Towards the low emittance upgrade for the CANDLE storage ring

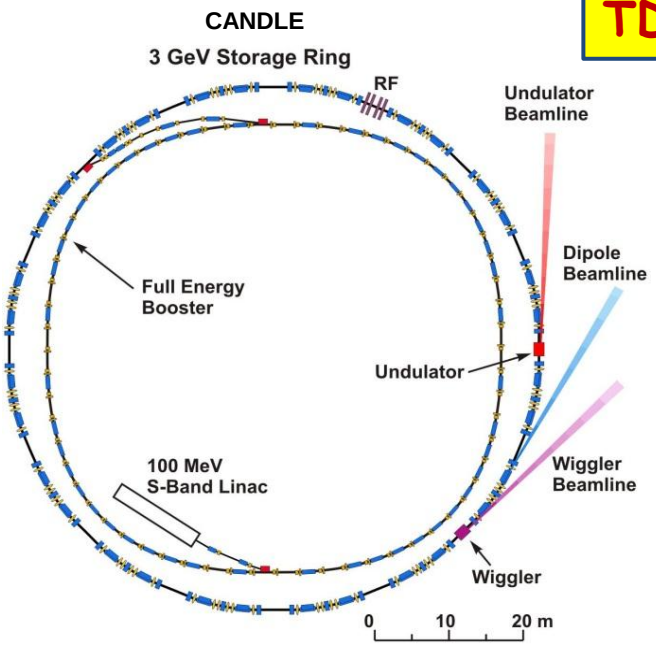
A. Sargsyan

Outline

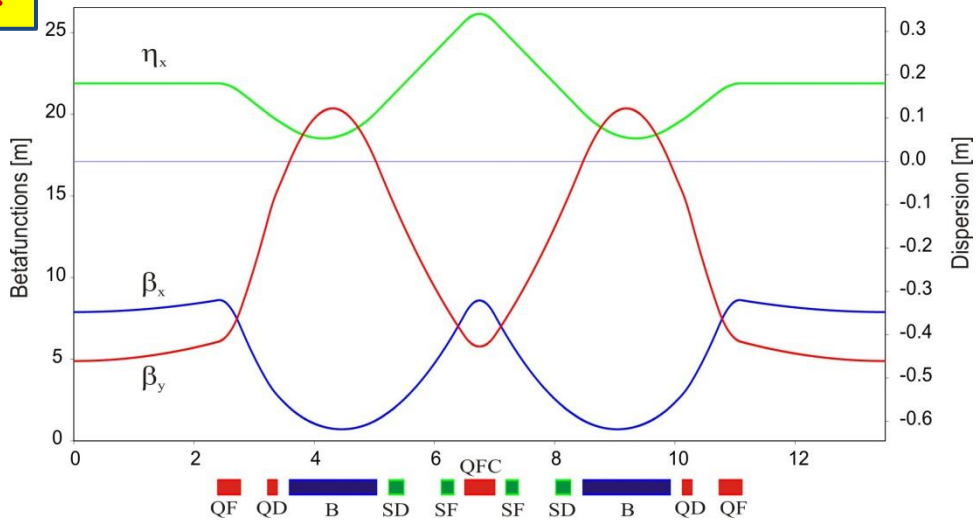
- Introduction
- Scenarios for low emittance upgrade
  - DBA lattice option
  - 4BA lattice option
- Possibility of low alpha operation
  - modification of original beam optics
  - implementation of inverse bend magnets
- Next Steps

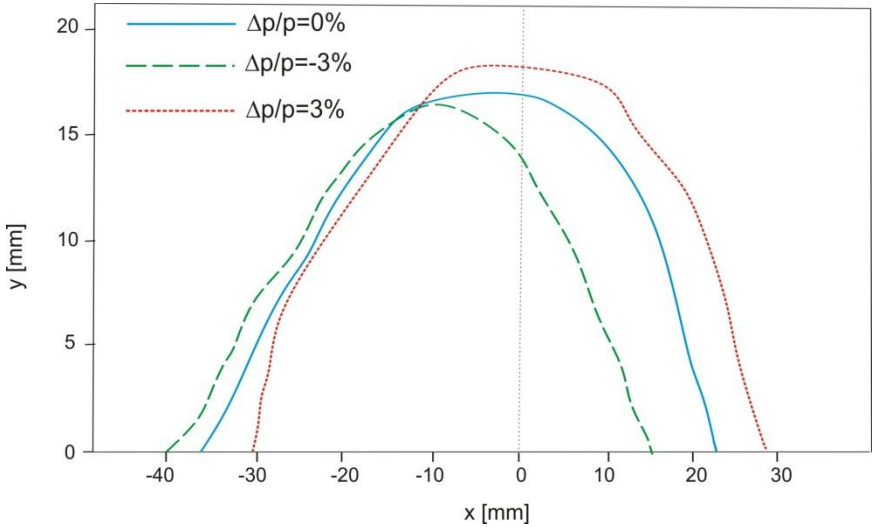
Introduction

TDR in 2002



Original DBA cell





On and off momentum DA

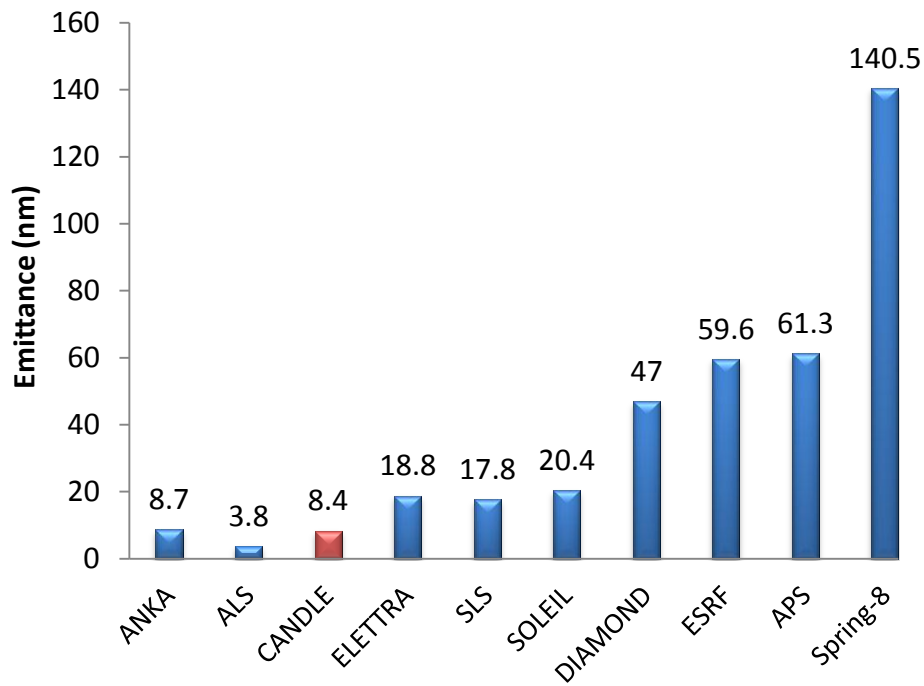
Parameter	Value
Circumference (m)	216
Number of DBA cells	16
Straight section length (m)	4.8
Current (mA)	350
Beam Energy (GeV)	3
Hor. emittance (nm rad)	8.4
RF momentum acceptance (%)	2.4
Betatron tunes (h/v)	13.22/4.26
Natural chromaticities (h/v)	-18.9/-14.9
Momentum compaction	0.002

Introduction

A non-complete list of storage rings

Name	Lattice type	Emit. (nm)	Energy (GeV)	Circ. (m)
ANKA	DDBA	46	2.5	110
ALS	TBA	2	1.9	197
CANDLE	DBA	8.4	3	216
ELETTRA	DBA	7	2.4	259
SLS	TBA	4.8	2.4	288
SOLEIL	DBA	3.9	2.75	354
DIAMOND	DBA	2.7	3	560
ESRF	DBA	4	6	844
APS	DBA	2.5	7	1104
SPring-8	DBA	3.4	8	1436

Beam emittance in case of 216m circumference and 3 GeV energy



$$\varepsilon[nm\,rad] = 1470\,E[GeV]^2 \frac{I_5}{J_x I_2} \sim \frac{E^2}{N_b^3}$$

$$J_x = 1 - \frac{I_4}{I_2}$$

$$I_2 = \oint_{bend} \frac{1}{\rho^2} ds$$

$$I_4 = \oint_{bend} \frac{\eta_x}{\rho}\left(\frac{1}{\rho^2} + 2k_1\right) ds, \qquad k_1 = \frac{e}{P_0}\frac{\partial B_y}{\partial x}$$

$$I_5 = \oint_{bend} \frac{H_x}{|\rho|^3} ds, \qquad H_x = \gamma_x \eta_x^2 + 2\alpha_x \eta_x \eta_x' + \beta_x \eta_x'^2$$

Introduction

- Implementation of MBA lattice cells ⟶ large number of cells ⟶ profit from the cubic scaling of emittance with angle per bending magnet
- Implementation of LGBs ⟶ Longitudinal field variation to "compensate" H_x variation ⟶ minimize I_5
- Implementation of vertically focusing bending magnets ⟶ maximize J_x
- Implementation of damping wigglers ⟶ strengthen the radiation damping
- etc.

Name	Lattice type	Emit. (pm)	Energy (GeV)	Circ. (m)
ANKA upgrade study	4BA	8600	2.5	110
ALS upgrade study	6-10BA	100	2.0	200
ELETTRA upgrade study	6BA	280	2.0	260
SLS upgrade studies	Hybrid 7BA	135	2.4	288
SIRIUS	5BA	280	3.0	518
MAX-IV	7BA	326	3.0	528
DIAMOND upgrade	4BA	280	3.0	562
ESRF upgrade	Hybrid 7BA	132	6.0	844
APS upgrade	Hybrid 7BA	65	6.0	1104
SPRING 8 upgrade study	6-10BA	68	6.0	1436

Scenarios for low emittance upgrade

Necessity for CANDLE storage ring low emittance upgrade!

Considered approaches

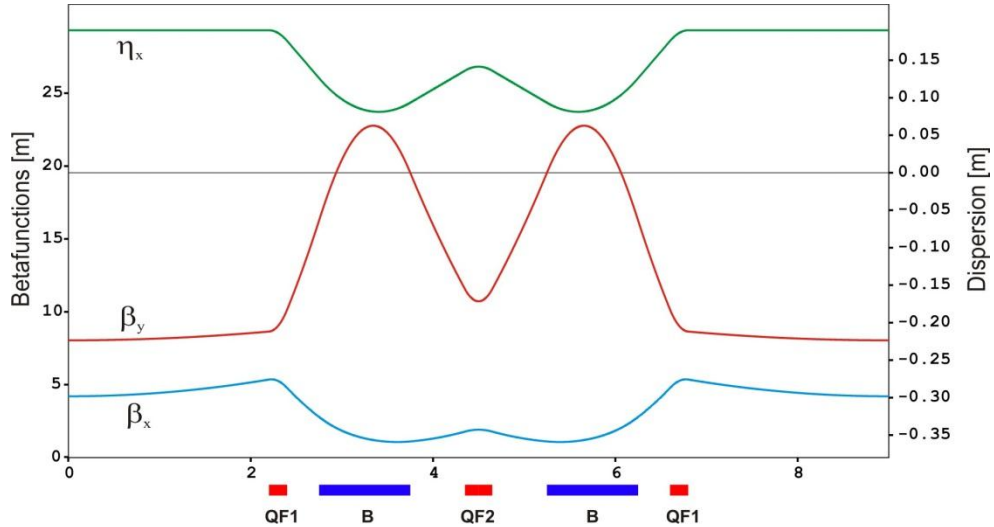
1. use more compact magnets with combined fields and keep the type of cells and the length of the ring circumference unchanged
2. apply MBA concept

Solutions so far

1. Emittance reduction from 8.4nm to 5.2nm
2. 4BA lattice providing 1.1nm beam emittance, however within 258m circumference instead of 216m

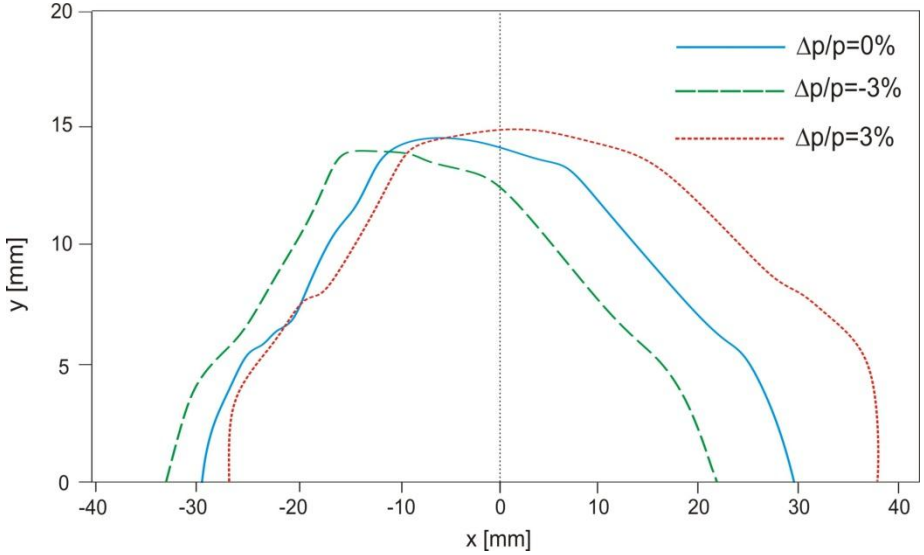
DBA lattice option

Modified DBA cell



Magnets	Dipole	QF1	QF2
Num. of magnets	48	48	24
Length (m)	1	0.2	0.3
Bend. angle (^{0})	7.5	-	-
Quad. component (T/m)	-9	38.2	33.92
Sext. component (T/m^2)	-59.2	76.81	236.55

Compensate chromaticity where it's created → Dipoles and quads contain sextupole component → Limited flexibility

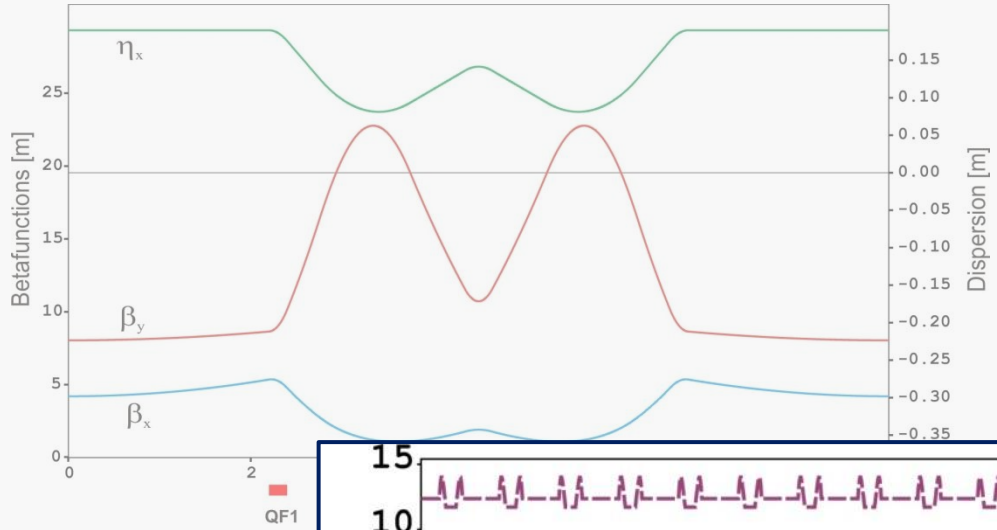


On and off momentum DA

Parameter	Value
Circumference (m)	216
Lattice type	DBA
Number of cells	24
Straight section length (m)	4.4
Beam Energy (GeV)	3
Hor. emittance (nm rad)	5.2
RF momentum acceptance (%)	2.1
Betatron tunes (h/v)	14.17/3.19
Natural chromaticities (h/v)	-13.64/ -24.27
Momentum compaction	0.0027

DBA lattice option

Modified DBA cell



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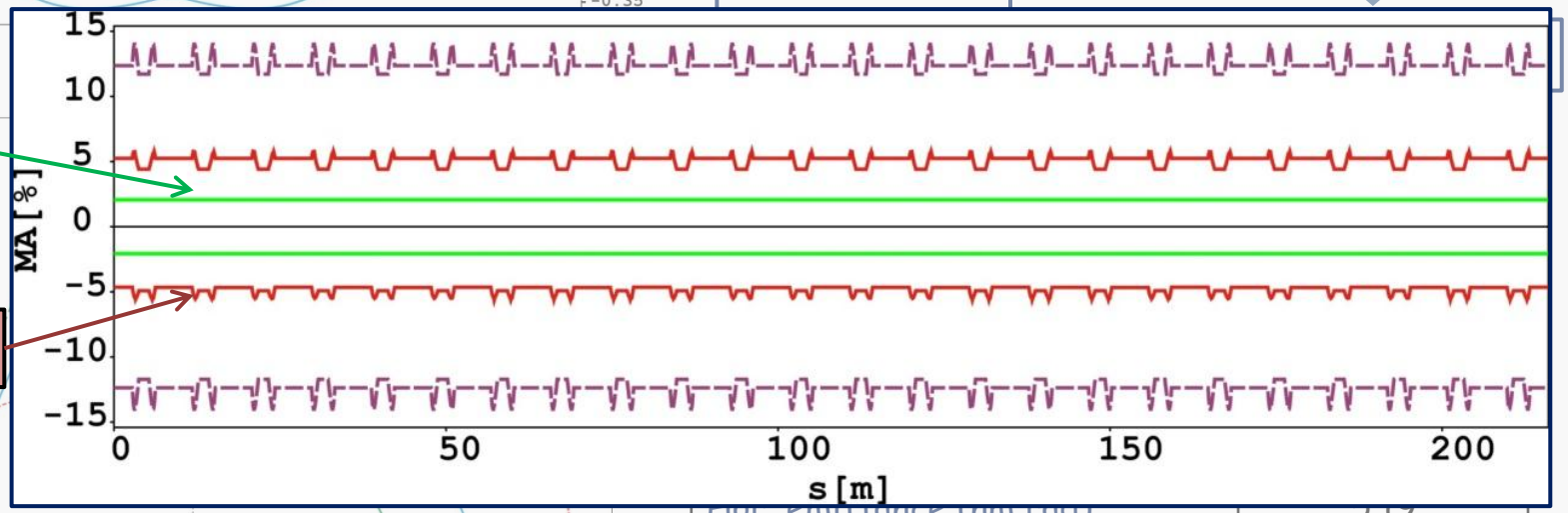
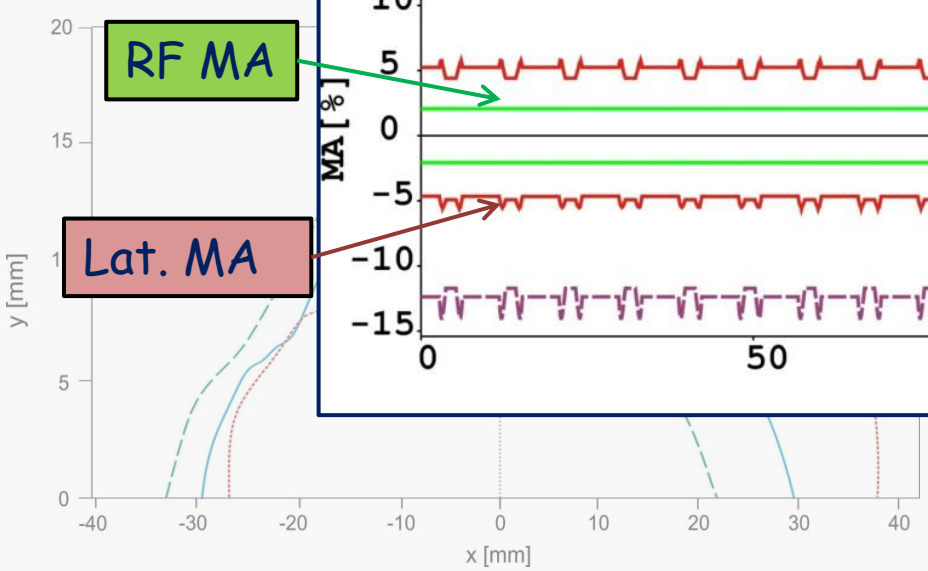
Compensate chromaticity where it's created

Dipoles and quads contain sextupole component



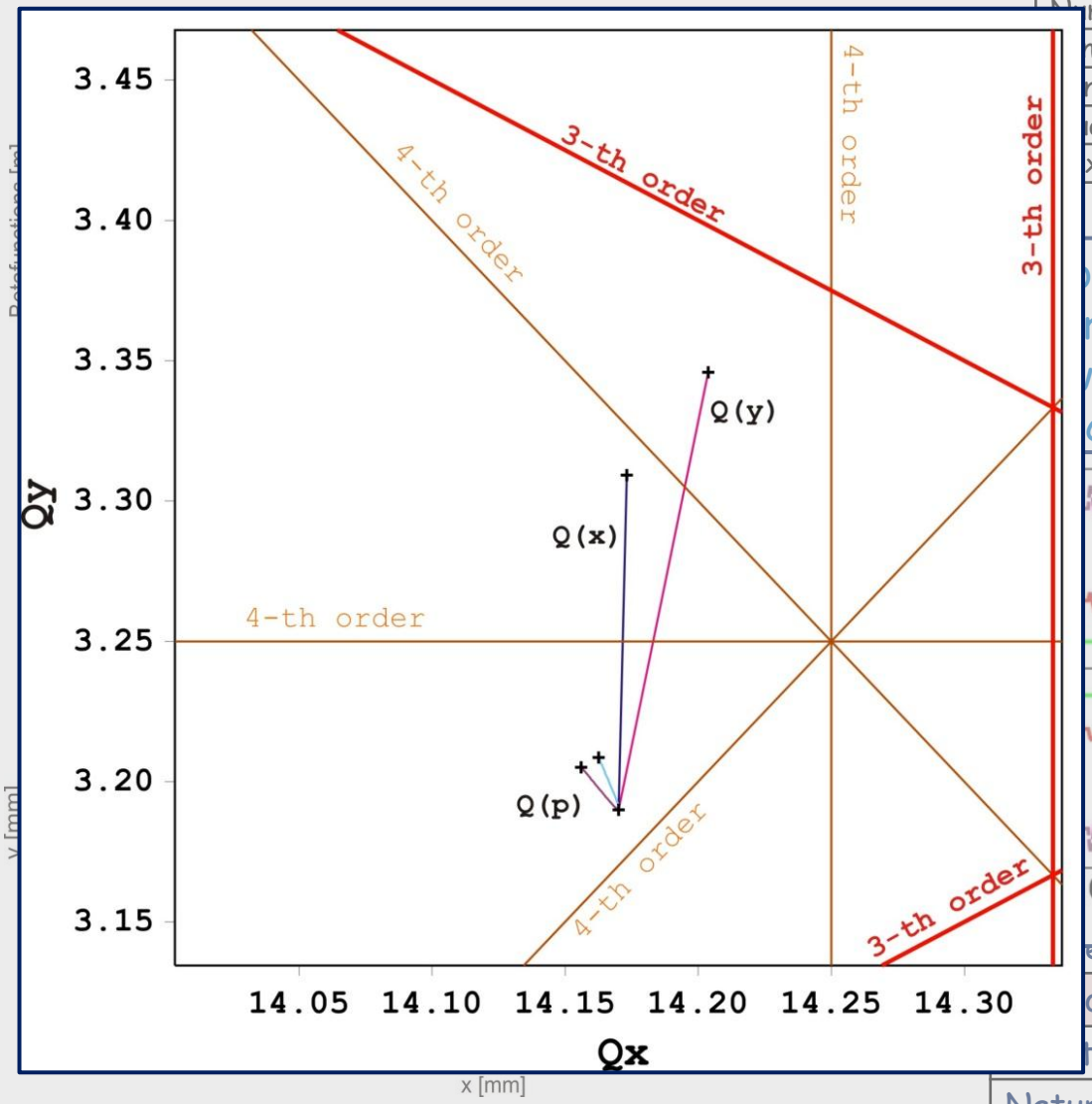


On and off momentum DA

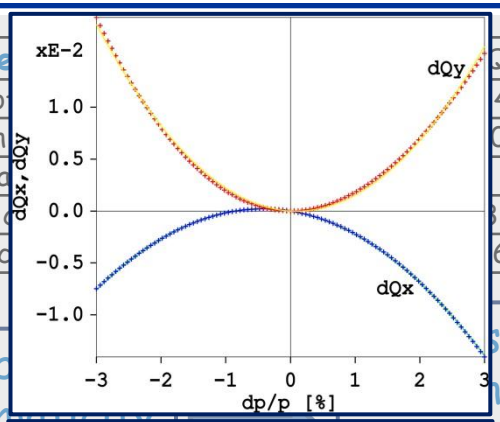
Hor. emittance (nm rad)	5.19
RF momentum acceptance (%)	2.1
Betatron tunes (h/v)	14.17/3.19
Natural chromaticities (h/v)	-13.64/ -24.27
Momentum compaction	0.0027

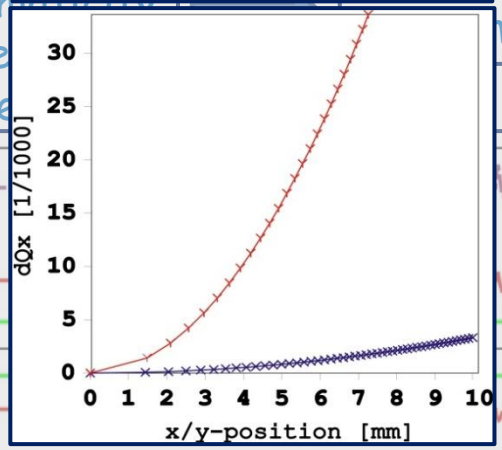
DBA lattice option

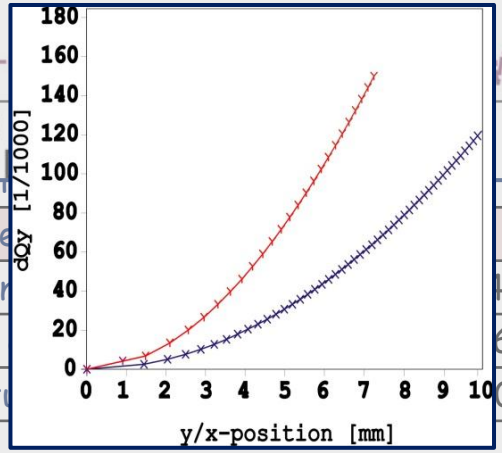
Modified DBA cell



On and off momentum DA







	QF1	QF2
	48	24
	0.2	0.3
	-	-
	38.2	33.92
	6.81	236.55

s and quads
h sextupole
mponent

200

2.1

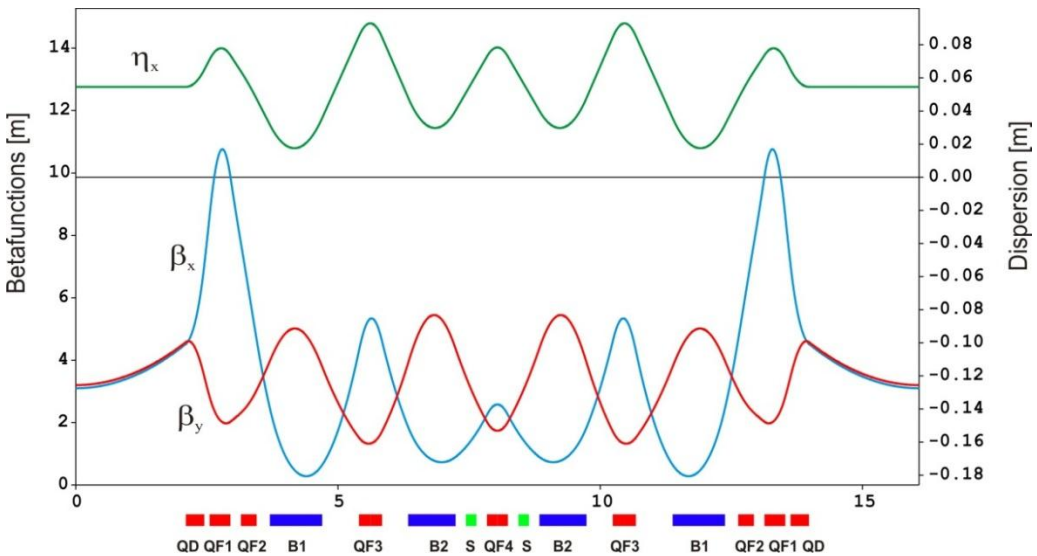
4.17/3.19

64/ -24.27

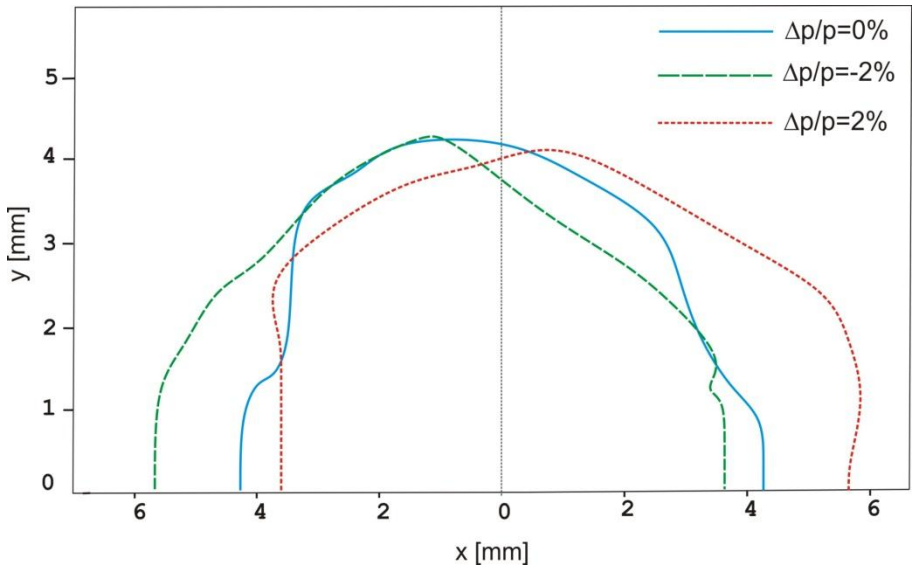
0.0027

4BA lattice option

4BA cell



Magnets	Bend. angle (^{0})	Quad. comp. (T/m)	Sext. Comp. (T/m^2)
B1 (1m)	6.25	-11	-36.5
B2 (0.9m)	5	-13.1	-210
QD (0.35 m)	-	-25.8	-391
QF1 (0.4 m)	-	33.9	228
QF2 (0.3 m)	-	6.9	-369
QF3 (0.44 m)	-	36	345
QF4 (0.4 m)	-	34.5	1060
S (0.2 m)	-	-	-896

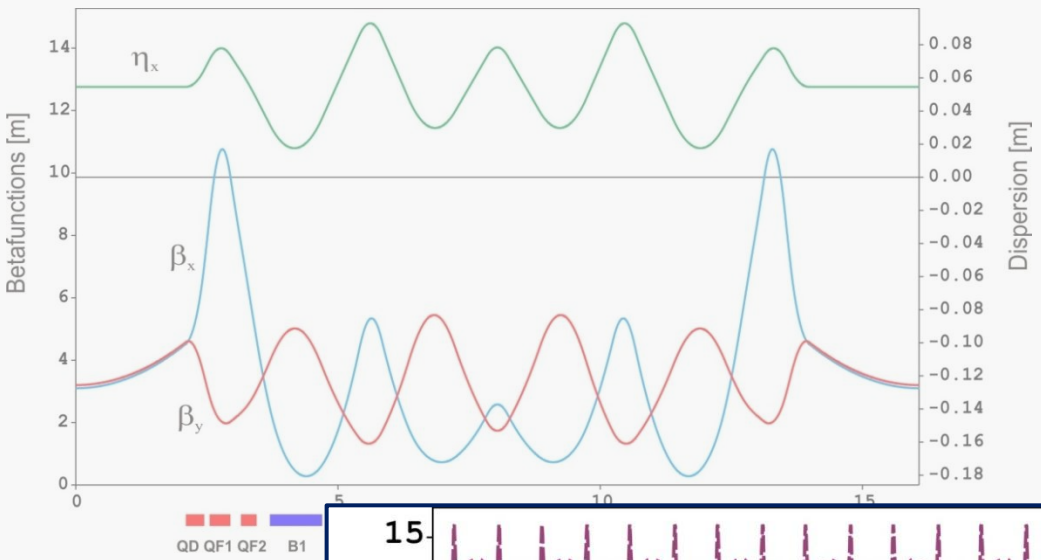


On and off momentum DA

Parameter	Value
Circumference (m)	258
Lattice type	4BA
Number of periods	16
Straight section length (m)	4.2
Beam Energy (GeV)	3
Hor. emittance (nm rad)	1.1
RF momentum acceptance (%)	3.9
Betatron tunes (h/v)	24.61/14.37
Natural chromaticities (h/v)	-38.27/-26.04
Momentum compaction	0.0007

4BA lattice option

4BA cell



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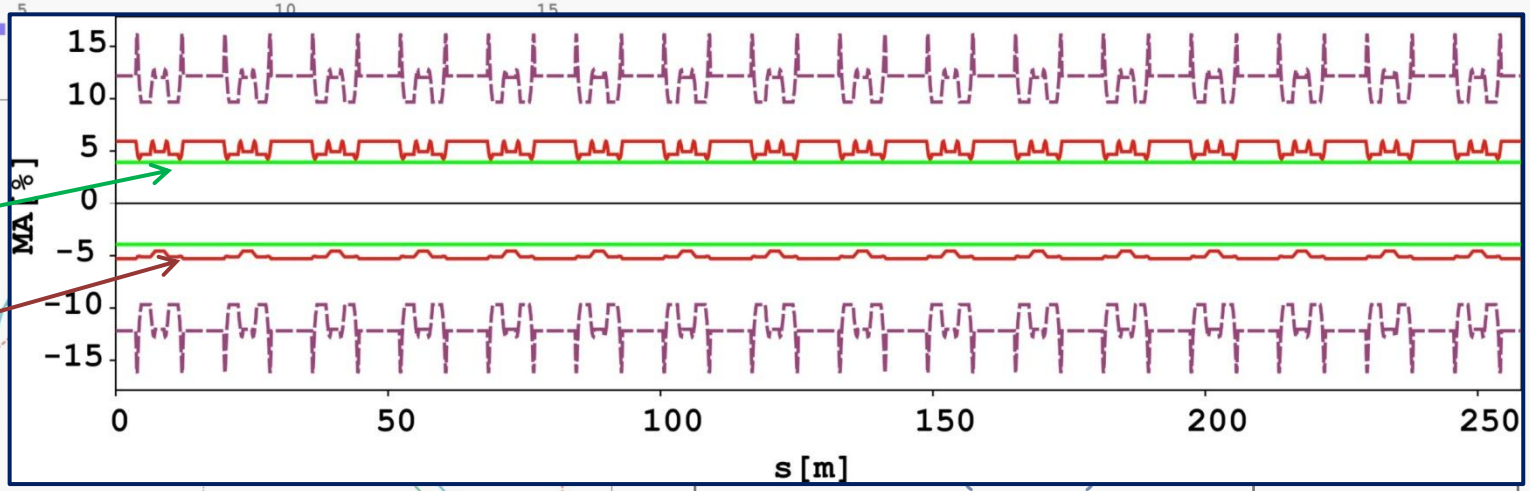

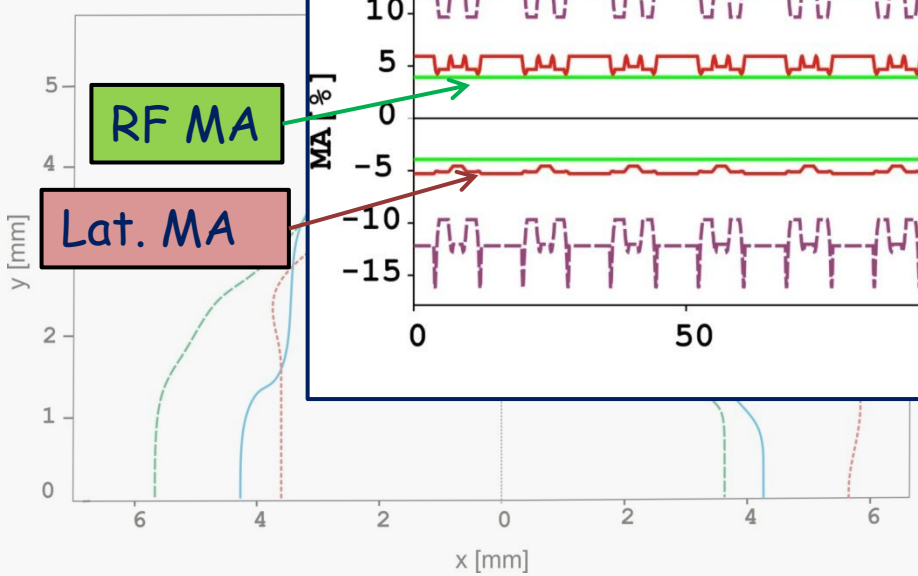

On and off momentum DA

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4BA lattice option

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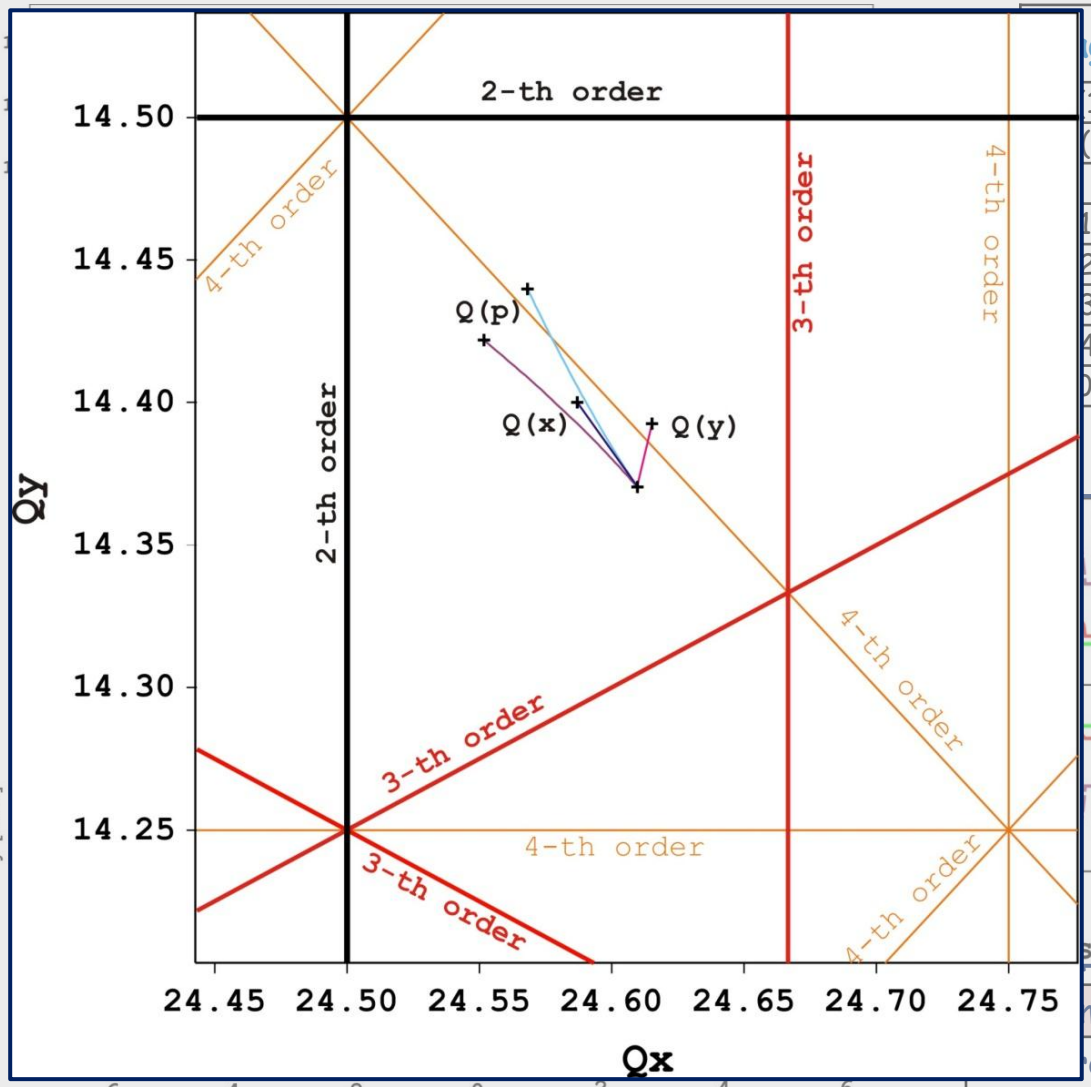
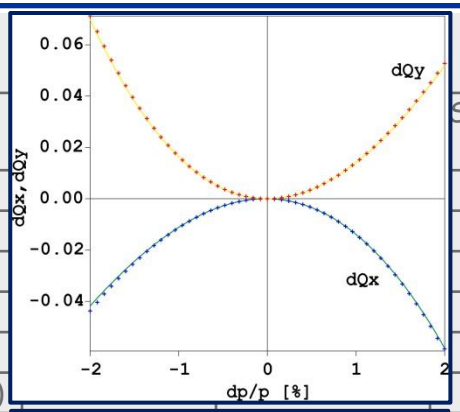
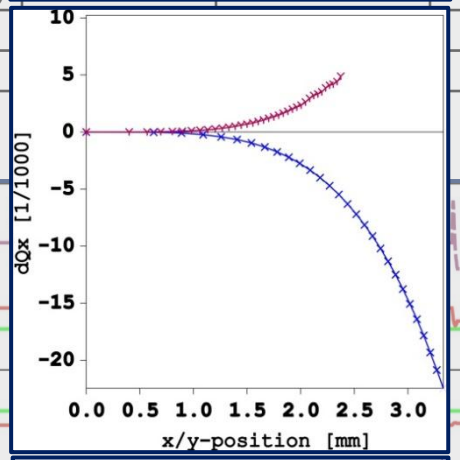
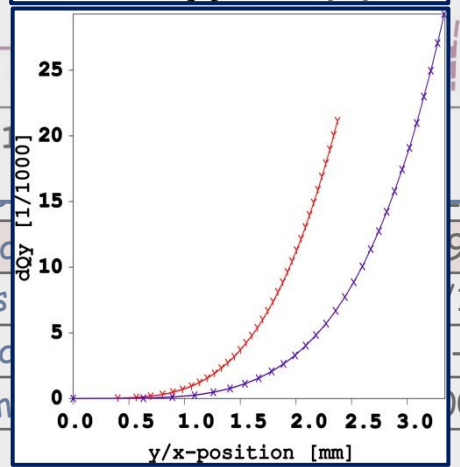








Sext. Comp. (T/m²)
-36.5
-210
-391
228
-369
345
1060
-896

Betafunctions [m]

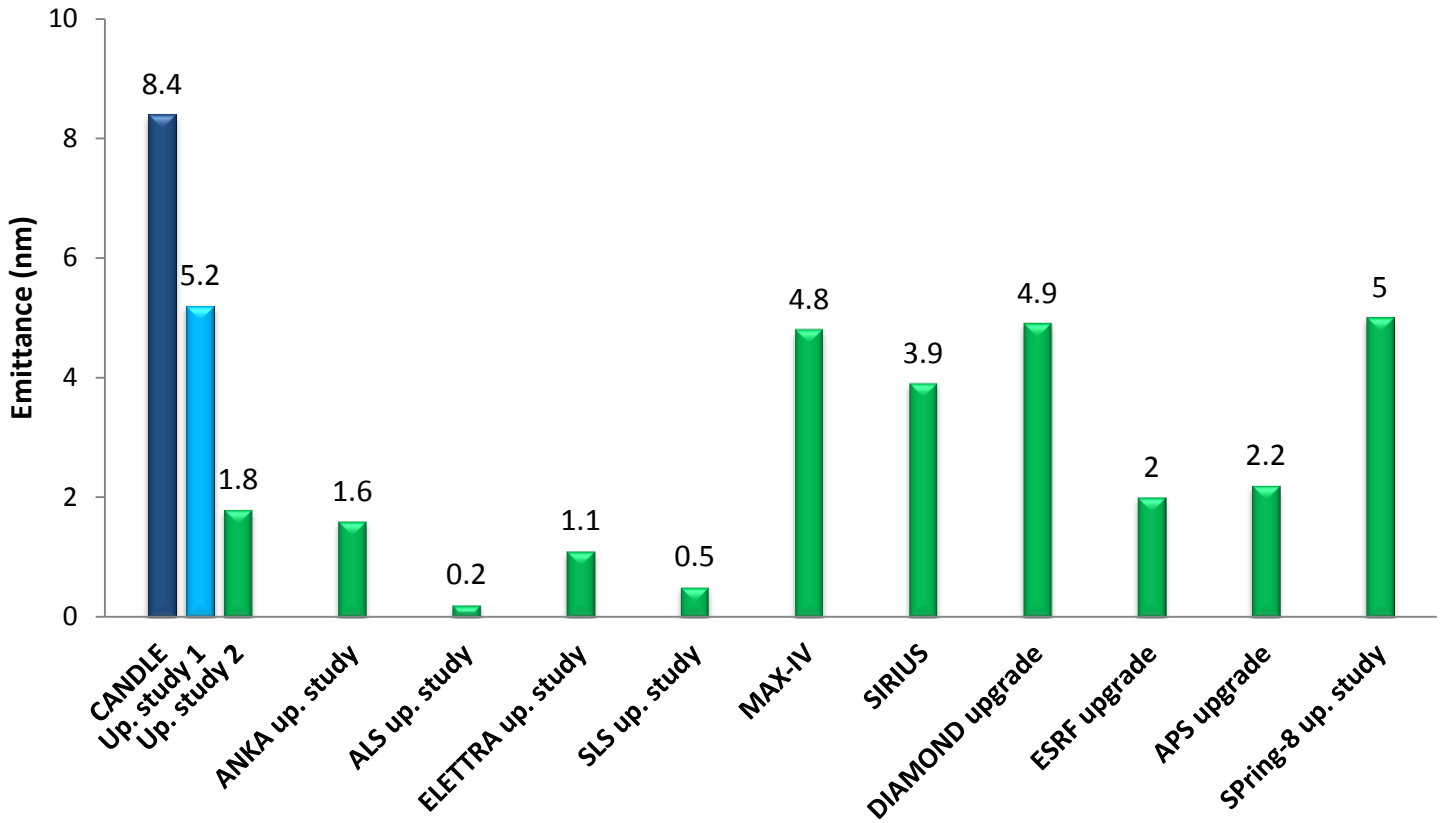
y [mm]

x [mm]

On and off momentum DA

Comparison

Beam emittance in case of 216m circumference and 3 GeV energy



Possibility of low alpha operation

Target

the decrease of alpha by two orders compared with 0.002 value of original CANDLE lattice

minimal modifications of the design lattice

Considered approaches

1. modification of the original beam optics by changing magnet fields
2. implementation of inverse bend magnets

Solutions so far

1. the reduction of alpha at the expense of the beam emittance increase by factor of about 7
2. twice lower emittance than in the first case but smaller momentum acceptance

MCF and longitudinal beam dynamics

$$\sigma_\tau \sim \sqrt{\alpha}$$

$$\frac{\Delta L}{L_0} = \alpha\delta$$

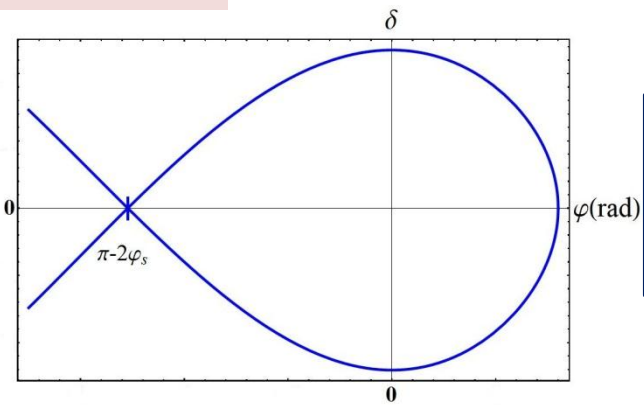
$$\alpha(\delta) = \alpha_0 + \alpha_1\delta + O(\delta^2)$$

longitudinal equations of motion

$$\begin{cases} \dot{\varphi} = \omega_0 h\left(\alpha_0\delta + \alpha_1\delta^2\right) \\ \dot{\delta} = \dfrac{\omega_0 e V_{rf}}{2\pi E_0}\left(\sin(\varphi_s + \varphi) - \sin\varphi_s\right) \end{cases}$$

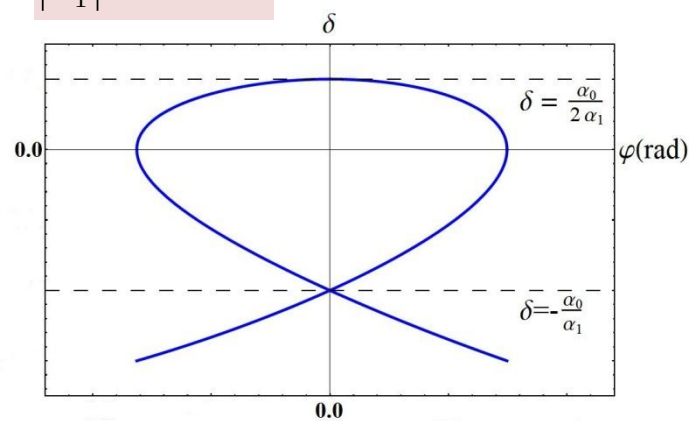
$$\delta_{linear}^{ac} = \sqrt{\frac{eV_{rf}\left((\pi - 2\varphi_s)\sin\varphi_s - 2\cos\varphi_s\right)}{\alpha_0 \pi E_0 h}}$$

$$\left|\frac{\alpha_0}{\alpha_1}\right| > \sqrt{3}\delta_{linear}^{ac}$$



rf cavity determines the size of the bucket

$$\left|\frac{\alpha_0}{\alpha_1}\right| < \sqrt{3}\delta_{linear}^{ac}$$

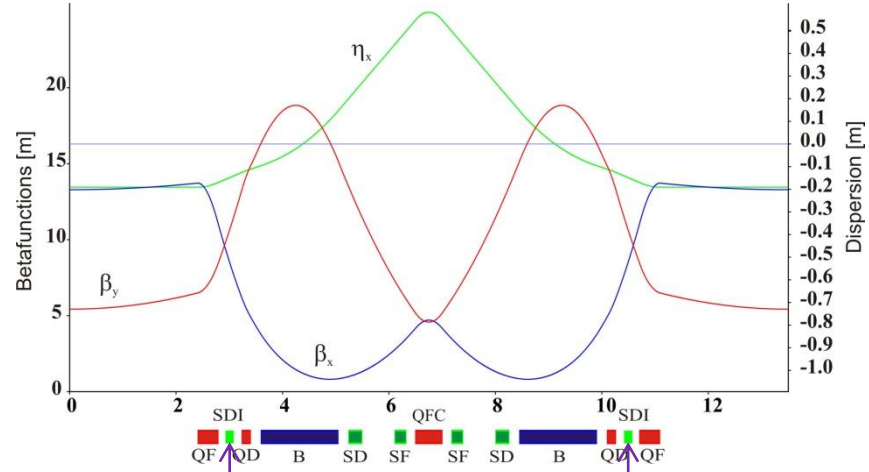


α_0/α_1 determines the size of the bucket

For independent control of transverse chromaticities and α_1 (longitudinal chromaticity) at least three families of sextupoles are needed.

Changing magnet fields

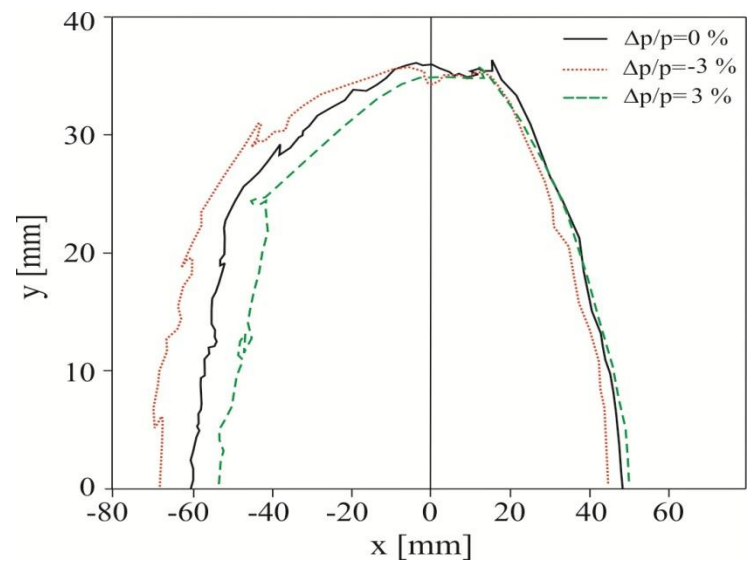
the standard approach of introducing negative dispersion in the straight sections



3rd family of sextupoles for simultaneous control of chromaticities and α_1

Parameter	Original lattice	1st solution
α_0	$2*10^{-3}$	$2*10^{-5}$
α_1 (with/without sext. opt.)	$3*10^{-3}$	$10^{-4}/-7.3*10^{-3}$
Emittance (nm rad)	8.4	59
rms energy spread (%)	0.104	0.095
RF momentum acceptance (%)	2.4	10
Betatron tunes h/v	13.22/4.26	12.22/4.26
Natural chrom. h/v	-18.93/-14.89	-18.73/-13.65
β_x/β_y at straight section mid. (m)	7.9/4.9	13.3/5.4
Maximum dispersion (m)	0.34	0.58

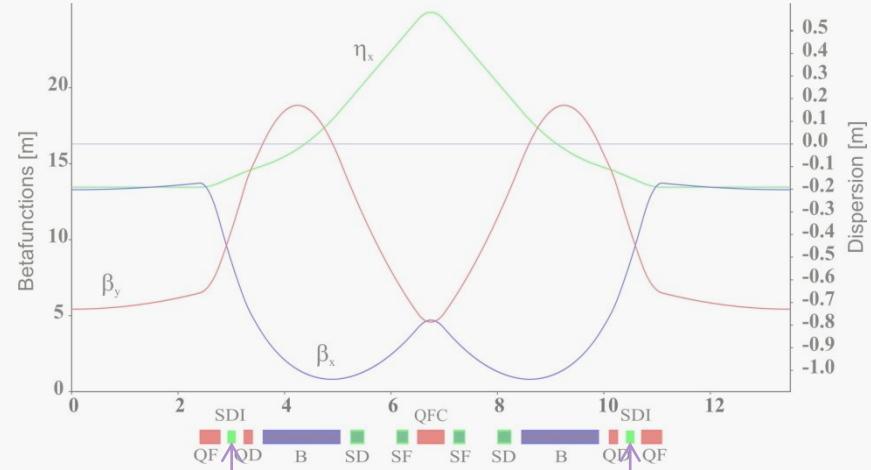
Sextupole optimization was done using Elegant



On and off momentum DA

Changing magnet fields

the standard approach of introducing negative dispersion in the straight sections



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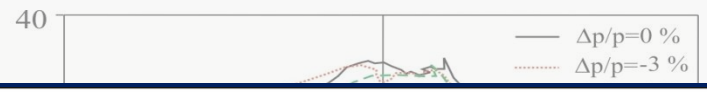
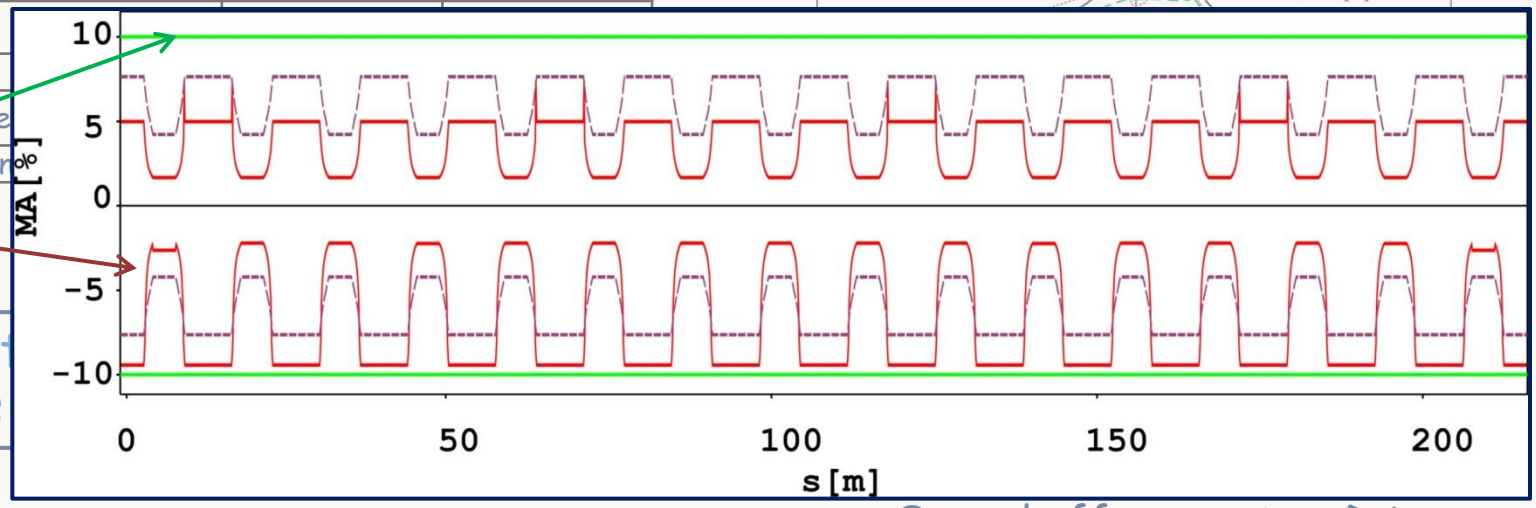
Nat		/v
β_x/β		se
Maximum dispersion		



RF MA

Lat. MA

Sext
was



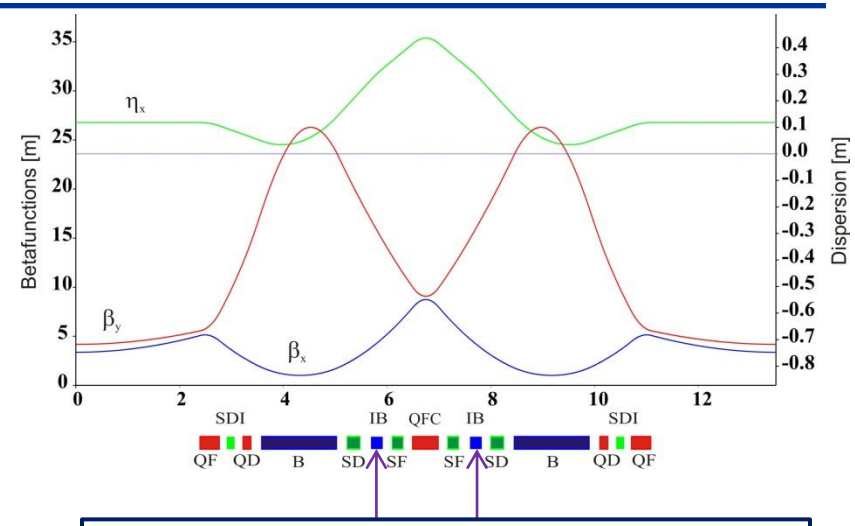
On and off momentum DA

Addition of inverse bend magnets

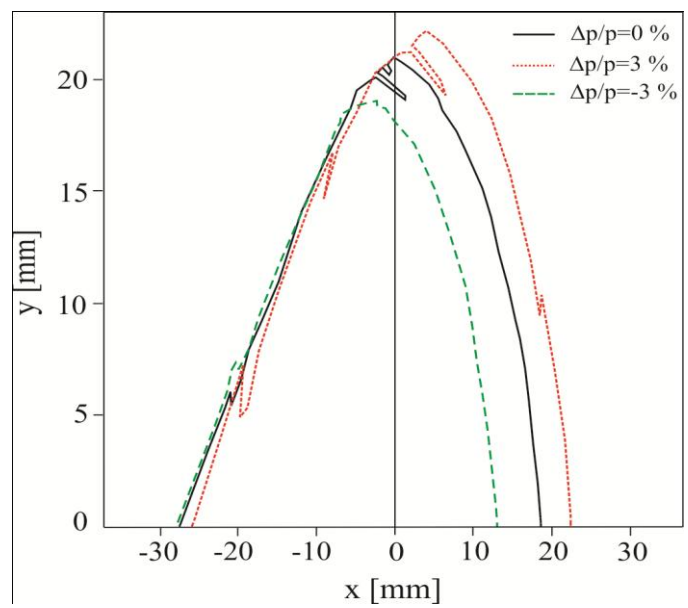
introducing inverse bending magnets (IB) in the area between defocusing SD and focusing SF sextupoles

Parameter	Original lattice	2nd solution
α_0	$2*10^{-3}$	10^{-4} ($2*10^{-5}$ is infeasible)
α_1 (with/without sext. opt.)	$3*10^{-3}$	$4*10^{-3}/6.3*10^{-3}$
Emittance (nm rad)	8.4	27
rms energy spread (%)	0.104	0.116
RF momentum acceptance (%)	2.4	1.25
Betatron tunes h/v	13.22/4.26	13.22/4.26
Natural chrom. h/v	-18.93/-14.89	-14.14/-19.13
β_x/β_y at straight section mid. (m)	7.9/4.9	3.37/4.17
Maximum dispersion (m)	0.34	0.44

In 2nd case we were not able to make any significant change in α_1 without exceeding the maximum attainable field of new sextupole family



0.22m long dipoles with -2.75° bending angle



On and off momentum DA

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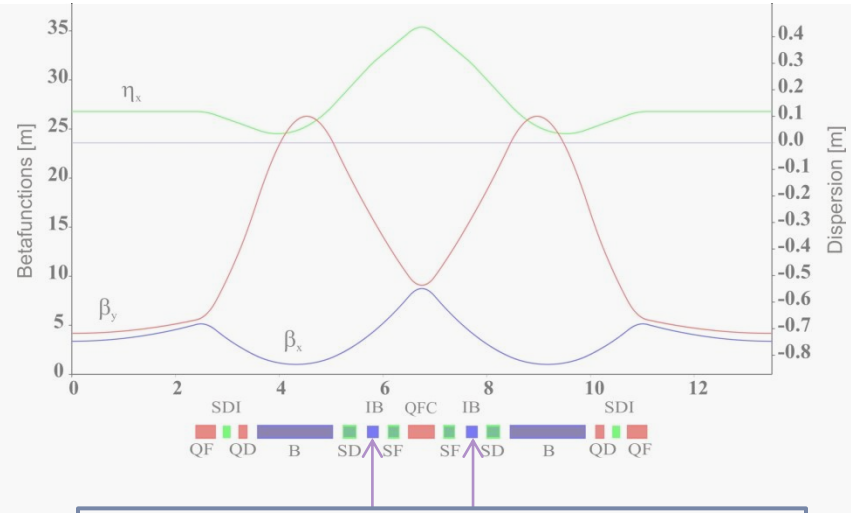

0.22m long dipoles with -2.75° bending angle

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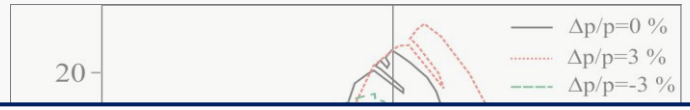
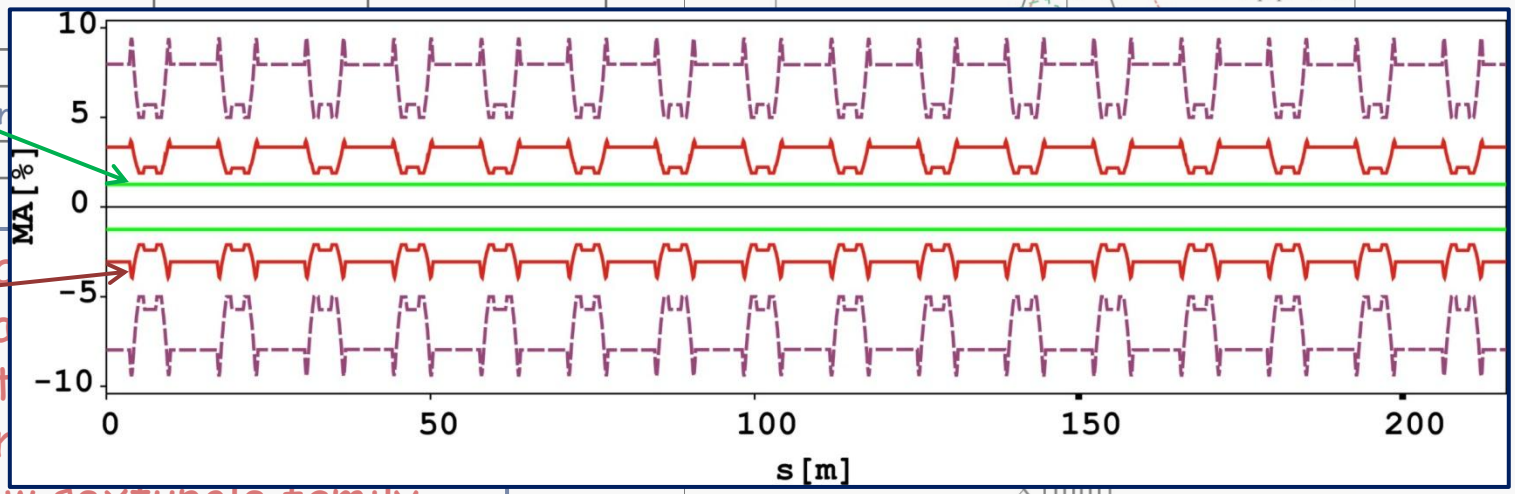
Emittance (nm rad)	8.4	27
rms energy spread (%)	0.104	0.116
RF momentum acceptance (%)	2.4	1.25
Betatron tunes h/v		
Natural chrom. h/v		
β_x/β_y at		
Maximum		



RF MA

Lat. MA



in α_1 wit
maximur
the new sextupole family

On and off momentum DA

Next steps

1. More research of nonlinear beam dynamics
2. Search of better working points
3. Dynamic aperture optimization with MOGA
4. Search of another low emittance solutions

THANK YOU FOR ATTENTION