Tracks Study of Primary Charged Particles Produced in p-p Collisions at 900 GeV Energy

By

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بسم الله الرحمن الرحيم

In the Name of Allāh, the Most Gracious, the Most Merciful

International Islamic University, Islamabad
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Final Approval

It is Certified that the work presented in this thesis entitled **"Tracks Study of Primary Charged Particles Produced in p-p Collisions at 900 GeV Energy"** is carried out by **Mr. Muhammad Farhan Taseer**, Registration No. 23-FBAS/MSPHY/F10 under my supervision and that in my opinion, it is fully adequate, in scope and quality, for the award of degree of MS Physics from International Islamic University, Islamabad.

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Declaration

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M. Farhan

Muhammad Farhan Taseer

Dedicated

To my parents

Basharat Ali Taseer

Munira Basharat Taseer (Late)

&

My beloved brother

Muhammad Furqan Taseer

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M. Farhan

Muhammad Farhan Taseer

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List of Abbreviations

CERN	European Organization for Nuclear Research
ISR	Intersecting Storage Rings
LHC	Large Hadron Collider
ATLAS	A Toroidal LHC Apparatus
CMS	Compact Muon Solenoid
ALICE	A Large Ion Collider Experiment
LHCb	Large Hadron Collider beauty
QGP	Quark Gluon Plasma
SPS	Super Proton Synchrotron
LEP	Linear Electron Positron
ITS	Inner Tracking System
SPD	Silicon Pixel Detectors
SDD	Silicon Drift Detectors
SSD	Silicon Strip Detectors
TPC	Time Projection Chamber
TRD	Transition Radiation Detector
TOF	Time of Flight
PID	Particle Identification Detection
EMCAL	Electromagnetic Calorimeter

HMPID	High Momentum Particle Identification
PHOS	Photon Spectrometer
PMD	Photon Multiplicity Detector
CPV	Charge Particle Veto
ACORDE	A Cosmic Radiation Detector
ZDC's	Zero Degree Calorimeters
IP	Interaction Point
FMD	Forward Multiplicity Detector
CG	Combinational Geometry
MC	Monte Carlo

ABSTRACT

Large Hadron collider (LHC) of CERN (European Organization For Nuclear Research) is the world's biggest particle accelerator. In LHC, first proton-proton collision occurred at centre of mass energy 900 GeV on 23rd November 2009 during the first running of this huge machine. On the basis of results obtained from proton-proton collisions, a total of 284 events were recorded that day in ALICE. The large number of events confirms the pseudo-rapidity (η) of charged primary particles $dN_{ch}/d\eta$ and $\eta = -\ln(\theta/2)$ where "θ" represents the polar angle with respect to beam line in the central pseudo-rapidity region. The aim of my research work is to investigate the production of primary charged particles in p-p collisions at 900 GeV energy using two different Monte Carlo simulation techniques, by ALICE offline framework and FLUKA software.

Chapter 01

Introduction to Elementary Particle Physics

This chapter includes some basic introduction to elementary particle physics, constituents of which the matter is composed and the underlying forces which exist between them. This chapter also encloses theories (classical and quantum) that describe the characteristic of particles and the forces which bind them to give a composite form.

1.1 Elementary Particles

A particle which is not made up from smaller particles is called elementary particle or fundamental particle. Such a particle has no sub-structure or internal structure and infact an elementary particle provides basis for the creation of basic building blocks of matter from which all other particles are made. In the Standard Model of Particle Physics, Quarks, Leptons (their anti-particles) and Gauge Bosons are elementary particles [25, 20].

The interactions of elementary particles with one another are not like what we see in macroscopic world. At macroscopic level, if we want to study how two particles or two objects interact, we simply suspend them at various separations and calculate the force between them. But the story is remarkably different in microscopic world because we can not pick a proton with a tweezer or tie an electron onto the end of a piece of string. The reason is very simple i.e. these particles (electron, proton, etc.) are very small. Therefore at microscopic level, almost all experimental information comes from three sources i.e. scattering events, decays and bound states [26].

The elementary particles can be produced through different methods. For electron and proton, the method is very simple as these are the stable constituents of ordinary matter. Thus electrons can be obtained simply by heating a piece of metal, while to obtain protons, we just need to ionize the hydrogen atom. However, there are three main sources for the production of elementary particles, i.e. cosmic rays, nuclear reactors and particle accelerators. Generally, the energy of collision must be higher in order to produce a heavier particle. This leads us to the fact that the lightest particles were discovered first because they needed less energy of collisions. However, with the passage of time, more powerful accelerators have been designed to find heavier and heavier particles which involved very high energy of collisions [27].

In particle physics, the definition of what is elementary or fundamental is always not sure and is based on experimental verifications at ever higher energies. Therefore we need very high energies in order to study the particles at very small length scales. That is why the study of elementary particles is also known as High Energy Physics [21].

1.2 Classification of Matter

The discovery of electron in 19th century, the discovery of atomic nucleus in 20th century and with the birth of particle physics, matter was thought to be composed of electrons, protons, neutrons and these particles interact to form atoms. But the latest researches have revealed that proton and neutron have internal structure and they are composite particles. Proton and neutron can be divided into quarks, while electron belongs to a family of particles known as leptons. Both quarks and leptons are elementary particles and they are considered to be the fundamental constituents of matter [15]. The interactions between quarks and leptons occurred through four fundamental forces, i.e. strong force, electro-magnetic force, weak force and gravitational force. These interactions are the results of exchange of force carrying particles between quarks and leptons [49, 13]. The Standard Model of particle physics consists of three generations of matter and each generation of matter is composed of two quarks and two leptons as shown in figure 1.1. The first generation carries up and down quarks plus two leptons i.e. electron and electron neutrino, the second generation consists of charm and strange quarks plus the two leptons i.e. muon and muon neutrino. While the third generation carries top and bottom quarks plus two leptons i.e. tau and tau neutrino [52]. In particle physics, the particles which obey Fermi-Dirac statistics are called fermions. The fermions can be elementary like electron or composite like proton and neutron [79].

Quarks	u Up	c Charm	t Top	γ Photon
Quarks	d Down	s Strange	b Bottom	g Gluon
Leptons	υ_e Electron-Neutrino	υ_μ Muon-Neutrino	υ_τ Tau-Neutrino	Z-boson
Leptons	e Electron	μ Muon	τ Tau	$W^{\pm}$ W-boson
	I	II	III	**Force Carriers**

Figure 1.1 Three generations of elementary constituents of matter [104]

1.2.1 Leptons

Leptons are elementary particles having spin 1/2. They do not interact through strong interactions. There are three generations of leptons, each consists of a charged lepton and its related neutrino called neutral lepton. Leptons also have three flavors i.e. electron, muon and tau, referred as charged leptons having electric charge (q = -e). Three neutral leptons or neutrino called electron-neutrino, mu-neutrino and tau-neutrino are also associated with charged leptons. Each charged lepton has a distinct antiparticle. The charged leptons have ability to interact through both electromagnetic and weak interactions while the neutral leptons interact via weak interaction only [60]. The electron is the most familiar and the only one which is stable while the other two charged leptons (muon and tau) are unstable. The Standard Model of particle physics assigns each lepton a weak isospin (z-component of a quantum mechanical property represented by a vector "T" which is loosely analogous to spin). An anti-neutrino is also associated with each neutrino. It may also possible that the two neutrinos are not distinct i.e. each neutrino may be its own antiparticle (so called Majorana neutrino) like photon which is its own antiparticle. Unlike quarks, there are no lepton-lepton bound states [63].

Table 1.1 Properties of Leptons [63]

Generations	Lepton	Symbol	Charge (e)	Weak Isospin (T_z)	Mass (MeV/c^2)	Lifetime (Seconds)	Spin (ħ)
1st generation	Electron	$\bar{e}$	-1	-1/2	0.5110	Stable	1/2
	Electron neutrino	υ_e	0	1/2	≤ 2.2 eV/c^2	Stable	1/2
2nd generation	Muon	μ	-1	-1/2	105.659	2.2×10^{-6}	1/2
	Muon neutrino	υ_μ	0	1/2	≤ 3.5 eV/c^2	Stable	1/2
3rd generation	Tau	T	-1	-1/2	1784	2.9×10^{-13}	1/2
	Tau neutrino	υ_τ	0	1/2	≤ 8.4 eV/c^2	Stable	1/2

1.2.2 Quarks

Quarks are also elementary particles and are regarded as one of the fundamental constituents of matter [71]. There are six types of quarks which are grouped into three generations as shown in table 1.2 and are named as up, down, charm, strange, top and bottom. Among the three generations of quarks, the first generation has the lowest masses. In a particle decay process, the heavier quarks are rapidly changed into up and down quarks which have the lowest masses. Therefore, the first generation of quarks (up and down) is generally stable. While the production of heavier quarks like charm, strange, top and bottom occurred only in high energy interactions [75].

All the quarks have fractional electric charge ($+\frac{2}{3}$e or - $\frac{1}{3}$e) and distinct antiparticles known as anti-quarks. The quarks with electric charge ($+\frac{2}{3}$ e) are called up type quarks (up, charm, top) and quarks with electric charge (- $\frac{1}{3}$e) are called down type quarks (down, strange, bottom). The bound states of quarks and anti-quarks are called hadrons. The hadrons are further divided into two sub-groups, three quarks combination is known as baryons [63]. The constituents of atomic nuclei, proton and neutron, are the two most common examples of baryons as shown in figure 1.2 [59].

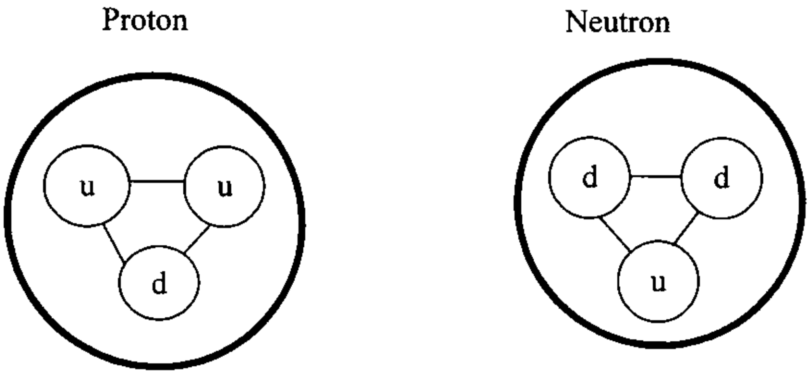

Figure 1.2 Quarks structure of Nucleons [32]

The hadrons made up of quark anti-quark pair are called mesons. The name suggested as the first meson discovered (the Pion) had intermediate properties between electron and proton [63]. In high energy hadron-hadron collisions, a hadron is not split into its constituents i.e. quarks. A hadron-hadron collision always results into hadrons rather producing free quarks. This factor also confirms our hypothesis that the quarks are always confined in a hadron and the force responsible for quarks confinement is a fundamental strong force [24].

Table 1.2 Properties of Quarks [63]

Generations	Quark (q)	Symbol	Charge (e)	Weak Isospin (T_z)	Mass (MeV/c^2)	Spin (ħ)	Baryon Number (B)
1st generation	up	U	2/3	1/2	336	1/2	1/3
	down	D	-1/3	-1/2	338	1/2	1/3
2nd generation	charm	C	2/3	1/2	1,500	1/2	1/3
	strange	S	-1/3	-1/2	540	1/2	1/3
3rd generation	top	T	2/3	1/2	170,900	1/2	1/3
	bottom	B	-1/3	-1/2	5,000	1/2	1/3

1.3 The Standard Model of Particle Physics

In particle physics, the Standard Model of elementary particles is the most accepted theory which describes all the known elementary particles interactions except gravity since 1978 [64]. The Standard Model is the combination of following theories:

(i) A particle structure model known as quark model.

(ii) A theory that unified the strong and electromagnetic interactions called the electro-weak theory.

(iii) A theory of strong interactions analogous to electrodynamics called quantum chromo-dynamics (QCD).

In the Standard Model, both quarks and leptons (and their anti-particles) are fermions having spin 1/2. However, we can differentiate quarks from leptons in the sense that quarks are those particles which are affected by the strong force as explained by a theory called QCD, while the strong force has no effect on leptons. The Standard Model grouped the constituents of ordinary matter (quarks and leptons) into three generations as shown in figure 1.3 [107].

Quarks	u Up	c Charm	t Top	γ Photon	**Force Carriers**
	d Down	s Strange	b Bottom	g Gluon	
Leptons	υ_e Electron-Neutrino	υ_μ Muon-Neutrino	υ_τ Tau-Neutrino	Z Z-boson	
	e Electron	μ Muon	τ Tau	$W^{\pm}$ W-boson	
		Higgs * Boson	(*it has recently confirmed)		

Figure 1.3 Standard Model of Particle Physics [42]

The theory that describes the unification of electro-magnetic and weak interaction is called **electroweak theory**. This theory describes a unified force at an energy level of above 200 GeV. Because at high energies, the weak and electro-magnetic interaction become really identical and were carried by four mass-less force carrying particles [108]. While the theory of strong interactions is based on three flavors of quarks and on eight gluons. The gluons are force carrying particles and are responsible for the transmission of strong force between the quarks. This theory is called **quantum chromo-dynamics (QCD)**. In this theory, the strong force between quarks is assumed to be relatively weak if they are very close to each other [107].

In the framework of Standard Model, gravity is not considered. The carrier particle of gravitational interaction, the graviton, has never been observed experimentally although its properties are derived from theoretical considerations. Therefore gravitation is not considered as a part of Standard Model [108].

1.4 A Short Description of Proton

In the framework of Standard Model, protons are fermions having spin 1/2 [74]. Protons are held together by the strong force whose mediators are gluons [105]. The total proton mass is the sum of the masses of quarks plus the kinetic energy of quarks and the energy of gluons. However, it is assumed that only 01% of the proton's mass is due to the rest mass of quarks. This assumption concluded that 99% mass of the proton is due to the kinetic energy of the quarks and the energy of gluons which binds the quarks together [33].

1.5 Overview of Present Work

Large Hadron Collider (LHC) of CERN (European Organization for Nuclear Research) is the world's biggest particle accelerator producing almost 15 million giga bytes data annually. The present work is based on one of the LHC detector called ALICE (A Large Ion Collider Experiment). The data of ALICE detector has been studied at 900 GeV energy using two different Monte Carlo techniques. First the data has been studied using ALICE offline framework which is based on Root and AliRoot softwares.

These softwares are especially designed to analyse the data produced by ALICE detector. While the data of ALICE detector has also been studied using FLUKA (Fully Integrated Monte Carlo simulation software package). The second chapter includes short review of fundamental forces, conservations laws and symmetries, and introduction to particle accelerators. While in the third chapter, brief introduction of experimental techniques like LHC and ALICE is given. This chapter also includes the definition of primary charged particles and some decay channels of p-p collisions. The fourth chapter is based on computing techniques which have been used to study the ALICE data. Finally the results of p-p collisions at 900 GeV energy using ALICE have been presented and discussed in chapter five, followed the conclusion and summary of the present studies. In the end, some suggestions and recommendations of the continuation of present work in future are given.

Chapter 02

Literature Review

2.1 Fundamental Forces and Interactions

There are four basic interactions which are responsible for all the different forces observed in nature from ordinary friction to the forces involved in supernova explosions. In order of decreasing strength, these are as follows [65]:

(i) Strong interaction
(ii) Electromagnetic interaction
(iii) Weak interaction
(iv) Gravitational interaction

Table 2.1 Characteristics of fundamental interactions [66]

Interaction	Force carriers	Mass (Gev/c^2)	Spin (ħ)	Source	Particles carrying charge	Range (m)
Strong	Gluon	0	1	Color charge	Quarks, gluon	10^{-15}
Electro-magnetic	Photon	0	1	Electric charge	q, e, μ, τ, $W^{\pm}$	∞
Weak	$W^{\pm}$, Z^0	80, 91	1, 1	Weak charge	q, e, μ, τ, $W^{\pm}$, Z^0	10^{-18}
Gravity	Graviton	0	2	Mass	q, e, μ, τ, $W^{\pm}$, Z^0	∞

2.2 Conservation Laws and Symmetries

Symmetry is defined as "an operation performed on a system that leaves the system invariant" and carries it in a configuration which is indistinguishable from the original one. If a decay or reaction does not occur in nature, then there must be a reason behind it which is usually described in terms of conservation laws. In nature, conservation laws and symmetries are related to each other in the sense that every symmetry yields a conservation law and every conservation law has a symmetry. For example, the laws of physics which govern our universe are symmetric with respect to translations in time. Therefore, the laws of physics work in the same way as they did yesterday.

In 1918, Emmy Noether presented a theorem which relates symmetries and conservation laws. According to Noether's theorem, "Every conservation law is a consequence of a particular symmetry in the laws of physics which governs the universe". For example, the conservation of momentum requires that the system should be invariant under translations in space while the angular momentum is conserved if the system is symmetrical under rotations about a point. Similarly, the electric charge is also conserved due to the invariance of electrodynamics under gauge transformations [28, 29].

Table 2.2 Conserved quantities in fundamental particle interactions [64]

Conserved quantity	Strong	Electro-magnetic	Weak
Energy	Yes	Yes	Yes
Momentum	Yes	Yes	Yes
Charge (q)	Yes	Yes	Yes
Baryon number (B)	Yes	Yes	Yes
Lepton number (L)	Yes	Yes	Yes
Hypercharge (Y)	Yes	Yes	NO ($\Delta Y = \pm 1, 0$)
Strangeness (S)	Yes	Yes	NO ($\Delta S = \pm 1, 0$)

2.3 A Brief Introduction to Particle Accelerators

Understanding of experimental tools is an important part of the study of particle physics. The accelerators, beams and detectors are used to accelerate the particles, to control their trajectories and to measure their properties. High energy physics research has always played a vital role in the development of particle accelerators. Now a days, accelerators and detectors have become the basic tools of research in Nuclear and Particle physics [48].

Accelerator

It is a scientific instrument which increases the kinetic energy of charged particles [44].

Particle Accelerator

- A particle accelerator (or atom smasher in the early 20th century) is a device that uses electromagnetic fields to propel ions or charged subatomic particles to high speeds and to contain them in well-defined beams [57].
- A particle accelerator is a device that accelerates electrically charged particles to extremely high speeds for the purpose of inducing high energy reactions or to produce high energy radiation [45].

2.3.1 Historical Background

In 1898, J. J. Thomson discovered the electron. At that time, Thomson did not know that he was using an accelerator. But we all know today that it was certainly an accelerator. He applied electric potential difference between two electrodes and accelerate the particles between these electrodes. He determined the charge to mass ratio of cathode rays. Thomson achieved the discovery of electron by studying the properties of beam itself rather using its impact on another beam or another target just as we do now a days. Accelerators have now become major tools in the study of high energy physics and particle physics to understand the nature of universe at deeper level. The present working accelerators are much complex and bigger, however they work on the same physical basis as the Thomson's device.

Before the invention of accelerators, almost all the experiments were based on natural radioactive sources and cosmic rays. For example, Ernest Rutherford discovered the atomic nucleus by using a radioactive source. Similarly, the discovery of proton and neutron were also achieved using radioactive sources. While the particles like positron, muon, charged pions and kaons were discovered in cosmic rays [106].

2.3.2 The Main Development

Many devices have been invented by the physicists since 1930 to accelerate the charged particles. The particles (electron, proton, deuteron, heavy ions, etc.) used in each case are accelerated by electric field. Magnetic field is also used in some cases to control the path of particles. The simplest type of accelerator has a single high voltage step of about ten million volts. Such accelerator is used to increase the energies of electron and proton up to 10 MeV. The second type of accelerator is based on series of low voltage steps which were applied as the particle travels in a straight line. Such type of accelerator produces electron energies up to 20 GeV. The third type of accelerator which is more general now a days carries magnetic field to hold a particle in a circular path [22].

The next step in the development of accelerators was the storage ring colliders. In this technique, two particles are collided head-on and as a result of collision, all of the particle's energy is available. At present, storage ring colliders have dominated the field of high energy physics. However, with the passage of time, development in the ring colliders occurred frequently. For example, the first type of ring collider is single ring collider which carries particles and anti-particles in the same magnetic channel. The first double ring proton collider was the CERN's ISR (Intersecting Storage Rings), 1972-1983. The discovery of W and Z particles were achieved by C. Rubbia and S. Van der Meer using CERN proton-antiproton storage ring and received the Noble Prize in 1984 [80].

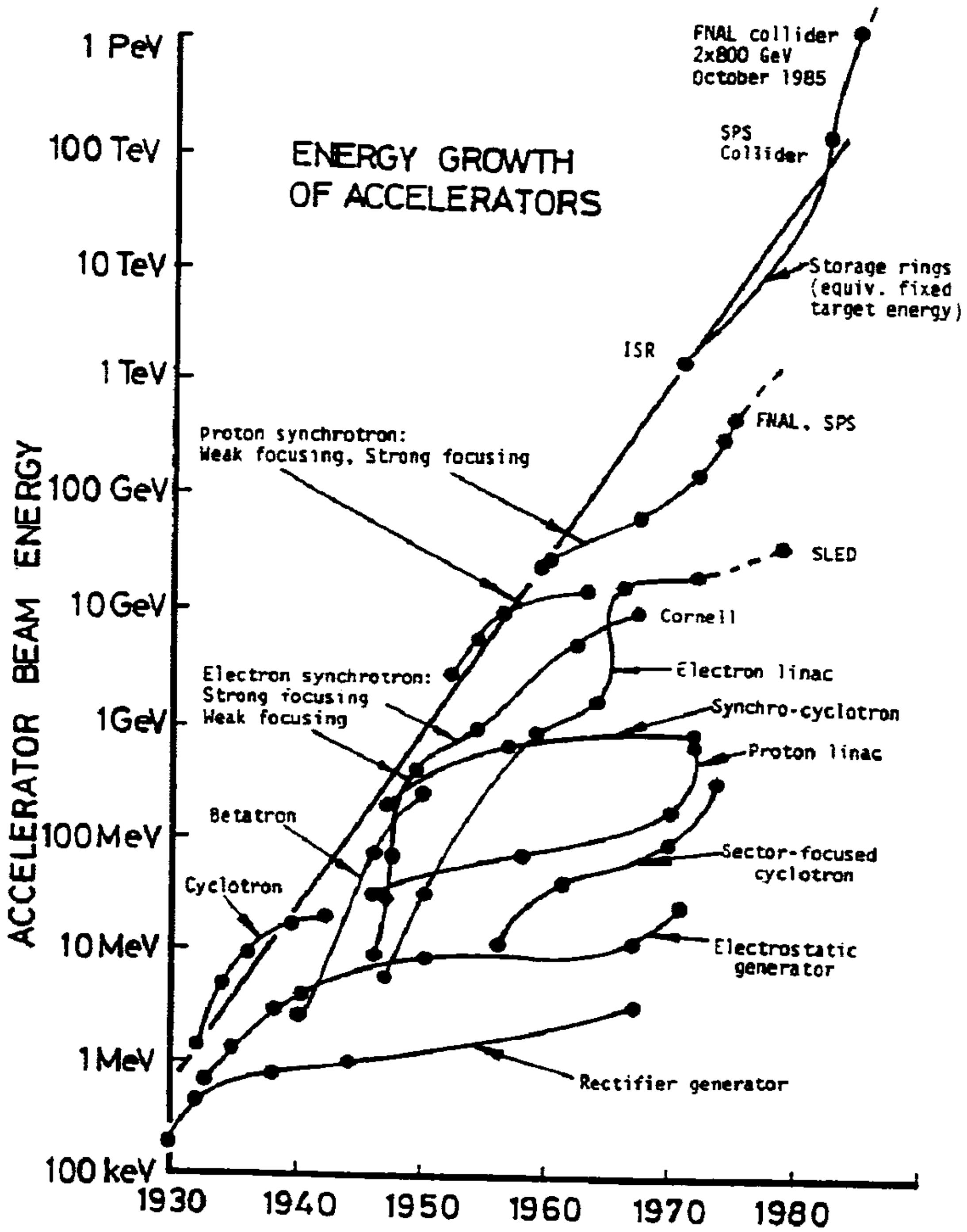

Figure 2.1 Livingston Chart shows energy growth of accelerators with the passage of time by using new technologies and ideas [56]

2.3.3 Present Situation of High Energy Particle Physics Accelerators

In the present situation, circular colliders have completely dominated the high energy field [70]. The proton community has built the superconducting collider LHC (Large Hadron collider) and is now working in CERN, Geneva, Switzerland.

Table 2.3 Properties of High-energy Physics Accelerators [70]

Accelerator	Particles	Beam- energy [GeV]	Centre of mass energy [GeV]	Luminosity $[cm^{-2}s^{-1}]$	Remarks
KEK (Japan)	p	12	5	-	Fixed target
AGS (Brookhaven)	p	33	8	-	Fixed target Polarized p
PS (CERN)	p e^+, e^-, p^-, ions	28 (p) 3.5 (e)	7 -	- -	Fixed target Injector
CESR (Cornell)	e^+, e^-	9	18	10^{32}	Collider
SPS (CERN)	p, e p, p^-	450 (p), 20(e) 2 x 315	30 (p), - 630	- 3×10^{30}	F. target, Injector Collider
SLC (SLAC)	e^+, e^-	-, -	100	6×10^{30}	Linear Collider
LEP I (CERN)	e^+, e^-	55	110	1.6×10^{31}	Collider
HERA (DESY)	e, p	30 (e), 820(p)	310	3×10^{31}	Collider S.C. p-ring
SSC (USA)	p, p	20	40	$\sim 10^{33}$	S.C. collider
LEP II	e^+, e^-	100	200	10^{32}	Collider
LHC (CERN)	p, p	08	16	$\sim 10^{34}$	S.C. Collider
CLIC (CERN)	e^+, e^-	01	02	$\sim 10^{33}$	Linear Collider

2.3.4 Applications of Particle Accelerators

Now a days, particle accelerators have wide range of applications. Some of them are as follows [43]:

(i) **Semi-conductor Industry:** In semi conductor industries, particle accelerators are widely used in the manufacturing of silicon chips. These silicon chips are then used in many electronic devices such as smart phones and computers.

(ii) **Medical Physics:** In medical physics, particle accelerators are playing very important role. With the help of particle accelerators, strong x-ray beams are generated by using synchrotron light sources. This method is used in the manufacturing of life saving drugs.

(iii) **Computing:** In Nuclear and Particle physics research laboratories, a very large amount of data is produced as a result of particles collisions. Particles accelerators have the ability to handle large amount of data. They are used to analyse and record this data.

(iv) **Nuclear Energy:** An important application of particle accelerators is in nuclear research where particle accelerators behave as reactants to treat nuclear waste. This process is used to make an alternative fuel thorium for the production of nuclear energy.

Chapter 03

Experimental Techniques

This chapter includes some experimental techniques which are used to produce and analyze the data. First a brief introduction of Large Hadron Collider (LHC) is given, followed by the description and detection techniques of a new state of matter called Quark Gluon Plasma (QGP). Then a brief introduction of ALICE (A Large Ion Collider Experiment) detector is given which is specifically designed to study the nature and properties of QGP.

3.1 Large Hadron Collider (LHC)

Large Hadron Collider (LHC) is the world's biggest and the highest-energy particle accelerator ever built on earth. The LHC is designed and built by the European Organization for Nuclear Research (CERN) near Geneva, Switzerland, about 100 meter underground [61, 36]. Physicists are expecting that they will be able to understand the predictions of different theories of particle physics and high-energy physics with the help of LHC. LHC will also help us in detail study of the recently reported Higgs Bosons [61]. A large family of new particles according to the predictions made by Super-Symmetry is also expected to be detected in LHC [100].

3.1.1 Purpose of Building LHC

LHC is built with the aim that it will explain some of the most fundamental questions of physics. Some possible issues which are expected to be explored by LHC collisions are as follows [16]:

- The Higgs mechanism which generates the masses of elementary particles actually observed in nature? [18] It is hoped that LHC will explain this phenomenon by finding the missing Higgs bosons [103, 109, 19].

- We know that all the known particles have super-symmetric partners. Then, is the super symmetry actually observed in nature? [77, 4, 12]
- The string theory has predicted the existence of extra dimensions through different models [58]. Is it possible to detect these extra dimensions? [68]
- What is the nature of dark matter and dark energy which are expected to account for 23% and 73% of the dark mass and dark energy of this universe respectively?
- QGP which has been discovered through RHIC (Relativistic Heavy Ion Collider). The LHC is used to investigate the nature and conditions for the formation of QGP.

3.1.2 Design and Working of LHC

The LHC has a circular tunnel of 27 kilometers in circumference and is built by the collaboration of scientists and physicists from more than 100 countries. It mainly consists of superconducting magnets which bend the proton beams to enhance the energy of the particles along all the way [48, 76].

Figure 3.1 LHC circular tunnel [34]

The circular tunnel of LHC contains two adjacent parallel proton beams which travel very fast, close to the speed of light, with very high energies in opposite directions [37]. In order to keep the beam-lines in circular path, 1232 dipole magnets are used while the other 392 quadrupole magnets have also been installed to focus the beam-lines on their circular track. The suitable arrangement of all the magnets is necessary in order to maximize the chances of interactions between the particles at four different intersecting points where the two beams cross. These superconducting magnets are made of copper-clad niobium-titanium and 96 tones of liquid helium is used to cool the magnets during operation which keeps the magnets at their operating temperature of 1.9K (-271.25 °C), a temperature colder than the outer space [99].

Inside the circular tunnel of LHC, protons are accelerated from 450 GeV to 3.5 TeV when it runs at full design power of 07 TeV. This process increases the field of superconducting dipole magnets from 0.54 tesla to 8.3 tesla. At this moment, the energy of each proton beam is 3.5 TeV and when one proton beam collides with the other, it gives total collision energy of 07 TeV. The protons having 07 TeV energy move at about 0.99999991 c (where "c" is the speed of light) [55]. Instead of continuous beams, the protons are entered in the circular tunnel of LHC in the form of 2808 bunches and the two beams interact at discrete intervals never shorter than 25 nano-seconds [54]. The protons are circulated for 10 to 24 hours in the main tunnel of LHC and the collisions occur between protons at four different intersecting points [51].

3.1.3 LHC Detectors

LHC contains six detectors which have been constructed underground at four different intersecting points [50]. A short description of LHC detectors according to BBC news is as follows [67]:

ATLAS: A Toroidal LHC Apparatus (ATLAS) is a general purpose detector of LHC which is used to look for the sign of new physics. This description also includes the finding of origin of mass and the extra dimensions.

CMS: Compact Muon Solenoid (CMS) is also a general purpose detector. It is mainly used for the detection of Higgs bosons. However, it also provides hints about the nature of dark matter.

ALICE: A Large Ion Collider Experiment (ALICE) is used to study a state of matter called quark-gluon plasma (QGP) which is believed to be present in the early universe shortly after Big Bang.

LHCb: Large Hadron Collider beauty (LHCb) is used to find the missing anti-matter which had been produced as a result of Big Bang.

The last two detectors of LHC, the Totem and LHCf, are much smaller in size. The Totem (Total elastic and diffractive cross-section measurement) is used to determine the total cross section of the particles and LHCf (Large Hadron Collider forward) is used to study the particles in the forward region of collisions [67].

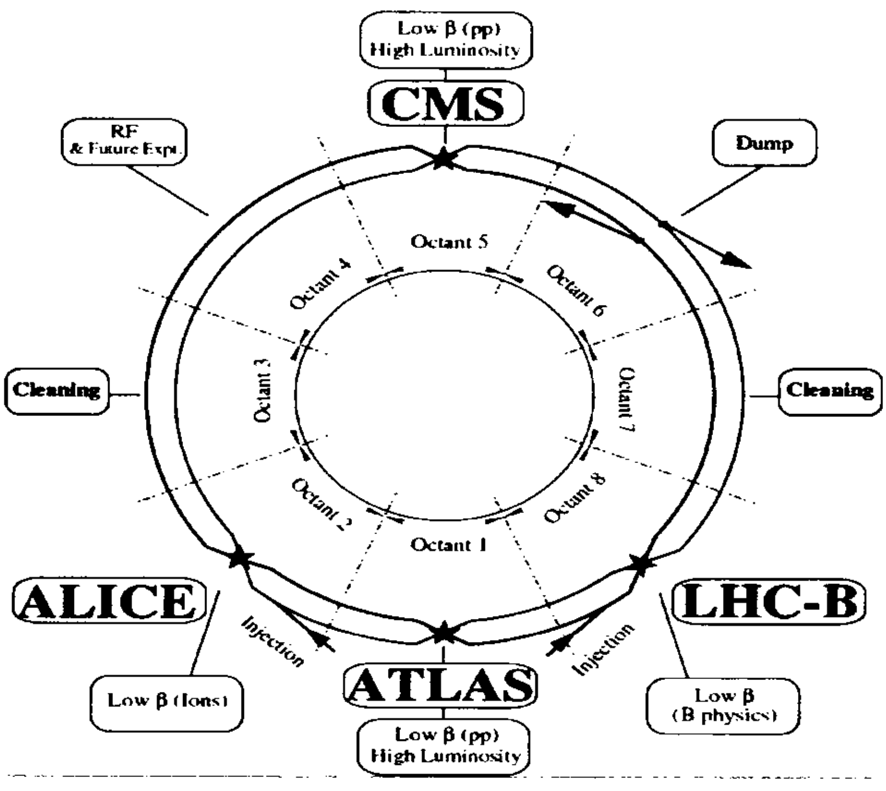

Figure 3.2 Schematic view of LHC detectors [35]

3.1.4 Worldwide LHC Computing Grid

The data produced by LHC is very large. Currently it is producing approximately 15 peta-bytes (15 million gigabytes) data annually [38]. In order to handle this massive amount of data, LHC computing grid [30] was constructed. The LHC computing grid is situated in CERN and the data is sent to many academic institutions around the world from LHC computing grid [38].

3.1.5 What makes LHC the world's best accelerator?

There are many features that make LHC prominent and different from the other particle accelerators. Some of them are as follows [39]:

(i) World's largest accelerator

LHC is the largest machine of the world ever built on earth having 27 kilometer circumference of its circular tunnel. A total of 9300 magnets have been installed inside the LHC and 10080 tons of liquid nitrogen is used to cool these magnets.

(ii) World's fastest race track

Trillions of protons travel in the circular tunnel of LHC with a speed 99.9999991% the speed of light "c" when it runs at full power. Therefore, LHC is considered the fastest race track on the earth.

(iii) World's hottest and the coldest machine

LHC has capability to work at extreme hot and extreme cold temperatures simultaneously. As a result of collision between two proton beams which travel in the circular tunnel of LHC, a temperature of more than 100000 times hotter as compared to the internal temperature of the sun is produced. On the other hand, the cryogenic distribution system of LHC keeps it at a super cool temperature of -271.3 °C (1.9 K).

(iv) World's most powerful supercomputer system

The main detectors of LHC are four and the data produced by each detector is very large. The data produced by a single detector of LHC is enough to fill around 100000 dual layers DVD'S annually.

3.2 Quark-Gluon Plasma (QGP)

The quark-gluon plasma (QGP) is a state of matter in which quarks are not confined to hadrons as with the normal matter. Actually quarks are free in this state. This state of matter also shows chiral symmetry which later broken during the process of hadronization when the quarks in QGP again form hadrons for the formation of a hot hadron gas. It is observed that the temperature limit for the formation of QGP is 170 MeV. This time limit is equivalent to an energy density of $\varepsilon_c \simeq 1\ \mathrm{GeV\,fm^{-3}}$. Such energy densities were first achieved with the help of Super Proton Synchrotron (SPS). The purpose of such researches is to understand a new state of matter called QGP and the transition into it. The more we are able to understand about QGP, the better we can explain strong force and quantum chromo-dynamics (QCD) [81].

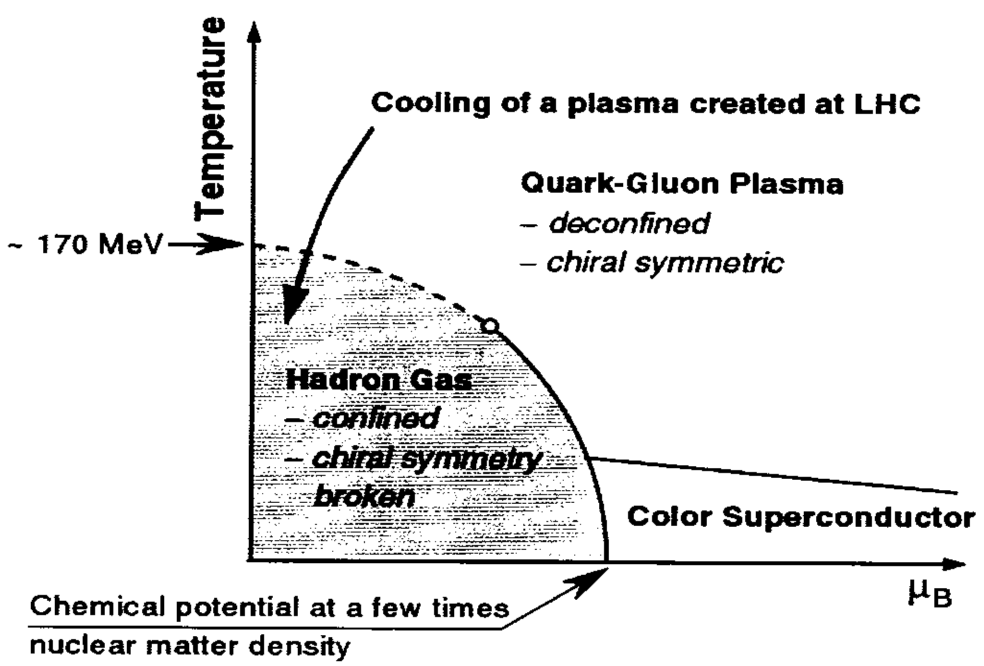

Figure 3.3 Phase diagram of the QCD, the arrow indicates the likely path the System will travel in the phase diagram and the solid line indicates transition, while the dashed one indicates a region of continuous transition [82].

3.3 QGP Detection Techniques

The QGP state of matter cannot be detected directly as this state of matter exists only for a very short interval of time. ALICE detector of LHC is especially designed to find this new state of matter called QGP [98]. There are many ways to study QGP. Some of them are as follows:

3.3.1 Charm Suppression

In heavy ion collisions, charm quarks can be formed as the colliding ions have very high energy densities. But due to colour screening effect, a lower number of charm quarks like those in the J/ψ mesons are observed. The J/ψ mesons can be formed only if the radius $r_{c\bar{c}}$ of $c\bar{c}$ pair is smaller than the Debye screening length ($\lambda_D \propto {}^1/_T$). However, when ($r_{c\bar{c}} > \lambda_D$), the colour screening screens the $c\bar{c}$ pair from one another, so they can not bind together to form $c\bar{c}$ pair. In this situation, the charm quarks make the other hadrons like D-mesons instead of creating J/ψ mesons. The critical temperature required to make D-mesons is 160 MeV which is very close to the critical temperature required to form QGP. That is why the suppression of bound charm states indicates that the temperature of the system is much suitable and is high enough to form QGP [98].

3.3.2 Thermodynamical Properties

QGP has maximum 37 degrees of freedom. The high degrees of freedom of QGP are responsible for a sharp change across the critical temperature when we draw a plot $\mathcal{E}/T^4$ where "$\mathcal{E}$" represents the energy density and "T" is the temperature. Since this energy density is proportional to the degrees of freedom, so many of the thermodynamical properties like transverse energy (dE_t/dy), hadron multiplicity (dN/dy) and average transverse momentum "p_t" corresponds roughly to energy density "$\mathcal{E}$", entropy density "s" and temperature "T" have an equivalent value and thus can be measured more easily in particle detectors [53].

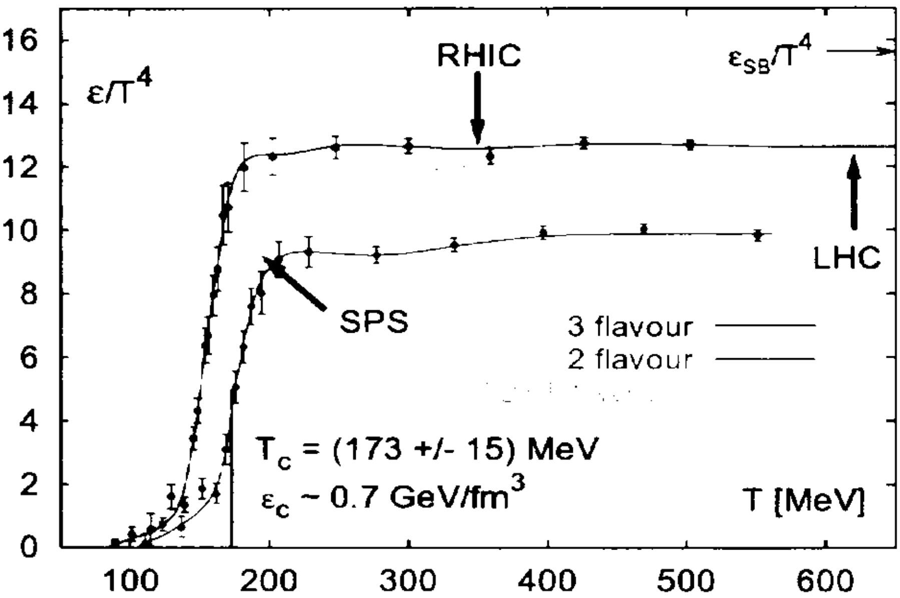

Figure 3.4 shows normalized energy density verses temperature from lattice QCD, the arrows show energies of SPS, RHIC and the LHC, the sudden change of $\varepsilon/_{T^4}$ show the phase transition from the hot hadron gas across the critical temperature [101].

3.3.3 Jets

QGP can also be studied by using jets. In collisions, jets of different particles are produced. In the jets, particles with high transverse momentum (p_t) will be slowed due to the creation of other matter from the collision and this process is known as jet quenching. The amount of jet quenching is increased with the increase of density and this fact helps us to study the initial density of matter in the collision of particles [98].

3.3.4 Strange Enhancement

In heavy ion collisions, strange quarks are also produced. But the yield of strange quark is enhanced in collision process unlike the charm quarks which are suppressed. In proton-proton collisions, the yield of ϕ mesons ($s\bar{s}$) is about 10% to 20% of that of the ($u\bar{u}$) pairs because the relative yield is significantly increased in heavy ion collisions [53].

3.4 A Large Ion Collider Experiment (ALICE)

A Large Ion Collider Experiment (ALICE) is one of the six detectors of LHC. ALICE is basically designed for heavy ion collisions at LHC, however it is also used for p-p collisions. It was designed and built by the collaboration of more than 1000 physicists from 105 physics institutions. The volume of ALICE is 16m × 16m × 26m = 6656m^3 [83]. It is a multi-layered particle accelerator with each layer of ALICE has a specific role in detecting different properties of particles that pass through it. Actually ALICE is a combination of several sub-detectors like a main barrel, muon spectrometer, a cosmic detector and some other detectors at small angles from the beam pipe [98]. Some more specifications of ALICE detector are as follows [40]:

- **Weight:** 10,000 tons
- **Size:** 16m high, 16m wide and 26m long
- **Design:** Central barrel plus single arm forward muon spectrometer

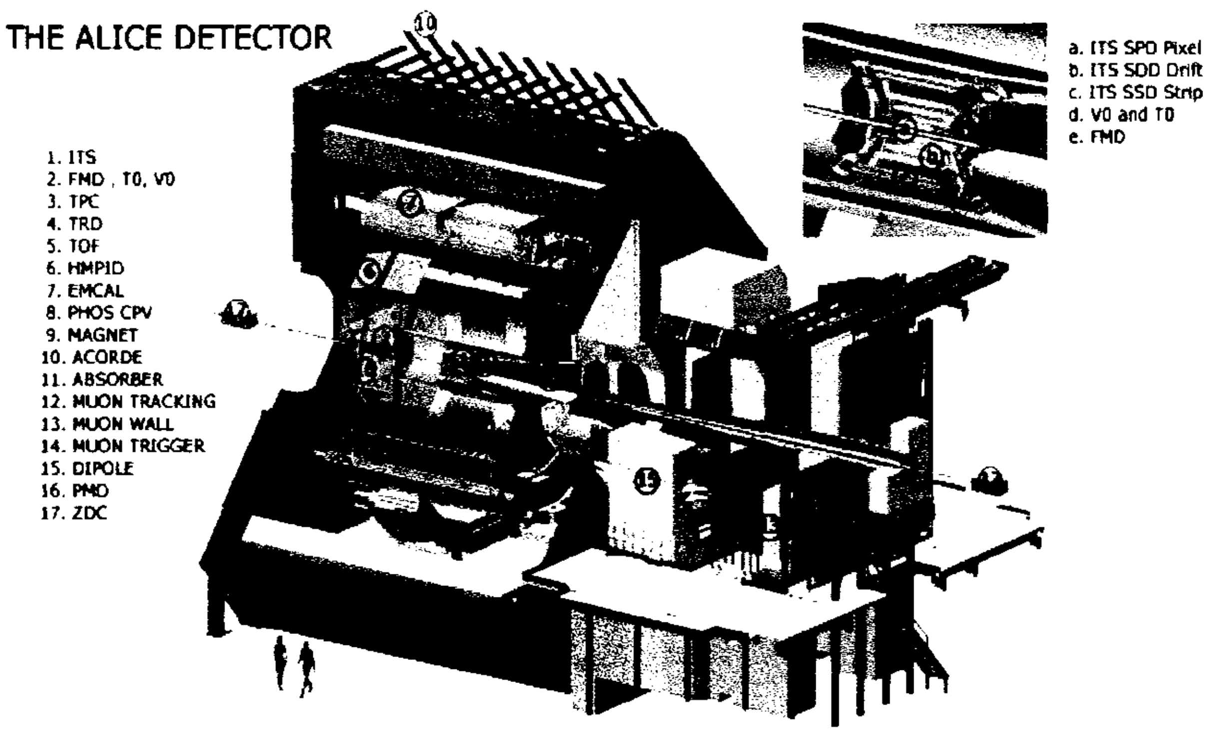

Figure 3.5 Layout of ALICE detector [84]

3.4.1 Role of ALICE in LHC Experimental Program

ALICE is especially design to study a state of matter called QGP. In ALICE experiment, when two lead ion beams collide at very high energies, they generate temperature which is more than 100,000 times hotter than the heart of the sun. This extremely high temperature melts the protons and neutrons and the quarks between them become free by loosing their bonds with gluons (particles that bind quarks together) which create a state of matter called QGP. The QGP state of matter is believed to be present in the early universe just after the Big Bang. This phenomenon also confirms that QGP generates the particles which constitute the matter of our universe today [84].

3.4.2 The Main Barrel of ALICE

The major portion of ALICE is in the magnet known as L3 magnet and the parts of ALICE experiment which lie in this magnet are called main barrel of ALICE. The main barrel of ALICE occupies a region having ($\theta = 45^{\circ} - 135^{\circ}$). These detectors are used to identify and track hadrons and electrons [85]. Actually the main barrel of ALICE is the combination of following detectors.

3.4.2.1 Inner Tracking System

The Inner Tracking System (ITS) is situated at the centre of the main barrel of ALICE. There are six semi-conductor detectors in ITS which are as follows [98]:

(i) Two Silicon Pixel Detectors (SPD)
(ii) Two Silicon Drift Detectors (SDD)
(iii) Two Silicon Strip Detectors (SSD)

The function of ITS is to provide information about the primary and the secondary vertex. ITS also provides information of a p_t spectrum for particles with low p_t [98].

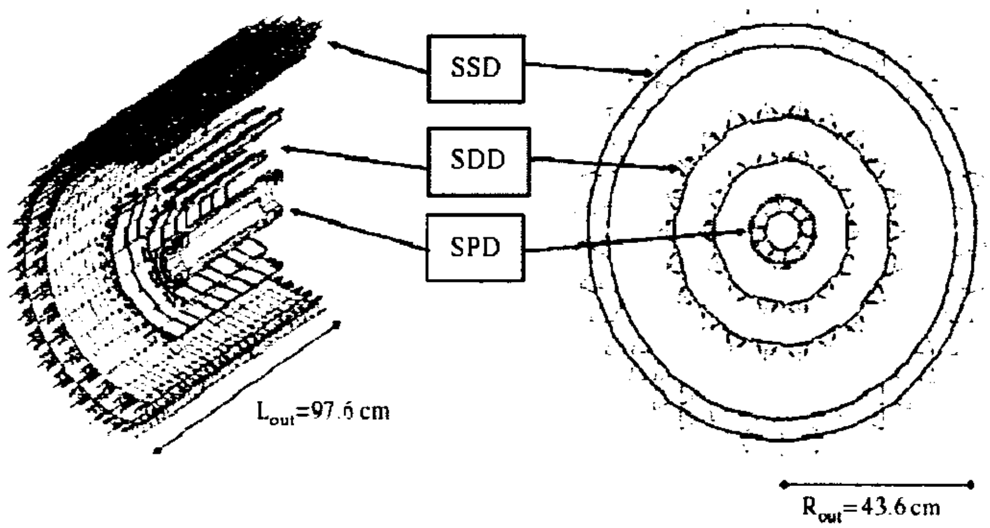

Figure 3.6 Overview of ITS [87]

3.4.2.2 Time Projection Chamber

In heavy ion collisions at LHC, a large number of daughter particles are produced. ALICE is used to measure the multiplicities of these daughter nuclei because ALICE has ability to measure high multiplicities up to a maximum of $dN_{ch}/d\eta = 8000$ [86]. TPC (Time Projection Chamber) of ALICE is able to deal 20000 charged tracks [88]. Therefore, a large TPC is selected in order to generate more and more tracking information. The basic purpose of TPC is particle tracking but it is also used to measure dE/dx and momentum information [89].

3.4.2.3 Transition Radiation Detector

In Transition Radiation Detector (TRD), a radiation is produced as the relativistic charged particle passes through the media of different dielectric constants. When the charged particle moves through the inner most layers of TRD which is a radiator and since this radiator is a foam, so the dielectric constant will alternate between the air present inside the radiator and the foam material. In this way, a transition radiation x-ray is produce if the momentum of the particle is greater enough. These radiations are then absorbed in the modules drift chamber [90]. The purpose of adding TRD is to enhance the ability of ALICE to identify electrons and pions [88].

3.4.2.4 Time of Flight

A large number of particles are passed through ALICE detector during run time. The Time of Flight (TOF) is used to measure the time of these particles. It also allows us to calculate their speed. We can determine the masses of the particles by using TOF as it already contains the momentum information of the particles. This phenomenon also enhanced the PID ability of the TOF detector for pions, kaons and protons [1].

3.4.2.5 Electromagnetic Calorimeter

The Electromagnetic Calorimeter (EMCAL) is used to measure photons from hard jets. The EMCAL reduced the bias of jet quenching studies which is helpful in improving the jet energy resolution [91]. In addition, EMCAL also enhanced the ability of ALICE to measure electrons, neutral hadrons and high momentum photons. This additional feature of EMCAL triggers detector readout on jets detection [53].

3.4.2.6 High Momentum Particle Identification

The High Momentum Particle Identification (HMPID) detector was designed for analysis purposes and it is used to test the PID ability of the other sub-detectors of the main barrel of ALICE like TPC, ITS and TOF. HMPID detector has ability to work in the region 1-5 GeV/c to identify the pions, kaons and the protons [92].

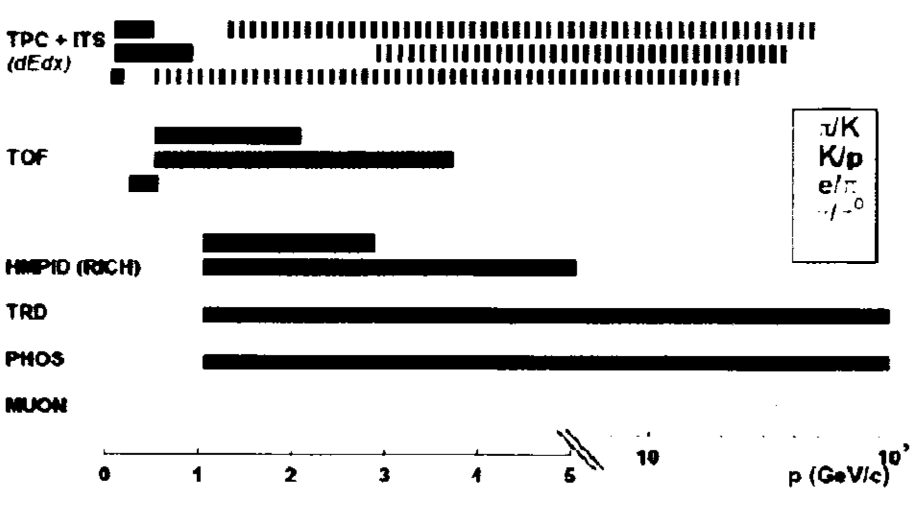

Figure 3.7 Momentum ranges of different detectors to identify different particles [69]

3.4.2.7 Photon Spectrometer

The Photon Spectrometer (PHOS) is used to measure the photons in the transverse momentum "p_t" range of 0.5 to 10 GeV/c [93]. In addition, PHOS is also used to calculate the jet quenching using higher p_t [98]. There are four modules of the PHOS and each module covers an area of $(1 \times 2)m^2$ having a weight of 3.2 tones. So the total area covered by the modules of PHOS is 08 m^2. They also have an azimuthal angle of 100^o and a pseudo-rapidity of $| \eta | \leq 0.12$ [88].

3.4.2.8 Photon Multiplicity Detector

The photon multiplicity detector (PMD) is used to study chiral symmetry and some other phenomenon near the phase boundary. In addition, PMD also determines the temperature and reaction plane of the system by using the information about anisotropic and radial flow [94]. The PMD is constructed in a hexagonal honeycomb structure and its each cell has a metal wall which protects the cell walls from different types of radiations like δ-rays moving between the cells [98].

3.4.2.9 A Cosmic Radiation Detector

A Cosmic Radiation Detector (ACORDE) is used to detect cosmic rays. The cosmic radiations which are detected by ACORDE are used for calibration and alignment of the individual detectors relative to one another. The combination of ACORDE with TRD, TPC and TOF is also helpful in studying some cosmic rays [88].

3.4.3 Muon Spectrometer

The Muon Spectrometer is used to detect the muons in the rapidity range of $-4 < \eta < -2.5$. A front absorber of muon spectrometer is used to reduce the number of incident hadrons and photons on the tracking chamber. This is because they are not able to deal high multiplicities efficiently. Muon spectrometer consists of 05 muon tracking stations, a warm dipole magnet before another absorber and four planes of RPC detectors. When a muon passes through the dipole, its track gives a curve and the momentum of the muon is determined with the help of RPC detectors [95].

3.4.4 Zero Degree Calorimeters

ALICE also consists of two Zero Degree Calorimeters (ZDCs). These ZDCs are placed 116 m [89] away from the interaction point (IP) on each side and are directly in line with the (IP). The ZDC is used to measure the protons and neutrons independently which are left in the beam after collisions by splitting the beam into three parts, i.e. positively charged, negatively charged and a neutral part. This beam splitting enables us to determine the number of nucleons involved in the collisions [72].

3.4.5 Forward Detectors

There are three Forward Detectors of ALICE known as T0, V0 and FMD. They were originally added as one detector which consists of Micro-Channel Plate (MCP) detectors. The MCP detectors are used to provide trigger and the exact multiplicity information. Actually MCP further splits into 03 sub detectors which are much cheaper and their production involves less research and development. These are as follows [96]:

- (i) T0 Detector
- (ii) V0 Detector
- (iii) Forward Multiplicity Detector

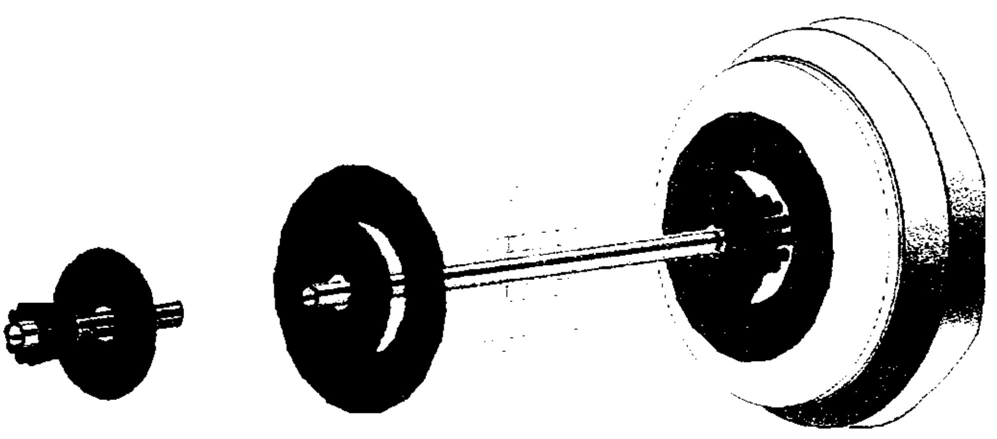

Figure 3.8 FMD shown as 3 brown and 2 grey segmented circles, T0 shown as 2 sets of green tubes and V0 shown as 2 grey circles. The muon absorber is in green on the right and the ITS is in the middle and grey [96].

3.5 Primary Charged Particles

The prompt particles (particles emitted from the first vertex) produced in the collisions and all decay products except products from weak decays of strange particles such as K^0 and Λ are known as primary charged particles [97].

3.5.1 Production of Primary Charged Particles in p-p Collisions

There are several production modes of primary charged particles in p-p collisions. For example, one of the production modes of primary charged particles in p-p collision is [62]:

$$p + p \rightarrow \pi^+ + \pi^+ \qquad (3.1)$$

And its inverse reaction is also measured at the same centre of mass energy. Another production mode of primary charged particles in p-p collision is:

$$p + p \rightarrow e^+ + e^+ \qquad (3.2)$$

In which positron is directly produced as a primary charged particle and muon-positron pair is also produced as [62]:

$$p + p \rightarrow e^+ + \mu^+ \qquad (3.3)$$

Some more decay channels of p-p collisions are as follows:

$$p + p \rightarrow \pi^+ + d \qquad (3.4)$$

$$p + p \rightarrow p + n + \pi^+ \qquad (3.5)$$

Chapter 04

Computing Techniques

This chapter includes some basic offline computing techniques and Monte Carlo generators which are necessary to analyse the data produced by ALICE detector. First a brief introduction of AliRoot, the ALICE offline framework is given, followed by the description of Simulation and Reconstruction. In the end, a brief introduction of a new Monte Carlo (MC) simulation technique called FLUKA is given.

4.1 Offline Framework

In order to process large amount of data, a frame work is necessary and a set of software tools used to process data is known as framework. At present, large amount of data is produced by particle accelerators working across the world. In order to handle such data, offline framework is used which has ability to reconstruct and analyse the physics data generated through real or simulated interactions [7].

4.1.1 Root Framework

An important part of offline framework is Root framework which is used to handle data applications at large scale. By using Root framework, scientists and physicists have developed many software packages. These software packages are widely used for event generation, event reconstruction and detector simulations [41]. There are many features of Root framework. For example, it consists of multidimensional histograms and some commonly used mathematical functions and algorithms. In addition, Root is also used for documentation and advanced visualization tools. Root framework uses C++ language. The users of Root can interact with Root by using a graphical user interface which consists of command line or batch scripts [8].

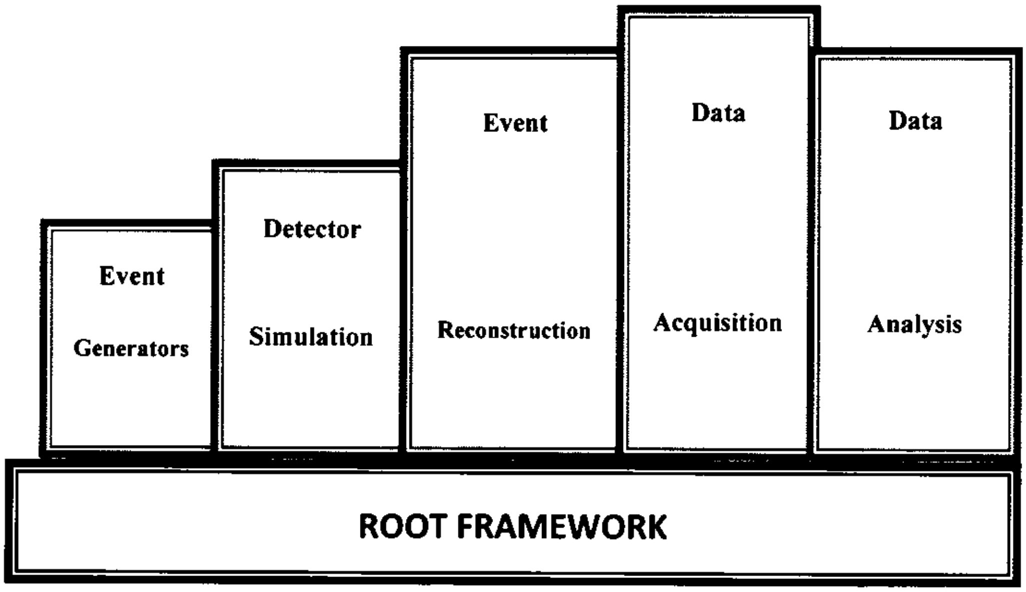

Figure 4.1 ROOT Framework and its applications to HEP [8]

The working of a Root program is very simple because it directly relates to only few libraries. However, during running of a Root program, the system automatically loads additional libraries according to the need of the program. At present, Root has a wide range of applications in research laboratories of Nuclear and Particle physics especially in CERN, DESY and Fermi Lab [8].

4.1.2 Application of Root in ALICE

For the ALICE experiment, engineers and physicists have developed Ali-En system. This Ali-En system is directly linked with the Root system [78]. Moreover, a system which is used to extend Root features on parallel computing systems is called Proof system [14]. In case of ALICE, the combination of Root and Proof system is used to analyze the large amount of data through a distributed parallel computing platform [8].

4.1.3 AliRoot Framework

In AliRoot framework, Monte Carlo event generators are used to produce data through simulation programs. The event generators are important in the sense that we can obtain complete information about the generated particles using the data produced by the event generators. Initially, the response of a detector is observed and then data is converted into a type of data which indicates the detector response. Hence "raw data" is produced through simulated events. This raw data (real or simulated) is taken as input for the analysis and reconstruction purposes. Finally the software and detector performance is evaluated by processing the simulated events and then comparing them with the particles generated by Monte Carlo generators [8].

AliRoot framework depends upon re-usability and modularity. The term Modularity is used to replace the different parts of our system without disturbing the other parts. While the term Re-usability is used to maintain the maximum backward compatibility of ALICE [9]. In the schematic figure of AliRoot framework, different codes are used to perform simulations. For example, GEANT3 [17], GEANT4 [3] and FLUKA [23]. The striking feature of these transport codes is that if we want to move from GEANT3 to GEANT4 and to FLUKA, there is no change in user code. The only thing which we have to do is to load few different shared libraries [9].

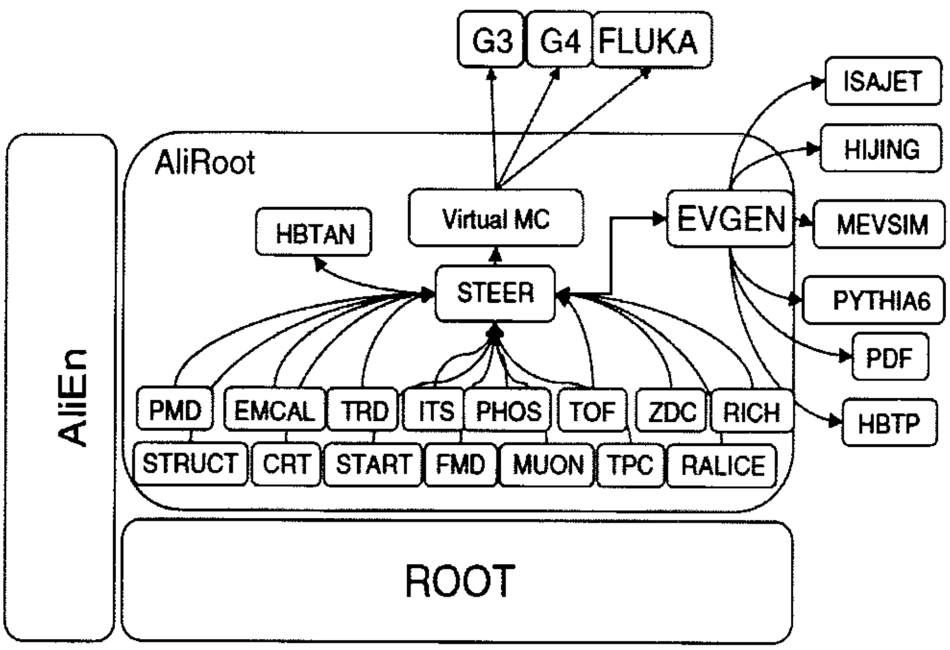

Figure 4.2 Schematic view of AliRoot Framework [9]

4.2 ALICE Simulation Framework

In heavy ion collisions, large amount of data is produced. So it is a big challenge for physicists to handle this large amount of data. Therefore, to get precise and accurate simulation results of the data produced by ALICE detector, the physicists have developed unique algorithms which are used to reconstruct and analyse the physics data [10]. The combination of these algorithms is commonly known as ALICE simulation framework. It is an AliRoot [73] object oriented (C++) framework based on Root [41].

4.2.1 AliRoot Simulation of ALICE

For the ALICE experiment, the framework used to collect data at different stages during the simulation process is known as AliRoot simulation framework [47]. In this framework, hits are used which represents the signals of the particles left in the detector. For example, it produces signals for position and precise energy deposition. In the next step, these hits are converted into another type of signals known as summable digits produced by the detector. These summable digits are now converted into a type of digits which are based on Root structure and contain the same information as raw data. Finally we obtain output of the raw data in the form of Date [31] which is a prototype to acquire data for the ALICE detector [11].

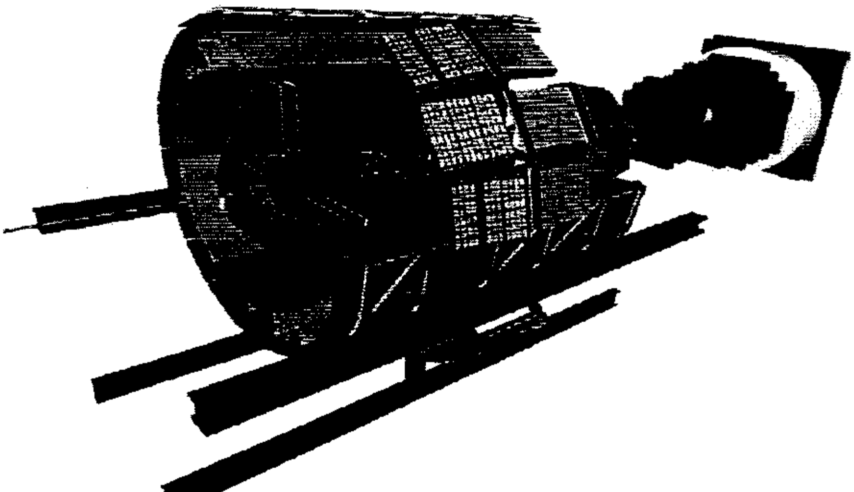

Figure 4.3 Simulation of ALICE detector using AliRoot simulation [11]

4.3 FLUKA

Fully integrated particle physics Monte Carlo simulation software package (FLUKA) is a general purpose Monte Carlo code which was initially designed in1989 [5]. It is the latest Monte Carlo simulation technique and is widely used in Nuclear and Particle physics as a basic research tool. In many cases, FLUKA is used to calculate particles transport and their interactions with matter. By using FLUKA, we can obtain very precise simulation results even in such complex cases where no experimental data is available directly. FLUKA has ability to simulate the basic constituents of matter and composite particles very precisely. For example, it can simulate electrons, protons, neutrons, etc. from 1KeV to thousands of TeV. Some more features of FLUKA include information about the evolution of time and tracking of radiations emitted from unstable residual nuclei. With the help of combinational Geometry (CG) package, FLUKA is able to handle very complex geometries. The CG package of FLUKA is used to track charged particles correctly even in the presence of electric or magnetic field. In addition, many visualization and debugging codes are also available in FLUKA. The main thing which makes distinctions between FLUKA and other simulation packages is that no programming is required from user side to run a FLUKA file [6].

4.3.1 Structure of FLUKA Input File

FLUKA is the latest Monte Carlo (MC) simulation technique which reads user input through an ASCII "standard input" file having the extension ".inp". The FLUKA input file contains many options (or commands) and each option has a specific role in making FLUKA input file. Some basic steps involved in the creation of FLUKA input file are as follows [2]:

- For documentation purposes, titles and commands are used. They are not compulsory but recommended to FLUKA users.
- It is mandatory for FLUKA users to define a particle source.
- Users must have to describe the geometry of the problem.
- The selection and description of the material (atoms or particles).
- Description of material assignments (material region).

- Users also have to load different detectors commonly called FLUKA input cards. The addition of these input cards is necessary in order to obtain precise and accurate simulation results.
- Description of biasing schemes. However this command is optional.
- Setting the boundaries of the problem such as energy cut-offs, step size, physical effects, etc.
- Initialization of random number sequence is also mandatory.
- Finally, FLUKA users also have to set number of requested histories and the starting signal.

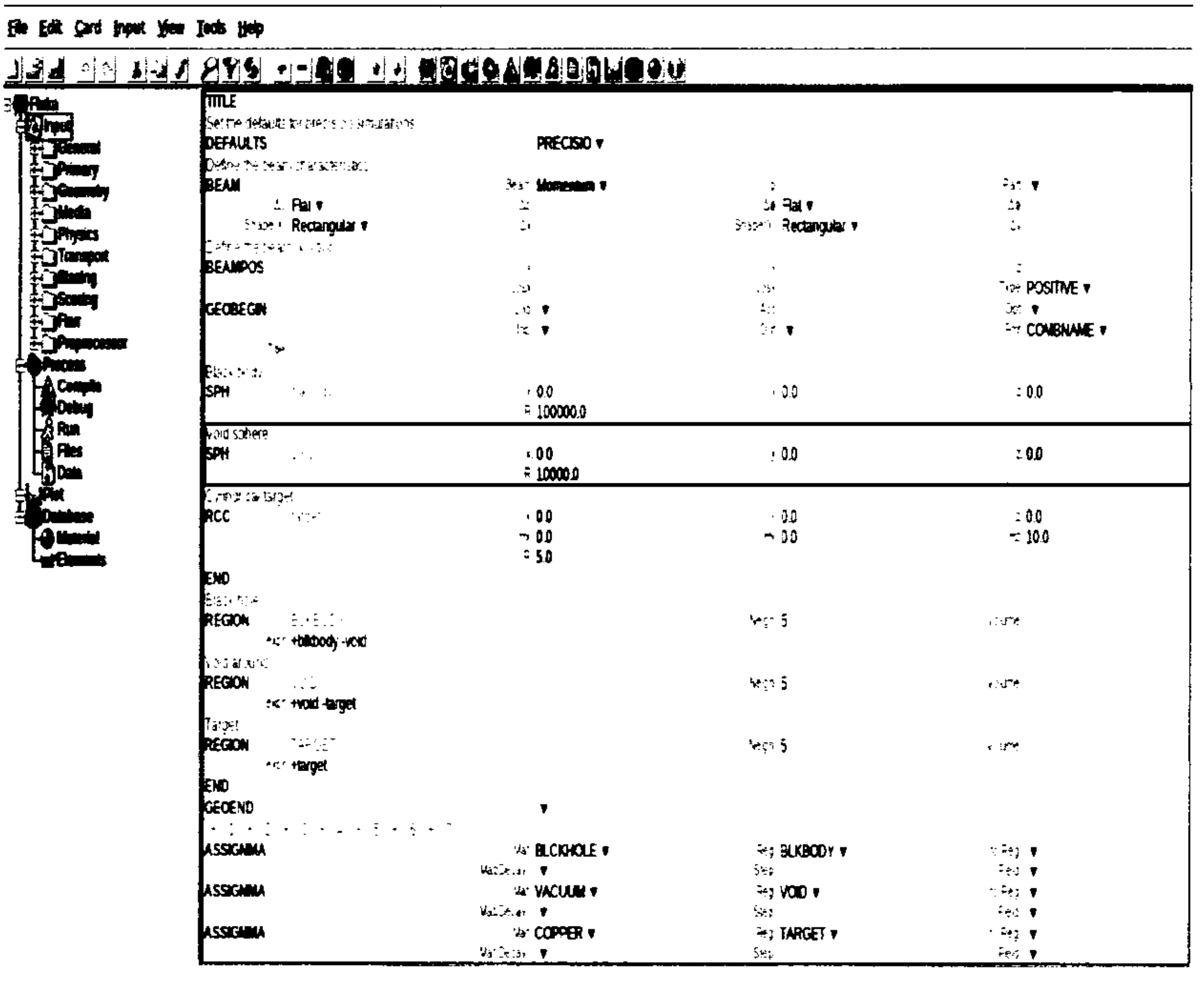

Figure 4.4 Schematic view of FLUKA input File

4.3.2 Applications of FLUKA

FLUKA is the latest Monte Carlo simulation package. It has wide range of applications in many fields. Some applications of FLUKA are as follows [6]:

(i) FLUKA is used to design a detector.

(ii) FLUKA is used in Accelerator Driven Systems.

(iii) FLUKA is also used in cosmic rays, neutrino physics, radiotherapy, etc.

(iv) FLUKA is used in electron and proton accelerator shielding to target design.

4.3.3 Flair for FLUKA

This is an advanced user interface of FLUKA. Flair is basically used to facilitate the users by editing FLUKA input files. However, many other features of flair are also used in FLUKA files. For example, it is used to execute FLUKA codes and visualization of output files. Some of the functions which flair performs are as follows [102]:

- In order to make easy and error free editing in FLUKA input files, flair is used as a front-end interface.
- It is also used in FLUKA input files for error correction and validations.
- Running of a program using flair is very interesting because it gives full information about the compiling debugging, running and monitoring status during run-time.
- To process data files, flair provides back-end interface for the processing of output files.
- Flair is also used to store and share different libraries and geometrical objects for many users and projects.

Chapter 05

Results and Discussions

In this chapter, the simulated results are presented and discussed. Here data of ALICE is studied using two different Monte Carlo (MC) techniques. First, the results of the production of primary charged particles in p-p collision at 900 GeV energy have been studied using ALICE Offline Framework. In the second method, results have been studied through a latest MC technique called FLUKA. The results obtained from both of the techniques are then discussed and compared. For all the data analysis, the performance of each MC technique is evaluated in a highly visual manner. This evaluation is necessary because fit parameters are often not easy to express in a few result diagrams.

5.1 Production of Primary Charged Particles in p-p collisions at 900 GeV Energy using ALICE Offline Framework

In p-p collisions, the accurate measurement of the transverse momentum p_t spectrum of charged particles produced in the energy range of LHC provides unique information about the soft and hard interactions. Here the measurement of a p_t spectrum of primary charged particles in p-p collisions at 900 GeV energy is presented. Actually, primary particles are those particles which are produced in collisions or decay products except those particles which are produced from weak decays of strange particles. The measurement performed covers a p_t range $0.5 < p_t < 3$ in GeV/c where both hard and soft processes are expected to contribute to particle production.

5.1.1 Results and Discussions of P_t Spectrum

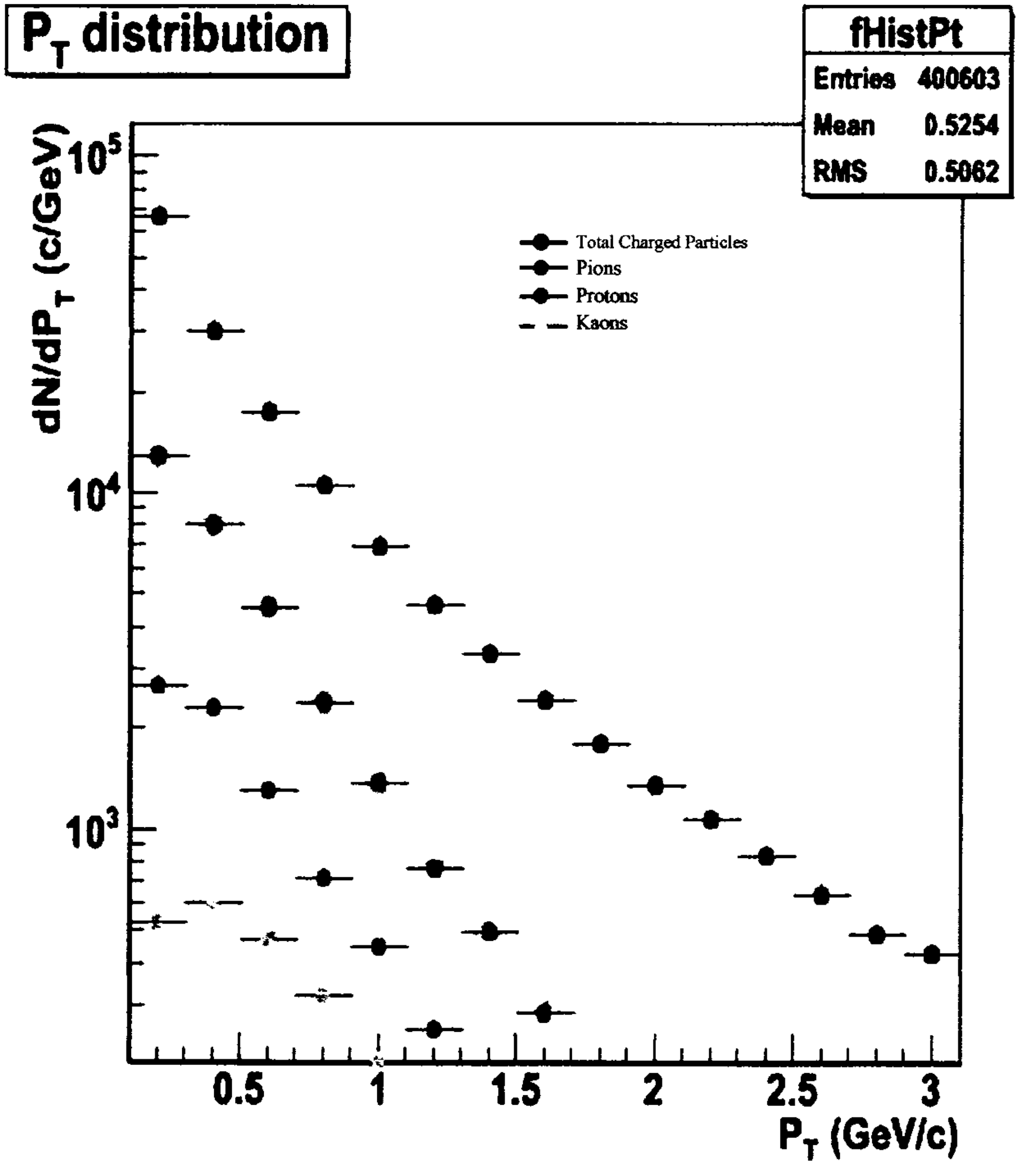

Figure 5.1 Monte Carlo Simulation results of the production of primary charged particles in p-p collision at 900 GeV energy using ALICE Offline Framework

This Monte Carlo technique is used to study the data of ALICE detector. Here ALICE data is studied at 900 GeV energy and as a result of p-p collisions, a large number of primary charged particles are produced as shown in figure 5.1. The data collection is made and the three primary charged particles i.e. pions, protons and kaons are taken for analysis purposes. The transverse momentum p_t spectrum of these primary charged particles is created which represents the productions of primary charged particles in different p_t ranges. In p_t distribution spectrum, the p_t of the particles produced is taken on x-axis having a p_t range $0.5 < p_t < 3$ in GeV/c. While the number of emerging primary charged particles as a function of p_t are taken on y-axis. The p_t spectrum represents the behavior of different primary charged particles in different p_t ranges and a specific marker color is assigned to each of the primary charged particle as shown in figure 5.1. In p_t spectrum,

- The black dots represent the total number of primary charged particles produced as a result of p-p collisions.
- The green dots represent the number of pions produced as a result of p-p collisions.
- The red dots represent the number of protons produced as a result of p-p collisions.
- The yellow dots represent the number of kaons produced as a result of p-p collisions.

The different color curves in the p_t spectrum represent the production of different charged particles in different p_t ranges. It is observed that the number of charged particles decreases as a function of transverse momentum for all the primary charged particles. However, saturation in the p_t spectrum is observed at about 1 GeV/c. Moreover, it is observed that in p_t spectrum more pions are produced as a result of p-p collisions as compared to protons and kaons. Hence one can conclude that the results of p_t spectrum provide a good way to study the behavior of primary charged particles produced in p-p collisions at 900 GeV energy.

5.2 Production of Primary Charged Particles in p-p collisions at 900 GeV Energy using FLUKA

In p-p collisions, the energy spectrums of primary charged particles produced in the energy range of Large Hadron Collider (LHC) provides a base line to understand the behavior of different primary charged particles. Here the measurement of energy spectrum of primary charged particles in p-p collisions at 900 GeV is presented using a new MC technique called FLUKA. In the present studies, an incident particle strikes with the target material at 900 GeV energy. Here the incident particle is proton and the target is hydrogen atom which consists of only one proton. The radius and thickness of the hydrogen atom is choosen to be 1 x 10^{-9}cm and 2 x 10^{-8}cm respectively while the beam position is set at (0, 0, -1). In order to obtain the desired simulation results, a USERBDX card has been added in the target region. Moreover, the number of incident particles are 1 x 10^{6} and the program is run for 05 cycles.

5.2.1 Results and Discussions of Energy Spectrums

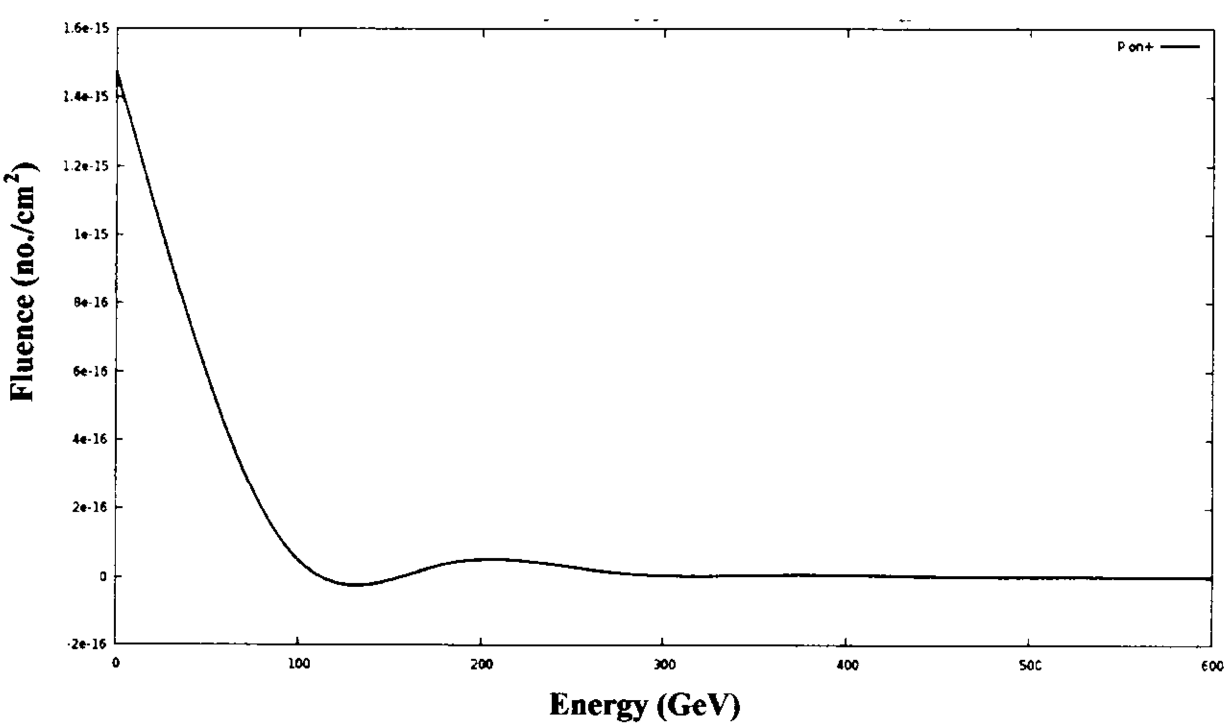

Figure 5.2 Monte Carlo simulation result of the production of π^+ in p-p collisions at 900 GeV energy using FLUKA

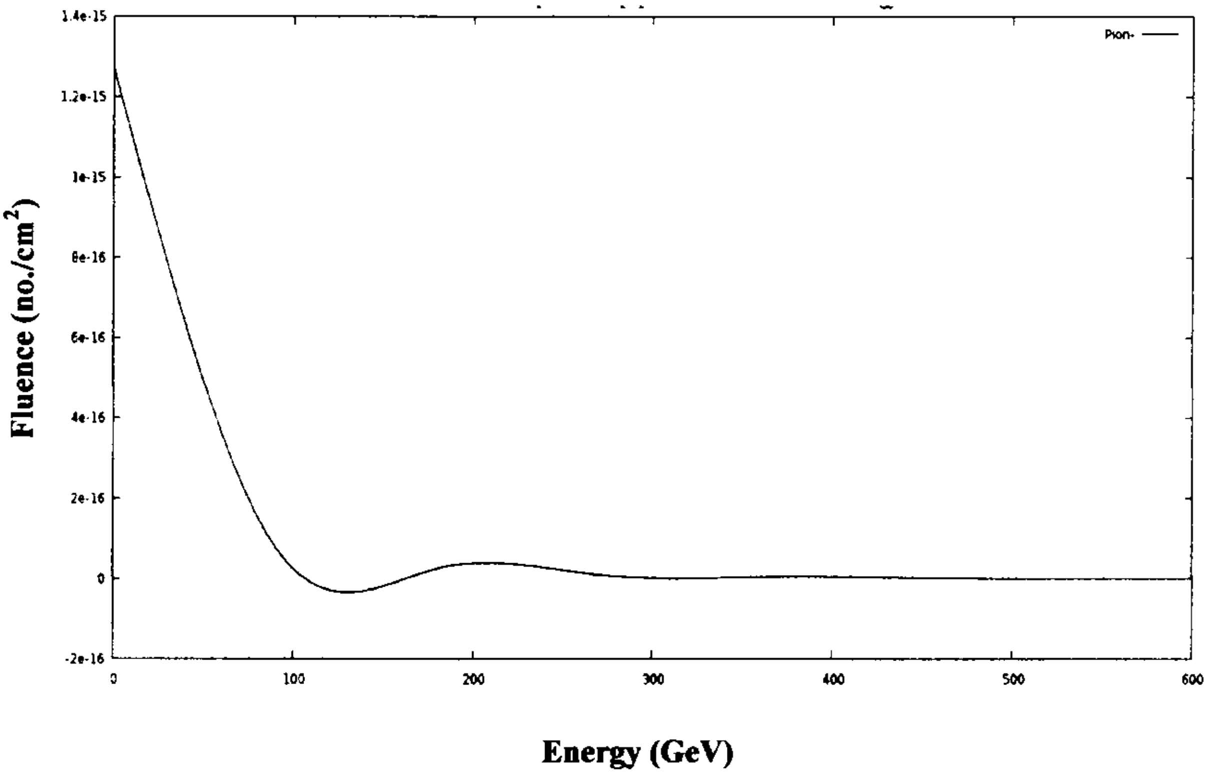

Figure 5.3 Monte Carlo simulation result of the production of π^- in p-p collisions at 900 GeV energy using FLUKA

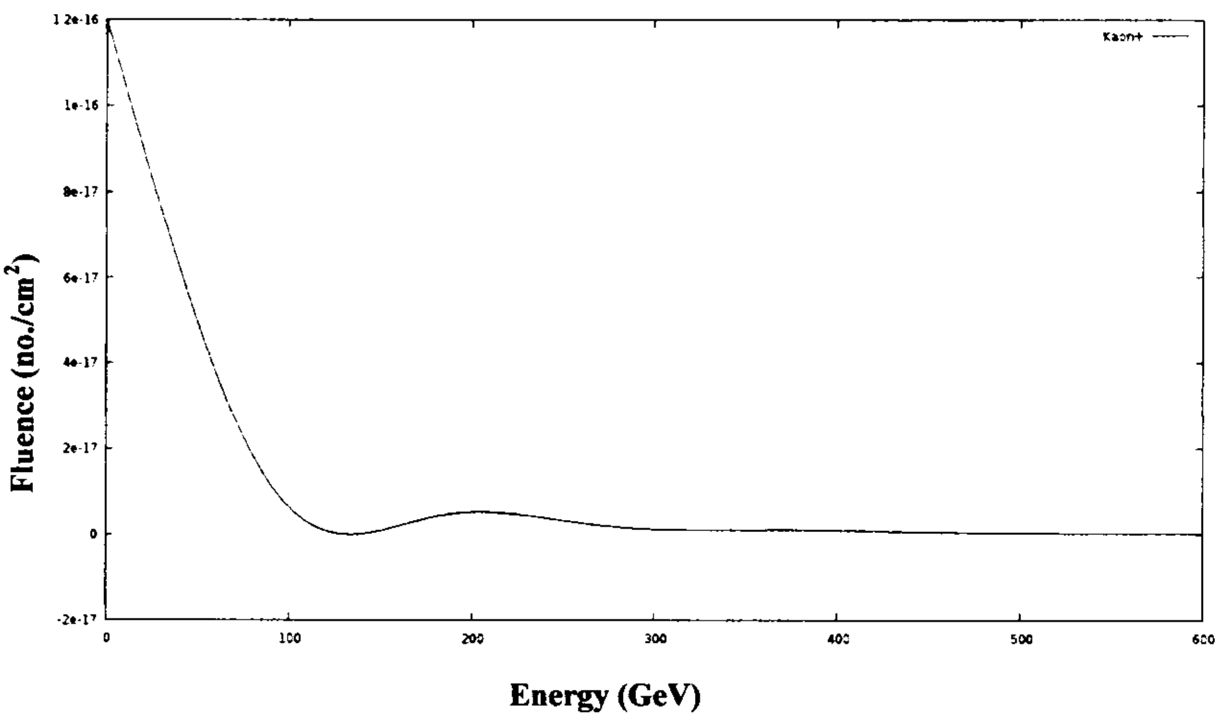

Figure 5.4 Monte Carlo simulation result of the production of K^+ in p-p collisions at 900 GeV energy using FLUKA

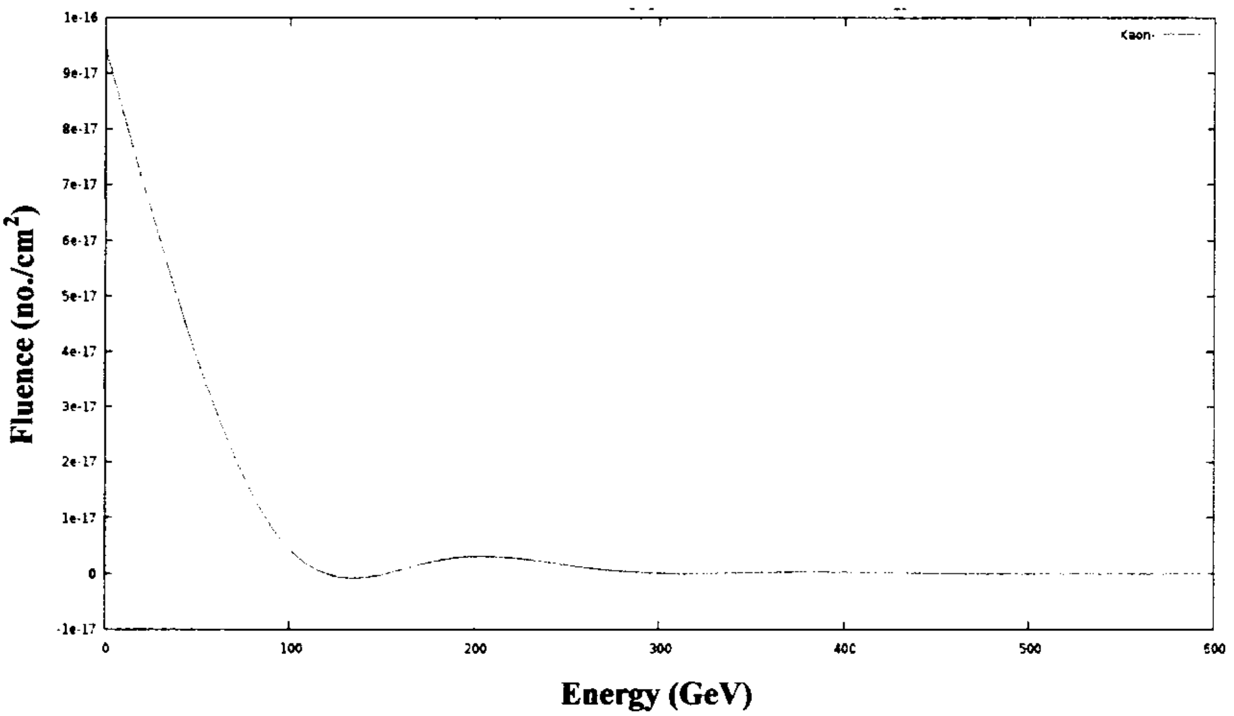

Figure 5.5 Monte Carlo simulation result of the production of K^- in p-p collisions at 900 GeV energy using FLUKA

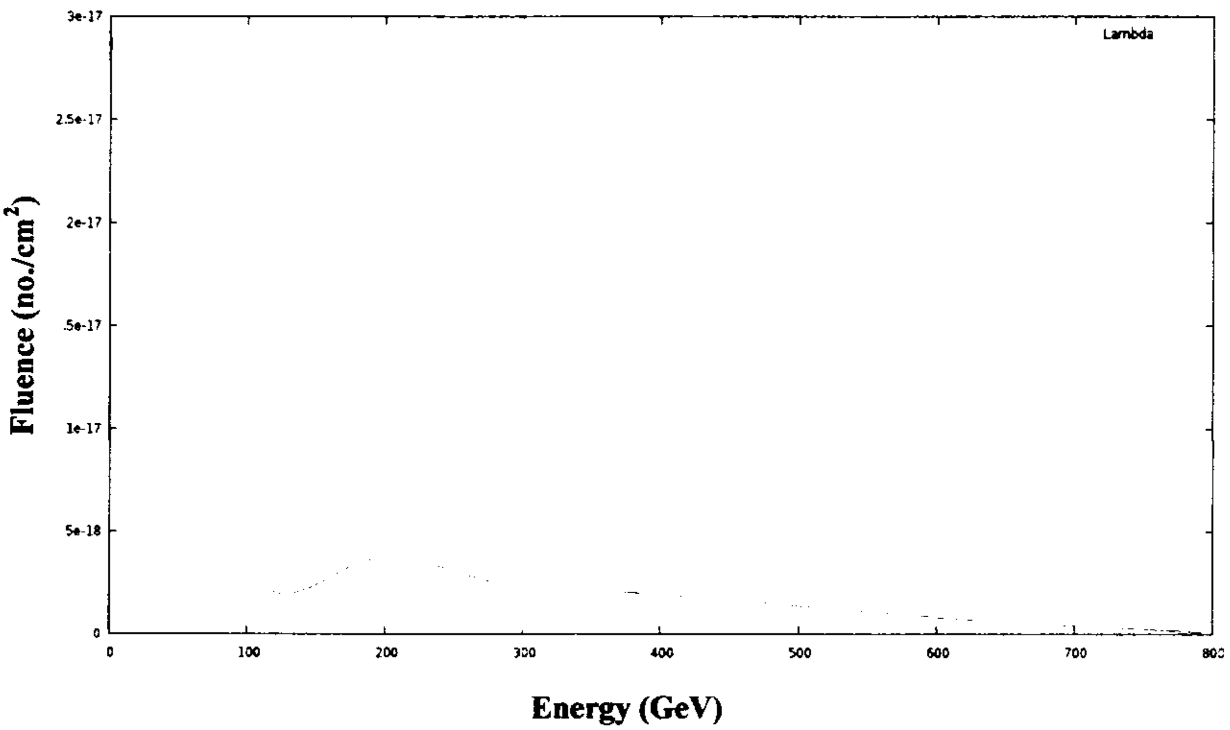

Figure 5.6 Monte Carlo simulation result of the production of Λ in p-p collisions at 900 GeV energy using FLUKA

In this Monte Carlo technique, p-p collisions have been studied at 900 GeV energy. Here data is produced using a new Monte Carlo technique called FLUKA and as a result of p-p collisions, a large number of primary charged particles are produced. The data collection is made and the five primary charged particles i.e. π^+, π^-, K^+, K^- and Λ are taken for analysis purposes. The energy spectrum of each primary charged particle is made separately which shows the number of primary charged particles produced in p-p collisions at 900 GeV energy as shown in figure 5.2, 5.3, 5.4, 5.5 and 5.6. In each energy spectrum, the kinetic energy (scattered energy) of emerging particles is taken on x-axis while fluence (number of particles emerged per cm^2) of the particles is taken on y-axis.

Figure 5.2 and 5.3 show the fluence of π^+ and π^- in p-p collisions at 900 GeV energy. It is found that the fluence of π^+ is 1.6 e^{-15} while the fluence of π^- is 1.4 e^{-15}. Moreover, it is observed that the number of π^+ and π^- produced in p-p collisions is greater at lower kinetic energies and their production decreases with the increase in the kinetic energy. The Maximum number of π^+ and π^- are produced between 0 to 100 GeV energy as shown by the sharp curve along y-axis in figure 5.2 and 5.3. However, when the kinetic energy of the particles produced in p-p collisions increases, there occurs slight variation in the curves at about 200 GeV which represents the production of only few particles (π^+ and π^-). At higher energies beyond 300 GeV, the curves become straight line parallel to x-axis which represents saturation in the production of π^+ and π^-. Hence it is concluded that fluence is the function of kinetic energy (scattered energy) of the particles produced and the fluence of π^+ and π^- decreases with the increase in kinetic energy.

Figure 5.4 and 5.5 show the fluence of K^+ and K^- in p-p collisions at 900 GeV energy. It is found that the fluence of K^+ is 1.2 e^{-16} while the fluence of K^- is 1 e^{-16}. Moreover, it is observed that the number of K^+ and K^- produced in p-p collisions is greater at lower kinetic energies and their production decreases with the increase in the kinetic energy. The Maximum number of K^+ and K^- are produced between 0 to 100 GeV energy as shown by the sharp curve along y-axis in figure 5.4 and 5.5. However, when the kinetic energy of the particles produced in p-p collisions increases, there occurs slight variation in the curves at about 200 GeV which represents the production of only few particles (K^+ and K^-). At higher energies beyond 300 GeV, the curves become straight line parallel to x-axis which represents saturation in the production of K^+ and K^- and the relation between energy and fluence remains same at higher energies. Hence it is concluded that fluence is the function of kinetic energy (scattered energy) of the particles produced and the fluence of K^+ and K^- decreases with the increase in kinetic energy.

In figure 5.6, the fluence of Λ in p-p collisions at 900 GeV energy is shown and it is 3 e^{-17}. It is observed that the number of Λ produced in p-p collisions are greater at lower kinetic energies and their production decreases with the increase in kinetic energy. The maximum number of Λ are produced between 0 to 100 GeV energy as shown by the sharp curve along y-axis in figure 5.6. But when we move ahead in the energy range, the variations in the curve starts at about 200 GeV which continue up to 800 GeV. Hence it is clear from figure 5.6 that fluence of Λ decreases continuously with the increase in kinetic energy (scattered energy).

Hence, the results of energy spectrums provide unique information to study the behavior and production of different primary charged particles in p-p collisions at 900 GeV energy.

Conclusion and Suggestions for Future Work

Production of primary charged particles in p-p collisions at 900 GeV has been studied in the present work. It is found, as expected, that a large number of primary charged particles are produced at this energy range. The transverse momentum spectrum and energy spectrums of the primary charged particles produced in p-p collisions with ALICE have been created using two different Monte Carlo Simulation techniques. From the results of energy and transverse momentum spectrums, it is found that at lower energies, the production of primary charged particles is greater and their production decreases with the increase in energy. It can be concluded that the production of primary charged particles in p-p collisions at 900 GeV energy can be well understood from the measurements performed in the present work. The work presented in this thesis also provides basis for the future studies of p-p collisions at higher LHC energies.

In the continuation of this work in future, one can measure the production cross sections of the different primary charged particles produced in p-p collisions at 900 GeV energy. The behavior of primary charged particles at different angles can also be studied. It is also possible to check the behavior of primary charged particles as a function of mass instead of energy. The measurement for the single and double differential cross sections with respect to energy and angle can also be performed in the continuation of this work.

Summary

The Large Hadron Collider (LHC) of CERN is the world's biggest particle accelerator producing almost 15 peta bytes (15 million giga bytes) data annually. The present work is based on one of the LHC detectors called ALICE (A Large Ion Collider Experiment) which is especially designed to study a state of matter called Quark Gluon Plasma (QGP). This state of matter is believed to be present in the early universe shortly after Big Bang. The ALICE detector was basically designed for heavy ion interactions but it is also used for p-p collisions. In the present work, primary charged particles produced in p-p collisions at 900 GeV energy with ALICE have been studied using two different Monte Carlo techniques. It is found that a large number of primary charged particles are produced in p-p collisions at 900 GeV energy. First the data of ALICE detector has been studied by making a transverse momentum p_t spectrum of three primary charged particles i.e. pion, proton and kaon at 900 GeV using ALICE Offline framework which is based on Root and AliRoot softwares. In the second technique, the data of ALICE detector has been studied by making energy spectrums of five primary charged particles i.e., π^+, π^-, K^+, K^- and Λ at 900 GeV using FLUKA which is the latest Monte Carlo technique. The results obtained from both methods are then discussed which show that the production of primary charged particles in p-p collisions at 900 GeV energy can be well understood from the measurements performed in the present work.

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Appendix

Input File

The input file of ALICE Offline Framework used to study the simulated data of ALICE in p-p collisions at 900 GeV energy is based on C++ coding which is as follows:

```
# Include "TChain.h"
# Include "TTree.h"
# Include "TH1F.h"
# Include "Tcanvas.h"

# Include "AliAnalysisTaskPtMC.h"
# Include "AliAnalysis Manager.h"

# Include "AliESDEvent.h"
# Include "AliESDInputHandler.h"

# Include "AliMCEventHandler.h"
# Include "AliMCEvent.h"

# Include "TParticlePDG.h"
Boesing
// Reviewd: A.Gheata (19/02/10)

Classinput (AliAnalysis TaskPtMC)
//___________________________________________________________

AliAnalysisTaskPtMC::AliAnalysisTaskPtMC (const char*name)
:AliAnalysisTaskSE(name),fOutputList(0),
fHistPt(0), fHistPtPion(0), fHistPtProton(0), fHistPtKaon(0)
{
```

```
        // Constructor

// DefineInput and Output slots here
// Input slot # 0 works with a TChain
Define Input (0, TChain::Class( ) );
Define Output (1, TList::Class( ) );
}
//_______________________________________________________________________
Void AliAnalysisTaskPtMC::UserCreatOutputObjects( )
{
        // Create Histograms
        // Called Once
fOutputList = new TList ( );
fHistPt = new TH1F("fHistPt", "P_{T} distribution", 15, 0.1, 3.1);
fHistPt->GetXaxis( )->SetTitle ("P_{T}(GeV/c)");
fHist->SetMarkerStyle (KFullCircle);

fHistPtPion = new TH1F("fHistPtPion", "P_{T} distribution of Pions", 15, 0.1,
3.1);
fHistPt->GetXaxis( )->SetTitle ("P_{T}(GeV/c)");
fHistPt->GetYaxis( )->SetTitle ("dN/dP_{T}(c/GeV)");

fHistPtProton = new TH1F("fHistPtProton", "P_{T} distribution of Protons", 15,
0.1, 3.1);
fHistPt->GetYaxis( )->SetTitle ("dN/dP_{T}(c/GeV)");
fHist->SetMarkerStyle (KFullCircle);

fHistPtKaon = new TH1F("fHistPtKaon", "P_{T} distribution of Kaons", 15, 0.1,
3.1);
fHistPt->GetXaxis( )->SetTitle ("P_{T}(GeV/c)");
fHistPt->GetYaxis( )->SetTitle ("dN/dP_{T}(c/GeV)");
fHist->SetMarkerStyle (KFullCircle);
```

```
fOutputList->Add(fHistPion);
fOutputList->Add(fHistProton);
fOutputList->Add(fHistKaon);
}
//_____________________________________________________________________
voidAliAnalysisTaskPtMC::UserExec(Option_t *)
{
// Main loop
//Called for each event
//Process MC truth

AliMCEvent*mcEvent = MCEvent ( );
        if (!mcEvent)
{
Printf ("ERROR: Could not retrieve MC event");
return;
}

        Printf ("MC particles: %d", mcEvent ->GetNumberOfTracks ( ));
        for (Int_t iTracks = 0; iTracks<mcEvent->GetNumberOfTracks( );
        iTracks++)
{
//TParticlePDG*pion = new TParticlePDG (211);
if (track-> M( )>0.1395 && track-> M( )<0.1399)
fHistPtPion->Fill(track->Pt( ));
if (track-> M( )>0.9382 && track-> M( )<0.9384)
fHistPtProton->Fill(track->Pt( ));
if (track-> M( )>0.4935 && track-> M( )<0.4938)
fHistPtKaon->Fill(track->Pt( ));
fHistPt->Fill(track->Pt( ));
} // track loop
```

```
// Post Output data
Post Data (1, fOutput List);
Post Data (2, fOutput List);
Post Data (3, fOutput List);
Post Data (4, fOutput List);
}
//______________________________________________________________________
voidAliAnalysisTaskPtMC::Terminate( Option_t*)
{
// Draw result to the screen
// Called Once at the end of query

fOutputList = dynamic_cast<TList*>(Get Output Data(1));
        if (!fOutputList)
{
Printf ("ERROR: fHistPt not available");
return;
}
fHistPtPion = dynamic_cast<TH1F*>(fOutputList->At(1));
if (!fHistPtPion)
{
Printf ("ERROR: fHistPtPion not available");
return;
}
fHistPtProton = dynamic_cast<TH1F*>(fOutputList->At(2));
if (!fHistPtProton)
{
Printf ("ERROR: fHistPtProton not available");
return;
}
fHistPtKaon = dynamic_cast<TH1F*>(fOutputList->At(3));
```

```
if (!fHistPtKaon)
{
Printf ("ERROR: fHistPtKaon not available");
return;
}
TCanvas*c1 = new TCanvas("AliAnalysisTaskPtMC","PtMC",10,10,510,510);
C1->cd(1)->SetLogy( );
fHistPt->DrawCopy ("E");
fHistPtPion->SetMarkerColor(2);
fHistPtPion->DrawCopy ("Esame");
fHistPtKaon->SetMarkerColor(4);
fHistPtKaon->DrawCopy ("Esame");
}
```