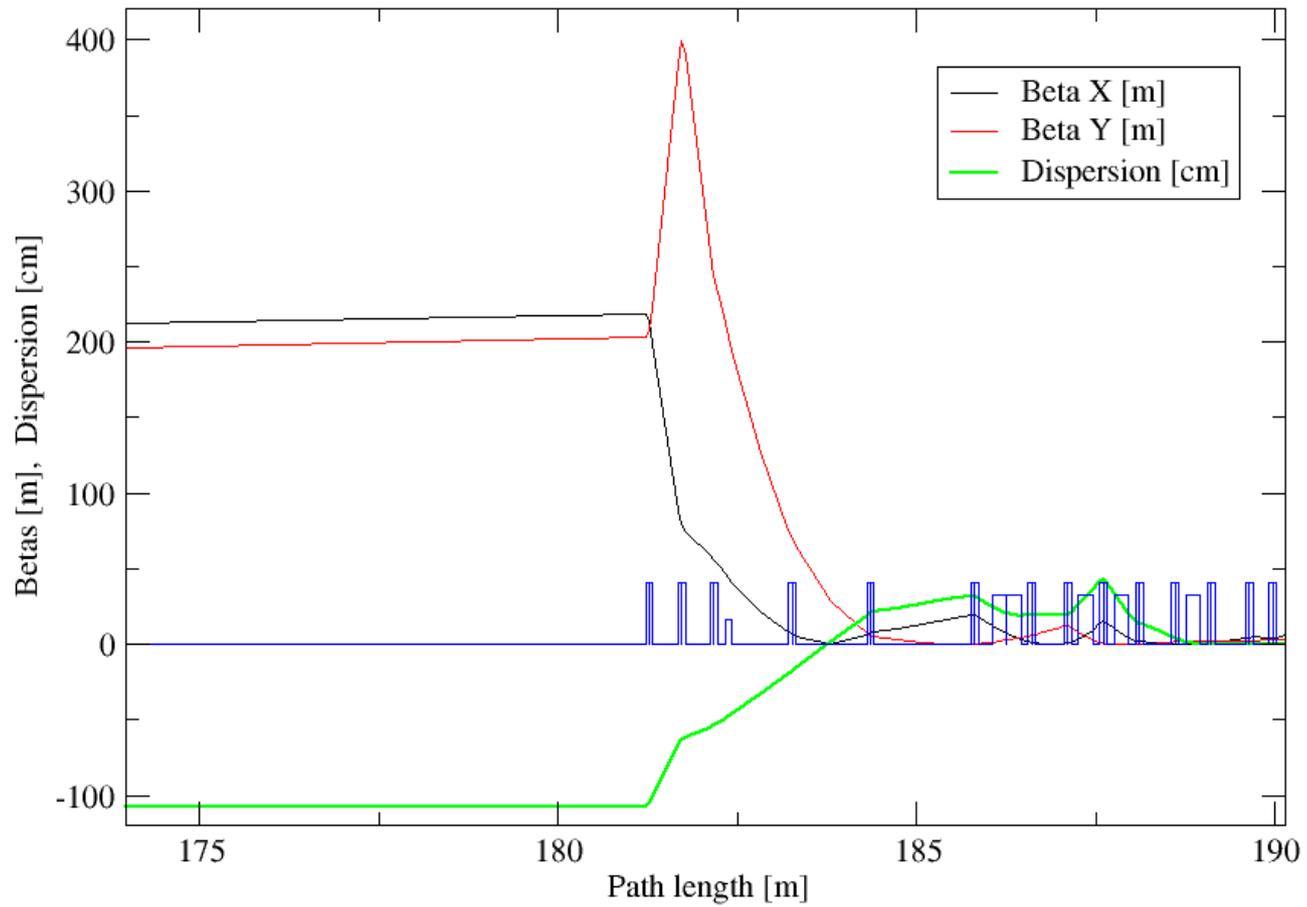
The phase advance from one wiggler to the next is a sensitive parameter for the optimization of the dynamic aperture



Cooling section

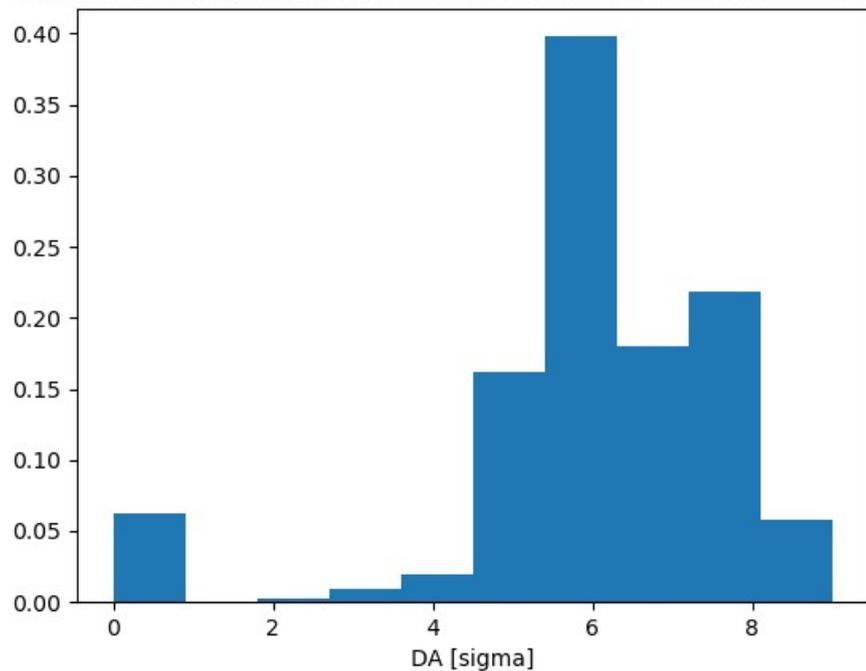
- Redistribution of cooling from longitudinal to horizontal direction is needed to provide 2 hrs of horizontal and 3 hrs of longitudinal cooling times
- Both the electron and ion beam have horizontal dispersion in the cooling section.
 - Ions 2.1 m, electrons 1m
- Increasing the dispersion increases redistribution, but also increases BBS heating and electron emittance.





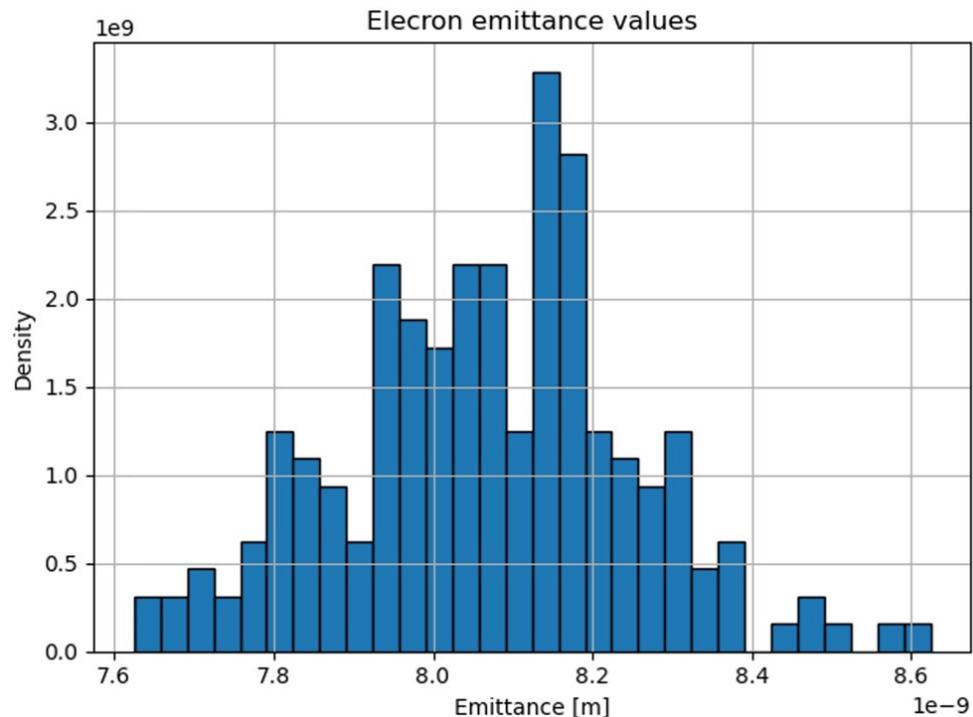
Misalignment tolerances

DA spread for misalignments after correction with 10um BPM errors



Error RMS values:

| | |
|---------------------|------------------------|
| Wigg: 50 μ m | Sextupole: 100 μ m |
| Quad: 50 μ m | BPM: 10 μ m |
| Dipole: 100 μ m | |



BPM and kicker at every quadrupole

Sextupoles set for linear chromaticity

Courtesy of J. Unger²⁰

Conclusion

- We found a compromise correcting the chromaticity, while keeping the emittance low
- The optics has a sufficient dynamic aperture in the presence of alignment and field errors