

Tolerances of multipole errors in FCC-ee lattice

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Optics Tuning and Corrections for Future colliders workshop





ility

Acknowledgment

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Outlook

- Introduction
- Dynamic aperture of ideal lattice (z , tt)
- Multipole error in dipole magnets
- Multipole errors in quadrupole magnets
- Summary



Introduction

- Particle tracking has been done mostly by ELEGANT code
- The dynamic aperture calculated in 4D (without SR and RF cavity)
- Multipoles have been calculated in $r = 10$ mm.

$$B_y(x, y) + iB_x = B_0 \sum_{n=0}^N (b_n + ia_n)(x + iy)^n$$

$$\Delta B_n(r_0) = b_n r_0^n$$

$$\Delta A_n(r_0) = a_n r_0^n$$

$$\Delta x' = \frac{\Delta B_n L}{(B\rho)}$$

- We calculated the dynamic aperture in the IP.
- The particles were tracked for 528 and 50 turns respectively for z and tt lattices.
- All multipole errors considered as systematic errors.

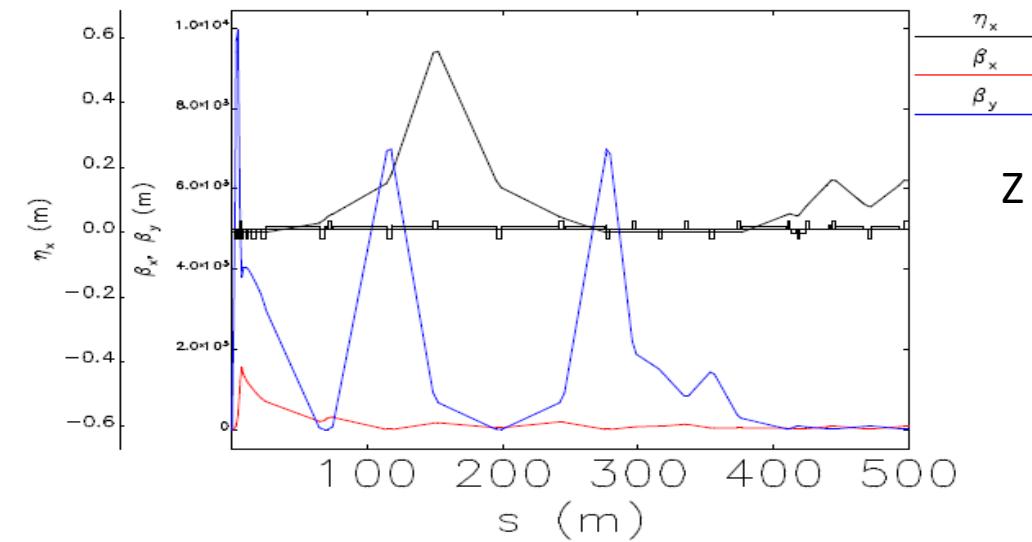


Ideal lattice

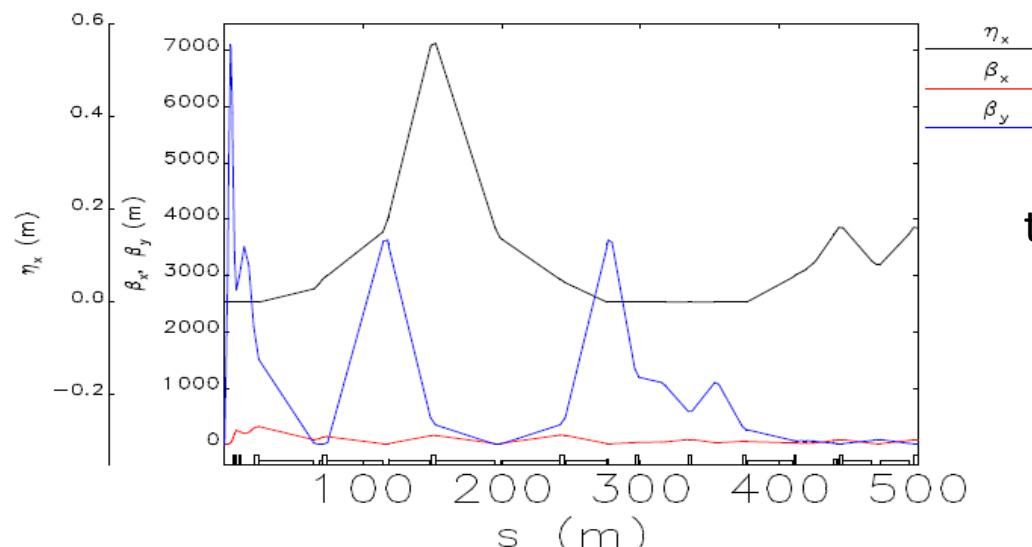
All calculations are based on lattice V22:

Z lattice main parameters

Parameter	unit	value
circumference	m	91174.117
Emittance(x/y)	m-rad	0.71e-9/1.42e-12
Tune(x/y)	-	214.260/ 214.380
Chromaticity(x,y)	-	0/0
1 st order momentum compaction factor	-	2.84e-5
BETX_max	m	4663.567
BETY_max	m	9924.567
BETX /BETY@IP	m	0.15380/0.0008
Dx @IP	m	-5.7370e-6



Z lattice functions

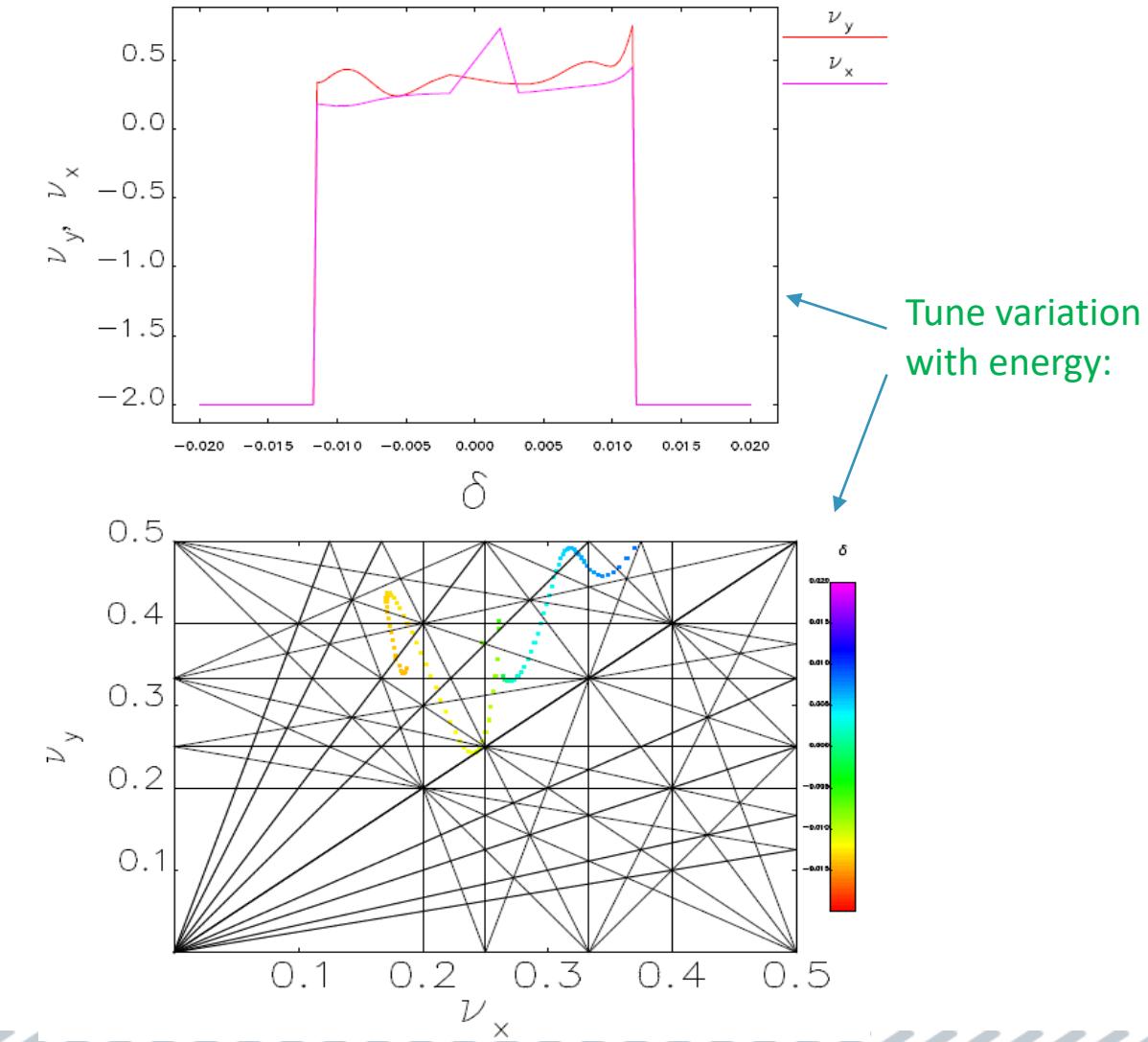
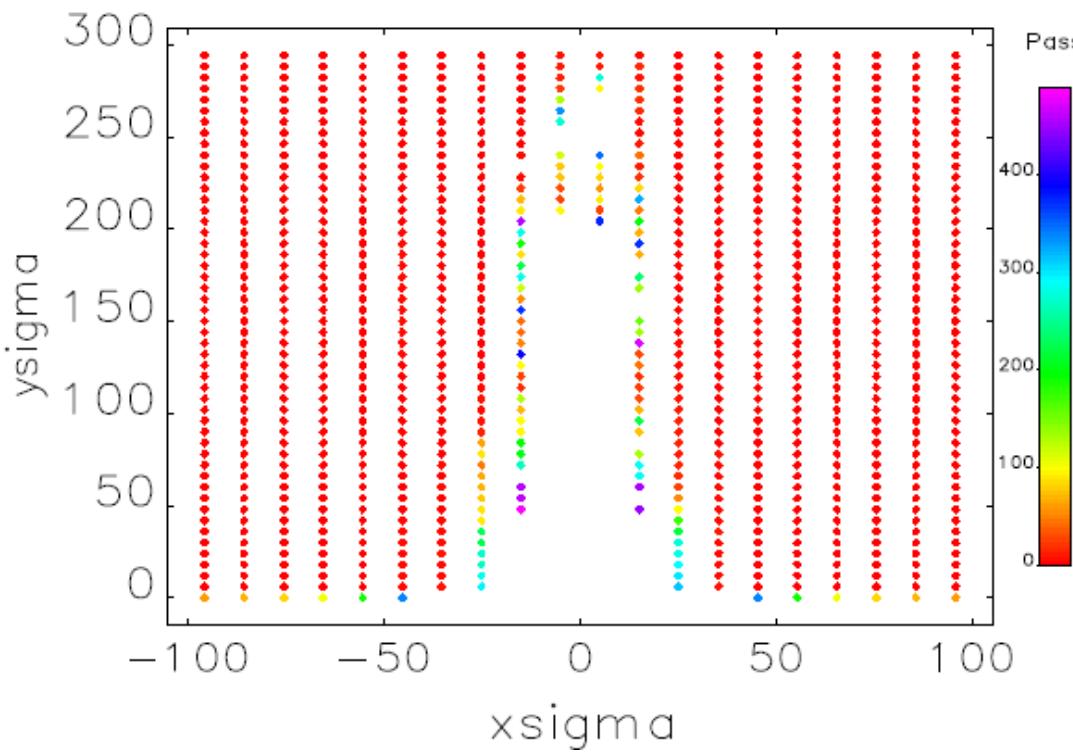


tt lattice functions



Ideal lattice (z)

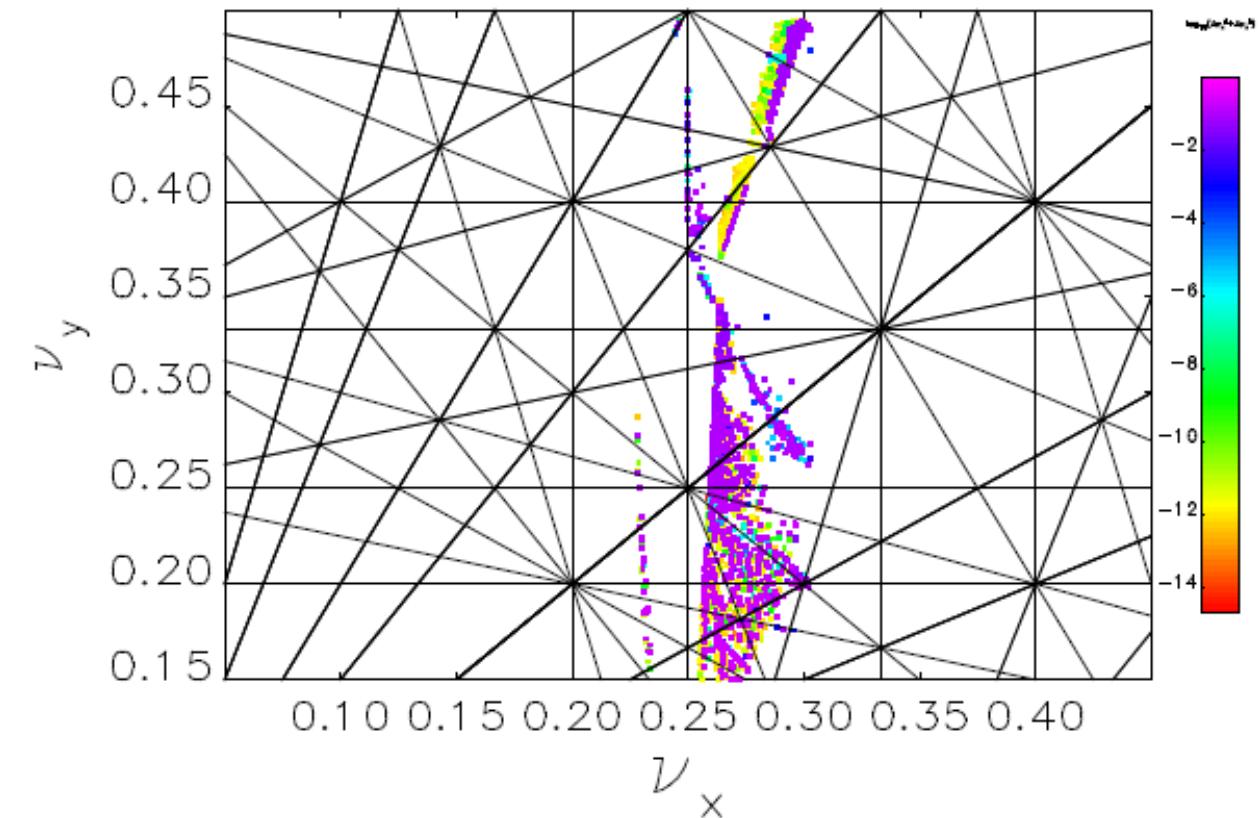
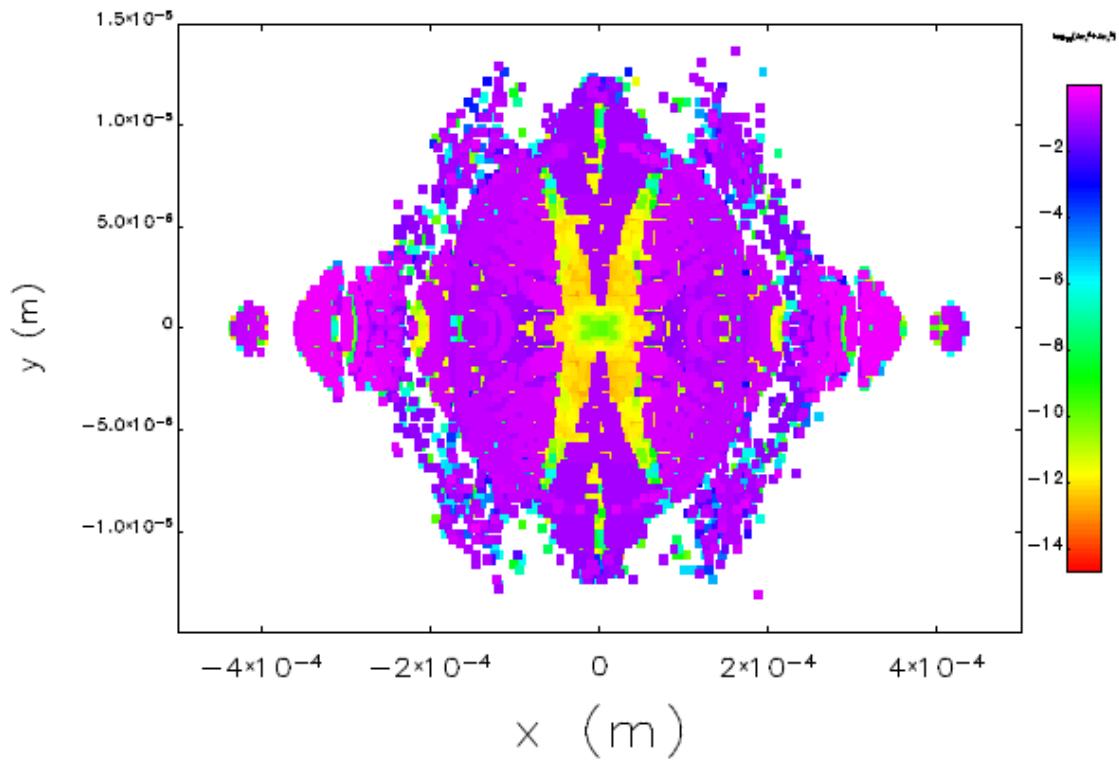
Particles have been tracked for 528 turns at IP. The beam size at the IP is $10.45 \mu\text{m}$ and 34 nm in x and y directions respectively.





Frequency map analysis for z lattice

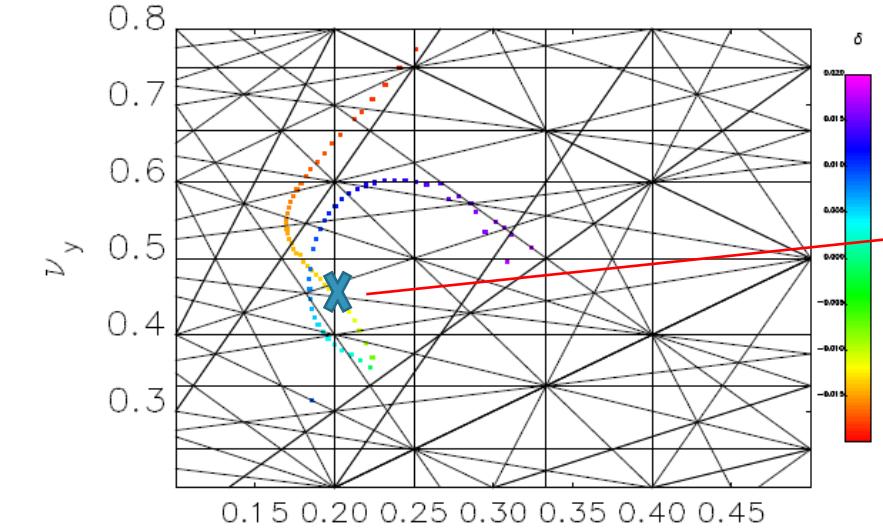
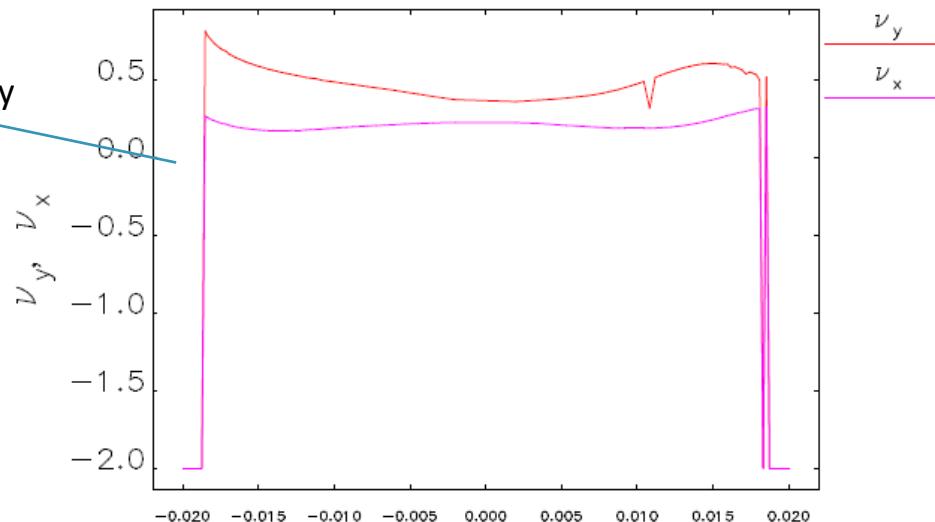
Frequency map analysis of lattice z



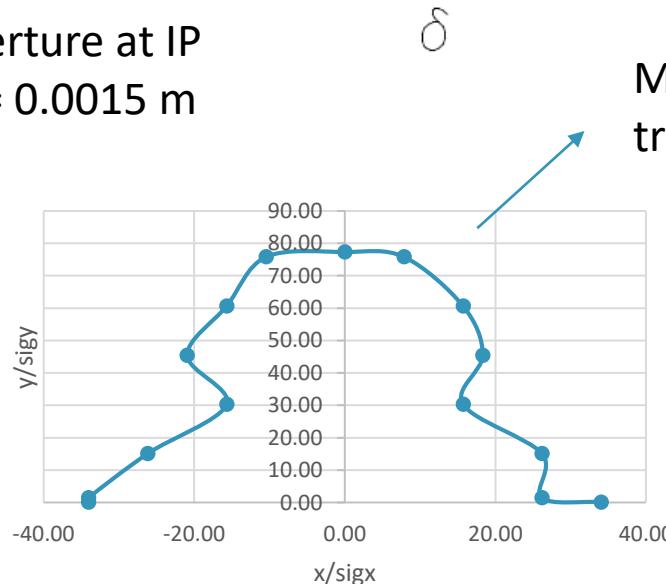


Ideal lattice tt

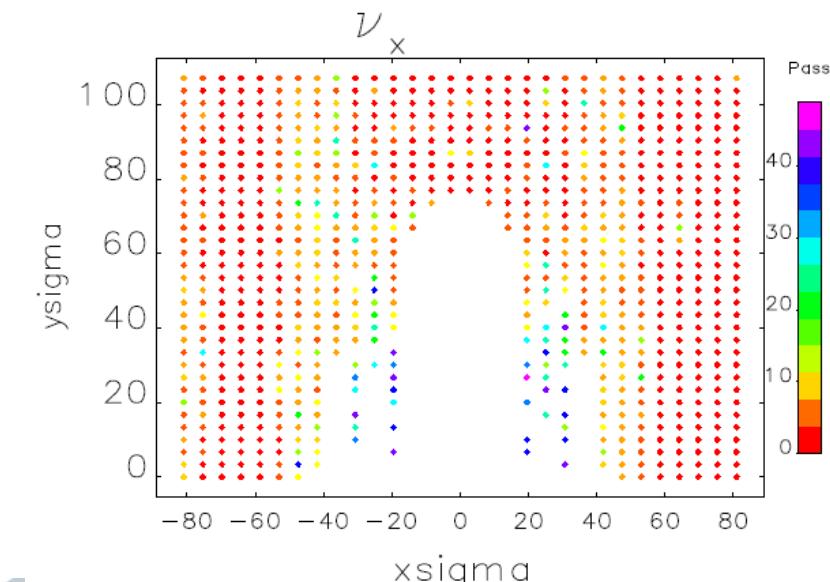
Tune shift
with energy



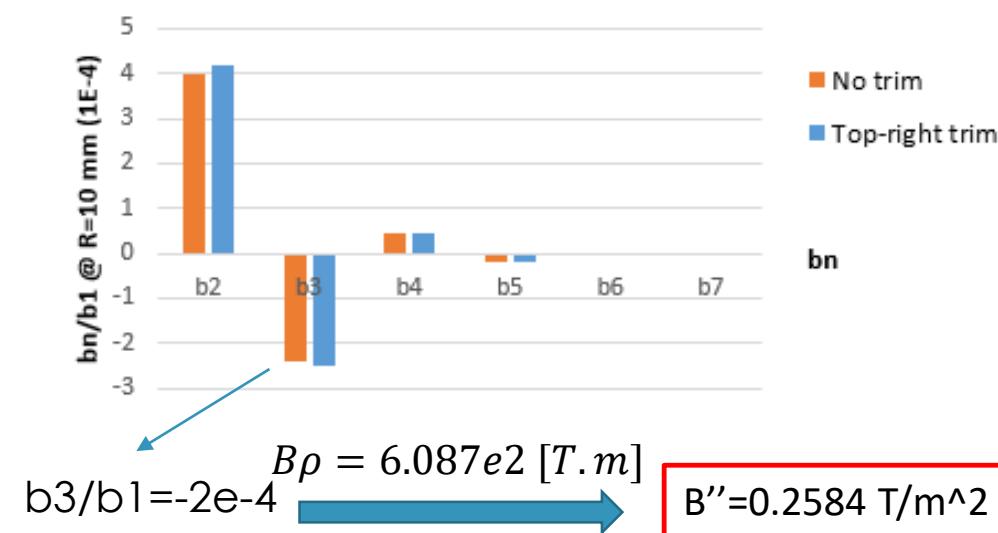
Dynamic aperture at IP
 $B_x=1$ m , $B_y=0.0015$ m



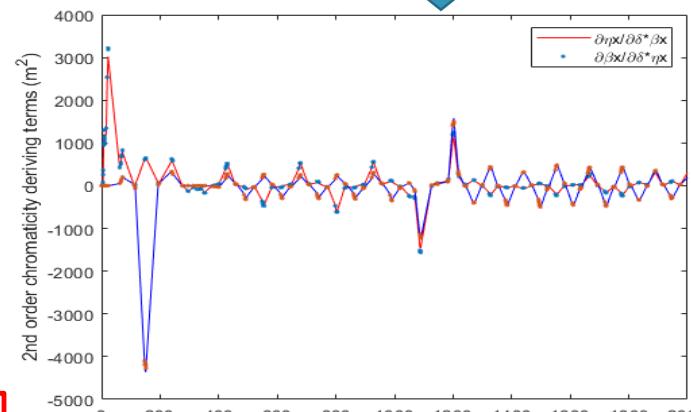
MADx-ptc
tracking



multipole errors in Dipole magnets



driving terms of second order chromaticity ($b_3/b_1 = -2e-4$)



- First order chromaticity

$$\xi_{x,y}^{(1)} = \mp \frac{1}{4\pi} \sum_{k=1}^N [(b_2 L)_k - 2(b_3 L)_k \eta_{x,k}] \beta_{(x,y),k}$$

- Second order chromaticity

$$\xi_{x,y}^{(2)} = -\frac{1}{2} \xi_{x,y}^{(1)} + \frac{1}{8\pi} \sum_{k=1}^N \left\{ 2(b_3 L)_k \frac{\partial \eta_{x,k}}{\partial \delta} \beta_{(x,y),k} - [(b_2 L)_k - 2(b_3 L)_k \eta_{x,k}] \frac{\partial \beta_{(x,y),k}}{\partial \delta} \right\}$$

Including $b_3/b_1 = -2e-4$ in all dipole magnets:

MADX results (PTC_NORMAL): lattice z

CH1x=-78.168

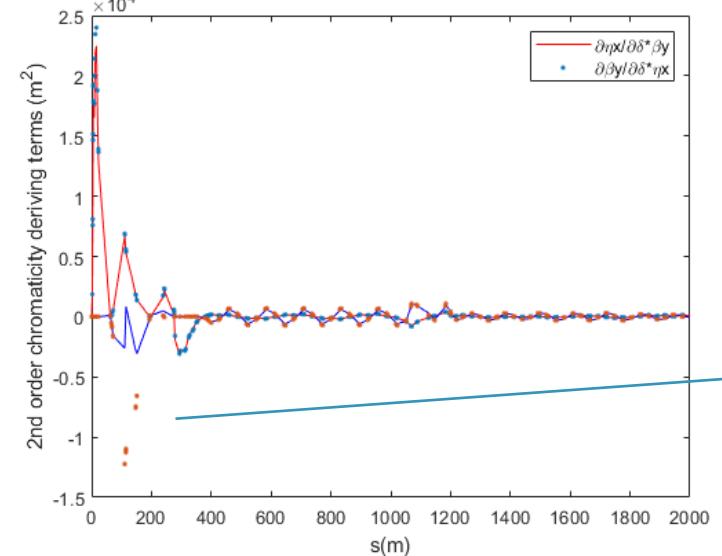
increasing the first order
chromaticity is mainly because
of the arc dipole magnets.

CH1y= 63.86

ELEGANT

CH1x=-78.64

CH1y= 66.93

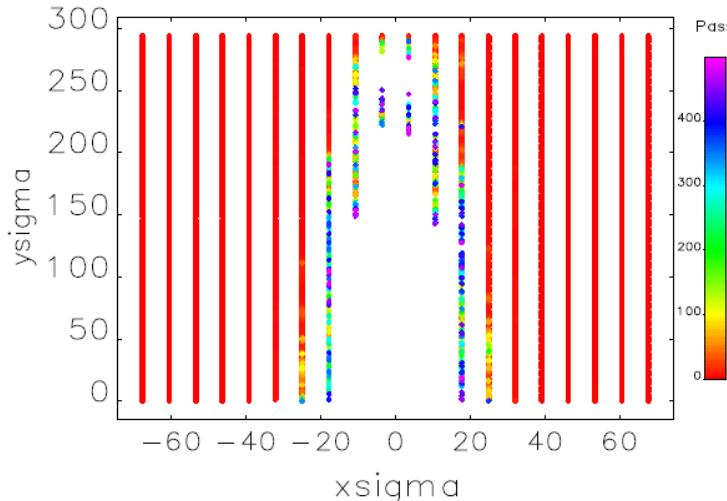


The term $\eta_x \frac{\partial \beta_x}{\partial \delta}$
deviate from ideal
curve in the presence
of b_3 in IR

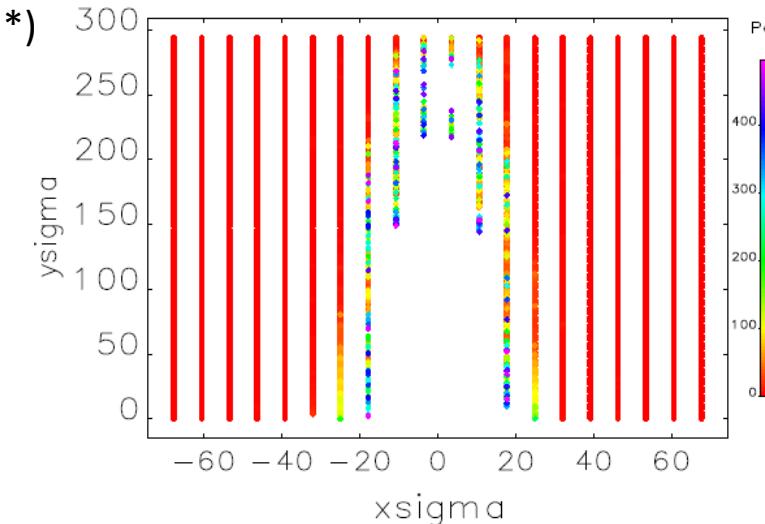


multipole errors in Dipole magnets (z lattice)

DA after including $b_3/b_1 = -2e-4$ in **only arc dipoles** (B1S.* , B1.* , B1L.*)

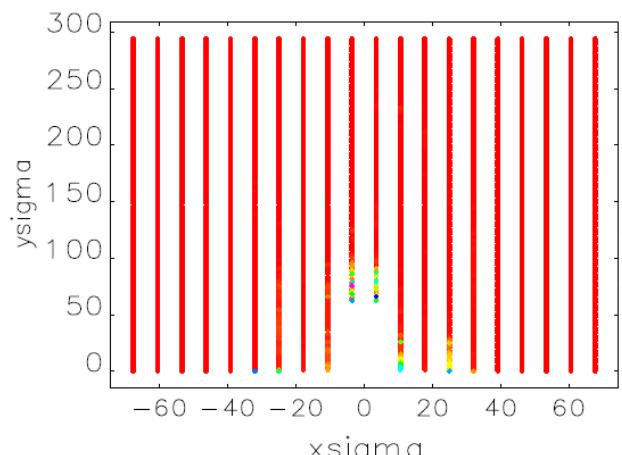


Correcting the
chromaticity
by arc sextupole

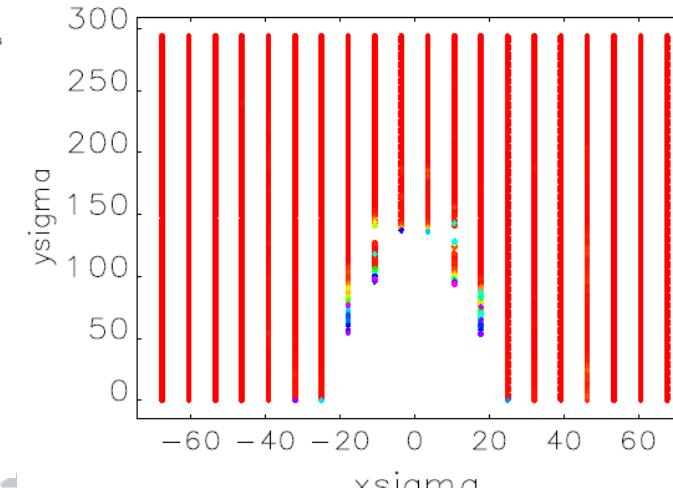


b3 in arc dipoles
does not affect DA
significantly

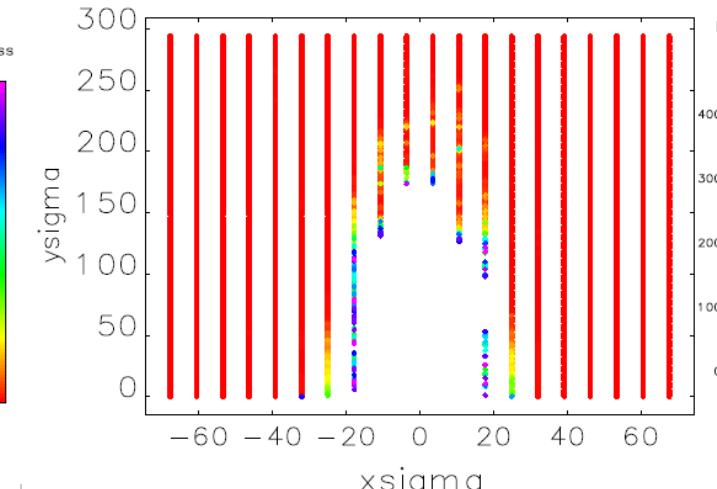
b3/b1 = -2e-4 in IR dipoles



b3/b1 = -0.5e-4 in IR dipoles



b3/b1 = -0.1e-4 in IR dipoles

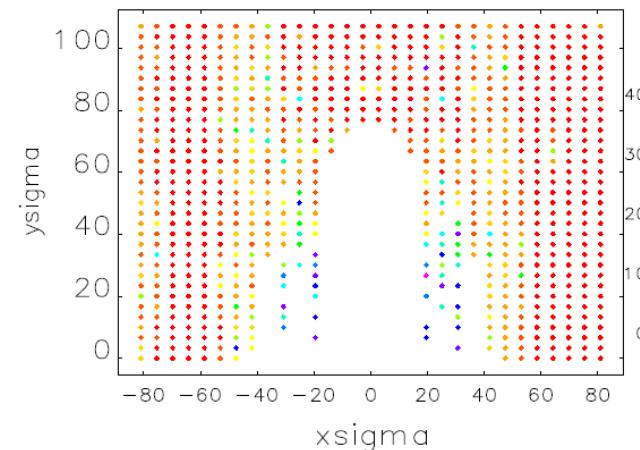


Correcting
the DA by arc
sextupoles
does not
improve the
DA

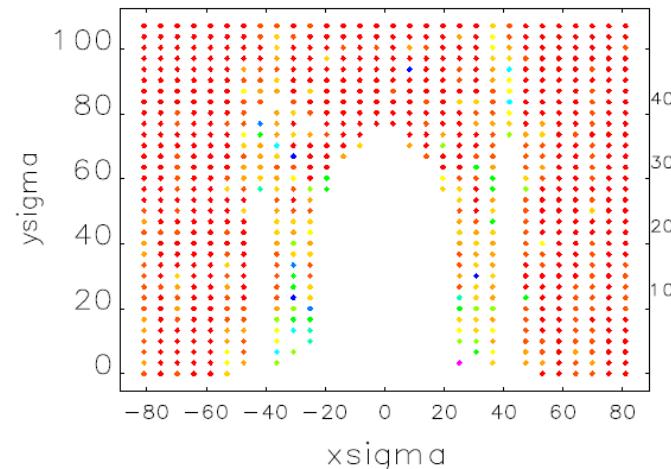


multipole errors in Dipole magnets (tt lattice)

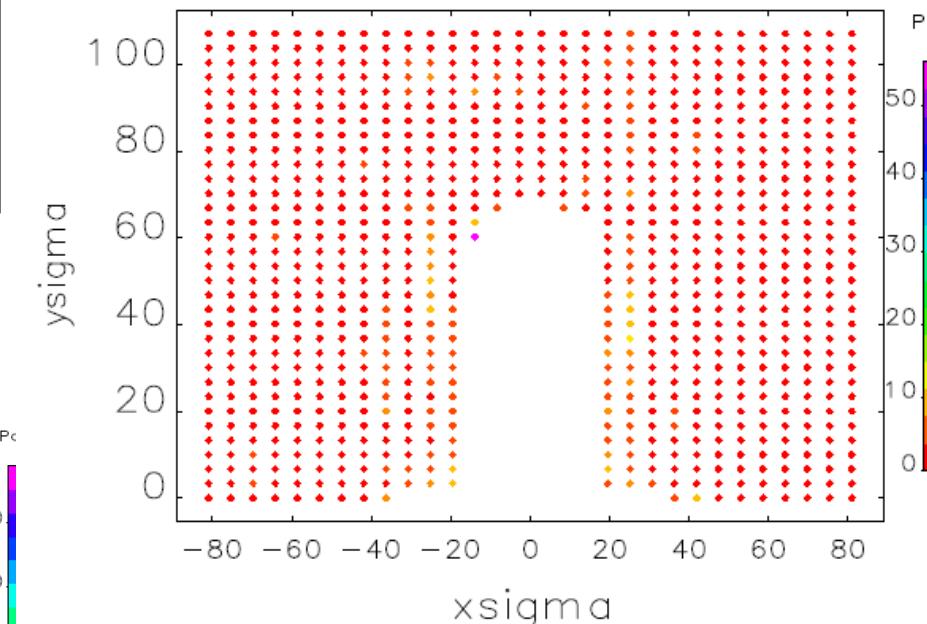
Ideal lattice dynamic aperture



$b3/b1 = -2e-4$ in arc dipoles



$b3/b1 = -1.e-4$ in IR dipoles



- $b3$ in arc dipoles does not effect DA
- $b3/b1 = -1.0*10^{-4}$ in IR slightly changes DA



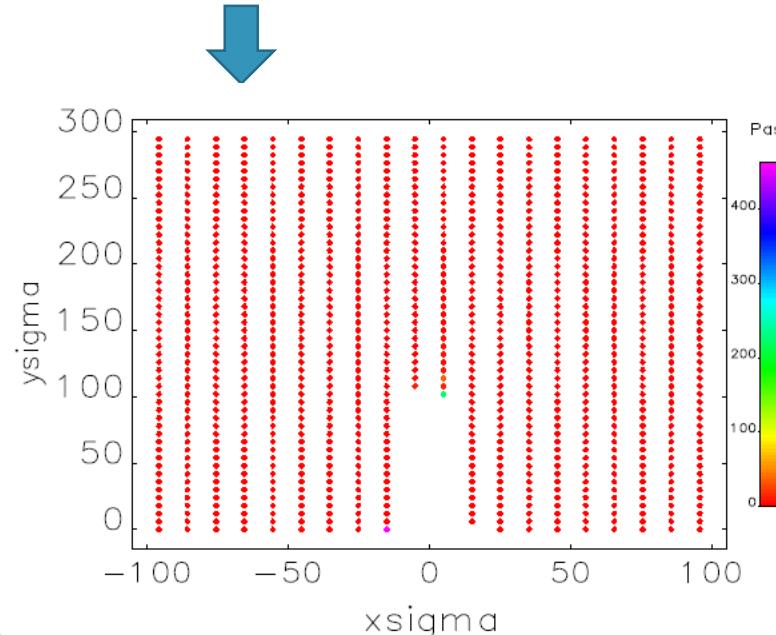
multipole errors in Dipole magnets

bility

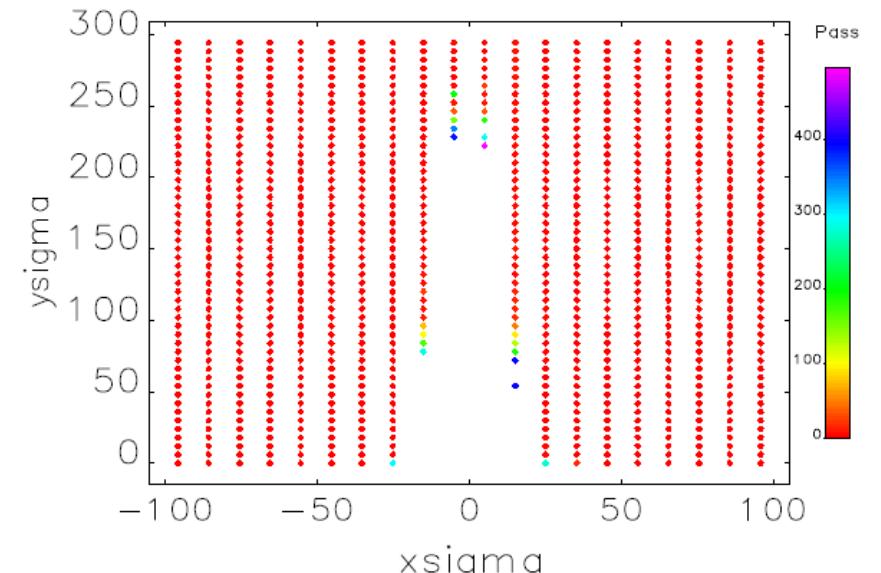
The effect of b5 error in dipole magnet on DA was investigated:

- b5 in the **arc dipole** magnets with **2 units** does not affect the DA in both z and tt lattice.
- b5 in **IR dipoles** strongly decrease the DA.
- For tt lattice, $B5/b1=0.5*10^{-4}$ slightly changes the DA

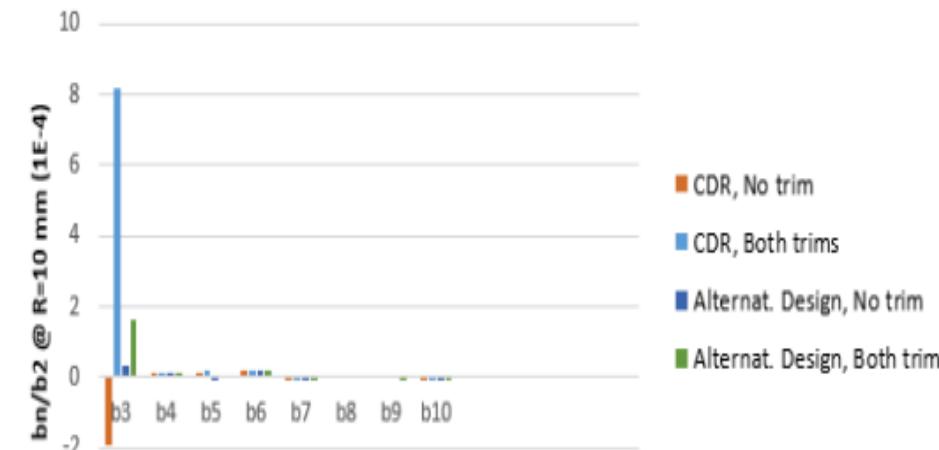
$b5/b1=0.5*10^{-4}$ → in all IR magnets (z lattice)



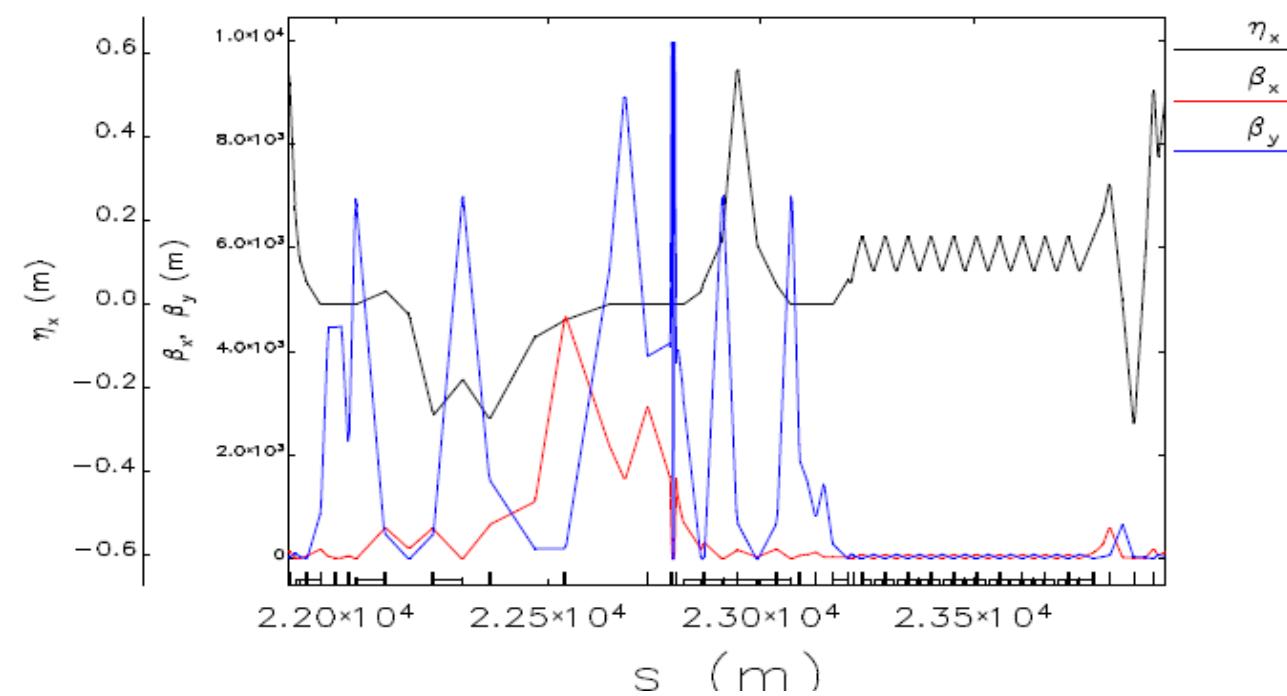
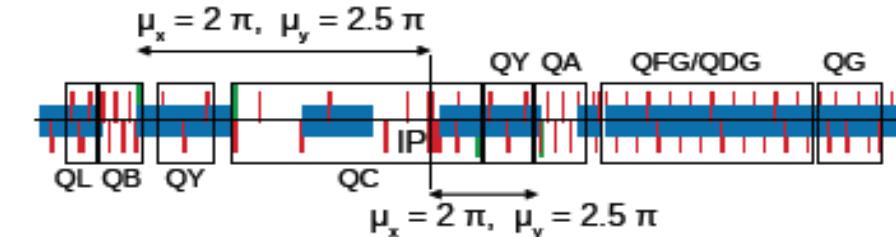
$B5/b1=0.1*10^{-4}$ in all IR magnets
 $B5/b1=0.01*10^{-4}$ in dipole BC?L.* (z lattice)



Multipole errors in quadrupole magnets

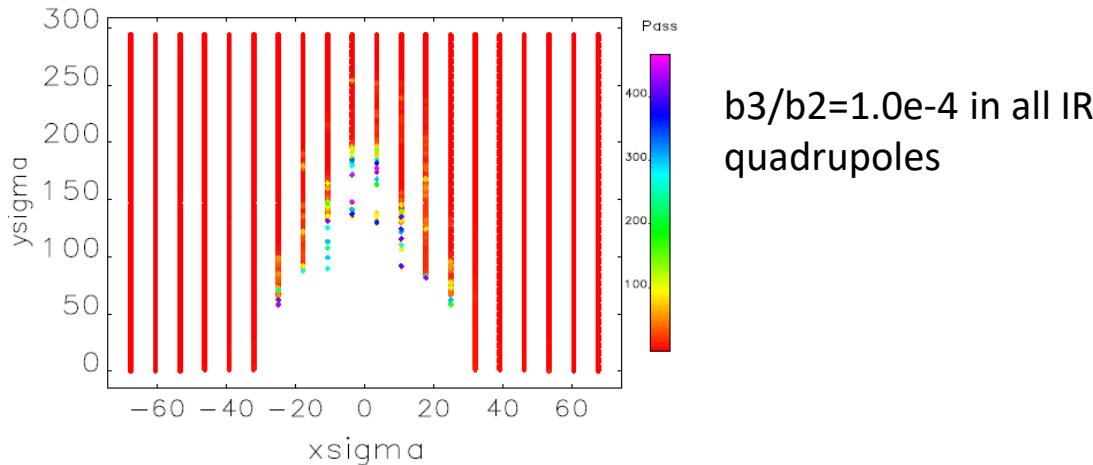


- b3 is the most dominant term
- In addition b3, the effect of b4 and b6 was investigated on the dynamic aperture.
- Multipoles of arc quadrupoles both in z and tt lattice do not affect DA
- Multipoles of quadrupoles QC and QY strongly decrease the DA.

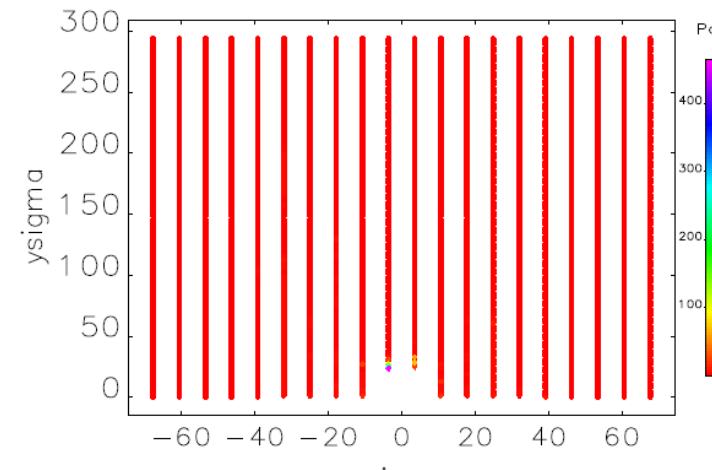


Multipole error in quadrupole magnets

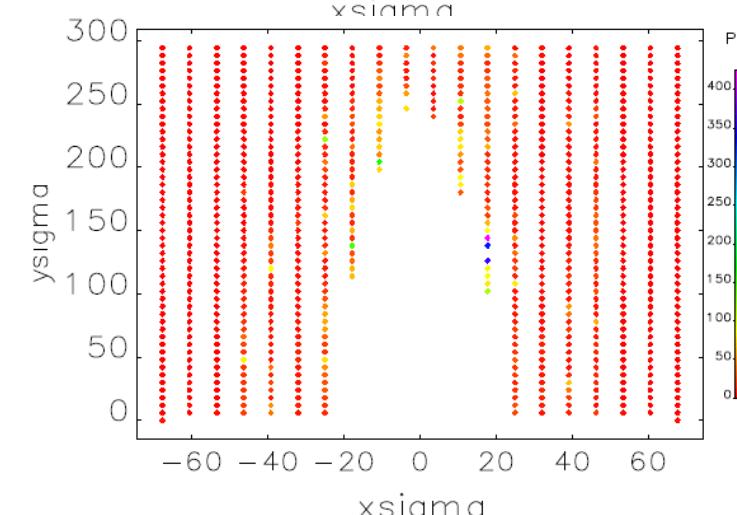
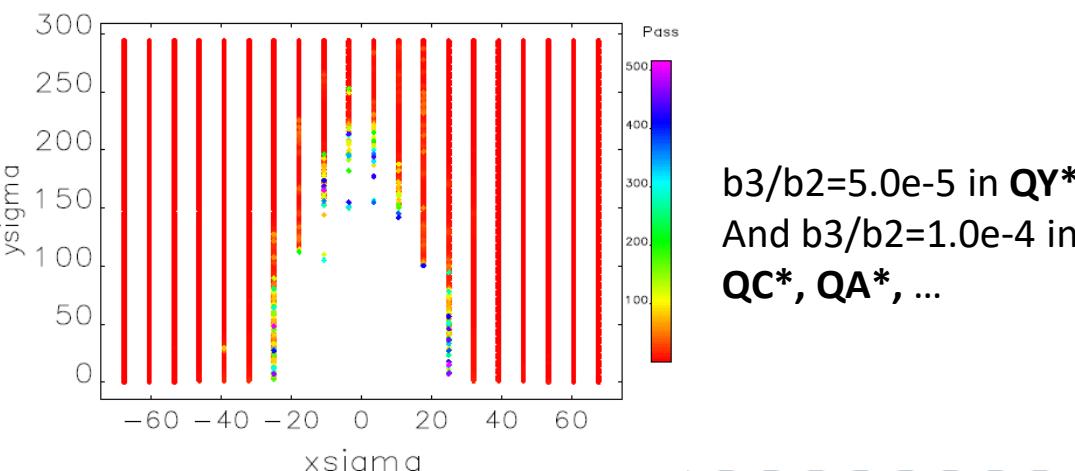
Sextupole error (b3) in IR quadrupoles magnets:



Octupole error(b4) in IR quadrupoles magnets:



b4/b2=1.0e-4 in quadrupoles (QC*, QT*, QY*, QA*) ,(QB, QG, QH, QL, QR, QU, QI)

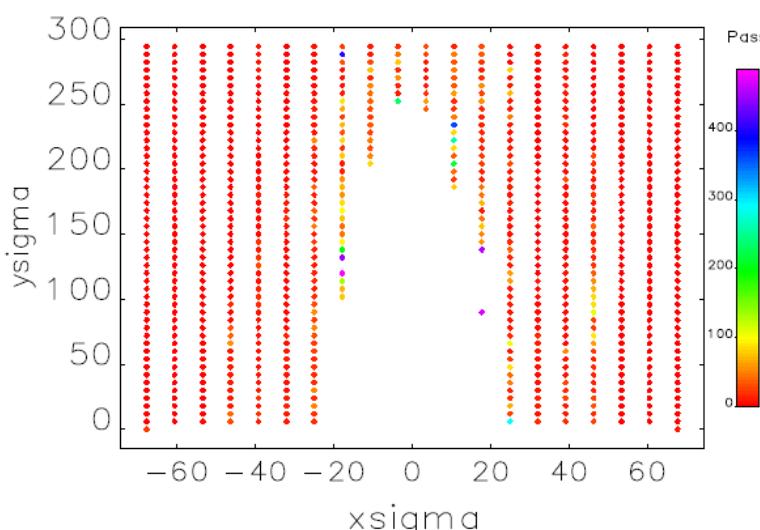




Multipole error in quadrupole magnets

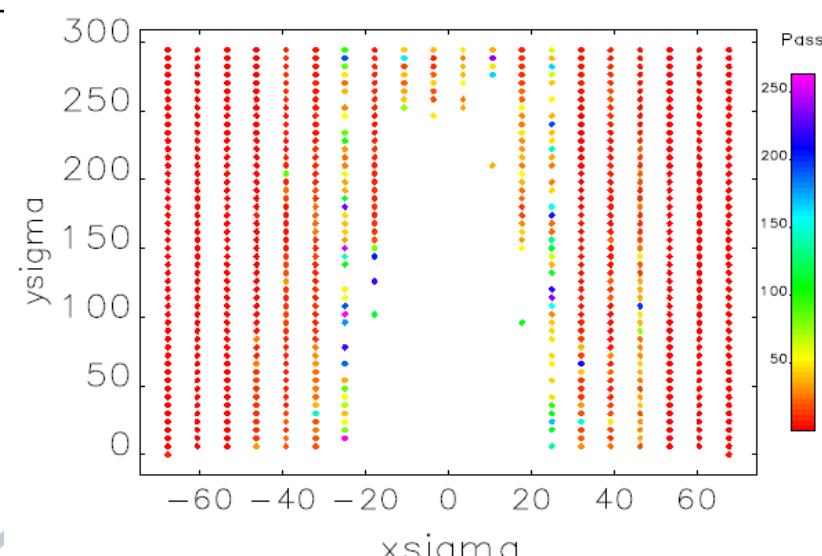
Tolerance of b4 in quadrupoles QY* (z lattice)

QY2.1, QY2.3, QY2.5, QY2.7	b4 = 1e-6
QY1.1, QY1.2, QY1.3, QY1.4	b4 = 1e-5
QY2.2, QY2.4, QY2.6, QY2.8	b4 = 1e-5
QY2L1, QY2L3, QY2L5, QY2L7	b4 = 1e-6
QY1L1, QY1L2, QY1L3, QY1L4	b4 = 1e-5
QY2L2, QY2L4, QY2L6, QY2L8	b4 = 1e-5



Tolerance of b4 in quadrupoles QC* (z lattice)

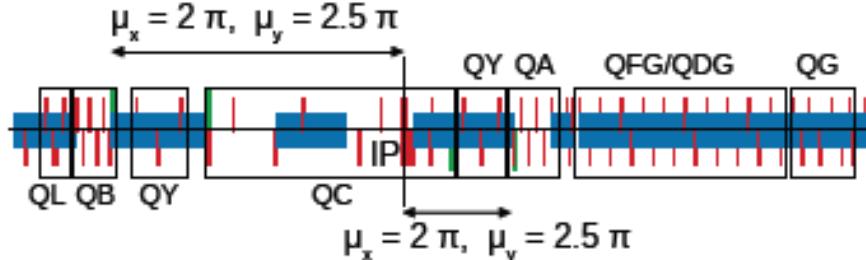
QC1.*	QC2.*
QC1L1.1, QC1L1.3, QC1L1.5, QC1L1.7	b4=1e-6
QC1L1.2,QC1L1.4,QC1L1.6,QC1L1.8	b4=1e-6
QC1R3.1,QC1R3.2,QC1R3.3,QC1R3.4	b4=1e-5
QC1R2.1,QC1R2.2,QC1R2.3,QC1R2.4	b4=1e-5
QC1L3.1,QC1L3.2,QC1L3.3,QC1L3.4	b4=1e-5
QC1L2.1,QC1L2.2,QC1L2.3,QC1L2.4	b4=1e-5
QC3*,QC4*,QC5*,QC6*,QC7*	b4=1e-5



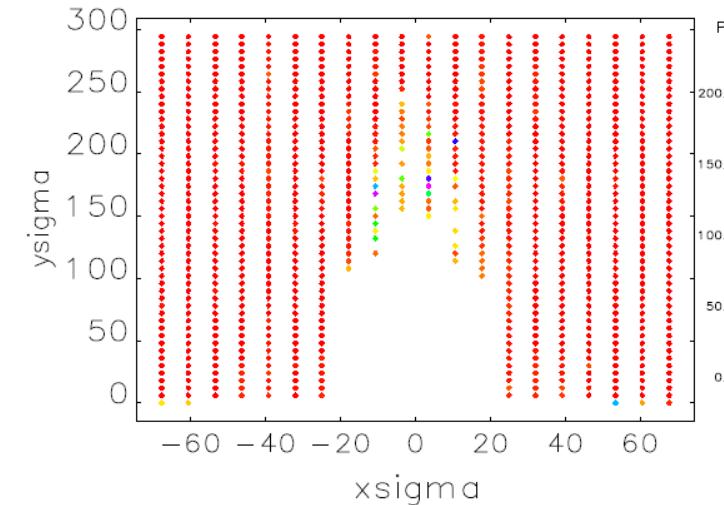
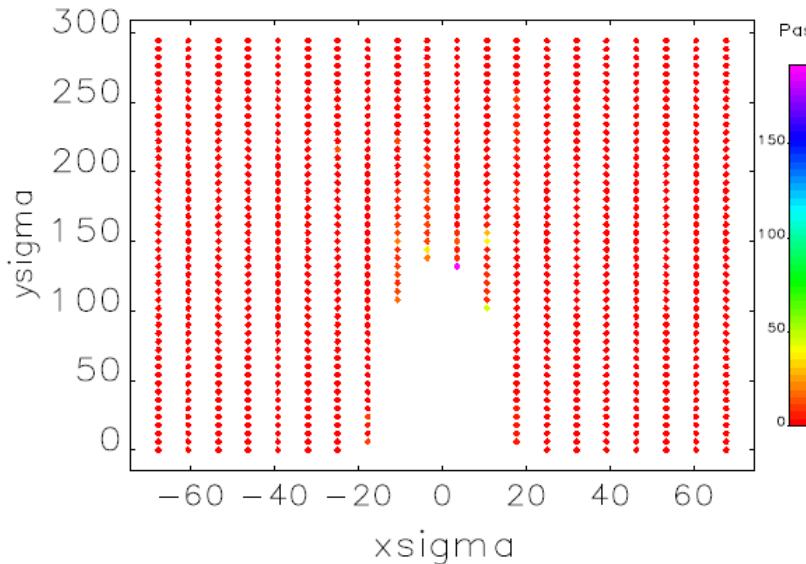


Multipole error in quadrupole magnets

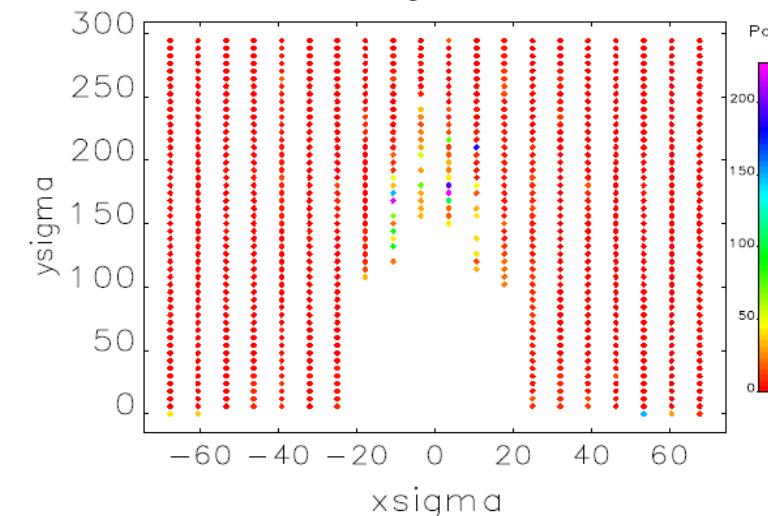
b6 in quadrupoles QA* and QB* (in addition the quadrupoles QC* and QY*) affects strongly DA of lattice z.



$b6=1.0e-5$ in QA*



$b6=1.0e-6$ in QY*



$b6=1.0e-6$ in QC*



Summary of tolerances

error/magnets	Lattice z (10^{-4})	Lattice tt (10^{-4})
b3 in arc dipoles	2	2
b3 in IR dipoles	0.1	1
b3 in arc quadrupoles	10	8
b3 in quadrupoles (QY*)	0.5	8
b3 in quadrupoles (QC*, QT*, QA*), (QB, QG, QH, QL, QR, QU, QI)	1	8
b4 in arc quadrupoles	10	10
b4 in quadrupoles (QC*, QY*)	0.01 – 0.1	0.1
b4 in quadrupoles (QT*, QA*), (QB, QG, QH, QL, QR, QU, QI)	1	1
b5 in IR dipole magnets	0.1	0.5
b5 in IR dipole magnets (BC?L.*)	0.01	0.5
Skew sextupole (a3) in quadrupoles (QC1*, QC2*)	1	5
b6 in arc / IR quadrupoles	5/0.1-0.01	5/1



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Further studying:

- Investigating sextupoles multipole errors
- Repeating the simulations in presence of synchrotron radiation
- Benchmarking the Elegant results with Xsuite code
- Looking for effect of octupole magnets on relieving the effect of multipole errors on DA



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Thank you for your attention