ILC Damping Ring Alternative Lattice Design (modified FODO)**

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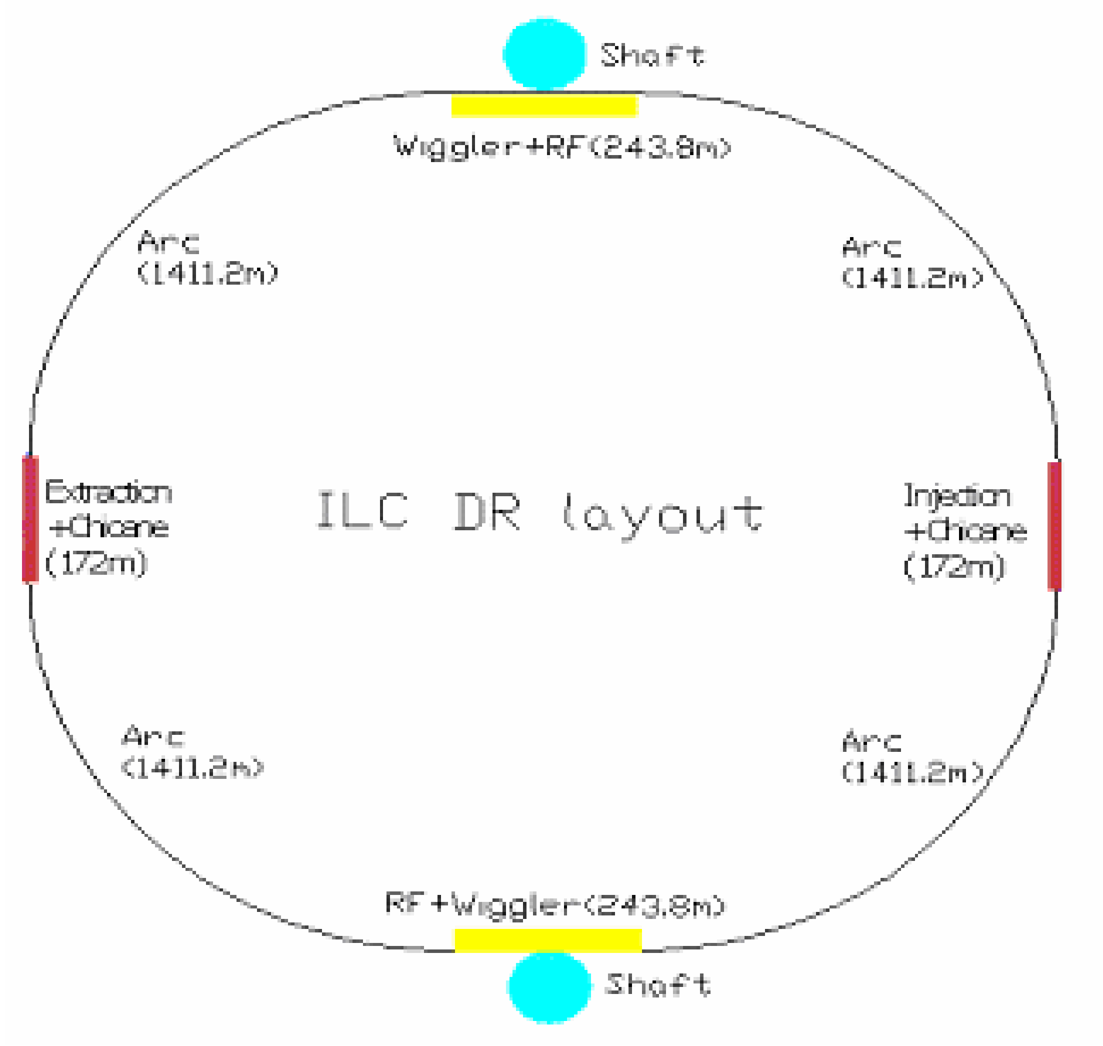
ILC DR Alternative Lattice Design Goals

1. Smaller number quadrupoles and sextupoles used (roughly two thirds), and lower cost.
2. Freely tunable momentum compaction factor in the range between 2×10^{-4} and 6×10^{-4}.
3. Better dynamic aperture.
4. Simpler layout, with only two wiggler sections and cryogenics shaft.

LAYOUT



4 arc sections.

4 straight sections, one for injection, one for extraction, and the other two for RF/wiggler.

Two shafts in all and no TL.

Beam is counter-rotating.

CONSIDERATIONS FOR THE ARC CELL

Scan some arc cell parameters.

- Arc cell number: from 120 to 240.
- Arc cell length: from 20 m to 40 m.
- The short drift length: from 1 m to 3 m.

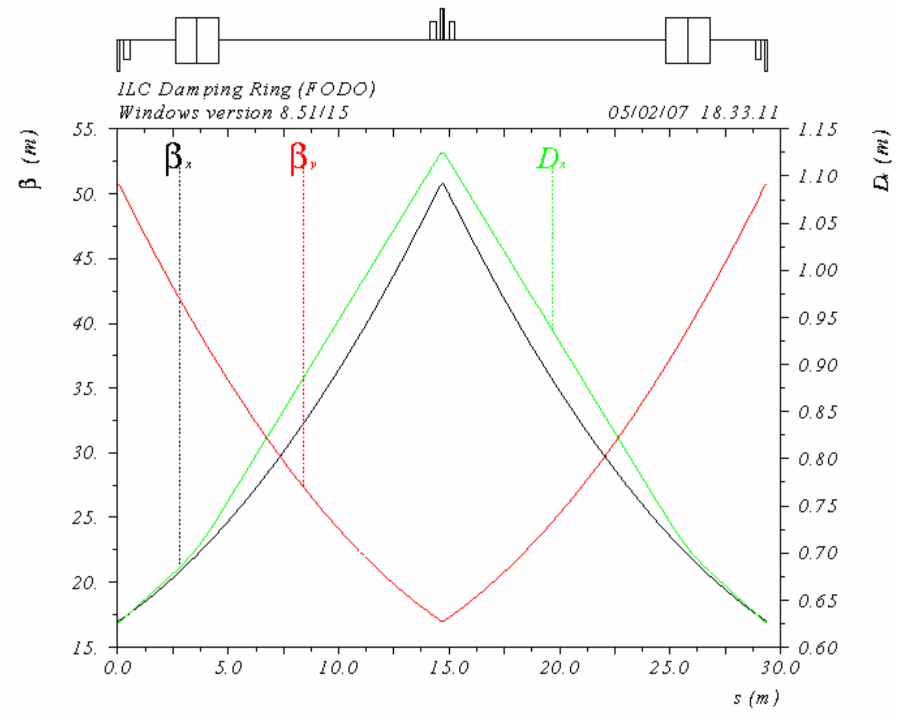
To get proper dispersion and beta functions at the sextupole location in a cell, suitable maximum beta function (less than 55 m, constrained by vacuum chamber), and freely tunable alpha with different arc cell phase advance.

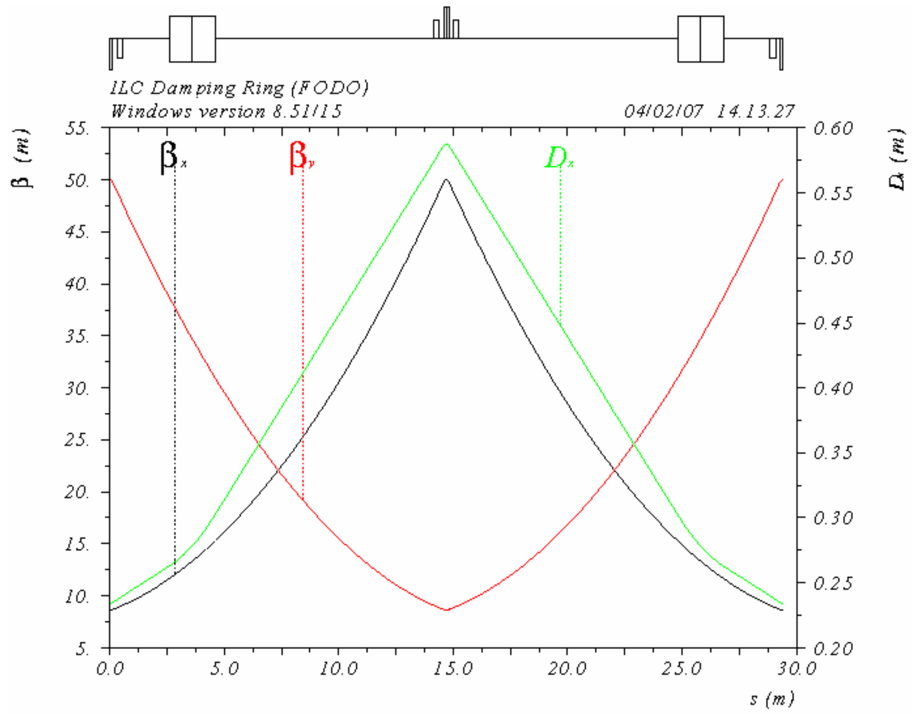
At last, we select the arc cell length to be 29.4 m, and the arc cell number to be 184.

Comparison with OCS6

	OCS8 (2007.06)	*FODO-4*
Circumference [m]	6695	6476.439
Arc cell	TME	FODO
Phase advance of arc cell	90/90	60/60~90/90
Momentum compaction [10^{-4}]	4	2~6
Quadrupoles in all	**682**	**448**
Dipoles in all	114 × **6** m +12 × **3** m	368 × **2** m
Sextupoles in all	**480**	**368**
Number of wiggler straights	**4**	**2**

Arc Cell Design



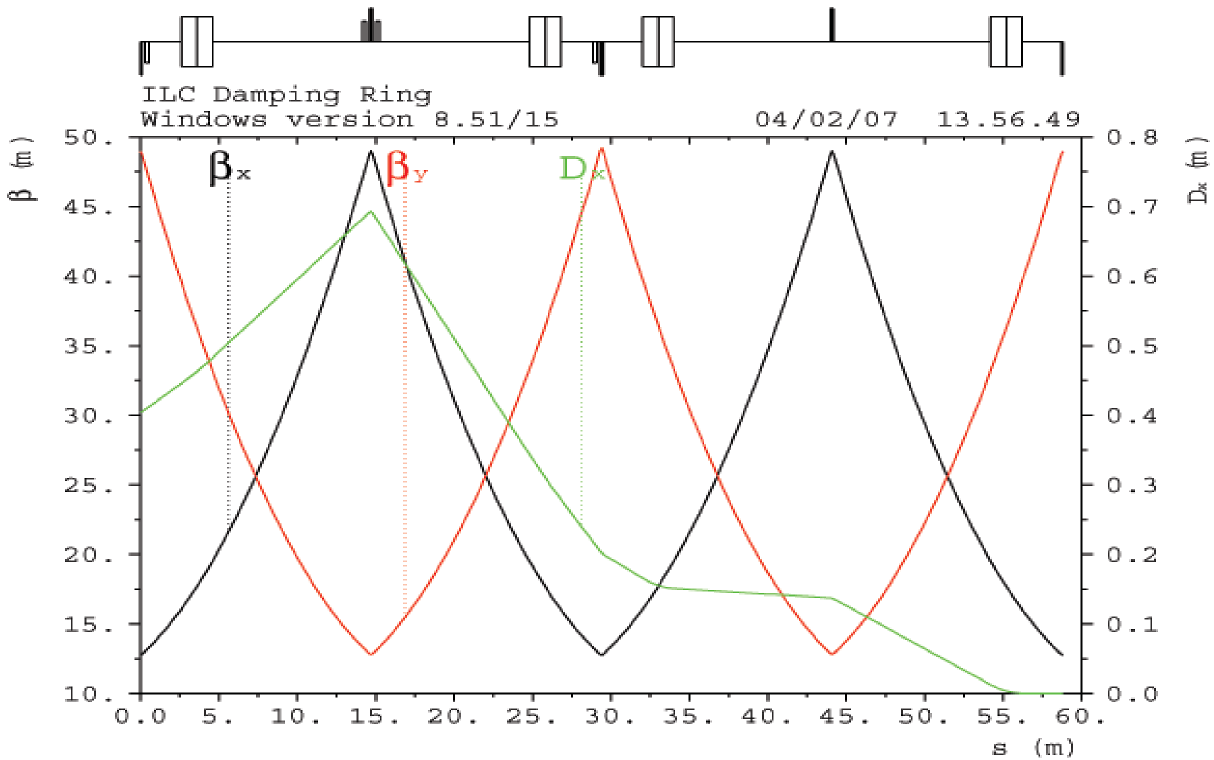


$$\beta^{\pm} = \frac{L_P(1 \pm \sin\frac{\mu}{2})}{\sin\mu} \qquad D^{\pm} = \frac{L_P\phi(1 \pm \frac{1}{2}\sin\frac{\mu}{2})}{4\sin^2\frac{\mu}{2}}$$

Left: 60/60 cell, corresponding to 6×10^{-4} alpha

Left: 90/90 cell, corresponding to 2×10^{-4} alpha

Dispersion Suppressor Design

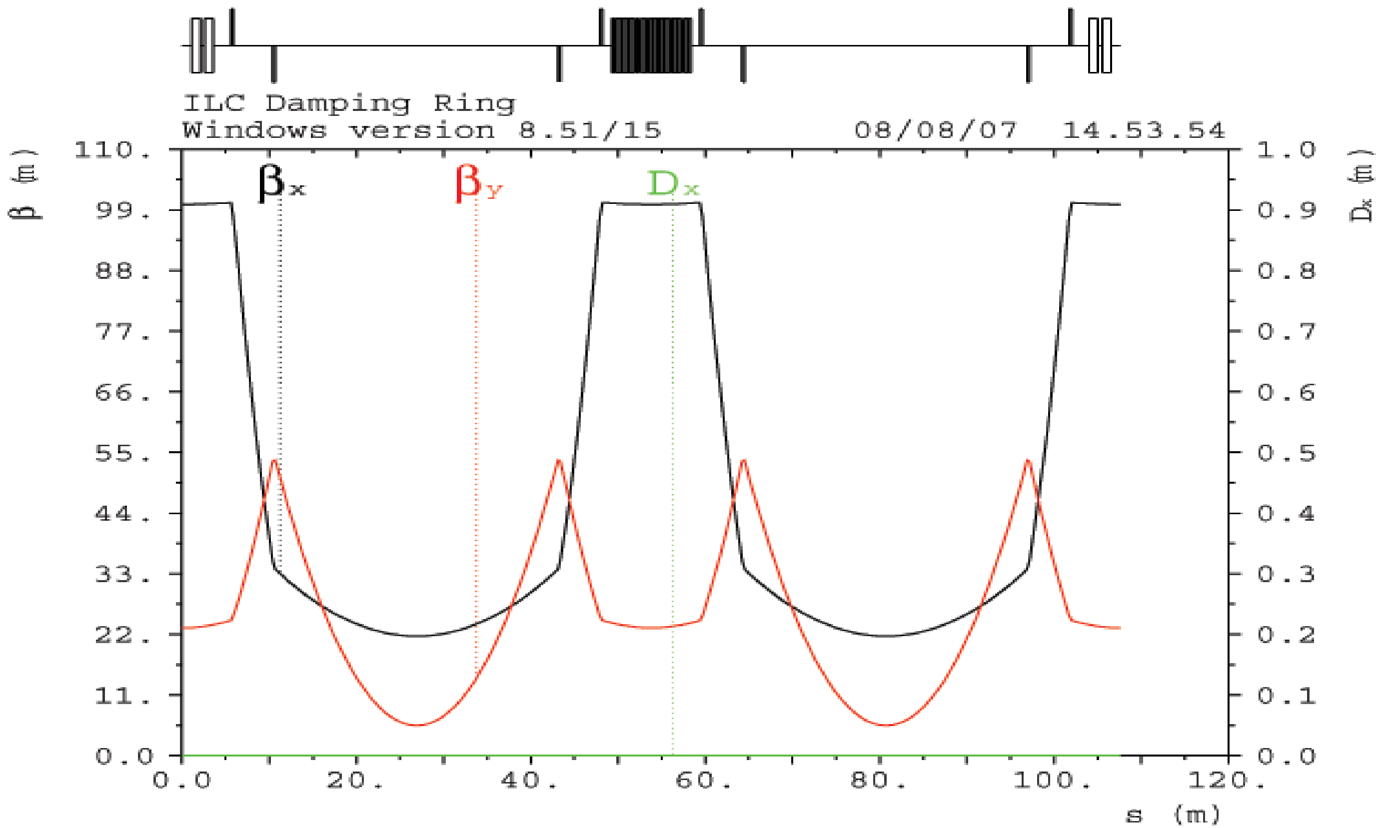


$$\varphi_1 = \varphi \cdot \left(1 - \frac{1}{4\sin^2\frac{\mu}{2}}\right)$$

$$\varphi_2 = \frac{\varphi}{4\sin^2\frac{\mu}{2}}$$

Add one arc cell after the last standard arc cell and **modify the bending angle** of these two cells according to the phase advance. The aim is to have undisturbed TWISS parameters in the dispersion suppressor.

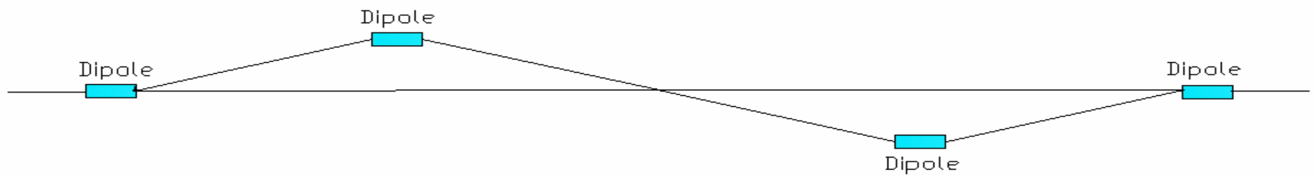
INJECTION/EXTRACTION DESIGN



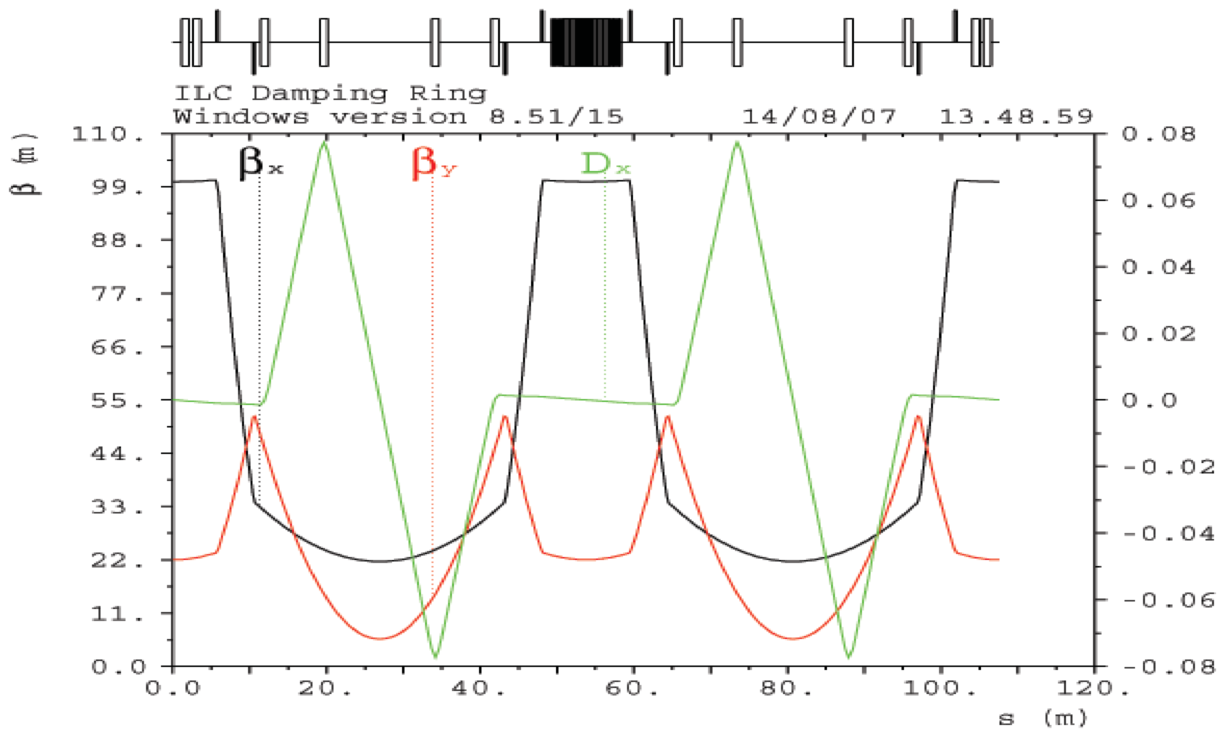
2 septums and 21 stripline kickers (lumped kickers)

uses two periodic cells, with the total horizontal phase advance matched to be 180 degree

CHICANE



Adjustment of one Chicane: $\pm 2\theta^2\left(l_c + 0.5 l_B\right)$

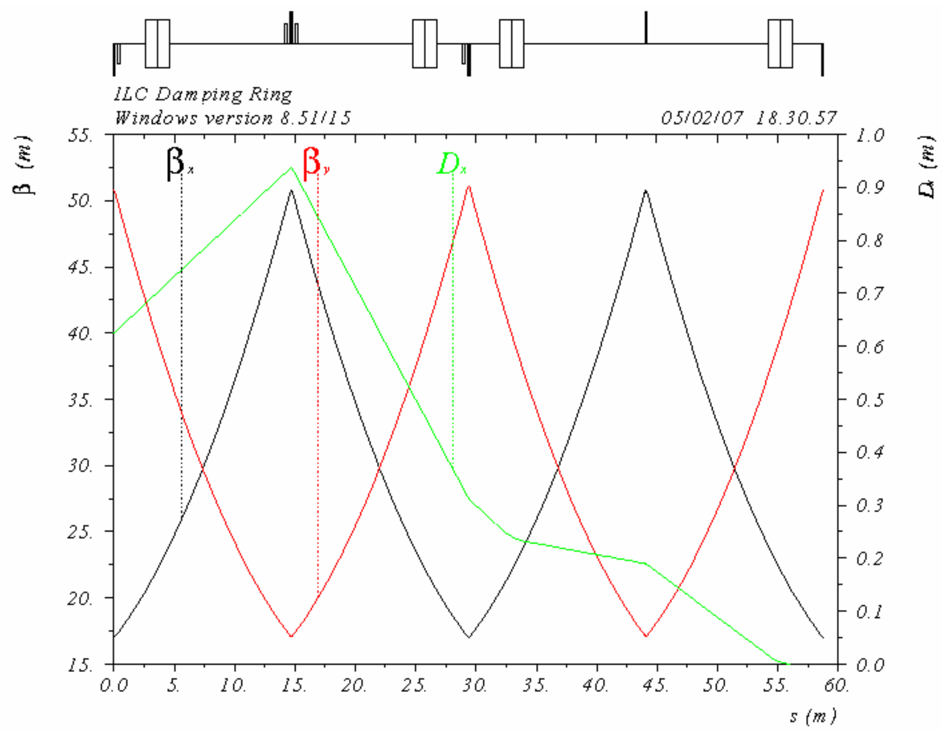


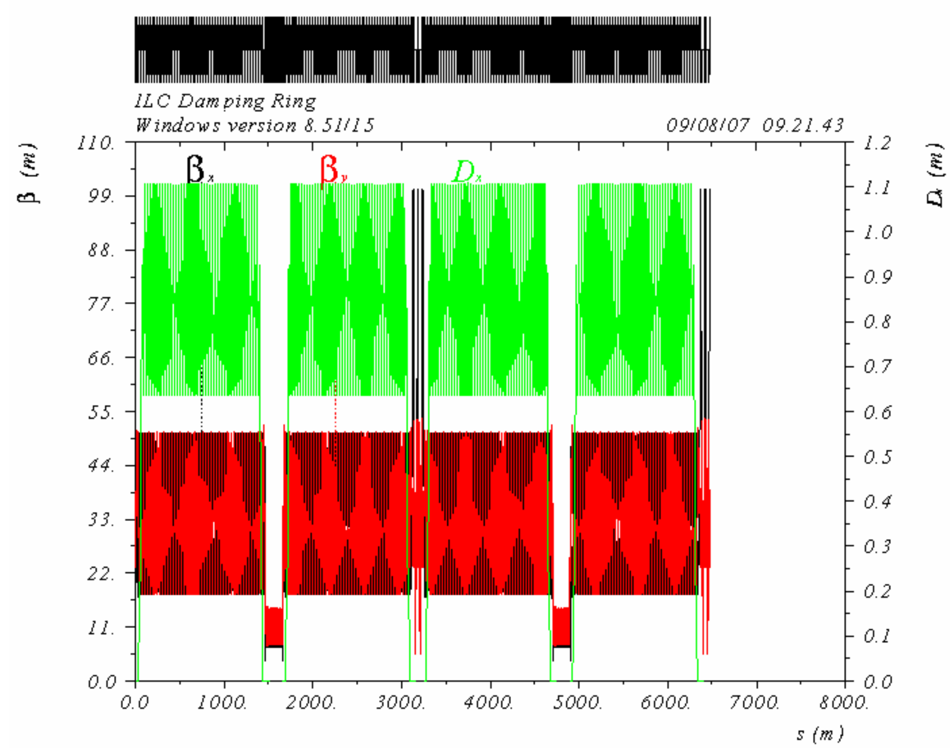
10^{-6} adjustable

4 Chicane

Emittance +9.2%

6×10^{-4} Momentum Compaction



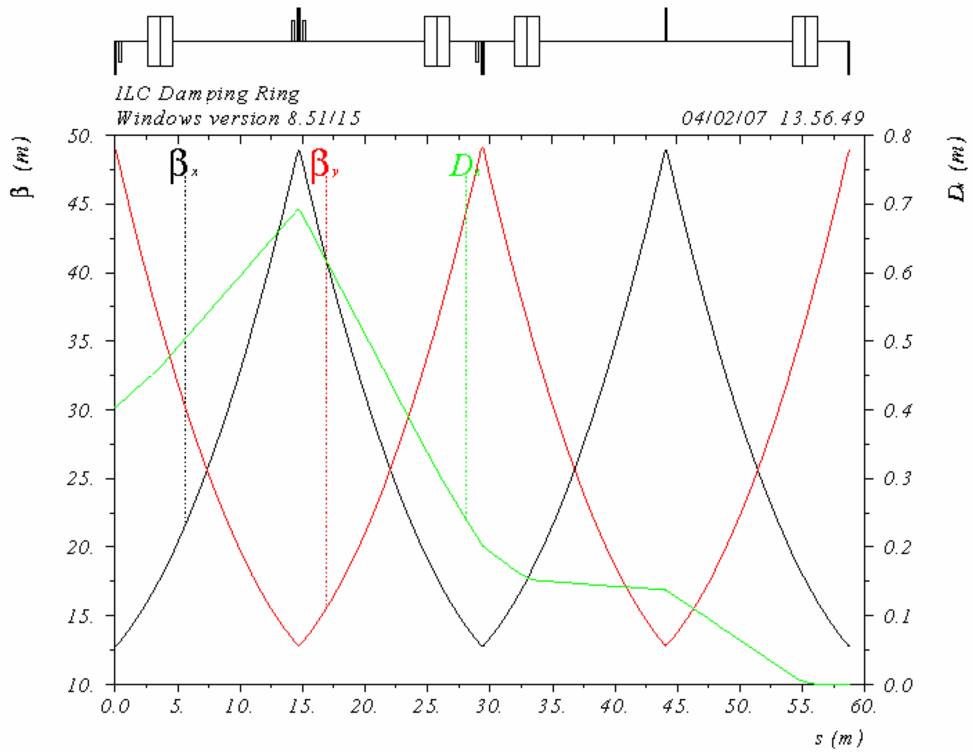


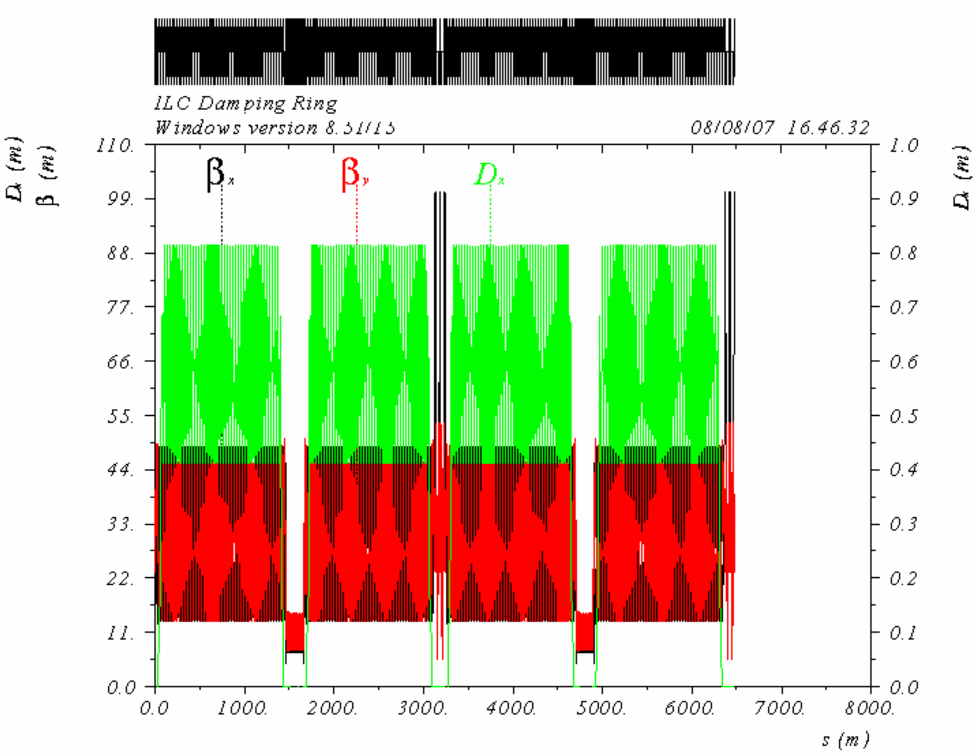
Dispersion suppressor

Total ring

60/60 cell, 6×10^{-4} momentum compaction

4×10^{-4} Momentum Compaction



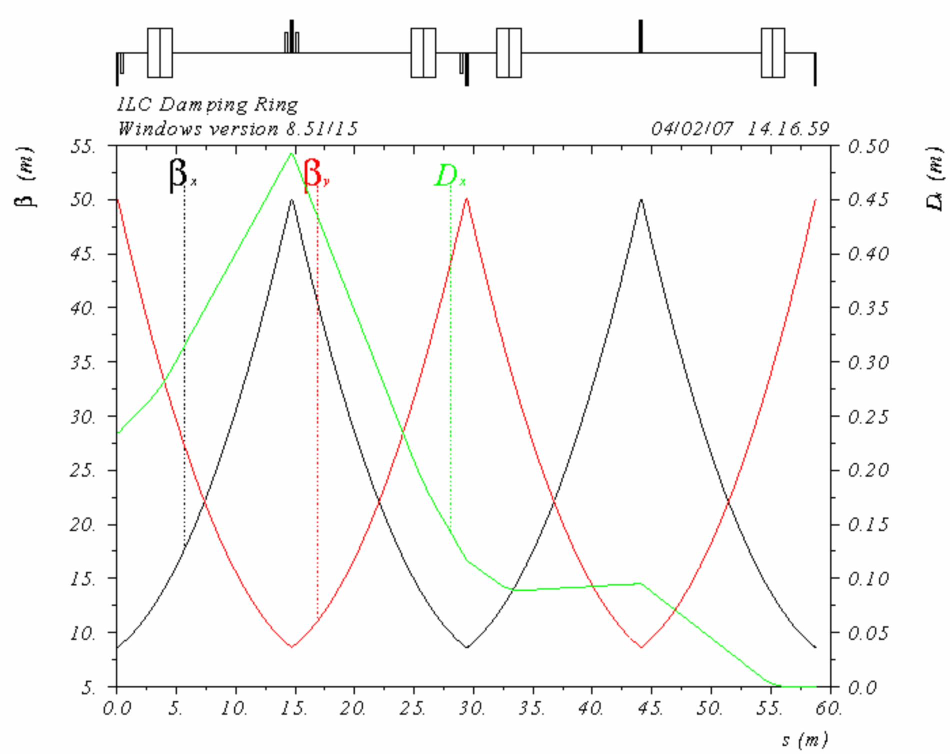


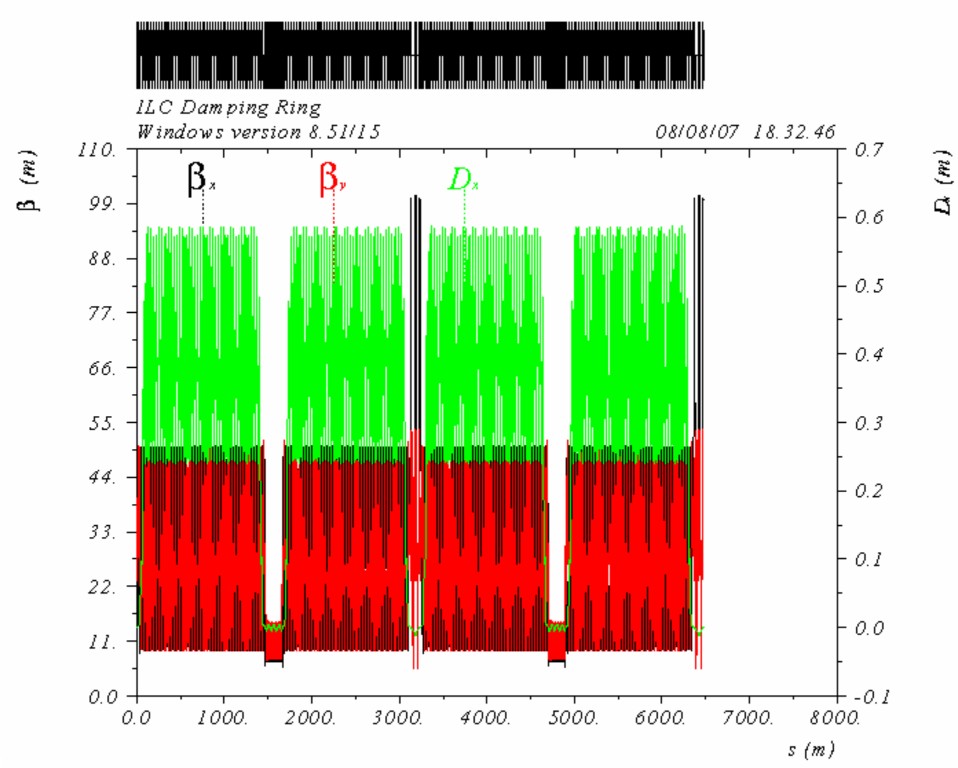
Dispersion suppressor

Total ring

72/72 cell, 4×10^{-4} momentum compaction

2×10^{-4} Momentum Compaction





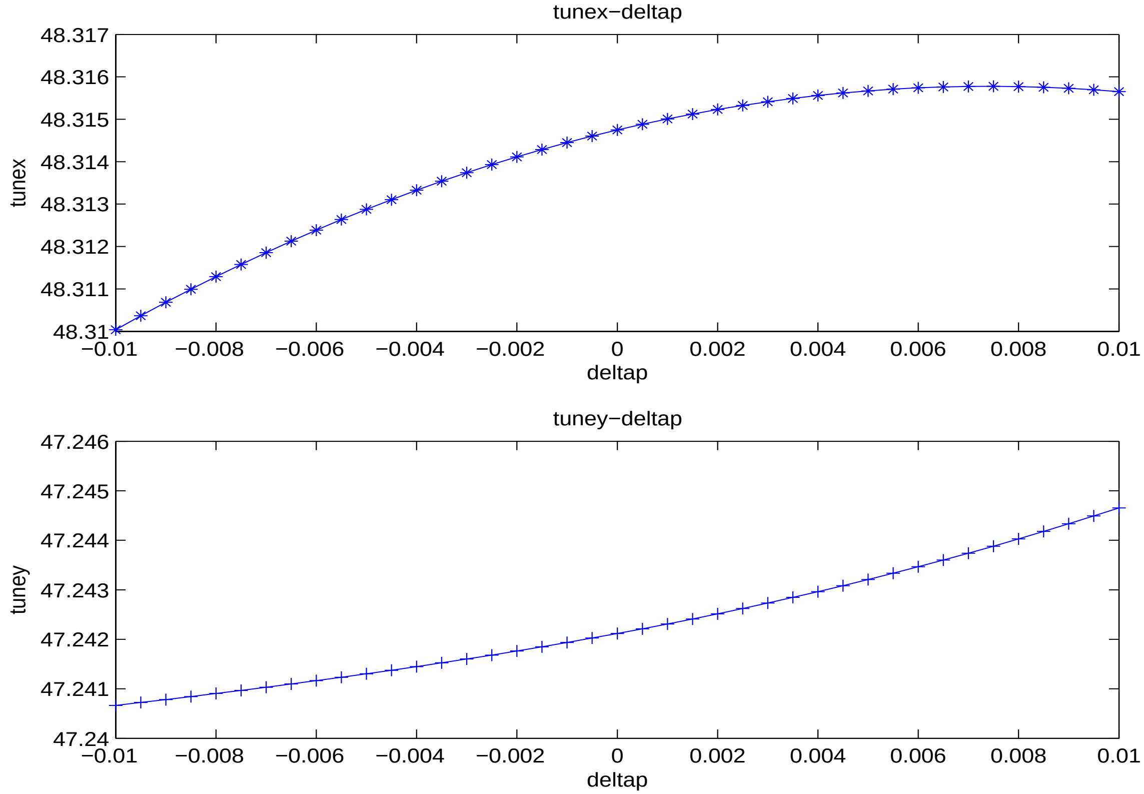
Dispersion suppressor　　　　　　Total ring

60/60 cell, 2×10^{-4} momentum compaction

TOTAL PARAMETERS OF THREE CRITICAL MODES

Parameter	$\alpha_P=2\times10^{-4}$	$\alpha_P=4\times10^{-4}$	$\alpha_P=6\times10^{-4}$
Circumference [m]	6476.439v	6476.439	6476.439
Harmonic number	14042	14042	14042
Energy [GeV]	5	5	5
Arc cell	FODO	FODO	FODO
Tune	58.29 / 57.25	48.29 / 47.24	41.29 / 40.25
Natural chromaticity	-74 / -73	-56 / -56	-46 / -46
Momentum compaction [10^{-4}]	2	4	6
Transverse damping time [ms]	25 / 25	25 / 25	25 / 25
Norm. Natural emittance [mm-mrad]	3.36	4.2	5.4
RF voltage [MV]	15	22	31
Synchrotron tune	0.038	0.061	0.091
Synchrotron phase [^{o}]	145	157	164
RF frequency [MHz]	650	650	650
RF acceptance [%]	1.21	1.48	1.65
Natural bunch length [mm]	9	9	9
Natural energy spread [10^{-3}]	1.28	1.28	1.28

Chromaticity correction



The chromaticity corrected to (0.3,0.31). The tune variation with momentum spread ±1%

HIGH ORDER MAGNETS ERRORS

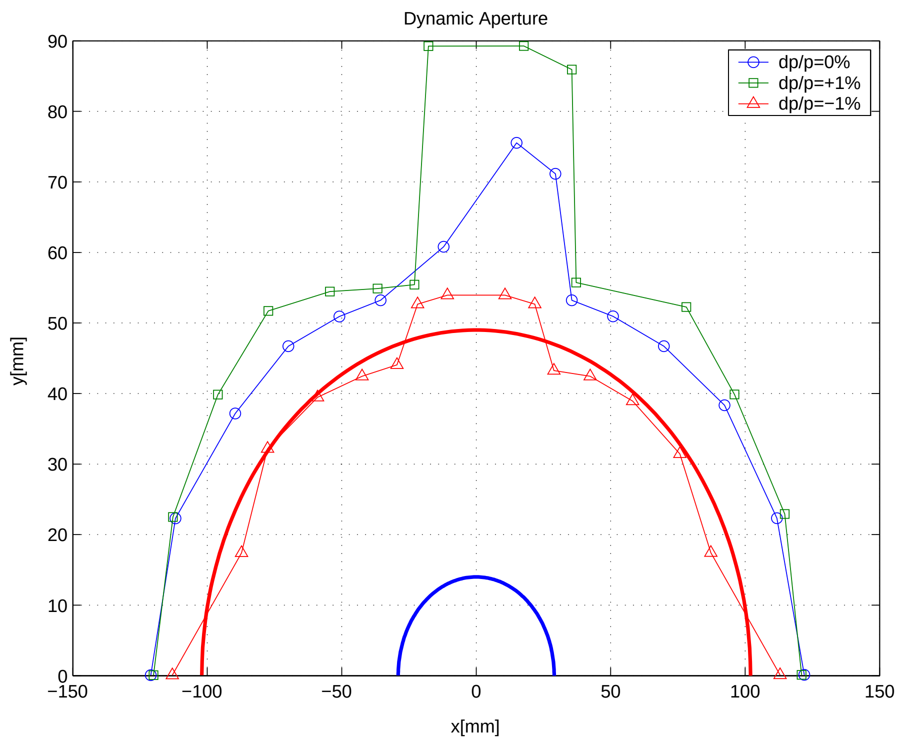
	Dipole (1×10^{-4})			Quadrupole (1×10^{-4})			Sextupole (1×10^{-4})		
Radius	30mm			30mm			30mm		
Error type	Sys	Ran	Φ(°)	Sys	Ran	Φ(°)	Sys	Ran	Φ(°)
1	0	0	0	0	0	0	0	0	0
2	0	1(3)	0	0	1(3)	0	0	0	0
3	1(3)	1	0	1	1	-80	0	10(20)	0
4	0	1	0	1	1	150	1	3	-85
5	1(3)	1	0	1	1	80	1	1	-130
6	0	1	0	1	1	0	1	1	-15
7	1(3)	1	0	1	1	180	1	1	66
8	0	0	0	1	1	5	1	1	203
9	0	0	0	1	1	75	1	1	1
10	0	0	0	1	1	180	1	1	-116
11	0	0	0	1	1	10	1	1	46
12	0	0	0	1	1	180	1	1	84
13	0	0	0	1	1	110	1	1	-291
14	0	0	0	1	1	25	1	1	-10
15	0	0	0	1	1	0	1	1	-182
16	0	0	0	1	1	0	1	1	0

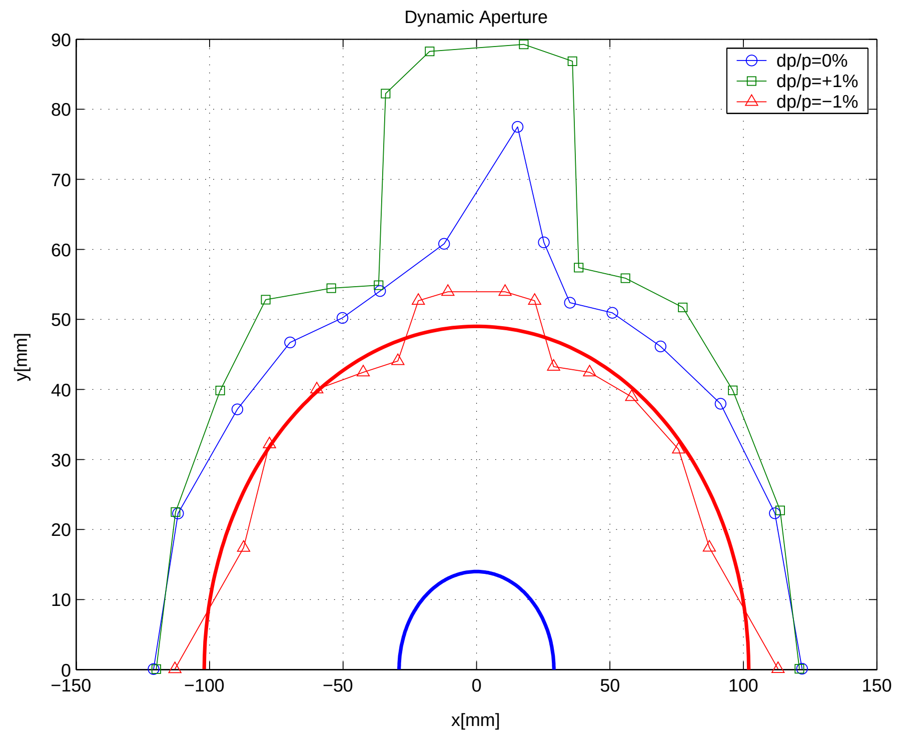
* Sys: system error; Ran: random error

Misalignment errors

Element	Δx (mm)	Δy (mm)	Δz (mm)	$\Delta\theta_x$ (mrad)	$\Delta\theta_y$ (mrad)	$\Delta\theta_z$ (mrad)
Dipole	0.1	0.1	0.1	0.2	0.2	0.2
Quadrupole	0.1	0.1	0.1	0.2	0.2	0.2
Sextupole	0.1	0.1	0.1	0.2	0.2	0.2

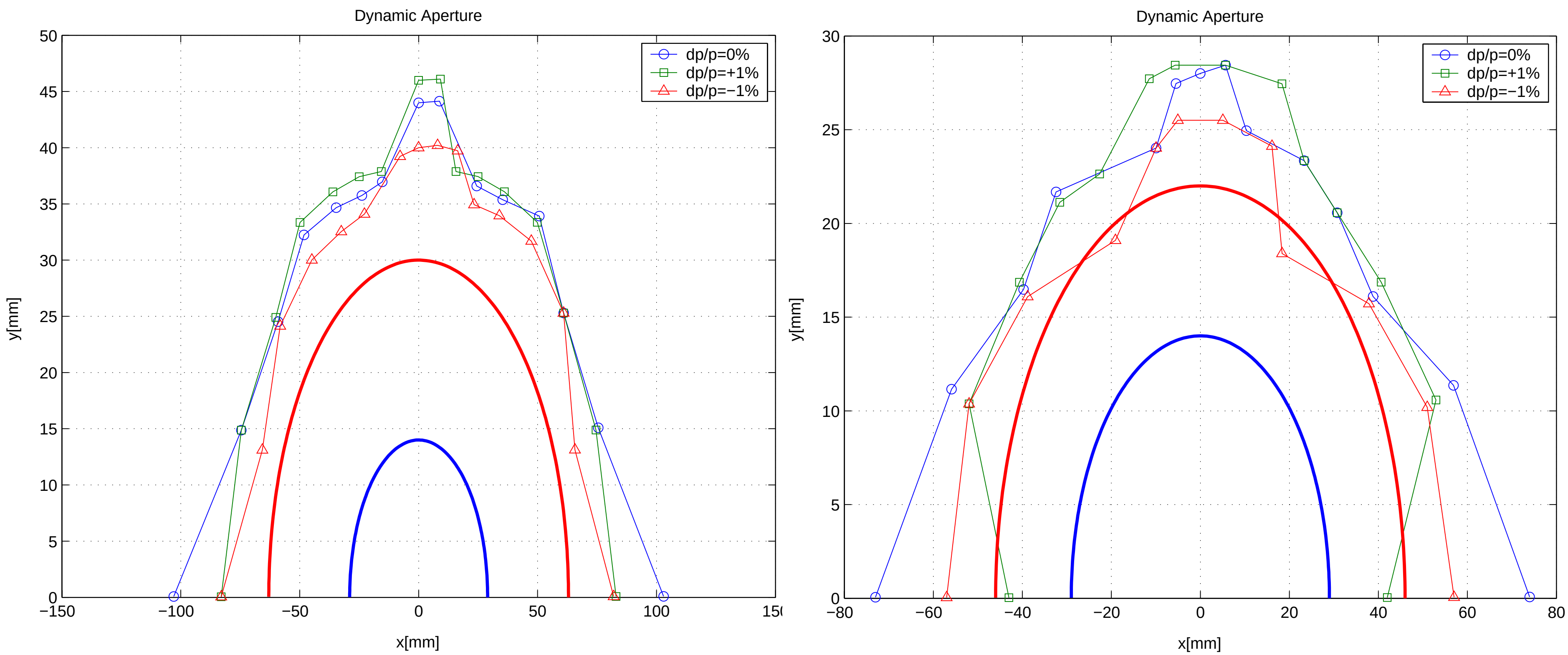
Dynamic Aperture 6×10^{-4} alpha case





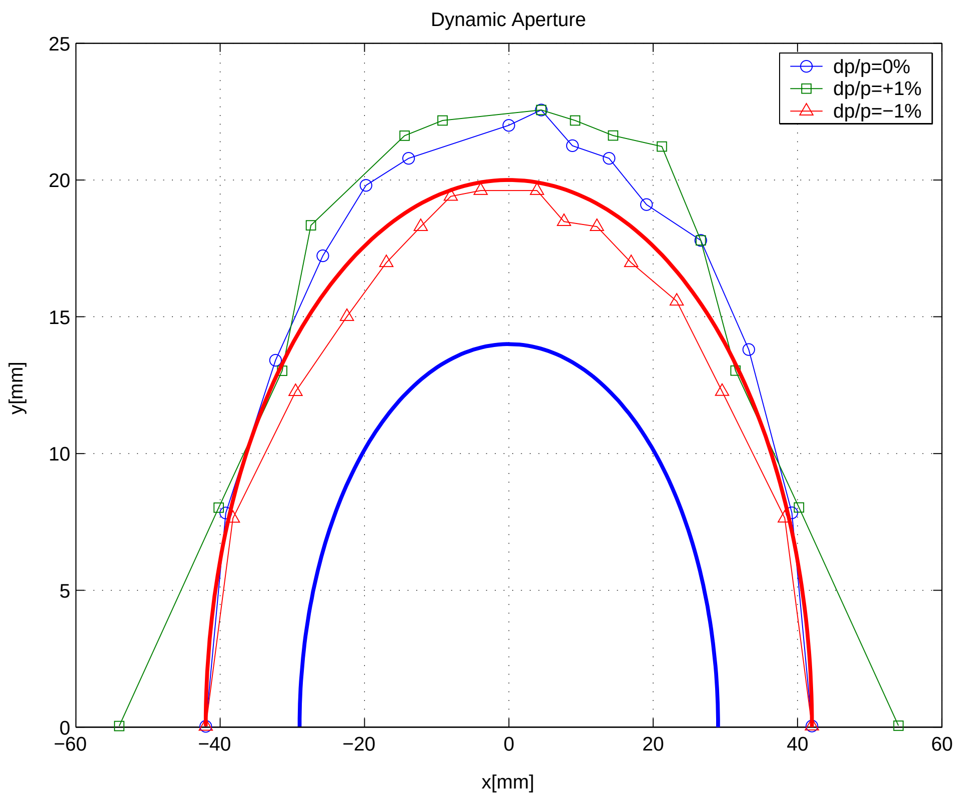
Left: no errors; Right: with high order magnets errors

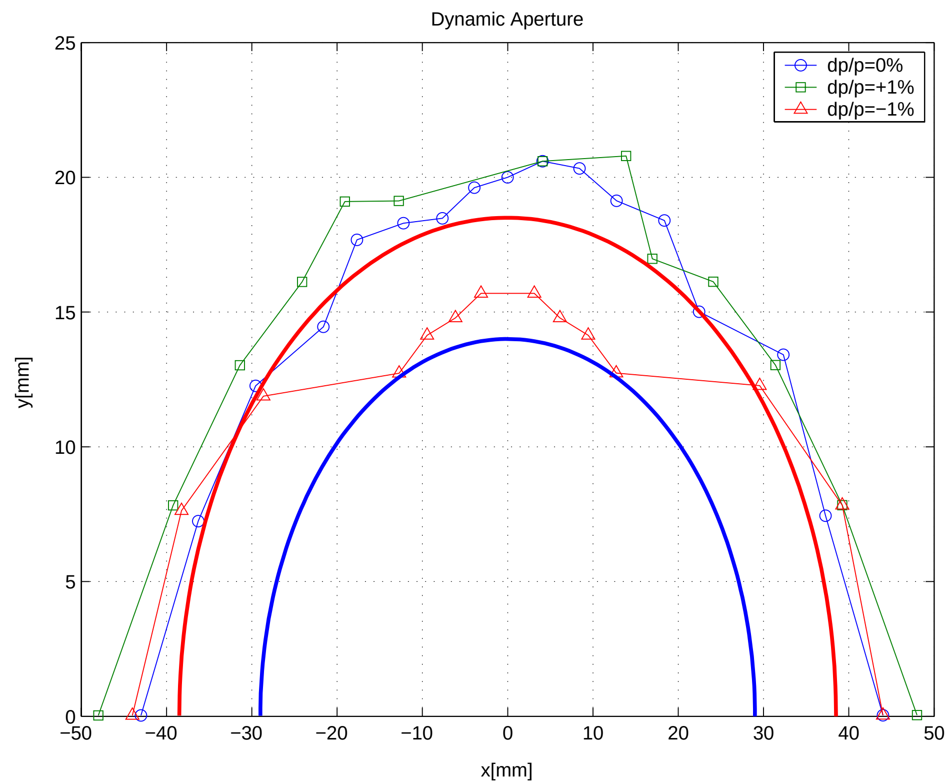
DYNAMIC APERTURE 4×10^{-4} ALPHA CASE



Left: no errors; Right: with high order magnets errors

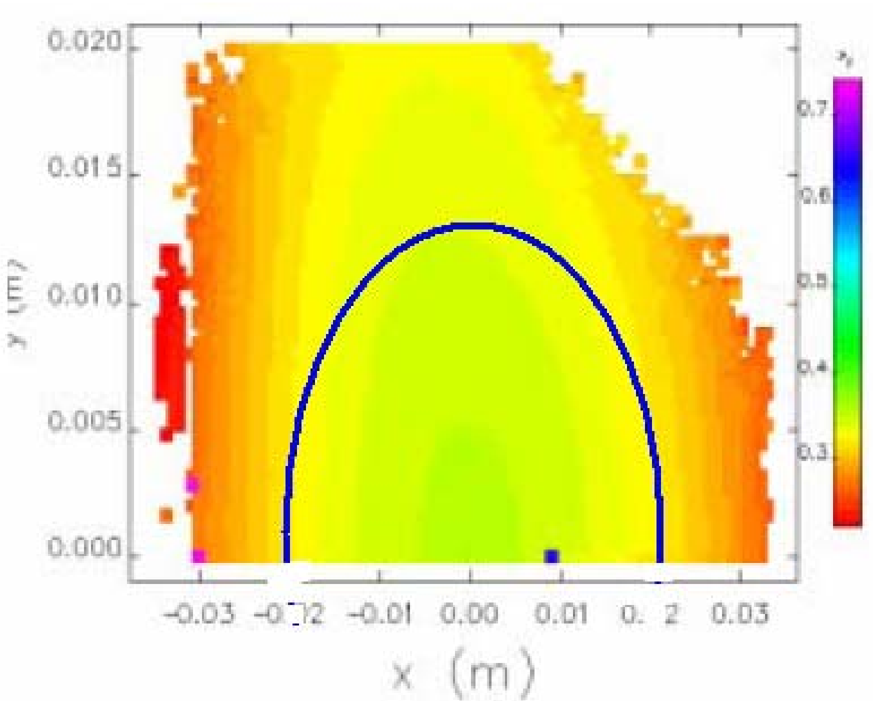
DYNAMIC APERTURE 2×10^{-4} ALPHA CASE

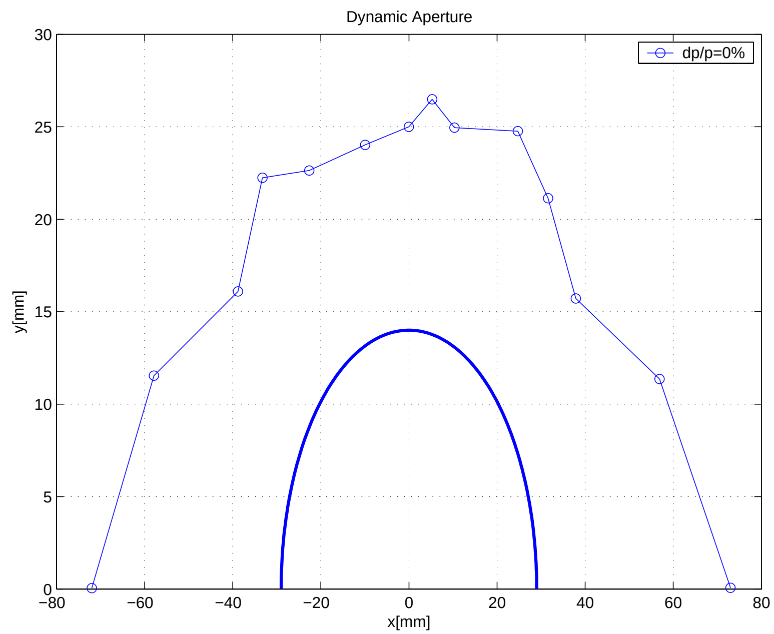




Left: no errors; Right: with high order magnets errors

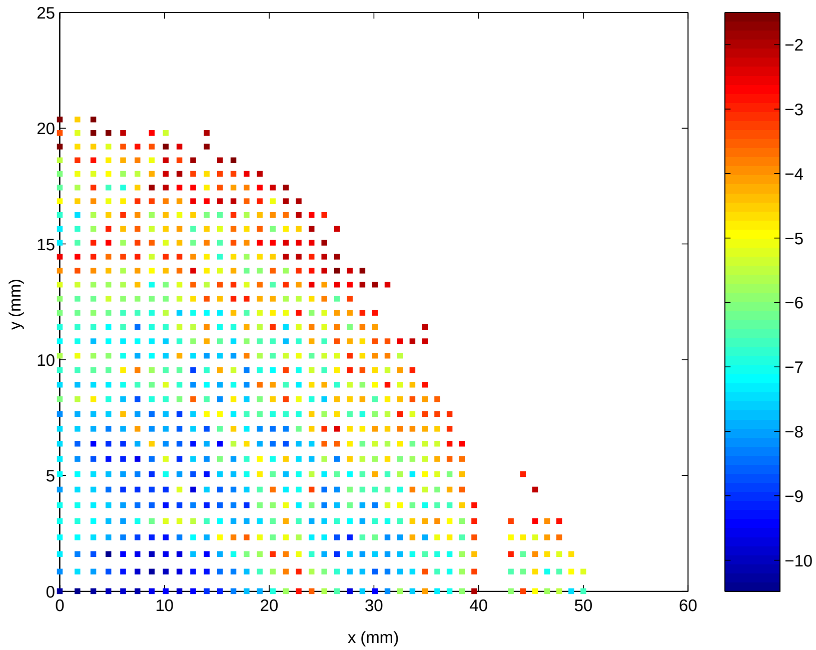
COMPARISON WITH OCS8 (PAC07)

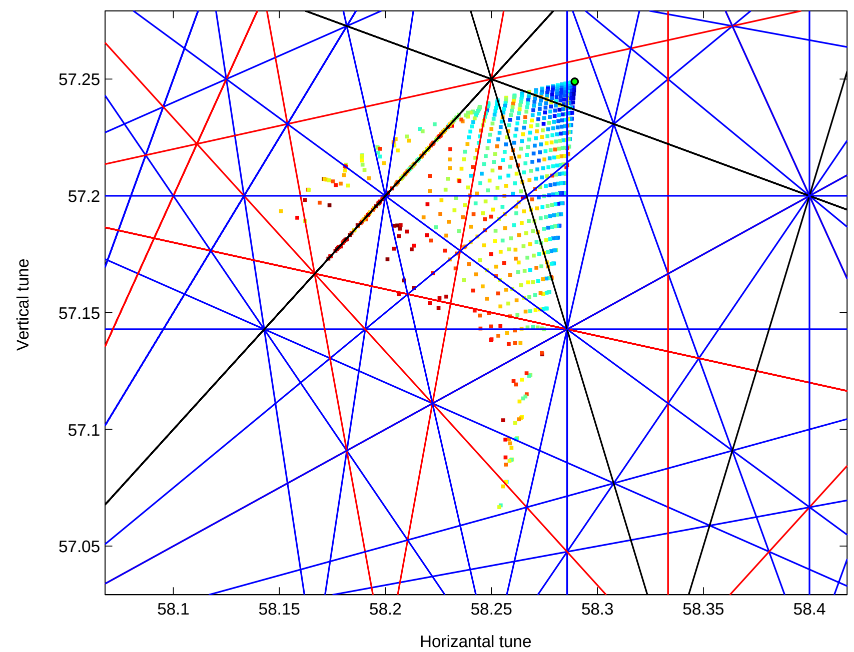




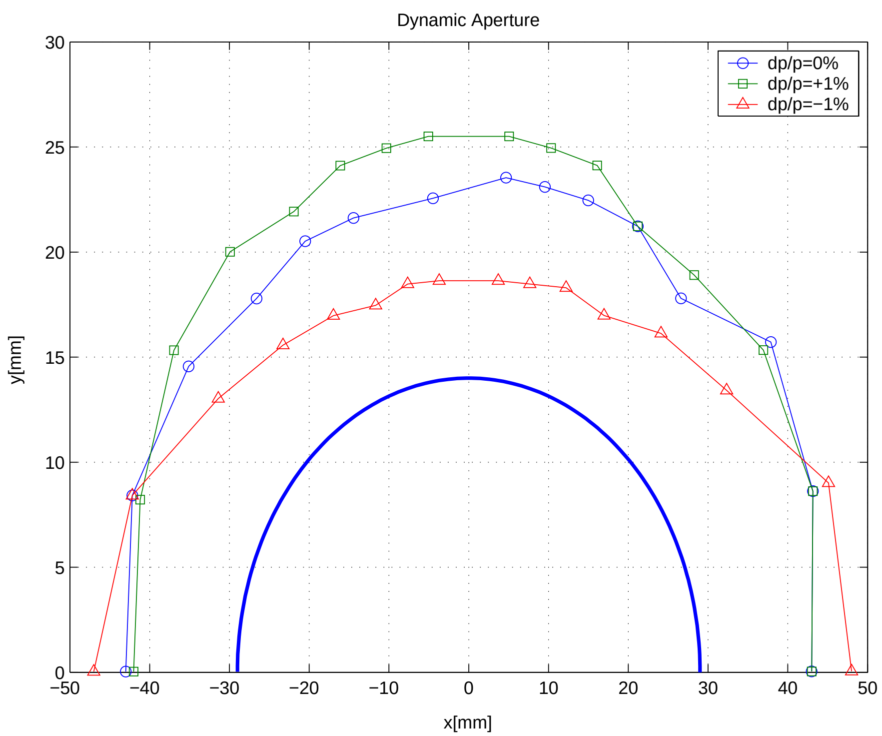
4×10^{-4} momentum compaction mode, on momentum particles, with errors

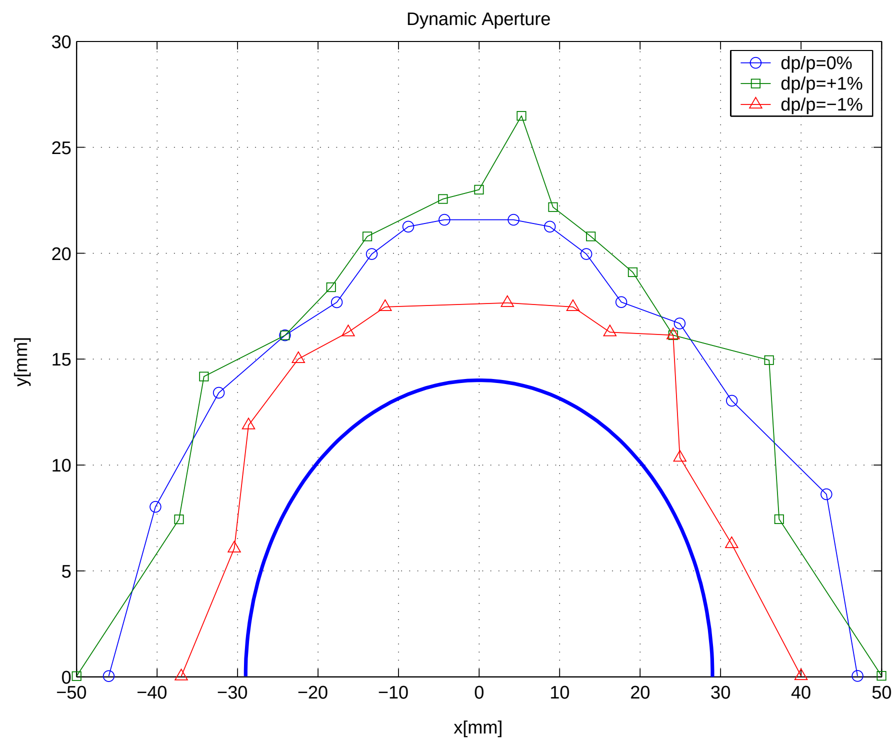
FMA Optimization Results





WITH HARMONIC SEXTUPOLES





2×10^{-4} momentum compaction mode, with 3 group harmonic sextupoles

Left: no errors; Right: with high order magnets errors

OTHERS

Element	Length [m]	Field or Gradient	Aperture[m]	Pole-tip field[T]
Dipole	2	0.2246 T	0.06	0.2246
Quadrupole	0.3	10 T/m	0.06	0.3
Sextupole	0.25	17.67 T/m2	0.06	0.00796

Touschek lifetime: $$\frac{1}{\tau} = \frac{r_e^2 c N_0}{8\pi\gamma^2 \delta_{\max}^3 \sigma_x \sigma_y \sigma_z} D(\varepsilon)$$

4×10^{-4} momentum compaction mode . Energy acceptance 1.48%, bunch population 2×1010, Touschek lifetime is 160 minutes

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