Beam Property Management at SuperKEKB 7-GeV Injector Linac

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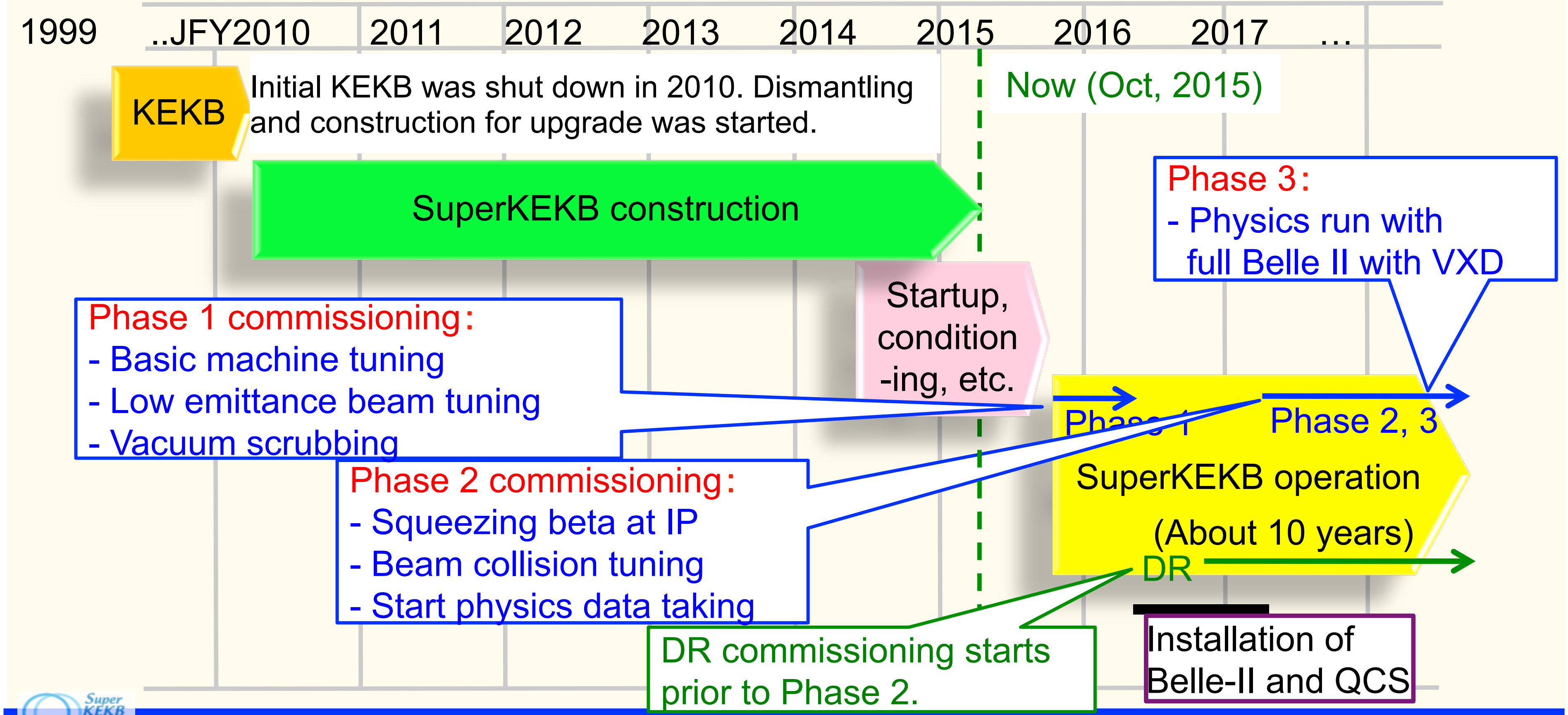
- Overview
- Linac
- Challenges
- Device property management
- Beam property management
- Conclusion

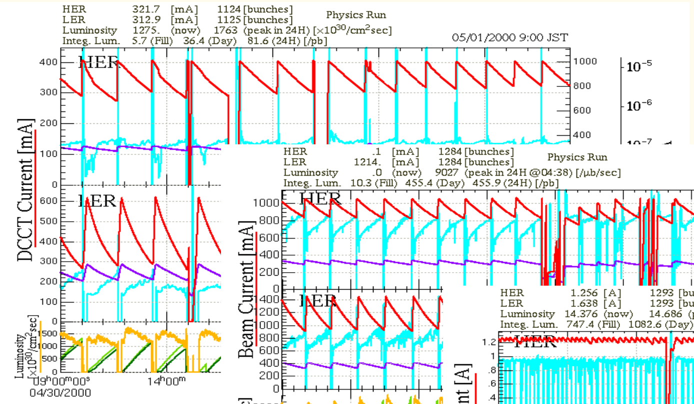
Linac Upgrade

SuperKEKB Schedule

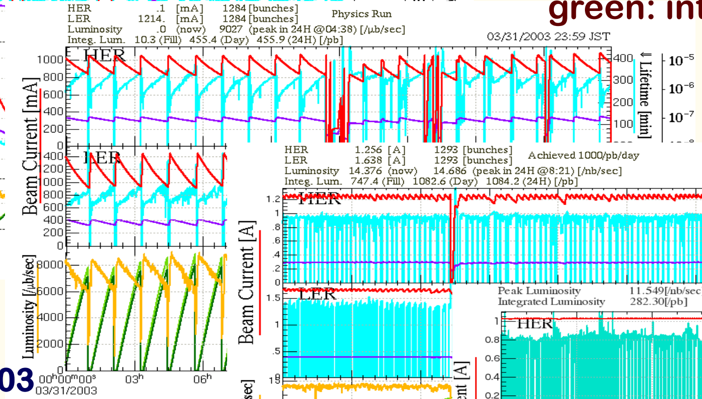


Initial KEKB Operation Improvements, base of SuperKEKB

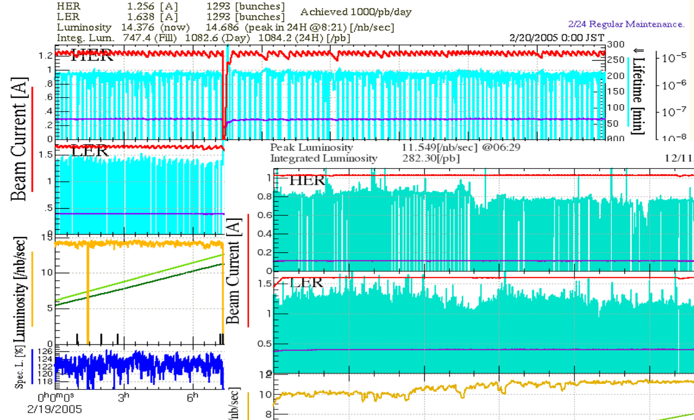
red: beam current (e-, e+)
violet: vacuum (e-, e+)
yellow: luminosity
green: integrated luminosity



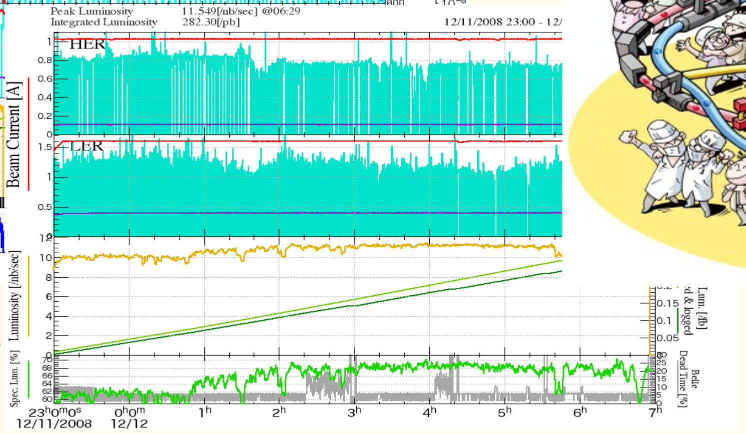
May.2000



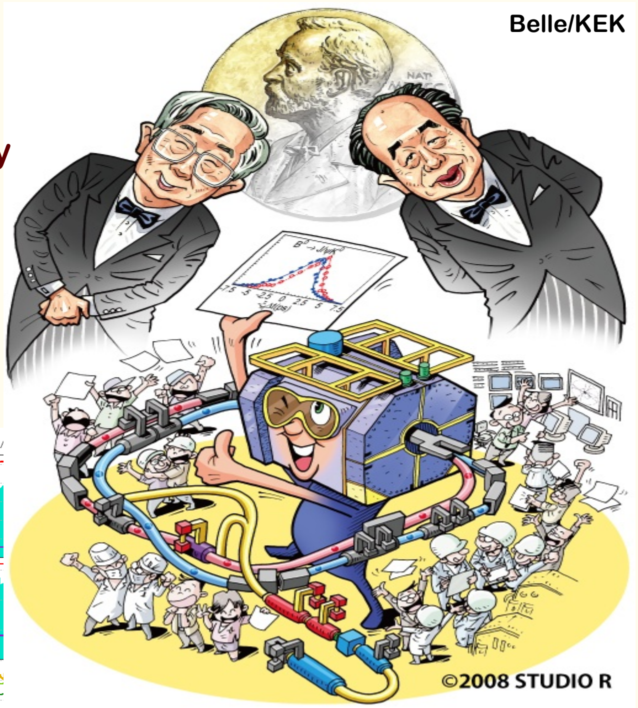
Apr.2003
Dual Bunch e+



Feb.2005
Continuous
Injections



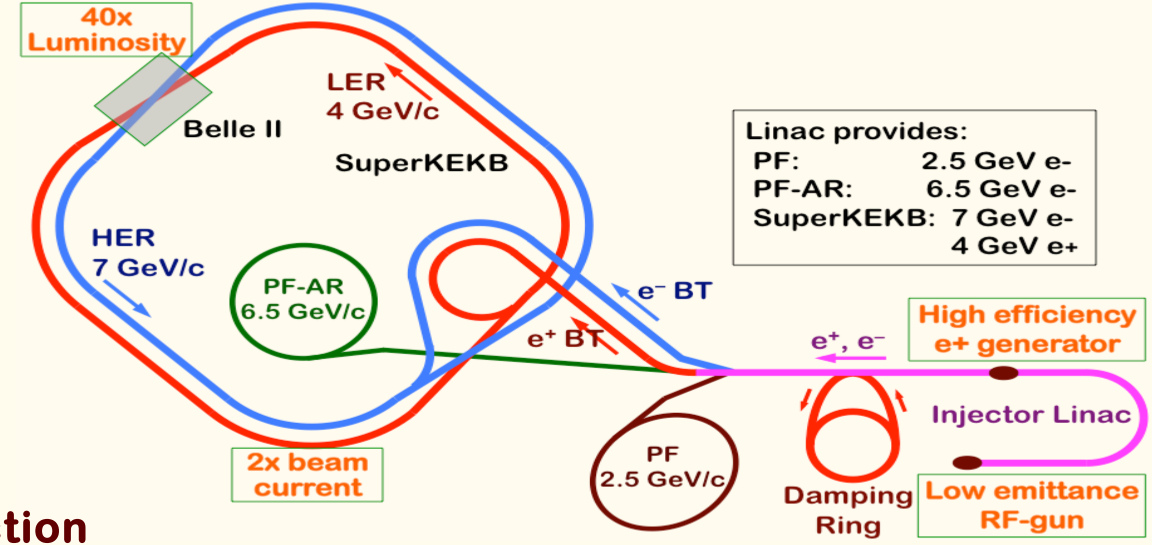
Dec.2008
Crab Cavities and
Simultaneous Injections



Still world highest
Luminosity

Mission of electron/positron Injector in SuperKEKB

- **40-times higher Luminosity for insight on the flavor structure of elementary particles**
  - 20-times higher collision rate with nano-beam scheme
    - → Low-emittance even at first turn → Low-emittance beam from Linac
    - → Shorter storage lifetime → Higher Linac beam current
  - Twice larger storage beam → Higher beam current at 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 design
  - Emittance preservation
    - with precise beam controls
  - 4+1 ring simultaneous injection

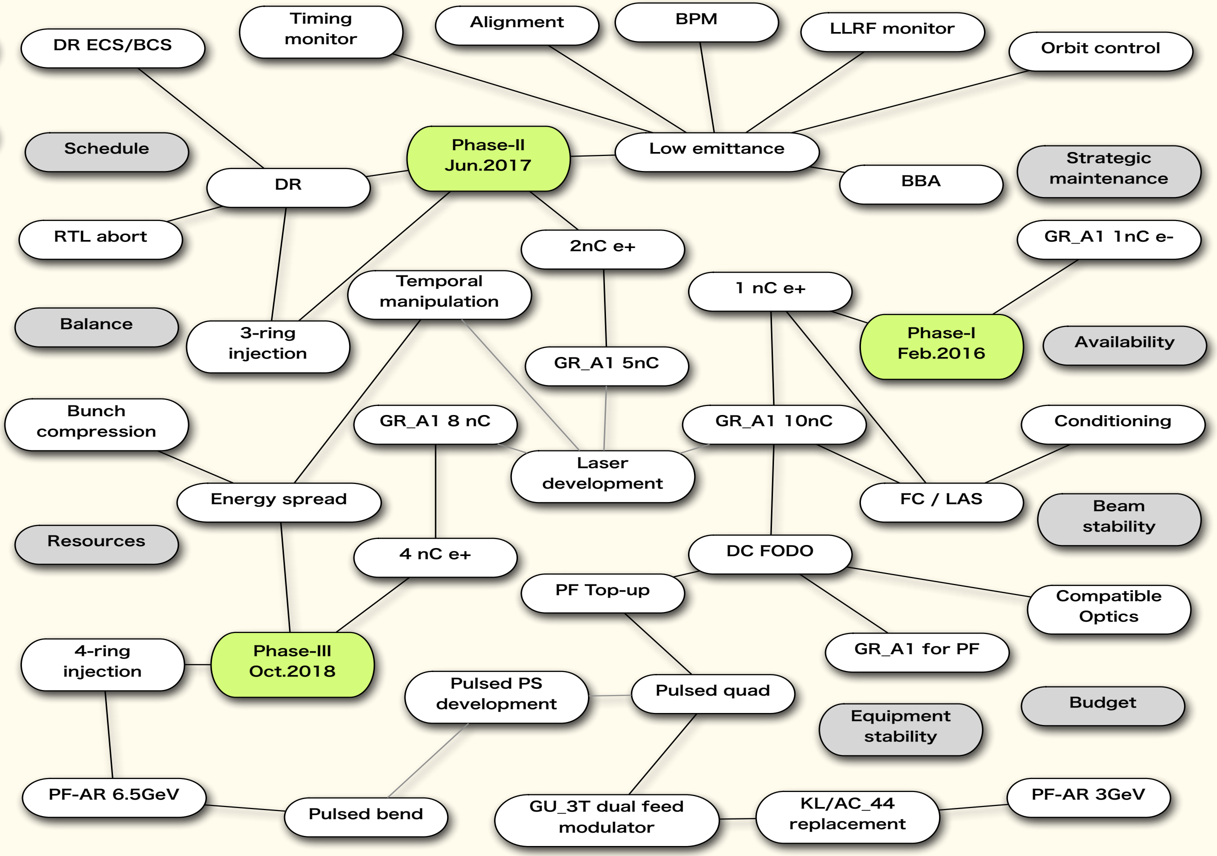


Designed Beam Properties

	SuperKEKB	(initial) KEKB
HER (e-) Energy (GeV)	7.0	8.0
LER (e+) Energy (GeV)	4.0	3.5
HER(e-) stored current (A)	2.6	1.1
LER(e-) stored current (A)	3.6	1.6
HER/LER beam lifetime (min.)	6	~200
Pulse repetition(max) (Hz)	50	50
Bunch per pulse	2	2
Emittance (mm·mrad)	20	100~1000
Beam charge (nC)	5	1
Energy spread (%)	0.1	0.125
Damping ring	for LER (e+)	n/a
Simultaneous Top-up	4 rings (SuperKEKB e-/e+, PF, PF-AR)	3 rings (KEKB e-/e+, PF)

Subjects to Consider

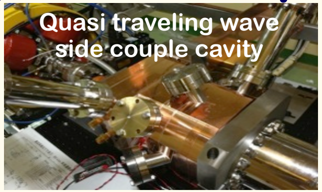
- **Too many subjects !**
- **Phronesis needed** (Greek: Practical wisdom, Ability to understand the Universal Truth)

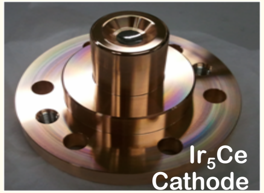


Linac Upgrade Progress towards SuperKEKB (1)

◆ High-charge low-emittance RF gun development

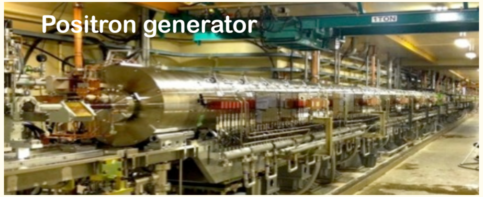
- ❖ QTWSC cavity and Ir5Ce photo cathode works well

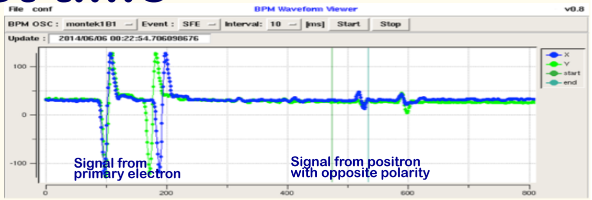




◆ Positron generation confirmation for the first time

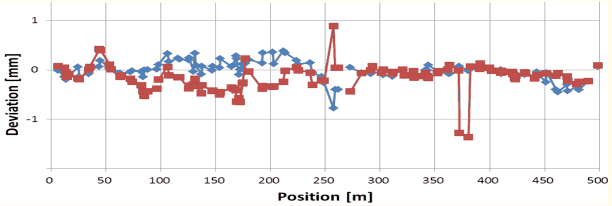
- ❖ Good agreement with the simulation results





◆ Precise alignment for emittance preservation

- ❖ Recovering after earthquake
- ❖ Reaching specification of 0.3mm

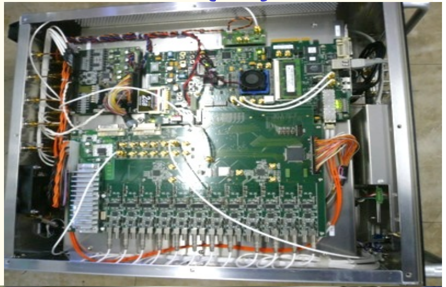


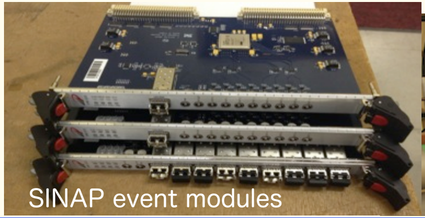
◆ Utility upgrade during summer 2014

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

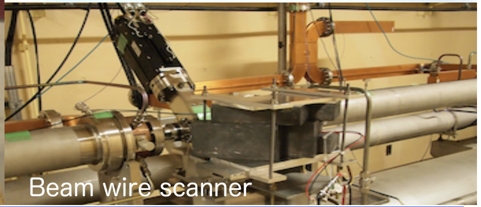
Linac Upgrade Progress towards SuperKEKB (2)

- **High power modulator upgrades**
- **Low-level RF controls/monitor**
  - 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.)
- **Event timing control system**
  - Combination of MRF and SINAP modules
  - Essential for PPM operation
  - Precise timing & synchronized controls
  - Bucket selection at DR and MR



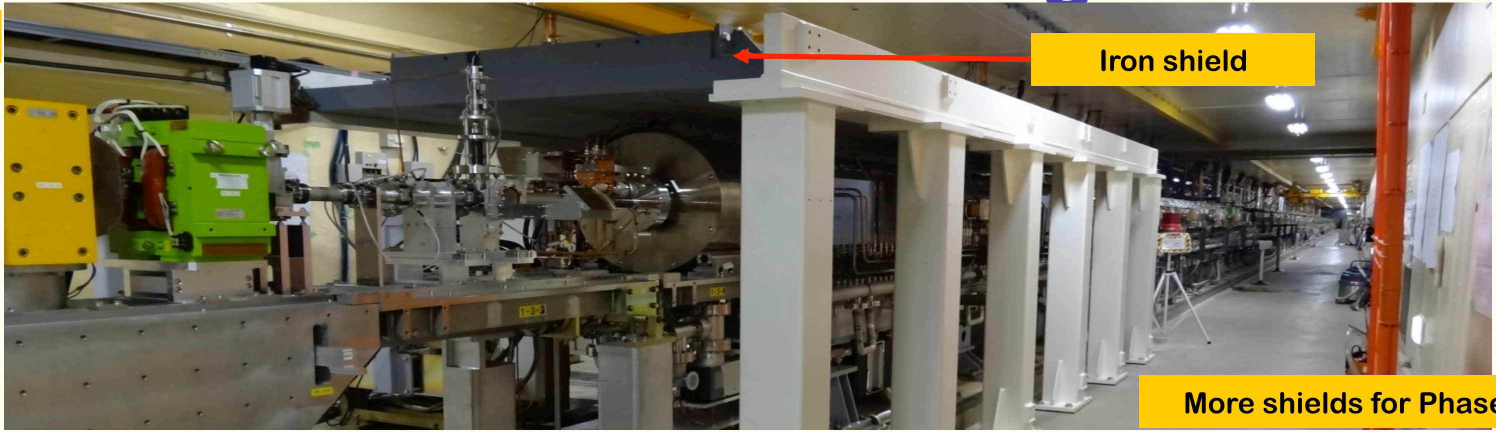


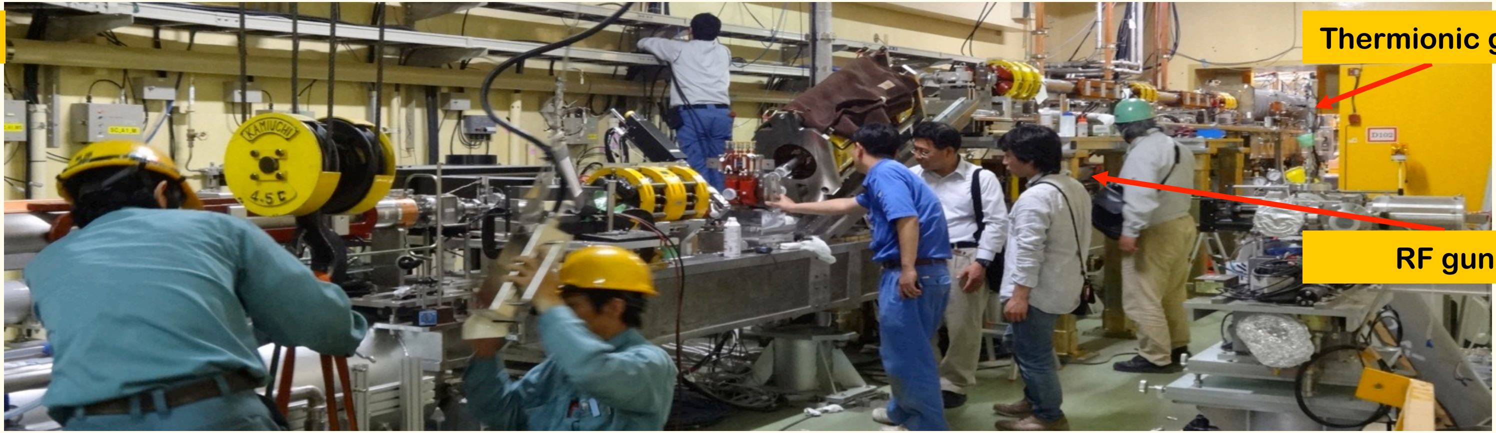
SINAP event modules



Beam wire scanner

Recent Works in Progress

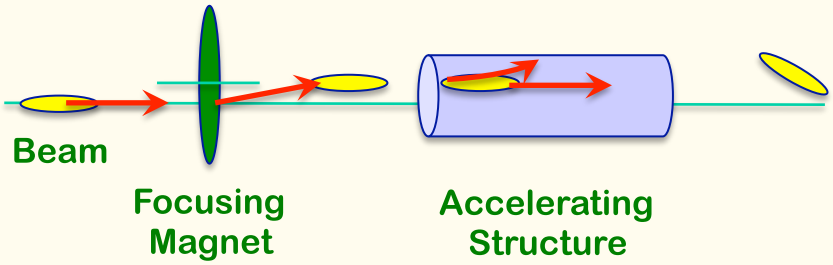




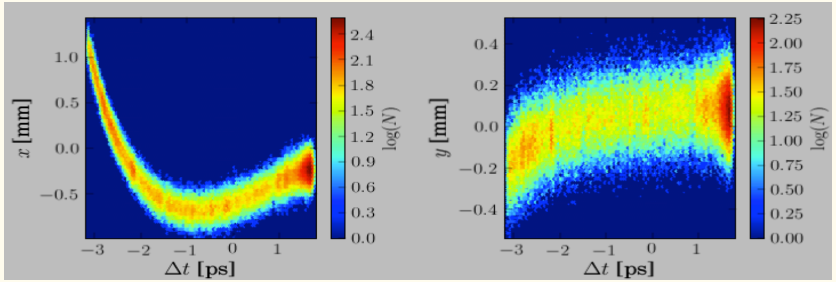
Device/Beam Property Management Challenges

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 beam tail
- **Distorted bunch in banana shape**
  - Projected 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**



Sugimoto et al.

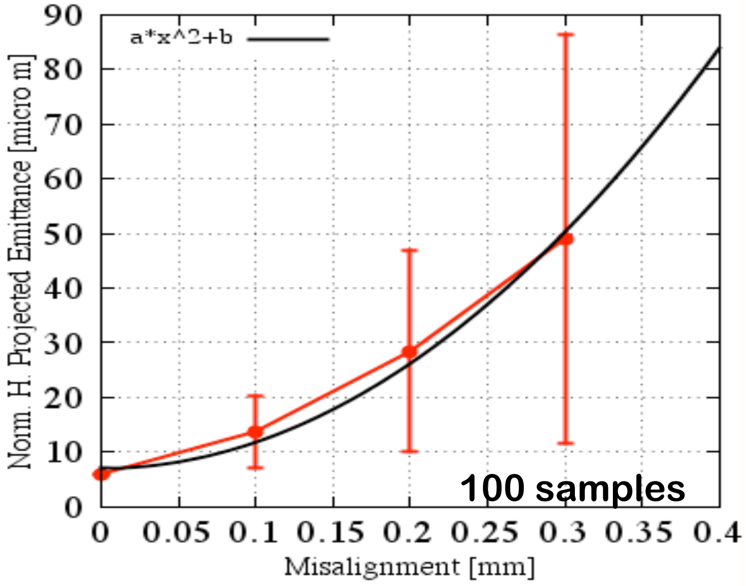


Transverse beam distribution in time direction

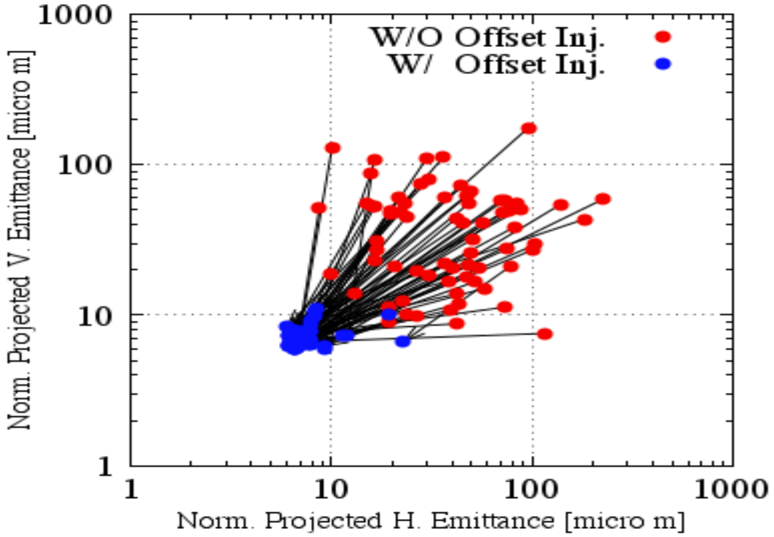
Emittance Preservation

- Initial offset controls should solve the issue
- Orbit have to be maintained precisely
- Mis-alignment should be <0.1mm locally, <0.3mm globally

Mis-alignment leads to Emittance blow-up



Orbit manipulation compensates it



Sugimoto et al.

SuperKEKB Controls

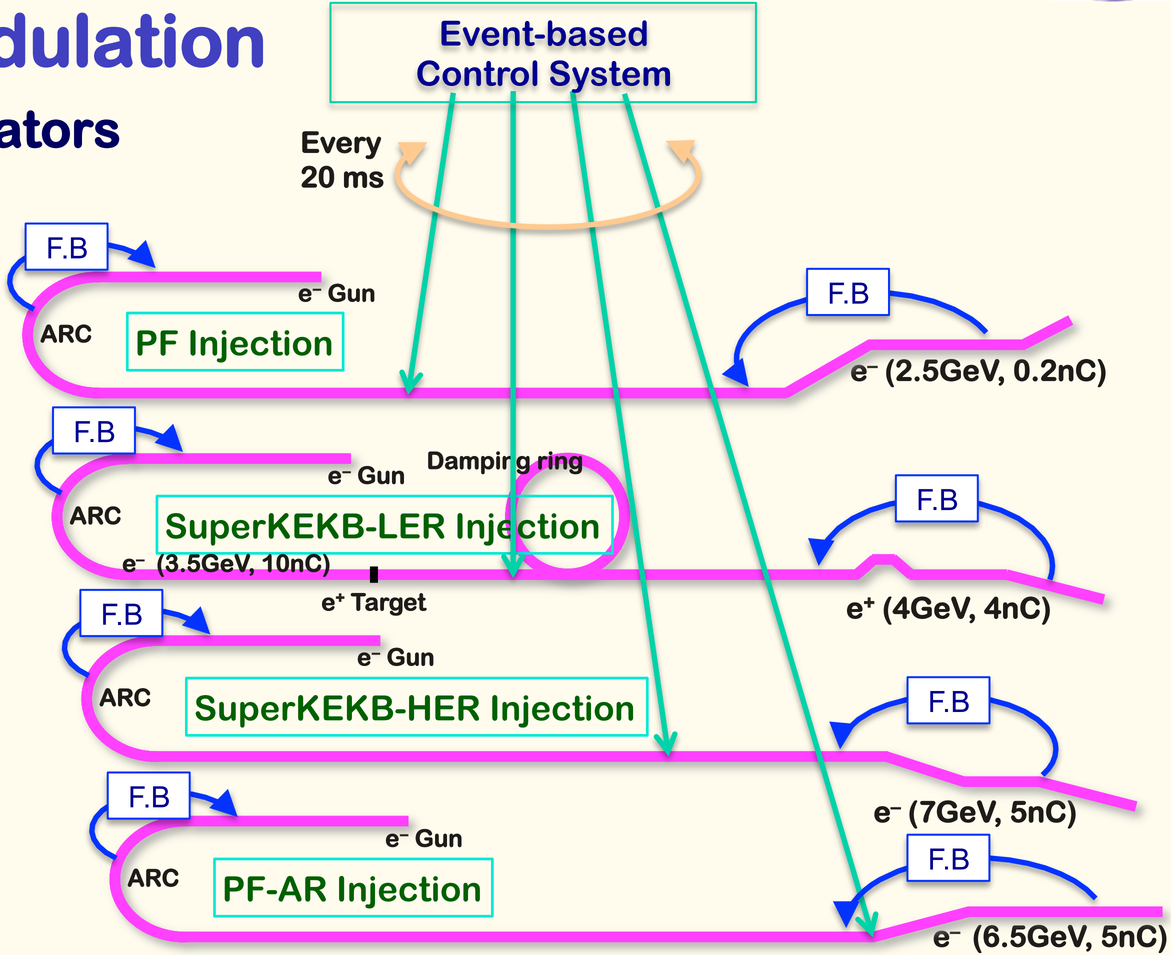
- Inherit Good part of KEKB Controls
  - EPICS
    - Robust basis, Software design efforts
  - Scripting languages
    - SADscripts, Python, … → Bright new idea to be realized in a day
- EPICS Channel Access (CA) Everywhere
  - Embed EPICS control software (IOC) everywhere possible
  - Reduce efforts on protocol design, testing, etc.
- Dual Tier: Another layer in addition to EPICS/CA
  - Event control system helps EPICS with another channel
  - Additional functionality, synchronization and speed

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 separate)
>200 parameters
for equipment controls
many more
for beam controls

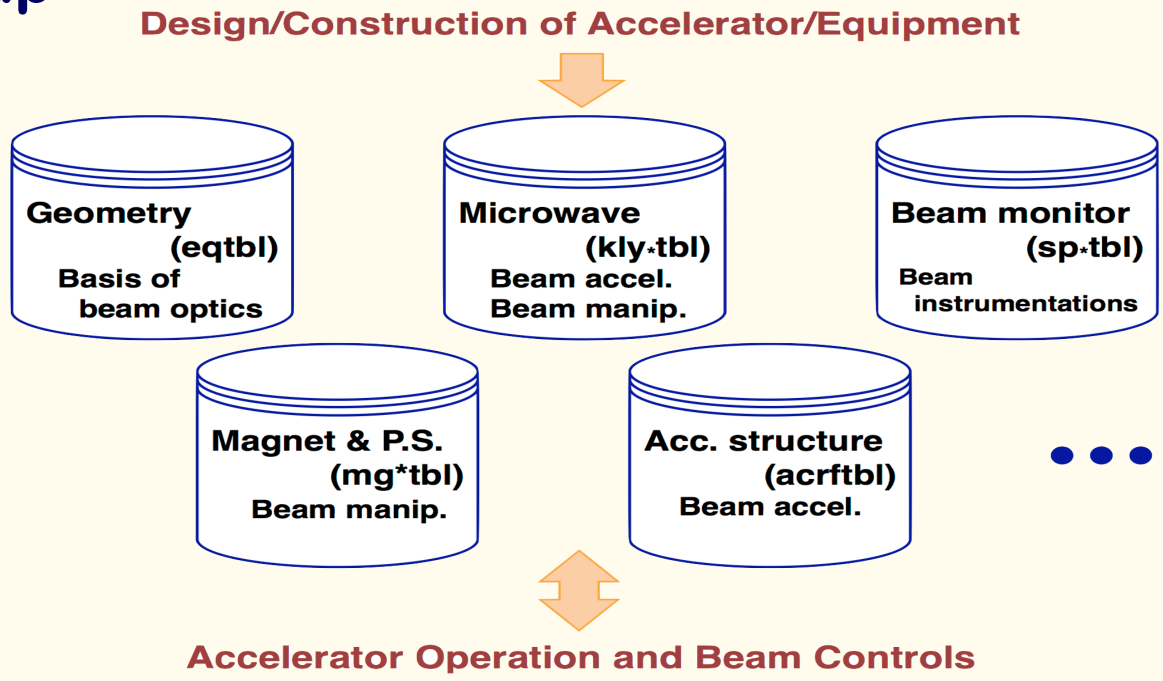


Controls for Beam Property

- Beam property management
  - Equipment property management
    - Calibration, Conversion, Local-closed-loop
  - Beam controls
    - Position/Orbit, Charge, Energy, Emittance
    - Beam/Equip. instrumentation statistics
    - Online simulation
      - Collection of qualified databases
        - Tight group collaborations
      - Polishing algorithms, databases
        - Daily operational meetings
        - Supervisory operational software
        - Protection systems

Database

- Collection of databases defines the accelerator machine
- Each equipment group is responsible for its database
- Controls group is responsible for database to be applied in operation



Database (example)

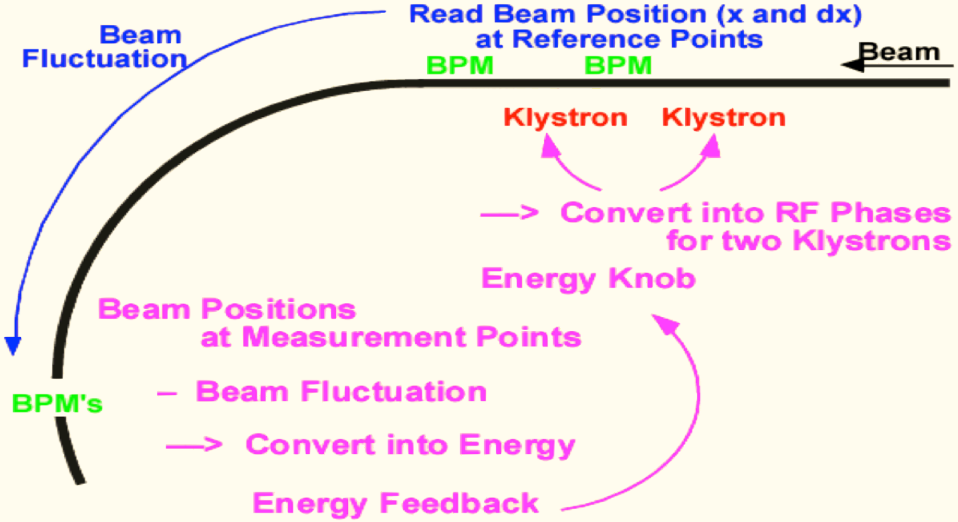
- **Magnets and power supplies**
  - beamline geometry (eqtbl)
    - including mechanical and effective length
  - hardware static information (mgtbl)
  - magnetic field excitation characteristics (mgbtbl)
    - polynomial function of degree up to nine at linac
      - Newton's method for inverse function
      - many other definitions are used in the ring for precision
      - current starts from zero, or starts from maximum
  - correction factors by beam operation (mgbftbl)
    - data analysis using online simulation code

Beam Feedback Loops

- Equipment has inherent instabilities caused by many sources
  - At the beginning of the KEKB project, we had to install many feedback loops for beam energy, orbit, charge, etc.
  - Simple PID (mostly Proportional and Integral), with limits
  - Scripts for prototypes, then ePID on IOCs
- SuperKEKB with demanding beam specification may require further considerations
  - Emittance preservation
  - PPM virtual accelerator (VA) handling
- Simulation VA should help organizing the loops

Energy Stabilization

- **Energy instability was sometimes found**
  - Closed feedback loops were formed
  - Beam positions were measured where dispersion function is large
  - RF phases at adjacent stations were changed
  - Loop parameters were beam mode dependent
  - Energy spread feedback using multi-electrode monitor was also implemented



Energy management

- **Beam at the end of linac is dependent on …**
  - maximum possible energy by accelerating structure
  - LLRF/beam crest tracking
  - 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

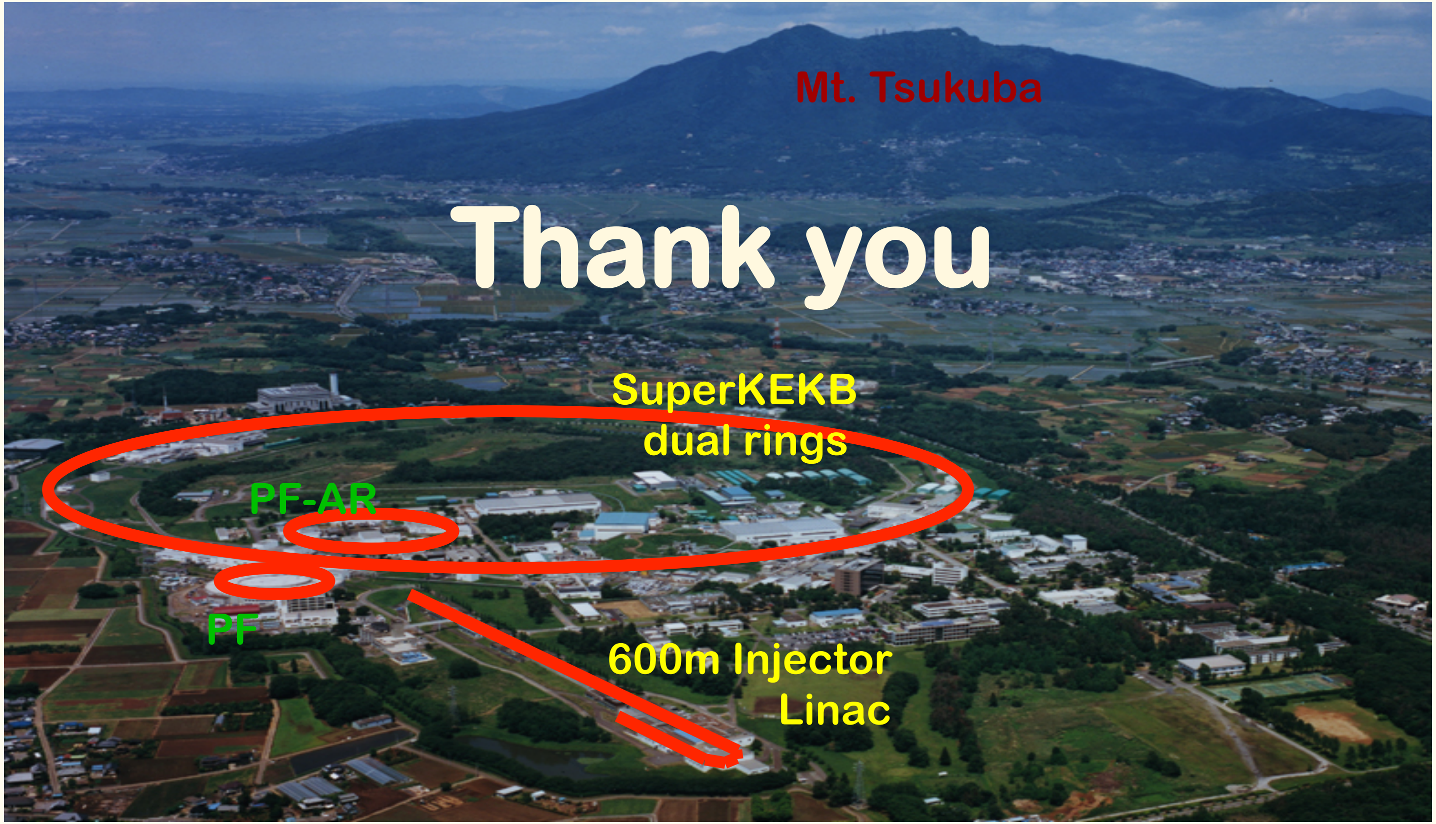
Implementations

- **Database**
  - Initial: Text-based database is read by memory-resident dynamic hash database used by middle-layer controls, with peripheral management
  - PPM virtual machines are separated using P.V. naming conventions
  - Proper separation of database and algorithms is important for improvement
  - Goal: Reasonable database management with more compornents into lower-layer controls (in EPICS IOC)
- **Operational software**
  - SADscript environment will handle most of beam optimizations
  - Well-designed interface would be provided through channel access
- **Needs balance between stability/performance and rapid-prototyping as the machine usage would change daily**
  - should be investigated in the commissioning phases I, II and III

Summary

Summary

- Beam property management will face another level of challenges
- Will start with qualified schemes that was confirmed in initial KEKB
- Will make progressive improvements up to Phase-III and so on
- Database content quality and separation from algorithm is important
- Well-designed interface is provided
- Algorithms for now are in scripts for present performance requirement
- Will balance between final beam quality and progressive operation
- Will select optimized route depending on available resources
- With some Phronesis we may enjoy coming beam commissiong


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