UNIVERSITY OF CALIFORNIA

Los Angeles

NO TITLE!?!

A dissertation submitted in partial satisfaction

of the requirements for the degree

Doctor of Philosophy in Physics

by

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The dissertation of Tyler Christopher Lam is approved.

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ACKNOWLEDGMENTS

VITA

2015	Undergraduate Research Intern, SLAC National Accelerator Laboratory
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CHAPTER 1

Experimental Apparatus

1.1 The Large Hadron Collider

The Large Hadron Collider (LHC) is a circular collider spanning the border between France and Switzerland, based at the European Organization for Nuclear Research (CERN). The central features of the LHC are the superconducting rings, located about 100 m underground with a circumference of 27 km, designed to collide counter-rotating beams of protons or heavy ions at highly relativistic energies. Along the rings lie four major experiments: ATLAS, CMS, ALICE, and LHCb. Both ALTAS and CMS are general purpose detectors, designed to probe a wide range of physics including the Higgs boson, precision measurements of fundamental constants, and physics beyond the standard model (BSM). The remaining two experiments are more specialized; ALICE measures quark gluon plasma produced in heavy ion collisions and LHCb focuses on b-quark physics and CP violation.

Two prominent aspects of the LHC are the high center of mass energy, referred to using the Mandelstam variable $\sqrt{s}$, and high instantaneous luminosity $\mathcal{L}$, often referred to as just luminosity. High $\sqrt{s}$ allows for the production of more massive particles, giving more access to possible BSM physics, while high luminosity is essential for measuring rare processes and precision measurements. A process with cross section σ will have a rate R given by

$$R = \mathcal{L}\sigma \tag{1.1}$$

The cross section σ is a measure of how probably a process is to occur, and is in units of area. They are frequently measured in barns, where 1 b $= 100$ fm^2. Conversely, luminosity uses units of Hz/b. In cases where the relevant quantity is the total number of events, the integrated luminosity can be defined as $\mathcal{L}_{\text{int}} = \int \mathcal{L}\,\mathrm{d}t$ to give

$$N_{\text{events}} = \mathcal{L}_{\text{int}}\sigma \tag{1.2}$$

The luminosity depends on the characteristics of the proton beam and can be written in terms of the operational parameters of the detector given by

$$\mathcal{L} = \frac{N_b^2 n_b f_{\text{rev}} \gamma_r}{4\pi\epsilon_n\beta^*}F \tag{1.3}$$

where N_b is the number of particles per bunch, n_b is the number of bunches per ring, f_{rev} is the LHC revolution frequency, γ_r is the Lorentz factor for the proton, ϵ_n is the transverse normalized beam emittance, β^* is the amplitude function at the collision point, and F is a geometric reduction factor based on the crossing angle of the two beams. The nominal design parameters of the LHC were intended to support a peak luminosity of 12 Hz/nb [2], but during run 2 was able to achieve nearly twice that value at 21.4 Hz/nb.

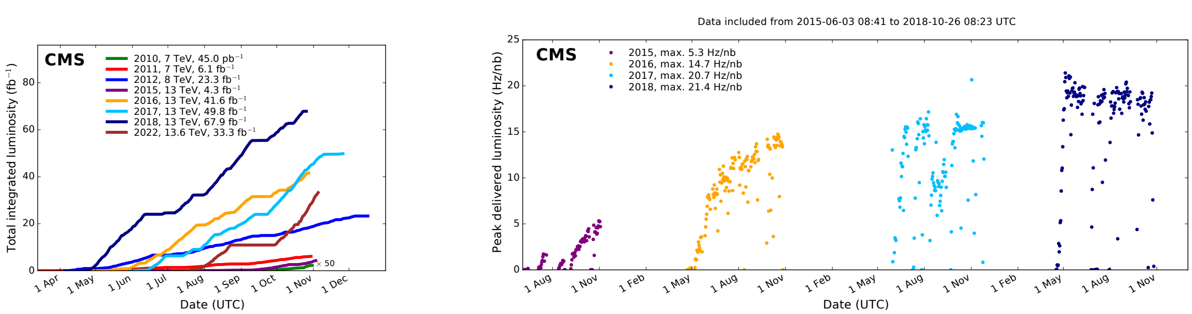

Figure 1.1: LHC luminosity report. Left: breakdown of the CMS integrated luminosity by year from 2010-2022. Right: peak instantaneous luminosity from 2016-2018 data taking [1]

The protons used in collisions begin as hydrogen atoms, which are first ionized using electric fields to strip the electrons. They are first accelerated to 50 MeV through a linear accelerator Linac2 before entering the Proton Synchrotron Booster (PSB), where they will reach a kinetic energy of 1.4 GeV. Next, the protons are accelerated by the Proton Synchrotron (PS) and Super Proton Synchrotron (SPS), where they are accelerated to 26 GeV and 450 GeV respectively. Finally, the beams are injected into the LHC where they undergo acceleration to 6.5 TeV, producing the desired center of mass energy of $\sqrt{s} = 13$ TeV.

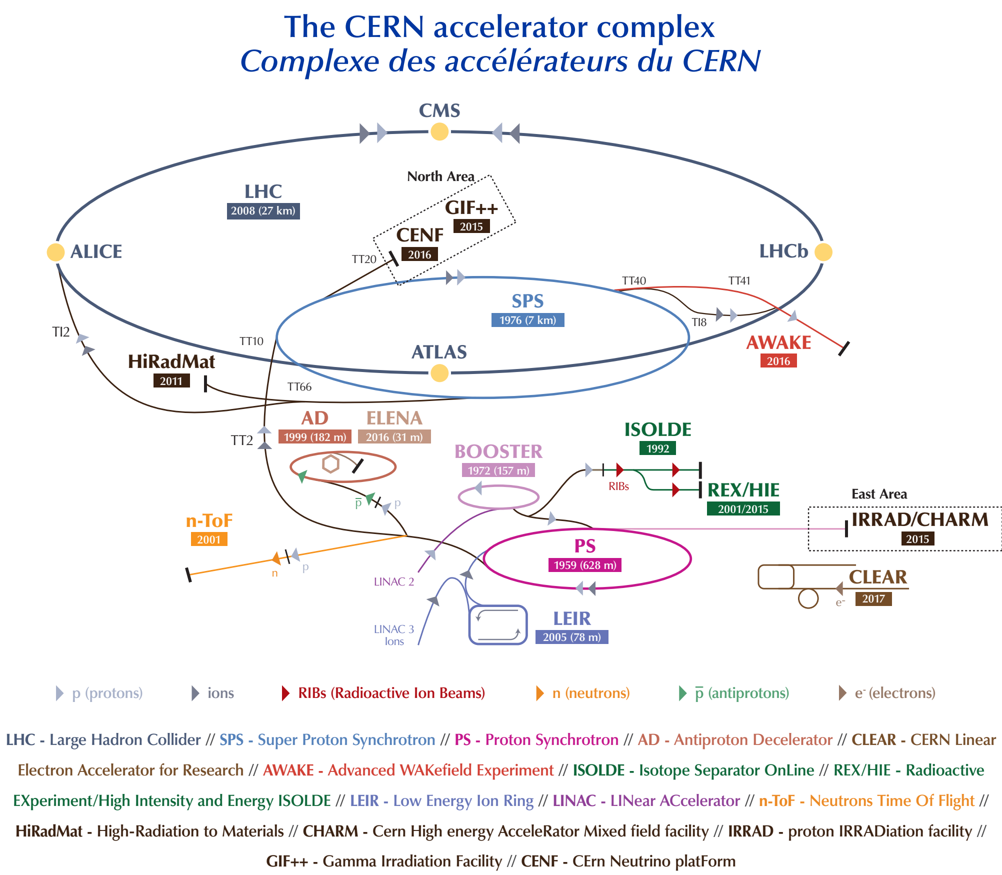

Figure 1.2: Diagram of the CERN accelerator complex during 2018 data taking [3]. Protons begin as hydrogen atoms at Linac2 and are accelerated in several stages to reach 6.5 TeV

REFERENCES

[1] CMS Collaboration. CMS luminosity - public results, 2018. URL: `https://twiki.cern.ch/twiki/bin/view/CMSPublic/LumiPublicResults`.

[2] Oliver Sim Brüning, Paul Collier, P Lebrun, Stephen Myers, Ranko Ostojic, John Poole, and Paul Proudlock. *LHC Design Report*. CERN Yellow Reports: Monographs. CERN, Geneva, 2004. URL: `https://cds.cern.ch/record/782076`, `doi:10.5170/CERN-2004-003-V-1`.

[3] Esma Mobs. The CERN accelerator complex - august 2018. complexe des accélérateurs du CERN - août 2018. Aug 2018. General Photo. URL: `https://cds.cern.ch/record/2636343`.