Computing at CERN

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International High School Teacher Programme – 2024/07/10

OED | Oxford English Dictionary
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computing, *n.*

Pronunciation:

Brit. /kəmˈpjuːtɪŋ/ , U.S. /kəmˈpjudɪŋ/

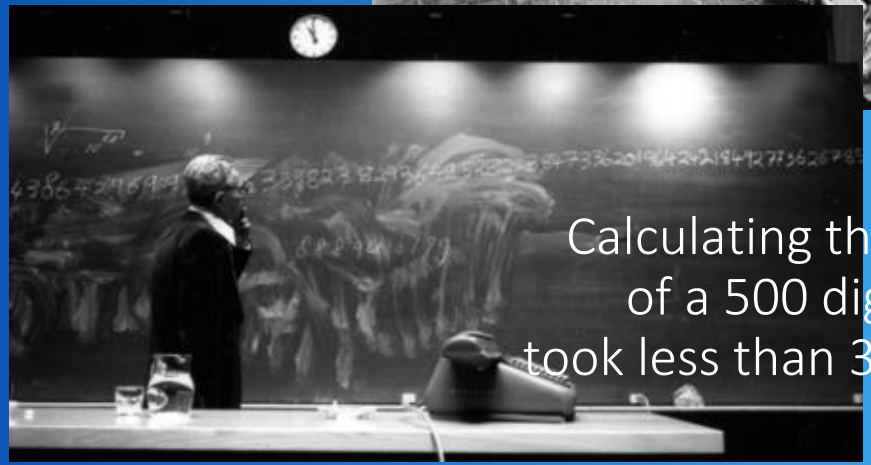
1. The action or an instance of calculating or counting; = computation *n.* 1a.

2. The action or practice of using computers, esp. as a professional or expert; the activity or operation of an electronic computer; (also) = computer science *n.*

Early “Computers”

Katherine Johnson NASA Hidden Figures!

CERN had 2 British Ladies from National Physical Lab Teddington (London)



Wim Klein

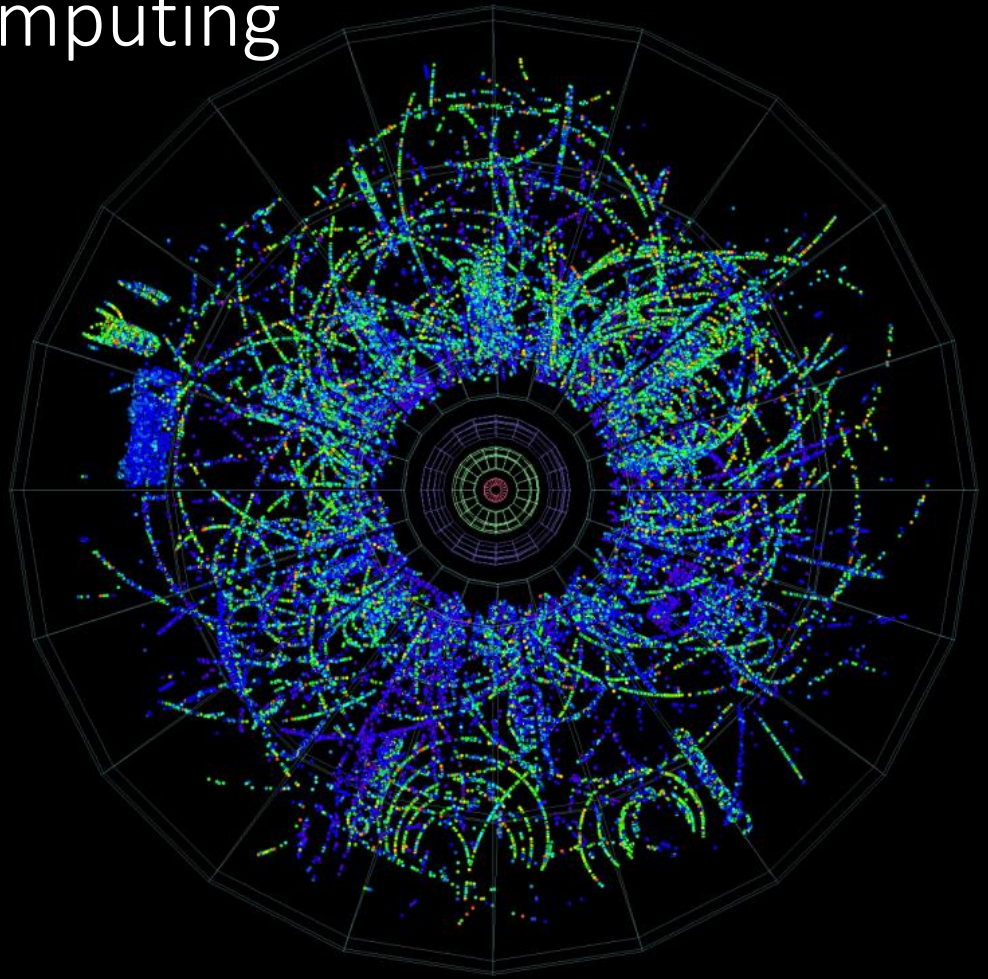
Calculating the 73rd root of a 500 digit number took less than 3 minutes…

1958: The Ferranti-Mercury arrived!

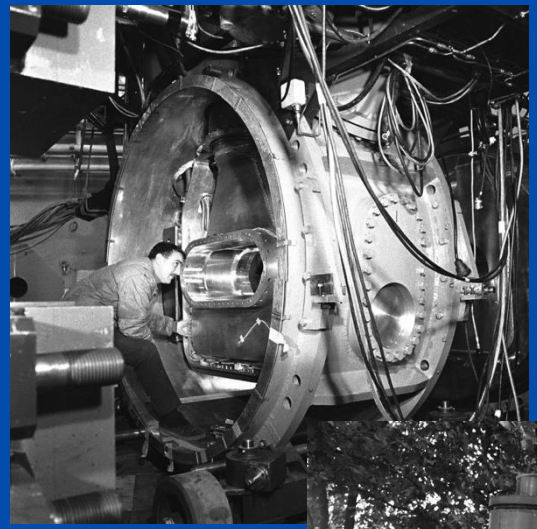
"..courage to go ahead and solve problems that seemed to difficult to do otherwise.."

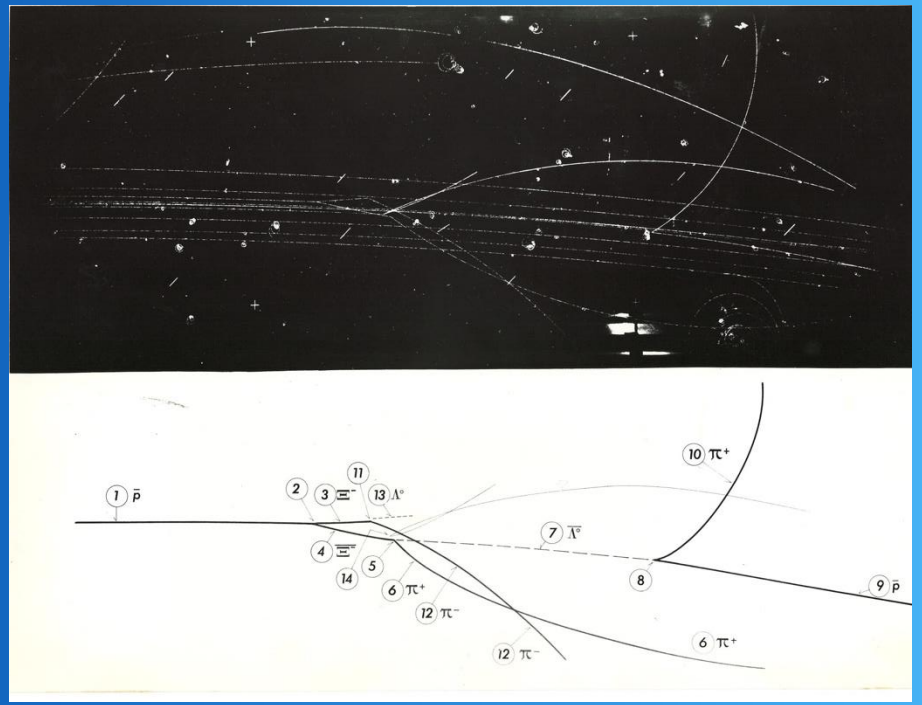
Computing

- Scientific
  - Compute, Storage, Network
- Technical
  - Design, Operation
- Administrative
  - HR, Finance, Projects
- Desktop
- Collaborative



Bubble Chamber





Bubble Chamber

Madeline Znoy

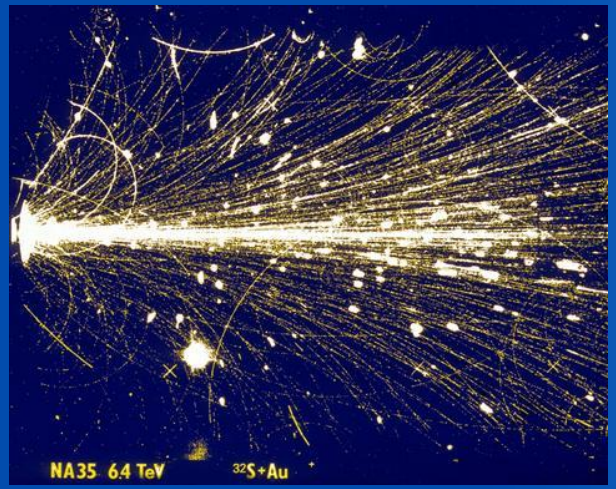
750 photos in a day!

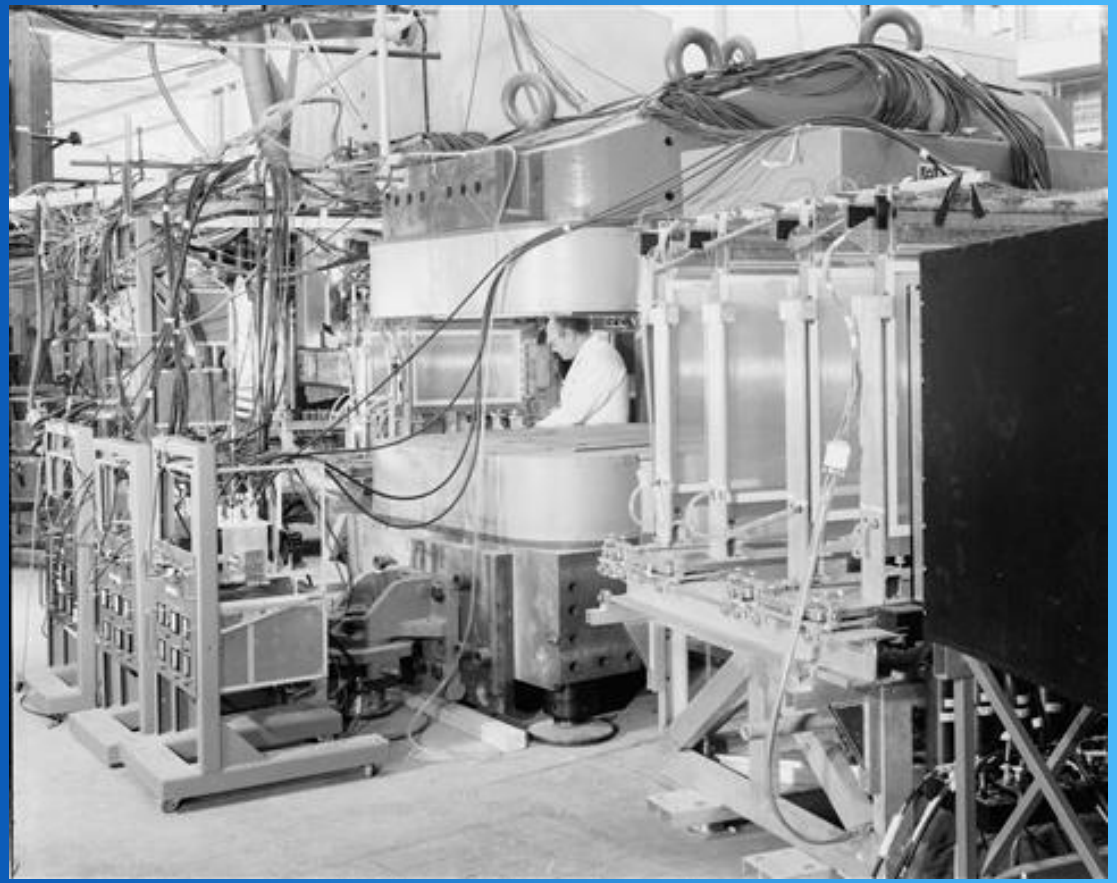
BEBC 1973-1984

6.3 million photos

3000 km of film

Spark Chambers





- 1965

Magnetostrictive readout

Momentous Events

1960: IBM 709 Vacuum tubes

1965: CDC 6600: #3

1972: New Computer Centre for a New Computer!

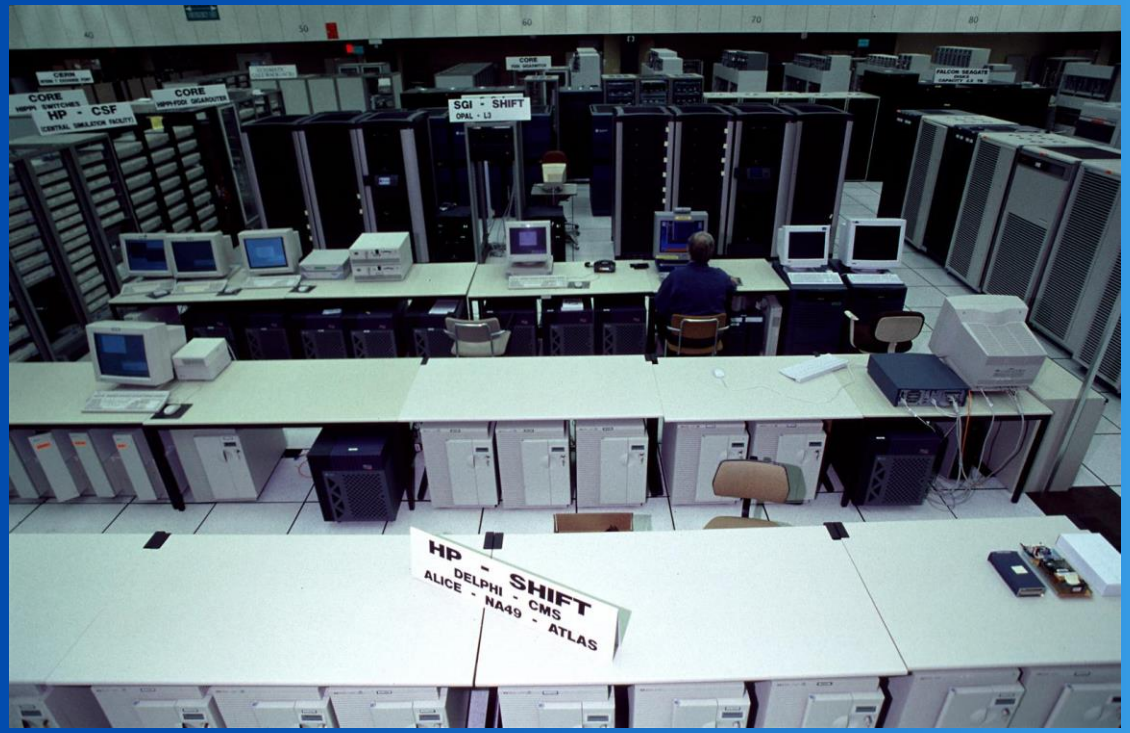
Mainframe Era

1983: 2 CDCs and an IBM 3081

Super Computers

1988: Cray XMP

RISC Workstations

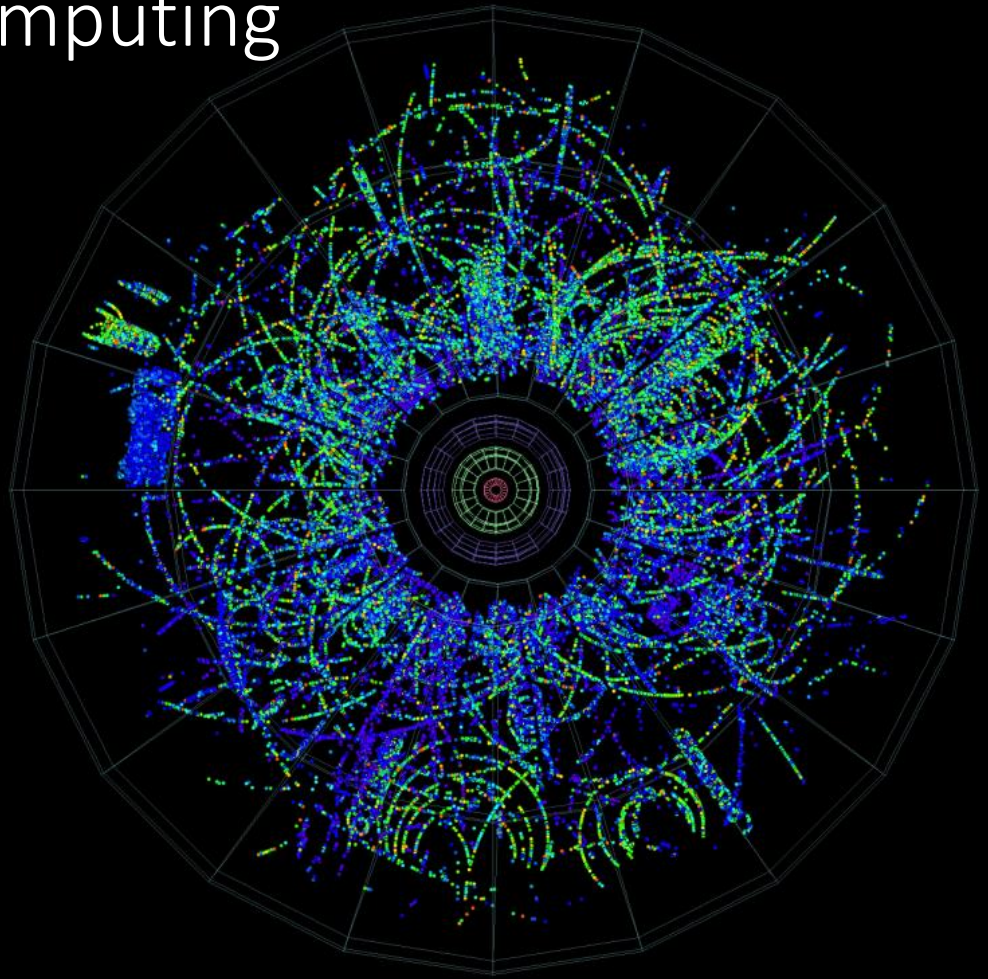


Comodity Computing

Farming in a Data Centre

Computing

- Networking



Networking

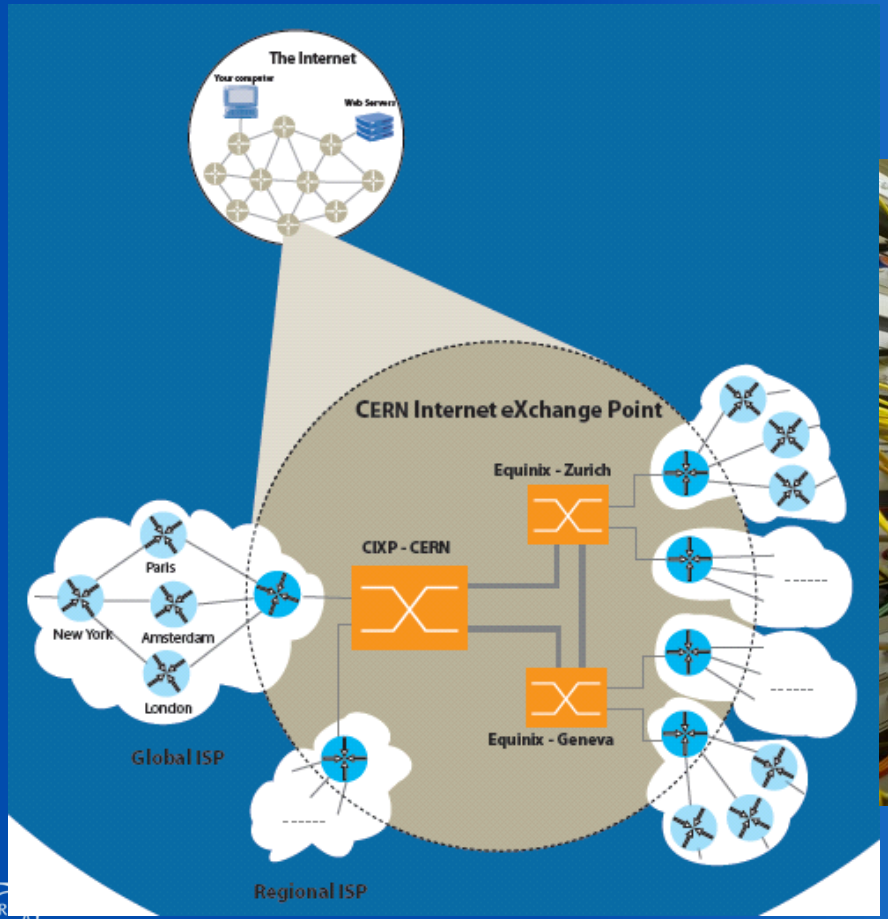
- Packet-switched network
- 1969 ARPANET
  - US DoD sponsored research at US Universities
  - Aim: communications network to survive a nuclear attack
  - Find next best route if one node obliterated
- 70s and 80s proliferation
  - US: NASA Science Net, CSnet, Energy Sciences Net, NSFnet
  - FR: CYCLADES
  - UK: Mark I, SERCnet
  - Commercial: Tymnet, CompuServ, BITnet, DECnet
  - Protocols: NCP, X.25 (1976), TCP/IP (1982)
  - CERnet

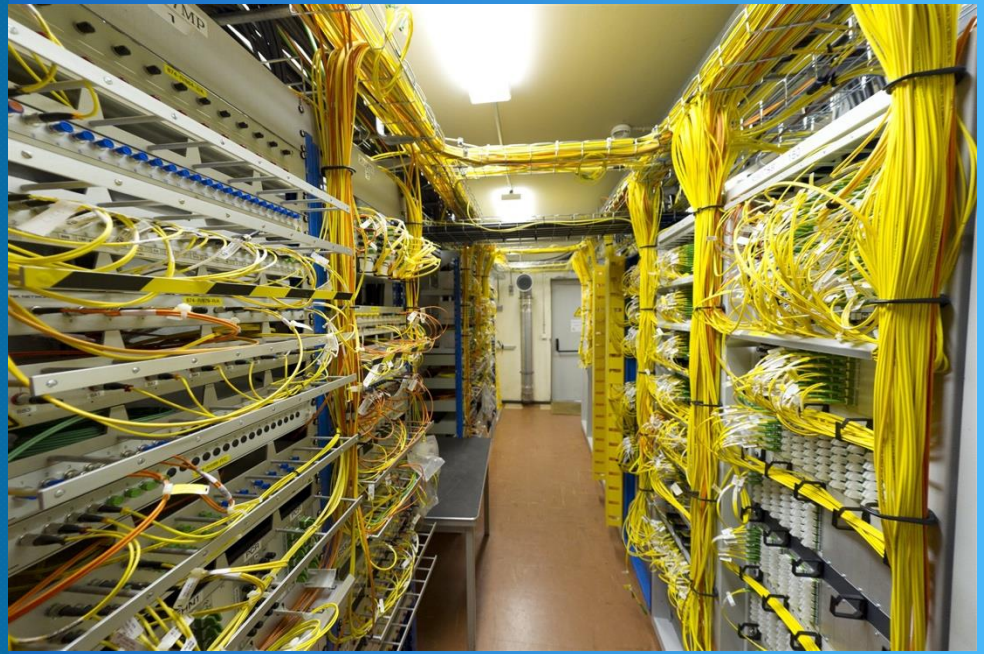
Networking

- Science without borders
  - 1968 Data exchange across the iron curtain – to IHEP in Soviet Union
  - 1988 first data connection between China and scientific world – IHEP to CERN

- Truly international Internet
  - 1989 first external TCP/IP connection
  - 1990 principle link US-EU from CERN
    - (1.5Mb/s)
  - 1991 80% of the internet capacity installed in Europe for international traffic was terminated at CERN

CERN Internet Exchange Point

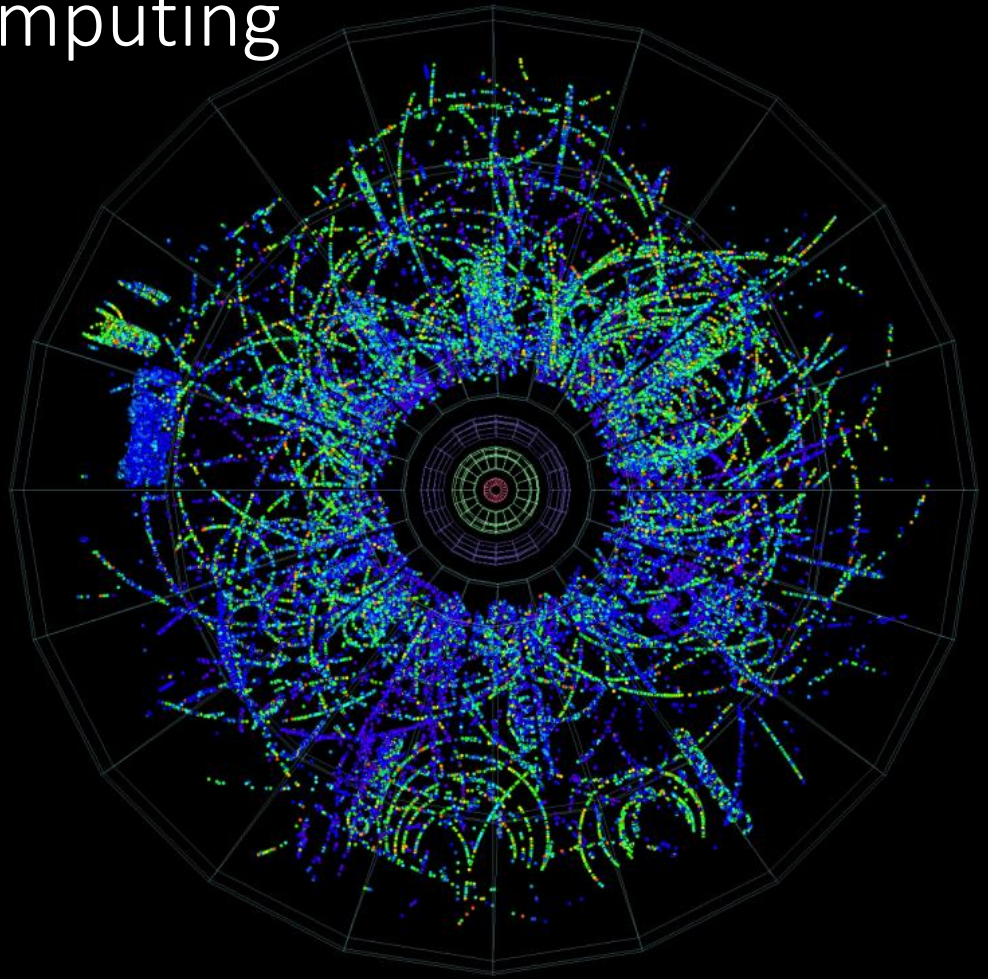




Internet … Web … Who?

Computing

- Information Management

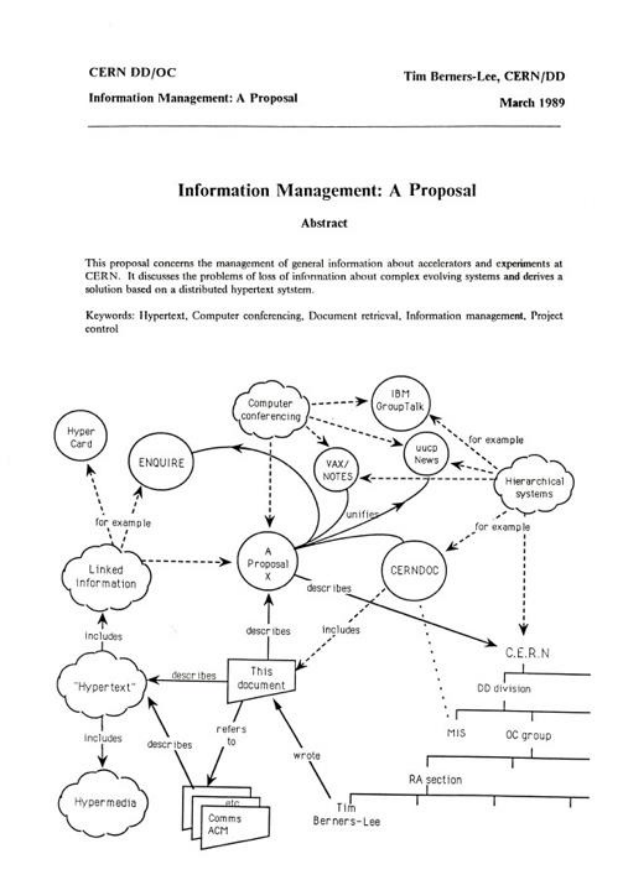


Information Management - *circa 1989*

- Keep track of LHC project and CERN?
  - Researchers turnover ~2 years
- Information about CERN and its experiments
  - Not hierarchical, or centrally controlled
    - A multiply connected web
  - Experts store locally, update independently
  - Community is distributed: remote access
- System to link it all together

- CERN is a model in miniature of the rest of world in a few years time

Distributed, Collaborative



CERN DD/OC

Information Management: A Proposal

Tim Berners-Lee, CERN/DD

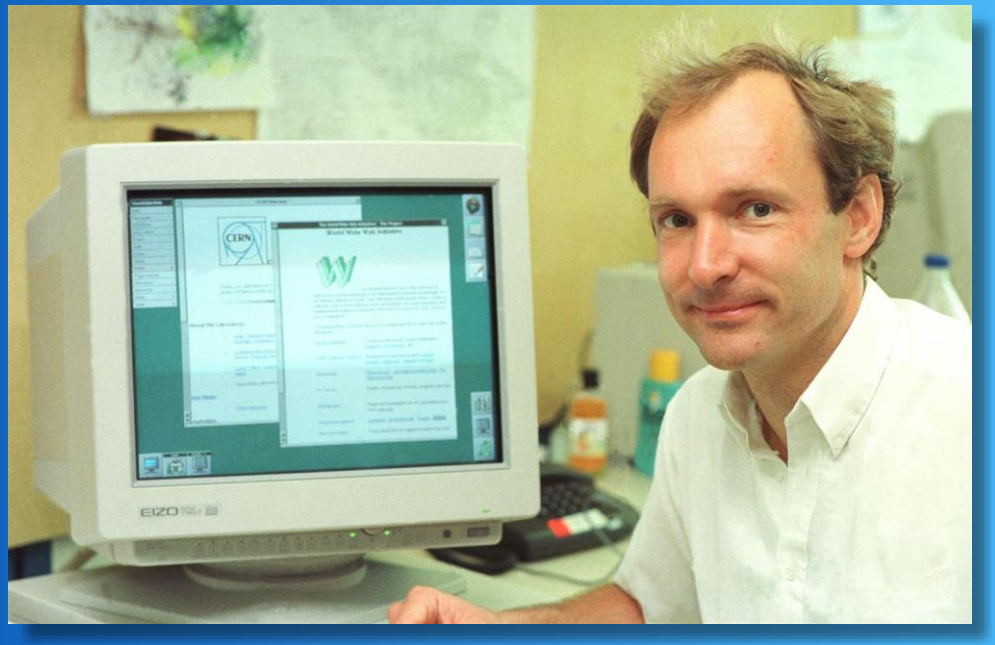
March 1989

Information Management: A Proposal

Abstract

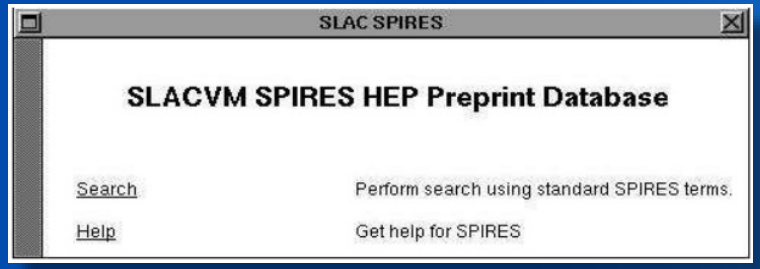
This proposal concerns the management of general information about accelerators and experiments at CERN. It discusses the problems of loss of information about complex evolving systems and derives a solution based on a distributed hypertext sytstem.

Keywords: Hypertext, Computer conferencing, Document retrieval, Information management, Project control



Growth of the Web

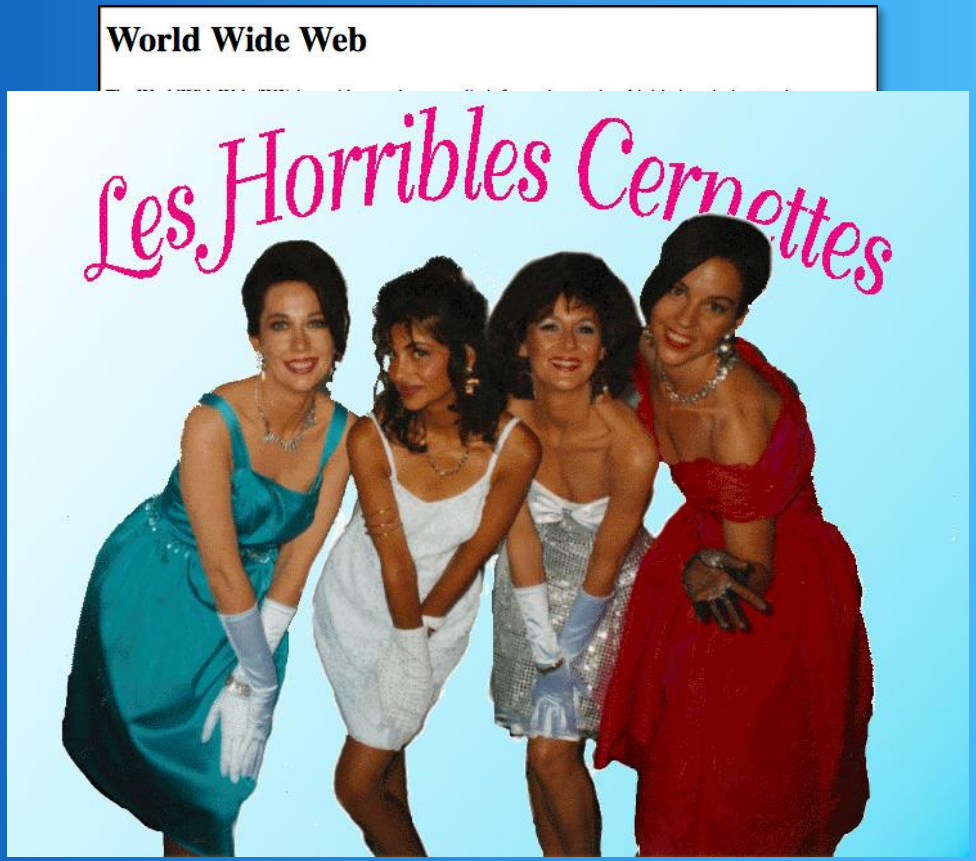
- Aug 1991 went public
  - Tim posted project to alt.hypertext and other internet groups



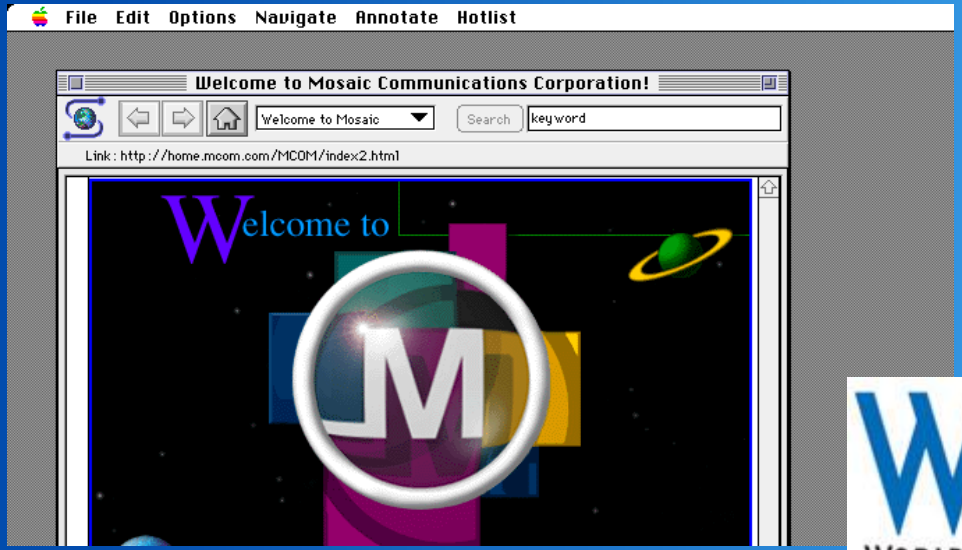
Dec 1991 First web server in US

1992 rapid expansion in HEP

- Universities and research institutes



Growth of the Web



- 1993 rapid expansion across the world
  - National Center for Supercomputing Applications (NCSA) at the University of Illinois released its Mosaic browser

Born in Science

©CERN

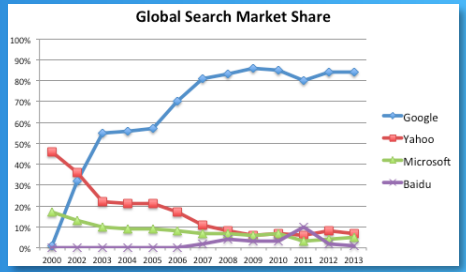
Collaborative development of new tools

Universal access to information:
a human right

Theme of Concern:
monopolies as gatekeepers
steer for profit, not for humanity

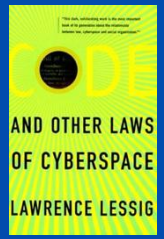
The Concentration of Power

Handful of platforms control which ideas and opinions are seen and shared



Ads

Engagement platforms
Competitive advantage from User giving data



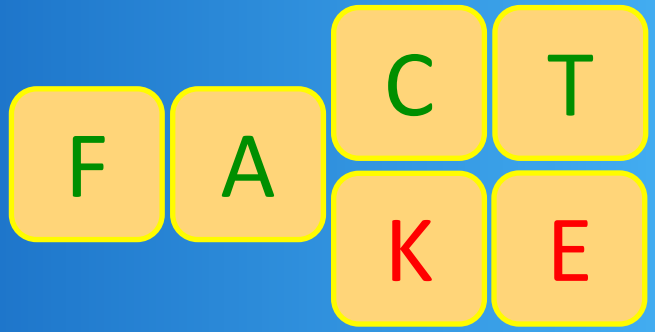
SW creators decide fundamental issues like freedom and privacy
Which content to remove, which users to kick-off
Private Law: EULA

WEAPONIZED AT SCALE

Conspiracy theories trend on social media platforms
Fake Twitter and Facebook accounts stoke social tensions
External actors interfere in elections

The {Mis|Dis}Information Age

- Word-of-the-Year 2018: Misinformation
  - Election tampering
  - Weaponization of falsity
  - Surveillance capitalism
  - Fake news
- Word-of-the-Year 2020: Pandemic
  - Vaccine distrust
  - Climate Change denial
  - Alternative facts



- Public mistrust
- Skepticism amoung government leaders

Evidence Chains

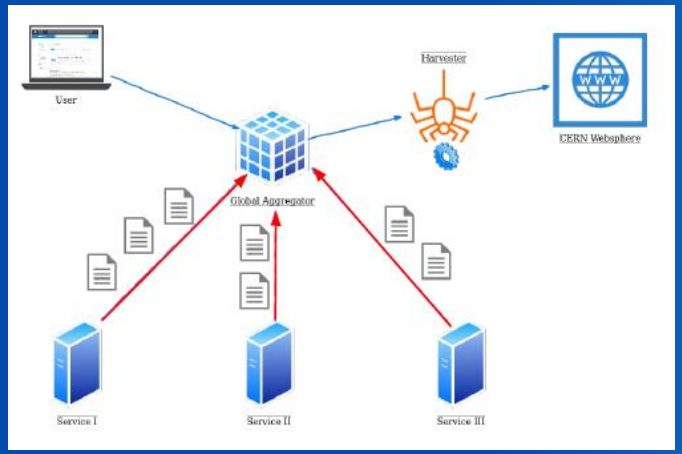
The research behind this announcement…

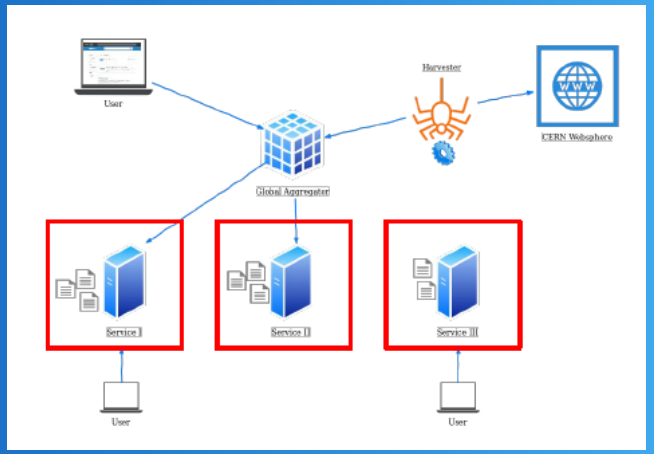
The data this research was based on…

The dominant theory in academia
The alternatives being discussed

Search @ CERN

Moving from a centralized commercial Enterprise Search solution …

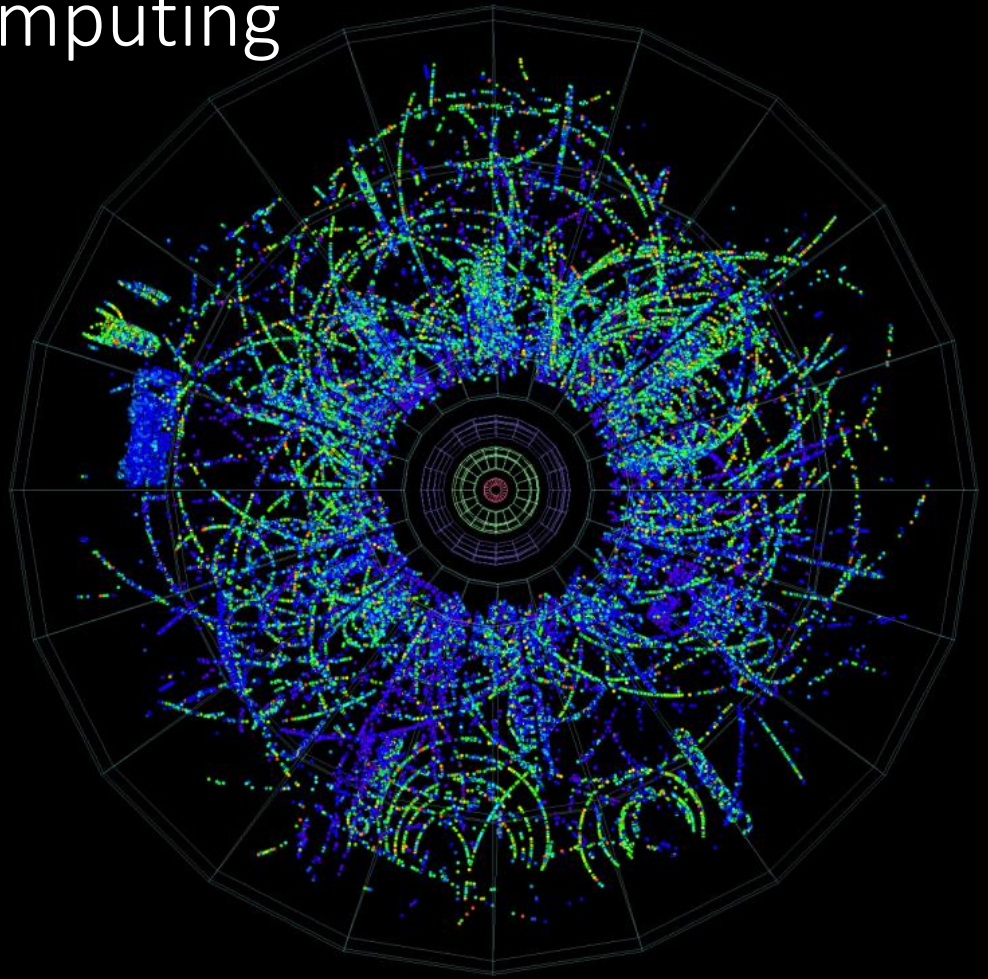




... to a distributed Open Source Enterprise Search solution

Computing

- The LHC Era

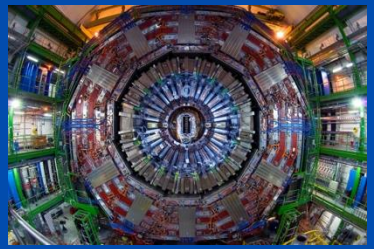


The LHC Data Challenge

Big Data

And bigger
on the way!

Big Data !



150 million sensors

Generating data 40 million times per second

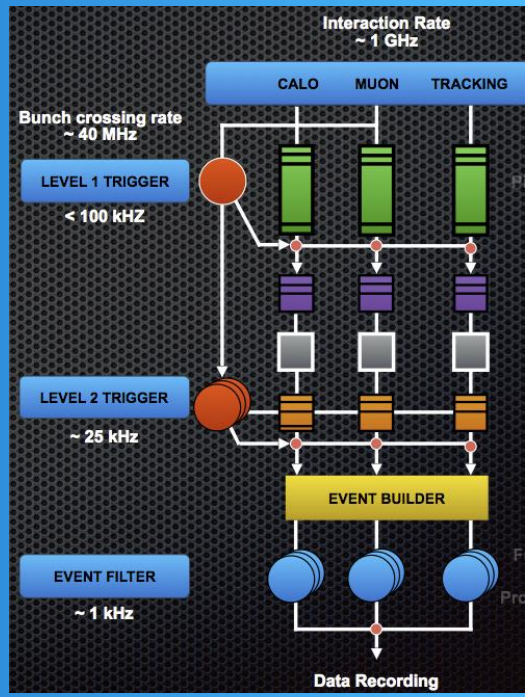
Hardware trigger in a few microseconds

eta Bytes / sec !

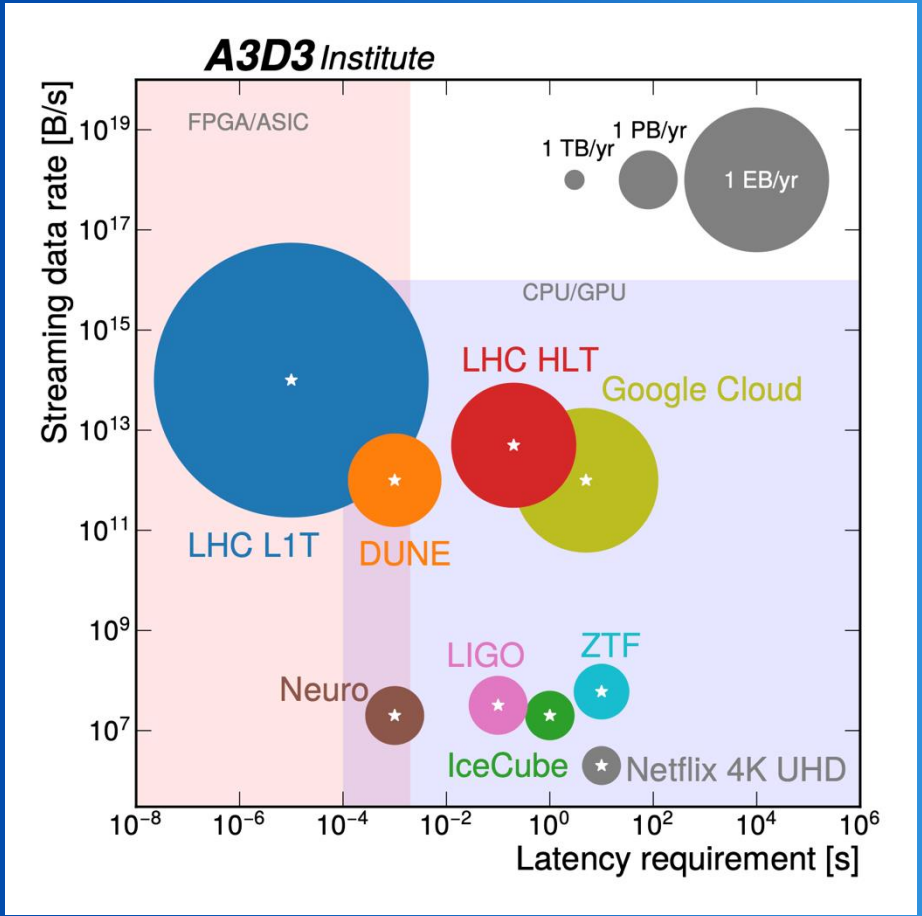
a Bytes / sec !

Select 100 per second

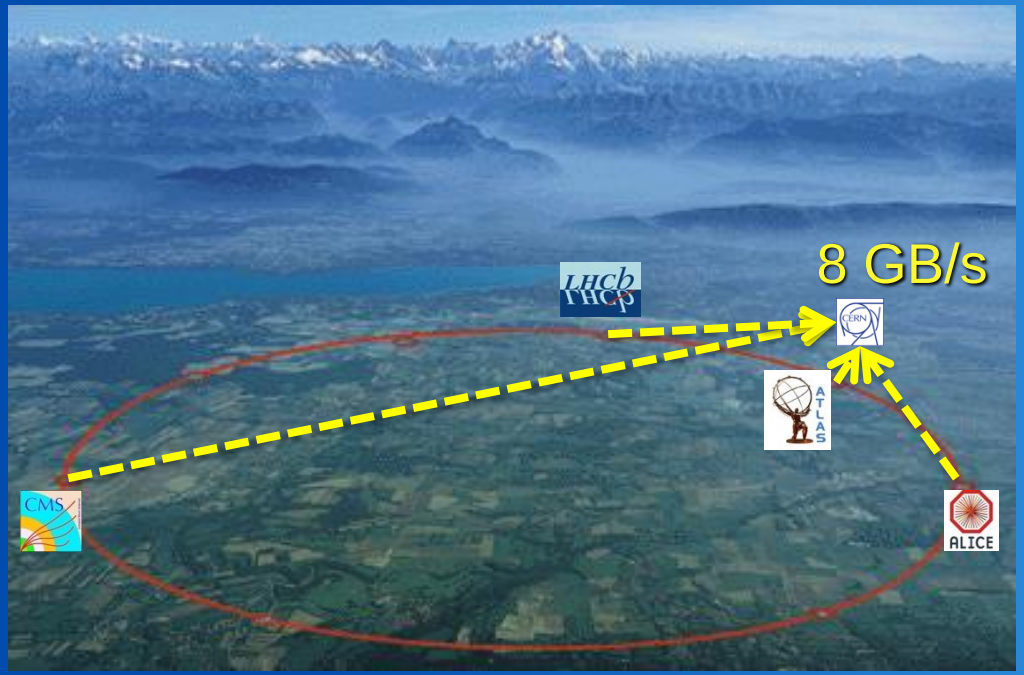
➔ Giga Bytes / sec !



Big Data in Context



Primary Storage



100,000 Disks
450,000 CPU Cores

20,000 1GB NICs
4,400 10GB NICs

The LHC Data Challenge

- Few places can store it
- Processing needs 3x CERN

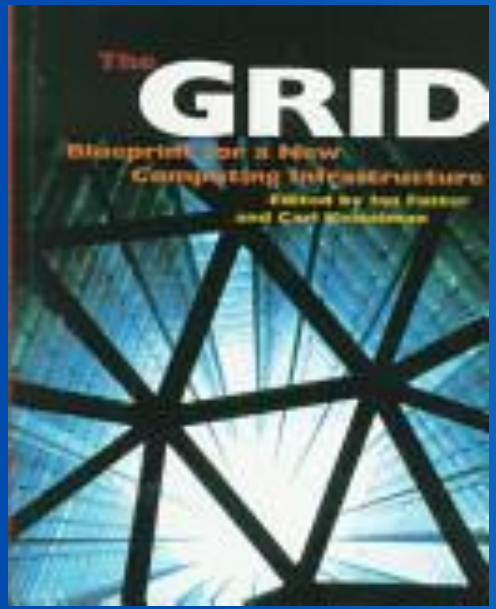
- HEP community distributed
  - Local funding for computing
- Distributed solution…

Models of Networked Analysis at Regional Centres

x 2 locations @ CERN

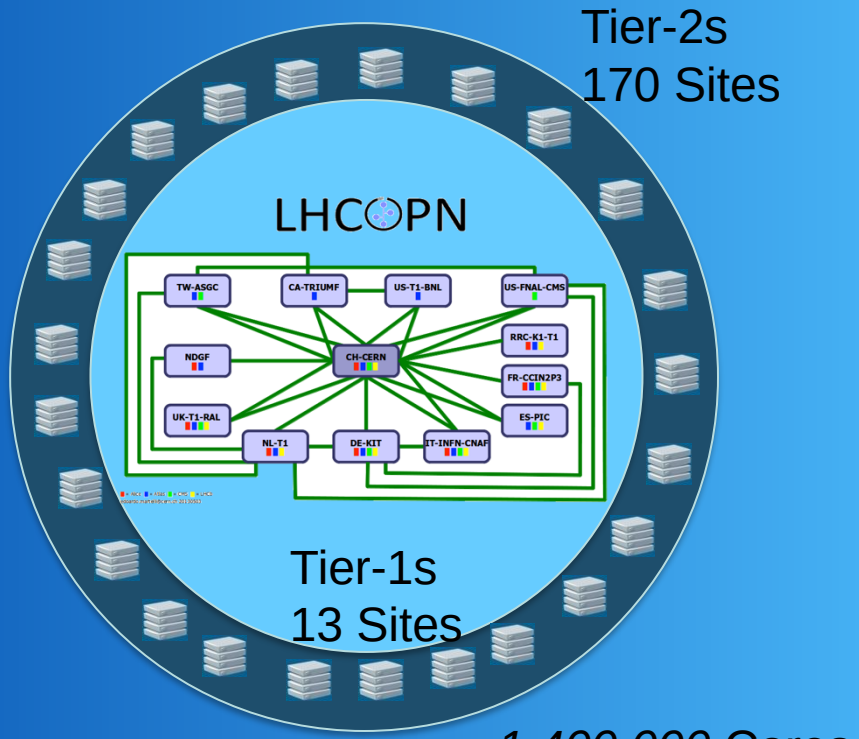
Solution: the Grid

- Use a Grid to unite computing resources of particle physics institutes around the world

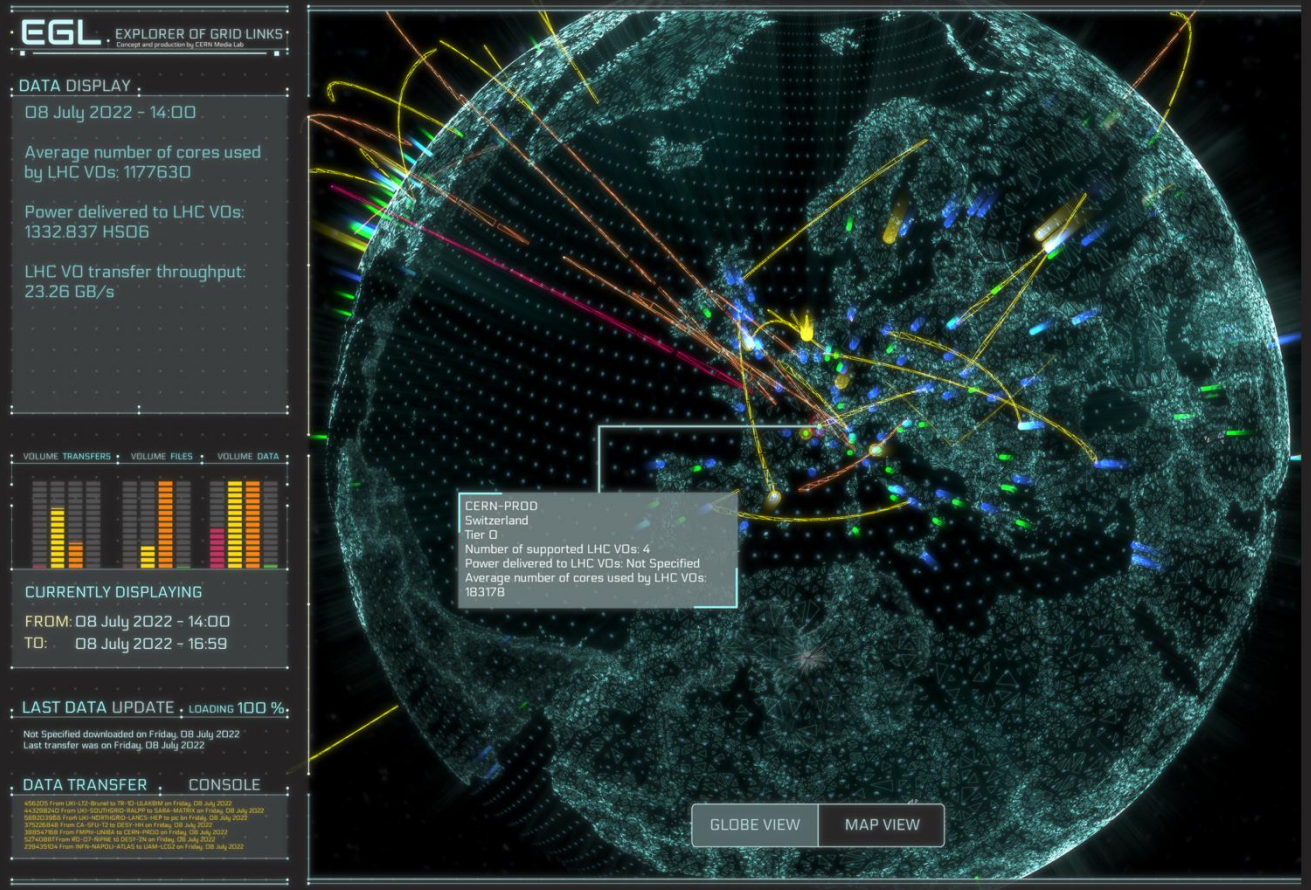


Worldwide LHC Computing Grid

- Tier-0 (CERN)
  - Data recording
  - Initial data reconstruction
  - Data distribution
- Tier-1
  - Permanent storage
  - Re-processing
  - Analysis
- Tier-2
  - Simulation
  - End-user analysis



WLCG: The Grid that Never Sleeps



500PB @ CERN

Stores, distributes, processes and analyses LHC experiments' data

1.4 million processing cores in 170 data centres and 42 countries

1500 Petabytes of CERN data stored world-wide

Cloud?

Cloud

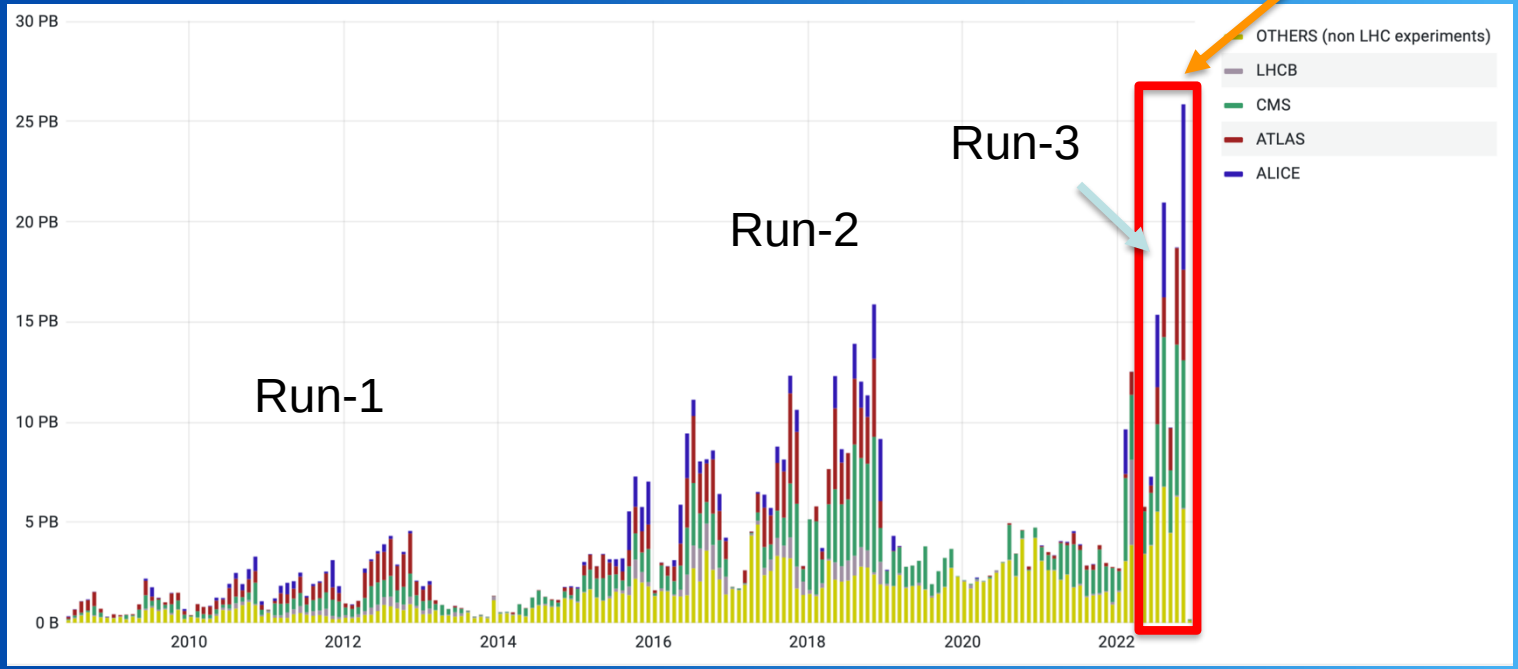
- On Demand
- Dynamically provisioned & metered by e.g. Amazon, Microsoft Azure

Grid

- Fixed size
- Collaborative, run by community

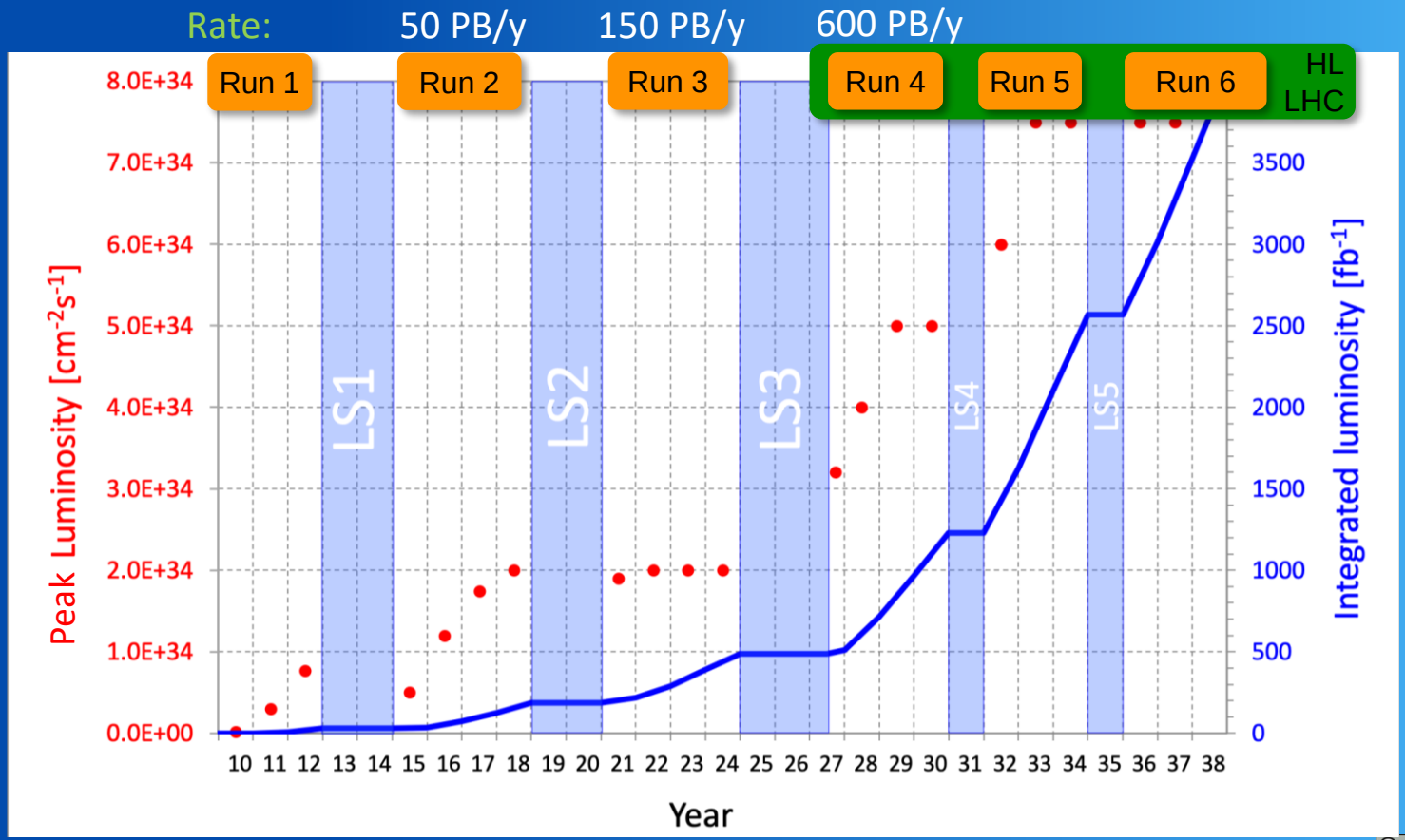
Run-3 data taking

Data written in the CERN tape storage per month

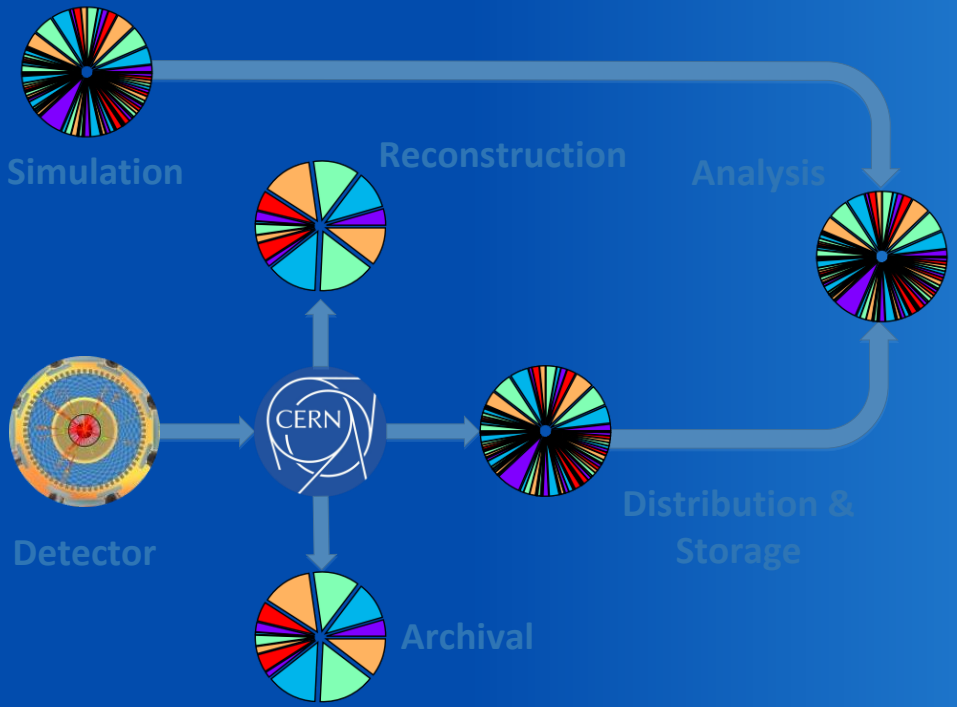


15PB 27PB

The LHC Data Challenge

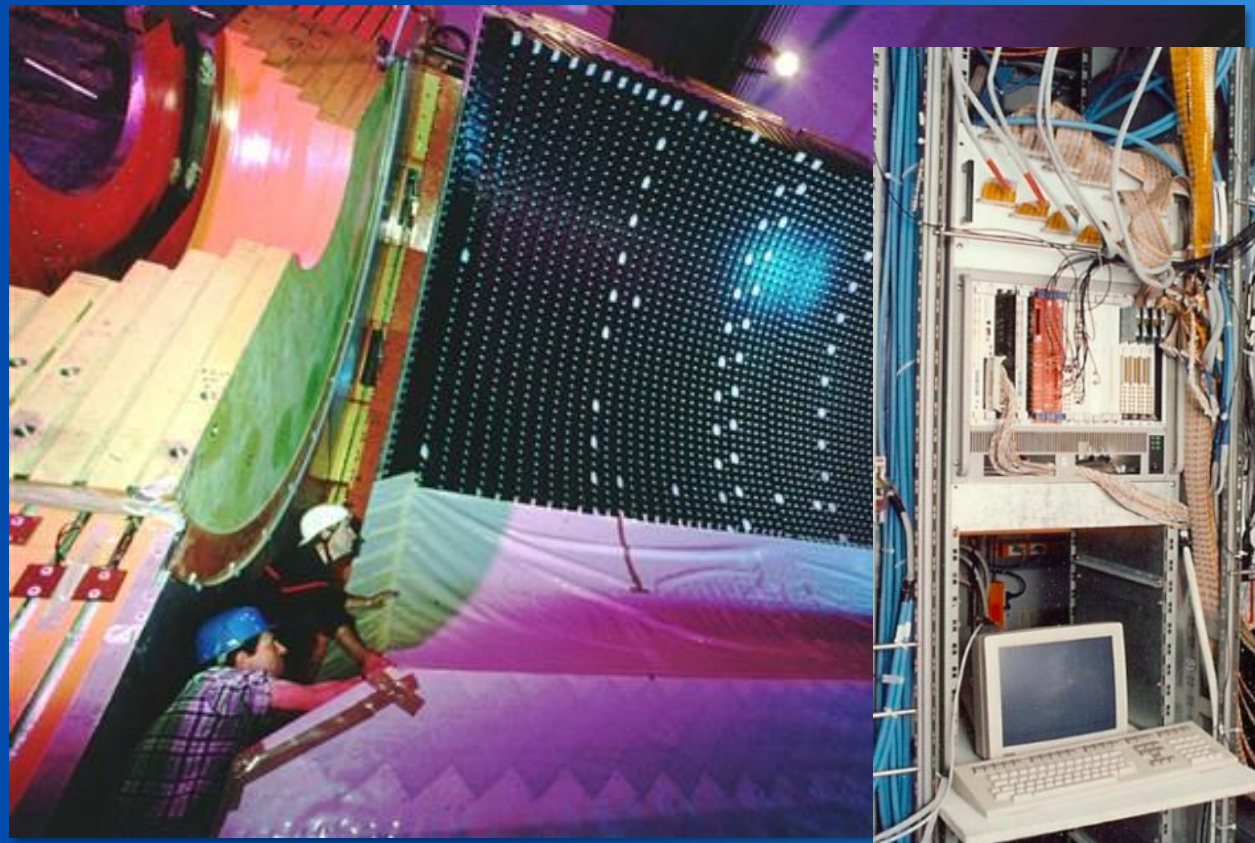


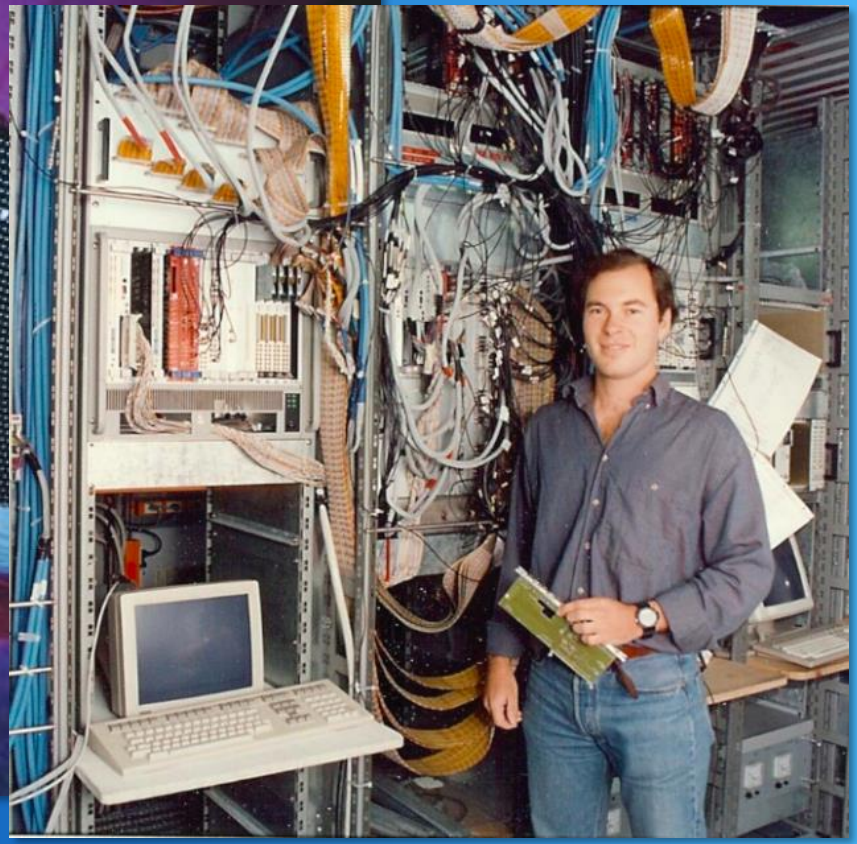
Computing throughout the Workflow



- More than half the CPU goes on simulation.
- Most of the rest is reconstruction.
- The remainder is analysis.

Where I learned to *weave*





Data Reduction / Analysis

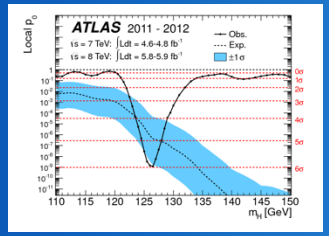
Publication

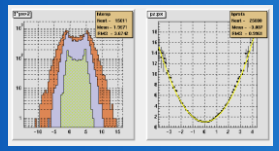
Reduced

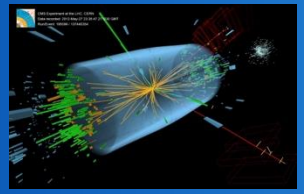
Reconstructed

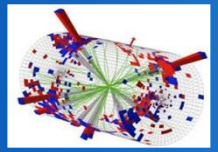
Raw

File Size









Files

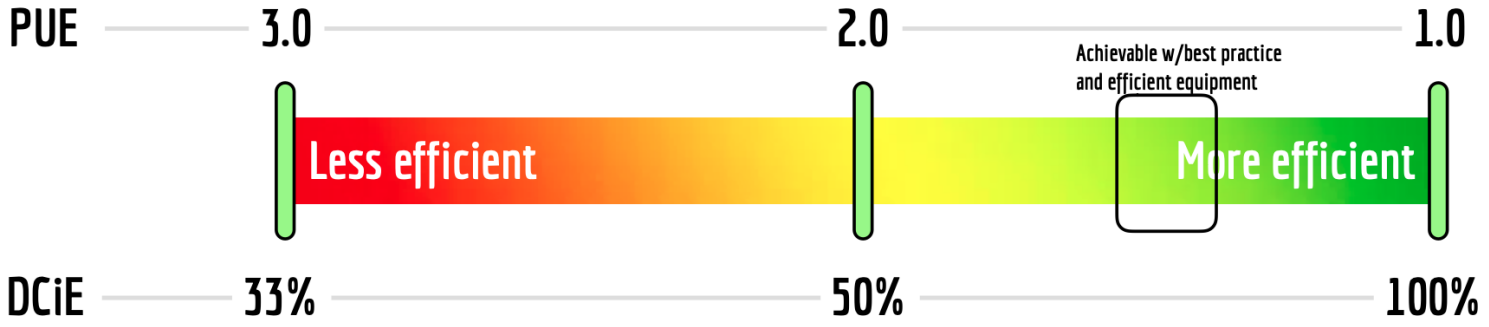
Researchers
T2s, T1s

Analysis Coordinators
T1s

Production Managers
T0, T1s

Green IT

$$\text{PUE} = \text{Power Usage Effectiveness} = \frac{\text{Total Facility Energy}}{\text{IT Equipment Energy}}$$

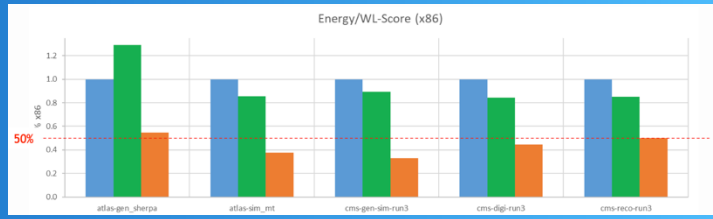


$$\text{DCiE} = \text{Data Center Infr. Efficiency} = \frac{1}{\text{PUE}}$$

Reducing IT's Energy Footprint: 3 lines of action

The Hardware

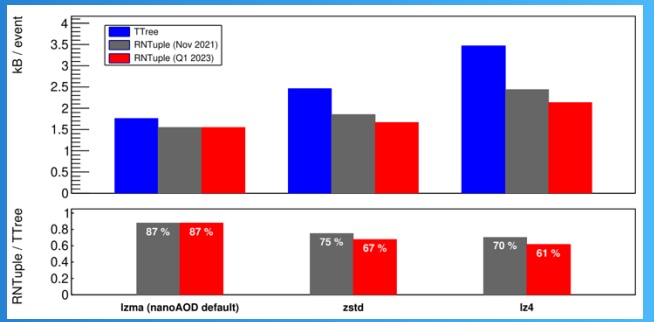
- Procuring power efficient hardware
- Extending hardware lifetime
- CPU virtualisation, Disk Server densificaiton, Tape evolution



ATLAS and CMS workloads: on ARM cf x86

The Software

- Improving software efficiency; focused C++ training courses
- Innovating computing models
- Using accelerators to improve efficiency of Generation & Simulation



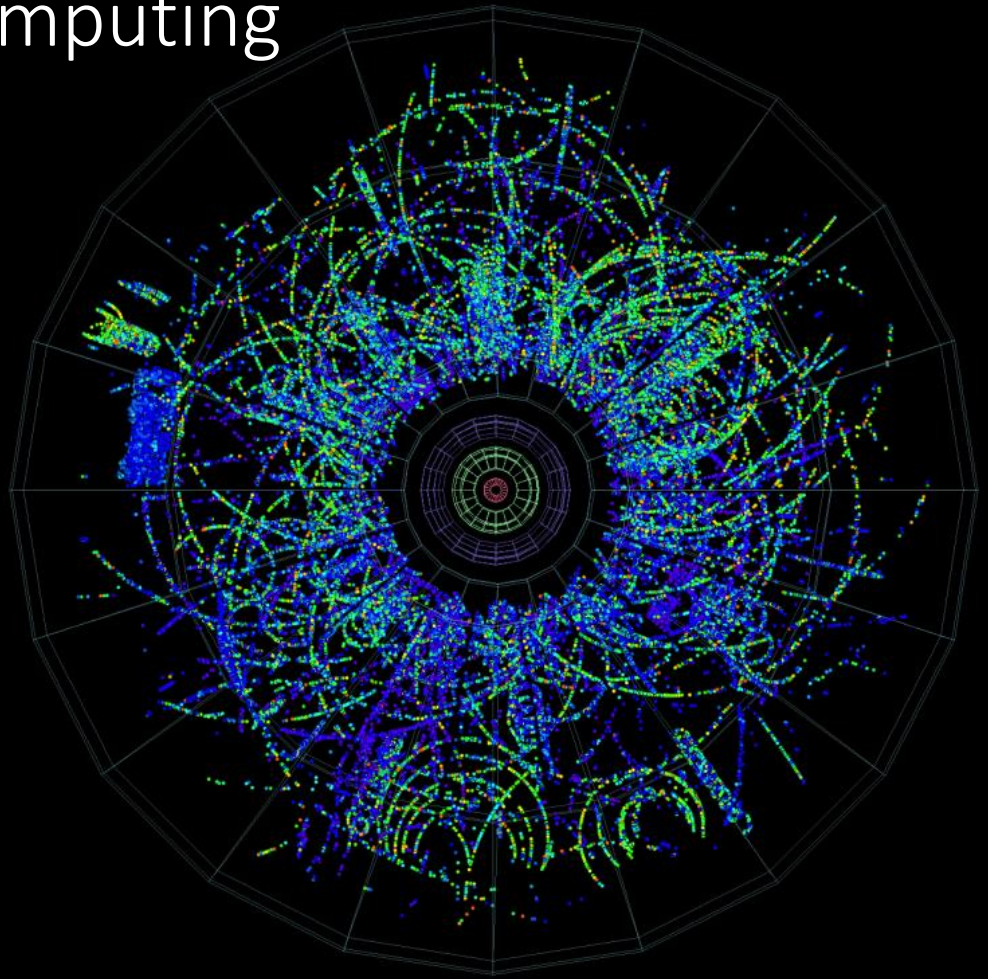
ROOT foundation layer: less CPU, less disk hungry

The Data Centre

- New data centre with efficient cooling and heat recovery
- An optimized hardware life-cycle

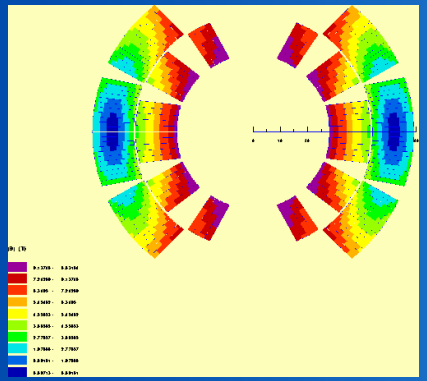
Computing

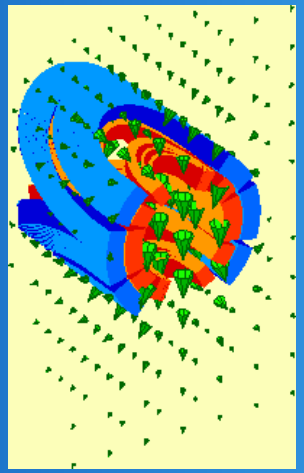
- Technical



Design

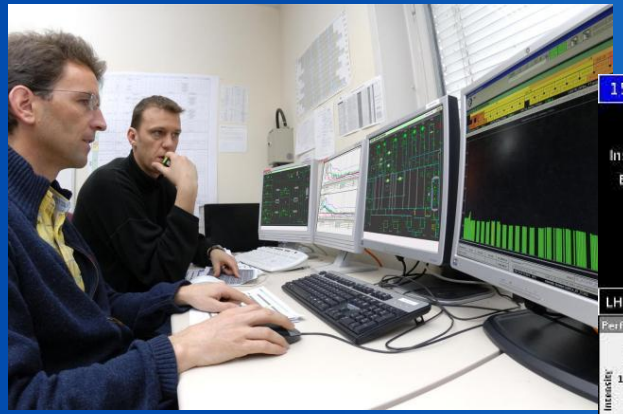
- Magnet Design

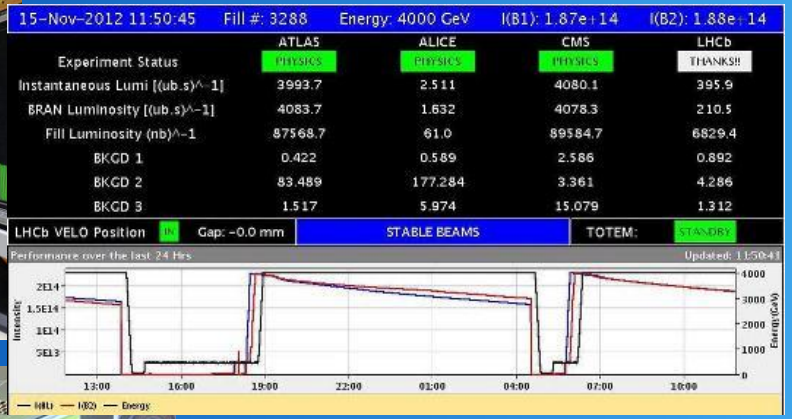




- Volunteer Computing
  - LHC@home
  - SixTrack
    - Simulates particles accelerating around the 27 km LHC to find their orbit stability

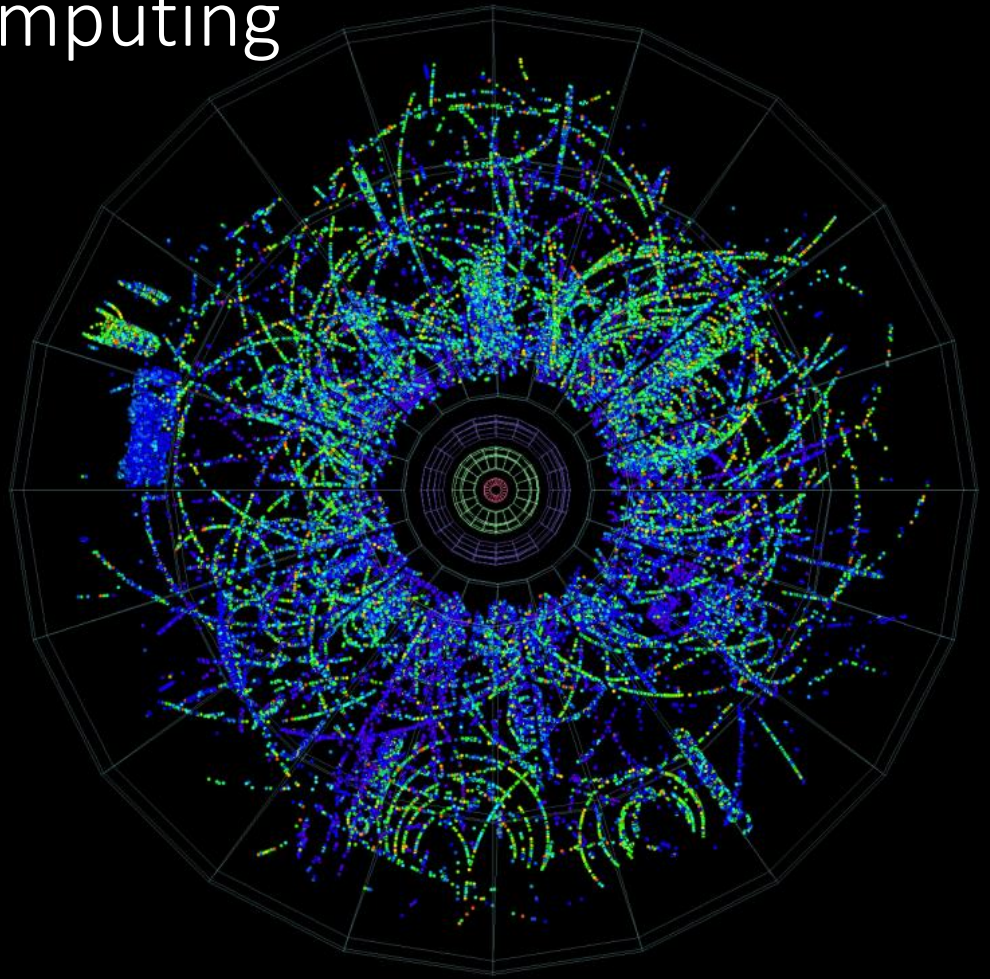
Operations



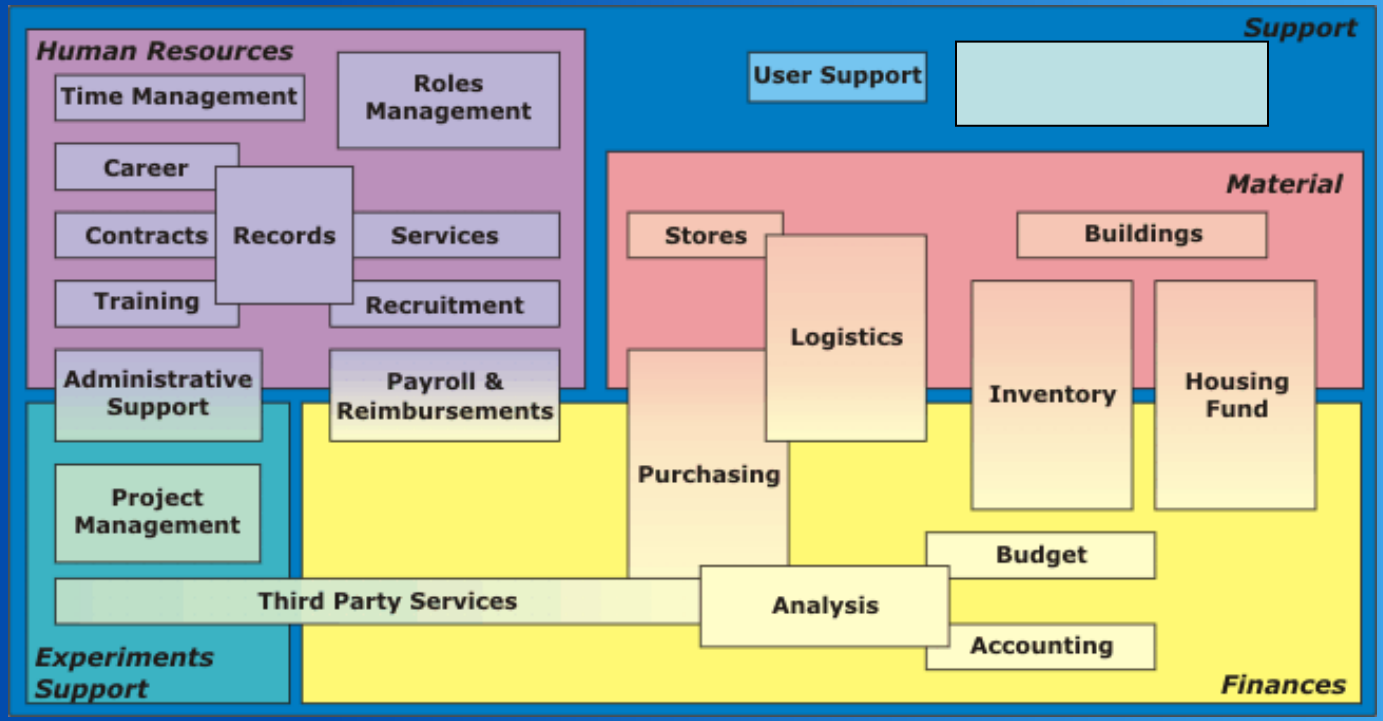


Computing

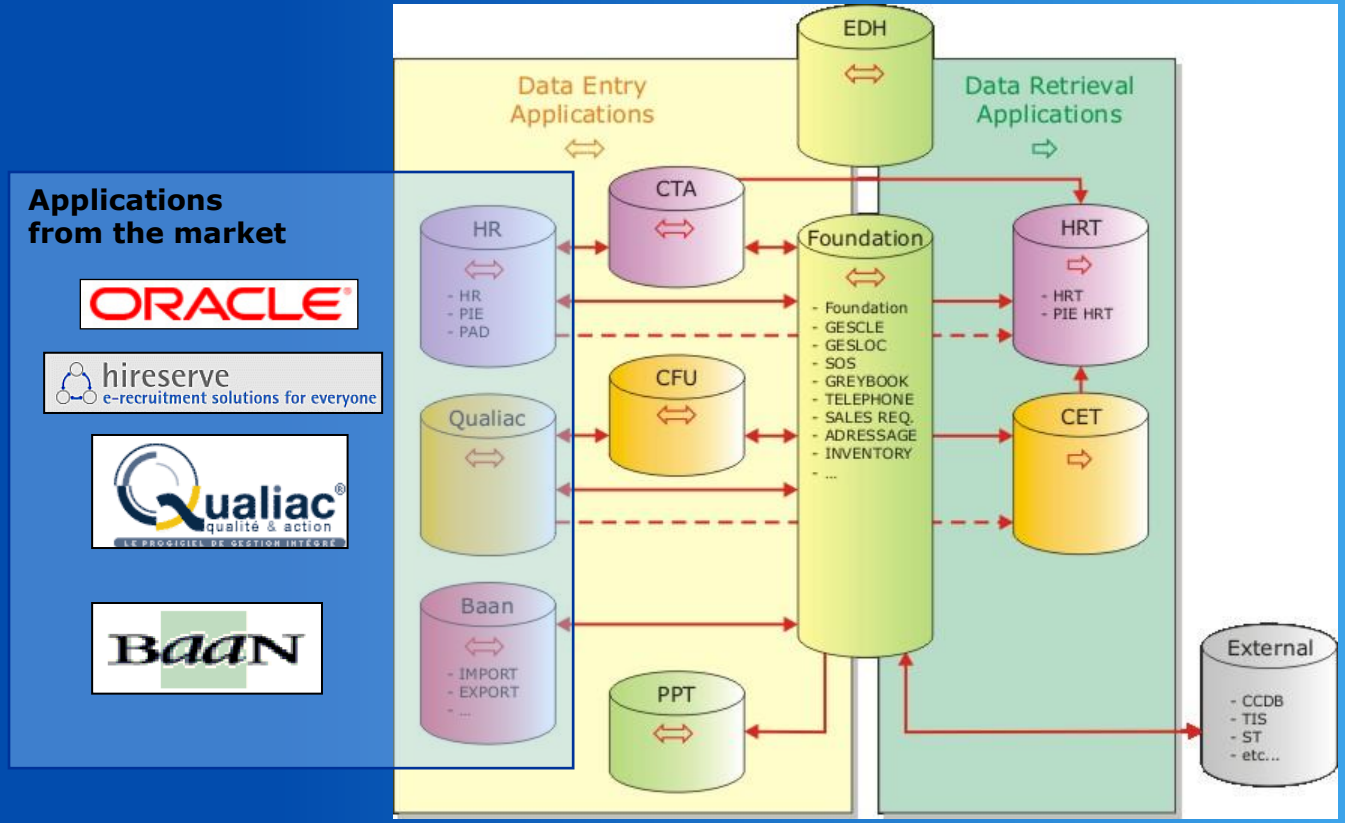
- Administrative
- Software



Administrative Information Services



Administrative Information Services

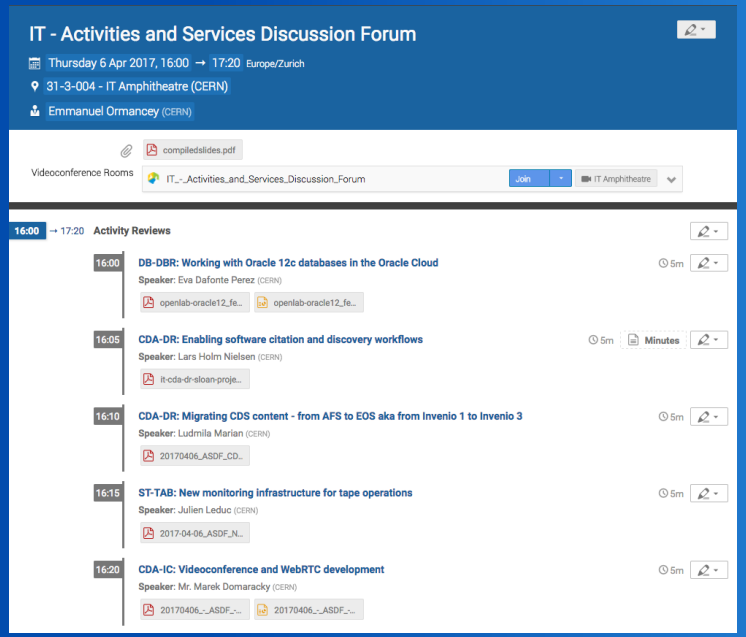


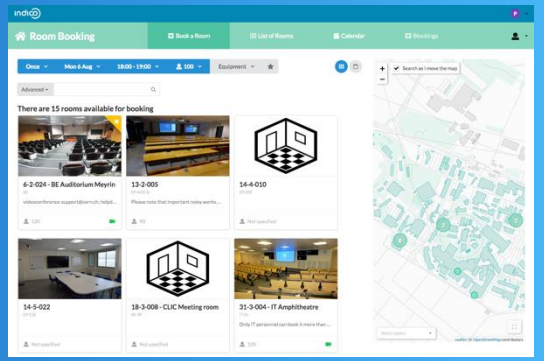
Conference, Meetings, Events...

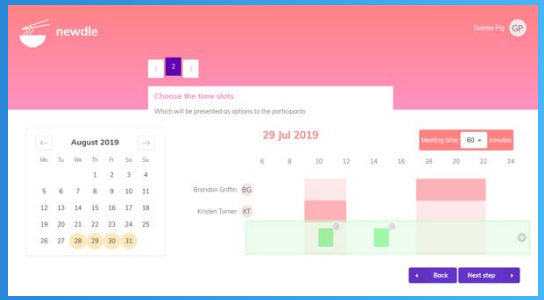
700k events total

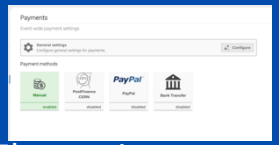
80k events in 2019

10k users /day

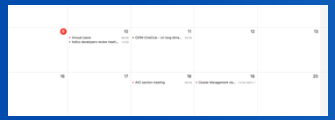




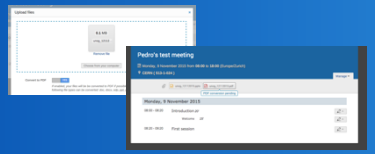




Electronic payment

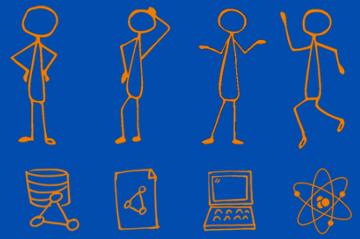


Exchange Intergration



PDF conversion

CERN Open Data

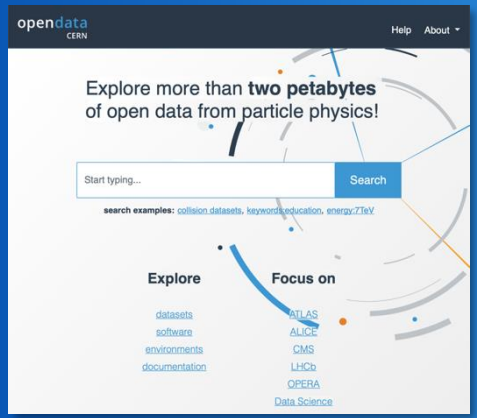


+

INVENIO
Powering Open Science

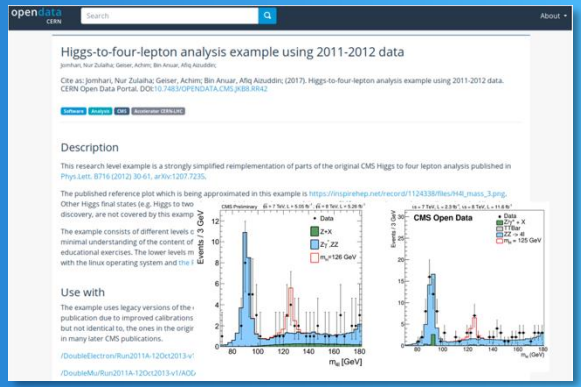
+

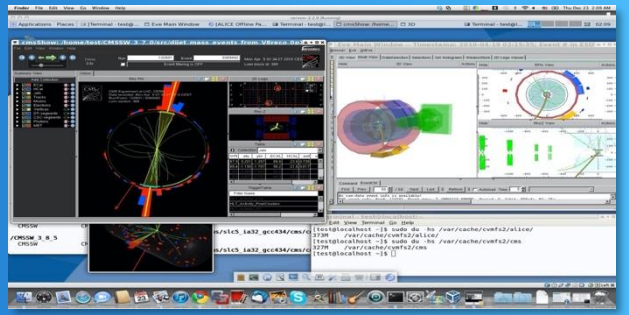
400 PB



http://opendata.cern.ch

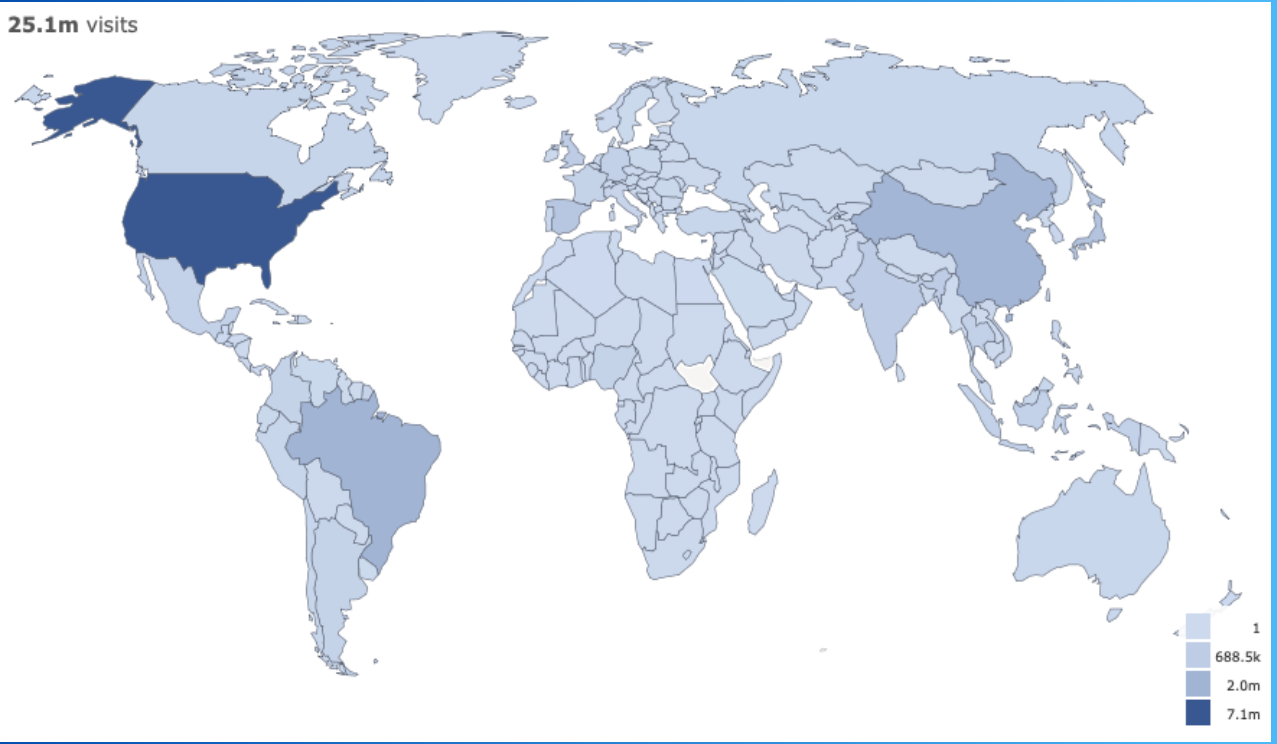
Education





Research

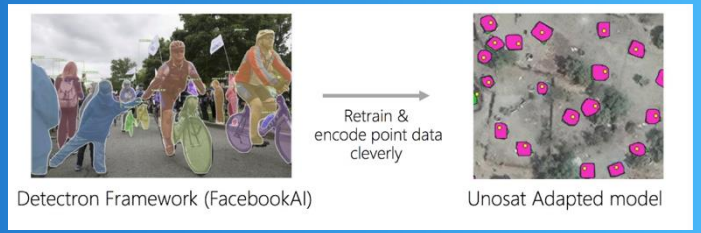
Zenodo: Open Science for All



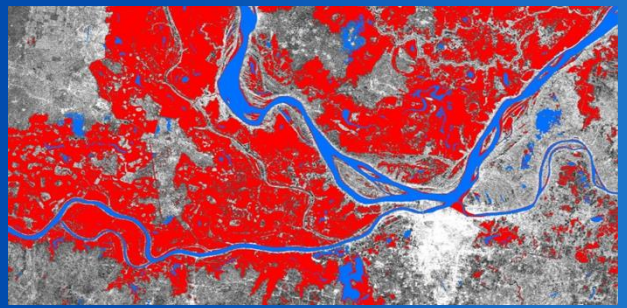
CERN as a host

UNOSAT
established at CERN in 2001,
based on IT infrastructure

Mapping shelters in refugee camps



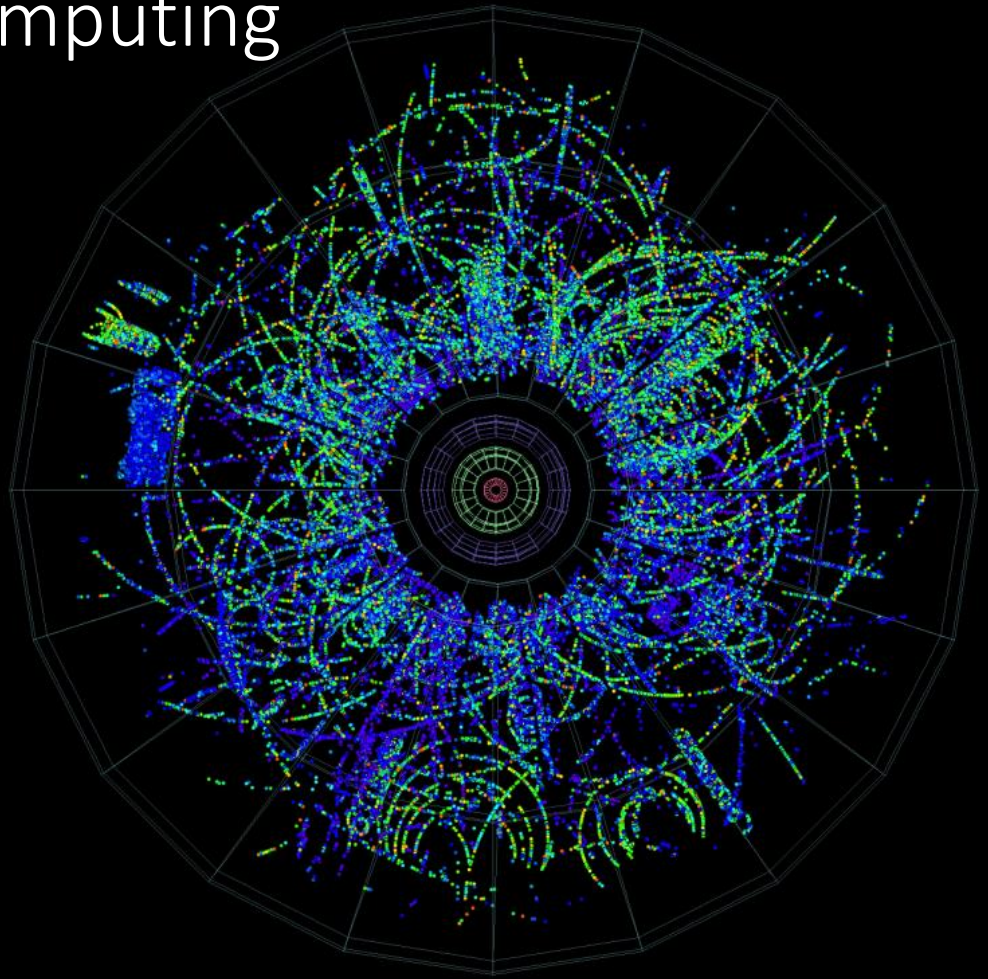
Flood detection



AI for Satellite
Imagery Analysis

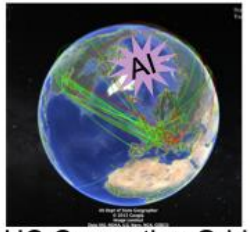
Computing

- Future



AI in HEP

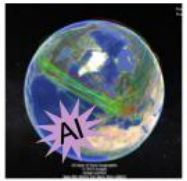
Role of AI: accelerator control, data acquisition, event triggering, anomaly detection, new physics scouting, event reconstruction, event generation, detector simulation, LHC grid control, analytics, signal extraction, likelihood free inference, background rejection, new physics searches, ...



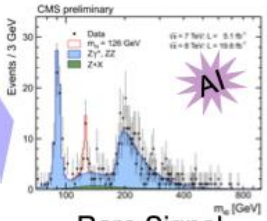
LHC Computing Grid
200k cores pledge to
CMS over ~100 sites

CERN Tier-0/Tier-1
Tape Storage
200PB total

CERN Tier-0
Computing Center
20k cores



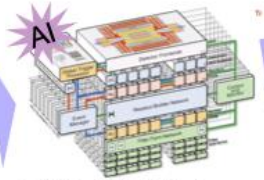
LHC Grid
Remote Access
to 100PB of data



Rare Signal
Measurement
~1 out of 10^6

Large Hadron Collider
40 MHz of collision

CMS Detector
1PB/s



CMS L1 & High-
Level Triggers
50k cores, 1kHz

Network traffic
prediction

Thanks to J-R. Vlimant

Quantum Technology Initiative

- Assess the **areas of potential quantum advantage** in HEP applications (QML, classification, anomaly detection, tracking)
- Develop **common libraries of algorithms, methods, tools**; benchmark as technology evolves
- Collaborate to the development of shared, **hybrid classic-quantum infrastructures**

Computing & Algorithms

- Identify and develop techniques for **quantum simulation** in collider physics, QCD, cosmology within and beyond the SM
- Co-develop quantum computing and sensing approaches by providing **theoretical foundations** to the identifications of the areas of interest

Simulation & Theory

- Develop and promote **expertise in quantum sensing** in low- and high-energy physics applications
- Develop quantum sensing approaches with emphasis on **low-energy particle physics measurements**
- Assess **novel technologies and materials** for HEP applications

Sensing, Metrology & Materials

- **Co-develop CERN technologies relevant to quantum infrastructures** (time synch, frequency distribution, lasers)
- Contribute to the **deployment and validation of quantum infrastructures**
- Assess requirements and **impact of quantum communication on computing applications** (security, privacy)

Communications & Networks

Open Quantum Institute
Pilot Phase

Global and inclusive access to quantum computing and the development of applications for the benefit of humanity

OQI
Open Quantum Institute

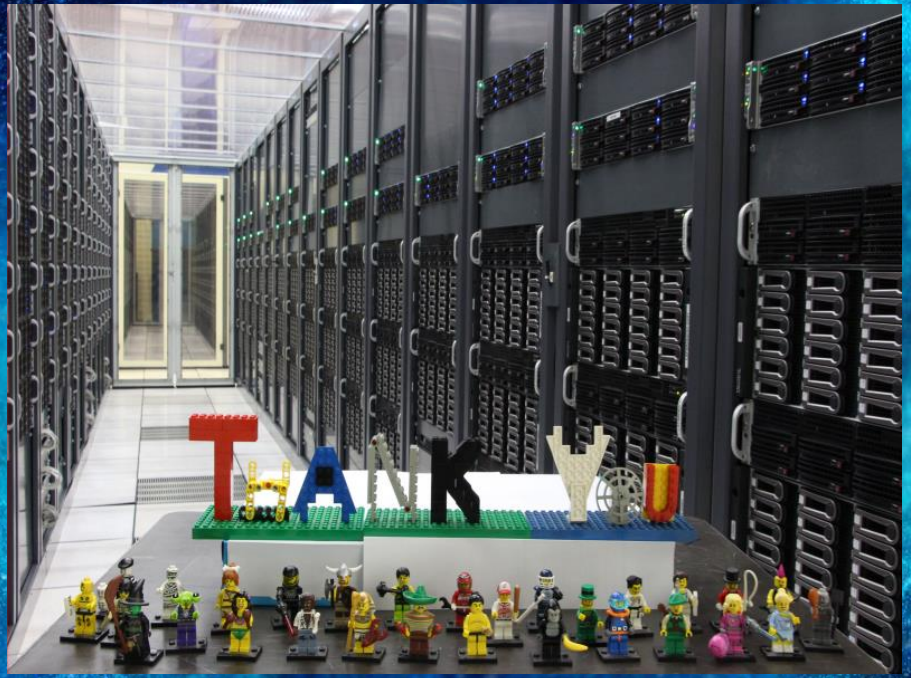
An initiative hosted by CERN, born at GESDA, supported by UBS

Take-aways

Fundamental science continues to be main inspiration for **revolutionary** ideas, due to revolutionary needs

Industry has well defined offer and demand. We do not. This is the key for **innovation**

…and **innovation** fosters technological advancements that percolates to society


THANK YOU

Want to Know More?

- Contact:
  - Tim.Smith@cern.ch
- More information:
  - IT Department: http://information-technology.web.cern.ch
  - The LHC Grid: http://wlcg.web.cern.ch
  - Google Street view in CC:
    - https://www.google.ch/maps/@46.232624,6.045747,3a,75y,162.48h,90t/data=!3m5!1e1!3m3!1sBU7JKhoaY_H9JVPFHcH8JA!2e0!3e5?hl=en
    - http://lego-scavenger-hunt.web.cern.ch
  - IT Archives: https://it-archives.web.cern.ch

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