Undulator Models and the Use of Long Straight Sections in the SPring-8 Storage Ring

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Contents

ID Model

- For simulation with small amplitudes

=> Halbach-type ID model will be enough.

- For simulation with large amplitudes, e.g. for simulation of beam injection

=> ID model with nonlinear fields adequate in a wide range of aperture is needed as an input of simulation code.

=> Also useful in analysis of some special (complicated) IDs

Use of 30m-LSS

- SPring-8 storage ring has four 30m-LSS in addition to normal straight sections. A long undulator is already installed and there remain three sections for innovative light sources for future use.
- Independent local tuning of lattice functions is required.

=> Dynamic aperture and momentum acceptance must be kept large.

Halbach-Type Model

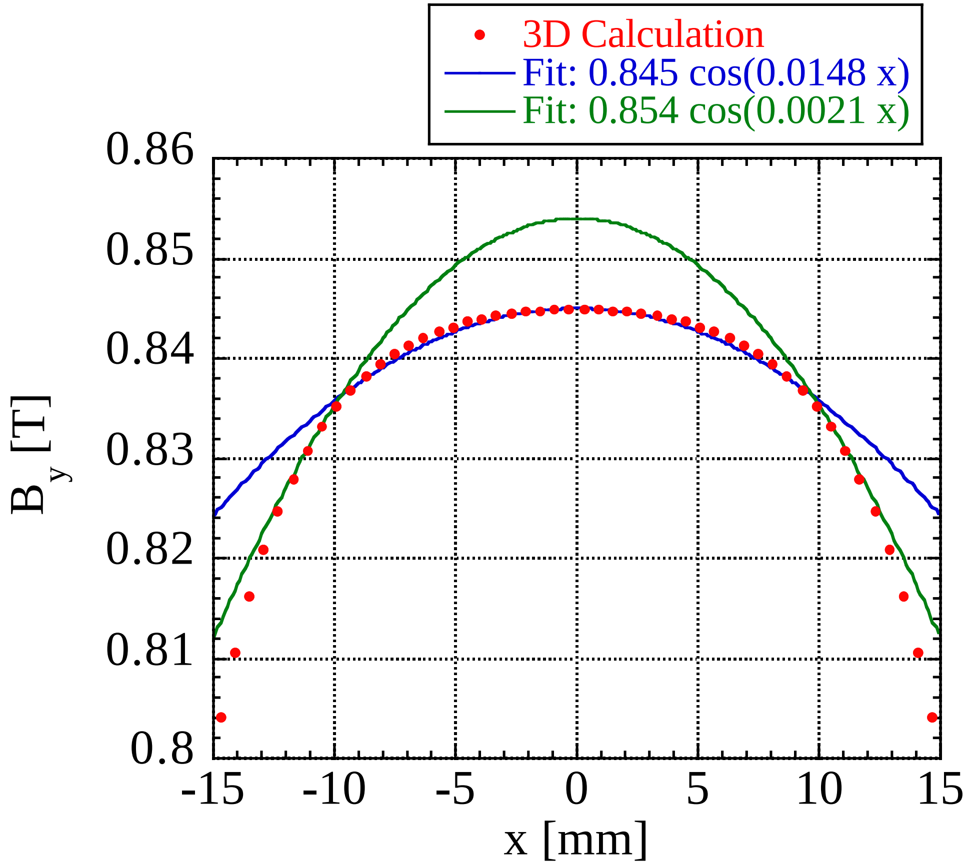
Example:

Magnetic Field of ID15

B_y = Acos(kx)

on median plane ($y=0$, $z=z_0$)

cf. E.Forest and K.Ohmi, KEK Report 92-14



by H.Tanaka

Amplitude of injected beam is about 10mm. Halbach-type model fits only locally and we need to extend the model.

Our Method

- **Put multipole thin lens at both ends of ID.**
- **Prepare 3D magnetic field data on appropriate mesh points.**
  (The field data is generated by our code or given as an input file and interpolated.)
- **Trace the elctron trajectory from the entrance to the exit of ID by solving the equation of motion.**
  (We used the Runge-Kutta of 4th order with 10mm step.)
- **Change the initial position and repeat to get mapping data.**
- **Fit the strengths of multipoles so that $(x, x', y, y')_{exit}$ is reproduced.**

We checked that the results are almost independ of the number of thin lens positions. So we put multipole thin lens at the entrance and exit of ID.

Example: ID17

Multi-Operation Mode Undulator:

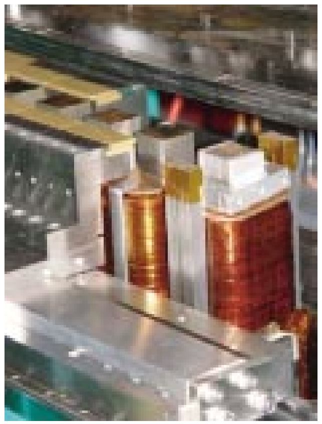
Figure-8 Mode → H / V Polarization

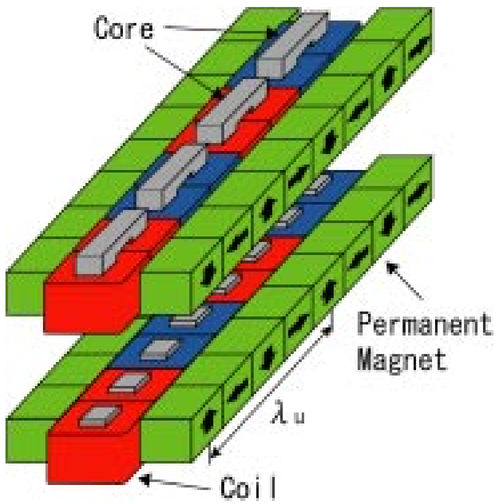
Helical Mode → Circ. Polarization

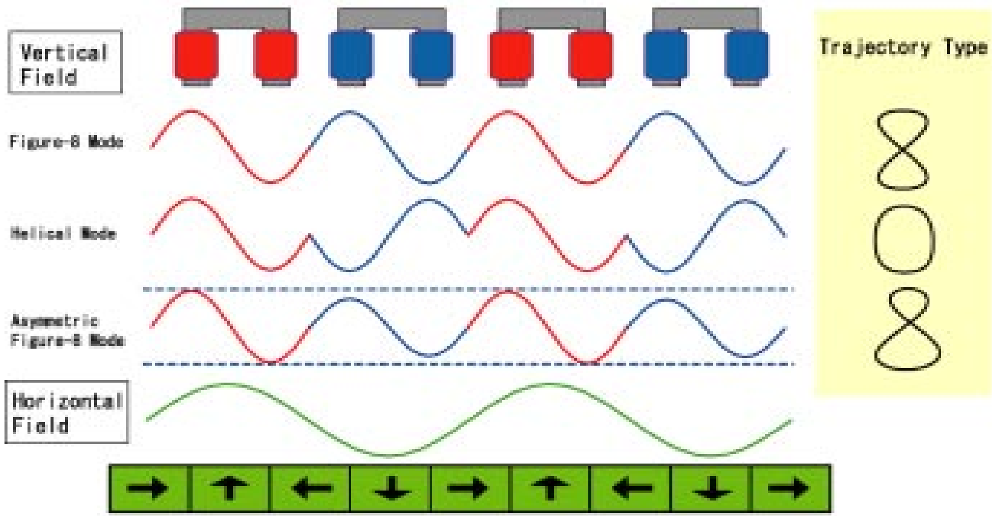
Asymmetric Figure-8 Mode

→ Fast Helicity Switching (>10Hz)

Total length	4.5m
Period length	13cm / 26cm
Number of periods	32 / 16
Gap	20mm
Maximum Ky (coil current)	5.0 (200A)
Maximum Kx	2.75







ID17 is now under tuning!

by K.Shirasawa

Magnetic Field of ID17

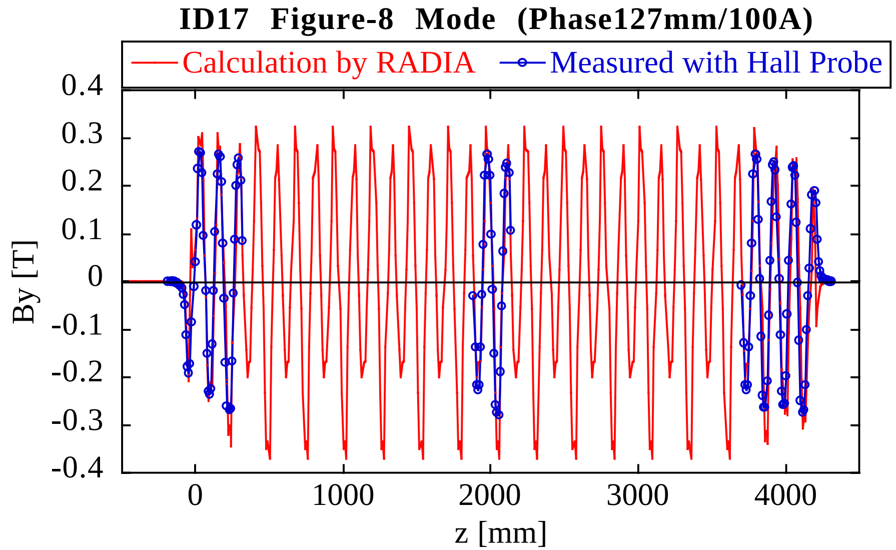
For 3D field calculations we used:

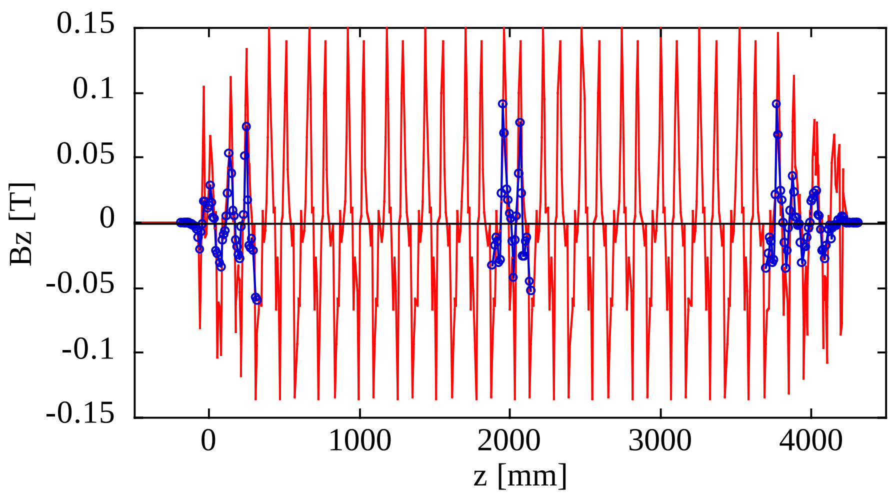
(1) our own code for IDs w/o iron yoke

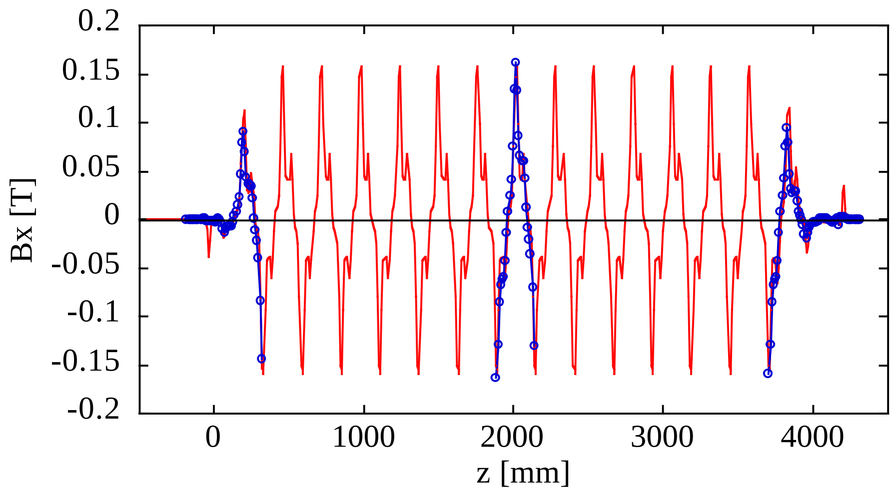
(2) RADIA developed at the ESRF

by P.Elleaume, et.al.

⇒ Calculate for 3 cells and repeat the data in the middle.



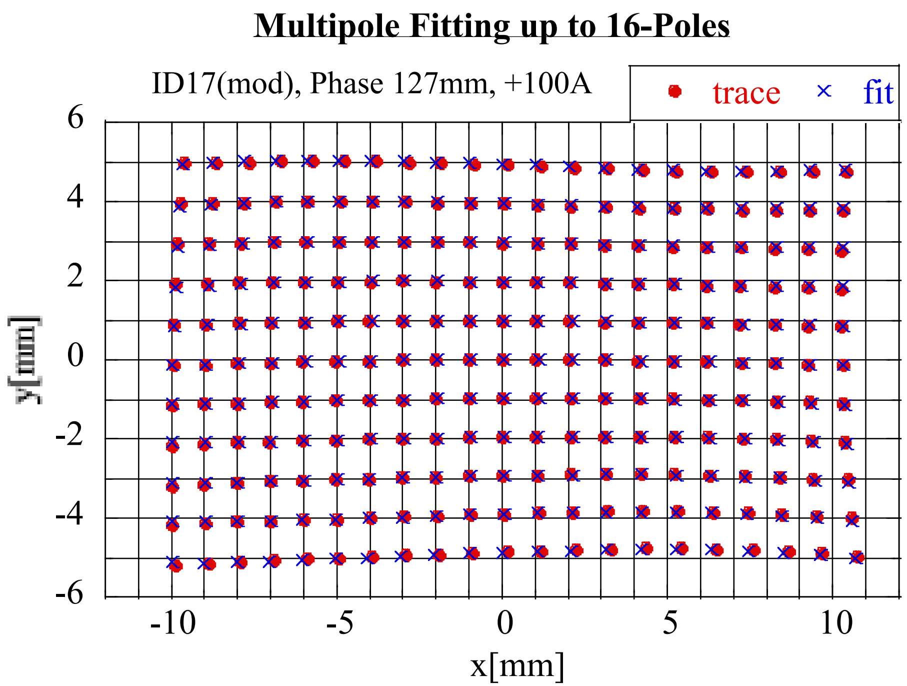


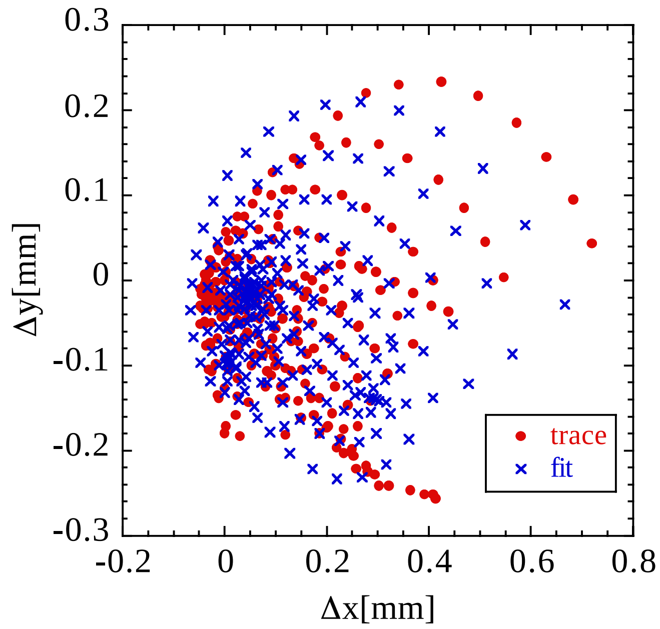


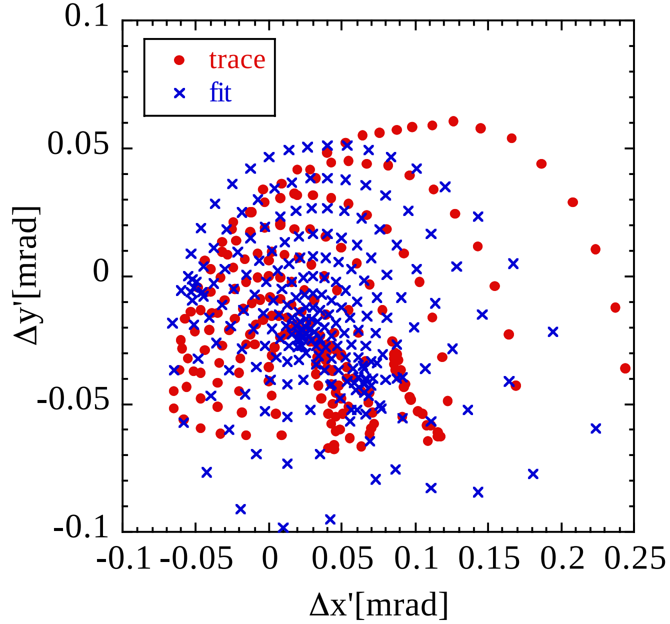
(example field data along off-axis at x=4mm, y=2mm)

by K.Shirasawa

Example of Multipole Fitting





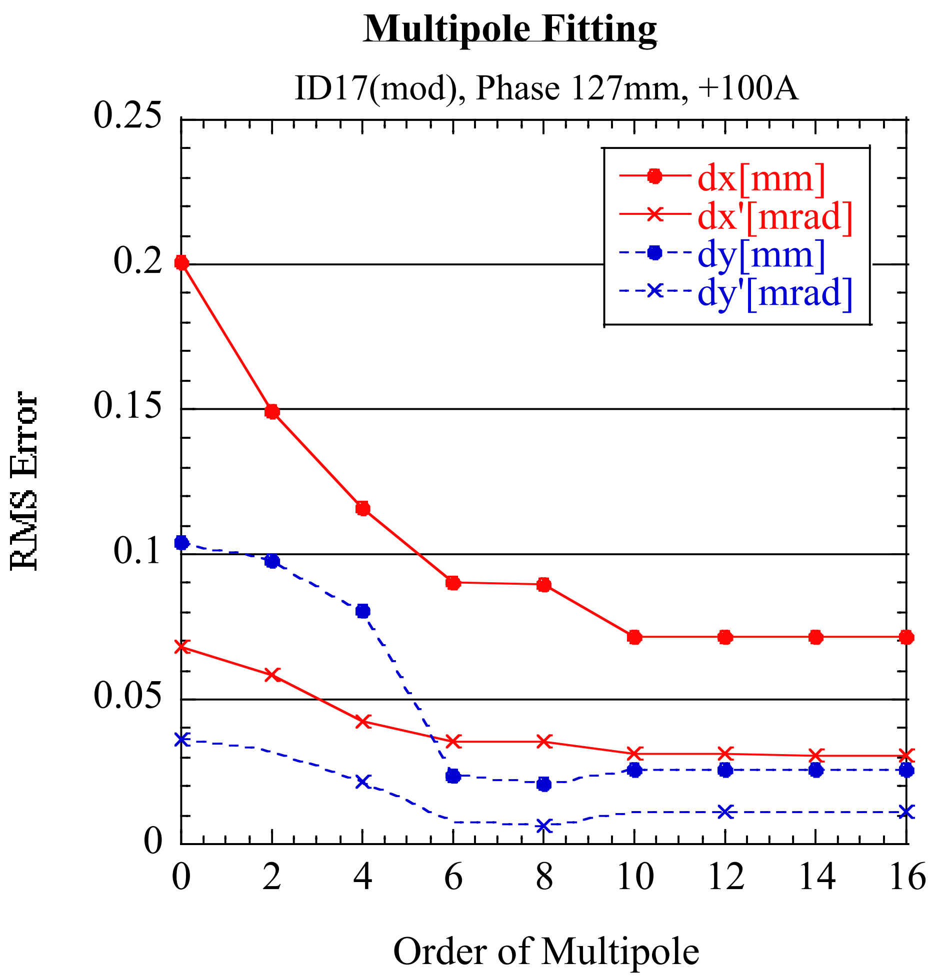


Fitting with up to 16-poles

Agreement is good but not perfect.

=> ... to be discussed later

Example of Multipole Fitting (cont.)



Fitting with up to 10-poles will be enough in this case.

Strength of Multipoles

Entrance

	PM Only (w/o Yoke)	"Default"	I=+100A	I=-100A
N4	-0.00011116	-0.0018663	0.0037541	-0.0052573
S4	9.9597e-06	0.00015046	4.4570e-05	-4.6742e-05
N6	0.00010288	0.0087676	0.51206	-0.50293
S6	-0.42487	0.29724	0.29036	0.28689
N8	-0.074613	2.9241	-5.3136	4.7213
S8	-0.024056	-1.1979	0.12922	-1.7631
N10	-1.9483	-66.899	-2250.7	2392.3
S10	-195.82	392.23	238.69	191.85

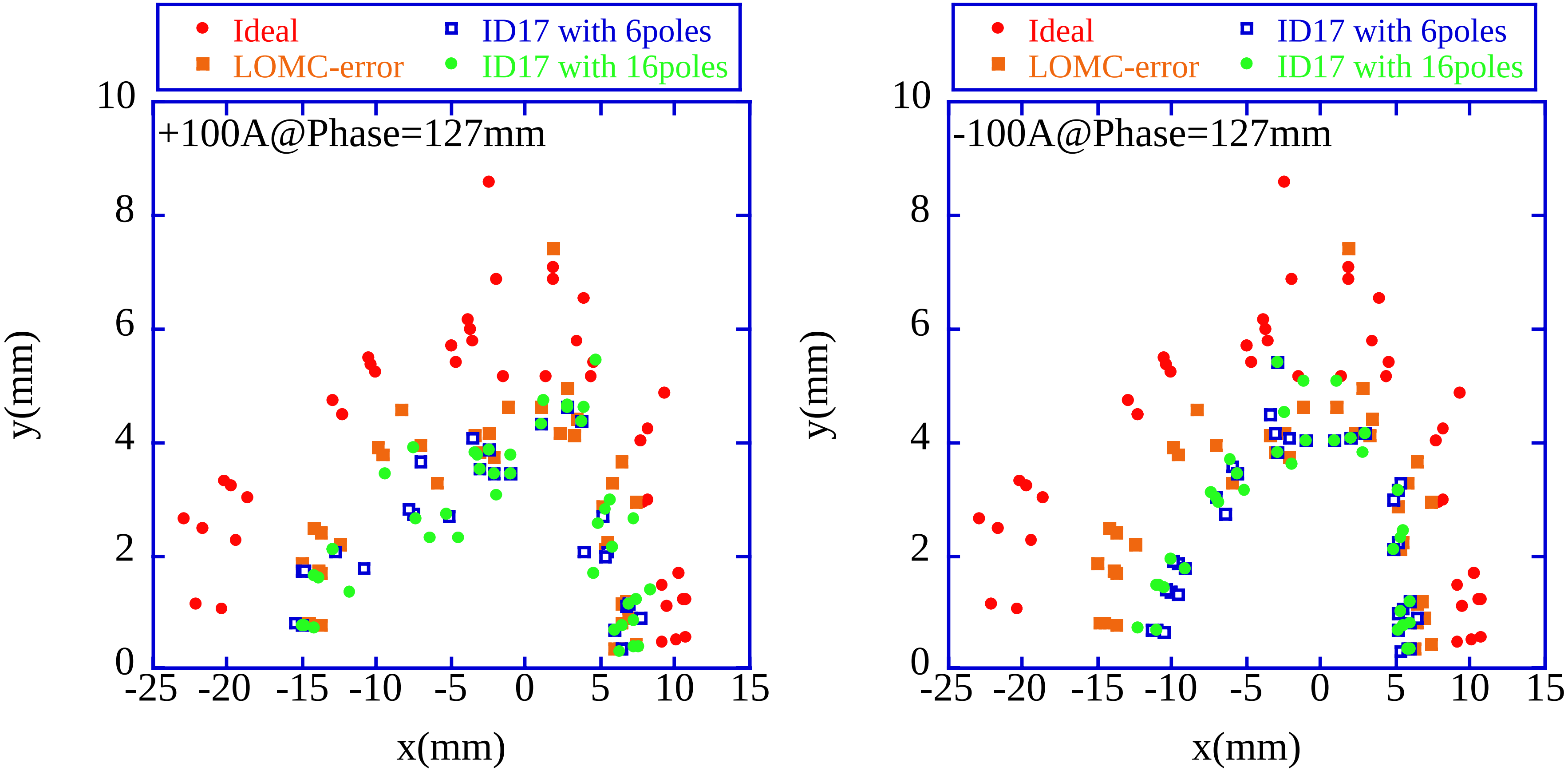
Exit

	PM Only (w/o Yoke)	"Default"	I=+100A	I=-100A
N4	-0.00010579	-0.0017337	0.0037167	-0.0054727
S4	-4.1264e-06	-6.5888e-05	-0.00012031	0.00019378
N6	0.00016917	0.0071736	-0.41479	0.41441
S6	0.42489	0.29397	0.28957	0.28844
N8	-0.10868	1.6554	-5.5162	5.8290
S8	-0.024460	-0.25619	0.12395	-1.3835
N10	2.5984	-60.071	1581.5	-1283.7
S10	200.36	343.45	197.75	311.90

- Quadrupole and decapole components increase by iron yoke.
- Sextupole component increases by the electromagnets.
- Tune shift is about 0.02 and beta distortion is about 15%.

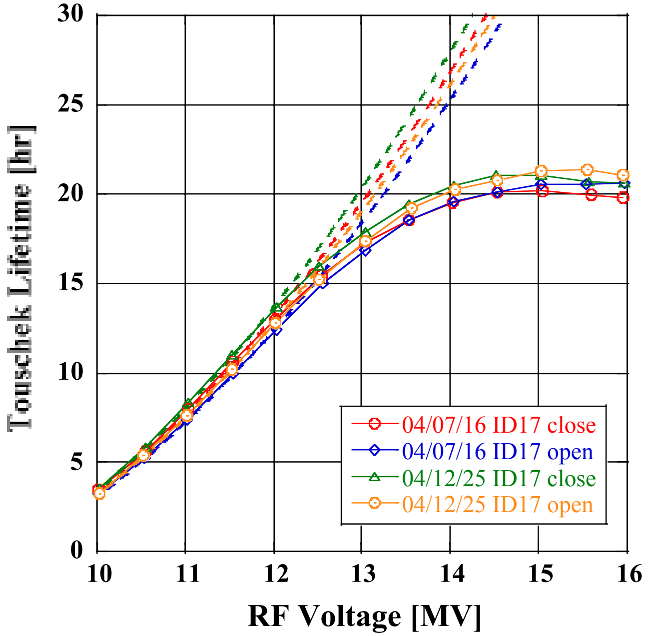
=> Correction by quadrupole (and sextupole) magnets are planned.

Simulation of Dynamic Aperture

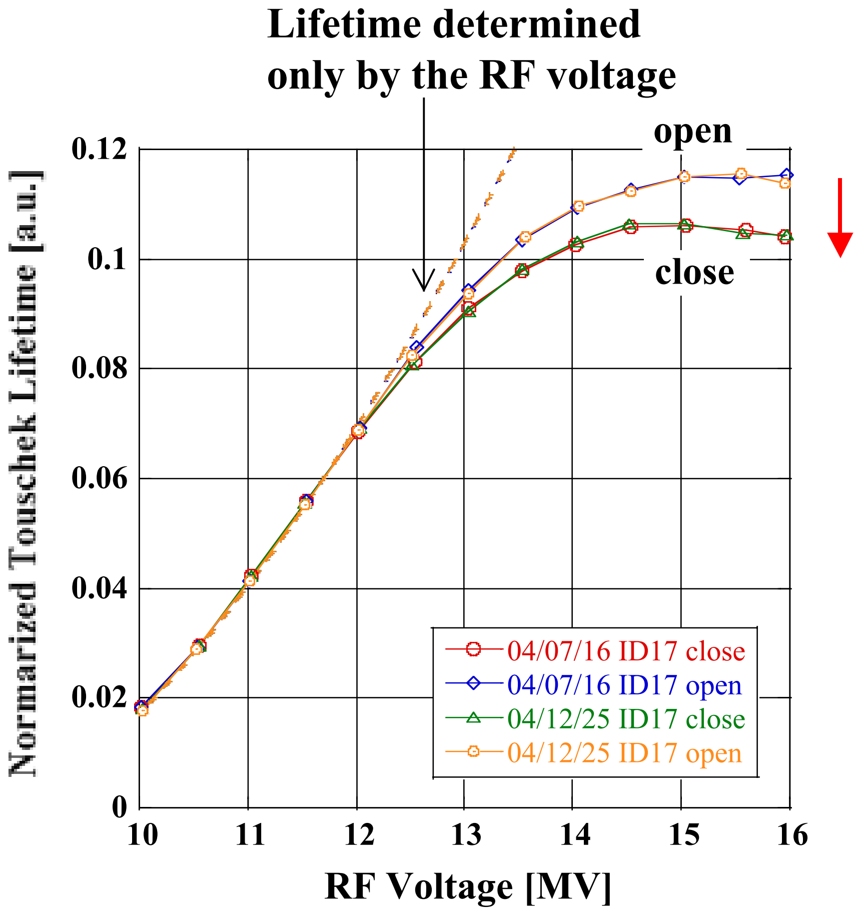


Injection efficiency etc. will be affected.

Effects on Beam Lifetime



Normalize data at low voltage.

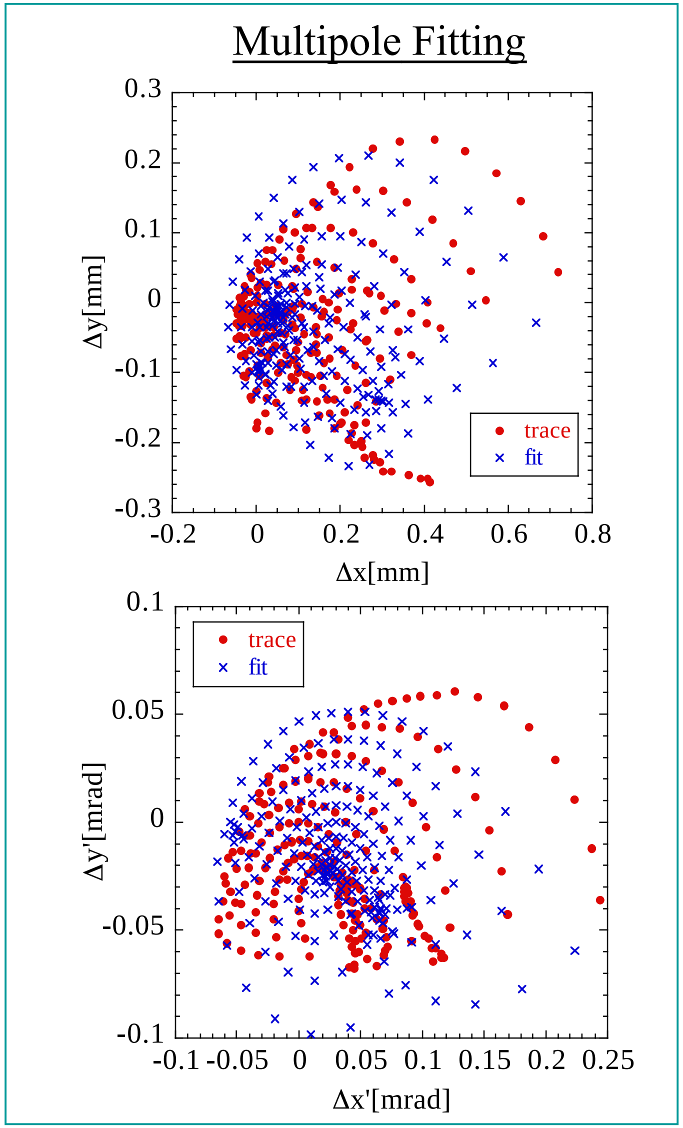


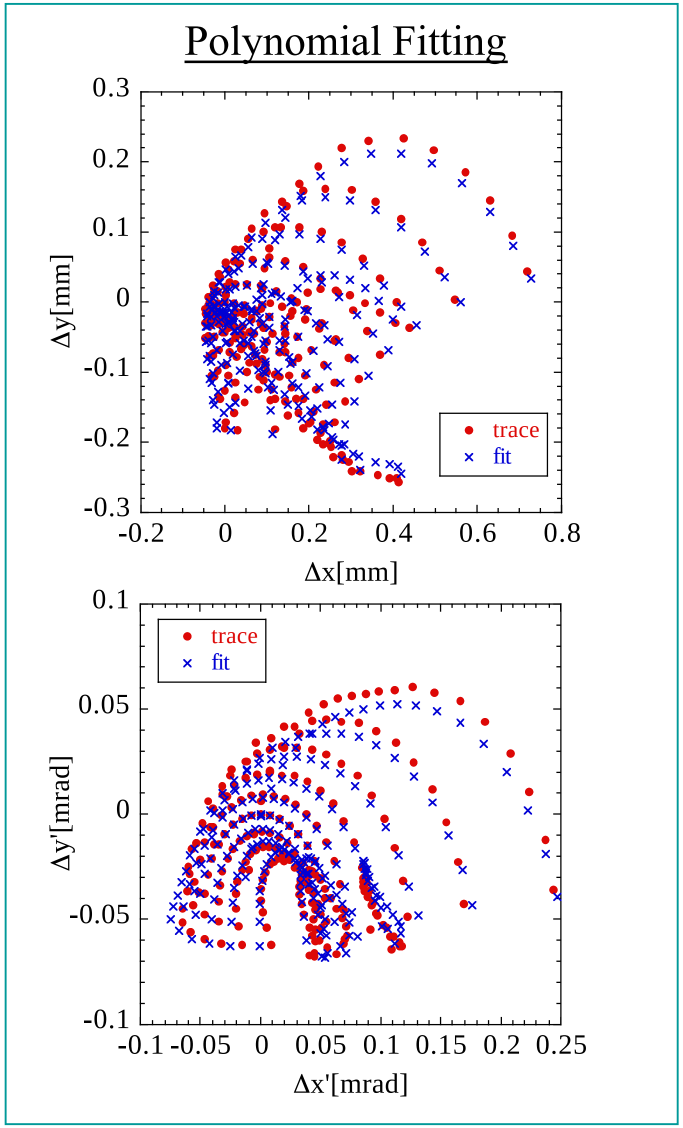
by M.Takao

ID17 is of out-vacuum type and the above results indicate that by closing the gap the momentum acceptance is reduced due to nonlinear fields or H-V coupling changed.

Improvement of the Model

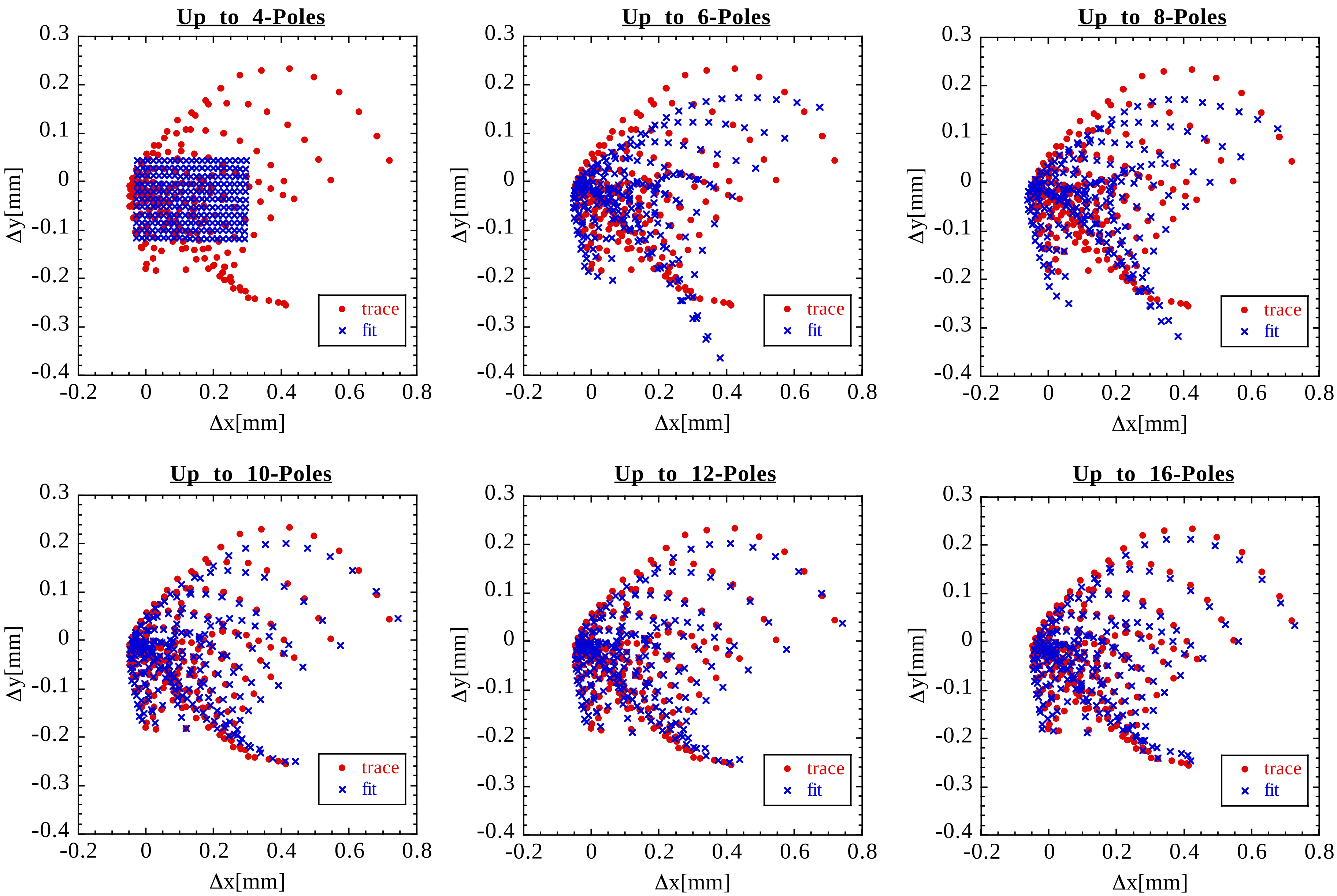
Use polynomials instead of multipoles.



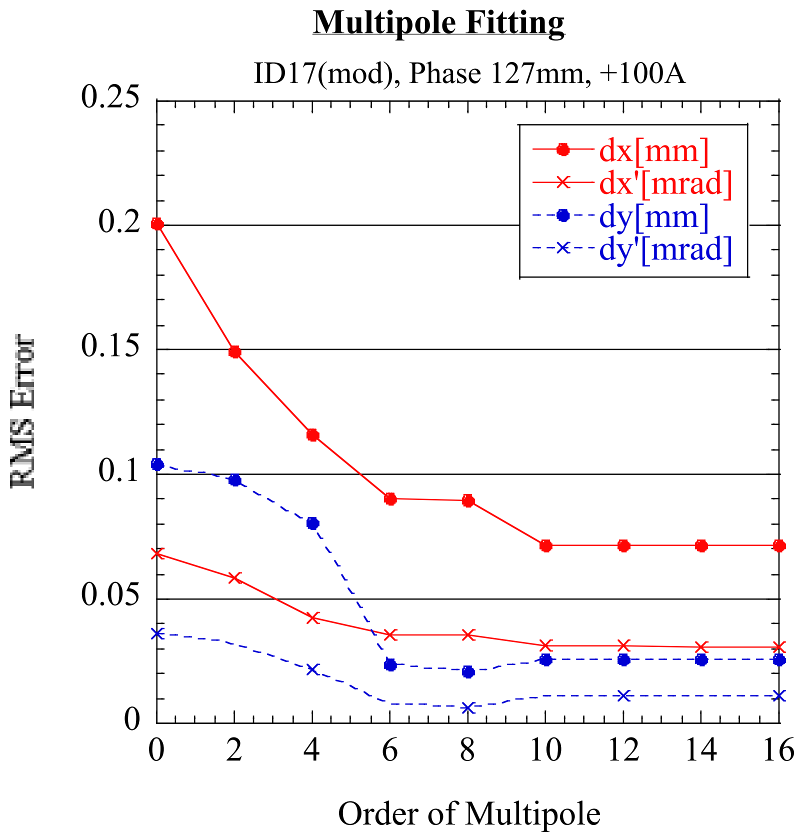


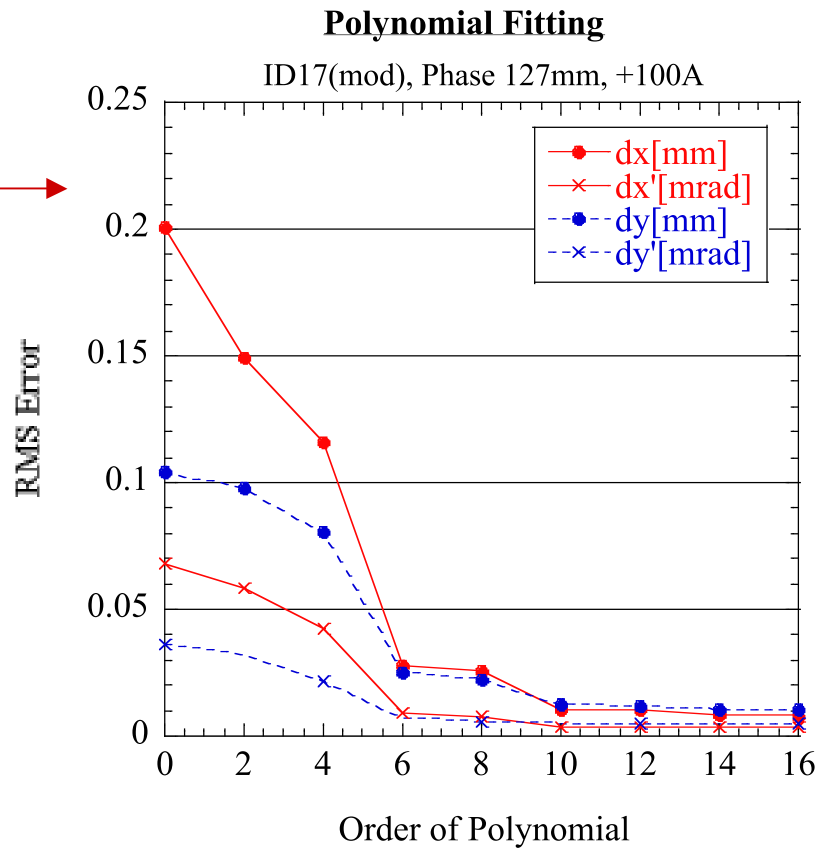
e.g. SX: $a_6(x^2 - y^2) + b_6 xy$ → SX: $a_6 x^2 + b_6 xy + c_6 y^2$

Dependence on the Order of Polynomial



Dependence on the Order of Polynomial (cont.)





Polynomial fitting is better and the results can be used as an input of a simulation code, though they do not represent real fields of multipole correctors.

=> We are planning to use the new scheme in our simulation code.

Use of 30m-LSS

SPring-8 will come to the next phase of using "insertion devices": There remain three sections of 30m-long straight sections for innovative light sources.

For the most efficient use of these sections independent local tuning of lattice functions (beta, phase, dispersion) is required.

=> Symmetry of the ring is lowered.

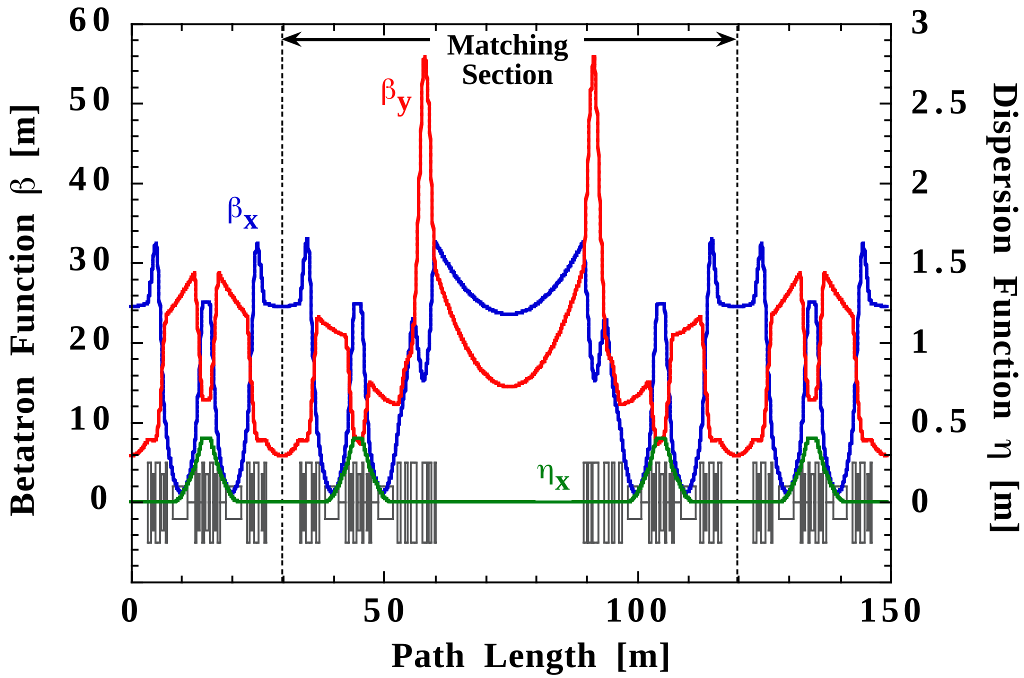
=> Dynamic aperture and momentum acceptance become small.

How do we manage?

Possible Solution

Present Condition of Matching Section

$\Delta\nu_x = 4\pi$, $\Delta\nu_y = 2\pi$, Sextupoles are weakly excited.



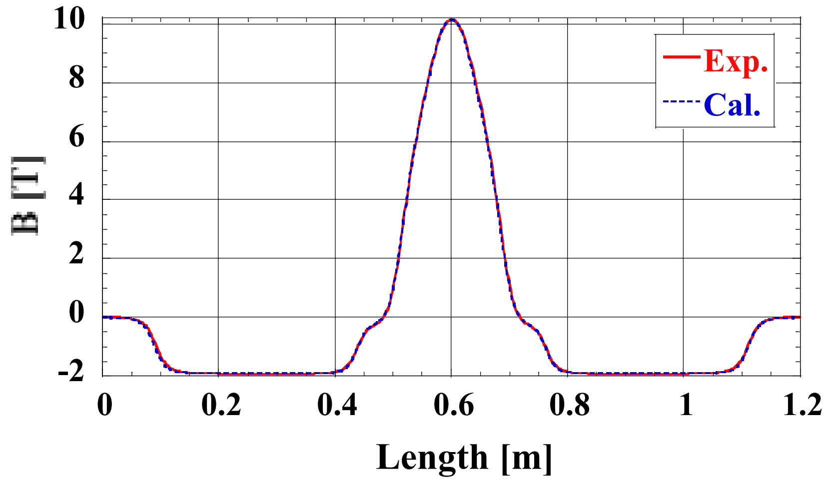
For independent local tuning of lattice functions:

1. **Keep Betatron Phase Matching** (for on-momentum particle)
2. **Make Local Chromaticity Correction** (for off-momentum particle)
3. **Add Counter-Sextupole** (for cancellation of nonlinear kick)

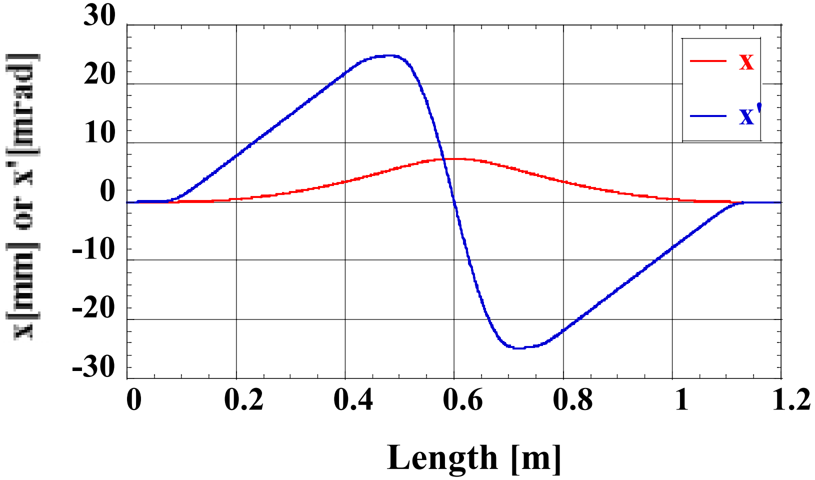
10T SCW as a Test Case

Basic Parameters	
Number of Poles:	**3**
S/C Wire:	**Nb_3Sn and NbTi**
Maximum Field:	**10T**
Stored Energy at 10T:	**400kJ**
Weight:	**1000kg**
Magnet Length:	**1m**
Pole Gap:	**42mm**
Beam Chamber:	**65mm(H), 20mm(V)**

Dipole Field



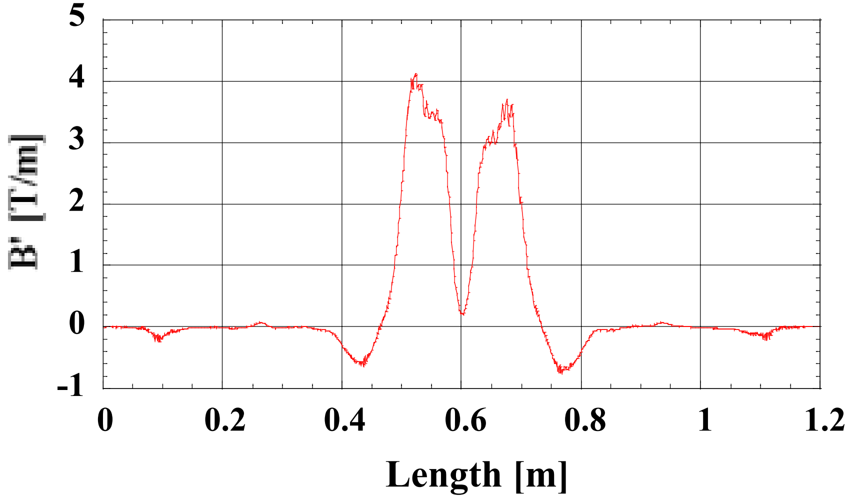
Orbit at 10T



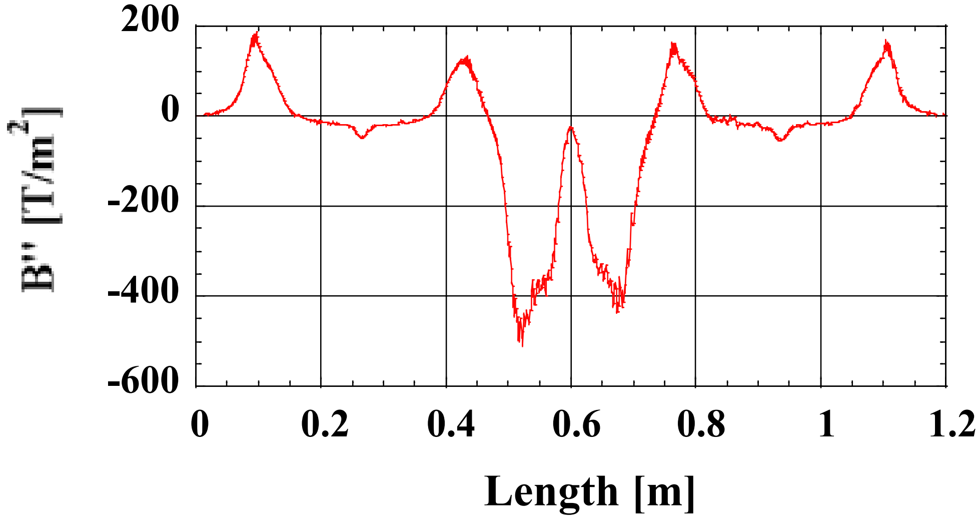
x_{max} = 7.3mm, x'_{max} = ± 25mrad

10T SCW as a Test Case (cont.)

Quadrupole Field: 0.50T (defocusing)



Sextupole Field: 45T/m (focusing)

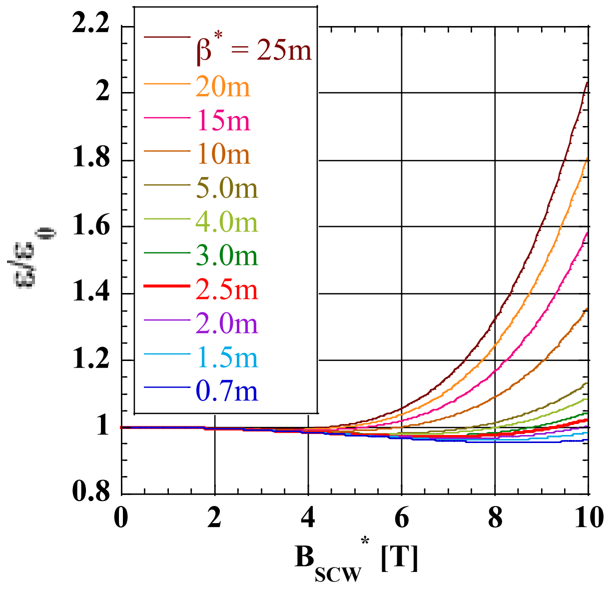


Fabricated at Budker INP by N.Mezentsev, et.al.

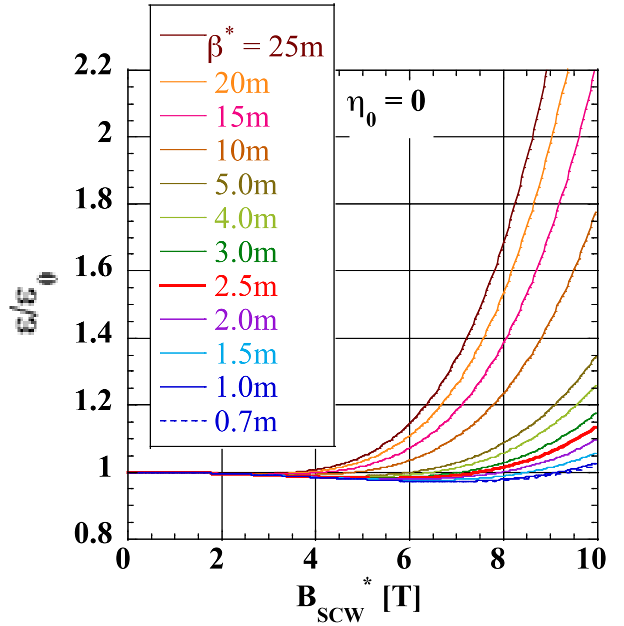
cf. M.Fedurin, et.al. NIM A448(2000)51, A470(2001)34.

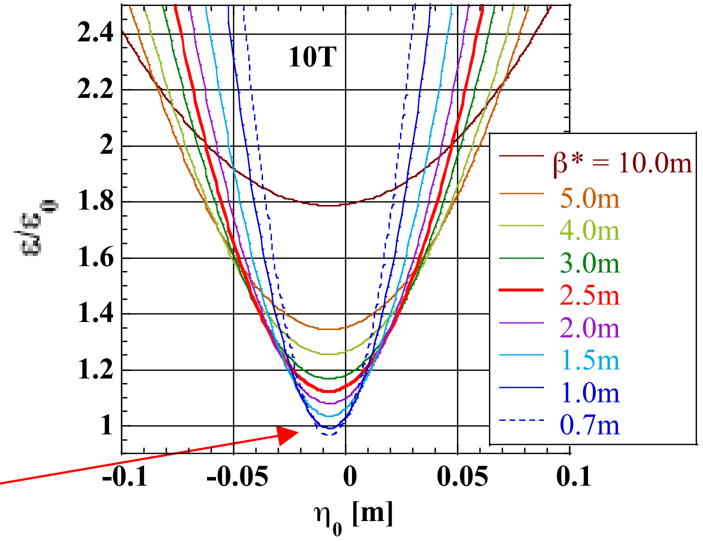
Emittance and SCW Field

Achromat Optics



Non-Achromat Optics





To keep the emittance small even at 10T

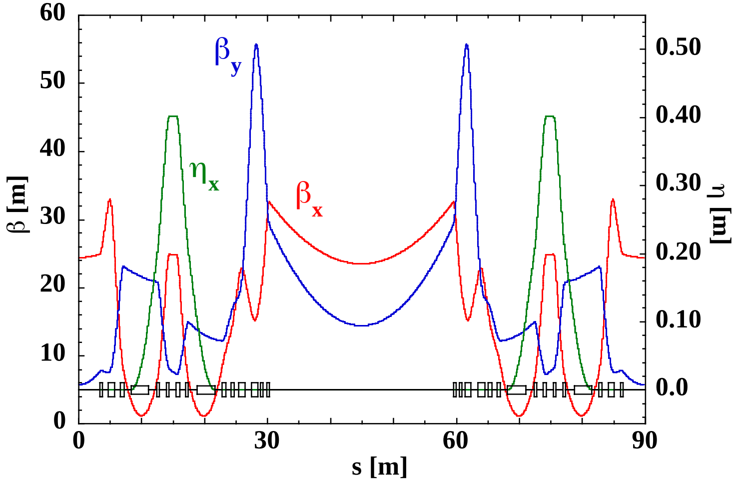
- **Horizontal beta must be small.**
- **Horizontal dispersion must be vanished** **or it must be controlled to cancel self-dispersion by the wiggler.**

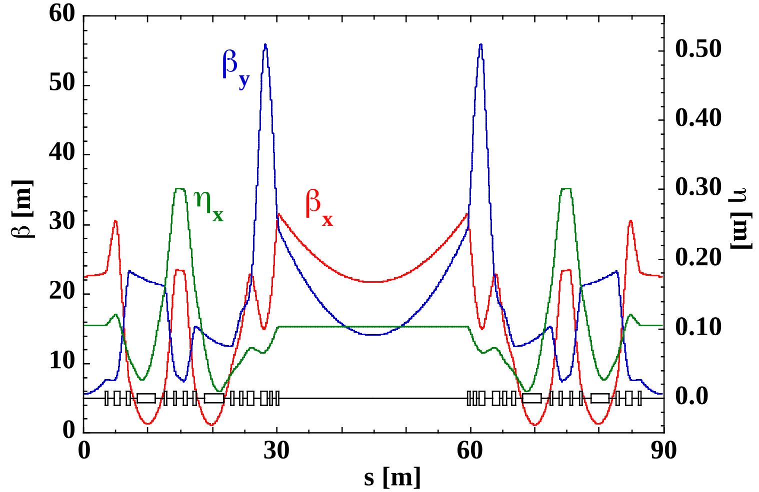
Minimum shifts due to self-dispersion.

Low-Beta Insertion at LSS (tentative)

Achromat Optics / Non-Achromat Optics

before

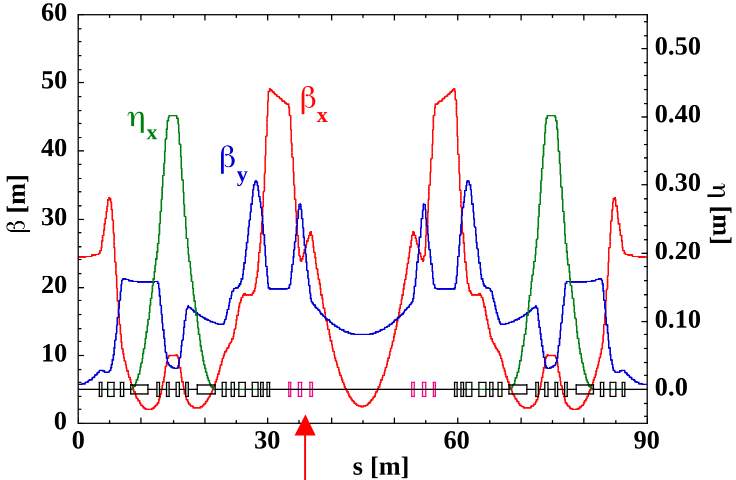


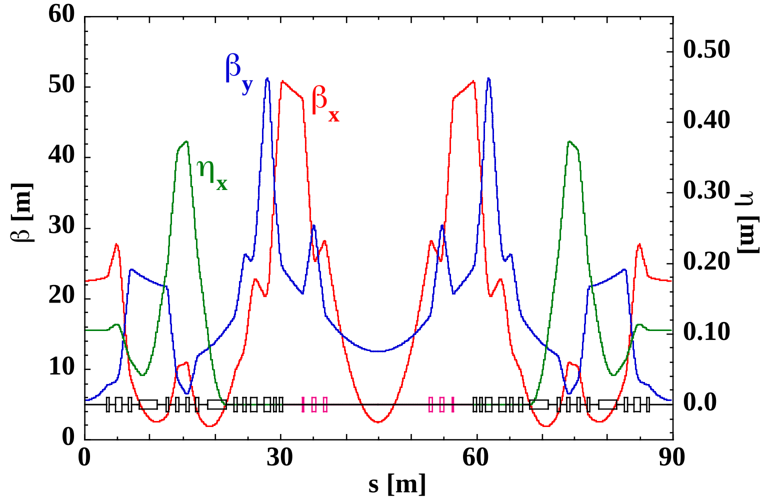


after

β_x=2.5m

η_x=0





Quadrupoles

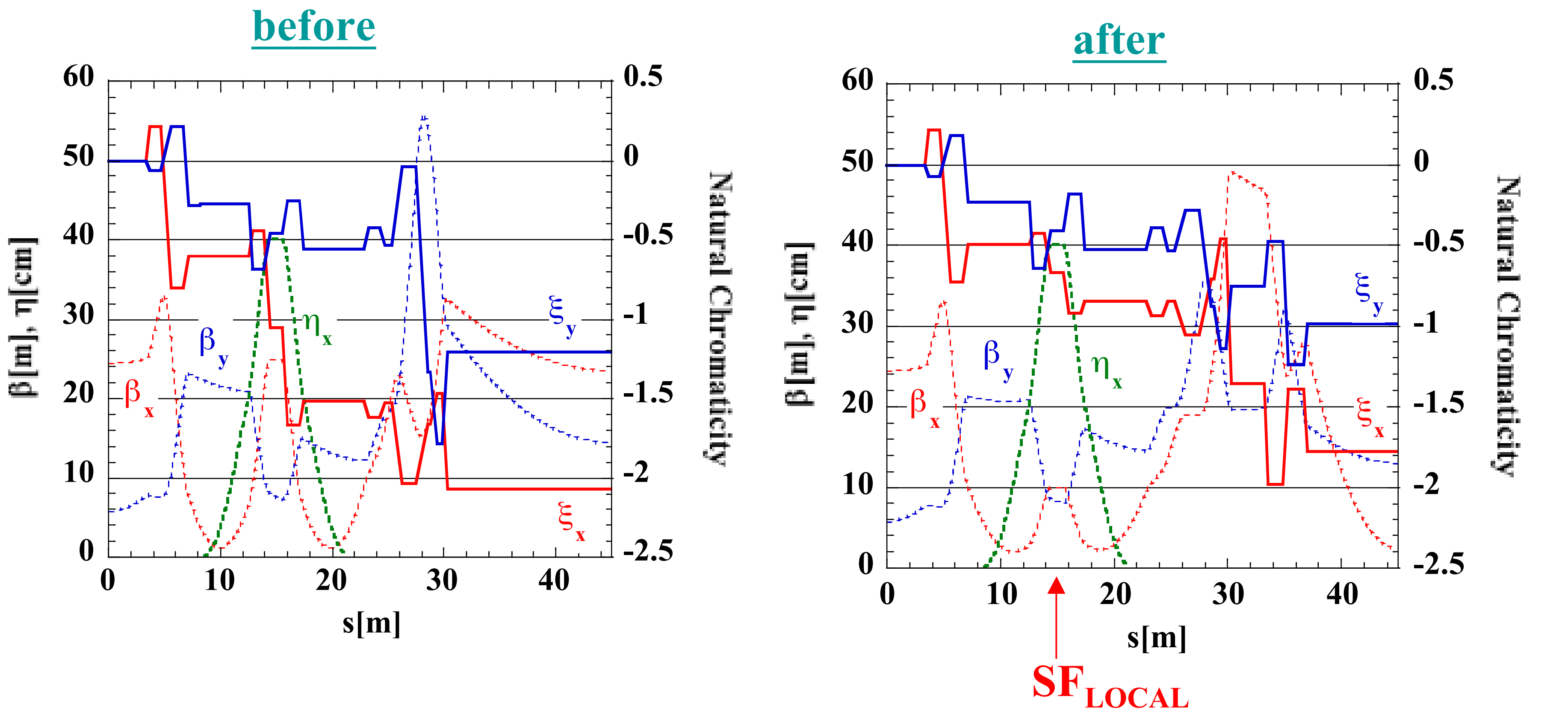
Ring Parameters

	Achromat Optics			Non-Achromat Optics		
	bef.	aft. SCW 0T	aft. 10T	bef.	aft. SCW 0T	aft. 10T
β_x [m]	23.5	2.5	-	21.7	2.5	-
β_y [m]	14.4	13.0	-	14.0	12.5	-
η_x [m]	0	0	-	0.103	0	-
σ_E/E	0.11	0.11	0.15	0.11	0.11	0.15
ε [nmrad]	**6.59**	**6.98**	**7.15**	**3.43**	**3.80**	**4.32**
ε_{eff} [nmrad]	6.59	6.98	7.15	3.71	4.08	4.84

Effective Emittance at Normal ID: $$\varepsilon_{\text{eff}} = \sqrt{\varepsilon^2 + \frac{\varepsilon\delta^2\eta_{\text{ID}}{}^2}{\beta_{\text{ID}}}}$$

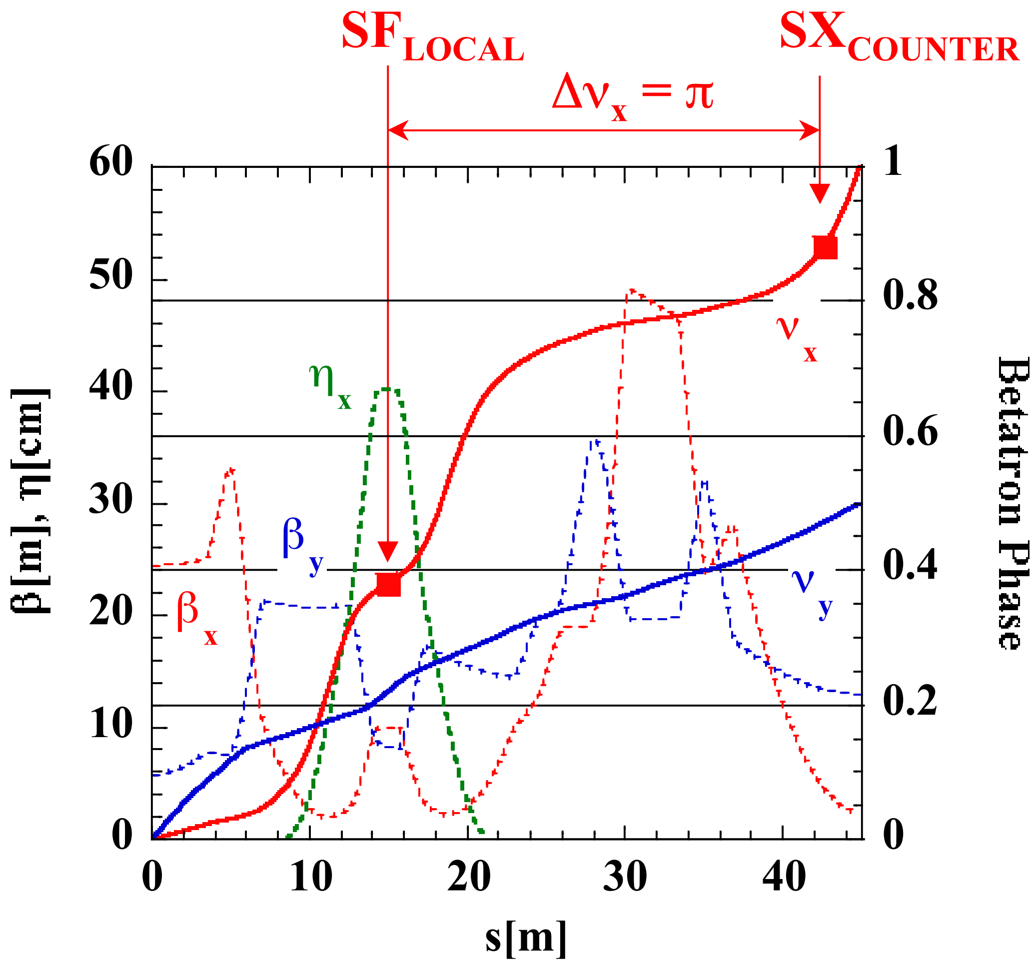
Local Chromaticity Correction

Achromat Optics (Half of the Matching Section)



Horizontal chromaticity (or betatron phase jump for off-momentum particles) should be corrected locally in consideration of beam injection and beam lifetime.

Counter-Sextupole



Similar to "noninterleaved sextupoles" scheme:

K.L.Brown, IEEE Trans. Nucl. Sci. NS-26 (1979) 3490.
L.Emery, in Proc. 1989 IEEE PAC (1989) p.1225.
K.Oide and H.Koiso, PR E47(1993) 2010.

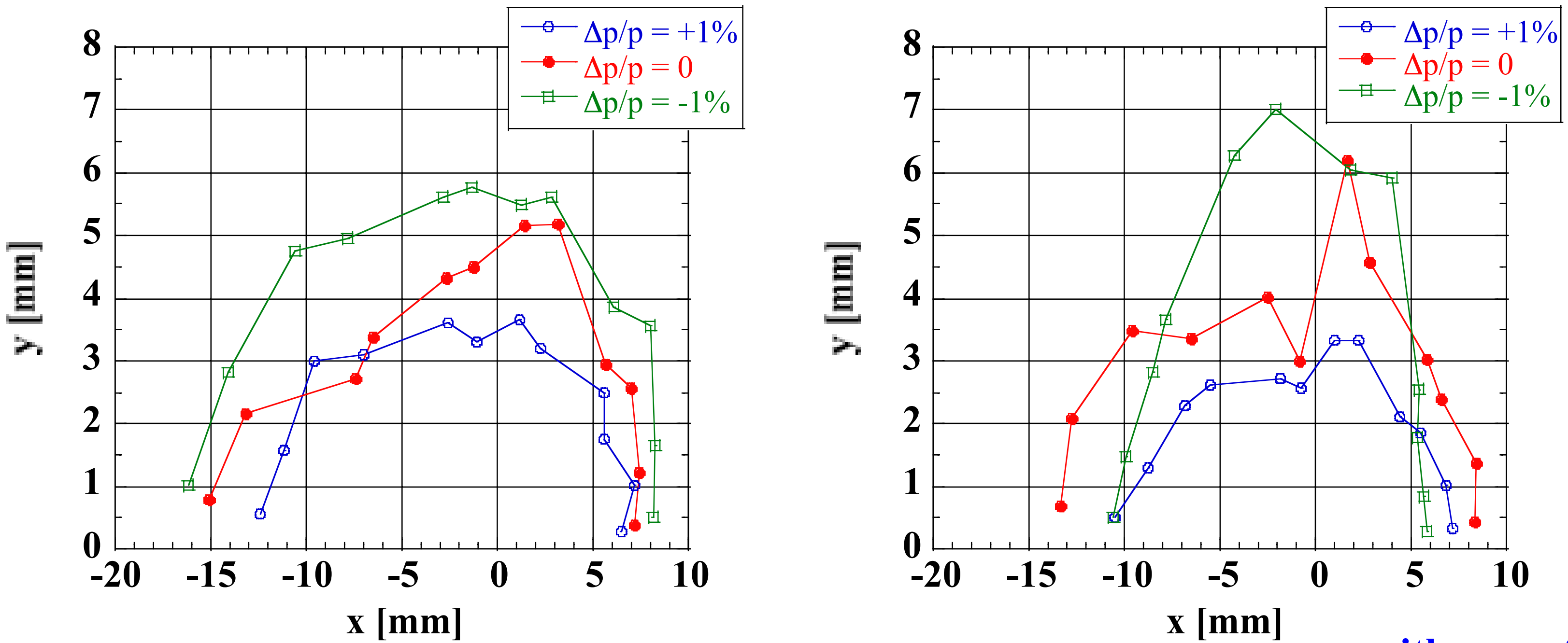
Dynamic Aperture

We checked that momentum acceptance is enlarged by using counter-sextupoles.

After tuning the strength of SF_{LOCAL}, $SX_{COUNTER}$ and other harmonic sextupoles...

Achromat Optics

before (w/o Low-Beta Insertion) after (with Low-Beta Insertion)



with error fields

The work is still in progress to get a better solution ...

Summary

- **ID model we presented is valid for a wide range of aperture. Obtained multipole/polynomial strengths can be used directly as an input of simulation code.**
- **We showed the effectiveness of this scheme by taking a "multi-operation mode undulator" ID17 as an example.**
- **For the most efficient use of LSSs independent local tuning of lattice functions (beta, phase, dispersion) is required.**
- **To keep the dynamic aperture and momentum acceptance we proposed the following scheme: "Betatron Phase Matching" & "Local Chromaticity Correction" & "Counter-Sextupole".**
- **Beam test of lattice modification is planned using one LSS (w/o insertion devices).**