Dynamic Aperture of the CLIC Damping Ring

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Introduction

The CLIC Damping Ring is ...

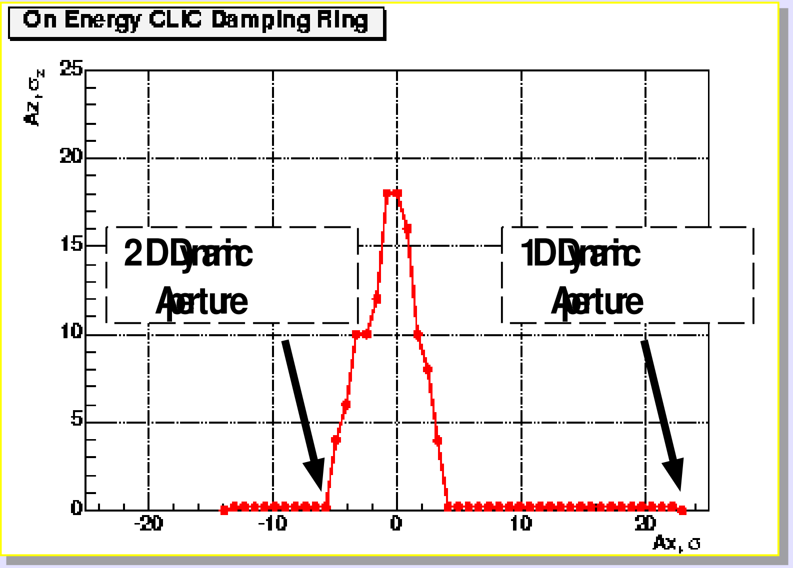
- The low equilibrium transverse emittance and small damping times
- Very strong focusing optics and small the dispersion function
- High natural chromatisity
- Strong sextupole magnets
- A lot of damping wigglers

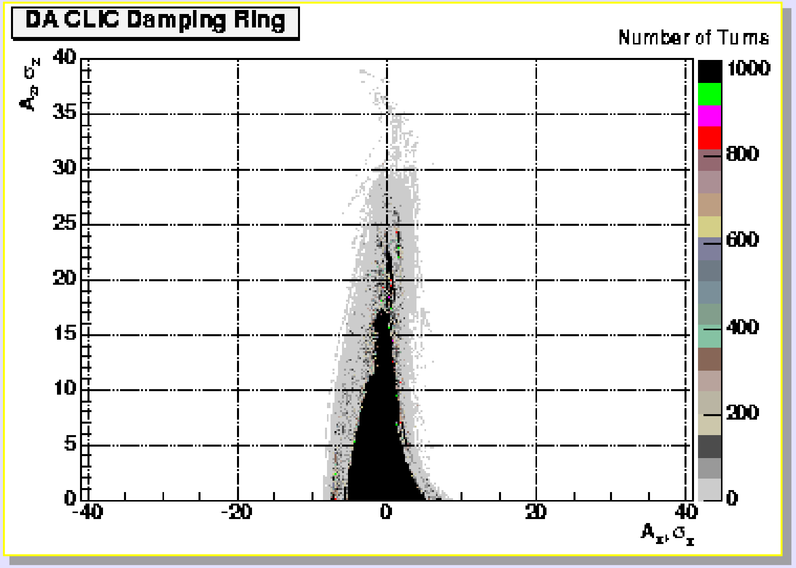
The Simulation of Nonlinear Particle Motion by Tracking Code Acceleraticum ™.

- *Dynamic Aperture Calculation*
- *Nonlinear and chromatisity effects*
- *Betatron Tune Scan*
- *Symplectic Integrator for Wiggler Field Distribution*

On Energy Dynamic Aperture

The lattice without damping wigglers

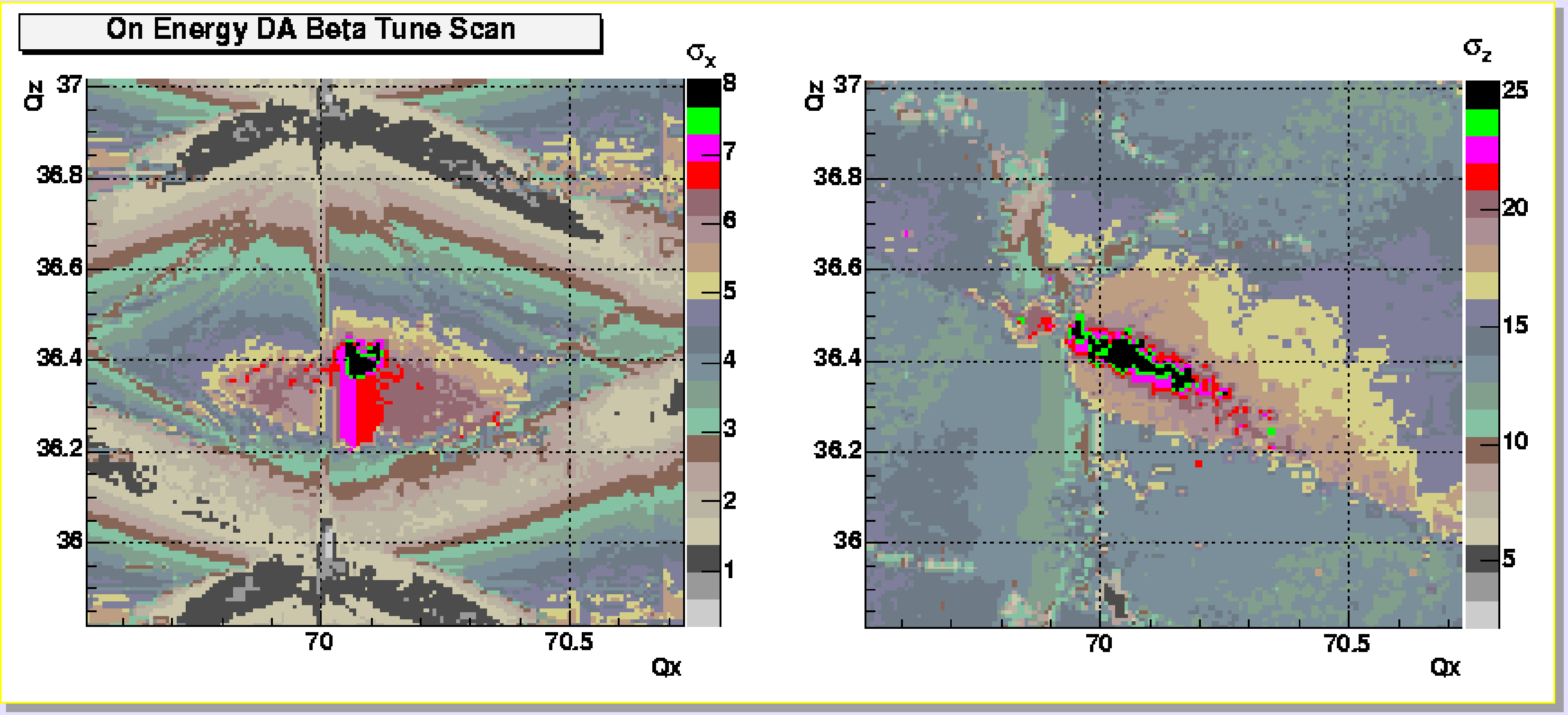




Very small 2D Dynamic Aperture due to Strong Coupling Sextupole Resonances

Betatron Tune Scan

Sextupole coupling resonances (2 superperiods)
$Q_x + 2\,Q_z = 142$ and $Q_x + 2\,Q_z = 144$
$Q_x - 2\,Q_z = -4$ and $Q_x - 2\,Q_z = -2$



Sextupole Harmonics

$$H_s(x,p_x,z,p_z;\theta) = J_x^{3/2}\sum(A_{3,n}^{3,0}\cos(3\phi_x - n\theta) + B_{3,n}^{3,0}\sin(3\phi_x - n\theta)$$

$$+A_{1,n}^{3,0}\cos(1\phi_x - n\theta) + B_{1,n}^{3,0}\sin(3\phi_x - n\theta))-$$

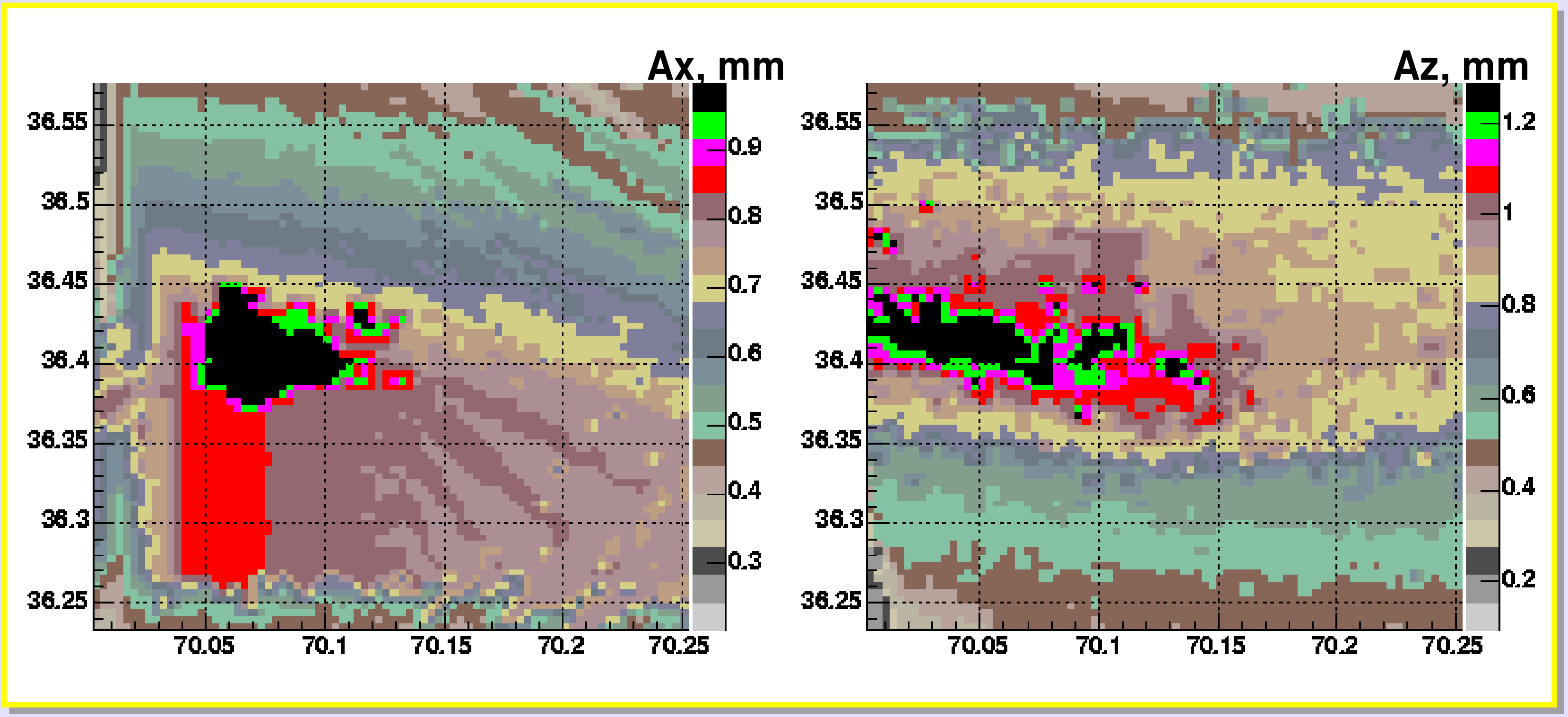
$$-J_x^{1/2}J_z\sum(A_{1,2,n}^{1,2}\cos(\phi_x + 2\phi_z - n\theta) + B_{1,2,n}^{1,2}\sin(\phi_x + 2\phi_z - n\theta)+$$

$$+A_{1,-2,n}^{1,2}\cos(\phi_x - 2\phi_z - n\theta) + B_{1,-2,n}^{1,2}\sin(\phi_x - 2\phi_z - n\theta)+$$

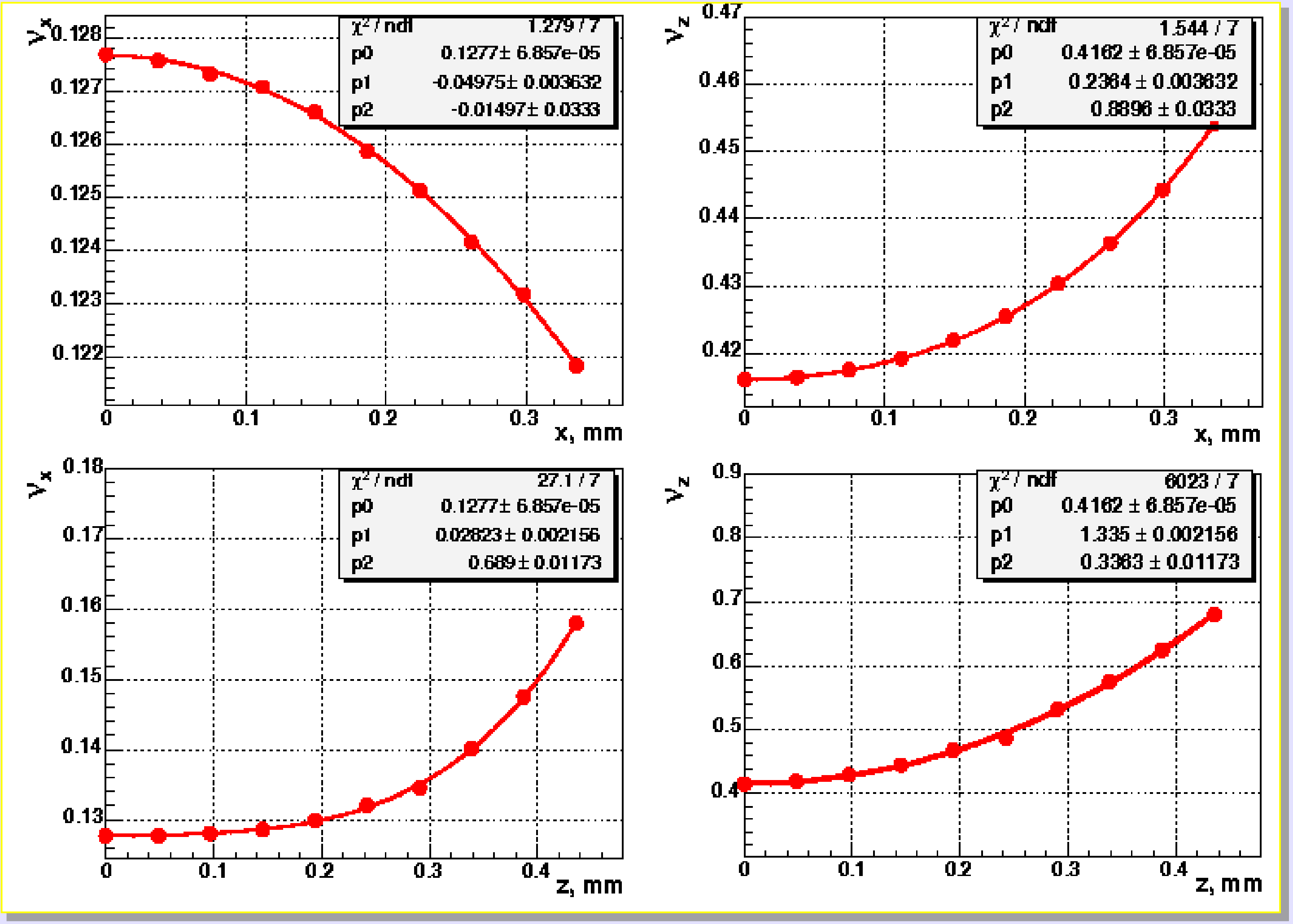
$$+A_{1,0,n}^{1,2}\cos(\phi_x - n\theta) + B_{1,0,n}^{1,2}\sin(\phi_x - n\theta)).$$

	A, $m^{-1/2}$	B, $m^{-1/2}$
(3,0,3,270)	-30.64	3.43
(3,0,1,70)	-0.01	0.08
(1,2,1,2,144)	72.02	2.4
(1,2,1,2,142)	-55.97	-2.6
(1,2,1,-2,-4)	74.83	3.4
(1,2,1,-2,-2)	45.98	1.5
(1,2,1,0,70)	0.77	0.6

Betatron Tune Scan



Dependence Tune of Amplitude



Dependence Tune of Amplitude

$$\Delta\nu_x = C_{xx}A_x^2 + C_{xz}A_z^2 = \alpha_{xx}J_x + \alpha_{xz}J_z$$

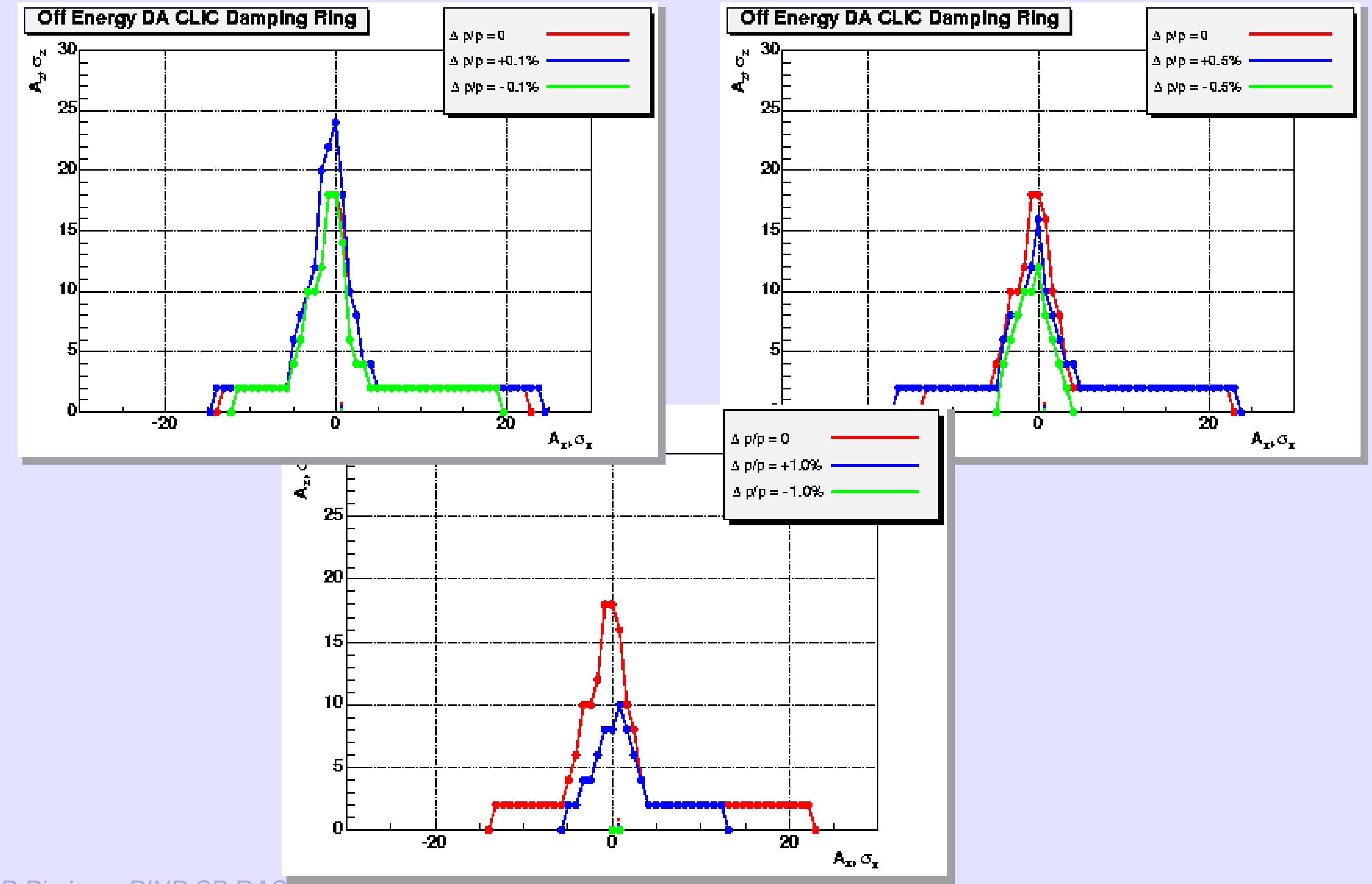
$$\Delta\nu_z = C_{zx}A_x^2 + C_{zz}A_z^2 = \alpha_{zx}J_x + \alpha_{zz}J_z$$

$$\alpha_{xz} = \alpha_{zx}$$

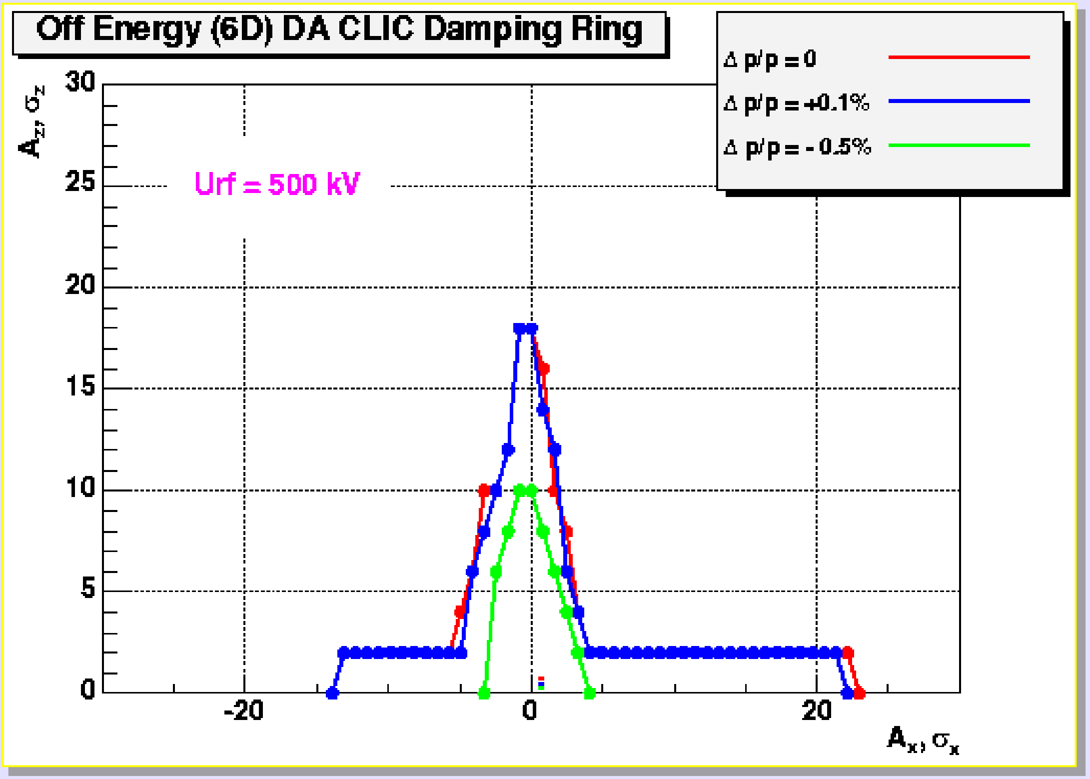
	C_{xx}	C_{zx}	C_{xz}	C_{zz}
1	-0.05 mm^{-2}	0.24 mm^{-2}	0.036 mm^{-2}	1.40 mm^{-2}
2	-0.14 mm^{-4}	0.86 mm^{-4}	0.41 mm^{-4}	-0.21 mm^{-4}

α_{xx}	α_{zx}	α_{xz}	α_{zz}
1.16 10^{5} m^{-1}	5.58 10^{5} m^{-1}	5.81 10^{5} m^{-1}	2.27 10^{7} m^{-1}

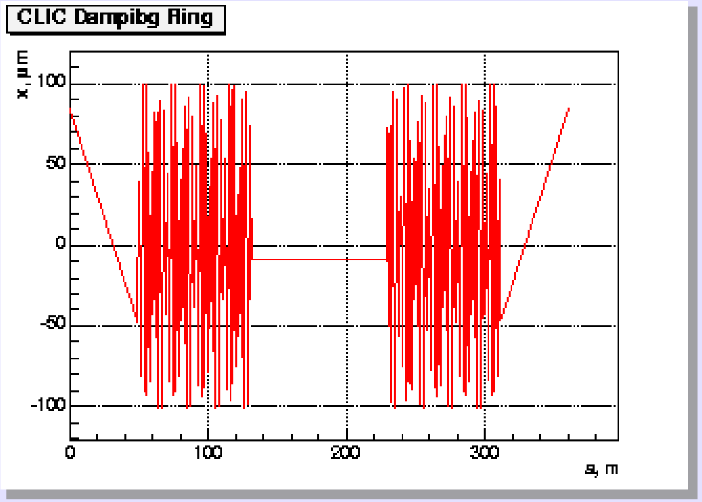
Off Energy Dynamic Aperture

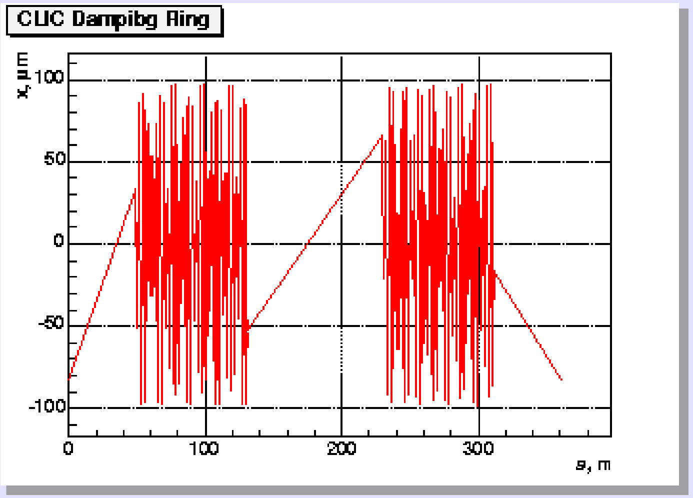


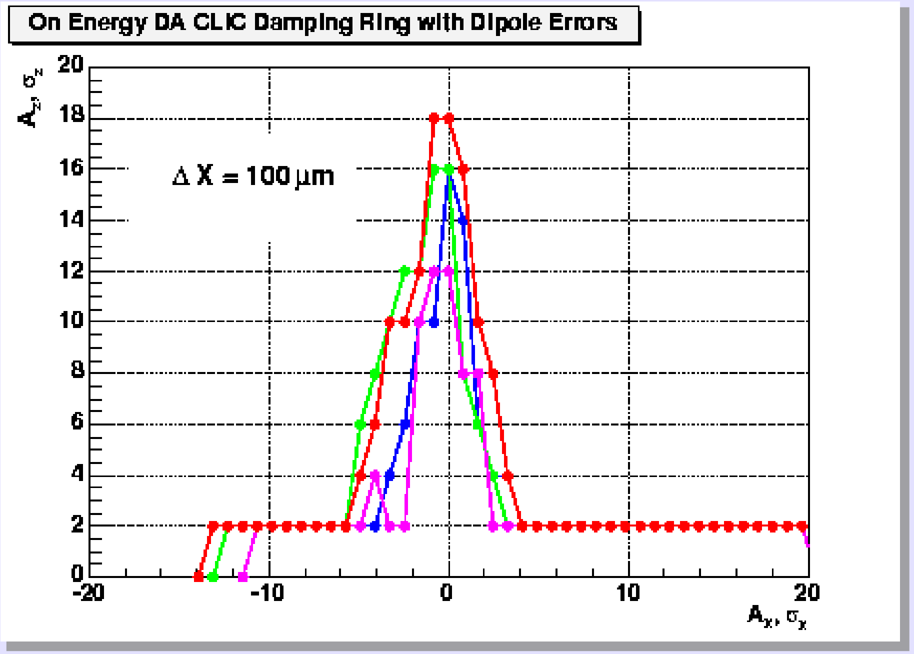
Off Energy Dynamic Aperture with Synchro-Betatron Oscillations



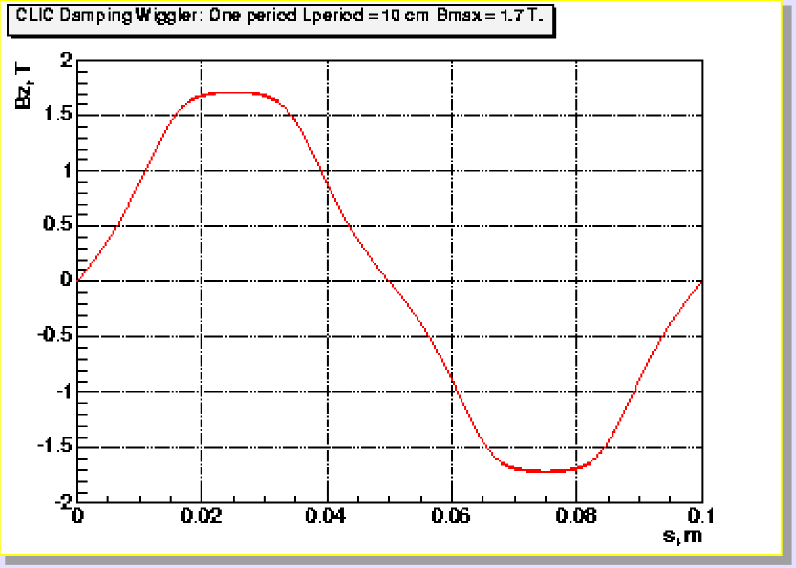
Dynamic Aperture with Dipole Errors



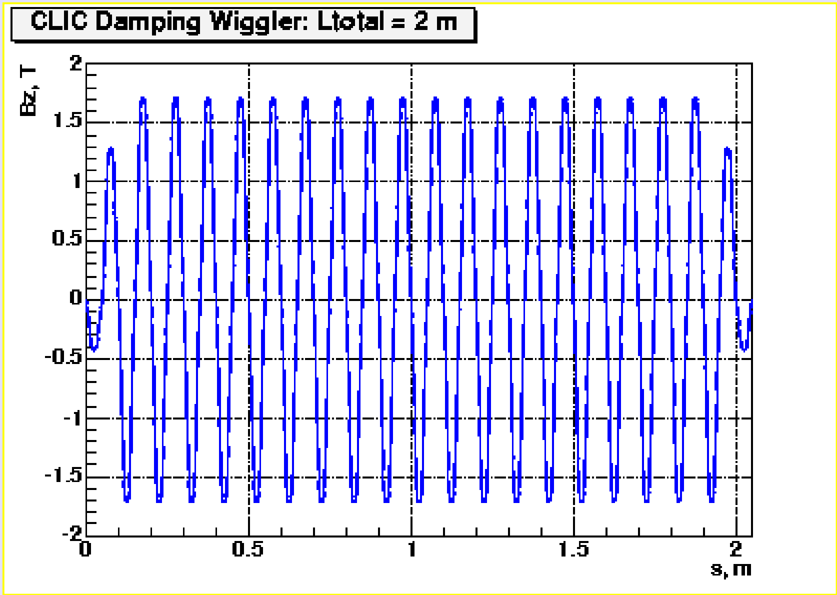




CLIC Damping Wiggler



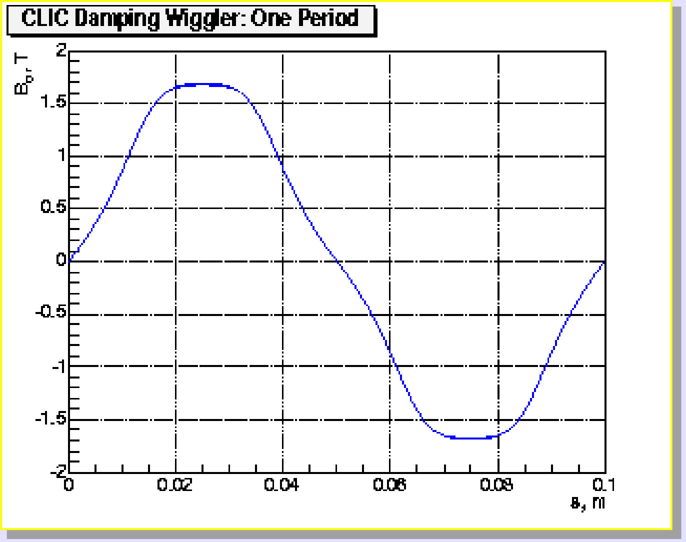
Maximum field is 1.7 T
Period length is 10 cm
Length of wiggler is 2 m
Number of poles is 41
Number of wigglers is 2x38

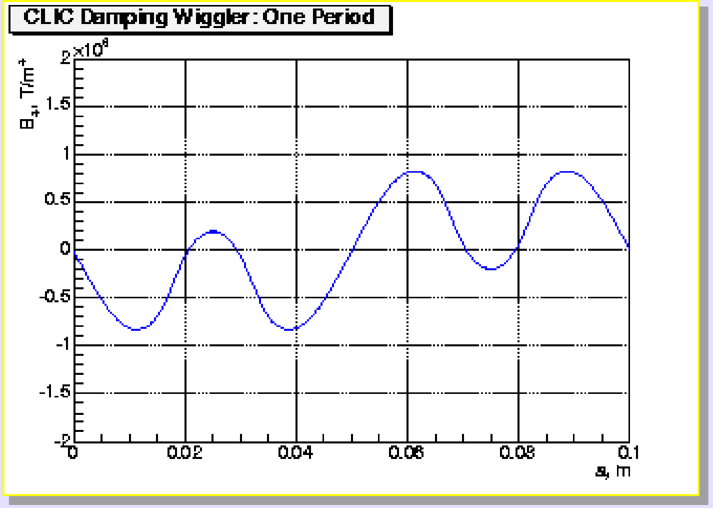


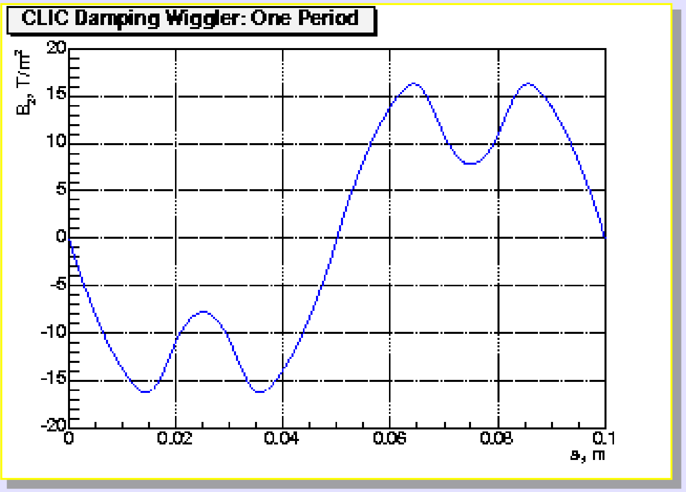
The poles sequence:
1/4, -3/4, 1, -1, . . .,.-1, 1, -3/4, -1/4
of maximum field

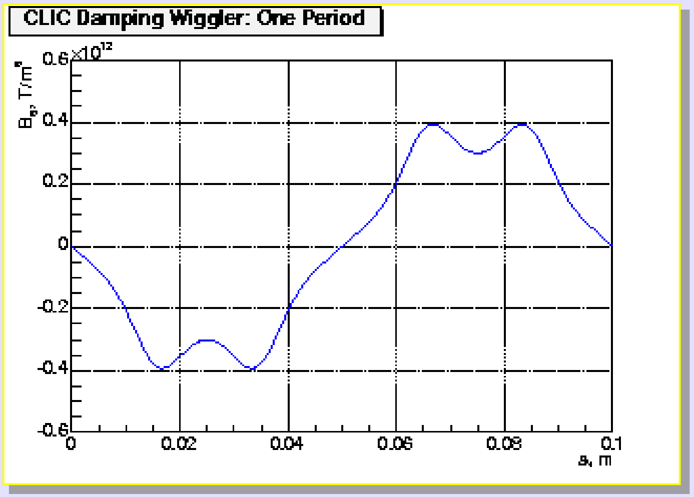
The input data is the result of the 3D simulation magnetic field by MERMAID.

Field Multipole Distribution



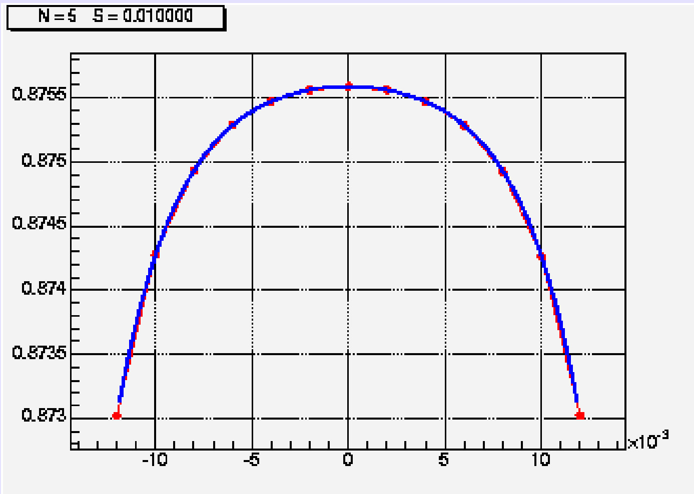


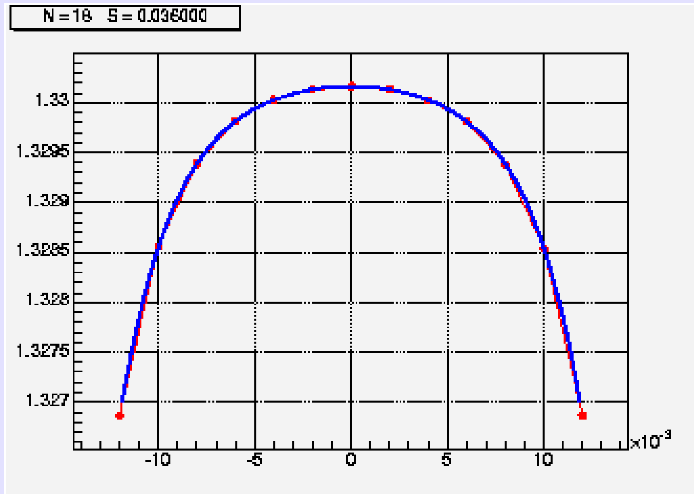




Construction Field Multipole from Field Map

The field distribution in the median plane
(horisontal step dx = 2 mm, longitudinal step ds = 2 mm)
Fit by polynom of 6 power





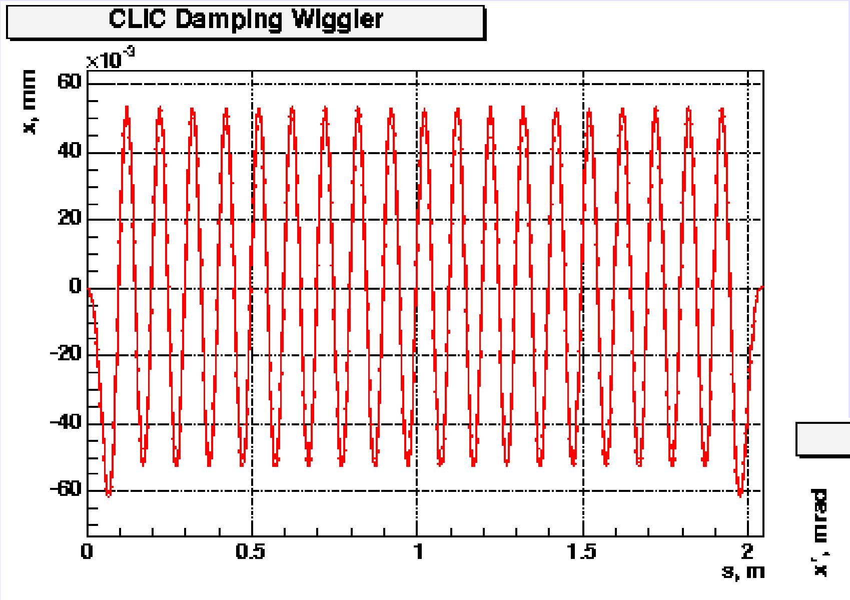
$$B_z(x, z=0, s) = \sum_n B_n(s)\frac{x^n}{n!}, \quad B_n(s) = \left.\frac{\partial^n B}{\partial x^n}\right|_{x,z=0}$$

Wiggler Simulation

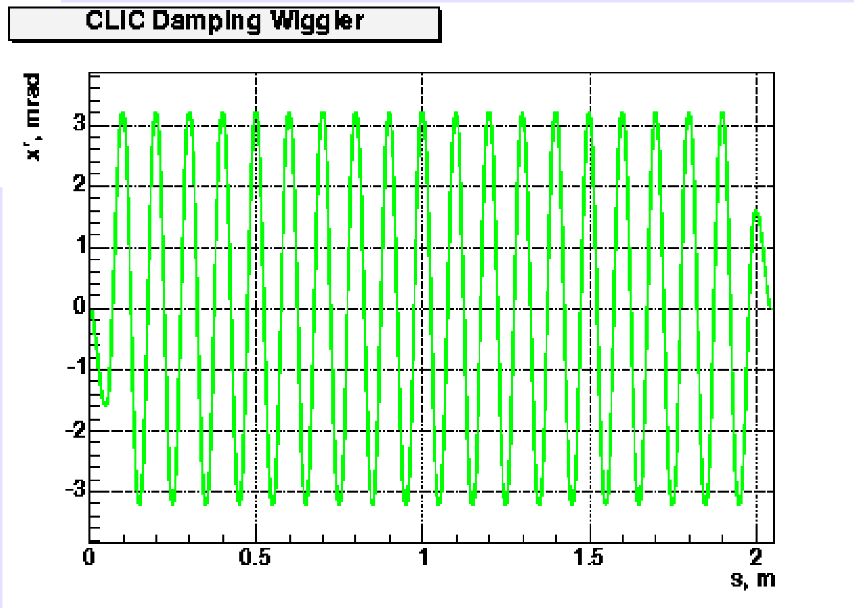
There are 3 options for the simulation of wiggler

- The Pure Sine Wiggler (+)
- The Thin Lens Model (-)
- The Symplectic Integrator using the field map (+)

Wiggler Orbit

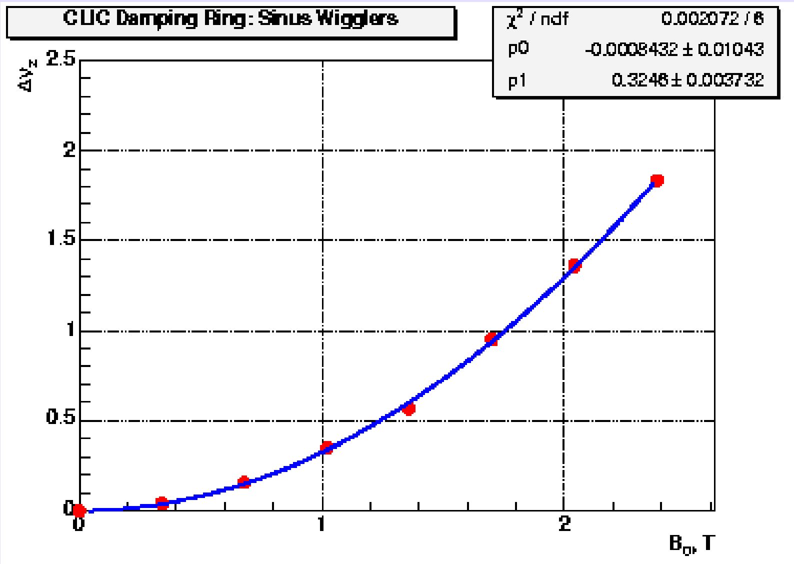


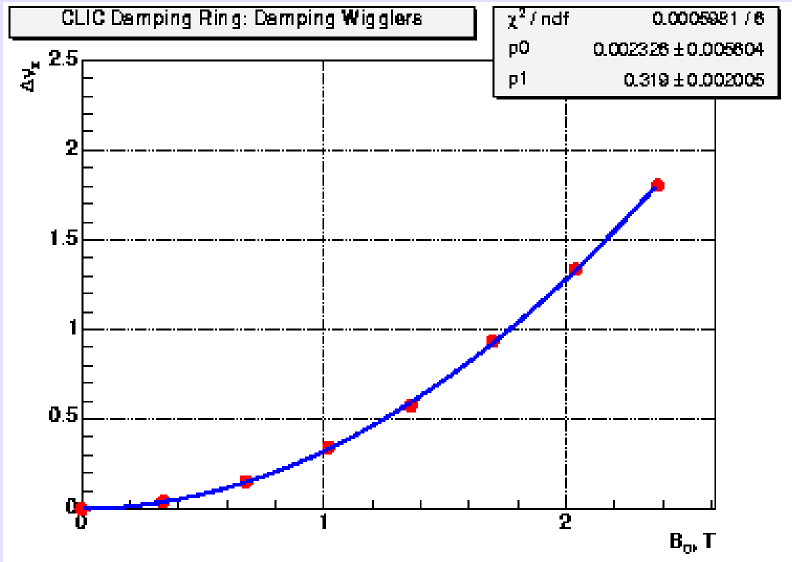
Xmax ~50µm.



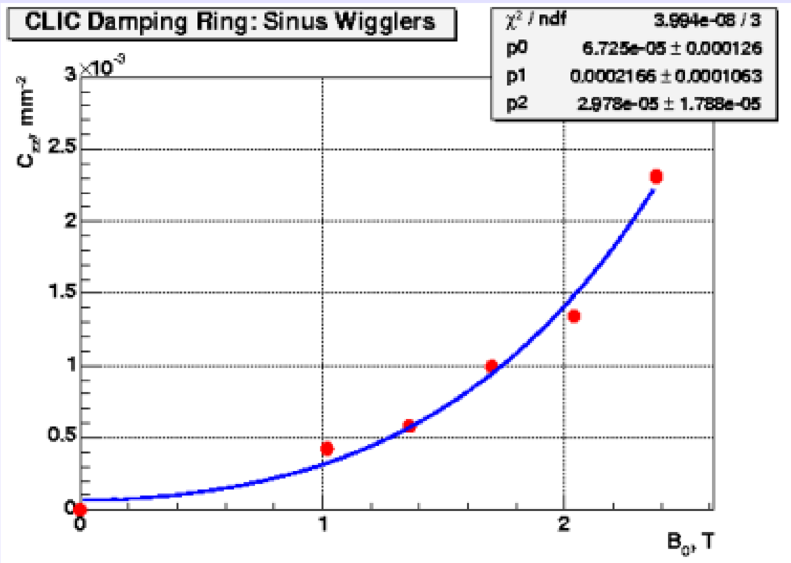
The damping wiggler is very similar to sine wiggler.

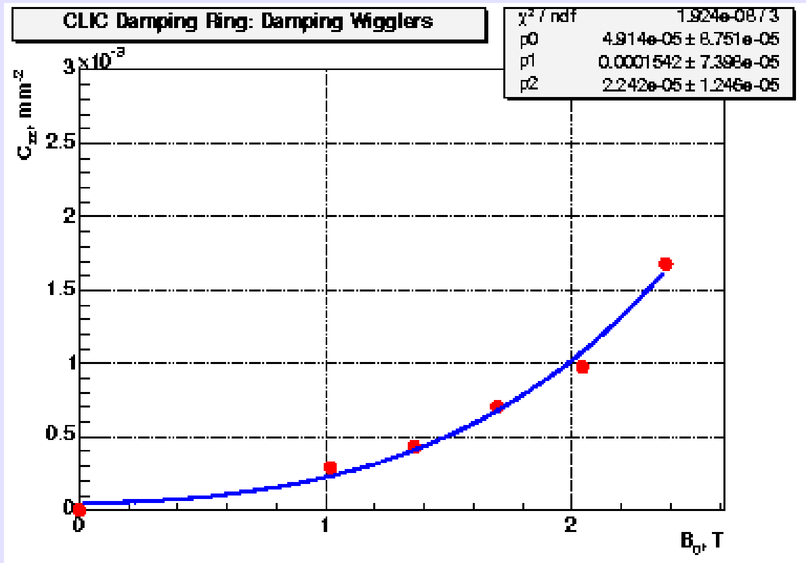
Tune Shift vs Wiggler Field





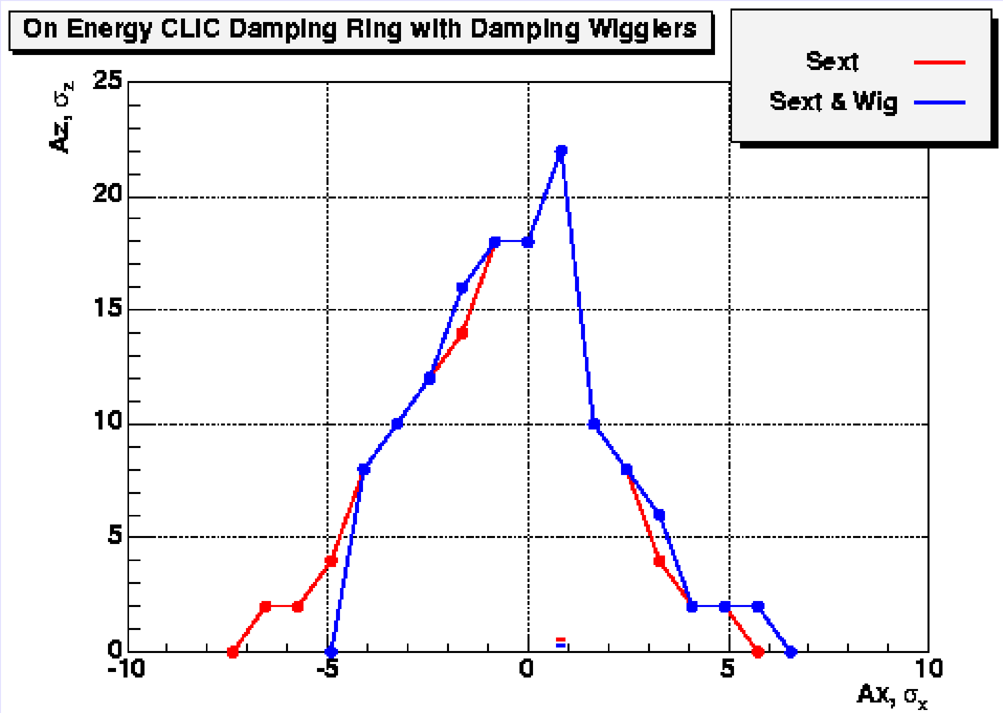
C_{zz} vs Wiggler Field





On Energy Dynamic Aperture

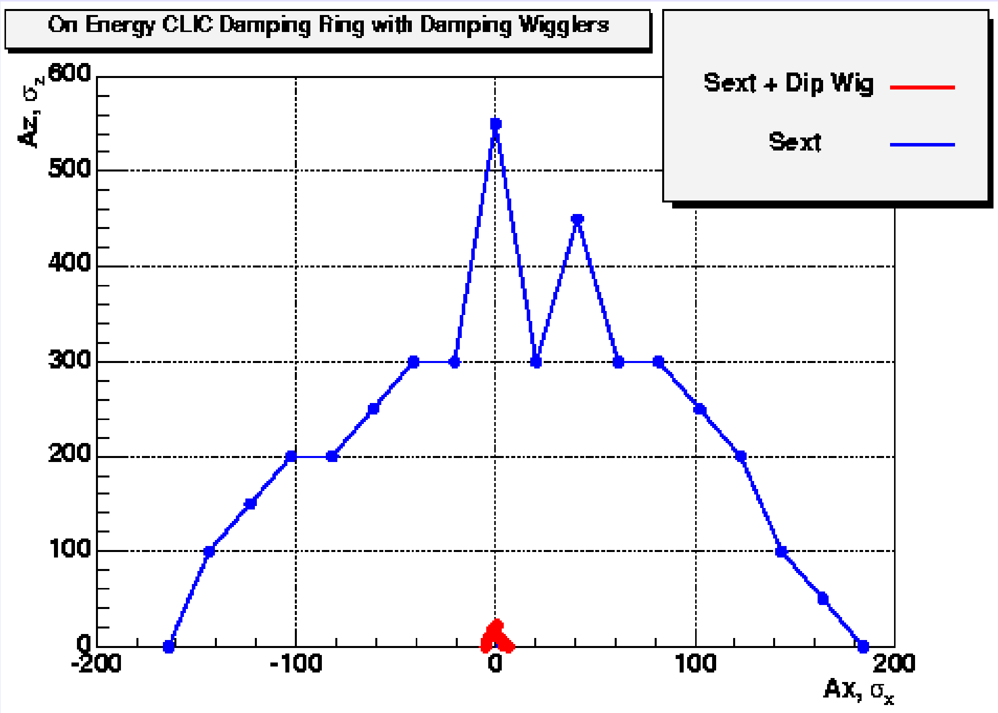
The lattice with damping wigglers



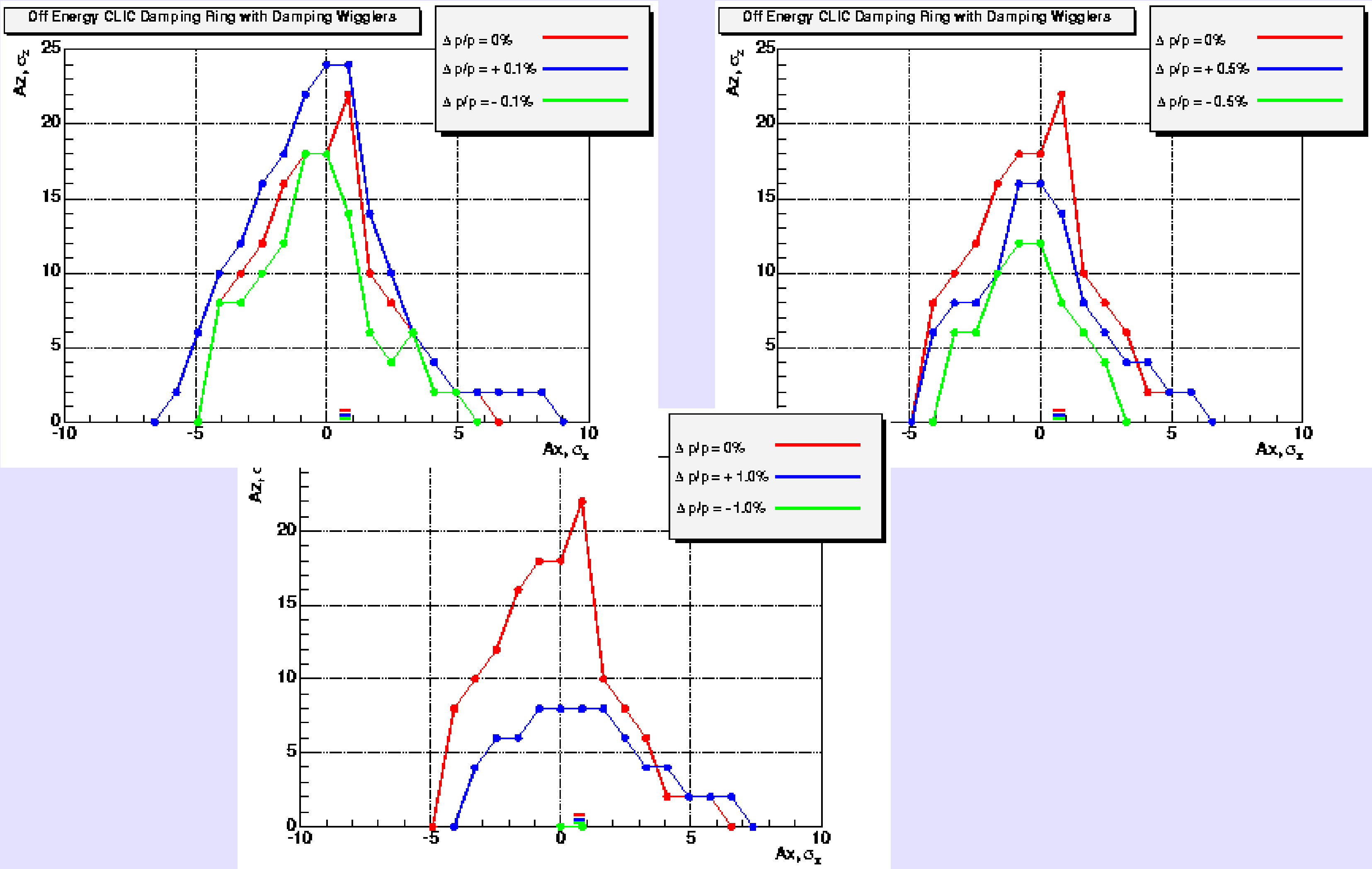
Dynamic aperture is limited by sextupole magnets.
Influence of damping wigglers can be neglected
for current sextupole petrubation.

On Energy Dynamic Aperture

Damping wigglers with only dipole component



Off Energy Dynamic Aperture



Recommendations

- Using another scheme of chromaticity correction in the unit cell (change vertical beta function for better separation, reduce sextupole strength and coupling sextupole harmonics)
- Using octupole magnets for nonlinearity correction
- Using achromat sextupole in dispersion free straight section
- Choice of good working point (by betatron tune scan)

Increase dynamic aperture of low emittance ring is very difficult task.
Special methods for correction natural chromatisity should be used.

Future Plans

- More detail simulation the CLIC damping ring with damping wigglers (others poles sequence, influence of high multipoles and synchro-betatron resonances, errors, etc)
- To make the thin lens model of the damping wiggler
- Detail calculation of dynamic aperture with alignment and field errors
- Simulation nonlinear particle motion with synchrotron radiation
- Calculation of nonlinear chromaticity of different parameters (betatron tune, nonlinear dispersion function, compaction factor, etc)
- Optimization of dynamic aperture