Magnetic measurement system for superconducting final focus quadrupoles for SuperKEKB

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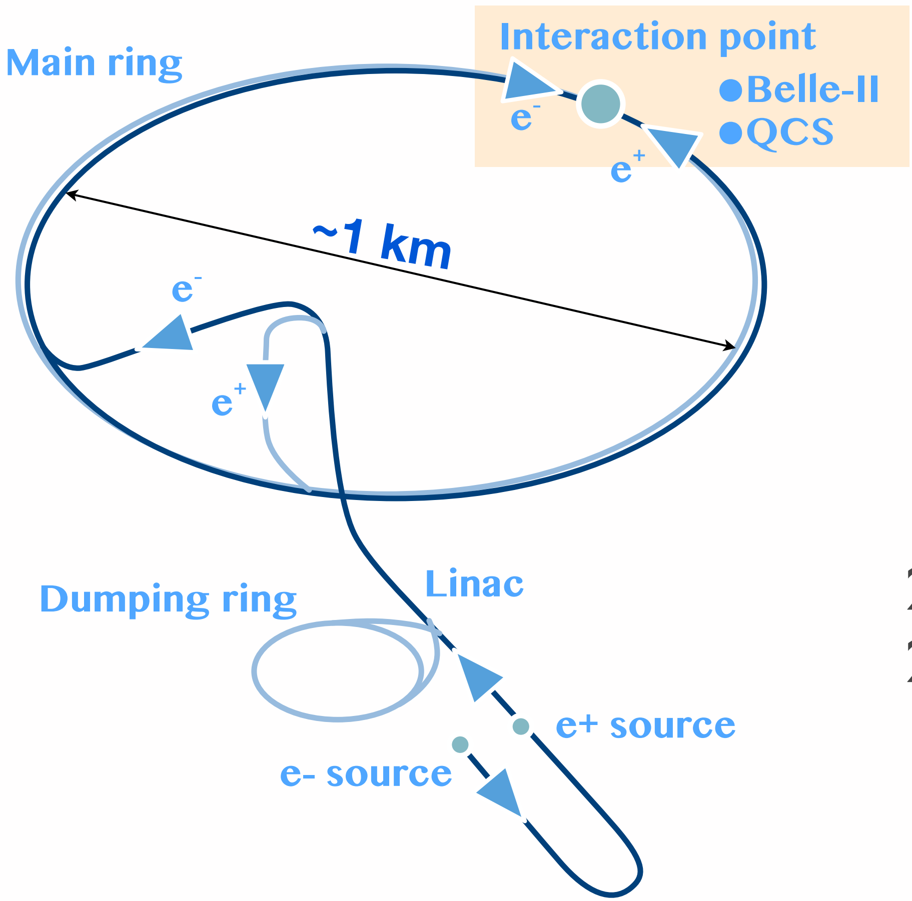
Contents

Introduction (SuperKEKB)

- SuperKEKB, high energy e+/e- collider is under construction at KEK
- SuperKEKB is aiming at high luminosity
  - Target luminosity : $8 \times 10^{35}\ cm^{-2}\ s^{-1}$(40 times larger than KEKB)



Main ring Circumference : 3 km

Colliding energy:

e^- : 7 GeV

e^+ : 4 GeV

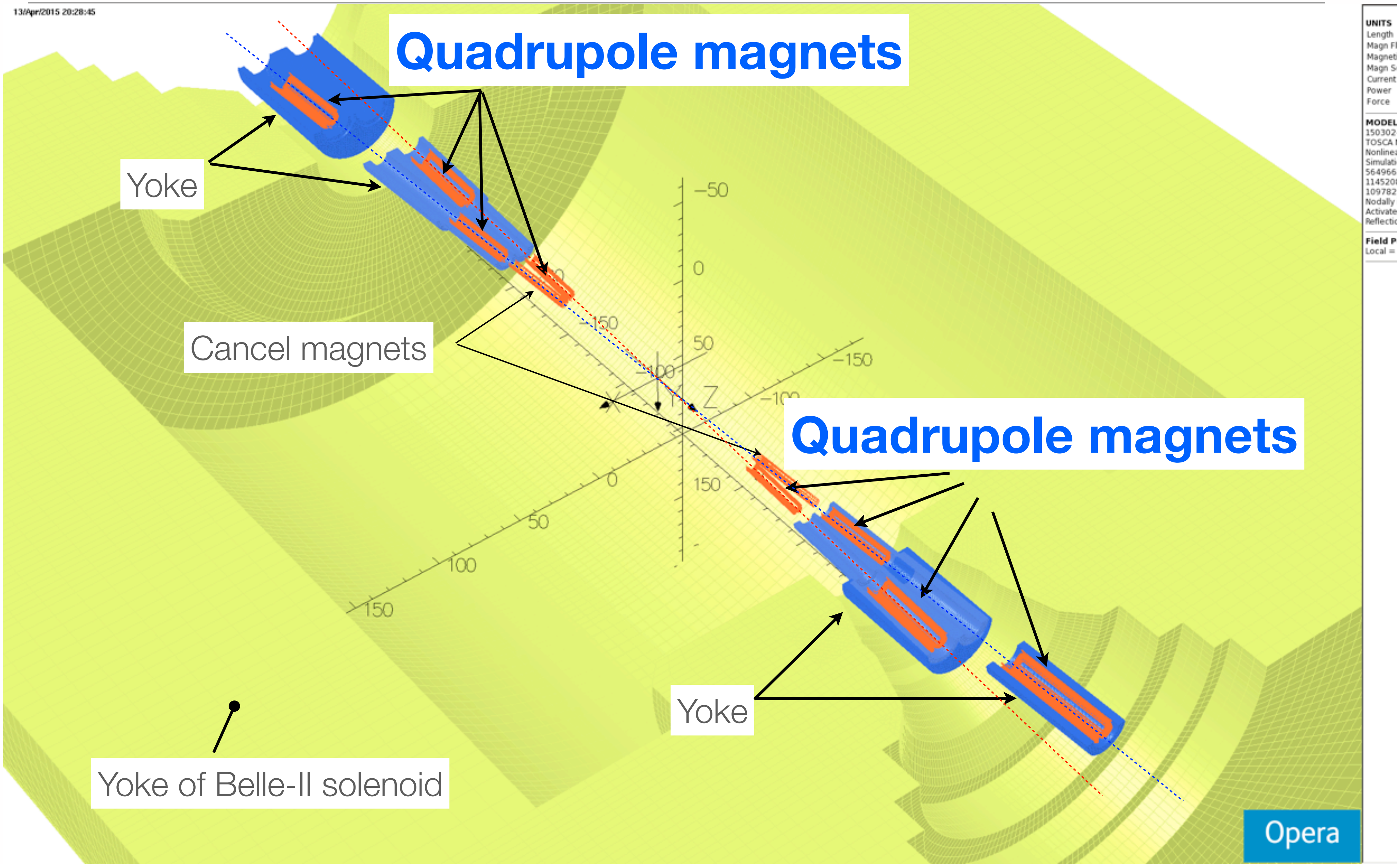
2016/Feb : Operation w/o collision

2018/Feb : Operation w/ collision

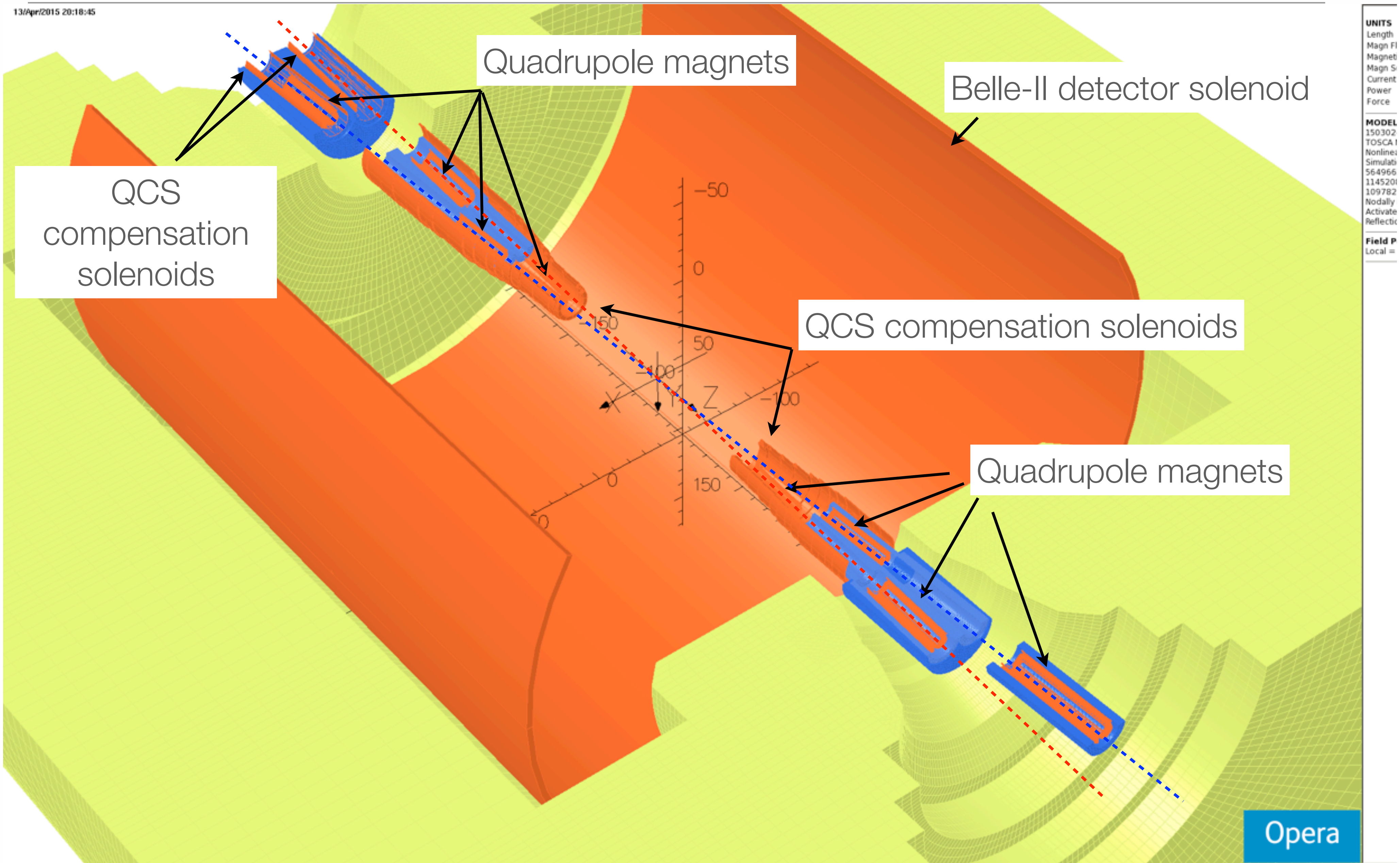
Introduction (final focus magnets system)

- One of key components at SuperKEKB is a final focus quadrupole magnet system (QCS)
- QCS squeezes e+/e- beams to 50 nm in vertical direction at an interaction point
- QCS will be installed in the detector solenoid (B_z= 1.5 T)
- QCS consists of
  - 8 SC quadrupole magnets
  - 43 SC corrector/cancel coils（ built by BNL)
  - 4 SC compensation solenoids
- All magnets of QCS will be operated in DC current mode.
- Construction of QCS has been completed on Feb. 2017 and installed at an interaction region (IR) of SuperKEKB. Now they are cooled down and starting magnetic measurement.

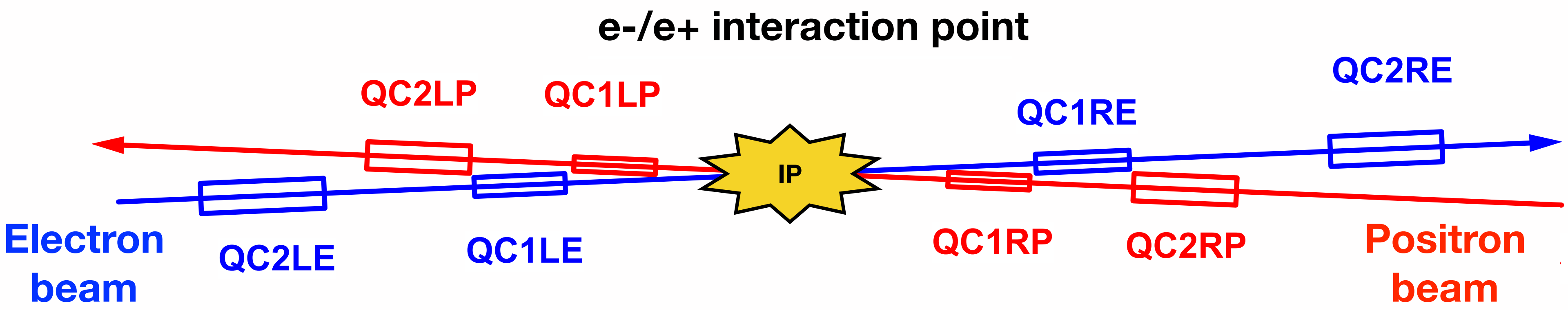
Quadrupole magnets at interaction region



Magnets layout at interaction region w/ solenoids

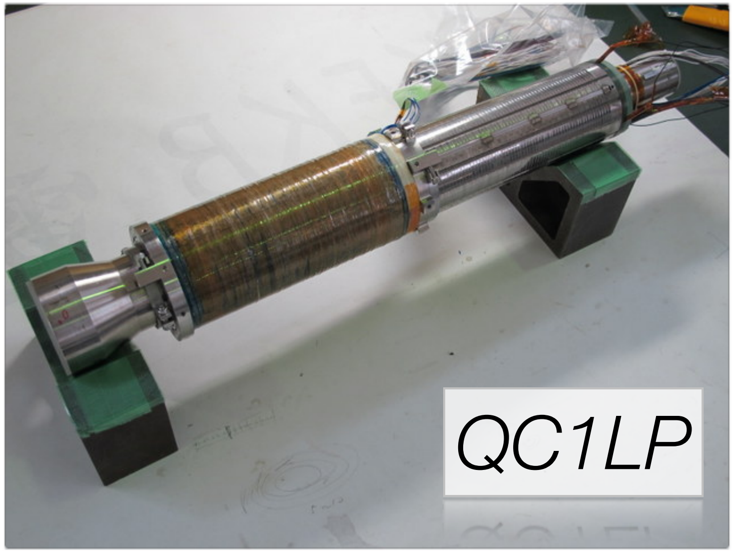


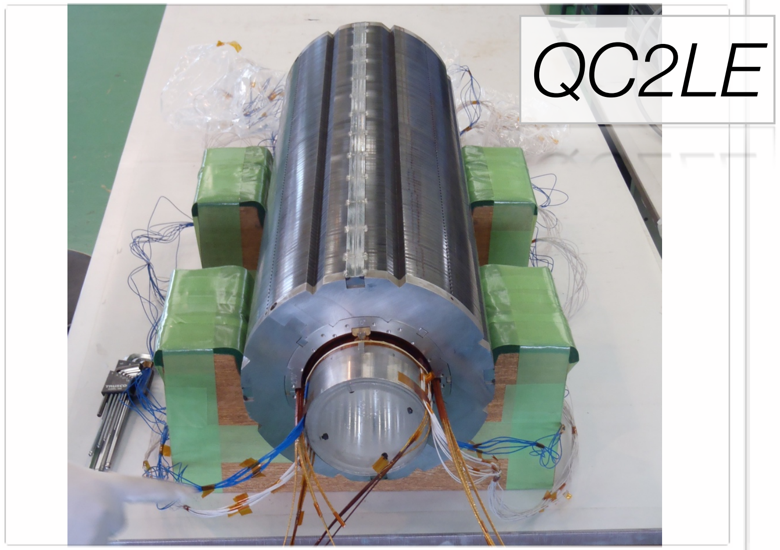
Main parameters of QCS quadrupoles



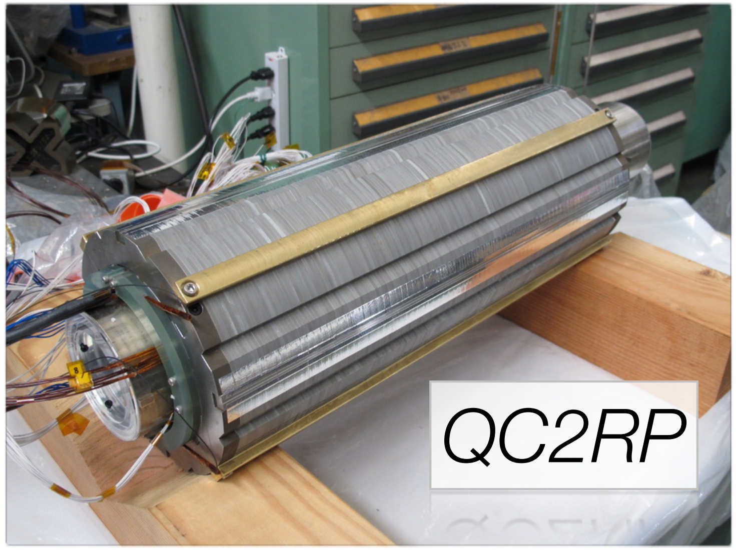
Magnet Name	G [T/m]	I [A]	Inner Radius [mm]	Effective Length [mm]
QC1LP/ QC1RP	68.94 / 68.89	1625 / 1624	25	334
QC2LP/ QC2RP	28.05 / 26.28	877.4 / 822.1	54	410
QC1LE/ QC1RE	72.21 / 70.89	1577 / 1486	33	373
QC2LE/ QC2RE	28.44 / 32.41	977.0 / 1068	59	537/419

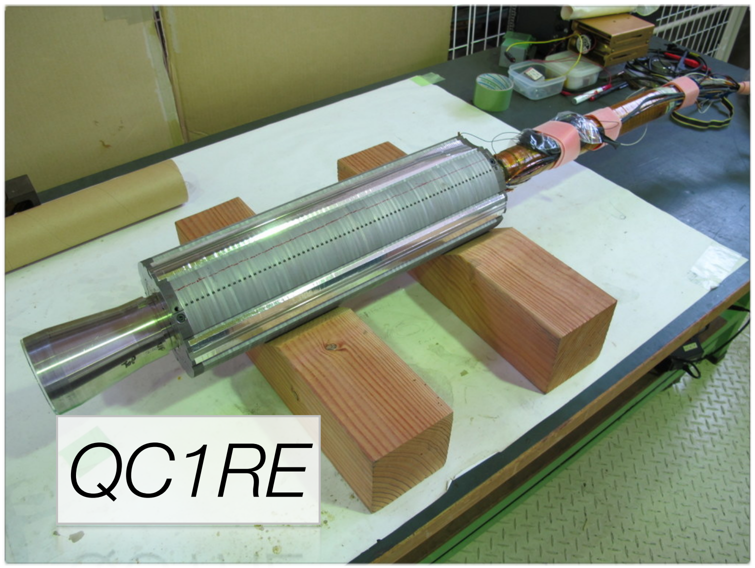
Quadrupole magnets (on left side of IP)



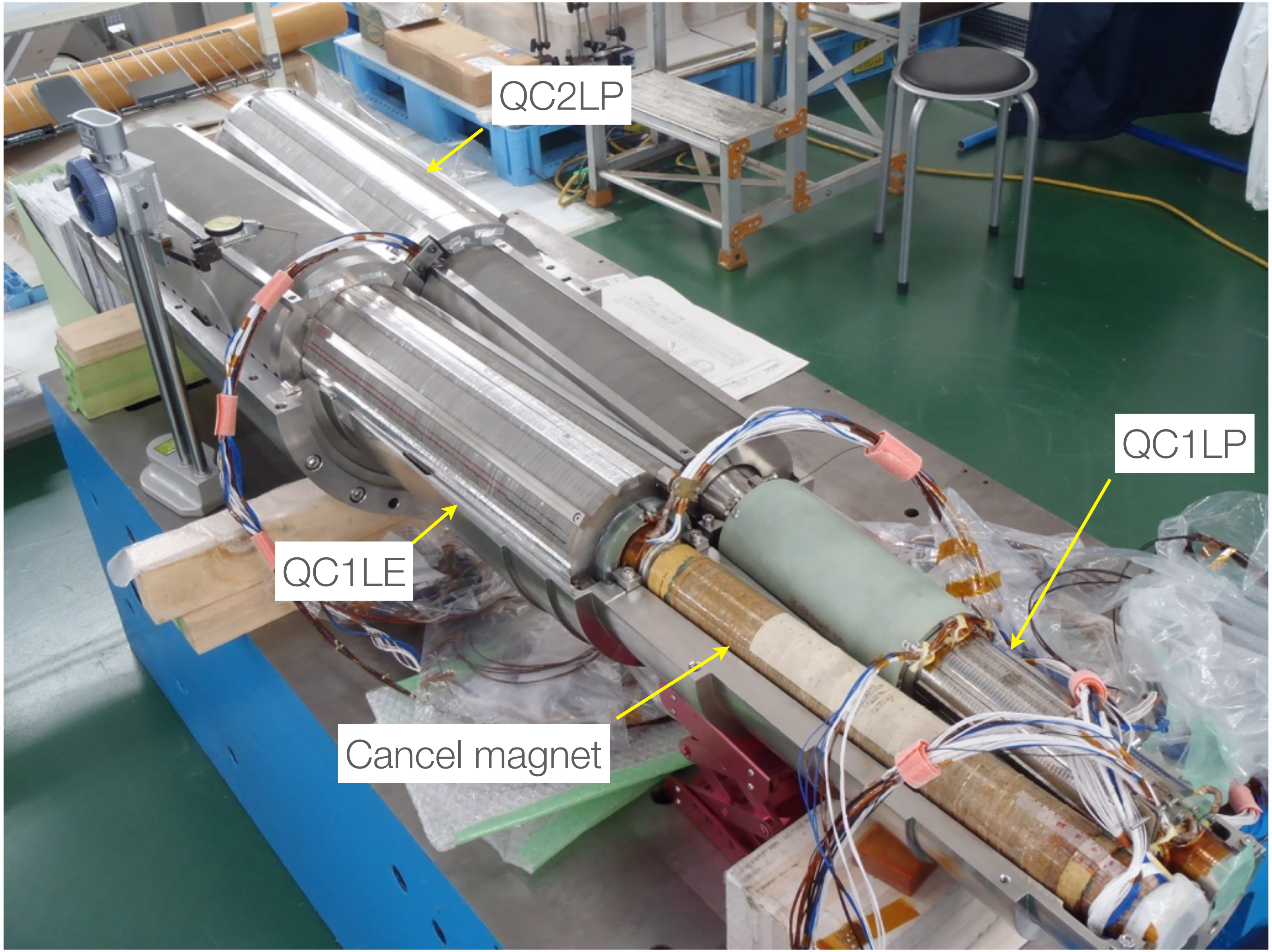


Quadrupole magnets (on right side of IP)

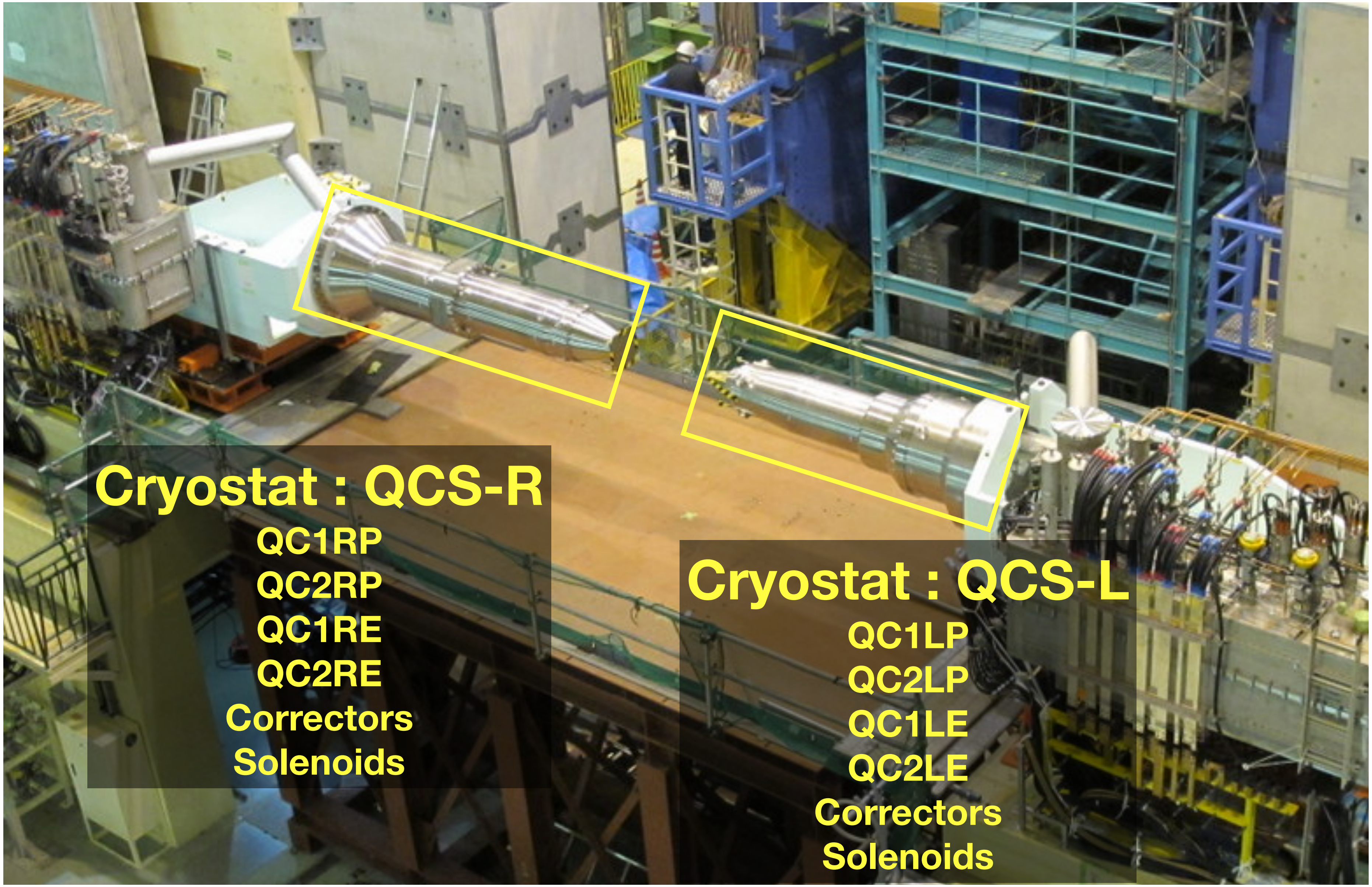




Assembled three quadrupole magnets



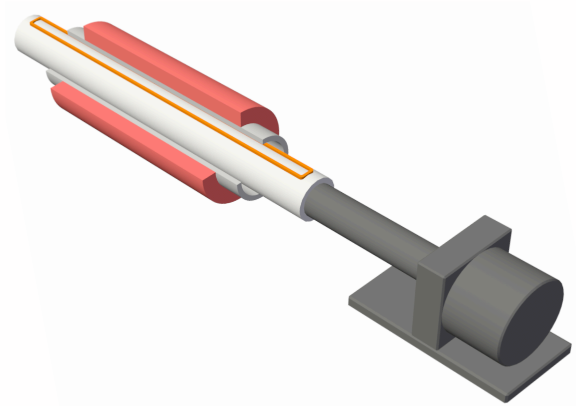
QCS at IR


Cryostat : QCS-R
QC1RP
QC2RP
QC1RE
QC2RE
Correctors
Solenoids
Cryostat : QCS-L
QC1LP
QC2LP
QC1LE
QC2LE
Correctors
Solenoids

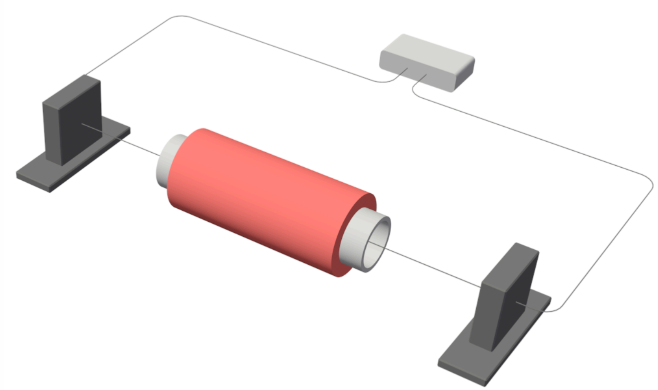
Magnetic measurements

Requirements for magnet measurements

- Field harmonics : < 10^{-4} to main quadrupole
  - Measurement method: Harmonic coil



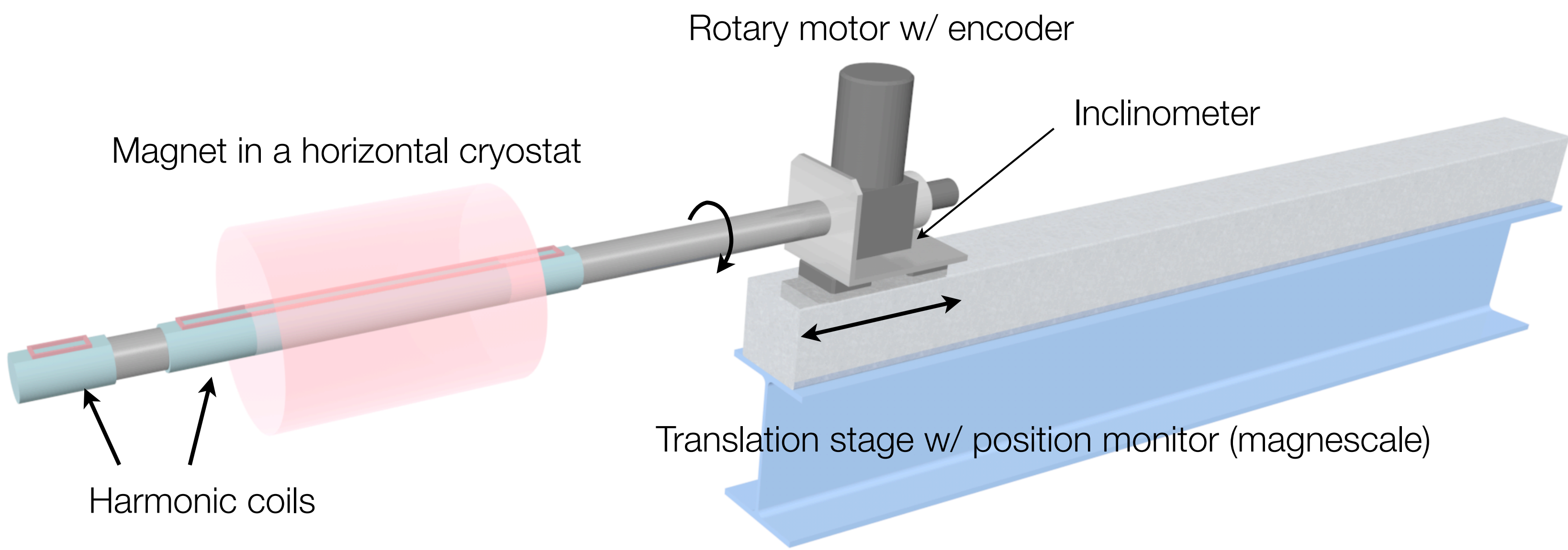
- Alignment error of magnet axis at very early stage of beam commissioning: < ~100 um
  - Measurement method : Single Stretched Wire
  - Expected Measurement precision : 100 μm
    - Precision by SSW : a few μm
    - Fiducialization of the system to the beam line : 50~100 μm
  - Should be measured at IR under solenoids field



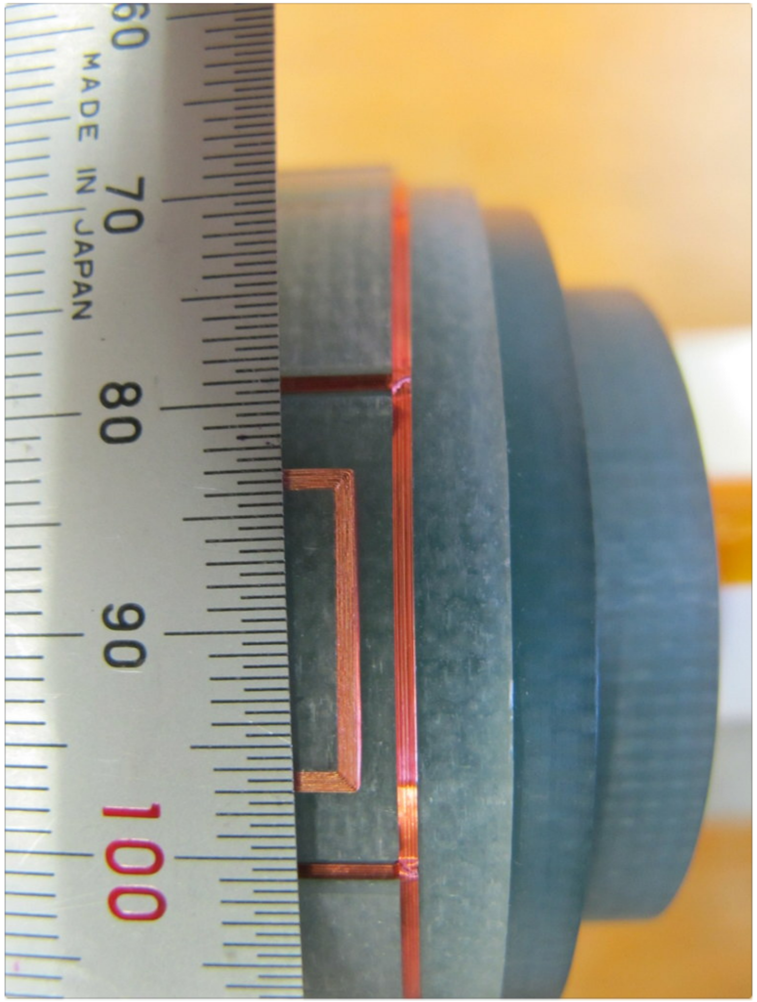
Harmonic coil measurement

Harmonic coil system

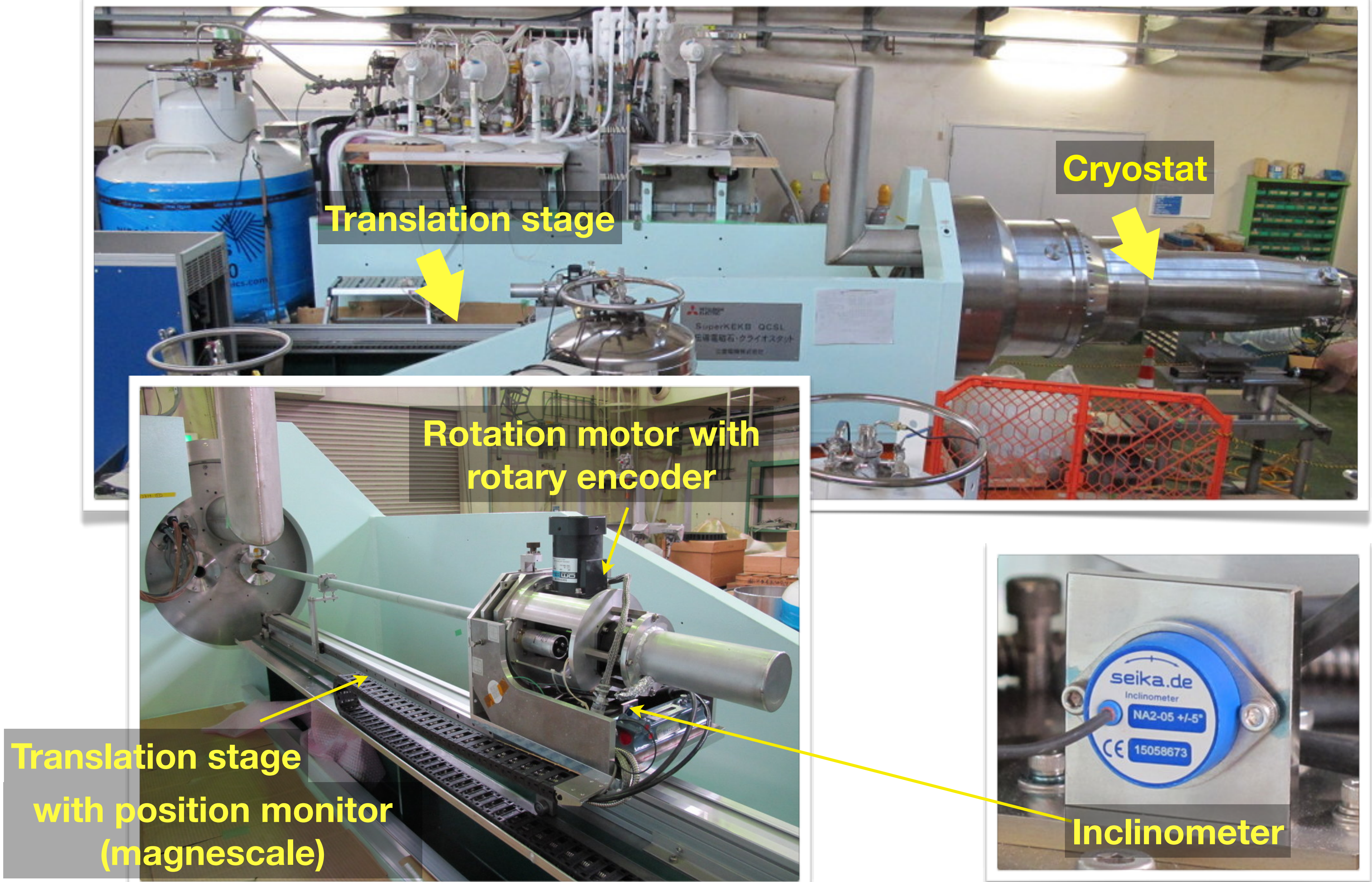
- Coil configuration
  - Long coil (L = 600 ~ 800 mm)
  - Short coil (L = 20 mm)
- Winding radius
  - R=12 mm
  - R=25 mm
  - R=33 mm
- Winding types
  - Tangential winding with analog quadrupole and dipole bucking
  - 2 dipole windings (for digital bucking)
  - 2 quadrupole windings (for digital bucking)
- Calibration has been done with reference dipole, quadrupole, and sextupole magnets
- Integrator: PDI5025 (Metrolab)



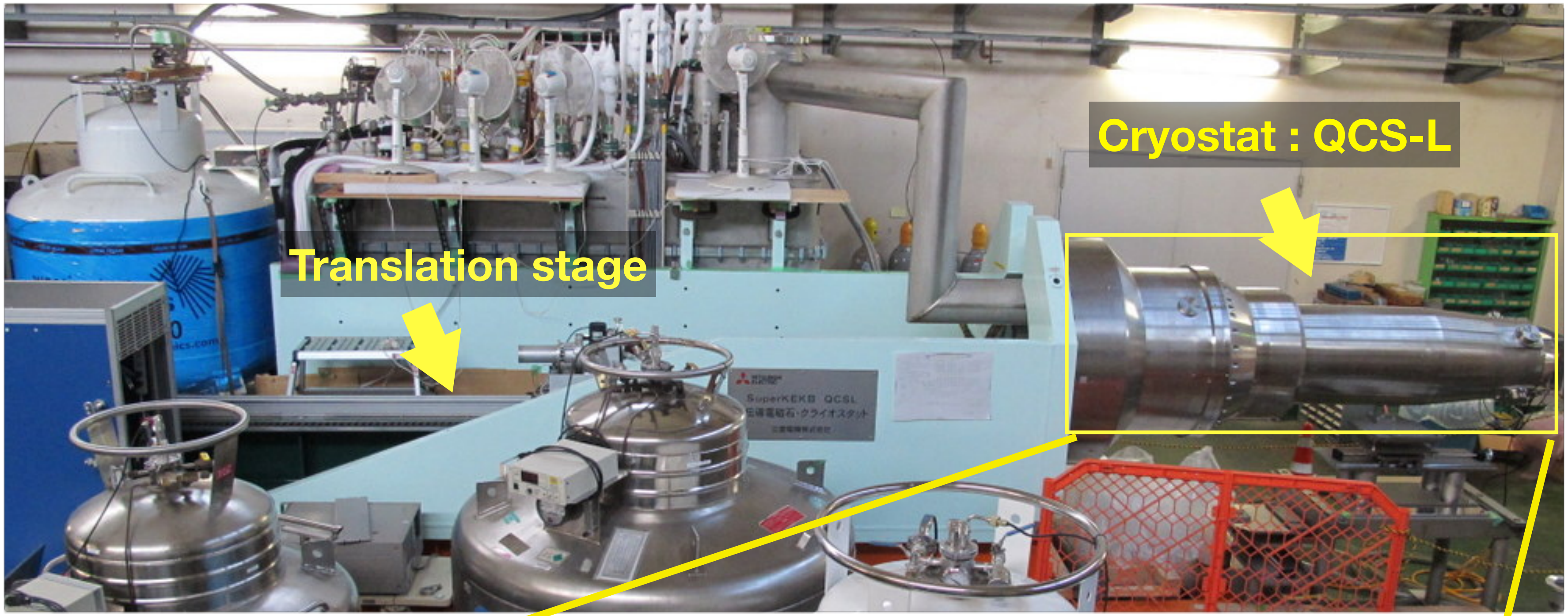
Harmonic coil



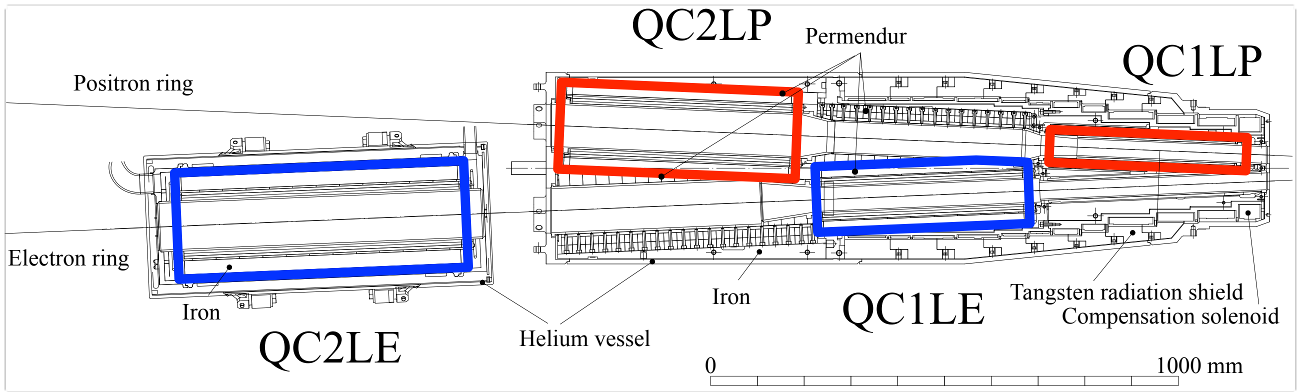
Measurement setup



Measurement setup

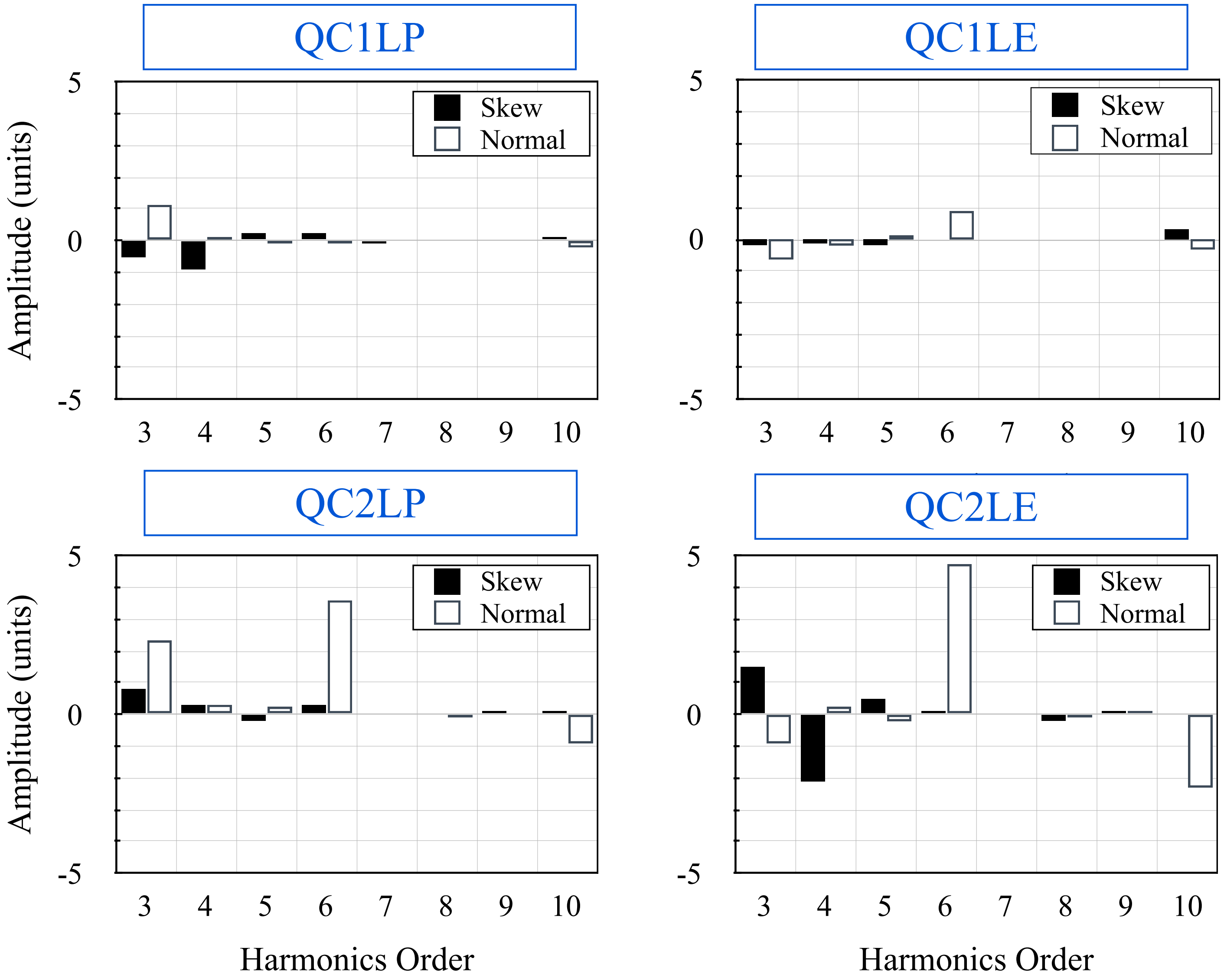


Top view



Measured multipoles

$$B_y + iB_x = B_2 \sum_{n=1}^{\infty} (b_n - ia_n) \left(\frac{x + iy}{r_0} \right)^{n-1}$$



Tolerance

(n=3) 10 units

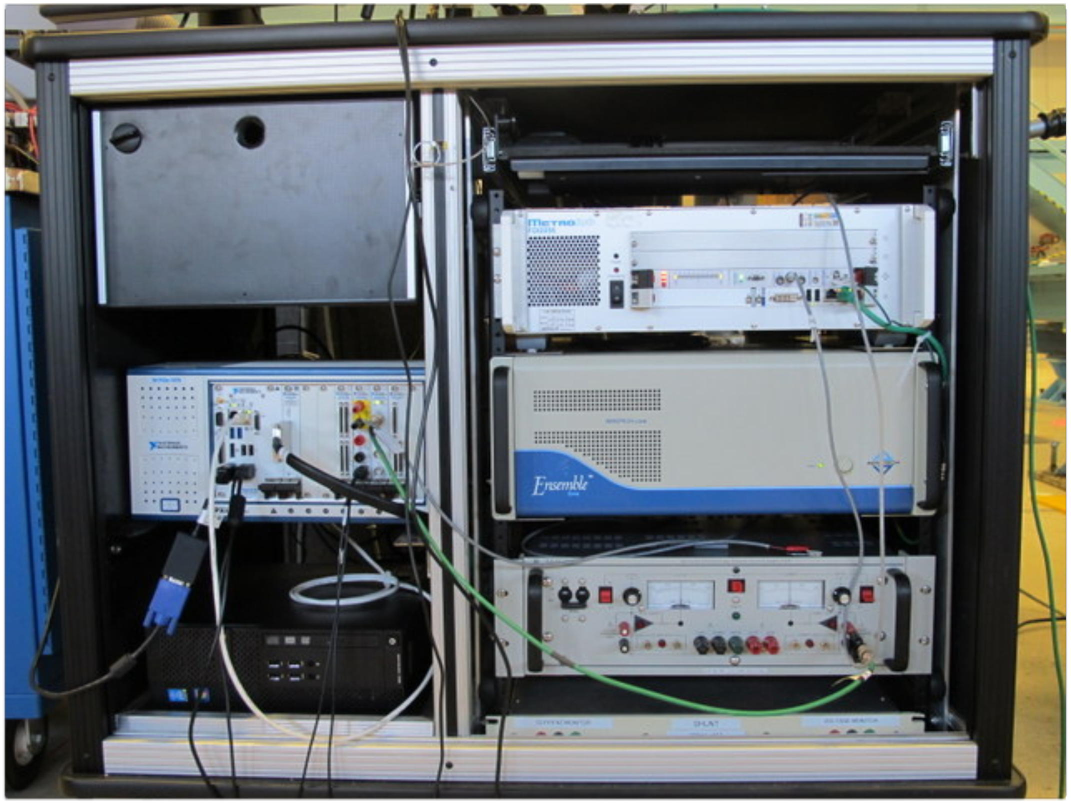
(n>3) 5 units

Multipole component for all magnets are less than 5 units

Single stretched wire

Single stretched wire system

- The system has been built by Fermilab (newly upgraded system)
  - Control and analysis are based on LabView and MATLAB
  - New type of Integrator from Metrolab
  - KEK uses this and feedback some bugs to Fermilab for improvement.
- Electronics
  - Integrator
    - Metrolab FDI2056
  - AC Power supply
    - KEPCO BOP 36-12M
  - Servomotor driver
    - Aerotech ensemble
  - PXI modules
    - Function generator
    - Digital voltmeter
    - Trigger module

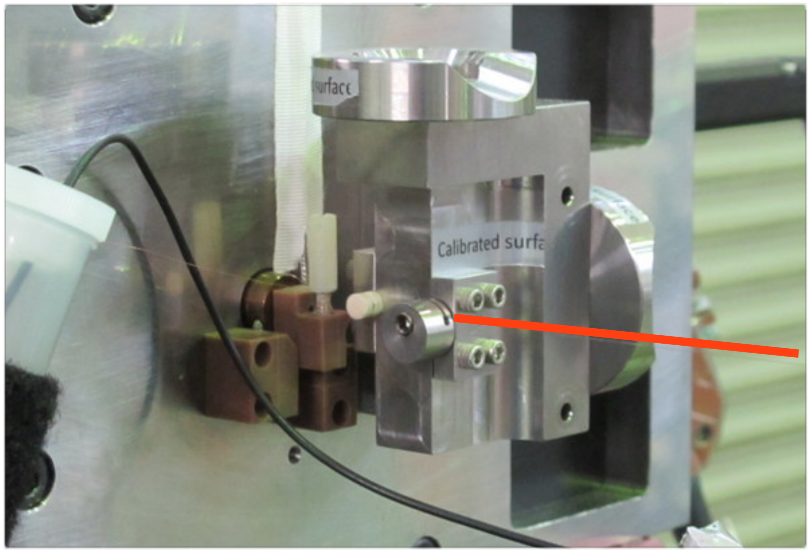


Single stretched wire system (cont.)

- x-y stage

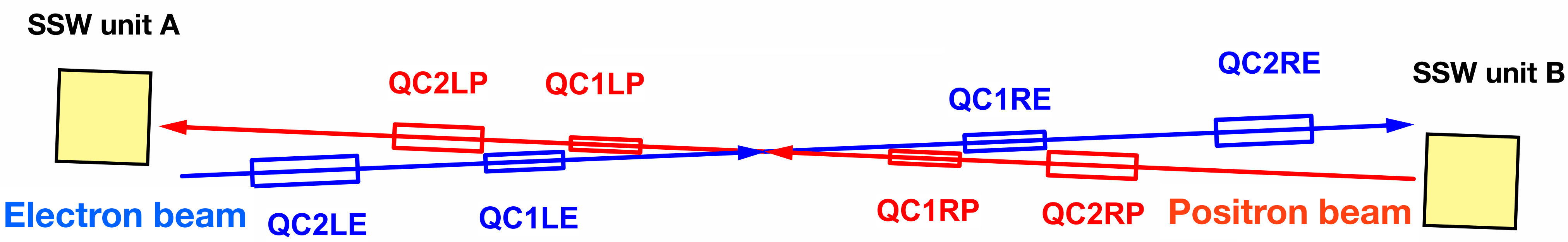
	x	y
Model (Aerotech co.)	ANT130-160-L	ATS 100-150-UF
Repeatability	0.1 um	0.7 um
Resolution	1 nm	0.5 um

- Wire
  - Be-Cu (ϕ 0.1 mm)
- Wire fixture
  - Ball bearing
- Tension control
  - Rotary motor monitoring tension gauge
  - Tension : 800 g



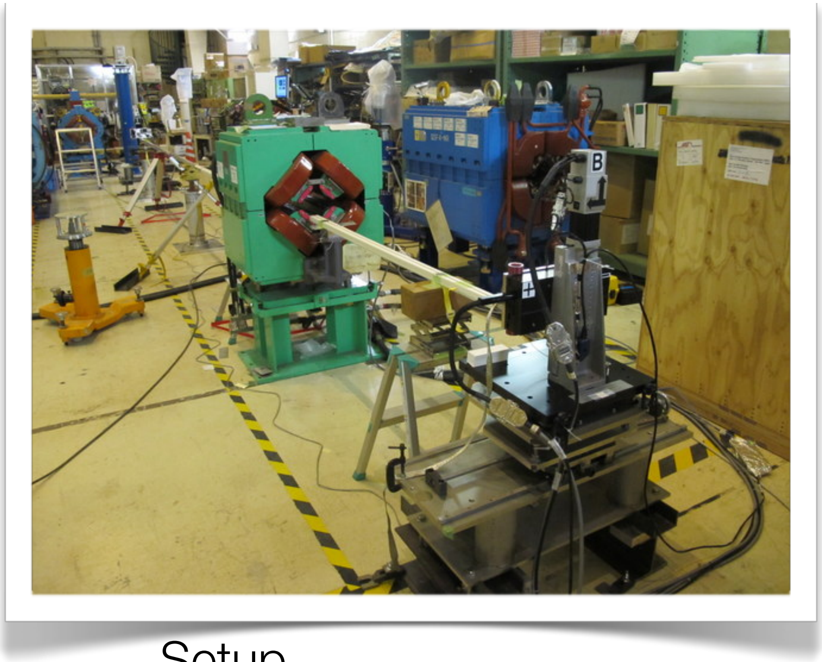
Specific conditions for QCS

- QCS quadrupoles are aligned at different longitudinal positions on beamlines
  - Magnet does not on center between two SSW units
- QCS is located inside Belle-II detector solenoid (B=1.5 T). QCS magnets will move if the solenoid is excited due to magnetic force.
  - We need to measure quadrupole magnet center while the solenoid is excited.
  - The solenoid generates dipole component because the beamlines are aligned at angle of 41.5 mrad with respect to the solenoid axis.
  - Long wire (~8 m)



SSW Measurement with normal conducting quadrupole magnet

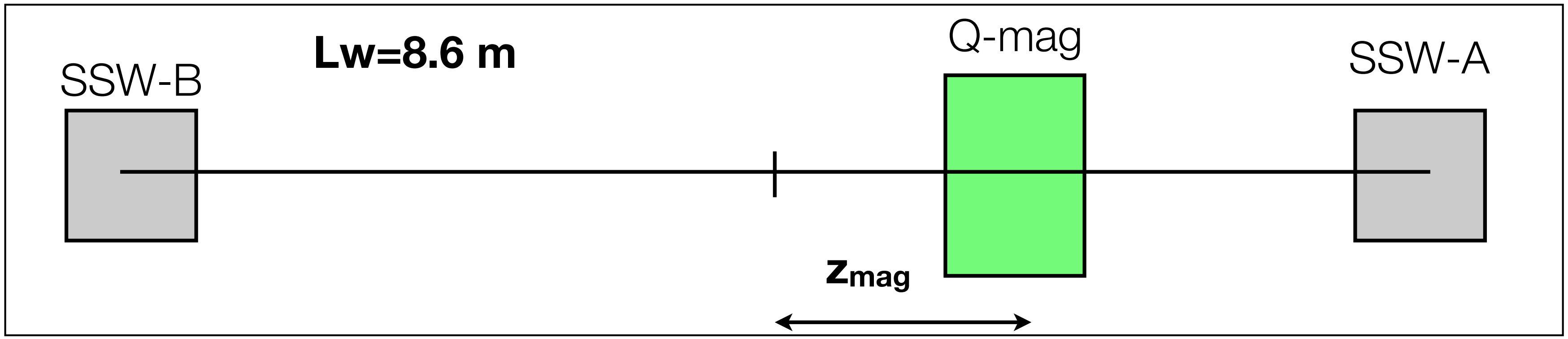
To check longitudinal position dependences, we performed SSW measurement with normal conducting magnet.



Setup

Parameters of the Q-magnet

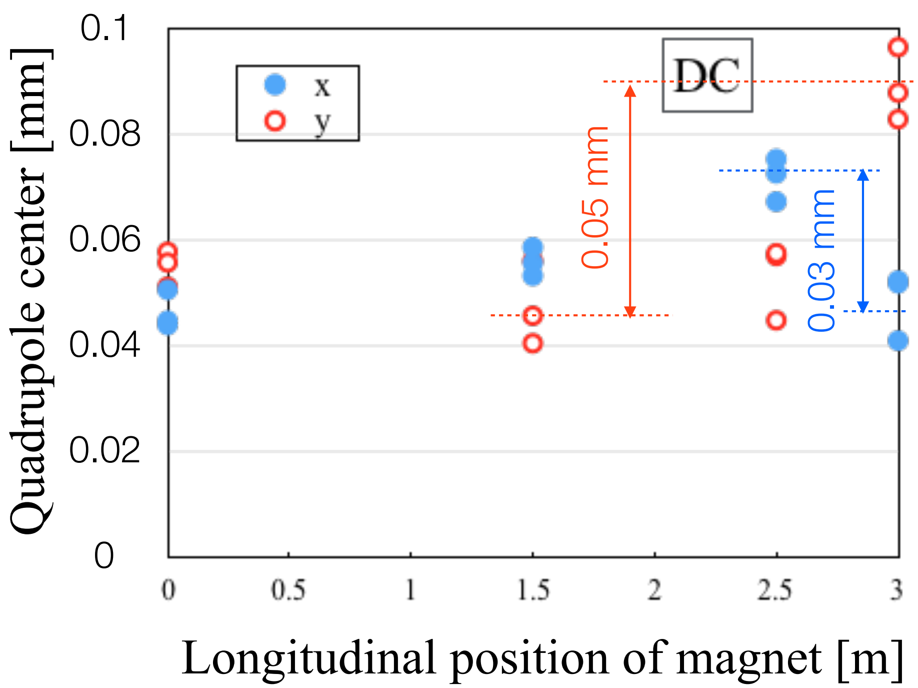
Bore : ϕ100
Yoke Length : 446 mm
I.T.F. : 0.0093 T/A
Integrated gradient : 4.8 T @ 500A

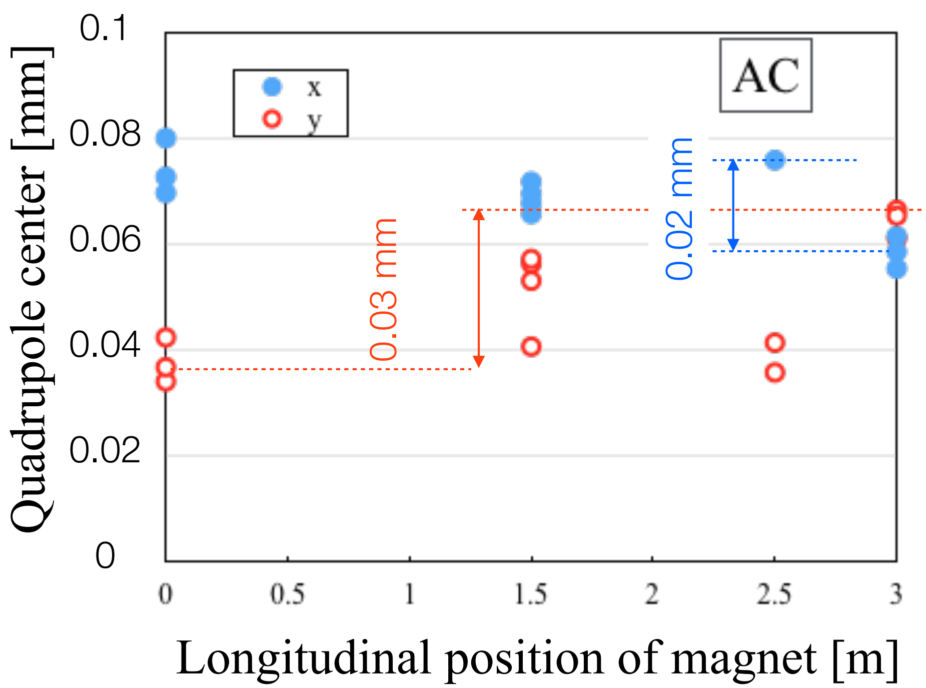


Magnet center vs magnet position

Wire length = 8.6 m
Step size = 20 mm

Reference magnet



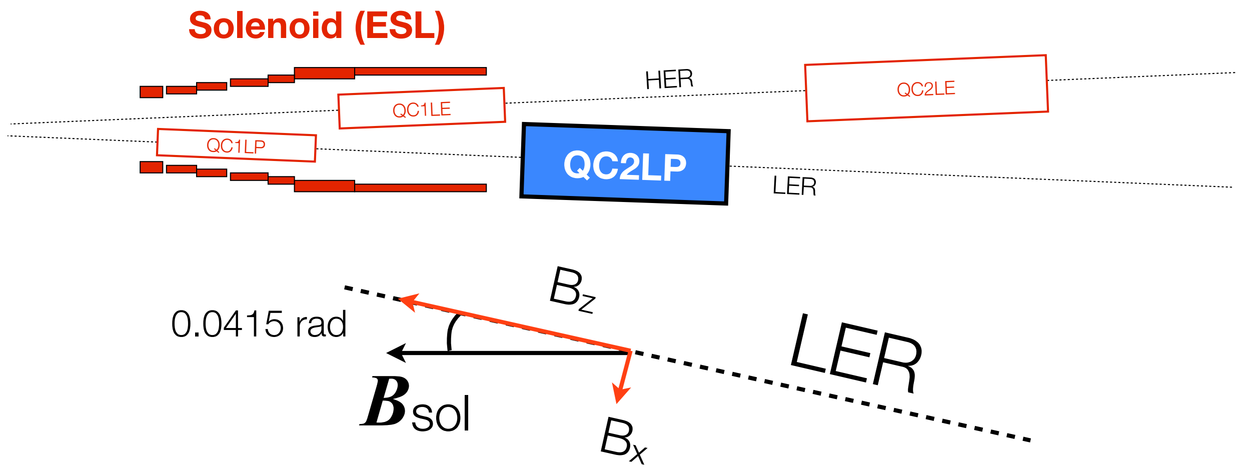


Δx = 0.03 mm
Δy = 0.05 mm

Δx = 0.02 mm
Δy = 0.03 mm

Difference between AC and DC : 0.03 mm at maximum

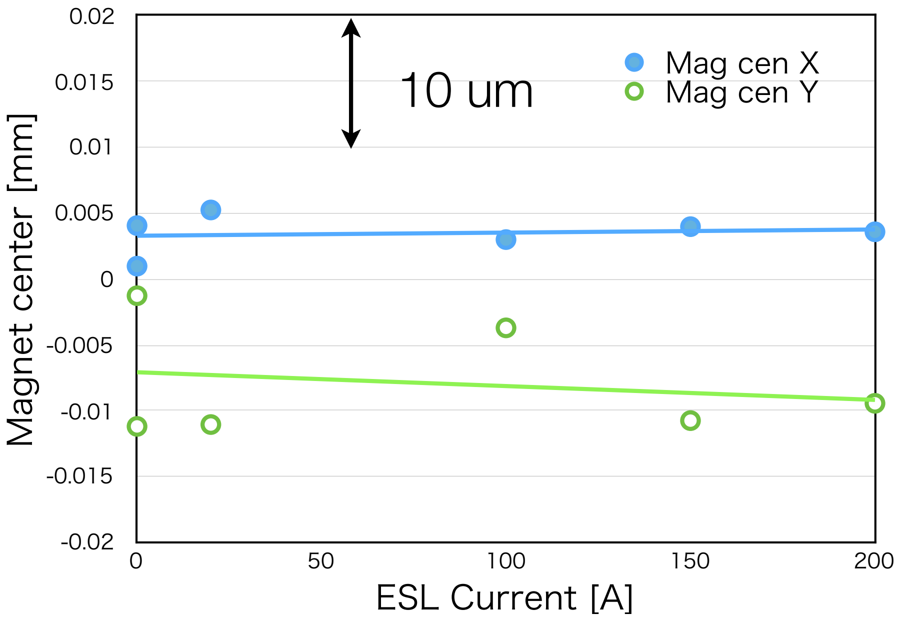
AC measurement of QC2LP with Solenoid (ESL)

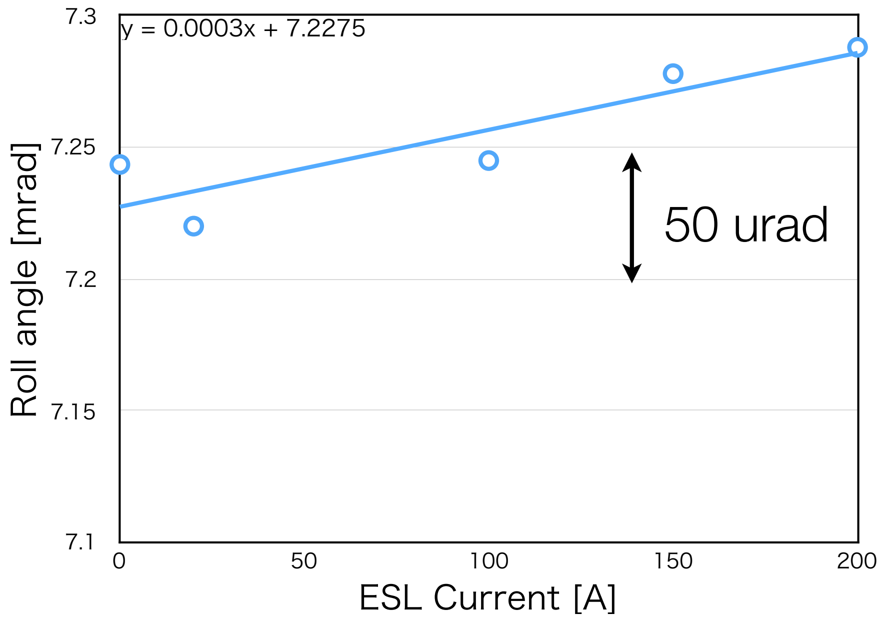


SC magnet in QCS-L

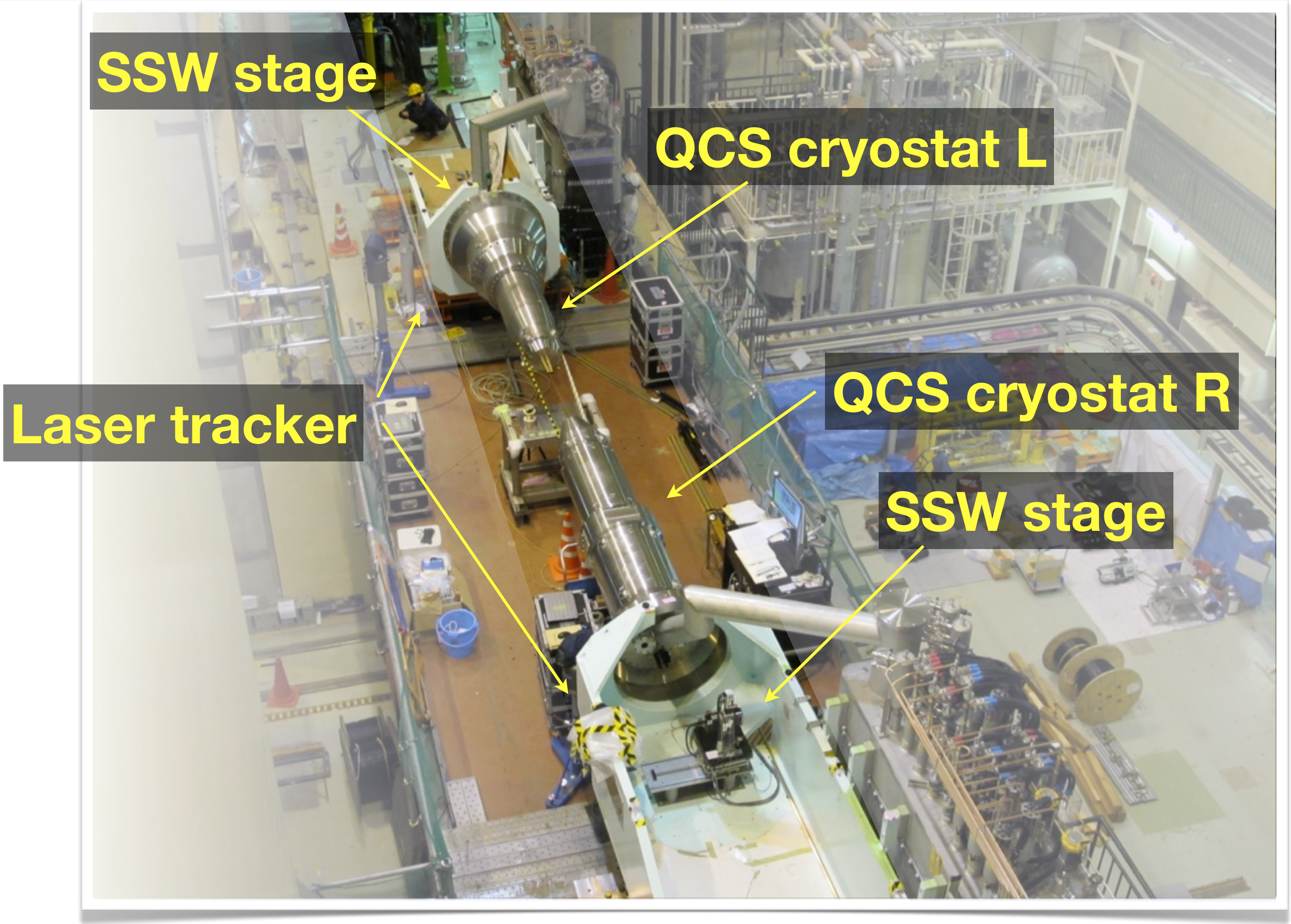
QC2LP
GL = 11.47 T @ I=877A

Solenoid (I=200A)
B_z L = 1.131 T
B_x L = 0.0488 T
dy = 4.2 mm

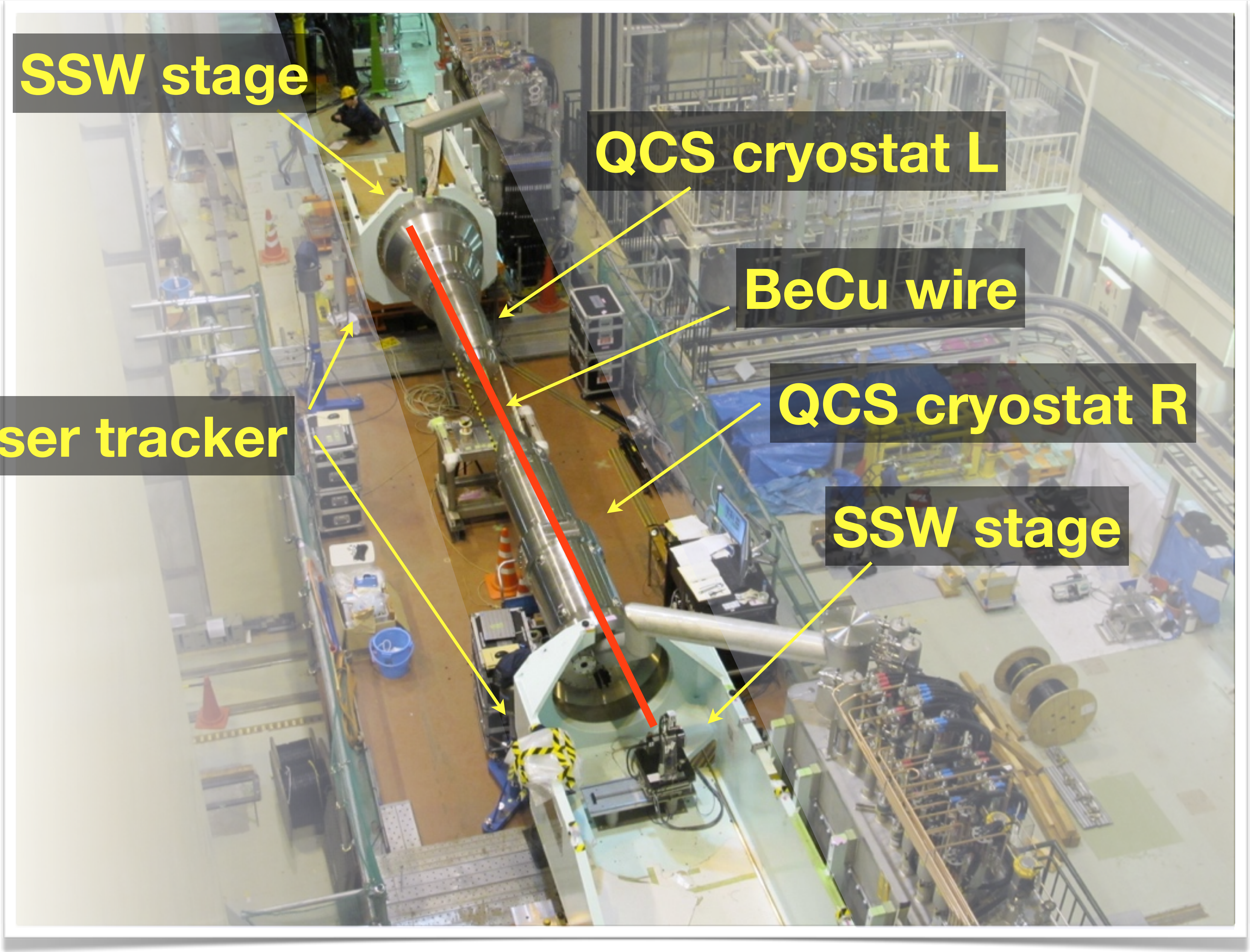




Warm measurement at IR (interaction region)



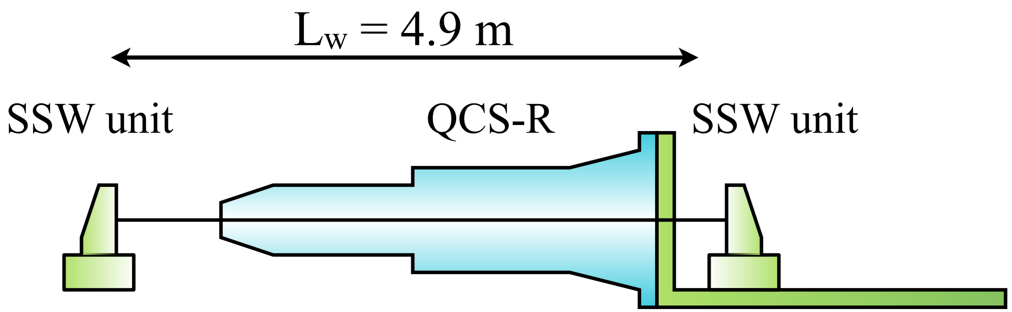
Warm measurement at IR (interaction region)



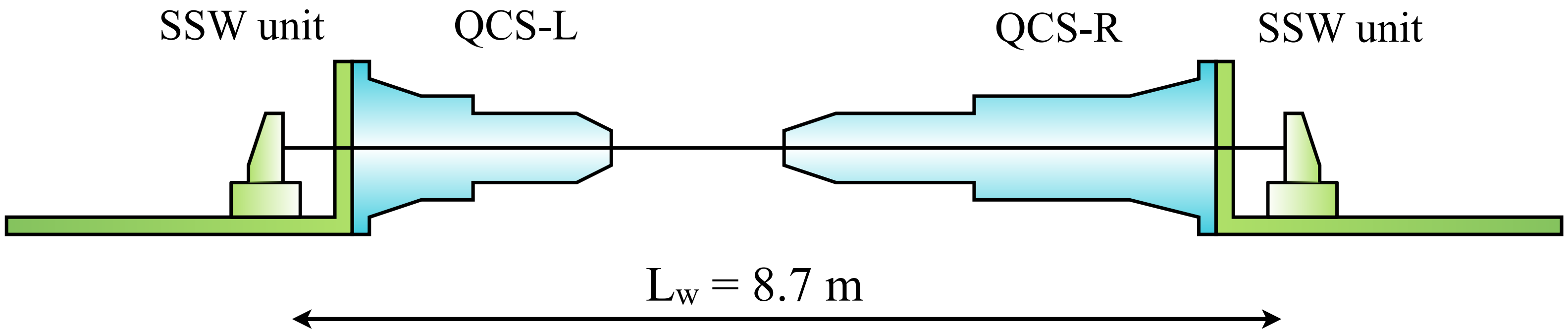
Set up

- SSW measurement were performed with 2 setup
  - Setup 1: A SSW unit is set on QCS-R end, and the other unit set on around IP
  - Setup 2: Two SSW units are set on end of QCS-R and QCS-L

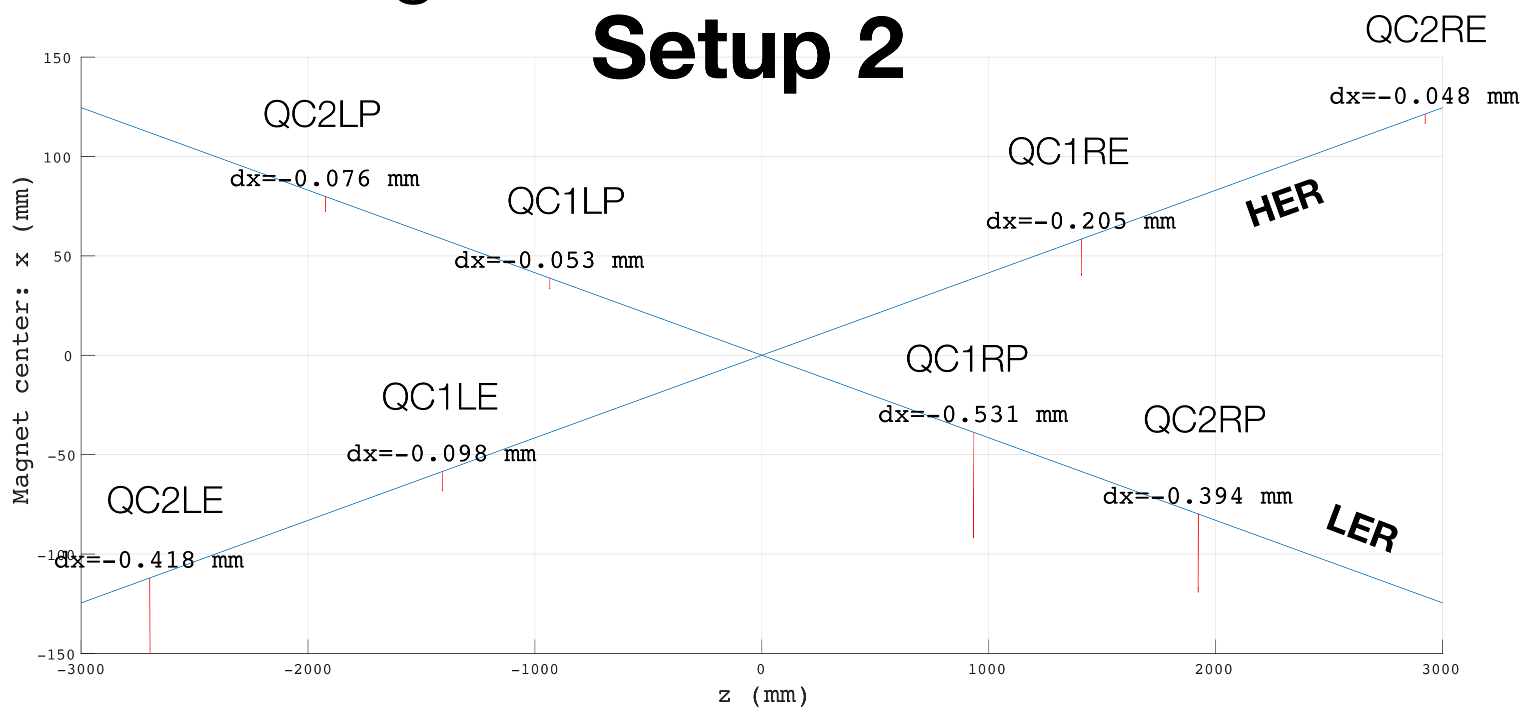
Set up 1

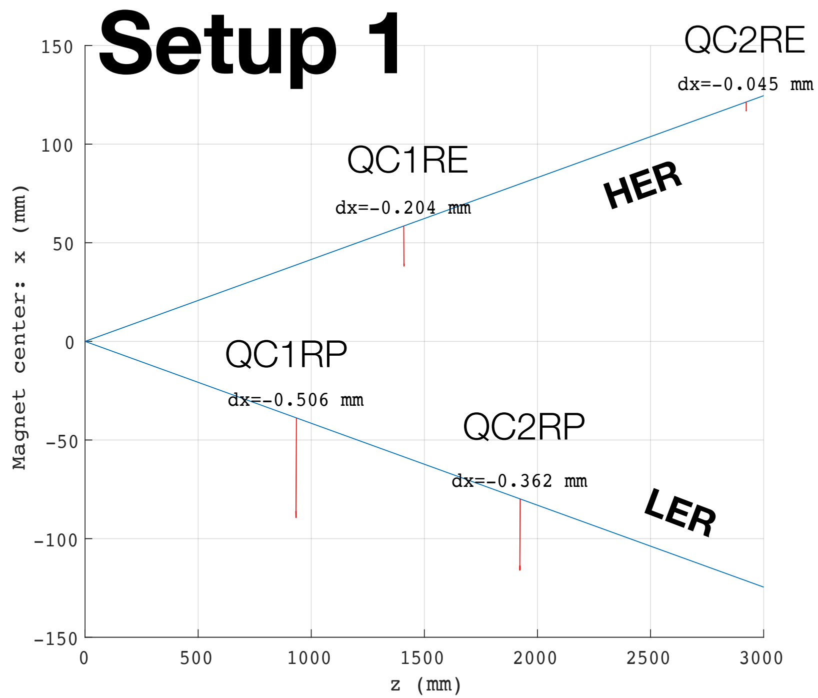


Set up 2



Horizontal misalignment





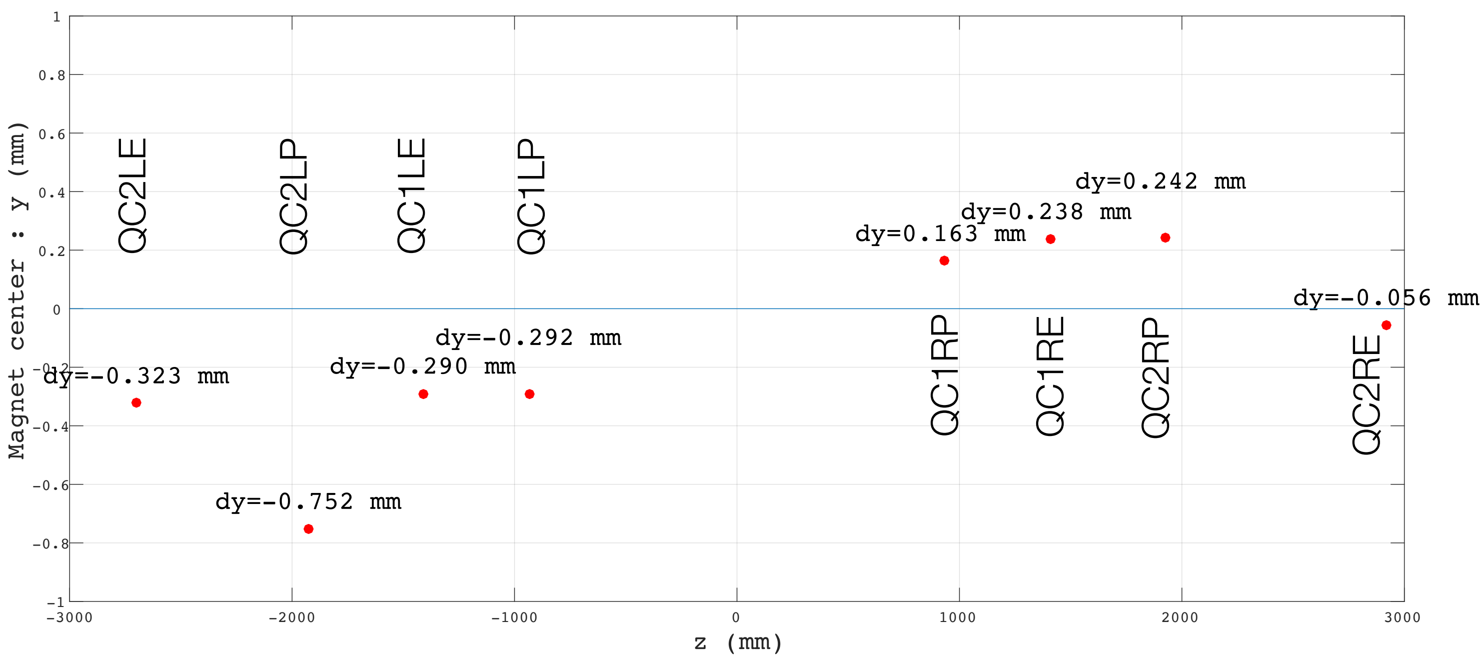
Difference between Set up 1 and 2 : Δx

LER (positron ring) : ~ -30 um

HER (electron ring): ~ 3 um

Vertical misalignment

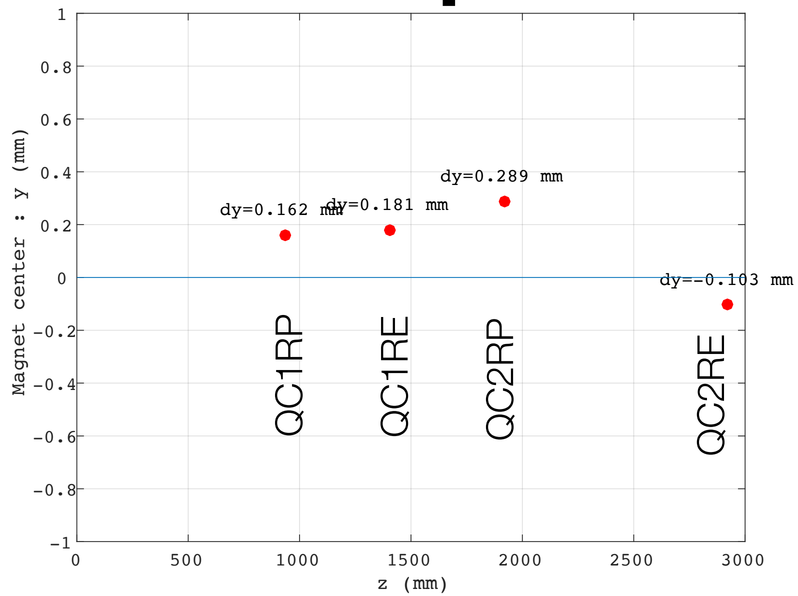
Set up 2



Difference between Set up 1 and 2 : Δy

QC1RP : 1 um
QC1RE : 57 um
QC2RP : 47 um
QC2RE : 47 um

Set up 1



All of magnets in left side of cryostat are low by 0.3 mm to 0.75 mm. It is expected the ground level will be down after detector will be installed, so we lifted up the left-side cryostat by 0.3 mm.

Summary

- QCS is SC final focus quadrupole magnet system of SuperKEKB
- Magnet measurement system of QCS
  - Harmonic coils
  - SSW
- Harmonic coil measurements show the higher harmonics of quadrupole magnets are smaller than tolerance
- We performed SSW measurement
  - Longitudinal magnet position dependence on SSW results is not shown.
  - Solenoid field effect can be eliminated by AC measurement
  - Large misalignment were found in vertical direction and the left side cryostat was re-aligned.
- Measurement schedule
  - 2017/Jun. - Aug. : Magnetic measurement at IR under the particle detector solenoid field
    - Harmonic coil measurements
    - SSW measurements