CERN

European Organization for Nuclear Research
Organisation Européenne pour la Recherche Nucléaire

The World Wide LHC Computing Grid and its evolution

Dr Bob Jones

CERN

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CERN was founded 1954: 12 European States
Today: 20 Member States

~ 2300 staff
~ 790 other paid personnel
> 10000 users

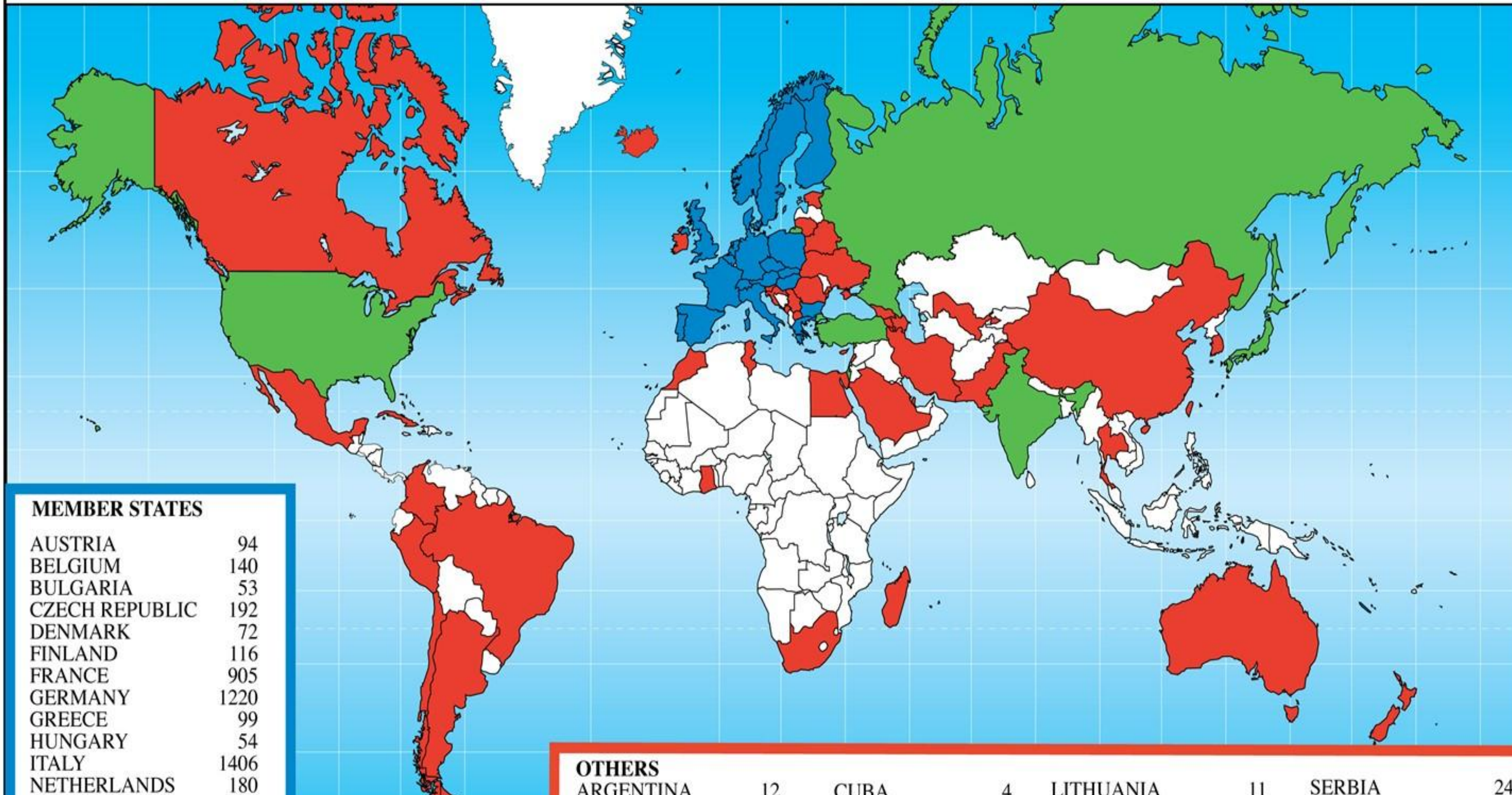
Budget (2011) ~1000 MCHF

20 Member States: Austria, Belgium, Bulgaria, the Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Italy, Netherlands, Norway, Poland, Portugal, Slovakia, Spain, Sweden, Switzerland and the United Kingdom

1 Candidate for Accession: Romania

8 Observers to Council: India, Israel, Japan, the Russian Federation, the United States of America, Turkey, the European Commission and

Distribution of All CERN Users by Nation of Institute on 27 June 2011



MEMBER STATES

AUSTRIA	94
BELGIUM	140
BULGARIA	53
CZECH REPUBLIC	192
DENMARK	72
FINLAND	116
FRANCE	905
GERMANY	1220
GREECE	99
HUNGARY	54
ITALY	1406
NETHERLANDS	180
NORWAY	93
POLAND	205
PORTUGAL	141
SLOVAKIA	63
SPAIN	339
SWEDEN	79
SWITZERLAND	359
UNITED KINGDOM	732

6542

OBSERVER STATES

INDIA	109
ISRAEL	60
JAPAN	190
RUSSIA	822
TURKEY	79
USA	1786

3046

OTHERS

ARGENTINA	12
ARMENIA	12
AUSTRALIA	22
AZERBAIJAN	1
BELARUS	19
BRAZIL	79
CANADA	160
CHILE	3
CHINA	87
CHINA (TAIPEI)	53
COLOMBIA	13
CROATIA	15
CUBA	4
CYPRUS	6
EGYPT	6
ESTONIA	18
GEORGIA	10
GHANA	1
HONG KONG	1
ICELAND	3
IRAN	15
IRELAND	13
KOREA	85
LEBANON	1
LITHUANIA	11
MADAGASCAR	1
MALTA	1
MEXICO	39
MONTENEGRO	1
MOROCCO	7
NEW ZEALAND	9
PAKISTAN	19
PERU	2
QATAR	1
ROMANIA	66
SAUDI ARABIA	2
SERBIA	24
SINGAPORE	1
SLOVENIA	31
SOUTH AFRICA	15
THAILAND	1
F.Y.R.O.M.	3
TUNISIA	1
UKRAINE	19
UZBEKISTAN	1

894

Answering fundamental questions…

- How to explain particles have mass?

  We have theories but need experimental evidence

- What is 96% of the universe made of ?

  We can only see 4% of its estimated mass!

- Why isn't there anti-matter in the universe?

  Nature should be symmetric…

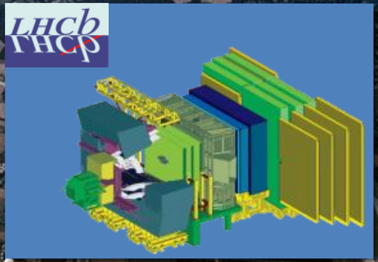
- What was the state of matter just after the « Big Bang » ?

  Travelling back to the earliest instants of the universe would help…

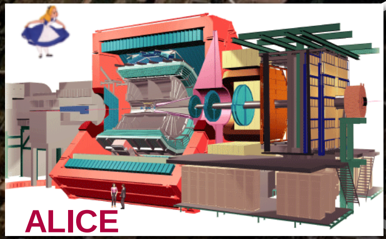
Accelerating Science and Innovation

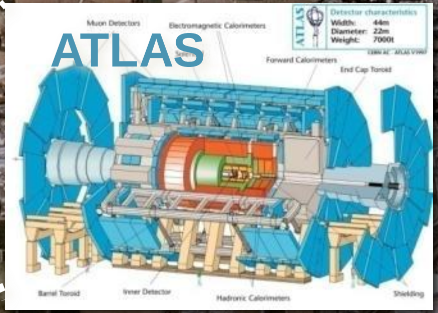
Enter a New Era in Fundamental Science

Start-up of the Large Hadron Collider (LHC), one of the largest and truly global scientific projects ever, is an exciting turning point in particle physics.

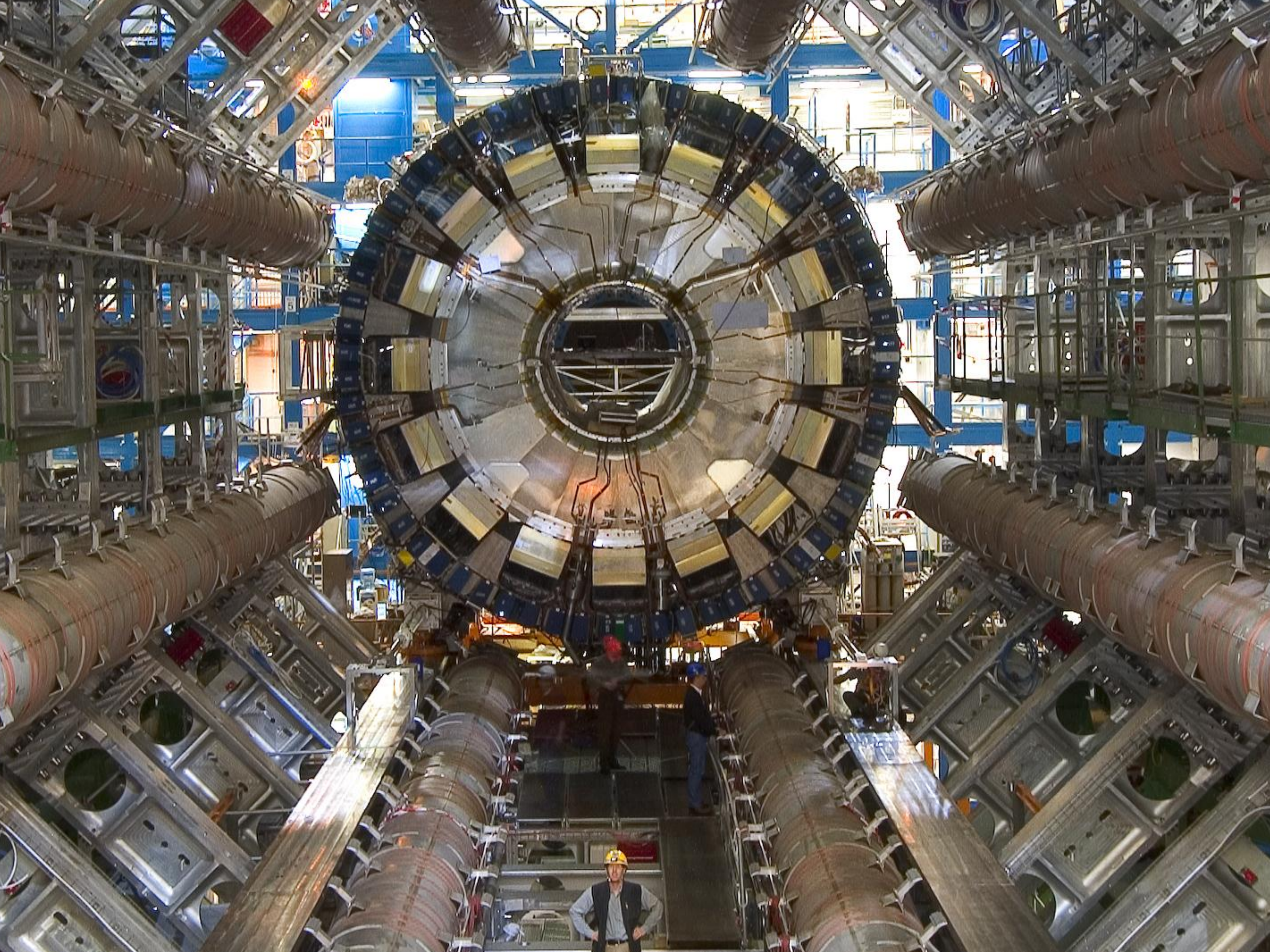


Exploration of a new energy frontier
Proton-proton collisions at E_{CM} = 14 TeV

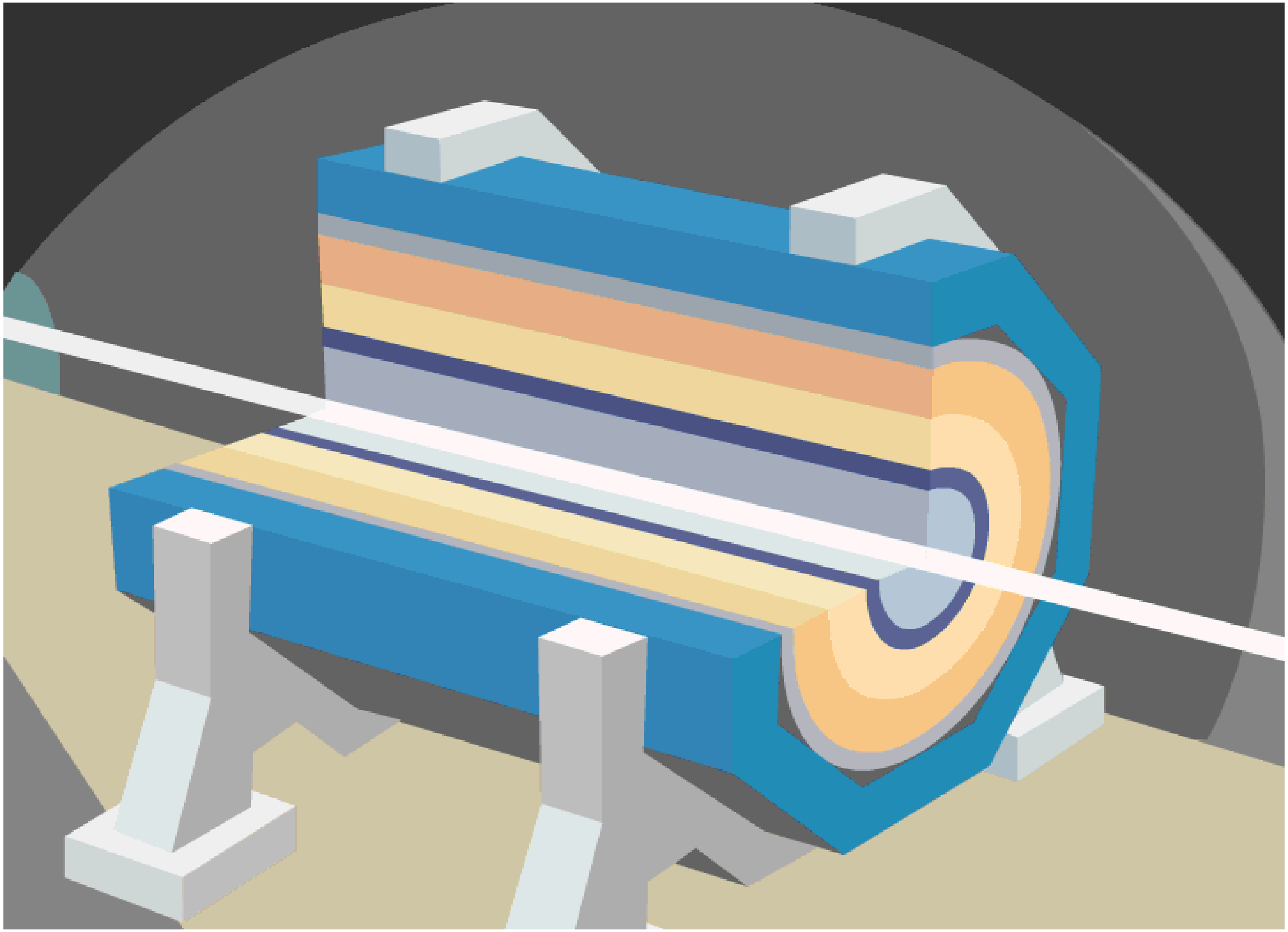




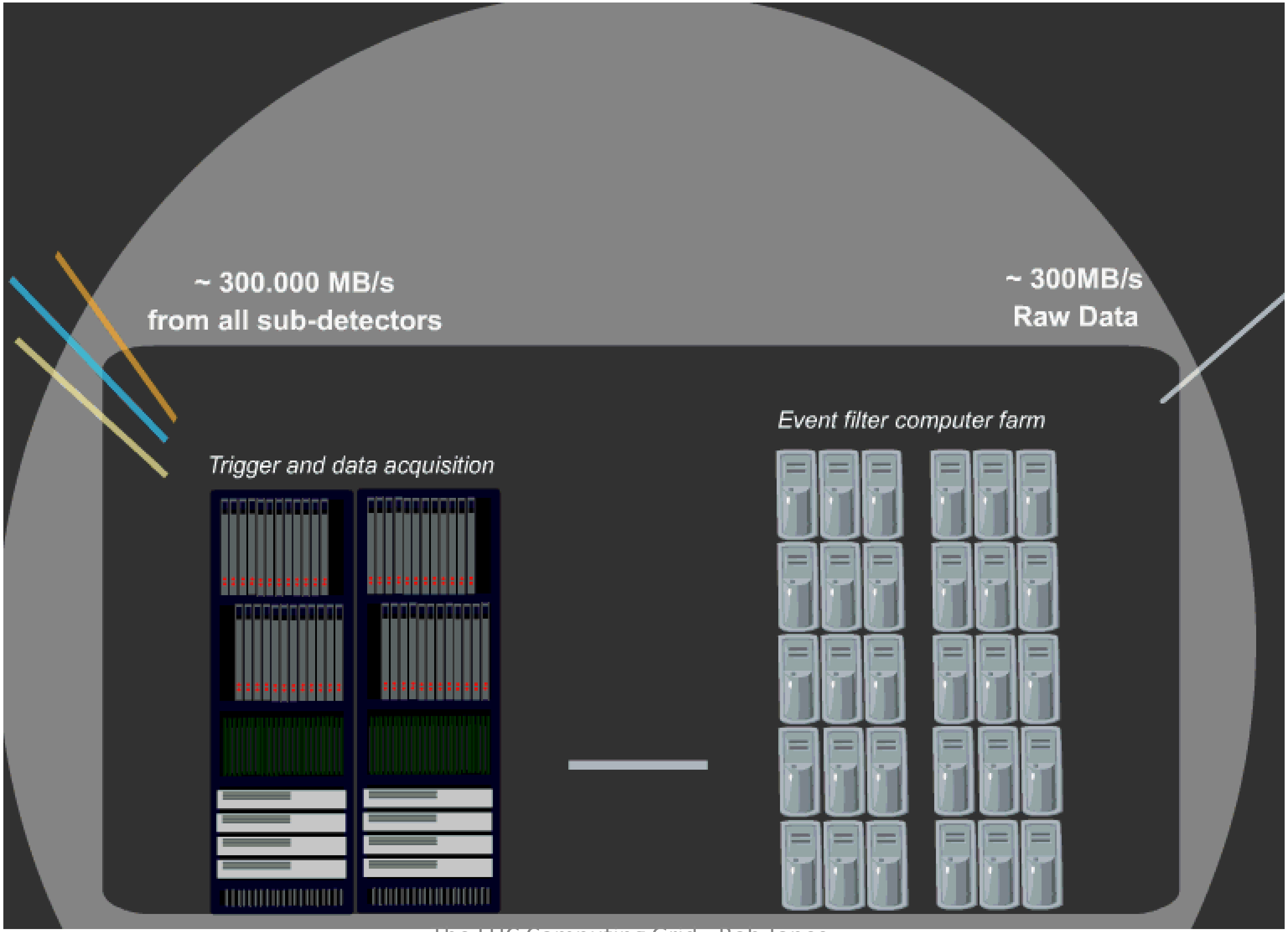
Inside the Large Hadron Collider



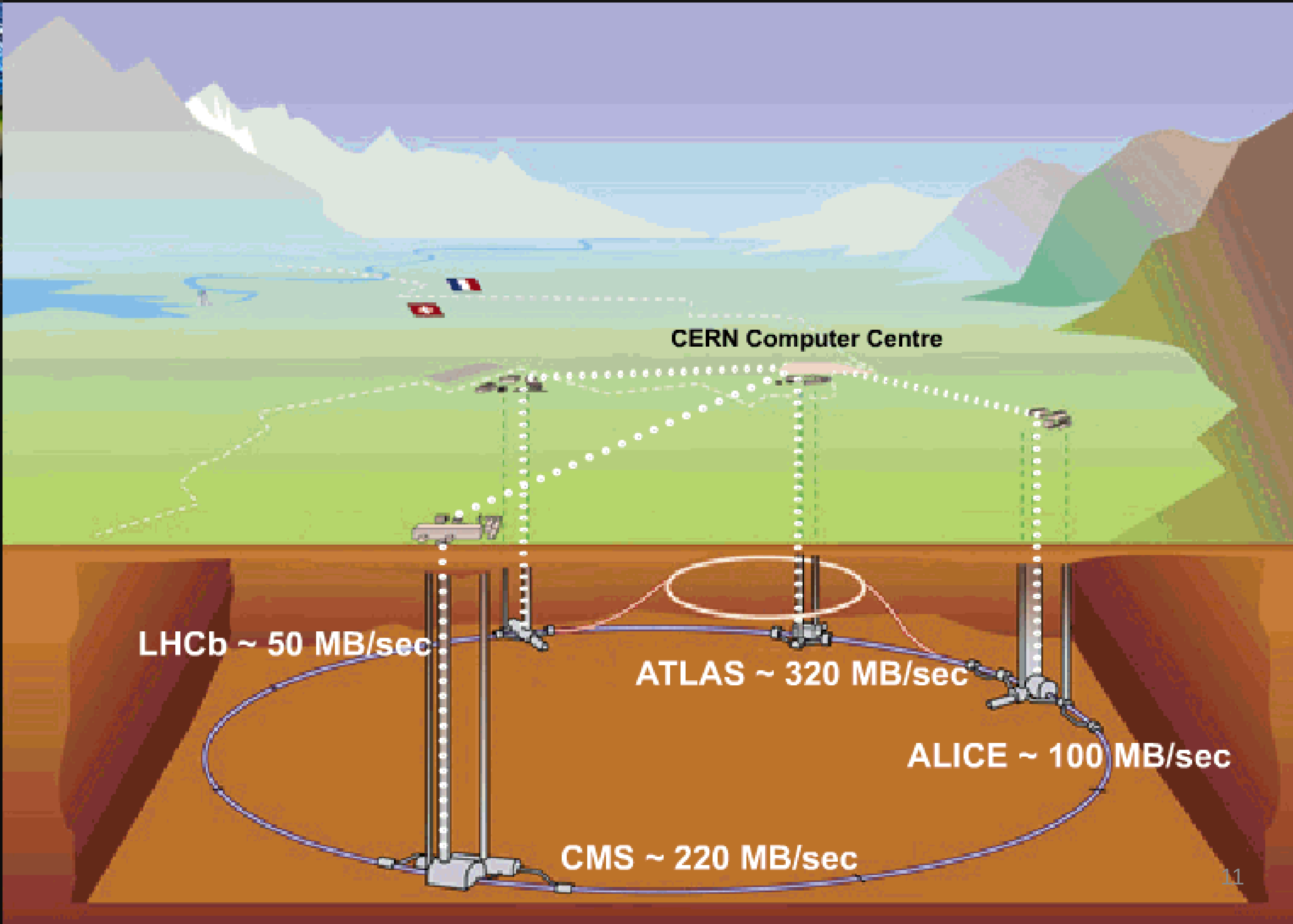
A collision @ LHC



The Data Acquisition



Data acquisition and storage for LHC @ CERN



WLCG
Worldwide LHC Computing Grid
LCG

The CERN Data Centre in Numbers

CERN IT Department

- Data Centre Operations (Tier 0)
  - 24x7 operator support and System Administration services to support 24x7 operation of all IT services.
  - Hardware installation & retirement
    - ~7,000 hardware movements/year; ~1800 disk failures/year
  - Management and Automation framework for large scale Linux clusters

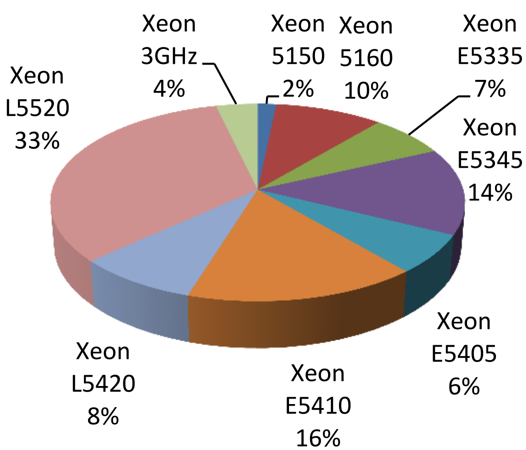
Racks	**828**
Servers	**8938**
Processors	**15,694**
Cores	**64,238**
HEPSpec06	**482,507**

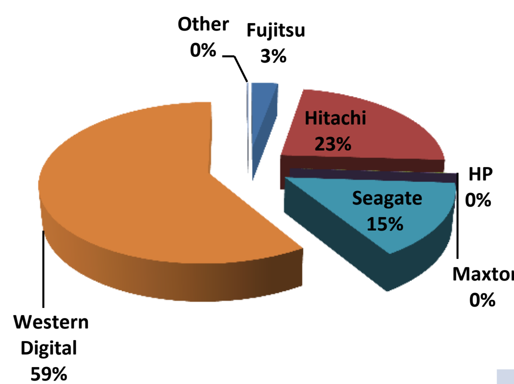
Disks	**64,109**
Raw disk capacity (TiB)	**63,289**
Memory modules	**56,014**
Memory capacity (TiB)	**158**
RAID controllers	**3,749**

Tape Drives	**160**
Tape Cartridges	**45000**
Tape slots	**56000**
Tape Capacity (TiB)	**34000**

High Speed Routers (640 Mbps → 2.4 Tbps)	**24**
Ethernet Switches	**350**
10 Gbps ports	**2000**
Switching Capacity	**4.8 Tbps**
1 Gbps ports	**16,939**
10 Gbps ports	**558**

IT Power Consumption	**2456 KW**
Total Power Consumption	**3890 KW**





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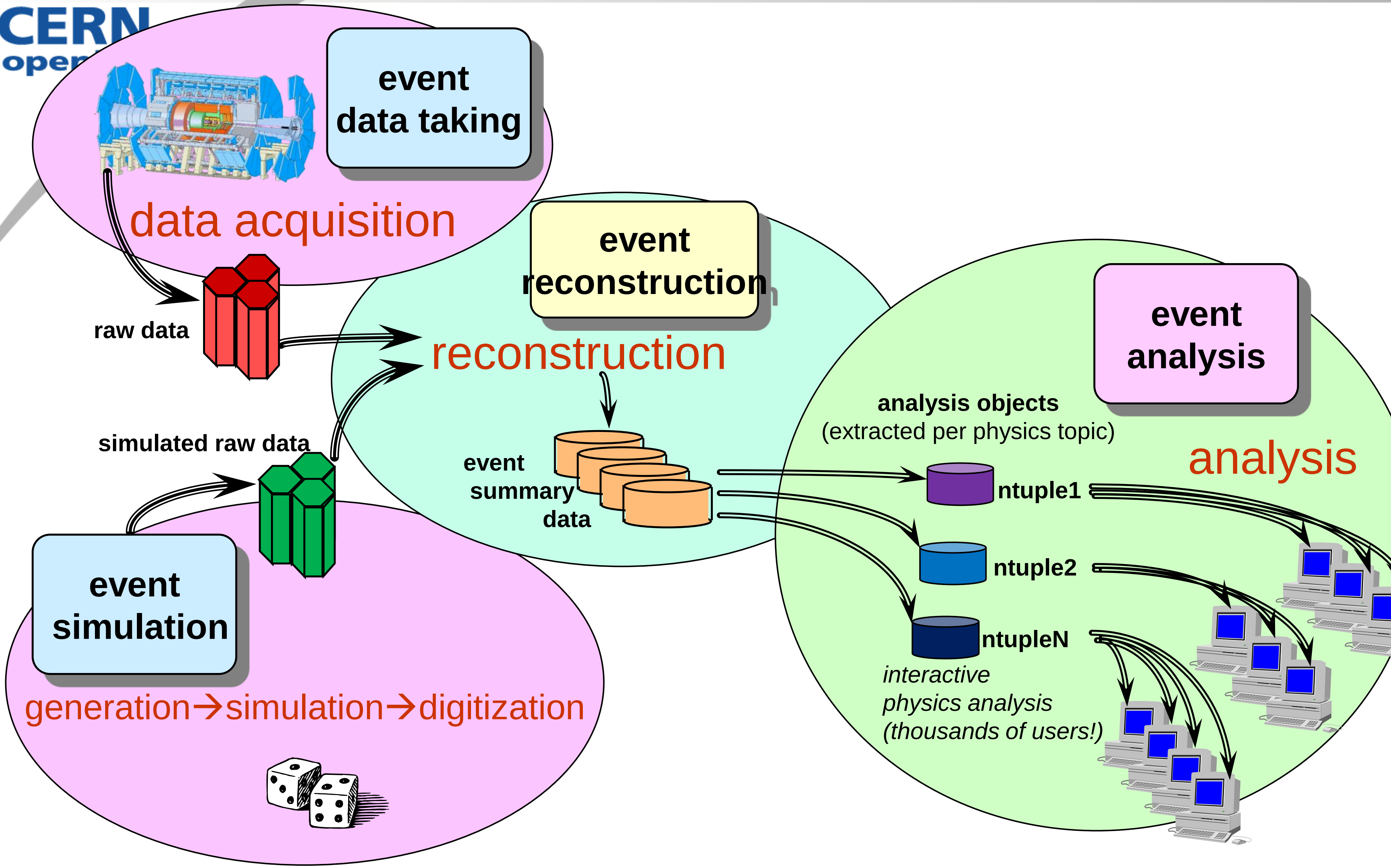
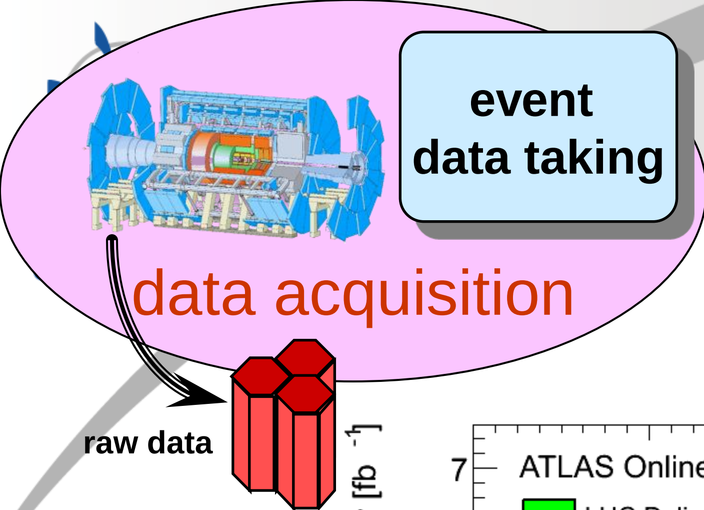
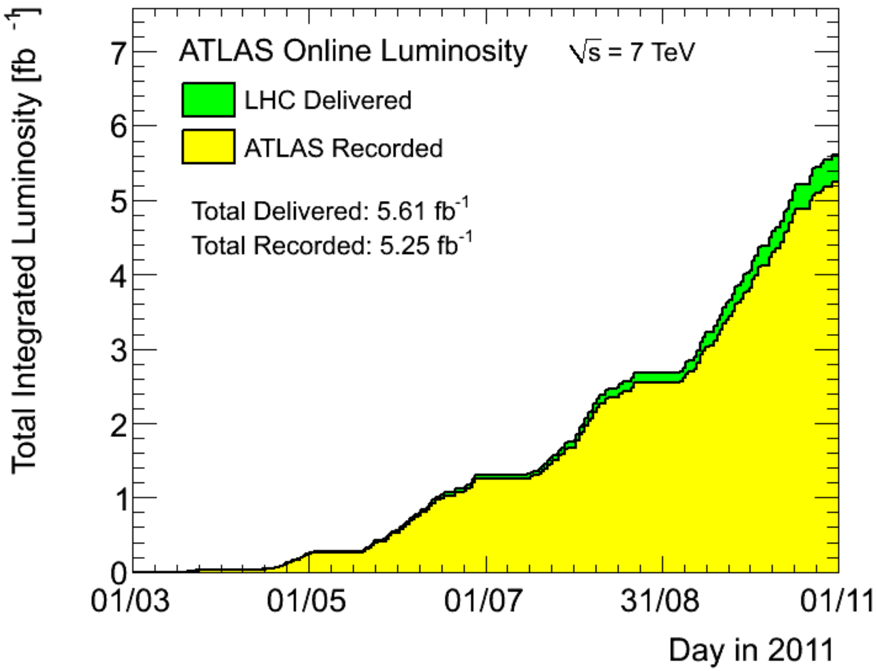
LHC-scale data processing

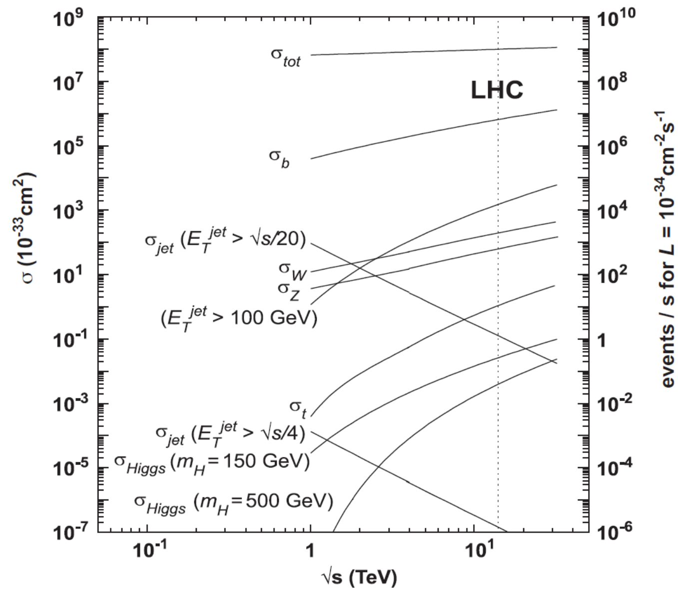




Event data taking

In 2011 LHC delivered 5.61 fb^{-1} of p-p collision data





Cross sections and event rates for various processes as a function of the proton-proton center-of-mass energy.

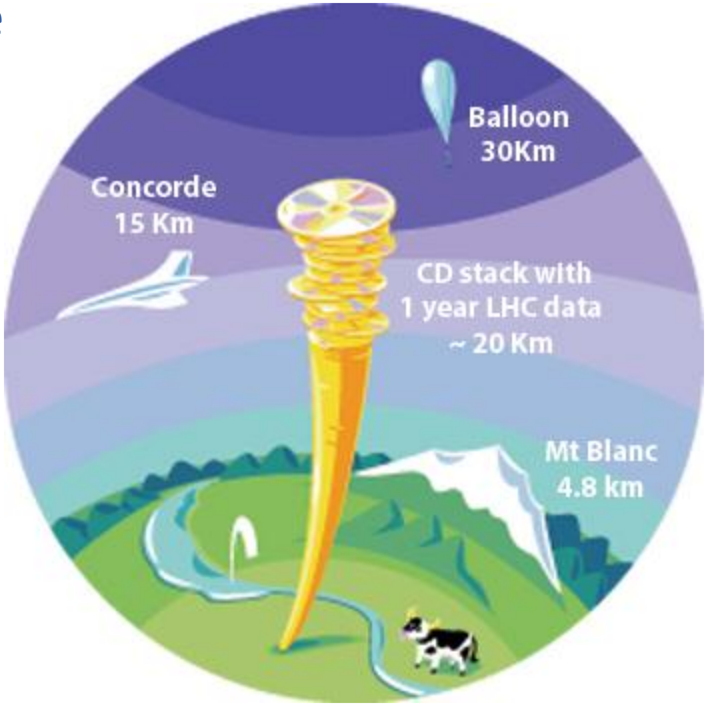
~300 billion inelastic proton-proton interactions

ATLAS uses a flexible trigger menu to determine which events are interesting enough to record…

ATLAS recorded 1.6 billion events in 2011

The LHC Data Challenge

- The accelerator will run for 20 years
- Experiments ***are*** producing more than **15 Million Gigabytes** of data each year (about 3 million DVDs – 550 years of movies!)
- LHC data analysis requires a computing power equivalent to **~100,000 of today's fastest PC processors**
- Requires many cooperating computer centres, as CERN can only provide ~20% of the capacity



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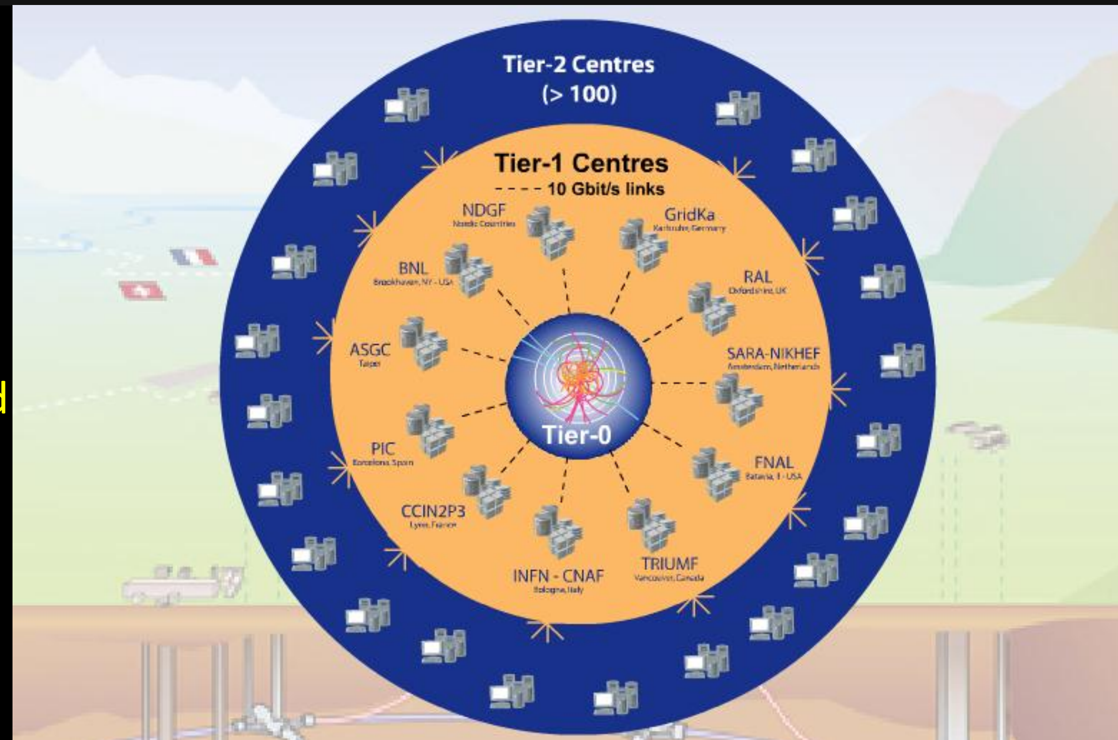
WLCG – what and why?

- A distributed computing infrastructure to provide the production and analysis environments for the LHC experiments
- Managed and operated by a worldwide collaboration between the experiments and the participating computer centres
- The resources are distributed – for funding and sociological reasons
- Our task was to make use of the resources available to us – no matter where they are located



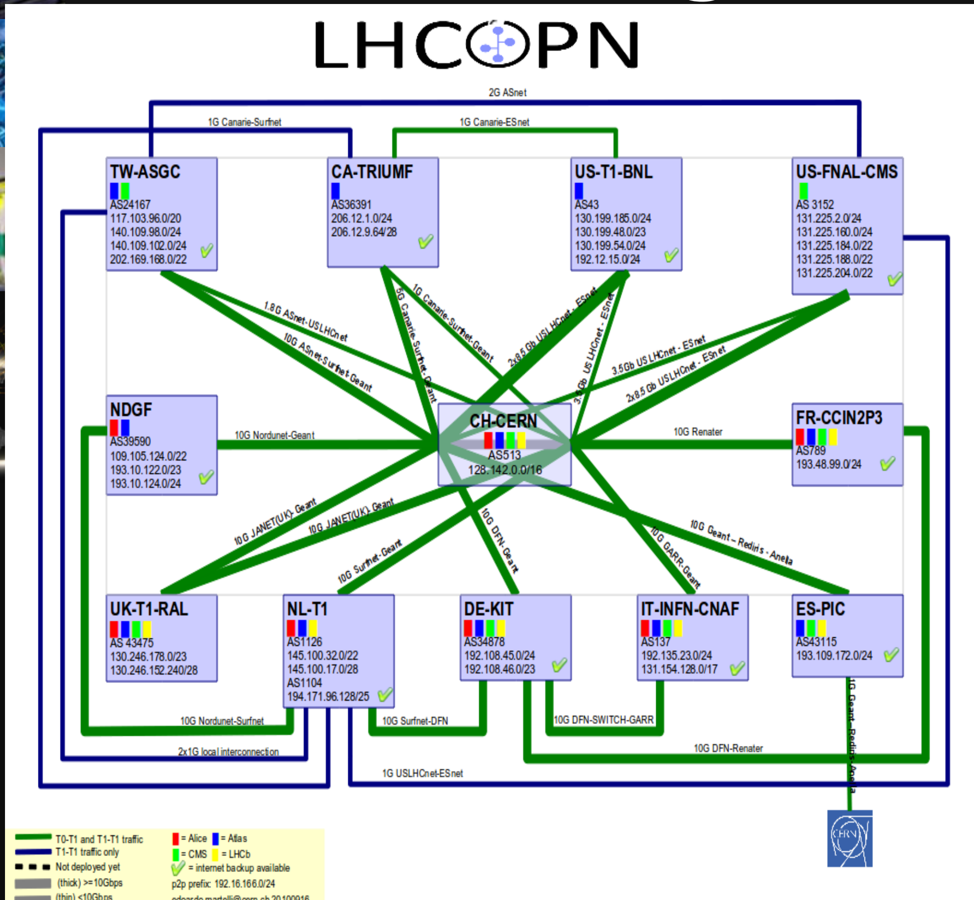
Tier-0 (CERN):
- Data recording
- Initial data reconstruction
- Data distribution

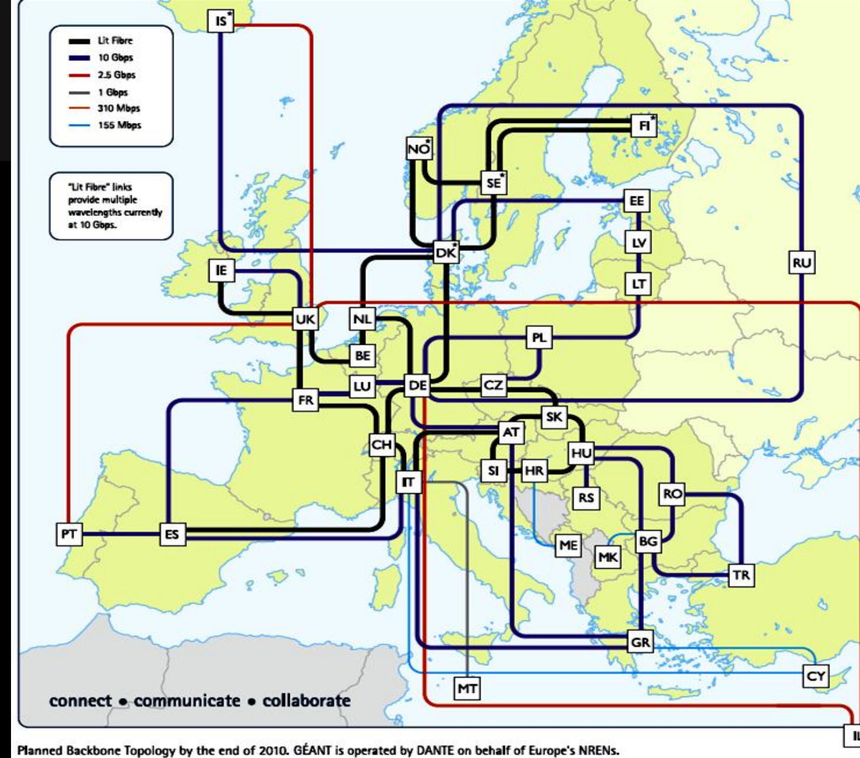
Tier-1 (11 centres):
- Permanent storage
- Re-processing
- Analysis

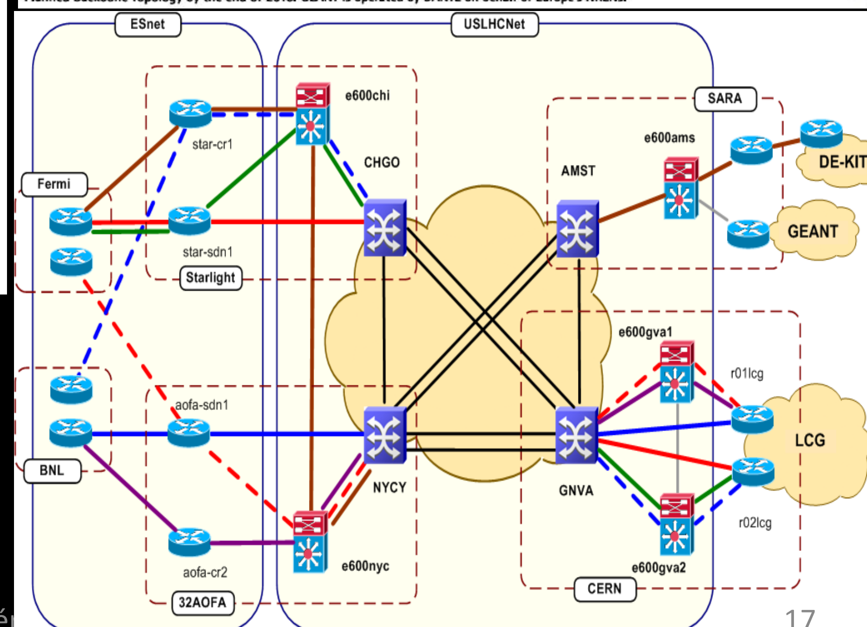
Tier-2 (~130 centres):
- Simulation
- End-user analysis

WLCG
Worldwide LHC Computing Grid

LHC Networking

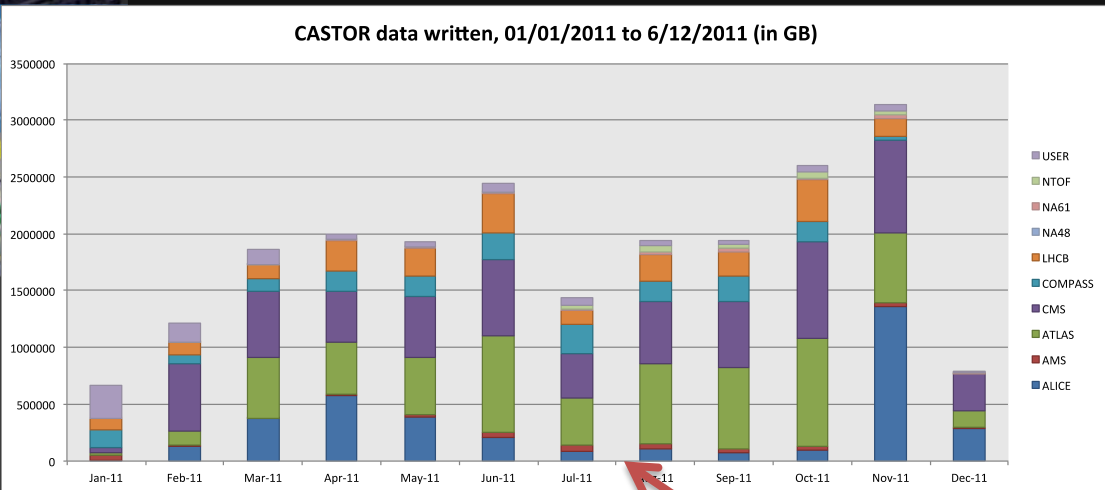


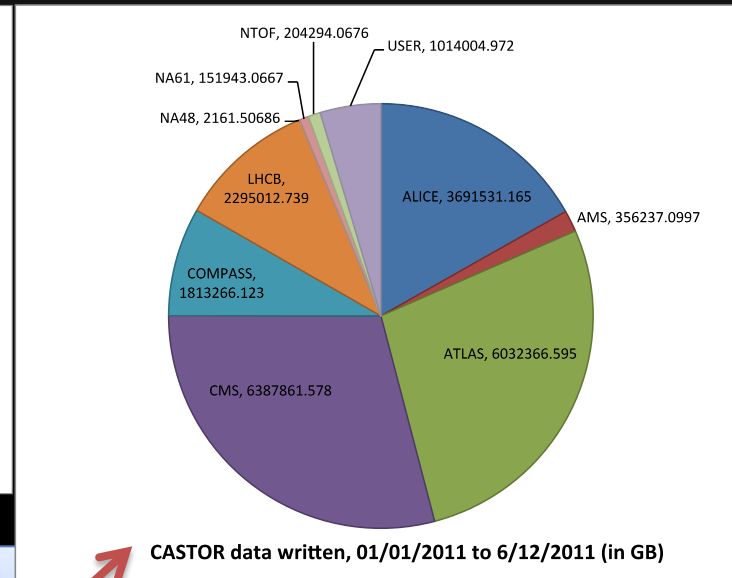




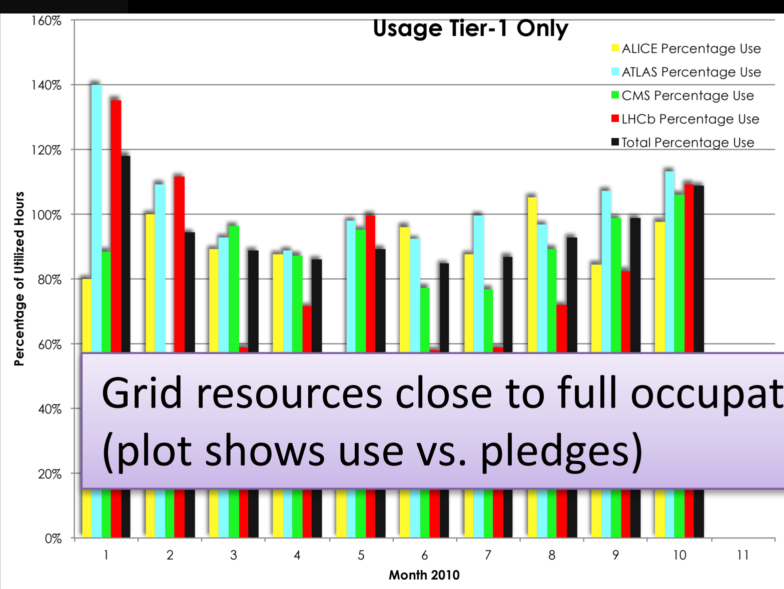
- Relies on
  - OPN, GEANT, US-LHCNet
  - NRENs & other national & international providers

WLCG in 2011

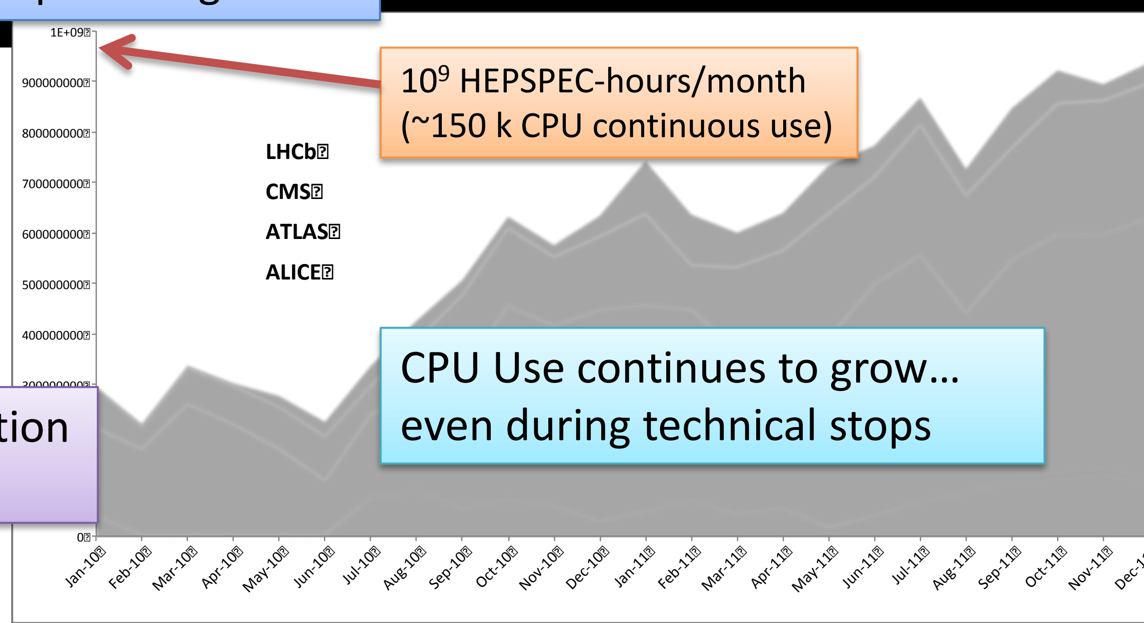




22 PB data written in 2011
More than 6 GB/s to tape during HI run



Grid resources close to full occupation
(plot shows use vs. pledges)

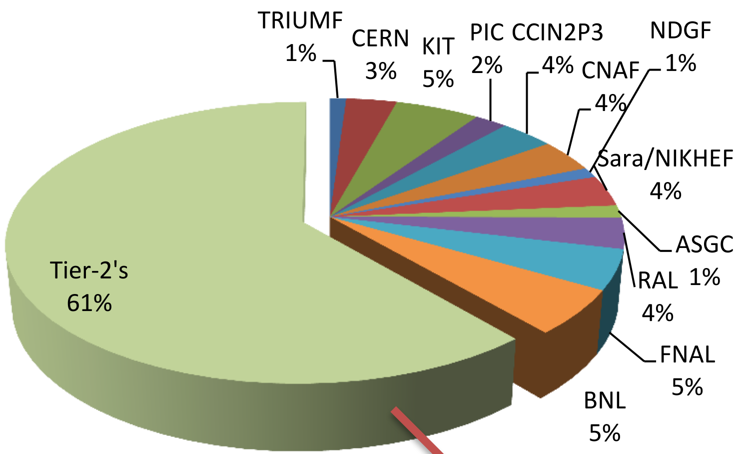


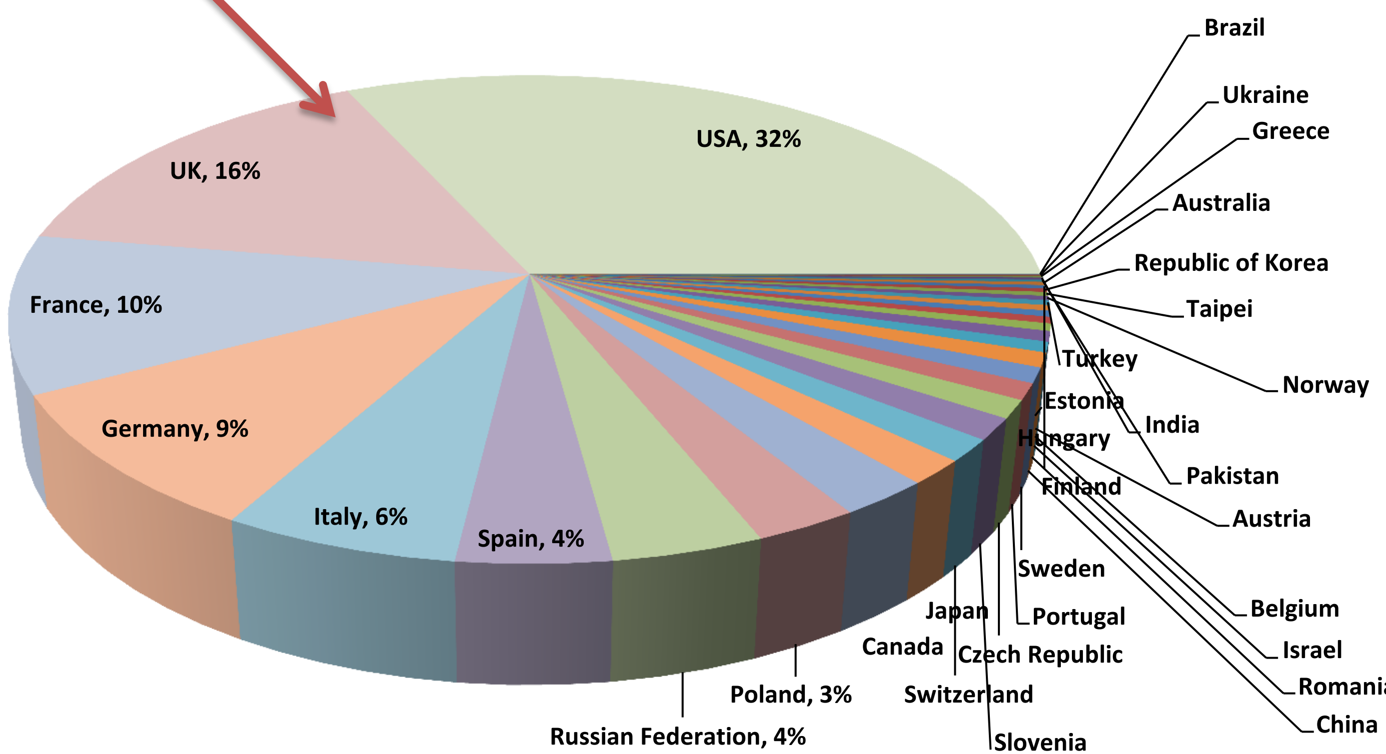
10^9 HEPSPEC-hours/month
(~150 k CPU continuous use)

CPU Use continues to grow…
even during technical stops

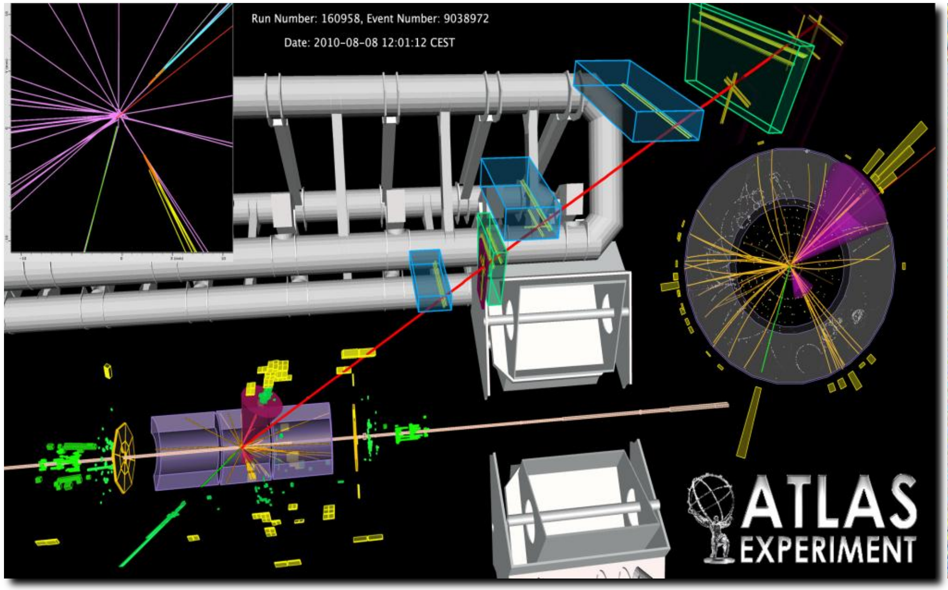
CPU – 11.2010-10.2011

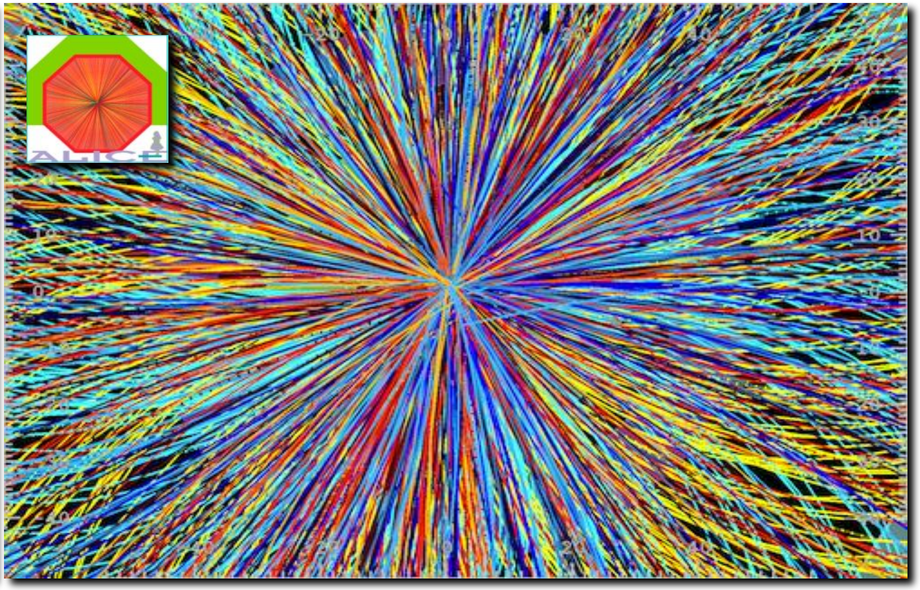
Significant use of Tier 2s for analysis

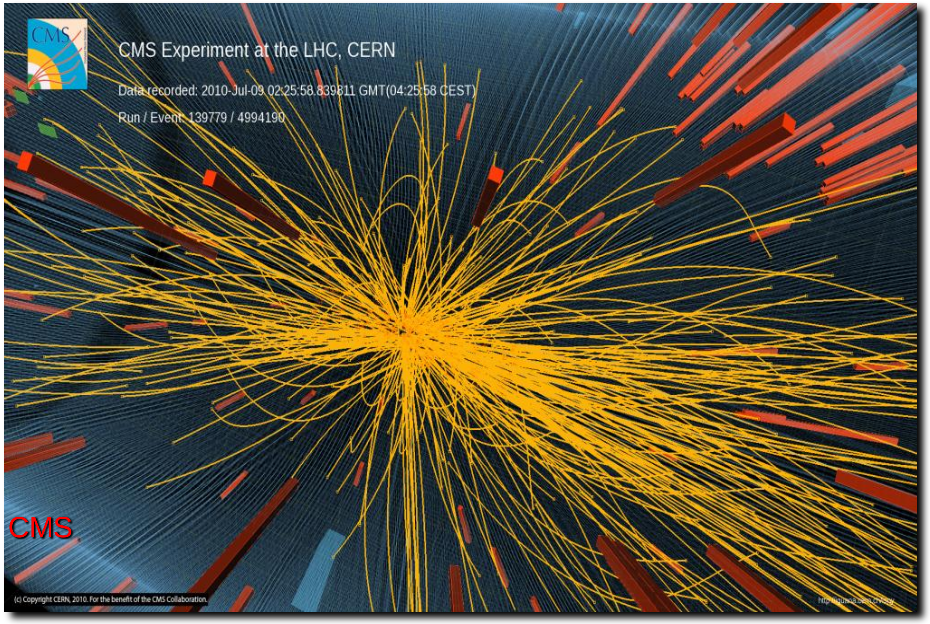


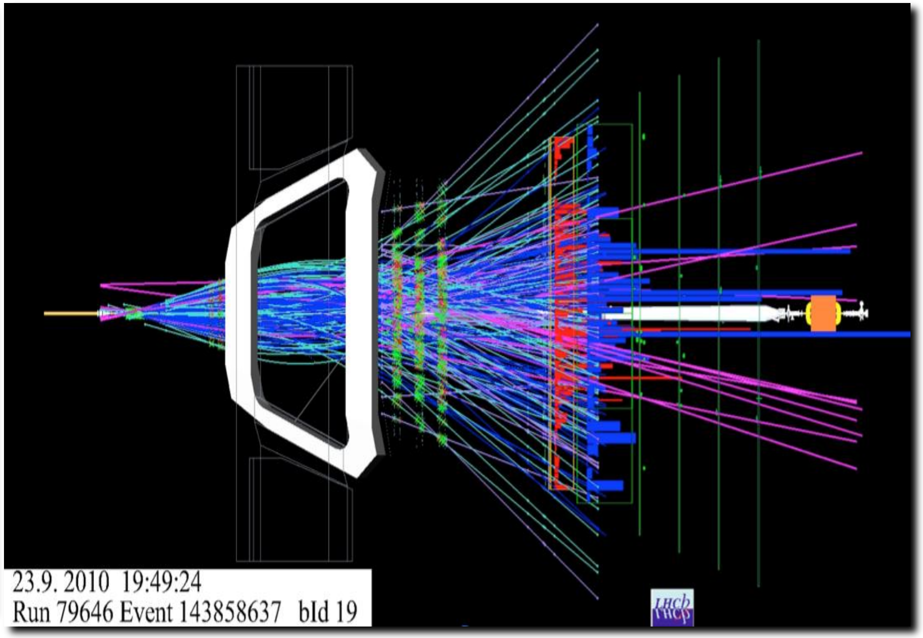


LHC @ 7 TeV


Run Number: 160958, Event Number: 9038972
Date: 2010-08-08 12:01:12 CEST
ATLAS
EXPERIMENT

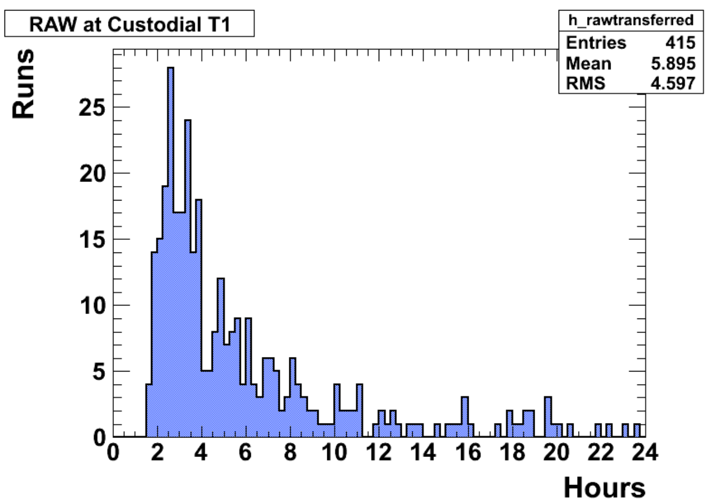

ALICE

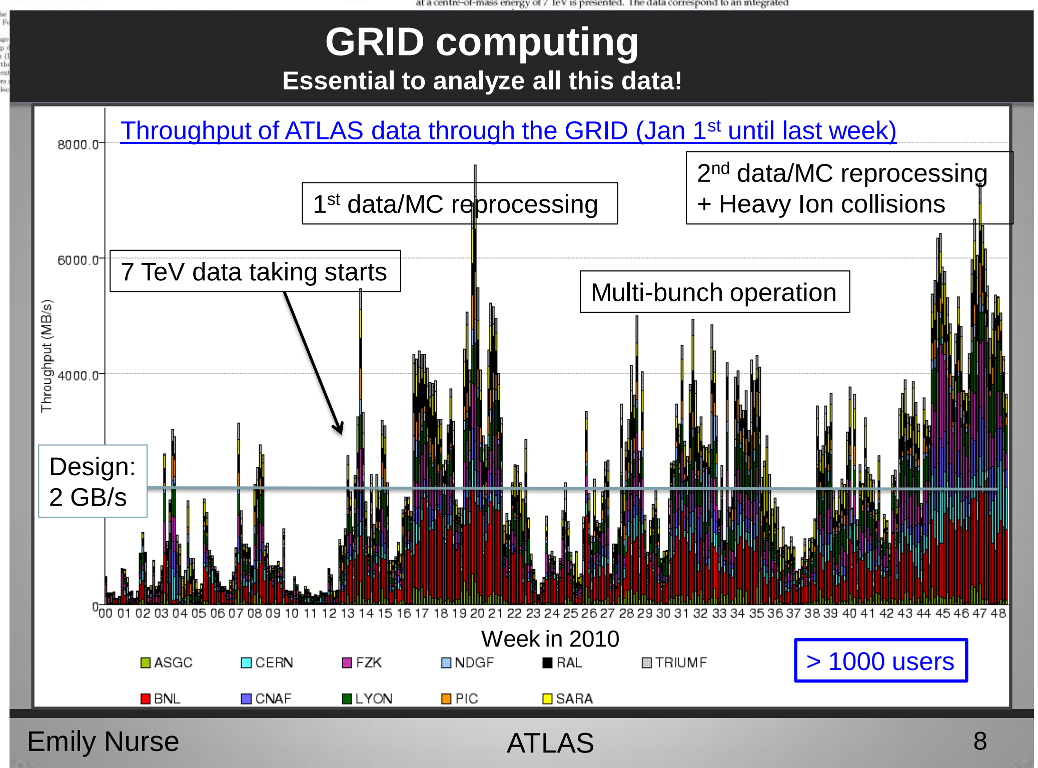

CMS Experiment at the LHC, CERN
Data recorded: 2010-Jul-09 02:25:58.839811 GMT(04:25:58 CEST)
Run / Event: 139779 / 4994190
CMS
(c) Copyright CERN, 2010. For the benefit of the CMS Collaboration.


23.9. 2010 19:49:24
Run 79646 Event 143858637 bId 19
LHCb

Data Reaches T2's within hours

CMS data to Tier-1's





13 pages of Authors / publication

Charged-particle multiplicities in pp interactions at $\sqrt{s} = 900$ GeV measured with the ATLAS detector at the LHC ☆,☆☆

ATLAS Collaboration

ARTICLE INFO

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900 GeV
ATLAS
LHC
Minimum bias

ABSTRACT

The first measurements from proton–proton collisions recorded with the ATLAS detector at th
are presented. Data were collected in December 2009 using a minimum-bias trigger during col
at a centre-of-mass energy of 900 GeV. The charged-particle multiplicity, its dependence on tran
momentum and pseudorapidity, and the relationship between mean transverse momentum and ch
particle multiplicity are measured for events with at least one charged particle in the kinematic
$|\eta| < 2.5$ and $p_T > 500$ MeV. The measurements are compared to Monte Carlo models of proton–
collisions and to results from other experiments at the same centre-of-mass energy. The charged-p
multiplicity per event and unit of pseudorapidity at $\eta = 0$ is measured to be 1.333 ± 0.003(s
0.040(syst.), which is 5–15% higher than the Monte Carlo models predict.

1. Introduction

Inclusive charged-particle distributions have been measured in pp and $p\bar{p}$ collisions at a range of different centre-of-mass energi
13]. Many of these measurements have been used to constrain phenomenological models of soft-hadronic interactions and to p
properties at higher centre-of-mass energies. Most of the previous charged-particle multiplicity measurements were obtained by sel
data with a double-arm coincidence trigger, thus removing large fractions of diffractive events. The data were then further correct
remove the remaining single-diffractive component. This selection is referred to as non-single-diffractive (NSD). In some cases, desig
as inelastic non-diffractive, the residual double-diffractive component was also subtracted. The selection of NSD or inelastic non-diffr
charged-particle spectra involves model-dependent corrections for the diffractive components and for effects of the trigger selecti
events with no charged particles within the acceptance of the detector. The measurement presented in this Letter implements a dif
strategy, which uses a single-arm trigger overlapping with the acceptance of the tracking volume. Results are presented as incl
inelastic distributions, with minimal model-dependence, by requiring one charged particle within the acceptance of the measureme
This Letter reports on a measurement of primary charged particles with a momentum component transverse to the beam dire

ATLAS Collaboration

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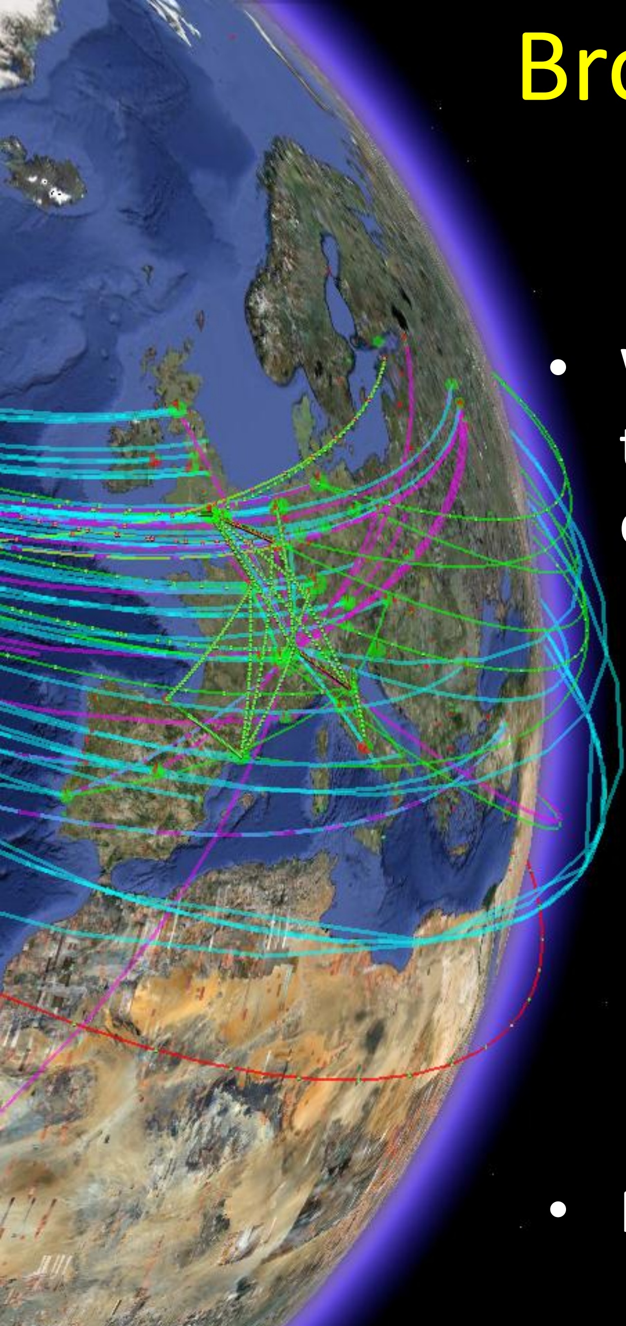


Broader Impact of the LHC Computing Grid

- WLCG has been leveraged on both sides of the Atlantic, to benefit the wider scientific community
  - Europe:
    - Enabling Grids for E-sciencE (EGEE) 2004-2010
    - European Grid Infrastructure (EGI) 2010--
  - USA:
    - Open Science Grid (OSG) 2006-2012 (+ extension?)
- Many scientific applications ➔

Archeology
Astronomy
Astrophysics
Civil Protection
Comp. Chemistry
Earth Sciences
Finance
Fusion
Geophysics
High Energy Physics
Life Sciences
Multimedia
Material Sciences
…

WLCG
Worldwide LHC Computing Grid

What is WLCG?

A distributed computing infrastructure to provide the production and analysis environments for the LHC experiments

- A collaboration
  - The resources are distributed and provided “in-kind”
- A service
  - Managed and operated by a worldwide collaboration between the experiments and the participating computer centres
- An implementation
  - Today general grid technology with high-energy physics specific higher-level services

Need to evolve the implementation while preserving the collaboration and the service

Collaboration

Coordination ,management & reporting

Coordinate resources & funding

Coordination with service & technology providers

Common requirements

Memorandum of Understanding

Framework

Service management

Service coordination

Operational security

Support processes & tools

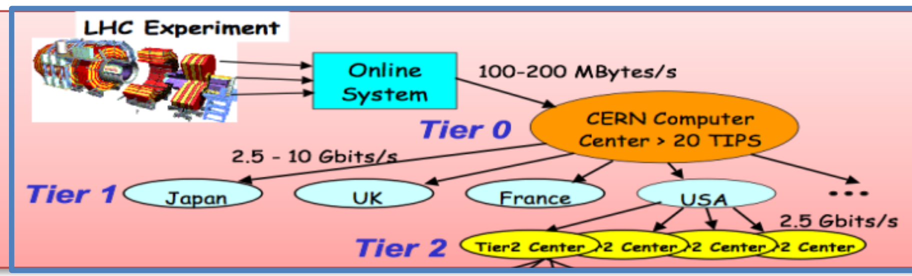
Common tools

Monitoring & Accounting

World-wide trust federation for CA's and VO's

Complete Policy framework

Distributed Computing services



Physical resources: CPU, Disk, Tape, Networks

How to evolve LHC data processing

Making what we have today more sustainable is a challenge

- Data issues
  - Data management and access
  - How to make reliable and fault tolerant systems
  - Data preservation and open access
- Need to adapt to changing technologies
  - Use of many-core CPUs
  - Global filesystem-like facilities
  - Virtualisation
- Network infrastructure
  - Has proved to be very reliable so invest in networks and make full use of the distributed system

CERN openlab in a nutshell

- A science – industry partnership to drive R&D and innovation
- Started in 2002, now in 10th year
- Evaluate state-of-the-art technologies in a challenging environment and improve them
- Test in a research environment today what will be used in industry tomorrow
- Training, Dissemination and Outreach

CERN openlab

www.cern.ch/openlab

PARTNERS

hp invent

intel

ORACLE

SIEMENS

CONTRIBUTOR (2012)

HUAWEI

A European Cloud Computing Partnership: big science teams up with big business

Strategic Plan

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

CERN: To support the computing capacity needs for the ATLAS experiment

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

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

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Timeline

Set-up (2011)

- Select flagships use cases
- Identify service providers
- Define governance model

Pilot phase (2012-2014)

- Deploy flagships
- Analysis of functionality, performance & financial model
- Success Stories

Full-scale cloud service market (2014 …)

- More applications
- More services
- More users,
- More service providers

Pilot Phase

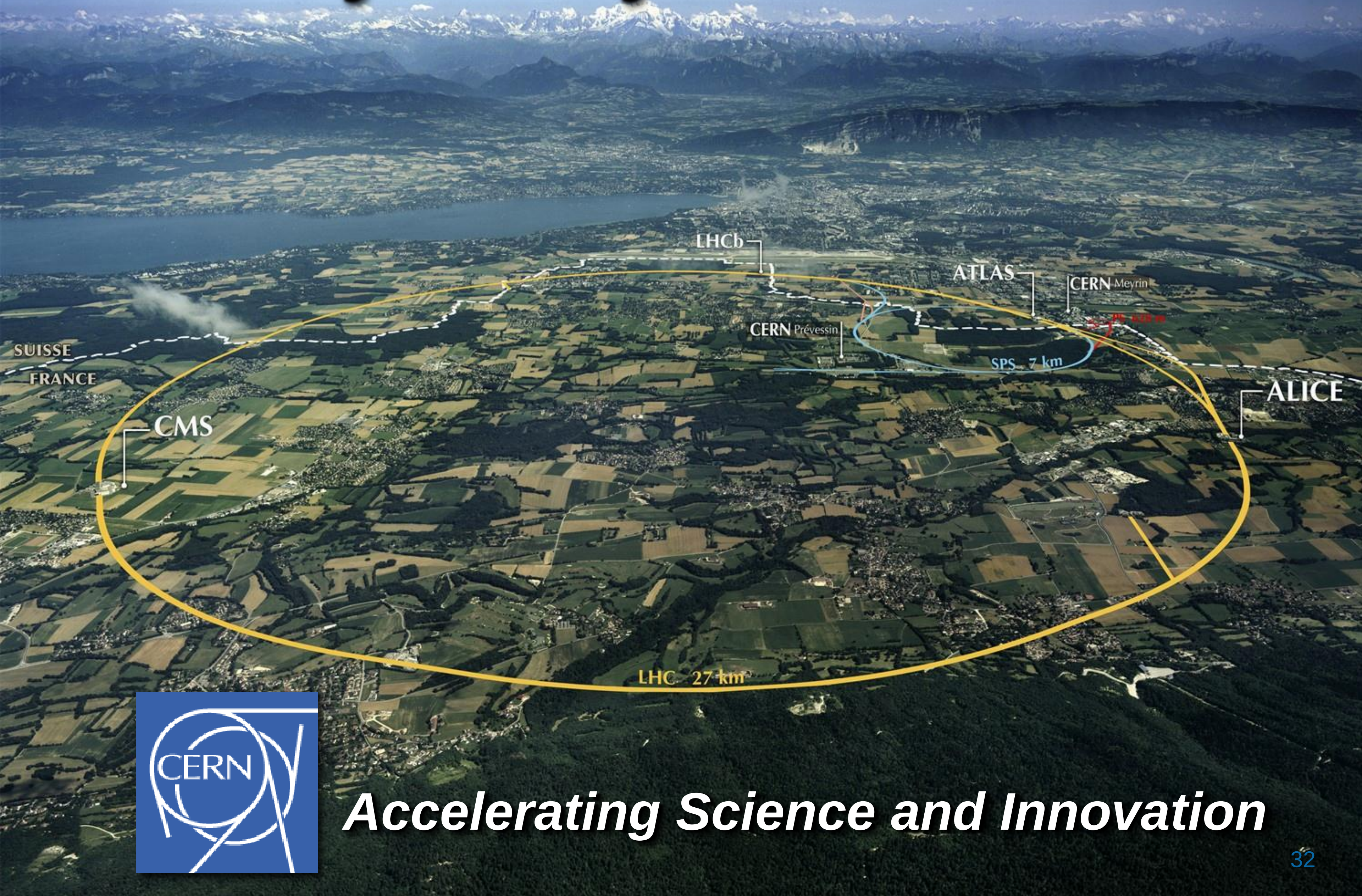
Explore / push a series of perceived barriers to Cloud adoption:

- **Security**: Unknown or low compliance and security standards
- **Reliability**: Availability of service for business critical tasks
- **Data privacy**: Moving sensitive data to the Cloud
- **Scalability / Elasticity**: Will the Cloud scale-up to our needs
- **Network performance**: Data transfer bottleneck; QoS
- **Integration**: Hybrid systems with in-house / legacy systems
- **Vendor lock-in**: Vendor dependency once data & applications are transferred to the Cloud
- **Legal concerns**: liability, jurisdiction, intellectual property
- **Transparency**: Clarity of conditions, terms and pricing

What will change in the coming years

- Massive adoption of virtualisation techniques by e-Science centres
  - To reduce operation costs
  - To simplify deployment of applications using images
  - To simplify middleware
- Federated identity system
  - Shibboleth/OpenID style network of trust
- “Grid extensions” added to clouds (first private then public)
  - Federated identity system, support for virtual organisations, etc.
  - Use of commercial cloud services as extensions to in-house resources
- Blurring of the borders between elements of e-infrastructure (networking, grid & supercomputing)
  - Because the users & funding agencies demand it
- Emergence of a data e-infrastructure

Thank you for your attention



Accelerating Science and Innovation