Study of Proton Production in p-p Collisions at Ultra-Relativistic Energies

by

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(2012)

بسم الله الرحمن الرحيم

IN THE NAME OF

ALLAH

THE MOST BENEFICENT

THE MERCIFUL

O MY LORD

INCREASE ME IN KNOWLEDGE

(Al QURAN SURA TAHA SECTION 16, 114)

International Islamic University, Islamabad
Faculty of Basic and Applied Sciences
Department of Physics

Approval

It is Certified that the work presented in this thesis entitled **"Study of Proton Production in p-p Collisions at Ultra-relativistic Energies"** is carried out by **Mr. Ahsan Mehmood Khan,** Registration No. 20-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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TO

MY PARENTS, MY PATERNAL UNCLE, AUNTY AND TO MY SWEET SISTER

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All glory be to Almighty **Allah**, the most merciful and the benevolent and His beloved **Prophet Muhammad (S.A.W)**.

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Author

Ahsan Mehmood Khan

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List of Abbreviations

ACORDE	A Cosmic Radiation Detector
ALICE	A Large Ion Collider Experiment
ATLAS	A Toroidal LHC Apparatus
CERN	European Organization for Nuclear Research
CMS	Compact Muon Solenoid
EMCAL	Electromagnetic Calorimeter
FLUKA	FLUktuierende KAskade
FMD	Forward Multiplicity Detector
GEANT	GEometry ANd Tracking
HMPID	High Momentum Particle Identification
IP	Interaction Point
ITS	Inner Tracking System
LHC	Large Hadron Collider
LHCb	Large Hadron Collider beauty
MC	Monte Carlo
MCNP	Monte Carlo N-Particle TransportCode
PHOS	Photon Spectrometer
PID	Particle Identification
PMD	Photon Multiplicity Detector
QCD	Quantum Chromo Dynamics
QGP	Quark Gluon Plasma
SDD	Silicon Drift Detectors
SPD	Silicon Pixel Detectors
SPS	Super Proton Synchrotron
SSD	Silicon Strip Detectors
TOF	Time Of Flight
TPC	Time Projection Chamber
TRD	Transition Radiation Detector
ZDC's	Zero Degree Calorimeters

Abstract

During the course of research thesis, the proton production at ultra-relativistic energies in proton-proton collision is studied. ALICE offline framework and FLUKA are used to observe the variations in the yield of proton production with varying energy during proton-proton collision. We used offline framework to simulate the proton production at different energies. By increasing the energies of beam abundance of proton production decreases. This variation is observed by plotting corresponding yield of proton against p_t (transverse momentum) distribution by adopting the ALICE offline framework. It is also observed in this study that fluence of the proton production also decreases with the increase in the energies by using FLUKA. Both these computing tools are based on Monte Carlo Simulations technique.

Chapter 01

Introduction

By the time of Greek Philosophers, ancient scientists thought that matter is composed of tiny particle called atoms. After that Dalton presented the idea that atoms are ultimate particle of an element which cannot be divided into further particles. He stated his theory in a lecture to the Royal institute in 1803.But with the passage of time our idea about indivisible atom has been changed. Now we know number of subatomic particles like electron, proton, neutrons, etc. While studying the conductivity of gas in a gas tube, scientist thought that there is subatomic particle which revolves around the centre heavy portion of an atom.

The electric charge is an indivisible quantity. This perception is theorized to enlighten the chemical properties of an atom, presented by British philosopher Richard Laming in early 1838. The name of this electric charged particle, electron is launched by Irish physicist George Johnstone Stoney in 1894 [12]. The electron is recognized as a particle by J. J. Thomson along with the team of British physicists in 1897 [87, 29, 91]. In 1897 while studying the effect of electric field in a gas tube J. J. Thomson showed, on applying the electric field these rays were deflected towards positive plate. As these were deflected towards anode so they have negative charge and these rays travel from cathode towards anode so tube is known as cathode rays tube. Due to negatively charged these rays are called electron. The electron is represented by symbol e^-, a subatomic particle carrying negative elementary electric charge. It is thought to be an elementary particle, as its substructure and components are not revealed yet [91]. The mass of electron is roughly 1/1836 than that of proton [31]. As electron is fermion, so its intrinsic spin (angular momentum) is a half integer value with the units of $\hbar$. Positron is the antiparticle of the electron which is indistinguishable to electron excepting it holds electric and other charges with opposite sign. During the collision of electron with positron, either both the particles may be annihilated completely by generating two or more gamma ray photons, or disperse each other. As it belongs to the first generation of leptonic family, contribute in weak, electromagnetic and gravitational interactions [2, 28]. Electrons behave as a particle as well as waves, a quantum mechanical feature, like matter, so it may diffract like light and can make collision with other particles. However, this dual nature of electron can be confirmed while performing experiments on electrons, because of its minute mass. Electron being fermions obeys Pauli Exclusion Principle, a fundamental approach of Fermi Dirac statistics, so same quantum state cannot occupy by two electrons. Theoretical predications of electron suggests, large number of electrons were produced in the universe after big bang, but beta decay of radioactive isotopes is also one of the sources of electron. Furthermore, high energy collisions occur due to entering the cosmic rays in atmosphere is also a source to create numerous electrons. It can absorb during nucleosynthesis process in the stars and can also be shattered due to annihilation with positrons. Laboratory appliances are able of controlling and observing individual electrons and electron plasma, but dedicated telescopes may sense electron plasma in external space. There are many applications of Electrons which includes welding, cathode ray tubes, electron microscopes, radiation therapy, lasers and particle accelerators.

Physicists Ernest Rutherford, James Frank, Henry Moseley and Gustav Hertz in their experiments in 1914, had widely recognized structure of atom as a intense nucleus having charge opposite to that of lower-mass electrons, revolve around the nucleus [7]. After the discovery of electron physicist though that there must be a positively charge centre of the nucleus which attracts the electron to revolve around the nucleus in a particular path. Rutherford discovery about the nucleus of an atom showed that these positive charges were concentrated in a very small fraction of the atom's volume. Eugen Goldstein had discovered canal rays in 1886 which is also acknowledged as anode rays. He used cathode having extremely small hole in it, and noticed that on applying potential difference to electrodes cathode rays(electron) are travelling away from cathode, at the same time the other rays are also produced travelling towards cathode and did pass through the canal of cathode so he called these rays as a canal rays. These rays are also named as positive rays as they carry positive charge.

Rutherford verified that all other nuclei are enclosed by hydrogen nucleus, in his experiment in 1917, reported in 1919, a result usually illustrated as the detection of proton [83]. In his earlier experiment he observed that radiations are produced, when alpha particle make impact on hydrogen gas and these radiation are due to hydrogen nuclei. He said this on the basis of their distinctive penetration mark in air and their form in scintillation detectors. In the Later experiments, Rutherford noticed that, when alpha particles are injected in air contains mostly nitrogen and after experimental results when alpha particles were created into pure gas (nitrogen), the signature of hydrogen nuclei are in scintillation detectors. Rutherford thought hydrogen is the lightest particle and is supported by Prout's law. As scientist discovered that hydrogen nuclei are consider as an elementary particle or basic constituent of every element, so he gave them a special name as particle. The name proton is given by him, to this new fundamental building block of the nucleus, after the sterilize singular of the Greek word for "first", πρῶτον.

The proton is represented by the symbol of p or p+ with positive electric charge 1of elementary charge. It is also a subatomic particle. In each atom one or more than one protons are existed along with neutrons. The atomic number is also referred to as number of proton in an atom. Protons are made up of three quarks known as baryons which are a sub type of hadrons and being fermions having spin-½[72]. The strong force, whose mediator is gluon, is responsible to bind two up quarks and one down quark of proton [4]. Mean square radius of proton is about 0.8 fm by approximately exponentially decaying the positive charge distribution [88]. Whereas mass of proton is $1.672621777(74)\times10^{-27}$ kg (938.272046(21) MeV/c^2[15]).

As electron and proton were discovered in 1886 and their properties were completely explained till 1895. This is very strange that till 1932 it was thought that an atom is made up of electron and proton. Lord Rutherford predicted in 1920 that some kind of neutral particle having mass equal to that of proton must be present in an atom, because he noticed that atomic masses of atoms could not be explained if it were supposed that atom is composed of electron and proton only. In 1932, James Chadwick discovered neutral particle having same mass as that of protons, named as neutron and considered as a part of atomic model. The periodic table is revised to its modern version and arrangement is made according to its atomic number and not by atomic weight. It was revealed that the neutron can be splitted into a proton, an electron, and a massless, neutral particle called neutrino.

The neutron is represented by the symbol n or n^0, having no electric charge. It is made up of three quarks one up and two down so it belongs to Hadron's family. As it present inside the dimensions of nucleus of an atom through strong interaction so it is also one of the subatomic particle or nucleon. This subatomic particle is also considered as key to the nuclear power production. In a stable nuclei bound neutrons are stable whereas free neutrons are unstable, they experience beta decay with mean life of below 15 minutes (881.5±1.5 s) [62]. After the discovery of neutron, in 1933 this was realized that it might mediate nuclear chain reaction. Neutron is Fermionic particle as it has spin half, by obeying Fermi-Dirac statistics whose concept is based upon Pauli Exclusion Principle.

The discovery of radioactivity was made by Henri Becquerel in 1896 which explain background of nuclear physics as discipline separate from atomic physics, during the investigation of phosphorescence in uranium salts. After one year J. J. Thomson discovered electron which indicates the internal structure of an atom. During 20th century **plum pudding** model was presented by J. J. Thomson which is the accepted model of atom. According to this model atom has large positively charged sphere and negatively charged electrons are embedded inside of it.

Particle physics is the study of the survival and the interactions of the particles which are the basic constituents of matter or radiation. Currently we are looking to understand, when the quantum field is excited, it happens only due to particles and make their interaction by following their dynamics. Mostly, the fundamental fields are the main concern in this area, every one of which may not be expressed as bound state of other fields. This position of fundamental fields and their dynamics are currently integrated in a theory known as Standard Model. Therefore, particle physics is broadly the study of particle's content of the Standard Model's and its possible extension. Modern particle physicists are keen for searching subatomic particles such as electron proton and neutron, these atomic constituent are composed of quarks which are produced by the scattering processes and radioactive processes, like photons, neutrinos, muons, and wide range of exotic particles. Nucleons and atoms are made up of smaller particles known as Subatomic particles. Subatomic particles are two types one is elementary particles which are not made of other particles and composite particles [64].

The Standard Model is a theory regarding the electromagnetic, weak and strong nuclear interactions which mediate the dynamics of familiar subatomic particles. This model is starting to develop from the middle to late 20th century and the existing form was finalized in the mid 1970s on the existence of quarks by after the experimental verification. Since then, discoveries of bottom quark in 1977, top quark in 1995 and tau neutrino in 2000 have given further acceptance to Standard Model. Because of its success in explaining a broad range of experimental results, the Standard Model is often considered as a theory of about everything. The discovery made by Sheldon Glashow's theory in 1960, about combining the electromagnetic and weak interactions was the first step towards the Standard Model [38]. In 1967 Steven Weinberg and Abdus Salam integrated the Higgs mechanism [40, 89, 79, 34, 33] into Glashow's electroweak theory, providing it its modern form. In the beginning of 1970, this was quiet apparent hadrons don't have fundamental point like objects.

Simulation is basically an imitation of real and physical objects or that physical process whose practical cost is too much. By applying the simulation we can study the performance of different practical apparatus. Simulation is based upon different programming languages by writing codes for them we can check the efficiency of different apparatus or setup. It is also useful because in minimum cost we can check the working of specific apparatus and also the mechanism happening at different stages of a specific project. Here ALICE offline framework and FLUKA is used to perform simulation for proton-proton collision which is based on Monte Carlo simulation technique. ALICE offline framework is based on ROOT and AliRoot Environment.

iv. Atoms of different elements combine in simple whole-number ratios to form chemical compounds.

v. In chemical reactions, atoms are combined, separated, or rearranged.

2.3 Rutherford's Scattering

Electron was first identified by Thomson, after that he presented the model of the atom along with Kelvin which is known as plum pudding model [57, 86]. During the study of radioactive substances, Earnest Rutherford discovered positively charged helium atom, the most energetic charged particle ejected by radioactive substances. In his experimental demonstration, the great majority of alpha particles was passed almost straight the thin layer of gold foil and suffered only small deflections [58]. It seemed clear that deflection was possible only due to the electric field inside the atom. According to Thomson's model the electric field is so small, so it does not create a big difference in the velocity of massive alpha particles.

In 1910, Earnest Rutherford with his two assistants, Hans Geiger and Earnest Marsden observed that deflection was possible up to 90 degrees and even more. They came to this conclusion after so many encounters at Thomson's atom [78, 39]. He argued that electric field is much greater than predicted by Thomson. To explain the electric field he proposed model of atom similar to the planetary system, positive charged is concentrated at centre of atom called nucleus. He suggested the majority of alpha particles conceded straight through thin gold foil but some deflected at large angles, as they passes very close to the nucleus these particles experienced large repulsive force as both the alpha particles and nucleus have same charge i.e. positive charge [82]. This force can be calculated by using coulomb's law.

$$F = \frac{kqQ}{r^2} = \frac{2Zke^2}{r^2} \qquad \text{.... (2.1)}$$

where Q=Ze is the nuclear charged for fixed target. He also proposed that in coulomb's field of nucleus, trajectory of alpha particle can be calculated and how the number of deflection vary with particles energy, foil's thickness and other's variables. The Rutherford's scattering diagram is shown in the figure 2.1 below.

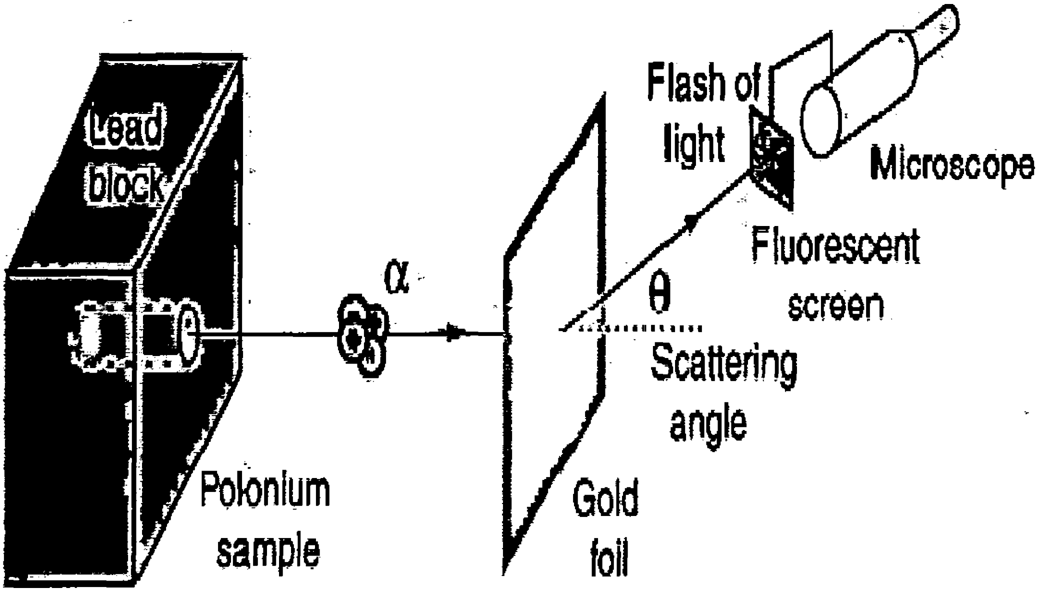

Figure 2.1 Schematic diagram of experimental setup for Rutherford Scattering [52].

2.3.1 Impact Parameter

The deflections of particles were observed on ZnS screen. Their path is characterized by impact parameter **b** [23]. The impact parameter is defined as the perpendicular distance from the nucleus to the alpha particle's original line of approach. The diagrammatical representation of impact parameter is given in the following figure 2.2.

$$b = \frac{Zke^2}{E\tan\left(\theta/_2\right)} \qquad \ldots.(2.2)$$

Where,

θ = angle of deflection to the impact parameter **b**.

E = energy of incident alpha particles.

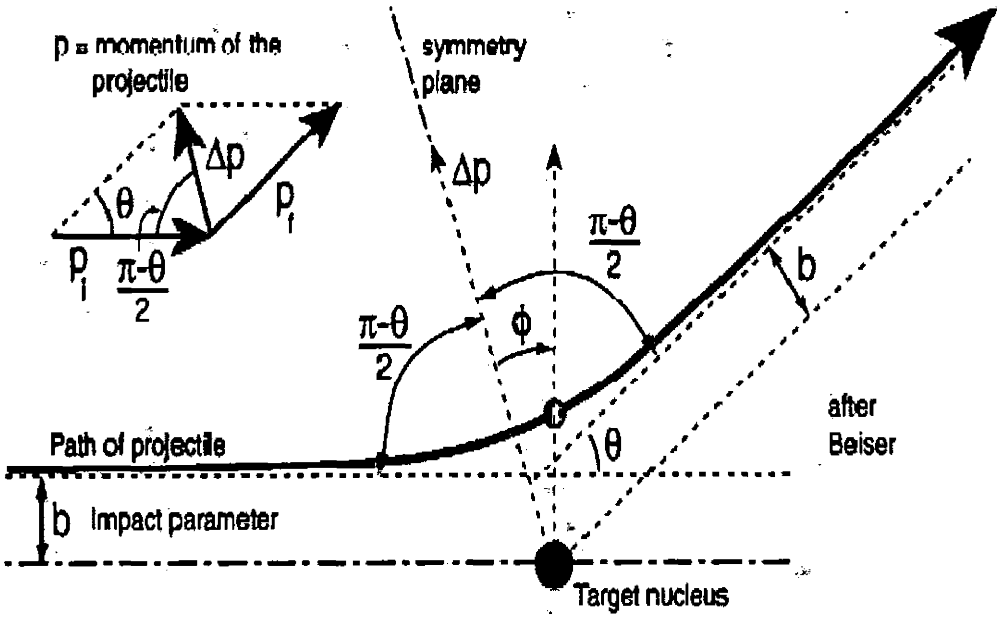

Figure 2.2 Schematic diagram for Rutherford Scattering showing different angles and impact parameters [52].

2.3.2 Rutherford Scattering Formula

As Rutherford's scattering is based on coulombs force and treated as orbit. This process of scattering is statistically measured as cross section of interaction with nucleus; the nucleus is the point charge Ze [35]. If detector is placed at a particular angle with respect to occurrence beam, then Rutherford's formula is able to tell the number of particles strikes the detector is given as follow.

$$N(\theta) = \frac{N_i n L Z^2 k^2 e^4}{4r^2 KE^2 \sin\left(\frac{\theta}{2}\right)^4} \qquad \dots(2.3)$$

N_i = number of incident alpha particles.

N = atoms per unit volume in target.

L = thickness of target.

Z = atomic number of target.

E = electron charge.

K = coulomb's constant.

R = target to detector distance.

KE = kinetic energy of incident particle.

θ = scattering angle.

2.4 Discovery of Proton

According to ancient researchers, nucleus is made up of proton and neutron. Because of the basic constitutes of nucleus, so these are called nucleons. The discovery of these subatomic particles leads towards the development of atomic theory. Through scientific discovery, proton contributes positive charge of an atom [75]. To get the atom as a neutral one scientists thought that positively charged proton remains at the centre of an atom, as negatively charged electron revolves around the nucleus of an atom.

2.4.1 Gas Discharge Tube Experiment

Large number of experiments was observed on gas discharge tube by J.J Thomson and other scientists of his era, to discover the negatively charged electron or cathode rays [76]. They also predict the properties of electron through different experiment on the same gas discharge tube. Scientists thought while emission of electron or cathode rays there must be a positively charged particles or rays also produced in the gas discharge tube. A German scientist Eugen Goldstein, while performing experiment on Crookes tubes observed that a beam of positively charged ions is also produced inside the gas discharge tube. In his experiment he used perforated cathode so that anode rays or positively charged particles coming out from anode can be seen easily on the other side of gas discharge tube [41]. This tube is filled with air at very low pressure of about 0.001mm of mercury. When high electrical potential of about 10,000 volts is applied between anode and cathode, then faint luminous light is observed behind the perforated cathode.

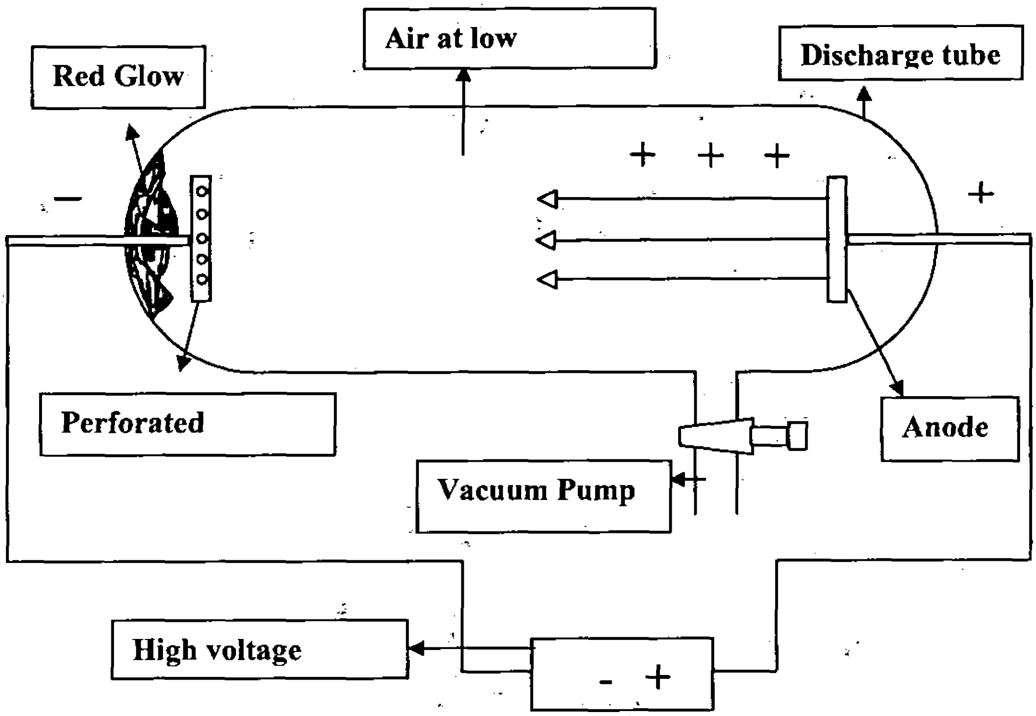

Figure 2.3 Gas Discharge Tube experiment showing anode rays [56]

These rays are coming from anode to cathode, due to hole in the cathode these rays passed through them and strike the tube behind the perforated cathode and produces faint red light. Due to the orientation of these rays, they are also called as anode rays. Goldstein named these rays as channel rays or canal rays because these passed through the channels in the cathode. These positively charged rays are formed due to the ionization of gas at very high voltage and low pressure [21]. The gas discharge tube experiment is shown in the above mentioned figure 2.3.

When the m/e ratio was measured by using different gas in discharge tube experiment, then this ratio is different for each gas but in each measurement it was observed that they contain positive ion. The mass of these positive rays or proton is slightly less than that of hydrogen atom. When hydrogen gas is used in the discharge tube then lightest positively charged ion is formed so they called it proton. It was also found that the mass of proton is 1837 times heavier than that of electron, therefore most of the mass of an atom is at concentrated at the centre. The relative mass of proton is 1a.m.u. but its absolute mass is 1.6×10^{-24} gram.

2.5 Standard Model

Standard Model is one of the basic theories of elementary particle physics. The model which is very useful in describing the properties of subatomic particles within a single framework is called standard model. This model is rather theoretical explanation of interactions of quarks and leptons [45, 42]. Quarks and leptons are the basic constitute of all the matter in the universe. Fundamental forces such as strong, weak and electromagnetic forces are responsible to bind the quarks and leptons together. When these quarks and leptons make interaction with each other then they exchange particles known as gauge bosons. Types of interaction with their relative strength and mediator boson are given in the table 2.1. But development of this model also involves experimental results and theoretical ideas and discussion. There are two basic theories work together in standard model. One is QCD that describes strong interaction and other is electroweak theory that describes electromagnetic and weak interactions.

FORCE	Relativistic Strength	Gauge Boson	Mass (rel. to Proton)	Charge	Spin
Strong	1	Gluon (g)	0	0	1
Electromagnetic	$\frac{1}{137}$	Photon (γ)	0	0	1
Weak	10^{-9}	$W^{\pm}$, Z	86,97	±1,0	1
Gravity	10^{-38}	Graviton (G)	0	0	2

Table 2.1 Notations and different values of parameters of Gauge Bosons as predicted in Standard Model [69].

This model was developed in mid to late 20th century, but when the existence of quarks was confirmed in 1970 then this formalism is finalized. Quarks carry color charge while leptons don't carry color charge. Spin is the intrinsic property of quarks and leptons, so fermions are the particles having half integral spin while bosons are the particles having zero or integral spin. The strong, weak and electromagnetic interactions are mediated by force carrier gauge bosons [61].

2.5.1 Quarks

Due to symmetries quark scheme tells that mesons and baryons are arranged in families. There are three constitutes of quarks explained by Gell-Mann and Zweig in 1964 through mathematical symmetries. These are up, down, strange quarks. The confirmation for the composition of proton and neutron was conformed in late 1960s and 1970s, so basic constitute of proton and neutron is quarks. In 974, j/psi was discovered unexpectedly in SLAC (Stanford linear accelerator collider), later on it is decided as a new pair of quarks having quarks and anti-quarks [61]. The fourth new quark was charm quark. Six quarks scheme was predicted by theorists Cabbibo, Kobayashi and Maskawa. Now there exists six types quarks up, down, strange, charm, top, bottom, with their anti quarks pair. At Fermilab a heavy meson was discovered in 1977, which fulfill six quarks model. Following table 2.2 shows quarks parameter for Standard Model.

Quarks having Intrinsic Spin as ½		
Generation	**Particle**	**Charge (e)**
I	Up (u) Down (d)	+2/3 -1/3
II	Charm (c) Strange (s)	+2/3 -1/3
III	Top (t) Bottom (b)	+2/3 -1/3

Table 2.2 Standard Model quark parameters showing charge [69]

2.5.2 Leptons

In early 19's electron, muon and neutrino were well known particles. As they are much less massive, so they behave differently from mesons and baryons. Muon is the heavier version of electron and mass of electron is nearly 2000 times less than that of proton whereas mass of muon is 9 times smaller than the mass of proton. Neutrino is massless particle. Electron and muon interact with matter through weak interaction.

In high energy collisions, these particles don't produce the large amount of new mesons and baryons like protons and neutrons. Electron and muon has its own neutrinos this was proved in 1962 in an experiment by using high energy beam [61]. This was the first evidence about the generations of pairs of fundamental particles. Tau is the heavy lepton discovered in 1974, soon after the discovery of j/psi meson. Leptons consist of three families such as electron, electron-neutrino, muon, muon-neutrino, tau, tau-neutrino [65]. A lepton having fundamental constituent of matter is an elementary particle [32]. The electron being first charged lepton, was theorized in the mid of 19th century by many scientists [36, 11, 22] and discovery was made in 1897 by J. J. Thomson [85]. Muon was the next lepton which was observed and in discovered in 1936 by Carl D. Anderson, but it was wrongly classified as a meson at the time [67]. The leptons parameter for Standard Model is given in the following table 2.3.

Leptons having Intrinsic Spin as ½			
Generation	**Particle**	**Charge (e)**	**Mass (GeV)**
I	Electron (e) Elecrton Neutrino (ν_e)	-1 0	5.1×10^{-4} $< 0.8 \times 10^{-8}$
II	Muon (μ) Muon Neutrino (ν_μ)	-1 0	0.105 $< 2.7 \times 10^{-4}$
III	Tau (τ) Tau Neutrino (ν_τ)	-1 0	1.777 < 0.035

Table 2.3 Standard Model lepton parameters showing charge, mass [69]

2.5.3 Structure of Proton

Proton is represented by a symbol p or p+. Proton is present inside the nucleus of an atom, so it is also known as sub atomic nucleonic particle. The charge on proton is positive electric charge 1 of elementary charge. In Standard Model, proton is baryon which is sub type of hadrons having three quarks, two up quarks and one down quark, whereas diameter of proton is 1.6-1.7 fm [5]. Due to having spin half it is fermions as it follows the Fermi-Dirac statistics by obeying Pauli Exclusion Principle. Proton can interact with matter through all the four interactions i.e. gravity, electromagnetic, weak and strong interactions. In Japan, Experiments are carried out on Super Kamiokande detector. These experiments awarded lower limits for the mean lifetime of proton. Proton decays into a neutral pion and antimuon after 6.6×10^{33} year and 8.2×10^{33} year for the decay into a positron and a neutral pion [68]. Quarks in proton are held together by strong force and mediated by gluon [27]. The proton has nearly exponentially decaying positive charge distribution with mean square radius of about 0.8 fm [14]. Structure of proton is shown in the following figure 2.4.

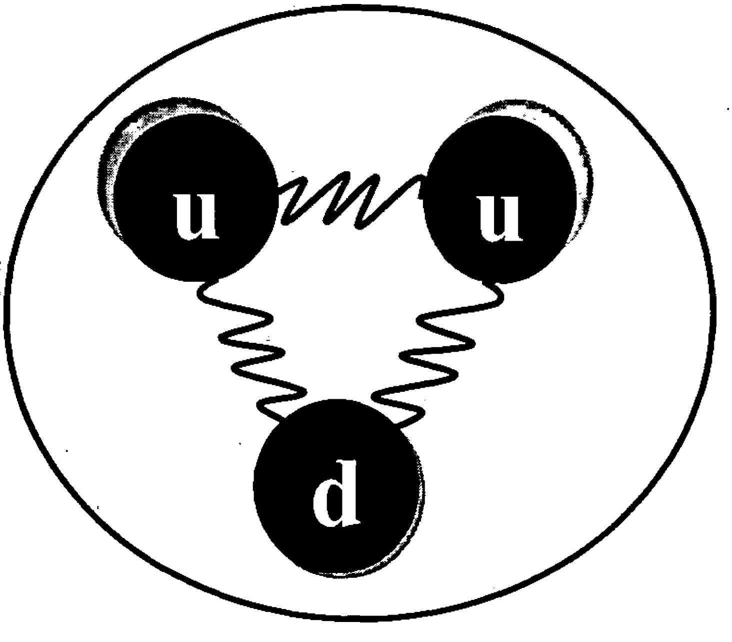

Figure 2.4 Structure of proton, two up, one down quarks [51]

2.6 Role of Basic Forces in Standard Model

All the matters in the nature are composed of four fundamental forces i.e. electromagnetic force, strong force, weak force and gravity. Gravity is responsible for our movement on earth, but Standard Model fails to explain gravity in a well defined way [61]. Standard Model is basically theory related to strong, weak and electromagnetic interactions [42, 45]. Every action in this world occurs due to these four forces. When two particles collide, new particles are formed so a certain force is responsible for creation of new particle. In particle physics these four forces are rather known as basic interaction between particles. We can't able to see repulsion or attraction without the presence of these forces. Some particles are affected by all the forces while many of them are not affected by all the forces.

2.6.1 Electromagnetic Force

As we know that electromagnetic force is the combination of electric and magnetic forces. These two forces are unified by James Clark Maxwell in his theory published in nineteenth century, describing the connection between electric and magnetic force in a single equation [30]. Feynman diagram for electromagnetic interaction is in figure 2.5.

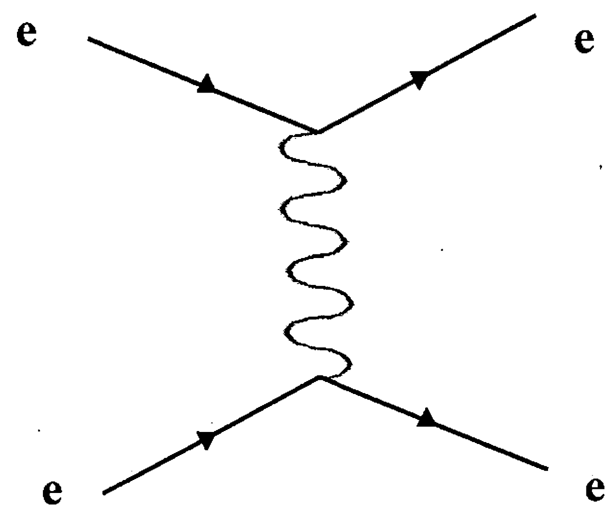

Figure 2.5 Feynman Diagram for electromagnetic interaction [37]

Later on special relativity also confirms Maxwell theory by using magnetic force between moving charge as a result of electrostatic force. The mediator of electromagnetic force is photon and is represented by U(1) gauge group [59].

2.6.2 Weak Force

When one quarks flavor changes into other quark flavor then the interaction is known as week interaction or weak force. The mediator of weak interaction is W, Z bosons and it is placed in SU(2) gauge group. Quarks and leptons don't have color so they interact through weak interactions [59]. One thing common to all weak interactions is that the probability of their occurrence is very low, indicating the relative weakness of the weak force compared to strong and electromagnetic force. For weak interaction, the distance between participating particles should be less than 10^{-17} meters [66]. Feynman diagram for weak interaction is represented in the following figure 2.6.

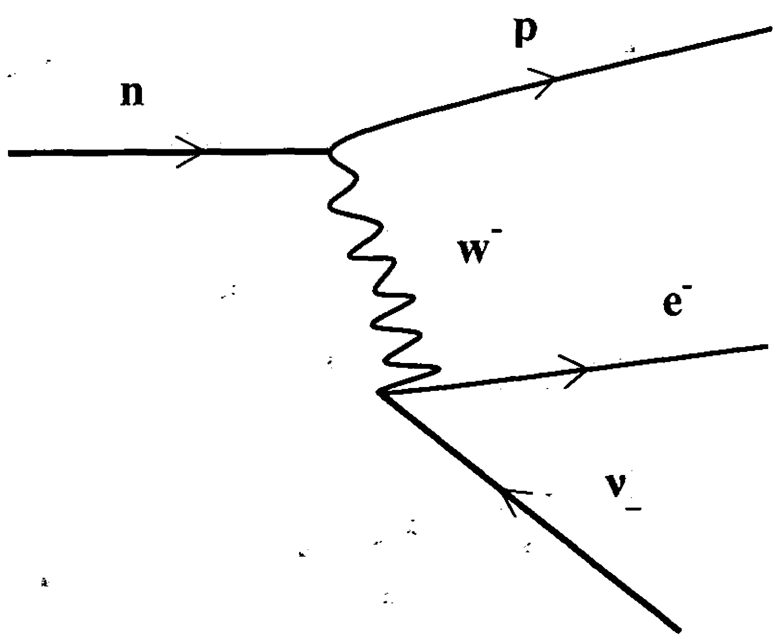

Figure 2.6 Feynman Diagram for weak interaction [37]

2.6.3 STRONG FORCE

As we know that strong force is short-range attractive force between nucleons. This force is responsible for binding the nucleons together, which does not depend upon electric charge [66]. This is the strongest force of all the forces and placed in gauge group SU(3). Those particles which don't have the property of color charge are mediated by gluons, so gluon is the mediator of strong interaction. Hediki Yukawa predicated that strong force is associated with massive particle, who's mass is about 100 MeV.

2.7 Quark Gluon Soup

After big bang this universe was highly dense plasma and so hot that neither nuclei nor nuclear particles were formed. The plasma consists of quarks, a basic constituent of nucleon, and boson the force carrier helps to keep the nucleon together. Plasma is an ionized gas but Quark-Gluon plasma is made up of exotic particles. At low temperature an d densities quarks and gluon attract each other more strongly as separated, this shows that why free quarks don't exist in nature. Physicists worked to create this plasma in laboratory to its different aspects experimentally. So plasma is produced as a result of collision between particles, accelerated towards each other in counter rotating beams in a high energy particles accelerated [55].

In April 2005, the creation of quark matter was confirmed by the result of Relativistic Heavy Ion Collider (RHIC) at Brookhaven National Laboratory's. The four research groups of RHIC were come together on the issue of production of quark-Gluon liquid of very low viscosity. Although the assumptions about QCD plasma are very close to transition temperature it behaves like Gas or liquid. Researchers thought that their assumptions of weak interaction interpretation from the lattice QCD result, where the entropy of the thickness of quark gluon plasma reaches the weak interacting limit [55]. From the weak interaction energy density and correlation shows significant deviation, many researchers told that there is no cause to consider QCD plasma very close to the transition point after weak interaction, like electromagnetic plasma [60]. As observed that methodically improvable perturbative QCD quasi-particle models do a very good job of imitating the lattice data for thermo-dynamical observables such as pressure, entropy, quark susceptibility which includes the aforementioned "significant deviation from the weakly interacting limit", below the temperatures on the order of 2 to 3 times the critical temperature for the transition [8, 9, 19].

2.8 Large Hadrons Collider (LHC)

In CERN (European Organization for Nuclear Research) Franco-Swiss border, Geneva near Switzerland, the world biggest and largest particles accelerator was built in 1998 to 2008 known as large hadrons colliders (LHC). More than 100 scientists and engineers from 100 countries built LHC [77]. The circumference of LHC is about 27 Kilometer lies under the tunnel. The aim is to build such a high energy particle accelerators is to test various theories about particle physics and high energy physics, especially to confirm the existence of missing Higgs boson predicted by peter Higgs in his theoretical explanation of Standard Model [3]. The first run of LHC was taken into operation on 8th September 2008 after the successful completion of LHC manufacturing. But after 9 days this detector was stopped due to magnetic quench incident, which damages the superconducting magnets and vacuum pipes was contaminated by the explosion of helium gas due to electric fault [71, 54]. In November 2009 it started to run again successfully at energy 450 GeV per beam [73]. On 30th march 2010, two beams collide at 3.5 TeV which sets the world record for the highest energy man made particle collisions [16]. These colliders are used as research tools by accelerating particles at high kinetic energy and observing their impact with other particles. Different detectors are installed at different position of LHC to explore different kind of operations.

i) ATLAS

A Toroidal experiment LHC ApparatuS (ATLAS) is a general purpose detector, aiming to detect highly massive particle which are not observable at low energy. When proton beam collide at the centre of the detector a large no of particles are produced with broad range of energies, this detector detect broad range of signals instead of focusing particles physical process. Length of the detector is 44 meters and diameter is about 25 meters, weighing 7000 Tones, built in June 2007 [1, 74].

ii) Compact Muon Solenoid (CMS)

Compact Muon Solenoid is a general purpose detector premeditated to study many aspect of proton collision at 14 TeV, centre of mass energy of LHC particle [53]. From 183 scientific institutions almost 3600 people representing 38 countries collaborated to form CMS and now is in operation. The main purpose of CMS is to explore new physics TeV scale, to discover Higgs boson, different aspect of heavy ion collision to collect evidence of physics beyond Standard Model.

iii) Large Hadrons Collider Beauty (LHCb)

Large Hadron Collider beauty is especially designed to know experiments of b-physics which measures the parameters of CP violation in the interactions of b-hadrons (heavy particle containing bottom quark. The explanation of matter-antimatter asymmetry of the universe is made with the study of LHCb. This detector detects the observational measurement of production cross-section and electroweak physics in the forward region. From 54 scientific institutes, representing 14 countries to collaborate to build and operate the detector [49]. The location of this detector is at 8 point on LHC tunnel close to Fernery-Voltaire, France just over the border of from Geneva.

Chapter 03

Research Techniques

3.1 Monte Carlo Simulations

A class of computer based algorithms which works on the repeated random sampling for computing result is known as Monte Carlo simulation method. When computer simulations are performed for various physical systems and mathematical system then we used Monte Carlo methods. These methods are simulated on computer to check the exact result with the help of deterministic algorithms by the help of these method theoretical derivations can also be complemented [10].

These methods are particularly helpful for simulating systems like fluids, chaotic objects, powerfully coupled solids and cellular composition at large degrees of freedom. With major uncertainty in input function, such as risk in business they model phenomena. For multi dimensional integrals in mathematics with difficult boundary conditions these methods are used. When we apply the Monte Carlo simulations in space investigation and oil discovery, their forecast of breakdown, cost over runs and schedule over runs are regularly improved than human perception or substitute "soft" methods [13]. It was named after the Monte Carlo Casino, a famous casino where the uncle of Ulam frequently risks away his money [18].

Monte Carlo technique is useful in computational physics and related fields. Monte Carlo methods are used to calculate statistical field theories of uncomplicated particle and polymer systems [43]. Monte Carlo technique can be used for solving many body problems of physics. In experimental particle physics, the methods of Monte Carlo simulations are used for manipulative detectors, perceptive their manners and evaluate experimental data with theory [46, 47].

3.2 A Large Ion Collider Experiment (ALICE)

ALICE is one of the six detectors which is situated at the Large Hadron Collider at CERN. ALICE is modeled and committed to observe the heavy ion collisions at LHC. The main purpose of this agenda is to observe and learn different aspect of nuclear matter at large temperature region above the critical temperature, defined by QCD for making transition of quarks and gluons moving freely in a deconfined phase. The energy densities attained by SPS and RHIC are much lower than energy reached by LHC at CERN [81]. The large temperature and energy density generate quark-gluon plasma. This provides a chance to search the nuclear matter's properties at high energy regime in depth. This also helpful to investigate the dynamics of hadronic matter by making transition from deconfined matter. Pb-Pb collisions are studied at the energy of 2.76 TeV per nucleon. ALICE use proton beams to collect assessment data and to follow a committed proton-proton collisions, deal with the ATLAS and CMS at LHC [20]. To understand its scientific goals, ALICE has difficult running situation which has approved [25] and argued [80] at the current Performance of LHC Workshop.

3.2.1 Detector's Construction

The set up of ALICE experiment is at the P2 cavern of LHC. ALICE is inherited surrounded by the solenoid magnet of L3 experiment. When L3 experiment is removed then inspection of magnetic cooling system was carried out. After this inspection, external circuit has been refurbished to in order to make the magnet operational at 0.5T which is its normal field. The requirements of ALICE tracking technique to measure particles with high transverse momentum at high resolution are fulfilled with the cooling system. The homogenous field is the basic requirement in tracking the particles in the environment of high multiplicity. This is achieved by minimizing diameter of axial gap in the doors of the magnet. For this purpose 200 tons of iron cap are installed. The resulting homogenous field gives variation in the volume of inner tracking system, less than 2% of the supposed significance; it can be used to differentiate in ALICE central detectors having wide range of recognition which observes the classification of central detectors having restricted taking [81].

3.2.2 Tracking System

The working of ALICE central detectors are maintained by automatic space frame structures which shrink quantity of material investigation. The space enclose slide on rails which helps in protection and installation. The tracking system is build up of cylinders observing the pseudo-rapidity range. Adjoining to the impact point six levels of Si detectors make up the

Internal Tracking System and is pursue by the main tracking detector Time Projection Chamber [81]. Transition Radiation Detector and Time Of Flight detector enveloping the TPC to complete the central system.

3.2.2.1 Inner Tracking System (ITS)

The Inner Tracking System (ITS) includes cylindrical layers of silicon detectors. Collision points are surrounded by these layers to measure the characteristics of emerging particles. These layers also help in pin-pointing the positions of emerging particles up to fraction of millimeter. ITS identify particles having heavy quarks by their points of decay. While working alone ITS depend upon low momentum spectrometer which develop the tracking aptitude of ALICE below 100 MeV/c of transverse momenta. In combination with other detectors ITS is able to determine the point of major vertex and of minor vertexes to identify small reside particles like Hyperons, D and B mesons with high accuracy. ITS layers have following silicon detectors including from the interaction point.

2 layers of Silicon Pixel Detector (SPD)

2 layers of Silicon Drift Detector (SDD)

2 layers of Silicon Strip Detector (SSD)

i) Silicon Pixel Detector (SPD)

The two deepest levels of the ITS are primary rudiments for the purpose of the spot of the main vertex and for measurement of the collision factor of minor tracks. SPD control the area of very high density. To deal with such densities, detectors of high accuracy and granularity are obligatory. Furthermore, the detector must be able to function in relatively high radiation surroundings while in the inner layer, the incorporated levels of standard running scenario, of total dose and fluence are projected to be 220 krad. In every pixel chip more than 99% channels are working with sensors of thickness 200 μm and chips of 300 μm and recorded signals on pixel chips are transferred to readout electronics wire bounded to the chips by printed circuit having 3 flexible layers. Three ASIC chips are planted inside the readout card with the help of these chips orientation points for pixel chips, slow run execution, complex outgoing data and take laser diodes supply the optical links are recorded.

ii) Silicon Drift Detector (SDD)

The thickness of Silicon drift detector is 300 μm and is accumulated with respectively 22 ladders having six sections each shape two central layers of ITS. For shapes of drift and collected field works, high voltage divider is incorporated in the sensor and CMOS charge provider which is used for observing drift velocity. The ideal spot resolution, 40 μm in the twisting plane is attained for a sensor by the homogeneous resistivity. This homogeneity in resistivity is gained by using neutron transmutation which is doped by n-type silicon material of high resistivity. The industrial manufacturing of silicon sections are formed with a yield of about 50%. Aluminum polymide micro cables, a transition cable wire is attached to the detector, are used to bias independently the two faces of module and connected to the high voltage divider by using thicker cable attached to the transition cable. The layout of this cable is up to 6 kV.

iii) Silicon Strip Detector (SSD)

Outmost two layers of ITS are called as silicon strip detector and is made up of 36 steps, every ladder had 26 two sided silicon strip sections. It is structured by hard and light-weight fibers of carbon forming triangular truss sited at two ends of ITS cylinder in two conical frame similar to the structure of SDD, these conical frames work for SDD and SSD, also support the SDD ladders , and in forward multiplicity detectors in silicon-rings. In SDD and SSD tape-automated bonding technology is used, which transmit signals to the front-end electronics from the detectors connected together with flexible Aluminium polymide micro cables. Pre amplified chips for determining continues yield and organized parameters used to form HAL25 twelve for every element, is shaped in radiation tolerant with 0.25 μm CMOS technology.

3.2.2.2 Time Projection Chamber (TPC)

Time Projection Chamber of ALICE is the key pathway tool. While working alone, TPC give the exact momentum dimension of the entire charged particle with momentum lower than 10 GeV/c. TPC provides momentum dimension up to 100 GeV/c, in combinations with other tracking devices. Furthermore information about charged particle recognition is gathered by the measurement of energy loss. The main objective of TPC is to attain better momentum resolution about few percent for particles having momentum range less than 5 GeV/c and 10% for the range

100 GeV/c when used in combination with other tracking detectors. The track range inside the TPC controls resolution on energy loss measurement. The correspondence measurements of pairs of particles having short relative momentum range requires two tracks resolution which is healthier than 5 MeV/c in four momentum space. A new tracking algorithm is developed for reconstruction and simulation to confirm these performances. By using high-quality track restoration which is independent of the particles momentum below 100 MeV/c efficiencies more than 95% can be achieved [20].

The TPC contains 5m long four cylindrical vessels where two vessels are field cage vessels filled by the mixture of Ne (90)-Co_2 (10) gas. These vessels of the TPC define active drift volume of radii 0.9 m and 2.5 m. To make isolation of TPC high voltage two additional vessels containing Co_2 filled volume is used. A high voltage electrode is biased in the middle of the field-cage, along the axis of the cylinder to create drift field to 100 kV. Two end plates are installed to support readout chambers and are fragmented in 18 trapezoidal segments.

3.2.3 Particles Identification System

Particle identification ability is essential, for many observables [20]. Measurements of energy loss in TPC and ITS, offers distinctions of pions, kaons and protons inside the central tracking system. It is able to find vertex, give the way to classify short lived particles like hyperons, by detection of hadronic decay. For the detection of large range of particles species and extensive momentum collection by position of corresponding detectors which fulfill the particle classification of central tracking system, an additional particle identification capability is required.

3.2.3.1 Transition Radiation Detector (TRD)

Transition Radiation Detector discriminates and identify high momentum electron against pions by matching the capacity of the transition radiation formed by ultra-relativistic electrons passing various objects with tracking information given by TPC and ITS. This detector is used as an electron spectrometer which realizes charm and beauty mesons via semi leptonic states by using their $e^+ e^-$ control. Trigger on electron having huge momentum and hadron measures is allowed by the electronics of TRD which is capable of fast tracking aptitude.

TRD's basic detection system includes a radiator foil, a polypropylene fiber which is fixed among 3 glass fibers imposed by Rohacell foils, alongwith time expansion chamber having readout pad of cathode and packed with a mixture of heavy gas. A single module is formed by stacking such six units. For full azimuthal coverage 108 super-modules are required.

3.2.3.2 Time Of Flight (TOF)

The outer most part of the inner barrel in the ALICE detector is Time Of Flight detector, as heavier particles move slowly so take much time to reach the surface of the detector. The measurement TOF inclusive the charged hadrons classification by combing with tracking information such as charged, momentum and energy loss composed by ITS and TPC. This improves the performance for classification of pions, kaons and protons in the intermediate range of momentum. To attain the desired result time resolution more than 100 ps is mandatory. Multi-gap Resistive chamber technology is introduced to attain such superb time resolution. Two layers of five parallel plate chambers having thin gap are stacked in TOF. Strips of different lengths are build up on barrel of 3.7 m radius are gathered in the stack of chamber [90].

3.2.3.3 High Momentum Particles Identification Detector (HMPID)

The High Momentum Particle Identification Detector is committed to broad dimensions of recognized hadrons for *p*t > 1 GeV *c*−1 [6]. The HMPID was considered as a single-arm arrangement having approval of 5% of the middle container segment space. HMPID will increase the PID potential of the ALICE experiment by permitting detection of particles outside the momentum space manageable throughout energy loss in ITS and TPC and time-of-flight measurements (in TOF). The detector was optimized to broaden the useful series for π/K and K/p bias. The detection system utilizes imaging technique of Cerenkov ring, enclosed by a liquid C6F14 radiator and a chamber of multi cable proportion having pad read out UV detector. A lean layer of CsI photocathode evaporates on the pad plane. The solid angle covered by HMPID is $-0.6 < \eta < 0.6$, 57.61° azimuthal reporting at 5 m from the contact point [26].

3.2.3.4 Photon Spectrometer

The outermost middle detector of ALICE is known as photon spectrometer, this detector covers solid angle $-0.12 < \eta < 0.12$, 100° azimuthal and placed at 5m from contact point. A highly segmented PbWO4 calorimeter, having multi wire proportional chamber for permitting to veto charged particle, is used to measure photons with large resolution and discriminate against charged hadrons. To improve the light output of PbWO4 crystals, calorimeter is become stable at temperature of -25°C. By the dimension of two photon decay channel to identify neutral mesons, segment of calorimeter provides position resolution. Additional identification of the particle can be done by using some other parameter such as TOF, isolation measurements etc.

3.2.4 Forward Muon Spectrometer

The forward muon spectrometer is a difficult detector system, Muon pairs are detected and identify by this detector. The main purpose of forward muon detector is to perform mass spectroscopy of charmonium and bottomium states at high resolution. On one side of the ALICE experiment, inside the forward multiplicity region the spectrometer is located. The spectrometer includes hadron absorber, protecting the spectrometer from the contact point and from the beam pipe [63].

3.2.5 Forwards Detectors

On both faces of interaction point different detectors, having well defined various objectives such as triggering, event choice, global features measurement etc are installed at huge rapidity.

i) **Zero Degree Calorimeter (ZDC)**

At a distance of 110m away from the contact point contained by the LHC tunnel, four small calorimeters are located known as zero degree calorimeters. These are consisting of congregation of tantalum or brass surrounded by quartz fiber. Proton viewers redirected by the first LHC dipole is identified by the brass Zero Degree Calorimeter and neutron observer by the tantalum Zero Degree Calorimeter. This provides trigger information and measure of impact parameter.

ii) Photon Multiplicity Detector

A honeycomb cell proportional chambers inserting inactive Lead converter are joined together to form photon multiplicity detector. On converse side of muon spectrometer from the interaction point at 3.6m away PMD is located.

iii) Forward Multiplicity Detector (FMD)

The Forward Multiplicity Detector is built up of five plates consisting of silicon pad detector. Two FMD positioned at one of the sides of muon spectrometer while three on the other side. When FMD works with ITS, then this detector gives rapidity exposure from -5.1 to 3.4 for finding of charged particles.

3.3 Offline Framework

AliRoot is the ALICE offline software framework package and is supported by the ROOT package to get benefits of different existing element like set of containers, incorporated input and output schemes development, C++ a programming language, having wide set of effectiveness Mathematical formulas, multi bound fit and minimization, citations instrument, entire figures scrutiny setting and graphical user passage position toolkit. The entire task such as event simulation, reconstruction and data analysis are performed by AliRoot. Different particles transport packages have been produced through virtual machine by using virtual Monte-Carlo technique, to allow control at run time between packages. Recently a new crossing point for GEANT3, GEANT4 and FLUKA are executed and new geometry of ROOT package is also approved. This is used as tool for browsing, construction of trail and visualization of detector geometry. These packages are used to define interface for feeding any type of geometrical uncertainty for example where am I and what is the effect of change of geometry if posted change by exterior application to the geometry. These facial appearances of an interface help in numerous ways such as simulation, reconstruction, visualization and event demonstration by using same geometry. ALICE offline framework needs the same environment as working at CERN. For this purpose ALICE environment known AliEn is the major development for offline framework. AliEn is scattered computing framework. It is working for worldwide scattered simulation and restoration tasks [81].

3.3.1 ROOT Framework

René Brun and Fons Rademakers after experiencing many years had developed interactive tools and simulation packages and guided flourishing Projects like PAW, PIAF and GEANT because twenty years old FORTRAN libraries reached their limits. Even though these tools are famous enough but still did not scale up confront presented by the Large Hadron Collider, where the data is a hardly any orders of degree superior than anything seen before. As work of computer science had already been playing a vital role in the development and progress of mankind in particular the field of Object Oriented Design and René and Fons were ready to take advantage of it. ROOT had grown in the perspective of the NA49 experiment at CERN. NA49 has caused a remarkable amount of data about 10 Terabytes per run. This rate supplies the perfect condition to enlarge and test the upcoming generation data analysis. One cannot reveal ROOT exclusive of affirm CINT, its C++ interpreter. CINT created by Masa Goto in Japan. It is an independent product which ROOT is using for the command line and script processor.

ROOT has a liberal, informal development style to facilitate heavily relies on the dissimilar and deep talent of the user community. The expansion of ROOT is a permanent conversation between users and developers. When it comes to accumulating and removal of great amount of data, physics cultivate the way with its Terabytes, but extra fields and industry pursue close behind as they gain more and more data over time. The users cooperate with ROOT through the graphical user boundary, the domination line. ROOT presents a logical and well incorporated set of module which simply inter-operate through object bus make available by the analyst thesaurus which provide broad Run Time Type Information (RTTI) which formulates ROOT a perfect fundamental transportation module on which an experiment's absolute data usage sequence can be built from DAQ, using the user and public memory classes for database, analysis and data presentation.

3.3.2 Simulation in the ALIROOT Framework

The STEER is the central module, the interface classes for the detector description and data structure is provided by this module. Particle stack implementations and run steering is also provided by central module, required for virtual Monte Carlo. The interface class AliGenerator work for event generator module. The AliDetector provides specification for detector specific module [24]. The interface TVirtualMC provide the transport MC through virtual MC. All these modules correspond to run steering, central module. This user code is designed according to various sub-detectors. These detector modules are different for different modules and don't allow to depend on each other.

At various steps of the simulation process, data is generated by AliRoot simulation framework A virtual file directory is developed by AliEn which enables transparent access to distributed data sets. When a particle pass through detector then the precise information acquired by the Transport MC, like energy deposition and position are represented by so-called hits. . Integrated digits that correspond to the untreated data before addition of noise and threshold subtraction, these hits are changed into signal formed by the detector. The importance of this method for the simulation of heavy ion collisions stretch out in detail, one original event can be used for more than few signal events, thus reducing computation time and data storage space. Figure (3.1) shows component view of AliRoot simulation framework.

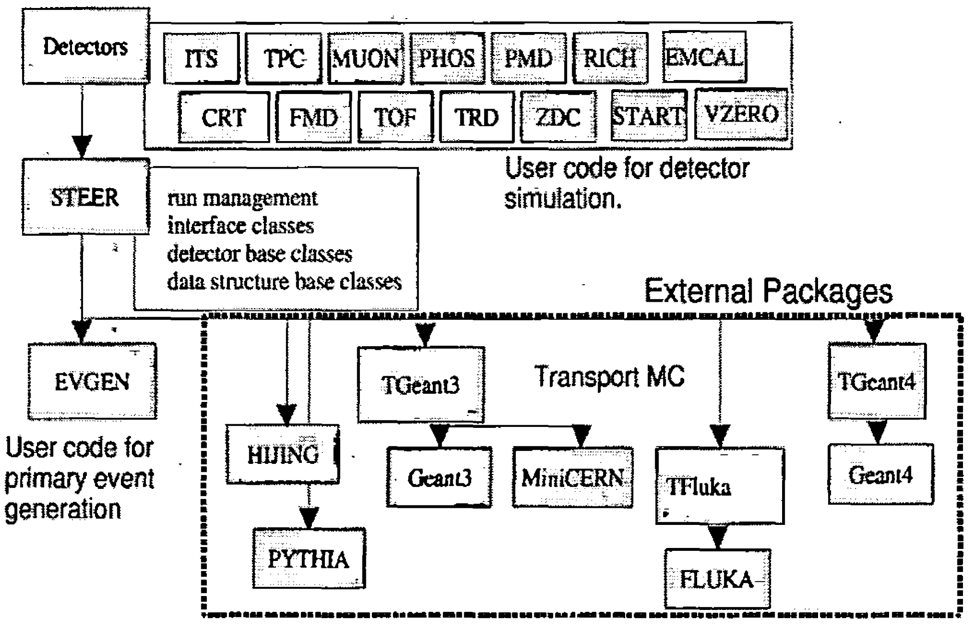

Figure 3.1 Component view of AliRoot simulation framework [24]

3.3.3 FLUKA

FLUKA is a wide range intention apparatus for computation of particle transport and exchange with matter, casing a comprehensive series of purpose spanning from proton and electron accelerator, cosmic rays, neutrino physics and radiotherapy etc.

The utmost precedence in the devise and expansion of FLUKA is the execution and upgrading of sound and present physical models. Tiny models are implemented when probable regularity among every reaction, conservation laws are obligatory at each event and outcome are verify in opposition to investigational data at particular contact level. Final forecast are acquired having smallest set of free factors unchanging for all energy, target and projectile grouping. FLUKA can replicate with great precision the contact and proliferation in matter of about 60 dissimilar particles. FLUKA can switch to extremely difficult geometries, using superior edition of famous Combinatorial Geometry (CG) package. The FLUKA CG has been premeditated to track suitably also charged particles in the existence of electric and magnetic fields. The FLUKA nucleon interface models are found on resonance assembly and decompose underneath a few GeV. Beside the code where effectiveness, precision, reliability and litheness have mutual sharing generous very efficient results is the FLUKA geometry. Entirely new, fast tracking tactic has been extended, with special interest to charged particle transport, particularly in magnetic fields. It is feasible to differentiate three unlike generation of "FLUKA" codes beside the years which can be generally recognized as the FLUKA of the '70s, the FLUKA of the '80s and the FLUKA of today. Most important modification and accompaniments have affected the physical form used, the code configuration, the tracking tactic and scoring.

Applications

Whereas FLUKA 86-87 was effectively a specialized program to compute defending of high energy proton accelerators, the current description can be hold as a common function apparatus for an absolute collection of applications. In addition to conventional objective design and protecting, radiations spoil isotope alteration, dosimetry and detector learning. Prediction of radiation harm has always been a conventional field of application of FLUKA, constrained however in earlier edition to hadron damage to accelerator components.

3.3.3.1 Development of FLUKA

It is easy to make a distinction among three different generation of "FLUKA" codes by recognized them beside years, such as the FLUKA of the '70s, the FLUKA of the '80s and the FLUKA of today. During research at CERN on hadron cascades in 1962 Johannes Ranft developed the first high-energy Monte Carlo transport code. This code was non-analogue and adopted as an apparatus for scheming and shielding of high energy proton accelerators. The first analogue code is written in 1967 and published at Rutherford's high energy lab known as FLUKA (FLUKtuierende KAskade). After the successful completion of construction of SPS in 1978, redesigned of FLUKA code was necessary. The previous versions of Ranft's programs were integrated into a distinct code whose name is also FLUKA. The newly developed code had the ability to carry out multi-material computation with varying geometries and to achieve energy deposition, star density and differential "fluxes". In 1987 when new invention of proton collider was planning having great luminosities and energies up to several TeV, FLUKA had great importance because of its use in superior high-energy hadron generator. The early developed versions were not capable of handling large multiplicities, strong magnetic field and energy deposition. So a new version of FLUKA is required to control and simulate these parameters. All these new generation of these codes are the branches of same code based on the same root. But, all new ``generation" characterize not only a perfection of the pervious program, but rather a quantum step in the code physics, design and goals. These codes are also known as FLUKA so as to remind historical development of it from early developed codes.

3.3.3.2 Particle Interactions and Transport

As FLUKA is high-energy particle transport code so it can simulate the interactions and propagation of more than 60 particles with extreme accuracy. Some of the interactions are listed below.

- Hadron-hadron and hadron-nucleus interactions up to 10000 TeV
- Nucleus-nucleus interactions up to 10000 TeV/n
- Charged particle transport and energy loss
- Neutron multi-group transport and interactions 0-20 MeV

- Electromagnetic interactions 1 keV – 10000 TeV

3.3.3.3 Flair for FLUKA

Flair is a superior user responsive interface for FLUKA to make easy the suppression of FLUKA input files, implementation of the code and revelation of the output files. It is developed completely on python and Tkinter. The main purpose to develop Flair for FLUKA is as follows.

- Front-end interface for an easy and almost error free editing as well as validation of the input file during editing.
- Interactive geometry editor and debugger.
- Debugging, compiling, running and monitoring of the status during a run.
- Back-end interface for post-processing of the output files and plot generation through an interface with gnuplot or 3D photo-realistic images with povray.
- Python API for manipulating the input files, post processing of the results and interfacing to gnuplot.

The idea of flair interface was to work on an intermediate level. Not too elevated, that covers the inner functionality of FLUKA from the user, and not so low that the user is in constant need of the FLUKA manual to verify the options for each card. The program reveals the card information in an understandable human way.

3.3.3.4 Interface

Interface of FLUKA is used to make easy communication between user and programming code. FLUKA interface is the opening window on which users can directly work by giving input parameters. In the input editor the user is working directly with the FLUKA cards using a small dialog for each card. Flair main window contains the following.

- a menu bar on top
- a tool-bar for fast access of the most common commands
- a status bar at the bottom to display some useful information
- and three frames in the middle:

- On the left frame, there is a tree browser for the various sections of the project. By expanding and left click on the appropriate node of the tree a different frame appears on the right ACTIVE frame. By right-clicking on the tree you can select in which frame top/bottom to display the content.
- The right/top and right/bottom frame encapsulates all the working frames used for editing the information stored in the project file.

The window-title displays the program name, version and the name of the project we are currently are working on. A "+" character infront of the title name means that the current project is modified. Figure 3.2 shows interface of FLAIR for FLUKA.

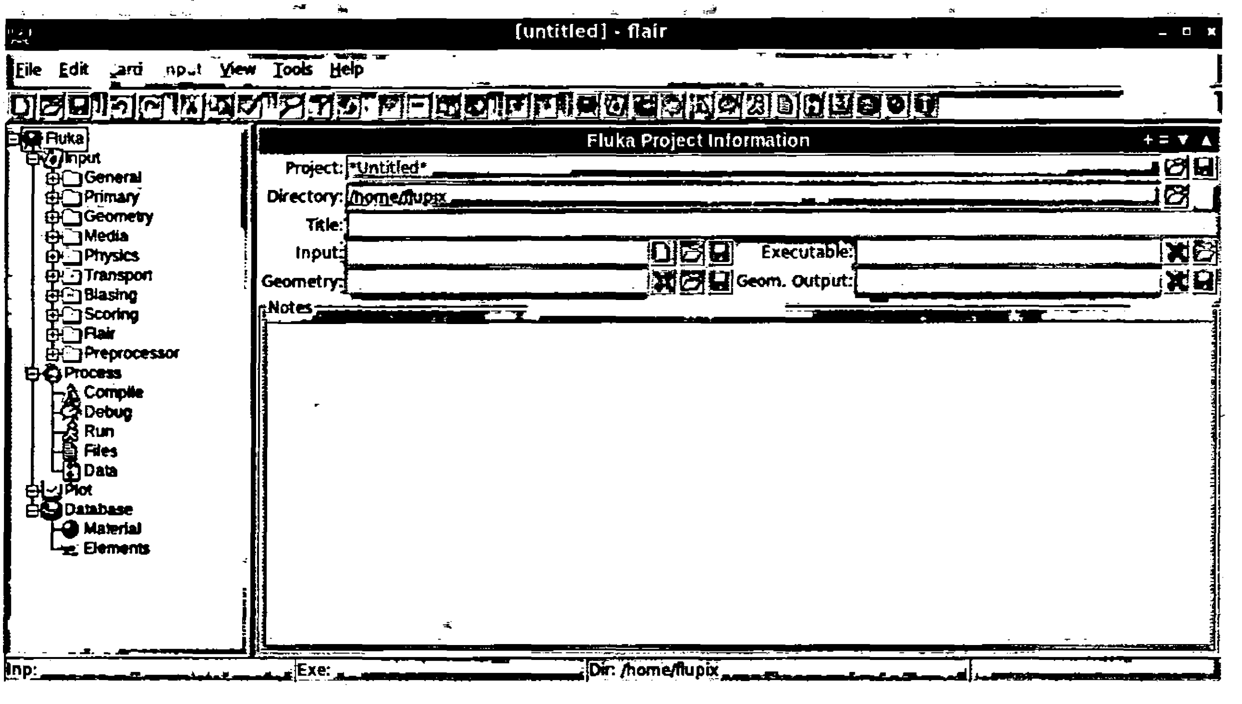

Figure 3.2 Figure shows interface for FLUKA with different components.

Chapter 04

Results and Discussions

The main objective of this research work is to observe the yield of proton at various energies during proton-proton collision by using different software packages such as ALICE offline computing frame work and FLUKA, the transport code of particles, which are based on same computing technique i.e. Monte Carlo simulation. In this section of research thesis proton production at ultra-relativistic energies during pp collision is presented and commented. In early phase of this section simulated result obtained by using ALICE offline computing is discussed and in later section the simulation results are obtained by using FLUKA, the transport code of particles is presented and commented.

4.1 Protons Production at Various Energies during p-p Collisions using ALICE Offline Computing Framework

In the proton-proton collision, the transverse momentum (p_t) spectrum for production of proton is measured accurately and precisely by using ALICE offline computing framework, in the energy regime described by Large Hadron Collider. Its aim is to permit particle detection over a wide momentum collection, powerful tracking with good resolution from 100 MeV/*c* to 100 GeV/c and outstanding determination of secondary vertices. The identification of Proton is done by combining various detectors, the particle production ratios as given by event generator, the competence of the Particle Identification algorithm is over 70% up to *p* 0 5 GeV/*c* for protons, in all cases the contamination with wrongly-identified particles is below 30%. The overall effective PID efficiency is limited by particle decays and absorption is about 50% for protons. Figure 4.1 shows the Monte Carlo simulation result of proton production in pp collision by using ALICE Offline Framework.

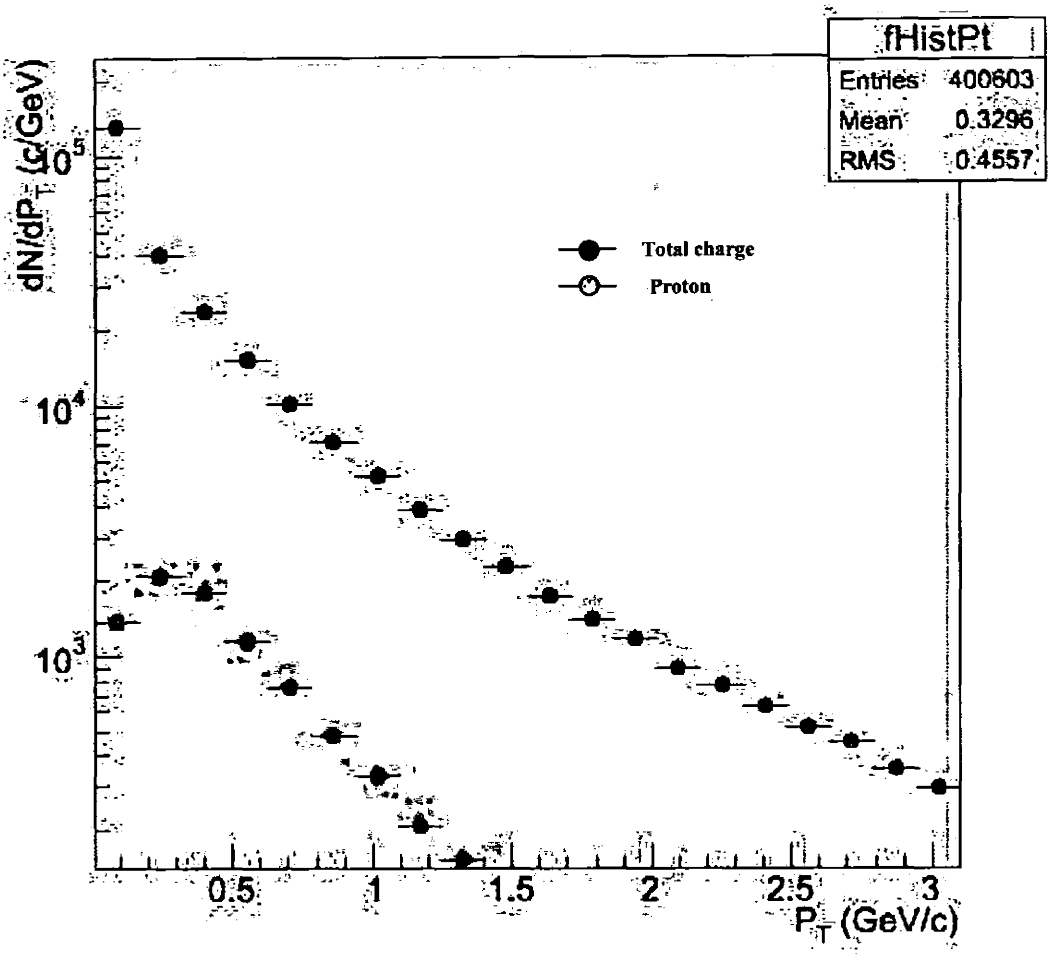

Figure 4.1 Monte Carlo Simulation results of the proton production in proton-proton collision at ultra-relativistic energy with help of ALICE Offline Framework.

4.1.1 Results and Discussions

ALICE offline framework which is based on the Monte Carlo simulation technique is used to obtain simulated result collected after pp collision at ultra-relativistic energies. During pp collision a large number of various particles are produced as primary and secondary charged particles by making elastic and inelastic collision. Here proton production at various ultra-relativistic energies is presented and discussed. The simulated result is shown in the graph as given above. The above mentioned graph shows the nature of proton production when the yield of proton production is plotted against transverse momentum (p_t) spectrum. In the simulated result the total charged particles are shown in black and green particles are the proton produced due to interaction of charged particles. The transverse momentum (p_t) distribution is plotted along x-axis and corresponding yield of proton is plotted along y-axis. The p_t distribution ranging for proton is $0 < p_t < 1.5$. The p_t spectrum shows that with the increase in the p_t distribution the abundance of proton decreases and at certain distribution range it becomes close to zero. The total charged particles also get saturated after certain p_t range.

- Black dots in the p_t spectrum represent the total number of primary charged particles produced as a result of p-p collisions.
- Green dots in the p_t spectrum represent the production of pions as a result of p-p collisions.

4.2 Protons Production at Various Energies during p-p Collisions using FLUKA Code

The energy spectrum of proton production is measured in the energy regime of Large Hadron Collider with great accuracy and precision. Here fluence of proton produced by using FLUKA, the transport code of particles, is analyzed and commented. FLUKA is also based on the same computing technique i.e. Monte Carlo simulation. The emission of different charged particles at various energies can also be observed by using FLUKA and simulated results can be obtained. The parameter used to obtain simulated result of proton production by running FLUKA is given below to understand the FLUKA input parameter and result obtained is also attached underneath.

In current research work, the projectile particles (protons) having different energies strike with the target material. Large numbers of protons are observed as a result of these collisions. To obtain cylindrical geometry of target RCC card is used in which radius of target is 0.000000001cm (1×10^{-9}) whereas its thickness is (0.00000002). The position of the projectile beam is also triggered by fixing the beam position at (0, 0,-1). The LAMBIAS card is introduced which controls the inelastic collision of particles by setting SDUM as INPERI and $\lambda_{\text{inelastic}}$ is 0.00000000001cm (1×10^{-11}). USRBDX is used to control the fluence of particles which records the energy of scattered particles ranging from 0.0001 to its highest value. The proton production is shown in the following figure.

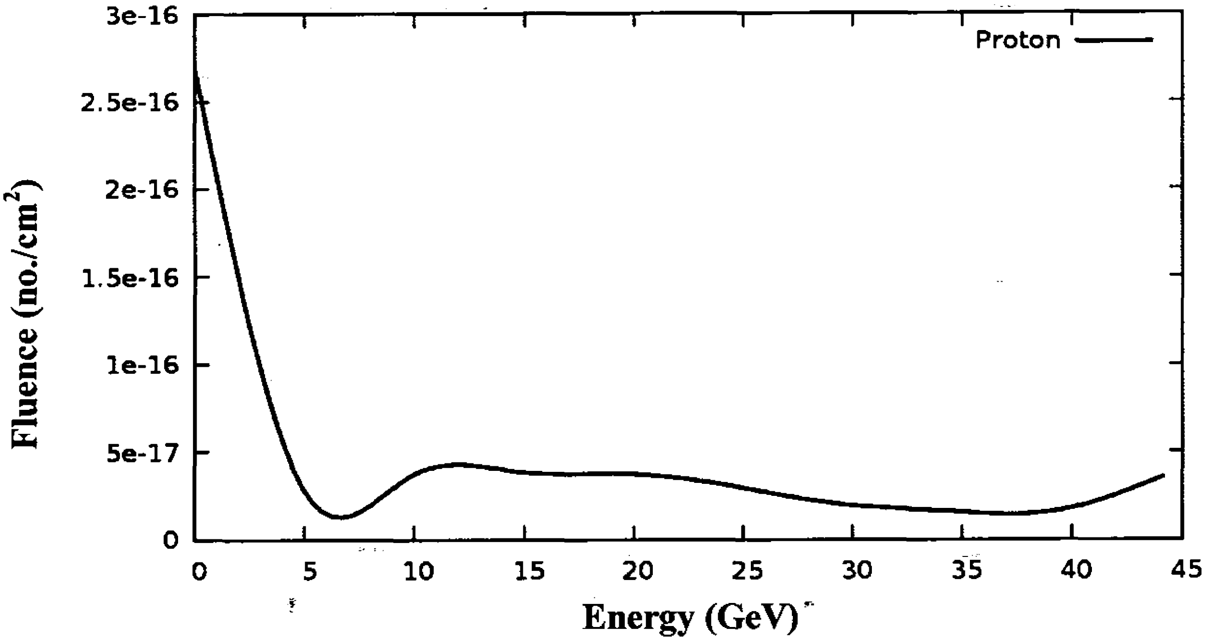

Figure 4.2 Figure shows the FLUKA results of protons production in p-p collisions at 50 GeV

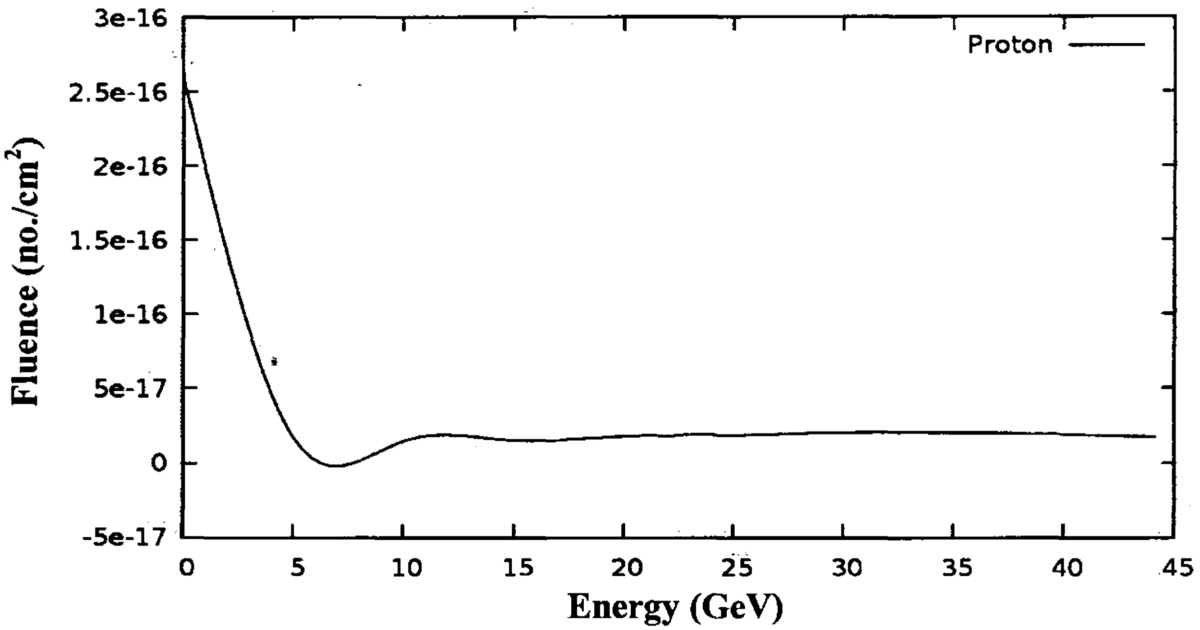

Figure 4.3 Figure shows the FLUKA results of protons production in p-p collisions at 100 GeV

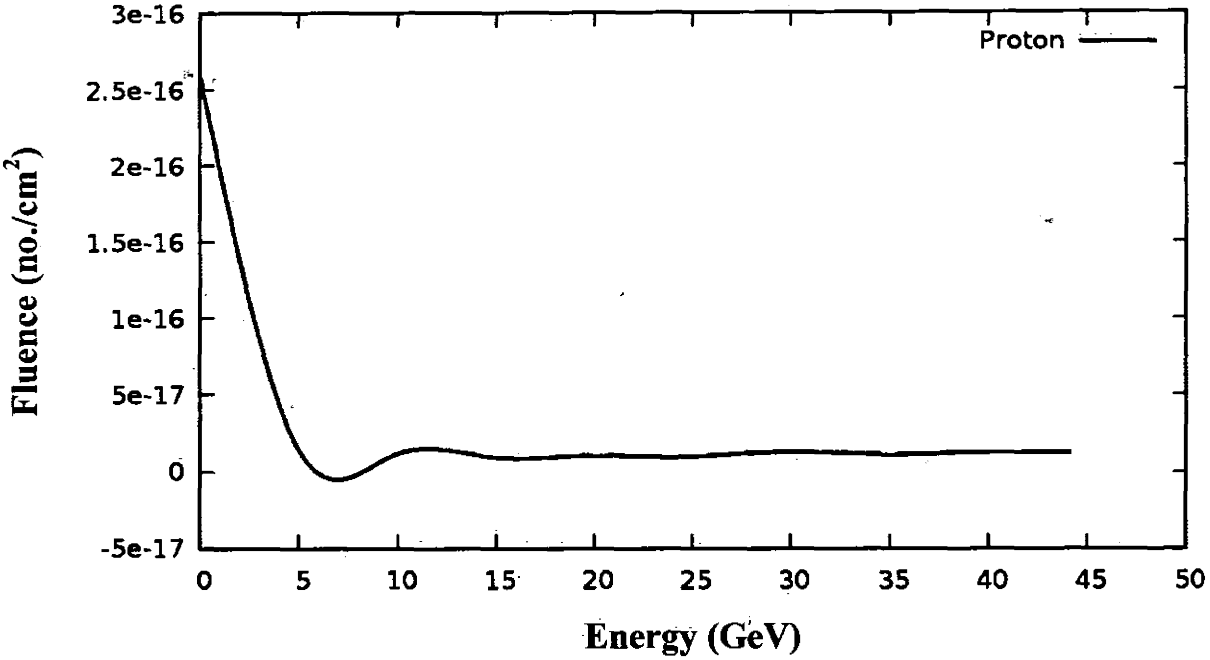

Figure 4.4 Figure shows the FLUKA results of protons production in p-p collisions at 150 GeV

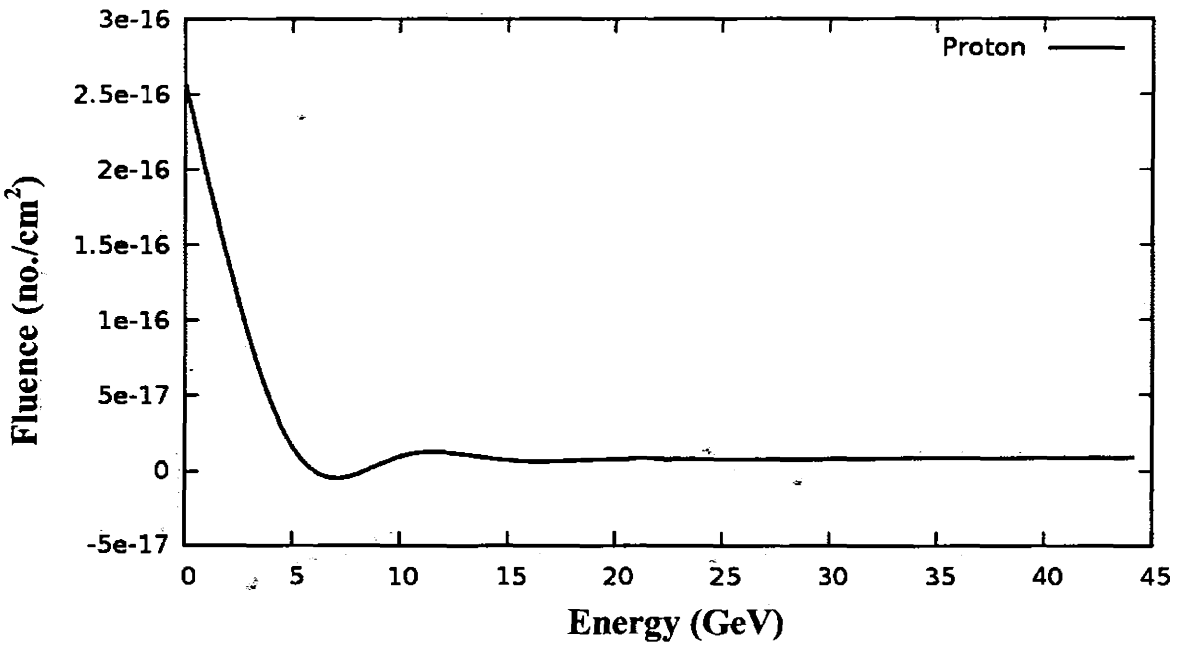

Figure 4.5 Figure shows the FLUKA results of protons production in p-p collisions at 200 GeV

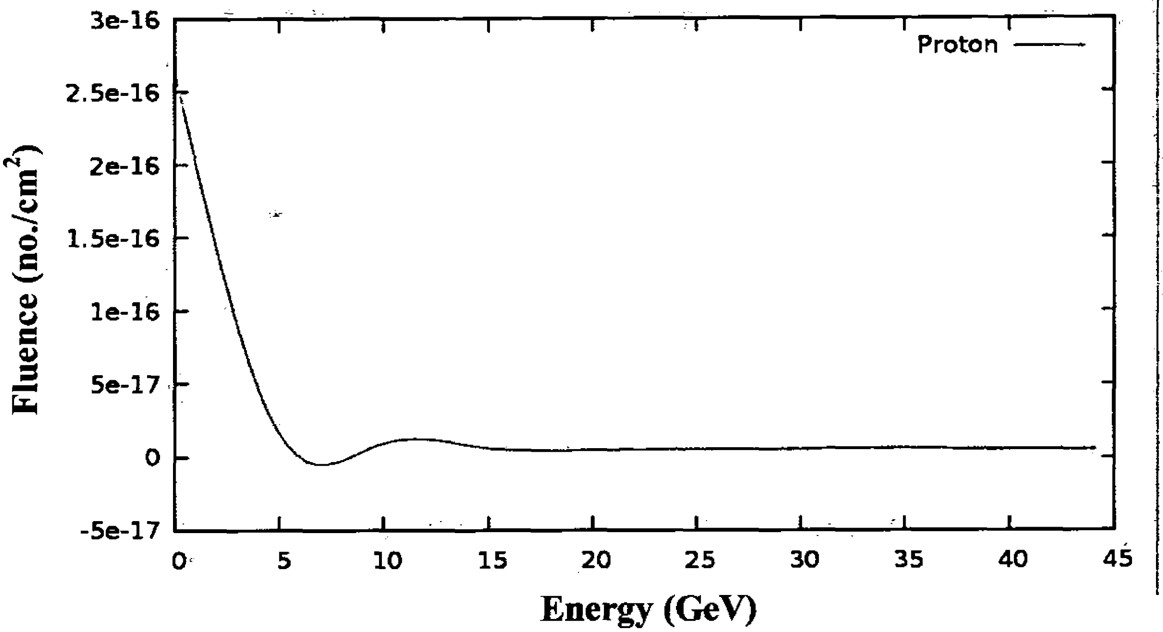

Figure 4.6 Figure shows the FLUKA results of protons production in p-p collisions at 300 GeV

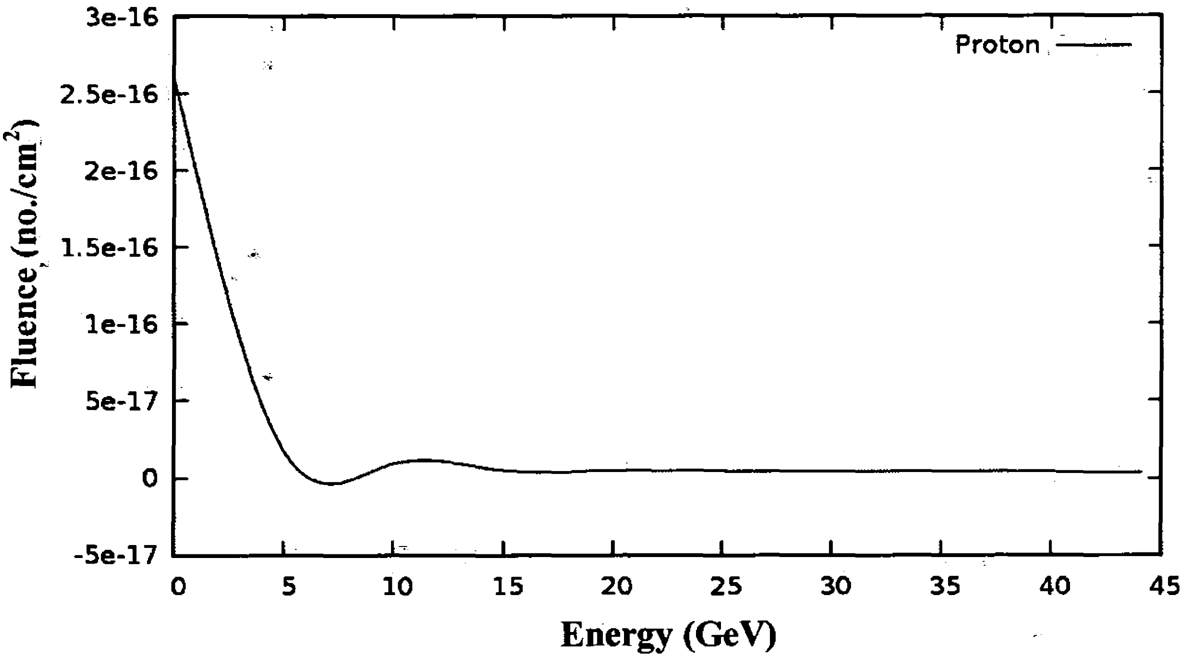

Figure 4.7 Figure shows the FLUKA results of protons production in p-p collisions at 600 GeV

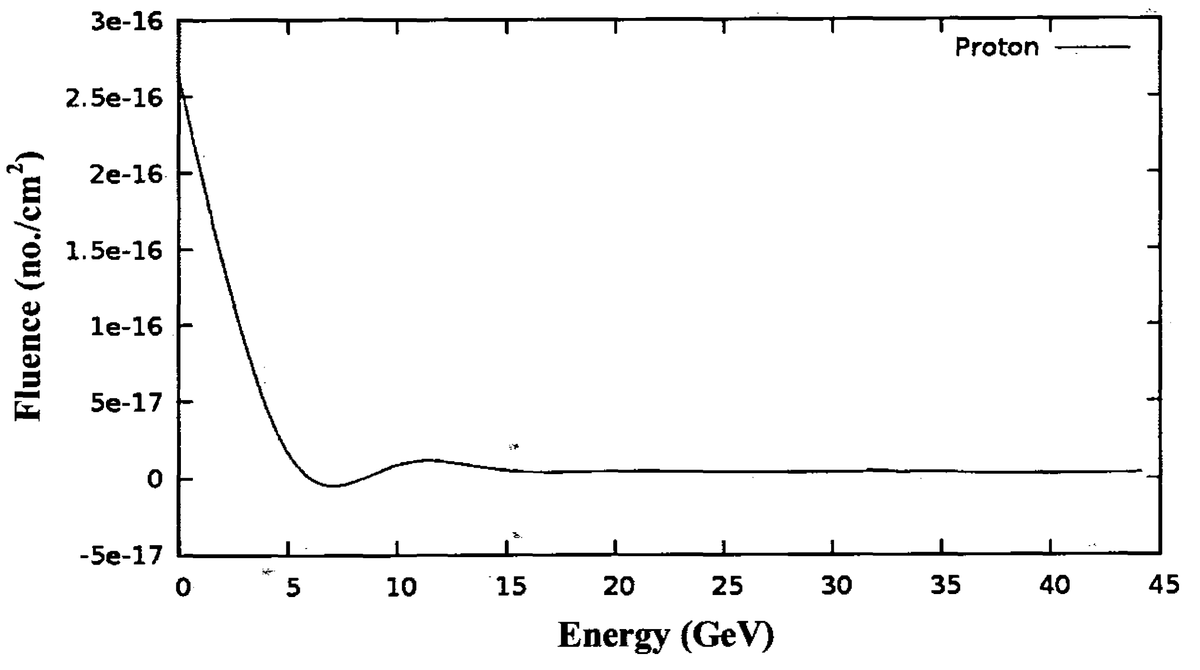

Figure 4.8 Figure shows the FLUKA results of protons production in p-p collisions at 500 GeV

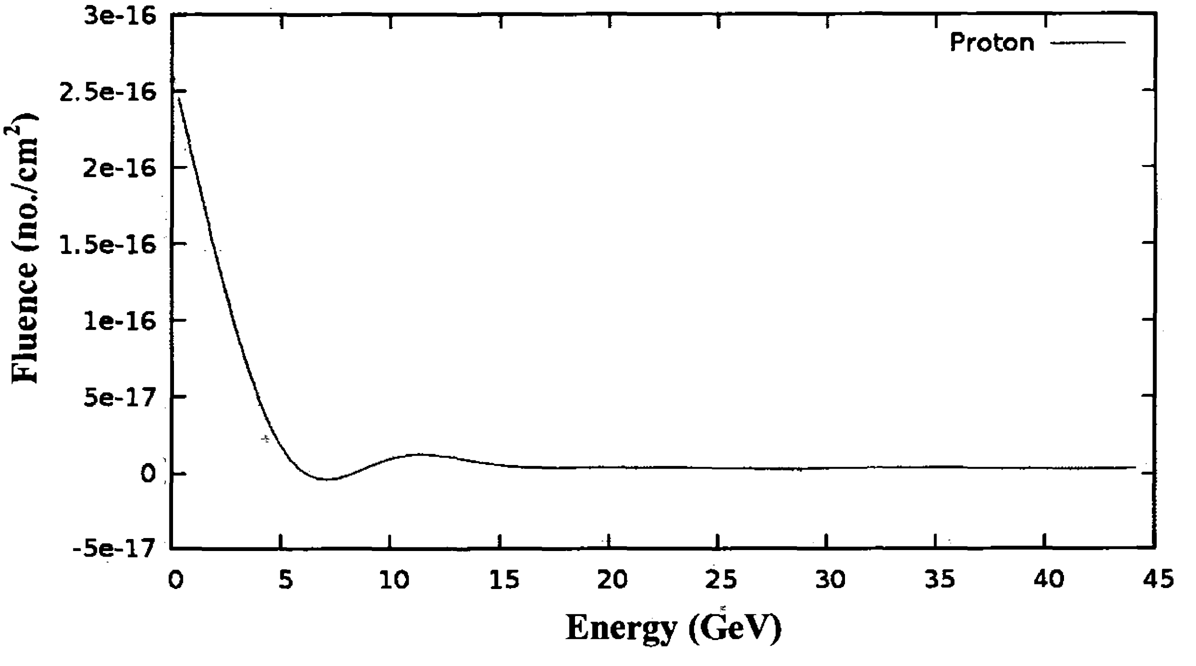

Figure 4.9 Figure shows the FLUKA results of protons production in p-p collisions at 600 GeV

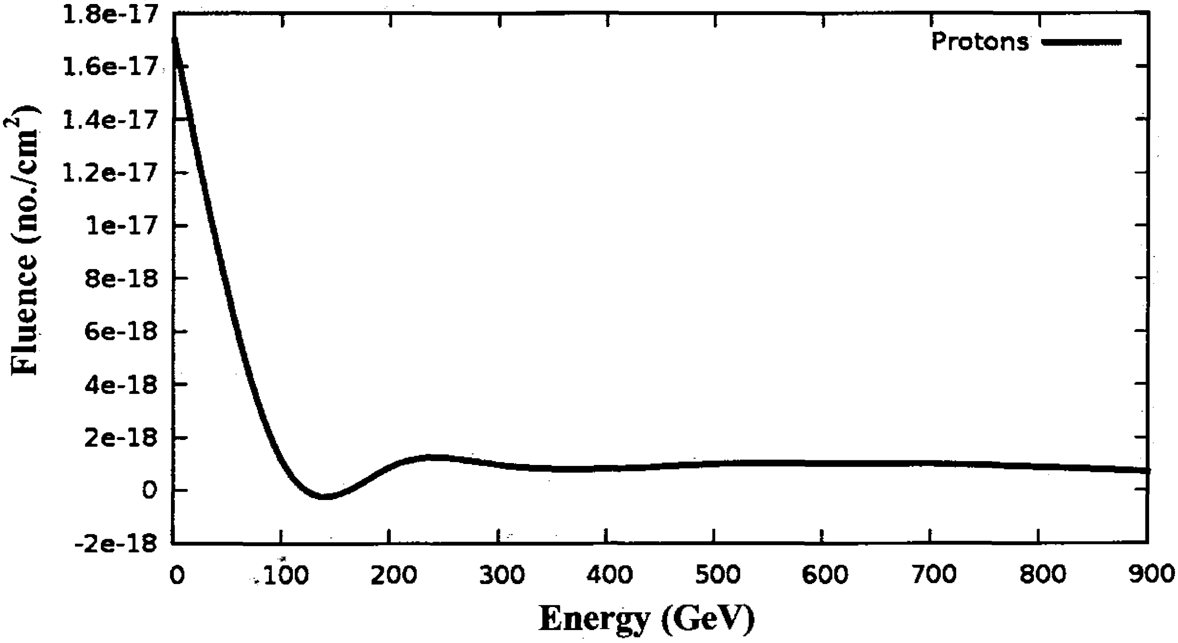

Figure 4.10 Figure shows the FLUKA results of protons production in p-p collisions at 2 TeV

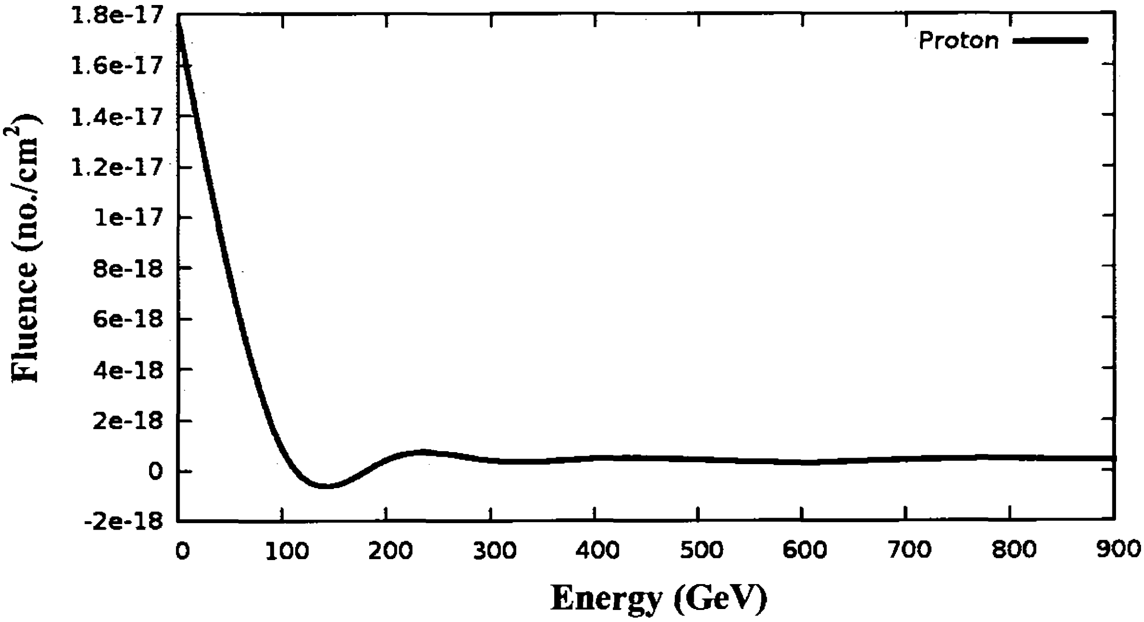

Figure 4.11 Figure shows the FLUKA results of protons production in p-p collisions at 5 TeV

4.2.1 Results and Discussions

The above mention graphs are plotted by using FLUKA, transport code based on the Monte Carlo simulation technique at various energy regimes. Huge numbers of bulk of particles are emitted in p-p collision at very high including primary and secondary particles. The main purpose of all these graphs is to observe the production of proton which is produced as the secondaries in the FLUKA run. The energy spectrum for proton production is different at different energies. Figure 4.2 to 4.10 shows behavior of fluence of proton production. The scattered energy of emitted particles is plotted along x-axis and energy range for first 8 graphs is 0 to 45 GeV. In the last two graphs the scattered energy range is from 0 to 900 GeV whereas the fluence (particles produced per cm^2) is drawn along y-axis.

Figure 4.2 shows the energy spectrum of proton at 50 GeV energy. In this figure it is observed that the fluence of proton is 2.5 e^{-16}. It can be seen that maximum number of protons are produced in the energy range of 0 to 2 GeV whereas in the energy range from 2 to 40 GeV, relatively less number of proton are produced. While observing figure 4.2 carefully in the energy range of 40 to 45 GeV, little number of proton are produced and curve shows saturation. This graph also shows that the fluence is a function of scattered energy of emerging particles and proton fluence decreases with increase in the scattered energy of particles which are emitted.

Figure 4.3 also shows that fluence of proton is 2.6 e^{-16}, whereas the fluence of proton in figure 4.4 is 2.55 e^{-16}. These graphs show small increase in the fluence of proton with increase in the energy of incident particles. The kinetic energy range of 0 to 2 GeV shows the maximum proton production while in the range 2 to 40 GeV relatively less number of proton are produced and above than 40 GeV graphs shows that particles are saturated.

Figures 4.5, 4.6, 4.7 and 4.8 show the same variation in the graph as mentioned above but these variations are small enough that can't be observe in usual way. one thing is common for all the above mentioned figure that fluence is the function of kinetic energy of secondary particle and in the energy range from 0 to 40 GeV shows same variation while from 40 to onward particles get saturated

Figures 4.10 and 4.11, the behavior of the proton production is different as discussed in early figures. These results are obtained due p-p interaction at TeV scale. In first case the energy of projectile is 2 TeV and 5 TeV for the next one. The energy spectrum of production of proton is different from others as discussed earlier. The shape of the curve is same it shows similar curve as the curves of figure 2.2 to .2.9, but there is big difference in the behavior of these curves because the range of scattered energy of emerging particles is from 0 to 900 GeV. The fluence recorded at two different energies 2 TeV and 5 TeV is 1.7 e^{-17} and 1.73 e^{-17} respectively. In the energy range 0 to 30 GeV, large number of protons is produced. As we go on increasing kinetic energy from 100 to 270 GeV shows fewer protons and above this scale shows saturation.

Hence, these results of energy spectrum give unique information to study the behavior of produced proton as a result of p-p collisions at different energy ranges.

Conclusions and Future Recommendations

In this research project the production of proton in p-p collisions at ultra-relativistic energies has been observed. It is seen that at these energies huge number of particles is formed having different characteristics. In the current research thesis, the transverse momentum spectrum and energy spectrums of proton produced as a result of p-p collisions has been observed, using ALICE offline computing framework and FLUKA software, transport codes of particles. As an outcome of this research work, it is concluded that the yields of produced proton amplify with increase in the energy of particles which are colliding. It is also set up that fluence of the produced proton reduces with increase in the kinetic energy of the particles.

In the extension of this work in future, at very high energies the production cross sections of protons and other charged particles produced in p-p collisions can also be measure. With varying angles the behavior of these charged particles can also study. It is also possible to test out the performance of protons and other 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 implemented in the continuation of this research.

Summary

ALICE is one of the six experiments working at LHC the world's largest particle accelerator positioned at Franco-Swiss border near Geneva with high energy range up to 7 TeV. In this research work, ALICE offline computing framework is used to study heavy ion collision which is one of its specialties although it is a general purpose detector. As a result of big bang large amount of Quark Gluon Plasma is produced in the nature, with the passage of get cool down to form the present state of matter in which we are living. In this study of p-p collision huge bulk of various particles having different characteristic such as transverse momentum (p_t) with their kinetic energies is observed. The simulated result obtained by using FLUKA and ALICE offline is based on the same simulation technique i.e. Monte Carlo simulation. By using these result proton production is observed at different ultra relativistic energy and these result are also discussed and commented. ALICE offline framework is based on ROOT and AliRoot analysis based on C++ scripting language. In these result large numbers of proton produced are observed by varying energies. Scattered energy of emerging particles is drawn along x-axis and their corresponding fluence along y-axis. The nature of curve obtained in the figure plotted above is observed carefully and precisely.

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APPENDIX-A

Input File

The input file of ALICE Offline Framework used to produce simulated data of p-p collisions at 900 GeV 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 "TParticlePDG.h"
// example of an analysis task creating p_t spectrum
// Authors: Panos Cristakoglou, Jan Fiete Grosse-Oetringhaus, Christian Klein-
Boesing
// Reviewd: A.Gheata (19/02/10)

Classinput (AliAnalysis TaskPtMC)
//____________________________________________________________________

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

```
// DefineInput and Output slots here
// Input slot # 0 works with a TChain
Define Input (0, TChain::Class( ) );
// Output slot # 0 writes into a TH1 container
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);
fHist->SetMarkerStyle (KFullCircle);

fHistPtProton = new TH1F("fHistPtProton", "P_{T} distribution of Protons", 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(fHistPt);
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++)
{
        if (!Track)
{
Printf ("ERROR: Could not retrieve track %d (mc loop)", iTracks);
Continue;
}
if (track-> M( )>0.9382 && track-> M( )<0.9384)
fHistPtProton->Fill(track->Pt( ));
fHistPt->Fill(track->Pt( ));
} // track loop

// Post Output data
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: Output list not available");
return;
}
fHistPt = dynamic_cast<TH1F*>(fOutputList->At(0));
        if (!fHistPt)
{
Printf ("ERROR: fHistPt not available");
return;
}
fHistPtProton = dynamic_cast<TH21F*>(fOutputList->At(2));
if (!fHistPtProton)
{
Printf ("ERROR: fHistPtProton not available");
return;
}
TCanvas*c1 = new TCanvas("AliAnalysisTaskPtMC","PtMC",10,10,510,510);
C1->cd(1)->SetLogy( );
fHistPtProton->DrawCopy ("Esame");
```