Upgrade of KEK Electron/Positron Linac for the Both SuperKEKB and Light Sources

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SuperKEKB Injector Upgrade and past KEKB

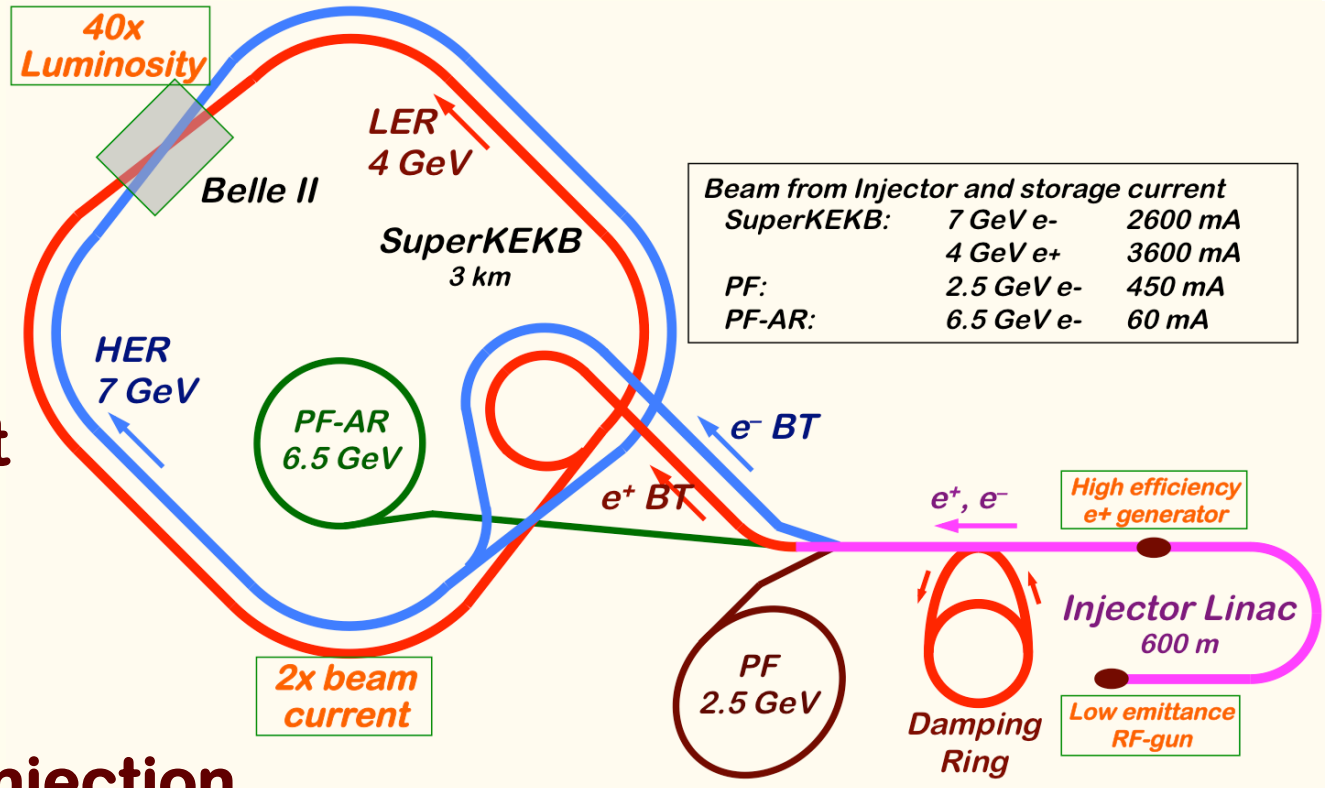
SuperKEKB Injector Linac Construction

Injector Linac Commissioning

Injector Linac Operation Consideration

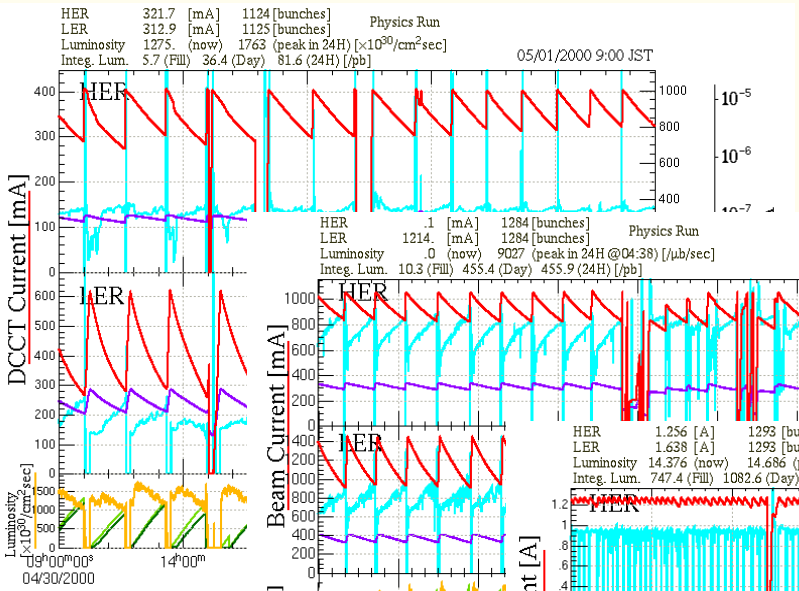
Mission of electron/positron Injector in SuperKEKB

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

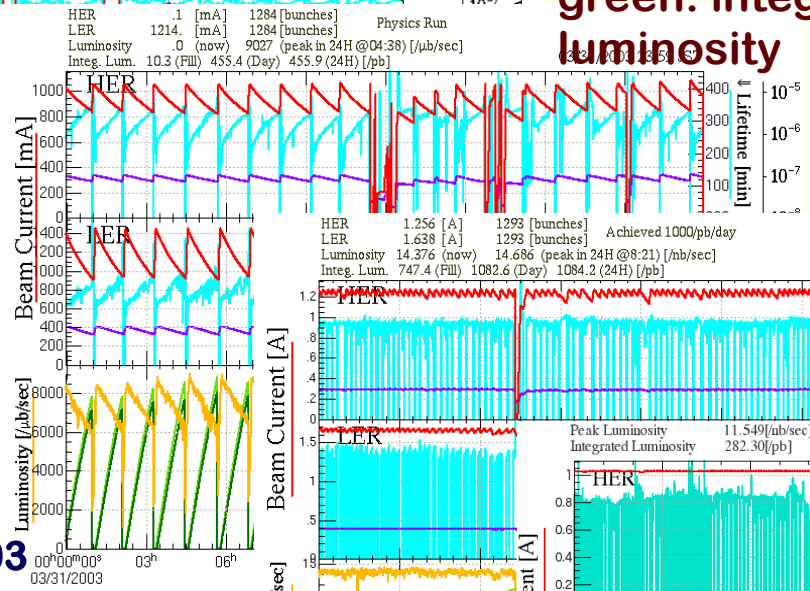


KEKB Operation Improvement (base of SuperKEKB)

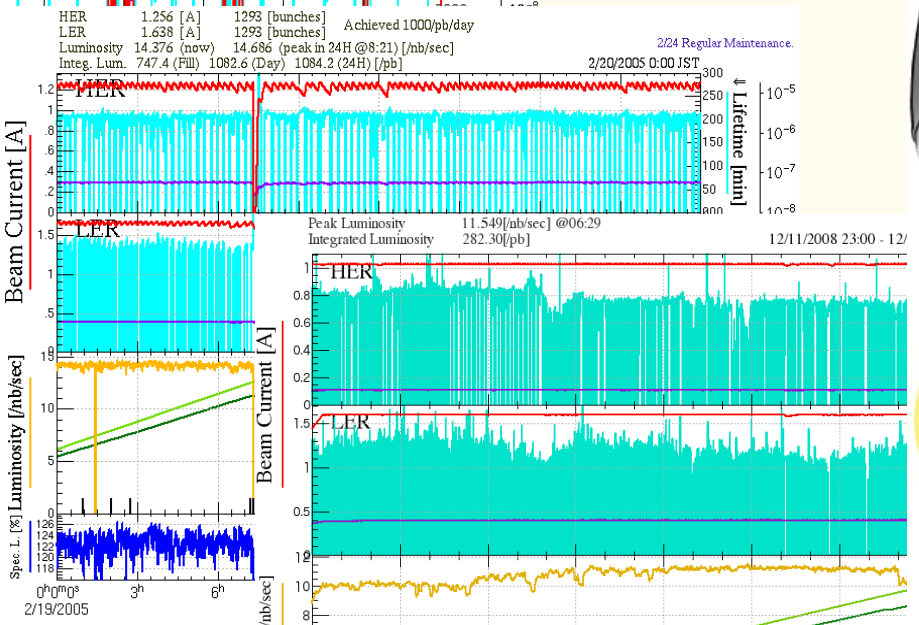
red: beam current (e-, e+)
purple: vacuum (e-, e+)
yellow: luminosity
green: integrated luminosity



May.2000

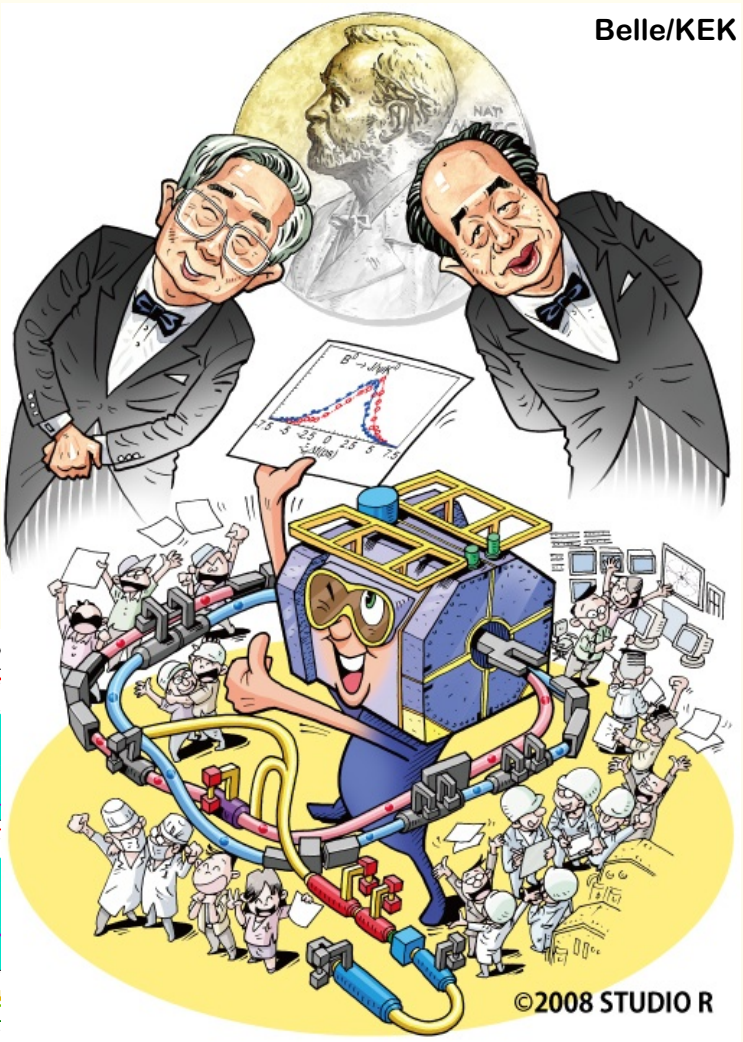


Apr.2003
Dual Bunch e+



Feb.2005
Continuous
Injections

Dec.2008
Crab Cavities and
Simultaneous Injection



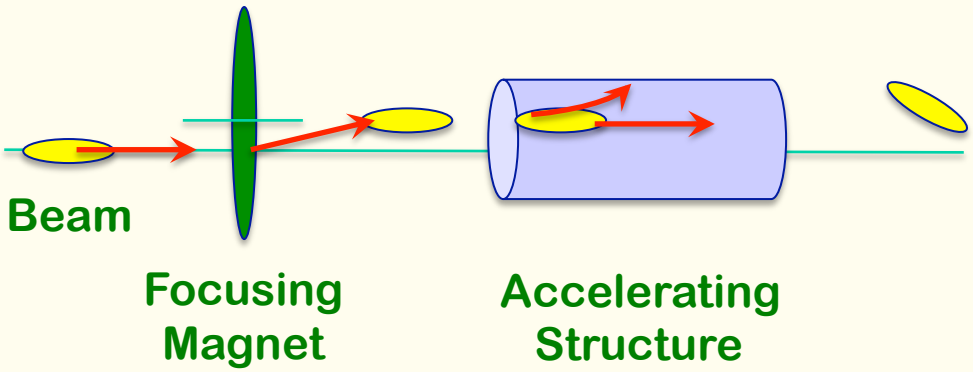
Keeps world luminosity record
2.1×10^{34}

Required injector beam parameters

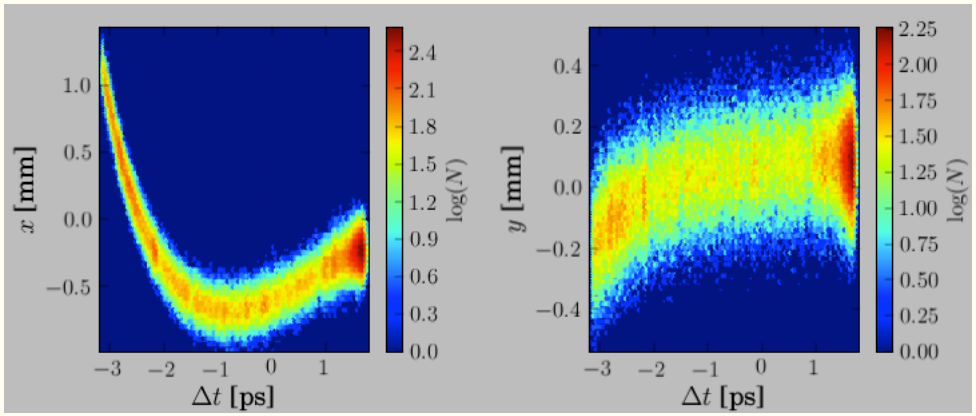
Stage	KEKB (2010)		Phase-I (2016)		SuperKEKB (final)	
Item	e+	e–	e+	e–	e+	e–
Energy	3.5 GeV	8.0 GeV	4.0 GeV	7.0 GeV	4.0 GeV	7.0 GeV
Bunch charge	Primary e-10nC → 1 nC	1 nC	Primary e-8nC → 0.4 nC	1 nC	Primary e-10nC → 4 nC	5 nC
Norm. Emittance ($\gamma\beta\varepsilon$) (μrad)	2100	200	2400	150	100/20 (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	3 rings (KEKB e–/e+, PF)		No top-up		4+1 rings (SuperKEKB e–/e+, DR, PF, PF-AR)	

Emittance Preservation and Alignment

- If Device is off center of the beam
  - Focusing magnet (quad) kicks the beam bunch
  - Accelerating structure (cavity) excites wakefield, to bend the tail
- Distorted bunch in banana shape
  - Emittance dilution or blow-up, even 100 times larger
    - Depending on the beam optics and the beam charge
- Alignment and orbit correction is crucial to preserve the emittance
  - The effect is proportional to the square of beam charge, 1 nC → 5 nC



Sugimoto et al.



Transverse beam distribution in time direction

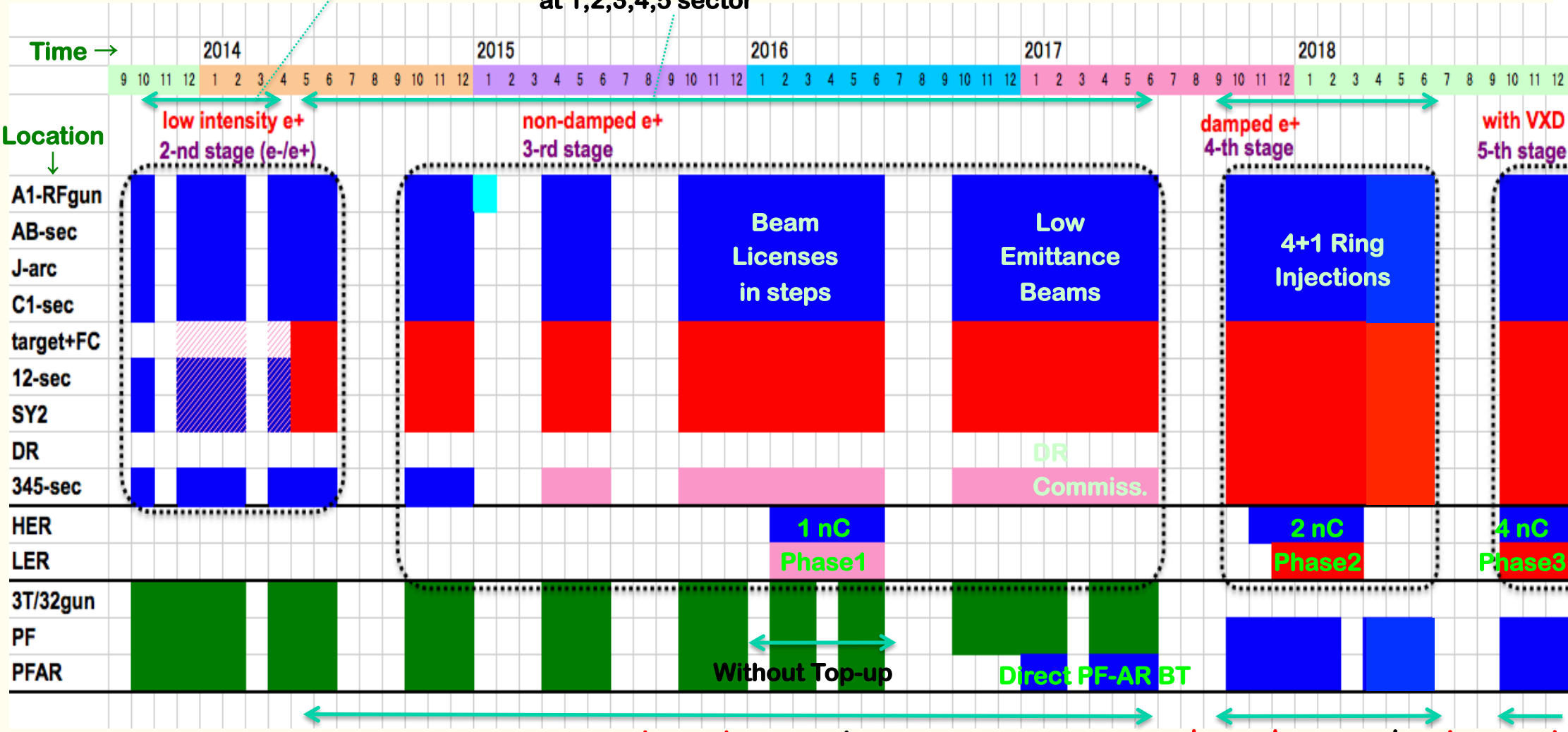
Linac Schedule Overview

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

Improved RF gun

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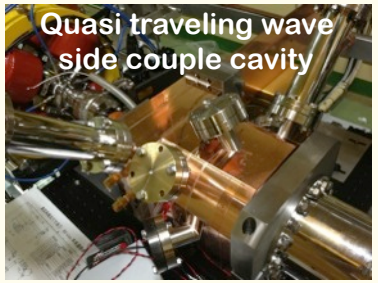
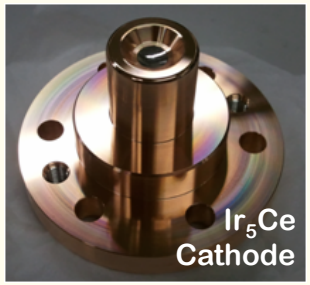
Linac Upgrade Progress towards SuperKEKB (1)

High-charge low-emittance RF gun development

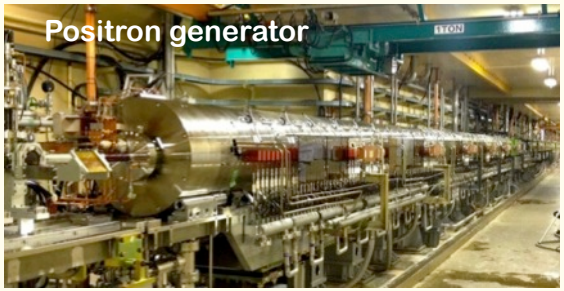
- QTWSC cavity and Ir5Ce photo cathode developments
- Laser development is underway





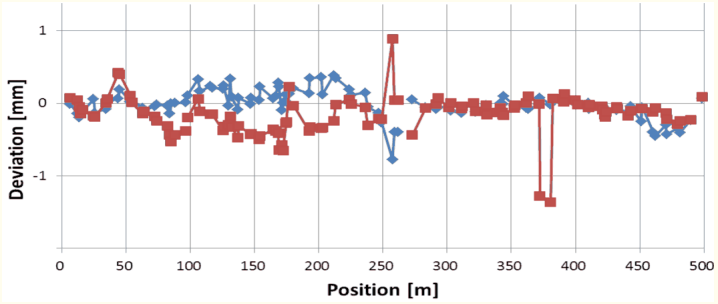
Positron generator commissioning

- 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 will be solved



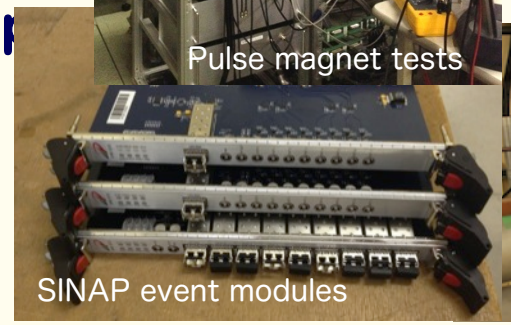
Utility upgrade during FY2014

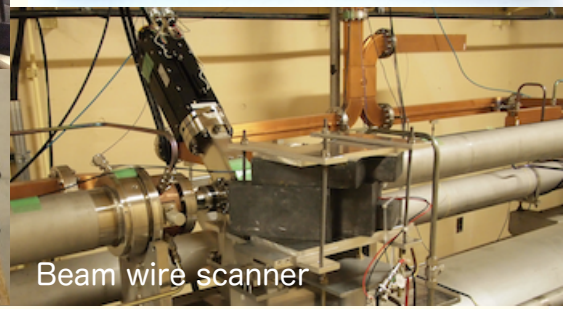
- for electricity (+1.5MW) and cooling water (+1400L/min)

Linac Upgrade Progress towards SuperKEKB (2)

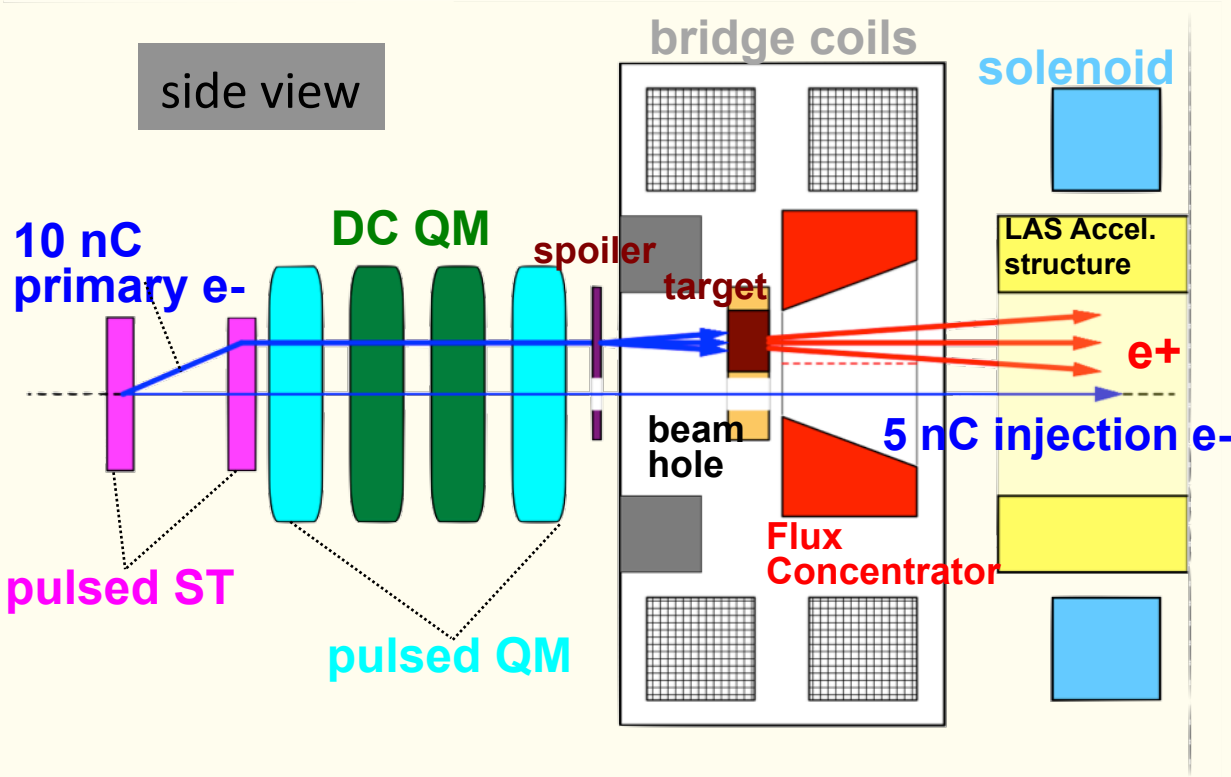
- High-power microwave modulator upgrades
- Low-level RF controls/monitor upgrades
  - Pulse-to-pulse modulation (PPM) between 4+1 rings
  - More spaces for increased number of devices
- Beam instrumentation
  - Large/small aperture beam position monitors (BPM)
  - Precise/fast and synchronized BPM readout 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 up
  - Combination of MRF & SINAP modules
  - Essential for PPM operation
  - Precise timing & synchronized controls
  - Bucket selection at DR and MR

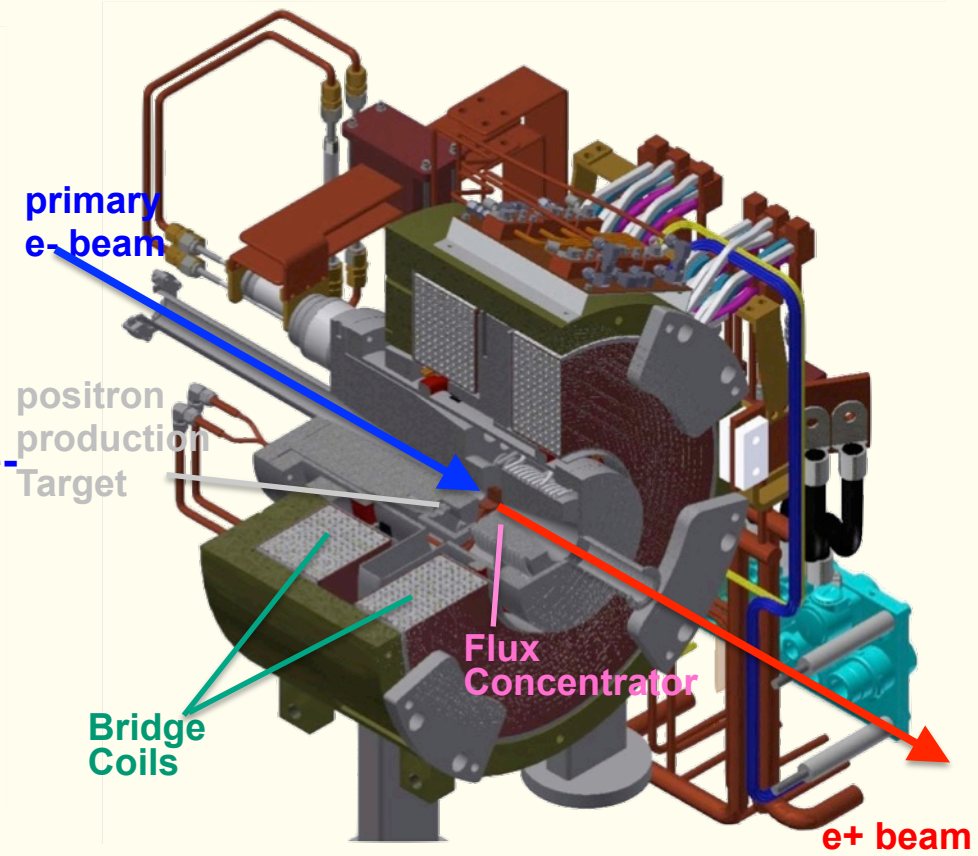

Pulse magnet tests


SINAP event modules


Beam wire scanner

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)
Resolving recent discharge difficulties at maximum field

RF-Gun development strategy for SuperKEKB

- **Cavity : Strong electric field focusing structure**
  - Disk And Washer (DAW) => 3-2, A-1(test)
  - Quasi Traveling Wave Side Couple (QTWSC) => A-1
  - Cut Disk Structure (CDS) => A-1 (test)

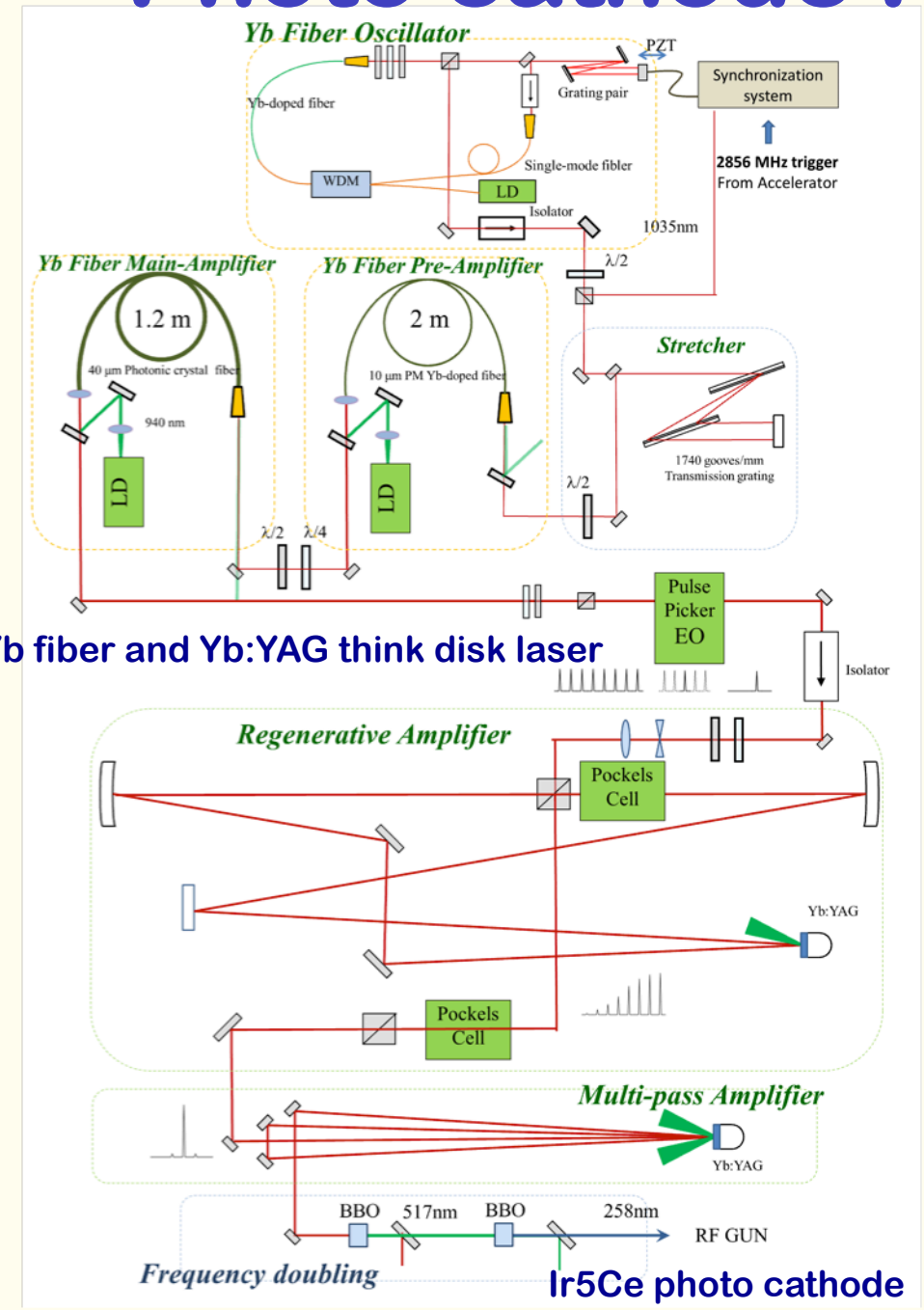
  => Reduce beam divergence and projected emittance dilution
- **Cathode : Long term stable cathode**
  - Middle QE (QE=10^{-4}～10^{-3} @266nm)
  - Solid material (no thin film) => Metal composite cathode

    => Started with LaB_6 (short life time)

    => Ir_5Ce (Ir_2Ce) has very long life time and QE>10^{-4} @266nm
- **Laser : Stable laser with temporal manipulation**
  - Fiber laser oscillator / amplifier = Yb doped
  - LD pumped laser medium => Nd / Yb doped
  - Temporal manipulation => Yb doped

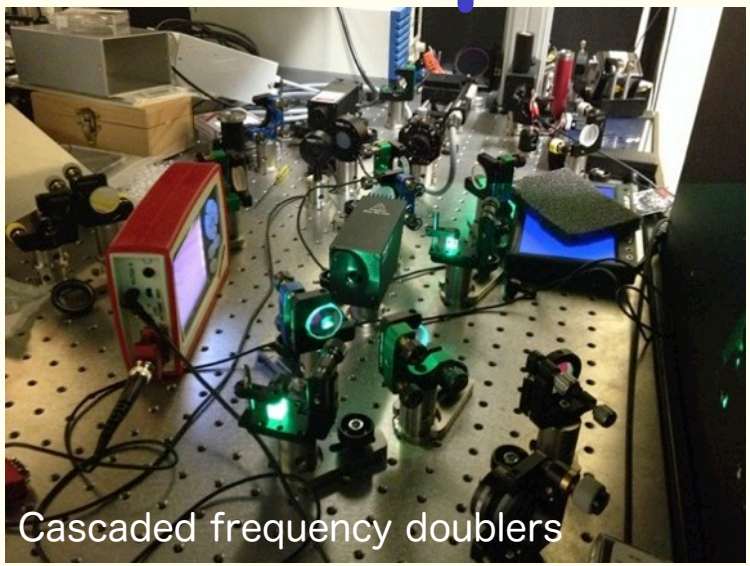
    => Minimum energy spread

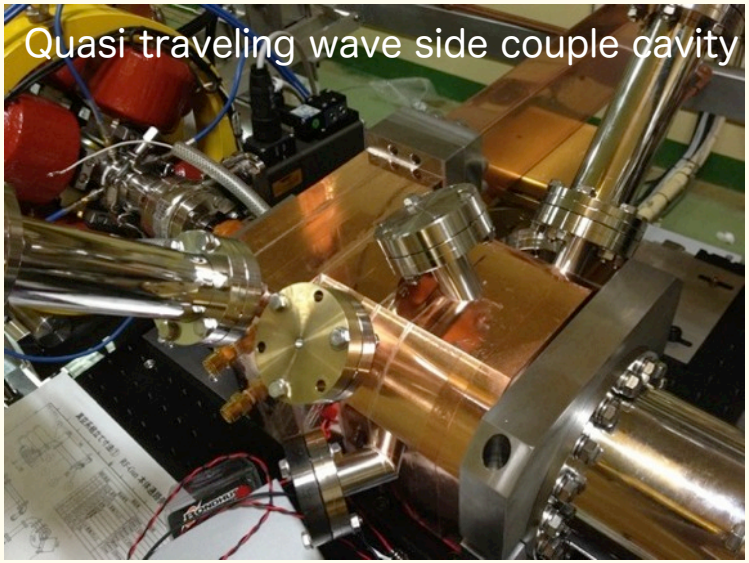
Photo cathode RF gun development

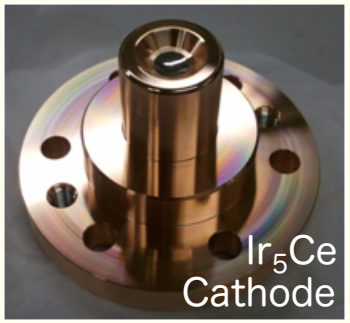


Yb fiber and Yb:YAG think disk laser

Ir5Ce photo cathode







- 5.6 nC / bunch was confirmed
- Next step: 50-Hz beam generation & Radiation control

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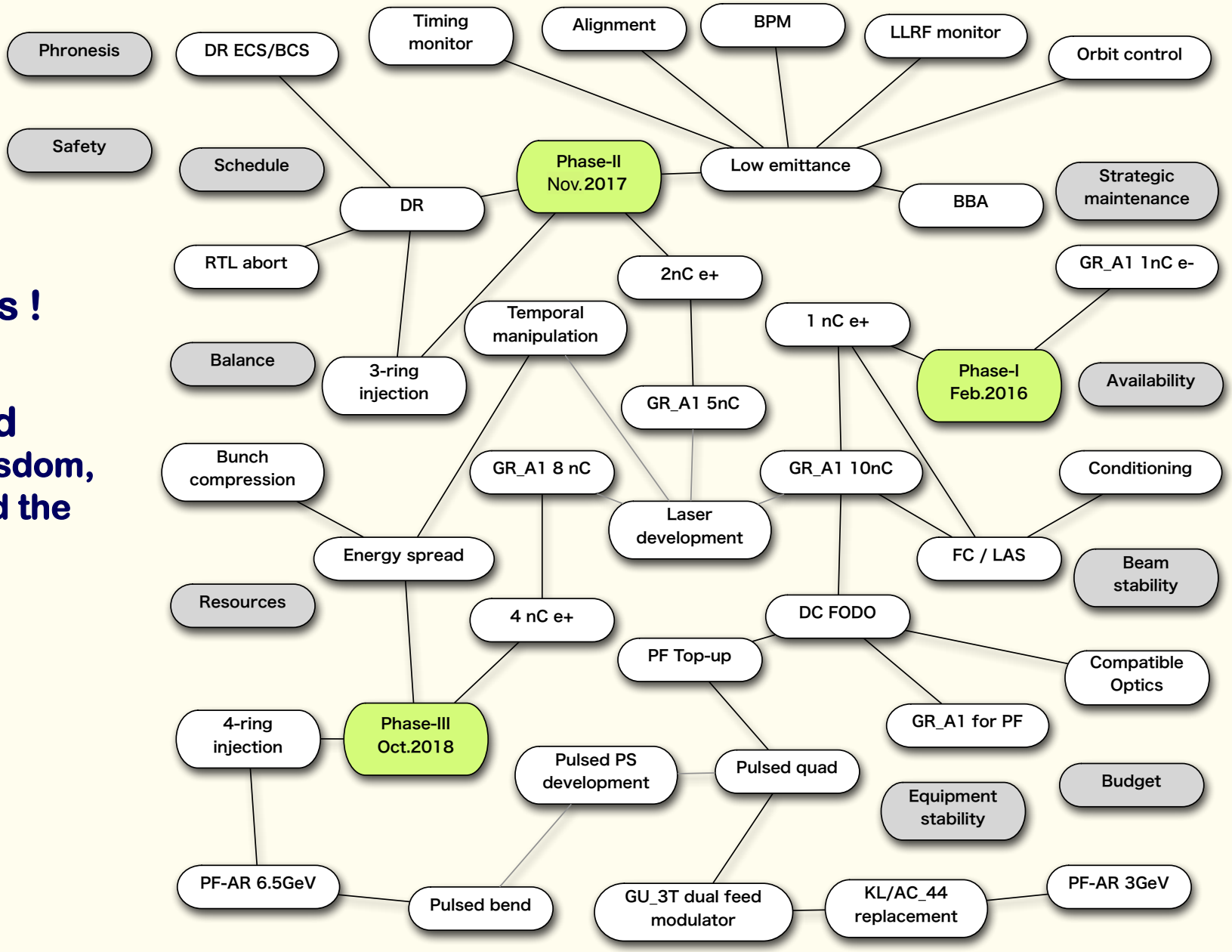
Subjects to Consider

- **Have to consider too many subjects !**
- **Phronesis needed**
  (Greek: Practical wisdom, Ability to understand the Universal Truth)



Energy management

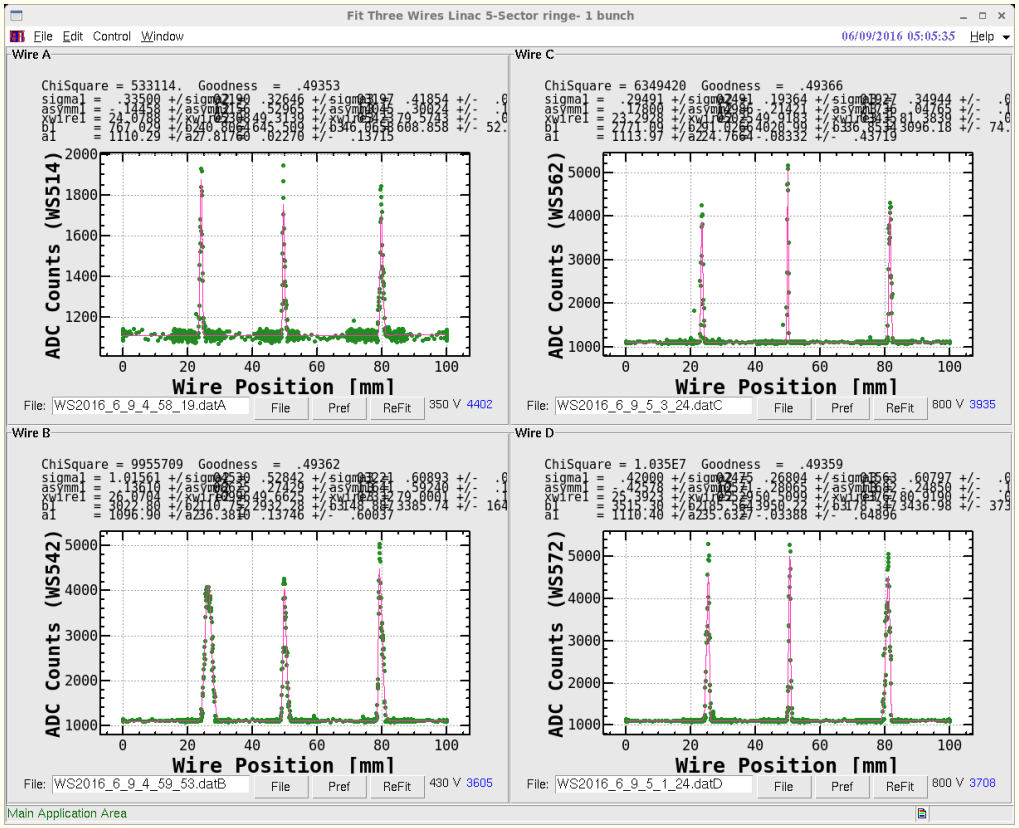
- **Beam at the end of linac is dependent on …**
  - maximum possible energy by accelerating structure
  - LLRF-beam crest
  - energy spread minimization condition by LLRF
  - vacuum, discharge, power-supply statistical conditions
    - reviewed daily to protect equipment
- **Energy profile along linac affects …**
  - overall beam optics conditions
  - emittance, stability, …

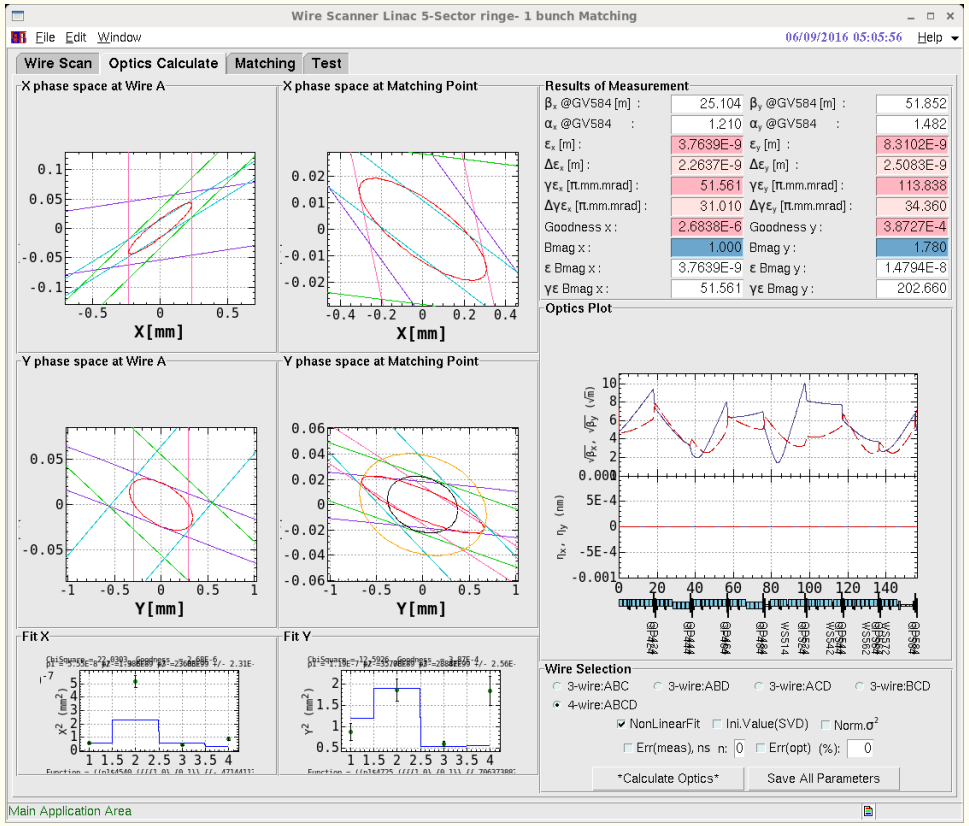
Emittance management

- **Beam emittance is dependent on …**
  - equipment alignment, 0.3mm for 500m, 0.1mm for 10m
    - alignment drift should be monitored
  - initial orbit to cancel beam profile distortion
  - beam energy profile along linac should be kept
  - beam position monitors for orbit-drift feedback loops
  - PPM operation between very different energies and charges
  - balance between fast/pulsed magnets and static magnets
  - continuous database improvement
  - algorithm should be polished

Linac Optics Measurement / Management

- Wire scanner is used to manage twiss parameters along linac
- ~6 sets of wire scanners will be installed





- Wire scanner measurements performed everyday
- If necessary (if "Bmag" is large), re-matching is performed by operator
- For pulse-to-pulse measurement, X-band deflector will be installed later

Typical SuperKEKB Phase-1 Daily Operation

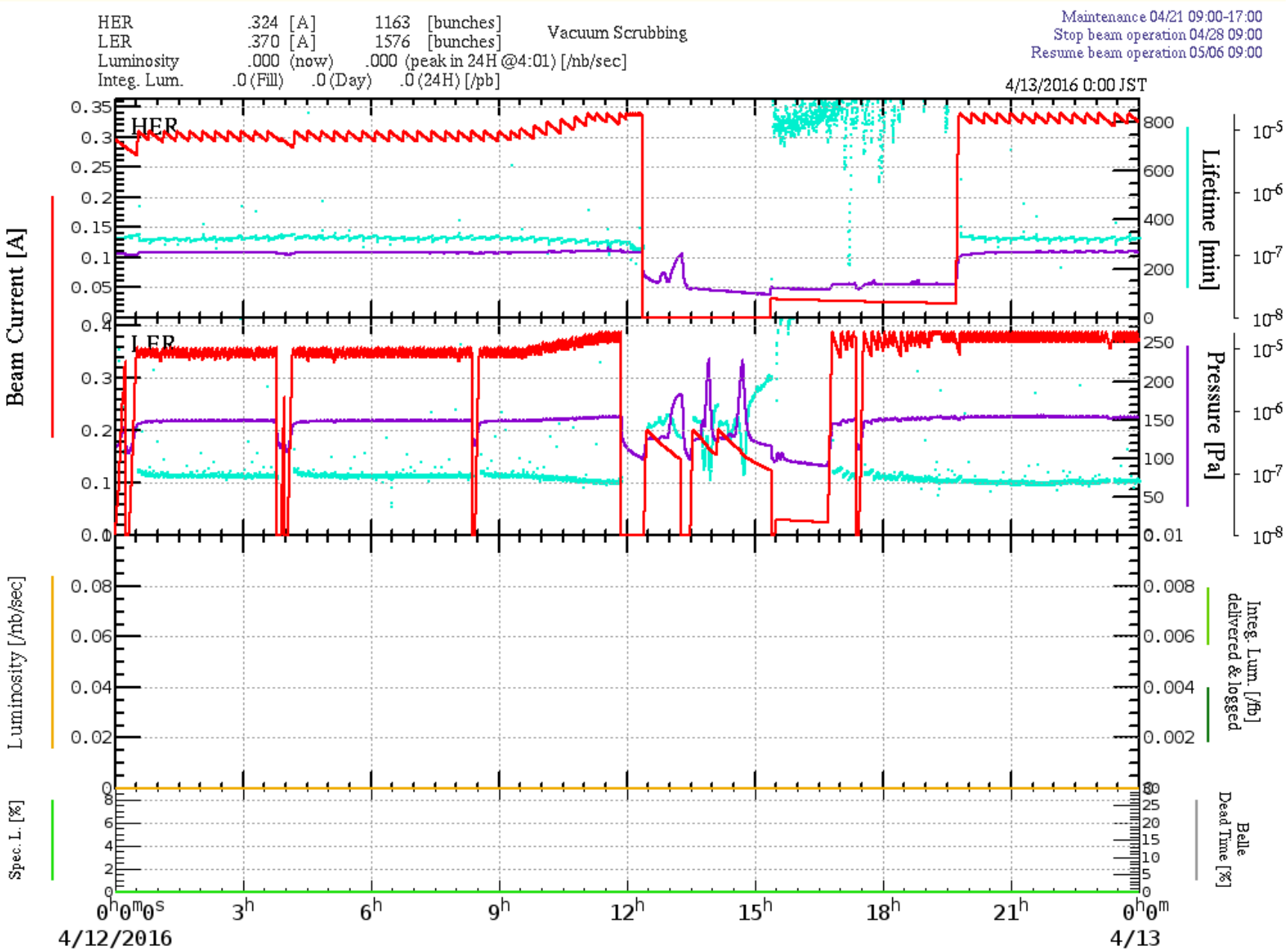
More than 300mA stored this week in the both e-/e+ rings (~1A in June)

In daytime increases beam current, and performs optics studies

In night time continue vacuum scrubbing

No collision yet

Collision expected at end of JFY2017



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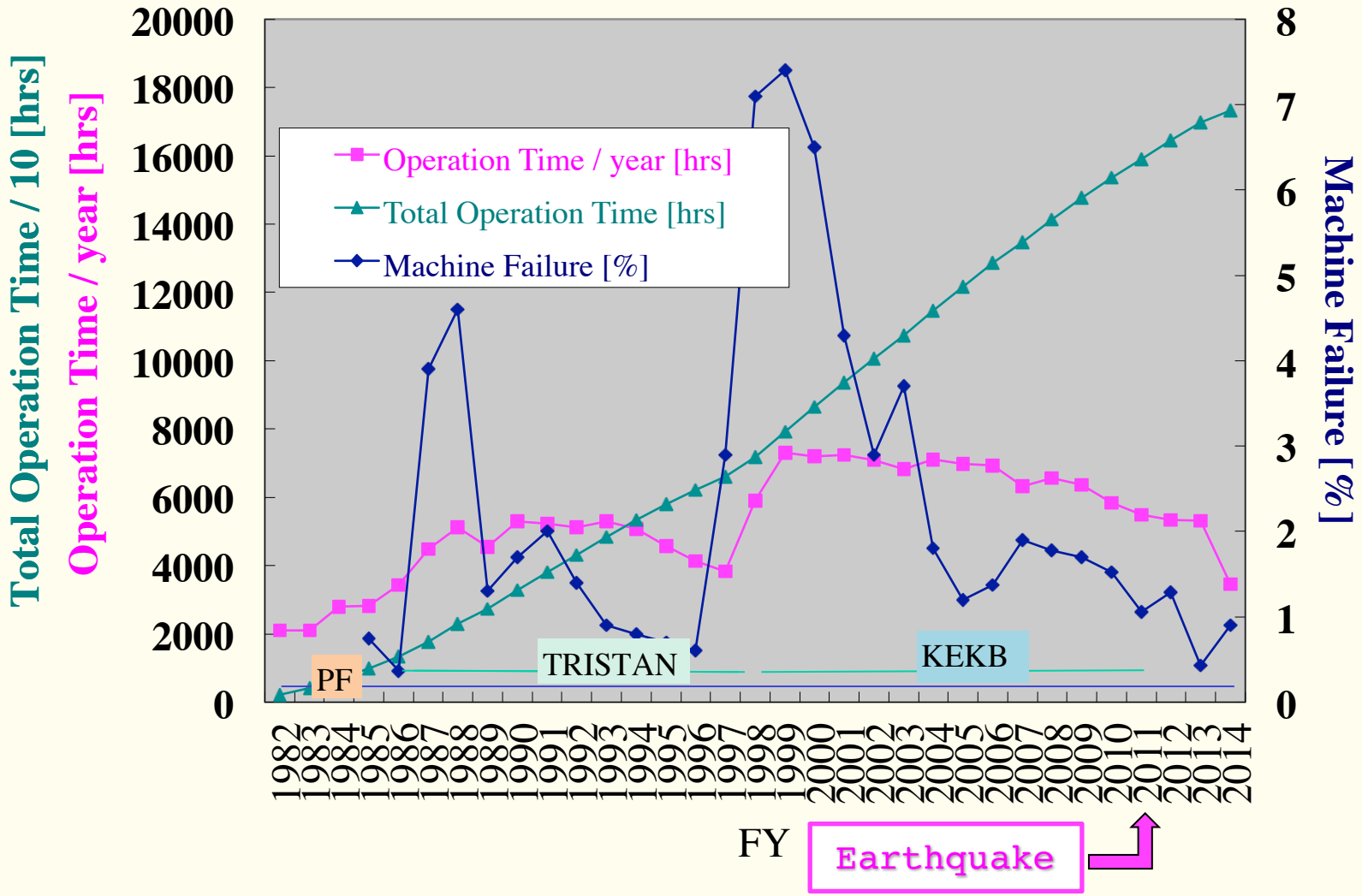
Radiation control licenses

- Step-by-step upgrade of beam limits
  - (Reduced during upgrade construction after KEKB injection)
- Final goal in linac is 1250/625 nA before/after target
- License applications
  - Fall.2013. 10 nA at #28 dump, 1250 nA at #A2 dump
  - Spring 2014. New utility rooms, 50 nA at #61 straight dump
  - Jun.2015. 200 nA at #15 target
  - Early 2016. 800 nA at #15 target, 625 nA at #61
  - Sometime 2017.(?) 1250 nA at #15 target
- Shield, shield, shield, shield …
  - Gun, 180deg-arc, Target, Electron stopper, Collimator, etc.

Injector Linac Operation History



Routine maintenance was important to improve the reliability (Failure rate includes rf trips)

SuperKEKB and PF/PF-AR Injections

- **Particle physics experiment**
  - Long-term fixed user group
  - Performance oriented
  - For yearly integrated luminosity performance
  - Minimum prevention maintenance
  - Can develop common under-standing between experiment and accelerator groups
  - Enthusiasm for improvements
  - Everyday is a training
- **Photon science experiments**
  - Short-term and many groups
  - Stability oriented
  - For maximum performance during assigned beam time
  - Routine scheduled maintenance
  - Bit of distance between experiment and accelerator groups
  - Peaceful operation
  - Learn through document

- Light-source injection was performed even during SuperKEKB upgrade

Injection for Both Experiments

- Proper operation schedule to meet experimental characteristics of those storage rings
- Search for common ground with respect for those experiments
- Should find and confirm solutions in gradual changes
- Improve the machine using virtual accelerator concept, if applicable

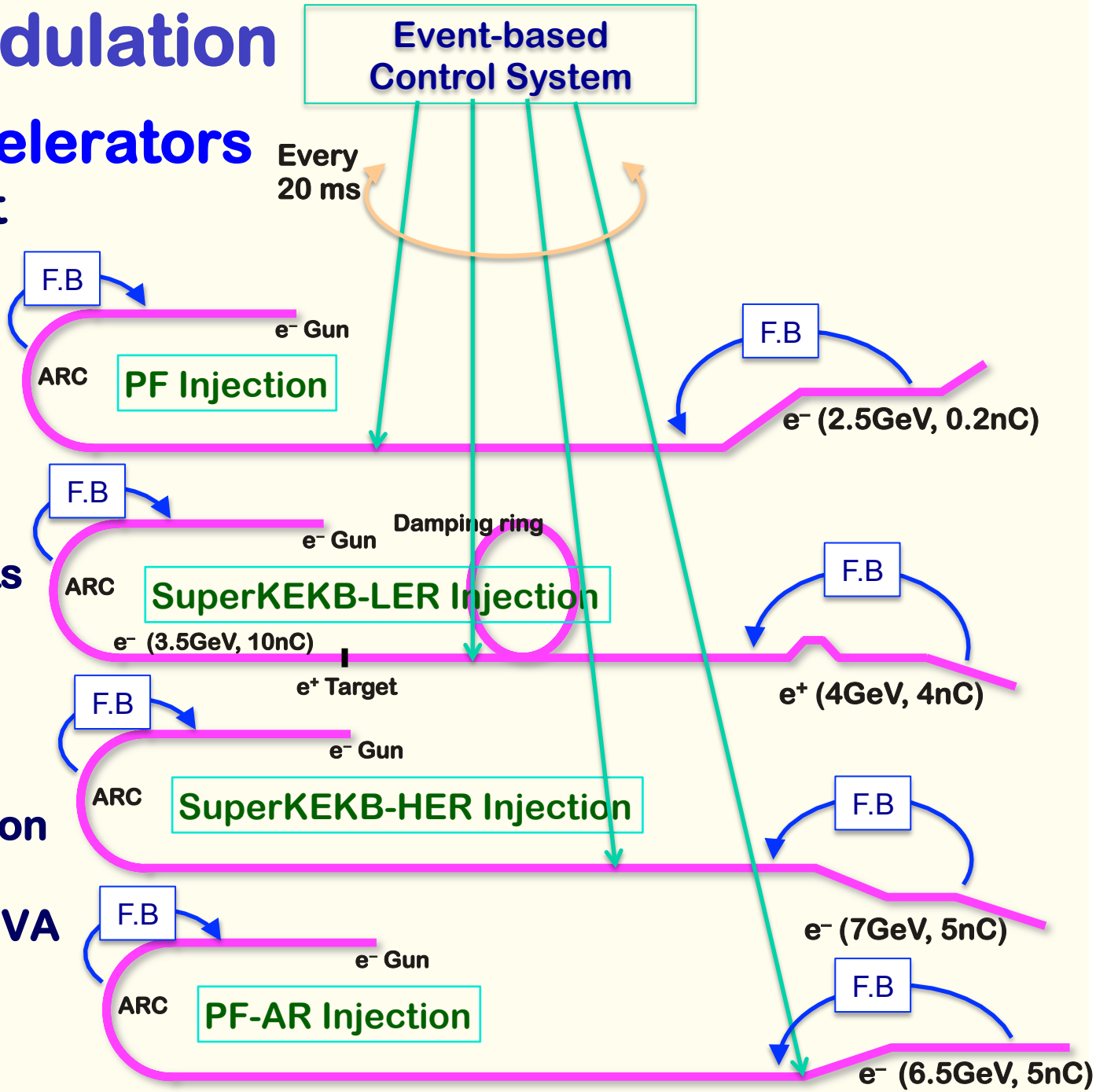
Pulse-to-pulse modulation

- **Four PPM virtual accelerators for SuperKEKB project**

Based on
Dual-tier controls with
EPICS and event-system

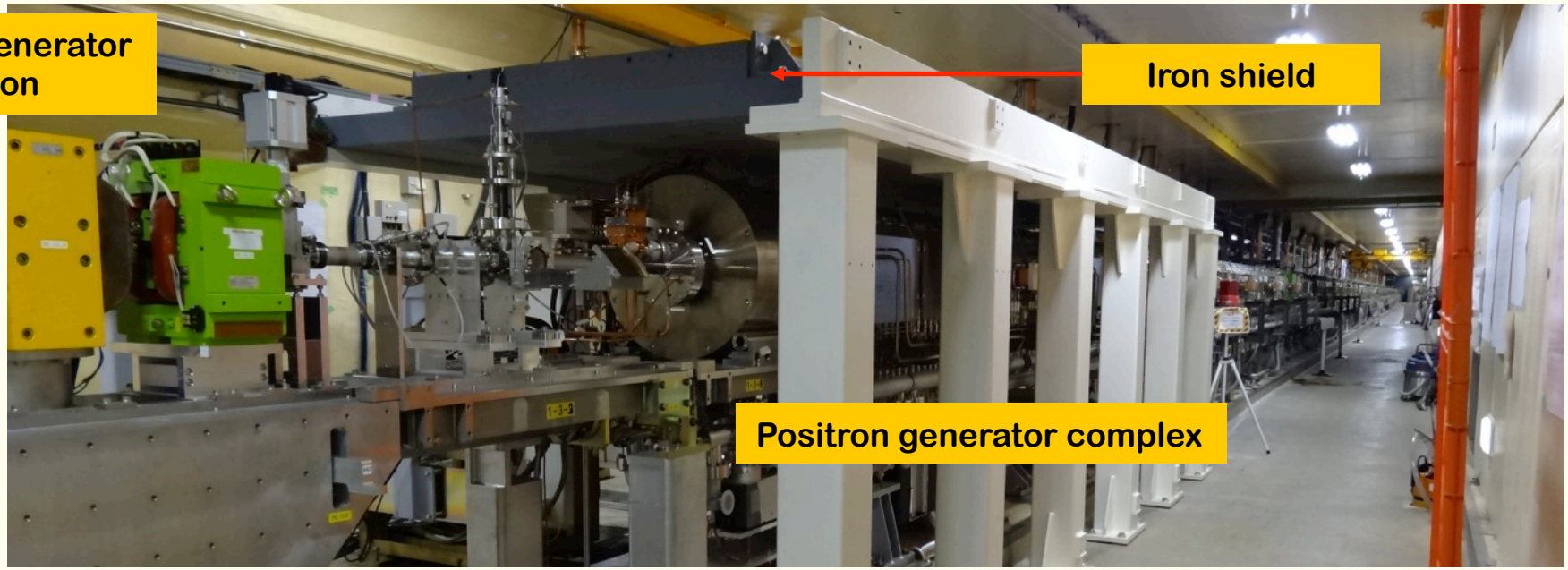
Independent parameter sets
for each VA (20ms)
>200 parameters
for equipment controls
many more
for beam instrumentation

maybe with additional PPM VA
of stealth beam
for measurement

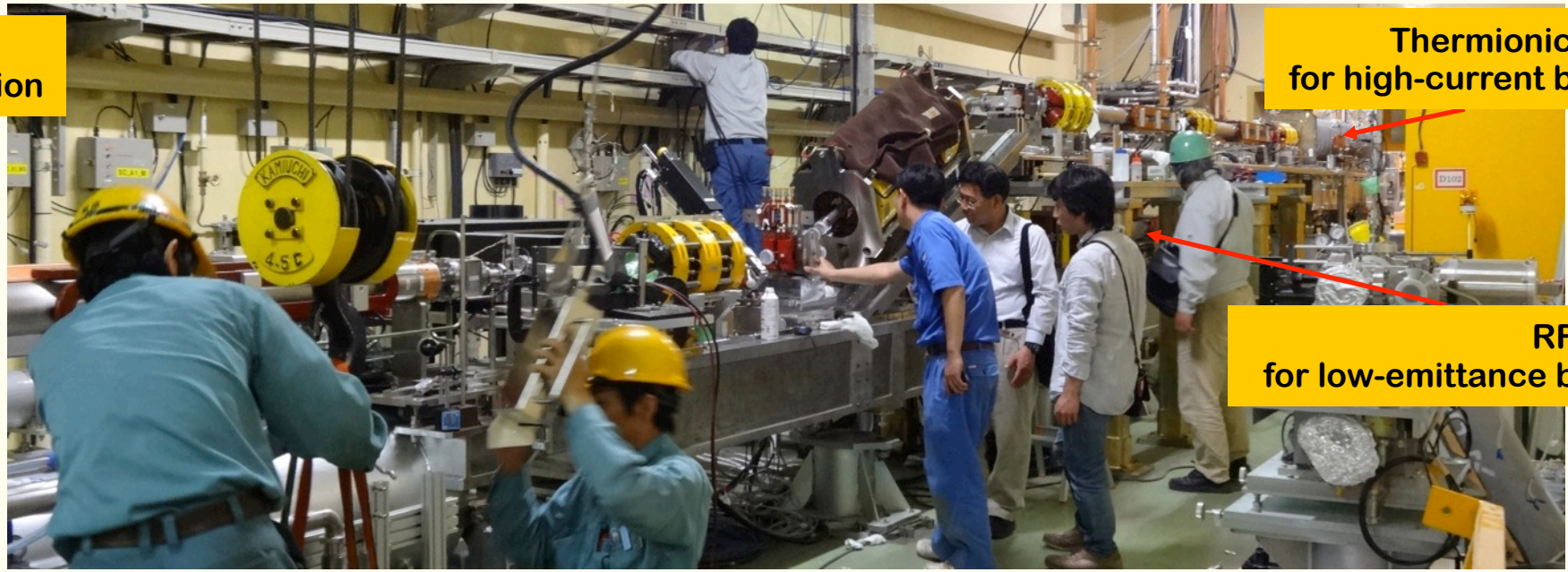


Field works on busy days

Positron generator at #15 region

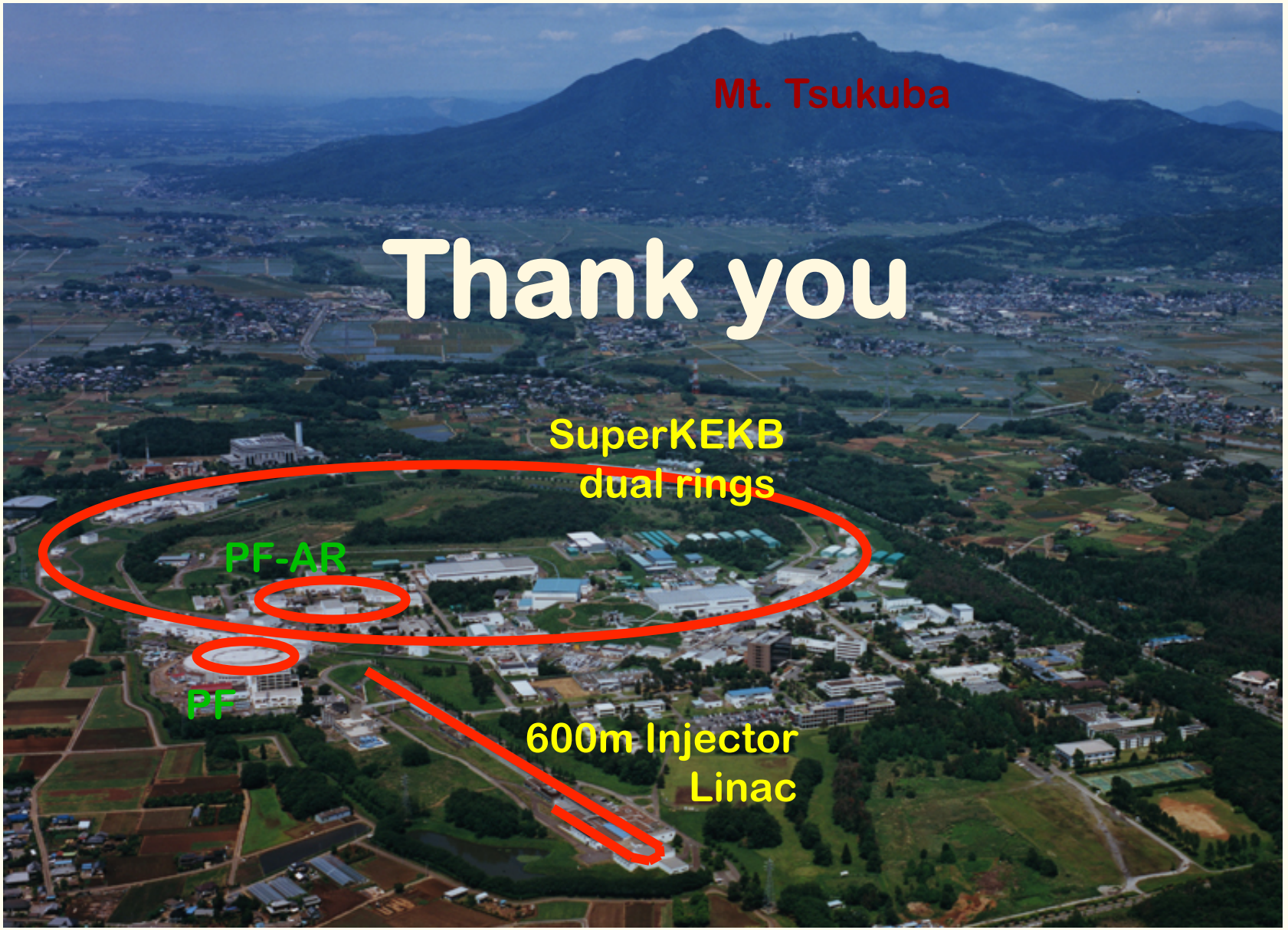


Guns at #A1 region



Summary

- We learned a lot during KEKB construction and operation
- It contributed to achieve the world highent luminosity
- Injection into SuperKEKB is another challenge with higher beam charge and lower 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
  - RF gun: following recommendations at review meetings
- Will balance between final beam quality and progressive operation
- Will balance between particle physics and photon science
- With some Phronesis we may enjoy beam commissioning



Conference papers at <http://www-linac.kek.jp/linac/>