Alignment of S-LSR

H. Souda, M. Tanabe, T. Ishikawa, M. Ikegami,
T. Takeuchi*, H. Tongu, T. Shirai, A. Noda

ICR, Kyoto University

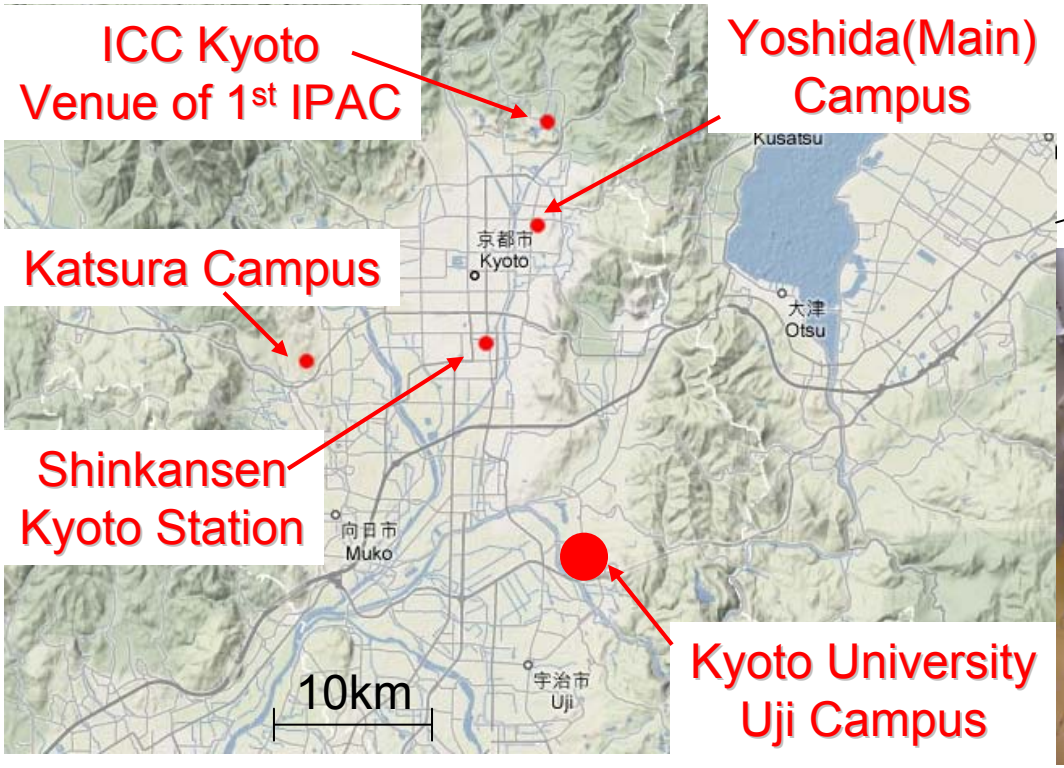
*Accelerator Engineering Corporation

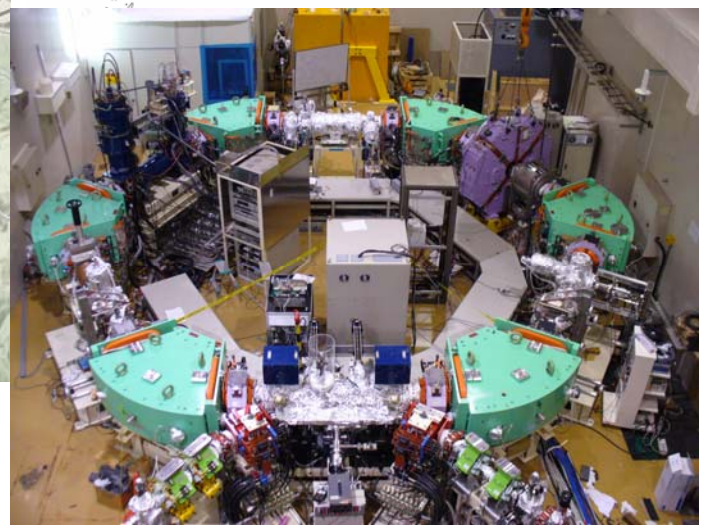
Contents

S-LSR at Kyoto University

S-LSR: Small Laser equipped Storage Ring

Constructed at Kyoto University(Uji campus)





Collaboration with NIRS(National Institute of Radiological Sciences)

Advanced Compact Accelerator Development project(JFY2001-2005)

Beam Cooling and Alignment

Main purpose = Beam Cooling

Electron Cooling of 7 MeV proton

→ Medical Application, Beam ordering

Laser Cooling of 40keV $^{24}Mg^{+}$

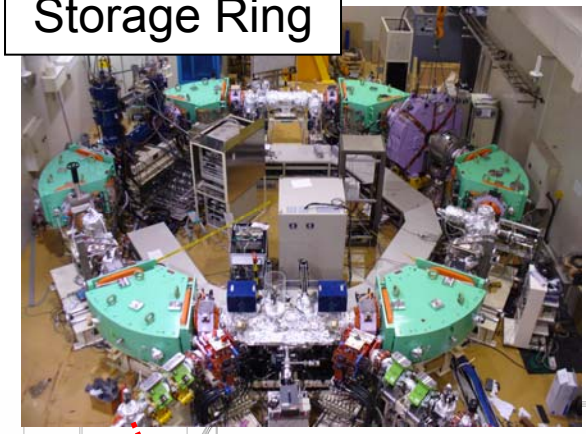
→ Low temperature limit, Crystalline Beam

- To get strong cooling force…
  Ion beam orbit must overlap electron/laser path
- Toward 3-dimensional Beam Crystallization…
  High periodicity(COD, Beta function) is necessary.

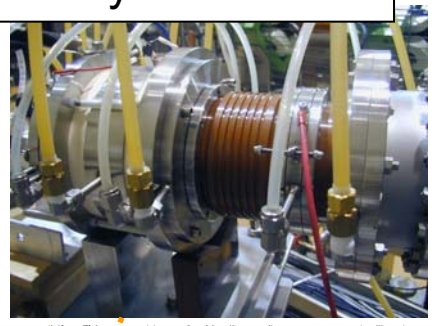
COD and beta function is important in alignment.

Overview of S-LSR

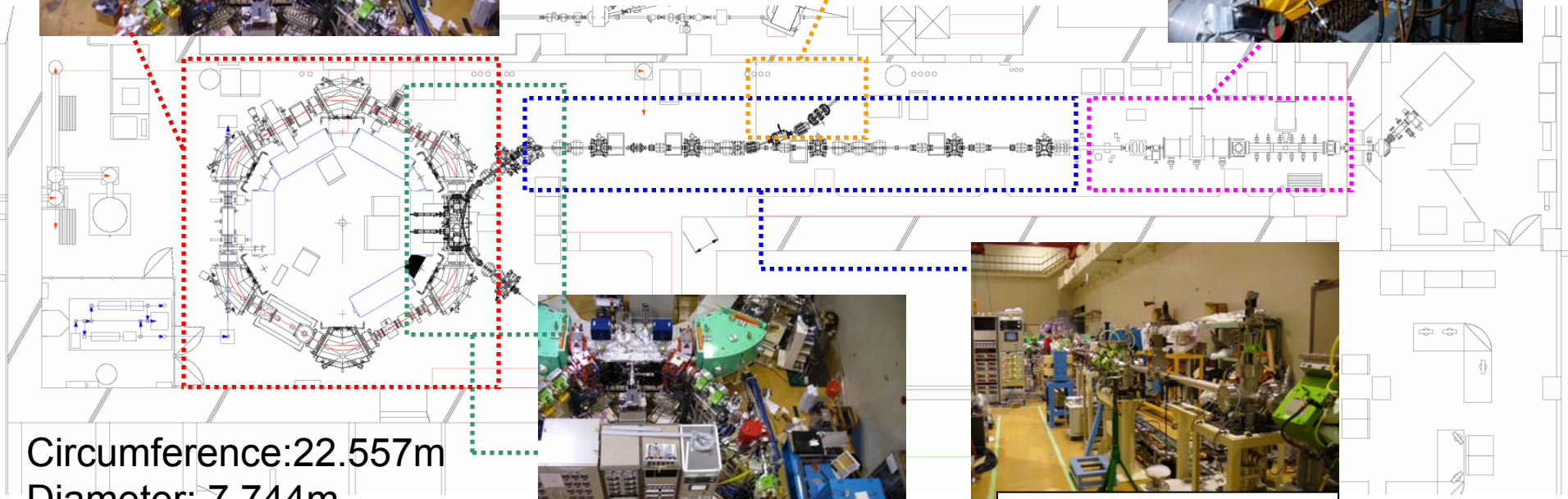
Storage Ring



Heavy Ion Source



Proton Linac(1988-)



Injection Line

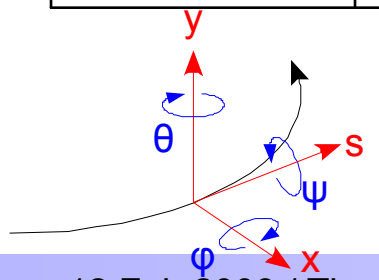
Beam Transport

Circumference:22.557m
Diameter: 7.744m
Number of BM: 6
Number of QM: 12(2 series)

Alignment tolerance

COD from Misalignment vs. Magnet field error

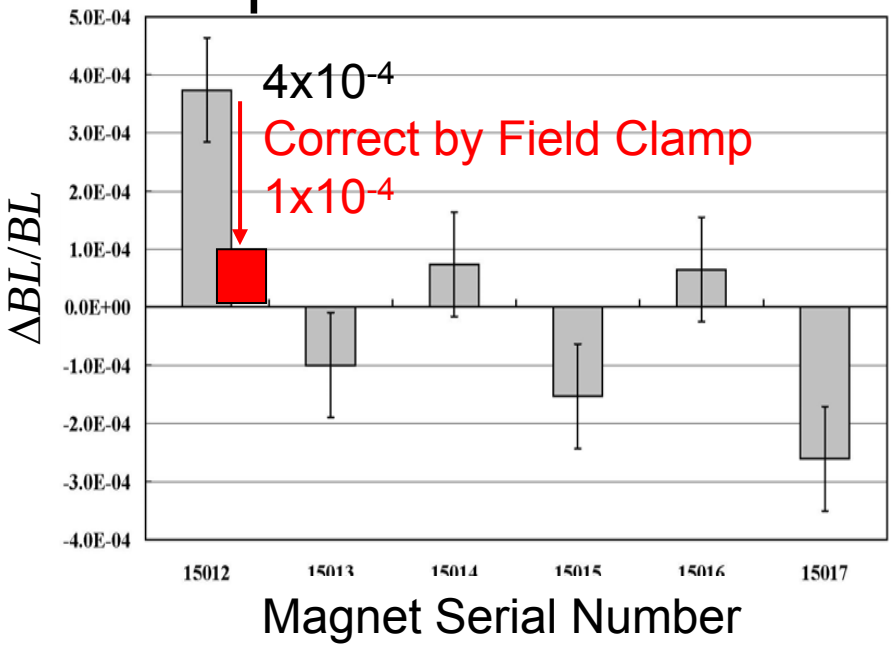
Bending Magnets			Quadrupole Magnets		
Error Source	Error Amount	COD (mm)	Error Source	Error Amount	COD (mm)
BL Product	Δ(BL/BL)= 1×10^{-4}	0.33 (Horizontal)	GL Product	Δ(GL/GL)= 1×10^{-3}	0.
X Position	D_x=0.1 mm	0.24 (H)	X Position	D_x=0.1 mm	0.11 (H)
Y Position	D_y=0.1 mm	0.02 (V)	Y Position	D_y=0.1 mm	0.11 (V)
S Position	D_s=0.1 mm	0.15 (H)	S Position	D_s=0.1 mm	0.
X Rotation	D_ϕ=0.05 mrad	0.06 (V)	X Rotation	D_ϕ=0.05 mrad	0.01 (V)
Y Rotation	D_θ=0.1 mrad	0.15 (H)	Y Rotation	D_θ=0.1 mrad	0.02 (H)
S Rotation	D_ψ=0.05 mrad	0.10 (V)	S Rotation	D_ψ=0.05 mrad	0.



Alignment Tolerance
Displacement: 0.1mm
Rotation:0.1mrad(BM) 1mrad(QM)

Bending Magnet Shuffling

Dipole BL Product



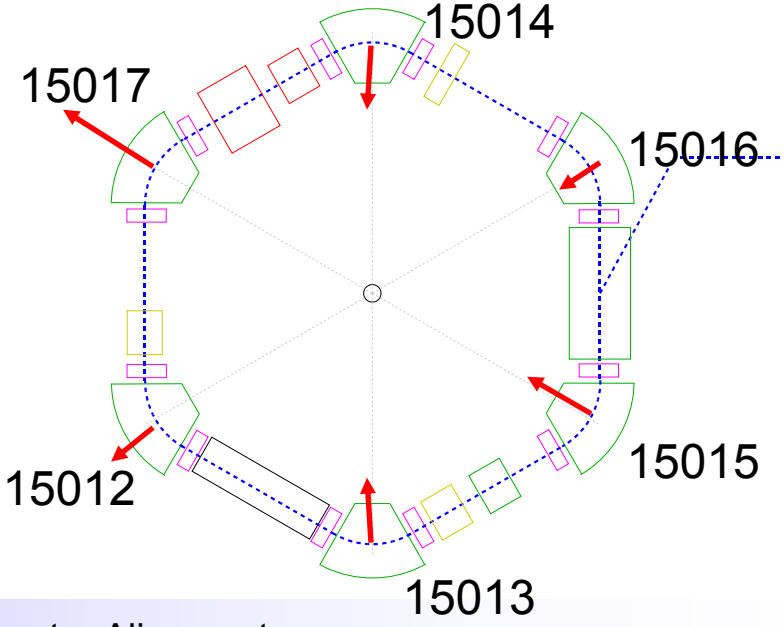
minimize COD

at (ν_x, ν_y) =(1.7,1.1)

6!/6 = 120 patterns

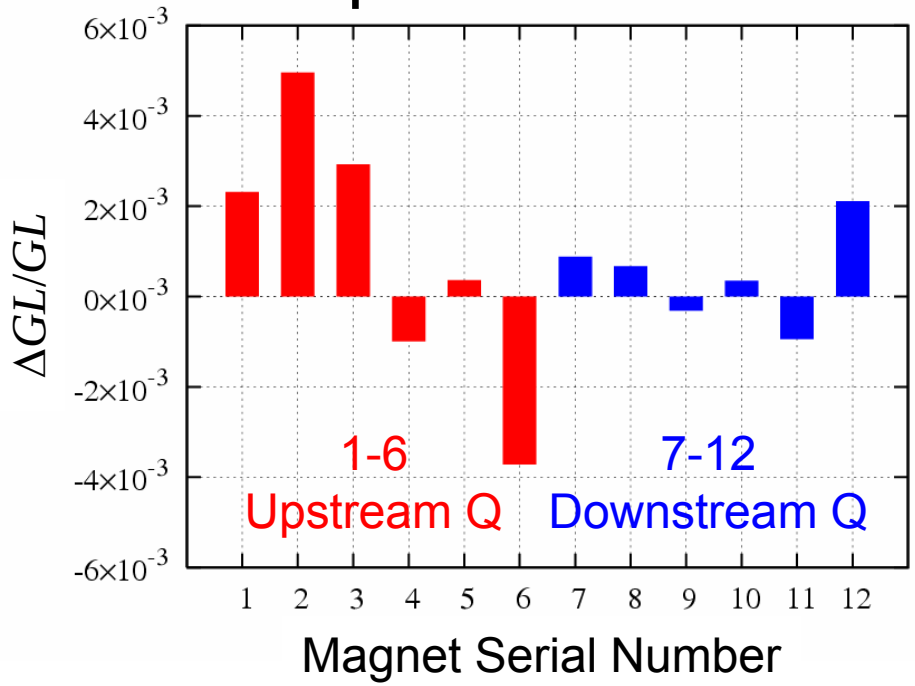
brute-force search by MAD

Ranking	H.COD Max	H.COD RMS
1st	0.782mm	0.319mm
2nd	0.595mm	0.328mm
:	:	:
120th	1.382mm	0.746mm



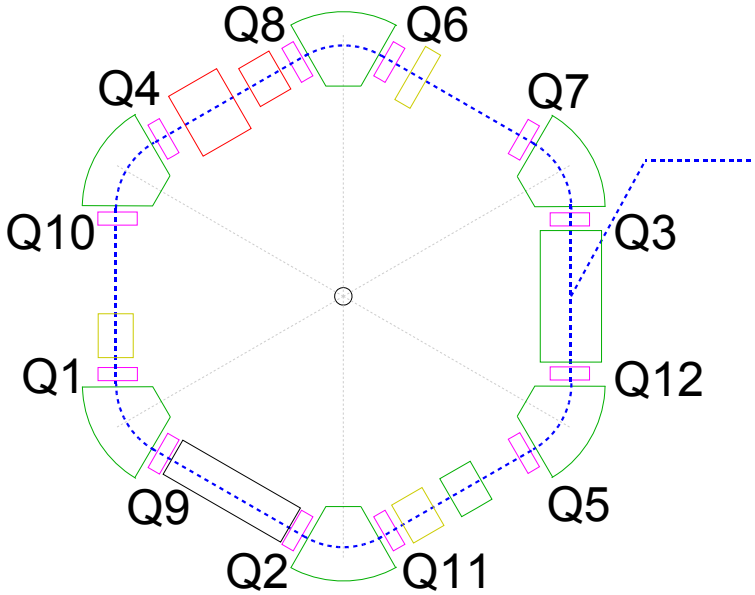
Quadrupole Magnet Shuffling

Quadrupole GL Product



6!x6! = 518400 patterns brute-force search by MAD

Ranking	$(\delta\nu_x, \delta\nu_y)$[x10^{-4}]
1st	(8.00, 6.19)
2nd	(7.47, 6.87)
:	:
518400	(5.57, 22.26)



minimize Beta function error

~minimize Betatron stopband

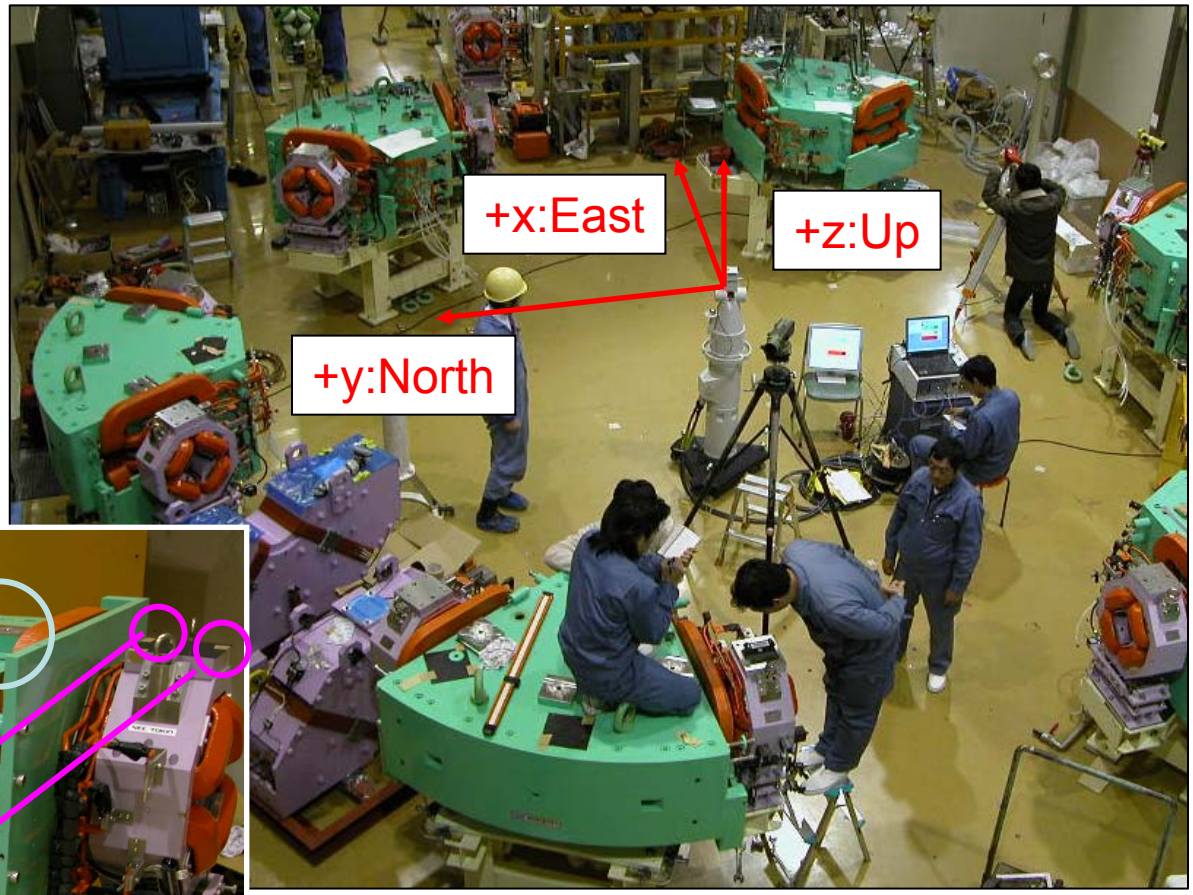
$$\delta\nu = 2(\nu - n/2)\left(\frac{\Delta\beta}{\beta}\right)_{\max}$$

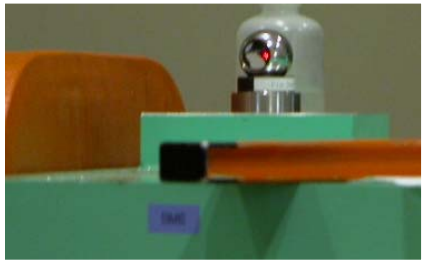
Alignment using Laser Tracker

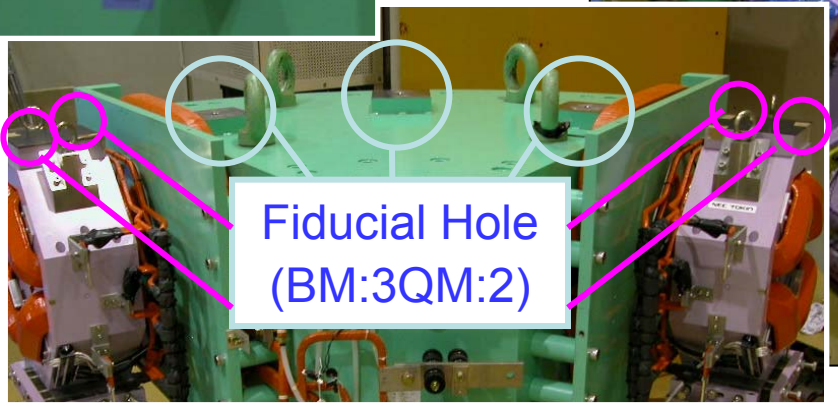
20 Dec 2004 ~ 24 Dec 2004
25 Jan 2005 ~ 26 Jan 2005

Alignment chief: T. Shirai(ICR, Kyoto Univ.)
Measurement: K. Mishima(PASCO)

Laser Tracker:
SMX Tracker4500
Total Station:
Leica TDA5005
Resolution ~50μm



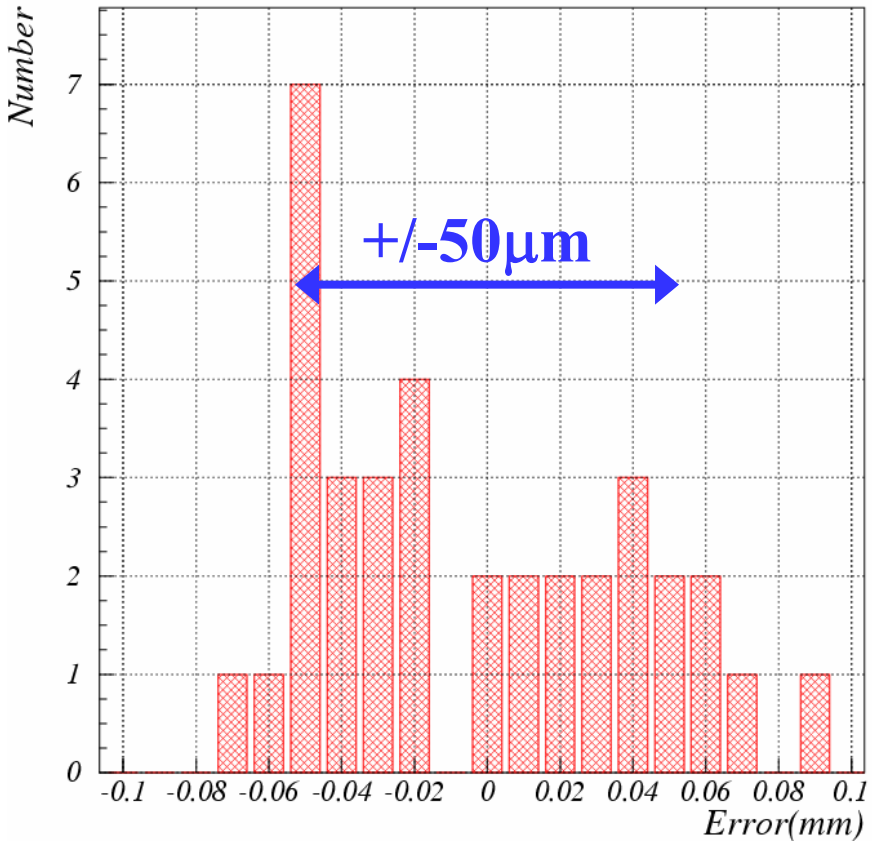




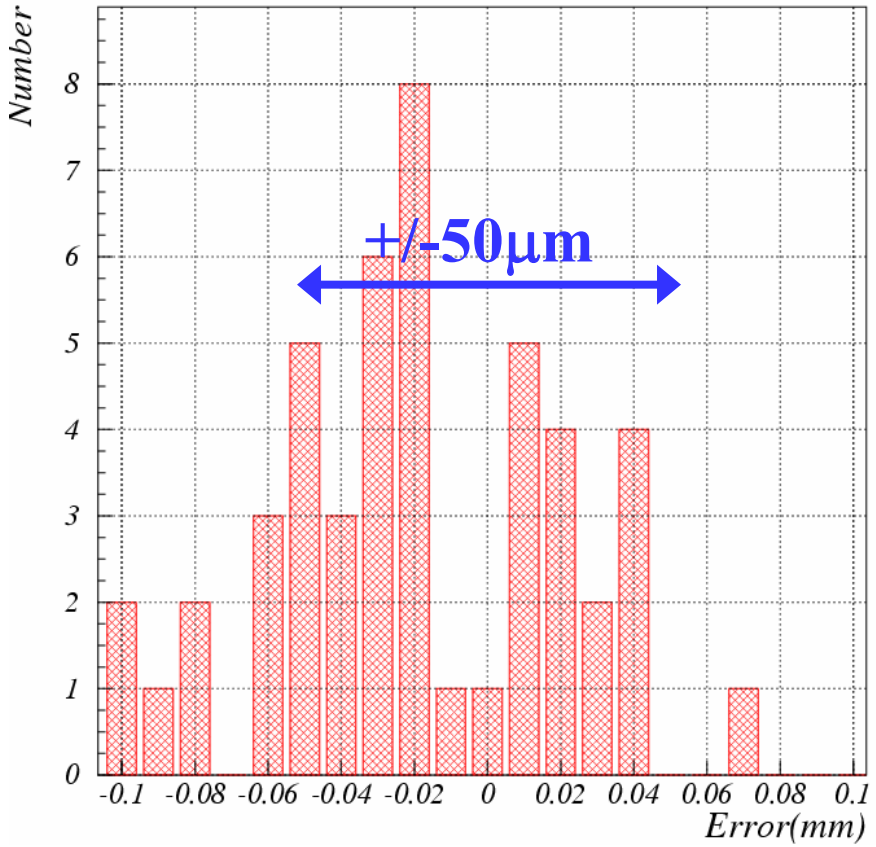
Result of Alignment

All displacements are less than 0.1mm
65% are less than 0.05mm

BM displacement

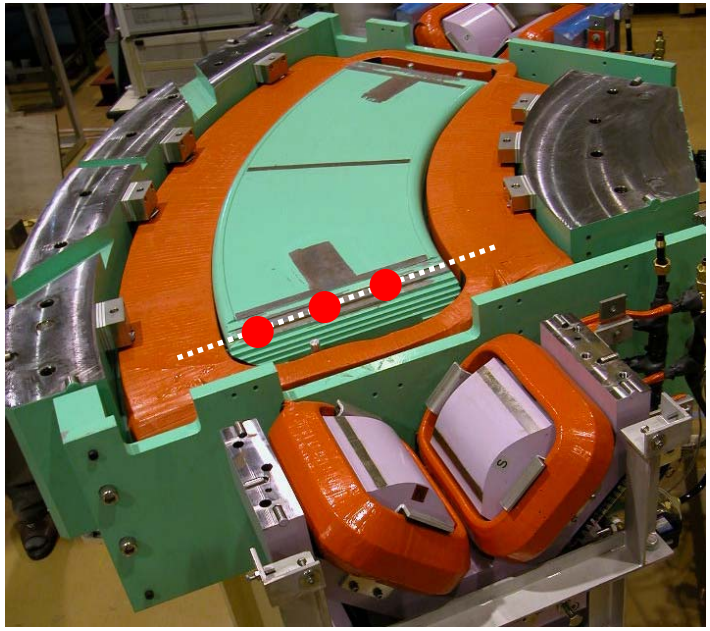


QM displacement



Measurement of magnet pole length

Actual pole length (base line of effective length)
is measured by laser tracker.

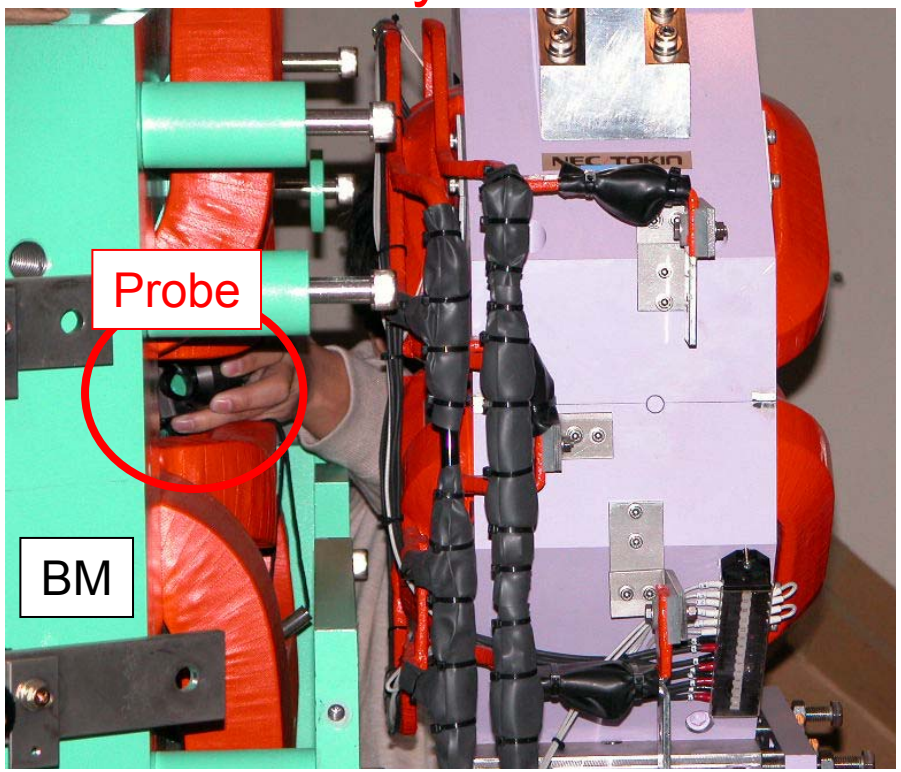


Reference plane
of Rogowski cut

Measure 3 points
to determine the line

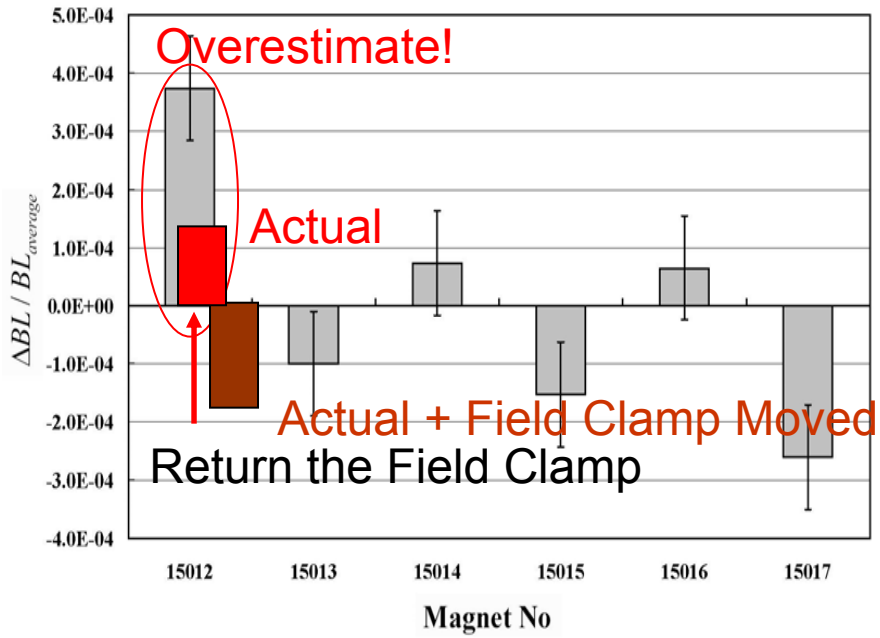
Knife-edge
contact type probe

Accuracy ~0.2mm



Measured magnet pole length

Serial No.	Location	Error
15012	BM3	Upstream 0.0 mm
		Downstream -0.4 mm
15013	BM4	-0.1 mm
		-0.1 mm
15014	BM5	0.0 mm
		-0.1 mm
15015	BM1	-0.1 mm
		-0.2 mm
15016	BM6	0.0 mm
		0.2 mm
15017	BM2	0.1 mm
		-0.1 mm

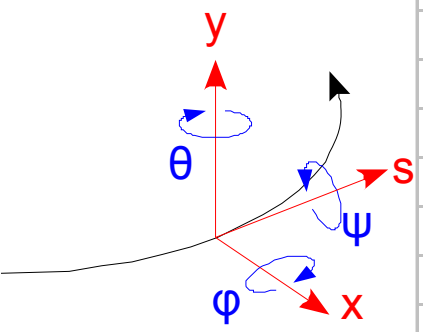


COD: Max 0.8mm → 1.0mm
RMS 0.3mm → 0.4mm
(5th of 120)

Effect to the Beam Optics

Translation

Rectangular Coordinate to Frenet-Serret Coordinate



	Dx[mm]	Dy[mm]	Ds[mm]	Dϕ[mrad]	Dθ[mrad]	Dφ[mrad]
BM1	-0.017	0.003	0.049	-0.037	-0.027	0.020
BM2	-0.010	0.027	-0.013	-0.007	-0.104	0.007
BM3	0.053	0.040	0.009	0.000	-0.032	-0.040
BM4	-0.029	0.043	0.008	-0.013	0.006	-0.010
BM5	0.031	-0.090	0.039	-0.037	-0.004	-0.013
BM6	0.048	-0.027	-0.004	-0.040	-0.018	-0.007
QM11	0.002	0.050	-0.026	-0.020	-0.169	-0.010
QM12	0.048	-0.030	0.012	0.030	0.174	-0.020
QM21	-0.050	-0.040	-0.032	0.010	-0.076	-0.010
QM22	0.003	0.080	-0.030	0.070	-0.130	-0.010
QM31	0.027	0.060	0.020	-0.020	-0.725	0.000
QM32	-0.019	-0.010	0.029	0.000	0.077	-0.050
QM41	0.046	0.000	-0.042	-0.030	0.277	-0.050
QM42	0.003	0.050	0.071	-0.030	-0.421	-0.020
QM51	-0.058	-0.070	0.084	-0.070	0.163	0.030
QM52	-0.032	-0.070	-0.079	-0.030	0.270	0.040
QM61	-0.017	-0.050	0.019	0.050	0.205	-0.040
QM62	-0.052	-0.070	-0.030	0.050	0.108	0.010

Beta Function

Beta function measurement

Change QM correction current

Measure betatron tune shift

$$\beta = \frac{4\pi}{kL}\frac{I_0 N_{\mathrm{main}}}{N_{\mathrm{corr}}}\frac{\Delta\nu}{\Delta I}$$

Position	β_x(meas)	β_x(MAD)
QM11	2.137	2.252
QM21	2.184	2.256
QM22	2.149	2.253
QM32	2.089	2.254
QM41	2.164	2.255
QM51	2.164	2.254
QM61	2.179	2.253

$$\Delta\beta_x/\beta_x = 0.06(2\sigma)$$

Stopband Measurement

Change QM main current

Measure beam life(>10sec)

around ν=1.5

$\delta\nu_x = 1.1\times10^{-3}$ (calc 0.8×10^{-3})

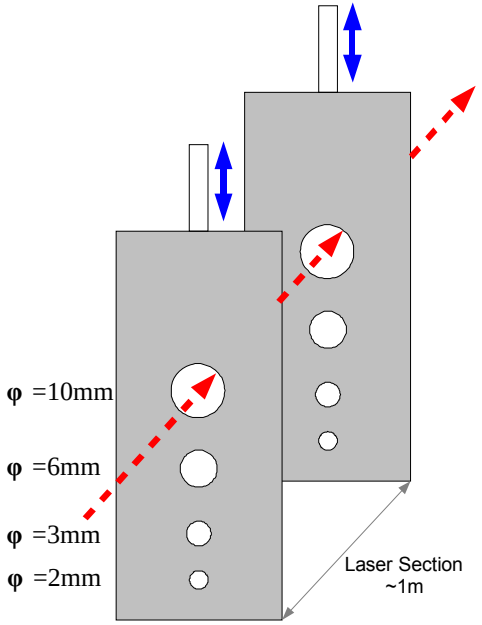
$\Delta\beta_x/\beta_x < 2\times10^{-3}$

$\delta\nu_y = 1.2\times10^{-3}$ (calc 0.6×10^{-3})

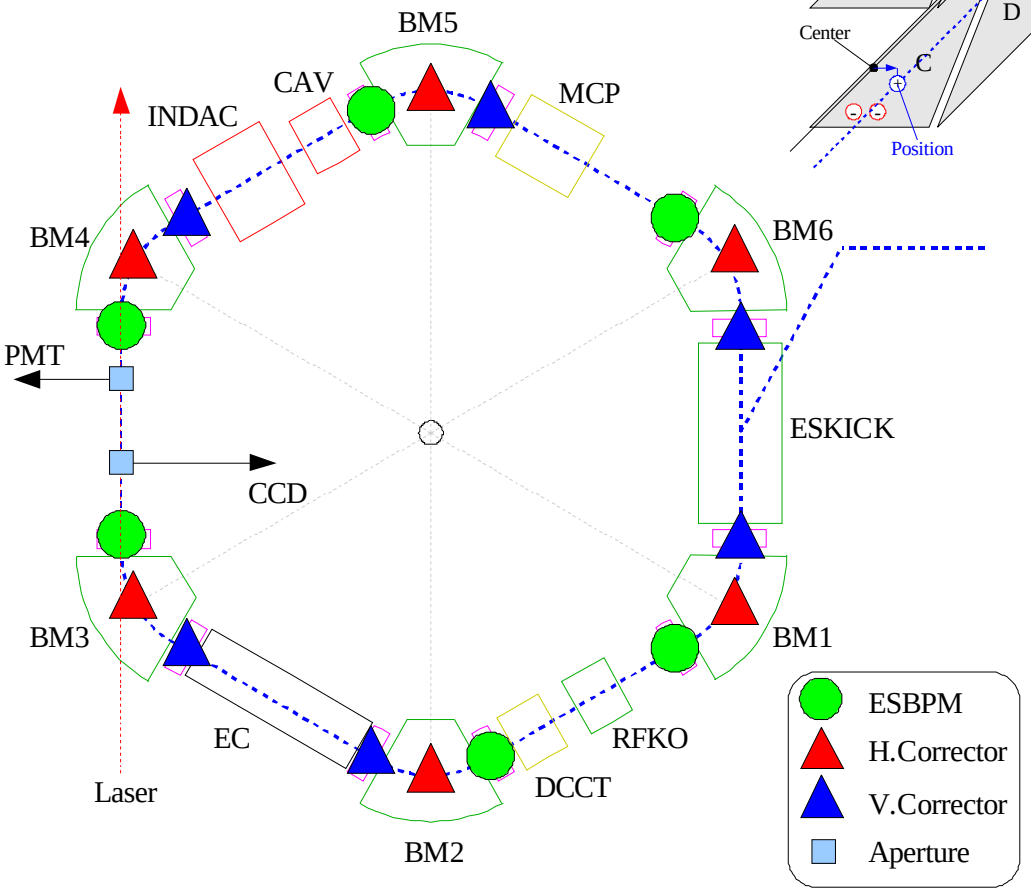
$\Delta\beta_y/\beta_y < 6\times10^{-3}$

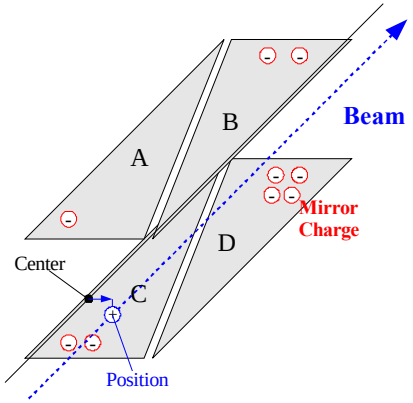
COD Measurement & Correction

6 Electrostatic BPMs(Triangle Plate)
6 Horizontal Correctors(BM Correction Current)
6 Vertical Correctors(BPM as Electrostatic Kicker)



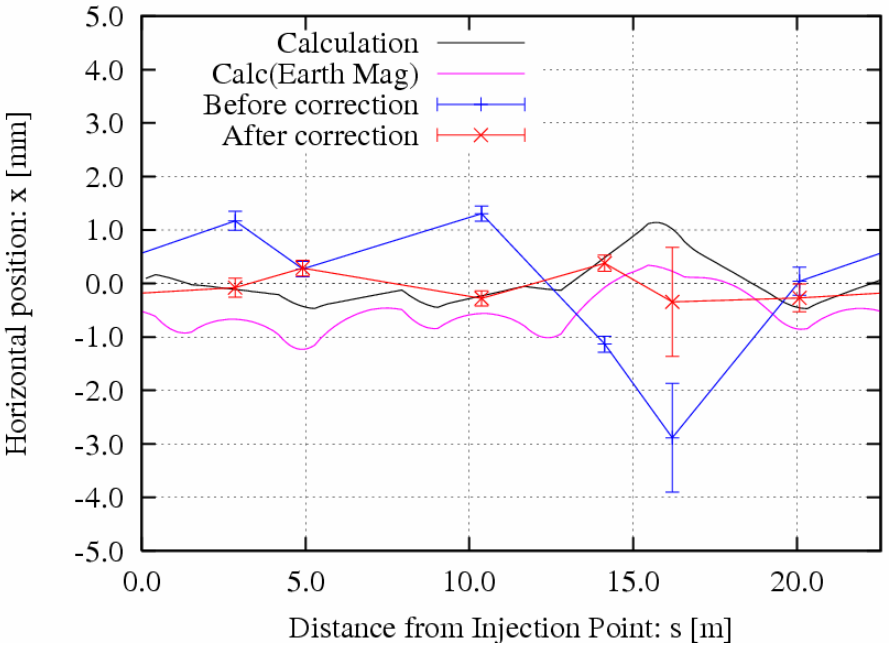
Alignment Target for
ion beam and Laser
Cross angle <0.2mrad



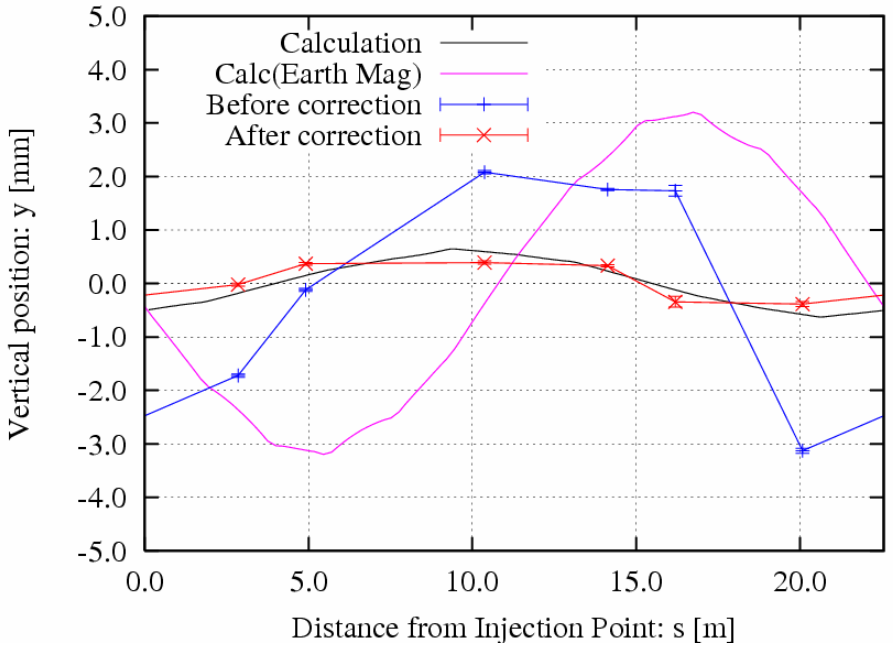


COD correction result

Horizontal COD



Vertical COD



40keV $^{24}Mg^{+}$ beam, ν = (1.644,1.197)

Max 2.9mm → 0.38mm
(calc 1.0mm)
RMS 0.85mm → 0.27mm
(calc 0.4mm)

Max 3.7mm → 0.39mm
(calc 0.7mm)
RMS 2.1mm → 0.33mm
(calc 0.4mm)

Summary

- Bending and quadrupole magnets of S-LSR was aligned using a laser tracker.
- Magnets are shuffled to minimize COD and betatron stopband.
- All magnets were aligned with displacements of less than 0.1mm, 65% are less than 0.05mm.
- Measured COD is the same order of calculation by alignment error, and corrected to +/-0.4mm.