ILC Damping Ring Alternative Lattice Design （Modified FODO）

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Most important update after Fermi GDE meeting (October 2007)

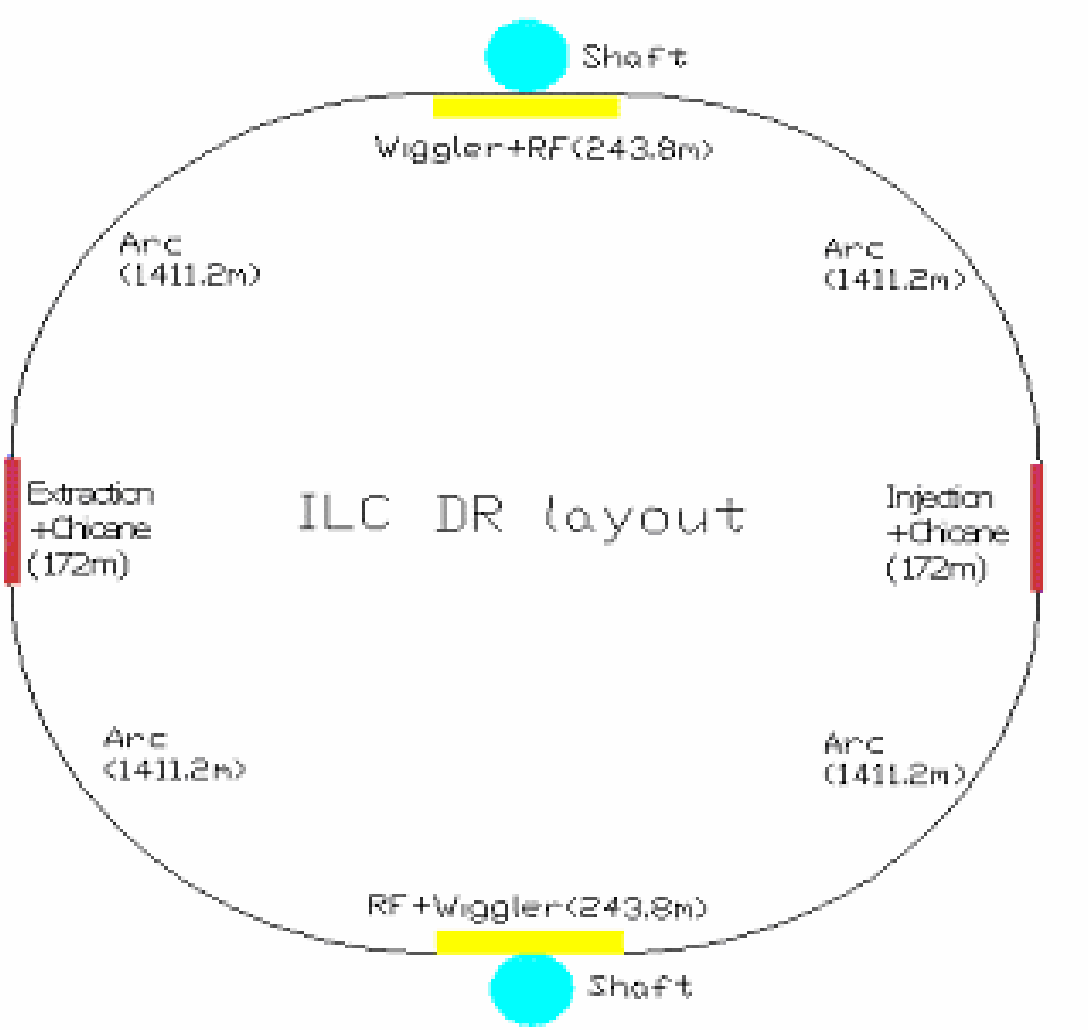
Re-matched the dispersion suppressor and the matching sections between dispersion suppressor and wiggler (injection) sections.

Now newest FODO DR lattice can truly be tuned with momentum compaction between 2e-4 and 6e-4, by only tuning the quadrupole's strength, not change any geometry of the ring (dipole strength in the dispersion suppressor do not change).

THE ADVANTAGE OF FODO LATTICE

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. Good dynamic aperture.
4. Simpler layout, with only two wiggler sections and cryogenics shaft, no long Transport Line for cryogenics needed.

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.

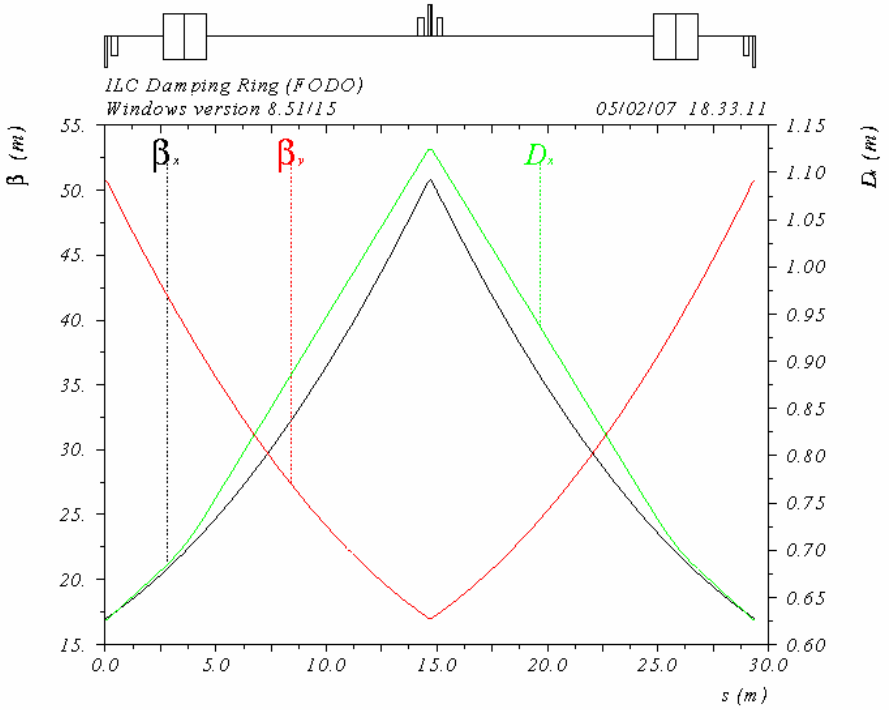
To get proper dispersion and beta functions at the sextupole location in a cell, suitable maximum beta function (less than 55 m, constrained by vacuum chamber), and freely tunable alpha with different arc cell phase advance.

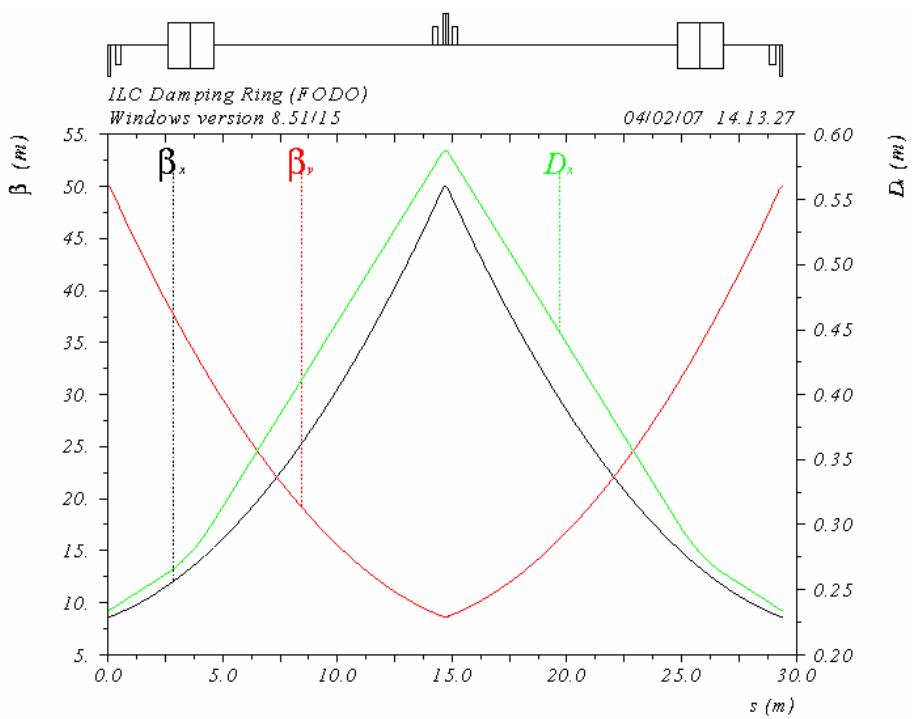
At last, we select the arc cell length to be 29.4 m, and the arc cell number to be 184.

COMPARISON WITH OCS8

	OCS8 (2007.10)	*FODO-4*
Circumference [m]	6476.439	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



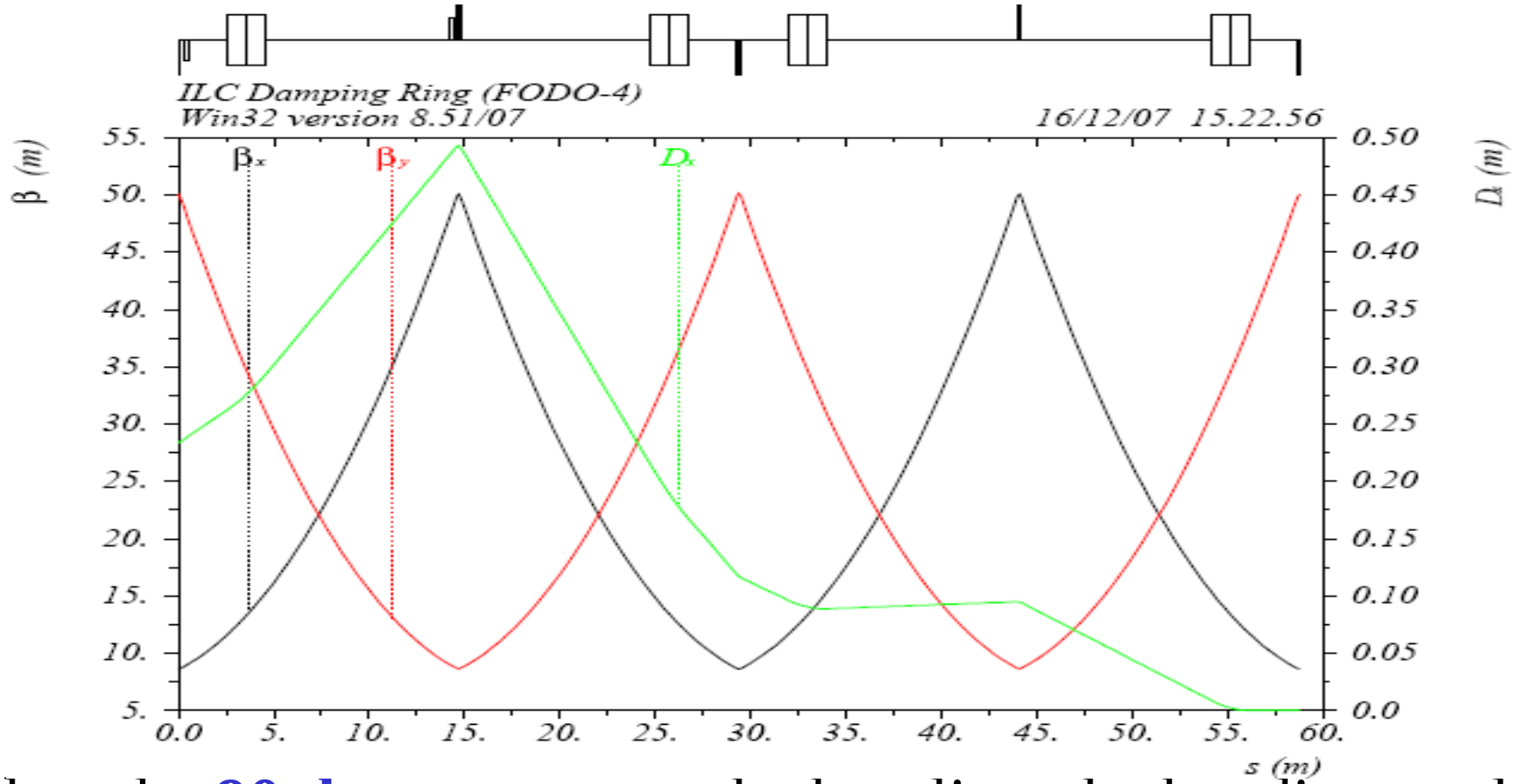


$$\beta^{\pm} = \frac{L_P(1 \pm \sin\frac{\mu}{2})}{\sin\mu} \qquad D^{\pm} = \frac{L_P\phi(1 \pm \frac{1}{2}\sin\frac{\mu}{2})}{4\sin^2\frac{\mu}{2}}$$

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

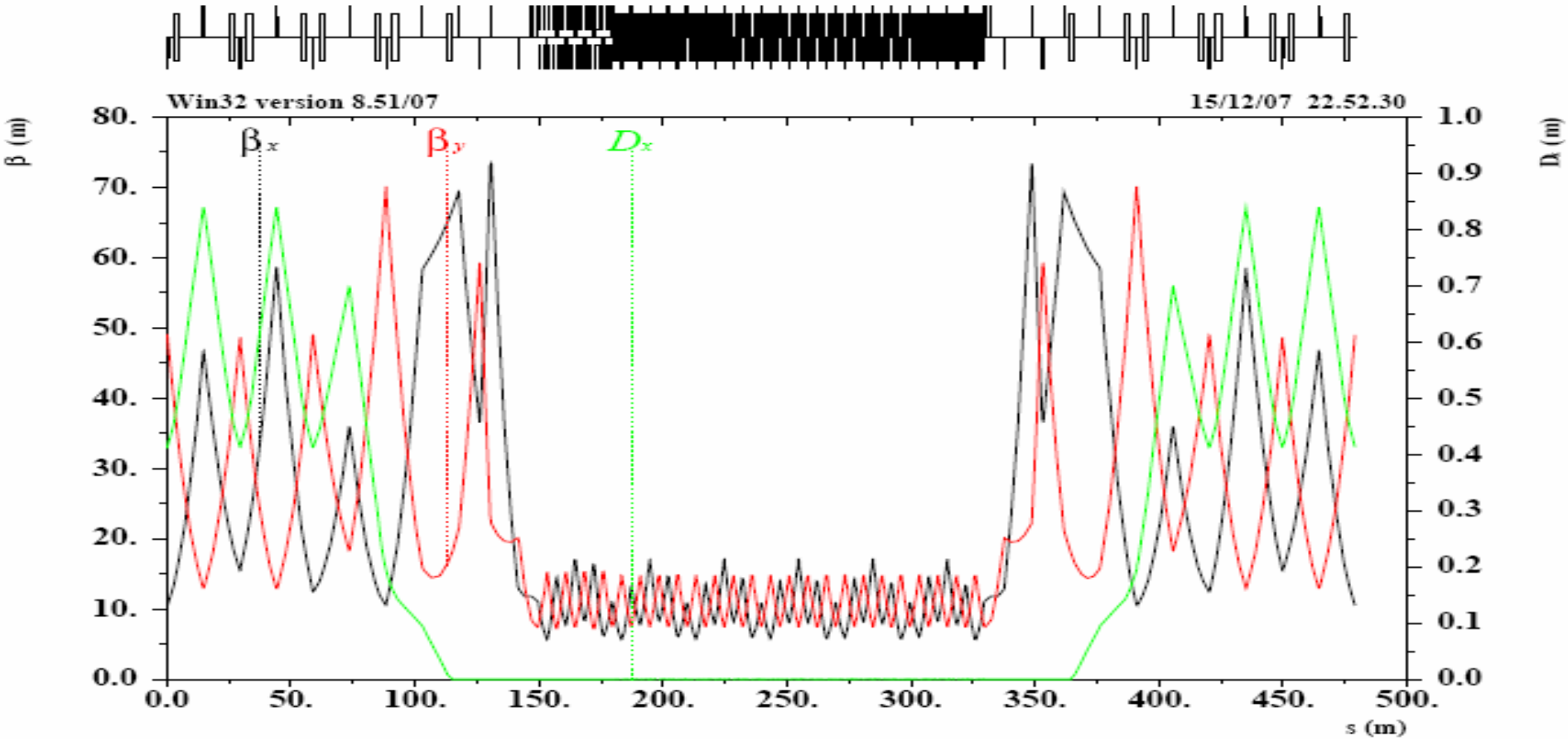
Left: 90/90 cell, corresponding to 2×10^{-4} alpha

DISPERSION SUPPRESSOR DESIGN (90 DEGREE CASE)



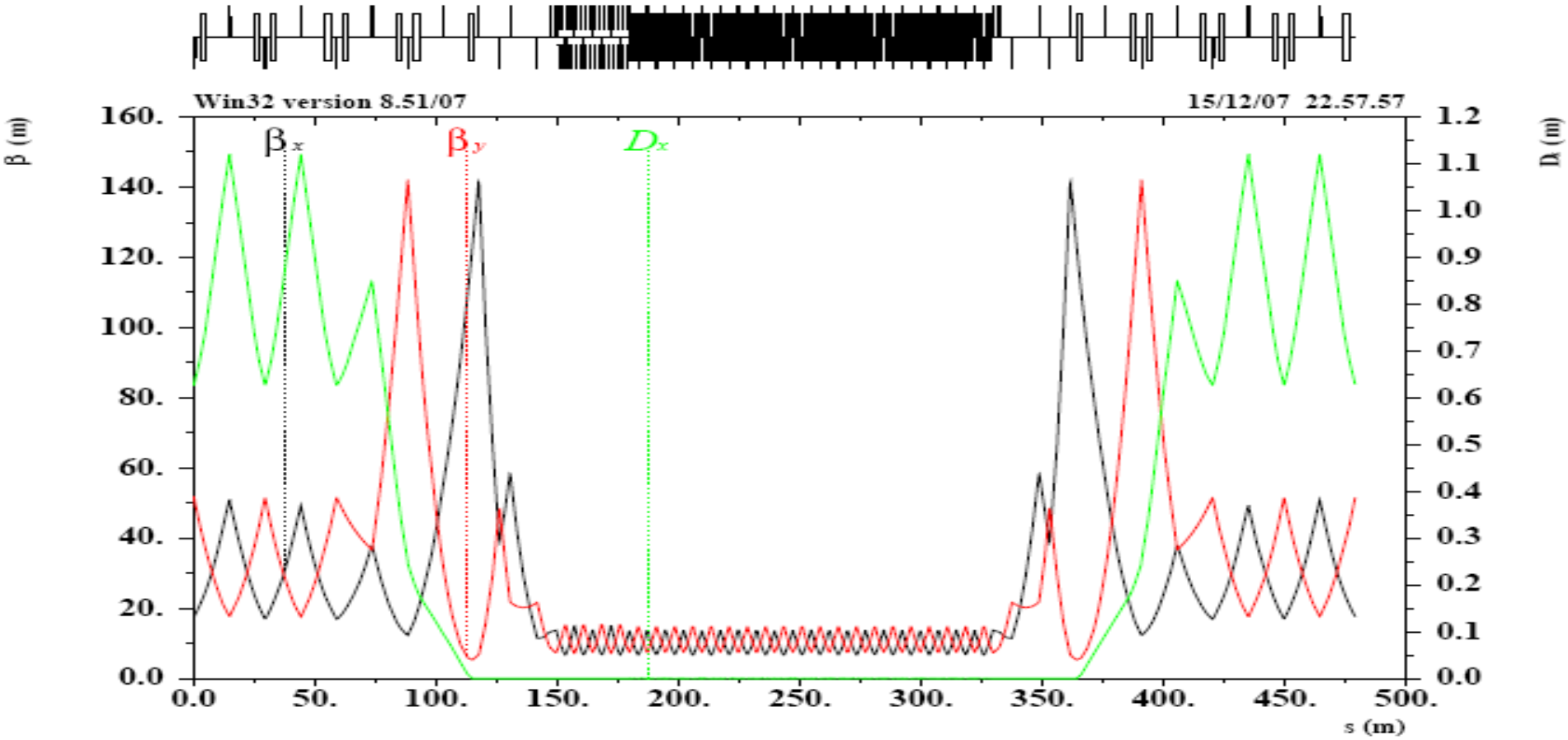
Select the **90 degree case** as the baseline, the bending angle in the dispersion suppressor is set to be half of the bending angle in the normal arc cell, so that zero dispersion at exit is got naturally for 90 degree case.

WIGGLER SECTION TOGETHER WITH DISPERSION SUPPRESSOR (72 DEGREE CASE)



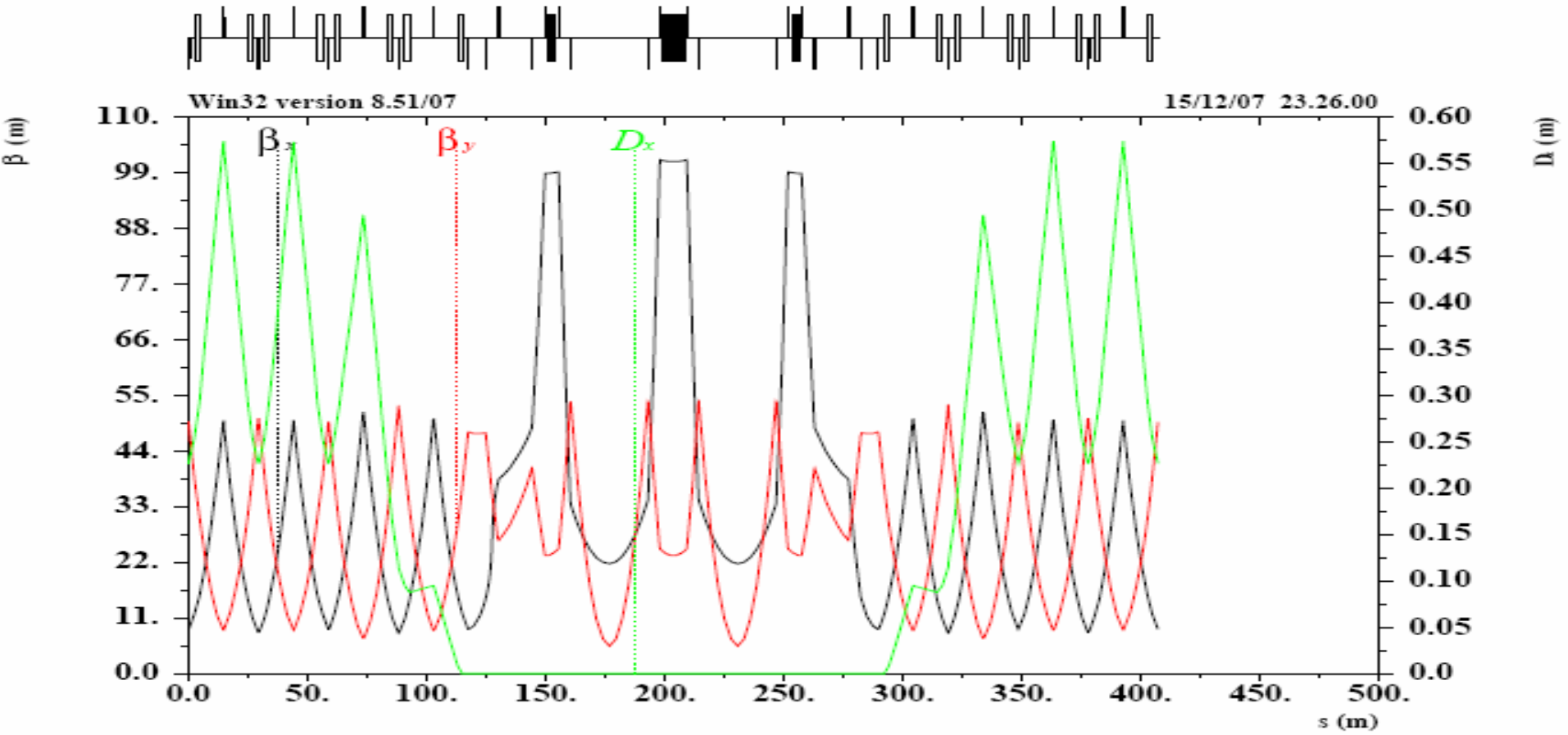
Tune the quadrupole's strength in the dispersion suppressor for the **72 degree case**, to make sure dispersion is free at exit, and dipole strength not changed (Geometry is the same).

WIGGLER SECTION TOGETHER WITH DISPERSION SUPPRESSOR (60 DEGREE CASE)



Tune the quadrupole's strength in the dispersion suppressor for the **60 degree case**, to make sure dispersion is free at exit, and dipole strength not changed (Geometry is the same).

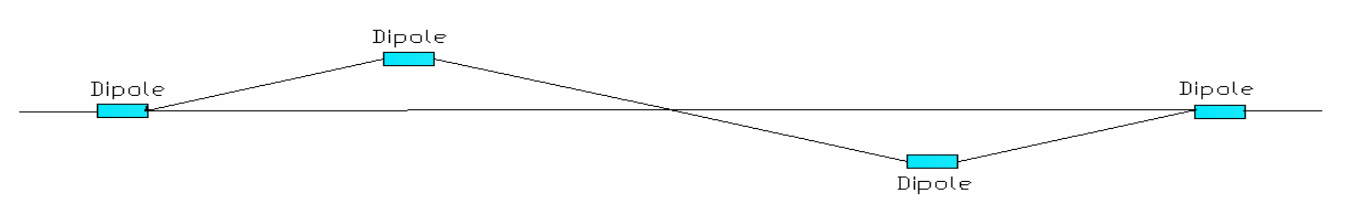
INJECTION/EXTRACTION DESIGN (90 DEGREE)



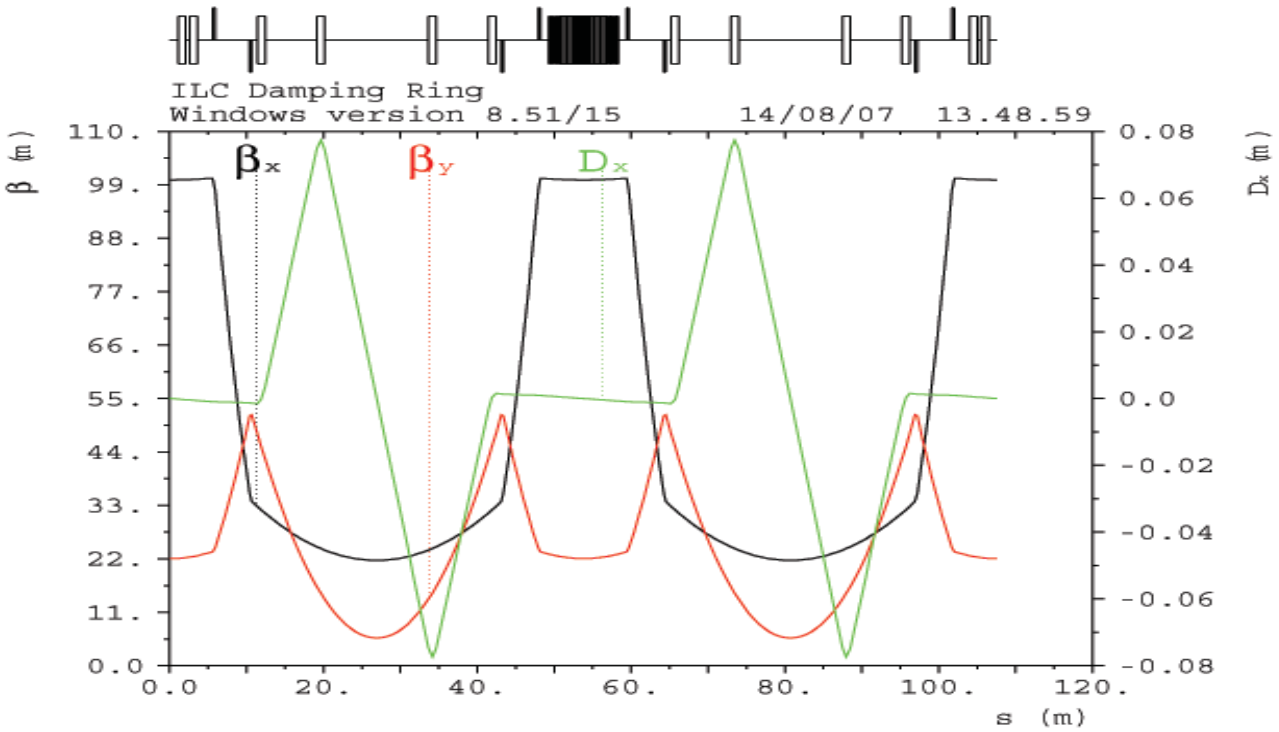
2 septums and 21 stripline kickers (lumped kickers)

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

CHICANE (90 DEGREE CASE)



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

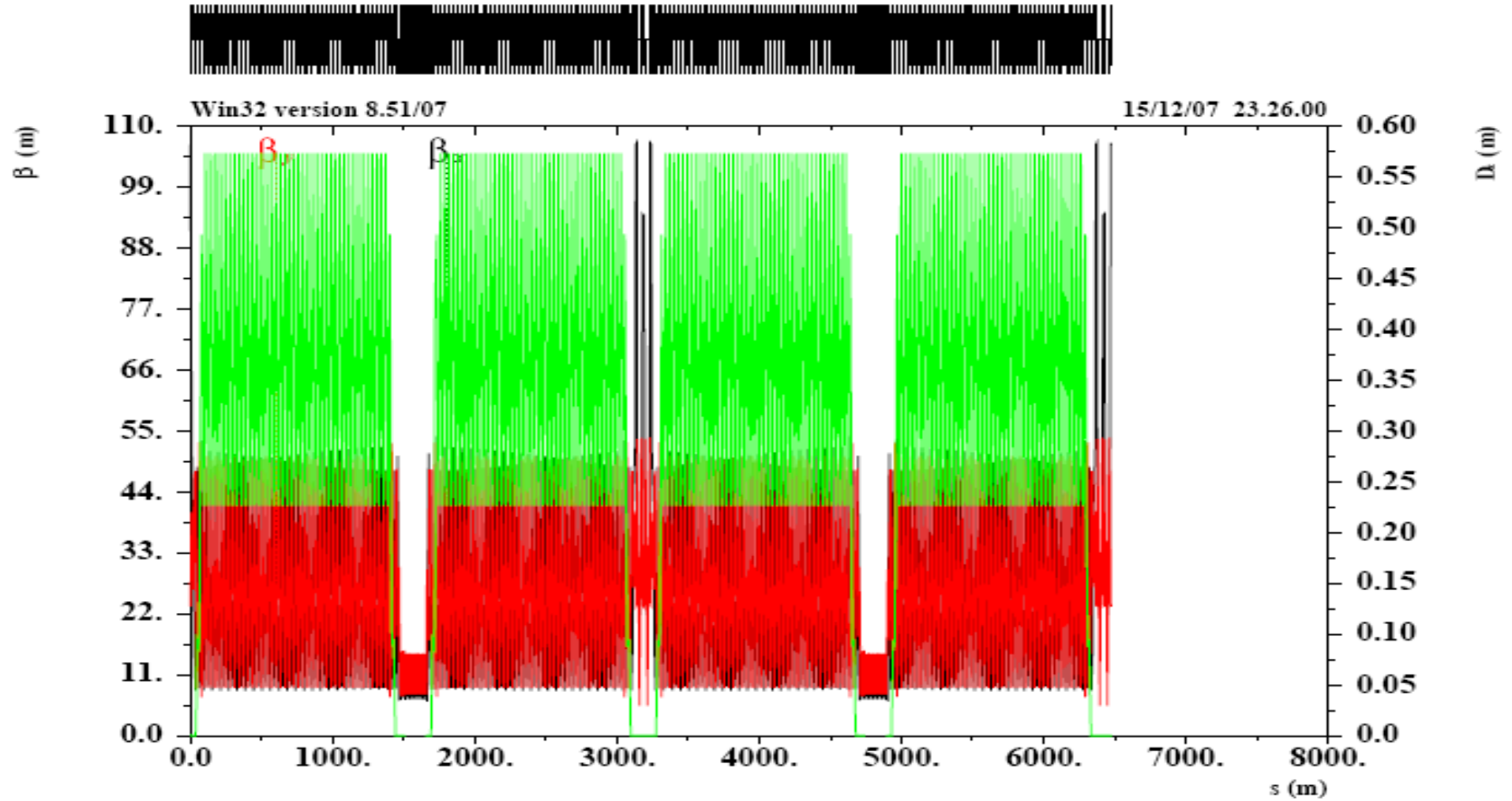


10^{-6} adjustable

4 Chicane

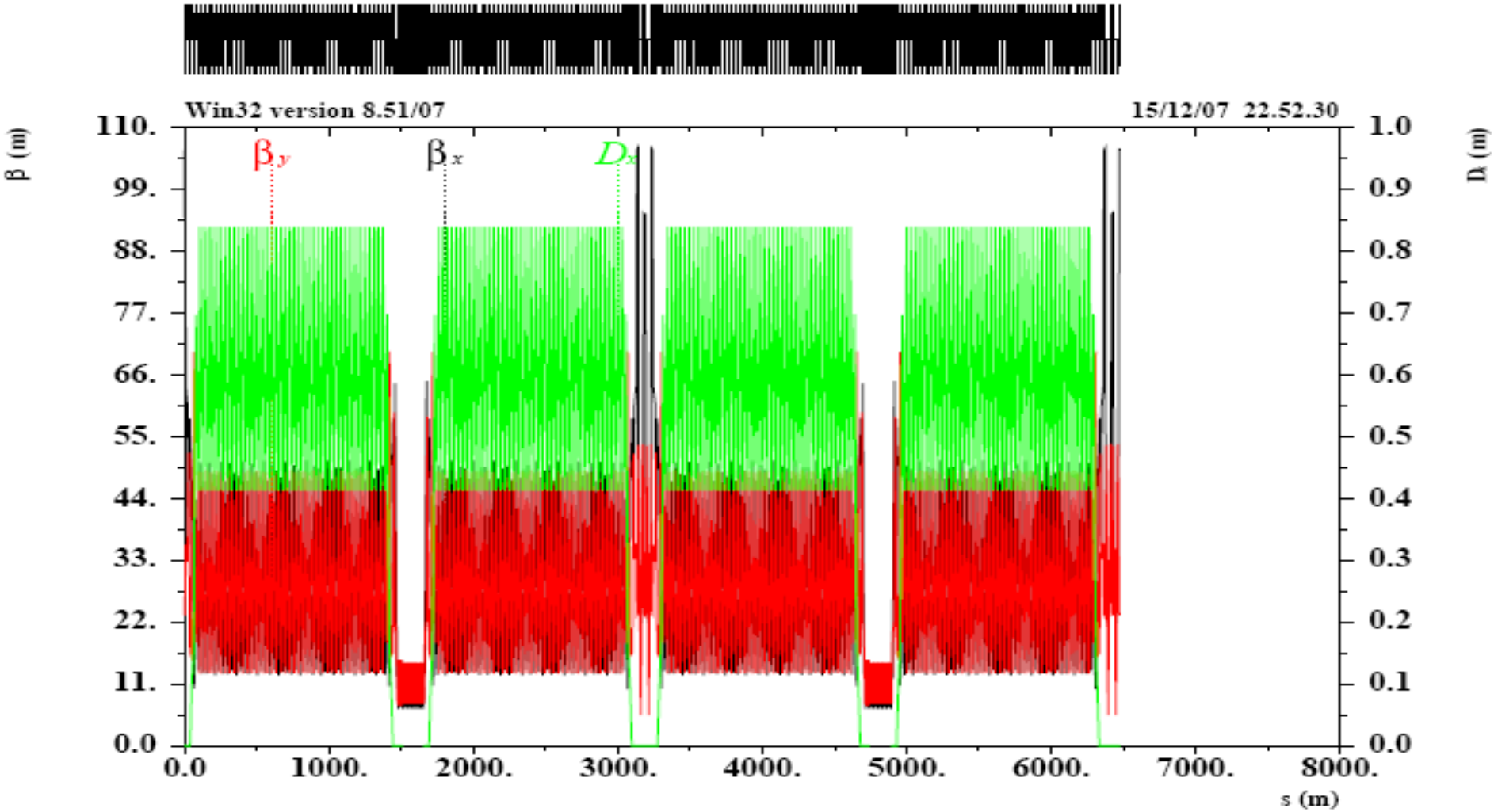
Emittance +9.2%

2×10^{-4} MOMENTUM COMPACTION



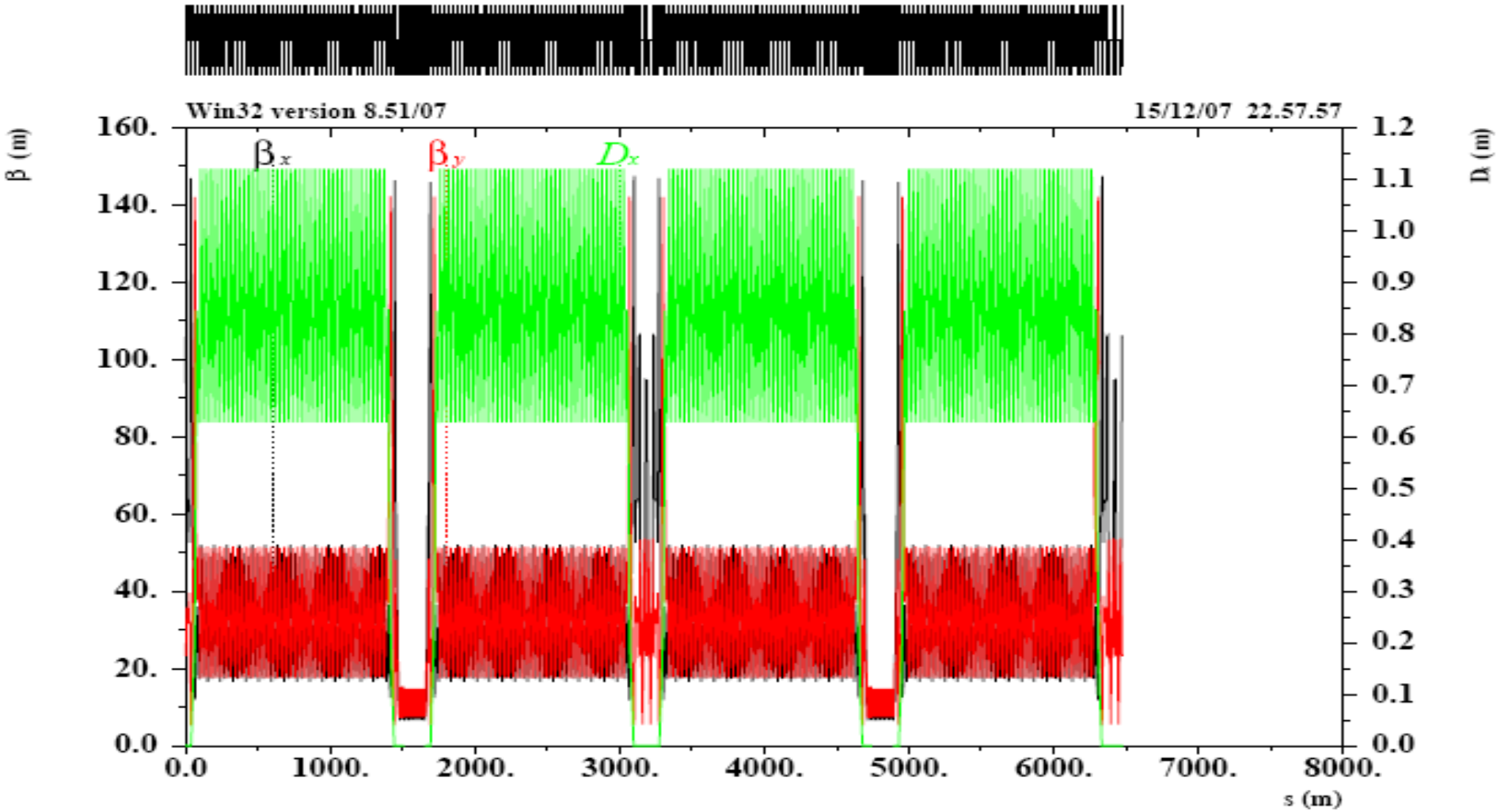
90/90 cell, 2×10^{-4} momentum compaction

4×10⁻⁴ MOMENTUM COMPACTION



72/72 cell, **4×10⁻⁴** momentum compaction

6×10^{-4} MOMENTUM COMPACTION

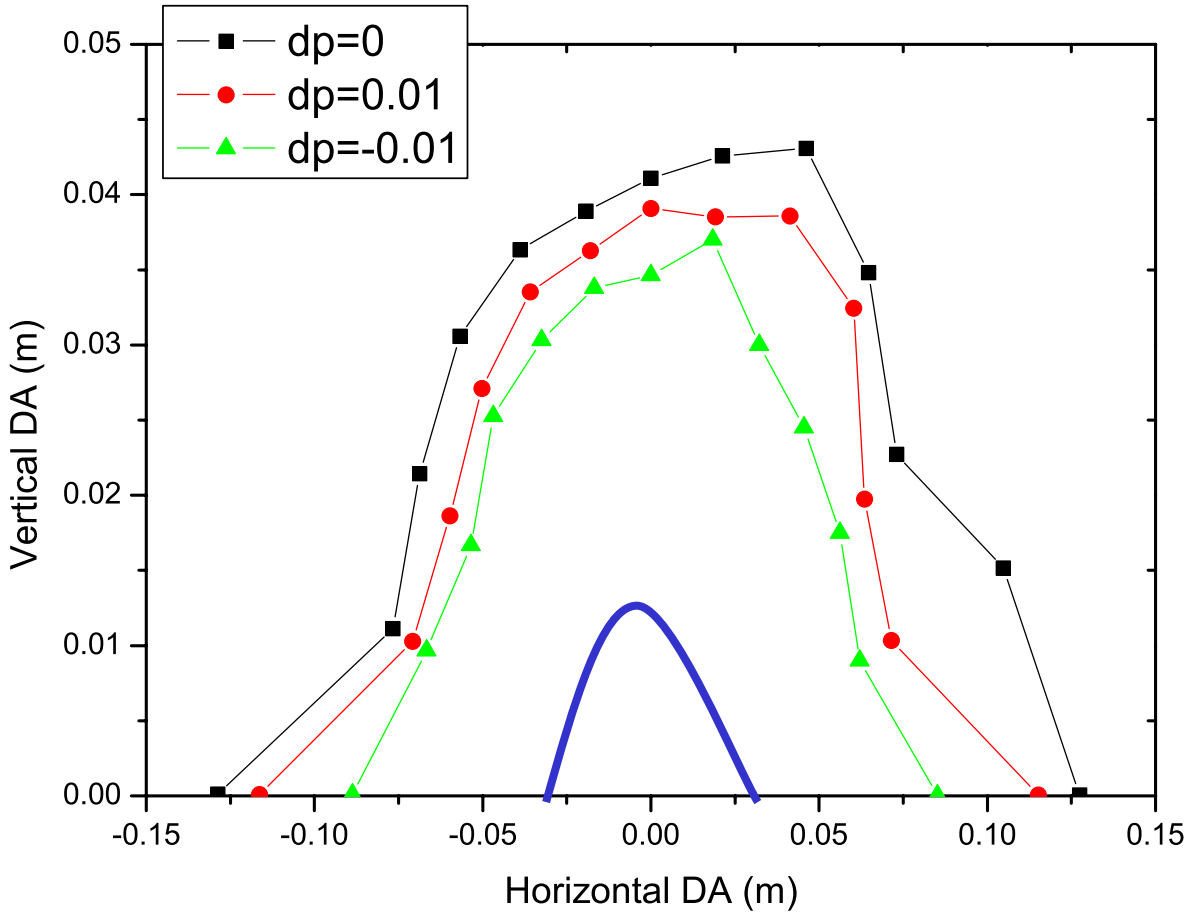


60/60 cell, **6×10^{-4}** momentum compaction

TOTAL PARAMETERS OF THREE CRITICAL MODES

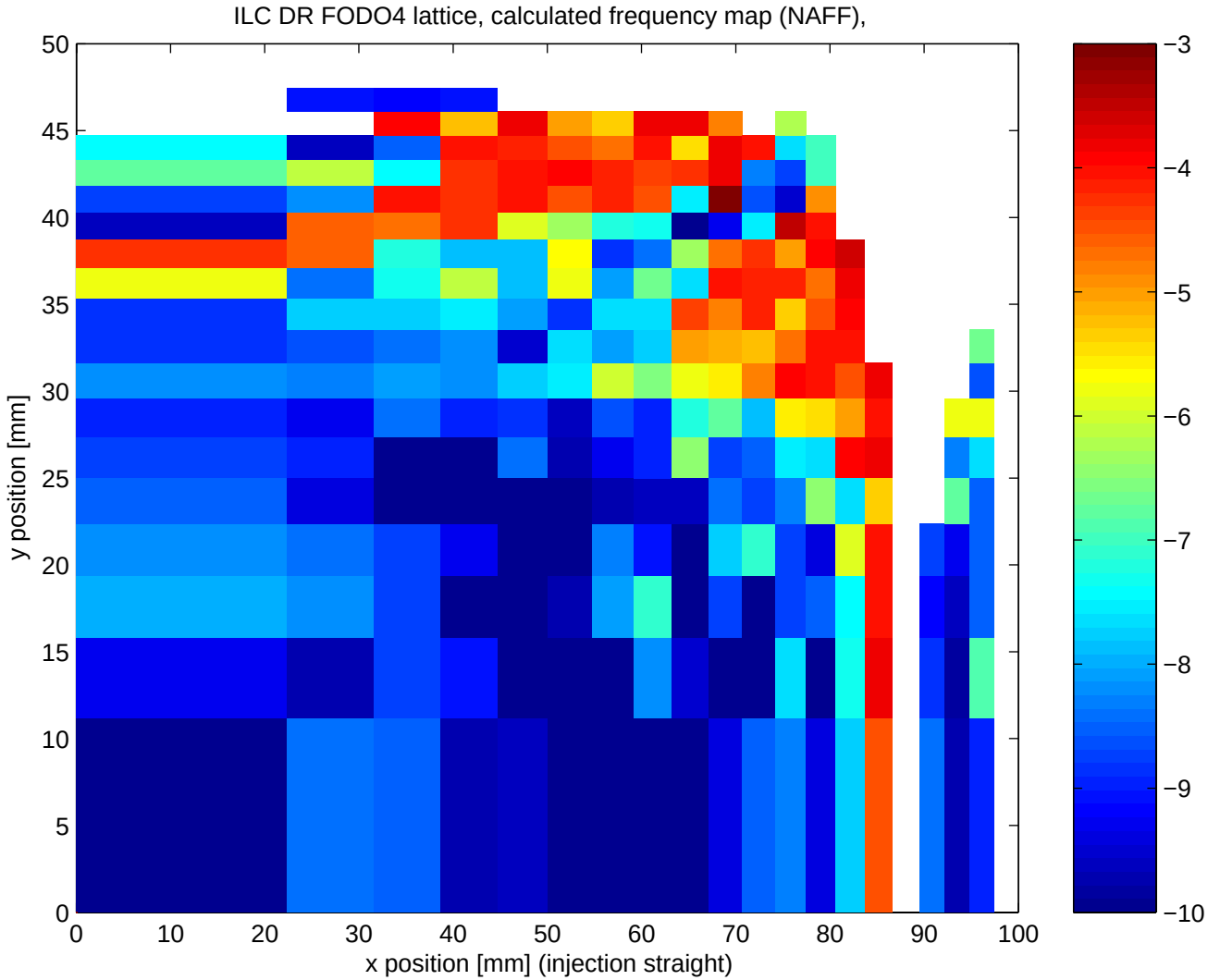
Parameter	$\alpha_P=2\times10^{-4}$	$\alpha_P=4\times10^{-4}$	$\alpha_P=6\times10^{-4}$
Circumference [m]	6476.439	6476.439	6476.439
Harmonic number	14042	14042	14042
Energy [GeV]	5	5	5
Arc cell	FODO	FODO	FODO
Tune	58.29 / 57.25	46.28 / 47.24	40.29 / 41.25
Natural chromaticity	-74 / -73	-54 / -55	-48 / -49
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

DYNAMIC APERTURE 6×10^{-4} ALPHA CASE

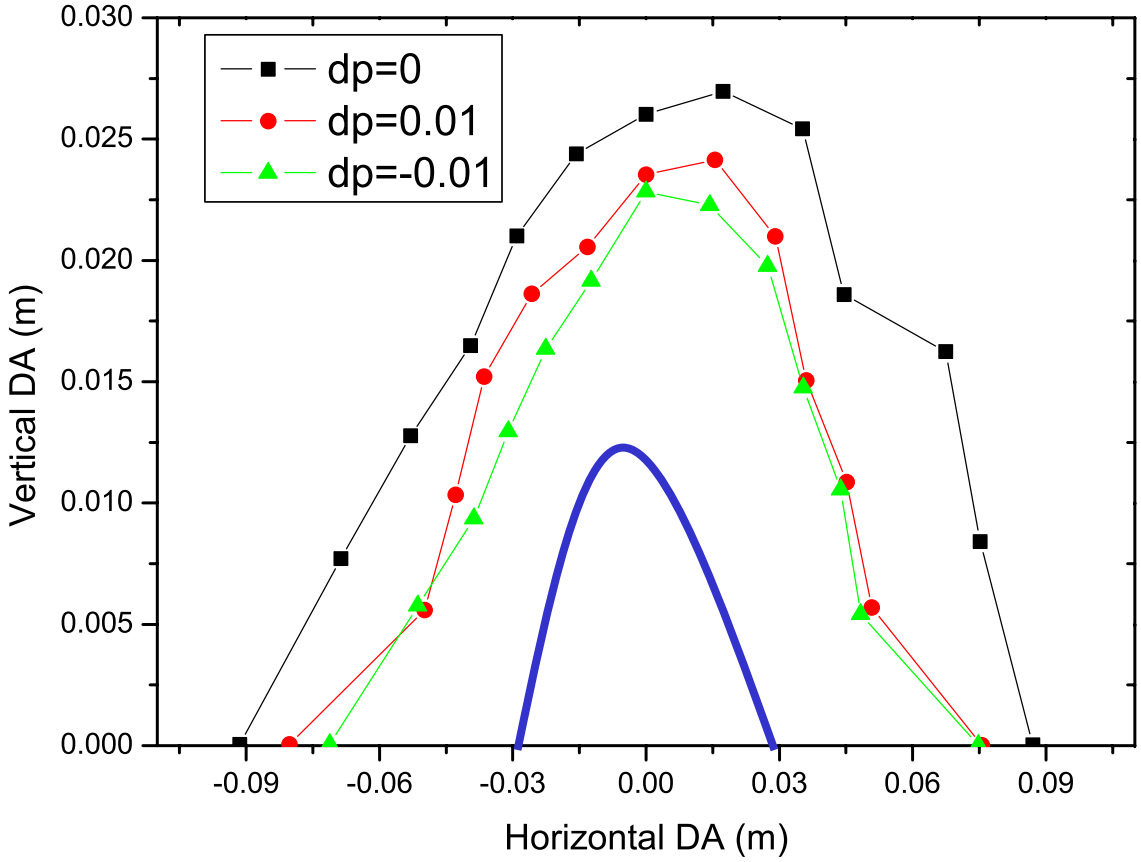


The blue line is **three times injected positron** bunch size.
Tracking for 1000 turns, no errors, using MAD.

FMA 6×10^{-4} ALPHA CASE

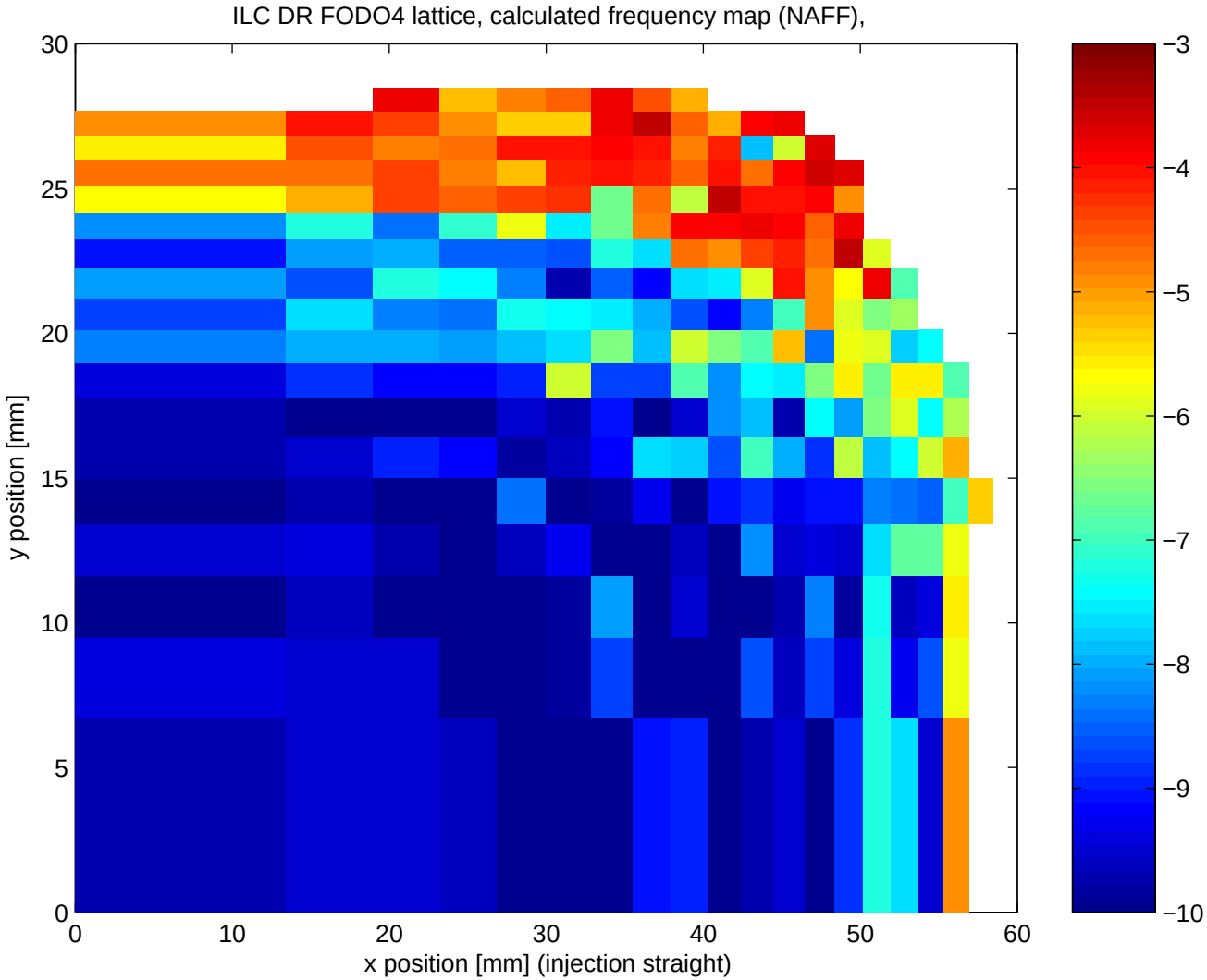


DYNAMIC APERTURE 4×10⁻⁴ ALPHA CASE

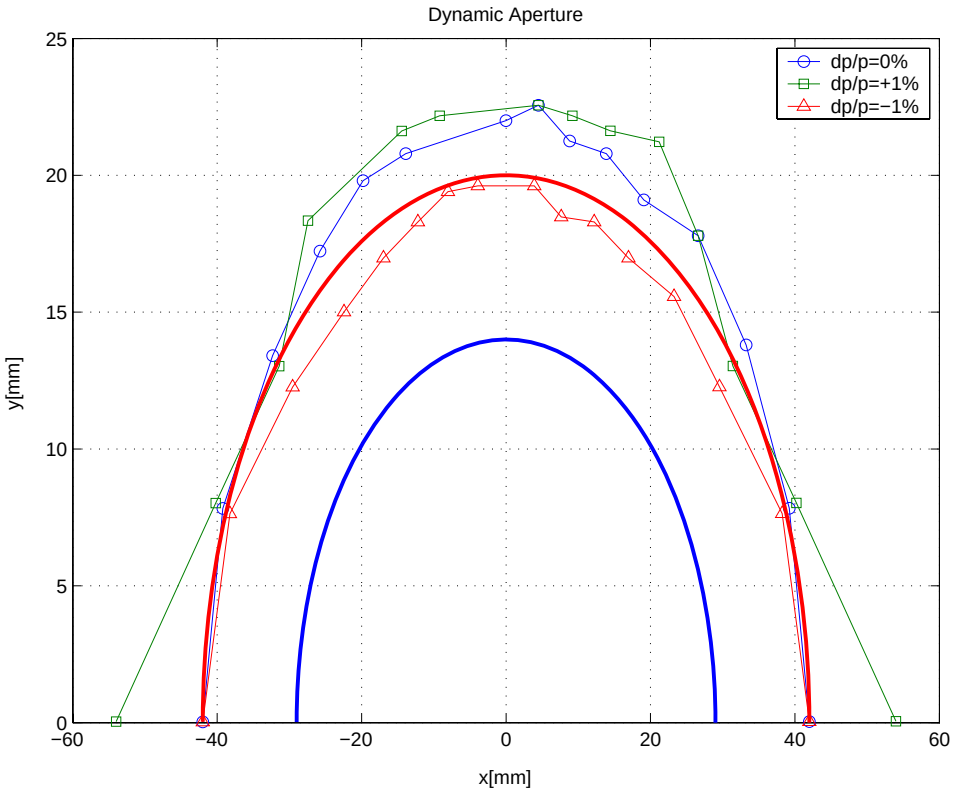


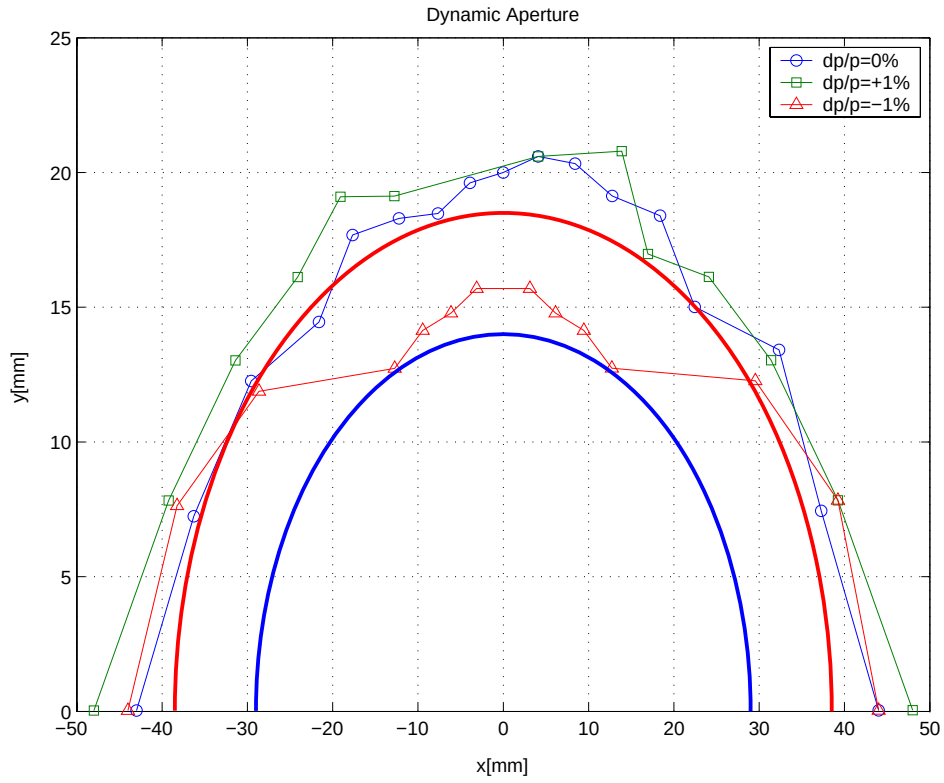
The blue line is **three times injected positron** bunch size.
Tracking for 1000 turns, no errors, using MAD.

FMA 4×10^{-4} ALPHA CASE



DYNAMIC APERTURE 2×10⁻⁴ ALPHA CASE (AT RESULTS)

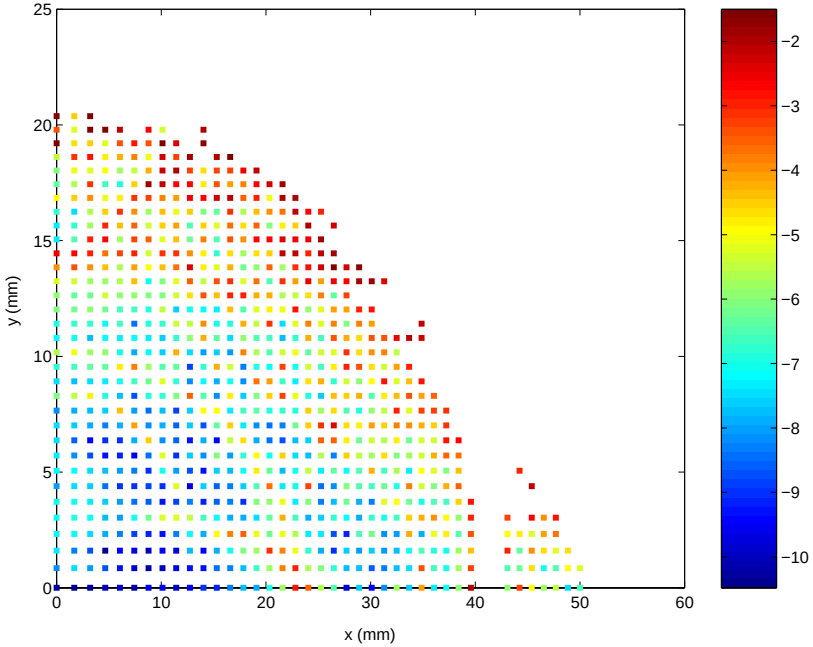


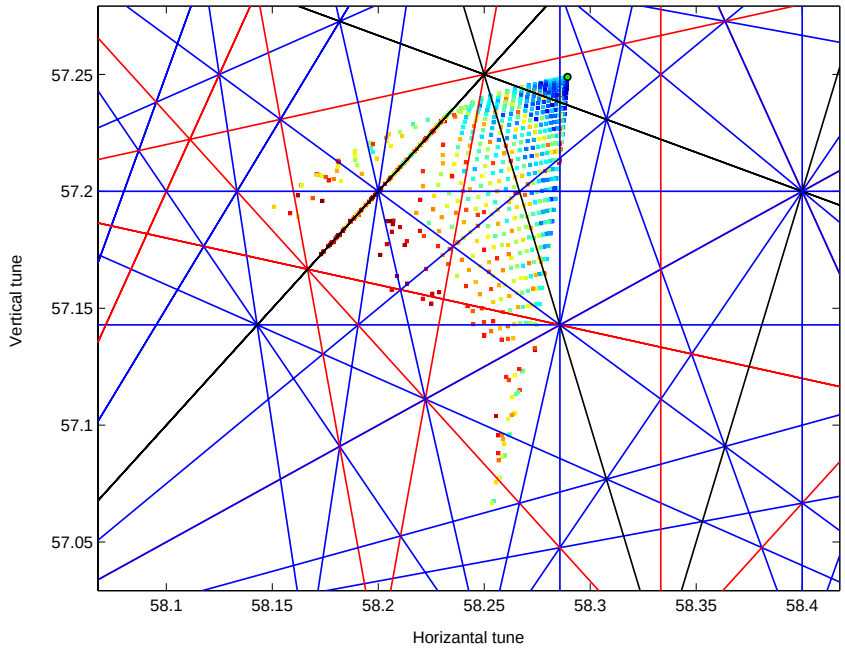


Left: no errors; Right: **with high order magnets errors**.

The blue line is **three times injected positron** bunch size.

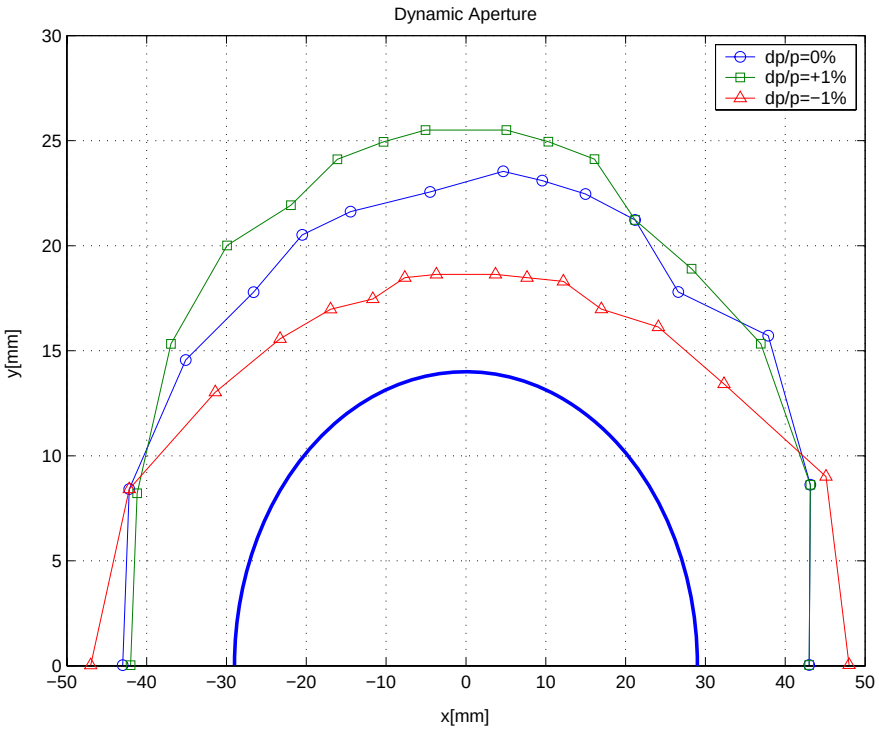
FMA OPTIMIZATION RESULTS

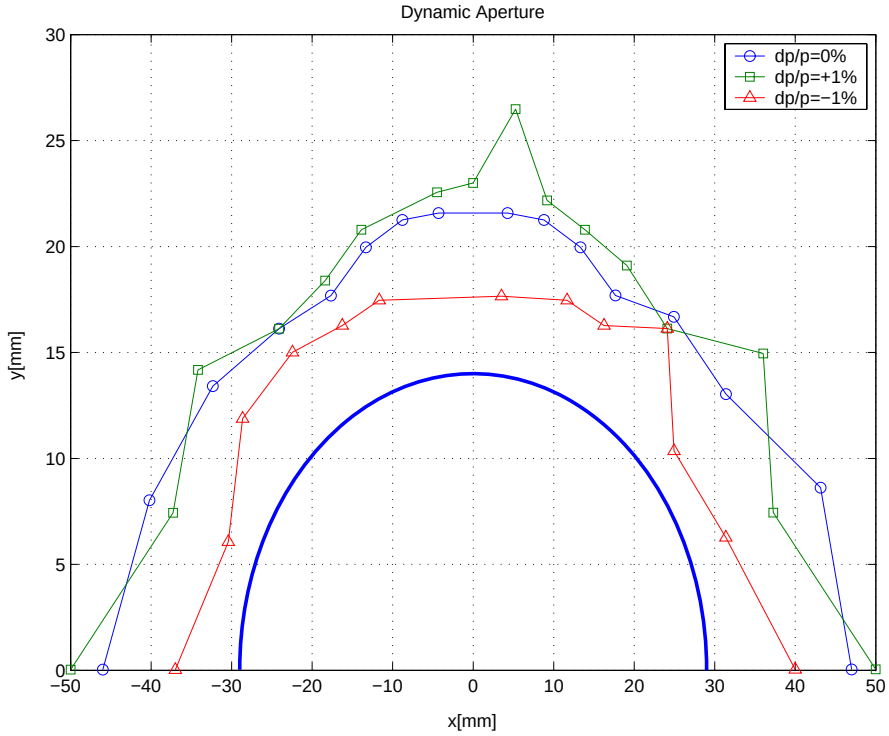




FMA is used to optimize the lattice and the DA. The optimized result for 2×10^{-4} momentum compaction mode

WITH HARMONIC SEXTUPOLES

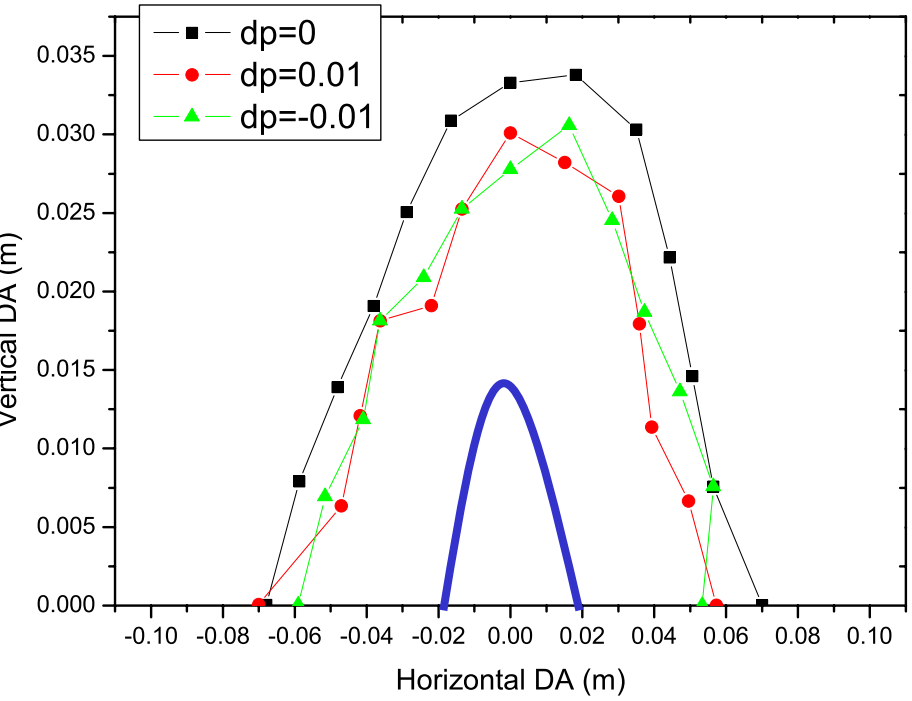


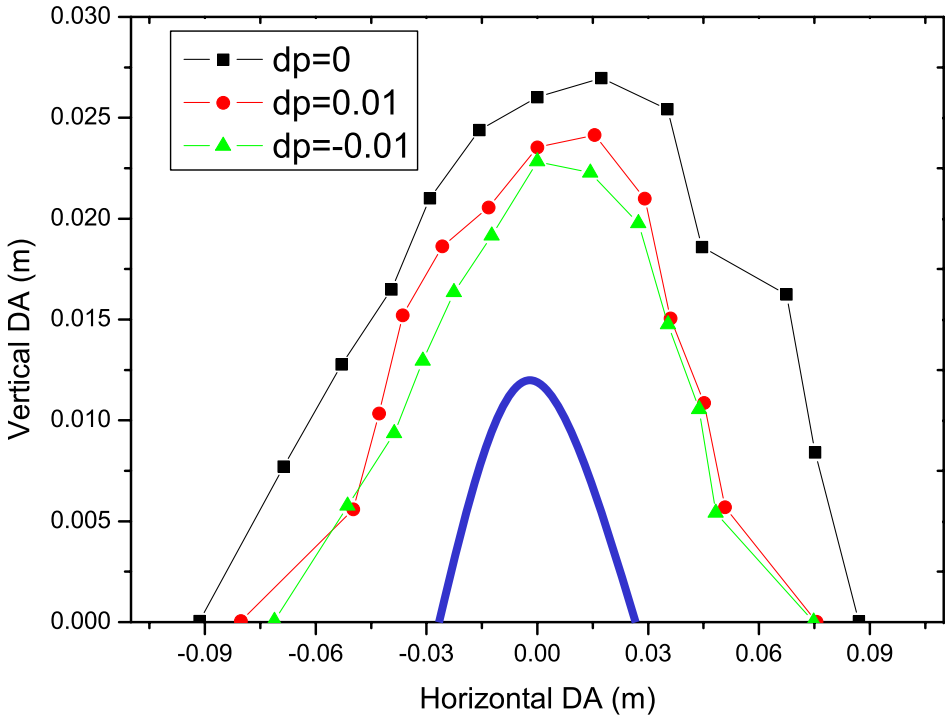


2×10^{-4} momentum compaction mode, with **3** group harmonic sextupoles

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

COMPARISON WITH OCS8 (MAD RESULTS)





4×10^{-4} momentum compaction mode, on momentum particles, without errors; Left: **OCS8**, Right: **FODO-4b**

The blue line is three times injected positron bunch size.

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 2×10^{10}, Touschek lifetime is 160 minutes

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