Computing challenges in particle physics

Overview of the dual challenges faced in particle physics - balancing the demands of data analysis and computing resources.

The Erasmus Summer School in Physics (E3F)

Unveiling the secrets of matter and light

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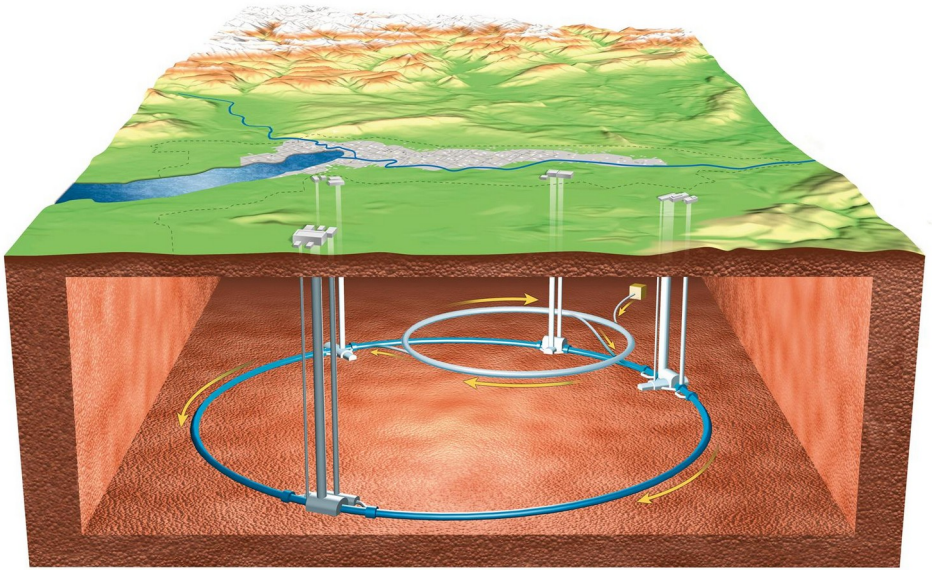
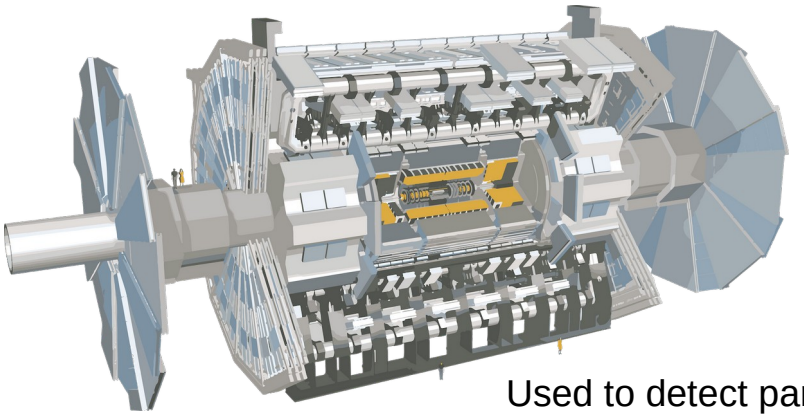
The ATLAS Experiment





Used to detect particle collisions

99% of data is not stored

ATLAS records over 10 PB of data per year

ATLAS processes 25 PB of data every week

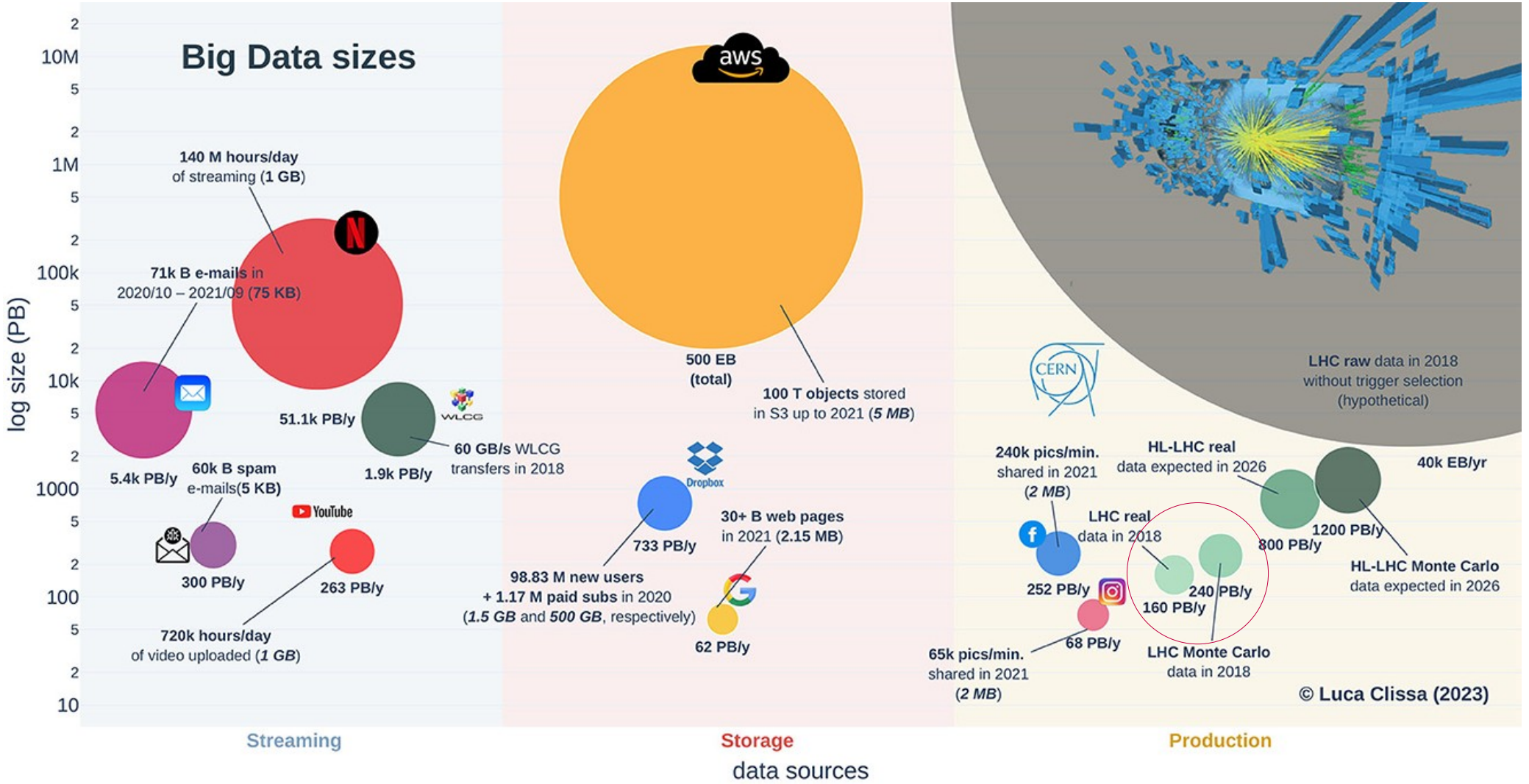
46
meters long & 25m of diameter

100
meters below ground

7000
tonnes

1000000000
collisions / second

Data size comparison (CERN LHC vs others)



Worldwide LHC Computing Grid (WLCG)

To manage all this data, the WLCG was created

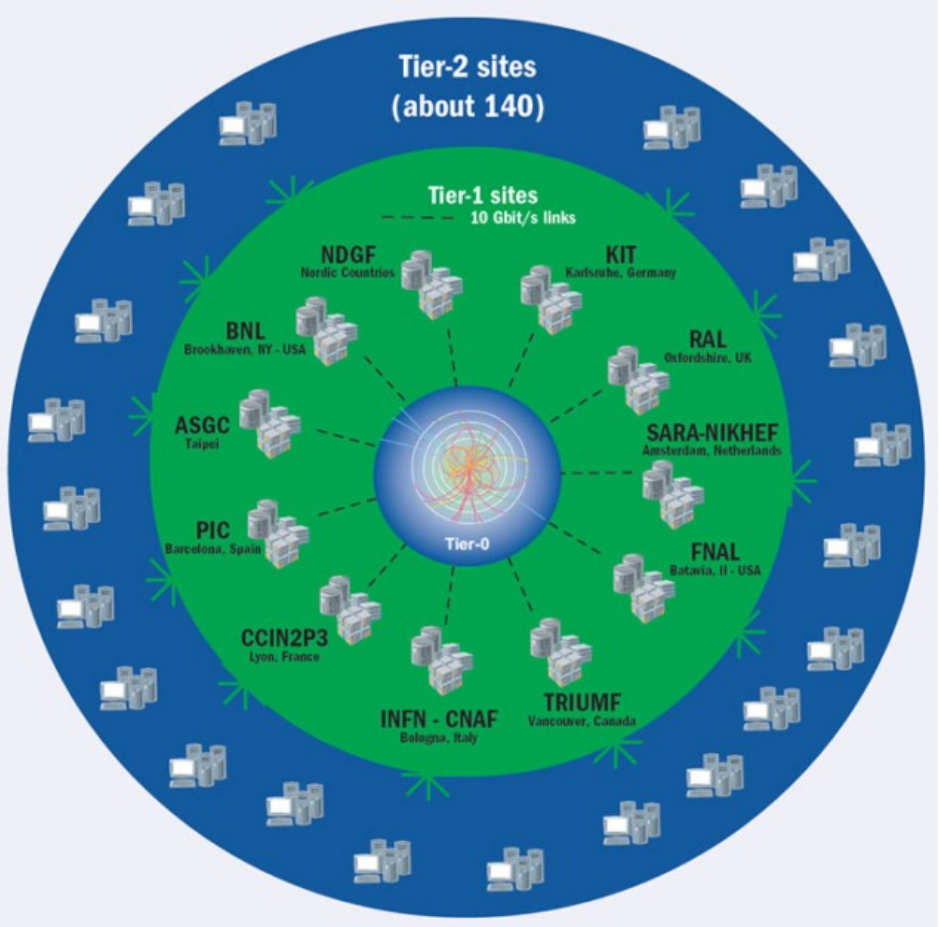
ATLAS Experiment provides the scientific community with datasets and tools for analysis

around 170 centers in 42 countries

1 EXABYTE of storage in total

Tiered structure:

- Tier 0 at CERN: raw data
- Tier 1: ~10 sites with data & calibration information
- Tier 2: ~140 sites with distributed data for scientific analysis



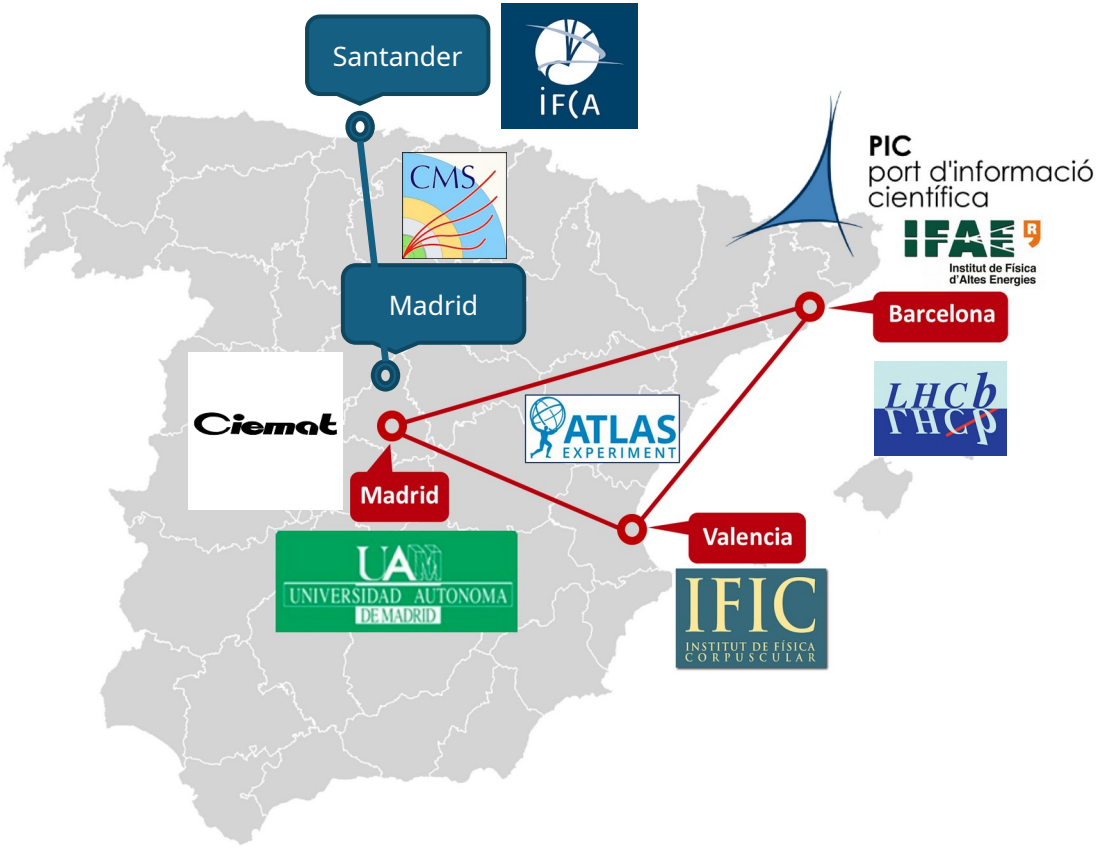
Spain is one of the 10 Tier 1 sites: Barcelona PIC

Spanish computing sites for the LHC (WLCG-ES sites)

Map of the Spanish contribution to ATLAS and other CERN experiments

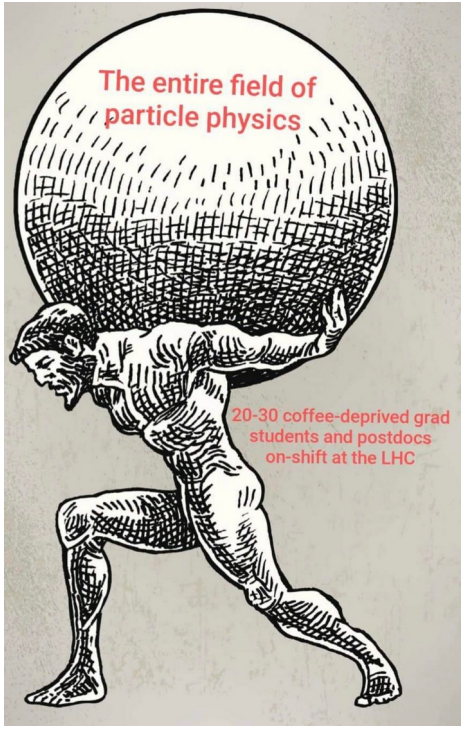
Composed by Tier 1 and Tier 2 centers

- Tier 1 (ATLAS, CMS, LHCb):
  - PIC-Barcelona
- Federated Tier 2s
  - 60% IFIC-Valencia
  - 25% IFAE-Barcelona
  - 15% UAM-Madrid
  - 75% Ciemat-Madrid
  - 25% IFCA-Santander



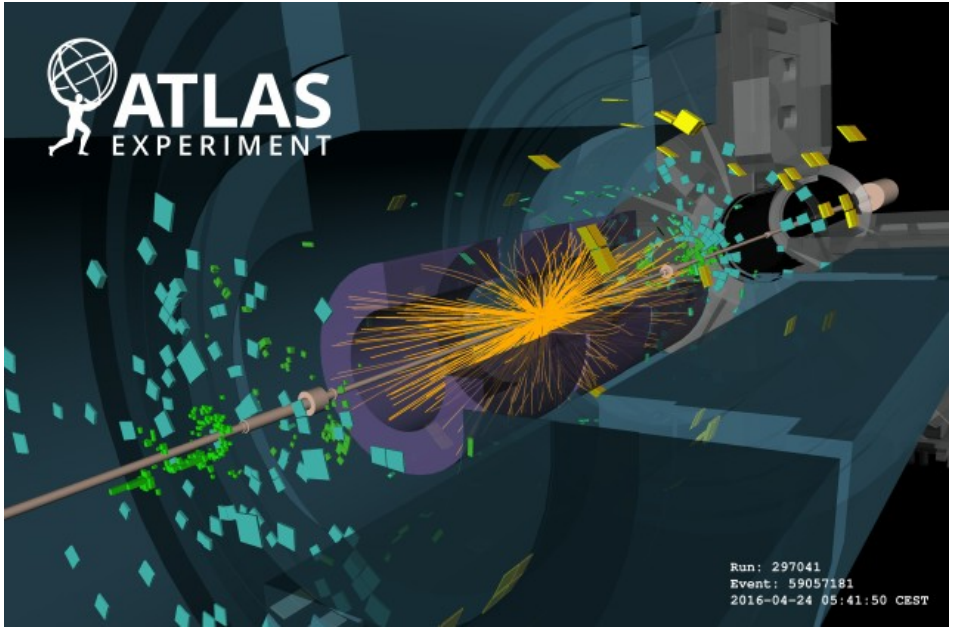
The Spanish ATLAS Tier 2 offers 3% of the ATLAS Tier 2 resources, will increase up to 5%

The two type of people in particle physics computing



Physicists: Scientific Analysis

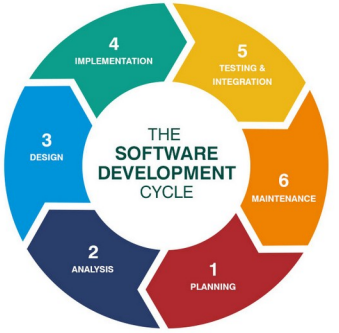
- Data Filtering and Trigger Systems: Essential for reducing the enormous collision data rates (1 GHz) to manageable levels (around 1-2 kHz), and preserve the most relevant events.
- Analysis Methods: Developing more efficient analysis facilities, including real-time analysis systems and machine learning techniques This is very important for speeding up the analysis process.
- Machine Learning Integration: Integrating ML into the workflow presents its own challenges, particularly in ensuring that the algorithms remain transparent and interpretable to physicists.
- Code Optimization and Efficiency: This reduces processing times and increases resources use efficiency. Code optimization for data analysis, simulation, and event reconstruction, but with ever-increasing data sizes is still a challenge.

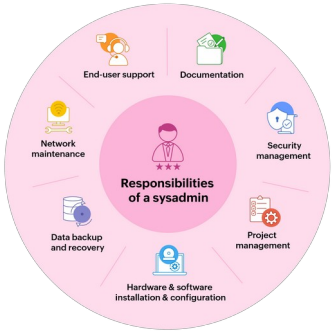


The ROOT software is used to perform data analysis. This software has been developed by physicists and computer scientists

https://root.cern/about/

IT, Computing & Sysadmin





Our tasks consist on developing software, maintaining and monitoring hardware and batch jobs performance. Our challenges are:

- Data Volume Access: Fast access to large data volumes is necessary to allow researchers analysis.
- Distributed Computing Resources: Managing and monitoring a distributed infrastructure efficiently is a challenge, particularly when it comes to data distribution, synchronization, security and effective use of computational resources.
- Framework for Analysis: Providing tools to perform analysis, such as libraries, programs, toolboxes, to optimize use of resources. The goal is that researchers have access to everything easily.

GRID computing and ATLAS analysis approaches

Grid Computing

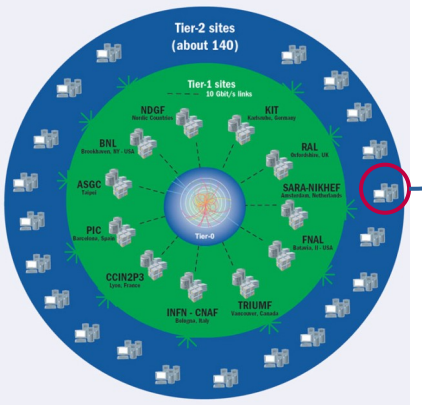
What is GRID Computing?

- Distributed computing over multiple Tier 2 nodes across the globe.
- Provides a shared pool of resources (CPU, storage, etc.) for high-demand tasks (derivation, analysis, simulation)

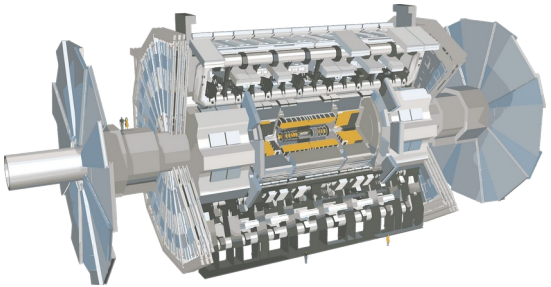
Computing resources are available 100% of the time

Each site has data and processing resources close to each other (storage servers + computing servers)

Submitting jobs to the GRID typically process them where the requested data is stored to avoid data transfers



ATLAS data life cycle to analysis



LHC DATA

trigger

reconstruction

derivation

MONTE CARLO DATA

simulation

generation

digitization

reconstruction

derivation

ANALYSIS

Personal computer (sample data)

GRID computing (whole datasets)

Complexity of Physics Events:

ATLAS is designed to observe rare phenomena, such as the Higgs boson or potential new particles.

The complexity of these events makes their analysis particularly challenging.

Researchers must develop detailed models and simulations (like Monte Carlo simulations) to compare with the experimental data, requiring a balance between accuracy and computational feasibility.

Analysis: connecting to Grid resources to compute

ssh me@grid-cern-false

Analysis software:
- Athena
- ROOT

The physcicist connects to the user interfaces for inline processing, then they submit the jobs with the selected dataset to the batch processing system of the GRID.

The GRID has the required libraries and analysis software available for running the jobs.

The physicists don't need to install or have complex frameworks in their computer.

Analysis: using your computer for testing, then the Grid for batch processing

Local analysis software
ssh me@grid-cern-false
for batch computing

Analysis software:
- Athena
- ROOT

The physicist has a small subset of data locally, then sends jobs with all data to the batch processing in the GRID.

The physicicist needs to have installed locally the required analysis software available for the jobs requiring it, and also access the GRID to submit jobs.

Physicists don't need to be connected to internet permanently, when they have the code ready, they submit it.

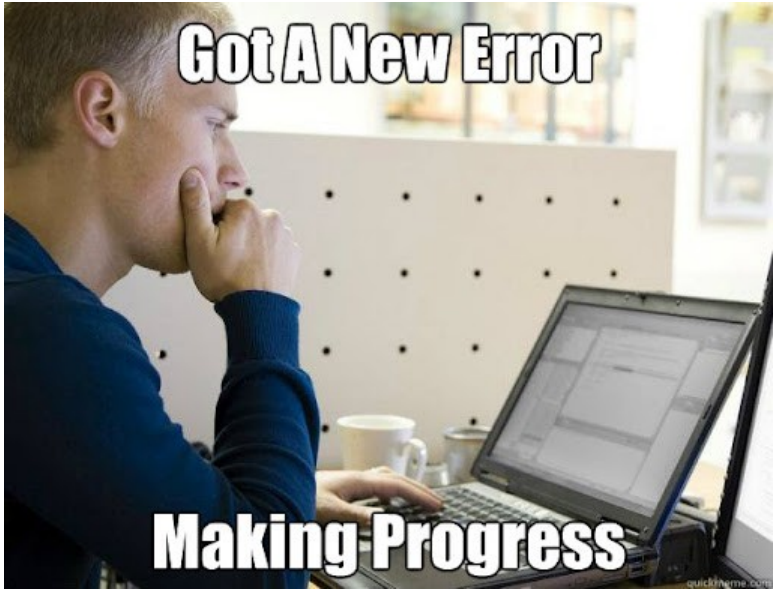
For the intrepid students

Want to try some fancy analysis? Here you can find the framework for it:

https://root.cern/about/

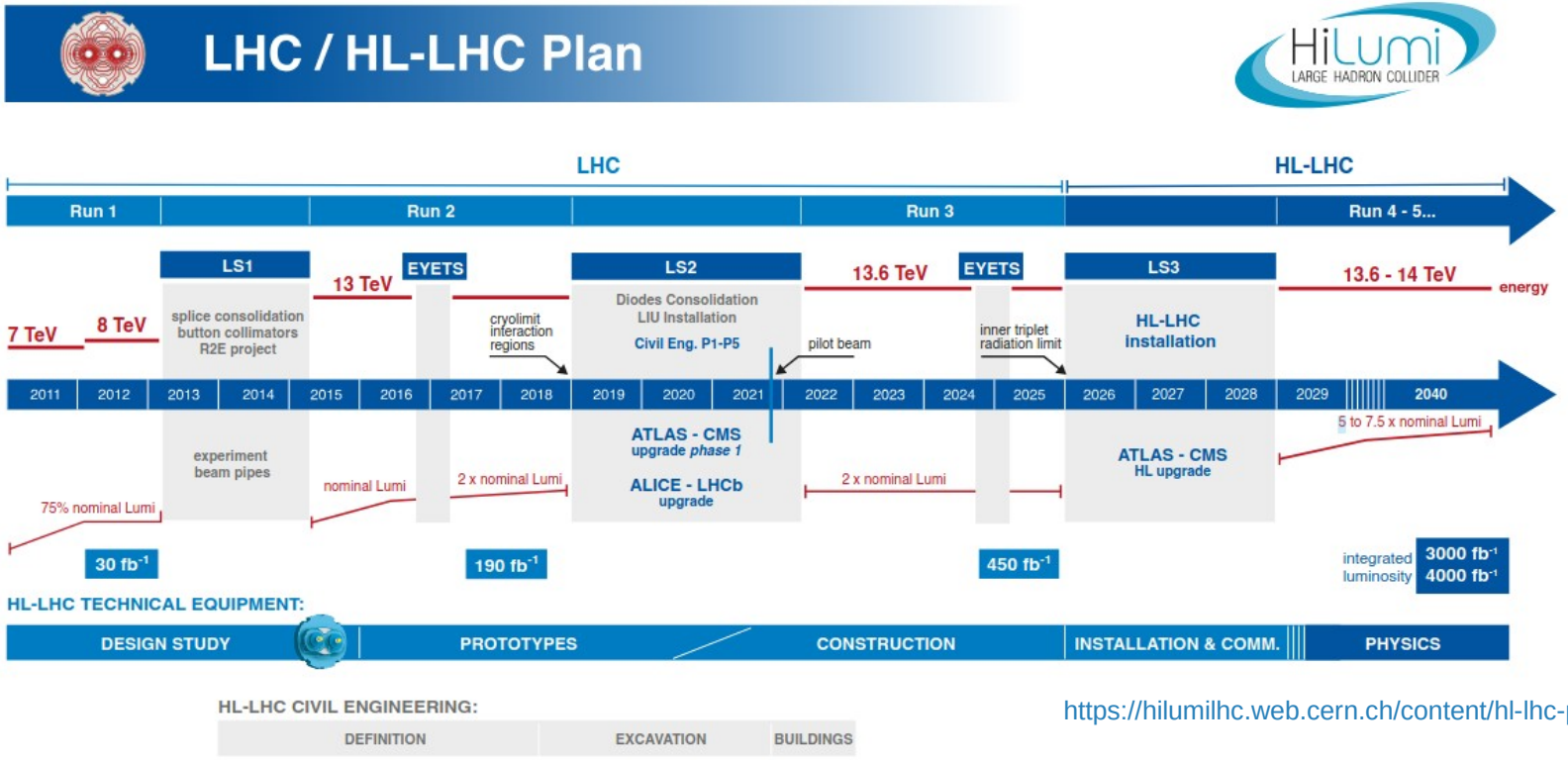
And here is some ATLAS data you can check:

https://atlas.cern/Resources/Opendata



High Luminosity: new challenges for analysis and computing resources

High Luminosity challenges in the near future

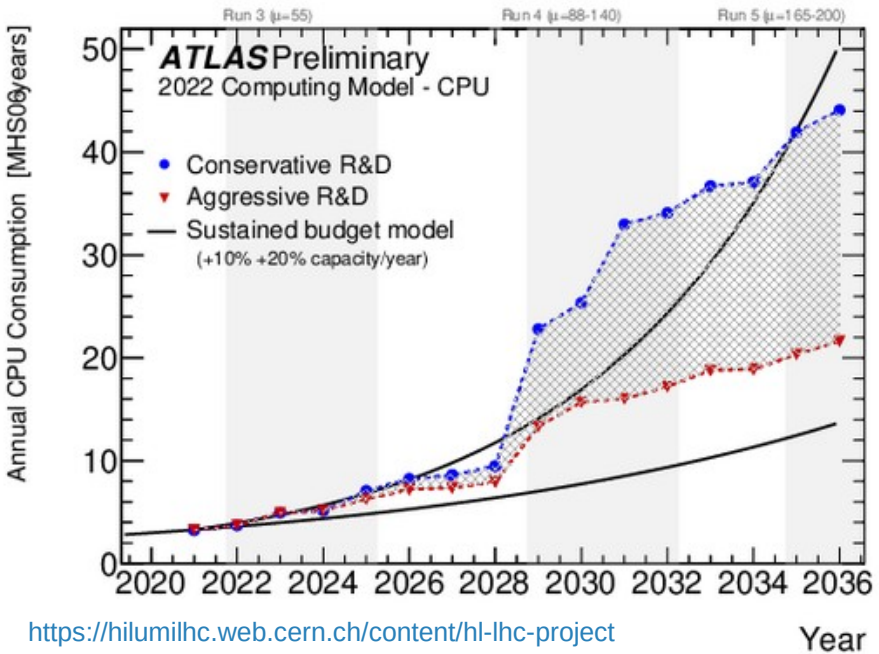


https://hilumilhc.web.cern.ch/content/hl-lhc-project

The upcoming HL-LHC will increase the collision rate by **a factor of 10**, leading to a proportional increase in the amount of data generated.

Current analysis approaches and computing resources will be insufficient to handle this additional load. Researchers will need to develop new methods, such as data reduction, code optimization, and the use of machine learning to process this data more efficiently.

High Luminosity challenges in the near future



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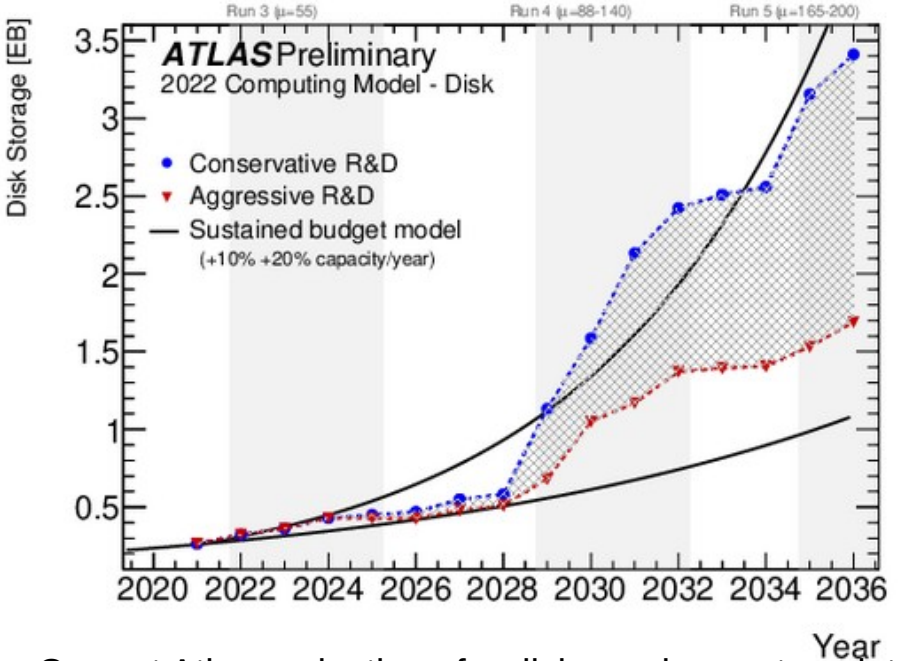
Current Atlas projections for CPU requirement evolution through the first two data taking runs of HL-LHC.



Current Atlas projections for disk requirement evolution through the first two data taking runs of HL-LHC.

Blue lines are the prediction of requirement increase once HL-LHC starts doing nothing.

Red lines are the prediction of requirements increase if we perform multiple changes to optimize storage, algorithms, datasets, etc.

Source: arXiv:2302.01317v1 [hep-ex] 2 Feb 2023

High Luminosity challenges in the near future

With an increase of **x10** data generation, the computing challenges are:

- Storage increase
- Computational increase
- Indexing & accessing data

For the analysis, a **x10** increase in data means:

- x10 data to analyze
- x10 more people working on analysis (?)
- x10 more workload
- x10 results (?)

Increase in budget is complex at a global scale:

- Public funding
- More projects
- Global economy affects allocation of resources

Optimal use of the actual and future computational and software resources is essential

- Reduce stored data (PHYSLITE)
- Better frameworks for analysis (analysis facility)
- Precise accounting of the resources and activity:
  - Efficiency: amount of computational resources used
  - Availability: % of time that the site is available
  - Reliability: % of time that the site is available without considering scheduled downtime
- Optimization of the analysis code

Analysis Facility: a new approach

What is the Analysis Facility?

- A new initiative designed to centralize high-performance computing resources for data analysis.
- It is aimed at speeding up the analysis process and provide powerful computational resources at Tier 2 sites.
- Researchers can run intensive analyses in near real-time, boosting productivity.

How It Works:

- Provides a scalable, on-demand infrastructure using modern cloud computing techniques.
- Direct integration with GRID resources for seamless data access.

However, it comes with a lot of invisible work for the computing infrastructure people, a budget increase to allocate more powerful resources for interactive use, increase in monitoring, maintaining, updating, preventing security risks, etc.

Analysis Facility

www.grid-cern-false-url.myhub

Analysis software:
- Athena
- ROOT

Additional:
- web server

The physicist logs in a website hosted in a remote machine, then it sends the jobs to the batch processing to the GRID.

The physicist only needs an internet connection and a web browser. High performance computing resources will be available for the user's interactive session.

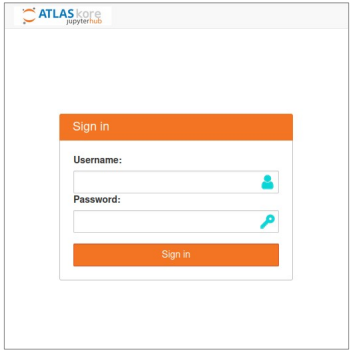
This approach requires that the site provides them with a complex infrastructure of hosting, authentication, available software, batch processing automated submit, etc.

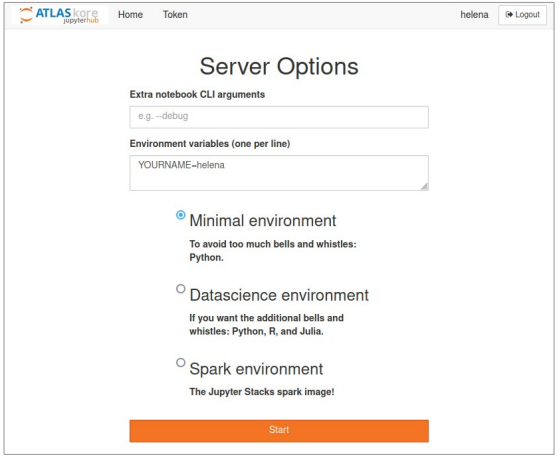
Analysis Facility @ IFIC, first steps

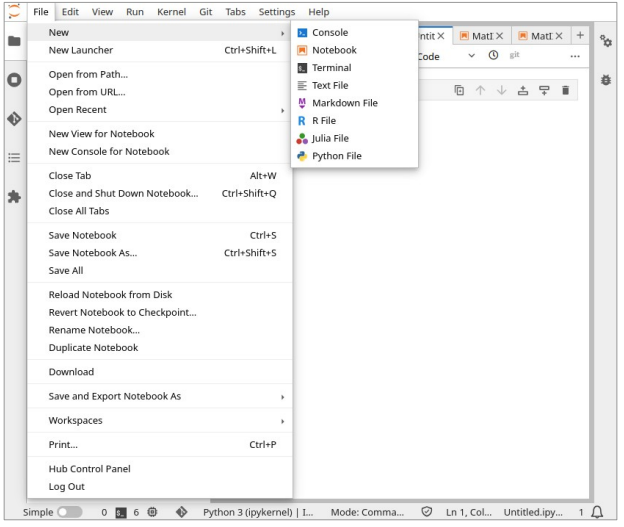
At IFIC we are starting with new Analysis Facility solutions for IFIC ATLAS researchers.

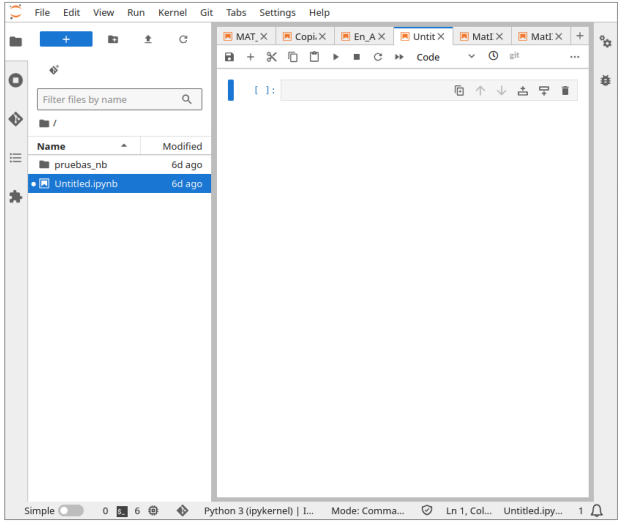
This solution is custom-made by us.

This is how it looks: a website where the researcher logs in and has access to all their data and programs to perform their analysis in powerful remote machines that provide all the framework needed.









More to come...

Take-home ideas

Take-home ideas

There are two points of view for the computing challenges in particle physics: analysis and computing resources

For analysis, there are different approaches, each of them requiring different computing resources

The current approaches allow scientific community to perform analysis using powerful computing resources, the GRID

However, when High Luminosity arrives, the current approaches are inefficient to absorb a x10 times increase in data production

In computing resources, performance assessing is key to plan future infrastructure needs

For analysis, new tools will need to be available, such as reducing data sizes, code optimization, analysis facility, machine learning, etc.

Students: If you plan to work in ATLAS, you should learn how to code efficiently !!

References

Introduction to ATLAS data preparation and analysis

https://root.cern/about/

https://atlas.cern/Resources/Opendata

arXiv:2302.01317v1 [hep-ex] 2 Feb 2023

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