Lattice Design for SuperB

LNF, SLAC, ILC DR group, KEK?

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The 12th KEKB Review

Topics

- Strategy of SuperB
- Machine parameters
- Lattice issues and Final Focus
- Dynamic aperture
- Summary

Low Emittance and Low Beta Scheme

SuperB Workshop at LNF

- Luminosity:

$$L \propto \frac{N \cdot \xi_y}{\beta_y}$$

- Small emittance and large crossing angle $(2\phi_x << 1)$ to make large Piwinski angle:

$$\varphi = \frac{\sigma_z}{\sigma_x}\tan\phi_x \approx \frac{\sigma_z \cdot \phi_x}{\sigma_x}$$

ϕ_x: Half crossing angle

- Beam-Beam parameters in the case of $\varphi >> 1$:

$$\xi_x \propto \frac{N \cdot \beta_x}{\left(\sigma_x \sqrt{1+\varphi^2}\right)^2} \approx \frac{N}{\left(\sigma_z \phi_x\right)^2}\beta_x$$

$$\xi_y \propto \frac{N \cdot \beta_y}{\sigma_y \sigma_x \sqrt{1+\varphi^2}} \approx \frac{N}{\sigma_z \phi_x}\sqrt{\frac{\beta_y}{\varepsilon_y}}$$

- If N increases proportionally to $\sigma_z\phi_x$, ξ_y is constant and luminosity increases with $\sigma_z\phi_x$. ξ_x decreases with $1/\sigma_z\phi_x$.
(if β_x, β_y/ε_y are constant)

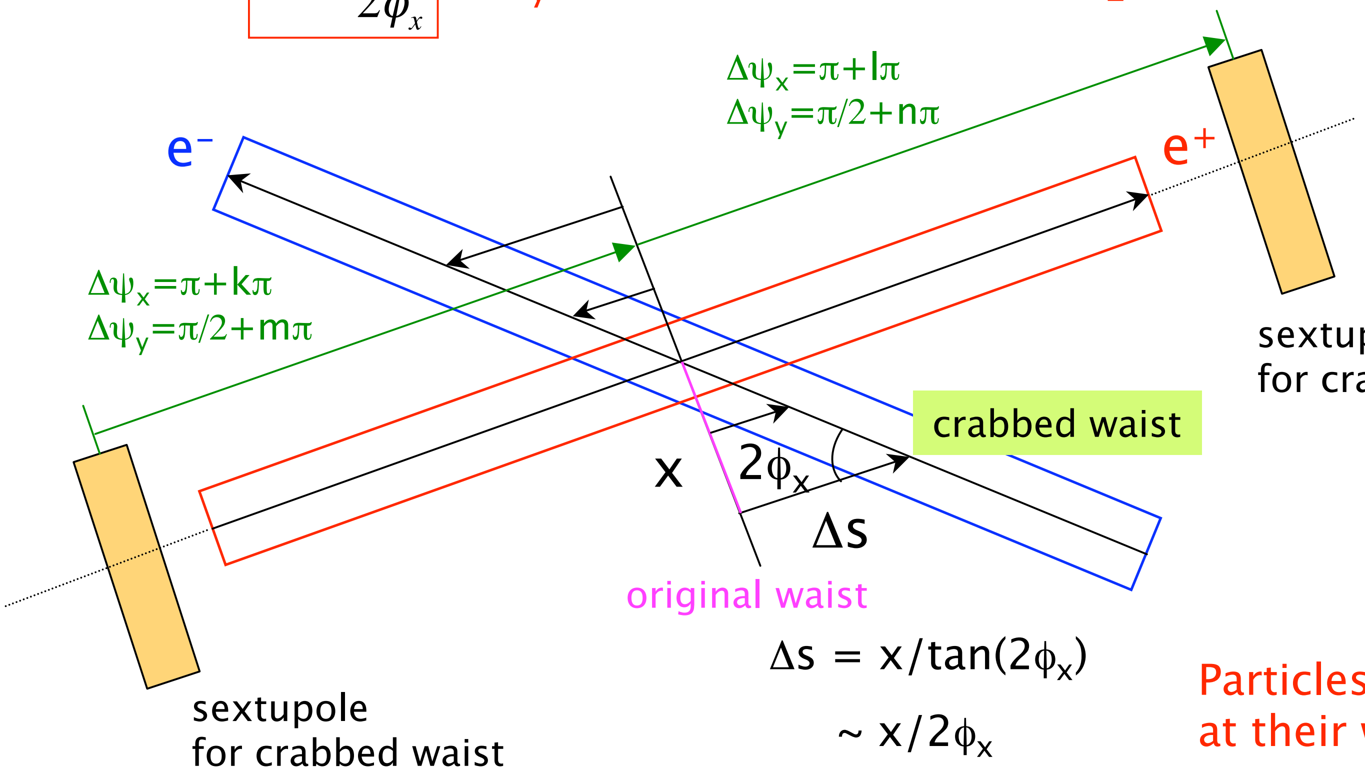
Crabbed Waist Scheme

- Waist position is adjusted by kick from sextupoles to suppress hourglass effect. ➡ $\Delta s \sim x/2\phi_x$
- Small σ_x and large ϕ_x
- Overlap area(longitudinal) of colliding bunches is $\sigma_x/2\phi_x$.

$$\beta_y \geq \frac{\sigma_x}{2\phi_x}$$

β_y can be small, while σ_z is free.

Shift of waist:
$\Delta s = x/2\phi_x$



k+l=even, m+n=odd
or
k+l=odd, m+n=even

$\Delta s = x/\tan(2\phi_x)$

$\sim x/2\phi_x$

Particles collide another beam at their waist point.

Comparison of Machine Parameters

		SuperB (Upgrade)	SuperKEKB (2006)	
Emittance	ε_x	0.8	9	nm
Horizontal beta	β_x^*	20	200	mm
Vertical beta	β_y^*	0.2	3	mm
Horizontal beam size	σ_x^*	4	42	μm
Bunch length	σ_z	6	3	mm
Half crossing angle	ϕ_x	17	15	mrad
Piwinski angle	φ	25.5	1	rad
Current(LER/HER)	I_b	3.95/2.17	10.4/4.4	A
Luminosity ($x10^{35}$)	L	24	8.25	$cm^{-2}s^{-1}$

Machine Parameters of SuperB

SuperB CDR

Parameter	Nominal		Upgrade		Ultimate		Unit
	LER	HER	LER	HER	LER	HER	
Energy	4	7	4	7	4	7	GeV
Luminosity	1×10^{36}		2.4×10^{36}		3.4×10^{36}		$cm^{-2}s^{-1}$
Beam current	2.28	1.3	3.95	2.17	4.55	2.6	A
Number of bunches	1733		3466				
Emittance $\varepsilon_x/\varepsilon_y$	1.6/0.004		0.8/0.002				nm
Beta β_x^*/β_y^*	20/0.3		20/0.2				mm
Beam size σ_x^*/σ_y^*	5.7/0.035		4/0.020				μm
Bunch length σ_z	6						mm
Full crossing angle $2\phi_x$	34						mrad
Momentum spread σ_δ	8.4×10^{-4}	9×10^{-4}	1×10^{-3}				
Momentum compaction α_p	1.8×10^{-4}	3×10^{-4}	1.8×10^{-4}	3×10^{-4}	1.8×10^{-4}	3×10^{-4}	
Total V_c	6	18	6	18	7.5	18	MV
Energy loss U_0	1.9	3.3	2.3	4.1	2.3	4.1	MeV
Damping time τ_x/τ_s	32/16		25/12.5				msec

Small beam currents are attractive!

Characteristics of Ring

- Extremely small emittance

ε_x = 0.8 nm

- Extremely small beta function at IP

β_x/β_y=20mm/200μm

- Large crossing angle at IP

$2\phi_x$=34 mrad

- Long bunch length

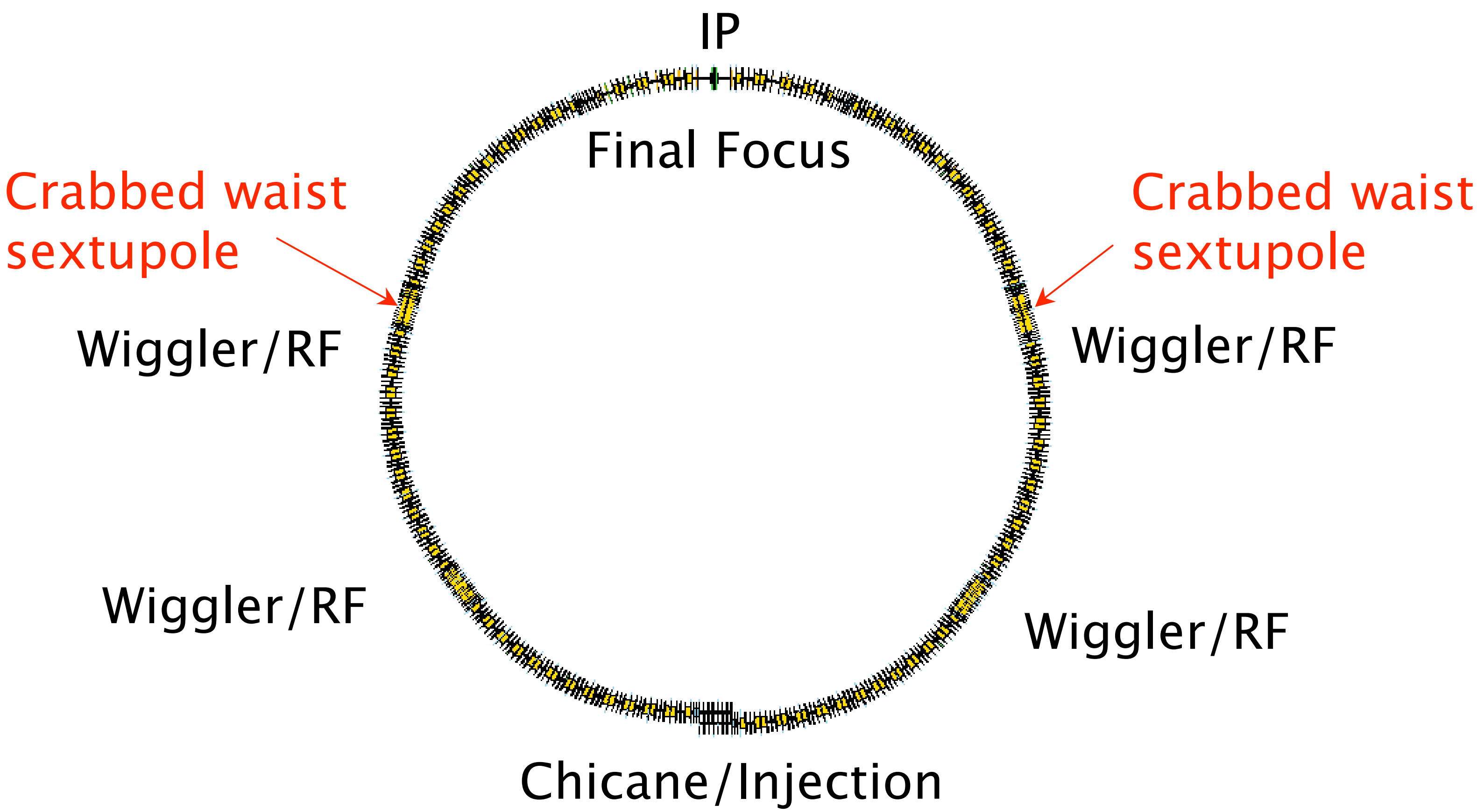
σ_z=6 mm

- Crabbed waist optics

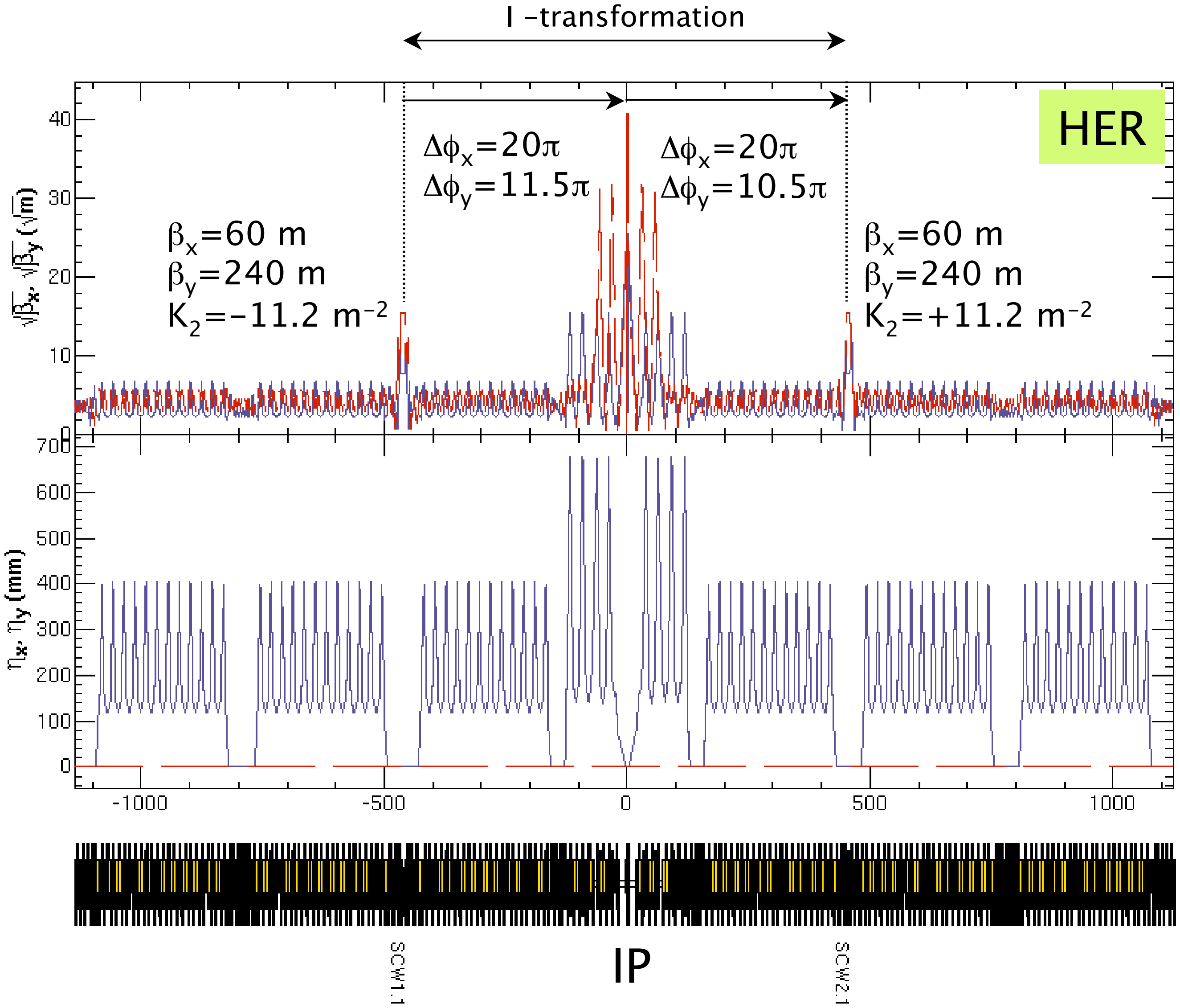
Strong sextupole pair at high beta region
Need proper phase advance to IP

Layout of Ring

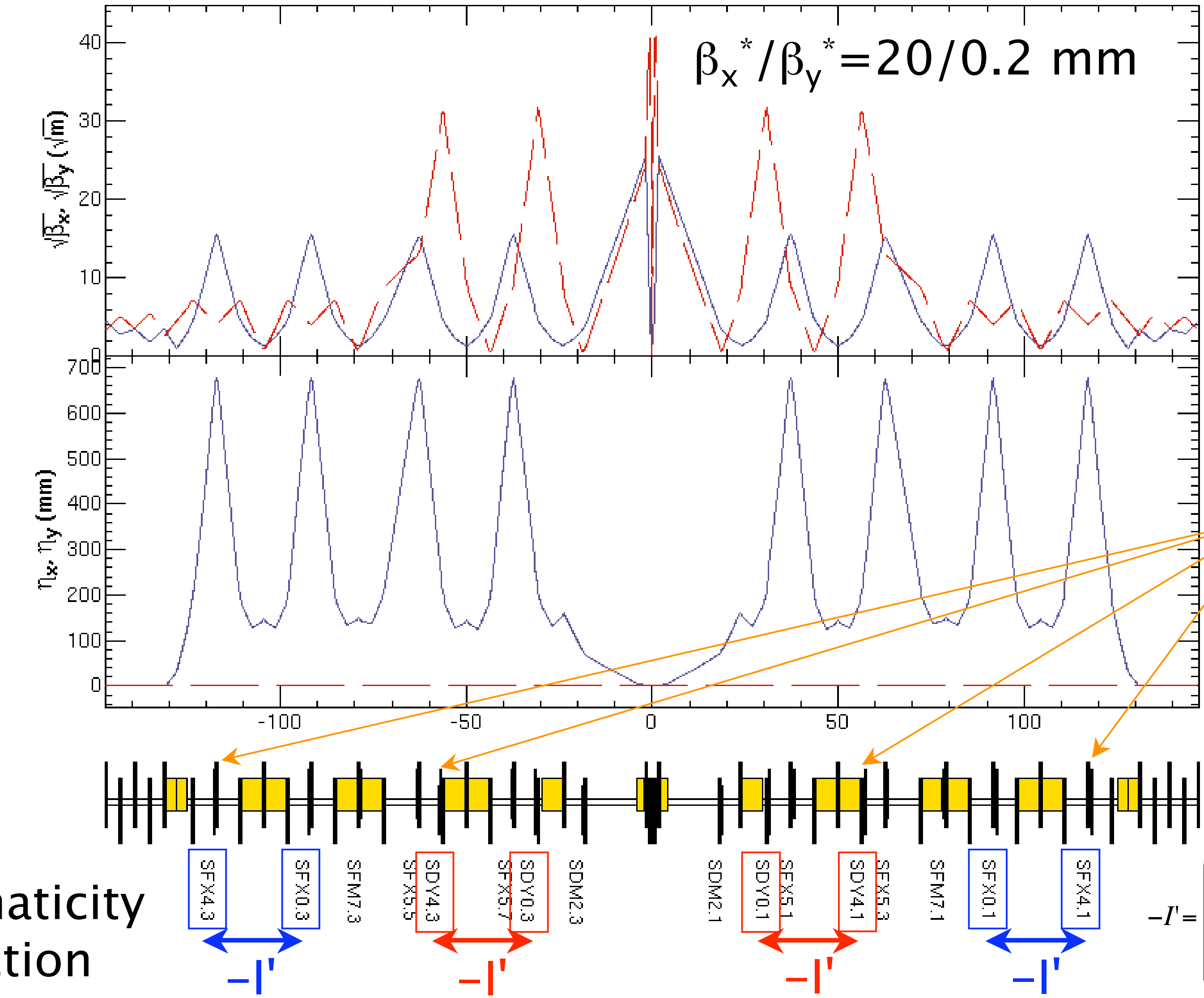
Circumference ~2.3 km



SuperB Lattice with Crabbed Waist



Lattice Design of Final Focus



Octupole magnets

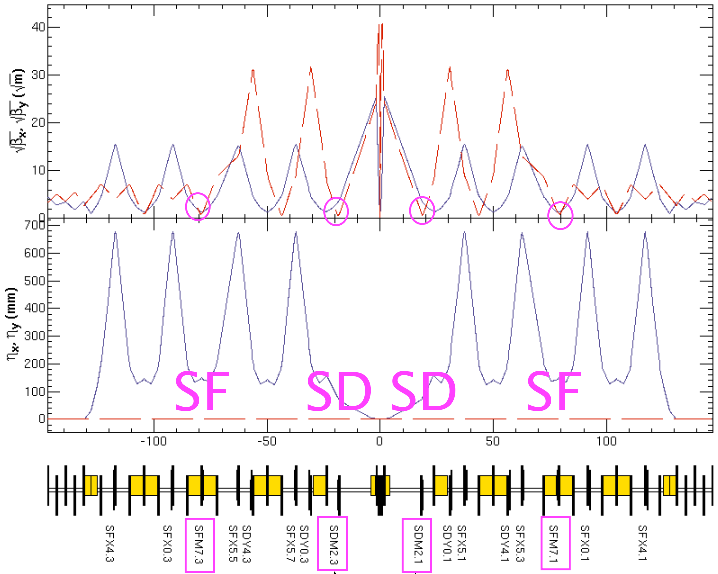
P. Raimondi

Local Chromaticity Correction

$$-I' = \begin{pmatrix} -1 & 0 & 0 & 0 \\ m_{21} & -1 & 0 & 0 \\ 0 & 0 & -1 & 0 \\ 0 & 0 & m_{43} & -1 \end{pmatrix}$$

Lattice Design of Final Focus (cont'd)

$\Delta p/p_0 = 0\ \%$

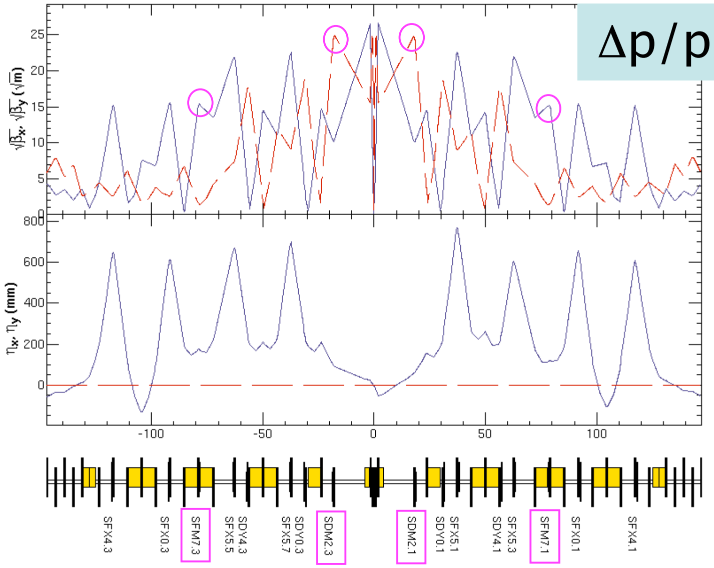


P. Raimondi

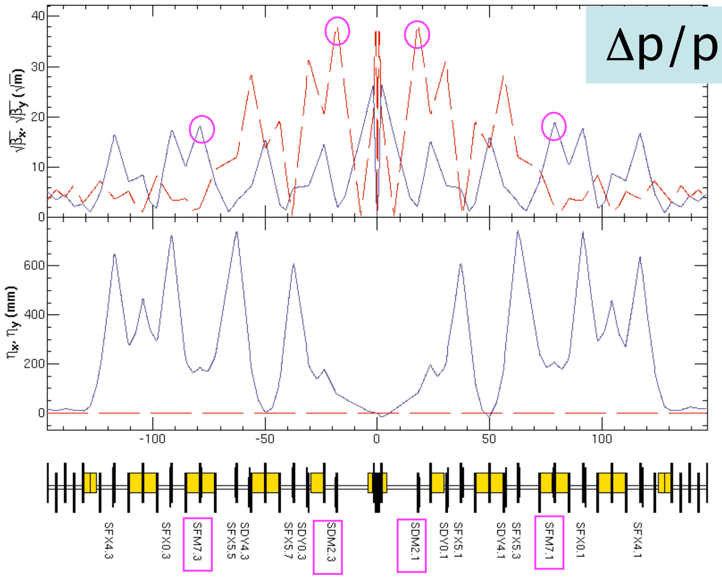
IP phase sextupoles

Small beta at on-momentum
becomes large at off-momentum.

$\Delta p/p_0 = +2\ \%$

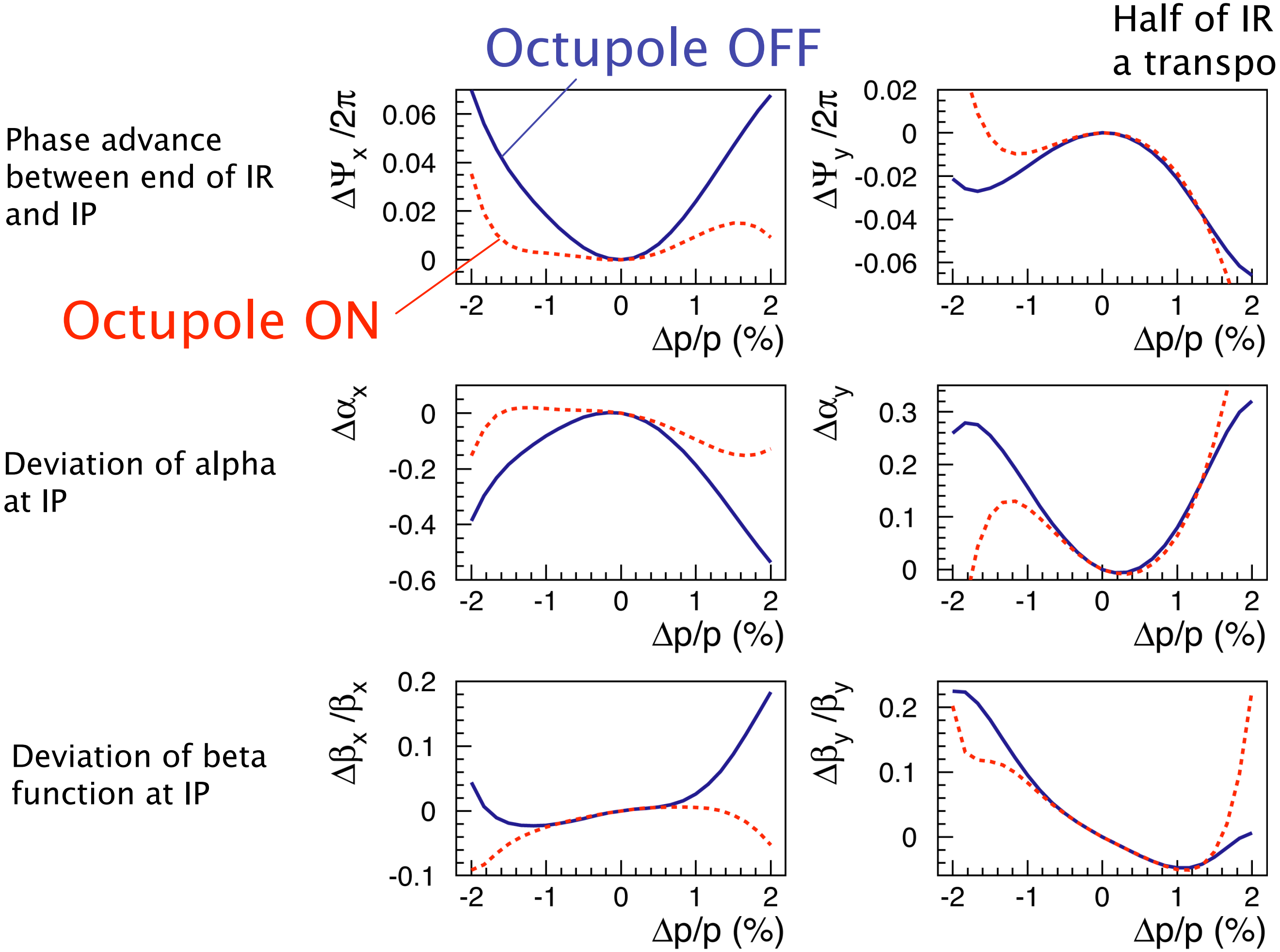


$\Delta p/p_0 = -2\ \%$



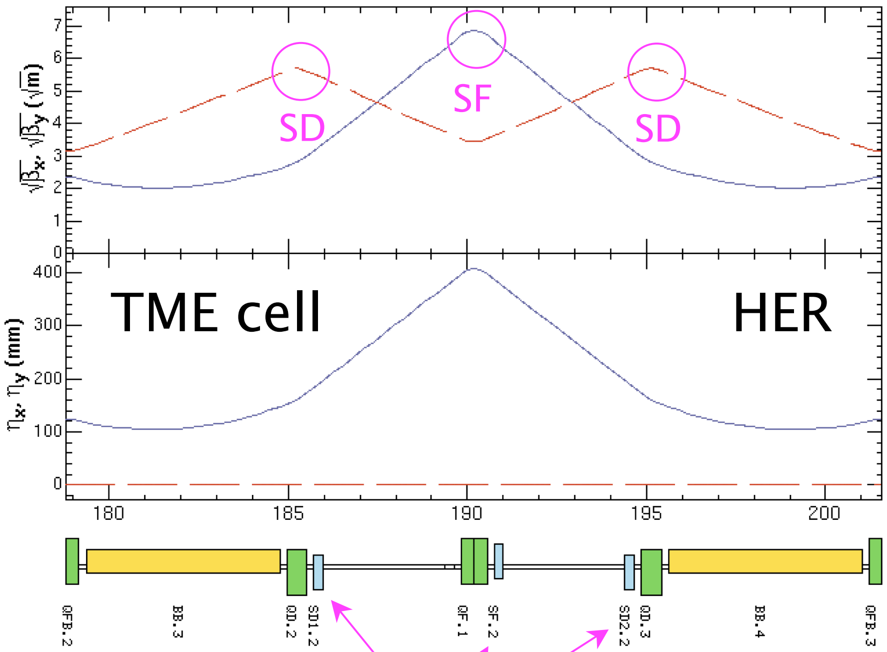
Chromatic Effect in Final Focus

Half of IR are considered to be a transport line.



The second order chromaticity can be corrected by octupoles.

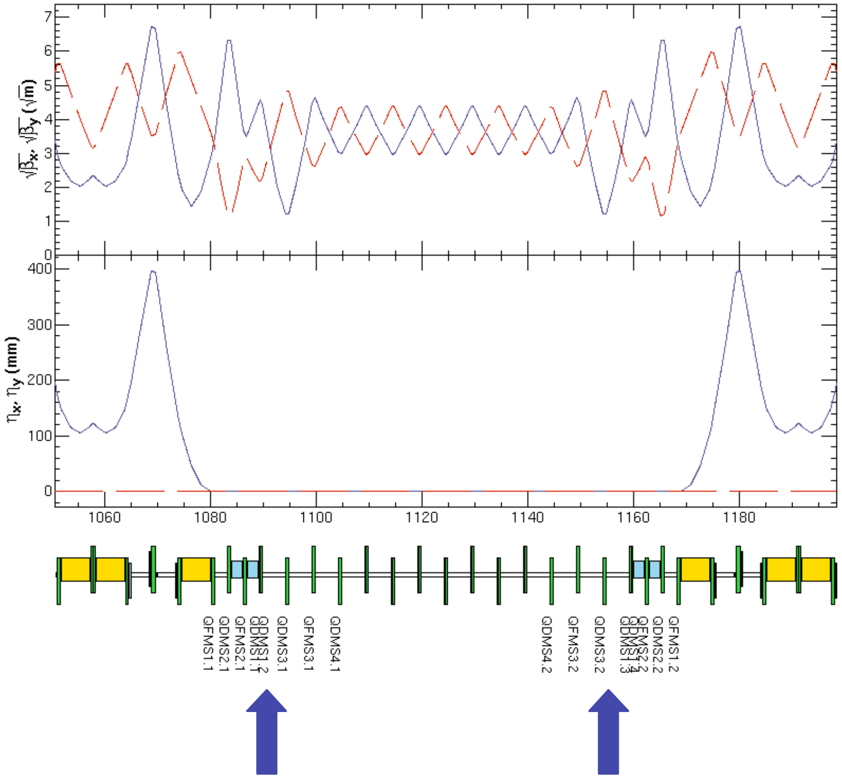
Arc Cells and Opposite Section of IP



M. Biagini

Beta becomes large at sextupoles.

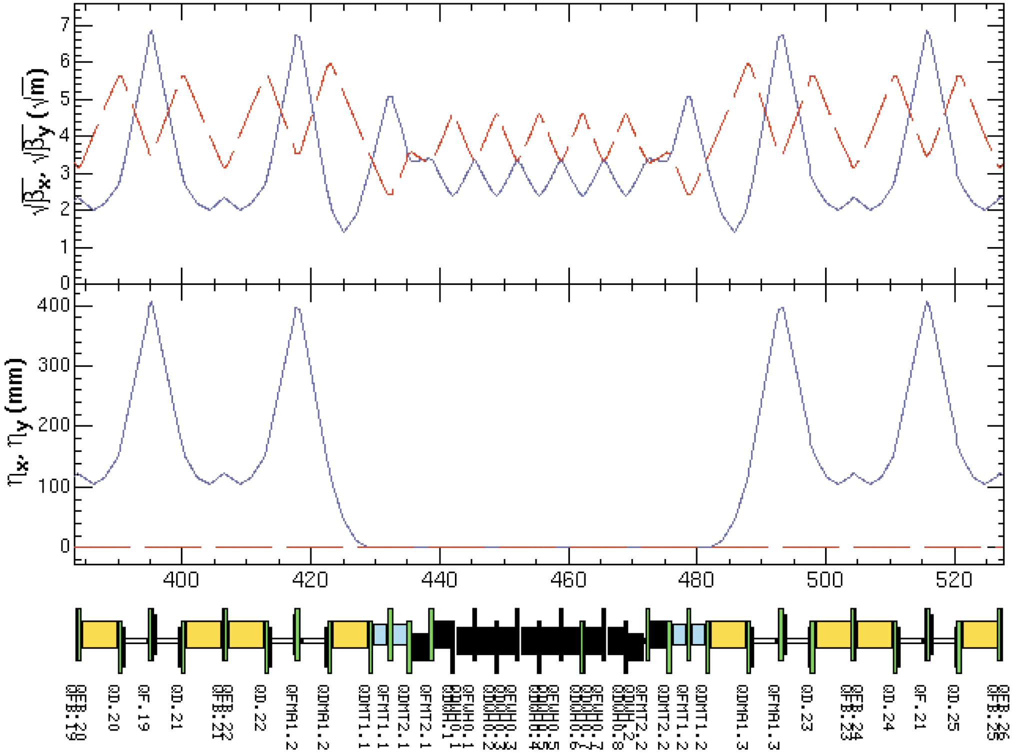
12 cells x 6 arcs
=72 cells in a ring



Betatron tunes are adjusted with 7 quadrupole families.

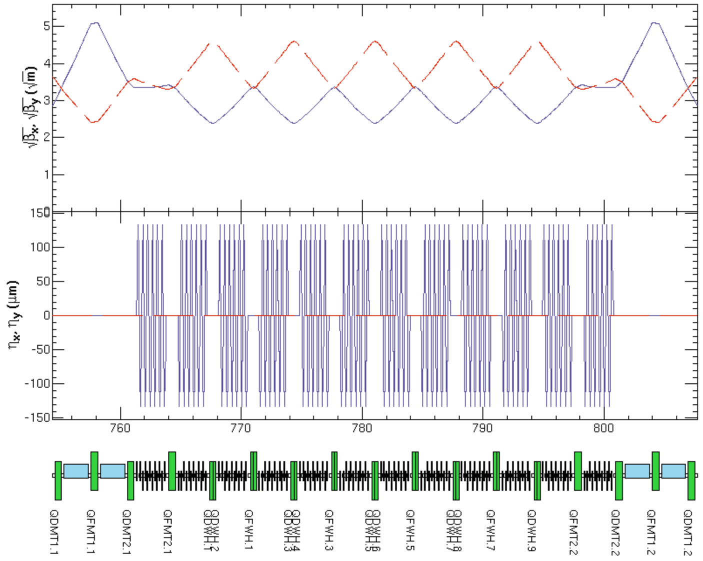
$\Delta\nu_x \sim \pm 0.5$
$\Delta\nu_y \sim \pm 0.5$

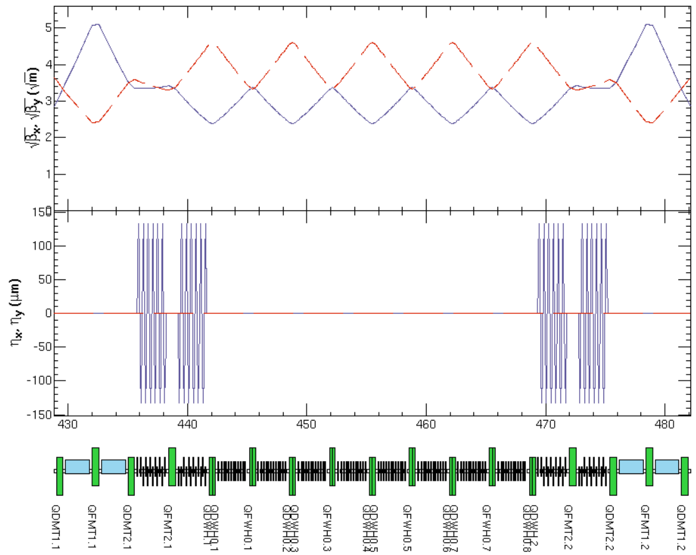
Wiggler/RF Straight Section



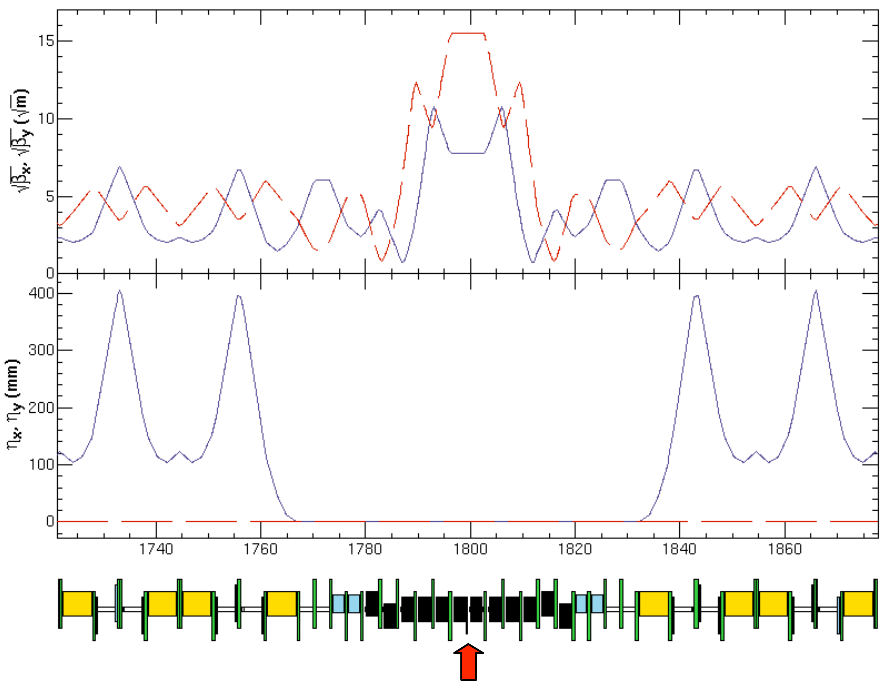
λ_p=0.4 m / B_0=0.83 T

Lattice design is similar to the ILC damping ring.



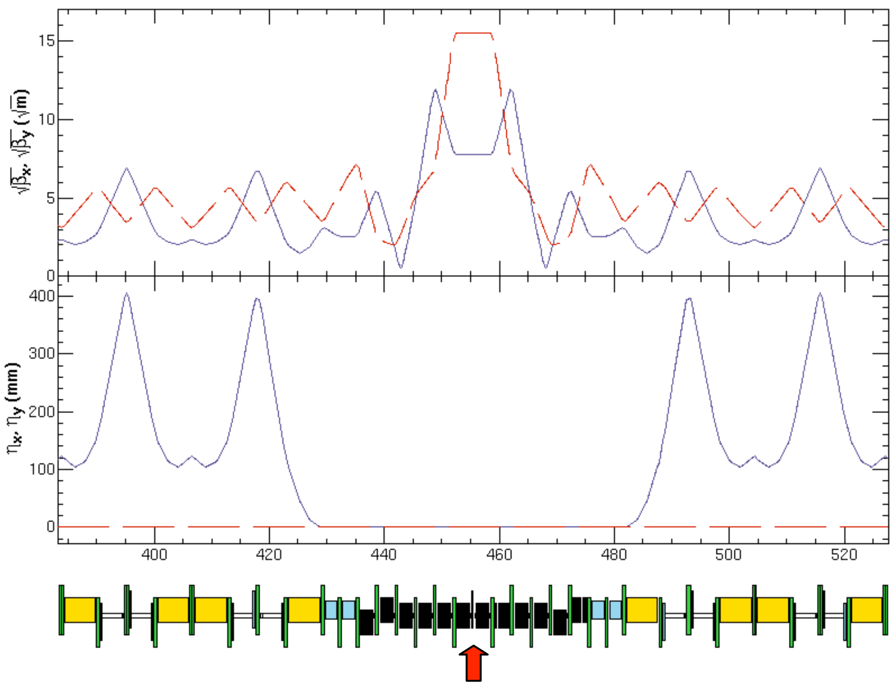


Sextupoles for Crabbed Waist



SCW1

$\psi_x{}^* - \psi_x = 20\pi$
$\psi_y{}^* - \psi_y = 11.5\pi$
$\beta_x/\beta_y = 60/240$ m
$K_2 = -11.2\ \mathrm{m}^{-2}$



SCW2

$\psi_x - \psi_x{}^* = 20\pi$
$\psi_y - \psi_y{}^* = 10.5\pi$
$\beta_x/\beta_y = 60/240$ m
$K_2 = +11.2\ \mathrm{m}^{-2}$

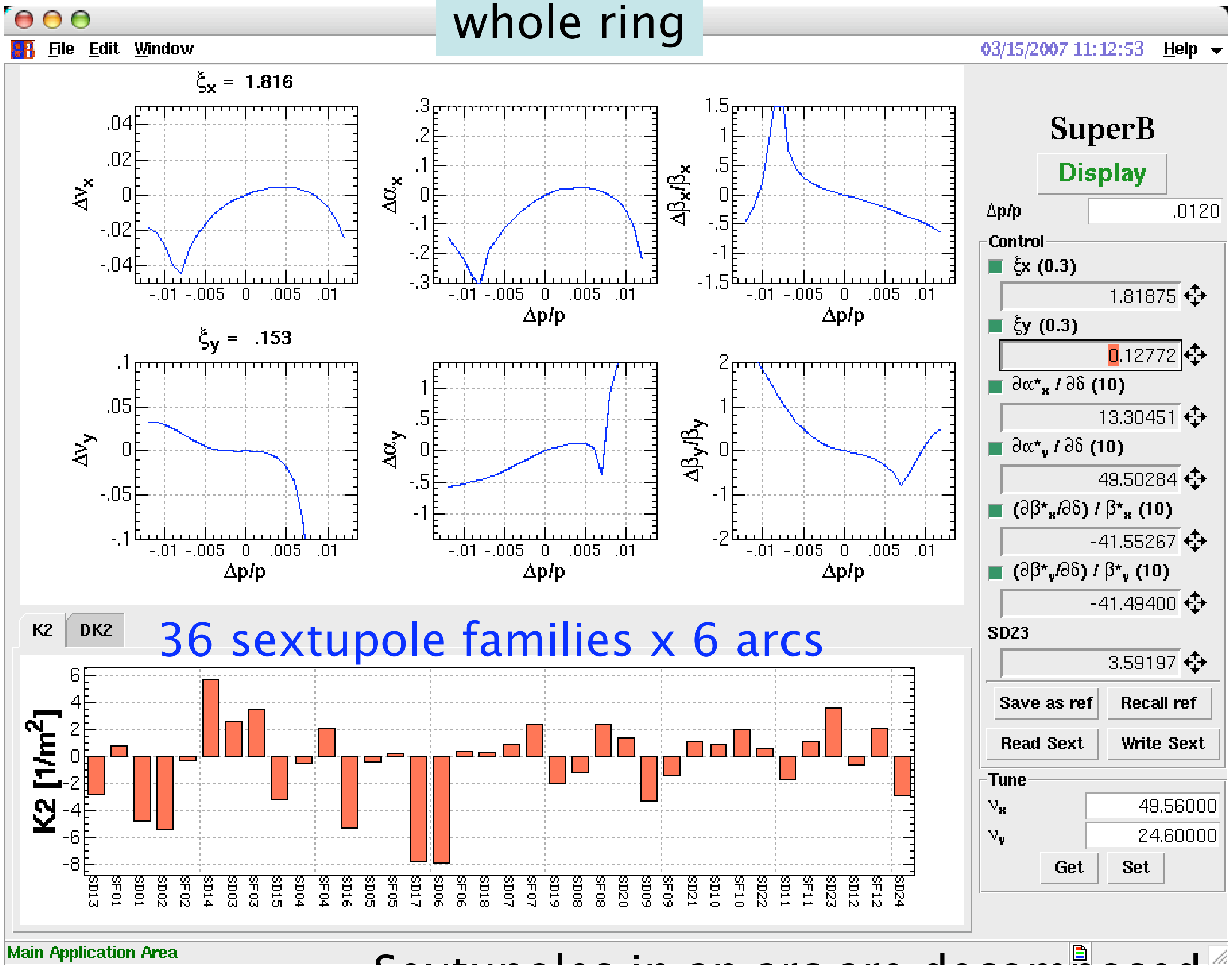
Required K_2:
(only for 2 sextupoles)

$$K_2 = \frac{1}{2\phi_x \beta_y^* \beta_{y,sext}} \sqrt{\frac{\beta_x^*}{\beta_{x,sext}}}$$

Chromaticity Correction with Crabbed Waist

whole ring

HER

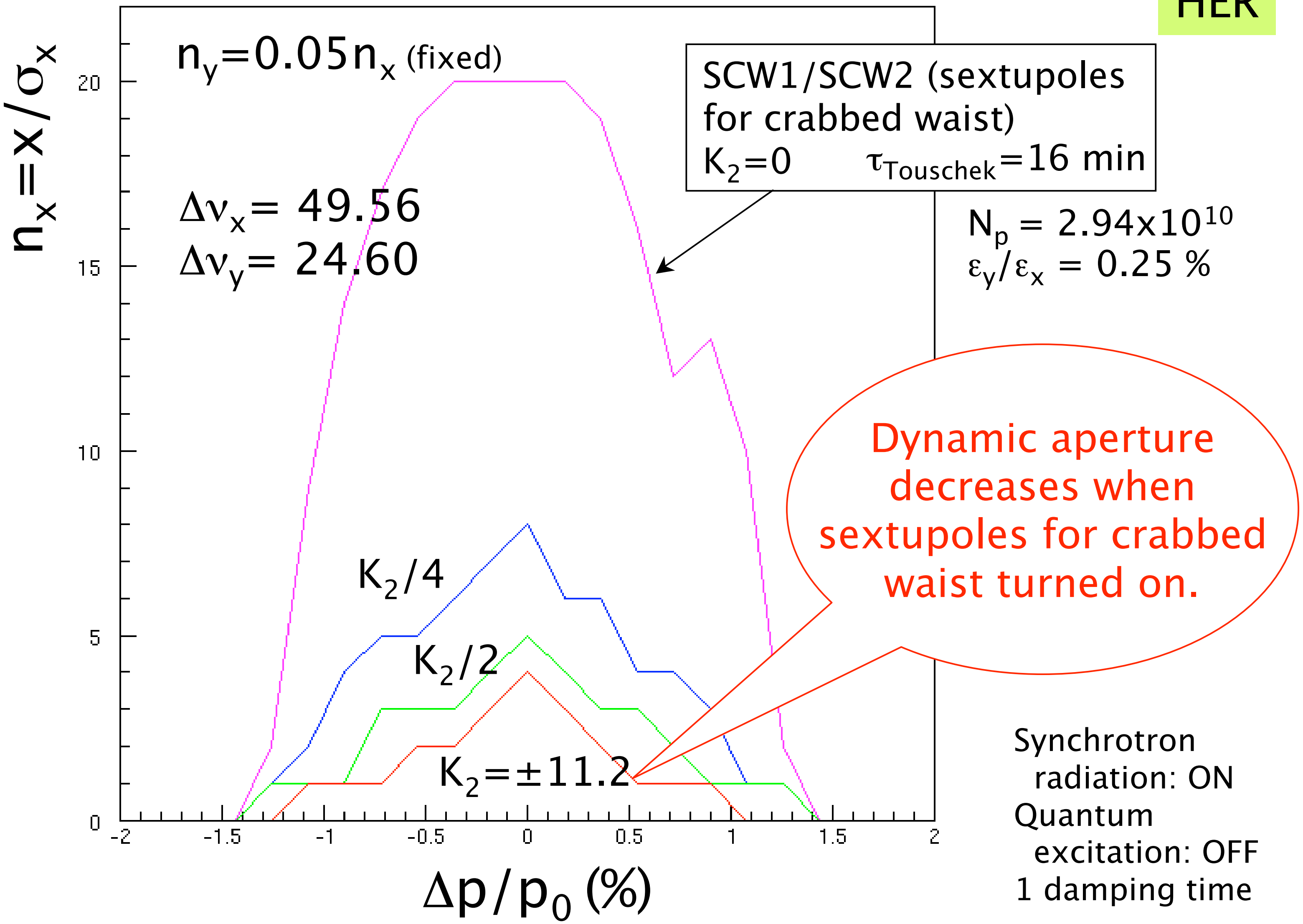


36 sextupole families x 6 arcs

Sextupoles in an arc are decomposed.

Dynamic Aperture

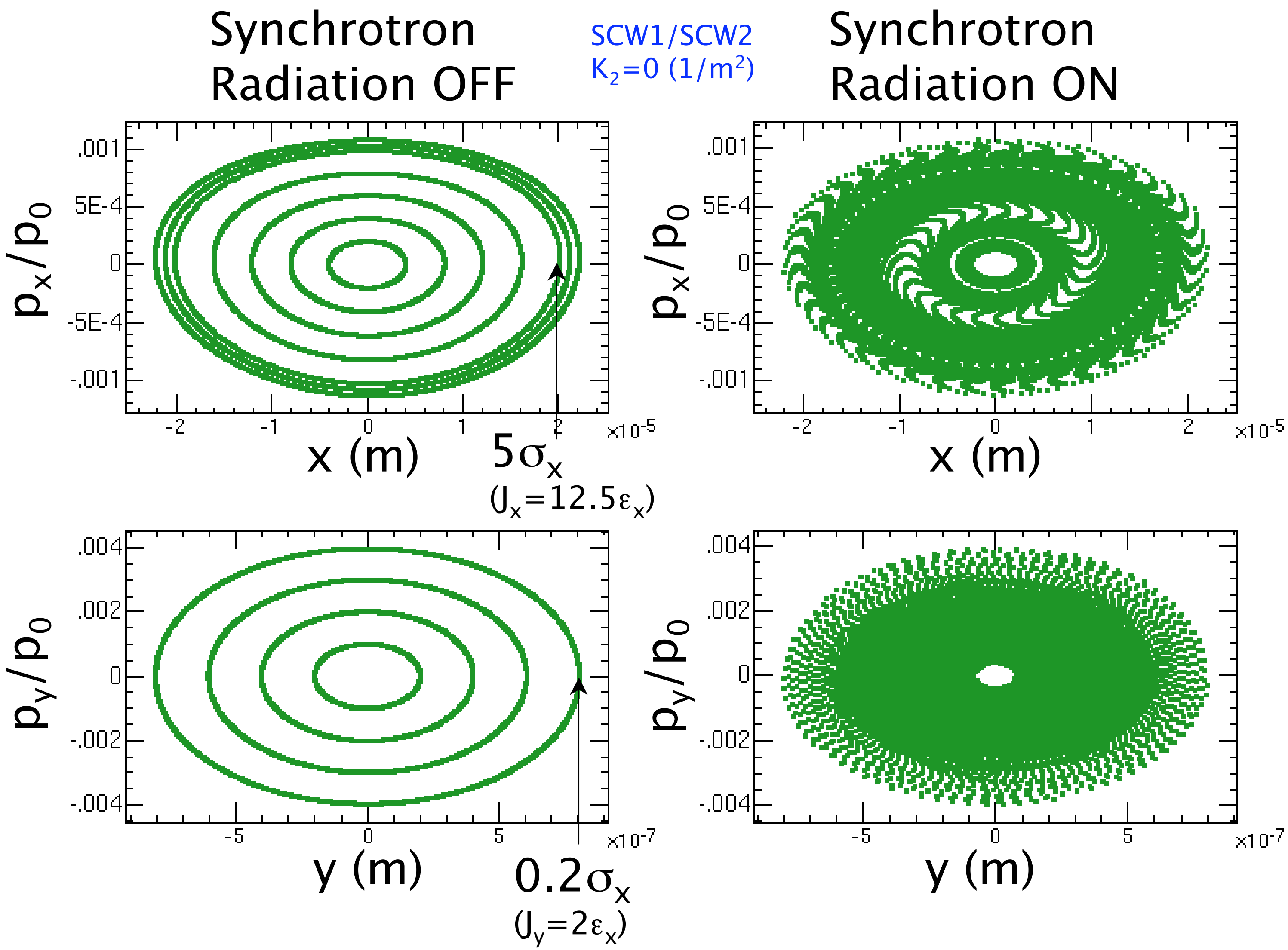
HER



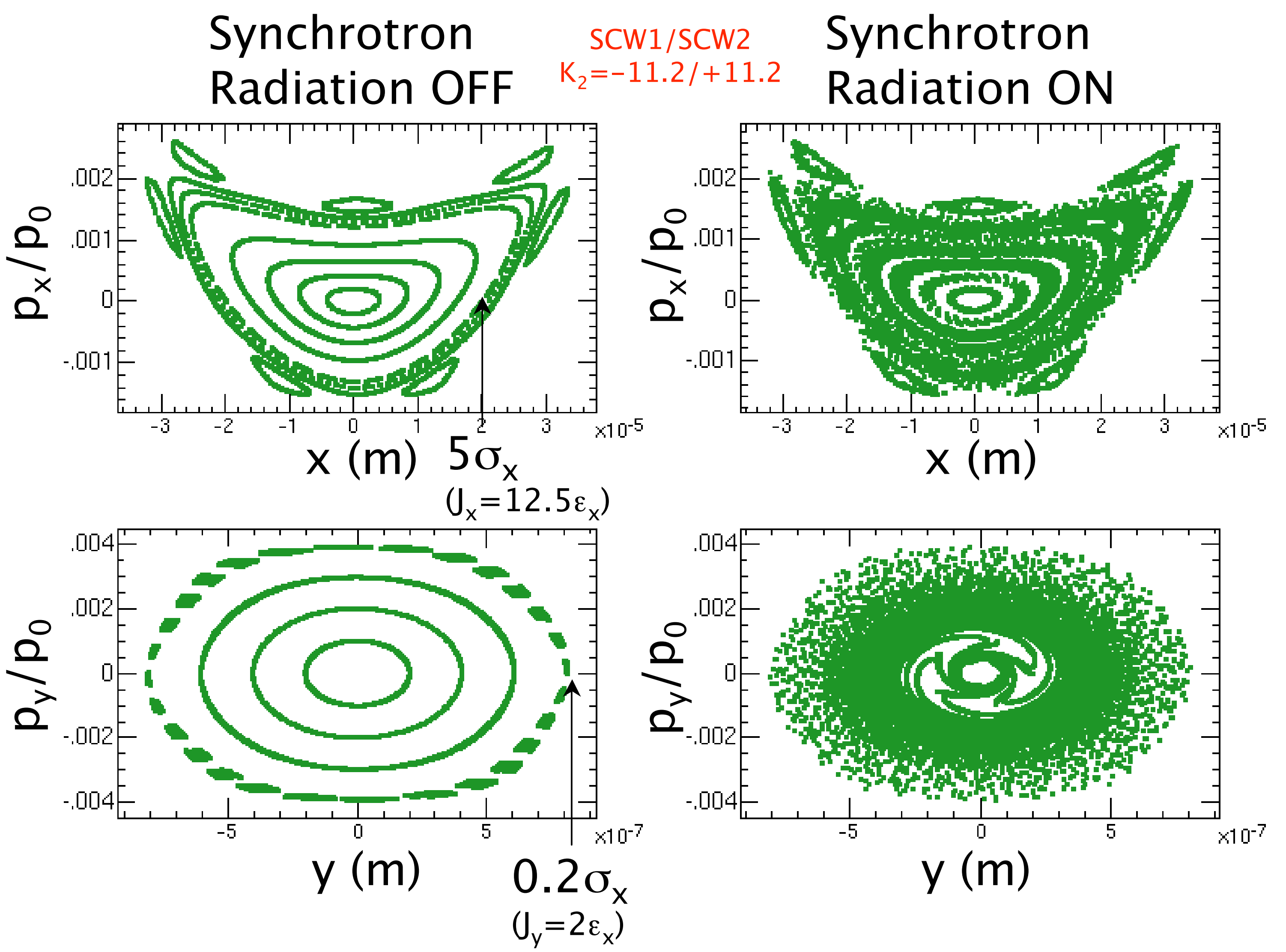
$N_p = 2.94 \times 10^{10}$
$\varepsilon_y/\varepsilon_x = 0.25$ %

Synchrotron radiation: ON
Quantum excitation: OFF
1 damping time

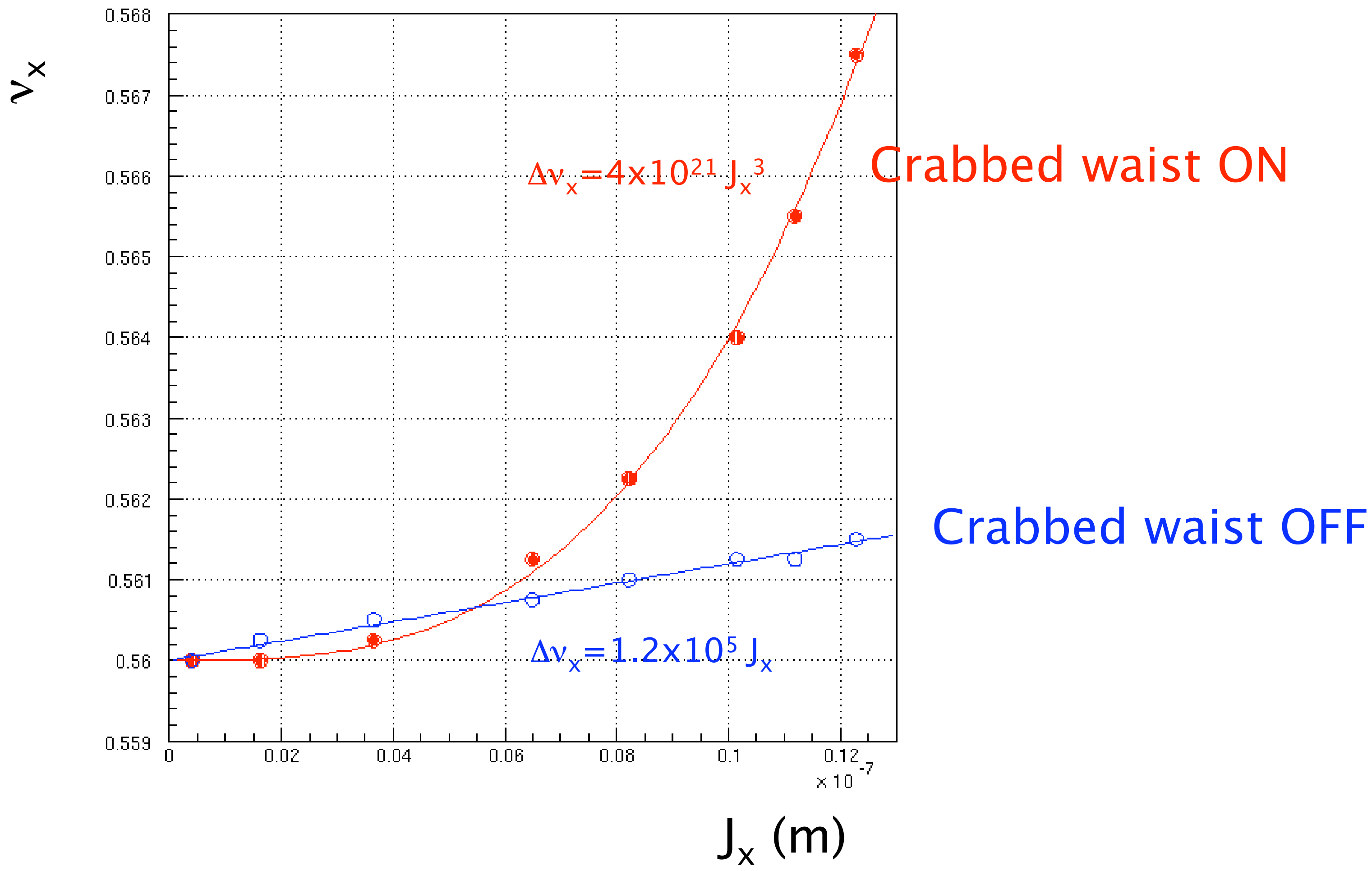
Phase Space: Crabbed Waist OFF



Phase Space: Crabbed Waist ON



Amplitude vs Tune dependence



When fringe effects is turned off for all magnets, amplitude dependence is disappeared.
But separatrix is similar and dynamic aperture is not improved at all.

Effects of Sextupoles to IP

Transformation (Sextupole to IP):

$$\exp(-:F_3:)\exp(-:\psi J:) = \exp(-:\psi J:)\exp\left(-:k_x X^3 + k_y XY^2:\right)$$

$$X = \frac{x}{\sqrt{\beta_x}} \qquad P_X = \frac{\alpha_x x + \beta_x x}{\sqrt{\beta_x}} \qquad k_x = \frac{\beta_x^{3/2} K_2}{6} \qquad k_y = \frac{\beta_x^{1/2}\beta_y K_2}{2}$$

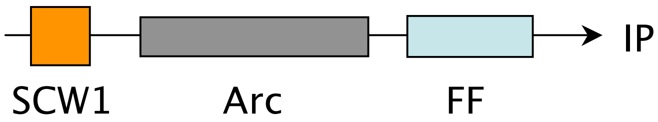
$$F_3 \approx C_{X^3} X^3 + C_{X^2 P_X} X^2 P_X + C_{XP_X^2} XP_X^2 + C_{P_X^3} P_X^3$$
$$+ C_{XY^2} XY^2 + C_{XP_Y^2} XP_Y^2 + C_{XYP_Y} XYP_Y + C_{P_X Y^2} P_X Y^2 + C_{P_X Y P_Y} P_X Y P_Y + C_{P_X P_Y^2} P_X P_Y^2$$

- Coefficient of XP_Y^2 (crabbed waist):

$$C_{XP_Y^2} = \sum_i \frac{\beta_{x,i}^{1/2}\beta_{y,i}K_{2,i}}{6}\left(\frac{1}{2}\cos\psi_{x,i} - \frac{1}{4}\cos\left(\psi_{x,i} - 2\psi_{y,i}\right) - \frac{1}{4}\cos\left(\psi_{x,i} + 2\psi_{y,i}\right)\right)$$

- Coefficient of X^3:

$$C_{X^3} = \sum_i \frac{\beta_{x,i}^{3/2}K_{2,i}}{6}\left(\frac{3}{4}\cos\psi_{x,i} + \frac{1}{4}\cos 3\psi_{x,i}\right)$$



	Crabbed Waist sextupole (SCW1)	Arc(SCW1→IR)+FF sextupoles
X^3	65 ↔	12
XP_Y^2	2227	148

*Sextupoles in FF are connected with –I'.

Summary

- Lattice of SuperB is designed for:
  - very small emittance;
  - Final Focus with very small beta functions at IP;
  - use of the PEP-II available magnets as much as possible.
- Crabbed waist is one of the most important issues.
- Dynamic aperture without crabbed waist sextupoles is fairly good as far as squeezing beta at IP very small.
- Dynamic aperture with crabbed waist is reduced by ~1/5(depends on strength of crabbed waist sextupoles). On-momentum aperture becomes small.
- In the crabbed waist scheme, good solution to keep large dynamic aperture has not been found so far.
  - Nonlinearity limits the dynamic aperture.
- How to control the nonlinearity ? Combination of sextupoles can cancel it ? This issue is under study.