Search for Higgs Decay to Dark Matter and Trigger Studies

João Carlos Arnauth Pela
of Imperial College London

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Abstract

Here the abstract of the thesis

Declaration

This dissertation is the result of my own work, except where explicit reference is made to the work of others, and has not been submitted for another qualification to this or any other university. This dissertation does not exceed the word limit for the respective Degree Committee.

João Pela

Acknowledgements

TODO:

- Family
- Friends
- Work colleagues (include CMS collaboration)
- more

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Preface

Thesis structure and so on...

“To my grand mother”

Contents

Chapter 1

Theory

TODO:

- Global status

1.1 Standard Model of Particle Physics

TODO:

- Very brief summary of the Standard Model.

The Standard Model (SM) of particle physics is the currently accepted model for describing the physics of elementary particles.

Leptons (J=1/2)				
Generation	Particle Name	Symbol	Mass (GeV/c^2)	Q/e
1^{st}	Electron	e	0.000511	1
	Electron Neutrino	ν_e	$< 3 \times 10^-9$	0
2^{nd}	Muon	μ	0.106	1
	Muon Neutrino	ν_μ	$< 1.9 \times 10^-4$	0
3^{rd}	Tau	τ	1.777	1
	Tau Neutrino	ν_τ	$< 1.82 \times 10^-2$	0

Table 1.1: List of leptons and their fundamental properties

Quarks (J=1/2)				
Generation	Particle Name	Symbol	Mass (GeV/c^2)	Q/e
1^{st}	Up	u	$1.5 - 3.3 \times 10^{-3}$	-2/3
	Down	d	$3.5 - 6 \times 10^{-3}$	1/3
2^{nd}	Charm	c	1.16-1.34	-2/3
	Strange	s	$70 - 130 \times 10^{-3}$	1/3
3^{rd}	Top	t	169-173	-2/3
	Bottom	b	$4.13 - 4.37$	1/3

Table 1.2: List of quarks and their fundamental properties

Bosons			
Particle Name	Mass (GeV/c^2)	Q/e	Spin
Photon (γ)	0	0	1
$W^{\pm}$	80.4	∓ 1	1
Z^0	91.2	0	1
Gloun (g)	0	0	1
Higgs (H^0)	> 114	0	0

Table 1.3: List of bosons and their fundamental properties

1.2 Higgs Mechanism

Summary of the Higgs Mechanism. Should include

- Motivations
- Explanation of the mechanism itself
- Consequences
- Possible decays

1.3 Higgs Invisible decays

TODO:

- Explain what are SM Higgs invisible decays.
- Go over the possibility of BSM invisible decays.

Chapter 2

Experimental Apparatus

2.1 The Large Hadron Collider

TODO:

- DONE: LHC location, size, particles used, energy usage.
- Basics of machine and operation
- How instantaneous luminosity is calculated include Instantaneous luminosity equation
- Delivered instantaneous luminosity Run I (proton-Proton)

The Large Hadron Collider (LHC)[1] is currently the world's largest particle accelerator and is capable to produce the highest energy particle beam ever made by mankind. This gigantic machine with a total perimeter of 26.7 kilometer was built at European Organization for Nuclear Research (CERN) in a circular tunnel at an average depth of 100 meters below ground under the Franco-Swiss border near Geneva, Switzerland. I Diagram of the LHC tunnel can be found in figure 2.1.

The LHC is a synchrotron machine with the capability to accelerate particles in two separated beam pipes with travel in opposite direction. These beams only cross and are allowed to collide in four specific points of the accelerator where huge particle detectors are installed to detect the products of such collisions. This experiments are name ATLAS[2], CMS[3], LHCb[4] and ALICE[5].

The accelerator as its name indicates can collide hadrons, more specifically proton or heavy ions. Up to now 3 modes of operation have been tried according to the particles being collided: proton-proton, proton-lead and lead-lead. Depending on the which configuration is chosen we are basically changing the quantity of nucleons available to

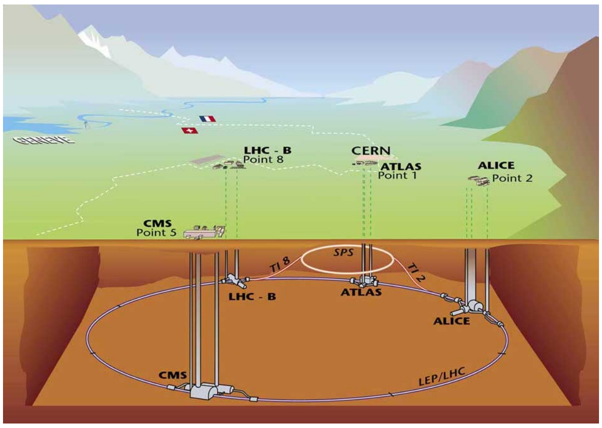

Figure 2.1: Underground diagram of the Geneva area showing the LHC location.

each colliding element. The maximum design energy per proton is 7 TeV and for each lead nucleon 2.76 TeV. The design luminosity for proton-proton is of 10^{34} $cm^{-2}s^{-1}$ and for lead-lead is of 10^{27} $cm^{-2}s^{-1}$.

The LHC is only the last element of a complex accelerator chain which step by step increases the energy of the particles. Protons are initially obtained by stipping the electrons of hydrogen gas. The are then accelerated at the Linear Particle Accelerator 2 (LINAC2) up to the energy of 50 MeV. After this initial step they are injected into the Proton Synchrotron Booster (PSB) and the energy ramps ups to 1.4 GeV. After protons are passed to the Proton Synchrotron (PS) where energy futher increases to 25 GeV subsequently they are the injected into the Super Proton Synchrotron (SPS) where the particle energy level reached 450 GeV. Finally, protons pass to the LHC where they can be accelerated to a maximum energy of 7 TeV. A simplified diagram of the CERN accelerator chain can be found in figure 2.2.

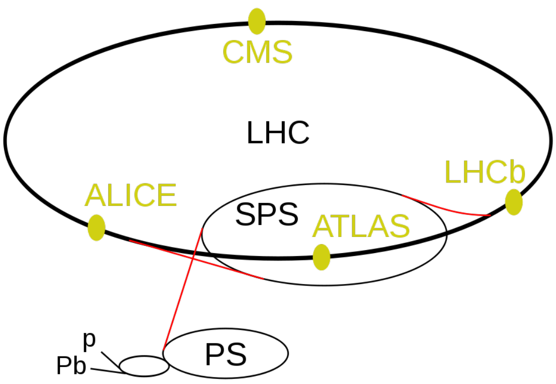

Figure 2.2: CERN Large Hadron Collider Experiment accelerator diagram.

Normal operation of the LHC therefore depends on the the upstream accelerators availability. The typically turn around time, the time necessary to stop the accelerator from running and restart collisions is around 2 hours. When stable beams are achieved, a single proton fill can be used to collide protons up to 24 hours, but it is common to restart more frequently to take profit of the higher collision rates possible right at the beginning of a new fill.

Some of the key parameters of the LHC proton-proton and lead-lead operation can be found in table 2.1.

		pp	**HI**	
Energy per nucleon	E	7	2.76	TeV
Dipole field at 7 TeV	B	8.33	8.33	T
Design Luminosity*	$\mathcal{L}$	10^{34}	10^{27}	$cm^{-2}s^{-1}$
Bunch separation		25	100	ns
No. of bunches	k_B	2808	592	
No. particles per bunch	N_p	1.15×10^{11}	7.0×10^{7}	
Collisions				
β-value at IP	β^*	0.55	0.5	m
RMS beam radius at IP	σ^*	16.7	15.9	μm
Luminosity lifetime	τ_L	15	6	hr
Number of collisions/crossing	n_c	≈ 20	-	

* For heavy-ion (HI) operation the design luminosity for Pb-Pb collisions is given.

Table 2.1: The machine parameters relevant for the LHC detectors.[6]

At the LHC we are looking for extremely rare processes as is can be seen in figure 2.3 the production cross section of a SM Higgs boson is more than 9 orders of magnitude smaller than the total proton-proton cross section.

To be able to record and study such rare processes we need to produce a significant amount of collisions. For this purpose the LHC was designed to operate at high instantaneous luminosity, L. This quantity is defined as,

$$L = \frac{N_b^2 n_b f_{\text{rev}} \gamma}{4\pi \epsilon_n \beta^*} F, \tag{2.1}$$

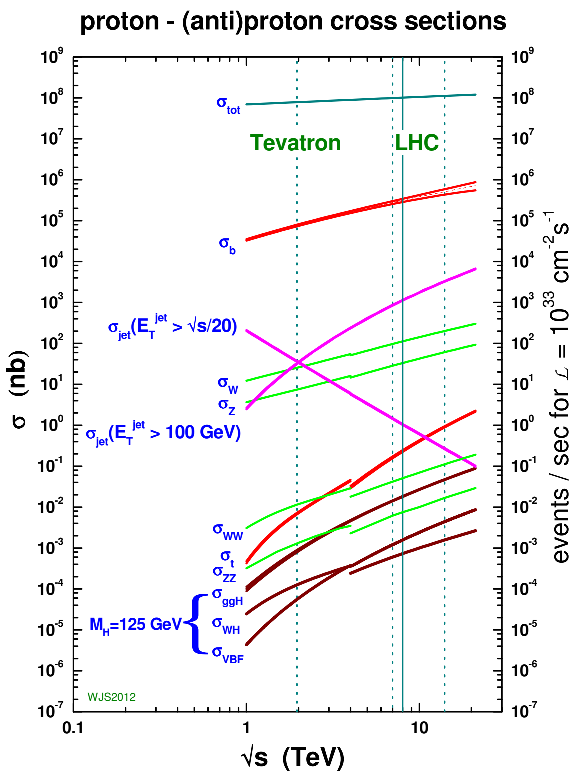

Figure 2.3: Cross sections for several processes for collisions of antiproton-proton and proton-proton as a function of the center of mass energy[**?**].

where N_b is the number of protons per bunch, n_b is the number of bunches, $f_{\rm rev}$ is the frequency of revolution, γ is the Lorentz factor, ϵ_n is the normalized emittance, $f_{\rm rev}$ is the beta function at the collision point and F is the reduction factor due to the crossing angle.

2.2 The Compact Muon Solenoid Experiment

The Compact Muon Solenoid (CMS) experiment is a general purpose experiment located at point 5 of the LHC. It was designed to study collisions at its centre and is composed os several sub-systems in an classic onion shaped structure.

2.2.1 Inner tracking system

The volume near the interaction point can be split according to the charged particle flux into three regions depending on the charged particle flux.

- one
- two
- three

2.2.2 Electromagnetic Calorimeter

The Electromagnetic Calorimeter (ECAL)

2.2.3 Hadronic Calorimeter

The Hadronic Calorimeter (HCAL)

2.2.4 Solenoid Magnet

Parameter	Value
Field	4 T
Inner Bore	5.9 m
Length	12.9 m
Number of turns	2168
Current	19.5 kA
Stored Energy	2.7 GJ
Hoop Stress	64 atm

Table 2.2: Parameters of the CMS superconducting solenoid

2.2.5 Muon System

2.2.6 Data Acquisition System

The Data Acquisition (DAQ)

2.2.7 Trigger System

The Level 1 Trigger (L1T) and High Level Trigger (HLT)

2.2.8 Computing

The Data Quality Monitoring (DQM)

2.2.9 Run II Updgrades

The upgrade tdr [7].

Chapter 3

Technical work

3.1 Level 1 Trigger Data Quality Monitoring System

Hello

Chapter 4

Physics Objects and Monte Carlo simulation

4.1 Physics objects definition

4.1.1 Electron

4.1.2 Muon

4.1.3 Tau

4.1.4 Jets

4.1.5 Missing Transverse Energy

4.2 Monte Carlo simulation

Chapter 5

Prompt Data Analysis

Chapter 6

Parked Data Analysis

Chapter 7

Run II Preparation

7.1 Run II trigger studies

7.2 Run II QCD Monte Carlo samples

Chapter 8

Conclusions

Summary of relevant results and their impact on Particle Physics

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[7] CMS Collaboration, “CMS Technical Design Report for the Level-1 Trigger Upgrade”,.

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Acronyms

CERN European Organization for Nuclear Research. 4, 5

CMS Compact Muon Solenoid. 7

DAQ Data Acquisition. 9

DQM Data Quality Monitoring. 9

ECAL Electromagnetic Calorimeter. 8

FCT Fundação para a Ciência e a Tecnologia. vi

HCAL Hadronic Calorimeter. 8

HLT High Level Trigger. 9

L1T Level 1 Trigger. 9

LHC Large Hadron Collider. 4–7, 18

LINAC2 Linear Particle Accelerator 2. 5

PS Proton Synchrotron. 5

PSB Proton Synchrotron Booster. 5

SM Standard Model. 2, 6

SPS Super Proton Synchrotron. 5