

My Thesis Title

Matthew Lawrence Joyce

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1. THE LARGE HADRON COLLIDER

1.1 *Introduction*

The Large Hadron Collider (LHC) is a 26.7 kilometer-long, two-ring particle accelerator and collider located on the border of France and Switzerland at the European Organization for Nuclear Research (CERN). During normal operations the LHC maintains two counter-rotating beams of proton bunches that collide at four interaction points (IP) with up to $\sqrt{s} = 14$ TeV center of mass energy and a luminosity of $10^{34}\text{cm}^{-2}\text{s}^{-1}$. The ALICE (Point 2), ATLAS (Point 1), CMS (Point 5), and LHC-b experiments each have a detector at one of these interaction points as seen in Figure 1.1 . The CMS and ATLAS are general-purpose detectors while LHC-b specializes in beauty quark studies. ALICE is a heavy-ion experiment which uses $^{208}\text{Pb} - p$ or $^{208}\text{Pb} - ^{208}\text{Pb}$ collisions that can also be produced by the LHC.

1.2 *Injection Complex*

In order to bring the protons from rest up to their target collision energy a series of accelerators, as shown in Figure 1.2, are used. The acceleration sequence begins with the injection of hydrogen gas into a duoplasmatron. Here a bombardment of electrons ionize the hydrogen atoms while an electric field pushes them through the duoplasmatron cavity. The result is 100 keV protons being passed on to a quadrupole magnet which guides them into the aperture of a linear accelerator (LINAC2). The radio frequency (RF) cavities in LINAC2 accelerate the protons up to 50 MeV. At this point the protons are sent into one of four rings in the Proton Synchrotron Booster (PSB). The PSB repeatedly accelerates the protons around a circular path until they reach an energy of 1.4 GeV. The bunches of protons from each PSB ring are then sequentially injected into the single-ringed Proton Synchrotron (PS). Each bunch injected into the PS are captured by one of the "buckets" (Figure 1.3) provided by the PS RF system which also manipulates the bunches into the desired profile and proton density. These proton bunches are accelerated to 25 GeV and injected into the Super Proton Synchrotron

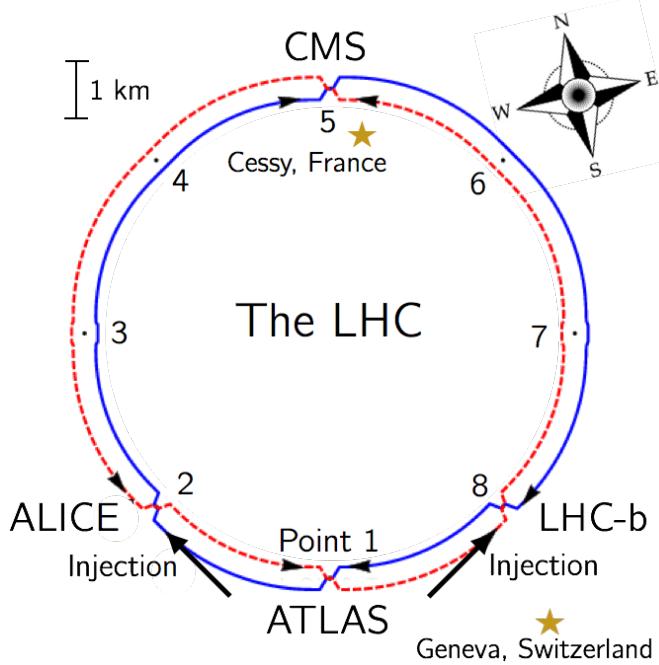


Fig. 1.1: Interaction points of the LHC

(SPS) where they are accelerated to 450 GeV. Finally the proton bunches are injected into the LHC ring where they are accelerated to 6.5 TeV and collided in 25 ns intervals to yield a center of mass energy of $\sqrt{s} = 13$ TeV.

1.3 Tunnel and Magnets

The LHC was designed to produce collisions with up to $\sqrt{s} = 14$ TeV. That requires confining and guiding 7 TeV protons around the circumference of the LHC ring. The ring is housed in a 4 meter-wide underground tunnel that ranges in depth between 45 and 170 meters below the surface. This tunnel was repurposed from the Large Electron-Positron (LEP) Collider which previously occupied the space. For this reason the tunnel is not completely circular but is instead made up of alternating curved and straight sections of 2500 m and 530 m in length respectively. The straight sections, labeled 1-8 in Figure 1.1, are used as either experimental facilities or sites for hardware necessary for LHC operations such as RF cavities for momentum cleaning, quadrupole magnets for beam focusing, and sextupole magnets for acceleration and betatron cleaning.

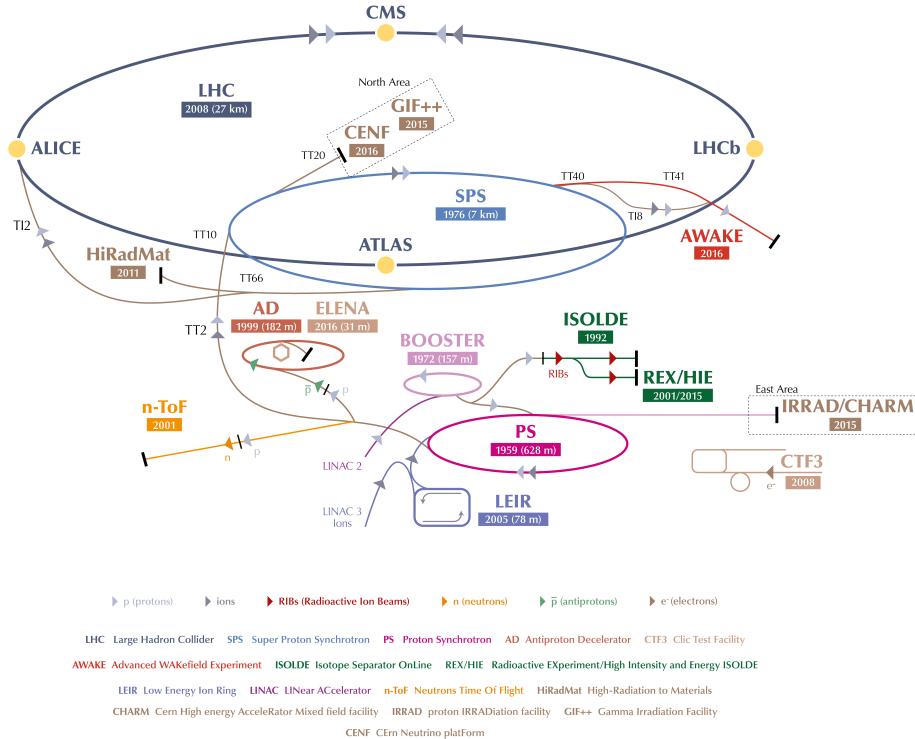


Fig. 1.2: Layout of LHC accelerator complex [4].

Steering a 7 TeV proton beam around the curved sections requires a magnetic field of 8.33 Tesla which is provided by 1223 superconducting dipole magnets cooled to 1.9 K. A cross section of the LHC dipole is shown in Figure 1.4. Supercooled liquid helium flows through the heat exchanger pipe to cool the iron yolk to a temperature of 1.9 K. Ultra high vacuum is maintained in the outer volume to provide a layer of thermal insulation between the inner volume and the outer steel casing. Inside the iron yolk is a twin bore assembly of niobium-titanium superconducting coils. Two parallel beam pipes are located within the focus of the superconducting coils. This is the ultra high vacuum region where the subatomic particles are confined as they travel around the LHC ring.

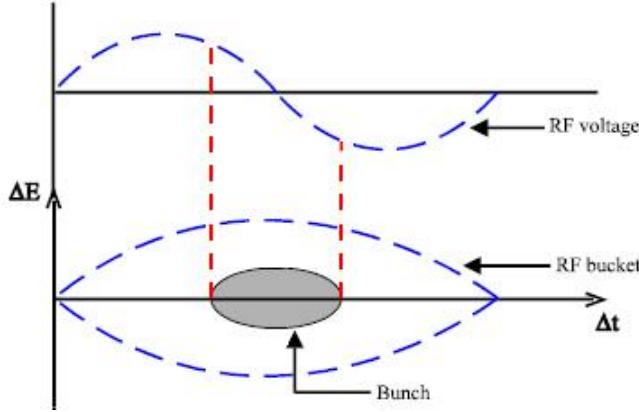


Fig. 1.3: Proton bunch capture onto RF bucket [1].

1.4 Luminosity

The number of events generated per second for specific process having cross-section σ_{event} is given by:

$$\frac{dN_{event}}{dt} = L\sigma_{event} \quad (1.1)$$

where L is the machine luminosity. The machine luminosity for a Gaussian beam distribution can be written in terms of the beam parameters as:

$$L = \frac{N_b^2 n_b f_{rev} \gamma_r}{4\pi \epsilon_n \beta_*} F \quad (1.2)$$

where N_b is particle density in each bunch, n_b is the number of bunches in each beam, f_{rev} is the frequency of revolution, and γ_r is the relativistic gamma factor. The variables ϵ_n and β_* are the normalized transverse beam emittance and the beta function at the IP respectively, while F is the geometric reduction factor depending due to the beams' crossing angle at the IP. [4]

The total number of events produced over a given amount of time would then be

$$N_{event} = \sigma_{event} \int L dt = \sigma_{event} L_{integrated}. \quad (1.3)$$

The integrated luminosity delivered each year to the CMS experiment is shown in 1.5. The analysis presented here uses data collected from the 2016, 2017, and 2018 campaigns which gives a combined integrated luminosity of 158.7 fb^{-1} .

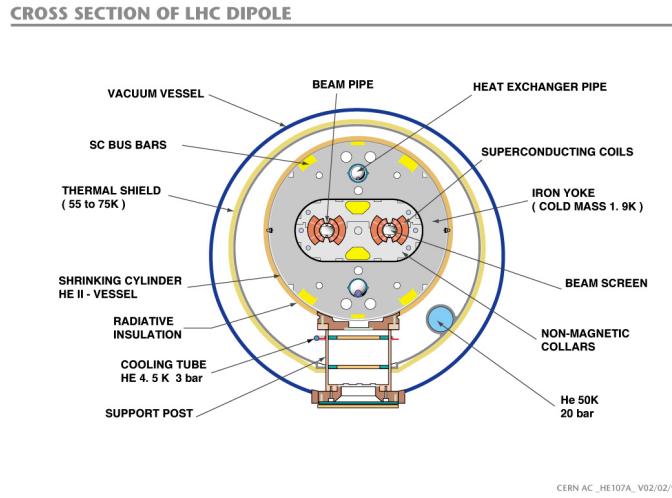


Fig. 1.4: Cross section of LHC dipole [2]

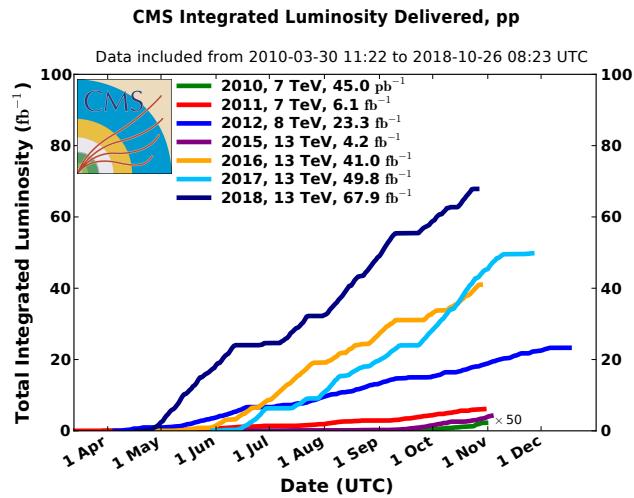


Fig. 1.5: Integrated luminosity delivered by the LHC to the CMS experiment each year from 2010-2018.

2. COMPACT MUON SOLENOID

2.1 scratch

Mention the location of CMS. Give an overview of what it was designed to do. Find a nice way to say that there is a lot of shit coming from the interaction region and we have to sort through it. We need to get charged particle momentum and energy, electromagnetic energy,

2.2 *Introduction*

About 100 meters below the town of Cessy, France at Point 5 is the Compact Muon Solenoid (CMS). The CMS is a general purpose detector weighing 14,000 tonnes with a length of 28.7 meters and a 15.0-meter diameter. A perspective view of the detector is shown in Figure 2.1.

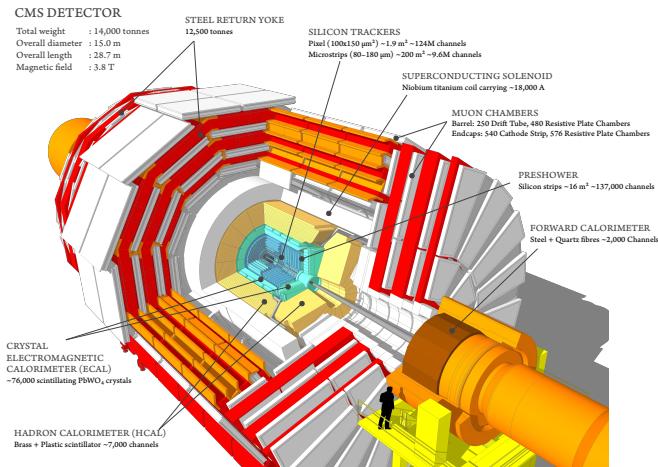


Fig. 2.1: Schematic of CMS detector

While the CMS detector was designed to study proton-proton collisions and heavy-ion collisions with center of mass energies up to 14 TeV and 5.5

TeV respectively, this document will focus on operating with proton-proton collisions.

With a total proton-proton cross-section of about 300 mb at the LHC design energy of $\sqrt{s} = 14$ TeV one expects [3]. At the LHC design luminosity of $10^{34}\text{cm}^{-2}\text{s}^{-1}$

3. THE STANDARD MODEL

4. SUPERSYMMETRY

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