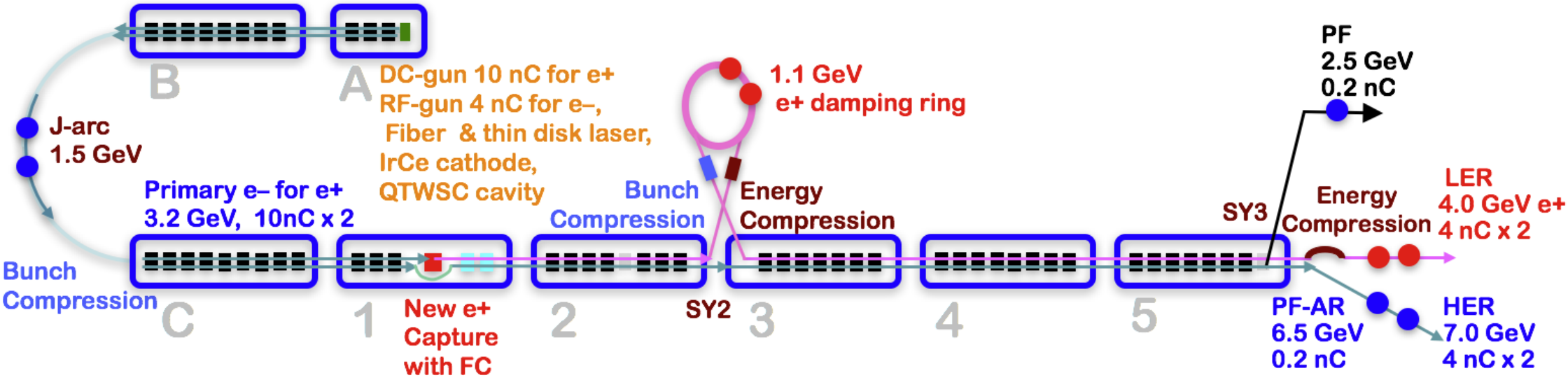
Electron/Positron Injector Linac and SuperKEKB Domestic Review Meeting

Kazuro Furukawa
Injector Linac, KEK

Injector Linac Overview

Injector linac configuration



Major upgrade items

- Photo-cathode RF-gun for low-emittance e-
- Flux concentrator, LAS structure, solenoids, quads for e+
- Pulsed magnets for adequate beam optics for each beam
- High-precision beam position monitor
- High-precision beamline alignment for low emittance

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)	

Domestic Accelerator Review

SuperKEKB Domestic Review

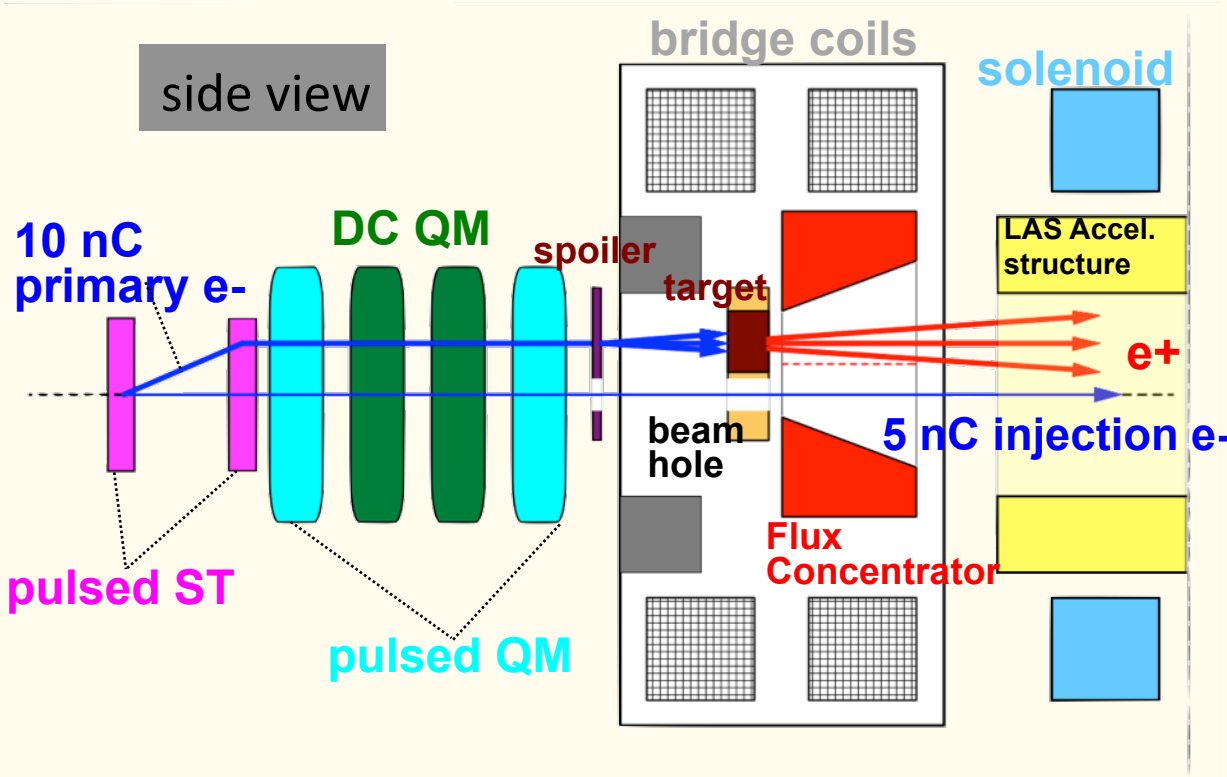
The third domestic review meeting

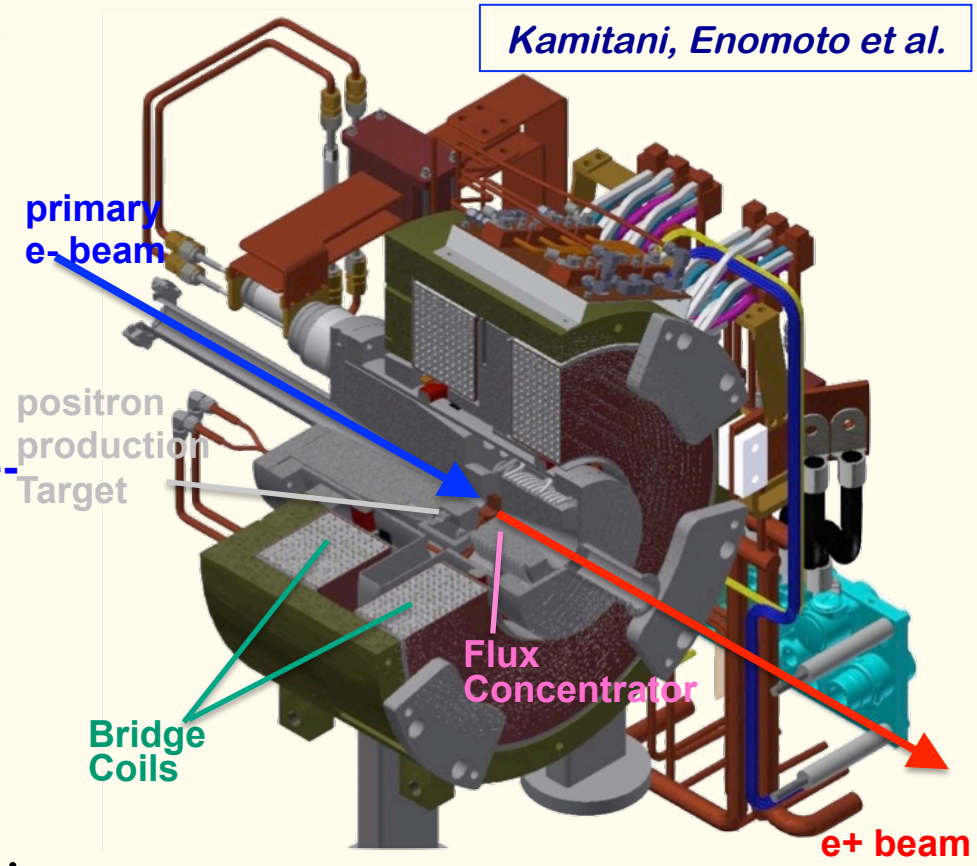
- On September 8th
- Reviewers of Atsushi Enomoto, Katsunobu Oide (chair), Kotaro Satoh, Fujio Naito, Tatsuo Nakada, Junji Haba, Kentaro Harada, Yosuke Honda, Shinichiro Michizono
- <http://accphys.kek.jp/indico/conferenceDisplay.py?confId=122>

- Positron source
- Photo cathode RF gun
- Accelerating structure
- Pulsed magnets
- DR timing system
- QCS
- Luminosity tuning
- Electron cloud instability in Phase 1 operation
- Beam background, MDI

- Two of them received recommendations

Positron generation for SuperKEKB

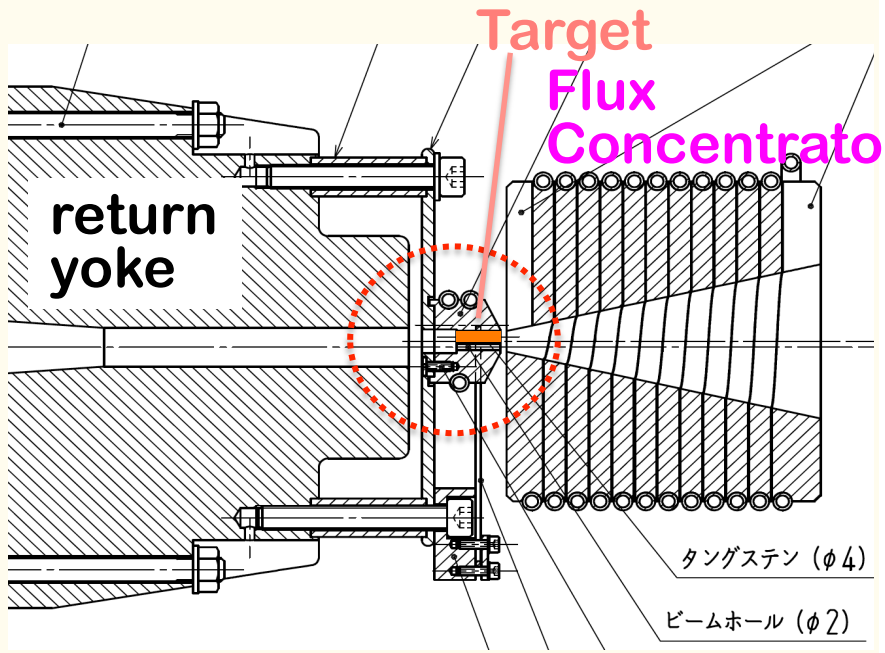


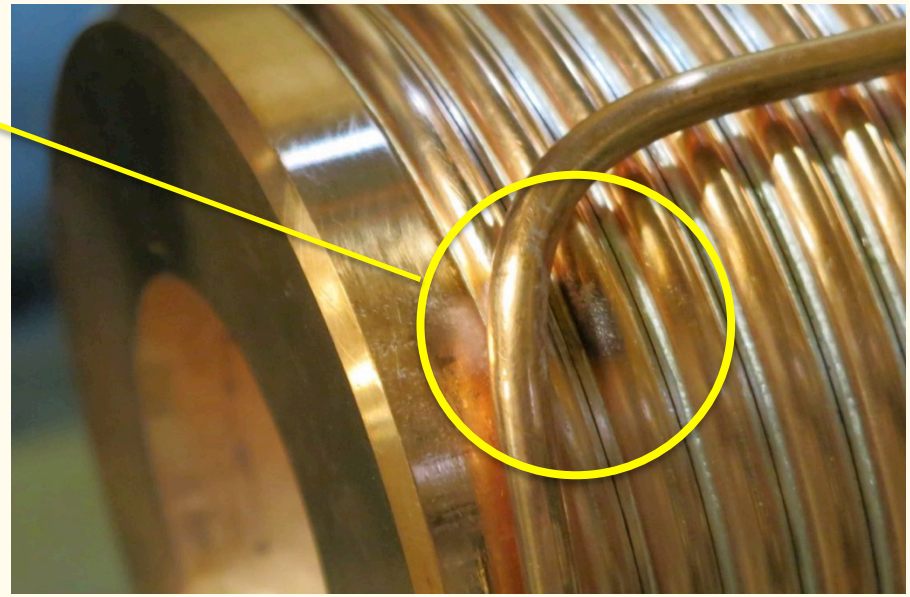


New positron capture section after target with
  Flux concentrator (FC) and large-aperture S-band structure (LAS)
Satellite bunch (beam loss) elimination with velocity bunching
Pinhole (2mm) for passing electrons beside target (3.5mm)
Replacement mechanism even under higher radiation
Resolving recent discharge difficulties at maximum field

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 of FC in August for Phase-2**
  - The operation current will be around half of the nominal. Nevertheless, a sufficient beam for Phase-2 should be available.





Positron source

Recommendation

- Avoid a fatal destruction by securing the discharge interlock activation within a pulse.
  - ——> The interlock system was re-examined, and it is believed that it did work within a pulse. (However, the pulse-to-pulse recording system was not working at the time. It should be made robust in the future.)

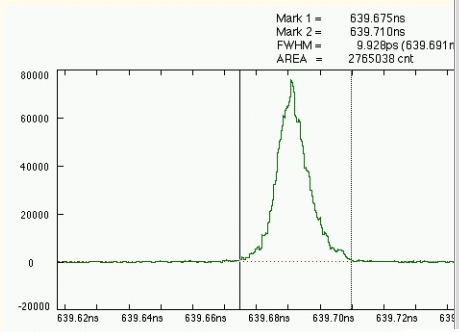
Consideration

- FC may provide 20% increase from 6 kA to 12 kA
  - Balanced man-power distribution should be necessary

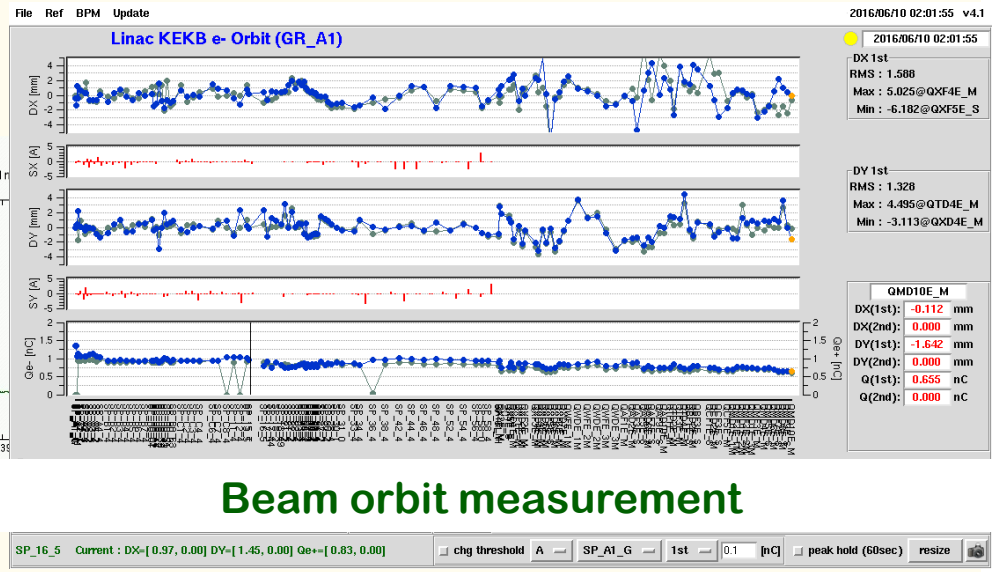
Development of Photo-cathode RF Gun

Yoshida et al.

- Succeeded in injection during SuperKEKB Phase 1 commissioning for 11 days
- Employs Yb-doped-fiber and Nd/Yb:YAG laser, Ir5Ce cathode, QTWSC or cut disk cavities
- Stability improving
- Beam instrumentation improvements and comparison with simulation codes underway

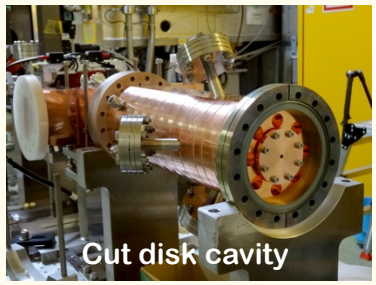


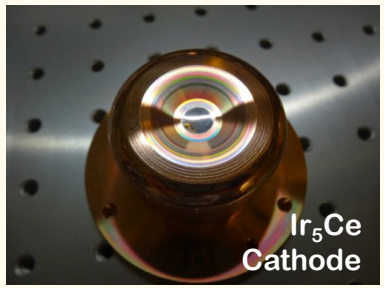
Bunch width

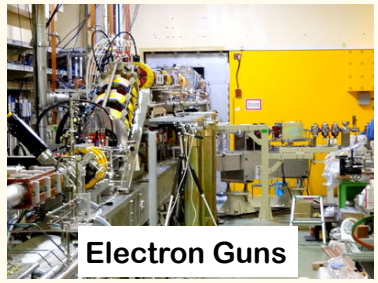


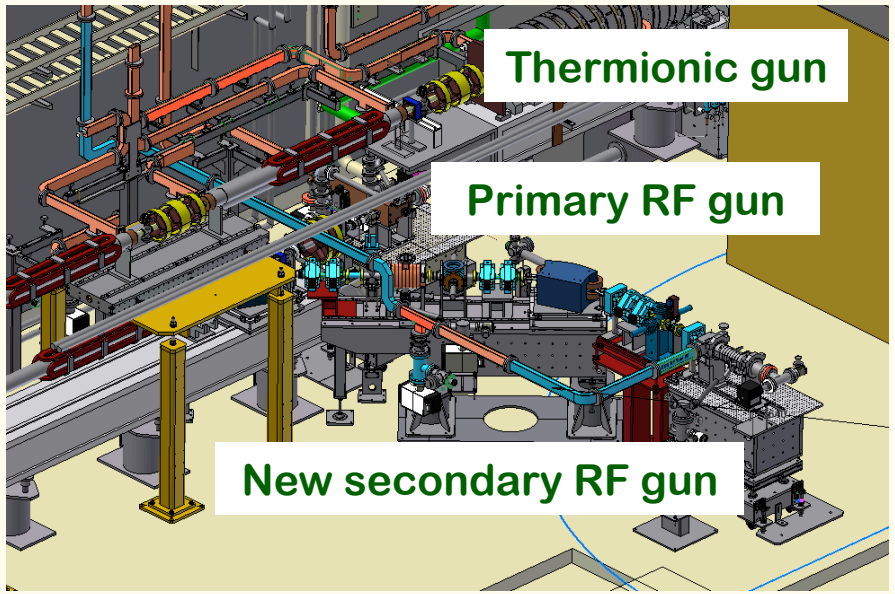
Beam orbit measurement

- Secondary RF gun is being constructed as a backup
- Incorporate suggestions by review committee for availability and so on









RF gun

Recommendations

- New technologies seem to be introduced too often. Further discussions on available facilities are necessary.
  - ==> Weekly meetings are held at the linac open space, in which members from other groups participate. Dr. Yosuke Honda, one of the reviewers, further contributes to the laser discussion weekly.
- Considering whole operation would stop on the gun failure, an existent technology should be employed
  - ==> As was recommended in past review meetings, existent technologies were applied for Phase-2. However, we are still open to Phase-3 options.

Injector Linac Issues

Longest shutdown for SuperKEKB

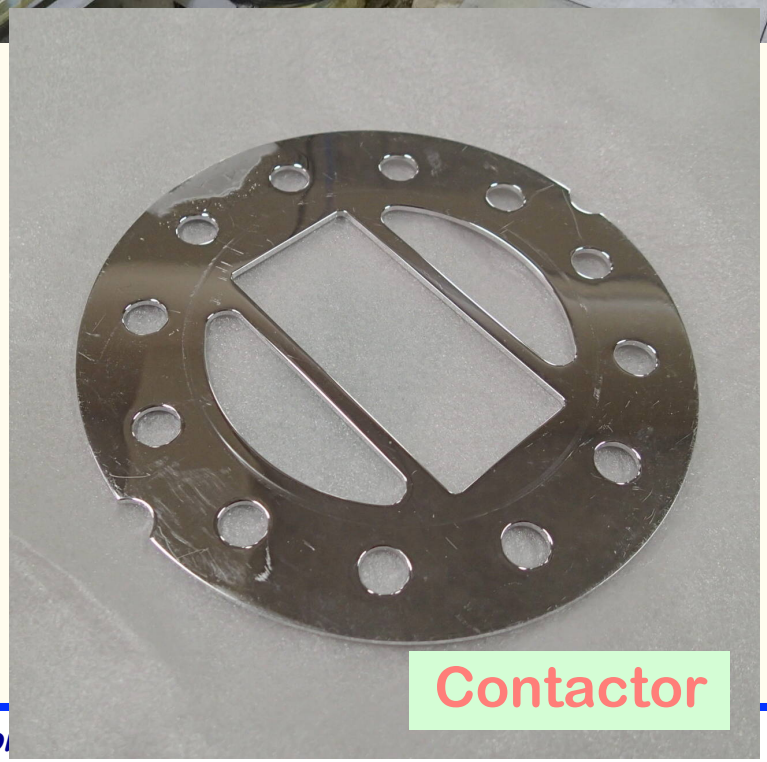
- **Many major constructions**
  - for 5 months from May to October 2017
    - Removal of a temporary thermionic gun of #3T
    - Removal of all quads from 3, 4, 5 sectors
    - Installation of 30 pulsed quads and 36 correctors
    - Installation of a energy compressor (#DN) at DR LTR
    - Installation of a bunch compressor (#DS) at DR RTL
    - Finalize the backup RF gun at #AS
    - Installation of a streak camera & wire scanners
    - Finalize 70 LLRF monitors and LLRF phase shifters
    - Installation of the event timing controls for DR

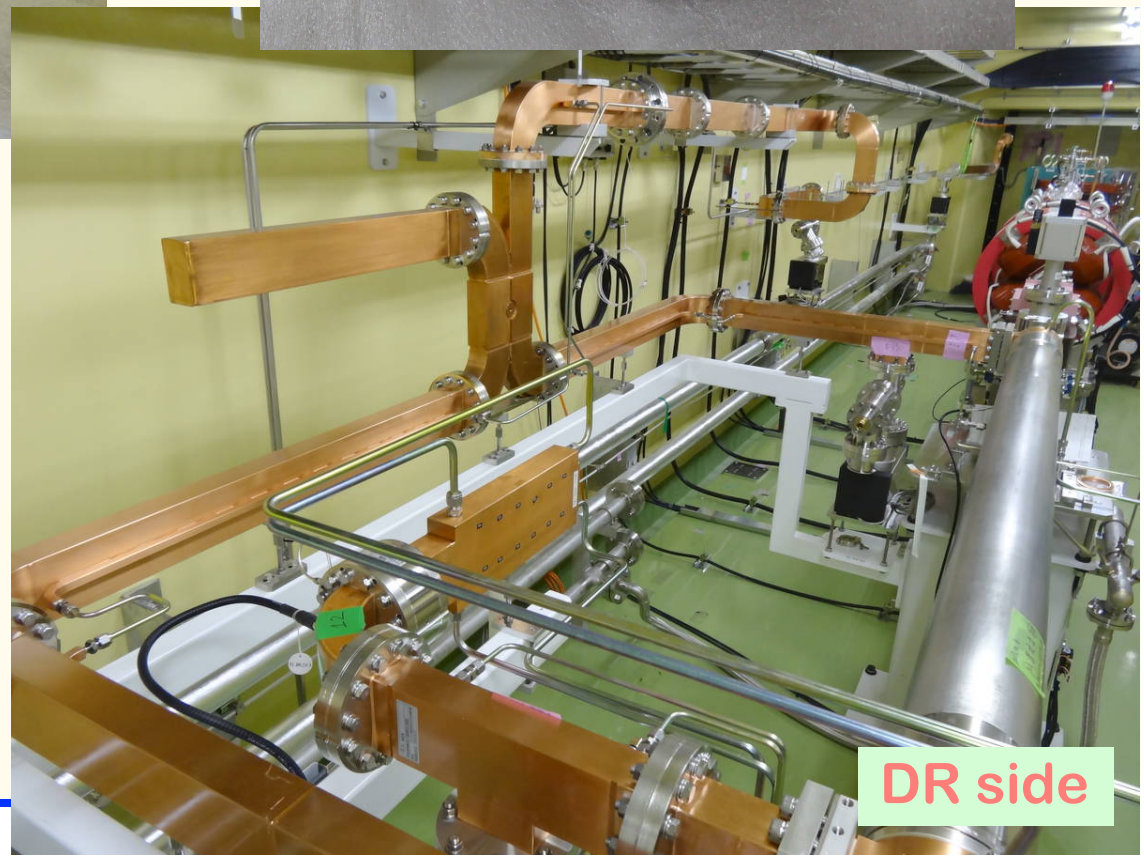
Waveguide fabrication issue

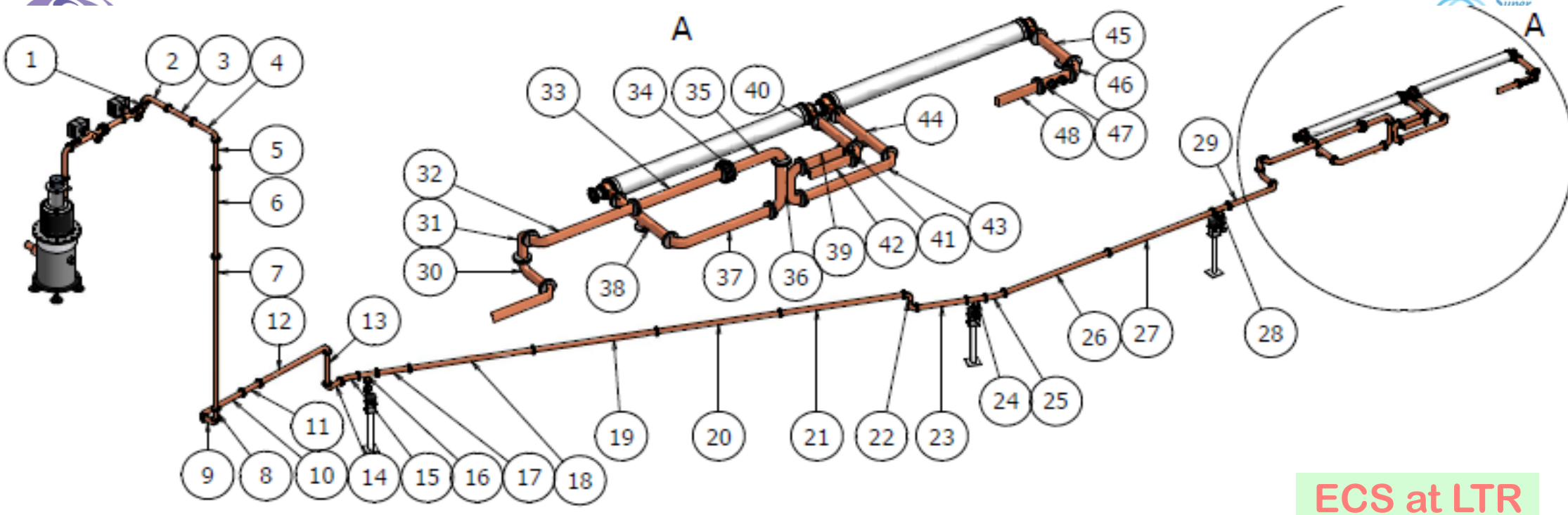
- **Wrong waveguide fabrication**
  - found on Sept.19 in LLRF test
    - Schematics from KEK and from the maker were correct
  - Waveguide flanges need to connect the both vacuum and RF with a help by 2-mm contactor
  - with slight taper surface design of 0°22"
  - Later, 31 waveguides out of ~100 were found to be wrong
    - 62 flanges were wrong
    - 1 waveguide of them is a backup
  - Opposite angle was programmed in NC machines
  - It can take 5 months to re-fabricate them all


Linac side


Flange


Contactor


DR side

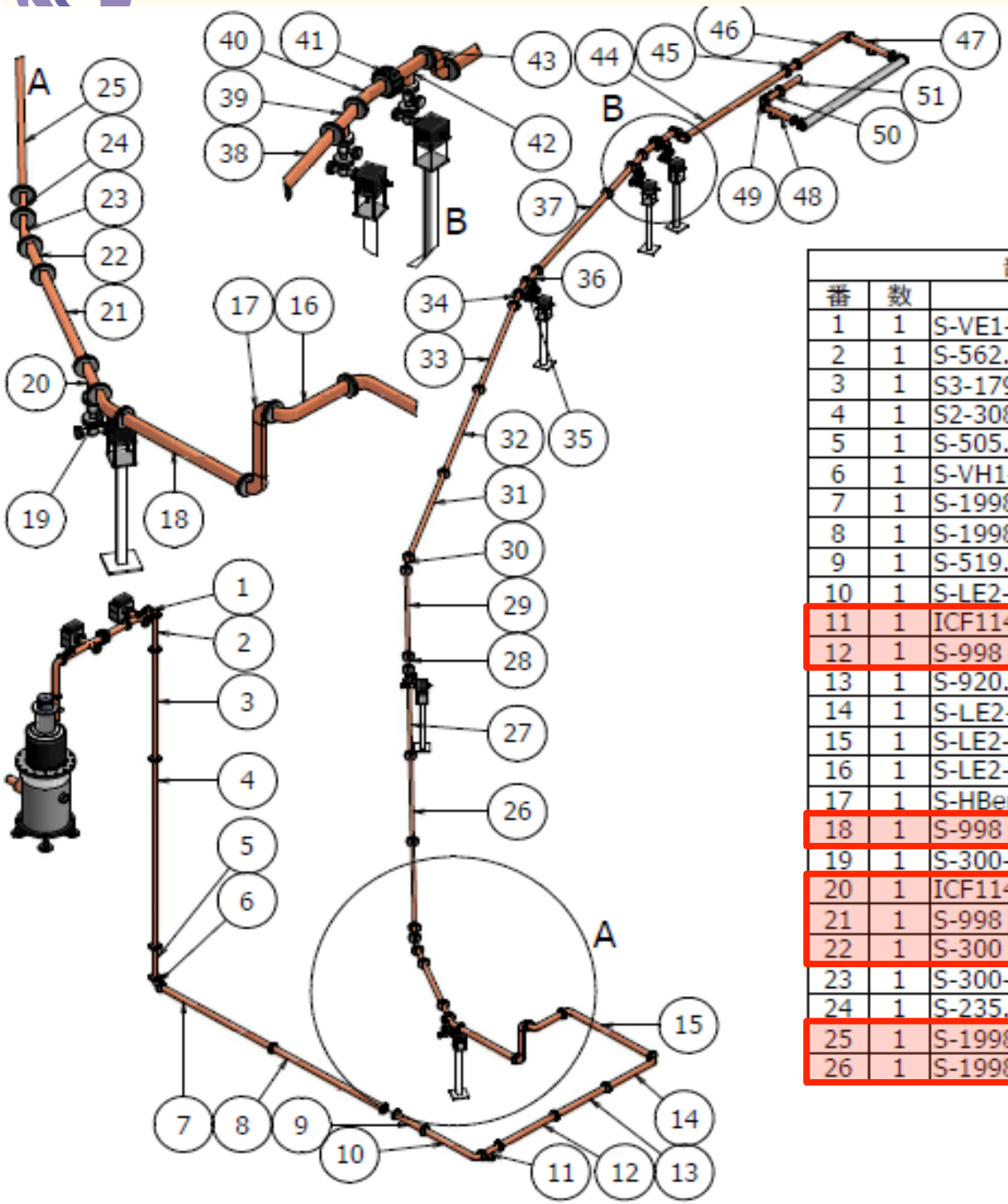


ECS at LTR

部品表				部品表				部品表			
番号	数量	部品名	備考	番号	数量	部品名	備考	番号	数量	部品名	備考
1	1	S-VE1-104×104		17	1	S-523.5		33	1	S-840.731	
2	1	S-LH2-105.5x500		18	1	S-1998		34	1	S-RF窓φ180×64.0	
3	1	S-550.7		19	1	S-1998		35	1	S-LH1-105.5×500	
4	1	S-LH2-105.5×500		20	1	S-1998		36	1	S-HB1-457	
5	1	S-562.5		21	1	S-1998		37	1	S-LE1-105.5X882.0	
6	1	S-S3-1798.5		22	1	S-H Bend299.5x211		38	1	RF-700.5	
7	1	S-S2-3083		23	1	S-802.47		39	1	S-D8-394	
8	1	S-208		24	1	ICF114&RF300		40	1	RF-467	
9	1	S-LH2-105.5×239.7		25	1	S-300-159.79R		41	1	S-E Bend104x104	
10	1	S-LE2-105.5x920.3		26	1	S-1998		42	1	LO-394	
11	1	S-379.7		27	1	S-1998		43	1	S-LE2-105.5×920.3	
12	1	S-LH1-105.5×1500		28	1	ICF114&RF300		44	1	RF-700.5	
13	1	S-645		29	1	S-LE2-105.5x920.3		45	1	RF-467	
14	1	S-LH2-105.5×297		30	1	S-LH1-105.5×335.5		46	1	S-E Bend104x104	
15	1	S-150.21R		31	1	S-LH1-105.5×257		47	1	S-F 300	
16	1	ICF114&RF300		32	1	S-LE2-105.5x920.3		48	1	LO-394	

LTR160808

BCS at RTL



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3	1	S3-1798.5		29	1	S-1998	
4	1	S2-3083		30	1	S-300-13.55R	
5	1	S-505.5		31	1	S-1998	
6	1	S-VH1-105.5×105.5		32	1	S-1998	
7	1	S-1998		33	1	S-1998	
8	1	S-1998		34	1	S-268.98	
9	1	S-519.4		35	1	S-300-13.55R	
10	1	S-LE2-105.5x920.3		36	1	ICF114&RF300	
11	1	ICF114&RF300		37	1	S-1998	
12	1	S-998		38	1	S-685.6	
13	1	S-920.9		39	1	ICF114&RF300	
14	1	S-LE2-105.5×920.3		40	1	S-300-13.55R	
15	1	S-LE2-105.5×1500		41	1	S-W2-RF窓φ180×64.0	
16	1	S-LE2-105.5X500		42	1	ICF114&RF300	
17	1	S-HBendW652x211		43	1	S-H Bend-W200x211	
18	1	S-998		44	1	S-1998	
19	1	S-300-30.74R		45	1	S-203.5	
20	1	ICF114&RF300		46	1	S-LE2-105.5×920.3	
21	1	S-998		47	1	RF-700.5	
22	1	S-300		48	1	RF-467	
23	1	S-300-13.55R		49	1	S-VE Bend104×104	
24	1	S-235.7		50	1	S-F 300	
25	1	S-1998		51	1	LO-394	
26	1	S-1998					

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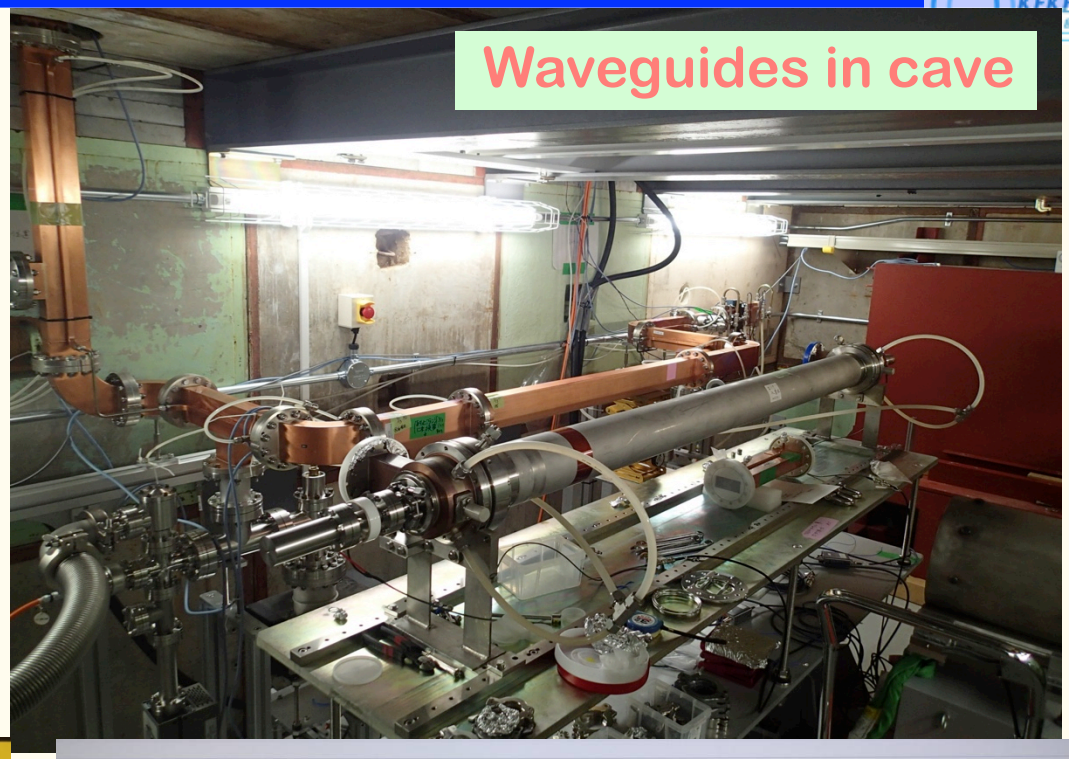
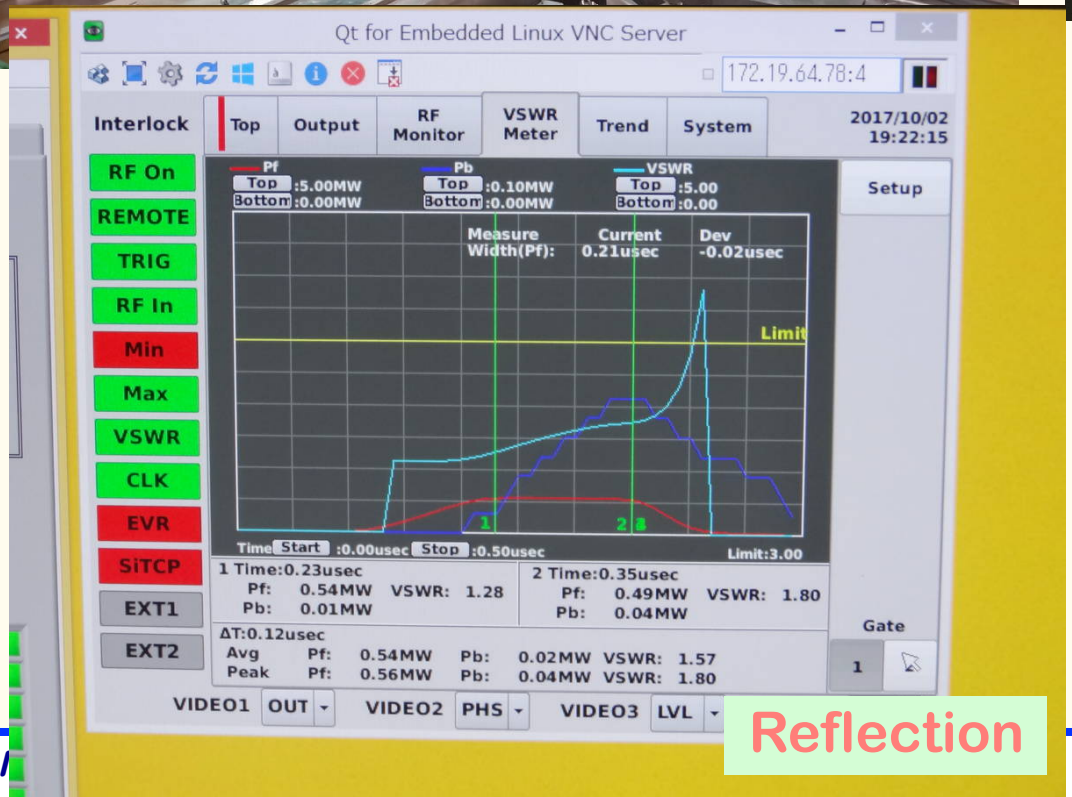
Recovery #1

- **Several countermeasures were examined**
  - Flange modification, flange replacement, contactor modification, etc.
  - Especially, contactor modification possibilities are investigated in detail, but found to be impractical
- **At first lower-power operation was tested**
  - On October 2nd
  - Nominal operational power and reflection (VSWR) should be 30 MW and 1.05 respectively
  - Minimum power for Phase-2 is 8 MW
  - A single connection test was performed up to 3 MW with continuous discharges at 1 Hz and VSWR of 1.7
- **In parallel new fabrications were prepared**
  - Initial plan suggests the beam availability at the end of January

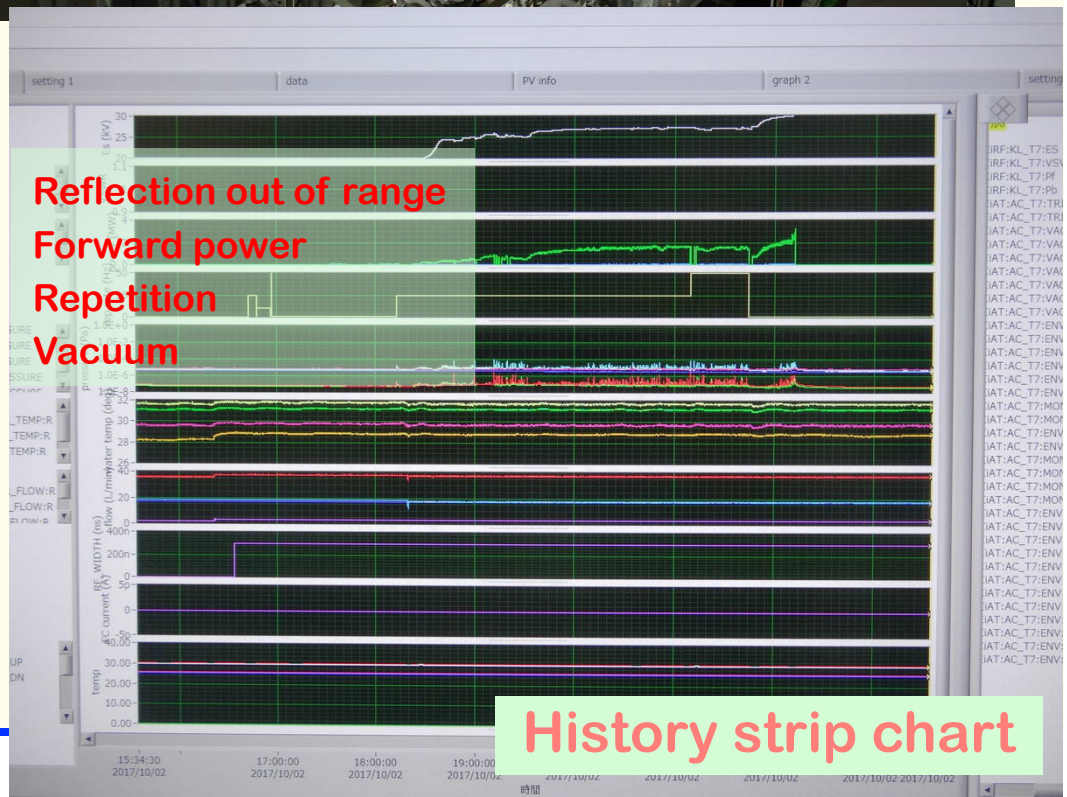
Test stand



Waveguides in cave



Reflection

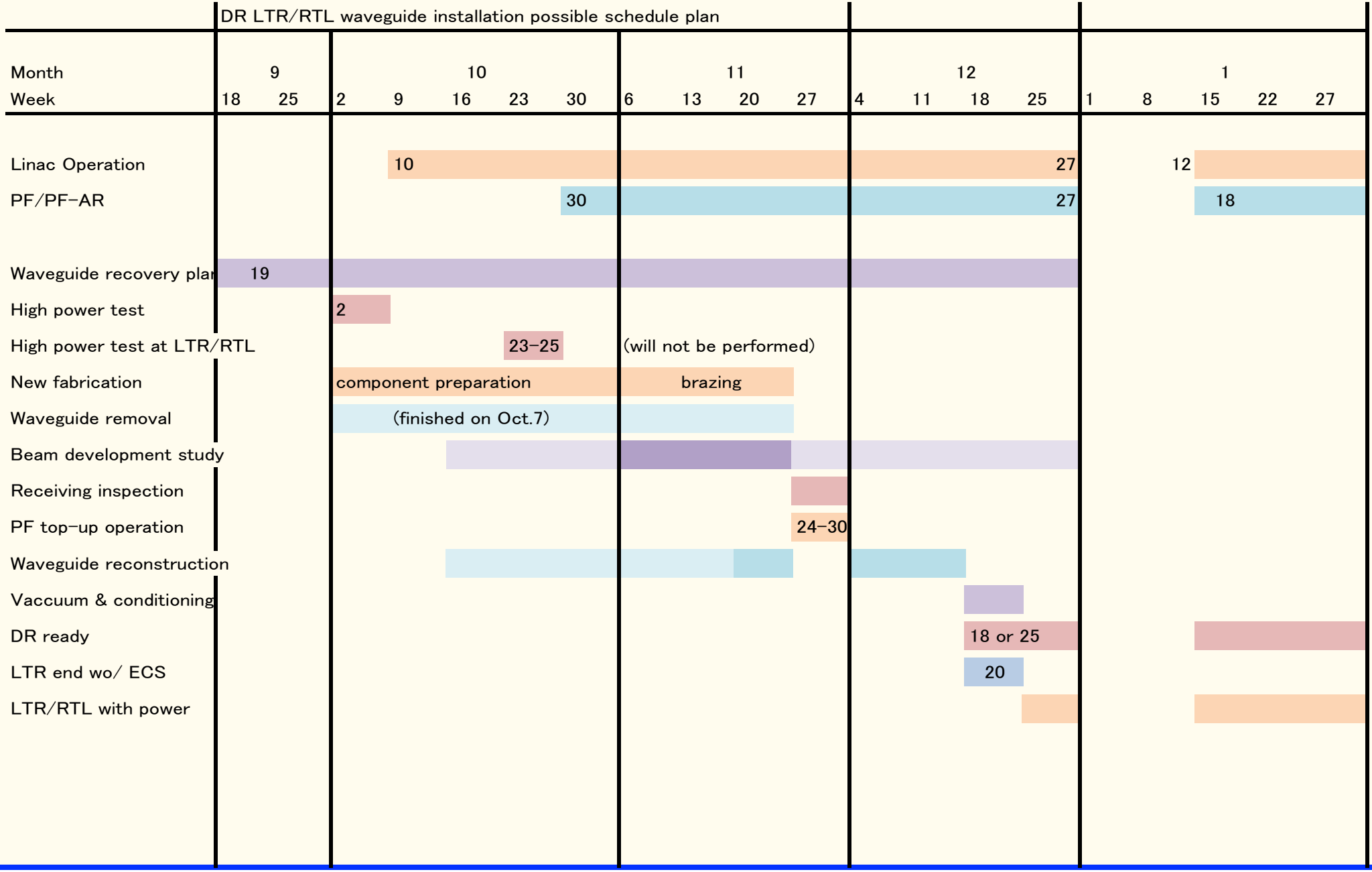


History strip chart

Recovery #2

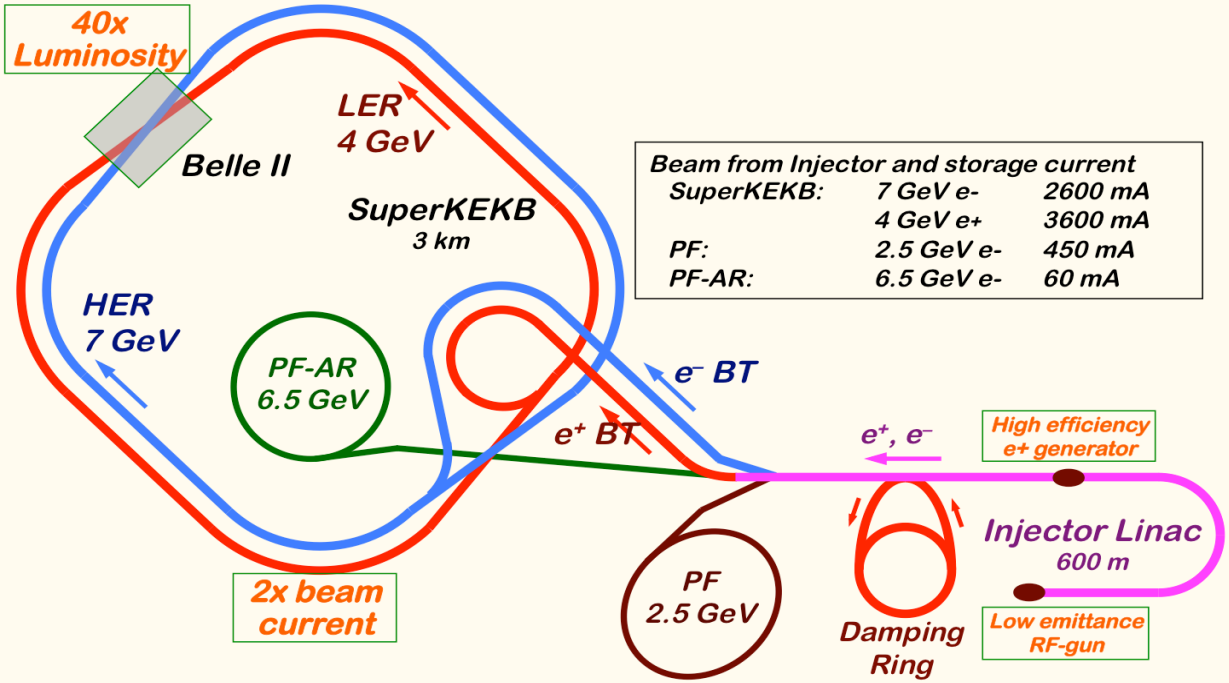
- Rearrangements and new fabrications of waveguides will be performed
  - 32 were removed (30 have bad flanges) on Oct.7
  - 10 (original length) will be fabricated
  - 4 (new, various lengths) will be fabricated
  - 20 (old, various lengths) will be reused
  - backups will be fabricated in parallel
- It was suggested to make system tests within this year
  - Zero-power beam delivery may be possible on Dec.20 to the end of LTR
  - Almost synchronized with DR construction (?)
  - Still barely acceptable with MR Phase-2 operation (?)

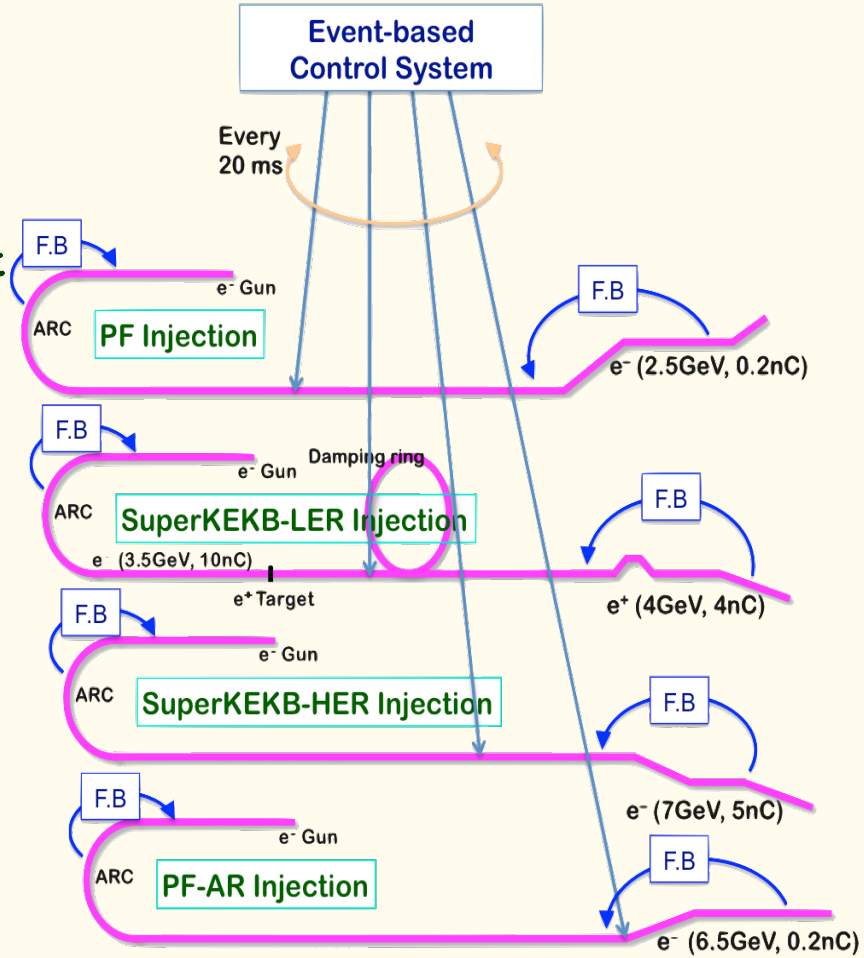
Recovery Schedule



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

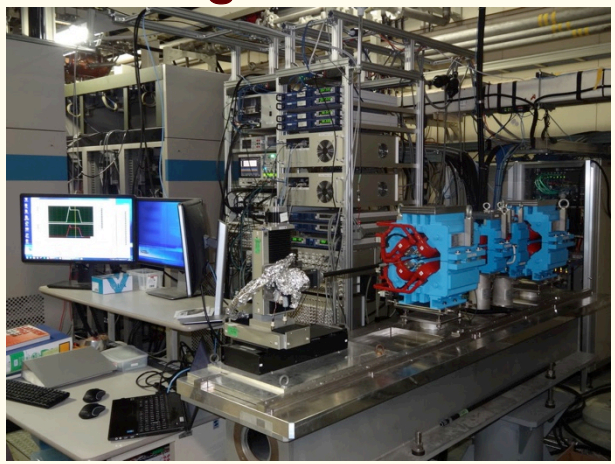


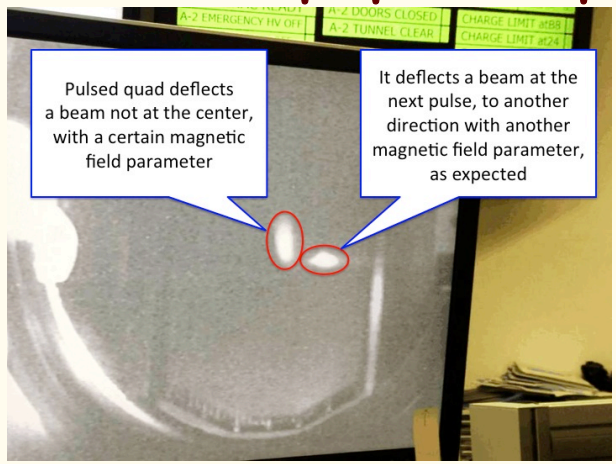


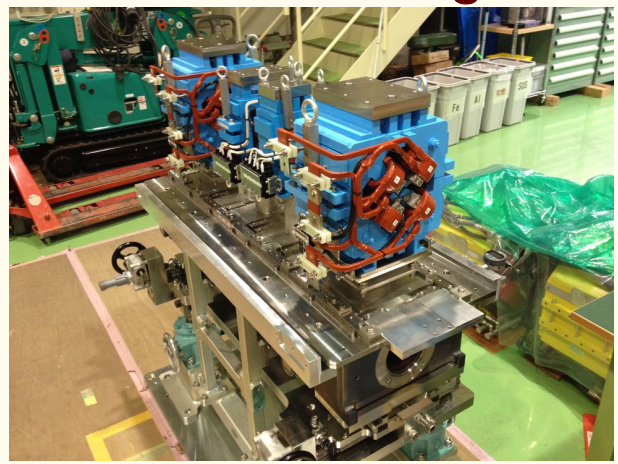
The single injector would behave as multiple injectors to multiple storage rings by the concept of virtual accelerator

Development and installation of pulsed magnets

- Pulsed magnet power supplies are scheduled in FY2017 for resource optimization
- 30 quads, 36 steerings, 2 bends, 13 girders are fabricated and installed in 2017
- Quads with advanced design at 1 mH, 330 A, 340 V, 1 ms with energy recovery up to 75%
- Essential for SuperKEKB low emittance injection and simultaneous injections
- 4+1 ring injections with virtual accelerator concept
- Risks against schedule and possible backup operation procedure are also investigated







- Long term tests at a stand
- Satisfies specifications
- Some more control capability
- Synchronous operation in 2017

- Beam test with two quads
- Successful 25 Hz beam switches
- Basic features are completed
- Event timing synchronization needed

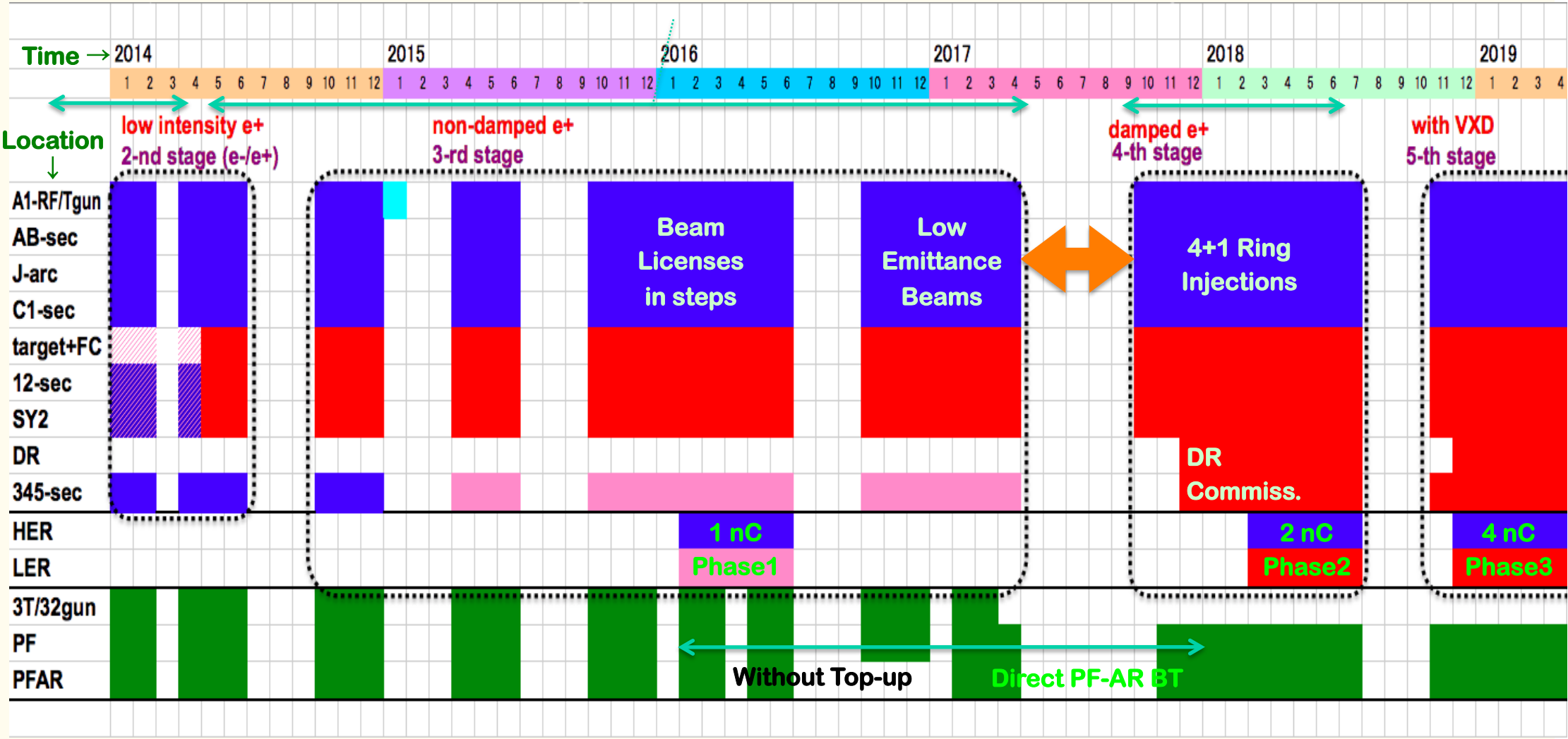
- Girders are tested as well
- In-house drawings to save rsc.
- 0.1mm alignment precision
- Ready for Phase-3 upgrade

- On going as expected, with long-term test in September for a month

Thanks

Linac Schedule Overview as of Jun.2017

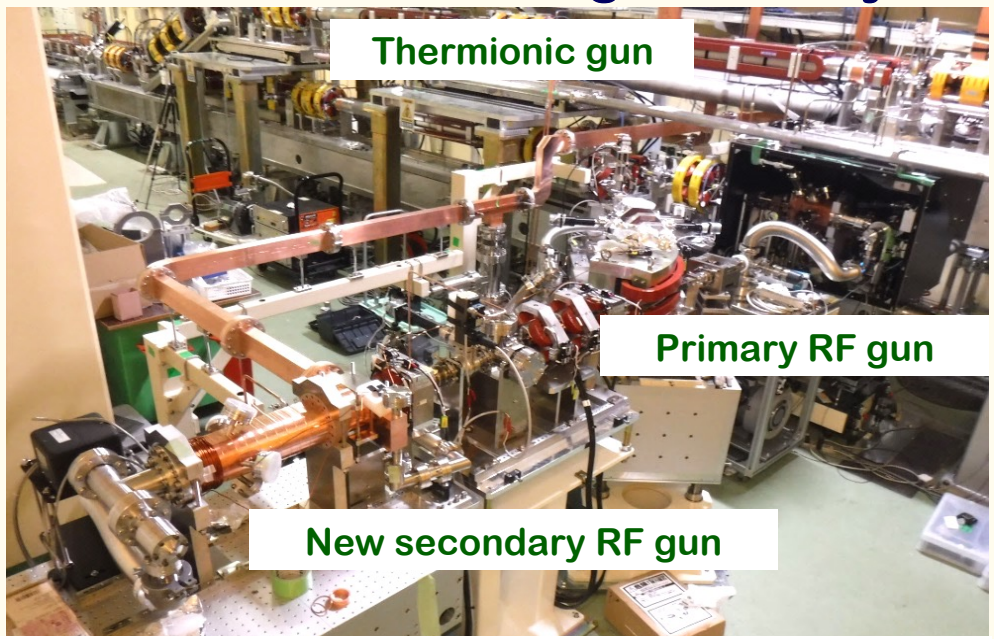
- **Long (5-month) shutdown for the first time in SuperKEKB project**
  - 9-month shutdown in 1997 during KEKB
  - DR construction, resource availability, etc
  - Installation of many important components during this shutdown

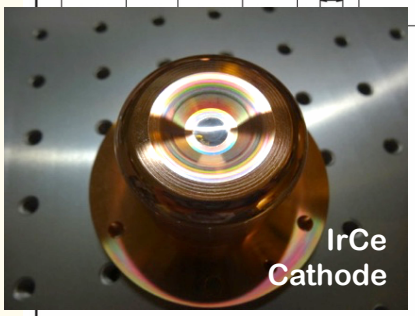


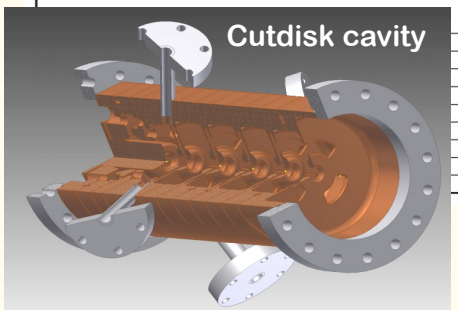
Progress of Photo-cathode RF Gun

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







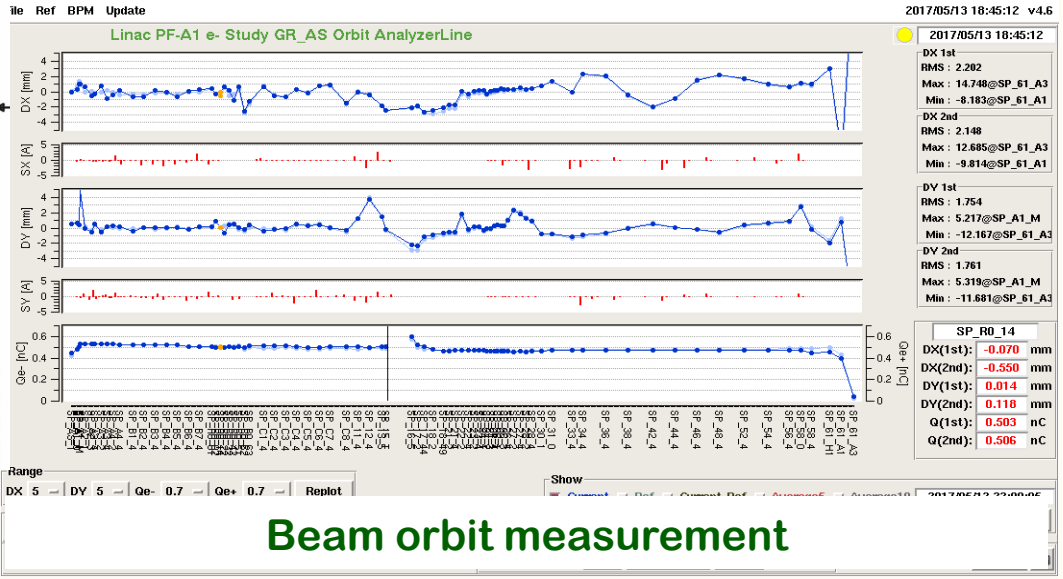
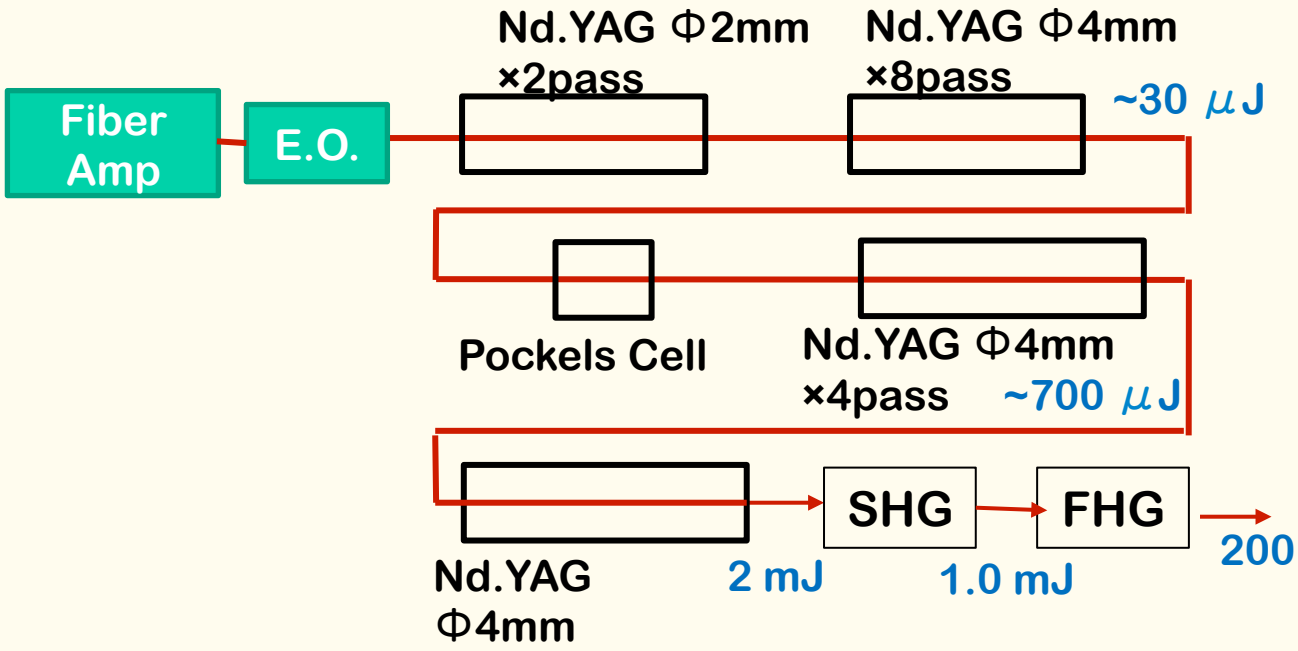
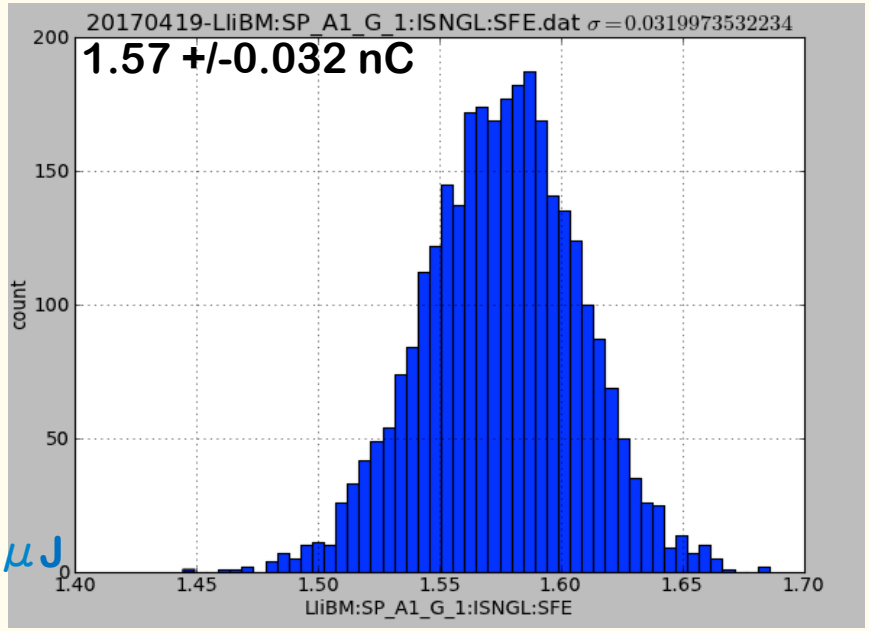


Photo-cathode RF gun: Laser

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



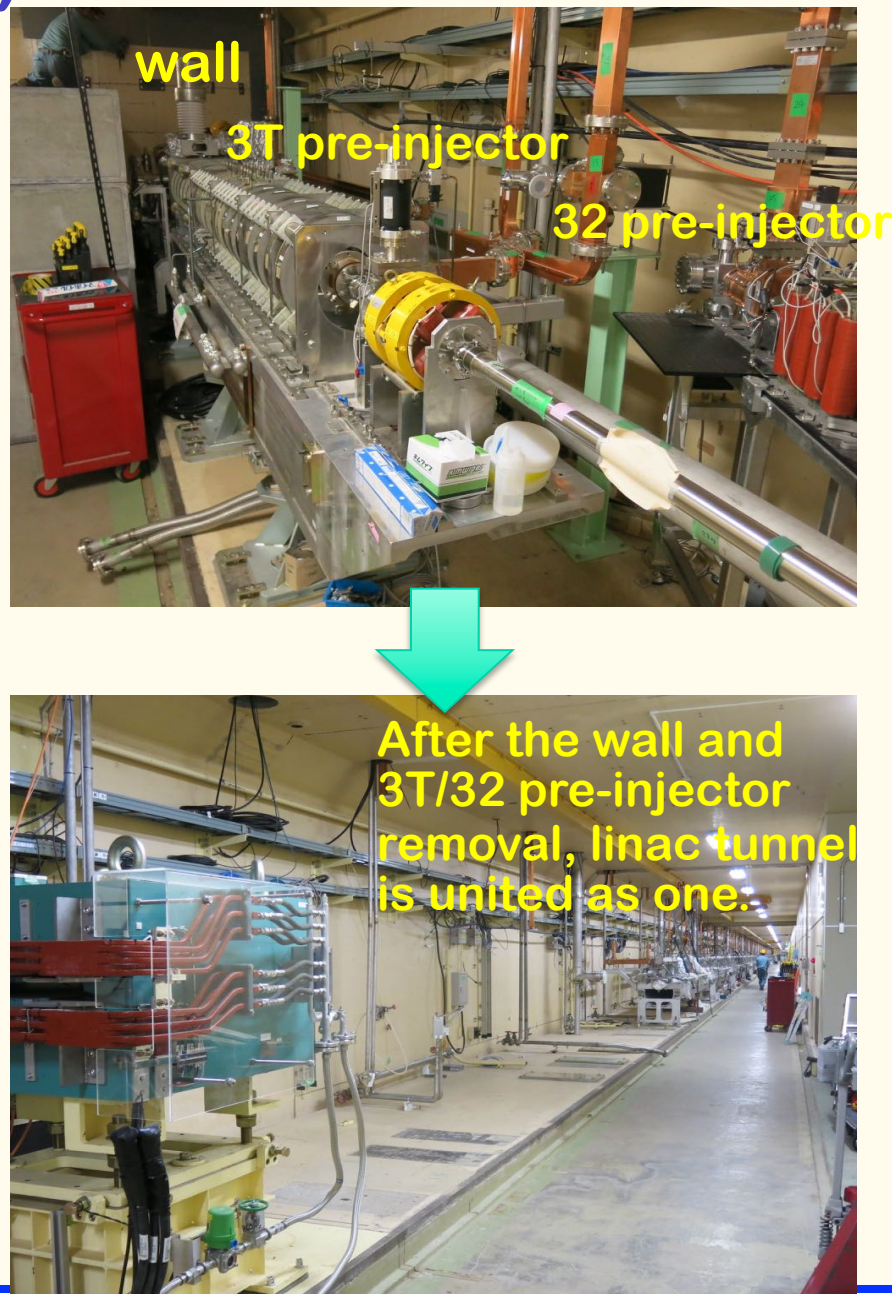


Beam charge stability

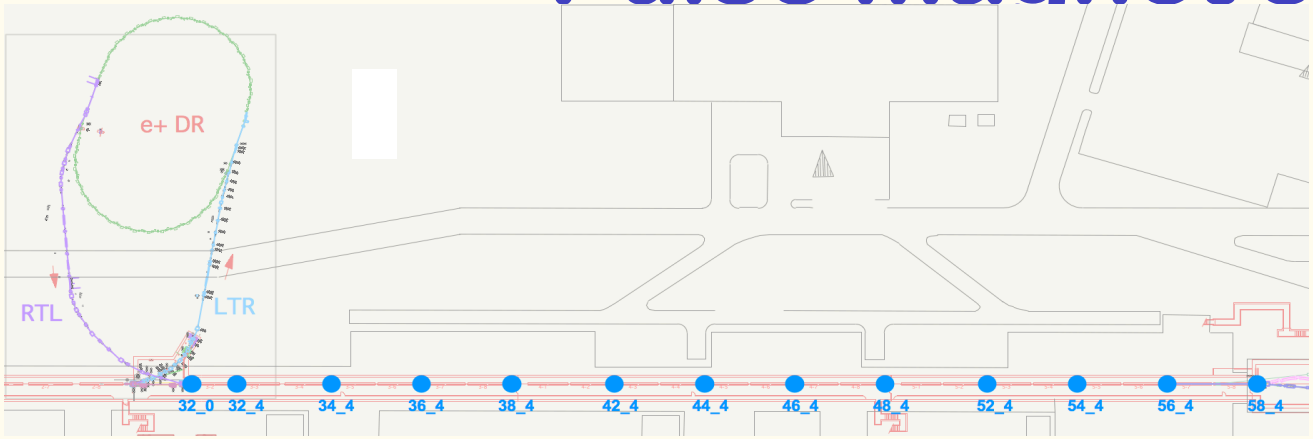
- Stable laser system for Phase-II.
  - 2 nC, 2 bunch stable operation will be expected.
    (2-bunch operation was already demonstrated.)
  - Two oscilllator (one will be commercial oscillator).
  - Two amplifier lines.
  - Spatial filter for one amplifier line.

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

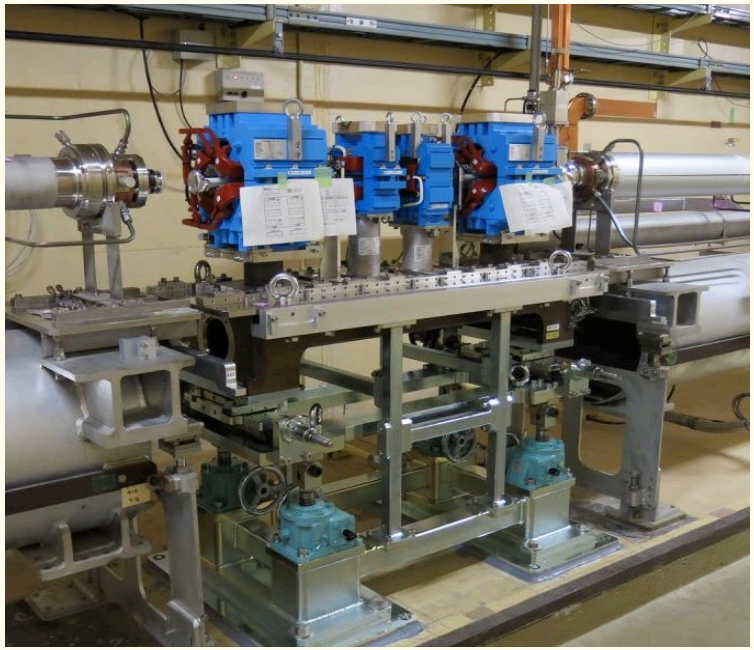
- KEK e+/e- linac has been divided into two regions by a wall at 3T.
- 3T/32 pre-injector has been used for PF, AR injection during upgrade construction and initial beam commissioning in linac upstream region.
- 3T/32 pre-injector is removed in May 2017 for DR commissioning.
- a regular accelerator module (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.



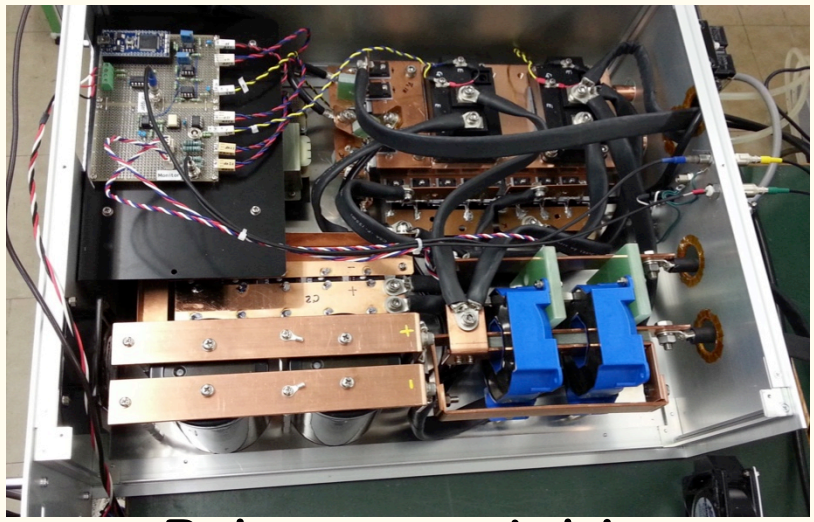
Pulse magnet system



- 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)

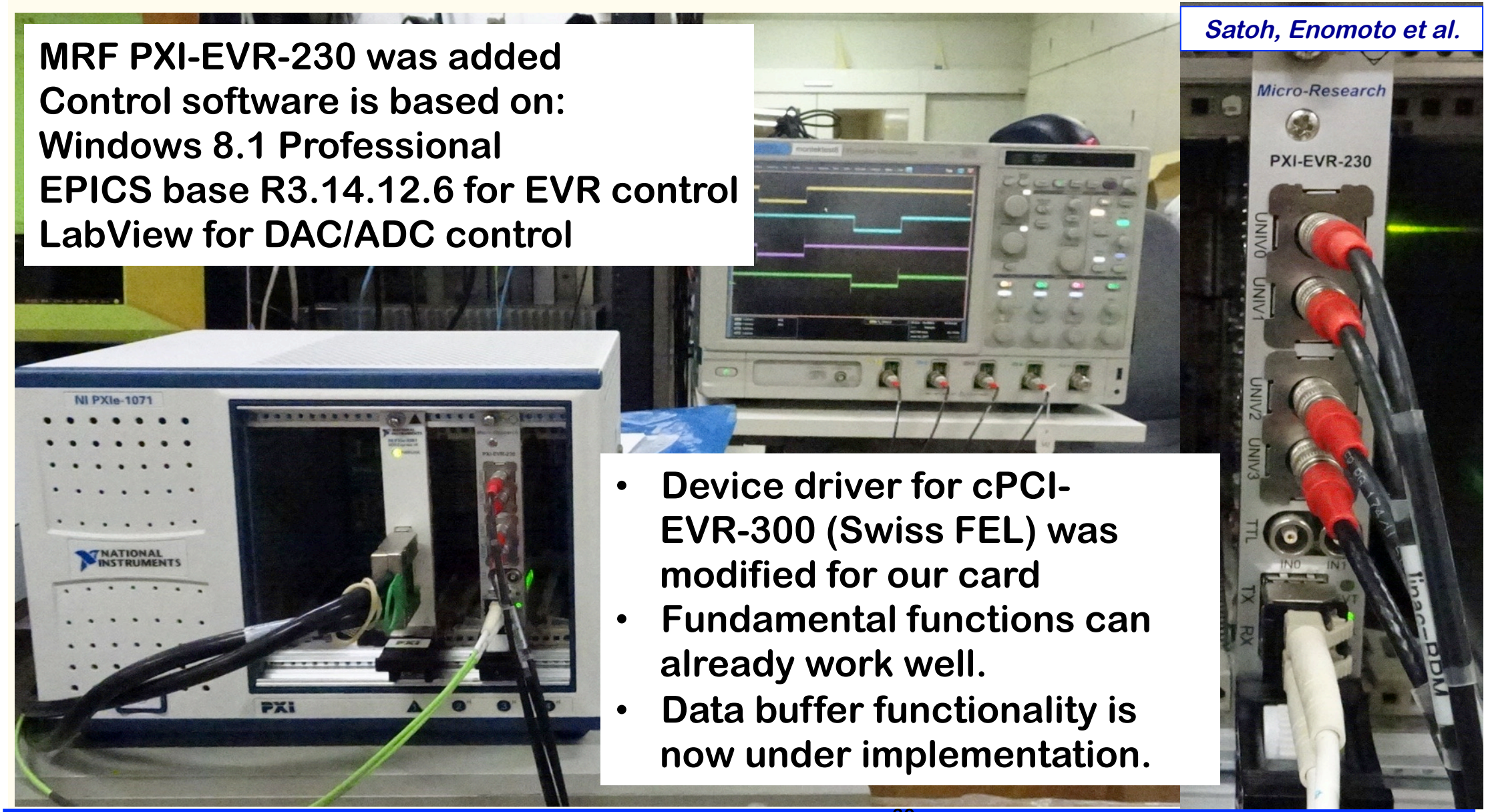


Pulse current driver

Event timing controls for pulsed quad & steering magnet controls

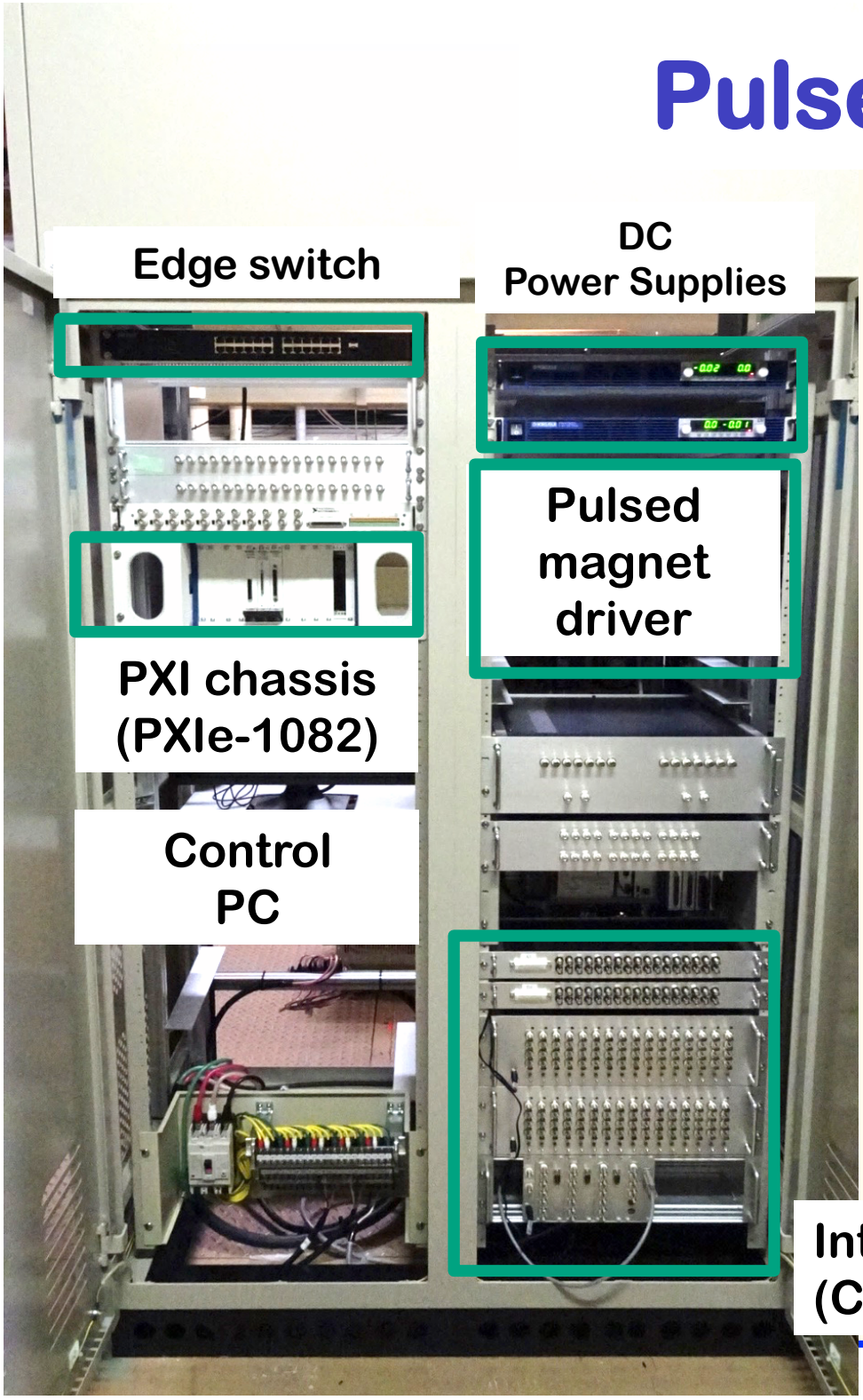
Satoh, Enomoto et al.

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

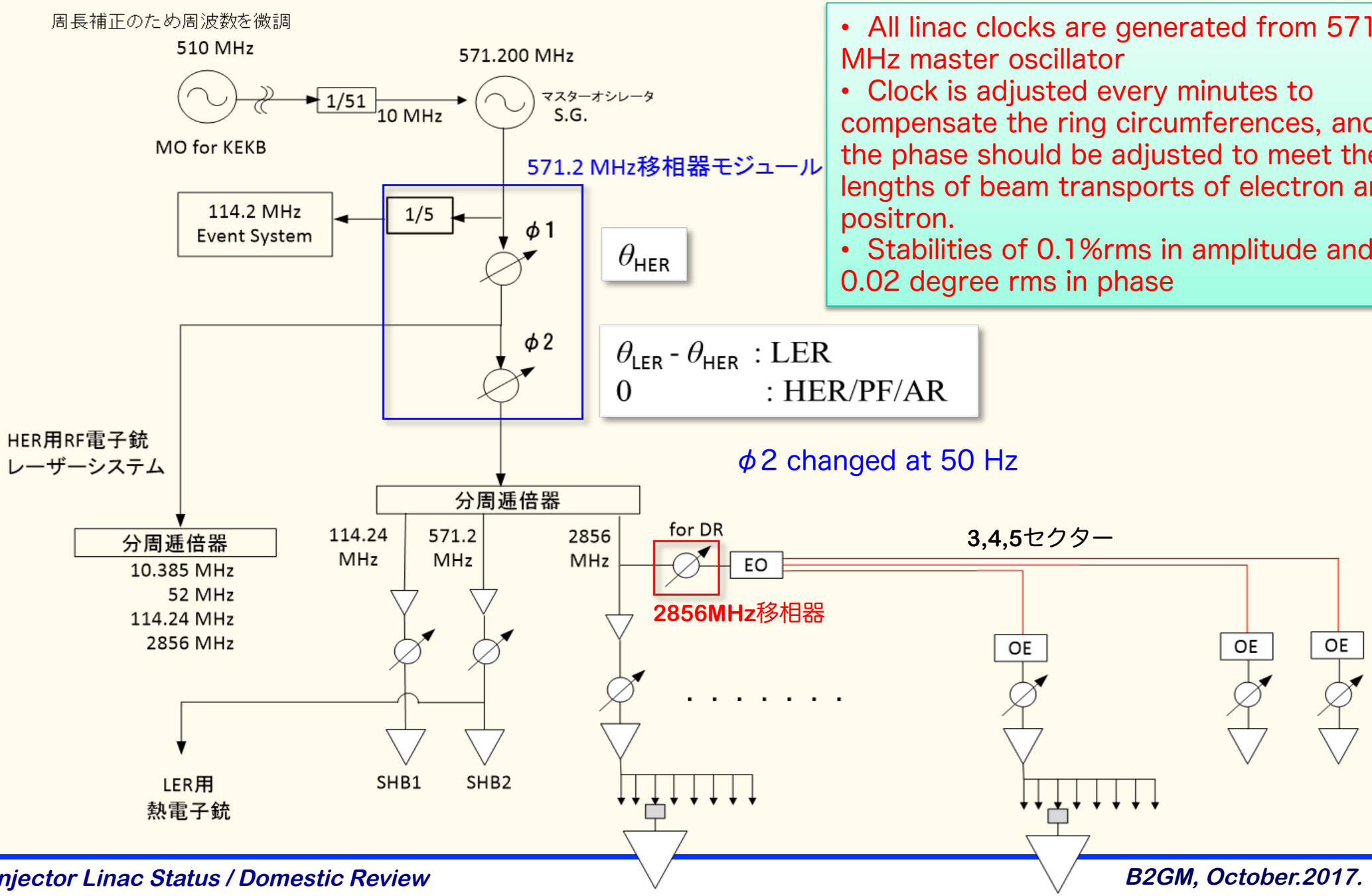


Remote controller
DAC (PXI-6733)
ADC (PXIe-6356)
PXI-EVR-230

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

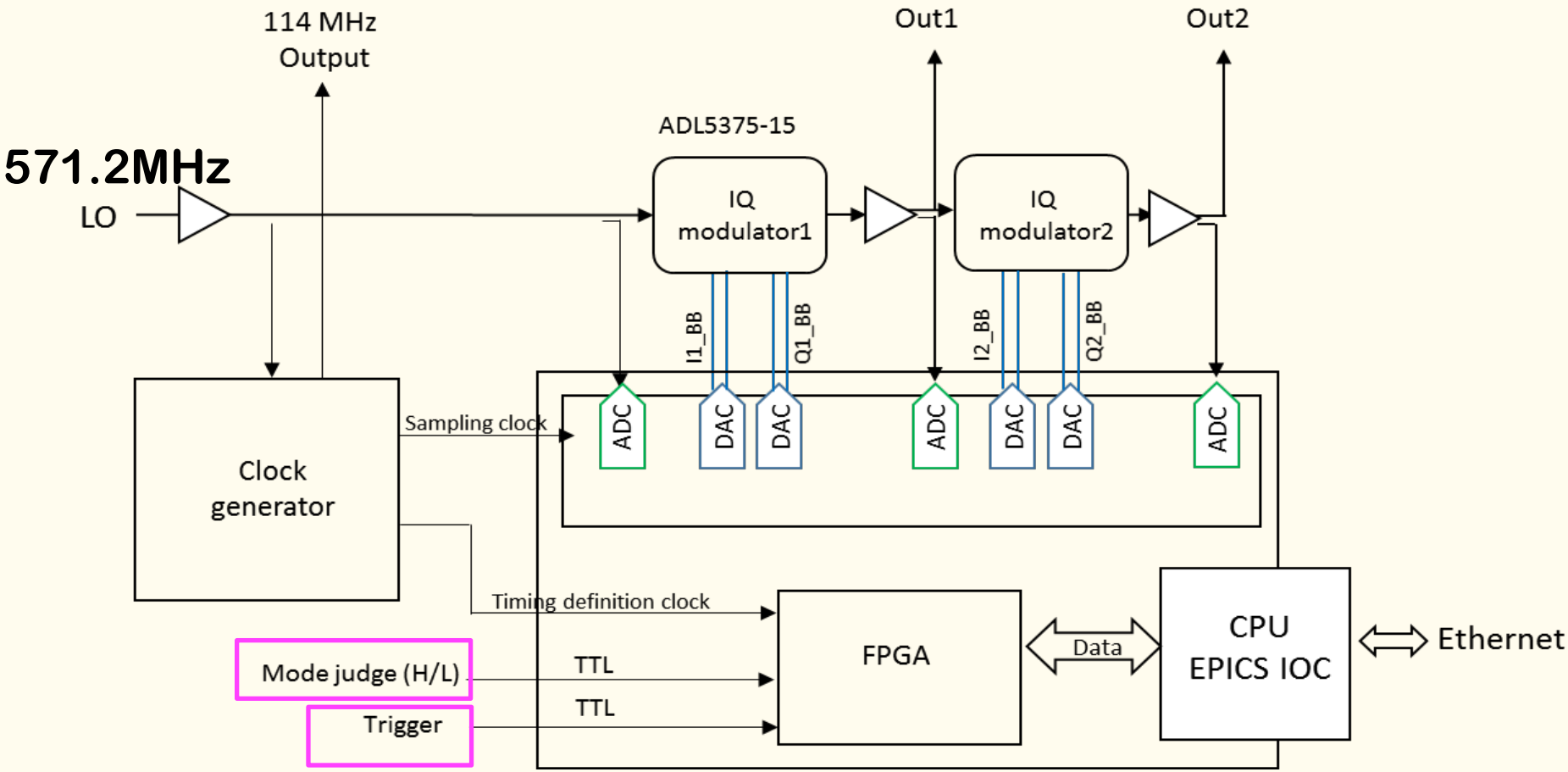
Interlock signal processing
(CompactRIO based system)

Development of 571.2MHz Master phase shifter

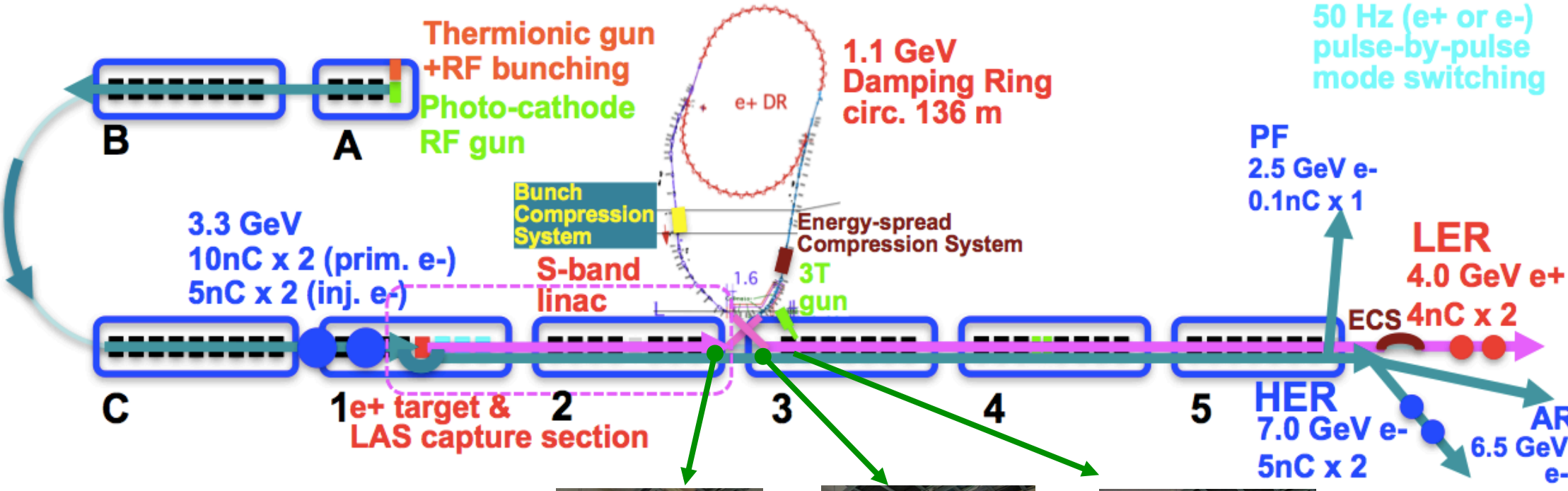


- All linac clocks are generated from 571.2 MHz master oscillator
- Clock is adjusted every minutes to compensate the ring circumferences, and the phase should be adjusted to meet the lengths of beam transports of electron and positron.
- Stabilities of 0.1%rms in amplitude and 0.02 degree rms in phase

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

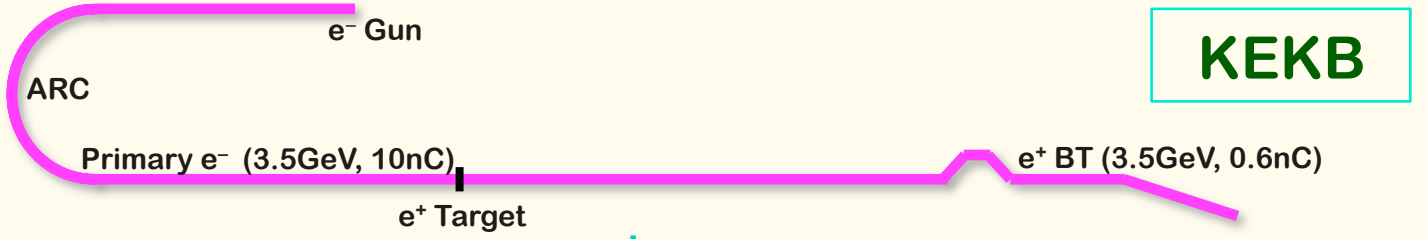
KL_DS/BCS

KL_DN/ECS

KL_32

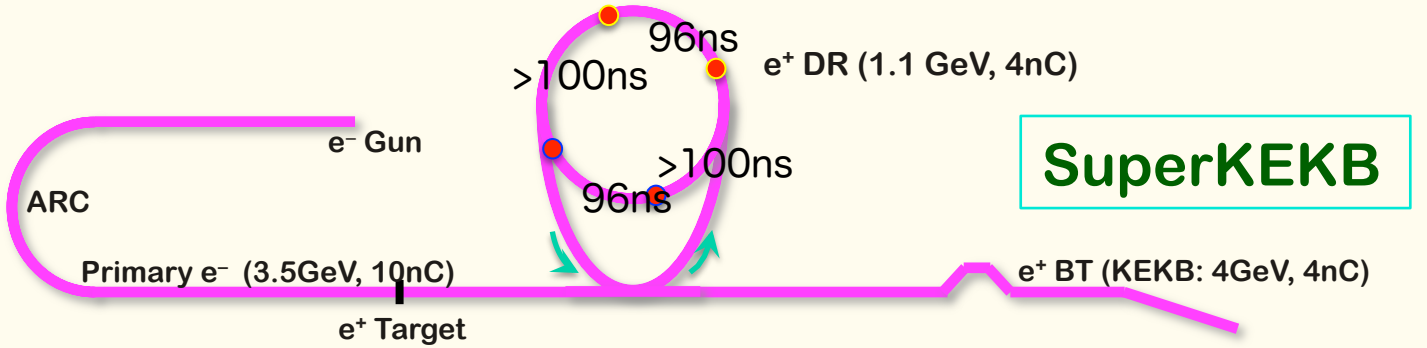
Bucket selection in Phase-2 with DR

- **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

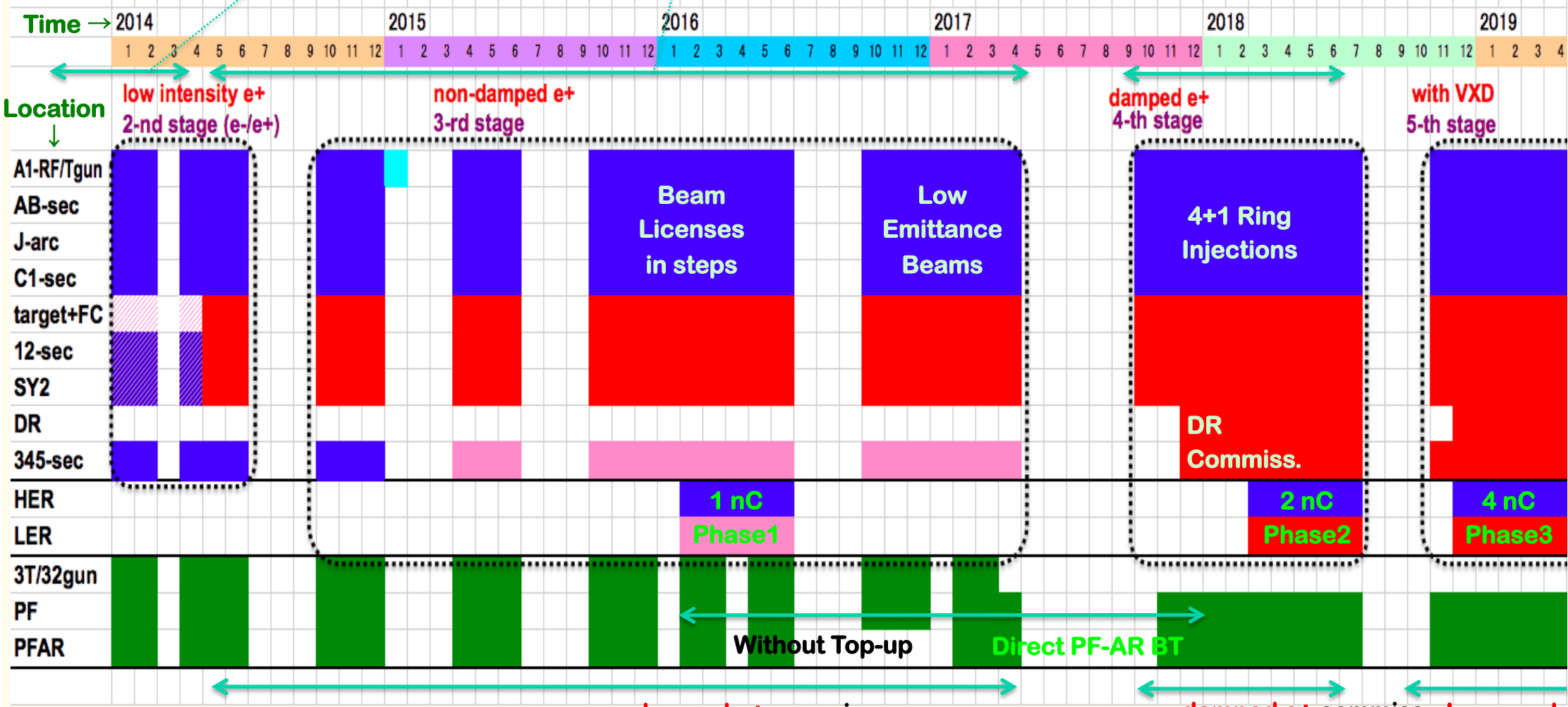
Linac Schedule Overview as of Jun.2017

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. at 1→5 Qe+ = 1~4nC
e- commiss.
at A→5 Qe- = 1~5nC

Improved RF gun

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, commissioning and development in parallel