The Worldwide LHC Computing Grid
Outline

• CERN & LHC

• LHC Computing

• Data Preservation & Open Access
LHC: an accelerator of 27 km
Four experiments: the coopetition

LHC

CMS Collaboration:
39 Countries, 169 Institutes and 3170 members

ATLAS Collaboration:
38 Countries, 174 Institutes and 3000 members

LHCB Collaboration:
15 Countries, 54 Institutes and 754 members

ALICE Collaboration:
33 Countries, 116 Institutes and over 1000 members
### LHC (Large Hadron Collider)

**14 TeV proton-proton accelerator-collider** built in the LEP tunnel (+ Lead-Lead collisions)

<table>
<thead>
<tr>
<th>Year</th>
<th>Event Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1983</td>
<td>First studies for the LHC project</td>
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<tr>
<td>1988</td>
<td>First magnet model (feasibility)</td>
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<tr>
<td>1994</td>
<td>Approval of the LHC by the CERN Council</td>
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<tr>
<td>1996-1999</td>
<td>Series production industrialisation</td>
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<td>1998</td>
<td>Start of civil engineering</td>
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<td>1998-2000</td>
<td>Placement of the main production contracts</td>
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<tr>
<td>2004-2009</td>
<td>Installation &amp; Commissioning</td>
</tr>
<tr>
<td>2010-2035</td>
<td>Physics exploitation</td>
</tr>
<tr>
<td></td>
<td>2010 – 2012 : Run 1 ;7 and 8 TeV</td>
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<tr>
<td></td>
<td>2015 – 2018 : Run 2 ; 13 TeV</td>
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<tr>
<td></td>
<td>2021 – 2023 : Run 3 (14 TeV)</td>
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<tr>
<td></td>
<td>2024 – 2025 : HL-LHC installation</td>
</tr>
<tr>
<td></td>
<td>2026 – 2035… : HL-LHC operation</td>
</tr>
</tbody>
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**HiLumi**

**CERN**

**IT Information Technology Department**

31 March 2017

BIST - WLCG
LHC 2010-2012: a rich harvest of collisions

- 2010: 0.04 fb\(^{-1}\)
  - 7 TeV CoM
  - Commissioning

- 2011: 6.1 fb\(^{-1}\)
  - 7 TeV CoM
  - … exploring limits

- 2012: 23.3 fb\(^{-1}\)
  - 8 TeV CoM
  - … production

\[ \Sigma \sim 30 \text{ fb}^{-1} \]
\[ \sim 2 \times 10^{15} \text{ collisions} \]

7 TeV and 8 TeV in 2012
Up to 1380 bunches with $1.5 \times 10^{11}$ protons
The Nobel Prize in Physics 2013 was awarded jointly to François Englert and Peter W. Higgs “for the theoretical discovery of a mechanism that contributes to our understanding of the origin of mass of subatomic particles, and which recently was confirmed through the discovery of the predicted fundamental particle, by the ATLAS and CMS experiments at CERN's Large Hadron Collider”.

31 March 2017
From *individual* theoretical physicist idea... to *collective innovation*!
Worldwide LHC Computing
16 Years of (W)LCG

• CERN Council approval in September 2001 following the initiative of Manuel Delfino (CERN IT Division Leader) and Les Robertson (Project Leader)
• LCG Project began in 2002, with support from several countries – including significant funding from UK & Italy and several others
• First small grid deployments late 2002/early 2003
• Real production use and program of data challenges started in 2004

Service challenges proposed in 2004
To demonstrate service aspects:
• Data transfers for weeks on end
• Data management
• Scaling of job workloads
• Security Incidents ("fire drills")
• Interoperability
• Support processes

Independent experimental data challenges

2004

E.g. DC04 (ALICE, CMS, LHCb)/DC02 (ATLAS)
in 2004 saw the first full chain of computing models on grids

2005

SC1 Basic transfer rates
SC2 Basic transfer rates
SC3 Sustained rates, data management, service reliability
SC4 Nominal LHC rates disk → tape tests, all Tier 1s, some Tier 2s

2006

2007

WLCG Collaboration formed

2008

CCRC'08 Readiness challenge, all experiments, full computing models, cosmic ray data

2009

STEP'09 Scale challenge, all experiments, full computing models, tape recall and analysis

2010

Cosmic ray data
LHC data

Focus on real and continuous production use of the service overall several years (simulations since 2003, cosmic ray data, etc.)

Data and service challenges to exercise all aspects of the service – not only for data transfers but for workloads, support structures, etc.

Frédéric Hemmer, 7.10.2016
The Worldwide LHC Computing Grid

CERN Tier-0 (Geneva & Budapest): data recording, reconstruction and distribution

Tier-1: permanent storage, re-processing, analysis

Tier-2: Simulation, end-user analysis

An International collaboration to distribute and analyse LHC data

Integrates computer centres worldwide that provide computing and storage resource into a single infrastructure accessible by all LHC physicists
LHC Computing Summary

2016: 49.4 PB LHC data/
58 PB all experiments/
73 PB total

ALICE: 7.6 PB
ATLAS: 17.4 PB
CMS: 16.0 PB
LHCb: 8.5 PB

Not Cumulative !!!!
2017:
- 225k cores → 325k
- 150 PB raw → 250 PB

2017-18/19:
- Upgrade internal networking capacity
- Refresh tape infrastructure
Clouds …
The Helix Nebula Science Cloud
public-private partnership

Strategic Plan

- Establish multi-tenant, multi-provider cloud infrastructure
- Identify and adopt policies for trust, security and privacy
- Create governance structure
- Define funding schemes

To support the computing capacity needs for the ATLAS experiment

Setting up a new service to simplify analysis of large genomes, for a deeper insight into evolution and biodiversity

To create an Earth Observation platform, focusing on earthquake and volcano research

To improve the speed and quality of research for finding surrogate biomarkers based on brain images

Updated
October 2016
The Hybrid Cloud Model

Brings together
• research organisations,
• data providers,
• publicly funded e-infrastructures,
• commercial cloud service providers

In a hybrid cloud with procurement and governance approaches suitable for the dynamic cloud market
Major challenges

1. Cloud computing is disrupting the way IT resources are provisioned
2. In-house resources, publicly funded e-infrastructure and commercial cloud services are not integrated to provide a seamless environment
3. Current organisational and financial models are not appropriate
4. The new way of procuring cloud services is also a matter of skills and education
5. Legal impediments exist
Helix Nebula Science Cloud Joint Pre-Commercial Procurement (PCP)

Procurers: CERN, CNRS, DESY, EMBL-EBI, ESRF, IFAE, INFN, KIT, STFC, SURFSara
Experts: Trust-IT & EGI.eu

The group of procurers have committed
• Procurement funds
• Manpower for testing/evaluation
• Use-cases with applications & data
• In-house IT resources

Resulting services will be made available to end-users from many research communities

Co-funded via H2020 Grant Agreement 687614

Total procurement budget >5.3M€
Data Preservation
Characteristics specific to particle physics

- **We throw away** most of our data before it is even recorded – “triggers”
- Our detectors are **relatively stable** over long periods of time (years) – not “doubling every 6 or 18 months”
- We make “**measurements**” – not “**observations**”
- Our projects typically last for **decades** – we need to keep data usable during at least this length of time
- We have **shared** “data behind publications” for more than 30 years… ([HEPData](https://hepdata.cern.ch))
CERN’s scientific diversity programme

**AD:** Antiproton Decelerator for antimatter studies
**AWAKE:** proton-induced plasma wakefield acceleration
**CAST, OSQAR:** axions
**CLOUD:** impact of cosmic rays on aerosols and clouds → implications on climate
**COMPASS:** hadron structure and spectroscopy
**ISOLDE:** radioactive nuclei facility
**NA61/Shine:** heavy ions and neutrino targets
**NA62:** rare kaon decays
**NA63:** radiation processes in strong EM fields
**NA64:** search for dark photons
**Neutrino Platform:** $\nu$ detectors
**R&D for experiments in US, Japan**
**n-TOF:** n-induced cross-sections
**UA9:** crystal collimation

~20 experiments, > 1200 physicists

31 March 2017
CERN Archive current numbers

Data:
- ~190 PB physics data (CASTOR)
- ~7 PB backup (TSM)

Tape libraries:
- IBM TS3500 (3+2)
- Oracle SL8500 (4)

Tape drives:
- ~100 archive

Capacity:
- ~70 000 slots
- ~25 000 tapes

Data to CASTOR tape, 2002-2017
Large scale media migration

• **Challenge:**
  - ~85 PB of data
  - 2013: ~51 000 tapes
  - 2015: ~17 000 tapes
  - Verify all data after write
    - 3x (255PB!) pumped through the infrastructure (read->write->read)
  - Liberate library slots for new cartridges
    - Decommission ~35 000 obsolete tape cartridges

• **Constraints:**
  - Be transparent for user/experiment activities
  - Preserve temporal collocation
  - Finish before LHC run 2 start
Large media migration: Repack

Part 1: Oracle 5 -> 8TB then empty 1TB

Part 2: IBM 4 -> 7TB then 1TB

Completed!

Total Tape Writing (TB)

Total Tape Reading, (TB)

LHC Run1
Tape contamination incident

Over 30m$^3$/min of airflows per library
- (Home vacuum cleaner: ~2m$^3$/min)
Operating environment required for new-generation drives: ISO-14644 Class 8 (particles / m$^3$):

<table>
<thead>
<tr>
<th>Class</th>
<th>&gt;0.5 um</th>
<th>&gt;1 um</th>
<th>&gt;5 um</th>
</tr>
</thead>
<tbody>
<tr>
<td>8</td>
<td>3 520 000</td>
<td>832 000</td>
<td>29 300</td>
</tr>
</tbody>
</table>
Future...

  - +7K tapes / year (~35'000 free library slots)

- Run-3 (-2022): ~150PB/year. Run-4 (2023 onwards): 600PB/year

- ... tape technology grows faster
  - tape roadmaps at 30% CAGR for at least 10 years
  - demo for 220TB tape by IBM/Fujifilm in April 2015

- but: market evolution is difficult to predict
  - Tape media: monopoly in shrinking market
  - Disk: “duopoly”
  - Cloud storage solutions
  - Disk capacity slowdown .. may slowdown tape products!
  - Storage slowdown == higher archiving costs
... and the past

- **LEP-era data**: ~370TB
  - **2000**: ~ 15,000 tapes
  - **2007**: ~ 1500 tapes
  - **2015**: 30 tapes… x 2 (replicated in separate buildings)
  - Cost: … in the context of a large tape operation
Open Access, open data
CERN Open Data Portal

- 2015
  - 40 TB of 2010 data

- 2016
  - 320 TB of 2011 data

- Curation, release of simulated data (MC)
  - Trigger information
  - Configuration files

31 March 2017

BIST - WLCG

http://github.com/cernopendata
Open Data as a Service

[Diagram showing Zenodo interface with emphasis on DOI 10.5281/zenodo.10594 and various icons representing data sharing and open access]

DOI 10.5281/zenodo.10594

License (Attribution-NonCommercial-NoDerivatives 4.0 International)

Sharing:
- Email
- Twitter
- Facebook
- Github

http://github.com/zenodo
Some (Societal) Impact of CERN Computing
UNOSAT powered by CERN IT

- Hosting databases and Geographic Information System (GIS) data server
- 16 terabytes of data stored at CERN Computer Centre – benefiting from economies of scale (~150 petabytes at CERN), i.e. UNOSAT share: 1/10000
- >10 gigabit/second bandwidth
- IT-support and development
- Virtual machines in CERN-cloud
- Computer security
- Research environment, collaboration
Hurricane Matthew: Haiti

May 2016

October 2016
The Future
Why High-Luminosity LHC ? (LS3)

Goal of HL-LHC project:
• 250 – 300 fb\(^{-1}\) per year
• 3000 fb\(^{-1}\) in about 10 years

By implementing HL-LHC

By continuous performance improvement and consolidation

Almost a factor 3

Around 300 fb\(^{-1}\) the present Inner Triplet magnets reach the end of their useful life (due to radiation damage) and must be replaced.
Europe’s top priority should be the **exploitation of the full potential of the LHC**, including the high-luminosity upgrade of the machine and detectors with a view to collecting **ten times more data than in the initial design, by around 2030**. This upgrade programme will also provide further exciting opportunities for the study of flavour physics and the quark-gluon plasma.

**HL-LHC from a study to a PROJECT**

300 fb\(^{-1}\) → 3000 fb\(^{-1}\)

including LHC injectors upgrade **LIU**
(Linac 4, Booster 2GeV, PS and SPS upgrade)
Scale of data tomorrow ...

Data: ~25 PB/year → 400 PB/year

Compute: Growth > x50

10 Year Horizon

What we think is affordable unless we do something differently

Frédéric Hemmer, 7.10.2016

30th Anniversary CC-IN2P3
WLCG preparations for HL-LHC

Detector design, trigger rates, etc.

Optimization of reconstruction, simulation, etc.

Architecture, memory, etc. → HEP SW Foundation roadmap

New grid/cloud models; optimisation of CPU/disk/network

31 March 2017
Summary

CERN & WLCG partners are

- World leaders in massive data handling
  - Using house & commercial services
  - Usable by other sciences as well

- Paving the way in Data Preservation & Open Access (incl. data)
Thank you for your attention

"The task of the mind is to produce future"
Paul Valéry