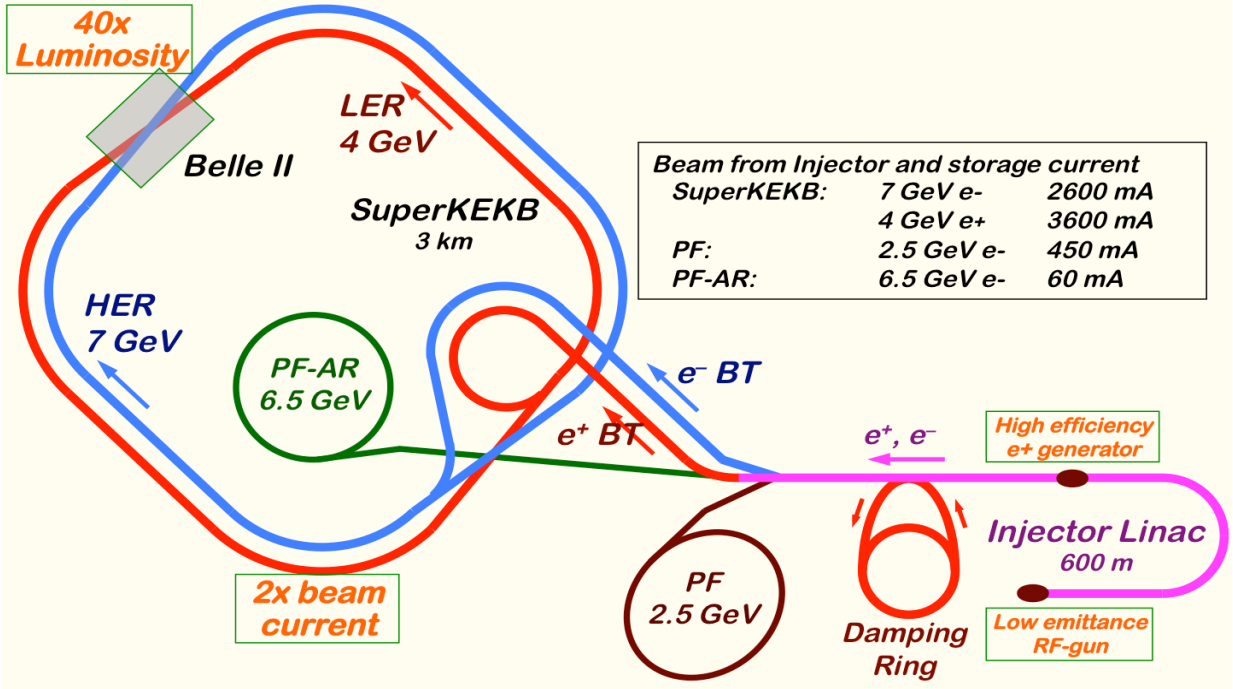
Progress of KEK Electron/Positron Injector Linac

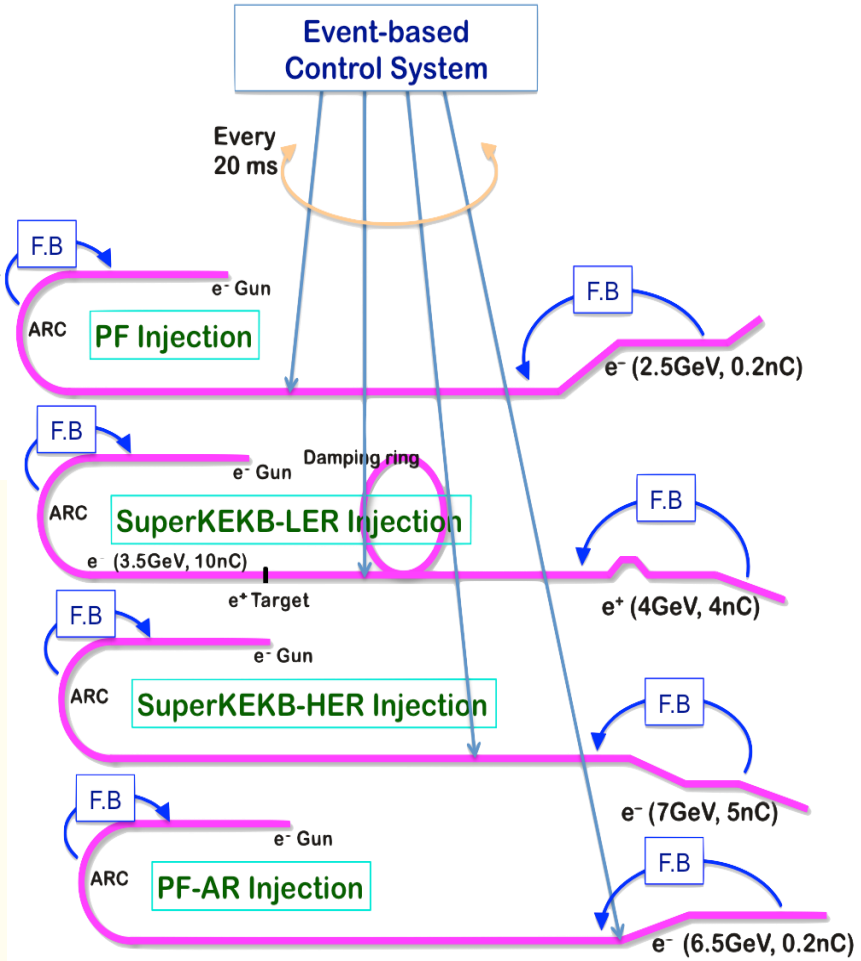
Mitsuhiro Yoshida

Injector Linac, KEK

Mission of Electron/positron Injector in SuperKEKB

- For 40-times higher luminosity in SuperKEKB collider
- Low emittance & low energy spread injection beam with 4-5 times more beam current
  - New high-current photo-cathode RF gun
  - New positron capture section
  - Damping ring construction
  - Optimized beam optics and correction
  - Precise beam orbit control with long-baseline alignment
  - Simultaneous top-up injection to DR/HER/LER/PF/PFAR
- Balanced injection for the both photon science and elementary particle physics experiments





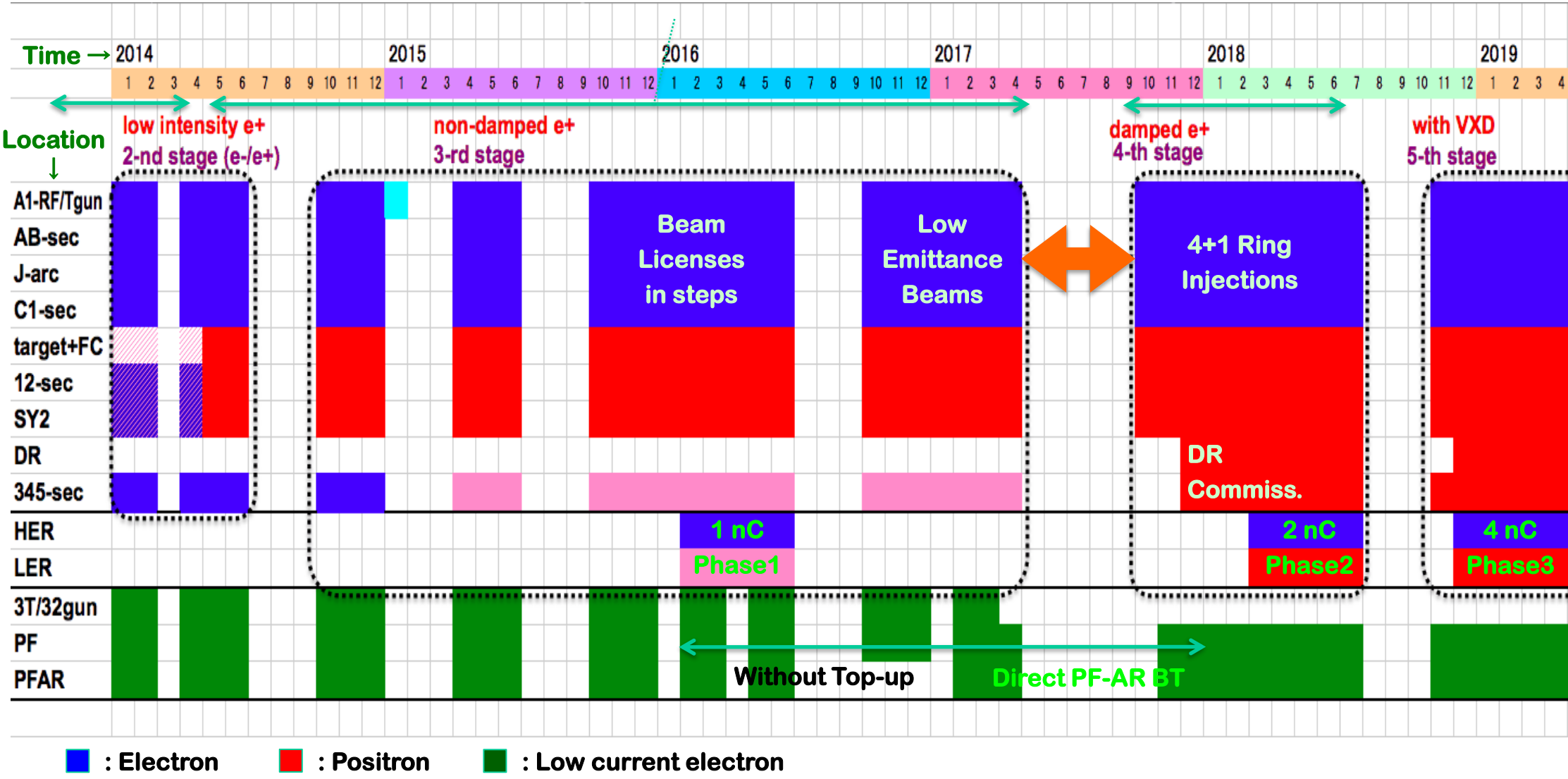
The single injector would behave as multiple injectors to multiple storage rings by the concept of virtual accelerator

Required injector beam parameters

Stage	KEKB (final)		Phase-I		Phase-II		SuperKEKB (final)	
Beam	e+	e–	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	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 (min.)	150	200	100	100	–	–	6	6
Bunch charge (nC)	primary e- 10 → 1	1	primary e- 8 → 0.4	1	0.5	1	primary e- 10 → 4	4
Norm. Emittance ($\gamma\beta\varepsilon$) (μrad)	1400	310	1000	130	200/40 (Hor./Ver.)	150	100/15 (Hor./Ver.)	40/20 (Hor./Ver.)
Energy spread	0.125%	0.125%	0.5%	0.5%	0.16%	0.1%	0.16%	0.07%
Bunch / Pulse	2	2	2	2	2	2	2	2
Repetition rate	50 Hz		25 / 50 Hz		25 / 50 Hz		50 Hz	
Simultaneous top-up injection (PPM)	3 rings (LER, HER, PF)		No top-up		Eventually		4+1 rings (LER, HER, DR, PF, PF-AR)	

Linac Schedule Overview as of Jun.2017

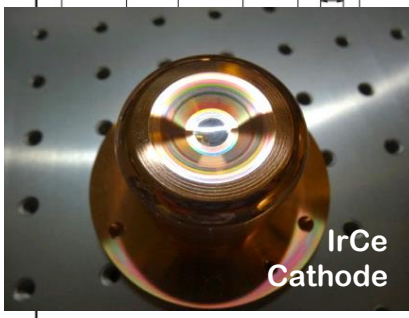
- **Long (5-month) shutdown for the first time in SuperKEKB project**
  - 9-month shutdown in 1997 during KEKB
  - DR construction, resource availability, etc
  - Installation of many important components during this shutdown

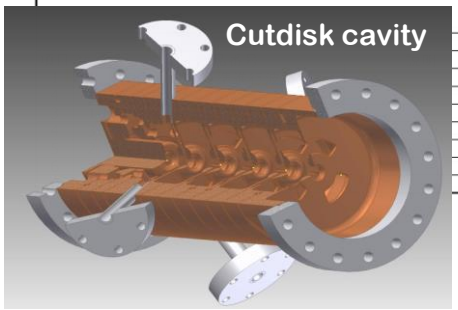


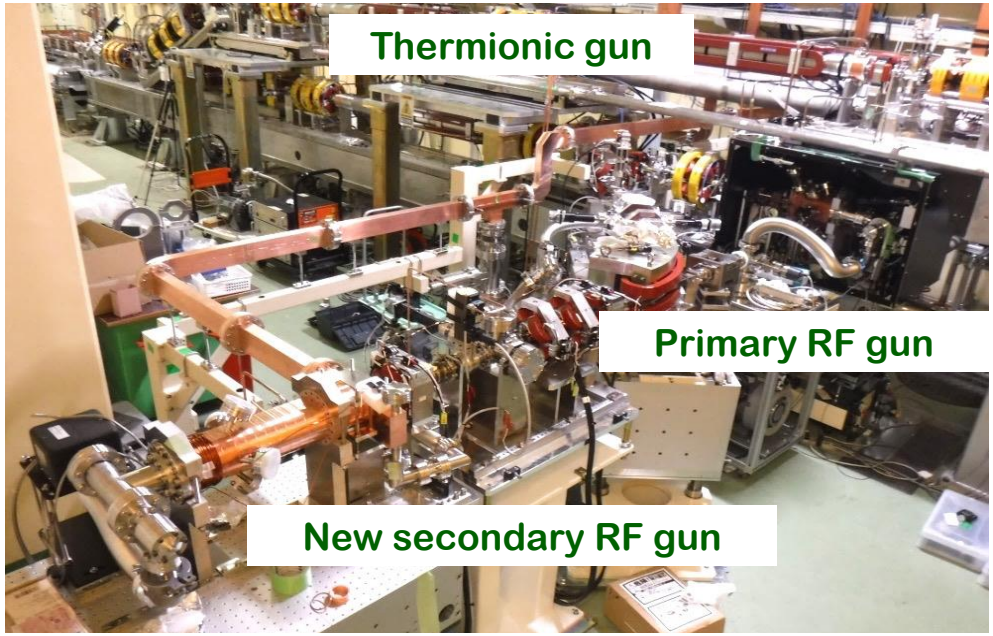
Progress of Photo-cathode RF Gun

Yoshida et al

- Succeeded in injection during SuperKEKB Phase-1 commissioning for 11 days
- Employs Yb-doped-fiber and Nd/Yb:YAG laser, Ir5Ce or Ir2Ce cathode, QTWSC or cutdisk structures
- Secondary RF gun was constructed for availability with Ir2Ce and cutdisk







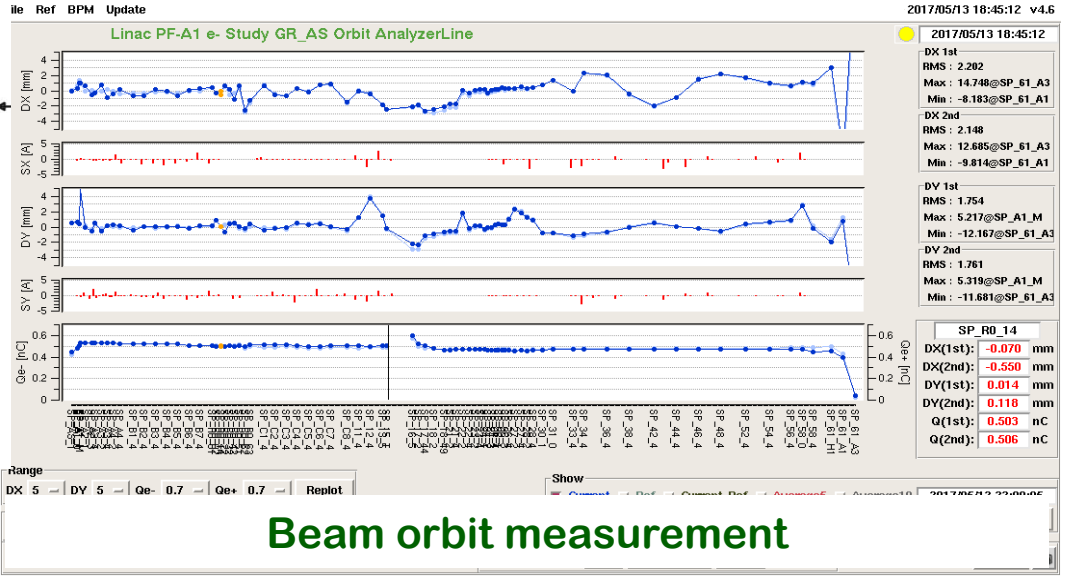
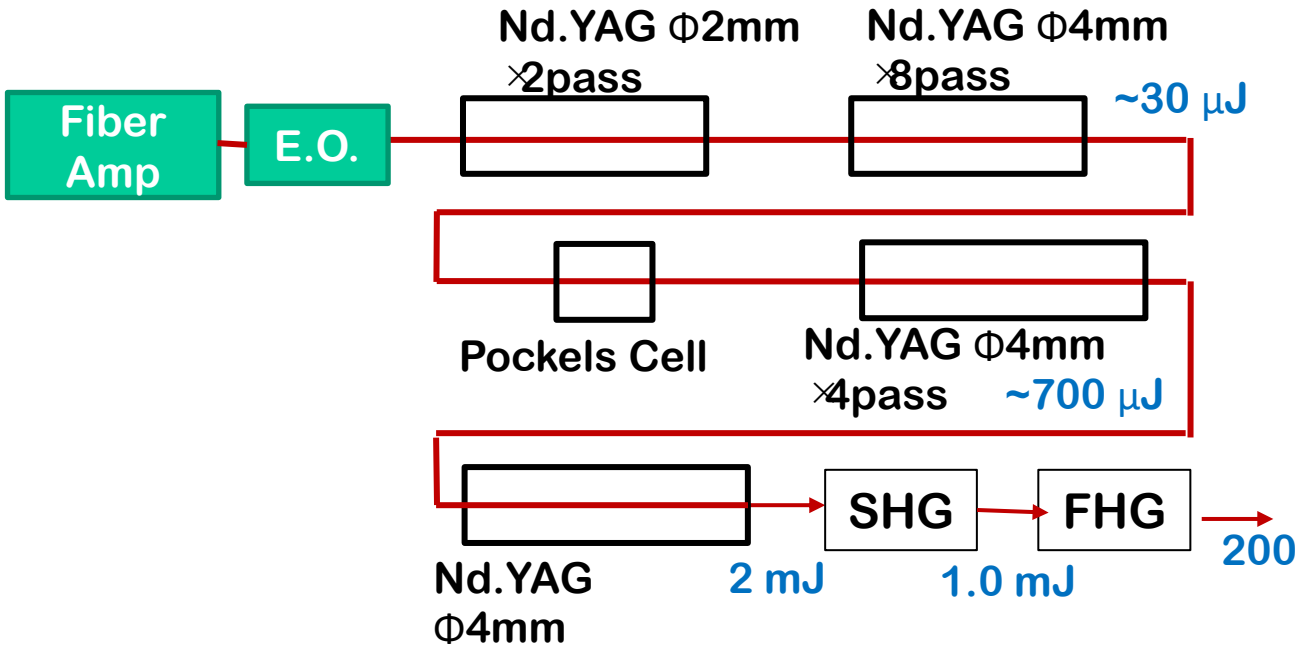
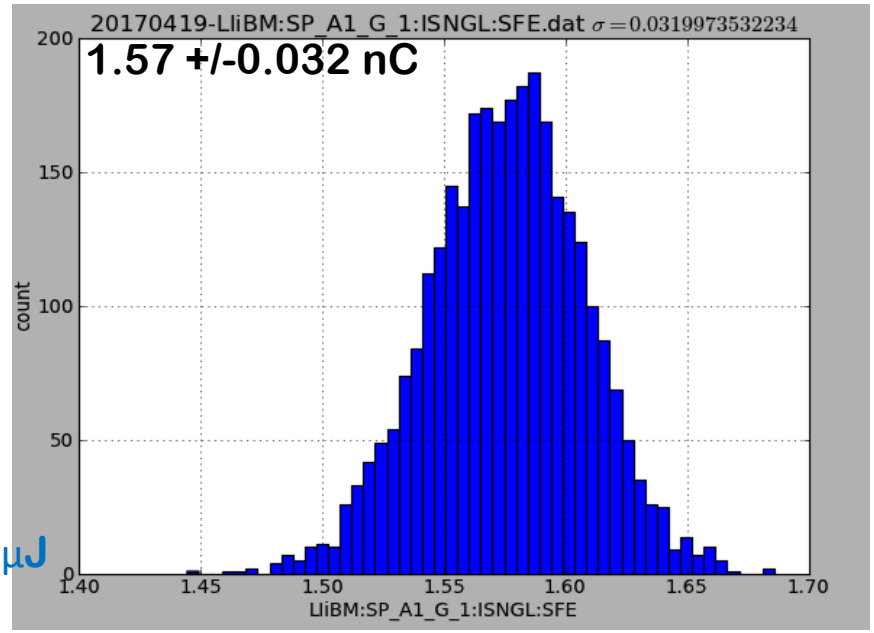


Photo-cathode RF gun: Laser

◆Yb:Fiber + Nd:YAG multi-pass amplifier



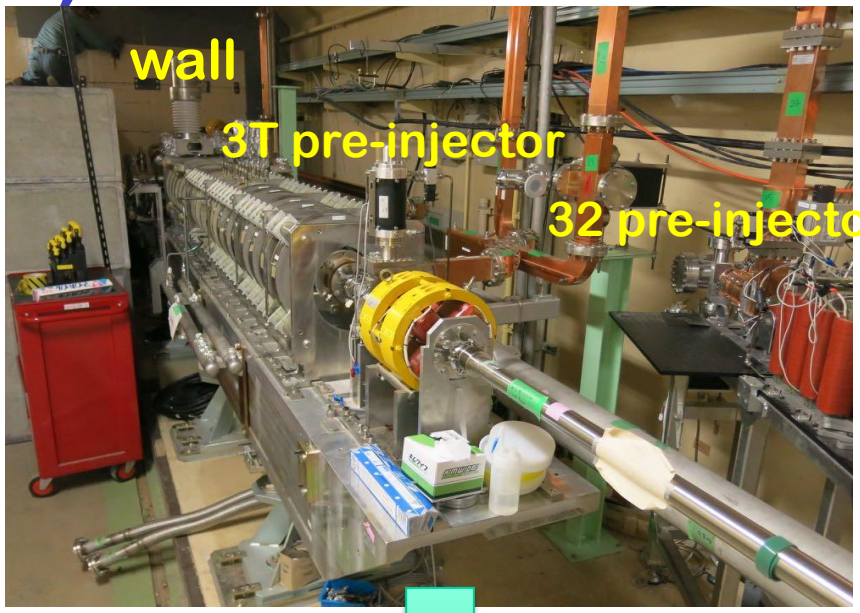


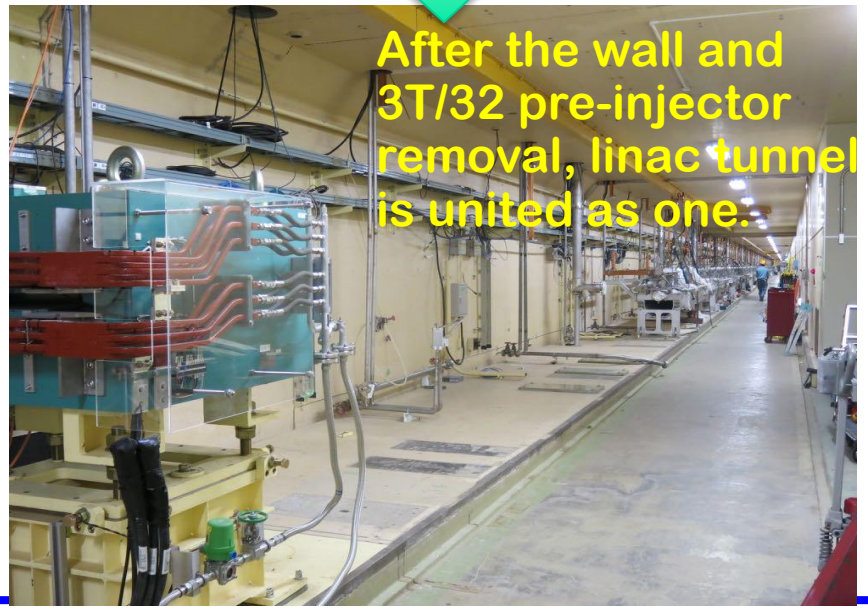
Beam charge stability

- Stable laser system for Phase-II.
  - 2 nC, 2 bunch stable operation will be expected.
    (2-bunch operation was already demonstrated.)
  - Two oscilllator (one will be commercial oscillator).
  - Two amplifier lines.
  - Spatial filter for one amplifier line.

Removal of temporary pre-injector (3T/32RFgun)

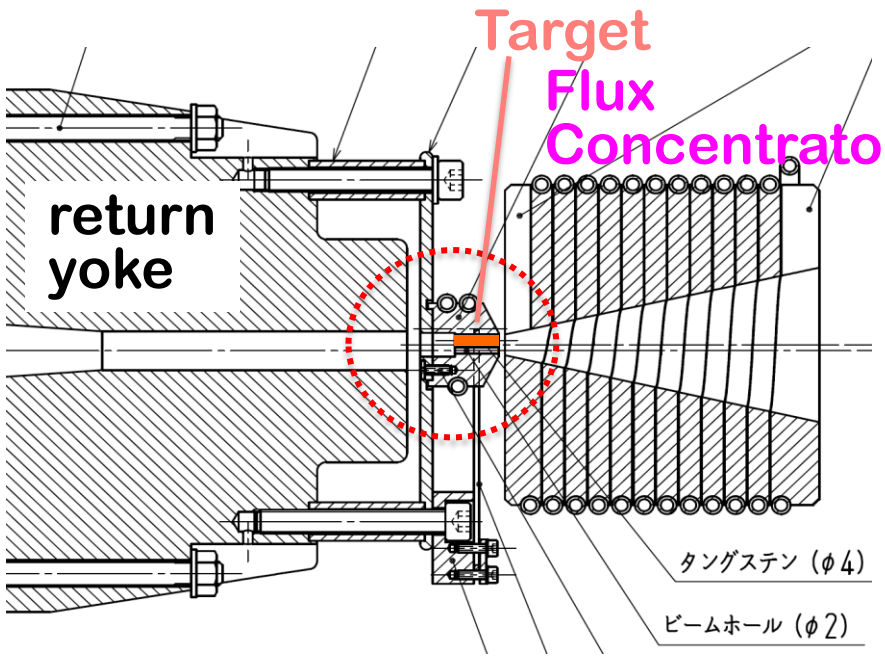
- KEK e+/e- linac has been divided into two regions by a wall at 3T.
- 3T/32 pre-injector has been used for PF, AR injection during upgrade construction and initial beam commissioning in linac upstream region.
- 3T/32 pre-injector is removed in May 2017 for DR commissioning.
- a regular accelerator module (3-2) is installed in this region for injection beam energy margin.
- AT/A1 pre-injector is used for all the storage rings (HER, LER, PF, AR) after autumn 2017. They share the same fate in case of linac troubles.
- PF, AR beam operation from October.
- DR commissioning from December 2017.

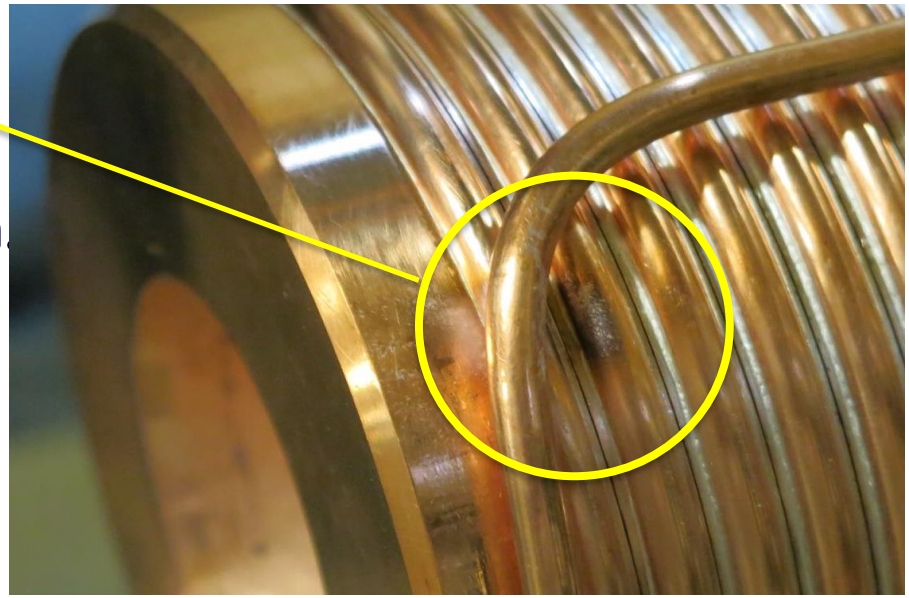




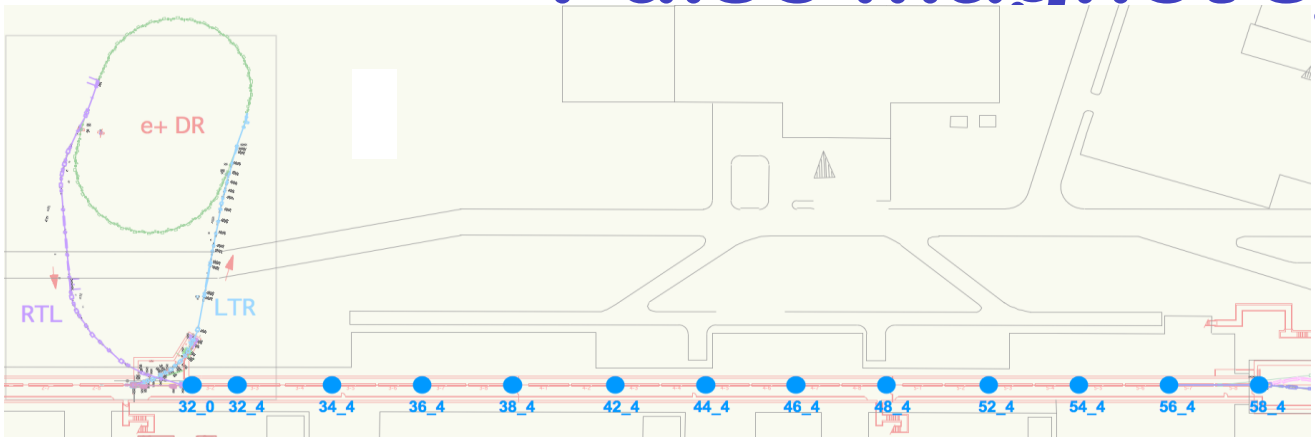
Positron Source status

- **Breakdown problem in Flux Concentrator** during 2017 April operation after beamline installation
  (Though we had no problem during test-stand operation at full-spec current.)
- **No e+ beam operation during April-May run.**
- **Inspection** of damaged FC
  - cooling down of residual-radiation since May 15
  - removal of FC base part from e+ station in June
  - visual search for damaged part
  - detailed inspection in August
  - recovery trial
- **Re-installation or replacement** to spare FC in August for 2017 autumn run & Phase-2 run.
  (During these period, operation current will be around half of the spec.)
- **Manufacturing of next FC assembly** on-going for stand-alone test and investigation of the breakdown issue for Phase-3 operation.



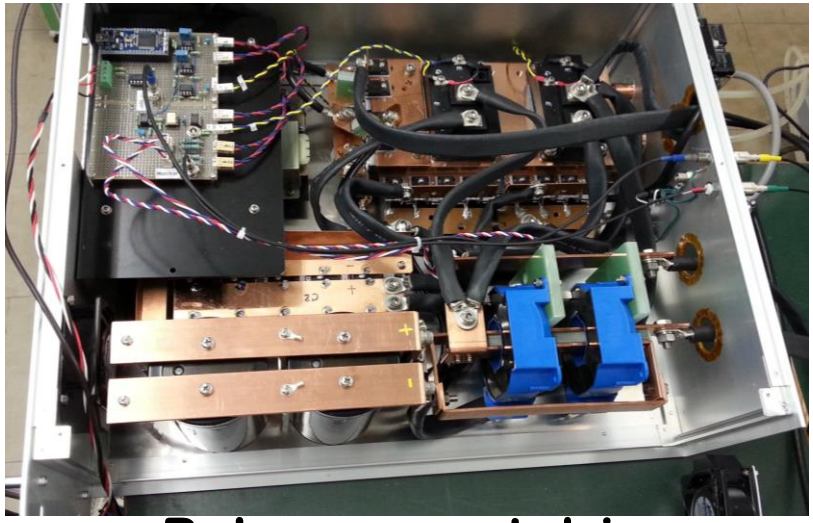


Pulse magnet system



- For pulse-by-pulse beam-mode switching and independent optics/orbit tuning, pulse magnet system is introduced.
- All the quads in Sector-3, 4, 5 are replaced by pulse-Qs and pulse-steerings are introduced.
- AT/A1 pre-injector merger line bends are replaced from DC to pulse magnets.
- Pulse magnets installation completed.
- Pulse power supply setting-up on-going.
- Test operation of pulse magnet system in September.
- Beam commissioning with pulse magnet system start in October 2017.

Pulse magnets (Q+ST+ST+Q)

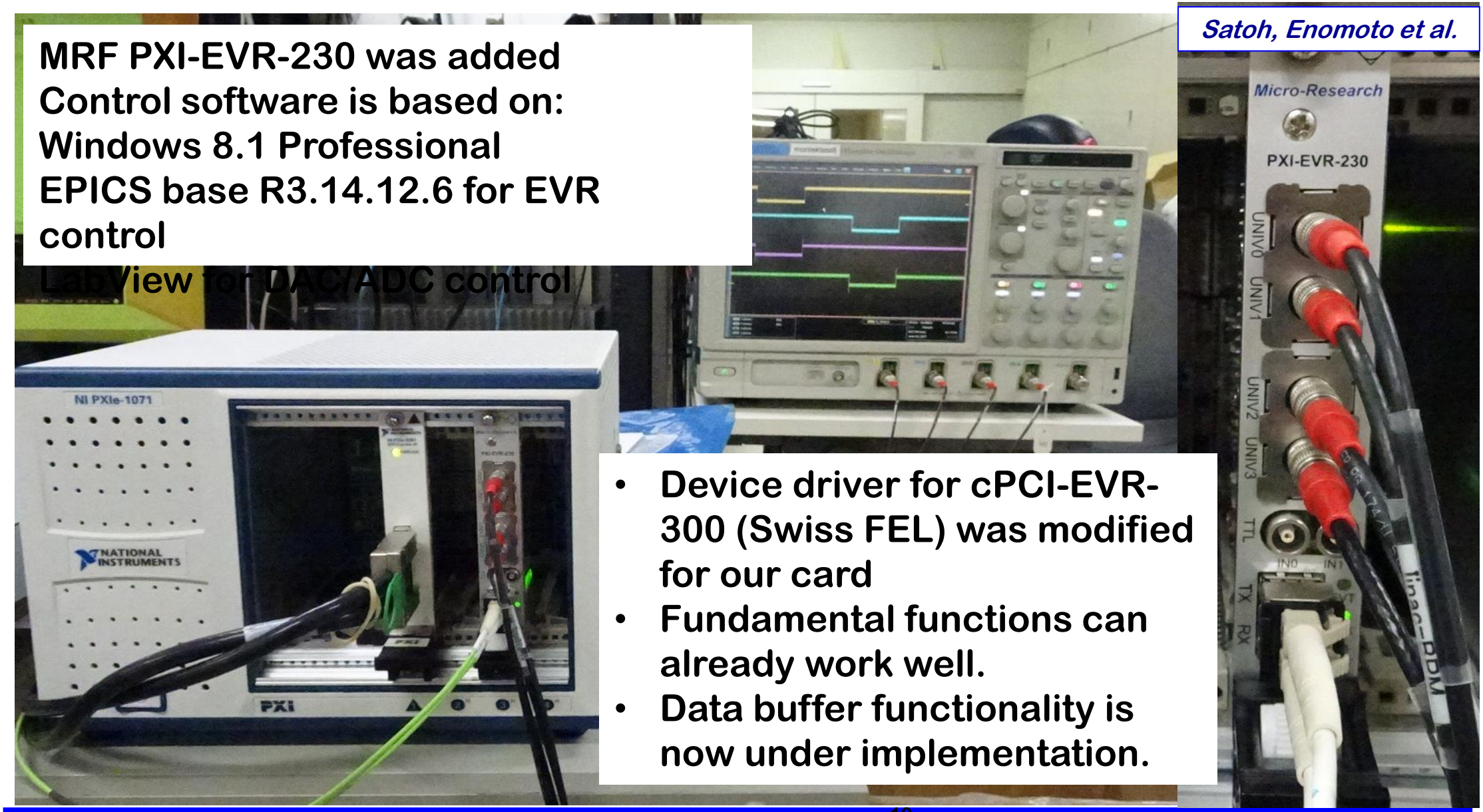


Pulse current driver

Event timing controls for pulsed quad & steering magnet controls

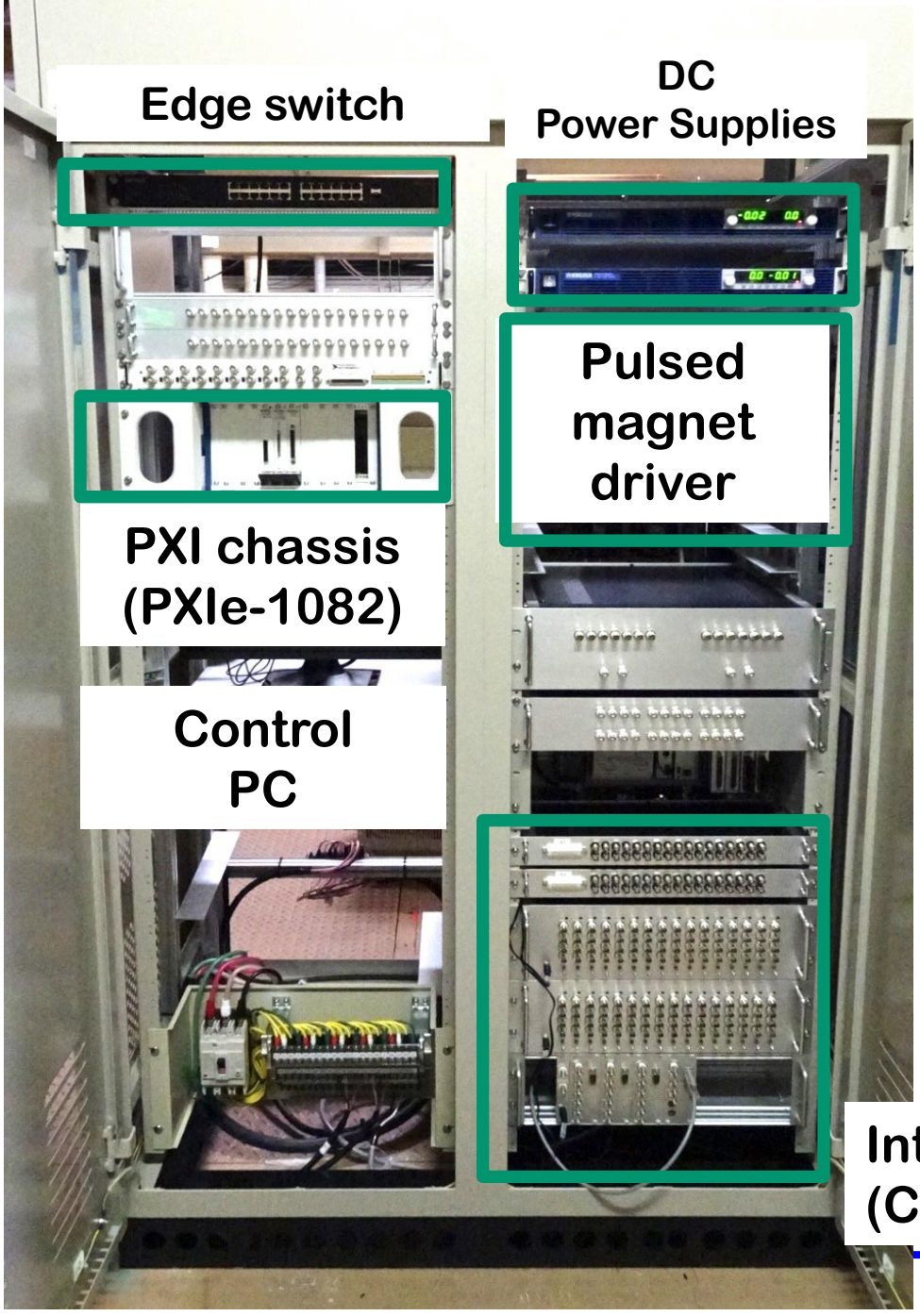
Satoh, Enomoto et al.

MRF PXI-EVR-230 was added
Control software is based on:
Windows 8.1 Professional
EPICS base R3.14.12.6 for EVR control
LabView for DAC/ADC control



- Device driver for cPCI-EVR-300 (Swiss FEL) was modified for our card
- Fundamental functions can already work well.
- Data buffer functionality is now under implementation.

Pulsed magnet rack

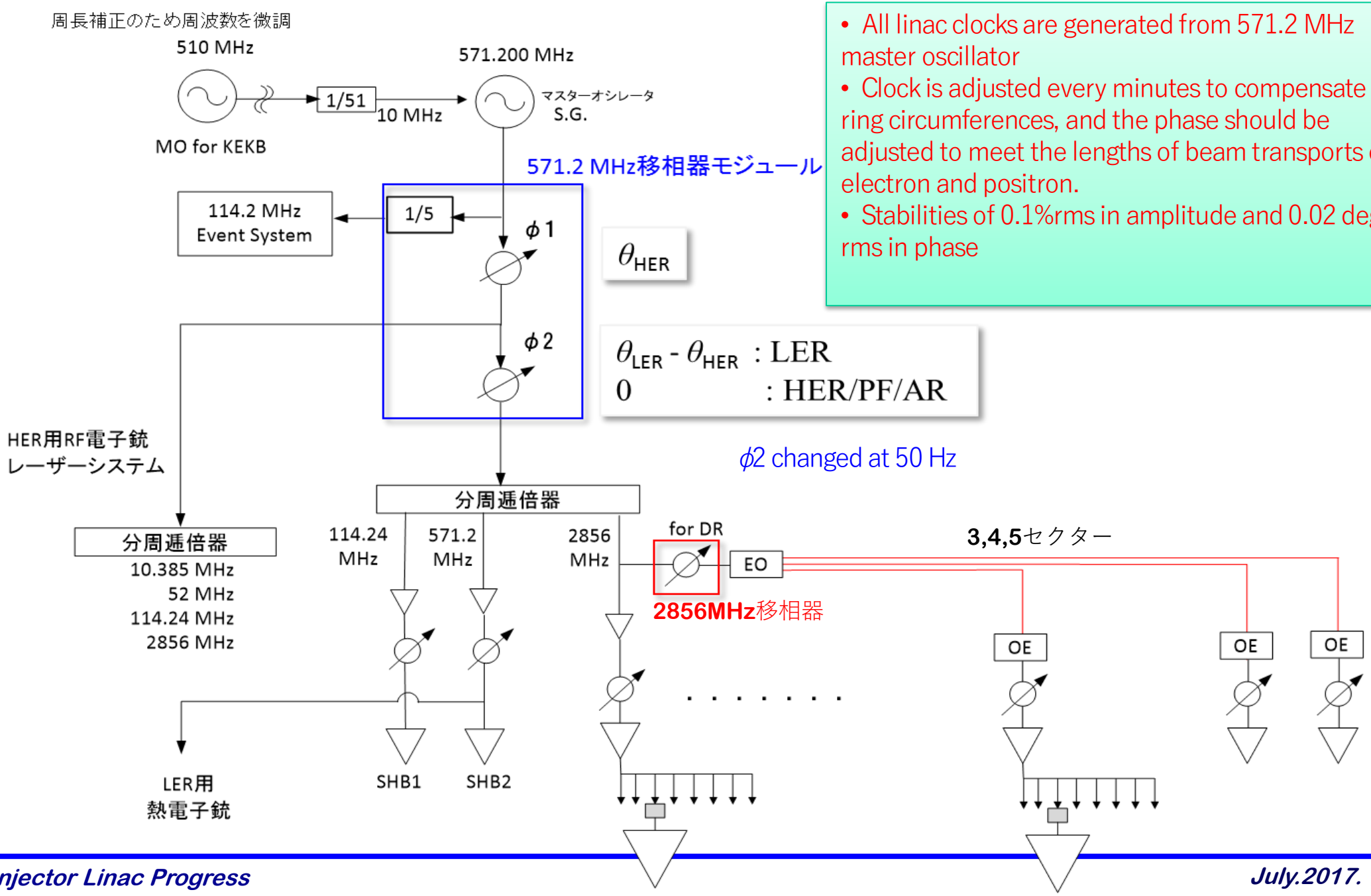


Remote controller
DAC (PXI-6733)
ADC (PXIe-6356)
PXI-EVR-230

- 13 racks are newly installed
- Small form-factor (4U) power supplies are tested more than 2 months at 50Hz

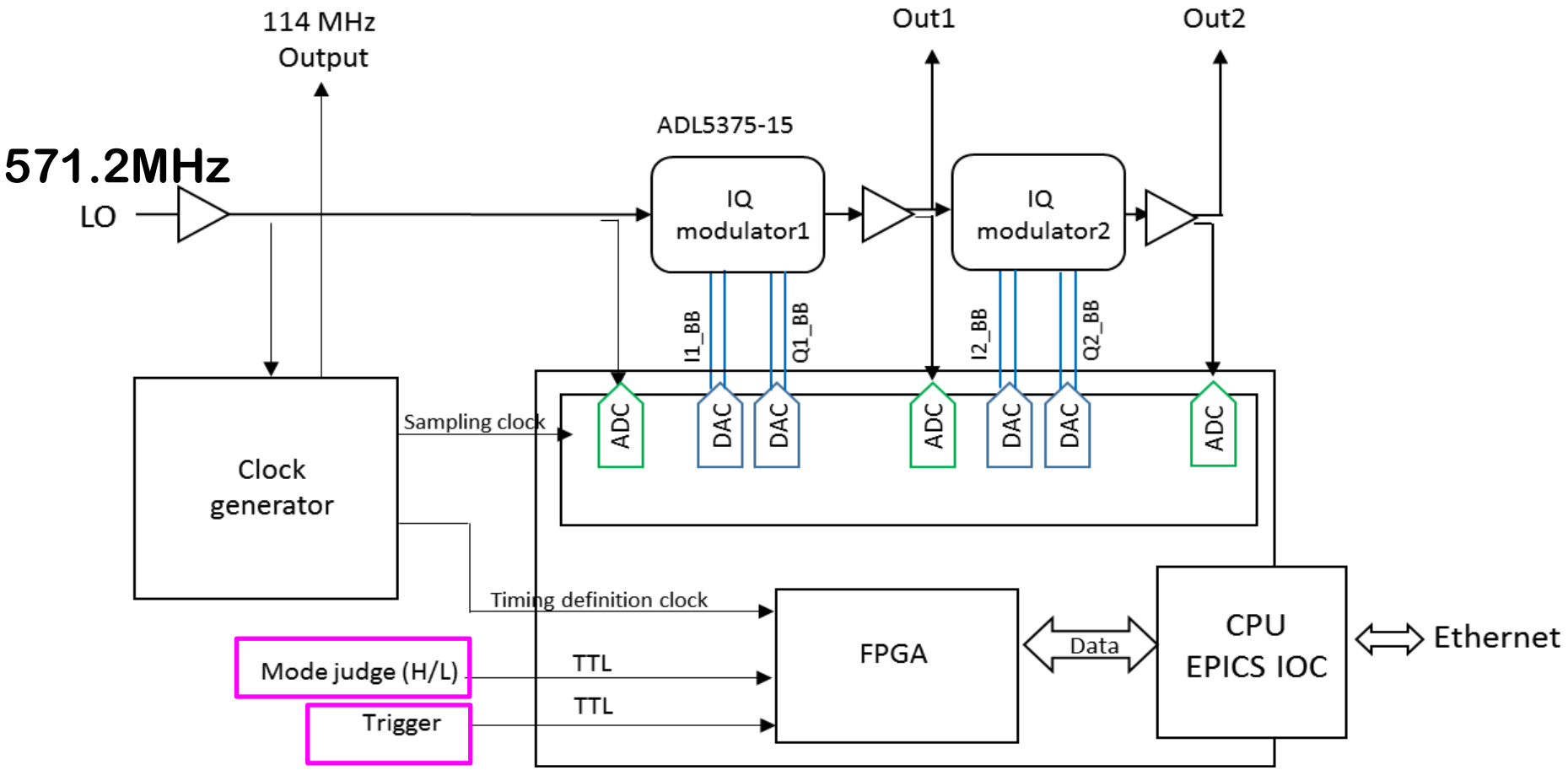
Interlock signal processing
(CompactRIO based system)

Development of 571.2MHz Master phase shifter

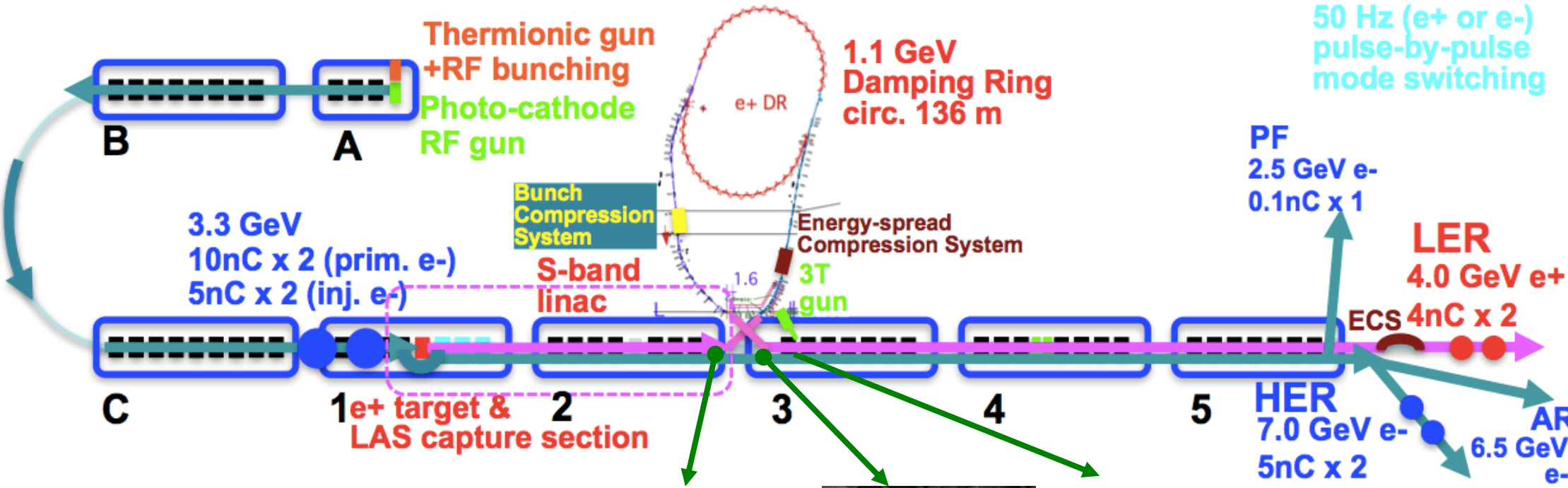


- All linac clocks are generated from 571.2 MHz master oscillator
- Clock is adjusted every minutes to compensate the ring circumferences, and the phase should be adjusted to meet the lengths of beam transports of electron and positron.
- Stabilities of 0.1%rms in amplitude and 0.02 degree rms in phase

571.2MHz Phase shifter



KL_DS, KL_DN , KL_32 Installation



	ECS	BCS
Voltage required [MV]	41	21.5
# 2m accelerator structure	2	1
Accelerator field [MV/m]	10.2	10.75
Operation power [MW]	29.0	19.0
Pulse width [μs]	0.8	0.8
Rep. rate [Hz]	50	50

KL_DS/BCS

KL_DN/ECS

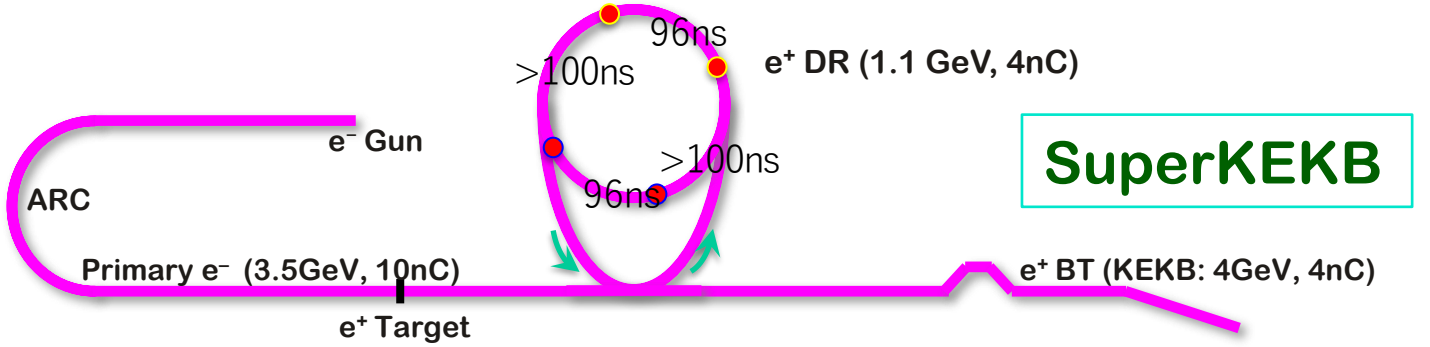
KL_32

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**

Kaji et al

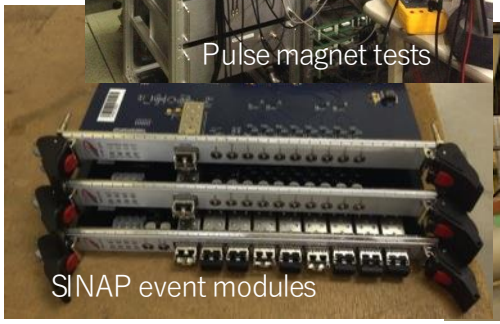
- **With DR, in order to select arbitrary bucket in MR, have to wait up to ~4.5 ms, even if a bucket in DR was carefully selected**
  - **Power supply can wait only 2 ms, one of only 2798 buckets in 5120 buckets can be selected, may have to change LLRF condition at latter half of linac every pulse**

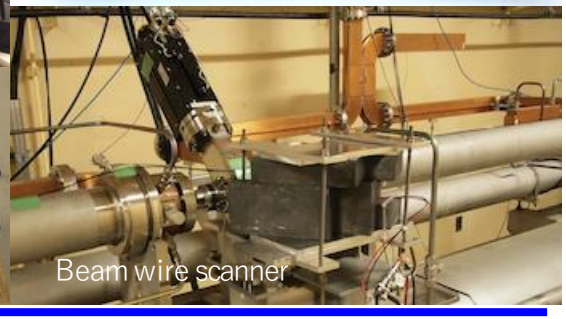


  - **Can be a big challenge in LLRF precision**

Many other Linac Upgrade Progress

- High-power microwave modulator upgrades
- Low-level RF controls/monitor upgrades
  - Pulse-to-pulse modulation (PPM) between 4+1 rings
  - More spaces for increasing 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.)
- Alignment to preserve beam emittance
  - Measurement precision reaching 0.1 ~ 0.3mm
  - Mover and orbit control development
- Event-based control and timing upgrade
  - Essential for pulse-to-pulse modulation
  - Precise timing & synchronized controls
  - Bucket selection at DR and MR





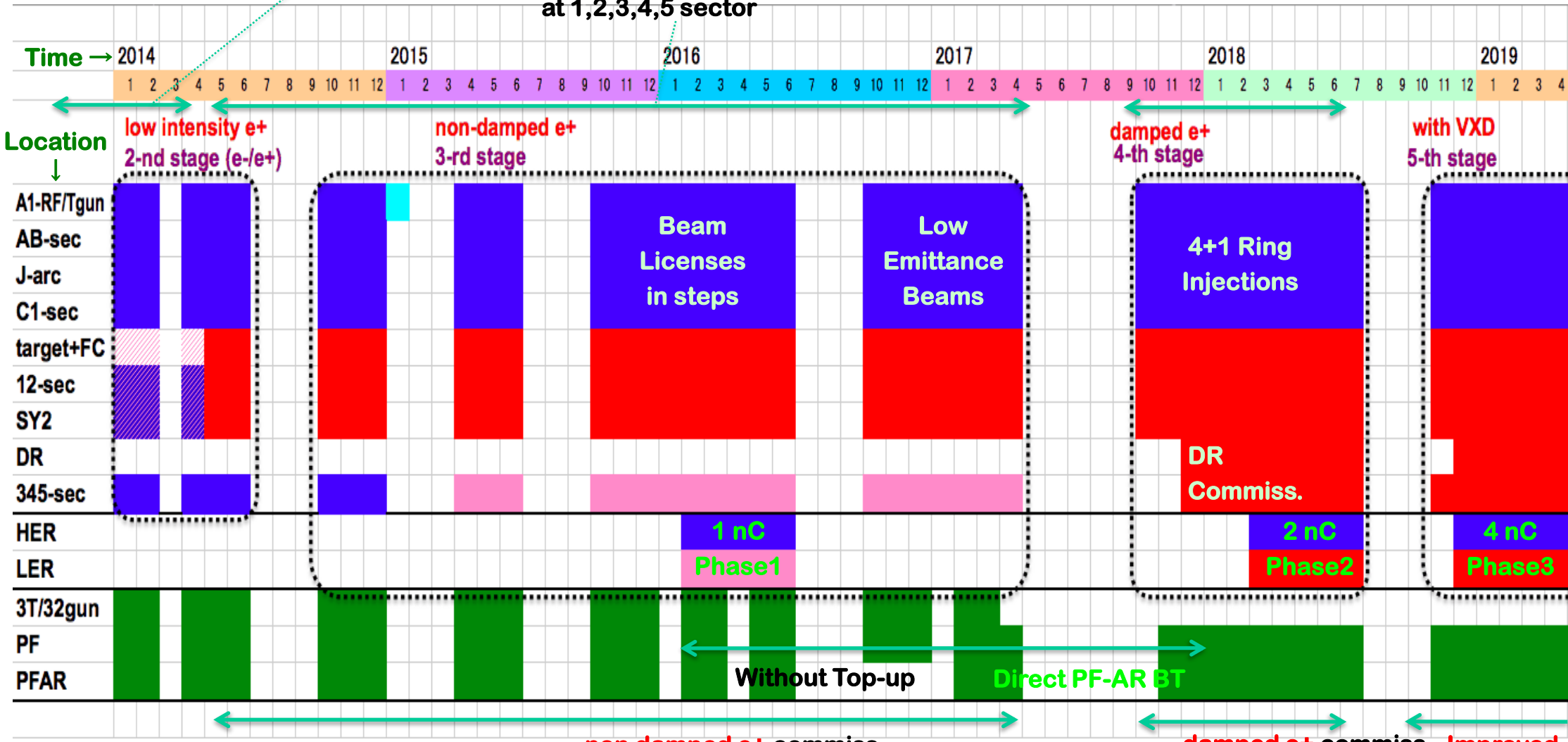
Linac Schedule Overview as of Jun.2017

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

Summary

- We learned a lot during KEKB operation
- Phase-2 injection into SuperKEKB is another challenge with higher beam current and lower transverse and longitudinal emittance
- Steady progress towards designed injection beam in steps
  - Alignment: almost confident on the measurement precision (0.1-mm local, 0.3-mm global), may need mover to maintain it for longer term
  - Positron generator: need discharge analysis
  - Thermionic gun: stably operated for primary electron for positron generation
  - RF gun: following recommendations at review meetings
  - Pulsed devices: global and synchronized operation
  - New modulators for energy and bunch compressors on DR beamlines
- Will balance between final beam quality and progressive operation
- Will select optimized route depending on available resources
  - Balance with injection operation for light sources, commissioing and development in parallel

Injection Energy Margin Recovery
(even while dropping Energy 8 GeV → 7 GeV)

- No backup/stand-by before J-Arc in KEKB operation
- Optimized for SuperKEKB ring injection reliability with larger beam currents and smaller emittance

Kamitani et al

- Temporary removal of units for construction
  - Should be recovered before phase-3
- A unit was removed to make a room for DR BT
- Positron deceleration capturing
- Lower acceleration in large aperture structures in the positron capture section
- An unit before J-Arc was converted into a stand-by for availability
- C-band structures were converted into S-band to help emittance preservation
- Degraded accelerating structures after 35 years of operation
  - Should be refurbished in the long run
- Larger beam current with larger beam loading