Racetrack FFAG muon decay ring for νSTORM

JB. Lagrange, J. Pasternak, Y. Mori

Outline

Outline

- Zero-chromatic FFAG

Outline

- Zero-chromatic FFAG
- Racetrack FFAG muon decay ring

Outline

- Zero-chromatic FFAG
- Racetrack FFAG muon decay ring
- Comparison

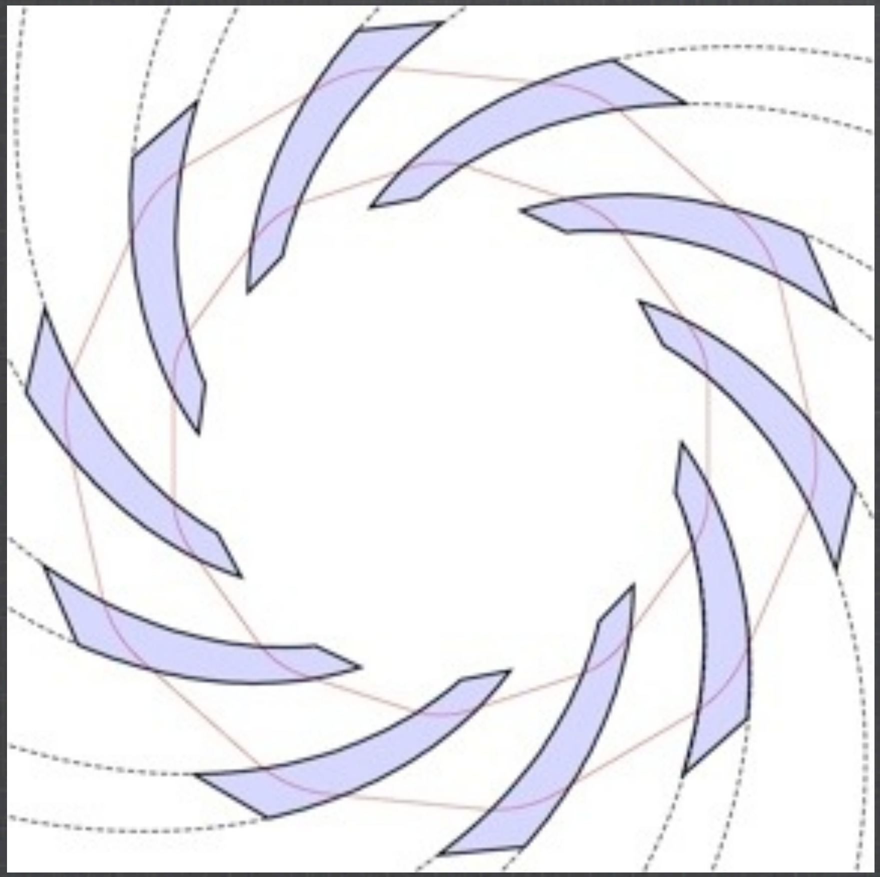
Outline

- Zero-chromatic FFAG
- Racetrack FFAG muon decay ring
- Comparison

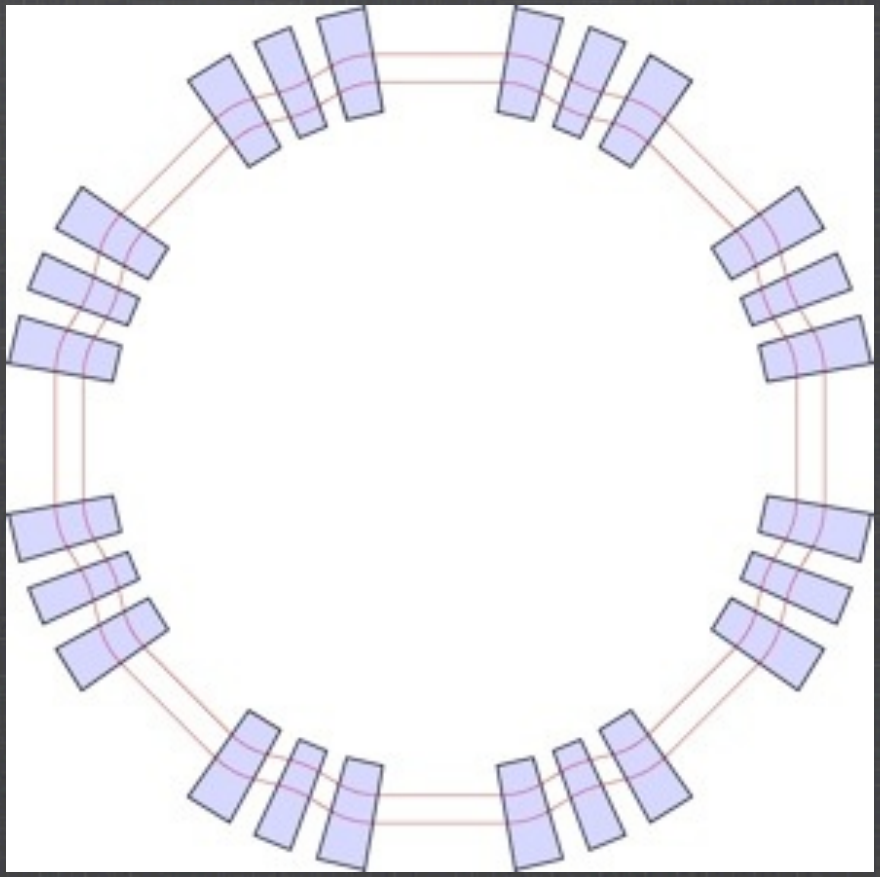
Circular scaling FFAG

Geometrical field index: $k = \frac{R}{\bar{B}} \frac{d\bar{B}}{dR}$

$$B(r,\theta) = B_0 \left(\frac{r}{r_0}\right)^k \cdot \mathcal{F}(\theta - \tan\zeta \ln \frac{r}{r_0})$$



Spiral sector

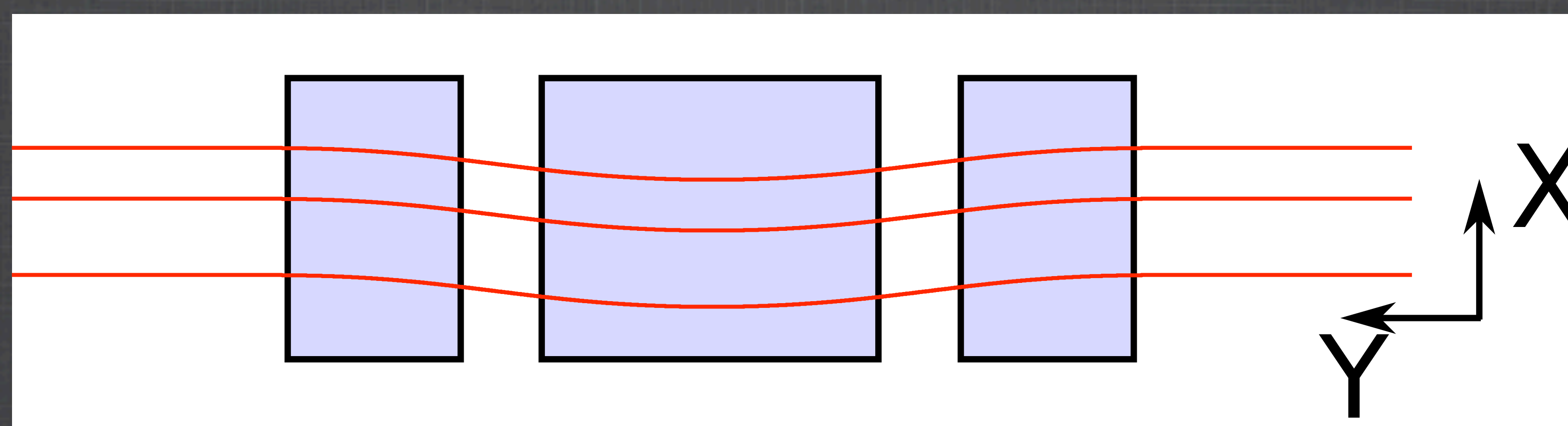


Radial sector

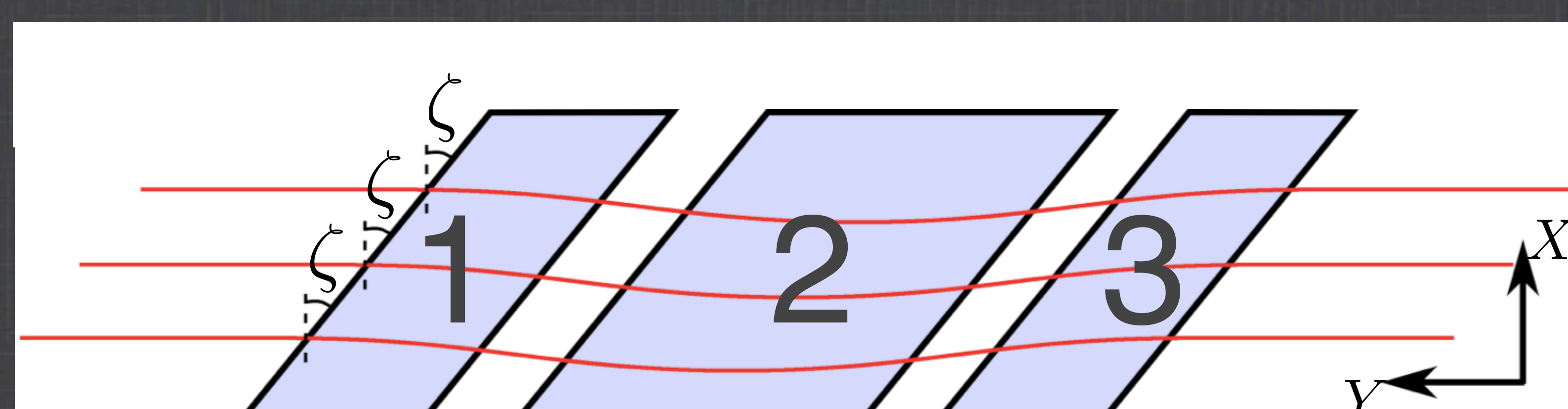
Straight scaling FFAG

Normalized field gradient: $m = \frac{1}{\bar{B}}\frac{d\bar{B}}{d\chi}$

$$B(X,Y) = B_0 e^{m(X-X_0)} \mathcal{F}\left(Y - (X - X_0)\tan\zeta\right)$$

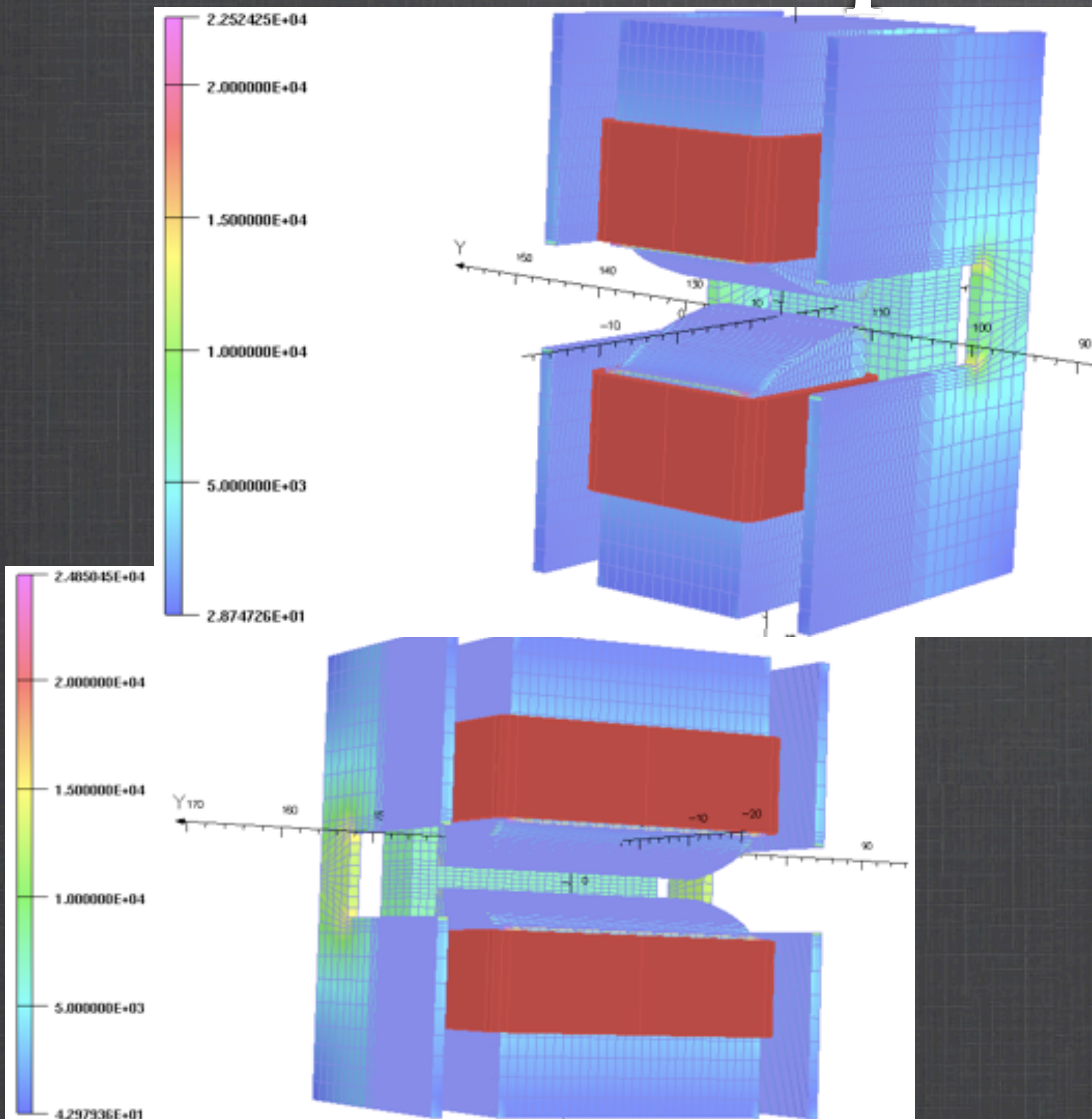


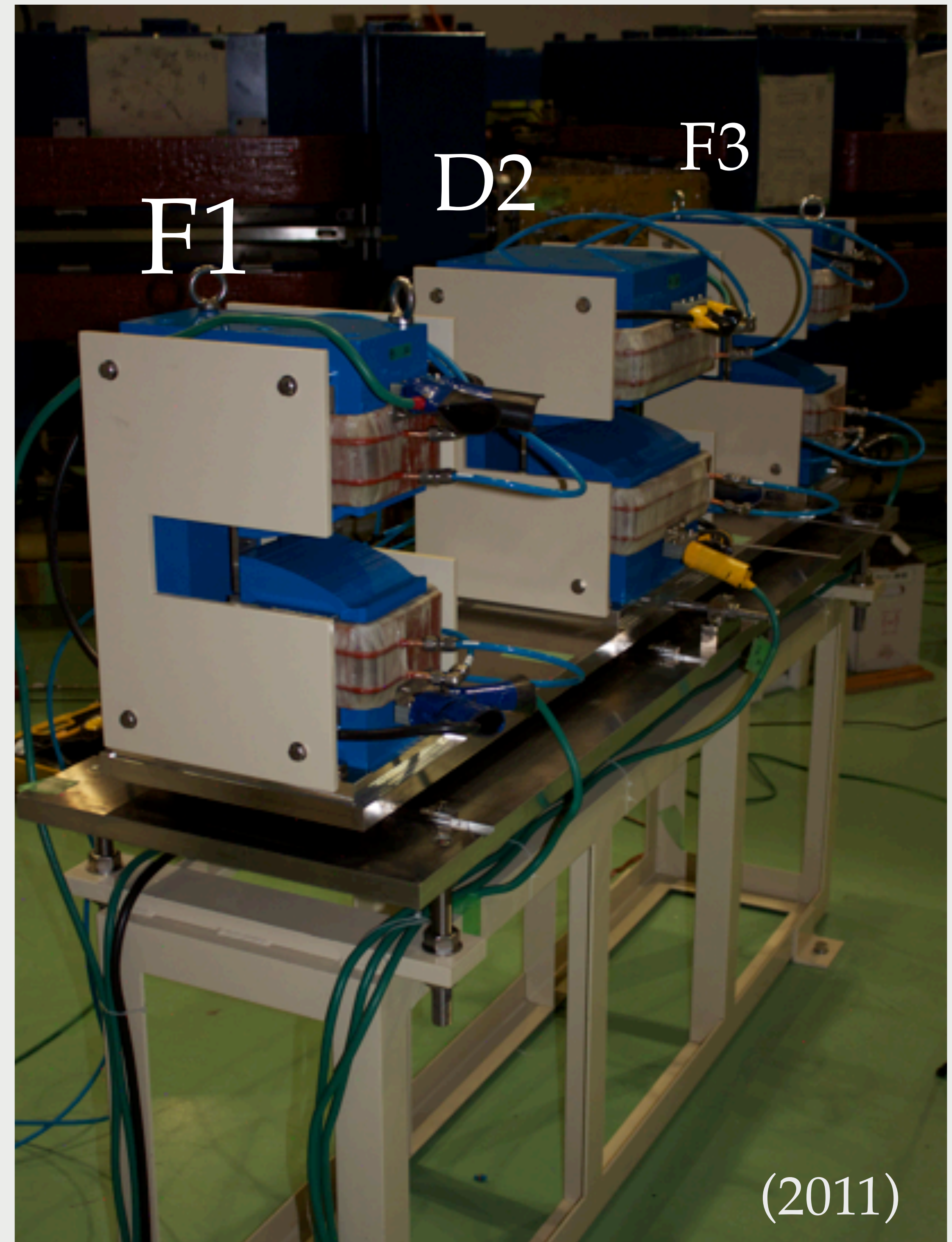
Rectangular case



Tilted straight case

Straight scaling FFAG experiment



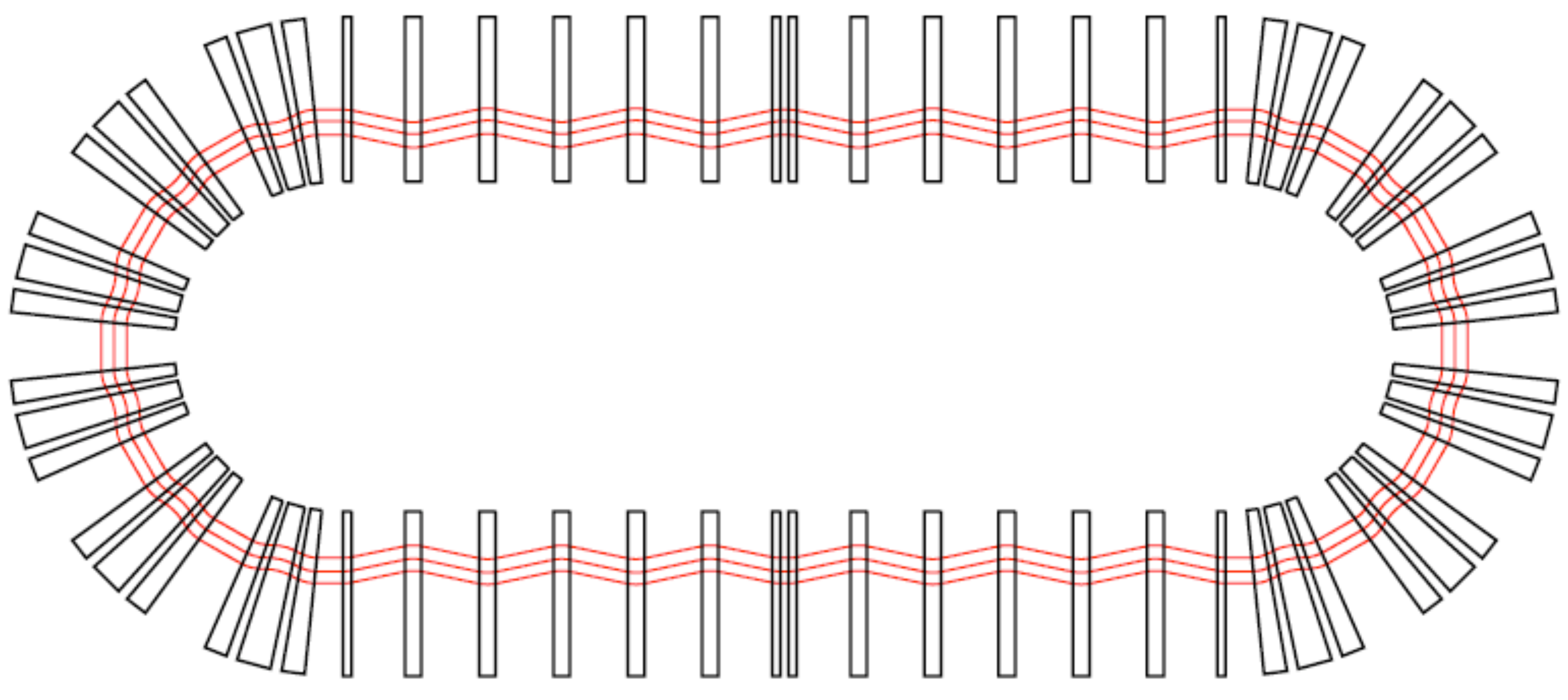


JB. Lagrange *et al.*, Straight scaling FFAG beam line, NIM A, vol. 691, pp. 55-63, ISSN 0168-9002 (2012).

Outline

- Zero-chromatic FFAG
- Racetrack FFAG muon decay ring
- Comparison

Racetrack FFAG



νSTORM Racetrack FFAG

νSTORM Racetrack FFAG

Constraints:

νSTORM Racetrack FFAG

Constraints:

- in the straight part, the scallop must be as small as possible to keep reasonable the size of the detector. 15 mrad has been chosen as the maximum angle.

νSTORM Racetrack FFAG

Constraints:

- in the straight part, the scallop must be as small as possible to keep reasonable the size of the detector. 15 mrad has been chosen as the maximum angle.
- in the dispersion matching section, a drift length of ~2.6 m is necessary for stochastic injection.

νSTORM Racetrack FFAG

Constraints:

- in the straight part, the scallop must be as small as possible to keep reasonable the size of the detector. 15 mrad has been chosen as the maximum angle.
- in the dispersion matching section, a drift length of ~2.6 m is necessary for stochastic injection.
- to keep the ring as small as possible, SC magnets (super-ferric, up to 3 T) in the arcs are considered. Normal conducting magnets are used in the straight part.

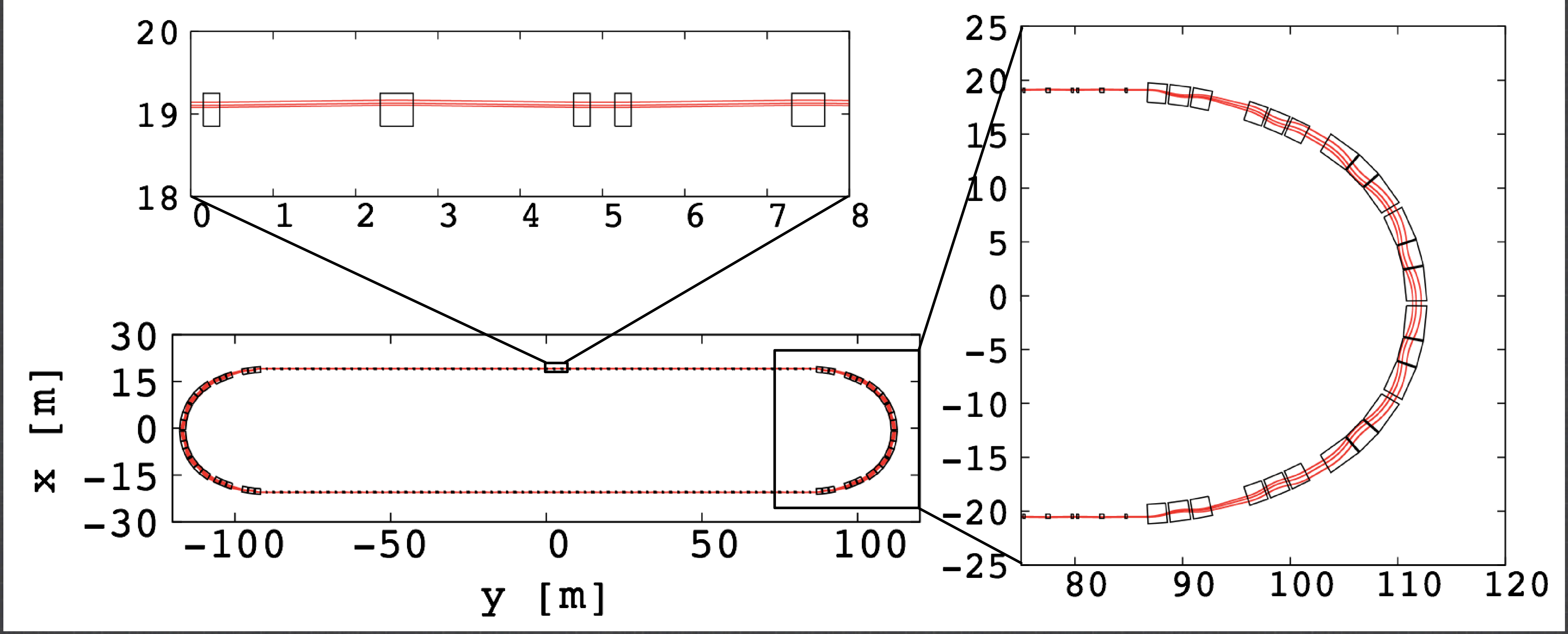
νSTORM Racetrack FFAG

Constraints:

- in the straight part, the scallop must be as small as possible to keep reasonable the size of the detector. 15 mrad has been chosen as the maximum angle.
- in the dispersion matching section, a drift length of ~2.6 m is necessary for stochastic injection.
- to keep the ring as small as possible, SC magnets (super-ferric, up to 3 T) in the arcs are considered. Normal conducting magnets are used in the straight part.
- large transverse acceptance is needed in both planes (1000π mm.mrad).

OPTION #1: "FODO-LIKE"

Straight: **175 m**, maximum scallop angle: **12 mrad**



Comparable straight length than FODO lattice

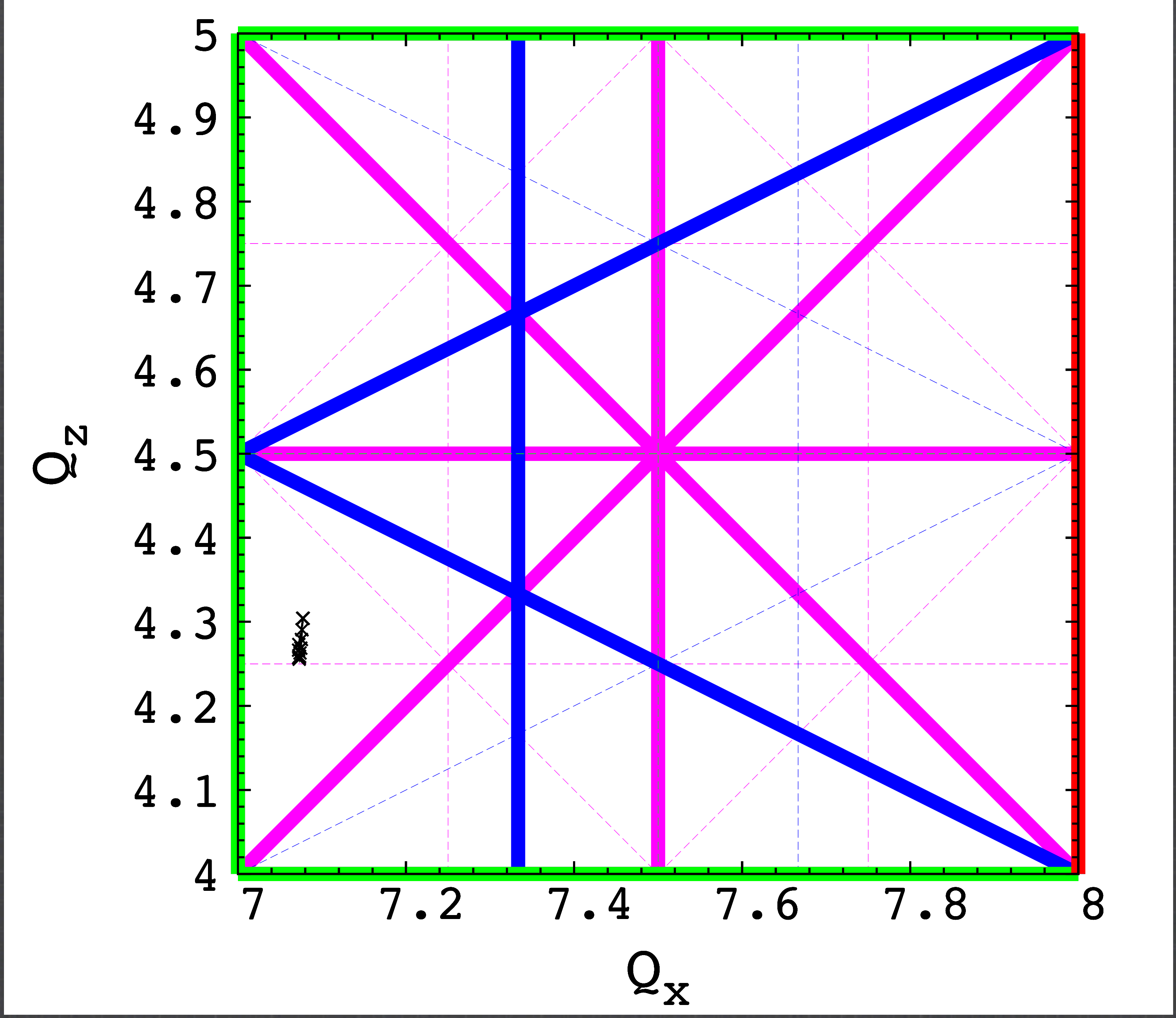
OPTION #1: "FODO-LIKE"

Cell parameters

	Circular Section	Matching Section	Straight Section
Type	FDF	FDF	DFD
Cell radius/length [m]	17.3	36.1	5
Opening angle [deg]	30	15	
k-value/m-value	6.202	26.785	5 m^{-1}
Packing factor	0.92	0.58	0.16
Horizontal phase advance /cell [deg]	90.0	90.0	15.8
Vertical phase advance /cell [deg]	21.1	23.7	16.8
Average dispersion /cell [m]	2.4	1.3	0.2
Number of cells /ring	4×2	4×2	35×2

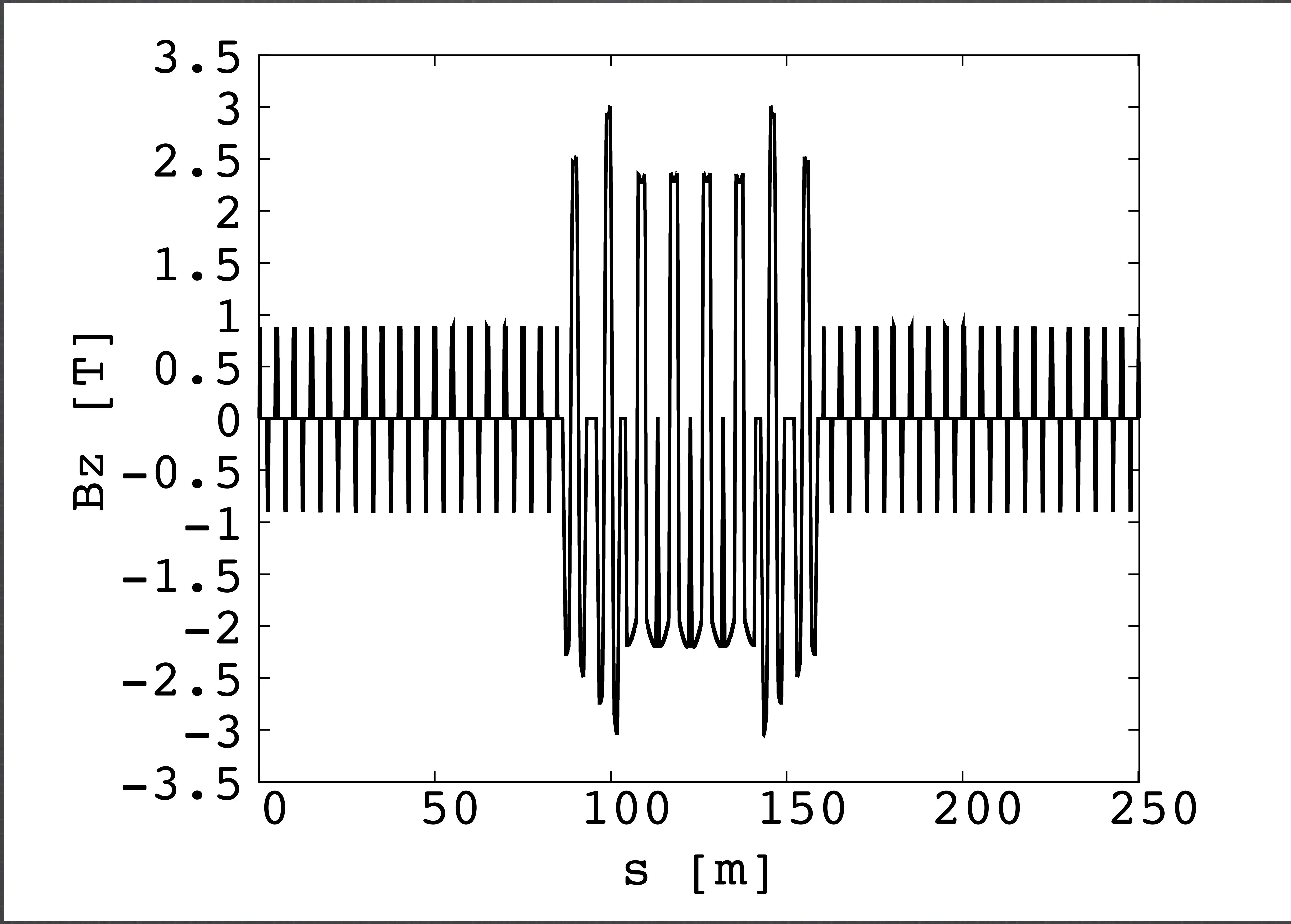
OPTION #1

Tune diagram $\frac{\Delta P}{P} = \pm 16\%$



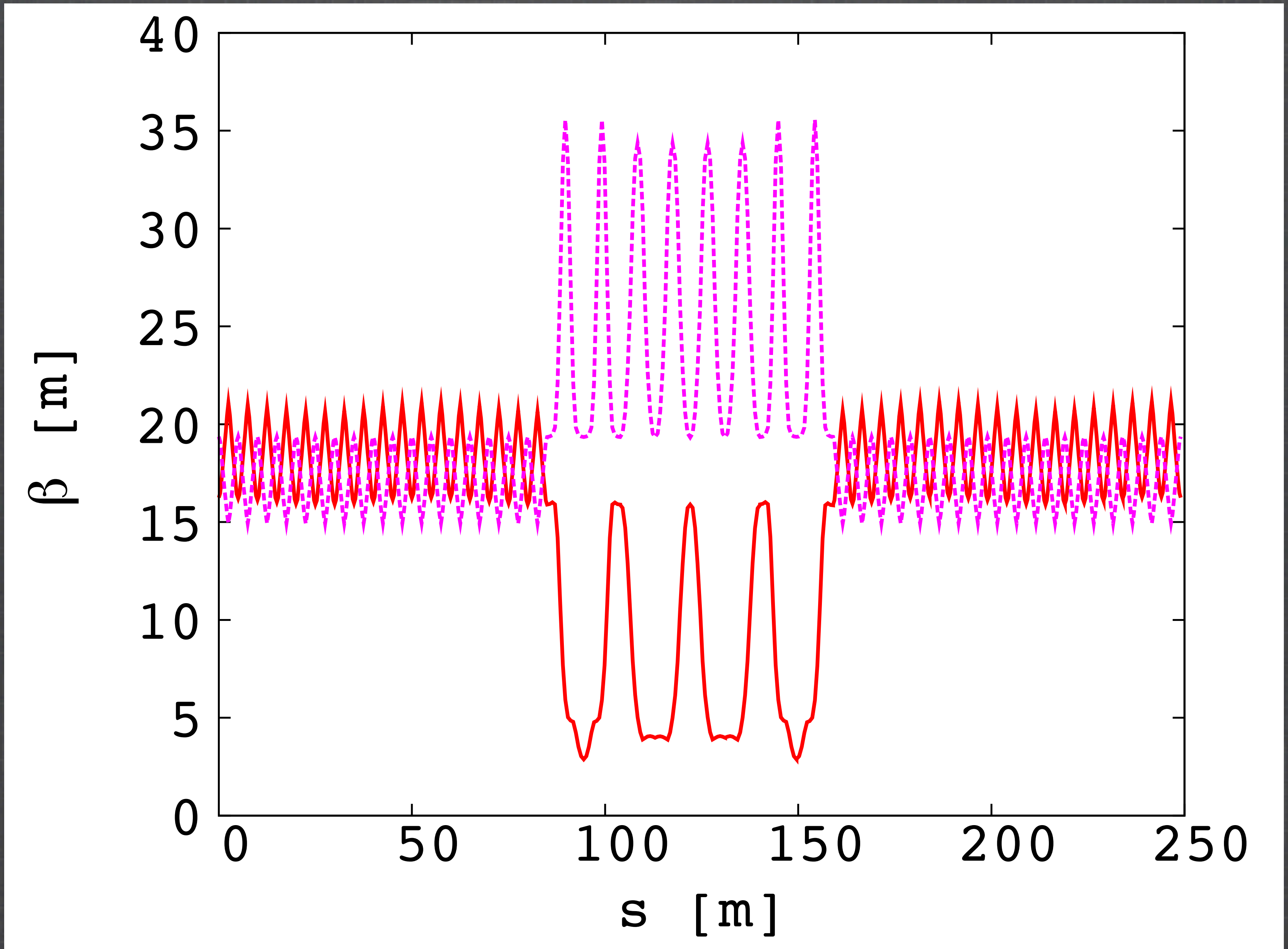
OPTION #1

Magnetic field for P_{max} (+16%)



OPTION #1

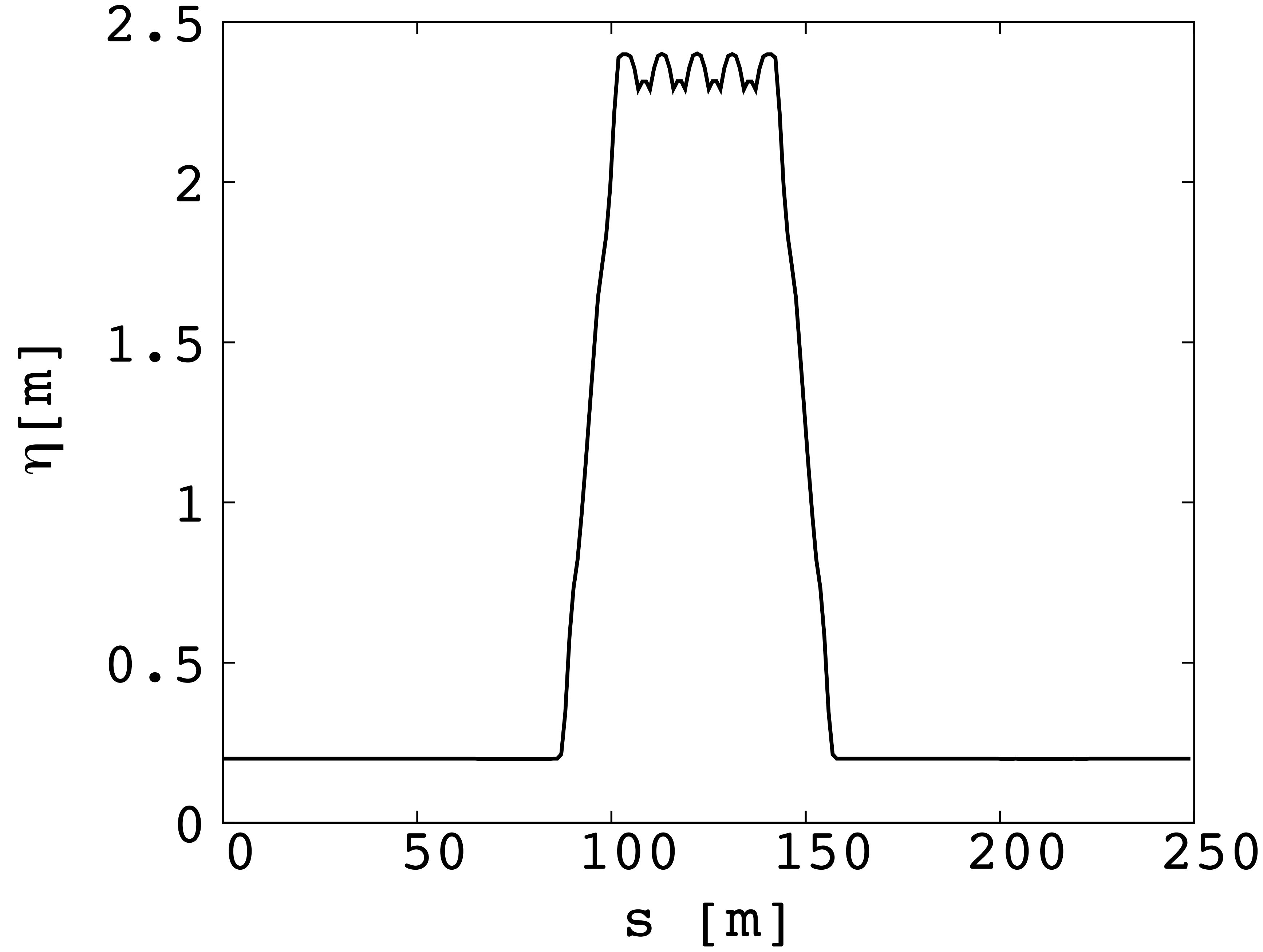
Beta-functions at matching momentum



Horizontal (plain red) and vertical (dotted purple) betafunctions for half of the ring.

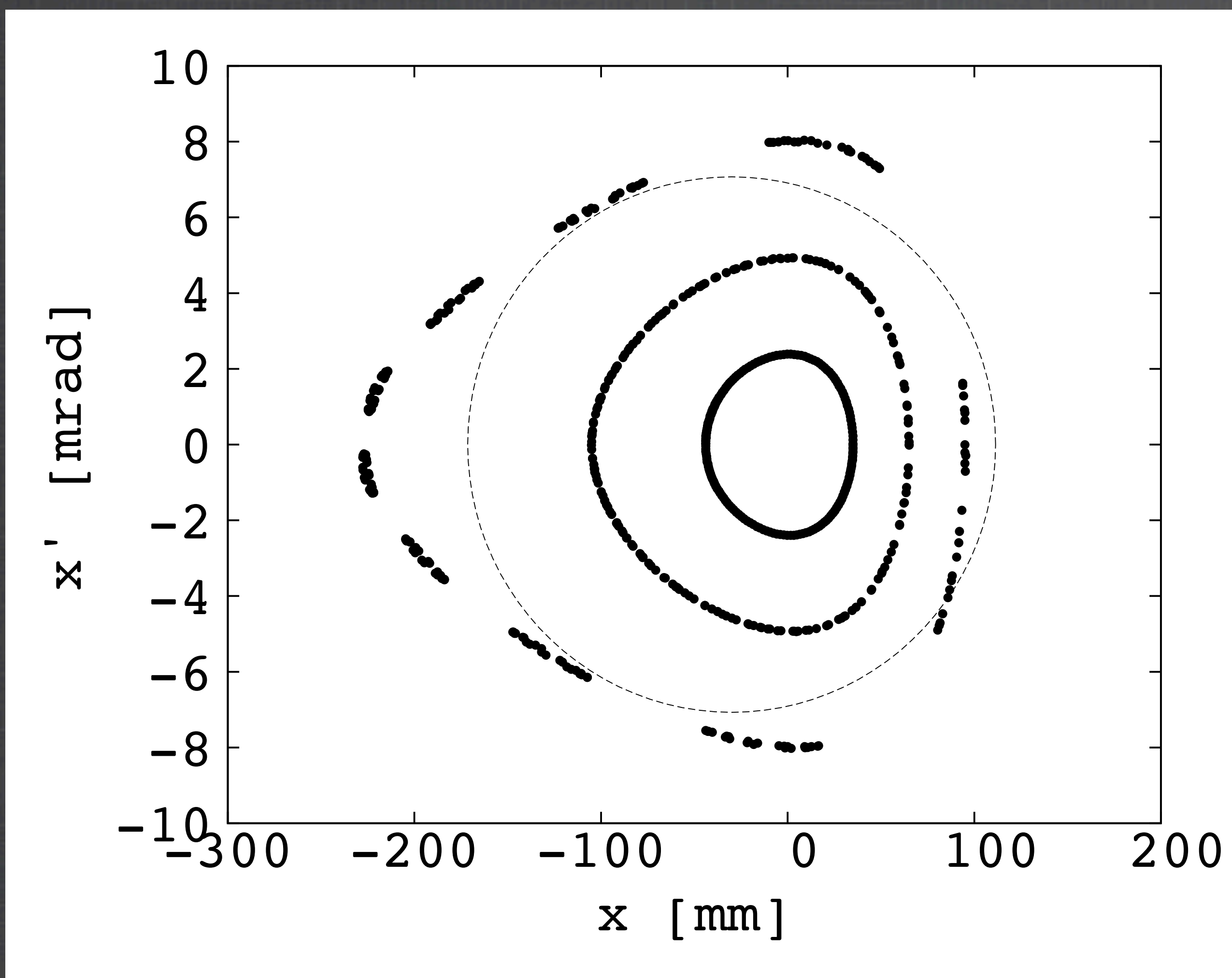
OPTION #1

Dispersion function at matching momentum

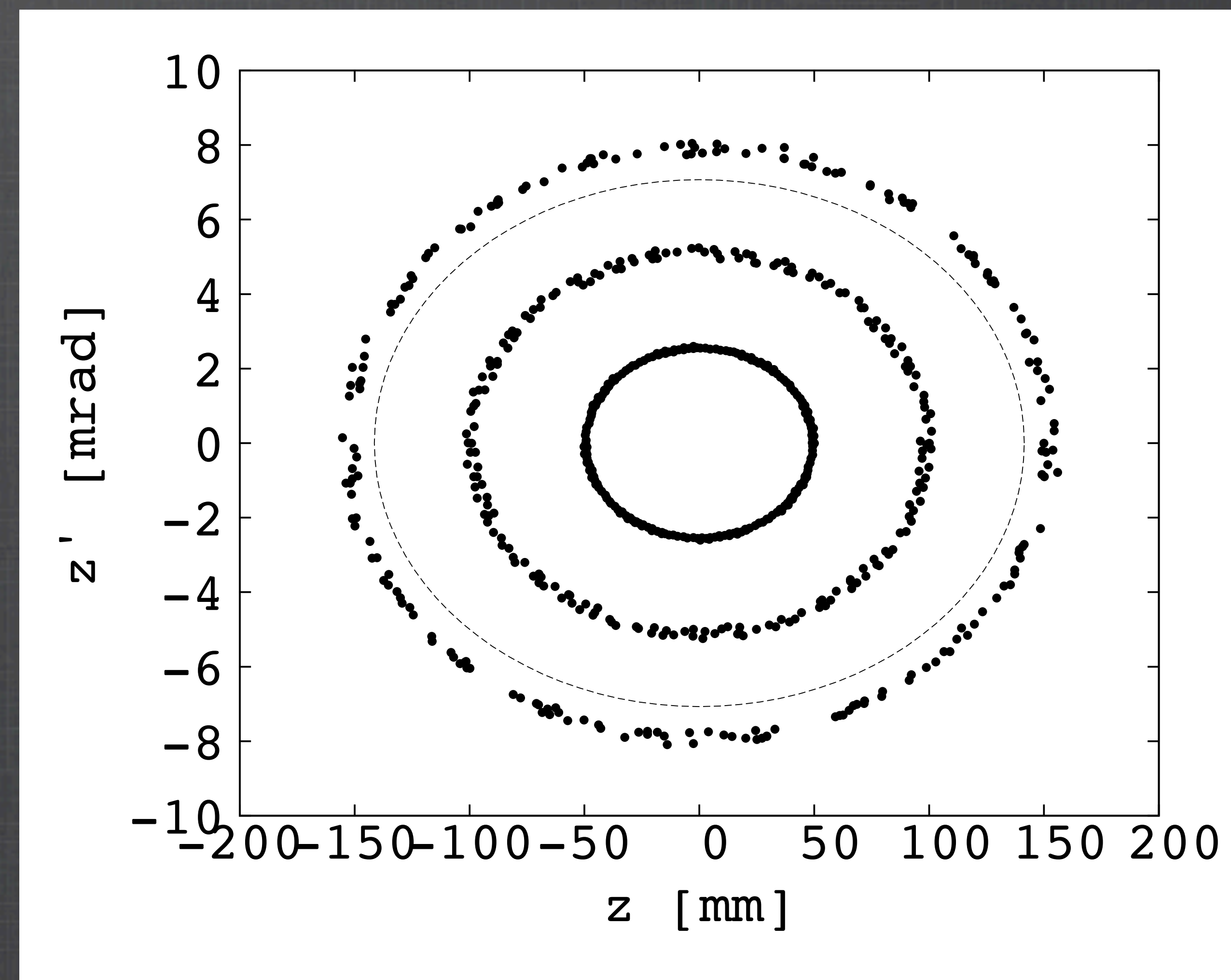


OPTION #1

Transverse acceptance



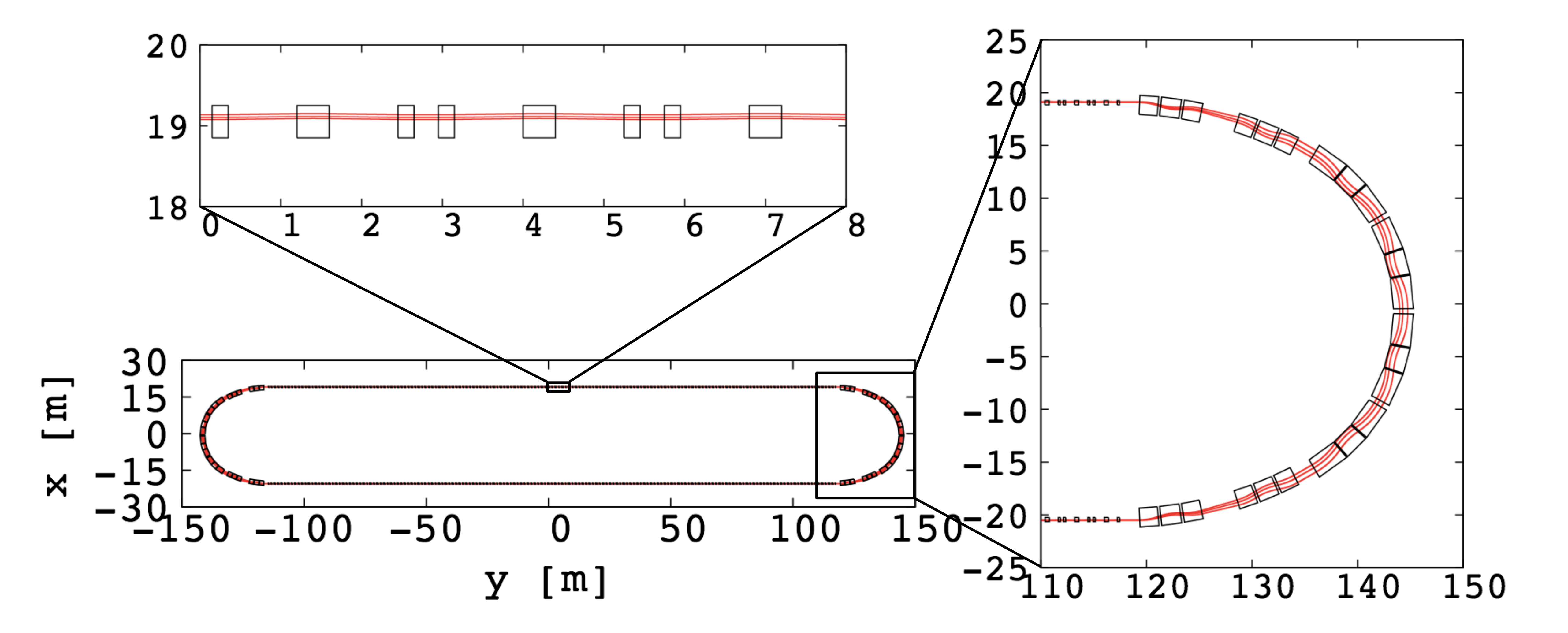
Maximum horizontal stable amplitude over 100 turns



Maximum vertical stable amplitude over 100 turns

OPTION #2: "LONG"

Straight: **230 m**, maximum scallop angle: **12.5 mrad**



Long straight length for a greater number of decayed pions.

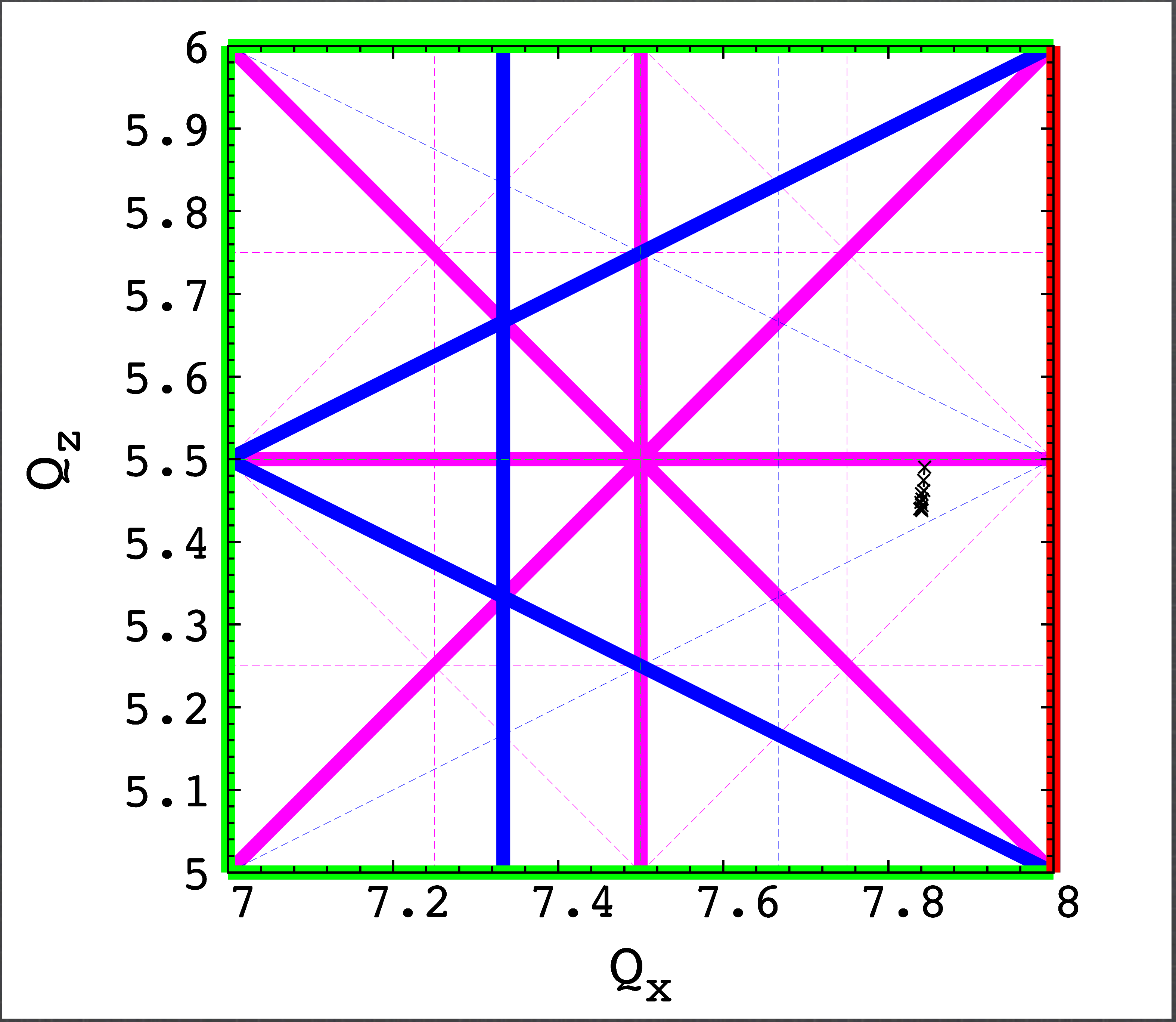
OPTION #2: "LONG"

Cell parameters

	Circular Section	Matching Section	Straight Section
Type	FDF	FDF	DFD
Cell radius/length [m]	17.3	36.1	2.8
Opening angle [deg]	30	15	
k-value/m-value	6.19	26.72	$5\ \mathrm{m}^{-1}$
Packing factor	0.92	0.58	0.29
Horizontal phase advance /cell [deg]	90.0	90.0	8.3
Vertical phase advance /cell [deg]	22.6	25.5	9.5
Average dispersion /cell [m]	2.4	1.3	0.2
Number of cells /ring	4×2	4×2	83×2

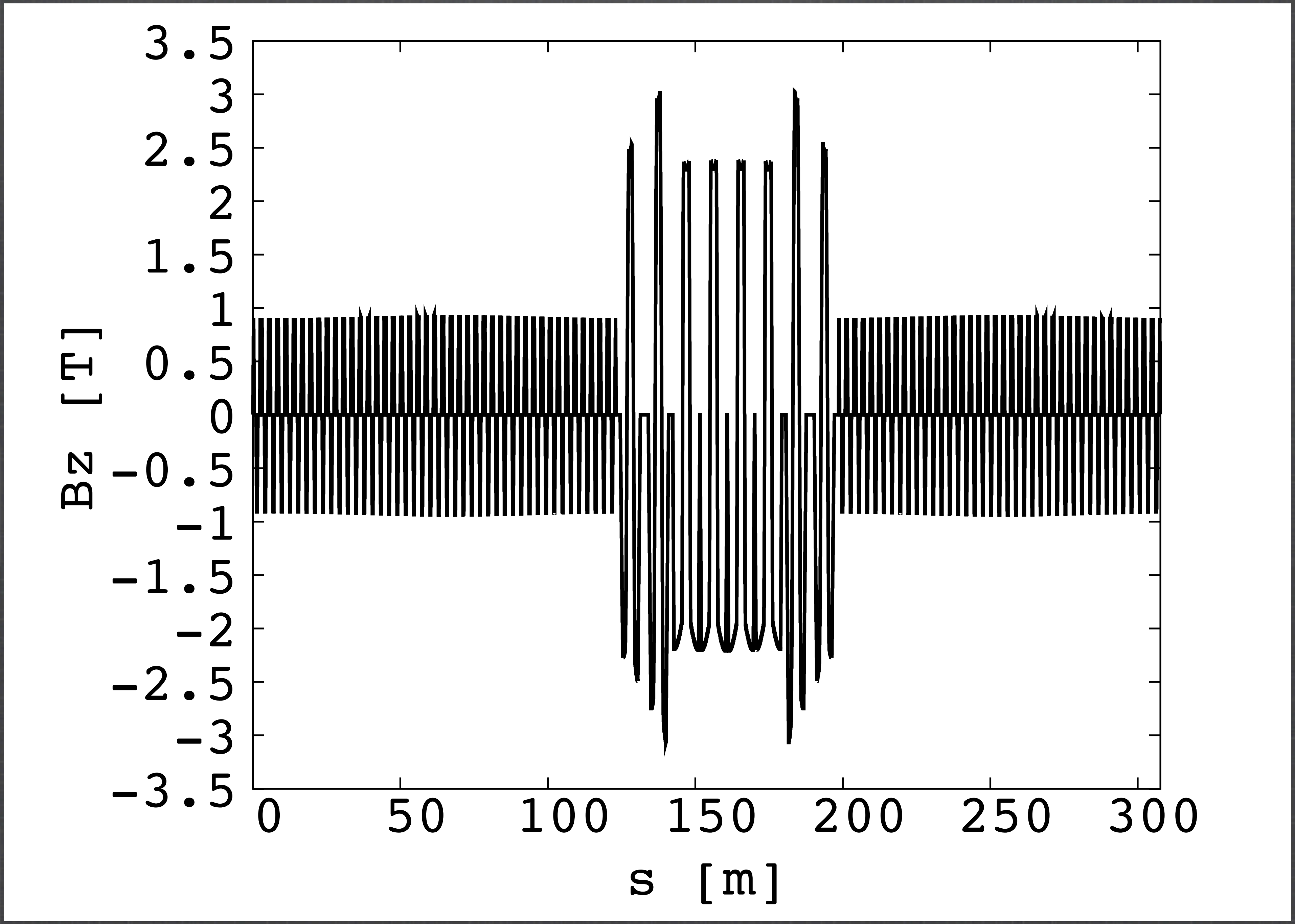
OPTION #2

Tune diagram $\frac{\Delta P}{P} = \pm 16\%$



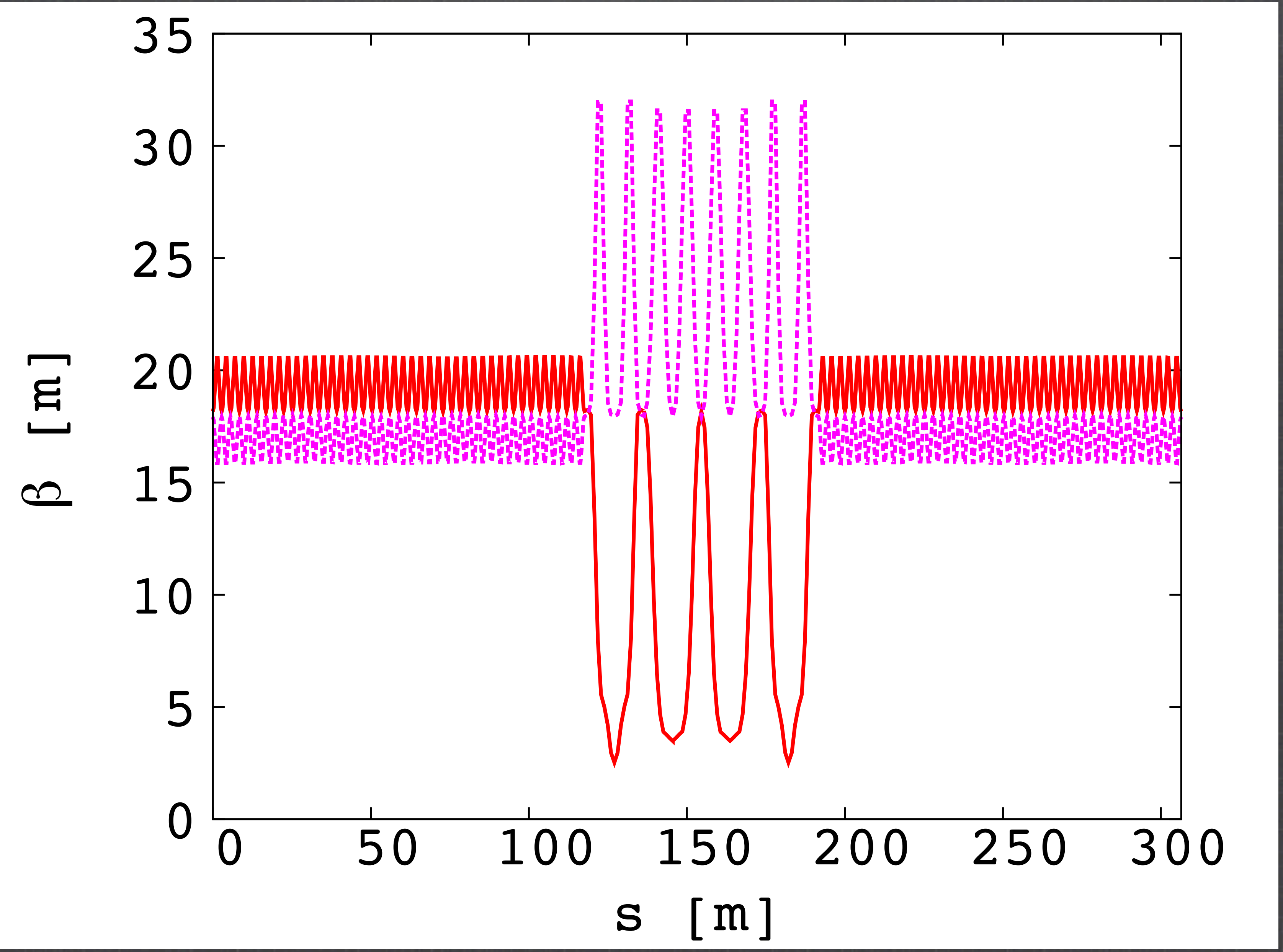
OPTION #2

Magnetic field for P_{max} (+16%)



OPTION #2

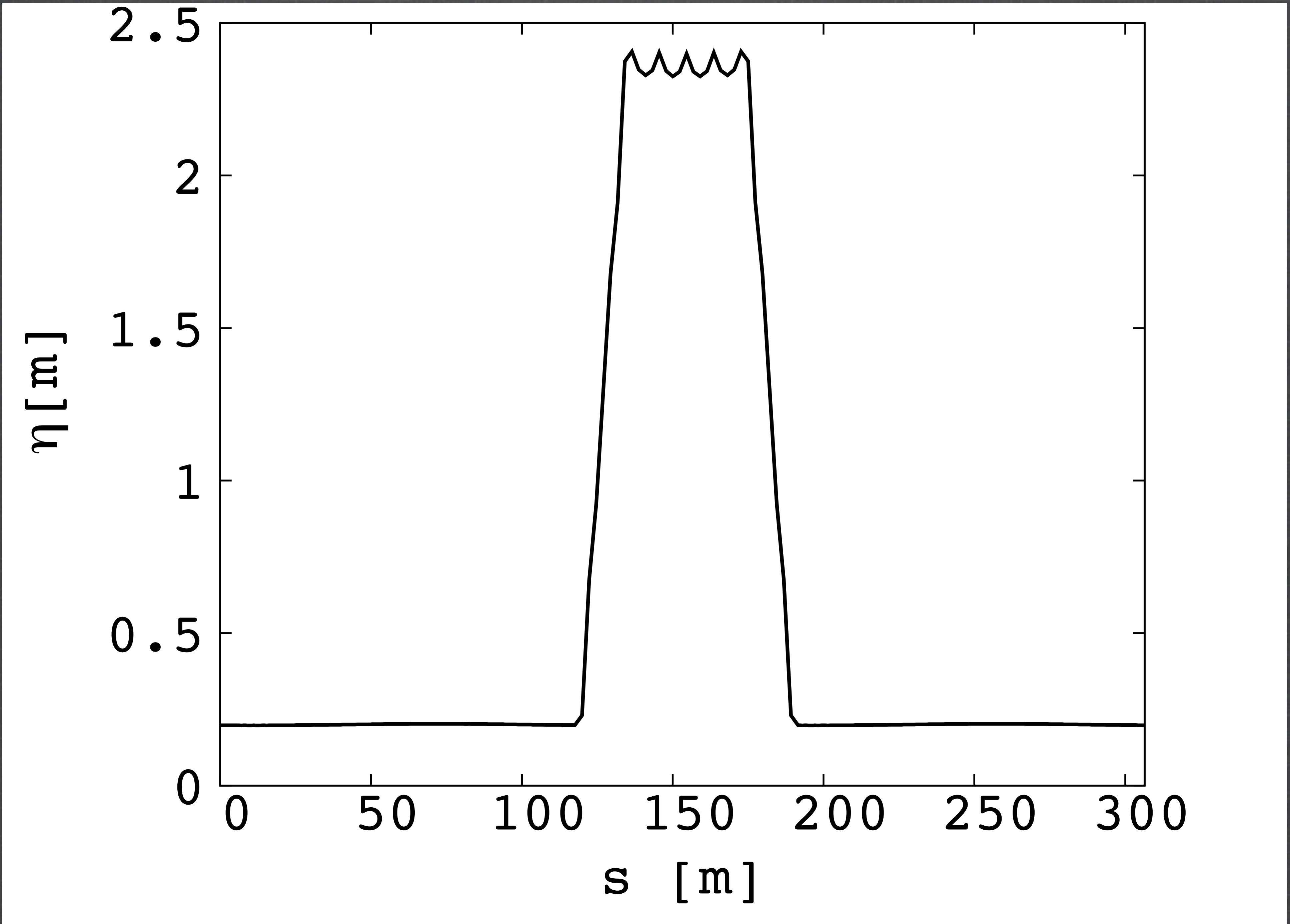
Beta-functions at matching momentum



Horizontal (plain red) and vertical (dotted purple) betafunctions for half of the ring.

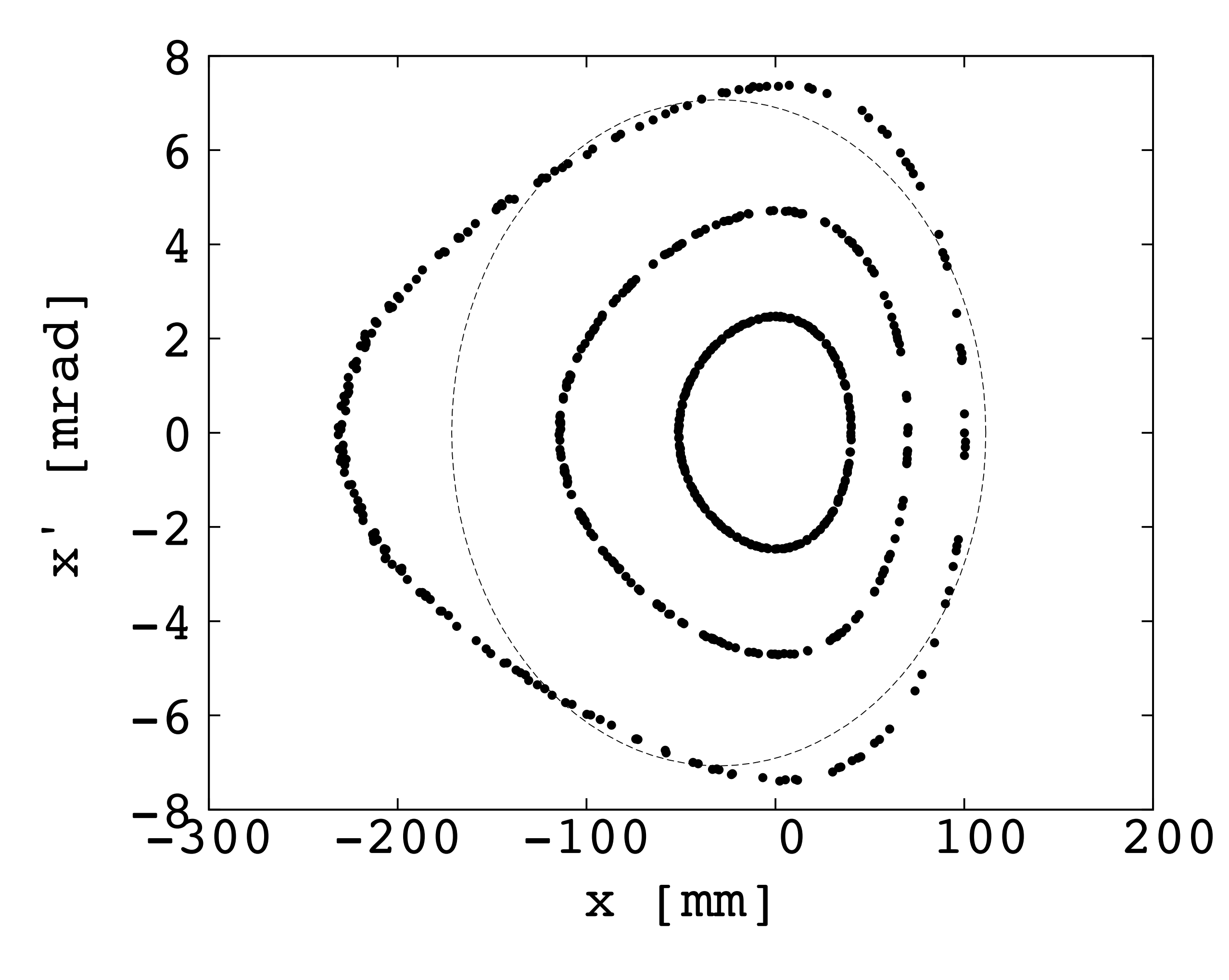
OPTION #2

Dispersion function at matching momentum

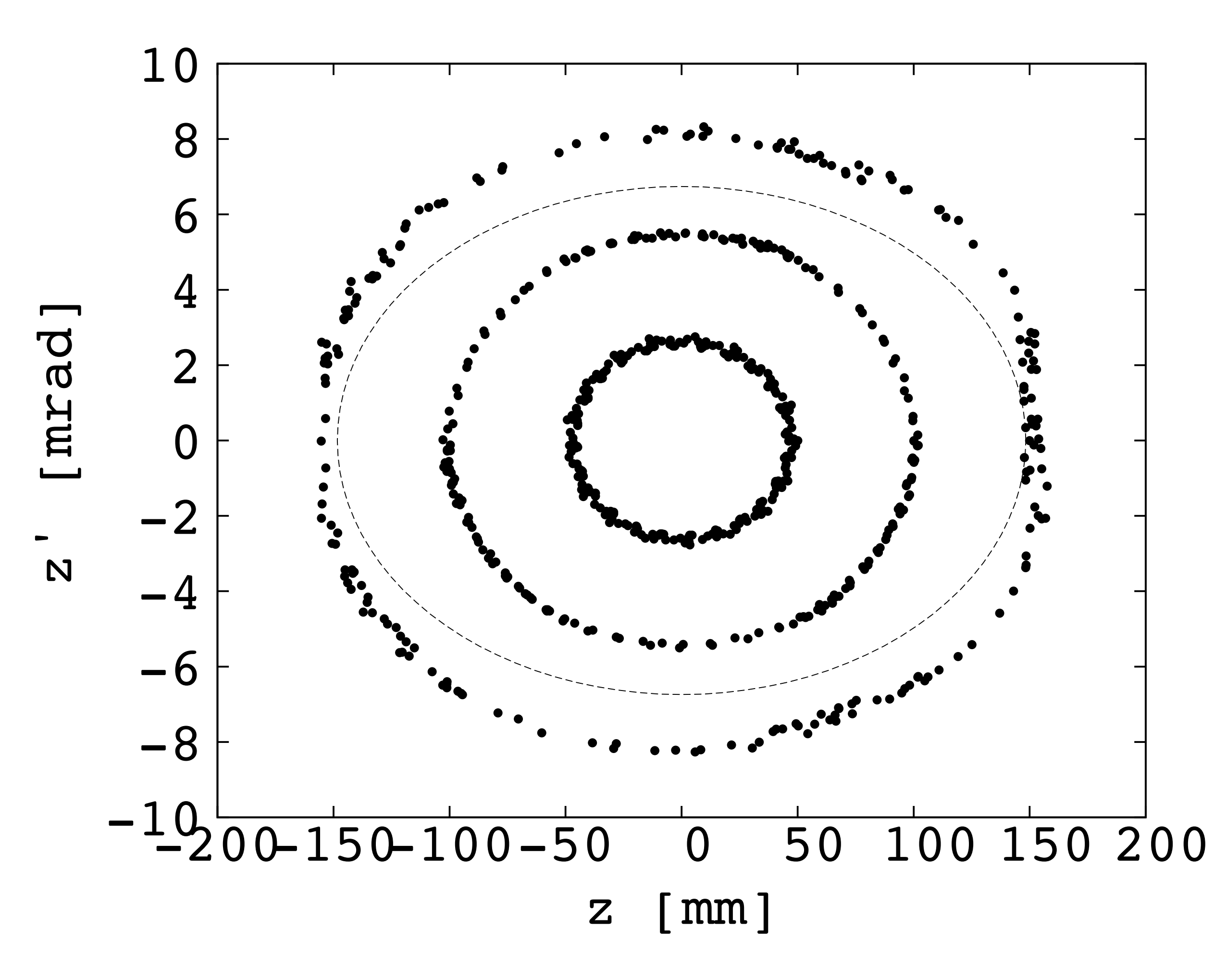


OPTION #2

Transverse acceptance



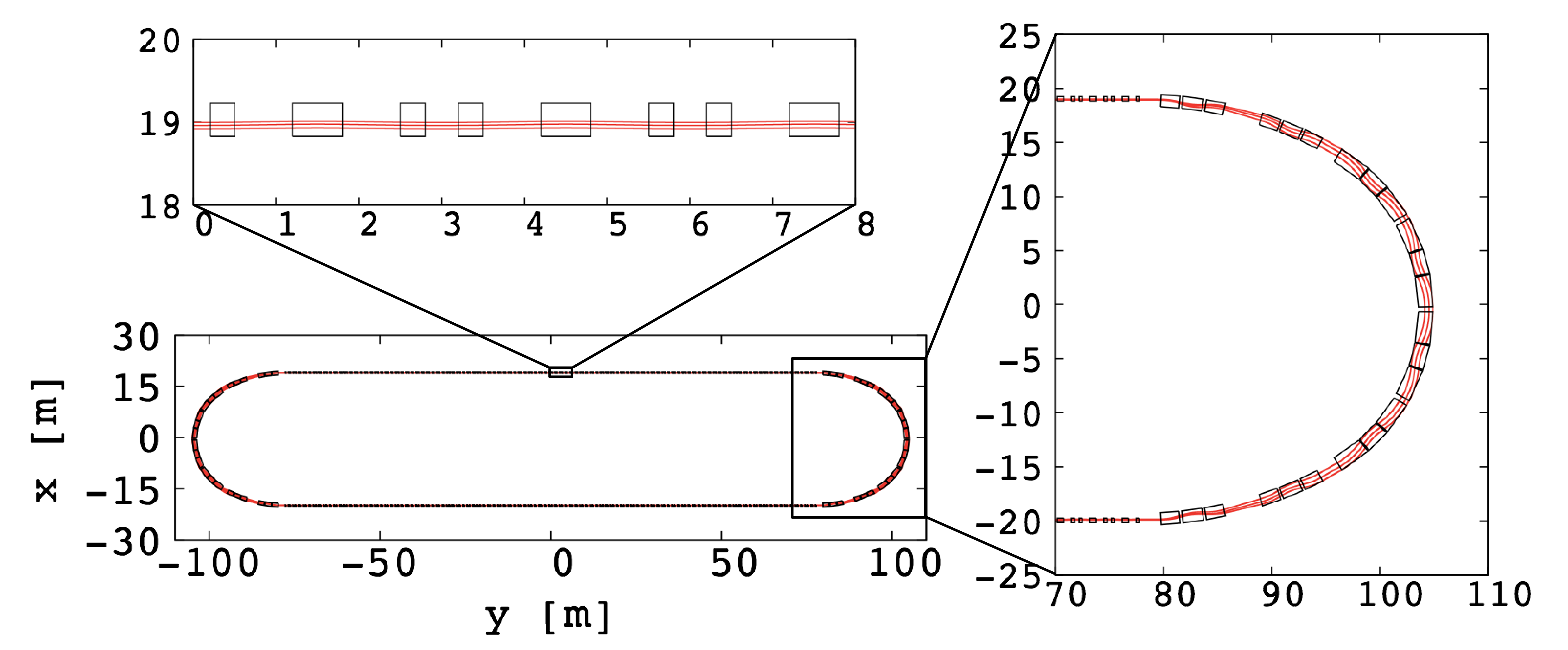
Maximum horizontal stable amplitude over 100 turns



Maximum vertical stable amplitude over 100 turns

OPTION #3: "LOW-COST"

Straight: **156 m,** maximum scallop angle: **13.9 mrad**



Short straight length for a cheaper lattice.

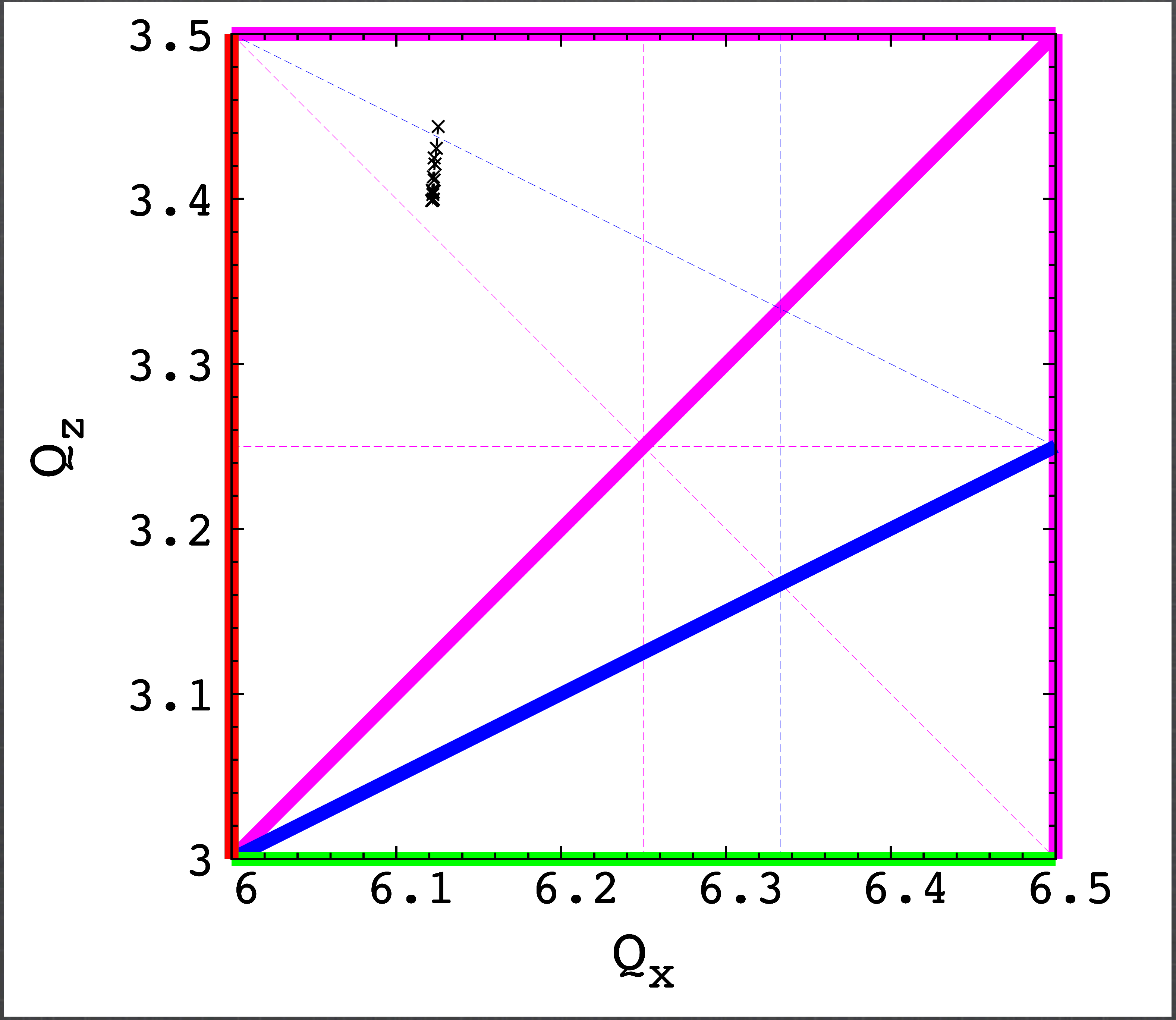
OPTION #3: "LOW-COST"

Cell parameters

	Circular Section	Matching Section	Straight Section
Type	FDF	FDF	DFD
Cell radius/length [m]	17	36.15	3
Opening angle [deg]	30	15	
k-value/m-value	6.21	26.83	$4\ m^{-1}$
Packing factor	0.92	0.58	0.4
Horizontal phase advance /cell [deg]	90.0	90.0	7.3
Vertical phase advance /cell [deg]	19.1	21.9	8.6
Average dispersion /cell [m]	2.4	1.3	0.25
Number of cells /ring	4×2	4×2	52×2

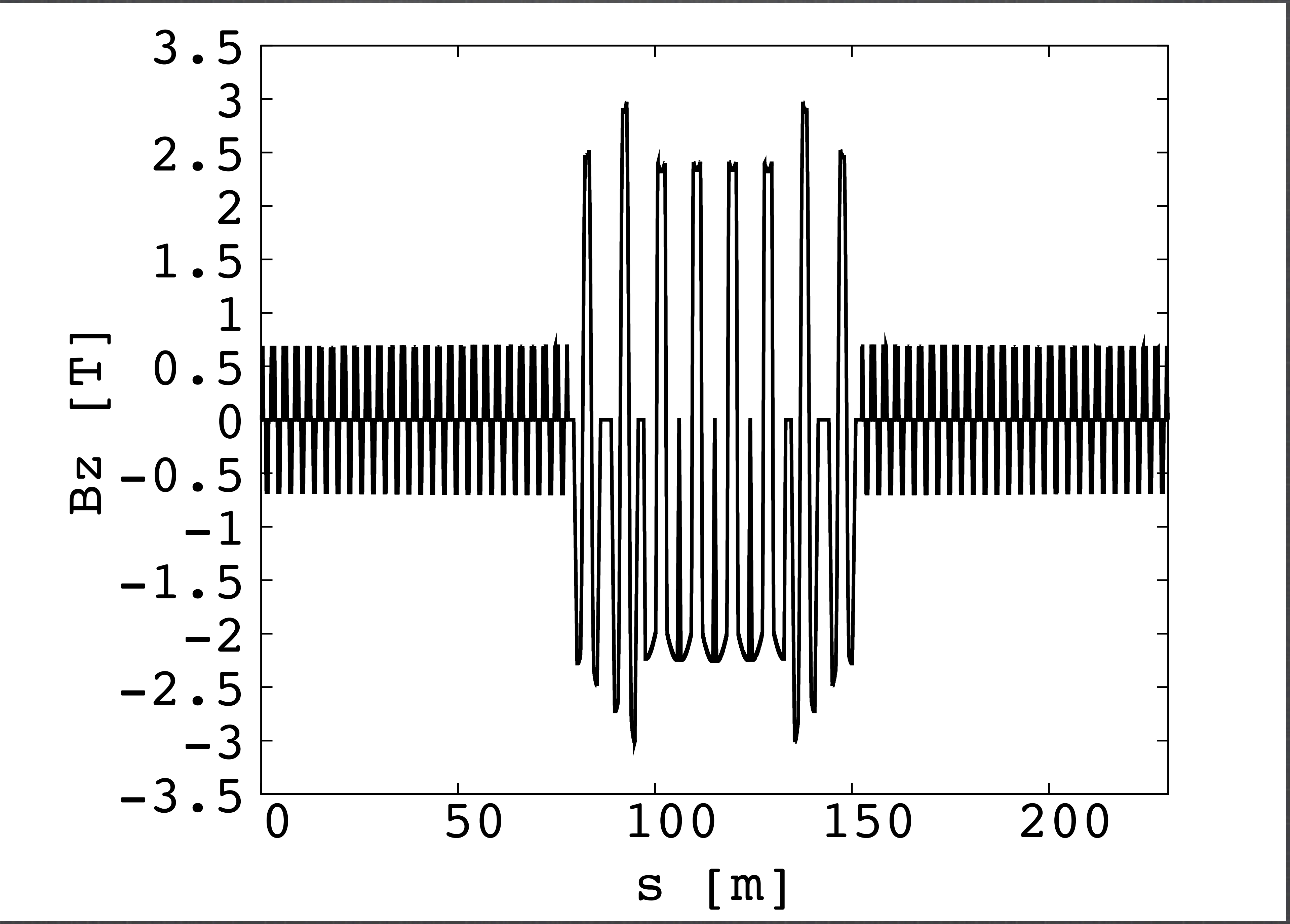
OPTION #3

Tune diagram $\frac{\Delta P}{P} = \pm 16\%$



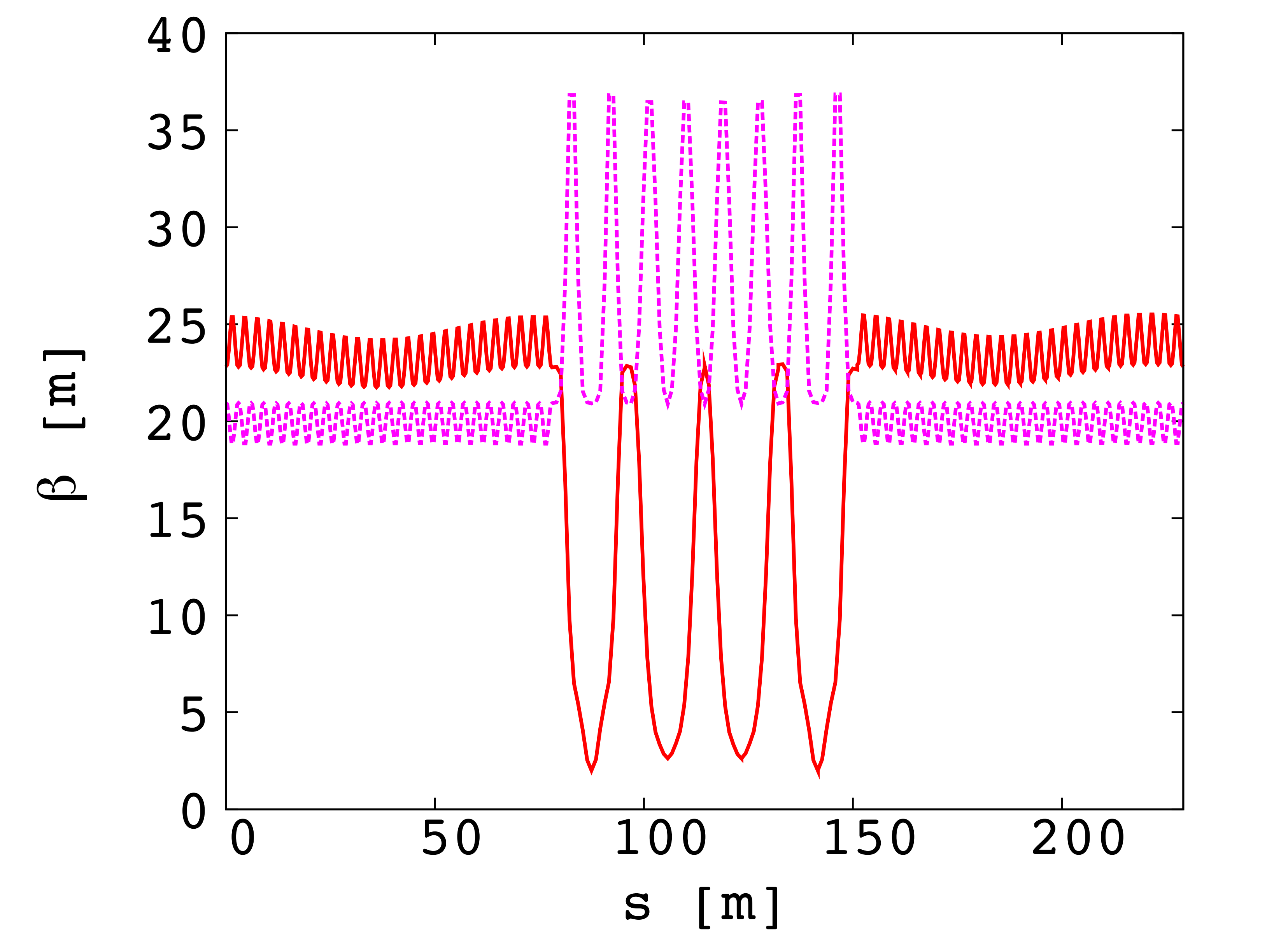
OPTION #3

Magnetic field for P_{max} (+16%)



OPTION #3

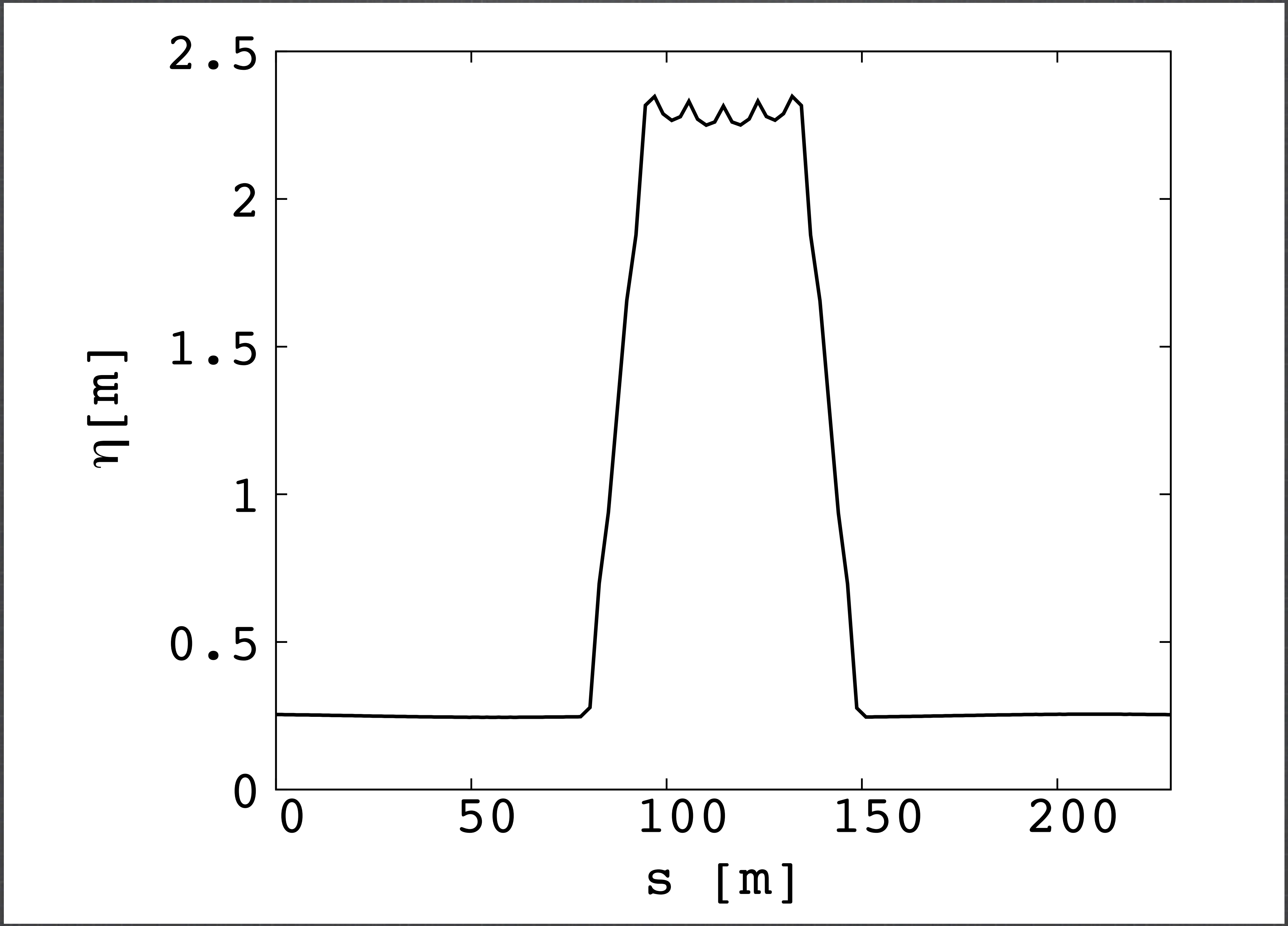
Beta-functions at matching momentum



Horizontal (plain red) and vertical (dotted purple) betafunctions for half of the ring.

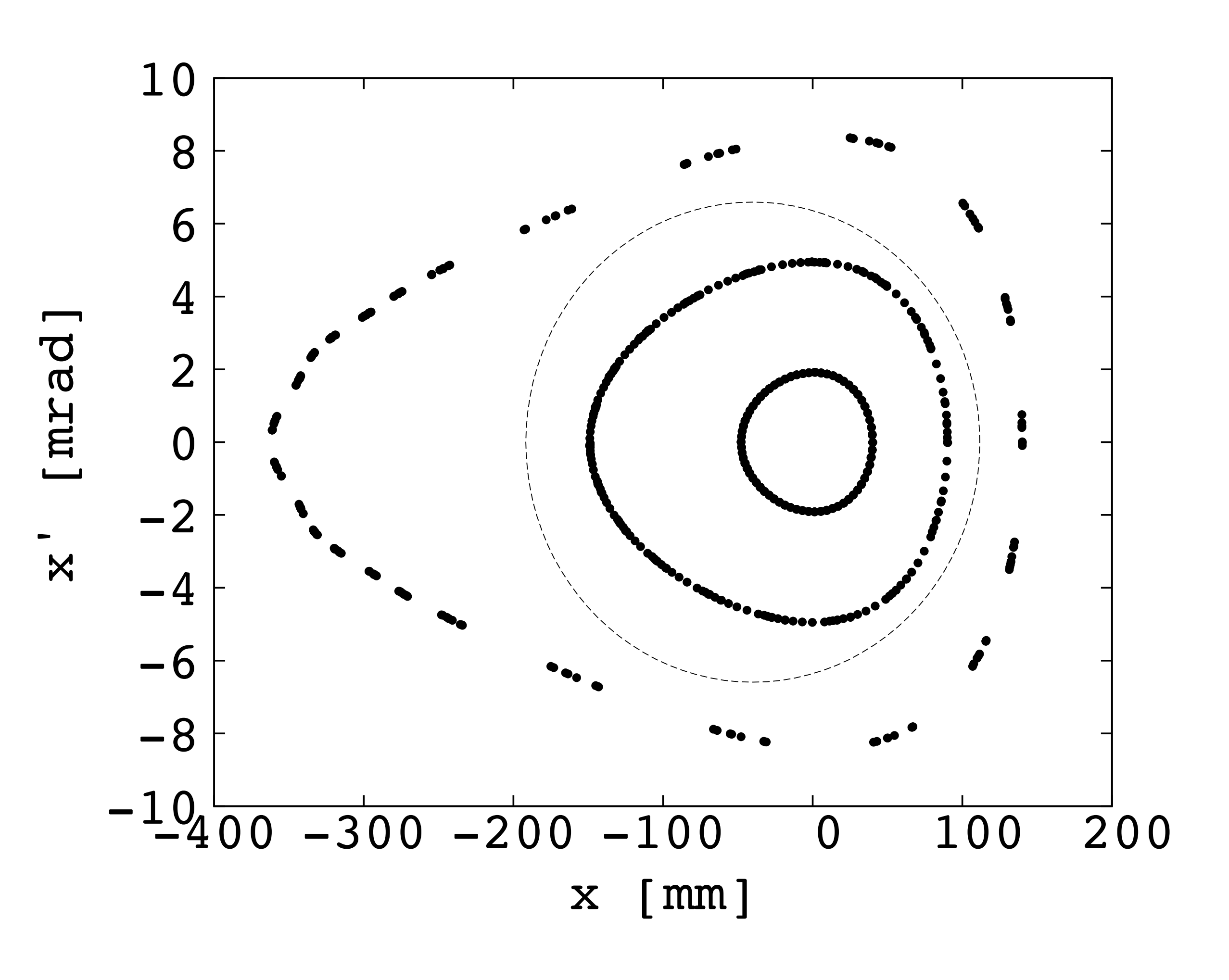
OPTION #3

Dispersion function at matching momentum

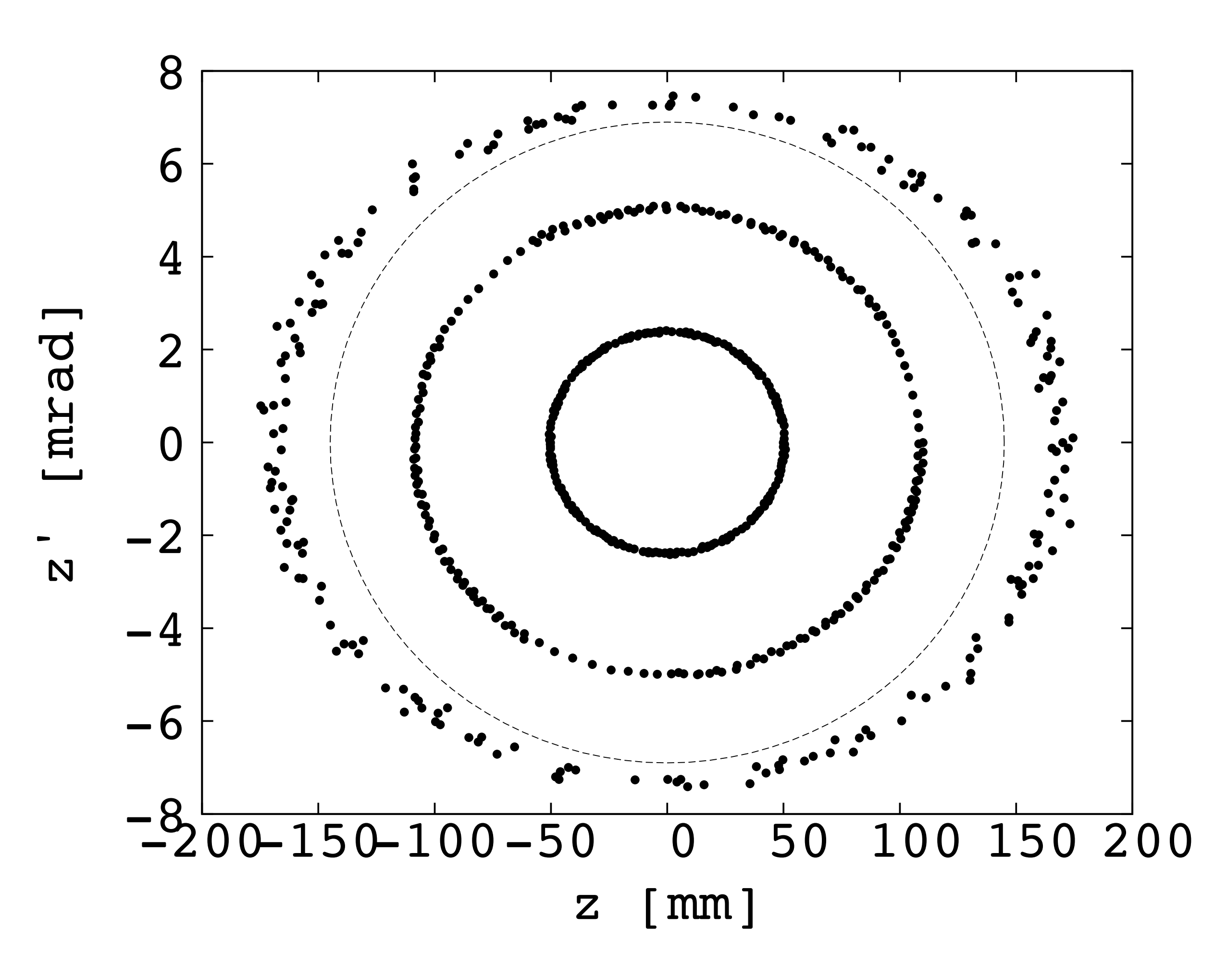


OPTION #3

Transverse acceptance



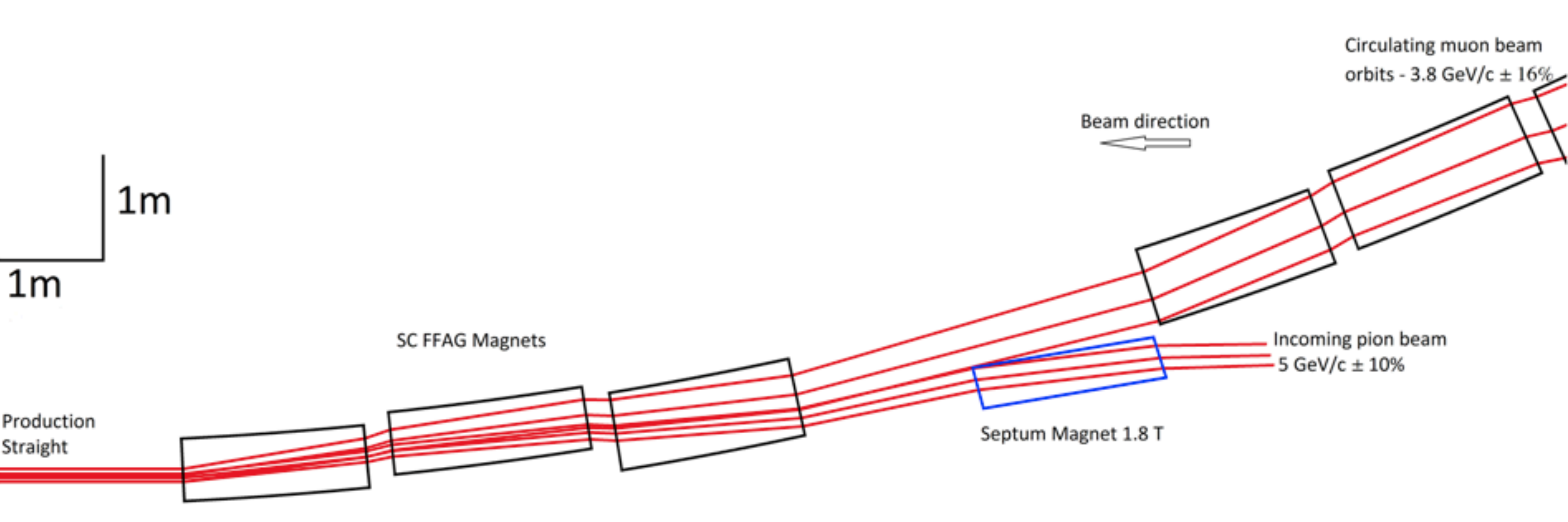
Maximum horizontal stable amplitude over 100 turns



Maximum vertical stable amplitude over 100 turns

Stochastic Injection

Preliminary results



Stochastic injection principle (J. Pasternak)

Outline

- Zero-chromatic FFAG
- Racetrack FFAG muon decay ring
- Comparison

Comparison

Parameters	FODO (Jun. 2013)	RFFAG "FODO-like"	RFFAG "long"	RFFAG "low-cost"
$L_{straight}$ [m]	185	175	230	156
Circumference [m]	480	500	613	460
Dynamical acceptance A_{dyn}	0.6	0.95	0.95	0.95
Momentum acceptance	±10%	±16%	±16%	±16%
π/POT within momentum acceptance	0.094	0.171	0.171	0.171
Fraction of π decay in one straight (F_s)	0.48	0.47	0.56	0.43
Straight-circumference ratio (Ω)	0.39	0.35	0.38	0.34
A_{dyn} x π/POT x F_s x Ω	**0.011**	**0.027**	**0.035**	**0.024**

4T magnet option

4T magnet (PAMELA type) would give several advantages:

- shrink the arc part of about 25 m,
- increase the straight/circumference ratio,
- better dispersion matching ($\eta_{max} < 2$ m),
- smaller excursion.

→

- Cheaper!
- Better performance!

Summary

Summary

- Promising results for racetrack FFAG ring as a muon decay ring for NuSTORM.

Summary

- Promising results for racetrack FFAG ring as a muon decay ring for NuSTORM.
- Quite flexible regarding the circumference.

Summary

- Promising results for racetrack FFAG ring as a muon decay ring for NuSTORM.
- Quite flexible regarding the circumference.
- Large 6D acceptance compared with FODO lattice.

Summary

- Promising results for racetrack FFAG ring as a muon decay ring for NuSTORM.
- Quite flexible regarding the circumference.
- Large 6D acceptance compared with FODO lattice.
- Cost may not be higher than FODO solution.

Summary

- Promising results for racetrack FFAG ring as a muon decay ring for NuSTORM.
- Quite flexible regarding the circumference.
- Large 6D acceptance compared with FODO lattice.
- Cost may not be higher than FODO solution.
- Larger momentum acceptance (±25% achieved previously) for wider magnets.

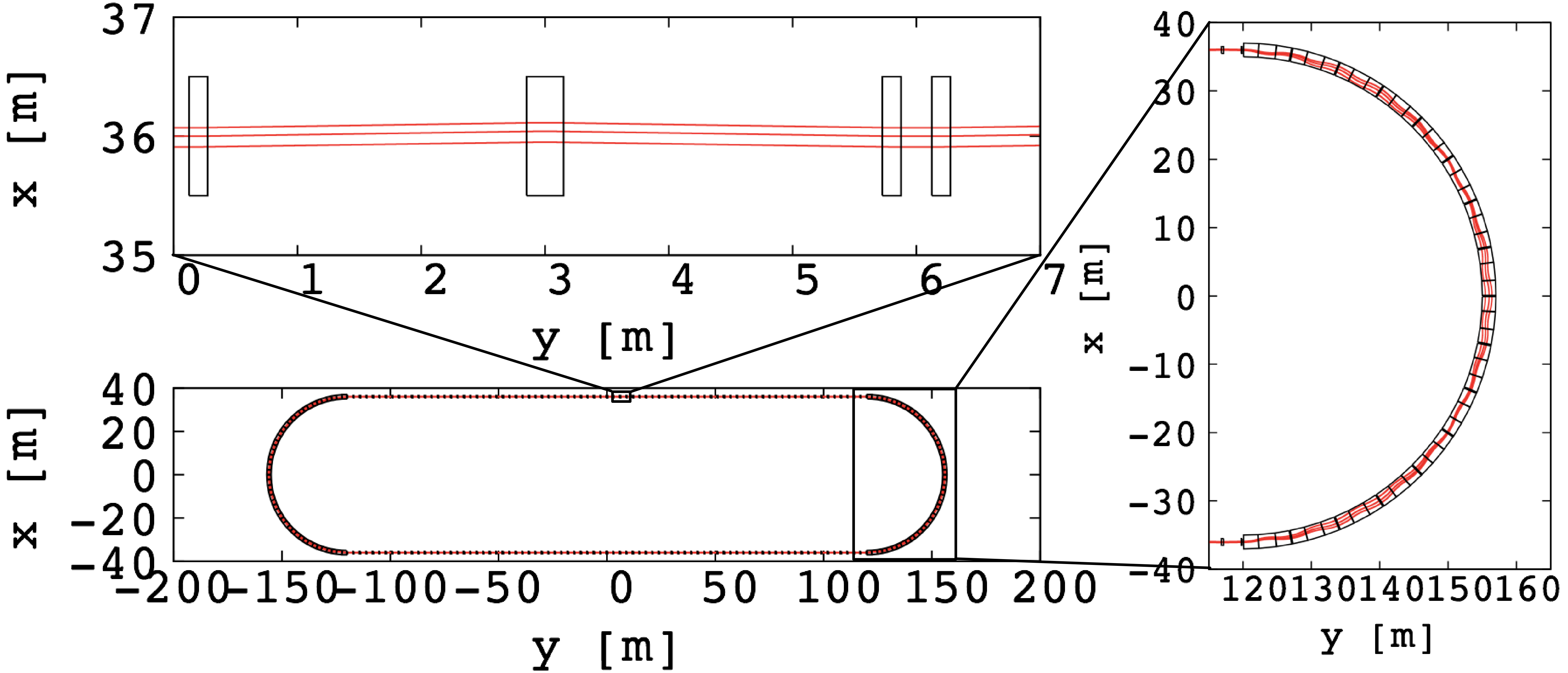
Thank you for your attention

Back-up slides

Normal conducting arcs

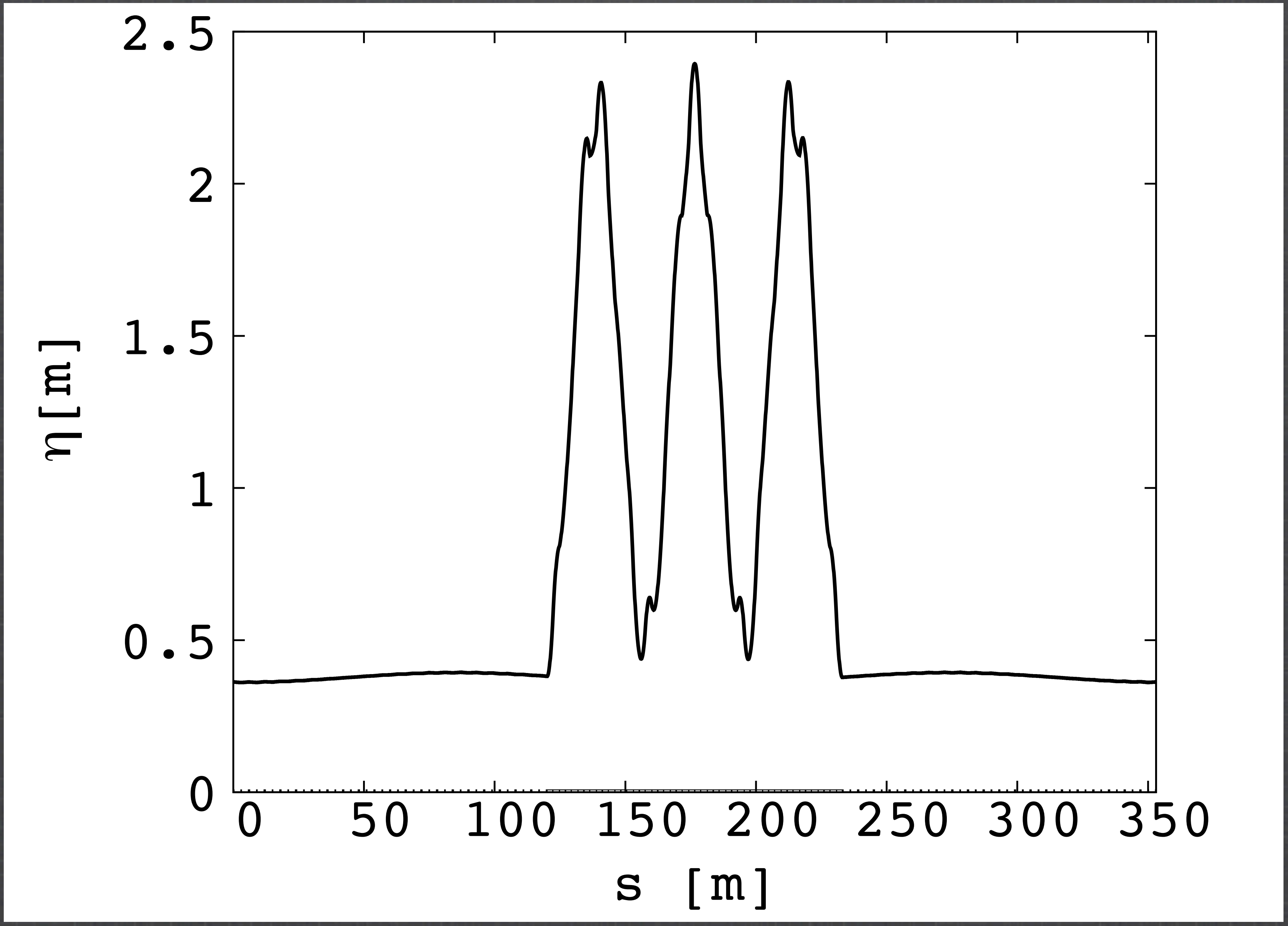
	Circular Section	Straight Section
Type	FDF	DFD
Cell radius [m]/opening angle [deg] or Length [m]	36/11.25	6
k-value or m-value	24.95	2.65 m^{-1}
Packing factor	0.96	0.10
Horizontal phase advance /cell [deg]	67.5	13.1
Vertical phase advance /cell [deg]	11.25	16.7
Average dispersion /cell [m]	1.39	0.38
Number of cells /ring	16×2	40×2

Normal conducting arcs



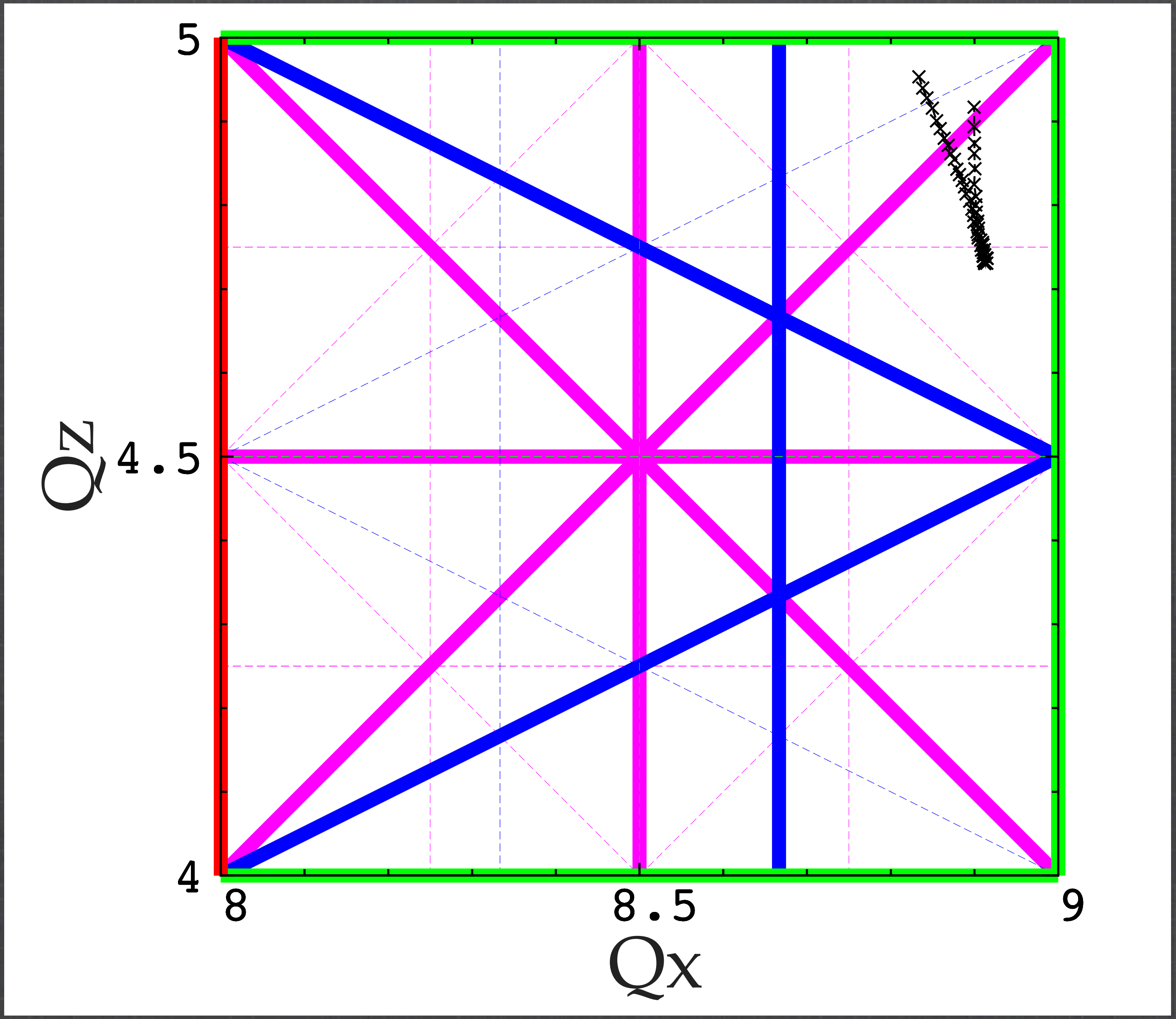
Normal conducting arcs

Dispersion function



Normal conducting arcs

Tune diagram $\frac{\Delta P}{P} = \pm 26\%$

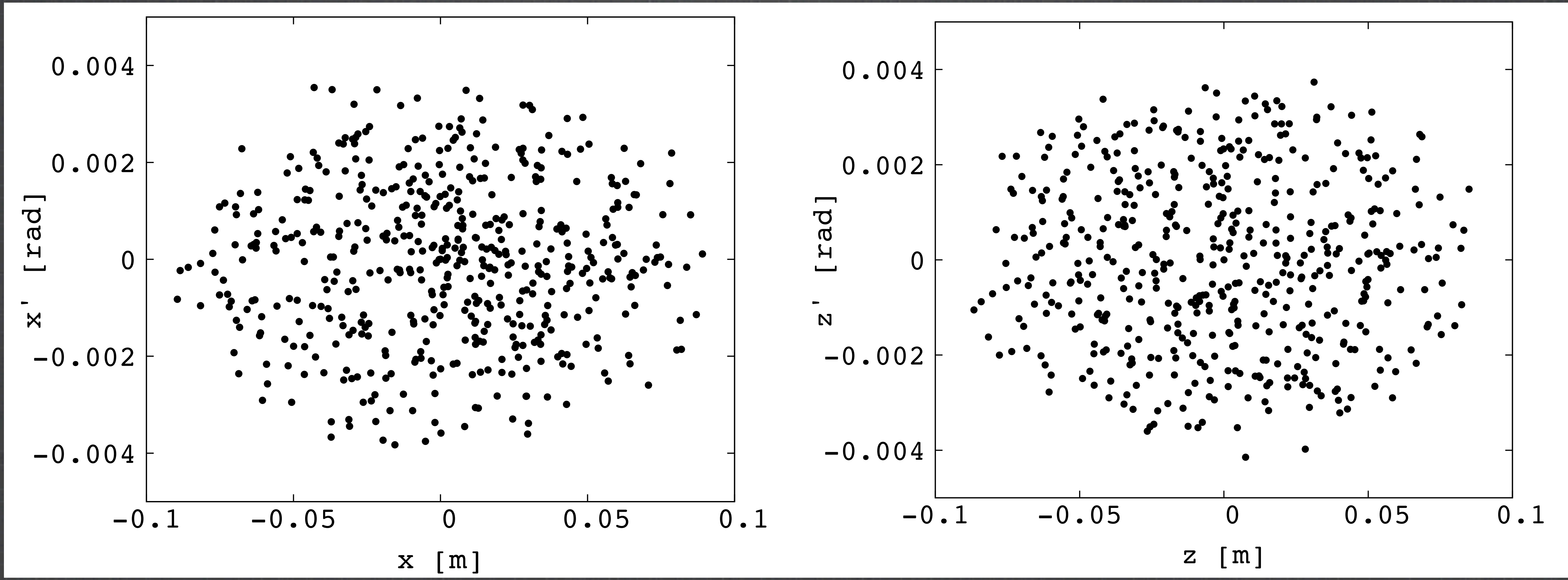


Normal conducting arcs

Multi-particle tracking **without dispersion matching.**

500 particles with a Waterbag distribution. Unnormalized emittances are 400 π $mm.mrad$ in transverse planes.

Momentum uniformly distributed around 3.8 GeV/c ±16%.



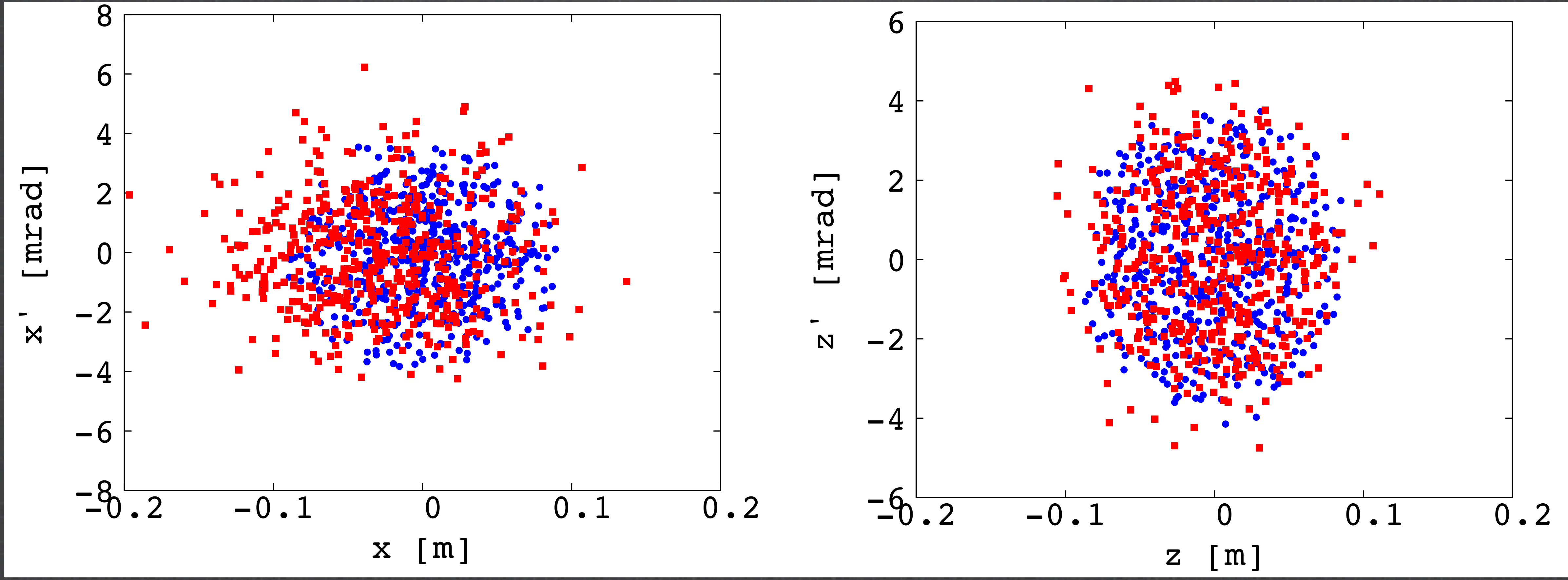
Injected Beam in the horizontal (left) and vertical (right) phase spaces

Normal conducting arcs

Multi-particle tracking **<u>without dispersion matching.</u>**

After 60 turns → no particle lost.

(no muon decay implemented in the simulation).



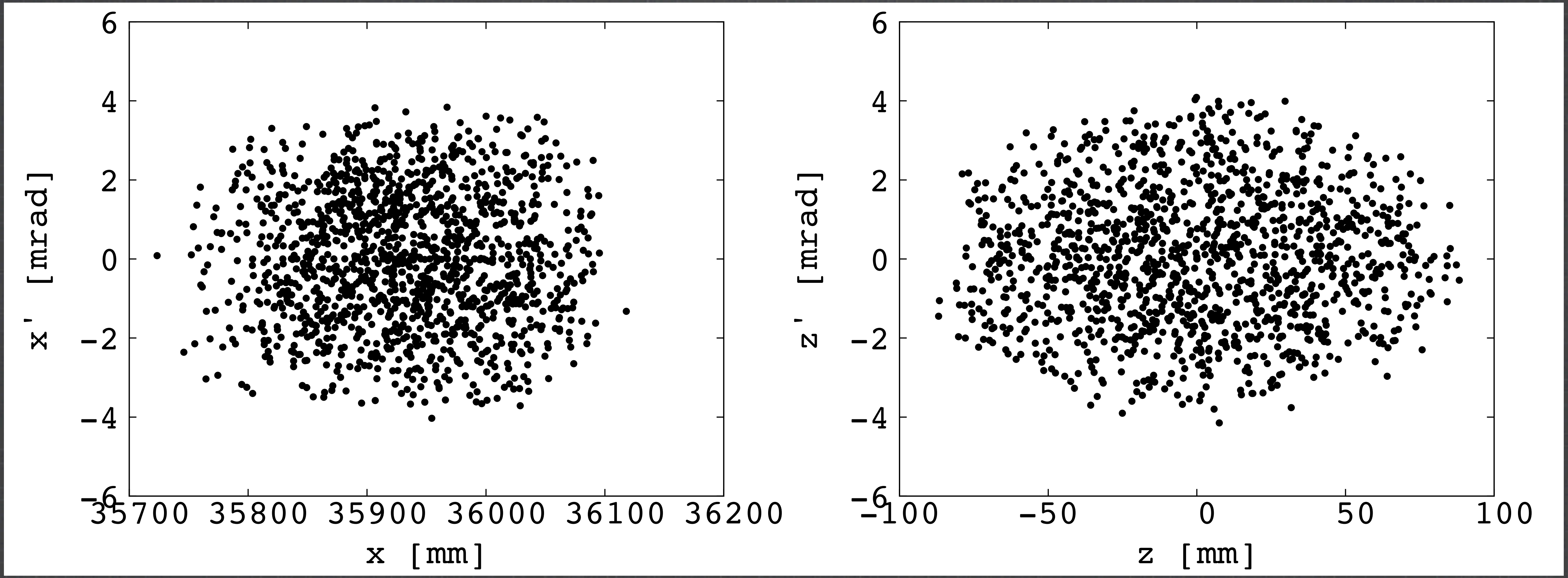
Results in the horizontal (left) and vertical (right) phase spaces

■ extraction
● injection

Normal conducting arcs

Multi-particle tracking **with dispersion matching.**

1350 particles with a Waterbag distribution. Unnormalized emittances are $400\ \pi\ mm.mrad$ in transverse planes. Momentum uniformly distributed around 3.8 GeV/c **±26%**.



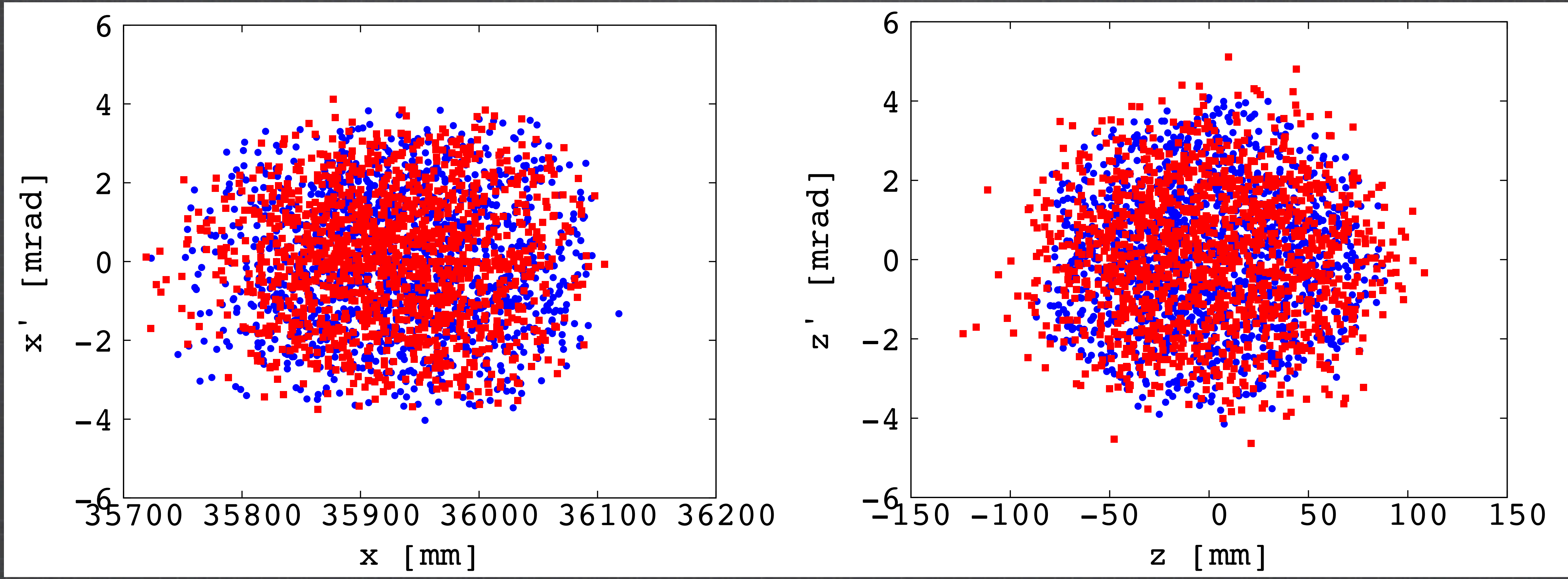
Injected Beam in the horizontal (left) and vertical (right) phase spaces

Normal conducting arcs

Multi-particle tracking **with dispersion matching.**

After 60 turns → 10 particles (0.7%) lost

(no muon decay implemented in the simulation).



Results in the horizontal (left) and vertical (right) phase spaces

■ extraction
● injection