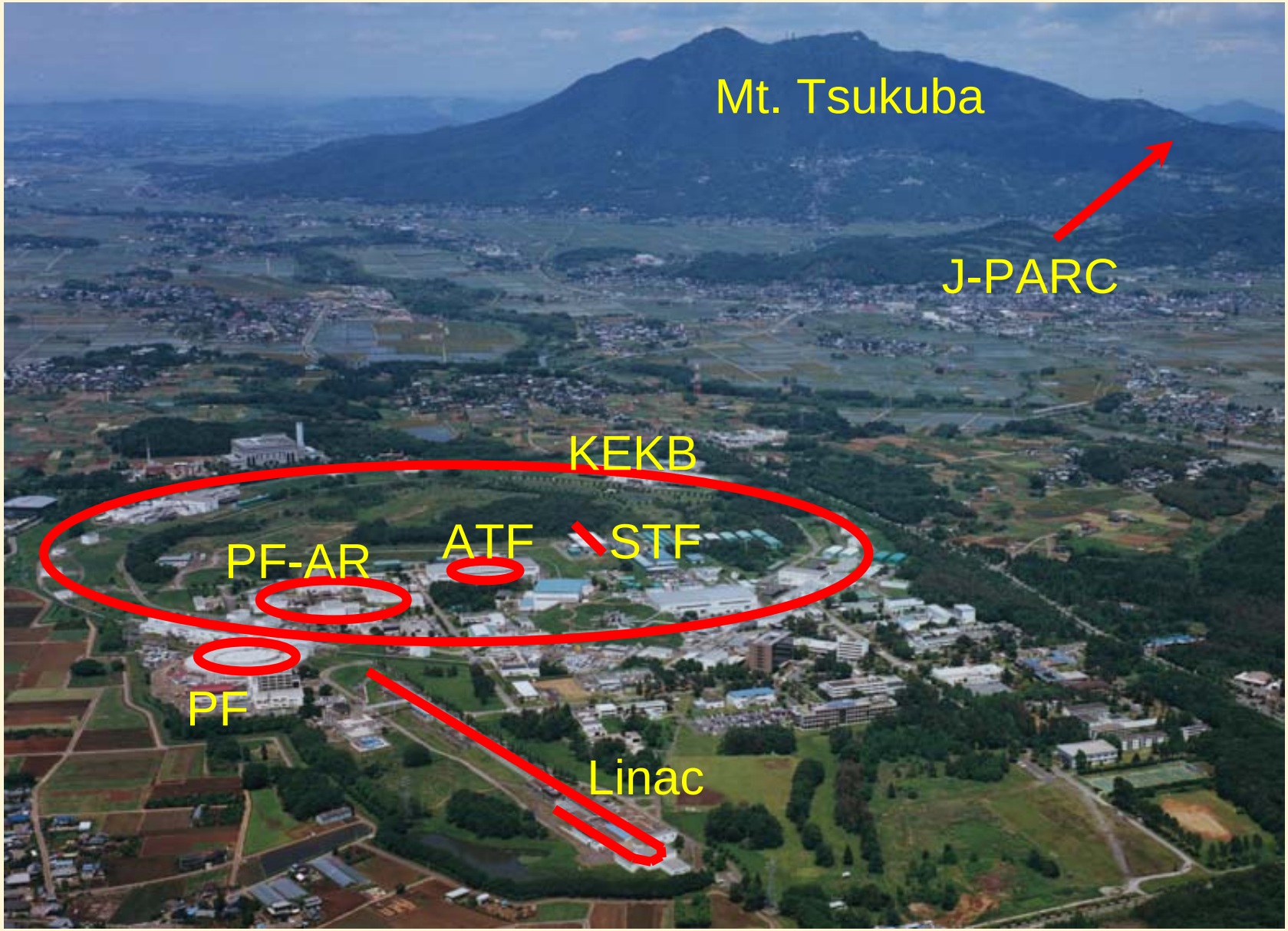
Control System of the KEKB Accelerator Complex

Evolution in several aspects

Kazuro Furukawa, KEK

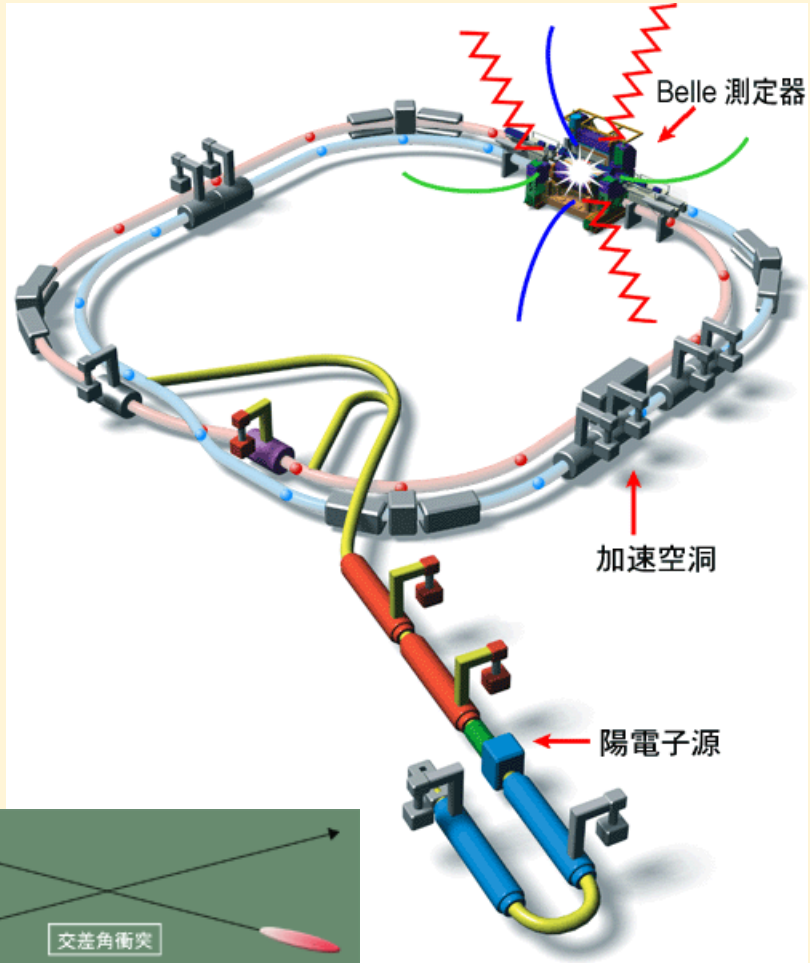
KEKB Control Group

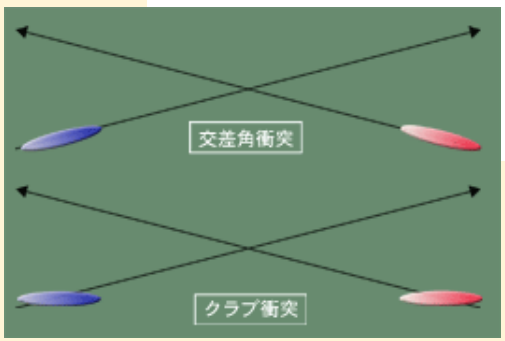
Linac Control Group


Mt. Tsukuba
J-PARC
KEKB
ATF
STF
PF-AR
PF
Linac

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



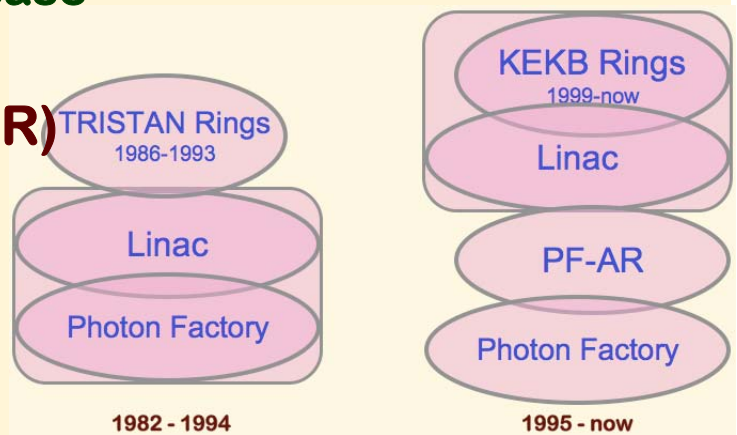


Increase of Luminosity with Crab Cavities

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
- Division changed at the end of Upgrade
- 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
- 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)
  - 30 VXI for rf measurement
  - 5 VME / 10 CAMAC for Timing
  - 20 VME for Beam monitors
- 2006~ (upgrade of BPM readout)
  - 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 ~400MB/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
      - ~2GB/day
    - SADscript-based viewer is one of the most used applications
      - With Data analysis capability, easy manipulations

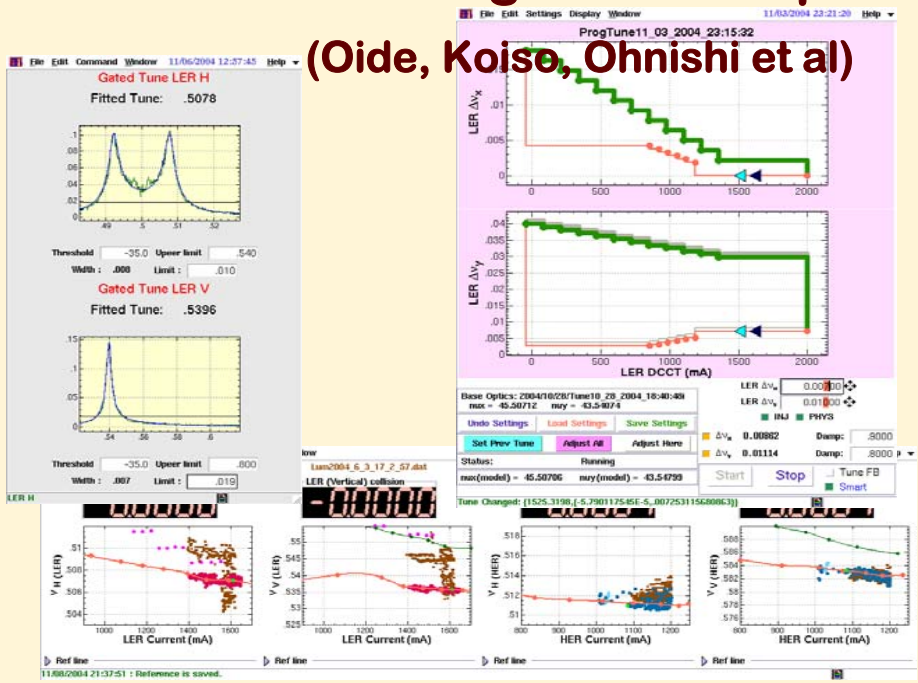
Scripting Languages

- **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

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

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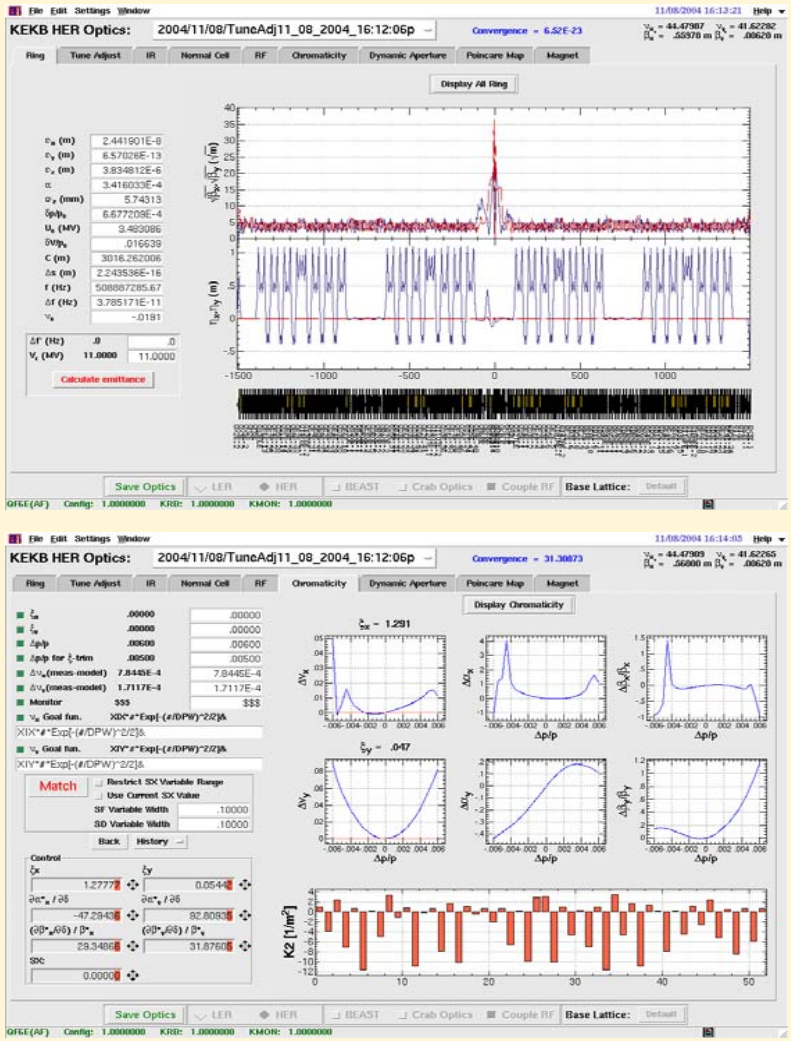


Optics Panels

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

- Linac had slow and gradual modernalization
  - No long Shutdown time, loosing good timing
- KEKB made big transition at the Construction
  - 5-year Shutdown, Big help from EPICS community
  - Runs without much modification ever since
- Control system design needed a balance between many aspects
  - Large and Small group differences
- EPICS and Scripting Languages brought a success to the both KEKB and Linac Beam Operations
- Linac and KEKB groups are ready to share more tasks for the future

Thank you

Thank you

KEKB Control System (Hardware)

- **GbE Fiber Optic Networks**
  - Single Broadcast Domain
  - Central Control Room and 26 Local Control Rooms
- **VME/IOC**
  - ~100 VME/IOC mostly with PowerPC CPU
- **Field bus**
  - ~200 VXI thru MXI for BPM Instrumentations
  - ~50 CAMAC for rf and Vacuum (inherited from TRISTAN)
  - ~200 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)

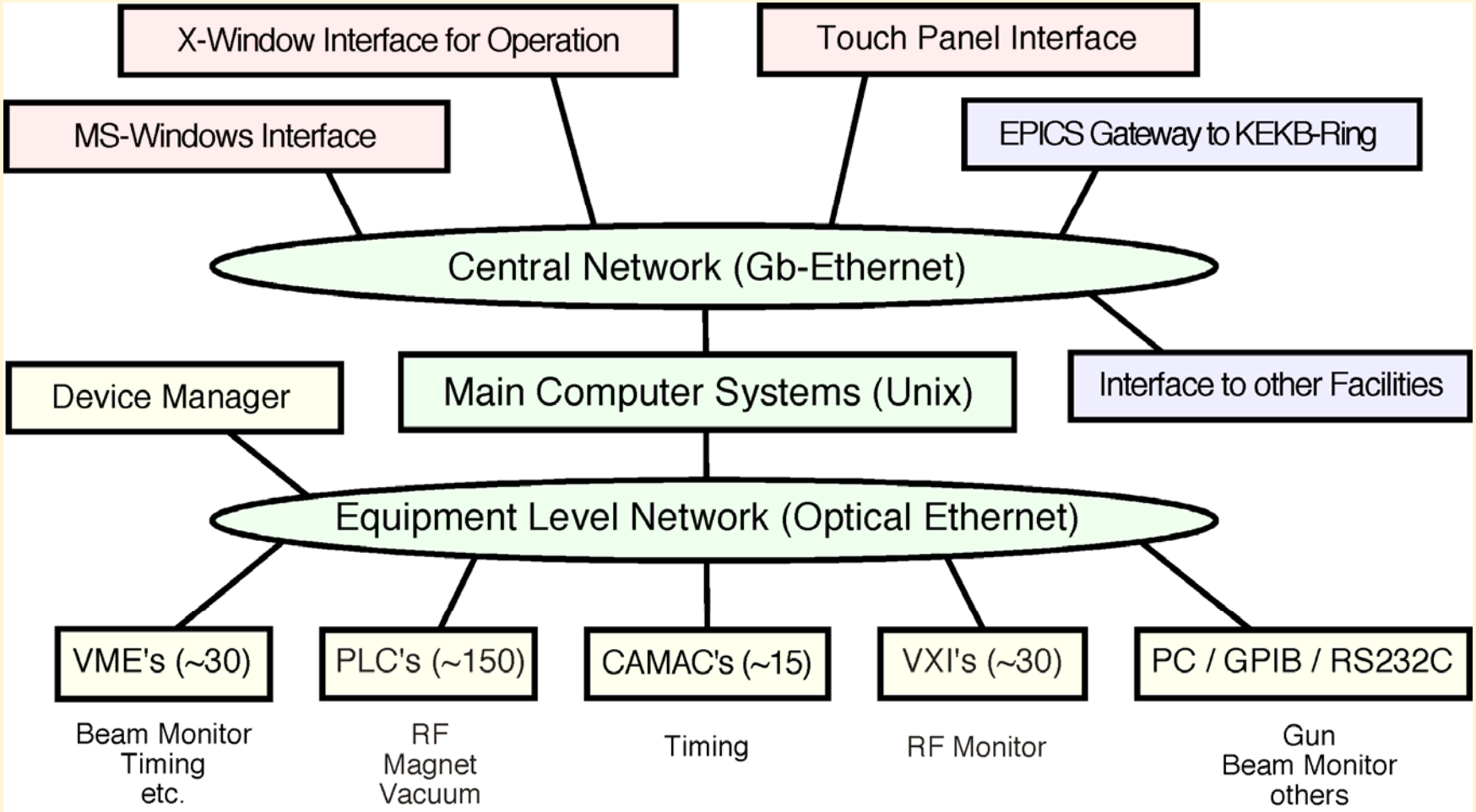
- EPICS 3.13.1 and 3.14.6,8
- VxWorks 5.3.1 mainly, and 5.5.1
  - Hope to upgrade EPICS/VxWorks Shortly
- IOC Development
  - CapFast, (VDCT) Perl, SADscript for Database Configuration
  - Oracle as a backend Database Management
    - Migration towards Postgresql
- Operational Application Development
  - MEDM(DM2k) for Startup
  - Python/Tk for Equipment Controls
  - SADScript/Tk for Beam Operation, etc

Linac; 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 (inherited by J-PARC as well)
  - Both of above should make future upgrade easier
  - (EPICS was not available widely at that time)

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**

EPICS

- Now is a kind standard, but …
- Object-oriented design support
  - Naming scheme, and/or design of new record
  - More software-engineering support favored
    - Several different efforts to provide better environment
      - Java IOC (M. Kraimer), Control system studio (M. Clausen), Data access (R. Lange)
- Security mechanisms
  - User, Host-based protection available
  - More security
    - Dynamic controls of security
    - Access logging
- Dynamic configuration of database
  - Dynamic creation / loading of records
  - Dynamic removal of records
    - Maybe some part of the codes can be shared with redundant-IOC project

Magnet Controls

- It is typical controls and still many things to do
- Many magnets and many power supplies
  - No one-to-one correspondence
  - Which hardware interface to use
- Procedures
  - Interlock status, on/off, analog with some precision, etc
  - Energy, kick - field - current conversions
    - How to represent those conversion curves
  - Timing synchronous operation
    - for tune change, orbit correction, etc.
  - Standardization

Phronesis

- Aristotle's view of wisdom.
- Contrary to Sophia; the ability to understand the universal truth
- Phronesis is the ability to find a way to achieve an overall goodness

Thank you