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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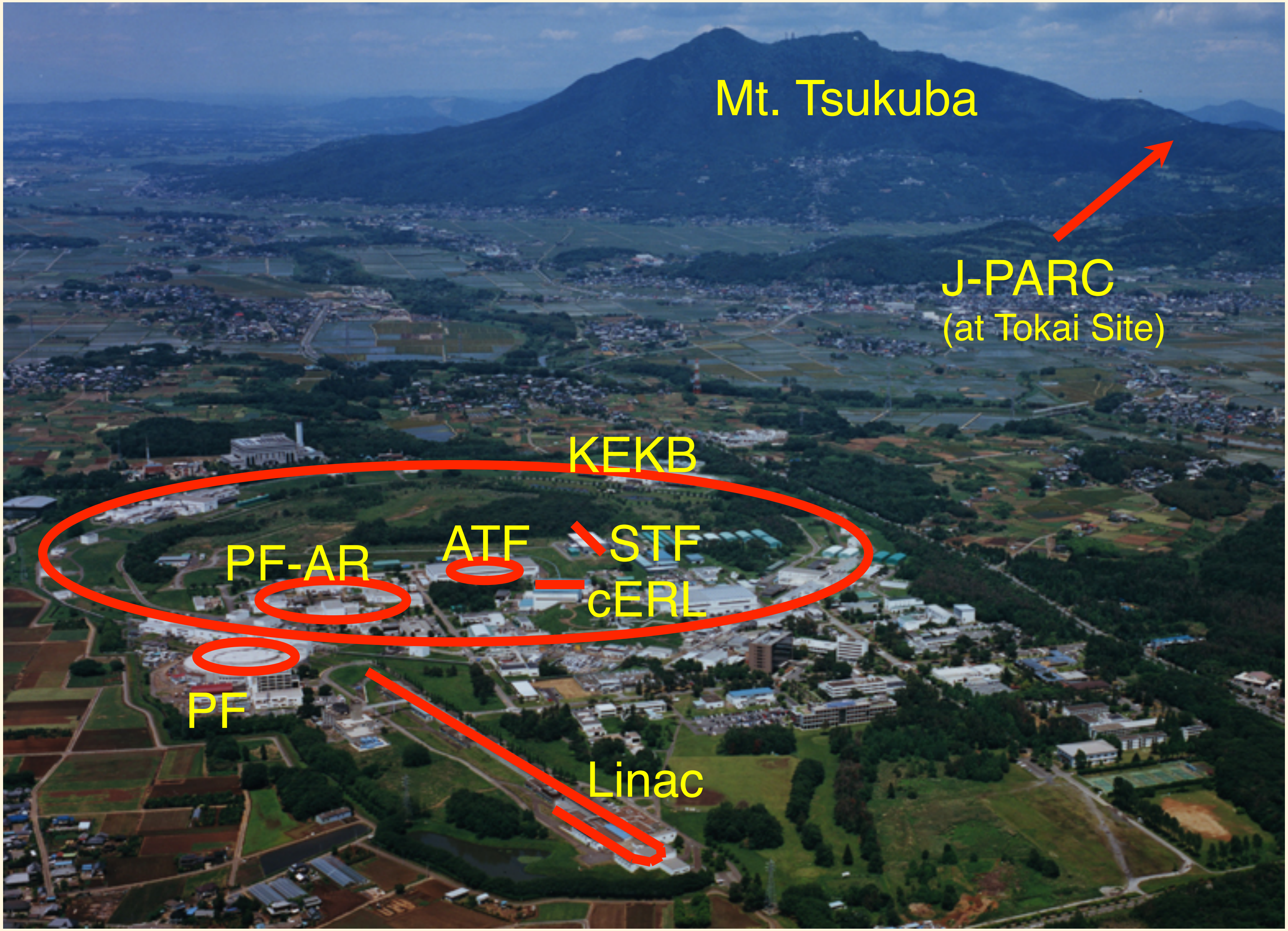
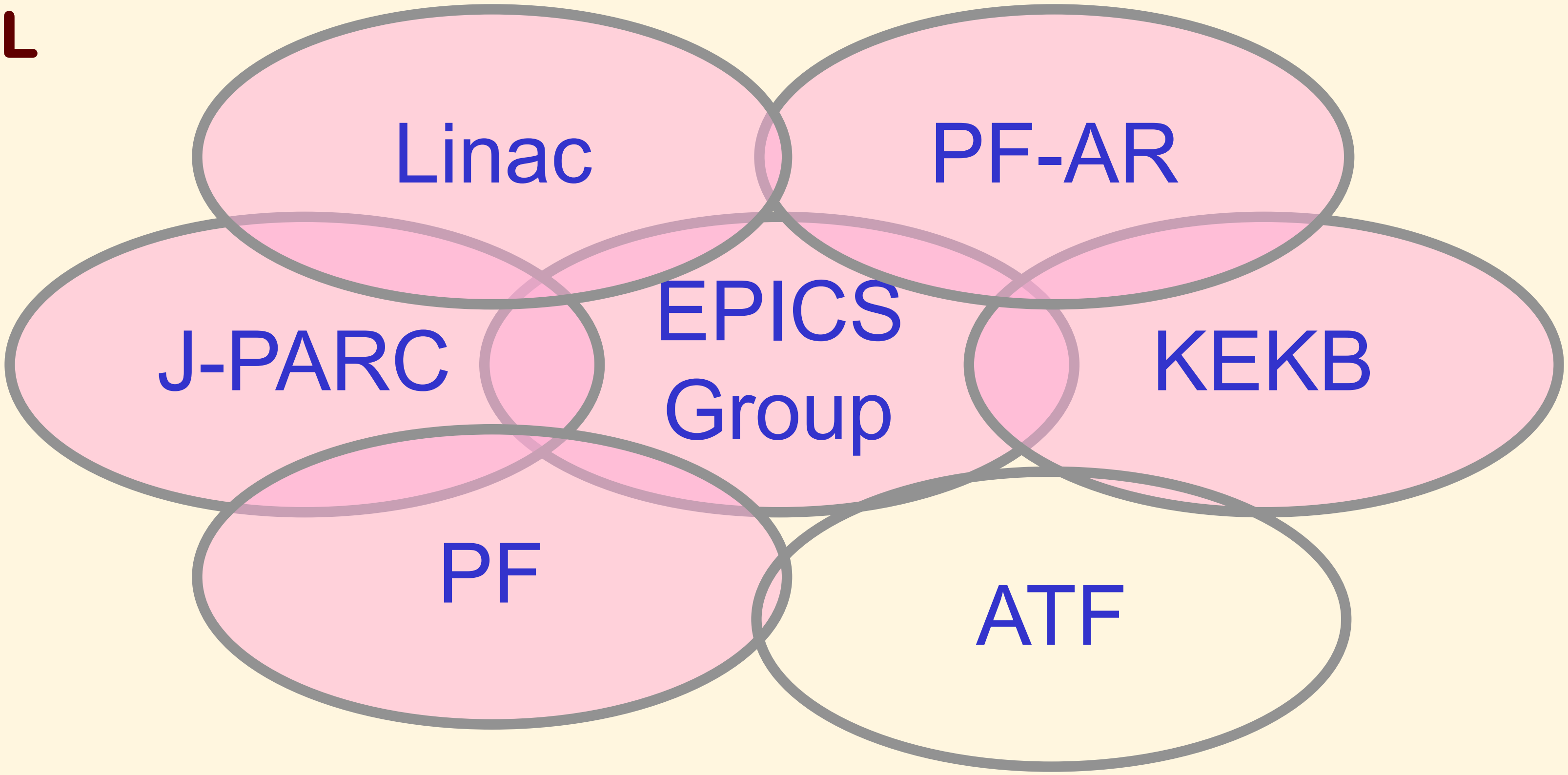
- **Several aspects of Evolution of the Accelerator Controls at the KEK**
  - **Communication Networks**
  - **Equipment Controllers**
  - **EPICS Environments**
  - **Scripting Languages**
- **Summary**


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

Accelerators/Control Systems in KEK

- **Operational Presently**
  - **Linac, PF, PF-AR, ATF, KEKB, J-PARC**
- **Under Construction**
  - **STF, cERL**
- **EPICS**
  - **KEKB, ...**



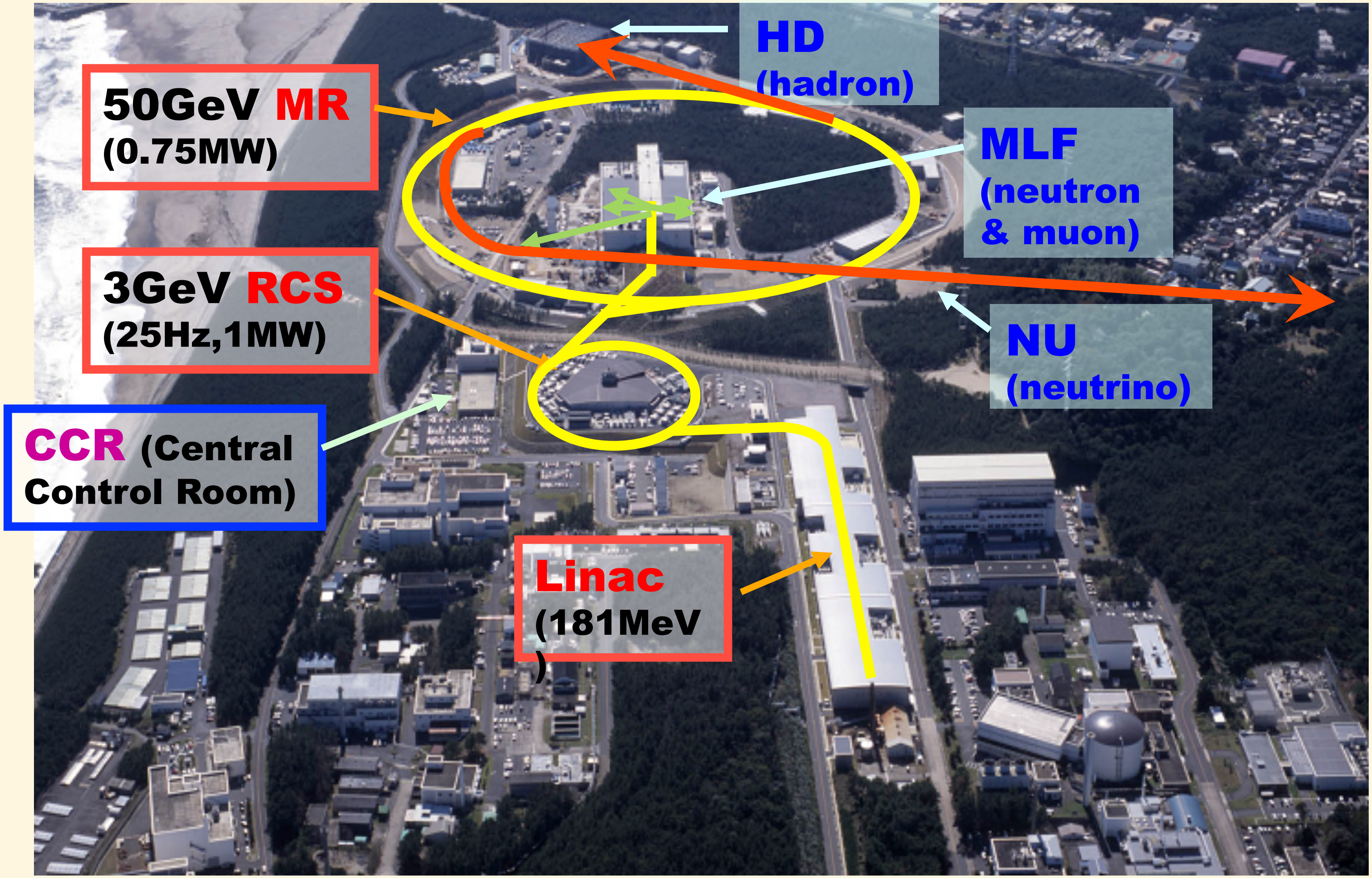
Control Systems

- 12GeV Proton Synchrotron (PS): Hardwire + Mini-computers
- 2.5GeV Electron Linac (Linac): 8 Mini-computers + >200 Micro-computers, Optical Networks
- Photon Factory (PF): Mini-computers -- Workstations
- TRISTAN ~33GeV: ~20 Mini-computers, CAMAC + NODAL Interpreter
- Upgraded PS: VME/VersaDOS + MAP
- Upgraded Linac: Unix servers, VME, PLC, CAMAC + TCP/IP + Home-grown RPC, Tcl/Tk, Gateway to EPICS
- ATF: VMS, CAMAC + V-System (Vista)
- KEKB: VME, CAMAC, VXI, ARCnet + EPICS + Python, SADscript
- PF-AR: the Same architecture as KEKB
- PF: Many of the Components with EPICS
- STF, cERL, SuperKEKB, ...

PF, PF-AR, ATF, STF

- **PF-AR**
  - Mostly the same environment as KEKB
    - Many CAMAC installations
- **PF**
  - Moved to EPICS environment
    - Mainly with Linux-VME
- **ATF**
  - Vista Controls environment with CAMAC
  - Linux and socket environment
  - EPICS devices
- **STF**
  - Test facility for ILC
  - Linux, ATCA test, PLC, ...
- **cERL**
  - Being built for ERL development
  - Will share the same environment with STF

J-PARC at Tokai Canpus



J-PARC Controls

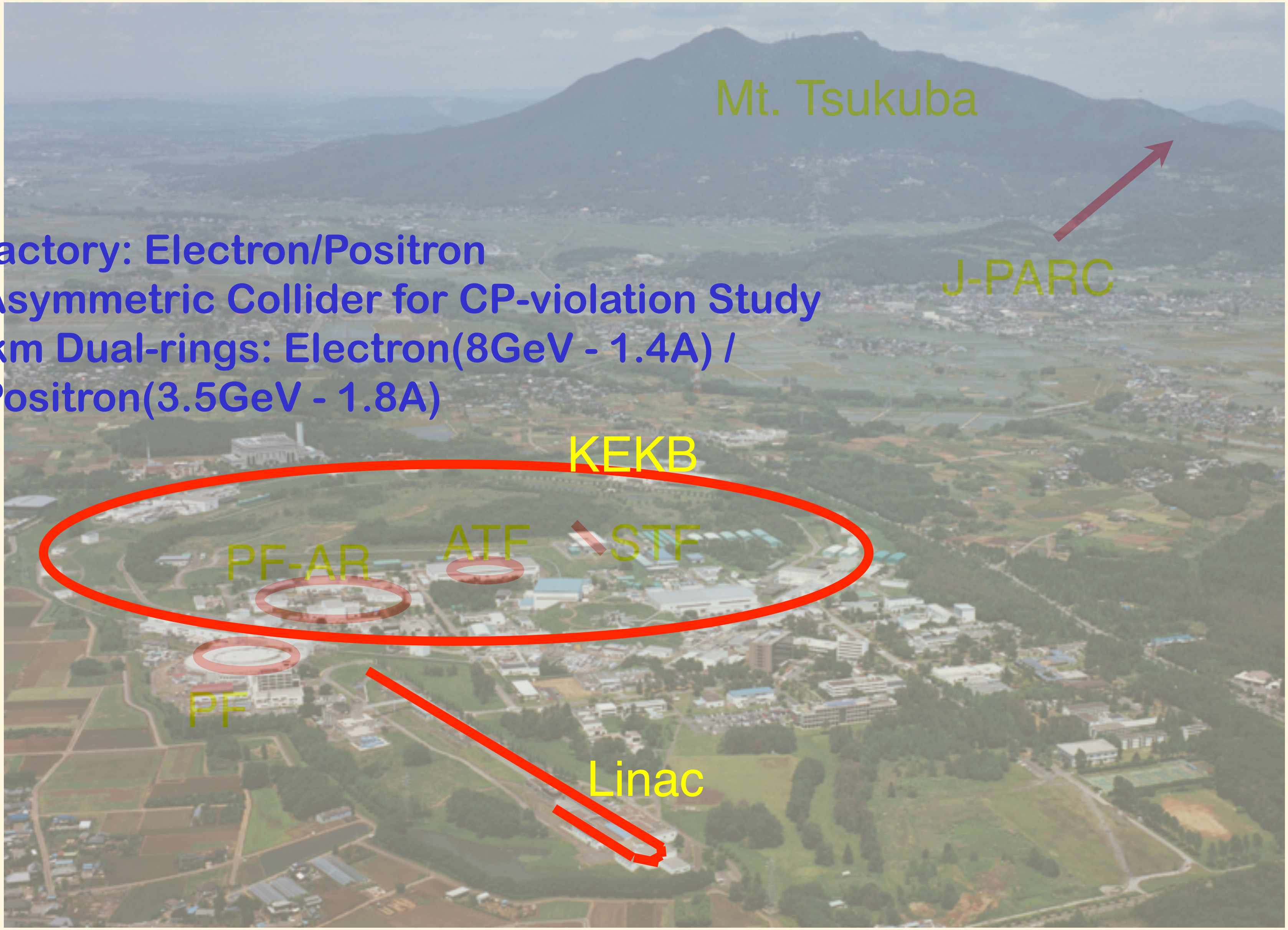
- We started the design in 1998
  - But nobody was dedicated at the beginning
- EPICS was chosen
  - The same reason as KEKB, EPICS was successful at KEKB
- IP/Ethernet-only field network was chosen
  - It was successful at Linac
- Device support
  - Development was started with Network-based device 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, user experiments in 2010

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 - TeraDev for PLC
RCS	Java +MEDM	SAD	VxWorks PowerPC Adv7501	- VME I/O Modules mainly by Advanet - TeraDev for PLC
MR	MEDM (or EDM)	SAD Python	Linux Intel-based GE Funac and Sanritz	(Network Devices) -NetDev for PLC, BPMC, EMB-LAN -WE7000 Drivers

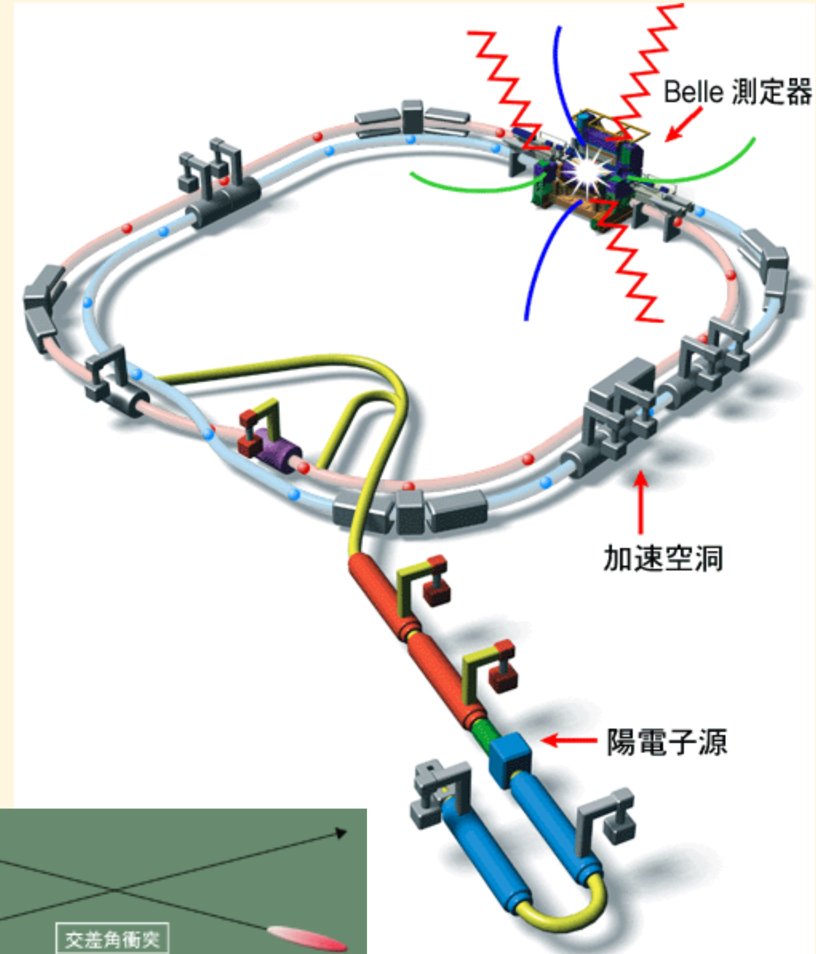
B-factory: Electron/Positron Asymmetric Collider for CP-violation Study

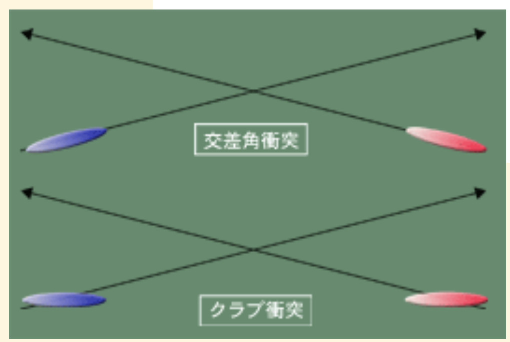
~3km Dual-rings: Electron(8GeV - 1.4A) / Positron(3.5GeV - 1.8A)



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**

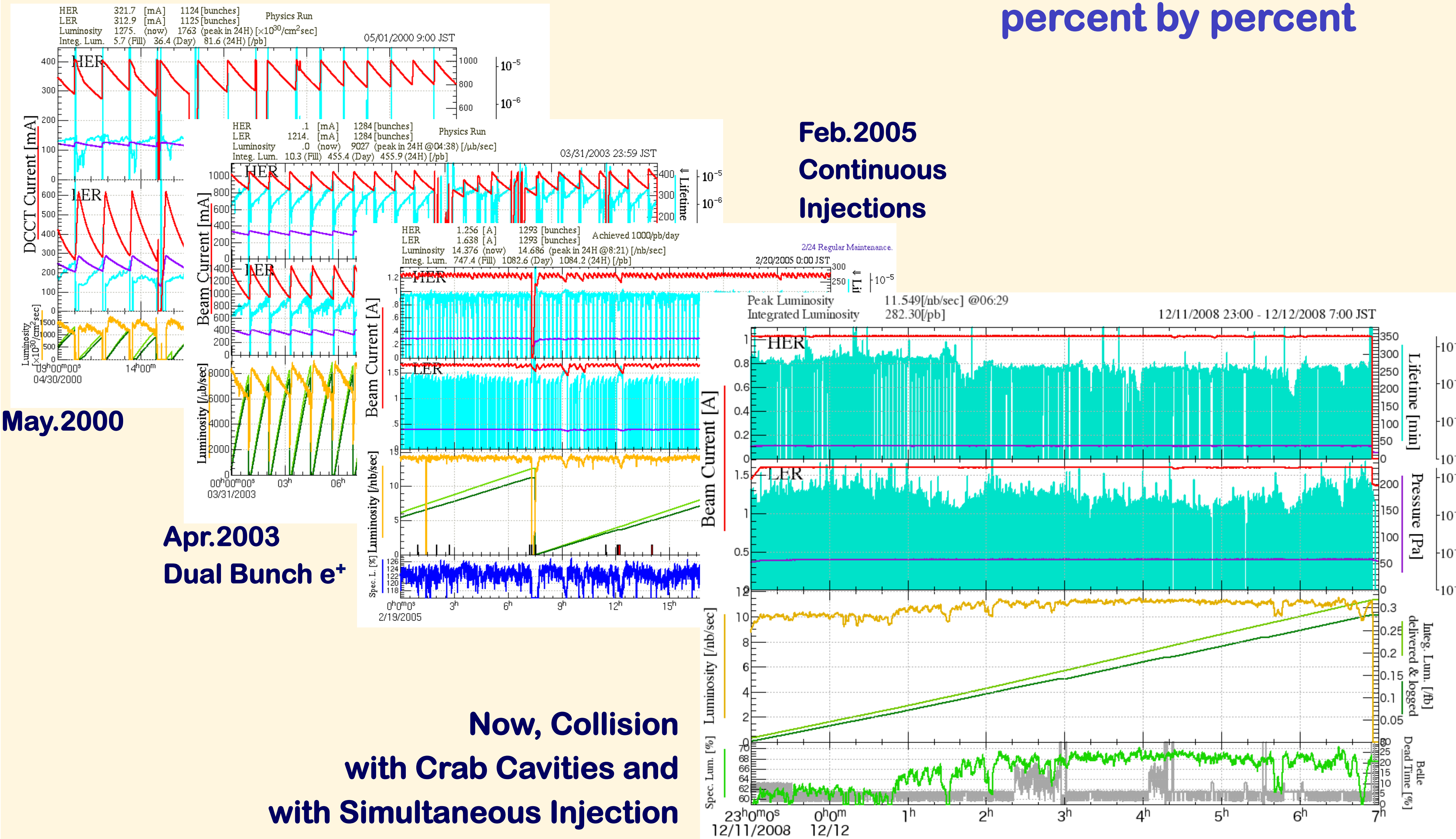




Increase of Luminosity with Crab Cavities

Increase of the Luminosity

percent by percent



May.2000

Apr.2003
Dual Bunch e+

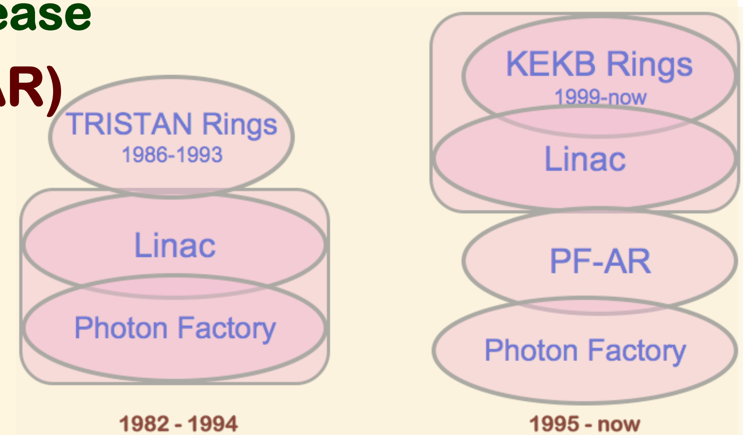
Feb.2005
Continuous Injections

Now, Collision with Crab Cavities and with 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+SADscript at KEKB
  - ¤ from Energy frontier to Luminosity frontier
- ❖Basically Single-user (Belle)

Communication Network at Linac

- **Fiber-optic Networks (1982~1996)**
  - Because of High-power modulators for rf systems
  - ~30 Loops to connect ~300 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 50 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
      - Single broadcast domain
  - ARCNet for equipment controllers
    - More than 200 network segments
  - MXI-1/2 for VXI-based frames
    - 20 segments, 200 frames
  - Keep some CAMAC Serial highways
    - 10 highways, 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)
  - 160 PLCs (programmable logic controller)
    - Linked via only Fiber-optic Ethernet/IP
      - Control communication with servers and program development
- 1995~ (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, etc (will retire soon)
- 2007~ (upgrade for 50Hz beam switching)
  - 17 (increasing) VME for fast "event" handling, timing, llrf controls, etc.
  - 24 Oscilloscopes with WindowsXP IOC for 100 BPMs
    - 10Gs/s, 50Hz acquisition, local processing with 25 calibration parameters/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 other measurements
  - PLCs for Magnet interlocks, and others

EPICS Transition at Linac

- Home-grown RPC at Linac (1990~/1993~)
  - At end of old mini-computer support
- Not complete transition to EPICS yet at Linac
  - Mixed EPICS devices and gateways to 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~)
    - Redundant EPICS environment as well (2008~)
- Real IOCs are increasing
  - PLC(rf,vacuum,magnet) and Linux, Oscilloscope(bpm) with Windows, VME(event-based 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

KEKB Control System (Hardware)

- **GbE Fiber Optic Networks**
  - Single Broadcast Domain for now
  - Central Control Room and 26 Local Control Rooms
- **VME/IOC**
  - ~100 VME/IOC mostly with PowerPC CPU
- **Fieldbus**
  - VXI thru MXI for BPM Instrumentations
  - CAMAC for rf and Vacuum (inherited from TRISTAN)
  - ~180 ArcNet network segments for Magnet Power Supplies, and other field Controllers
  - GPIB for Instrumentations, RS232C, Modbus+ for PLCs
- **Host Computers**
  - (HP-UX/PA-Risc,) Linux/x86 Controls Server
  - (3 Tru64/Alpha with TruCluster)
  - Several Linux
  - Many MacOSX
  - (Solaris/Sparc for VxWorks)

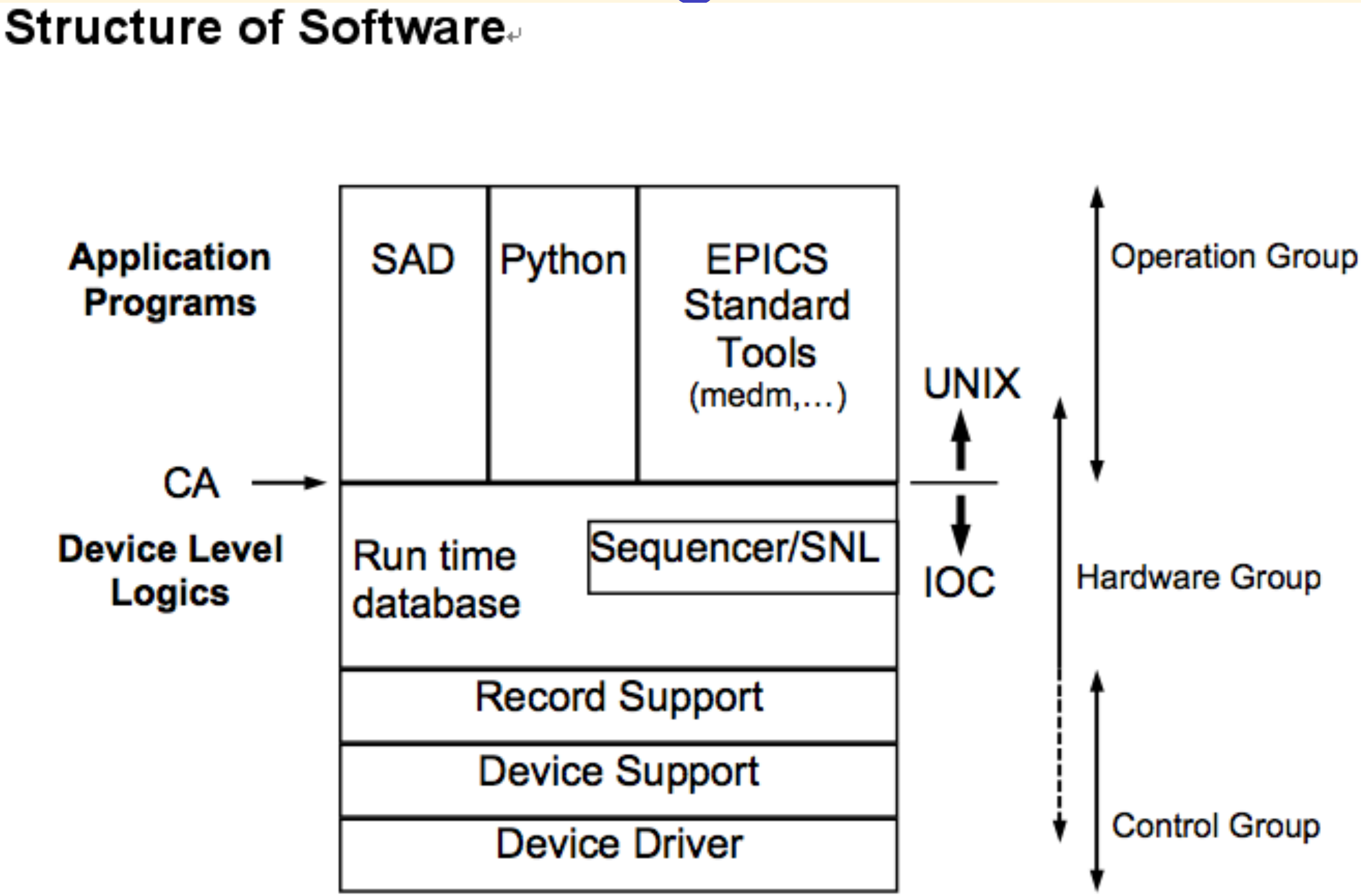
KEKB Control System (Software)

- **EPICS 3.13.1 mainly, with increasing 3.14.9**
- **VxWorks 5.3.1 mainly, with increasing 5.5.1**
  - **Hope to upgrade EPICS/VxWorks Shortly**
  - **VxWorks 6.7 is also under testing**
- **IOC Development**
  - **CapFast, VDCT, Perl, SADscript for Database Configuration**
  - **Oracle as a backend Database (Partially)**
- **Operational Application Development**
  - **MEDM(DM2k) for Startup**
  - **Python/Tk for Equipment Controls**
  - **SADScript/Tk for Beam Operation, etc**

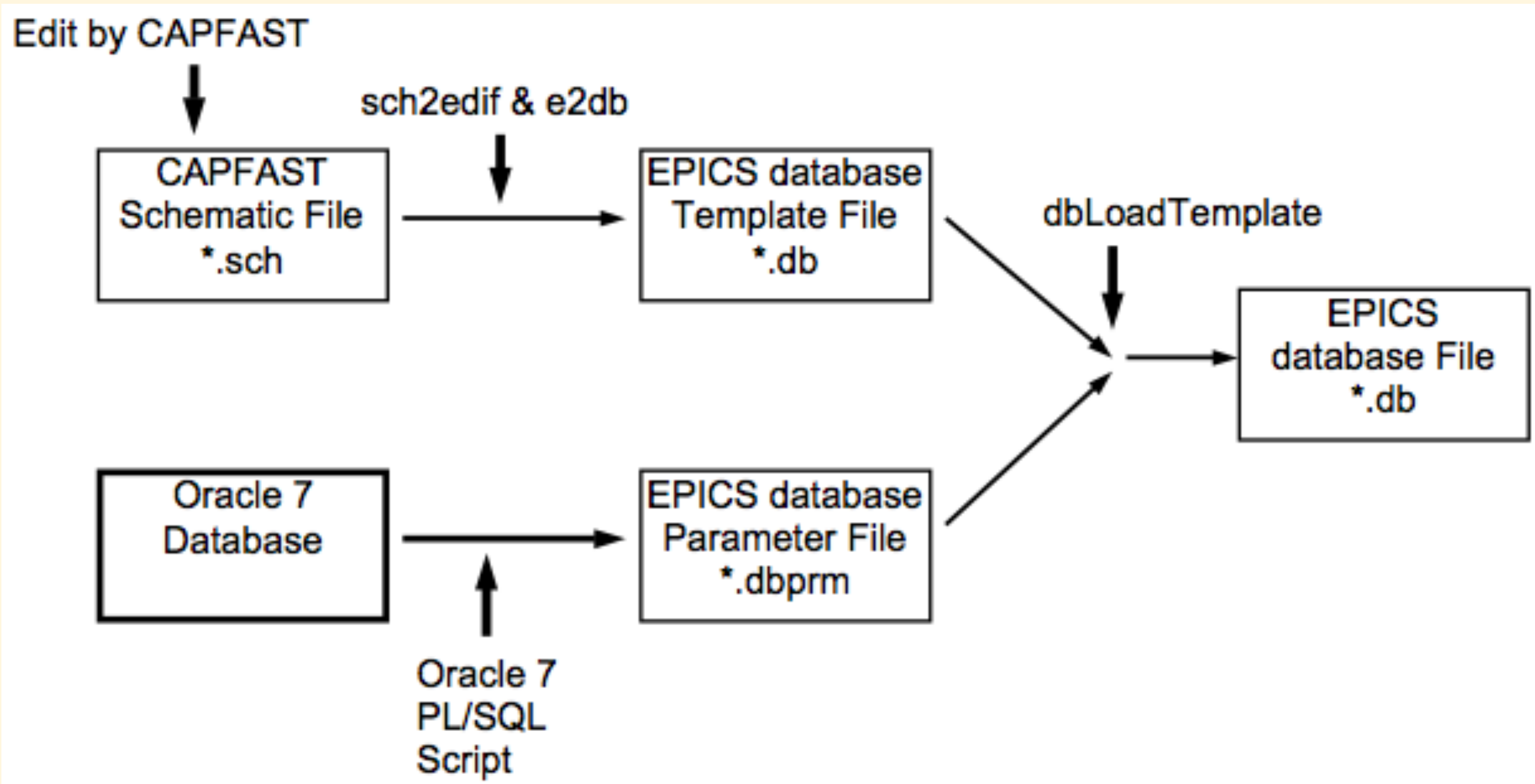
IOC and Records

- There are Several Groups in KEKB
  - Each IOC is Assigned to a Group
    - MG, RF, VA, BM, etc
  - About 100 in Total
  - About 250k Records in Total
  - Most Groups Follow Naming Convention
    - Accelerator GroupName DeviceType
    - DeviceName
    - Property
- Some EPICS Databases are Generated from Oracle Database

IOC Configuration



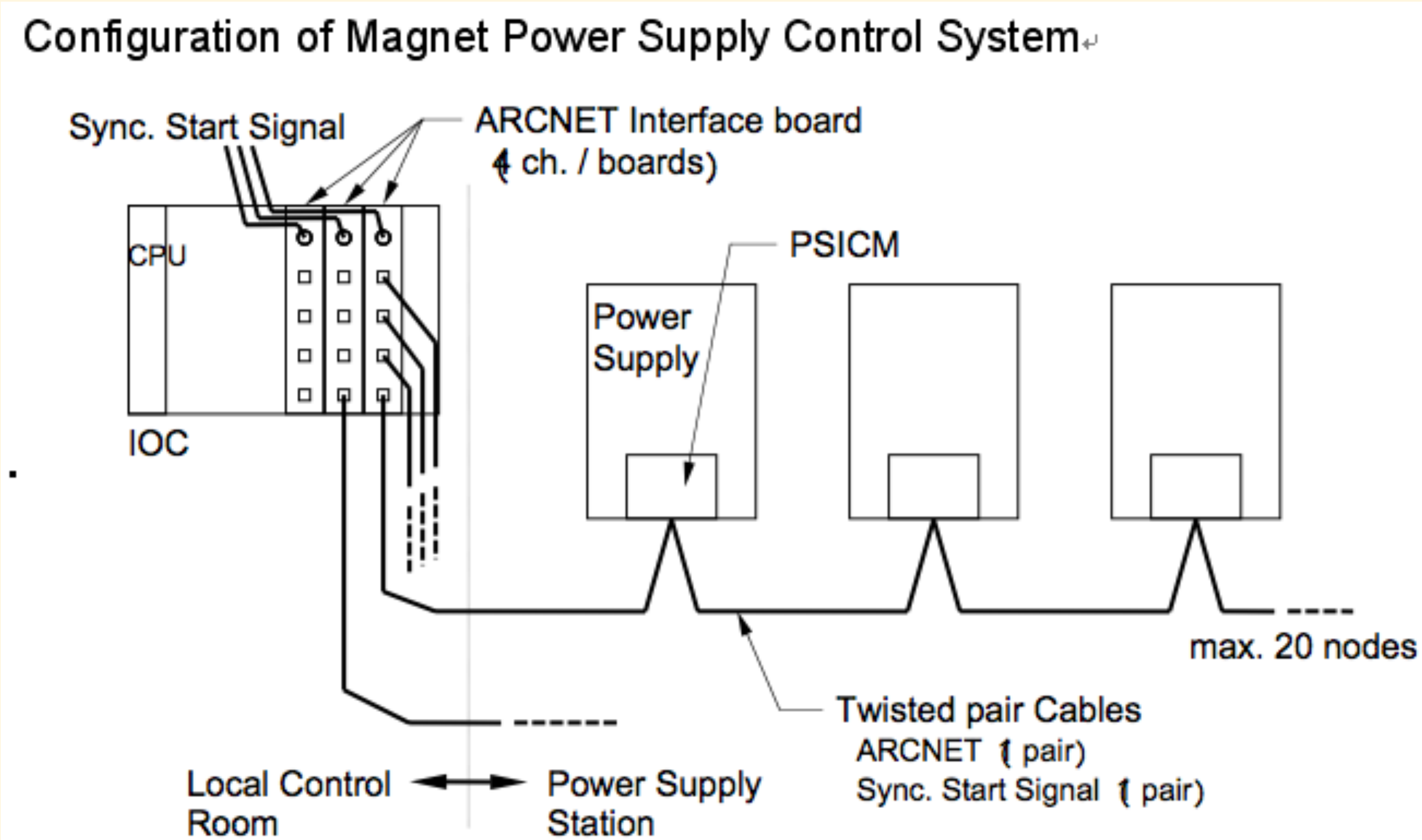
IOC Database with Oracle



Magnet Controls

- ~5000 Magnets, ~2500 Power Supplies
  - No One-to-one Correspondence
  - Basic Controls thru ARCnet
  - Voltmeter Scanner for Analog Read-out
  - PLC for Interlocks
- IOC Manages All Controls
  - Interlock Status, On/Off, etc
  - Energy - Field - Current
  - Synchronous Operation
    - for Tune change, Orbit Correction, etc.
  - Standardization
- Special Large Subroutine Record
  - "hugesub" Record and C Routine

Magnet Controls



Linac Controls

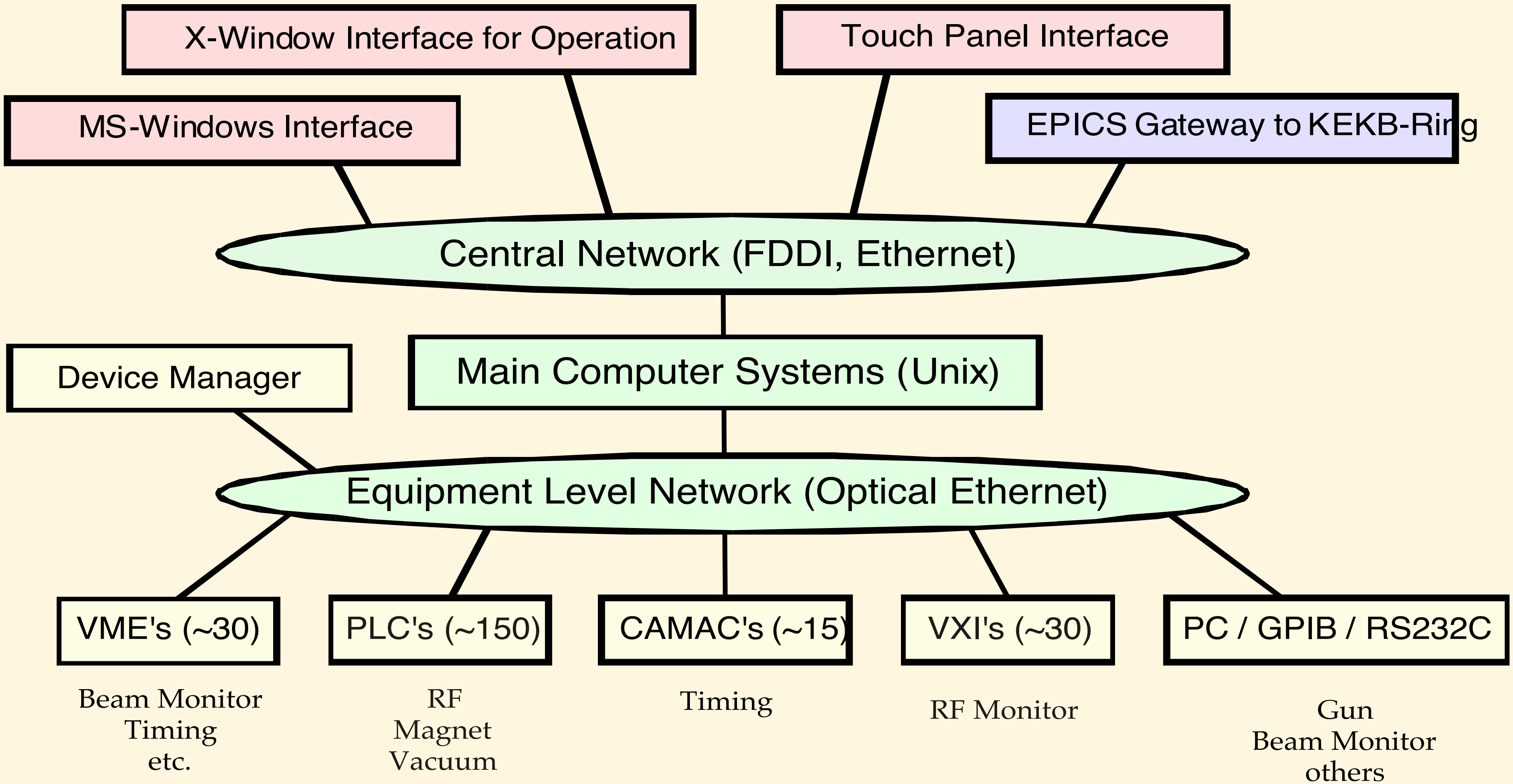
- KEKB = Factory Machine => Reliable Operation
- Controls should be Robust and Flexible
- ~1000 devices and ~10000 signals
- Frequent Beam Mode Switches
  - Four very Different Beam Modes, 360 times/day
  - Now 20ms switching with event-based controls
- Precise Controls of Beam Parameters
  - Energy, Orbit, Emittance, Charge, Energy spread, Timing, etc.

History and Design Concept

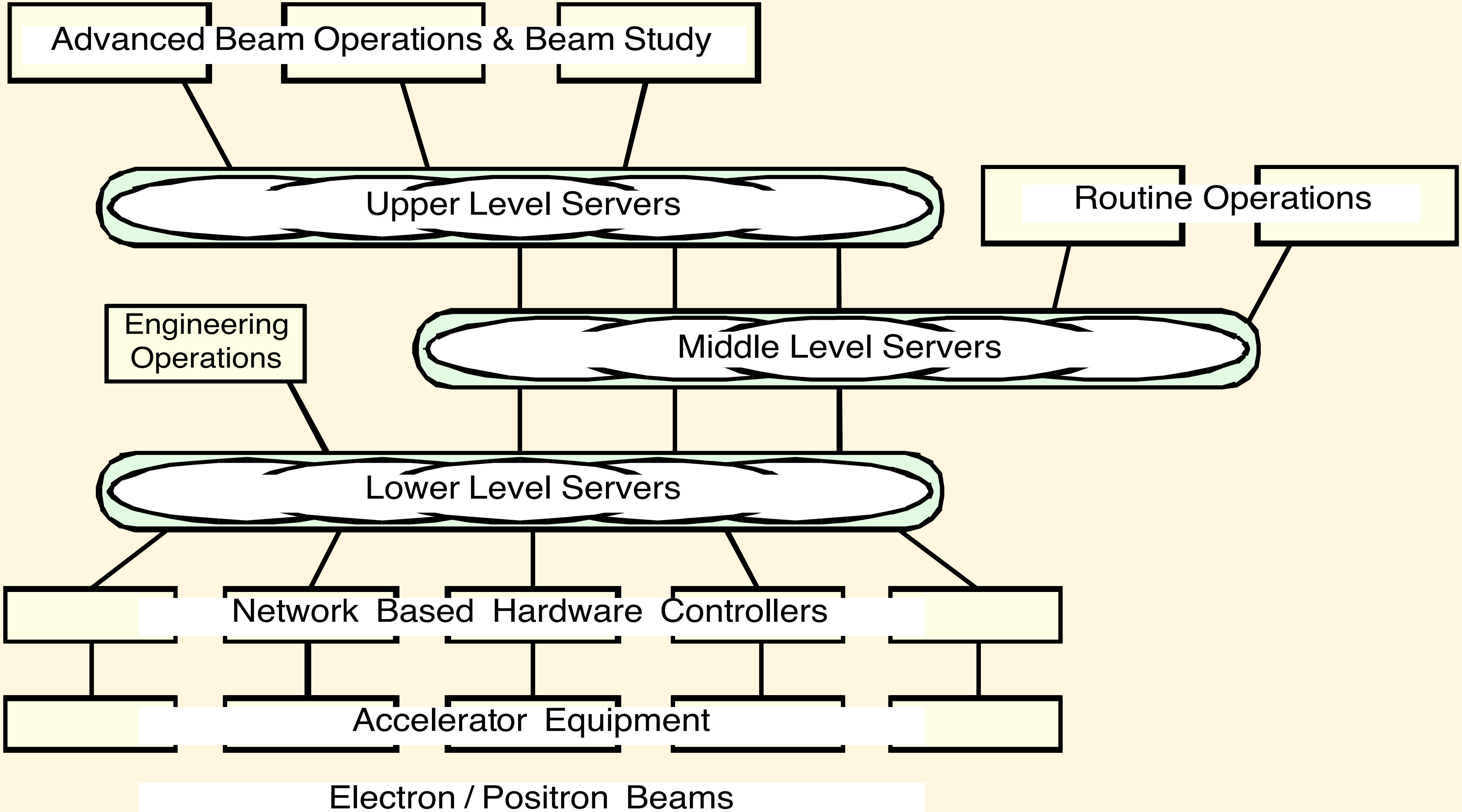
- **History**
  - 1978-1982: Construction of First Computer-controlled System with 8 mini-computers, >200 micro-computers, >30 optical loop networks
  - 1989-1992: Design of the next system
  - 1993-1997: Installation and expansion for KEKB
- **Design Concept**
  - Use of International and/or de-facto Standards
  - Use of Optical IP Networks for every Device controllers
    - No new field Networks, only IP Network (to be inherited by J-PARC)
  - Both of above should make future upgrade easier
  - (EPICS was not available widely at that time)

Physical Structure

- **Multi-tier, Multi-hardware, Multi-client, ...**



Multi-tier Logical Structure



Software Architecture (old)

- **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

Why EPICS in my case

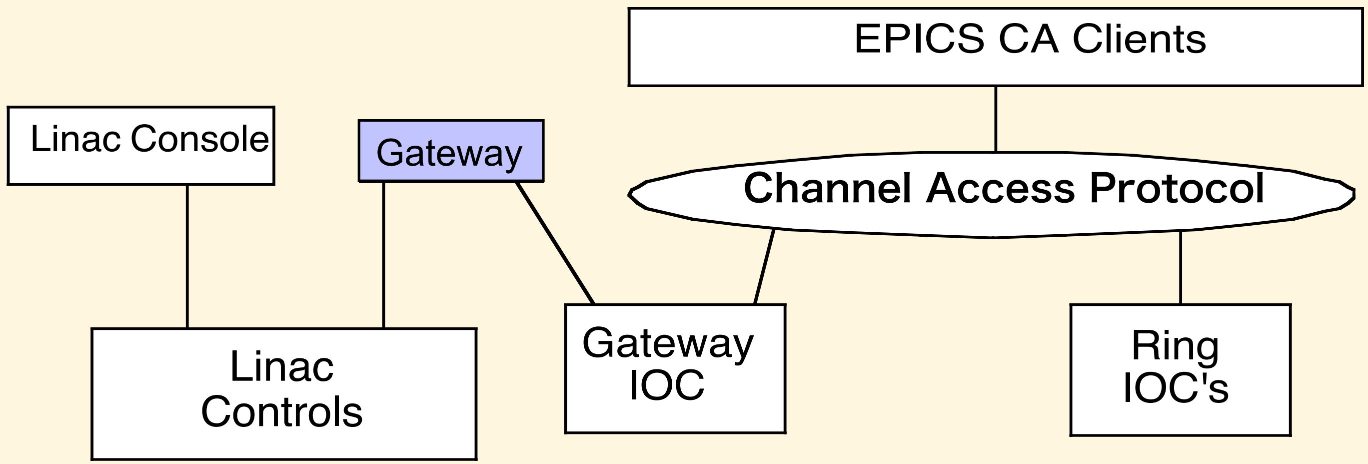
- We made too much effort on duplicate development on many control systems
- Our goal is to achieve high performance in the accelerator and the physics experiments
- Reuse of available resources is preferable
- Devices in Linac have been modernized, and development of EPICS device supports became possible
- Anyway we need interface to down-stream accelerators esp. KEKB
- Want to merge several archive formats in Linac
- May expect (?) man-power from other groups
- May contribute to world-wide EPICS collaboration

Building EPICS Gateway

- **Common Control System at the Top (of Linac and Ring)**
  - Needs too much resources
- **Port EPICS onto our VME/OS9-LynxOS (1994)**
  - Failed to get support/budget for LynxOS at Linac
  - (EPICS Maintenance with an unsupported Platform ?)
- **Special Gateway Software, which interfaces to both the Linac Controls and EPICS IOCs as a Client**
  - Built to ensure the feasibility at 1995
- **Portable Channel Access Server**
  - Implemented with EPICS 3.12 and being used on HP-UX since 1996
  - It is being used for several application software including Alarm display
- **Software IOC with 3.14**
  - Being used and being extended on Linux since 2003

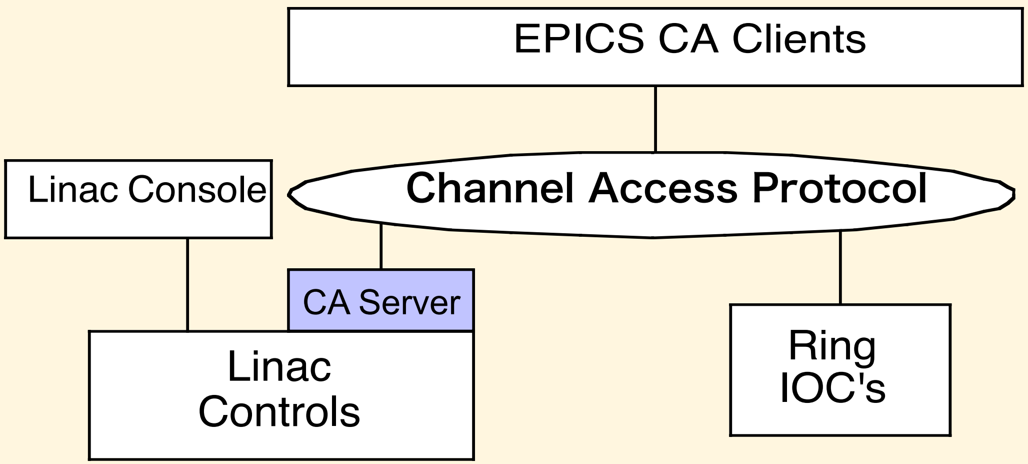
Use of Existing EPICS IOC (Gateway IOC)

- **Software availability**
  - **Portable Channel Access Server was not available at around 1995**
- **Channel Access Server Emulation with Available Software Components**
  - **New gateway software which is clients to the both Linac and EPICS, and group of EPICS soft records**
  - **Real-time Operation is possible both ways using Monitors**
- **Tested for Magnet Controls**
  - **MEDM panels were written**



Portable Channel Access Server (PCAS)

- **Protocol Conversion**
  - **Client to Linac Controls with Home-grown RPC and Cache Memory, Interface to Upper-level Servers (not directly to Lower-level Hardware Servers)**
  - **Server to EPICS environment, with some Name wrapping**
- **Implemented for Linac in 1996-**
  - **for Magnets, RF, Beam Instrumentations**
  - **>4000 Records are available**
  - **Write-access Possible, normally Read-only**
  - **Still used for KEKB Unified Alarm, Operation Status, etc.**



Soft IOC

- IOCcore is available on Unix in EPICS 3.14
  - We have Tru64unix, Linux, HP-UX
- Simple
  - IOCcore hides the complexity of Channel Access, etc
  - We design the device support to Upper-level Linac Servers, as we access to hardware in normal IOC
- All standard EPICS facilities are available
  - Alarms, Operation Limits, Links, Periodic processing, Monitors, etc.
- Implemented for Linac on Linux since 2003
  - For RF, Beam Instrumentation, Vacuum, etc.
  - >5000 Records are available and extending
- Most records are archived in Channel Archiver and KBlog
  - KBlog is used to analyze correlations between Linac/Ring
  - (Developed Java viewer of the archive at One Time)
  - Channel Archiver/Viewer from SNS is used for Linac Internals

General Comparisons

- **Symmetry**
  - Gateway IOC is Symmetric between outside and inside of EPICS
    - Accessing from/to EPICS goes thru the same Gateway
  - Others are (somewhat) asymmetric
- **Name Resolution**
  - PCAS can resolve names dynamically (at run-time)
    - Consumes less memory (?)
  - SoftIOC has to be prepared with static database
    - May be expected to give better response
    - Can be impossible for a large installations
- **Database processing and associate fields**
  - SoftIOC provides EPICS database Facilities like Limits, Alarms, Links, etc.
    - If we archive them, Archive Deadband is most necessary
- **Implementation of Gateway**
  - SoftIOC is relatively straight forward
    - Simply adding device supports

Application software

- Most records from the Linac Soft IOC are archived both in Channel Archiver and in KBlog
  - KBlog is used to analyze correlations between Linac/Ring
  - (Developing Java viewer of the archive)
- KEKB Alarm is connected to Linac PCAS
  - May migrate to Linac SoftIOC
    (Linac PCAS is currently based on EPICS 3.12)
- Some other applications utilize PCAS as well
  - (Many others access Linac Controls directly now)
- Small number of Records are going thru Gateway IOC, historically

Performance

- **EPICS Gateway and Channel Archiver**
  - are Running on Linux 2.4.20 (Redhat) with Intel Xeon 2.4GHz and Memory of 2GB
    - About 10% of CPU usage
    - Monitors/Archives all of ~2200 Channels (partial in Kblog)
    - Can process 5400~6600 Channel Access Requests over Network
  - Archive size is about 400MB/day (300MB/day in Kblog)
    - Both Channel Archiver and KBlog collect Data

Archiver/Logger

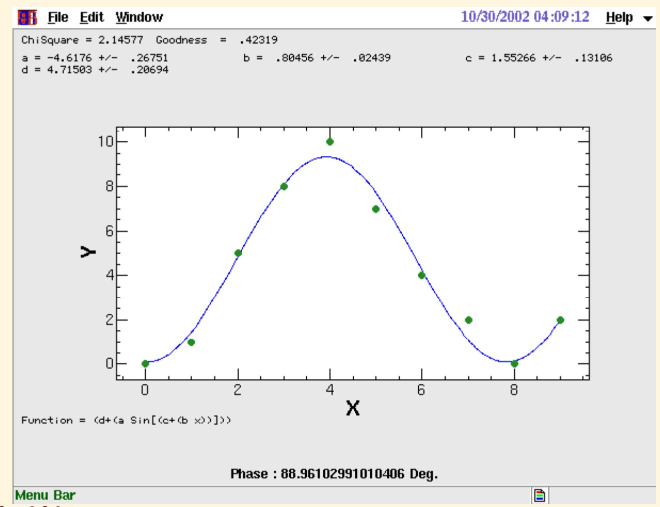
- **Linac**
  - Several archivers with group-dependent filters
  - Replaced with two EPICS archivers (2000~)
    - Channel archiver, with Java viewer, and Web-based viewer
    - KEKBlog, SADscript-based viewer
      - Both ~500MB/day, Dynamic ADEL changes
- **KEKB**
  - KEKBlog, since 1998
    - Once 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, one of the most-used applications in controls
      - 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
    - Mostly replaced Windows/VisualBasic-based environment
  - (Now) Mixture of Tcl/Tk, SADscript/Tk, Python/Tk
    - SADscript has most accelerator design capability
      - Covers most 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 introduced as a front-end**
  - Not Real Symbolic Manipulation (Thus fast)
  - Data Manipulations (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, Compound widgets, etc
  - Relational Database
  - Inter-Process Communication (Exec, Pipe, etc)
    System[ ], OpenRead/Write[ ], BidirectionalPipe[ ], etc.
  - Beam Operation with Full Accelerator Modeling Capability
    - Online and offline under the same environments
    - Also Used for non-Accelerator Applications (Archiver viewer, Alarm handler, etc.)
  - Comparable to XAL, MATLAB, but very different architecture

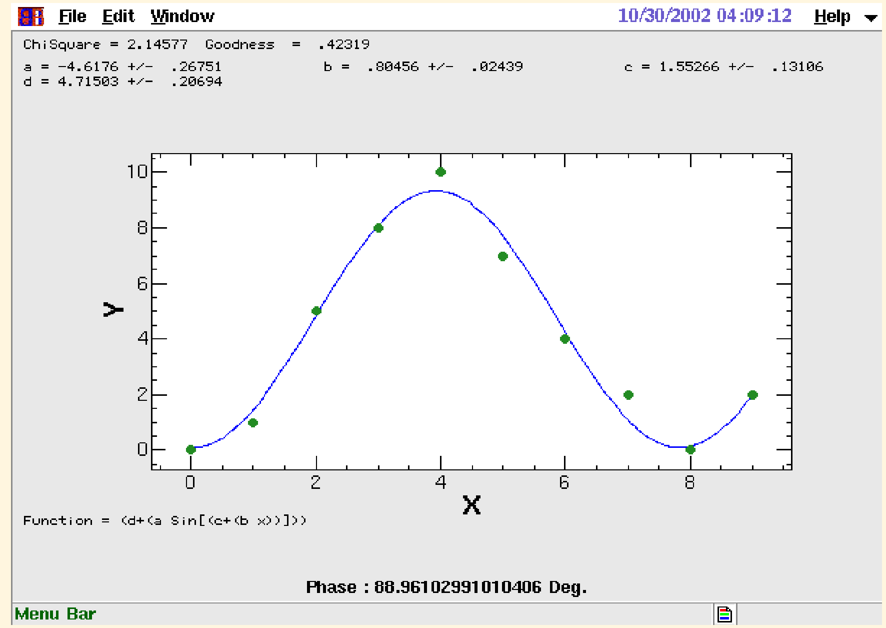


SADScript

- **Mathematica-like Language**
  - Not Real Symbolic Manipulation (Fast)
  - EPICS CA (Synchronous and Asynchronous)
    - CaRead/CaWrite[ ], CaMonitor[ ], etc.
  - (Oracle Database)
  - Tk Widget
  - Canvas Draw and Plot
  - KBFrame on top of Tk
  - Data Processing (Fit, FFT, …)
  - Inter-Process Communication (Exec, Pipe, etc)
    - System[ ], OpenRead/Write[ ], BidirectionalPipe[ ], etc.
  - Greek Letter
  - Full Accelerator Modeling Capability
  - Also Used for non-Accelerator Applications

SADScript

◆Data manipulation/plot example



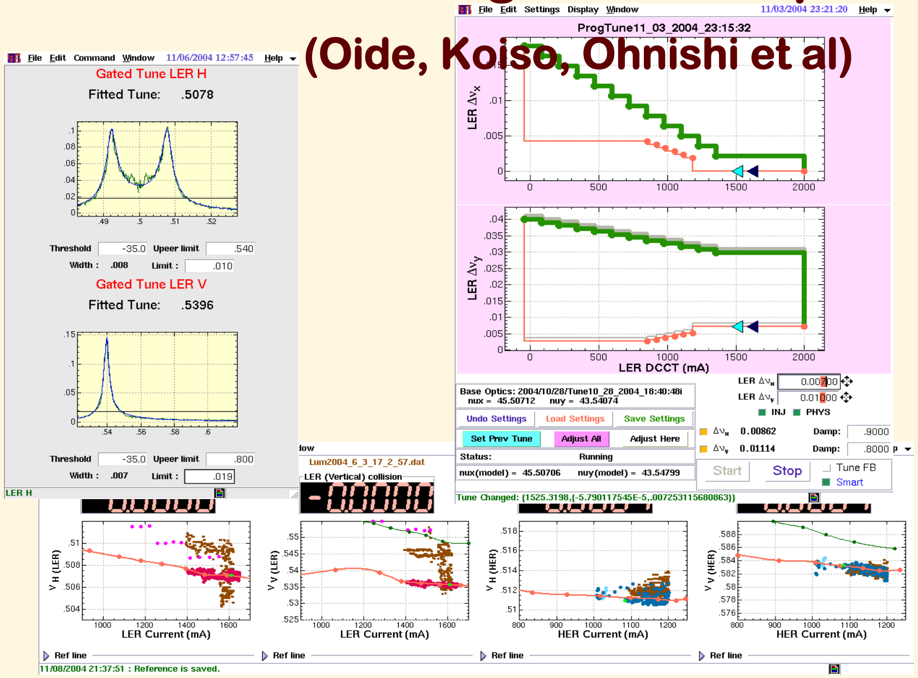

```
FFS;
w=KBMainFrame["w1",fm,Title->"t1"];
$DisplayFunction=CanvasDrawer;
W1=Frame[fm];
c1=Canvas[w1,Width->600,Height->400,
 Side->"top"];
Canvas$Widget=c1;
data = {{0,0}, {1,1}, {2,5}, {3,8}, {4,10}, {5,7}, {6,4}, {7,2}, {8,0}, {9,2}}
fit = FitPlot[data,a Sin[x b + c] + d, x, {a,5},{b,1},{c,1},{d,5},
 FrameLabel->{"X","Y"}];
phase = StringJoin["Phase : ", (c/.fit[[1]]) 180/Pi, " Deg."];
f1=KBFComponentFrame[w1,Add->{KBFText[Text->phase]}];
TkWait[];
Exit[];
```

Virtual Accelerator in SADscript

A 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)



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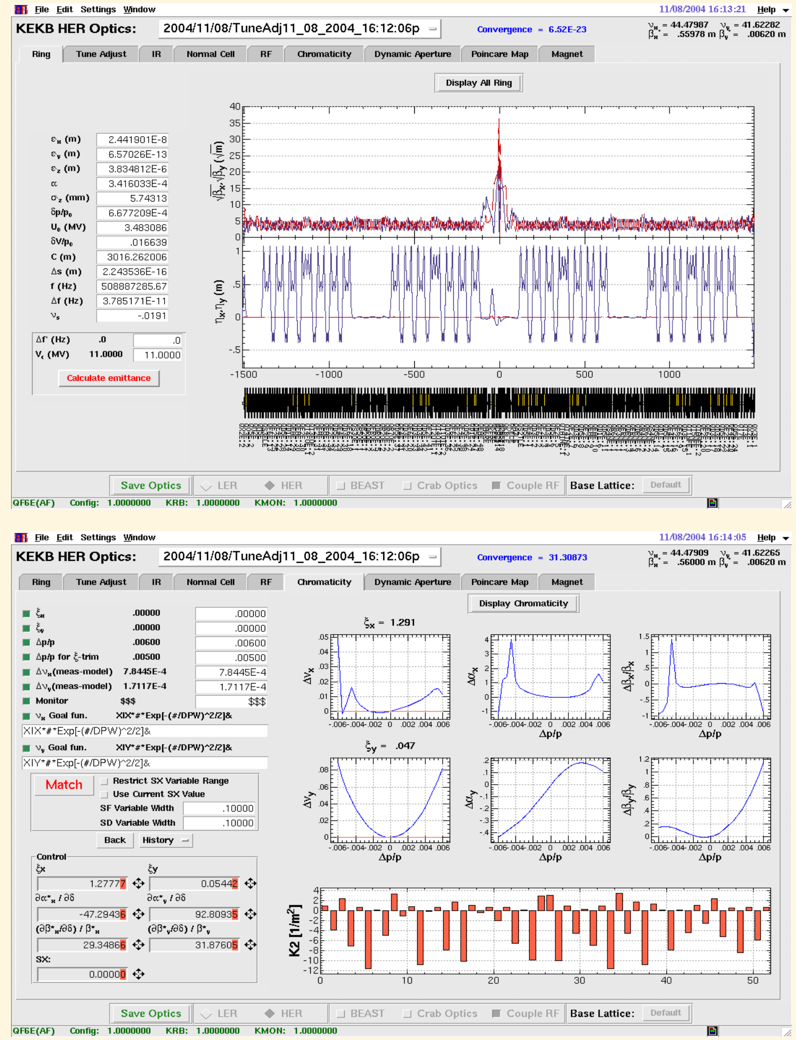


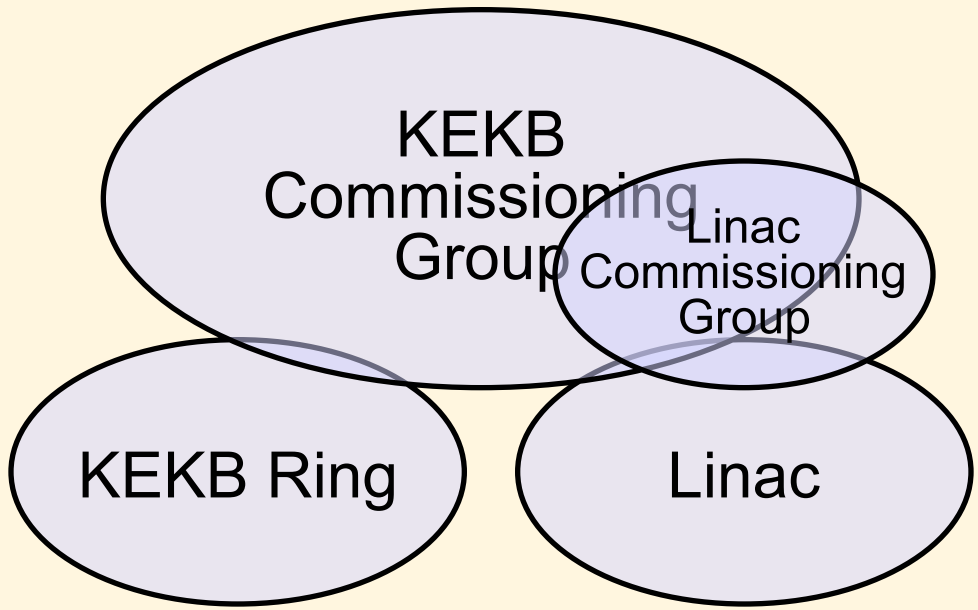
Tune Measurement/Changer

Optics Panels

KEKB Commissioning Groups

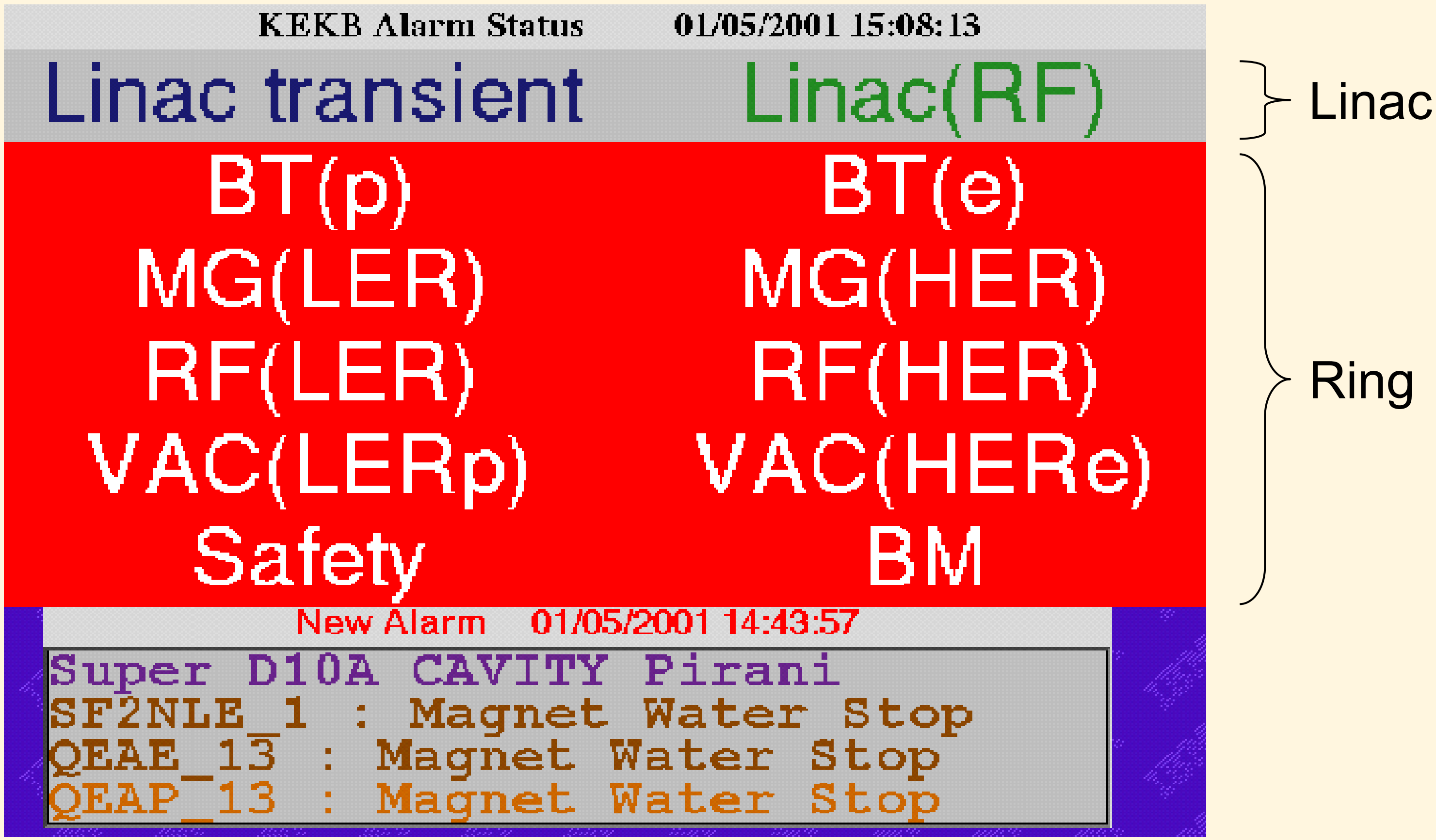
- **Formation of Commissioning Group (KCG)**
  - **Linac Commissioning (LCG)**
    - **7 from Linac**
    - **~10 from Ring**
  - **KEKB Ring Commissioning Group (KCG)**
    - **All LCG**
    - **~20 from Ring**
    - **Several from Detector (BCG)**
  - **Commissioning software base was formed during Linac Commissioning (1997~)**

    Tcl/Tk, SAD/Tk , Python/Tk



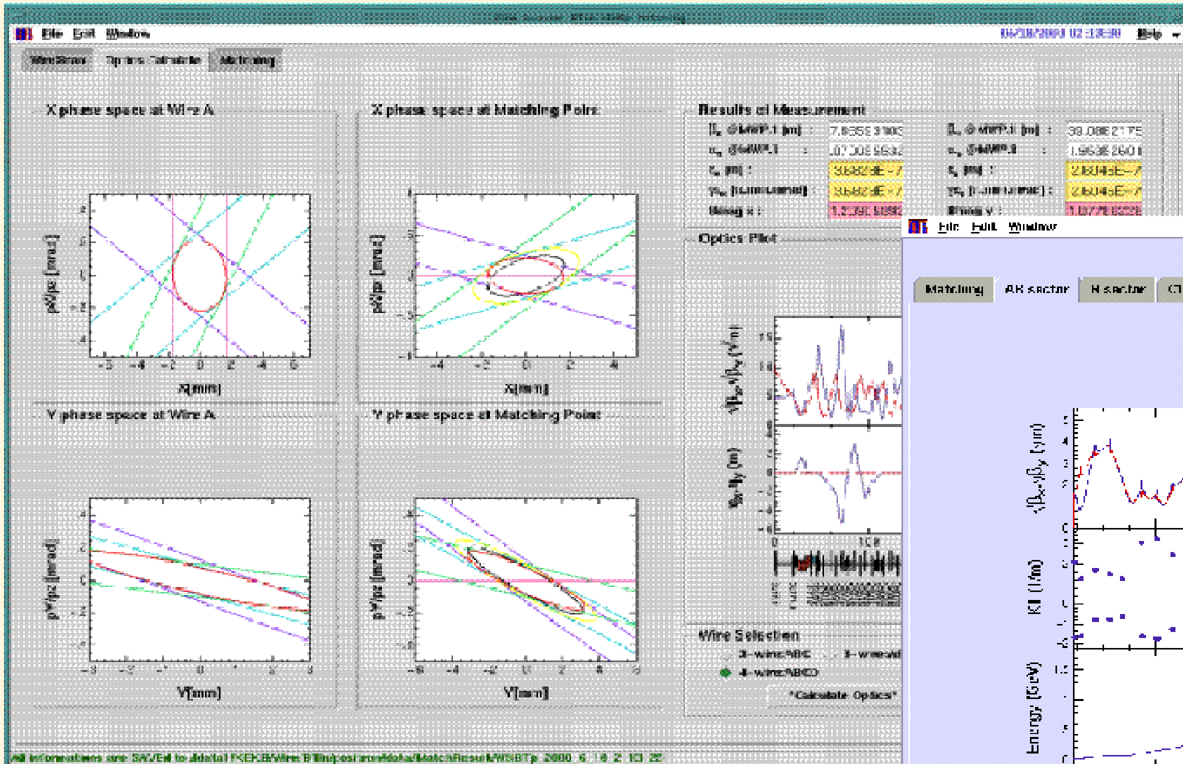
KEKB Alarm Panel

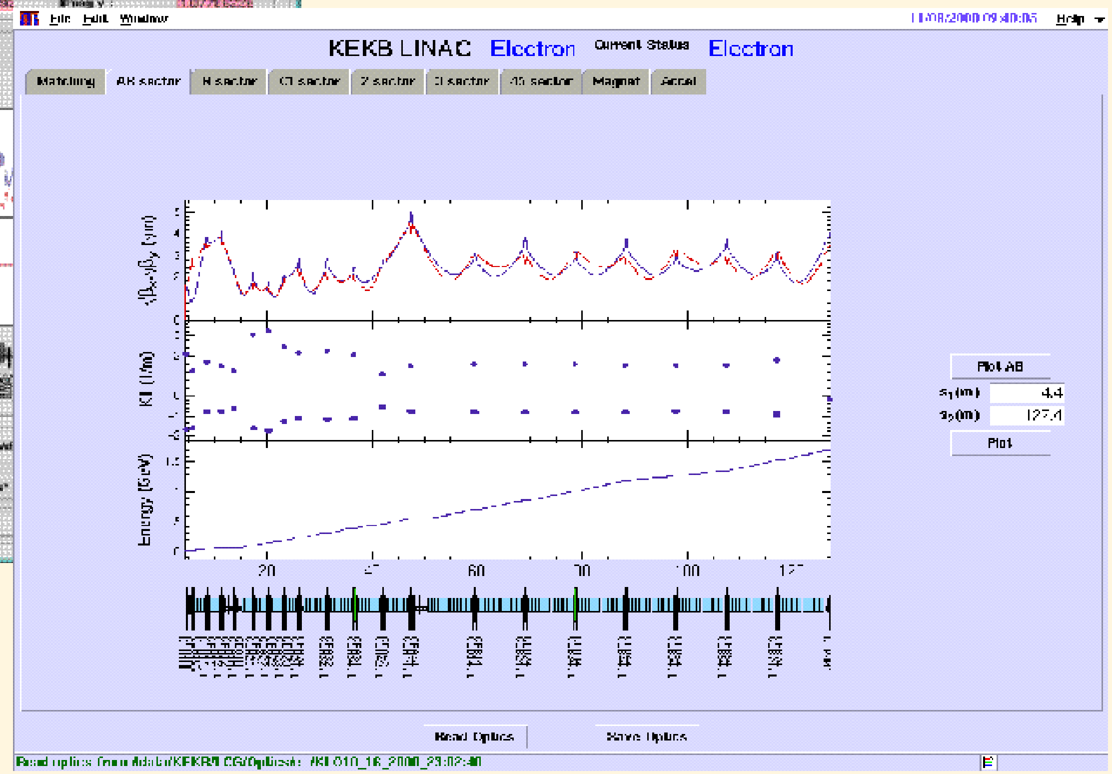
◆**KEKB Alarm Main Panel covers Linac Alarms as well. ~10,000 Records are Monitored in One Panel. Detailed alarm information/history is available in a separate panel**



Beam Optics Panels in SAD

◆Beam Optics Matching and Optimization Panels in SADscript

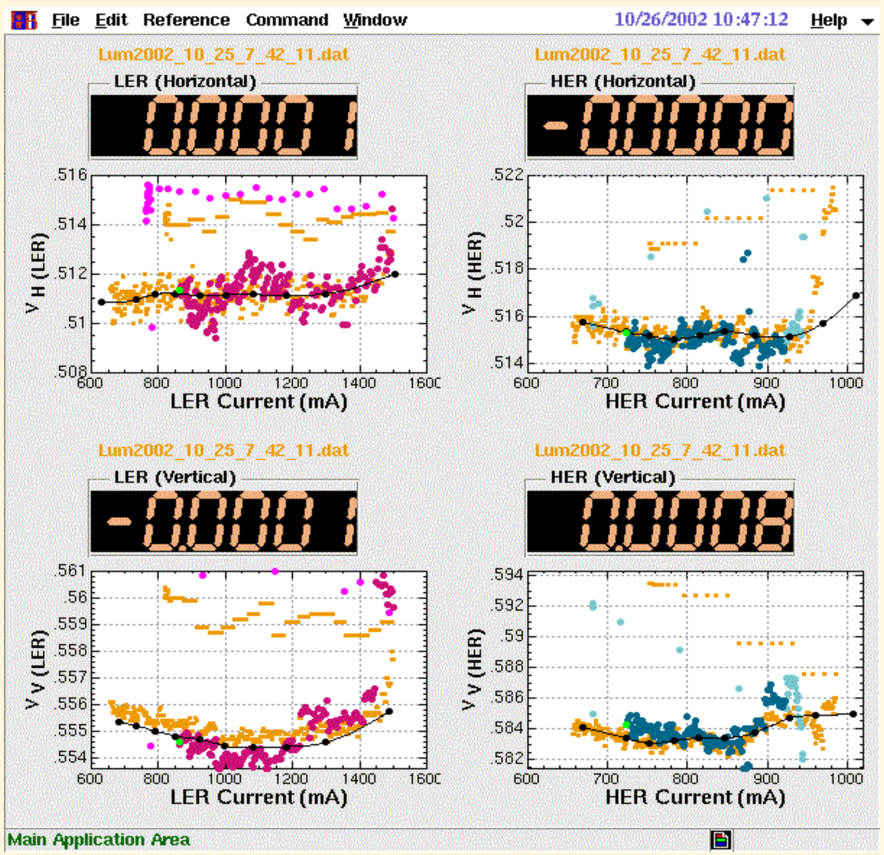


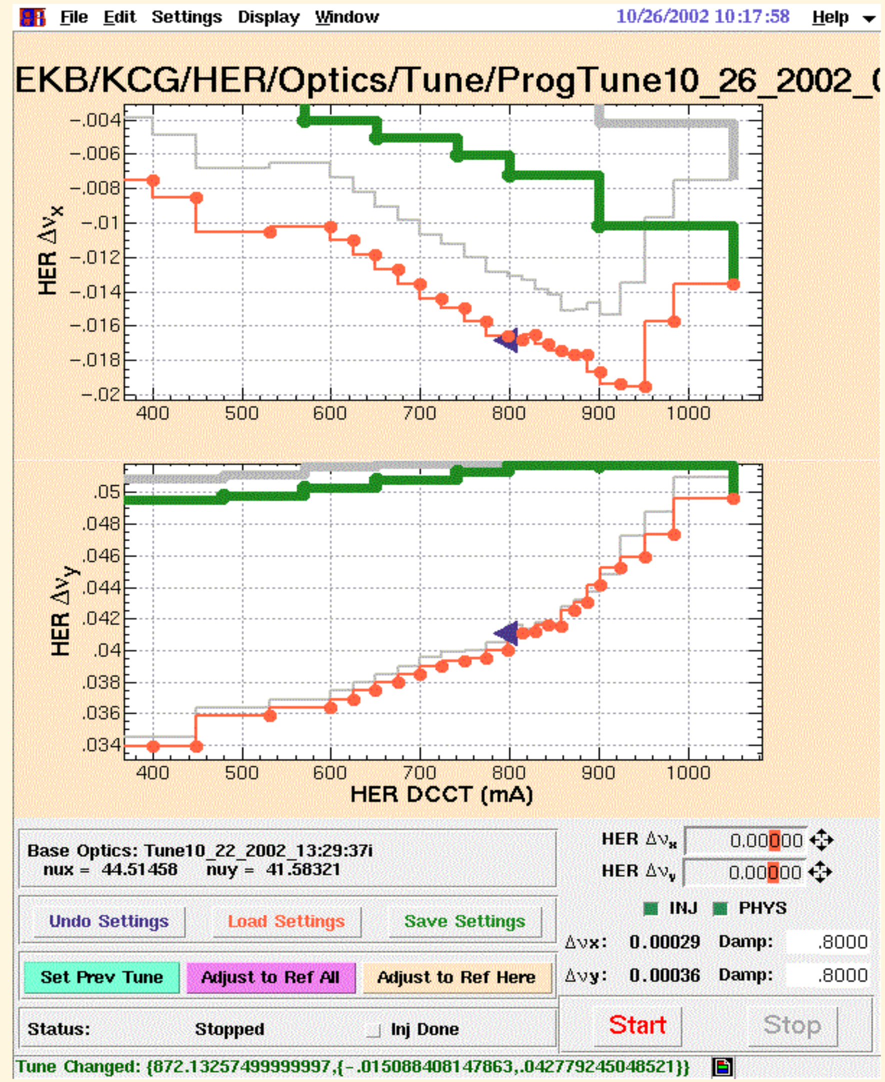


◆Some Parameters goes thru EPICS Gateways, others directly to Linac

KEKB Operation Panel Examples

- **Tune Measurement and Tune Changer**

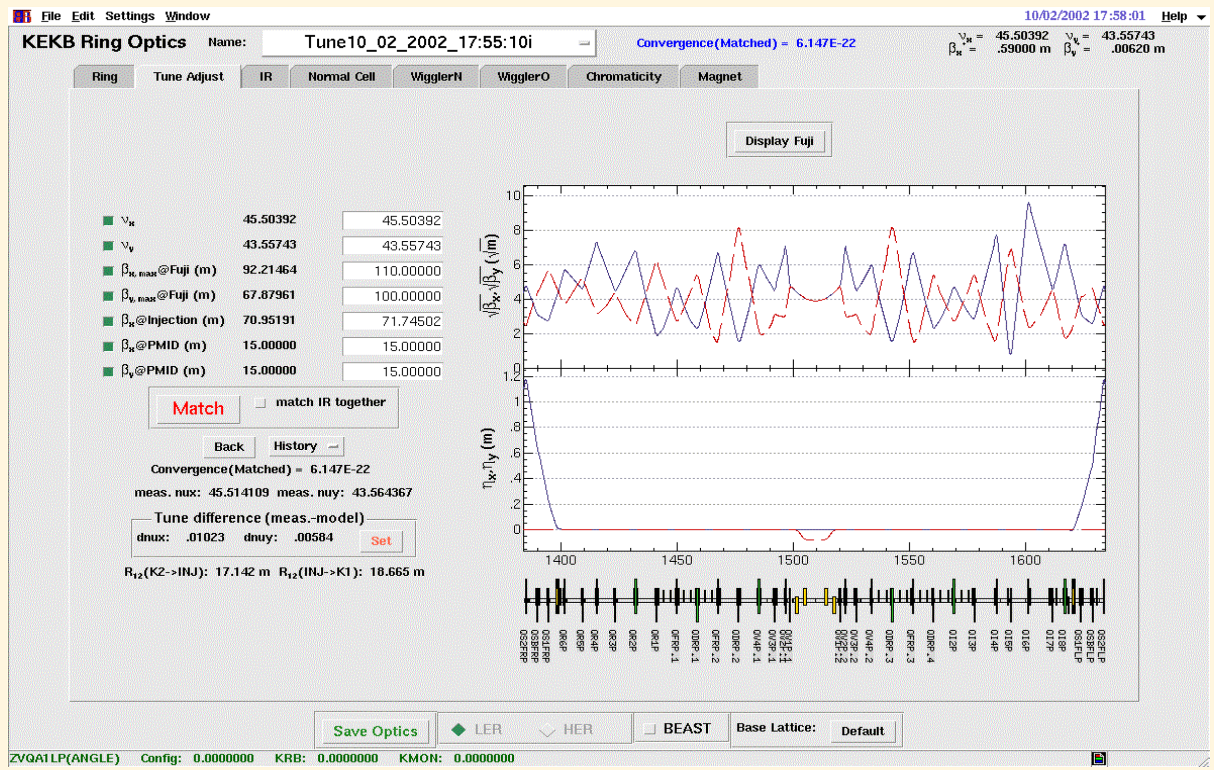




Virtual Accelerator in KEKB

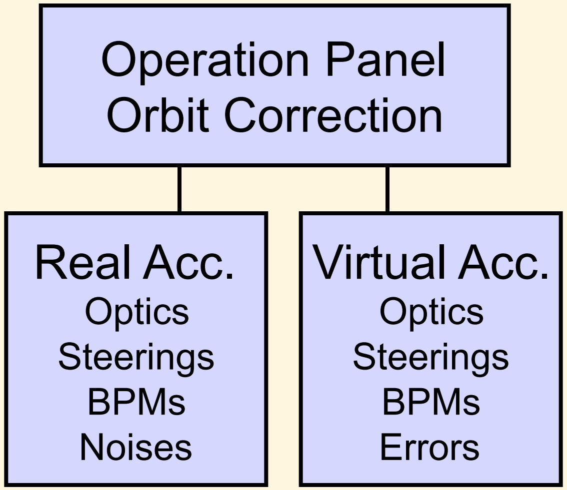
◆Tune/Optics Server

- Keep A Model of Real Accelerator
- Can Change Tune, Chromaticity, etc, on Request by Other Panels
- Act as a Virtual Accelerator



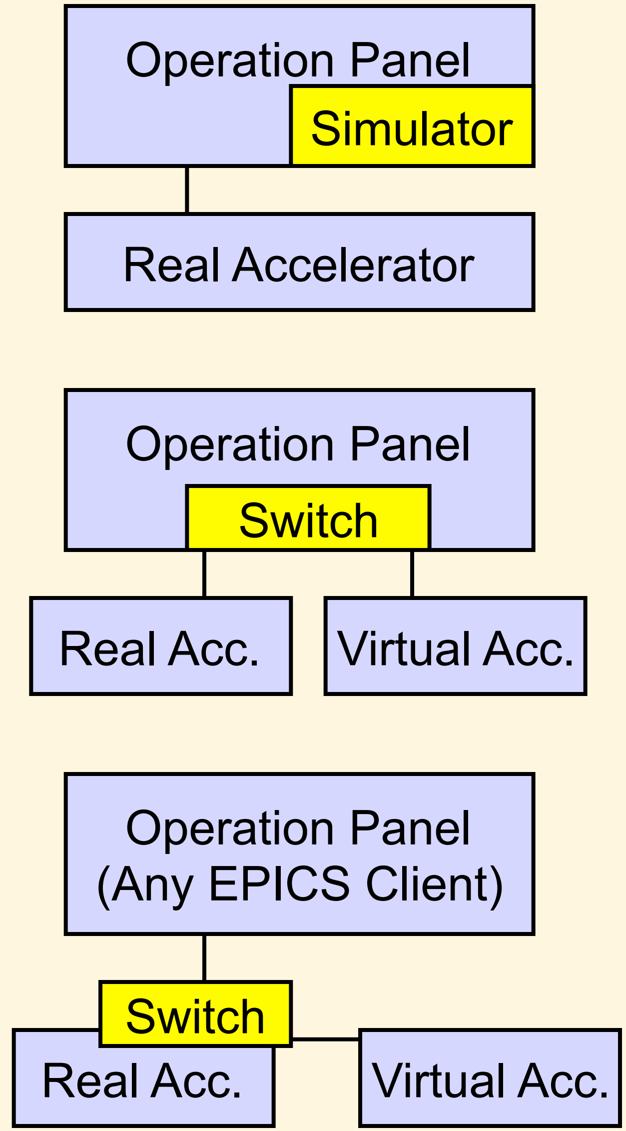
Example Virtual Accelerator

- Virtual Accelerator may Provide
  the Both Fake Steerings and Fake BPMs
  Maybe with Simulated Errors/Noises
- Orbit Correction Application may Work
  On Those Fake Information



Virtual Accelerator with EPICS

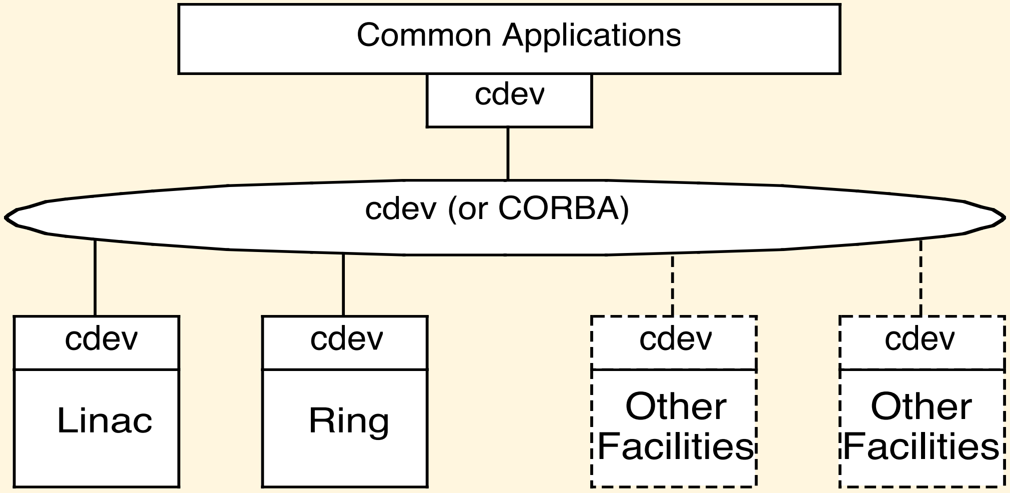
- **Fake Accelerator Implementation**
  - **With EPICS Channel Access**
- **In A Single SAD Application**
  - **Built-in Simulator in Operation Panel**
  - **Only SAD Applications**
- **Separate Simulator (Virtual Accelerator)**
  - **Needs Some Switching Mechanism**
- **Separate Simulator (Virtual Accelerator)**
  - **In EPICS Semantics (EPICS Simulation Server)**
  - **Any Operation Panel (not only SAD)**
  - **SAD Simulation Server should Act as EPICS Channel Access Server**



Virtual Accelerator

Other Implementation Possibilities

- **Upper Level Protocol Like**
  - **CORBA**
    - Used in Several Lab.
  - **Cdev**
    - May be Used in LHC (?)
- **May Cover Systems Not On EPICS**
- **Not Covered in This Talk**



EPICS Simulation Mode

EPICS Database - Simulation Mode

A set of fields to support simulation are supplied on all hardware input records.

SIMM = YES makes this record a simulation record.

A link to a database value to put the record into simulation mode is specified in the SIML. A non-zero number puts the record into simulation mode.

SVAL is the engineering units value used when the record is in simulation mode.

SIOL is a database location from which to fetch SVAL when the record is in simulation mode.

SIMS is the alarm severity of the record if it is in simulation mode.

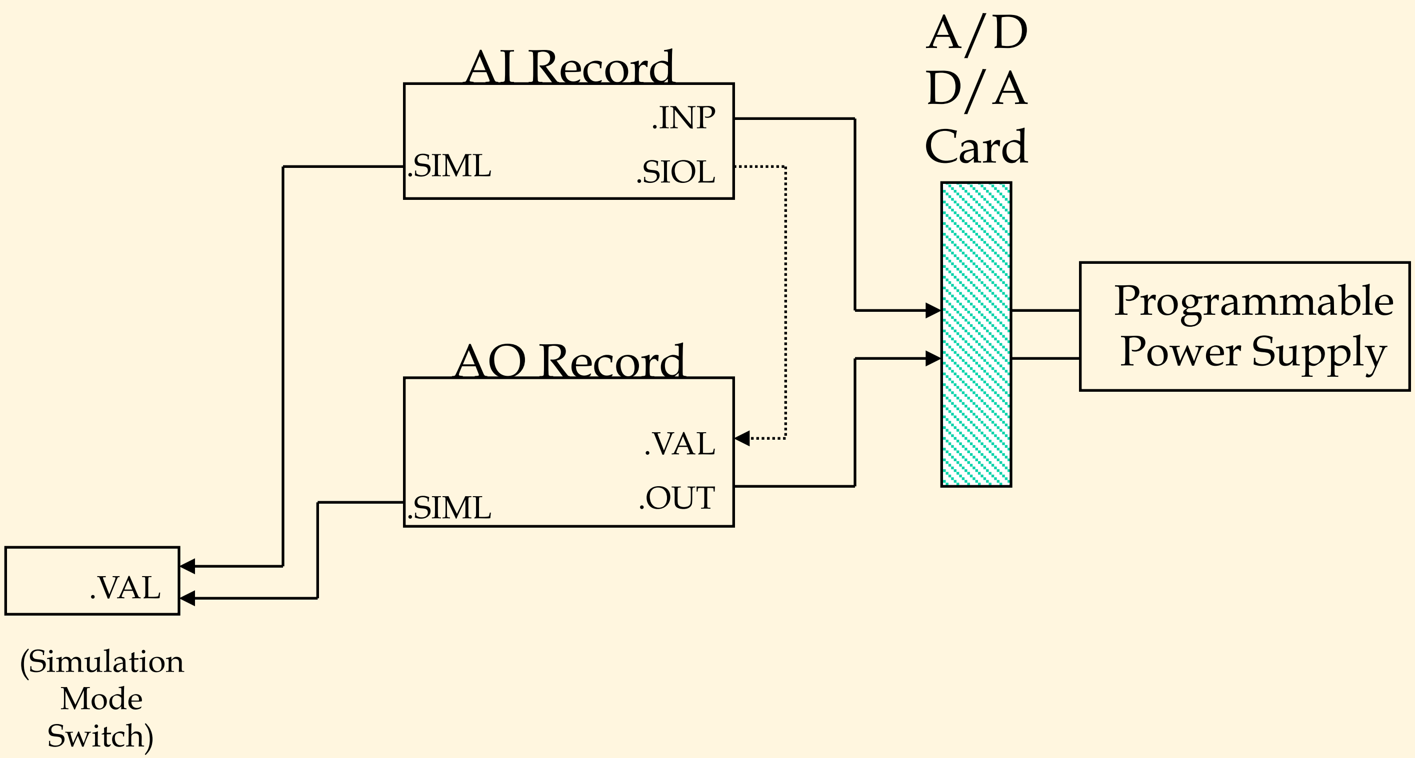
- **That is, EPICS Records may have Proxy Records**

EPICS Simulation Mode

- **SIMM - Simulation Mode**
  - »This field has either the value YES or NO. By setting this field to YES, the record can be switched into simulation mode of operation. While in simulation mode, input will be obtained from SIOL instead of INP.
- **SIML - Simulation Mode Location**
  - »This field can be a constant, a database link, or a channel access link. If SIML is a database or channel access link, then SIMM is read from SIML. If SIML is a constant link then SIMM is initialized with the constant value but can be changed via dbPuts.
- **SVAL - Simulation Value**
  - »This is the record's input value, in engineering units, when the record is switched into simulation mode, i.e. when SIMM is set to YES.
- **SIOL - Simulation Value Location**
  - »This field can be a constant, a database link, or a channel access link. If SIOL is a database or channel access link, then SVAL is read from SIOL. If SIOL is a constant link then SVAL is initialized with the constant value but can be changed via dbPuts.
- **SIMS - Simulation Mode Alarm Severity**
  - »When this record is in simulation mode, it will be put into alarm with this severity and a status of SIMM.

Simulation Mode

- **EPICS Simulation Mode Simple Example**
  - **Tests Logic without Hardware**

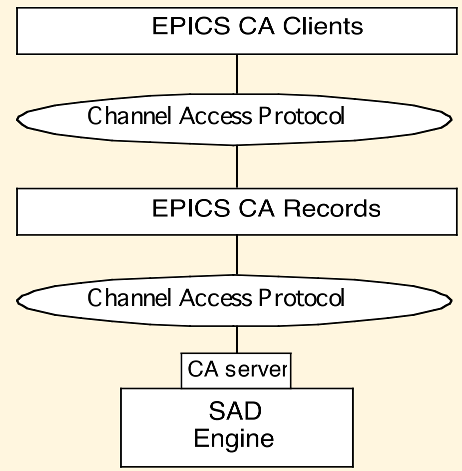


SAD as EPICS Simulator

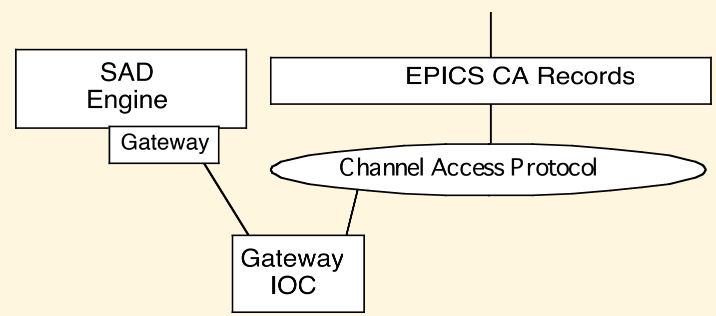
- **Implementing a Virtual Accelerator**
- **SAD Simulator in Channel Access Server**
  - Serves Channel Values Requested by Channels (Records) in Simulation Mode (SIOL), Acting as a Channel Access Server
  - Slightly more Difficult to Implement (at the First Stage)
- **SAD Simulator in Channel Access Client**
  - Provides Channel Values Needed by Channels (Records) in Simulation Mode (SVAL)
  - Easier to Implement (?)
    - Needs Some Studies

Channel Access Server

- **Using Portable Channel Access Server**
  - **Needs Interface from Server-side Channel Access Library to SAD**
    - **Written in C++**



- **Using IOC Core of EPICS-3.14 (or Later)**
  - **Needs Device Support for SAD**
    - **Maybe Easier**
- **Using Intermediate Soft Records**
  - **SAD may act as an EPICS Client**
    - **Maybe Easier**



KEKBLOG and ZLOG

- **KEKBlog/kblog Archiver is Used from the Beginning of the Commissioning**
  - **~2GB / day**
  - **Several Viewer Tools**
    - **Very often Used to Analyze the Operation Status**
- **Zlog Operation Log**
  - **Zope, Python, PostgreSQL**
    - **EPICS direct inputs / Human operator inputs**
    - **Mostly In Japanese**
    - **Figure/Picture Storing**

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**
  - Embedded IOC, IEC61131-3 Standards (?)
- **FPGA usage**
  - More embedded controllers / instrumentations
- **VME will be kept, μTCA will be installed**
  - VME may decrease
- **More and more reliability considerations**
  - Surveillance, Testing environments, Redundancy, etc.
- **More operation side developments**

Recent Improvements

- **PLCs with Embedded EPICS (Linux)**
  - from Ethernet/IP-only to Channel-Access-only
- **Event system introduction**
  - Single fiber to distribute globally synchronized, 10ps timing, 50Hz interrupts, data, etc
  - Another control layer besides EPICS
- **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

Collaboration

- **Please help us in above new fields**
- **Let's help each other**
- **Asian activities on EPICS should be kept**

Summary

- **Control systems at KEK are evolving based on changes and advances in**
  - in accelerator design concepts
  - in available technologies
  - Control system design needed balances between many aspects

- **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)

- **EPICS and Scripting Languages brought great success to the both KEKB and Linac Beam Operations**

Thank you


KYOTO
23-28 MAY 2010
KYOTO INTERNATIONAL CONFERENCE CENTER
INTERNATIONAL ORGANIZING COMMITTEE
[URL] http://ipac10.kek.jp
[E-mail] ipac10@kek.jp
SCIENTIFIC PROGRAM COMMITTEE
LOCAL ORGANIZING COMMITTEE
第壱回
The 1st International Particle Accelerator Conference
IPAC'10

Backup slides

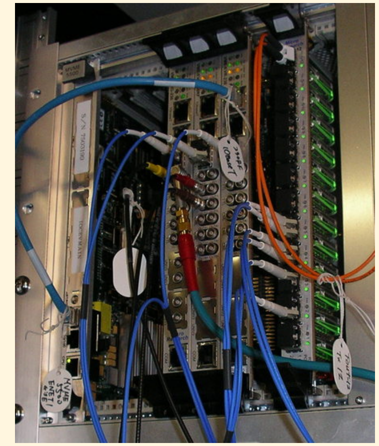
KEKB & Linac

- **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**
  - **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

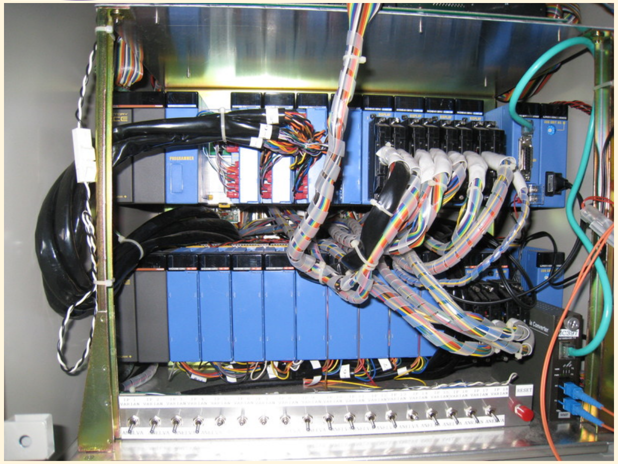
EVR & LLRF

(previous) PLC usage at KEK

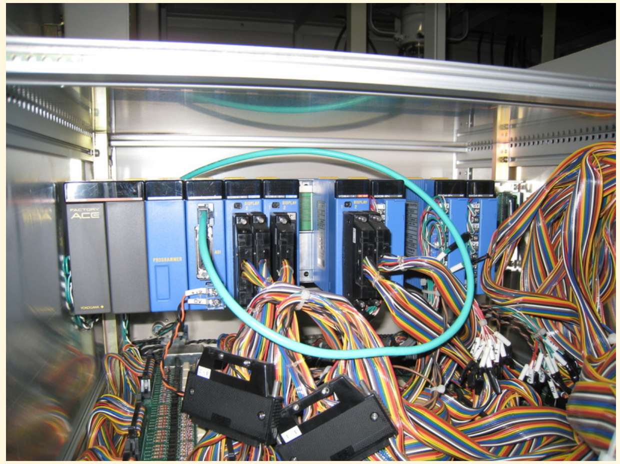
- **At Linac**
  - We enforced that all the controllers should be connected over IP/ Ethernet
  - PLC was much cost-effective compared with VME
    - if the speed requirement allows
  - Products from OMRON, Mitsubishi, Yokogawa were installed
    - Only Yokogawa (FAM3) increased, because maintenance 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 for PLC

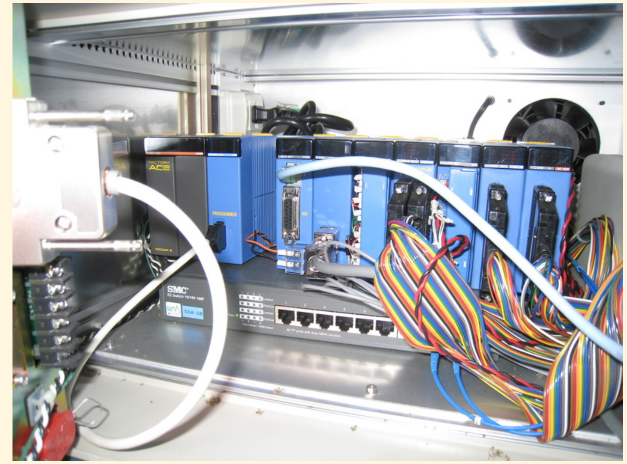
- **Ideal at the beginning**
  - Separate software development at control group, at equipment group, or at industrial company
  - Later, integration test IP/Ethernet
- **Logic management**
  - Same logics could be placed at ladder software, in EPICS database/sequencer (or in high-level applications)
- **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**



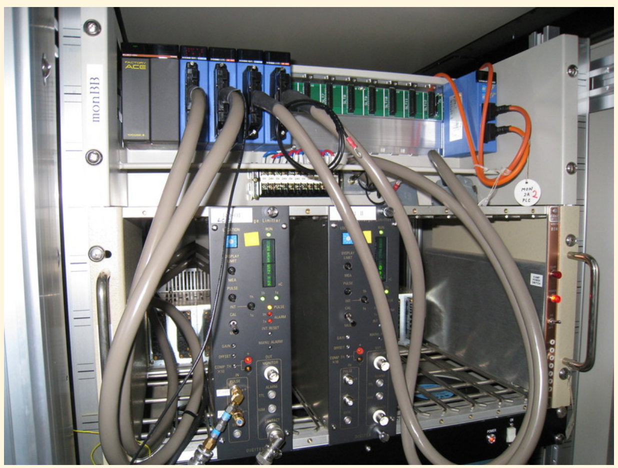
Vacuum Controller Internal



Magnet Controller Internal



RF Controller Internal



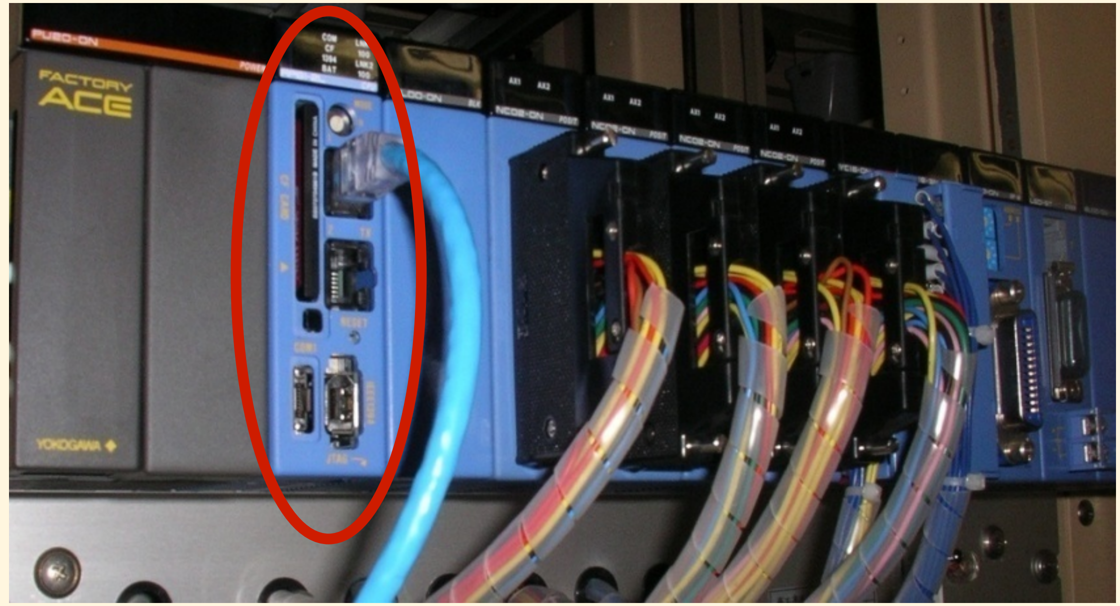
Safety Controller

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



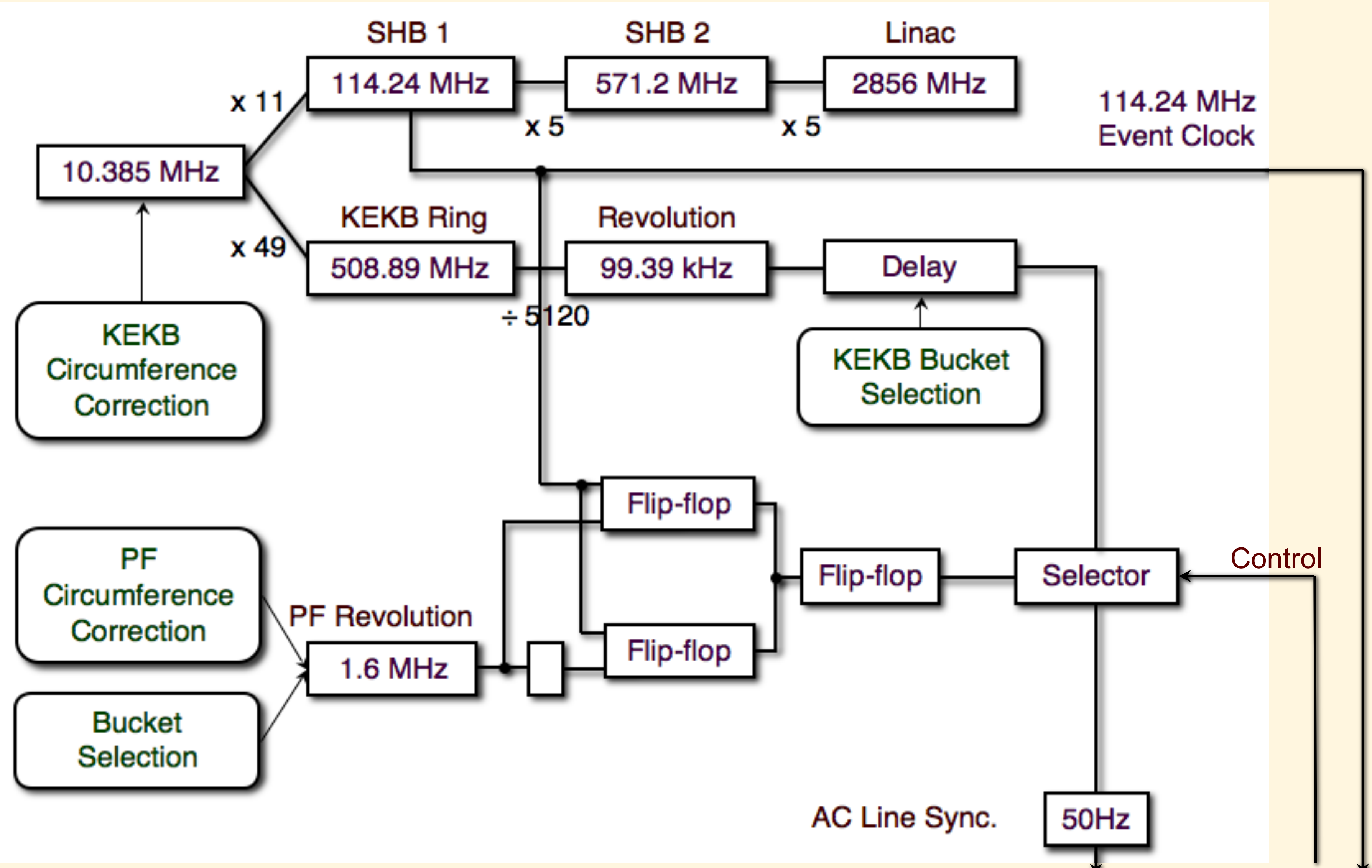
Beam mask controller

- 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

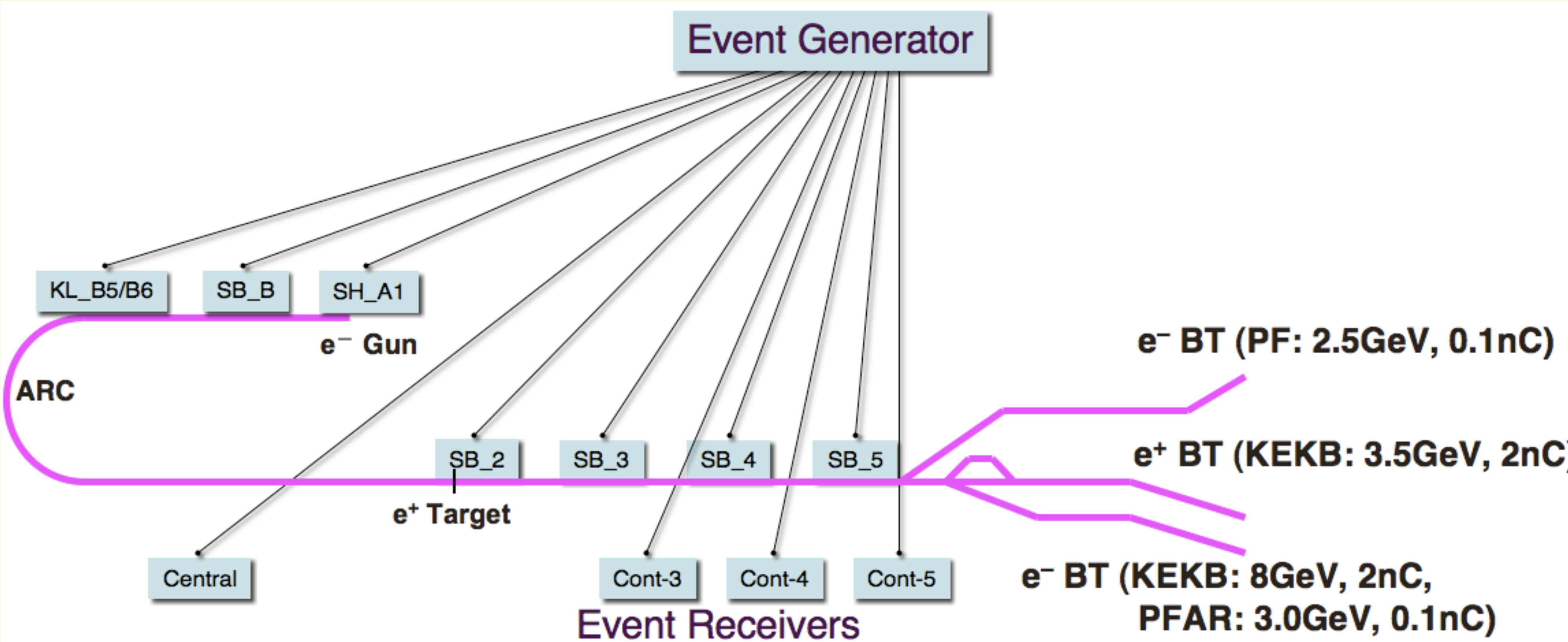
Event System

- **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 at KEKB
  - 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, EPICS 3.14.9 (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

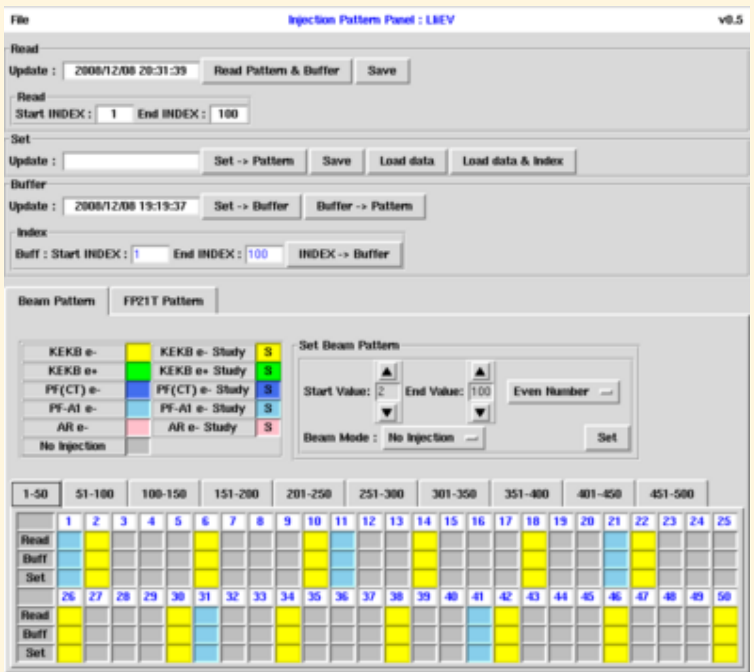


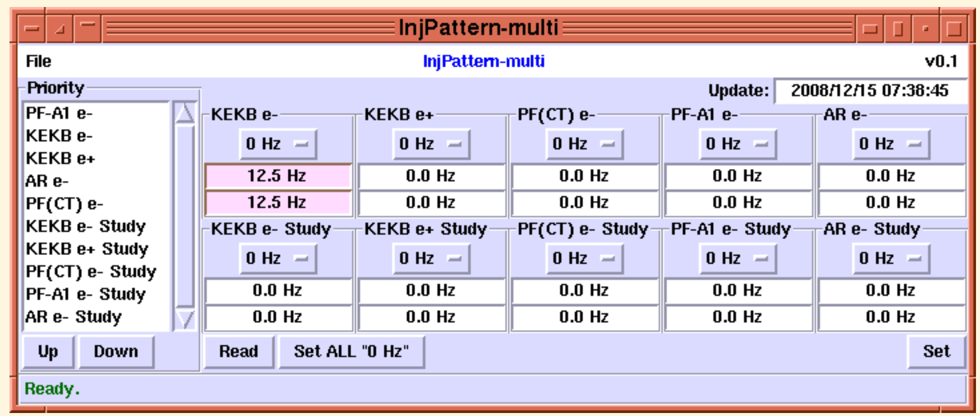
Beam mode pattern generation

- 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

Pulse 1	Pulse 2	Pulse 3		Pulse n
Beam Mode 1	Beam Mode 2	Beam Mode 3	....	Beam Mode n



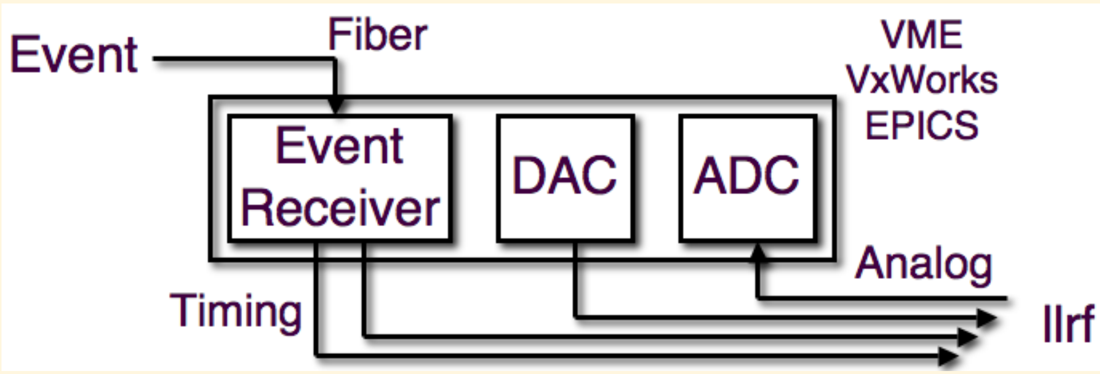


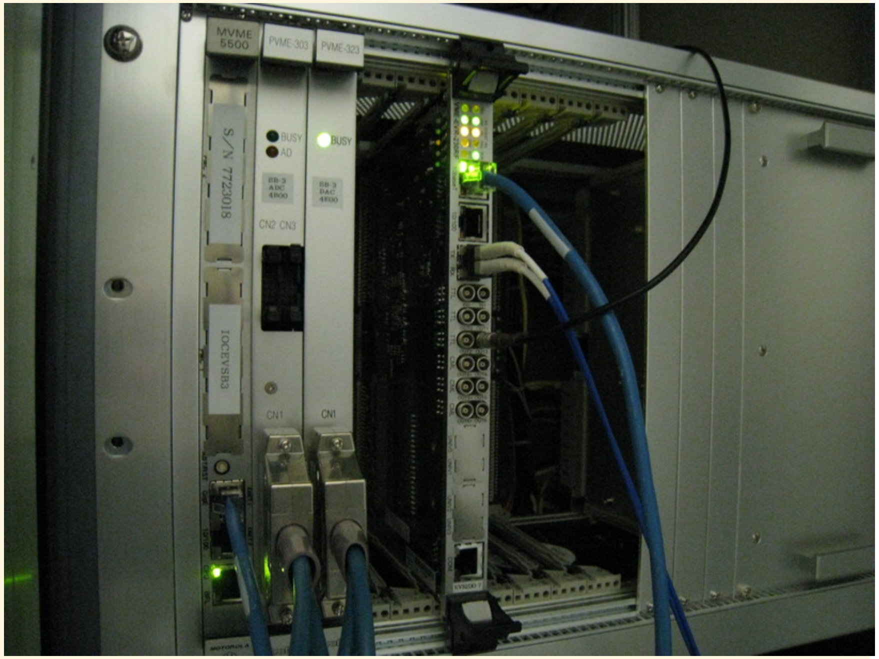
Manual pattern designer

A version for current operation

LLRF

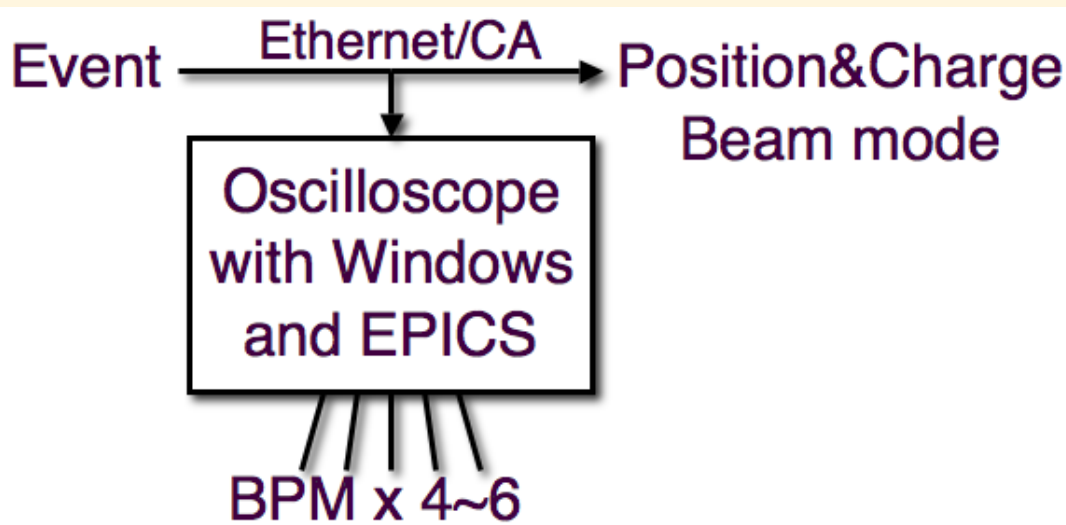
- Timing and analog signals are essential for absolute energy, energy spread, and dual-bunch energy equalization.
- Signals can be switched pulse-by-pulse.
- Driver klystrons (SB), energy tuner klystron (KL), and sub-harmonic bunchers (SH) are managed by the event system.

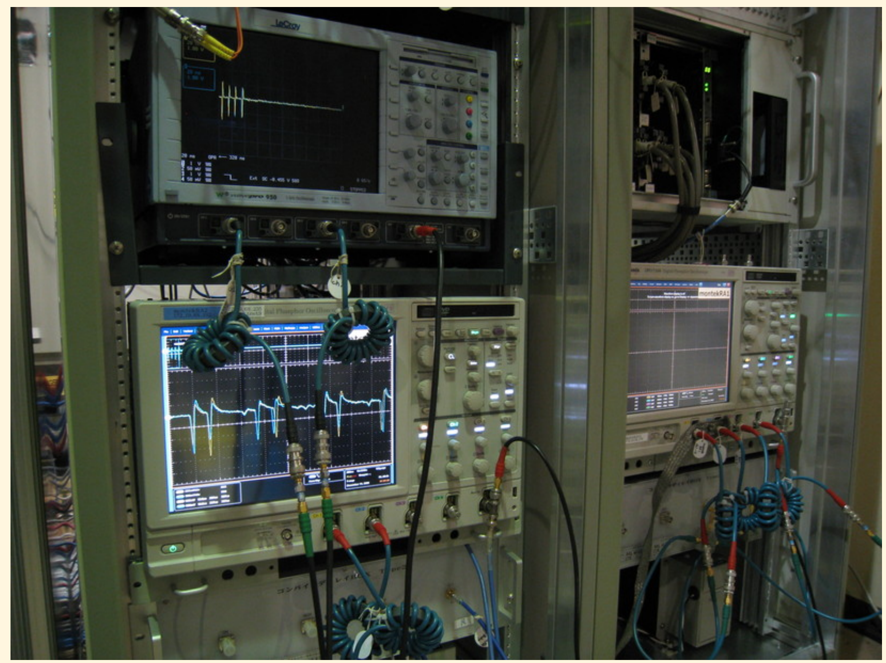




BPM

- 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.





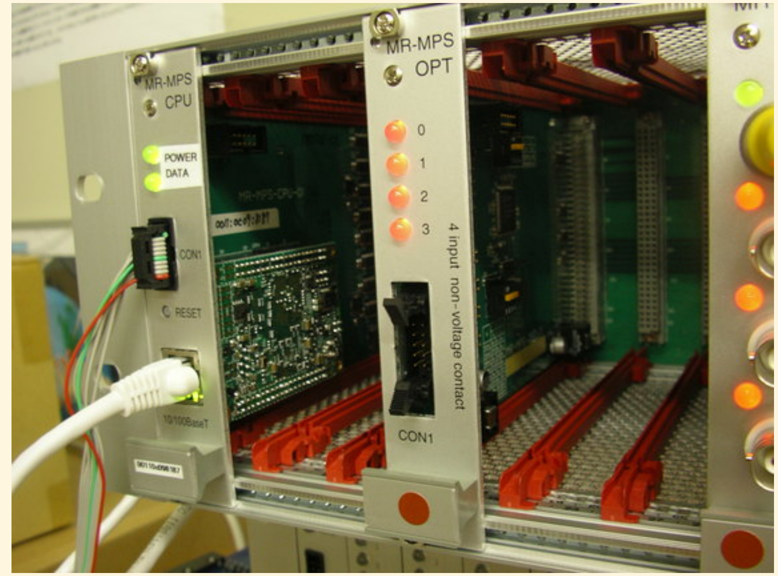
Parameters

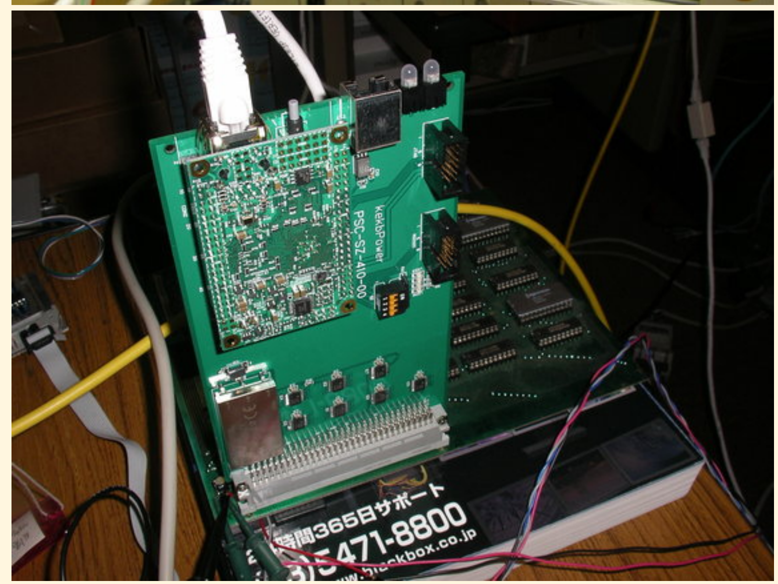
- Parameters switching via Event system
  - RF Timing x~35
  - LLRF x~11
  - Gun voltages, fast delays, x4
  - Pulsed magnets x~12
  - Injection system x~4
  - BPM over channel access x~100
- Basically sufficient for fast beam mode switching
- More parameters next year
- Integrity monitors
- Improved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

Embedded EPICS with FPGA

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

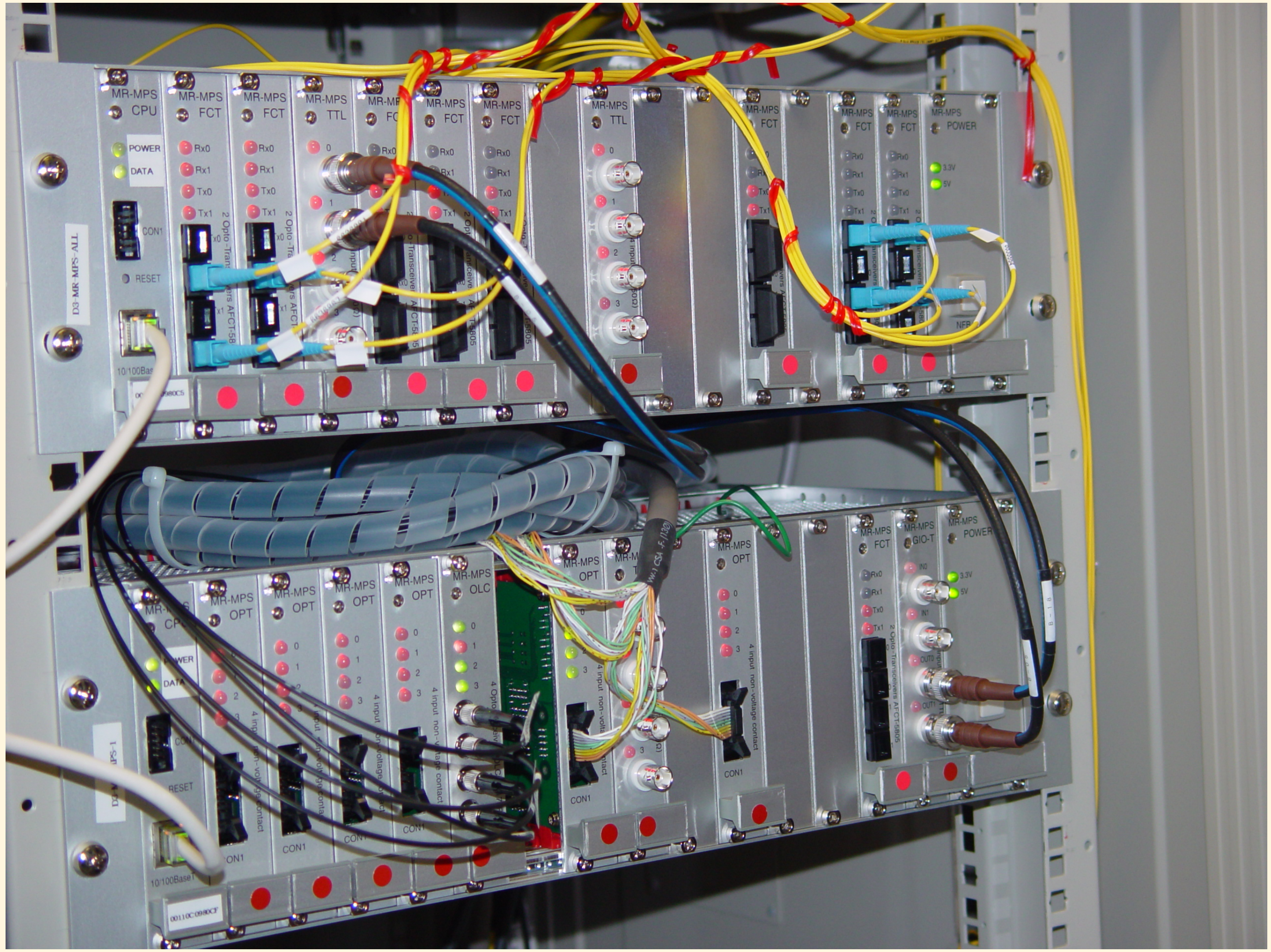
- **J-PARC MPS**
- **KEKB Magnet**
- **Linac RF**





J-PARC MR MPS Operational

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

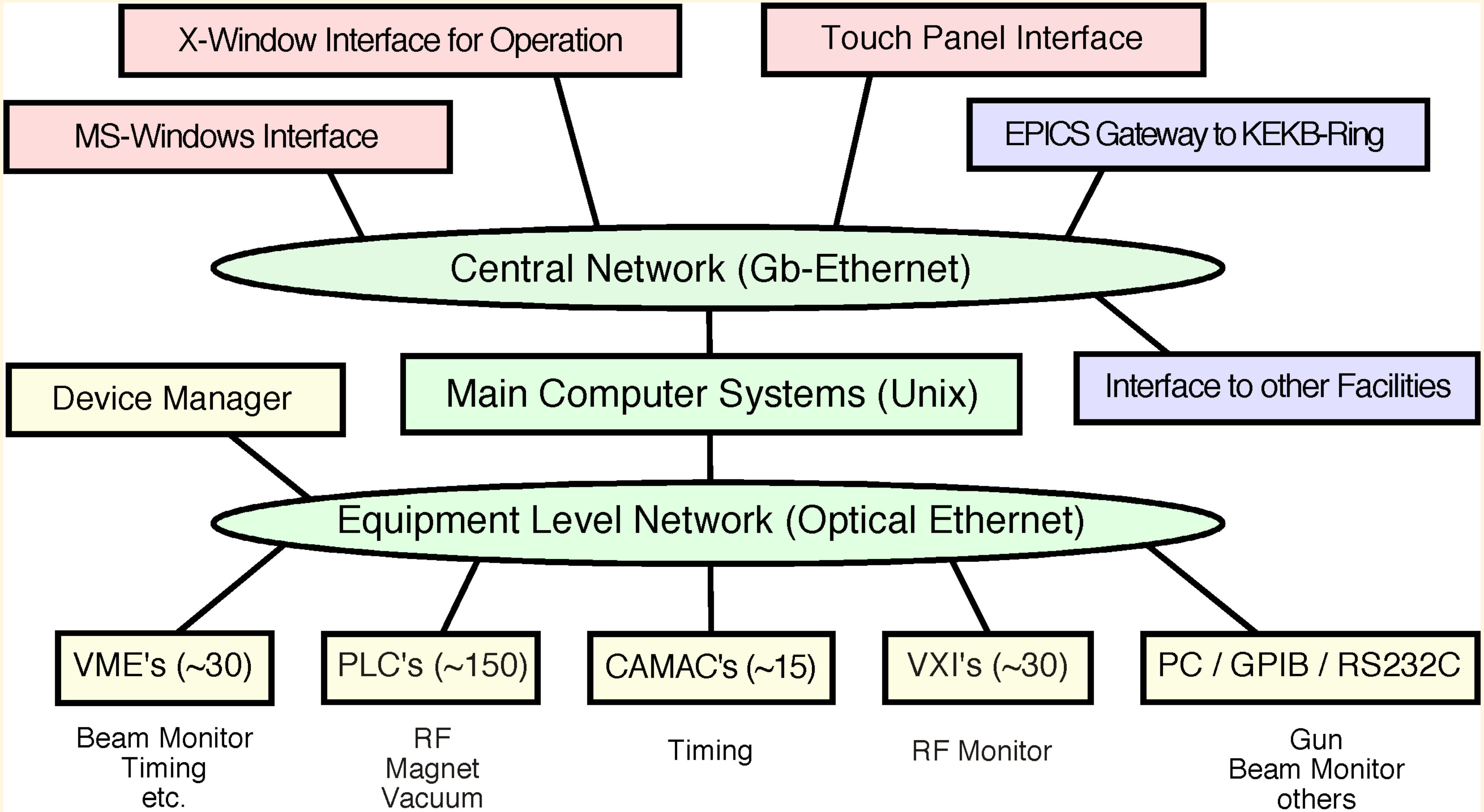


Thank you

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**