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 UNESCO
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

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
- MALTA: 1
- MEXICO: 39
- MONTENEGRO: 1
- MOROCCO: 7
- F.Y.R.O.M.: 3
- THAILAND: 1
- TUNISIA: 1
- UKRAINE: 19
- UNITED STATES: 1786

OBSERVER STATES
- INDIA: 109
- ISRAEL: 60
- JAPAN: 190
- RUSSIA: 822
- TURKEY: 79

TOTAL USERS: 6542
TOTAL OBSERVER STATES: 3046
TOTAL OTHERS: 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

LHC ring:
27 km circumference
Inside the Large Hadron Collider
The ATLAS experiment

The LHC Computing Grid

Bob Jones September 2011

7000 tons, 150 million sensors generating data 40 million times per second i.e. a petabyte/s
A collision @ LHC
The Data Acquisition

The LHC Computing Grid - Bob Jones
September 2011
Data acquisition and storage for LHC @ CERN

- LHCb ~ 50 MB/sec
- ATLAS ~ 320 MB/sec
- ALICE ~ 100 MB/sec
- CMS ~ 220 MB/sec
The CERN Data Centre in Numbers

- **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

<table>
<thead>
<tr>
<th>Racks</th>
<th>828</th>
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<tr>
<td>Servers</td>
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<td>Raw disk capacity (TiB)</td>
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<tr>
<td>Memory modules</td>
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<tr>
<td>Memory capacity (TiB)</td>
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</tr>
<tr>
<td>RAID controllers</td>
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</tr>
</tbody>
</table>

| 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  |
| 1 Gbps ports            | 16,939|
| 10 Gbps ports           | 558   |

| IT Power Consumption    | 2456 KW|
| Total Power Consumption | 3890 KW|

May 2012 - Frédéric Hemmer
LHC-scale data processing

- Data acquisition
  - Raw data
  - Simulated raw data

- Event data taking

- Event reconstruction
  - Event summary data
  - Analysis objects (extracted per physics topic)

- Event analysis
  - Interactive physics analysis (thousands of users!)

- Event generation → Simulation → Digitization

- Data acquisition flow:
  - Raw data → Event data taking → Event reconstruction → Event analysis

- Analysis objects:
  - ntuple1
  - ntuple2
  - ntupleN

- Interactive analysis

LHC physics analysis and databases - M. Limper - 13 March 2012
In 2011 LHC delivered 5.61 fb\(^{-1}\) of p-p collision data

\~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
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
Relies on

- OPN, GEANT, US-LHCNet
- NRENs & other national & international providers
22 PB data written in 2011
More than 6 GB/s to tape during HI run

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

CPU Use continues to grow... even during technical stops

Grid resources close to full occupation (plot shows use vs. pledges)
CPU – 11.2010-10.2011

Significant use of Tier 2s for analysis

Tier-2's 61%

USA, 32%

UK, 16%

France, 10%

Germany, 9%

Italy, 6%

Spain, 4%

Poland, 3%

Russian Federation, 4%

Switzerland

Slovenia

Japan

Portugal

Czech Republic

Canada

Brazil

Ukraine

Greece

India

Pakistan

Australia

Finland

Republic of Korea

Taipei

Norway

Turkey

Estonia

Hungary

Austria

Belgium

Israel

Romania

China

Tier -2's

1%

3%

5%

2%

4%

4%

1%

1%

4%

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1%

5%

TRIUMF

CERN

KIT

PIC CCIN2P3

CNAF

Sara/NIKHEF

ASGC

RAL

FNAL

BNL

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Norway

Turkey

Estonia

Hungary

Austria

Belgium

Israel

Romania

China

Tier -2's

1%

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PIC CCIN2P3

CNAF

Sara/NIKHEF

ASGC

RAL

FNAL

BNL

CERN

3%

5%

4%
LHC @ 7 TeV
Data Reaches T2’s within hours

Throughput of ATLAS data through the GRID (Jan 1st until last week)

1st data/MC reprocessing
2nd data/MC reprocessing + Heavy Ion collisions

7 TeV data taking starts
Multi-bunch operation

Design: 2 GB/s

Emily Nurse
ATLAS

> 1000 users
Charged-particle multiplicities in pp interactions at $\sqrt{s} = 900$ GeV measured with the ATLAS detector at the LHC

Abstract

The first measurements from proton-proton collisions recorded with the ATLAS detector at the LHC are presented. Data were collected in December 2008 using a minimum-bias trigger during collisions at a centre-of-mass energy of 900 GeV. The charged-particle multiplicity, its dependence on transverse momentum and pseudorapidity, and the relationship between measured transverse-momentum and charged-particle multiplicities are measured for events with at least one charged particle in the kinematic range $|\eta| < 1.2$ and $p_T > 100$ MeV. The measurements are compared to Monte Carlo models of proton-proton collisions and results are obtained from other experiments at the same centre-of-mass energy. The charged-particle multiplicity per event and the cumulative factorial distribution in the laboratory frame are presented. A factorial fit to the charged-particle multiplicity distribution gives a good description of the data.

1. Introduction

Inclusive charged-particle distributions have been measured in pp and p+p collisions at a range of different centre-of-mass energies. Many of these measurements have been used to constrain phenomenological models of soft-hadronic interactions and to properties at higher centre-of-mass energies. Most of the previous charged-particle multiplicity measurements were obtained using data with a dE/dx trigger, which does not remove the single-diffractive component. This selection is referred to as non-single-diffractive (NSD). In some cases, data from an inclusive trigger were also recorded. The inclusive charged-particle spectra involves model-dependent corrections for the diffractive components and for effects of the trigger selection events with no charged particles within the acceptance of the detector. The measurement presented in this Letter fulfils this criterion, which is a single-track trigger which accepts the correct track, observed inclusive distributions, with minimal model-dependence, by requiring one charged particle within the acceptance of the measurement. This Letter reports the measurements of several charged-particle interactions with a momentum transverse mass greater than the beam energy.
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 ➔
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
What is WLCG today?

Service coordination
Service management
Operational security
Support processes & tools
Common tools
Monitoring & Accounting
World-wide trust federation for CA’s and VO’s
Complete Policy framework
Memorandum of Understanding
Coordinate resources & funding
Common requirements
Coordination with service & technology providers
Coordination, management & reporting
Collaboration

Distributed Computing services
Physical resources: CPU, Disk, Tape, Networks

The LHC Computing Grid - Bob Jones
September 2011
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
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

To support the computing capacity needs for the ATLAS experiment

To set 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

Email: contact@helix-nebula.eu  Twitter: HelixNebulaSC  Facebook: HelixNebula.TheScienceCloud
• Select flagships use cases
• Identify service providers
• Define governance model

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

• More applications
• More services
• More users,
• More service providers

**Timeline**

Set-up (2011)

Pilot phase (2012-2014)

Full-scale cloud service market (2014 … )
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