Damping Ring Commissioning

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for SuperKEKB Commissioning Group

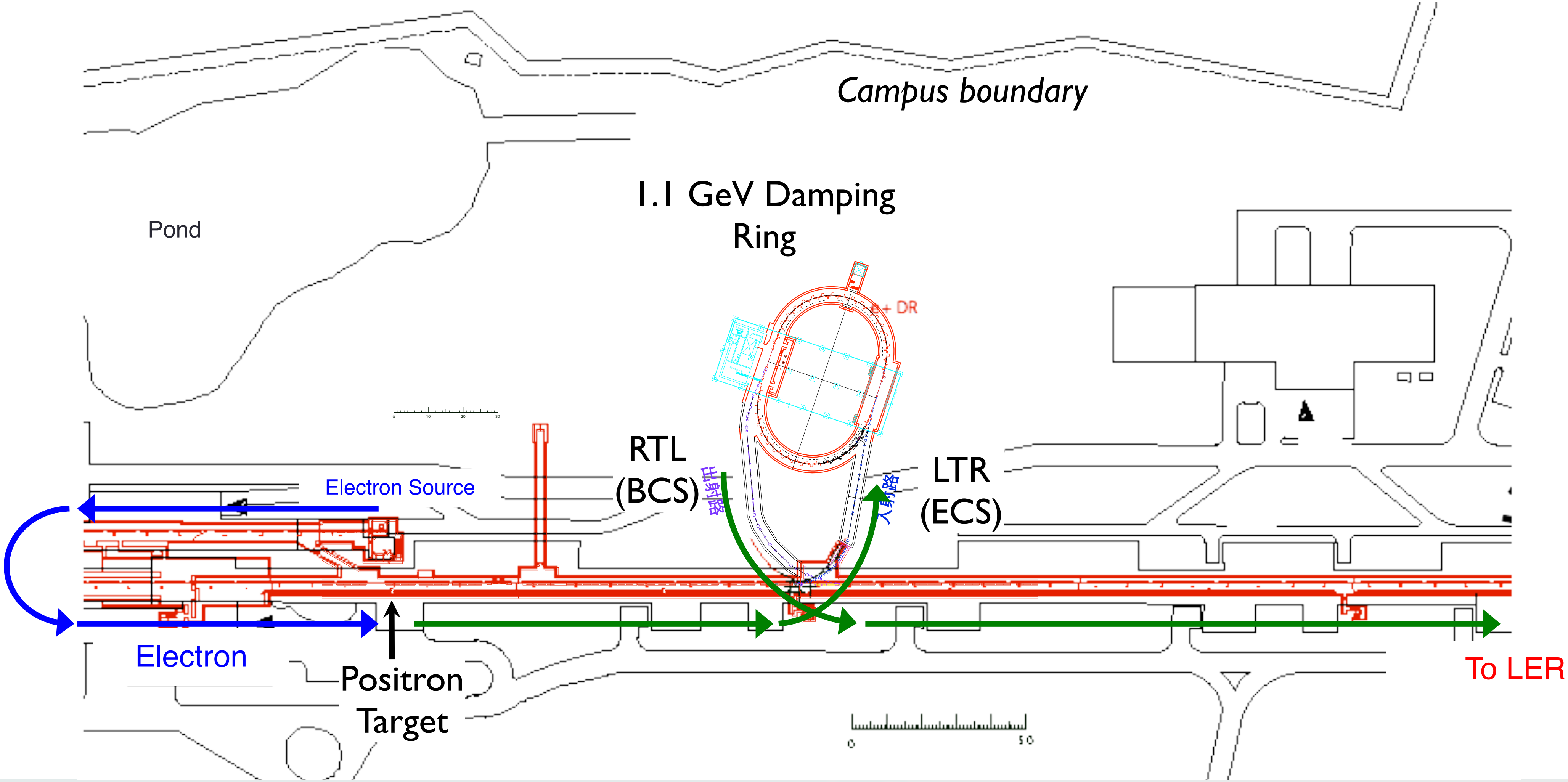
The 22nd KEKB Accelerator Review Committee

Contents

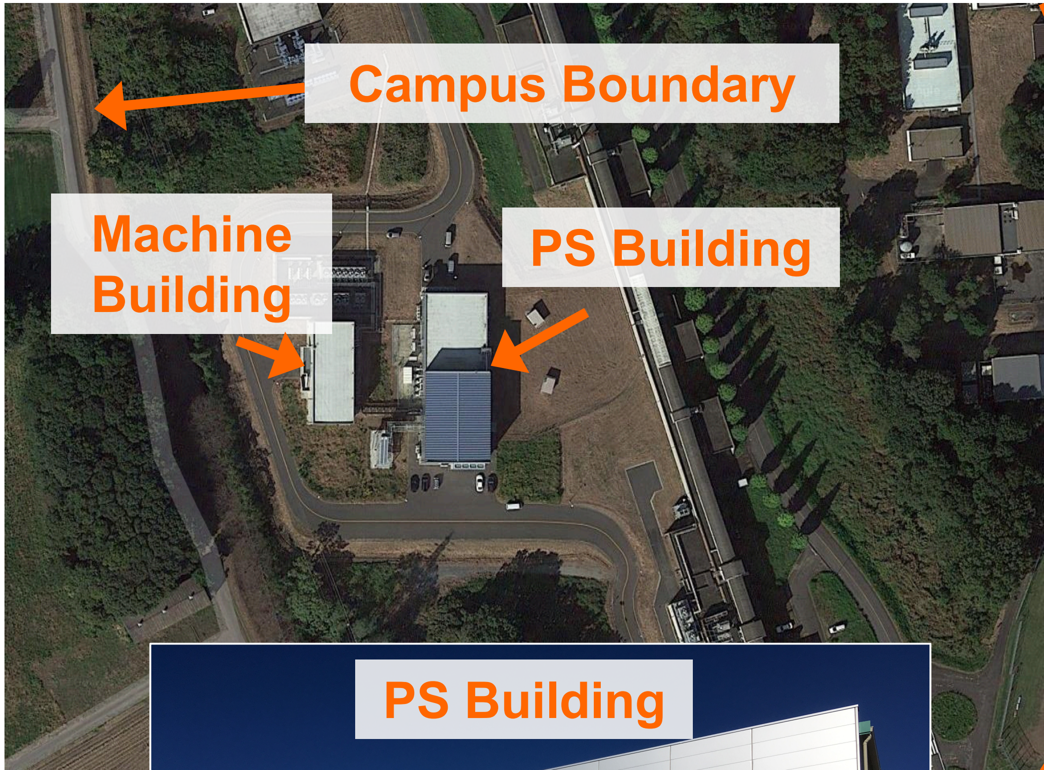
Introduction

SuperKEKB Positron Damping Ring (DR)

- 1.1 GeV positron beam is injected from LINAC.
- After 40 ms storage, the beam is extracted from DR and re-injected to LINAC.
- Then accelerated up to 4 GeV and injected to the main ring (LER).



Site



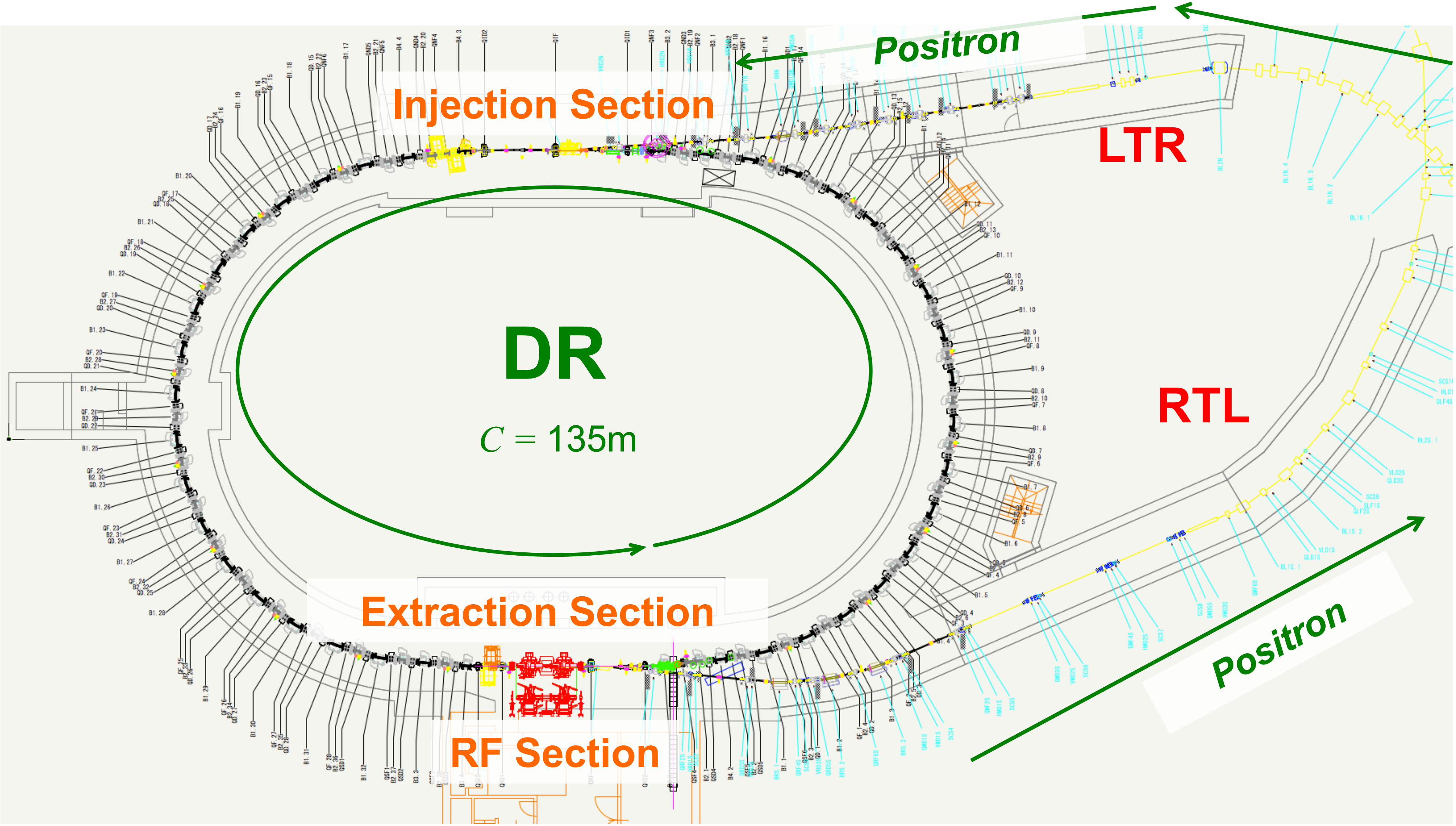
Campus Boundary
Machine Building
PS Building

PS Building

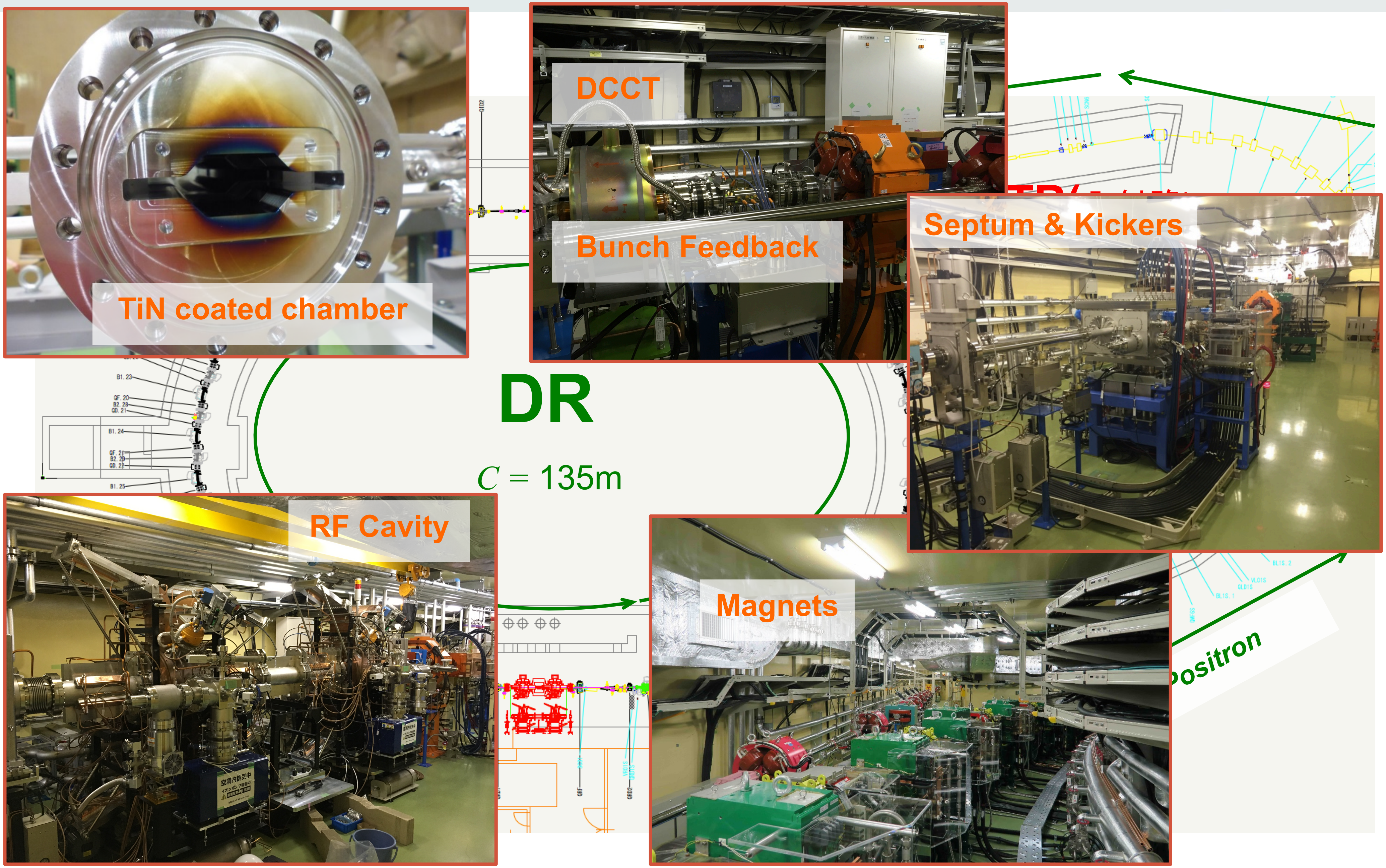
We are here.
高エネルギー加速器
研究機構研究本館
高エネルギー加速器
研究機構4号館
高エネルギー加速器
研究機構 ドミトリー
笹乃家
いなほ幼稚園

Layout

- Consists of 2 arc 2 straight sections.



Hardware


TiN coated chamber
DCCT
Bunch Feedback
Septum & Kickers
DR
C = 135m
RF Cavity
Magnets
ositron

Hardware

- Magnet (DC)
  - Bend : 78 units
  - Steering : 88 units
  - Quadrupole : 84 units
  - Sextupole : 74 units
- Magnet (AC)
  - Injection&Extraction kicker
  - Injection&Extraction septum
- BPM (turn-by-turn): 83 units
- Beam Size Monitor (SR):
- Beam Loss Monitor:
  - ion chamber, optical fiber

- Transverse Bunch Feedback System
- Beam Current Monitor
  - DCCT
  - CT (BPM bottom electrode)
  - bunch current monitor
- RF Cavity : 2 units
- Beam Pipe: ~110 units
  - Ante-chamber structure
  - TiN coated

All systems are working well.

Design Concept

- **Requirement on emittance**
  Should be less than 50 nm considering the coherent oscillation at the LER injection and the dynamic aperture of LER.

  --> No difficulty in achieving emittance of ~50 nm with ordinary FODO lattice

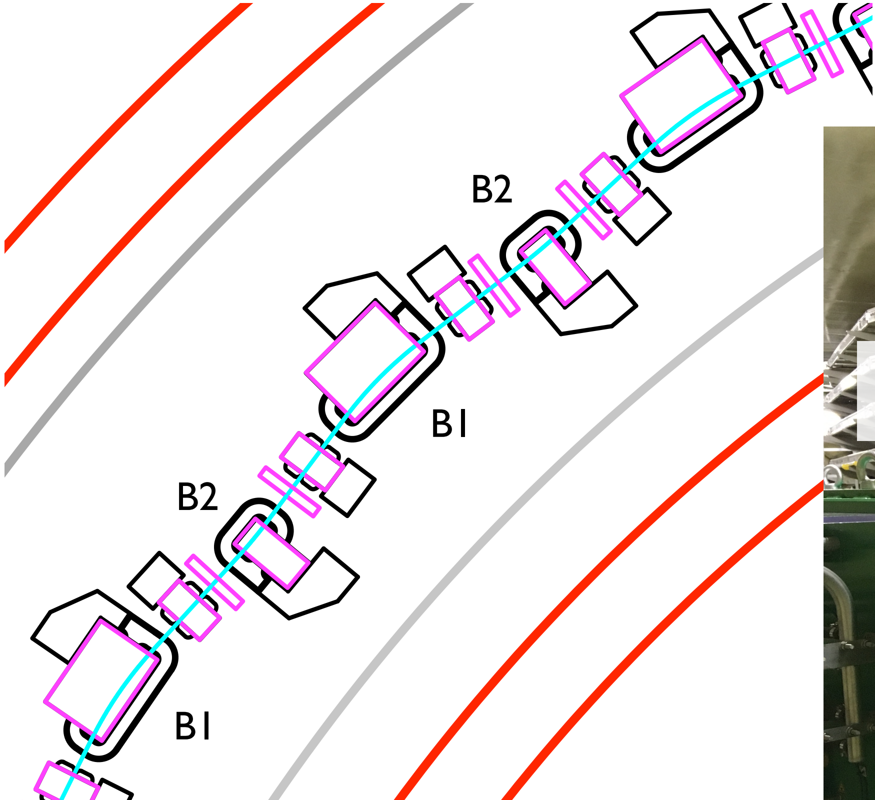
- **Requirement on damping time**
  Beam emittance should be damped from 1400 nm to 50 nm within 40 ms.
  Damping time should be less than 12.8 ms

$$\tau \propto^{-1} \oint \frac{1}{\rho^2} ds \propto \sum_{\text{bend}} \theta_{\text{bend}}^2$$

--> Apply negative bend to FODO cell.

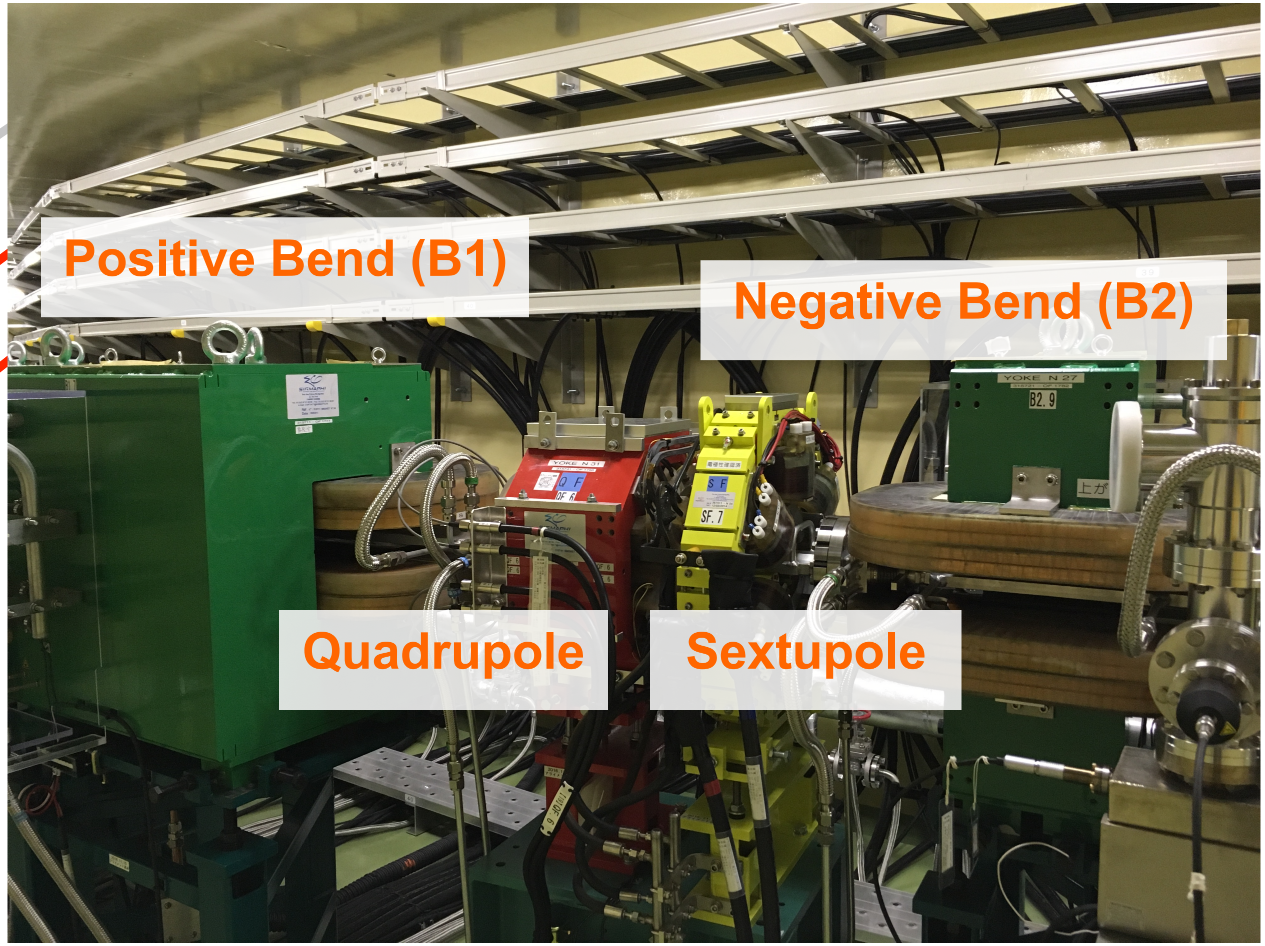
FODO Cell with Negative Bend

- Apply negative bend to shorten the radiation damping time.



- B1 : Positive Bend (angle >0)
- B2 : Negative Bend (angle <0)

Dipole field ~ 1.3 T



Lattice Parameters Optimized for 8nC/Bunch

Parameters		Unit
Energy	1.1	GeV
Circumference	135.498295	m
# of bunch	2	
# of bunch / train	2	
Max. stored current	70.8	mA
Energy loss per turn	0.0847	MV
Damping time (τ_x / τ_y / τ_z)	11.5 / 11.7 / 5.8	msec
Emittance (ε_x /ε_y / ε_z)	41.5 / 2.1 / 3600	nm
ε_y / ε_x	5	%
ν_x / ν_y / ν_s	8.240 / 7.170 / -0.0257	
Energy spread	0.055	%
Bunch length	6.6	mm
Mom. Comp. factor	0.0141	
# of cells	32	
Total RF voltage	1.4	MV
RF frequency	509	MHz

Lattice Prepared for Beam Commissioning

Parameters		Unit
Energy	1.1	GeV
Circumference	135.498295	m
# of bunch	2	
# of bunch / train	2	
Max. stored current	70.8	mA
Energy loss per turn	0.0847	MV
Damping time (τ_x / τ_y / τ_z)	11.5 / 11.7 / 5.8	msec
Emittance (ε_x /ε_y / ε_z)	25.8 / 1.3 / 3400	nm
ε_y / ε_x	5	%
ν_x / ν_y / ν_s	9.240 / 7.170 / -0.017	
Energy spread	0.055	%
Bunch length	6.2	mm
Mom. Comp. factor	0.0089	
# of cells	32	
Total RF voltage	1.0	MV
RF frequency	509	MHz

Actual Operation Parameters in Beam Commissioning

New Model

Parameters		Unit
Energy	1.1	GeV
Circumference	135.498295	m
# of bunch	2	
# of bunch / train	2	
Max. stored current	11	mA
Energy loss per turn	0.0847	MV
Damping time (τ_x / τ_y / τ_z)	11.5 / 11.7 / 5.8	msec
Emittance (ε_x /ε_y / ε_z)	29.2 / 1.5 / 3630	nm
ε_y / ε_x	5	%
ν_x / ν_y / ν_s	8.830 / 6.280 / -0.018	
Energy spread	0.055	%
Bunch length	6.6	mm
Mom. Comp. factor	0.0100	
# of cells	32	
Total RF voltage	1.0	MV
RF frequency	509	MHz

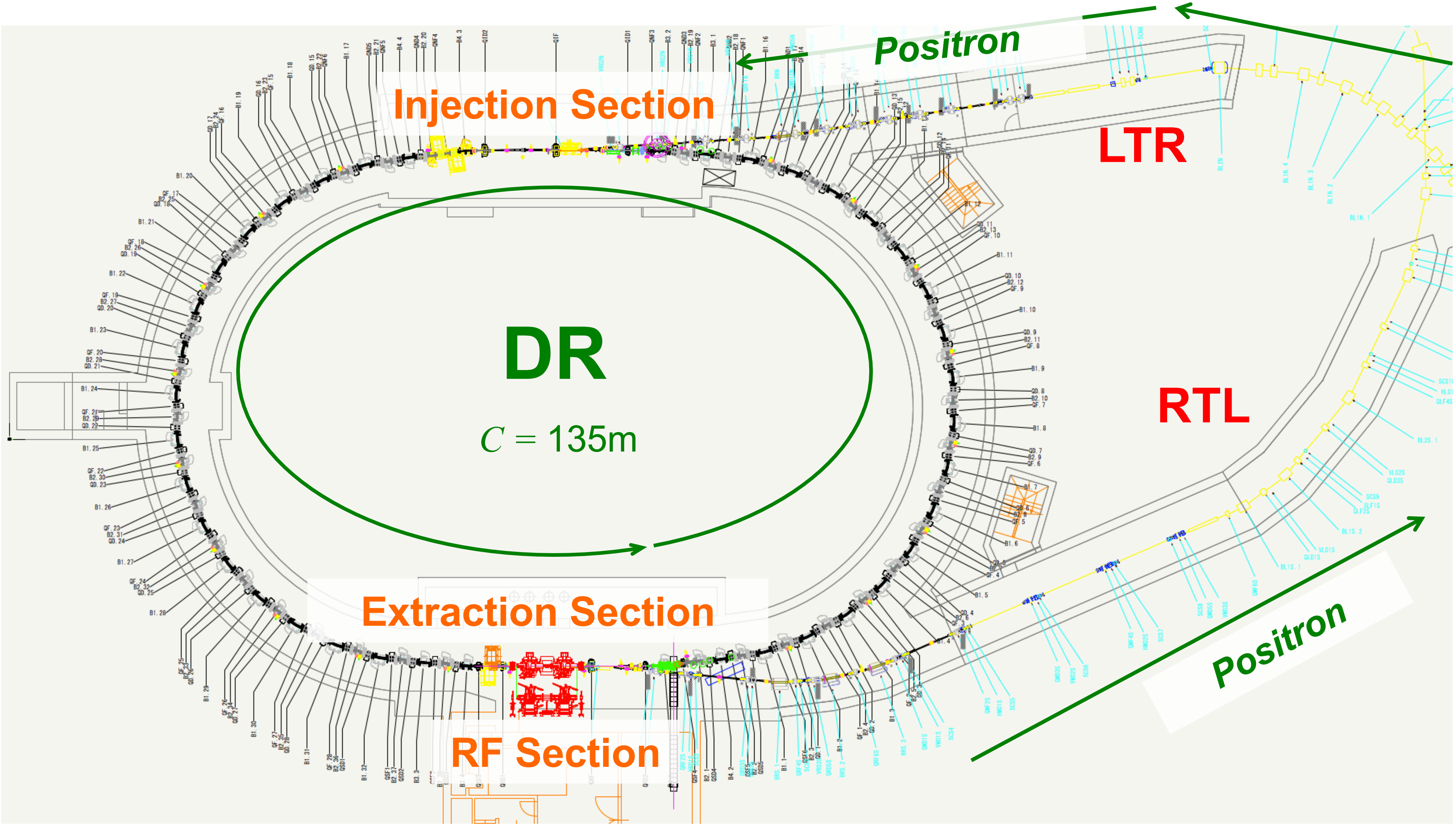
Not confirmed

Not confirmed

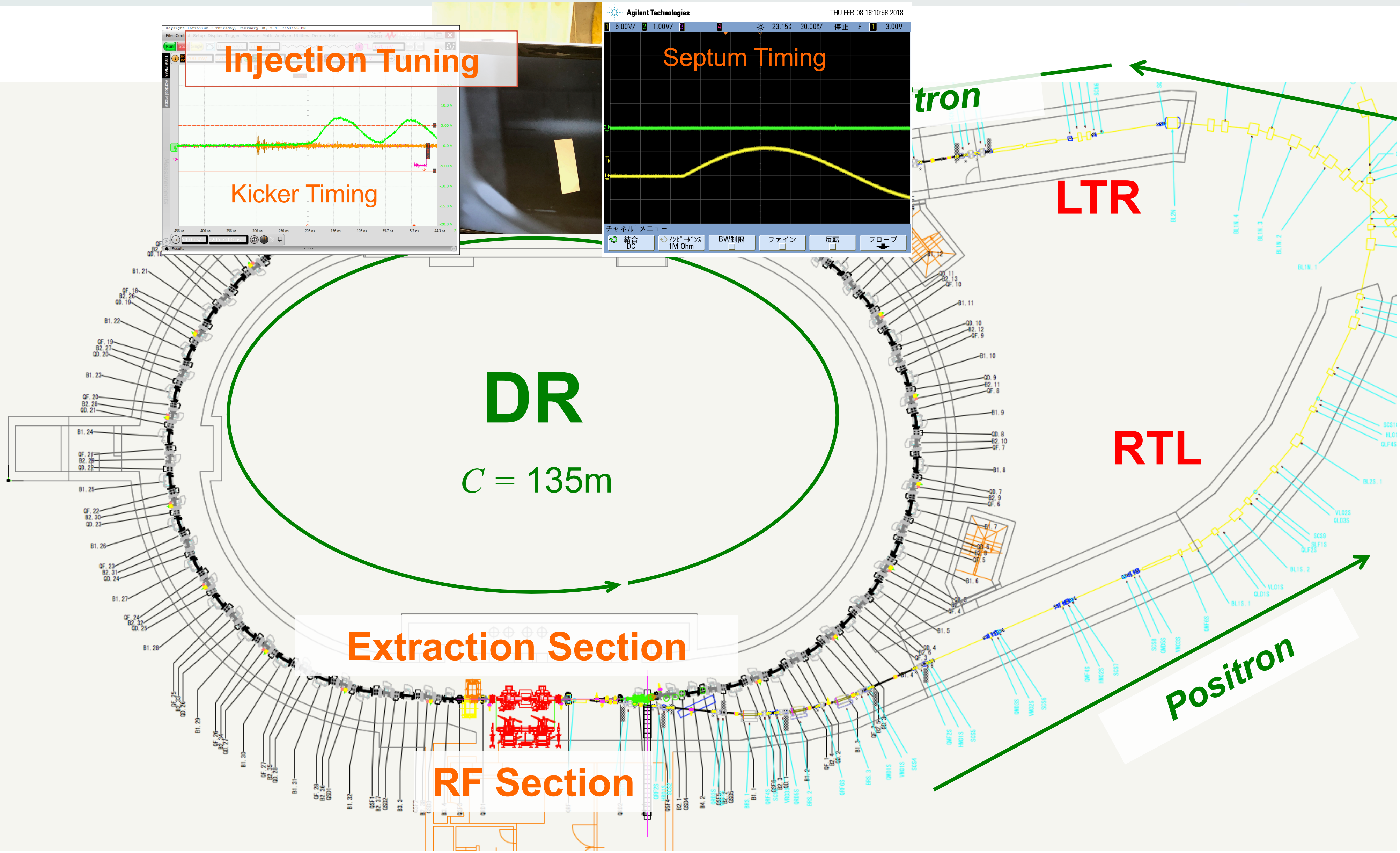
Commissioning Overview

Starts from 02/08

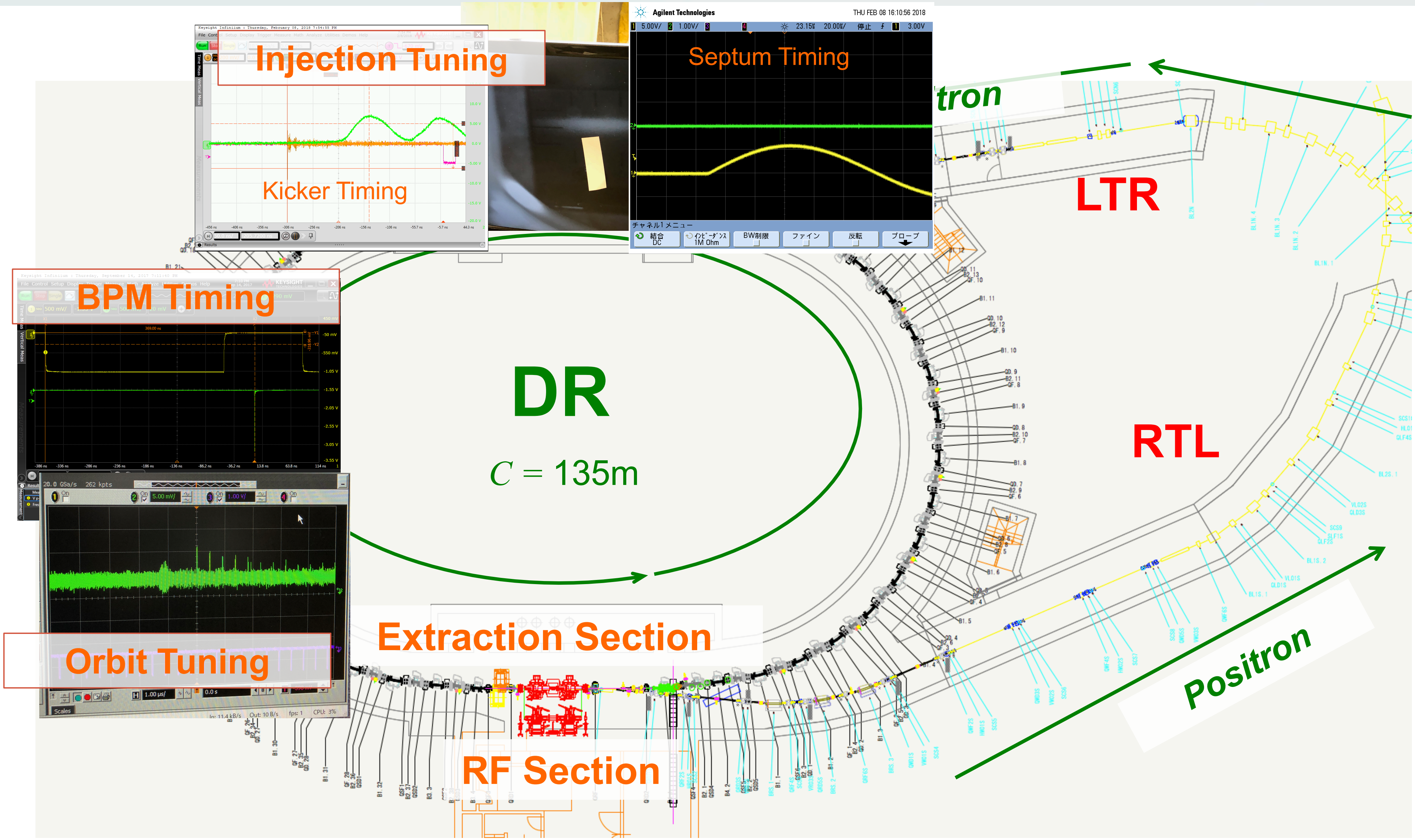
The First 3 Days



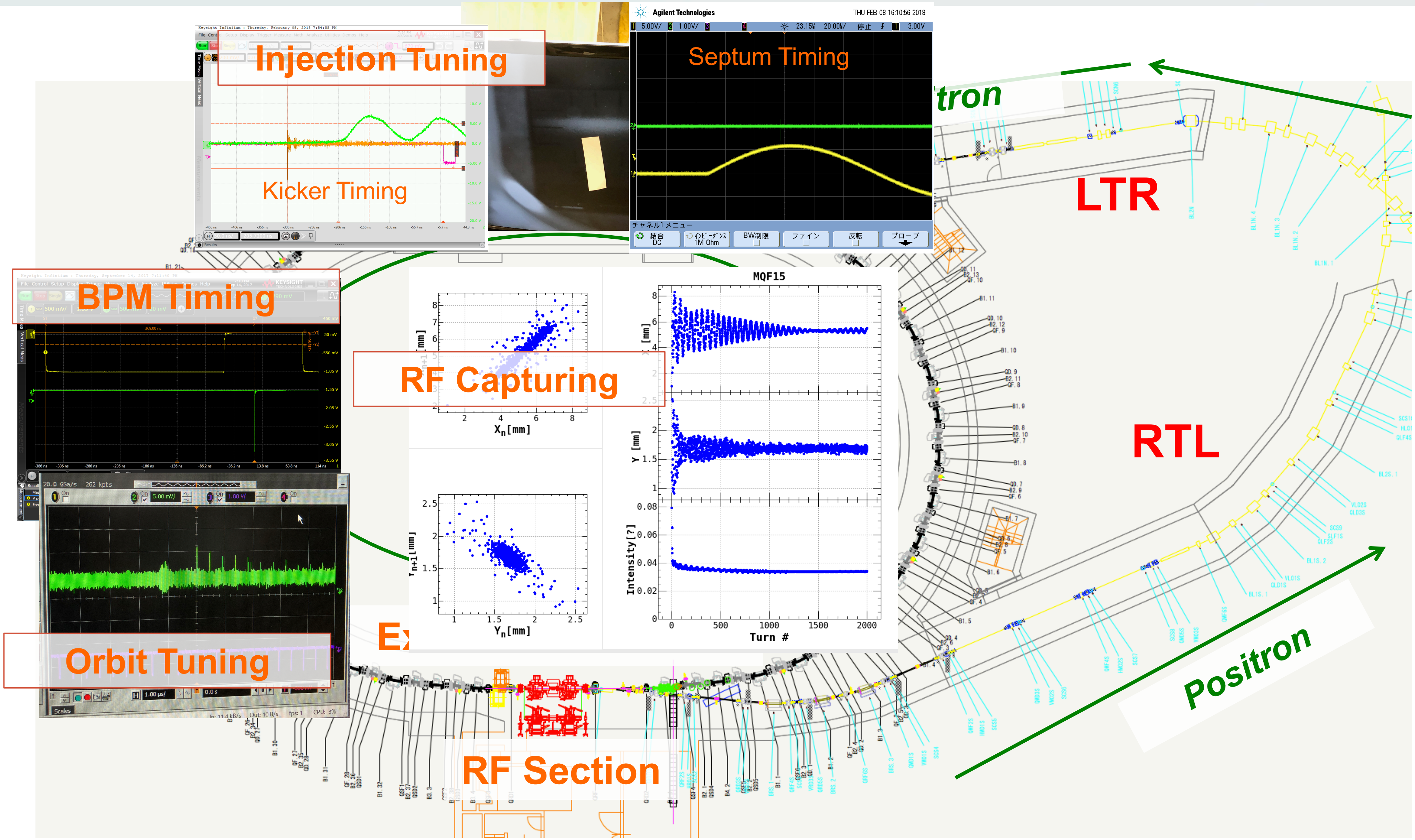
The First 3 Days



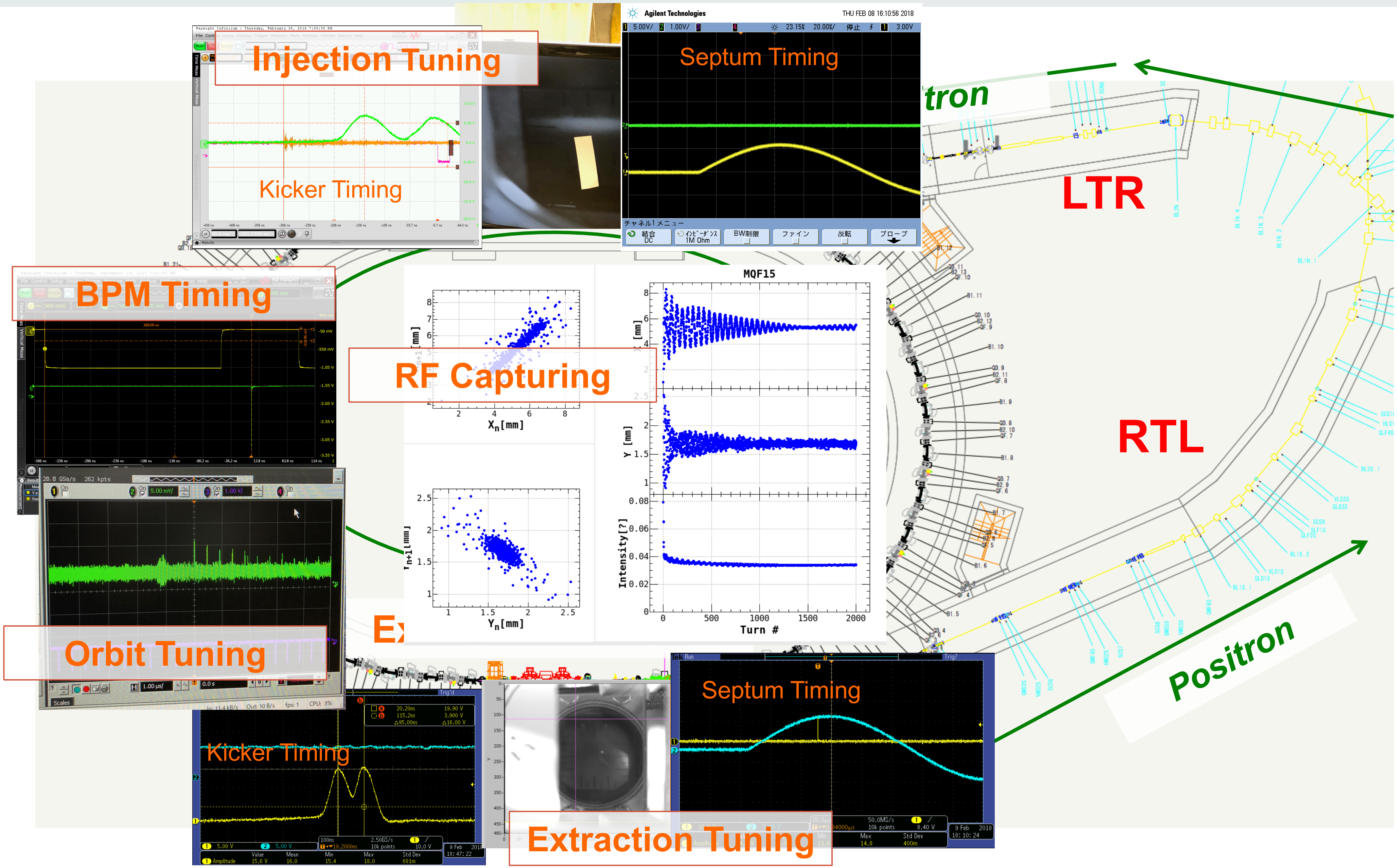
The First 3 Days



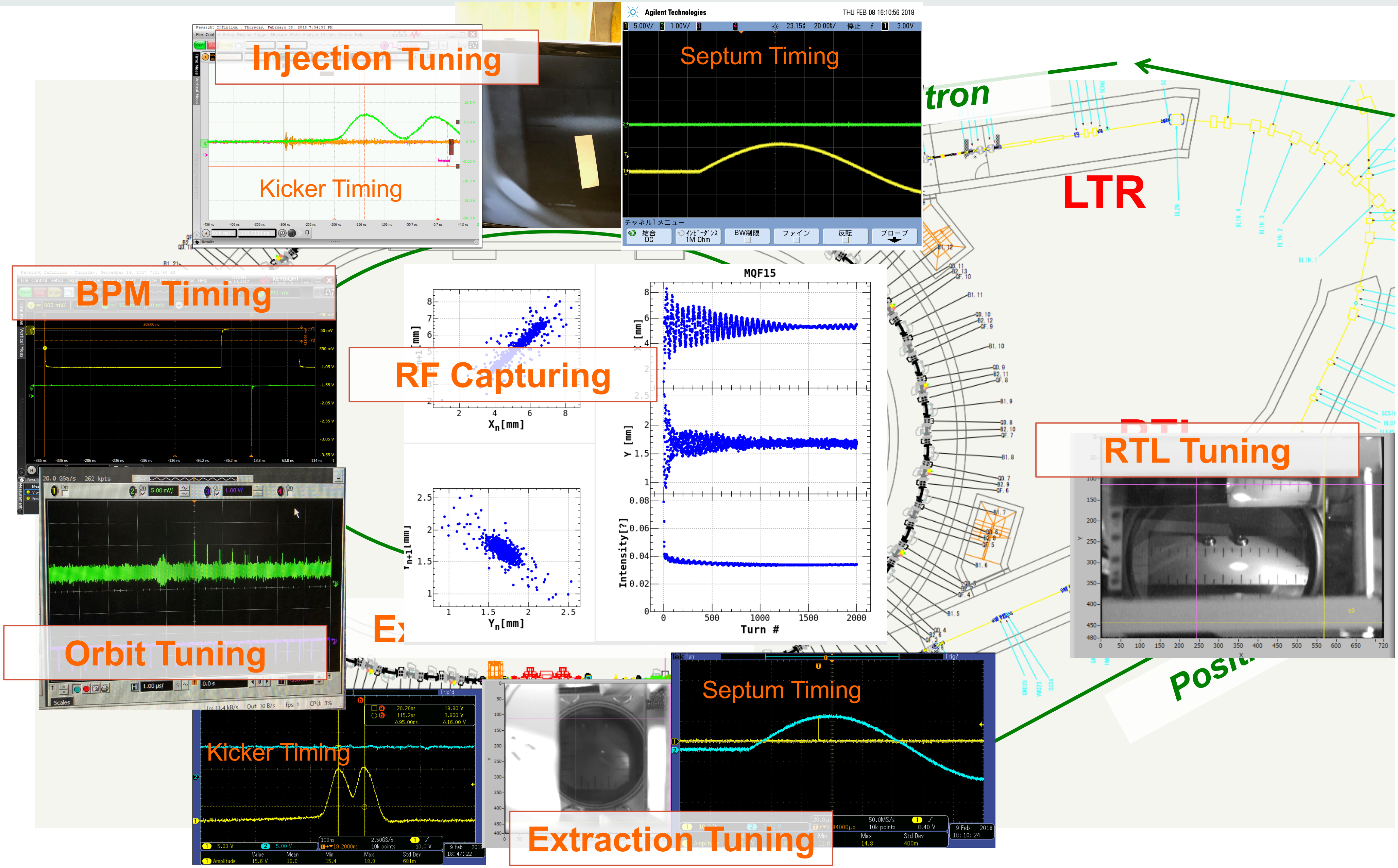
The First 3 Days



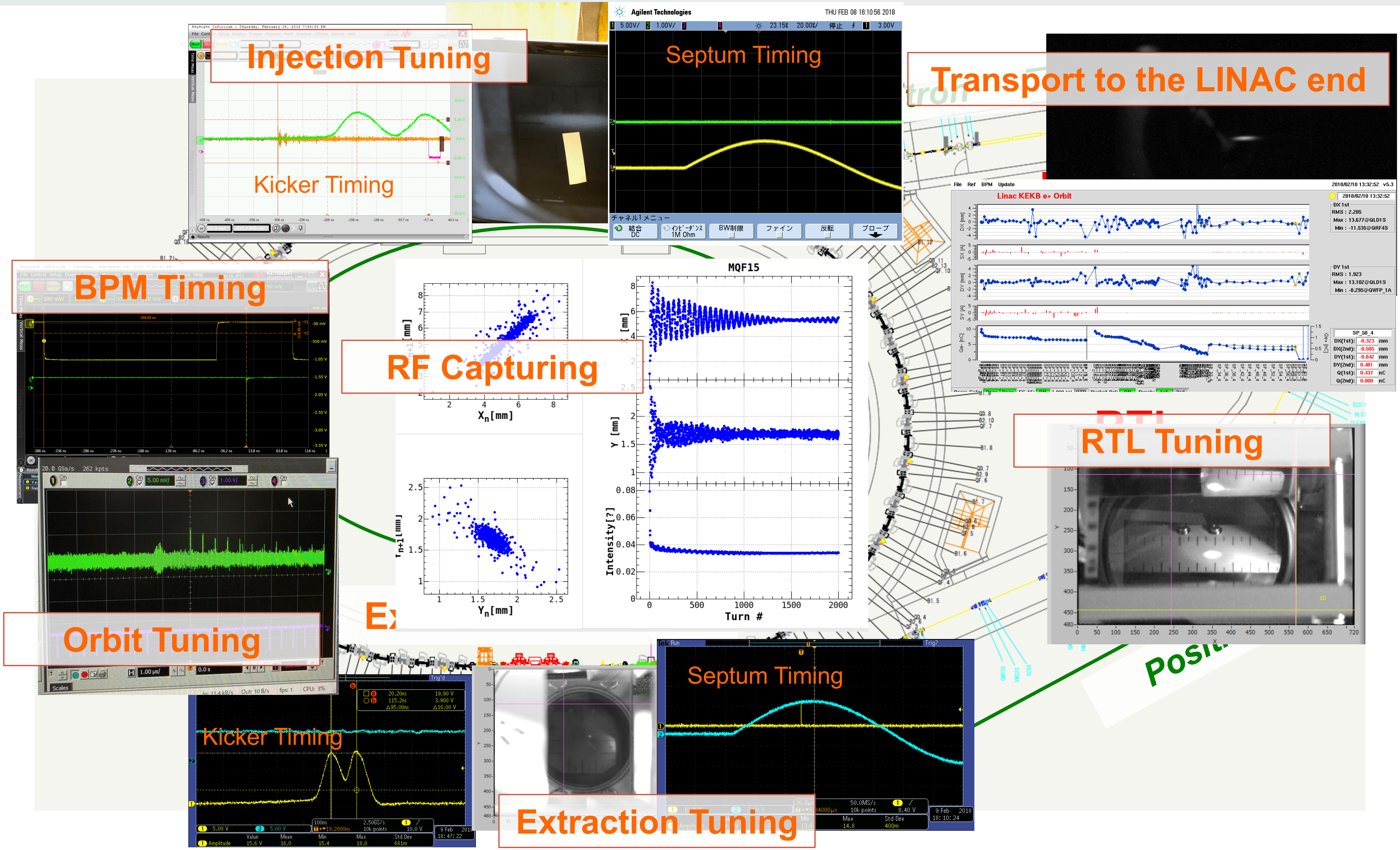
The First 3 Days



The First 3 Days



The First 3 Days



Overview

- Rough tuning has been successfully finished within the first 3 days.

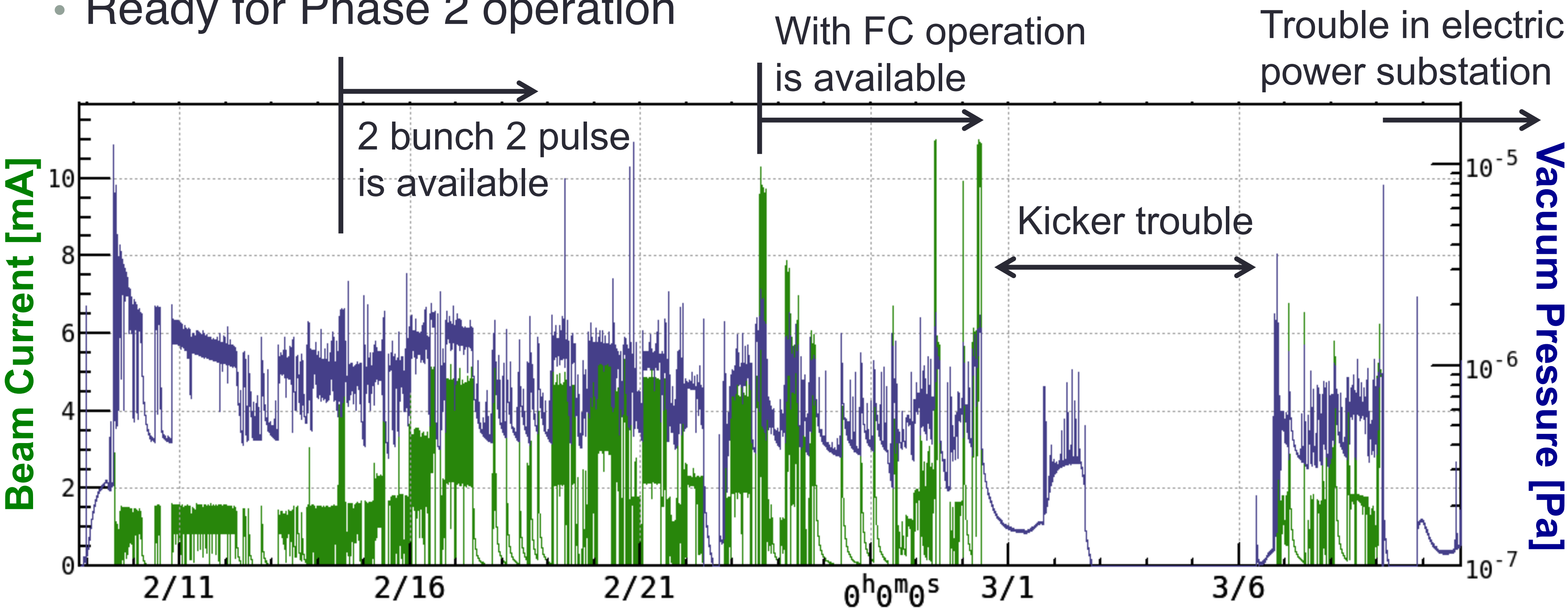
- Then, we started fine tuning of LTR, DR and RTL including LINAC.
  - Test of operation mode (repetition rate, # of pulse and # of bunch)
  - Hardware startup and calibration.
  - Software/hardware bug hunt
  - Optics study
  - etc.

- Vacuum scrubbing of beam pipes is progressing in parallel to beam tuning.

- National inspection of the DR facility has been successfully passed.

Operation History

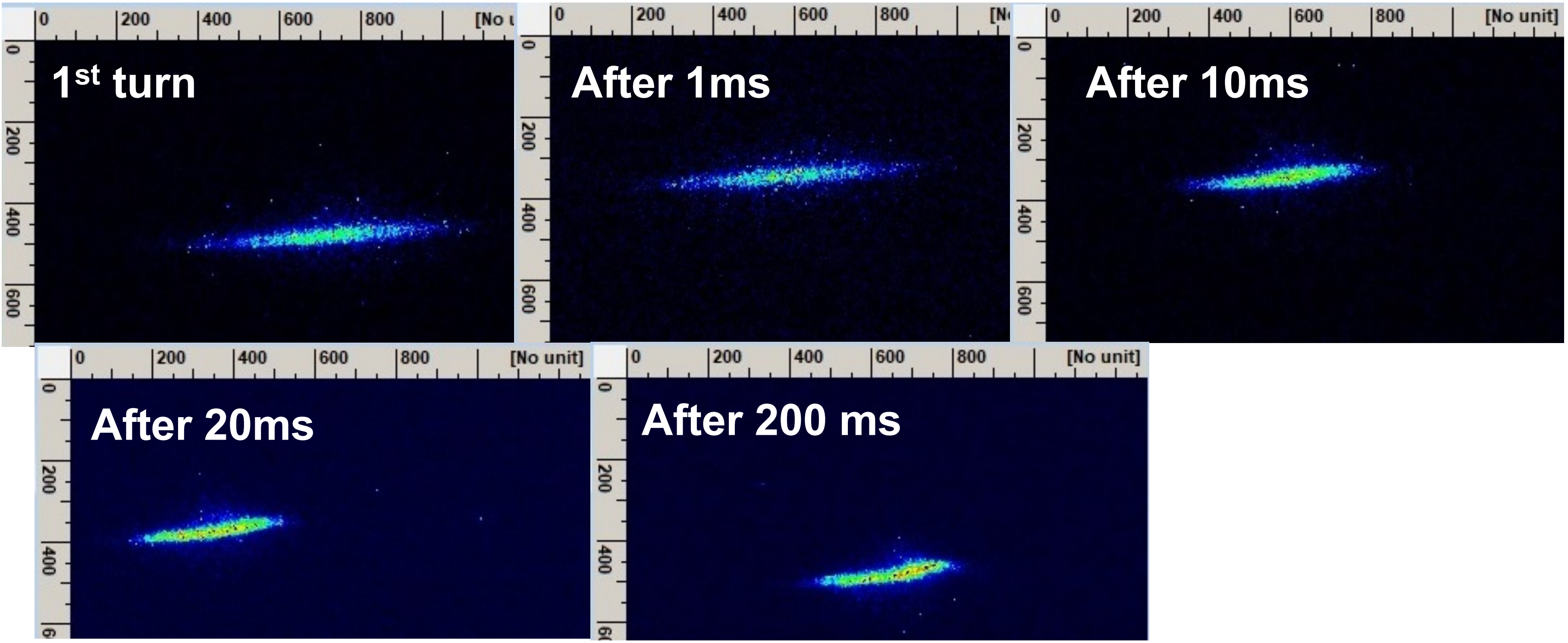
- DR ring was started up very smoothly.
- No fundamental problem in the commissioning period.
- Maximum beam current so far is 11 mA (2 pulse x 2 bunch)
- No serious vacuum pressure raise is observed. → Shibata-san's talk
- Beam dose is ~0.7 Ah
- Ready for Phase 2 operation



Beam Size Measurement

H. Ikeda

- Transverse beam profile obtained with a gated camera.



- Damping of both transverse and longitudinal beam sizes is confirmed qualitatively.
- Further calibration and data analysis is ongoing.

→ Ikeda-san's talk

Beam Optics Measurement

Optics Tuning

- Numerical simulation study showed,
  - No elaborated low emittance tuning is necessary.
  - Orbit correction is sufficient to reach target emittance coupling of 5~10%
- Limited # of tuning knobs compared to the main ring.
  # of independent quadrupoles is 30 (Two in arc cell and 28 in straight sections)
- Total number of turn-by-turn (TbT) BPMs is 83.
  - COD measurement with averaging mode is mainly used in the optics study.
  - TbT mode is mainly used in injection tuning.
- Correction with bump orbit is limited by maximum field strength of steering magnets.
- Only betatron and horizontal dispersion functions are considered in the optics correction.

Tune Estimation at the Frist Injection Tuning

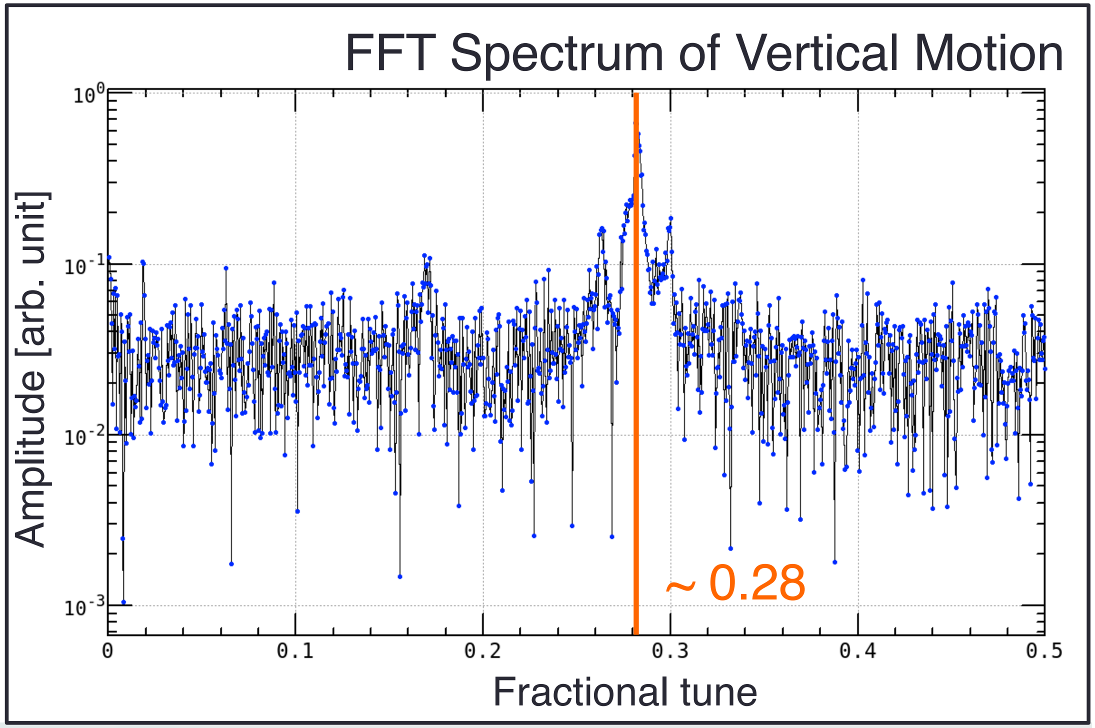
- Original tune of the model lattice $(\nu_x,\ \nu_y) = (9.24, 7.17)$
- Tune scan is performed using the model lattice.
- Finally, the model lattice tune arrived at $(\nu_x,\ \nu_y) = (9.10, 7.02)$
- While measured tune evaluated with TbT BPM $(\nu_x,\ \nu_y) = (N_x - .17, N_y + .28)$
- Guess the integer part from the model lattice,

$$(\nu_x,\ \nu_y) = (8.83, 7.28)$$

- Thus, the difference between the model and real lattice is

$$(\Delta\nu_x,\ \Delta\nu_y) \sim (-0.27, 0.26)$$

- COD response due to dipole kick is measured to ensure the integer part.



Closed Orbit Response from Dipole Kick

- Compare with the model lattice $(\nu_x,\ \nu_y) = (8.83, 7.28)$
- Integer part of vertical tune seems to be smaller.

Horizontal dipole kick

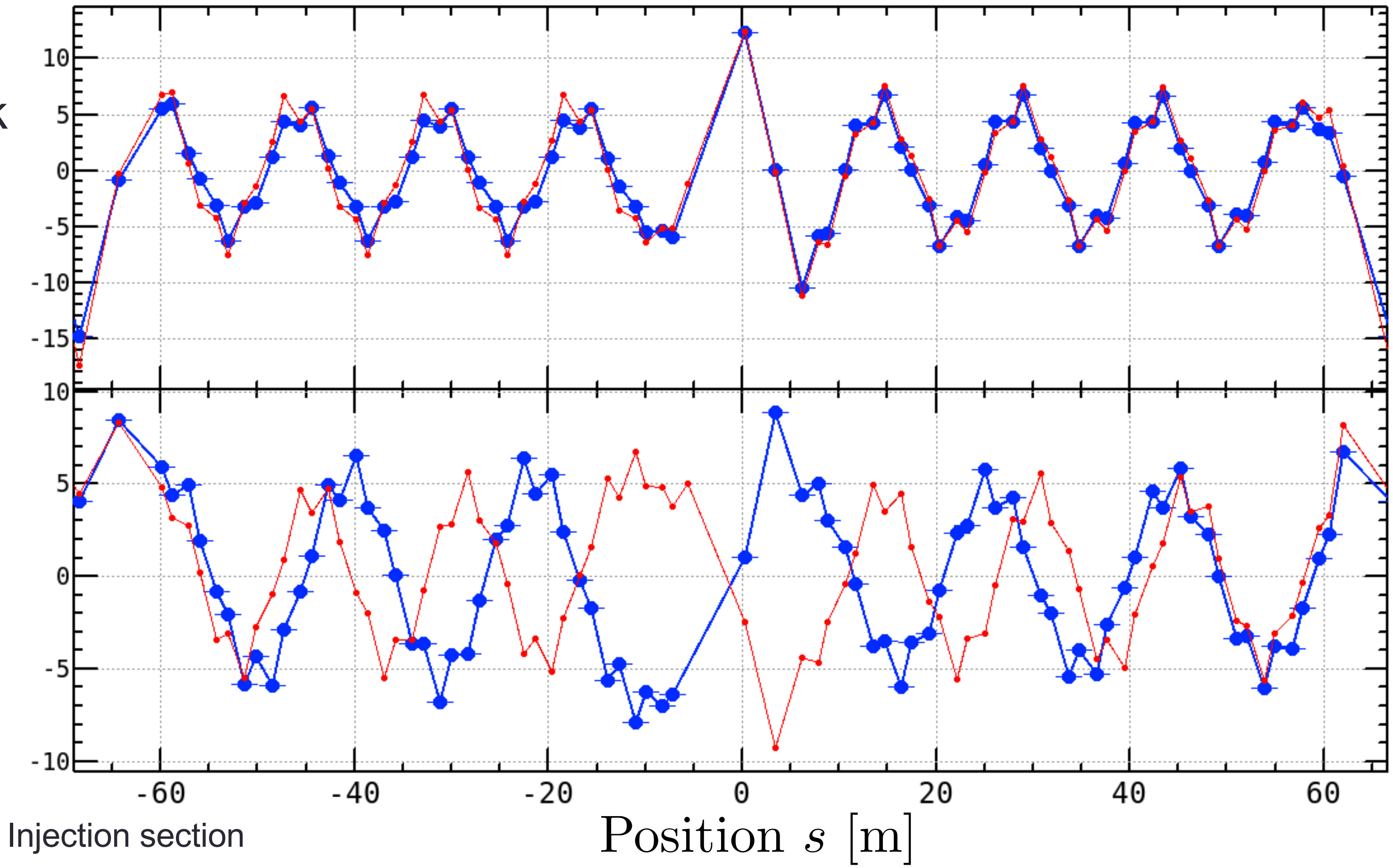
$\Delta x/\Delta K_0$ [m/rad]

Blue: Measurement

Red: Model

Vertical dipole kick

$\Delta y/\Delta K_0$ [m/rad]



Closed Orbit Response from Dipole Kick

- Adjust the integer part of the model vertical tune.

$$(\nu_x,\ \nu_y) = (8.83, 6.28)$$

- Good agreement between the model and measurement

Horizontal dipolåçe kick

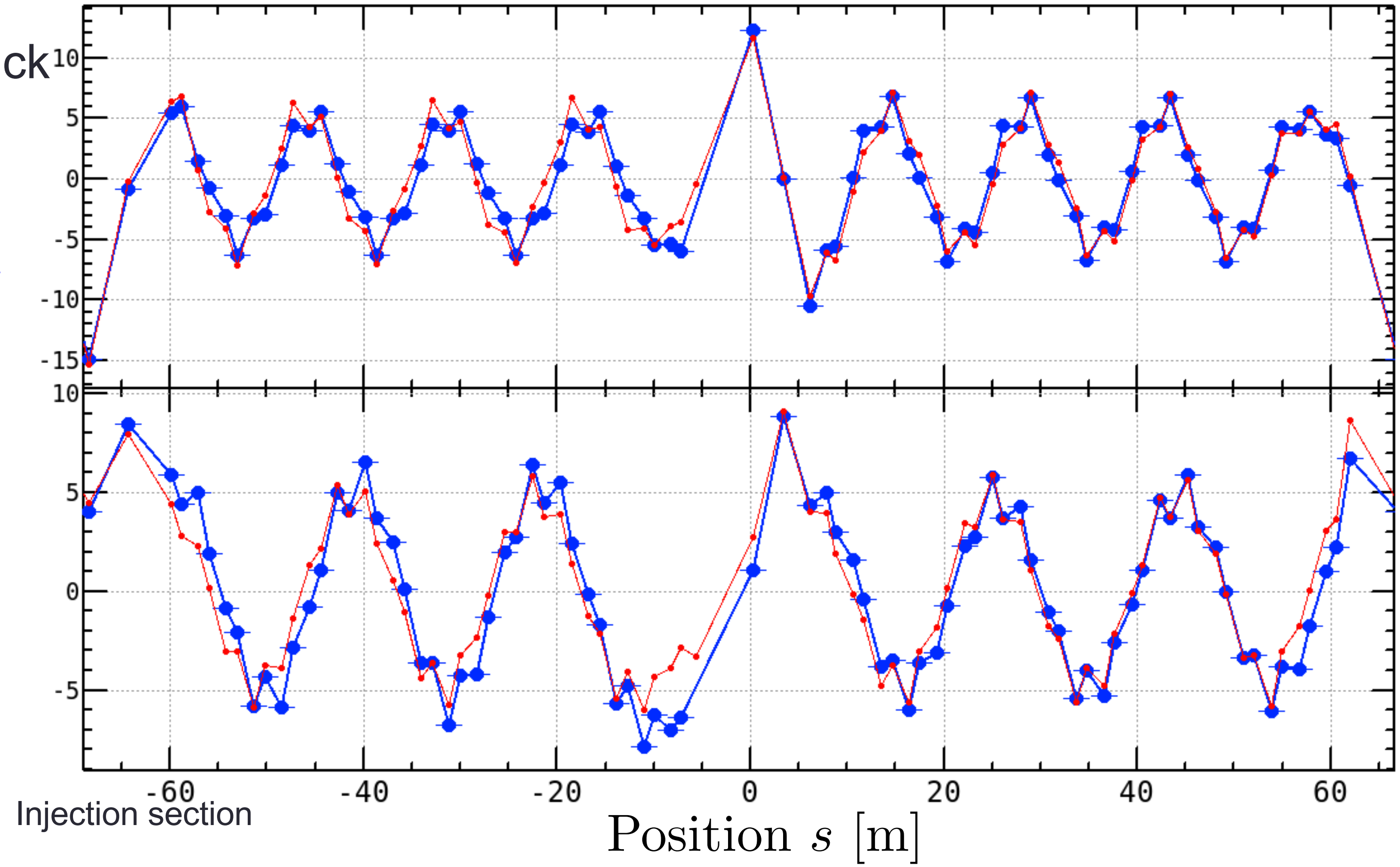
$\Delta x / \Delta K_0$ [m/rad]

Blue: Measurement

Red: Model

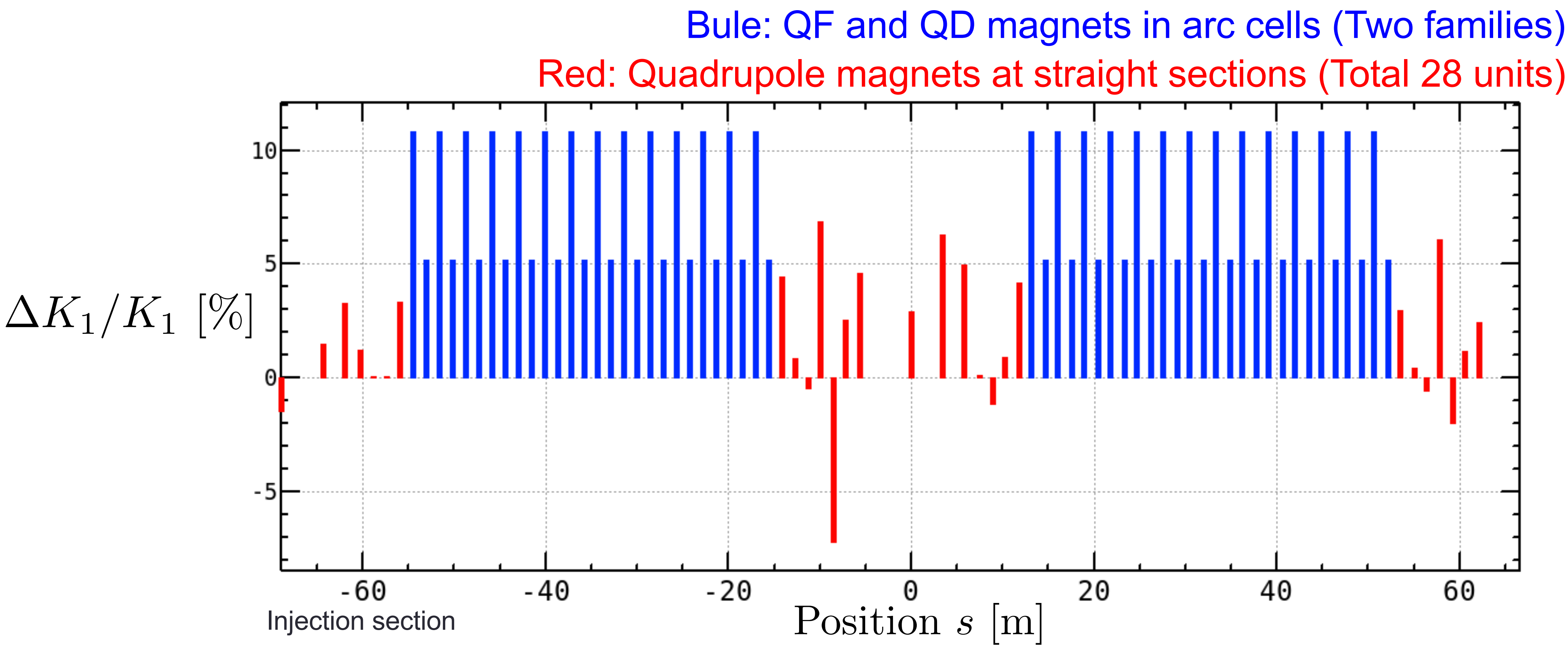
Vertical dipole kick

$\Delta y / \Delta K_0$ [m/rad]



Initial Correction to Remove the Tune Difference

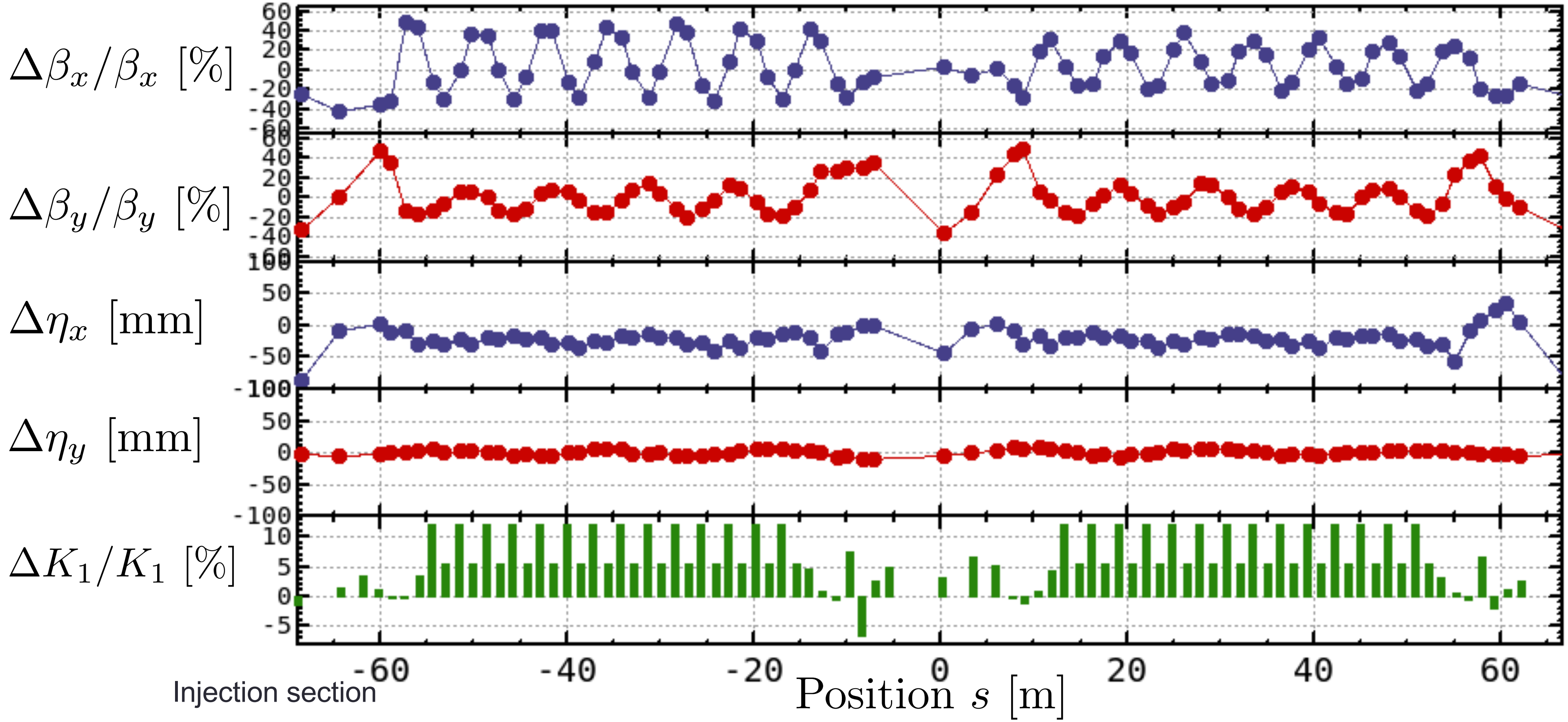
- Rough correction quadrupole families to make the model and the real tunes are consistent each other.



- Large correction factor of 5~10% level.
- Assume this factor to in the following optics study.

Beta Function and Dispersion

- Beta function is extracted from COD response from dipole kicks
- Dispersion function is measured by changing frequency of RF cavity.



$$(\Delta\beta_x/\beta_x)_{\rm rms} \sim 25\ \%$$

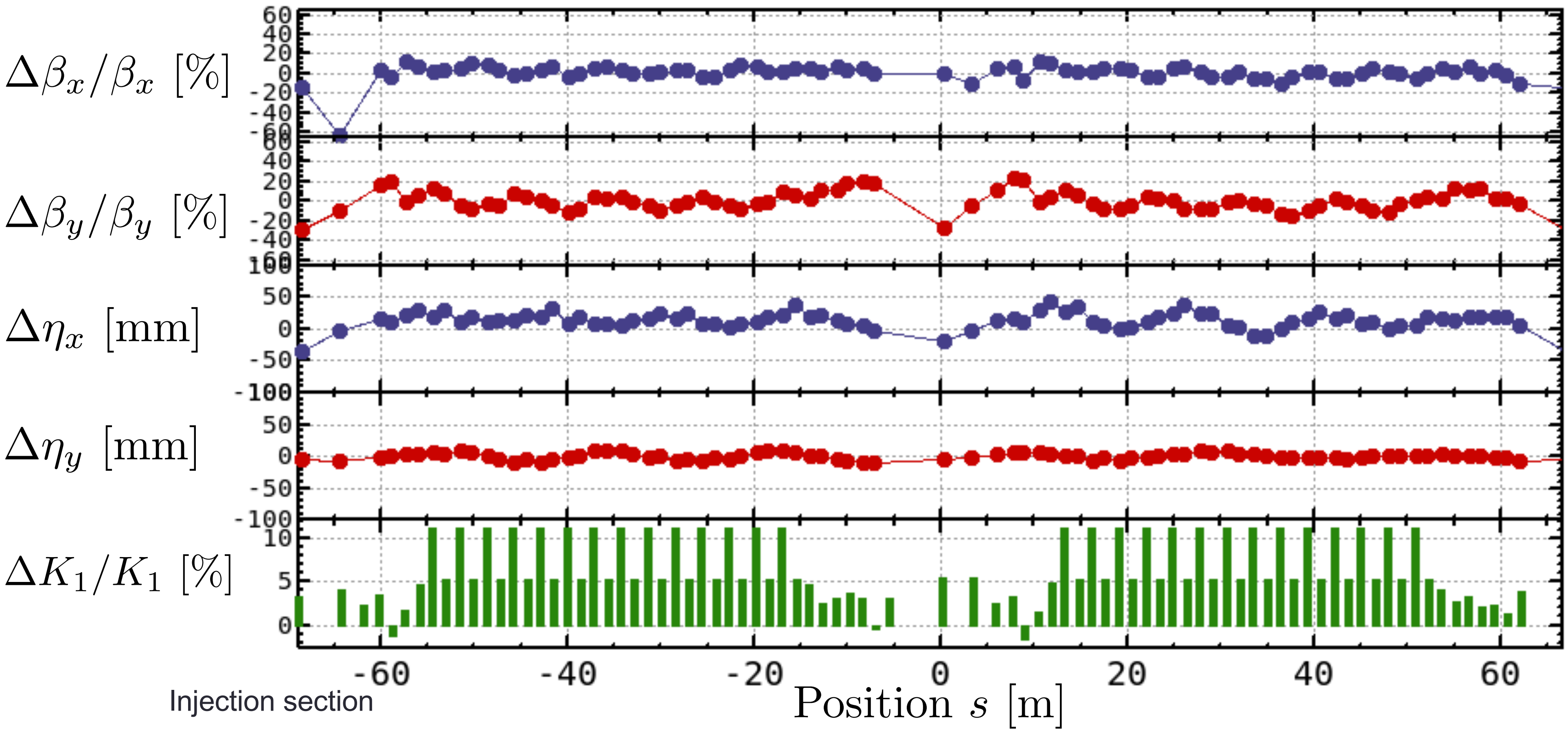
$$(\Delta\beta_y/\beta_y)_{\rm rms} \sim 18\ \%$$

$$(\Delta\eta_x)_{\rm rms} \sim 29\ \rm mm$$

$$(\Delta\eta_y)_{\rm rms} \sim 5\ \rm mm$$

Beta Function and Dispersion

- Correction with All (30) quadrupole families.



$(\Delta\beta_x/\beta_x)_{\rm rms} \sim 9\ \%$

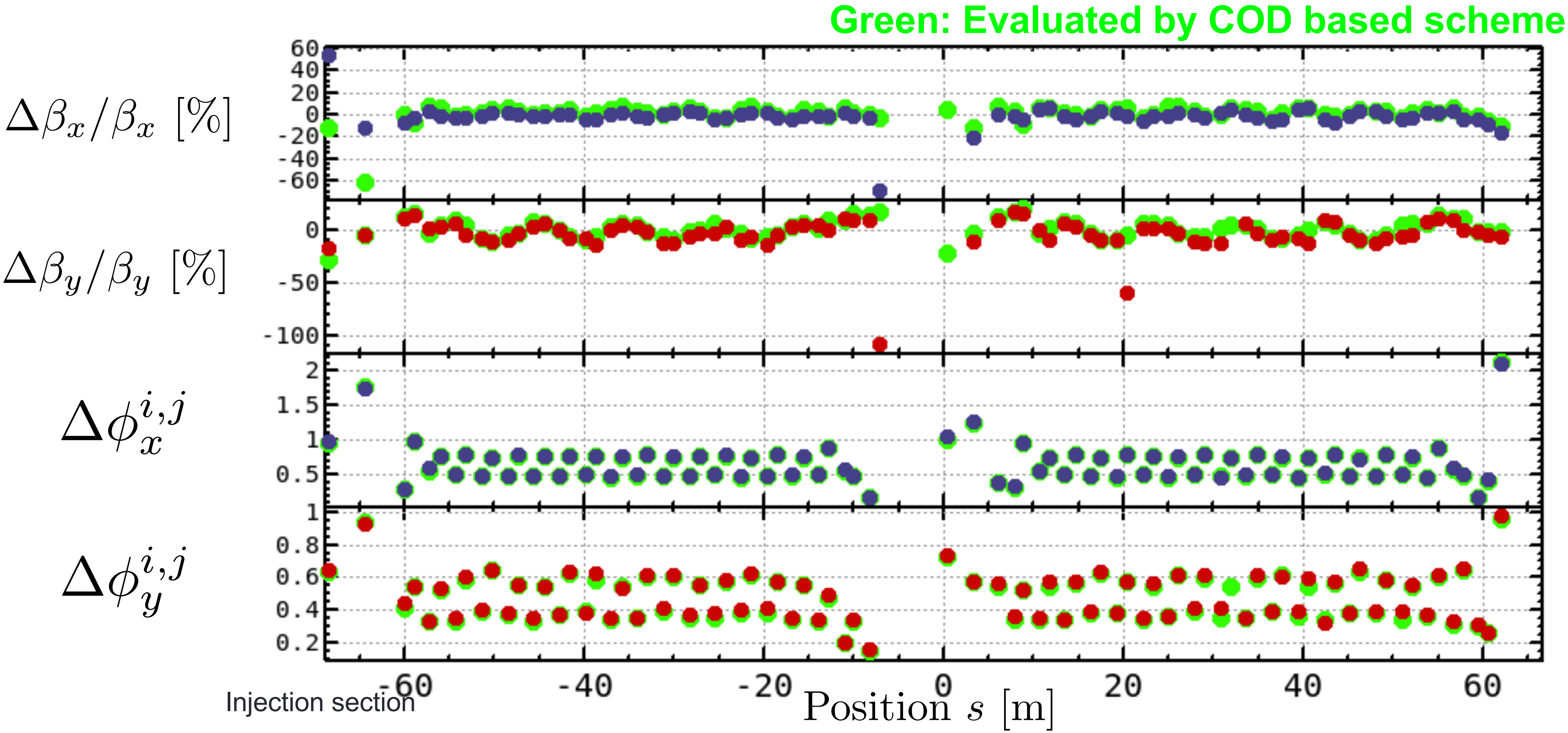
$(\Delta\beta_y/\beta_y)_{\rm rms} \sim 10\ \%$

$(\Delta\eta_x)_{\rm rms} \sim 17$ mm

$(\Delta\eta_y)_{\rm rms} \sim 5$ mm

Beta Measurement with Turn-by-Turn Data

- Excite betatron oscillation by transverse feedback kickers.

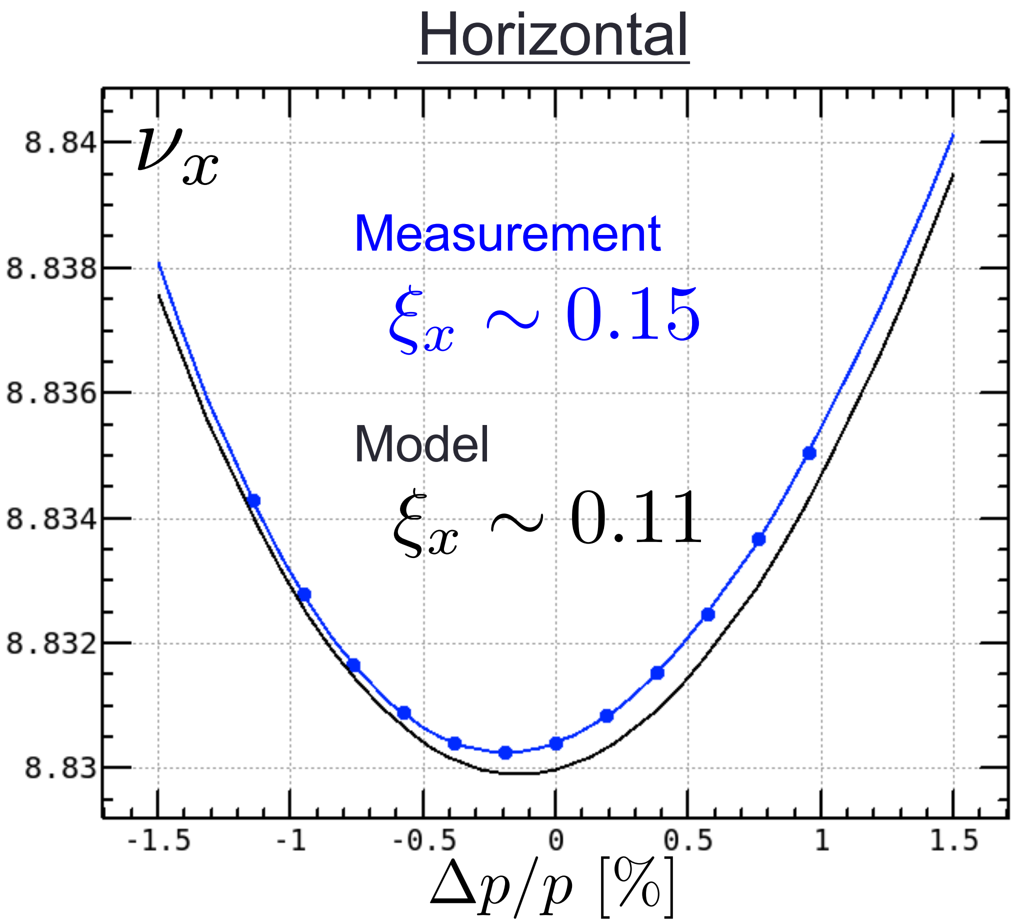


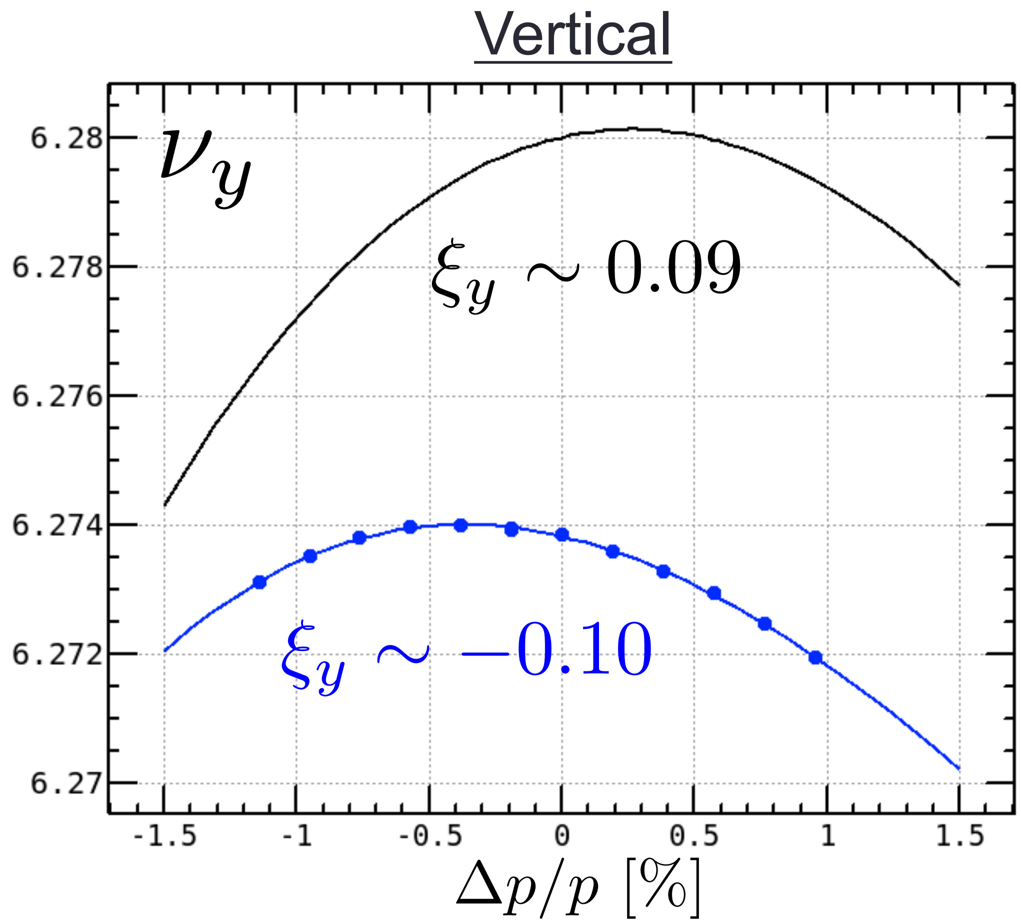
$$(\Delta\beta_x/\beta_x)_{\rm rms} \sim 11\ \% \qquad (\Delta\beta_y/\beta_y)_{\rm rms} \sim 16\ \%$$

- Detail study on TbT measurement and analysis will be performed.

Tune Chromaticity

- Measure betatron tune with changing the frequency of RF cavity.



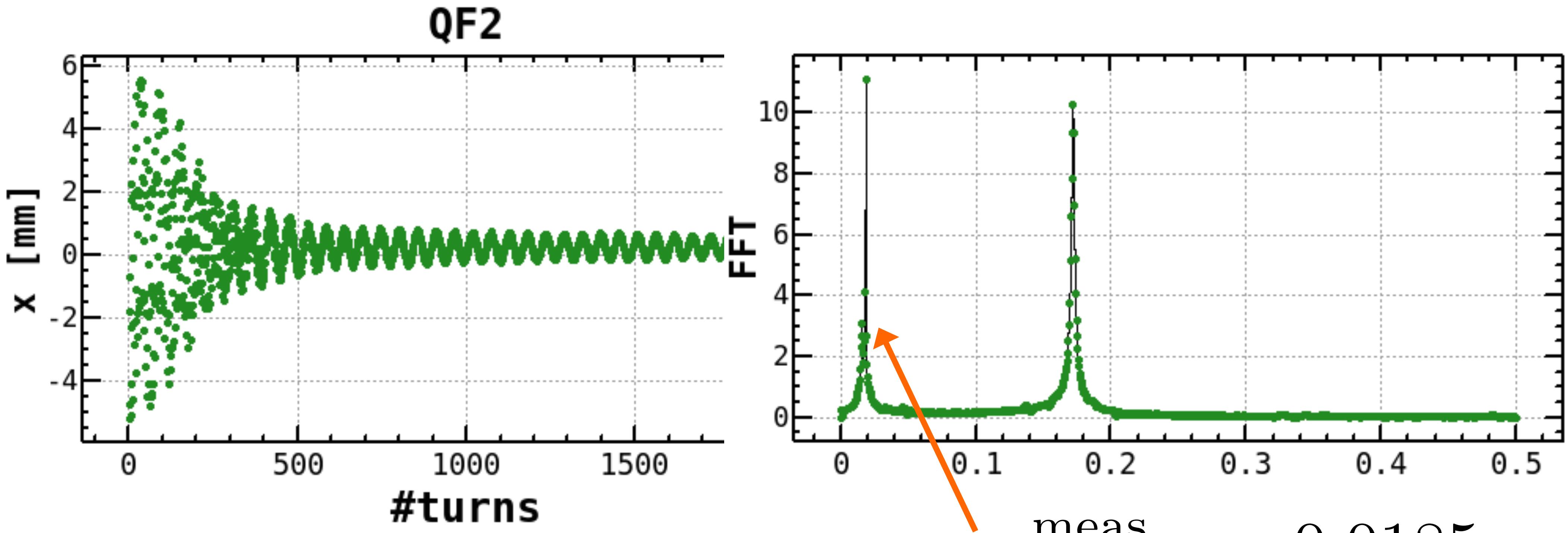


- Deviation from the model value is less than 0.2 even without any off-momentum optics correction.

Synchrotron Tune

Y. Ohnishi

- Measure synchrotron tune from TbT BPM data of the injected beam with energy offset.



$$\nu_s^{\mathrm{meas}} = -0.0185$$

- Good agreement with the model lattice.

$$\nu_s^{\mathrm{model}} = -0.0185$$

Possible Source of the Large Correction Factors

- Investigation performed so far
  - Magnetic interference between magnets? -> 10% is too big
  - Bugs in lattice modeling? (Main bend magnet has large saggita) -> Not found so far
  - Residual current loop in the tunnel? -> Not found so far
  - Bugs in the excitation curve? -> Not found so far
  - Calibration errors in field measurement? -> 10% is too big

- Plan to perform optics study at a drastically different tune point.

  Check correction factor after the optics correction,

  If the correction factor stays in same level

  -> Quadrupole magnets are really suspicious.

  If the correction factor changes

  -> Unexpected quadrupole field in the beam line.

- Plan to perform field measurement by an other system.

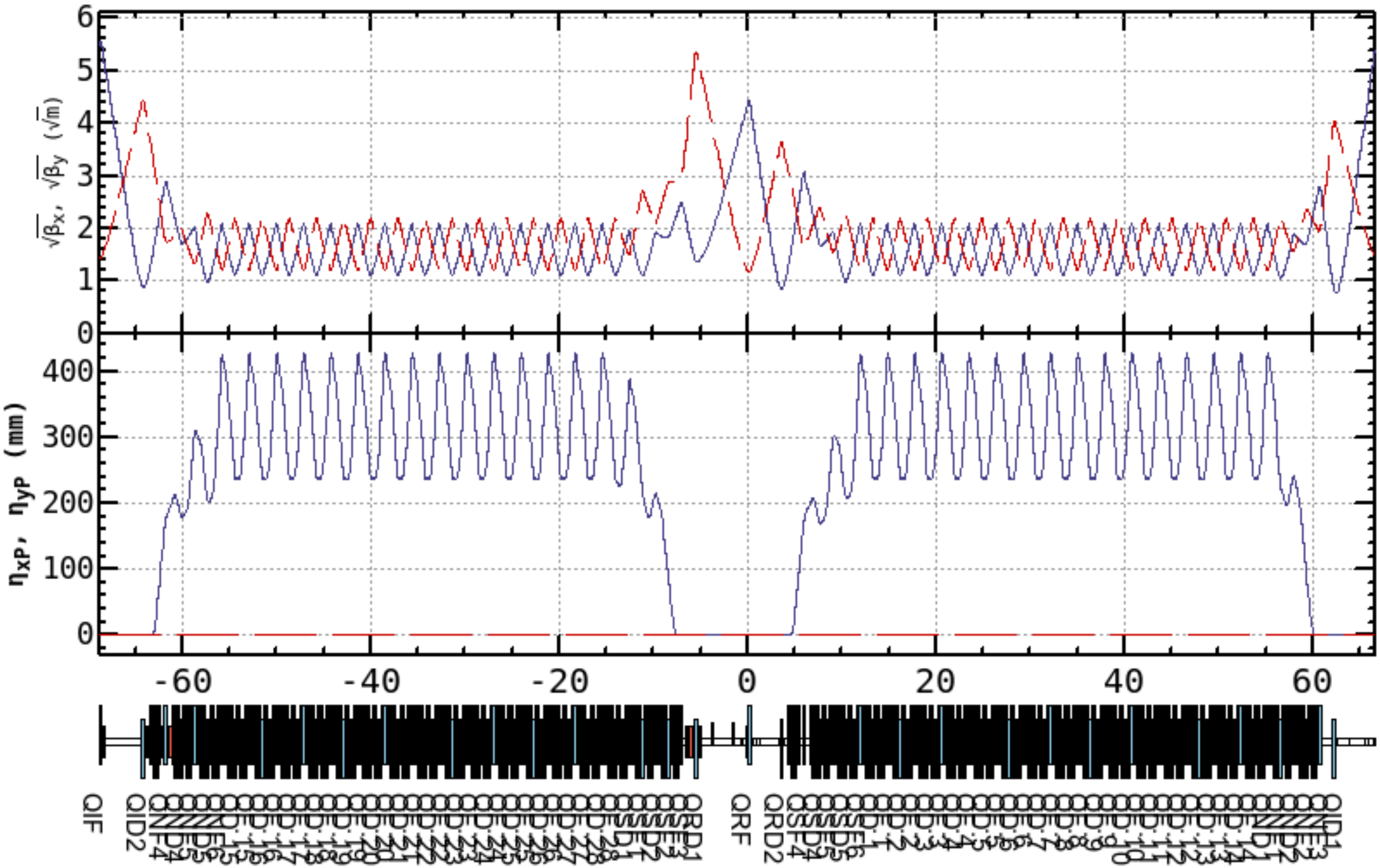
Summary

- DR ring operation was started up very smoothly.
- No fundamental difficulty in the beam commissioning.
- Inexplicably-large correction factor to quadrupole magnets is necessary for better orbit&optics control.
- Beam size and bunch length in DR are not confirmed yet.
- We are ready for Phase 2 operation.

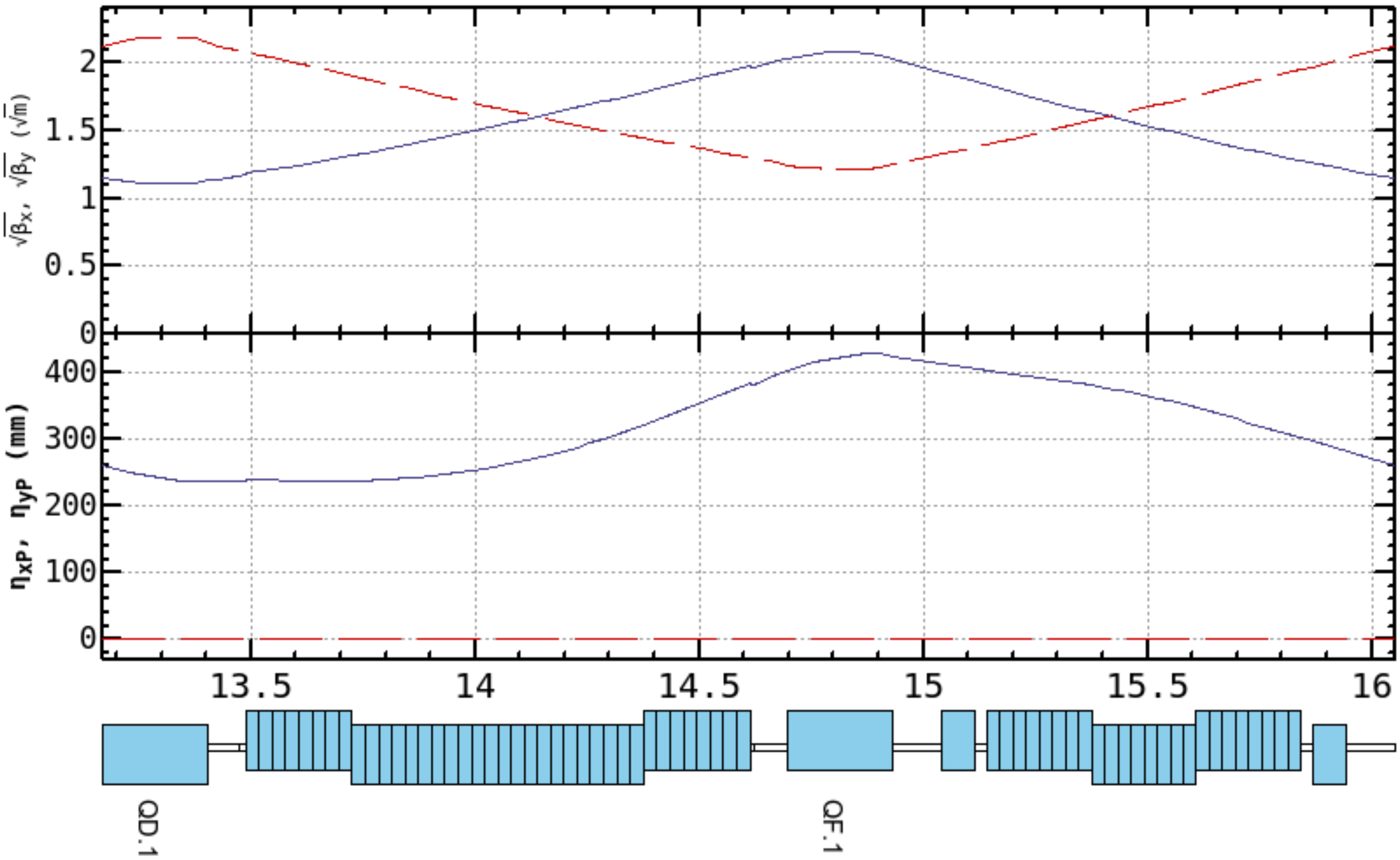
  Long-term stability of DR will be tested in Phase 2 operation.

Thank you for attention

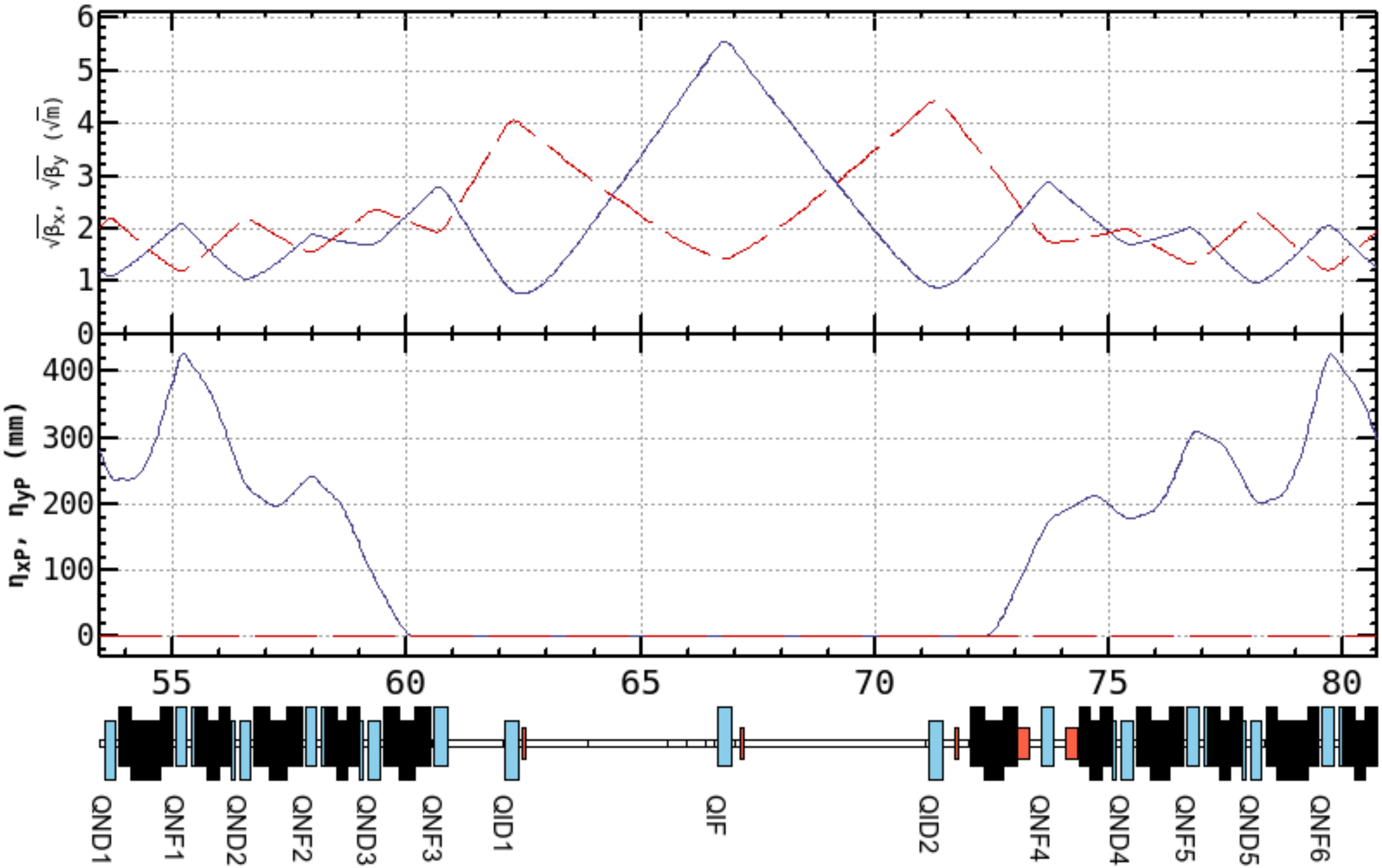
DR Optics



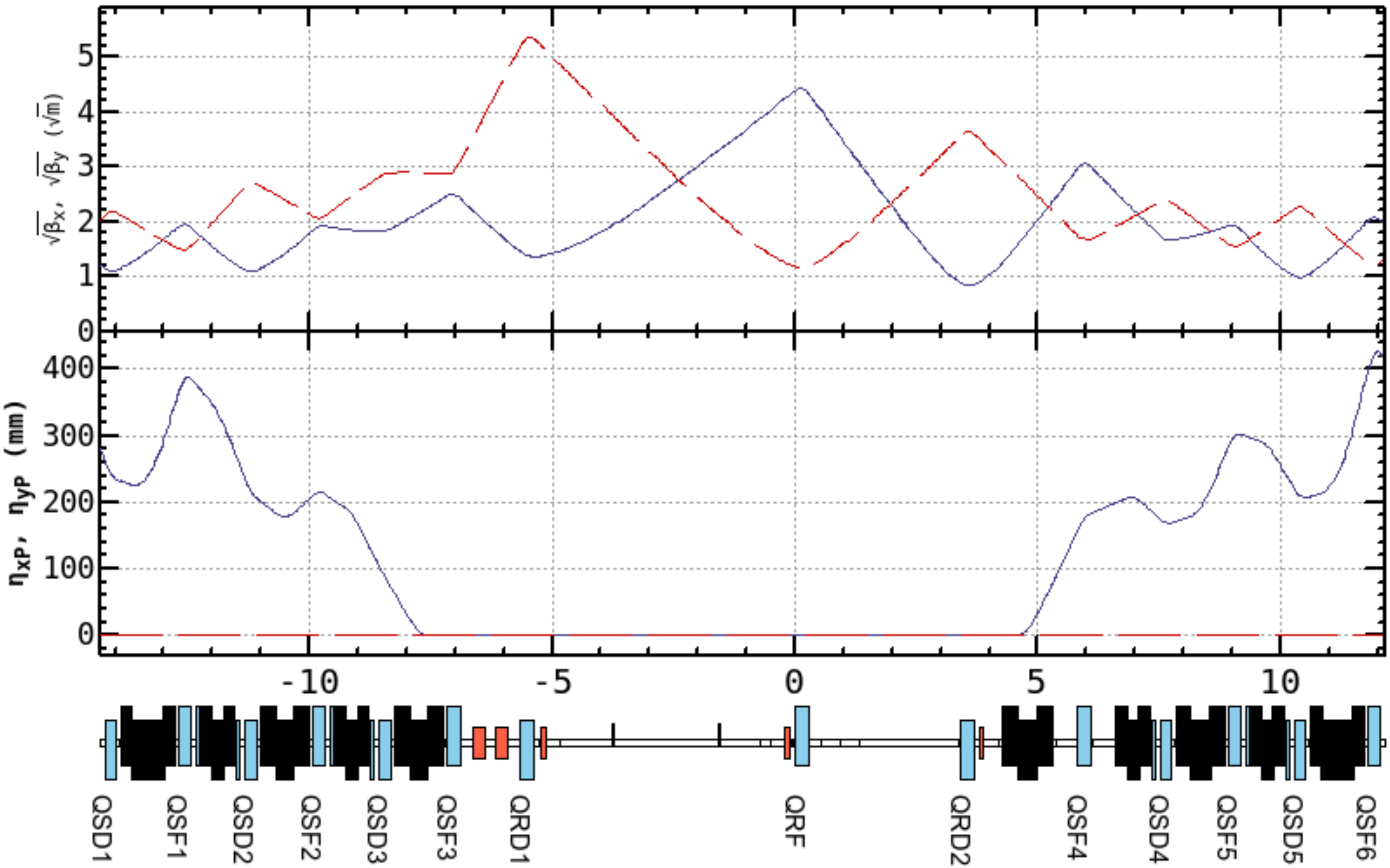
DR Optics - Arc Cell -



DR Optics - Injection Section -

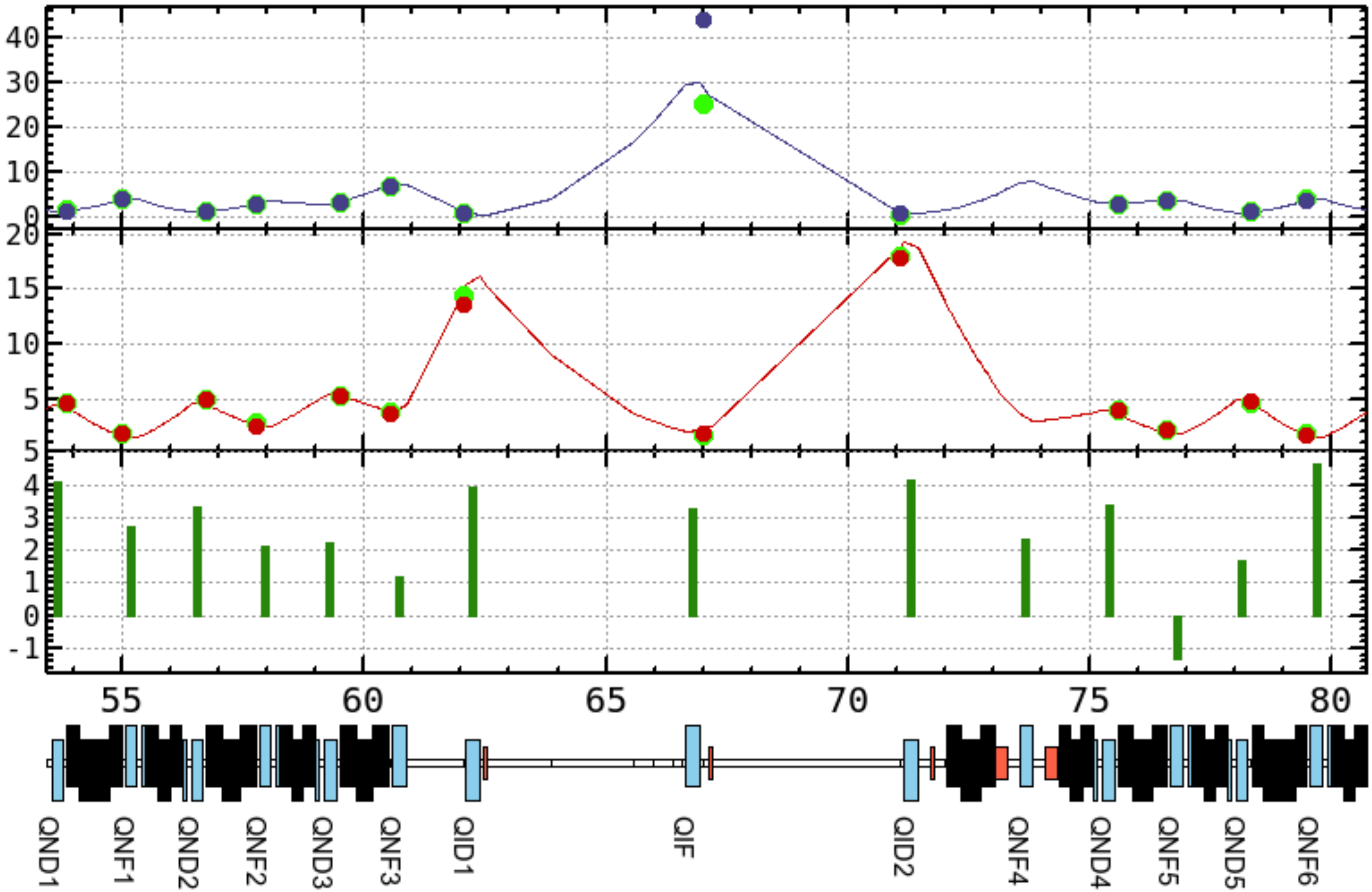


DR Optics - Extraction Section -



Measured Beta Function at Injection Section

Green: Evaluated by COD based scheme



Requirements for LINAC in Phase-2

	Positron LER 4 GeV	Electron HER 7 GeV
Normalized emittance*1 $\gamma\beta\varepsilon_x$ / $\gamma\beta\varepsilon_y$	200 / 40 [μm] with *DR*	150 / 150 [μm]*2
Energy spread*3 σ_δ	0.16 [%]	0.10 [%]
Bunch charge at injection point*4	0.5 [nC]	1.0 [nC]

*1 Area of 95.4 % occupied by particles defines ±2σ. The emittance is derived from σ.
*2 100 μm is preferable for Phase 2.4(4x4).
*3 Energy acceptance is 3 σ.
*4 Charge intensity of one bunch. Double for 2-bunch injection.

Thermionic gun is available for HER injection in Phase 2.
Damping Ring is necessary for LER injection.

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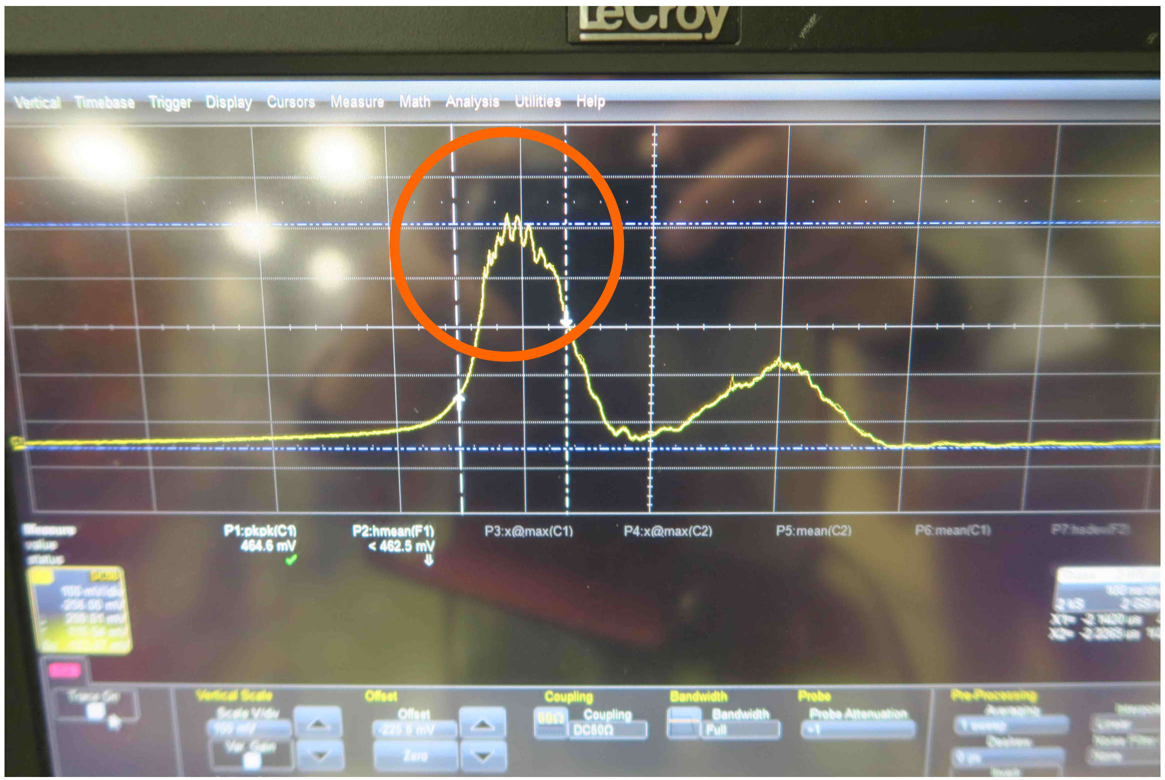
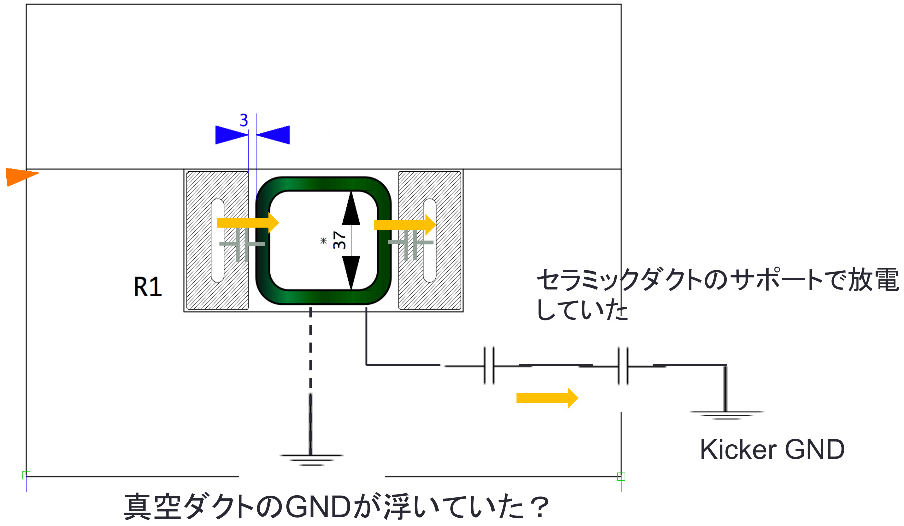
Machine Parameters in Phase III

Y. Ohnishi

2013/July/29	LER	HER	unit	
E	4.000	7.007	GeV	
I	3.6	2.6	A	
Number of bunches	2,500			
Bunch Current	1.44	1.04	mA	
Circumference	3,016.315		m	
$\varepsilon_x/\varepsilon_y$	3.2(1.9)/8.64(2.8)	4.6(4.4)/12.9(1.5)	nm/pm	():zero current
Coupling	0.27	0.28		includes beam-beam
β_x^*/β_y^*	32/0.27	25/0.30	mm	
Crossing angle	83		mrad	
α_p	3.18×10^{-4}	4.53×10^{-4}		
σ_δ	$8.10(7.73)\times10^{-4}$	$6.37(6.30)\times10^{-4}$		():zero current
V_c	9.4	15.0	MV	
σ_z	6.0(5.0)	5(4.9)	mm	():zero current
ν_s	-0.0244	-0.0280		
ν_x/ν_y	44.53/46.57	45.53/43.57		
U_0	1.86	2.43	MeV	
$\tau_{x,y}/\tau_s$	43.2/21.6	58.0/29.0	msec	
ξ_x/ξ_y	0.0028/0.0881	0.0012/0.0807		
Luminosity	8×10^{35}		$cm^{-2}s^{-1}$	

Irregular Signal of Injection Kicker





- Discharge due to a floating GND?
- After changing grounding route, the Irregular signal is not observed.