Event System and Embedded IOCs at KEK

Recent Activities at KEK
MRF Event System for 50Hz Beam Switching
F3RP61, PLC-Embedded IOCs, etc
ATCA/μTCA for LLRF

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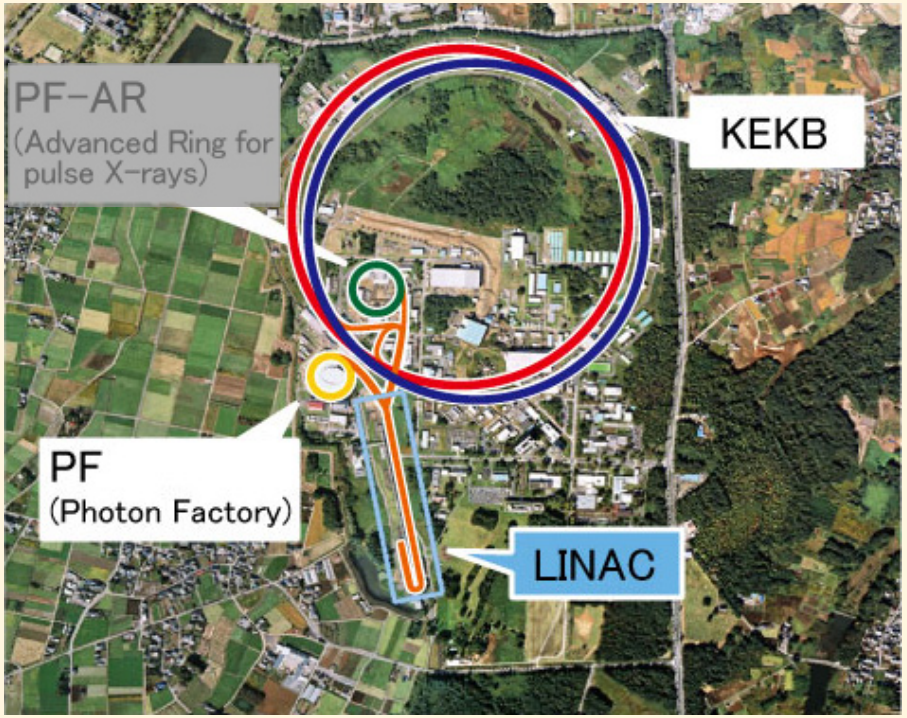
For Linac and KEKB Control Groups

Oct.2009.

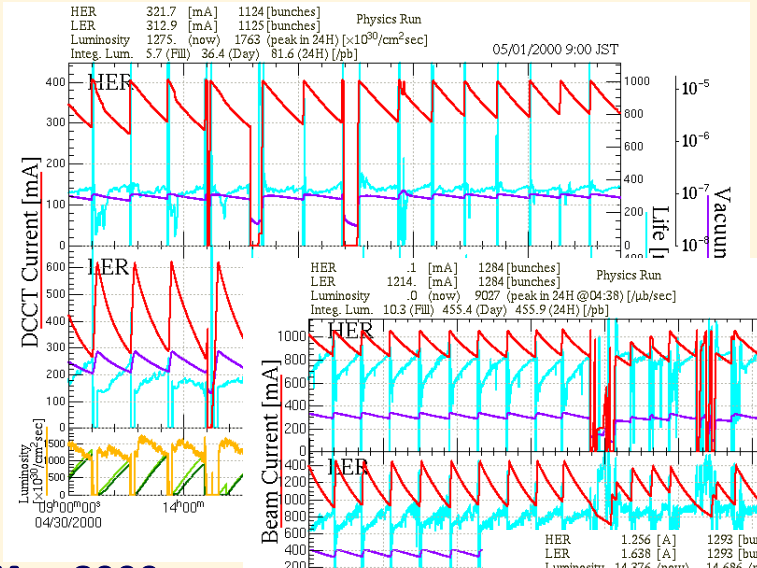
Simultaneous Injection Requirements

- **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)**

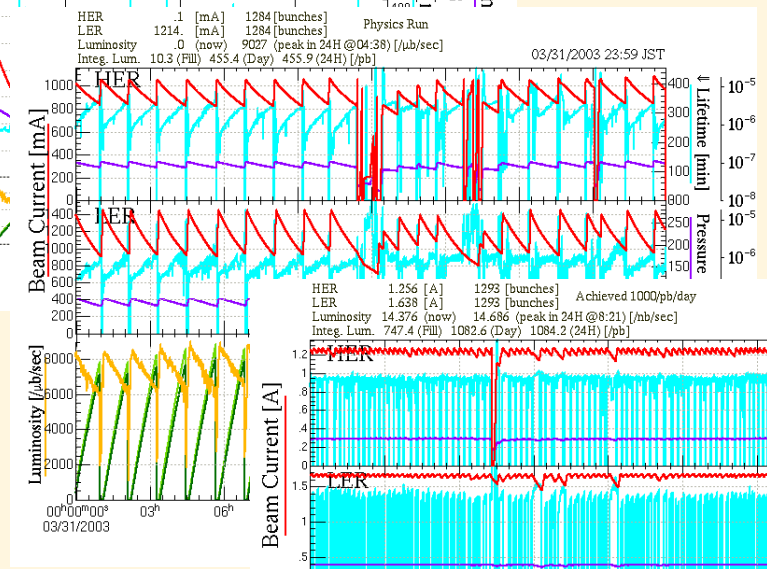


- **At first simultaneous top-up injections to three rings at KEKB and PF**
  - **Switching beams at 50Hz**
  - **For stable operation and higher quality exp. results**

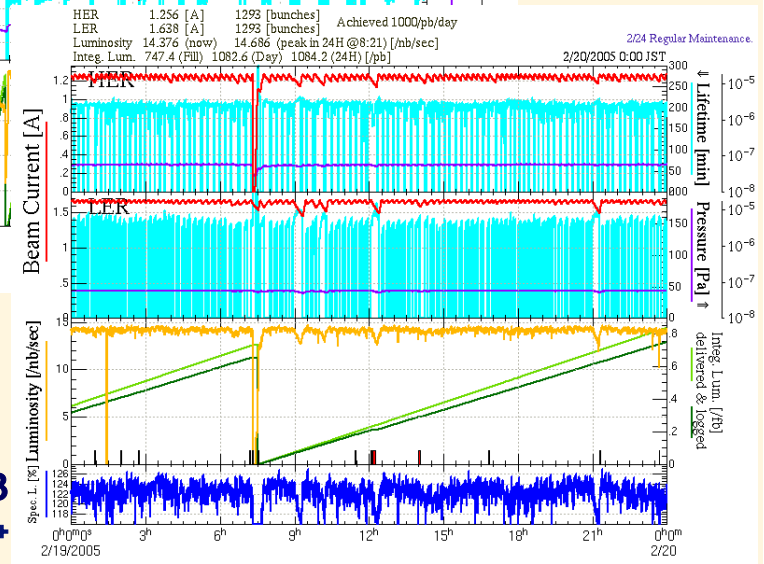
KEKB Operation Improvement



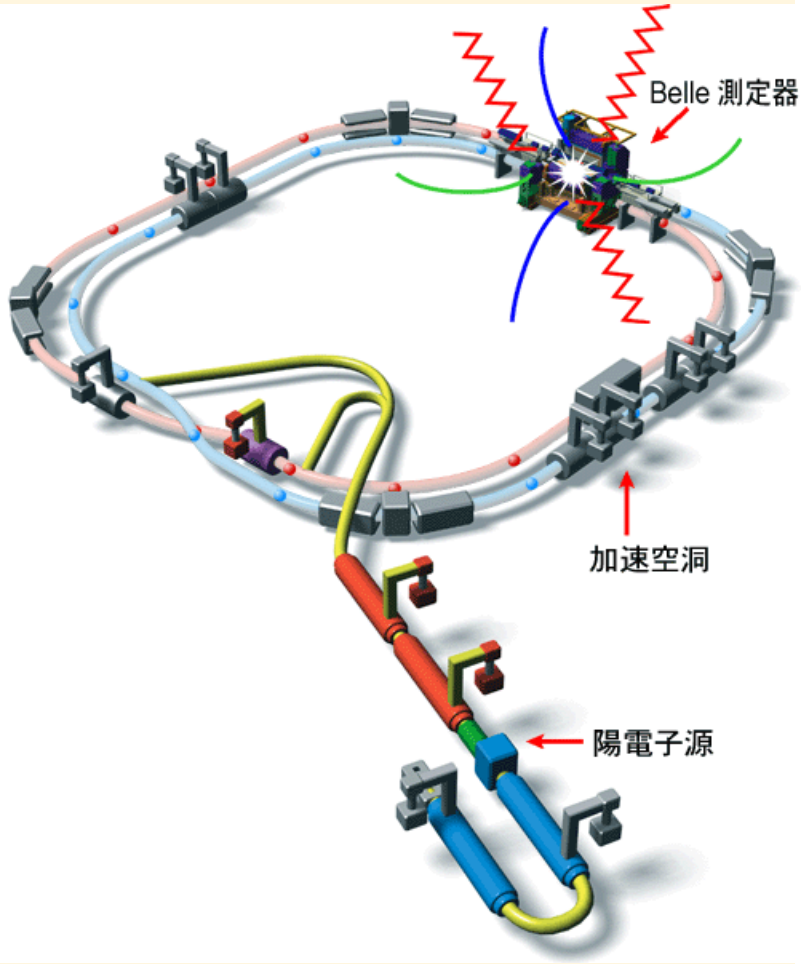
May.2000



Feb.2005
Continuous
Injections

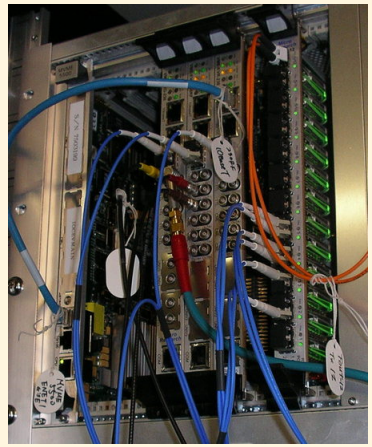


Apr.2003
Dual Bunch e+



Linac & PF & KEKB

- **Simultaneous Continuous Injection to PF, KEKB-HER and KEKB-LER**
  - **50Hz Beam Pulses are Shared between 3 Rings**
    - With very different Beam Properties, in Energy, Charge, etc.
  - **50Hz Beam Instrumentation (Beam Position Monitor)**
    - Only Passive Components other than Oscilloscope (Tek-DPO7104)
      - Windows-embedded (3GHz Intel), EPICS-3.14.9, VC++
    - One Oscilloscope reads 2-5 BPMs, 24 Oscilloscopes Installed
      - Synchronized 100-BPM Read-out
  - **Introduction of Event System, EVG230-EVR230RF from MRF**
    - 10 EVR's Installed, 1/3 of Old Timing Stations Replaced
      - VxWorks-5.5.1, EPICS-3.14.9, (Gave-up with RTEMS)
    - Event drives Low-level RF in VME, BPM Oscilloscopes over Network
    - Gun Parameters, Pulsed Magnets, Kickers, etc are Controlled 50Hz
    - Beam Pattern Rules on Client Script, can be Downloaded every second
  - **More Development Needed**
    - Flavoured Beam Feedback Systems
    - Event System Integrity Monitor

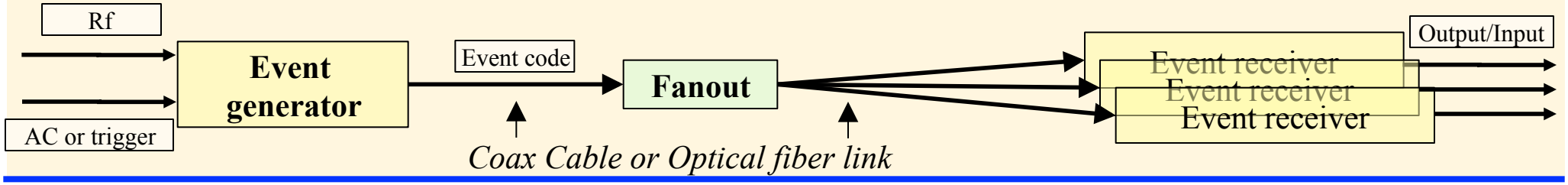


EVG & Timing

EVR & LLRF

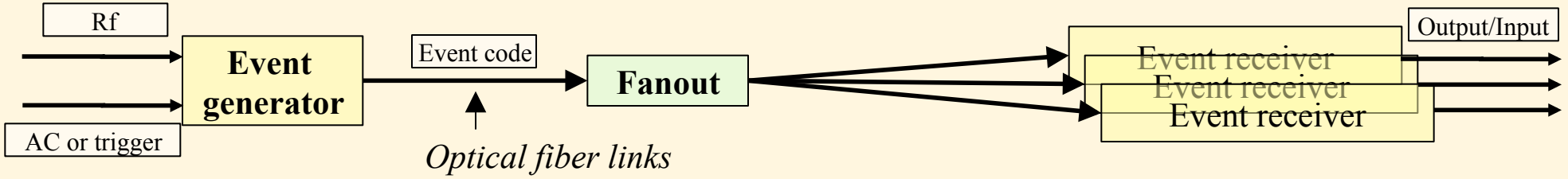
Event System

- **Many accelerator system require timing signals and accompanying information (event)**
  - **Several facilities 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**



Event System

- **Distribution mechanism of timing with data/information**
- **Developed based on experiences at several accelerator institutes**
  - APS at Argonne (ANL/APS)
  - Swiss Light Source (PSI/SLS)
  - DIAMOND
  - (TRISTAN, KEKB, Linac)
  - **New Event System (EVG/EVR-200/230)**
    - Employment at many accelerator institutes
      - DIAMOND, SLS, BEPCII, LCLS, Shanghai, KEK-Linac, Australia, …
      - (SNS), (LANL), (BNL), …
    - Many functionalities
      - Bit rate up to 2.5Gbps, Event rate 50-125MHz, ~10ps precision,
      - 8bit signal, 2kbyte data buffer, EPICS support

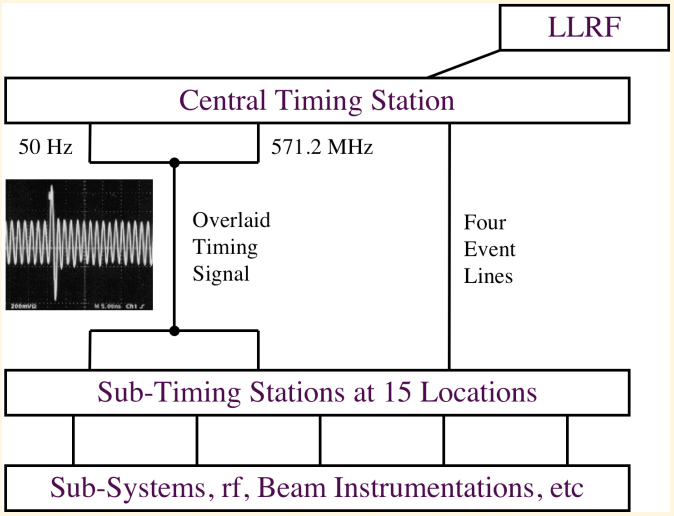


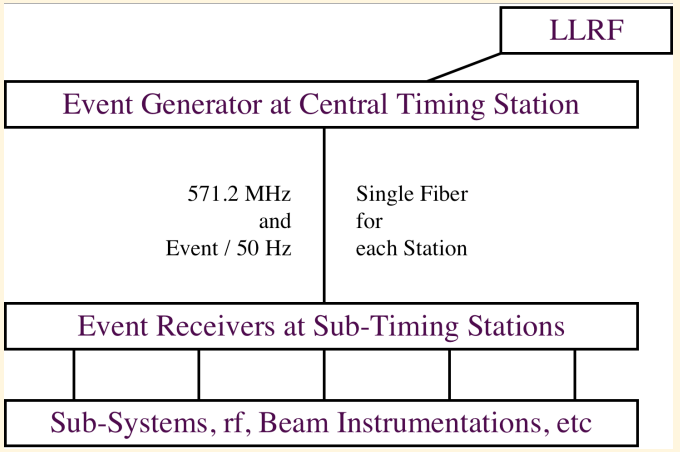
The stimulus to send an event can be:
- **pulse on a hardware input**
- **software event** (write to a register)
- an entry in an **event playback RAM**

When an event code is received the receiver can:
- **output a pulse, of specified delay and width**
- **trigger a software action (process an EPICS record)**

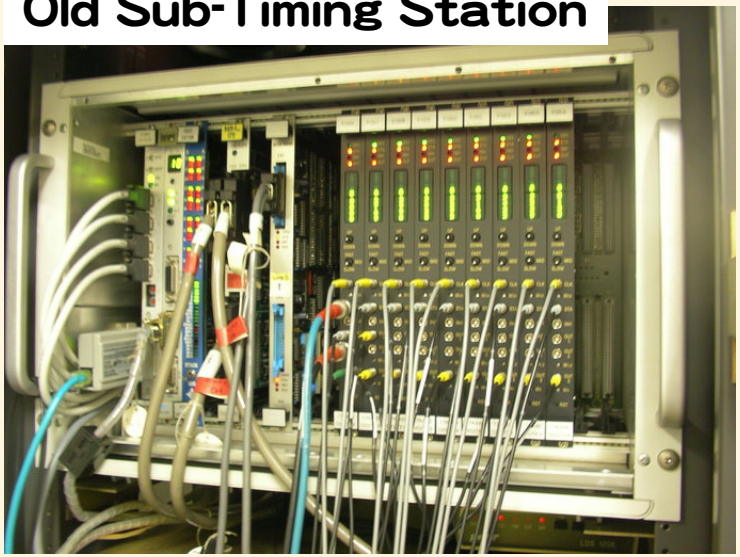
Each event receiver can be programmed to respond in a different way to the same event code.

Timing System





Old Sub-Timing Station



New Event Receiver Station (Timing) 16 outputs

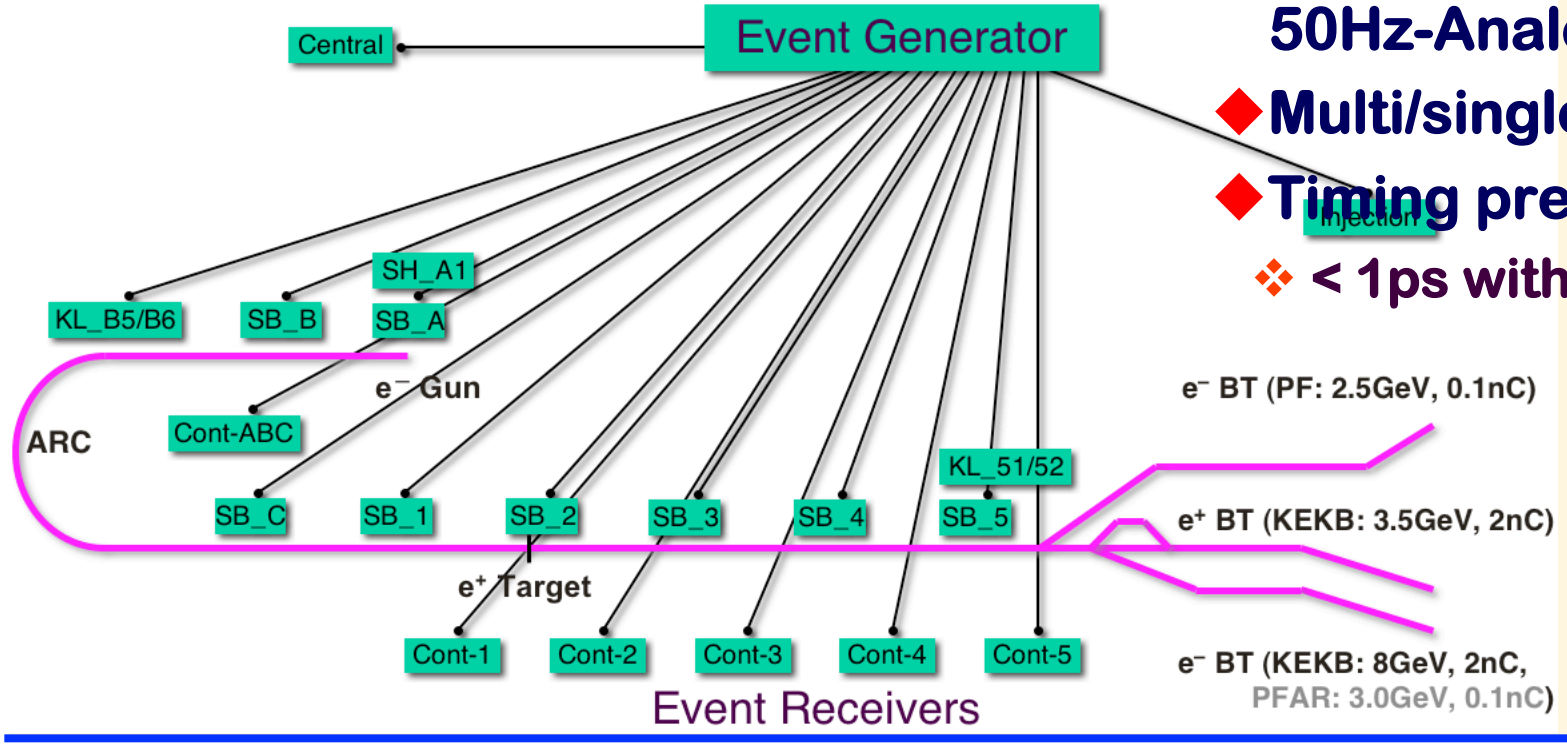
Event System

- **Quasi-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

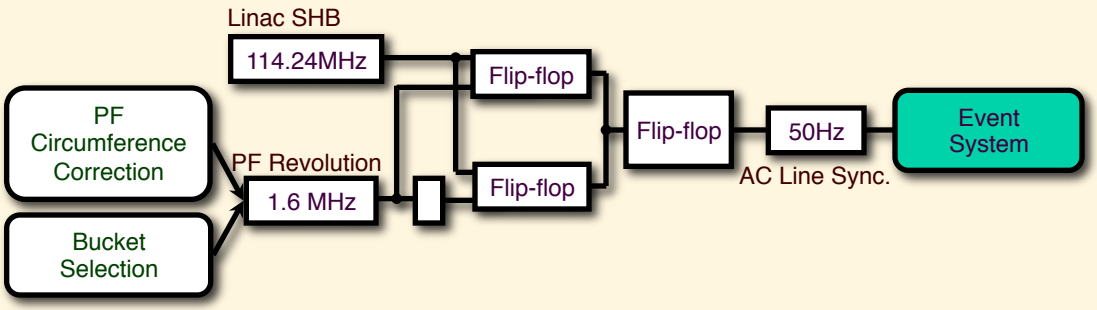
- MRF's series-230 Event Generator / Receivers.
- VME64x and VxWorks v5.5.1.
- EPICS R3.14.9 with DevSup v2.4.1.
- 17 event receivers for now.

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

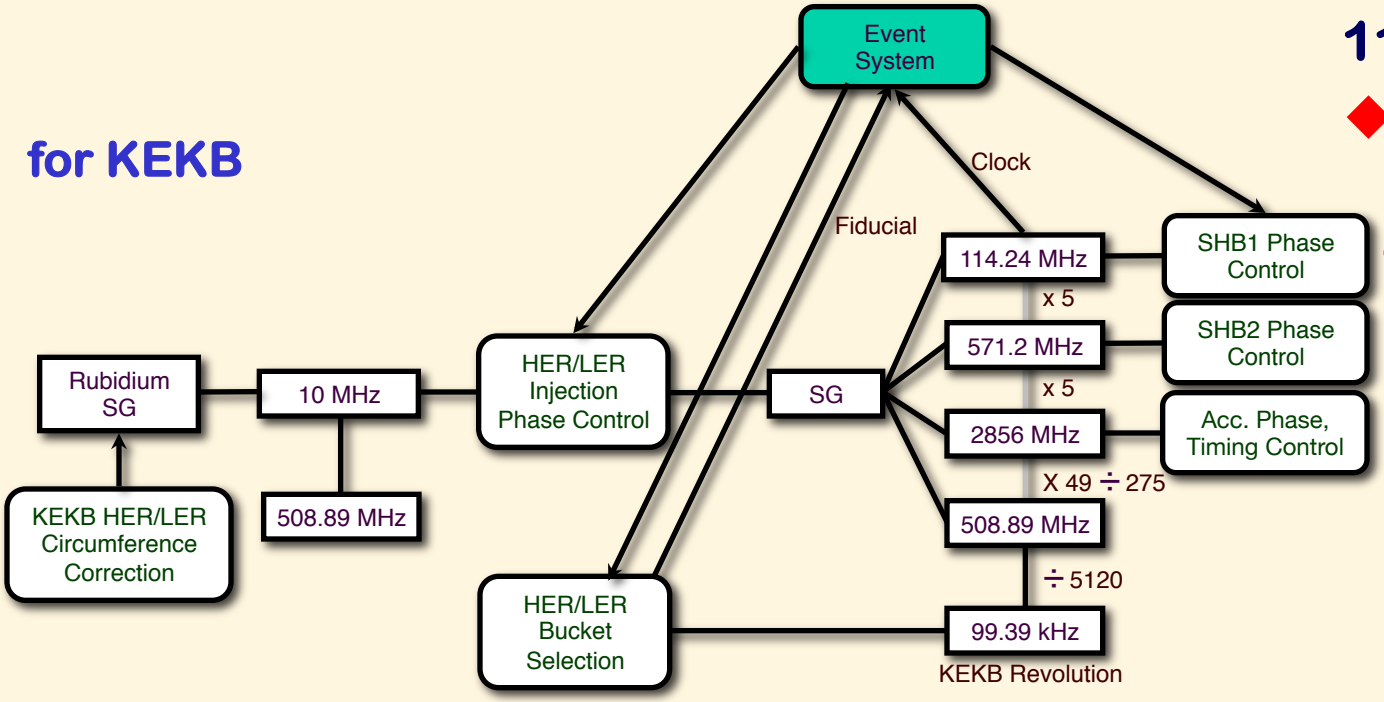


Synchronization Scheme

for PF

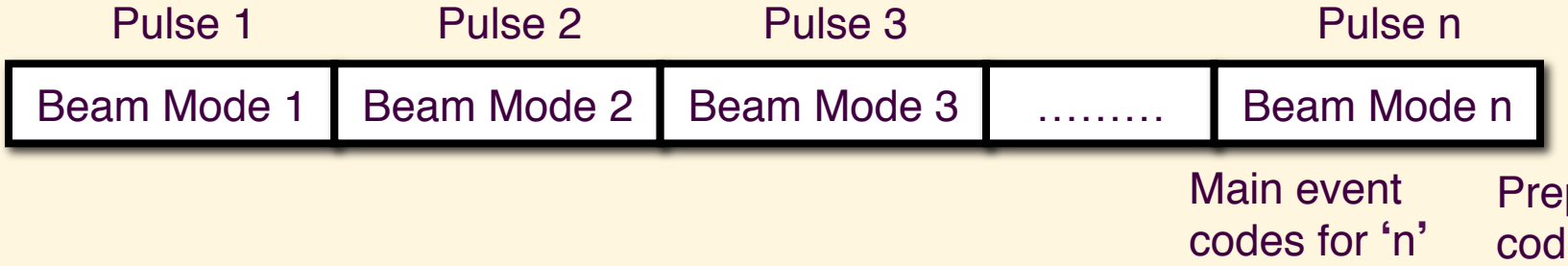


for KEKB



- **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



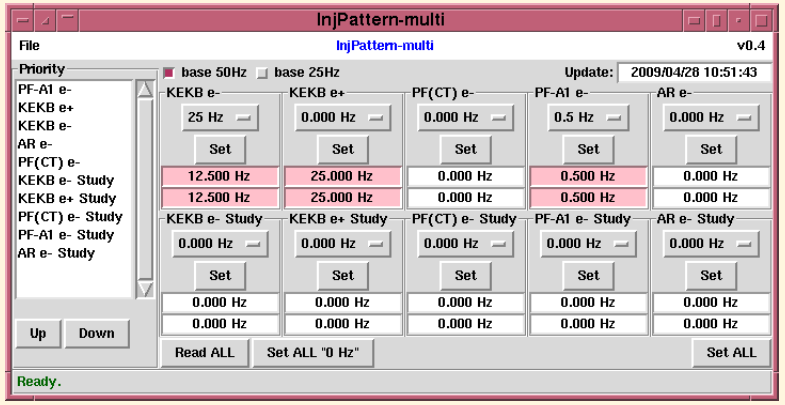
- Every pulse (every 20ms) corresponds to a beam mode.
- 10 different beam modes are defined (for KEKB e+, etc).
- One beam mode may contain many event codes.
  - At least one main code and a preparation code for the next pulse.
- About 50 event codes are defined.
  - Some events correspond to many functions, 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.
- Pattern generator software arbitrates requests from downstream rings.
  - There are many pattern rules due to pulse device features and limitations.
  - Pattern generator software is written in scripting languages to meet daily changes during the commissioning stage.

Beam Mode Pattern Generators

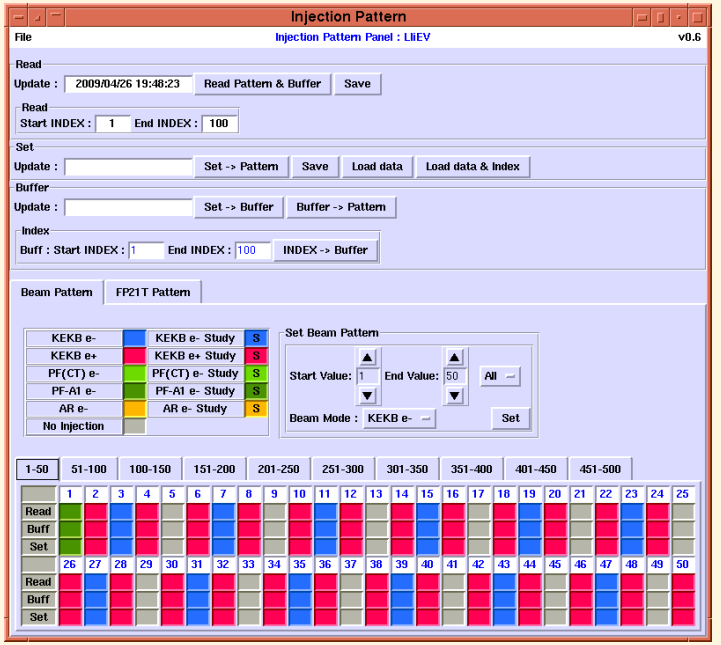
There are several versions

- Because we were commissioning new pulsed hardware equipment, the beam optics schemes, event system itself, etc, since autumn 2008
- One of them is mostly used, remote or human controllable, automatic-prioritized arbitrated, etc

Remote controlled automatic pattern arbitrator



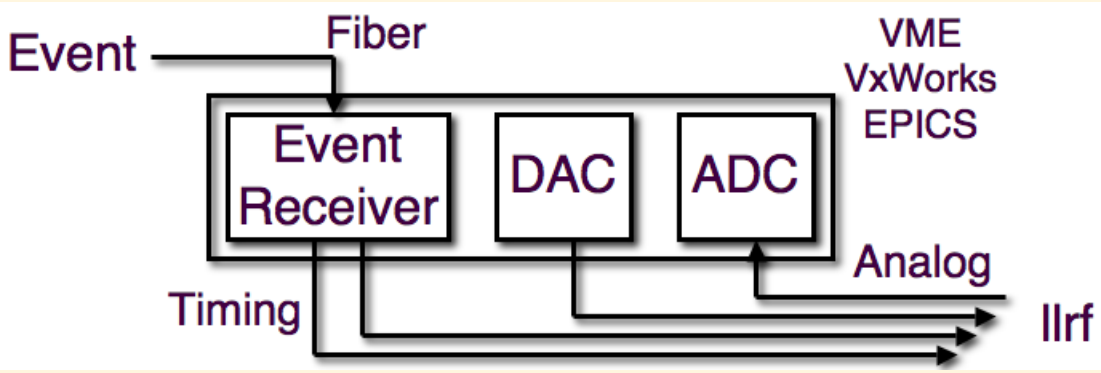
Manual pattern generator

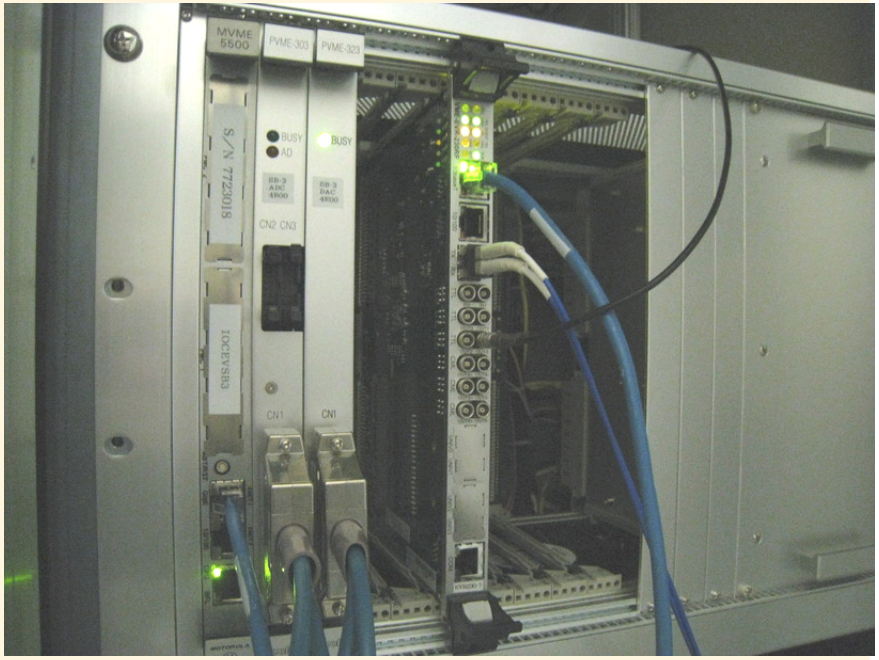


- Typical operation in 2009.
  - ~25Hz for KEKB LER
  - ~12.5Hz for KEKB HER
  - ~0.5Hz for PF

LLRF

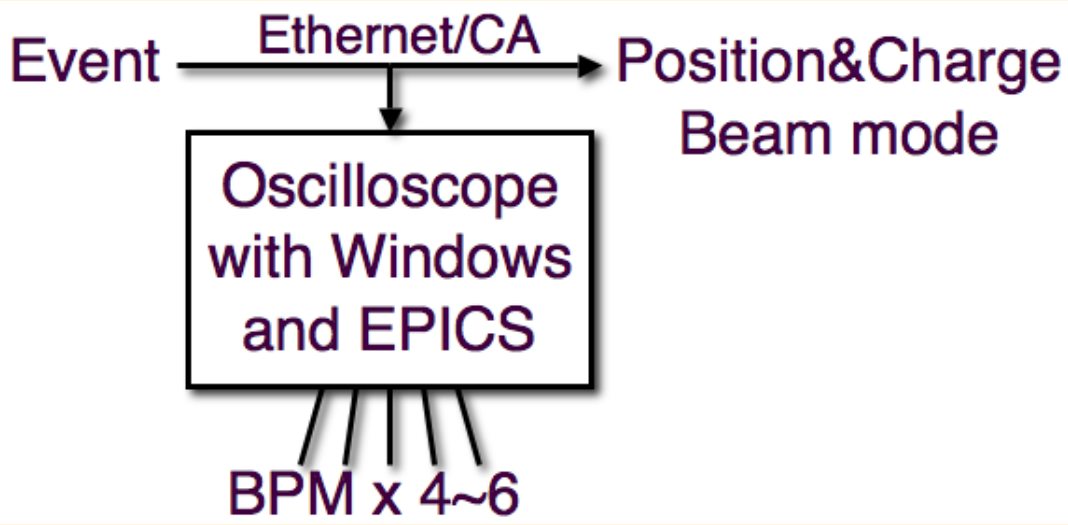
- LLRF Timing/analog signals are essential for absolute energy, energy spread, and dual-bunch energy equalization.
- Signals are switched pulse-by-pulse.
- Value changes are triggered by a preparation event.
- Driver klystrons (SB), energy tuner klystron (KL), and sub-harmonic bunchers (SH) are managed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

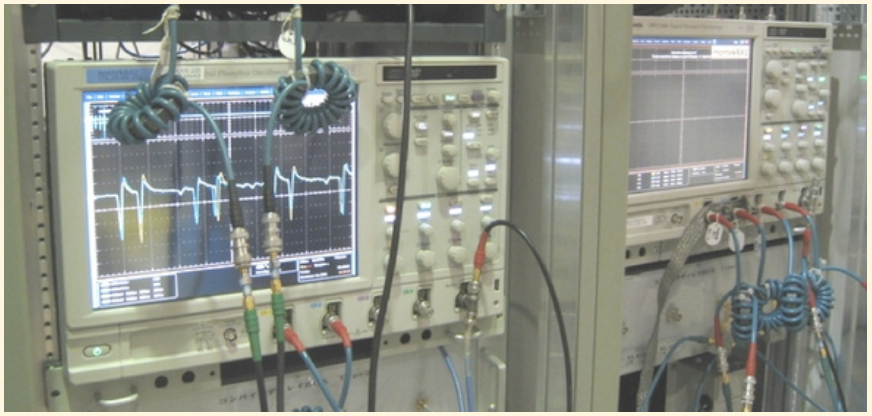




BPM

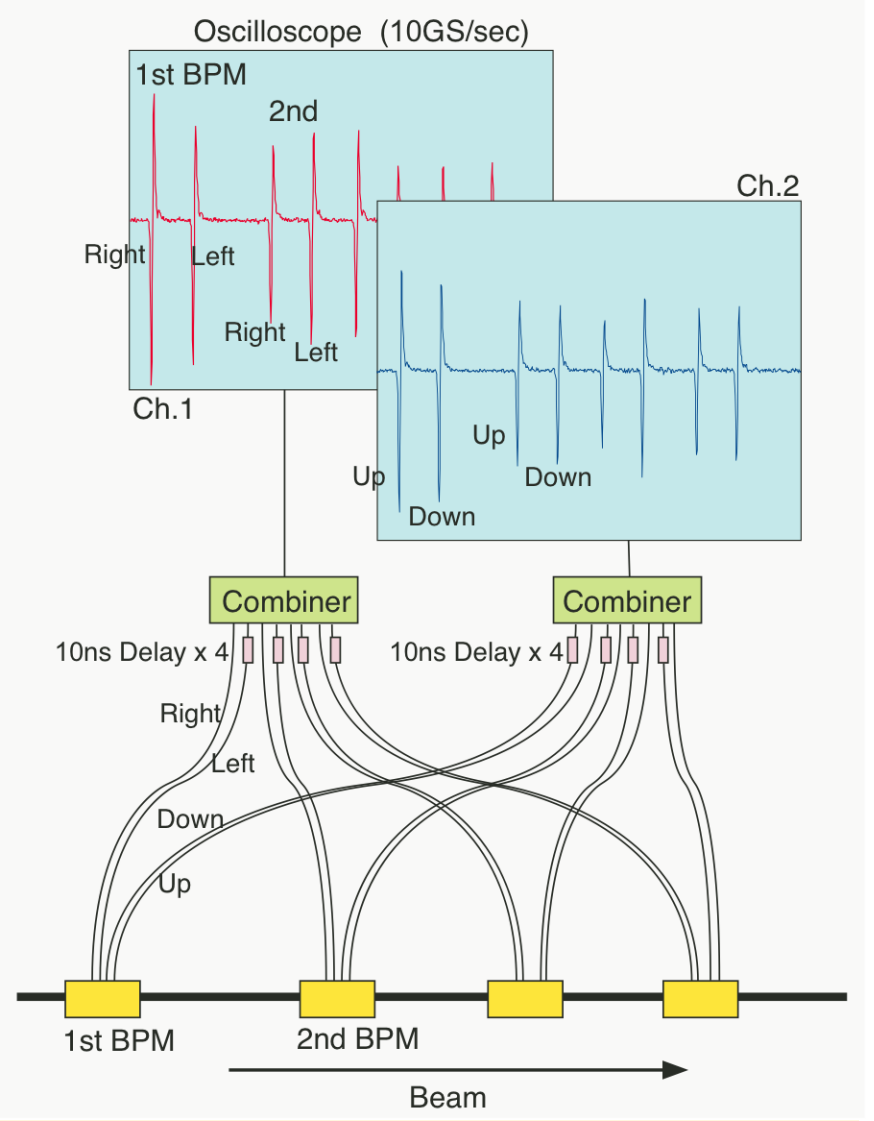
- Tektronix DPO7104 can acquire data at >50Hz.
  - With embedded EPICS
- Beam modes are recognized by events through CA network.
- Clients can monitor data of an interested beam mode.
- 26 oscilloscopes are installed.
- 100 BPMs are synchronized. (100 BPMs at BT as well soon)





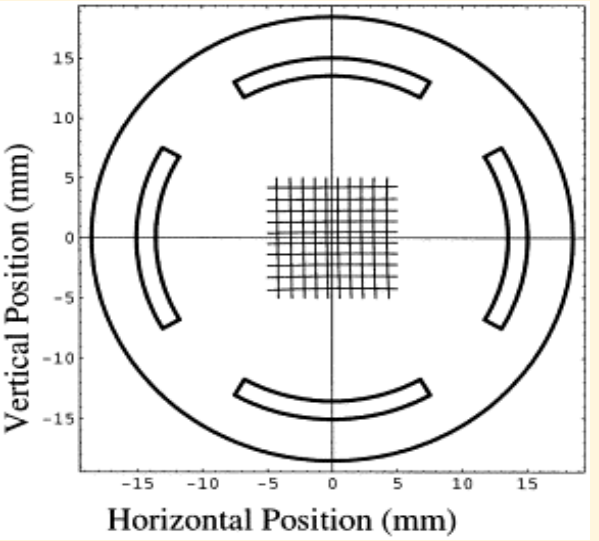
Measurement and Data Acquisition

- 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



Database and Calibration Factors

- Pulse timing value for each electrode, each monitor, each of four beam modes
- Dynamic range (voltage) for each beam mode
- Mapping information up to 3rd order polynomial
- Cable loss for each electrode, combiner loss, charge conversions for single/multi-bunch beams
- About 40 coefficients for each BPM
- Processed on one of 24 DPO7104s in the framework of EPICS software then served directly to clients at 50Hz



100 BPMs — 24 x DPO7104 — Clients

- Old system served at 1Hz

100 BPMs — 19 x TDS680B — 19 VMEs — ~5 Unix — Clients

Embedded IOC on Oscilloscope

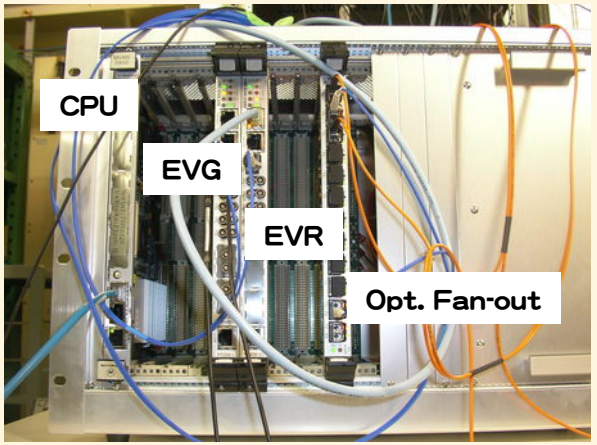
- DPO7104, 10Gs/s, 4ch, 8bit
  - Windows-XP
  - Cygwin software development environment
  - Microsoft Visual C++ 2008
    - http://www-linac.kek.jp/cont/epics/win32/
  - EPICS 3.14.8.2
  - Fast data-acquisition at ~150Hz was tricky, but was possible
  - Event triggers the data acquisition
  - Beam positions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

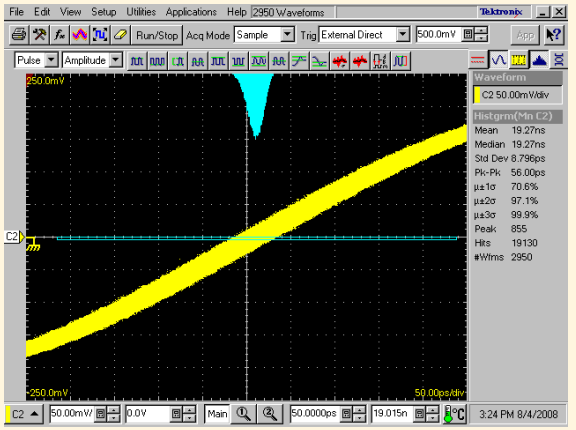
Parameters

- Parameters switching via Event system
  - LLRF :14x4
  - HP RF Timing :~60
  - Gun voltages, fast delays, :4
  - Pulsed magnets :14
  - Injection system :4
  - BPM over channel access x~100
- Basically sufficient for fast beam mode switching
- More parameters comming
- Integrity monitors
- Improved slow beam feedback, fast feedback, etc.

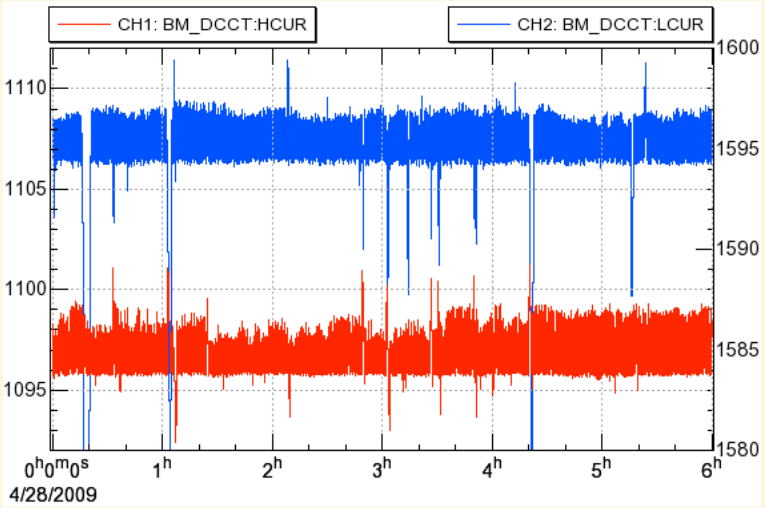
Linac Event System

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

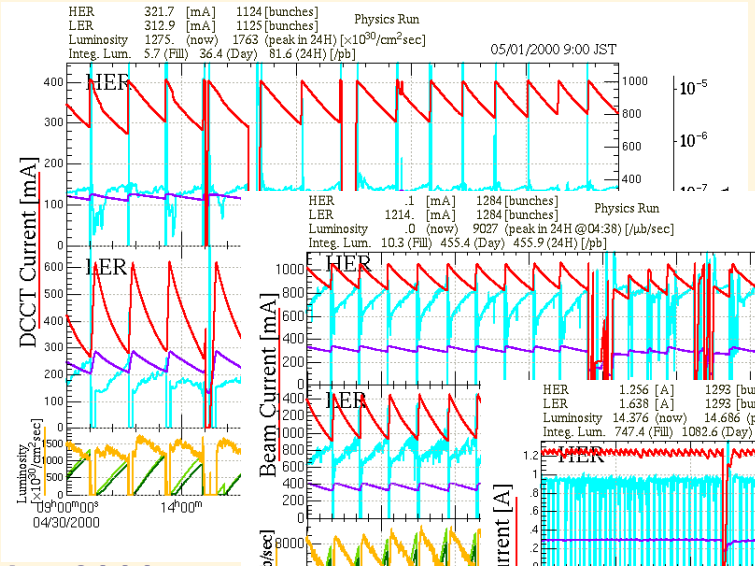




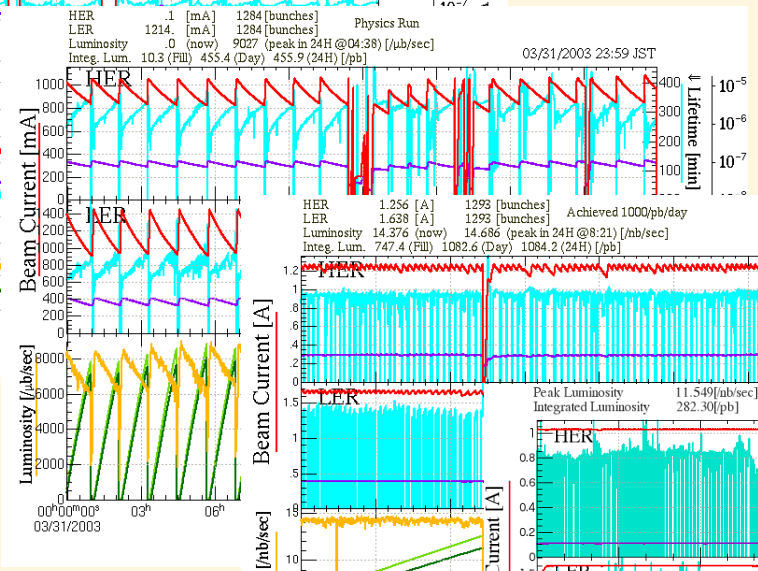
- **Beam currents are kept within**
  - KEK 2mA (improving)
  - PF 0.1mA (in 450mA)



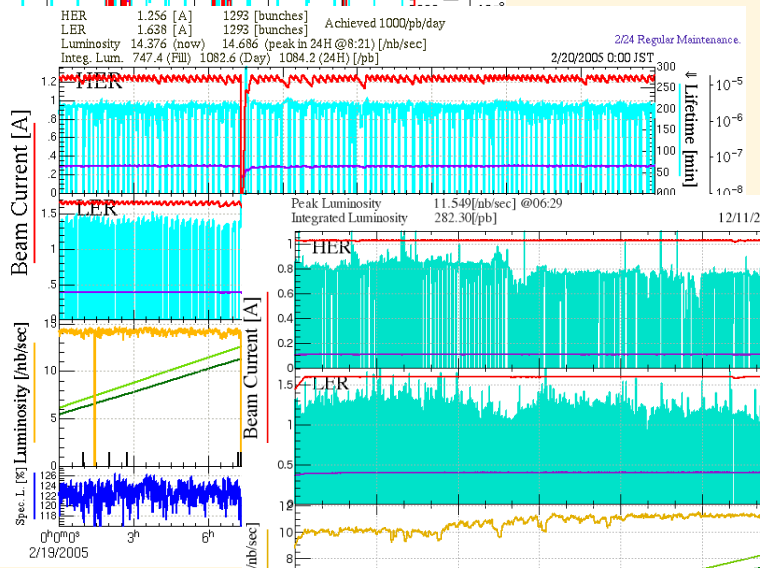
KEKB Operation Improvement



May.2000

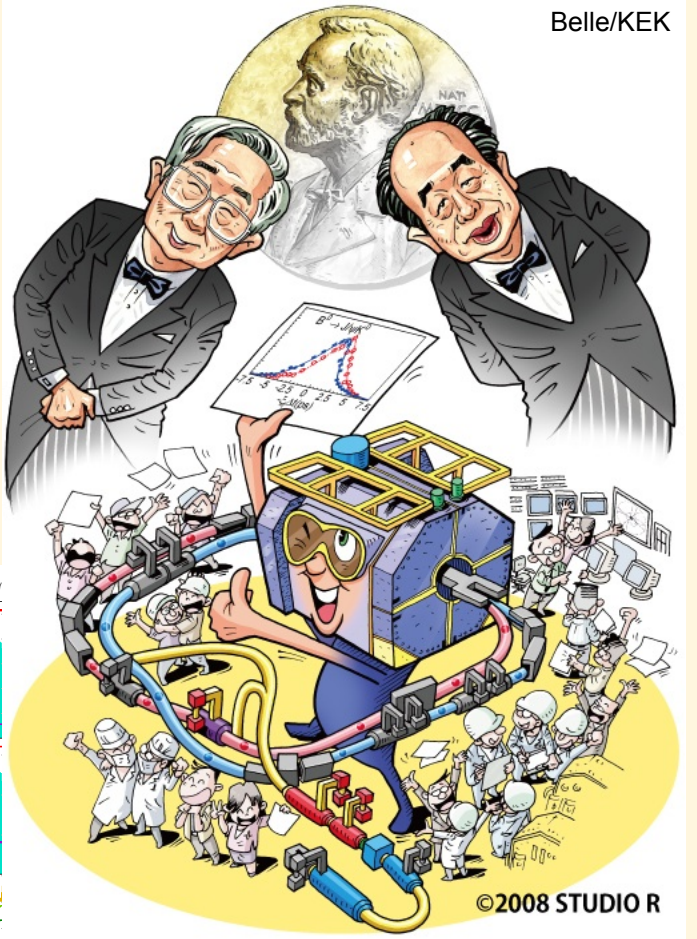


Feb.2005
Continuous
Injections



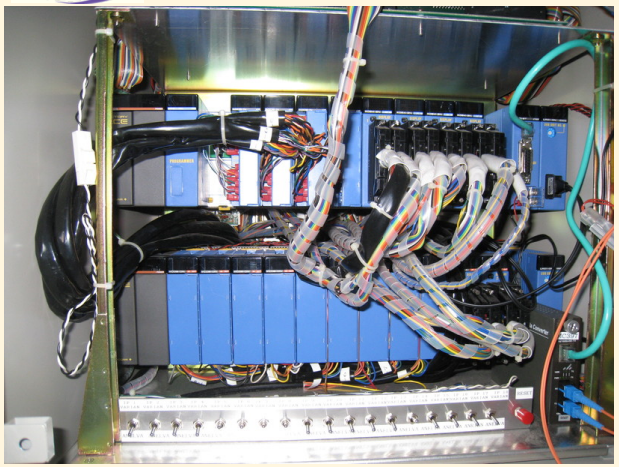
Apr.2003
Dual Bunch e⁺

Dec.2008
Crab Cavities and
Quasi-simultaneous Injection

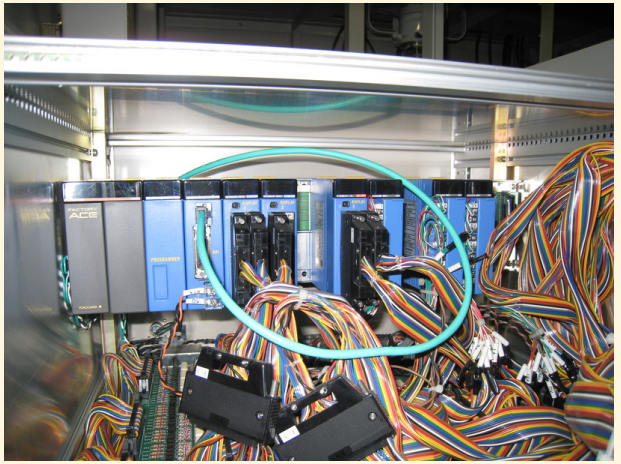


(Initial) PLC usage at KEK

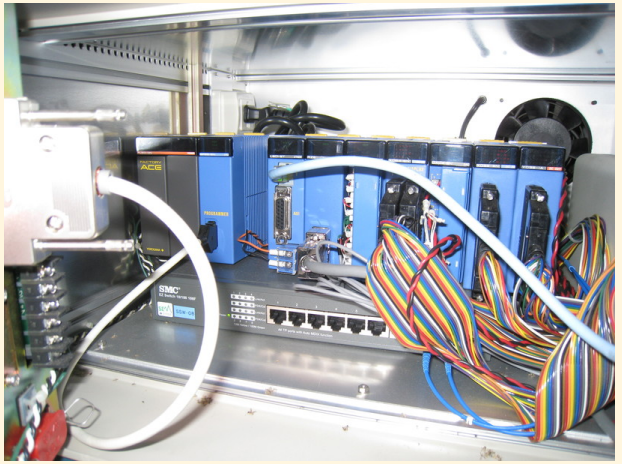
- At e–/e+ Linac
  - We enforced that all the new controllers should be connected over IP/Ethernet since 1993 (instead of other field networks)
  - PLC was much cost-effective compared with VME
    - if the speed requirement allows
  - Products from OMRON, Mitsubishi, Yokogawa, etc. were installed
    - Only Yokogawa (FAM3) remained and others were removed, because maintenance capability over network was better
      - Ladder software downloadable over IP/Ethernet, etc.
      - (Recently Mitsubishi also added that feature)
  - 170 PLCs (with Ethernet) used for RF, Magnets, Vacuum, (Safety), etc
- At J-PARC
  - Many installations with the same reasons as e-Linac
- At KEKB
  - Used indirectly at many devices, over serial or GPIB links
- Even custom hardware modules can be designed (I/O Open)



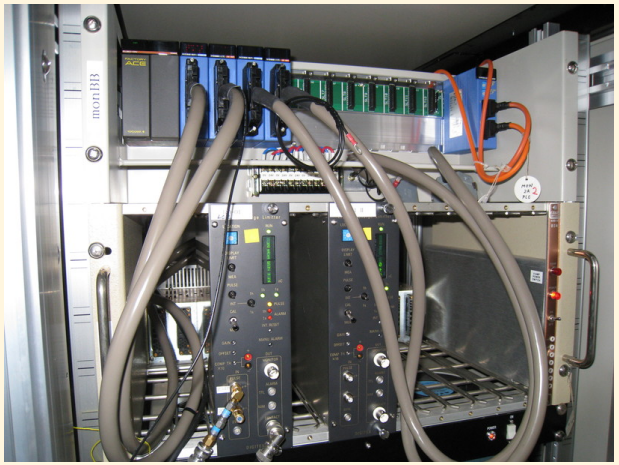
Vacuum Controller Internal



Magnet Controller Internal



RF Controller Internal



Safety Controller

Touch Panel Display for RF

Software management with PLCs

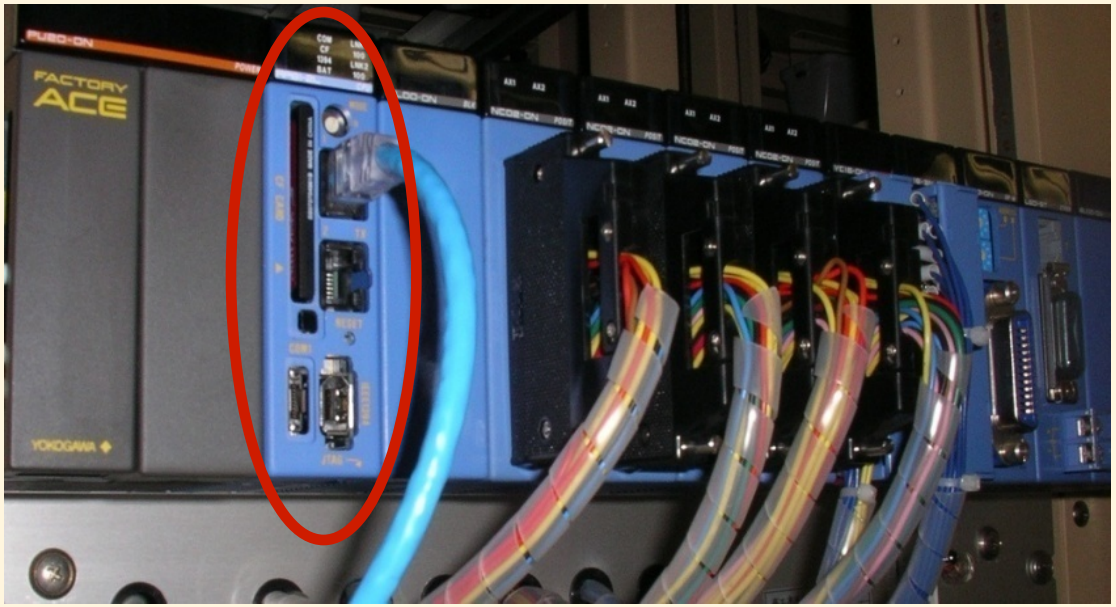
- **Ideal at the beginning with ladder software**
  - Separate software developments at control group, at equipment group, or at industrial company
  - Later, integration test with IP/Ethernet
- **Logic management, however**
  - Same logics could be placed at ladder software, and in EPICS database/squencer (or in high-level applications)
- **Speed requirement**
  - Closed loop over Ethernet was slow, sometimes un-reliable
  - Interrupts were possible, but slow and complicated
- **Thus, hoped to run EPICS on PLC**

EPICS on PLC

- VxWorks CPU was available on PLC (Yokogawa, Mitsubishi)
  - Besides normal sequence / ladder CPU
  - However, license management of vxWorks …
- Yokogawa starts to provide Linux (2.6) on PLC CPU (F3RP61)
  - Brave enough to choose open source environment
    - We negotiate with Yokogawa to remove any license issues
  - Odagiri/KEK, Uchiyama/SHI-RIKEN, Yamada/KEK made much effort to realize the implementation, (no need for asynchronous records)
  - Takuya-Nakamura/MSC-KEK tailored the environment for KEKB
    - Procserv, pcmon, NFS, …
- Six new PLC IOCs are used in KEKB operation
  - Since September 2008 and later, six in total
    - Many will be installed in 2010-2011 for vacuum, rf, …
  - Beam mask controllers and Pulsed-quad controllers
  - No trouble at all, they run more than 1 year
- ~20 new IOCs are also used in J-PARC operation now

F3RP61 (e-RT3 2.0)

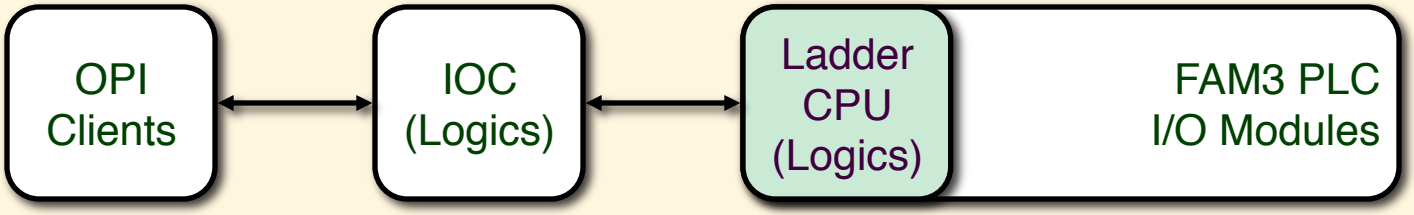
Linux 2.6.24
PPC 533MHz
128Mbyte RAM
100BaseTx x 2
USB
IEEE1394
Serial
PCI
I/O Bus for FAM3 Module Interface
can access to mature FAM3 I/O Modules
Can be combined with conventional ladder CPU
Software development environment (ELDK)



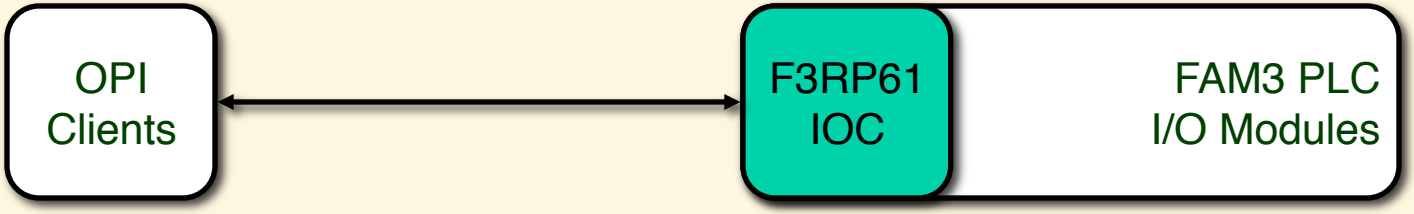
KEKB Beam mask controller

Simple Usage under EPICS

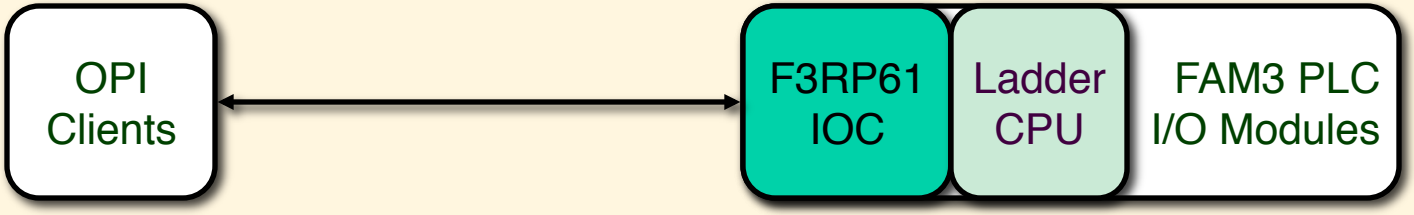
Conventional PLC usage with asynchronous access



PLC usage with F3RP61 with only synchronous access and maybe with sequencer



If necessary, we can combine



Device Support

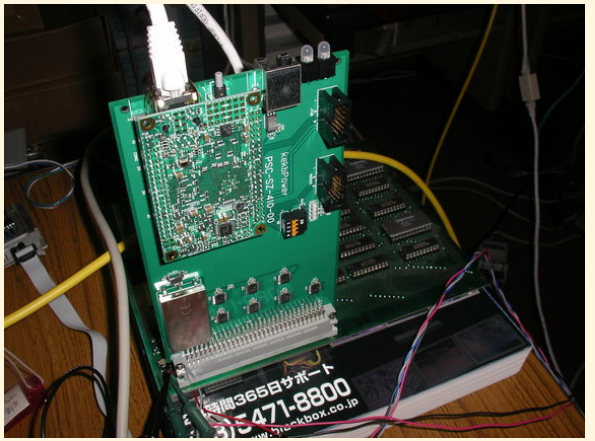
- No need for asynchronous access
  - Direct access to all I/O modules
- Can access to registers on ladder CPU
  - If necessary
- Interrupts also possible
- Logics can be database links or sequencers
- Did extend the number of EPICS developers

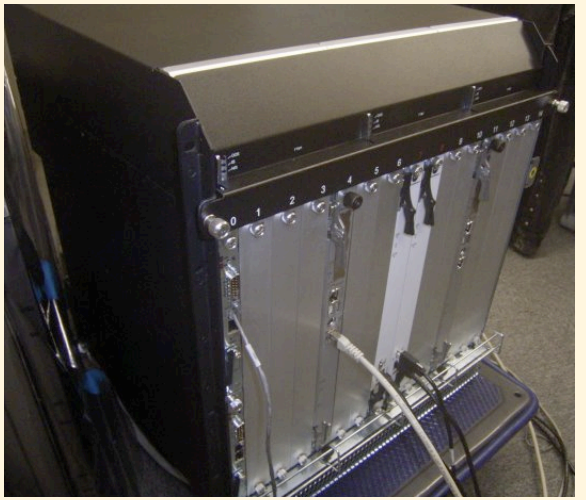
- Source code and documents
  - http://www-linac.kek.jp/cont/epics/f3rp61/

- PREEMPT_RT realtime developement (Yamada, Yokogawa Co., et al)

Other Developments at KEK

- Embedded IOC on FPGA controller
  - By A. Akiyama, et al
- Embedded IOC on oscilloscopes
  - By M. Satoh, et al
- Redundant IOC (RIOC with OSI supports)
- Redundant Gateway
- ATCA IOC with HPI/SAF support for RIOC
  - ATCA for STF/ILC-LLRF and μTCA for cERL-LLRF
- Automatic test system environment
  - By A. Kazakov, et al
- Wireshark protocol analyzer for CA
  - By Klemen Zagar, et al

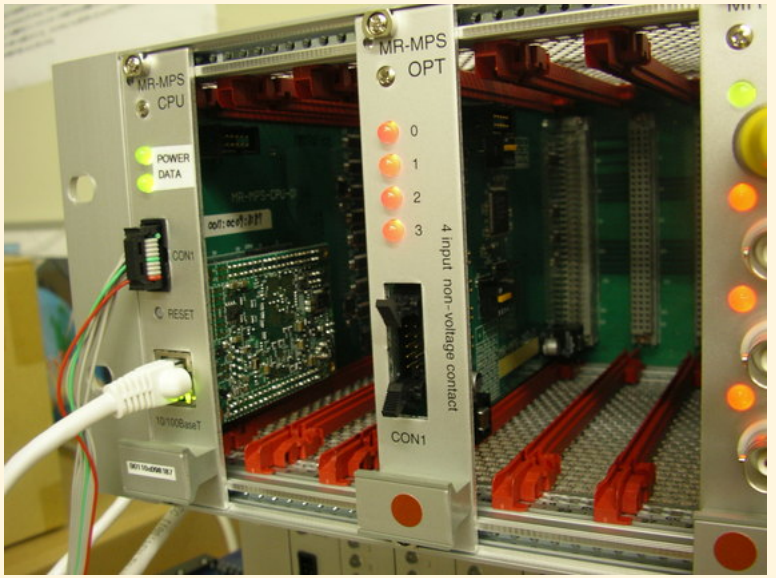


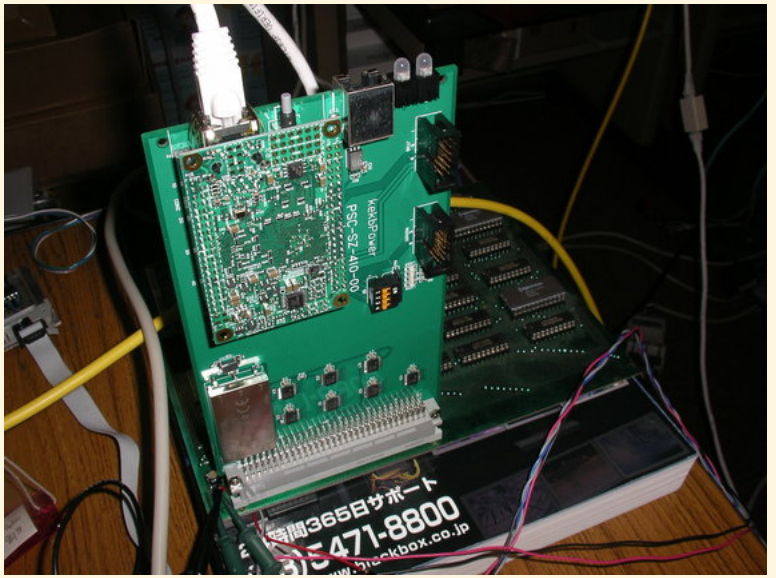


Embedded EPICS with FPGA

- Suzaku/atmark-techno
  - FPGA Vertex-4
  - PPC Linux-2.6
  - EPICS 3.14

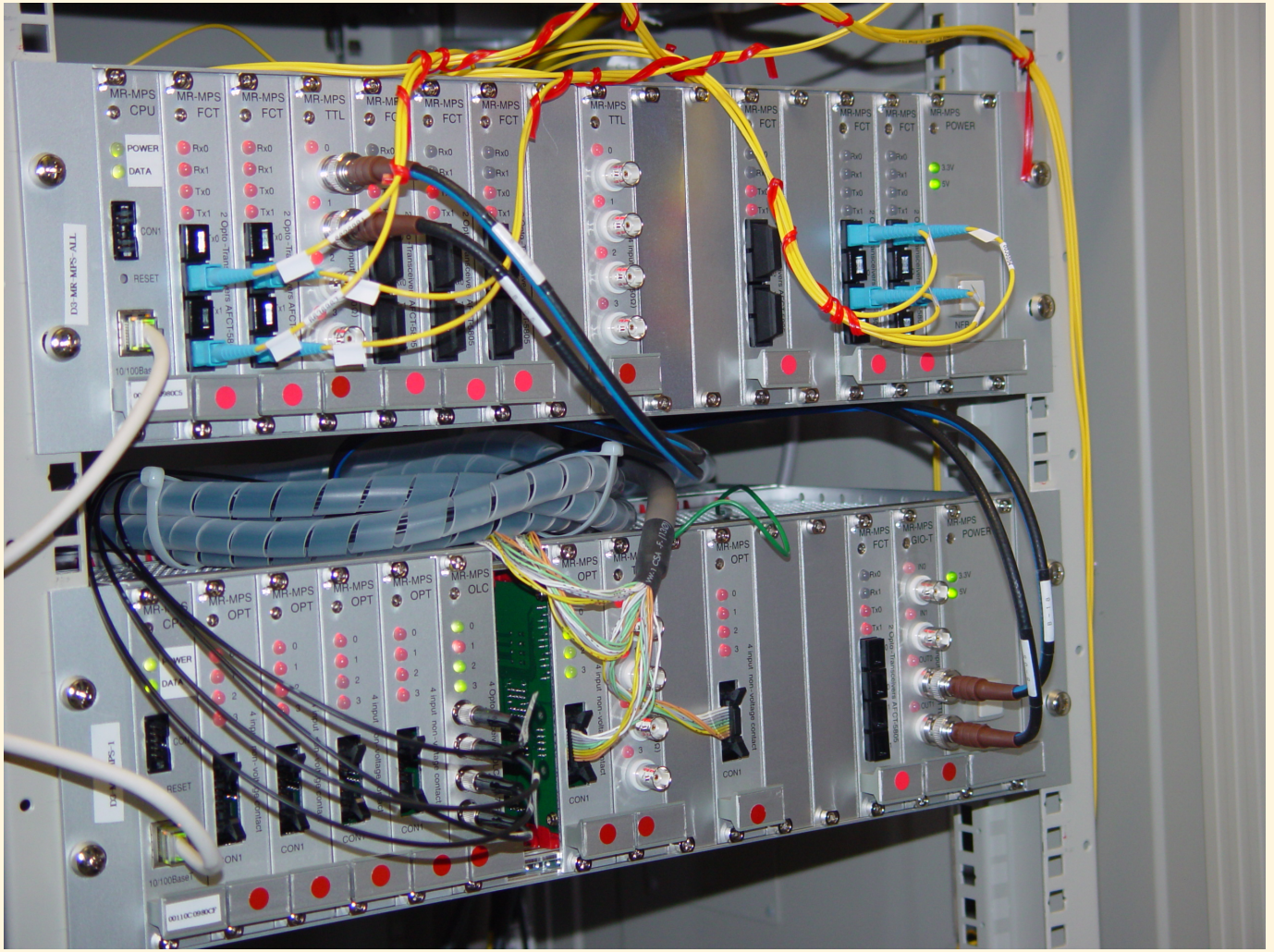
- J-PARC MPS
- KEKB Magnet
- Linac RF





J-PARC MR MPS Operational

- Akiyama, Nakagawa, et al.
- Several Different Interfaces



Thank you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23-28 MAY 2010
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SCIENTIFIC PROGRAM COMMITTEE
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The 1st International Particle Accelerator Conference
IPAC'10

Old FAM3 failure considerations

- 10Base network interface 15 years ago was weak against broadcast storm
  - If we make a Ethernet loop, all the FAM3 in the segment had died.
- Our rf modulators are very noisy because of its grounding scheme and the voltage of 50kV, and 15-year-old PLC sometimes fails/stops and needs reboot
  - About five PLC failures per 60 rf PLCs per year
  - About one PLC failure per 50 other PLCs per year
- Recent version has a redundant memory system in CPU module and relatively strong against noises
- Chemical capacitors have a lifetime of 8 years
  - We used more than 10 years, and found one failure for 100 PLCs
- Mechanical relays (if it is used) have lifetime
  - Electronical lifetime 100k times
  - Mechanical lifetime 10M times