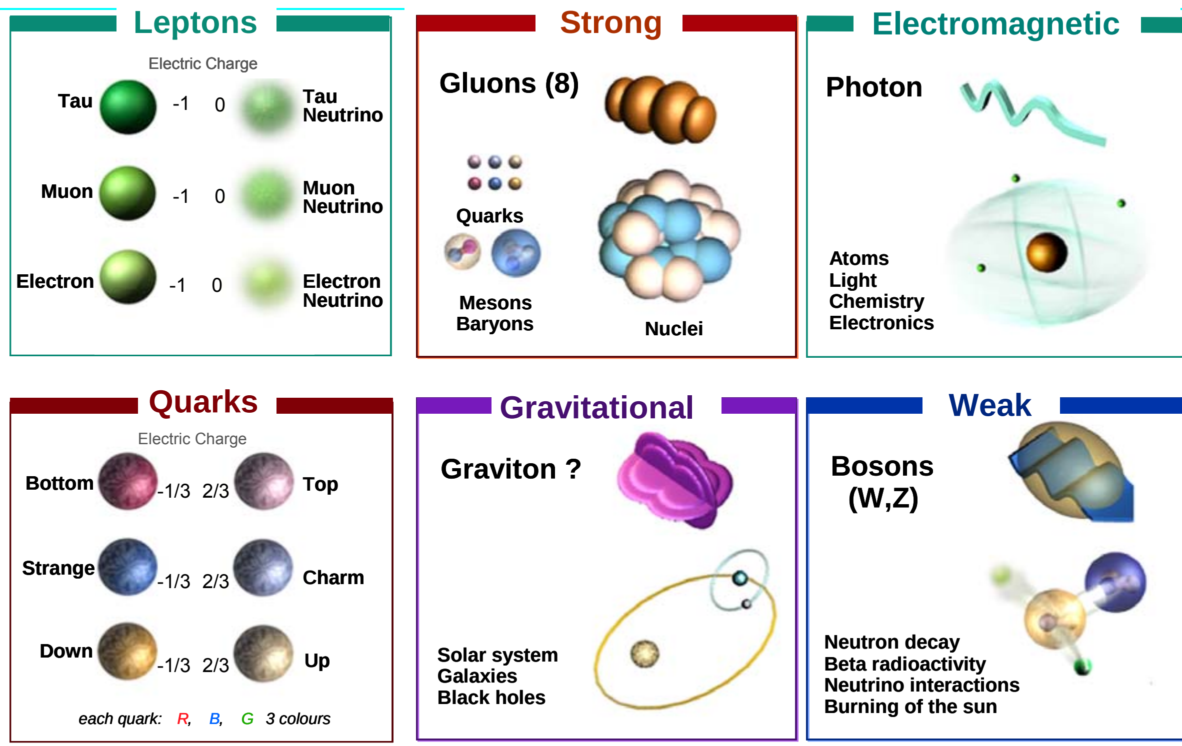
L'expérience CMS au collisionneur d'hadrons LHC et le World LHC Computing Grid

Giacomo BRUNO

Centre de Recherche CP3, Departement de Physique - UCL

Inauguration Tier2 / Green, UCL, 31 Octobre 2008

Elementary Particles and Fundamental Interactions



The particle drawings are simple artistic representations

✓The predictions of a relativistic quantum field theory, called **the Standard Model**, are consistent with all experimental observations related to 3 out of 4 fundamental interactions (gravity is left out) in phenomena occurring at the energy scale of up to 100 GeV.

✓Some Standard Model predictions make non sense at **the yet unexplored TeV scale.** The minimum to cure this behaviour would be the existence of one additional, and yet unobserved, elementary particle: **the Higgs boson**.

✓A fit of SM predictions to experimental precision results constrains **the Higgs mass to be around 100 GeV** (100 times heavier than the proton).

Unanswered Questions

a. Are the particles fundamental or do they possess structure ?
b. Why are there three generations of quark and lepton - are there more ?
c. What is the nature of the dark matter that pervades our galaxy ?
d. Are protons unstable ?
e. Are there new states of matter at exceedingly high density and temperature?
f. Do the neutrinos have mass, and if so why are they so light ?
g. Can gravity be included in a theory with the other three interactions ?
h. What is the origin of mass?
i. Why is the charge on the electron equal and opposite to that on the proton?
j. Why is there overwhelmingly more matter than anti-matter in the Universe ?

Higgs’ identikit

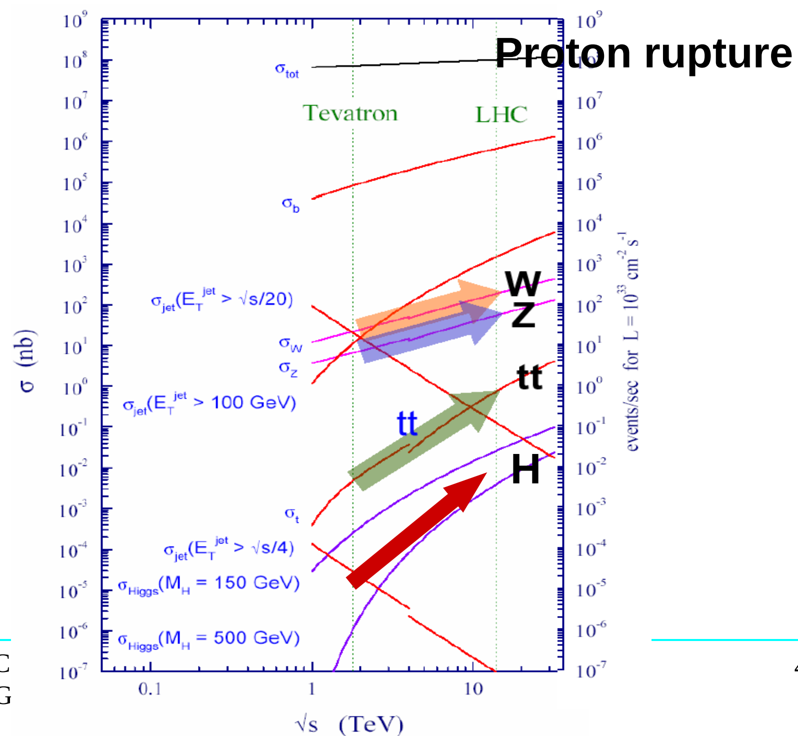
- The Higgs is heavy
  - Most easily produced in heads-on collisions at O(TeV)
- The Higgs is rare
  - SM prediction: to produce 1 (light) Higgs per second need to collide every second 2x (10^{18} protons having 7 TeV) in an area of 1000 μm² .
  - Production rate increases rapidly with beam energy
  - A Heavier Higgs is even more rare

Energy (mass) available (producible) in collisions

- Fixed target
  - Beam Particle Energy = 1 TeV
  - Proton Target (M ~1 GeV)

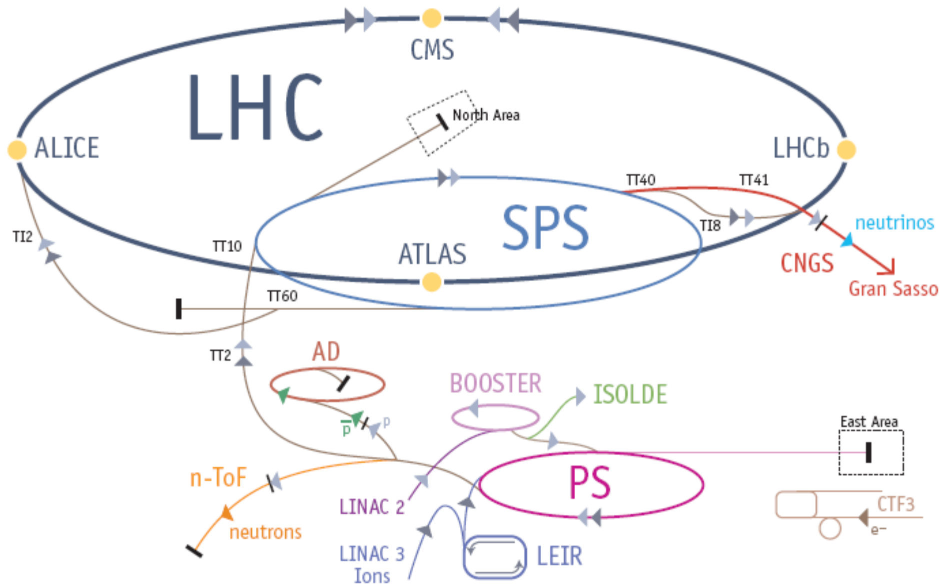
  43.3 GeV
- Heads-on collisions
  - Beam Particle Energy = 1 TeV

  E_{cm}=2 TeV

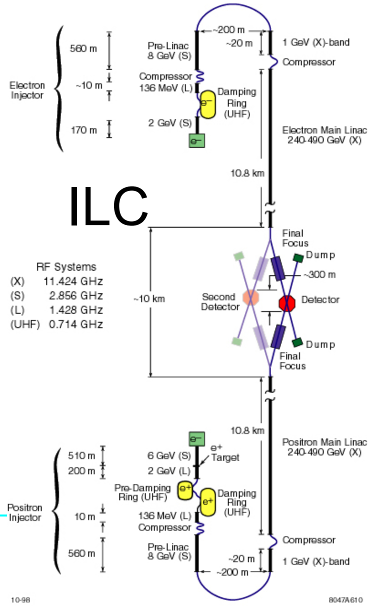


The LHC

- C→Collider
  - Highest producible masses for given beam energy
- (C→Circular)
  - Can have more time to accelerate particles → high energy beams
  - Can inject more and more particles in the ring → high intensity beams
  - Can re-cycle non interacted beams → eco-friendly..
- H→ Hadron (protons)
  - Higher cross section
  - Lower beam energy losses



LHC Superconducting RF accelerating cavities



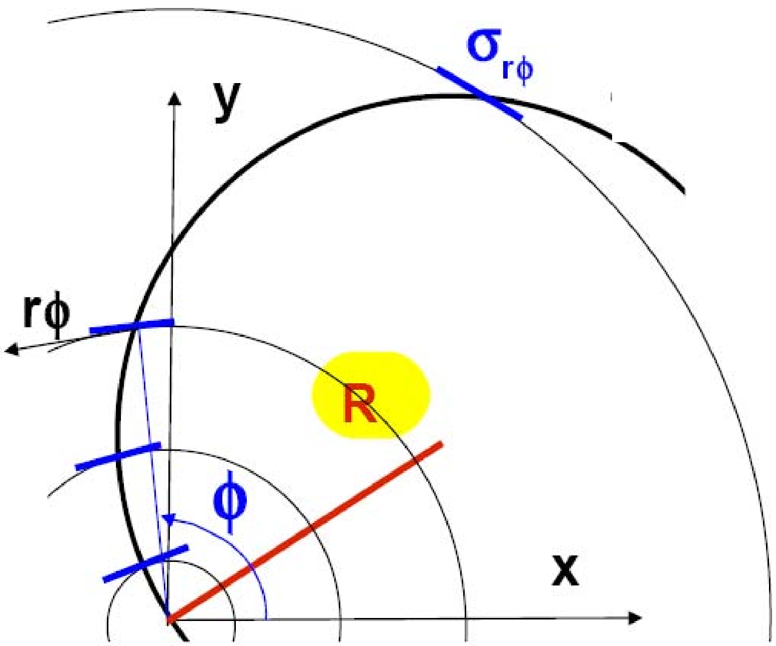
L→ Large

p = q B R

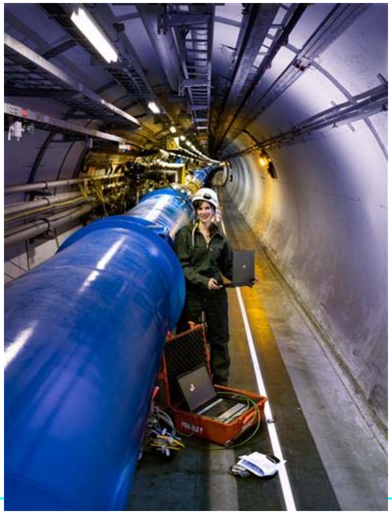
- In convenient units:

$$p_T[GeV/c] = 0.3\, B[Tesla]\, R[m]$$

$$\vec{B} = B.\vec{1}_z$$



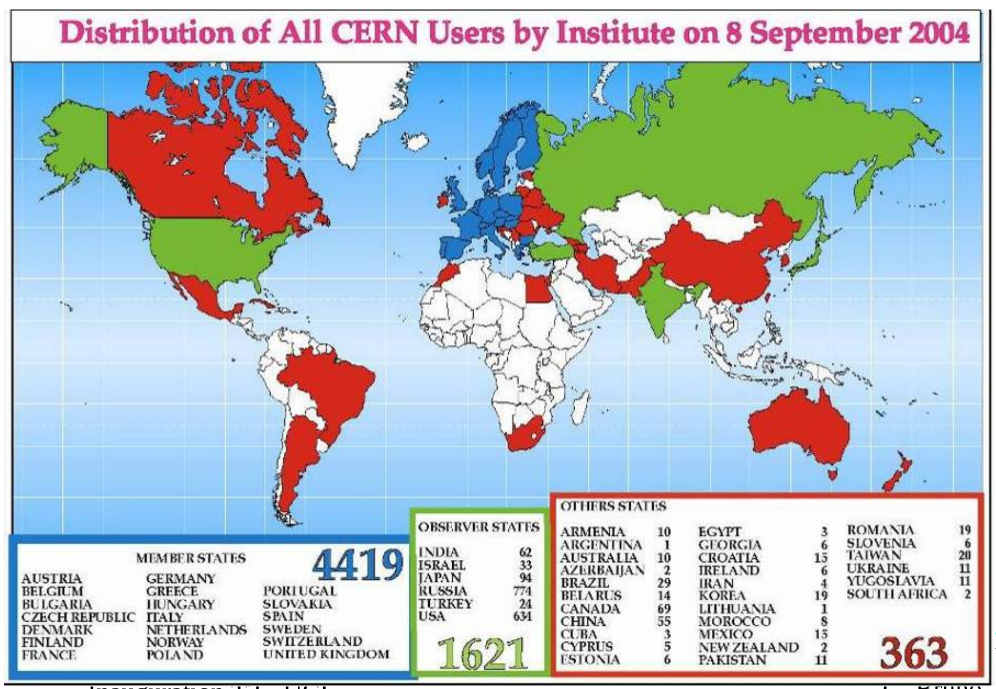
- P=7000 GeV/c, B=8 T → R=3 km
  - LHC radius is 4.2 km (27 km long)
- Technological limitation from superconducting dipole magnets
  - 1232 dipole magnets of 15 m length cooled with liquid helium at -271°C providing 8.3 T
  - 10 years of R&D at CERN
  - 5 years of industrialization
  - 3 years of production
- September 19th incident caused by
  - "faulty electrical connection in a region between two of the accelerator's magnets". CERN DG

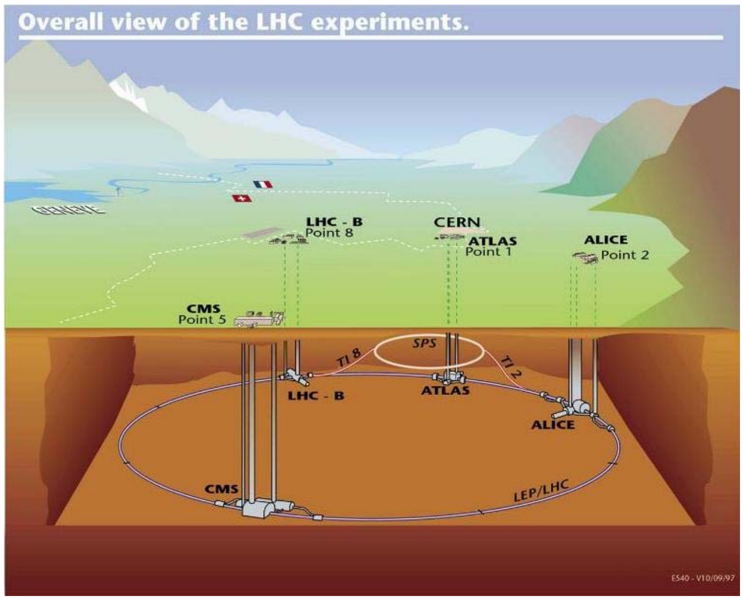


Engineers checking the electronics of the cryogenic instrumentation under a dipole magnet.

The European Organization for Nuclear Research (CERN)

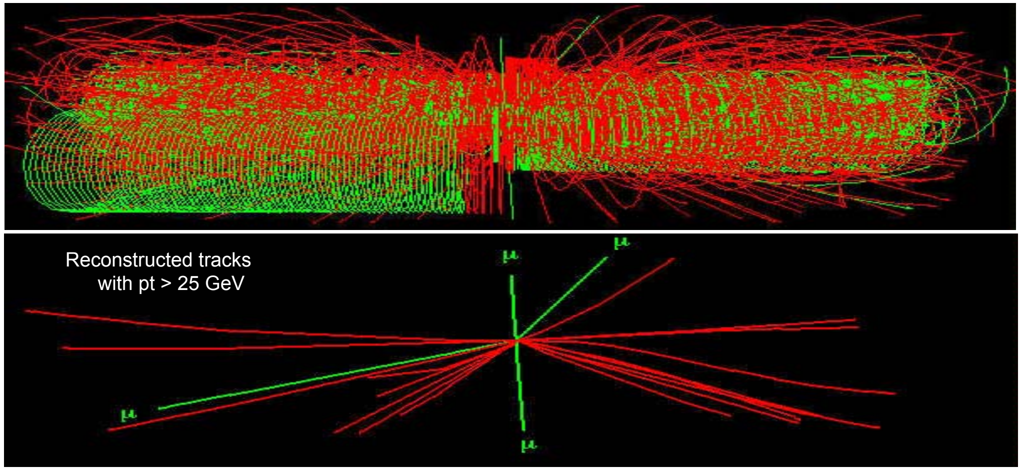
- Accelerator Facilities
  - SuperProtonSynchroton (proton/antiproton up to 400 GeV – 7 km long – discovery of W and Z particles)
  - LEP (now dismantled - electron and positron up to 100 GeV – 27 km long - precision tests of Standard Model)
  - LHC (protons up to 7 TeV - LEP tunnel)
    - Four experiments: ATLAS, CMS, ALICE and LHCB



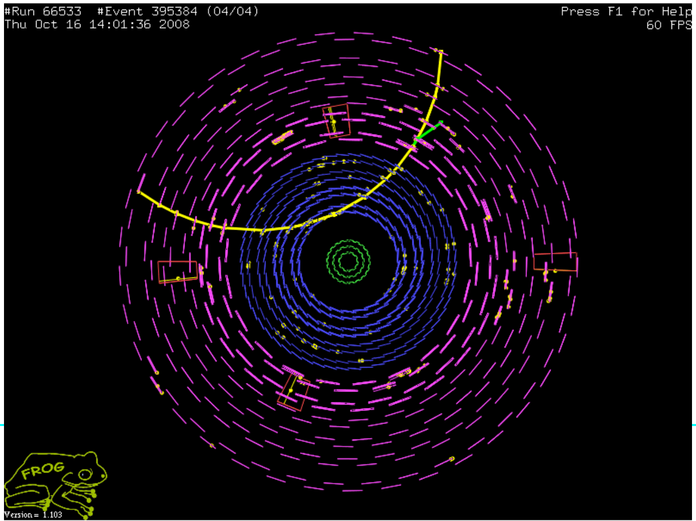


“Events”

- an LHC event - something like this repeats every 25 ns

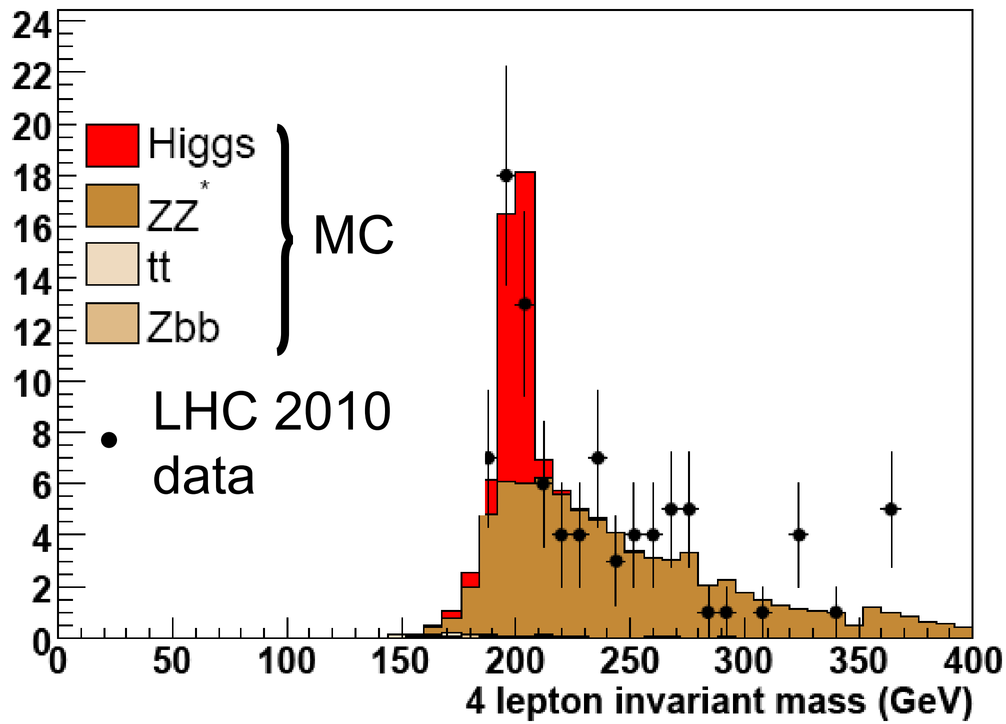


- A real cosmic event (all we have for now..)

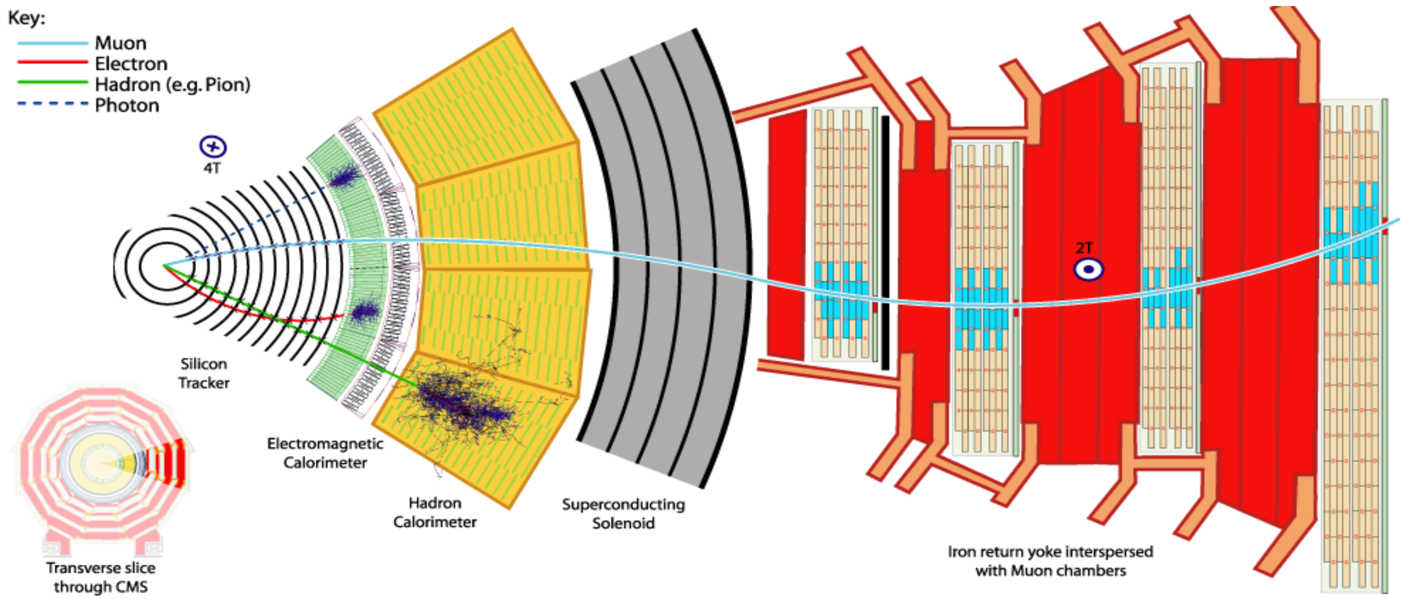


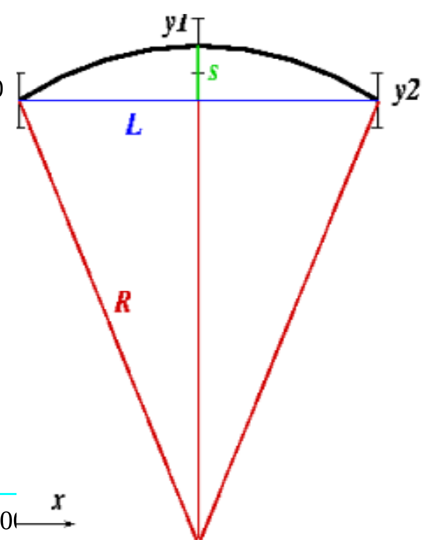
2010, the could-be Higgs Discovery

- One Higgs decay mode
  - $H \to ZZ \to e^+e^-\mu^+\mu^-$
- Measure e and μ
- Compute Higgs mass assuming decay chain above
- Red peak width determined by detector quality (precision of energy measurement, ...)



Particle identification and measurement



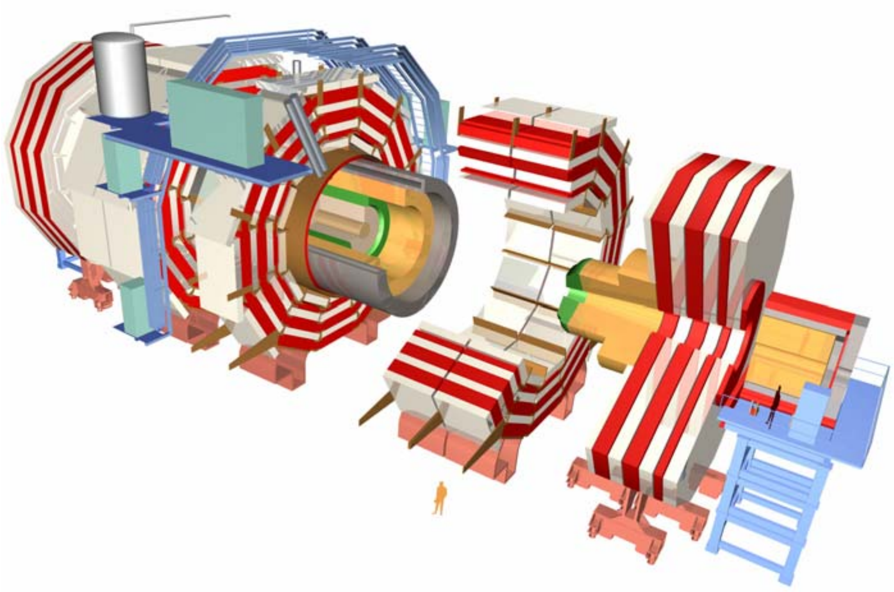


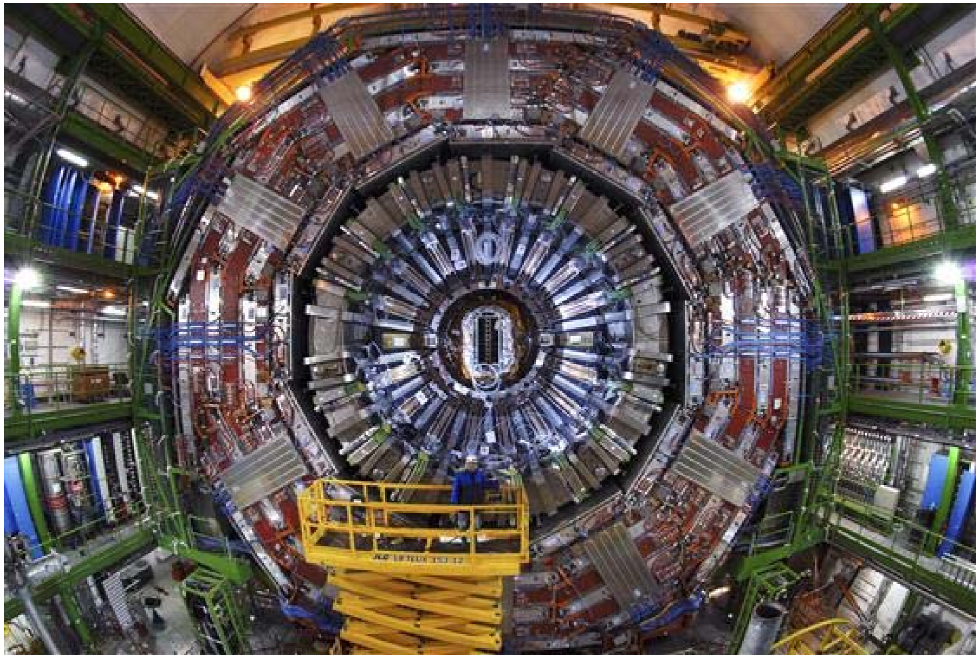
$$p_t = \frac{qBL^2}{8s}$$

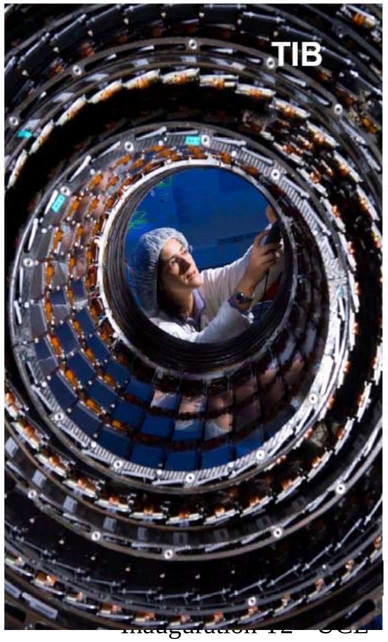
$$\frac{\Delta p_T}{p_T} = \frac{\Delta s}{s} = \Delta s \frac{8R}{L^2} = \Delta s \frac{8 p_T}{0.3 B L^2}$$

$\Delta pt/pt$=1% at pt=100 GeV → Δs=10 μm for B=4 T and L=1 m

The CMS Detector







- 200 Institutes
  - 6 Belgian universities (UA, UCL, UG, ULB, UMH, VUB).
    - Silicon Strip Tracker
    - Tier2

The LHC Data Challenge

- 40 million collisions per second
- After online filtering, 100 collisions of interest per second
- 1 Megabyte of data per collision
  - recording rate: 0.1 Gigabyte/sec/experiment
- 10^9 collisions recorded each year
  - stored data: 1 Petabyte/year/experiment
- In addition:
  - Need as many fully simulated events
  - Data needs to be "reconstructed"
    - go from individual detector channel electronic signals to particles
  - Detectors needs to be calibrated
    - And data corrected
  - Data needs to be analyzed to extract final results

1 Megabyte (1MB)
A digital photo

1 Gigabyte (1GB)
= 1000MB
5GB = A DVD movie

1 Terabyte (1TB)
= 1000GB
World annual book production

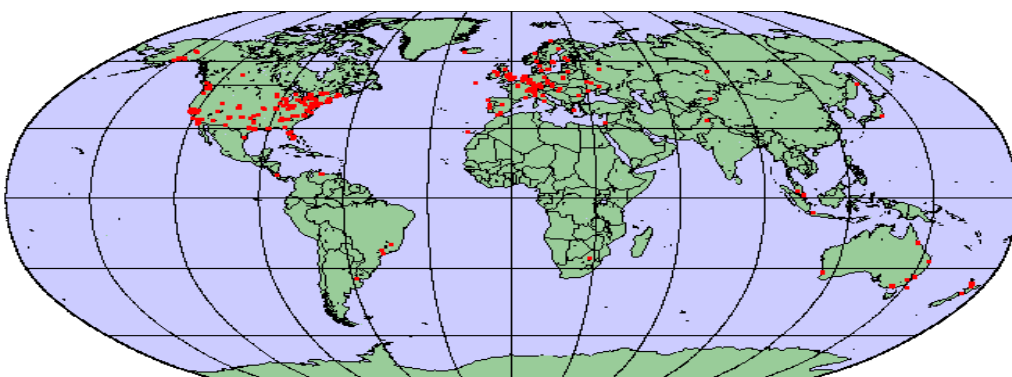
1 Petabyte (1PB)
= 1000TB
Annual production of one LHC experiment

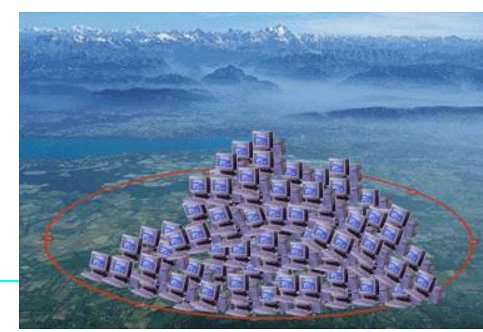
1 Exabyte (1EB)
= 1000 PB
3EB = World annual information production

The LHC Data Challenge (II)

- Problem: even with Computer Centre upgrade, CERN can provide only a fraction of the necessary resources.
  - CMS needs: 30000 CPUs, 25 000 TB disk, 35 000 TB tape

- Solution: CERN has over 500 partners institutes in the world. Most have and/or need significant computing resources (in general also for several other scientific purposes). Build a Grid that **unites these computing resources.**
  - share loads
  - absorb fluctuations in computing resources demand



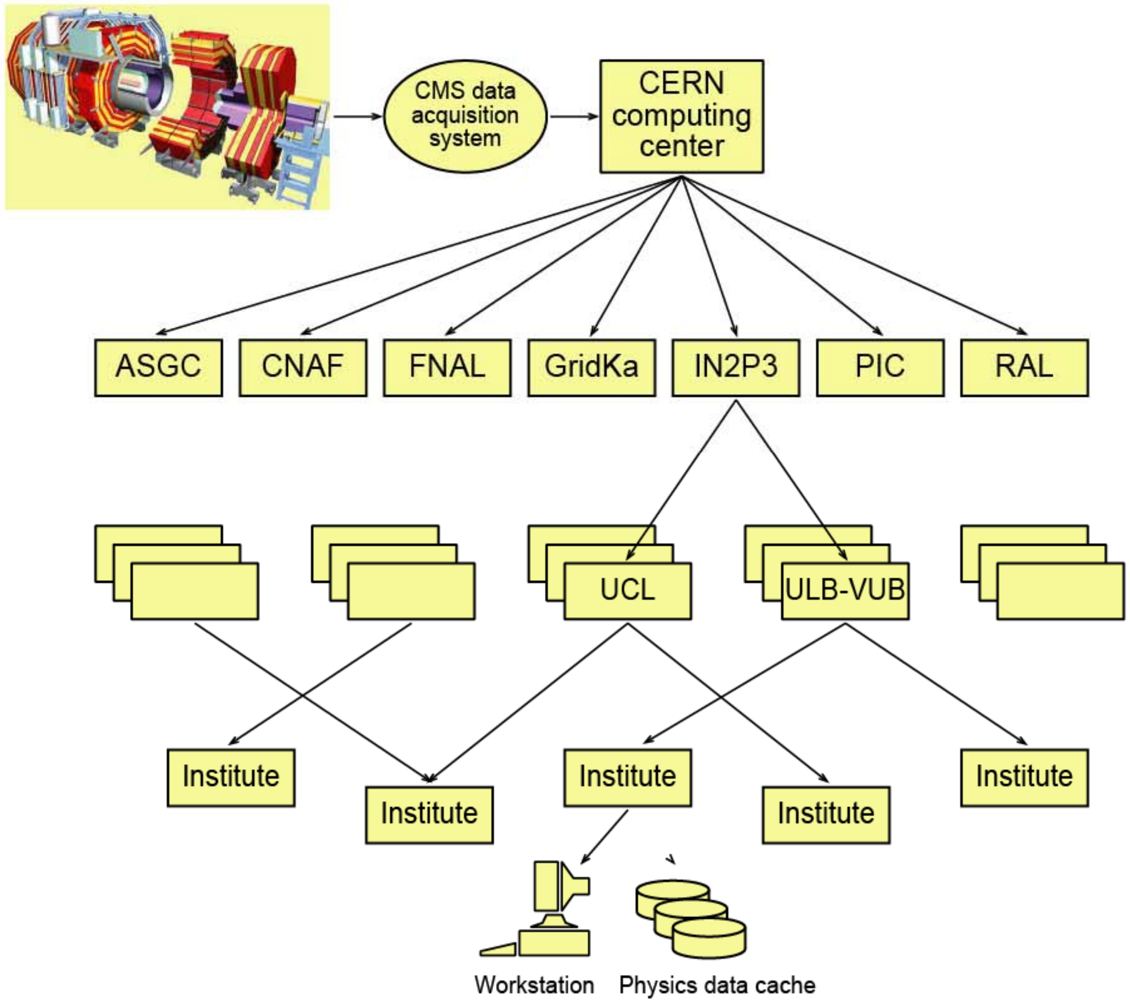


Grid Projects

- CERN projects:
  - World LHC Computing Grid (WLCG)

- EU-funded projects led by CERN:
  - Enabling Grids for E-SciencE (EGEE)
    - 260 sites, 72,000 CPUs, 20 PB storage
    - 150 Virtual Organizations

CMS Computing Model



Tier 0 (level 0)
- permanent storage of raw data
- distribution of raw data to Tier 1
- detector calibration and alignment

Tier 1 (level 1)
- partial copy of raw data
- subsequent data reconstruction passes
- long term storage of processed data

Tier 2 (level 2)
- MC production
- partial copy of reconstructed data
- physics analysis

Outlook

- Particle Physics aims at pushing forward our fundamental comprehension of the Universe we live in

- It prepares the ground for far-future Applied Science

- It already pushes applied science beyond its frontiers