ERL@CESR Control System

- R. Helmke
- 8-3-2007

Introduction

- We are early in the design of the ERL@CESR control system
  - Most important decisions are yet to be made
  - Solicit expert advice
- Will try to make remarks brief and welcome comments

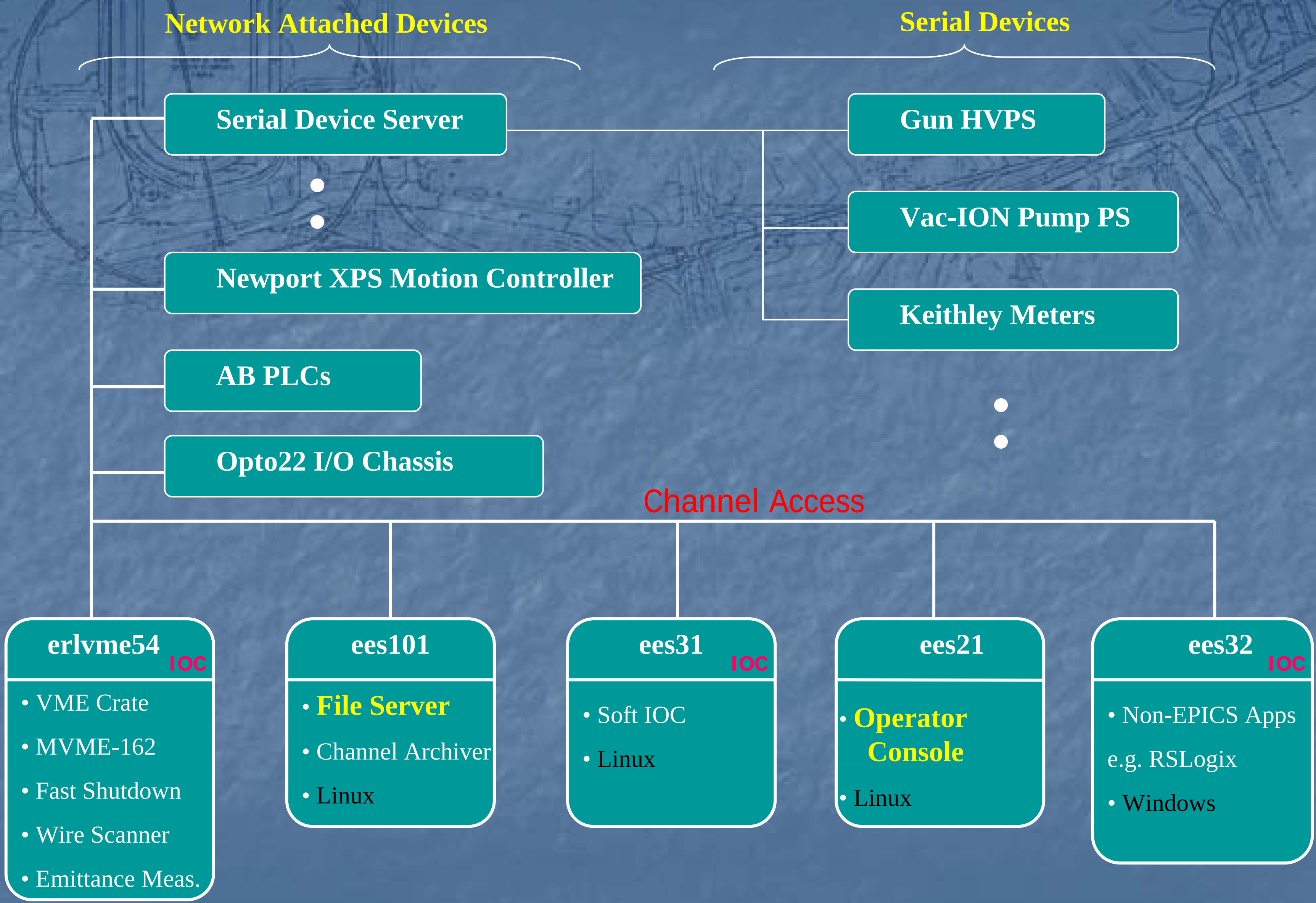
Outline

- Accomplishments with Phase 1A Gun and Injector control systems
- "Perspectives" of the ERL@CESR control system
  - Historical
  - Values
  - EPICS
  - Database
  - Component
  - Network
  - Security/Availability
- Issues and Questions to be addressed

ERL Gun Prototype Control (“W128”)

- Prototype ERL Gun has been constructed in Room W128 Wilson Lab.
- Controls for the Gun and associated instrumentation based on EPICS software.
  - Provided our first significant experience with EPICS and opportunity to assess feasibility of using EPICS for an ERL control system.

Gun Development Lab EPICS Controls



The Gun control system implemented in Room W128 includes the following:

- IOCs
  - Two VME crates with IOC based on a CPU running VxWorks (5.2) and EPICS version 3.13.10.
    - We are using an older model CPU, MVME-162 with limited memory. The limitations of this CPU have led us to use an older version of EPICS.
    - This older version of EPICS works well with other EPICS tools from newer version of EPICS used elsewhere in our controls.
  - Multiple Soft-IOCs running on Linux (Scientific Linux 3), EPICS version 3.14.7

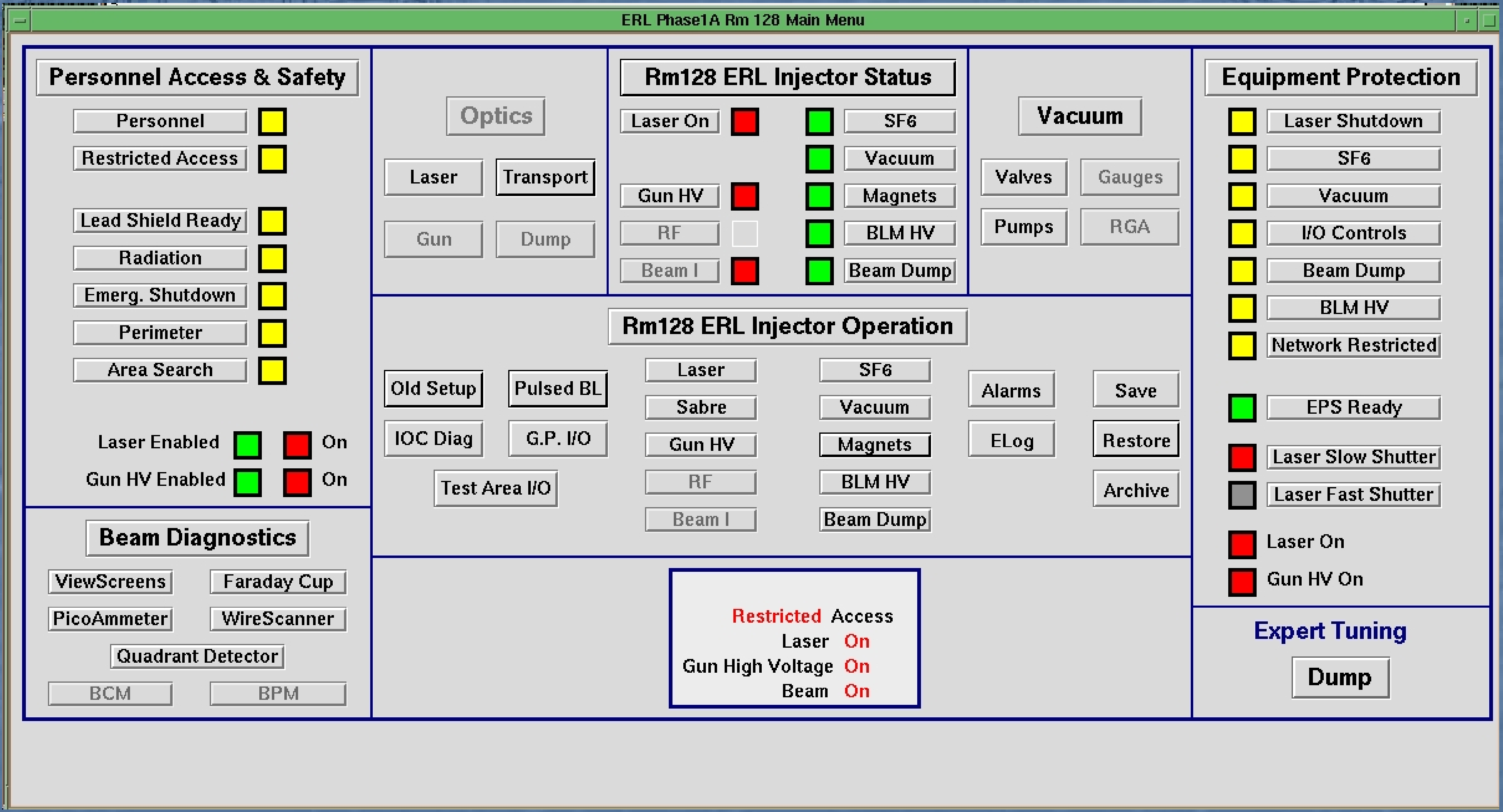
The Hardware used in the control system for Room 128 includes

- **VME** cards
  - Fast Shutdown Monitor, a custom built VME card design to meet the need for a fast machine protection system
  - Oregon Micro Systems VME58 Stepper Motor Controller
  - Industry Pack Modules for Analog Input and Output, Encoder Input, and AC Line Synchronization
  - CESR Timing System cards
- Devices connected via **Serial** Communications links (virtual serial links via MOXA Ethernet serial device server)
  - Vacuum Ion Pump controllers, Gamma MPC, EOS-900
  - Keithley Voltage and Current Meters
  - Gun HV Power Supply
  - Nova II Laser Optical Power Meter
  - Sabre Argon Laser
  - AVR8000 Video Switch
  - Leybold IM540 Ionization Gauge Controller
  - Omega Temperature Process Controller
- **Network** Connected Devices
  - Allen Bradley ControlLogix PLCs
  - Opto22 Modular I/O
  - Newport XPS Motion Controller

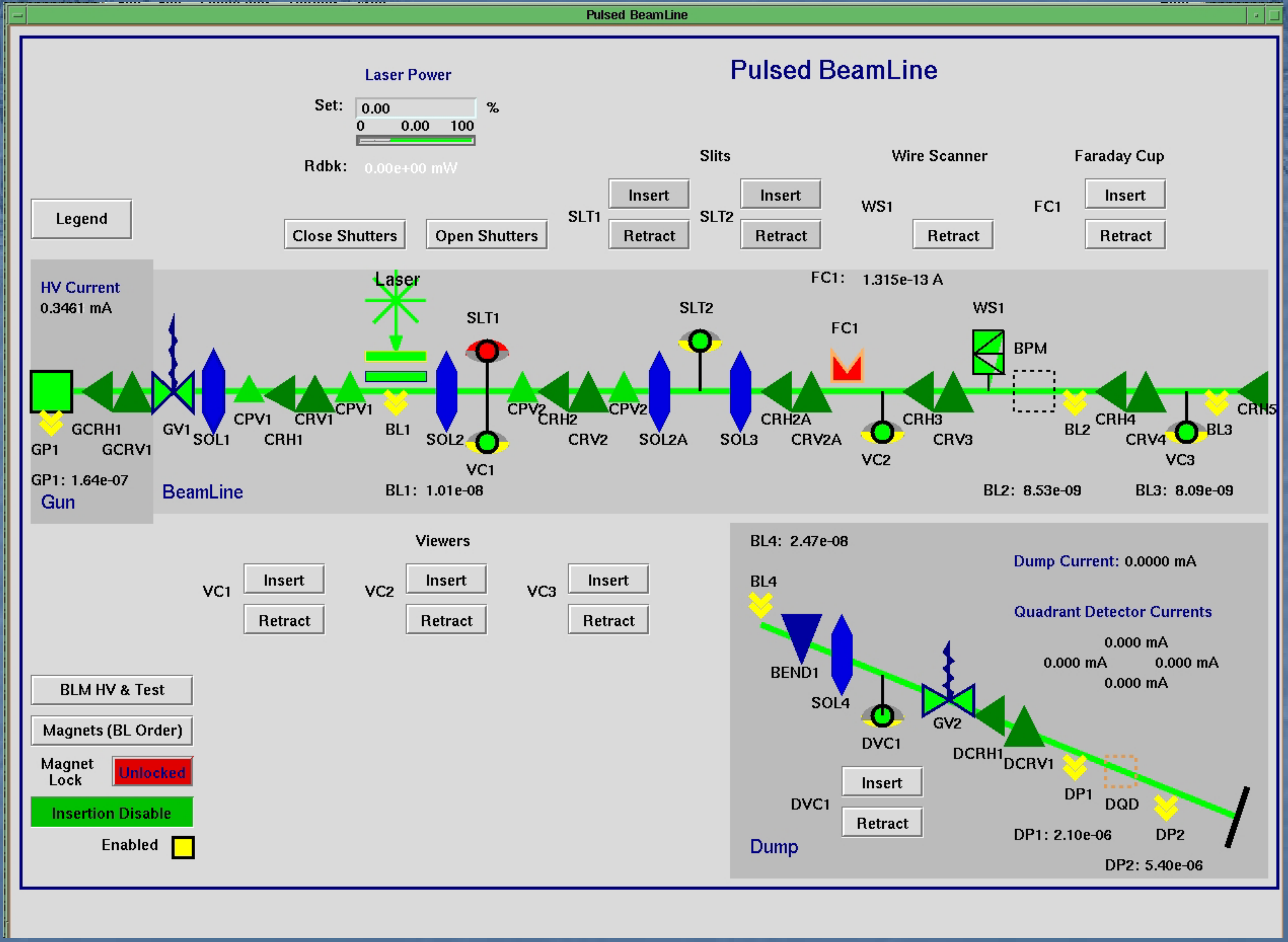
Non-EPICS Software

- Manufacturer supplied software is used along side of EPICS, generally for hardware configuration:
  - RSLogix for **Allen-Bradley PLCs**
  - IOManager for **Opto22** products
  - Nport Administrator Suite for managing **MOXA** serial device servers.
- **Timing System** – Standalone configuration software

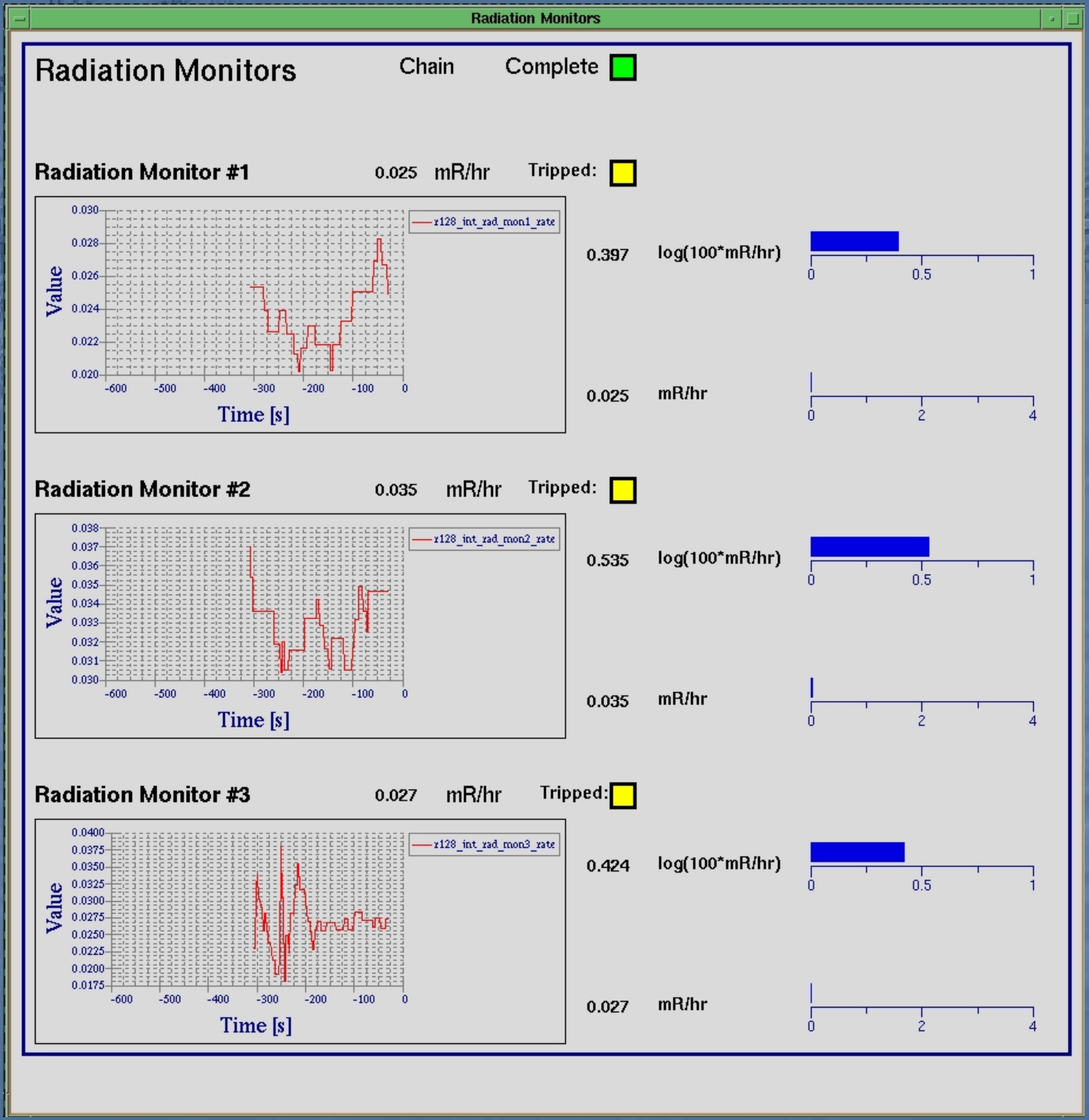
W128 Main Screen



W128 Beamline Screen



Example of EDM Screen



W128 Security

- "**Restricted Mode**"
  - Original goal to "Totally" Isolate W128 Controls when running
  - Needed outside access to operate
  - Conflict with Software development
- Seeking the right **balance** of **security** and flexible **access** for the Ph1a Injector and ERL@CESR

Experience with EPICS in W128 has been positive and successful.

- EPICS IOCs and software tools mostly **problem free**
- Extensive **documentation**
- Console screens created using **EDM** (**GUI** – no code written)
- EPICS **Tech-Talk** (email forum) useful in solving problems

However...

- Even small installation (W128) required **creating device drivers** for new hardware
  - With experience creating an EPICS device driver becomes straight forward
  - software supplied by hardware manufacturer useful as basis of EPICS driver.
- Some control elements in W128 have **not** been **integrated into** the **EPICS** control system:
  - **Viewscreen** Image Acquisition and Processing.
    - Viewscreen images come from traditional analog signal video cameras and Firewire based digital video cameras
    - Signal acquisition and processing is handled by Matlab running on a Windows based PC.
  - **Laser Beam Analyzer**
    - Laser beam profile analyzer instrument with dedicated software application that runs on a Windows PC
  - **Residual Gas Analyzers**
    - Using vendor supplied (non-EPICS) software for readout of RGAs.

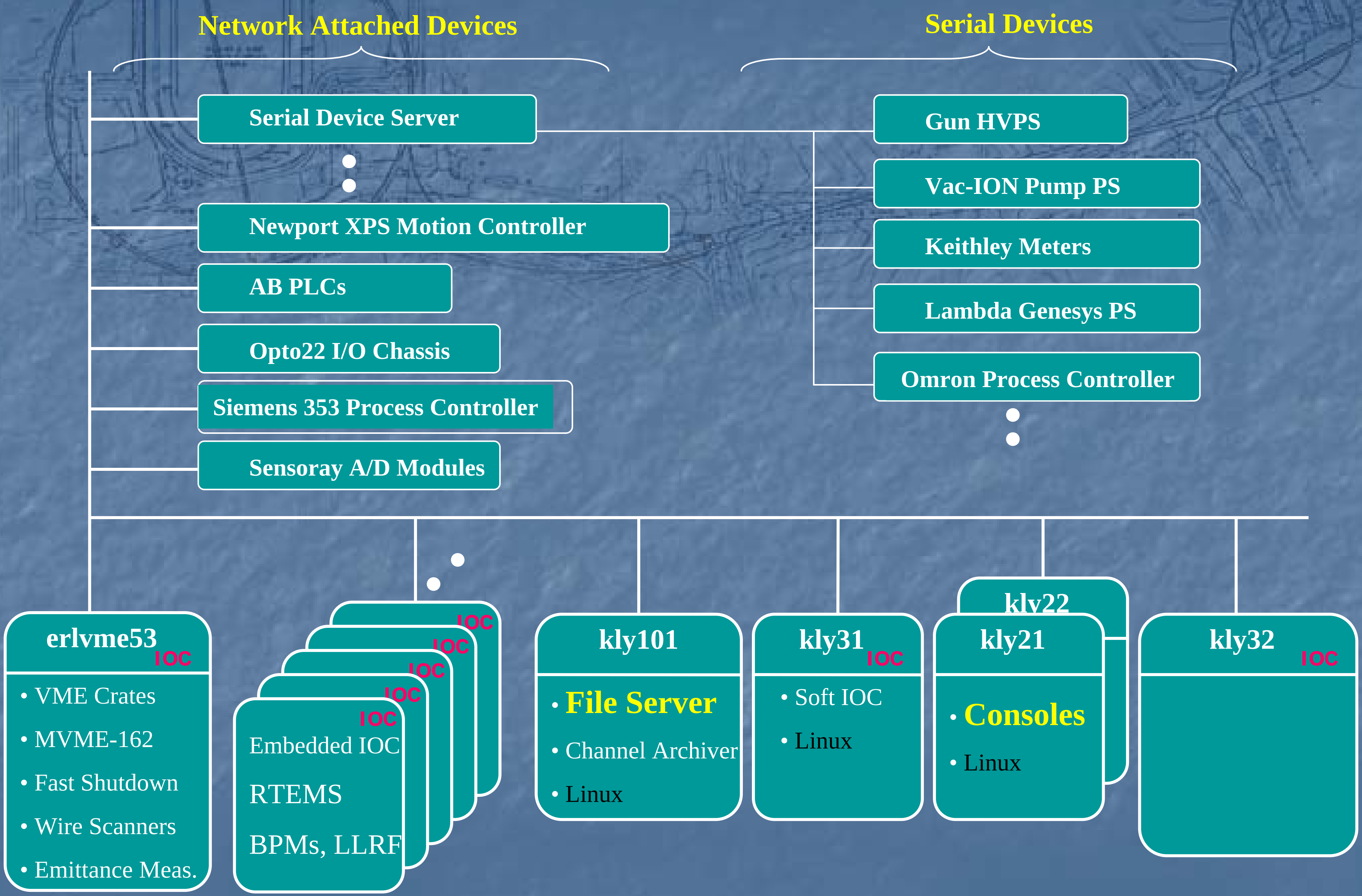
Phase1A Injector Controls Design Objectives

- Second EPICS control system started for ERL Injector prototype to be constructed in Wilson Lab. 'L0'.
  - Operate ERL prototype injector in R/D environment
  - Incorporate W128 Gun Controls
  - Gain further experience with EPICS-based controls

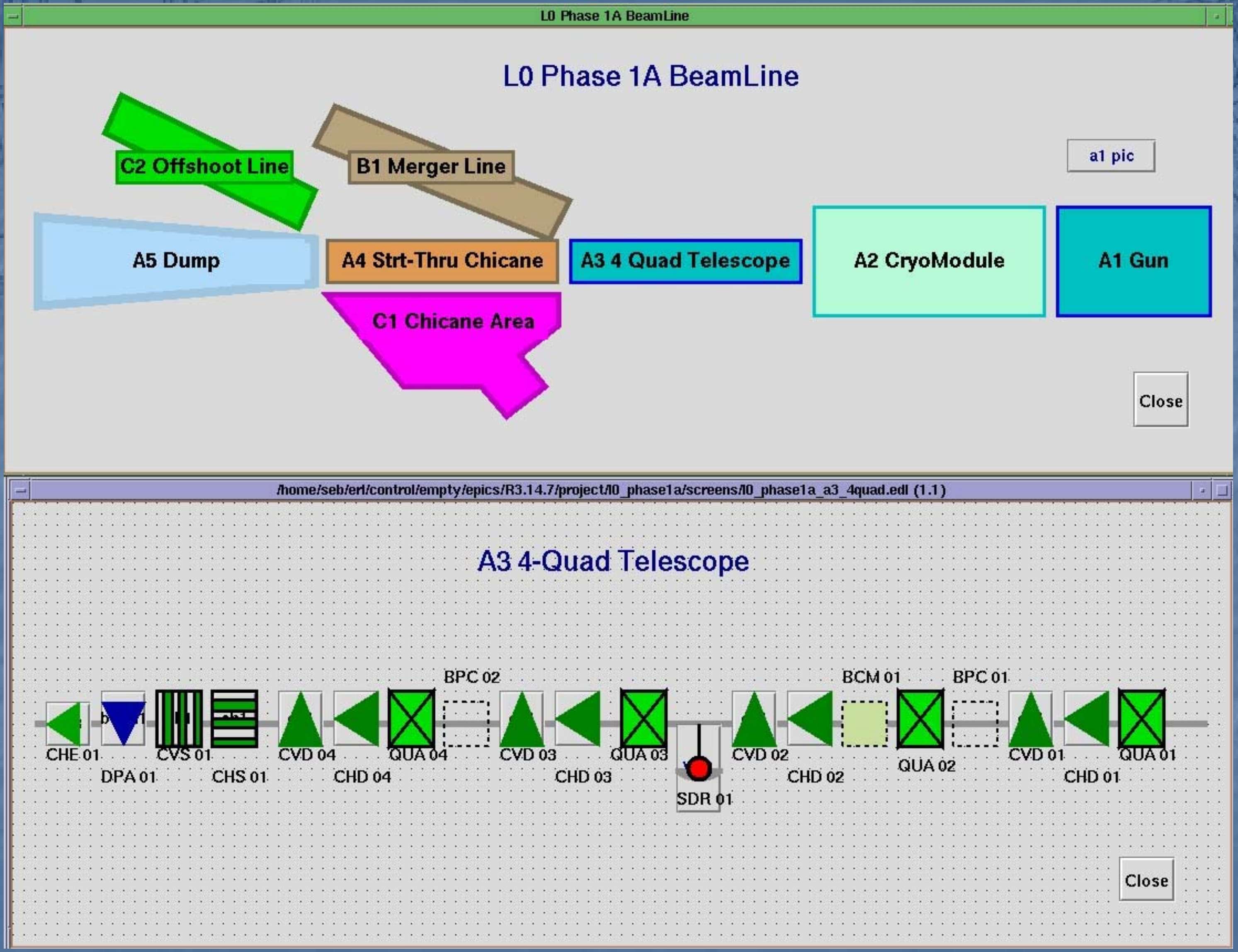
ERL Phase 1a

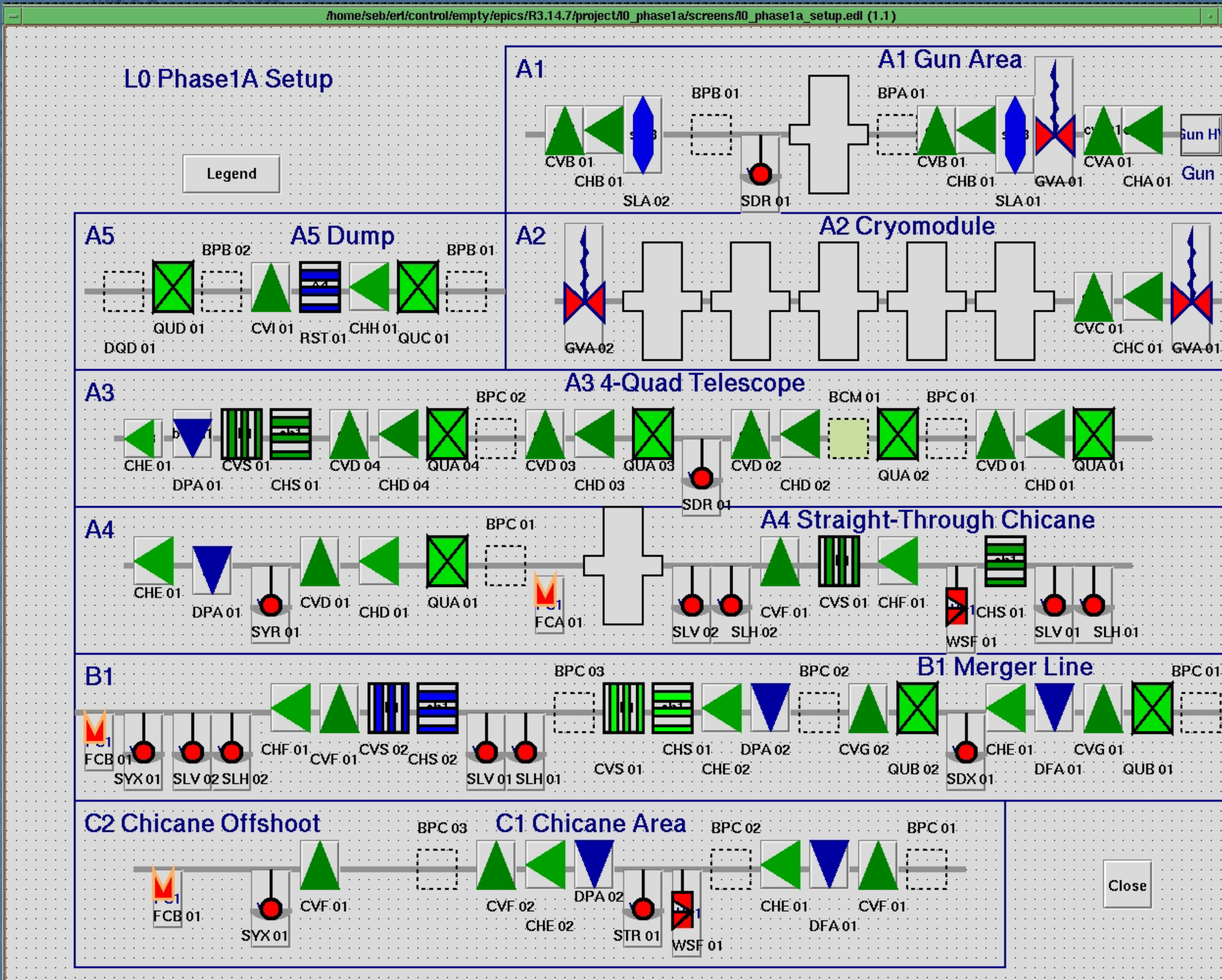
- EPICS controls for Phase 1a will include and expand on the controls created for Room W128:
  - New IOCs
    - **Low Level RF** - The RF Controls for the superconducting RF cavities in Phase 1a will include embedded processors running a real time operating system (**RTEMS**) and an EPICS IOC. This will require additional expertise for running RTEMS and EPICS on the embedded processor, uCDIMM 5812. [already in use at other facilities]
    - **Laser Beam Analyzer** - The hardware vendor's software Laser Beam Analyzer (LBA) includes an Active-X server component. In Phase 1a an **IOC** will run on the same computer as the LBA software and access LBA data through **Active-X**. This will require additional expertise for running EPICS on Windows.
  - New Hardware Types
    - Low Level RF Controllers (embedded IOC, see above)
    - Siemens/Moore 353 Process Controller (network connected device readout via MODBUS/TCP)
    - Allen-Bradley CompactLogix PLCs (Cryo)
    - Sensoray 2519 analog data acquisition modules (network enabled)
    - Lambda Genesys DC Power Supplies (serial communications device)
    - Emerson Commander SE Variable Speed Motor Controller (serial communications device)
    - VME Cryogenic Temperature Sensor Card (a VME card built for CESR)
    - Note that EPICS device drivers have been created for these items as part of the preparations for the Horizontal Test Cryomodule.
  - Preparations for ERL Phase 1a also include a **new control room** with multiple EPICS operator consoles.

Phase 1a Injector Controls

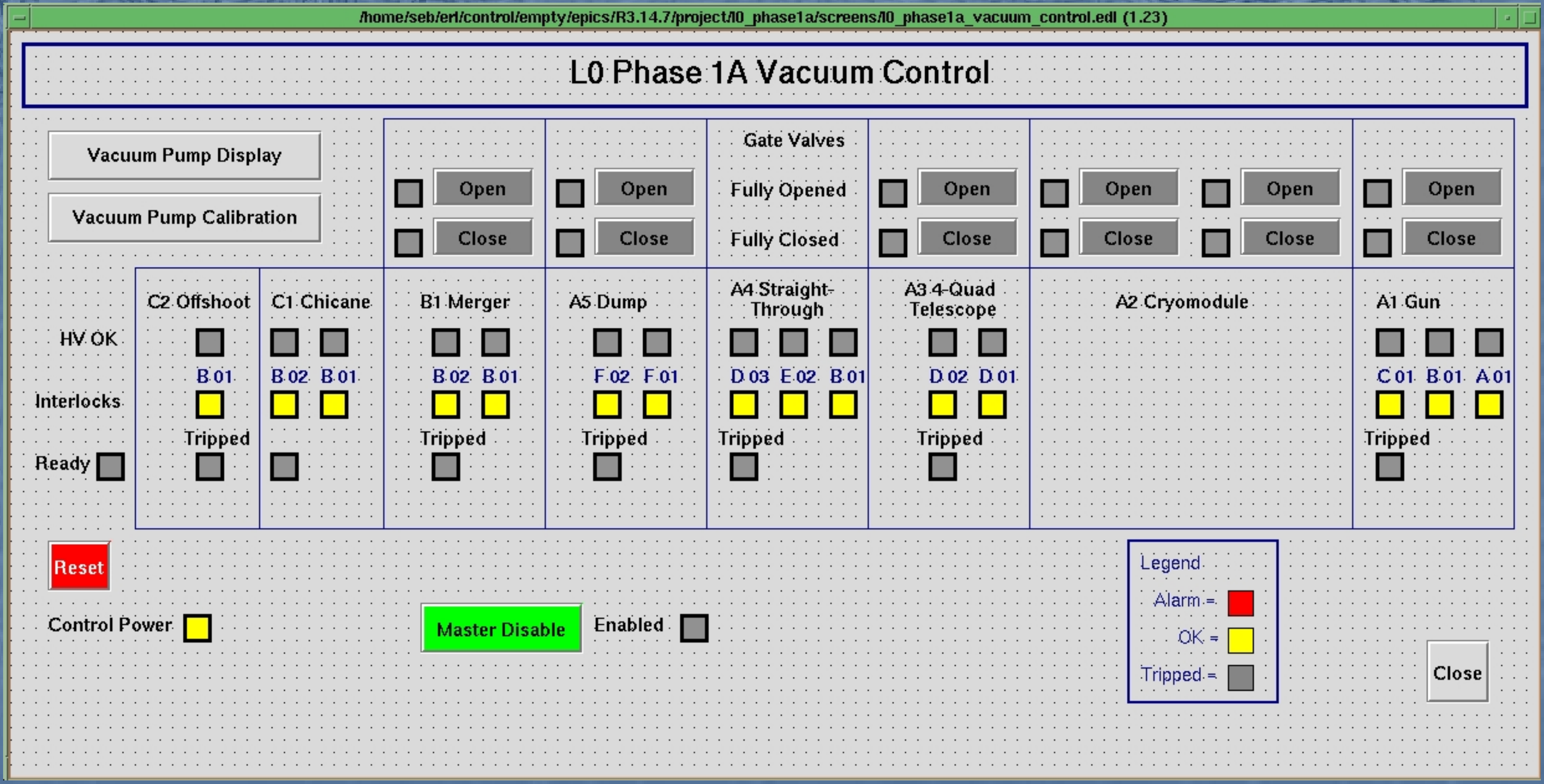


Ph1A Console Display

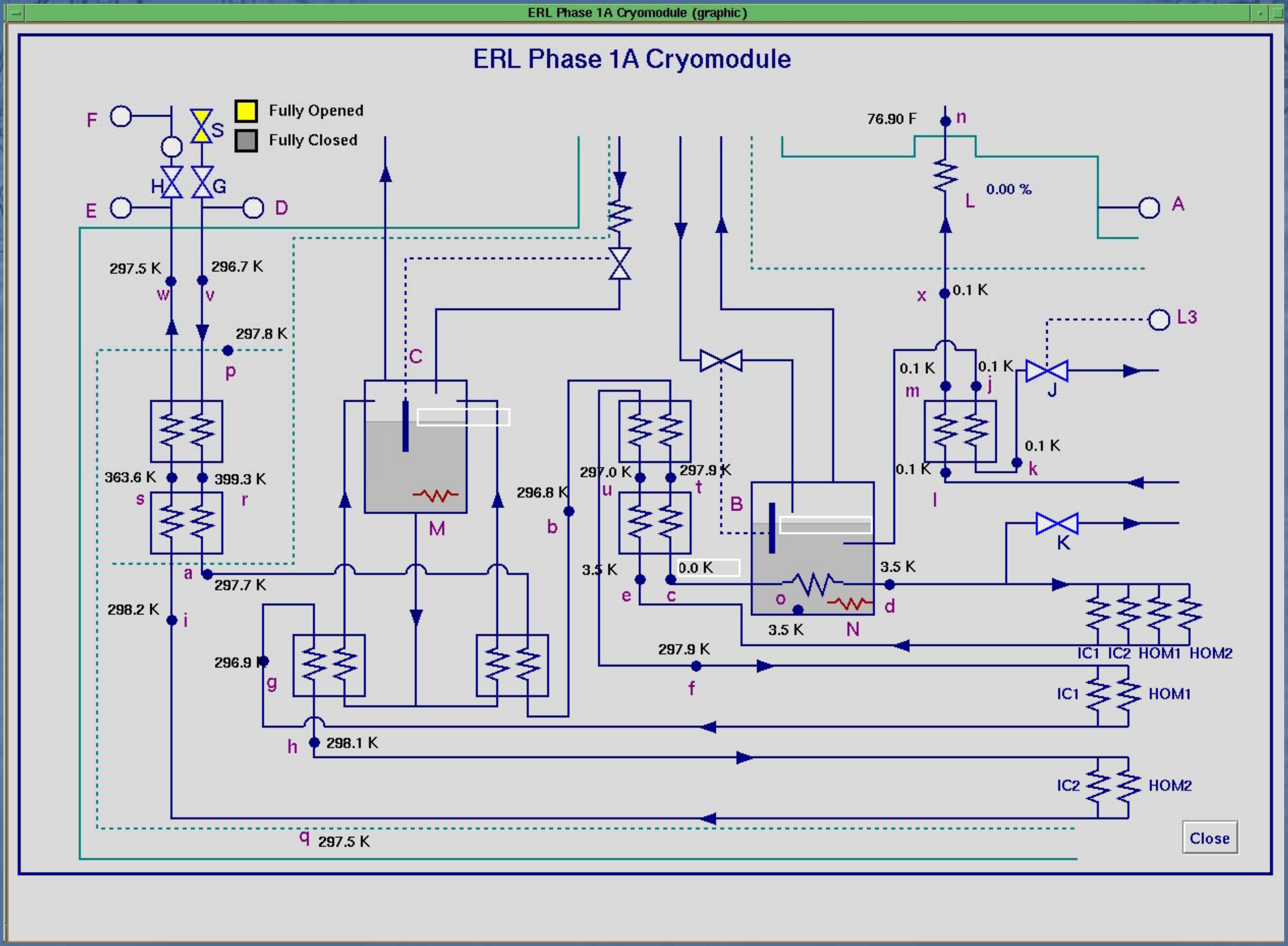



/home/seb/erl/control/empty/epics/R3.14.7/project/l0_phase1a/screens/l0_phase1a_setup.edl (1.1)
L0 Phase1A Setup
Legend
A1
A1 Gun Area
BPB 01
BPA 01
CVB 01
CHB 01
SLA 02
SDR 01
CVB 01
CHB 01
SLA 01
GVA 01
CVA 01
CHA 01
Gun
A5
A5 Dump
BPB 02
BPB 01
QUD 01
DQD 01
CVI 01
RST 01
CHH 01
QUC 01
A2
A2 Cryomodule
GVA 02
CVC 01
CHC 01
GVA 01
A3
A3 4-Quad Telescope
BPC 02
BCM 01
BPC 01
CHE 01
DPA 01
CVS 01
CHS 01
CVD 04
CHD 04
QUA 04
CVD 03
CHD 03
QUA 03
SDR 01
CVD 02
CHD 02
QUA 02
CVD 01
CHD 01
QUA 01
A4
A4 Straight-Through Chicane
BPC 01
CHE 01
DPA 01
SYR 01
CVD 01
CHD 01
QUA 01
FCA 01
SLV 02
SLH 02
CVF 01
CVS 01
CHF 01
WSF 01
CHS 01
SLV 01
SLH 01
B1
B1 Merger Line
BPC 03
BPC 02
BPC 01
FCB 01
SYX 01
SLV 02
SLH 02
CHF 01
CVF 01
CVS 02
CHS 02
SLV 01
SLH 01
CVS 01
CHS 01
CHE 02
DPA 02
CVG 02
QUB 02
SDX 01
CHE 01
DFA 01
CVG 01
QUB 01
C2 Chicane Offshoot
C1 Chicane Area
BPC 03
BPC 02
BPC 01
FCB 01
SYX 01
CVF 01
CVF 02
CHE 02
DPA 02
STR 01
WSF 01
CHE 01
DFA 01
CVF 01
Close

Vacuum Status Screen



Cryo Screen



ERL Phase 1A Cryomodule (graphic)
ERL Phase 1A Cryomodule
Fully Opened
Fully Closed
F
S
H
G
E
D
76.90 F
n
L
0.00 %
A
297.5 K
w
296.7 K
v
x
0.1 K
L3
297.8 K
p
C
0.1 K
m
0.1 K
j
J
0.1 K
k
0.1 K
l
363.6 K
s
399.3 K
r
296.8 K
b
297.0 K
u
297.9 K
t
B
M
K
a
297.7 K
3.5 K
e
0.0 K
c
3.5 K
o
d
298.2 K
i
3.5 K
N
IC1 IC2 HOM1 HOM2
296.9 K
g
297.9 K
f
IC1
HOM1
h
298.1 K
IC2
HOM2
q
297.5 K
Close

Ph1A Injector Controls Status to date

- W128 Gun Controls
  - in regular use
  - Will be incorporated
- HTC controls just being completed
- Injector Controls ~Half complete
- ~2FTE working on Controls software

Outline

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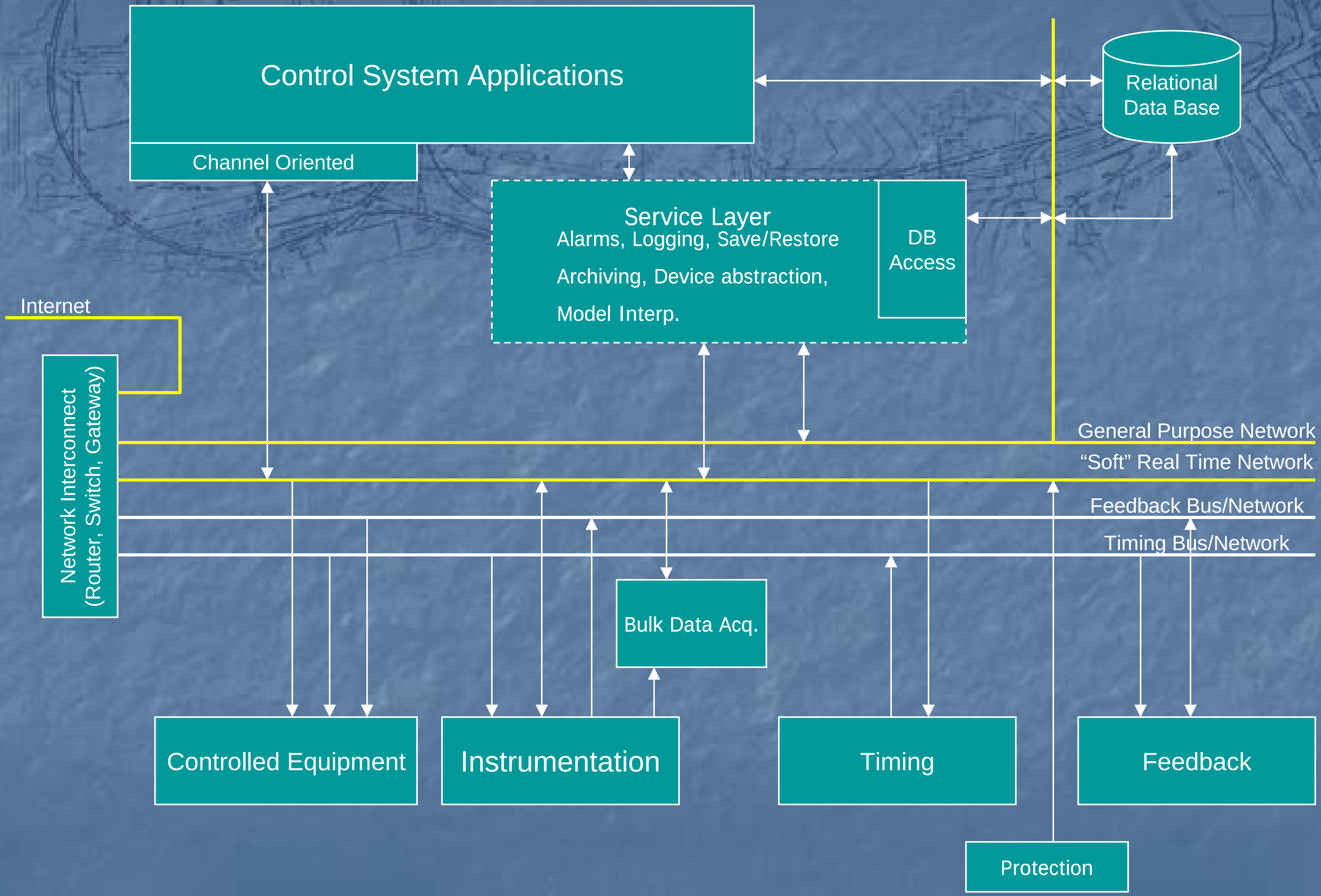
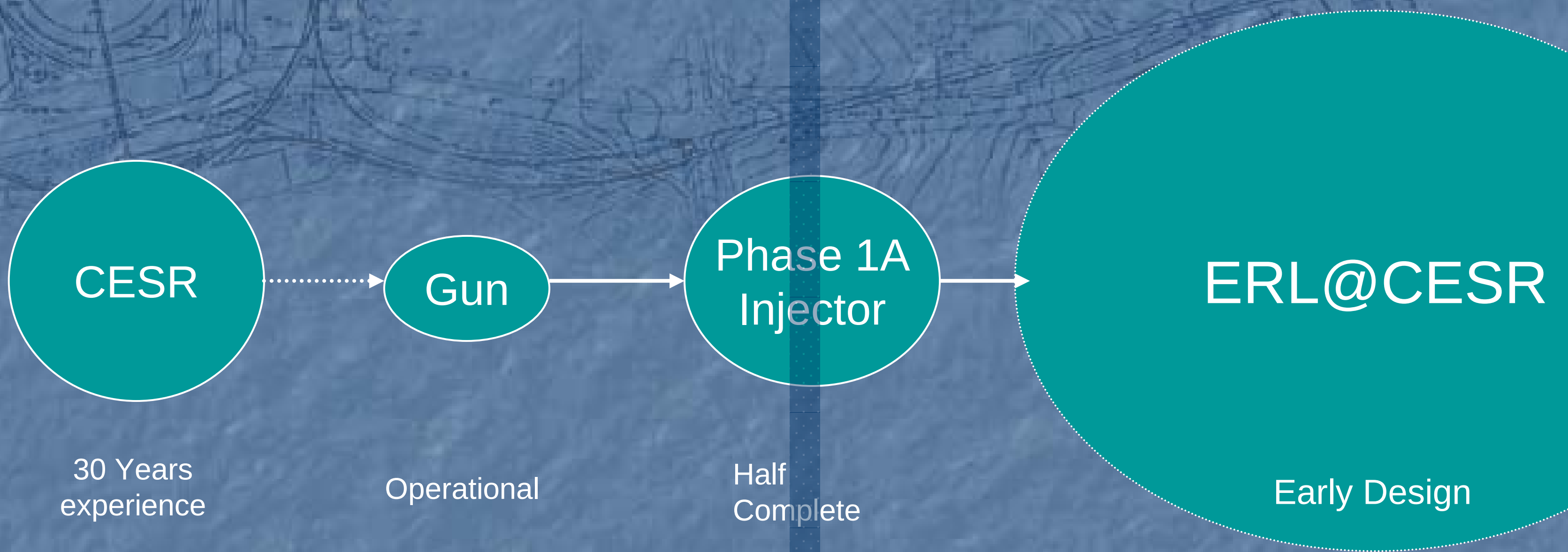
- "Perspectives" of the ERL@CESR control system
  - Historical
  - Values
  - EPICS
  - Database
  - Component
  - Network
  - Security/Availability
- Issues and Questions to be addressed

Control System Schematic

"Standard Model"



Historical Perspective



CESR	Gun	Phase 1A Injector	ERL@CESR
30 Years experience	Operational	Half Complete	Early Design
Proprietary Xbus/MPM Fortran	EPICS	EPICS	EPICS?
<2 FTE Evolved			

Now

SCALE

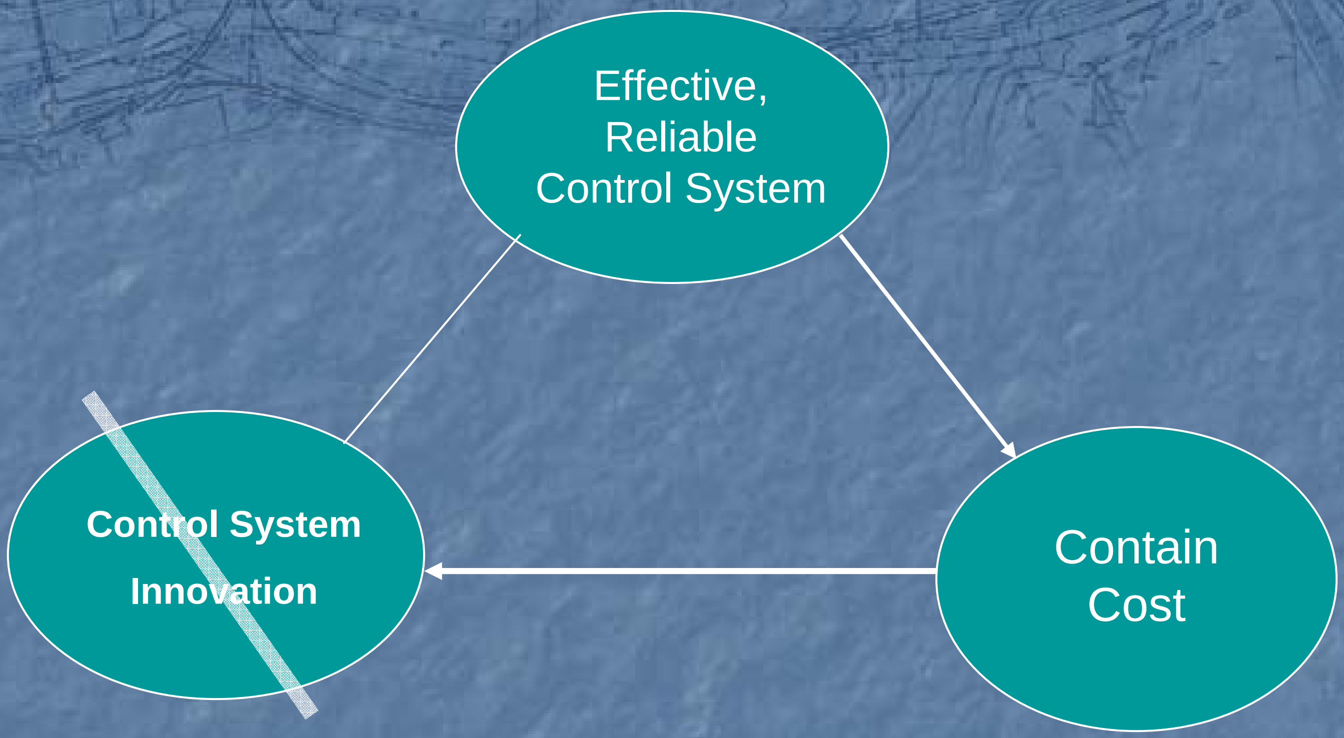
30

3

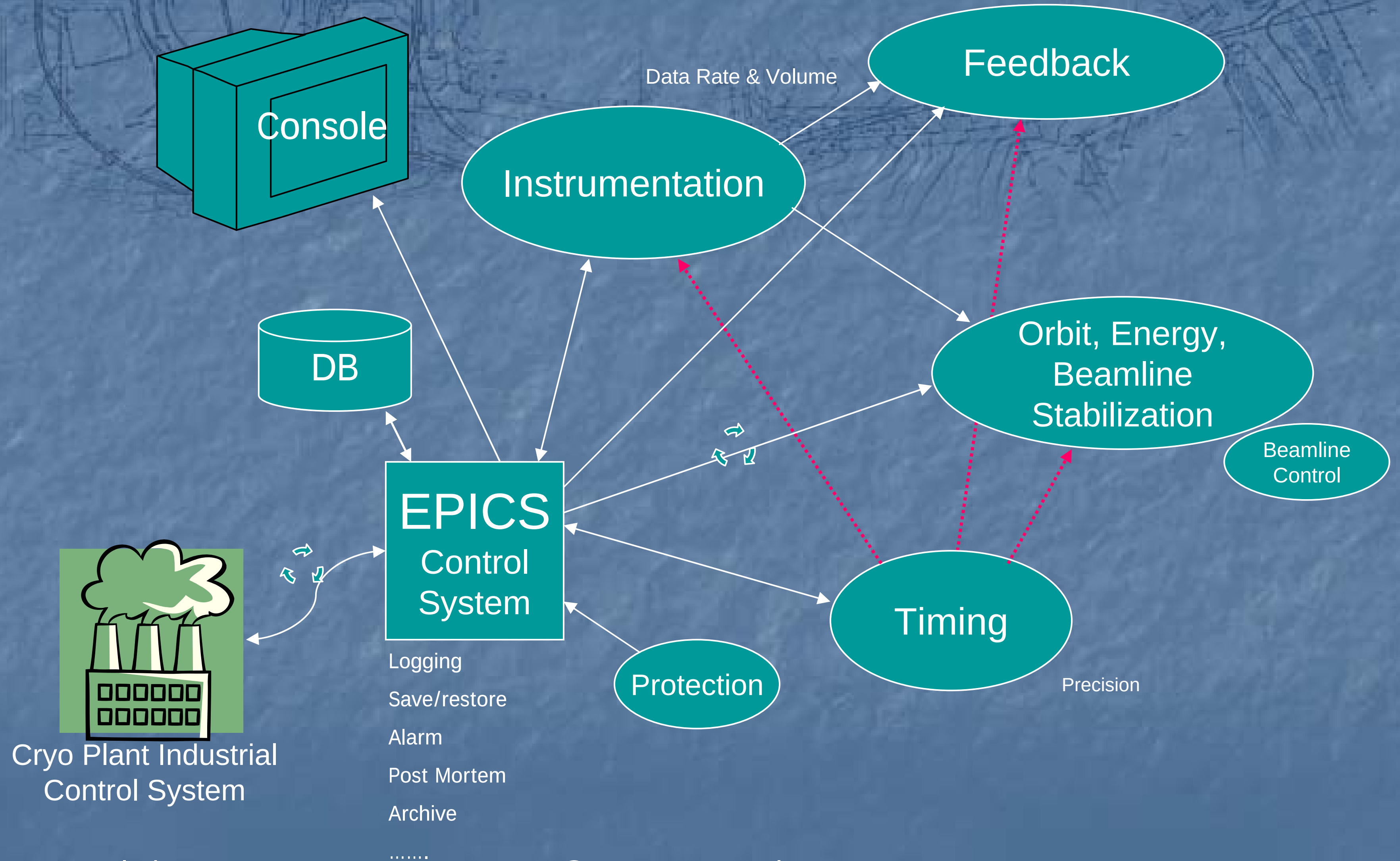
10

100(+)

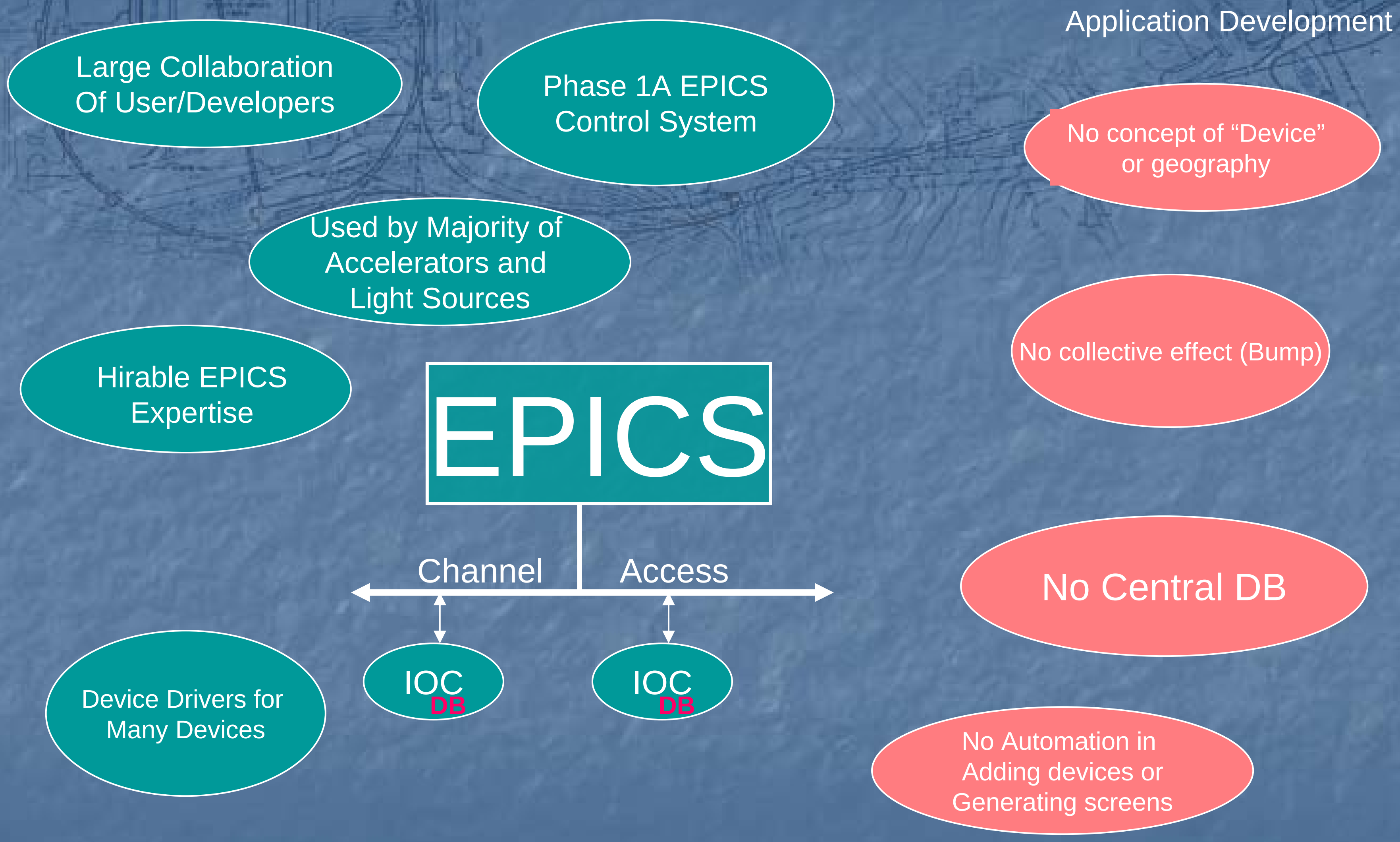
Values Perspective



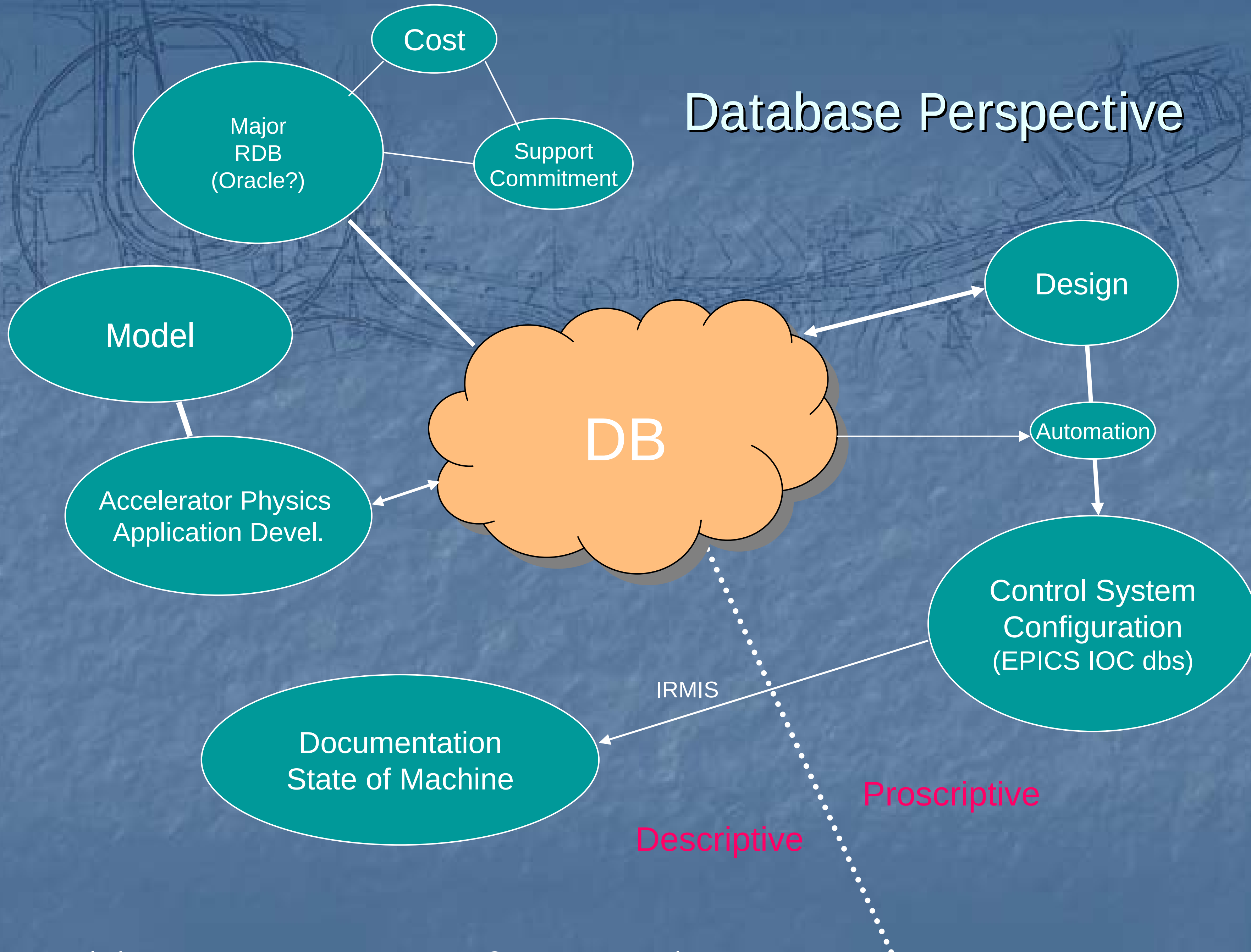
Component Perspective



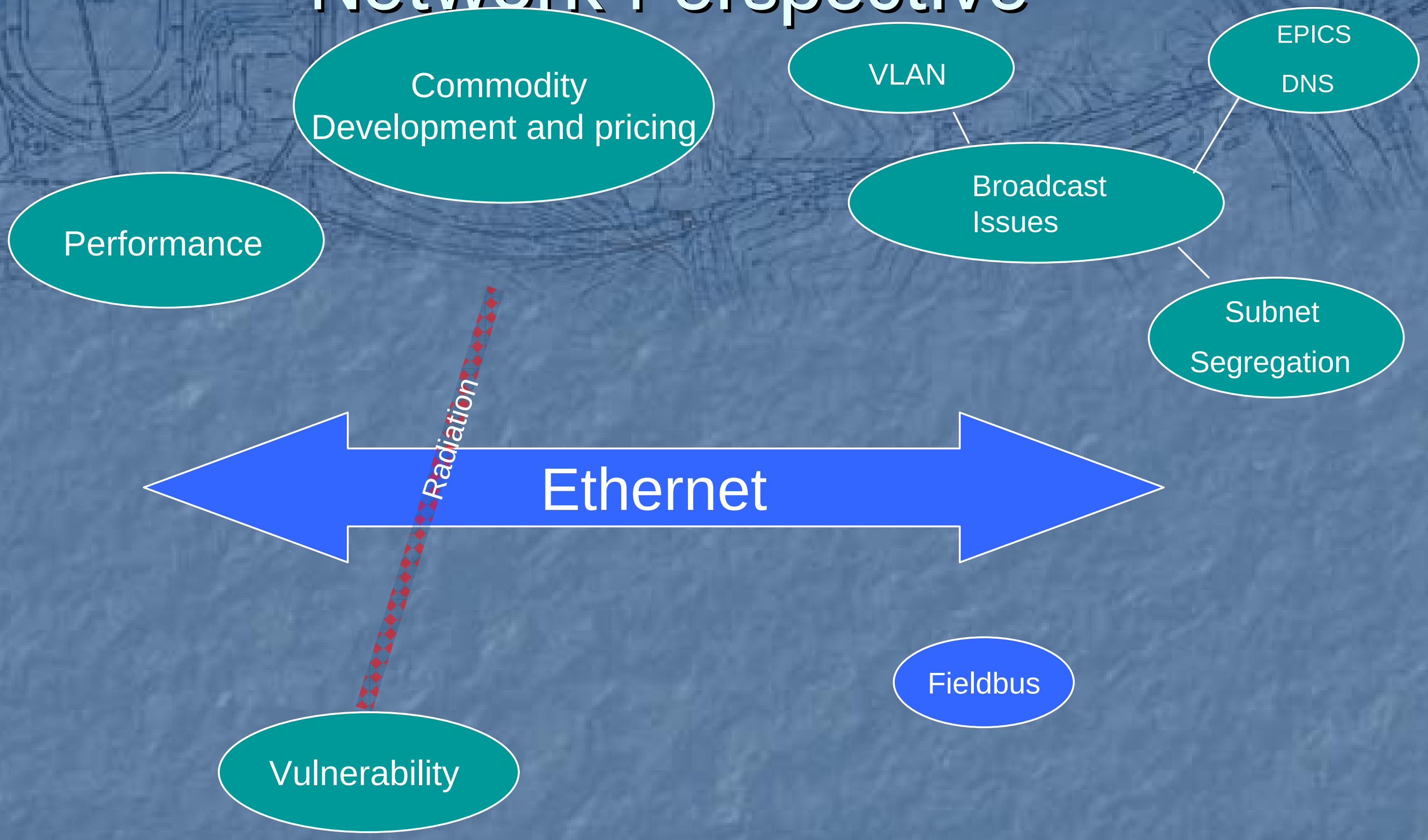
EPICS Perspective



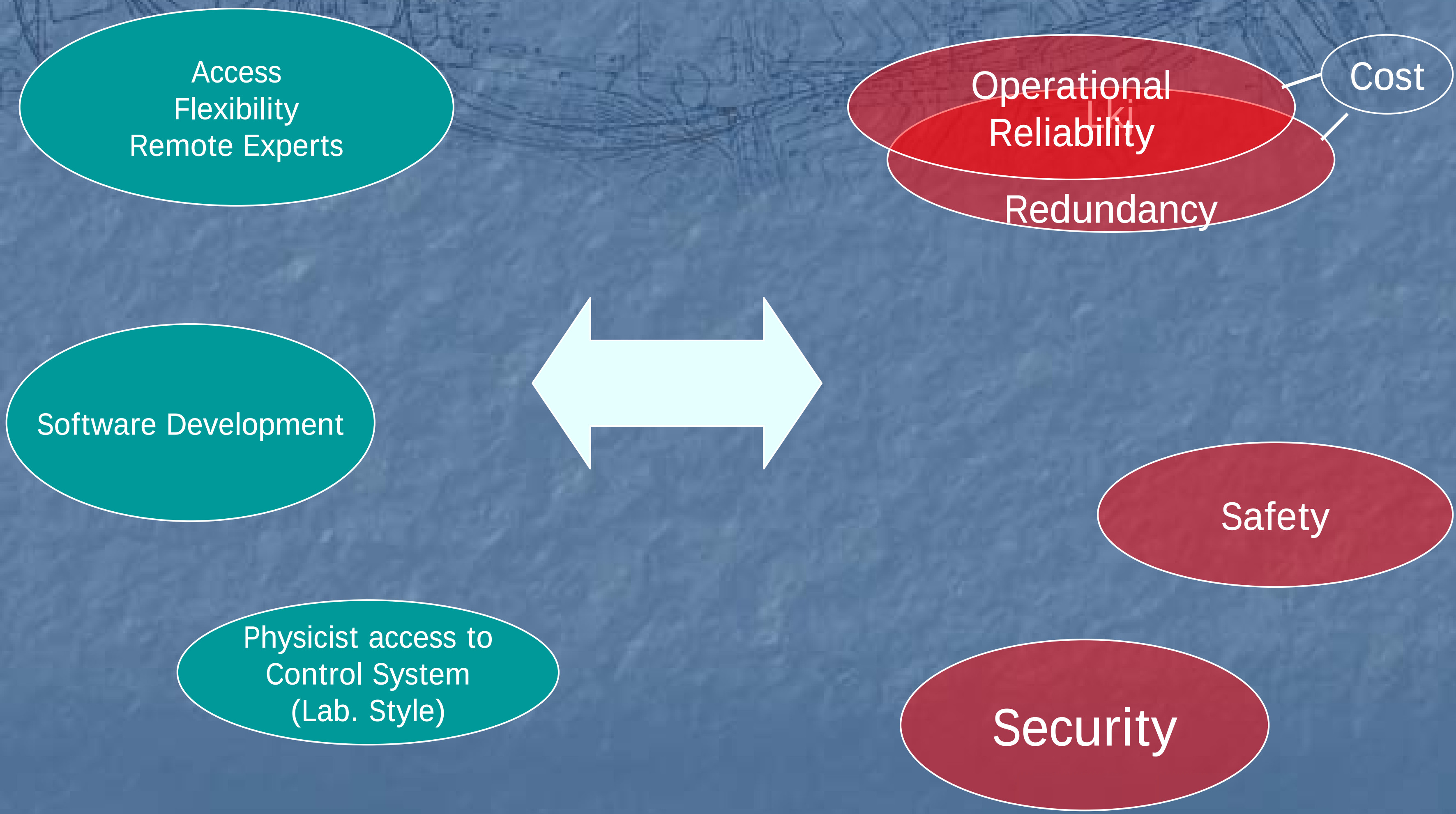
Database Perspective



Network Perspective



Security/Reliability Perspective



Important Issues and Questions to be Resolved

- **ERL vs SR** - Are there fundamental structural aspects of control system design that we must incorporate because we're controlling an ERL instead of a Storage Ring?
- **Database** – What are the costs, benefits, tradeoffs, associated with deploying an RDB for ERL@CESR? If we do, how early and deeply in the design process should this deployment be? What tools should we use for this?
- **Automation** – If we use an RDB, what tools/approach should we use to automate generation of EPICS IOC databases, etc.?
- **Data** – How do we best collect, archive, catalog, and access the large amount of instrumentation, configuration, and simulation data that will be generated?
- **Application Development** – What Tools, Language(s), Approaches should we deploy for sophisticated (e.g. physics) application development?
- **Models/Simulation** – How do we best incorporate models and simulation into our control system?
- **Network Performance** – What steps must we take in deploying our control network to avoid problems of performance, broadcast/multicast congestion, vulnerability to misbehaving network devices or other network concerns?
- **Availability and Reliability** – What measures should we take to ensure adequate availability and reliability? Where should we deploy redundancy?
- **Security** – What is the right balance between security on the one hand and access, flexibility, efficiency on the other? How do we achieve this?
- **Radiation** – What special measures have to be taken to protect against radiation damage to the extensively distributed electronics and optical fiber cable inherent in the control system?
- **What Else?**

End of Presentation

Slides beyond this point are for reference use

Lessons from CESR Control System

- Highly successful operation of substantially complex accelerator [what fraction of ERL or other machines?]
- Optimized for CESR
- Reflects “Style” of Lab.
  - As Simple as Possible – but no simpler
- X-Bus Field bus and MPM database
  - Direct memory access
  - Flat – no hierarchy – no network latency
  - 30 year useful life
- Economical - Minimal staff - ~2FTE (Software)
- But – not a choice for ERL@CESR

ERL Controls – Basic Assumptions

- **Will carefully study decisions in current and recently commissioned accelerators**
  - **Examples: SNS, Diamond, SLS, , , ,**
  - **Use software, tools, techniques from other facilities wherever possible**
  - **Advancing the state of the art in Controls systems is a NON-goal**
- Use EPICS for basic control
- Build on Experience with Phase 1A Injector Controls
- High Speed (GigE and 10GigE) Commodity Ethernet for primary connectivity
- Embedded IOCs likely to run RTEMS, Soft IOCs to run Linux on PCs
- Standard PLCs (AB? (and OPTO22??))
- (EPICS) interface to Standalone Cryo Plant industrial control system
- EPICS interface to separate Feedback-Orbit/Beamline stabilization system
  - Separate path for high speed/volume instrumentation data – e.g. BPMs
- Choose Primary Language and Tool(s) (XAL?, MatLab?) for Appl. Devel.
  - Look Carefully at XAL For collective control
  - EPICS "gateway" to MatLab [and Labview???] for Physics Application Devel.
- Careful use of Relational DataBase for design and operation

Build on Current Experience with Phase 1A Controls

- The controls for the full ERL will differ most dramatically from Phase 1a in terms of the number of controls points.
- Current plans for the ERL control system include an
  - (embedded) IOC per RF cavity as well as
  - (embedded) IOC per Beam Position Monitor (BPM).

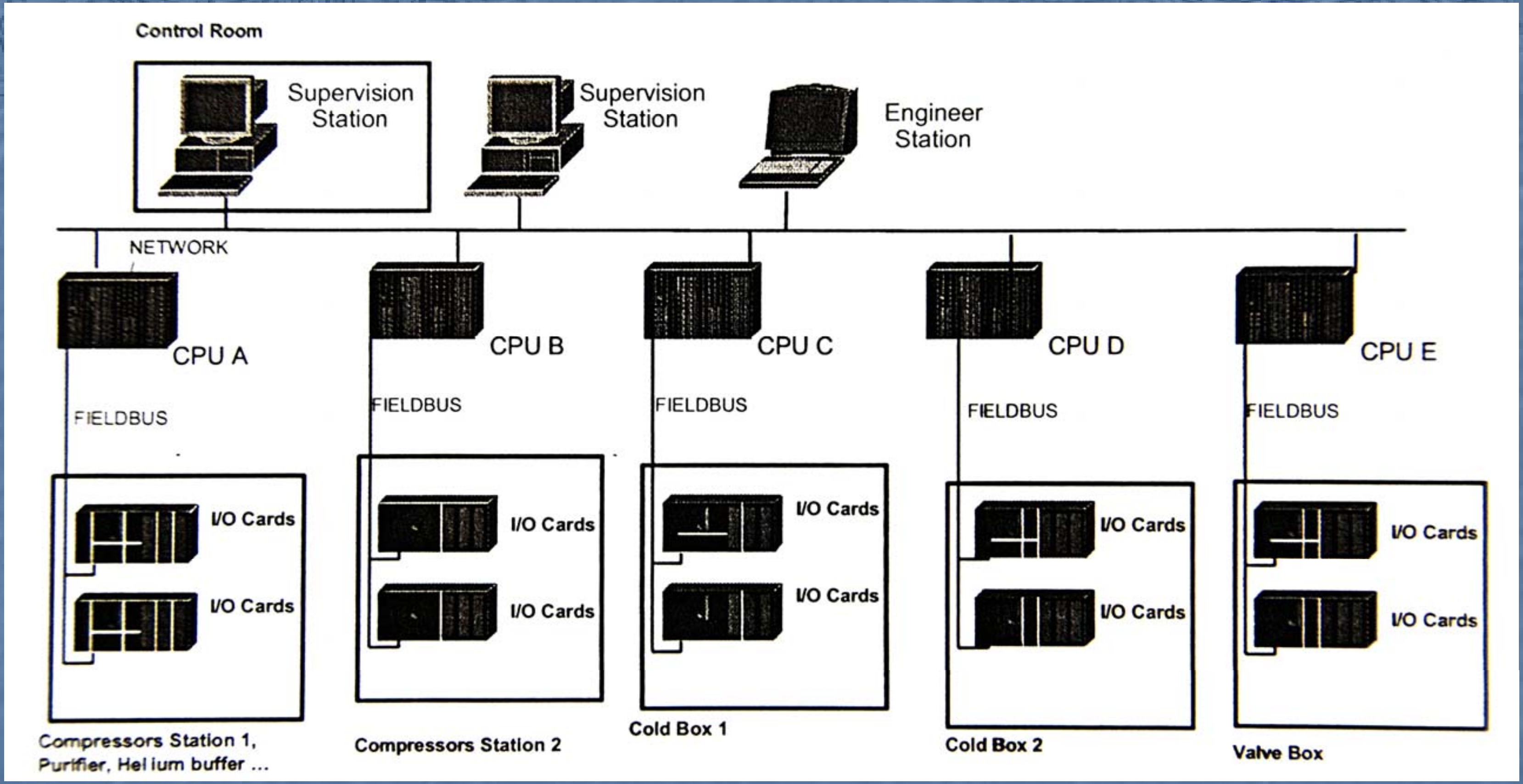
System	Number of IOCs
RF Control	400
BPM	100
Beam Line	25
Cryogenics	25
Gun, Magnets, ...	50
Total	600

- EPICS will scale to this size installation
  - SNS EPICS-based control system successfully includes 500 IOCs
  - SNS has identified network traffic management as an issue requiring attention in such a large system

Cryogenics Plant
Industrial Control

- The Cryogenics Plant will come with its own standalone industrial control system
- Capable of operation independent of ERL Control System
- Few details available now from Air Liquide or Linde
- Local Consoles and Remote Console Interface for ERL Control System
- Different process control interface
  - Air Liquide – Fieldbus
  - Linde – Siemens
- Need gateway to ERL EPICS control system
  - Monitor, Archive, PM,,
- Need to maintain control loops necessary to provide near constant load for Cryo Plant under changing load in RF cavities (heaters), etc.

Air Liquide Industrial control



BPM, Timing, Feedback, Stabilization Systems

- There are machine instrumentation or control aspects which require dedicated solutions outside the scope of EPICS:
  - BPM System
    - Data rates and data volume exceed EPICS capabilities
    - ERL EPICS control has to have access to data
  - Timing System
    - the distribution of timing and RF phase information in an ERL is a difficult problem that will require dedicated hardware
    - Control and Monitoring of Timing System hardware from EPICS is not fundamentally different from the other types of supervisory tasks performed by EPICS.
  - Feedback/Orbit Stabilization
    - Bandwidth issues will mean that feedback and beam orbit control/stabilization will require dedicated hardware outside the framework of EPICS
    - monitoring and configuration of beam orbit feedback would be part of EPICS controls.

EPICS is Limited

- EPICS provides an atomic view of the state of an accelerator
  - no awareness of
    - devices,
    - groups of records that belong to a physical or logical device.
  - Various EPICS users have created overlying software layers designed to create a more object oriented view of the accelerator.
  - Additionally a choice must be made regarding a framework for implementing
    - high level machine operations and
    - machine studies applications including the possibility of Integration of accelerator modeling.
- In response to these needs SNS has, for example, created XAL, a programming and application framework.
    - XAL APPLICATION PROGRAMMING FRAMEWORK, ICALEPCS 2003
  - LCLS has also adopted XAL and like SNS uses
    - XAL in conjunction with
    - Matlab.
  - The DIAMOND light source high level software is based on
    - Matlab and the
    - Accelerator Toolbox developed at SPEAR.
      OVERVIEW OF ACCELERATOR PHYSICS STUDIES AND HIGH LEVEL SOFTWARE FOR THE DIAMOND LIGHT SOURCE, PAC 2005
- ERL@CESR will require a planned approach to high level applications along the lines implemented at these other EPICS facilities.

Issue: EPICS control system relies on multiple independent configuration files.

- In a large EPICS control system the management of information about the state of the accelerator and the related EPICS configuration files is a major task requiring planning and resources.
- Adding a single piece of hardware can require changes to a half dozen separate files
  - IOC database configuration
  - IOC startup script, Archiver configuration
  - Alarm Handler configuration
  - display screens
  - backup and restore scripts
  - ...
- Database could reduce errors and speed implementation
- While a consensus as to how to best accomplish this alongside the EPICS framework has not emerged there are models for how to go about this.
  - SNS EPICS Configuration Database , EPICS Collaboration Meeting May, 2001
  - LARGE-SCALE PC MANAGEMENT AND CONFIGURATION FOR SNS DIAGNOSTICS, BEAM INSTRUMENTATION WORKSHOP 2004
  - DATABASE USE IN APPLICATION PROGRAMMING AT SNS, ICALEPCS 2005

Relational Database
IRMIS

- IRMIS (Integrated Relational Model of Installed Systems)
  - Developed by EPICS Collaboration
  - “Descriptive” rather than “Prescriptive”
  - Based on EPICS widely distributed Real-time database in IOCs and other CA servers
  - IRMIS keeps comprehensive database of every PV in real-time by being aware of every IOC reboot (using ‘PV-Crawler’ application)
  - Uses generalized Entity Relations
  - Three main hierarchies: Control Flow, Power, and Housing
  - Being Extended beyond control systems

Software Infrastructure Maintenance

- Every software (and smart hardware) component we incorporate has an interlocking set of version compatibility with:
  - operating system
  - Compiler
  - Firmware
  - debugging tool
  - software middleware component
  - security patches
  - ...
- Maintenance contracts have to be maintained for the life of the accelerator

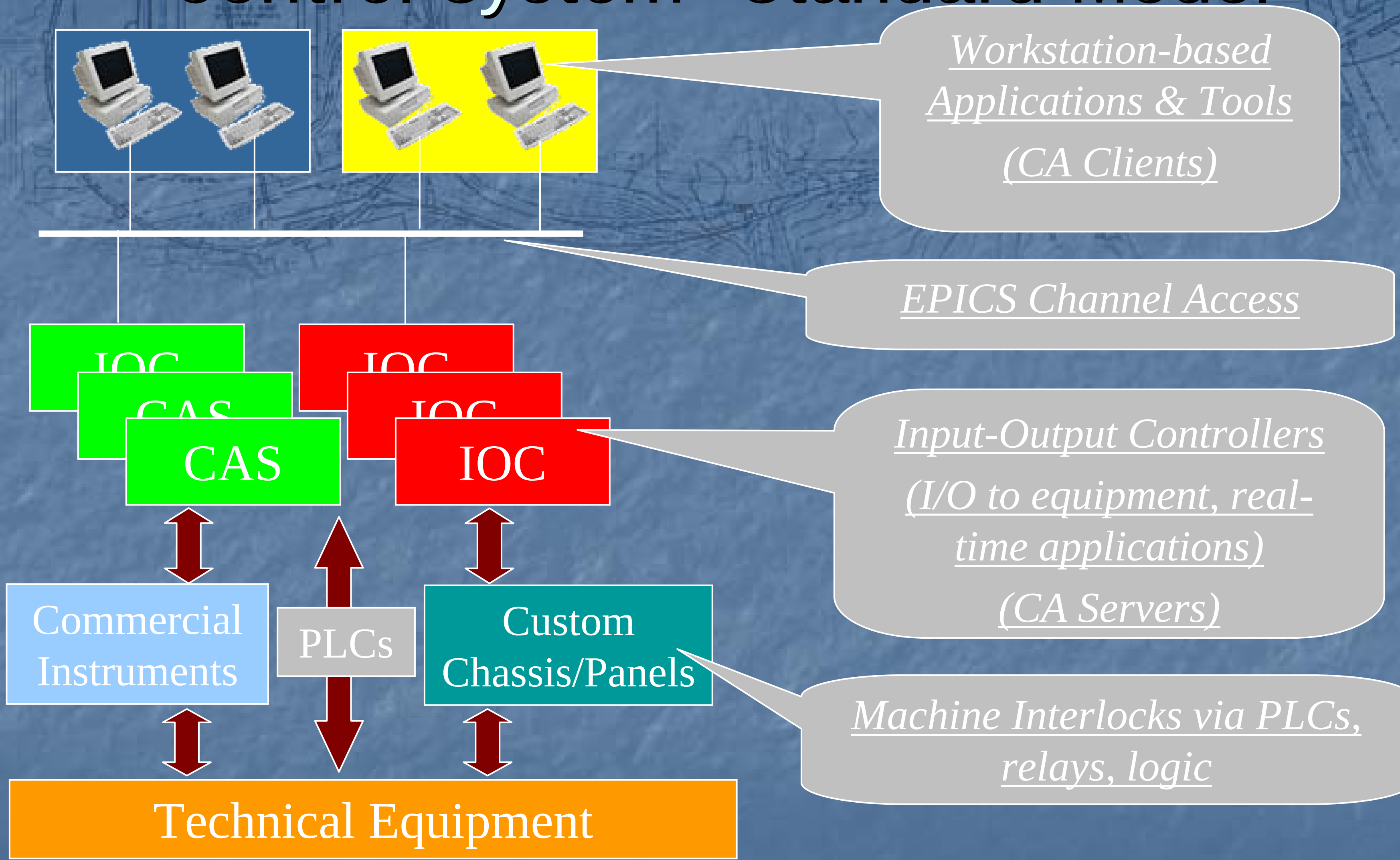
Radiation

- Control System is highly vulnerable to radiation damage
  - Complex electronics (processors, network interfaces) distributed to the device level
  - Interconnection dependent upon many, widely distributed, high speed, fiber optic cables
  - Difficult to shield against
  - Low level (possibly intermittent) error rate could be:
    - Extremely difficult to detect
    - Expensive to protect against (redundancy and voting)
    - Disruptive to repair (e.g. pull new network fiber cables)

Control System General Requirements and Goals

- In recent years a fairly consistent model has evolved to meet the following needs of modern accelerators and light sources:
  - Operator interface for facility control and monitoring
  - Automation, sequencing, and “slow” feedback
  - Data acquisition for accelerator physics and diagnostics
  - Archiving, retrieval and analysis of machine data
  - Physics modeling and simulation
  - Save/Restore of machine configuration
  - Alarm management
- ...While achieving these overall goals and values:
  - High availability/reliability
  - Flexibility for refinement and growth
  - Contained initial and ongoing cost

Control System “Standard Model”



J. Carwardine 2005

EPICS

- Based on **Channel Access** network protocol
- The Input/Output Controllers, **IOC**s, (and other CA Servers, **CAS**s) collectively constitute the distributed database reflecting the state of the accelerator and implement the interface to the controlled hardware.
- EPICS includes both:
  - Traditional IOCs, typically VME crate based hardware with a real-time operating system, as well as...
  - Soft-IOCs, typically a PC running a commonplace operating system running such as Linux or Windows.

EPICS applications and software tools include:

- EDM (Extensible Display manager) and MEDM (Motif Editor and Display Manager)
- StripTool
- Probe
- Channel Archiver and Channel Archive Viewer
- BURT (Back-Up and Restore Tool)
- Alarm Handler
- VDCT Visual Database Configuration Tool
- Software interfaces to Matlab, Labview, and Tcl [?]
- EPICS Gateway

EPICS – Cont.

- EPICS **Tech-Talk** (e-mail list server) a useful resource in solving problems
- The Extensive **documentation** at EPICS web site makes understanding and commissioning an EPICS control system straight forward
- EPICS **IOC**s and **tools** (for most part) problem free
- EPICS requires specialized **device drivers** for each type of hardware used
- There are many hardware types already supported by EPICS. If you choose only hardware already supported by EPICS it is possible to create an EPICS control system **without having to write any software**, however if you want to use hardware not already supported in EPICS you must write software for a device driver.

However...

- EPICS Records are Atomic only
- No sense of "Device"
- No sense of Geography
- No Collective (Effect)(e.g. "bump")[??]
- No Central DB
- No Support for writing sophisticated applications (More about Matlab, Labview, XAL, etc. later) [??]