Pulse-to-pulse Beam Modulation and Event-based Beam Feedback System at KEKB Linac

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KEK

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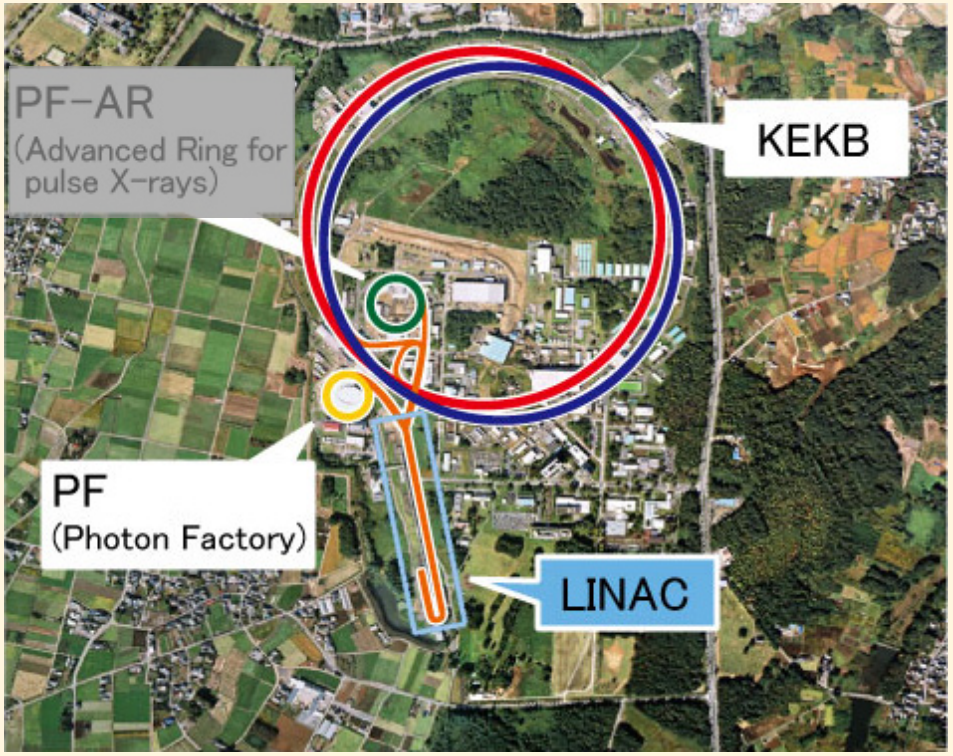
KEK Electron Accelerator Complex

- **Linac clients**
  - **KEKB Asymmetric Collider**
    HER 8-GeV e– 1nC x2
    LER 3.5-GeV e+ 1nC x2
    (with 10nC primary e–)
  - **PF 2.5-GeV e– 0.1nC**
  - **PF-AR 3-GeV e– 0.2nC**

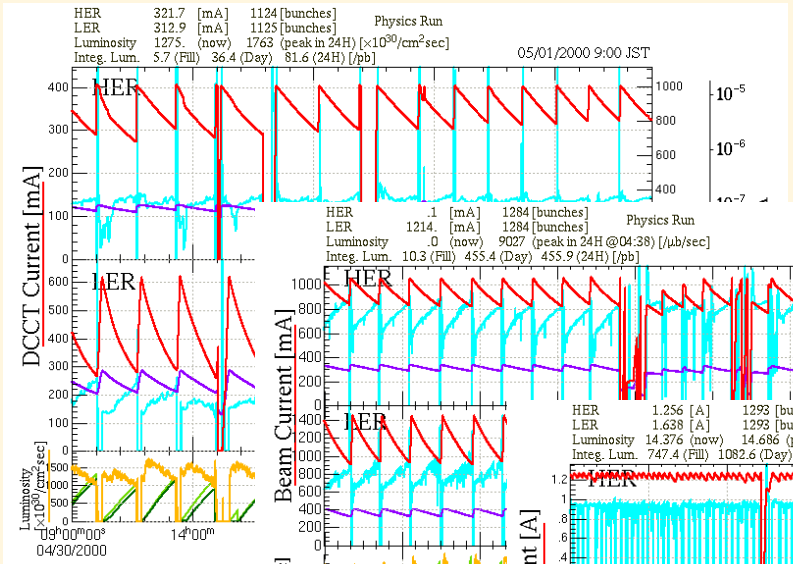


- **Improvement efforts at Linac were carried in several steps**

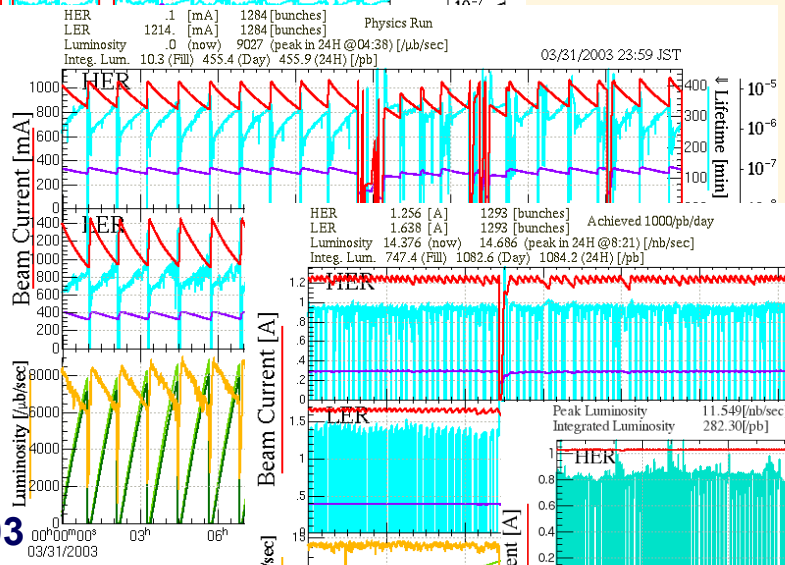
Contents

- Past feedback loops at KEK linac
- Simultaneous top-up injections
  - Beam instrumentation
- Event-based closed feedback loops
- Conclusion

KEKB Operation Improvement

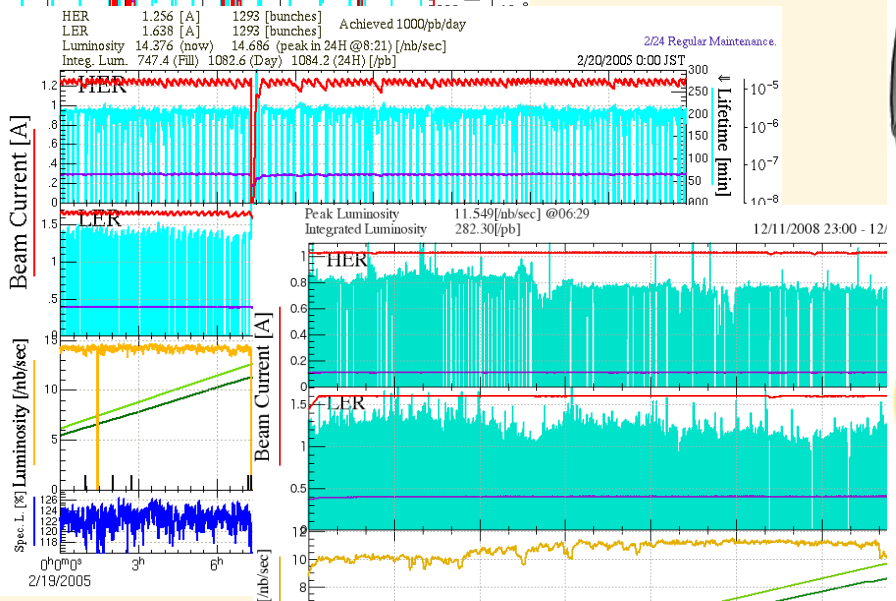


May.2000



Apr.2003

Dual Bunch e+



Feb.2005

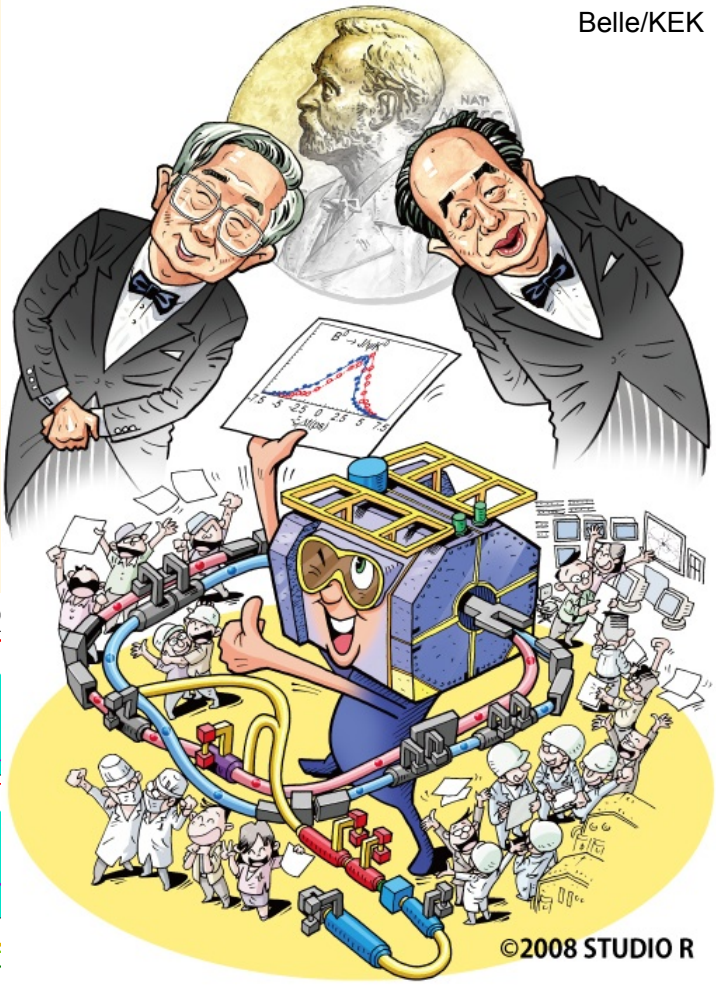
Continuous

Injections

Dec.2008

Crab Cavities and

Simultaneous Injection

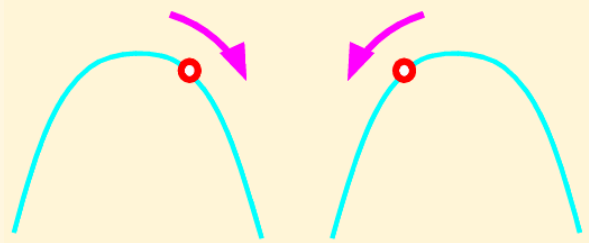


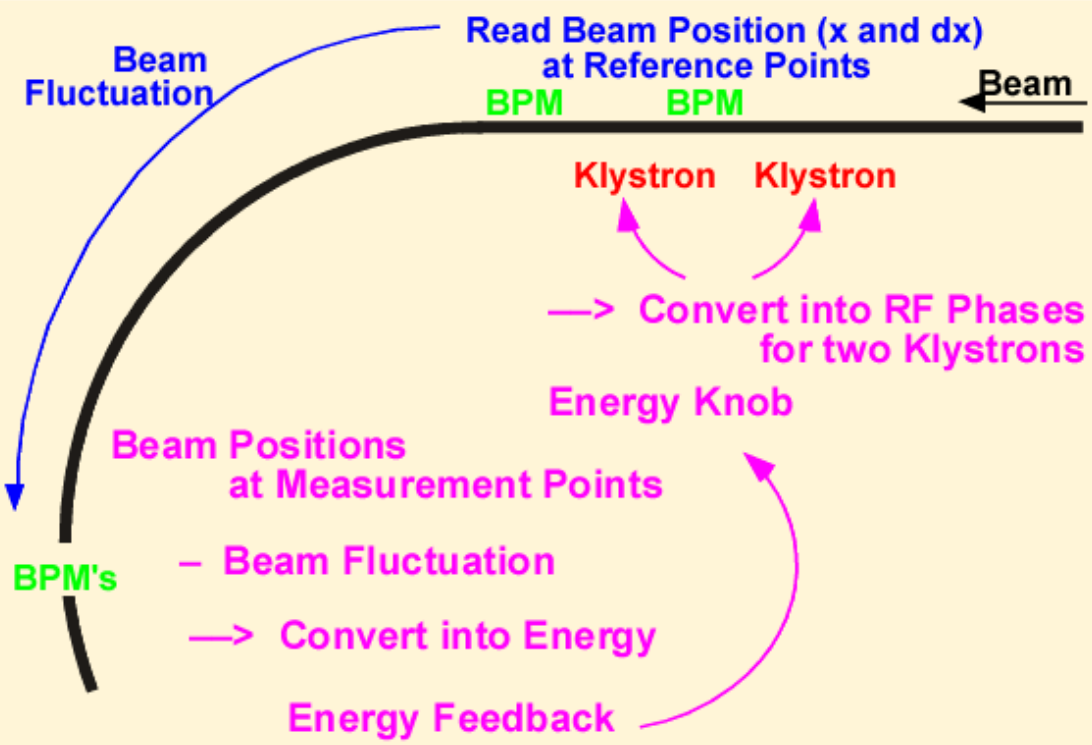
Linac Beam Instabilities at Commissioning

- **Beam instabilities were observed at the beginning of commissioning (2000~2005)**
  - Energy, orbit, energy spread, emittance, charge
- **Fluctuation source hunting**
  - Analysis by correlation, tolerance, single value decomposition, time-dependent correlation, etc
  - Many of them caused by simple failures of equipment, utility (temperature, power), or design deficiencies
  - But it took some time to fix... During that time,
- **Simple and slow beam feedback loops were effective**
  - Sometime, more sophisticated method like down-hill simplex was performed (that may hide the important defects)

Energy Stabilization

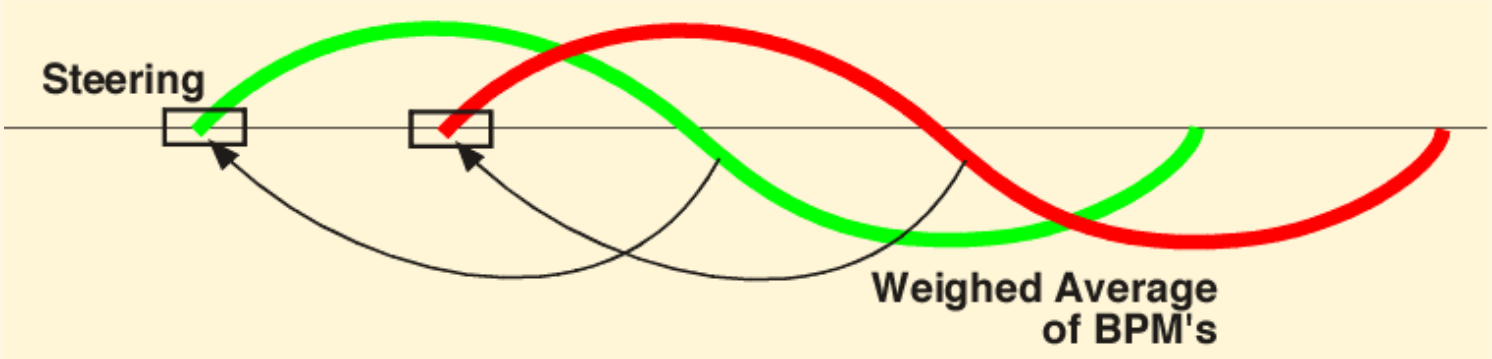
- **Energy instability was sometimes found**
  - Closed feedback loops were formed
  - Beam positions were measured where dispersion function is large
  - RF phases at adjacent stations were changed
  - Loop parameters were beam mode dependent
  - Energy spread feedback using multi-electrode monitor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





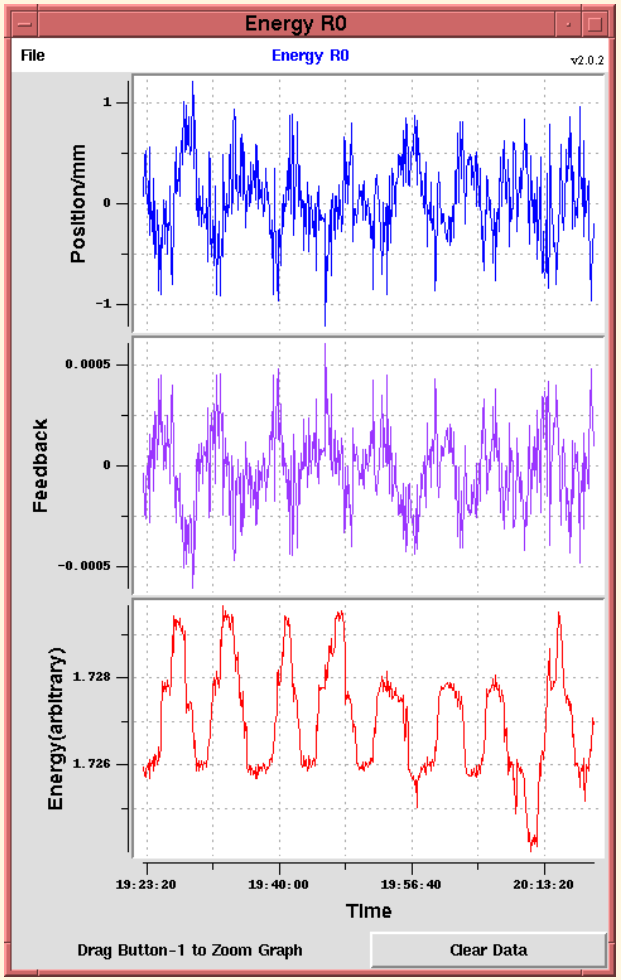
Simple Orbit Stabilization

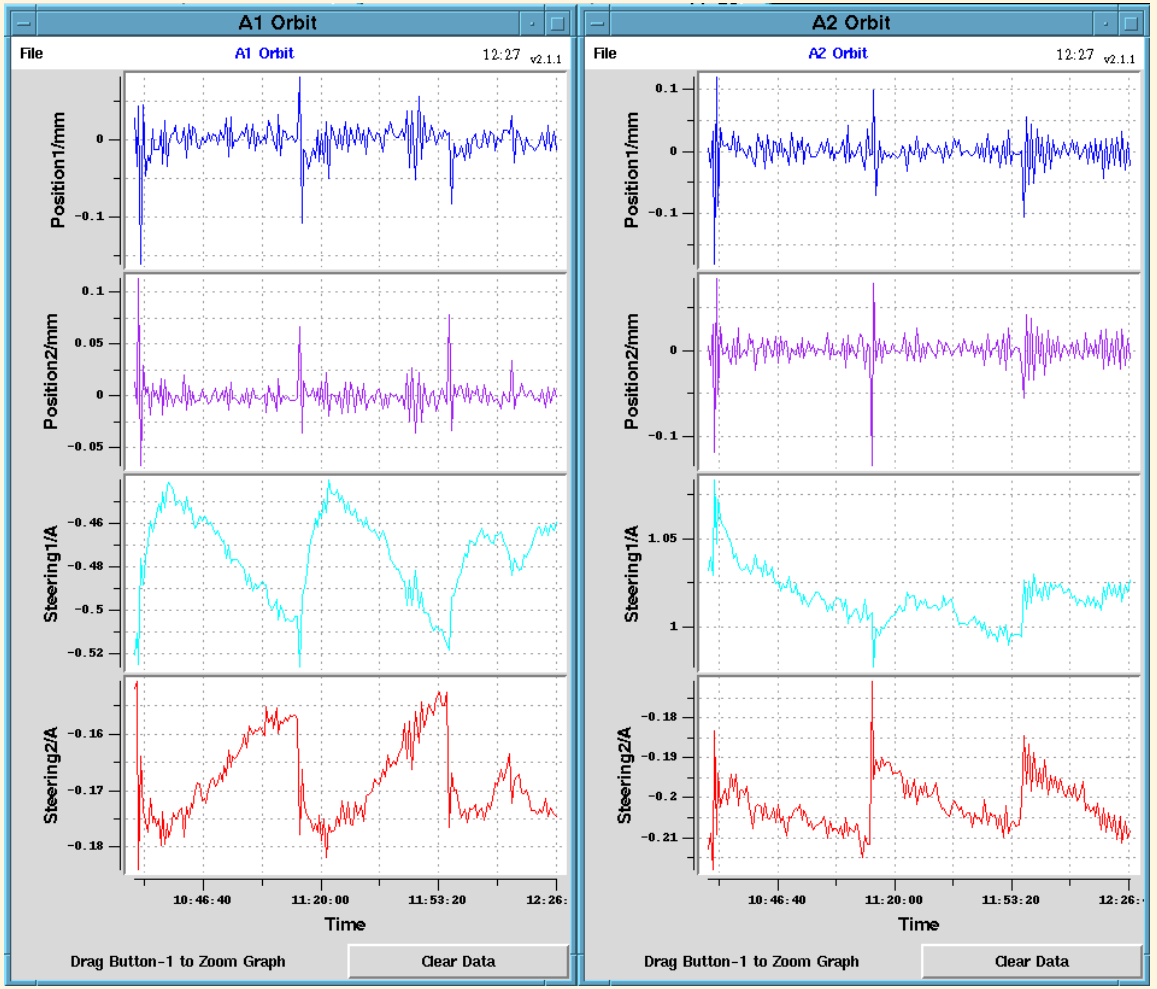
- **If Orbit became unstable**
  - Beam positions were measured where betatron phases are 90degree apart
  - Corresponding steering magnets are adjusted
  - If the orbit fluctuation was large, weighed average of BPMs based on response functions to beam kick or energy change
  - The same method was applied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



Simple Stabilization Examples

- 7-min energy change, later attributed to air conditioner at the 1st high power source
- 40-min orbit change, later attributed to RF source for a buncher cavity





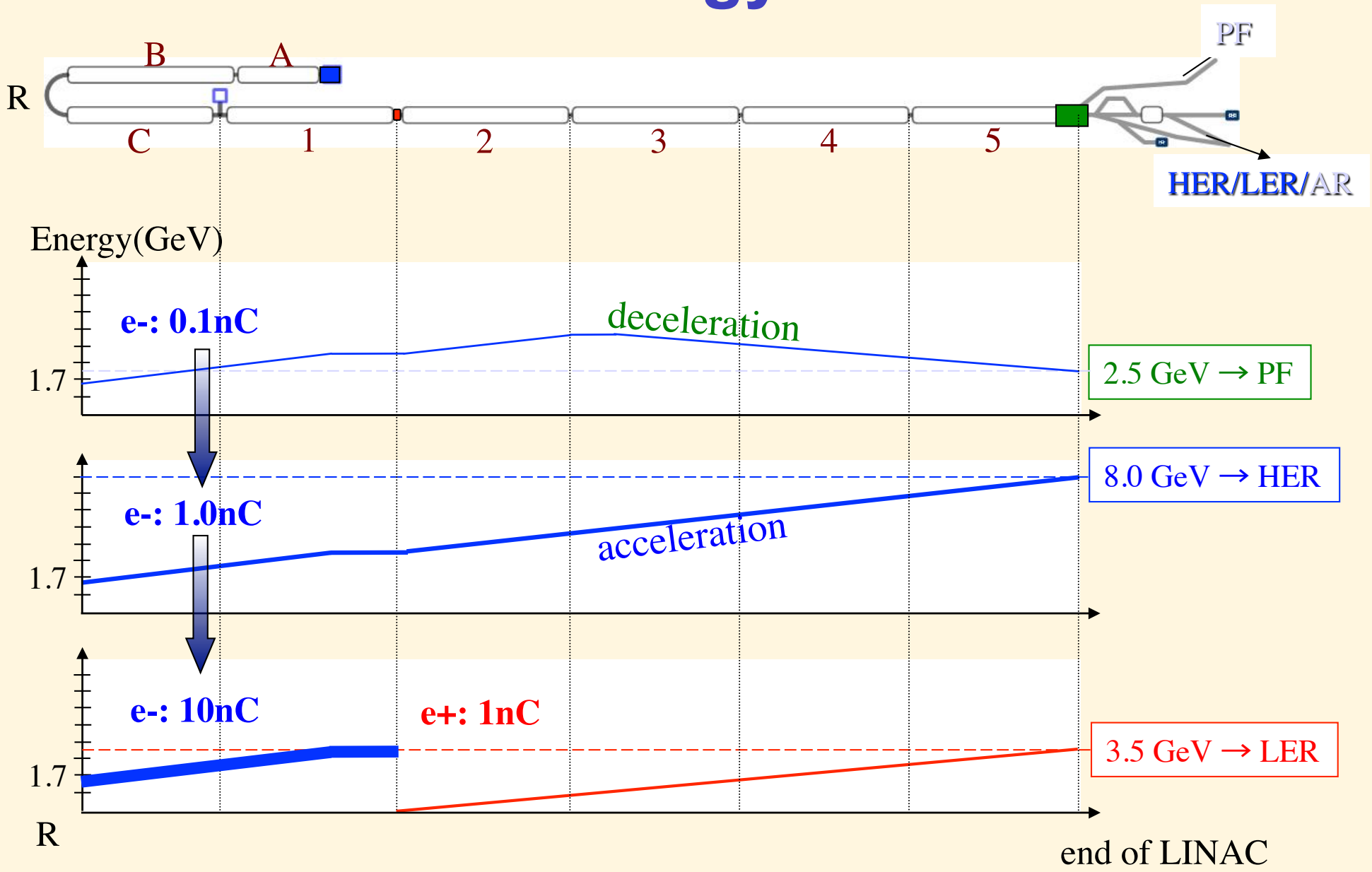
Implementation and Results

- Those closed loops were implemented in a scripting computer language with graphical user interface
  - With separate activity management/monitor panel
  - As standard simple PI (Proportional-Integral) controller
- Very effective during commissioning
- Instability sources were identified and fixed
  - Became unnecessary later during normal operation
- Effective during beam study
  - With unusual and scanning beam condition
- 1Hz measurement at the beginning
  - 50Hz measurement was hoped

Fast beam switching or Simultaneous Injection

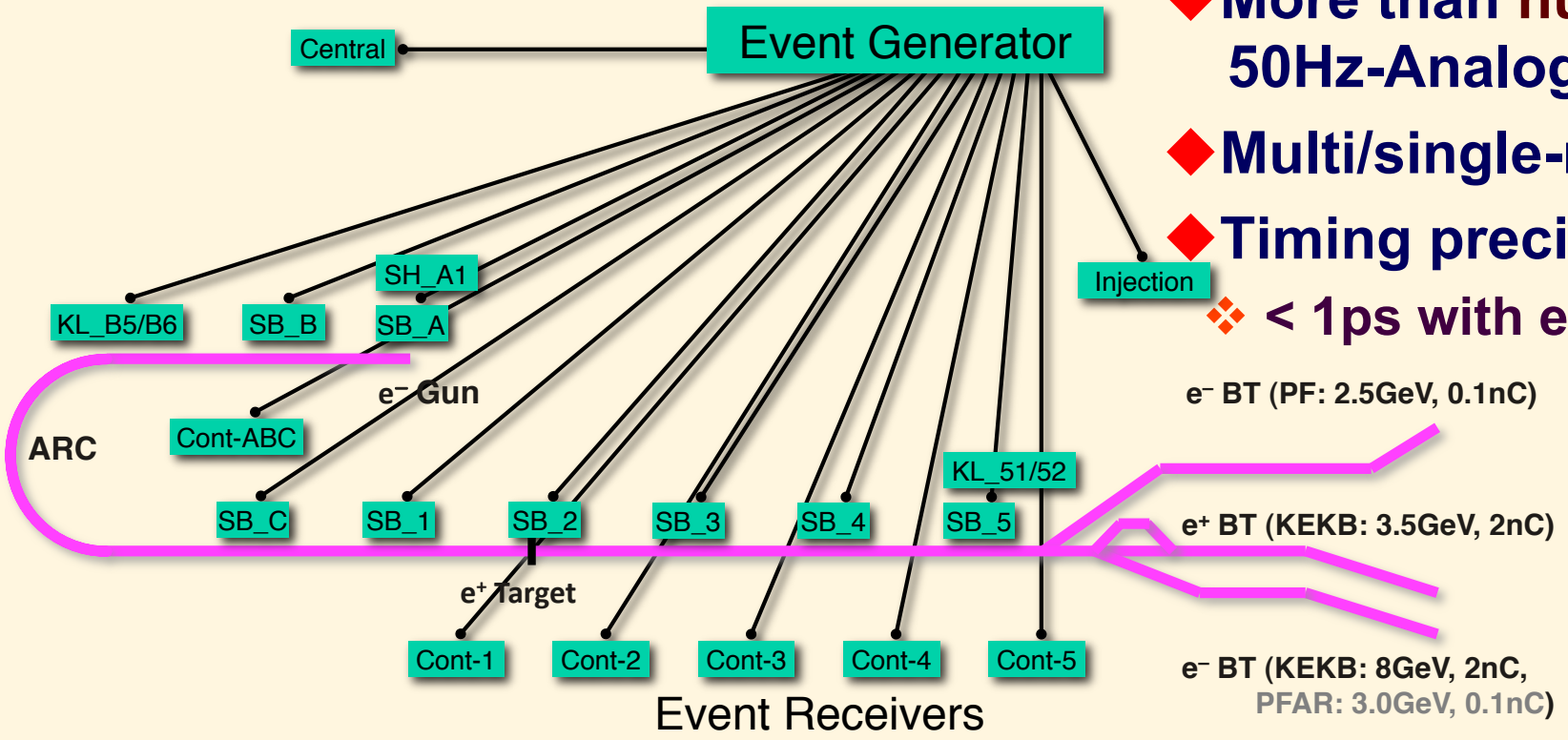
- Luminosity degradation on beam studies at PF and PF/AR
- Sensitive luminosity tuning with Crab cavities
- Future SuperKEKB injections with shorter lifetime
- PF top-up injection for higher quality experiments
  - CERN/PS switches beams every 1.2s (PPM)
  - SLAC/SLC switched beams at 180 Hz
- KEK Linac had switched beams 360 times a day in 2008 (just before simultaneous injection)
  - 10~120seconds per switching

Linac Energy Profile



Event System Configuration

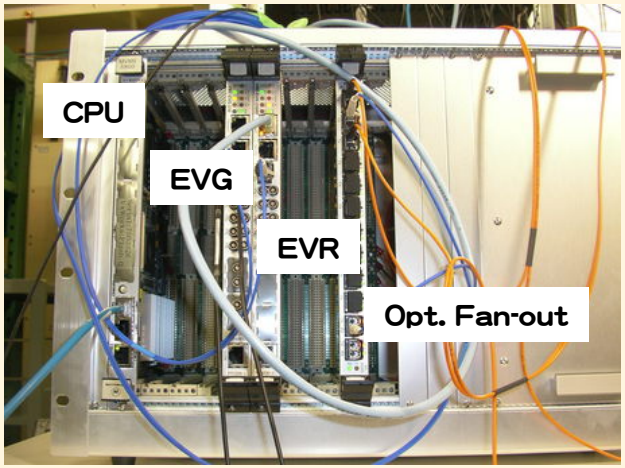
- MRF's series-230 Event Generator / Receivers
- VME64x and VxWorks v5.5.1
- EPICS R3.14.9 with DevSup v2.4.1
- 17 event receivers up to now

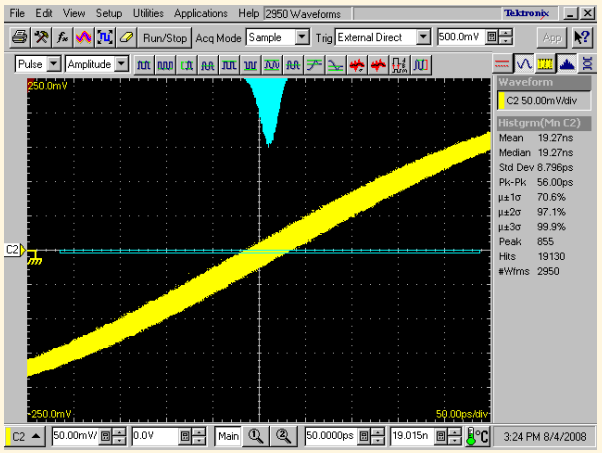


- 114.24MHz event rate, 50Hz fiducials
- More than hundred 50Hz-Analog/Timing data
- Multi/single-mode fiber
- Timing precision is < 10ps.
  - < 1ps with external module.

Linac Event System

- **Satisfies the requirements**
  - Event rate : 114.24MHz (bit rate : ~2.3GHz)
  - Fiducial rate : 50Hz
  - Timing jitter (Short term) : ~8ps
  - No. of defined events : ~50
  - No. of receiver stations : 17
  - No. of Fast parameters : ~130





EVR & LLRF

Event Manipulation

Human Operator

Injection Programs

Arbitrate and Generate Beam Mode Pattern (in PythonTk)
- considering priorities of the rings
- equalizing pulsed power supply interval
- in 4 arrays (waveforms) of length 2 (40ms) to 500 (10s)
- each element corresponds to a 20-ms time slot and a beam mode

Generate Events for the Next 20-ms Time Slot (in Event Generator)
- reading two consecutive elements from the beam mode pattern
- generate several events for the next pulse
- generate preparation events for the next after next

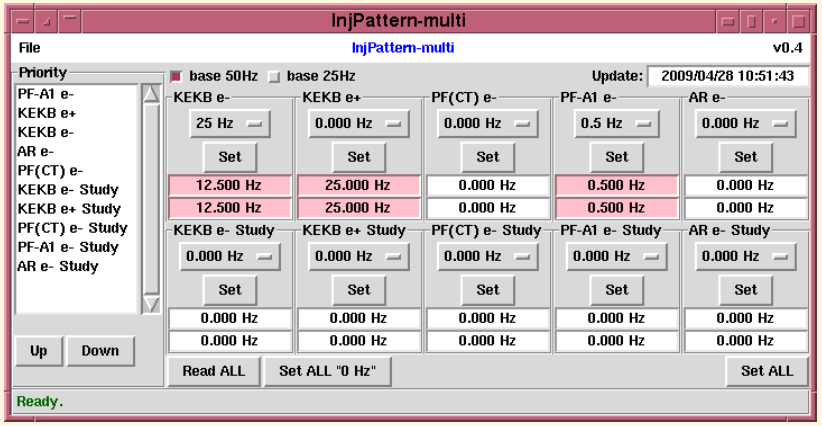
Generate Signals based on Received Events (in Event Receiver)
- generate pulsed signals as prepared in the previous time slot
- program the signals (enable/disable, delays, etc) for the next
- start to generate analog signals for the next

Beam Mode Pattern Generators

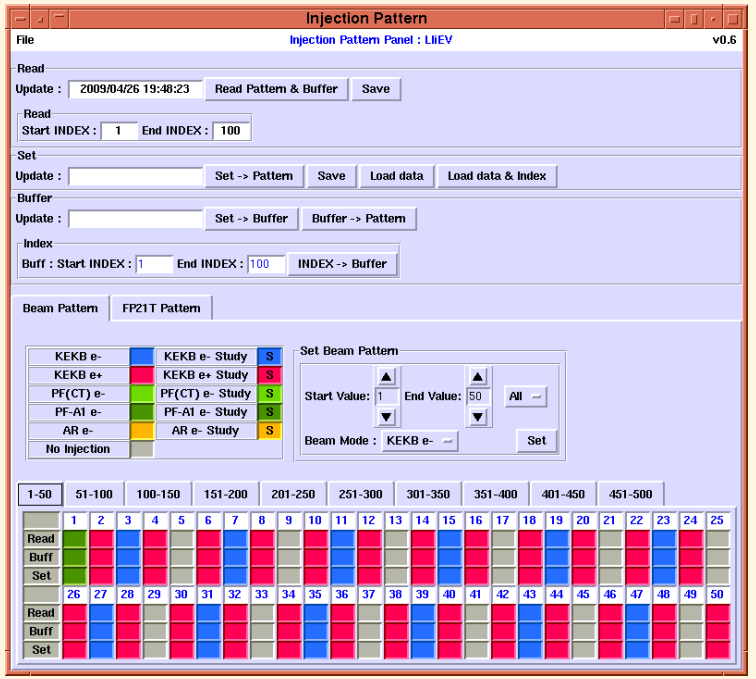
Pattern panel arbitrates requests

- From downstream rings with priorities, or human operators
- There are several pattern rules due to pulse device features and limitations
- Pattern arbitrator software was written in scripting languages to meet daily changes during the commissioning stage

Remote controlled automatic pattern arbitrator



Manual pattern generator



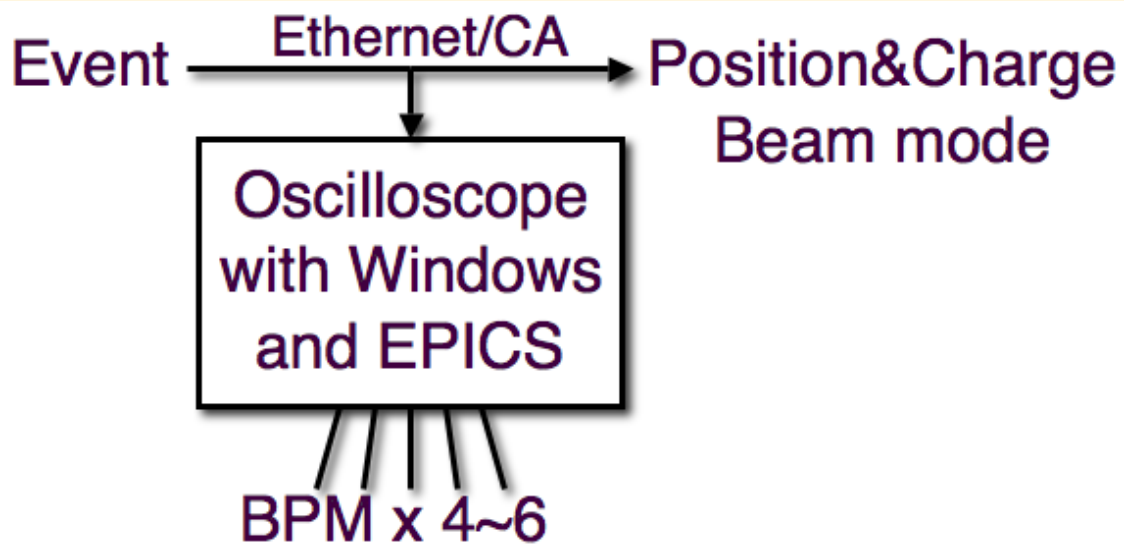
- Recent typical operation.
  - ~37Hz for KEKB LER
  - ~12.5Hz for KEKB HER
  - ~0.5Hz for PF

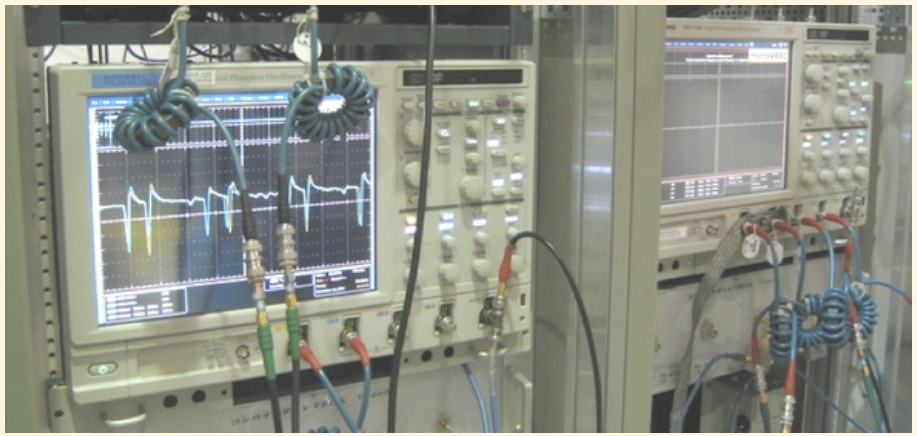
Parameters

- **Parameters switched via event system**
  - **LLRF phase/timing : 14x4**
    - Overall energy profile, dual-bunch energy equalization, final energy adjustment
  - **HP RF timing : ~60**
    - Energy profile and backup management
  - **Gun voltages, picosecond delay : 4**
    - Beam charge selection, dual bunch selection, bunching
  - **Pulsed magnets/solenoid : 14**
    - Beam transport selection, orbit controls, positron focusing
  - **Injection phase interface : 2**
  - **Bucket selection interface : 2**
  - **BPM : ~100x3**
- **Sufficient for fast beam mode switching**
- **Integrity monitors soon**

BPM

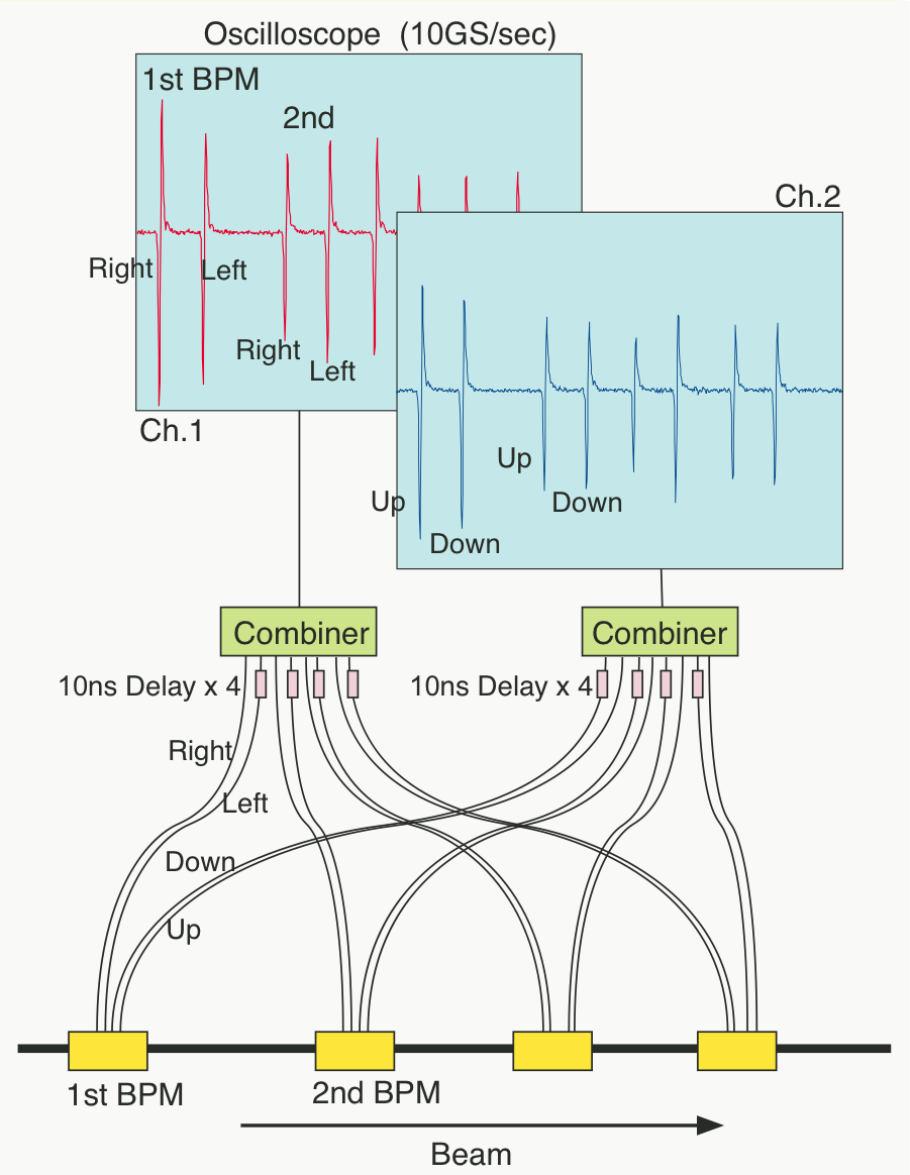
- Tektronix DPO7104 can acquire data at >=50Hz
  - With embedded EPICS
- Beam modes are recognized by events through CA network
- Clients can monitor data of an interested beam mode
- 26 oscilloscopes are installed
- 100 BPMs are synchronized. (100 BPMs at BT as well soon)





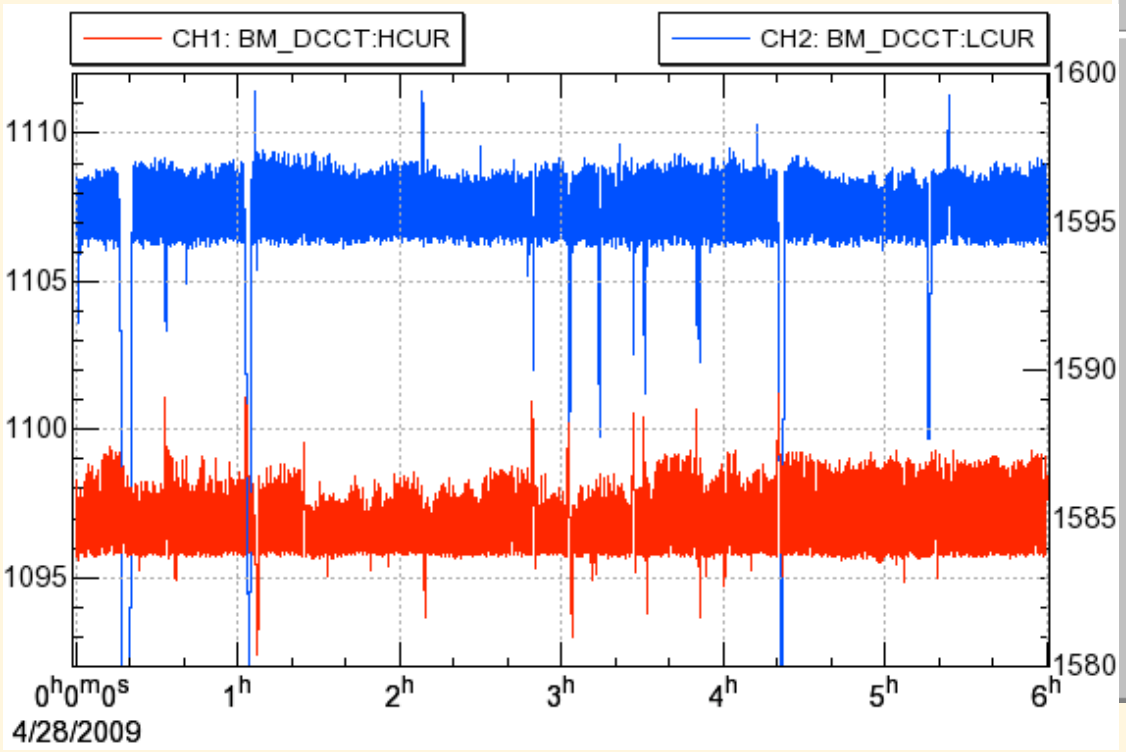
Measurement and Data Acquisition

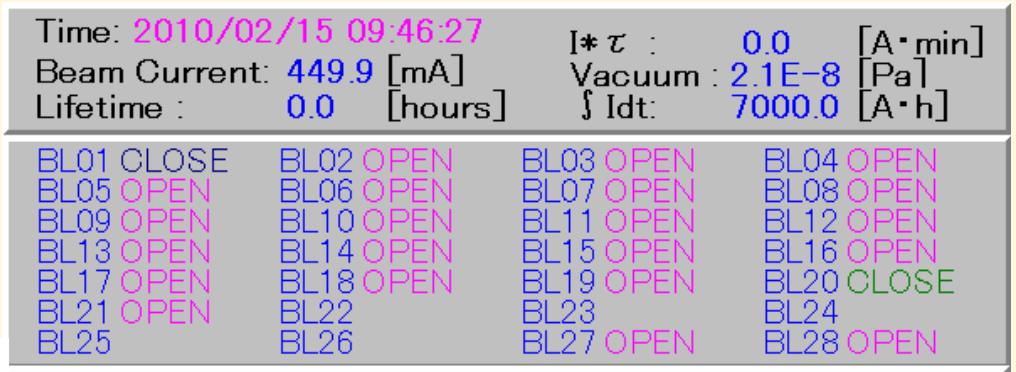
- Originally much efforts to develop detectors, shaping amplifiers
  - No budget for all BPMs
- Switched to direct waveform acquisition
  - Minimized active components, then minimized calibration tasks, maintenance
  - Equal-length cables
  - One oscilloscope covers about 5 BPMs, or combined 20 (or 40) waveforms
  - 5 - 10Gs/s (with additional interpolation)
  - Possible to measure dual bunches
  - Solved many issues at once!
  - Extract each signal, apply calibration factors, send to upper layer at 50Hz

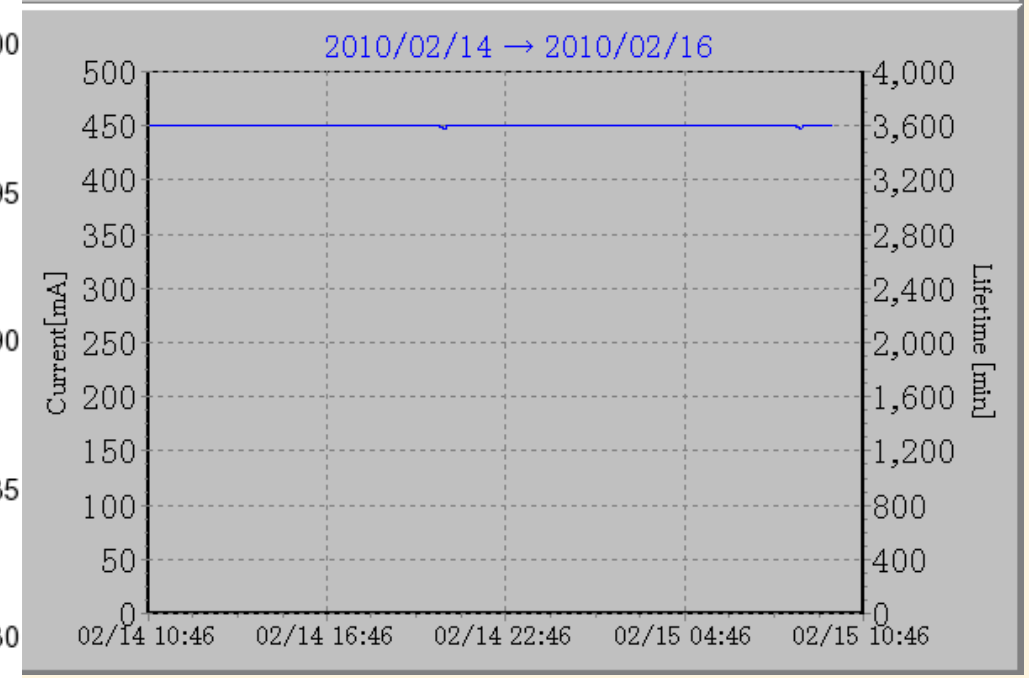


Simultaneous Top-up Injection Results

- **Beam currents are kept within**
  - **KEKB 1mA (~0.05%)**
  - **PF 0.05mA (~0.01%)**

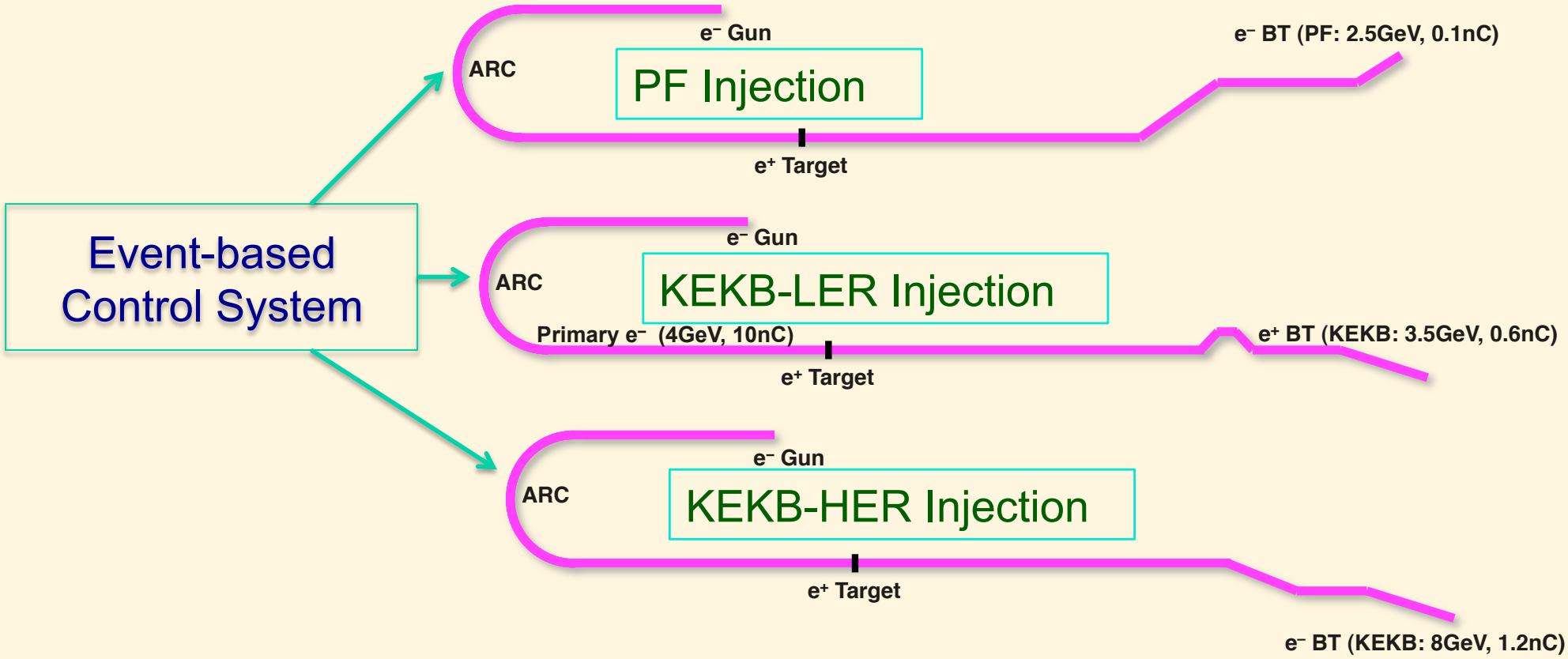






Three Virtual Accelerators

- **Controls and instrumentations are essentially mode-dependent, and mutually independent**
- **Selecting a real machine out of three virtual machines**
  - **Managing three parameter sets**

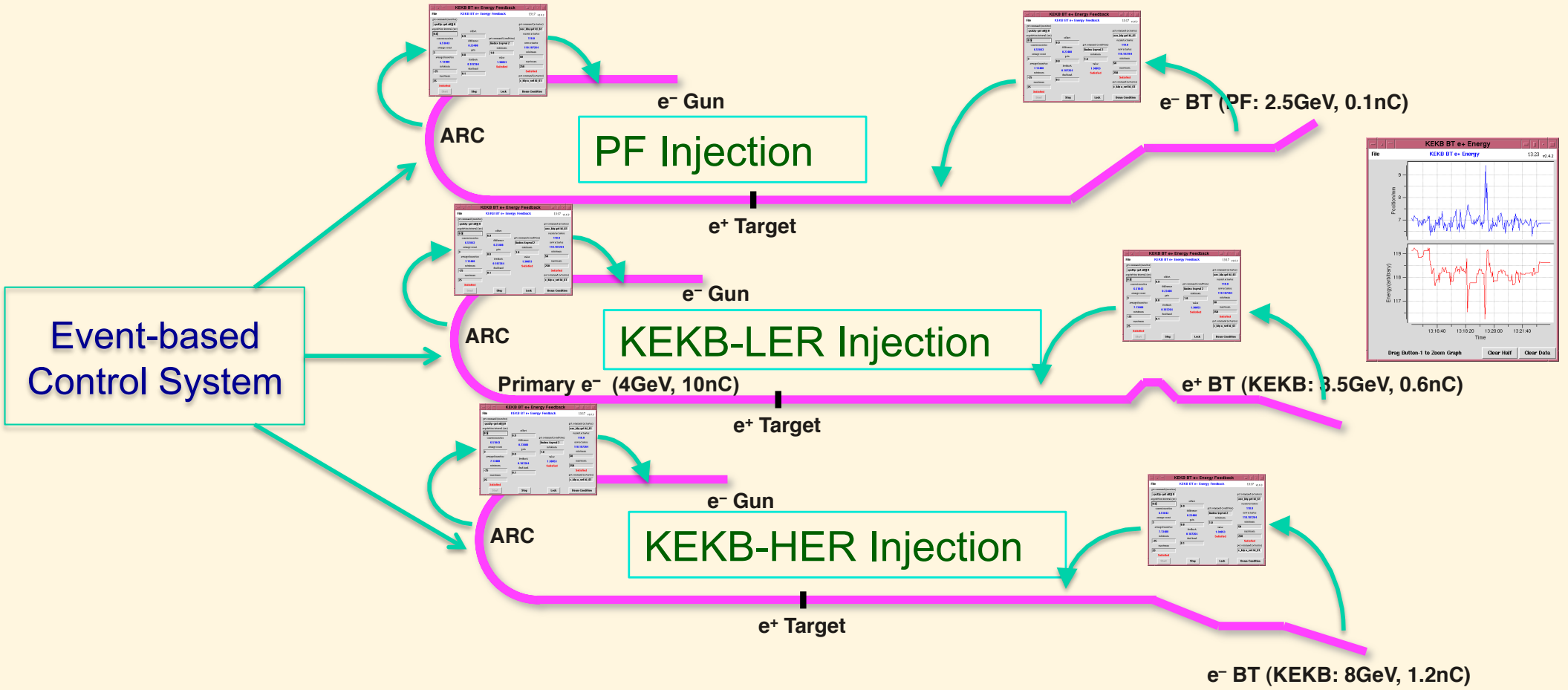


Combined Event-based Feedback Loops

- Simultaneous injections are managed by independent parameters for three virtual accelerators of KEKB-HER, KEKB-LER and PF
- On each of virtual accelerators, closed feedback loops for energies using the same procedure were installed
- As parameters are independently managed, no modification to the software was necessary

Three-fold Independent Closed Loops

- **Feedback loop software act on one of three virtual machines**
  - **Managing independent parameter sets**



Results and Future

- No signs of instabilities up to now (other than white noise)
- No fast oscillation was observed with 50Hz measurement
- Event-based feedback loops may be useful during beam study, or when some equipment or utility became unstable
- Orbit feedback loops should be applied with pulsed steering magnets. Also energy-spread stabilization may be possible
- In the future SuperKEKB project, when new equipment will be installed, event-based feedback loops should be necessary
- Fast processing implemented in a compiler language is under development

Conclusion

- Closed beam feedback loops for beam characteristics were useful under certain condition
- Pulse-to-pulse modulated simultaneous injection improved the experiment performance
- Event-based feedback loops were implemented
- Feedback system will be necessary in the future project with additional equipment

Acknowledgement: Event-based controls was not possible without help from EPICS community. Thanks to them all over the world.

Thank you