Simultaneous Injections to KEKB and PF

and Event-based Control System

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For Linac Commissioning Group
and for Linac and KEKB Control Group

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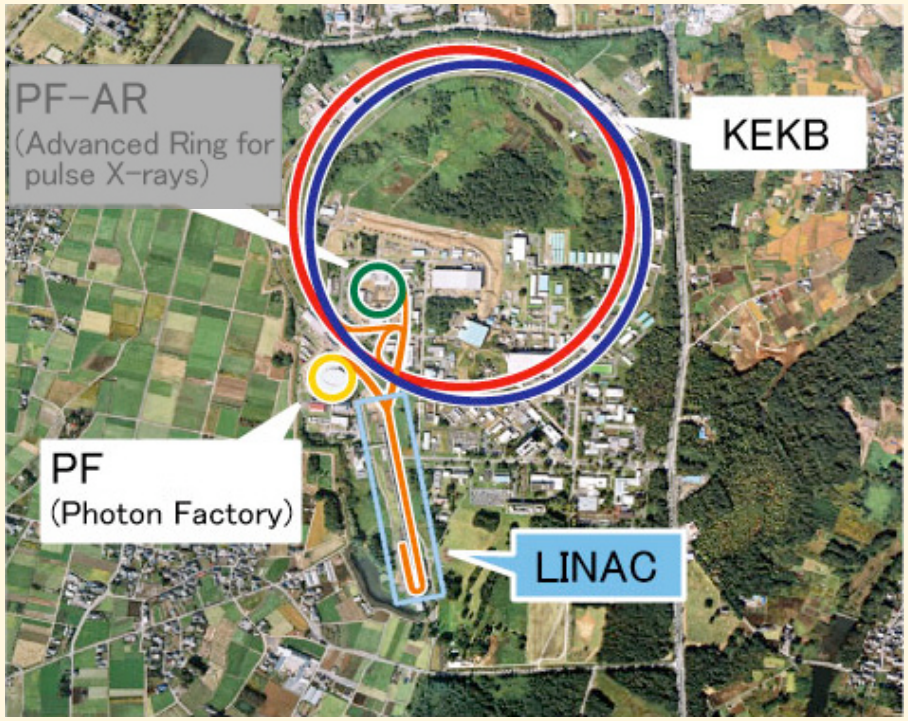
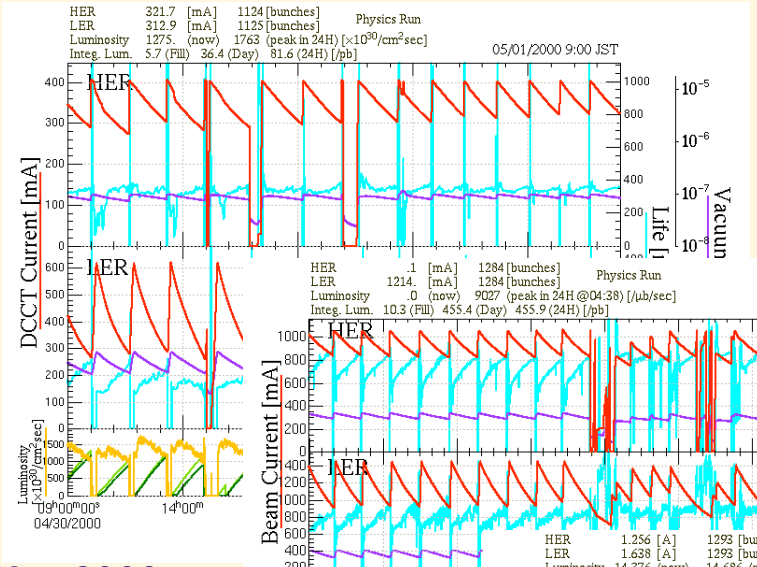
Electron Accelerator Complex

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

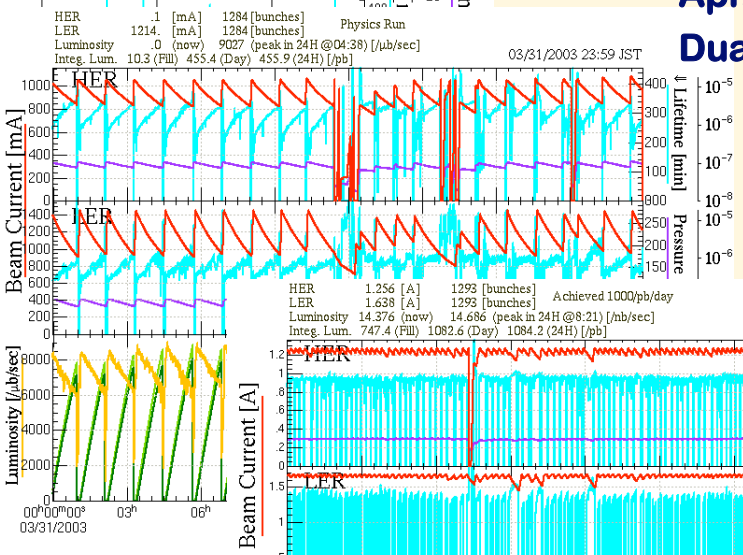


- **At first simultaneous top-up injections to three rings at KEKB and PF**
  - **Switching beams at 50Hz**
  - **For stable operation and higher quality exp. results**

KEKB Operation Improvement

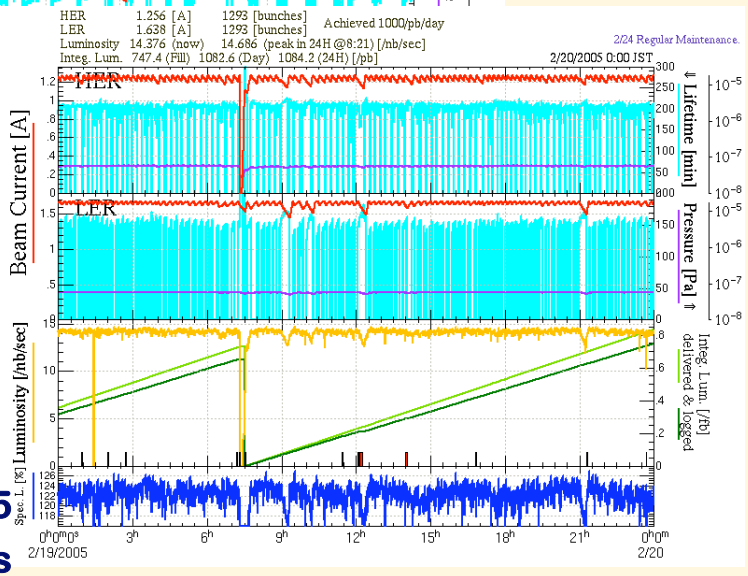


May.2000



Apr.2003

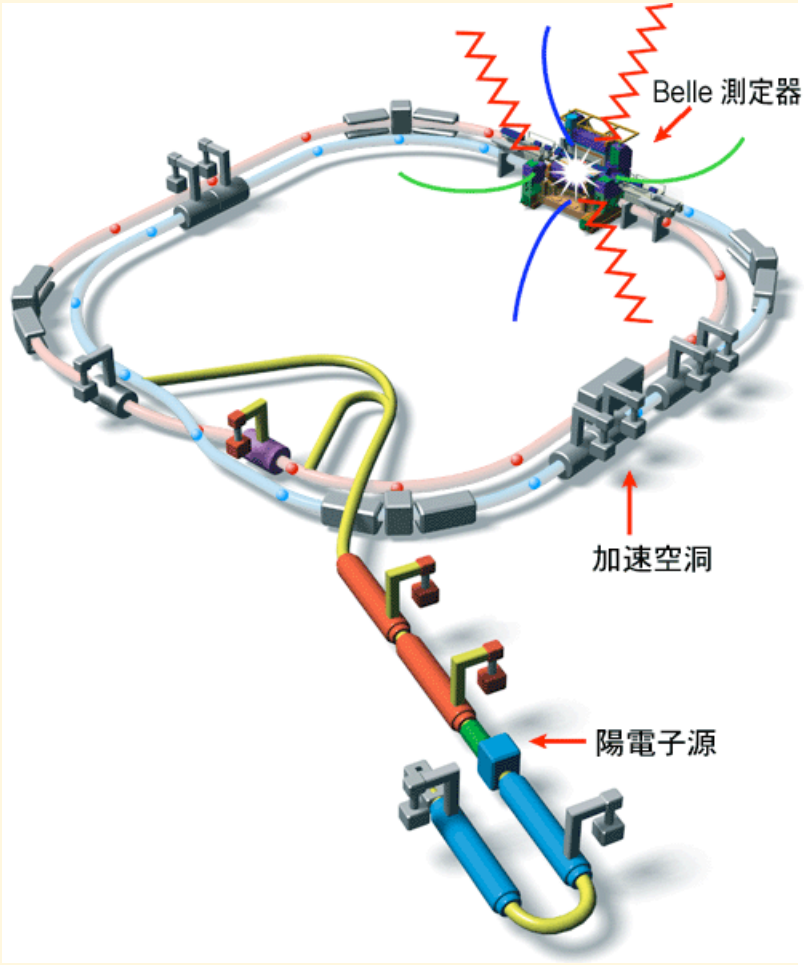
Dual Bunch e+



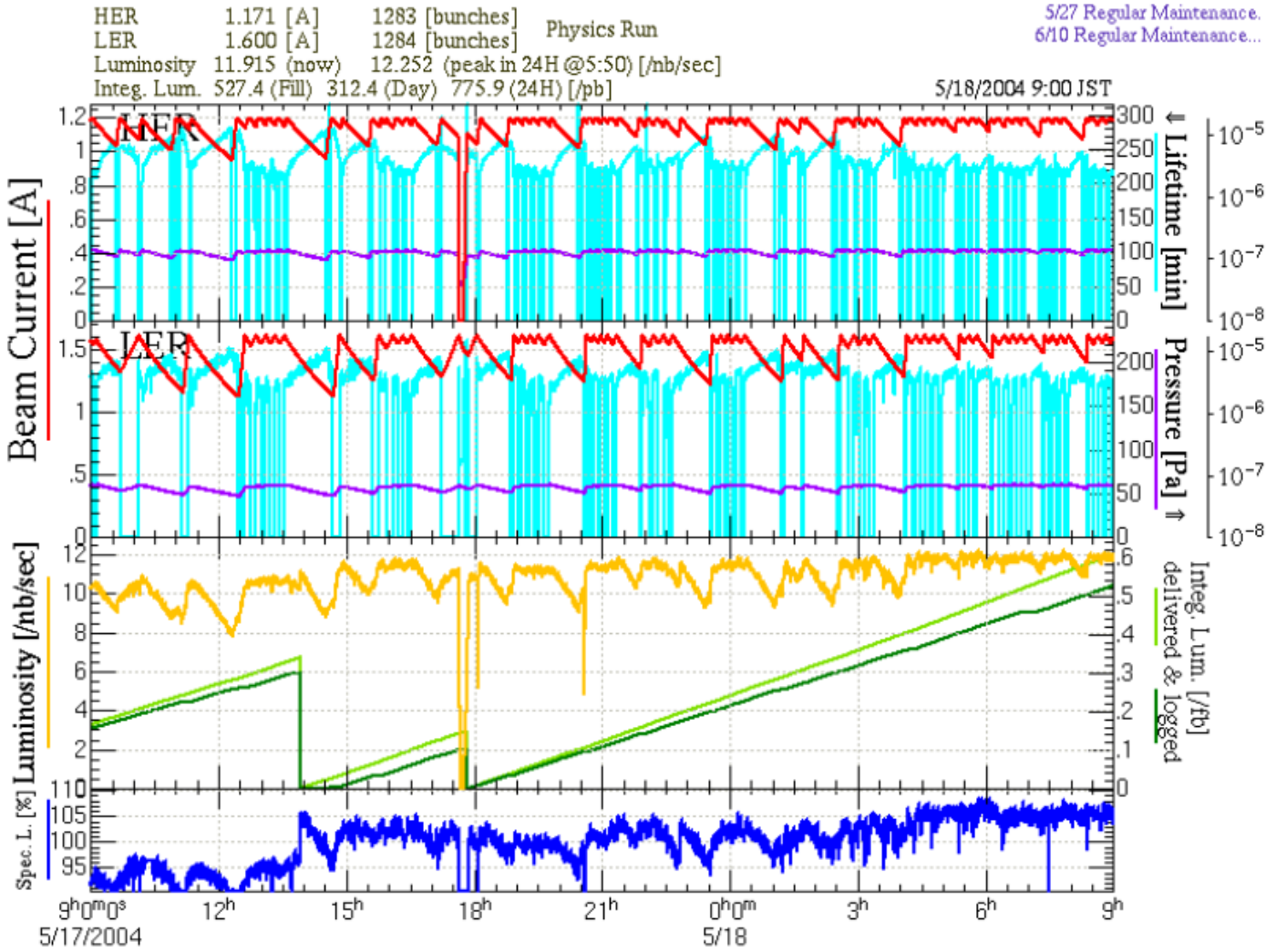
Feb.2005

Continuous

Injections



KEKB Injections during Beam Studies at PF and PF/AR



Motivation

- Was suggested since 2004

- Luminosity degradation on beam studies at PF and PF/AR
- Future SuperKEKB injections with shorter lifetime
- Sensitive luminosity tuning with Crab cavities
- 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, 10~120seconds per switching

Requirements

- Maximum beam rate of 50Hz x 2bunches should be kept
- Most pulsed power supplies were designed to operate at constant rate
- Most Linac magnets were not pulsed (except positron focusing)
  - Thus, it took much time for standardization
- Approx. 1000 devices in Linac
  - 600 active devices (gun, RF, magnets, etc), 100 passive devices (BPM, WS, etc), and static devices
- No resources for separate linac
- 20ms beam switching became the solution
  - At first HER/PF, later HER/LER/PF

Hardware and Operation Improvements

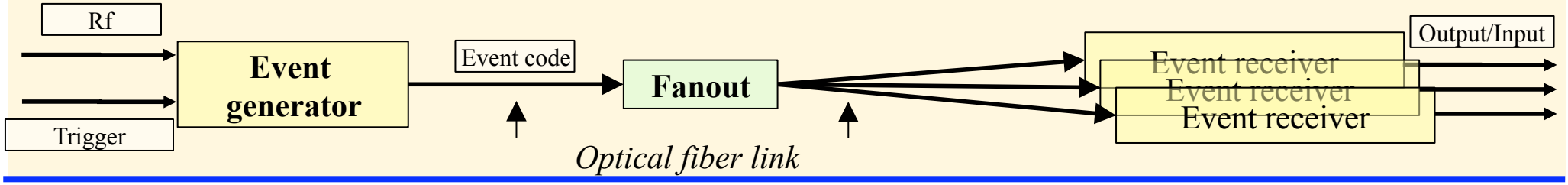
- Separate BT for PF (2005)
- Pulsed bending magnet for PF (2007)
- PF beam from common gun (A1) (2007)
- Beam charge safety interlock (2007)
- Event-based fast control system (2008)
- Pulsed steering magnets (2008)
- Electron bypass hole at positron target (2008)
- Interface between ring-linac RF (2008)
- Multi-energy linac optics (2008)
- Simultaneous injections (Apr.2009)

Fast Controls

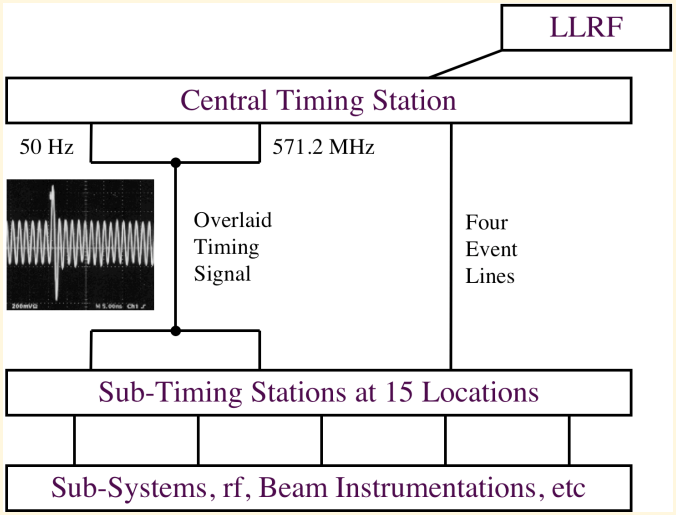
- ~100 parameter switching within 20ms
  - Keep most of magnet fields with compatible optics
  - Control llrf to change energy
- Pulsed magnet triggers and delays
  - Delays to keep the constant rate for certain power-supplies
- LLRF phases and delays
- Gun voltage and fine delay
- Interface to bucket selection, etc
- Ethernet-based controls are not reliable enough
- FPGA and fiber-optic RocketIO might be the way ?

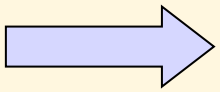
Event System

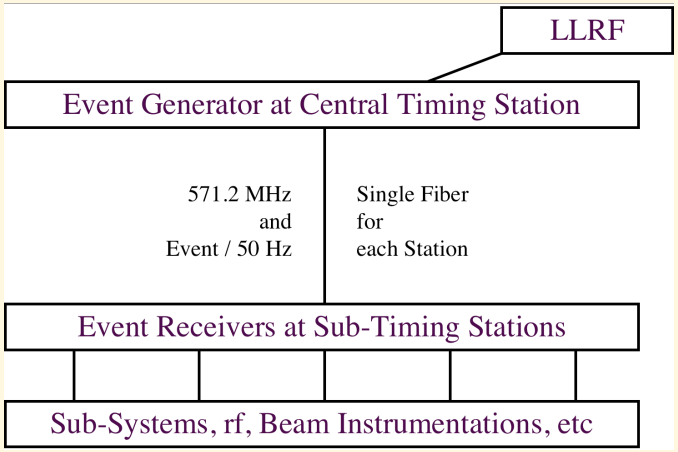
- **Many accelerator system require timing signals and accompanying information (event)**
  - **Several primitive facilities are combined and used at KEKB and Linac**
    - **Fast Timing signals are provided with delay module TD4/TD4V**
      - **Need timing trigger and rf clock**
    - **(Slow) Events are provided in another facility**
      - **Combining Hardware and Software**
  - **Event/Timing Systems which distribute the both timing and event are developed at Argonne/SLS/Diamond, and are employed at many institutes (Event Generator/Receiver)**
    - **Fast Timing, rf clock, Hardware event, Software Interrupt, can be handled in one combined system with a single fiber cable**
    - **Especially in EPICS, event can be connected EPICS Event directly, so record/database programming is possible**



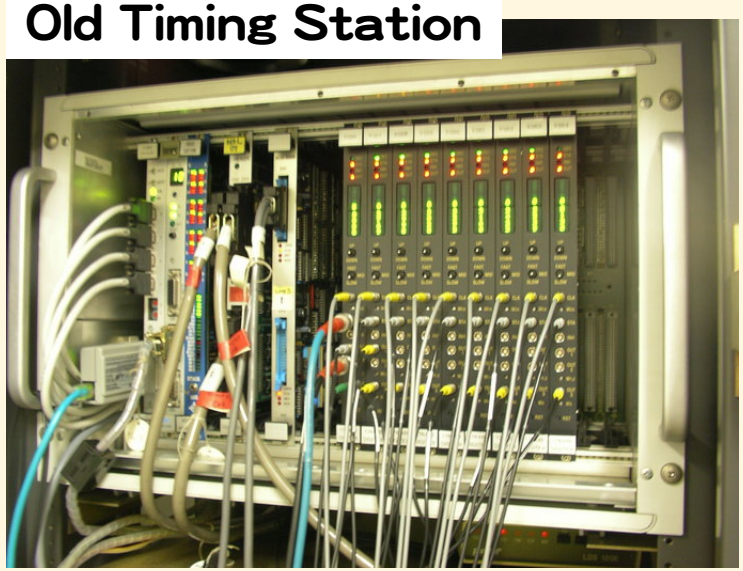
Timing System







Old Timing Station



New Event Receiver Station with 16 outputs

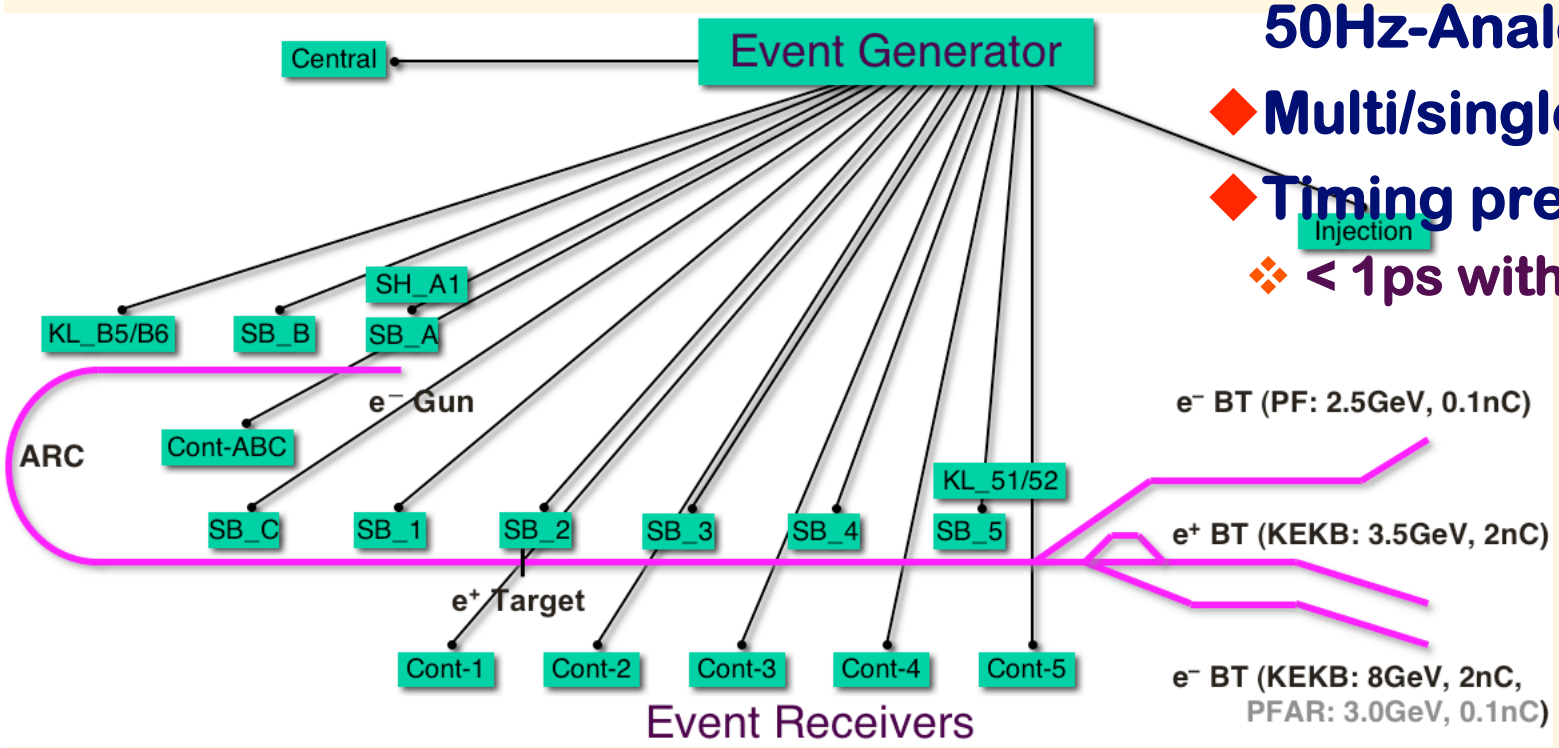
Event System

- **Simultaneous Injection**
  - to KEKB-HER, KEKB-LER, and PF
  - 2.5GeV to 8GeV, 0.1nC to 10nC
- **Stable stored beam current at three rings**
  - Should improve collision tuning with Crab cavities
  - Should improve the quality of experimental data at PF
- **Fast switching of many device parameters**
  - In 20ms / 50Hz
  - Should be reliable because beam power is much different
- **MRF Series 230 Event Generator / Receiver**
  - VxWorks 5.5.1, MVME5500 (Originally with RTEMS but…)
  - Timing precision less than 10ps is sufficient (TD4 provides 3ps)
  - Multi-mode fiber, and single-mode fiber for longer distance

Event System Configuration

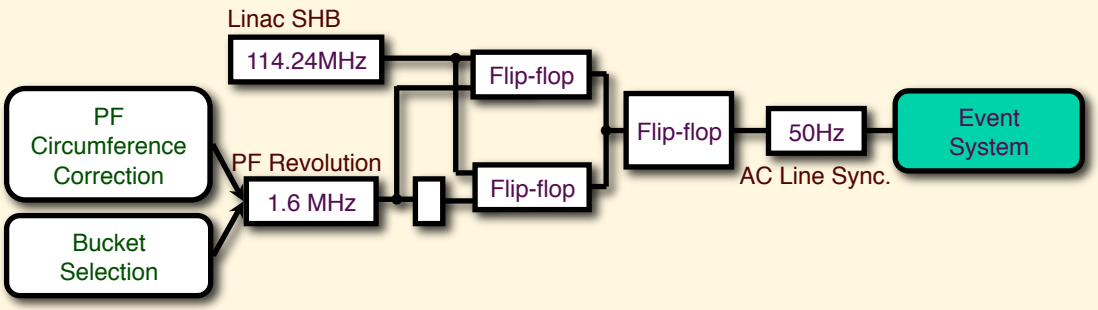
- MRF's series-230 Event Generator / Receivers
- VME64x and VxWorks v5.5.1
- EPICS R3.14.9 with DevSup v2.4.1
- 17 event receivers up to now

- 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.

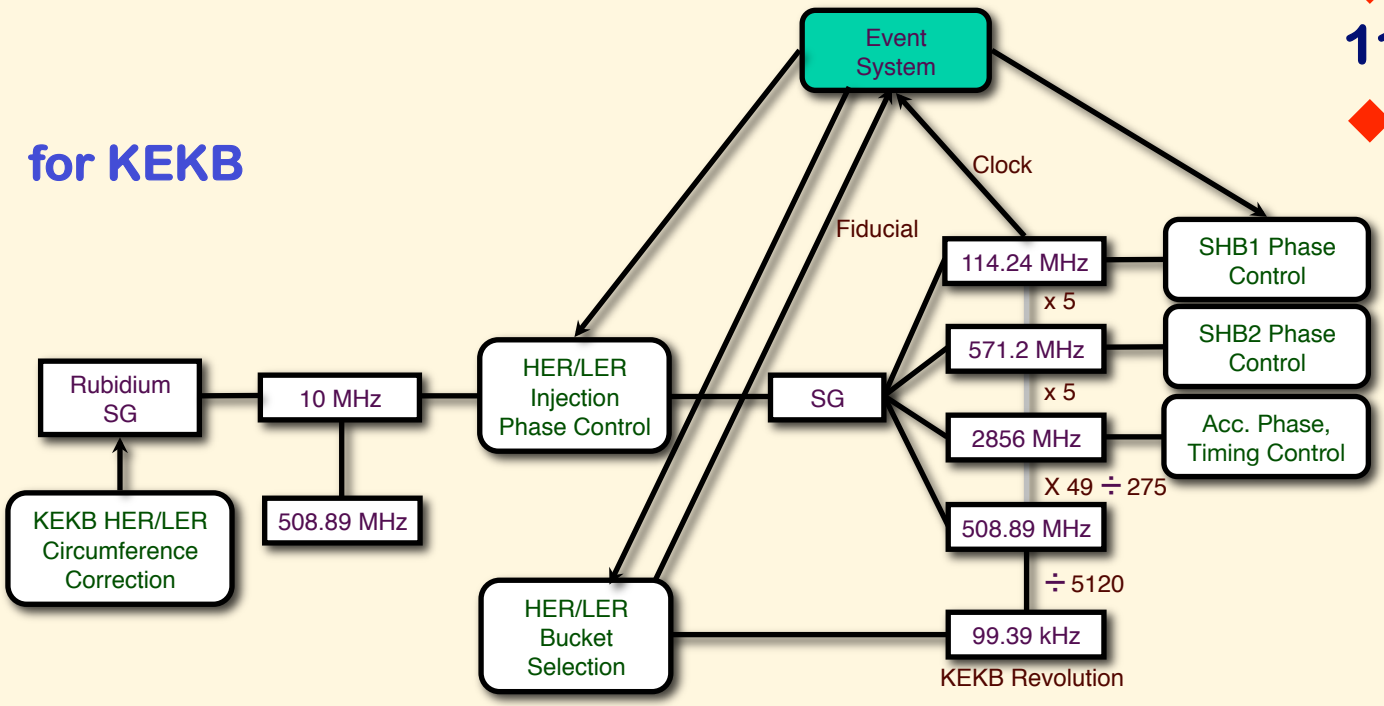


Synchronization Scheme

for PF

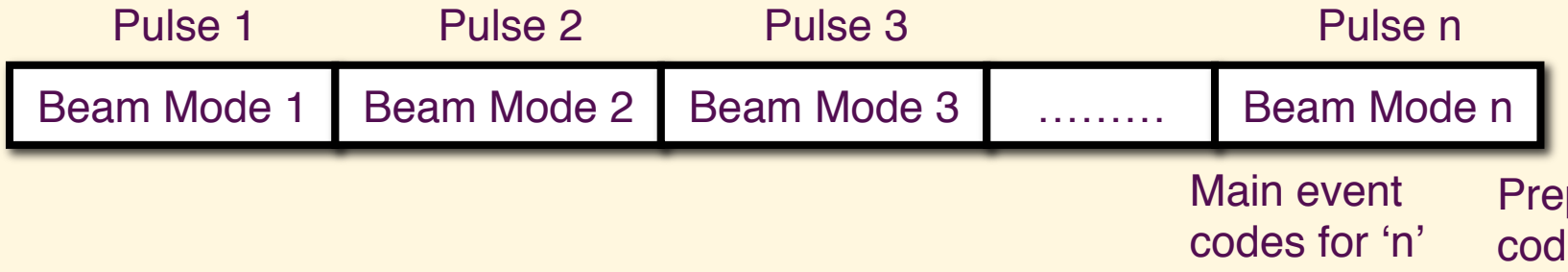


for KEKB



- **Synchronization Req.**
  - KEKB : < 30ps
  - PF : < 300~700ps
- **Linac rf is Synchronized to KEKB rf**
- **Event Clock is 114.24MHz**
- **We have to manage**
  - Circumference compensation
  - Bucket selection
  - Injection phase controls

Beam Mode Pattern Generation



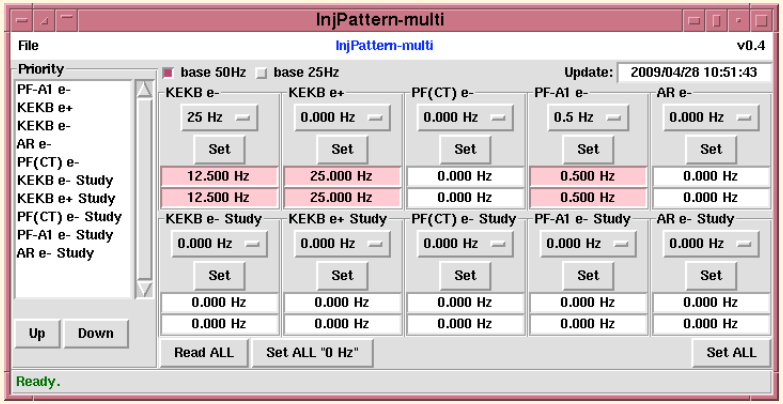
- Every pulse (every 20ms) corresponds to a beam mode
- 10 different beam modes are defined (for KEKB e+, etc)
- One beam mode may contain several event codes
  - At least one main code and a preparation code for the next pulse
- About 50 event codes are defined
  - Some events correspond to many functions, and others to specific devices
- Beam pattern buffer length (n) can be 2 to 500 (20ms x 500 = 10 seconds)
- A new pattern can be loaded at the end of the previous pattern
  - Otherwise, the pattern repeats forever.
- Main events and preparation events in sequence
  - Main events trigger timing signals
  - Preparation events trigger software to exchange analog and delay parameters

Beam Mode Pattern Generators

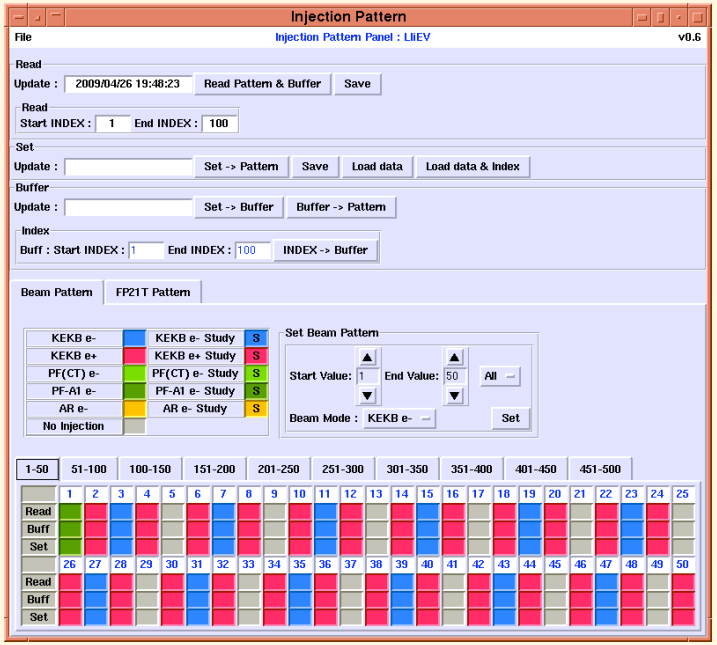
Pattern panel arbitrates requests

- 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



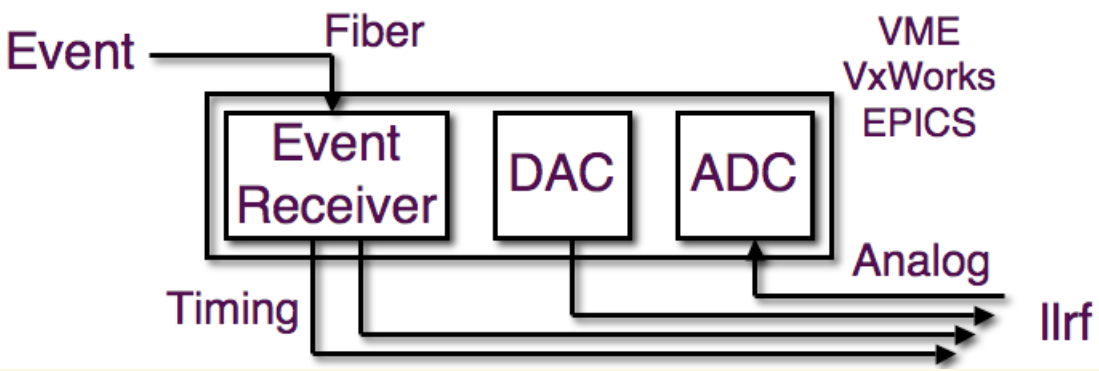
Manual pattern generator

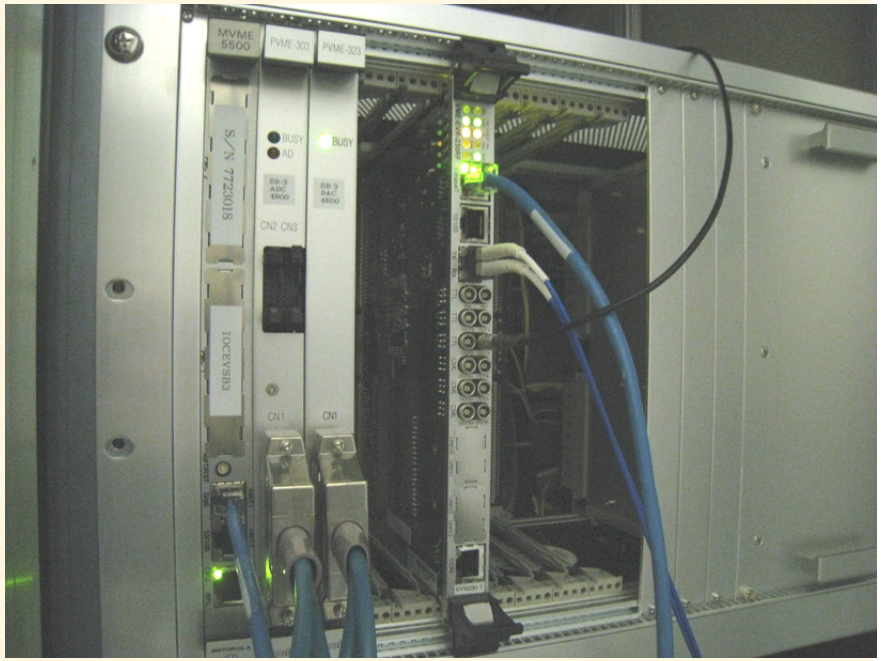


- Typical operation in 2009.
  - ~25Hz for KEKB LER
  - ~12.5Hz for KEKB HER
  - ~0.5Hz for PF

LLRF

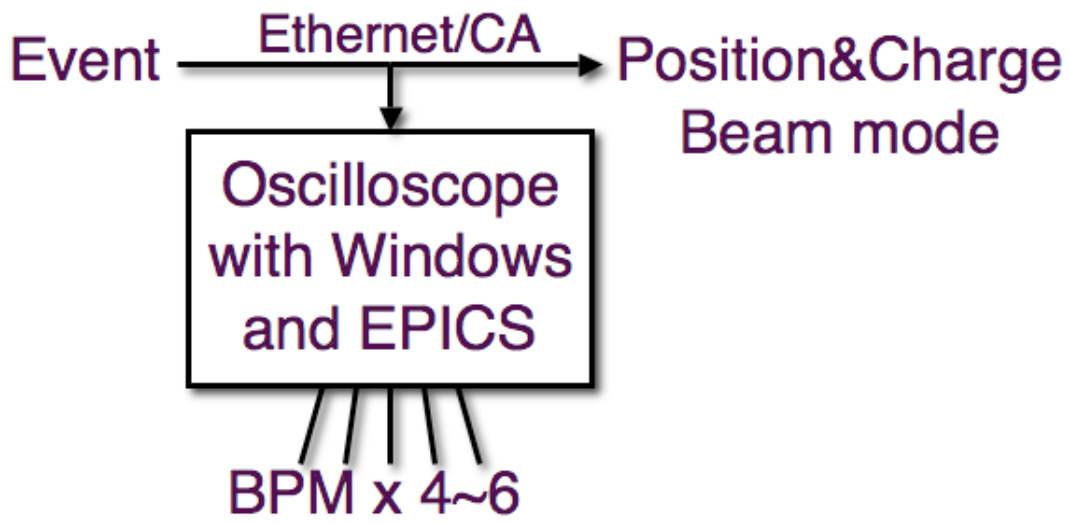
- LLRF Timing/analog signals are essential for absolute energy, energy spread, and dual-bunch energy equalization
- Signals are switched pulse-by-pulse
- Value changes are triggered by a preparation event
- Driver klystrons (SB), energy tuner klystron (KL), and sub-harmonic bunchers (SH) are managed by the event system

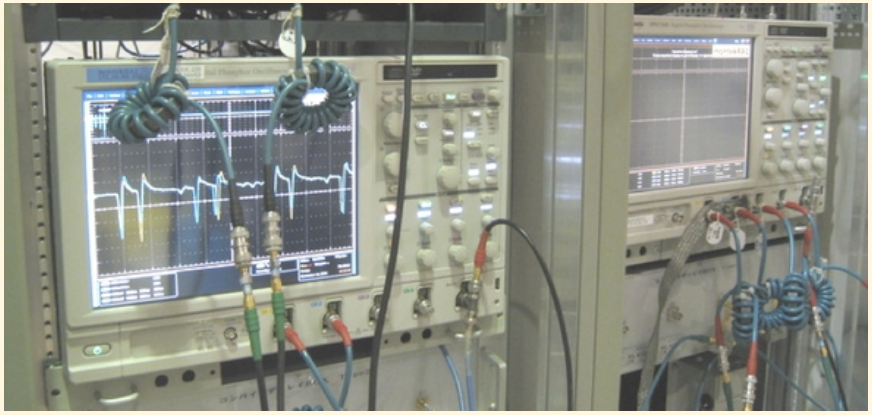




BPM

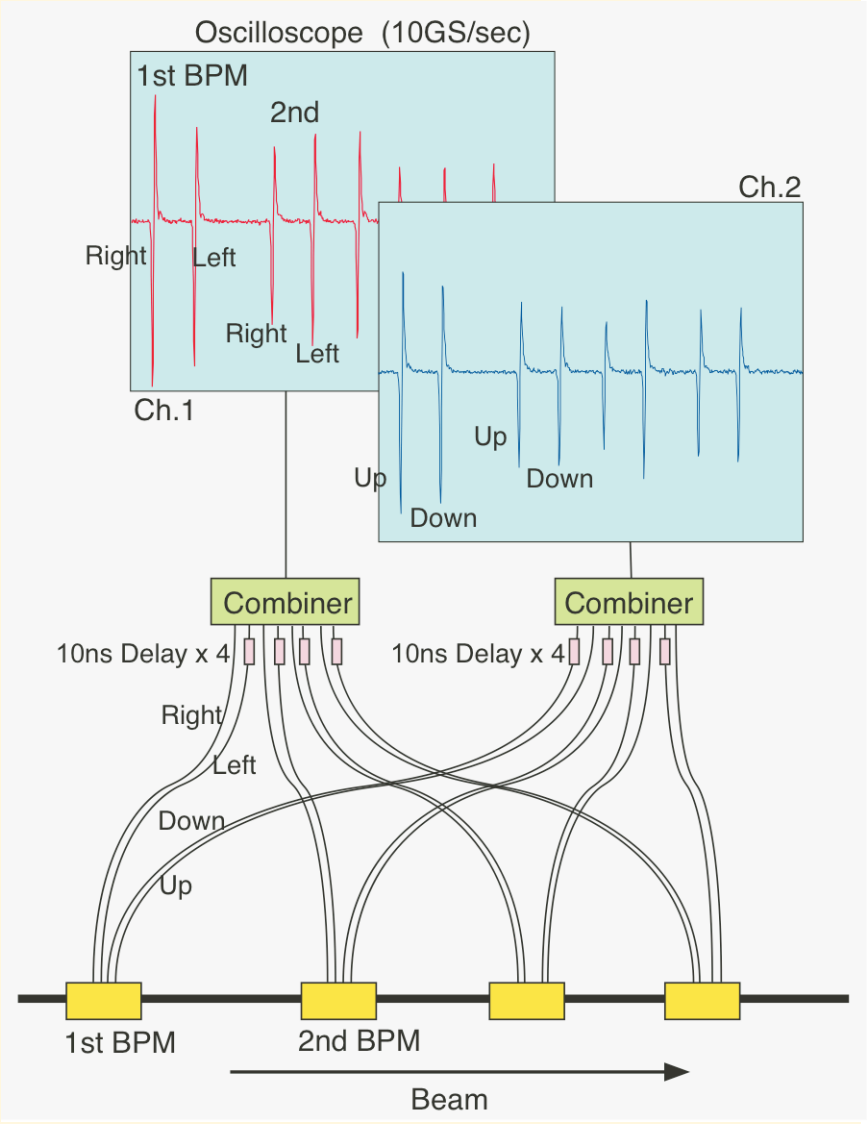
- Tektronix DPO7104 can acquire data at >50Hz.
  - With embedded EPICS
- Beam modes are recognized by events through CA network.
- Clients can monitor data of an interested beam mode.
- 26 oscilloscopes are installed.
- 100 BPMs are synchronized. (100 BPMs at BT as well soon)





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



Embedded IOC on Oscilloscope

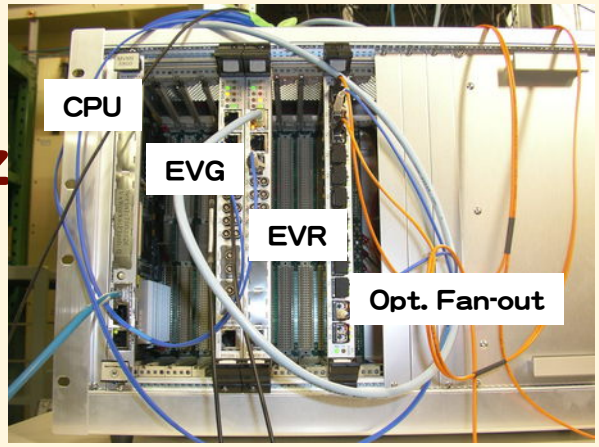
- **DPO7104, 10Gs/s, 4ch, 8bit**
  - Windows-XP
  - Cygwin software development environment
  - Microsoft Visual C++ 2008
    - http://www-linac.kek.jp/cont/epics/win32/
  - EPICS 3.14.8.2
  - Fast data-acquisition at ~150Hz was tricky, but was possible
  - Event triggers the data acquisition
  - Beam positions and charges are calculated based on ~30 coefficients, and tagged with beam modes
  - 50Hz processing is stable at Linac
  - Very efficient for us

Parameters

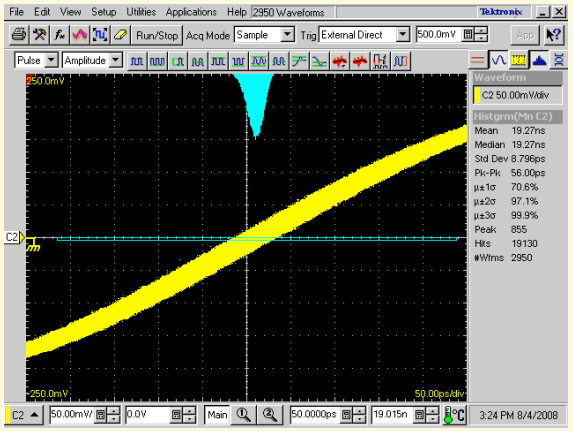
- **Parameters switching via Event system**
  - LLRF phase/timing : 14x4
  - HP RF timing : ~60
  - Gun voltages, picosecond delay : 4
  - Pulsed magnets/solenoid : 14
  - Injection phase : 2
  - Bucket selection : 2
  - BPM : ~100x3
- **Basically sufficient for fast beam mode switching**
- **More parameters comming**
- **Integrity monitors**
- **Improved slow beam feedback, fast feedback, etc.**

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



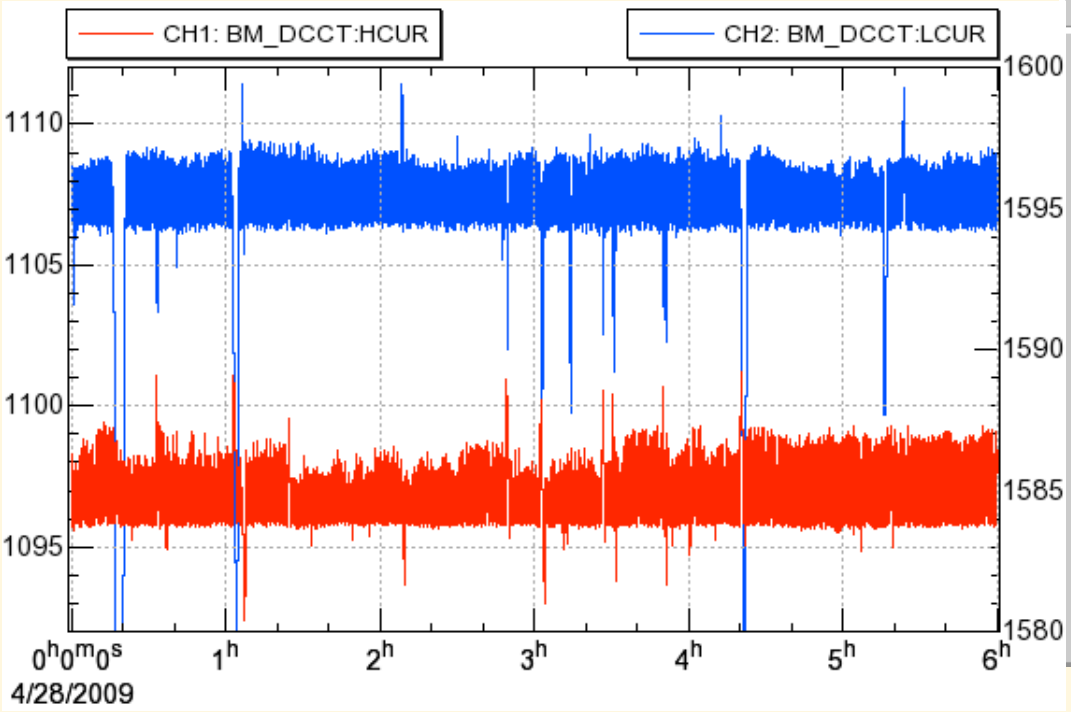
- CPU stopped 4 times since Sep.2008 for 18 stations

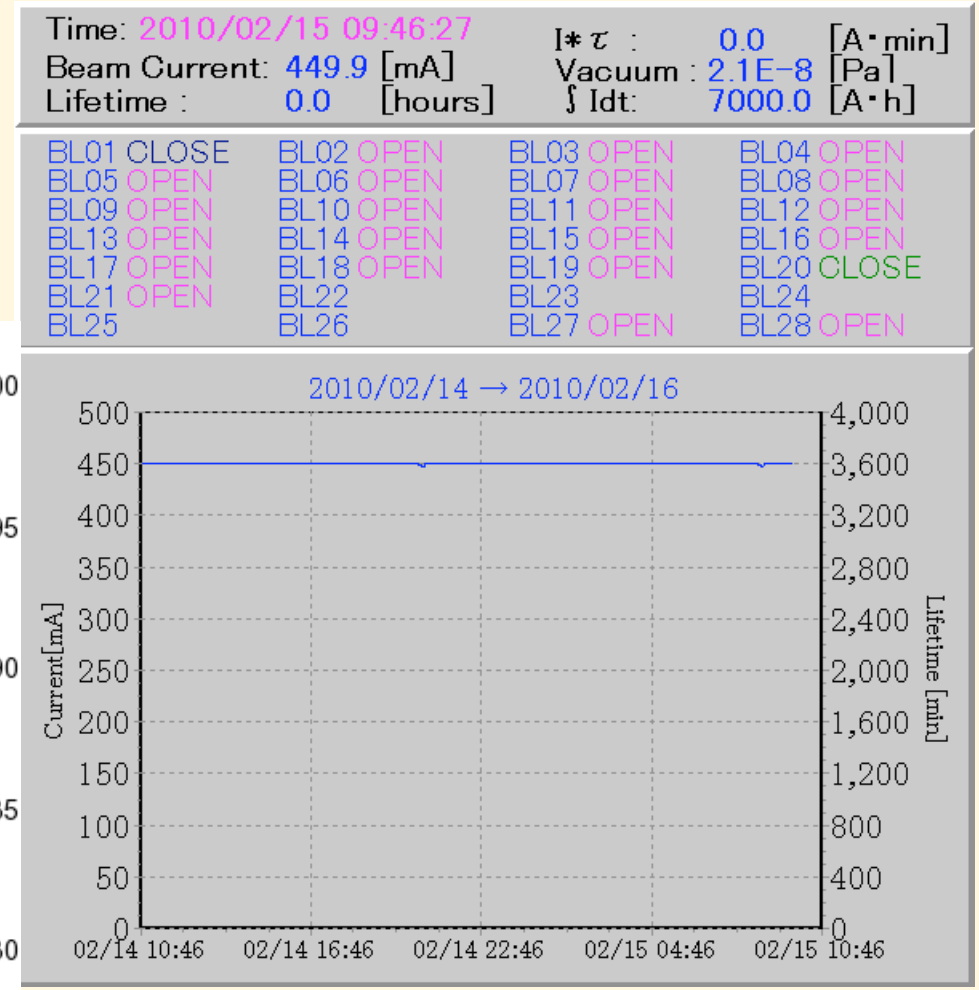


EVR & LLRF

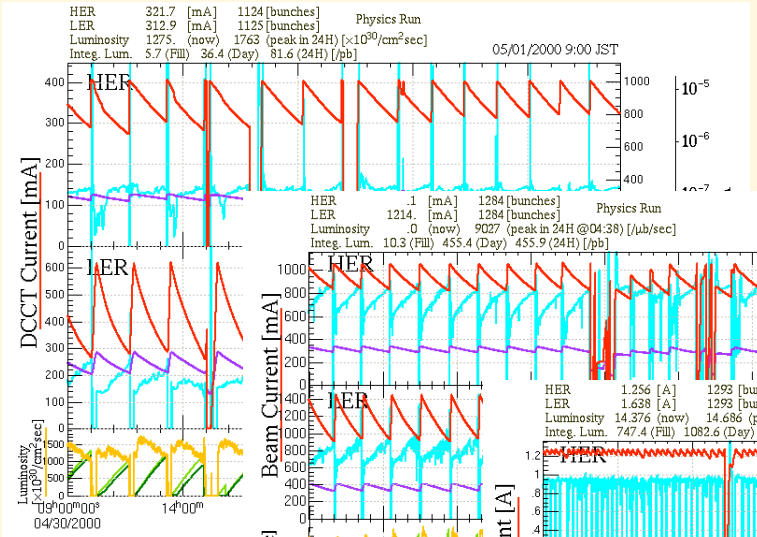
Beam Current

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





KEKB Operation Improvement



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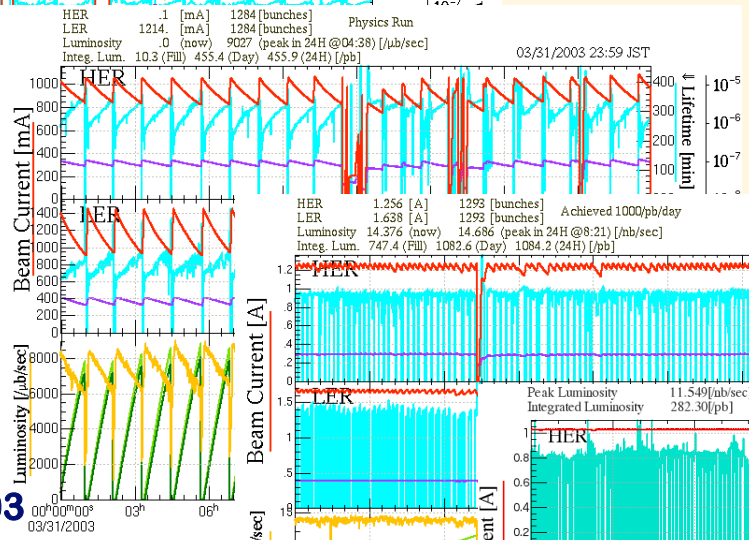

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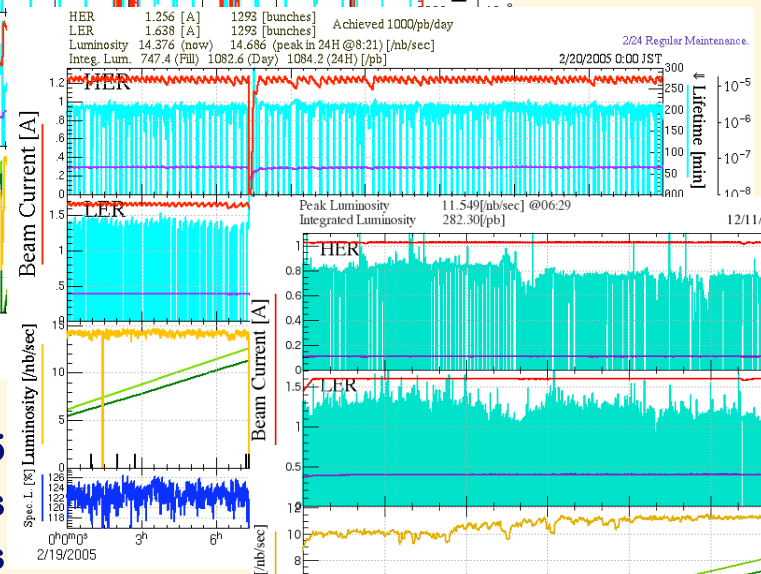
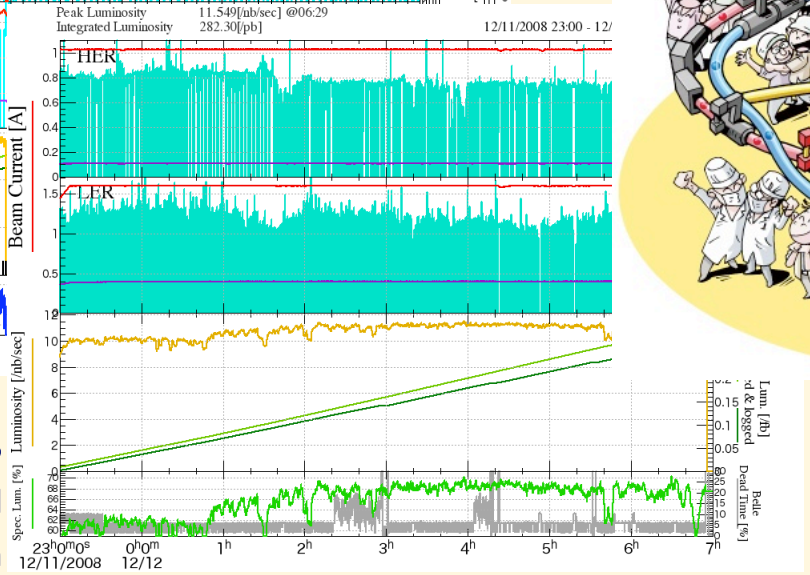
Dual Bunch e+



Feb.2005

Continuous

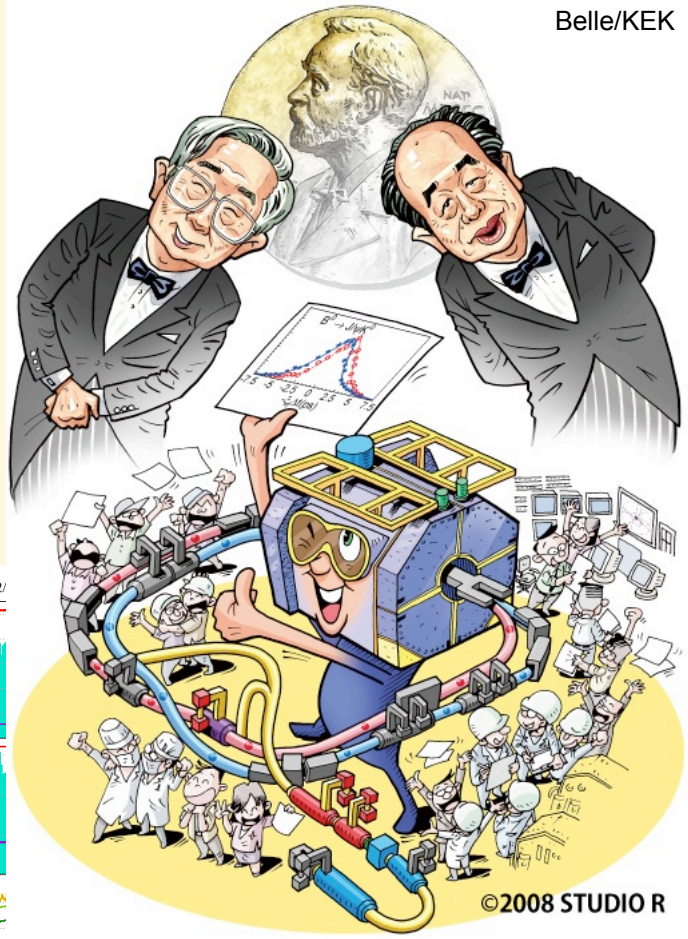
Injections



Dec.2008

Crab Cavities and

Simultaneous Injection



Summary

- **Simultaneous injection to HER/LER/PF was successful**
  - Development and installation for various kind of hardware
  - Another layer of controls based on a fast event system
    - Pulse-to-pulse reprogramming of event system
  - Beam optics diagnosis down to ~1%
  - More integrity monitors may be necessary for longer term
  - Need for consideration on PF-AR injection
    - ex. 4-GeV positrons for PF-AR (?)

- **Simultaneous injection will be the base for SuperKEKB as well**

Thank you