Solving the Mysteries of the Universe with Big Data

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Accelerating Science and Innovation

What is CERN?

- The European Particle Physics Laboratory based in Geneva, Switzerland
  - Current accelerator: The Large Hadron Collider (LHC)
- Founded in 1954 by 12 countries for fundamental physics research in a post-war Europe
- Today, it is a global effort of 20 member countries and scientists from 110 nationalities, working on the world's most ambitious physics experiments
- ~2'300 personnel, > 10'000 users
- ~1 billion CHF yearly budget

CERN openlab

- **A unique research partnership between CERN and the ICT industry**
- Objective: The advancement of cutting-edge computing solutions to be used by the worldwide Large Hadron Collider (LHC) community

CERN openlab

www.cern.ch/openlab

Partners

HP

HUAWEI

intel

ORACLE

SIEMENS

Contributors

rackspace
the open cloud company

Associates

Yandex

WHY do we need a “CERN”?

Fundamental Physics Questions

- What is 95% of the Universe made of?
  - We only observe a fraction! What is the rest?
- Why is there no antimatter left in the Universe?
  - Nature should be symmetrical, or not?
- What was matter like during the first second of the Universe, right after the "Big Bang"?
  - A journey towards the beginning of the Universe gives us deeper insight
- Why do particles have mass?
  - Newton could not explain it – the Higgs mechanism seems now to be the answer

CERN has built the LHC to enable us to look at microscopic big bangs to understand the fundamental behaviour of nature

CERN

So, how do you get from this ←

to this →

Higgs boson-like particle discovery claimed at LHC

COMMENTS (1665)

By Paul Rincon
Science editor, BBC News website, Geneva

The moment when Cern director Rolf Heuer confirmed the Higgs results

Cern scientists reporting from the Large Hadron Collider (LHC) have claimed the discovery of a new particle consistent with the Higgs boson.

Relat

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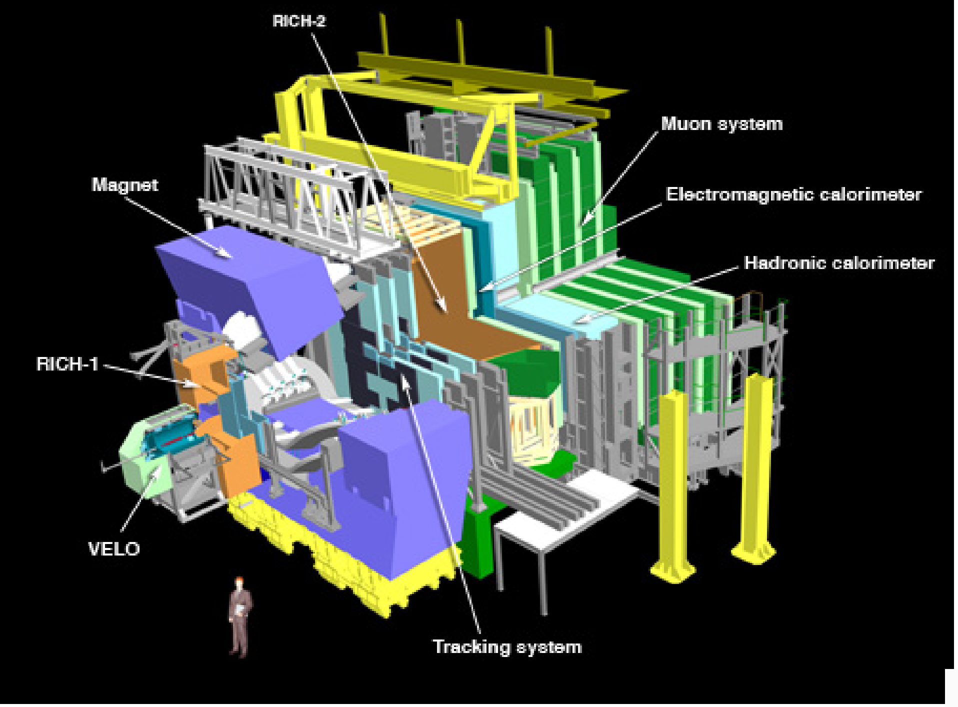
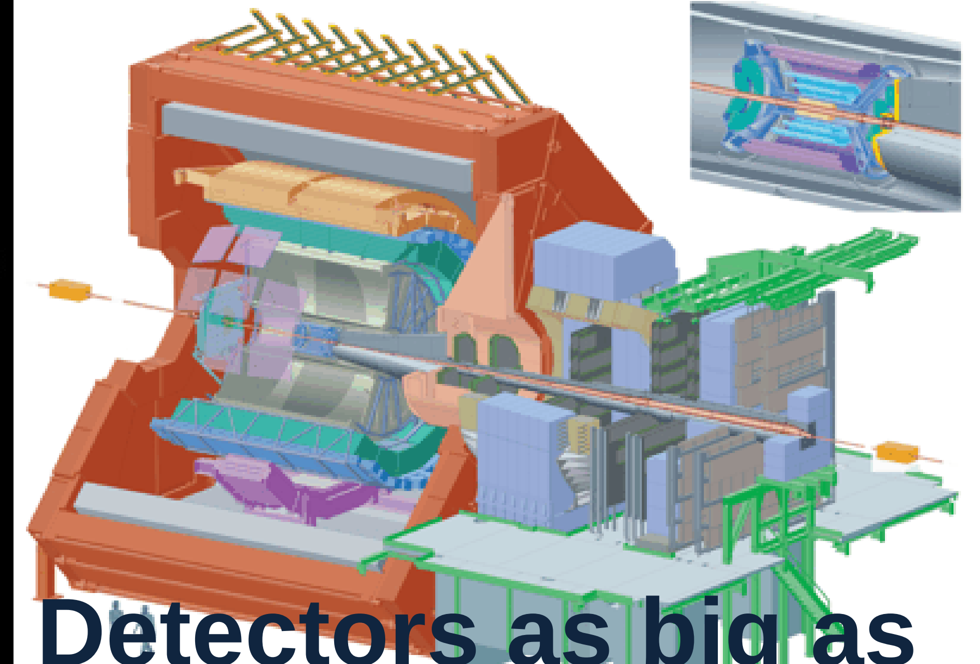
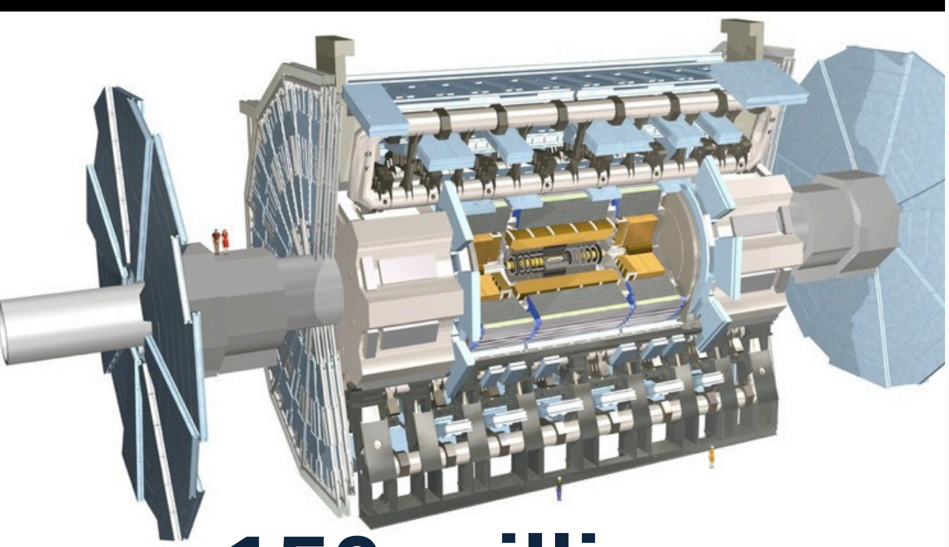
Some facts about the LHC

- Biggest accelerator (largest machine) in the world
  - 27 km circumference, 9300 magnets
- Fastest racetrack on Earth
  - Protons circulate 11245 times/s (99.9999991% the speed of light)
- Emptiest place in the solar system – high vacuum inside the magnets:
  - Pressure 10^{-13} atm (10x less than pressure on the moon)
- World's largest refrigerator: -271.3 ° C (1.9K)
- Hottest spot in the galaxy
  - During Lead ion collisions create temperatures 100 000x hotter than the heart of the sun; new record 5.5 Trillion K
- World's biggest and most sophisticated detectors
  - 150 Million "pixels"
- Most data of any scientific experiment
  - 15-30 PB per year





Detectors as big as 5-storey buildings

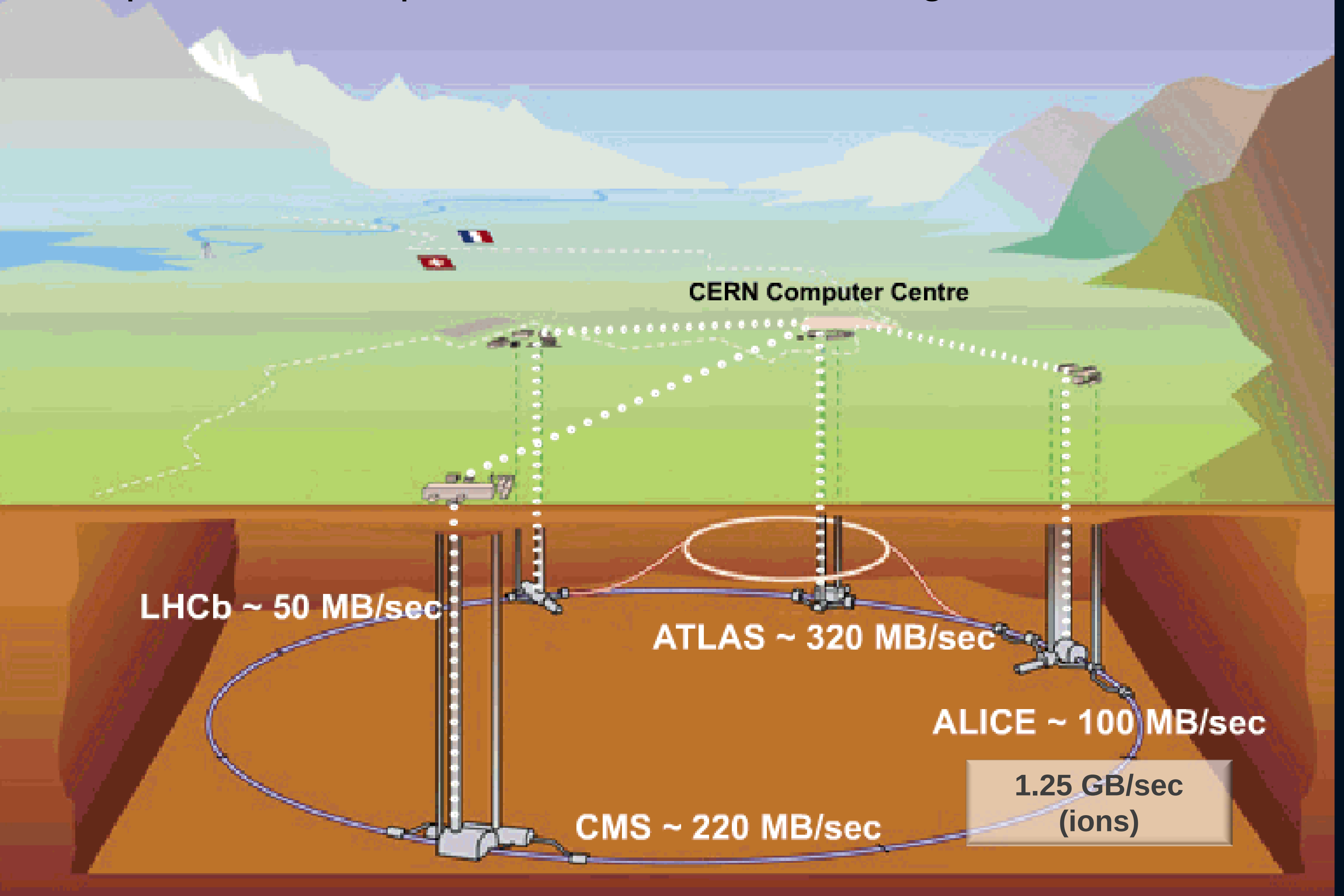


150 million sensors deliver data …

… 40 million times per second

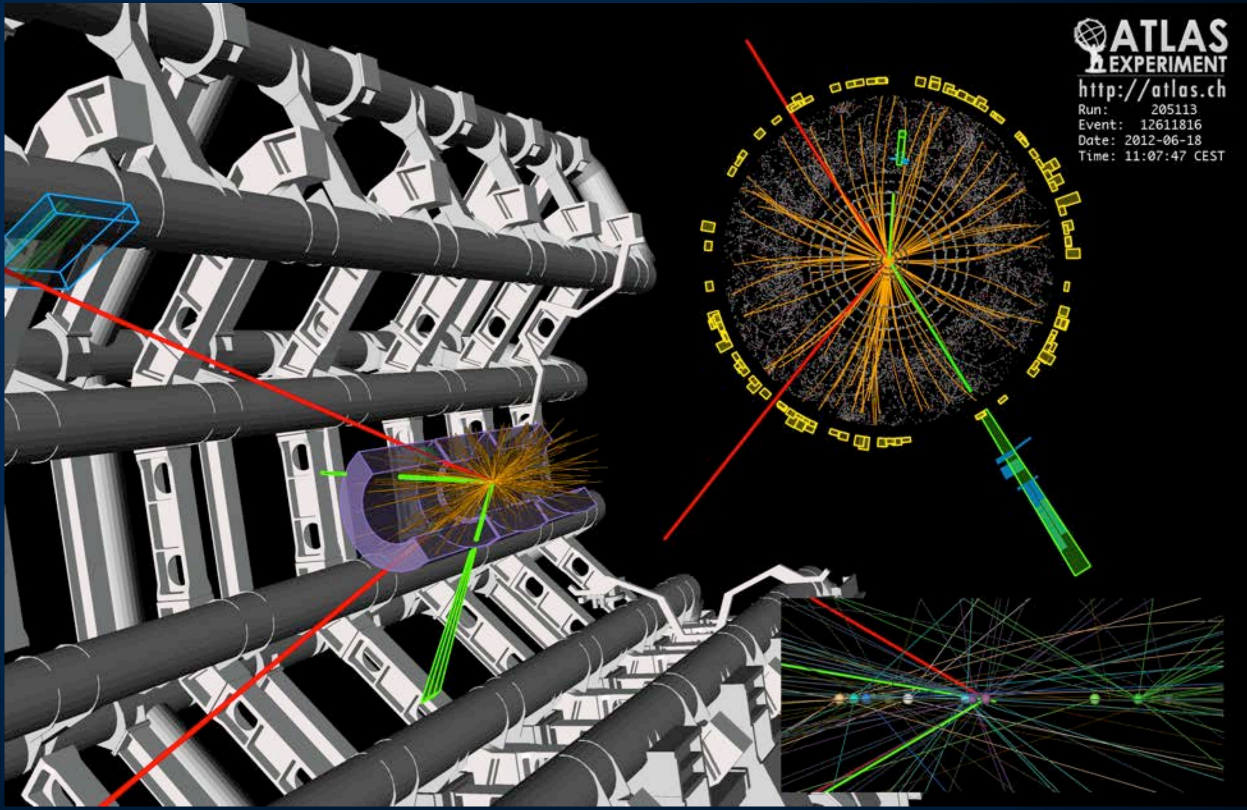
Tier 0 at CERN:

Acquisition, First pass reconstruction, Storage & Distribution

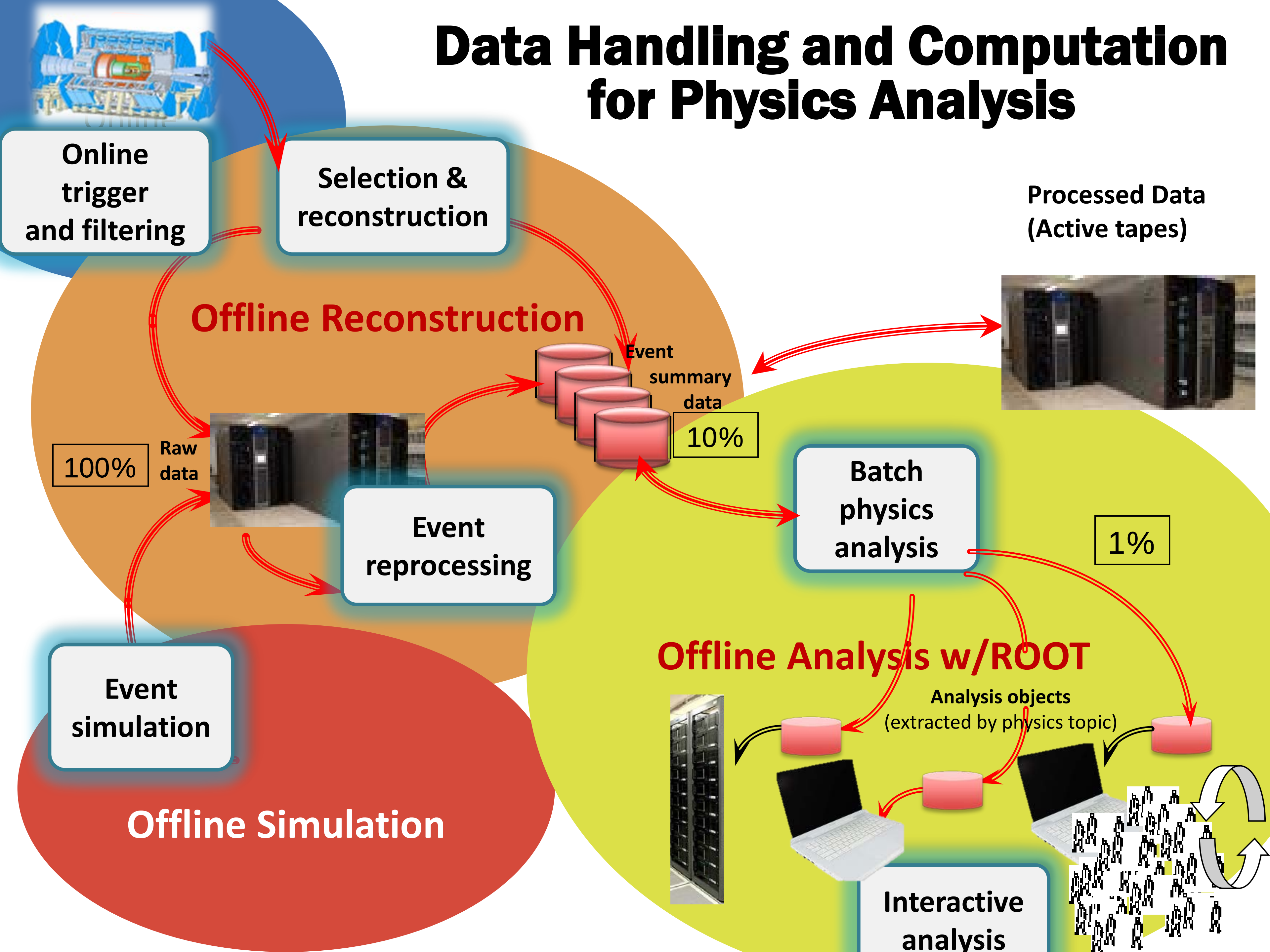


What is this data?

- Raw data:
  - Was a detector element hit?
  - How much energy?
  - What time?
- Reconstructed data:
  - Particle type
  - Origin
  - Momentum of tracks (4-vectors)
  - Energy in clusters (jets)
  - Calibration information

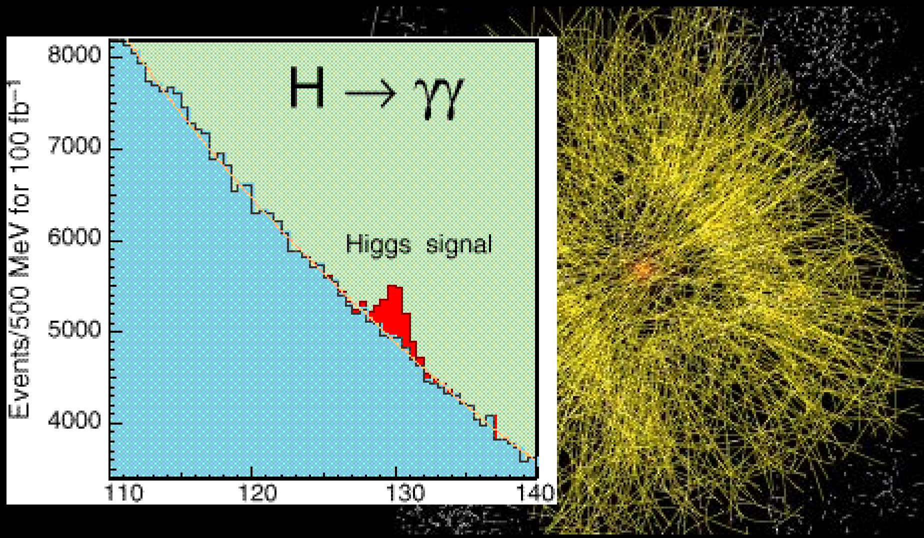


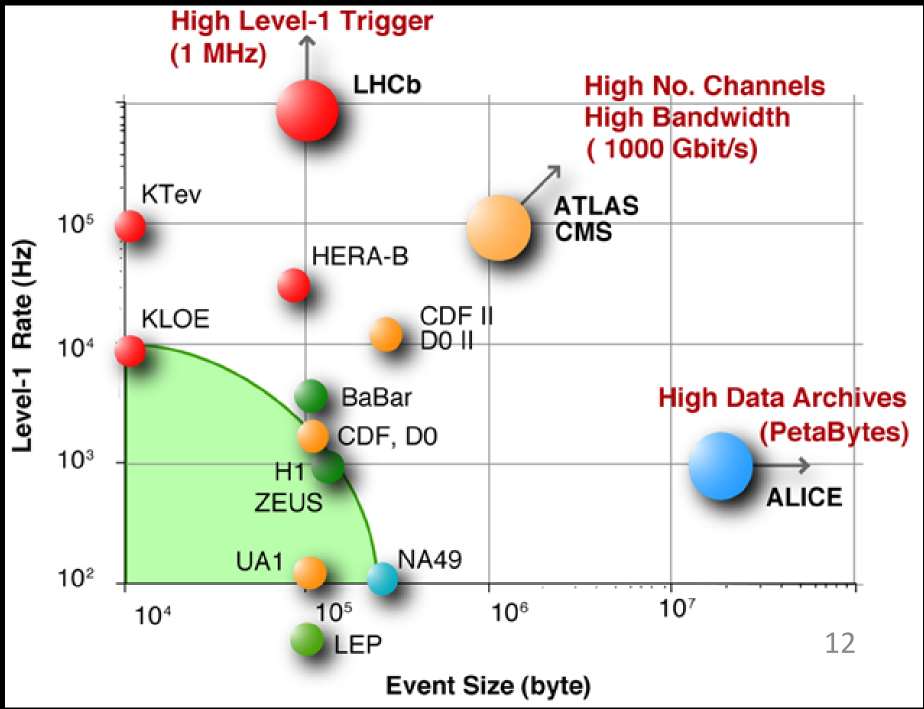
Data Handling and Computation for Physics Analysis



The LHC Computing Challenge

- Signal/Noise: 10^{-13} (10^{-9} offline)
- Data volume
  - High rate * large number of channels * 4 experiments
  - ➔ **15 PetaBytes of new data each year** → 30 PB in 2012
- Overall compute power
  - Event complexity * Nb. events * thousands users
  - ➔ **200 k cores** → 350 k cores
  - ➔ **45 PB of disk storage** → 150 PB
- Worldwide analysis & funding
  - Computing funding locally in major regions & countries
  - Efficient analysis
  - ➔ **GRID technology**





So, what are our issues with Big Data?

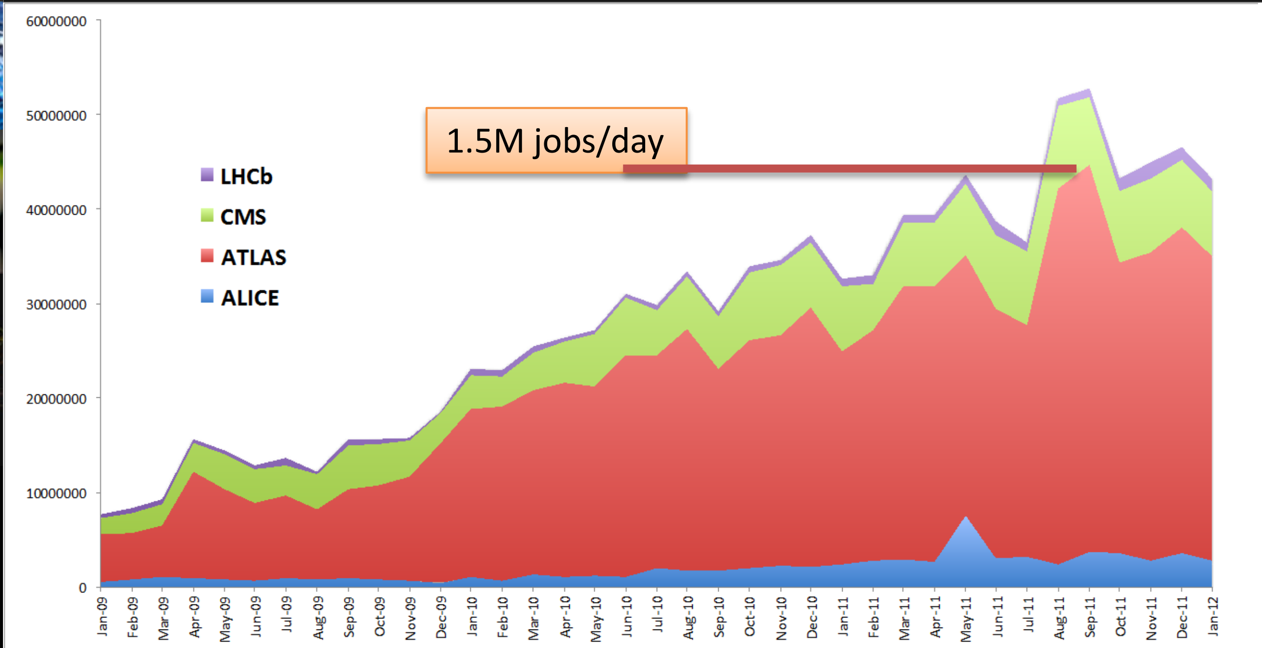
Credit: A. Pace

Wolrd-wide LHC Computing Grid

- Today >140 sites
- >350k x86 PC cores
- >150 PB disk

Tier 0 Tier 1 Tier 2

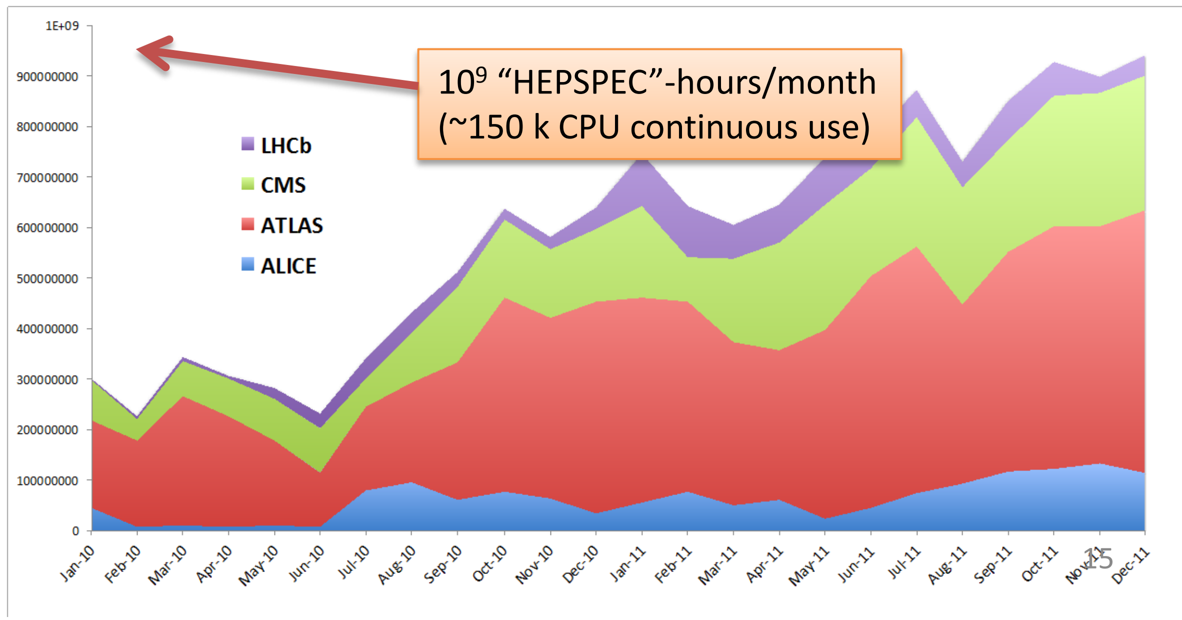
Processing on the grid



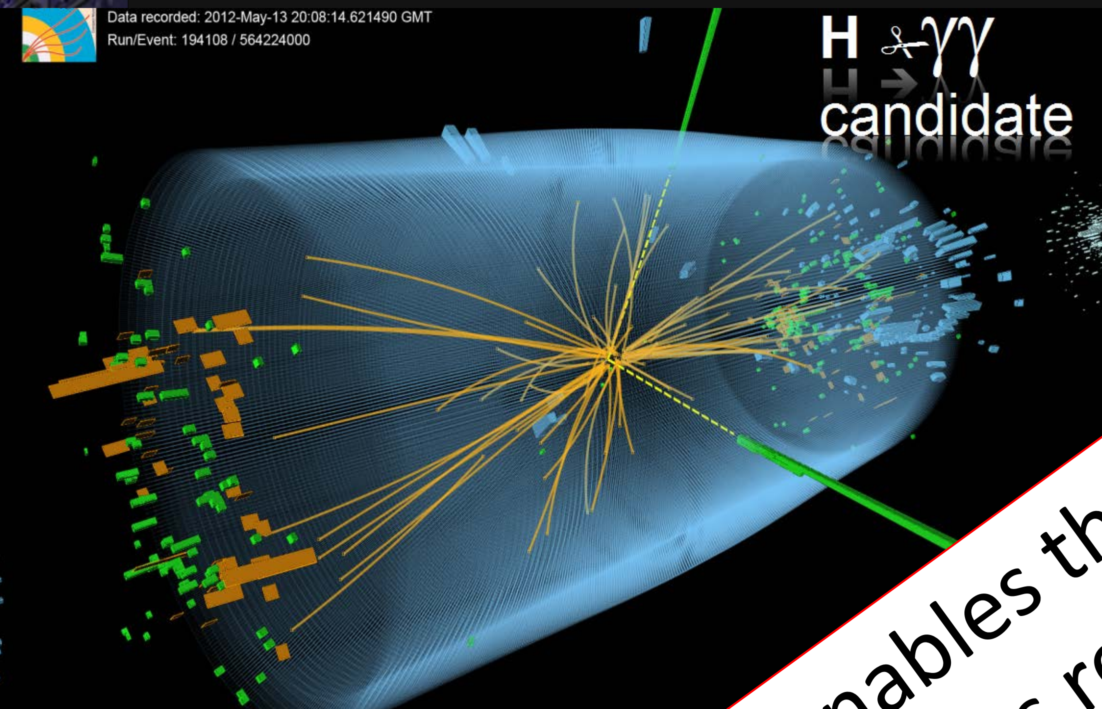
Usage continues to grow…
- \# jobs/day
- CPU usage

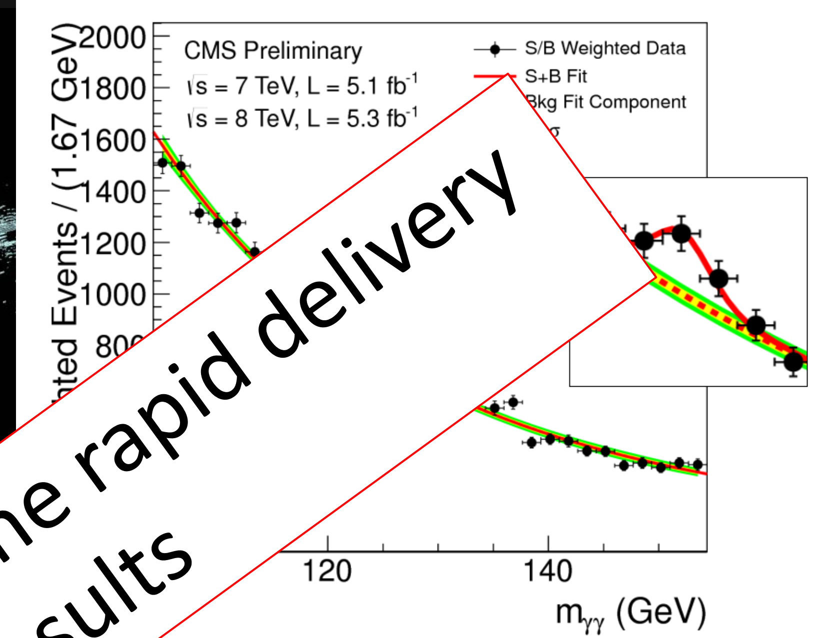
~ 150,000 years of CPU delivered each year

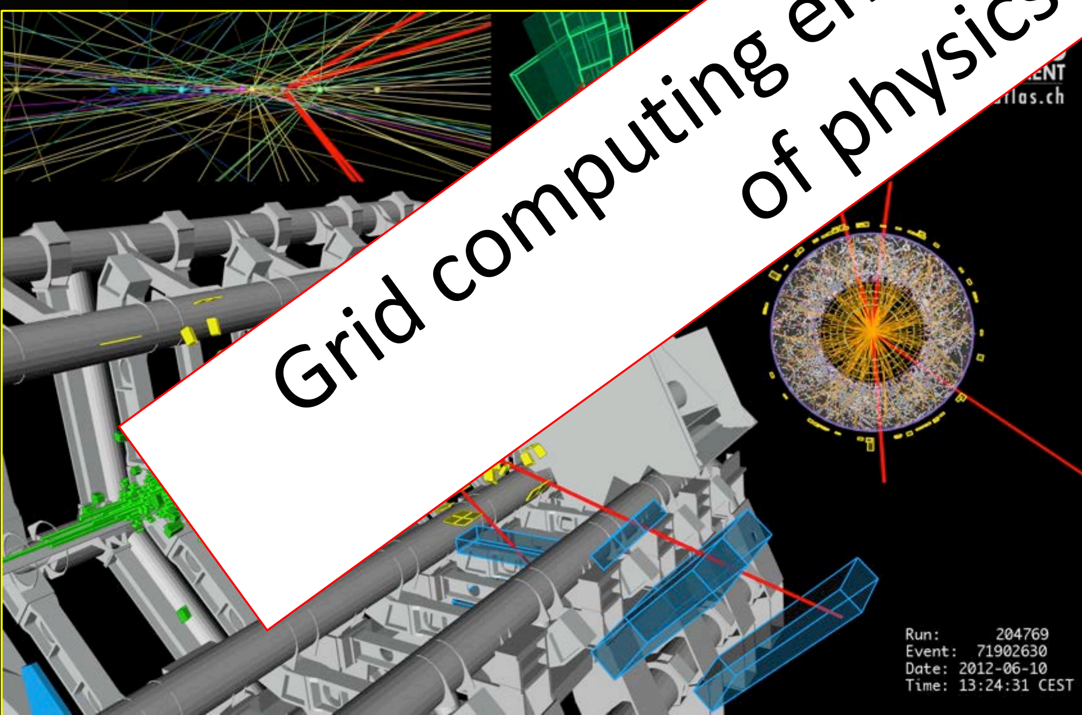
This is close to full capacity
We always need more!

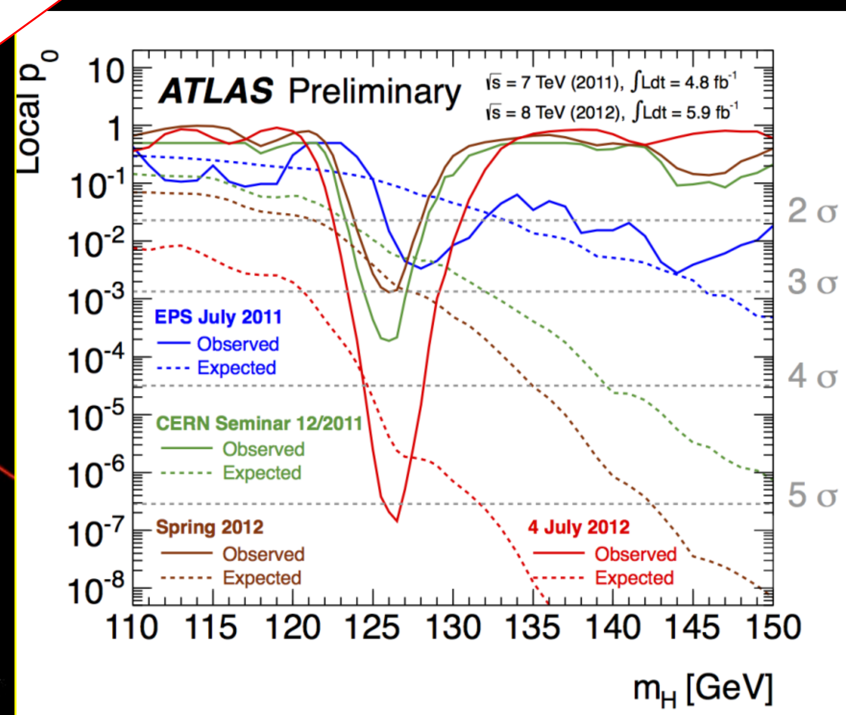


WLCG Worldwide LHC Computing Grid









Grid computing enables the rapid delivery of physics results

Tier-0: Central Data Management

- **Hierarchical Storage Management: CASTOR**
  - Rich set of features:
    - Tape pools, disk pools, service classes, instances, file classes, file replication, scheduled transfers (etc.)
  - DB-centric architecture
- **Disk-only storage system: EOS**
  - Easy-to-use, stand-alone, disk-only for user and group data with in-memory namespace
    - Low latency (few ms for read/write open)
    - Focusing on end-user analysis with chaotic access
    - Adopting ideas from other modern file systems (Hadoop, Lustre, etc.)
    - Running on low-cost hardware (JBOD and SW RAID)

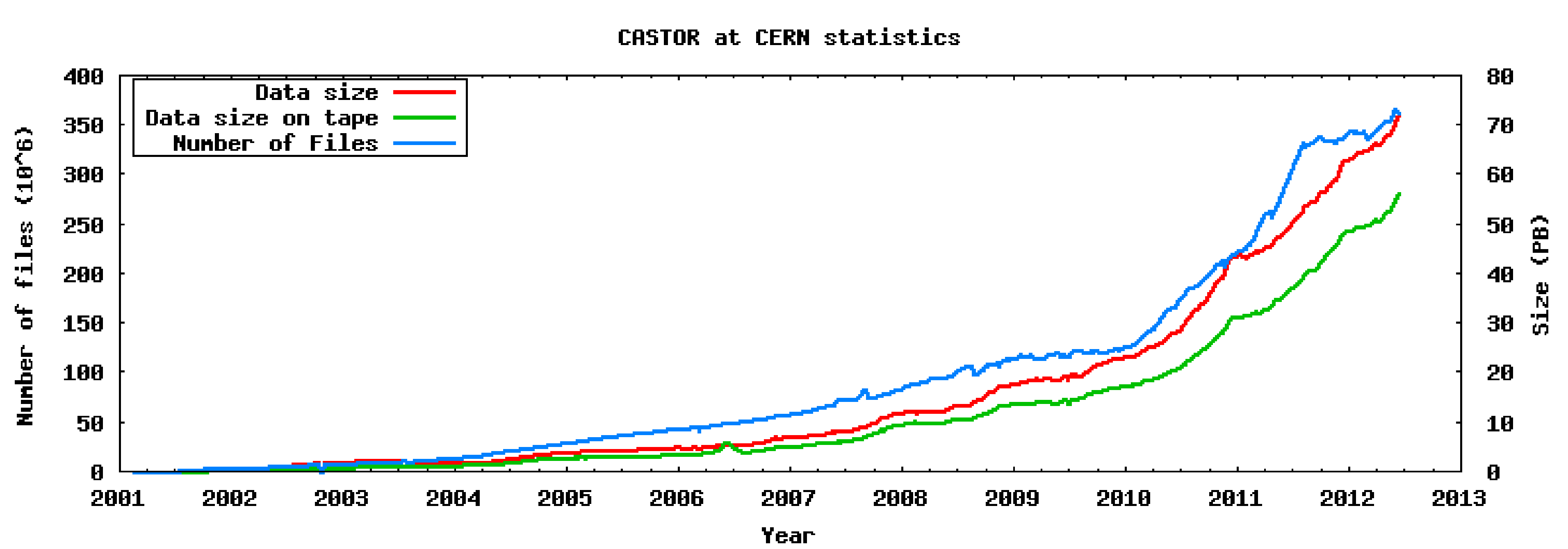
Active tapes

- Inside a huge storage hierarchy tapes may be advantageous!

We use tape storage products from multiple vendors

CASTOR current status

(end 2012)

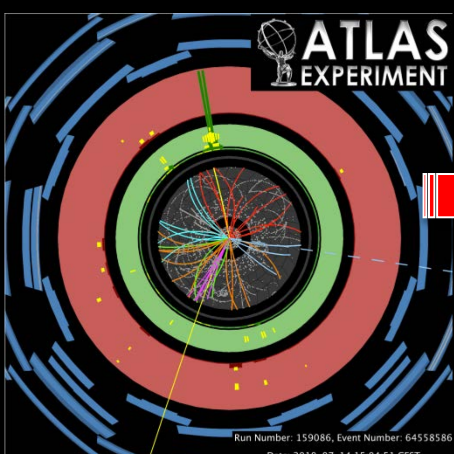


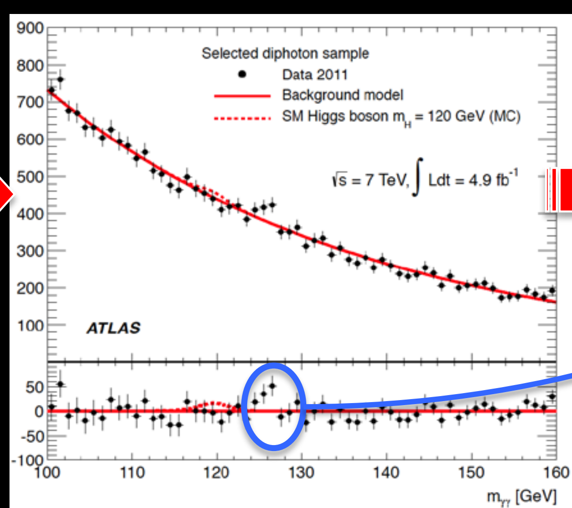
66 petabytes across 362 million files

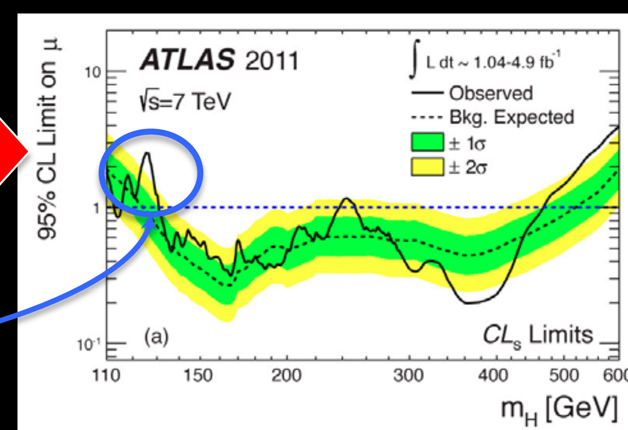
Credit: J. Iven

Big Data Analytics

- **Huge quantity of data collected, but most of events are simply reflecting well-known physics processes**
  - New physics effects expected in a tiny fraction of the total events:
    - “The needle in the haystack”
- **Crucial to have a good discrimination between interesting events and the rest, i.e. different species**
  - Complex data analysis techniques play a crucial role

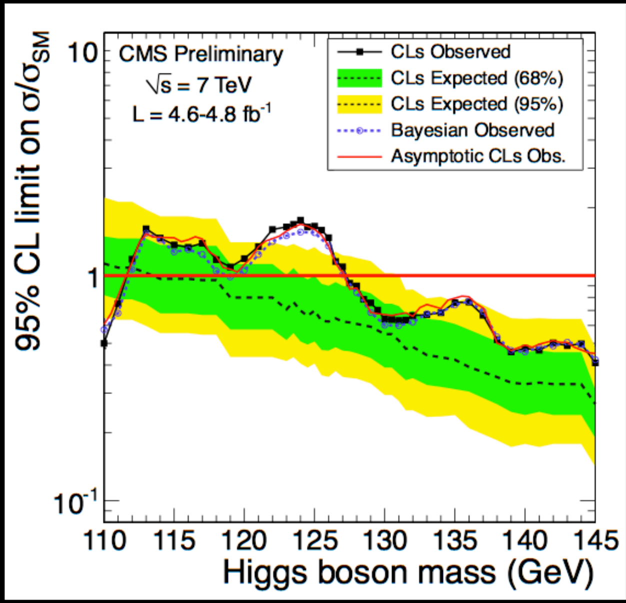




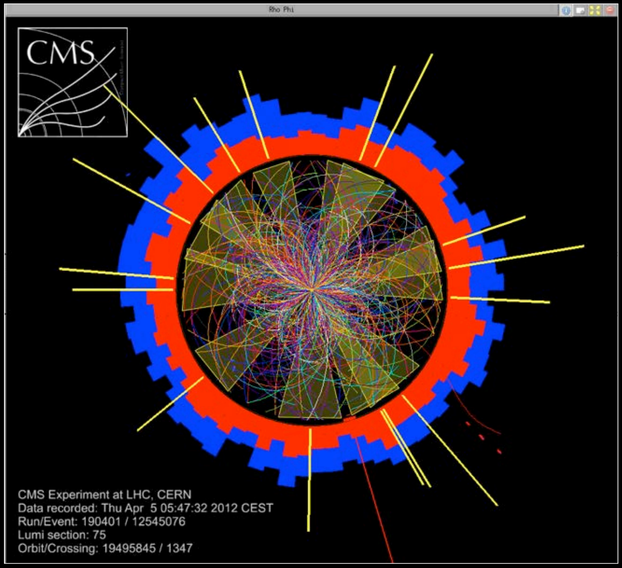


Credit: A. Lazzaro

ROOT Object-Oriented toolkit



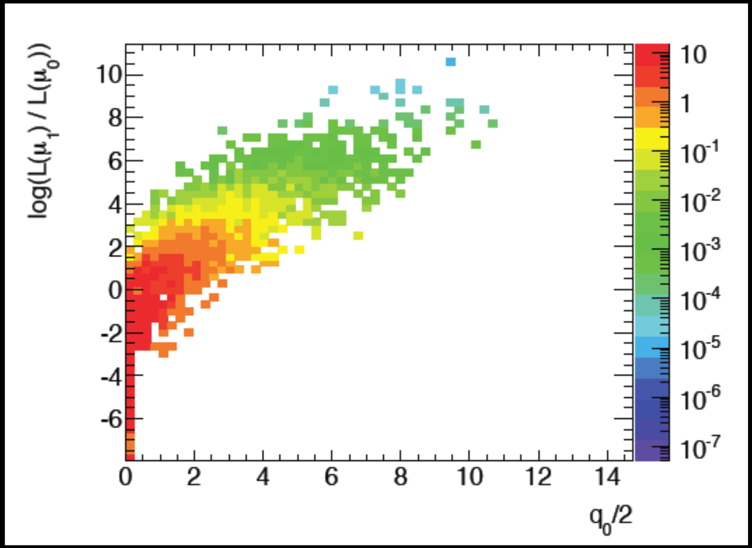
- Data Analysis toolkit
  - Written in C++ (millions of lines)
  - Open source
  - Integrated interpreter
  - Multiple file formats
  - I/O handling, graphics, plotting, math, histogram binning, event display, geometric navigation
  - Powerful fitting (RooFit) and statistical (RooStats) packages on top
  - In use by all our collaborations

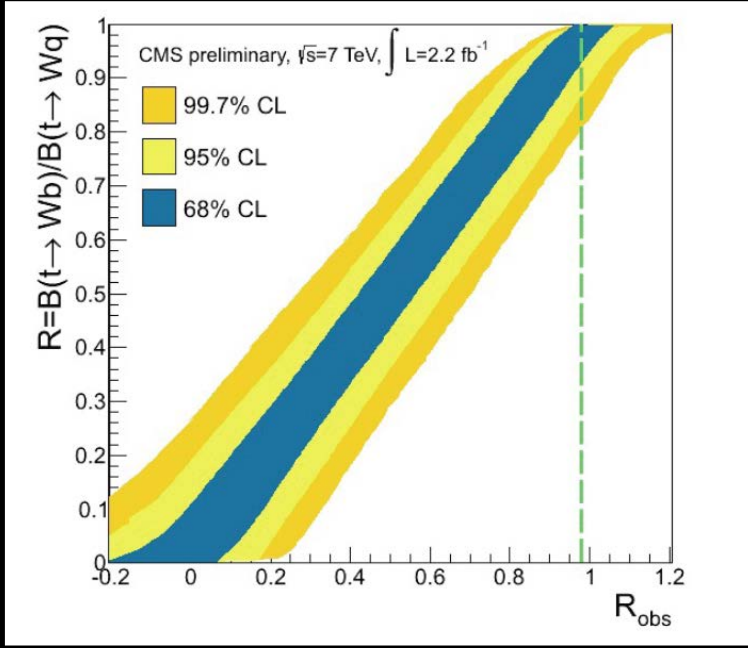


Credit: F. Rademakers

RooFit/RooStats

- Standard tool for producing physics results at LHC
  - Parameter estimation (fitting)
  - Interval estimation (e.g limit results for new particle searches)
  - Discovery significance (quantifying excess of events)
- Implementation of several statistical methods (Bayesian, Frequentist, Asymptotic)
- New tools added for model creation and combinations





Credit: L. Moneta

ROOT files

- **Default format for all our data**
- **Organised as Trees with Branches**
  - Sophisticated formatting for optimal analysis of data
    - Parallelism, prefetching and caching
    - Compression, splitting and merging

Over 100 PB stored in this format (All over the world)

Big Data at CERN

- All of this needs to be covered!

Credit: A. Pace

Conclusions

- Big Data Management and Analytics require a solid organisational structure at all levels
- Must avoid "Big Headaches"
  - Enormous file sizes and/or enormous file counts
  - Data movement, placement, access pattern, life cycle
  - Replicas, Backup copies, etc.
- Big Data also implies Big Transactions/Transaction rates
- Corporate culture: our community started preparing more than a decade before real physics data arrived
  - Now, the situation is well under control
  - But, data rates will continue to increase (dramatically) for years to come: Big Data in the size of Exabytes!

There is no time to rest!

References and credits

- http://www.cern.ch/
- http://wlcg.web.cern.ch/
- http://root.cern.ch/
- http://eos.cern.ch/
- http://castor.cern.ch/
- http://panda.cern.ch/
- http://www.atlas.ch/

I am indebted to several of my colleagues at CERN for this material, in particular:
Ian Bird, WLCG project Leader
Alberto Pace, Manager of the Data Services Group at CERN and the members of his group

Q & A

CERN openlab

Backup