

# A bit of physics in a week of computing

**Sébastien Ponce**

sebastien.ponce@cern.ch

**CERN**

Thematic CERN School of Computing on IT Services 2024

## CERN missions

# Missions of CERN

## Research

Seeking [...] answers to questions about the Universe

## Technology

Advancing the frontiers of technology

## Collaborating

Bringing nations together through science

## Education

Training the scientists of tomorrow

# What it means everyday

## Buid and operate accelerators

- from LINAC to LHC
- 24h/7

## Buid and operate detectors

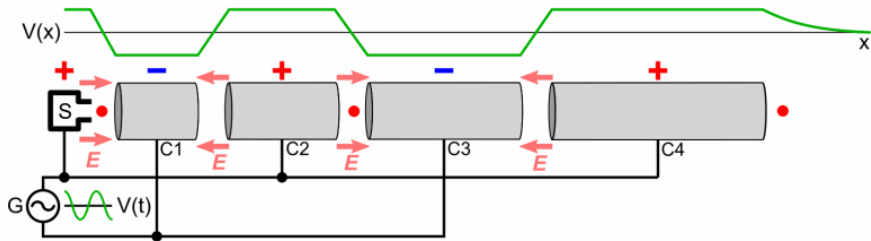
- Alice, Atlas, CMS, LHCb, ...
- store the generated data

## Physics publications

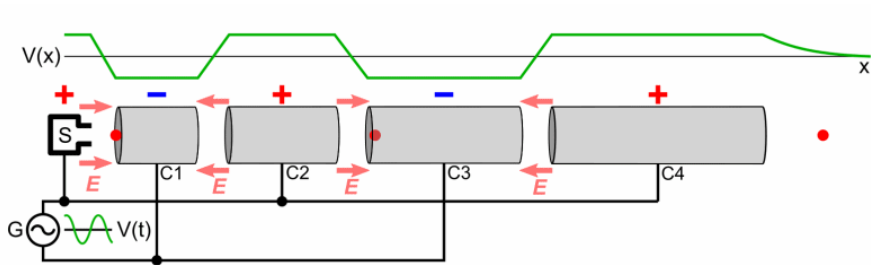
- provide analysis facilities

# Accelerators

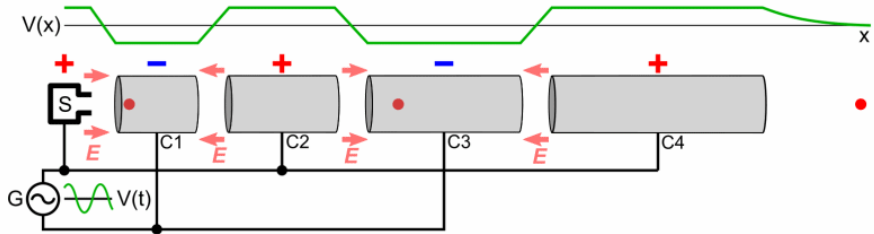
# Linac accelerators



# Linac accelerators

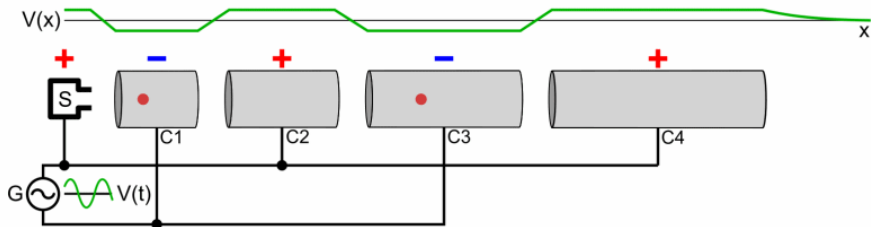


# Linac accelerators

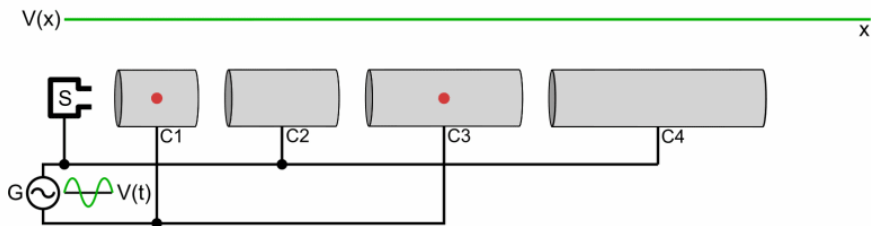




# Linac accelerators

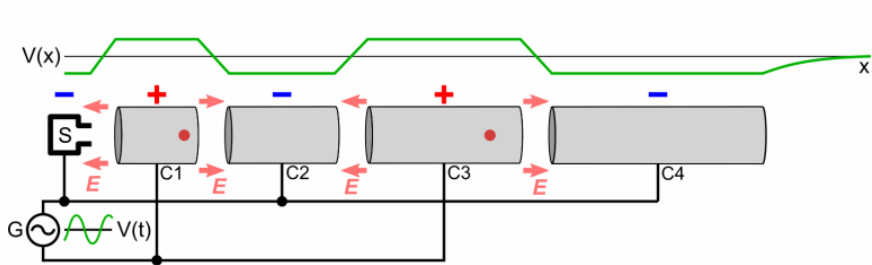


# Linac accelerators

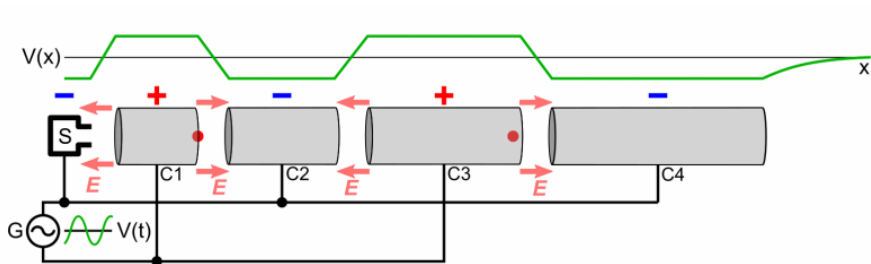




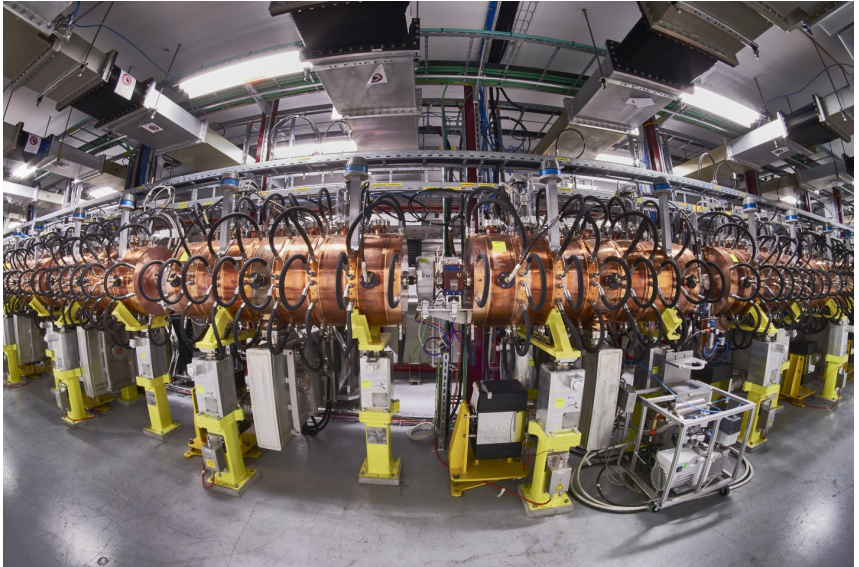
# Linac accelerators



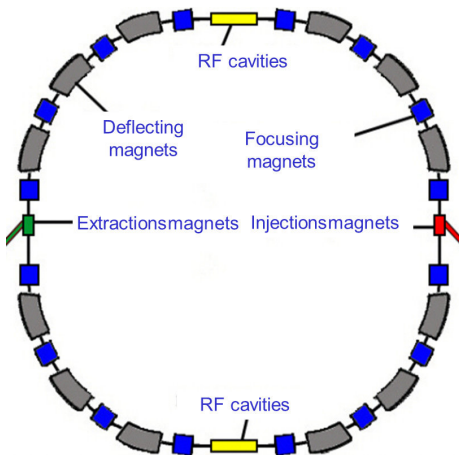
# Linac accelerators



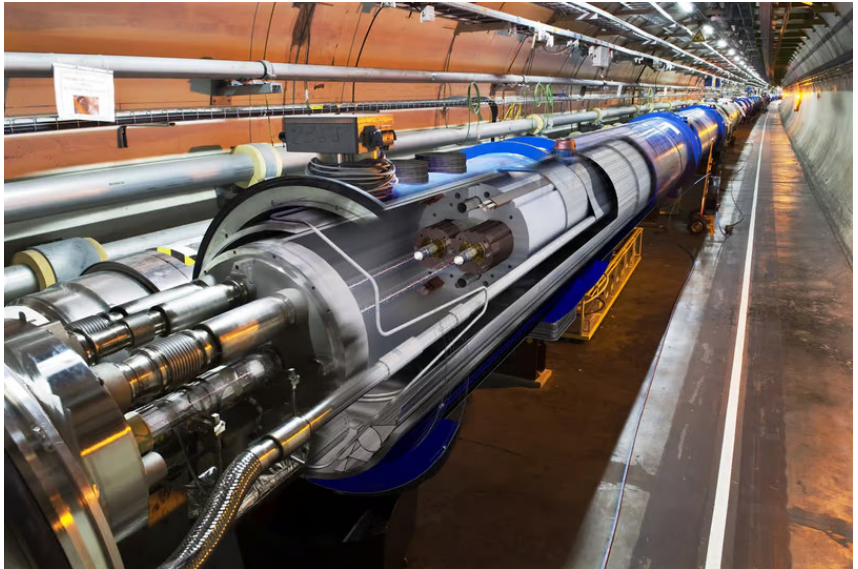
# In real life - Linac 4



# Circular accelerators

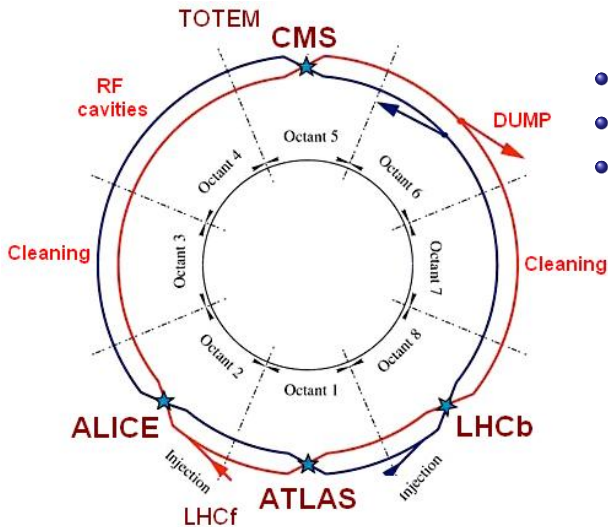


# In real life - LHC



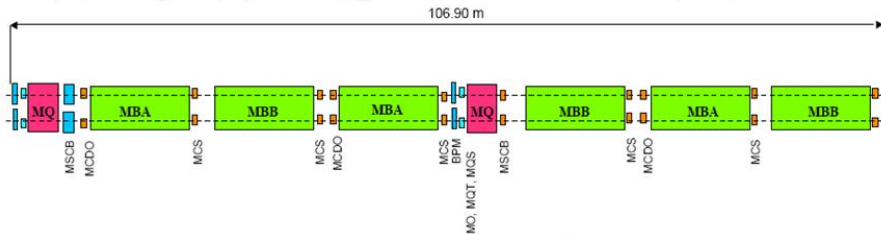


# LHC layout

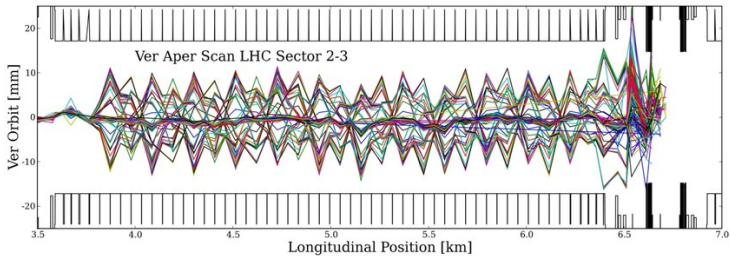
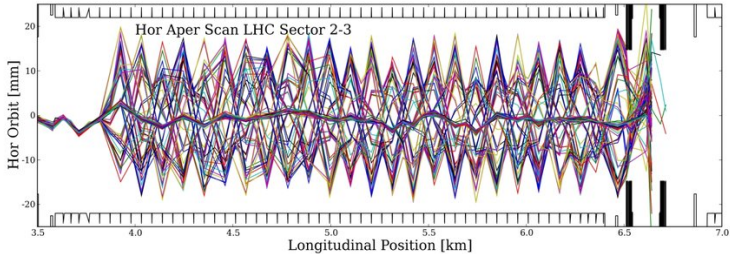


- 8 sectors
- 23 arc cells each
- 1232 bending magnets

# LHC Cell layout

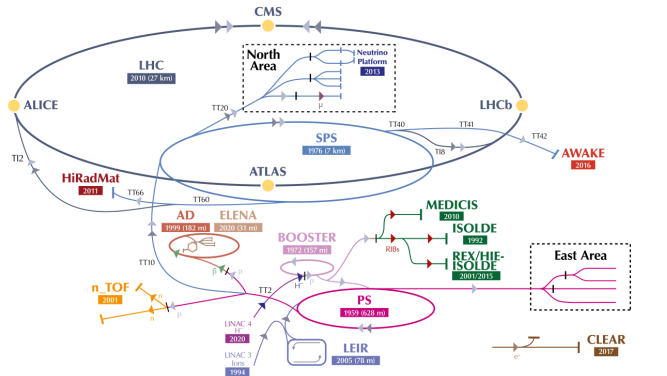


# Beam oscillations layout



# CERN accelerator complex

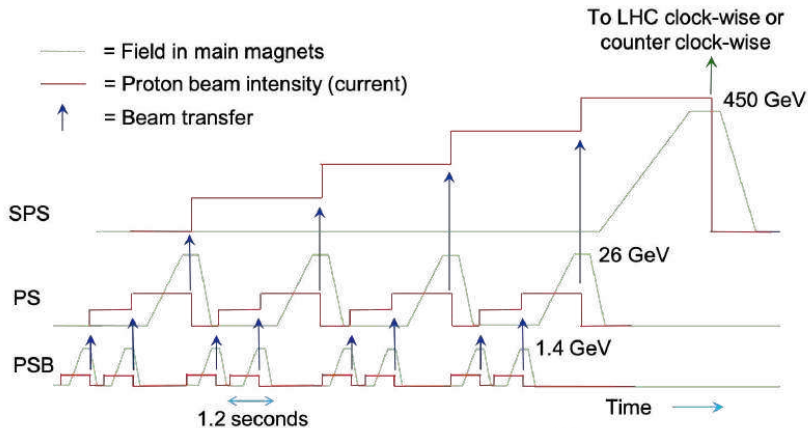
The CERN accelerator complex  
*Complexe des accélérateurs du CERN*



▶  $H^-$  (hydrogen anions)
 ▶  $p$  (protons)
 ▶ ions
 ▶ RIBs (Radioactive Ion Beams)
 ▶  $n$  (neutrons)
 ▶  $\bar{p}$  (antiprotons)
 ▶  $e^-$  (electrons)
 ▶  $\mu$  (muons)

LHC - Large Hadron Collider // SPS - Super Proton Synchrotron // PS - Proton Synchrotron // AD - Antiproton Decelerator // CLEAR - CERN Linear Electron Accelerator for Research // AWAKE - Advanced WAKEfield Experiment // ISOLDE - Isotope Separator OnLine // REX/HIE-ISOLDE - Radioactive Experiment/High Intensity and Energy ISOLDE // MEDICIS // LEIR - Low Energy Ion Ring // LINAC - LINear ACcelerator //   
 n\_TOF - Neutrons Time Of Flight // HiRadMat - High-Radiation to Materials // Neutrino Platform

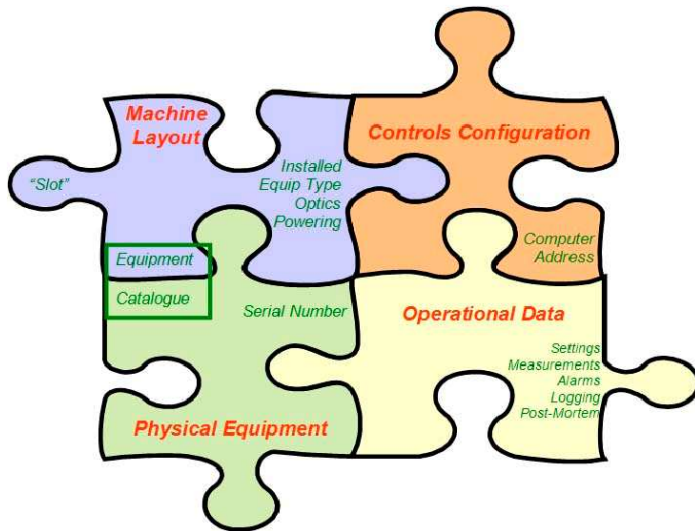
# Machine cycles



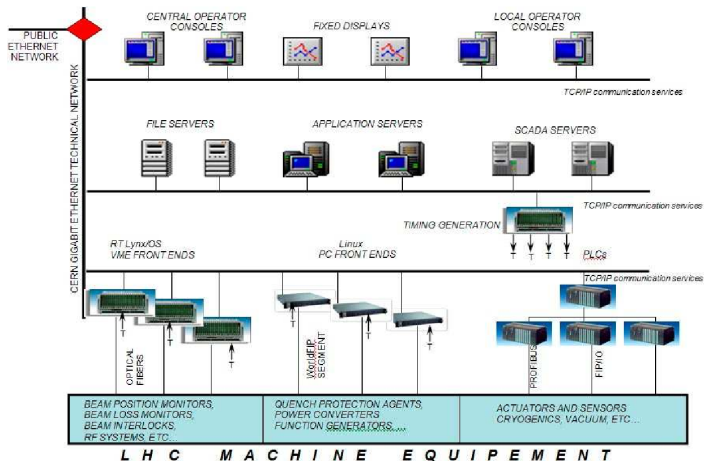
DBOD



# The LHC control system



# The control system



# Web applications at the front



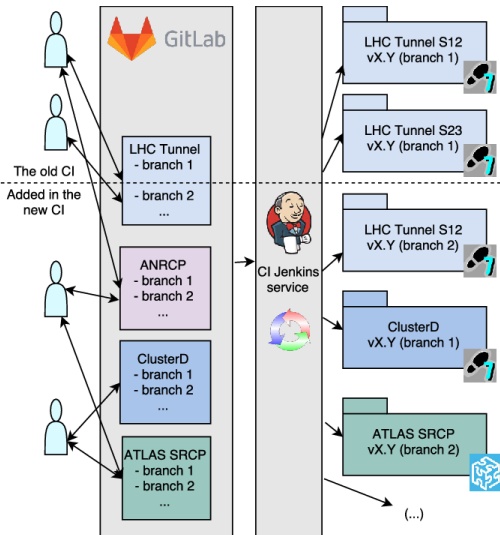


# Example of the cryogenic systems

- Data Storage (pressures, temperatures, actuator positions, etc)
  - 100 000 different sensors, 80 millions datapoints per day
- Remote virtual machines to operate
- SWAN (Service for Web based Analysis, from BE)
  - daily data analysis on archived data
- GitLab stores and executes Python scripts every night
  - performing various calculations on cryogenic data
- confluence website to perform daily follow-up operations



# Behind the Cryo control



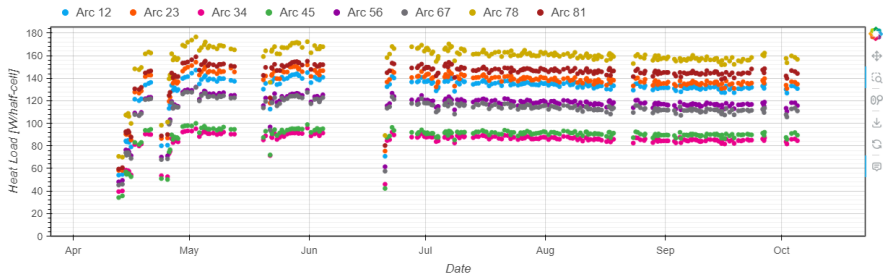
# Beam heat loads fill by fill



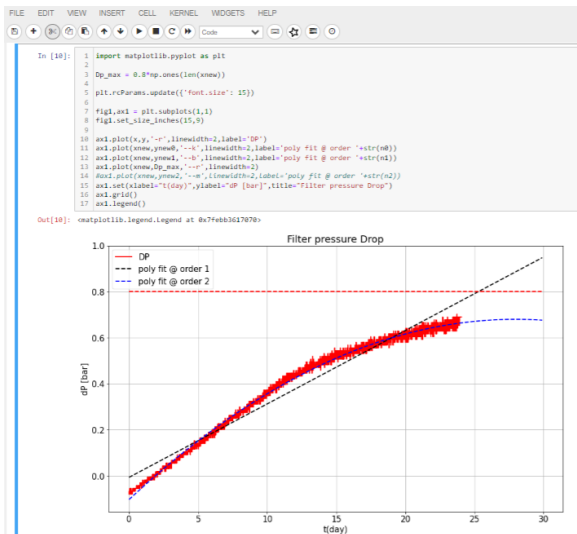
CERN Beam Performance Tracking

 GitLab

## Peak Heatload



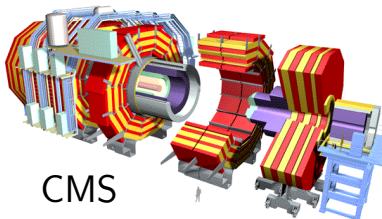
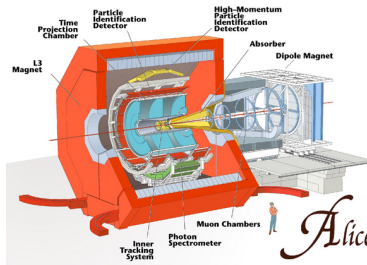
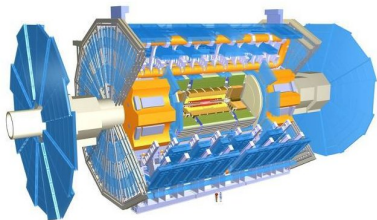
# Slow process detection



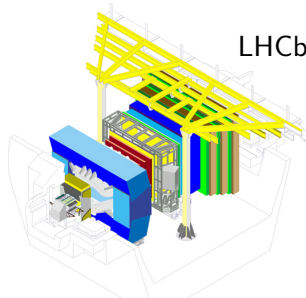
# Particle Detectors

# 4 major detectors

## Atlas



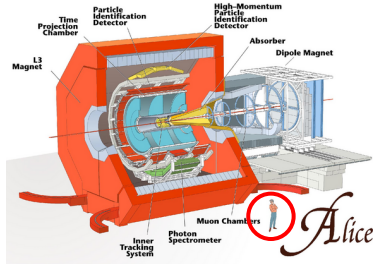
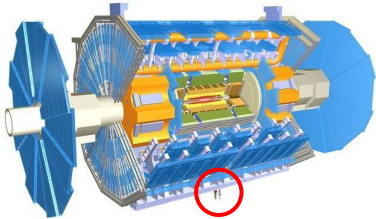
## CMS



## LHCb

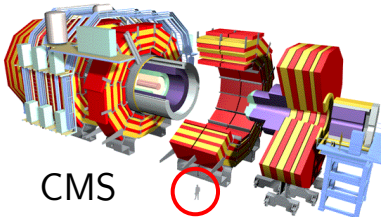
# 4 major detectors

## Atlas

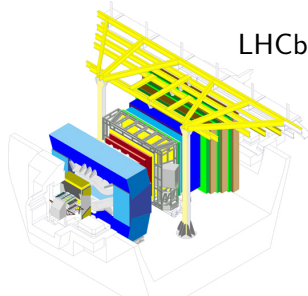


*Alice*

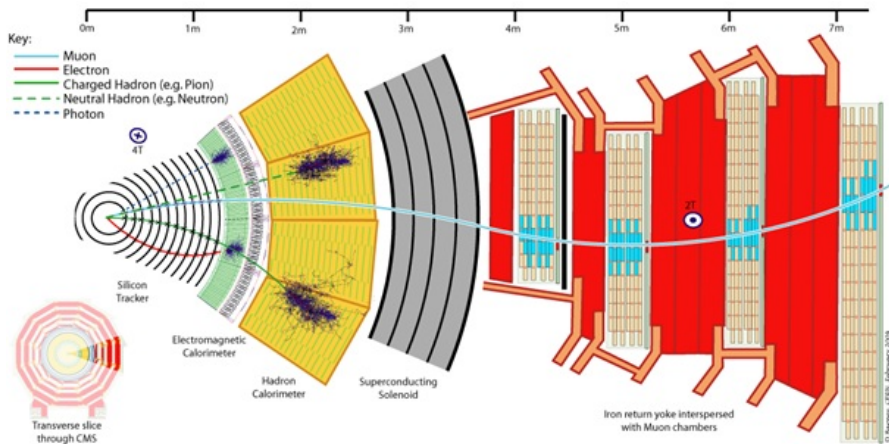
## CMS



## LHCb

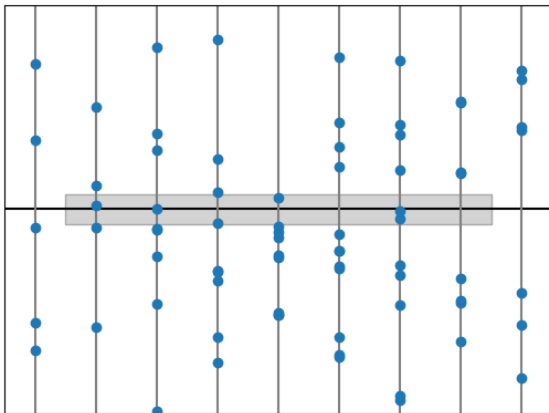


# Anatomy of a particle detector

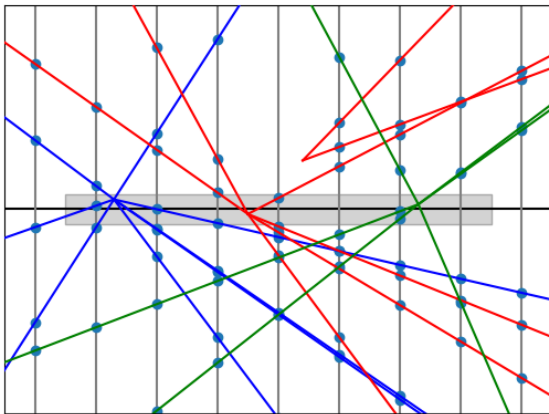




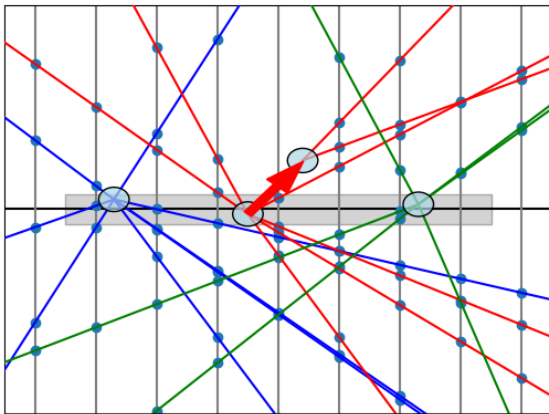
# Tracking



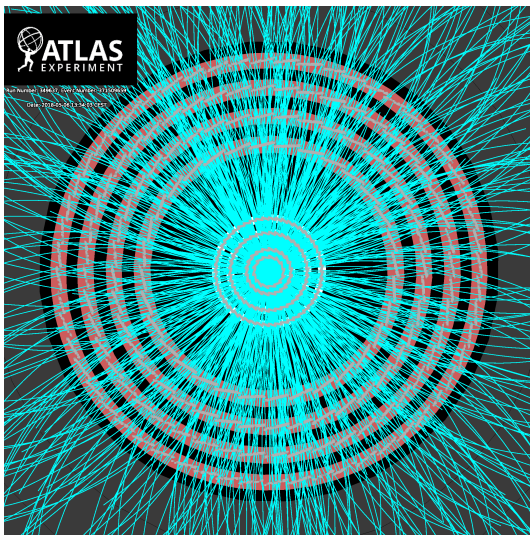
# Tracking



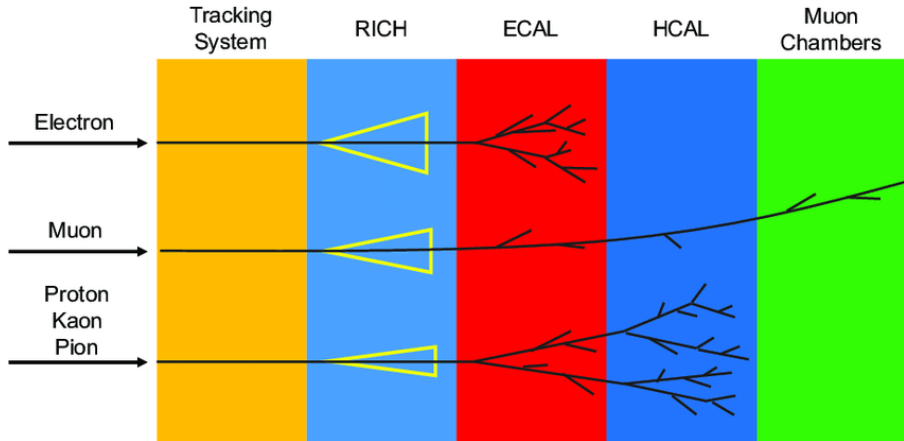
# Tracking



# Real life tracking



# Particle identification



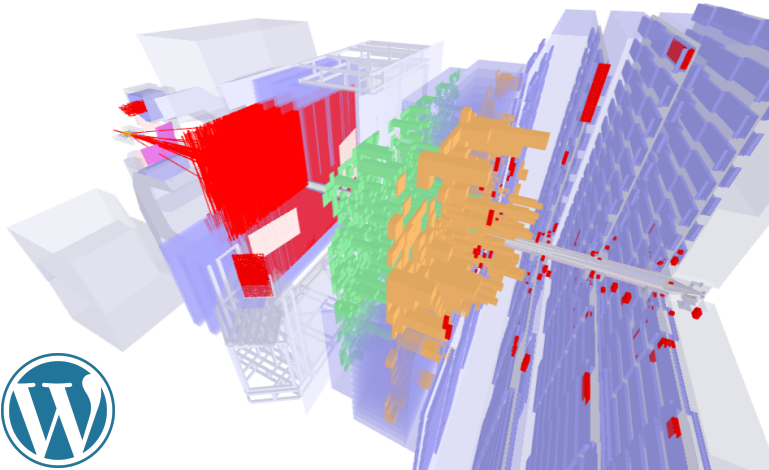
# Particle identification real life



LHCb Experiment at CERN

Run / Event: 254479 / 5406004

Data recorded: 2022-11-19 00:26:35 GMT



# Experiment controls

The screenshot displays the ATLAS Detector Control interface. At the top, there's a status bar for the LHC and ATLAS, showing 'READY' and 'OK' for various systems. The main area features a 3D cutaway model of the ATLAS detector, showing the inner detector (ID), calorimeter (CALO), muon spectrometer (MUSP), and service systems (SERVIC). Below the model, there are several control panels and data displays:

- ATLAS Detector Control Table:** A table listing various detector components and their status.
 

| System | ID    | CALO | MUSP  | SERVIC |
|--------|-------|------|-------|--------|
| LHC    | READY | OK   | READY | OK     |
| FXK    | READY | OK   | READY | OK     |
| SCT    | READY | OK   | READY | OK     |
| IRT    | READY | OK   | READY | OK     |
| IDE    | READY | OK   | READY | OK     |
| LAR    | READY | OK   | READY | OK     |
| TL     | READY | OK   | READY | OK     |
| MDT    | READY | OK   | READY | OK     |
| RPC    | READY | OK   | READY | OK     |
| TGC    | READY | OK   | READY | OK     |
| CSC    | READY | OK   | READY | OK     |
| MUON   | READY | OK   | READY | OK     |
| CIC    | READY | OK   | READY | OK     |
| EXT    | READY | OK   | READY | OK     |
| TDQ    | READY | OK   | READY | OK     |
| LHC    | READY | OK   | READY | OK     |
| FWD    | READY | OK   | READY | OK     |
| SAFETY | READY | OK   | READY | OK     |
| DCS DE | READY | OK   | READY | OK     |
- Inner Detector Control Table:** A table listing inner detector components.
 

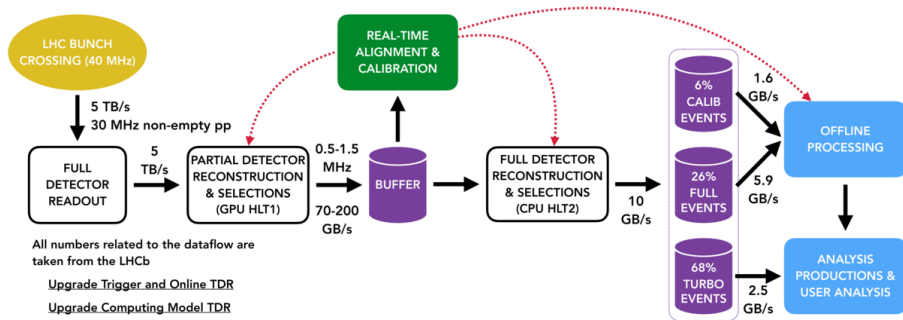
| System         | TRT   | SCT | PX    |
|----------------|-------|-----|-------|
| BARREL B LAYER | READY | OK  | READY |
| DISC           | READY | OK  | READY |
| INF            | READY | OK  | READY |
| BARREL A       | READY | OK  | READY |
| ENDCAP C       | READY | OK  | READY |
| INF            | READY | OK  | READY |
| BARREL A       | READY | OK  | READY |
| BARREL C       | READY | OK  | READY |
| ENDCAP A       | READY | OK  | READY |
| ENDCAP C       | READY | OK  | READY |
| INF            | READY | OK  | READY |
| EMBA           | READY | OK  | READY |
| EMBC           | READY | OK  | READY |
| HEFCAL A       | READY | OK  | READY |
| HEFCAL C       | READY | OK  | READY |
| INF            | READY | OK  | READY |
| LBA            | READY | OK  | READY |
| LBC            | READY | OK  | READY |
| EBA            | READY | OK  | READY |
| ESB            | READY | OK  | READY |
| INF            | READY | OK  | READY |
| BARREL A       | READY | OK  | READY |
| BARREL C       | READY | OK  | READY |
| ENDCAP A       | READY | OK  | READY |
| ENDCAP C       | READY | OK  | READY |
| MDT INF        | READY | OK  | READY |
| RPC SIDE A     | READY | OK  | READY |
| RPC SIDE C     | READY | OK  | READY |
| RPC INF        | READY | OK  | READY |
| TGC SIDE A     | READY | OK  | READY |
| TGC SIDE C     | READY | OK  | READY |
| TGC INF        | READY | OK  | READY |
| CSC SIDE A     | READY | OK  | READY |
| CSC SIDE C     | READY | OK  | READY |
| CSC INF        | READY | OK  | READY |
- Calorimeter Control Table:** A table listing calorimeter components.
 

| System         | LAR   | TRT | SCT   | PX |
|----------------|-------|-----|-------|----|
| BARREL B LAYER | READY | OK  | READY | OK |
| DISC           | READY | OK  | READY | OK |
| INF            | READY | OK  | READY | OK |
| BARREL A       | READY | OK  | READY | OK |
| ENDCAP C       | READY | OK  | READY | OK |
| INF            | READY | OK  | READY | OK |
| BARREL A       | READY | OK  | READY | OK |
| BARREL C       | READY | OK  | READY | OK |
| ENDCAP A       | READY | OK  | READY | OK |
| ENDCAP C       | READY | OK  | READY | OK |
| INF            | READY | OK  | READY | OK |
| EMBA           | READY | OK  | READY | OK |
| EMBC           | READY | OK  | READY | OK |
| HEFCAL A       | READY | OK  | READY | OK |
| HEFCAL C       | READY | OK  | READY | OK |
| INF            | READY | OK  | READY | OK |
| LBA            | READY | OK  | READY | OK |
| LBC            | READY | OK  | READY | OK |
| EBA            | READY | OK  | READY | OK |
| ESB            | READY | OK  | READY | OK |
| INF            | READY | OK  | READY | OK |
| BARREL A       | READY | OK  | READY | OK |
| BARREL C       | READY | OK  | READY | OK |
| ENDCAP A       | READY | OK  | READY | OK |
| ENDCAP C       | READY | OK  | READY | OK |
| MDT INF        | READY | OK  | READY | OK |
| RPC SIDE A     | READY | OK  | READY | OK |
| RPC SIDE C     | READY | OK  | READY | OK |
| RPC INF        | READY | OK  | READY | OK |
| TGC SIDE A     | READY | OK  | READY | OK |
| TGC SIDE C     | READY | OK  | READY | OK |
| TGC INF        | READY | OK  | READY | OK |
| CSC SIDE A     | READY | OK  | READY | OK |
| CSC SIDE C     | READY | OK  | READY | OK |
| CSC INF        | READY | OK  | READY | OK |
- Muon Spectrometer Control Table:** A table listing muon spectrometer components.
 

| System         | RPC   | MDT | TRT   | SCT | PX    |
|----------------|-------|-----|-------|-----|-------|
| BARREL B LAYER | READY | OK  | READY | OK  | READY |
| DISC           | READY | OK  | READY | OK  | READY |
| INF            | READY | OK  | READY | OK  | READY |
| BARREL A       | READY | OK  | READY | OK  | READY |
| ENDCAP C       | READY | OK  | READY | OK  | READY |
| ENDCAP A       | READY | OK  | READY | OK  | READY |
| INF            | READY | OK  | READY | OK  | READY |
| EMBA           | READY | OK  | READY | OK  | READY |
| EMBC           | READY | OK  | READY | OK  | READY |
| HEFCAL A       | READY | OK  | READY | OK  | READY |
| HEFCAL C       | READY | OK  | READY | OK  | READY |
| INF            | READY | OK  | READY | OK  | READY |
| LBA            | READY | OK  | READY | OK  | READY |
| LBC            | READY | OK  | READY | OK  | READY |
| EBA            | READY | OK  | READY | OK  | READY |
| ESB            | READY | OK  | READY | OK  | READY |
| INF            | READY | OK  | READY | OK  | READY |
| BARREL A       | READY | OK  | READY | OK  | READY |
| BARREL C       | READY | OK  | READY | OK  | READY |
| ENDCAP A       | READY | OK  | READY | OK  | READY |
| ENDCAP C       | READY | OK  | READY | OK  | READY |
| MDT INF        | READY | OK  | READY | OK  | READY |
| RPC SIDE A     | READY | OK  | READY | OK  | READY |
| RPC SIDE C     | READY | OK  | READY | OK  | READY |
| RPC INF        | READY | OK  | READY | OK  | READY |
| TGC SIDE A     | READY | OK  | READY | OK  | READY |
| TGC SIDE C     | READY | OK  | READY | OK  | READY |
| TGC INF        | READY | OK  | READY | OK  | READY |
| CSC SIDE A     | READY | OK  | READY | OK  | READY |
| CSC SIDE C     | READY | OK  | READY | OK  | READY |
| CSC INF        | READY | OK  | READY | OK  | READY |
- Physics Data Displays:** Several plots showing detector performance metrics like 'Stability', 'Type', 'Rate', and 'DAQ' over time.



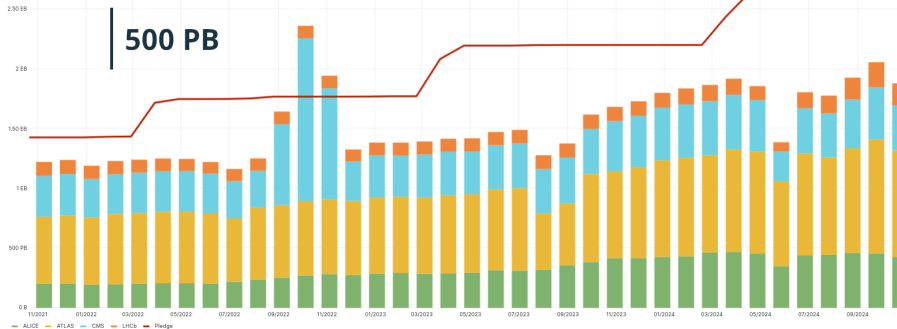
# Triggers





# Physics Results

# Storage



<https://monit-grafana-open.cern.ch/d/mHqFLAbik/wlcc-storage-space-accounting>



# The Grid



DBOD

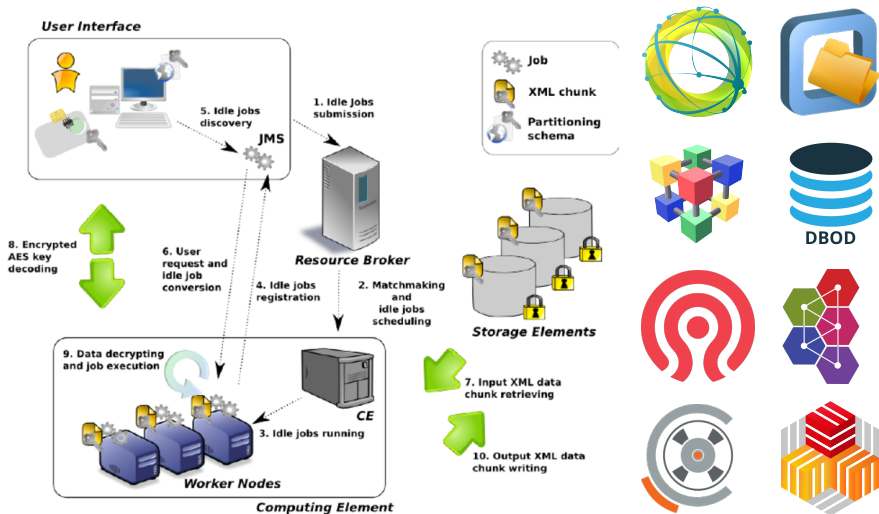
# Catalogs, LFNs, replicas, ...

## From DIRAC's documentation - concepts

- **Logical File Name** : identifies a File  
A file can have several Replica
- **Replica** : a physical copy of an LFN stored at a StorageElement
- **StorageElement** : a physical storage endpoint
- **Catalog** : namespace of the DataManagement  
Files and their metadata are listed there

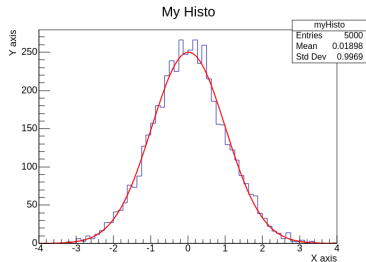


# Scheduling physics jobs



# The physics code - ROOT and python

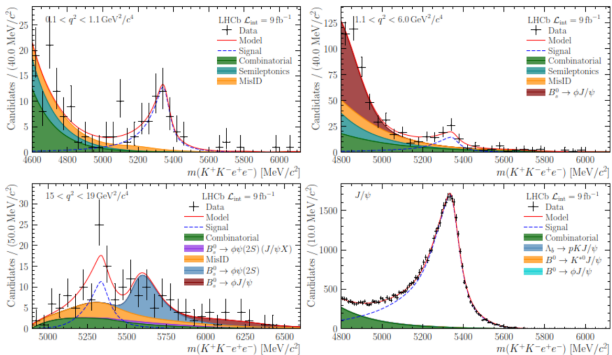
```
In [7]: import ROOT
In [8]: %jsroot on
In [9]: h = ROOT.TH1F("myHisto","My Histo:X axis;Y axis",64, -4, 4)
h.FillRandom("gaus")
Warning in <TROOT::Append>: Replacing existing TH1: myHisto (Potential memory leak).
In [10]: fitResultPtr = h.Fit("gaus","S")
*****
Minimizer is Minuit2 / Migrad
Chi2      = 43.9136
NDF       = 51
Edm       = 2.99816e-07
Ncalls    = 53
Constant  = 249.985 +/- 4.42695
Mean      = 0.0155223 +/- 0.0141501
Sigma     = 0.989831 +/- 0.0105598 (limited)
In [11]: c1 = ROOT.gROOT.GetListOfCanvases().FindObject("c1")
c1.Draw()
```



# Publication

## Test of lepton flavour universality with $B_s^0 \rightarrow \phi \ell^+ \ell^-$ decays

Lepton flavour universality is tested here for the first time using  $B_s^0$  decays. The  $B_s^0 \rightarrow \phi e^+ e^-$  decay, in particular, was never observed before. Branching fraction ratios between the  $B_s^0 \rightarrow \phi e^+ e^-$  and  $B_s^0 \rightarrow \phi \mu^+ \mu^-$  decays are measured in three regions of dilepton mass squared,  $q^2$ , with  $0.1 < q^2 < 1.1$ ,  $1.1 < q^2 < 6.0$ , and  $15 < q^2 < 19$   $\text{GeV}^2/c^4$  as shown in the image on the left. This is the first dedicated lepton universality test in the high  $q^2$  region. The results agree with the SM expectation.



# Conclusion



# Conclusion

**Physics is essentially computing !  
 And IT services are essential**



# Sources



[Taking a closer look at lhc.](#)

<https://www.lhc-closer.es/>.



[Fabiana Lauro.](#)

General purpose tools for longitudinal beam dynamics studies, 2023.

[Presented 2023.](#)



[Heather Gray.](#)

Tasi 2022 lectures on lhc experiments, 07 2023.



[Stefano Redaelli, Ilya Agapov, R Calaga, Bernd Dehning, M. Giovannozzi, Federico Roncarolo, and Rogelio Tomas.](#)

First beam based aperture measurements in the arcs of the cern large hadron collider.

[05 2009.](#)



[B. Frammery.](#)

The lhc control system.

[2005.](#)



[Czeslaw Fluder, V. Lefebvre, Marco Pezzetti, A. Gonzalez, P. Plutecki, and Tomasz Wolak.](#)

Automation of the software production process for multiple cryogenic control applications.

[10 2017.](#)



[Atlas control main page.](#)

<https://atlas.cern/updates/news/coordination-collisions>.



[Lhcb event display.](#)

<https://lhcb-eventdisplay.web.cern.ch/>.



[Denis Derkach, Mykola Hushchyn, and Nikita Kazeev.](#)

Machine learning based global particle identification algorithms at the lhcb experiment.

[EPJ Web of Conferences, 214:06011, 01 2019.](#)

# Sources



[Lhcb trigger data flow.](#)

<https://lhcb.github.io/starterkit-lessons/first-analysis-steps/dataflow-run3.html>.



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