



Beam Feedback System Challenges at SuperKEKB Injector Linac

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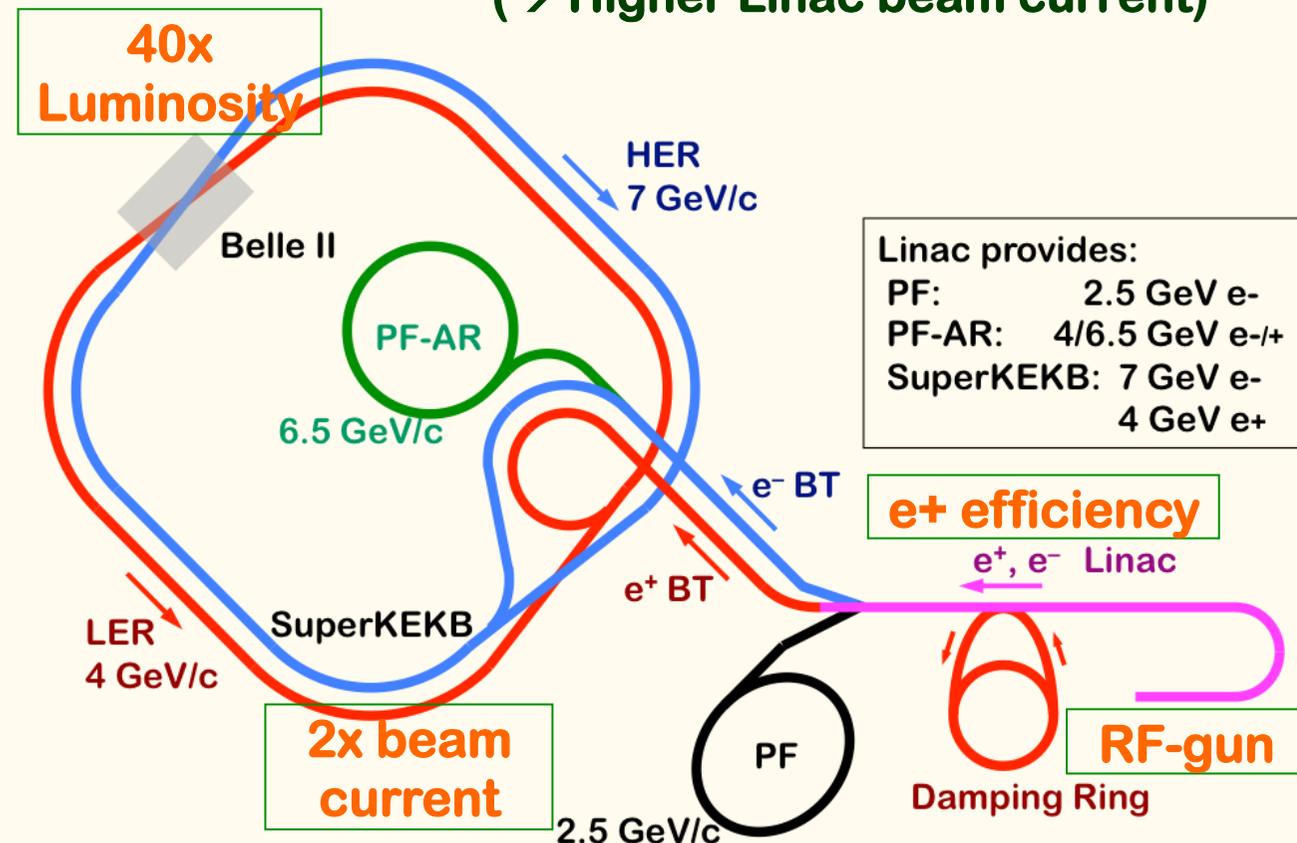
SuperKEKB and electron/positron Injector Linac

◆ 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

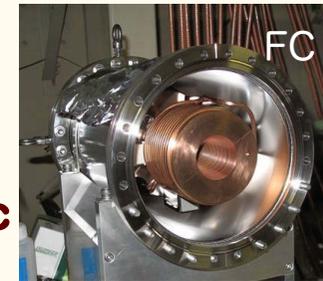
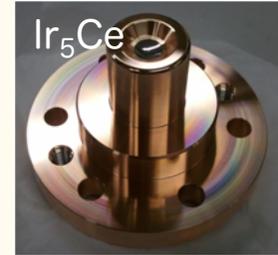
- ❖ Low emittance e^-
 - ❖ with high-charge RF-gun
- ❖ Low emittance e^+
 - ❖ with damping ring
- ❖ Higher e^+ beam current
 - ❖ with new capture section
- ❖ Emittance preservation
 - ❖ with precise beam control
- ❖ 4+1 ring simultaneous injection



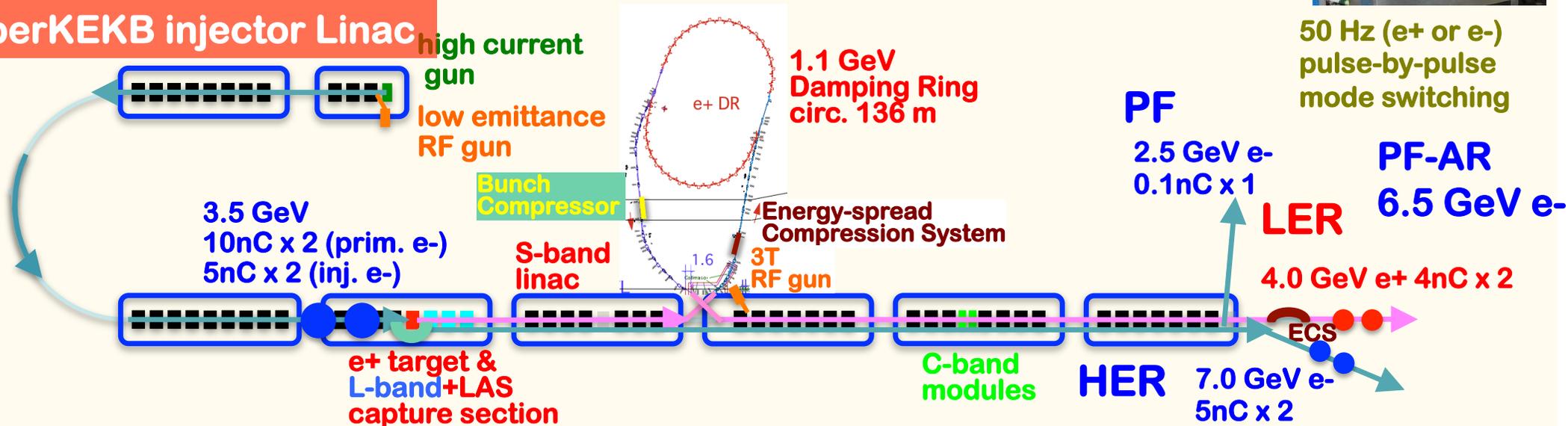


Linac Upgrade for SuperKEKB

- ◆ 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



SuperKEKB injector Linac



Main features of controls at (previous) KEBB

◆ 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

◆ 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

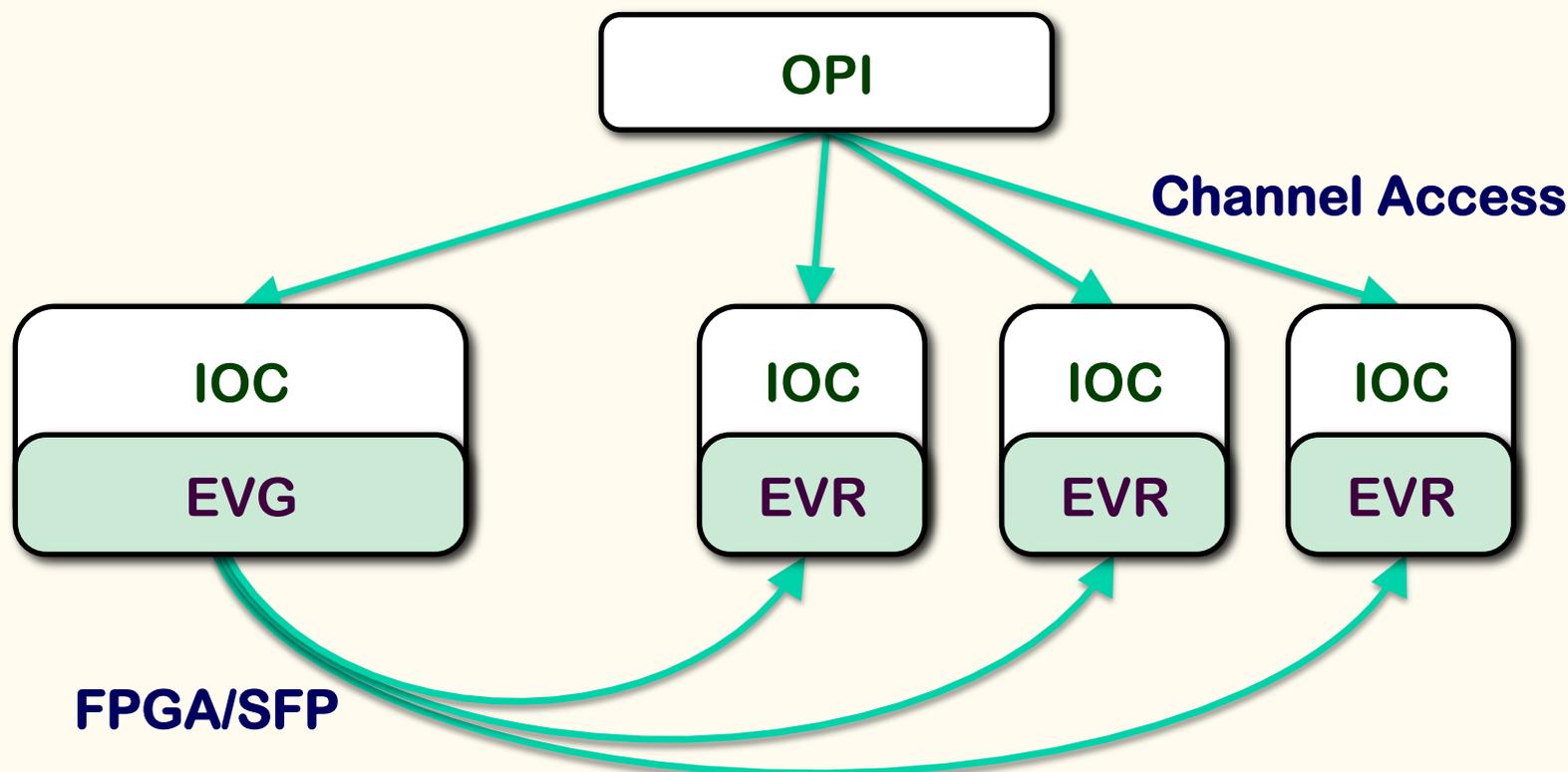
Dual-tier Controls

◆ IOC controls via Conventional EPICS CA

✧ Above 1ms, ordered controls

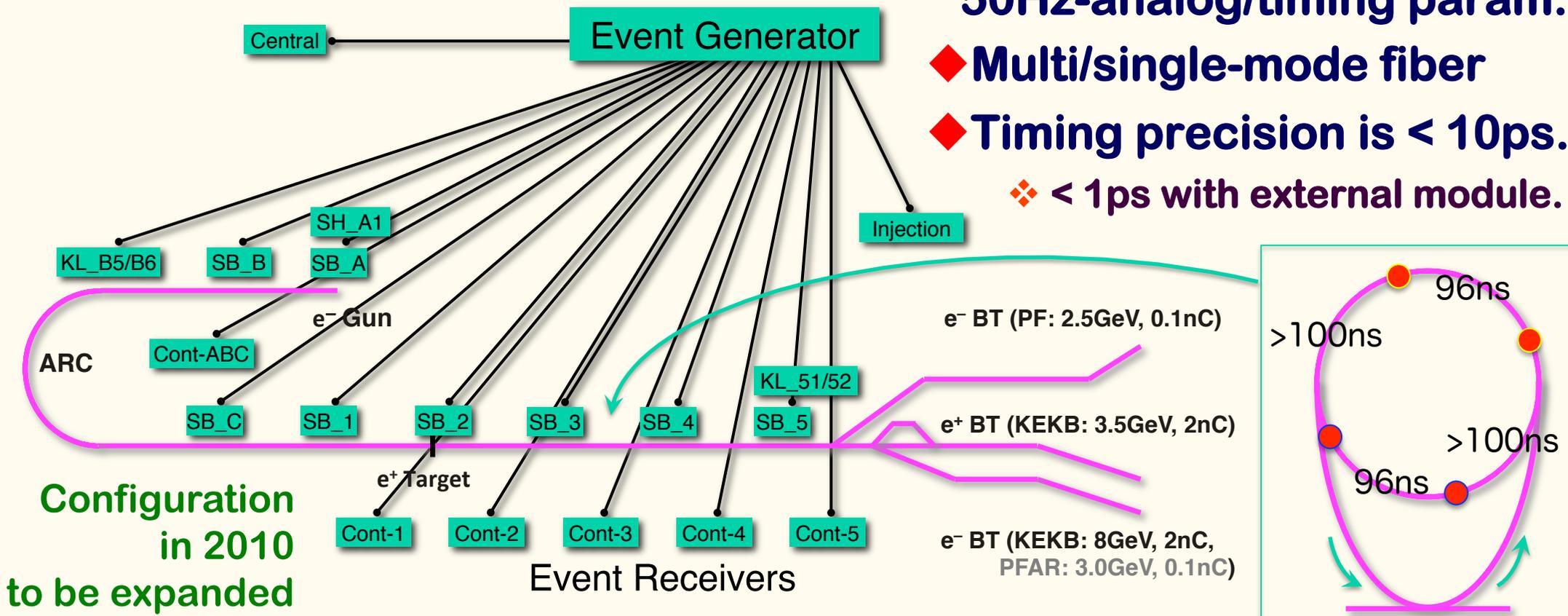
◆ Fast FPGA controls via SFP/Fiber (MRF)

✧ 10ps ~ 100ms, 114MHz synchronous controls



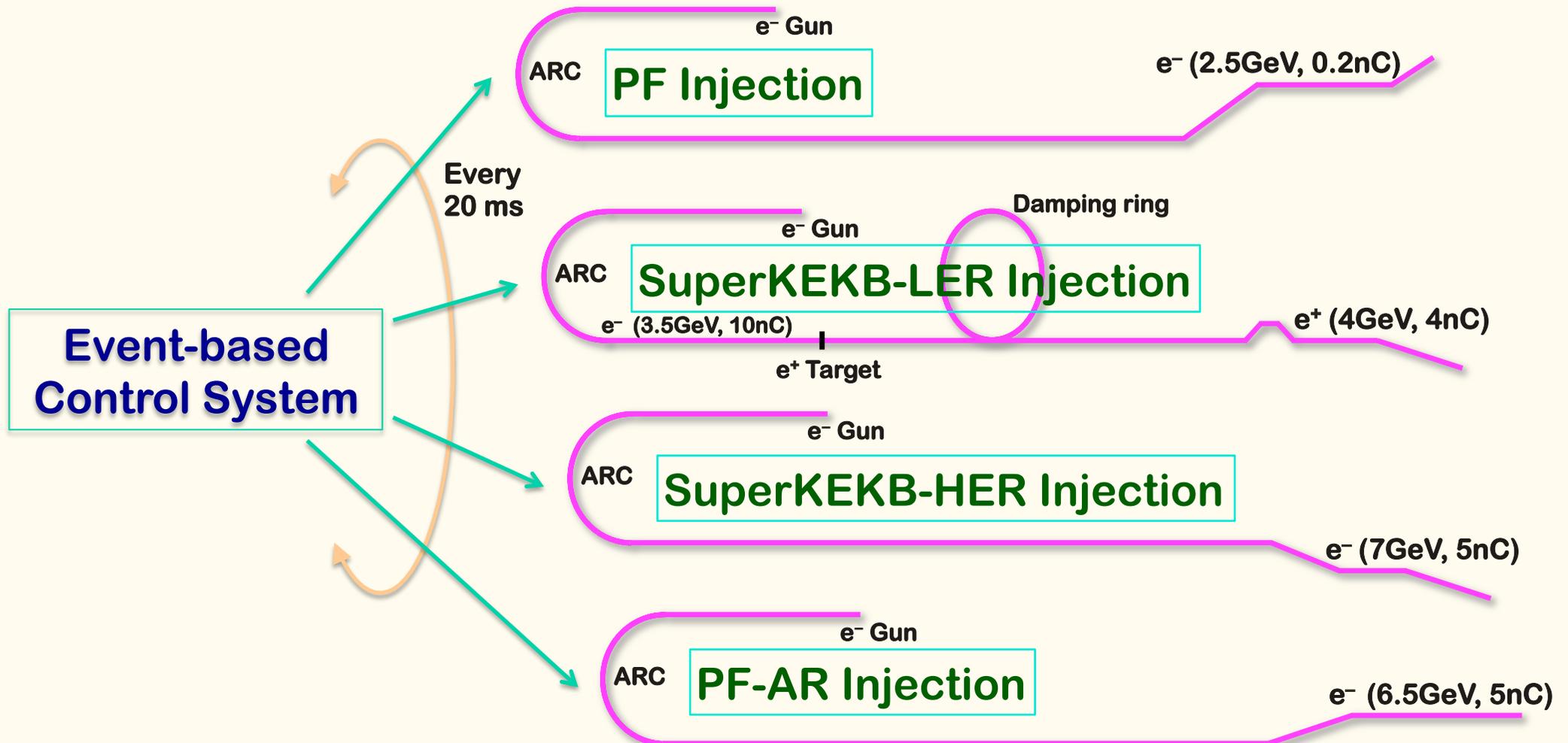
Fast, Global, and Synchronous Controls

- ◆ 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
- ◆ 114.24MHz event rate, 50Hz fiducial
- ◆ ~200 dynamic 50Hz-analog/timing param.
- ◆ Multi/single-mode fiber
- ◆ Timing precision is < 10ps.
 - ❖ < 1ps with external module.



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

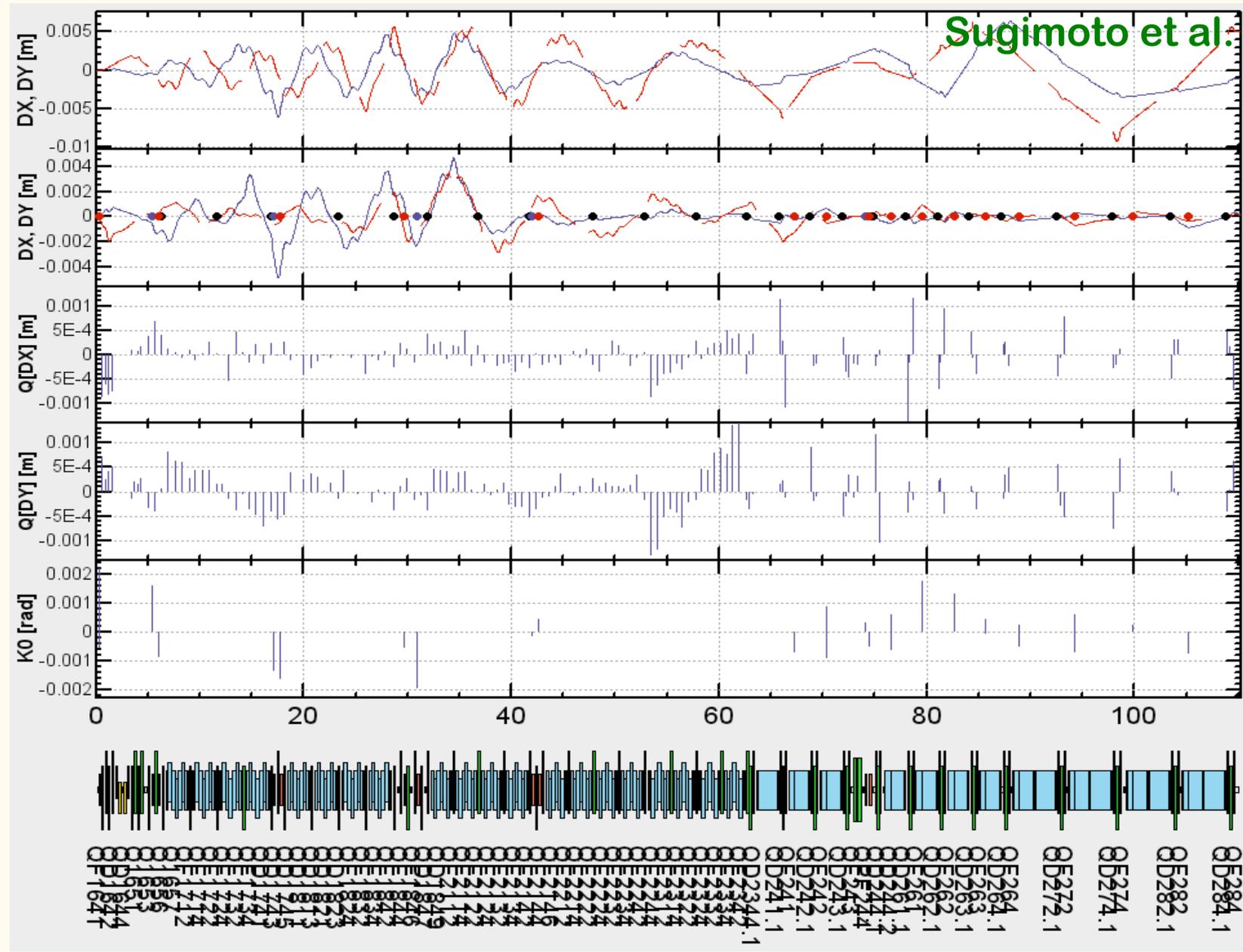
Orbit before correction

Orbit after correction

Horizontal displacement

Vertical displacement

Corrector K0



Beam Feedback Loops

- ◆ **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

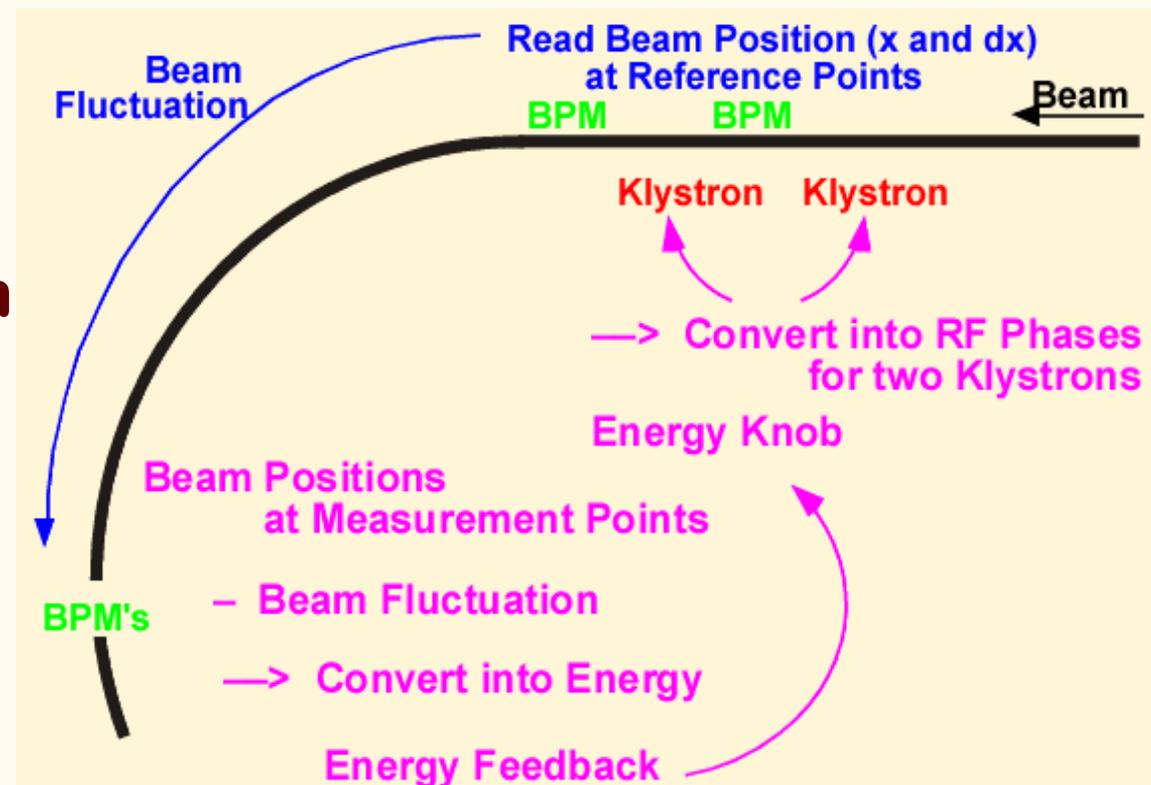
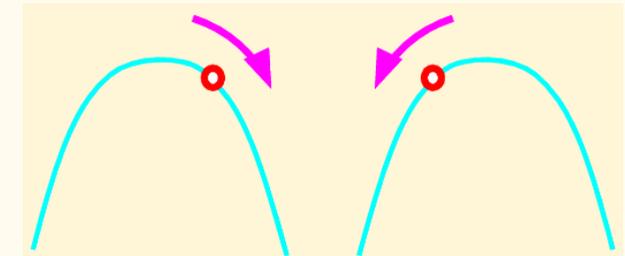
- ◆ **SuperKEKB with demanding beam specification may require further considerations**
 - ❖ Emittance preservation
 - ❖ PPM VA handling

- ◆ **Simulation VA may help organize the loops**

Energy Stabilization

◆ Energy instability was sometimes found

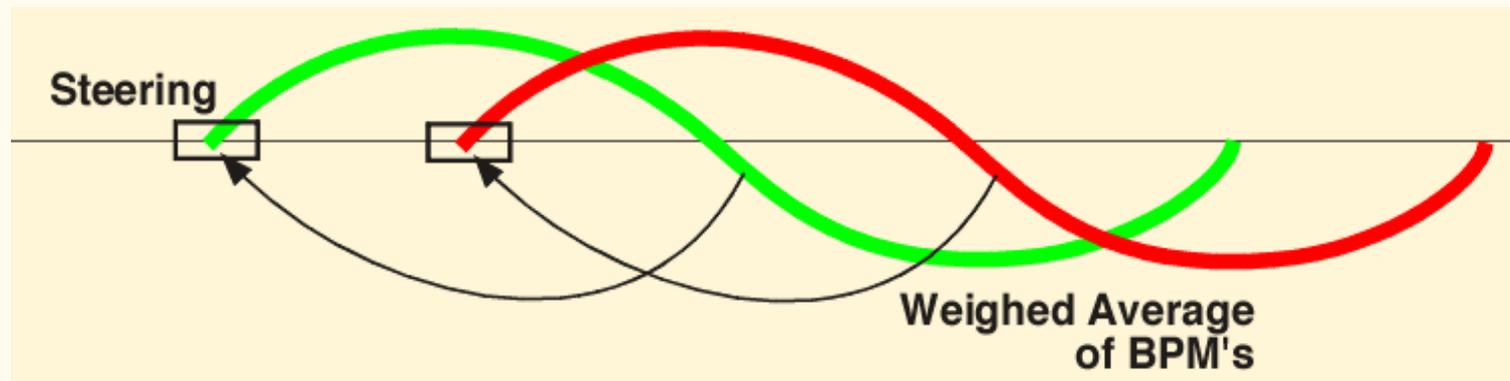
- ❖ Closed feedback loops were formed
- ❖ Beam positions were measured where dispersion function is large
- ❖ RF phases at adjacent stations were changed
- ❖ Loop parameters were beam mode dependent
- ❖ Energy spread feedback using multi-electrode monitor was also implemented



Simple Orbit Stabilization

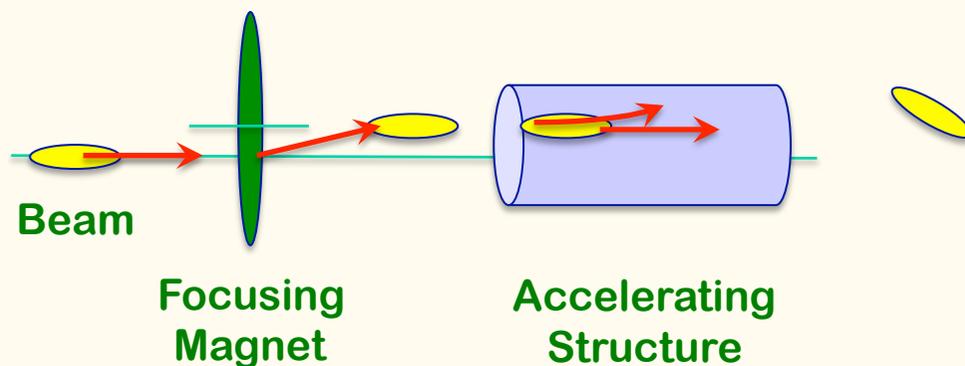
◆ If Orbit became unstable

- ❖ 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

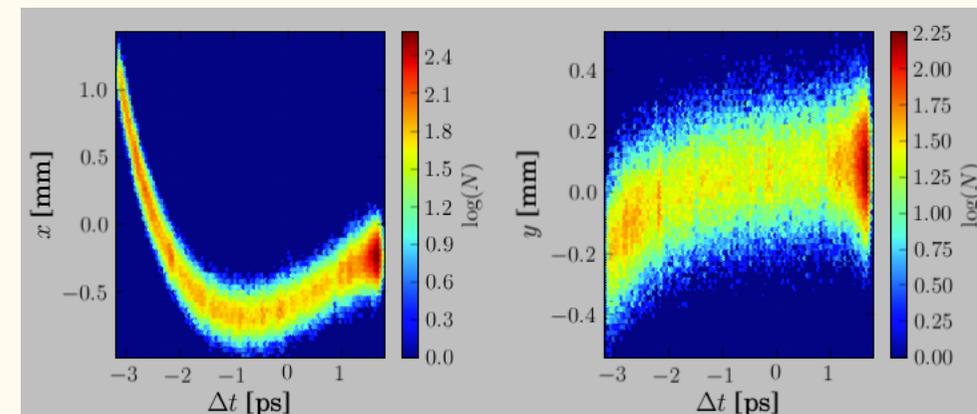


Emittance Preservation

- ◆ **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**



Sugimoto et al.

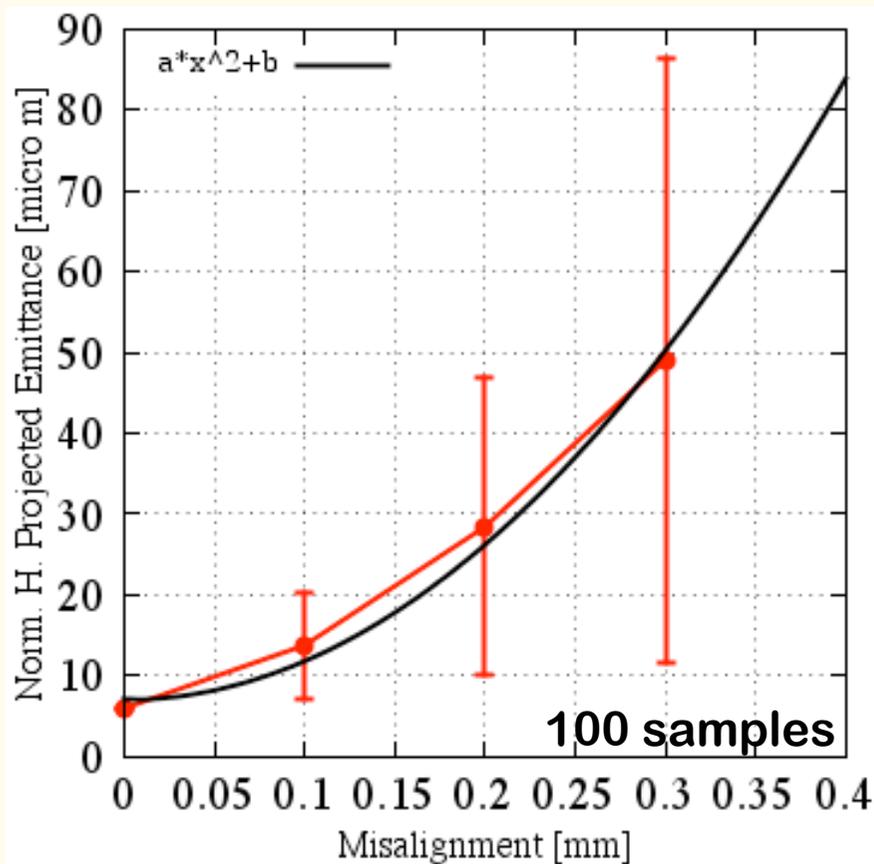


Transverse distribution in time direction

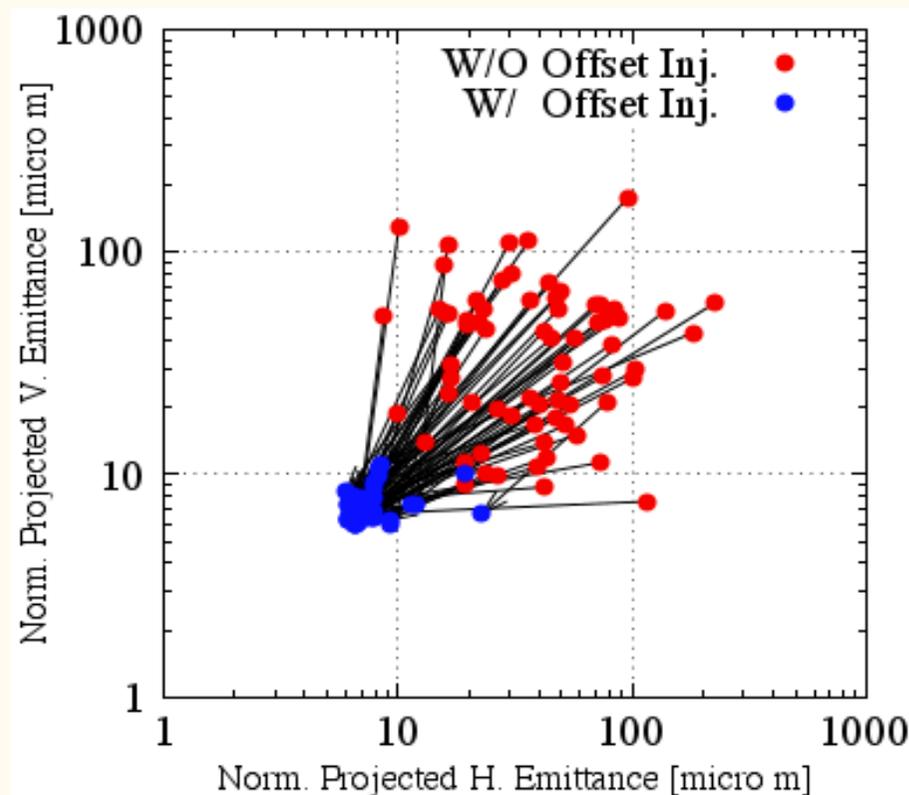
Emittance Dilution

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

Mis-alignment leads to Emittance blow-up



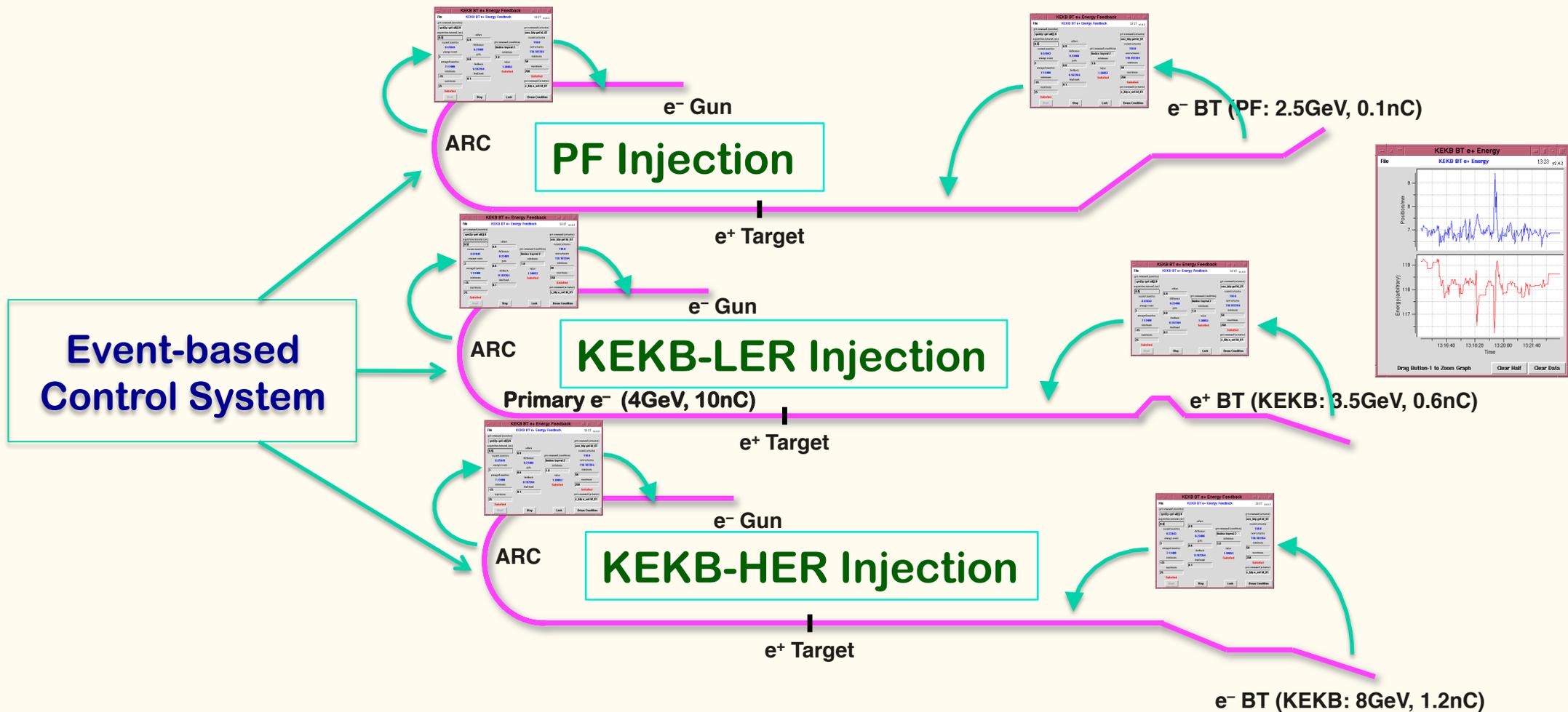
Orbit manipulation compensates it



Sugimoto et al.

Multiple Closed Loop Controls Overlapped

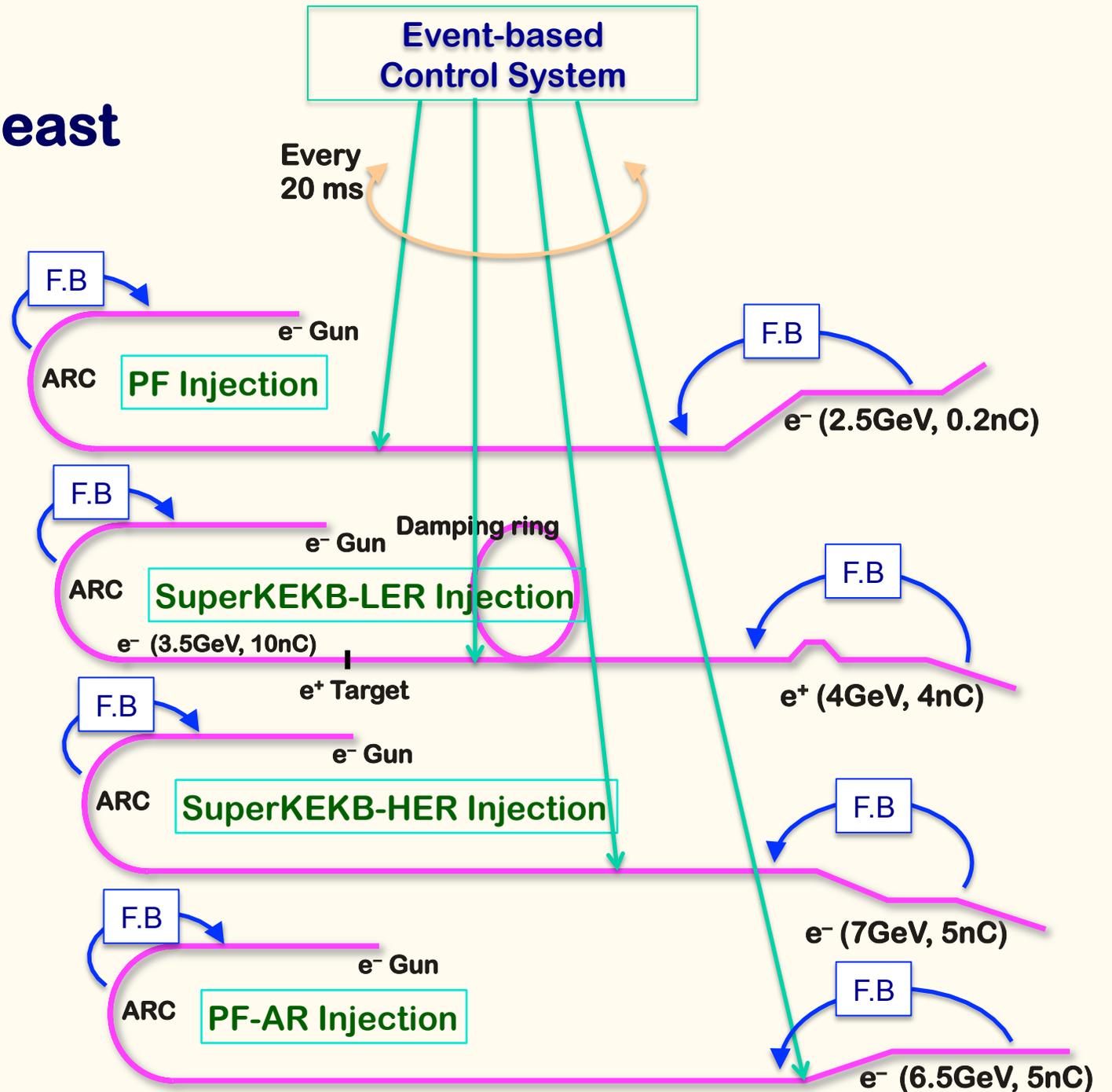
- ◆ Closed loops were installed on each PPM VA independently
- ❖ Tested at KEKB





◆ Four PPM VAs at least for SuperKEKB

(maybe with additional PPM VA for stealth beam)



Feedback loop life cycle

◆ 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 Irif, timing, magnetic field, etc
- ❖ often without knowing the origin of the instability

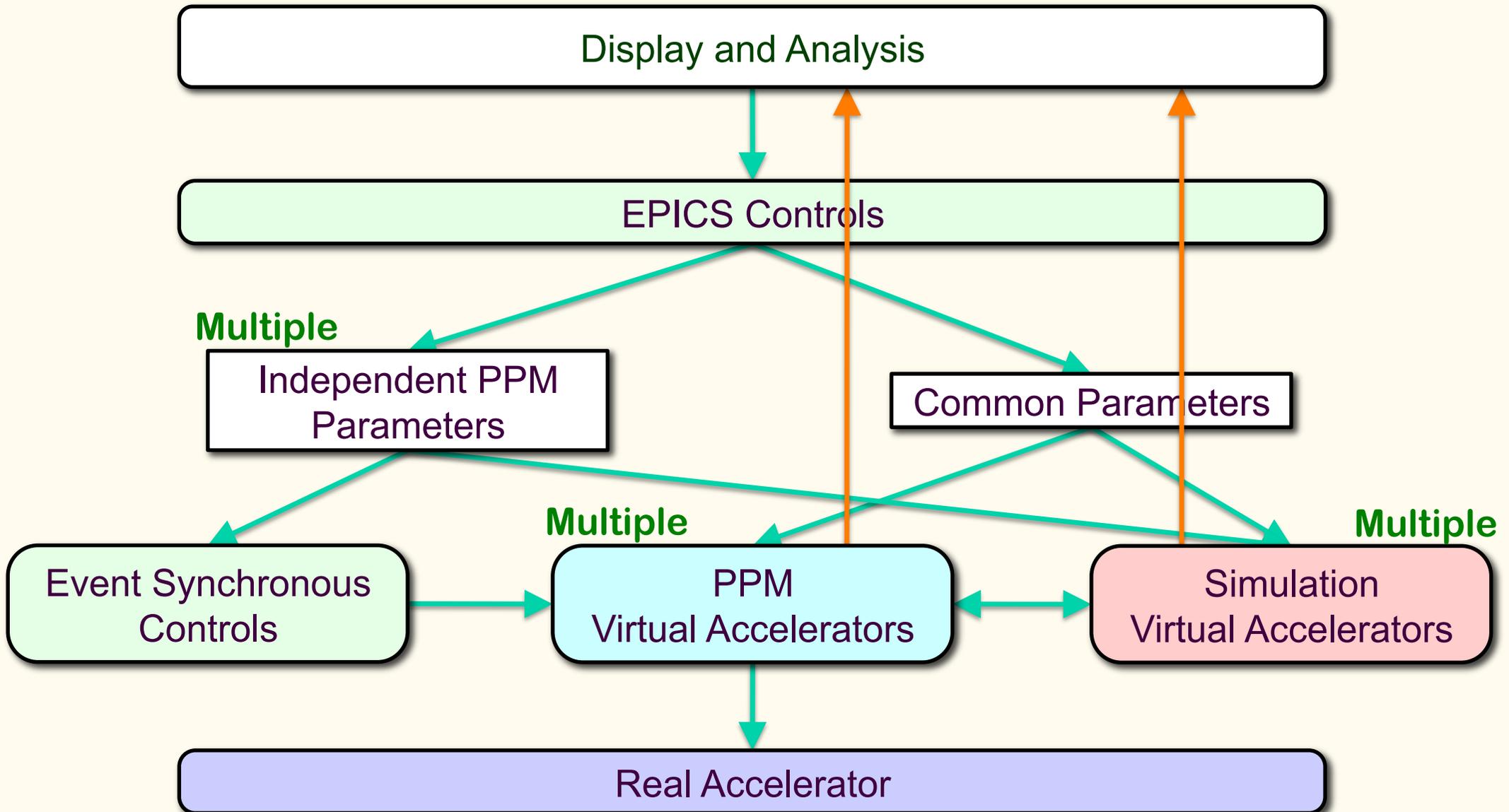
◆ Instability hunting, and fixing

◆ Beam study, or machine study using beam

◆ If fixed, remove corresponding feedback loop



System Construction



Conclusion

- ◆ **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**

