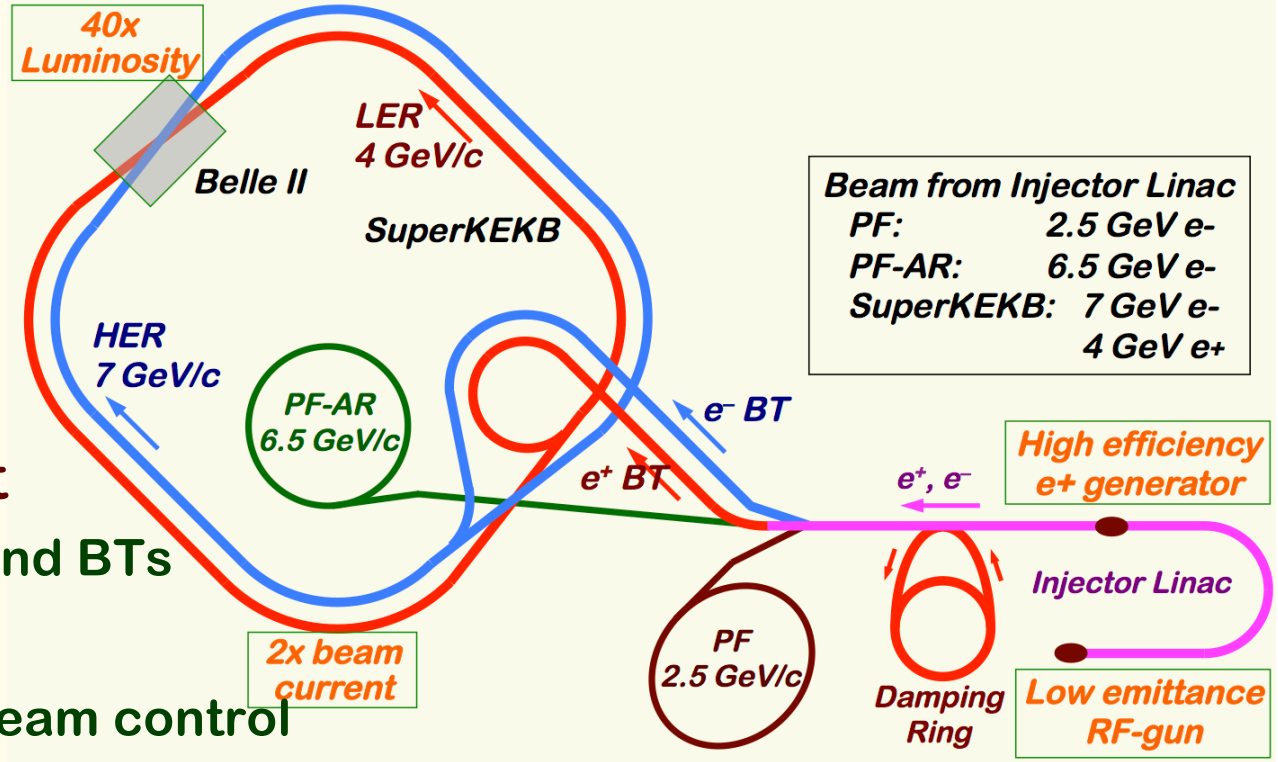
Present Status of Injector Linac and Damping Ring

Kazuro Furukawa

for injector linac and damping ring, KEK

Mission of electron/positron Injector Complex in SuperKEKB

- **40-times higher Luminosity**
  - 20-times higher collision rate with nano-beam scheme
    - → Low-emittance even at first turn → Low-emittance beam from Injector
    - → Shorter storage lifetime
  - Twice larger storage beam → Higher beam current from Injector
- **Injector challenges**
  - Low emittance e-
    - with high-charge RF-gun
  - Low emittance e+
    - with damping ring
  - Higher e+ beam current
    - with new capture section and BTs
  - Emittance preservation
    - with precise alignment & beam control
  - 4+1 ring simultaneous injection



Required injector beam parameters

Stage	KEKB (final)		Present Phase-I		SuperKEKB (final)	
Beam	e+	e–	e+	e–	e+	e–
Energy	3.5 GeV	8.0 GeV	4.0 GeV	7.0 GeV	4.0 GeV	7.0 GeV
Stored current	1.6 A	1.1 A	1 A	1 A	3.6 A	2.6 A
Life time	150 min.	200 min.	100 min.	100 min.	6 min.	6 min.
Bunch charge	Primary e-10nC → 1 nC	1 nC	Primary e- 8nC → 0.4 nC	1 nC	Primary e-10nC → 4 nC	5 nC
Norm. Emittance ($\gamma\beta\varepsilon$) (μrad)	2100	200	2400	150	100/20 (Hor./Ver.)	50/20 (Hor./Ver.)
Energy spread	0.125%	0.125%	0.5%	0.5%	0.1%	0.1%
No. of Bunch / Pulse	2	2	2	2	2	2
Repetition rate	50 Hz		25 / 50 Hz		50 Hz	
Simultaneous top-up injection (PPM)	3 rings (KEKB e–/e+, PF)		No top-up		4+1 rings (SuperKEKB e–/e+, DR, PF, PF-AR)	

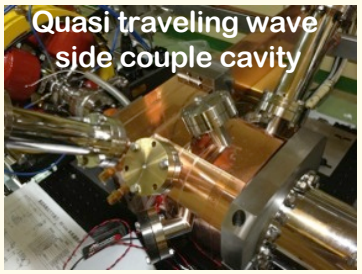
Progress

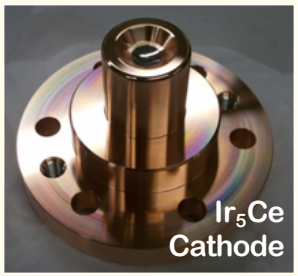
- 2010: Beam design and hardware developments
- 2011-2014: Recovery from earthquake, mainly because of soft-structure girder design
- 2012-: Linac construction and commissioning
- 2012-: Step-by-step acquirement of beam licenses
- 2016: Phase-1
- 2017: Damping ring commissioning, Phase-2
- Continuous: Light source injections
- …

Linac Upgrade Progress towards SuperKEKB (1)

High-charge low-emittance RF gun development

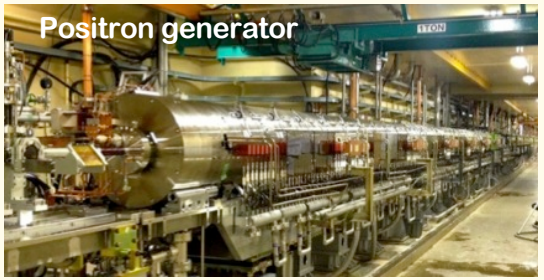
- QTWSC cavity and Ir5Ce photo cathode developments
- Laser development is underway





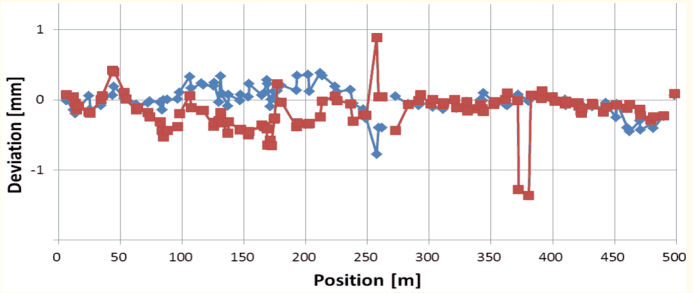
Positron generator commissioning

- Good agreement with the simulation results
- Will solve discharge issues



Precise alignment for emittance preservation

- Recovering after large earthquake in 2011
- Reaching specification of 0.1~0.3mm
- Longer term stability should be solved



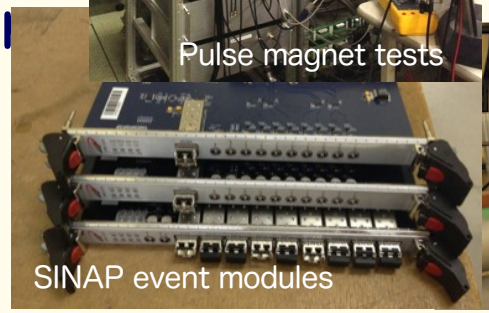
Utility upgrade during FY2014

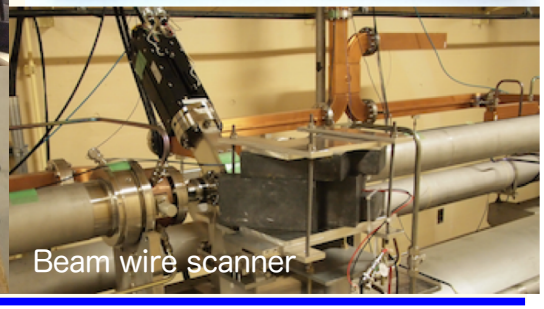
- for electricity (+1.5MW) and cooling water (+1400L/min)

Linac Upgrade Progress towards SuperKEKB (2)

- High-power microwave modulator upgrades
- Low-level RF controls/monitor upgrades
  - Pulse-to-pulse modulation (PPM) between 4+1 rings
  - More spaces for increased number of devices
- Beam instrumentation
  - Large/small aperture beam position monitors (BPM)
  - Precise/fast and synchronized BPM readout system
  - Wire scanners and beam loss monitors
  - Streak cameras
  - (Deflectors, etc.)
- Pulsed magnet developments
  - ~3 bends, ~30 quads, ~40 steerings
  - Even with energy recovery
- Event-based control and timing system u
  - Combination of MRF & SINAP modules
  - Essential for PPM operation
  - Precise timing & synchronized controls
  - Bucket selection at DR and MR

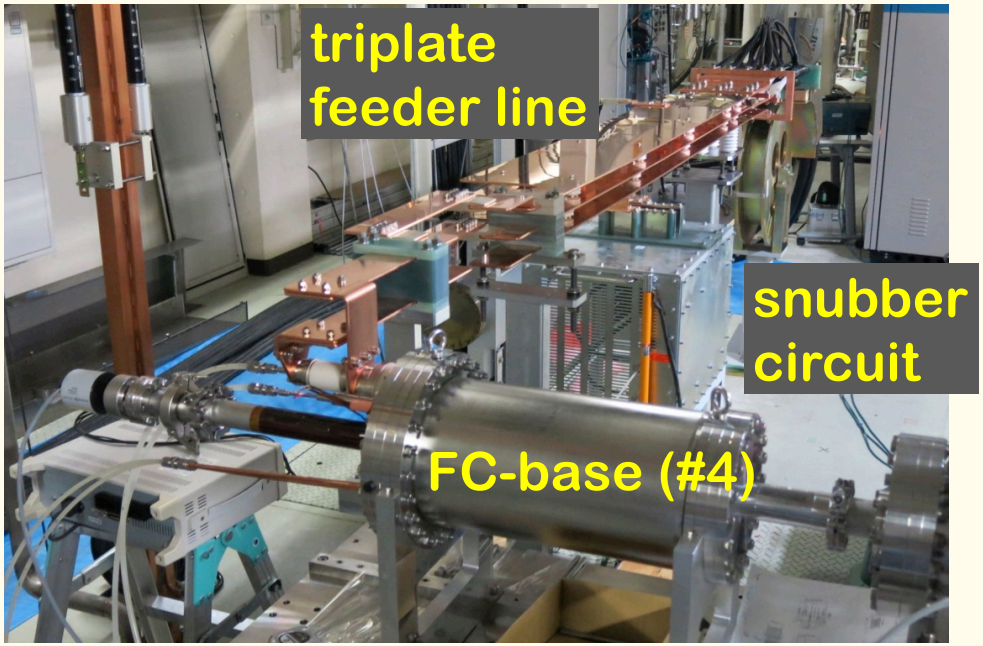

Pulse magnet tests

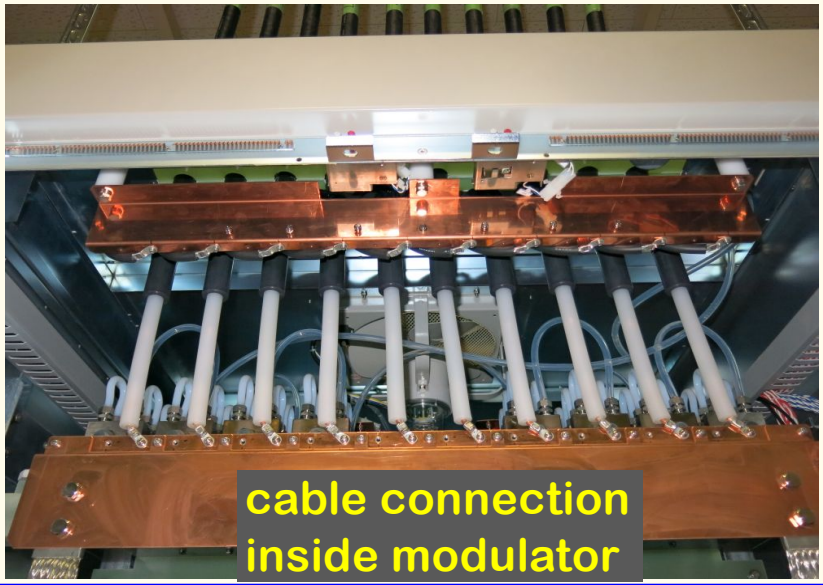

SINAP event modules


Beam wire scanner

FC test stand (2015 July)

- test operation performed with
  - spare FC-base (#4)
  - 12-kA pulse modulator
  - new coaxial cables
  - new triplate feeder line
  - snubber circuit
  - but w/o bridge coils
- full-spec (12 kA) operation for continuous 200 hours achieved with no serious breakdowns and problems

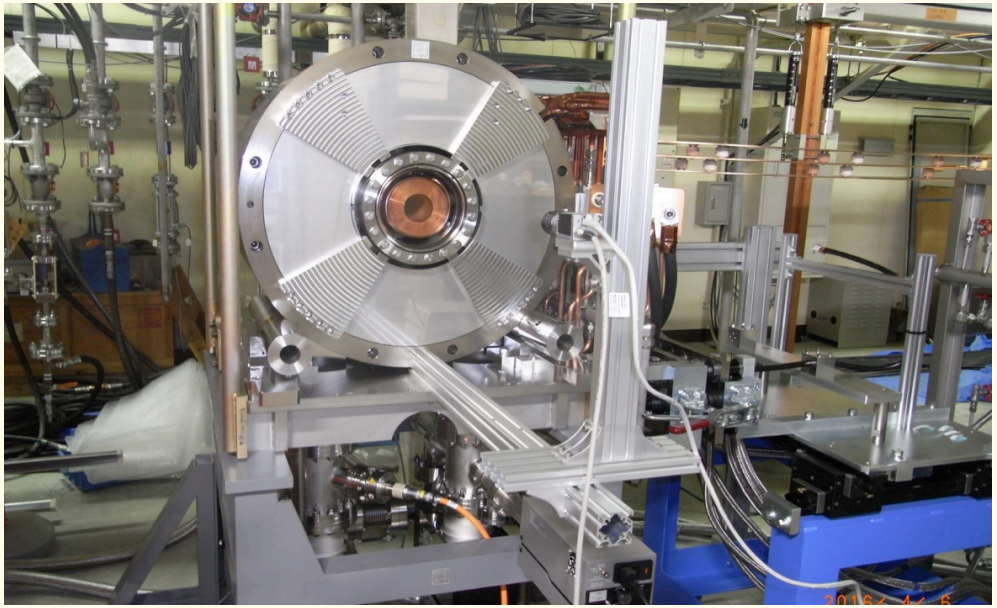


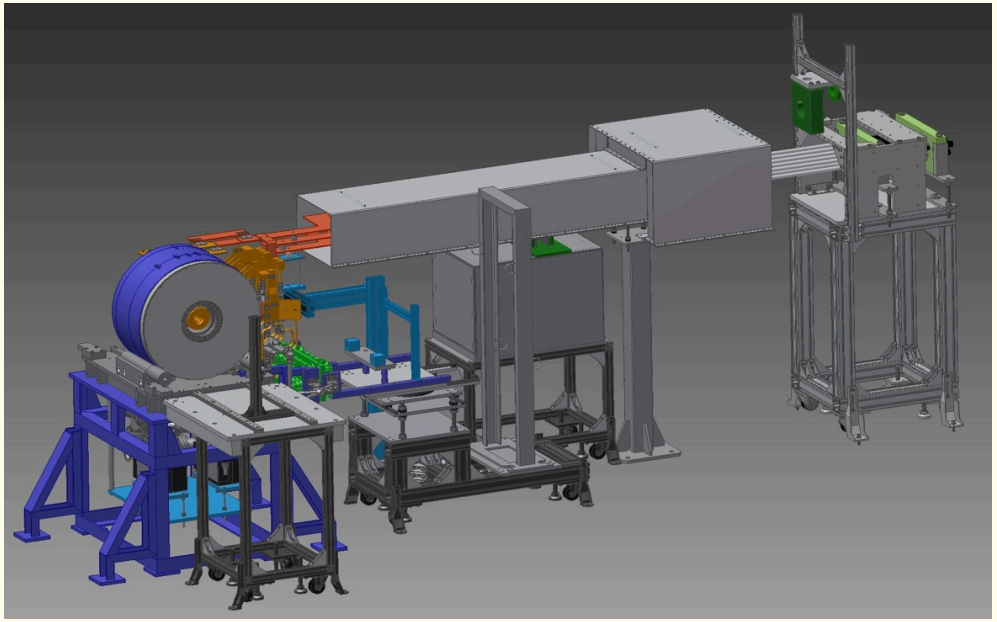


FC assembly #2 & test stand

- Operation test with BC field is essential.
- FC assembly #1 is radio-activated in the beam line.
- Construct assembly #2 for operation with BC field at test stand.

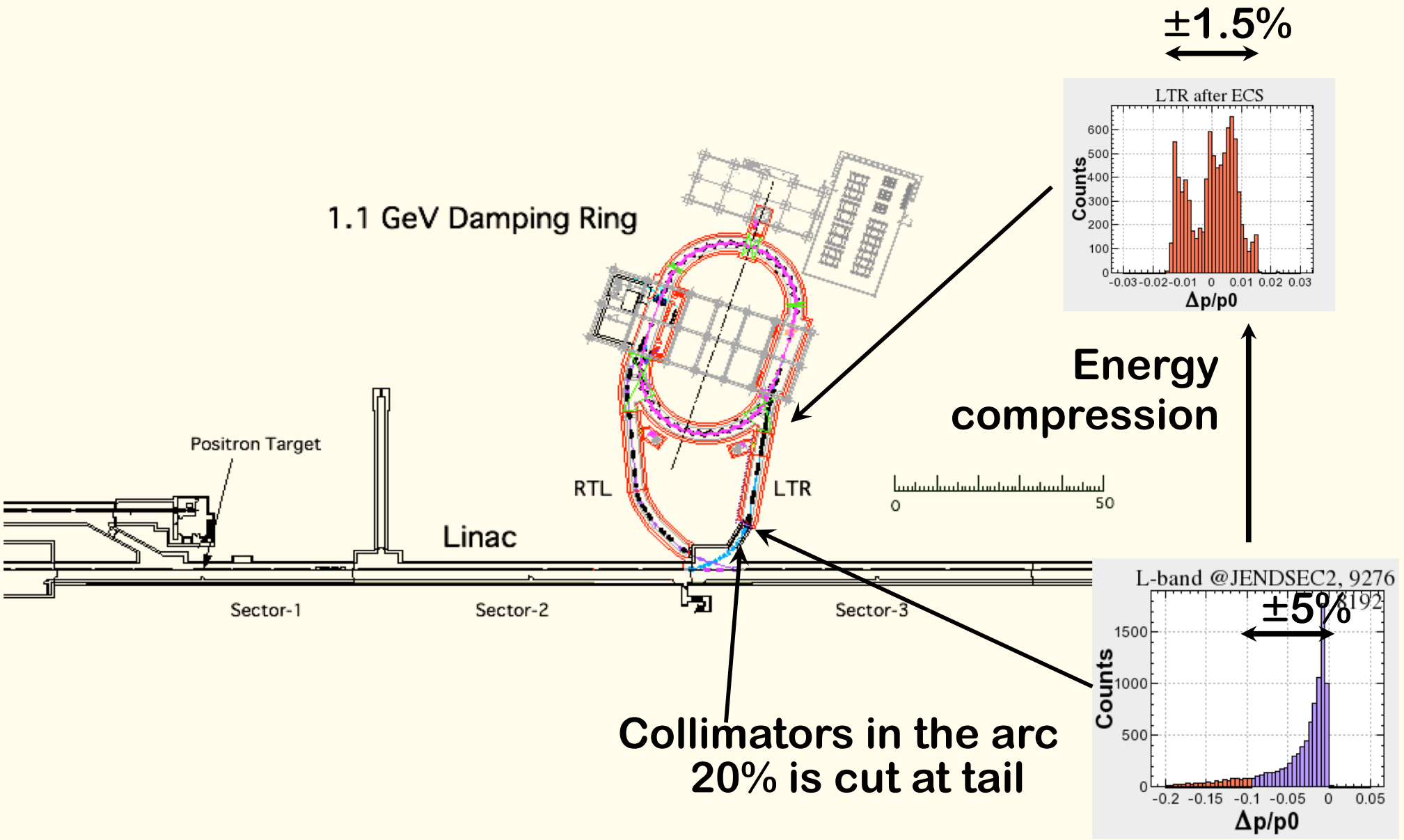
- Test-1: operation with FC-head #4 (not work-hardened model) to see what happens in the same situation as the damaged FC.
  [2016 June, soon]
- Test-2: operation with FC-head #5 (well work-hardened model) to check the operability at full current (12 kA) under the BC field.
  [2016 August ~]





Damping Ring System Layout

M. Kikuchi

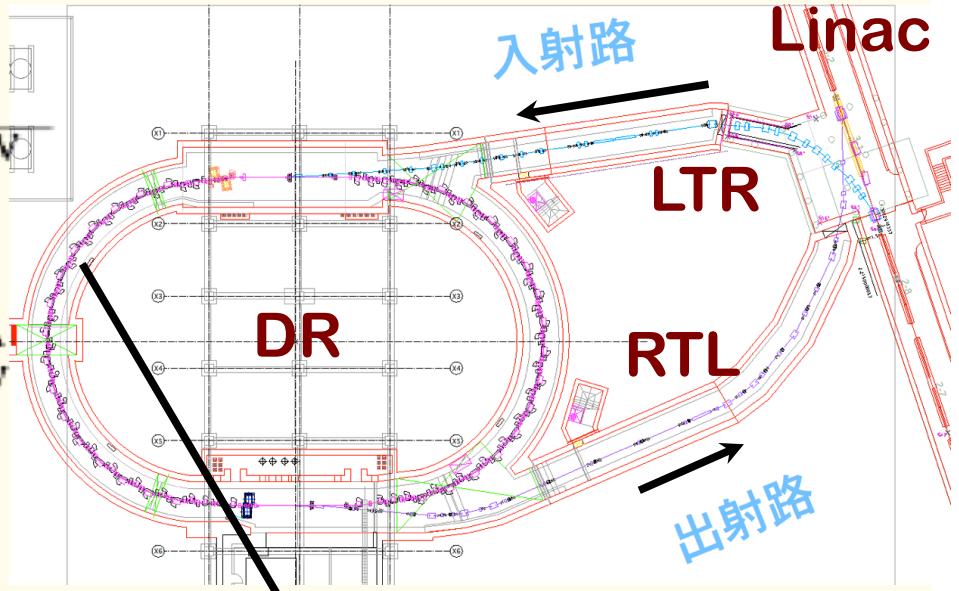


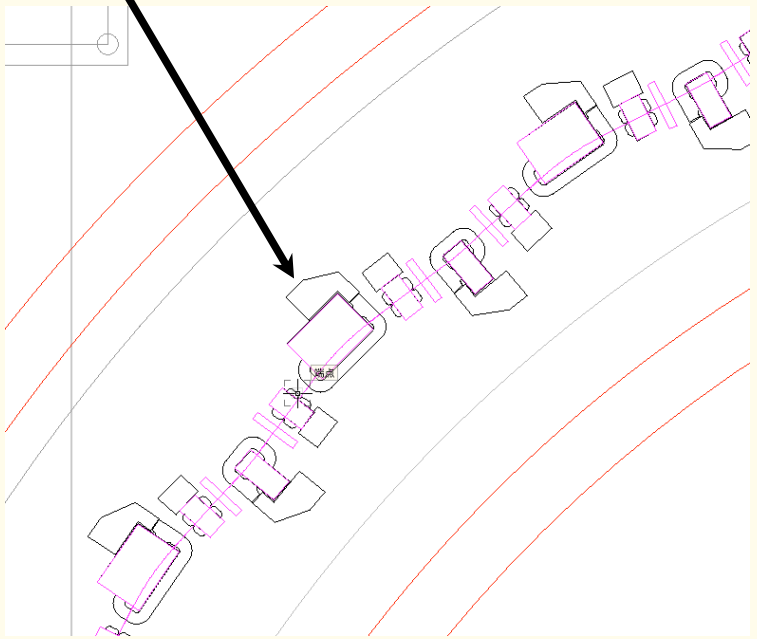
Damping Ring Beam Parameters

M. Kikuchi

Table 3: Parameters of the Damping Ring

Energy		1.1		GeV
Number of bunch trains		2		
Number of bunches / train		2		
Circumference		135.498295		m
Maximum stored current		70.8		mA
Energy loss per turn		0.0847		MV
Horizontal damping time		11.57		ms
Injected-beam emittance		1400		nm
Equilibrium emittance (h/v)		41.5 / 2.08		nm
Coupling		5		%
Emittance at extraction (h/v)		42.9 / 3.61		nm
Cavity voltage	0.5	1.0	1.4	MV
Bucket height	0.81	1.24	1.5	%
Energy spread		5.5×10^{-4}		
Synchrotron tune	0.0152	0.0217	0.0257	
Equilibrium bunch-length	11.07	7.79	6.58	mm
Phase advance/cell (h/v)		64.39 / 64.64		deg
Momentum compaction factor		0.0142		
Bend-angle ratio		0.35		
Bend radius		2.7		m
Number of normal-cells		40		
RF frequency		509		MHz
Chamber size(normal cell)	$34^H \times 24^V$ w/ antechamber			mm





Hardware Status

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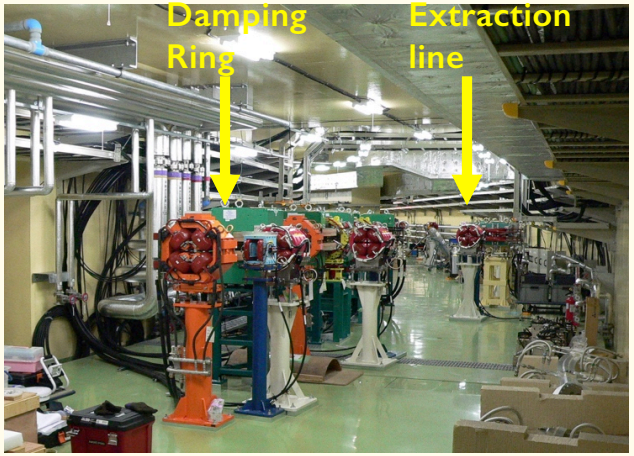
- LTR / RTL beam transport lines
  - Magnet: Installation completed
  - vac. chamber:
    - installation, beam instrumentation in 2016 / 2017
- DR
  - Magnet: Installation completed (except for steerings in the straight)
  - Vacuum chamber: installation is underway



DR and the extraction line


Installation of vac. chambers

  - Power supplies for the magnets:
    - All delivered. Tuning will be done in 2017.
    - Steering PS will be delivered in 2017.

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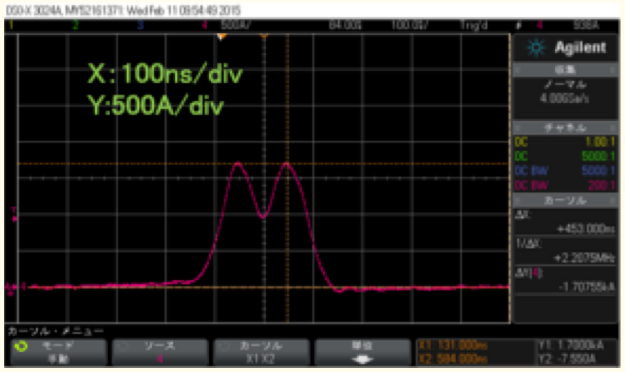
- Beam instrumentation:
  - Most of sensors, electronics and cables delivered.
  - Cabling of BPM completed in FY2015.



Pulse shape of the kickers.

- Kicker system for injection/extraction:
  - Magnets and the power supplies are delivered.
  - Double half-sine pulse for the two bunches
  - No ringing after pulse

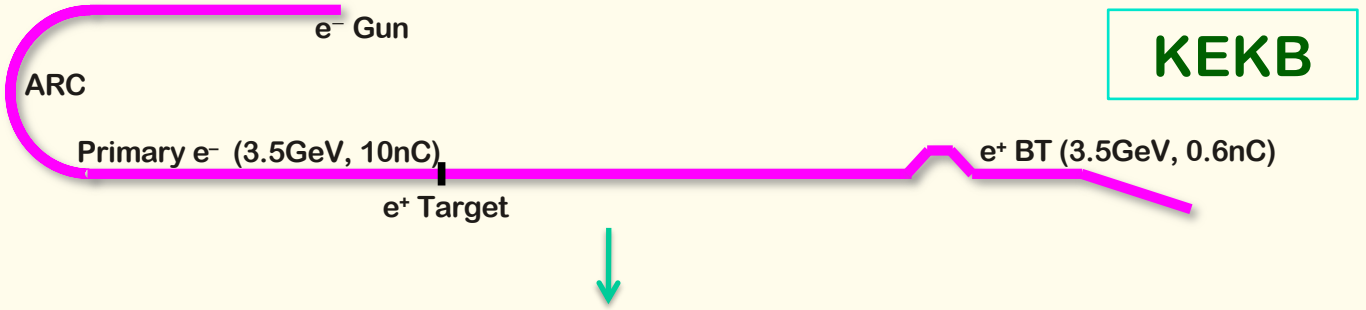
- Septum magnets for injection/extraction:
  - Magnets and pulsers are delivered.

Septum magnet for injection.

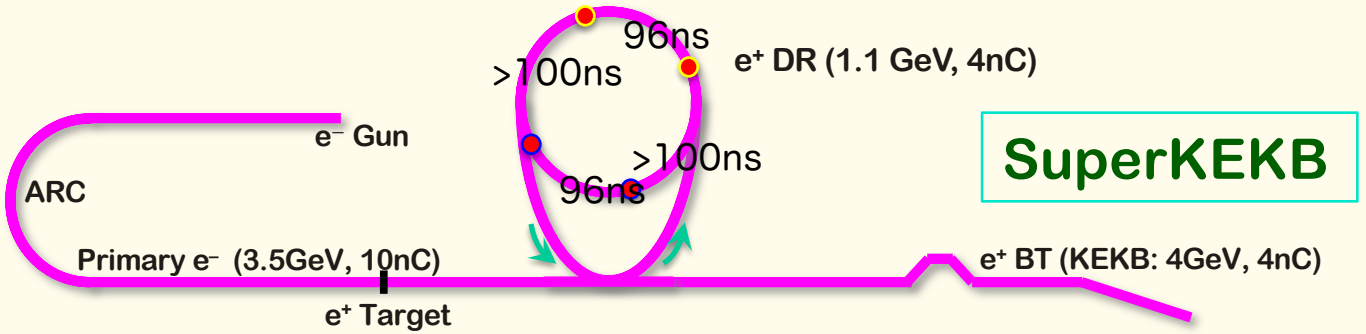
- Two RF cavities were fabricated.
  - installed in the tunnel in June 2016.

Bucket selection in Phase-2 with DR

- Without DR, simply wait up to 5120 x 96 ns ~ 490 μs
  - 96 ns : highest common frequency between linac – ring



- With DR, in order to select arbitrary bucket in MR, have to wait up to ~4.5 ms, even if a bucket in DR was carefully selected
  - Power supply can wait only 2 ms, one of only 2798 buckets in 5120 buckets can be selected, may have to change LLRF condition at latter half of linac every pulse



  - Can be a big challenge in LLRF precision

Construction Schedule

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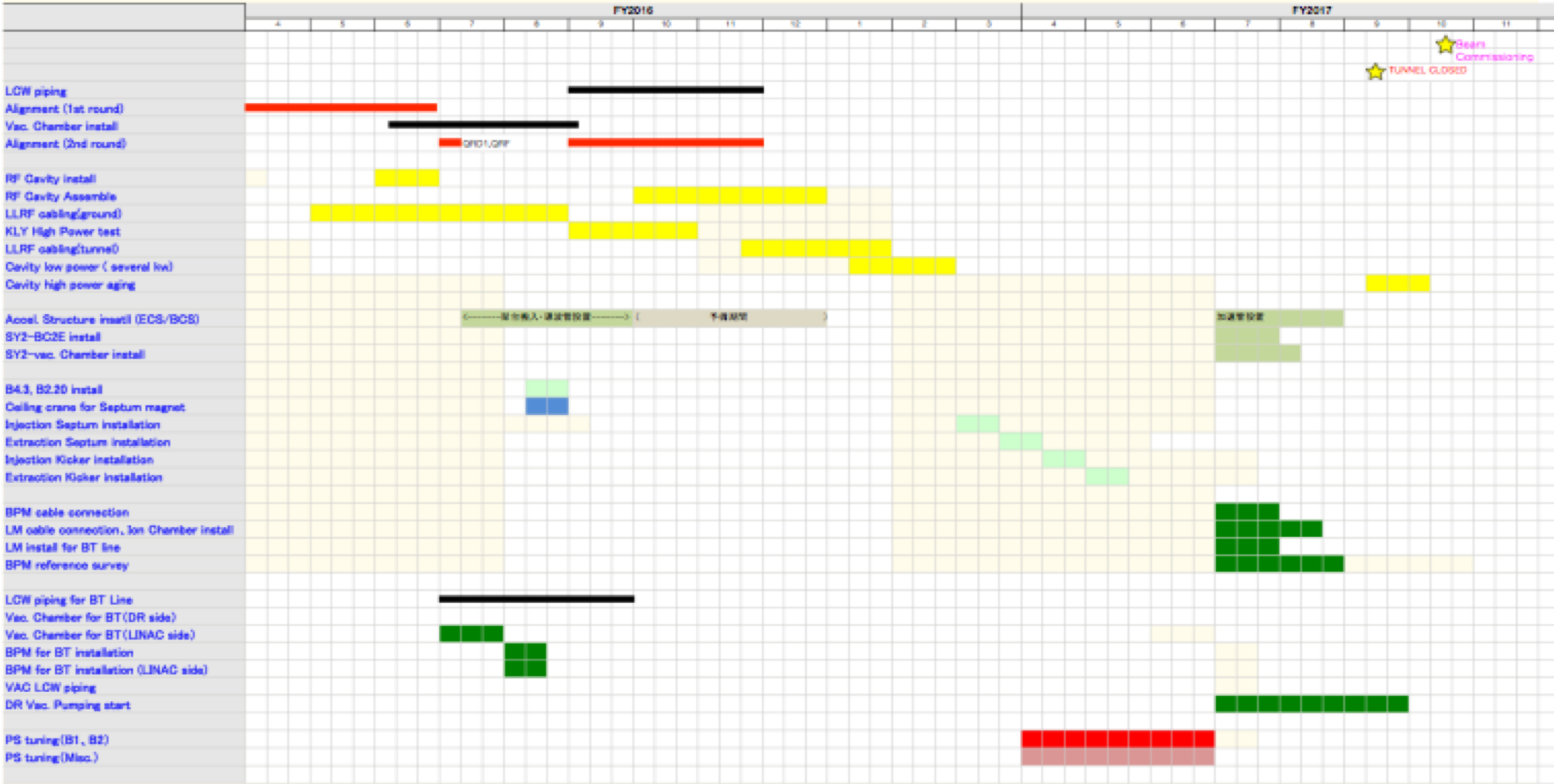


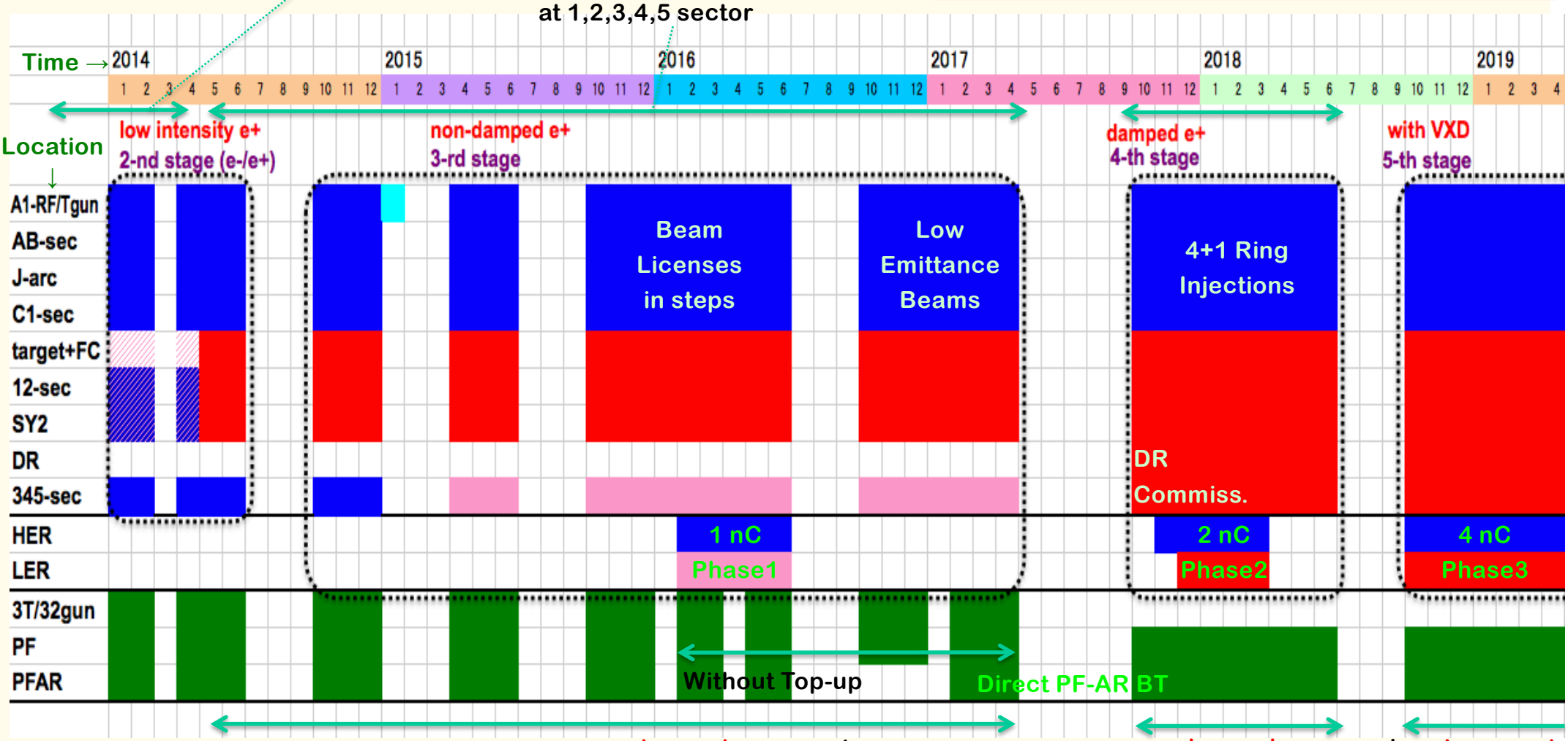
Linac Schedule Overview

RF-Gun e- beam commissioning at A,B-sector

e- commiss. at A,B,J,C,1

e+ commiss. at 1,2 sector (FC, DCS, Qe- 50%)
e- commiss. at 1,2,3,4,5 sector

Phase1: high emittance beam for vacuum scrub
Phase2,3: low emittance beam for collision



: Electron
: Positron
: Low current electron

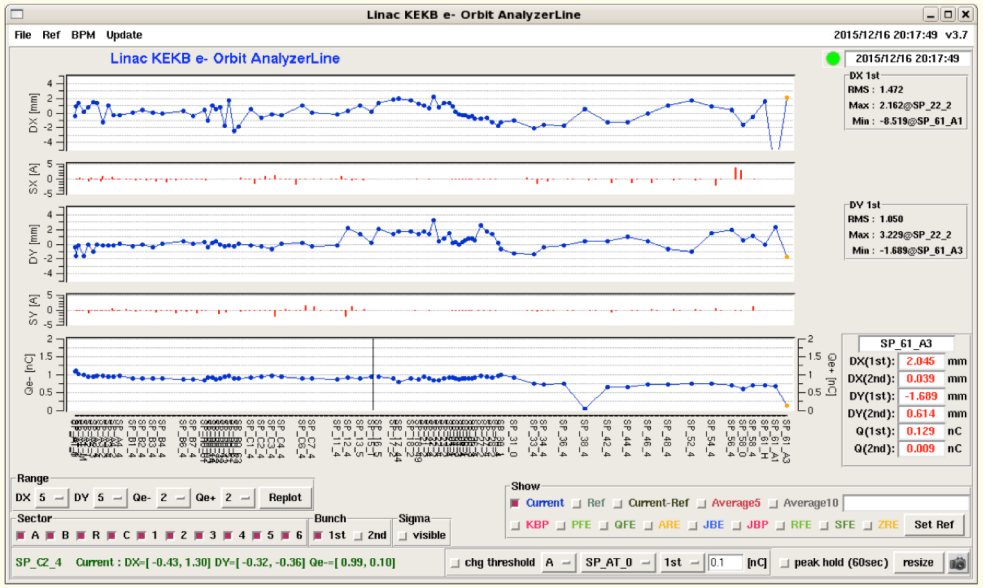
non damped e+ commiss.
at 1,2, 3,4,5 sectors
e- commiss. at A→5 sectors

damped e+ commiss. Improved RF gun
at 1→5 Qe+ = 1~4nC
e- commiss.
at A→5 Qe- = 1~5nC

Injector Beam Commissioning for Phase-1

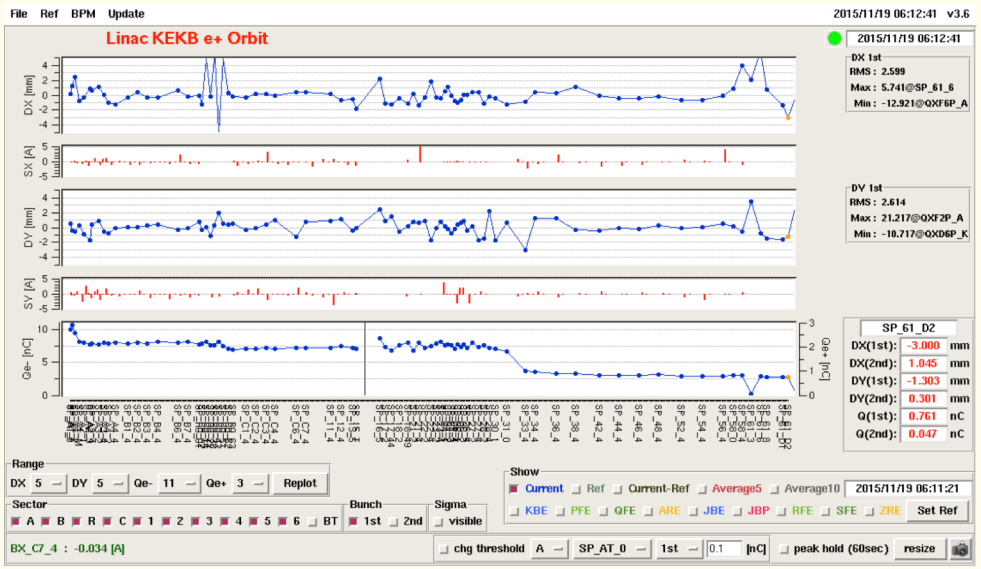
Electron beam

- Thermionic gun at the beginning
- 1 nC per bunch
- 2 bunches per pulse
- 50 pulse per second



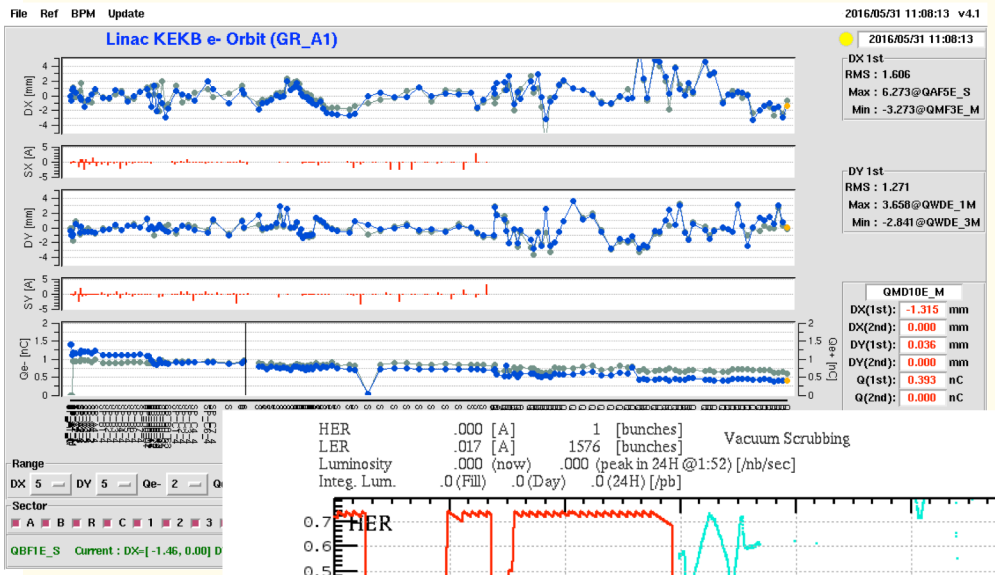
Positron beam

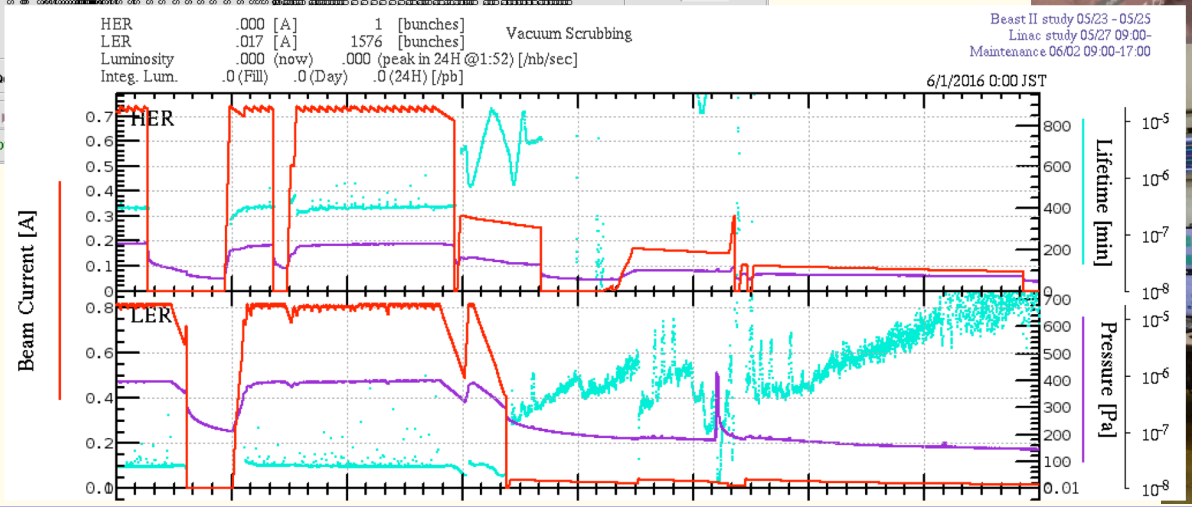
- Primary electron with 7-8 nC per bunch
- Positron of 0.7 nC at linac end without damping ring

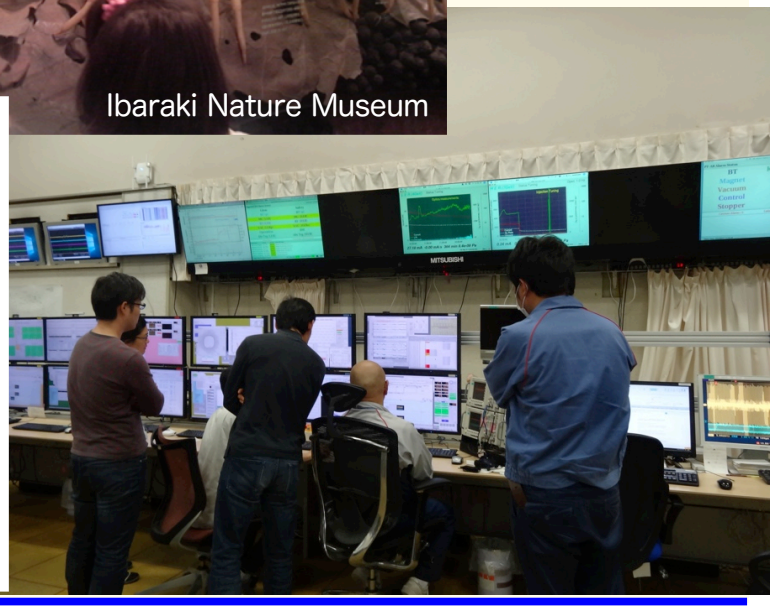


Progress: RF gun

- MR injection from RF gun during Phase-1 was recommended in the last gun review, and was planned for May 2016 since the last year
- On May 31, even an unusual centipede (~15cm!!) managed to visit the operation room to celebrate the first injection into HER

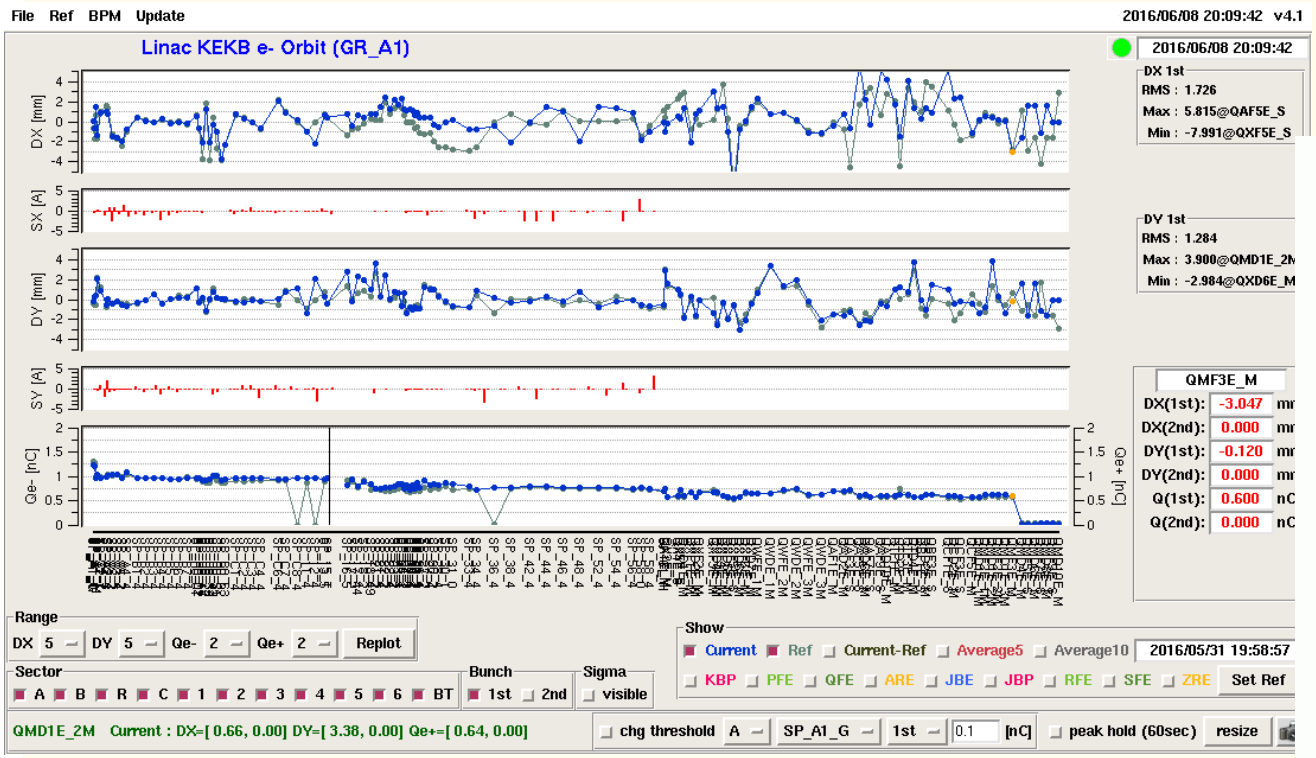


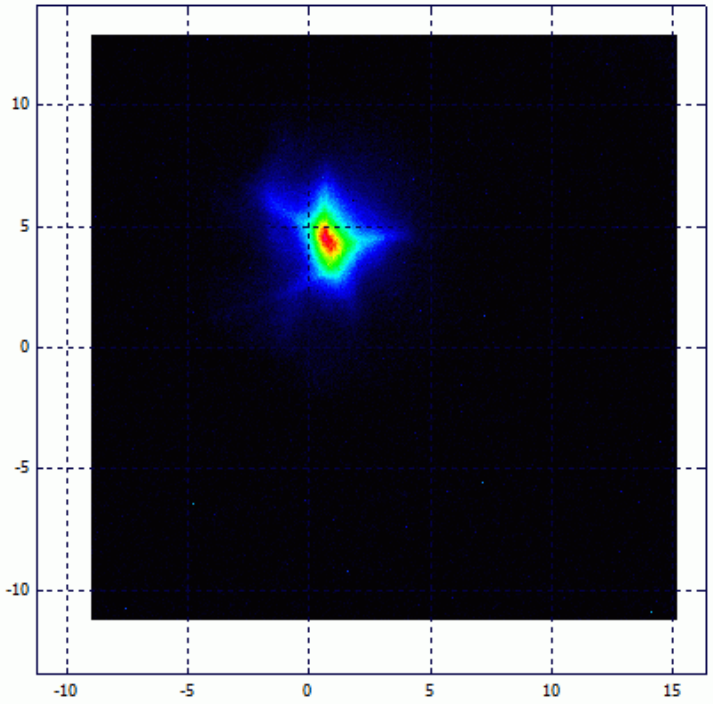




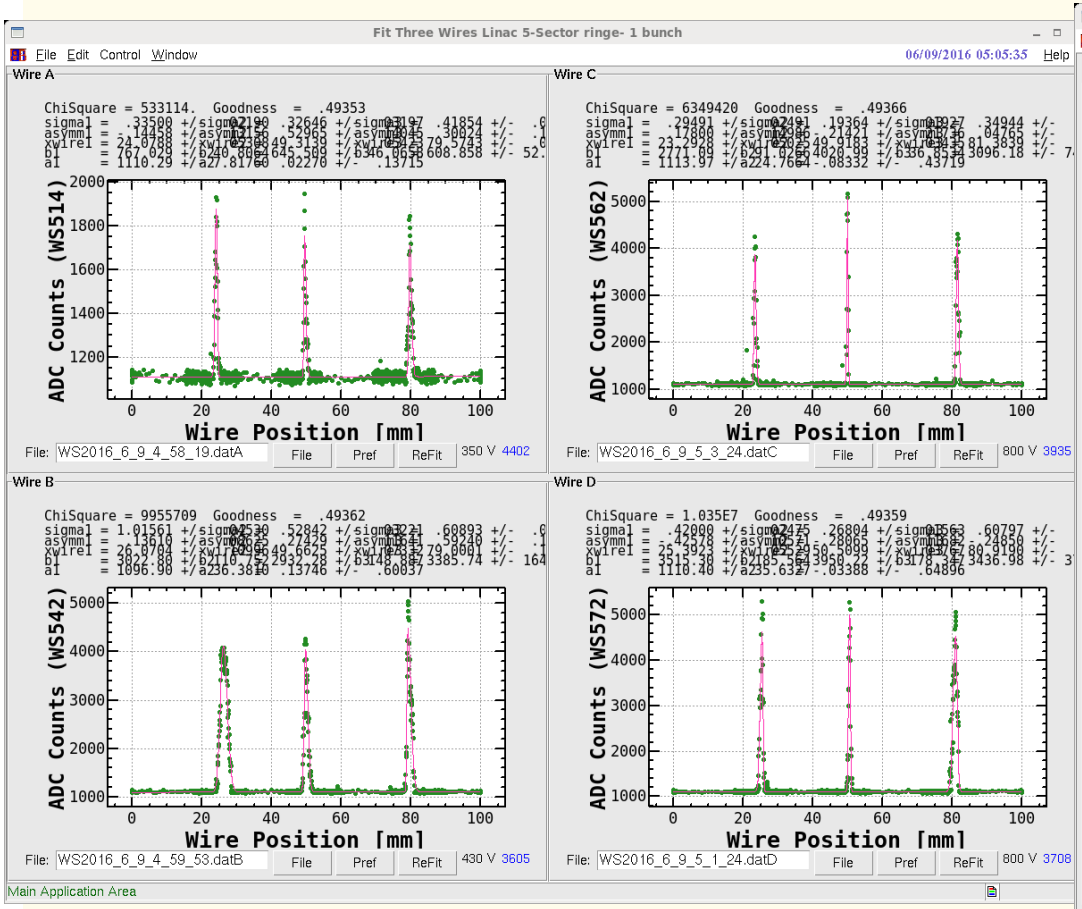
Beam from RF gun

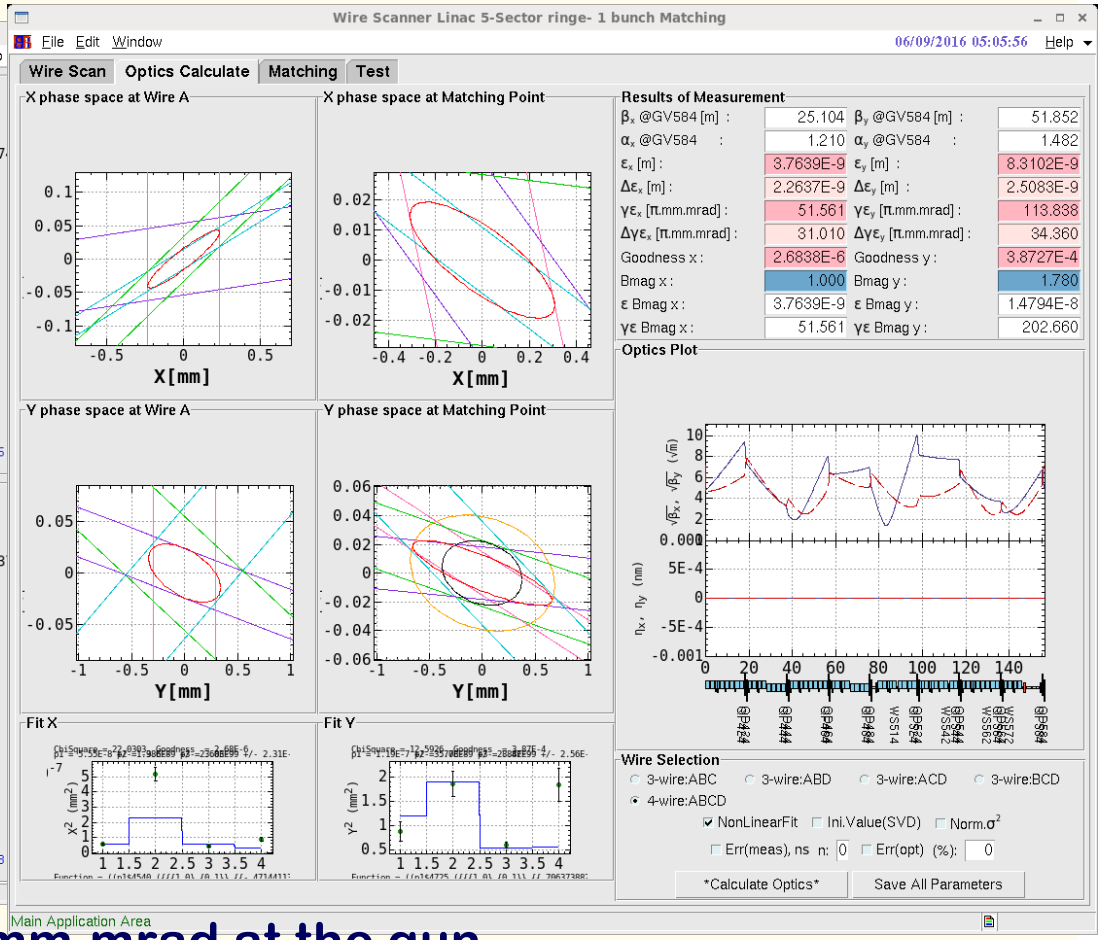
- Successful Injection into MR for the first time, on May.31
- And continuing the RF gun operation since Jun.8





Wire Scanner Measurement

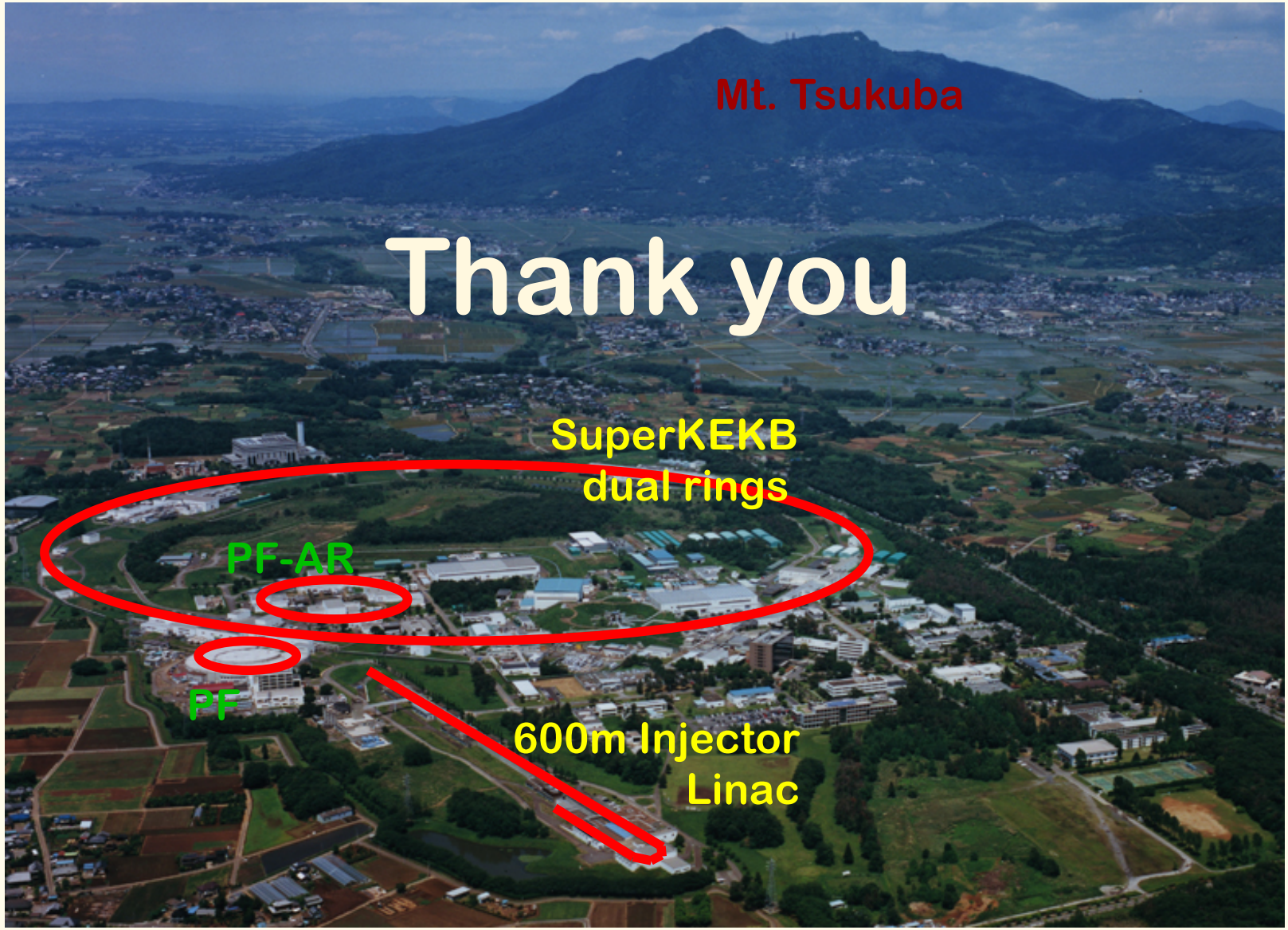




- Present beam: 1nC/bunch, 25Hz, 20mm.mrad at the gun,
  30~200 mm.mrad at the linac end, ? Energy spread
- Phase-2: 2nC/bunch, 50Hz, 20 mm.mrad at the linac end, 0.1% energy spread
- Phase-3: 4-5nC/bunch
- Much room to enjoy the improvements

Summary

- Injection into SuperKEKB is another challenge with higher beam charge and lower transverse and longitudinal emittance
- Steady progress towards designed injection beam in steps
  - Alignment: almost confident on the required precision (0.1-mm local, 0.3-mm global), need to maintain for longer term
  - Positron generator: another license test, need discharge analysis
  - Thermionic gun: re-commissioned for primary electron for positron generation
  - RF gun: successful HER injection, following recommendations at review meetings
  - Need more radiation shield
  - Need much construction left for 2017
- Will balance between final beam quality and progressive operation
- Will select optimized route depending on available resources
  - Negotiation with light sources
  - Commissioning and development in parallel (no other choices)


Mt. Tsukuba
Thank you
SuperKEKB
dual rings
PF-AR
PF
600m Injector
Linac