

Crab waist interaction region for FCC-ee and the arc second attempt (one quarter of the ring IR: v. 6-14-3, arc: v14)

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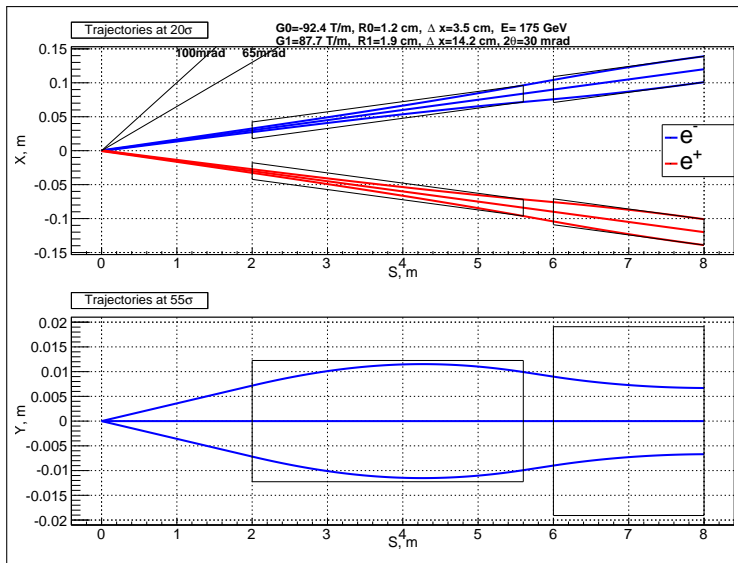
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Parameters for crab waist

| | Z | W | H | tt |
|---|-------------|------|-----|-----|
| Energy [GeV] | 45 | 80 | 120 | 175 |
| Perimeter [km] | 100 | | | |
| Crossing angle [mrad] | 30 | | | |
| Particles per bunch [10^{11}] | 1 | 4 | 4.7 | 4 |
| Number of bunches | 29791 | 739 | 127 | 33 |
| Energy spread [10^{-3}] | 1.1 | 2.1 | 2.4 | 2.6 |
| Emittance hor. [nm] | 0.14 | 0.44 | 1 | 2.1 |
| Emittance ver. [μm] | 1 | 2 | 2 | 4.3 |
| β_x^*/β_y^* [m] | 0.5 / 0.001 | | | |
| Luminosity / IP [$10^{34} \text{ cm}^{-2} \text{ s}^{-1}$] | 212 | 36 | 9 | 1.3 |
| Energy loss / turn [GeV] | 0.03 | 0.3 | 1.7 | 7.7 |

Final Focus layout

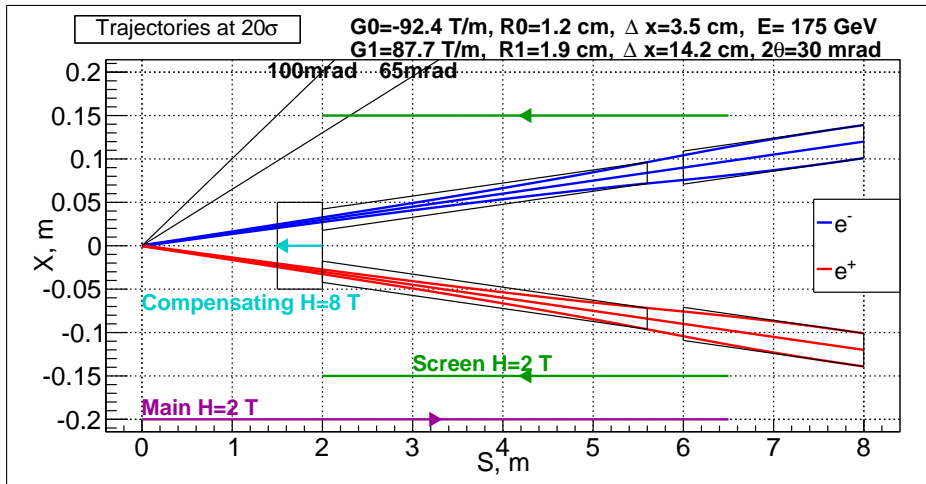


Rectangles represent bare apertures.

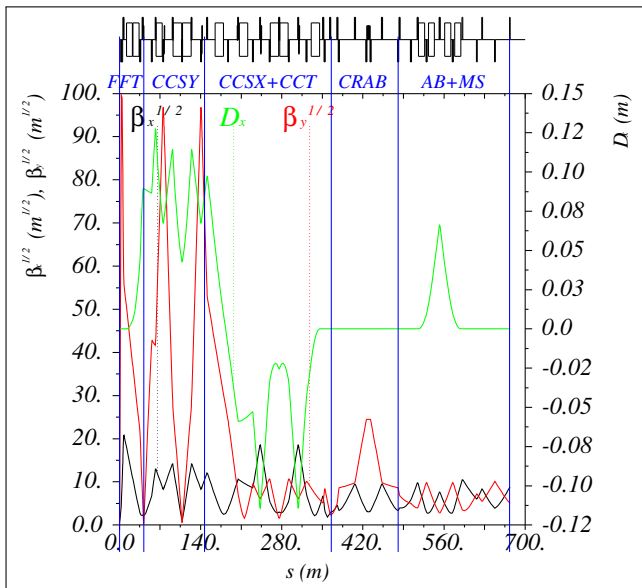
| | L [m] |
|----|-------|
| Q0 | 3.6 |
| Q1 | 2 |

| | R [m] |
|----|-------|
| Q0 | 0.012 |
| Q1 | 0.019 |

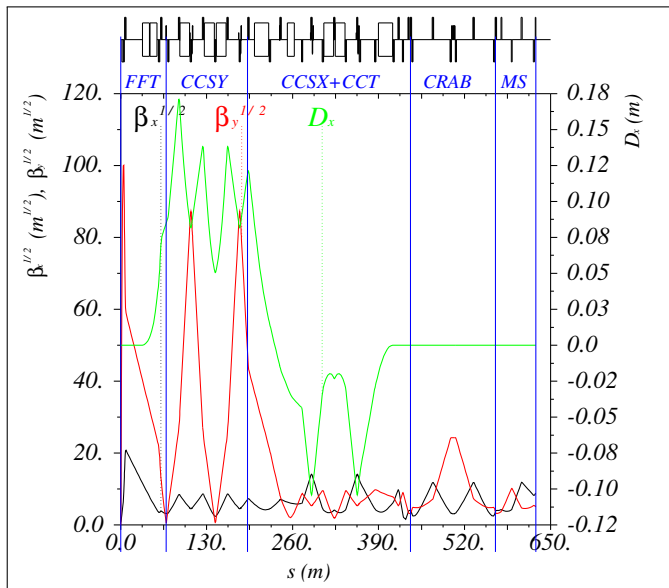
Final Focus layout: sketch of solenoids



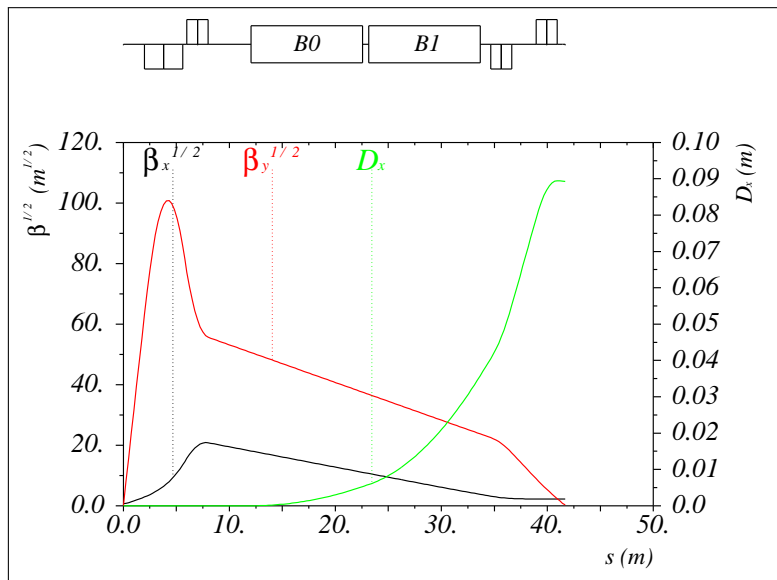
Interaction Region optical functions: Old



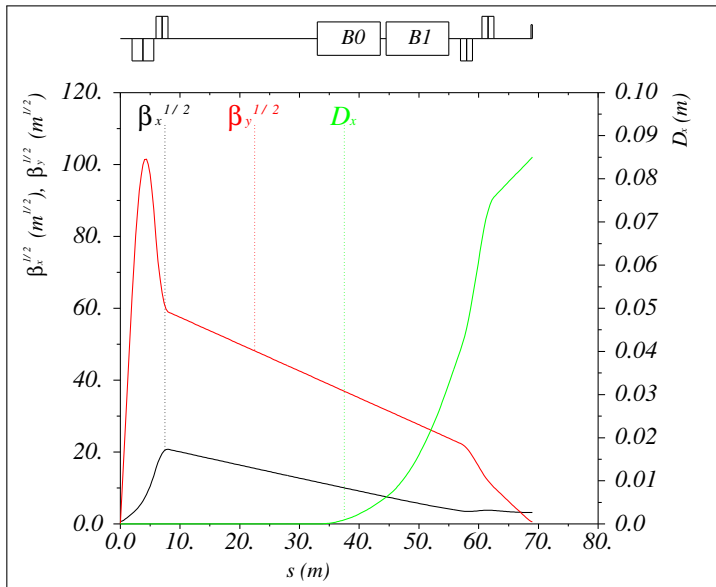
Interaction Region optical functions: New



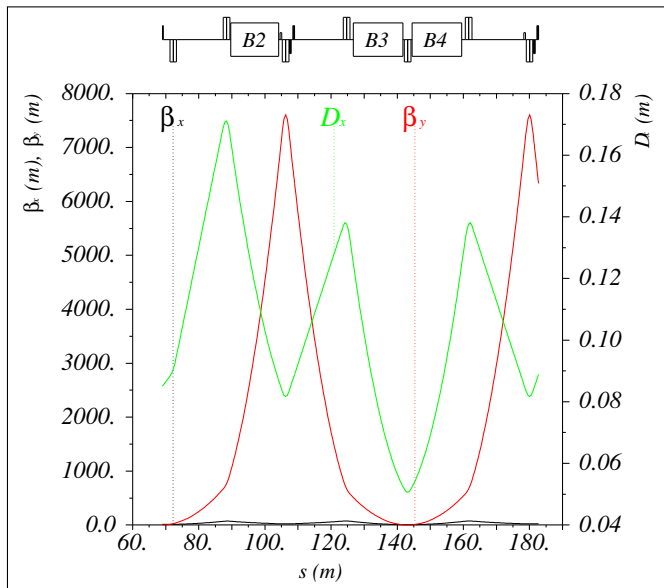
Final Focus Telescope: Old



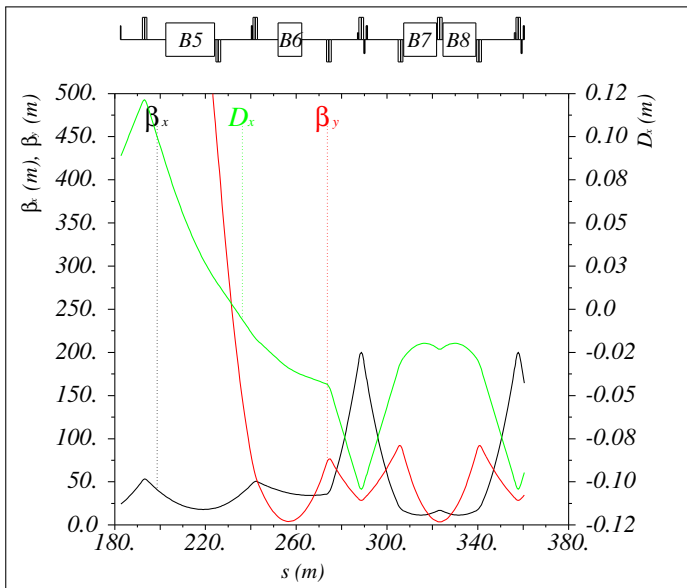
Final Focus Telescope: New



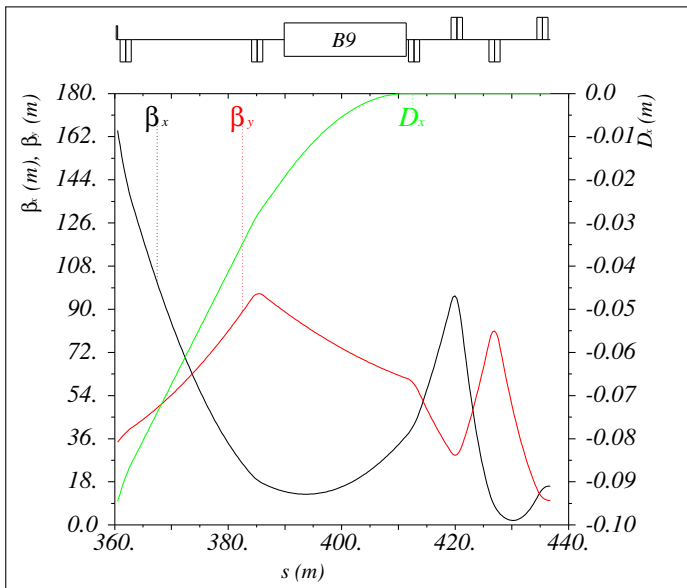
Y Chromaticity Correction Section



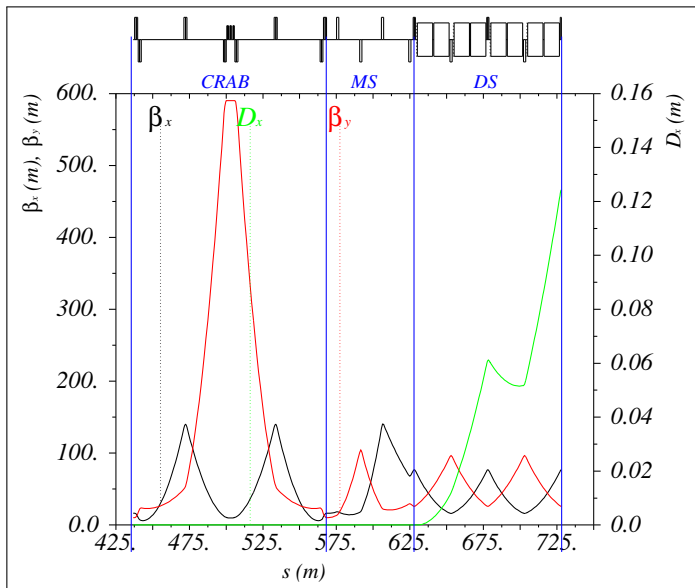
X Chromaticity Correction Section



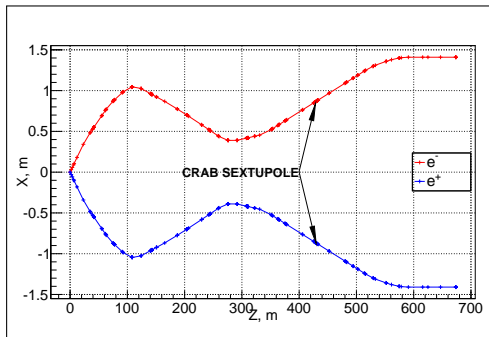
Chromaticity Correction Telescope



CRAB, MS, DS sections



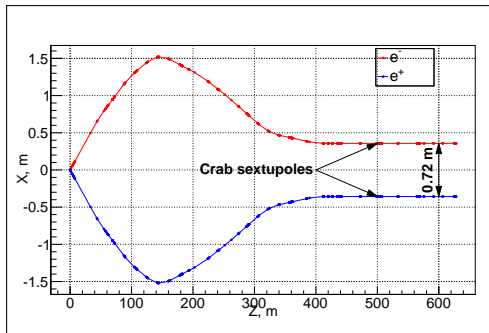
Interaction Region layout: Old



Before the achromatic bend at the crab sextupole each beam is diverging at ± 4.4 mrad.
Energy loss $\Delta U = 0.11$ GeV

| | L [m] | B [T] | ϕ [mrad] |
|-----|----------|----------|------------------|
| B0 | 10.5 | 0.06 | 1 |
| B1 | 10.5 | 0.21 | 3.7 |
| B2 | 10.5 | 0.21 | 3.8 |
| B3 | 14.5 | 0.21 | 5.2 |
| B4 | 14.5 | 0.21 | 5.2 |
| B5 | 14.5 | 0.03 | 0.6 |
| B6 | 14.5 | 0.01 | 0.2 |
| B7 | 14.5 | -0.13 | -3.2 |
| B8 | 14.5 | -0.13 | -3.2 |
| B9 | 14.5 | -0.11 | -2.8 |
| B10 | 10.5 | 0.06 | 1 |

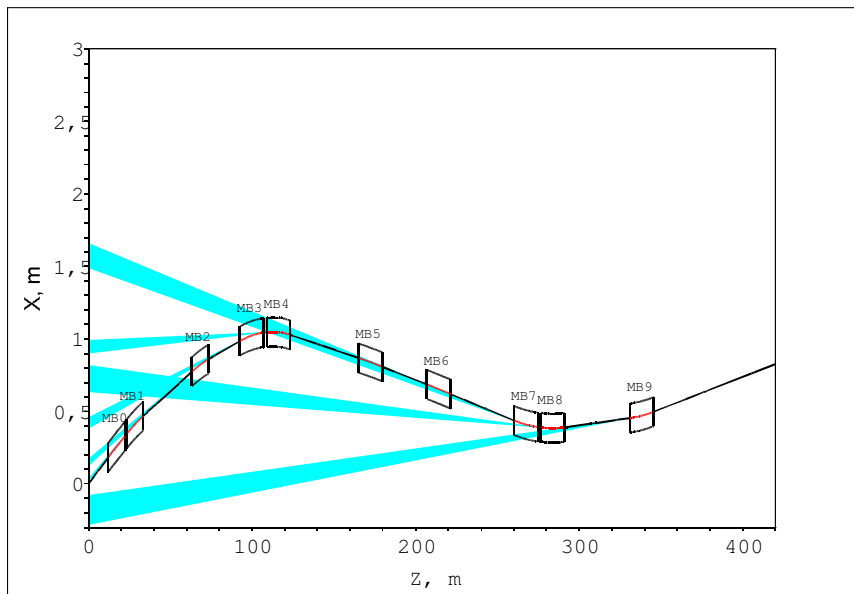
Interaction Region layout: New



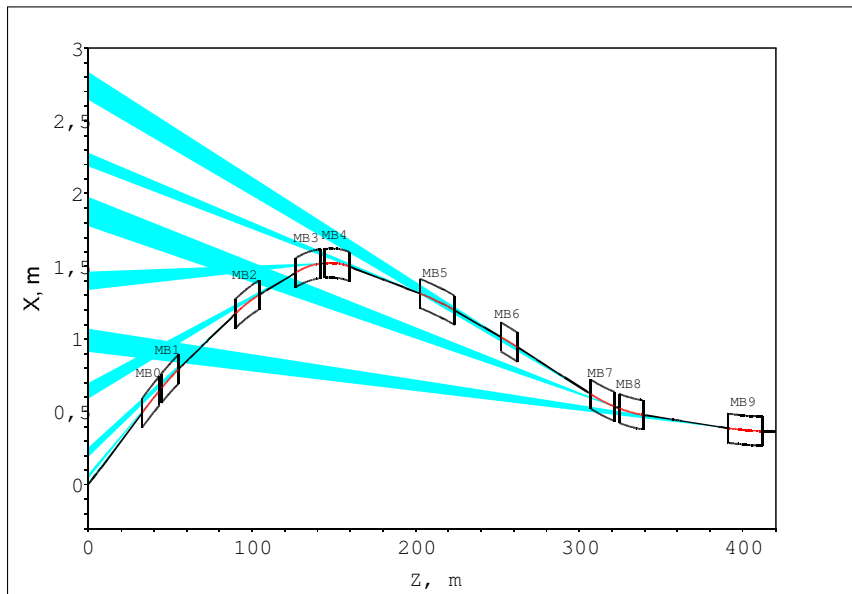
Energy loss $\Delta U = 0.1 \text{ GeV}$

| | L [m] | B [T] | ϕ [mrad] |
|----|----------|----------|------------------|
| B0 | 10.5 | 0.06 | 1 |
| B1 | 10.5 | 0.17 | 3 |
| B2 | 14.5 | 0.17 | 4.2 |
| B3 | 15 | 0.22 | 5.6 |
| B4 | 15 | 0.22 | 5.6 |
| B5 | 21.5 | 0.06 | 2.2 |
| B6 | 10.5 | 0.04 | 0.7 |
| B7 | 14.5 | -0.11 | -2.7 |
| B8 | 14.5 | -0.11 | -2.7 |
| B9 | 21.5 | -0.05 | -1.8 |

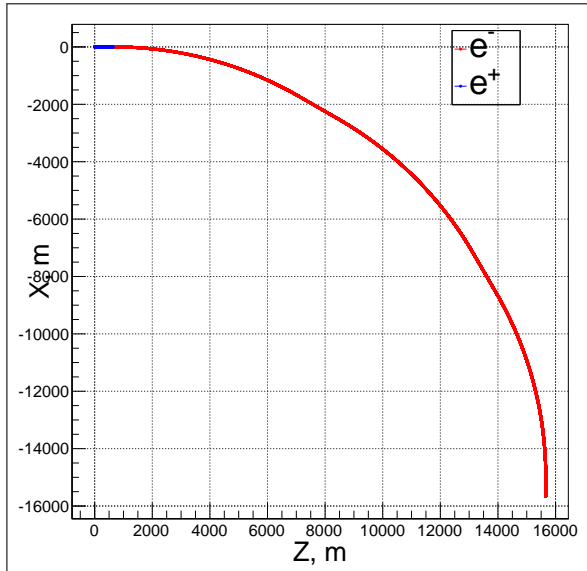
Old synchrotron radiation fans from S. Glukhov



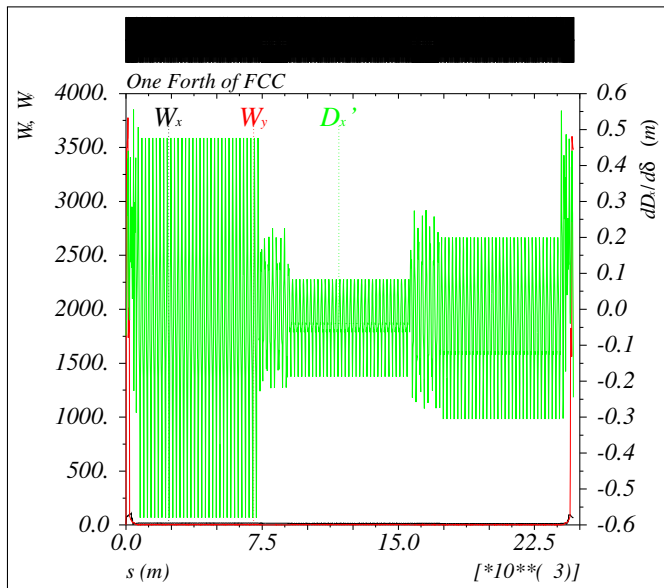
New synchrotron radiation fans from S. Glukhov



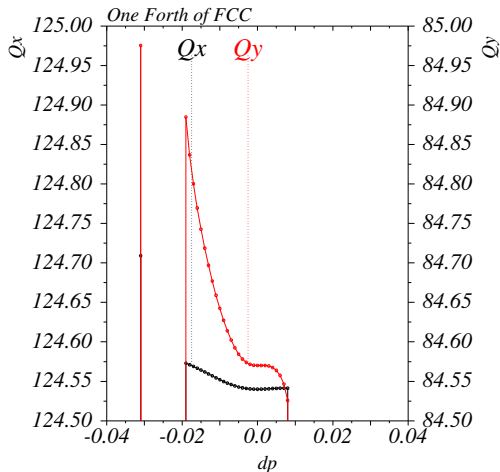
Quarter layout



Chromaticity: Montague functions, {124.54; 84.57}

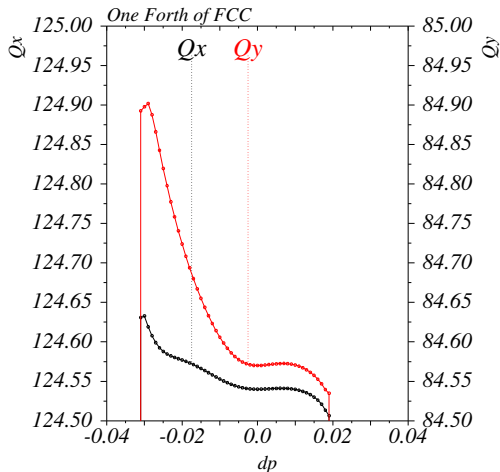


Energy acceptance I: [-1.9%;+0.8%]



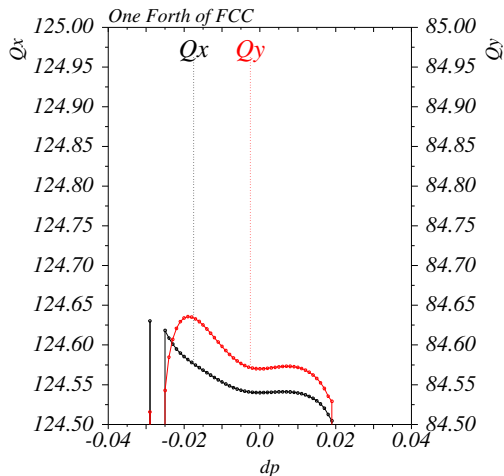
| | Value | $\Delta Q(2\%)$ |
|-----------|-------------------|-----------------|
| Q_x | 124.54 | |
| Q'_x | 0 | 0 |
| Q''_x | 170 | 0.034 |
| Q'''_x | $-4.5 \cdot 10^4$ | -0.059 |
| Q''''_x | $-5.3 \cdot 10^6$ | -0.035 |
| Q_y | 84.57 | |
| Q'_y | 0 | 0 |
| Q''_y | 387 | 0.077 |
| Q'''_y | $-5.3 \cdot 10^5$ | -0.7 |
| Q''''_y | $-4.3 \cdot 10^6$ | -0.029 |

Energy acceptance II: [-3.1%;+1.9%]



| | Value | $\Delta Q(2\%)$ |
|-----------|-------------------|-----------------|
| Q_x | 124.54 | |
| Q'_x | 0 | 0 |
| Q''_x | 170 | 0.034 |
| Q'''_x | $-5.1 \cdot 10^4$ | -0.068 |
| Q''''_x | $-4.8 \cdot 10^6$ | -0.032 |
| Q_y | 84.57 | |
| Q'_y | 0 | 0 |
| Q''_y | 387 | 0.077 |
| Q'''_y | $-1.4 \cdot 10^5$ | -0.182 |
| Q''''_y | $1.9 \cdot 10^6$ | -0.013 |

Energy acceptance (wrong arms of IR): [-2.5%;+1.9%]



| | Value | $\Delta Q(1.5\%)$ |
|-----------|-------------------|-------------------|
| Q_x | 124.54 | |
| Q'_x | 0 | 0 |
| Q''_x | 171 | 0.034 |
| Q'''_x | $-5.3 \cdot 10^4$ | -0.07 |
| Q''''_x | $-4.4 \cdot 10^6$ | -0.029 |
| Q_y | 84.57 | |
| Q'_y | 0 | 0 |
| Q''_y | 387 | 0.077 |
| Q'''_y | $-1.1 \cdot 10^5$ | -0.15 |
| Q''''_y | $9 \cdot 10^6$ | -0.06 |

How does it work (chromaticity estimations)?

Montague functions first order

$$b_{y,1} = \frac{1}{\beta_y} \frac{\partial \beta_y}{\partial \delta},$$

$$a_{y,1} = \frac{\partial \alpha_y}{\partial \delta} - \frac{\alpha_y}{\beta_y} \frac{\partial \beta_y}{\partial \delta}.$$

Montague functions second order

$$b_{y,2} = \frac{1}{\beta_y} \frac{\partial^2 \beta_y}{\partial \delta^2},$$

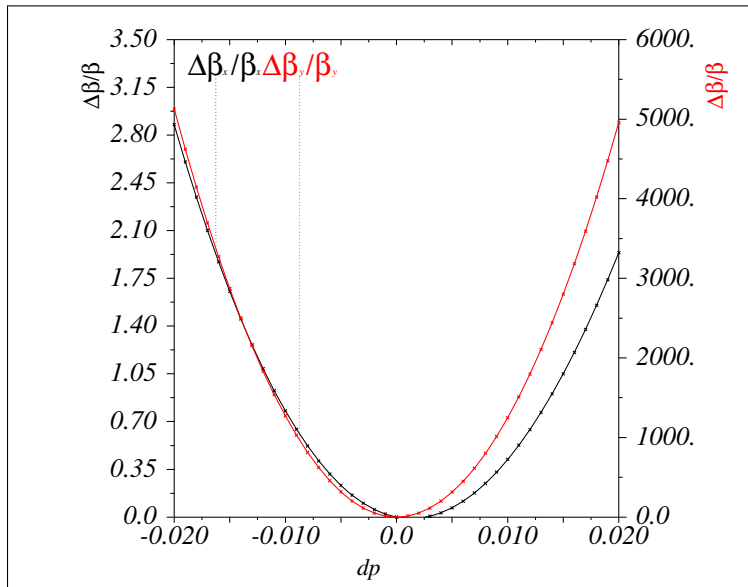
$$a_{y,2} = \frac{\partial^2 \alpha_y}{\partial \delta^2} - \frac{\alpha_y}{\beta_y} \frac{\partial^2 \beta_y}{\partial \delta^2}.$$

How does it work (chromaticity estimations)?

Chromaticity

$$\begin{aligned}\frac{\partial \varphi_y}{\partial \delta} &= \frac{1}{2} \int_0^\pi \beta_y (K_1 - K_2 \eta_0) ds, \\ \frac{\partial^2 \varphi_y}{\partial \delta^2} &= -2 \frac{\partial \varphi_y}{\partial \delta} - \int_0^\pi \beta_y K_2 \eta_1 ds + \frac{1}{2} \int_0^\pi \beta_y b_{y,1} (K_1 - K_2 \eta_0) ds, \\ \frac{\partial^3 \varphi_y}{\partial \delta^3} &= 6 \frac{\partial \varphi_y}{\partial \delta} - \int_0^\pi \beta_y (K_1 - K_2 \eta_0) (a_{y,1}^2 + b_{y,1}^2) ds + \\ &+ 3 \int_0^\pi \beta_y (K_2 \eta_1 - K_2 \eta_2) ds + \frac{3}{2} \int_0^\pi \beta_y b_{y,2} (K_1 - K_2 \eta_0) ds.\end{aligned}$$

Final Focus Telescope: beta chromaticity



Parameters of one quarter of the ring

| | |
|-----------------------------|---------------------|
| | tt |
| Energy [GeV] | 175 |
| Perimeter [m] | 24655.9 |
| Momentum compaction | $5.7 \cdot 10^{-6}$ |
| Emittance hor. [nm] | 1.3 |
| Energy spread [10^{-3}] | 1.6 |
| β_x^* / β_y^* [m] | 0.5 / 0.001 |
| Energy loss / turn [GeV] | 2.12 |

What is done?

- 1 Closed ring is ready, files are in
`/afs/cern.ch/eng/fcc/ee/TLEP_V14_IR_6-14-3`
- 2 At the end of IR the distance between the beams is 0.72 m.
- 3 Energy acceptance $[-3.1%;+1.9\%]$.
- 4 Synchrotron radiation fans are shifted away from IP.

What are next possible steps?

- 1 Install solenoids.
- 2 Change phase advance per cell to odd multiple of $\pi/4$ e.g. $3\pi/4$.
- 3 Make the cell symmetrical.
- 4 Four families of sextupoles in the arc and octupoles in IR.
- 5 Dynamic aperture studies, 6d tracking.
- 6 Eliminate X chromaticity correction section?

Questions and exclamation

- 1 Head-tail instability with large nonlinear chromaticity?
- 2 Synchrotron radiation from quadrupoles?
- 3 Final focus quadrupoles?
- 4 Solenoids?
- 5 Synchrotron radiation background for detector?
- 6 Feedback, please!