



CRYOGENICS OPERATIONS 2008

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Organized by CERN

The LHC Control System

Philippe Gayet

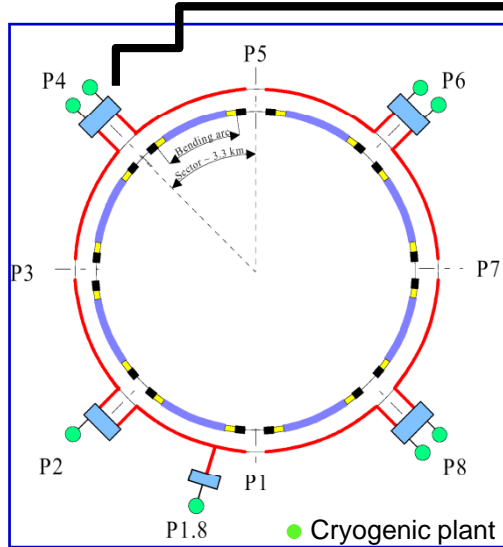
On behalf of AB-CO-IS



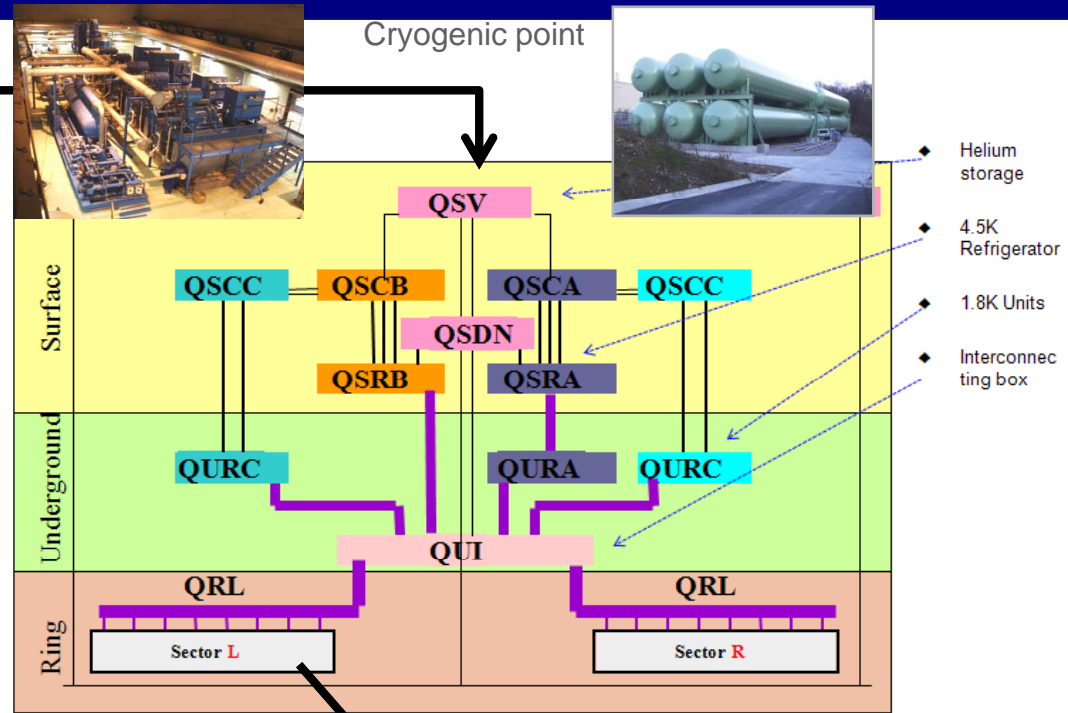
LHC Cryogenics Architecture

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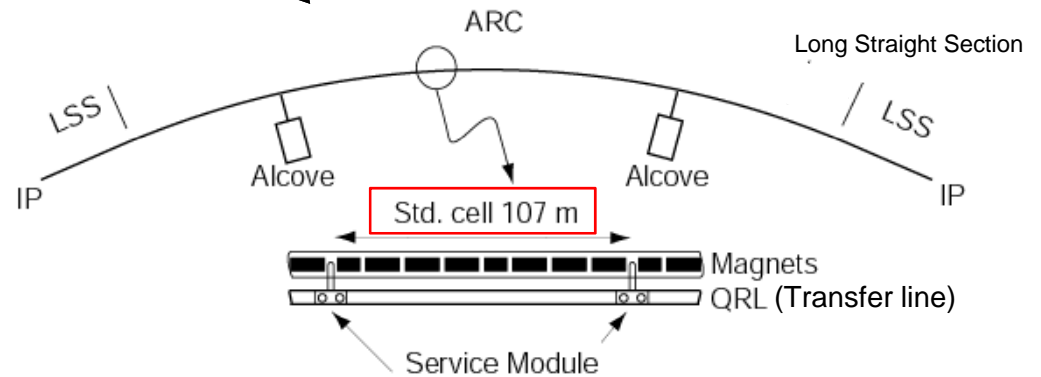
LHC cryogenics overview



LHC tunnel (27 km)



3.3 km





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Deployment constraints

- **Application production by various team**
 - » CERN internal
 - » External company (initial tight schedule)
 - » Produced by external collaboration
- **Staged commissioning**
 - » Commission a new cryogenics component without stopping the already running ones
- **8 years of deployment with evolving technology and requirements**
 - » Evolution Radiation environment prevision
 - » Increased number of channels from 30000 to 60000



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Operational constraints for CS

- **Reliability**
 - » Avoid Cryogenic downtime
- **Efficiency**
 - » The complexity of the controlled process is such that the operator duty shall be alleviated by a very high level of automation and efficient diagnostics facilities
- **Ergonomic**
 - » Compatible with former operation practices
 - » Homogeneous, intuitive, adapted to a large system
 - » Seamless integration of various control hardware components



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HARDWARE



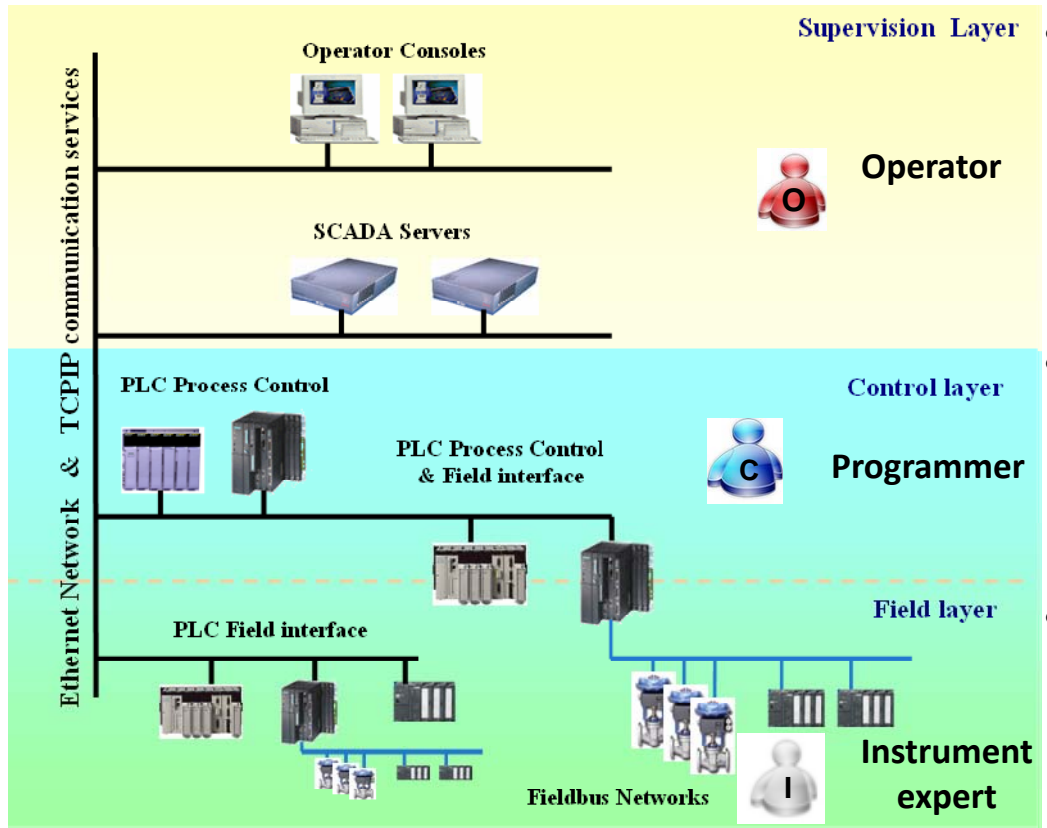
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LHC control a BIG step forward

- **LEP 2 (1992-2000) (2 layers solution)**
 - » 11 Supervision servers Used Operator workstations
 - » 20 PCU directly connected to process I/O
 - » 8000 I/O
- **LHC SPECIFIED (1999) (3 layers solution)**
 - » 20 OWS connected to 5 supervision servers
 - » 29 PCU connected to process I/O through 421 Field interfaces (remote I/O board or fieldbuses)
 - » 30000 I/O



Specification Architecture



Supervision layer

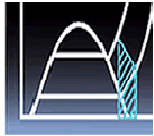
- Interface for operation Team
- All operators action are taken from this level

Process control layer

- PLC : the control logic is performed at that level
- Programmers act on that Level

Field layer

- Interface to process direct I/O Boards, Fieldbuses



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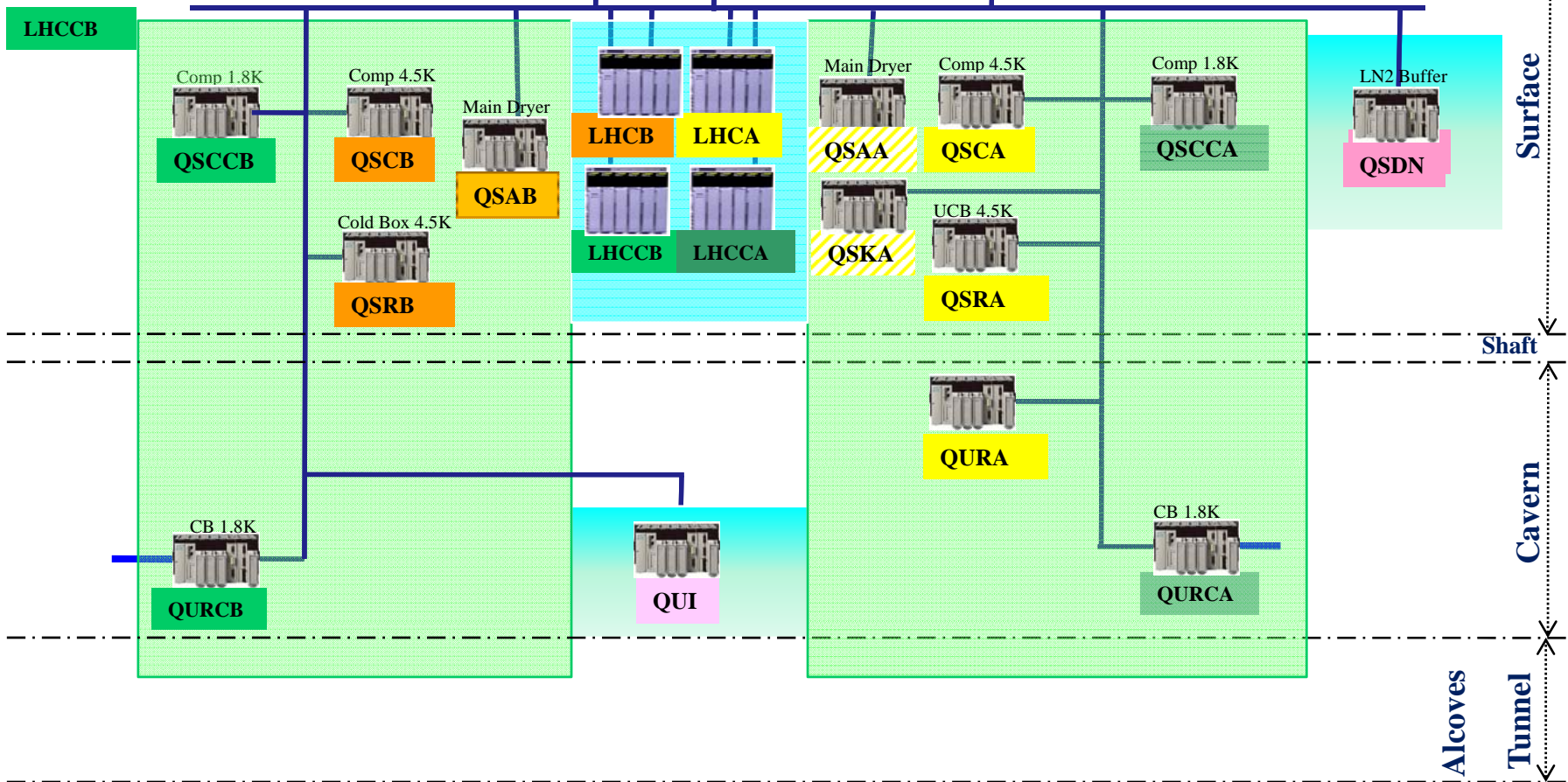
Reception Architecture

Cryo operation SCADA
Data Servers



Local & Central
Control Rooms


- LHCA
- LHCCA
- LHCB
- LHCCB

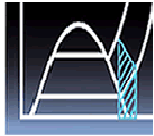




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Adaptation during project

- **Control Layer and Field layer**
 - » Dependency of closed loop to the network led o the suppression of Quantum PLC (2007)
 - » Introduction of FIP for instrument under  Environment
 - » Doubling of I/O numbers compared to Specification
 - » Migration from PL7 and concept to UNITY (2001)



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Operational Architecture

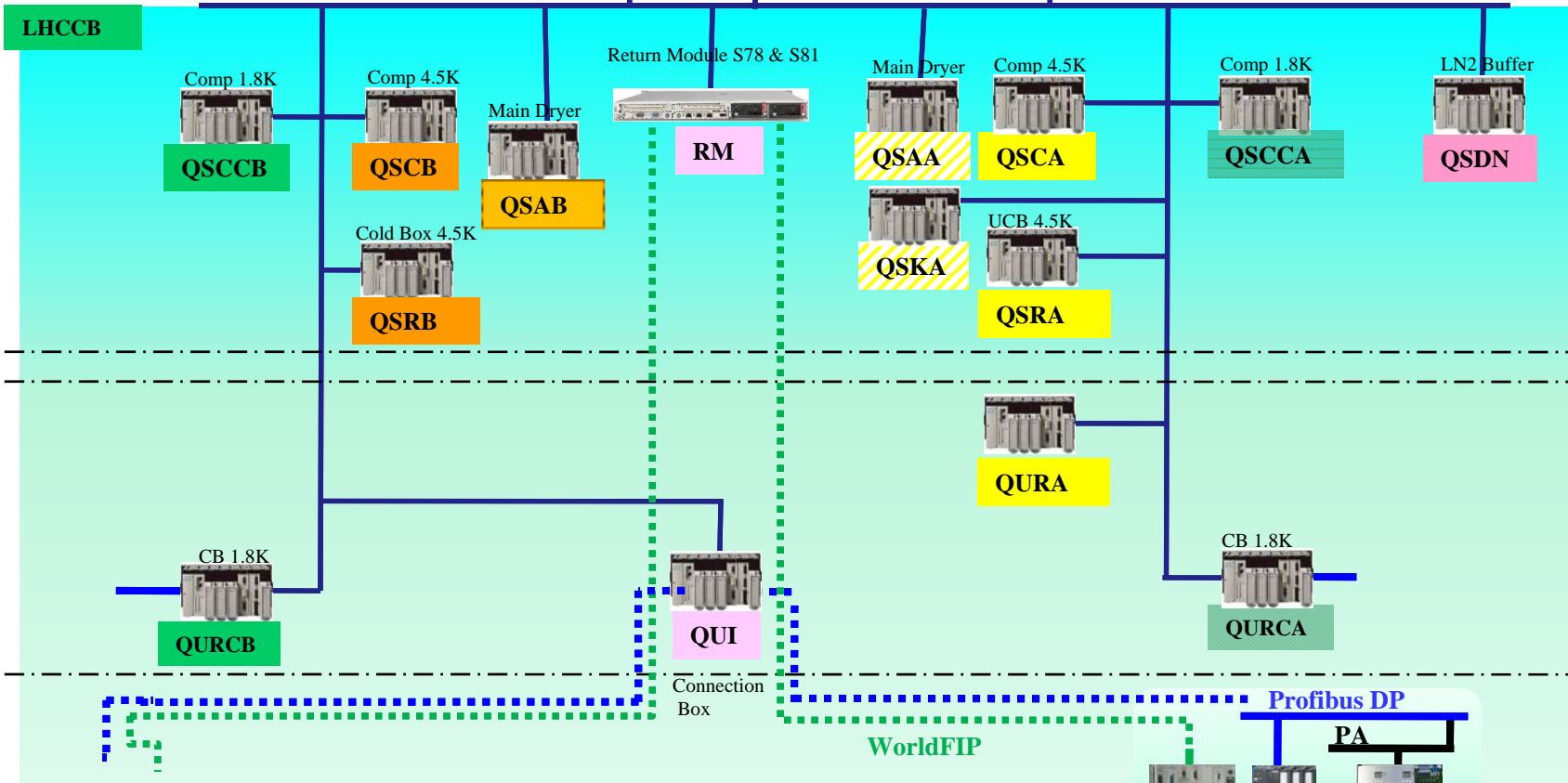
Cryo operation SCADA

Data Servers



Local & Central Control Rooms

- LHCA
- LHCCA
- LHCB
- LHCCB



Surface

Shaft

Cavern

Alcoves

Tunnel





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QRL Architecture

Cryo operation SCADA
Data Servers



Local & Central
Control Rooms



Ethernet (TN)

PLC
Schneider

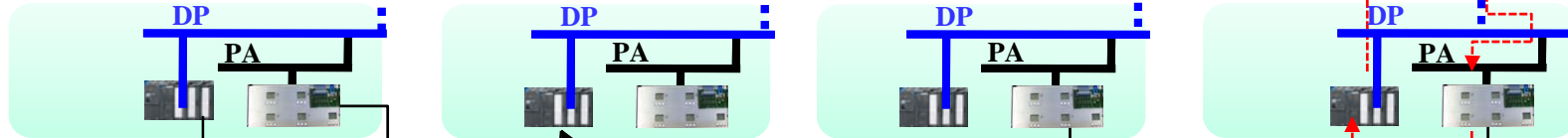


PLCs
siemens

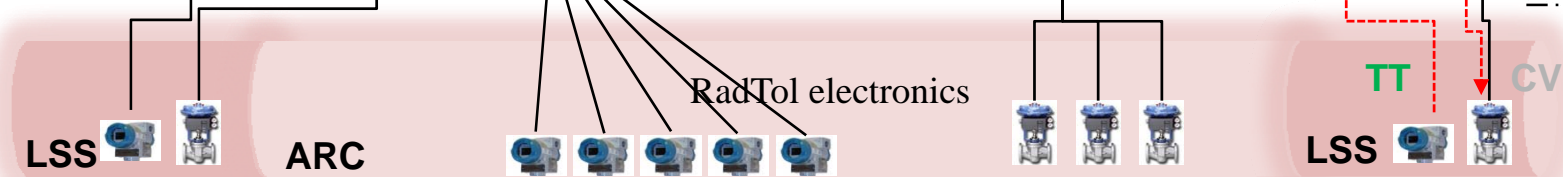


Profibus DP

Protected areas



QRL



shaft (~100 m)
Alcoves
Tunnel

LHC Tunnel (3.3 Km)



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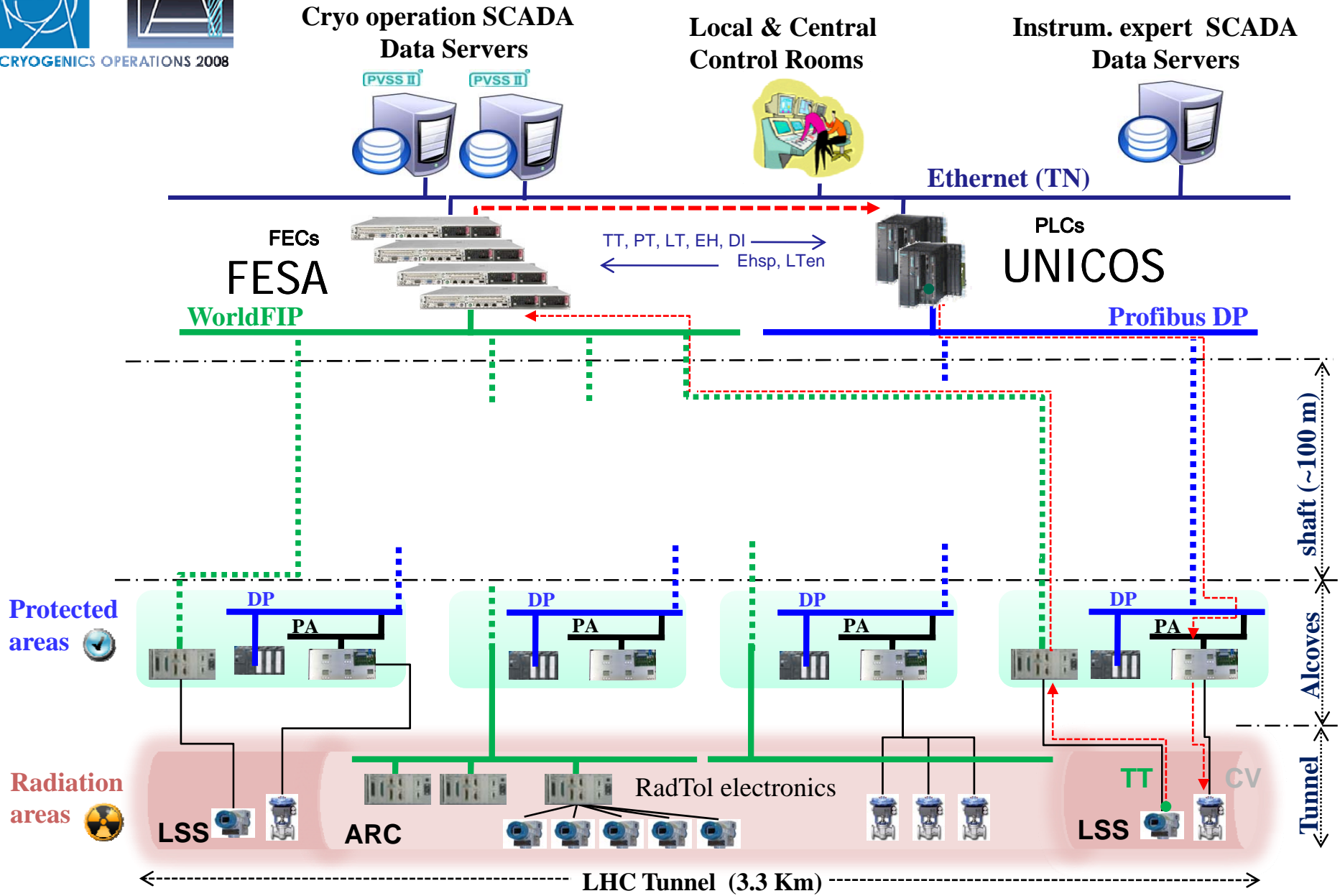
Adaptation during project

- **Control Layer and Field layer evolution**
 - » Introduction Of FESA FEC for FIP (2004) to take profit of the AB-CO support on that hardware type
 - » Development of UNICOS on Siemens PLC (2004) and use of them for Tunnel control (2004) To reduce the number of components improve the reliability and allow the use of instrumentation maintenance software for cryogenic valves



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Tunnel Architecture





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Learned lesson

- **Absolute necessity of Layer Independence**
- **Choose always scalable solutions**
- **In house mastering of the technology allow the proper adaptation to the user requirement evolution**

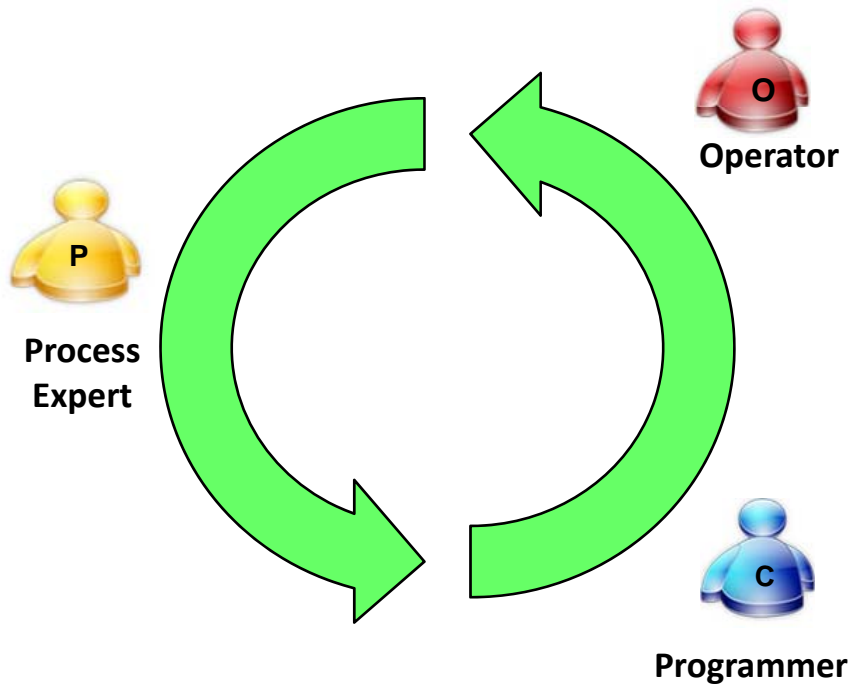


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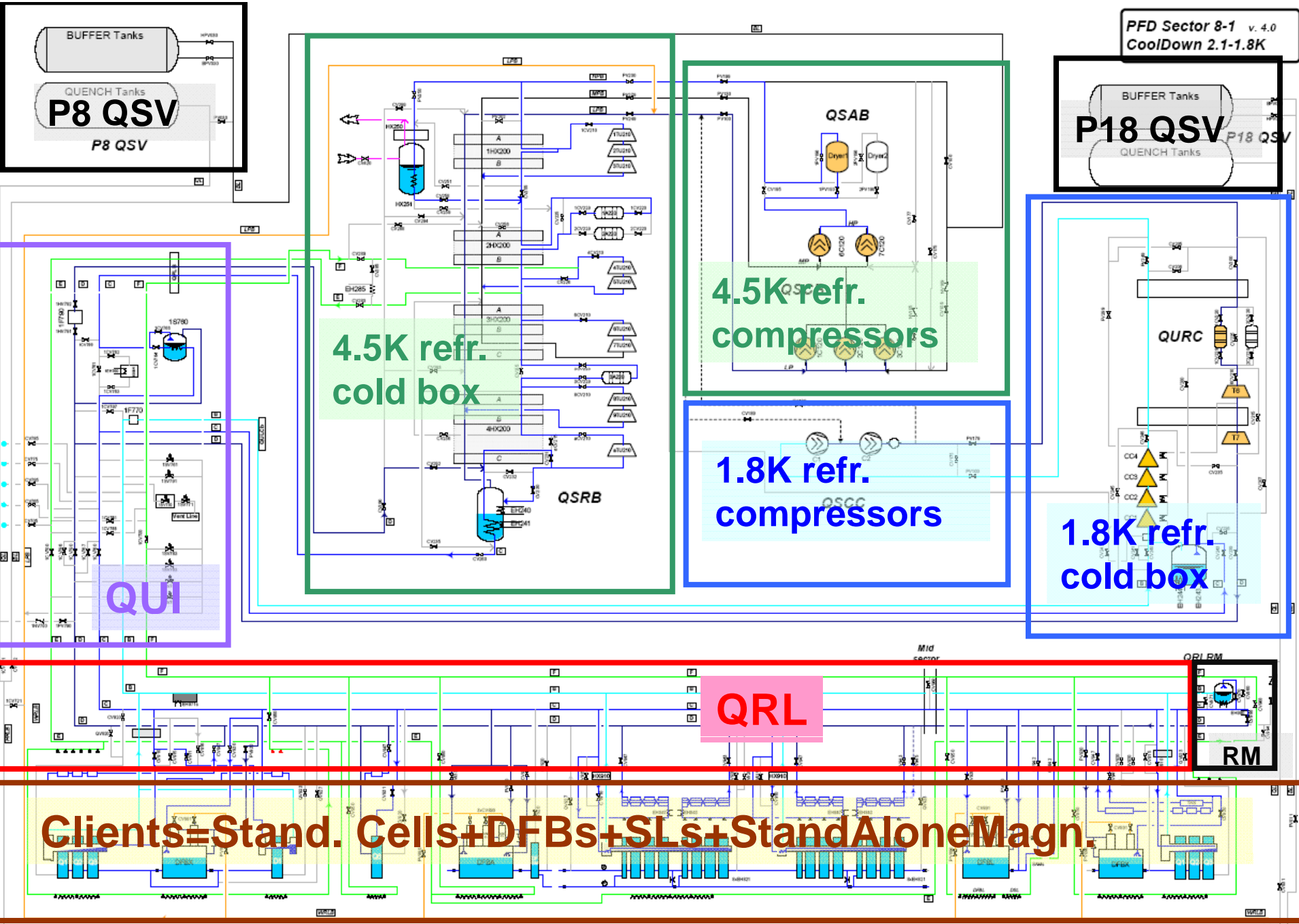
SOFTWARE



SOFTWARE CYCLE



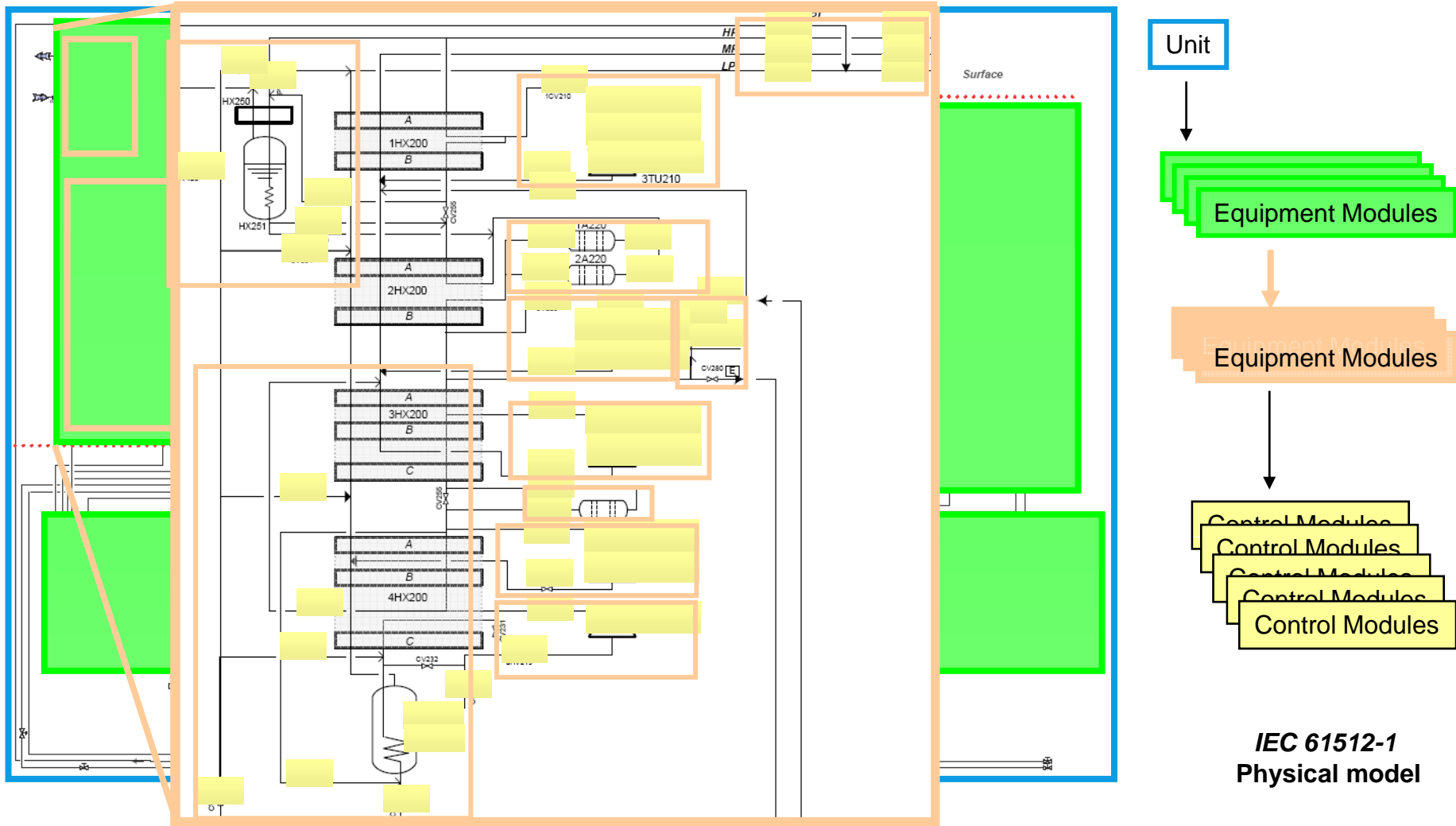
- This iterative cycle implies a good communication between the actors.
- All partner shall have a common understanding without knowing the details of the other specialties
- The cycle will perform several loops and the more you approach the operation the shortest it is.
- The quality shall no be forgotten but must remain manageable
- No regression or side effect must be generated by control logic modifications.





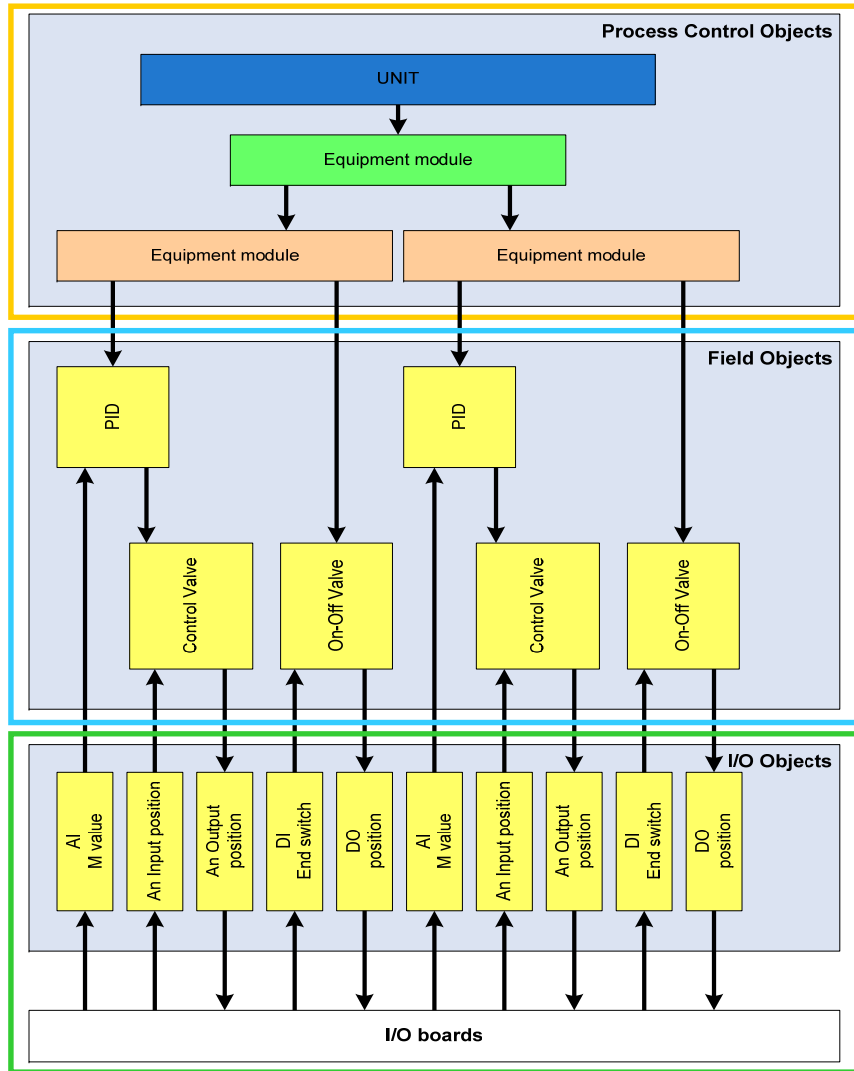
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Hierarchical Process Functional Analysis





Control system breakdown

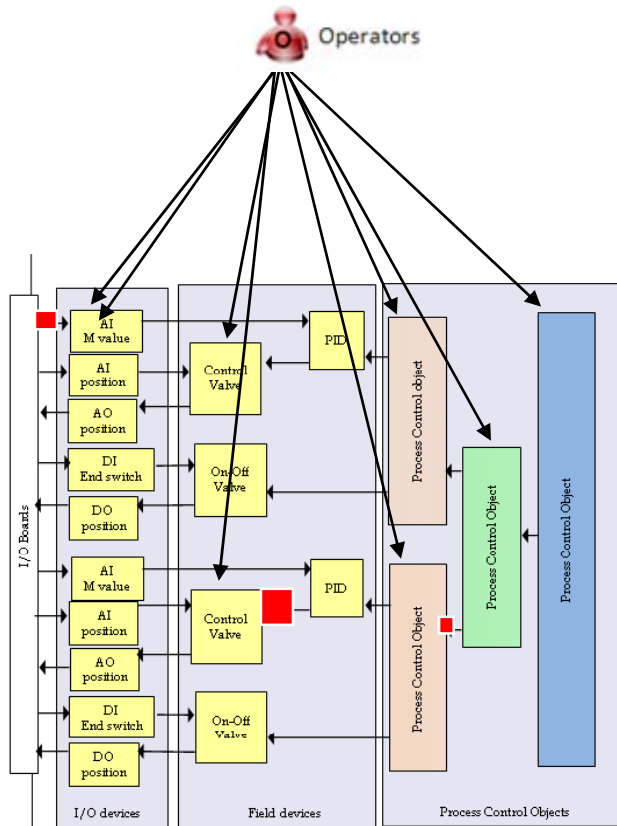


Process Control Objects:
automation of a group of
dependent device

Field Objects: image of the real
devices : valves, motors, pumps..

I/O Objects: Interface the process

Control and Operation principles



- Automation duties are performed in PLC

- » Automatic startup/stop sequences
- » Closed loop control
- » Interlock action and automatic recovery

- But Operation team must be able to :

- » Take manual control of any individual control device to overcome automatic request :
 - Online tune the close loop
 - Simulate Input in case of sensor failures
 - Brake the closed loop
 - Put part of the controlled system in special condition to face degraded environment.
 - Test new control strategy manually before implementation



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Learned lesson

- **Chosen breakdown analysis and control implementation is successful and adapted to all cryogenics systems, the software cycle was efficient, we have experienced regression but now the process is mastered**
- **Possibility of online modification was mandatory for commissioning period but the modifications will be reduced and even suppressed during the operation to avoid downtime as these actions weaken the control system**
- **The capabilities to overcome implemented logic given to Operators have been extensively used and was necessary**



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Operator user interface



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Principles & Functionality

- **Homogeneous user interface**
 - » Panels with identified roles
 - » Enforced rules to present the information
 - » Common interaction to devices
 - » Access to all information related to one device by one click
- **Access right to distinguish between users**
- **Post mortem tools and integrated diagnostics**
- **Monitoring on the control system itself**





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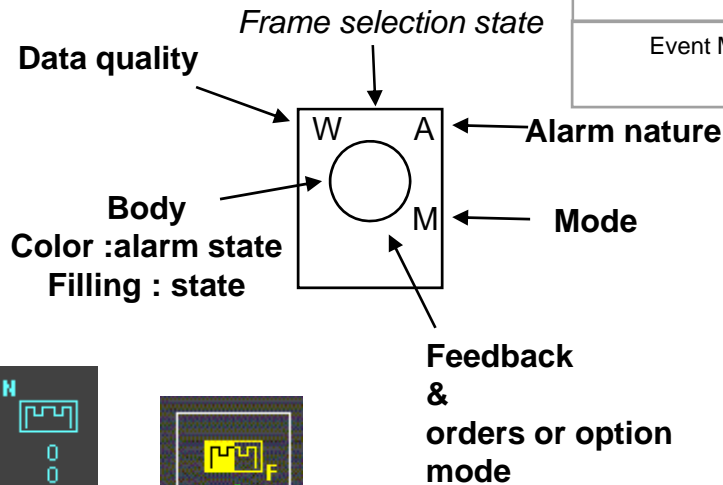
rules of information presentation

Data quality	Letter	Color	Priority
Invalid	N	Cyan	Highest
IO Error	E	Orange	Highest
IO Simulated	S		High
Forced <> Auto	W		Normal
Manual <> Auto			
Position Warning			
...			

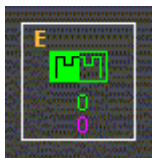
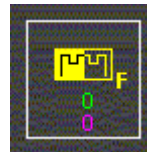
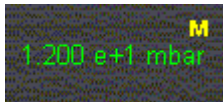
Alarm	Letter	Color	Priority
Full Stop Interlock	F	Red	Highest
Stop Interlock	S		High
Start Interlock	I		Normal
Position Alarm	P		

Mask	Letter	Color	Priority
Alarm Blocked (in PLC)	B	Yellow	Highest
Alarm Masked (in PVSS)	M		High
Event Masked	e		High

Body	Color	Priority
Invalid	Cyan	Highest
Alarm Unack.	Red Blinking	High
Alarm	Red	Normal
Forced Mode	Yellow	Low
Auto Mode	Green	Lowest



Mode	Letter	Color
Auto	None	None
Manual	M	White
Local	L	White
Forced	F	Yellow
Regulation	R	White
Tracking	T	White



Data not connected

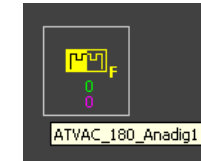
Data invalid



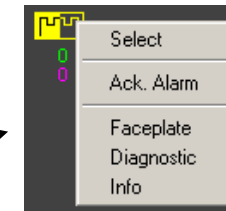
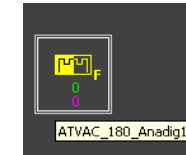
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Homogeneous interaction

- Mouse over
- Mouse click
 - ✓ Select if user authorized: operator minimum
- Mouse double click
 - ✓ Select, open faceplate
- Mouse right click
 - ✓ Menu
- Device selected:
 - ✓ White box around
 - ✓ Contextual button opened in context area
 - ✓ Device name set in the footer of the graphicalFrame

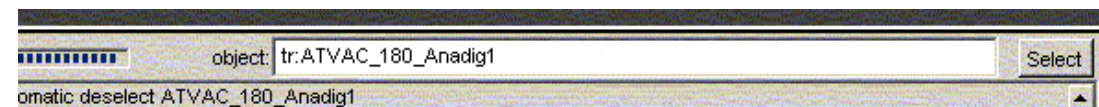
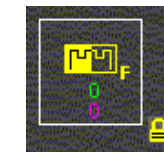


Device selected mouse over



Device selected

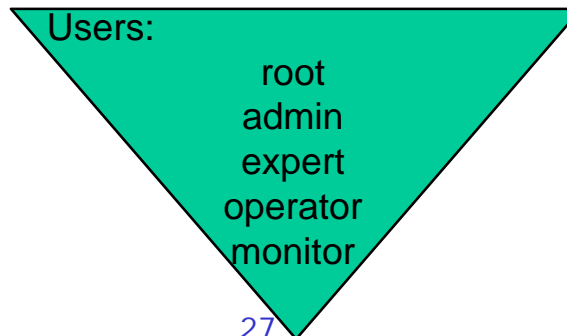
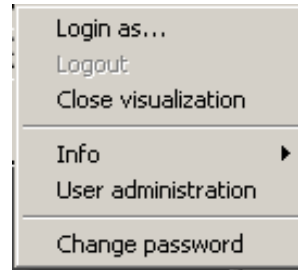
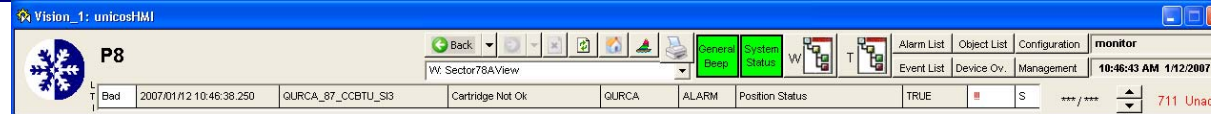
Device selected By another UIM No action possible





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Access and privilege right

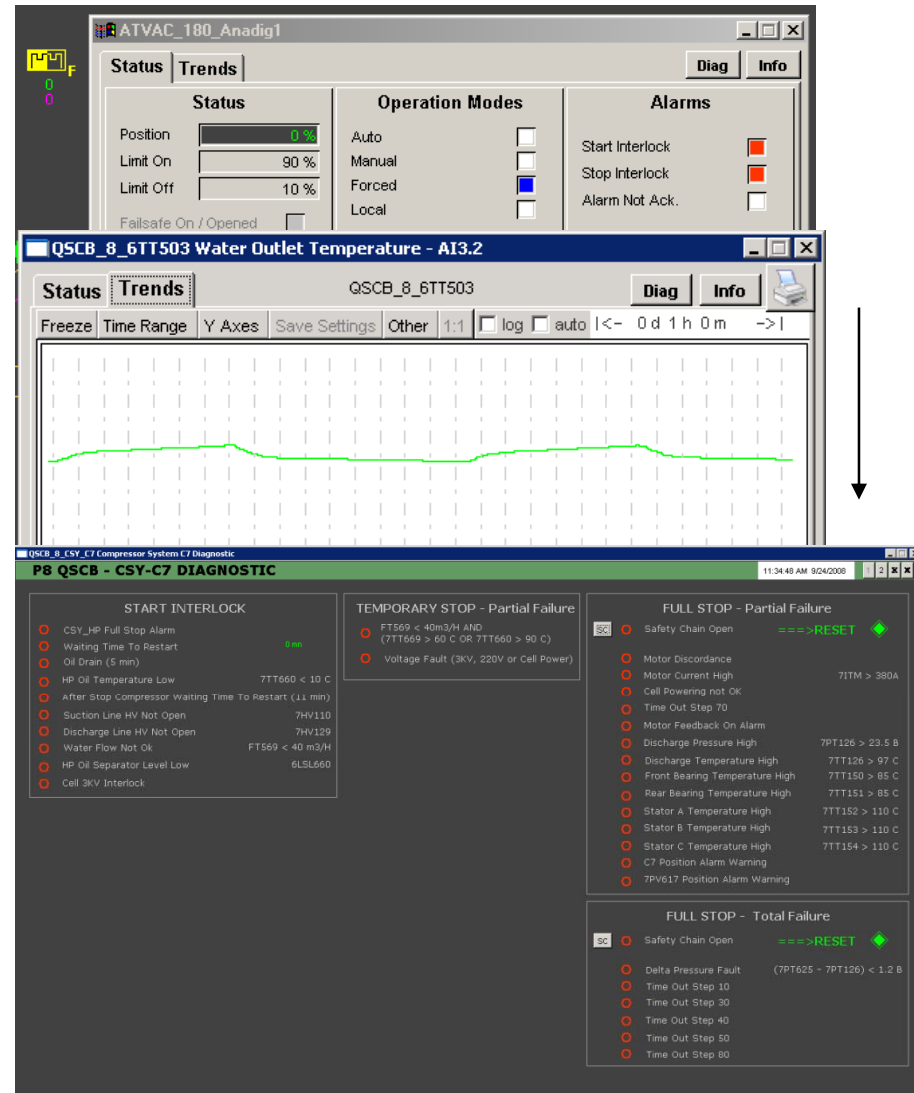




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Device analysis

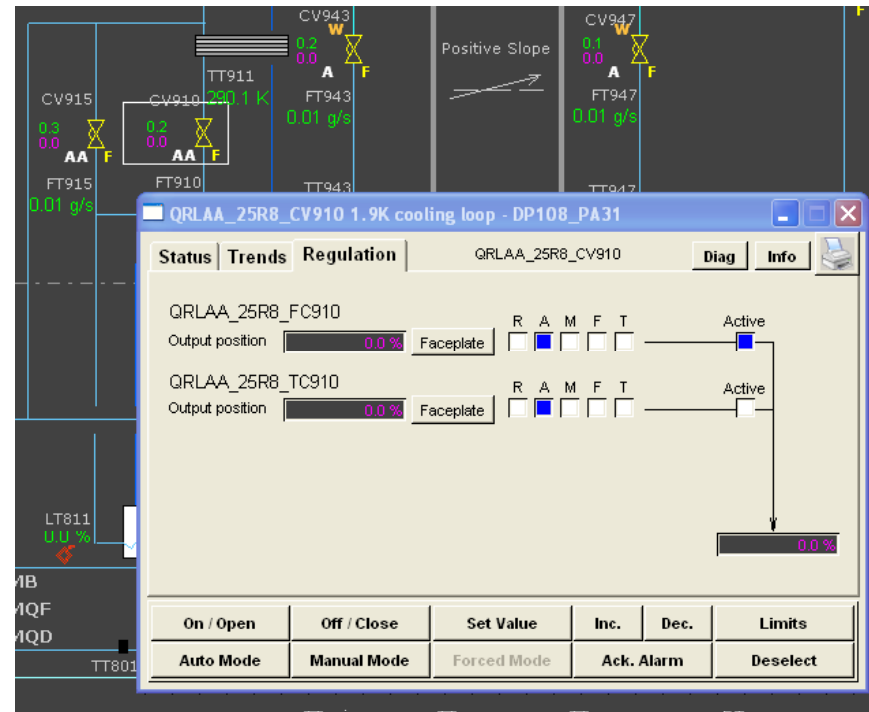
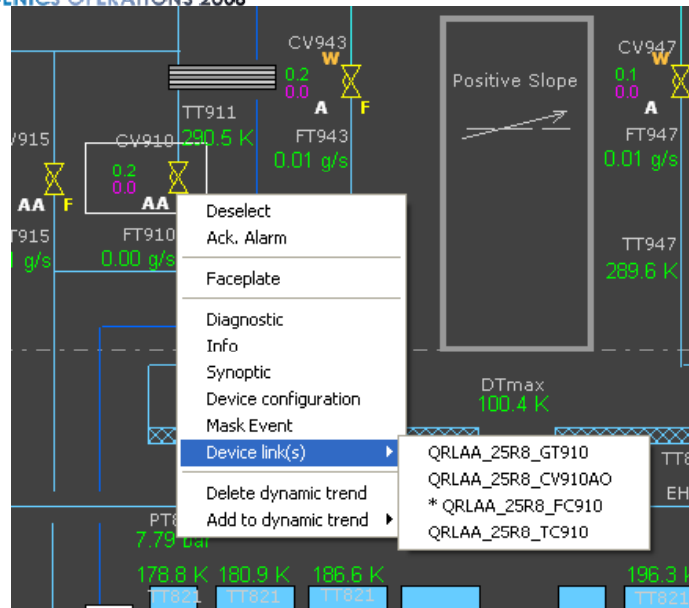
- Data area
- Trend area
- Diagnostic: PVSS panel





Easy navigation between devices

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The window displays the PID parameters for QRLAA_25R8_FC910. It includes a 'Trends' tab with a graph showing SP=L and OUT=L. The 'Operation Modes' section has checkboxes for Active, Regulation (R), Auto (A), Manual (M), Forced (F), and Tracking (T). The 'PID Parameters' section includes fields for P (1.000), I (20.000), D (0.000), and Td (0.000). The 'SetPoints Limits' section has fields for High (30.000 g/s) and Low (0.000 g/s). The 'Output Limits' section has fields for High (100.0%) and Low (0.0%). The 'Warnings' section has checkboxes for I/O Error and I/O Simulated. The bottom control panel includes buttons for SetPoint, Output, PID, and Limits, and a 'Select' button.

The window shows the 'PID Parameters' section of the QRLAA_25R8_FC910 PID for CV910 with instrument FT910. It features a table with columns for Saved, Active, and New values for P, I, D, and Td parameters. The 'New' column for P is highlighted with a blue selection box. Buttons for Save, Restore, OK, Apply, and Cancel are at the bottom.

Parameter	Saved	Active	New
P	1.000	1.000	1.000
I	20.000	20.000	20.000
D	0.000	0.000	0.000
Td	0.000	0.000	0.000



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Integrated system diagnostics

Vision_1: unicosHMI

P8

T: Surveillance_interface_HPA

11:19:33 AM 1/12/2007

713 Unack

Application

Application Operation panel

Main Data Server

System name: P8_82; DS hostname: cs-ccr-q8ds2; OWS hostname: cwe-864-q1

state: Application Name

P8 LHCCA
P8
P8 LHCCB
SECTOR 78

current System name: P8_81

current Application name: P8 LHCCA

current default panel: unicos_scripts

Application alarm summary:

state	description
	2007.01.12 11:18:43.058: Diskspace OK
	2006.02.21 11:59:02.125:
	2006.12.18 11:04:29.548: Communication CFP_SHC8_LHCCA -> DS driver
	2006.12.08 10:43:41.895: Time synchro CFP_SHC8_LHCCA -> DS driver
	2006.12.18 11:00:29.455: Modbus state DS driver 2 -> CFP_SHC8_LHCCA
	2006.12.18 11:03:11.550: CFP_SHC8_LHCCA Communication Status with
	2007.01.03 16:30:10.000: CFP_SHC8_LHCCA Communication Status with
	2006.12.08 10:43:52.634: Communication CFP_SH8_GSCCA -> DS driver
	2006.12.08 10:43:46.385: Time synchro CFP_SH8_GSCCA -> DS driver 2
	2006.12.18 11:00:29.445: Modbus state DS driver 2 -> CFP_SH8_GSCCA
	2006.12.08 10:43:44.710: CFP_SH8_GSCCA Communication Status with
	2007.01.03 16:29:59.486: Communication CFP_UX85_QUIRCA -> DS driver
	2006.12.08 10:43:47.115: Time synchro CFP_UX85_QUIRCA -> DS driver
	2007.01.04 09:54:04.958: Modbus state DS driver 2 -> CFP_UX85_QUIRCA
	2006.12.08 10:43:46.385: Time synchro CFP_UX85_QUIRCA -> DS driver 2
	2006.12.08 16:30:17.841: driver 2 OK
	2006.12.08 10:43:52.555: Archive boolean_18k 6 Ok
	2006.12.08 10:43:52.615: Archive event_18k 8 Ok
	2006.12.08 10:44:02.385: PVSS DB file size Ok
	2006.12.19 12:20:53.287: LHCLogging 1 Ok

Alarm List

Alarms displayed: 292; Unack Alarms displayed: 0

Sh.	Local Time	Description	Value
SI1	2006.09.06 11:22:47.456	LHCLogging 1	0
SI1	2006.09.06 12:31:11.000	CFP_UX85_QUIRCA Communication Status with Quantum	0
SI1	2006.09.06 12:31:14.000	CFP_SHC8_LHCCA Communication Status with CFP_UX85_QUIRCA	0
SI1	2006.09.06 12:31:15.450	CFP_UX85_QUIRCA Communication Status with Quantum	10
SI1	2006.09.06 12:31:18.600	CFP_SHC8_LHCCA Communication Status with CFP_UX85_QUIRCA	10
SI1	2006.09.06 14:42:19.300	CFP_UX85_QUIRCA Communication Status with Quantum	0
SI1	2006.09.06 14:42:23.750	CFP_UX85_QUIRCA Communication Status with Quantum	10
SI1	2006.09.07 07:31:13.180	CFP_UX85_QUIRCA Communication Status with Quantum	0
SI1	2006.09.07 07:31:16.470	CFP_UX85_QUIRCA Communication Status with Quantum	10
SI1	2006.09.07 08:45:10.580	CFP_UX85_QUIRCA Communication Status with Quantum	0
SI1	2006.09.07 08:45:15.270	CFP_UX85_QUIRCA Communication Status with Quantum	10
SI1	2006.09.06 06:44:16.502	Time synchro CFP_SH8_GSCCA -> DS driver 2	10
SI1	2006.09.06 06:49:13.171	Time synchro CFP_SH8_GSCCA -> DS driver 2	10
SI1	2006.09.10 23:04:20.521	Time synchro CFP_SH8_GSCCA -> DS driver 2	10
SI1	2006.09.10 23:09:17.162	Time synchro CFP_SH8_GSCCA -> DS driver 2	0
SI1	2006.09.11 20:14:57.060	CFP_UX85_QUIRCA Communication Status with Quantum	0
SI1	2006.09.11 20:14:59.150	CFP_SHC8_LHCCA Communication Status with CFP_UX85_QUIRCA	0
SI1	2006.09.11 20:14:59.700	CFP_SHC8_LHCCA Communication Status with CFP_UX85_QUIRCA	10
SI1	2006.09.11 20:15:01.350	CFP_UX85_QUIRCA Communication Status with Quantum	10
SI1	2006.09.12 02:08:10.510	CFP_UX85_QUIRCA Communication Status with Quantum	0
SI1	2006.09.12 02:08:14.890	CFP_UX85_QUIRCA Communication Status with Quantum	10
SI1	2006.09.12 03:50:10.400	CFP_UX85_QUIRCA Communication Status with Quantum	0
SI1	2006.09.12 03:50:13.460	CFP_UX85_QUIRCA Communication Status with Quantum	10
SI1	2006.09.12 12:22:13.736	Archive event_48k 14	0
SI1	2006.09.12 12:32:44.332	Archive event_48k 14	10
SI1	2006.09.12 15:05:10.930	CFP_UX85_QUIRCA Communication Status with Quantum	0
SI1	2006.09.12 15:00:15.550	CFP_UX85_QUIRCA Communication Status with Quantum	10
SI1	2006.09.12 16:39:10.810	CFP_UX85_QUIRCA Communication Status with Quantum	0
SI1	2006.09.12 16:39:15.350	CFP_UX85_QUIRCA Communication Status with Quantum	10
SI1	2006.09.12 16:59:10.580	CFP_UX85_QUIRCA Communication Status with Quantum	0
SI1	2006.09.12 16:59:13.500	CFP_SHC8_LHCCA Communication Status with CFP_UX85_QUIRCA	0
SI1	2006.09.12 16:59:14.950	CFP_UX85_QUIRCA Communication Status with Quantum	10
SI1	2006.09.12 16:59:17.100	CFP_SHC8_LHCCA Communication Status with CFP_UX85_QUIRCA	10

Remaining time: 2007.01.12 11:19:29 INFO AIAO widg
2007.01.12 11:19:29 INFO DIDO widg



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Post mortem tools

Alarm List

[P2_21] [P2_22] Alarms displayed: **741** Unack Alarms displayed: **125** Lines displayed: 100 M

Filter: Alert Text Device Domain Nature Time Acknowledge ALL alarms From: 2006-08-09 15:27:32 To: 2006-08-09 15:37:32

Event List

[P2_21] [P2_22] Events: **52459** Lines displayed: 100 Buffer: Events 52459 Position 52360 to 52459 M

Filter: Application Device Alias Description Invalid Time zone = LOCAL TIME From: 2006-08-09 12:00:36 To: 2006-08-09 13:58:19

Local Time	Alias	Description	Domain	Nature	Bit	Event	Inv
2006.08.09 12:02:55.500	QSRA_2_PV297	Bypass Valve 80K	QSRA	ONOFF	Auto Manual Request Warning	Rising	
2006.08.09 12:02:55.500	QSRA_2_PV297	Bypass Valve 80K	QSRA	ONOFF	Output Order Value Status	Rising	
2006.08.09 12:02:58.500	QSRA_2_PV297	Bypass Valve 80K	QSRA	ONOFF	Off/Closed Status	Falling	
2006.08.09 12:03:00.000	QSRA_2_PV297	Bypass Valve 80K	QSRA	ONOFF	On/Opened Status	Rising	
2006.08.09 12:03:14.500	QSRA_2_PV297	Bypass Valve 80K	QSRA	ONOFF	Auto Manual Request Warning	Falling	
2006.08.09 12:03:14.500	QSRA_2_PV297	Bypass Valve 80K	QSRA	ONOFF	Output Order Value Status	Falling	
2006.08.09 12:03:18.000	QSRA_2_PV297	Bypass Valve 80K	QSRA	ONOFF	On/Opened Status	Falling	
2006.08.09 12:03:21.000	QSRA_2_PV297	Bypass Valve 80K	QSRA	ONOFF	Off/Closed Status	Rising	
2006.08.09 13:57:43.500	QURA_2_2HV335	Discharge Atm Valve 2HV335 Closed	QURA	LOCAL	Off/Closed Status	Rising	
2006.08.09 13:57:45.750	QURA_2_2HV430	He Purge/Pump Valve	QURA	LOCAL	Off/Closed Status	Falling	
2006.08.09 13:57:49.750	QURA_2_2HV430	He Purge/Pump Valve	QURA	LOCAL	Off/Closed Status	Rising	
2006.08.09 13:57:54.000	QURA_2_2HV430	He Purge/Pump Valve	QURA	LOCAL	Off/Closed Status	Falling	
2006.08.09 13:57:56.250	QURA_2_2HV430	He Purge/Pump Valve	QURA	LOCAL	Off/Closed Status	Rising	
2006.08.09 13:58:07.750	QURA_2_2HV430	He Purge/Pump Valve	QURA	LOCAL	Off/Closed Status	Falling	
2006.08.09 13:58:19.750	QURA_2_2HV430	He Purge/Pump Valve	QURA	LOCAL	Off/Closed Status	Rising	
2006.08.09 13:58:21.500	QURA_2_2HV332	Purge Pump Turb Valve 2HV332 Closed	QURA	LOCAL	Off/Closed Status	Rising	
2006.08.09 14:26:37.250	QSRA_2_1P304	Purge Pump Start Request	QSRA	ONOFF	On/Opened Status	Falling	
2006.08.09 14:26:37.250	QSRA_2_1P304	Purge Pump Start Request	QSRA	ONOFF	Position Warning	Falling	
2006.08.09 14:26:35.980	QSRA_2_1P304on	Conditioning Pump 1P304	QSRA	DI	Position Status	FALSE	!!!



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Adaptation during project

- **Supervision layer**
 - » scalability and performance during first commissioning and political decision pushed us to migrate from PCVUE to PVSS (2002) to solve
 - » performances and commissioning constraints lead to increase the number of server from 5 to 15
 - » Number of task to be performed and the complexity of the duty imposed to increased number of operator consoles from 12 to 30
 - » Safety issues and early diagnostics Implied the necessity to access/operate from remote location (20 clients per sites)
 - » Necessity to develop a dedicated application for instrumentation experts

Adapted supervision tools



CRYO

295.0 K
108.576

295.1 K

QRLHA_05R4_TT950 v3.3 -- Screen return - FIP_RFP_11_06

Status | Tendency | Trend TT/R | Trend Volt | Diag | Info

CRYOGTW_CFC_SH4_QRFOP_P DATA Connection OK

Calculations		Flags								WFIP Infos			
Temperature	295.1 K		b7	b6	b5	b4	b3	b2	b1	b0	GTW Name	CFC_SH4_QRFOP_P	
Resistance	108.615 ohm	Config	0	0	0	0	0	0	1	0	Bus	CBVWMB_SH4_QRFOP	3
Offset	0.000 ohm	Gain	0	0	0	0	0	1	0	0	Agent	<input type="checkbox"/>	11
Gain Constant	100	Diag HF	0	0	0	0	0	0	0	0	Channel		6
		Diag LF	0	0	0	0	0	0	0	0			

Measurements		Raw data								Warnings		
Sensor Voltage	-2762 -20.06 mV	B0	B1	B2	B3	B4	B5	B6	B7	<input type="checkbox"/> Disable		
Reference Voltage	-2542 -18.46 mV	F5	37	F6	11	02	04	00	00	<input type="checkbox"/> I/O Error		
Reference Voltage Typical	10 mV	Identified Card Configuration								<input type="checkbox"/> Reset		
		Calibration Curve								<input type="checkbox"/> Bad configuration		
		Calib. Curve Redundant								<input checked="" type="checkbox"/> Filtering Active: Median		

Diag | Info

Alarms / Limits

Warnings

Limits

Deselect

Reset | Disable | RawData | Calibration | Set Constants | Next >> | Deselect

CIET: Cryogenics Instrumentation Expert Tool



CRYOGENICS OPERATIONS 2008

Learned lesson

- **For such a large project scalability of the supervision system is absolute necessity**
- **“When you give your hand to the operator they want your arm”**
 - » Many additional functionalities had to be added (xy diagrams, bar-graph, device links,....)
- **Supervision tools must be adapted to the User needs :**
 - » Instrument expert requirements are far from the cryogenic operator ones and the tools shall be separated.



Conclusion

- **Despite of the evolution of the project requirements and planning the control system for LHC has (almost) always be delivered in time and fulfilled the Users needs.**
 - » Chosen 3 independent layers architecture
 - » Choice of scalable components
 - » Decision to use an enforced control methodology
 - » In house mastering of the technology even for parts that had to be subcontracted.
 - » Excellent cooperation and mutual understanding of the control and cryogenic teams