ABANT IZZET BAYSAL UNIVERSITY

THE GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES

A COMPARISON STUDY OF INDUCED EAS OF ULTRA HIGH ENERGY COSMIC RAYS FOR DIFFERENT PRIMARY PARTICLES

THESIS FOR THE DEGREE OF MASTER OF SCIENCE

NAMIK ÖZDEMİR

BOLU, JUNE 2016

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APPROVAL OF THE THESIS

A COMPARISON STUDY OF INDUCED EAS OF ULTRA HIGH ENERGY COSMIC RAYS FOR DIFFERENT PRIMARY PARTICLES submitted by **NAMIK ÖZDEMİR** in partial fulfillment of the requirements for the degree of Master in **the Department of Physics, Abant Izzet Baysal University** by,

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June 20, 2016

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Director, **Graduate School of Natural and Applied Sciences**

To my family

DECLARATION

I hereby declare that all information in this document has been obtained and presented in accordance with academic rules and ethical conduct. I also declare that, as required by these rules and conduct, I have fully cited and referenced all material and results that are not original to this work.

Namık ÖZDEMİR

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ABSTRACT

A COMPARISON STUDY OF INDUCED EAS OF ULTRA HIGH ENERGY COSMIC RAYS FOR DIFFERENT PRIMARY PARTICLES
THE DEGREE OF MASTER OF SCIENCE
NAMIK ÖZDEMİR
ABANT IZZET BAYSAL UNIVERSITY GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES
IN THE DEPARTMENT OF PHYSICS
(SUPERVISOR: PROF. DR. HALUK DENİZLİ)

BOLU, JUNE 2016

Cosmic rays consist of 87% of hydrogen (protons), 12% of helium and about 1% of heavier nuclei such as carbon, oxygen, silicon, iron etc. Primary cosmic particles interact with the molecules of the atmosphere and produce an Extensive Air Shower (EAS). CORSIKA (COsmic Ray SImulations for KAscade) is a detailed Monte Carlo program to study the evaluation and properties of EAS in the atmosphere. In this study, We analyzed unthinning data set of CORSIKA for different primary particles (proton, carbon and iron) at energy of $5x10^{16}$ eV. Size of the shower core and momentum dependence of the particles produced by the shower in observation level are studied. The affect of different energy cuts for each particles of simulated EAS is also discussed. Simulation is done with high energy hadronic model QGSJET (Quark Gluon String model with JETs) and low energy hadronic model GHEISHA which is a very refined model with many details of nuclear effects. Motivation of the study is to understand the percentage of the contributions of observables (e, gamma and muon) in the data taken with the prototype at Karlsruhe Institute of Technology (KIT). This prototype is developed for TAUWER (The TAU-neutrino multitoWER Detector Experiment) project.

KEYWORDS: Cosmic rays, CORSIKA, Primary particles, Simulation

ÖZET

YÜKSEK ENERJİLİ KOZMİK IŞINLARIN KAPSAMLI DUŞ YAĞMURLARI İLE UYARILAN FARKLI BİRİNCİL PARÇACIKLARIN KARŞILAŞTIRILMASI ÇALIŞMASI
YÜKSEK LİSANS
NAMIK ÖZDEMİR
ABANT İZZET BAYSAL ÜNİVERSİTESİ FEN BİLİMLERİ ENSTİTÜSÜ
FİZİK ANABİLİM DALI
(TEZ DANIŞMANI: PROF. DR. HALUK DENİZLİ)

BOLU, HAZİRAN - 2016

Kozmik ışınların %87`i proton, %12`si helyum ve kalan %1`ise karbon, oksijen, silikon ve demir gibi daha ağır çekirdeklerden oluşmaktadır. Birincil kozmik parçacıklar atmosferde bulunan moleküller ile etkileşime girerler ve kapsamlı duş yağmurları üretirler. CORSIKA, atmosferde oluşan kapsamlı duş yağmurlarının özelliklerini ve değerlendirilmesi incelemek için oluşturulan detaylı bir Monte Carlo programıdır. Bu çalışmada, $5x10^{16}$ eV enerji seviyesindeki farklı birincil parçacıklar için unthin CORSIKA datası analiz edildi. Gözlem düzeyinde duş yağmurları ile üretilen parçacıkların momentum ilişkisi ve çekirdekten uzaklığı incelenmiştir. Ayrıca, kapsamlı duş yağmurlarınn simülasyonunda her bir parçacık için farklı değerlerde enerji kesimlerinin etkiside tartışıldı. Simülasyon, yüksek enerjili hadronik model QGSJET ve nükleer etkilerinin birçok detayı konusunda çok iyi seviyede olan düşük enerjili hadronik model GHEISHA ile yapılmıştır. Çalışmanın motivasyonu, Karlsruhe Teknoloji Enstitüsü (KIT)`den alınan portotip ile elde edilen verilerin (elektron, gama ve müon) gözlemlenmesine katkı sağlamaktır. Bu portotip TAUWER projesi için geliştirilmiştir.

ANAHTAR KELİMELER: Kozmik ışınlar, Birincil parçacıklar, Simülasyon

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LIST OF ABBREVIATIONS AND SYMBOLS

CR	**:** Cosmic Ray
EAS	**:** Extensive Air Shower
TAUWER	**:** The TAU-neutrino multitoWER Detector Experiment
KIT	**:** Karlsruhe Institute of Technology(KIT)
CORSIKA	**:** COsmic Ray SImulations for Kascade
PAO	**:** Pierre Auger Observatory
SF	**:** Surface Detector
FD	**:** Flfluorescence Detector
MeV	**:** Mega electron volt
St	**:** Station

ACKNOWLEDGEMENTS

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THEORETICAL BACKGROUND

First of all, when high energy cosmic ray particles penetrate the Earth atmosphere they interact and generate a cascade of secondary particles, that is called Extensive Air Showers (EAS). The only way to get information on these particles is to study EAS cascades which they initiate. Some cosmic rays have been observed with energies as high as 10^{20} eV. Although modern cosmic ray physics is more similar with astrophysics, dealing with the origin and composition of cosmic rays, early cosmic ray physics was more closely similar with elementary particle physics. Moreover, when a cosmic ray enters the atmosphere it collides with the nucleus of an air atom, producing a number of secondary particles. These go on to make further collisions, and the number of particle grows. In the end, the energy of the shower particles is cut down to the point where ionization losses to overcome and their number start to falling. EAS depends on the energy and type of the incident primary particle. The number of particles in EAS as a function of atmospheric depth is particularly related to the type and energy of the primary particle which can be simulated by CORSIKA code. This gives rise to many secondary particles of high energies in the atmosphere creating conditions favorable to creating meta- and unstable particles. A realistic air shower simulation system which includes electromagnetic interaction algorithms and the hadronic model is QGSJET. The simulation was performed for different primary particles (proton, carbon and iron nuclei) at the high energy range of 5×10^{16} eV for different zenith angle of 0^0.

AIM AND SCOPE OF THE STUDY

This thesis discusses general questions related to the properties of cosmic rays with energy of 5×10^{16} eV. The origin and nature of the cosmic rays with the high energies is one of the most enigmatic questions in physics. Different primary particles are measured indirectly from the secondaries in the extensive air showers developing in the Earth`s atmosphere. Thesis starts with an overview of the basics of cosmic ray knowledge, such as energy, energy spectrum, interactions and review of ongoing experiments. In the following chapter further details of the simulation processes of shower is discussed. The analysis of the profile of the shower in observation level is presented in chapter three. The last chapter summarizes the work done in the thesis and concluded.

1. INTRODUCTION

A general picture about the basics of cosmic rays is given in this chapter. Cosmic rays developed from high altitude space missions to the ground based detection of ultra high energy particles.

1.1 What is Cosmic Ray

Cosmic rays are high energy particles traveling through the universe, some of which reach the Solar System and enter the Earth`s atmosphere. These particles are relativistic ionized atomic nuclei and have a large range of energies.

1.2 History of Cosmic Ray

Victor Hess discovered cosmic rays in 1912 in a series of high altitude balloon lights. In that period, Barcikowski et al. (2011) suggested that physicists knew of an anomalous radiation that would discharge electroscopes, early instruments used to measure electric charge. The source of this radiation was unknown, and scientists speculated whether the source of the radiation was terrestrial or extra terrestrial in origin. Taking electroscopes on manned balloon flights in excess of 5 km in altitude, Hess found that the rate of these discharges increased with altitude, showing that the radiation was coming from space. The actual name “cosmic ray” was coined ten years later by Robert Andrews Millikan in 1925.

1.3 Cosmic Ray Energy Spectrum

Cosmic rays are measured with a large range of energies, from as low as 10^9 eV to as high as 10^{20} eV in a steady power law in energy with a spectral index of close to -3 across the entire range of energies. Figure 1 shows the all particle spectrum as measured by a variety of cosmic ray experiments. Figure 1.1 shows the cosmic ray spectrum above 10^{17} eV (Barcikowski, 2011, p. 2).

The steady E^{-3} power law gives rise to large differences in the flux of cosmic rays. At low energies, cosmic rays are very numerous. Indeed, secondary muons

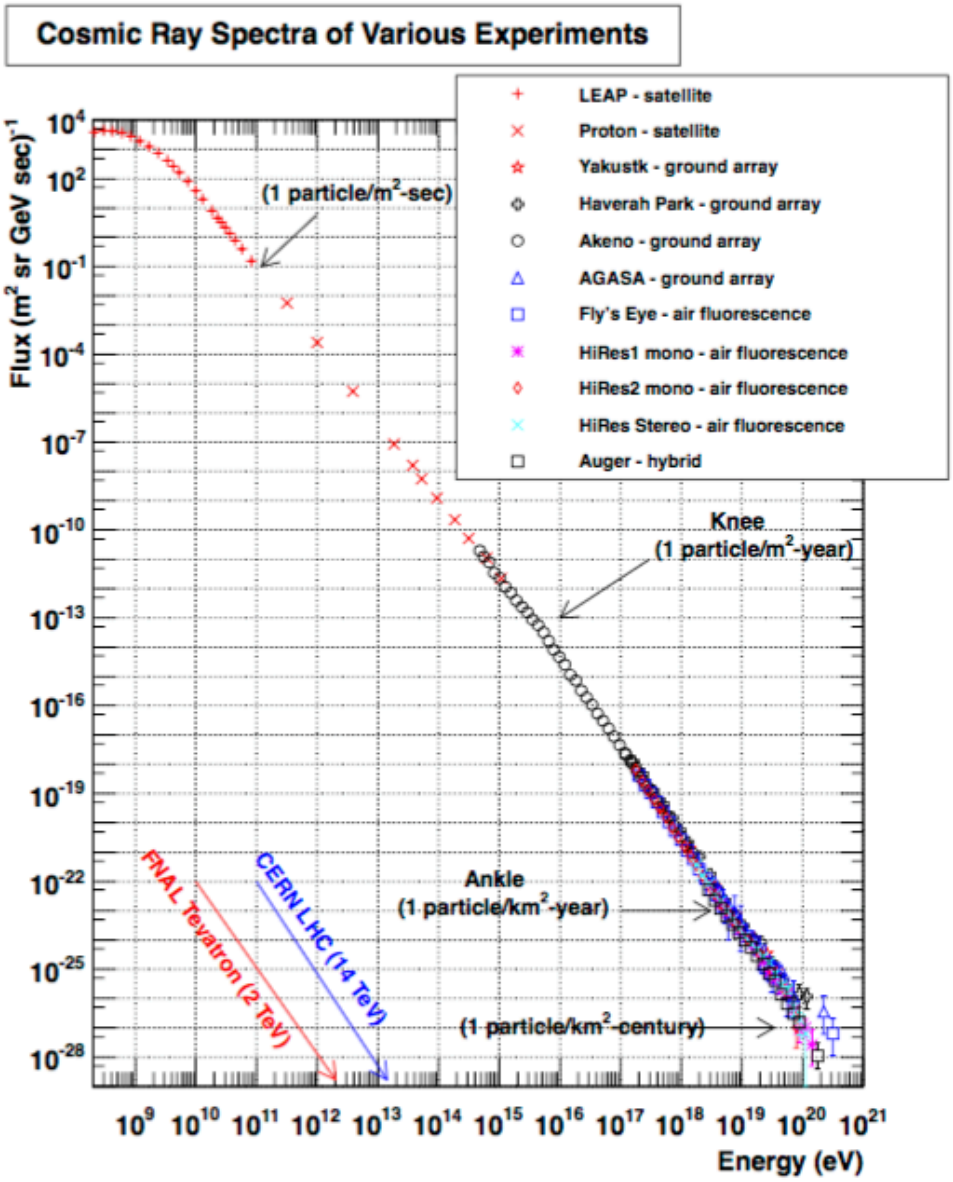

Figure 1.1. The all particle cosmic ray spectrum as measured by various experiements.

from low energy cosmic rays are a regular background for ground array cosmic ray detectors. On the other hand, above $10^{19.5}$ eV, cosmic rays are rare, having a flux of approximately 1 $km^{-1}year^{-1}$. The orders of magnitude differences in cosmic ray flux require dramatically different methods of cosmic ray detection. At energies below 10^{15} eV , the flux is large enough that direct detection methods are possible. Such an

experiment would involve attaching a particle detector to a high altitude balloon or satellite. Much above this 10^{15} eV , the low flux of cosmic rays requires the use of the cosmic ray`s interaction in the atmosphere or the extensive air shower (EAS). When a cosmic ray enters the atmosphere, it interacts with oxygen and nitrogen nuclei and creates a cascade of secondary particles. This air shower will reach approximately one particle per GeV at its maximum. (Barcikowski, 2011, p. 2).

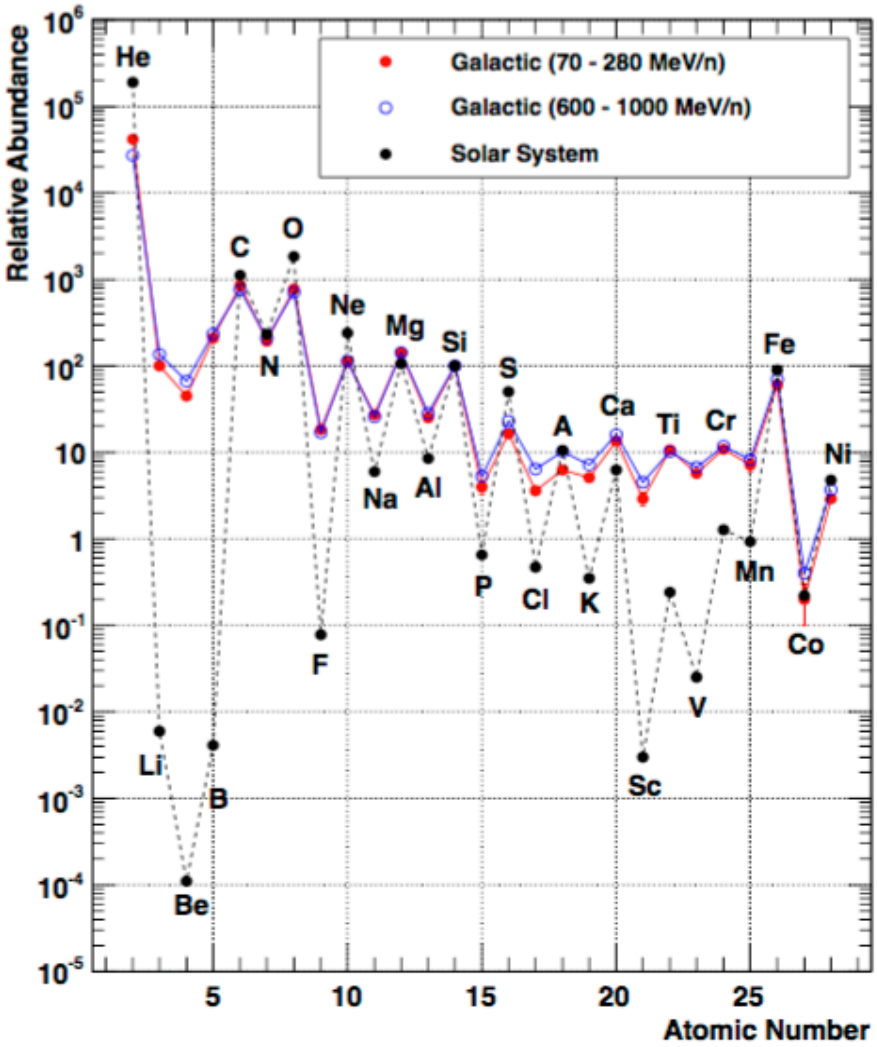

Figure 1.2. The relative abundances of cosmic rays measured at Earth compared to the Solar system abundances.

The main features of the cosmic ray composition at low energies ($<10^{14}$ eV) were known by 1950 and still remain unclear at higher energies. The relative abundances of cosmic rays are similar to the abundances of common elements in the Solar system, as shown in figure 1.2 (Barcikowski, 2011, p. 14). This consistency

indicates that the composition of cosmic ray material injected into the interstellar medium (ISM) is very similar to that of the nebula that formed the Solar system. On the contrary a striking difference can be seen between these two compositions. Chemical elements including Li, Be, B, F, Sc, Ti, V, Cr, Mn which are rare in the Solar system are many orders of magnitude more abundant in the cosmic rays. Since these elements are essentially absent as end products of stellar nucleosynthesis, they are generated as spallation products of abundant cosmic rays interacting with hydrogen or helium nuclei in the interstellar gas. For instance, Li, Be, B isotopes are mainly created from fragmented progenitors C, N and O nuclei (Juan Wu, 2012, p.6).

The charged secondary particles in the air shower excite nitrogen gas in the atmosphere, which then emit ultra-violet (UV) photons via fluorescence. Nitrogen flfluorescence can be measured using telescopes sensitive in the UV. Additionally, secondary particles may be detected directly with particle counters on the ground. This phenomena was discovered by Pierre Victor Auger in 1938, by measuring coincident hits on particle counters placed a few meters apart. Auger made estimates of cosmic ray energies of greater than 10^{11}eV . Close inspection of Figure XX reveals subtle features in the cosmic ray spectrum. There are two steepenings, known colloquially as the "knee" and the "second knee" at 10^{15} eV and 10^{17} eV respectively. There is also a softening above $5\times10^{18.5}$ eV known as the "ankle" and a sharp cutoff after $5\times10^{19.5}$ eV. Each of these features has important implications for the sources of cosmic rays, their composition, and their propagation both inside and outside the Galaxy (Barcikowski, 2011, p. 3).

1.4 Extensive Air Shower

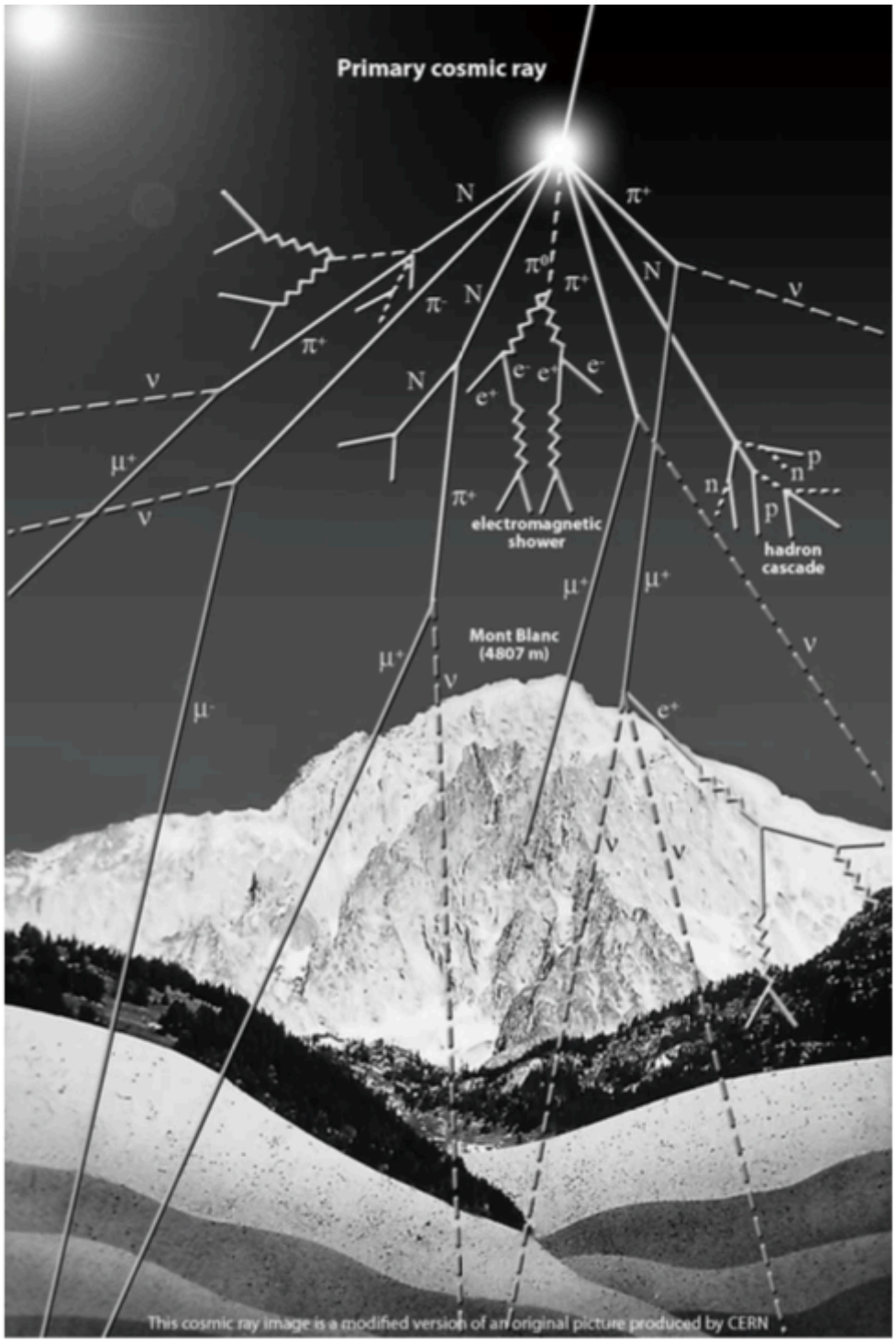

Figure 1.3. Impression of an air shower induced by a (primary) cosmic ray. When air showers were discovered by Auger, pions were not yet known.

Above ~ 10^{14} eV, the flux of cosmic rays decreases to the point where direct detection of the primary particles is not statistically visible. Above this energy the CRs must be detected indirectly, by observing their interactions with the Earth's atmosphere. The first interaction will typically produce a shower of pions, which carry away about half of the total energy (depending on the exact elasticity of the interaction), while the remnant CR primary continues to interact again. The development of the shower can be imagined by following the behaviour of the pions, produced in the first few interactions (Newton, 2005, p. 7-8).

Depending on the energy of the cosmic ray that initiated the cascade, air showers can consist of millions or even billions of particles such as electrons, positrons, pions, muons, gammas and neutrinos. An impression of an air shower is shown in Figure 1.3 (Harmsma, 2011, p.5).

According to Newton (2005), Monte Carlo simulations can be performed to model the development of EASs, but the lack of knowledge of the physical processes which occur at high energies, leads to discrepancies between different models. Studies of particle cross-sections and the multiplicity of secondaries, have been carried out in accelerators up to centre-of-mass energies equivalent to fixed target energies of 10^{15} eV (in the rest frame of one particle), and the results extrapolated to energies of ~ 10^{20} eV, but some assumptions must still be made. (Newton, 2005, p. 8-9)

The better understanding of hadronic interactions led to improvements in air shower models, which in turn allowed for a better interpretation of cosmic-ray data. Detection techniques from accelerator physics were applied to high-altitude balloon experiments, allowing a direct measurement of cosmic-ray composition at the top of the atmosphere. These composition results were then compared with the composition of matter at possible acceleration sites in the cosmos (Harmsma, 2011, p. 6).

1.5 On going Experiments

1.5.1 Ground-based

1.5.1.1 The Karlsruhe Shower Core and Array Detector (KASCADE)

The KArlsruhe Shower Core and Array DEtector-Grande (KASCADE-Grande) is an extensive air shower experiment to study the cosmic-ray primary composition and hadronic interactions in the energy range E = 10^{16} - 10^{18} eV. The experiment is situated on site of the Forschungszentrum Karlsruhe in Germany. It measures simultaneously the electromagnetic, muonic, and hadronic components of extensive air showers. As an extension of the former KASCADE experiment running successfully since 1996, KASCADE Grande was built by reassembling 37 stations of the former EAS-TOP experiment basically the electromagnetic detectors running between 1987 and 2000 at Campo Imperatore, Grand Sasso Loboratories, Italy. It basically consists of three major components; a scintillator array, a central detector system with a hadron calorimeter, and a large area muon tracking 4. Its schematic layout is shown in figure 1.5 and appearance from top in figure 1.4. For ground-based experiments astrophysically relevant parameters like energy, mass, or direction of incoming cosmic ray particles have to be deduced from the particle distributions in the EAS which they initiate in the atmosphere. Therefore, as many different observables as possible have to be measured simultaneously from which the properties of the primaries have to be calculated. (KASCADE – Grande, 2015).

Detector consists of the field array (200m x 200m) consists of 252 detector stations arranged on a rectangular grid with a distance of 13 meters to each other. 16 (resp. 15) of the stations form a so-called cluster with an electronics container in the center and which act as an independent shower experiment. In the middle of the array one can see the building with the KASCADE central detector.

Figure 1.4. View from South-West on the KASCADE Array

In each station there are up to four electron/gamma-detectors and one muon detector under a iron lead absorber of about 20 attenuation lengths. The absorber serves as shielding against the electomagnetic component of an extensive air shower. Only muons with energies greater than 250MeV are able to penetrate the absorber. The effective detection area per station is about 3.2 x m^2 for both detector types (Schellart, 2006, p.9).

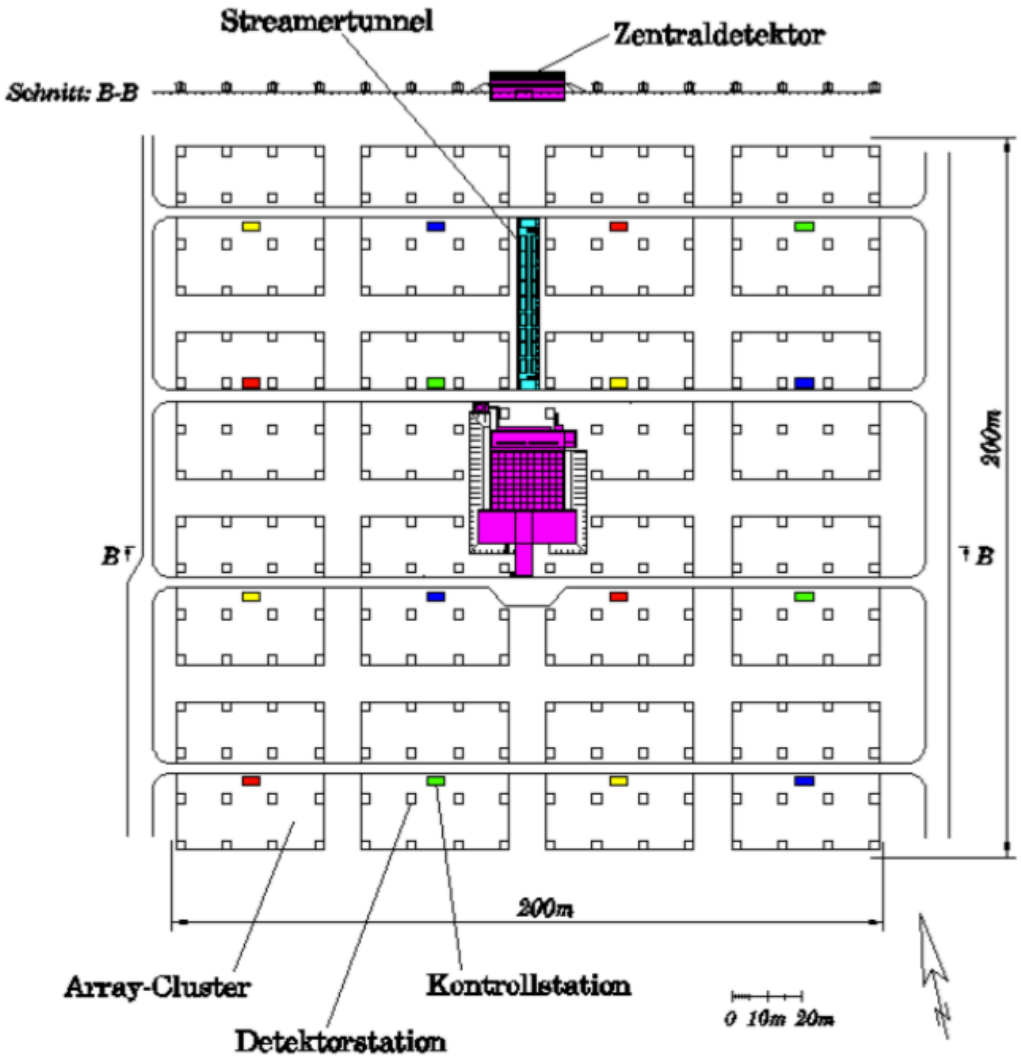

Figure 1.5. A Schematic Layout of KASCADE-Grande

1.5.1.2 Pierre Auger Observatory

The pierre Auger Observatory is the world's largest Physics experiment for the study of cosmic ray detector. The Observatory is located in the southern hemisphere in western Argentina province of Mendoza close to the city of Malargue. And it covers an semi-desert area of 3000 square kilometres in figure 1.6. The

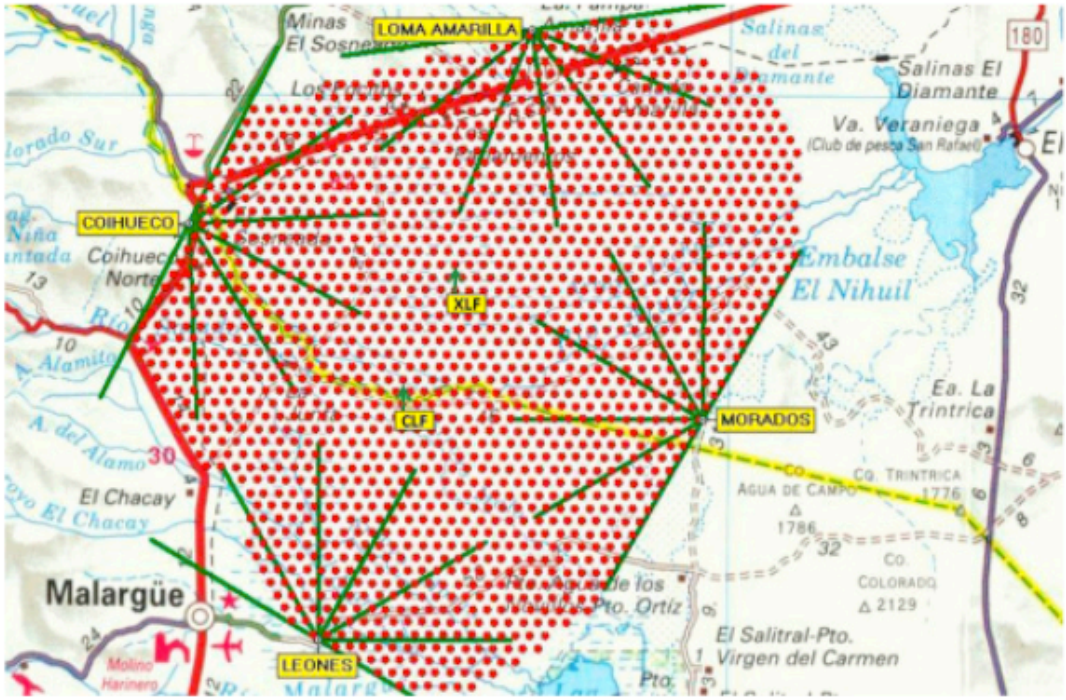

Figure 1.6. Each dot corresponds to one of the 1660 surface detector stations. The four fluorescence detector enclosures are shown, each with the 3 degree field of view of its six telescopes. Also shown are the two laser facilities, CLF and XLF, near the Observatory

Purpose of the experiment is to study cosmic rays with the highest energy. Cosmic rays with this energy are so rare that passes through an area of one square kilometer every 100 years. For this reason, studying those cosmic rays include covering extremely large areas. When a cosmic particle strikes the Earth's atmosphere an altitude at 10-20 kilometers. It produces a shower of particles, which in turn produce billions of other particles at lower energies, which are dispersed in the atmosphere at the speed of light. A small proportion of these particles reach the detectors on Earth

and produce a signal whose intensity increases with their quantity. As well, the billions of particles produced while travelling through the atmosphere cause an extremely small quantity of light to be emitted.

The simulation of detector signals proceeds in two steps. First, showers of typically 10^{10} particles for Ultra High Energy Cosmic Ray (UHECR) energies are simulated with the 3D simulation program CORSIKA. It uses different models of hadronic interactions for high (E_{lab} above 80 GeV) and low energy (E_{lab} below 80 GeV) intervals (Jakub Vicha and Jiri Chudoba, 2015).

According to one of the last research paper, Jakub Vicha and Jiri Chudoba et al. (2015) of this experiment an upgrade of the Pierre Auger Observatory with muon detectors is planned to be built in the future. Reliable determination of the mass composition, especially at the highest energies, with large enough statistics seems to be the crucial point in further studies of UHECR open questions (origins of the spectrum features, UHECR sources, lack of muons in MC simulations). Measurement of the muon component with a large surface array (full duty cycle) could be one way to answer these questions. However, the observed inconsistency of model predictions and measured data for the muon component is an issue that needs to be fixed simultaneously. Accompanying measurements with more types of muon detectors combined with the measurement of the electromagnetic component could be not only beneficial, but also necessary.

The Pierre Auger Observatory has made key measurements of the highest energy cosmic rays. Cosmic ray showers with zenith angle < 60° are defined as vertical showers, while those with 60° < zenith angle < 80° are defined as horizontal showers (The Pierre Auger Collaboration, 2015, p. 10).

There are two complementary techniques for the simultaneous observation old cosmic ray shower of this experiment. And the surface an air flfluorescence detectors were designed to accomplish complementary results of air showers created by ultra high energy cosmic rays. Also, Cherenkov surface detector was established and communications with data using wireless technology for each water SD. Besides, air flfluorescence telescopes record air shower development in the atmosphere above the surface array. There are four air fluorescence sites on the perimeter of the array, each

with six telescopes. Using these analysis techniques was new. Also, the observatory was serving as a test background for advanced detector techniques for the next generation of cosmic ray experiments (The Pierre Auger Collaboration, 2015, p.9).

Figure 1.7. The fluorescence detector enclosure Los Leones (top) and a surface detector station (bottom).

Figure 1.6 shows examples of the fluorescence detector (left) and a surface (right) detector elements. This area is generally at, with detectors located at altitudes between 1340 m and 1610m. Hence, the composition measurements could be interpreted as an evolution from light to heavier nuclei if current hadronic interaction models describe well the air shower physics (The pierre Auger Collaboration, 2015, p.9).

According to the last published paper, They ask what the following questions of their own, the Pierre Auger Collaboration is planning an upgrade to the Observatory to allow a definition of the primary composition on an event by event basis at the highest energies. Moreover, the required electron-muon discrimination in the surface detector stations will be achieved by installing a $4\times m^2$ scintillation detector on top of each water Cherenkov detector. Once approved, the upgrade is expected to be completed by 2018 with Observatory operation through 2025. (The pierre Auger Collaboration, 2015, p.).

1.5.1.3 IceCube

IceCube, the South Pole neutrino observatory, is a cubic-kilometer particle detector made of Antarctic ice and located near the Amundsen-Scott South Pole Station. It is the first detector, designed to observe the cosmic rays from deep with the South Pole. IceCube project in Antarctica, use neutrinos from the sky to search for cosmic sources of some of the highest-energy particles in nature. It is an international high-energy neutrino observatory being built and installed in the clear deep ice below the South Pole Station. It uses the Antarctic ice shield to detect high energy neutrinos and discover new neutrino sources in the sky. Scientists who an international group of responsible for the scientific research improve the IceCube collaboration. They are explored working on events which is exploding stars, gamma ray bursts and cataclysmic phenomena involving black holes and neutron stars (Wouter Van De Pontsele, 2015, p.5).

As shown figure 1.8, IceCube consists of 5160 digital optical modules (DOMs), each with a ten-inch photomultiplier tube and associated electronics. The DOMs are connected to vertical strings, frozen into 86 boreholes, and arrayed over a cubic kilometer from 1450 meters to 2450 meters depth. The strings are deployed on a hexagonal grid with 125 meters spacing and hold 60 DOMs each. The vertical separation of the DOMs is 17 meters. Eight of these strings at the center of the array were deployed more compactly, with a horizontal separation of about 70 meters and a vertical DOM spacing of 7 meters. This denser configuration forms the Deep Core

subdetector, which lowers the neutrino energy threshold to about 10 GeV, creating the opportunity to study neutrino oscillations (ICECUBE official page).

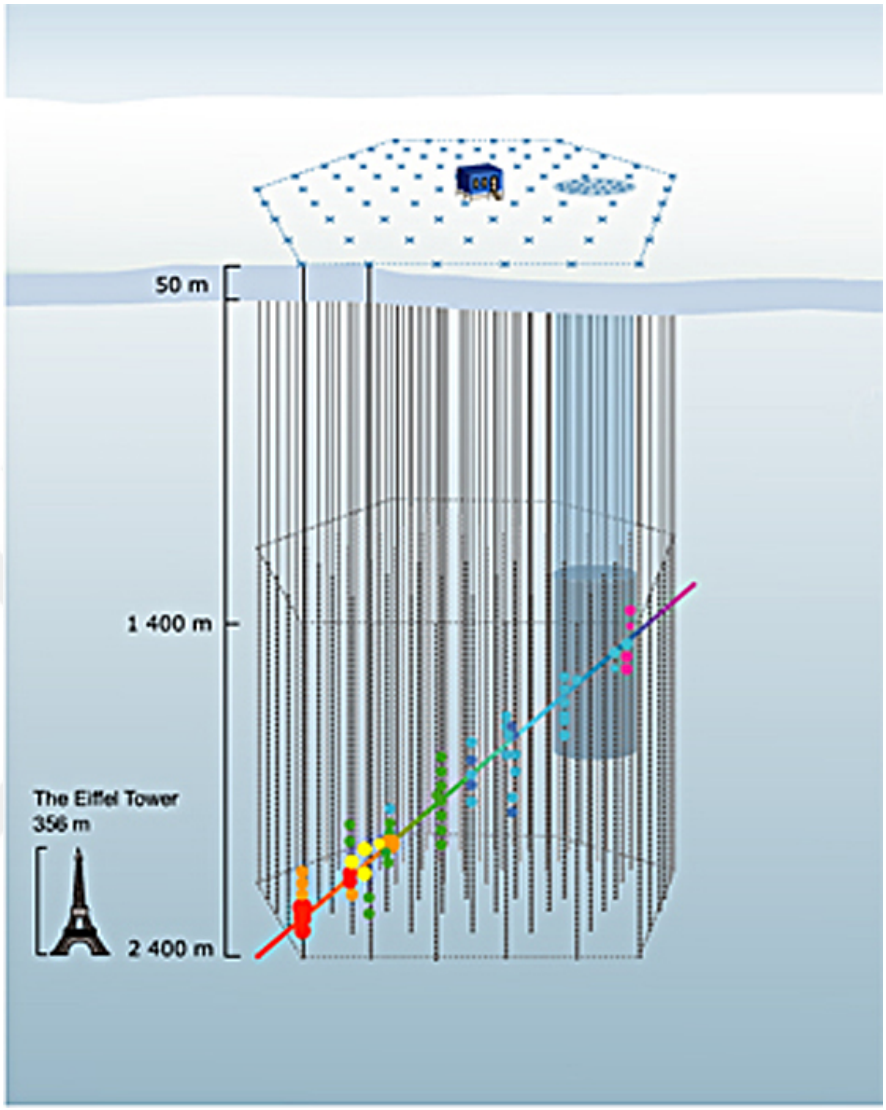

Figure 1.8. Schematic Layout of IceCube.

Neutrinos obviously are not observed directly but when they happen to interact with the ice. They produce electrically charged secondary particles that in turn emit Cherenkov light, as a result of travelling through the ice faster than light travels in ice. On the other hand, cosmic rays charged particles, which means that their path band and shift as they pass through magnetic fields in space. So, that makes it difficult to trace their origins.

1.5.2 Satellite

1.5.2.1 Payload for Antimatter Matter Exploration and Light-nuclei Astrophysics (PAMELA)

Figure 1.9. The PAMELA instrument.

The PAMELA (a Payload for Antimatter Matter Exploration and Light-nuclei Astrophysics) experiment is a satellite-borne apparatus designed to study charged particles in the cosmic radiation with a particular focus on antiparticles (antiprotons and positrons). PAMELA is installed inside a pressurized container attached to a Russian Resurs DK1 earth observation satellite that was launched into space by a Soyuz-U rocket on June 15, 2006 from the Baikonur cosmodrome in Kazakhstan. The satellite orbit is elliptical and semipolar, with an altitude varying between 350 km and 600 km, at an inclination of 70°. The PAMELA mission is devoted to the investigation of dark matter, the baryon asymmetry in the Universe, cosmic ray generation and propagation in our galaxy and the solar system, and studies of solar modulation and the interaction of cosmic rays with the earth`s magnetosphere. The primary scientific

goal is the study of the antimatter component of the cosmic radiation by searching for evidence of dark matter particle annihilations by precisely measuring the antiparticle (antiproton and positron) energy spectra, searhing for antinuclei, and testing cosmic-ray propagation models through precise measurements of the antiparticle energy spectrum and precision studies of light nuclei and their isotopes.

The PAMELA apparatus is composed of a time of flight system (ToF: S1, S2,S3), a magnetic spectrometer, an anticoincidence system (CARD, CAT, CAS), an electromagnetic calorimeter, a shower tail catcher scintillator (S4), and a neutron detector (Figure 1.9). Details of the appratus discussed (Picozza, 2014). The figure 1.10 shows a summary of the most significative and recent PAMELA measurements.

Results on the antiparticle component of the cosmic radiation obtained from PAMELA collaboration are discussed driani, 2014 positron energy spectrum and positron fraction were measured from 400 MeV up to 200 GeV revealing a positron excess over the predictions of commonly used propagation models interpreted either as evidence that the propagation models should be revised or in terms of dark matter annihilation or a pulsar contribution. The antiproton spectrum was measured over the energy range from 60 MeV to 350 GeV. The antiproton spectrum is consistent with secondary production and significantly constrains dark matter models. The energy spectra of protons and helium nuclei were measured up to 1.2 TeV. The spectral shapes of these two species are different and cannot be described well by a single power law. For the first time the electron spectrum was measured up to 600 GeV complementing the information obtained from the positron data. Nuclear and isotopic composition was obtained with unprecedented precision(Adriani O. vd., 2014).

The variation of the low energy proton, electron and positron energy spectrawas measured from July 2006 until December 2009 accurately sampling the unusual conditions of the most recent solar minimum activity period (2006-2009) (Picozza, 2014). Low energy particle spectra were accurately measured also for various solar events that occurred during the PAMELA mission.

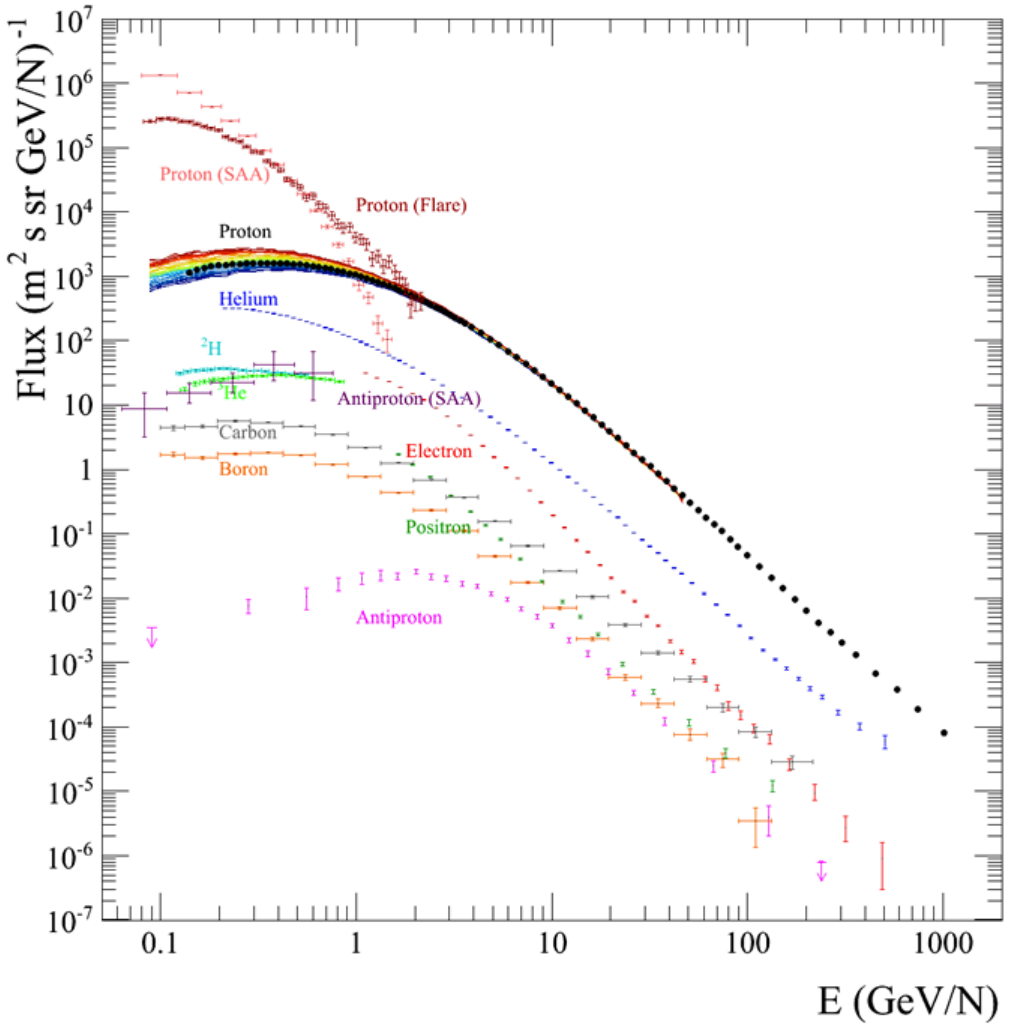

Figure 1.10. Most recent result from PAMELA measurements.

The Earth`s magnetosphere was studied measuring the particle radiation in different regions of the magnetosphere. Energy spectra and composition of sub-cutoff and trapped particles were obtained. For the first time a belt of trapped antiprotons was detected in the South Atlantic Anomaly region. The flux was found to exceed that for galactic cosmic ray antiprotons by three order of magnitude.,

1.5.2.2 The Alpha Magnetic Spectrometer (AMS)

AMS is the only major particle physics experiment on the ISS. In its first four years on orbit, AMS has collected more than 60 billion cosmic ray events (electrons, positrons, protons, antiprotons, and nuclei of helium, lithium, boron, carbon, oxygen and etc.) up to multi-TeV energies(Ting and Zuccon, 2015). The experiment began on

May 19, 2011, when space shuttle Endeavour delivered the AMS to the International Space Station, ISS for short. To distinguish if the observed new phenomena are from dark matter, measurements are underway by AMS to determine the rate at which the positron fraction falls beyond its maximum, as well as the measurement of the antiproton to proton ratio. As seen in Figure 1.11, the antiproton to proton ratio stays constant from 20 GeV to 450 GeV kinetic energy. This behavior cannot be explained by secondary production of antiprotons from ordinary cosmic ray collisions. Nor can the excess of antiprotons be easily explained from origin (Cern, 2015).

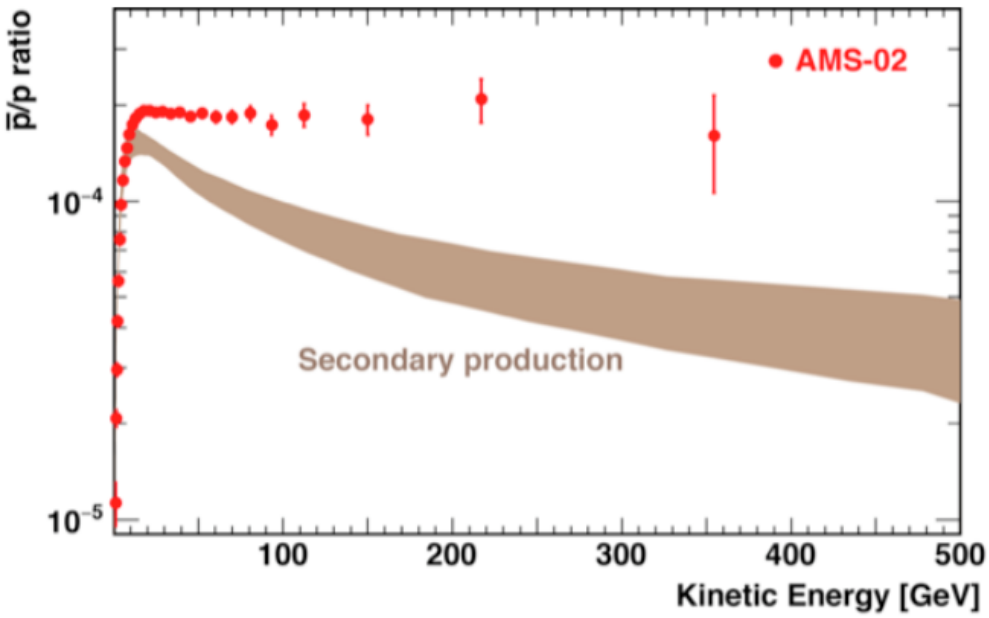

Figure 1.11. Antiproton to proton ratio measured by AMS. As seen, the measured ratio cannot be explained by existing models of secondary production.

The AMS results on the positron fraction, the electron spectrum, the positronspectrum, and the combined electron plus positron spectrum are consistent with dark matter collisions and cannot be explained by existing models of the collision of ordinary cosmic rays. There are many new models showing that the results may be explained by new astrophysical sources (such as pulsars) or new acceleration and propagation mechanisms (such as supernova remnants).

The latest AMS measurements of the positron fraction, the antiproton/protonratio, the behavior of the fluxes of electrons, positrons, protons, helium, and other nuclei provide precise and unexpected information. The accuracy

and characteristics of the data, simultaneously from many different types of cosmic rays, require a comprehensive model to ascertain if their origin is from dark matter, astrophysical sources, acceleration mechanisms or a combination.

The Alpha Magnetic Spectrometer looks for dark matter, antimatter and missing matter from a module on the International Space Station. The question of the nature of dark matter, the cause of matter-antimatter asymmetry in the universe, or the structure of matter in neutron stars are all related to the basics of physics. As well, AMS has the potential to provide important contributions to these topics in the next few years and to fundamentally change our worldview (AMS Official Page).

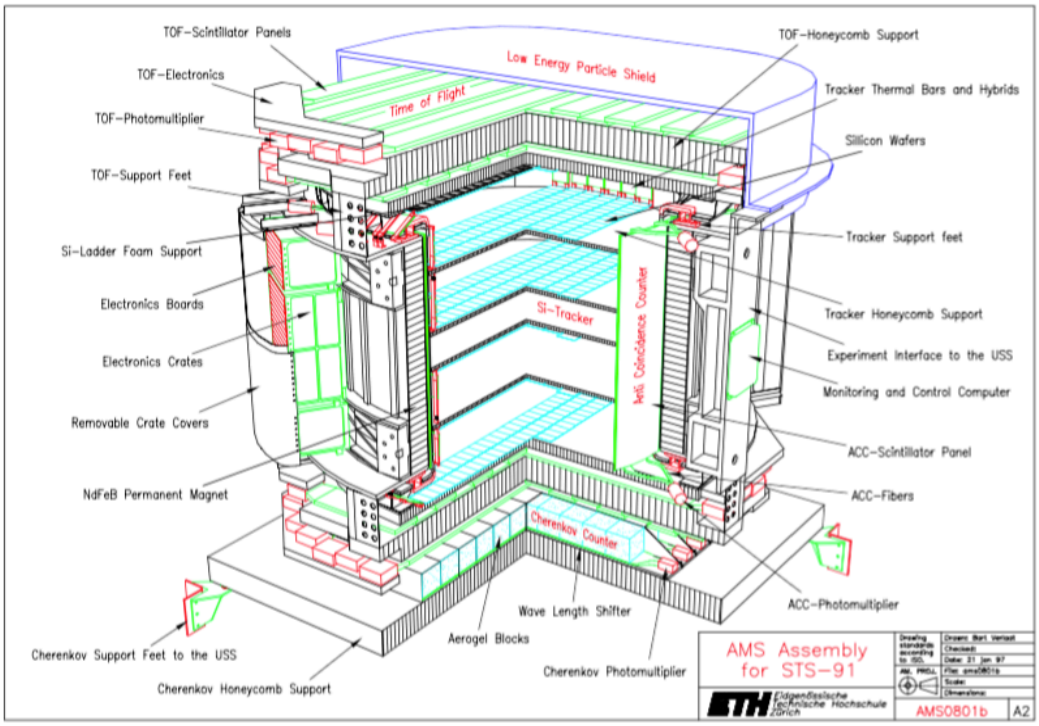

Figure 1.12 A Schematic Layout of AMS.

According to M. Aguilarof vd. (2013) suggested that a precision measurement by the Alpha Magnetic Spectrometer on the International Space Station of the positron fraction in primary cosmic rays in the energy range from 0.5 to 350 GeV. The very accurate data show that the positron fraction is steadily increasing from 10 to 250 GeV, but, from 20 to 250 GeV, the slope decreases by an order of magnitude. The positron fraction spectrum shows no fine structure, and the positron to electron ratio shows no observable anisotropy. Together, these features show the existence of new physical

phenomena. These observations show the existence of new physical phenomena, whether from a particle physics or an astrophysical origin. A Schematic Layout of AMS is in figure 1.12.

As an external payload on the ISS through at least 2024, AMS will continue to collect and analyze an increasing volume of statistics at highest energies which, combined with indepth knowledge of the detector and systematic errors, will produce valuable insight(AMS Official web page).

1.5.2.3 Fermi Gamma-ray Space Telescope

NASA's Fermi Gamma-ray Space Telescope is a powerful space observatory that opens a wide window on the universe. Gamma rays are the highest-energy form of light, and the gamma-ray sky is spectacularly different from the one we perceive with our own eyes. Fermi enables scientists to answer persistent questions across a broad range of topics, including supermassive black-hole systems, pulsars, the origin of cosmic rays, and searches for signals of new physics.

More technically, Fermi observes light in the photon energy range of 8000 electronvolts (8 keV) to greater than 300 billion electronvolts (300 GeV). An electronvolt is a unit of energy close to that of visible light; Fermi observes photons with energy levels thousands to hundreds of billions of times greater than what the unaided eye can see.

After five years of operations, on Aug. 11, 2013, Fermi entered an extendedphase of its mission, a deeper study of the high-energy cosmos. This is a significant step toward the science team's planned goal of a decade of observations, ending in 2018 on figure 2.13.

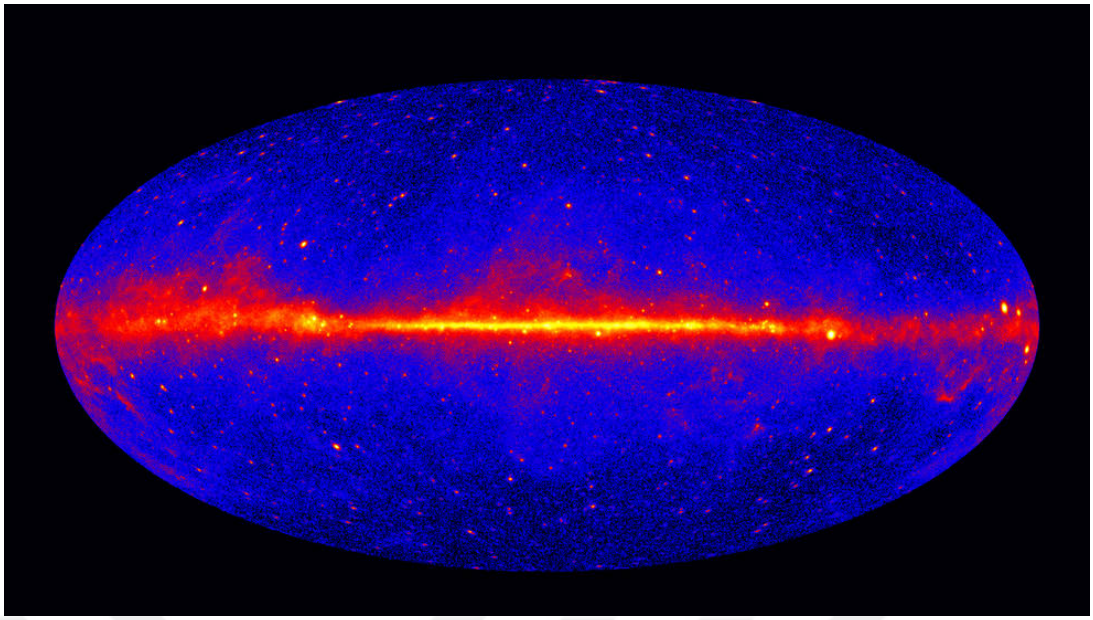

Figure 1.13. This view shows the entire sky at energies greater than 1 GeV on five years of data from the LAT instrument on NASA's Fermi Gamma-ray Space Telescope. Brighter colors indicate brighter gamma-ray sources.

2. MATERIALS AND METHODS

2.1 Simulation Tool: Cosmic Ray Simulations for Kascade (CORSIKA)

CORSIKA (COsmic Ray SImulations for KAscade) is a detailed Monte Carlo program to study the evolution of EAS in the atmosphere initiated by photons, protons, nuclei, or any other particle.

A program widely used for simulation of extensive air showers is CORSIKA(COsmic Ray SImulations for KAscade). It provides detailed information on shower content and development depending on the primary particle. Protons, light nuclei up to iron, photons, and many other particles can be treated as primaries. The particles are tracked through the atmosphere until they undergo reactions with the air nuclei or - in the case of instable secondaries - decay. CORSIKA was originally developed to perform simulations for the KASCADE experiment which is mentioned in chapter 1 at Karlsruhe and has been refined over the past years. It has developed into a tool that is used by many groups. The hadronic interactions at high energies may be described by five reaction models alternatively: The VENUS, QGSJET, and DPMJET models are based on the Gribov-Regge theory, while SIBYLL is a minijet model. Hadronic interactions at lower energies are described either by the more sophisticated GHEISHA interaction routines or the rather simple ISOBAR model. In particle decays all decay branches down to the %1 level are taken into account (D. Heck, vd. 1998, p. 2).

The CORSIKA code has originally been developed on the basis of three well established program systems. The first was written in the 1970s by Grieder. Its general program structure has been adopted in CORSIKA and its ISOBAR routines, a simple hadronic interaction model, may be used as a quick alternative for the hadronic interactions at low energies. The second part, the interaction generator HDPM, was developed by Capdevielle inspired by the Dual Patron Model. It describes the hadronic interactions of protons at high energies in good agreement with the measured collider data. The third program deals with the simulation of the electromagnetic part of an air shower. We incorporated the code EGS4 used successfully in the detector simulation

of particle physics experiments. It was slightly modified to the requirements of air shower simulations. These programs were merged together and formed the first version of CORSIKA in 1998 (D. Heck, vd. 1988, p.2).

2.2 Physics

2.2.1 Hadronic Interactions

Hadronic interactions are simulated within CORSIKA by several models depending on energy. If the energy is high enough, the interaction is treated alternatively with one of the models VENUS , QGSJET, DPMJET, SIBYLL, or HDPM. The former are well documented and the interested reader is refered to the literature. The high energy models reach their limit, if the cm energy available for generation of secondary particles drops below a certain value. This value is presently set at 12 GeV corresponding to a laboratory energy of 80 GeV for the transition to GHEISHA. If GHEISHA is replaced by the ISOBAR model the transition energy is lowered to E_{cm} = 10 GeV rsp. E_{lab} = 50 GeV . In an EAS, however, the bulk of particles interacts at cm energies far below these values. Below these transition energies the user may select between the GHEISHA routines or the ISOBAR model. The GHEISHA routines as implemented in CORSIKA are taken from the detector simulation code GEANT3. This detector simulation code is used by many high energy experimental groups, and therefore much experience on the validity of the GHEISHA routines exists(D. Heck, vd. 1998, p. 29)

2.2.2 Strong interactions at high energies

Table 2.1 gives an overview on essential features of the available high energy hadronic interaction models. A comparison of the interaction models is given inprevious sections and the effects on observables of EAS are discussed there in detail.

Table 2.1. Basic features of the interaction models used.

	VENUS	QGSJET	DPMJET	SIBYLL	HDPM
Gribov-Regge	+	+	+		+
Minijets		+	+	+	+
Sec. Interactions	+				
N-N Interaction	+	+	+		
Superposition				+	+
Max. Energy (GeV)	2×10^7	$> 10^{11}$	$> 10^{11}$	$> 10^{11}$	10^8

QGSJET (Quark Gluon String model with JETs) is an extension of the QGS model, which describes hadronic interactions on the basis of exchanging supercritical Pomerons. Pomerons are cut according the Abramovskii-Gribov-Kancheli rule and form two strings each. Additionally QGSJET includes minijets to de scribe the hard interactions which are important at the highest energies. In the case of nucleus-nucleus collisions the participating nucleons are determined geometrically by Glauber calculations, assuming a Gaussian distribution of the nuclear density for the light nuclei with A less than 10 and a Woods-Saxon distribution for the heavier nuclei. The collision is treated by application of the percolation evaporation fragmentation mechanism of the spectator parts of the involved nuclei. Thus in peripheral collisions spallation like reactions happen, while in central collisions a more or less complete fragmentation into many small fragments takes place (D. Heck, vd. 1998, p. 31-32).

2.2.3 Strong interactions at low energies

The GHEISHA package is recommended for the treatment of low energy hadronic interactions. We coupled it to CORSIKA in the same way as it is implemented into the detector simulation code GEANT3. The GHEISHA routines are designed for laboratory energies up to some hundred GeV. We use them only at laboratory energies below 80 GeV to treat the interactions of hadronic projectiles with the nuclei of the atmosphere. The cross sections for elastic and inelastic interactions are interpolated and extrapolated from tabulated values derived from experimental data

and stored within the GHEISHA package. Neutron capture is taken into account as a third process for neutrons with E_{lab} less than 0.033 GeV . As the atmosphere does not contain fissile materials, we have eliminated the routines treating nuclear fission. From the cross sections the type of interaction is chosen at random, and the multiplicity and kinematic parameters of the secondary particles are sampled with the appropriate GHEISHA reaction routine (D. Heck, vd. 1998, p. 33)

The GHEISHA routines treat low energy neutrons in a very consistent way. This must be compared with the ISOBAR model, in which the low energy neutrons are scattered around without energy loss in a rather unrealistic manner, thus resulting in numerous low energy neutrons. Therefore we recommend the use of the GHEISHA option despite the longer calculation times. It should be noted, that in GHEISHA only the elements H, Al, Cu, and Pb are tabulated as target materials and that the interesting cross section data for the target elements N, O, and Ar which compose the atmosphere must be detained by interpolation, with a loss of accuracy (D. Heck, vd. 1998, p. 34).

2.3 Longitudional Distribution

CORSIKA with the theoretical description of shower development, we used the longitudinal development of the shower, because there are simple intuitive theoretical models an input file, similar as the one shown in 2.2 was used. Showers were simulated, varying in primary energy 5×10^{16} eV. The primary particles were proton, carbon and iron. The interaction model for hadrons used was QGSJET in CORSIKA.

2.4 Particles

CORSIKA program recognizes 50 elementary particles. All these particles can be tracked through the atmosphere, are able to interact, decay, and produce secondary particles.

2.5 Coordinate System

The coordinates in CORSIKA are defined with respect to a Cartesian coordinate system with the positive x-axis pointing to the magnetic north, the positive yaxis to the west, and the z-axis upwards. The origin is located at sea level. This definition is necessary, because the Earth`s magnetic field is taken into account. The zenith angle θ of a particle trajectory is measured between the particle momentum vector and the negative z-axis, and the azimuthal ϕ angle between the positive x-axis and the x-y component of the particle momentum vector (i.e. with respect to north) proceeding counterclockwise (D. Heck, vd. 1998, p. 6).

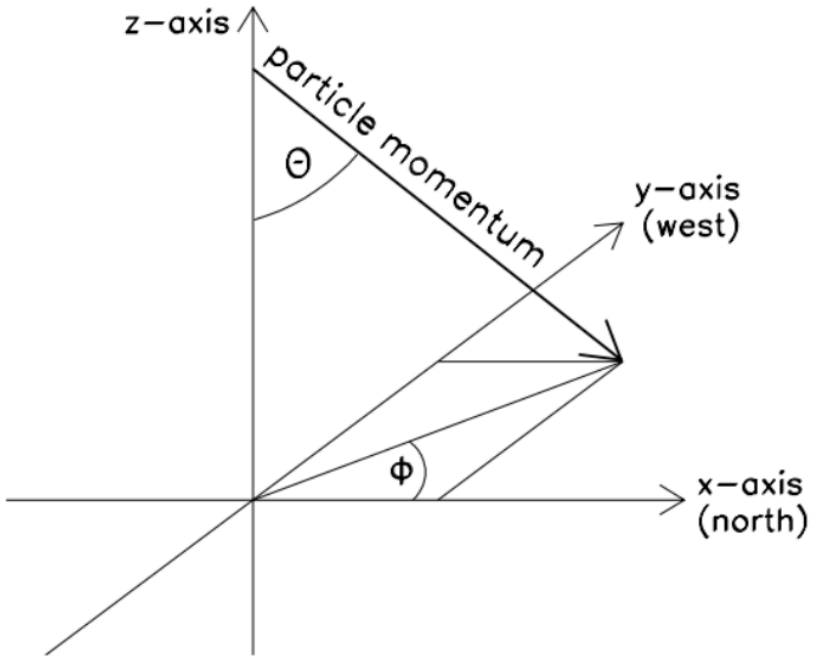

Figure 2.1. Coordinate system in CORSIKA.

2.6 Input Cards

As the first step of this section, It changed default options for one of the each simulation in figure 2.2.

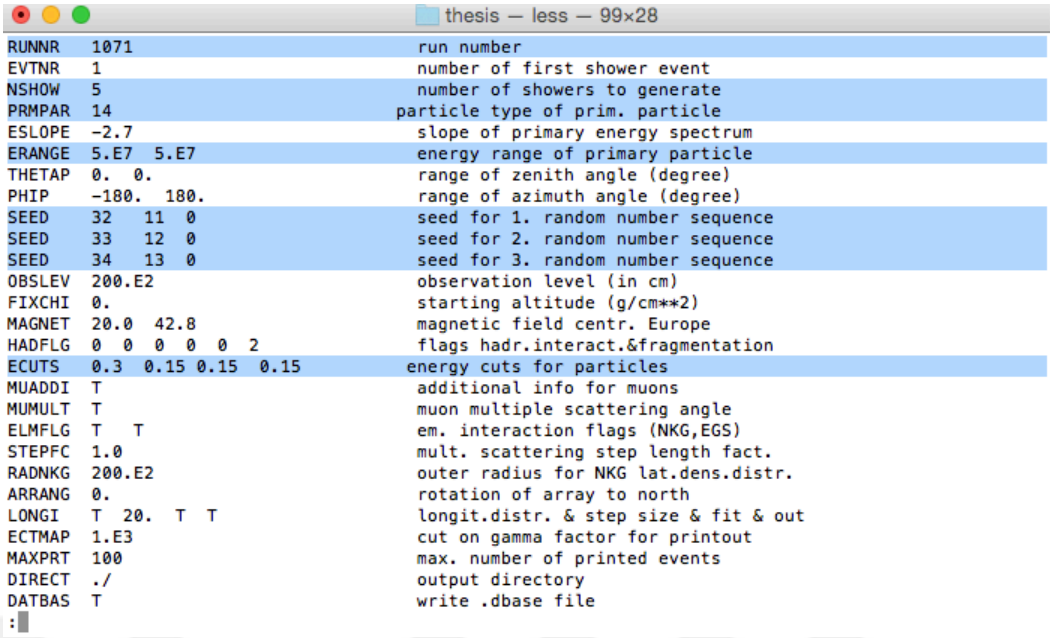

Figure 2.2. Input cards for proton particle with ECUT I

2.7 Compiling and Running

The version we used for the study is the modified version of corsika-6990. Three simple steps to start installing.

1. download corsika-6990.tar.gz from website.
2. type "tar -zxf corsika-6990.tar.gz" in command line.
3. go to directory "cd corsika-6990" and type "./cocount" to install

One has to do some selection during the installation process. After successfully finished installation it produces an executable which you run with an input card. Figure 2.3 is an example of input card we used in our analysis. During analysis we produce different cards. Each time run number RUNNR, Primary particle PRMPAR, seeding SEED, energy cuts ECUTs have been changed. We use proton (PRMPAR 14), carbon (PRMPAR 1204) and iron (PRMPAR 5626) as primary particles. Energy of the incoming primary particle is selected as $5x10^7$ GeV (ERANGE 5.E7 5.E7). Different set of Energy cuts selected to see the effect.

Case 1 → ECUT I	0.3	0.15	0.15	0.15
Case 2 → ECUT II	0.05	0.05	0.05	0.05
Case 3 → ECUT III	0.3	0.1	0.05	0.05

unit is in GeV. In first case, CUT corresponds to 0.3 GeV for hadrons 0.15 GeV for muons 0.15 GeV for electrons and 0.15 GeV for photons.

There are two major output files produced by a simulation run. The control printout (.lst file) allows to survey the simulation run. The particle output file is written to the data file DATnnnnnn with nnnnnn being the run number specified in the keyword RUNNR. This file becomes very large when simulating showers in great detail. In the CERENKOV version an additional file CERnnnnnn might be written. Optionally a tabular output (gammas, electrons, and muons particles at ground and longitudinal development of charged particles) is written out to the file DATnnnnnn.tab. Further on the longitudinal distributions of particle numbers and energy deposits may be written to file DATnnnnnn.long. The output file DATnnnnnn.dbase is destined to be used in a data base for examining the content of an air shower library. If the INCLINED option is used in combination with the INCLIN keyword an output file DATnnnnnn.inclined is written, which has the same binary structure as a standard CORSIKA particle output file DATnnnnnn. The INCLINED option internally makes use of the COAST package.

Binary outfile of corsika is converted to ASCII file and run offine fortran program for the detailed analysis. Fortran program produces histograms given next chapter.

3. RESULTS AND DISCUSSIONS

In this chapter, analysis of different primary particles (proton, iron and carbon) are discussed. Also, effect of energy cut used in CORSIKA is presented.

3.1 Proton as a primary particle

3.1.1 Profile of showers

In this section, shower of 5×10^{16} eV proton is simulated by CORSIKA with energy cut 0.3 0.15 0.15 0.15 GeV. This corresponds to 0.3 GeV for hadrons, 0.15 GeV for muons, 0.15 GeV for electrons and 0.15 GeV for photons. 21608985 particles produced in this shower in which 28% of them are electrons, 55% of them gammas, 8% of them muons and 9% of them are other particles such as kaons, pions, neutron, protons etc. Additionaly, to measure the distance from the center of the shower, we evalute R which is defined as

$$R = \sqrt{(x - x_c)^2 + (y - y_c)^2} \tag{3.1}$$

where x_c and y_c are found by

$$x_c = \frac{\sum_{i=1}^{n} x_i}{n} \quad , \quad y_c = \frac{\sum_{i=1}^{n} y_i}{n} \tag{3.2}$$

3.1.1.1 Electron and Positron

Figure 3.1 shows e^- and e^+ profile of the shower. There are a total of 6004829 e^- and e^+ in five shower. Mean value of the x distribution is -0.1892x10^{-01} with RMS of 22.12 while mean value of y distribution is -0.3285x10^{-02} with 22.22 RMS. The core of the shower can be seen from the 2-Dimensional plot of x vs y which is at the bottom right corner of figure 3.1. R distribution (distance from shower center) of the shower

is given at the middle left of figure 3.1. As one can see from the R distribution plot most of the e^- and e^+ are inside a circle with radius 50 meter. This could be more clear from the table 3.1 that 80% of them are in 30m, 90% them are in

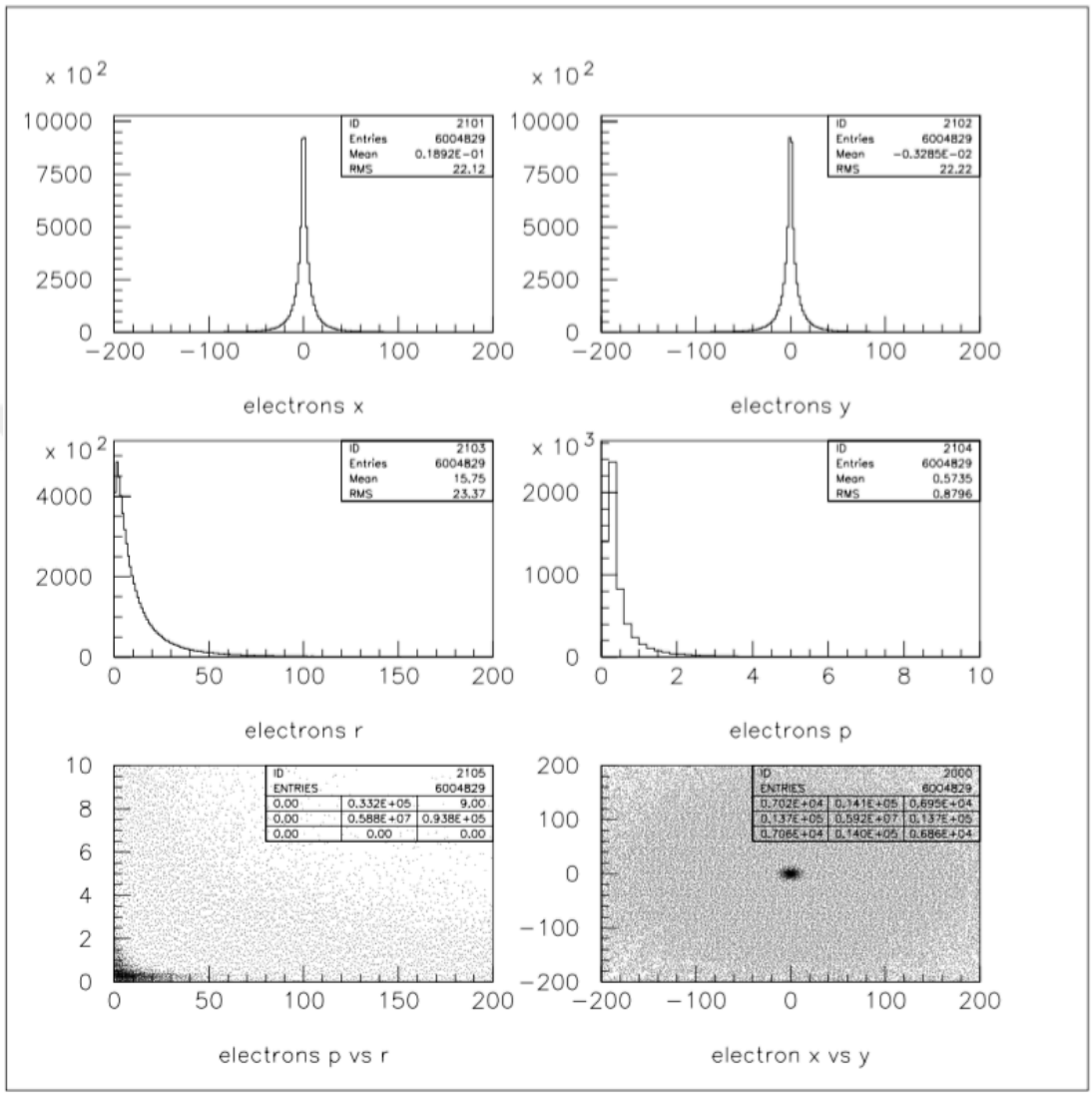

Figure 3.1. One-dimensional plots of x and y (top left and right), r and p (center left and right), two-dimensional plots of x-y and p-r (bottom left and right) of electrons and positrons for $5x10^{16}$ eV proton shower with ECUT I

50 m and 90% them are in 50 m and 94% of them are in 100 m. Middle right plot in figure 3.1 shows momentum distribution of e^- and e^+ in the shower. Average momentum of them is 0.5735 GeV and most of them have a momentum of 2 GeV or less. Bottom left plot in figure 3.1 is the 2-Dimensional plot of momentum vs distance

from the center of shower. e^- and e^+ with momentum less than 1 GeV are populated around distance less than 20m. The rest of particles are spread around.

3.1.1.2 Gammas

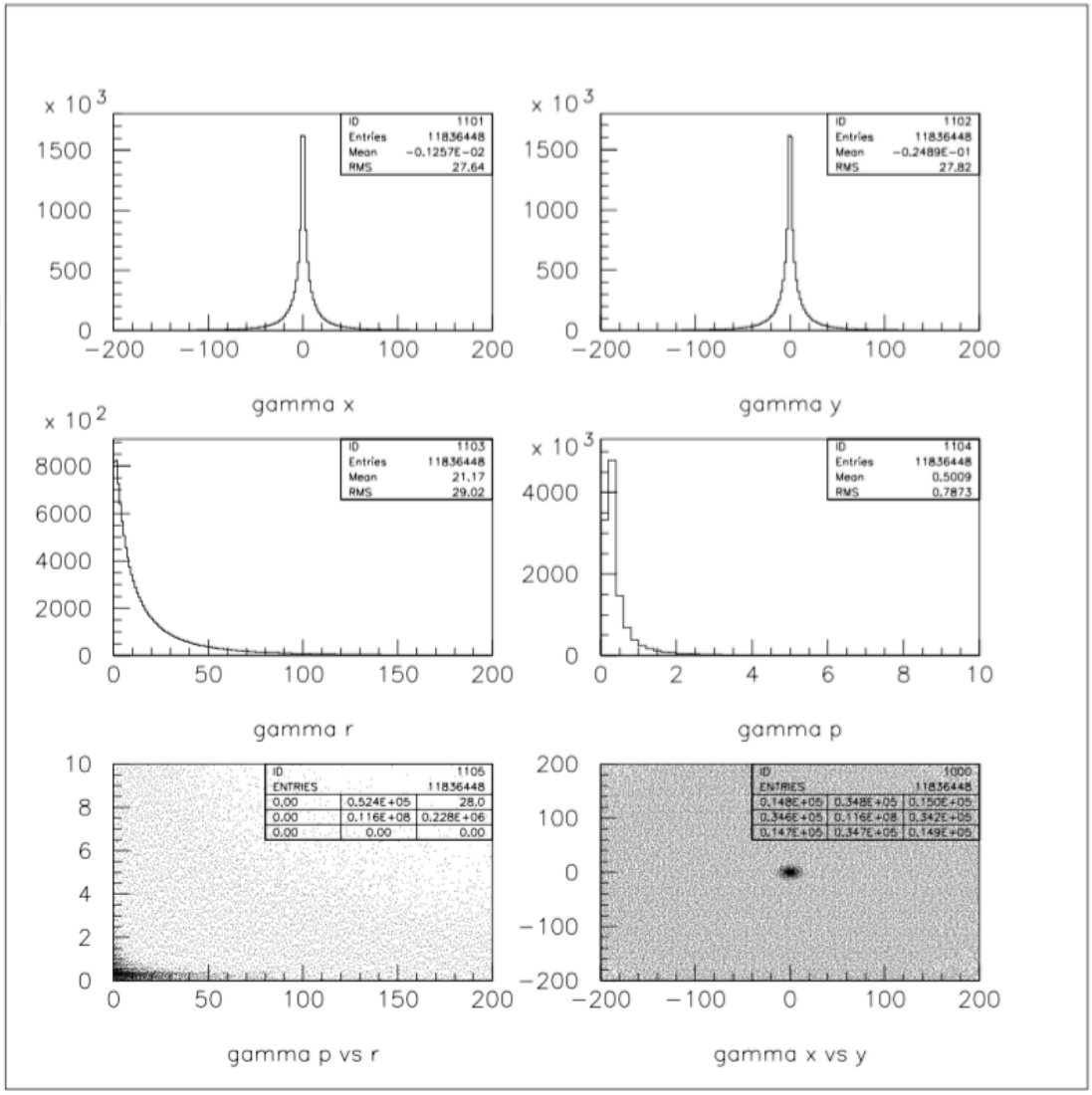

Figure 3.2. One-dimensional plots of x and y (top left and right), r and p (center left and right), two-dimensional plots of x-y and p-r (bottom left and right) of gammas for $5x10^{16}$ eV proton shower with ECUT I.

Figure 3.2 shows gamma profile of the shower. There are a total of 11836448 in five shower. Mean value of the x distribution is $-0.1257x10^{-02}$ with RMS of 27.64 while mean value of y distribution is $-0.2489x10^{-01}$ with 27.82 RMS. The core of the

shower can be seen from the 2-Dimensional plot of x vs y which is at the bottom right corner of figure 3.2. R distribution (distance from shower center) of the shower is given at the middle left of figure 3.2. As one can see from the R distribution plot most of the are inside a circle with radius 50 meter. This could be more clear from the table 3.2 that 72% of them are in 30 m, 86% them are in 50 m and 94% of them are in 100 m. Middle right plot in figure 3.2 shows momentum distribution of in the shower. Average momentum of them is 0.5009 GeV and most of them have a momentum of 2 GeV or less. Bottom left plot in figure 3.2 is the 2-Dimensional plot of momentum vs distance from the center of shower. Gammas with momentum less than 1 GeV are populated around distance less than 20m. The rest of particles are spread around.

3.1.1.3 Muons

Figure 3.3 shows muon profile of the shower. There are a total of 1824941 muon in five shower. Mean value of the x distribution is -0.1339 with RMS of 92.40 while mean value of y distribution is 0.9632×10^{-01} with 92.59 RMS. The core of the shower can be seen from the 2-Dimensional plot of x vs y which is at the bottom right corner of figure 3.3. R distribution (distance from shower center) of the shower is given at the middle left of figure 3.3. As one can see from the R distribution plot most of the muons are inside a circle with radius 50 meter. This could be more clearly seen from the table 3.3 that 5% of them are in 30 m, 11% them are in 50 m and 21% of them are in 100 m. Middle right plot in figure 3.3 shows momentum distribution of μ in the shower. Average momentum of them is 2.962 GeV and most of them have a momentum of 2 GeV or less. Bottom left plot in figure 3.3 is the 2-Dimensional plot of momentum vs distance from the center of shower. Muons with momentum less than 1 GeV are populated around distance less than 20m. The rest of particles are spread around.

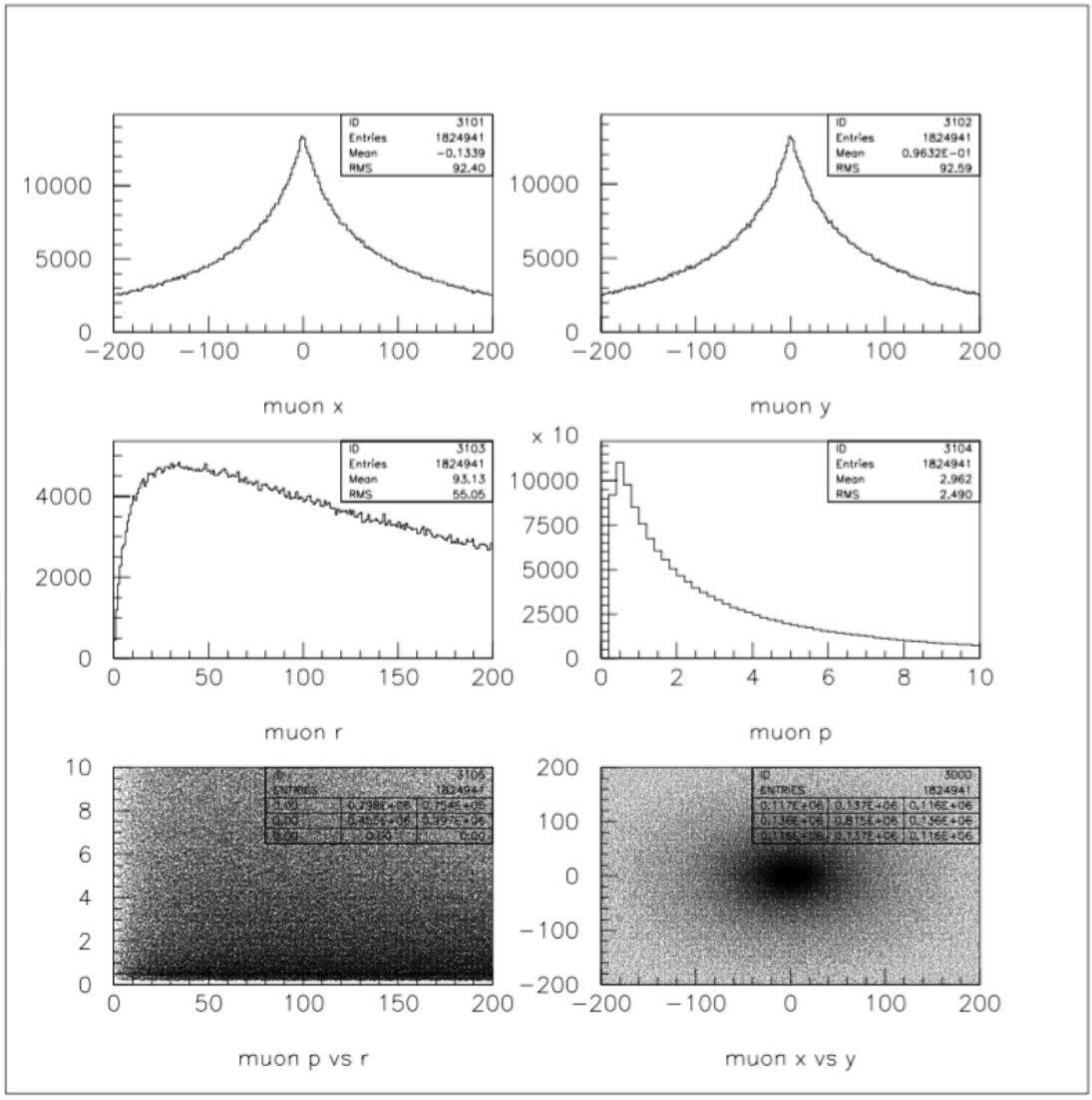

Figure 3.3. One-dimensional plots of x and y (top left and right), r and p (center left and right), two-dimensional plots of x-y and p-r (bottom left and right) of muons for $5x10^{16}$ eV proton shower with ECUT I

3.1.2 Momentum analysis

To understand the contributions coming from all particles, we decided to see the percentage of particles in a momentum intervals. For each particle we divide momentum interval in a two different way. In one categorization we wanted to see what is the percentage of particles with momentum less than 500 MeV and greater than 500 MeV. Motivation of this was muons have momentum much greater than 500 MeV.

The other categorization is to divide less than 500 MeV momentum into smaller intervals. Reason for that was most of e^- and e^+ have momentum less than 500 MeV. Table 3.1, 3.2, 3.3 are summarizing our result. We select a core with different radius (100 m, 50 m and 30 m). Average number of particles produced in 5 showers is 4321797 and 28% of them are e^- and e^+, 55% of them gammas 8% of them are muons and rest other particles.

3.1.2.1 Electron and Positron

Number of particles in the shower descreases from 100 to 30 meter. Average of 28% of total particles produced in a shower are e^- and e^+. 71% of these e^- and e^+ have momentum less than 500 MeV. Since we have a cut of 0.15 GeV for EM components, we did not see any e^- and e^+ with momentum less than 150 MeV. 39% of e^- and e^+ have momentum between 150 MeV and 250 MeV, 18% of them

Table 3.1. Total number of electrons and positrons in five different shower for different momentum interval for $5x10^{16}$ eV primary Proton shower with ECUT I.

	Total #	100 m	50 m	30 m
Total # of particles	21608985			
Final # of electrons	6004829	5644832	5418971	4849490
P < 500 MeV	4278646	3962229	3769702	3273490
P > 500 MeV	1726183	1682603	3769702	1576000
150 < P < 250 MeV	2337391	2109972	1985767	1673623
250 < P < 350 MeV	1091144	1034754	992035	876456
350 < P < 450 MeV	629006	604181	584624	532018
450 < P < 550 MeV	401258	387287	376659	349106

between 250 MeV and 350 MeV. 10% of them between 350 MeV and 450 MeV, and 6% of them between 450 MeV and 550 MeV. This numbers are approximately same (less than 2% charge) if we define a shower core with 100 m radius, 50 m radius, 30 m radius and evaluate the percentage.

When we define the core with 100 m radius, 94% of total e^- and e^+ are inside the core. 70% of those have momentum less than 500 MeV while 37% between 150 MeV and 250 MeV, 18% of them between 250 MeV and 350 MeV. 11% between 350 MeV and 450 MeV, and 7% between 450 MeV and 550 MeV.

For core with 50 m radius, 90% of total e^- and e^+ are inside the core. 70% of those have momentum less than 500 MeV while 37% between 150 MeV and 250 MeV, 18% of them between 250 MeV and 350 MeV. 11% between 350 MeV and 450 MeV, and 7% obetween 450 MeV and 550 MeV.

For core with 30 m radius, 81% of total e^- and e^+ are inside the core. 68% of those have momentum less than 500 MeV while 35% between 150 MeV and 250 MeV, 18% of them between 250 MeV and 350 MeV. 11% between 350 MeV and 450 MeV, and 7% between 450 MeV and 550 MeV.

3.1.2.2 Gammas

Average of 55% of total particles produced in a shower are gammas. 76% of these have momentum less than 500 MeV. Since we have a cut of 0.15 GeV for EM components, we did not see any with momentum less than 150 MeV.

Table 3.2. Total number of gammas in five different shower for different momentum interval for $5x10^{16}$ eV primary Proton shower with ECUT I

	Total #	100 m	50 m	30 m
Total # of particles	21608985			
Final # of gammas	11836448	11164434	10280324	8614842
P < 500 MeV	8996944	8406673	7597599	6114062
P > 500 MeV	2839504	2757761	2682725	2500780
150 < P < 250 MeV	5277774	4867783	4302958	3338185
250 < P < 350 MeV	2165488	2050396	1888531	1559651
350 < P < 450 MeV	1157946	1107899	1107899	897410
450 < P < 550 MeV	714378	687274	656113	656113

45% of have momentum between 150 MeV and 250 MeV, 18% of them between 250 MeV and 350 MeV. 10% of them between 350 MeV and 450 MeV, and 6% of them between 450 MeV and 550 MeV. This numbers are approximately same (less than 1% charge) if we define a shower core with 100 m radius, 50 m radius, 30 m radius and evaluate the percentage.

For core with 100 m radius, 94% of total gammas are inside the core. 75% of those have momentum less than 500 MeV while 44% between 150 MeV and 250 MeV, 18% of them between 250 MeV and 350 MeV. 10% between 350 MeV and 450 MeV, and 6% obetween 450 MeV and 550 MeV.

For core with 50 m radius, 87% of total gammas are inside the core. 74% of those have momentum less than 500 MeV while 42% between 150 MeV and 250 MeV, 18% of them between 250 MeV and 350 MeV. 10% between 350 MeV and 450 MeV, and 6% between 450 MeV and 550 MeV.

For core with 30 m radius, 73% of total gammas are inside the core. 71% of thosehave momentum less than 500 MeV while 39% between 150 MeV and 250 MeV, 18% of them between 250 MeV and 350 MeV. 10% between 350 MeV and 450 MeV, and 7% o between 450 MeV and 550 MeV.

3.1.2.3 Muons

Number of particles in the shower descreases from 100 to 30 meter. Also, these particles percentage increases in momentum ranges. On the other hand, Particles have a momentum cut of 0.3 MeV for EM components. Accordingly, We produce more muons. Average of 8% of total particles produced in a shower are muons. 8% of these muons have momentum less than 500 MeV. Since we have a cut of 0.15 GeV for EM components, we did not see any muons with momentum less than 150 MeV. 0.5% of μ's have momentum between 150 MeV and 250 MeV, 3% of them between 250 MeV and 350 MeV. 3% of them between 350 MeV and 450 MeV, and 3% of them between 450 MeV and 550 MeV. This numbers are approximately same (less than 1% charge) if we define a shower core with 100 m radius, 50 m radius, 30 m radius and evaluate the percentage.

Table 3.3. Total number of muons in five different shower for different momentum interval for $5x10^{16}$ eV primary Proton shower with ECUT I

	Total #	100 m	50 m	30 m
Total # of particles	21608985			
Final # of muons	1824941	395721	197984	87532
P < 500 MeV	149093	5687	2630	1089
P > 500 MeV	1675848	390034	195354	86443
150 < P < 250 MeV	8380	248	98	43
250 < P < 350 MeV	54476	1813	787	314
350 < P < 450 MeV	58104	2366	1125	1162
450 < P < 550 MeV	55035	2482	1162	511

For core with 100 m radius, 22% of total muons are inside the core. 1% of those have momentum less than 500 MeV while 0.06% between 150 MeV and 250 MeV, 0.5% of them between 250 MeV and 350 MeV. 1% between 350 MeV and 450 MeV, and 1% obetween 450 MeV and 550 MeV.

For core with 50 m radius, 11% of total muons are inside the core. 1% of those have momentum less than 500 MeV while 0.05% between 150 MeV and 250 MeV, 0.4% of them between 250 MeV and 350 MeV. 1% between 350 MeV and 450 MeV, and 1% between 450 MeV and 550 MeV.

For core with 30 m radius, 5% of total muons are inside the core. 1% of those have momentum less than 500 MeV while 0.05% between 150 MeV and 250 MeV, 0.4% of them between 250 MeV and 350 MeV. 1% between 350 MeV and 450 MeV, and 1% obetween 450 MeV and 550 MeV.

3.2 Carbon as a primary particle

3.2.1 Profile of showers

In the following section, shower of $5x10^{16}$ eV carbon is simulated by CORSIKA with energy cut 0.3 0.15 0.15 0.15 GeV. This corresponds to 0.3 GeV for hadrons, 0.15 GeV for muons, 0.15 GeV for electrons and 0.15 GeV for photons. 17933558 particles produced in this shower in which 25% of them are electrons, 49% of them gammas, 13% of them muons and 13% of them are other particles such as kaons, pions, neutron, protons etc.

3.2.1.1 Electrons and Positrons

Figure 3.4 shows e^- and e^+ profile of the shower. There are a total of 4451246 e^- and e^+ in five shower. Mean value of the x distribution is $0.3041x10^{-01}$ with RMS of 25.97 while mean value of y distribution is $0.3767x10^{-02}$ with 26.11 RMS. The core of the shower can be seen from the 2-Dimensional plot of x vs y which is at the bottom right corner of figure 3.4. R distribution (distance from shower center) of the shower is given at the middle left of figure 3.4. As one can see from the R distribution plot most of the e^- and e^+ are inside a circle with radius 50 meter. This could be more clear from the table 3.4 that 80% of them are in 30 m, 90% them are in 50 m and 94% of them are in 100 m. Middle right plot in figure 3.4 shows momentum distribution of e^- and e^+ in the shower. Average momentum of them is 0.5743 GeV and most of them have a momentum 2 GeV less than.

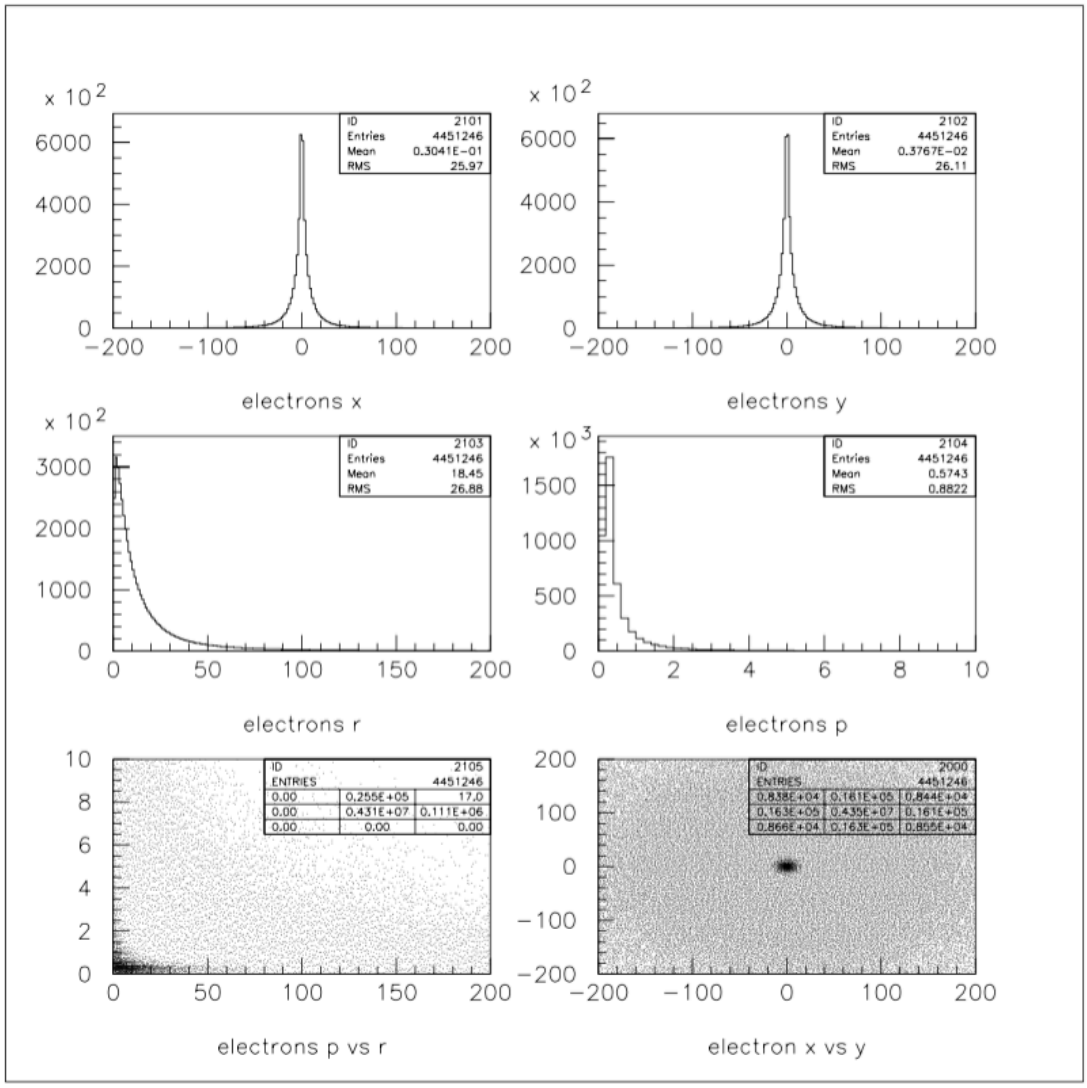

Figure 3.4. One-dimensional plots of x and y (top left and right), r and p (center left and right), two-dimensional plots of x-y and p-r (bottom left and right) of electrons and positrons for $5x10^{16}$ eV proton shower with ECUT I

Bottom left plot in figure 3.4 is the 2-Dimensional plot of momentum vs distance from the center of shower. e^- and e^+ with momentum less than 1 GeV are populated around distance less than 20 m. The rest of particles are spread around.

3.2.1.2 Gammas

Figure 3.5 shows gamma profile of the shower. There are a total of 8802330 gammas in five shower. Mean value of the x distribution is 0.8678×10^{-02} with RMS of 31.03 while mean value of y distribution is 0.2449×10^{-01} with 31.24 RMS. The core of the shower can be seen from the 2-Dimensional plot of x vs y which is at the bottom right corner of figure 3.5. R distribution (distance from shower center) of the shower is given at the middle left of figure 3.5. As one can see from the R distribution plot most of the gammas are inside a circle with radius 50 meter. This could be more clear from the table 3.5 that 72% of them are in 30 m, 86% them are in 50 m and 94% of them are in 100 m. Middle right plot in figure 3.5 shows momentum distribution of gamma in the shower. Average momentum of them is 0.5013 GeV and most of them have a momentum of 2 GeV or less. Bottom left plot in figure 3.5 is the 2-Dimensional plot of momentum vs distance from the center of shower. Gammas with momentum less than 1 GeV are populated around distance less than 20m. The rest of particles are spread around.

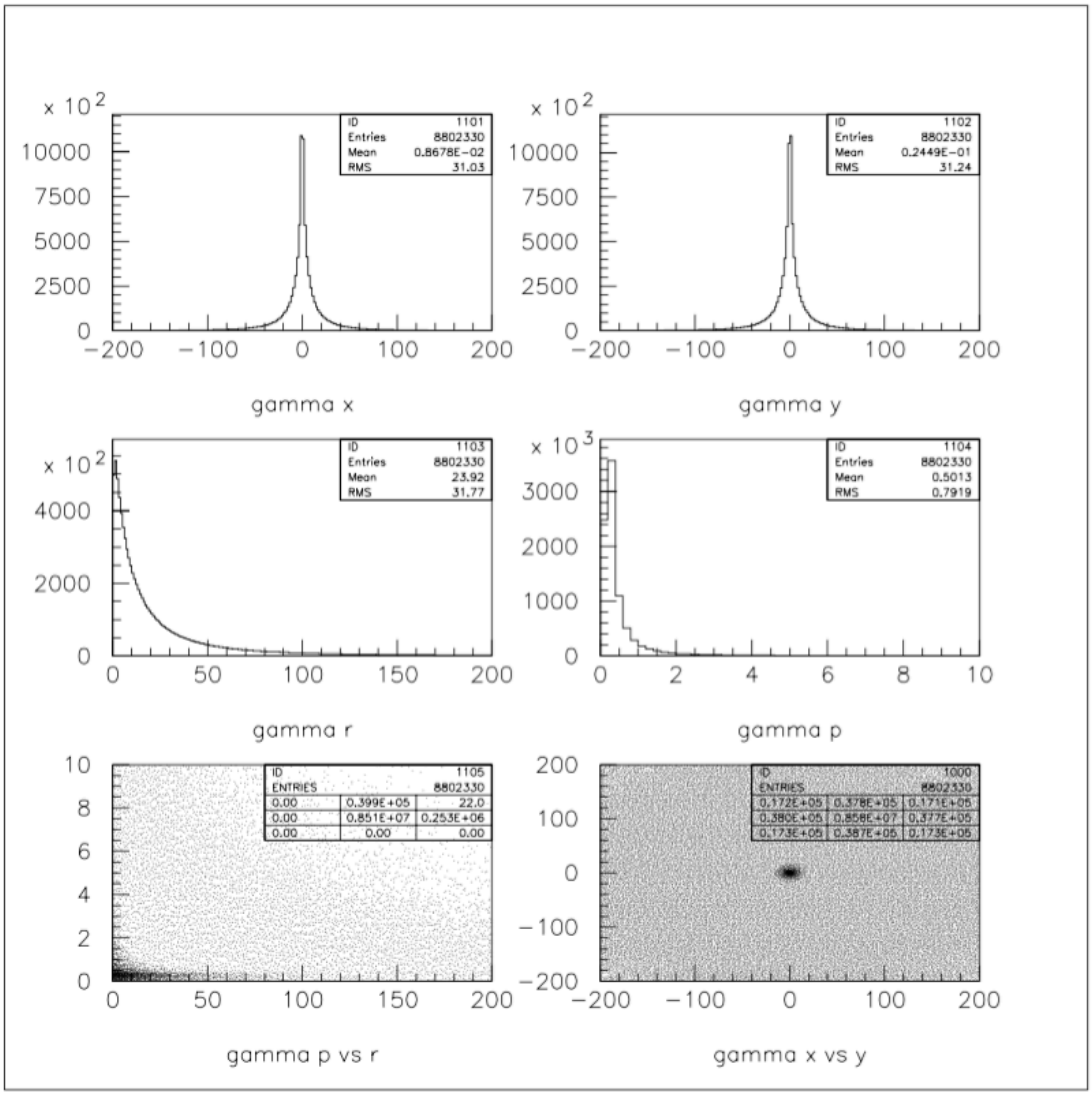

Figure 3.5. One-dimensional plots of x and y (top left and right), r and p (center left and right), two-dimensional plots of x-y and p-r (bottom left and right) of gammas for $5x10^{16}$ eV proton shower with ECUT I

3.2.1.3 Muons

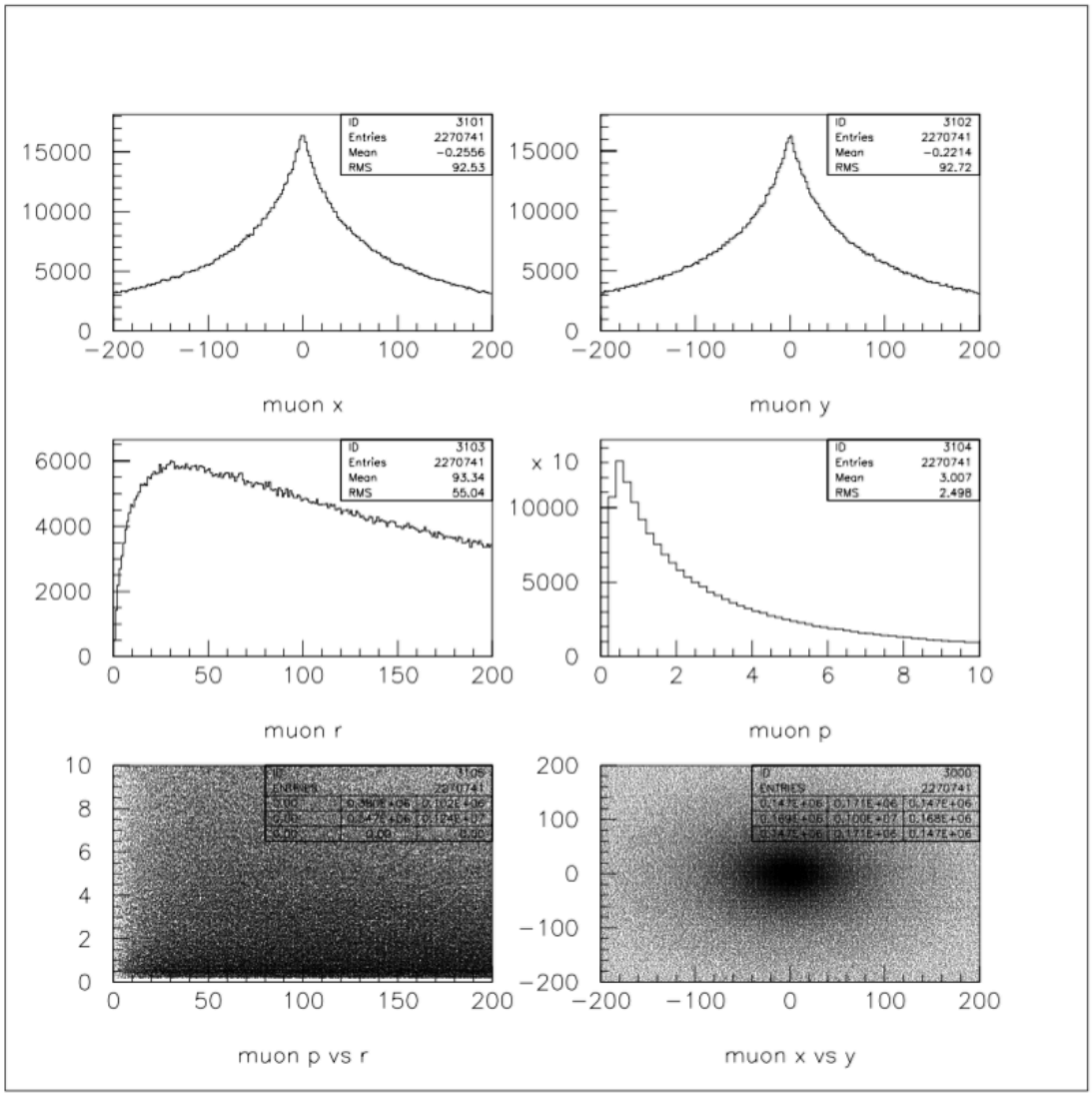

Figure 3.6. One-dimensional plots of x and y (top left and right), r and p (center left and right), two-dimensional plots of x-y and p-r (bottom left and right) of muons for $5x10^{16}$ eV proton shower with ECUT I

Figure 3.6 shows muon profile of the shower. There are a total of 2270741 muons in five shower. Mean value of the x distribution is -0.2556 with RMS of 92.53 while mean value of y distribution is -0.2214 with 92.72 RMS. The core of the shower can be seen from the 2-Dimensional plot of x vs y which is at the bottom right corner of figure 3.6. R distribution (distance from shower center) of the shower is given at the middle left of figure 3.6. As one can see from the R distribution plot most of the muons are inside a circle with radius 50 meter. This could be more clearly seen from the table 3.6 that 5% of them are in 30 m, 11% them are in 50 m and 21% of them are in 100 m.

Middle right plot in figure 3.6 shows momentum distribution of muon in the shower. Average momentum of them is 3.007 GeV and most of them have a momentum of 2 GeV or less. Bottom left plot in figure 3.6 is the 2-Dimensional plot of momentum vs distance from the center of shower. Muons with momentum less than 1 GeV are populated around distance less than 20m. The rest of particles are spread around.

3.2.2 Momentum analysis

To understand the contributions coming from all particles, we decided to see the percentage of particles in a momentum intervals. For each particle we divide momentum interval in a two different way. In one categorization we wanted to see what is the percentage of particles with momentum less than 500 MeV and greater than 500 MeV. Motivation of this was muons have momentum much greater than 500 MeV. The other categorization is to divide less than 500 MeV momentum into smaller intervals. Reason for that was most of e^- and e^+ and having momentum less than 500 MeV. Table 3.1, 3.2, 3.3 are summarizing our result. We analyzed inside a distance of 100 m, 50 m and 30 m from a shower of core. Average number of particles produced in 5 showers is 3586712 and 25% of them are e^- and e^+, 49% of them gammas 13% of them are muons and rest other particles.

3.2.2.1 Electron and Positron

Number of particles in the shower descreases from 100 to 30 meter. Also, these particles percentage increases in momentum ranges. On the other hand, Particles have a momentum cut components. Therefore, we produce more e^- and e^+. Average of 25% of total particles produced in a shower are e^- and e^+. 71% of these e^- and e^+ have momentum less than 500 MeV. Since we have a cut of 0.15 GeV for EM components, we did not see any e^- and e^+ with momentum less than 150 MeV. 39% of e^- and e^+ have momentum between 150 MeV and 250 MeV, 18% of them between 250 MeV and 350 MeV. 10% of them between 350 MeV and 450 MeV, and 7% of them between 450 MeV and 550 MeV. This numbers are approximately same (less

than 1% charge) if we define a shower core with 100 m radius, 50 m radius, 30 m radius and evaluate the percentage.

Table 3.4. Total number of electrons and positrons in five different shower for different momentum interval for primary Carbon particle in ECUT I

	Total #	100 m	50 m	30 m
Total # of particles	17933558			
Final # of electrons	4451246	4102631	3885168	3406772
P < 500 MeV	3171502	2874075	2694502	2290019
P > 500 MeV	1279744	1228556	1190666	1116753
150 < P < 250 MeV	1733270	1530135	1418065	1170153
250 < P < 350 MeV	808398	750599	709243	612779
350 < P < 450 MeV	465654	438116	418233	372370
450 < P < 550 MeV	297661	281667	270453	245476

For core with 100 m radius, 92% of total e^- and e^+ are inside the core. 70% of those have momentum less than 500 MeV while 37% between 150 MeV and250 MeV, 18% of them between 250 MeV and 350 MeV. 11% between 350 MeV and 450 MeV, and 7% between 450 MeV and 550 MeV.

For core with 50 m radius, 87% of total e^- and e^+ are inside the core. 69% of those have momentum less than 500 MeV while 36% between 150 MeV and 250 MeV, 18% of them between 250 MeV and 350 MeV. 11% between 350 MeV and 450 MeV, and 7% between 450 MeV and 550 MeV.

For core with 30 m radius, 77% of total e^- and e^+ are inside the core. 67% of those have momentum less than 500 MeV while 34% between 150 MeV and 250 MeV, 18% of them between 250 MeV and 350 MeV. 10% between 350 MeV and 450 MeV, and 7% between 450 MeV and 550 MeV.

3.2.2.2 Gammas

Number of particles in the shower descreases from 100 to 30 meter. Also, these particles percentage increases in momentum ranges. On the other hand, Particles have a momentum cut components. Therefore, we produce more gammas. 49% of total particles produced in this shower are gammas. 76% of these gammas have momentum less than 500 MeV. Since we have a cut of 0.15 GeV for EM components, we did not see any gamma with momentum less than 150 MeV. 45% of gamma have momentum between 150 MeV and 250 MeV, 18% of them between 250 MeV and 350 MeV. 10% of them between 350 MeV and 450 MeV, and 6% of them between 450 MeV and 550 MeV. This numbers are approximately same (less than 1% charge) if we define a shower core with 100 m radius, 50 m radius, 30 m radius and evaluate the percentage.

Table 3.5. Total number of gammas in five different shower for different momentum interval for primary Carbon particle in ECUT I

	Total #	100 m	50 m	30 m
Total # of particles	17933558			
Final # of gammas	8802330	8125538	7367188	6046617
P < 500 MeV	6699517	6116438	5436229	4279646
P > 500 MeV	2102813	2009100	1930959	1766971
150 < P < 250 MeV	3936369	3543935	3077641	2335869
250 < P < 350 MeV	1609198	1490365	1350996	1090954
350 < P < 450 MeV	860267	805481	747797	629191
450 < P < 550 MeV	528455	498104	468761	405719

For core with 100 m radius, 92% of total gammas are inside the core. 75% of those have momentum less than 500 MeV while 44% between 150 MeV and 250 MeV, 18% of them between 250 MeV and 350 MeV. 10% between 350 MeV and 450 MeV, and 6% between 450 MeV and 550 MeV.

For core with 50 m radius, 84% of total gammas are inside the core. 74% of those have momentum less than 500 MeV while 42% between 150 MeV and 250 MeV, 18% of them between 250 MeV and 350 MeV. 10% between 350 MeV and 450 MeV, and 6% between 450 MeV and 550 MeV.

For core with 30 m radius, 69% of total gammas are inside the core. 71% of those have momentum less than 500 MeV while 39% between 150 MeV and 250 MeV, 18% of them between 250 MeV and 350 MeV. 10% between 350 MeV and 450 MeV, and 7% between 450 MeV and 550 MeV.

3.2.2.3 Muons

Number of particles in the shower descreases from 100 to 30 meter. Also, these particles percentage increases in momentum ranges. On the other hand, Particles have a momentum cut components. Therefore, we produce more muons. Average of 13% of total particles produced in a shower are muons. 8% of these muons have momentum less than 500 MeV. Since we have a cut of 0.15 GeV for EM components, we did not see muon with momentum less than 150 MeV. 0.4% of muons have momentum between 150 MeV and 250 MeV, 3% of them between 250 MeV and 350 MeV. 3% of them between 350 MeV and 450 MeV, and 3% of them between 450 MeV and 550 MeV. This numbers are approximately same (less than 1% charge) if we define a shower core with 100 m radius, 50 m radius, 30 m radius and evaluate the percentage.

For core with 100 m radius, 22% of total muons are inside the core. 1% of those have momentum less than 500 MeV while 0.05% between 150 MeV and 250 MeV, 0.4% of them between 250 MeV and 350 MeV. 1% between 350 MeV and 450 MeV, and 1% between 450 MeV and 550 MeV.

For core with 50 m radius, 11% of total muons are inside the core. 1% of those have momentum less than 500 MeV while 0.05% between 150 MeV and 250 MeV, 0.4% of them between 250 MeV and 350 MeV. 1% between 350 MeV and 450 MeV, and 1% between 450 MeV and 550 MeV.

For core with 30 m radius, 5% of total muons are inside the core. 1% of those have momentum less than 500 MeV while 0.03% between 150 MeV and 250 MeV, 0.03% of them between 250 MeV and 350 MeV. 1% between 350 MeV and 450 MeV, and 1% between 450 MeV and 550 MeV.

Table 3.6. Total number of muons in five different shower for different momentum interval for primary Carbon particle in ECUT I

	Total #	100 m	50 m	30 m
Total # of particles	17933558			
Final # of muons	2270741	488521	243671	106375
P < 500 MeV	173994	6272	2913	1197
P > 500 MeV	2096747	482249	240758	105178
150 < P < 250 MeV	9803	251	119	32
250 < P < 350 MeV	63611	2013	918	367
350 < P < 450 MeV	67383	2613	1227	536
450 < P < 550 MeV	65793	2804	1307	528

3.3 Iron as a primary particle

3.3.1 Profile of showers

In the following section, shower of $5x10^{16}$ eV iron is simulated by CORSIKA with energy cut 0.3 0.15 0.15 0.15 GeV. This corresponds to 0.3 GeV for hadrons, 0.15 GeV for muons, 0.15 GeV for electrons and 0.15 GeV for photons. 15834619 particles produced in this shower in which 22% of them are electrons, 43% of them gammas, 17% of them muons and 18% of them are other particles such as kaons, pions, neutron, protons etc.

3.3.1.1 Electrons and Positrons

Figure 3.7 shows e^- and e^+ profile of the shower. There are a total of 3450797 e^- and e^+ in five shower. Mean value of the x distribution is $-0.4230x10^{-01}$ with RMS of 29.64 while mean value of y distribution is $-0.1387x10^{-01}$ with 29.65 RMS. The core of the shower can be seen from the 2-Dimensional plot of x vs y which is at the bottom right corner of figure 3.7. R distribution (distance from shower center) of the shower is given at the middle left of figure 3.7. As one can see from the R distribution plot most of the e^- and e^+ are inside a circle with radius 50 meter. This could be more clear from the table 3.7 that 80% of them are in 30 m, 90% them are in 50 m and 94% of them are in 100 m. Middle right plot in figure 3.7 shows momentum distribution of e^- and e^+ in the shower. Average momentum of them is 0.5762 GeV and most of them have a momentum of 2 GeV or less. Bottom left plot in figure 3.7 is the 2-Dimensional plot of momentum vs distance from the center of shower. e^- and e^+ with momentum less than 1 GeV are populated around distance less than 20m. The rest of particles are spread around.

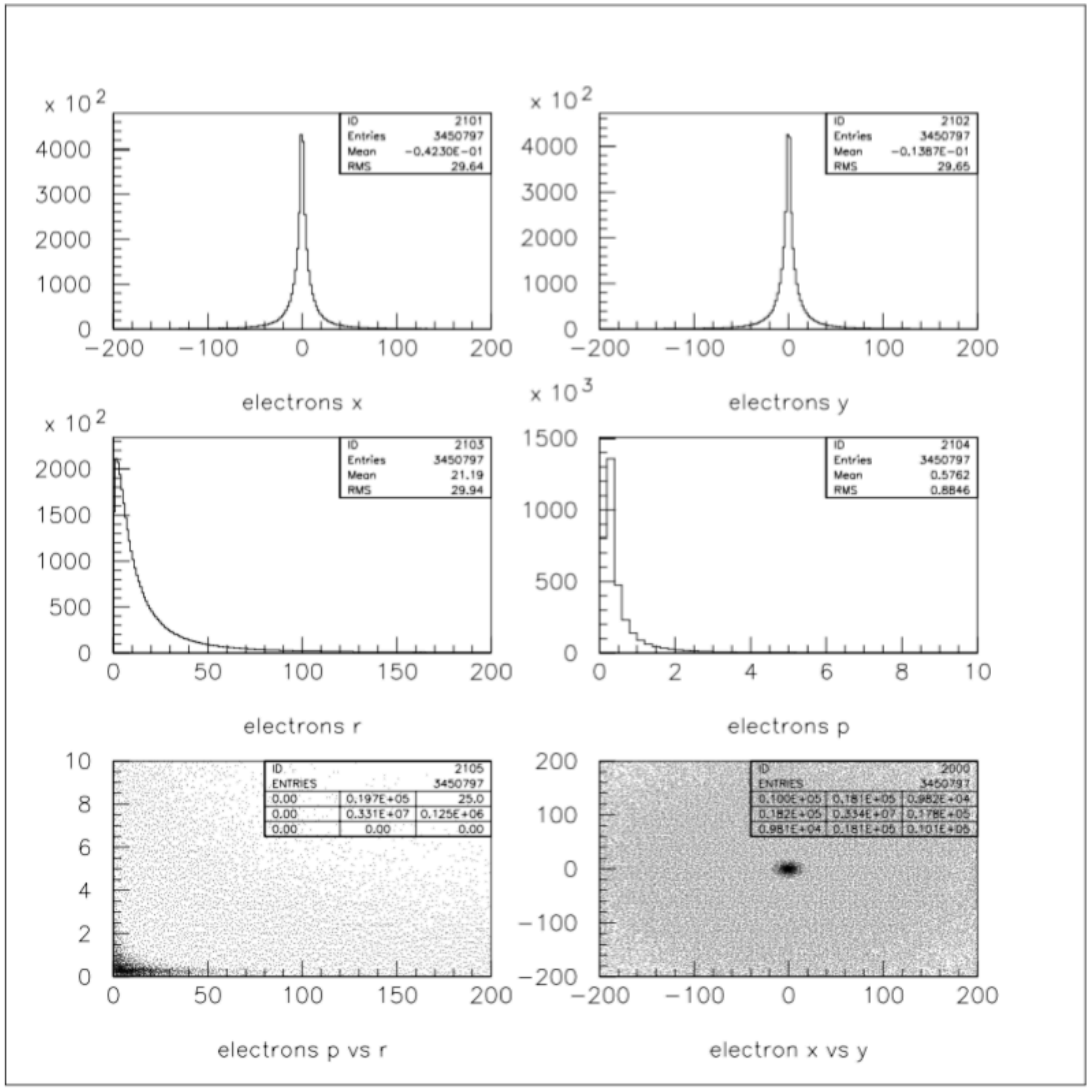

Figure 3.7. One-dimensional plots of x and y (top left and right), r and p (center left and right), two-dimensional plots of x-y and p-r (bottom left and right) of electrons and positrons for $5x10^{16}$ eV proton shower with ECUT I

3.3.1.2 Gammas

Figure 3.8 shows gamma profile of the shower. There are a total of6818407 gammas in five shower. Mean value of the x distribution is $0.2025x10^{-01}$ with RMS of 34.20 while mean value of y distribution is $0.5712x10^{-01}$ with 34.31 RMS. The core of the shower can be seen from the 2-Dimensional plot of x vs y which is at the bottom right corner of figure 3.8. R distribution (distance from shower center) of the shower

is given at the middle left of figure 3.8. As one can see from the R distribution plot most of

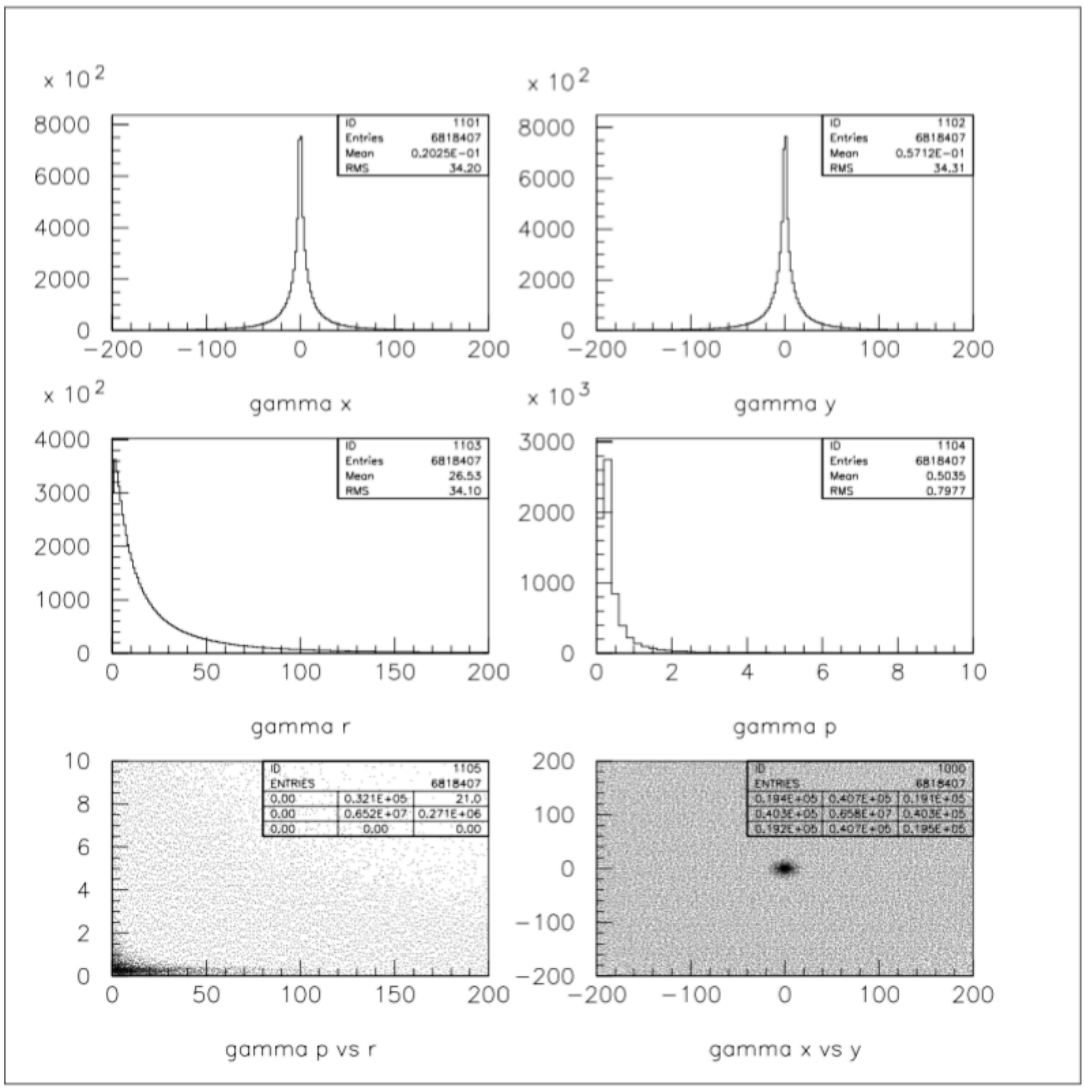

Figure 3.8. One-dimensional plots of x and y (top left and right), r and p (center left and right), two-dimensional plots of x-y and p-r (bottom left and right) of gammas for $5x10^{16}$ eV proton shower with ECUT I.

the gammas are inside a circle with radius 50 meter. This could be more clear from the table 3.8 that 80% of them are in 30 m, 90% them are in 50 m and 94% of them are in 100 m. Middle right plot in figure 3.8 shows momentum distribution of gammas in the shower. Average momentum of them is 0.5035 GeV and most of them have a momentum of 2 GeV or less. Bottom left plot in figure 3.8 is the 2-Dimensional plot of momentum vs distance from the center of shower. Gammas with momentum less

than 1 GeV are populated around distance less than 20m. The rest of particles are spread around.

3.3.1.3 Muons

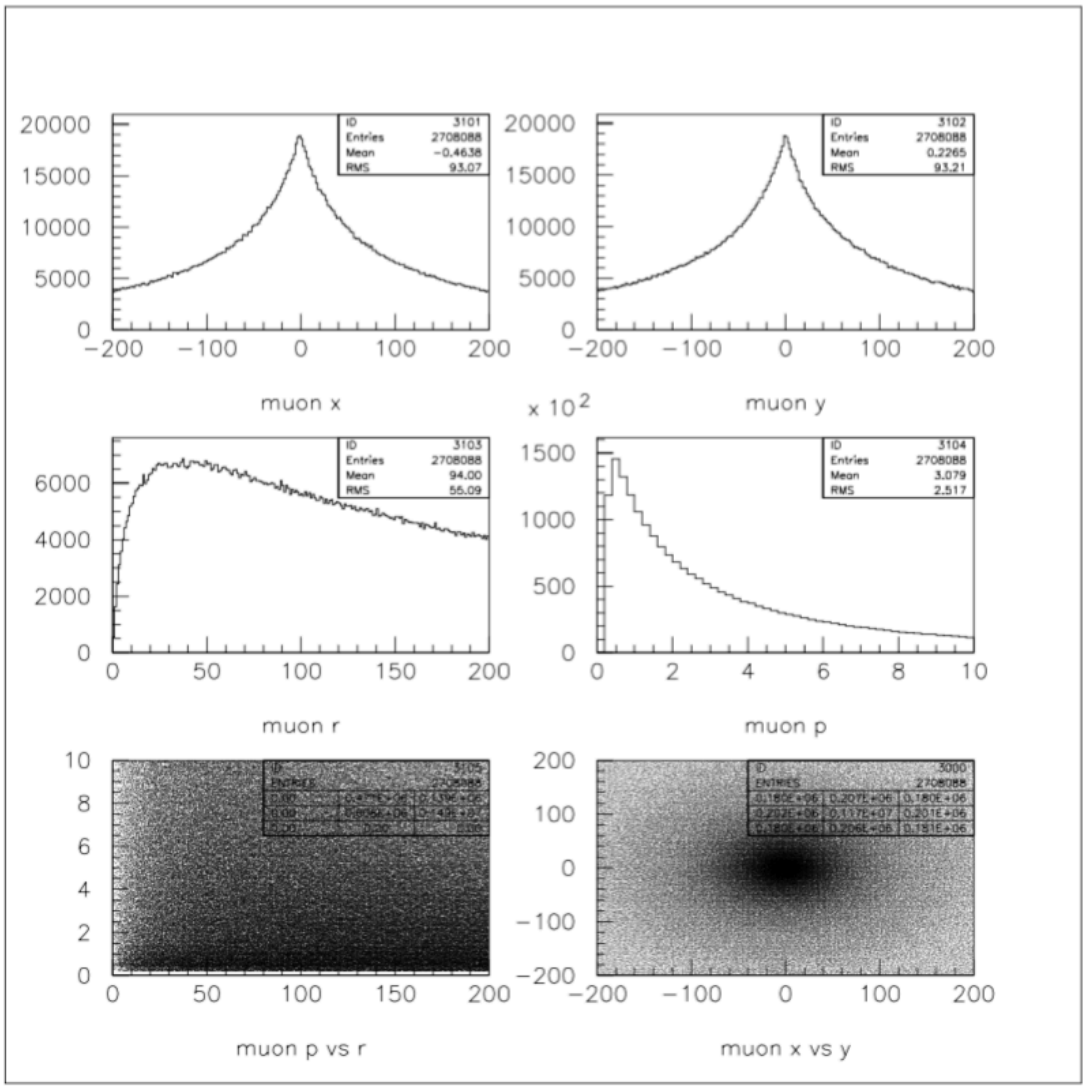

Figure 3.9. One-dimensional plots of x and y (top left and right), r and p (center left and right), two-dimensional plots of x-y and p-r (bottom left and right) of muons for $5x10^{16}$ eV iron shower with ECUT I

Figure 3.9 shows muon profile of the shower. There are a total of 4451246 muons in five shower. Mean value of the x distribution is -0.4638 with RMS of 93.07 while mean value of y distribution is 0.2265 with 93.21 RMS. The core of the shower can be seen from the 2-Dimensional plot of x vs y which is at the bottom right corner

of figure 3.9. R distribution (distance from shower center) of the shower is given at the middle left of figure 3.9. As one can see from the R distribution plot most of the muons are inside a circle with radius 50 meter. This could be more clear from the table 3.9 that 80% of them are in 30 m, 90% them are in 50 m and 94% of them are in 100 m. Middle right plot in figure 3.9 shows momentum distribution of muon in the shower. Average momentum of them is 3.079 GeV and most of them have a momentum of 2 GeV or less. Bottom left plot in figure 3.9 is the 2-Dimensional plot of momentum vs distance from the center of shower. Muons with momentum less than 1 GeV are populated around distance less than 20m. The rest of particles are spread around.

3.3.2 Momentum analysis

3.3.2.1 Electrons and Positrons

Table 3.7. Total number of electrons and positrons in five different shower for different momentum interval for primary Iron particle in ECUT I

	Total #	100 m	50 m	30 m
Total # of particles	15834619			
Final # of electrons	3450797	3108874	2904166	2491519
P < 500 MeV	2454714	2169858	2005030	1665551
P > 500 MeV	996083	939016	899136	825968
150 < P < 250 MeV	1342182	1154630	1054853	851203
250 < P < 350 MeV	624676	566160	527071	444759
350 < P < 450 MeV	361051	331782	312191	271607
450 < P < 550 MeV	230102	212956	201567	178837

Average of 22% of total particles produced in a shower are e^- and e^+ .71% of these e^- and e^+ have momentum less than 500 MeV. Since we have a cut of 0.15 GeV for EM components, we did not see any e^- and e^+ with momentum less than 150 MeV. 39% of e^- and e^+ have momentum between 150 MeV and 250 MeV, 18% of them between 250 MeV and 350 MeV. 10% of them between 350 MeV and 450 MeV, and

7% of them between 450 MeV and 550 MeV. This numbers are approximately same (less than 1% charge) if we define a shower core with 100 m radius, 50 m radius, 30 m radius and evaluate the percentage.

For core with 100 m radius, 90% of total e^- and e^+ are inside the core. 70% of those have momentum less than 500 MeV while 37% between 150 MeV and 250 MeV, 18% of them between 250 MeV and 350 MeV. 11% between 350 MeV and 450 MeV, and 7% between 450 MeV and 550 MeV.

For core with 50 m radius, 84% of total e^- and e^+ are inside the core. 69% of those have momentum less than 500 MeV while 36% between 150 MeV and 250 MeV, 18% of them between 250 MeV and 350 MeV. 11% between 350 MeV and 450 MeV, and 7% between 450 MeV and 550 MeV.

For core with 30 m radius, 72% of total e^- and e^+ are inside the core. 67% of those have momentum less than 500 MeV while 34% between 150 MeV and 250 MeV, 18% of them between 250 MeV and 350 MeV. 11% between 350 MeV and 450 MeV, and 7% between 450 MeV and 550 MeV.

3.3.2.2 Gammas

Average of 43% of total particles produced in a shower are gammas. 76% of these have momentum less than 500 MeV. Since we have a cut of 0.15 GeV for EM components, we did not see any gamma with momentum less than 150 MeV. 45% of gammas have momentum between 150 MeV and 250 MeV, 18% of them between 250 MeV and 350 MeV. 10% of them between 350 MeV and 450 MeV, and 6% of them between 450 MeV and 550 MeV. This numbers are approximately same (less than 1% charge) if we define a shower core with 100 m radius, 50 m radius, 30 m radius and evaluate the percentage.

For core with 100 m radius, 90% of total gammas are inside the core. 75% of those have momentum less than 500 MeV while 43% between 150 MeV and 250 MeV, 18% of them between 250 MeV and 350 MeV. 10% between 350 MeV and 450 MeV, and 6% between 450 MeV and 550 MeV.

For core with 50 m radius, 81% of total gammas are inside the core. 73% of those have momentum less than 500 MeV while 42% between 150 MeV and 250 MeV, 18% of them between 250 MeV and 350 MeV. 10% between 350 MeV and 450 MeV, and 6% between 450 MeV and 550 MeV.

Table 3.8. Total number of gammas in five different shower for different momentum interval for primary Iron particle in ECUT I

	Total #	100 m	50 m	30 m
Total # of particles	15834619			
Final # of gammas	6818407	6148839	5494676	4419296
P < 500 MeV	5181060	4613406	4037552	3113105
P > 500 MeV	16337347	1535433	1457124	1306191
150 < P < 250 MeV	3045074	2672483	2285039	1699358
250 < P < 350 MeV	1244421	1124224	1003742	793313
350 < P < 450 MeV	664590	607894	555605	457758
450 < P < 550 MeV	409479	377089	349624	296203

For core with 30 m radius, 65% of total gammas are inside the core. 70% of those have momentum less than 500 MeV while 38% between 150 MeV and 250 MeV, 18% of them between 250 MeV and 350 MeV. 10% between 350 MeV and 450 MeV, and 7% between 450 MeV and 550 MeV.

3.3.2.3 Muons

Average of 17% of total particles produced in a shower are muon. 8% of these muons have momentum less than 500 MeV. Since we have a cut of 0.15 GeV for EM components, we did not see any muon with momentum less than 150 MeV. 0.4% of muons have momentum between 150 MeV and 250 MeV, 3% of them between 250 MeV and 350 MeV. 3% of them between 350 MeV and 450 MeV, and 3% of them between 450 MeV and 550 MeV. This numbers are approximatelysame (less than 1% charge) if we define a shower core with 100 m radius, 50 m radius, 30 m radius and evaluate the percentage.

For core with 100 m radius, 21% of total muons are inside the core. 1% of those have momentum less than 500 MeV while 0.05% between 150 MeV and 250 MeV, 0.4% of them between 250 MeV and 350 MeV. 1% between 350 MeV and 450 MeV, and 1% between 450 MeV and 550 MeV.

Table 3.9. Total number of muons in five different shower for different momentum interval for primary Iron particle in ECUT I

	Total #	100 m	50 m	30 m
Total # of particles	15834619			
Final # of muons	2708088	567841	280649	121911
P < 500 MeV	192499	6561	3055	1254
P > 500 MeV	2515589	561280	277594	120657
150 < P < 250 MeV	10574	277	116	35
250 < P < 350 MeV	70135	2095	977	373
350 < P < 450 MeV	74876	2720	1296	564
450 < P < 550 MeV	71741	2881	1288	544

For core with 50 m radius, 10% of total muons are inside the core. 1% of those have momentum less than 500 MeV while 0.04% between 150 MeV and 250 MeV, 0.3% of them between 250 MeV and 350 MeV. 1% between 350 MeV and 450 MeV, and 1% between 450 MeV and 550 MeV.

For core with 30 m radius, 5% of total muons are inside the core. 1% of those have momentum less than 500 MeV while 0.03% between 150 MeV and 250 MeV, 0.3% of them between 250 MeV and 350 MeV. 1% between 350 MeV and 450 MeV, and 0.4% between 450 MeV and 550 MeV.

3.4 Effects of energy cuts

3.4.1 Proton analysis

3.4.1.1 Profile of showers

Energy cut II

In this section, shower of $5x10^{16}$ eV proton is simulated by CORSIKA with energy cut 0.05 0.05 0.05 0.05 GeV. This corresponds to 0.05 GeV for hadrons, 0.05 GeV for muons, 0.05 GeV for electrons and 0.05 GeV for photons. 39798680 particles produced in this shower in which 24% of them are electrons, 65% of them gammas, 5% of them muons and 6% of them are other particles such as kaons, pions, neutron, protons etc.

Electrons and positrons

Figure 3.10 shows e^- and e^+ profile of the shower. There are a total of 9678571 e^- and e^+ in five shower. Mean value of the x distribution is $0.3804x10^{-01}$ with RMS of 32.46 while mean value of y distribution is $-0.1551x10^{-01}$ with 32.61 RMS. The core of the shower can be seen from the 2-Dimensional plot of x vs y which is at the bottom right corner of figure 3.10. R distribution (distance from shower center) of the shower is given at the middle left of figure 3.10. As one can see from the R distribution plot most of the e^- and e^+ are inside a circle with radius 50 meter. This could be more clear from the table 3.10 that 80% of them are in 30 m, 90% them are in 50 m and 94% of them are in 100 m. Middle right plot in figure 3.10 shows momentum distribution of e^- and e^+ in the shower. Average momentum of them is 0.3007 GeV and most of them have a momentum of 2 GeV or less. Bottom left plot in figure 3.10 is the 2-Dimensional plot of momentum vs distance from the center of shower. e^- and e^+ with momentum less than 1 GeV are populated around distance less than 20m. The rest of particles are spread around.

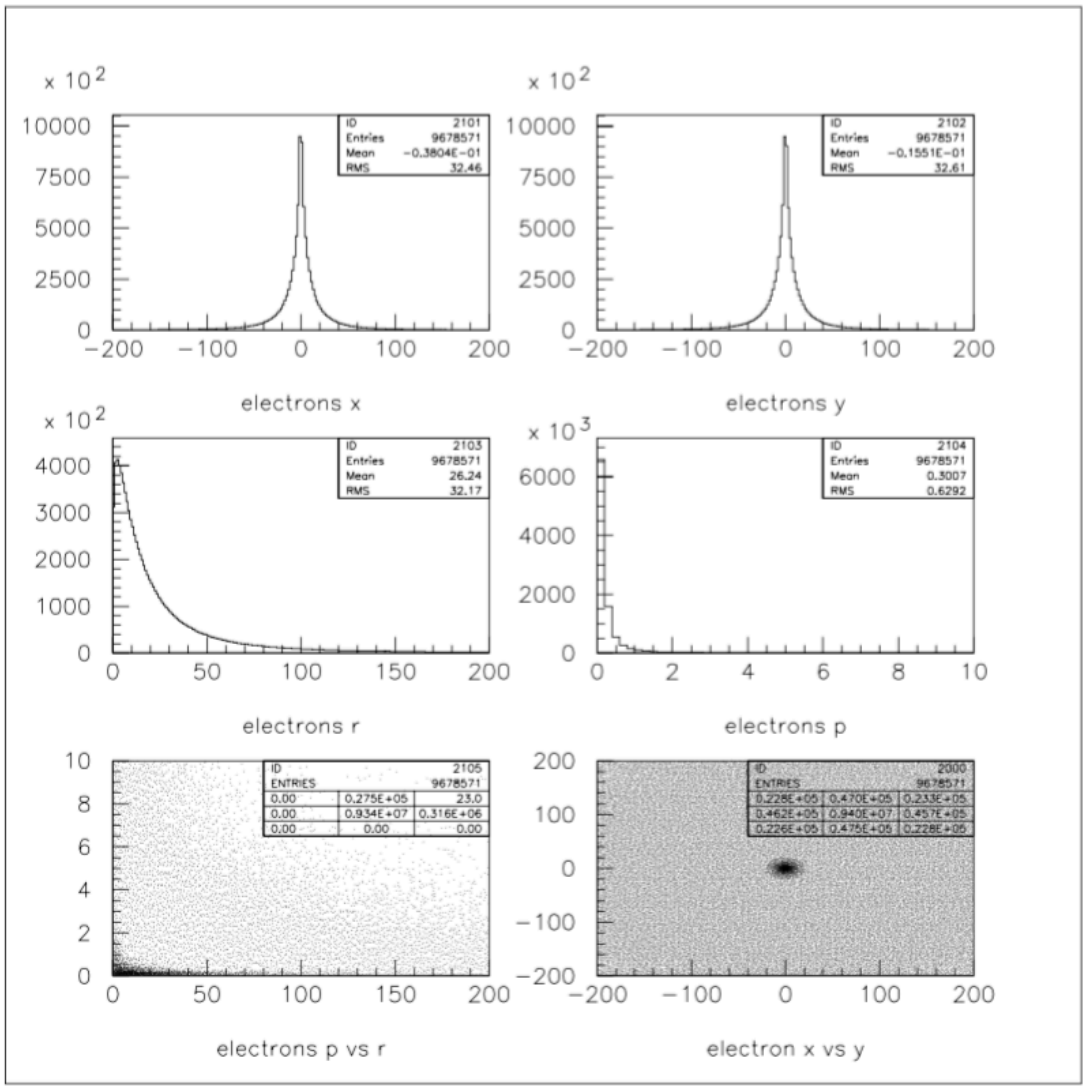

Figure 3.10. One-dimensional plots of x and y (top left and right), r and p (center left and right), two-dimensional plots of x-y and p-r (bottom left and right) of electrons and positrons for $5x10^{16}$ eV proton shower with ECUT II.

Gammas

Figure 3.11 shows gamma profile of the shower. There are a total of 25729680 gammas in five shower. Mean value of the x distribution is $-0.2160x10^{-01}$ with RMS of 43.68 while mean value of y distribution is $0.5816x10^{-01}$ with 43.88 RMS. The core of the shower can be seen from the 2-Dimensional plot of x vs y which is at the bottom right corner of figure 3.11. R distribution (distance from shower center) of the shower is given at the middle left of figure 3.11. As one can see from the R distribution plot most of the gammas are inside a circle with radius 50 meter. This could be more clear from the table 3.11 that 80% of them are in 30 m, 90% them are in 50 m and 94% of

them are in 100 m. Middle right plot in figure 3.11 shows momentum distribution of gamma in the shower. Average momentum of them is 0.2436 GeV and most of them have a momentum of 2 GeV or less. Bottom left plot in figure 3.11 is the 2-Dimensional plot of momentum vs distance from the center of shower. Gammas with momentum less than 1 GeV are populated around distance less than 20m. The rest of particles are spread around.

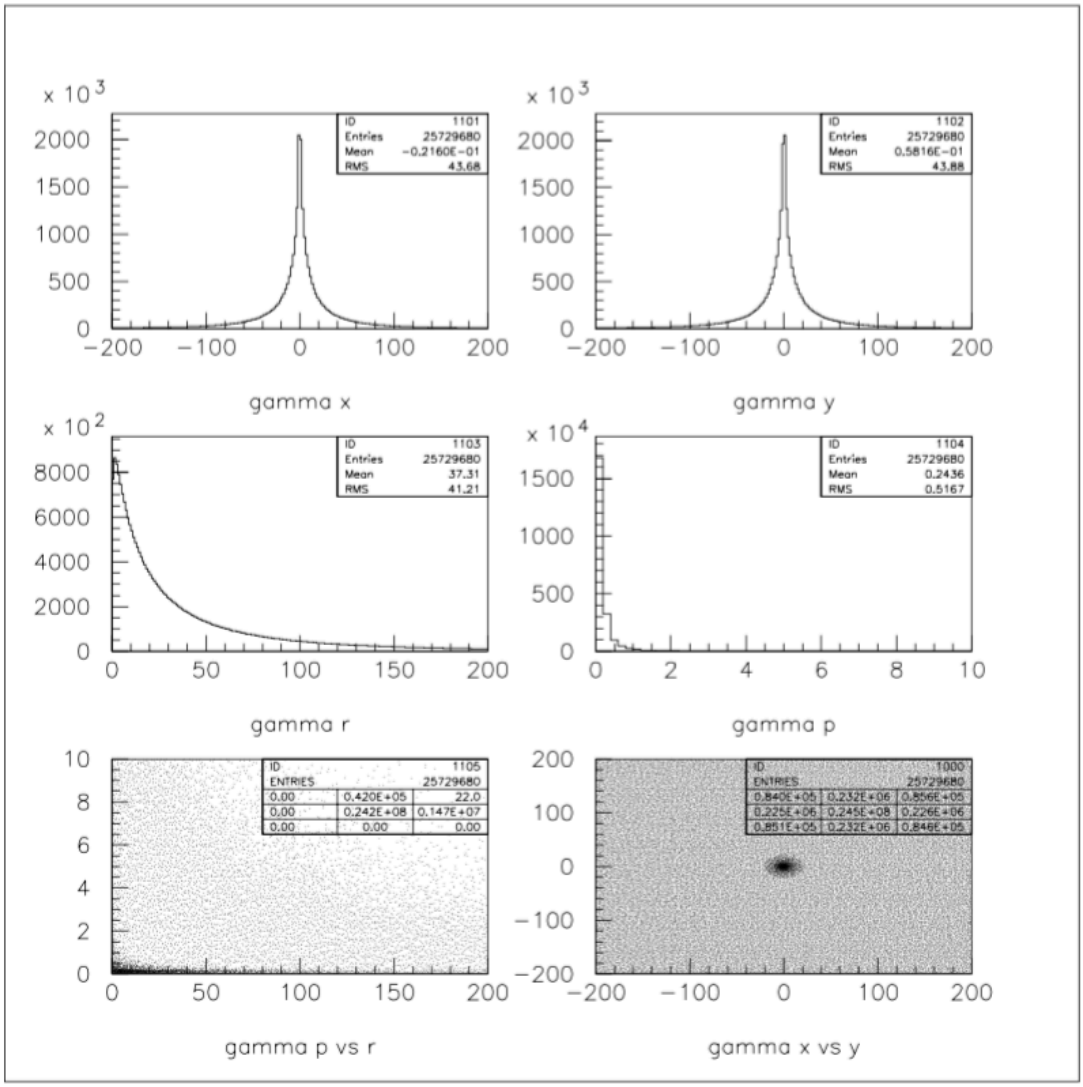

Figure 3.11. One-dimensional plots of x and y (top left and right), r and p (center left and right), two-dimensional plots of x-y and p-r (bottom left and right) of gammas for $5x10^{16}$ eV proton shower with ECUT II

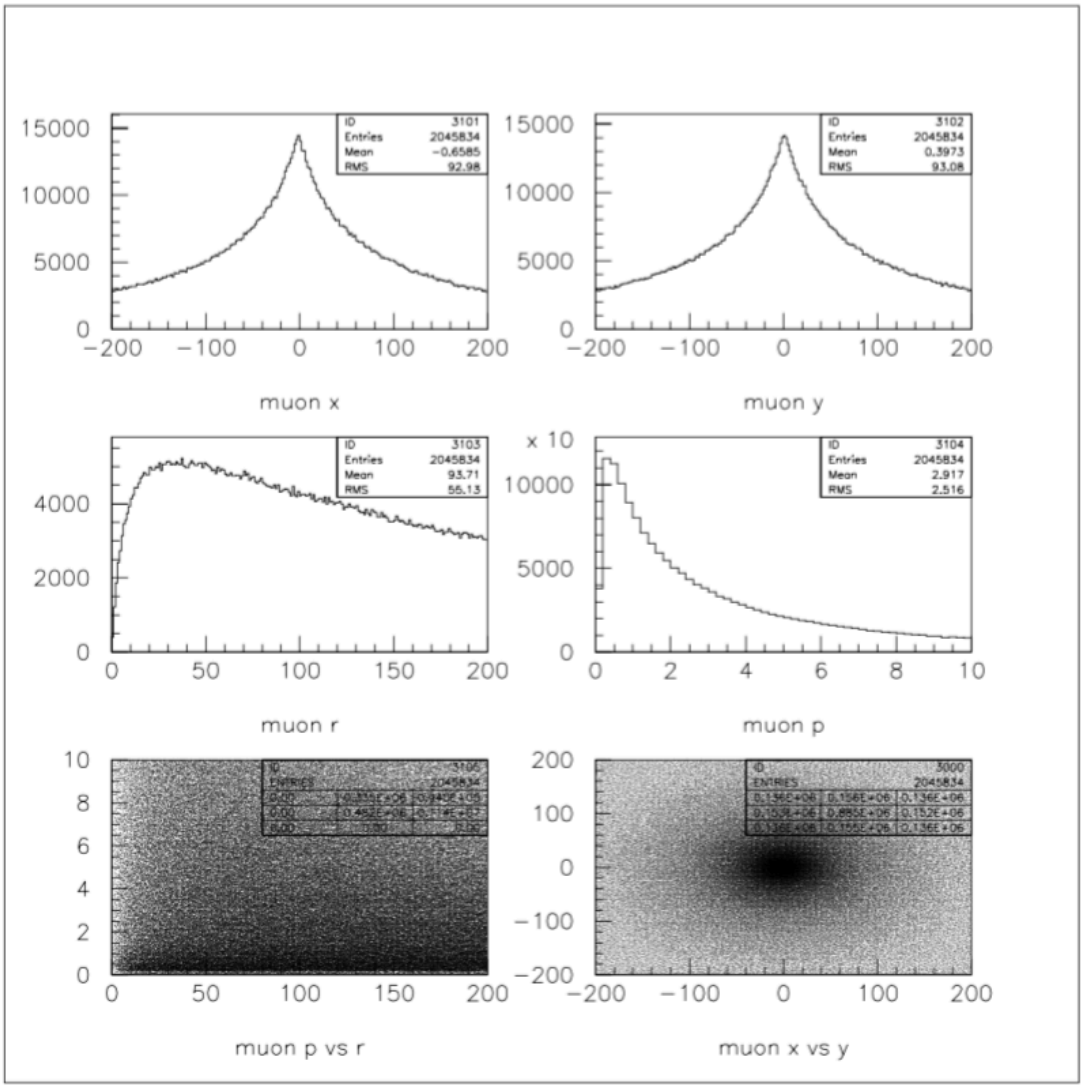

Figure 3.12. One-dimensional plots of x and y (top left and right), r and p (center left and right), two-dimensional plots of x-y and p-r (bottom left and right) of muons for $5x10^{16}$ eV proton shower with ECUT II.

Figure 3.12 shows muon profile of the shower. There are a total of 2045834 muons in five shower. Mean value of the x distribution is -0.6585 with RMS of 92.98 while mean value of y distribution is 0.3973 with 93.08 RMS. The core of the shower can be seen from the 2-Dimensional plot of x vs y which is at the bottom right corner of figure 3.12. R distribution (distance from shower center) of the shower is given at the middle left of figure 3.12. As one can see from the R distribution plot most of the muons are inside a circle with radius 50 meter. This could be more clear from the table 3.12 that 80% of them are in 30 m, 90% them are in 50 m and 94% of them are in 100

m. Middle right plot in figure 3.12 shows momentum distribution of muon in the shower. Average momentum of them is 2.917 GeV and most of them have a momentum of 2 GeV or less. Bottom left plot in figure 3.12 is the 2-Dimensional plot of momentum vs distance from the center of shower. Muons with momentum less than 1 GeV are populated around distance less than 20m. The rest of particles are spread around.

Energy cut III

In the following section, shower of $5x10^{16}$ eV proton is simulated by CORSIKA with energy cut 0.3 0.1 0.05 0.05 GeV. This corresponds to 0.3 GeV for hadrons, 0.1 GeV for muons, 0.05 GeV for electrons and 0.05 GeV for photons. 43678956 particles produced in this shower in which 25% of them are electrons, 67% of them gammas, 4% of them muons and 4% of them are other particles such as kaons, pions, neutron, protons etc.

Electrons and positrons

Figure 3.13 shows e^- and e^+ profile of the shower. There are a total of 10851652 e^- and e^+ in five shower. Mean value of the x distribution is $-0.4169x10^{-01}$ with RMS of 31.31 while mean value of y distribution is $0.7503x10^{-02}$ with 31.50 RMS. The core of the shower can be seen from the 2-Dimensional plot of x vs y which is at the bottom right corner of figure 3.13. R distribution (distance from shower center) of the shower is given at the middle left of figure 3.13. As one can see from the R distribution plot most of the e^- and e^+ are inside a circle with radius 50 meter. This could be more clear from the table 3.13 that 80% of them are in 30 m, 90% them are in 50 m and 94% of them are in 100 m. Middle right plot in figure 3.13 shows momentum distribution of e^- and e^+ in the shower. Average momentum of them is 0.2863 GeV and most of them have a momentum of 2 GeV or less. Bottom left plot in figure 3.13 is the 2-Dimensional plot of momentum vs distance from the center of shower. e^- and e^+ with momentum less than 1 GeV are populated around distance less than 20m. The rest of particles are spread around.

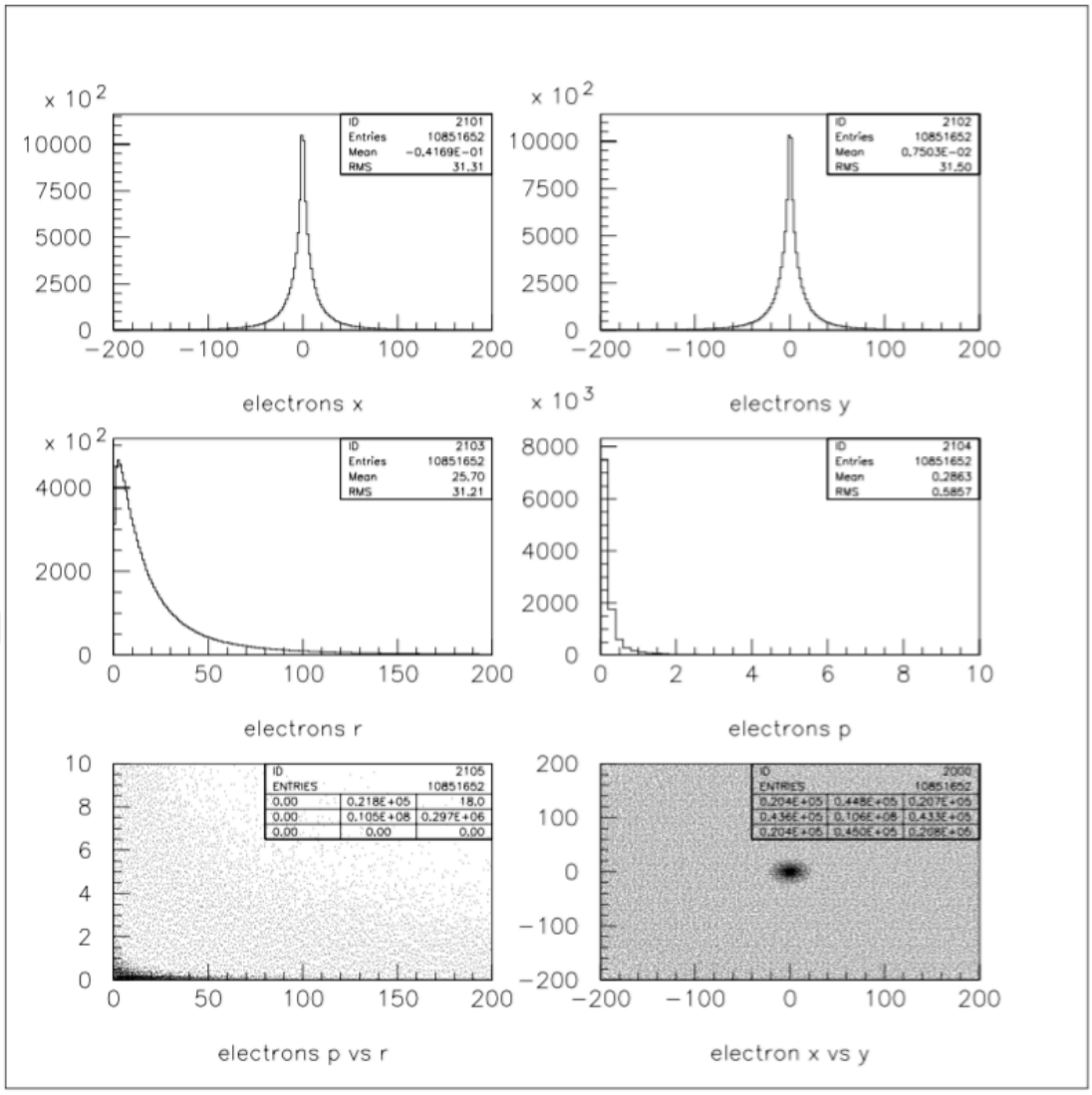

Figure 3.13. One-dimensional plots of x and y (top left and right), r and p (center left and right), two-dimensional plots of x-y and p-r (bottom left and right) of electrons and positrons for $5x10^{16}$ eV proton shower with ECUT III

Gammas

Figure 3.14 shows gamma profile of the shower. There are a total of 29252480 gammas in five shower. Mean value of the x distribution is $-0.1894x10^{-01}$ with RMS of 42.91 while mean value of y distribution is $0.5184x10^{-01}$ with 43.13 RMS. The core of the shower can be seen from the 2-Dimensional plot of x vs y which is at the bottom right corner of figure 3.14. R distribution (distance from shower center) of the shower is given at the middle left of figure 3.14. As one can see from the R distribution plot most of the gammas are inside a circle with radius 50 meter. This could be more clear

from the table 3.14 that 80% of them are in 30 m, 90% them are in 50 m and 94% of them are in 100 m.

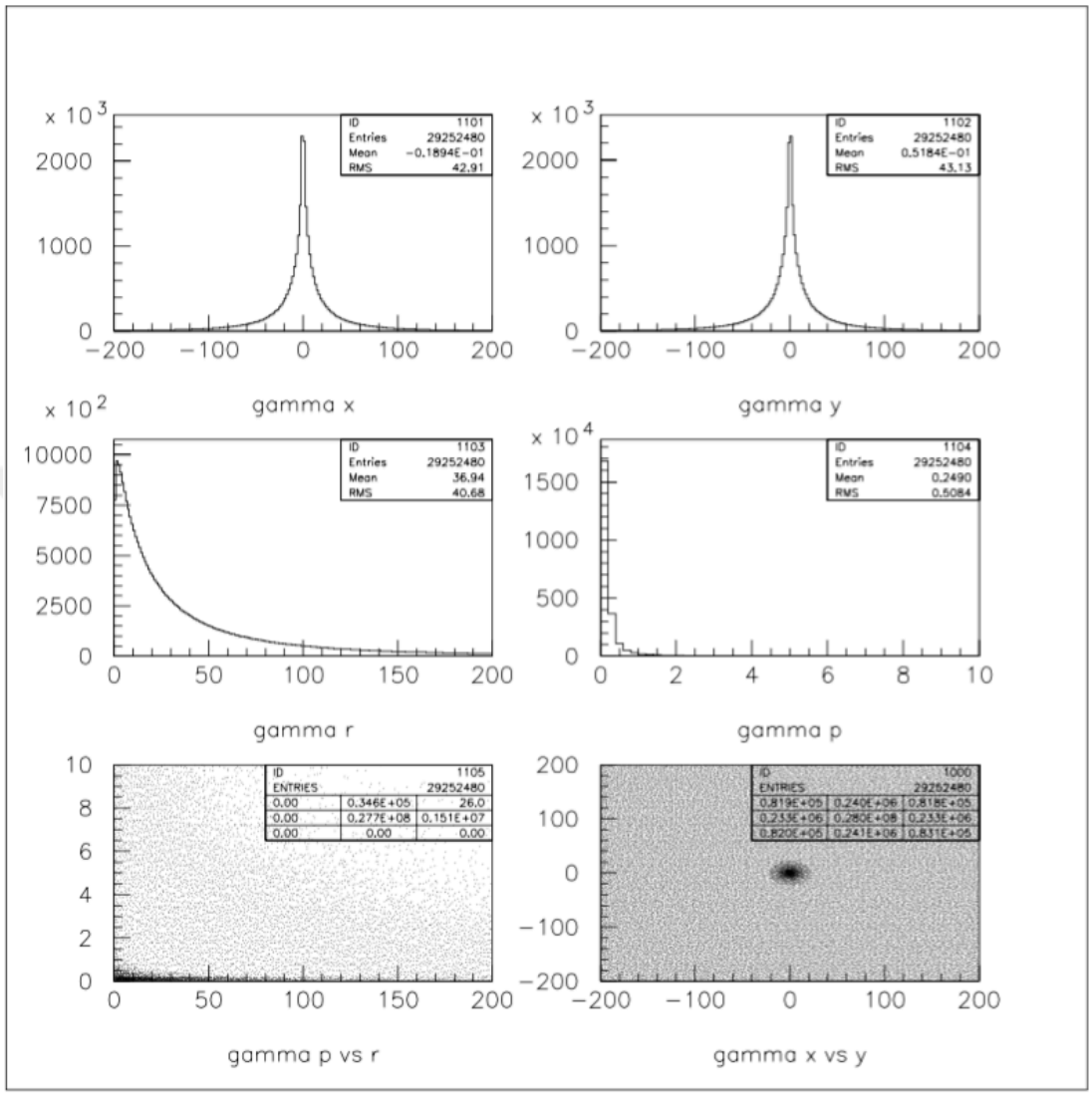

Figure 3.14. One-dimensional plots of x and y (top left and right), r and p (center left and right), two-dimensional plots of x-y and p-r (bottom left and right) of gammas for $5x10^{16}$ eV proton shower with ECUT III.

Middle right plot in figure 3.14 shows momentum distribution of gamma in the shower. Average momentum of them is 0.2490 GeV and most of them have a momentum of 2 GeV or less. Bottom left plot in figure 3.14 is the 2-Dimensional plot of momentum vs distance from the center of shower. Gammas with momentum less

than 1 GeV are populated around distance less than 20m. The rest of particles are spread around.

Muons

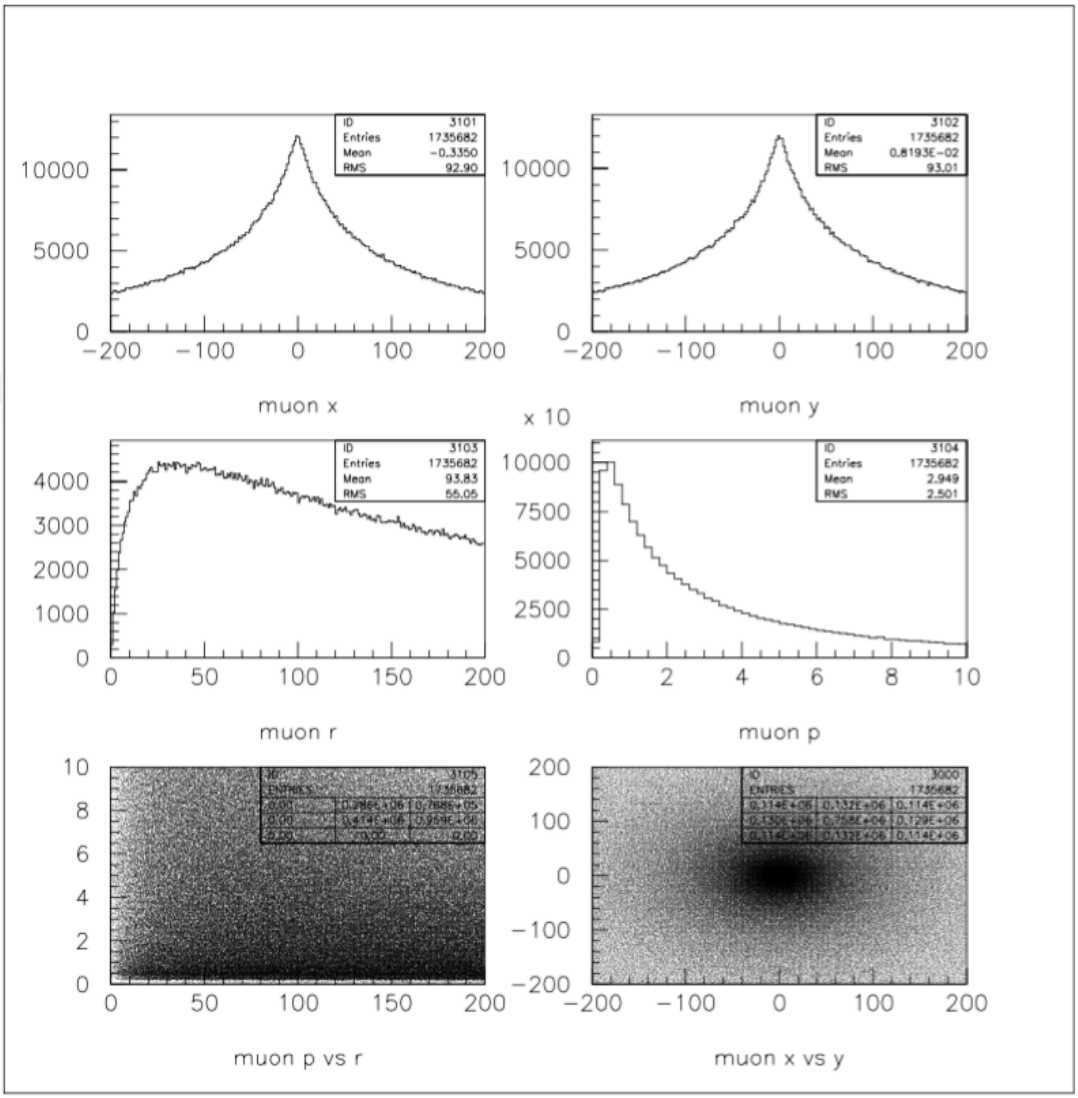

Figure 3.15. One-dimensional plots of x and y (top left and right), r and p (center left and right), two-dimensional plots of x-y and p-r (bottom left and right) of muons for $5x10^{16}$ eV proton shower with ECUT III

Figure 3.15 shows muon profile of the shower. There are a total of 1735682 muons in five shower. Mean value of the x distribution is -0.3350 with RMS of 92.90 while mean value of y distribution is $0.8193x10^{-02}$ with 93.01 RMS. The core of the shower can be seen from the 2-Dimensional plot of x vs y which is at the bottom right corner of figure 3.15. R distribution (distance from shower center) of the shower is

given at the middle left of figure 3.15. As one can see from the R distribution plot most of the are inside a circle with radius 50 meter. This could be more clear from the table 3.15 that 80% of them are in 30 m, 90% them are in 50 m and 94% of them are in 100 m. Middle right plot in figure 3.15 shows momentum distribution of muon in the shower. Average momentum of them is 2.949 GeV and most of them have a momentum of 2 GeV or less. Bottom left plot in figure 3.15 is the 2-Dimensional plot of momentum vs distance from the center of shower. Muons with momentum less than 1 GeV are populated around distance less than 20m. The rest of particles are spread around.

3.4.1.2 Momentum analysis

Energy cut II

Electrons and positrons

Average of 24% of total particles produced in a shower are e^- and e^+. 87% of these e^- and e^+ have momentum less than 500 MeV. Since we have a cut of 0.15 GeV for EM components. 58% of e^- and e^+ have momentum between 0 MeV and 150 MeV, 16% of them between 150 MeV and 250 MeV. 8% of them between 250 MeV and 350 MeV. 4% of them between 350 MeV and 450 MeV, and 3% of them between 450 MeV and 550 MeV.

Table 3.10. Total number of electrons and positrons in five different shower for different momentum interval for primary Proton particle in ECUT II

	Total #	100 m	50 m	30 m
Total # of particles	39798680			
Final # of electrons	9678571	7336051	6719013	5530470
P < 500 MeV	8504934	6206377	5621433	4496558
P > 500 MeV	1173637	1129674	1097580	1033912
0 < P < 150 MeV	5626046	3591183	3166418	2406188
150 < P < 250 MeV	1579226	1397081	1295910	1070535
250 < P < 350 MeV	731480	681294	645154	558908
350 < P < 450 MeV	419834	396057	378774	338231
450 < P < 550 MeV	268518	255106	245352	223633

This numbers are approximately same (less than 1% charge) if we define a shower core with 100 m radius, 50 m radius, 30 m radius and evaluate the percentage.

For core with 100 m radius, 75% of total e^- and e^+ are inside the core. 85% of those have momentum less than 500 MeV while 49% between 0 MeV and 150 MeV, 19% of them between 150 MeV and 250 MeV. 9% of them between 250 MeV and 350 MeV. 5% between 350 MeV and 450 MeV, and 3% between 450 MeV and 550 MeV.

For core with 50 m radius, 69% of total e^- and e^+ are inside the core. 84% of those have momentum less than 500 MeV while 47% between 0 MeV and 150 MeV, 19% of them between 150 MeV and 250 MeV. 10% of them between 250 MeV and 350 MeV. 6% between 350 MeV and 450 MeV, and 4% between 450 MeV and 550 MeV.

For core with 30 m radius, 57% of e^- and e^+ are inside the core. 81% of those have momentum less than 500 MeV while 44% between 0 MeV and 150MeV, 19% of them between 150 MeV and 250 MeV. 10% of them between 250 MeV and 350 MeV. 6% between 350 MeV and 450 MeV, and 4% between 450 MeV and 550 MeV.

Gammas

Average of 65% of total particles produced in a shower are gammas. 93% of these gammas have momentum less than 500 MeV. Since we have a cut of 0.15 GeV for EM components. 69% of gammas have momentum between 0 MeV and 150 MeV, 14% of them between 150 MeV and 250 MeV. 6% of them between 250 MeV and 350 MeV. 3% of them between 350 MeV and 450 MeV, and 2% of them between 450 MeV and 550 MeV. This numbers are approximately same (less than 1% charge) if we define a shower core with 100 m radius, 50 m radius, 30 m radius and evaluate the percentage.

For core with 100 m radius, 83% of total gammas are inside the core. 91% of those have momentum less than 500 MeV while 65% between 0 MeV and 150 MeV, 15% of them between 150 MeV and 250 MeV. 6% of them between 250 MeV and 350 MeV. 3% between 350 MeV and 450 MeV, and 2% between 450 MeV and 550 MeV.

Table 3.11. Total number of gammas in five different shower for different momentum interval for primary Proton particle in ECUT II

	Total #	100 m	50 m	30 m
Total # of particles	39798680			
Final # of gammas	25729680	21257095	17742184	13055046
P < 500 MeV	23804703	19412432	15965062	11422886
P > 500 MeV	1924977	1844663	1777122	1632160
0 < P < 150 MeV	17710097	13843961	11013998	7519840
150 < P < 250 MeV	3587665	3227683	2803276	2128615
250 < P < 350 MeV	1460691	1355955	1230186	995919
350 < P < 450 MeV	780277	733449	681367	574647
450 < P < 550 MeV	480002	454189	427992	371501

For core with 50 m radius, 69% of total gammas are inside the core. 90% of those have momentum less than 500 MeV while 62% between 0 MeV and 150 MeV, 16% of them between 150 MeV and 250 MeV. 7% of them between 250 MeV and 350 MeV. 4% between 350 MeV and 450 MeV, and 2% between 450 MeV and 550 MeV.

For core with 30 m radius, 51% of total gammas are inside the core. 87% of those have momentum less than 500 MeV while 58% between 0 MeV and 150 MeV, 16% of them between 150 MeV and 250 MeV. 8% of them between 250 MeV and 350 MeV. 4% between 350 MeV and 450 MeV, and 3% between 450 MeV and 550 MeV.

Muons

Average of 5% of total particles produced in a shower are muons. 10% of these muons have momentum less than 500 MeV. Since we have a cut of 0.15 GeV for EM components. 1% of muons have momentum between 0 MeV and 150 MeV, 16% of them between 150 MeV and 250 MeV. 3% of them between 250 MeV and 350 MeV. 3% of them between 350 MeV and 450 MeV, and 3% of them between 450 MeV and 550 MeV. This numbers are approximately same (less than 1% charge) if we define a shower core with 100 m radius, 50 m radius, 30 m radius and evaluate the percentage.

Table 3.12. Total number of muons in five different shower for different momentum interval for primary Proton particle in ECUT II

	Total #	100 m	50 m	30 m
Total # of particles	39798680			
Final # of muons	25729680	21257095	17742184	13055046
P < 500 MeV	23804703	19412432	15965062	11422886
P > 500 MeV	1924977	1844663	1777122	1632160
0 < P < 150 MeV	17710097	13843961	11013998	7519840
150 < P < 250 MeV	3587665	3227683	2803276	2128615
250 < P < 350 MeV	1460691	1355955	1230186	995919
350 < P < 450 MeV	780277	733449	681367	574647
450 < P < 550 MeV	480002	454189	427992	371501

For core with 100 m radius, 21% of total muons are inside the core. 2% of those have momentum less than 500 MeV while 0.1% between 0 MeV and 150 MeV, 0.3% of them between 150 MeV and 250 MeV. 1% of them between 250 MeV and 350 MeV. 1% between 350 MeV and 450 MeV, and 1% between 450 MeV and 550 MeV.

For core with 50 m radius, 10% of total muons are inside the core. 2% of those have momentum less than 500 MeV while 0.1% between 0 MeV and 150 MeV, 0.4% of them between 150 MeV and 250 MeV. 1% of them between 250MeV and 350 MeV. 1% between 350 MeV and 450 MeV, and 1% between 450 MeV and 550 MeV.

For core with 30 m radius, 5% of total muons are inside the core. 2% of those have momentum less than 500 MeV while 0.1% between 0 MeV and 150 MeV, 0.4% of them between 150 MeV and 250 MeV. 1% of them between 250 MeV and 350 MeV. 1% between 350 MeV and 450 MeV, and 1% between 450MeV and 550 MeV.

Energy cut III

Electrons and positrons

Average of 25% of total particles produced in a shower are e^- and e^+. 89% of these e^- and e^+ have momentum less than 500 MeV. Since we have a cut of 0.15 GeV for EM components. 59% of e^- and e^+ have momentum between 0 MeV and 150 MeV, 16% of them between 150 MeV and 250 MeV. 7% of them between 250 MeV and 350 MeV. 4% of them between 350 MeV and 450 MeV, and 3% of them between 450 MeV and 550 MeV. This numbers are approximately same (less than 1% charge) if we define a shower core with 100 m radius, 50 m radius, 30 m radius and evaluate the percentage.

For core with 100 m radius, 76% of total e^- and e^+ are inside the core. 85% of those have momentum less than 500 MeV while 50% between 0 MeV and 150 MeV, 19% of them between 150 MeV and 250 MeV. 9% of them between 250 MeV and 350 MeV. 5% between 350 MeV and 450 MeV, and 3% between 450 MeV and 550 MeV.

Table 3.13. Total number of electrons and positrons in five different shower for different momentum interval for primary Proton particle in ECUT III

	Total #	100 m	50 m	30 m
Total # of particles	43678956			
Final # of electrons	10851652	8275651	7604284	6261558
P < 500 MeV	9611569	7074121	6432444	5152879
P > 500 MeV	1240083	1201530	1171840	1108679
0 < P < 150 MeV	6395495	4122549	3647759	2774357
150 < P < 250 MeV	1777248	1589079	1481489	1227621
250 < P < 350 MeV	812509	764708	727832	632815
350 < P < 450 MeV	463987	442315	425188	381191
450 < P < 550 MeV	295072	282808	273488	250354

For core with 50 m radius, 70% of total e^- and e^+ are inside the core. 85% of those have momentum less than 500 MeV while 48% between 0 MeV and 150 MeV, 19% of them between 150 MeV and 250 MeV. 10% of them between 250 MeV and 350 MeV. 6% between 350 MeV and 450 MeV, and 4% between 450 MeV and 550 MeV.

For core with 30 m radius, 58% of total e^- and e^+ are inside the core. 82% of those have momentum less than 500 MeV while 44% between 0 MeV and 150 MeV, 20% of them between 150 MeV and 250 MeV. 10% of them between 250 MeV and 350 MeV. 6% between 350 MeV and 450 MeV, and 4% between 450 MeV and 550 MeV.

Gammas

Average of 67% of total particles produced in a shower are gammas. 93% of these gammas have momentum less than 500 MeV. Since we have a cut of 0.15 GeV for EM components. 69% of gammas have momentum between 0 MeV and 150 MeV, 14% of them between 150 MeV and 250 MeV. 6% of them between 250 MeV and 350 MeV. 3% of them between 350 MeV and 450 MeV, and 2% of them between 450 MeV and 550 MeV. This numbers are approximately same (less than 1% charge) if we

define a shower core with 100 m radius, 50 m radius, 30 m radius and evaluate the percentage.

Table 3.14. Total number of gammas in five different shower for different momentum interval for primary Proton particle in ECUT III

	Total #	100 m	50 m	30 m
Total # of particles	43678956			
Final # of gammas	29252480	24396667	20400360	14978867
P < 500 MeV	27180718	22396931	18465575	13196638
P > 500 MeV	2071762	1999736	1934785	1782229
0 < P < 150 MeV	20292890	16036835	12789970	8720425
150 < P < 250 MeV	4071149	3702023	3226155	2450600
250 < P < 350 MeV	1647466	1546362	1408548	1141085
350 < P < 450 MeV	873204	829315	774253	653667
450 < P < 550 MeV	533712	509574	482582	419971

For core with 100 m radius, 83% of total gammas are inside the core. 92% of those have momentum less than 500 MeV while 66% between 0 MeV and 150 MeV, 15% of them between 150 MeV and 250 MeV. 6% of them between 250 MeV and 350 MeV. 3% between 350 MeV and 450 MeV, and 2% between 450 MeV and 550 MeV.

For core with 50 m radius, 70% of total gammas are inside the core. 91% of those have momentum less than 500 MeV while 63% between 0 MeV and 150 MeV, 16% of them between 150 MeV and 250 MeV. 7% of them between 250 MeV and 350 MeV. 4% between 350 MeV and 450 MeV, and 2% between 450 MeV and 550 MeV.

For core with 30 m radius, 51% of total gammas are inside the core. 88% of those have momentum less than 500 MeV while 58% between 0 MeV and 150 MeV, 6% of them between 150 MeV and 250 MeV. 8% of them between 250 MeV and 350 MeV. 4% between 350 MeV and 450 MeV, and 3% between 450 MeV and 550 MeV.

Muons

Average of 4% of total particles produced in a shower are muons. 9% of these muons have momentum less than 500 MeV. Since we have a cut of 0.15 GeV for EM

components, we did not see any muon with momentum less than 150 MeV 2% of them between 150 MeV and 250 MeV. 3% of them between 250 MeV and 350 MeV. 3% of them between 350 MeV and 450 MeV, and 3% of them between 450 MeV and 550 MeV. This numbers are approximately same (less than 1% charge) if we define a shower core with 100 m radius, 50 m radius, 30 m radius and evaluate the percentage.

Table 3.15. Total number of muons in five different shower for different momentum interval for primary Proton particle in ECUT III

	Total #	100 m	50 m	30 m
Total # of particles	43678956			
Final # of muons	1735682	366389	181690	79113
P < 500 MeV	155622	5281	2405	981
P > 500 MeV	1580060	361108	179285	78132
150 < P < 250 MeV	28535	582	223	77
250 < P < 350 MeV	49386	1630	732	301
350 < P < 450 MeV	52232	2074	997	417
450 < P < 550 MeV	50204	2094	945	394

For core with 100 m radius, 21% of total muons are inside the core. 1% of those have momentum less than 500 MeV while 0.2% of them between 150 MeV and 250 MeV. 0.4% of them between 250 MeV and 350 MeV. 1% between 350 MeV and 450 MeV, and 1% between 450 MeV and 550 MeV.

For core with 50 m radius, 10% of total muons are inside the core. 1% of those have momentum less than 500 MeV while 0.1% of them between 150 MeV and 250 MeV. 0.4% of them between 250 MeV and 350 MeV. 1% between 350 MeV and 450 MeV, and 1% between 450 MeV and 550 MeV.

For core with 30 m radius, 5% of total muons are inside the core. 1% of those have momentum less than 500 MeV while 0.1% of them between 150 MeV and 250 MeV. 0.4% of them between 250 MeV and 350 MeV. 1% between 350 MeV and 450 MeV, and 1% between 450 MeV and 550 MeV.

3.4.2 Carbon analysis

3.4.2.1 Profile of showers

Energy cut II

In this section, shower of $5x10^{16}$ eV carbon is simulated by CORSIKA with energy cut 0.05 0.05 0.05 0.05 GeV. This corresponds to 0.05 GeV for hadrons, 0.05 GeV for muons, 0.05 GeV for electrons and 0.05 GeV for photons. 40883728 particles produced in this shower in which 24% of them are electrons, 63% of them gammas, 6% of them muons and 7% of them are other particles such as kaons, pions, neutron, protons etc.

Electrons and positrons

Figure 3.16 shows e^- and e^+ profile of the shower. There are a total of 9739116 e^- and e^+ in five shower. Mean value of the x distribution is $-0.4167x10^{-01}$ with RMS of 33.77 while mean value of y distribution is $0.1586x10^{-01}$ with 33.96 RMS. The core of the shower can be seen from the 2-Dimensional plot of x vs y which is at the bottom right corner of figure 3.16. R distribution (distance from shower center) of the shower is given at the middle left of figure 3.16. As one can see from the R distribution plot most of the e^- and e^+ are inside a circle with radius 50 meter. This could be more clear from the table 3.16 that 80% of them are in 30 m, 90% them are in 50 m and 94% of them are in 100 m. Middle right plot in figure 3.7 shows momentum distribution of e^- and e^+ in the shower. Average momentum of them is 0.2929 GeV and most of them have a momentum of 2 GeV or less. Bottom left plot in figure 3.16 is the 2-Dimensional plot of momentum vs distance from the center of shower. e^- and e^+ with momentum less than 1 GeV are populated around distance less than 20m. The rest of particles are spread around.

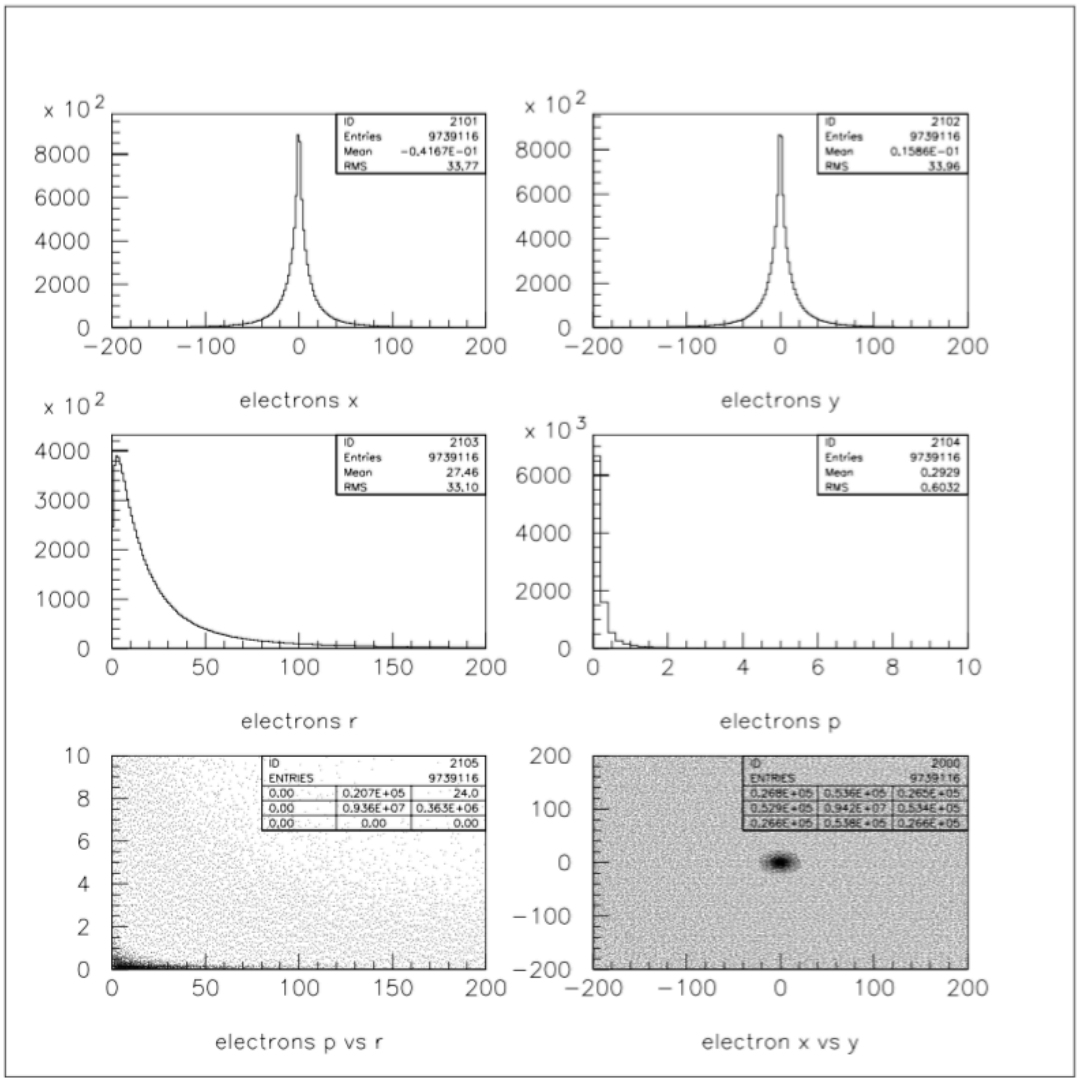

Figure 3.16. One-dimensional plots of x and y (top left and right), r and p (center left and right), two-dimensional plots of x-y and p-r (bottom left and right) of electrons and positrons for $5x10^{16}$ eV carbon shower with ECUT II.

Gammas

Figure 3.17 shows gamma profile of the shower. There are a total of 25933606 gammas in five shower. Mean value of the x distribution is $-0.1850x10^{-01}$ with RMS of 44.44 while mean value of y distribution is $0.1903x10^{-01}$ with 44.67 RMS. The core of the shower can be seen from the 2-Dimensional plot of x vs y which is at the bottom right corner of figure 3.17. R distribution (distance from shower center) of the shower is given at the middle left of figure 3.17. As one can see from the R distribution plot most of the gammas are inside a circle with radius 50 meter. This could be more clear

from the table 3.17 that 80% of them are in 30 m, 90% them are in 50 m and 94% of them are in 100 m.

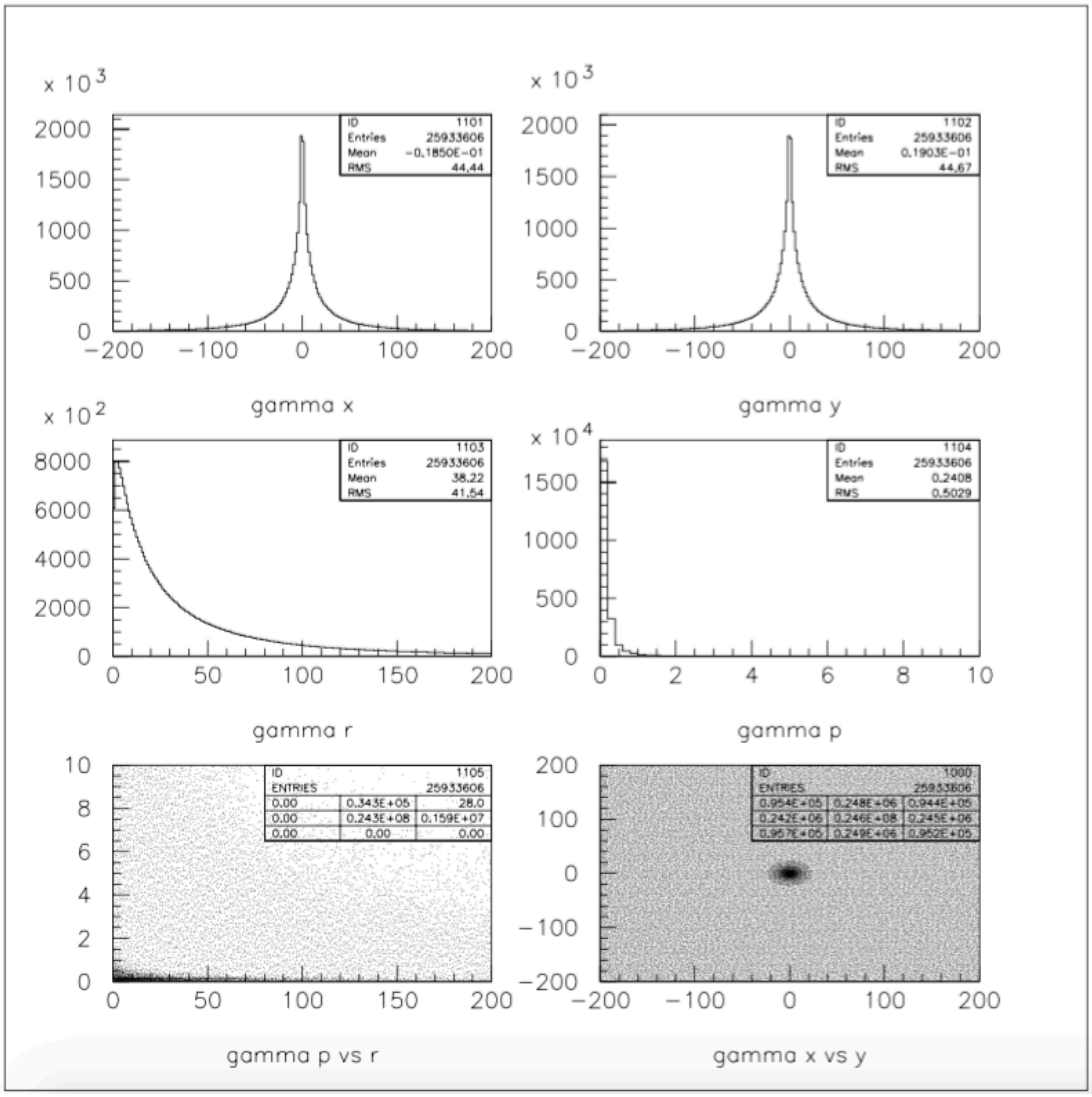

Figure 3.17. One-dimensional plots of x and y (top left and right), r and p (center left and right), two-dimensional plots of x-y and p-r (bottom left and right) of gammas for $5x10^{16}$ eV carbon shower with ECUT II

Middle right plot in figure 3.17 shows momentum distribution of gamma in the shower. Average momentum of them is 0.24.08 GeV and most of them have a momentum of 2 GeV or less. Bottom left plot in figure 3.17 is the 2-Dimensional plot of momentum vs distance from the center of shower. Gammas with momentum less than 1 GeV are populated around distance less than 20m. The rest of particles are spread around.

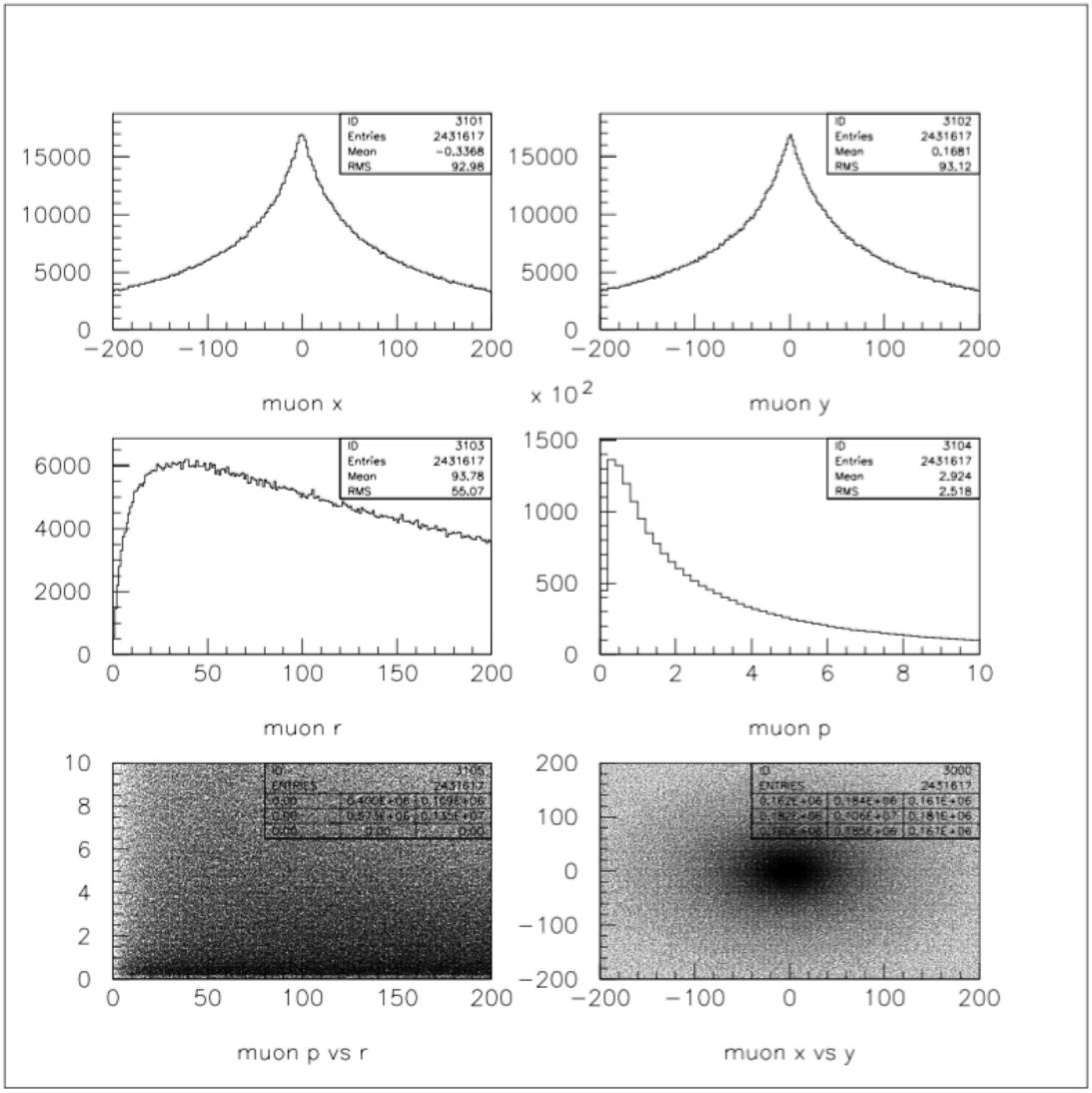

Figure 3.18. One-dimensional plots of x and y (top left and right), r and p (center left and right), two-dimensional plots of x-y and p-r (bottom left and right) of muons for $5x10^{16}$ eV carbon shower with ECUT II

Figure 3.18 shows muon profile of the shower. There are a total of 2431617 muons in five shower. Mean value of the x distribution is -0.3368 with RMS of 92.98 while mean value of y distribution is 0.1681 with 93.12 RMS. The core of the shower can be seen from the 2-Dimensional plot of x vs y which is at the bottom right corner of figure 3.18. R distribution (distance from shower center) of the shower is given at the middle left of figure 3.18. As one can see from the R distribution plot most of the muons are inside a circle with radius 50 meter. This could be more clear from the table 3.18 that 80% of them are in 30 m, 90% them are in 50 m and 94% of them are in 100

m. Middle right plot in figure 3.18 shows momentum distribution of muon in the shower. Average momentum of them is 2.924 GeV and most of them have a momentum of 2 GeV or less. Bottom left plot in figure 3.18 is the 2-Dimensional plot of momentum vs distance from the center of shower. Muons with momentum less than 1 GeV are populated around distance less than 20m. The rest of particles are spread around.

Energy cut III

In the following section, shower of $5x10^{16}$ eV carbon is simulated by CORSIKA with energy cut 0.3 0.1 0.05 0.05 GeV. This corresponds to 0.3 GeV for hadrons, 0.1 GeV for muons, 0.05 GeV for electrons and 0.05 GeV for photons. 42718152 particles produced in this shower in which 25% of them are electrons, 64% of them gammas, 6% of them muons and 5% of them are other particles such as kaons, pions, neutron, protons etc.

Electrons and positrons

Figure 3.19 shows e^- and e^+ profile of the shower. There are a total of 10490980 e^- and e^+ in five shower. Mean value of the x distribution is $-0.2949x10^{-01}$ with RMS of 32.72 while mean value of y distribution is $0.1549x10^{-02}$ with 32.95 RMS. The core of the shower can be seen from the 2-Dimensional plot of x vs y which is at the bottom right corner of figure 3.19. R distribution (distance from shower center) of the shower is given at the middle left of figure 3.19. As one can see from the R distribution plot most of the e^- and e^+ are inside a circle with radius 50 meter. This could be more clear from the table 3.19 that 80% of them are in 30 m, 90% them are in 50 m and 94% of them are in 100 m. Middle right plot in figure 3.19 shows momentum distribution of e^- and e^+ in the shower. Average momentum of them is 0.3074 GeV and most of them have a momentum of 2 GeV or less. Bottom left plot in figure 3.19 is the 2-Dimensional plot of momentum vs distance from the center of shower. e^- and e^+ with momentum less than 1 GeV are populated around distance less than 20m. The rest of particles are spread around.

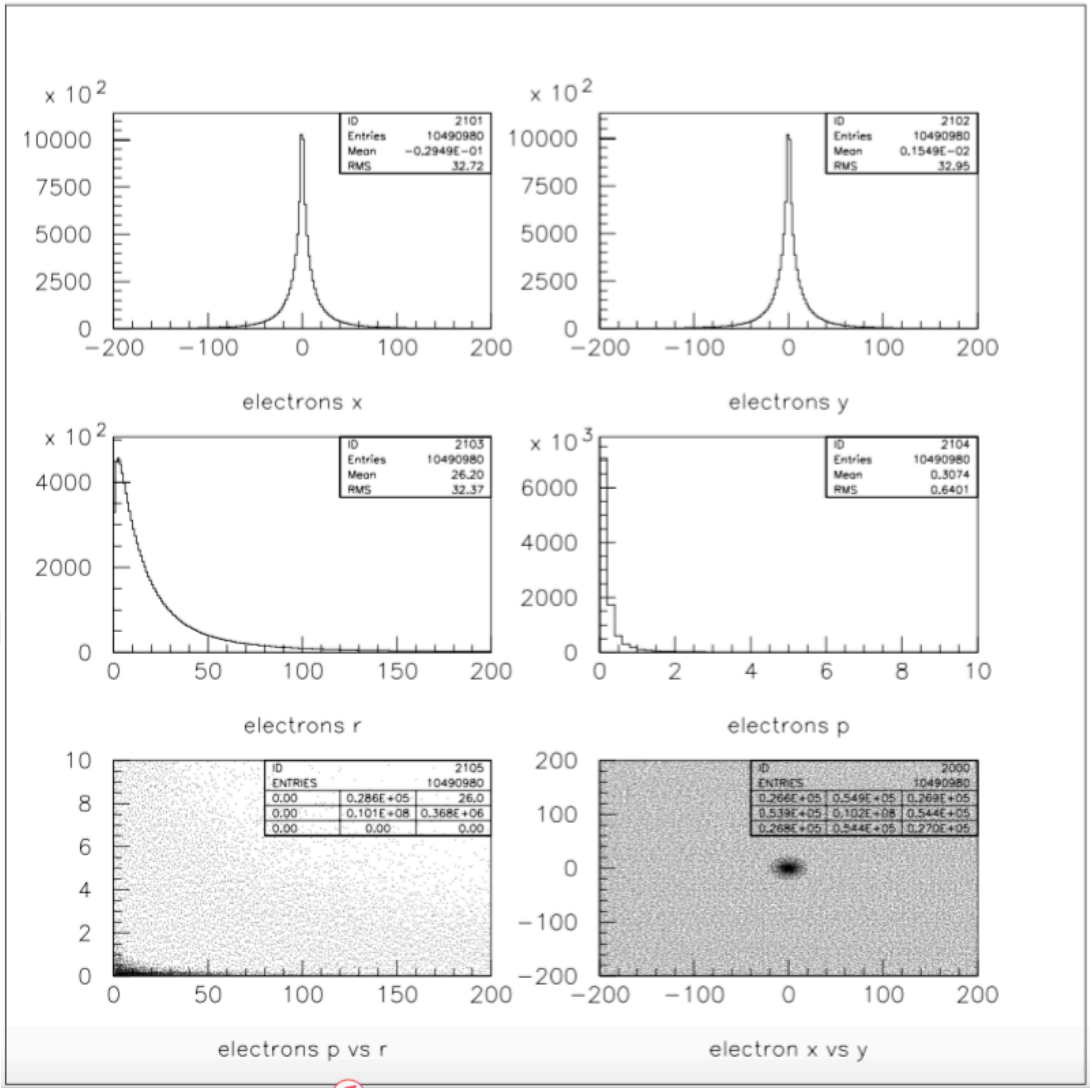

Figure 3.19. One-dimensional plots of x and y (top left and right), r and p (center left and right), two-dimensional plots of x-y and p-r (bottom left and right) of electrons and positrons for $5x10^{16}$ eV carbon shower with ECUT III

Gammas

Figure 3.20 shows gamma profile of the shower. There are a total of 27272935 gammas in five shower. Mean value of the x distribution is $-0.4648x10^{-01}$ with RMS of 43.17 while mean value of y distribution is $0.2772x10^{-01}$ with 43.42 RMS. The core of the shower can be seen from the 2-Dimensional plot of x vs y which is at the bottom right corner of figure 3.20.

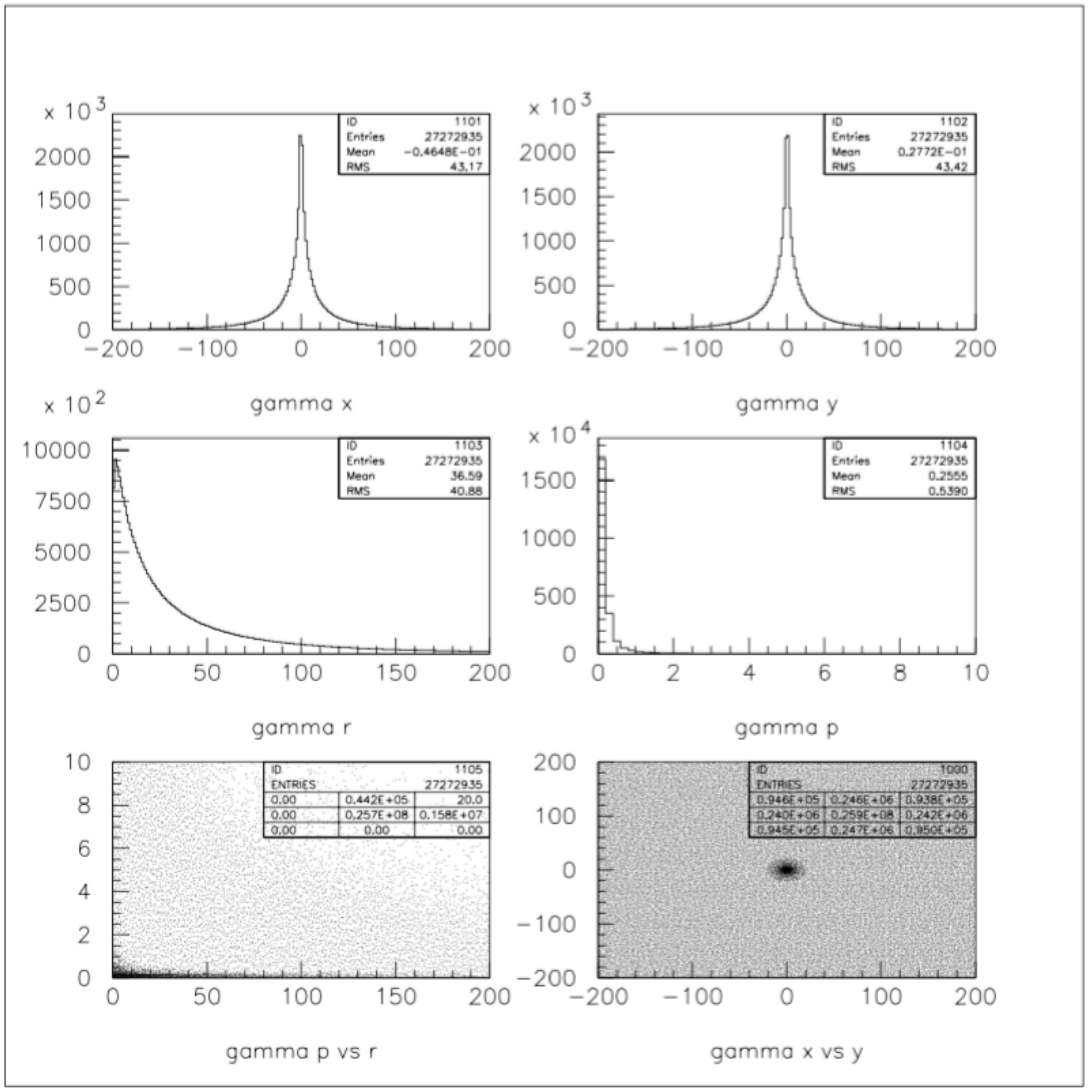

Figure 3.20. One-dimensional plots of x and y (top left and right), r and p (center left and right), two-dimensional plots of x-y and p-r (bottom left and right) of gammas for $5x10^{16}$ eV carbon shower with ECUT III

R distribution (distance from shower center) of the shower is given at the middle left of figure 3.20. As one can see from the R distribution plot most of the gammas are inside a circle with radius 50 meter. This could be more clear from the table 3.20 that 80% of them are in 30 m, 90% them are in 50 m and 94% of them are in 100 m. Middle right plot in figure 3.20 shows momentum distribution of gamma in the shower. Average momentum of them is 0.2555 GeV and most of them have a momentum of 2 GeV or less. Bottom left plot in figure 3.20 is the 2-Dimensional plot of momentum vs distance from the center of shower. Gammas with momentum less than 1 GeV are populated around distance less than 20m. The rest of particles are spread around.

Muons

Figure 3.21 shows muon profile of the shower. There are a total of 2403903 muons in five shower. Mean value of the x distribution is -0.5373 with RMS of 92.61 while mean value of y distribution is 0.2273 with 92.72 RMS. The core of the shower can be seen from the 2-Dimensional plot of x vs y which is at the bottom right corner of figure 3.21. R distribution (distance from shower center) of the shower is given at the middle left of figure 3.21. As one can see from the R distribution plot most of the muons are inside a circle with radius 50 meter. This could be more clear from the table 3.21 that 80% of them are in 30 m, 90% them are in 50 m and 94% of them are in 100 m. Middle right plot in figure 3.21 shows momentum distribution of muon in the shower. Average momentum of them is 2.976 GeV and most of them have a momentum of 2 GeV or less. Bottom left plot in figure 3.21 is the 2-Dimensional plot of momentum vs distance from the center of shower. Muons with momentum less than 1 GeV are populated around distance less than 20m. The rest of particles are spread around.

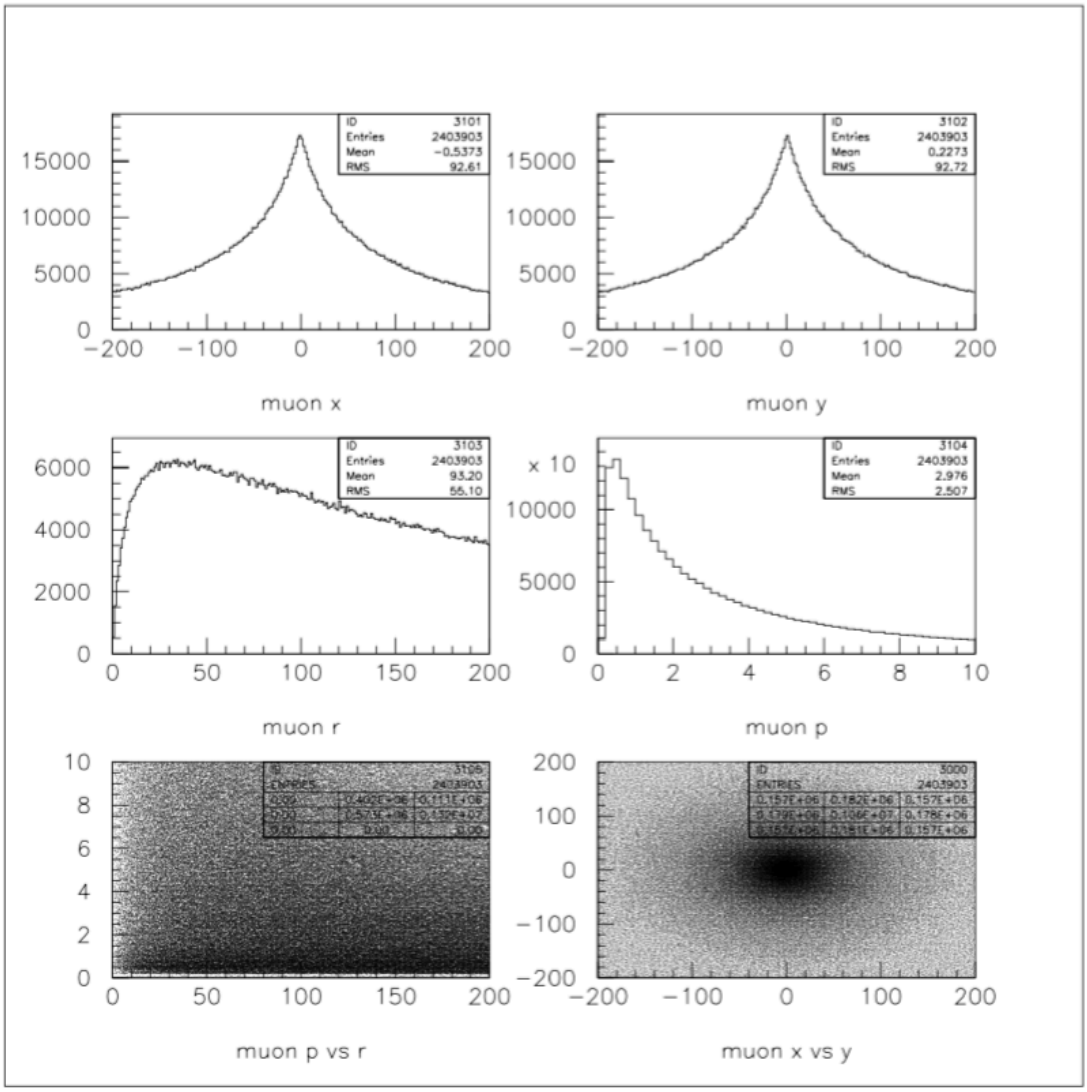

Figure 3.21. One-dimensional plots of x and y (top left and right), r and p (center left and right), two-dimensional plots of x-y and p-r (bottom left and right) of muons for $5x10^{16}$ eV carbon shower with ECUT III

3.4.2.2 Momentum analysis

Energy cut II

Electrons and positrons

Table 3.16. Total number of electrons and positrons in five different shower for different momentum interval for primary Carbon particle in ECUT II

	Total #	100 m	50 m	30 m
Total # of particles	40883728			
Final # of electrons	9739116	7299894	6643926	5406411
P < 500 MeV	8593623	6206337	5588026	4423250
P > 500 MeV	1145493	1093557	1055900	983161
0 < P < 150 MeV	5692261	3596409	3152935	2371610
150 < P < 250 MeV	1594160	1396172	1287529	1053105
250 < P < 350 MeV	735140	678209	637929	546359
350 < P < 450 MeV	422830	395223	375507	331662
450 < P < 550 MeV	269791	253741	242627	218712

Average of 24% of total particles produced in a shower are e^- and e^+. 88% of these e^- and e^+ have momentum less than 500 MeV. Since we have a cut of 0.15 GeV for EM components. 58% of e^- and e^+ have momentum between 0 MeV and 150 MeV, 16% of them between 150 MeV and 250 MeV. 8% of them between 250 MeV and 350 MeV. 4% of them between 350 MeV and 450 MeV, and 3% of them between 450 MeV and 550 MeV. This numbers are approximately same (less than 1% charge) if we define a shower core with 100 m radius, 50 m radius, 30 m radius and evaluate the percentage.

For core with 100 m radius, 75% of total e^- and e^+ are inside the core. 85% of those have momentum less than 500 MeV while 49% between 0 MeV and 150 MeV, 19% of them between 150 MeV and 250 MeV. 9% of them between 250 MeV and 350 MeV. 5% between 350 MeV and 450 MeV, and 3% between 450 MeV and 550 MeV.

For core with 50 m radius, 68% of total e^- and e^+ are inside the core. 84% of those have momentum less than 500 MeV while 47% between 0 MeV and 150 MeV, 19% of them between 150 MeV and 250 MeV. 10% of them between 250 MeV and 350 MeV. 6% between 350 MeV and 450 MeV, and 4% between 450 MeV and 550 MeV.

For core with 30 m radius, 56% of total e^- and e^+ are inside the core. 82% of those have momentum less than 500 MeV while 44% between 0 MeV and 150 MeV, 19% of them between 150 MeV and 250 MeV. 10% of them between 250 MeV and 350 MeV. 6% between 350 MeV and 450 MeV, and 4% between 450 MeV and 550 MeV.

Gammas

Average of 63% of total particles produced in a shower are gammas. 93% of these have momentum less than 500 MeV. Since we have a cut of 0.15 GeV for EM components. 69% of gammas have momentum between 0 MeV and 150 MeV, 14% of them between 150 MeV and 250 MeV. 5% of them between 250 MeV and 350 MeV. 3% of them between 350 MeV and 450 MeV, and 2% of them between 450 MeV and 550 MeV. This numbers are approximately same (less than 1% charge) if we define a shower core with 100 m radius, 50 m radius, 30 m radius and evaluate the percentage.

For core with 100 m radius, 82% of total gammas are inside the core. 92% of those have momentum less than 500 MeV while 65% between 0 MeV and 150 MeV, 15% of them between 150 MeV and 250 MeV. 6% of them between 250 MeV and 350 MeV. 3% between 350 MeV and 450 MeV, and 2% between 450 MeV and 550 MeV.

For core with 50 m radius, 68% of total gammas are inside the core. 90% of those have momentum less than 500 MeV while 62% between 0 MeV and 150 MeV, 16% of them between 150 MeV and 250 MeV. 7% of them between 250 MeV and 350 MeV. 4% between 350 MeV and 450 MeV, and 2% between 450 MeV and 550 MeV.

Table 3.17. Total number of gammas in five different shower for different momentum interval for primary Carbon particle in ECUT II

	Total #	100 m	50 m	30 m
Total # of particles	40883728			
Final # of gammas	25933606	21241927	17625947	12827119
P < 500 MeV	24035460	19439013	15899940	11260149
P > 500 MeV	1898146	1802914	1726007	1566970
0 < P < 150 MeV	17888313	13875209	10983047	7424712
150 < P < 250 MeV	3623850	3229624	2787768	2096086
250 < P < 350 MeV	1472991	1355461	1222783	978977
350 < P < 450 MeV	783290	728913	672853	561324
450 < P < 550 MeV	481625	450913	422567	362387

For core with 30 m radius, 50% of total gammas are inside the core. 88% of those have momentum less than 500 MeV while 58% between 0 MeV and 150 MeV, 16% of them between 150 MeV and 250 MeV. 8% of them between 250 MeV and 350 MeV. 4% between 350 MeV and 450 MeV, and 3% between 450 MeV and 550 MeV.

Muons

Average of 6% of total particles produced in a shower are muons. 10% of these muons have momentum less than 500 MeV. Since we have a cut of 0.15 GeV for EM components, 1% of muons have momentum between 0 MeV and 150 MeV, 3% of them between 150 MeV and 250 MeV. 3% of them between 250 MeV and 350 MeV. 3% of them between 350 MeV and 450 MeV, and 3% of them between 450 MeV and 550 MeV. This numbers are approximately same (less than 1% charge) if we define a shower core with 100 m radius, 50 m radius, 30 m radius and evaluate the percentage.

For core with 100 m radius, 21% of total muons are inside the core. 2% of those have momentum less than 500 MeV while 0.1% of have momentum between 0 MeV and 150 MeV, 0.3% of them between 150 MeV and 250 MeV. 1% of them between 250 MeV and 350 MeV. 1% between 350 MeV and 450 MeV, and 1% between 450 MeV and 550 MeV.

Table 3.18. Total number of muons in five different shower for different momentum interval for primary Carbon particle in ECUT II

	Total #	100 m	50 m	30 m
Total # of particles	40883728			
Final # of muons	2431617	503771	250492	109771
P < 500 MeV	248831	8459	4142	1787
P > 500 MeV	2182786	495312	246350	107984
0 < P < 150 MeV	16025	342	170	80
150 < P < 250 MeV	61002	1641	845	380
250 < P < 350 MeV	69072	2389	1188	513
350 < P < 450 MeV	69332	2669	1261	532
450 < P < 550 MeV	66181	2883	1320	549

For core with 50 m radius, 10% of total muons are inside the core. 2% of those have momentum less than 500 MeV while 0.1% of have momentum between 0 MeV and 150 MeV, 0.3% of them between 150 MeV and 250 MeV. 1% of them between 250 MeV and 350 MeV. 1% between 350 MeV and 450 MeV, and 1% between 450 MeV and 550 MeV.

For core with 30 m radius, 5% of total muons are inside the core. 2% of those have momentum less than 500 MeV while 0.1% of have momentum between 0 MeV and 150 MeV, 0.3% of them between 150 MeV and 250 MeV. 1% of them between 250 MeV and 350 MeV. 1% between 350 MeV and 450 MeV, and 1% between 450 MeV and 550 MeV.

Energy cut III

Electrons and positrons

Average of 25% of total particles produced in a shower are e^- and e^+. 87% of these have momentum less than 500 MeV. Since we have a cut of 0.15 GeV for EM components. 57% of e^- and e^+ have momentum between 0 MeV and 150 MeV, 16% of them between 150 MeV and 250 MeV. 8% of them between 250 MeV and 350 MeV. 4% of them between 350 MeV and 450 MeV, and 3% of them between 450 MeV and 550 MeV. This numbers are approximately same (less than 1% charge) if we define a shower core with 100 m radius, 50 m radius, 30 m radius and evaluate the percentage.

Table 3.19. Total number of electrons and positrons in five different shower for different momentum interval for primary Carbon particle in ECUT III

	Total #	100 m	50 m	30 m
Total # of particles	42718152			
Final # of electrons	10490980	7945302	7284160	6012497
P < 500 MeV	9175974	6684491	6062327	4866613
P > 500 MeV	1315006	1260811	1221833	1145884
0 < P < 150 MeV	6023673	3836456	3391099	2590415
150 < P < 250 MeV	1722243	1515521	1406370	1164320
250 < P < 350 MeV	801380	741748	700938	607093
350 < P < 450 MeV	464533	435824	415561	370470
450 < P < 550 MeV	298326	281779	270119	245378

For core with 100 m radius, 76% of total e^- and e^+ are inside the core. 84% of those have momentum less than 500 MeV while 48% between 0 MeV and 150 MeV, 19% of them between 150 MeV and 250 MeV. 9% of them between 250 MeV and 350 MeV. 5% between 350 MeV and 450 MeV, and 4% between 450 MeV and 550 MeV.

For core with 50 m radius, 69% of total e^- and e^+ are inside the core. 83% of those have momentum less than 500 MeV while 47% between 0 MeV and 150 MeV, 19% of them between 150 MeV and 250 MeV. 10% of them between 250 MeV and

350 MeV. 6% between 350 MeV and 450 MeV, and 4% between 450 MeV and 550 MeV.

For core with 30 m radius, 57% of total e^- and e^+ are inside the core. 81% of those have momentum less than 500 MeV while 43% between 0 MeV and 150 MeV, 19% of them between 150 MeV and 250 MeV. 10% of them between 250 MeV and 350 MeV. 6% between 350 MeV and 450 MeV, and 4% between 450 MeV and 550 MeV.

Gammas

Average of 64% of total particles produced in a shower are gammas. 92% of these have momentum less than 500 MeV. Since we have a cut of 0.15 GeV for EM components. 68% of gammas have momentum between 0 MeV and 150 MeV, 14% of them between 150 MeV and 250 MeV. 6% of them between 250 MeV and 350 MeV. 3% of them between 350 MeV and 450 MeV, and 2% of them between 450 MeV and 550 MeV. This numbers are approximately same (less than 1% charge) if we define a shower core with 100 m radius, 50 m radius, 30 m radius and evaluate the percentage.

For core with 100 m radius, 83% of total gammas are inside the core. 91% of those have momentum less than 500 MeV while 65% between 0 MeV and 150 MeV, 15% of them between 150 MeV and 250 MeV. 6% of them between 250 MeV and 350 MeV. 4% between 350 MeV and 450 MeV, and 2% between 450 MeV and 550 MeV.

For core with 50 m radius, 70% of total gammas are inside the core. 90% of those have momentum less than 500 MeV while 62% between 0 MeV and 150 MeV, 16% of them between 150 MeV and 250 MeV. 7% of them between 250 MeV and 350 MeV. 4% between 350 MeV and 450 MeV, and 2% between 450 MeV and 550 MeV.

Table 3.20. Total number of gammas in five different shower for different momentum interval for primary Carbon particle in ECUT III

	Total #	100 m	50 m	30 m
Total # of particles	42718152			
Final # of gammas	27272935	22578705	18961585	14061218
P < 500 MeV	25139207	20543484	17005310	12268418
P > 500 MeV	2133728	2035221	1956275	1792800
0 < P < 150 MeV	18582935	14578000	11687787	8052714
150 < P < 250 MeV	3836646	3439684	2998250	2292672
250 < P < 350 MeV	1579061	1458553	1325133	1077545
350 < P < 450 MeV	849414	793832	737383	623588
450 < P < 550 MeV	524211	492817	464068	403175

For core with 30 m radius, 52% of total gammas are inside the core. 87% of those have momentum less than 500 MeV while 57% between 0 MeV and 150 MeV, 16% of them between 150 MeV and 250 MeV. 8% of them between 250 MeV and 350 MeV. 4% between 350 MeV and 450 MeV, and 3% between 450 MeV and 550 MeV.

Muons

Average of 6% of total particles produced in a shower are muons. 9% of these have momentum less than 500 MeV. Since we have a cut of 0.15 GeV for EM components, we did not see any muon with momentum less than 150 MeV, 2% of them between 150 MeV and 250 MeV. 3% of them between 250 MeV and 350 MeV. 3% of them between 350 MeV and 450 MeV, and 3% of them between 450 MeV and 550 MeV. This numbers are approximately same (less than 1% charge) if we define a shower core with 100 m radius, 50 m radius, 30 m radius and evaluate the percentage.

For core with 100 m radius, 21% of total muons are inside the core. 1% of those have momentum less than 500 MeV while 0.2% of them between 150 MeV and 250 MeV. 0.4% of them between 250 MeV and 350 MeV. 1% between 350 MeV and 450 MeV, and 1% between 450 MeV and 550 MeV.

Table 3.21. Total number of muons in five different shower for different momentum interval for primary Carbon particle in ECUT III

	Total #	100 m	50 m	30 m
Total # of particles	42718152			
Final # of muons	2403903	513268	256960	112994
P < 500 MeV	209075	7248	3302	1345
P > 500 MeV	2194828	506020	253658	111649
150 < P < 250 MeV	38420	906	340	113
250 < P < 350 MeV	66374	2143	977	357
350 < P < 450 MeV	70103	2720	1294	574
450 < P < 550 MeV	67527	2918	1379	606

For core with 50 m radius, 11% of total muons are inside the core. 1% of those have momentum less than 500 MeV while 0.1% of them between 150 MeV and 250 MeV. 0.4% of them between 250 MeV and 350 MeV. 1% between 350 MeV and 450 MeV, and 1% between 450 MeV and 550 MeV.

For core with 30 m radius, 5% of total muons are inside the core. 1% of those have momentum less than 500 MeV while 0.1% of them between 150 MeV and 250 MeV. 0.4% of them between 250 MeV and 350 MeV. 1% between 350 MeV and 450 MeV, and 1% between 450 MeV and 550 MeV.

3.4.3 Iron analysis

3.4.3.1 Profile of showers

Energy cut II

In this section, shower of 5×10^{16} eV iron is simulated by CORSIKA with energy cut 0.05 0.05 0.05 0.05 GeV. This corresponds to 0.05 GeV for hadrons, 0.05 GeV for muons, 0.05 GeV for electrons and 0.05 GeV for photons. 38840793 particles produced in this shower in which 23% of them are electrons, 61% of them gammas,

7% of them muons and 9% of them are other particles such as kaons, pions, neutron, protons etc.

Electrons and positrons

Figure 3.22 shows e^- and e^+ profile of the shower. There are a total of 9043841 e^- and e^+ in five shower. Mean value of the x distribution is 0.5230×10^{-01} with RMS of 35.27 while mean value of y distribution is $0.3743.10^{-01}$ with 35.45 RMS. The core of the shower can be seen from the 2-Dimensional plot of x vs y which is at the bottom right corner of figure 3.22. R distribution (distance from shower center) of the shower is given at the middle left of figure 3.22. As one can see from the R distribution plot most of the e^- and e^+ are inside a circle with radius 50 meter. This could be more clear from the table 3.22 that 80% of them are in 30 m, 90% them are in 50 m and 94% of them are in 100 m. Middle right plot in figure 3.22 shows momentum distribution of e^- and e^+ in the shower. Average momentum of them is 0.3019 GeV and most of them have a momentum of 2 GeV or less. Bottom left plot in figure 3.22 is the 2-Dimensional plot of momentum vs distance from the center of shower. e^- and e^+ with momentum less than 1 GeV are populated around distance less than 20m. The rest of particles are spread around.

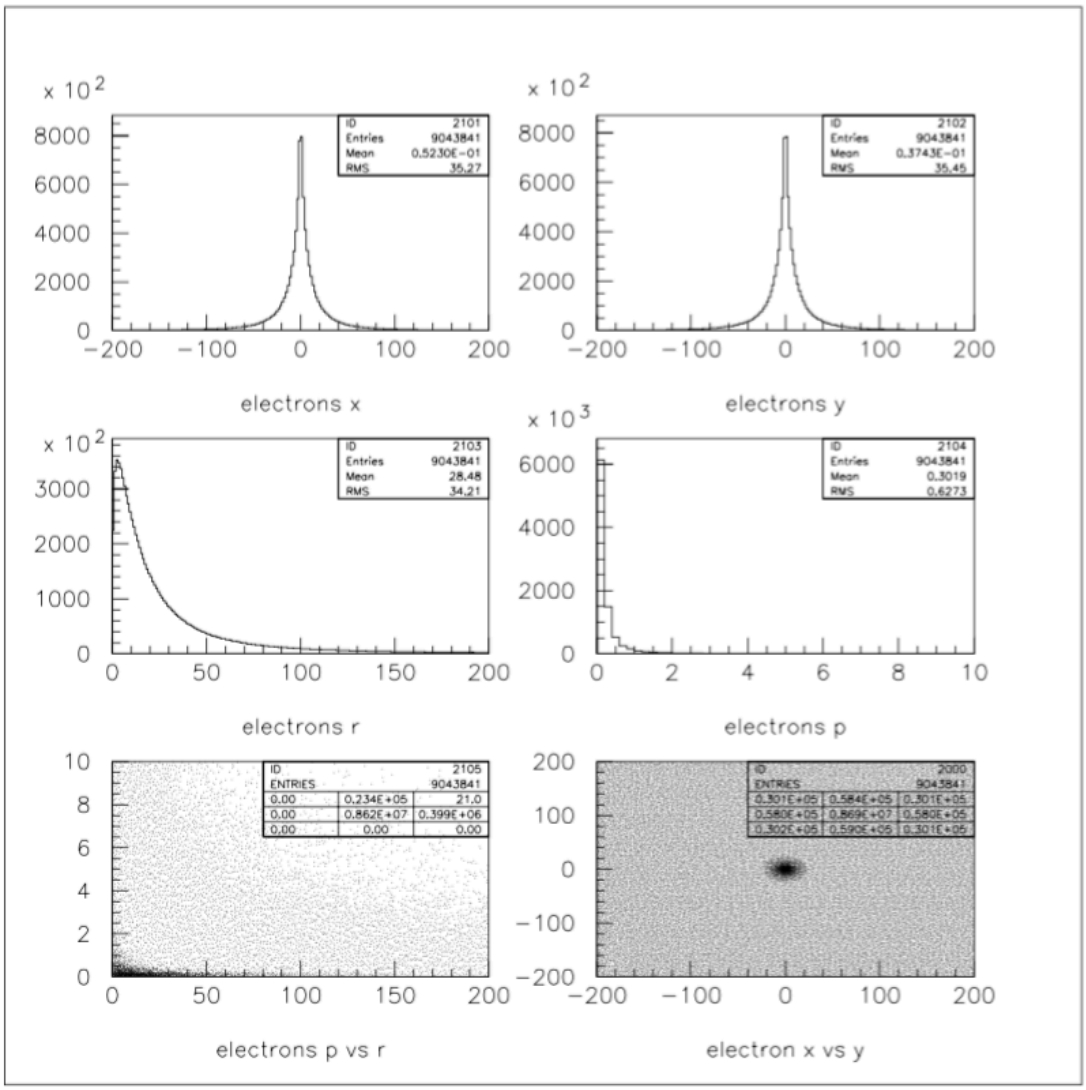

Figure 3.22. One-dimensional plots of x and y (top left and right), r and p (center left and right), two-dimensional plots of x-y and p-r (bottom left and right) of electrons and positrons for $5x10^{16}$ eV iron shower with ECUT II

Gammas

Figure 3.23 shows gamma profile of the shower. There are a total of 23791323 gammas in five shower. Mean value of the x distribution is $-0.4394x10^{-01}$ with RMS of 45.35 while mean value of y distribution is $0.7355x10^{-01}$ with 45.57 RMS. The core of the shower can be seen from the 2-Dimensional plot of x vs y which is at the bottom right corner of figure 3.23. R distribution (distance from shower center) of the shower is given at the middle left of figure 3.23. As one can see from the R distribution plot most of the gammas are inside a circle with radius 50 meter. This could be more clear from the table 3.23 that 80% of them are in 30 m, 90% them are in 50 m and 94% of

them are in 100 m. Middle right plot in figure 3.23 shows momentum distribution of gamma in the shower. Average momentum of them is 0.2370 GeV and most of them have a momentum of 2 GeV or less. Bottom left plot in figure 3.23 is the 2-Dimensional plot of momentum vs distance from the center of shower. Gammas with momentum less than 1 GeV are populated around distance less than 20m. The rest of particles are spread around.

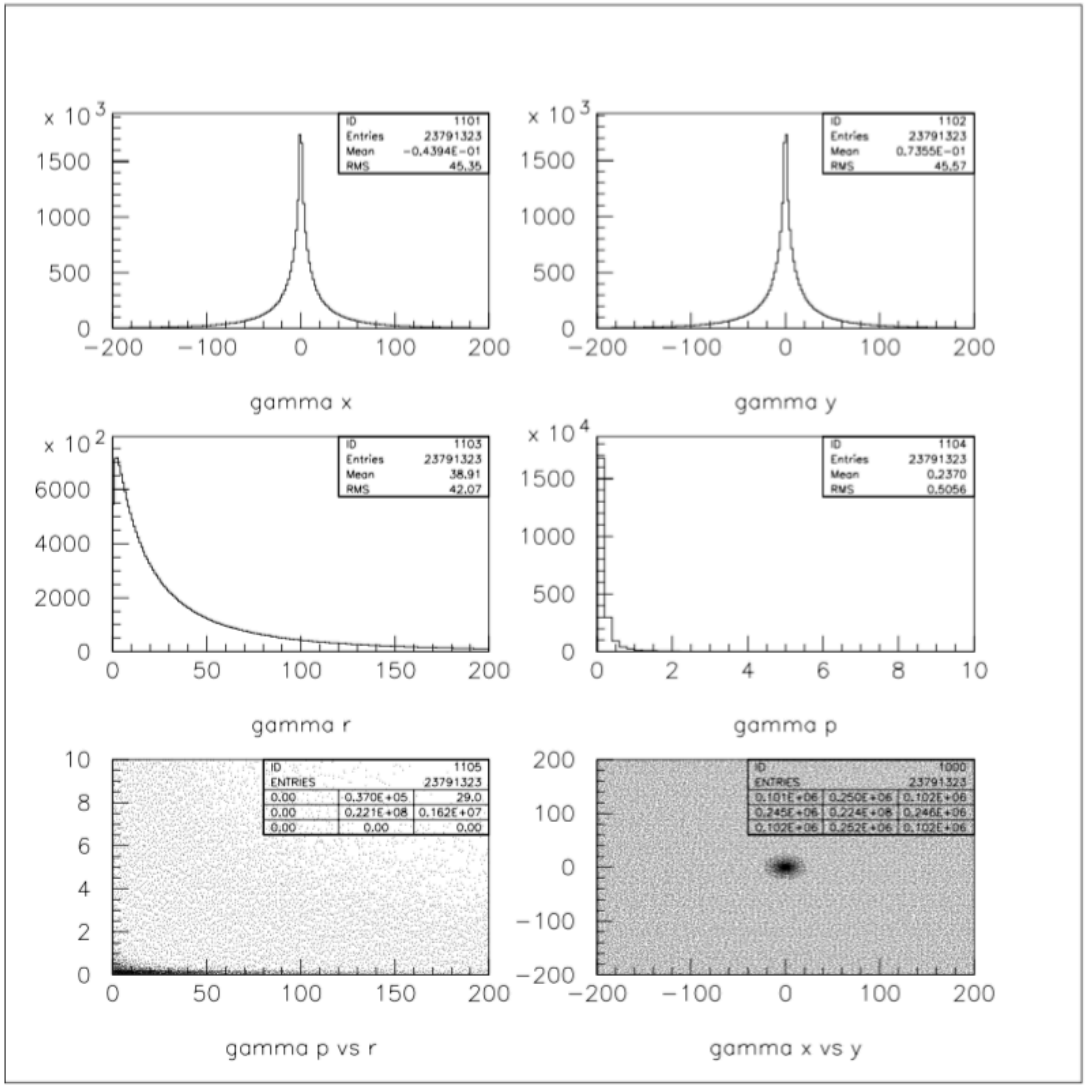

Figure 3.23. One-dimensional plots of x and y (top left and right), r and p (center left and right), two-dimensional plots of x-y and p-r (bottom left and right) of gammas for $5x10^{16}$ eV iron shower with ECUT II

Muons

Figure 3.24 shows muon profile of the shower. There are a total of 2805366 muons in five shower. Mean value of the x distribution is -0.3945 with RMS of 92.86 while mean value of y distribution is -0.1321 with 93.02 RMS. The core of the shower can be seen from the 2-Dimensional plot of x vs y which is at the bottom right corner of figure 3.24. R distribution (distance from shower center) of the shower is given at the middle left of figure 3.24. As one can see from the R distribution plot most of the muons are inside a circle with radius 50 meter.

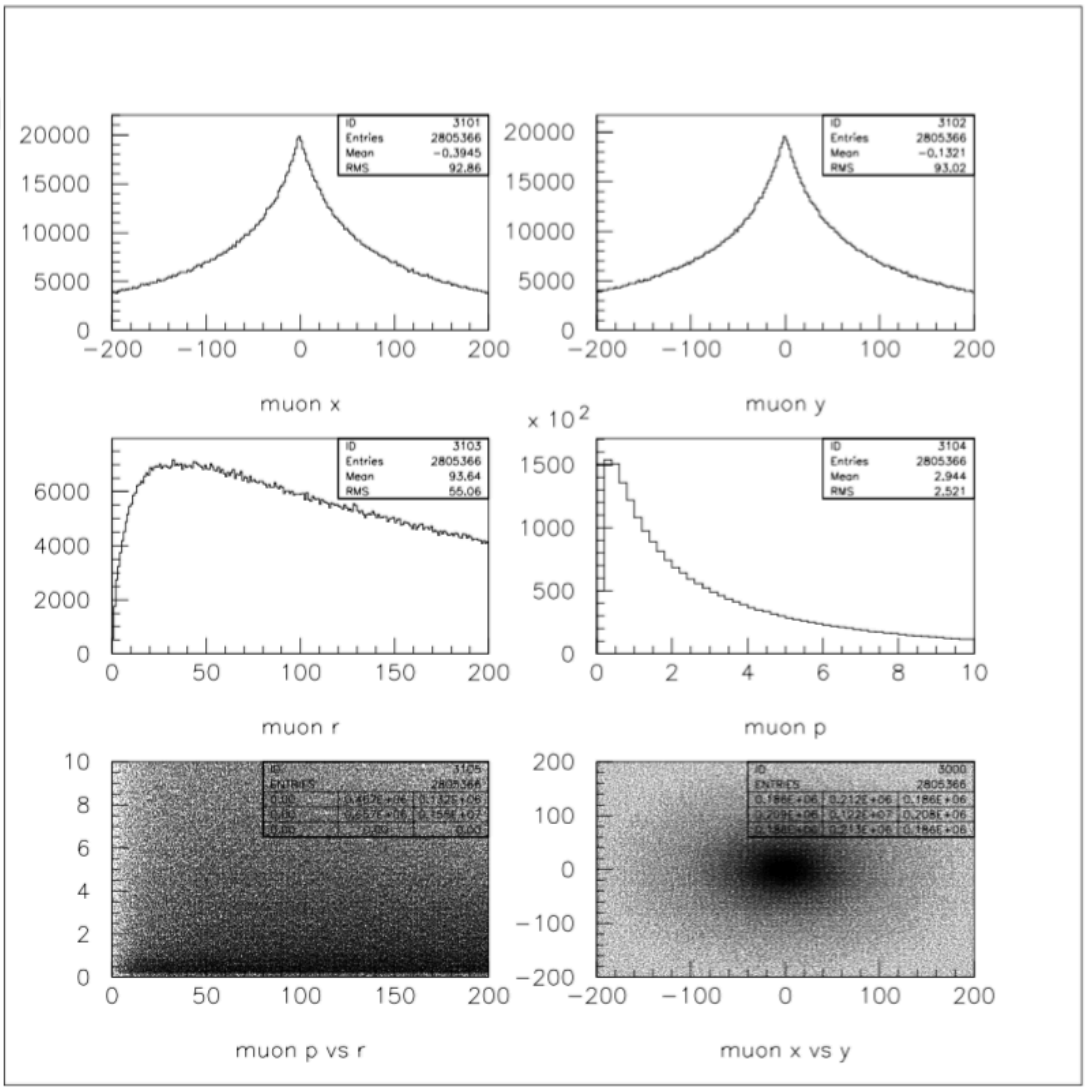

Figure 3.24. One-dimensional plots of x and y (top left and right), r and p (center left and right), two-dimensional plots of x-y and p-r (bottom left and right) of muons for $5x10^{16}$ eV iron shower with ECUT II

This could be more clear from the table 3.24 that 80% of them are in 30 m, 90% them are in 50 m and 94% of them are in 100 m. Middle right plot in figure 3.24 shows momentum distribution of muon in the shower. Average momentum of them is 2.944 GeV and most of them have a momentum of 2 GeV or less. Bottom left plot in figure 3.24 is the 2-Dimensional plot of momentum vs distance from the center of shower. Muons with momentum less than 1 GeV are populated around distance less than 20m. The rest of particles are spread around.

Energy cut III

In the following section, shower of 5×10^{16} eV iron is simulated by CORSIKA with energy cut 0.3 0.1 0.05 0.05 GeV. This corresponds to 0.3 GeV for hadrons, 0.1 GeV for muons, 0.05 GeV for electrons and 0.05 GeV for photons. 40634329 particles produced in this shower in which 24% of them are electrons, 62% of them gammas, 7% of them muons and 5% of them are other particles such as kaons, pions, neutron, protons etc.

Electrons and positrons

Figure 3.25 shows e^- and e^+ profile of the shower. There are a total of 9660843 e^- and e^+ in five shower. Mean value of the x distribution is -0.4224x10^{-01} with RMS of 34.72 while mean value of y distribution is -0.5882x10^{-01} with 34.86 RMS. The core of the shower can be seen from the 2-Dimensional plot of x vs y which is at the bottom right corner of figure 3.25. R distribution (distance from shower center) of the shower is given at the middle left of figure 3.25. As one can see from the R distribution plot most of the e^- and e^+ are inside a circle with radius 50 meter. This could be more clear from the table 3.25 that 80% of them are in 30 m, 90% them are in 50 m and 94% of them are in 100 m. Middle right plot in figure 3.25 shows momentum distribution of e^- and e^+ in the shower. Average momentum of them is 0.3043 GeV and most of them have a momentum of 2 GeV or less. Bottom left plot in figure 3.25 is the 2-Dimensional plot of momentum vs distance from the center of shower. e^- and e^+ with momentum less than 1 GeV are populated around distance less than 20m. The rest of particles are spread around.

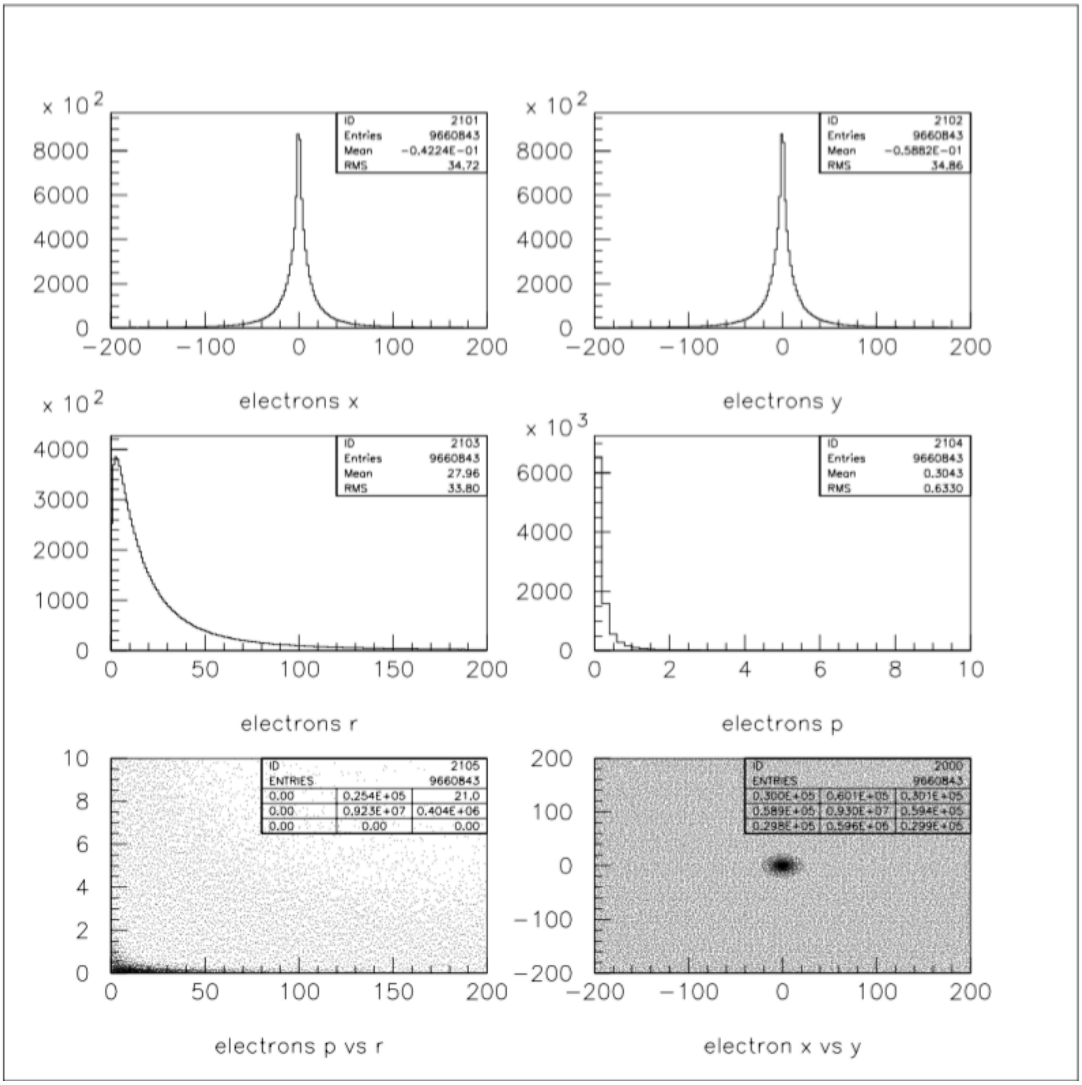

Figure 3.25. One-dimensional plots of x and y (top left and right), r and p (center left and right), two-dimensional plots of x-y and p-r (bottom left and right) of electrons and positrons for $5x10^{16}$ eV iron shower with ECUT III

Gammas

Figure 3.26 shows gamma profile of the shower. There are a total of 25254372 gammas in five shower. Mean value of the x distribution is $-0.3576x10^{-01}$ with RMS of 44.79 while mean value of y distribution is $-0.7912x10^{-02}$ with 45.01 RMS. The core of the shower can be seen from the 2-Dimensional plot of x vs y which is at the bottom right corner of figure 3.26. R distribution (distance from shower center) of the shower is given at the middle left of figure 3.26. As one can see from the R distribution plot most of the gammas are inside a circle with radius 50 meter. This could be more clear from the table 3.25 that 80% of them are in 30 m, 90% them are in 50 m and 94% of

them are in 100 m. Middle right plot in figure 3.26 shows momentum distribution of in the shower. Average momentum of them is 0.2451 GeV and most of them have a momentum of 2 GeV or less. Bottom left plot in figure 3.26 is the 2-Dimensional plot of momentum vs distance from the center of shower. Gammas with momentum less than 1 GeV are populated around distance less than 20m. The rest of particles are spread around.

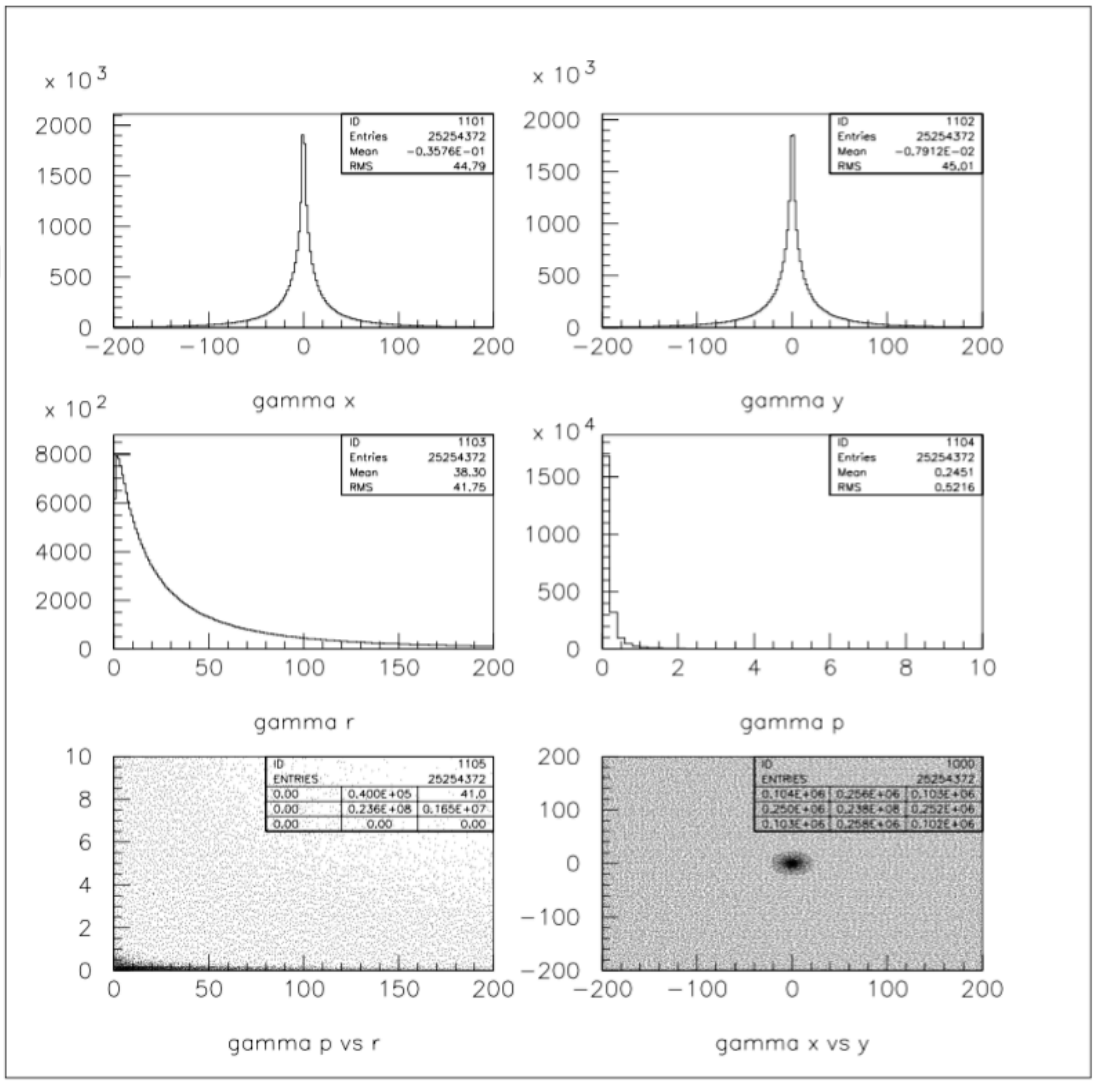

Figure 3.26. One One-dimensional plots of x and y (top left and right), r and p (center left and right), two-dimensional plots of x-y and p-r (bottom left and right) of gammas for $5x10^{16}$ eV iron shower with ECUT III

Muons

Figure 3.27 shows muon profile of the shower. There are a total of 2777182 muons in the shower. Mean value of the x distribution is -0.2391×10^{-01} with RMS of 92.75 while mean value of y distribution is 0.2266×10^{-01} with 92.94 RMS. The core of the shower can be seen from the 2-Dimensional plot of x vs y which is at the bottom right corner of figure 3.27. R distribution (distance from shower center) of the shower is given at the middle left of figure 3.27.

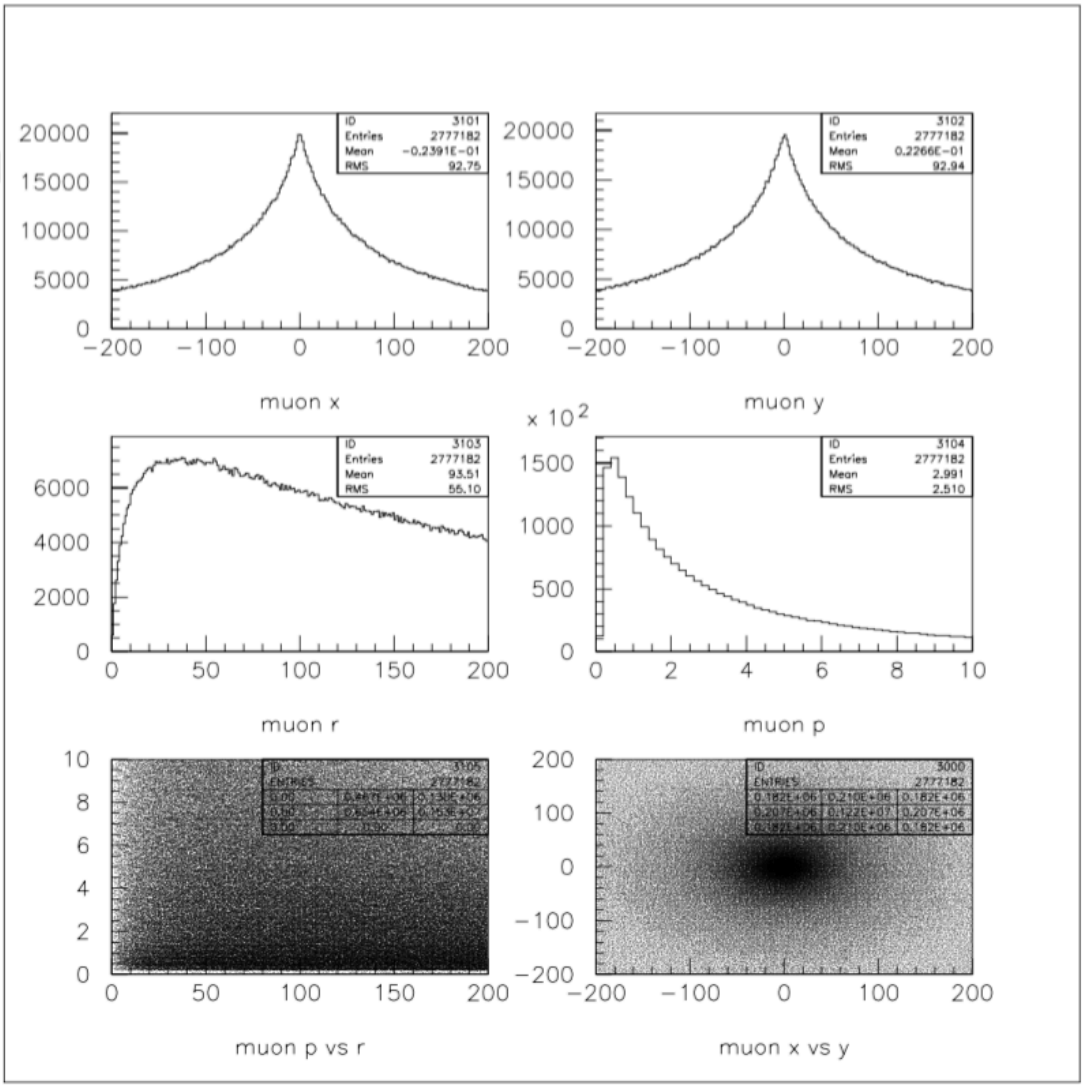

Figure 3.27. One One-dimensional plots of x and y (top left and right), r and p (center left and right), two-dimensional plots of x-y and p-r (bottom left and right) of muons for 5×10^{16} eV iron shower with ECUT III

As one can see from the R distribution plot most of the muons are inside a circle with radius 50 meter. This could be more clear from the table 3.27 that 80% of them are in 30 m, 90% them are in 50 m and 94% of them are in 100 m. Middle right plot in figure 3.27 shows momentum distribution of muons in the shower. Average momentum of them is 2.991 GeV and most of them have a momentum of 2 GeV or less. Bottom left plot in figure 3.27 is the 2-Dimensional plot of momentum vs distance from the center of shower. Muons with momentum less than 1 GeV are populated around distance less than 20m. The rest of particles are spread around.

3.4.3.2 Momentum analysis

Energy cut II

Electrons and positrons

Average of 23% of total particles produced in a shower are e^- and e^+. 88% of these e^- and e^+ have momentum less than 500 MeV. Since we have a cut of 0.15 GeV for EM components. 58% of e^- and e^+ have momentum between 0 MeV and 150 MeV, 16% of them between 150 MeV and 250 MeV. 8% of them between 250 MeV and 350 MeV. 4% of them between 350 MeV and 450 MeV, and 3% of them between 450 MeV and 550 MeV. This numbers are approximately same (less than 1% charge) if we define a shower core with 100 m radius, 50 m radius, 30 m radius and evaluate the percentage.

For core with 100 m radius, 74% of total e^- and e^+ are inside the core. 84% of those have momentum less than 500 MeV while 49% between 0 MeV and 150 MeV, 19% of them between 150 MeV and 250 MeV. 9% of them between 250 MeV and 350 MeV. 5% between 350 MeV and 450 MeV, and 4% between 450 MeV and 550 MeV.

For core with 50 m radius, 67% of total e^- and e^+ are inside the core. 83% of those have momentum less than 500 MeV while 47% between 0 MeV and 150 MeV, 19% of them between 150 MeV and 250 MeV. 10% of them between 250 MeV and

Table 3.22. Total number of electrons and positrons in five different shower for different momentum interval for primary Iron particle in ECUT II

	Total #	100 m	50 m	30 m
Total # of particles	38840793			
Final # of electrons	9043841	6707782	6070501	4909024
P < 500 MeV	7936104	5659410	5064138	3980824
P > 500 MeV	1107737	1048372	1006363	928200
0 < P < 150 MeV	5234177	3263512	2844593	2127598
150 < P < 250 MeV	1479064	1276070	1168699	947527
250 < P < 350 MeV	687306	625238	583698	495704
350 < P < 450 MeV	396139	365475	344708	301163
450 < P < 550 MeV	253124	234898	222881	198760

350 MeV. 6% between 350 MeV and 450 MeV, and 4% between 450 MeV and 550 MeV.

For core with 30 m radius, 54% of total e^- and e^+ are inside the core. 81% of those have momentum less than 500 MeV while 43% between 0 MeV and 150 MeV, 19% of them between 150 MeV and 250 MeV. 10% of them between 250 MeV and 350 MeV. 6% between 350 MeV and 450 MeV, and 4% between 450 MeV and 550 MeV.

Gammas

Average of 61% of total particles produced in a shower are gammas. 92% of these have momentum less than 500 MeV. Since we have a cut of 0.15 GeV for EM components. 69% of have momentum between 0 MeV and 150 MeV, 14% of them between 150 MeV and 250 MeV. 6% of them between 250 MeV and 350 MeV. 3% of them between 350 MeV and 450 MeV, and 2% of them between 450 MeV and 550 MeV. This numbers are approximately same (less than 1% charge) if we define a shower core with 100 m radius, 50 m radius, 30 m radius and evaluate the percentage.

Table 3.23. Total number of gammas in five different shower for different momentum interval for primary Iron particle in ECUT II

	Total #	100 m	50 m	30 m
Total # of particles	38840793			
Final # of gammas	23791323	19257756	15919228	11543134
P < 500 MeV	1808695	17556620	14300628	10086607
P > 500 MeV	1107737	1835019	1618600	1456527
0 < P < 150 MeV	16308576	12491996	9850225	6634655
150 < P < 250 MeV	3335109	2931048	2516705	1882249
250 < P < 350 MeV	1362518	1235511	1107342	881664
350 < P < 450 MeV	728178	668628	613230	507855
450 < P < 550 MeV	448580	414971	386160	328521

For core with 100 m radius, 81% of total gammas are inside the core. 91% of those have momentum less than 500 MeV while 65% between 0 MeV and 150 MeV, 15% of them between 150 MeV and 250 MeV. 6% of them between 250 MeV and 350 MeV. 3% between 350 MeV and 450 MeV, and 2% between 450 MeV and 550 MeV.

For core with 50 m radius, 67% of total gammas are inside the core. 90% of those have momentum less than 500 MeV while 62% between 0 MeV and 150 MeV, 16% of them between 150 MeV and 250 MeV. 7% of them between 250 MeV and 350 MeV. 4% between 350 MeV and 450 MeV, and 2% between 450 MeV and 550 MeV.

For core with 30 m radius, 49% of total gammas are inside the core. 87% of those have momentum less than 500 MeV while 57% between 0 MeV and 150 MeV, 16% of them between 150 MeV and 250 MeV. 8% of them between 250 MeV and 350 MeV. 4% between 350 MeV and 450 MeV, and 3% between 450 MeV and 550 MeV.

Muons

Average of 7% of total particles produced in a shower are muons. 10% of these have momentum less than 500 MeV. Since we have a cut of 0.15 GeV for EM components, 1% of them between 0 MeV and 150 MeV, 2% of them between 150 MeV and 250 MeV. 3% of them between 250 MeV and 350 MeV. 3% of them between 350 MeV and 450 MeV, and 3% of them between 450 MeV and 550 MeV. This numbers are approximately same (less than 1% charge) if we define a shower core with 100 m radius, 50 m radius, 30 m radius and evaluate the percentage.

Table 3.24. Total number of muons in five different shower for different momentum interval for primary Iron particle in ECUT II

	Total #	100 m	50 m	30 m
Total # of particles	38840793			
Final # of muons	2805366	582625	281369	127173
P < 500 MeV	280669	9492	4670	2036
P > 500 MeV	2524697	573133	285083	125137
0 < P < 150 MeV	17766	405	214	89
150 < P < 250 MeV	68611	1895	1012	448
250 < P < 350 MeV	78009	2597	1292	588
350 < P < 450 MeV	78038	3005	1425	616
450 < P < 550 MeV	75879	3251	1485	594

For core with 100 m radius, 21% of total muons are inside the core. 1% of those have momentum less than 500 MeV while 0.1% of them between 0 MeV and 150 MeV. 0.3% of them between 150 MeV and 250 MeV. 0.4% of them between 250 MeV and 350 MeV. 1% between 350 MeV and 450 MeV, and 1% between 450 MeV and 550 MeV.

For core with 50 m radius, 10% of total muons are inside the core. 1% of those have momentum less than 500 MeV while 0.1% of them between 0 MeV and 150 MeV. 0.4% of them between 150 MeV and 250 MeV. 0.5% of them between 250 MeV and 350 MeV. 1% between 350 MeV and 450 MeV, and 1% between 450 MeV and 550 MeV.

For core with 30 m radius, 5% of total muons are inside the core. 1% of those have momentum less than 500 MeV while 0.1% of them between 0 MeV and 150 MeV. 0.4% of them between 150 MeV and 250 MeV. 0.5% of them between 250 MeV and 350 MeV. 1% between 350 MeV and 450 MeV, and 1% between 450 MeV and 550 MeV.

Energy cut III

Electrons and positrons

Average of 24% of total particles produced in a shower are e^- and e^+. 88% of these e^- and e^+ have momentum less than 500 MeV. Since we have a cut of 0.15 GeV for EM components. 58% of e^- and e^+ have momentum between 0 MeV and 150 MeV, 16% of them between 150 MeV and 250 MeV. 8% of them between 250 MeV and 350 MeV. 4% of them between 350 MeV and 450 MeV, and 3% of them between 450 MeV and 550 MeV. This numbers are approximately same (less than 1% charge) if we define a shower core with 100 m radius, 50 m radius, 30 m radius and evaluate the percentage.

For core with 100 m radius, 75% of total e^- and e^+ are inside the core. 84% of those have momentum less than 500 MeV while 48% between 0 MeV and 150 MeV, 19% of them between 150 MeV and 250 MeV. 9% of them between 250 MeV and 350 MeV. 5% between 350 MeV and 450 MeV, and 4% between 450 MeV and 550 MeV.

For core with 50 m radius, 68% of total e^- and e^+ are inside the core. 83% of those have momentum less than 500 MeV while 47% between 0 MeV and 150 MeV, 19% of them between 150 MeV and 250 MeV. 10% of them between 250 MeV and 350 MeV. 6% between 350 MeV and 450 MeV, and 4% between 450 MeV and 550 MeV.

For core with 30 m radius, 55% of total e^- and e^+ are inside the core. 81% of those have momentum less than 500 MeV while 43% between 0 MeV and 150 MeV, 19% of them between 150 MeV and 250 MeV. 10% of them between 250 MeV and 350 MeV. 6% between 350 MeV and 450 MeV, and 4% between 450 MeV and 550 MeV.

Table 3.25. Total number of electrons and positrons in five different shower for different momentum interval for primary Iron particle in ECUT III

	Total #	100 m	50 m	30 m
Total # of particles	40634329			
Final # of electrons	9660843	7203411	6538252	5311638
P < 500 MeV	8465334	6068611	5447343	4302302
P > 500 MeV	1195509	1134800	1090909	1009336
0 < P < 150 MeV	5571786	3492023	3054952	2296220
150 < P < 250 MeV	1582720	1371453	1258971	1025308
250 < P < 350 MeV	735485	671646	628600	536047
350 < P < 450 MeV	424651	393268	371735	326208
450 < P < 550 MeV	273740	255088	242354	216781

Gammas

Average of 62% of total particles produced in a shower are gammas. 92% of these have momentum less than 500 MeV. Since we have a cut of 0.15 GeV for EM components. 68% of have momentum between 0 MeV and 150 MeV, 14% of them between 150 MeV and 250 MeV. 6% of them between 250 MeV and 350 MeV. 3% of them between 350 MeV and 450 MeV, and 2% of them between 450 MeV and 550 MeV. This numbers are approximately same (less than 1% charge) if we define a shower core with 100 m radius, 50 m radius, 30 m radius and evaluate the percentage.

For core with 100 m radius, 81% of total gammas are inside the core. 91% of those have momentum less than 500 MeV while 65% between 0 MeV and 150 MeV, 15% of them between 150 MeV and 250 MeV. 6% of them between 250 MeV and 350 MeV. 4% between 350 MeV and 450 MeV, and 2% between 450 MeV and 550 MeV.

For core with 50 m radius, 68% of total gammas are inside the core. 90% of those have momentum less than 500 MeV while 62% between 0 MeV and 150 MeV, 16% of them between 150 MeV and 250 MeV. 7% of them between 250 MeV and 350 MeV. 4% between 350 MeV and 450 MeV, and 2% between 450 MeV and 550 MeV.

For core with 30 m radius, 49% of total gammas are inside the core. 87% of those have momentum less than 500 MeV while 57% between 0 MeV and 150 MeV, 16% of them between 150 MeV and 250 MeV. 8% of them between 250 MeV and 350 MeV. 4% between 350 MeV and 450 MeV, and 3% between 450 MeV and 550 MeV.

Table 3.26. Total number of gammas in five different shower for different momentum interval for primary Iron particle in ECUT III

	Total #	100 m	50 m	30 m
Total # of particles	40634329			
Final # of gammas	25254372	20560848	17060790	12447321
P < 500 MeV	23308612	18725829	15311943	10867284
P > 500 MeV	1945760	1835019	1748847	1580037
0 < P < 150 MeV	17258708	13303882	10533089	7141634
150 < P < 250 MeV	3546397	1371453	2697314	2027898
250 < P < 350 MeV	1456034	3130422	1190355	952313
350 < P < 450 MeV	781287	1324969	662247	550876
450 < P < 550 MeV	480952	720091	415251	354825

Muons

Average of 7% of total particles produced in a shower are muons. 9% of these have momentum less than 500 MeV. Since we have a cut of 0.15 GeV for EM components, we did not see any muon with momentum less than 150 MeV. 2% of them between 150 MeV and 250 MeV. 3% of them between 250 MeV and 350 MeV. 3% of them between 350 MeV and 450 MeV, and 3% of them between 450 MeV and 550 MeV. This numbers are approximately same (less than 1% charge) if we define a shower core with 100 m radius, 50 m radius, 30 m radius and evaluate the percentage.

Table 3.27. Total number of muons in five different shower for different momentum interval for primary Iron particle in ECUT III

	Total #	100 m	50 m	30 m
Total # of particles	40634329			
Final # of muons	2777182	589070	293598	128827
P < 500 MeV	237761	8127	3813	1546
P > 500 MeV	2539421	580943	289785	127281
150 < P < 250 MeV	43798	1007	414	121
250 < P < 350 MeV	75088	2470	1146	468
350 < P < 450 MeV	79656	3023	1469	616
450 < P < 550 MeV	77240	3274	1547	636

For core with 100 m radius, 21% of total muons are inside the core. 1% of those have momentum less than 500 MeV while 0.2% of them between 150 MeV and 250 MeV. 0.4% of them between 250 MeV and 350 MeV. 1% between 350 MeV and 450 MeV, and 1% between 450 MeV and 550 MeV.

For core with 50 m radius, 11% of total muons are inside the core. 1% of those have momentum less than 500 MeV while 0.1% of them between 150 MeV and 250 MeV. 0.4% of them between 250 MeV and 350 MeV. 1% between 350 MeV and 450 MeV, and 1% between 450 MeV and 550 MeV.

For core with 30 m radius, 5% of total muons are inside the core. 1% of those have momentum less than 500 MeV while 0.1% of them between 150 MeV and 250 MeV. 0.4% of them between 250 MeV and 350 MeV. 1% between 350 MeV and 450 MeV, and 1% between 450 MeV and 550 MeV.

4. CONCLUSIONS

In this thesis we have presented results from the shower simulations done by Corsika. The primary particles for these simulations were proton, carbon and iron since these are the main primary particles in Cosmic Rays. We applied different energy cuts on the shower particles to see the effects. Figure 3.3, 3.6, 3.9 show the distribution of muons on the ground for proton, carbon and iron primaries with a range of energies. The highest energy muons which are all found close to the shower core. These muons are produced in the decay of secondary particles maybe pions with very small angular dispersion very early in shower development. The zenith angle for the primary particle was taken zero because it applied vertical extensive air shower. The High Energy shower was modelled by QGSJET II and for the low energy GHEISHA was chosen. We concluded three different case of ECUT study of primary particle proton with energy $5x10^{16}$ eV is performed for core which is circle with 30 m radius. Number of particles in the shower increases from CASE I to CASE II. Percentage in momentum ranges also increases CASE I has a momentum cut of 0.15 MeV and CASE II has 0.05 MeV for EM components. So we produce more electrons and gammas. CASE I has a momentum cut of 0.3 MeV and CASE II has 0.05 MeV for muons. So more muons are produced. For core which is circle with radius 50 m radius and 100 m radius. Number of particles produced in shower and percentage in momentum ranges also increases. These increased percentages are implemented in the input of MINIUT fit effect is not more than two sigma. On the other hand, three different primary particle (proton, iron and carbon) with energy 5×10^{16} eV and same ECUT (CASE III) is performed. We studied for core which is circle with 30 m radius. Number of muons in the shower increases from low Z to high Z. But percentage in momentum ranges is not changed. For core which is circle with radius 50 m and 100 m that number of muons produced in shower increases from proton to carbon and to iron but percentage in momentum ranges is not changed.

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