
CERN

Data Science for Improving CERN's Accelerator Complex Control Systems

Manuel Martín Márquez

International Conference on Computing in High Energy and Nuclear Physics
CHEP 2015 – Okinawa, Japan

The Large Hadron Collider (LHC)

Largest machine in the world

27km, 6000+ superconducting magnets

Fastest racetrack on Earth

Protons circulate 11245 times/s (99.9999991% the speed of light)

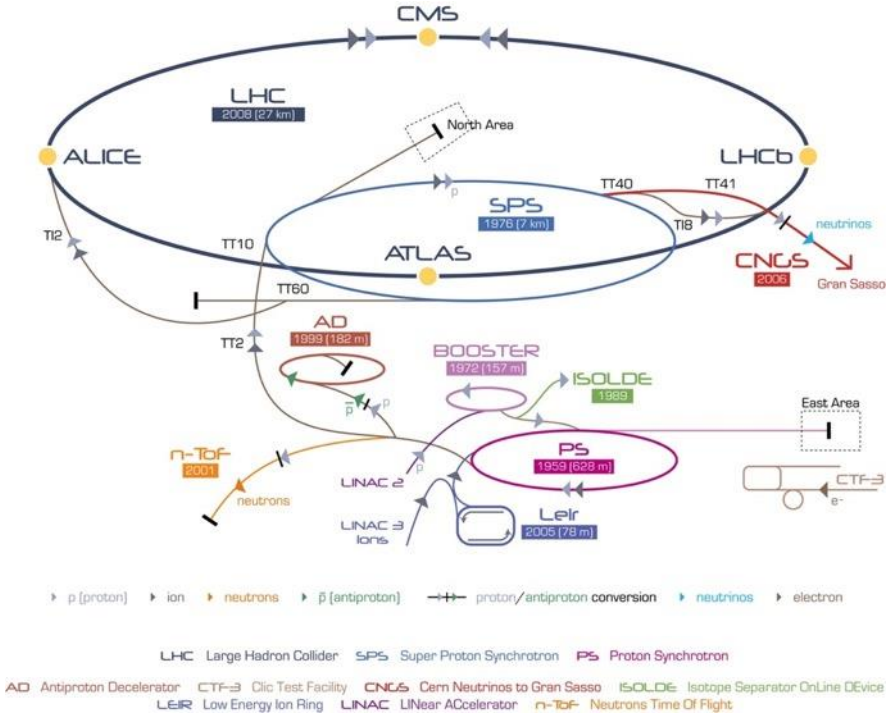
Emptiest place in the solar system

High vacuum inside the magnets

Hottest spot in the galaxy

During Lead ion collisions create temperatures 100 000x hotter than the heart of the sun;

CERN's Accelerator Complex



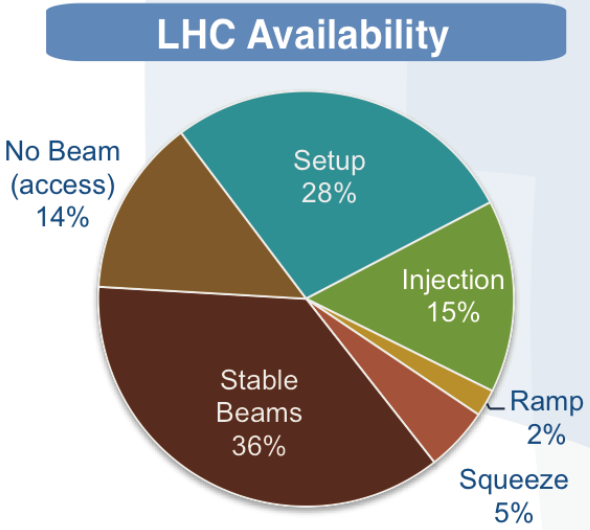
Accelerator Control and Operation

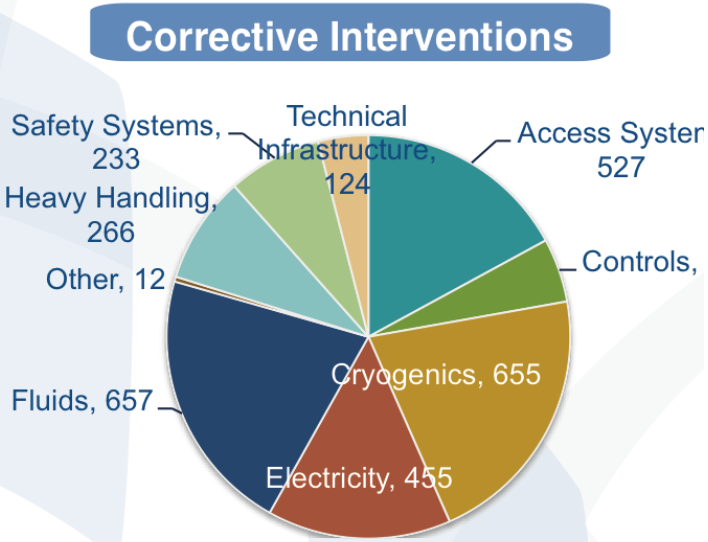
Improve Control and Operations

Million of sensors, large number of control devices, front-end equipment, etc.

Many critical systems: Cryogenics, Vacuums, Machine Protection, etc.

The Challenge





Maximize operation efficiency and availability

Reduce and predict faults and corrective interventions

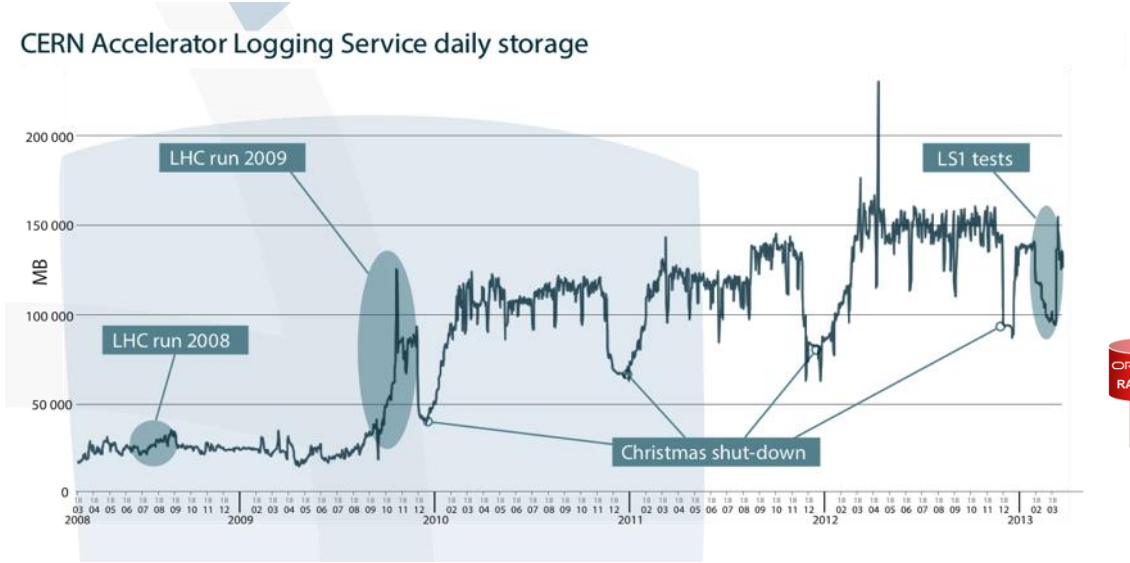
Data Analytics Challenges

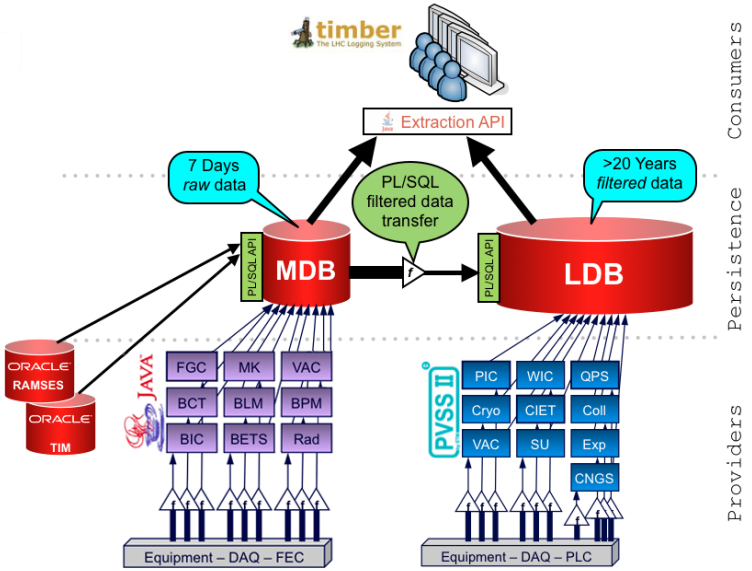
- A look into the future

				2015
Parameter	**2010**	**2011**	**2012**	**design value**
Beam energy	3.5	3.5	4	7
β* in IP 1 and 5 (m)	2.0/3.5	1.5/1.0	0.6	0.55
Bunch spacing (ns)	150	75/50	50	25
Max. number of bunches	368	1380	1380	2808
Max. bunch intensity (protons per bunch)	1.2×10^{11}	1.45×10^{11}	1.7×10^{11}	1.15×10^{11}
Normalized emittance at start of fill (mm mrad)	≈2.0	≈2.4	≈2.5	3.75
Peak luminosity ($cm^{-2}s^{-1}$)	2.1×10^{32}	3.7×10^{33}	7.7×10^{33}	1×10^{34}
Max. mean number of events per bunch crossing	4	17	37	19
Stored beam energy (MJ)	≈28	≈110	≈140	362

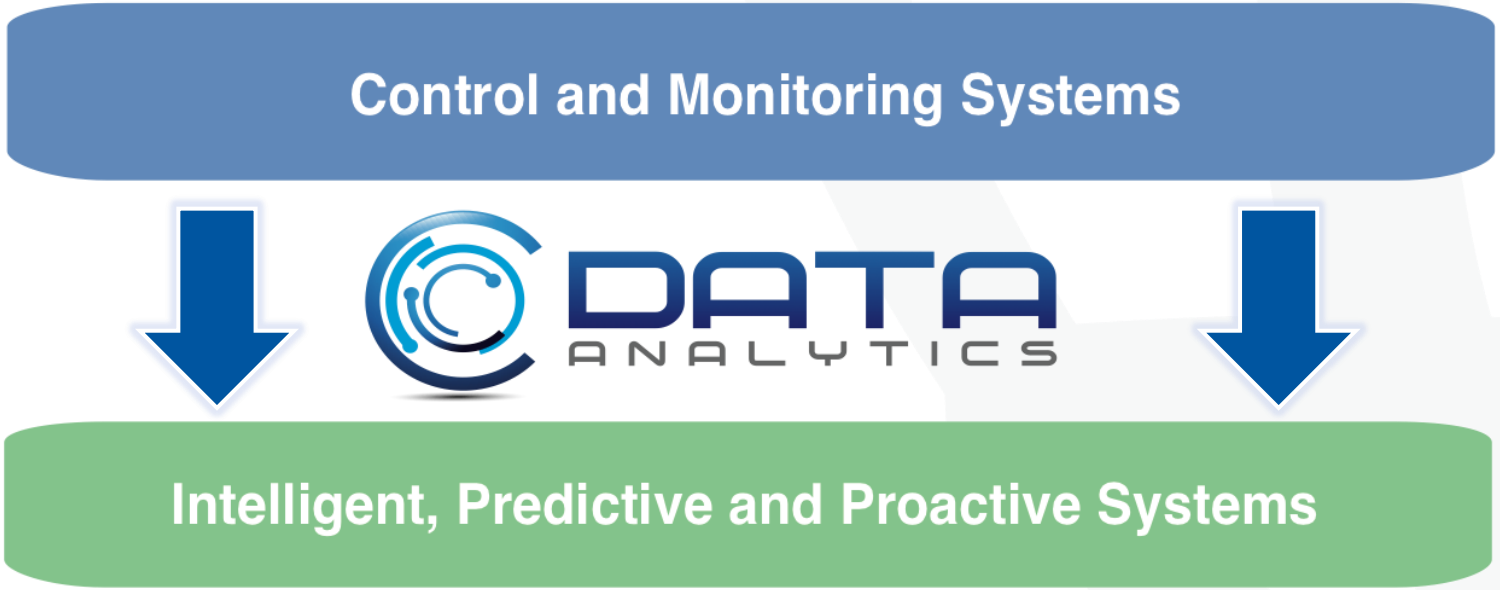
Data Analytics Challenges

- Profit from our data investment



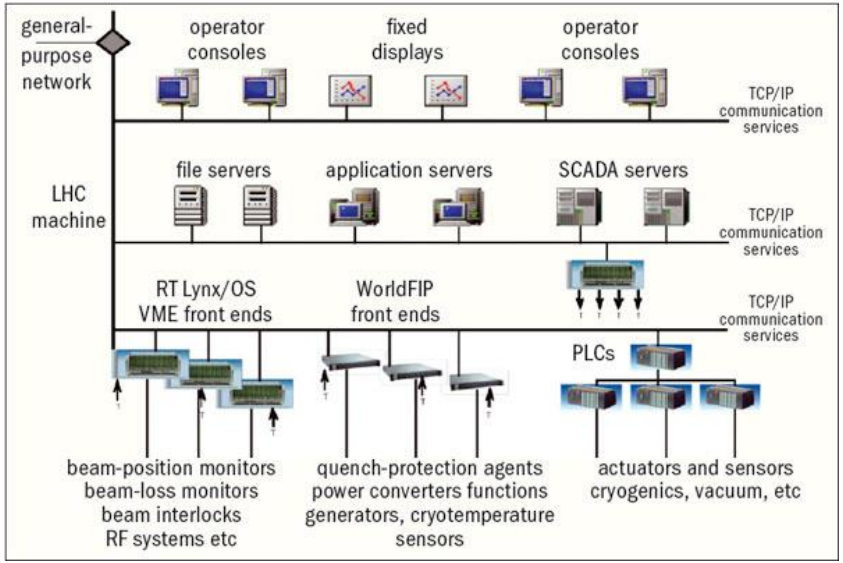


Data Analytics Objective



CERN's Data Analytics Use Cases

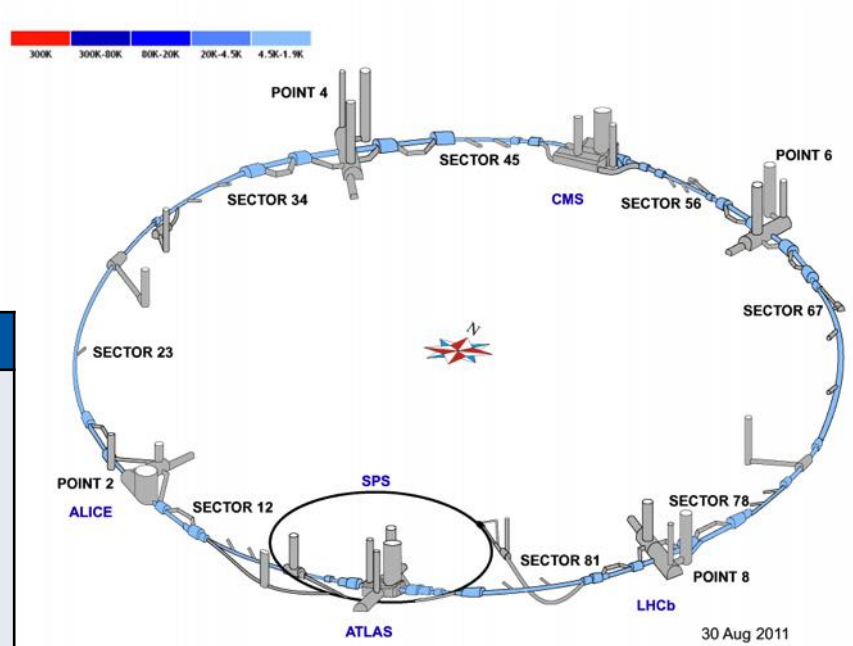
- Control System
  - **Cryogenics**
  - Vacuum
  - Machine Protection
  - Power Converters
  - QPS



Largest Cryogenics Installation

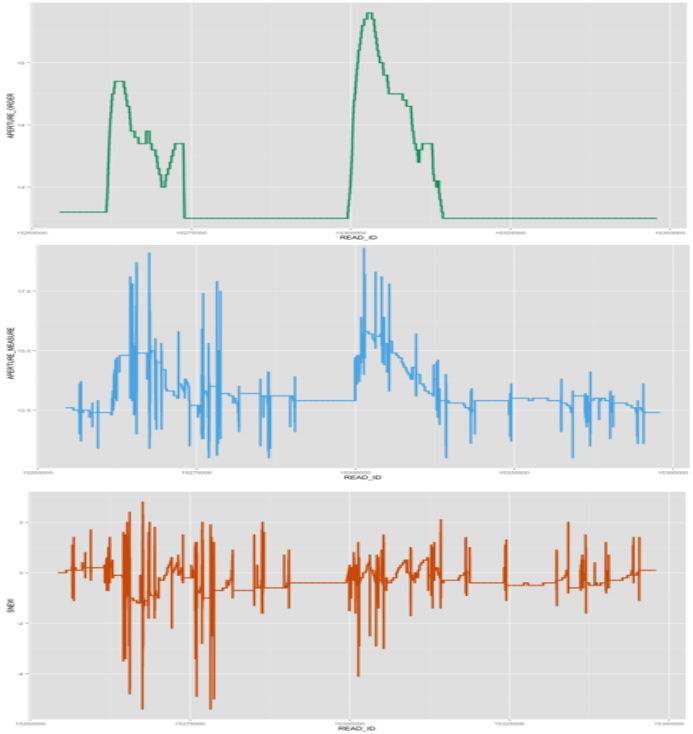
- 27 km of decentralized instrumentation and control
- 50k I/O, 11k actuators, ~5k control loops
- Control:
  - ~100 PLCs (Siemens, Schneider),
  - ~40 FECs (industrial PCs)
- Supervision: 26 SCADA servers

Instrument/Actuators	Total
Temperature [1.6 – 300 K]	10361
Pressure [0 – 20 bar]	2300
Level	923
Flow	72
Flow	2633
Control valves	3692
On/Off valves	1835
Manual valves	1916
Virtual flow meters	325
Controllers (PID)	4833



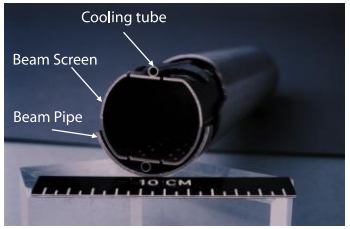
Faulty Cryogenics Valve Detection

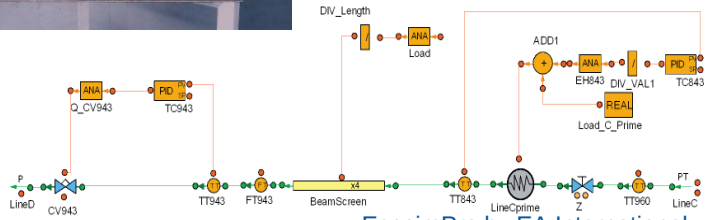
- Signals used:
  - S = aperture order - aperture measured
- Features extractions based on S
  - Variance
  - Percentile 99.9
  - Rope distance – R(S) $R(S) = \frac{1}{N}\sum_{i=2}^{N}|S(i) - S(i-1)|$
  - Noise Band – B(S) (Pxx be the power spectrum of the signal S, from 0 to 0.5Hz, where S has been previously mean-centred). $B(S) = \frac{\left|\sum_{k=1}^{N_{fft}/2} Pxx(k)\right|^2}{\sum_{k=1}^{N_{fft}/2} Pxx(k)^2}$
- **Automatic Faulty Valves Detection System**
  - SVM - Support Vector Machine



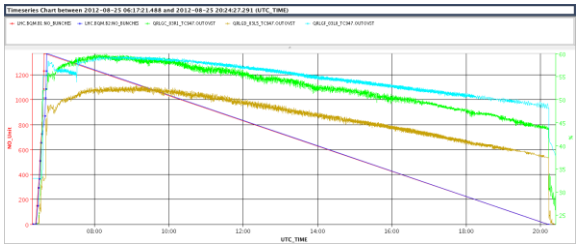
Anomaly Detection on Beam Screen Cryogenic Control

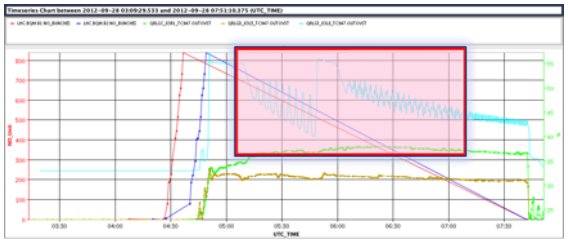
- PID output (time series) segmentation
- Characterization + Feature extraction
- Features based classification

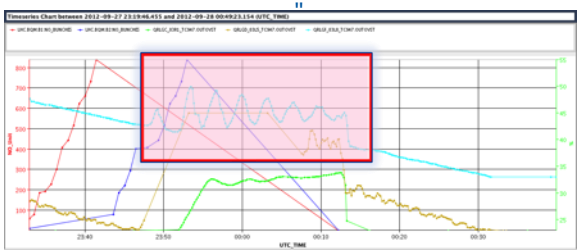




EcosimPro by EA International







Source: EN-ICE (Benjamin Bradu, Enrique Blanco)

Data Discovery - Accelerator Complex Operations

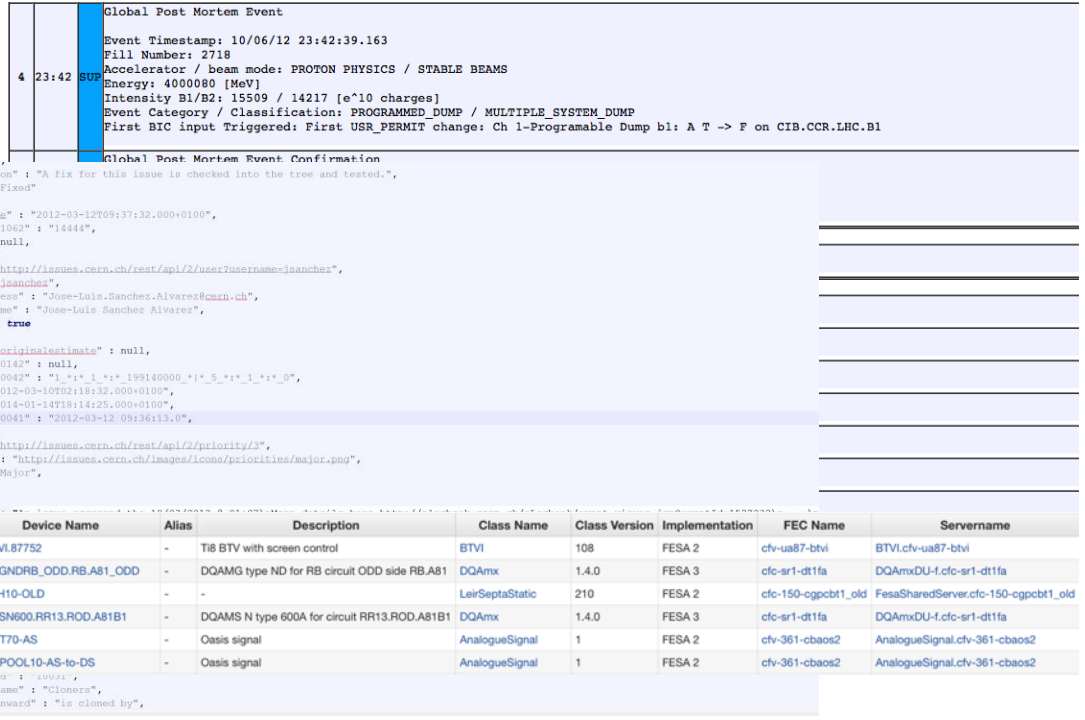
Integrating Data Sources

- Electronic Logbook
- Controls Configuration DB
- JIRA (JSON)

Text analysis

Better LHC Operations

- Events Analysis
- Correlate Information
  - Fault Tracking System
  - Operational Modes
  - Operational Issues
  - Control Equipment



Search Box

Search within

Selected Refinements

Complex

LHC

Reset

Available Refinements

Logbook

Complex

Search for specific value...

- TESTS (188442)
- PS Complex (131865)
- SPS (101456)
- HISTORY (30181)
- ISOLDE (22262)
- BE-BI (7241)
- UA9 (2647)
- TE-ABT (2504)
- TE (2373)
- RF (1741)
- SHUTDOWN (766)
- TE-VSC (663)
- EN-ICE (244)
- R2E (197)
- AT-MCS (20)

Select All

Logbook

Events

- Event Date
- Event Comment
- Operational Mode
- Line Name

Faults

- Fault Groupname
- Fault Name
- Fault Description
- Fault Start Date

Summary of Faults

191,688	1,804	0.94%	0.00	0.00%	0.00%	100.00%
Total Events	Total Faults	Fault Percentage	TI Major Events	PS Complex	SPS	LHC

Fault Analysis

beam dump, BSRT beam, cable shorted, causing orbit fluctations, circuit breaker, cold box, cold compressor, communication problem, communication stop, compressor trip, cryogenics problem, current lead, electrical glitch, electrical interuption, electrical problem, Faulty temperature gauge, headtail instability, injection septa, interlocked positions, Lost communication, oil pump, Optical link, power converter, Power converter, power cut, power glitch, power module, power problem, power supply, power trigger power supply, provoking loss, required access, right jaw, Settings mismatch, stable filter, stopped water, temperature sensor, vacuum problem, Vacuum problem, warm compressor

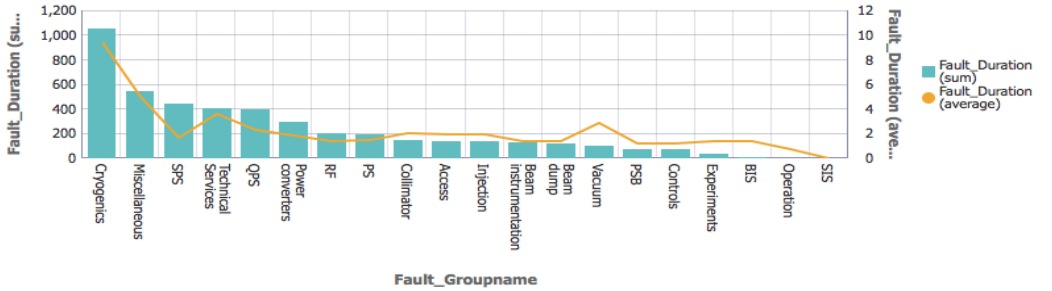
Explore: Fault Description Terms by Relevancy

Component Container

Faults Duration Analysis

Actions

Fault_Duration (sum), Fault_Duration (average) by Fault_Groupname



Sort: Fault_Groupname by Fault

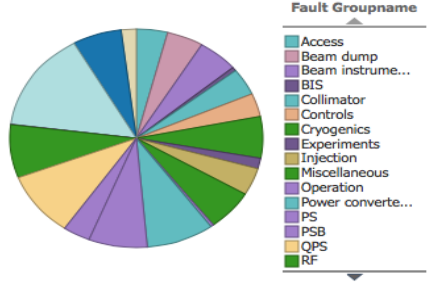
Page 1 of 1 | 1-20 of 20 | 50 per page

Category axis: Fault_Groupname

Chart

Actions

Fault Id (unique values) by Fault Groupname



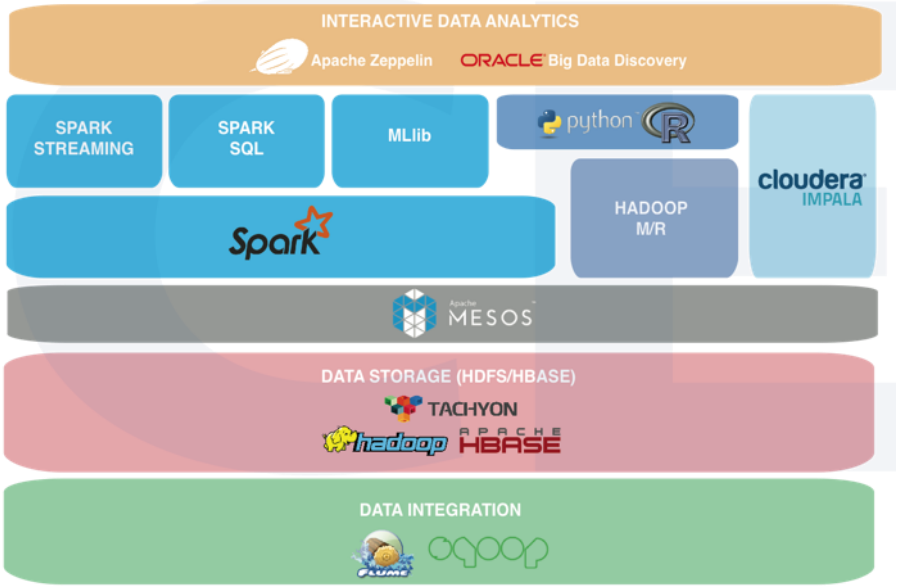
Sort: Complex

Page 1 of 1

Color: Fault Groupname

Big Data Analytics as a Service

- Batch Processing
  - Highly heterogeneous data
  - Tools (Matlab, R, Python)
- Near-real-time processing
  - Low Latency (order of second)
  - Expert knowledge + inferred
  - Scalability and fault tolerant
- Visual Analytics
  - Data discovery and exploration
- Data Repositories
  - Store large amount of data
  - Integrate with existing repositories



www.cern.ch