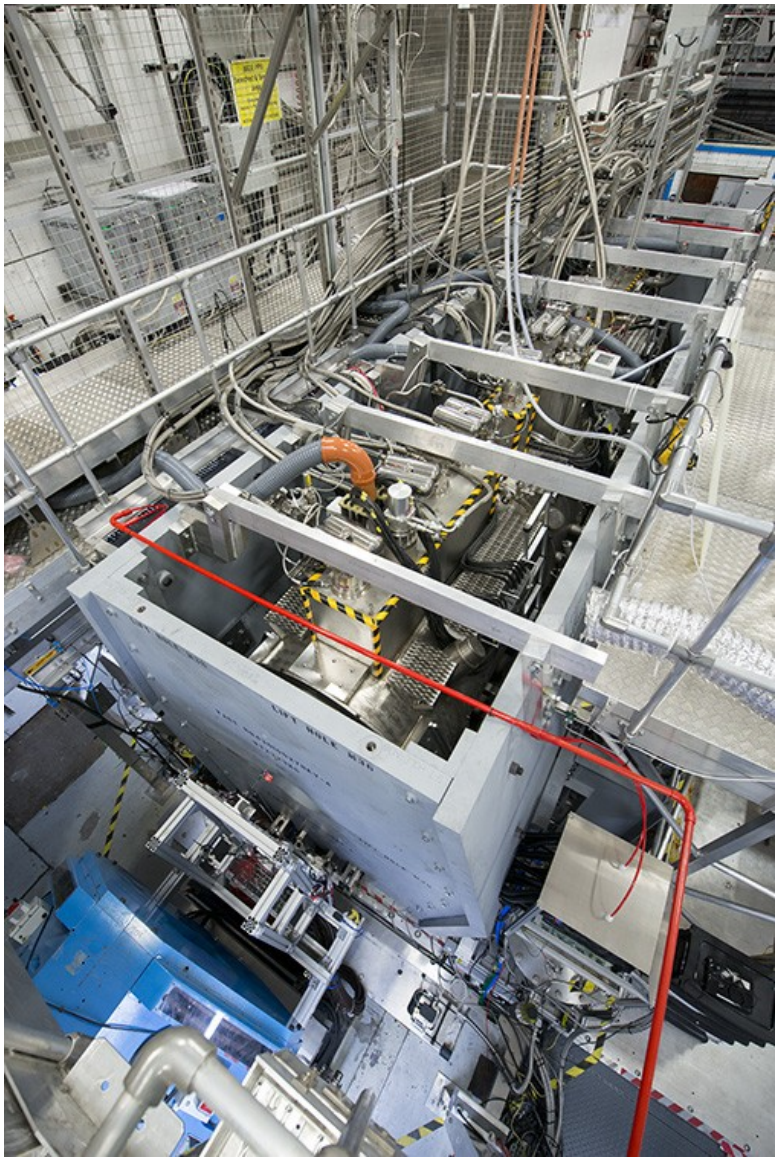
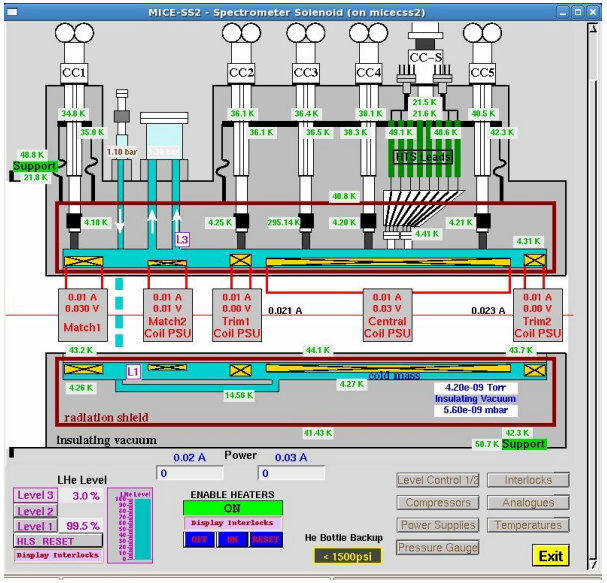


Brief Overview of EPICS.



Pierrick Hanlet

18 Februrary 2020

Outline

I Introduction

II Simple View of EPICS

III Standard Deployment of EPICS

IV EPICS Features and Tools

V Present Work

VI Merging ACNET/EPICS

VII Conclusions

Outline

I Introduction

II Simple View of EPICS

III Standard Deployment of EPICS

IV EPICS Features and Tools

V Present Work

VI Merging ACNET/EPICS

VII Conclusions

Introduction

- Some refer to EPICS as a "toolkit"
  - Toolkit (to me) implies user interfaces and applications only
  - I prefer the word "framework"

- EPICS is:
  - a framework from which to build a control system
  - open source software
  - an international collaboration
  - an end-to-end set of tools and applications

- EPICS history – *see Andrew Johnson's talk following this*

Introduction

- Fermilab control system, based on acnet protocol, is driven by the client – *see Beau's talk Thursday*

- EPICS has a different paradigm than our control system in that the front end can be built to exploit all of the functionality of a field device, e.g. in the attributes:
  - Alarms: severity and limits
  - Calibration
  - Some aspects of archiving
  - Scanning
  - Sequencing
  - Timestamp
  - Control limits
  - Operating limits

Introduction

- There is little incentive for new employees to learn ACNET if they don't imagine staying at Fermilab; however, those who learn EPICS can bring this skill set elsewhere. Hence, the long term maintainability of ACNET is in question – *and we're not getting younger!*
- Most use of controls is from the client side, namely with "ACNET" consoles and applications.
- The use of EPICS within AD controls does not necessitate the abandoning of familiar applications.
- We have developed front ends to talk to the DPM via DRF3
  - well underway – *see talk on Thursday*
- Thus can connect FE information to familiar ACNET applications
- EPICS GUIs would also be developed with the front ends so that users can use either/both ACNET/EPICS GUIs

Outline

I Introduction

II Simple View of EPICS

III Standard Deployment of EPICS

IV EPICS Features and Tools

V Present Work

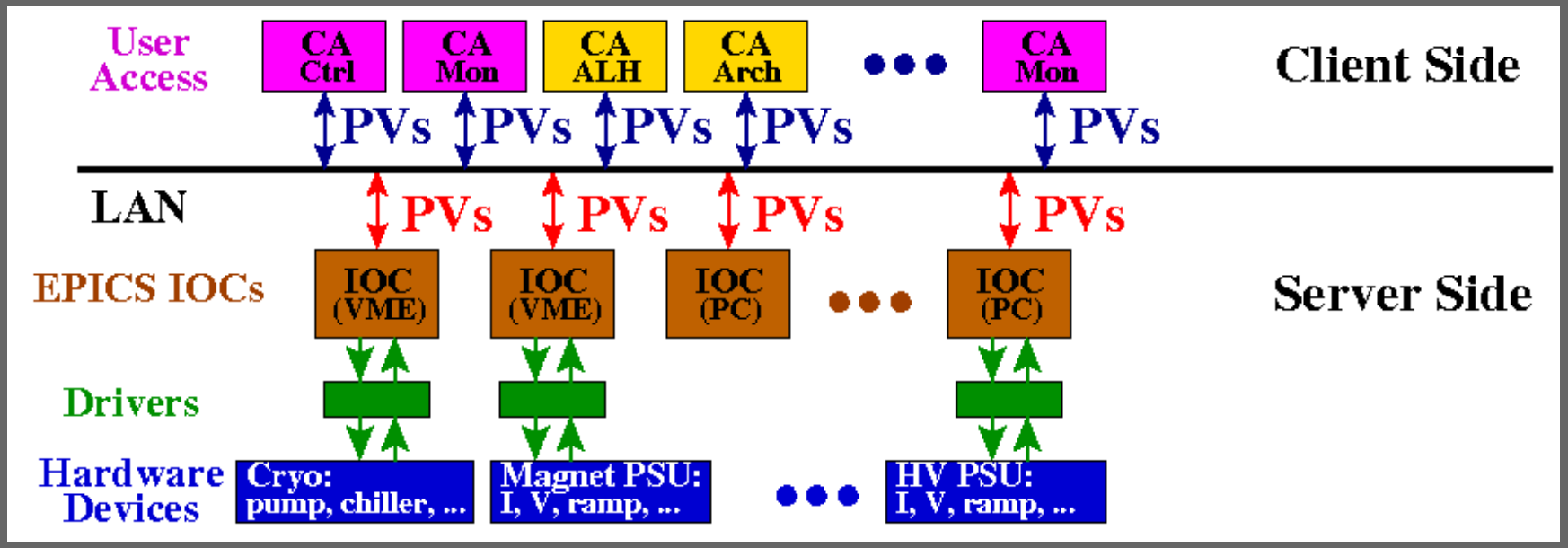
VI Merging ACNET/EPICS

VII Conclusions

A Simple View of EPICS

Experimental Physics & Industrial Control Systems

- HW+Drivers connect to LAN via IOCs (Input/Output Controllers)
- IOC is controller (VME, PC, …) and its software
- IOCs create PVs (process variables) to represent HW parameters
- PVs further described with native fields
- PVs available on LAN to other IOCs or clients
- Client Side are different GUIs, alarms, archives, displays, …



A Simple View of EPICS

- EPICS "base": the main core of EPICS, comprising the build system and tools, common and OS-specific interface libraries, Channel Access and PV Access client and server libraries, static and run-time database access routines, the database processing code, and standard record, device and driver support.

- EPICS versions:
  - 3.x.y channel access, most commonly used
  - 4.x.y PVaccess, newer and not commonly used
  - 7.x.y = v3 + v4 combines the two

- For modernization and PIP-II, writing EPICS-based front ends means that we can start now with the software because it will be transferable to any new platform that we will choose and use in the future – only requires rebuilding for new architecture

A Simple View of EPICS

- Features
  - Interfaces: serial, gpib, ethernet, modbus, snmp, …
  - Platforms: linux, windows, mac, VME, android, raspberry pi, …
  - International support: experts around the world – rarely waited >1hr for help
  - Many, many device drivers already written

- EPICS version 7: – *see Andrew Johnson's talk Thursday*
  - combination of v3 (channel access) and v4 (PV access)
  - can use v3 IOCs and it still works
  - base has ~175k lines of code from 57 contributors
  - Code is mostly C (~60%) and C++ (~25%)
  - v7 has structured data – added from Channel Access
  - PVaccess allows for high bandwidth data (not just slow controls)
  - already stable but remaining bugs cleared and should be as robust as v3-14-xx by PIP-II era

A Simple View of EPICS

- Many “record” types: e.g.
  - data types (binary, float, multi-bit, waveform, structures)
  - calculations
  - functional (heartbeat, computer status, busy, ...)
  - sequences
  - aSub: C/C++ function inputs PVs, processes, and outputs PVs
- Record types have native “fields” to further describe record: e.g.
  - alarm
  - units
  - operating limits
  - scanning rates: time based, I/O interrupt, passive
  - fanouts and forward links
  - description
  - dozens of fields; these are defined in xxx.dbd files
- Records are used to create PVs
- PVs are used to create IOCs
- IOCs then can completely describe a hardware device

A Simple View of EPICS

- Fields common to all record types:

Field	Type
•SCAN	GBLCHOICE
•PINI	GBLCHOICE
•PHAS	SHORT
•EVNT	SHORT
•PRIO	GBLCHOICE
•DISV	SHORT
•DISA	SHORT
•SDIS	INLINK
•PROC	UCHAR
•DISS	GBLCHOICE
•LSET	SHORT
•LCNT	UCHAR
•PACT	UCHAR
•FLNK	FWDLINK

- Fields common to most record types:

Name	Summary
•INP	Input Link
•DTYP	Device Type
•RVAL	Raw Value
•VAL	Value
•SIMM	Simulation Mode
•SIML	Simulation Mode Location
•SVAL	Simulation Value
•SIOL	Simulation Value Location
•SIMS	Simulation Mode Alarm Severity

- For example an ai (analog input) record has ~50 fields which fall into:
  - scan parameters
  - read and convert parameters
  - operator display parameters
  - alarm parameters
  - monitor parameters
  - run-time parameters

A Simple View of EPICS

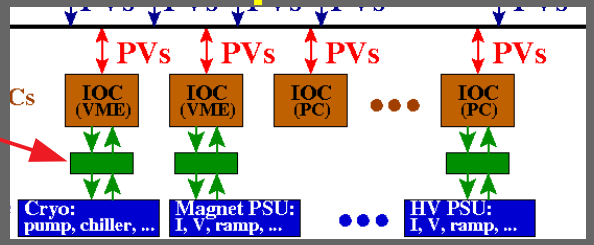
- A PV (Process Variable) is a representation of a hardware parameter
  - e.g. temperature, voltage, current, flow, ...
- Fields (attributes) further define a PV
  - dozens of possible fields
- Examples:

```
record(ai, ‘MyPVName’) {
        field(DESC, ‘This is my favorite PV’)
        field(SCAN, ‘.1 second’)
        field(EGU, ‘l/s’)
        field(HHSV, ‘Major’)
        field(HSV, ‘Minor’)
        field(HIHI, ‘7.2’)
        field(HIGH, ‘5.6)
        field(FLNK, ‘MyNextFavPV.PROC’)
}
```

```
record(calc,"MICE-BL-ISIS-01:DBMLS") {
        field(DESC,"ISIS Beam Loss difference")
        field(INPA,"MICE-BL-ISIS-01:IBMLS")
        field(INPB,"MICE-BL-ISIS-01:ABMLS")
        field(CALC,"A-B")
        field(HOPR,"3.0")
        field(LOPR,"-3.0")
        field(SCAN,"Passive")
        field(FLNK,"MICE-BL-ISIS-02:ABMLS.PROC")
}
```

A Simple View of EPICS

- Support modules are analogous to modules one might add to a kernel; i.e. they aren't required for a stable OS, but are required for a server's specific function.
- Many support modules for HW already written
- Some support modules are effectively drivers for specific hardware
  - user written
  - found on EPICS website
  - ask EPICS user community



- One of the larger packages which contains many support modules is synApps

A Simple View of EPICS

- Airedale
- Bit8
- CAEN
- FINS
- FINStcp
- FINSudp
- GeaDenco
- HVSy127
- HVSy4527
- HVSy527
- Hy8401ip
- Hy8402ip
- Hy8515
- LeyboldTD20
- LuminOx
- NIKHEF_hall_probe
- OmronE5AC
- OxInstCryojet-2-18-3
- Riello
- SecurityProbe
- StreamDevice-2-7
- StreamDevice-2-8
- TCW181B
- Tracker
- WTI
- wienerPL508

- adam4017
- alive-1-0-1
- areaDetector-R3-4
- asyn4-18
- asyn4-19
- asyn4-34
- asyn4-35
- autosave-5-10
- busy-1-4
- busy-1-6
- caLab_1320
- calc-2-8
- calc-R3-5
- calc-R3-7-1
- camac-2-7
- cdb
- cdb-python
- cmsIon
- commitrevision.bash
- cp2800
- devIocStats-3-1-9
- gpib
- iocStats-3-1-15

- ip-2-10
- ip-2-20
- ipac-2.11
- ipac-2.15
- itc503
- keithley2700
- leyboldC2
- leyboldTD20
- makeall.bash
- mks937
- modbusR2-11
- modbusR2-3
- modbusR2-4
- motor-6-11
- seq-2.0.12
- seq-2.1.11
- seq-2.2.4
- seq-2.2.5
- snmp
- sscan-2-11-2
- sscan-2-6-6
- std-2-8
- std-3-5

Outline

I Introduction

II Simple View of EPICS

III Standard Deployment of EPICS

IV EPICS Features and Tools

V Present Work

VI Merging ACNET/EPICS

VII Conclusions

Standard Deployment of EPICS

- An EPICS IOC is created from 3 layers:
  - base
  - support modules – built against base
  - code specific to the IOC and built from base and selected support modules

Presently, I have 3 versions of base: v3.14.12.8, v3.16, v7.0.3.1

- I also have several versions of Support modules
- I use soft links to point to the version that I want
  - e.g. ~/epicsDEV/base = ~/epicsPRO/base-7.0.3.1
  - this model may change

To set up our standard deployment:
https://cdcvs.fnal.gov/redmine/projects/ad-controls-dept/wiki/Building_an_EPICS_IOC_on_a_clx_Machine

Standard Deployment of EPICS

- **Software directory structure:**
- **Development**

/home/epics/epicsDEV/base		**(build tools and core)**
	/Support	**(modules: asyn, seq, ipac…)**
	/iocTops	**(IOCs – built from base+Support)**
	/Extensions	**(user applications)**
	/Config	**(configuration files)**
	/Software	**(external libraries)**

- **Production**

/usr/local/epics/base
/usr/local/epics/Support
/usr/local/epics/Config
/home/epics/epicsPRO/iocTops

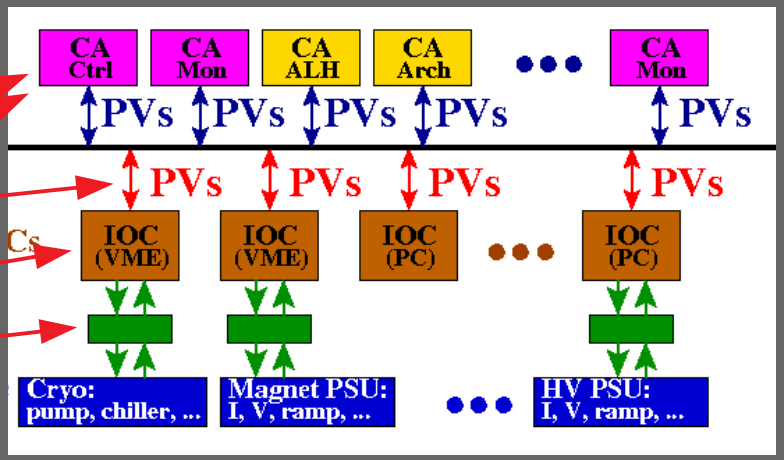
Standard Deployment of EPICS

My directory structure:

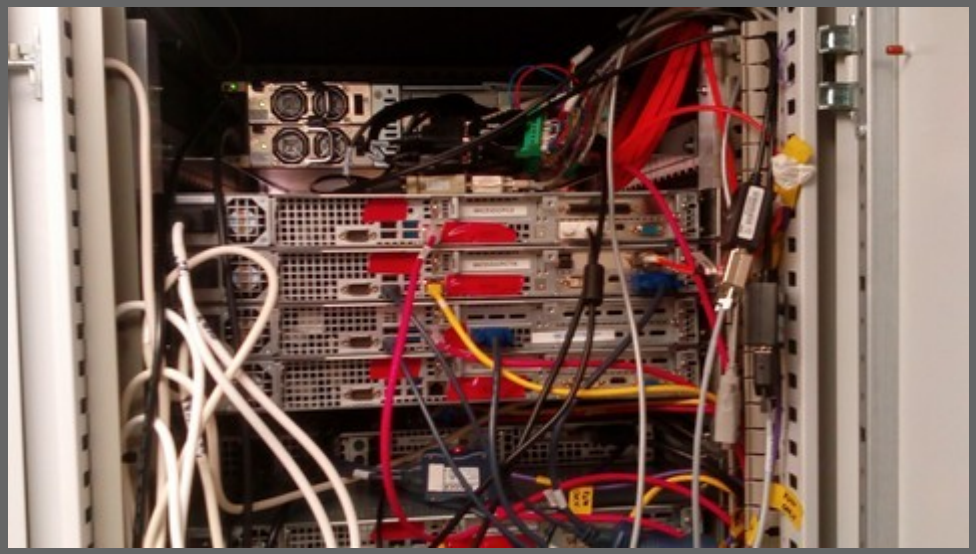
/home/epics/epicsDEV/base	(build tools and core code)
/Support	(modules: asyn, seq, ipac…)
/iocTops	(IOCs – built from base+Support)
/Extensions	(user applications)
/Config	(configuration files)
/Software	(external libraries)

/home/epics/epicsPRO

/home/epics/epicsDEV/Extensions
/Config
/iocTops
/Support



Standard Deployment of EPICS



Outline

I Introduction

II Simple View of EPICS

III Standard Deployment of EPICS

IV EPICS Features and Tools

V Present Work

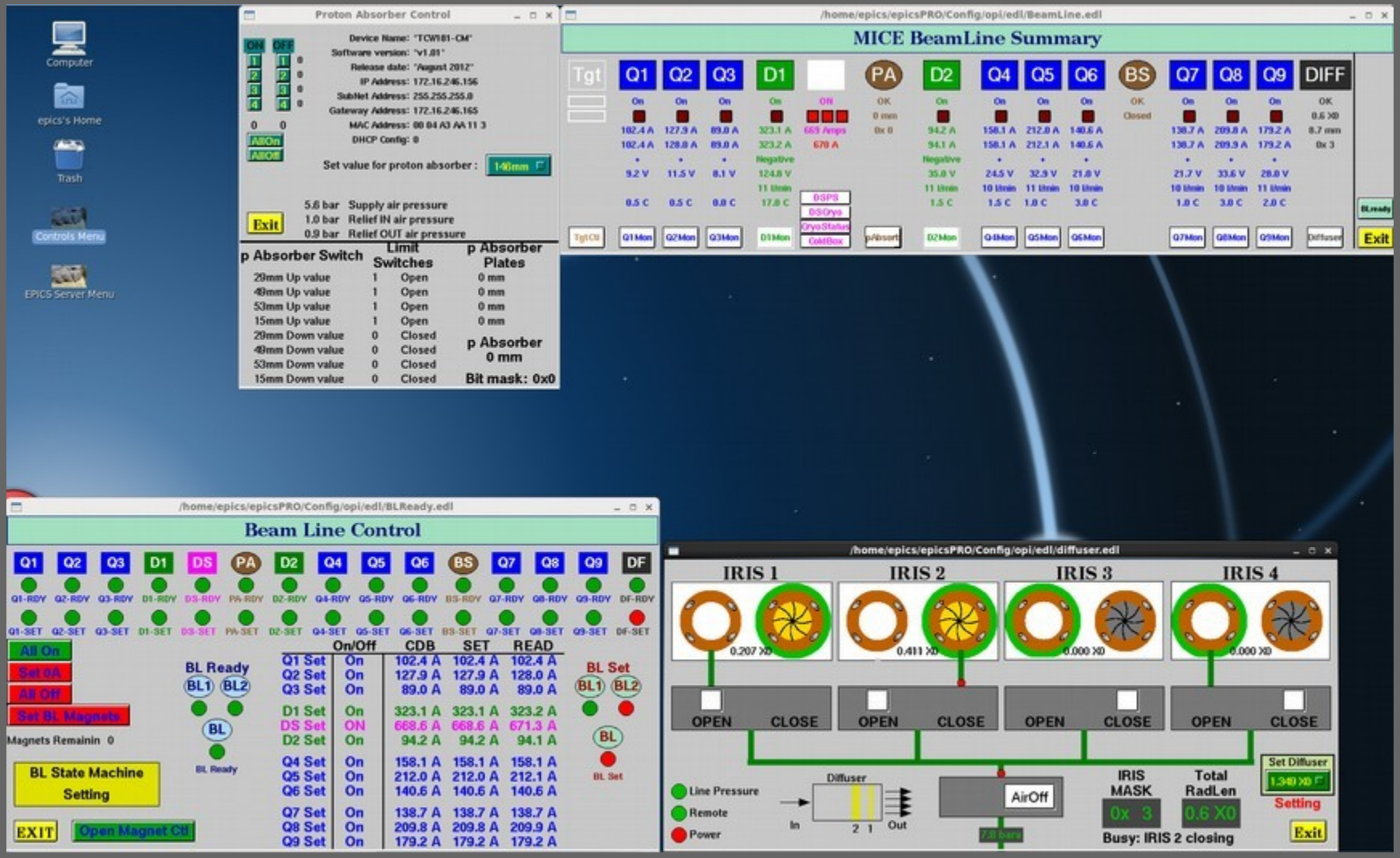
VI Merging ACNET/EPICS

VII Conclusions

EPICS Features and Tools

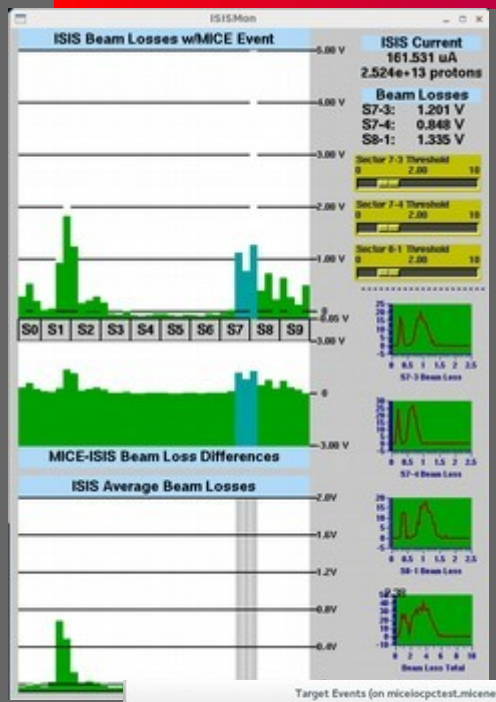
- EPICS Base
  - Robust and well supported
  - Build tools – nested Makefiles
  - Configuration usually only requires modification to 1 (or 2) files
  - Supported platforms (VME, linux, MAC, windows, R-pi, android, …)
  - I/O and interrupts under the hood (only need configuration)
- Graphical User Interfaces
  - Historically, I've used edm for GUIs
  - Simple to learn
  - ascii configuration files
  - But, it's not sexy
  - Avoided Control System Studio (CSS) because of eclipse, now has new java version called Phoebus (work in progress)
  - Browser based, very configurable, on the fly GUIs

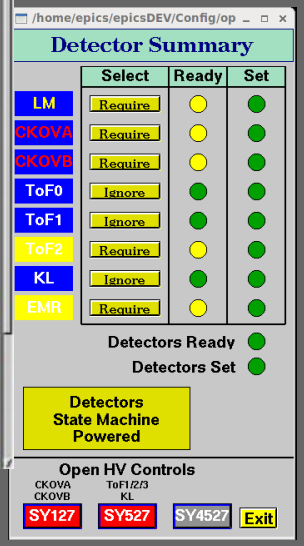
Examples

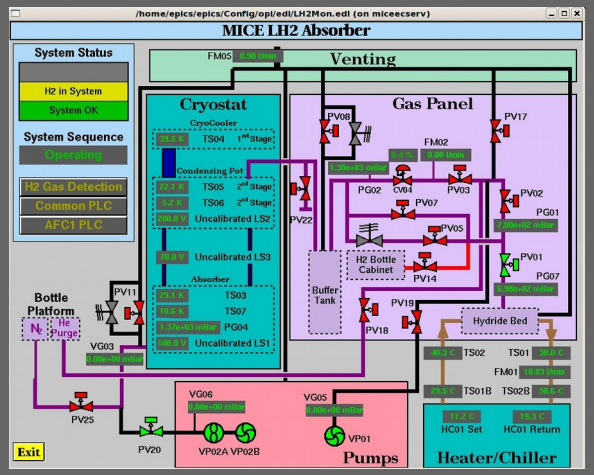

Proton Absorber Control
Device Name: "TCW181-CM"
Software version: "v1.01"
Release date: "August 2012"
IP Address: 172.16.246.156
SubNet Address: 255.255.255.0
Gateway Address: 172.16.246.165
MAC Address: 00 04 A3 AA 11 3
DHCP Config: 0
Set value for proton absorber :
Exit
5.6 bar Supply air pressure
1.0 bar Relief IN air pressure
0.9 bar Relief OUT air pressure
p Absorber Switch
Limit Switches
p Absorber Plates
29mm Up value 1 Open 0 mm
49mm Up value 1 Open 0 mm
53mm Up value 1 Open 0 mm
15mm Up value 1 Open 0 mm
29mm Down value 0 Closed
49mm Down value 0 Closed
53mm Down value 0 Closed
15mm Down value 0 Closed
p Absorber 0 mm
Bit mask: 0x0
/home/epics/epicsPRO/Config/opi/edl/BeamLine.edl
MICE BeamLine Summary
Tgt Q1 Q2 Q3 D1 PA D2 Q4 Q5 Q6 BS Q7 Q8 Q9 DIFF
Exit
/home/epics/epicsPRO/Config/opi/edl/BLReady.edl
Beam Line Control
Q1 Q2 Q3 D1 DS PA D2 Q4 Q5 Q6 BS Q7 Q8 Q9 DF
All On
Set 0A
All Off
Set BL Magnets
Magnets Remainin 0
BL State Machine Setting
EXIT
Open Magnet Ctl
BL Ready
BL1 BL2
BL
On/Off CDB SET READ
Q1 Set On 102.4 A 102.4 A 102.4 A
Q2 Set On 127.9 A 127.9 A 128.0 A
Q3 Set On 89.0 A 89.0 A 89.0 A
D1 Set On 323.1 A 323.1 A 323.2 A
DS Set ON 668.6 A 668.6 A 671.3 A
D2 Set On 94.2 A 94.2 A 94.1 A
Q4 Set On 158.1 A 158.1 A 158.1 A
Q5 Set On 212.0 A 212.0 A 212.1 A
Q6 Set On 140.6 A 140.6 A 140.6 A
Q7 Set On 138.7 A 138.7 A 138.7 A
Q8 Set On 209.8 A 209.8 A 209.9 A
Q9 Set On 179.2 A 179.2 A 179.2 A
BL Set
/home/epics/epicsPRO/Config/opi/edl/diffuser.edl
IRIS 1 IRIS 2 IRIS 3 IRIS 4
OPEN CLOSE
Line Pressure
Remote
Power
Diffuser
In Out
AirOff
IRIS MASK
Total RadLen
Set Diffuser
Setting
Busy: IRIS 2 closing
Exit

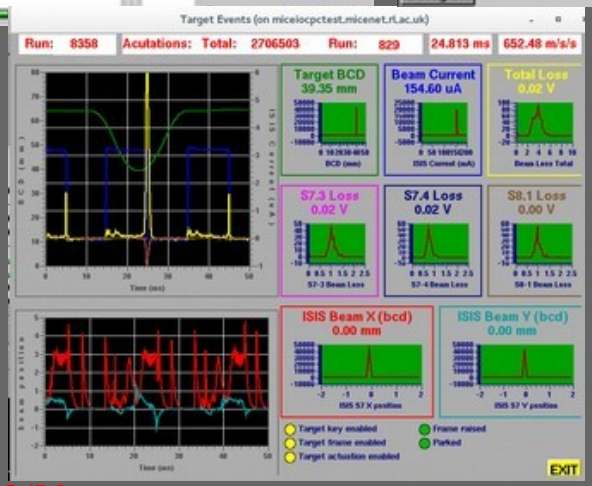
Examples

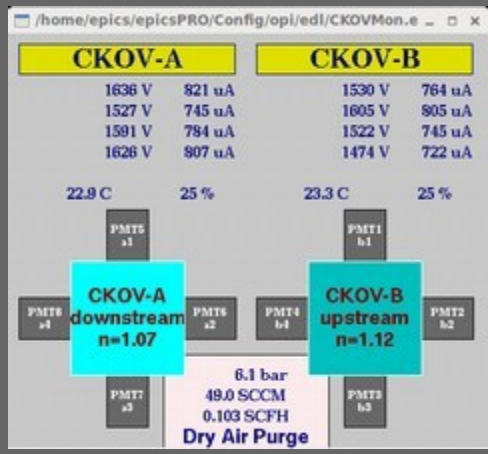
Synoptic Displays





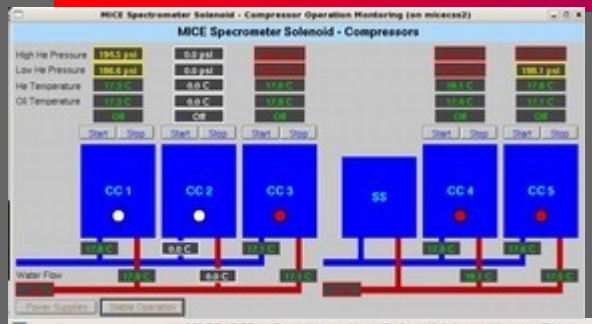


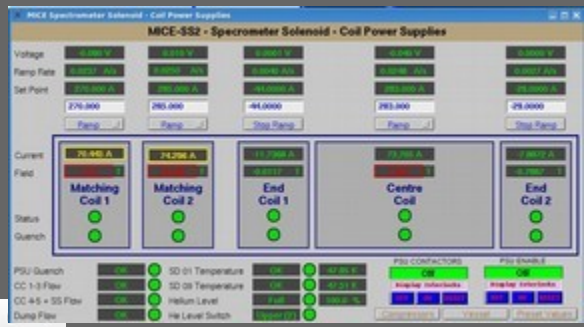


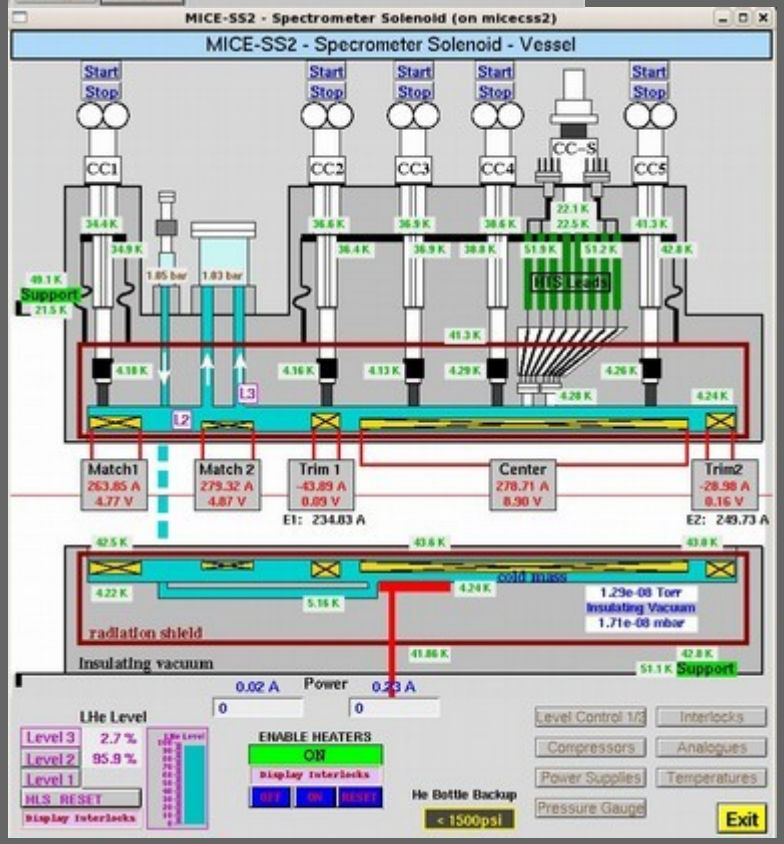


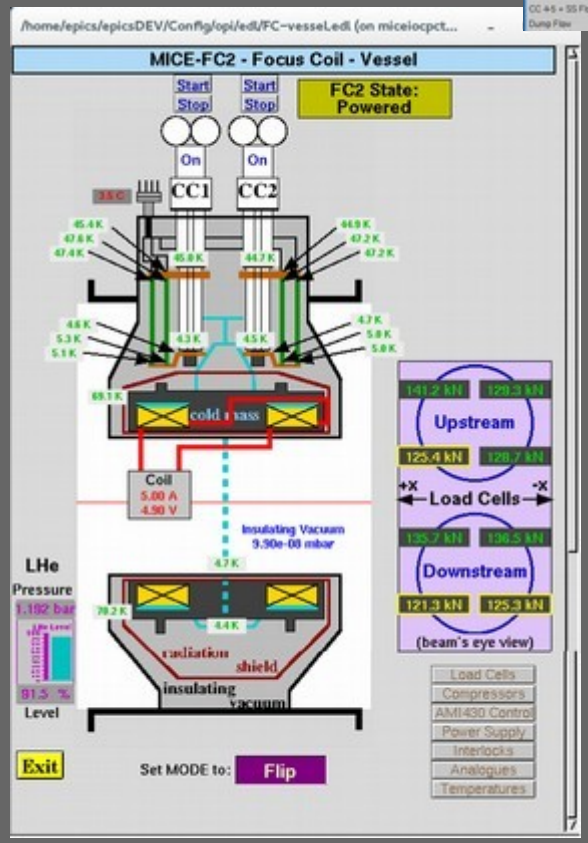
Examples

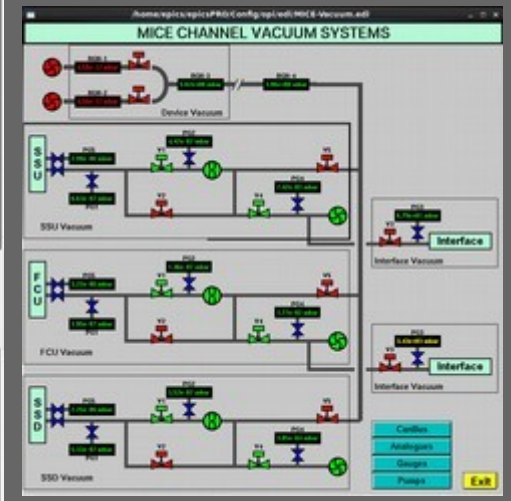
Synoptic Displays





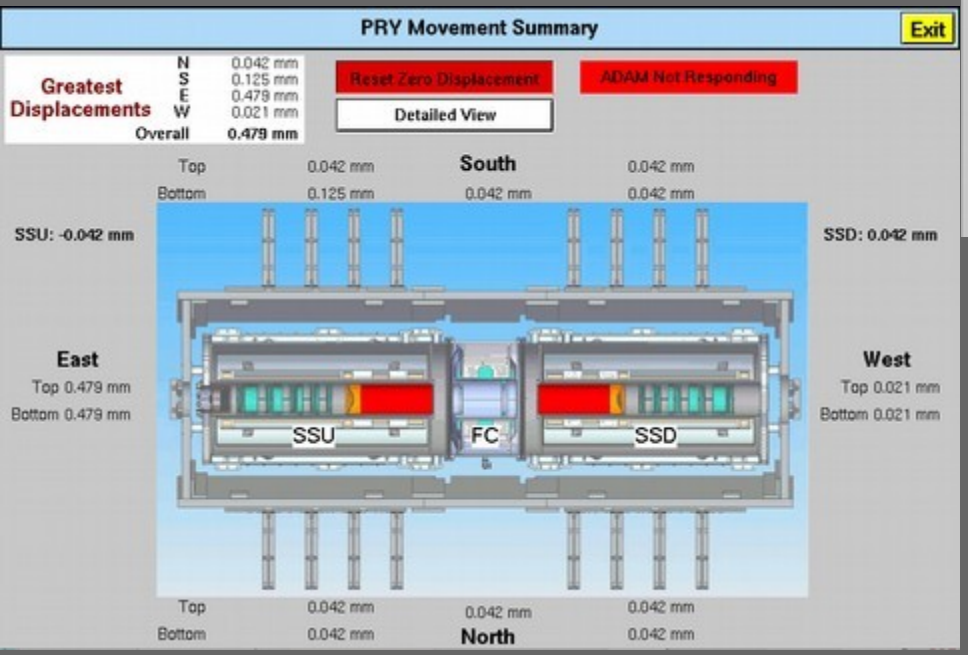


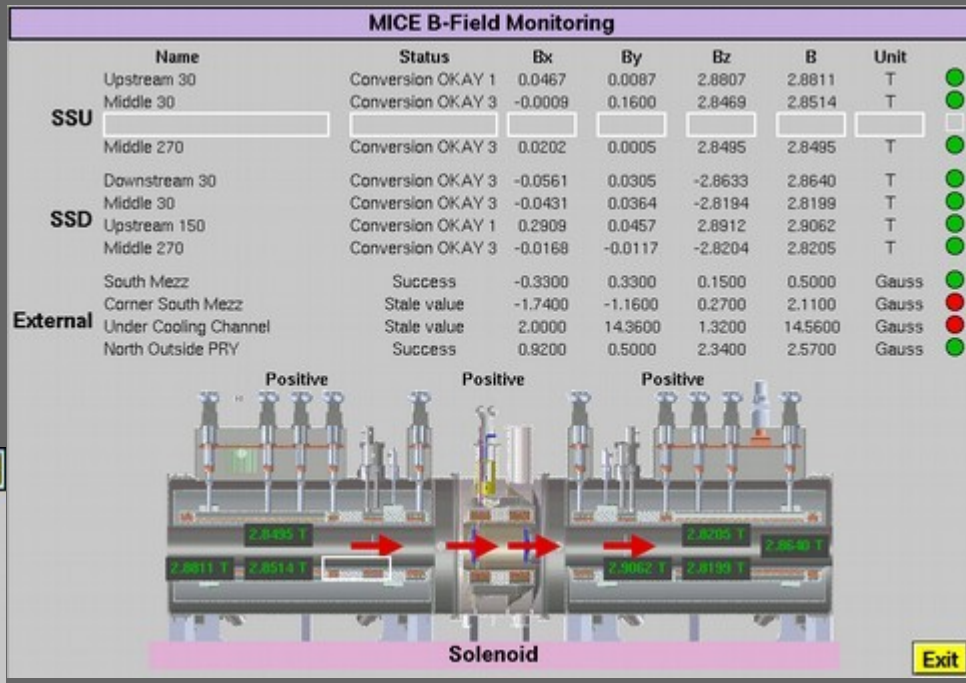




Examples

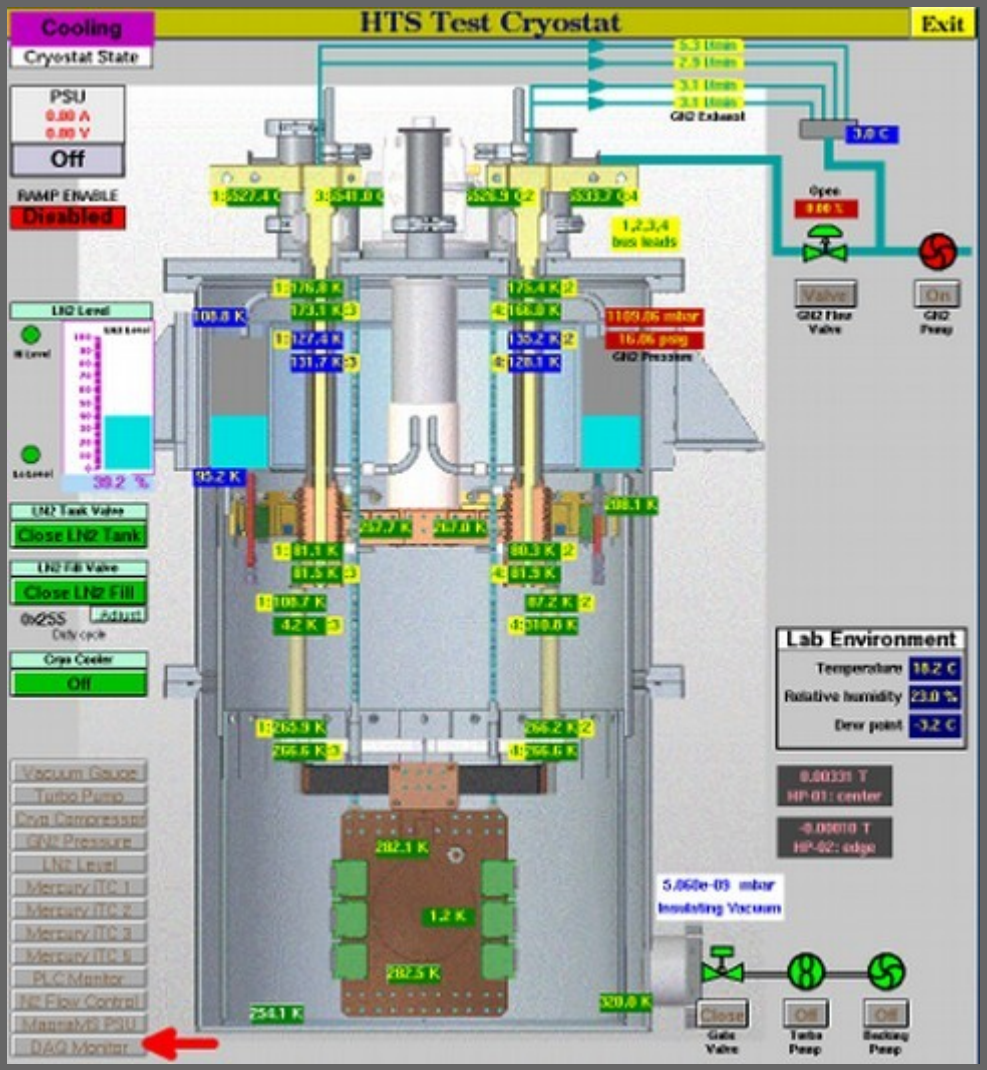
PRY Movement

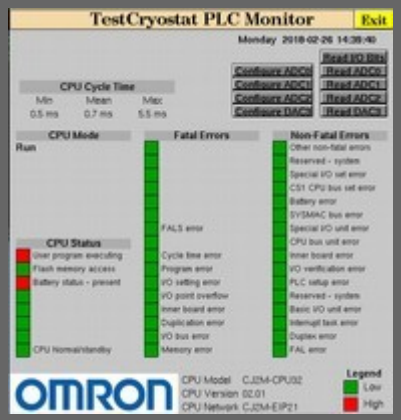




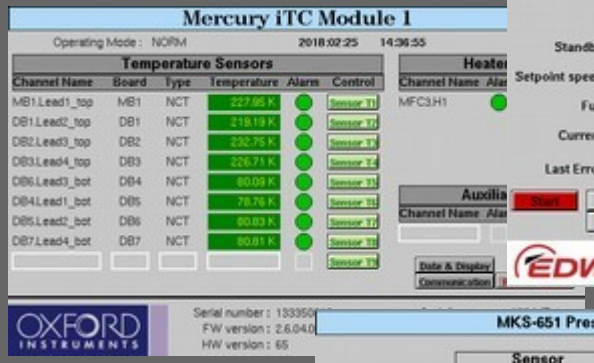
Magnetic Fields

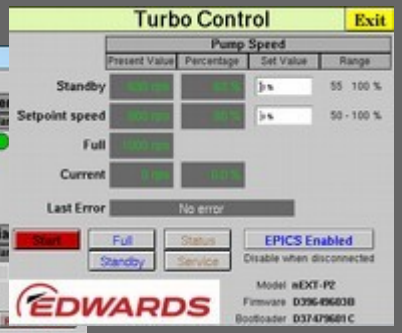
Examples

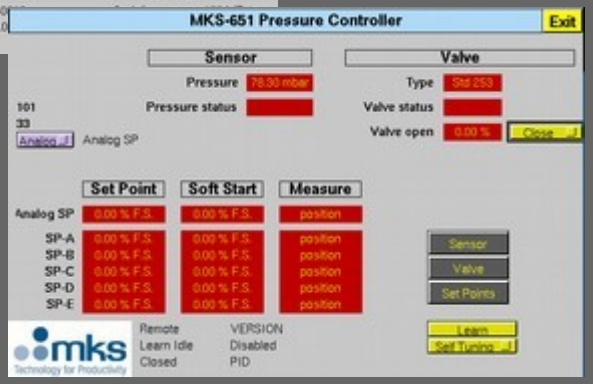

HTS Test Cryostat
Exit
Cooling
Cryostat State
PSU
Off
RAMP ENABLE
Disabled
GN2 Exhaust
1,2,3,4 bus leads
GN2 Pressure
LN2 Level
LN2 Tank Valve
Close LN2 Tank
LN2 Fill Valve
Close LN2 Fill
Cryo Cooler
Off
Lab Environment
Temperature 18.2 C
Relative humidity 23.0 %
Dew point -3.2 C
Insulating Vacuum
Vacuum Gauge
Turbo Pump
GN2 Pressure
LN2 Level
Mercury iTC 1
Mercury iTC 2
Mercury iTC 3
Mercury iTC 4
PLC Monitor
MKS Flow Control
MagnetVS PSU
DAQ Monitor


TestCryostat PLC Monitor
Exit
CPU Cycle Time
CPU Mode
Fatal Errors
Non-Fatal Errors
CPU Status
OMRON


AMI186 LN2 Level
Exit
Sensor Length -5.0 -5.0
High Setpoint Limit 95.0 0.0
Low Setpoint Limit 5.0 0.0
Upper Control Limit 95.0 0.0
Lower Control Limit 0.0 0.0
Sampling Interval 0.1 min 0.0
Units Percent
Save Configuration
Level 0.0 %
AMI


Mercury iTC Module 1
Temperature Sensors
OXFORD INSTRUMENTS

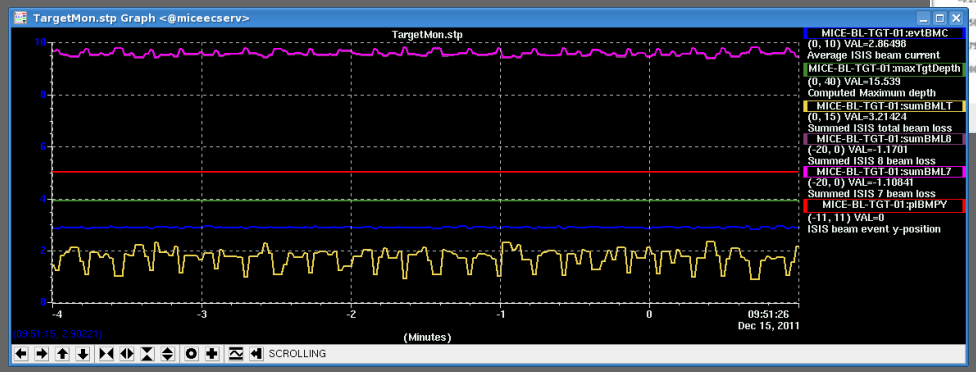

Turbo Control
Exit
Pump Speed
Standby
Setpoint speed
Full
Current
Last Error
No error
EPICS Enabled
EDWARDS


MKS-651 Pressure Controller
Exit
Sensor
Valve
Pressure
Pressure status
Type
Valve status
Valve open
Analog SP
Set Point
Soft Start
Measure
mks

EPICS Features and Tools

- Archiver
  - Historically, I used Channel Archiver, but little support for it now
  - Testing Archive Appliance – SLAC
  - Millions of PVs
  - Clusterable
  - Staged storage

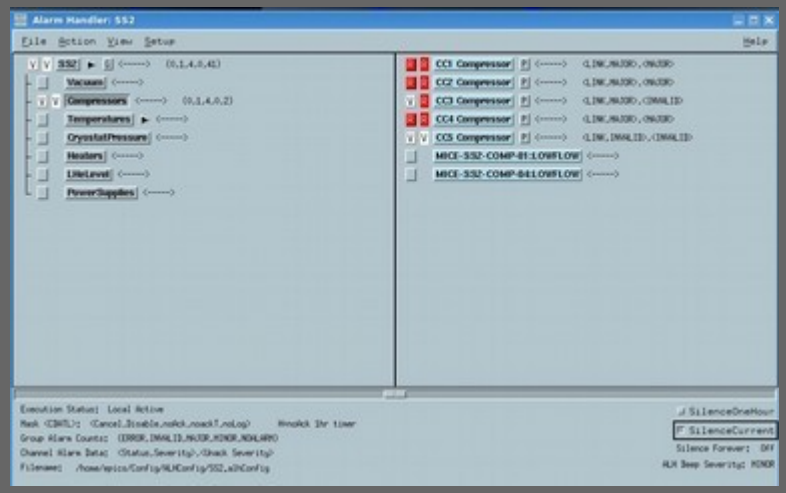
- StripTool



- Probe

EPICS Features and Tools

- Alarms
  - Limits are HIHI, HIGH, LOW, LOLO
  - Severity is MAJOR, MINOR, NO_ALARM
  - Assuming that hardware is fail-safe, I set HIGH & LOW limits to alarm when tolerance affects desired result, and HIHI & LOLO limits are set to alarm prior to a hardware fail-safe event
  - ForcePVs allow dynamic enabling/disabling of PVs
  - Using the State Machines, limits are set dynamically with state transitions



EPICS Features and Tools

- Gateway
  - Makes copies of PVs on different subnets to ensure control access to PVs
  - Filters: by IP address, by user, by PV
  - Filter none, read, or read/write
  - Filter by calculation
  - Ex. at Diamond: strict limited access to controls network, another gateway to allow operator access, another for general users

- Security
  - IOC access
  - Security levels can be changed dynamically
  - Filters: by IP address, by user, by PV

EPICS Features and Tools

- There are many newer features and tools than I have not shown here. We are actively evaluating many of them. Examples are:
  - areaDetector (n-dimensional data) – *see Mark River's talk Thursday*
  - Phoebus – (purely java based CSS without eclipse) integrated tools on a browser like platform

Outline

I Introduction

II Simple View of EPICS

III Standard Deployment of EPICS

IV EPICS Features and Tools

V Present Work

VI Merging ACNET/EPICS

VII Conclusions

Present Work

- All development work on VCLX4
- Rebuilt my code to run with EPICS-7
- Learn motor and areaDetector modules
- Five EPICS IOCs – front ends
  - Environment IOC (resurrected and modified for Fermilab)
  - Tomco 7kW RF Amplifier (2 days to write)
  - TSV-3000 RF Amplifier
  - Converting a VME 162 to a linux based 7805 and building a motor controller
  - areaDetector – cameras
  - SoC
- Archiver Appliance – modern archiver (works)
- Phoebus evaluation

Examples: archiver (3), striptool, edm/phoebus GUIs

Outline

I Introduction

II Simple View of EPICS

III Standard Deployment of EPICS

IV EPICS Features and Tools

V Present Work

VI Merging ACNET/EPICS

VII Conclusions

Merging EPICS with ACNET

- So, should we completely switch to EPICS?
  - ACNET is a mature system
  - Change is too dramatic for those embedded in ACNET

- However, most use of controls is client-side
- Keep ACNET consoles and applications
- Feed EPICS IOCs to ACNET
  - Doing this with DRF3 and the DPMs
  - Operators still see ACNET consoles
  - Can also have EPICS GUIs (edm and/or Phoebus)
- New front ends can come online as EPICS IOCs
  - When hardware is upgraded to linux-based system, IOC will only need to be recompiled for new platform, but not re-written

Merging EPICS with ACNET

- The tough part is the mapping: – *see talk on Thursday*

IOC

- PV
  - field
  - field
  - field
- PV
  - field
  - field
  - field
-
-
- PV
  - field
  - field
  - field

ACNET

- Device
  - read
  - set
  - control
- Device
  - read
  - set
  - digital alarms
-
-
- Device
  - read
  - set
  -

Outline

I Introduction

II Simple View of EPICS

III Standard Deployment of EPICS

IV EPICS Features and Tools

V Present Work

VI Merging ACNET/EPICS

VII Conclusions

Conclusions

- Many thanks to Denise for helping to set up new tools
- Need to design configuration: servers, archiver, IOC nodes
- Several tests in progress
  - Historically, I've used edm for GUIs, now learning CSS/Phoebus
  - linux based VME controller and motor driver
  - areaDetector for cameras
  - Archive Appliance
  - EPICS-7 development
  - template for SoC EPICS deployment
- EPICS IOCs can "easily" be used in conjunction with ACNET applications – well underway
- Standard EPICS setup being deployed

Outline

I Introduction

II Simple View of EPICS

III Standard Deployment of EPICS

IV EPICS Features and Tools

V State Machines

VI Present Work

VII Merging ACNET/EPICS

VIII Conclusions

State Machines – Problem

- Different sub-systems have different needs
- Each sub-system has 10^1–10^3 PVs
- Many PVs have up to 4 alarm limits
- Each PV has different archiving needs
- For different operational states:
  - the PVs of interest change
  - the alarm limits change
  - the archiving needs change
  - the list of critical PVs change

Too much room for human error!

e.g. Powering a superconducting magnet

State Machines – Problem, no Problem

EPICS state notation language employed:

- define equipment operational states
- for each state:
  - define transitions out of state
  - set alarm limits
  - set archiving features
  - define critical variables
- check for software interlocks; e.g. quench
- check for errors
- check for transition

All parameters come from configuration database (CDB) – ensures correct settings

State Machine Requirements

Subsystem Owners must enumerate the states and provide:

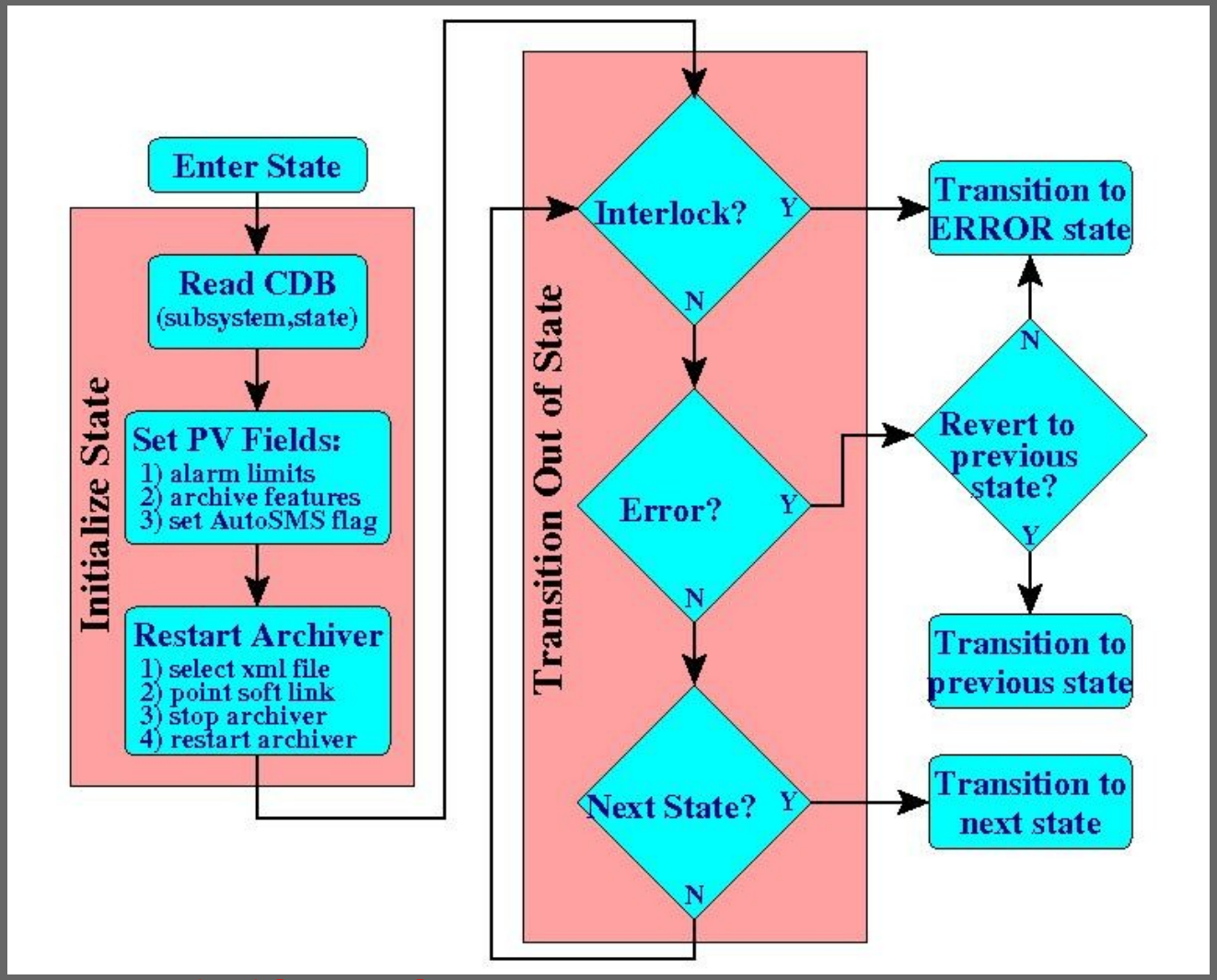
1) Description of state
2) Transition into state
3) PVs of interest
4) Alarm limits for PVs
5) Archiving features for PVs
6) AutoSMS (auto dialer) flag
7) Hardware interlocks
8) Software “interlocks” (enables)

- Required for each state
- Loaded into the CDB

State Machine Algorithm

For each subsystem & state, the algorithm:

- Transitions:
- manual
- automatic



State Machine: SS Example

Spectrometer Solenoid Magnets:

1)Offline
2)Pumping: establish insulating vacuum
3)Pumped: insulating vacuum established
4)PreCooling: N_2 pre-cooling (down to T~100K)
5)Cooling: cryo-coolers lower shield/cold mass T
6)LHeFilling: add liquid He
7)Cold: cold and stable
8)Ramping: applying current
9)Powered: stable operation
10)Quenched: quench detected
11)Error: error requires operator intervention
12)Testing: interlocks disabled for manual testing
13)Warming

State Machine: Target Example

Target Example:

1)Offline
2)Parked_Powered
3)Raised_Holding
4)Raised_Actuating
5)Moving_Holding
6)Lowered_Holding
7)Lowered_Actuating
8)Error
9)Unknown