Vacuum Controls and Interlocks

CERN Accelerator School
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Outline

- Introduction
- Architecture
  - “3 tiers” architecture
  - Example of the LHC vacuum system
- Mapping the equipment to the controls hardware
  - Operational & control models
  - SCADA server
- Databases
- Displaying vacuum data
- Case studies
  - Control of residual gas analysers at DESY
  - PLC based bake-out controllers at CERN
  - Web server based applications at ESRF
- Interlocks

Vacuum Control Systems

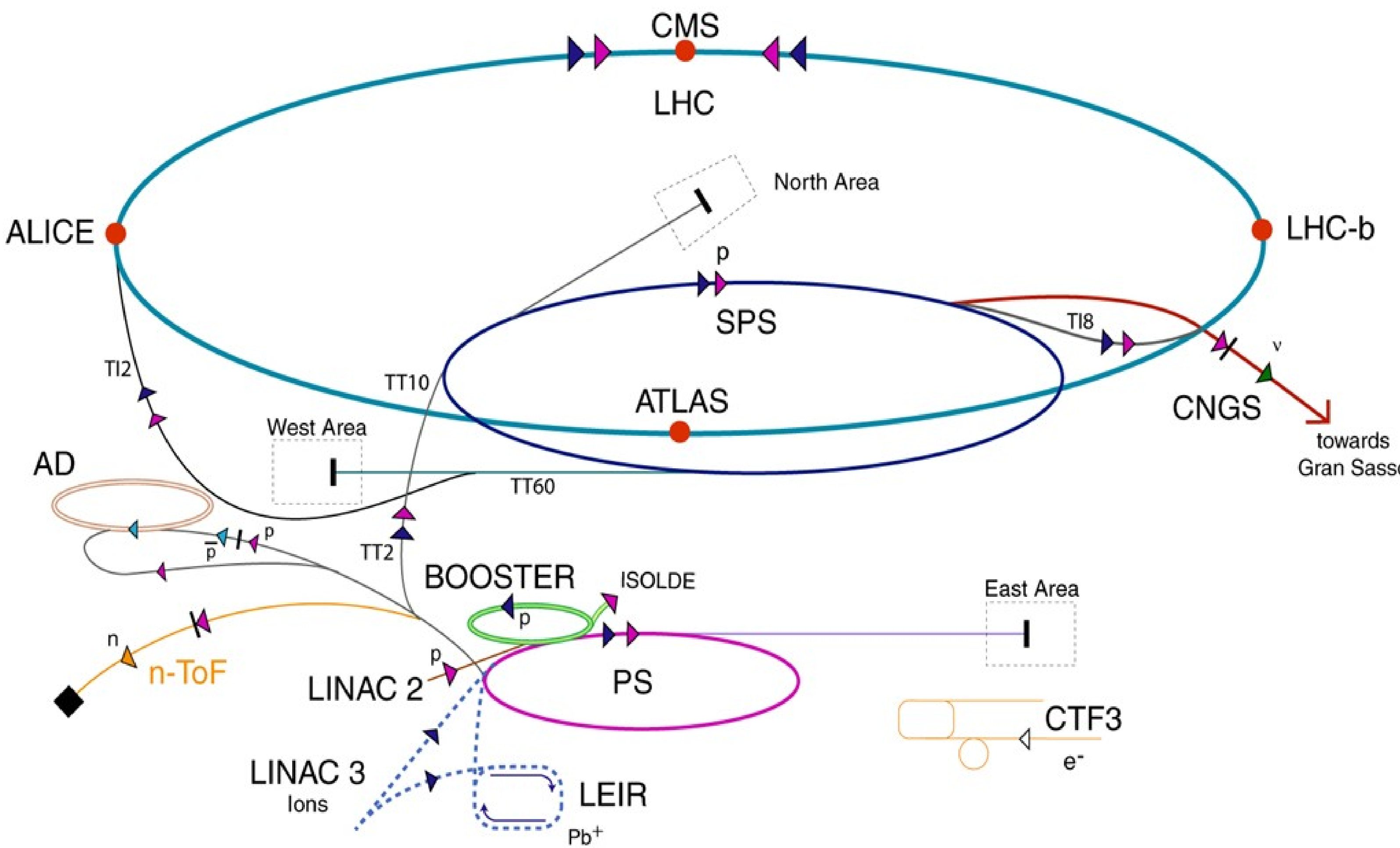
- In most cases, a subset of the general control system
- Share common network infrastructure
- Use standardised communication protocol

- Accept a large variety of equipment to control
- Buy “off the shelf” equipment

- Minimise differences in interfaces to application programs for each accelerator

- Preserve investment over accelerator lifetime

CERN Accelerator Network



protons
ions
neutrons

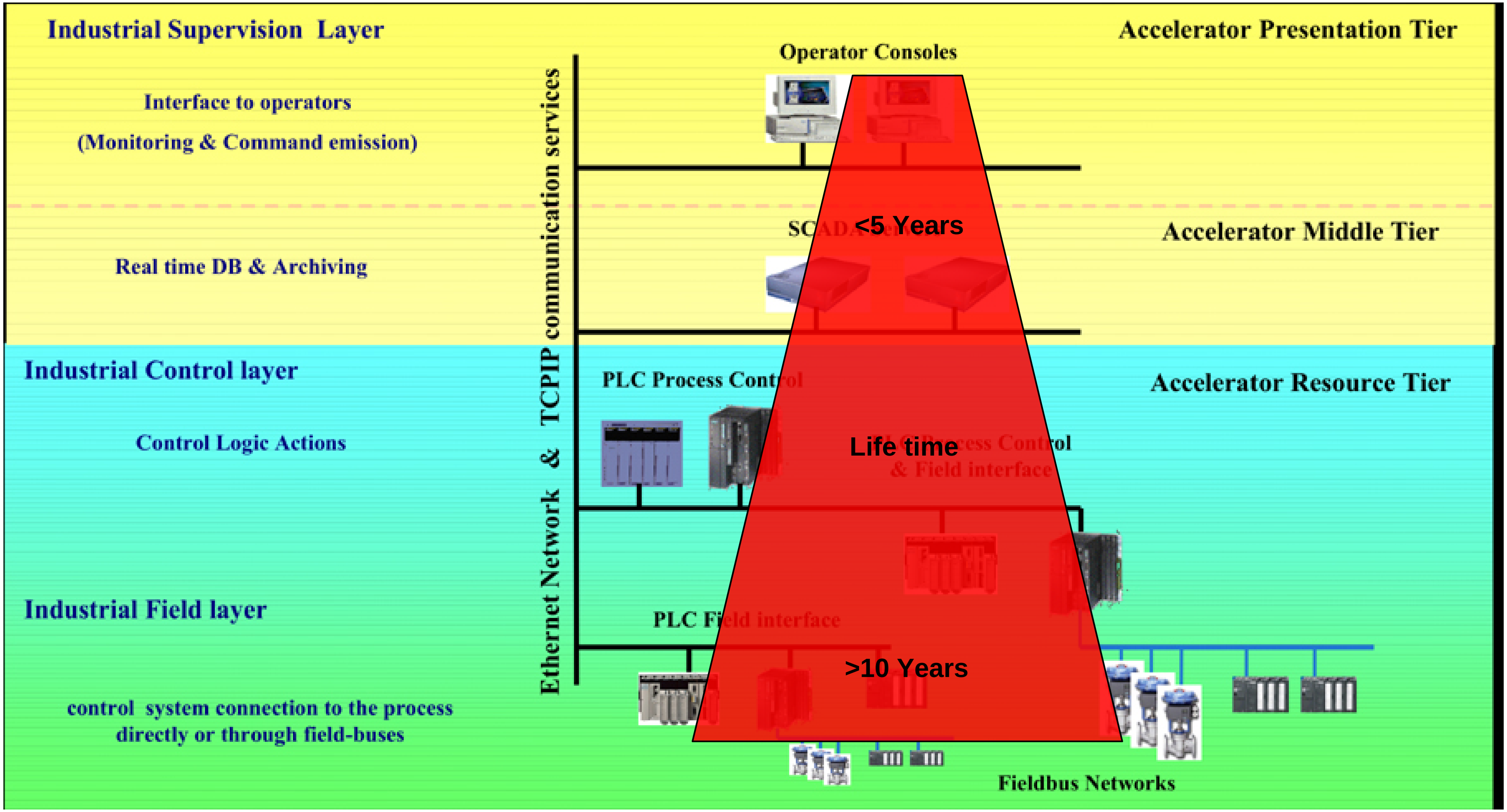
antiprotons
electrons
neutrinos

AD Antiproton Decelerator
PS Proton Synchrotron
SPS Super Proton Synchrotron

LHC Large Hadron Collider
n-ToF Neutron Time of Flight
CNGS CERN Neutrinos Gran Sasso

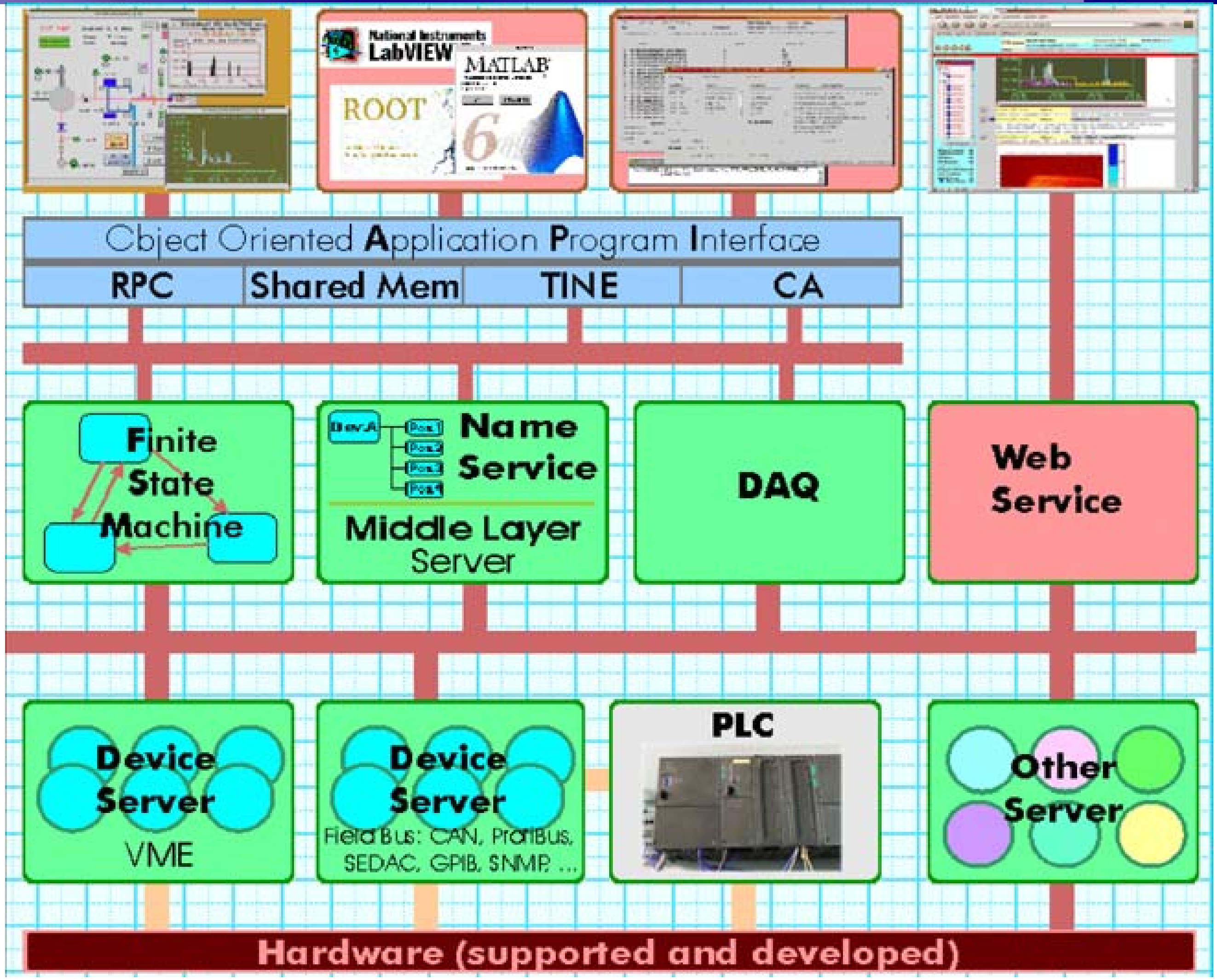
CTF3 CLIC Test Facility 3

Global Architecture (1)



Picture courtesy Ph. Gayet, CERN

Global Architecture (2)



Presentation Layer

Application Layer

Equipment Layer

Picture courtesy O. Hensler, DESY

Advantages of the layered approach

- Better definition of common services
- More “generic” applications
  - Alarm handling, logging, etc.
- Better suited for “object oriented” programming
- Concentrate the Application Programming Interfaces (API) in few places
  - Interface with commercial products like LabView, MathLab
- Accommodate different lifetime of components
  - < 5 years for the presentation layer
  - 10 to 15 years for the equipment layer

Industrial standards

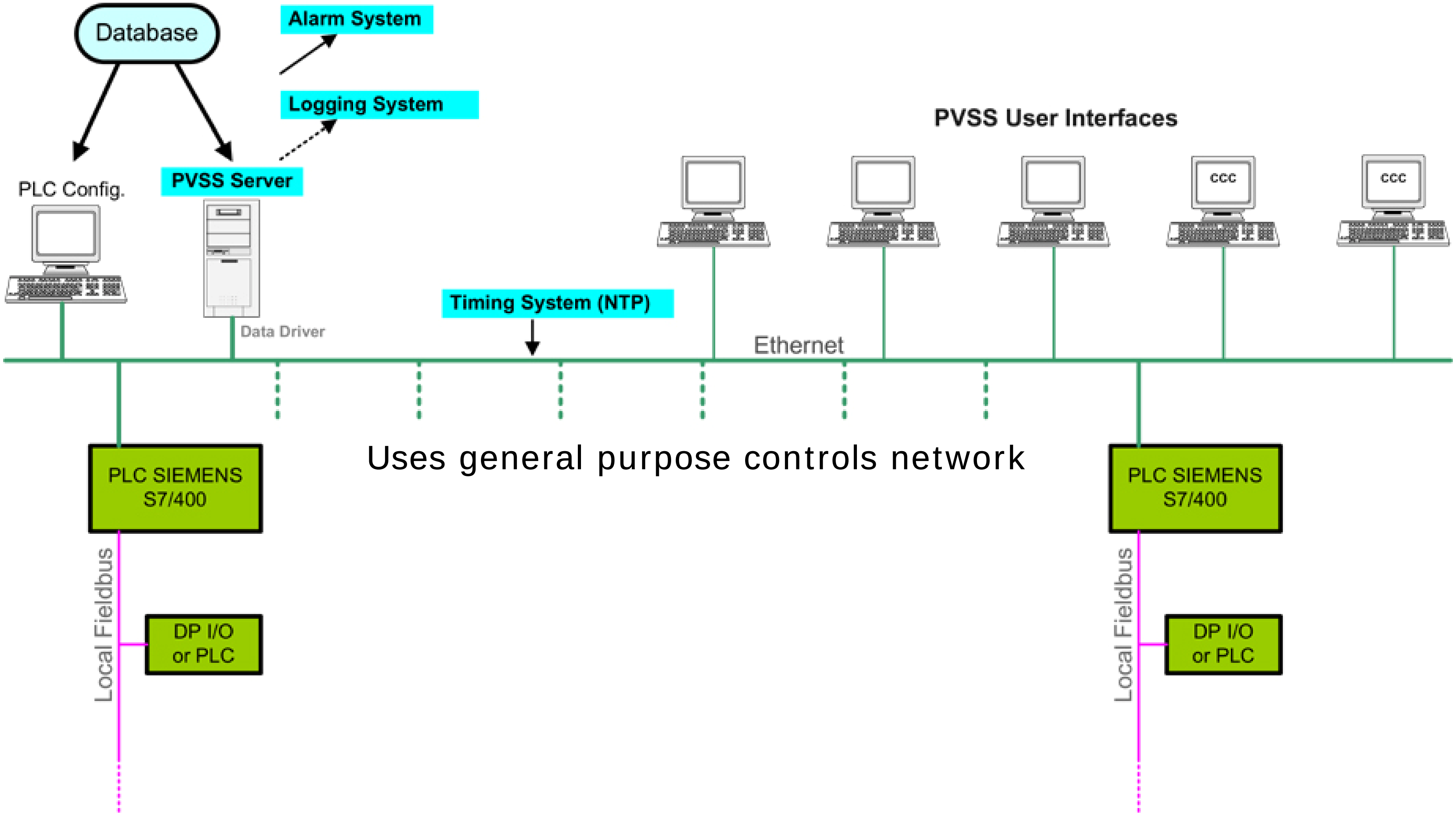
- Use industrial and well documented standards
- TCP/IP for communication
- UNIX and Windows in upper and middle layers
- PLCs for the lower layer

- Allows for outsourcing the maintenance

BUT

- More vulnerable to outside attacks (hackers)
  - Cryogenic controls for LHC magnet tests already stopped once
  - A digital oscilloscope was used as remote computer...

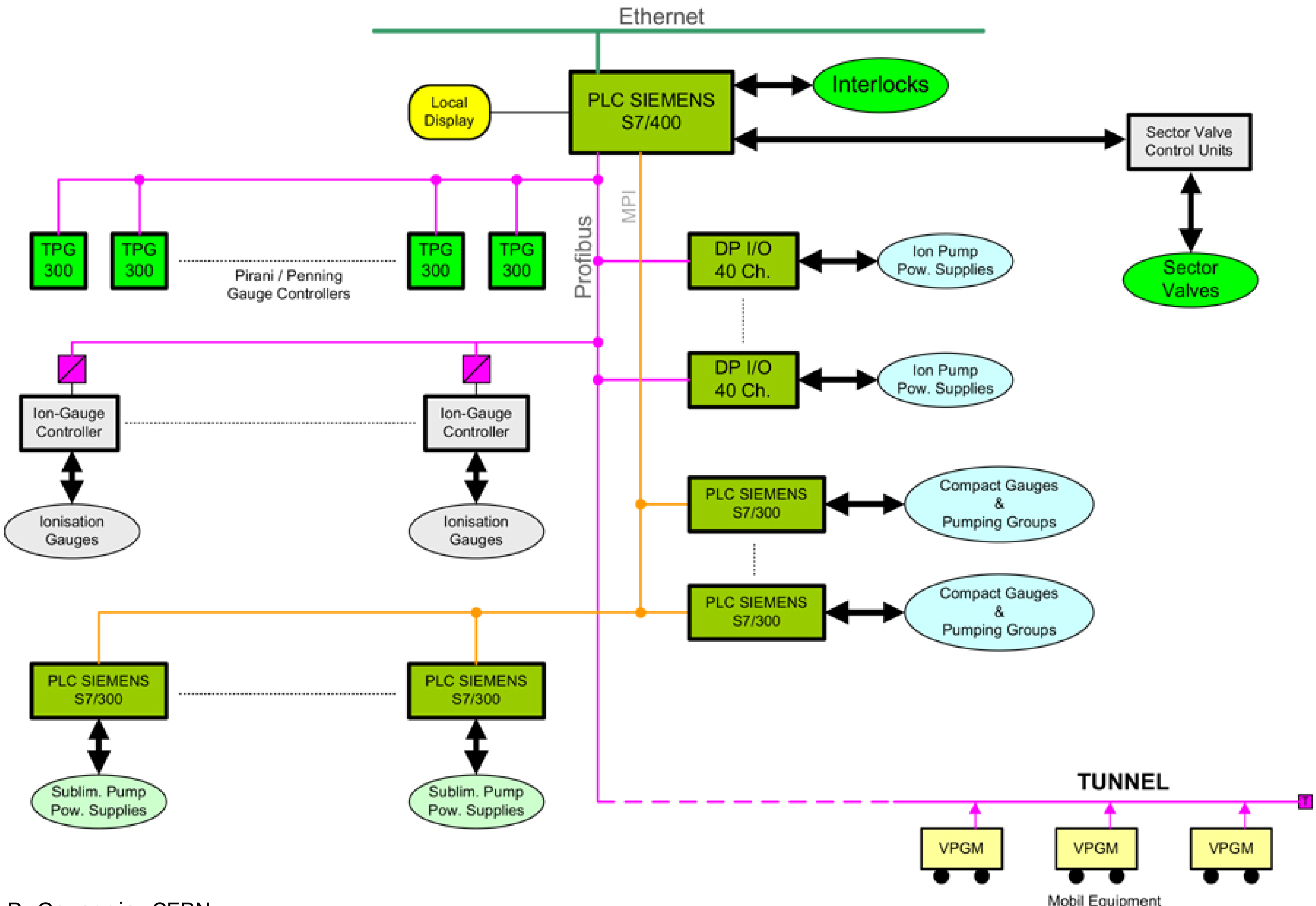
Vacuum Architecture (upper layers)



Uses general purpose controls network

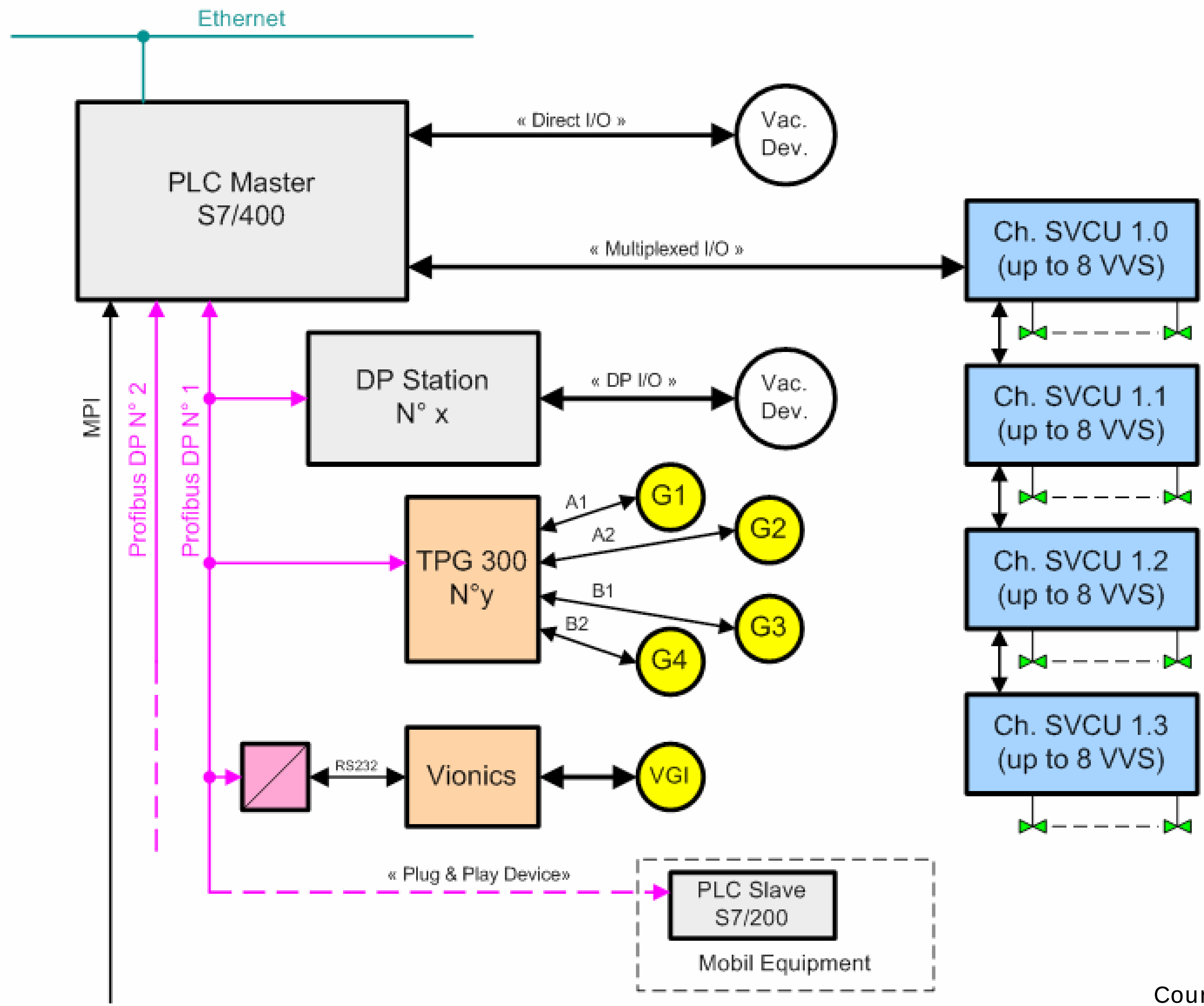
Courtesy R. Gavaggio, CERN

Vacuum Architecture (lower layer)



Courtesy R. Gavaggio, CERN

Access to Individual Equipment (1)



Courtesy R. Gavaggio

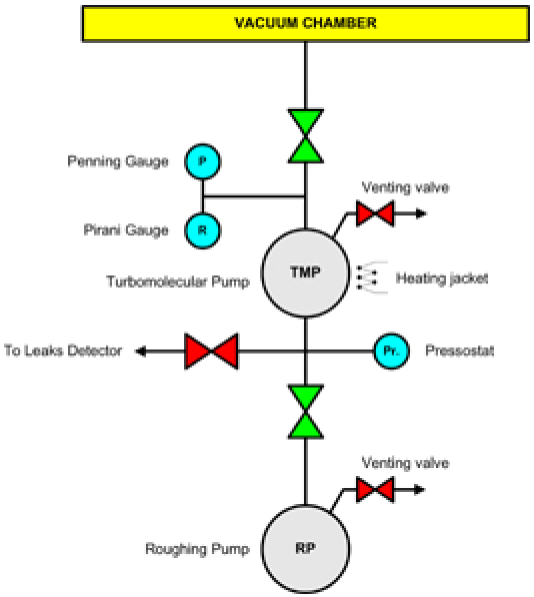
The equipment must be recognised automatically

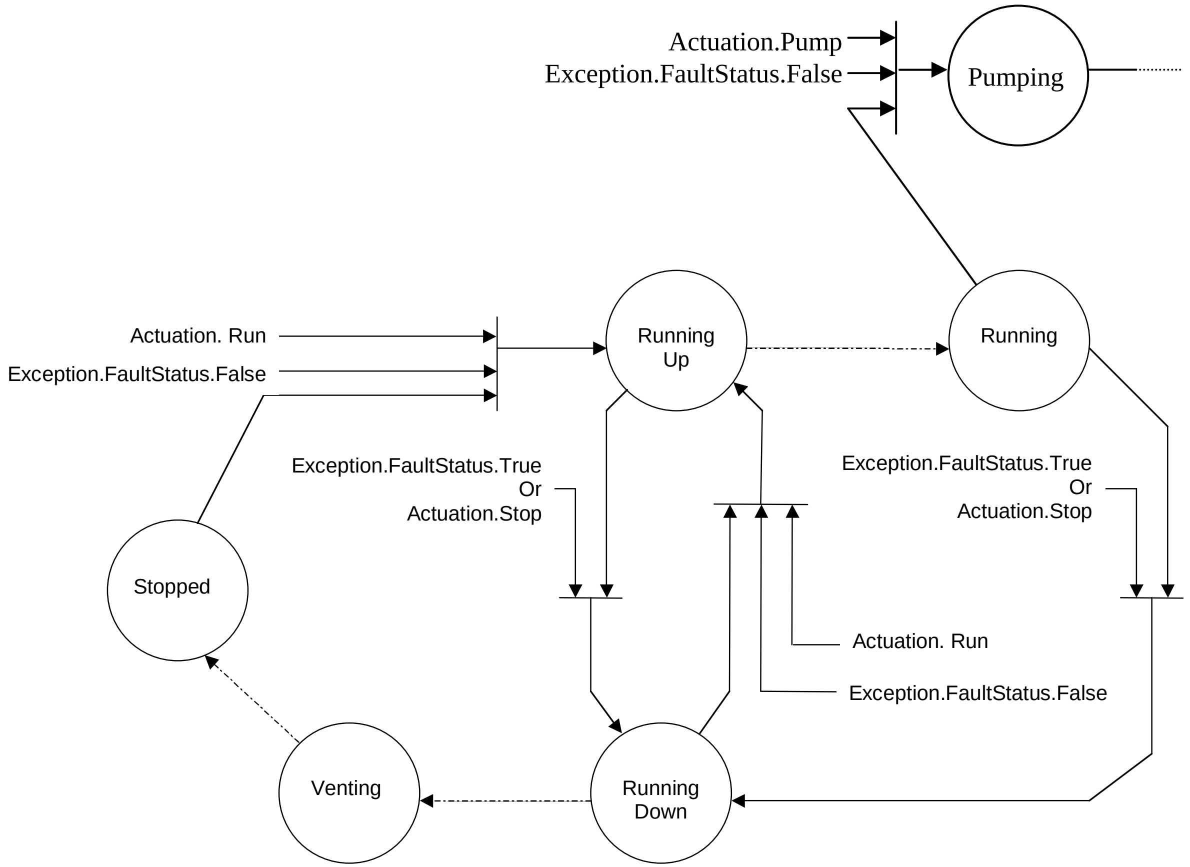
therefore

The control system must know

- WHICH mobile equipment is connected to it
  - Done by software
- WHERE an equipment is connected to it
  - Hardware solutions (DESY)
    - Hardware code in the connection plug
  - Some information entered by an operator (LEP & LHC)
    - LEP: -> Half cell
    - **LHC: -> ?** **Location**
      Magnet insulation vacuum
      He distribution line vacuum
      Beam vacuum: beam 1 or beam 2

Functional model of an equipment
Example of a pumping station

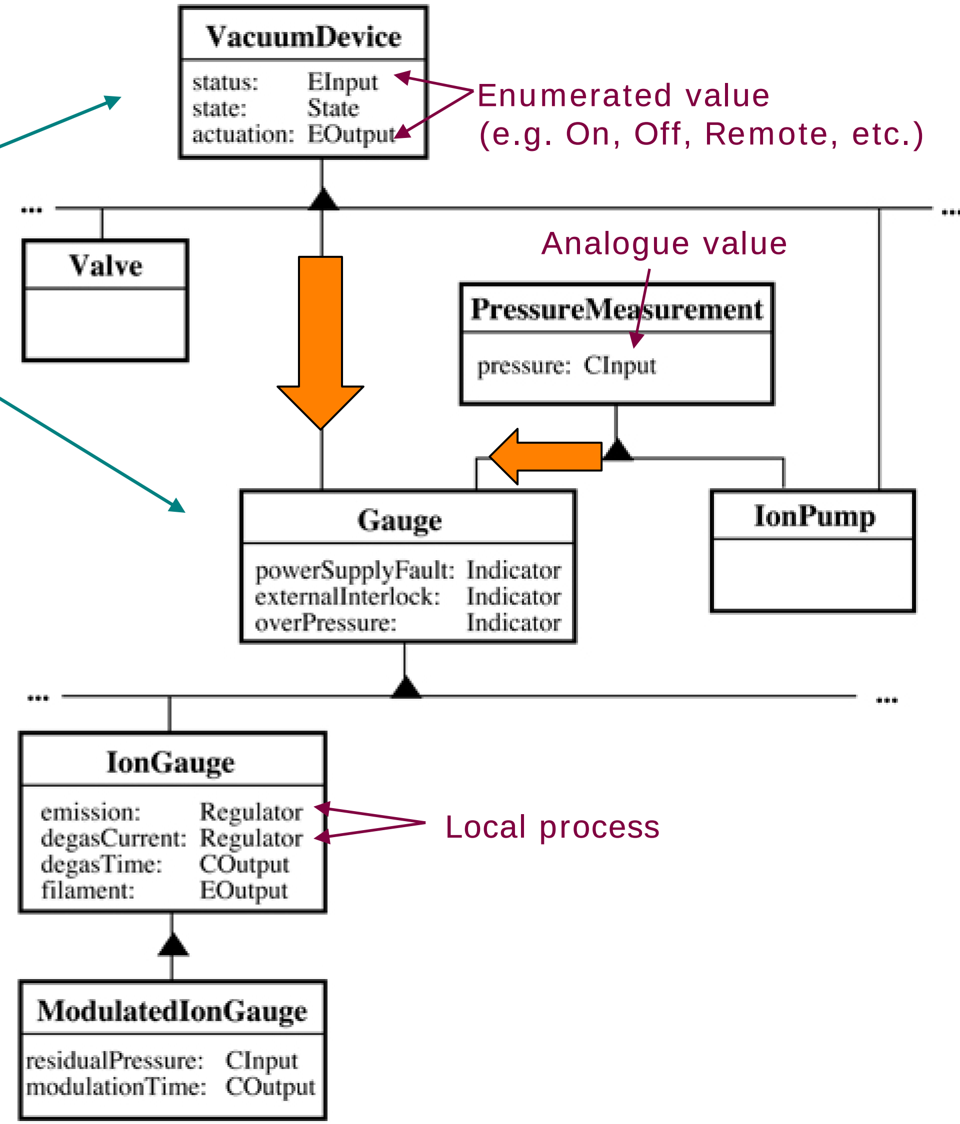




Control (or software) model

Define classes

Inherit attributes and methods



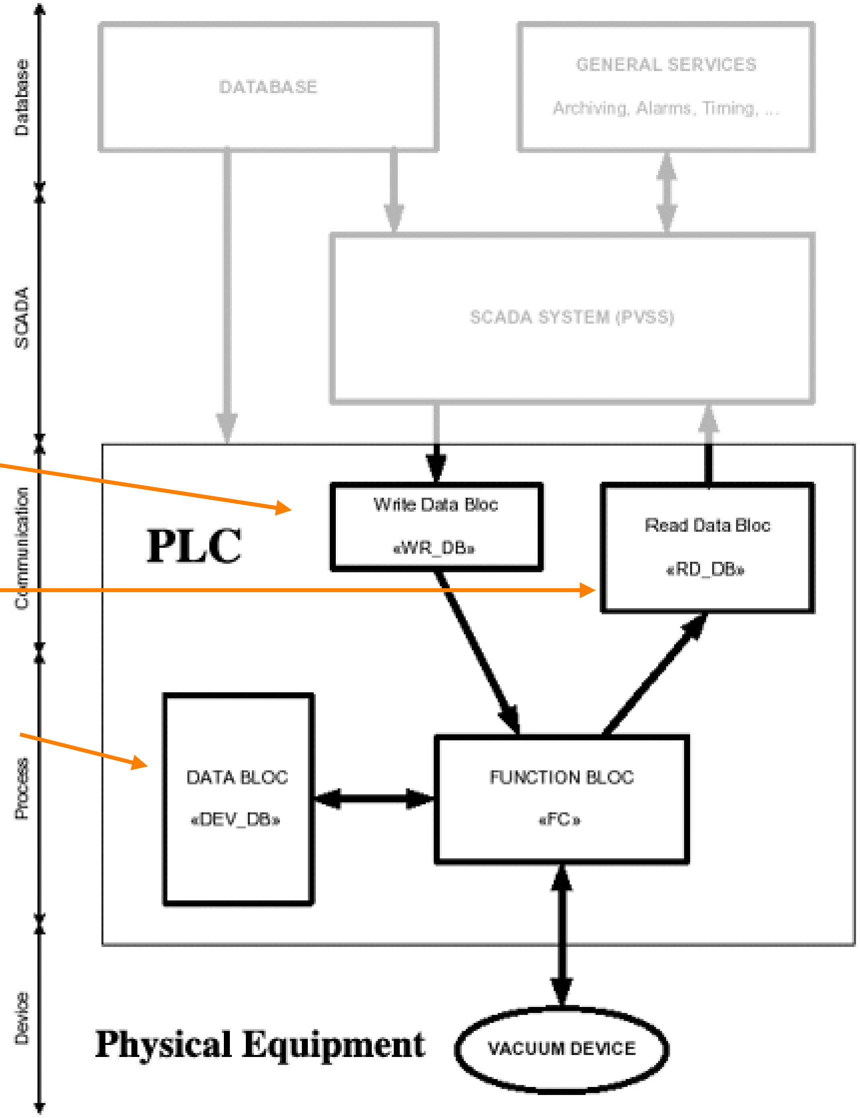
The model is independent from the hardware and software implementation

Organisation of PLC data blocks

One data block for data TO the PLC
- Commands, set points, etc.

One data block for data FROM the PLC
- Acquired values, states, timestamps, etc.

One data block for specificity of equipment



Courtesy R. Gavaggio, CERN

Lower layer of LHC vacuum controls

Memory mapping of PLC data blocks

One data block description for each subtype of equipment

One data block in memory for each instance of an equipment

- Identification data
- Offset to the data in the PLC memory
- Diagnostic and raw access, etc.

Offset \ Struct. →	VRPI_WK	VG_TPG	VV_SPS	VV_STD	VGP_C	VG_C
0..25	Dev_Name [24]	Dev_Name [24]	Dev_Name [24]	Dev_Name [24]	Dev_Name [24]	Dev_Name [24]
26	Dev_Family	Dev_Family	Dev_Family	Dev_Family	Dev_Family	Dev_Family
27	Dev_Type	Dev_Type	Dev_Type	Dev_Type	Dev_Type	Dev_Type
28..29	Dev_SubType	Dev_SubType	Dev_SubType	Dev_SubType	Dev_SubType	Dev_SubType
30	Machine	Machine	Machine	Machine	Machine	Machine
31	Subsystem	Subsystem	Subsystem	Subsystem	Subsystem	Subsystem
32	Sector_Addr	Sector_Addr	Sector_Addr	Sector_Addr	Sector_Addr	Sector_Addr
33						
34	Display_Pos	Display_Pos	Display_Pos	Display_Pos	Display_Pos	Display_Pos
35						
36	Main_Part	Main_Part	Main_Part	Main_Part	Main_Part	Main_Part
37						
38	WR_DB	WR_DB	WR_DB	WR_DB	WR_DB	WR_DB
39						
40	WR_Offset	WR_Offset	WR_Offset	WR_Offset	WR_Offset	WR_Offset
41						
42	RD_DB	RD_DB	RD_DB	RD_DB	RD_DB	RD_DB
43						
44	RD_Offset	RD_Offset	RD_Offset	RD_Offset	RD_Offset	RD_Offset
45						
46	Fieldbus	DP_Fieldbus	Card_Addr	Fieldbus	Fieldbus	Fieldbus
47	DP_Addr	DP_Addr		DP_Addr	DP_Addr	DP_Addr
48	Diagno_Addr	DP_Diagno_Addr	SVCU_Set_DB	Diagno_Addr	Diagno_Addr	Diagno_Addr
49						
50	AI_Addr_Ptr	TPG_Channel	Sect_After_Addr	DI_Addr_Ptr	AI_Addr_Ptr	AI_Addr_Ptr
51						
52		Base_Addr	OP_CLR_Flag			
53						
54	DO_Off_Addr_Ptr	Free	OP_CLR_Delay	DO_Addr_Ptr	DO_Addr_Ptr	DO_Addr_Ptr
55						
56						
57						
58	DO_On_Addr_Ptr		Moving_Time_Out	Free	Vgr_Int_DB	Free
59						
60			Int_Flag (.0), Vlv_Flag (.1)		Free	
61			Free_Sync_Byte			
62	Pumps_Nbr					
63						
64	Rack_Addr	Cntr_1			ADC_Raw_Value	ADC_Raw_Value
65		Free_Sync_Byte				
66	Free				Man_On_Duration	Filter_Cntr
67						
68				Timer_VLV		
69						
70	ADC_Raw_Value				Auto_On_Duration	
71						
72	Time_Out1					
73	Wait_Flag					
74	PS_Current (Real)				Auto_Off_Duration	
75						
76						
77						
78	Time_Out2					
79						
80						
81						

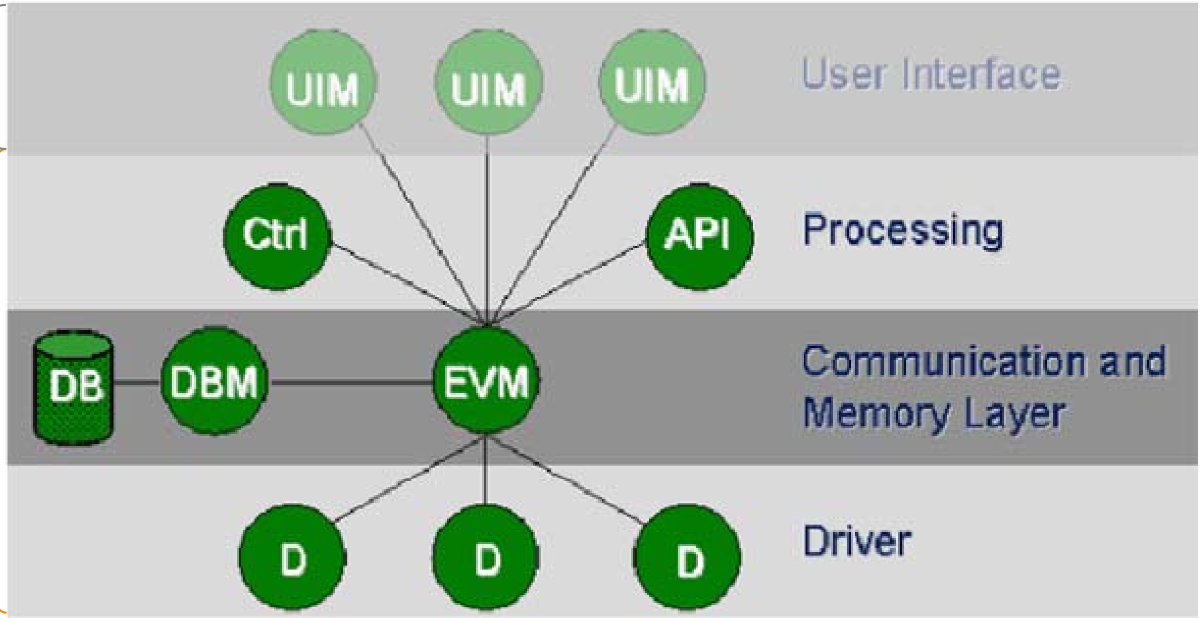
Courtesy R. Gavaggio, CERN

SCADA Server (1)

- "Supervisory Control And Data Acquisition"
  - Data acquisition, logging and archiving
  - Alarm handling
  - Access control mechanism
  - Human Machine Interface including many standard features e.g. alarm display or trending

Application layer

Middle layer



Industrial product chosen by CERN:

PVSS

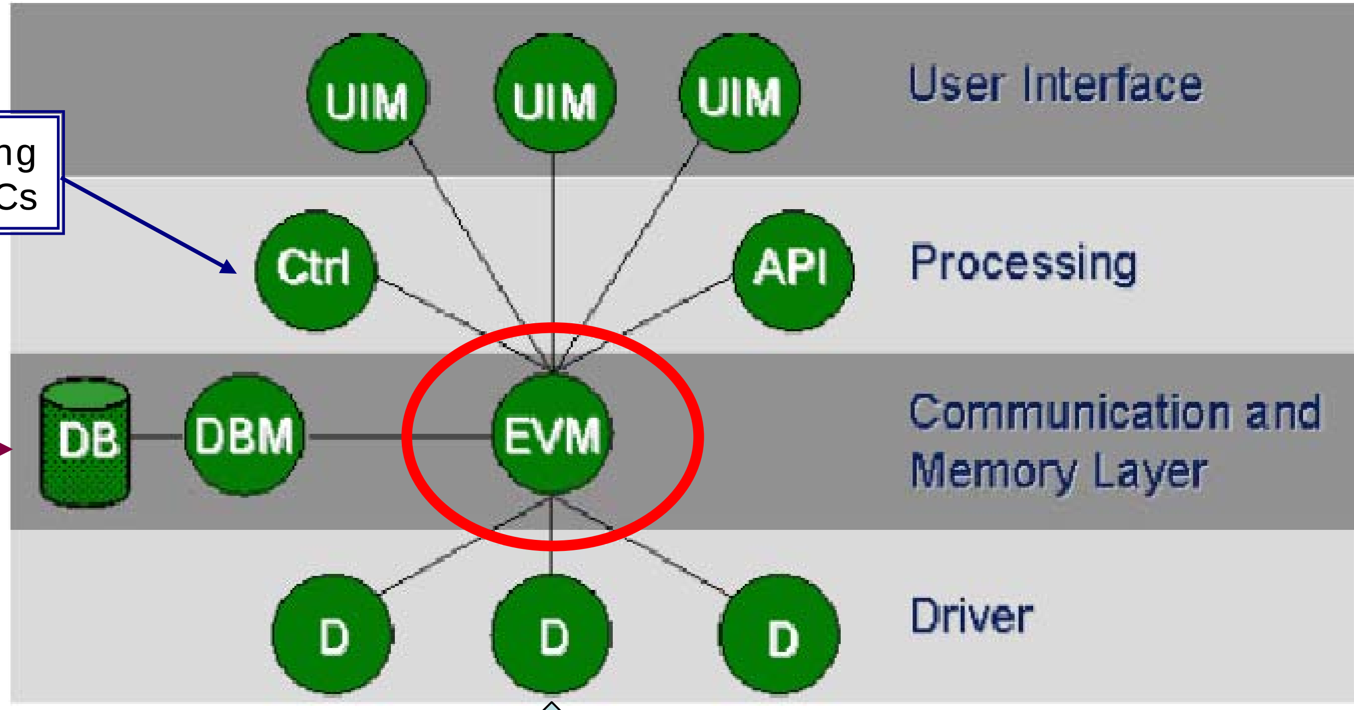
Supplier: ETM (Austria)

SCADA Server (2)

- Built around the “Event Manager”
  - Get and dispatch the data to all processes

Global processes driving equipment from several PLCs

Runtime database holding all process variables

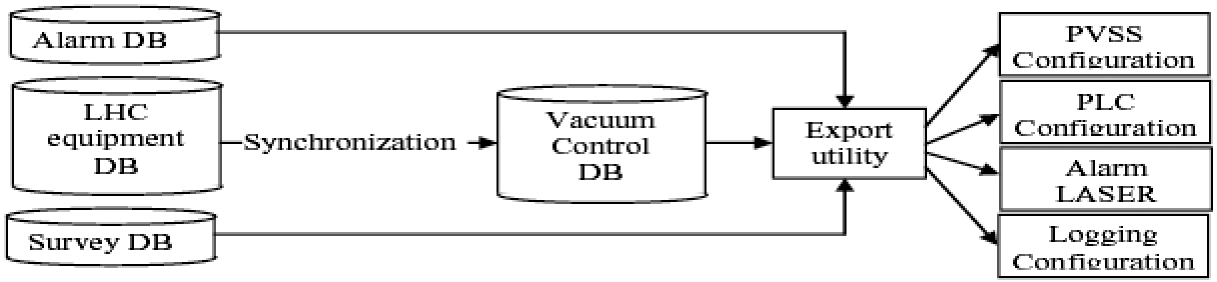


To / From the PLCs

Courtesy C. Gaspar at al., CERN

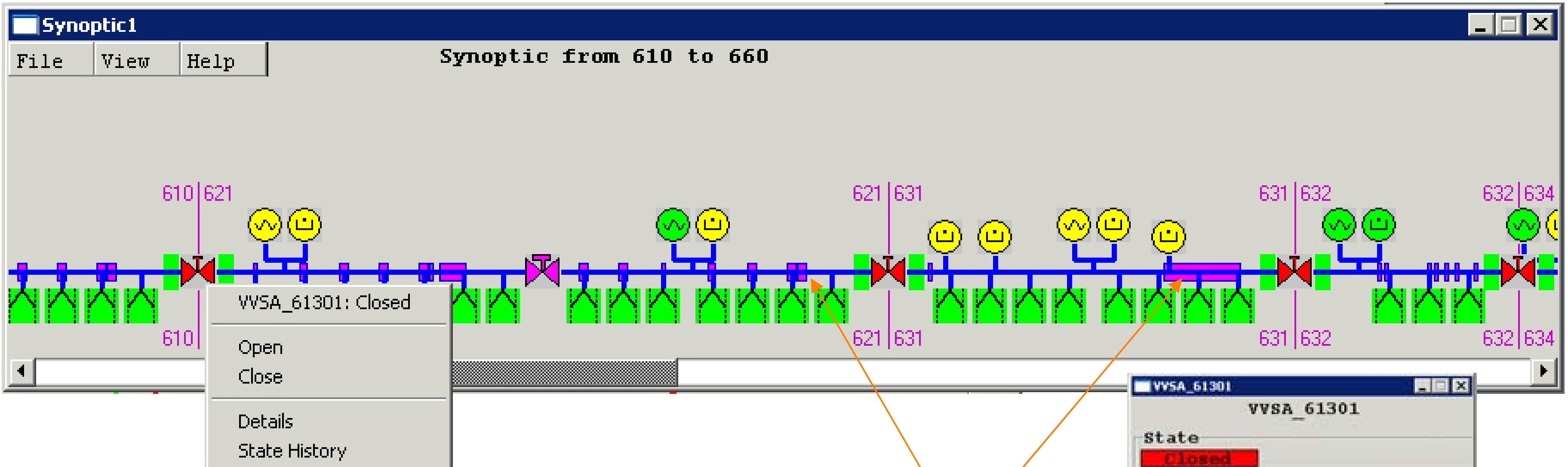
Avoid as much as possible "hard coding"

- Describe the software structure
  - "data blocks" for PLCs, "data point types" for PVSS
- Describe the "layout"
  - Sequence of equipment in an accelerator, Vacuum sectors the equipment belongs to, etc.
  - Geographical locations



Courtesy I. Laugier, CERN

Synoptic view



Non-vacuum equipment shown to ease localisation

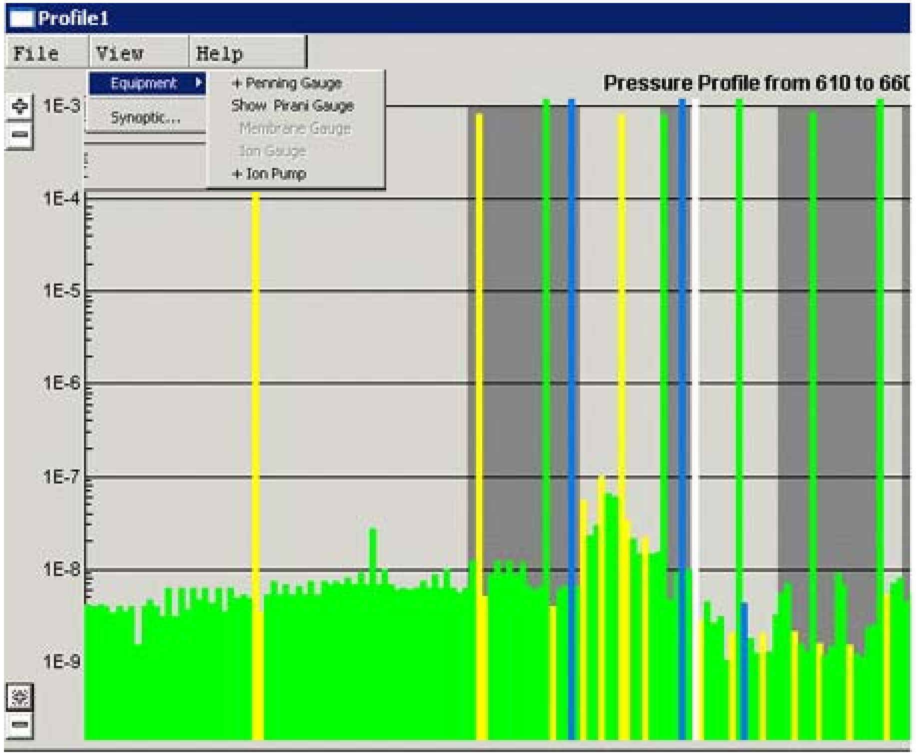
Use “point & click” to get more details

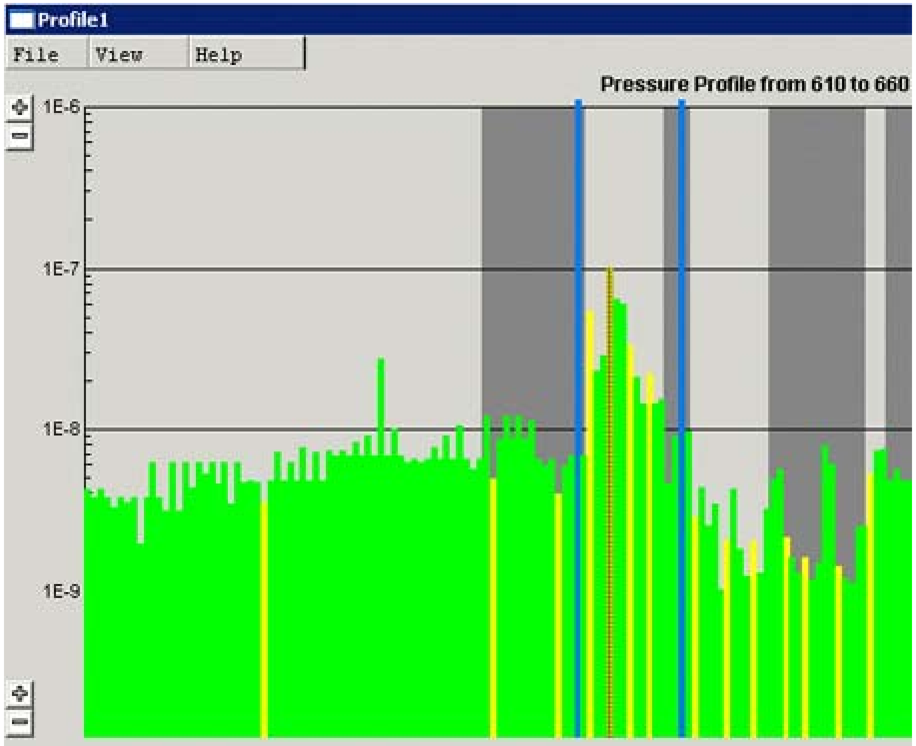
Commands via the associated control pannel

Pressure profiles

Many different vacuum devices return a pressure value
BUT
Their useful ranges do not overlap

Must select the useful devices



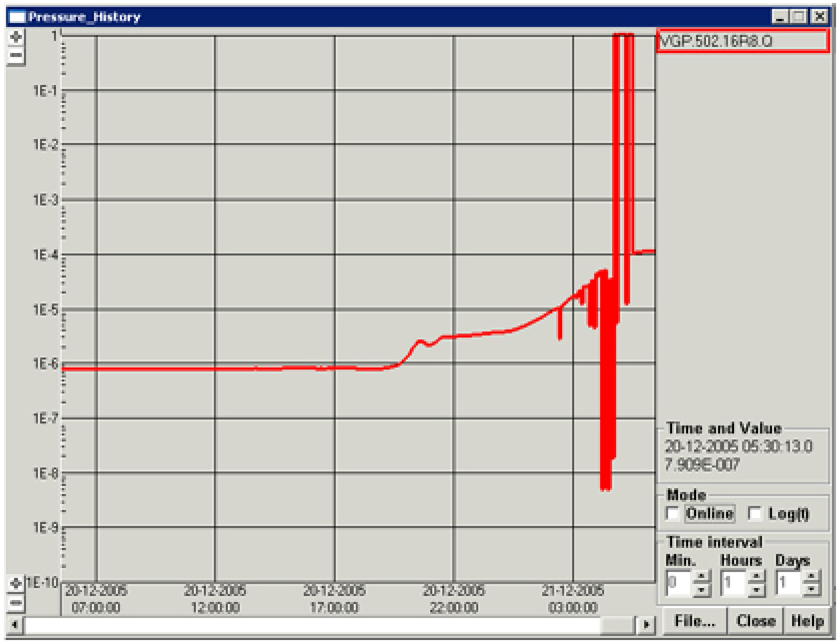


Adjust scales to useful range

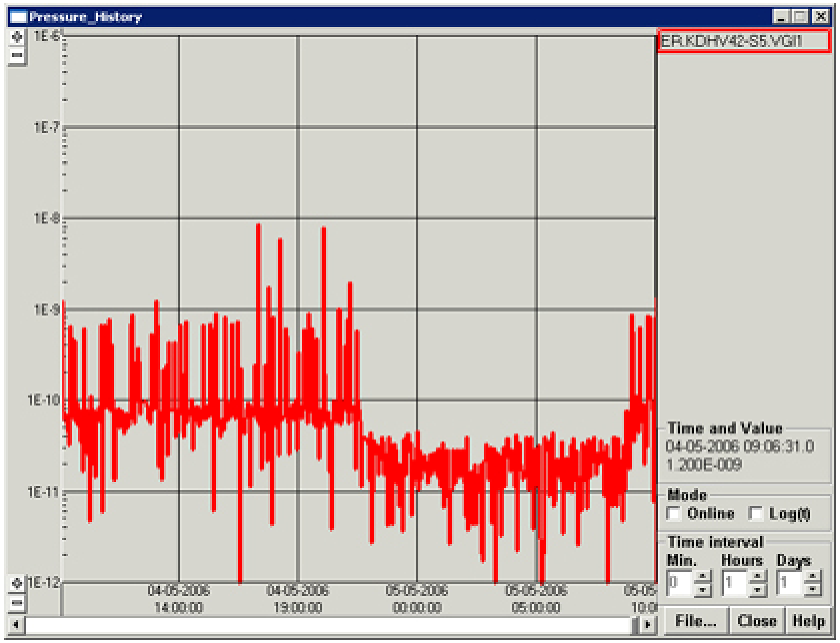
Pressure history

Useful to follow trends

Diagnostic for unexpected behaviour



Pressure versus time during the warm up of the LHC helium distribution line



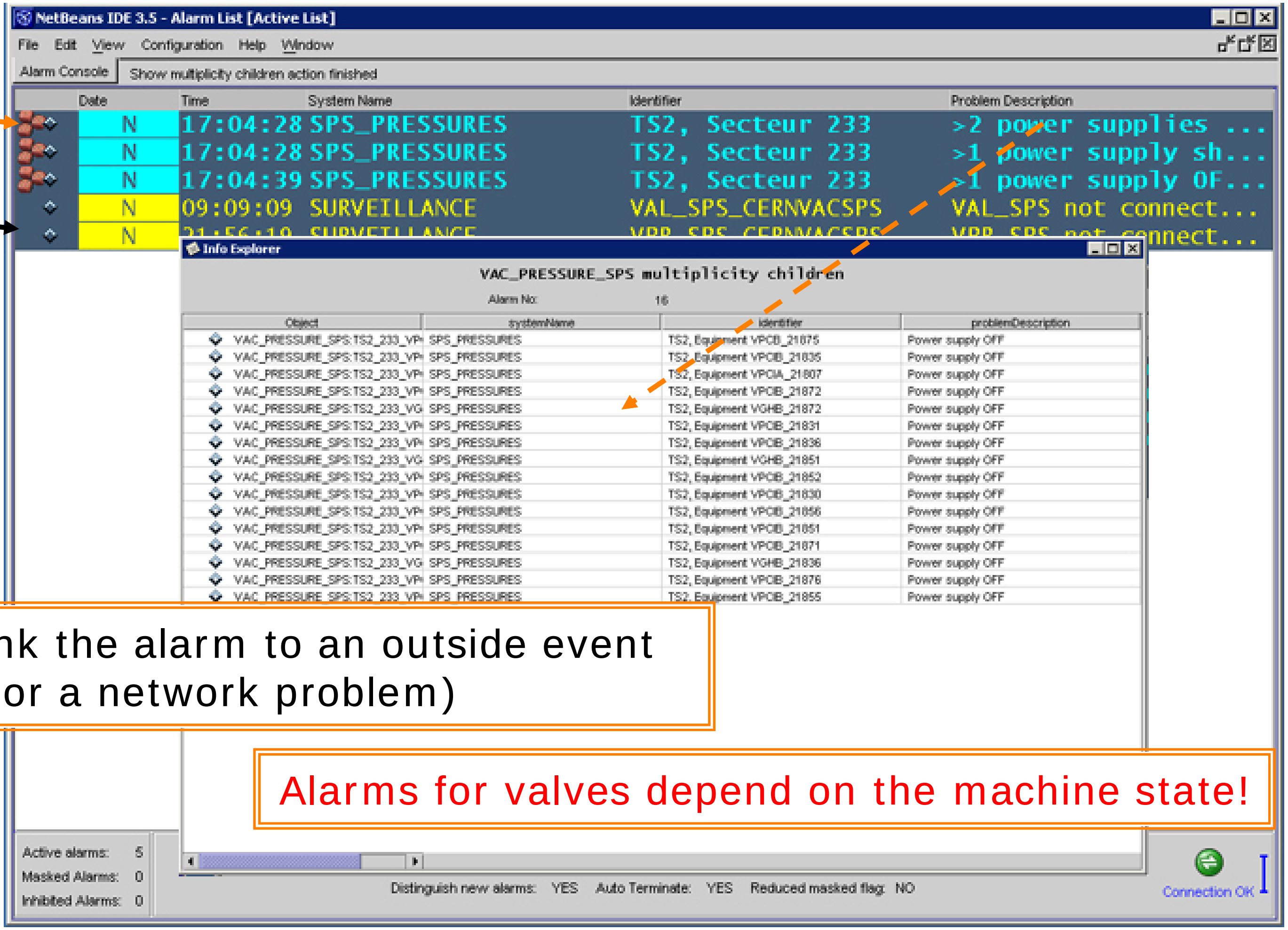
Noisy ion-gauge reading in LEIR during beam injection
Reason? Beam losses, electrical noise?

Required functionality:
multi-system correlation
e.g. Pressure versus temperature e.g. Pressure versus beam current

Minimise de number of alarms displayed to the operators

Compound alarm

Simple alarm



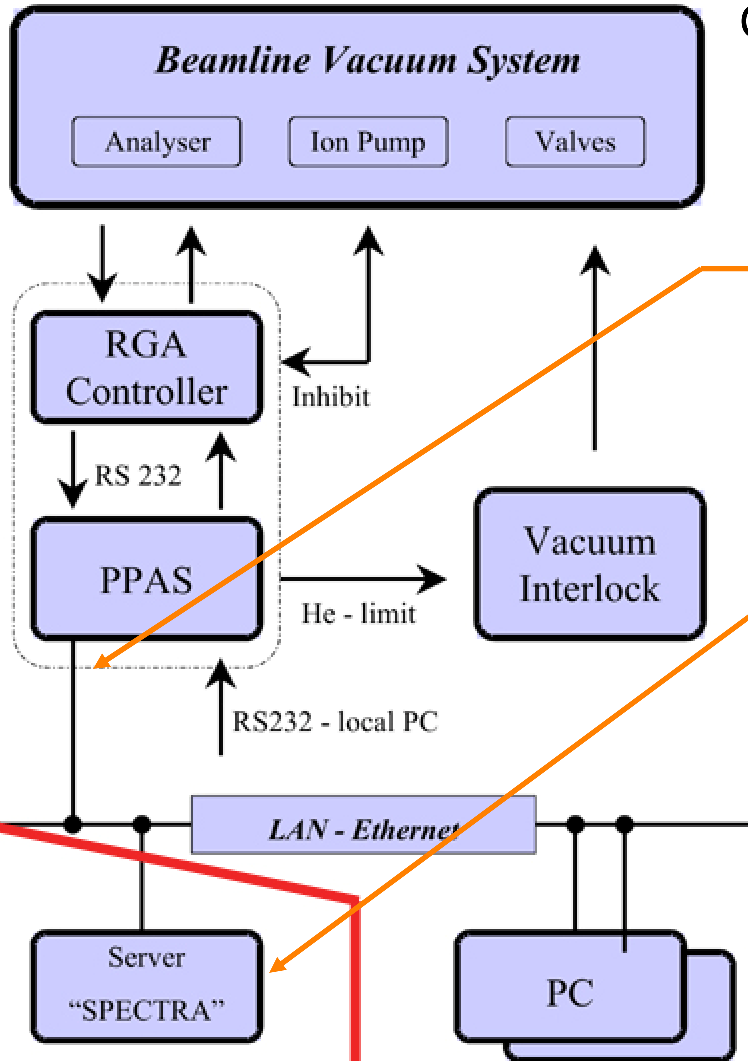
Whenever possible, link the alarm to an outside event (e.g. a power failure, or a network problem)

Alarms for valves depend on the machine state!

Control of Residual Gas Analysers

Controlling residual gas analysers:
Partial Pressure Alarm System
(DORIS beam lines , DESY)

Equipment layer



Direct interface to Ethernet

Dedicated server
(can be RGA manufacturer's solution)

Middle layer

Presentation layer

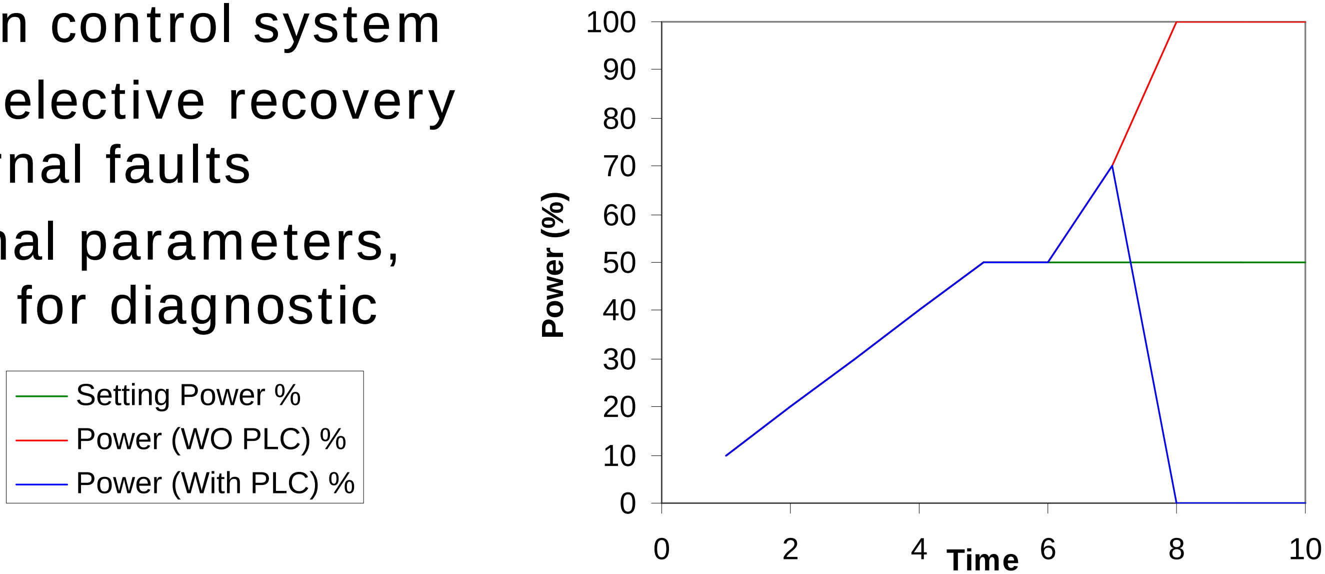
Courtesy U. Hahn, DESY

Individual control boxes for every channel

- Off the shelf equipment, but quite expensive
- Little remote diagnostic
- No integration of system wide parameters (e.g. pressure)

PLC based multi channel controllers

- Built-in possibility to connect to the main control system
- Allow for selective recovery from external faults
- Use external parameters, like power for diagnostic

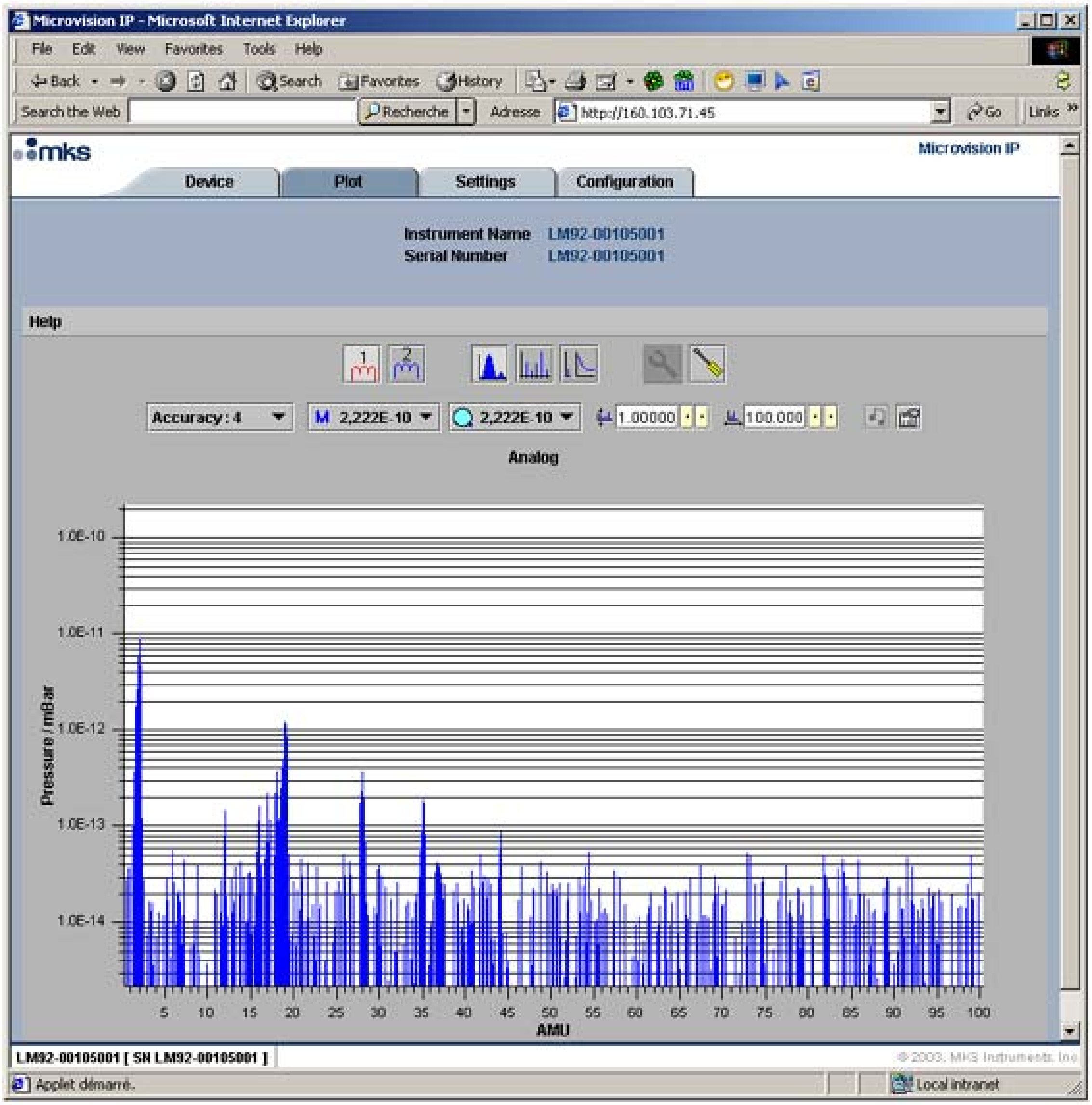


Courtesy S. Blanchard, CERN

WEB-Server based applications (1)

- WEB Server can be embedded in controls equipment
  - In PLCs
  - In industrial RGA control units
- Each PLC or control unit has its own server
  - Each WEB server brand has tools to develop simple applications
  - Not (yet?) adequate for complex controls
- Why use them?
  - Allow access to local processes when the main control system is down (e.g. maintenance periods)
  - Allow for easy prototyping of user interface

WEB-Server based applications (2)



Example for
Residual Gas Analysers
(ESRF)

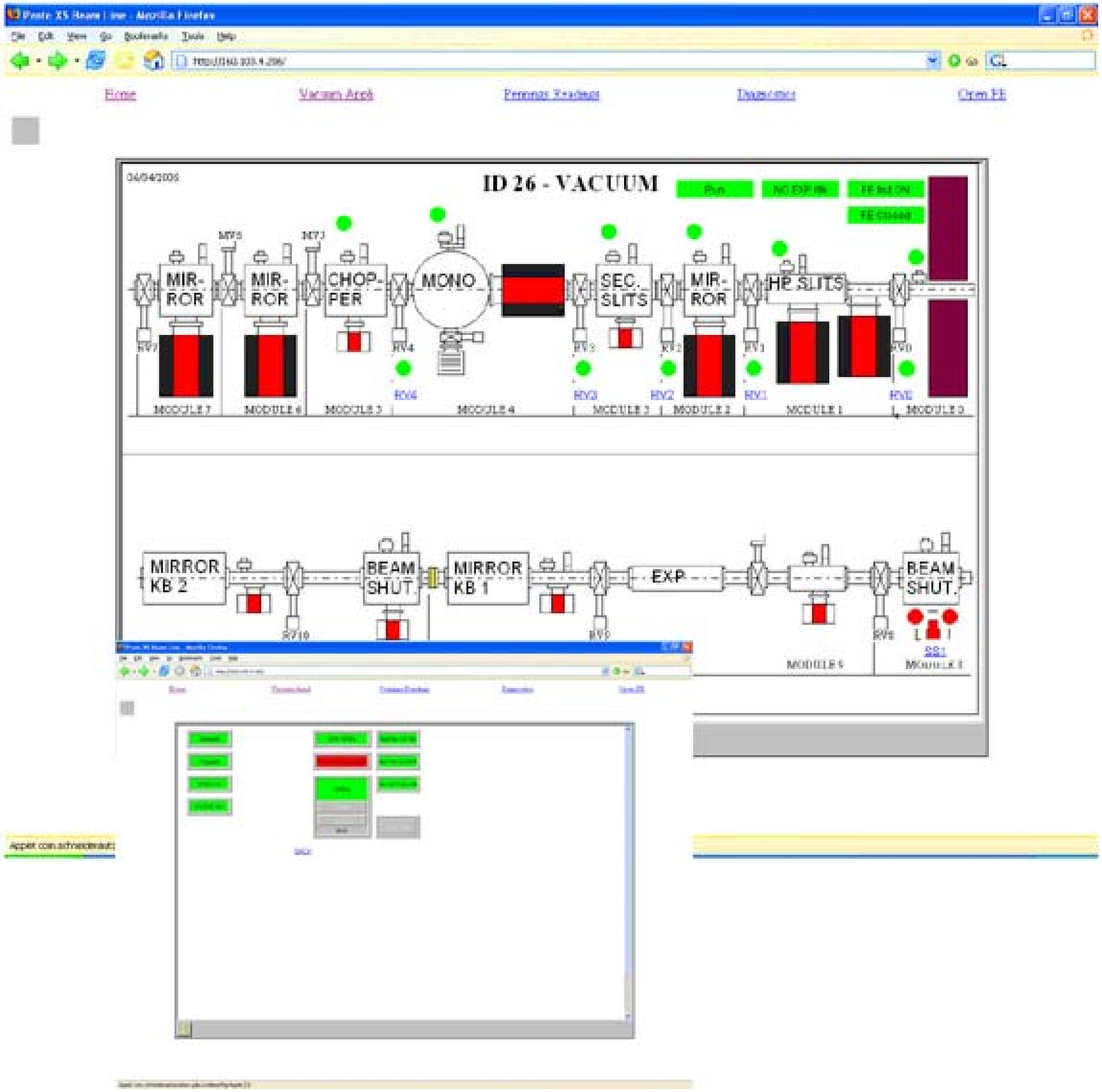
The RGA control unit is equipped with an integrated WEB-server and is installed inside the Synchrotron Ring.

The control unit is installed at 3m distance from the analyser head and shielded with 3mm of Pb.

An Ethernet cable connects the control unit with the LINUX-PC running the dedicated TANGO server to control the unit during machine operation.

The WEB-server is only used for maintenance work during shutdowns.

Courtesy D. Schmied, ESRF



Example for
beam line controls (PLC)
(ESRF)

New PLC for the controls of valves, shutters, absorbers and vacuum interlocks.

Appears really useful on beam lines since their set-up is much more dynamic and changes are quickly updated and ready to be tested.

Again the web server is only used for maintenance during shutdowns. During the machine operation a dedicate TANGO server takes over its duty.

Courtesy D. Schmied, ESRF

Protect the vacuum system

- Divide the vacuum system into maintainable lengths
  - -> Sector valves

Use robust sensors

- ion-pumps, cold-cathode gauges

Implement redundancy

- Use voting scheme to close (e.g. 2 faults out of 3)
- Require all sensors in good state to open

Protect the valves against high energy beam impact

- In case of vacuum failure

-> trigger beam abort

-> wait for confirmation

-> close sector valves

Protect individual components

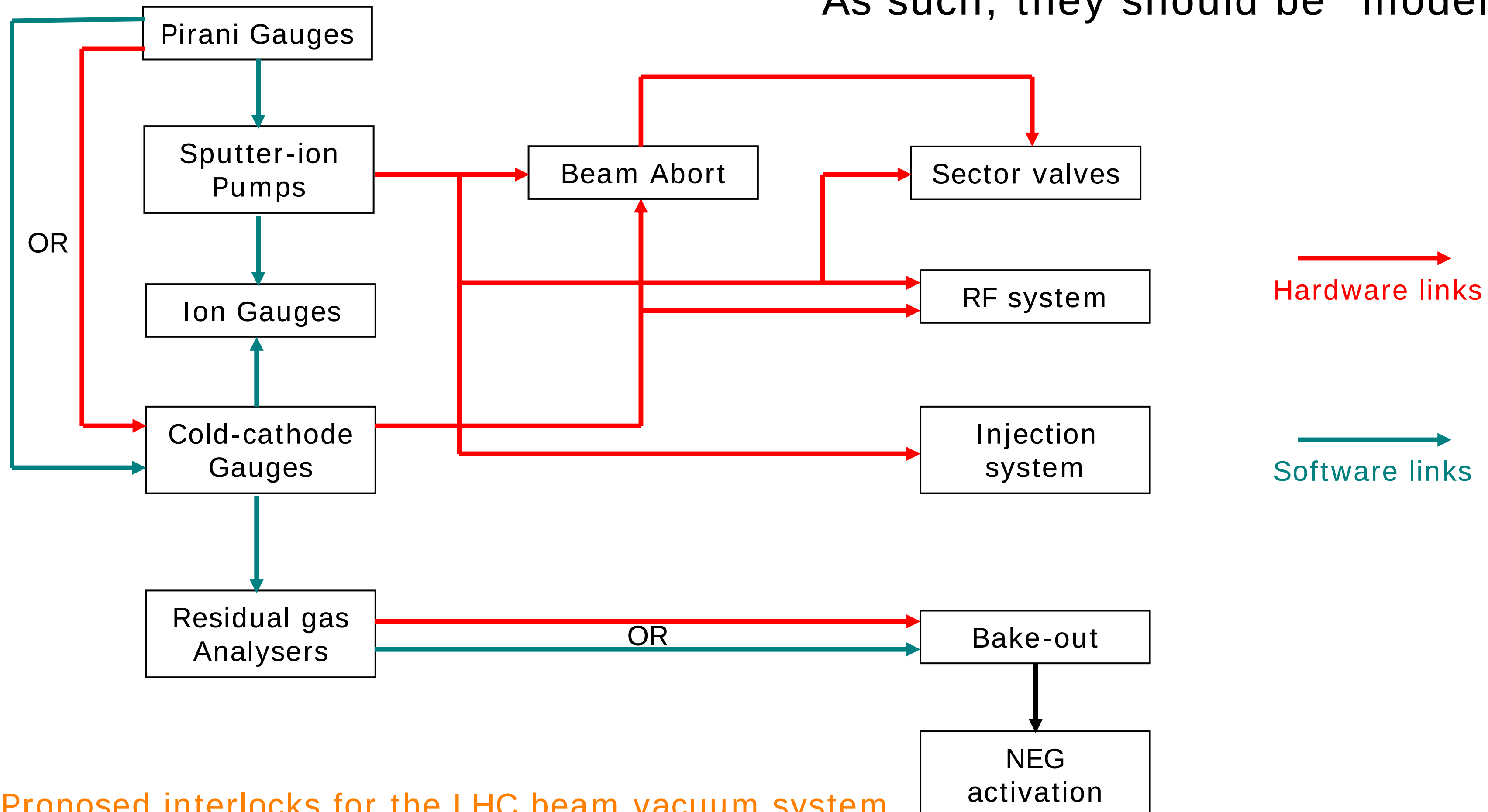
- Not too difficult as long as the equipment is on
- Monitor the raw value proportional to pressure
- Sometime monitor auxiliary parameters
  - e.g. emission for a hot-cathode gauge
- More tricky when equipment is off
  - Avoid damaging filaments of hot cathode devices
- Need a chain of sensors
- At least one able to work at atmospheric pressure

Interlocks to other systems

- e.g. RF cavities, electrostatic septa

Interlocks (3)

Interlocks should be considered as a global process
As such, they should be “modelised”



Proposed interlocks for the LHC beam vacuum system

Benefits of modern PLC based approach

Better overall performance than previous systems

- Equipment polling time < 500 ms when 400 devices connected to the same master PLC
- Logging pressures from 200 gauges in SPS once per second could be achieved recently

Very high reliability

- Few equipment failures, mainly power supply related
- Comprehensive remote diagnostics of the PLCs

Easy to reconfigure after layout changes

- Configuration files generated from a central database
- Can be downloaded without stopping the PLC

Thanks to the following colleagues:

- C. Gaspar (CERN)
- R. Gavaggio (CERN)
- U. Hahn (DESY)
- O. Hensler (DESY)
- I. Laugier (CERN)
- Ph. Gayet (CERN)
- D. Schmied (ESRF)

And thank you for your attention!