Arc Optics, global Q’ correction and emittance variation

Bastian Haerer (CERN BE-ABP-LAT, Karlsruhe Institute of Technology (KIT))
for the FCC-ee lattice design team

FCC-ee Week 2016
11-15 April 2016

SPONSORED BY THE
Federal Ministry of Education and Research

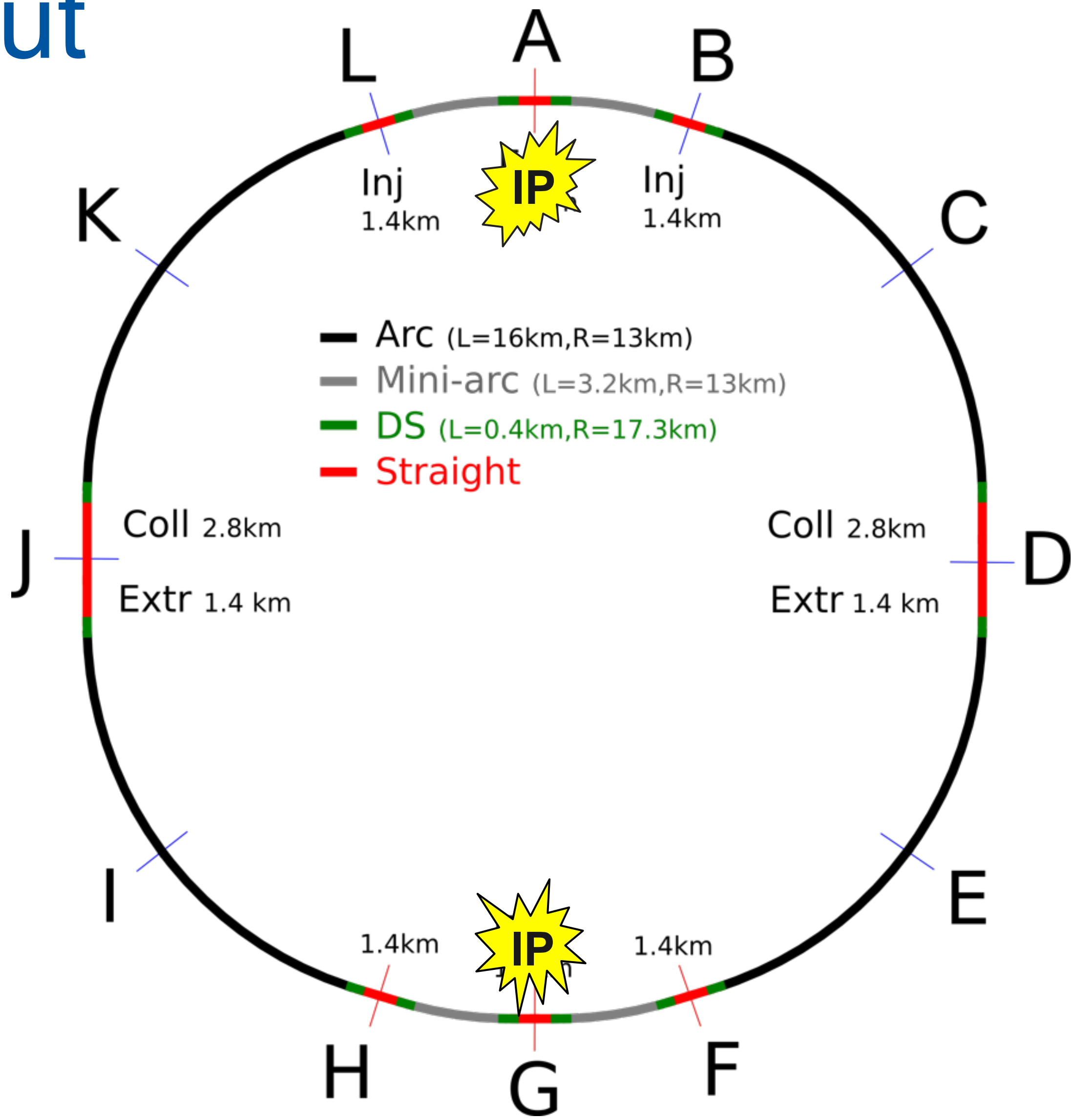
Karlsruhe Institute of Technology

Arc Lattice

Courtesy Michael Hauschild

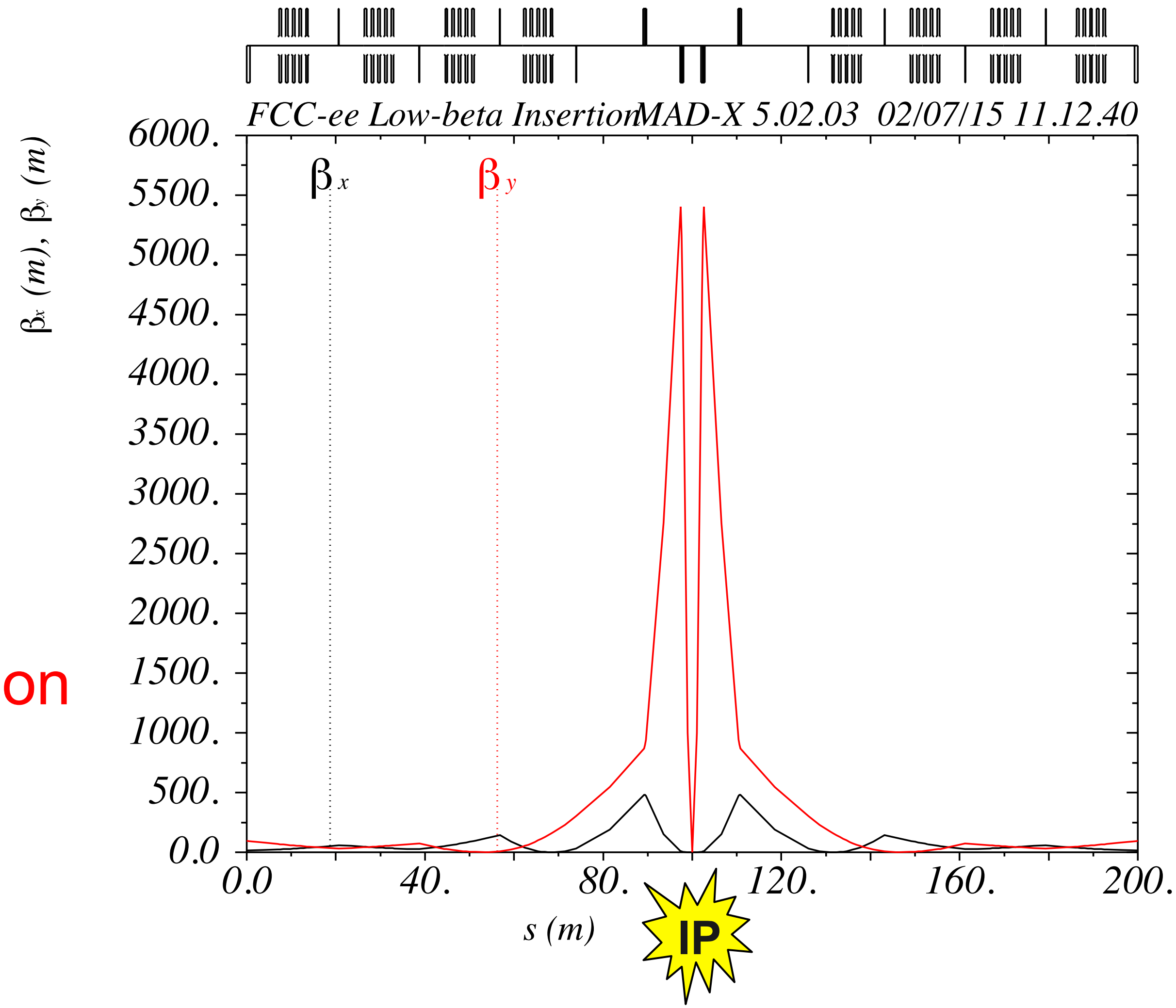
FCC-ee Layout

- 100 km circumference
- 2 IPs / Experiments
- 6 Long Straight Sections
- 2 Extended Straight Sections



Interaction Region

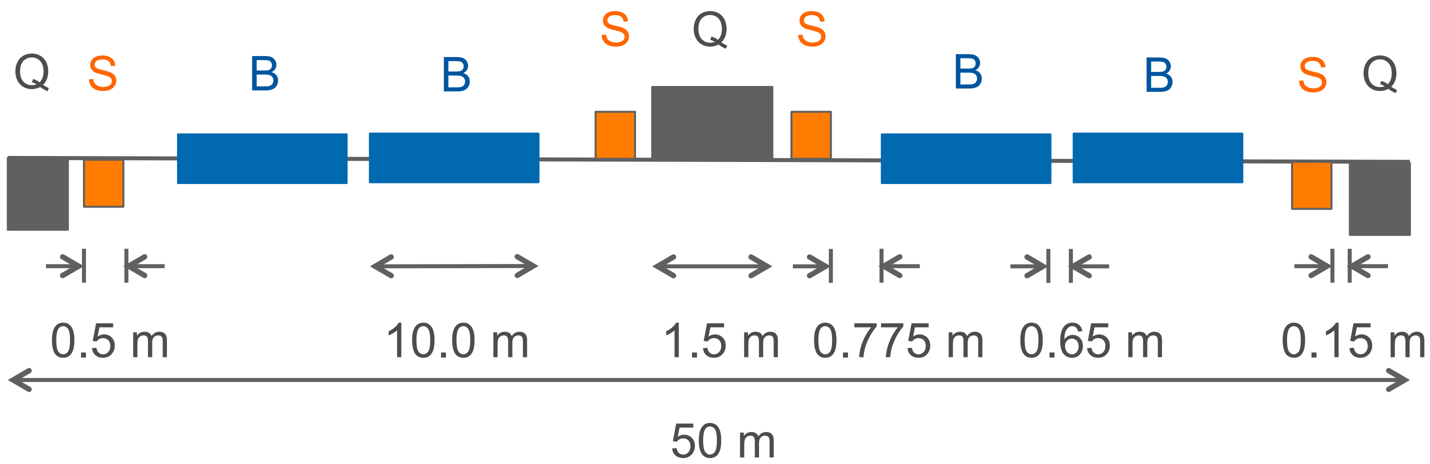
- 2 IPs
  β* = 1m/2mm
  L* = 2 m
- Optimisation
  of the arc lattice:
  → no local CCS
  in the interaction
  regions



Arc FODO cell

Completely symmetric!

Layout already considers space for absorbers, flanges etc.!



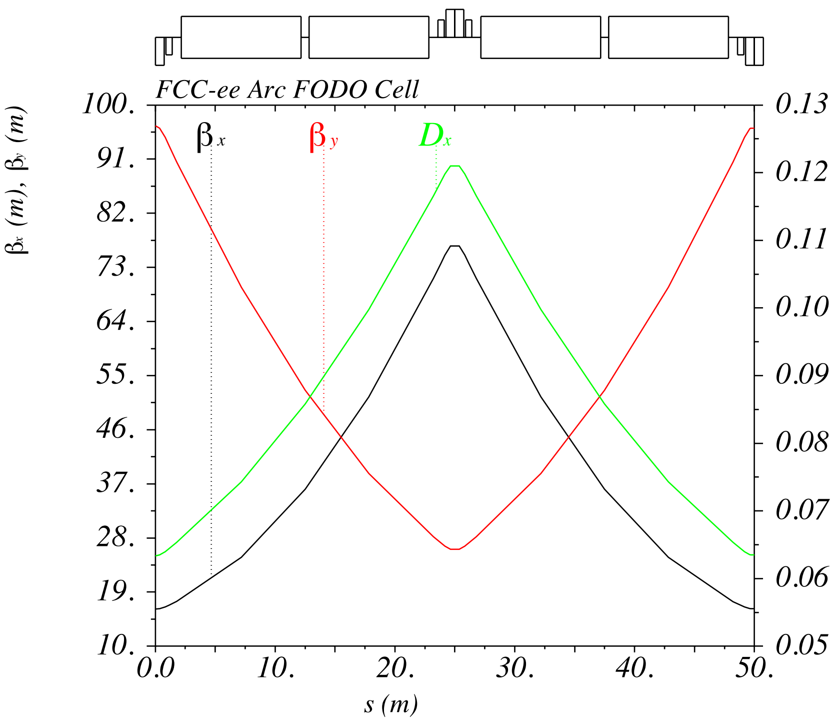
B = bending magnet, Q = quadrupole, S = sextupole

$N_{dipoles}$ = 6152 (192 half bend)
($\rho \approx$ 9.79 km, θ = 1.02 mrad, B = 60 mT)

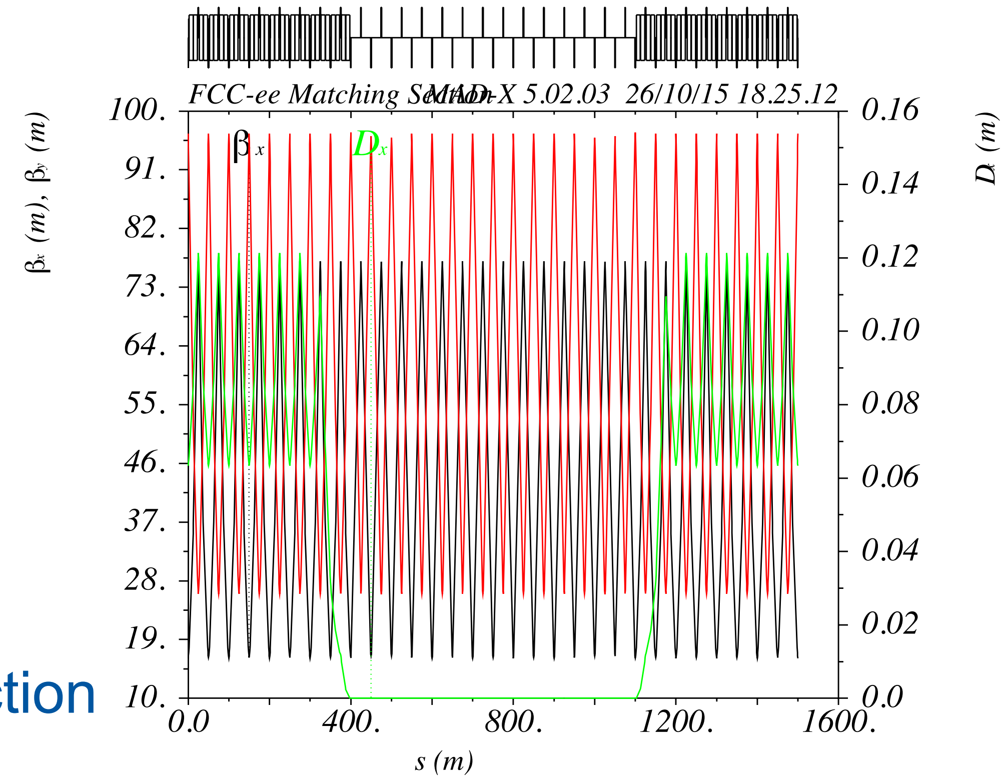
Phase advance:
Ψ = 90°/60°

Optical functions

Arc FODO cell



Mini straight section



Horizontal emittance

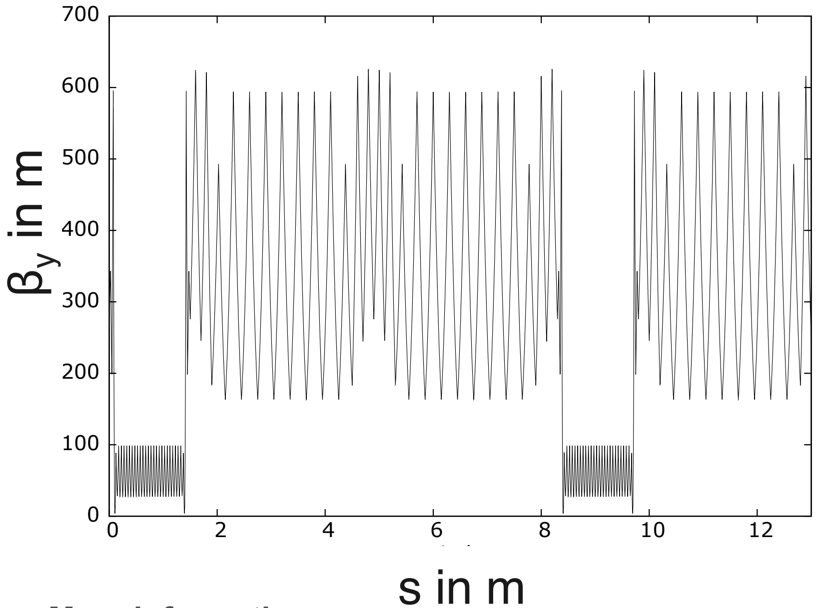
- Lattices with modified cell length were studied to obtain required horizontal emittances

$$\varepsilon = \left(\frac{\delta p}{p}\right)^2 \left(\gamma D^2 + 2\alpha D D' + \beta D'^2\right)$$

$$\hat{D} = \frac{L_{cell}^2}{\rho} \cdot \left(1 + \frac{1}{2}\sin\left(\frac{\psi_{cell}}{2}\right)\right) \Big/ \sin^2\left(\frac{\psi_{cell}}{2}\right)$$

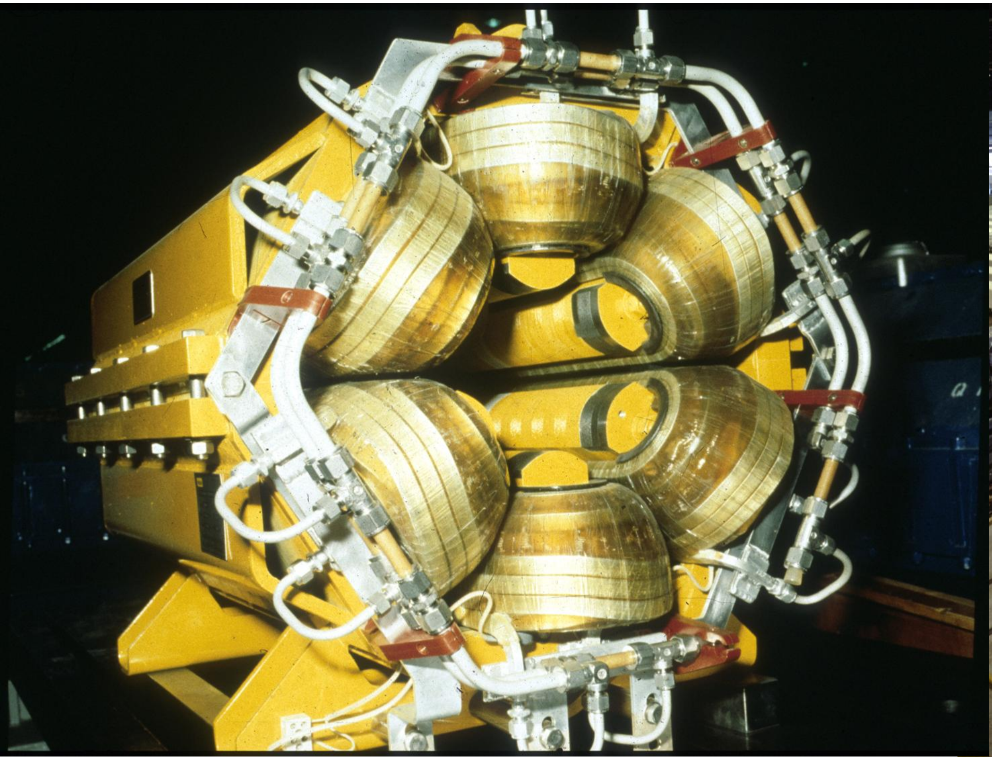
Beam energy	Cell length L	Emittance ε_x
175 GeV	50 m	1.00 nm rad
120 GeV	50 m	0.47 nm rad
80 GeV	100 m	1.74 nm rad
45.5 GeV	300 m	14.15 nm rad

Cell length 300 m



More information:
B. Haerer, FCC-ee: Lattice optimization and emittance tuning, FCC-Week 2015, Washington, D.C.

Global Q' correction



Sextupole magnet for LEP

Hall full of LEP magnets waiting to be installed in November 1987

Chromaticity

- Change of the tune with energy deviation
- Textbook: $\Delta Q = \xi \cdot \Delta p / p$
- In our case not precise enough: $\left(\delta = \Delta p / p\right)$

$$Q(\delta) = Q_0 + \frac{\partial Q}{\partial \delta}\delta + \frac{1}{2}\frac{\partial^2 Q}{\partial \delta^2}\delta^2 + \frac{1}{6}\frac{\partial^3 Q}{\partial \delta^3}\delta^3 + \ldots$$

Natural chromaticity compared

	β^*_y = 1 mm	β^*_y = 2 mm	ΔQ (δp = 0.1 %, β^*_y = 2 mm)
Q_x	503.08	505.08	
Q_x'	-584.26	-587.67	-1.18
Q_x''	-3818.40	-3847.84	-0.01
$Q_x^{(3)}$	-1.43×10^8	-1.52×10^8	-0.20
$Q_x^{(4)}$	1.45×10^{13}	-1.41×10^{13}	-9.40
Q_y	335.14	337.14	
Q_y'	-2059.23	-860.42	-1.72
Q_y''	-4.18×10^6	-1.04×10^6	-2.09
$Q_y^{(3)}$	-1.19×10^{11}	-0.21×10^{11}	-27.75
$Q_y^{(4)}$	-4.53×10^{15}	-0.53×10^{15}	-351.67

Montague functions

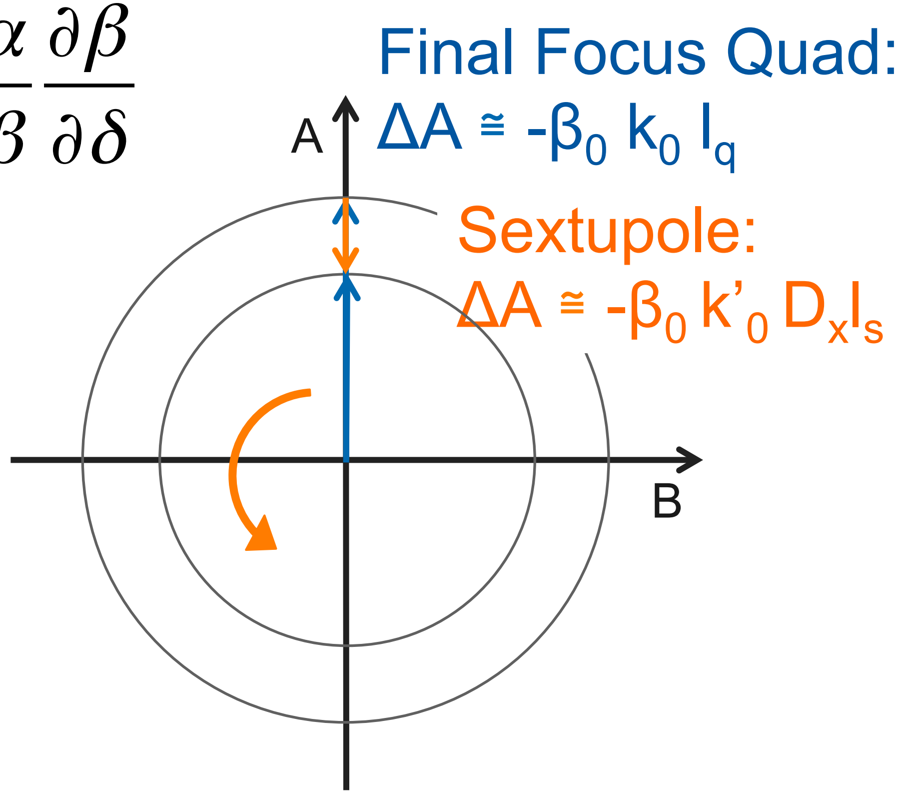
- Chromatic variables

$$B = \frac{1}{\beta}\frac{\partial \beta}{\partial \delta} \qquad A = \frac{\partial \alpha}{\partial \delta} - \frac{\alpha}{\beta}\frac{\partial \beta}{\partial \delta}$$

- W-vector

$$\vec{W} = \frac{1}{2}\left(B + iA\right)$$

$$= \frac{1}{2}\sqrt{A^2 + B^2}\, e^{i2\psi}$$

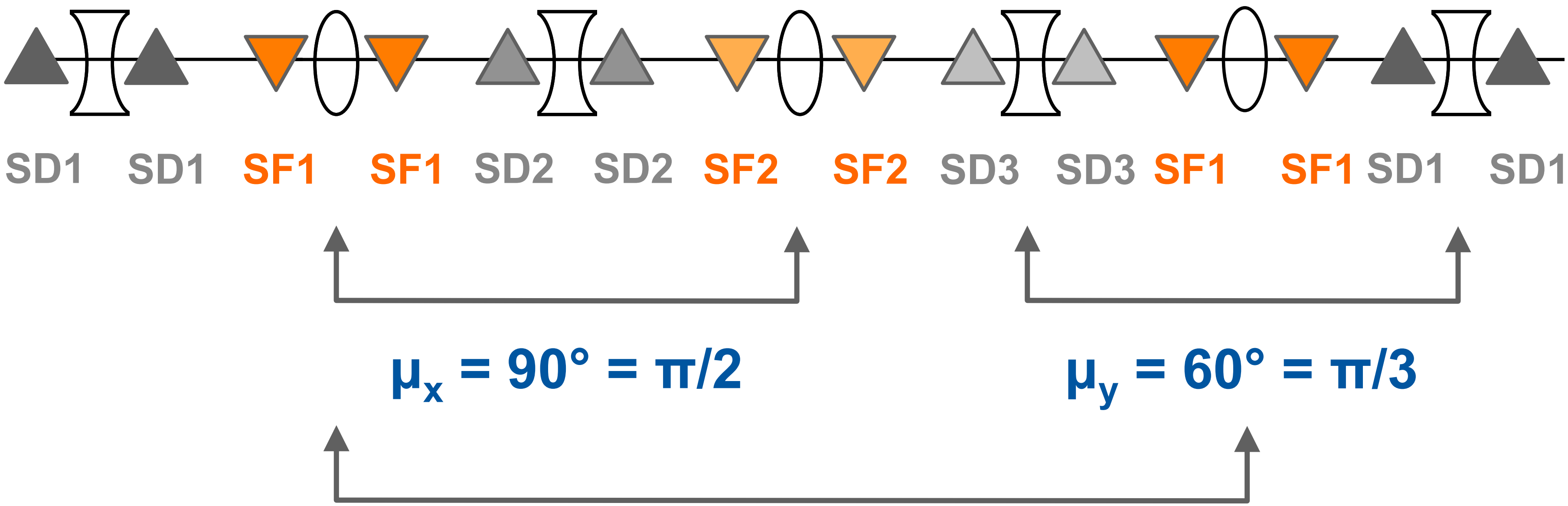


Rotates with twice the phase advance!

FCC-ee sextupole scheme

Horizontal plane: 2 families

Vertical plane: 3 families

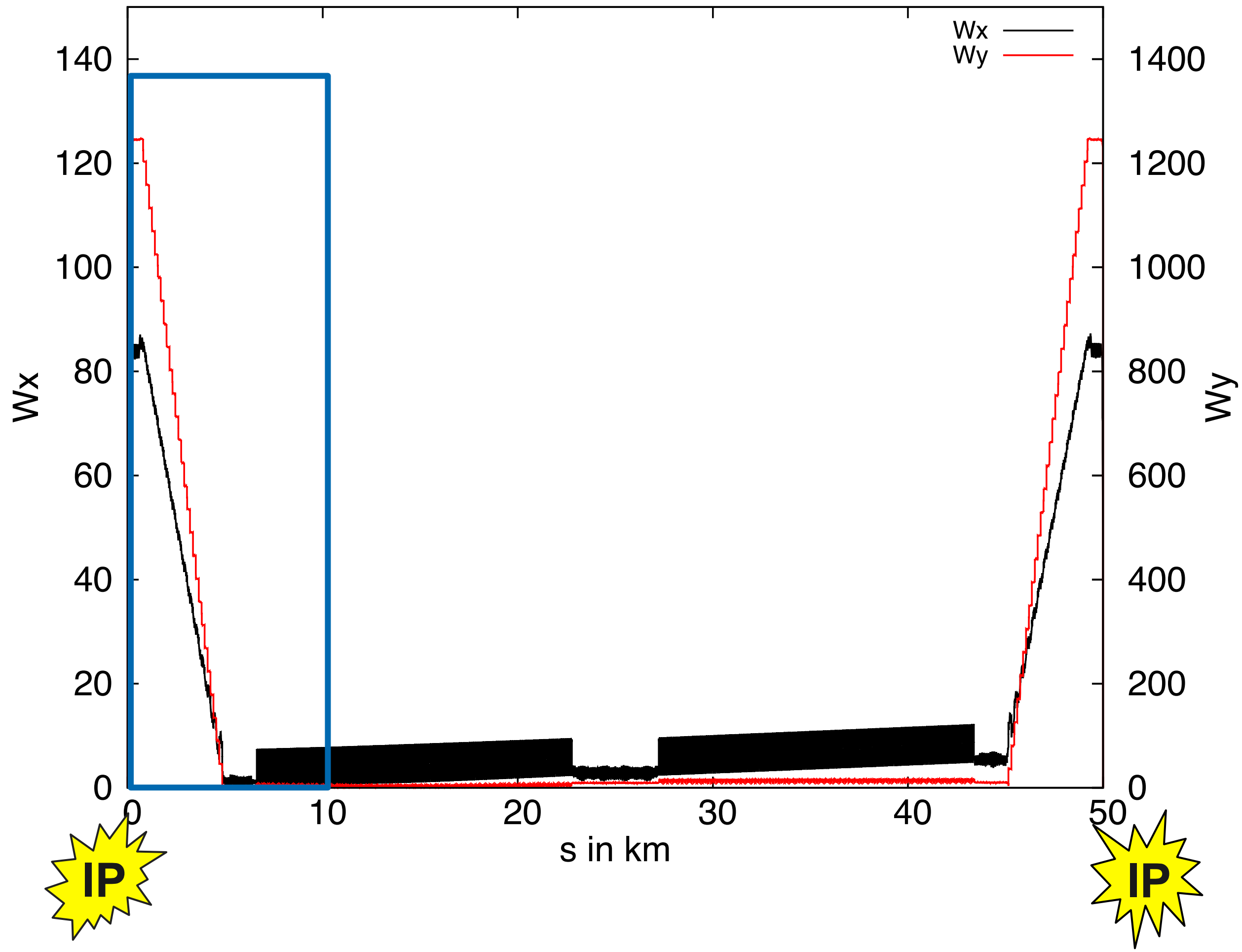


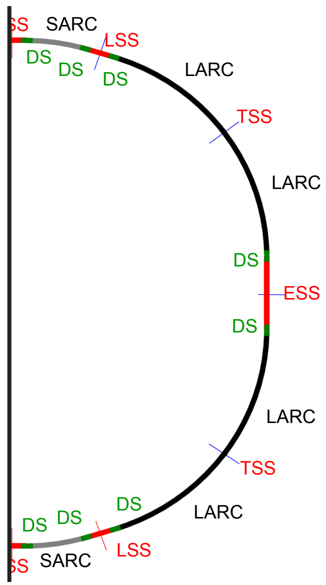
$\mu_x = 90° = \pi/2$

$\mu_y = 60° = \pi/3$

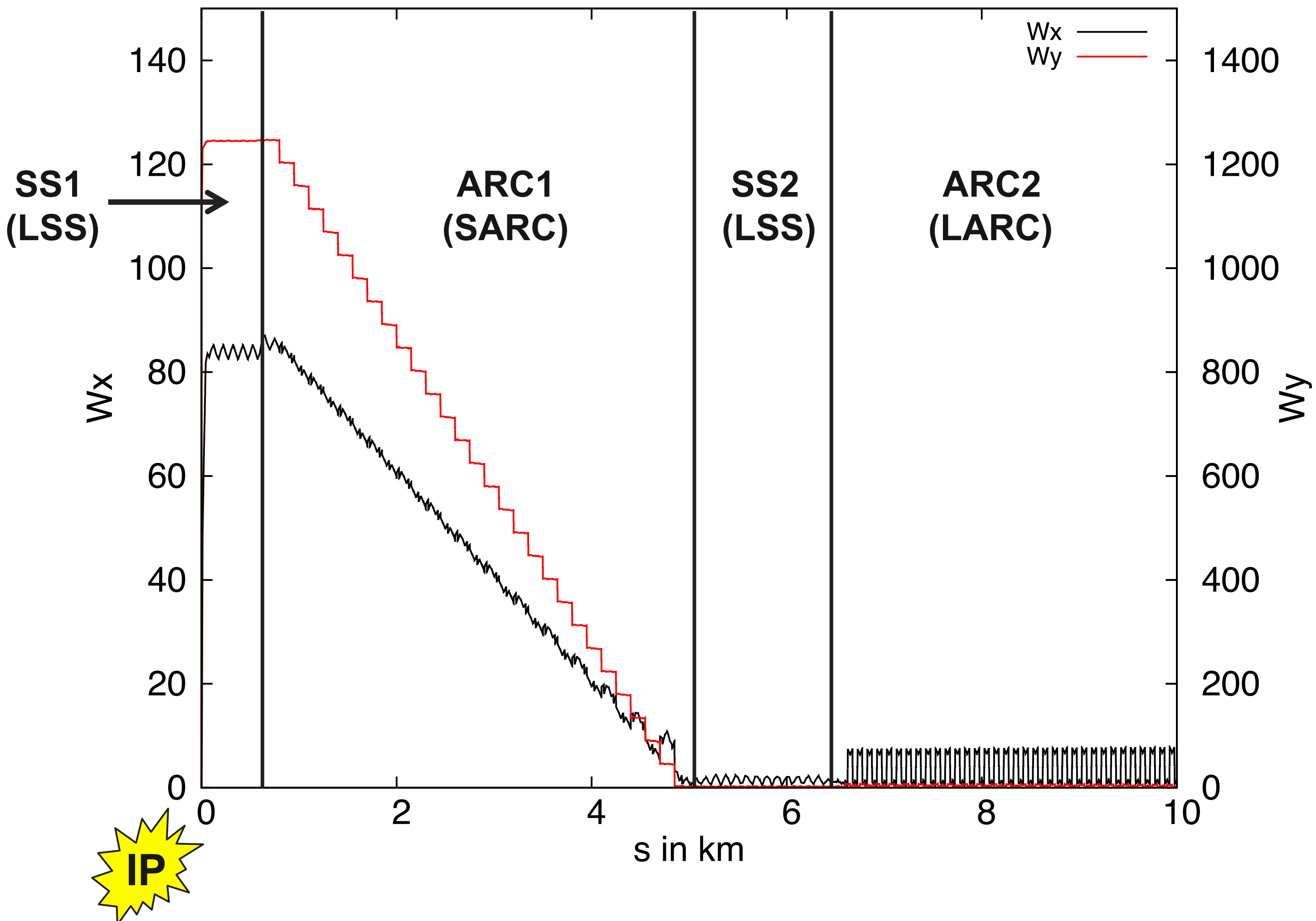
$\mu_x = 180° = \pi$ (→ -I transformation)

W functions in the half-ring

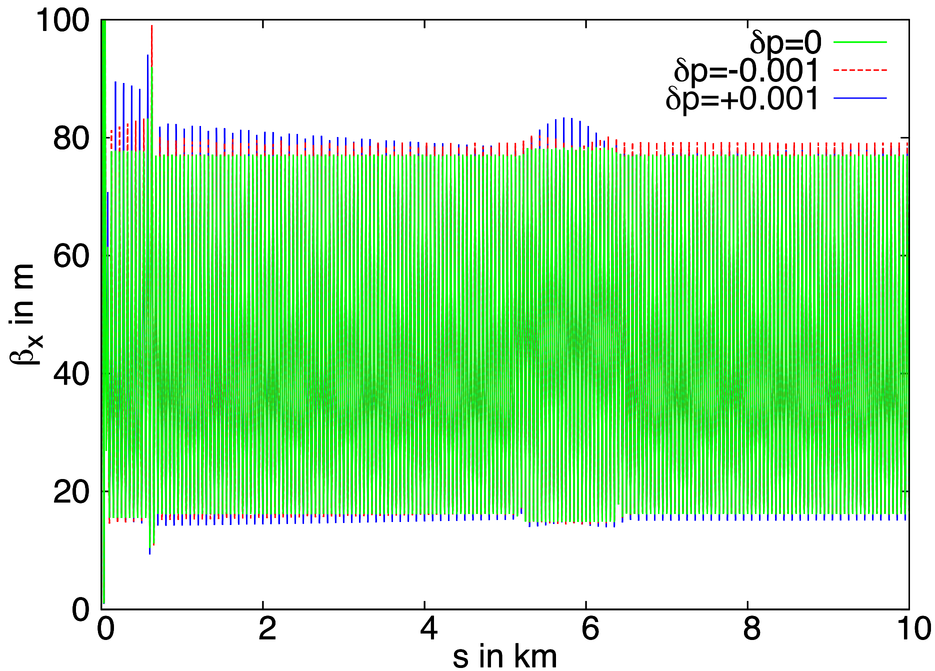




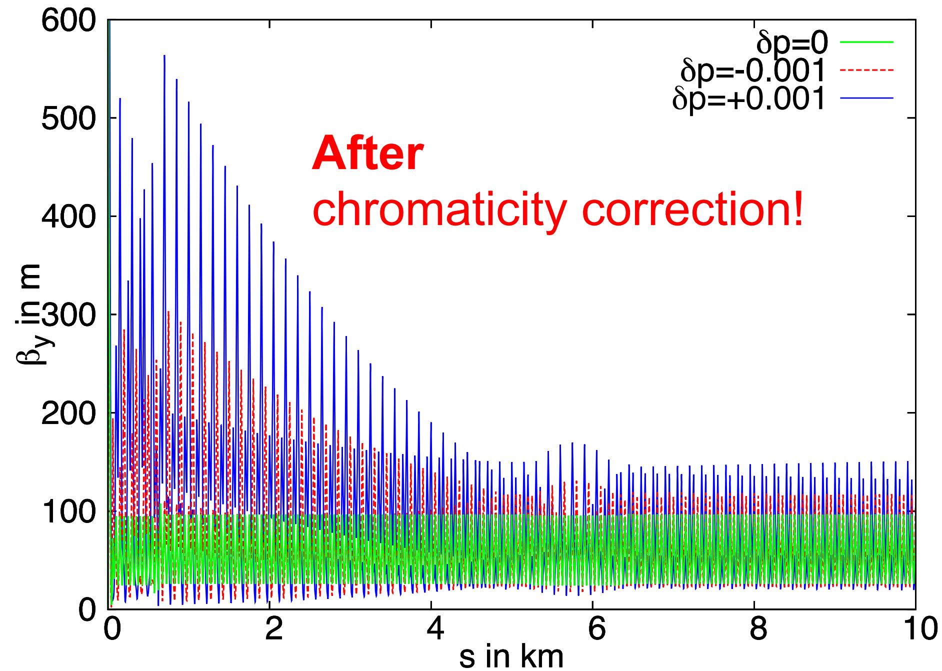
W functions: 0-10 km



Beta functions



x plane



y plane

- Relative energy deviation $\delta p/p = \pm 0.001$

Momentum acceptance

- At 175 GeV beam energy 2 % energy acceptance is required due to energy loss by beamstrahlung at the IP

  → Matching of the W functions is not sufficient

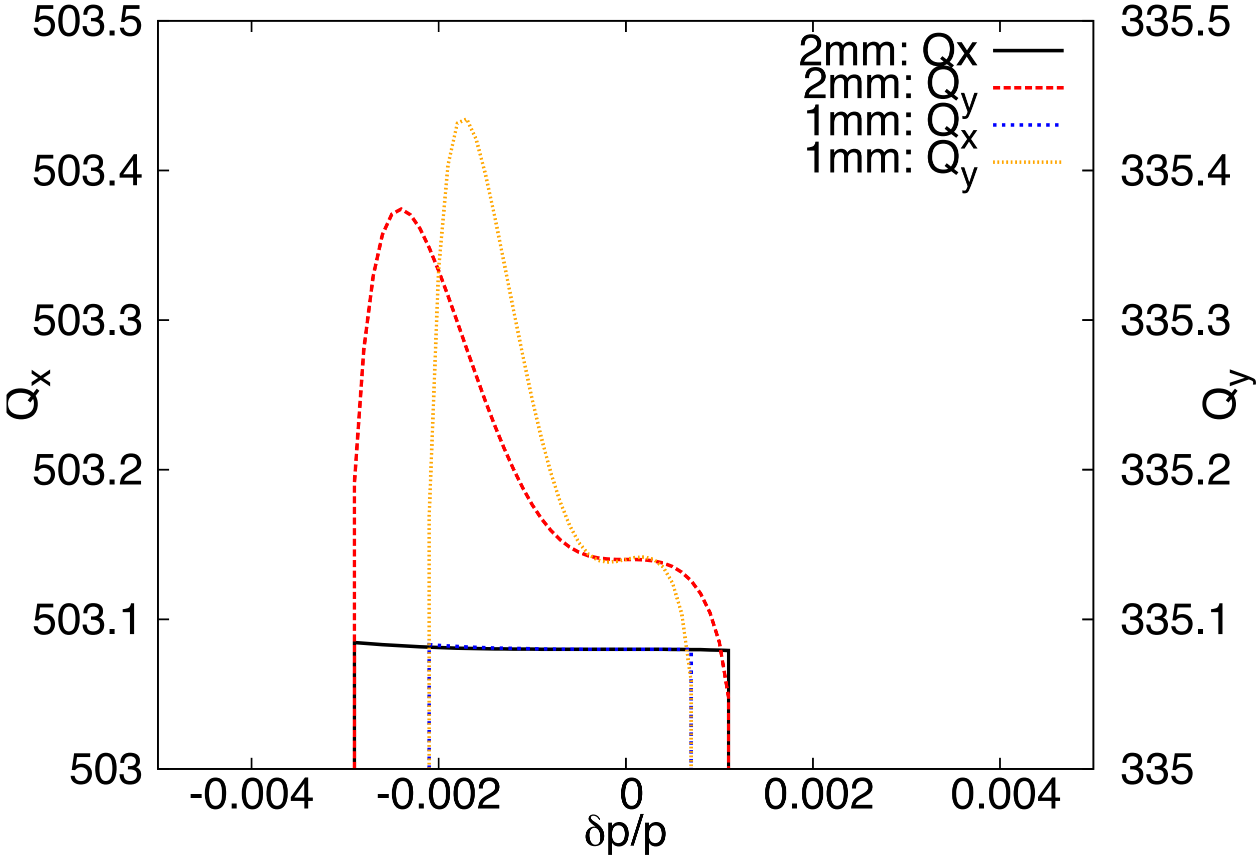
- **The tune is a function of the energy deviation**

$$Q(\delta) = Q_0 + \frac{\partial Q}{\partial \delta}\delta + \frac{1}{2}\frac{\partial^2 Q}{\partial \delta^2}\delta^2 + \frac{1}{6}\frac{\partial^3 Q}{\partial \delta^3}\delta^3 + \ldots$$

Modify tune function to increase momentum acceptance by

- Choice of β^*_y
- Modifying the linear chromaticity
- Different sextupole schemes
- Different optimisation methods

Choice of β^*_y



β^*_y = 1 mm:

[-0.21%, 0.07%]

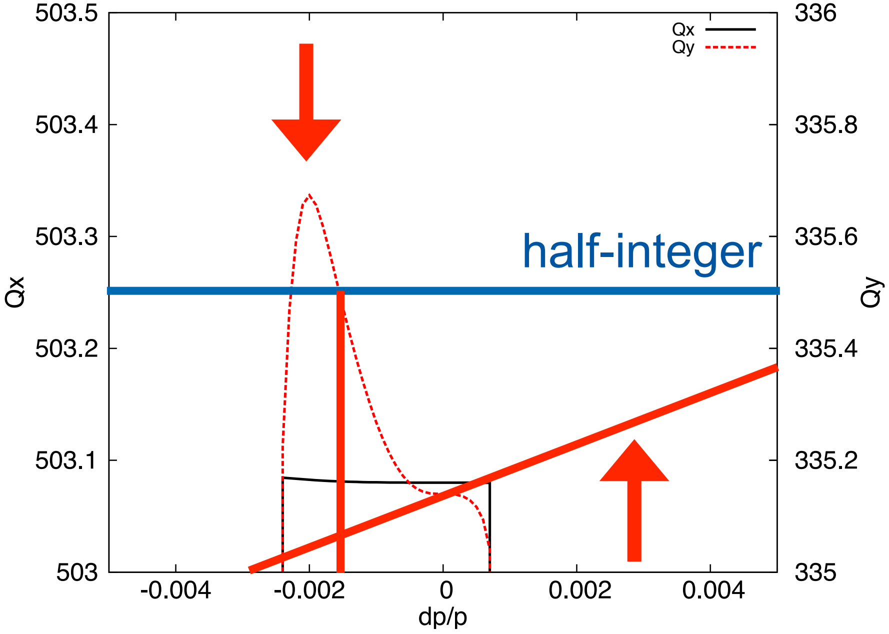
β^*_y = 2 mm:

[-0.29%, 0.11%]

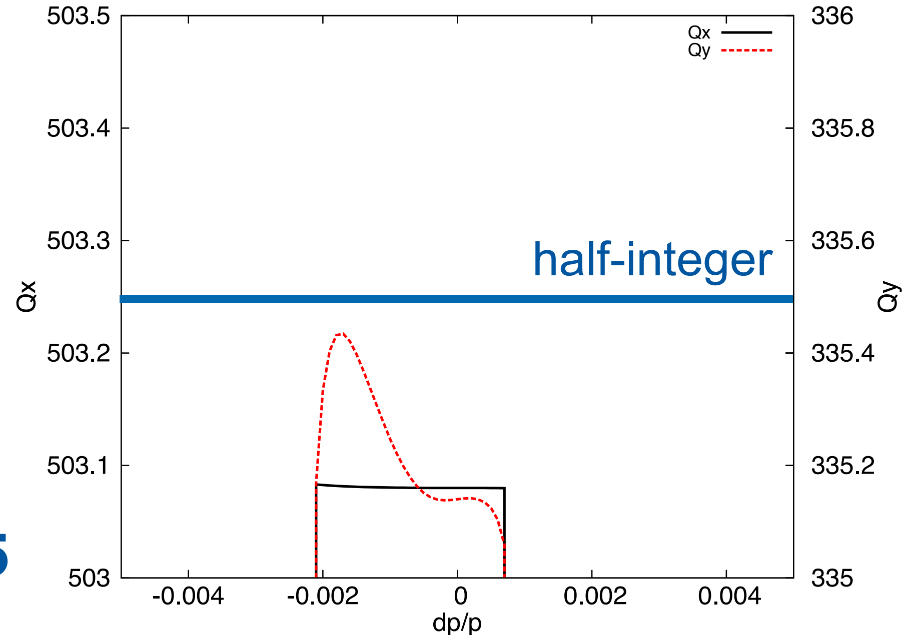
+43 %

Optimising the momentum acceptance

$Q'_y = 0$ **[-0.15%, 0.07%]**

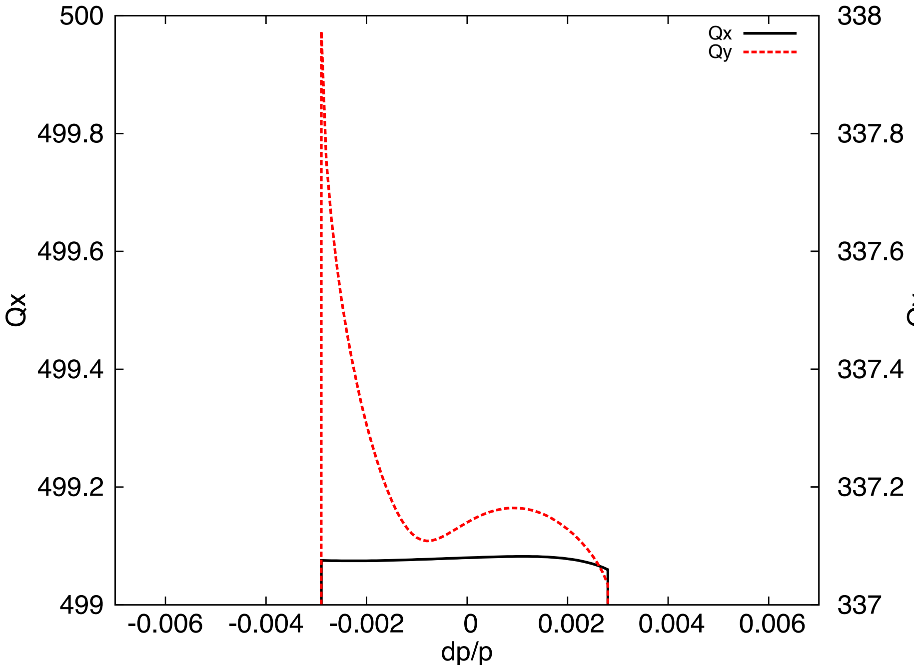


add linear chromaticity

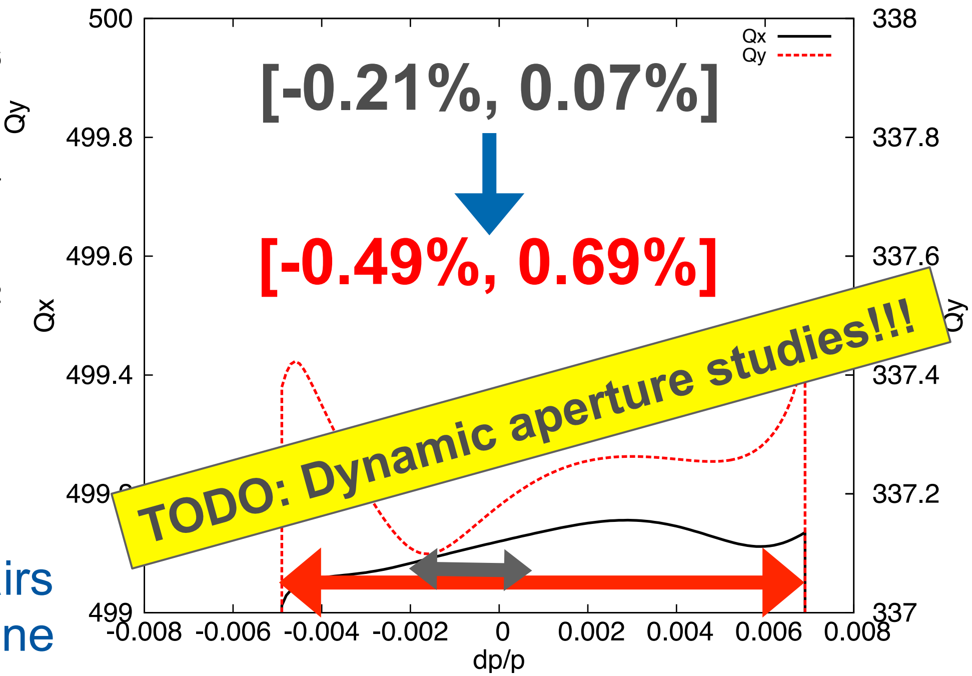


[-0.21%, 0.07%] $Q'_y = 15$

Different sextupole schemes



6 sextupole families per arc per plane

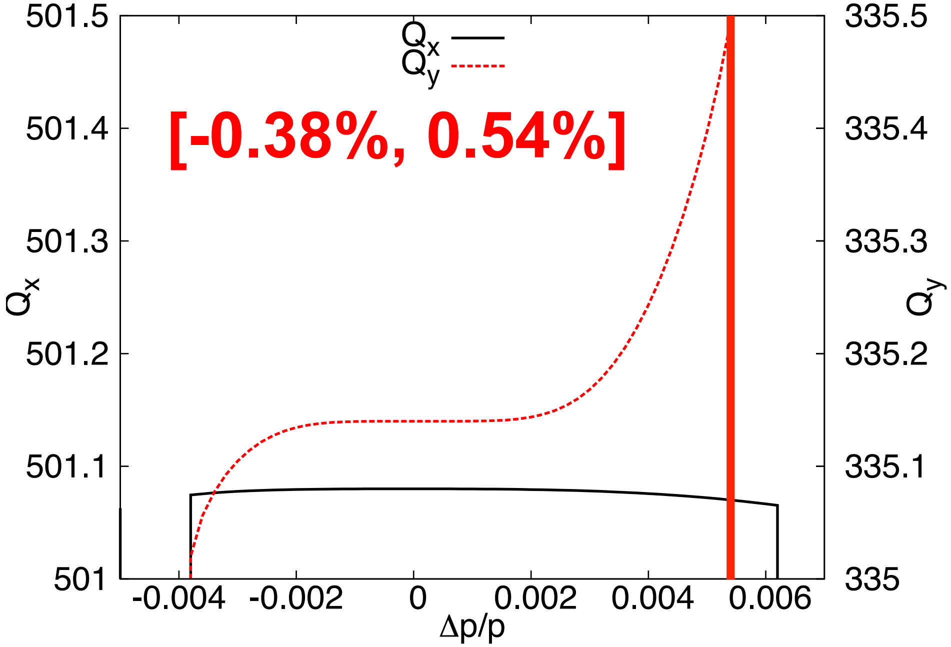


6 sextupole families + 12 free sextupole pairs per arc per plane

Vary individual sextupole pairs to flatten Q(Δp/p)

Downhill-Simplex-Optimisation

Algorithm implemented in Fortran calls MAD-X and optimises strengths of 6/6, 12/12 and 54/54 families



Largest momentum acceptance: 6/6 families per plane

Andreas Doblhammer

Summary of the last year

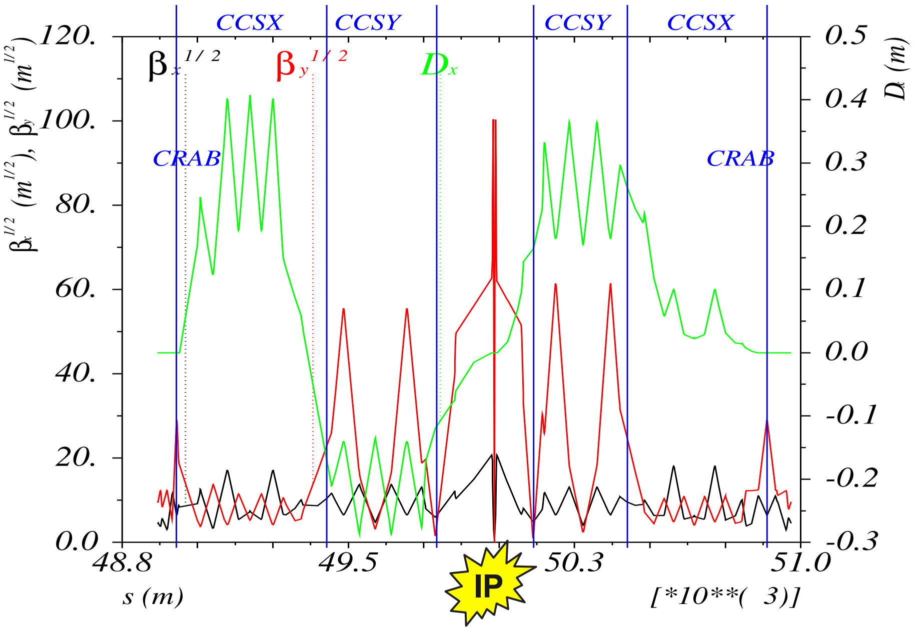
- Sextupole schemes for global Q' correction have been studied systematically

- Methods to increase momentum acceptance have been developed with considerable success!

- Sophisticated sextupole scheme for the arcs is worth to be studied
  → Momentum acceptance has been increased by >5 times
  → Relaxes requirements for the local CCS

Outlook

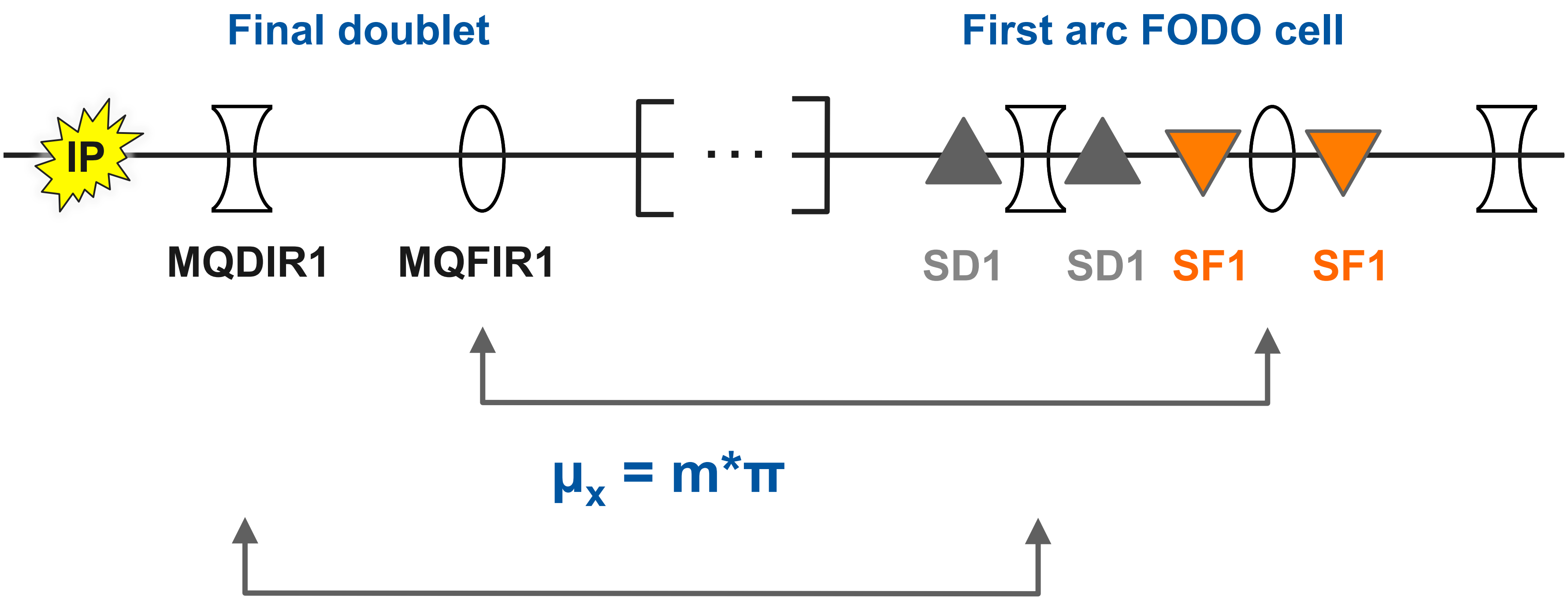
Interaction region designed byA. Bogomyagkov:



- Combine optimised arcs with local chromaticity correction scheme (CCS)
- Maybe remove local CCS of horizontal plane
- Dynamic aperture studies!

Thank you for your attention!

Phase advance FD – 1st Sext.



$\mu_x = m*\pi$

$\mu_y = n*\pi$

(m,n integer)