UNIVERSITÀ DEGLI STUDI DI MILANO

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A machine learning approach to the electrons and photon classification with the ATLAS detector at the LHC

Autore:
Pietro Daniele

Matricola:
906962

Codice P.A.C.S.:
07.05.-t

Relatore:
Prof. Leonardo Carlo Carminati

Corelatori:
Dott. Ruggero Turra
Dott. Davive Mungo

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Chapter 1

LHC and ATLAS

1.1 The LHC

The CERN Large Hadron Collider is a two-ring, superconducting accelerator and collider installed in the long LEP tunnel (27 km)[1] and it provides pp collisions and heavy-ion (e.g. Pb-Pb) collision.
Inside the accelerator, two high-energy particle beams travel at close to the speed of light before they are made to collide. The beams travel in opposite directions in separate beam pipes – two tubes kept at ultrahigh vacuum. They are guided around the accelerator ring by a strong magnetic field maintained by superconducting electromagnets[2]

1.1.1 Lattice Layout

The basic layout of the LHC follows the LEP tunnel geometry. The LHC has eight arcs and straight sections. Each straight section is approximately 528 m long and can serve as an experimental or utility insertion. The two high luminosity experimental insertions are located at diametrically opposite straight sections: the ATLAS experiment is located at point I and the CMS experiment at point 5.
Two more experimental insertions are located at point 2 and point 8 which also contain the injection systems for Beam J and Beam 2, respectively. The injection kick occurs in the vertical plane with the two beams arriving at the LHC from below the LHC reference plane. The beams only cross from one magnet bore to the other at these four locations.
The remaining four straight sections do not have beam crossings. Insertion 3 and 7 each contain two collimation systems. Insertion 4 contains two RF systems: one independent system for each LHC beam. The straight section at point 6 contains the beam dump insertion where the two beams are vertically extracted from the machine using a combination of horizontally deflecting fast-pulsed ('kicker') magnets and vertically-deflecting double steel septum magnets. Each beam features an independent abort system. [1]
The protons travel inside along th LHC ring in opposite direction. The LHC beams are controlled by superconducting magnets, which have a working temperature of 1.9 K. There are two kinds of superconducting magnets:
- the superconducting dipole magnets, which thanks to a 8.33 T magnetic field drive protons along the ring (circular orbit);
- superconducting quadrupole magnets, which keep the beams focused.

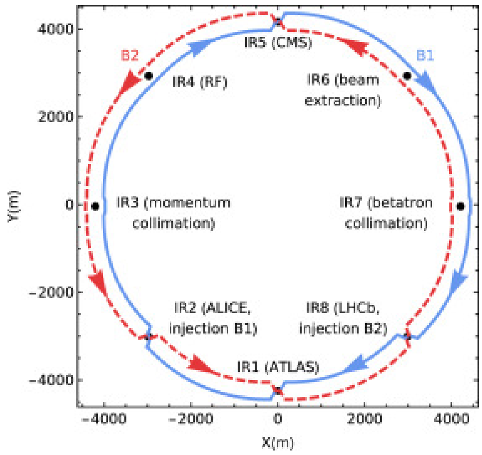
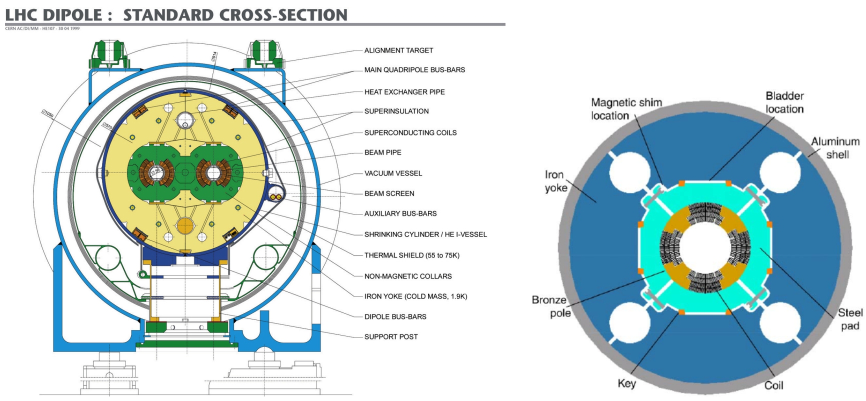


Figure 1.1: LHC structure



(a) *LHC dipole* (b) *LHC quadpole*

Figure 1.2: LHC's superconducting magnets

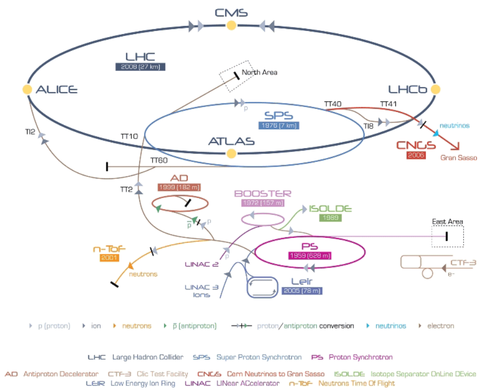


Figure 1.3: LHC and CERN's complex accelerator

1.1.2 The CERN accelerator complex

Before being insert into LHC ring, particle beam is accelereted by the CERN accelerator complex. It is a succession of machins with increasingly higher energies. Each machine injects the beam into the next one, which takes over to bring the beam to an even higher energy, and so on. In the LHC—the last element of this chain—each particle beam is accelerated up to the record energy of 6.5 TeV. Specifically, in LHC protons are obtained by stripping electrons from hydrogen atoms, which are taken from a bottle containing hydrogen. Then protons are injected into the PS Booster (PSB) at an energy of 50 MeV from Linac2. The booster accelerates them to 1.4 GeV. The beam is then fed to the Proton Synchrotron (PS) where it is accelerated to 25 GeV. Protons are then sent to the Super Proton Synchrotron (SPS) where they are accelerated to 450 GeV. They are finally transferred to the LHC (both in a clockwise and an anticlockwise direction) where they are accelerated for 20 minutes to 6.5 TeV. Beams circulate for many hours inside the LHC beam pipes under normal operating conditions.
In addition to accelerating protons, the accelerator complex can also accelerate lead ions. [3]

1.1.3 Proton-proton collisions

The numer of events per second generated in the LHC collisions is given by:

$$N_{event} = L\sigma_{event}$$

where σ_{event} is the cross section for the event under study and L the machine luminosity. L depends only on the beam parameters and can be written for a Gaussian beam distribution as:

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

where N_b is the number of particles per bunch, n_b the number of bunches per beam, f_{rev} the revolution frequency, γ_r the relativistic gamma factor, ϵ_n the normalized transverse beam emittance, β^* the beta function at the collision point and F the geometric luminosity reduction factor due to the crossing angle at the IP. a[0]

[0] $F = \frac{1}{\sqrt{1+(\frac{\eta_c\sigma_z}{2\sigma^*})^2}}$ where η_c is the full crossing angle at the IP, σ_z the RMS bunch length and σ_* the transverse RMS beam size at the IP.

Bibliography

[1] European organization for nuclear research, *LHC design report*, CERN libraries, Geneva (2004). http://cds.cern.ch/record/782076/files/

[2] F. Gianotti, *Collider physics: LHC*, EP Division, CERN, Geneva, Switzerland. https://cds.cern.ch/record/458489/files/p219.pdf

[3] https://cds.cern.ch/record/2255762/files/CERN-Brochure-2017-002-Eng.pdf