



# Industrial Smart Monitoring

*CERN IoT Workshop*

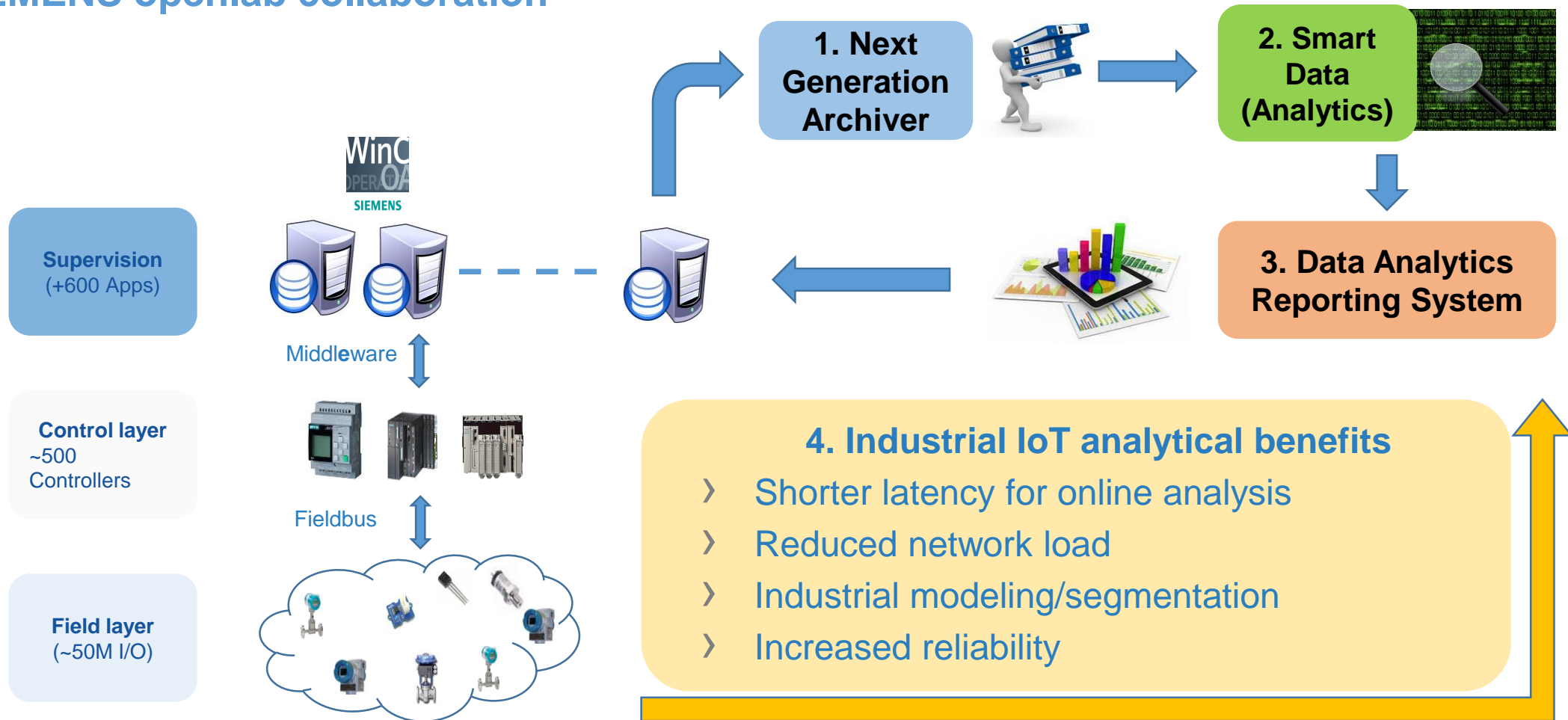
Filippo Tilaro, Fernando Varela (BE/ICS)

07/11/2017



# Control monitoring: Ingestion, Analysis, Reporting

SIEMENS openlab collaboration



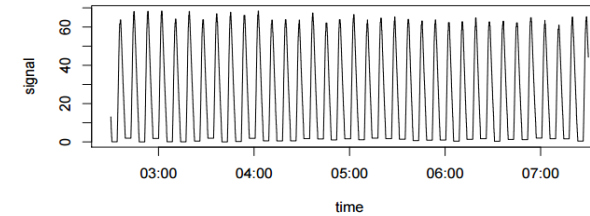
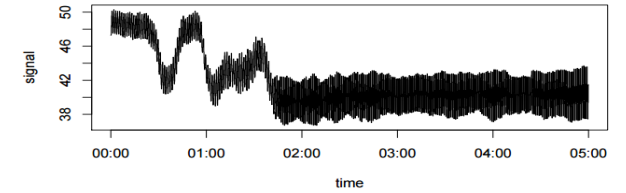
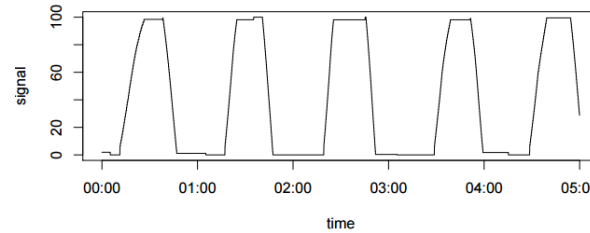
# Enhance industrial monitoring with Smart Data

*Extending the SCADA monitoring capabilities: some examples of analysis*

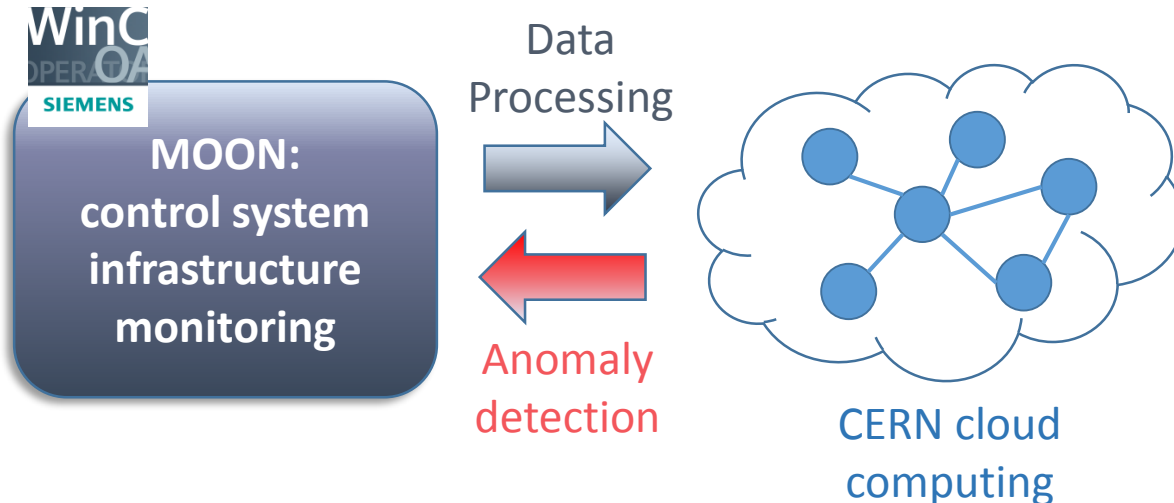
# Anomaly detection

## 1. Detect anomalous oscillation:

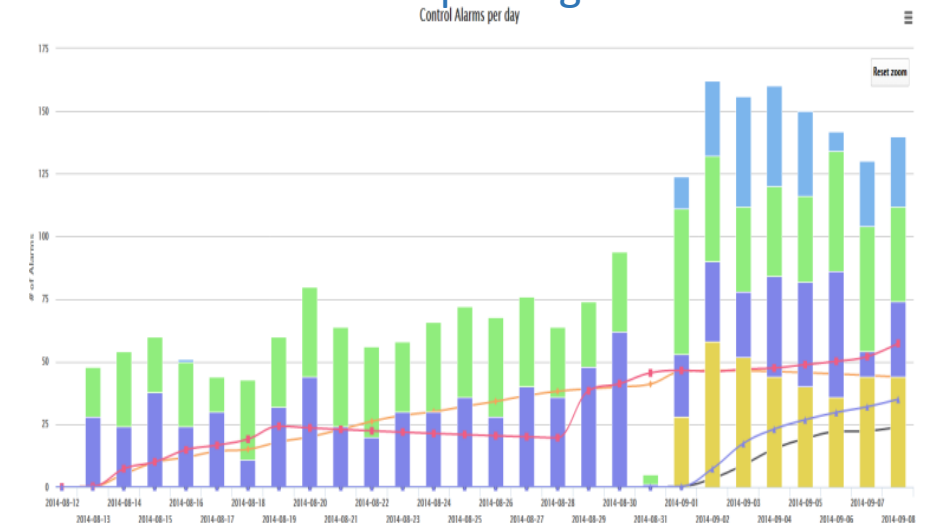
- Control system stability
- Increased communication load
- Maintenance (use of actuators)
- Performances (Physic time)



## 2. Detect system/hardware malfunctions



## Web Reporting



# Post-mortem analysis

## Root-cause analysis and fault prediction

Short	Local Time	Alias	Description	Domain	Nature	Name	Value
W	2013.09.27 15:49:37.810	CMSCSC_Di_61InPresAI	PTxx24 - Rack 61 input	CSC_Details		PTxx24 - Rack 61 input pres	FALSE
W	2013.09.27 15:49:42.890	CMSCSC_Di_68InPresAI	PTxx24 - Rack 68 input	CSC_Details		PTxx24 - Rack 68 input pres	FALSE
W	2013.09.27 15:49:42.890	CMSCSC_Di_70InPresAI	PTxx24 - Rack 70 input	CSC_Details		PTxx24 - Rack 70 input pres	FALSE
W	2013.09.27 15:49:42.890	CMSCSC_Di_69InPresAI	PTxx24 - Rack 69 input	CSC_Details		PTxx24 - Rack 69 input pres	FALSE
W	2013.09.27 15:49:43.090	CMSCSC_Di_65InPresAI	PTxx24 - Rack 65 input	CSC_Details		PTxx24 - Rack 65 input pres	FALSE
W	2013.09.27 15:52:09.900	CMSCSC_Di_66OutPresAI	PTxx25 - Rack 66 output	CSC_Details		PTxx25 - Rack 66 output pres	TRUE
W	2013.09.27 15:52:09.900	CMSCSC_Di_69OutPresAI	PTxx25 - Rack 69 output	CSC_Details		PTxx25 - Rack 69 output pres	TRUE
W	2013.09.27 15:52:09.900	CMSCSC_Di_70OutPresAI	PTxx25 - Rack 70 output	CSC_Details		PTxx25 - Rack 70 output pres	TRUE
W	2013.09.27 15:52:09.900	CMSCSC_Di_67OutPresAI	PTxx26 - Rack 67 output	CSC_Details		PTxx26 - Rack 67 output pres	TRUE
W	2013.09.27 15:52:09.900	CMSCSC_Di_68OutPresAI	PTxx26 - Rack 68 output	CSC_Details		PTxx26 - Rack 68 output pres	TRUE
W	2013.09.27 15:52:09.900	CMSCSC_Di_69OutPresAI	PTxx26 - Rack 69 output	CSC_Details		PTxx26 - Rack 69 output pres	TRUE
W	2013.09.27 15:52:09.900	CMSCSC_Di_64OutPresAI	PTxx26 - Rack 64 output	CSC_Details		PTxx26 - Rack 64 output pres	TRUE
W	2013.09.27 15:52:09.900	CMSCSC_Di_65OutPresAI	PTxx25 - Rack 65 output	CSC_Details		PTxx25 - Rack 65 output pres	TRUE
W	2013.09.27 15:52:10.440	CMSCSC_Di_63OutPresAI	PTxx25 - Rack 63 output	CSC_Details		PTxx25 - Rack 63 output pres	TRUE
W	2013.09.27 15:52:10.440	CMSCSC_Di_62OutPresAI	PTxx25 - Rack 62 output	CSC_Details		PTxx25 - Rack 62 output pres	TRUE
W	2013.09.27 15:52:10.440	CMSCSC_Di_61OutPresAI	PTxx25 - Rack 61 output	CSC_Details		PTxx25 - Rack 61 output pres	TRUE
W	2013.09.27 15:52:12.890	CMSCSC_Di_66OutPresAI	PTxx26 - Rack 66 output	CSC_Details		PTxx26 - Rack 66 output pres	TRUE
W	2013.09.27 15:52:12.890	CMSCSC_Di_68OutPresAI	PTxx26 - Rack 68 output	CSC_Details		PTxx26 - Rack 68 output pres	TRUE
W	2013.09.27 15:52:12.950	CMSCSC_Di_DiRack66PCO	Distribution rack 66 PCO	CSC_Details		Full Stop Alarm Status	TRUE
W	2013.09.27 15:52:12.950	CMSCSC_Di_DiRack61PCO	Distribution rack 61 PCO	CSC_Details		Full Stop Alarm Status	TRUE
W	2013.09.27 15:52:13.370	CMSCSC_Di_61OutPresAI	PTxx26 - Rack 61 output	CSC_Details		PTxx26 - Rack 61 output pres	TRUE
W	2013.09.27 15:52:32.110	CMSCSC_Di_AlarmInRack66	Some alarms in rack 66	CSC_Details		Rack 66 alarm	TRUE
W	2013.09.27 15:52:32.110	CMSCSC_Di_AlarmInRack61	Some alarms in rack 61	CSC_Details		Rack 61 alarm	TRUE
W	2013.09.27 15:57:47.130	CMSCSC_Yb_AtmPisSensAI	PTD101 - Atmospheric pressure	CSC_Details		PTD101 - Atmospheric pres	TRUE

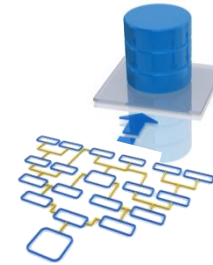


Event lists generated

⊗ by the same fault

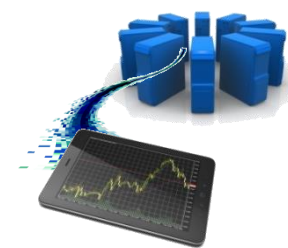
Data

Analyze



Identify and detect fault / abnormal pattern for Diagnosis and Prognostics based on domain knowledge

Learn



Provide experts with Root-cause and Gap Analysis using Rules and Patterns Mining

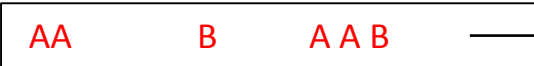
Diagnose



Forecasts, Trends and Early-Warnings to increase Operating Hours

Sequence: Confidence: 83.3 % / Appearance count: 5
CMSCSC_Di_62PRegAI   Alarm Unacknowledged   Rising
CMSCSC_Di_62PRegAI   Position Status (HH-LL)   Rising
CMSCSC_Di_62PRegAI   Alarm Unacknowledged   Rising
CMSCSC_Di_62PRegAI   Position Status (HH-LL)   Rising
CMSCSC_Di_YC60995   Auto Off/Close Request Status   Falling
CMSCSC_Di_YC60995   Auto On/Open Request Status   Rising
CMSCSC_Di_YC60995   Off/Closed Status   Falling
CMSCSC_Di_YC60995   On/Opened Status   Rising
CMSCSC_Di_YC60995   Output Order Value Status   Rising

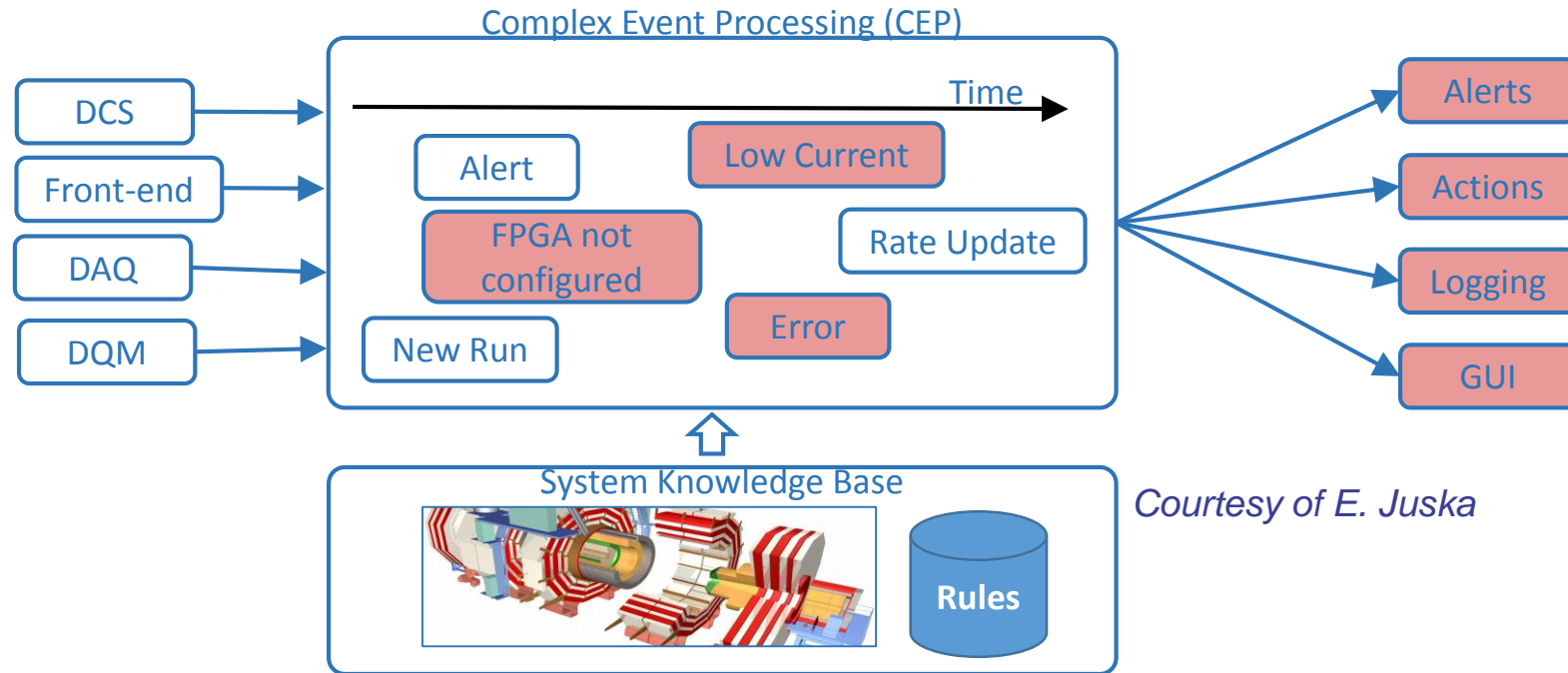
Pattern



# Expert systems

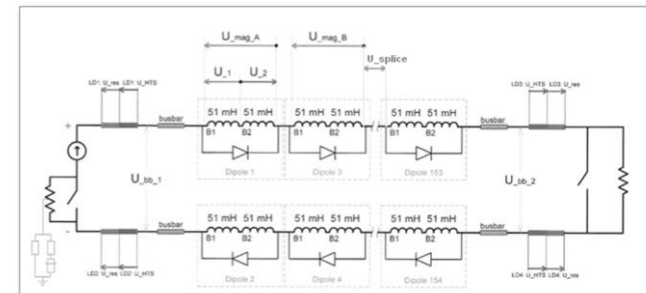
## 1. Formalization of experts' knowledge

- Orchestrate complex systems by combining huge datasets (ex: automatize the operator routines)



## 2. Predictive maintenance

- LHC Circuits monitoring:
  - Detect anomalous/aging hardware
  - DSL for the rules definitions
  - Distributed environment for rules assessment

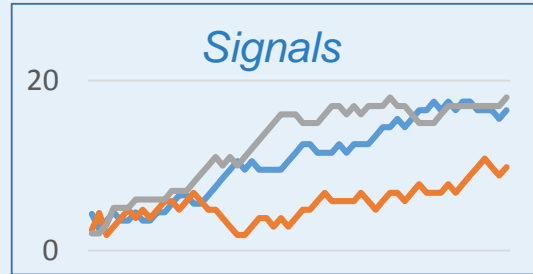




# Knowledge Discovery

Extract system/subsystem interdependency

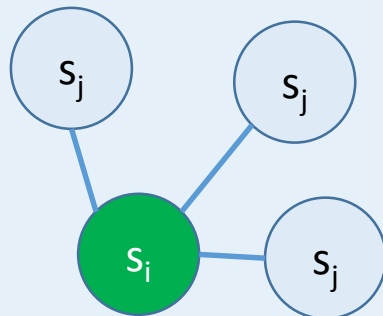
## Correlation and K-NN



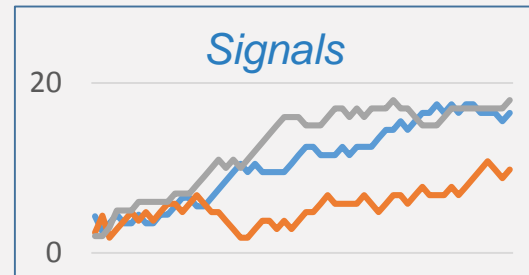
Pearson Correlation Index

$$d_{ij} = -\ln|a_{ij}|$$

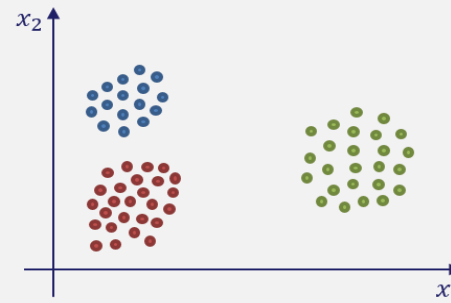
$$E(d_i) = \sum_{j=1}^k d_{ij} * P(j|i)$$



## Stochastic clustering

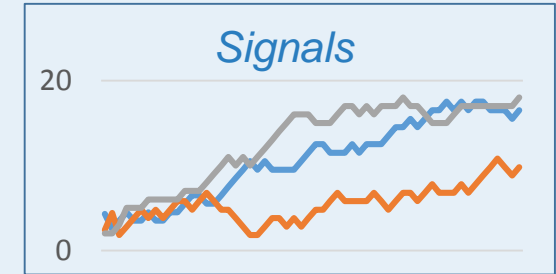


K-Mean & Davies-Bouldin index



$$P(X_j = k) = \binom{n}{k} * P(g_j)^k * (1 - P(g_j))^{n-k}$$

## Experts' knowledge



- Statistical indexes:
  - Cluster and single signals derivatives
  - $\beta$  = tolerance factor.

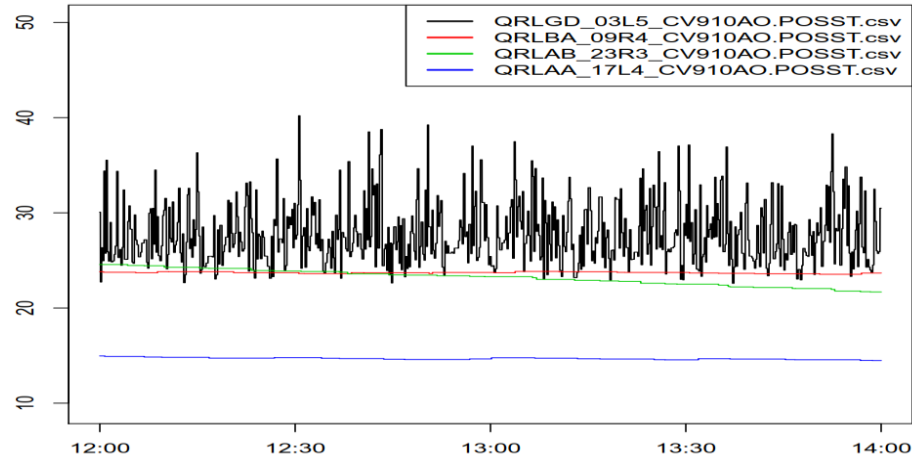
$$\left\{ \begin{array}{l} x_i = x_{i-1} + \frac{dt}{\nabla T f + dt} (x_i - x_{i-1}) \\ tw^{-1} \left( \sum_{tw} \nabla x_i - \nabla X \right) > \beta, \\ X = \{x_i \in Cluster\}, tw = \text{time window} \end{array} \right.$$



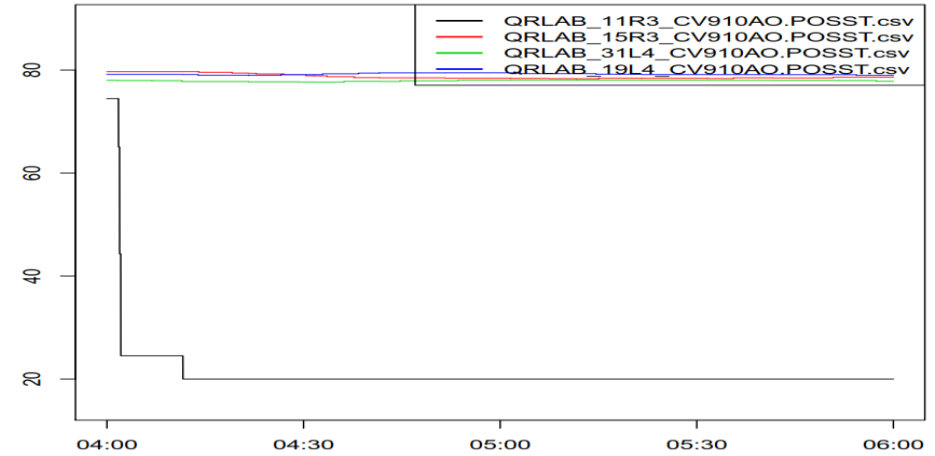
# Signals Correlation and K-NN in action!

Detection of different anomalies in Cryogenics

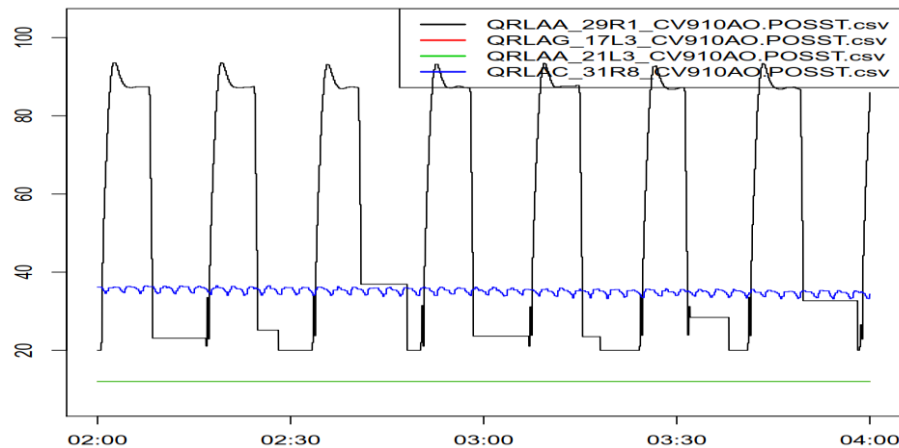
Flipping fault detection



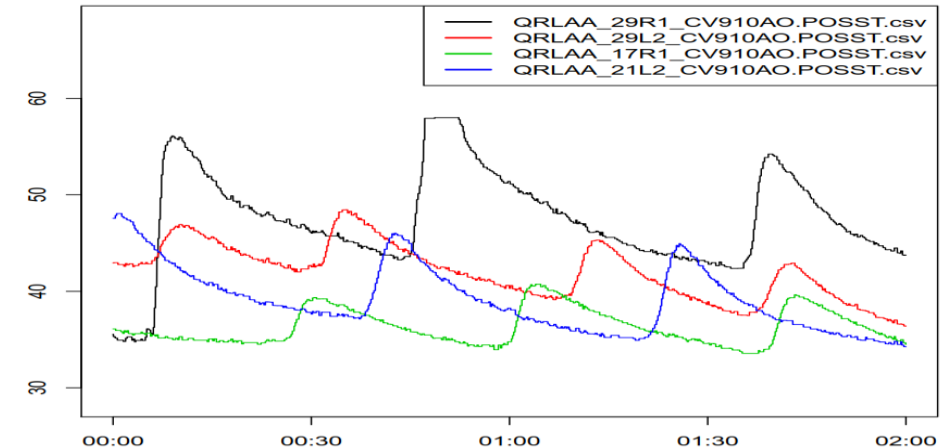
Signal offset detection



Oscillation detection



Faulty amplitude detection



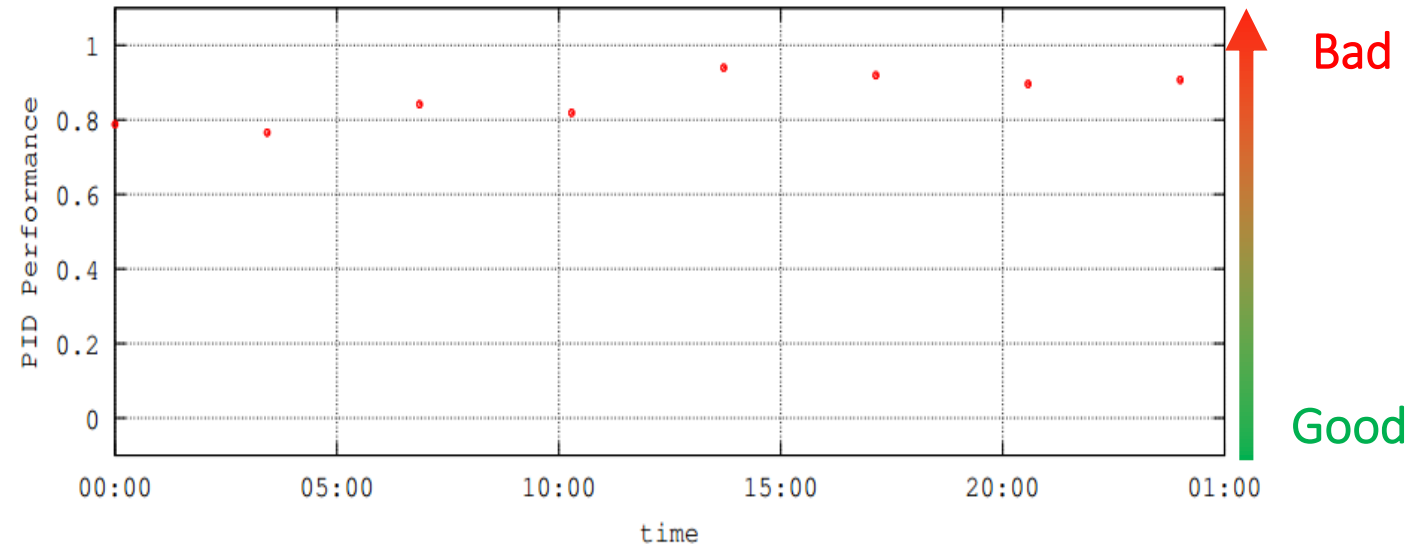
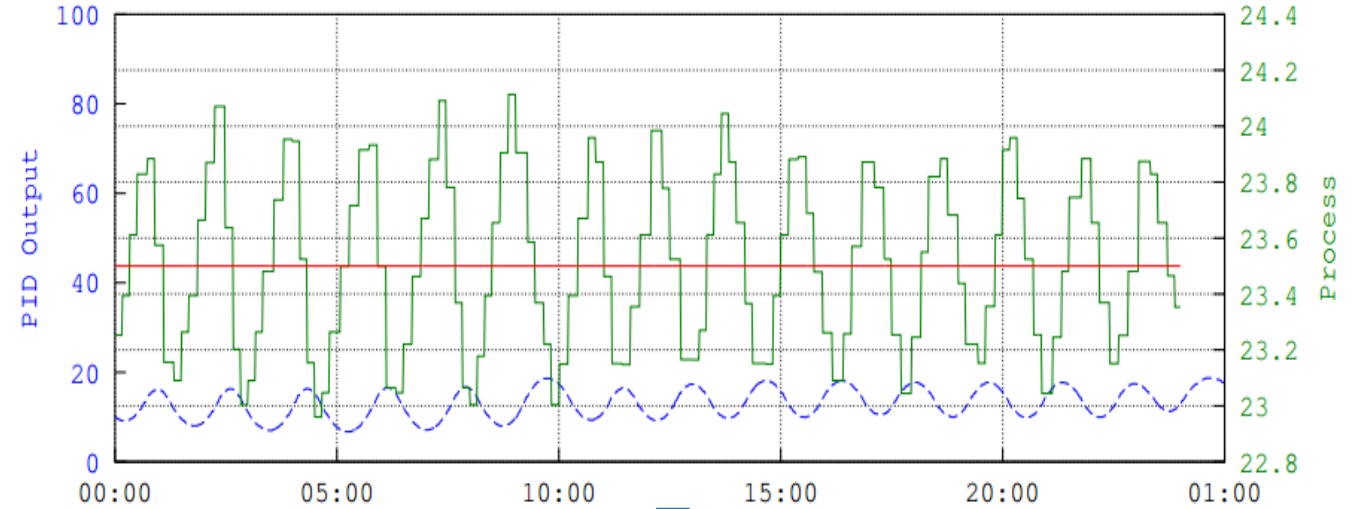
# Evaluate system performances

## › PID anomaly detection:

- Learning each PID model from the historical data
- Extraction of similar PID models
- Comparison of PID behaviours:
  - on the single PID level
  - similar PID

## › Efficiency of control process:

- Comparison of PID performances
- Time/actions taken/energy consumed to reach steady points
- Stability of the controlled variable

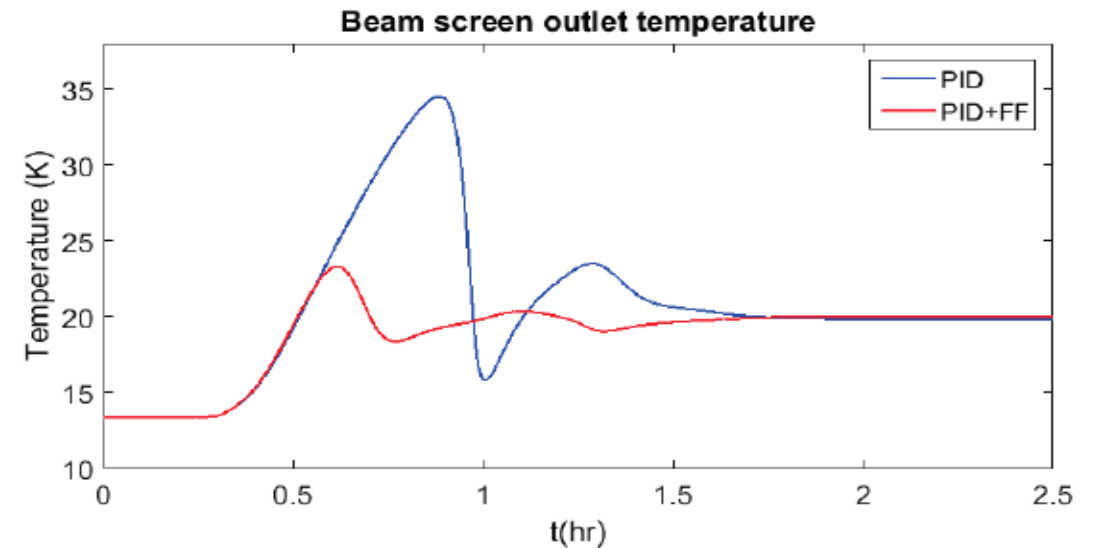
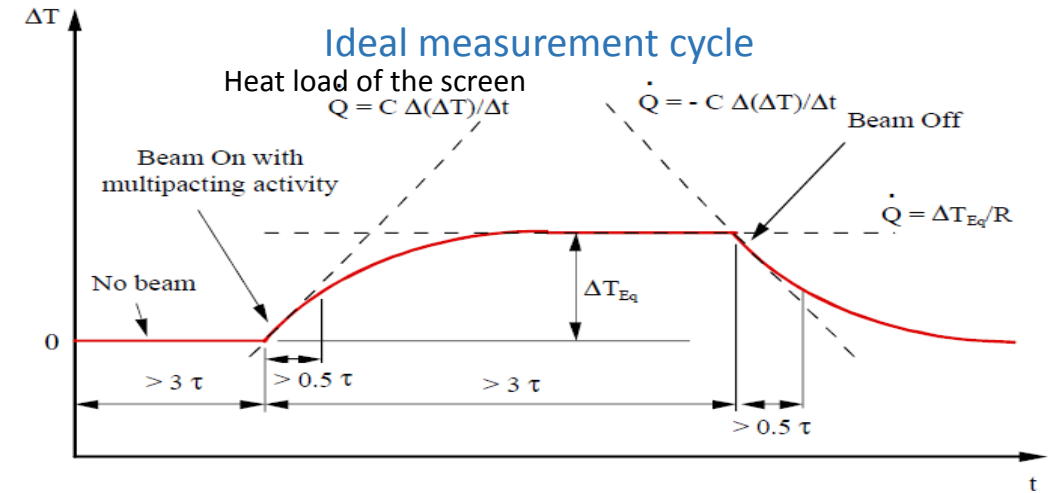
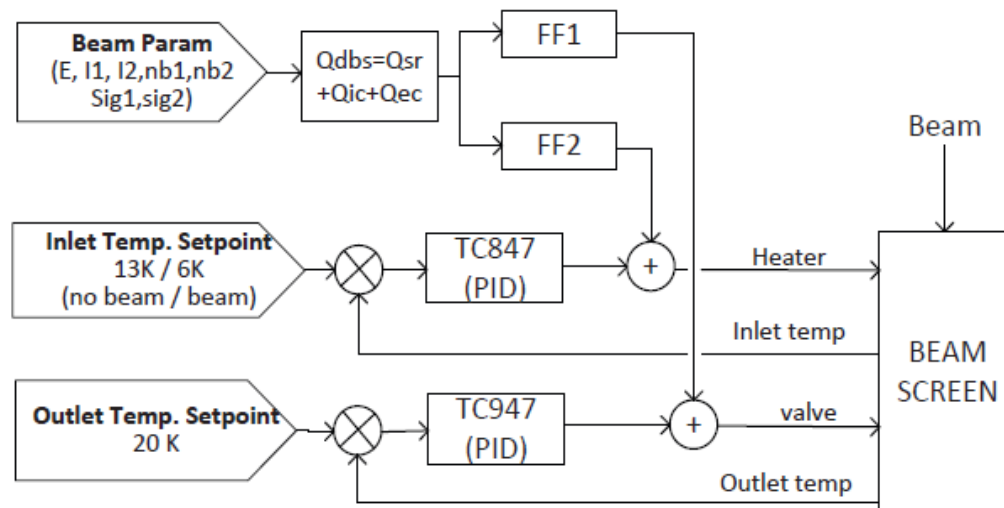
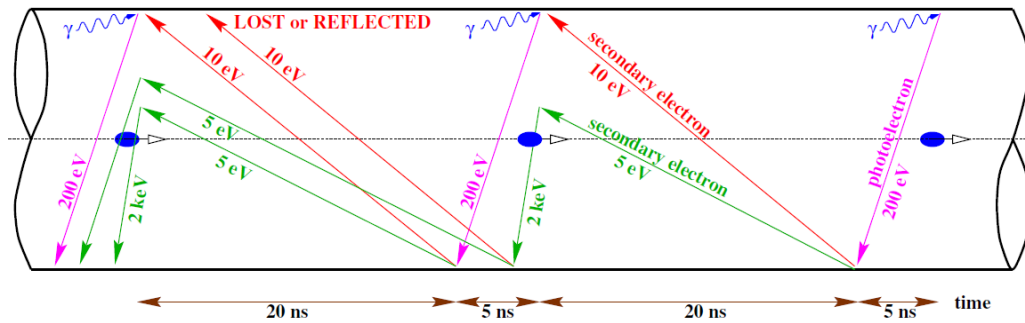


# Modelling

(BE-ICS-PCS)

## Electron cloud heat load estimation

- Interference with the control system



# Industrial IoT analytical model

*Industrial IoT analytical requirements for CERN control systems*

# Data ingestion

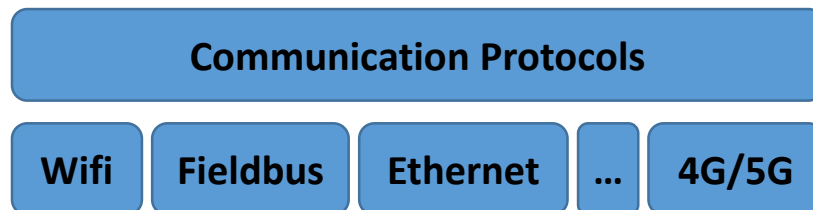
## Make data available for analytics

### > Online ingestion

- Collection of data streams in real time
- Time window to operate over the data
- Distribute the data to multiple analyzers

### > Offline ingestion

- Data lake and not separated storages
- Archive huge dataset
- Distributed environment & data locality



- > Ingestion from field devices and SCADA
- > Multi-protocol support
  - Application specific requirements
- > Time synchronization
- > Reduced impact on ICS
  - Network load across the nodes/SCADA
  - Not invasive fieldbus communication
  - Latency among nodes

# Data abstraction and Security

## Data modelling for analytics

### > Security and privacy

- Data encryption
- Securing the communication among nodes
- Anonymizing the data before sending them to public cloud

Security/Privacy

Data Abstraction

Communication Protocols

Wifi

Fieldbus

Ethernet

...

4G/5G

### > Homogenous data modeling

- Consistent references across control systems
- Different data types: process measurements, control alarms, logs
- Different measurement units ( ex: temperature in C/K)

### > Data validation

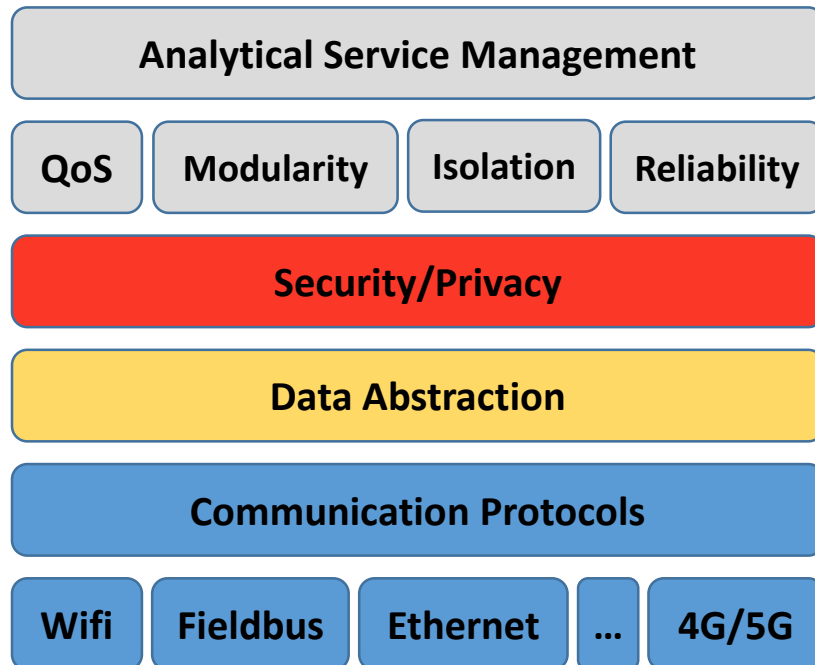
- Data quality embedded in the model
  - By code like in OPC
  - By comparing neighbors' values
- Operations in the model

### > Data resolution

- Information reduction to run analysis and storage capabilities

# Analytical service management

## Key features for control analytics

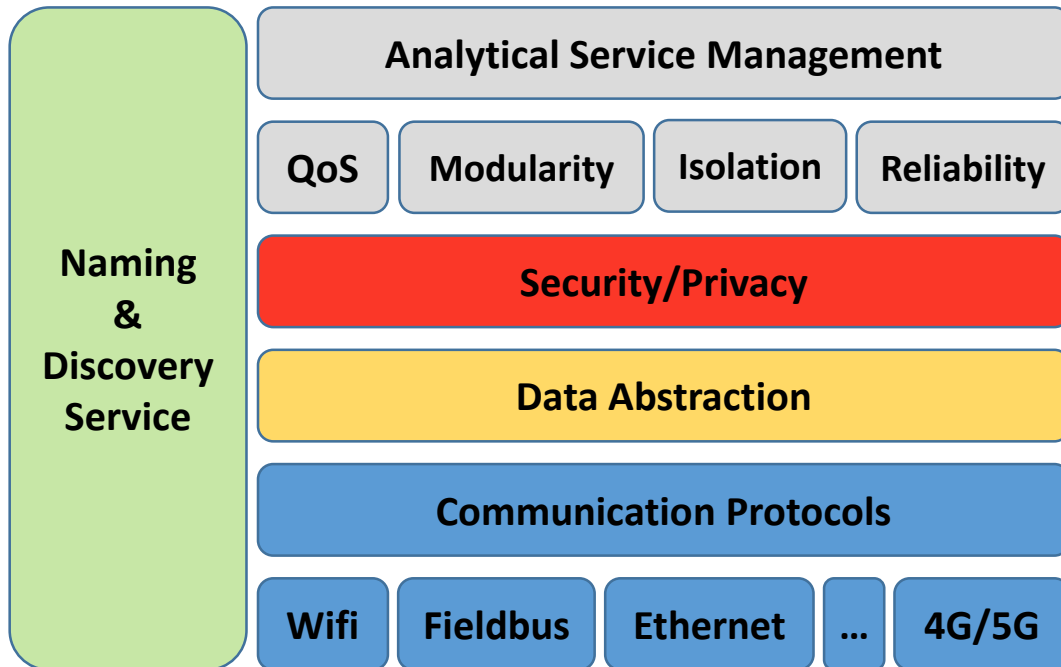


- › **Quality of Service**
  - Set different analytical priorities and service levels
- › **Modularity and Isolation**
  - Add/replace IoT devices
  - No single point of failure
  - Detect and isolate fault/crash
- › **Multi-platform support**
- › **Reliability**
  - Check the service status
  - Maintain the network topology during the transmission of anomalies
  - Do not disrupt the control process
- › **Analytical optimization**
  - Workload allocation based on devices resources, topology, special HW, data sources proximity, latency, network usage ...



# Naming and discovery service

## Description of control resources



### > **Dynamic device registration**

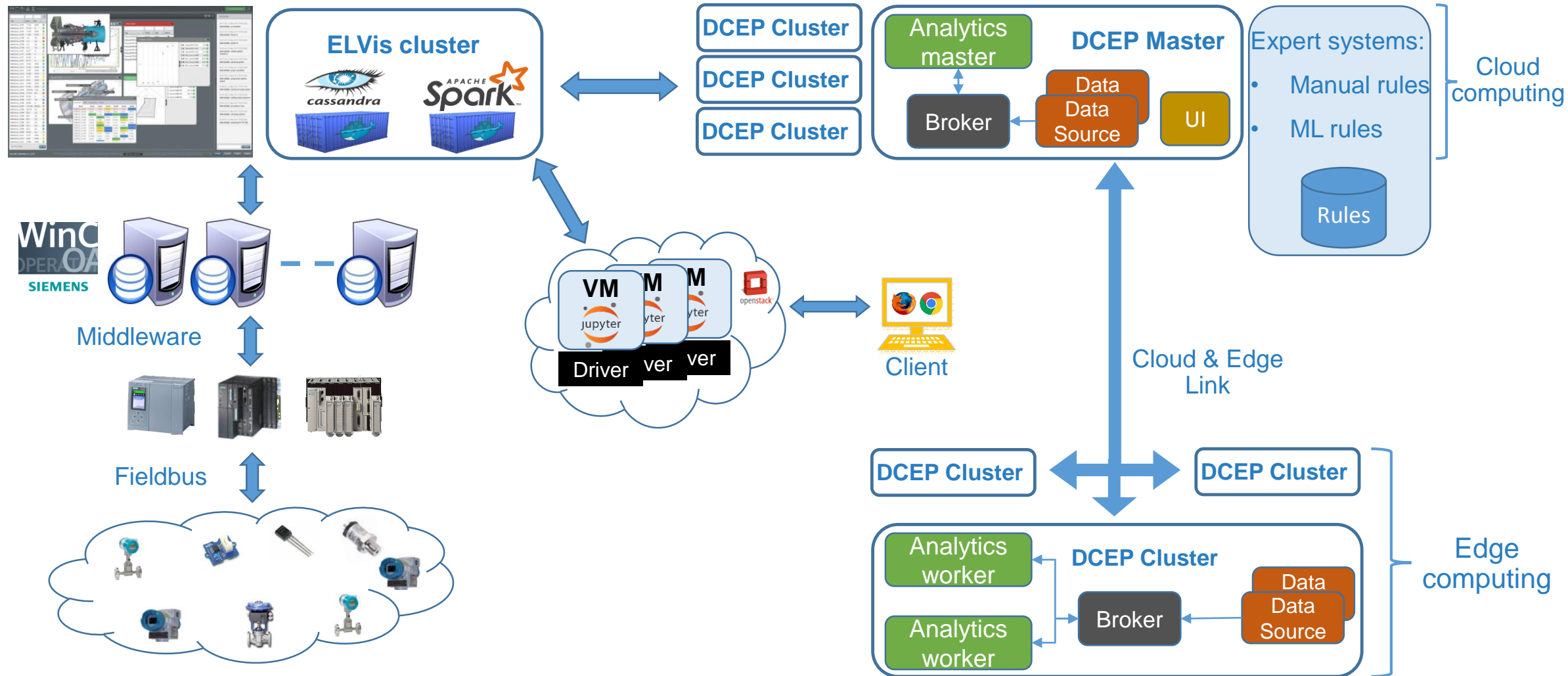
- In line with the control system structure
- Sensors description
- Available resources
- Dynamic configuration

### > **Service discovery**

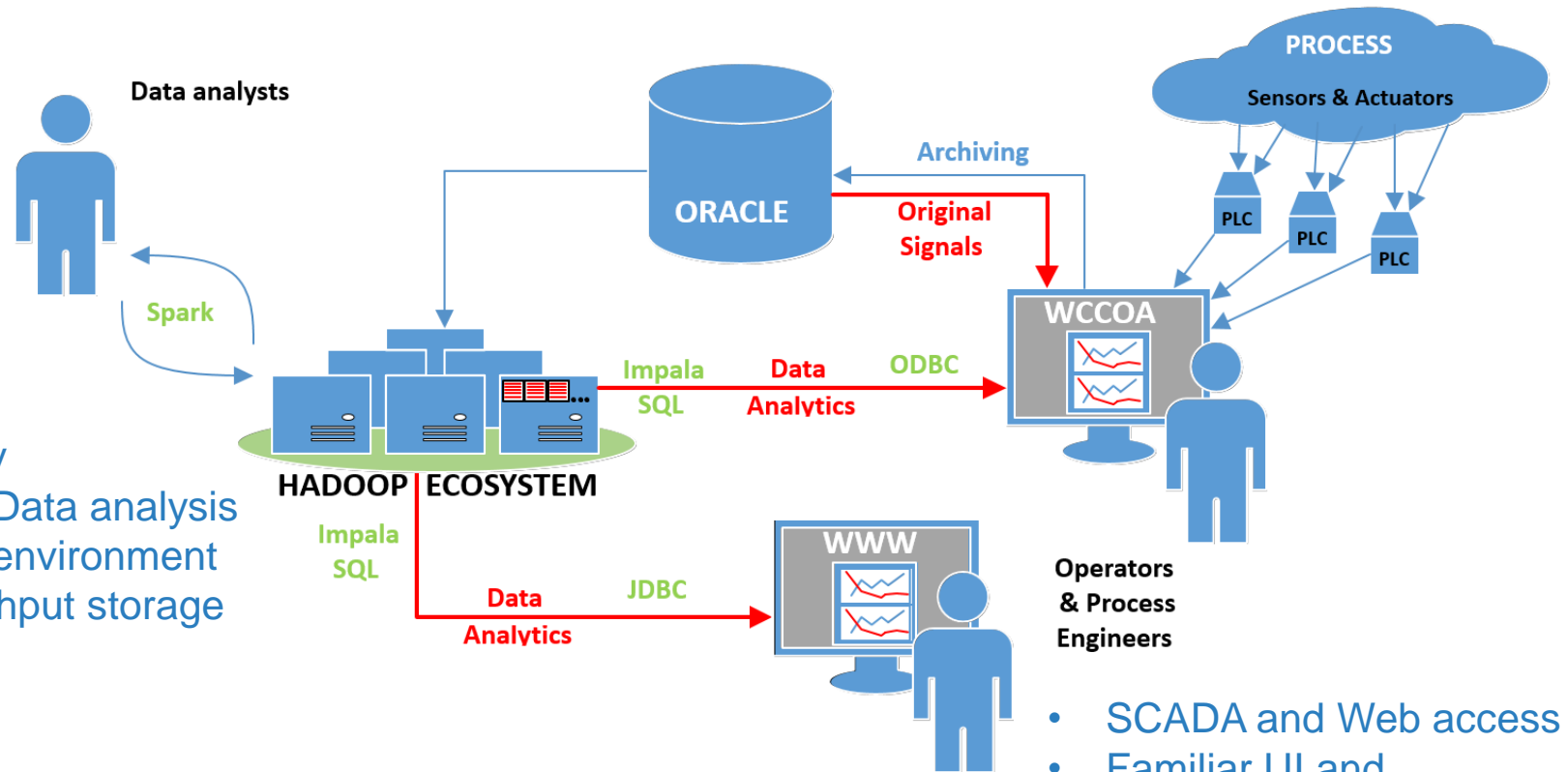
- Services endpoints
- Permitted operations
- Event subscription
- Dynamic update due to device mobility

# Smart Data for Industrial Control Systems

Combining cloud and edge computing into a single framework



- Data locality
- API for Big Data analysis
- Distributed environment
- High throughput storage



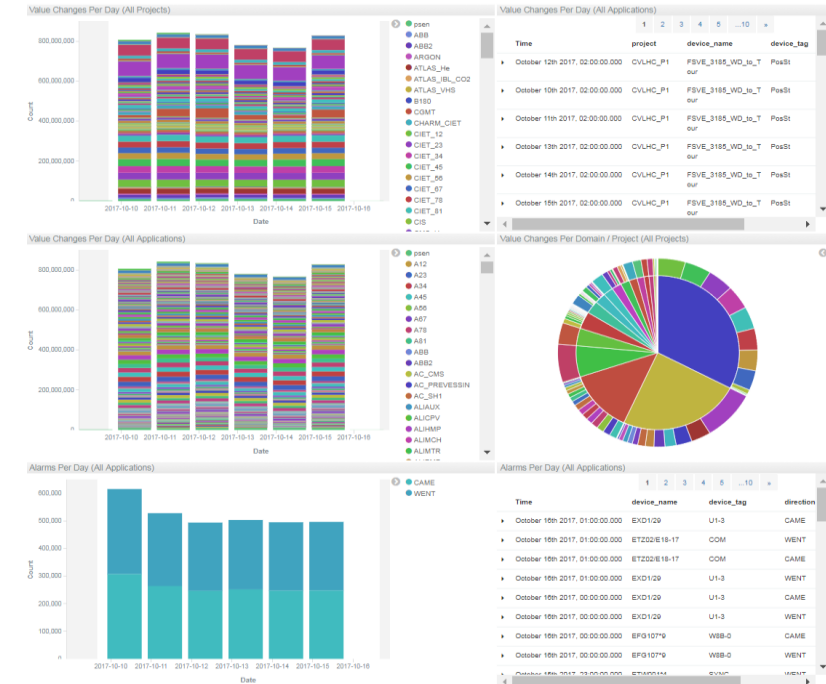
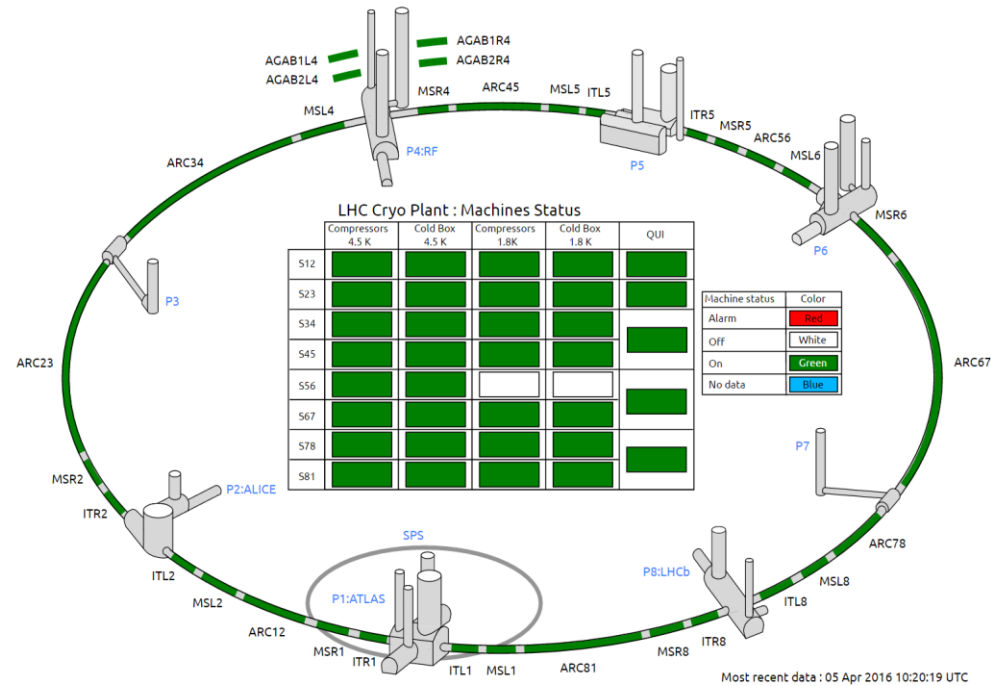
- SCADA and Web access
- Familiar UI and functionalities
- Rapid prototyping

# Data Analytics Reporting for Industrial Control Systems

*Display analytics results on the operator's screen and web-frontend.*

# Big data visualization for control

(Courtesy of B. Copy and J. Hamilton)



## Features:

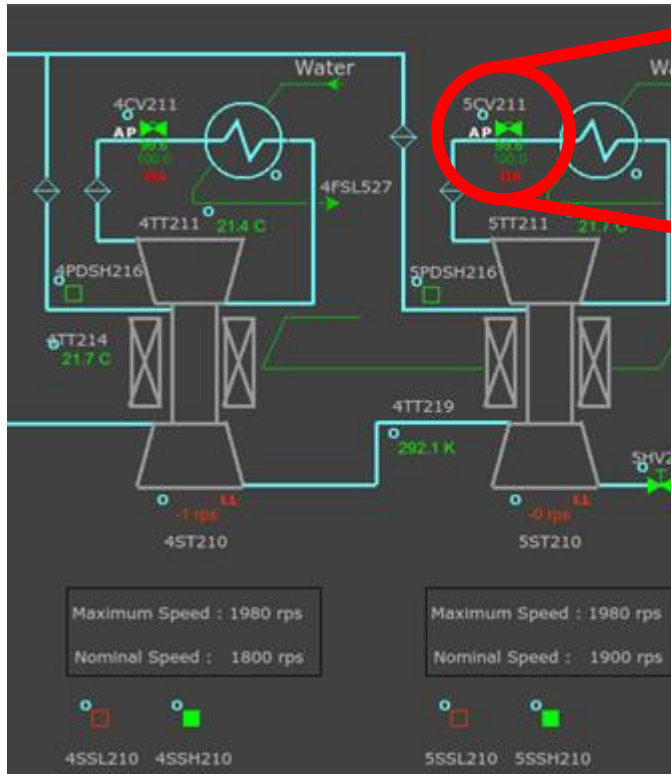
- Faster data extraction
- Database query protection mechanism

- Data distribution
- User friendly navigation
- Easy to access

- Multiple sources
- Multiple output formats (Charts, Table, Text)
- Similar to the Atlas DDV (DCS Data Viewer)

# Data Analytics Reporting System for WinCC OA

Attract operators attention



5CV211  
AP  
99.6  
100.0  
DA

Easy and direct access to the analytics results

1 - QSRB\_6\_4CV211 Brake valve 4TU210

QSRB\_6\_4CV211

Time Range: From: 2016-09-11 00:00:00.000 Until: 2016-09-18 00:00:00.000

No.	TS Begin	TS End	Type	Comment
5	2016.09.16 08:00:00.000	2016.09.16 10:00:00.000	Correlation Analysis	KNN-graph and correlati
6	2016.09.16 08:00:00.000	2016.09.16 10:00:00.000	Correlation Analysis	KNN-graph and correlati
7	2016.09.16 10:00:00.000	2016.09.16 12:00:00.000	Correlation Analysis	KNN-graph and correlati
8	2016.09.16 12:00:00.000	2016.09.16 14:00:00.000	Correlation Analysis	KNN-graph and correlati
9	2016.09.16 12:00:00.000	2016.09.16 14:00:00.000	Correlation Analysis	KNN-graph and correlati
10	2016.09.16 14:00:00.000	2016.09.16 16:00:00.000	Correlation Analysis	KNN-graph and correlati
11	2016.09.16 16:00:00.000	2016.09.16 18:00:00.000	Correlation Analysis	KNN-graph and correlati
12	2016.09.16 18:00:00.000	2016.09.16 20:00:00.000	Correlation Analysis	KNN-graph and correlati
13	2016.09.16 20:00:00.000	2016.09.16 22:00:00.000	Correlation Analysis	KNN-graph and correlati

Present Selected Present All Present Last...

On Off Set Value... Inc. Dec. Allow-Restart Limits  
Auto Mode Manual Mode Forced Mode Ack. Alarm Select

AnalysisModule: AnalysisResults

English, US [en\_US.iso88591]

### DATA ANALYTICS - INDIVIDUAL ANALYSES VIEW

Options

Type	Alias	Begin
2	CA QSRB 6 4CV211AO	2016-09-16 00:00:00
2	CA QSRB 6 4CV211AO	2016-09-16 02:00:00
2	CA QSRB 6 4CV211AO	2016-09-16 04:00:00
2	CA QSRB 6 4CV211AO	2016-09-16 06:00:00
2	CA QSRB 6 4CV211AO	2016-09-16 08:00:00
2	CA QSRB 6 4CV211AO	2016-09-16 10:00:00
2	CA QSRB 6 4CV211AO	2016-09-16 12:00:00
2	CA QSRB 6 4CV211AO	2016-09-16 14:00:00
2	CA QSRB 6 4CV211AO	2016-09-16 16:00:00
2	CA QSRB 6 4CV211AO	2016-09-16 18:00:00
2	CA QSRB 6 4CV211AO	2016-09-16 20:00:00
2	OA QSRB 6 5CV211AO	2016-09-15 17:00:00

Analysis ID: 60552446-b650-11e6-a4fc-02163e008c5b

Object: QSRB\_6\_5CV211AO.PosSt

Type: Oscillation Analysis

TS Begin: 2016.09.15 17:00:04.000 Additional Information

TS End: 2016.09.15 21:59:50.000

Signals in time

Trend Options

Value over value trend

Trend Options

Amplitude-Period juxtaposition

Table Options

No.	Amplitude	Period
1	0.58264794125926	110.89204545455
2	0.64330856478838	118.28484848485
3	0.85347594872231	153.67716535433
4	0.85969552681293	134.6
5	0.9733114467467	152.4765625
6	1.0841298811063	165.39830508475
7	1.3140846365301	157.39516129032
8	1.3954806029795	172.71681415929
9	1.862287386939	171.20175438596

# Conclusions

- › **Main idea: combine cloud and edge computing in a single analytical framework**
- › **Siemens involvement:**
  - New collaboration with an IoT group
  - Existing collaboration with the cloud computing group
- › **Initial phase**
  - Requirements definitions
  - Initial prototype of the analytical framework
  - Integration with CERN control systems



# Thank you!

*CERN BE-ICS*

<https://be-dep-ics.web.cern.ch/>