FFAG ACCELERATORS FOR PRISM & GANTRY FOR CARBON THERAPY

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Kyoto University

FFAG09J, Nov. 2009

REQUIREMENTS FOR PRISM

- Very large transverse acceptance
  - horizontal: 30 000π mm.mrad
  - vertical: 3 000π mm.mrad
- Momentum acceptance: 68MeV ±20%

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SCALING STRAIGHT LINES

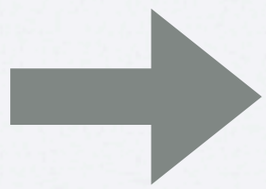
Straight section = Bending section with infinite radius

$$\lim_{r_0\to\infty}\left(\frac{r}{r_0}\right)^k = \lim_{r_0\to\infty}\left[\left(1+\frac{x}{r_0}\right)^{\frac{r_0}{x}}\right]^{\frac{x}{r_0}k} = \left[\lim_{r_0\to\infty}\left(1+\frac{x}{r_0}\right)^{\frac{r_0}{x}}\right]^{\frac{n}{\rho}x} = e^{\frac{n}{\rho}x}$$

with $r = x + r_0$

$$k = \frac{r_0}{\rho}n$$

$$n = \frac{\rho}{B}\left(\frac{dB}{dx}\right)_{z=0}$$



$$B_z = B_0 e^{\frac{n}{\rho}(X-X_0)}$$

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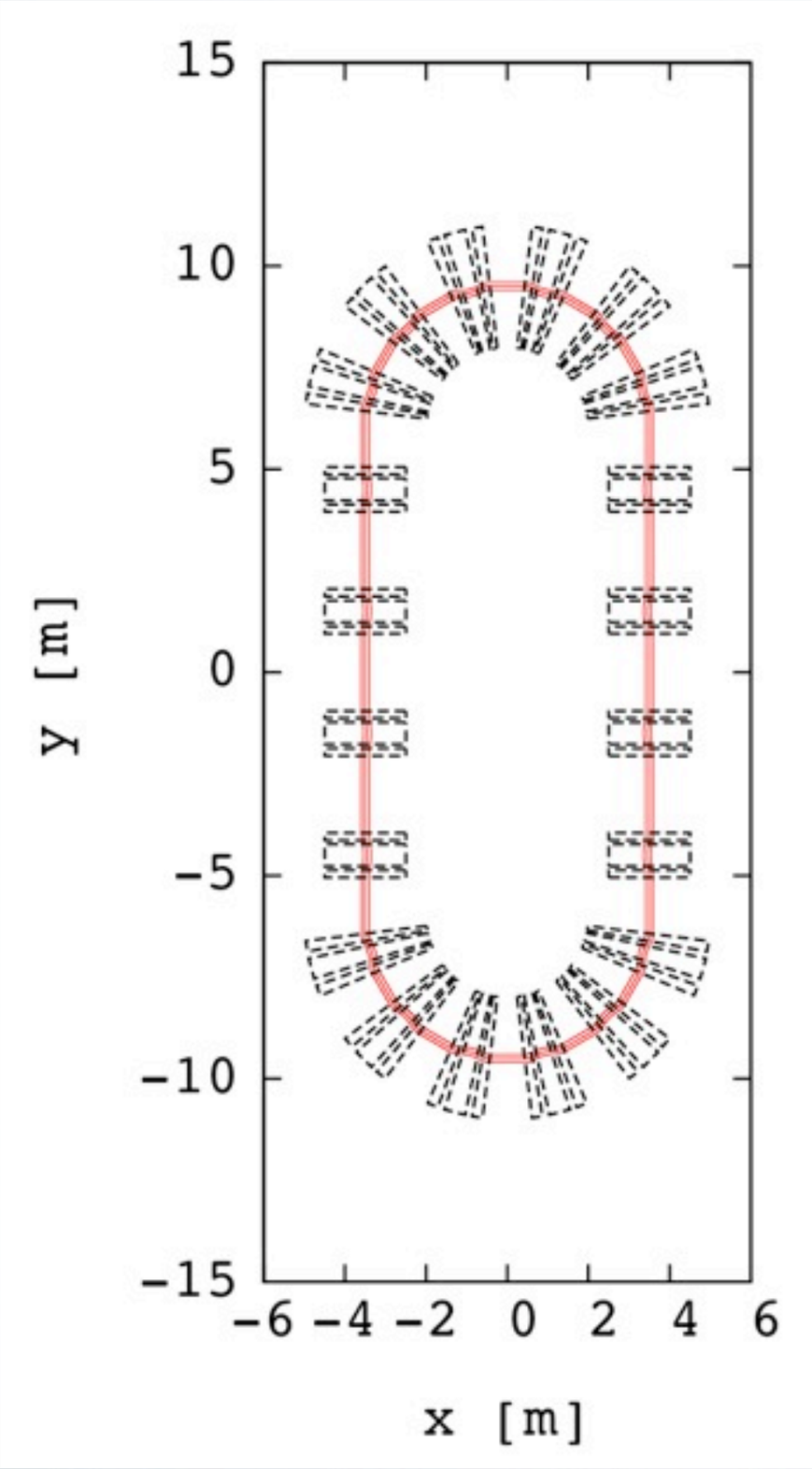
NEW PROPOSAL FOR PRISM



Bending cell	
k	6.5
Average radius	3.5 m
Phase advances:	
horizontal μ_x	90 deg.
vertical μ_z	90 deg.
Dispersion	0.47 m

Straight cell	
n/ρ	$2.14\,m^{-1}$
Length	$3\,m$
Phase advances:	
horizontal μ_x	24 deg.
vertical μ_z	75 deg.

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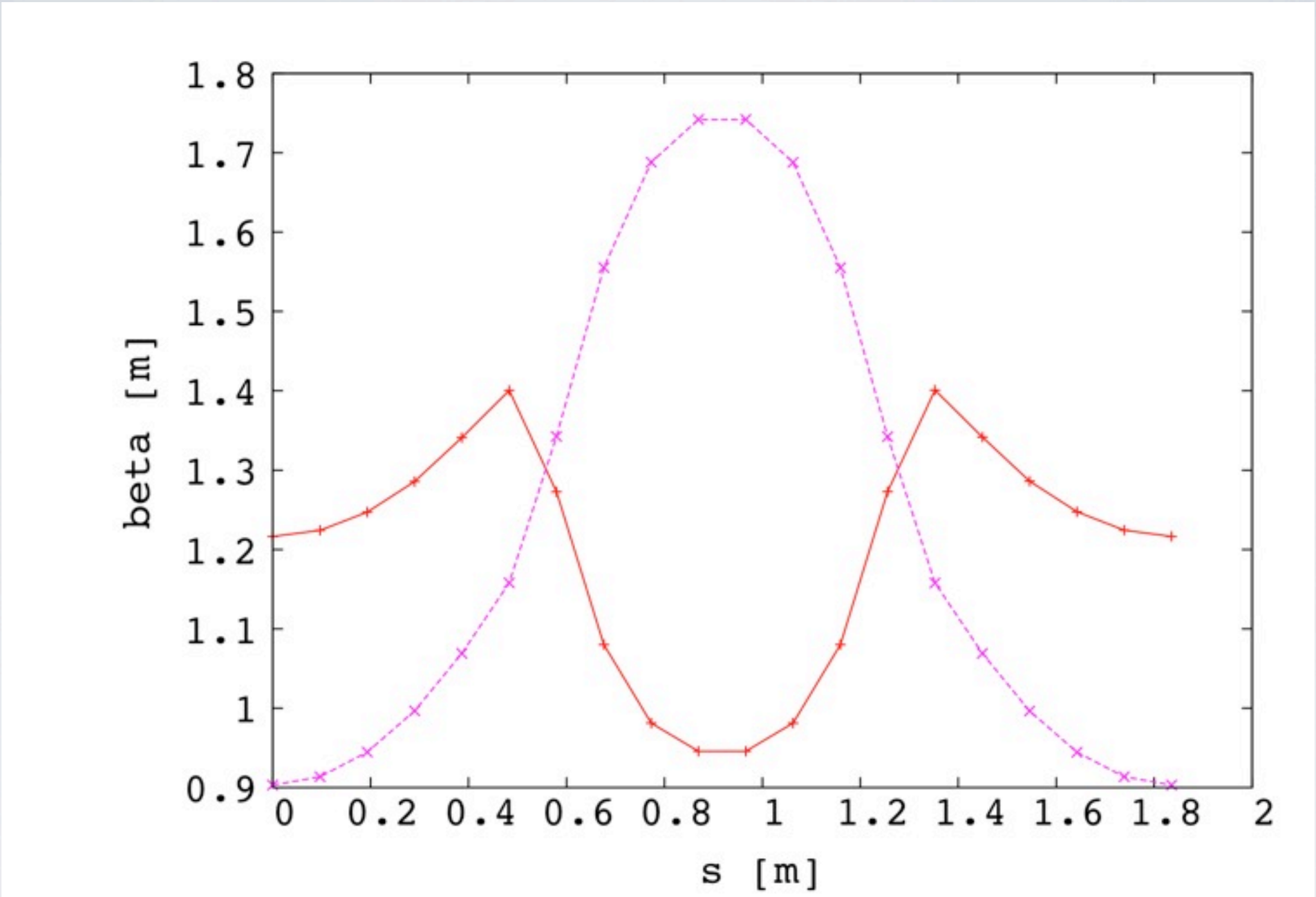

Betafunctions of bending cell.
(red: horizontal, purple: vertical)

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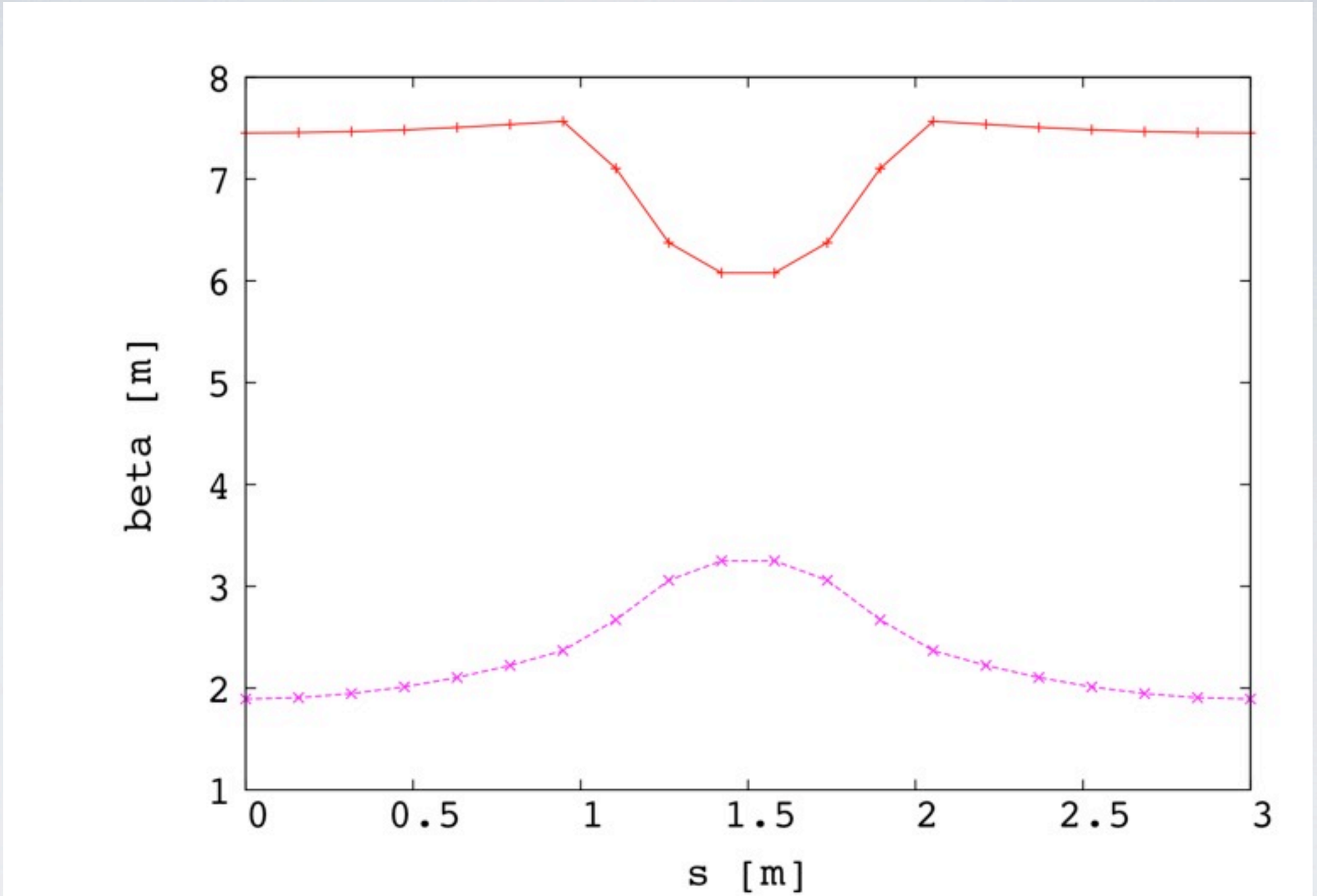

Betafunctions of straight cell.
(red: horizontal, purple: vertical)

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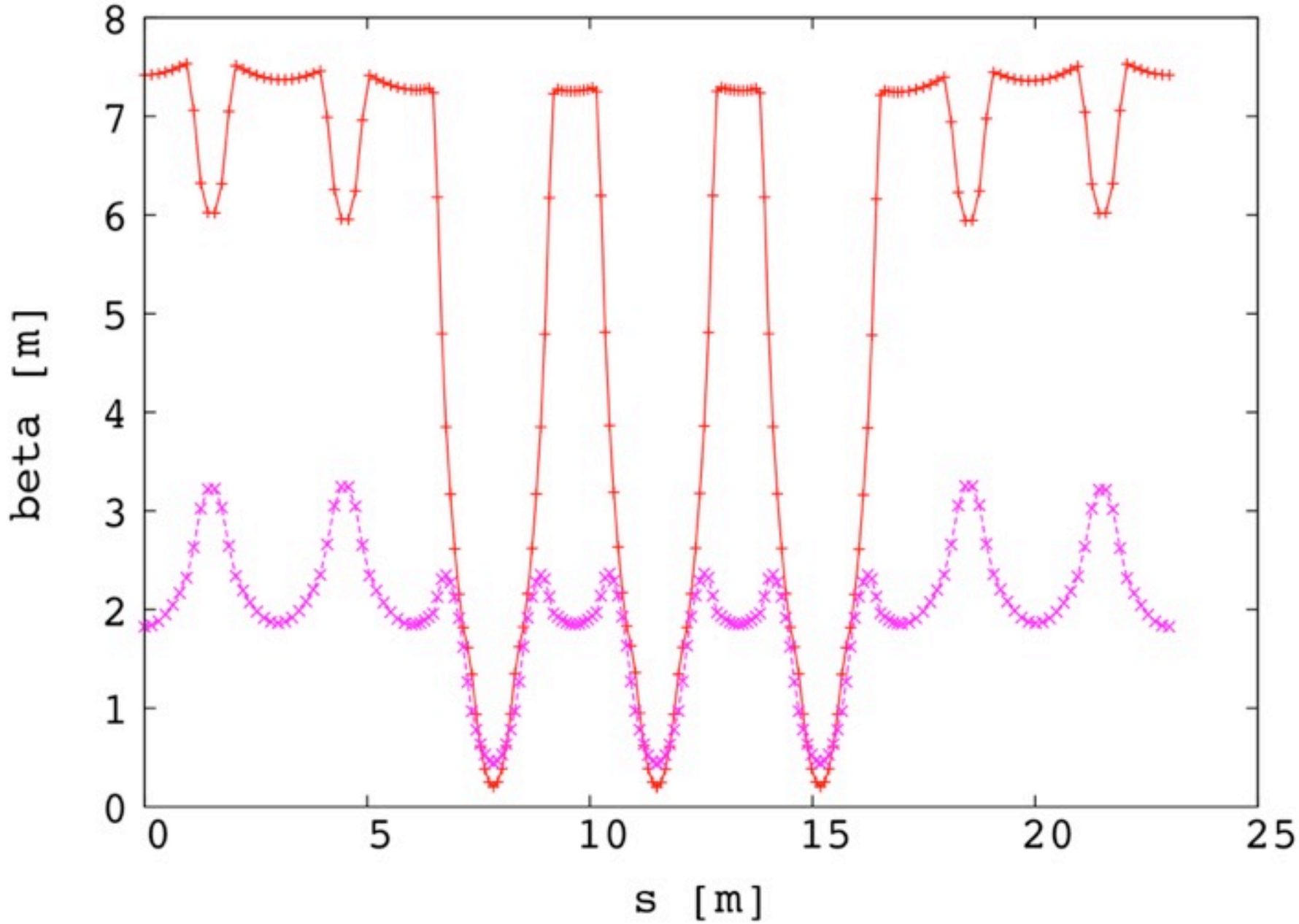

Betafunctions of bending and straight cells (half ring)
(red: horizontal, purple: vertical)

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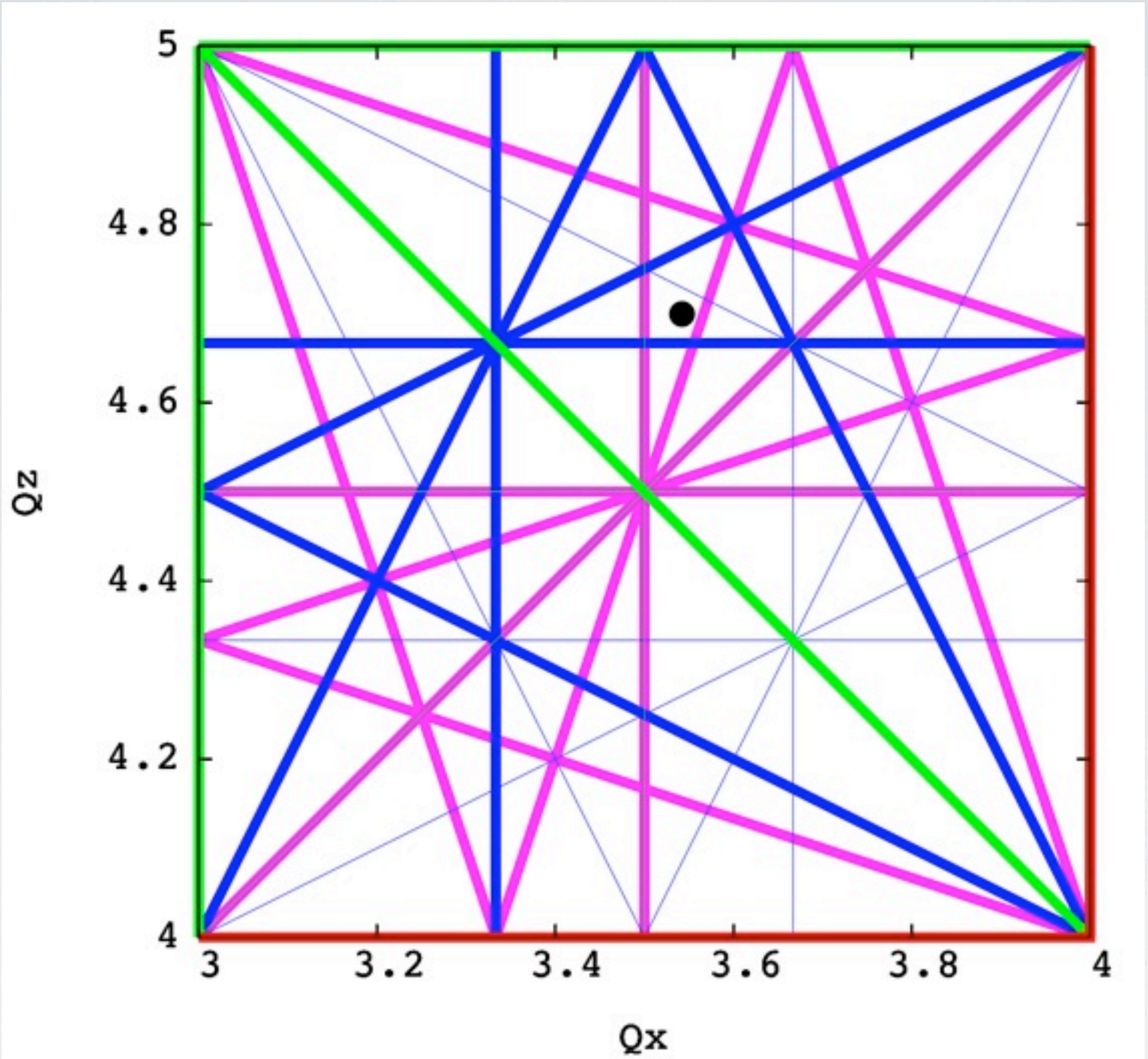

WORKING POINT

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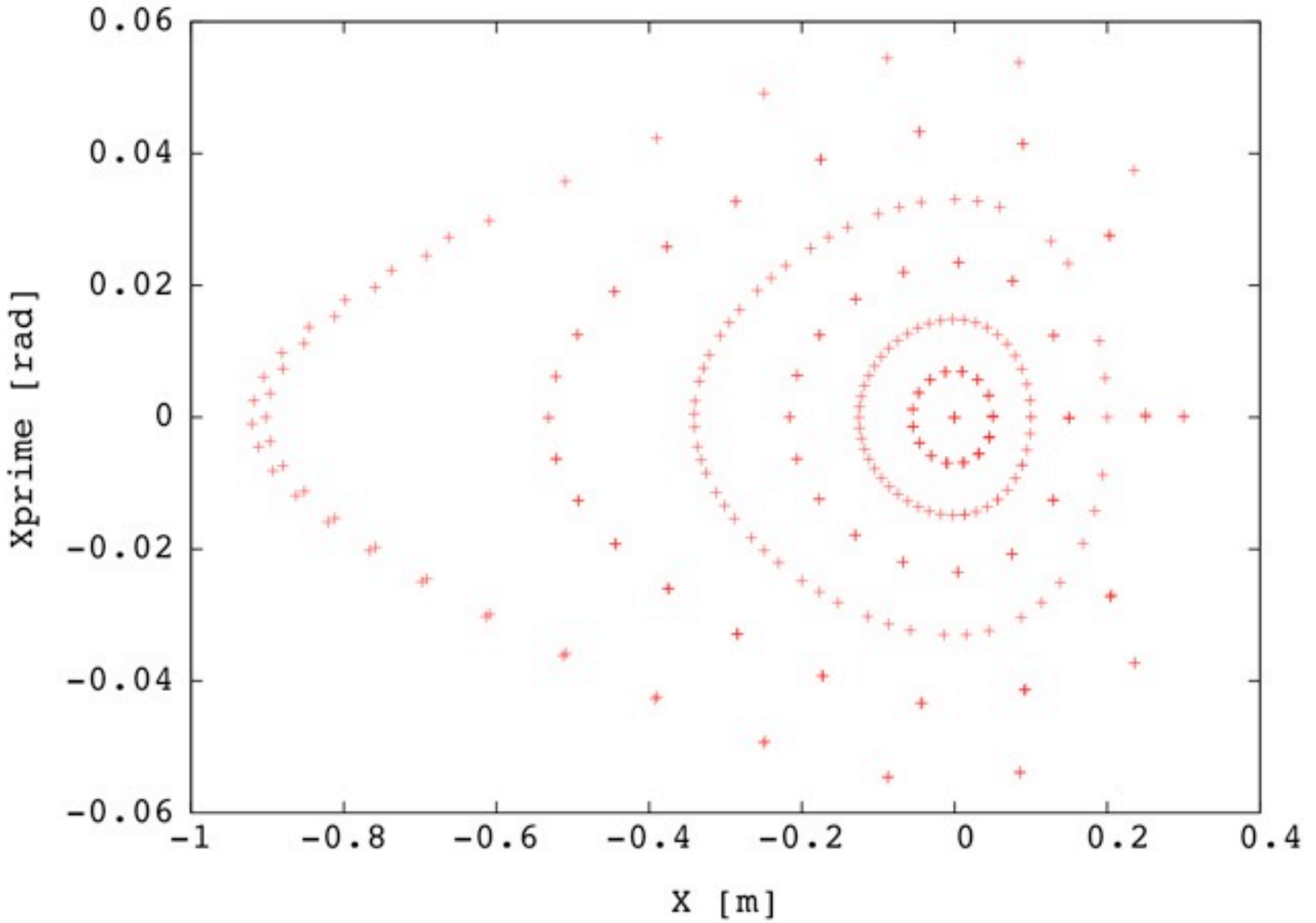

Horizontal Poincarre map with a small vertical deviation

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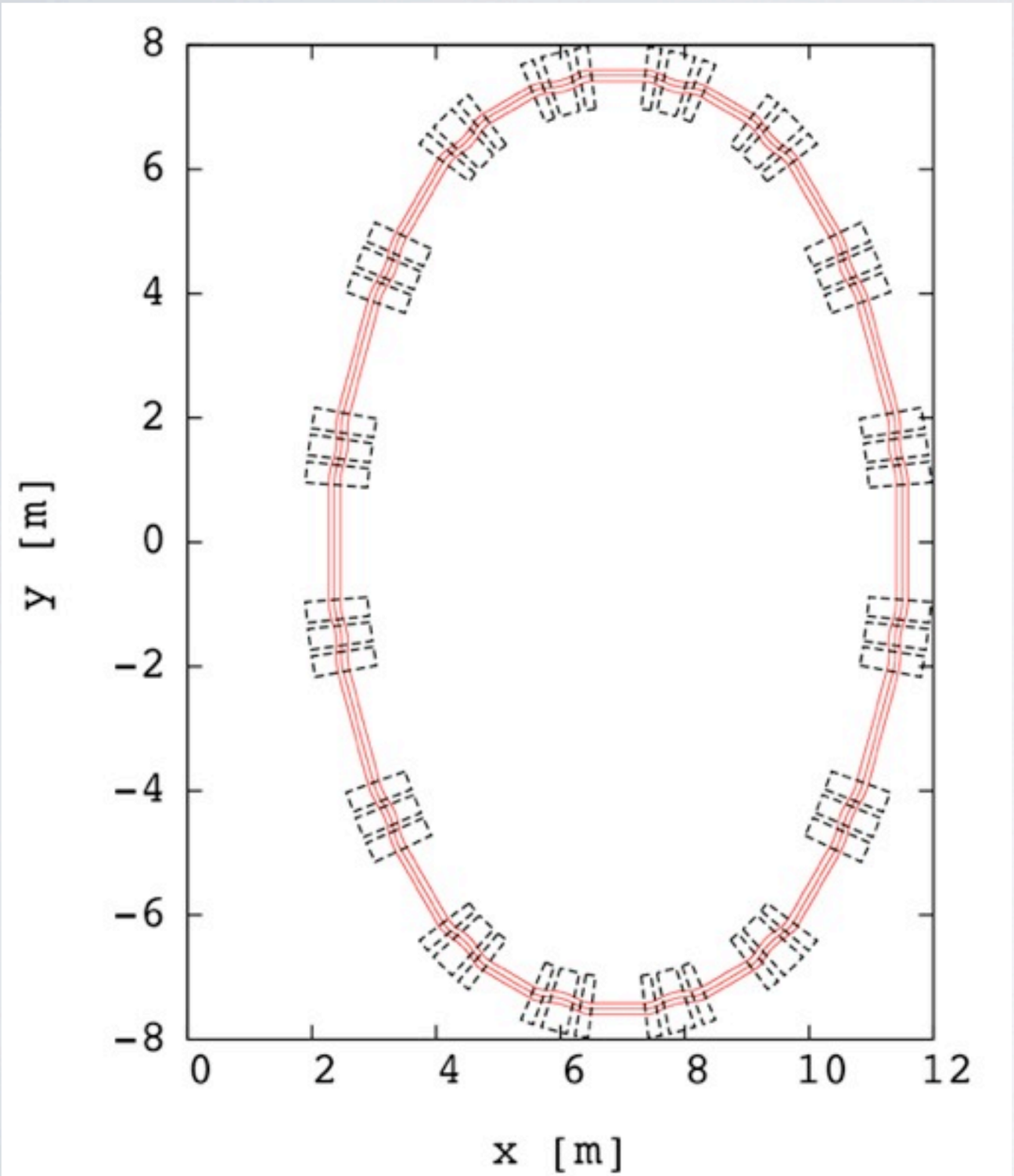
LATTICE ONLY WITH BENDS



Bending cell	
k	6.5
Average radius	3.5 m
Phase advances:	
horizontal μ_x	90 deg.
vertical μ_z	90 deg.
Dispersion	0.47 m

Bending cell with big radius	
k	23.6
Average radius	11.5 m
Phase advances:	
horizontal μ_x	81 deg.
vertical μ_z	77 deg.

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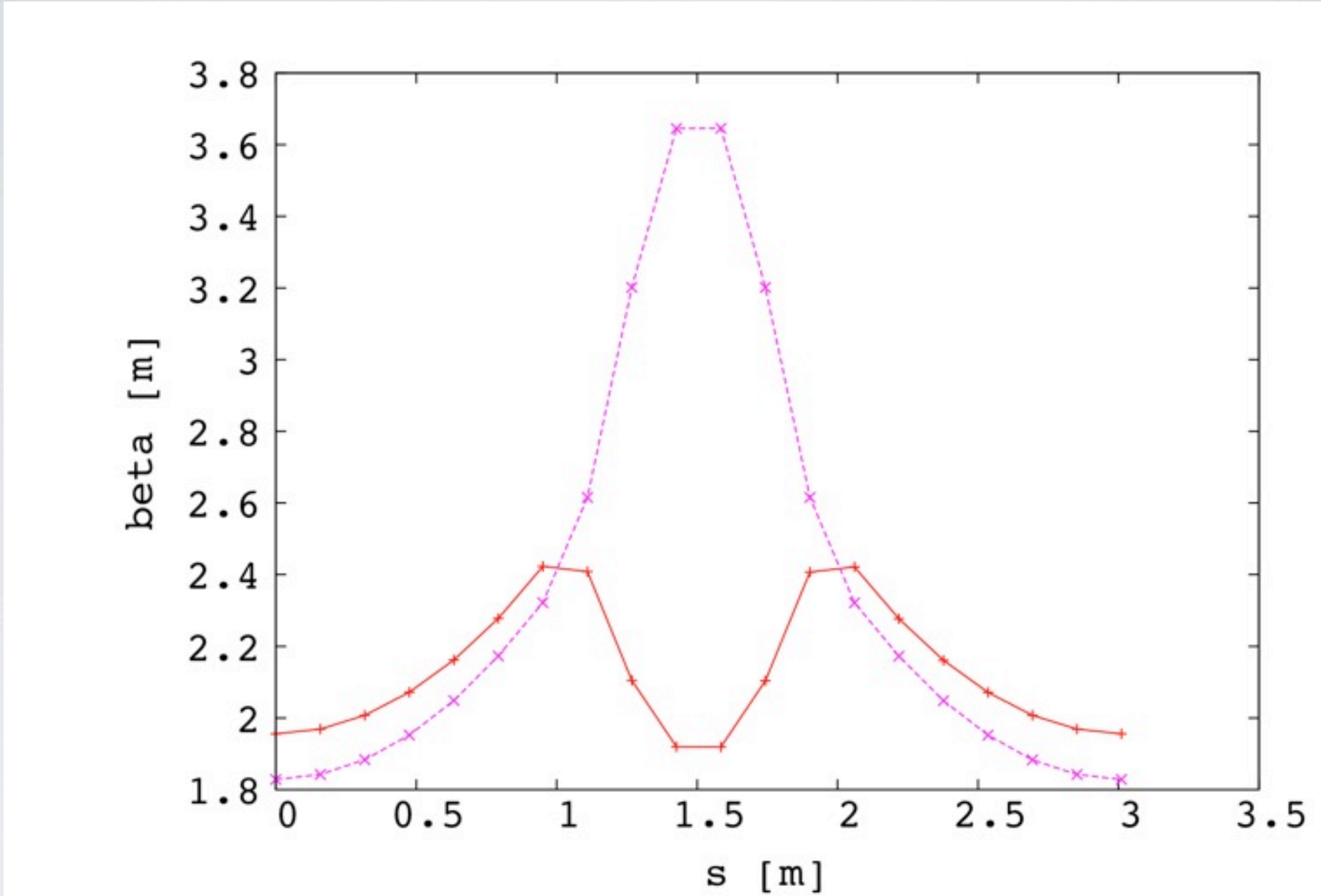

Betafunctions of big radius cell.
(red: horizontal, purple: vertical)

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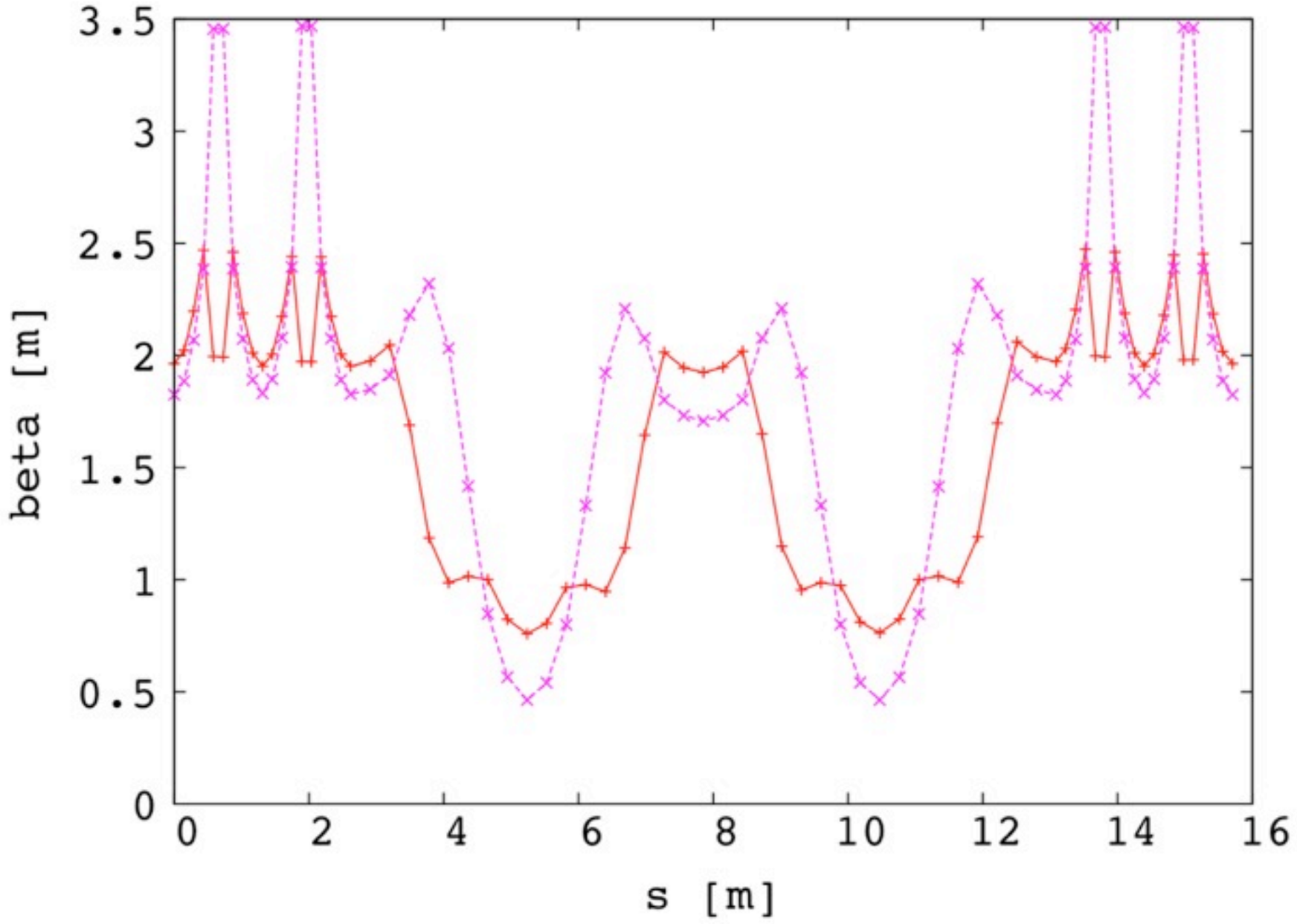

Betafunctions of half of the ring (red: horizontal, purple: vertical)

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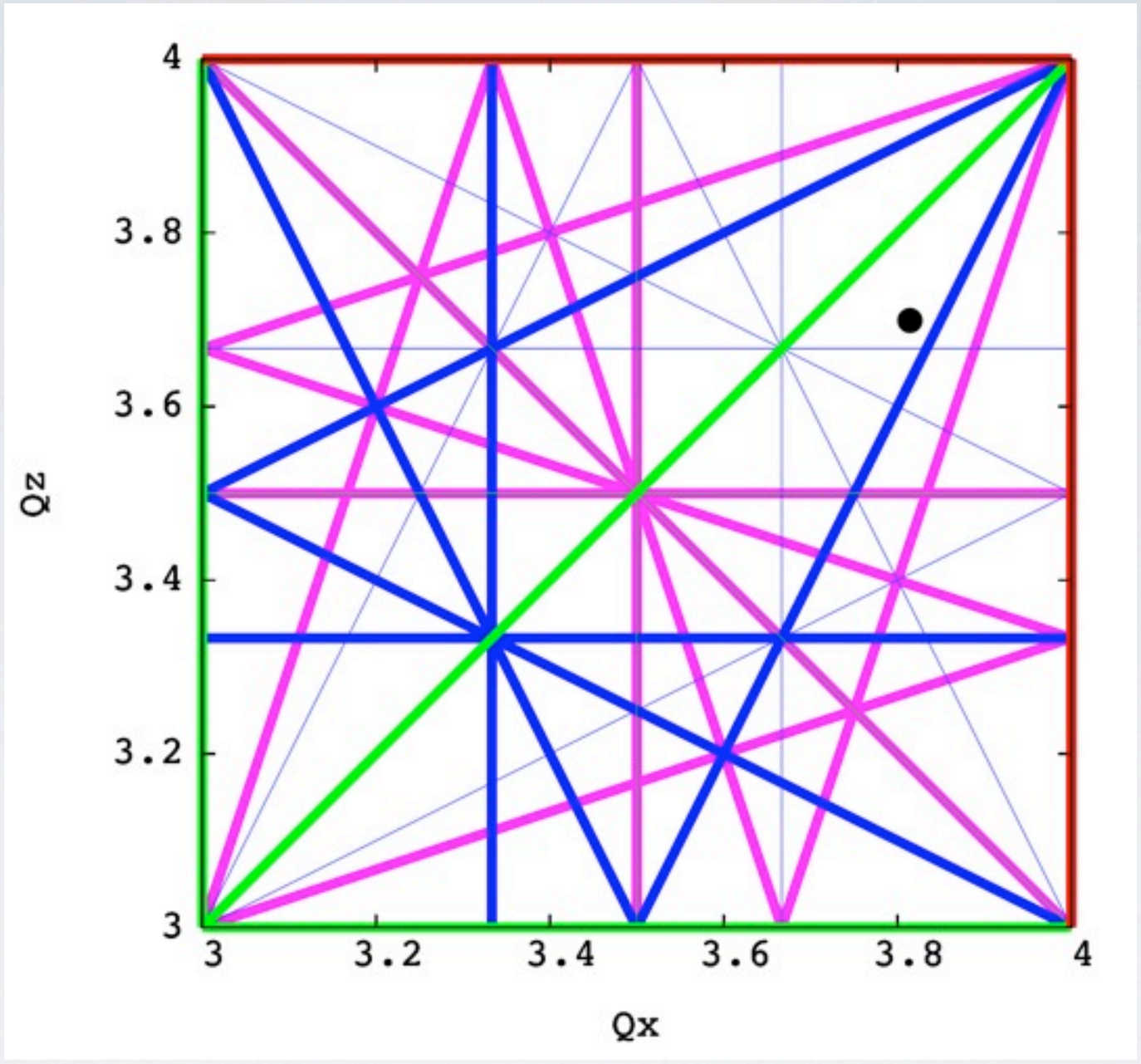

WORKING POINT

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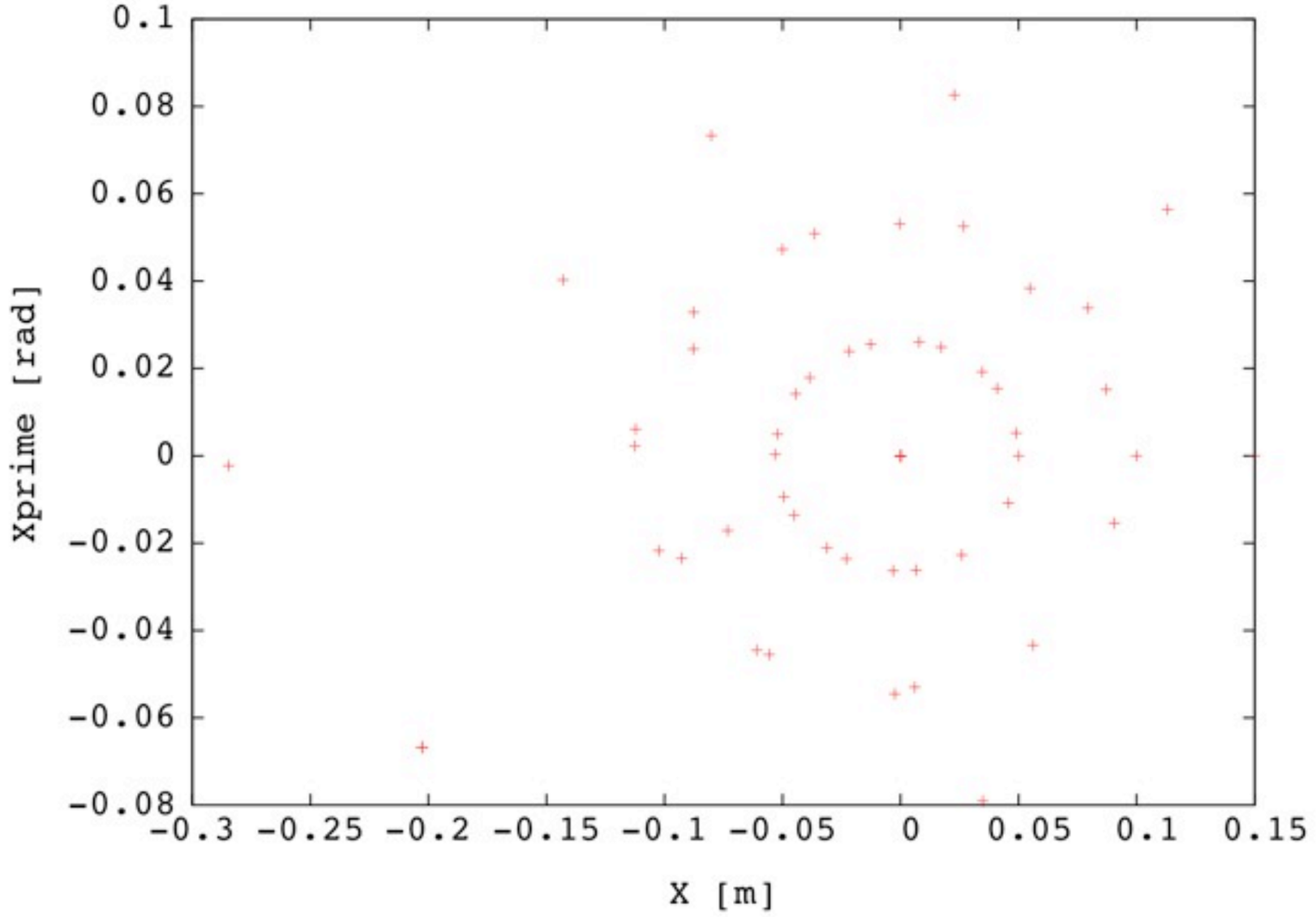

Horizontal Poincarre map with a small vertical deviation

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SUMMARY

- acceptance is limited in this case because of
  - bad choice of working point?
  - modulation of the betafunctions?
  - low superperiodicity?
  - something else?

SCALING FFAG GANTRY CONCEPTS FOR CARBON THERAPY

PRELIMINARY WORK

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REQUIREMENTS

- Transport line for carbon ions up to 400MeV/c
- Momentum acceptance: ±20%
- Dispersion = 0 at the beginning and at the end of the line
- same betafunctions in horizontal and vertical, and their derivative is nul.

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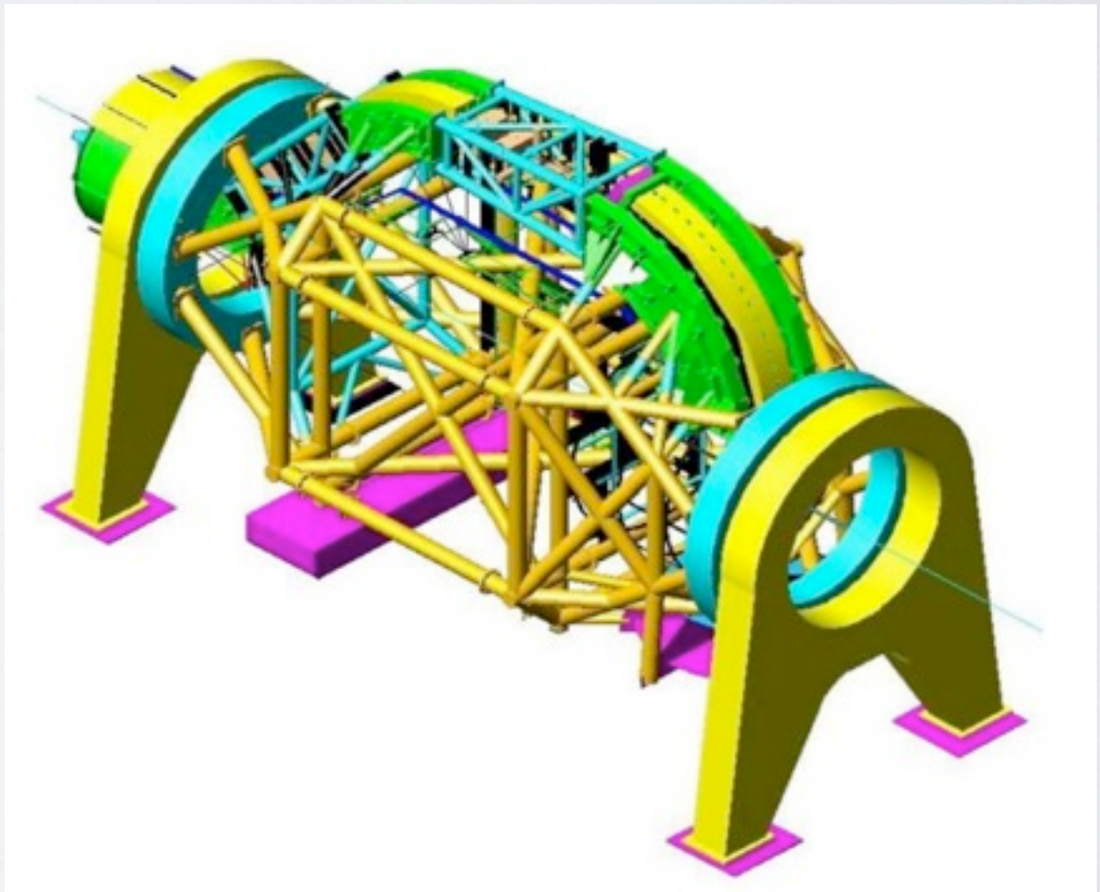
- Existing carbon gantry: Heidelberg
    - Length: 26m, height: 16m
    - weight of the whole system: 600 Tons

→ Huge system!



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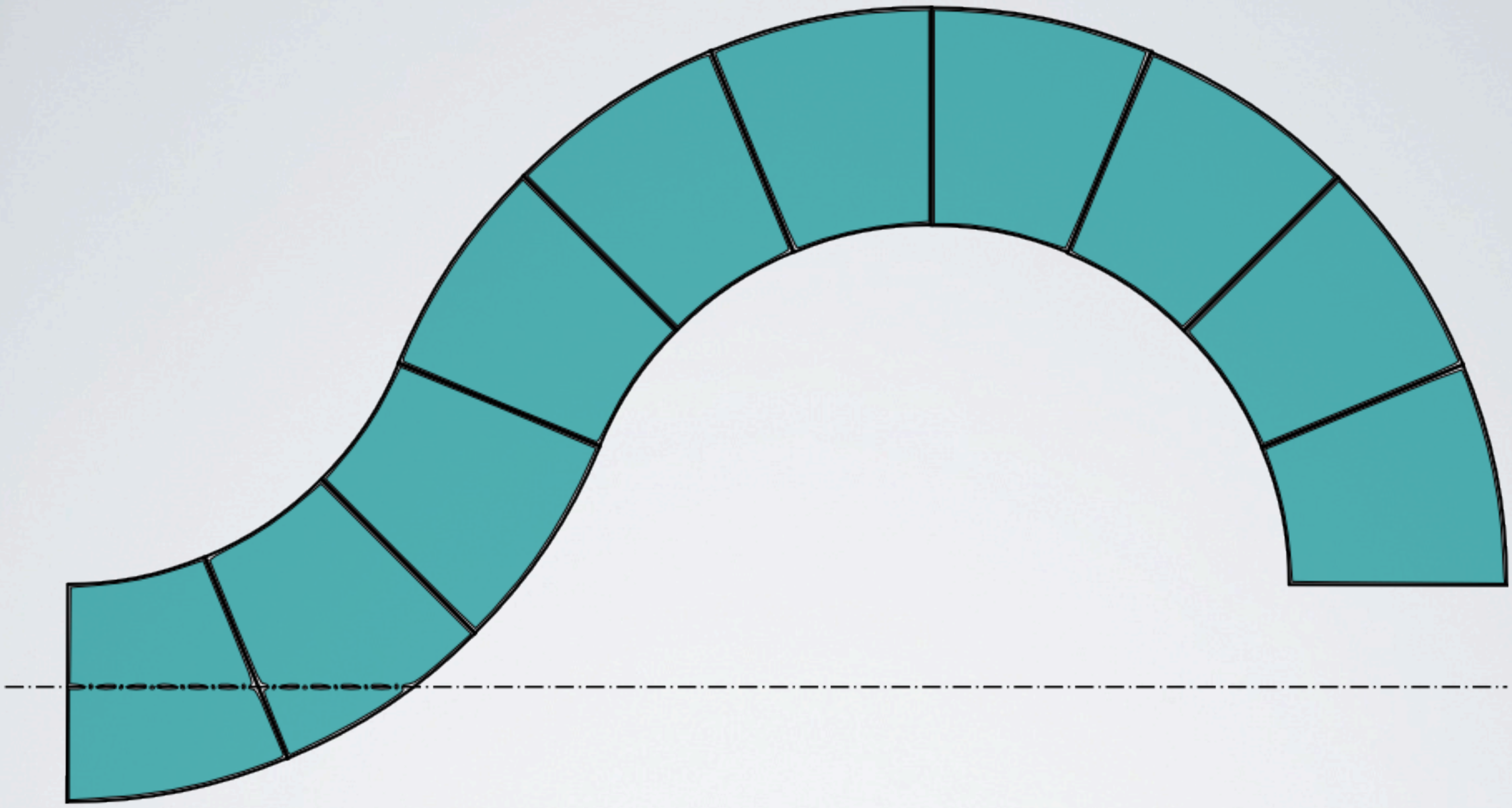

SCHEME OF AN FFAG GANTRY

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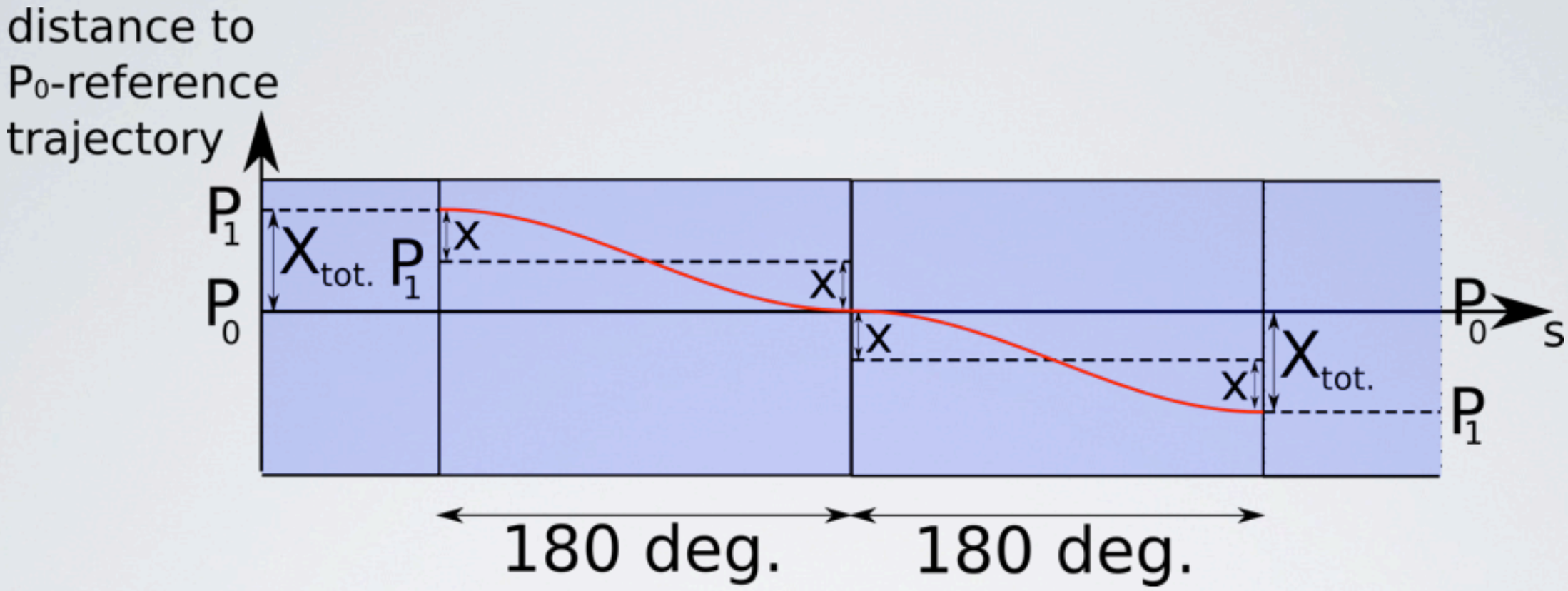

REVERSED DISPERSION

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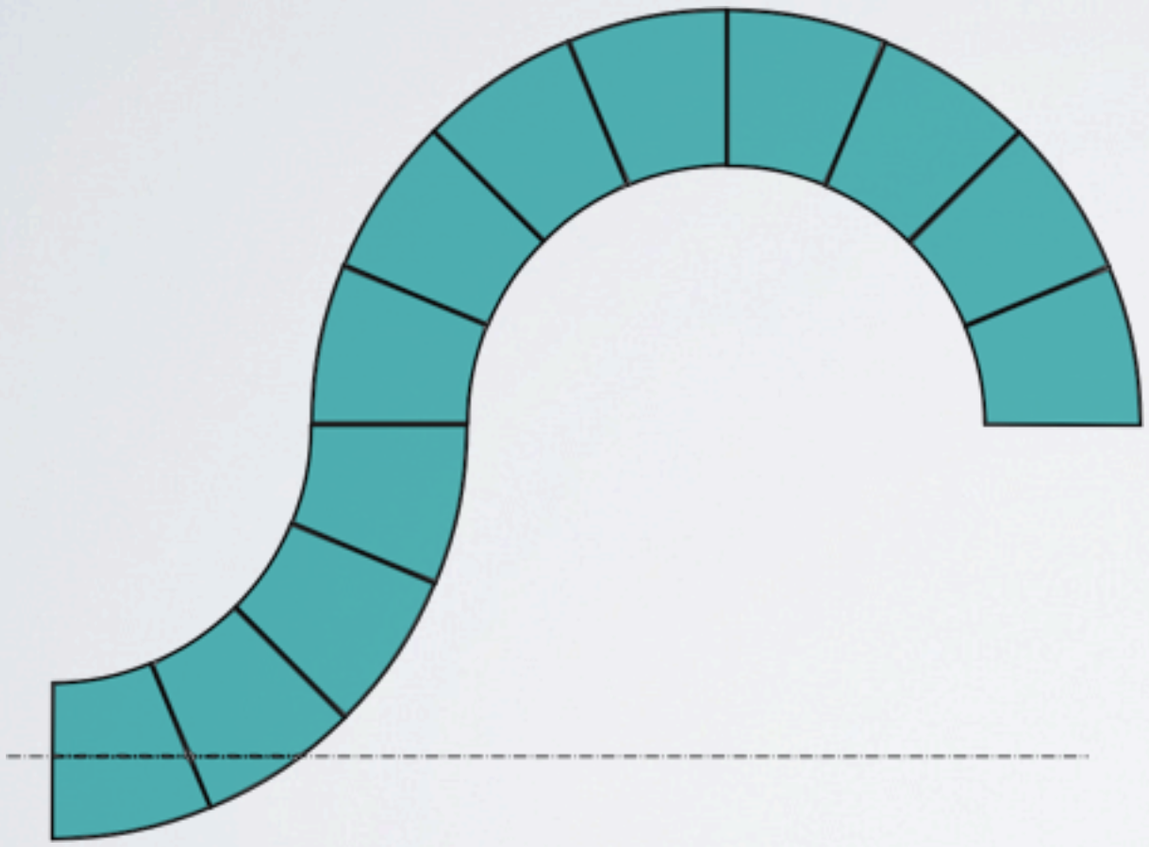

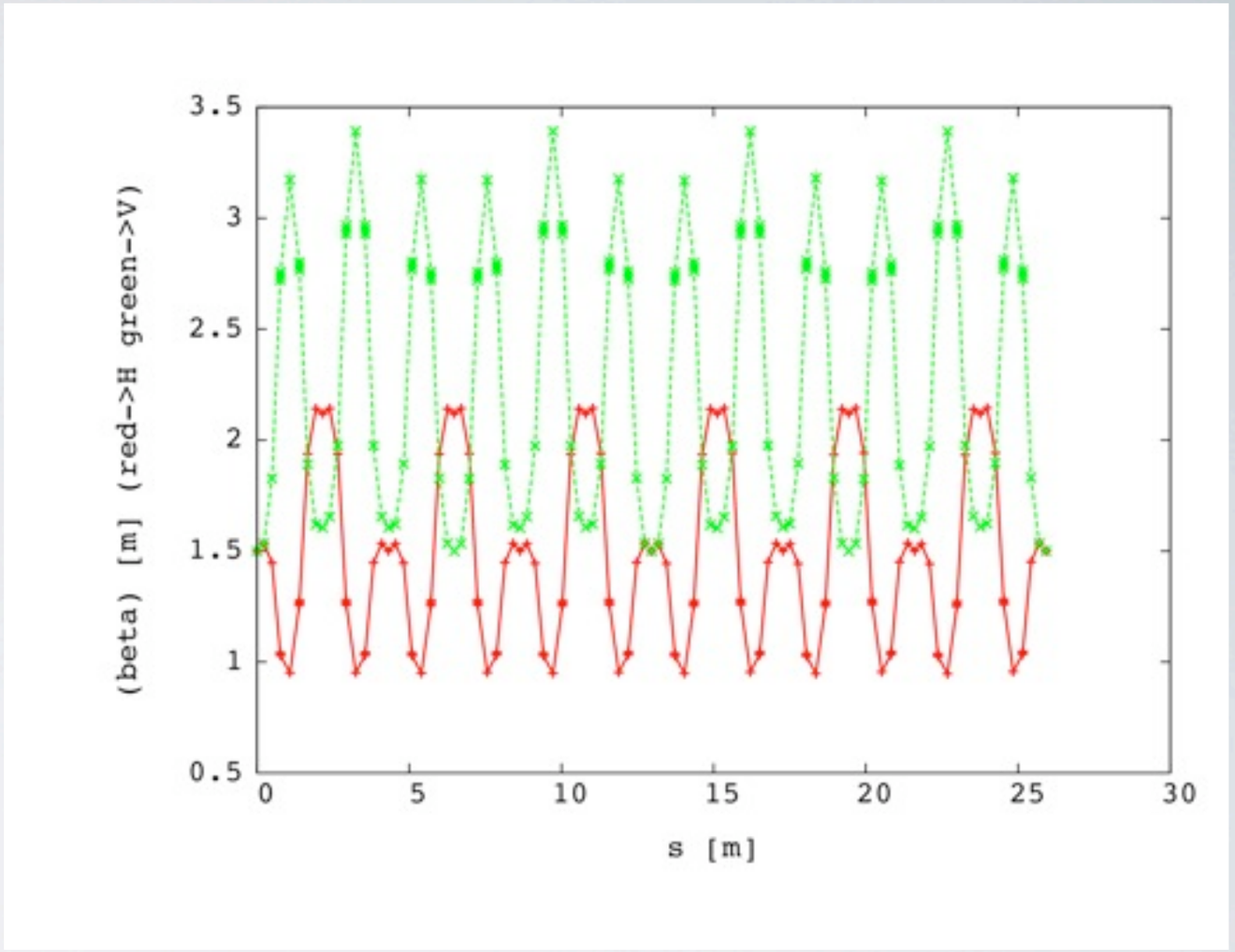

POSSIBLE, BUT...

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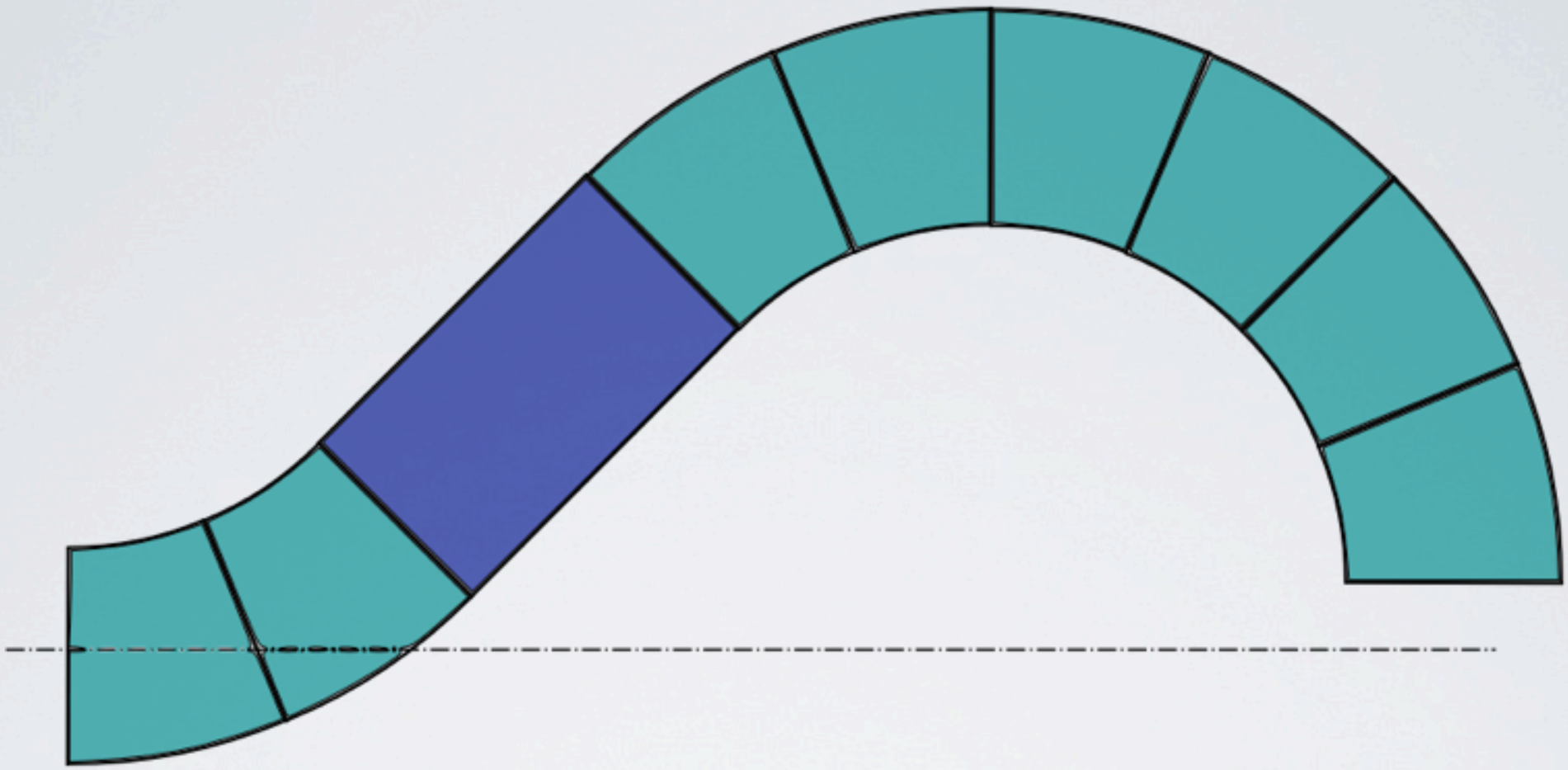

ADVANCED SCALING FFAG

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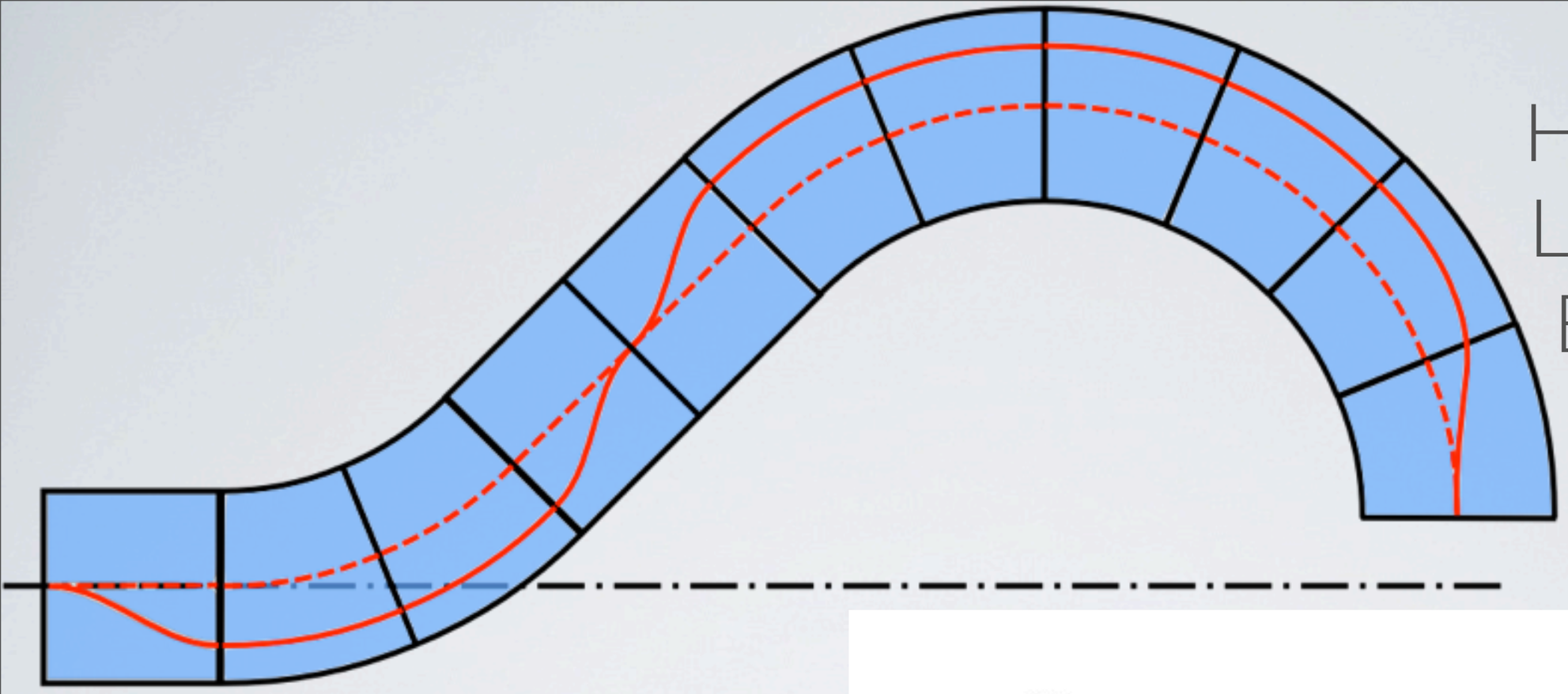
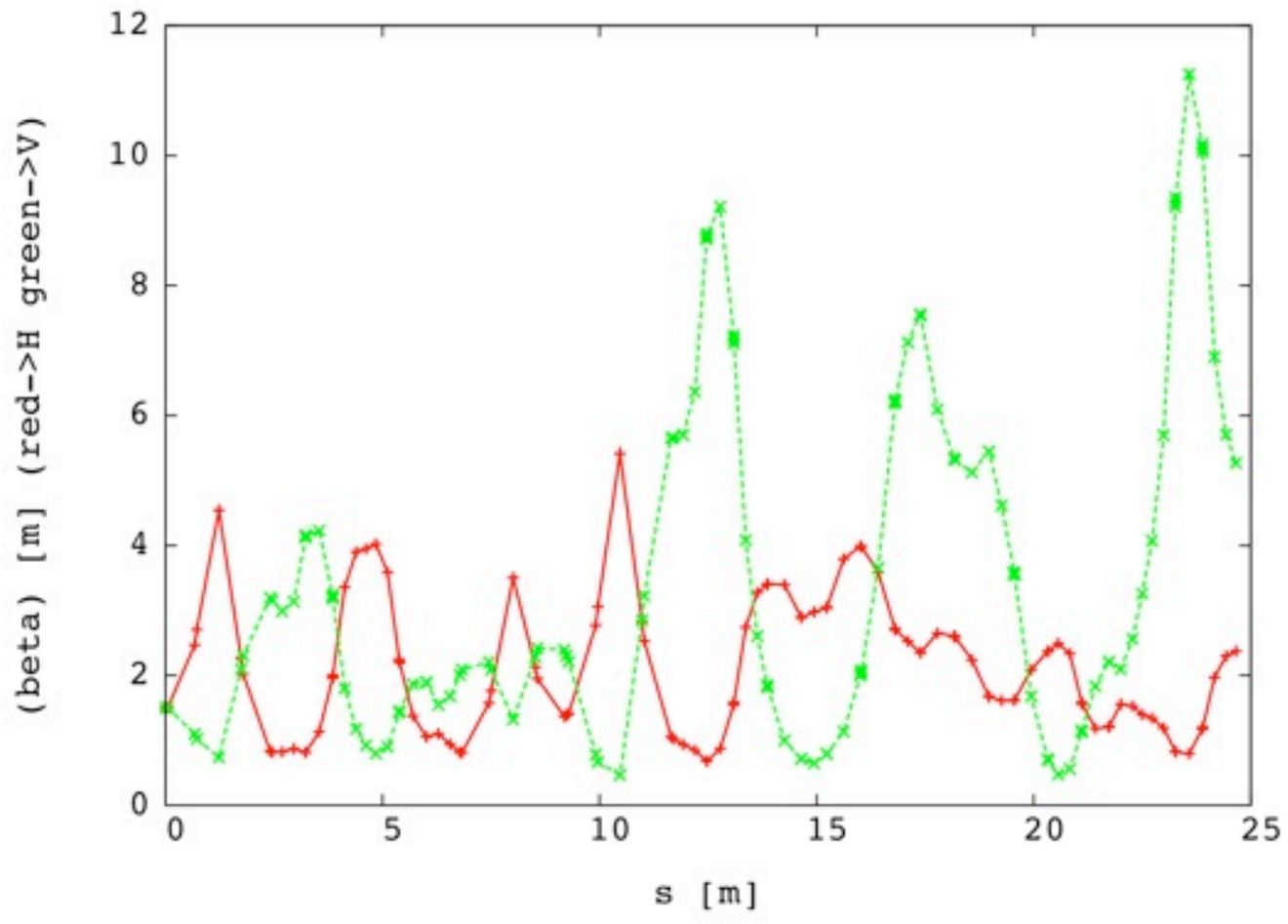


Height: 6.5m.
Length: 19m.
Bmax: 4.5T.

but dispersion is not 0
at the end of the line



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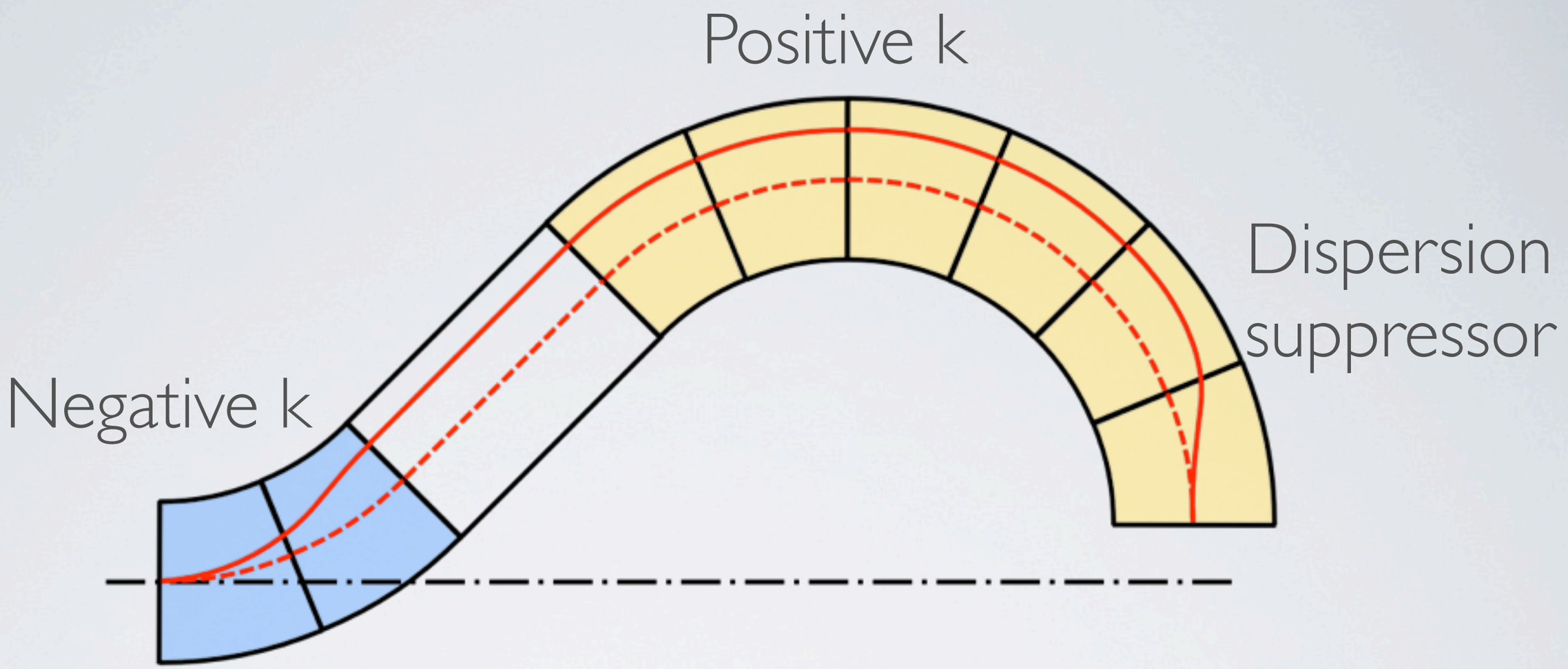

NEGATIVE-K CELLS & DISPERSION SUPPRESSOR

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SUMMARY

- different schemes could be possible
- need tracking!

THANK YOU FOR YOUR ATTENTION

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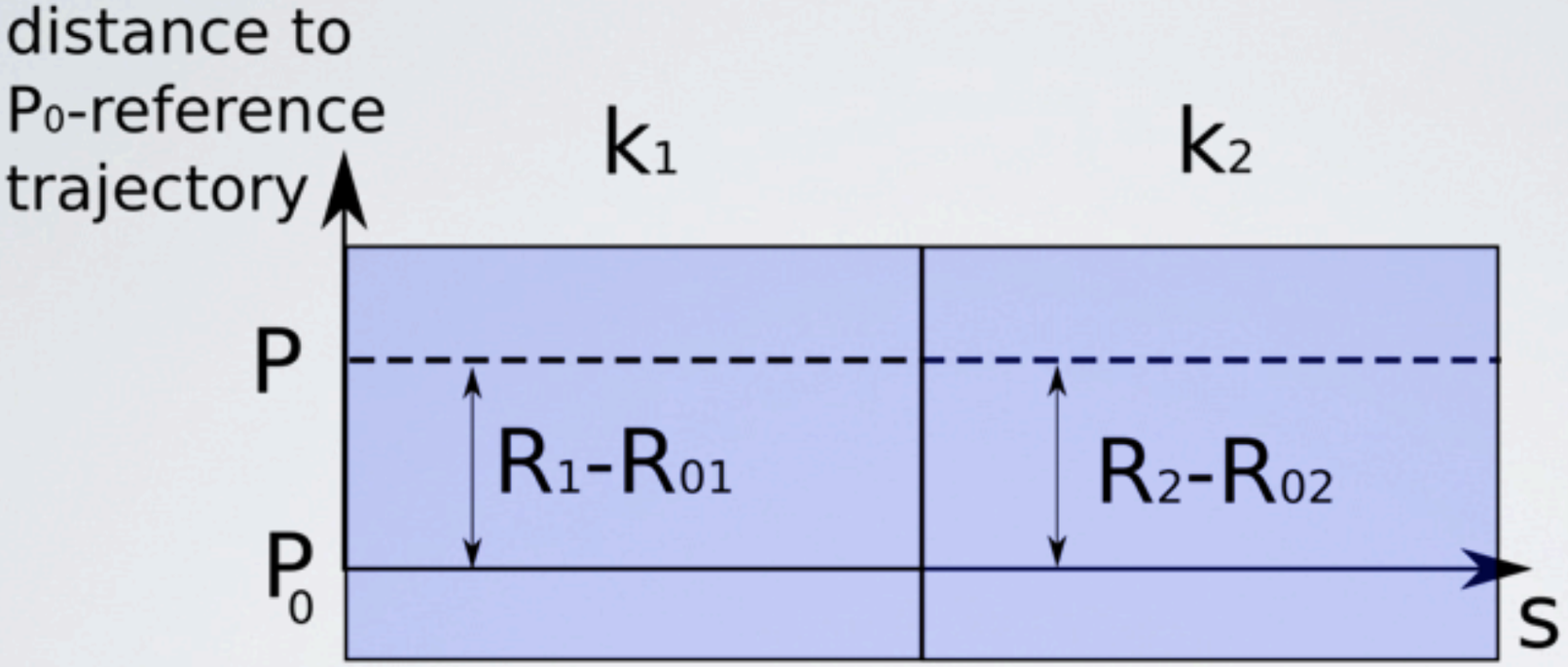
CHANGE RADIUS



$$R_1 - R_{01} = R_2 - R_{02}$$

$$R = R_0 \left(\frac{P}{P_0} \right)^{\frac{1}{k+1}}$$

1st order

$$\frac{R_{01}}{R_{02}} = \frac{k_1 + 1}{k_2 + 1}$$

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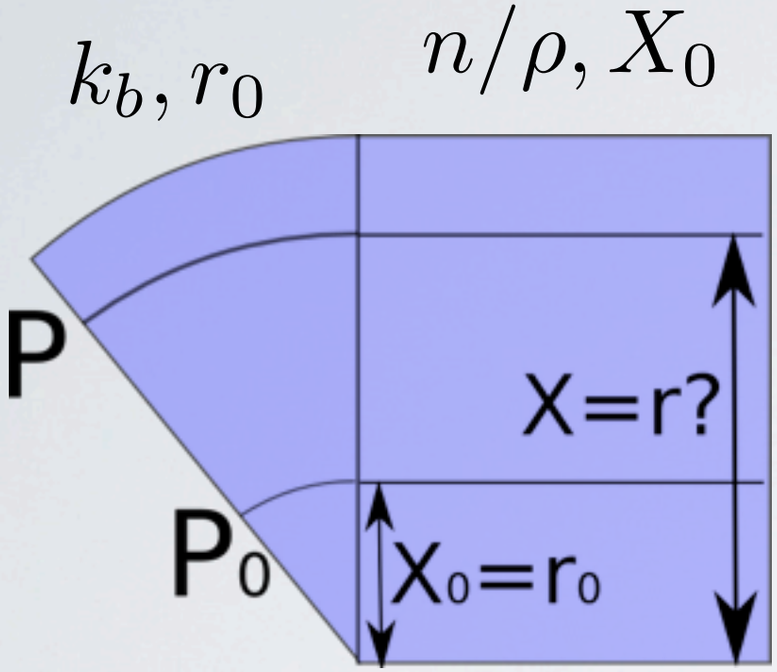
MISMATCH BEND-STRAIGHT



Straight cell: $B_z = B_{0s} e^{\frac{n}{\rho_s}(X - X_0)}$

Bending cell: $B_z = B_{0b} \left(\frac{r}{r_0} \right)^{k_b}$

Matching of P0: $B_{0s}\rho_s = B_{0b}\rho_b$

Matching of P: $B_{0s}\rho_s e^{\frac{n}{\rho}(X - X_0)} = B_{0b}\rho_b \left(\frac{r}{r_0} \right)^{k_b+1}$

1st order

$$1 + (k_b + 1)\left(\frac{r - r_0}{r_0}\right) = 1 + \frac{n}{\rho_s}(X - X_0) \quad \Rightarrow \quad \frac{n}{\rho_s} = \frac{k_b + 1}{r_0}$$

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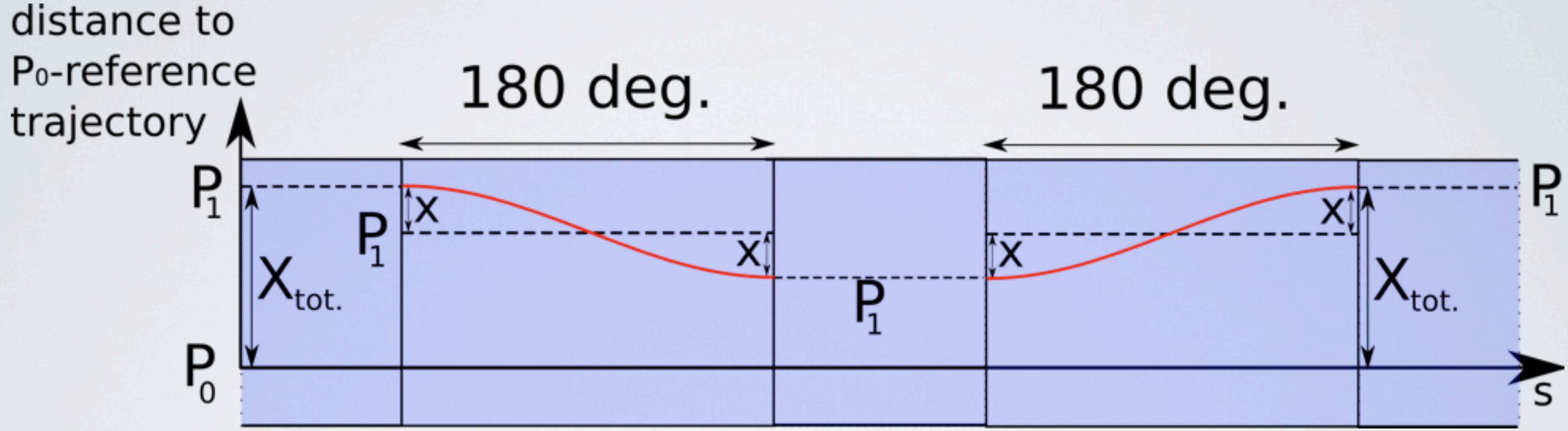
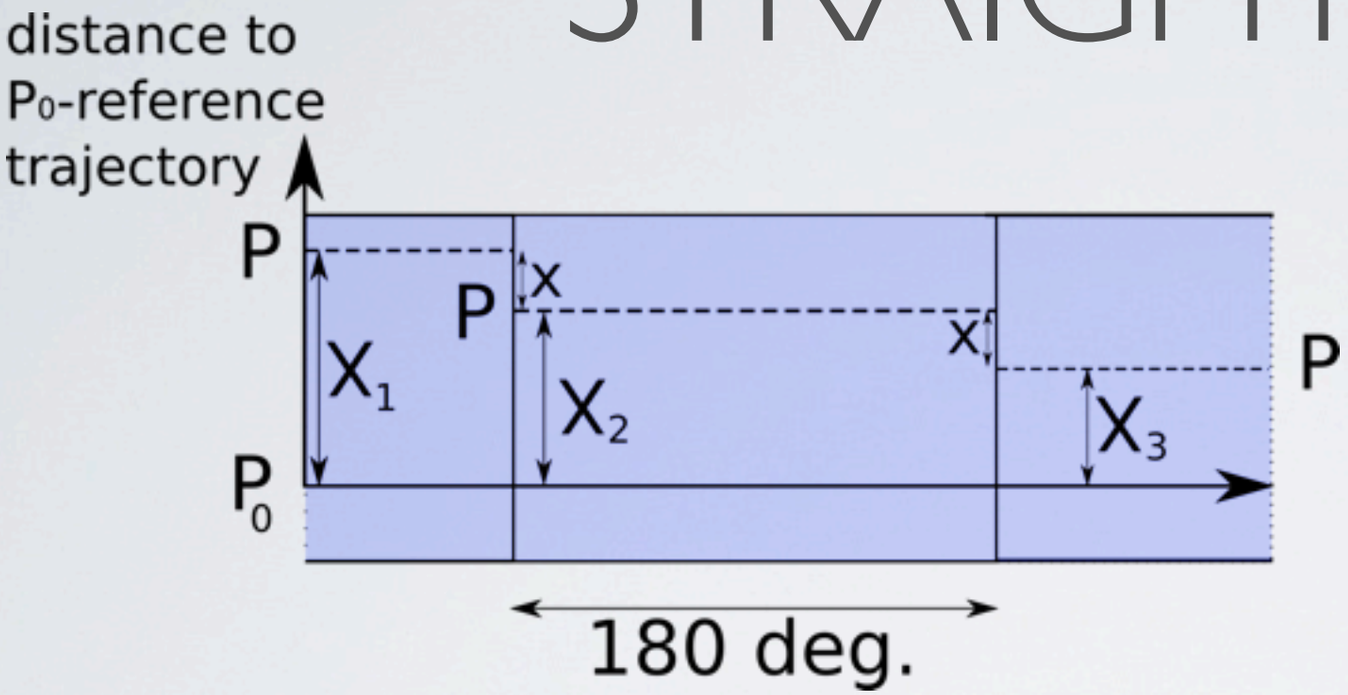
DISPERSION SUPPRESSOR



Bending: k_1 k_2 k_3 k_2 k_1

Straight: $\left(\frac{n}{\rho}\right)_1$ $\left(\frac{n}{\rho}\right)_2$ $\left(\frac{n}{\rho}\right)_3$ $\left(\frac{n}{\rho}\right)_2$ $\left(\frac{n}{\rho}\right)_1$

DISPERSION SUPPRESSOR IN STRAIGHT LINES



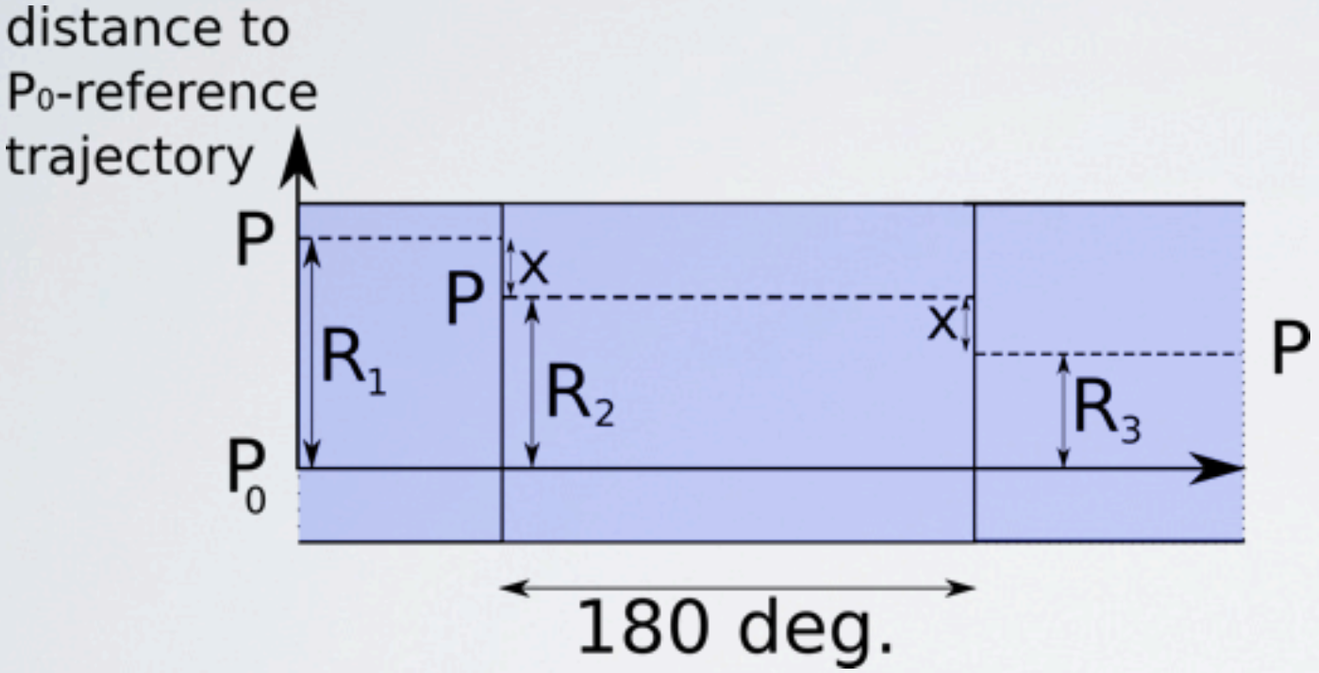
$$X_2 - (X_1 - X_2) = X_3$$

$$2X_2 = X_1 + X_3$$

$$X = \frac{\rho}{n} \ln(\frac{P}{P_0})$$

$$2\frac{\rho_2}{n_2} = \frac{\rho_1}{n_1} + \frac{\rho_3}{n_3}$$

DISPERSION SUPPRESSOR IN BENDING LINES



$$R_2 - (R_1 - R_2) = R_3$$

$$2R_2 = R_1 + R_3$$

$$P = P_0 \left(\frac{R_0 + R_i}{R_0} \right)^{k_i+1}$$

1st order in ΔR/R

$$\frac{2}{k_2+1} = \frac{1}{k_1+1} + \frac{1}{k_3+1}$$

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