



# Simultaneous Injections to KEKB and PF

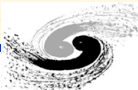
## and Event-based Control System

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For Linac Commissioning Group  
and for Linac and KEKB Control Group

March 2010.





# 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

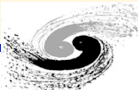
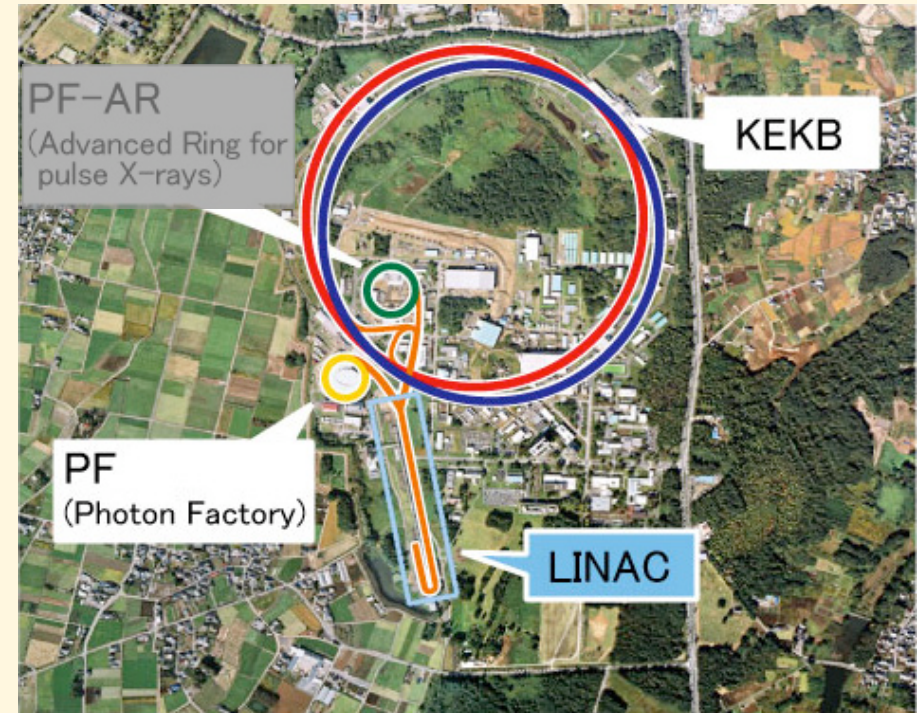
❖ PF-AR 3-GeV  $e^-$  0.2nC

## ◆ At first simultaneous

## top-up injections to three rings at KEKB and PF

❖ Switching beams at 50Hz

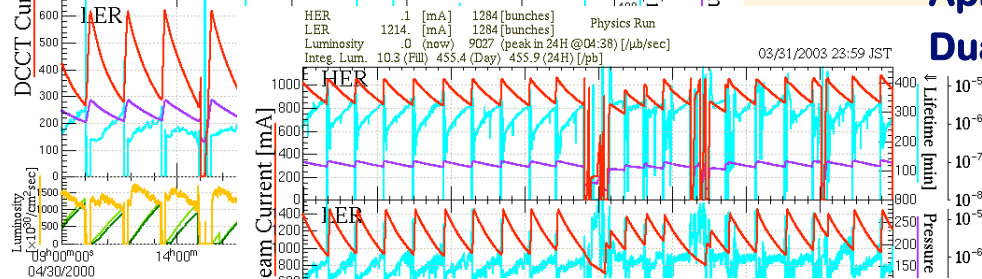
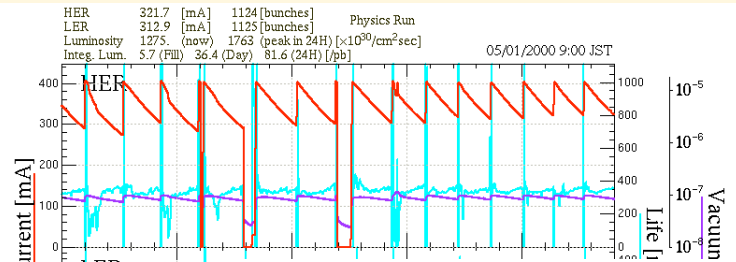
❖ For stable operation and higher quality exp. results



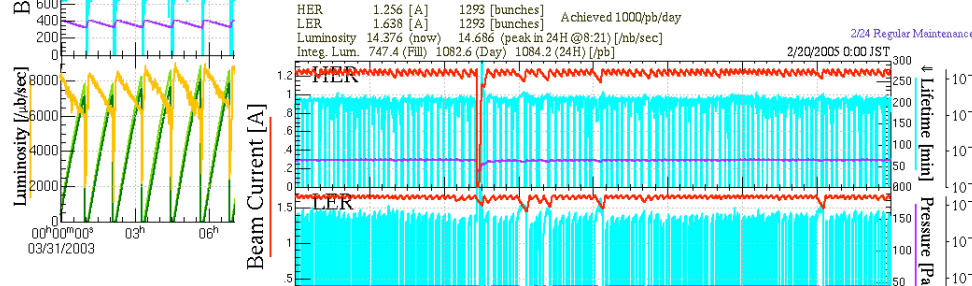


# KEKB Operation Improvement

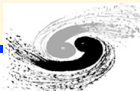
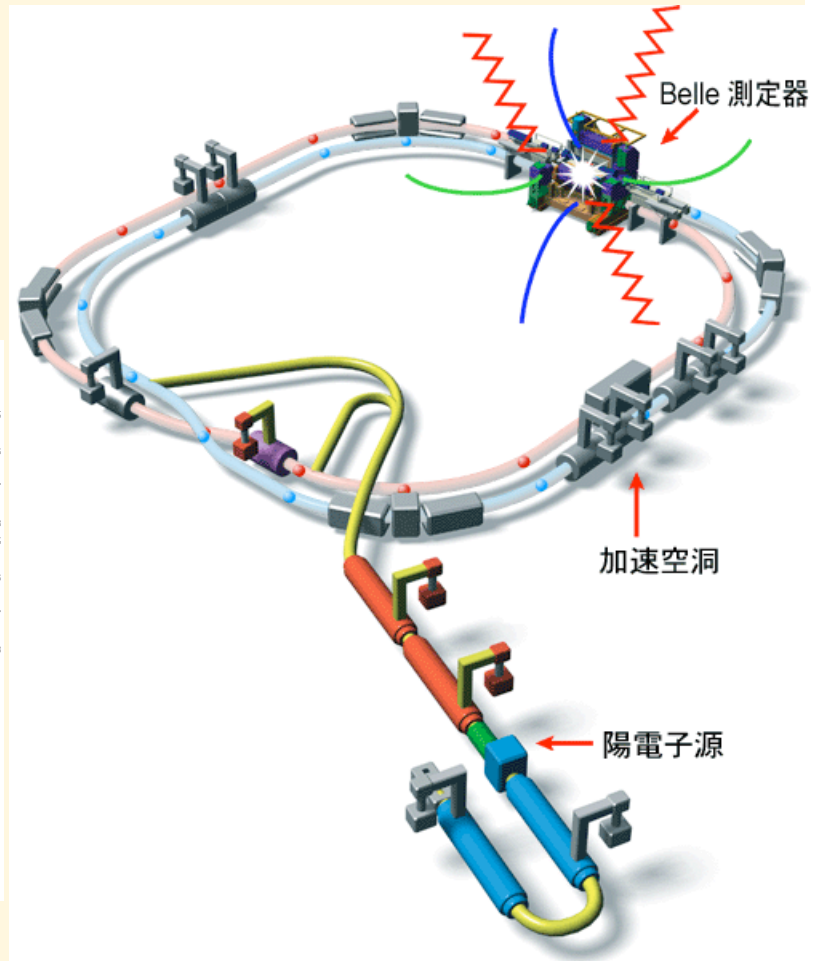
Apr.2003  
Dual Bunch e<sup>+</sup>



May.2000



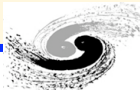
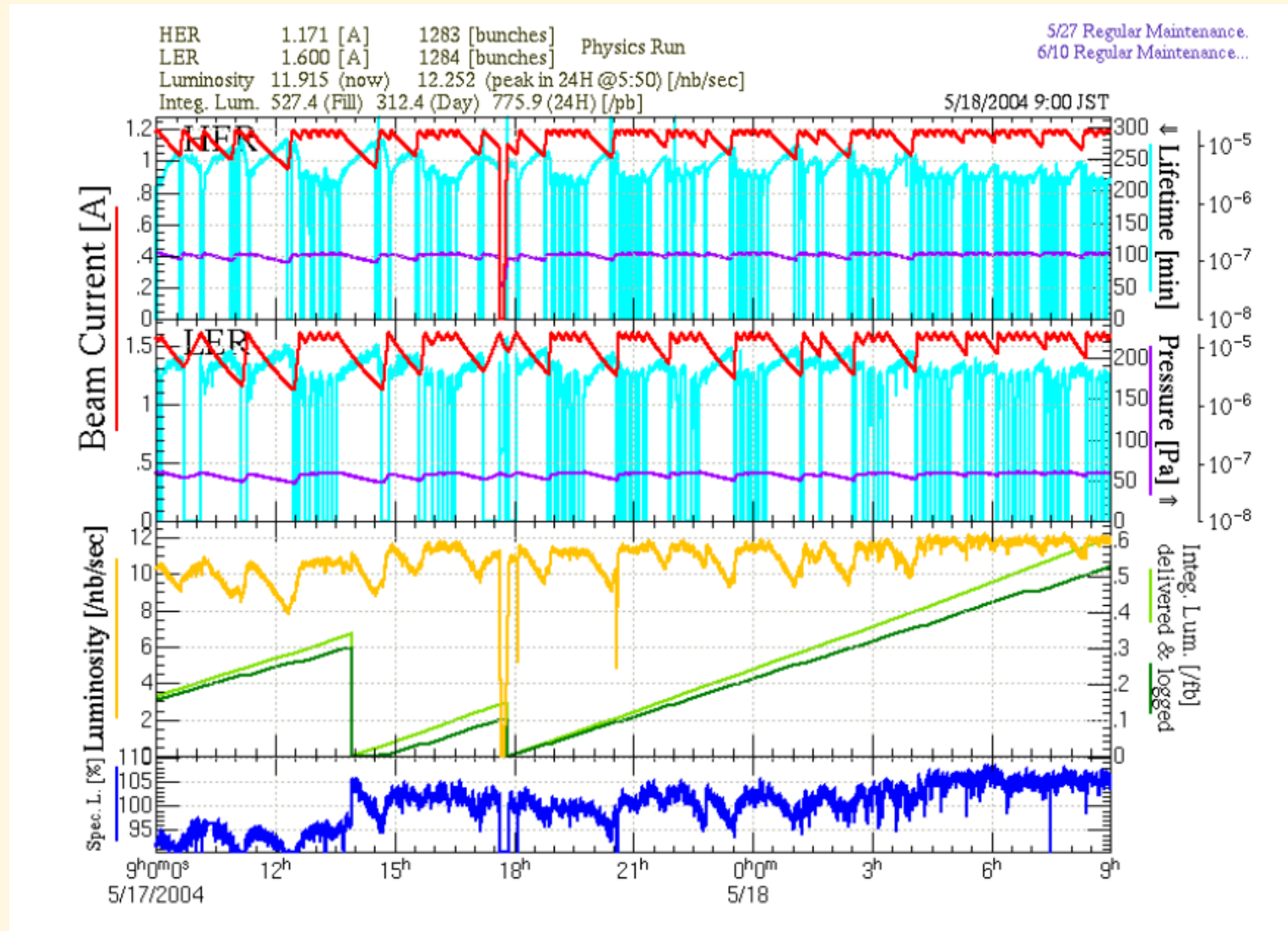
Feb.2005  
Continuous  
Injections



Simultaneous Injection



# KEKB Injections during Beam Studies at PF and PF/AR





# Motivation

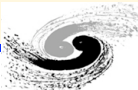
- ❖ **Fast beam switching or simultaneous injection was suggested since 2004**
- ◆ **Luminosity degradation on beam studies at PF and PF/AR**
- ◆ **Future SuperKEKB injections with shorter lifetime**
- ◆ **Sensitive luminosity tuning with Crab cavities**
- ◆ **PF top-up injection for higher quality experiments**
  - ❖ **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

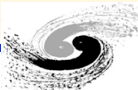
- ◆ **Maximum beam rate of 50Hz x 2bunches should be kept**
- ◆ **Most pulsed power supplies were designed to operate at constant rate**
- ◆ **Most linac magnets were not pulsed (except positron focusing coil)**
  - ❖ **Thus, it took much time for mag-field standardization**
- ◆ **Approx. 1000 devices 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**





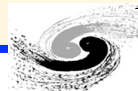
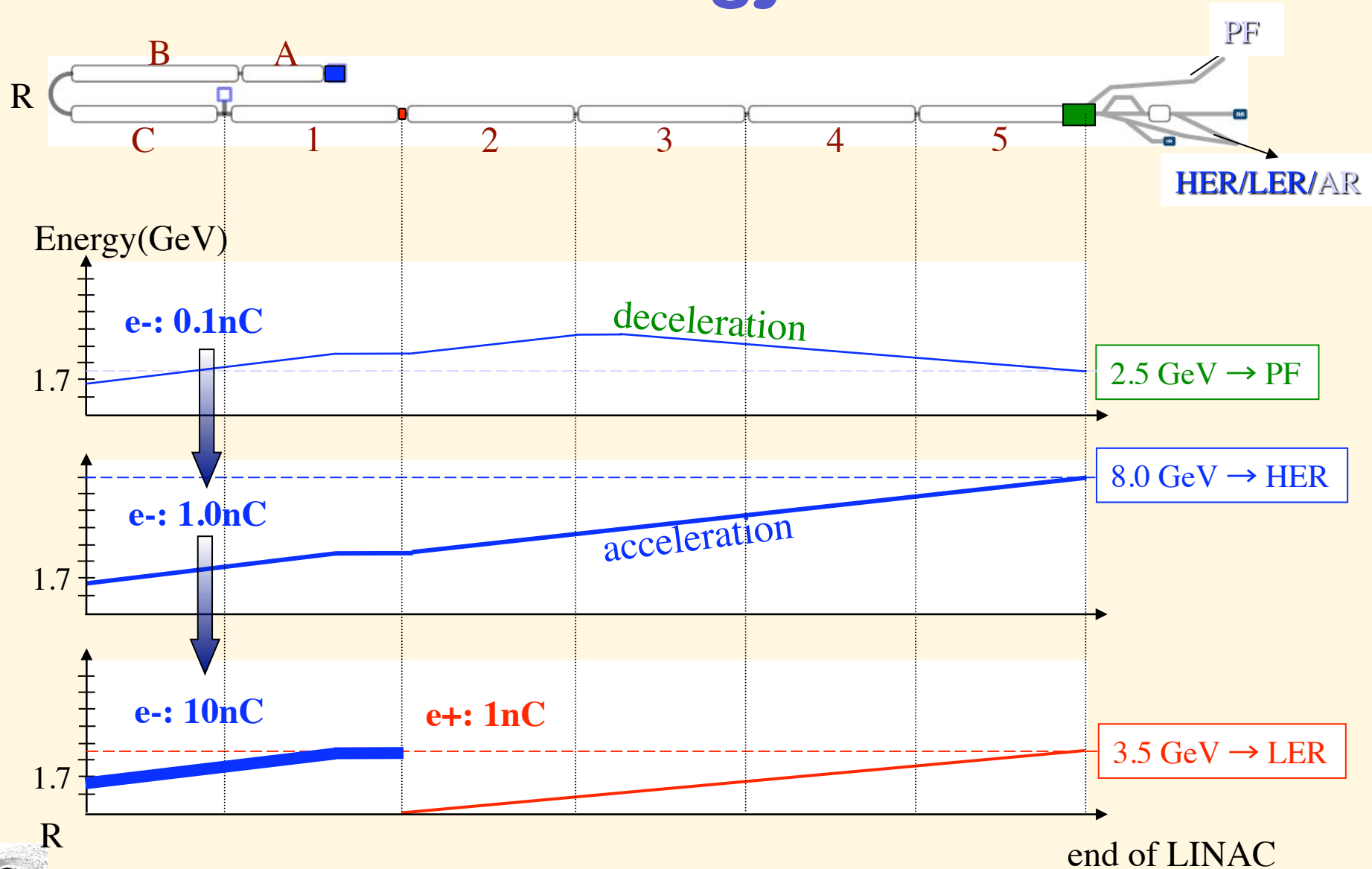
# Hardware and Operation Improvements

- ◆ **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)**





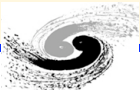
# Linac Energy Profile





# Fast Controls

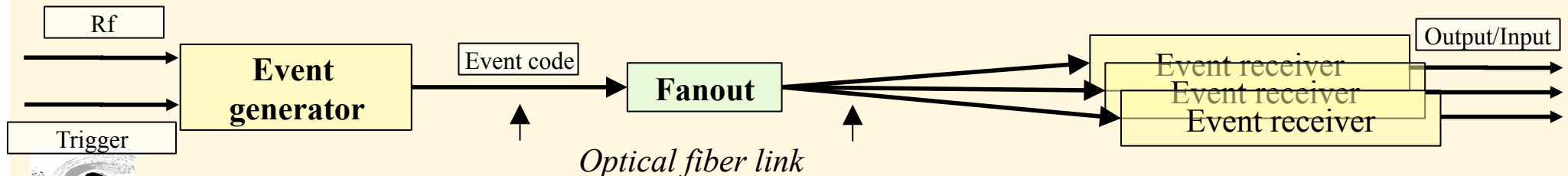
- ◆ **~100 parameter switching within 20ms**
  - ❖ **Keep most of magnet fields with compatible optics**
  - ❖ **Control llrf to change energy**
- ◆ **Pulsed magnet triggers and delays**
  - ❖ **Delays to keep the constant rate for certain power-supplies**
- ◆ **LLRF phases and delays**
- ◆ **Gun voltage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



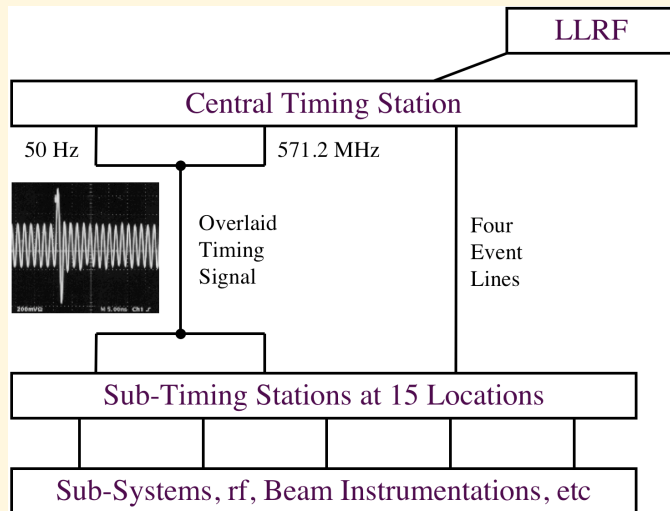


# Event System

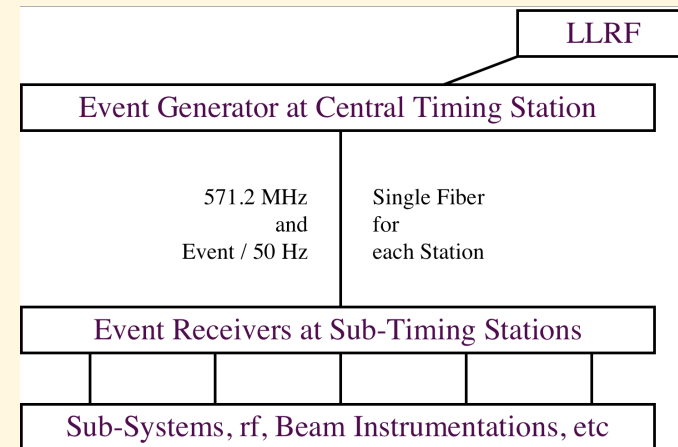
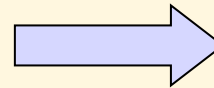
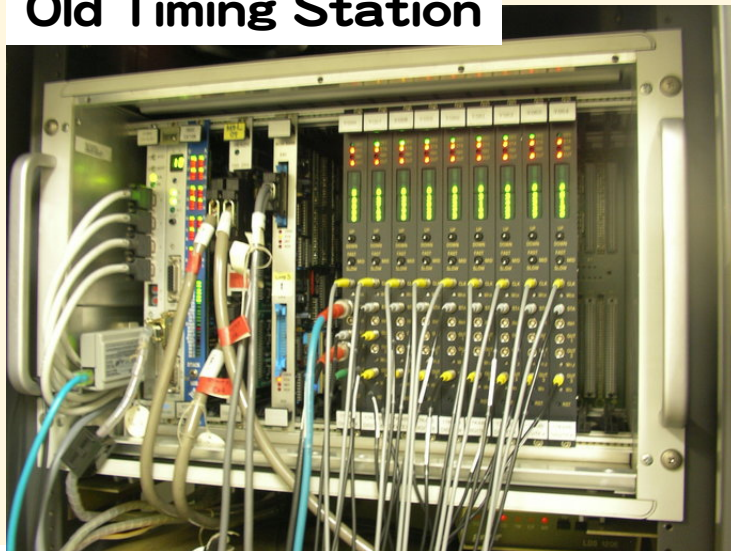
- ◆ **Many accelerator system require timing signals and accompanying information (event)**
  - ❖ **Several primitive facilities are combined and used at KEKB and Linac**
    - ✧ **Fast Timing signals are provided with delay module TD4/TD4V**
      - ◆ Need timing trigger and rf clock
    - ✧ **(Slow) 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

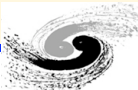
- ❖ Should improve collision tuning with Crab cavities
- ❖ Should improve the quality of experimental data at PF

## ◆ Fast switching of many device parameters

- ❖ In 20ms / 50Hz
- ❖ Should be reliable because beam power is much different

## ◆ MRF Series 230 Event Generator / Receiver

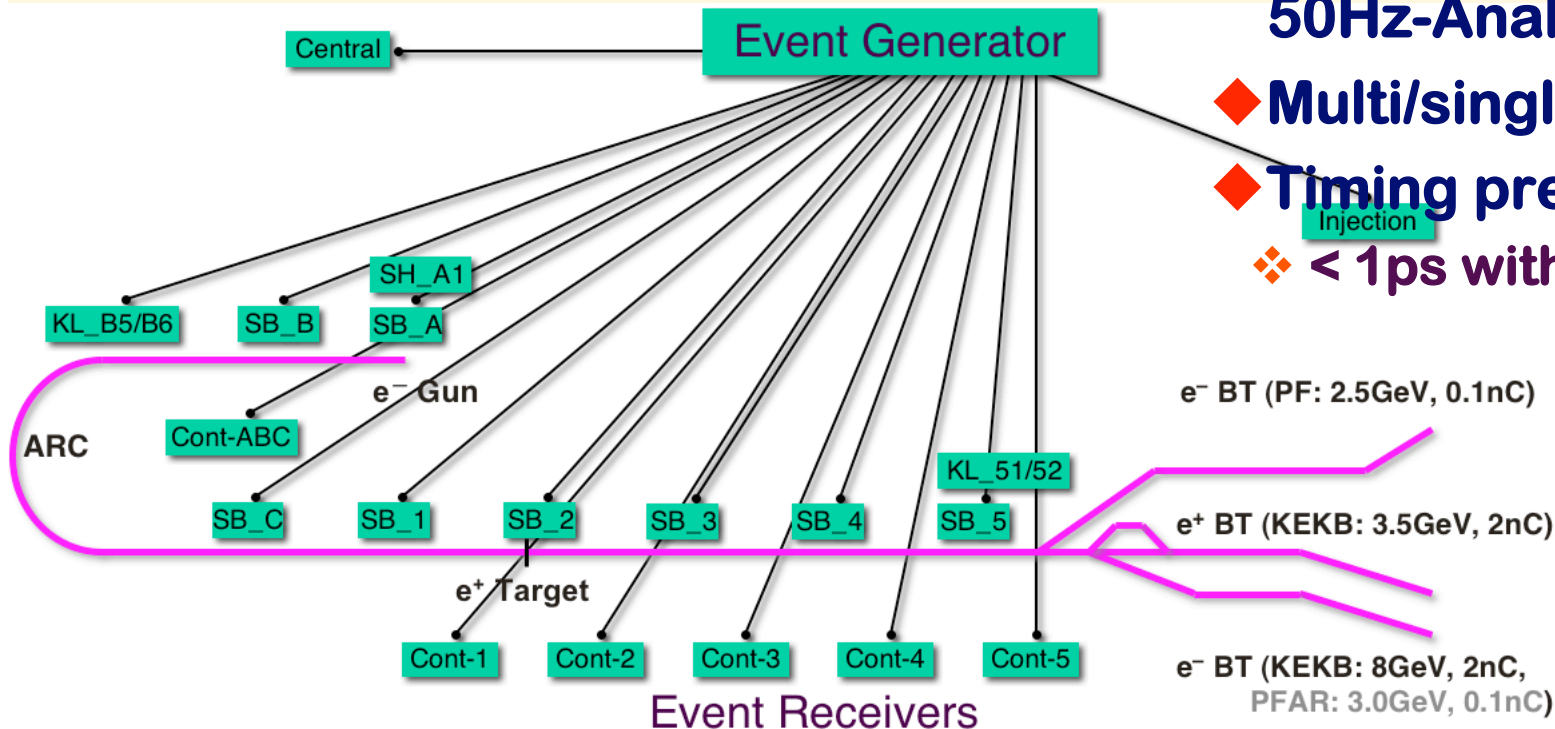
- ❖ VxWorks 5.5.1, MVME5500 (Originally with RTEMS but...)
- ❖ Timing precision less than 10ps is sufficient (TD4 provides 3ps)
- ❖ Multi-mode fiber, and single-mode fiber for longer distance





# Event System Configuration

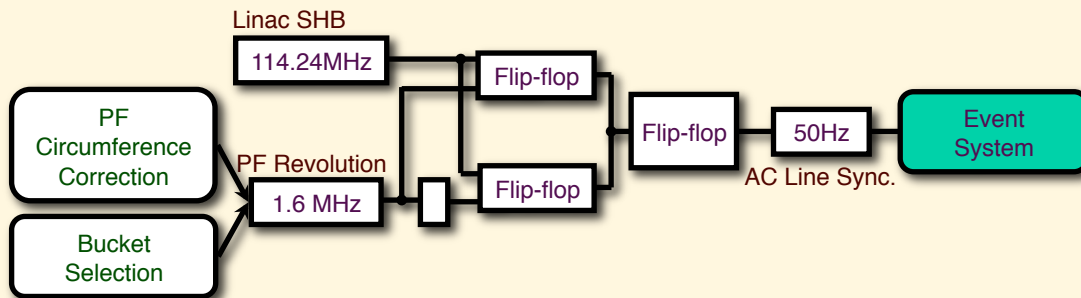
- ◆ MRF's series-230 Event Generator / Receivers
- ◆ VME64x and VxWorks v5.5.1
- ◆ EPICS R3.14.9 with DevSup v2.4.1
- ◆ 17 event receivers up to now
- ◆ 114.24MHz event rate, 50Hz fiducials
- ◆ More than **hundred** 50Hz-Analog/Timing data
- ◆ Multi/single-mode fiber
- ◆ Timing precision is < 10ps.
  - ◆ < 1ps with external module.



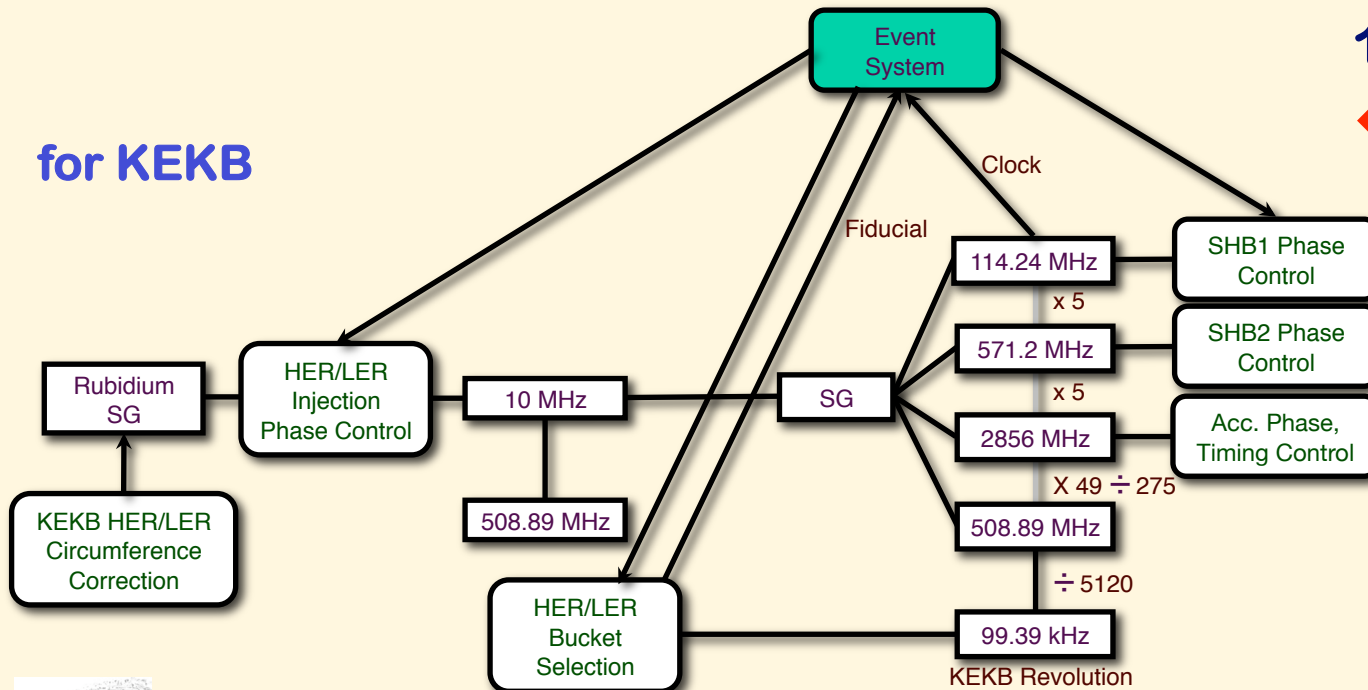


# Synchronization Scheme

## 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

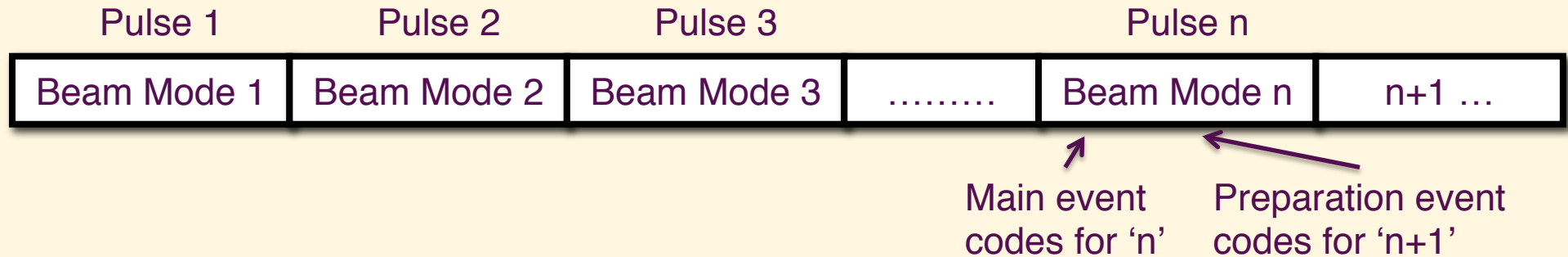
❖ Bucket selection

❖ 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**





# Event Manipulation

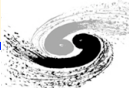
Human Operator

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



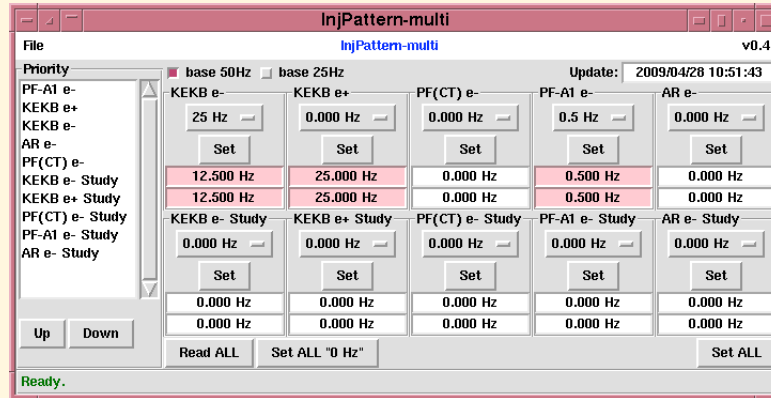


# Beam Mode Pattern Generators

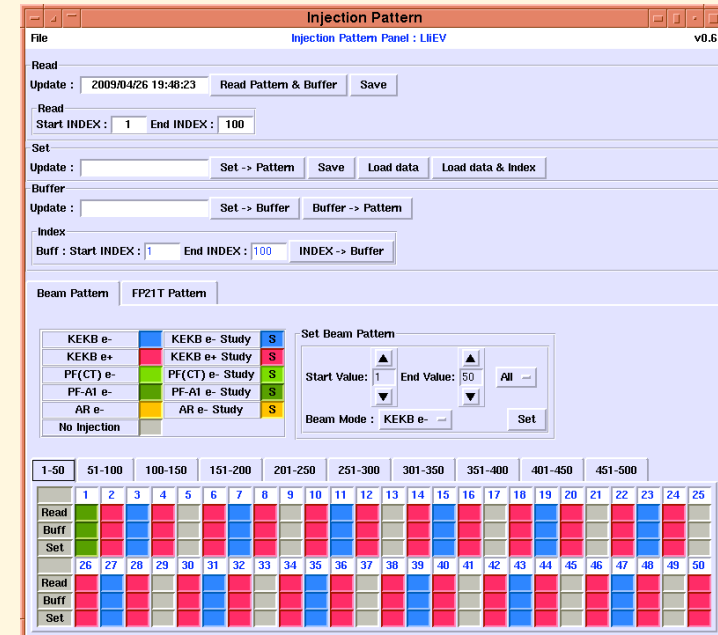
## ◆ Pattern panel arbitrates requests

- ❖ 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

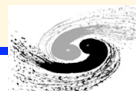


Manual pattern generator



## ❖ Typical operation in 2009.

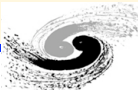
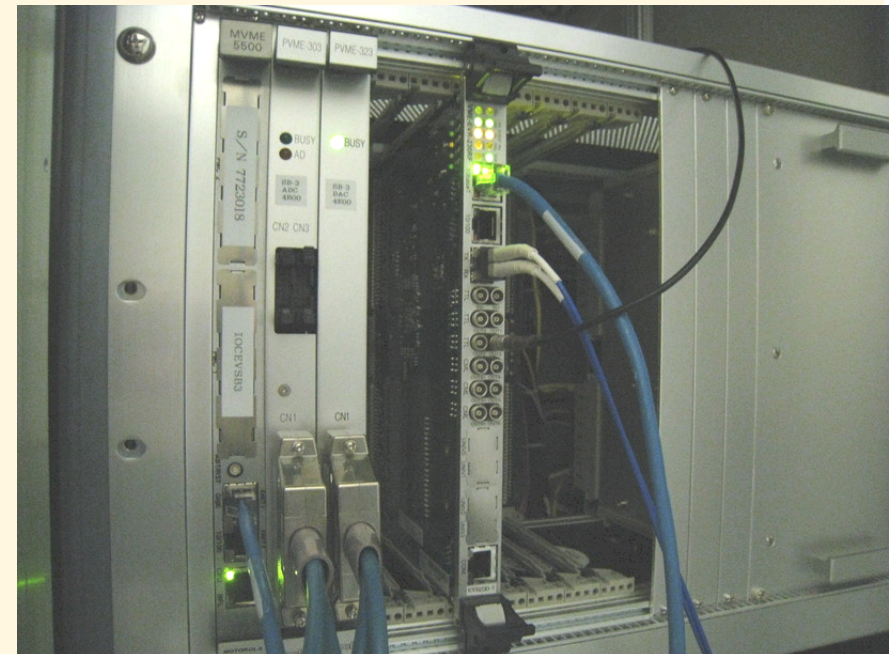
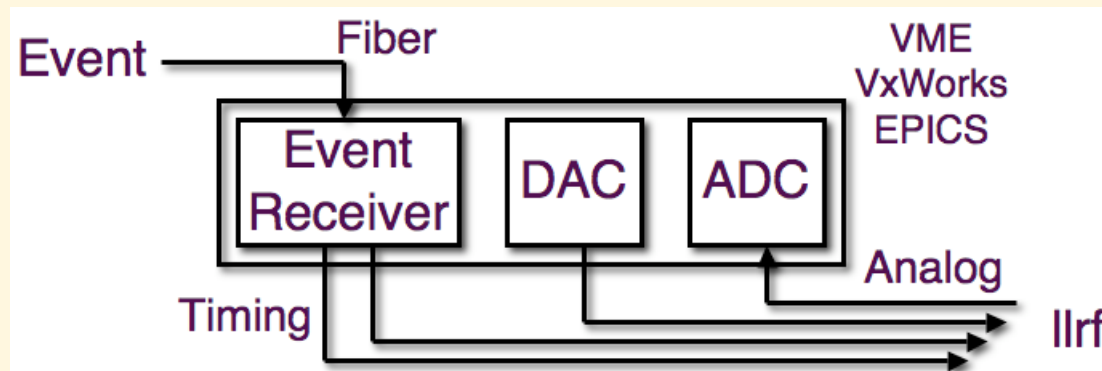
- ❖ ~25Hz for KEKB LER
- ❖ ~12.5Hz for KEKB HER
- ❖ ~0.5Hz for PF





# LLRF

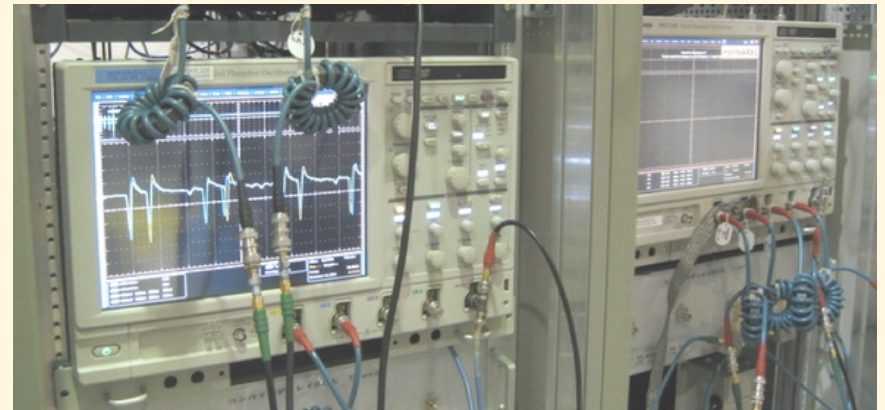
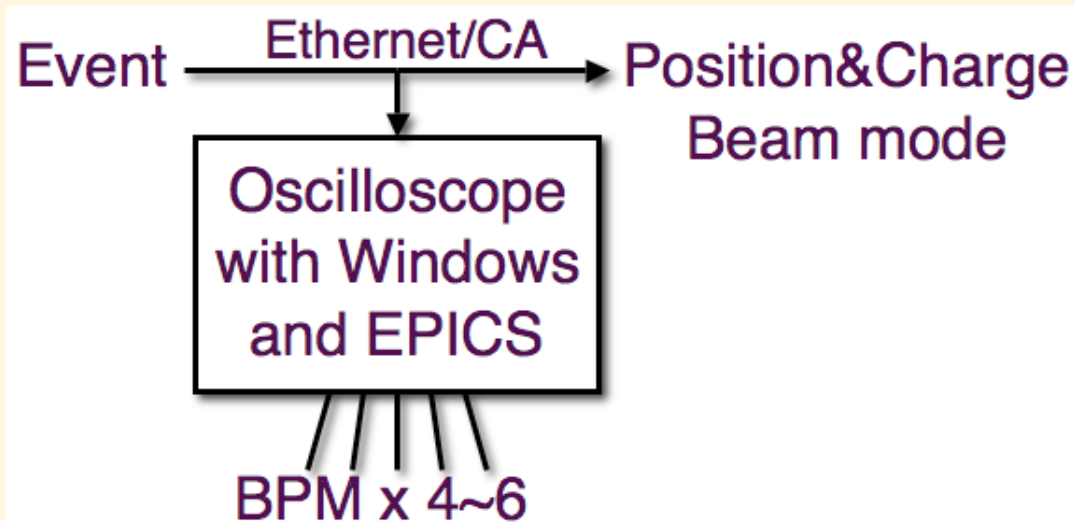
- ◆ LLRF Timing/analog signals are essential for absolute energy, energy spread, and dual-bunch energy equalization
- ◆ Signals are switched pulse-by-pulse
- ◆ Value changes are triggered by a preparation event
- ◆ Driver klystrons (SB), energy tuner klystron (KL), and sub-harmonic bunchers (SH) are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





# BPM

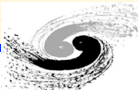
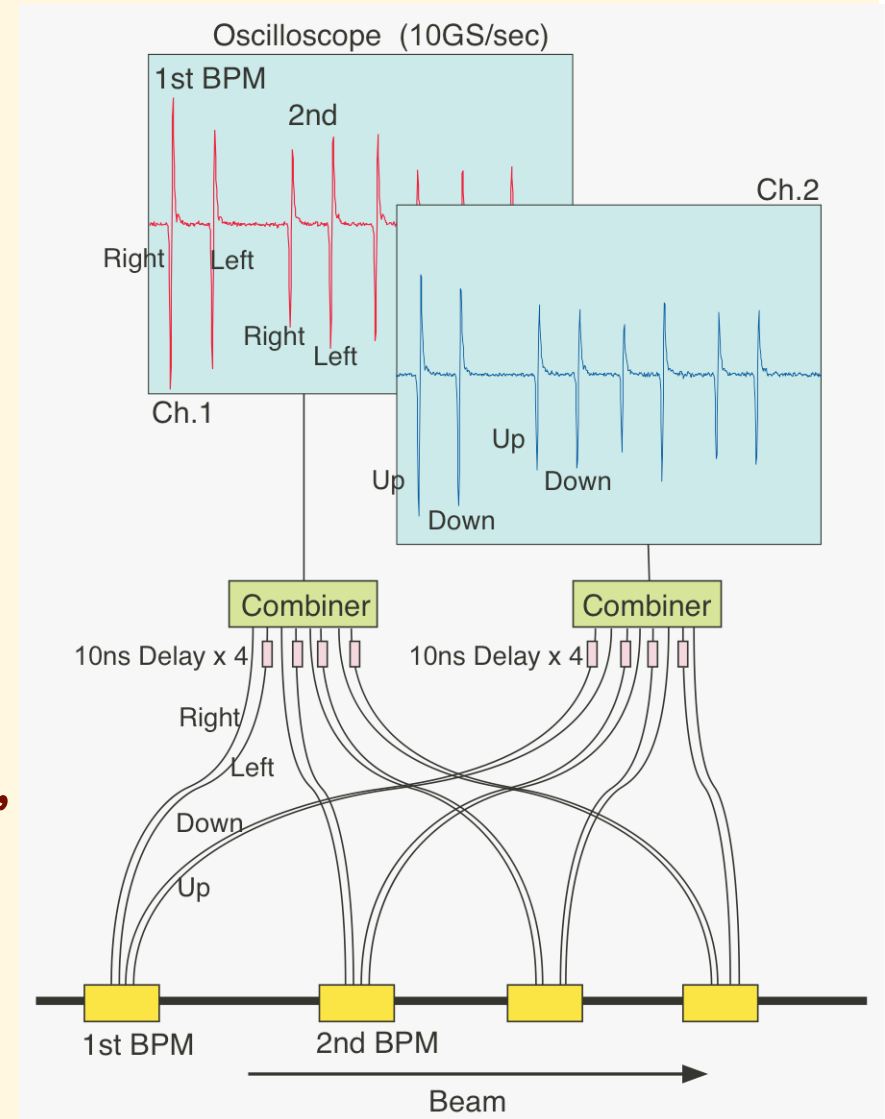
- ◆ Tektronix DPO7104 can acquire data at >50Hz.
  - ❖ With embedded EPICS
- ◆ Beam modes are recognized by events through CA network.
- ◆ Clients can monitor data of an interested beam mode.
- ◆ 26 oscilloscopes are installed.
- ◆ 100 BPMs are synchronized. (100 BPMs at BT as well soon)





# 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

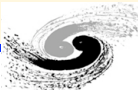
- ❖ Fast data-acquisition at ~150Hz was tricky, but was possible

- ❖ 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

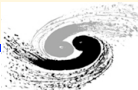
- ❖ Very efficient for us





# 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 coming**
- ◆ **Integrity monitors**
- ◆ **Improved slow beam feedback, fast feedback, etc.**



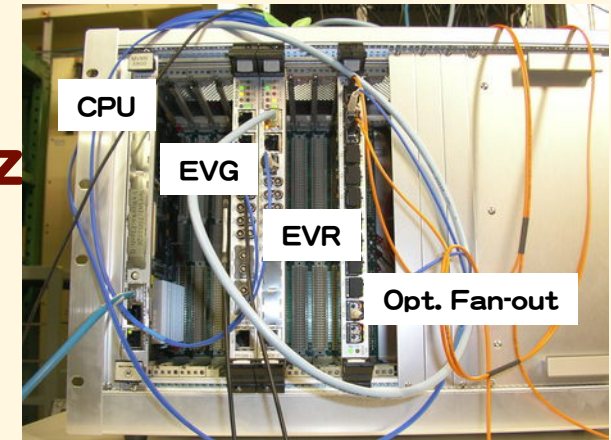


# Linac Event System

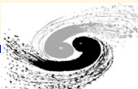
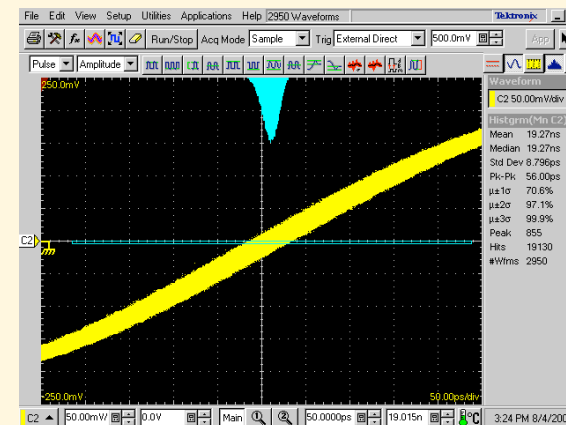
## ◆ Satisfies the requirements

- ❖ 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**





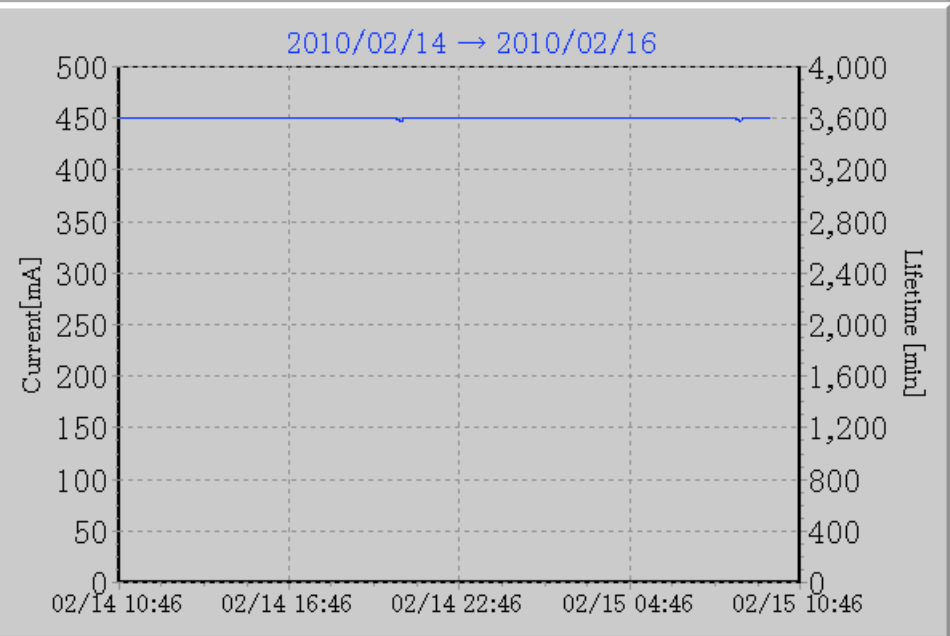
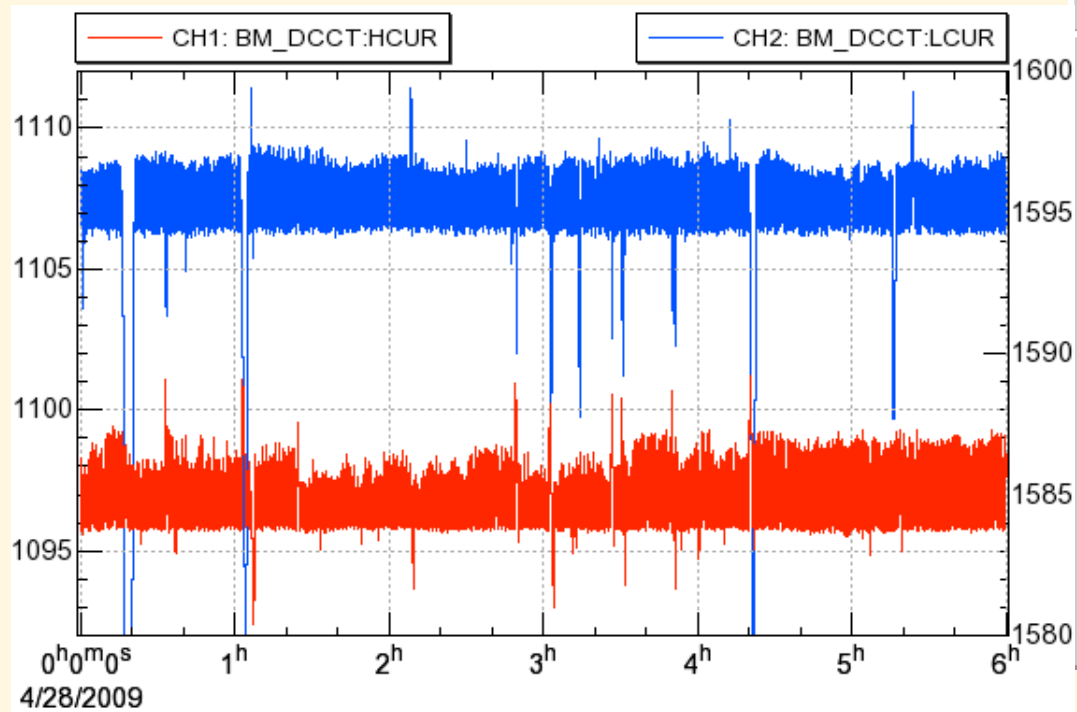
# Beam Current

◆ Beam currents are kept within

- ❖ KEKB 1mA (~0.05%)
- ❖ PF 0.05mA (~0.01%)

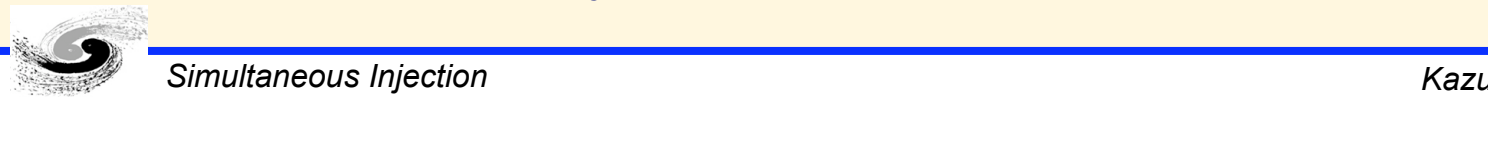
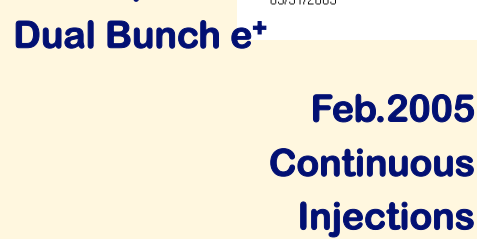
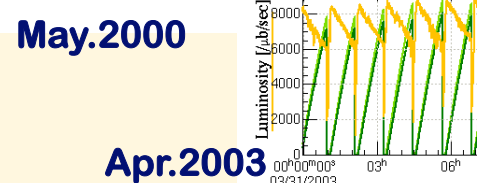
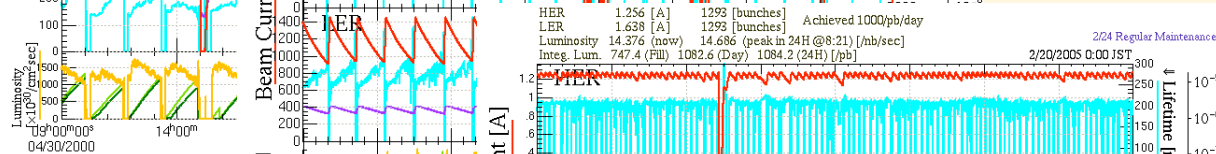
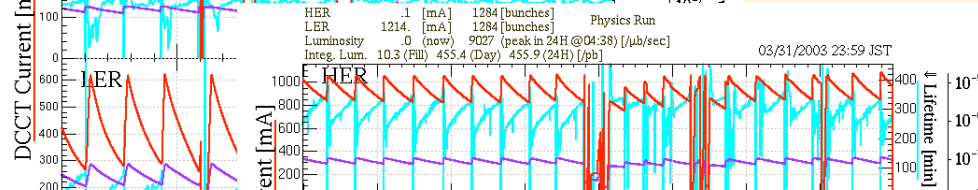
Time: 2010/02/15 09:46:27  
 Beam Current: 449.9 [mA]    I\*τ : 0.0 [A·min]  
 Lifetime : 0.0 [hours]    Vacuum : 2.1E-8 [Pa]  
 Idt: 7000.0 [A·h]

BL01 CLOSE	BL02 OPEN	BL03 OPEN	BL04 OPEN
BL05 OPEN	BL06 OPEN	BL07 OPEN	BL08 OPEN
BL09 OPEN	BL10 OPEN	BL11 OPEN	BL12 OPEN
BL13 OPEN	BL14 OPEN	BL15 OPEN	BL16 OPEN
BL17 OPEN	BL18 OPEN	BL19 OPEN	BL20 CLOSE
BL21 OPEN	BL22	BL23	BL24
BL25	BL26	BL27 OPEN	BL28 OPEN





# KEKB Operation Improvement



May.2000

Apr.2003

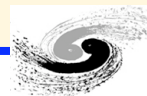
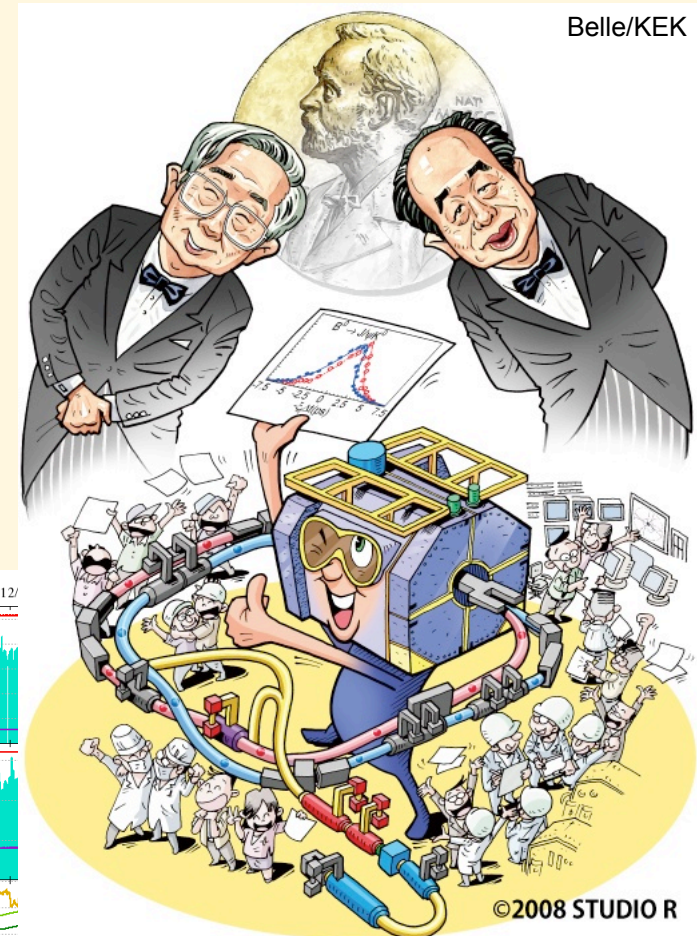
Dual Bunch e<sup>+</sup>

Feb.2005

Continuous Injections

Dec.2008

Crab Cavities and Simultaneous Injection



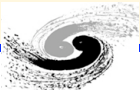


## Summary

### ◆ 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

