# Accelerator Controls at KEK

## Mainly KEKB and Linac Evolution at Tsukuba Site

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**KEKB and Linac Control Groups**

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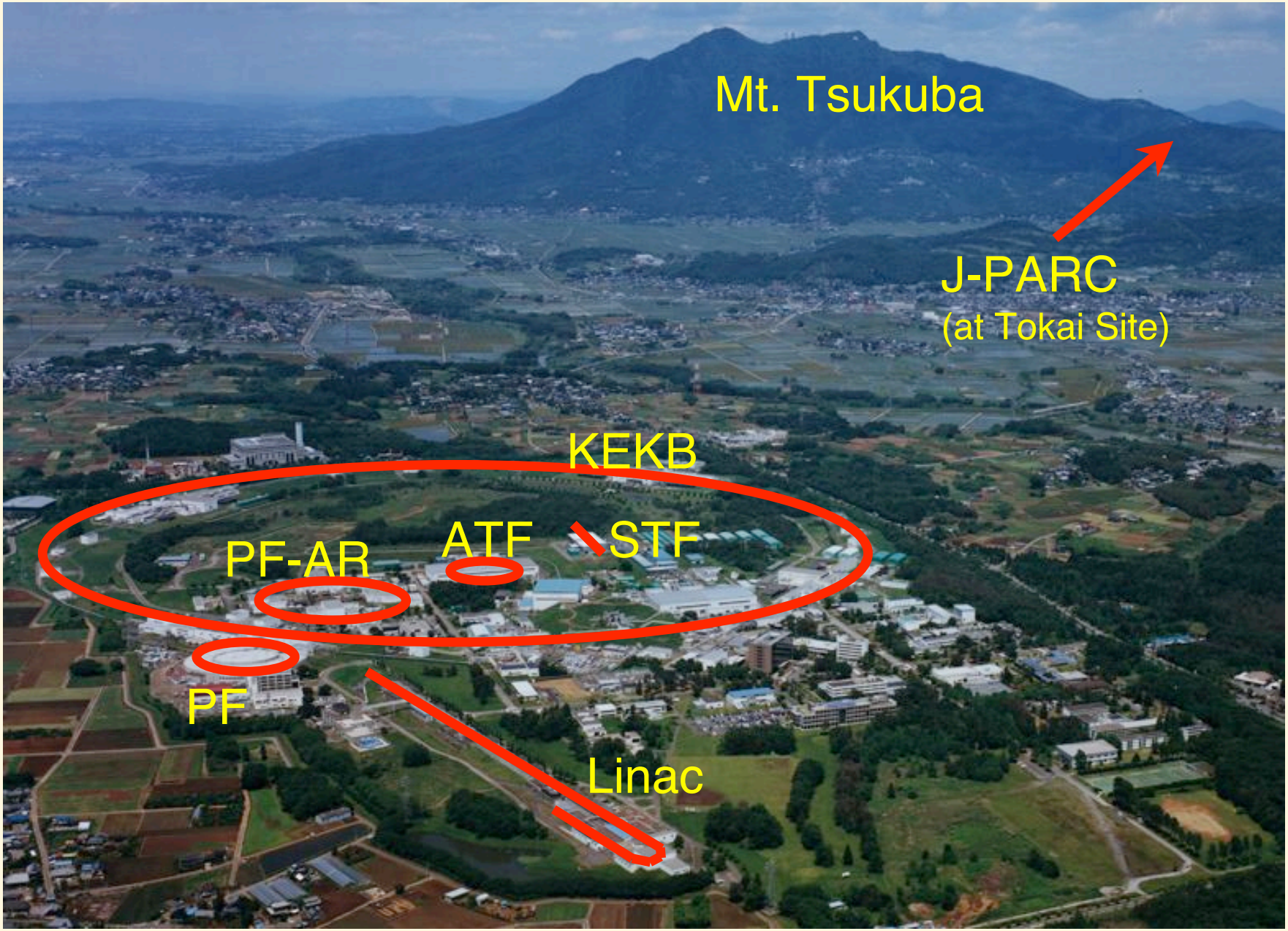
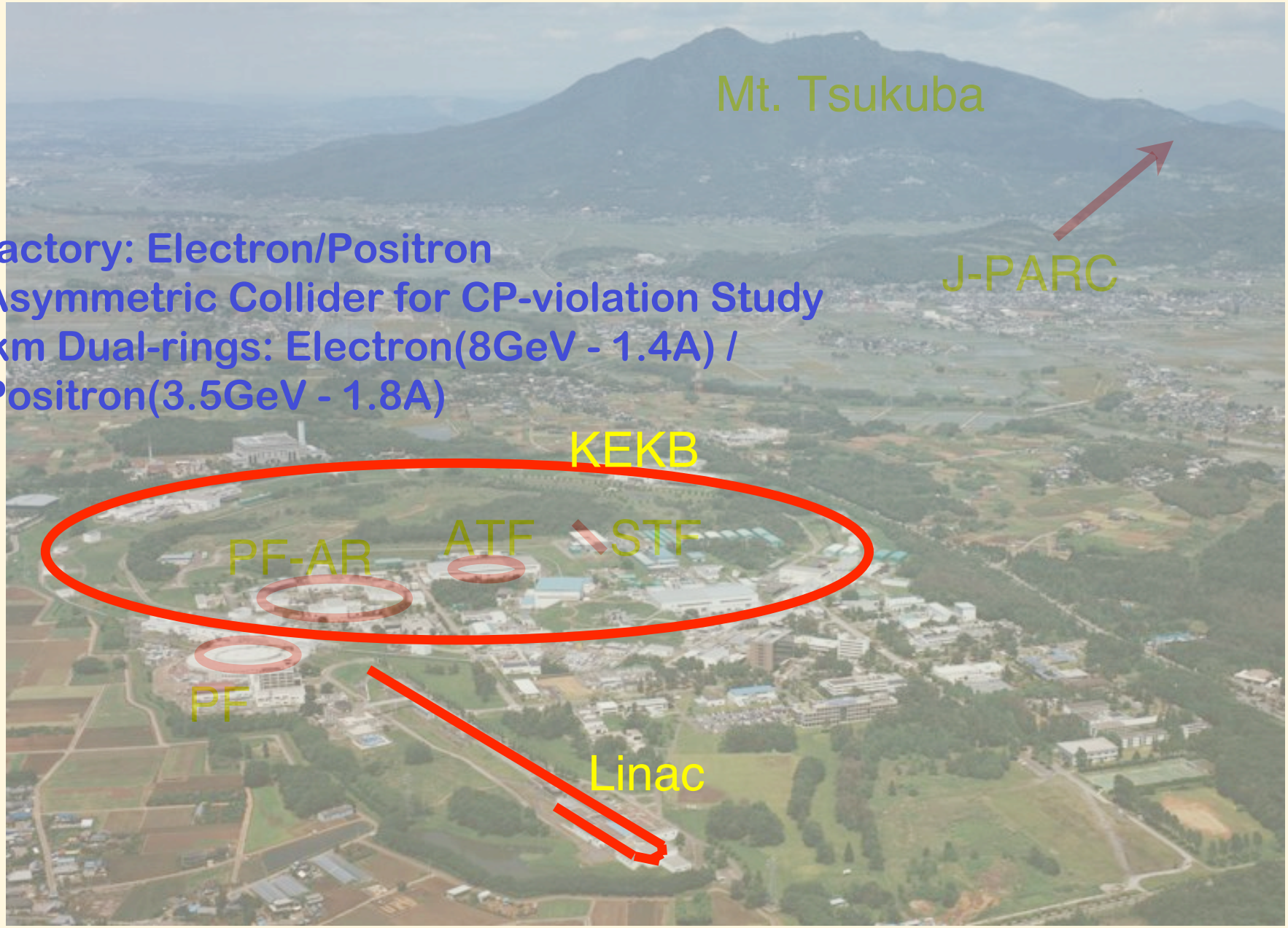
**Jan. 28. 2009.**

- Several aspects of Evolution of the Accelerator Controls at the KEK
  - Communication Networks
  - Equipment Controllers
  - Gradual Approach to EPICS
  - Scripting Languages
- Summary


Mt. Tsukuba
J-PARC
(at Tokai Site)
KEKB
ATF
STF
PF-AR
PF
Linac

# PF, PF-AR, ATF, STF

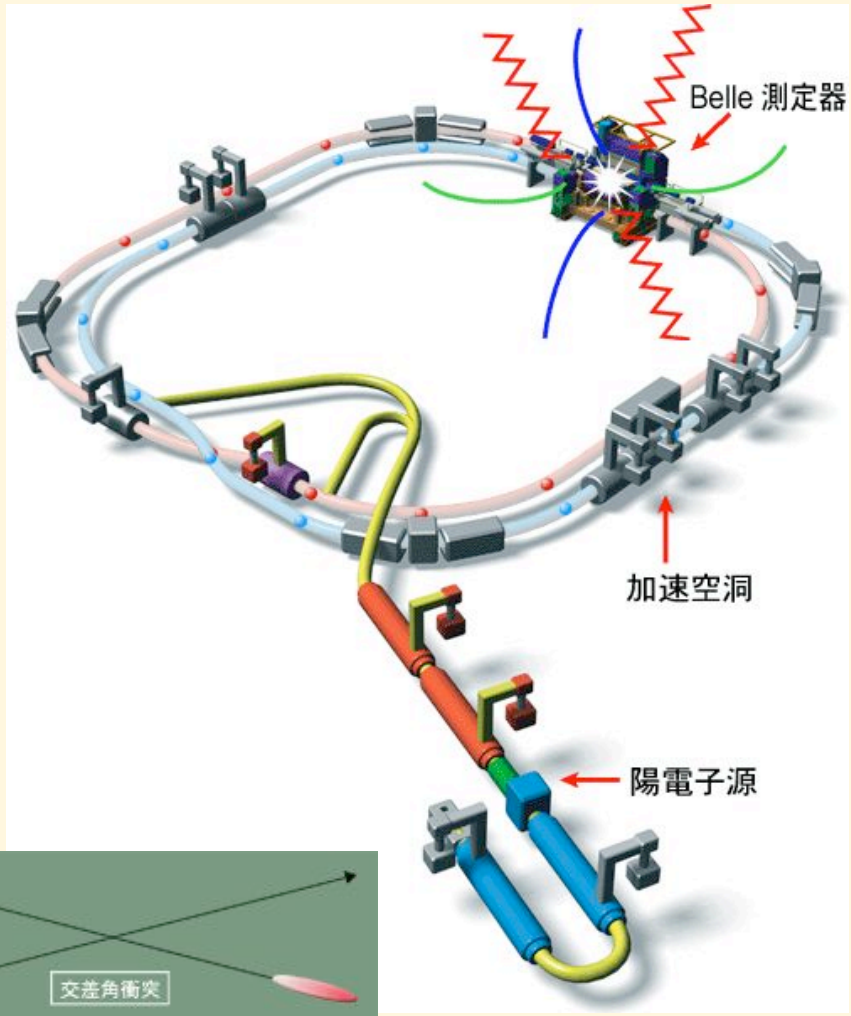
- **PF-AR**
  - Mostly the same environment as KEKB
    - Still many CAMAC installations
- **PF**
  - Moved to EPICS environment
    - Mainly with Linux-VME
- **ATF**
  - Vista environment with CAMAC
  - Linux and socket environment
- **STF**
  - Test accelerator for ILC
  - Linux, ATCA test

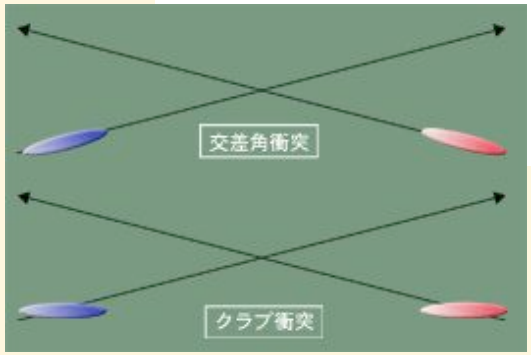



**B-factory: Electron/Positron**
**Asymmetric Collider for CP-violation Study**
**~3km Dual-rings: Electron(8GeV - 1.4A) /**
**Positron(3.5GeV - 1.8A)**

# KEKB and Linac

- **KEKB B-factory: Electron/Positron Asymmetric Collider for CP-violation Study**
  - ~3km Dual-rings: Electron(8GeV - 1.4A) / Positron(3.5GeV - 1.8A)
    - Stable and Robust Operation
    - Many Active Operation Parameters
    - Importance of Controls
- **Linac:**
  - ~600m, 50Hz
  - 8GeV 2nC Electron, 3.5GeV 1.2nC Positron
    - Beam switchings for PF and PF-AR rings

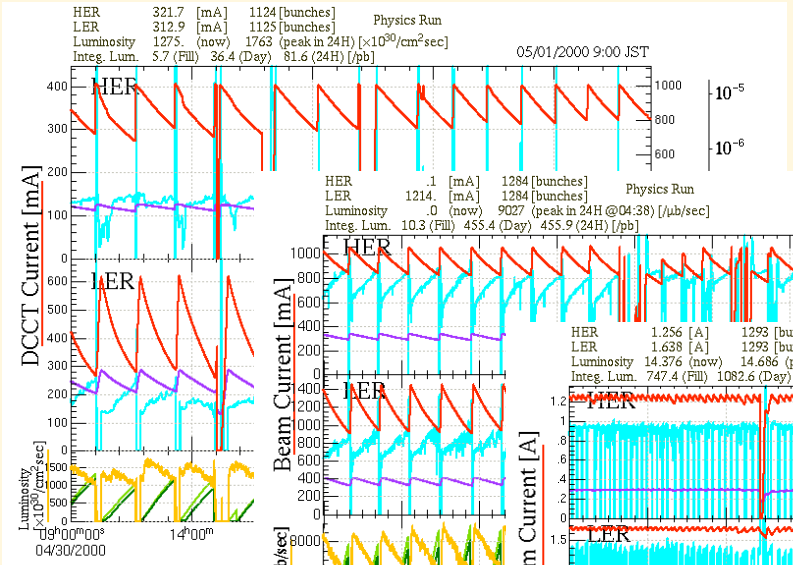


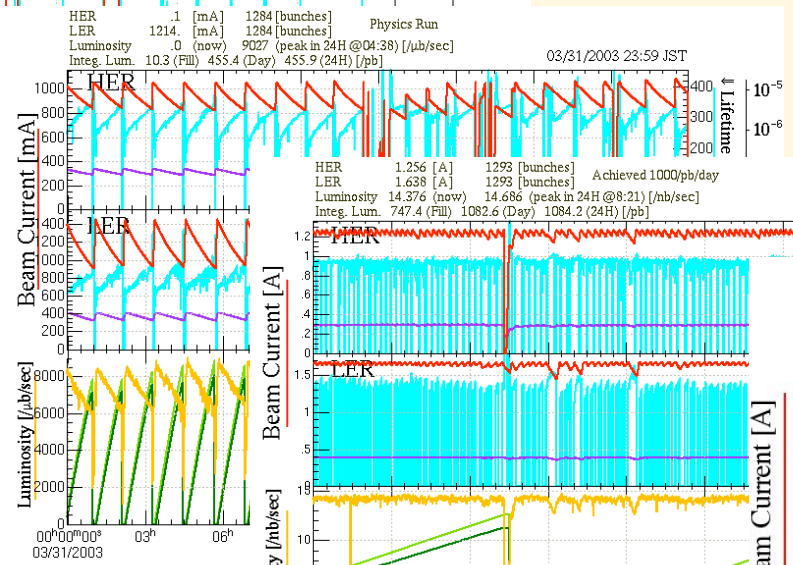

Increase of Luminosity with Crab Cavities

# Increase of the Luminosity

## percent by percent



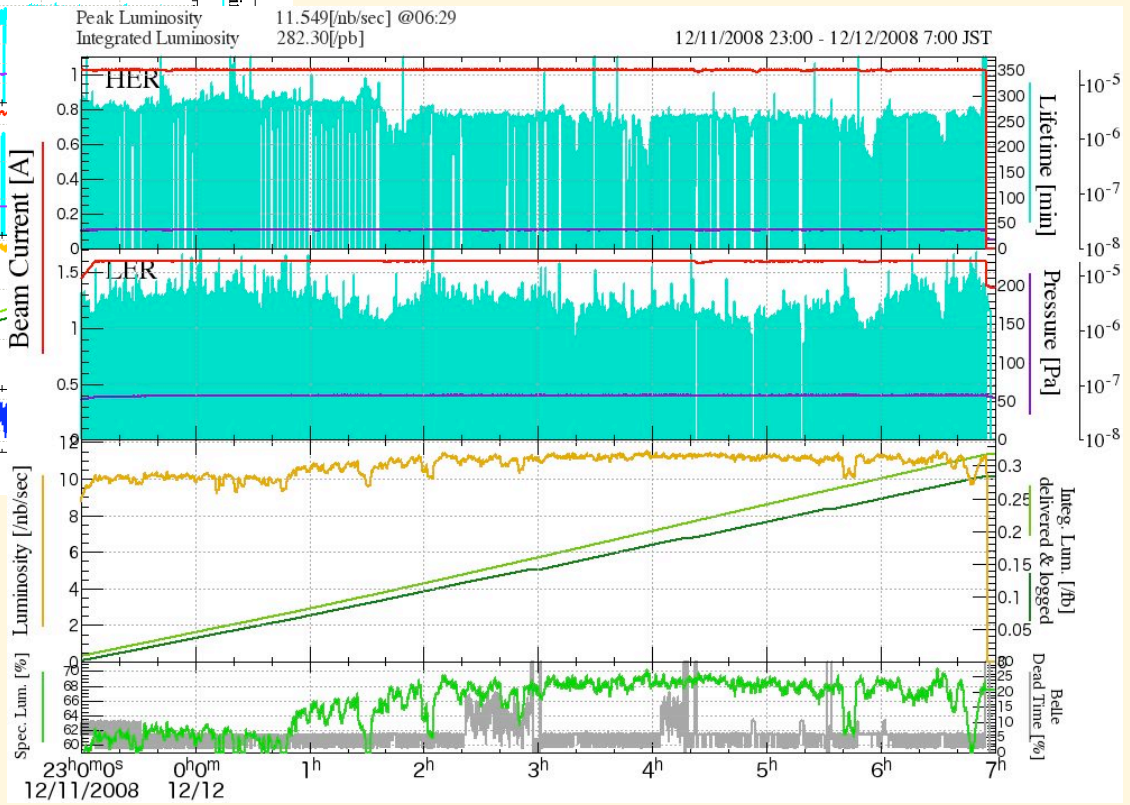

May.2000




Apr.2003
Dual Bunch e+




Feb.2005
Continuous
Injections

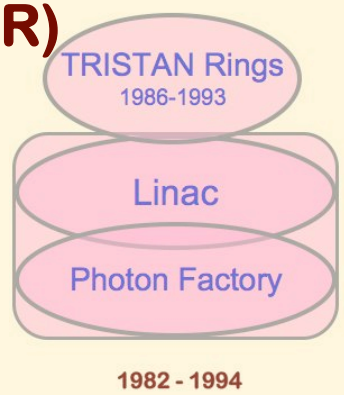


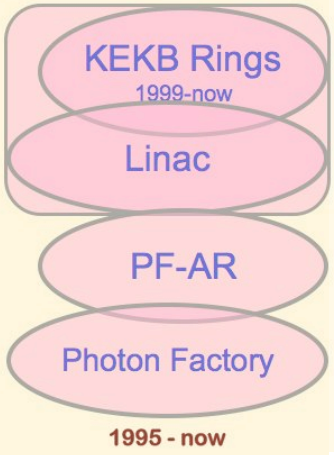

Now, Collision
with Crab Cavities and
with Quasi-simultaneous Injection

# KEKB and Linac Control Systems

## Linac

- Controls Upgrade (1990~)1993
  - De-facto (and International) Standards, IP-only Networks
  - No long Shutdown for KEKB upgrade
  - 3.5-times Energy increase, 10-times current increase
- Three indirect User Facilities (KEKB, PF, PF-AR)
- Fewer resources




## KEKB

- 5-year Shutdown after TRISTAN 1994-1998
  - Precision requirements were much different for KEKB
- Complete transition of Controls
  - from Nodal at TRISTAN to EPICS+SAD at KEKB
  - from Energy frontier to Luminosity frontier
- Basically Single-user (Belle)

# Communication Network at Linac

- **Fiber-optic Networks (1982~)**
  - Because of High-power modulators for rf systems
  - ~30 Loops to connect many equipment controllers
  - However, the fiber-optic Technology was not mature enough yet
    - Often Failed and Loop Topology made it difficult to identify the trouble
- **All IP network (1993~)**
  - Still all Fiber-optic
    - (Faster Ethernet enables shorter packets and less failures)
  - Inherited at J-PARC Controls as well
- **Gradual Transition of Technologies**
  - From FDDI + 10Base-FL to 1000Base-LX + 100Base-Fx
- **Redundancy (1996~)**
  - At more than 40 Ethernet links
  - Helped continuous operation in spite of a failure at night
    - Redundant Transceivers, then Rapid Spanning-tree and HSRP/VRRP

# Communication Network at KEKB

- **TRISTAN**
  - Token Ring and CAMAC Serial highways
    - Token ring between mini-computers
    - CAMAC serial highways to equipment controllers
- **KEKB**
  - IP Network for EPICS
    - FDDI+10BaseT to GbE+100Base-Tx
      - Sometimes unnecessary excess broadcast
  - ARCNet for equipment controllers
    - More than 200 network segments
  - MXI-2 for VXI-based frames
    - 20 segments
  - Keep some CAMAC Serial highways
    - About 50 Crates

# Equipment Controllers at Linac

- 1982~(1997) (1st generation)
  - 300 microprocessor-based controllers
    - Linked together with home-grown fiber-optic network
- 1993~now (upgrade of controls)
  - 150 PLCs (programmable logic controller)
    - Linked via only Fiber-optic Ethernet/IP
      - Control communication with servers and program development
- 1995~now (upgrade for KEKB)
    - Direct Fiber-optic Ethernet/IP to each Controllers
  - 30 VXI for rf measurement
  - 7 VME / 10 CAMAC for Timing (will retire soon)
  - 20 VME for Beam monitors (will retire soon)
- 2007~ (upgrade for 50Hz beam switching)
  - 13 (increasing) VME for “event” handling, timing, llrf controls, etc.
  - 24 Oscilloscopes with WindowsXP IOC for 100 BPMs
    - 10Gs/s, 50Hz acquisition, local processing with 20 calibration parameter/BPM

# Equipment Controllers at KEKB

## TRISTAN

- Mostly CAMAC
  - Equipment group responsibility: CAMAC module and outside

## KEKB

- 100 VME/IOC without Analog processing
- 200 VXI/MXI mainframes for 900 BPMs
- 50 CAMAC crates are kept for rf and vacuum
- ARCNet boards for Magnet ps. settings, and others
- GPIB for Magnet ps. readback, and others
- PLCs for Magnet interlocks, and others

# EPICS Transition at Linac

- Home-grown RPC at Linac (1990~/1993~)
  - Bad timing but no choice because of end of old mini-computer support
- No real transition to EPICS yet at Linac
  - There are middleware and applications
- LynxOS Transition was developed (1994~1996)
  - To cover both RPC and EPICS with pthread, posix
    - Mostly working, Failed to get funding for Hardware/Software upgrade
- Gateways to EPICS in several ways
  - Software-only IOC and Gateway (Clients to both RPC/CA)
  - Portable Channel Access Server of EPICS-3.12 (1995~)
  - Soft-IOC with device support to Linac RPC (2002~)
- Real IOCs are increasing
  - PLC(rf,vacuum,magnet) and Linux, Oscilloscope(bpm) with Windows, VME(llrf and timing)
  - RPC servers read EPICS IOCs, EPICS gateways read RPC servers

# EPICS Transition at KEKB

- Some candidates discussed after Nodal at TRISTAN
  - RPC/CORBA based control design
  - Reflective memory (hardware shared memory) design
- No other choice than EPICS for KEKB
  - No man-power for control system software
  - The choice at SSC
  - International collaboration was attractive

# Archiver/Logger

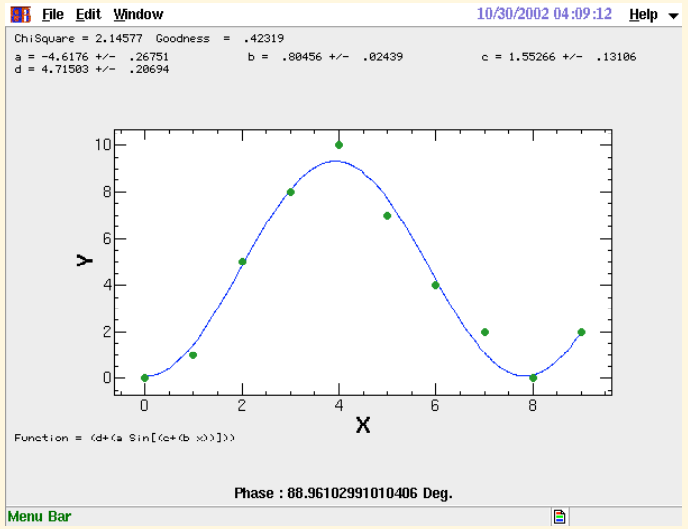
- **Linac**
  - Several archivers with different filters and stored in ascii
  - Replaced with two EPICS archivers (2002)
    - Channel archiver, with Java viewer, and Web-based viewer
    - KEKBlog, SADscript-based viewer
      - Both ~500MB/day, Dynamic ADEL changes
- **KEKB**
  - KEKBlog, since 1998
    - Once there was a plan to replace it with Channel Archiver
      - Data conversion, no much performance difference
    - Only ADEL-based filter
      - ~4GB/day
    - SADscript-based viewer is one of the most-used applications
      - With Data analysis capability, easy manipulations

# Scripting Languages

- Heavy use because of rapid prototyping
- Linac
  - (1992~) Tcl/Tk as Test tools on Unix
  - (1997~) Tcl/Tk as Main Operator Programming Tool
  - (Now) Mixture of Tcl/Tk, SADscript/Tk, Python/Tk
    - SADscript has most accelerator design capability
      - Covers many features like MATLAB, Mathematica, XAL, MAD
- KEKB
    - (Nodal interpreter and Fortran covered everything at TRISTAN)
  - Python covers many areas which is not covered by medm
  - SADscript is used by operators and physicists everyday
    - Realization of novel ideas in hours
      - Only some ideas are effective, so rapid prototyping is important

# SADScript

- **Accelerator Modeling Environment**
  - MAD-like Environment was created during TRISTAN
  - Needs for Conditionals, Flow-controls, Data manipulations, Plot, GUI
- **Mathematica-like Language**
  - Not Real Symbolic Manipulation (Thus fast)
  - Data Processing (Fit, FFT, …), List Processing (Mathematica-like)
  - EPICS CA (Synchronous and Asynchronous)
    CaRead/CaWrite[ ], CaMonitor[ ], etc.
  - Tk Widget
    - Canvas Draw and "Plot"
    - KBFrame on top of Tk
    - Greek Letters
  - Relational Database
  - Inter-Process Communication (Exec, Pipe, etc)
    System[ ], OpenRead/Write[ ], BidirectionalPipe[ ], etc.

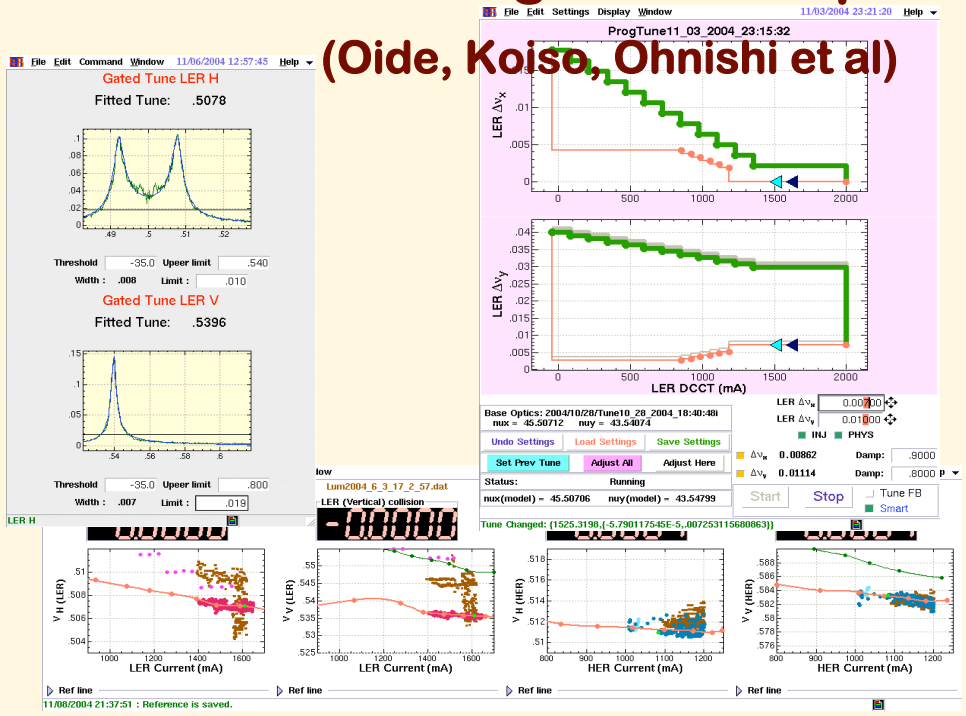



  - Beam Operation with Full Accelerator Modeling Capability
    - Also Used for non-Accelerator Applications (Archiver viewer, Alarm handler, etc.)
  - Comparable to XAL, MATLAB, but very different architecture

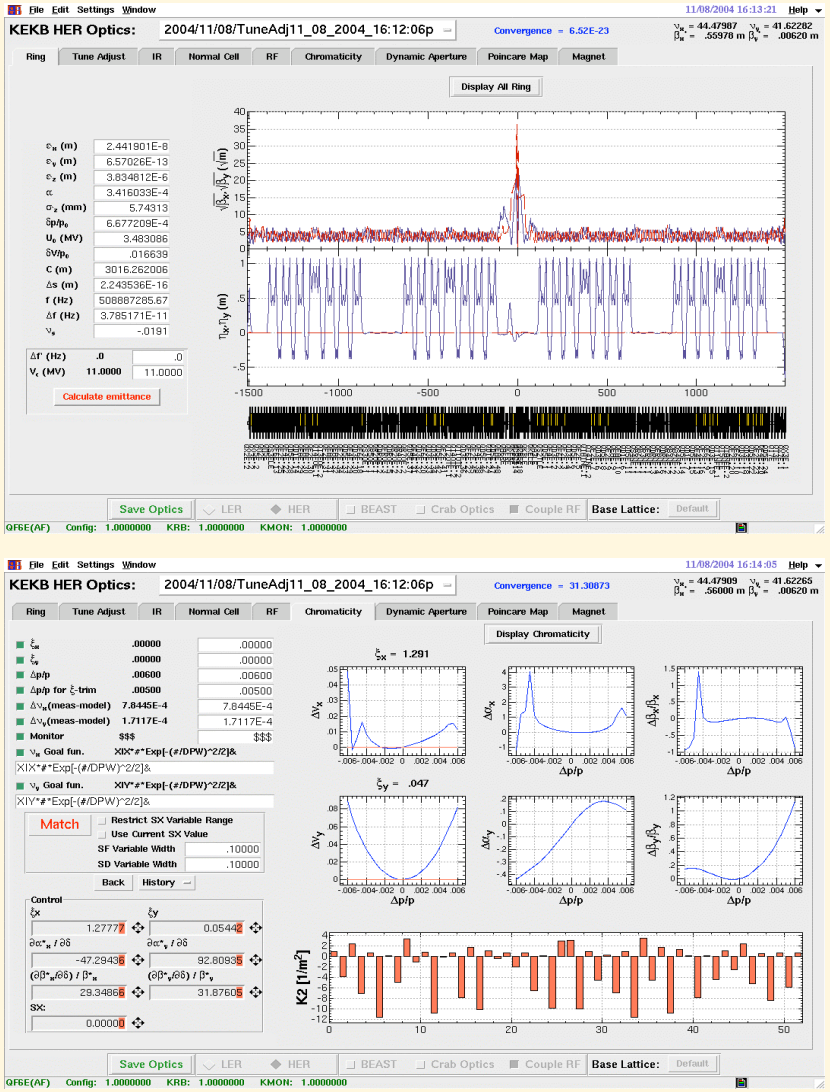
# Virtual Accelerator in SADscript

## For Example in KEKB

- most Beam Optics Condition is maintained in the Optics Panel
- Other Panels Manipulate Parameters Communicating with the Optics Panel (Oide, Koiso, Ohnishi et al)




Tune Measurement/Changer




Optics Panels

# Recent Improvements

- PLCs with Embedded EPICS (Linux)
  - from Ethernet-only to Channel-Access-only
- Event system introduction
  - Single fiber to distribute synchronized, 10ps timing, 50Hz interrupts, data, etc
- EPICS-embedded Oscilloscopes (Windows)
- FPGA-based EPICS-embedded controllers (Linux)
- Zlog operation log improvements
  - Used also at J-PARC, RIKEN, and BINP
- Reliability improvement studies
  - Redundant IOC, ATCA and EPICS, Test systems

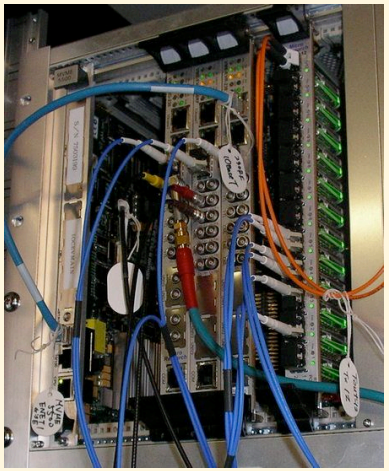
# KEKB & Linac

- **Further Electron-Positron Collider Experiments at KEKB**
  - Contributed Nobel Prize to Kobayashi-Maskawa
- **Maintenance Difficulties**
  - In Software and Hardware after 10-years of Operation
  - Transition from CAMAC to PLC, etc.
  - Transition to Newer versions of Software
    - After Stable Usage of VxWorks-5.3.1, EPICS-3.13.1.
- **Still Intensive Use of Scripting Languages**
  - SAD-script, Python, Tcl.
- **Zlog operation log improvements**
  - Used also at RIKEN, J-PARC, and BINP
- **Adding New Devices**
  - For Improved Machine Performance
  - New Hardware like Linux-embedded
    PLC Controller (F3RP61)
    for Beam-mask, Pulsed-quad, etc.
    - EPICS-3.14.9, Linux-2.6 , Procserv, Pcmon, Asyn

**PLC with Embedded Linux/EPICS**

# 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
  - **Intruduction 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

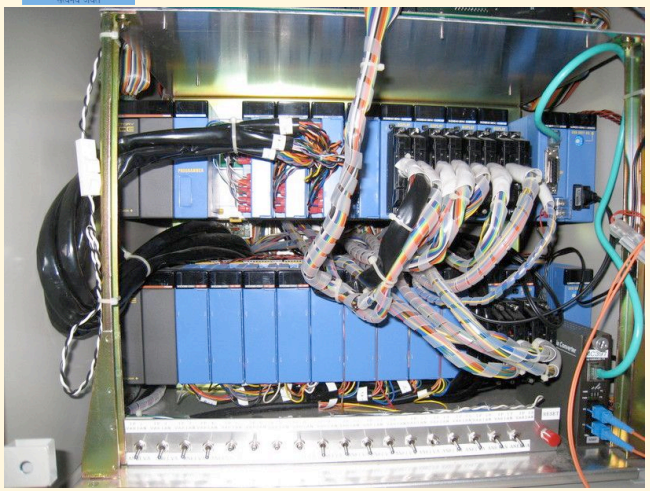
EVR & LLRF

# (previous) PLC usage at KEK

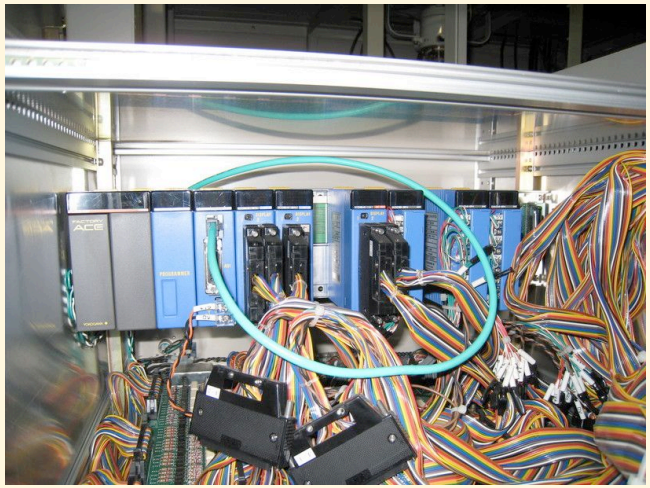
- **At Linac**
  - We enforced that all the controllers should be connected over IP/Ethernet
  - PLC was much cost-effective compared with VME
    - if the speed requirement allows
  - Products from OMRON, Mitsubishi, Yokogawa were installed
    - Only Yokogawa (FAM3) increased, because maintenance capability over network was better
      - Ladder software downloadable over IP/Ethernet
      - (Recently Mitsubishi also added that feature)
  - 150 PLCs used at Linac for RF, Magnets, Vacuum, Safety, etc
- **At J-PARC**
  - Many installations with the same reason as Linac
- **At KEKB**
  - Used indirectly at many devices, over serial or GPIB links

# Software management

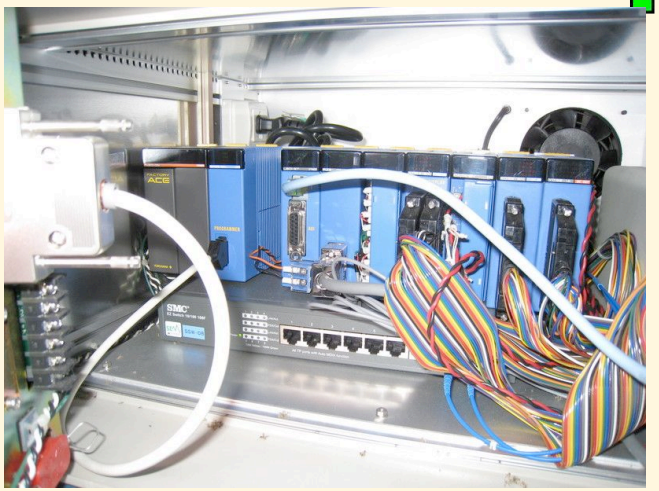
- **Ideal at the beginning**
  - Separate software development at control group, at equipment group, or at industrial company
  - Later, integration test  IP/Ethernet
- **Logic management**
  - Same logics could be placed at ladder software, in EPICS database/sequencer (or in high-level applications)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



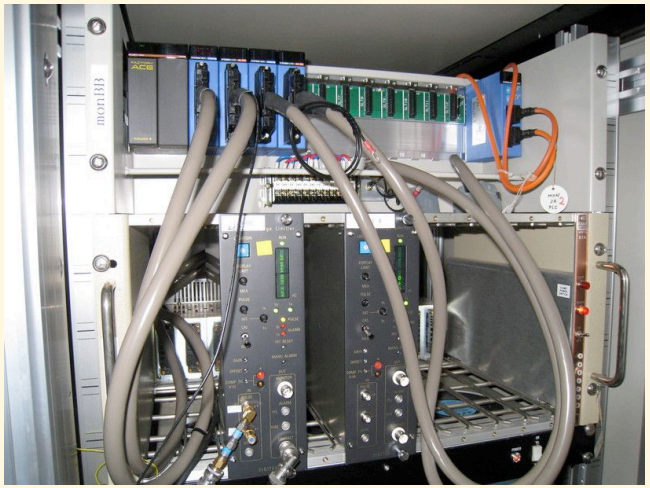
Vacuum Controller Internal



Magnet Controller Internal



RF Controller Internal



Safety Controller

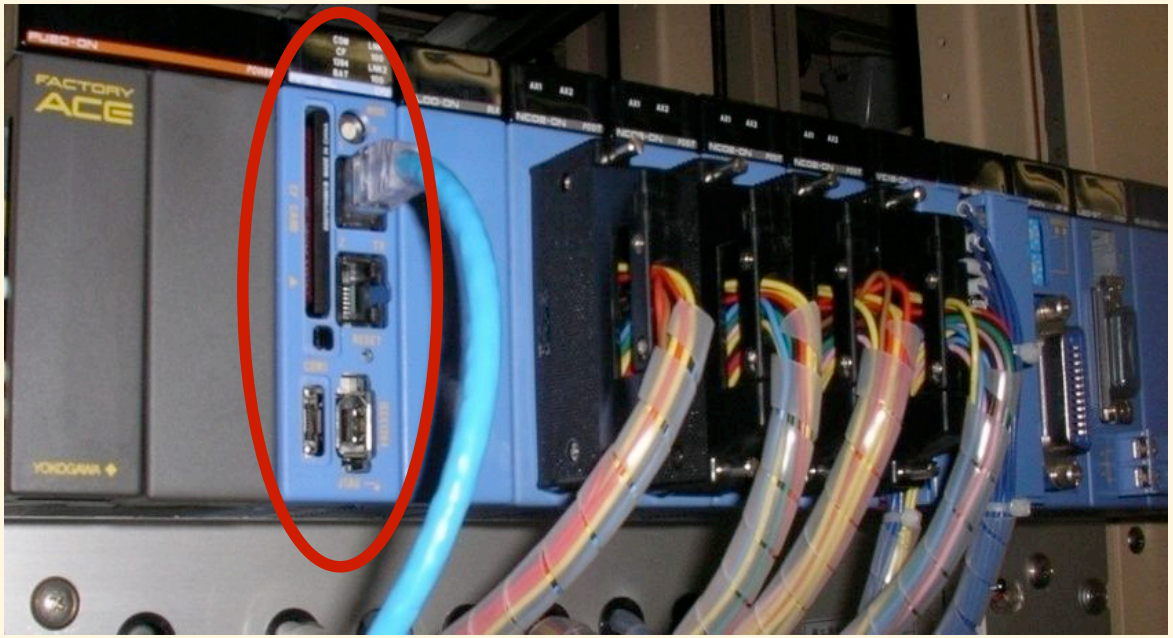

Touch Panel Display for RF

# EPICS on PLC

- VxWorks was available on PLC (Yokogawa, Mitsubishi)
  - We use VME for realtime performance with VxWorks
  - License management of vxWorks …
- Yokogawa starts to provide Linux (2.6) on PLC CPU
  - Brave enough to choose open source environment
    - We negotiate with Yokogawa to remove any license issues
  - Odagiri/KEK, Uchiyama/SHI, Yamada/KEK made much effort to realize the EPICS implementation
  - Takuya-Nakamura/MSC tailored the environment for KEKB
    - Procserv, pcmon, NFS, …
- Three of them are used in KEKB operation
  - Beam mask controller and Pulsed-quad controller
  - It already ran for three months without any troubles/stops

# F3RP61

- Linux 2.6.24
- PPC 533MHz
- 128Mbyte RAM
- 100BaseTx x 2
- USB
- IEEE1394
- Serial
- PCI
- I/O Bus for FAM3 Module Interface
- Software development environment

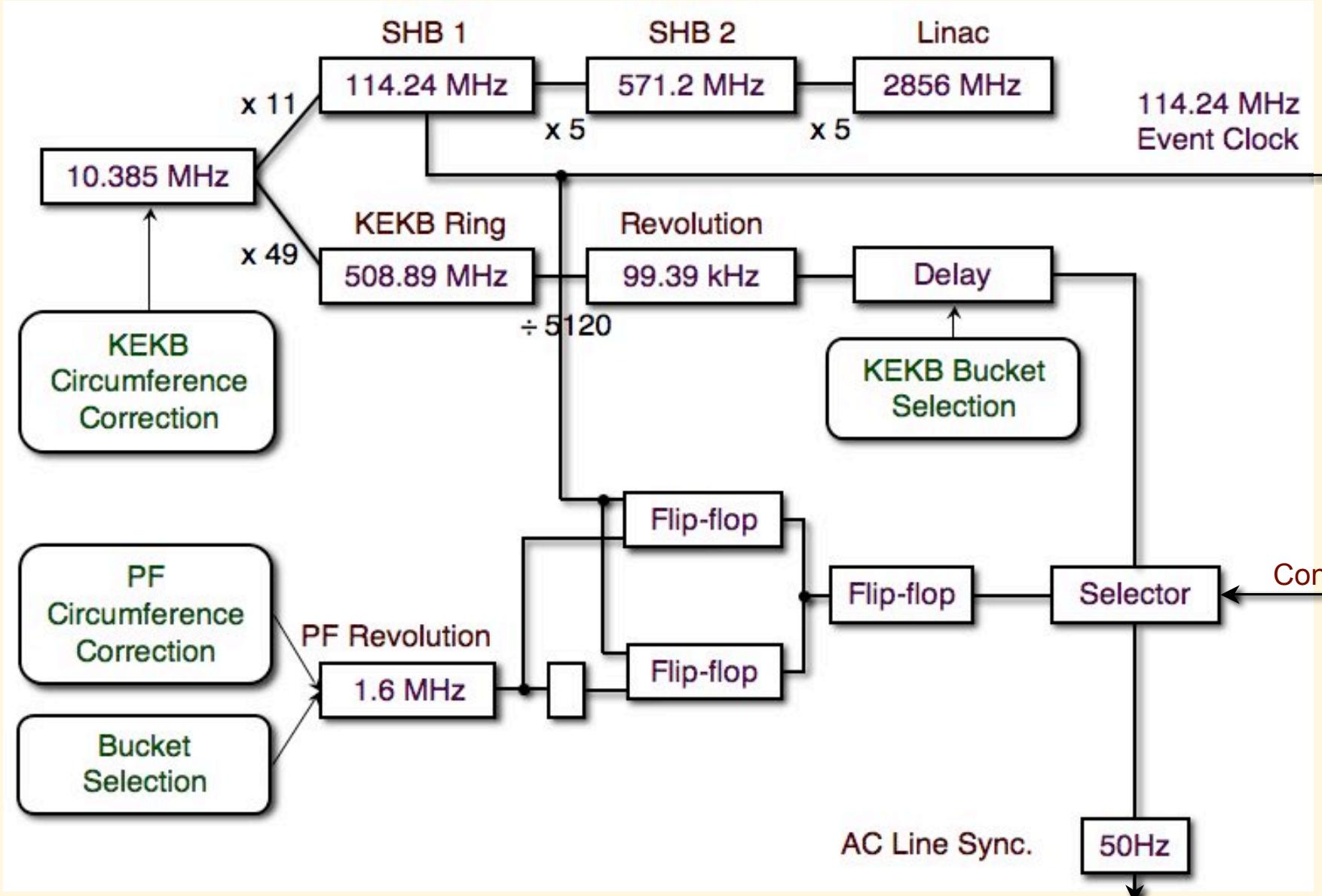



Beam mask controller

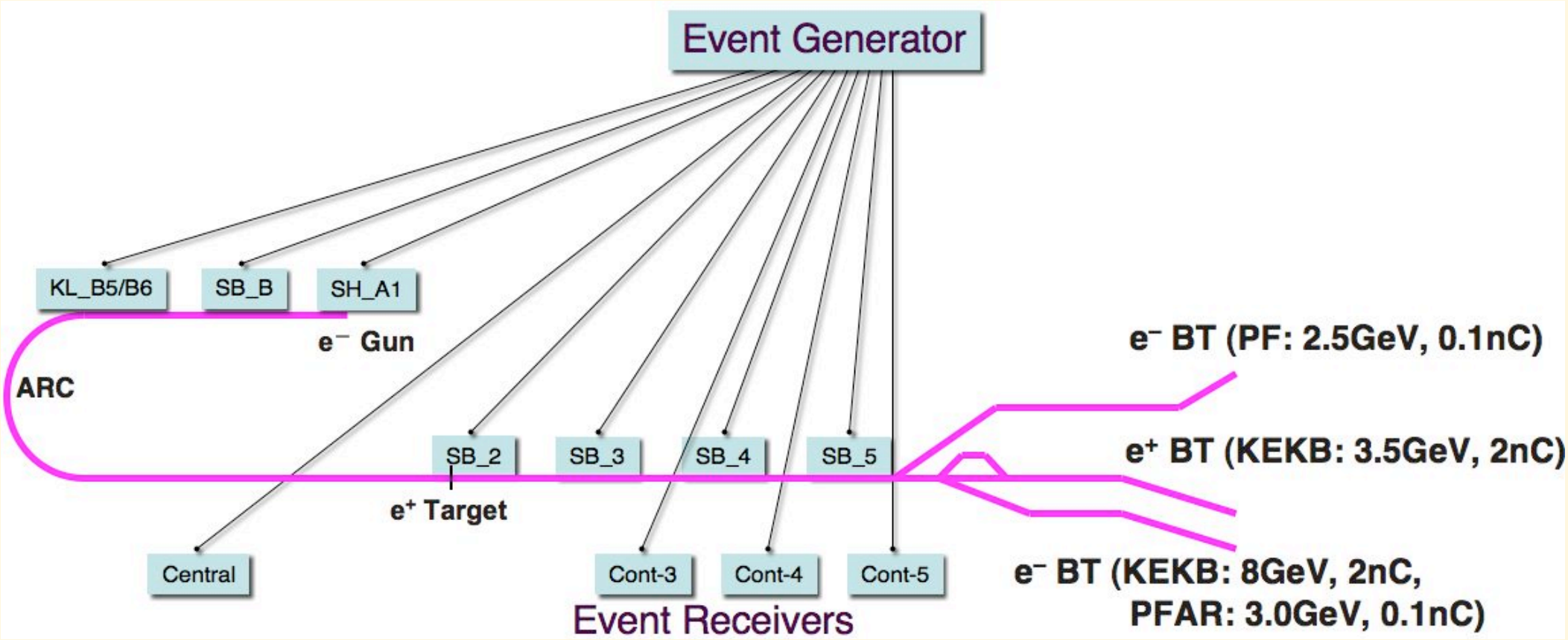
# Event System

- **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 (TD4 provides 3ps)
  - Multi-mode fiber and single-mode fiber for longer distance

# Basic synchronization outside of EVG



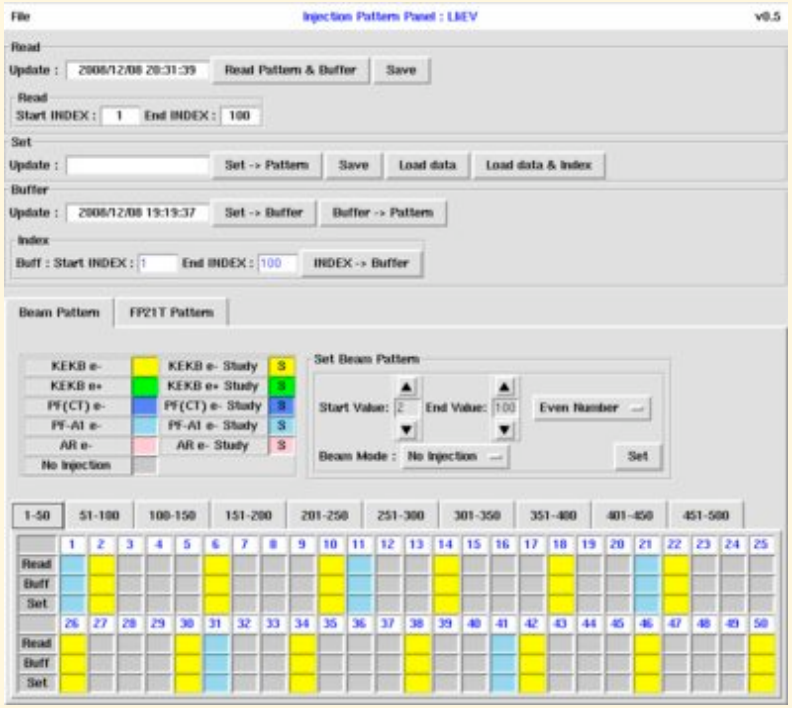
# Event system configuration, autumn 2008

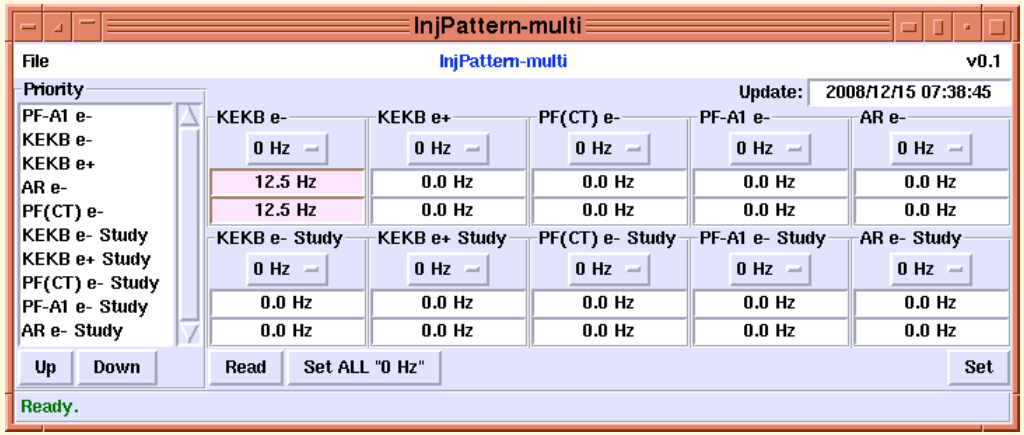


# Beam mode pattern generation

- 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.
- 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 is 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.

# Beam mode pattern generation

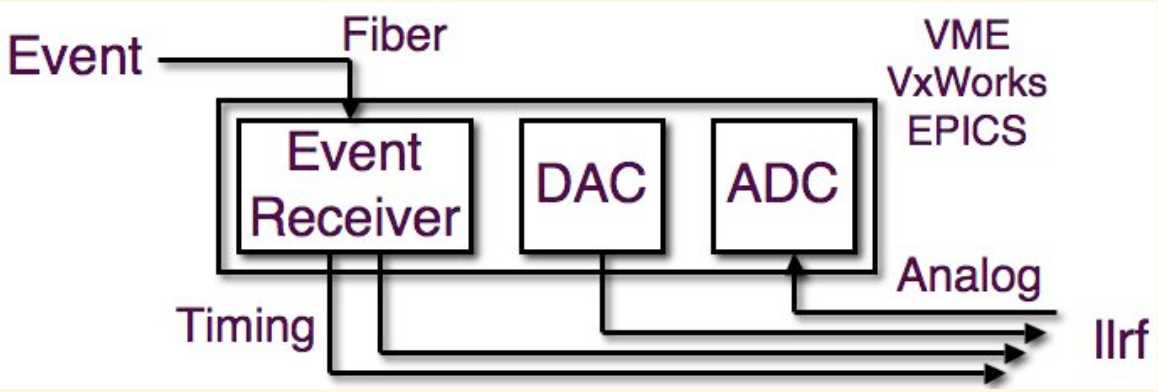



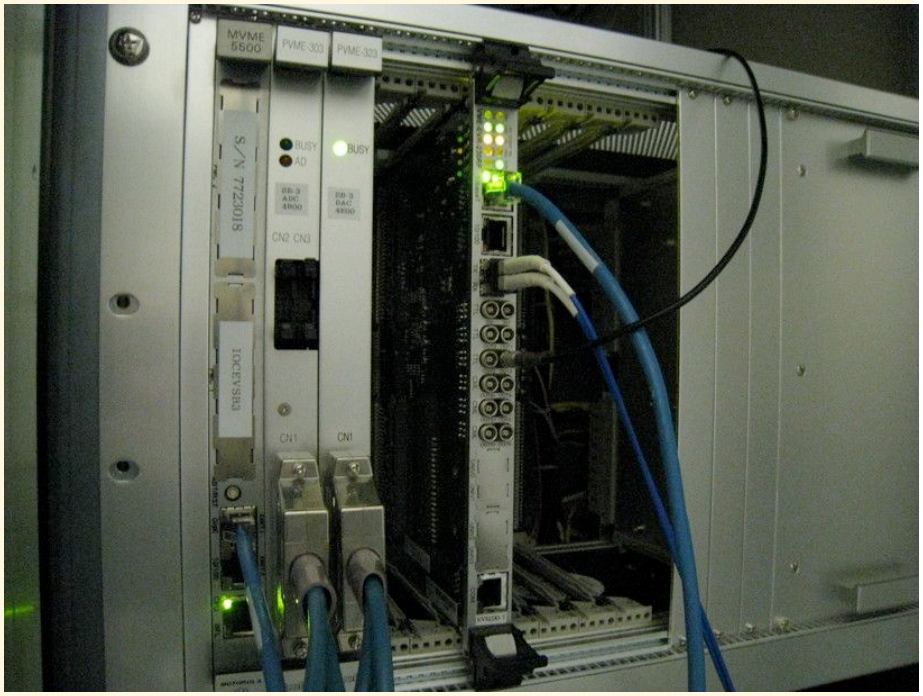

**Manual pattern designer**

**A version for current operation**

# LLRF

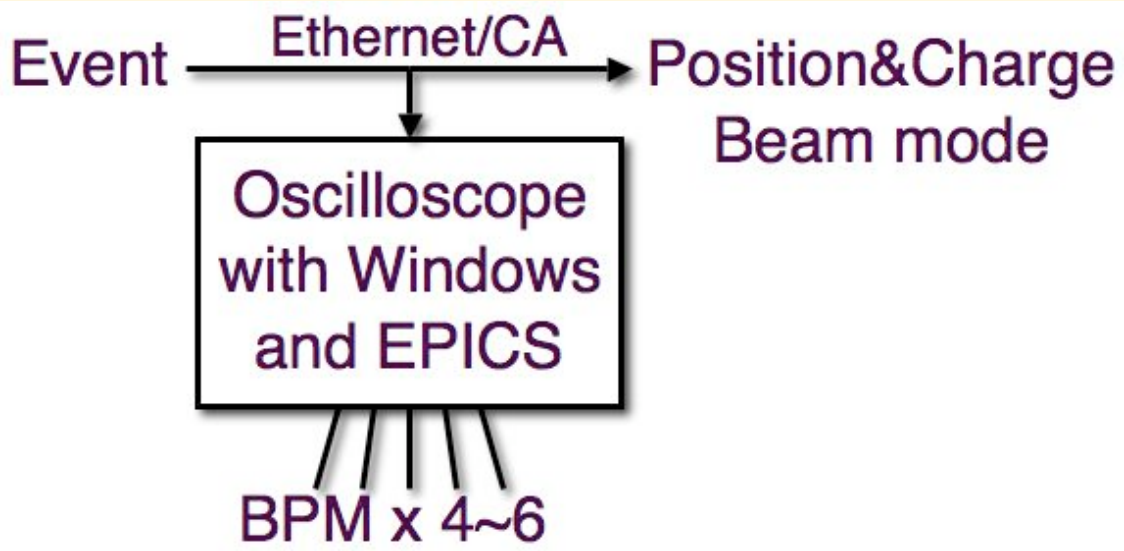
- Timing and analog signals are essential for absolute energy, energy spread, and dual-bunch energy equalization.
- Signals can be switched pulse-by-pulse.
- Driver klystrons (SB), energy tuner klystron (KL), and sub-harmonic bunchers (SH) are managed by the event system.

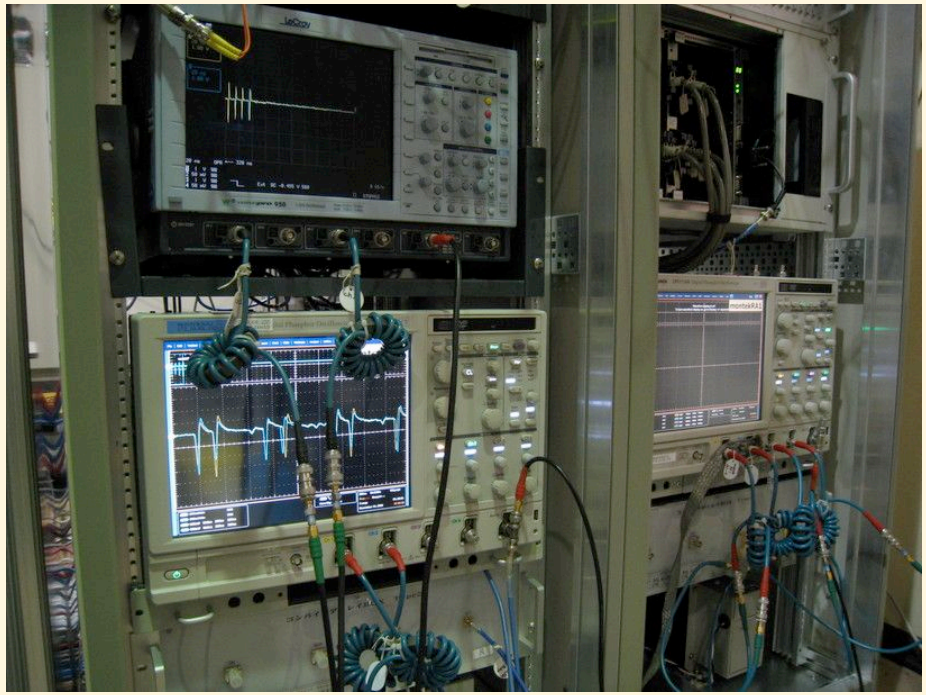


# BPM

- DPO7104 can acquire data in 50Hz .
- Beam modes are recognized by events through network.
- Clients can monitor data of an interested beam mode.
- 100 BPMs are synchronized.



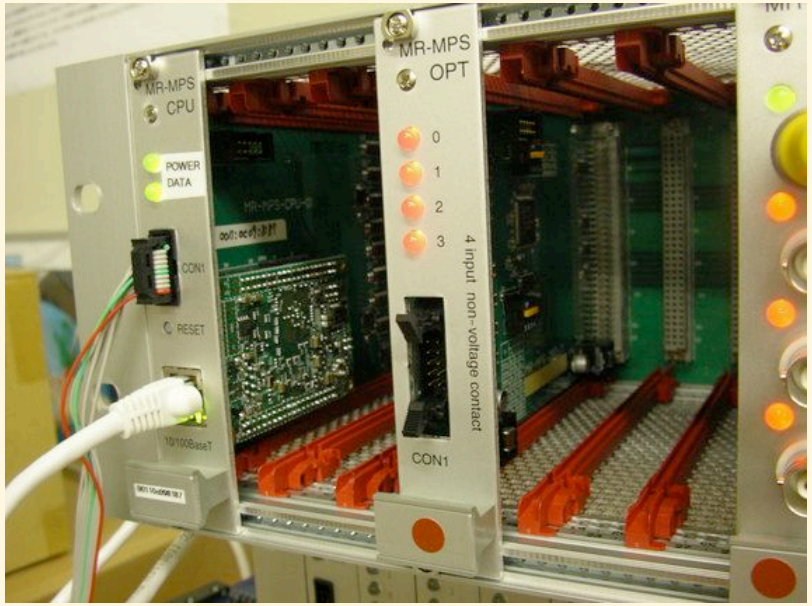



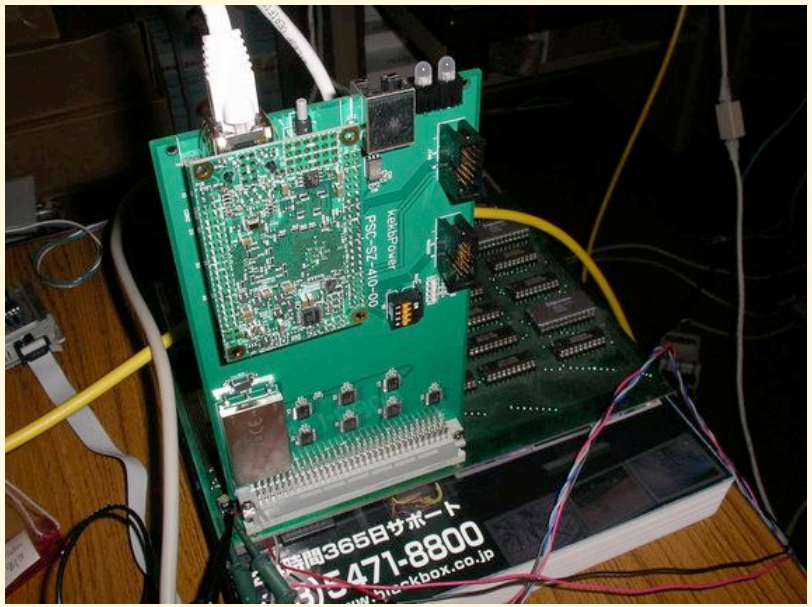
# Parameters

- Parameters switching via Event system
  - RF Timing x~35
  - LLRF x~11
  - Gun voltages, fast delays, x4
  - Pulsed magnets x~12
  - Injection system x~4
  - BPM over channel access x~100
- Basically sufficient for fast beam mode switching
- More parameters next year
- Integrity monitors
- Improved slow beam feedback, fast feedback, etc.

# Embedded EPICS with FPGA

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

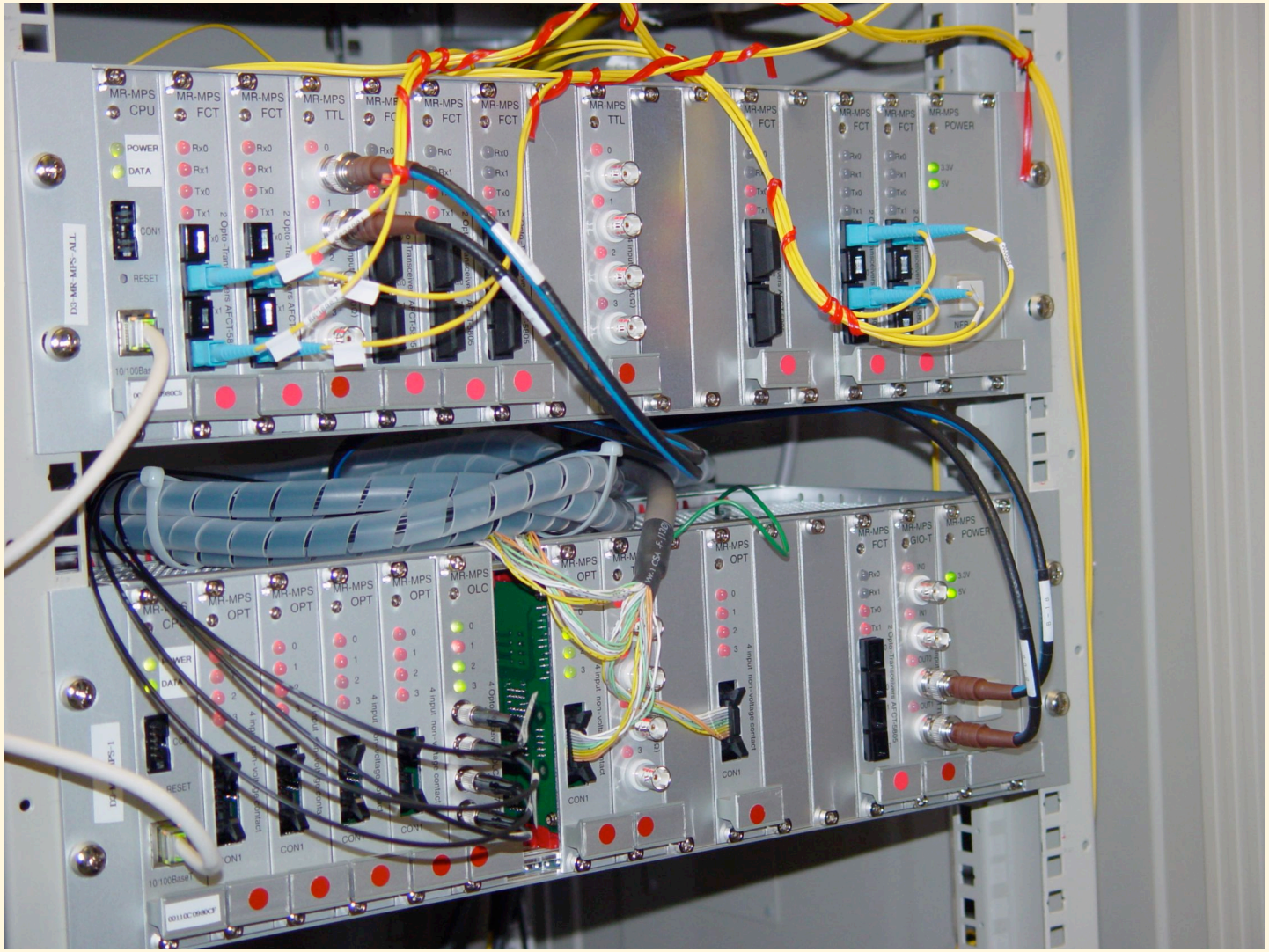


- J-PARC MPS
- KEKB Magnet
- Linac RF

# J-PARC MR MPS Operational

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



# Near Future

- SADscript
  - Will be maintained, but should look more at XAL - CSS
- EPICS
  - Still many hopes waiting to be realized
- More integration between control systems
- PLC usage
  - IEC61131-3 Standards
- FPGA usage
  - More embedded controllers / instrumentations
- More reliability considerations
  - Testing environments, Surveillance, Redundancy, etc.
- More operation side developments

**Linac and KEKB groups will share the tasks**

# Summary

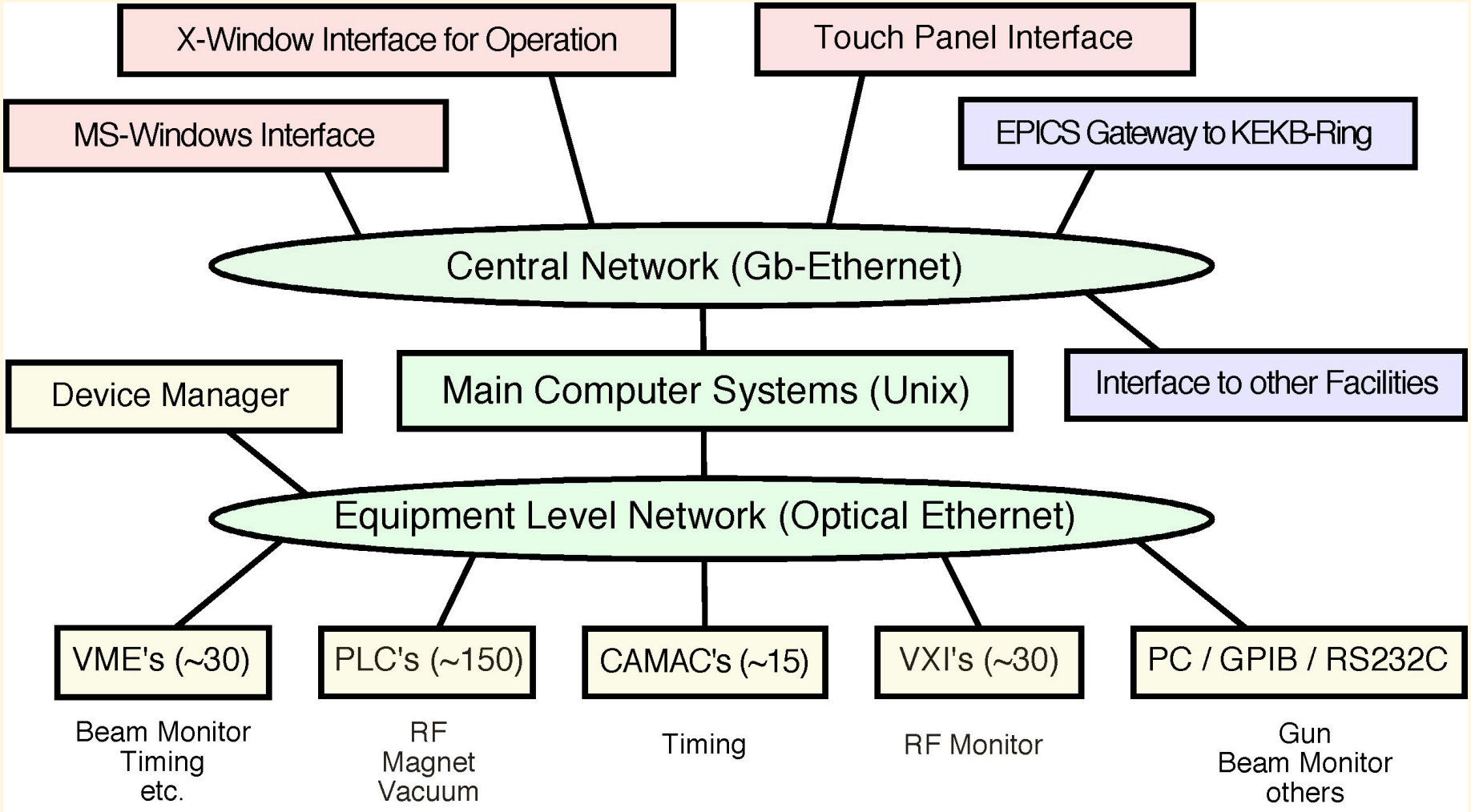
- Control system design needed balances between many aspects
- EPICS and Scripting Languages brought great success to the both KEKB and Linac Beam Operations
- Control Architecture Has Changed
  - Tried to establish unified controllers (before 15 years ago)
  - Tried to use only Ethernet/IP networks (15 to 5 years ago)
  - Trying to use only EPICS-embedded controllers (now)

# Thank you

# Thank you

# Linac; Physical Structure

- **Multi-tier, Multi-hardware, Multi-client, …**



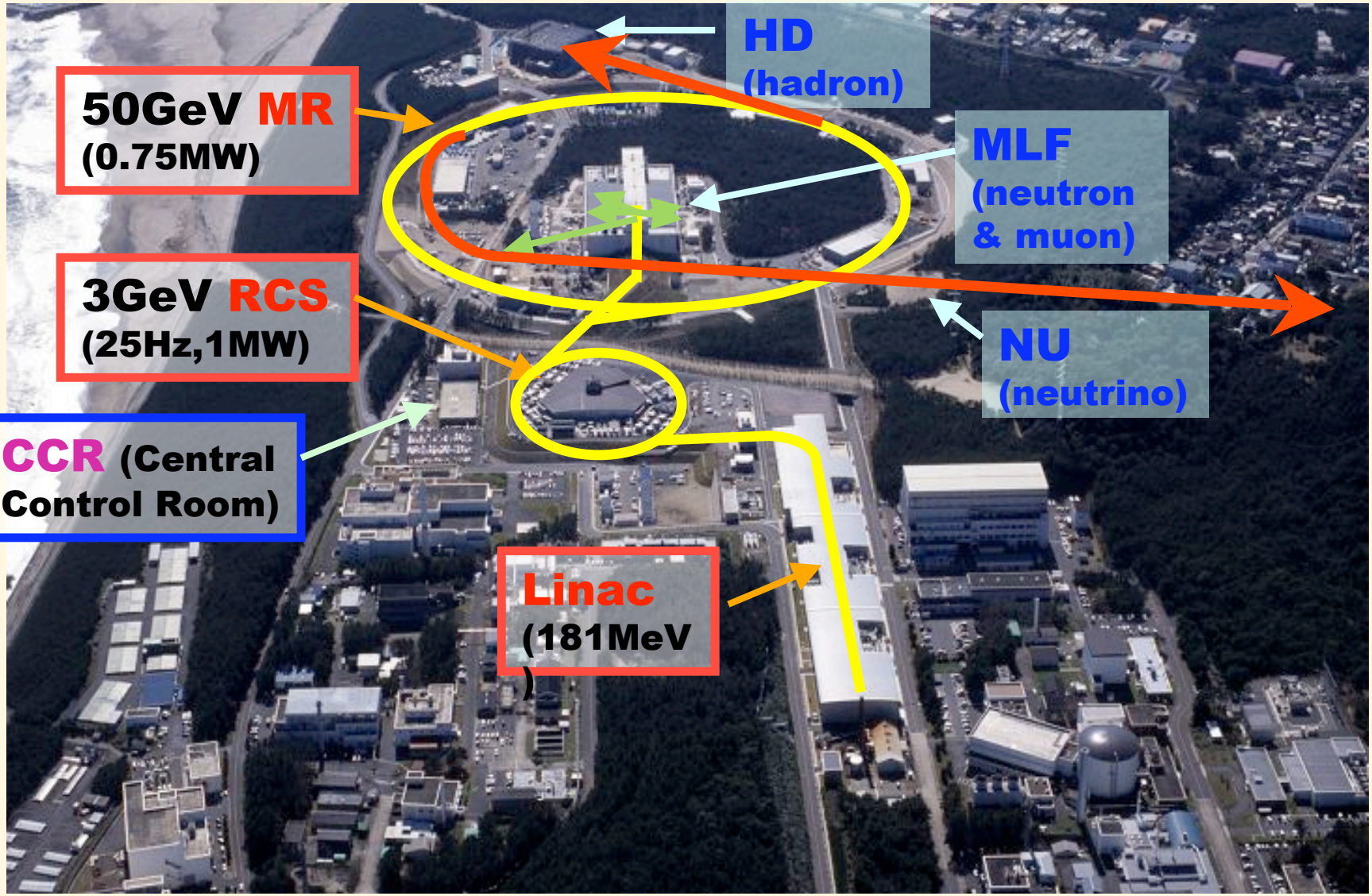
# Linac; Software Architecture

- **Base control software structure for Multi-platform**
  - any Unix, OS9, LynxOS (Realtime), VMS, DOS, Windows, MacOS
  - TCP - UDP General Communication Library
  - Shared-Memory, Semaphore Library
  - Simple Home-grown RPC (Remote Procedure Call) Library
  - Memory-resident Hash Database Library
- **Control Server software**
  - Lower-layer servers (UDP-RPC) for control hardware
  - Upper-layer server (TCP-RPC) for accelerator equipment
  - Read-only Information on Distributed Shared Memory
  - Works redundantly on multiple servers
- **Client Applications**
  - Established applications in C language with RPC
  - Many of the beam operation software in scripting language,
    - Tcl/Tk
    - SADscript/Tk

# Network with only IP/Ethernet

- The policy chosen when we upgrade Linac in 1993
  - Make network management simpler
    - Faster switches, routing, network-booting, etc.
  - Avoid Hardware failure and analysis effort with old field network
    - Home-grown field networks need much dedicated man-power
  - Cost for optical Ethernet went down at around 1995
    - Linac has high-power modulator stations, noise source
  - Nowadays many facilities have this policy with GbE
    - J-PARC controls basically followed this
  - More and more intelligent network devices
    - ex. Oscilloscopes with Windows/3GHz-Pentium built-in
    - Even EPICS IOC, MATLAB, or others can be embedded
  - Network components can be replaced one-by-one
  - Security consideration will be more and more important

# J-PARC at Tokai Canpus



# J-PARC Controls

- We started the design in 1998
  - But nobody was dedicated at the beginning
- EPICS was chosen
  - The same reason as KEKB, EPICS was successful at KEKB
- IP/Ethernet-only field network was chosen
  - It was successful at Linac
- Device support
  - Development was started with Network-based device supports
  - WE7000, FAM3 PLC, EMB-Lan etc.
  - Later, Integrated into NetDev by Odagiri
- Mixed application environment with Java, SAD, XAL, Python
- Good practice for inter-institute developments with different cultures
- Under commissioning, soon to commission MR beam

# EPICS Software Environment

| Accelerator | OPI Applications Basic | High-Lvl. | IOC/VME OS,H/W | Drivers (slightly old) |
|---|---|---|---|---|
| Linac | Java +MEDM | XAL /JCE | VxWorks PowerPC Adv7501 | - VME I/O Modules mainly by Advanet<br>- TeraDev for PLC |
| RCS | Java +MEDM | SAD | VxWorks PowerPC Adv7501 | - VME I/O Modules mainly by Advanet<br>- TeraDev for PLC |
| MR | MEDM (or EDM) | SAD Python | Linux Intel-based GE Funac and Sanritz | (Network Devices)<br>-NetDev for PLC, BPMC, EMB-LAN<br>-WE7000 Drivers |