Beam Feedback System Challenges at SuperKEKB Injector Linac

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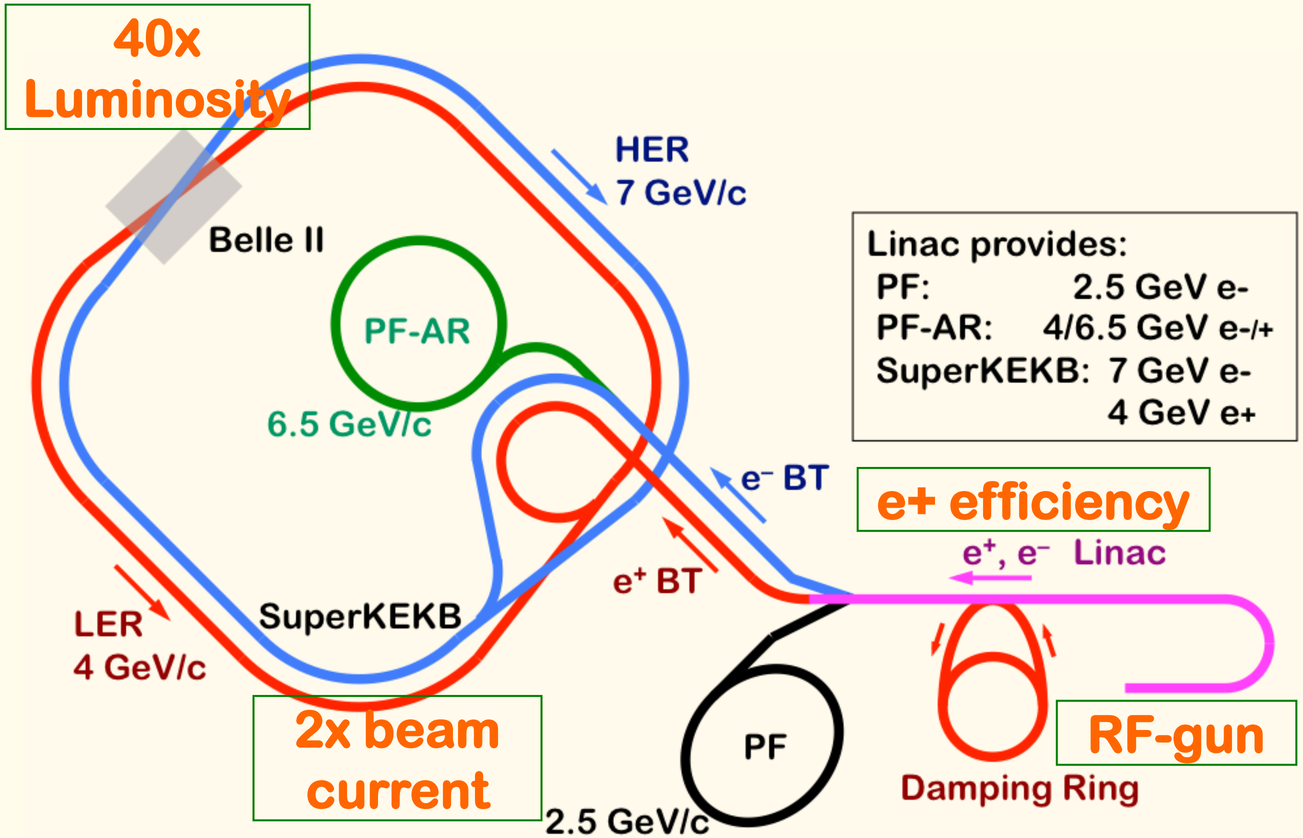
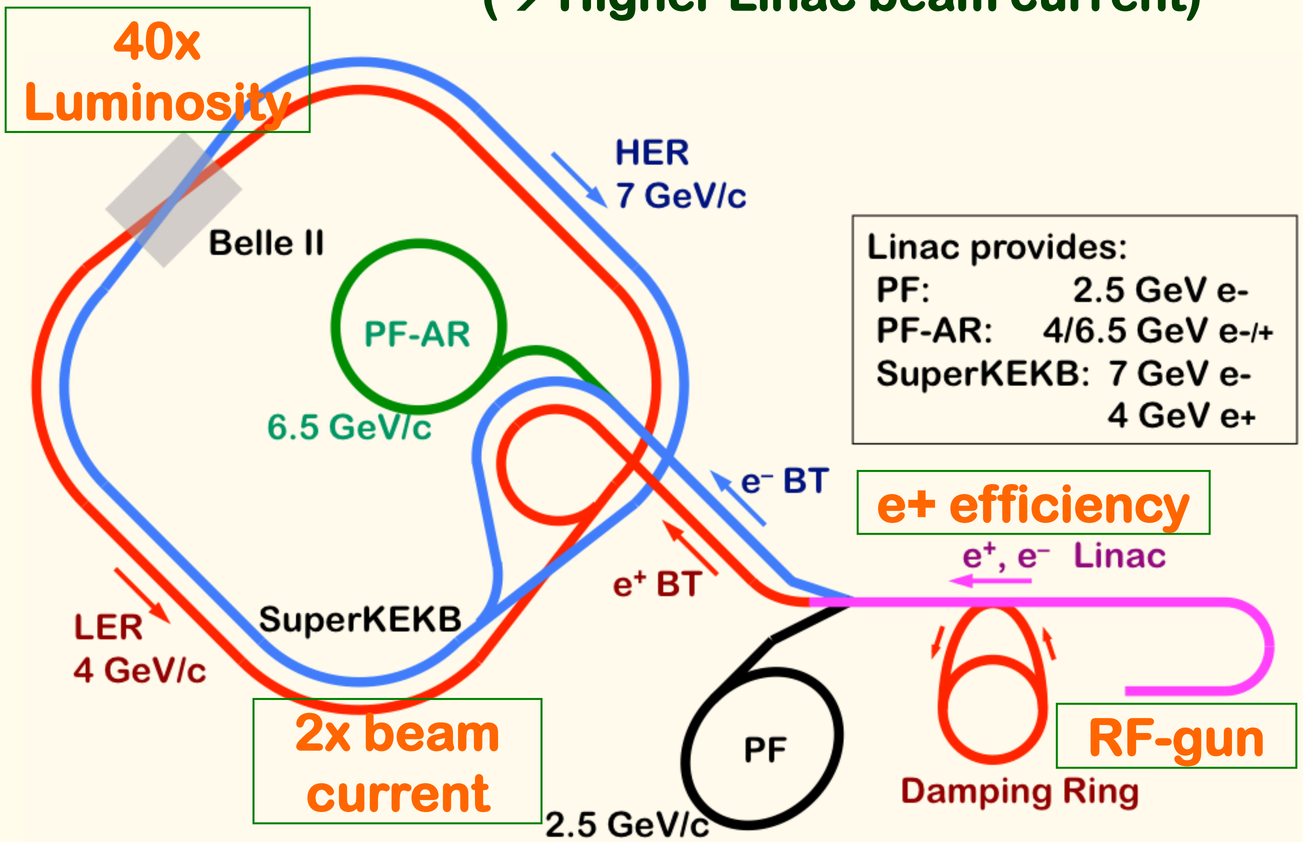
SuperKEKB and electron/positron Injector Linac

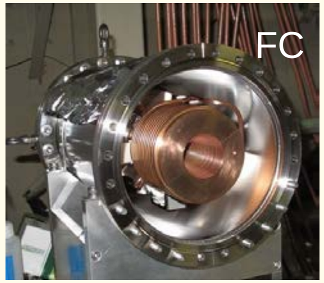


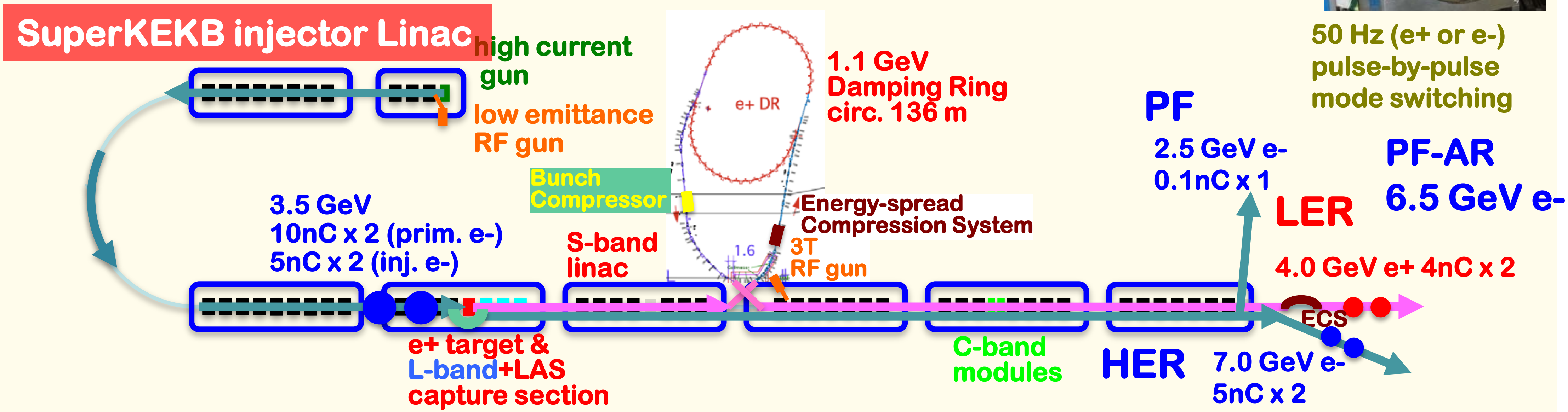
SuperKEKB and electron/positron Injector Linac

- **Asymmetric e+/e- Collider for B-physics**
  - Flavor structure of elementary particles, and possibly new physics
- **40-times higher Luminosity compared with that of KEKB (WR)**
  - Twice larger storage beam → Higher beam current at Linac
  - 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)
- **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



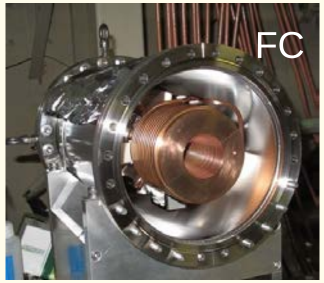
Linac Upgrade for SuperKEKB

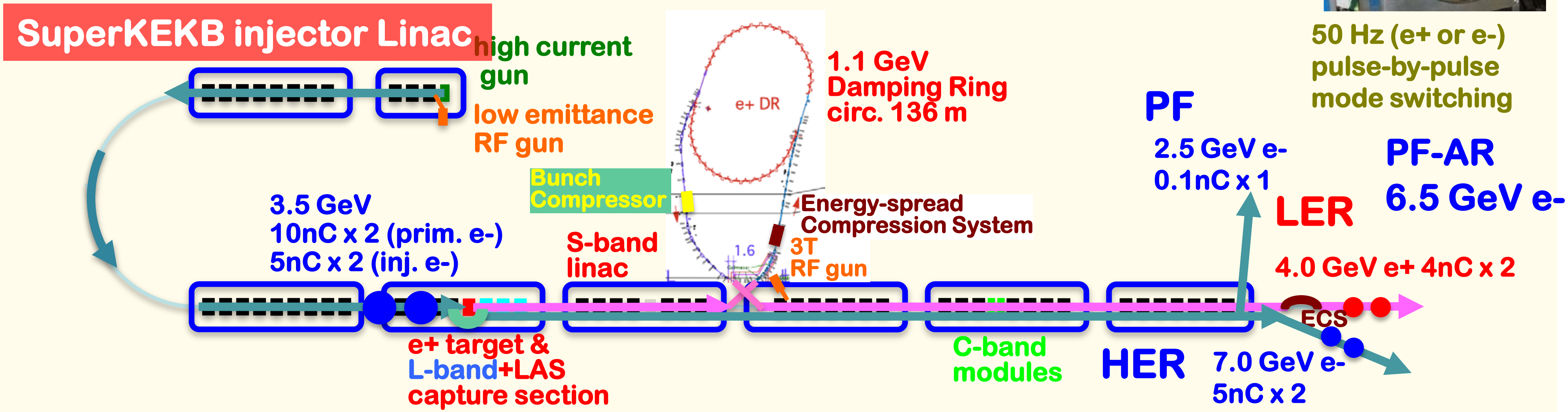




Linac Upgrade for SuperKEKB

- **Higher Injection Beam Current**
  - To Meet the larger stored beam current and shorter beam lifetime in the ring
  - 4~8-times larger bunch current for electron and positron
- **Lower-emittance Injection Beam**
  - To meet nano-beam scheme in the ring
  - Positron with a damping ring, Electron with a photo-cathode RF gun
  - Emittance preservation by alignment and beam instrumentation
- **Quasi-simultaneous injections into 4 storage rings (PPM)**
  - SuperKEKB e^-/e^+ rings, and light sources of PF and PF-AR
  - Improvements to beam instrumentation, low-level RF, controls, timing, etc





Main features of controls at (previous) KEKB

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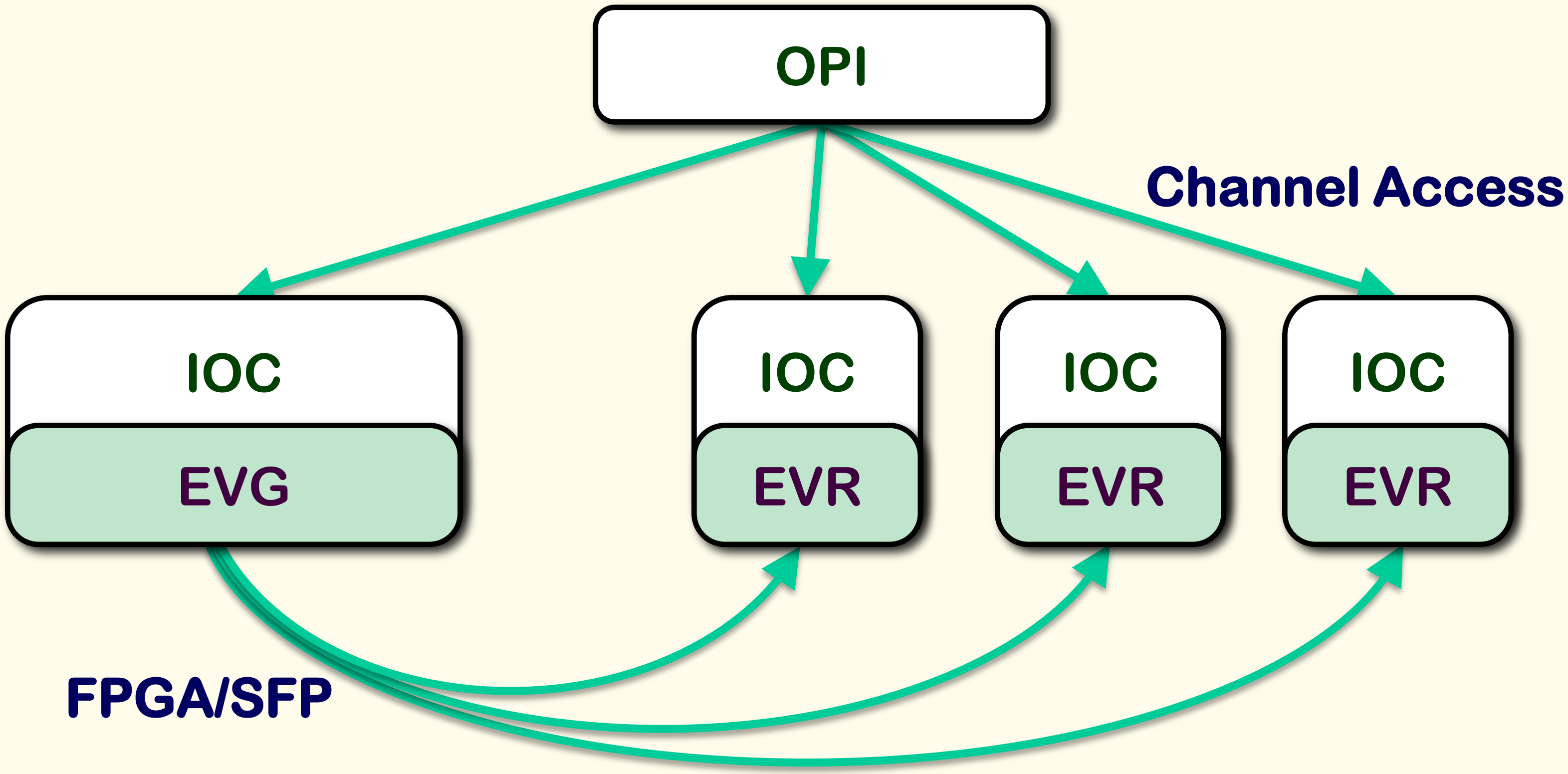
- **EPICS as Main control Software Toolkit**
  - Provided a robust basis of equipment controls
  - Reduced software design efforts much
- **Scripting Languages for Operational Software**
  - SADscript/Tk, Python/Tk, Tcl/Tk used much
    - Especially, SADscript as a bridge btw. Accelerator simulation, Numeric manipulation, Graphic interface and EPICS controls
  - Bright new idea in the morning meeting could make the operation much advanced in the evening
    - Great tool to optimize the operation

SuperKEKB Controls

SuperKEKB Controls

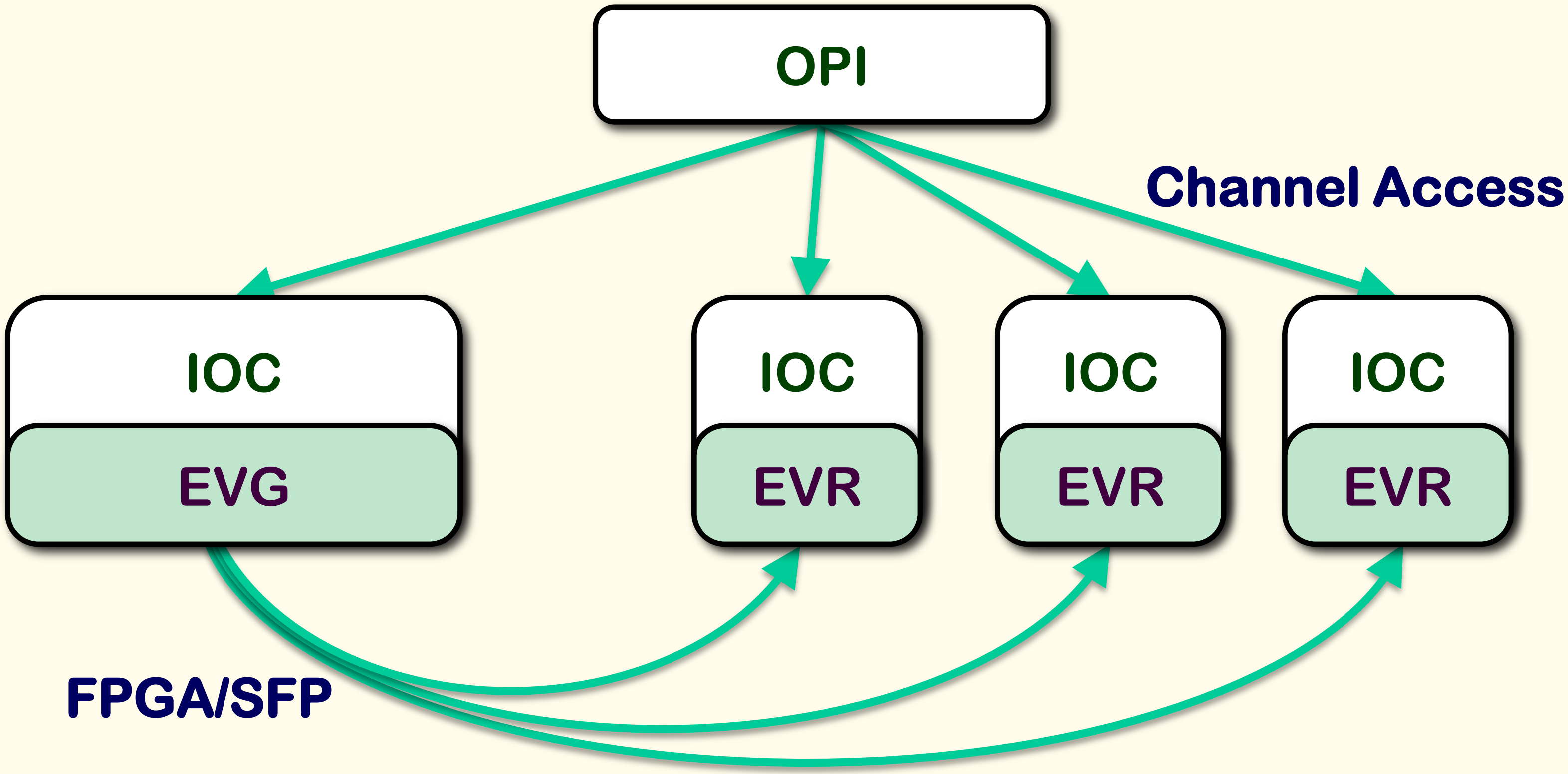
- **Inherit Good part of KEKB Controls**
  - EPICS
  - Scripting languages
- **EPICS Channel Access (CA) Everywhere**
  - Embed EPICS control software (IOC) everywhere possible
  - Reduce efforts on protocol design, testing, etc
- **Dual Tier: Another layer in addition to EPICS/CA**
  - Event system helps EPICS with another channel
  - Additional functionality, synchronization and speed

Dual-tier Controls

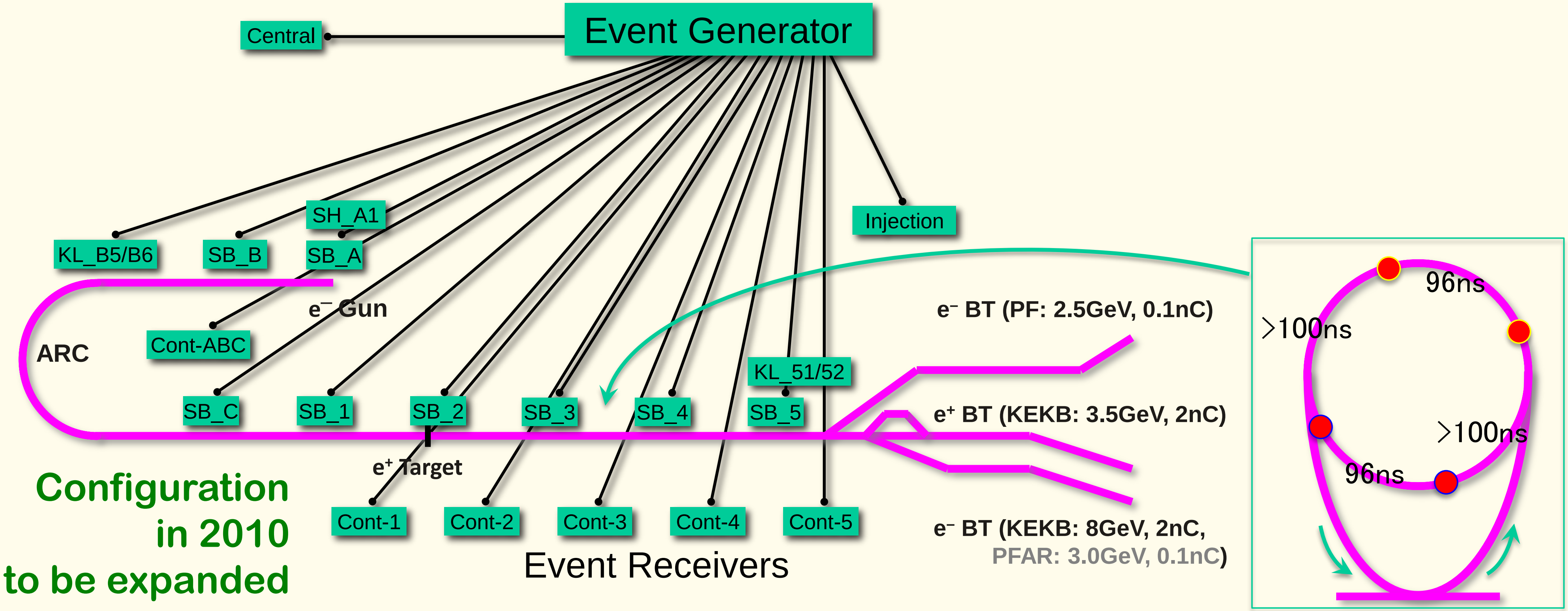


Dual-tier Controls

- **IOC controls via Conventional EPICS CA**
  - Above 1ms, ordered controls
- **Fast FPGA controls via SFP/Fiber (MRF)**
  - 10ps ~ 100ms, 114MHz synchronous controls



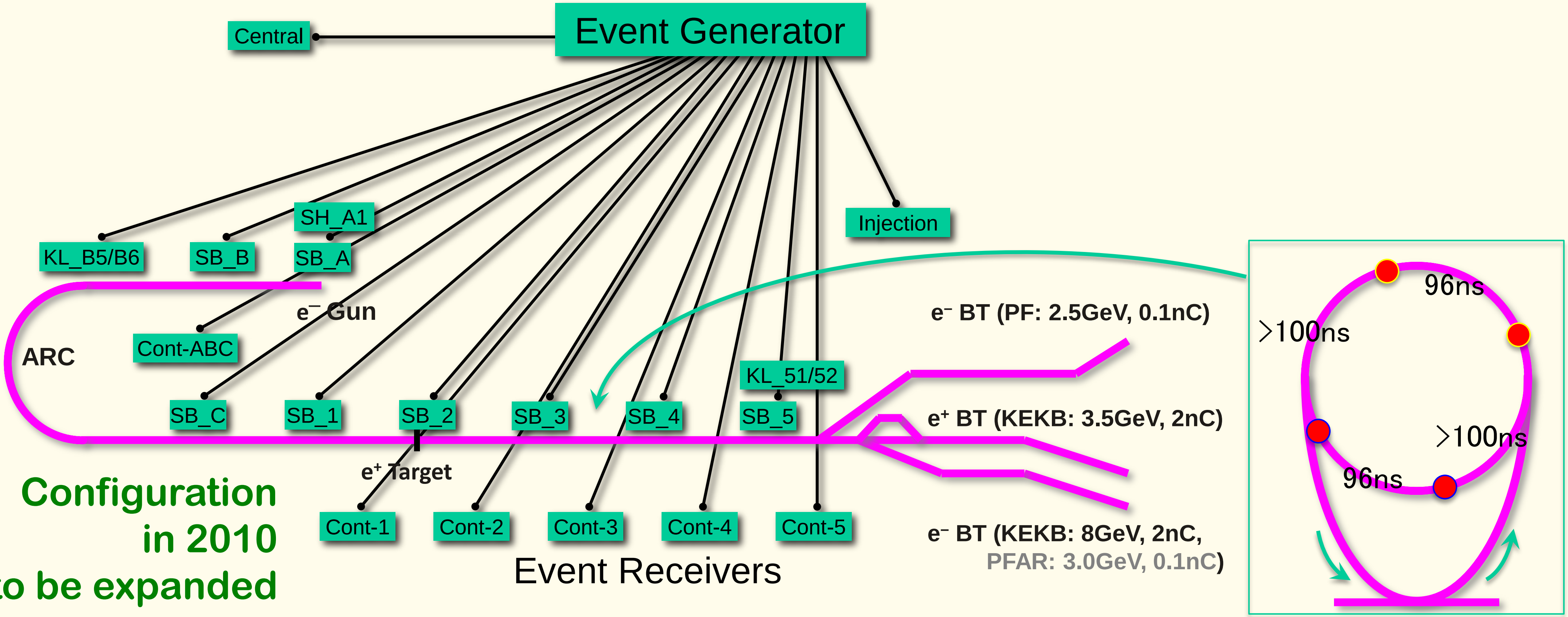
Fast, Global, and Synchronous Controls



Configuration in 2010 to be expanded

Fast, Global, and Synchronous Controls

- MRF's series-230 (and SINAP's) Event Generator / Receivers
- VME64x and VxWorks v5.5 / v6.8
- EPICS R3.14.x with mrfioc1/2
- 18 event receivers in KEKB
- More Home-grown receivers



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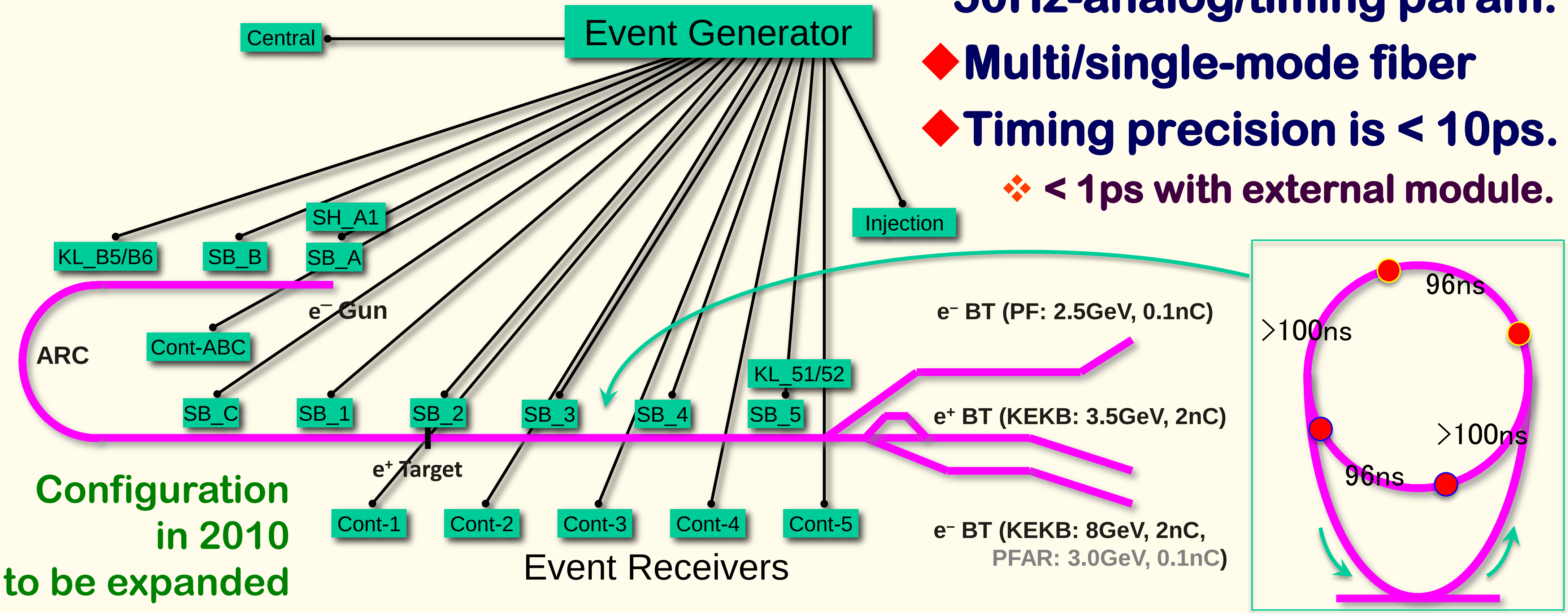
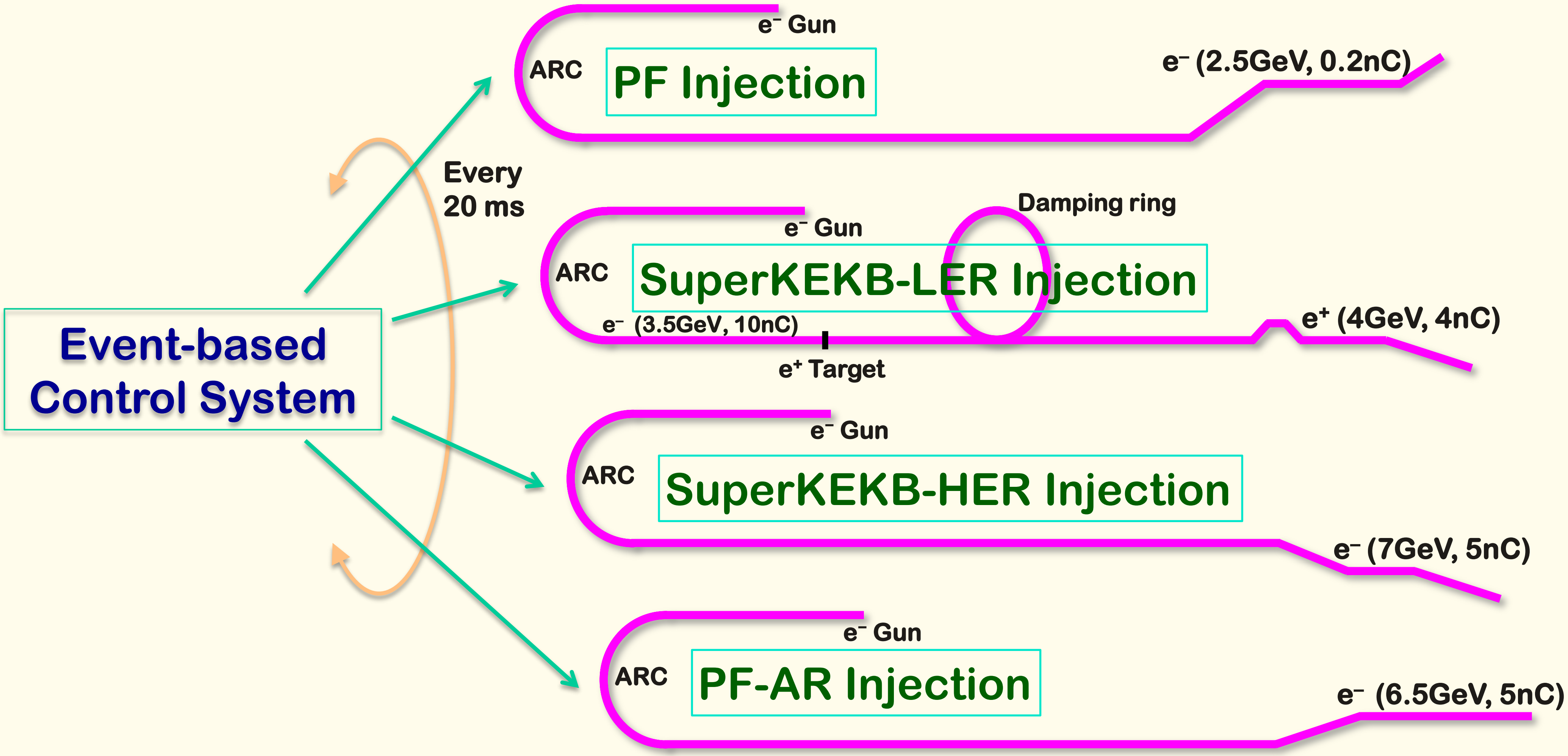
- 18 event receivers in KEKB
- More Home-grown receivers
- 114.24MHz event rate, 50Hz fiducial
- ~200 dynamic 50Hz-analog/timing param.
- Multi/single-mode fiber
- Timing precision is < 10ps.
  - < 1ps with external module.



Configuration in 2010 to be expanded

Single Machine, Multiple Virtual Accelerators (VAs)

- **Pulse-to-pulse modulation (PPM), one of the VAs is active at a time**
- **Independent parameter set for each VA, ~200 parameters are switched every 20ms pulse**



Two kinds of Virtual Accelerators (VAs)

- **Virtual Accelerator Models (VAs)**
- **PPM VAs, that represent independent accelerator views for different purposes**
  - by using dual-tier controls
- **Simulation VAs, that represent physics models of accelerators in simulation codes**
  - by using SADscript codes through EPICS CA, normally
  - even before the machine completion

(Offline) Orbit Correction Test in Sim. VA

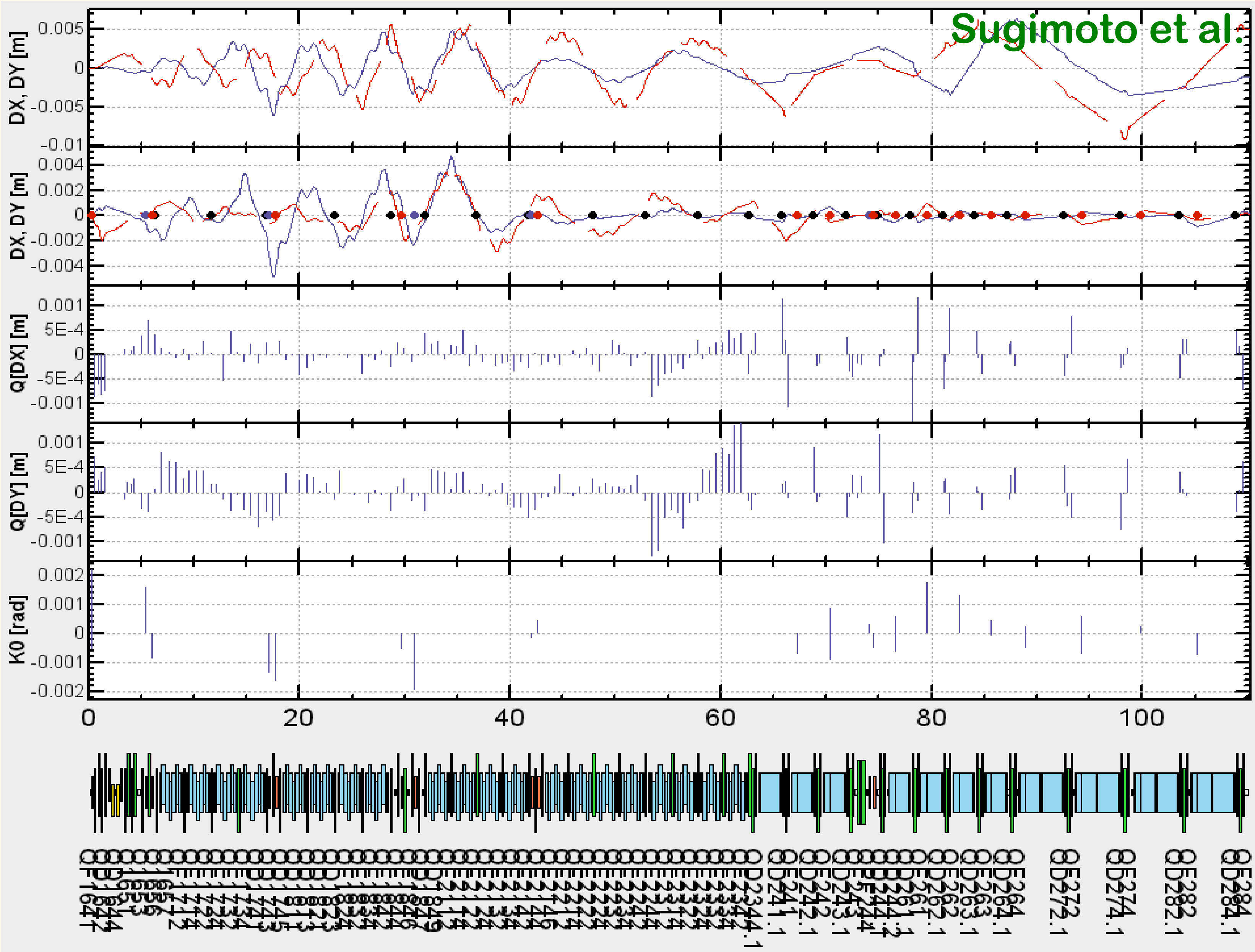
Orbit before correction

Orbit after correction

Horizontal displacement

Vertical displacement

Corrector K0



Beam Feedback Loops

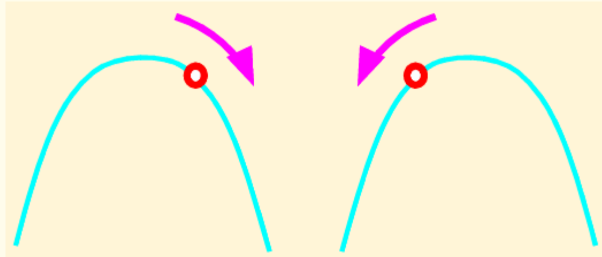
Beam Feedback Loops

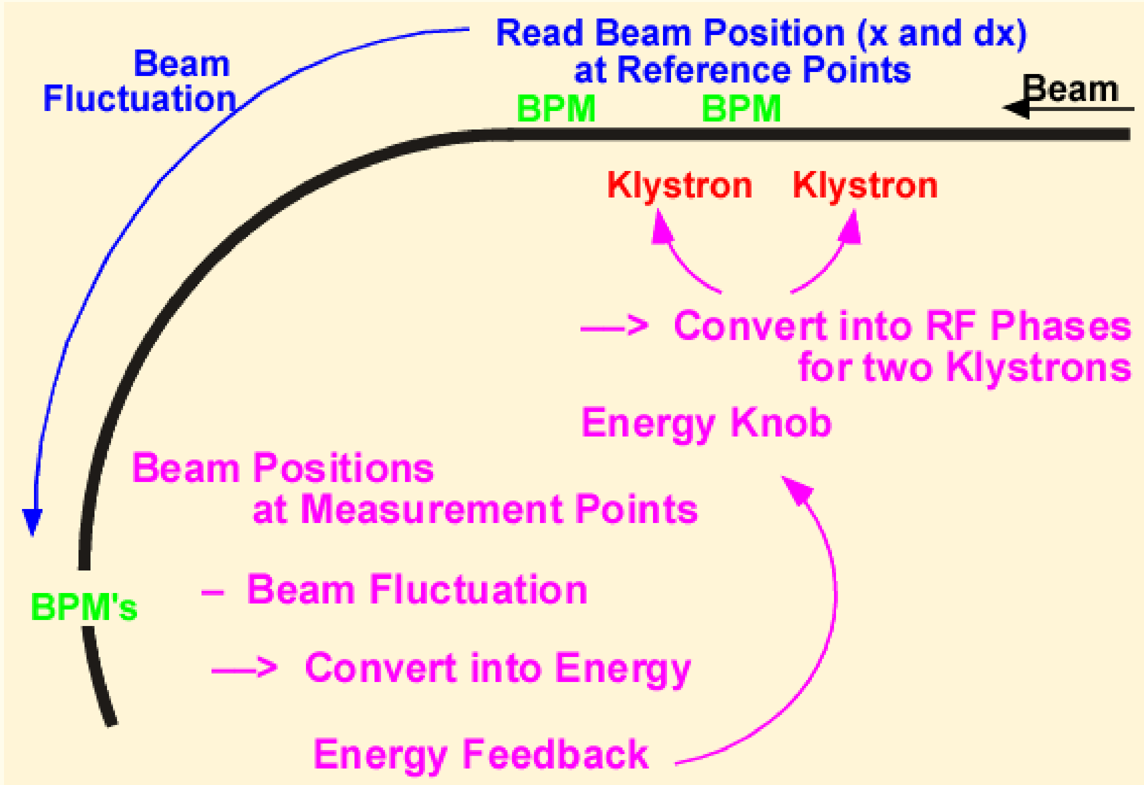
- Equipment has inherent instabilities caused by many sources
  - At the beginning of the KEKB project, we had to install many feedback loops for beam energy, orbit, charge, etc.
  - Simple PID (mostly Proportional and Integral), with limits
  - Scripts for prototypes, then ePID on IOCs
- SuperKEKB with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

Energy Stabilization

◆ Energy instability was sometimes found

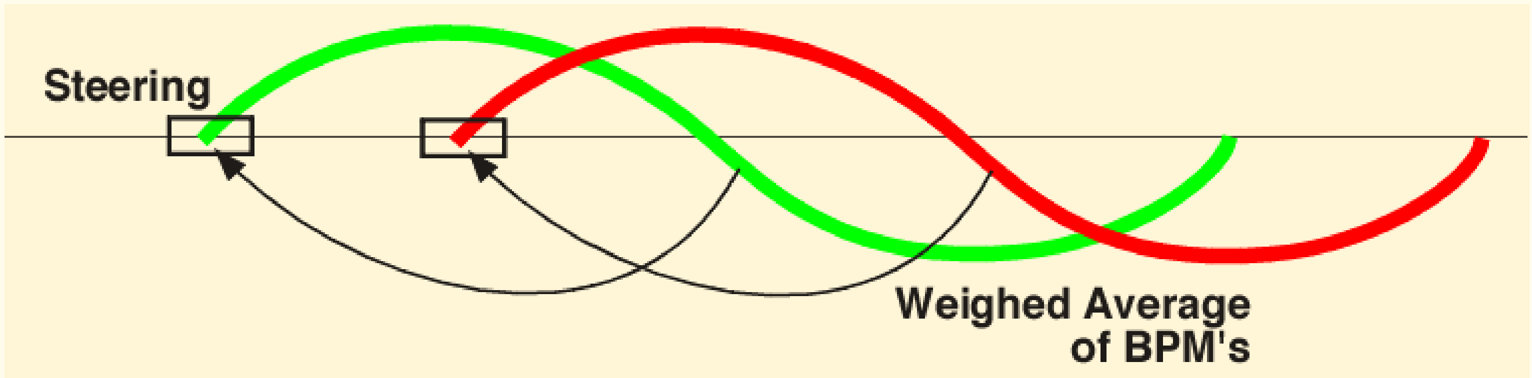
- Closed feedback loops were formed
- Beam positions were measured where dispersion function is large
- RF phases at adjacent stations were changed
- Loop parameters were beam mode dependent
- Energy spread feedback using multi-electrode monitor was also implemented



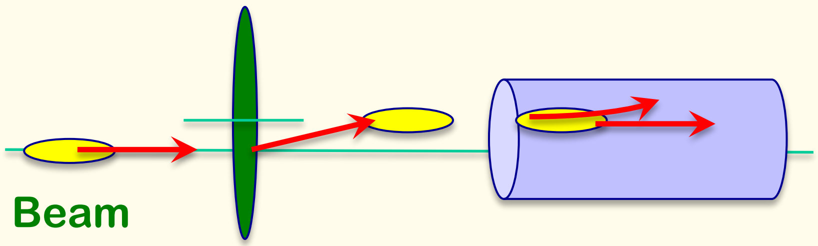


Simple Orbit Stabilization

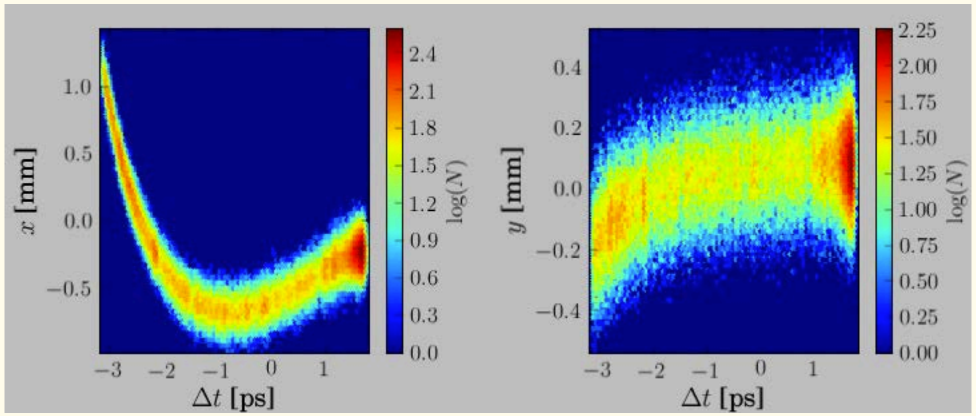
- **If Orbit became unstable**
  - Beam positions were measured where betatron phases are 90degree apart
  - Corresponding steering magnets are adjusted
  - If the orbit fluctuation was large, weighed average of BPMs based on response functions to beam kick or energy change
  - The same method was applied to equipment stabilization



Emittance Preservation



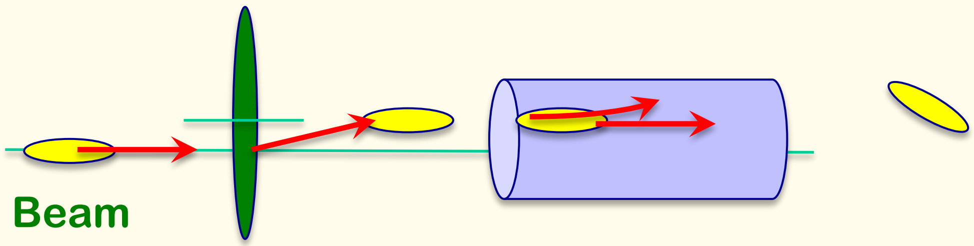
Sugimoto et al.



Transverse distribution in time direction

Emittance Preservation

- **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
  - Depending on the beam optics and the beam charge
- **Orbit correction is crucial to preserve the emittance**



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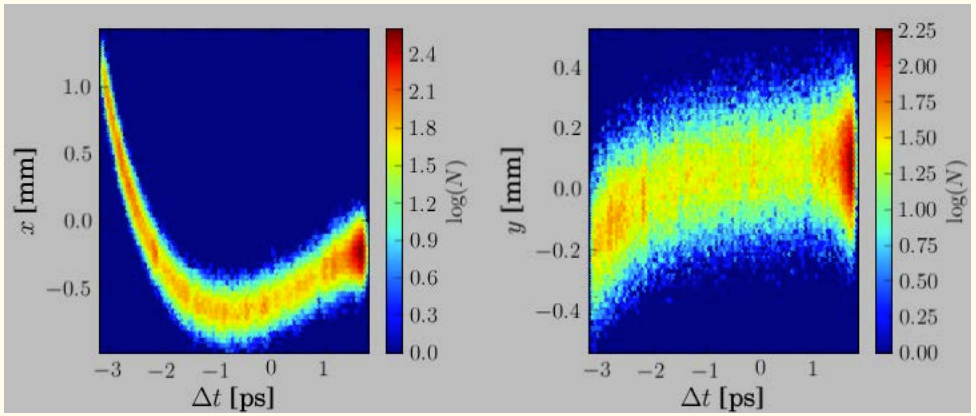
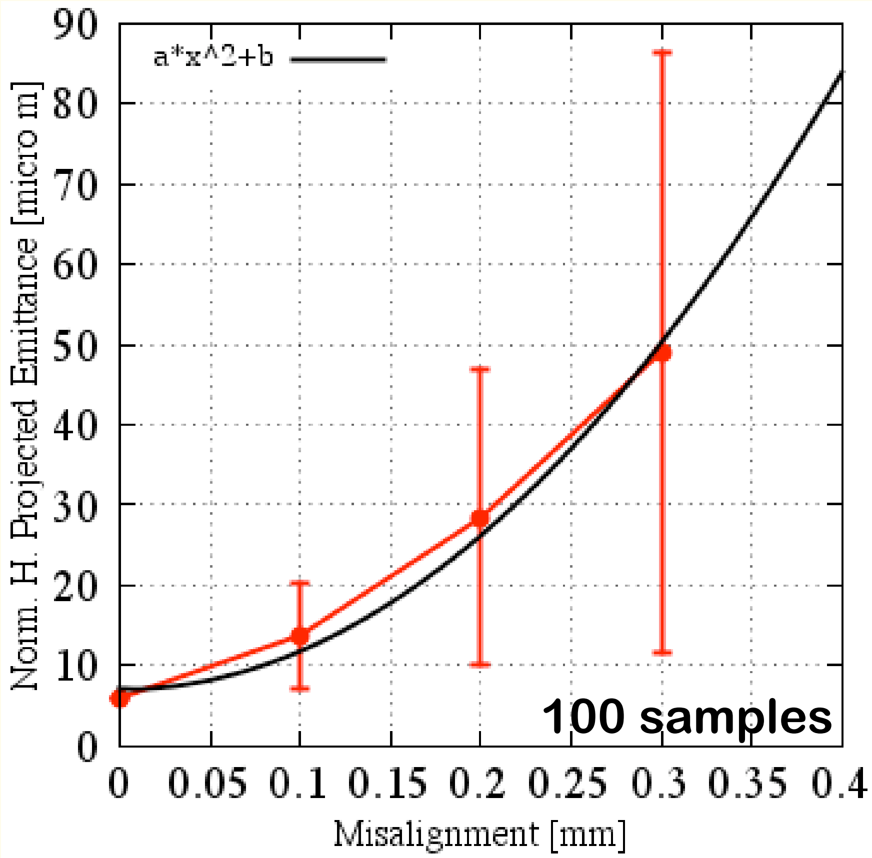


Transverse distribution in time direction

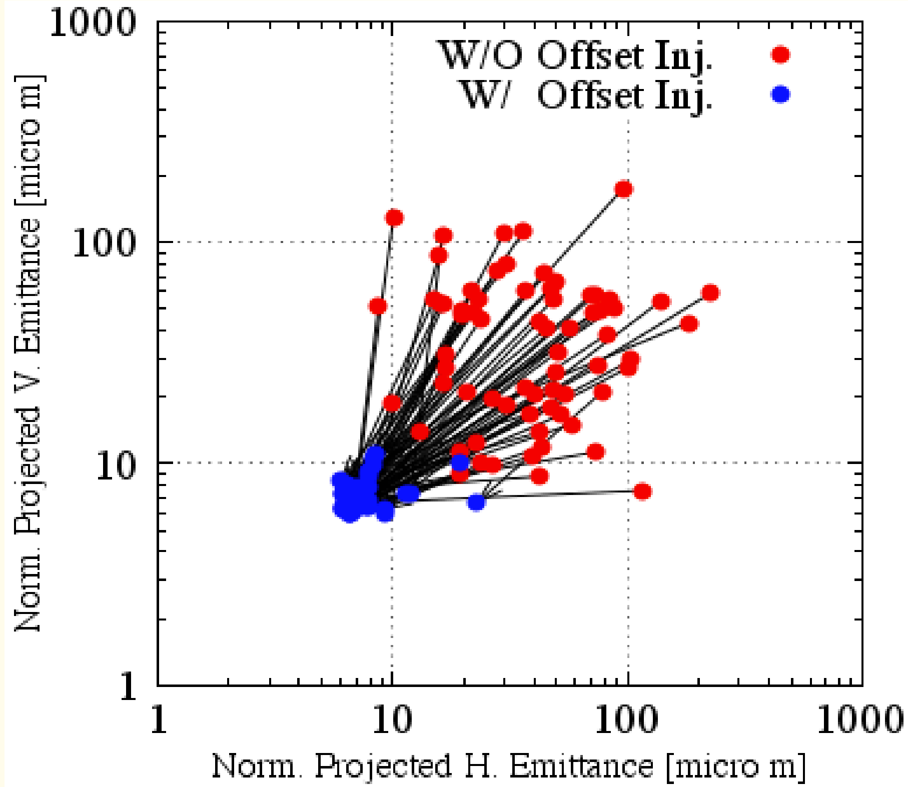
Emittance Dilution

- Offset injection may solve the issue
- Orbit have to be maintained precisely

Mis-alignment leads to Emittance blow-up



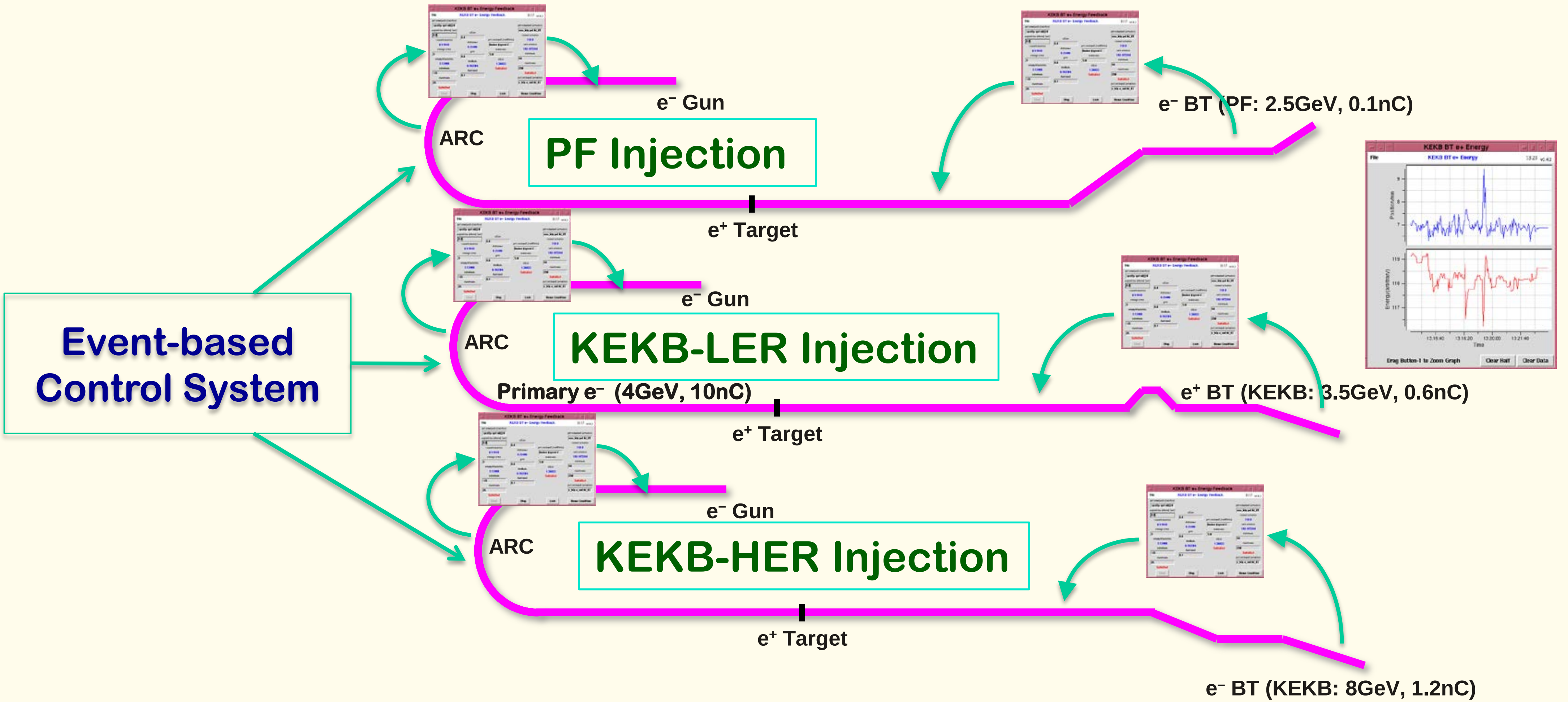
Orbit manipulation compensates it



Sugimoto et al.

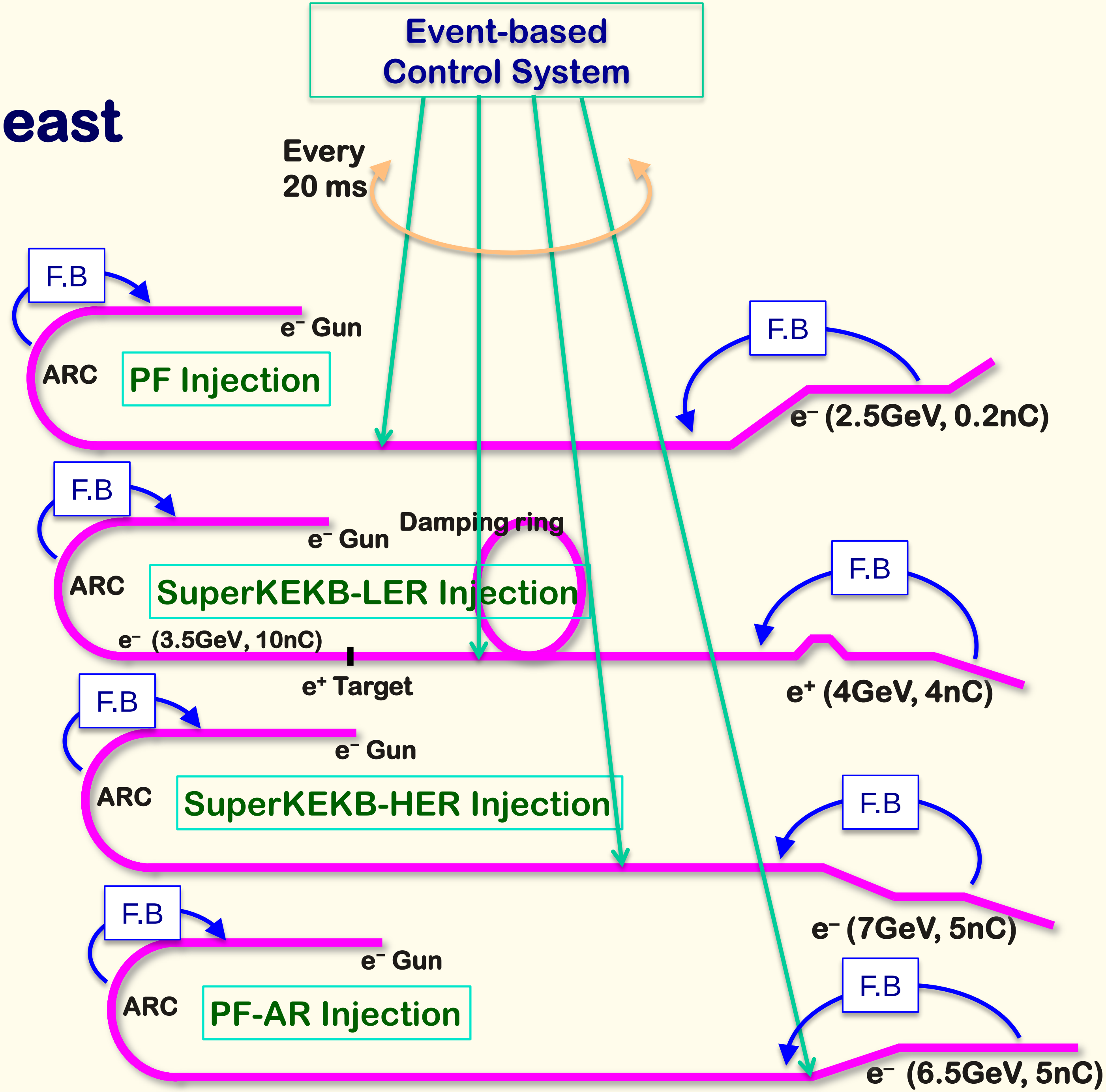
Multiple Closed Loop Controls Overlapped

- **Closed loops were installed on each PPM VA independently**
  - **Tested at KEKB**



- **Four PPM VAs at least for SuperKEKB**

(maybe with additional PPM VA for stealth beam)

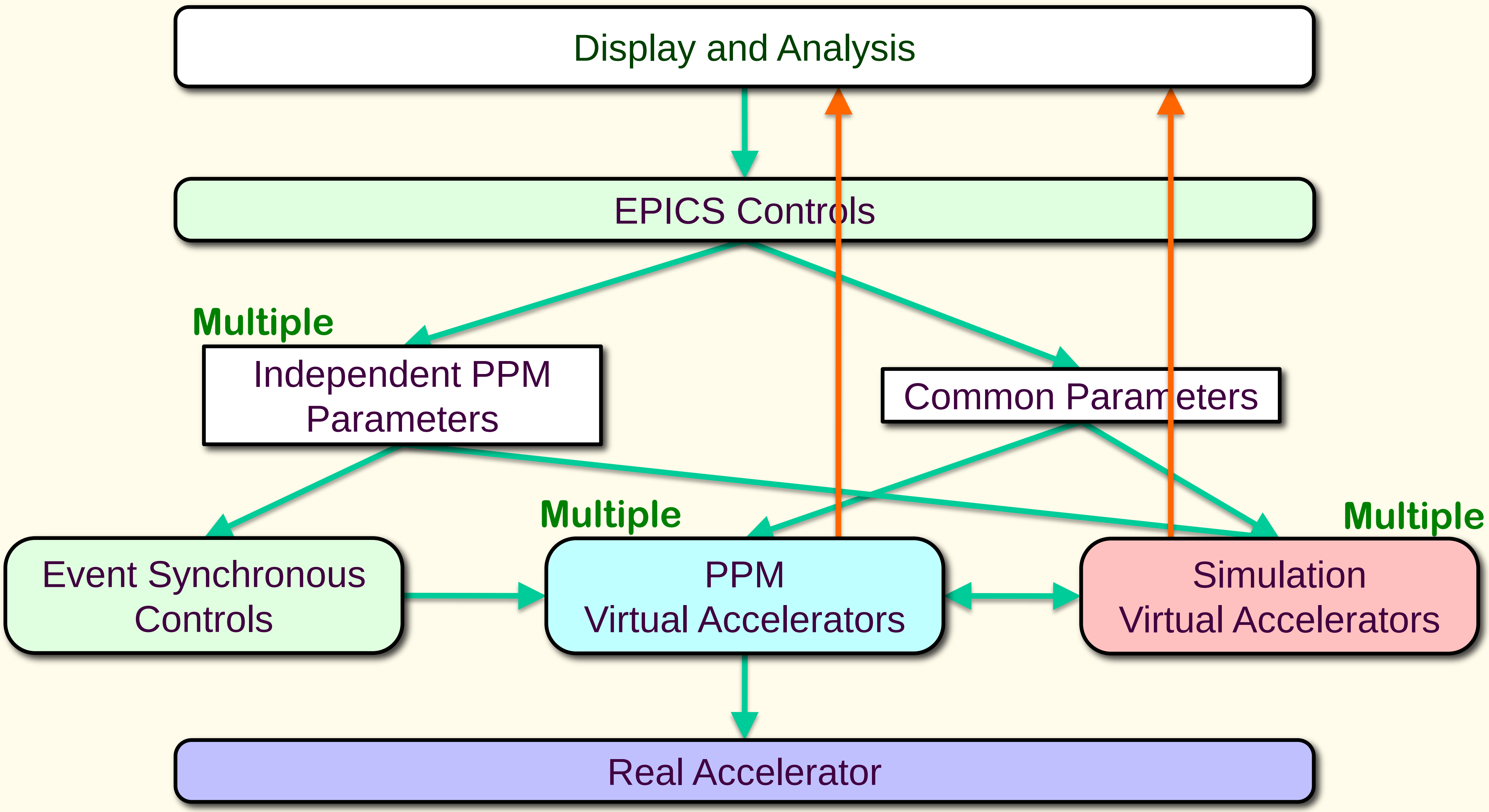


Feedback loop life cycle

Feedback loop life cycle

- **Installation of feedback loops**
  - for beam properties like beam orbit, energy, energy spread, bunch length, charge, dual-bunch equality, as well as device properties like llrf, timing, magnetic field, etc
  - often without knowing the origin of the instability
- **Instability hunting, and fixing**
- **Beam study, or machine study using beam**
- **If fixed, remove corresponding feedback loop**

System Construction



Conclusion

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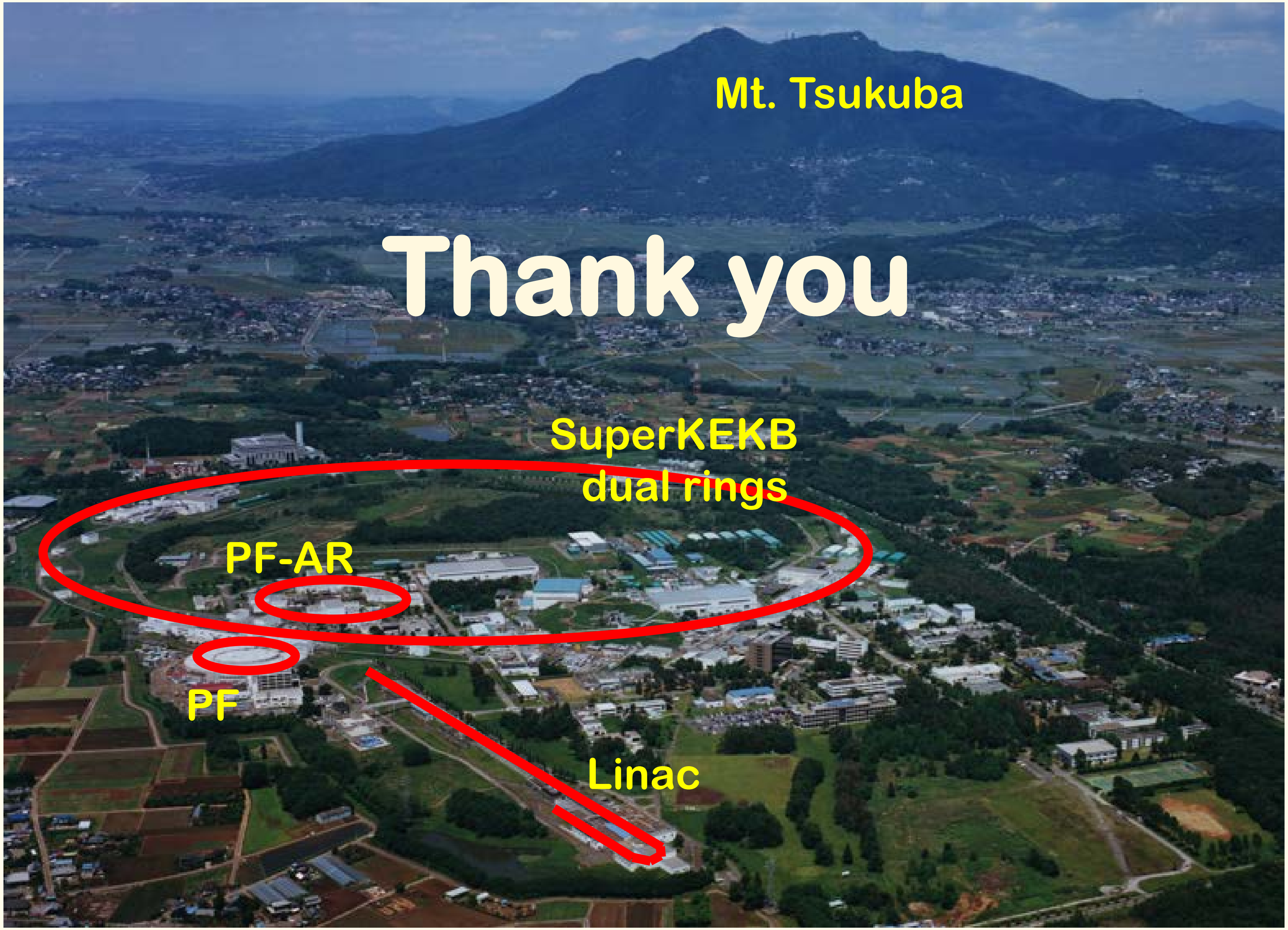
- SuperKEKB requires demanding beam parameters at injector linac
  - Even under PPM
- Models of PPM VAs and simulation VAs may help design feedback loops
  - Energy, orbit, energy spread, charge
  - Emittance preservation (via orbit stabilization)
- We should be prepared for full commissioning from 2015
- With Phronesis (Greek: Practical wisdom, Ability to understand the Universal Truth), we believe we can achieve the goal


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