Simulation of APPLE ID for APS-U

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Outline

- Introduction to the "Generating Function" (GF) Method
- Simulation of end_poles
- Benchmark Results
- Application to APS-U
- Summary

Introduction

- GF-method was developed by J. Bahrdt and G. Wüstefeld[1] at BESSY (“BESSY” method)
- Applicable to any magnetic field, if the field
  - can be represented analytically
  - can be differentiated and integrated
- Very useful for ID simulation
  - Has periodic field
  - The differentiation/integration can be calculated easily
- Extremely useful for APPLE or similar ID simulation
  - Complex undulator structures – generates universal polarization mode depends on individual row’s longitudinal position and undulator gap (5D parameter space)
  - Total filed is the linear superposition of field from each rows – no needs on repeatedly ID field calculation

[1] J. Bahrdt and G. Wüstefeld, “Symplectic tracking and compensation of dynamic field integrals in complex undulator structures,” PRSTAB 14, 040703 (2011).

GF-Method

GF function – making a canonical transformation $(x, p_x, y, p_y) \rightarrow (x, p_{xf}, y, p_{yf})$

Solve the Hamiltonian-Jacobi equation through a Taylor expansion

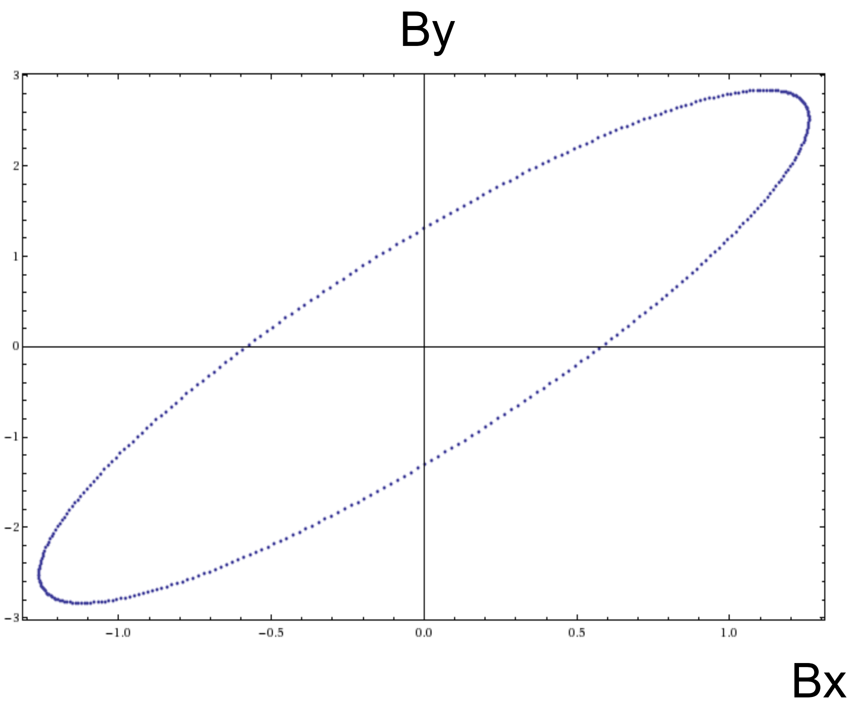
step size

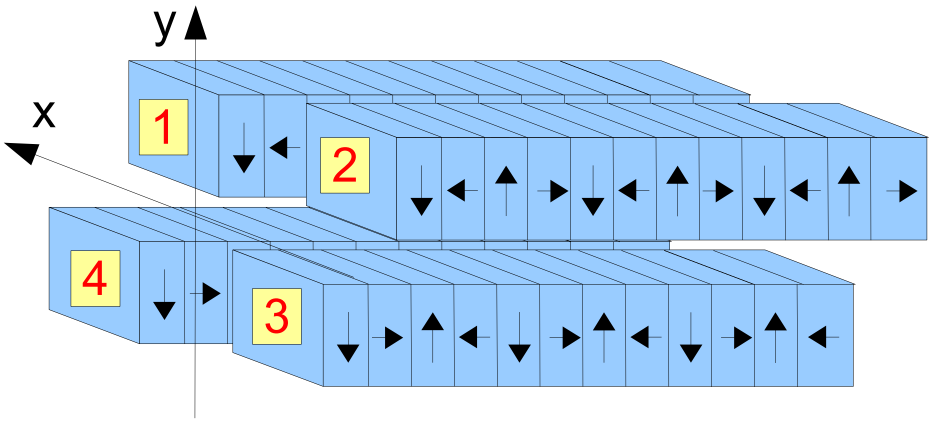
$$x_f = x + p_{xf}\Delta z - f_{101}$$
$$y_f = y + p_{yf}\Delta z - f_{011}$$
$$p_{xf} = \left[(1 - f_{011y})(p_x + f_{002x} + f_{003x}) + f_{011x}(p_y + f_{002y} + f_{003y})\right]/p_n$$
$$p_{yf} = \left[(1 - f_{101x})(p_y + f_{002y} + f_{003y}) + f_{101y}(p_x + f_{002x} + f_{003x})\right]/p_n$$
$$p_n = (1 - f_{101x})(1 - f_{011y}) - f_{101y}f_{011x}$$

Uses gauge $A_z = 0$

$$\begin{cases} f_{101} = \int A_x dz \\ f_{011} = \int A_y dz \\ f_{002} = -\frac{1}{2}\int (A_x^2 + A_y^2) dz \\ f_{003} = \frac{1}{2}\left[\int A_x dz \int \frac{\partial(A_x^2 + A_y^2)}{\partial x} dz' + \int A_y dz \int \frac{\partial(A_x^2 + A_y^2)}{\partial y} dz'\right] \end{cases}$$

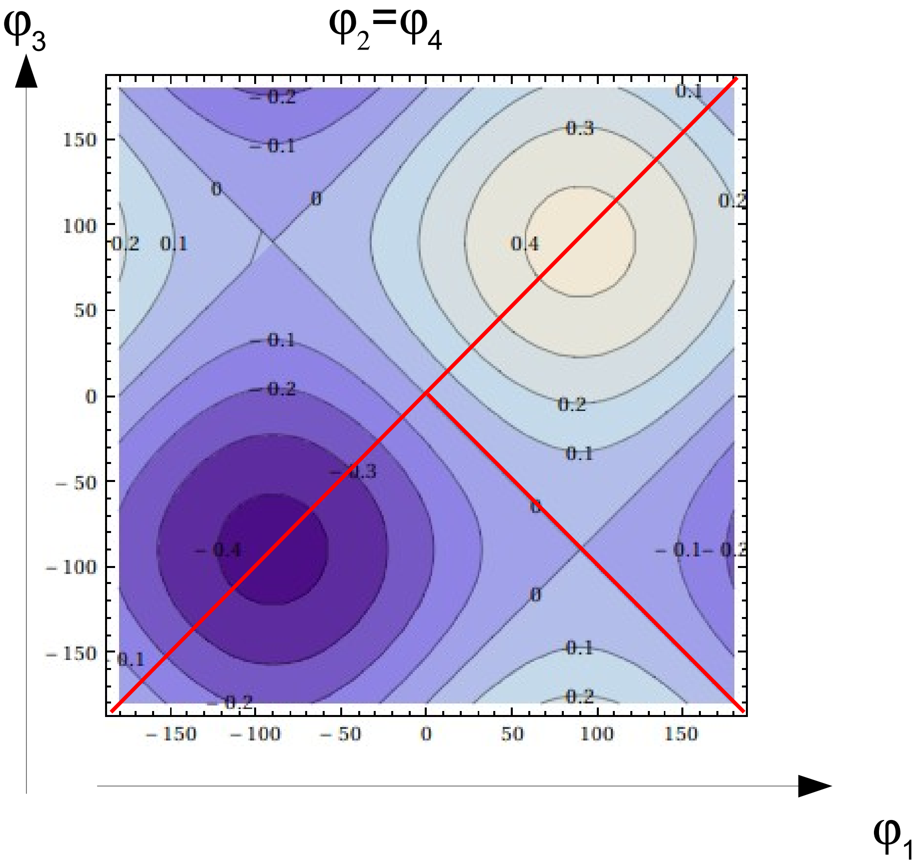
APPLE Device – Universal Mode



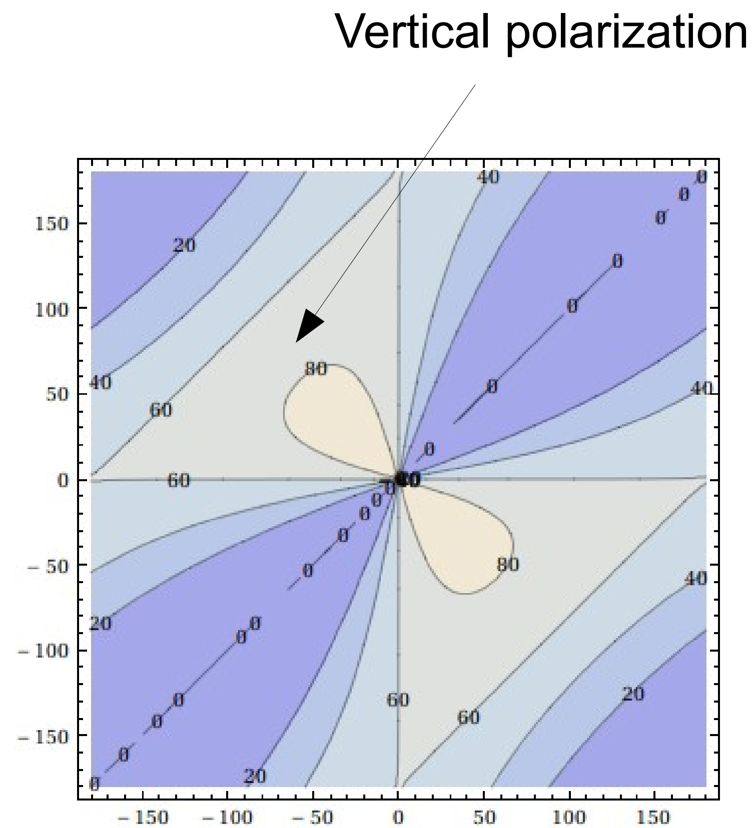


Can generate any state of polarization!

$$\theta_1 = \theta_3 \qquad \theta_2 = \frac{\pi}{2} \qquad \theta_4 = -\frac{\pi}{5}$$



Ellipse area (0 – linear mode)



Inclined Angle

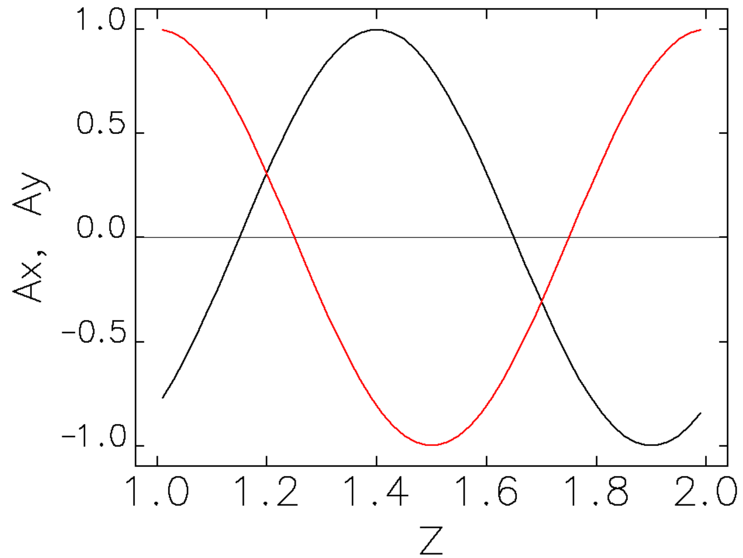
Red line – most APPLE device operational parameter space

APPLE Field

integration is easily be done for 1 or more period

Fast tra

$$A_{x,i} = \sum_{j=1}^{n} f(x, y, gap) \sin(k_{zj} \cdot z + \varphi_i)$$



Total filed:

$$A_x = \sum_{j=1}^{n} (C_x \cdot \sin(k_{zj} \cdot z) + D_x \cdot \cos(k_{zj} \cdot z))$$

$$A_y = \sum_{j=1}^{n} (C_y \cdot \sin(k_{zj} \cdot z) + D_y \cdot \cos(k_{zj} \cdot z))$$

The GF method is implemented in elegant with expansion to universal mode

– φ_i can be varied freely.

End_pole Configuration

- To preserve beam orbit going through undulator unchanged (in linear approximation), the ID field should satisfy following conditions

$$\int B_x\, dz = 0 \quad \int B_y\, dz = 0$$

$$\int dz \int B_x\, dz' = 0 \quad \int dz \int B_y\, dz' = 0$$

with $B_x = B_0 \cos(k_z * z + \theta_x) \quad B_y = B_0 \cos(k_z * z + \theta_y)$

which means $\theta_{x,y} = 0 \text{ or } \pi$

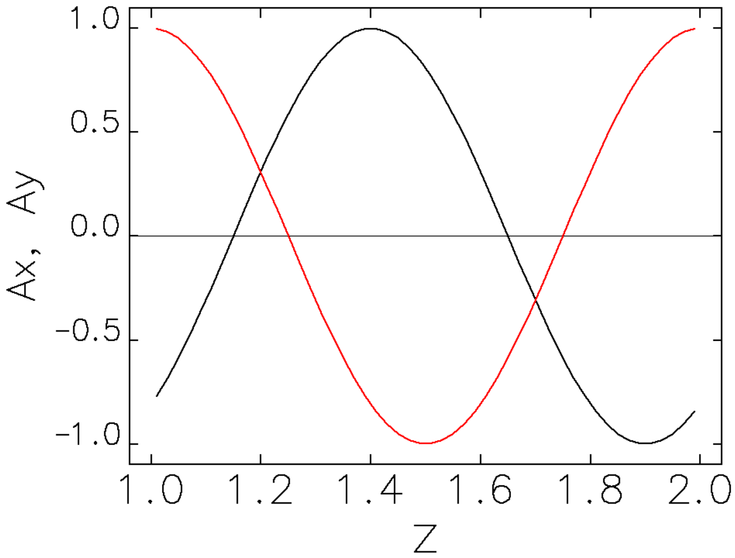
Ax,y has to be at zero crossing at the entrance and exit

- The conditions is filled through careful end-poles configuration design
- The simulation routine must preserve this feature

Simulation of End_poles

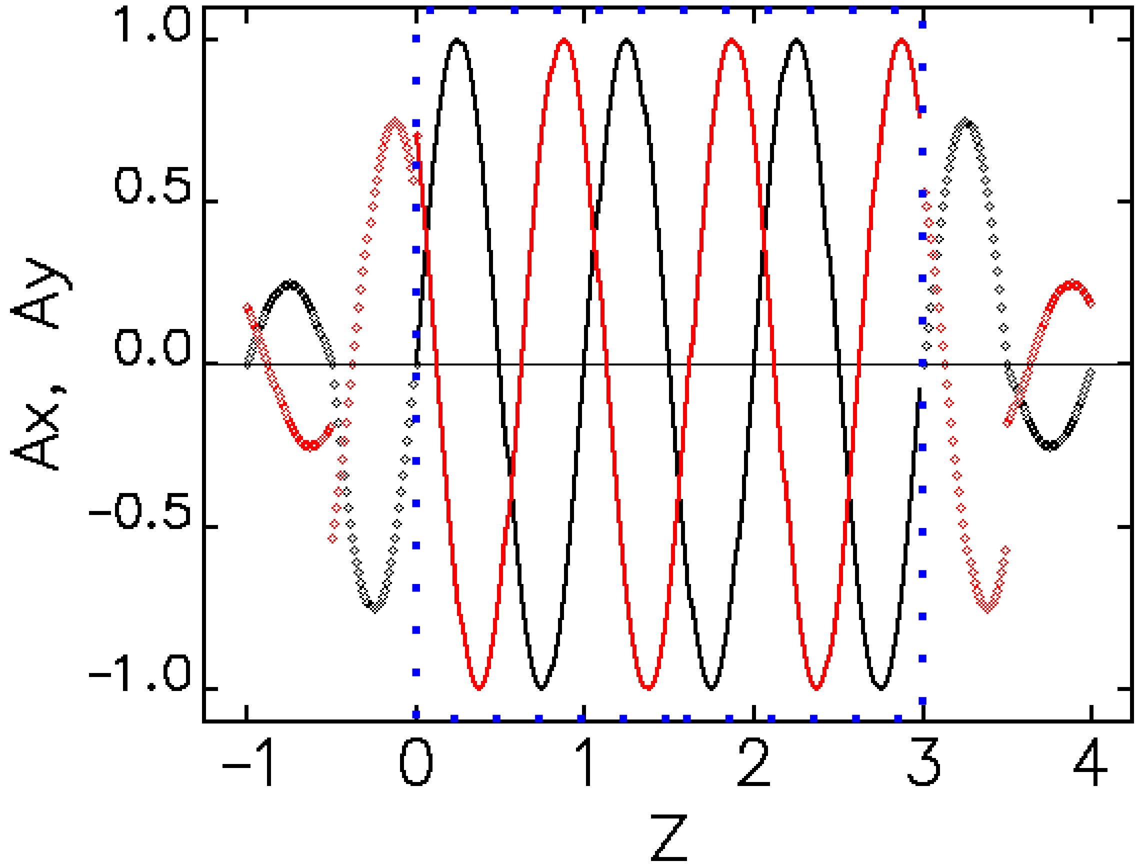
- Universal mode – Ax,y can not be zero at the same time at any z location
  - Unmatched beam orbit if only simulate normal poles
- Reduced strength end_pole approximation (half period)

  0.25, -0.75, 1, -1, ..., 0.75, -0.25
- Replace end_pole effect with matching section
- Improved end_pole configuration (future)

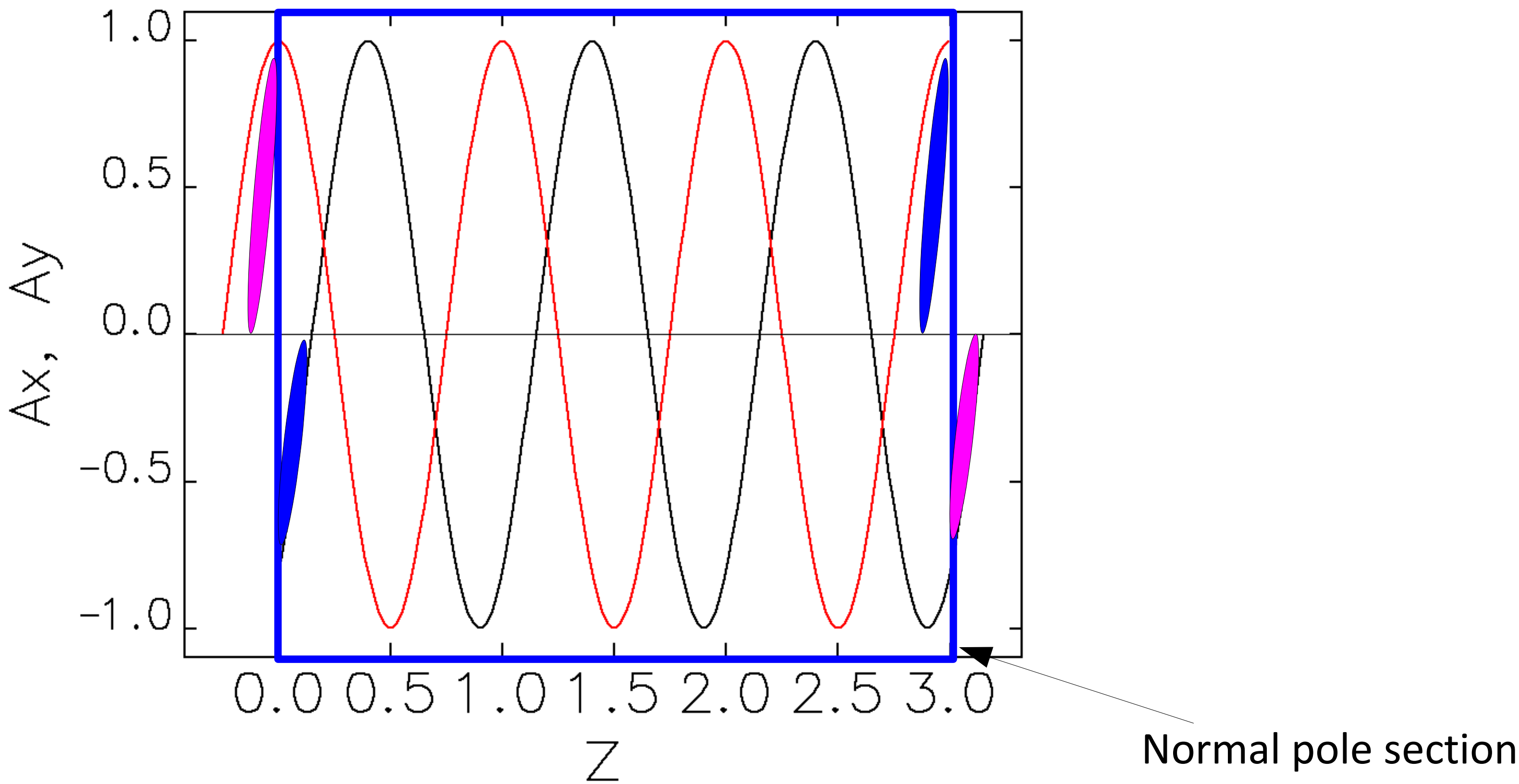


Reduced Strength End_pole Approximation

- Easy to implement
- Non-zero Ax,y at entrance/exit and discontinuous function
- Good result agrees with other methods (J. Bahrdt)

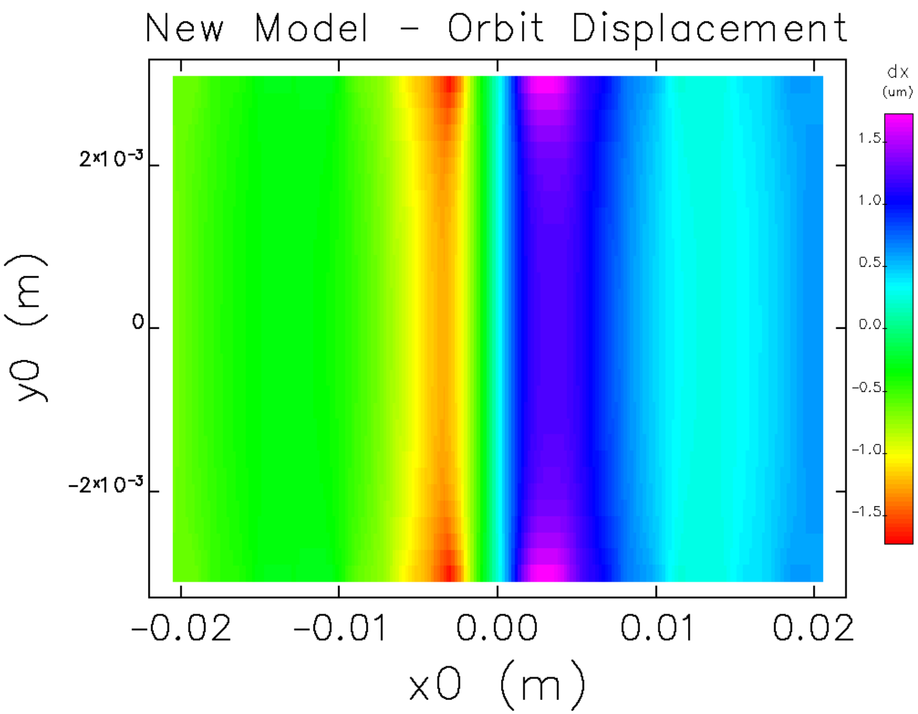


Replace End_pole Effects with Matching Section

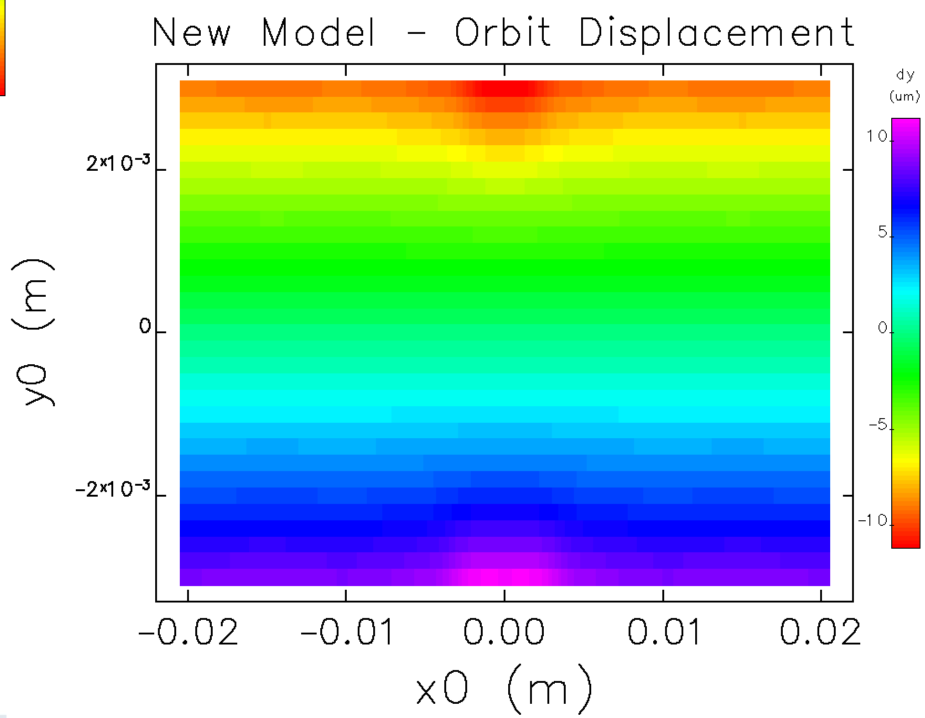


- Add (red) or remove (blue) part field region at the entrance/exit (also used in CWIGGLER)
- Guaranty orbit match for any polarization mode
- Implementation becomes a little bit harder – calculation of dzx, dzy (x,y dependent)

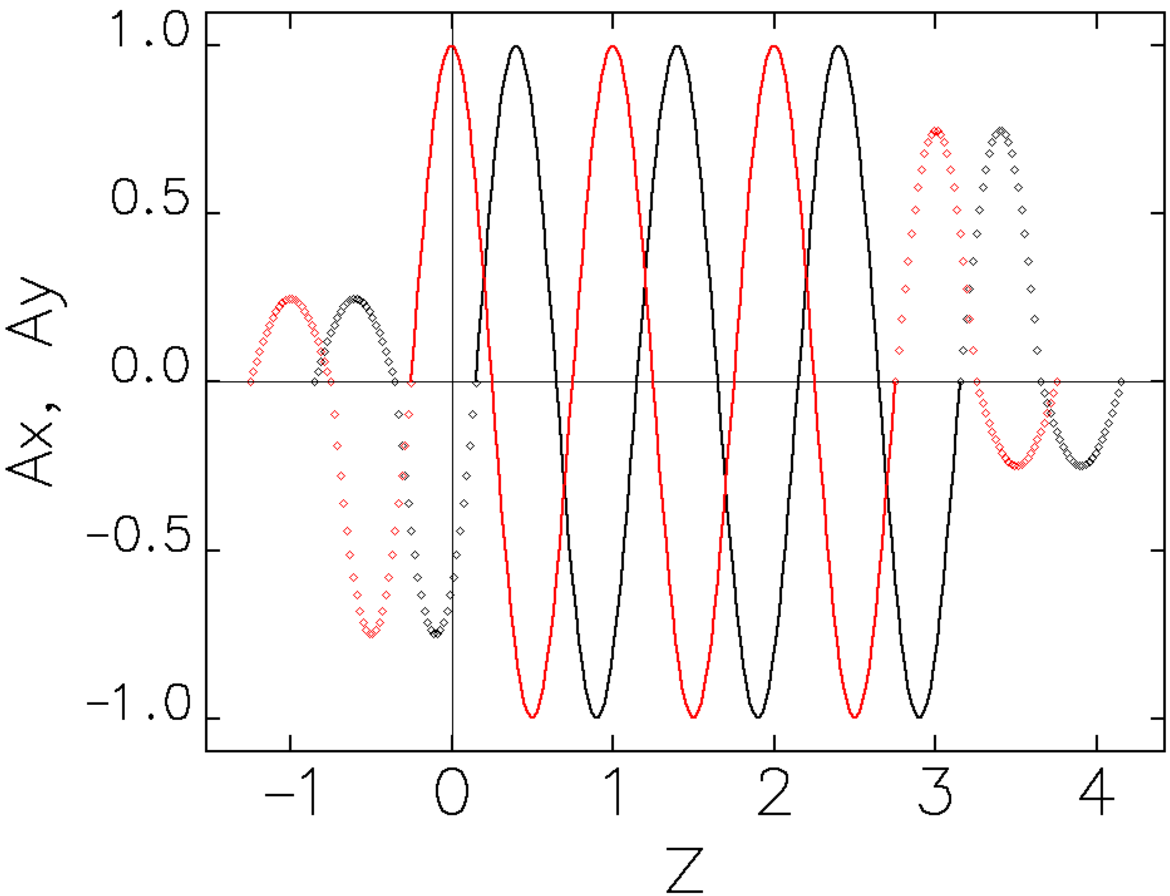
Simulation Result - Orbit Mismatch



Non-linear effects
A few micron meters



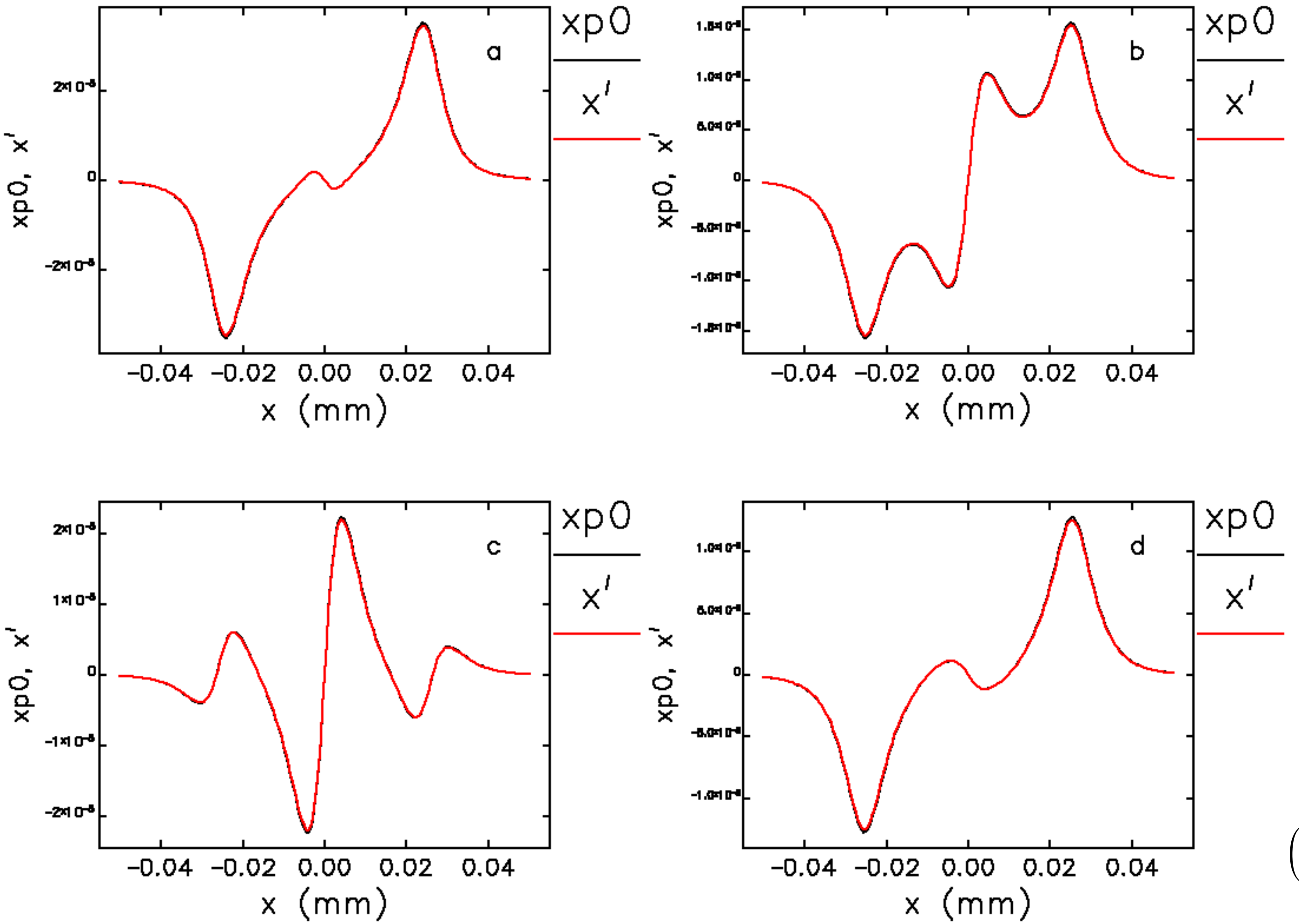
Improvement (future)



To make model more close to real situation

With/without reduced strength end-pole – only a few percent off of the total kick strength

Benchmark Result – comparing with theoretic value



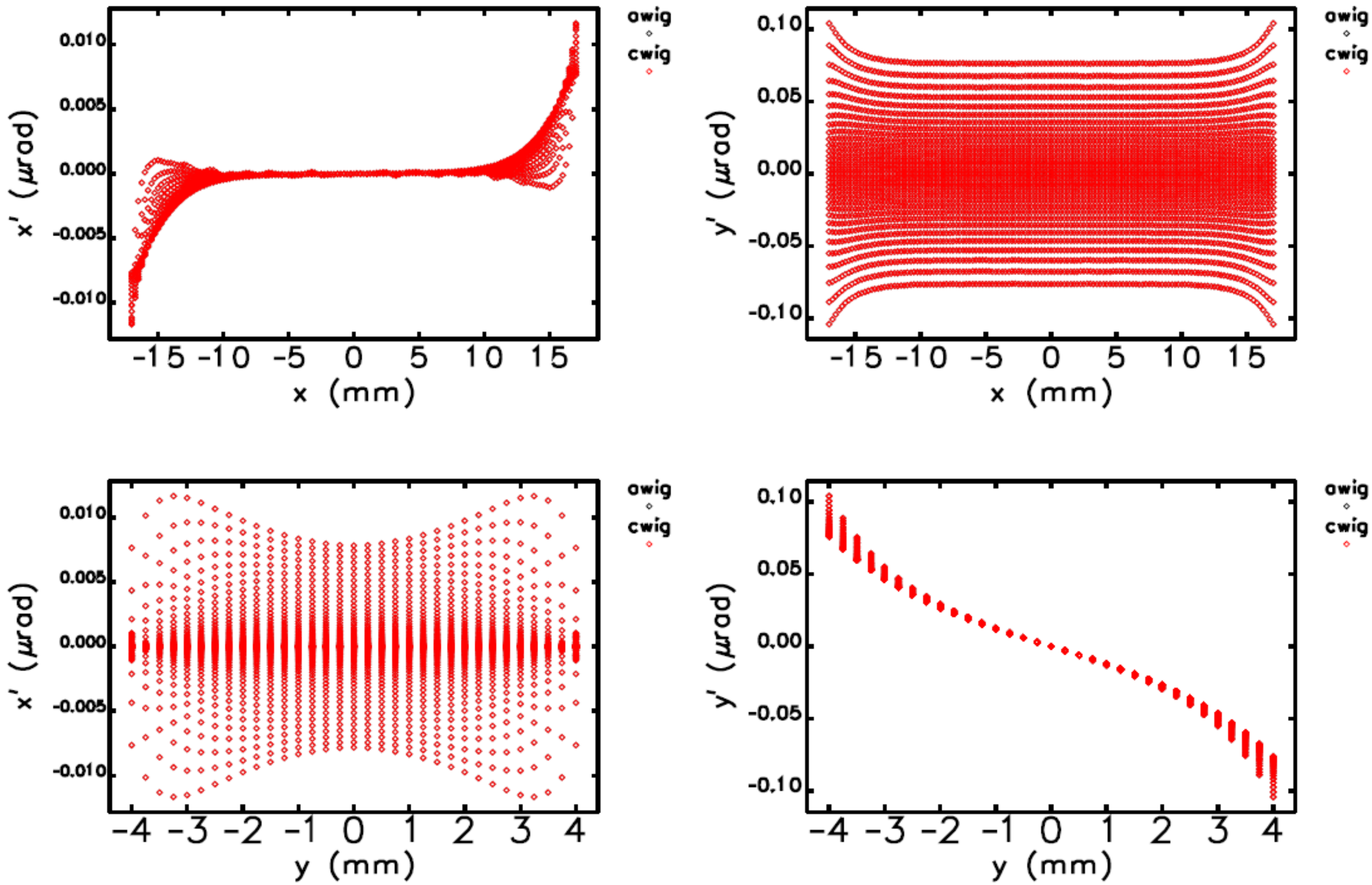
$$(a)\ \theta_2=\theta_4=0$$

$$(b)\ \theta_2=\theta_4=\frac{\pi}{2}$$

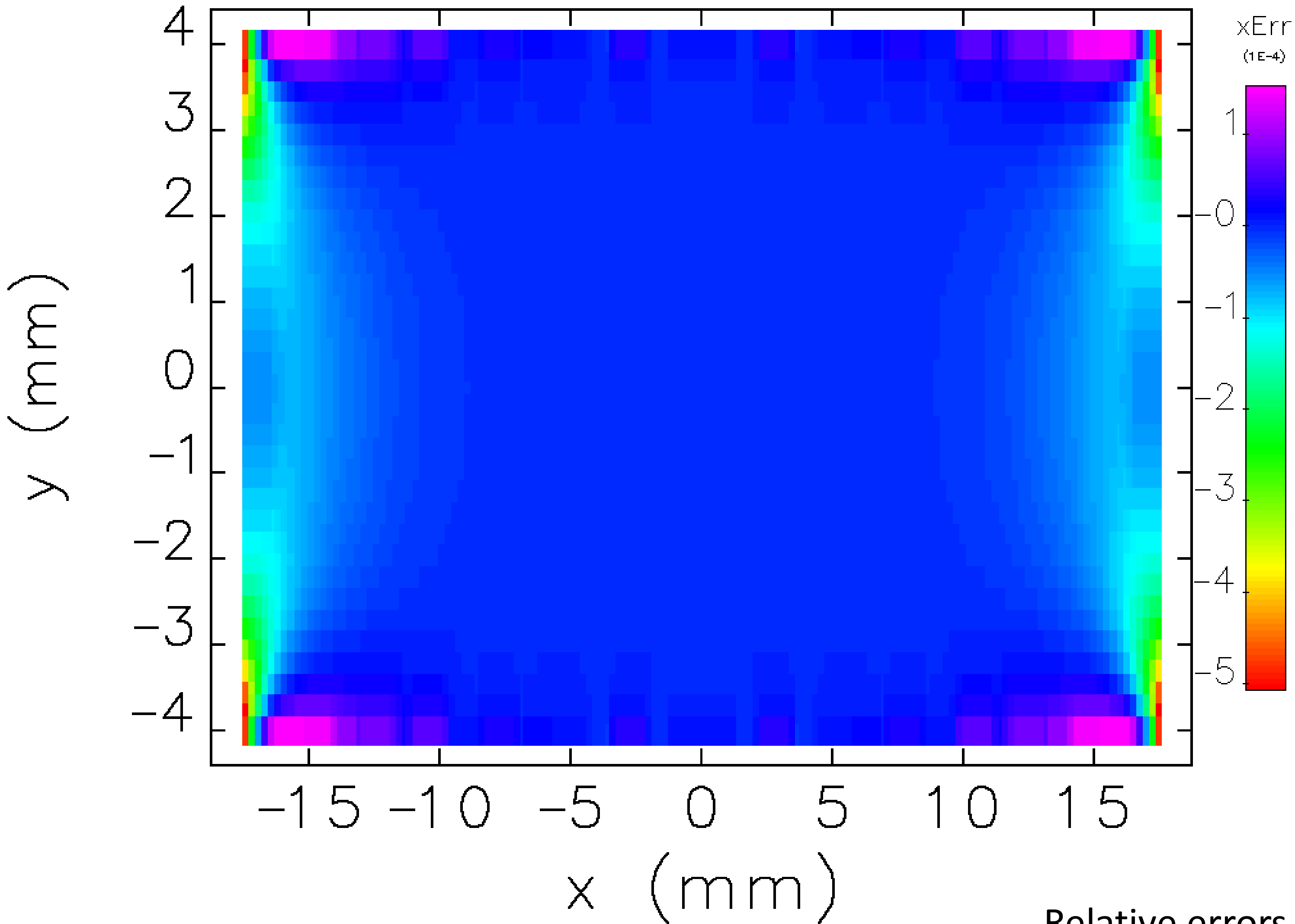
$$(c)\ \theta_2=\theta_4=\pi$$

$$(d)\ \theta_2=-\theta_4=\frac{\pi}{2}$$

Benchmark Result – comparing with elegant



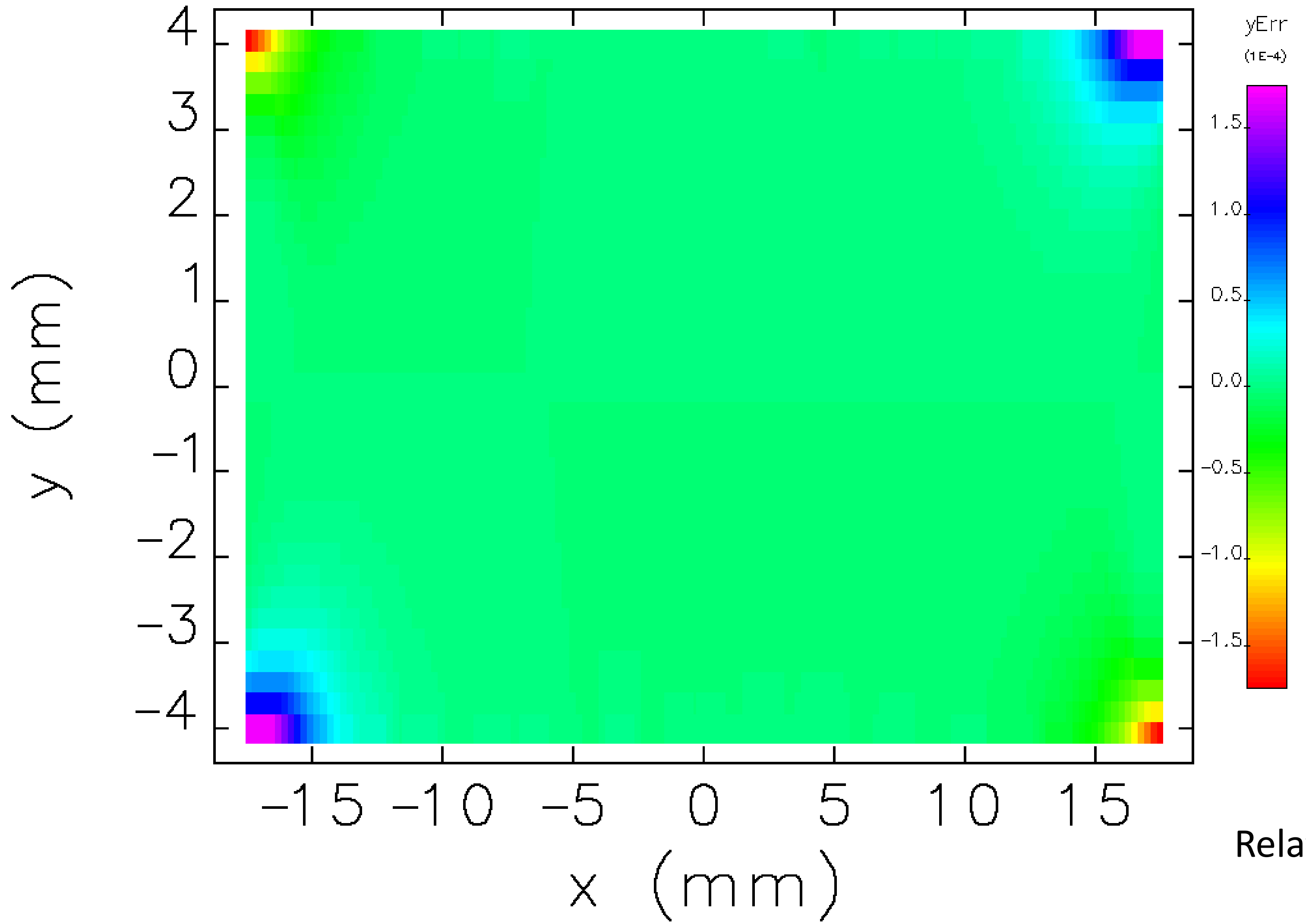
U28 (planar undulator) Black: GF method; red: CWIGGLER (Y. Wu's canonical tracking) method
Calculation CPU time: ~30s (GF) vs. ~30min (CWIGGLER) (first harmonic, 9 step per period)
CWIGGLER is good: strong wiggler field; rich longitudinal harmonics.



$$\frac{\Delta x'}{x'_{max}}$$

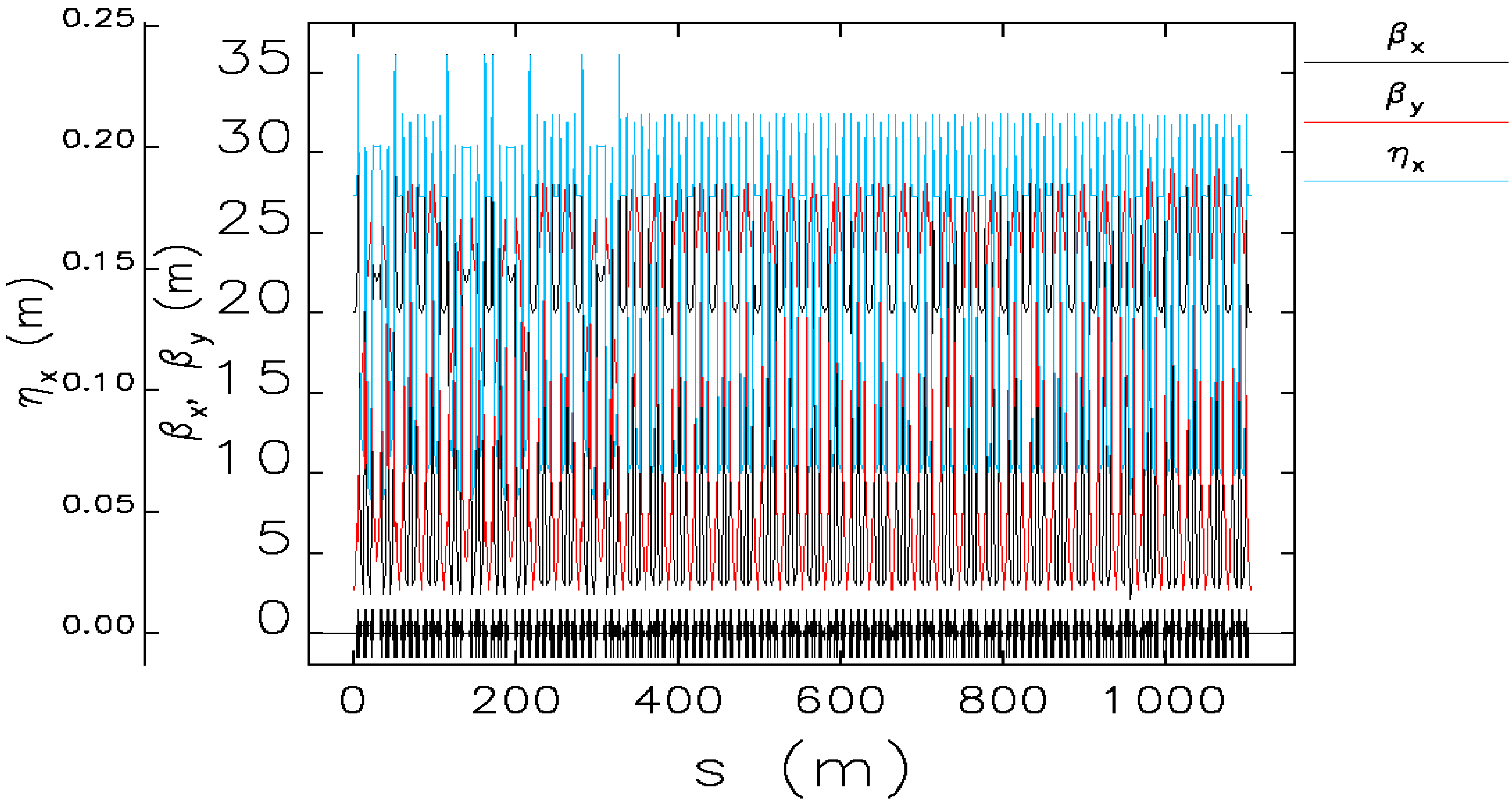
Relative errors 10^(-4) level

$$\frac{\Delta y'}{y'_{max}}$$



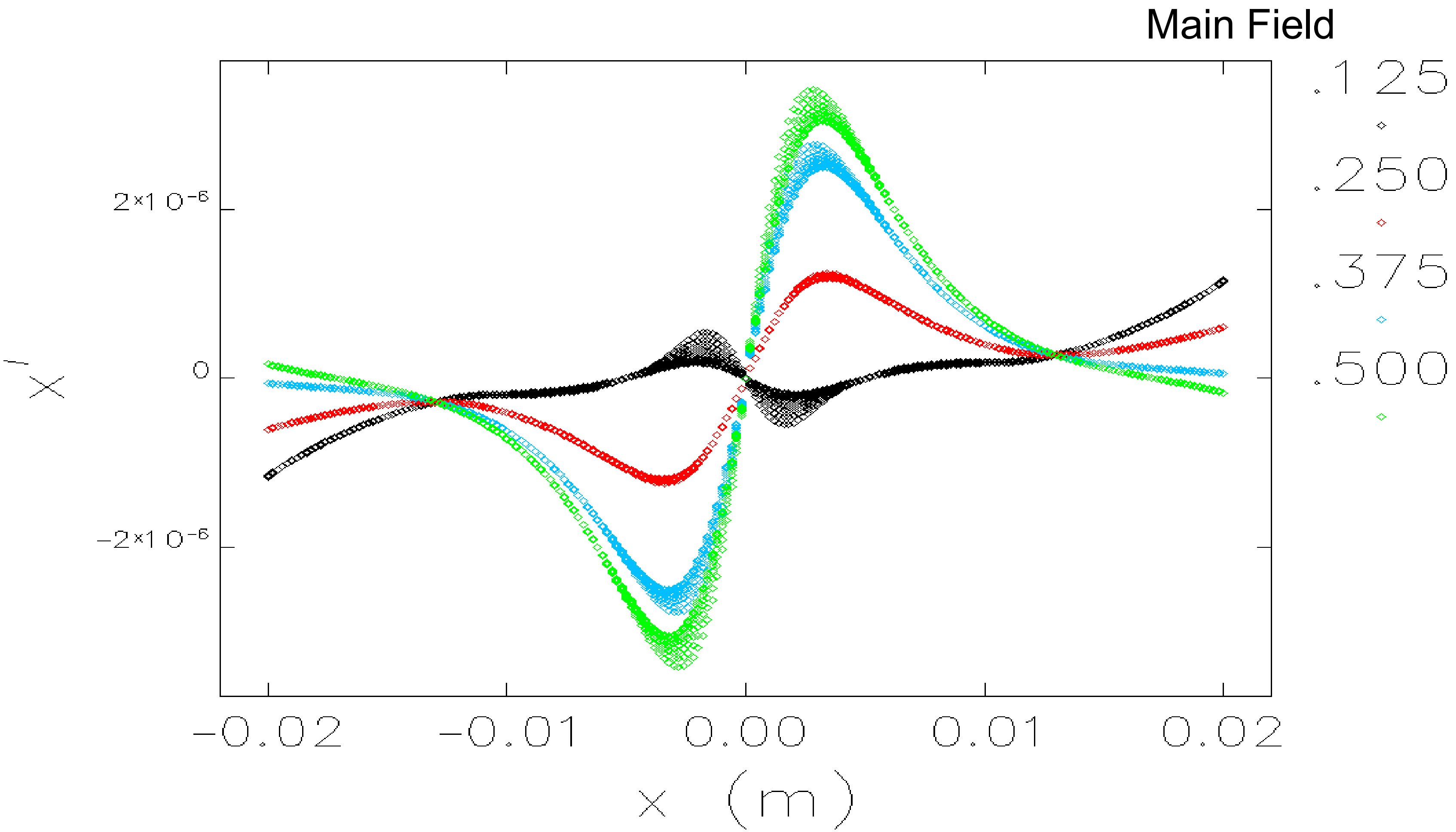
Relative errors

APS-U Optics



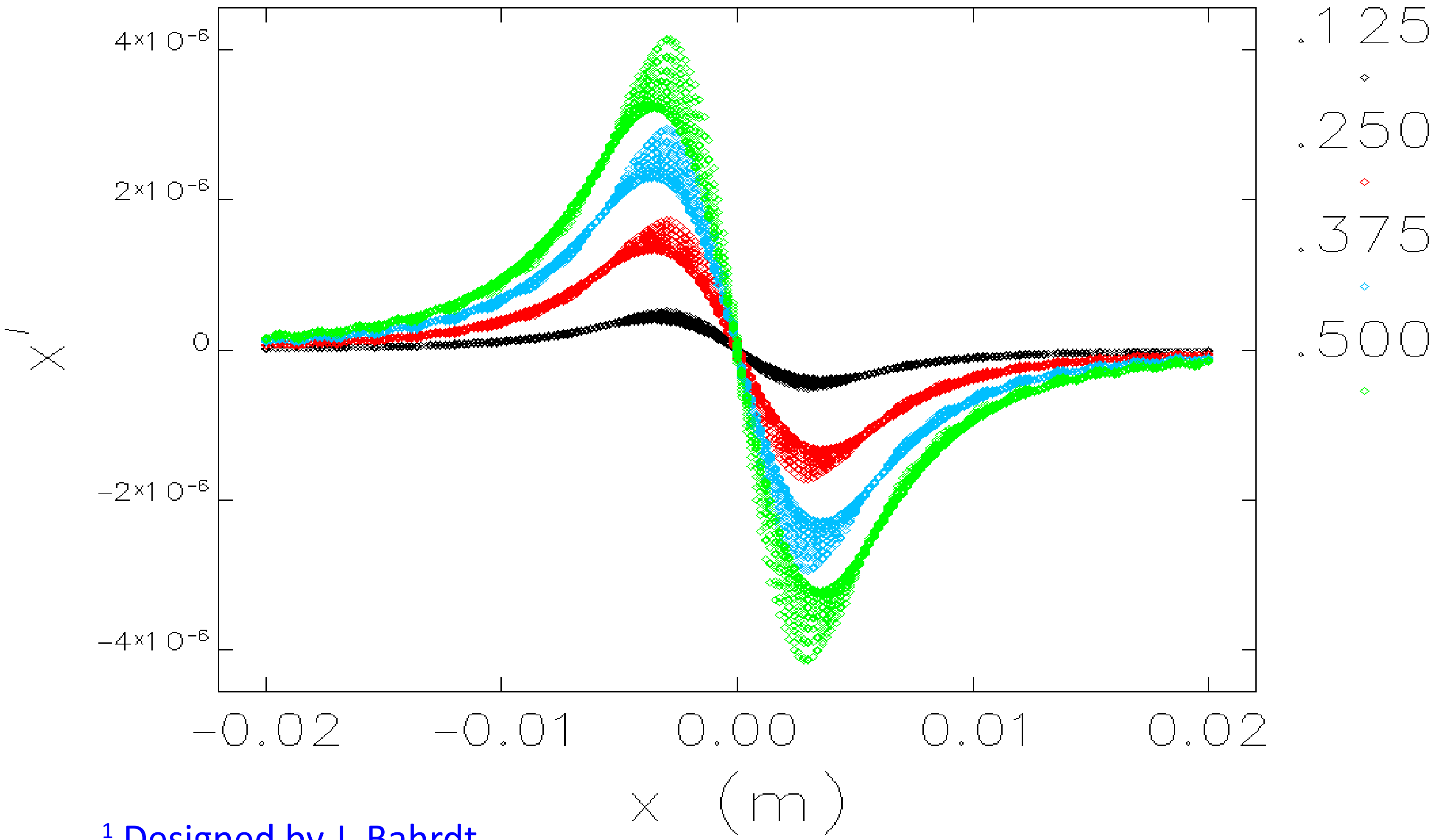
Courtesy by M. Borland

APPLE ID for APS-U[1]



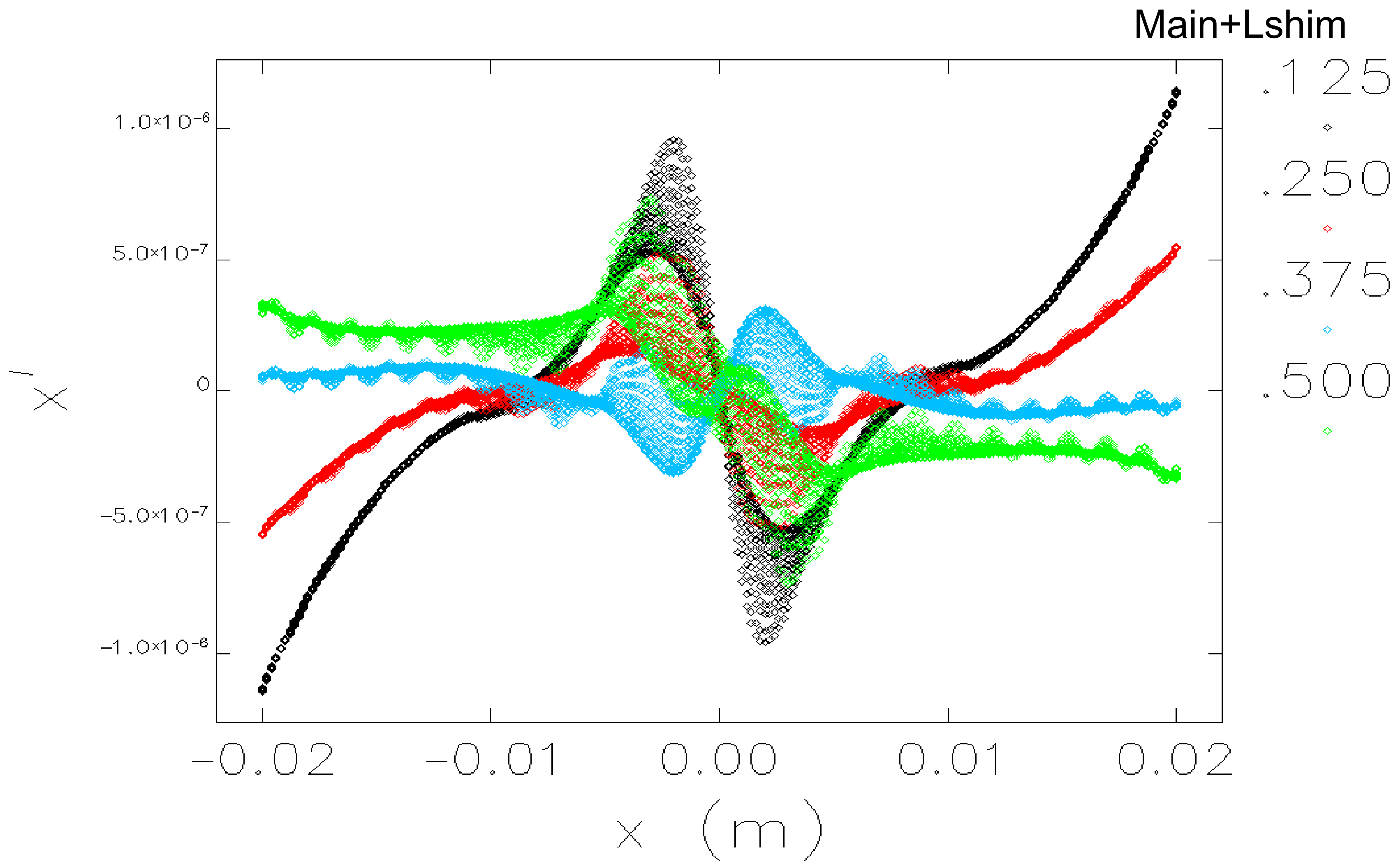
[1] Designed by J. Bahrdt

L-shim

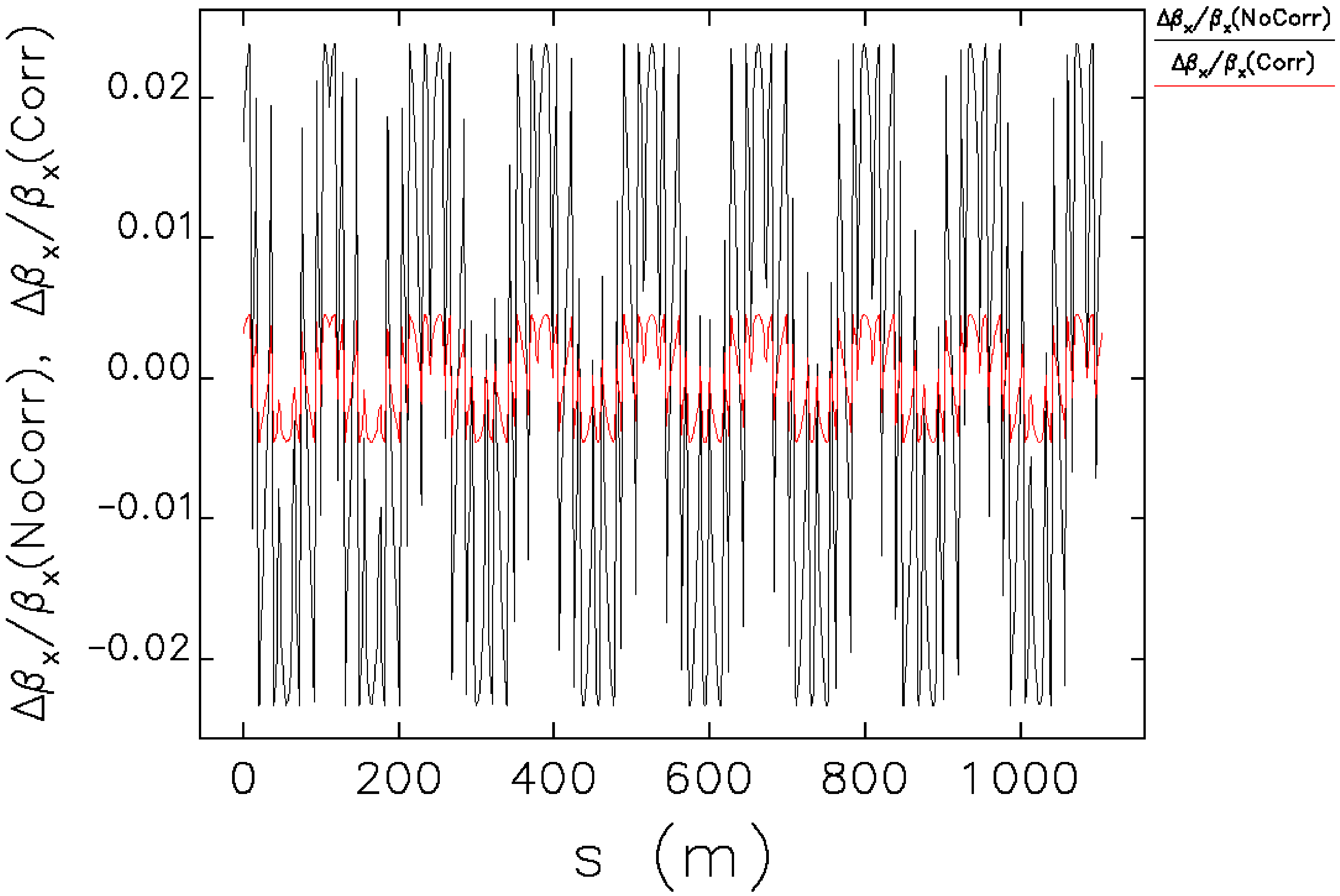


[1] Designed by J. Bahrdt

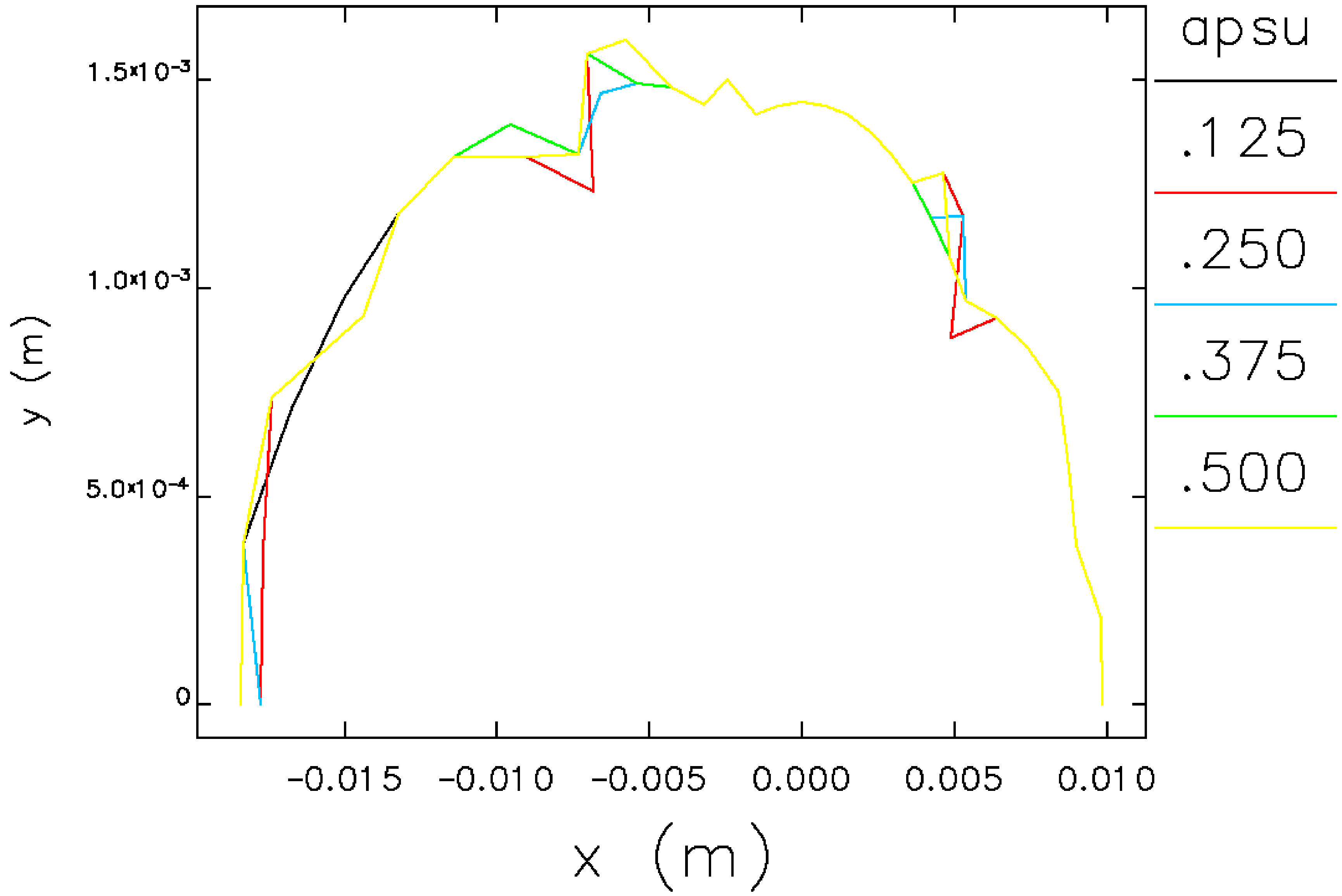
Not scaled properly



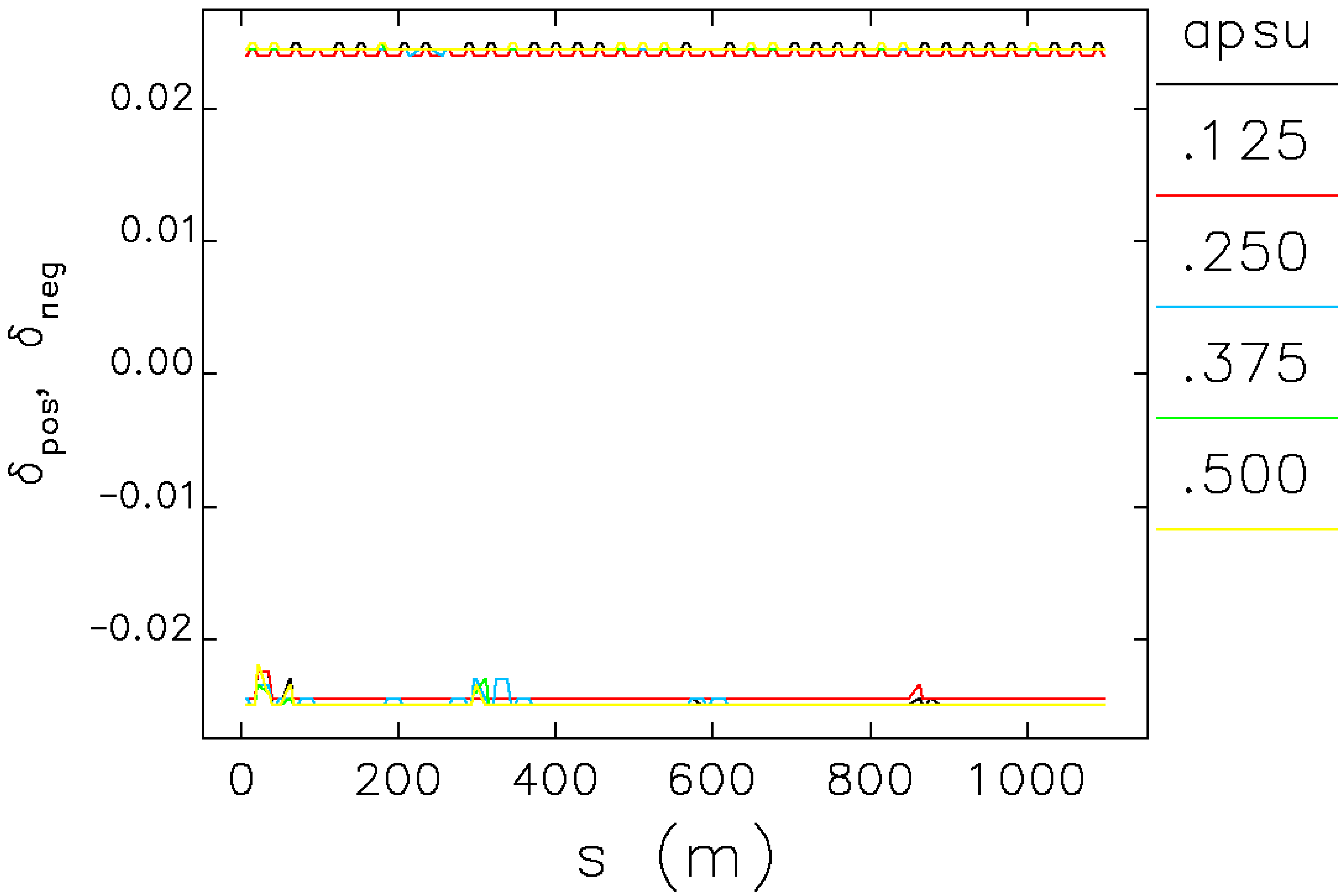
Main+Lshim
.125
.250
.375
.500
1.0×10⁻⁶
5.0×10⁻⁷
0
−5.0×10⁻⁷
−1.0×10⁻⁶
x'
−0.02
−0.01
0.00
0.01
0.02
x (m)



Δβx/βx(NoCorr)
Δβx/βx(Corr)
0.02
0.01
0.00
−0.01
−0.02
0
200
400
600
800
1000
s (m)
Δβx/βx(NoCorr), Δβx/βx(Corr)



1.5x10⁻³
1.0x10⁻³
5.0x10⁻⁴
0
y (m)
-0.015
-0.010
-0.005
0.000
0.005
0.010
x (m)
apsu
.125
.250
.375
.500



apsu
.125
.250
.375
.500
0.02
0.01
0.00
−0.01
−0.02
δ_{pos}, δ_{neg}
0
200
400
600
800
1000
s (m)

Summary

- GF-method + L-shim correction is implemented in elegant
- Applicable to universal mode
- Improved end_pole effects treatment
- Excellent agreement with other methods
- Fast tracking speed (period field)
- Perturbation to APS-U optics checked