CERN LHC

The Large Hadron Collider is currently being installed in a 27-kilometer ring buried deep below the countryside on the outskirts of Geneva, Switzerland. When its operation begins in 2007, the LHC will be the world's most powerful particle accelerator. High-energy protons in two counter-rotating beams will be smashed together in a search for signatures of supersymmetry, dark matter and the origins of mass.

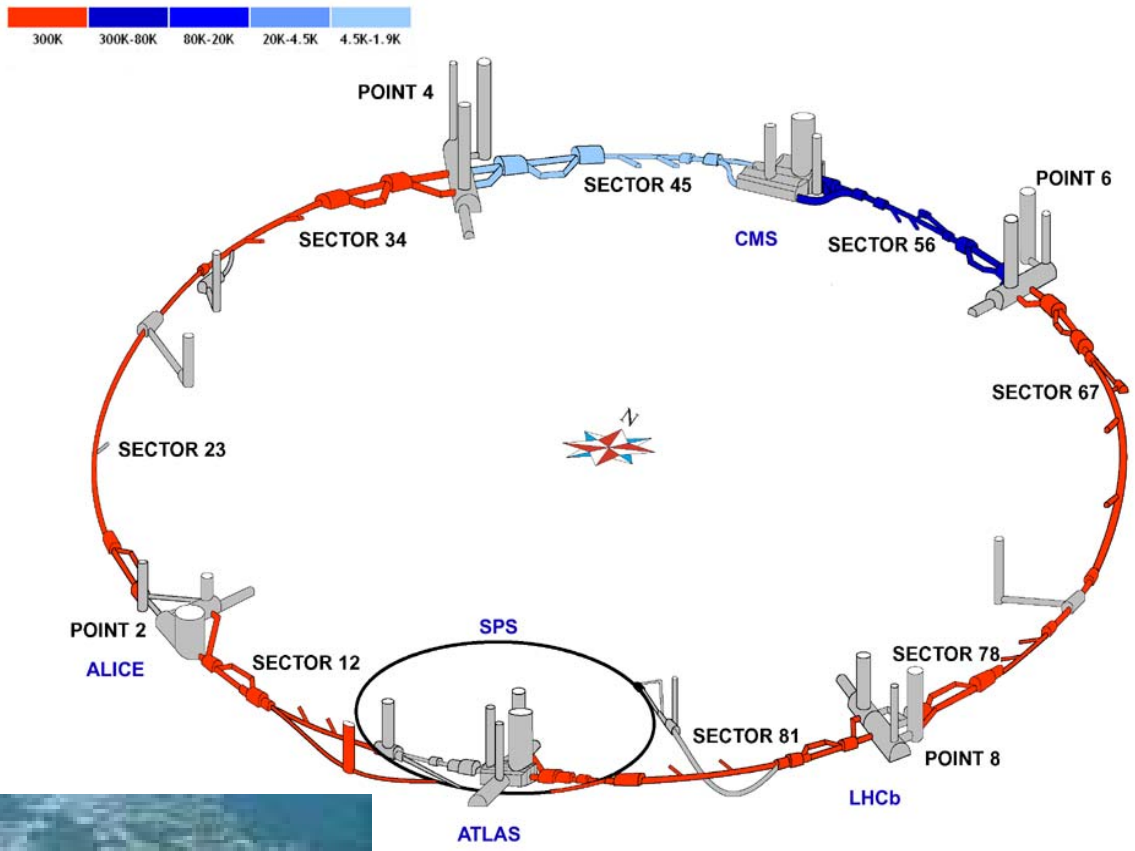
The beams are made up of bunches containing billions of protons. Traveling at a whisker below the speed of light they will be injected, accelerated, and kept circulating for hours, guided by thousands of powerful superconducting magnets.

For most of the ring, the beams travel in two separate vacuum pipes, but at four points they collide in the hearts of the main experiments, known by their acronyms: ALICE, ATLAS, CMS, and LHCb. The experiments' detectors will watch carefully as the energy of colliding protons transforms fleetingly into a plethora of exotic particles.

The detectors could see up to 600 million collision events per second, with the experiments scouring the data for signs of extremely rare events such as the creation of the much-sought Higgs boson.

Mike Lamont, CERN

- The Large Hadron Collider (LHC) is being built in a circular tunnel 27 km in circumference. The tunnel is buried around 50 to 175 m. underground. It straddles the Swiss and French borders on the outskirts of Geneva.



The Large Hadron Collider (LHC) is a 27km long circular accelerator built at CERN, near Geneva Switzerland.

The beam will be running on September 10, 2008.

Each Collider Beam at LHC

- Each proton beam at full intensity will consist of 2808 bunches per beam moving in a circular tunnel 27 km in circumference.

- Each bunch contains 1.15×10^{11} protons.

- Each proton beam is few cm. long with transverse dimensions of the order 1 mm, but at the collision point of LHC it is 16 microns (when fully squeezed).

- The particles in the LHC are ultra-relativistic and move at 0.999999991 the speed of light (7 TeV).

- Total beam energy at top energy, nominal beam, 362 MJ
(2808 bunches * $1.15*10^{11}$ protons @ 7 TeV each. =
$2808*1.15*10^{11}*7*10^{12}*1.602*10^{-19}$ Joules = 362 MJ per beam)

- The energy content of TNT is 4.68 MJ/kg, thus it is equivalent to
362/4.68 = 77.4 kg of TNT

Each Collider Beam at LHC

- The distance from one bunch to the next is 7.5 m. Since it takes light 25 nanoseconds (or 25 ns) to travel 7.5 m, and the protons are practically moving at the speed of light, head-on meetings between bunches at every collision point occur every 25 ns, or 40 million times per second.

- The bunch spacing in the LHC is 25 ns., however, there are bigger gaps (e.g. to allow dump kickers the time to get up etc.). Because of the gaps we get

  an average crossing rate = number of bunches * revolution frequency = $2808 * (3*10^8)/(27*10^3\ \text{m}) = 31.6$ MHz.

- 31.6 MHz times 19 events per crossing at nominal luminosity gives us 600 million inelastic events per second.

Collision rate

- The total proton-proton cross section at 7 TeV is approximately 110 mbarns. This total can be broken down in contributions from:

  - inelastic (= 60 mbarn)
  - single diffractive (= 12 mbarn)
  - elastic (= 40 mbarn)

- The cross section from elastic scattering of the protons and diffractive events will not be seen by the detectors as it is only the inelastic scatterings that give rise to particles at sufficient high angles with respect to the beam axis.

- By definition,

  Event rate = Luminosity * Cross section

Searching for Particles

- Event rates are governed by
  - Cross section $\sigma(E)[cm^2]$ –physics
  - Luminosity $[cm^{-2}s^{-1}] = N_1N_2f / A$
    - N_1N_2= particles/bunch
    - f = crossing frequency
    - A = area of beam at collision
    - $N_{events} = \sigma \int Ldt$
    - Acceptance and efficiency of detectors
- Higher energy: threshold, statistics
- Higher luminosity: statistics

With 10^{34} Luminosity ($m^{-2}\ s^{-1}$)

Luminosity Equation:

$$L = \frac{f\ E}{\varepsilon_n}\frac{n_b N_p^2}{\beta^*}$$

- **Quantities we cannot easily change:**
  - ***f*: revolution frequency of the LHC**
    - **set by radius and c**
  - ***E*: beam energy**
    - **set by physics goals**
  - **ε_n: beam emittance at injection**
    - **set by getting the beam into the LHC**

- **Quantities we can easily change**
  - **n_b: number of bunches**
    - **Factor of 3 lower initially**
  - **β^* : strength of final focus**
    - **Factor of ~2 possible**
  - **N_p: protons per bunch**
    - **Can be as small as we want**
    - **Initially, can be within a factor of ~2 of design**

A high rate of collisions requires small bunch size, many protons per bunch, and many bunch crossings per unit time. These properties, which depend on the design of the collider, can be combined into a single useful parameter, luminosity.

Collision rate

- Inelastic event rate at nominal luminosity, with 10^{34} luminosity ($m^{-2}\ s^{-1}$), is

  $10^{34} * 60 * 10^{-3} * 10^{-24}$ = 600 million/second

  (1 barn = $10^{-24}\ m^2$)

- The average crossing rate =

  number of bunches * revolution frequency =

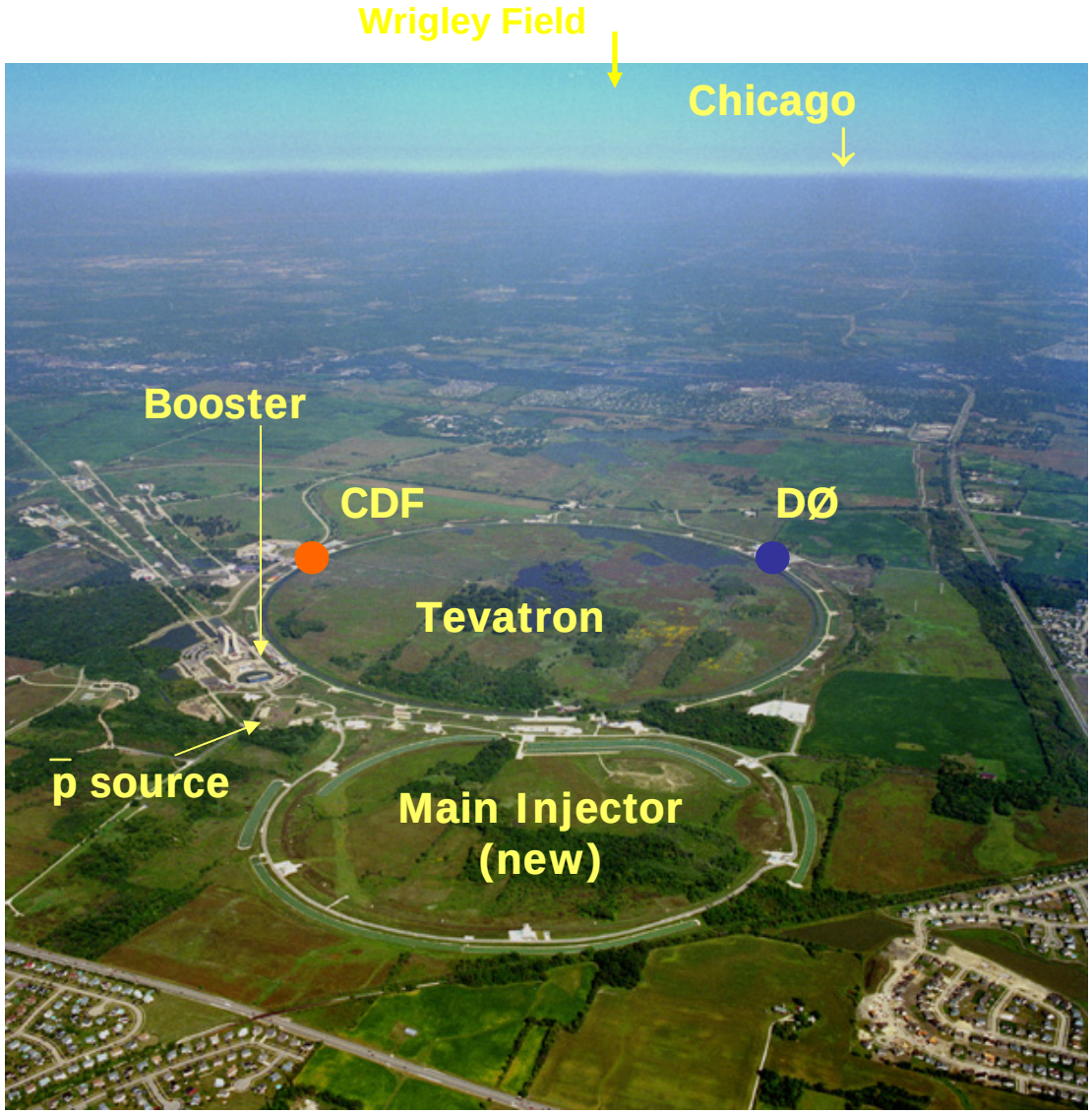
  2808 * $(3*10^8)/(27*10^3\ m)$ = 31.6 MHz = 1/(32 ns)

  Thus, the bunch spacing in the LHC is 32 ns.

- 31.6 MHz times the number of inelastic events per crossing at nominal luminosity gives us our 600 million inelastic events per second. Thus, it has around 19 inelastic events per crossing.

Tevatron

Fermilab



- Collide protons and anti-protons at CDF and D0
- Center of mass energy is 1.96 TeV
- 36 x 36 bunches
- 396 ns between crossings
- About 5 inelastic scatterings per crossing

Tevatron

- Tevatron (proton/anti-proton)

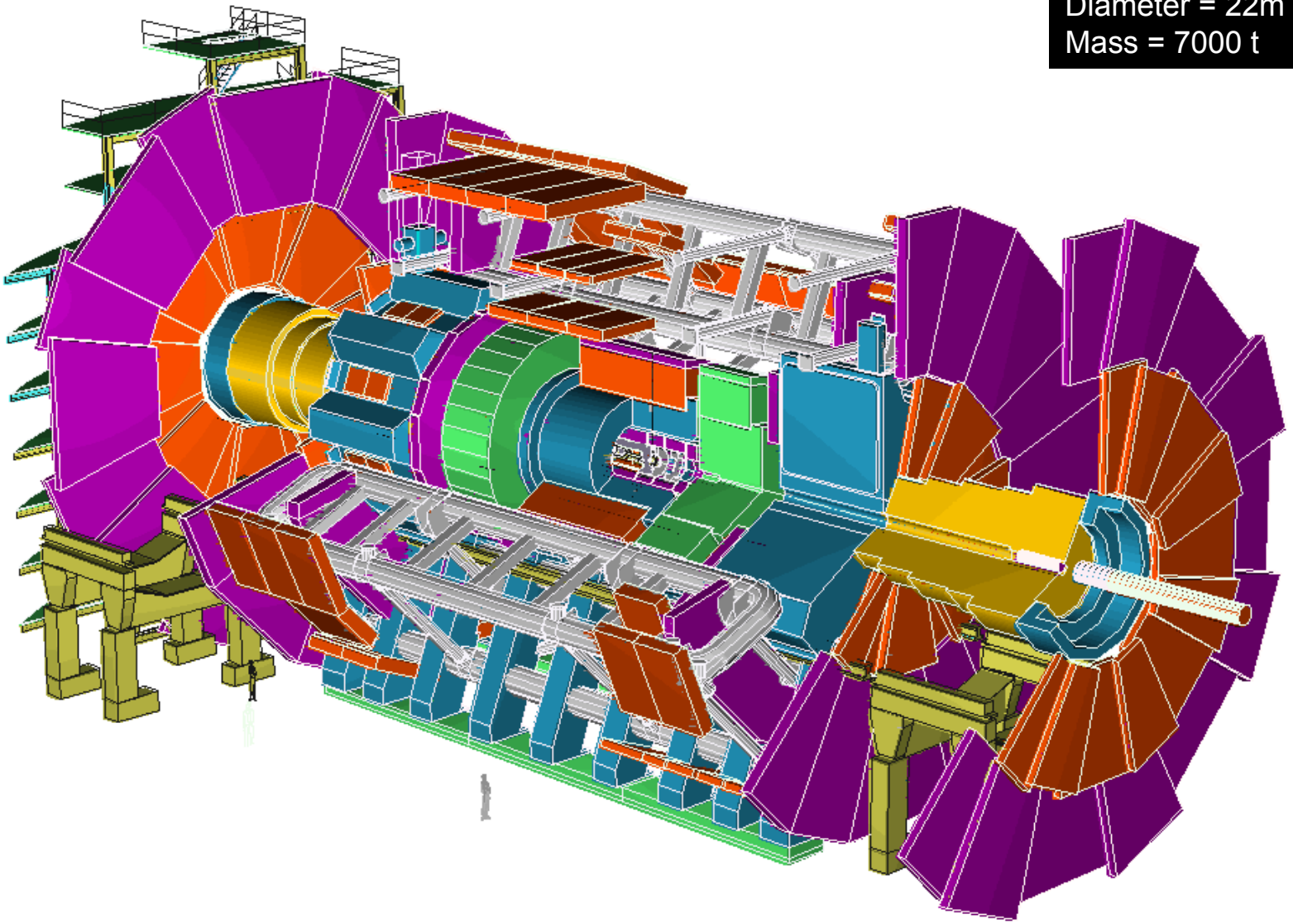
  980 GeV beam energy - 36 bunches of 2.3×10^{11} protons gives an energy per beam around 1.3 MJ

- LHC beam power = 280 x Tevatron!

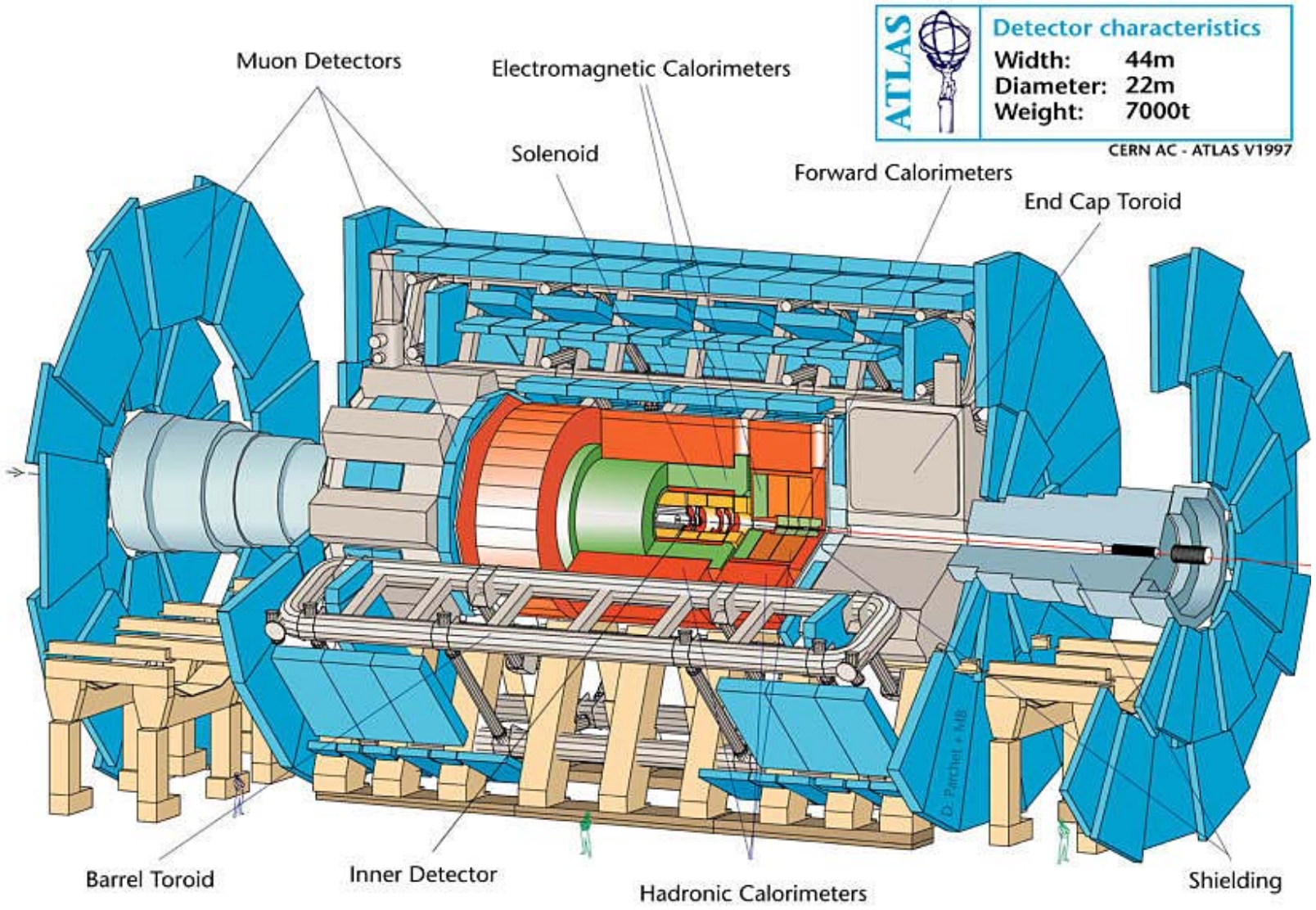
Two large Detectors at LHC

ATLAS = A Toroidal LHC ApparatuS

Length = 44m
Diameter = 22m
Mass = 7000 t



ATLAS Revisited



CMS

The compact Muon Solenoid Experiment