Recent Status of Electron/Positron Injector Linac

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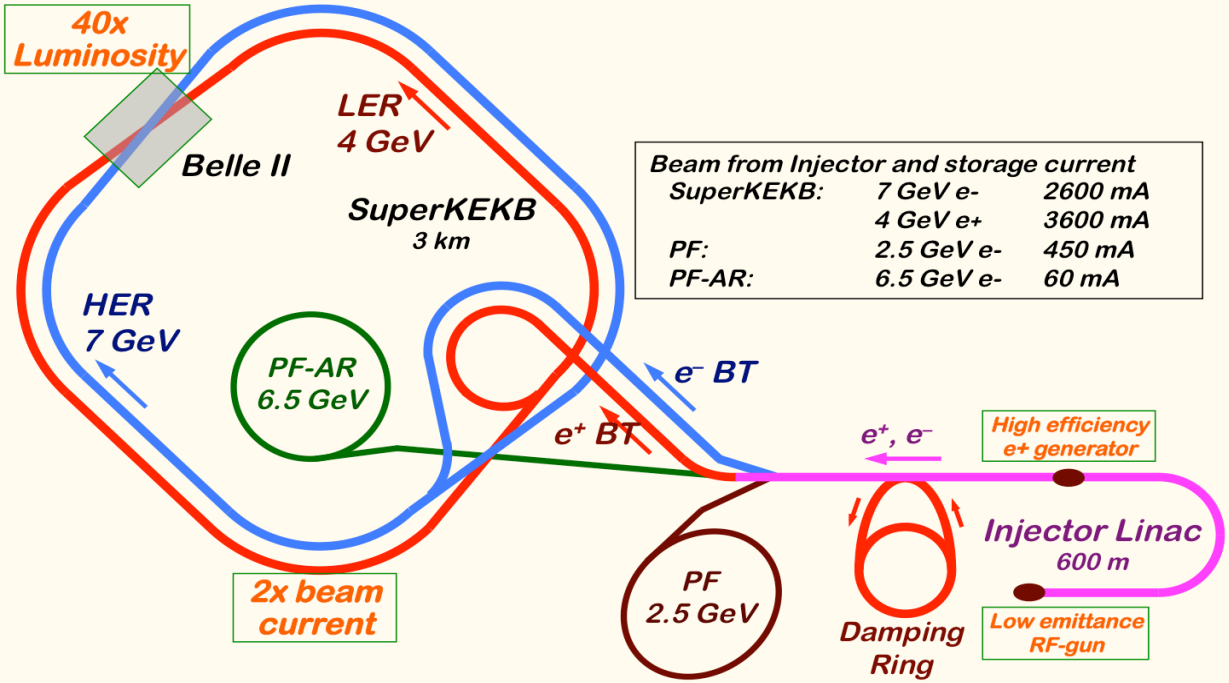
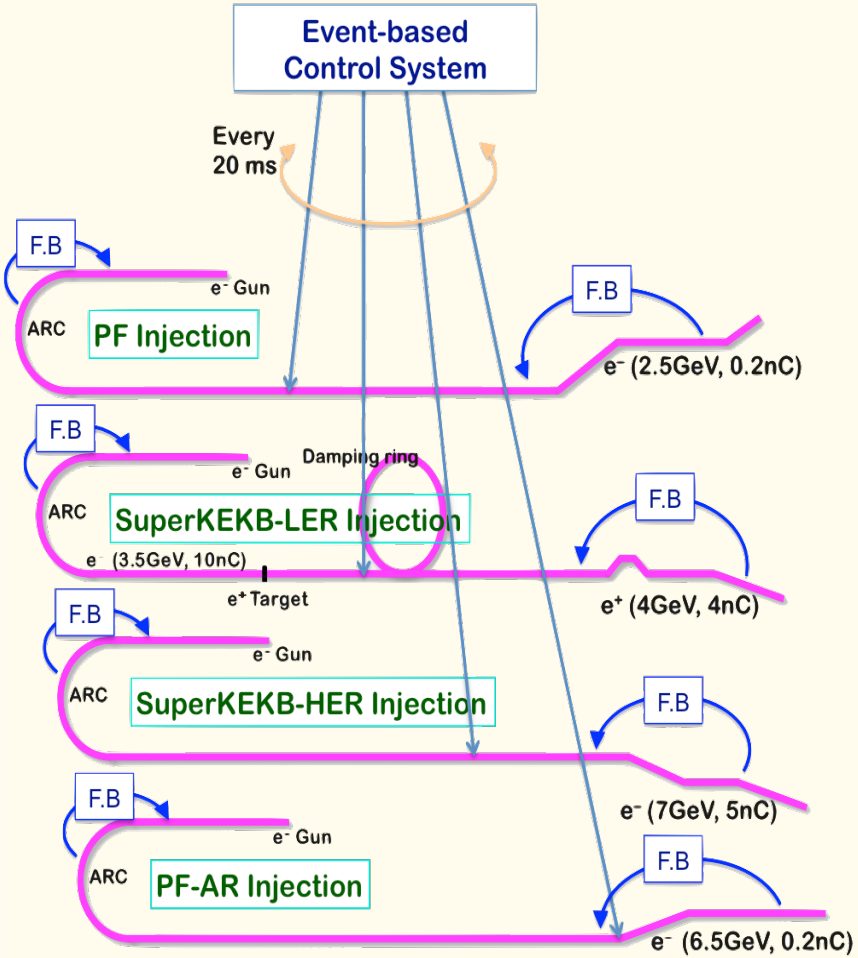
Many slides from Y. Enomoto and S. Matsumoto

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 higher 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

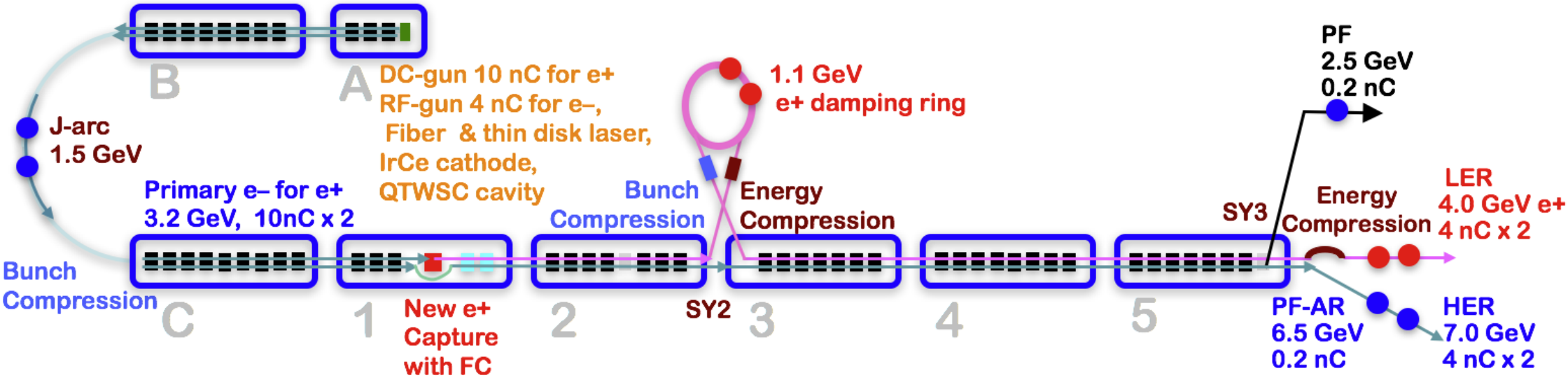




The single injector would behave as multiple injectors to multiple storage rings by the concept of virtual accelerator

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 Hz		25 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)	

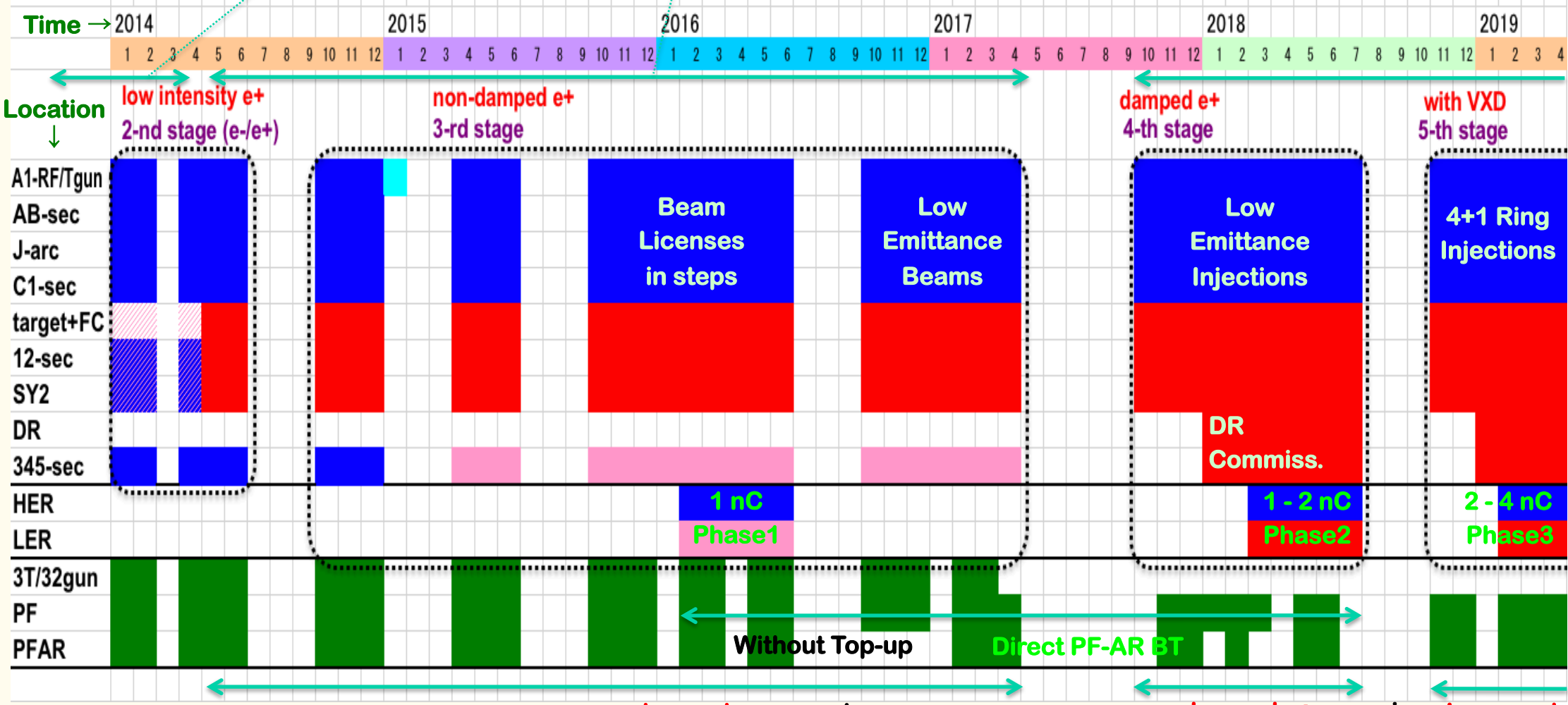
Linac Schedule Overview as of Feb.2018

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

e- commiss. at A,B,R,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

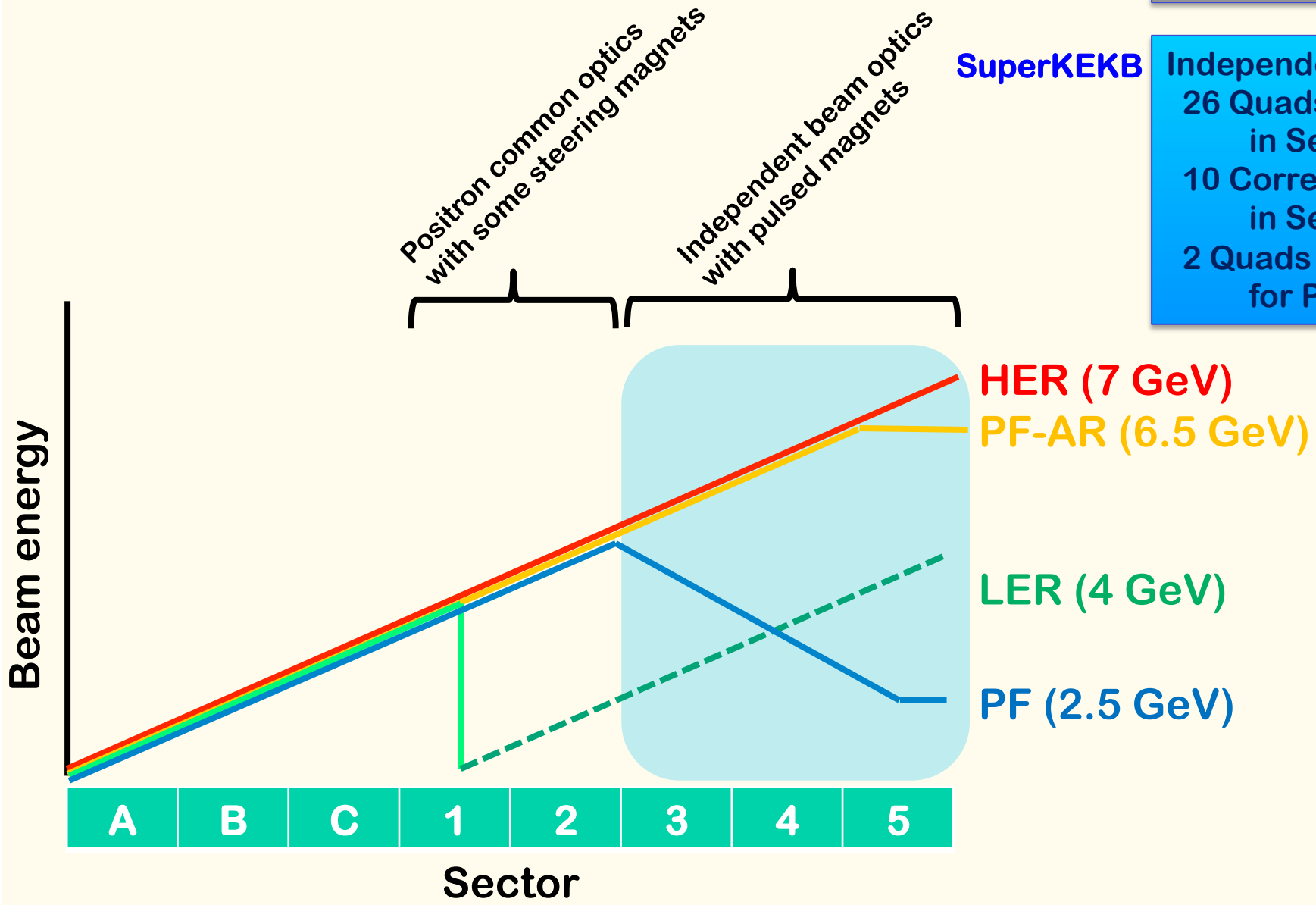
damped e+ commiss. at 1→5 Qe+ = 1~4nC
e- commiss. at A→5 Qe- = 1~4nC

Improved RF gun

Newly Installed Pulsed Magnets

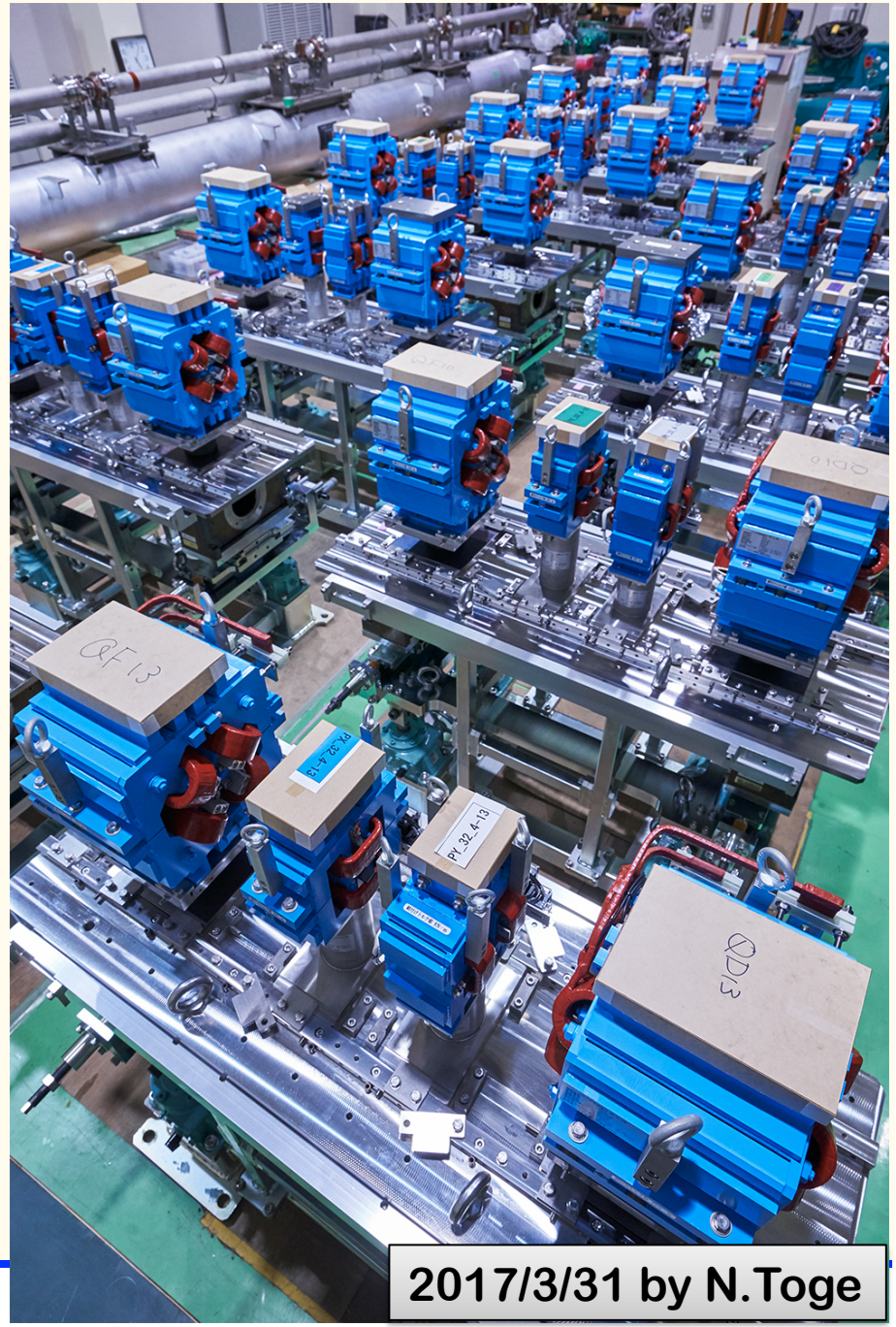
KEKB Common optics was enough

SuperKEKB Independent beam optics with
- 26 Quads and 26 Correctors in Sectors 3 – 5
- 10 Correctors in Sectors 1 and 2
- 2 Quads for Positron Target



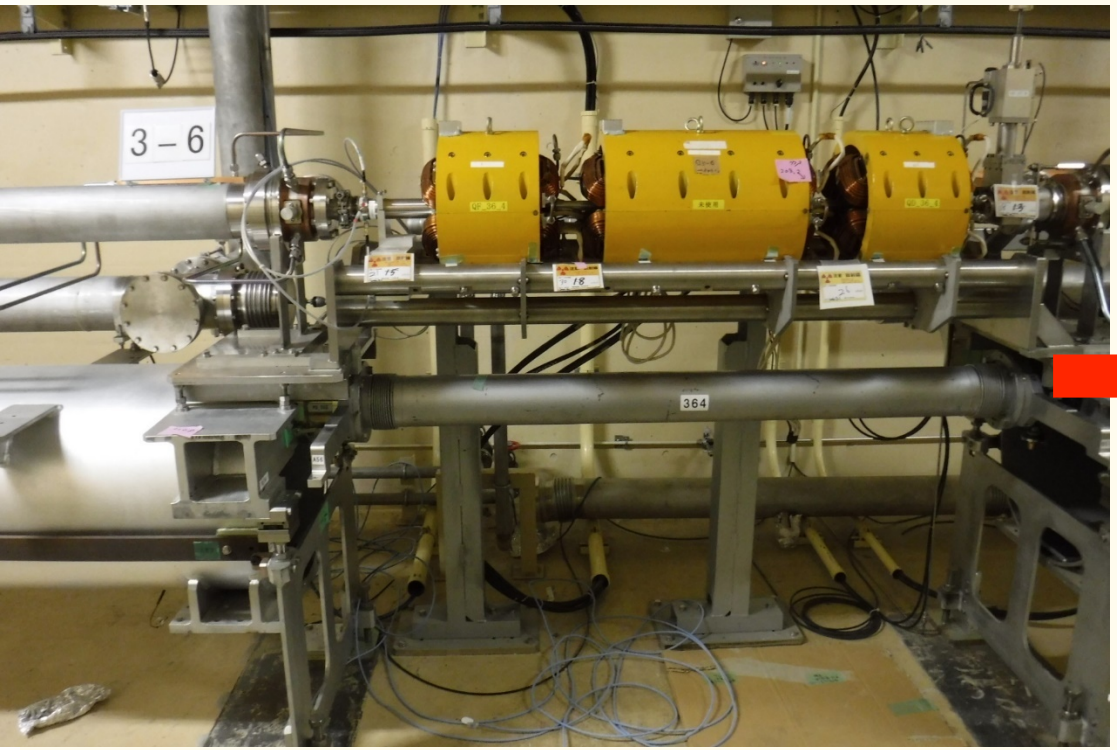
Pulsed Magnet Installation 1

- Installation during long shutdown at summer 2017
  - Not possible before Phase 1 without DR because of the aperture
  - Replacement for 64 magnets
  - In 99 days between May and October
  - All components including magnets, girders, cabling, cooling water, controls, etc.
  - In parallel with other replacements and installations



2017/3/31 by N.Toge

Pulsed Magnet Installation 2



- 13 New girders
  - each for 2 quads and 2 correctors
  - ready for 10 μm alignment to realize low emittance preservation in Phase 3

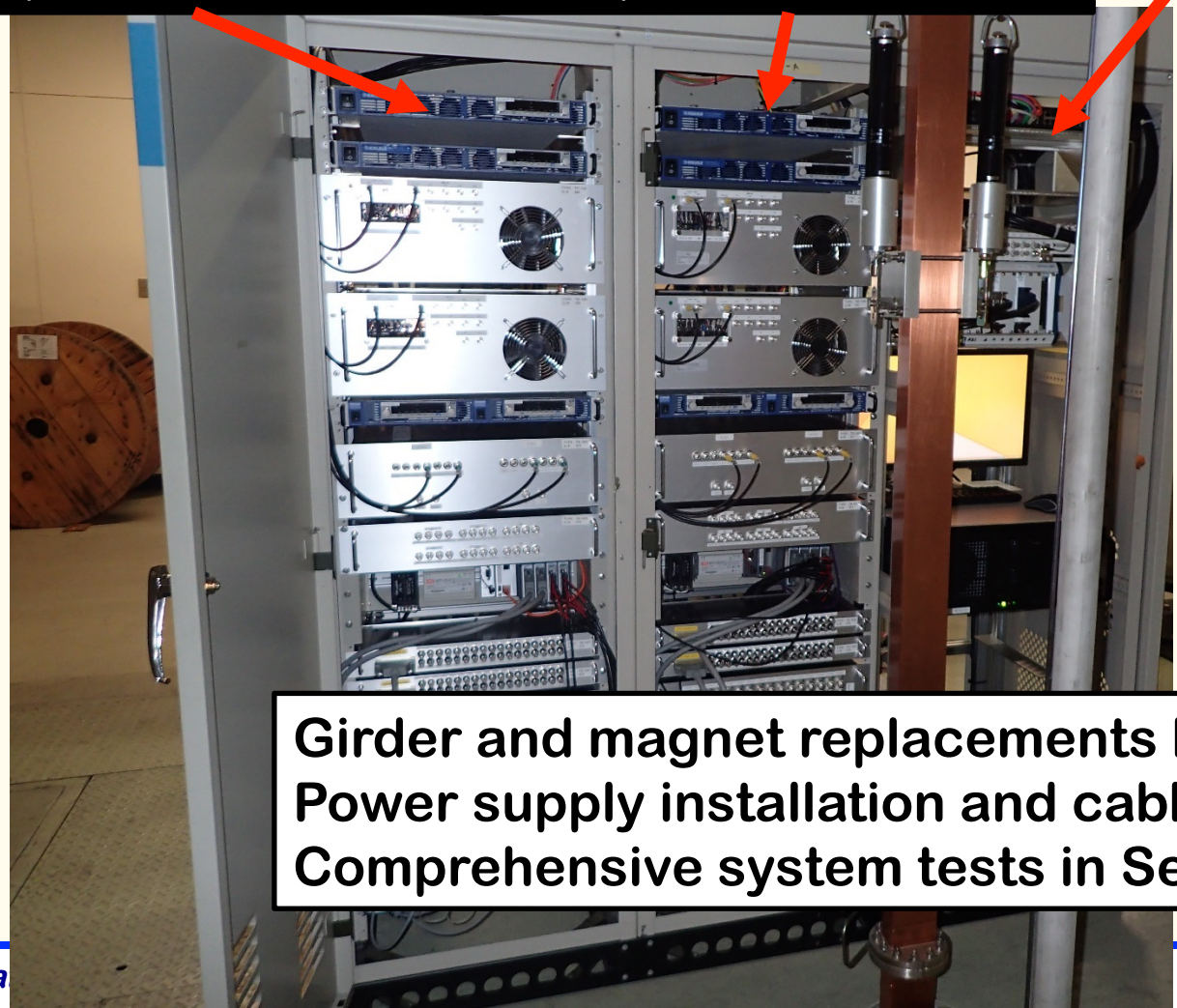
Pulsed Magnet Installation 3

Standard cabinet configuration for pulsed magnets
4 quads and 4 correctors for a half sector

Pulsed power supplies & Interlock system for 2 quads and 2 correctors

Pulsed power supplies & Interlock system for 2 quads and 2 correctors

Controls

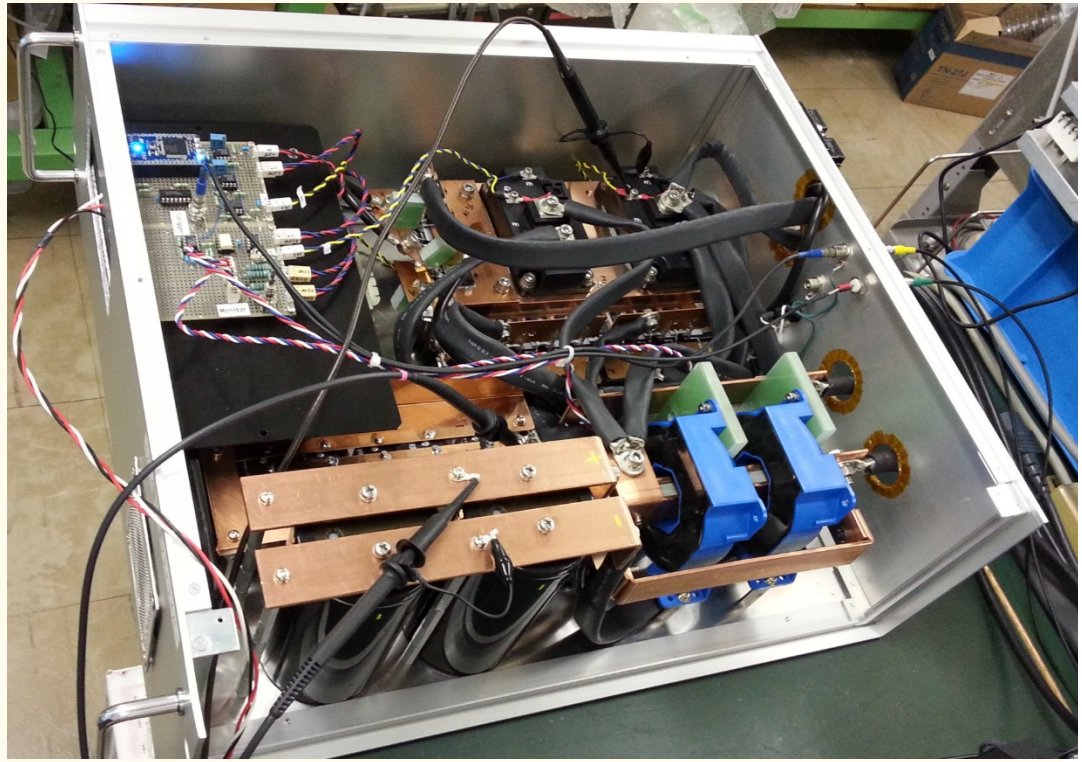


Girder and magnet replacements before July
Power supply installation and cabling before September
Comprehensive system tests in September for a month

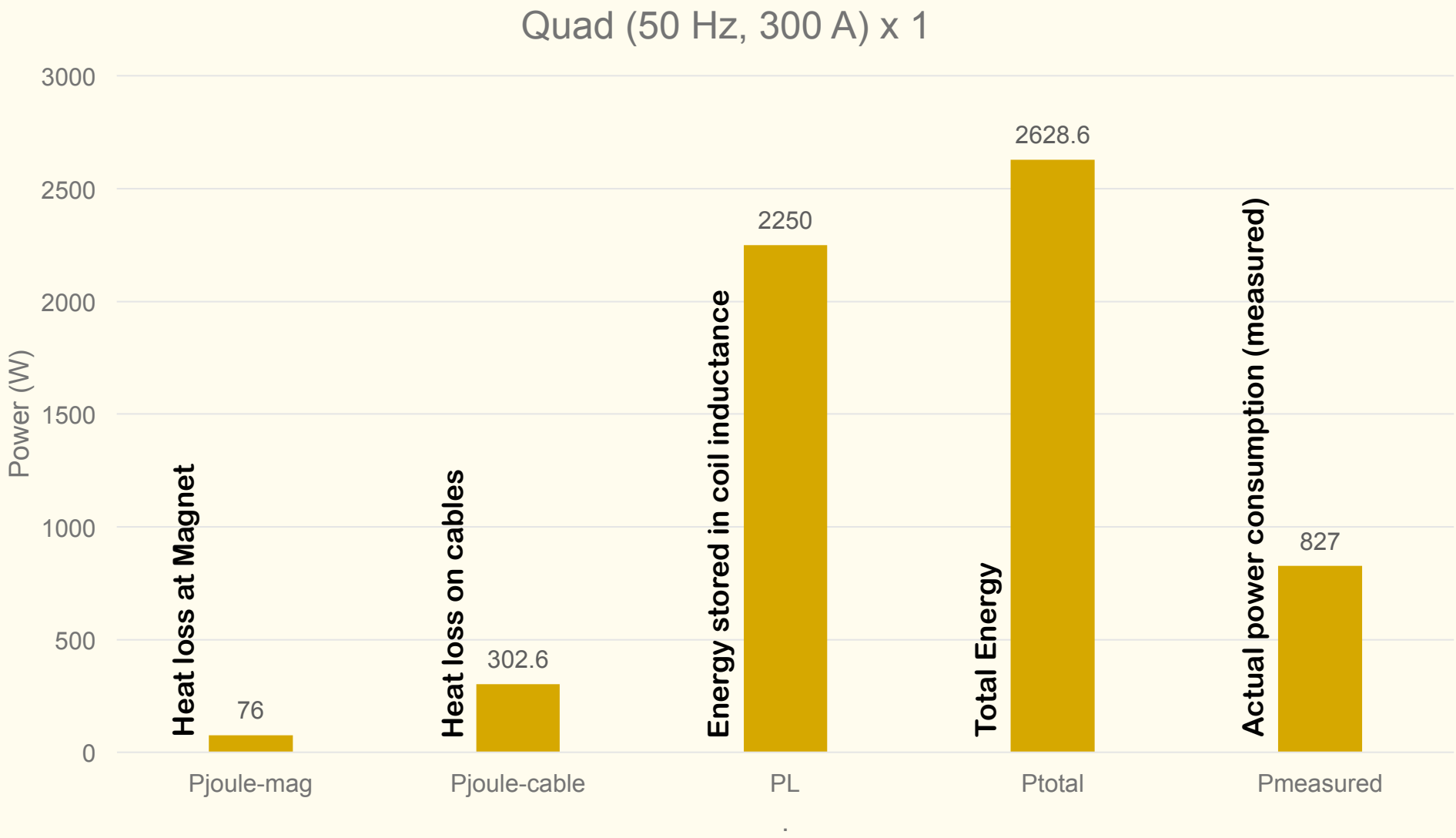
Performance of Quad Power Supply

- High performance with energy recovery
  - Total energy recovery rate of 68.5% (measured)
  - No need for additional wall power (only 39kW for all new magnets)
- High precision and high stability by analog feedback with IGBT
  - Stability of 0.01% for 24 hours
- Flexible synchronous controls with global event control system
  - Independent pulse-by-pulse modulation at 50 Hz

- Drives a 1 mH coil at 330 A, 340 V, 1.5 ms risetime

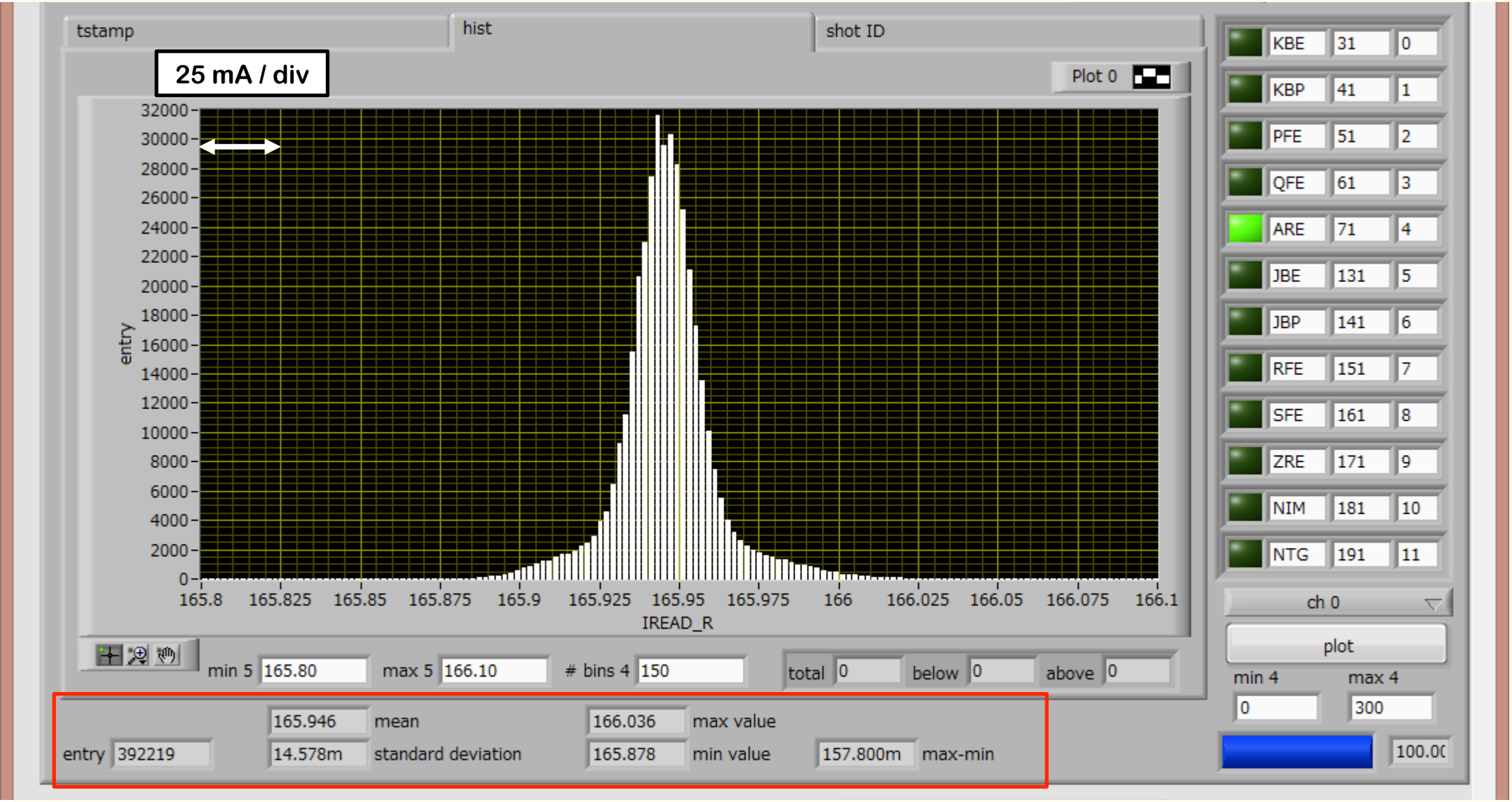


Power Consumption Measurement



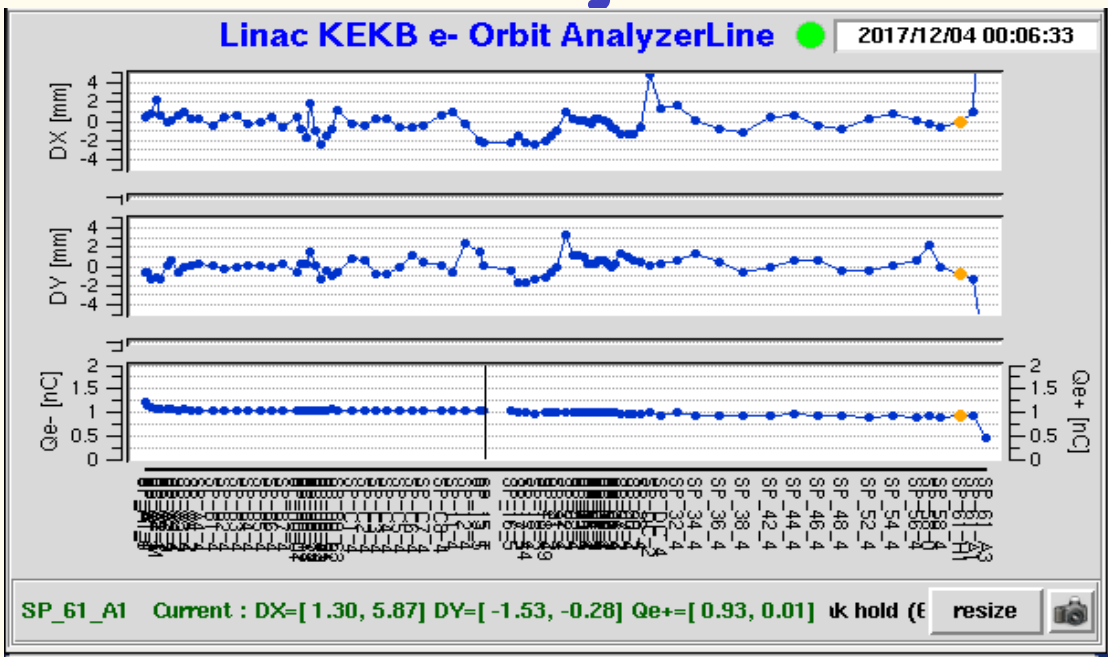
Energy recovery ratio = 1 - $P_{measured}$ / P_{total} = 68.5 %

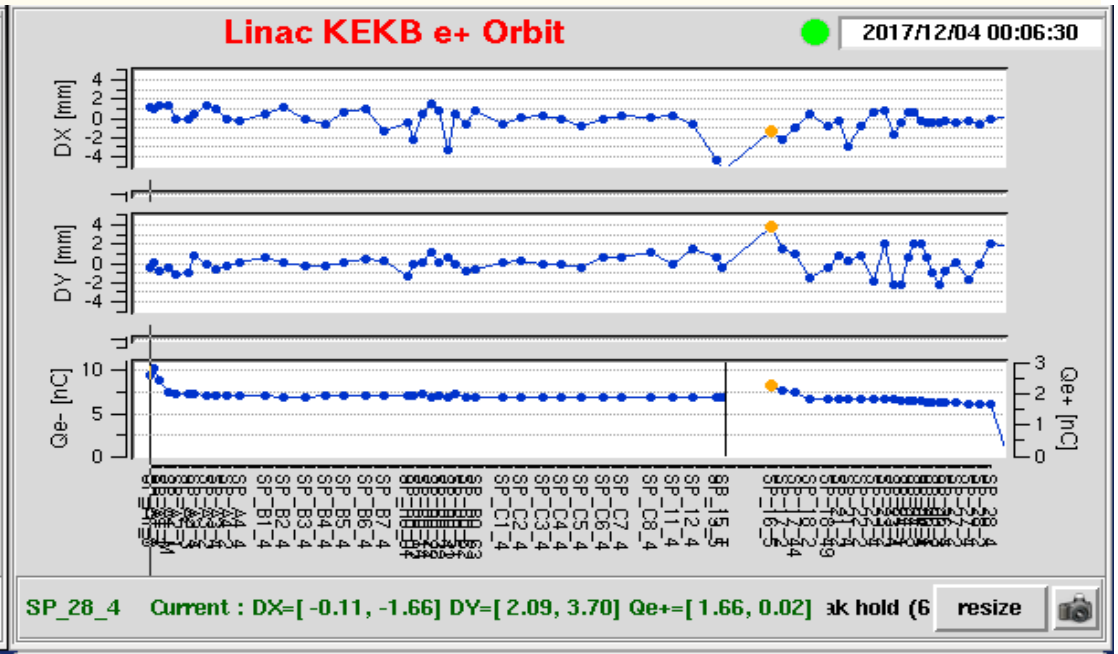
Stability of Quad Power Supply

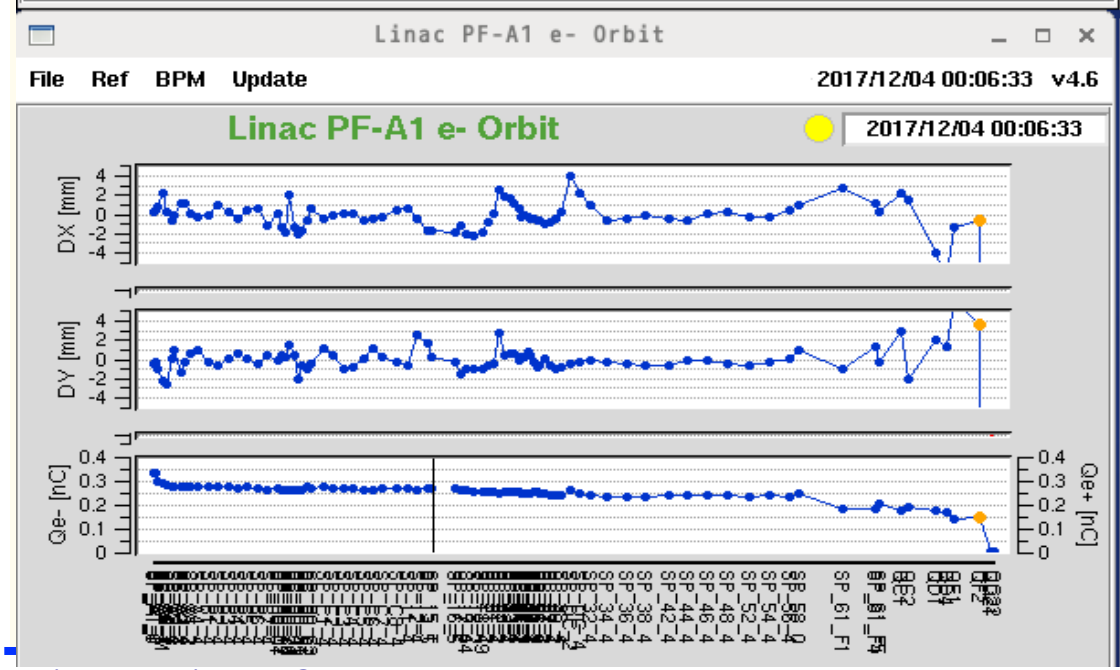


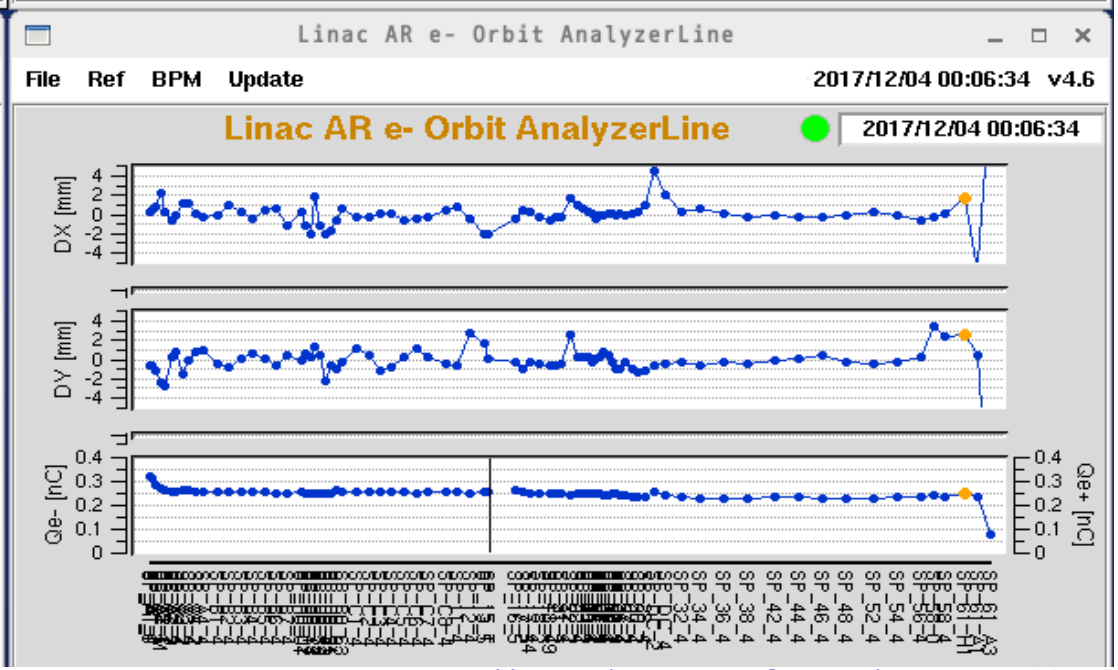
0.014578 A / 165.946 A = 0.0107% / 24 hours (for PF_52_4 magnet)

New Pulsed Magnets enabled Simultaneous PF/PF-AR Injections And 2 Test Beam Accelerations





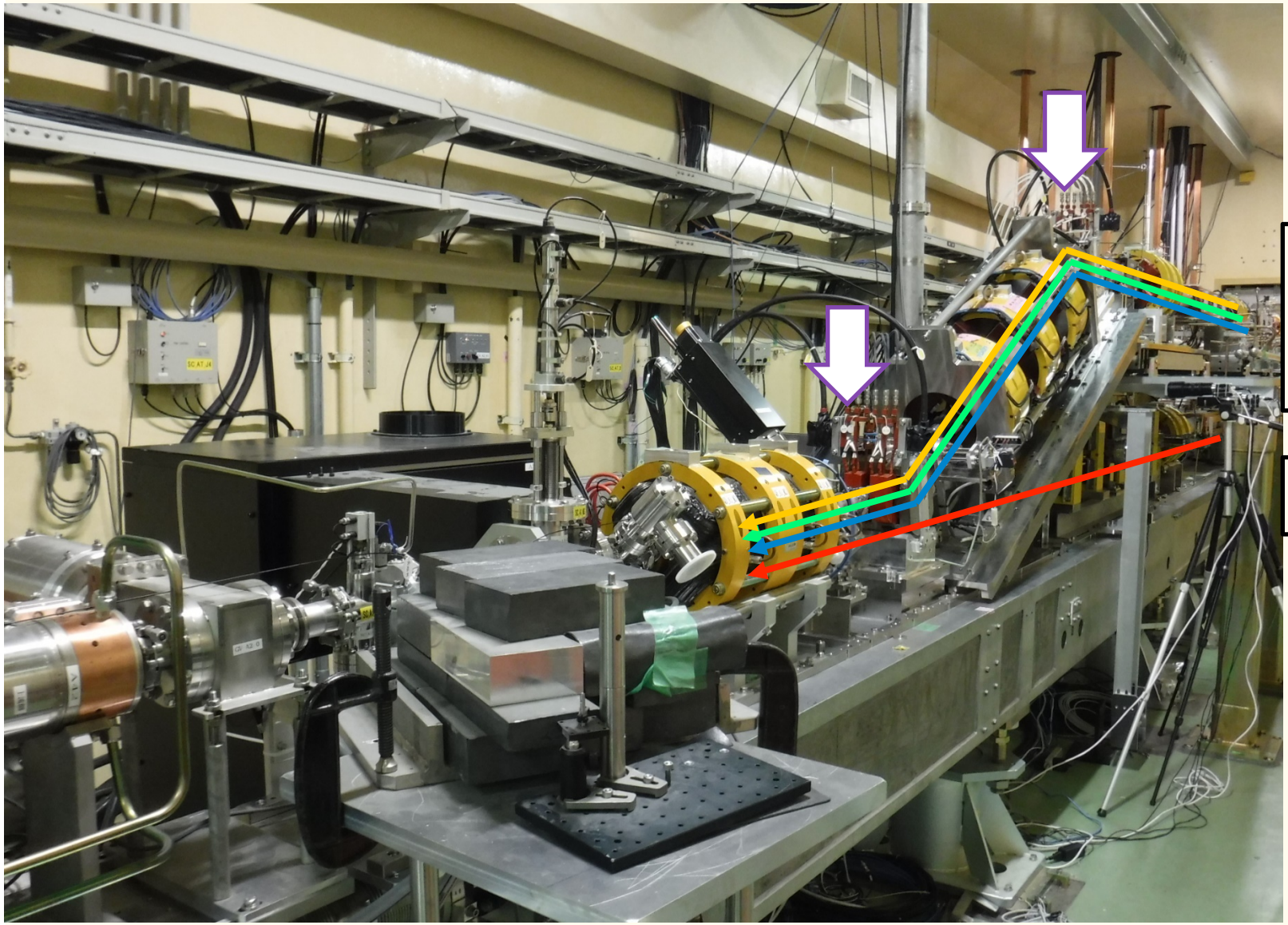




For Phase 3

- Pulsed bending magnet addition for switching between RF electron gun / thermal electron gun
- Pulsed corrector additions for offset injection (orbit control) to enable lower emittance
- 40 magnet replacements if budget allows

Planning Pulsed Bend for Merger Line



24-degree Merger Bend x2

Thermionic Gun

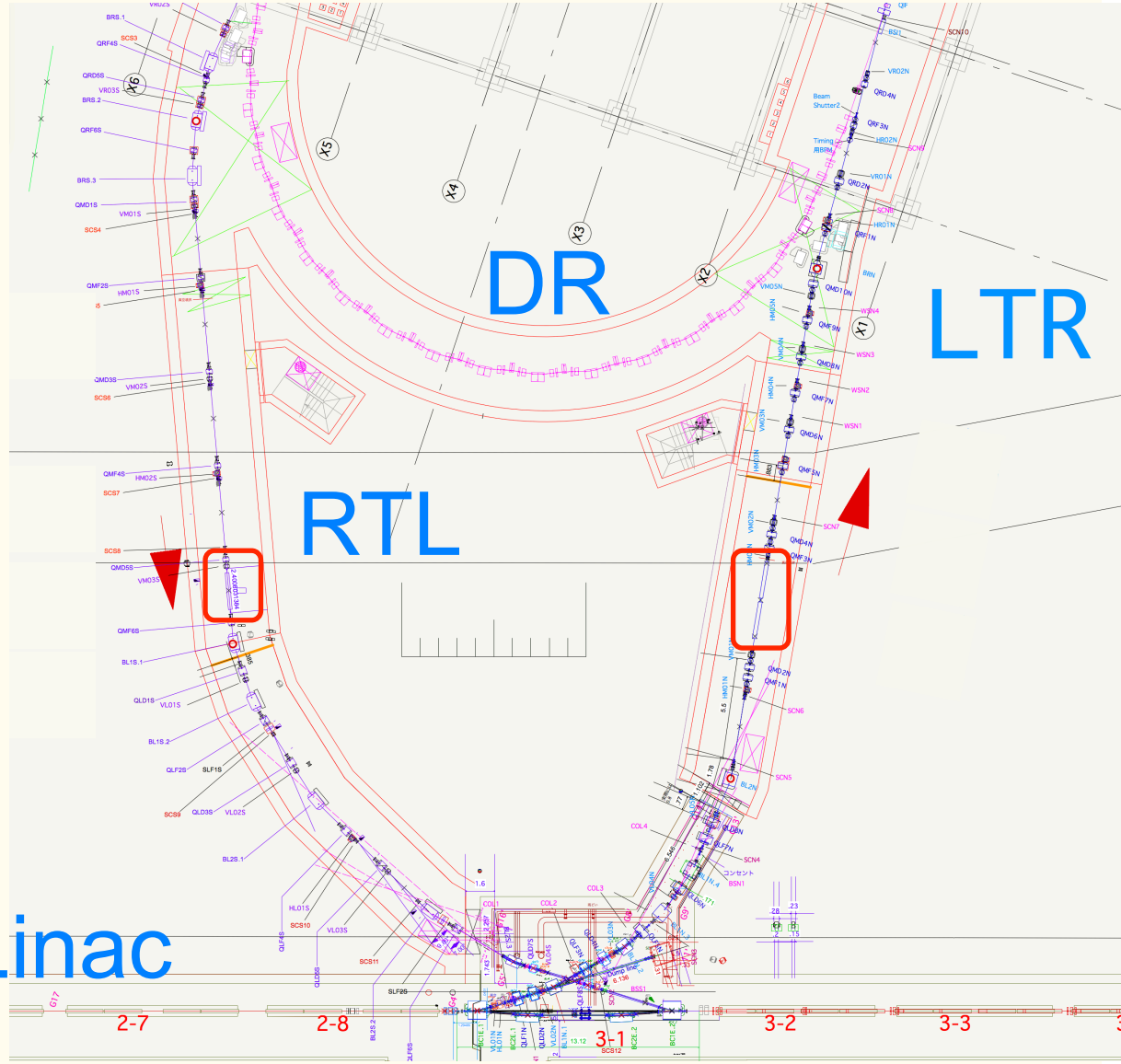
PF-AR
LER (primary e– for e+)
PF

HER

Photo RF Gun

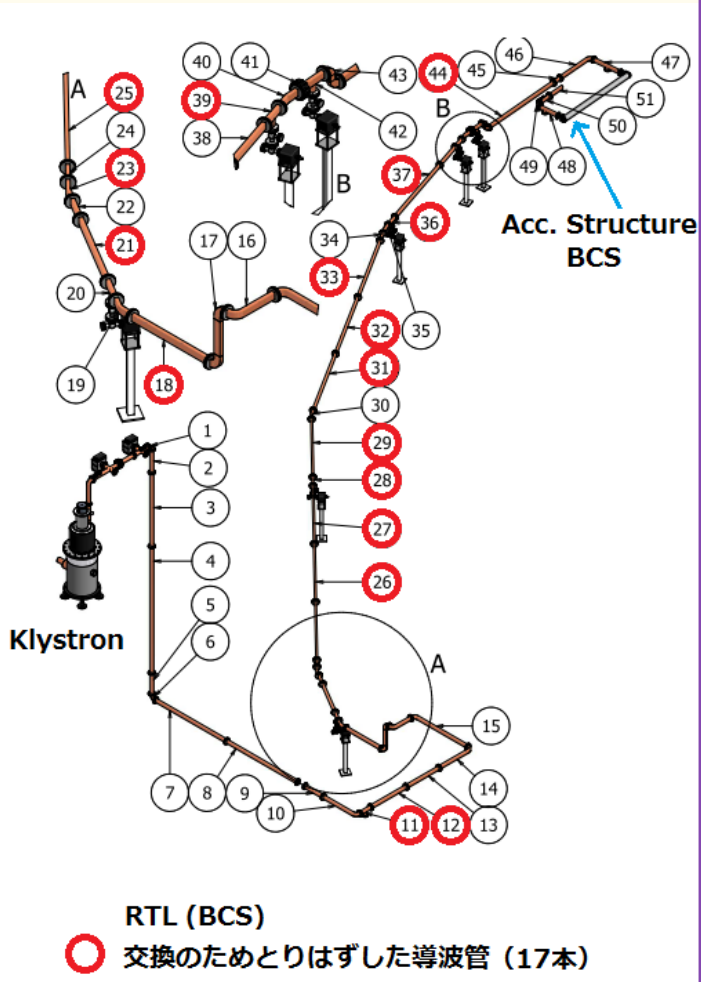
DR LTR / RTL Waveguides

- Accelerating structures for energy / bunch compressors on DR LTR / RTL beam lines
- 45-m waveguides from linac gallery
- Fabrication errors of ~150 μm were found (while schematics from KEK and from maker were correct)

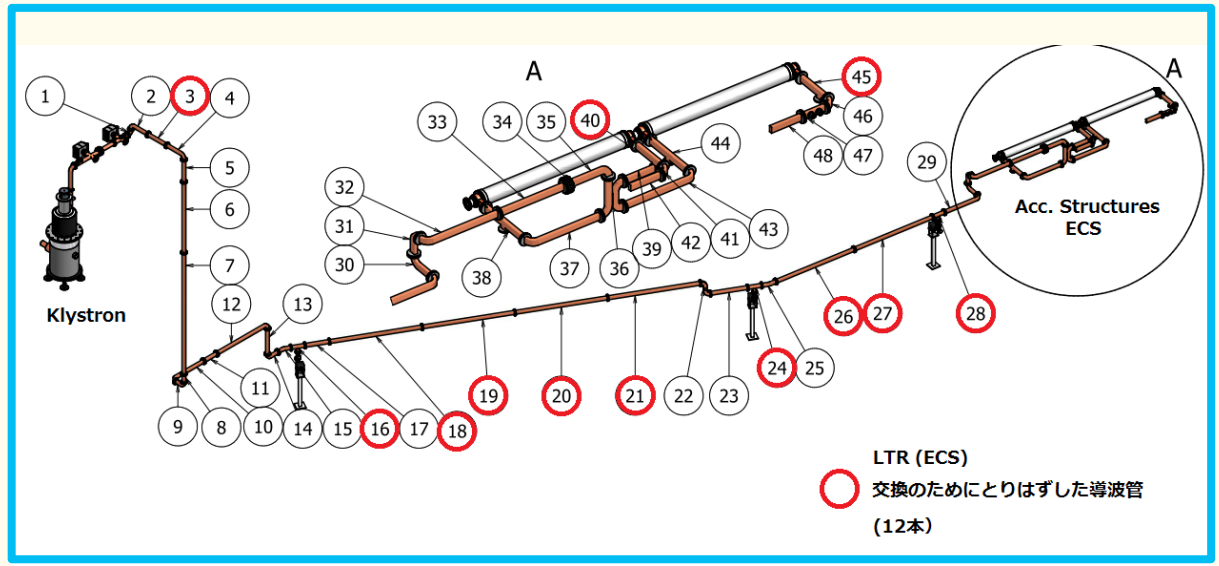


DR LTR / RTL Waveguides

- Components with Red circles had to be replaced

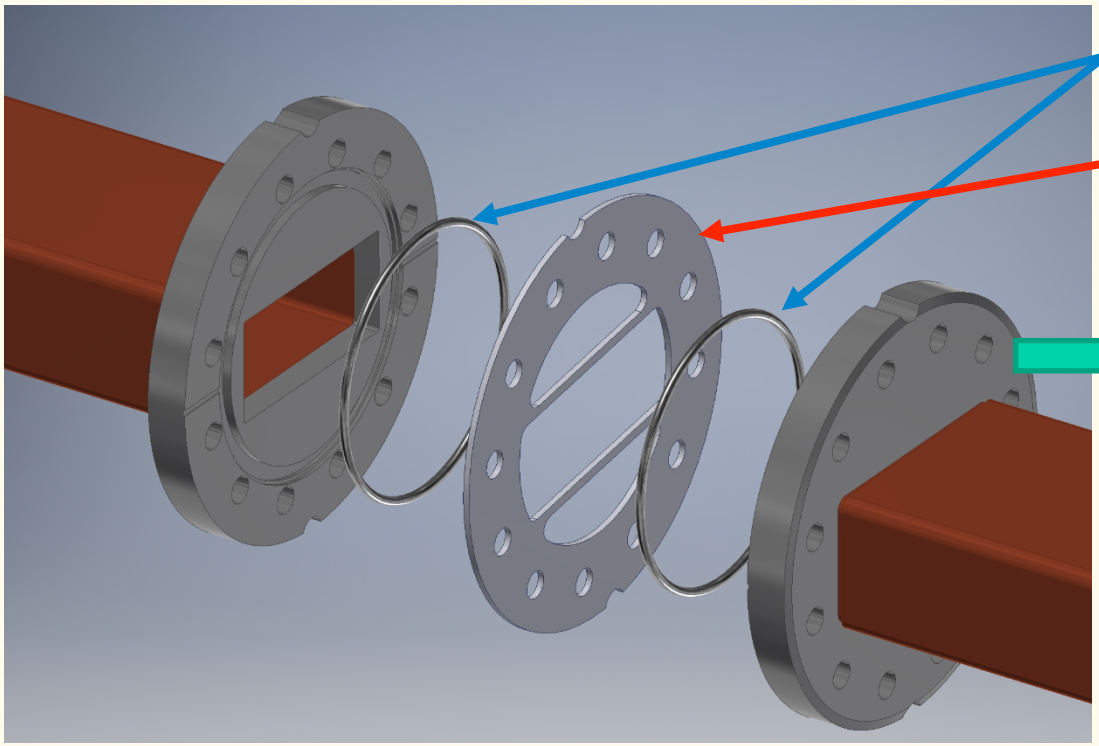


Bunch Compressor on RTL



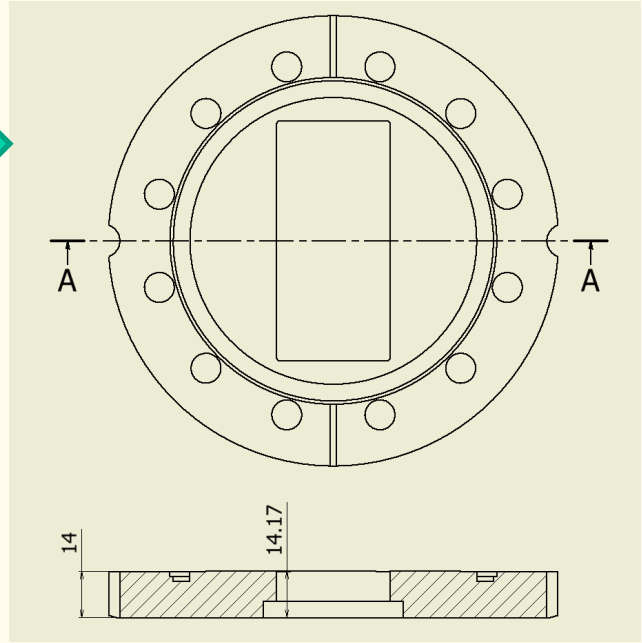
Energy Compressor on LTR

Structure of Waveguide Flange

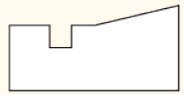


Metal Seal (Vacuum)

RF Contactor (Electric)



Emphasized figures



Correct

Wrong

only 150 μm difference

Fabrication Error and Recovery

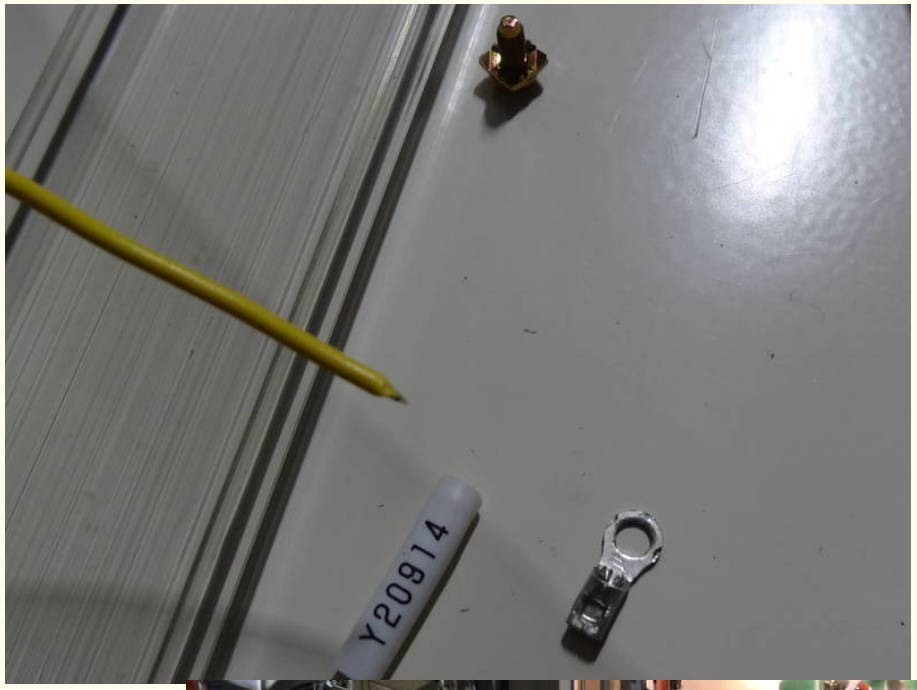
- September 2017
  - A large reflection was observed from the middle of waveguides in the low-power test
  - Fabrication errors in 58 waveguide flanges were identified
- October 2017
  - High power test was performed at a test stand
    - Discharge at the gap prevents the power only up to 10% of the nominal power

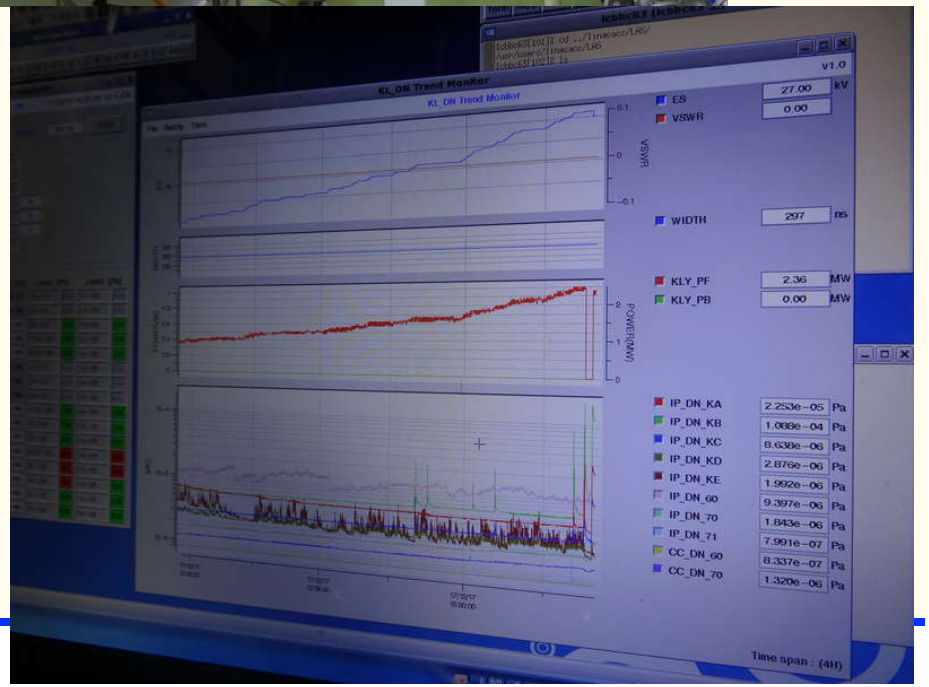
All 29 wrong waveguides were replaced; some were replaced with the ones with different length, others were newly fabricated

Fabrication Recovery

- Early October 2017
  - Removal of all erroneous waveguides from the tunnel
- Till November 2017
  - Fabrication, preparation and test of replacement waveguides
- Late November – early December 2017
  - Re-installation in between linac operation
- December 17 and 24, 2017
  - High-power verification of whole system in between DR construction
- January 2018
  - Intermittent RF conditioning in between DR construction
  - Reached nominal power for Phase 2 and 3 operation
  - Confirmed the designed energy compression of one third on LTR

LTR/ECS – RTL/BCS Waveguide Conditioning





Summary

- **New Pulsed Magnets**
  - Successful fabrication and installation of home-grown low-cost pulsed magnet system during 2017 summer shutdown
  - 1-month test was performed as scheduled
  - Experienced no large troubles so far and enabled stable simultaneous accelerations with different energy beams
- **Erroneous Waveguides**
  - Replacements of 29 waveguides were performed successfully even during light source operation and SuperKEKB commissioning / construction
  - Achieved the designed energy compression without any harmful impact against DR commissioning
- **Injector is ready for Phase-2 commissioning**

Thank you