Foundations of Physics III
Quantum and Particle Physics
Lecture 14

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CERN – a world laboratory

- Founded 1954 as joint venture of 12 states:

  (Belgium, Denmark, France, (West) Germany, Greece, Italy, Netherlands, Norway, Sweden, Switzerland, United Kingdom, and Yugoslavia)
- Name: Conseil Europeen our la Recherche Nucleaire
- First accelerator 1957: 600 MeV synchrotron SC.
- Since then: accelerators with ever increasing energies
- Noble prices: Rubbia/van der Meer (1984) and Charpak (1992)
- Noble laureates: Bloch, Ting, Steinberger
- Tim Berners-Lee resident at CERN –
  the place where the web was born.
- The present: The LHC - biggest scientific experiment ever.

Historical photos

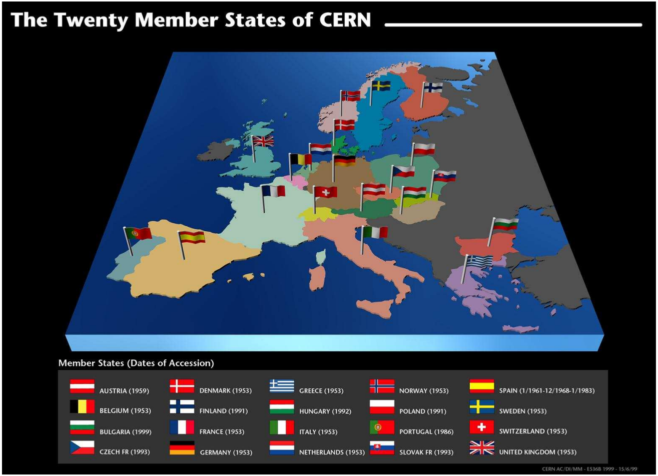
Sur le terrain du futur institut nucléaire

Sous la conduite de M. A. Picot, les membres du Conseil européen pour la recherche nucléaire se sont rendus hier à Meyrin pour reconnaître le terrain où s'élèvera le Centre nucléaire (voir en Dernière heure)

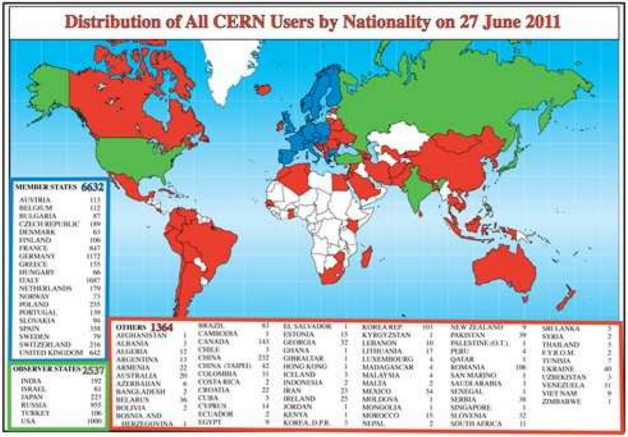
(Photo Freddy Bertrand, Genève)

La Suisse du 30 octobre 1953

CERN member states



Distribution of CERN users



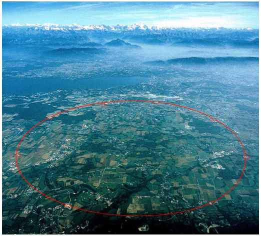
The LHC

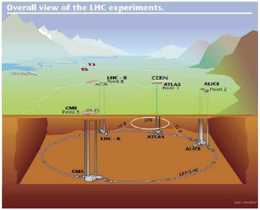
- 27km circumference
- High vacuum (10^{-10} Torr $\approx$ 3 million molecules/cm^3, pressure at 1000 km altitude), 1.9 Kelvin, 36800 tons cold mass
- 1600 super-conducting magnets at 8T, each with mass around 22t.
- *pp* collisions at 14 TeV c.m. energy

  ($E_p = 7$ TeV $= 1.12 \cdot 10^{-6}$ J $\approx$ 1 mosquito, $v_p = 0.999999991c$)
- Protons in 2808 bunches per beam, each bunch with 200 billion (200 G) protons.

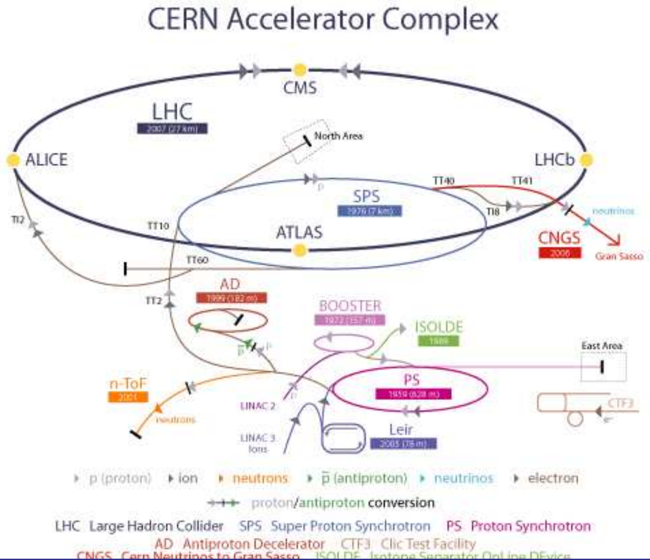
  ($1.29 \cdot 10^5$ J / bunch $\times$ 2808 bunches $\approx$ 360 MJ energy stored in one beam)
- Interaction frequency: 40 MHz

  (collisions every 25ns)



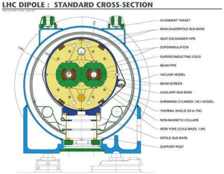


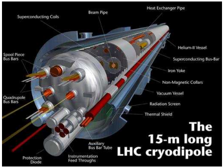
Accelerating protons at LHC



Technology: The LHC dipoles

- Protons will be accelerated to $v \approx c$. To keep them in the ring, they will permanently be under a centripetal acceleration produced by Lorentz Force.
- Centripetal acceleration:
$$a \approx c^2/r \Longrightarrow a \approx 2 \cdot 10^{13}\ \text{m}/\text{s}^2$$
(About $2 \cdot 10^{12}$ times the acceleration due to gravity.)
- This is achieved with the dipole magnets: $B \approx 8.3$ T, $L \approx 14.3$ m and $m \approx 35$ tons





Status

- LHC design: collide two counter-rotating beams of protons (or heavy ions). *pp* collisions are foreseen at an energy of 7 TeV per proton.
    - Beams move around the ring inside a continuous vacuum.
    - Guided by super-conducting magnets.

      (Magnets are cooled by a the world's largest cryogenics system.)
    - Beams will circulate at high energy for hours, colliding inside the four main LHC experiments (i.e. detectors).
- First beams successfully circulated on 10th September 2008.
- Unfortunately on 19th September a serious fault developed damaging a number of super-conducting magnets. Repair required long technical intervention, replacing magnets etc..
- Therefore, no beam in LHC before September 2009.
- Until now: Collisions at 900 GeV, 2.36 and 7 TeV c.m. energy.
- This year: Go up to 8 TeV c.m. energy.

Detectors: Some general thoughts

- Basic principle: Interaction of particles with matter.

  (matter provided by material of the detector)
- Obviously: The more matter, the more interaction.
- Design principles:
  - Hermetic (don't want to loose particles) – beams must still enter.
  - Need to distinguish particles, therefore different subsystems.
  - Detector needs "provisioning" (electronics, cooling, etc.), will induce "inactive" matter.

Detecting charged particles

- Typically, the following particles are "stable", i.e. reach the detector to be detected: $e^\pm$, $\mu^\pm$, $\pi^\pm$, $K^\pm$, p, $\bar{p}$.
- They loose energy and are deflected through:
  - Inelastic collisions with atomic electrons

    (Leads to ionisation and therefore, electrical currents.)
  - Bremsstrahlung

    (In the field of a nucleus, light particles, such as positrons or electrons loose energy by emission of "Bremsstrahlung" photons, scaling like $Z^2\alpha^3$ in the field of nuclei with charge Z.)
  - Emission of Cherenkov photons

    (If the velocity of the particle is larger than the speed of light inside the material, photons are emitted, forming a cone with angle $\cos\theta_c = 1/(\beta n)$, where n is the refraction index of the material.)
  - Elastic scattering from nuclei
  - Nuclear reactions
- In addition detector's magnetic fields bend charged particles

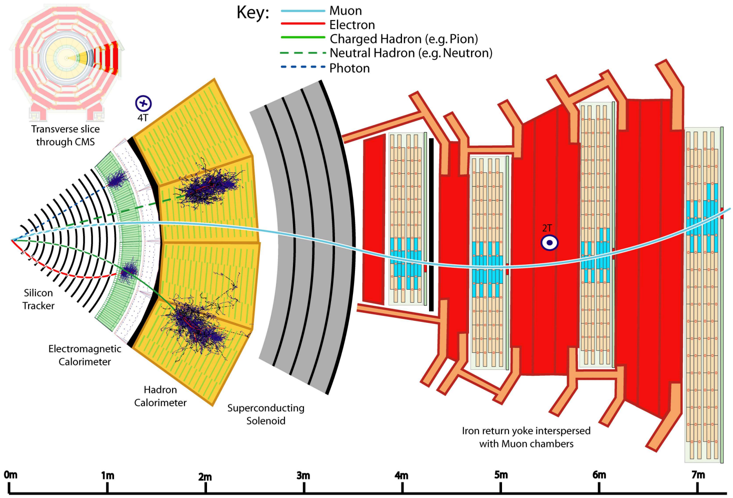
  (allows for charge-to-mass ratio).

Detecting neutral particles

- Typically, the following particles are “stable”, i.e. reach the detector to be detected: γ, K_L^0, n
- For photons there’s a number of reactions:
  - Photoelectric effect
  - Compton effect
  - Pair production

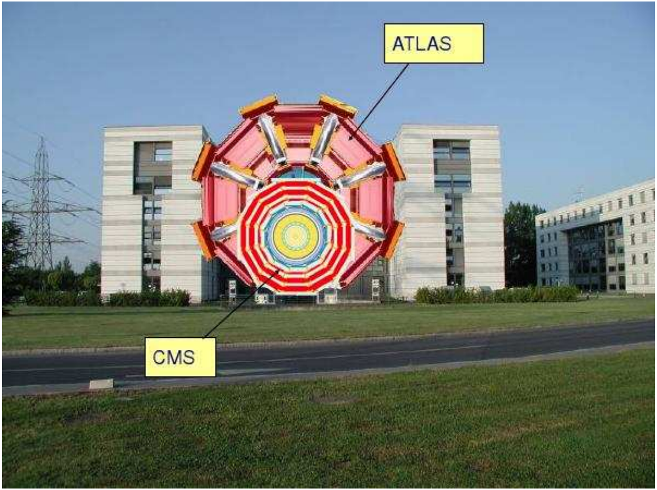
  leading to full electromagnetic showers in the detectors when combined with similar effects for the electrons.
- Other neutrals experience nuclear reactions, depositing their energy in the detector. This is parametrised by the free hadronic path length X_0.
- Neutrinos typically do not interact with the detectors, since they need huge masses to compensate the small weak cross sections.

Scheme of particle detection

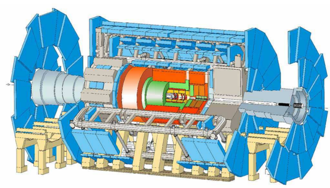


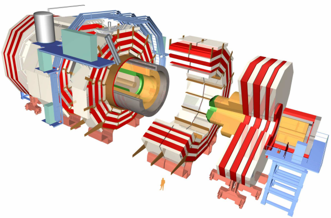
Multi-purpose detectors at the LHC: ATLAS and CMS

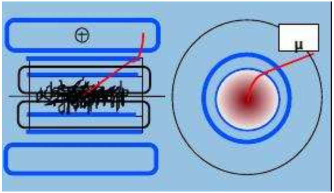
- Main principle: Try to detect everything ...
  ... but at least the **muons**
- Build detector in layers around interaction zone, add magnetic field(s) to bend charged particles' trajectories.
  ATLAS and CMS have two different magnetic field configurations: toroid vs. solenoid.
- Muons are interesting: at LHC high-energy muons come from the decay of heavy objects.
- Typically, they are simple to track/detect: They do not interact too much with the matter of the detector.
  So, naively, whatever charged particle leaves the detector, it must be a muon $\Longrightarrow$ build muon chambers at the outside.

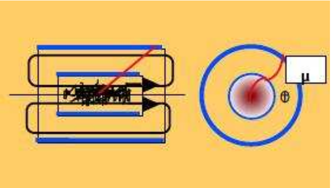

ATLAS
CMS

- Different field configurations of ATLAS and CMS:



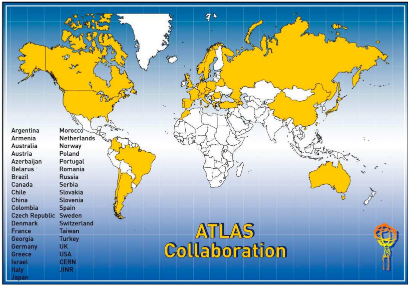






For example: ATLAS

- $>$ 3000 physicists from $>$ 170 institutions in 38 countries



- Weight: 7000 tons, about 100 empty 747 jets or 1 Tour Eiffel
- Size: 45 m long, 25 m diameter, about half a big as Note Dame
- Data-taking: Amount of data: about 500 GByte/s, compressed to about 27 data CD's/minute.

For example: CMS

- CMS technical data: Solenoid
  - Solenoid is a cylinder of super-conducting wires made from Niobium-Titanium, cooled down to 4 Kelvin
  - CMS' solenoid dimensions: length=13m, diameter = 5.9m, 20kA$\Longrightarrow$ 4T
- CMS technical data: Tracker
  - 220 m^2 of silicon sensors. 6m long, 2.2m diameter, 60M electronic channels for read-out.
- CMS technical data: Electromagnetic Calorimeter
  - Scintillation light in lead-tungstate crystals (PbWO4) 64000 crystals in barrel, 16000 in end-caps.
- CMS technical data: Hadronic calorimeter
  - Barrel: 36 brass wedges, each with 35 tons; end-caps: recuperated Russian brass ship artillery shells.

Learning outcomes

- Accelerators and detectors:
  Understand basic principles of particle acceleration and detection.