Chapter One

(1-1)Introduction

Elementary-particle physics deals with the fundamental constituents of matter and their interactions. In the past several decades an enormous amount of experimental information has been accumulated, and many patterns and systematic features have been observed. Highly successful mathematical theories of the electromagnetic, weak, and strong interactions have been devised and tested. These theories, which are collectively known as the standard model, are almost certainly the correct description of Nature, to first approximation, down to a distance scale 1/1000th the size of the atomic nucleus. There are also speculative but encouraging developments in the attempt to unify these interactions into a simple underlying framework, and even to incorporate quantum gravity in a parameter-free "theory of everything." In this article we shall attempt to highlight the ways in which information has been organized, and to sketch the outlines of the standard model and its possible extensions.

And accelerator physics is a branch of applied physics, concerned with designing, building and operating particle accelerators. As such, it can be described as the study of motion, manipulation and observation of relativistic charged particle beams and their interaction with accelerator structures by electromagnetic fields. It is also related to other fields for example the Microwave engineering (for acceleration/deflection structures in the radio frequency range), Optics with an emphasis on geometrical optics (beam focusing and bending) and laser physics (laser-particle interaction) and Computer technology with an emphasis on digital signal processing; e.g., for automated manipulation of the particle beam.

The experiments conducted with particle accelerators are not regarded as part of accelerator physics, but belong (according to the objectives of the experiments) to, e.g., particle physics, nuclear physics, condensed matter physics or materials physics. The types of experiments done at a particular accelerator facility are determined by characteristics of the generated particle beam such as average energy, particle type, intensity, and dimensions.

Experimentalists for many decades' used a beam of particles to reveal the inner structure of atoms. These have progressed from naturally occurring alpha and beta particles, courtesy of natural radioactivity, through cosmic rays to intense beams of electrons, protons, and other particles at modern accelerators, the particle accelerator is the device that accelerates charged particles to very high speeds (High Energy) using electric and/or magnetic fields. The original idea had been to accelerate particles to high energy through a series of small pushes from relatively low accelerating voltages.

(1-2)The purpose of the research

The purpose of the research will illustrate the importance of linear accelerators and its centrality in the research of elementary particle physics because it is the only way to discover a new particles.

(1-3)The importance of studying particle physics accelerators

Research using beams from particle accelerators has told us much of what we know about the basic building blocks of matter, and about nature’s (fundamental forces).

In controlled laboratory settings, the highest-energy accelerators physically the largest recreate conditions that have not occurred since the Big Bang. Such accelerators probe the deepest level in nature.

They are central in the effort to unravel the mysteries of dark matter and dark energy. But that’s only part of the reason to care.

Most of accelerators, only room-sized or smaller, serve as essential tools for biomedical and materials research, for diagnosing and treating illnesses, and for a growing host of tasks in manufacturing, in energy technology, and in homeland security.

(1-4)The problem of the research

The main problem of this research is to understand how the International linear collider(ILC) work and how to discover a new particle through this accelerator to fill the gaps of elementary particle physics researches, those are incomplete in many important respects.

(1-5)Outline of the project

This research contains four chapters: chapter one Introduction ,Chapter two the elementary particle physics, Chapter three dedicated for accelerator physics, Chapter four the International linear collider(ILC) and conclusions.

Chapter Tow

Elementary particle physics

(2-1)Introduction

All matter is made up from molecules, and molecules are bound states of atoms. For example, water consists of water molecules which are bound states of one oxygen atom and two hydrogen atoms. This state of affairs is reflected in the chemical formula H_2O [4].

The word atom from the Greek atoms, which means (indivisible), the early Greeks believed that atoms were the indivisible constituent of matter that they regarded them as elementary particle [1].

There are 92 different atoms seen in nature (element 43, technetium, is not occurring in nature, but it has been man-made).
Atoms have a nucleus, and electrons are orbiting around these nuclei. The size of the atoms (the size of the outer orbit of the electrons) is of the order of $1/100000000$ cm, the nucleus is 100000 Times smaller.
The atom is therefore largely empty [4].

The nucleus contains protons and neutrons, also called nucleons. The proton has an electric charge of $+1$(in units where the charge of the electron is-1), the neutron is electrically neutral [4].
The number of electrons in an atom equals the number of protons in the nucleus, and consequently atoms are electrically neutral [4].

(2-1-1)The fundamental forces in nature

All natural phenomenon's can be described by four fundamental force acting between particles they are the nuclear force, the electromagnet force, the week force and the gravitational force [1].

Nuclear force is an attractive force between nucleons greater than approximately $10^{-15}m$ .The electromagnet force which binds atoms and molecules together to form ordinary matter, as strength of approximately $10^{-2}m$ times that of the nucleus force. This long range force decreases in magnitude as the invers square of the separation between interacting particles. The weak force is a short range force that tends to produce in instability in certain nuclei.

It is responsible for decay processes, and it is strength is only about 10^{-5} times that of the nuclear force. Finally the gravitational force is along range that has strength of only about 10^{-39}times that of the nuclear force. Although this familiar interaction is the force that holds the planets, stars, and galaxies together; it is effect on elementary particles in negligible [1].

In modern physic the nature between the interaction particle is carried a step further, this interaction is described in term of the exchange of entities called field particle or exchange particle , field particle are also called gauge bosons. The interacting particles continuously emit and absorb field particle. The emission of a field particle by one particle and it is absorption by another manifest as a force between the two interacting particles [1].

In the case of the electromagnetic interaction for instance, the field particle are photons. In language of the modern physic the electromagnet force is said to be mediated by photons and photons are the field particle of the electromagnetic field likewise the nuclear force is mediate by field called gluons. The weak force is mediated by field particle called wands bosons and the gravitational is propose to be mediated by the field particle called graviton this interaction their range and their relative strengths are summarized in the coming table (2-1) [1].

Table (2-1) shows the fundamental forces and the interactions

Interactions	Relative strength	Range of force	Mediating field particle	Mass of field particle (Gev/c^2)
Nuclear	1	Short (≈ 1FM)	Gluon	0
Electromagnet	10^{-2}	∞	Photon	0
Weak	10^{-5}	Short (≈ 10^{-3}FM)	$W^{\pm}Z^{0}$bosons	80.4,80.4,91.2
Gravitational	10^{-39}	∞	Graviton	0

(2-2)The classification of particles

The particles can be put into two categories, matter particles and gauge bosons. The matter particles are the quarks and leptons [3].

(2-2-1)Quarks and Leptons

A quark can be defined as fermion that carries the color charge of QCD, while a lepton is a fermion with no color charge. Both have spin$\frac{1}{2}$.

So far there are known to be six kinds of quarks (called six quark "flavors") and six kinds of leptons (six leptons "flavors"). It is not understood why there are six, nor whether more will be found as machines become available to look at higher energies. The quarks are called, for historical reasons up, down, strange, charmed, bottom, top. They are denoted by the first letters of their names and they naturally fall into doublets (called "families" or "generations")

$$\binom{u}{d}\binom{c}{s}\binom{t}{b}$$

The top row has electric charge $q=\frac{2}{3}e$ and the bottom row has $q=-\frac{1}{3}e$, where e the magnitude of the electrons electric charge is [3].

Five of the quarks have been studied experimentally for some time. The t-quarkmust exist, given the requirements of the electroweak theory and the measured properties of the b-quark see table (2-2), but its mas in not yet measured [3].

Table No (2-2) shows Quark classification

q	Q	D	U	S	C	B	T
d	$-\frac{1}{3}$	-1	0	0	0	0	0
u	$\frac{2}{3}$	0	1	0	0	0	0
s	$-\frac{1}{3}$	0	0	-1	0	0	0
c	$\frac{2}{3}$	0	0	0	1	0	0
b	$-\frac{1}{3}$	0	0	0	0	-1	0
t	$\frac{2}{3}$	0	0	0	0	0	1

The flavors of leptons are also arranged in three families of doublets,

$$\begin{pmatrix} \nu_e \\ e \end{pmatrix} \begin{pmatrix} \nu_\mu \\ \mu \end{pmatrix} \begin{pmatrix} \nu_\tau \\ \tau \end{pmatrix}$$

The electron (e), muon (μ), and tau (τ) have electric charge $-e$, while each has its own neutrino of electric charge zero.

A lepton number can be defined for each family; it is observed experimentally to be conserved. The neutrino masses are not measured yet; they are consistent with zero, but most theorists do not expect them to be zero.

As with the quarks, the leptons masses are not understood, $\nu_\tau$has not been directly observed, but given the requirements of the electroweak theory and the properties of the τ, it must exist see table (2-3) [3].

Table No (2-3) shows Lepton classification

l	Q	L_e	L_μ	L_τ
e	-1	1	0	0
ν_e	0	1	0	0
μ	-1	0	1	0
ν_μ	0	0	1	0
τ	-1	0	0	1
ν_τ	0	0	0	1

The quarks and leptons are the basic particles of matter. In addition, other particles transmit the forces; they are all bosons (integral spin) [3].

(2-2-2)Mesons

The first significant theory of the strong force was proposed by Yukawa in 1934. Yukawa assumed that the proton and neutron are attracted to one another by some sort of field, just as the electron is attracted to the nucleus by an electric field and the moon to the earth by a gravitational field. This field should properly be quantized [8].

Yukawa's particle came to be known as the *meson* (meaning "middle-weight).in the same spirit the electron is called a *lepton* ("light-weight"), whereas the proton and neutron are *baryons* ("heavy-weight").

Now, Yukawa knew that no such particle had ever been observed in the laboratory, and he therefore assumed his theory was wrong. But at the time a number of systematic studies of cosmic rays were in progress, and by 1937 two separate groups (Anderson and Neddermeyer on the west coast, and street and Stevenson on the east) has identified particles matching Yukawa's description [8].

For a while everything seemed to be in order. But as more detailed studies of the cosmic ray particles were undertaken. They had the wrong lifetime and they seemed to be significantly lighter than Yukawa had predicted; worse still, different mass measurements were not consistent with one another.

Finally in 1947, when Powell and his co-workers at Bristol discovered that there are actually tow middle-weight particles in cosmic rays, which they called π (or "Pion") and μ (or "muon") [8].

The true Yukawa meson is the π; it is produced copiously in the upper atmosphere, but ordinarily disintegrated long before reaching the ground [8].

(2-2-3)Photons

In 1905 Einstein proposed the daring idea that electromagnetic radiation is quantized and appears only in precisely defined energy packets called photons [4].

In some respect the photon is a very modern particle, having more in common with the *w* and *z* (which were not discovered until 1983) than with the classical trio. Moreover, it's hard to say exactly when or by whom the photon was really discovered, although the essential stages in the process are clear enough [8].

The first contribution was made by plank in 1900. Plank was attempting to explain the so-called *blackbody spectrum* for the electromagnetic radiation emitted by a hot object. Statistical mechanics, which had proved brilliantly successful in explaining other thermal processes, yielded nonsensical results when applied to electromagnetic fields [8].

In particular, it led to the famous "ultraviolet catastrophe" predicting that the ultraviolet catastrophe and fit the experimental curve if he assumed that electromagnetic radiation is quantized, coming in little package of energy.

$$E = h\nu \tag{2-1}$$

Where ν is the frequency of the radiation and h is the constant, which Planck adjusted to fit the data, the modern value of Planck's constant is

$h = 6.626 \times 10^{-27} erg\ s.$

Planck did not profess to know why the radiation was quantized; he assumed that it was due to a peculiarity in the emission process, for some reason a hot surface only gives off electromagnetic radiation in little squirts [8].

(2-2-4)Antiparticles

Antiparticles may have some properties different from those of the corresponding particles; they are still just “particles”. For example, a particle and its antiparticle have exactly the same mass and both fall downwards in the earth’s gravitational field. The antiparticle of the electron is called a positron, and it has the same mass as the electron, but the opposite electric charge.

The importance of the concept of antiparticles follows from a law of nature: to each particle there corresponds an antiparticle that has precisely the same mass, and whose other properties are exactly defined with respect to those of the particle [4].

For example, the electric charge has the opposite sign. The law mentioned allows for the possibility that the antiparticle corresponding to a particle be the particle itself. In that special case the charge of the particle must necessarily be zero. The photon is such a particle. It is its own antiparticle.

There is a standard way to denote an antiparticle: by means of a bar above the particle name or symbol. Thus one could write electron and that would mean a positron [4].

For example, a proton contains three quarks, two u and one $d$quark, and an antiproton simply contains the corresponding antiparticles, two anti-up quarks $\bar{u}$and one anti down-quark $\overline{d}$ [4].

(2-3)The Standard Model

In 1979, Sheldon Glashow (b. 1932), Abdus Salam (1926–1996), and Steven Weinberg (b. 1933) won a Nobel Prize in Physics for developing a theory that unifies the electromagnetic and weak interactions. This electroweak theory postulates that the weak and electromagnetic interactions have the same strength when the particles involved have very high energies [1].

The combination of the electroweak theory and quantum chromo dynamics (QCD) for the strong interaction is referred to in high-energy physics as the Standard Model**.** Although the details of the Standard Model are complex, its essential ingredients can be summarized with the help of Figure (Although the Standard Model does not include the gravitational force at present, we include gravity in Figure because physicists hope to eventually incorporate this force into a unified theory) [1].

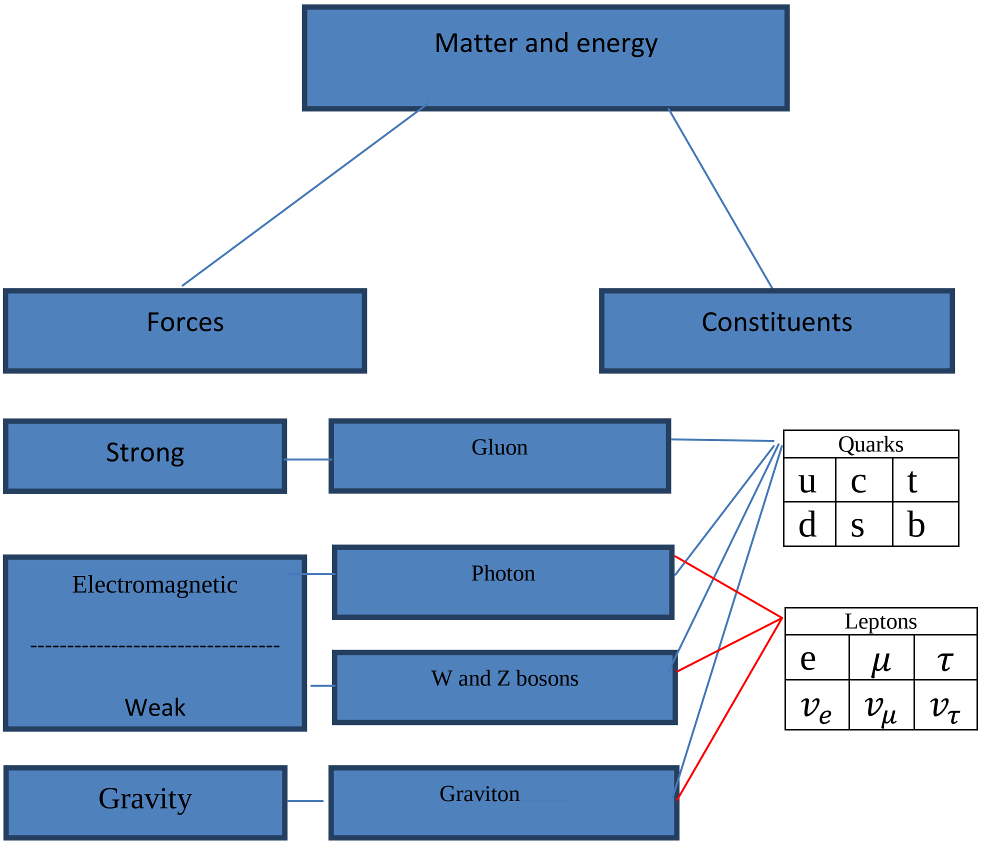

Figure (2-1) the standard model of particle physics

This diagram shows that quarks participate in all the fundamental forces and leptons participate in all except the strong force [1].

The Standard Model does not answer all questions. A major question still unanswered is why, of the two mediators of the electroweak interaction, the photon has no mass but the W and Z bosons do. Because of this mass difference, the electromagnetic and weak forces are quite distinct at low energies but become similar at very high energies, when the rest energy is negligible relative to the total energy. The behavior as one goes from high to low energies is called symmetry breaking because the forces are similar, or symmetric, at high energies but are very different at low energies [1].

The nonzero rest energies of the W and Z bosons raise the question of the origin of particle masses. To resolve this problem, a hypothetical particle called the Higgs boson**,** which provides a mechanism for breaking the electroweak symmetry, has been proposed. The Standard Model modified to include the Higgs boson provides a logically consistent explanation of the massive nature of the W and Z bosons. Unfortunately, the Higgs boson has not yet been found, but physicists know that its rest energy should be less than 1 TeV [1].

To determine whether the Higgs boson exists, two quarks each having at least 1 TeV of energy must collide. Calculations show that such a collision requires injecting 40 TeV of energy within the volume of a proton, however.

Because of the limited energy available in conventional accelerators using fixed targets, it is necessary to employ colliding-beam accelerators called colliders. The concept of colliders is straightforward. Particles that have equal masses and equal kinetic energies, traveling in opposite directions in an accelerator ring, collide head-on to produce the required reaction and form new particles [1].

The Higgs interaction is as yet hypothetical. It involves a neutral spin 0 particle called the Higgs particle. The strength of its interaction with any particle is proportional to the mass of that particle, and is very weak (except For the heaviest particles such as the top quark for which its strength actually exceeds that of the weak and electromagnetic interactions) [1].

Chapter Three

Accelerator physics

(3-1)Introduction

A particle accelerator is a scientific instrument that produced a directional stream of electrically charged particles, usually electrons or protons. The accelerator also boosts the energy of this beam.

Particle beams are used for many kinds of research, and for medical and industrial applications.

All accelerators use electromagnetic forces to boost the energy of stable charged particles. These are injected into the machine from a device that provides a high intensity source of low-energy particles, for example an electron gun (a hot filament), or a proton ion source. The accelerators used for nuclear structure studies may be classified into those that develop a steady accelerating field (DC machines) and those in which radio frequency electric fields are used (AC machines). All accelerators for particle physics are of the latter type [7].

(3-2)The invention of particle accelerators

In the earliest particle accelerators a static electric field accelerated charged particles to higher energies than conventional voltage sources could deliver. In the 1920's the work of Rolf Wideröe, a Norwegian engineer, led directly toward the modern linear accelerator [9].

Wideröe's work also intrigued Ernest O. Lawrence, a young scientist at the University of California at Berkeley. In the 1930's, Lawrence became the first to apply the work to a circular accelerator when he invented the cyclotron [9].

The cyclotron opened up whole new avenues of research in nuclear physics, including the production of unstable nuclei and non-naturally occurring elements. It also enabled particle-beam treatment of cancer [9].

Since then, advances in technology have driven a million-fold increase in accelerator energies, which now exceed 3 trillion volts. The field has progressed from accelerator beams that strike stationary targets to accelerators with counter-rotating beams called colliders. The beams collide head-on and make full use of both beams' energy.

The biggest accelerators stretch for miles.

The Large Hadron Collider, called the *LHC*, a proton-proton collider in Europe, is the world's highest-energy particle accelerator.

The Relativistic Heavy Ion Collider at Brookhaven National Laboratory Collides gold nuclei with each other.

The Fermi lab Tevatron in Illinois, until recently the world's highest-energy accelerator, was shut down in 2011. It Collided protons with antiprotons and produced the top quark, the most massive elementary particle known.

These are among the grandest scientific instruments ever built [9].

(3-3)How accelerators work

An accelerator's intended use dictates selection of the charged-particle beams characteristics. The particles are always electrically charged electrons, positrons (anti-electrons), protons, antiprotons, various nuclei or ions (atoms with an imbalance of electrons and protons) [9].

To create a large accelerator for discovery science, accelerator physicist's work with engineers to design, build, install commission and operate components like those described here and on the facing page. (Industrial and medical accelerators are much smaller) [9].

Generally the accelerator is composed of,

A. The source produces the charged particles to be accelerated.

B. Vacuum chamber, the beam travels through a pipe evacuated to as low a pressure as possible to minimize scattering of the beam particles by gas particles that remain in the pipe.

C. Magnets bend the particles along the correct path and keep them concentrated in a narrow beam.

D. Accelerating structures. Electric fields accelerate the beam.

E. Cooling systems. Either water or ultralow- temperature liquid helium removes heat dissipated in accelerator components.

Superconducting magnets and accelerating structures require liquid helium to achieve superconductivity.

F. Injection/extraction systems guide particles into/out of the accelerator or from one accelerator to another.

G. Beam diagnostics provide information about the beam intensity (current), position, beam profile, and beam loss. The information is transmitted to a control room.

Many accelerators have an enormous amount of energy in the beam. A special subsystem can nearly instantly detect malfunctions and trigger special magnets to “dump” the beam at a safe location to prevent damage to the accelerator [9].

(3-4)DC accelerators

The earliest type of DC accelerator was the Cockcroft–Walton machine, in which ions pass through sets of aligned electrodes that are operated at successively higher potentials. These machines are limited to energies of about 1MeV, but are still sometimes used as injectors as part of the multistage process of accelerating particles to higher energies [7].

The most important DC machine in current use is the van de $Graaff$ accelerator and an ingenious version of this, known as the tandem van de$Graaff$, that doubles the energy of the simple machine, is shown schematically in Figure (3-1). The key to this type of device is to establish a very high voltage. The van de $Graaff$ accelerator achieves this by using the fact that the charge on a conductor resides on its outermost surface and hence if a conductor carrying charge touches another conductor it will transfer its charge to the outer surface of the second conductor [7].

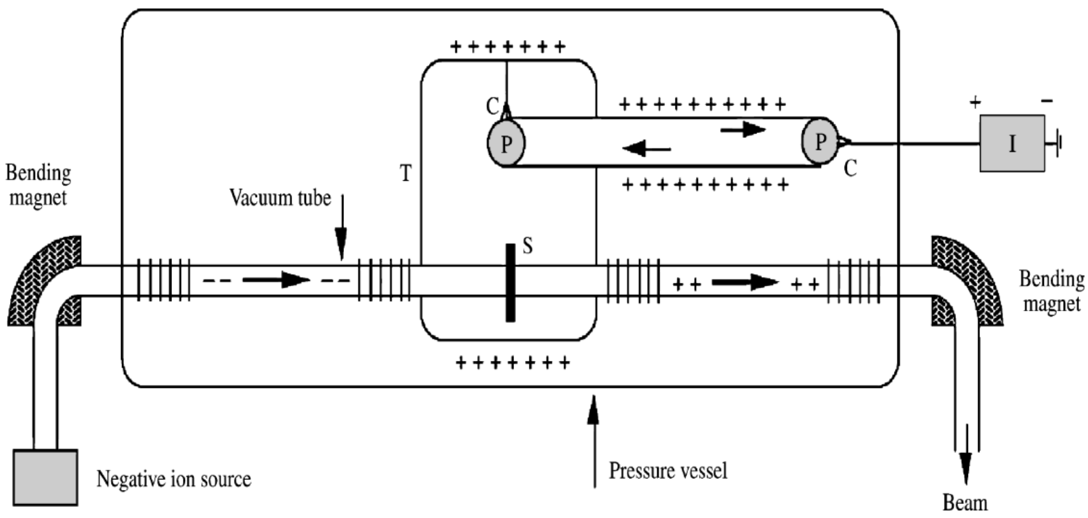

Figure (3-1) Principle of the tandem van de $Graaff$ accelerator

In Figure (3-1), a high voltage source at I passes positive ions to a belt via a comb arrangement at C. The belt is motor driven via the pulleys at P and the ions are carried on the belt to a second pulley where they are collected by another comb located within a metal vessel T. The charges are then transferred to the outer surface of the vessel, which acts as an extended terminal. In this way a high voltage is established on T. Singly charged negative ions are injected from a Source and accelerated along a vacuum tube towards T [7].

(3-5)AC accelerators

Accelerators using radio frequency $(r.f.)$ electric fields may conveniently be divided into linear and cyclic varieties [7].

(3-5-1)Linear accelerators

In a linear accelerator (or $linac$) for accelerating ions, particles pass through a series of metal pipes called drift tubes, that are located in a vacuum vessel and connected successively to alternate terminals of an $(r.f.)$ oscillator, as shown in Figure (3-2) Positive ions accelerated by the field move towards the first drift tube [7].

If the alternator can change its direction before the ions passes through that tube, then they will be accelerated again on their way between the exit of the first and entry to the second tube, and so on. Thus the particles will form bunches. Because the particles are accelerating, their speed is increasing and hence the lengths of the drift tubes have to increase to ensure continuous acceleration. To produce a useful beam the particles must keep in phase with the $(r.f.)$ field and remain focused [7].

In the case of electrons, their velocity very rapidly approaches the speed of light and the variation of the $linac$ method that is more efficient is used to accelerate them [7].

Bunches of particles pass through a straight evacuated wave guide with a periodic array of gaps similar to the ion accelerator

Radio frequency oscillations in the gaps are used to establish a moving electromagnetic wave in the structure, with a longitudinal component of the electric field moving in phase with the particles. As long as this phase relationship can be maintained, the particles will be continuously accelerated.

Radio frequency power is pumped into the waveguide at intervals to compensate for resistive losses and gives energy to the electrons. The largest electron *linac* is at the SLAC laboratory in Stanford USA, and has a maximum energy of 50 GeV. It is over 3 km long [7].

An ingenious way of reducing the enormous lengths of high-energy *linacs* has been developed at the Continuous Electron Beam Accelerator Facility (CEBAF) at the Jefferson Laboratory in the USA. This utilizes the fact that above about 50MeV, electron velocities are very close to the speed of light and thus electrons of very different energies can be accelerated in the same drift tube. Instead of a single long *linac*, the CEBAF machine consists of two much shorter linacs and the beam from one is bent and passed through the other. This can be repeated for up to four cycles. Even with the radiation losses inherent in bending the beams, very intense beams can be produced with energies between 0.5 and 6.0 GeV [7].

CEBAF is proving to be an important machine in the energy region where nuclear physics and particle physics descriptions overlap.

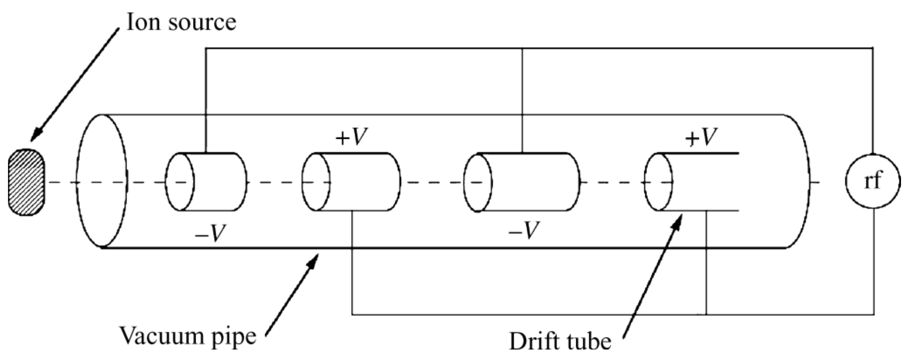

Figure (3-3) acceleration in a linear ion accelerator

(3-5-2)Cyclic accelerators

Cyclic accelerators used for low-energy nuclear physics experiments are of a type called cyclotrons. They are also used to produce beams of particles for medical applications, including proton beams for radiation therapy [7].

Cyclotrons operate in a somewhat different way to cyclic accelerators used in particle physics, which are called synchrotrons. In a cyclotron, 5 charged particles are constrained to move in near-circular orbits by a magnetic field during the acceleration process. There are several types of cyclotron; and one will be described. This is illustrated

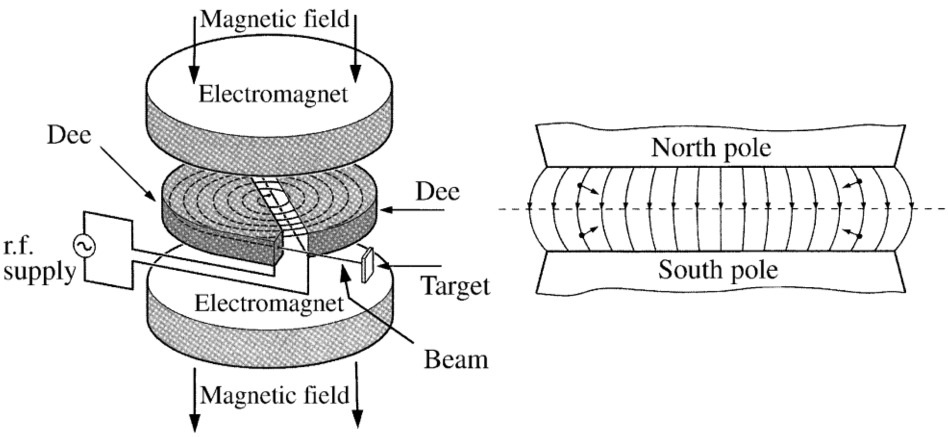

Figure (3-4) Schematic diagram of a cyclotron

Schematically in Figure (3-4). The accelerator consists of two ‘Dee’-shaped sections across which an $(r.f.)$ electric field is established. Charged ions are injected into the machine near its center and are constrained to traverse outward in spiral trajectories by a magnetic field. The ions are accelerated each time they pass across the gap between the Dees. At the maximum radius, which corresponds to the maximum energy, the beam is extracted [7].

The shape of the magnetic field, which is also shown in Figure (3-4), ensures that forces act on particles not orbiting in the medium plane to move them closer to this plane. This brief description ignores the considerable problems that have to be overcome to ensure that the beam remains focused during the acceleration. The principle of a synchrotron is analogous to that of a linear accelerator, but where the acceleration takes place in a near circular orbit rather than in a straight line. The beam of particles travels in an evacuated tube called the beam pipe and is constrained in a circular or near circular path by an array of dipole magnets called bending magnets (Figure (3-4)). Acceleration is achieved as the beam repeatedly traverses one or more cavities placed in the ring where energy is given to the particles. Since the particles travel in a circular orbit they continuously emit radiation, called in this context synchrotron radiation. The amount of energy radiated per turn by a relativistic particle of mass m is proportional to$(\frac{1}{m^4})$.

For electrons the losses are thus very severe, and the need to compensate for these by the input of large amounts of $(r.f.)$ power limits the energies of electron synchrotrons [7].

(3-5-3)Limitation of the cyclotron

- Cannot accelerate neutral particles.
- Not useful in acceleration of electrons.
- With increased velocity the beam gets out of the phase with the oscillating electric field [10].

(3-5-4)Application of the cyclotron

- Important research tools in nuclear physics.
- Used for medical purpose e.g. Radiation surgery and therapy.
- Radioactive beam production [10].

(3-6)Fixed-target machines and colliders

Both linear and cyclic accelerators can be divided into fixed-target and colliding beam machines. The latter are also known as colliders, or sometimes in the case of cyclic machines, storage rings. In fixed-target machines, particles are accelerated to the highest operating energy and then the beam is extracted from the machine and directed onto a stationary target, which is usually a solid or liquid. Much higher energies have been achieved for protons than electrons, because of the large radiation losses inherent in electron machines mentioned earlier. The intensity of the beam is such that large numbers of interactions can be Produced, which can either be studied in their own right or used to produce secondary beams [7].

The main disadvantage of fixed-target machines for particle physics has been mentioned earlier: the need to achieve large Centre-of-mass energies to produce new particles. Almost all new machines for particle physics are therefore colliders, although some fixed-target machines for specialized purposes are still constructed [7].

(3-7)Particle Interactions with Matter

In order to be detected, a particle must undergo an interaction with the material of a detector [7].

The first possibility is that the particle interacts with an atomic nucleus. For example, this could be via the strong nuclear interaction if it is a hadron or by the weak interaction if it is a neutrino [7].

If the energy is sufficiently high, new particles may be produced, and such reactions are often the first step in the detection process. In addition to these short-range interactions, a charged particle will also excite and ionize atoms along its path, giving rise to ionization energy losses, and emit radiation, leading to radiation energy losses. Both of these processes are due to the long-range electromagnetic interaction. They are important because they form the basis of most detectors for charged particles [7].

Both of these processes are due to the long-range electromagnetic interaction. They are important because they form the basis of most detectors for charged particles. Photons are also directly detected by electromagnetic interactions, and at high energies their interactions with matter lead predominantly to the production of e^+e^-pairs via the pair production process $\gamma \to e^+ + e^-$, which has to occur in the vicinity of a nucleus to conserve energy and momentum [7].

(3-7-1)Short-range interactions with nuclei

For hadrons, the most important short-range interactions with nuclei are due to the strong nuclear force which, unlike the electromagnetic interaction, is as important for neutral particles as for charged ones, because of the charge-independence of the strong interaction. Both elastic scattering and inelastic reactions may result. At high energies, many inelastic reactions are possible, most of them involving the production of several particles in the final state [7].

Many hadronic cross-sections show considerable structure at low energies due to the production of hadronic resonances, but at energies above about 3 GeV, total cross-sections are usually slowly varying in the range 10–50 mb and are much larger than the elastic cross-section [7].

(3-7-2)Ionization energy losses

Ionization energy losses are important for all charged particles, and for particles other than electrons and positrons they dominate over radiation energy losses at all but the highest attainable energies. The theory of such losses, which are due dominantly to Coulomb scattering from the atomic electrons, was worked out by Bethe, Bloch and others in the 1930s. The result is called the Bethe–Bloch formula, and for spin-0 bosons with charge $\pm q$ (in units of e), mass M and velocity v, it takes the approximate form (neglecting small corrections for highly relativistic particles) [7].

$$-\frac{dE}{dx} = \frac{dq^2 n_e}{\beta^2}\left[\ln\left(\frac{2m_e c^2\beta^2\gamma^2}{I}\right) - \beta^2\right] \quad (3\text{-}1)$$

Where x is the distance travelled through the medium.

$$D = \frac{4\pi\alpha^2\hbar^2}{m_e} = 5.1 \times 10^{-25} MeV\ cm^2 \quad (3\text{-}2)$$

m_eIs the electron mass, $\beta = \frac{v}{c}$ and $\gamma = (1-\beta^2)^{-\frac{1}{2}}$.

The other constants refer to the properties of the medium are, $n_e$is the electron density, and I is the mean ionization potential of the atoms averaged over all electrons which is given approximately by $I = 10$ Z eV for Z greater than 20 [7].

The corresponding formula for spin $-\frac{1}{2}$particles differs from this, but in practice the differences are small and may be neglected in discussing the main features of ionization energy loses [7].

(3-7-3)Radiation energy losses

When a charged particle traverses matter it can also lose energy by radioactive collisions, especially with nuclei. The electric field of a nucleus will accelerate and decelerate the particles as they pass, causing them to radiate photons, and hence lose energy. This process is called bremsstrahlung (literally 'braking radiation' in German) and is a particularly important contribution to the energy loss for electrons and positrons [7].

(3-7-4)Interactions of photons in matter

In contrast to heavy charged particles, photons have a high probability of being absorbed or scattered through large angles by the atoms in matter.

Consequently, a collimated mono-energetic beam of I photons per second traversing a thickness dx of matter will lose

$$dI = -I\frac{dx}{\lambda} \tag{3-3}$$

Photons per second, where

$$\lambda = (n_a\sigma_\gamma)^{-1} \tag{3-4}$$

Is the mean free path before absorption or scattering out of the beam, and σ_γ is the total photon interaction cross-section with an atom. The mean free path λ is analogous to the collision length for hadronic reactions [7].

Chapter Four

International linear collider

(4-1)INTRODUCTION

The International Linear Collider (ILC) is a 200–500 GeV (extendable to 1TeV) Centre-of-mass high luminosity linear electron-positron collider, Based on 1.3 GHz superconducting radio-frequency (SCRF) accelerating technology [5].

Its parameters have been set by physics requirements first outlined in 2003, updated in 2006, and thoroughly discussed over many years with the physics user community. The physics parameters have been reviewed continuously and found to be robust to advances in the science, including the recent discovery of a Higgs boson at the Large Hadron Collider at CERN.

The collider design is the result of nearly twenty years of R&D. The heart of the ILC, the superconducting cavities, is based on over a decade of pioneering work by the TESLA collaboration in the 1990s. Some other aspects were based on the R&D carried out for the JLC/GLC and NLC projects which were based on room-temperature accelerating structures. Since 2005, the design of the ILC Accelerator has continued as a worldwide international collaboration coordinated by the Global Design Effort (GDE) under a mandate from the International Committee for Future Accelerators (ICFA) [5].

Drawing on the resources of over 300 national laboratories, universities and institutes worldwide, the GDE produced the ILC Reference Design Report (RDR) in August 2007.

The most important aspects of the ILC physics program are,

(1) Measurement of the properties of the newly-discovered Higgs boson with very high precision.

(2) Measurement of the properties of the top quark with very high precision.

(3) Searches for and studies of new particles expected in models of physics at the TeV energy scale.

The specie capabilities of the ILC in these areas are reviewed in the various sections of this report.

The physics program of the ILC is still broader, encompassing precision electroweak measurements, detailed studies of the W and Z boson couplings, tests of Quantum Chromo dynamics, and other topics [5].

(4-2)The ILC Technical Design

The International Linear Collider (ILC) is a high-luminosity linear electron-positron collider based on GHz superconducting radio-frequency (SCRF) accelerating technology. Its center-of-mass-energy range is 200–500 GeV (extendable to1 TeV). A schematic view of the accelerator complex, indicating the location of the major sub-systems, is shown in Figure (4-1).

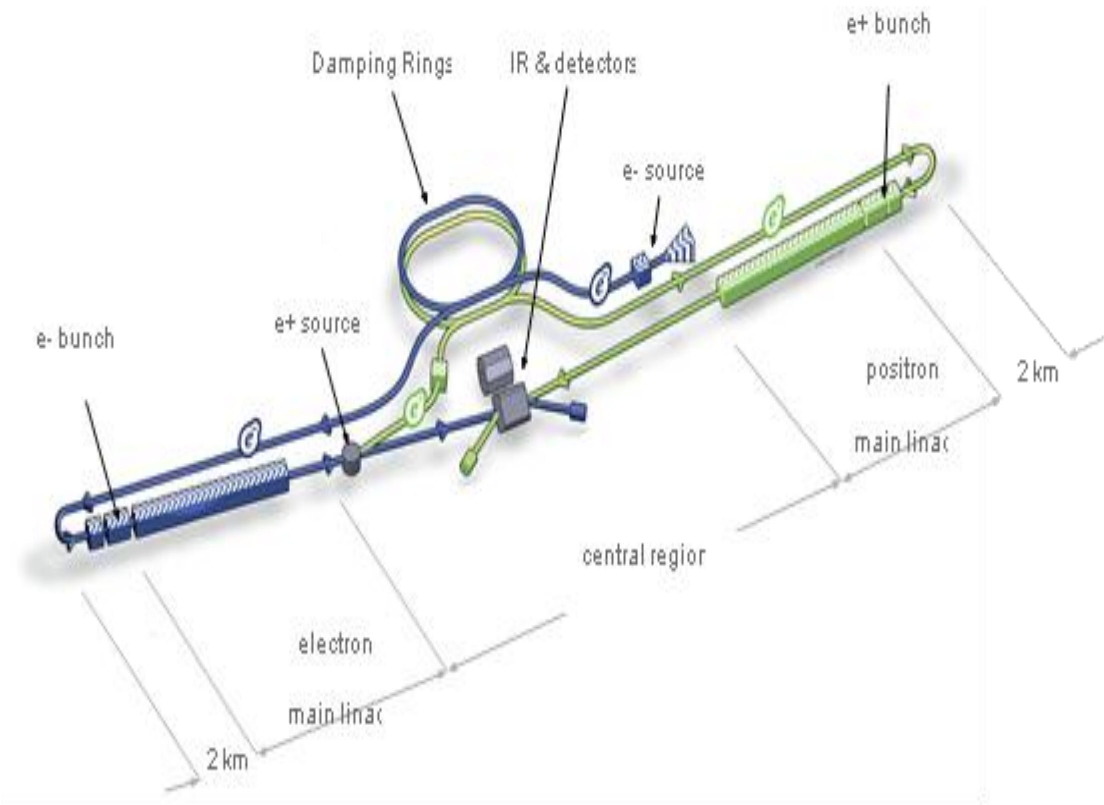

Figure (4-1) Schematic layout of the ILC

• A polarized electron source based on a photocathode DC gun.

• A polarized positron source in which positrons are obtained from electron-positron pairs by converting high-energy photons produced by passing the high-energy main electron beam through an undulator.

• 5 GeV electron and positron damping rings (DR) with a circumference of 3.2 km, housed in a common tunnel.

• Beam transport from the damping rings to the main linacs, followed by a two-stage bunch- compressor system prior to injection into the main linac.

•Two 11 km main linacs, utilizing 1.3 GHz SCRF cavities operating at an average gradient of31.5 MV/m, with a pulse length of1.6 Ms.

•Two beam-delivery systems, each 2.2 km long, which bring the beams into collision with a 14 $mrad$ crossing angle, at a single interaction point which can be occupied by two detectors in a so-called “push-pull” configuration [5].

(4-3)Detection techniques in the ILC

The ILC has been designed to enable two experiments (SID and ILD) sharing one interaction region using a push-pull approach. This two detector design is motivated by the enhanced scientific productivity of past collider facilities which benefited from independent operation of multiple experiments, providing complementary strengths, cross-checking and confirmation of results, reliability, insurance against mishaps, competition between collaborations, as well as increased number of involved scientific personnel [5].

(4-3-1)The SID detector

SID is a compact detector based on a powerful silicon pixel vertex detector, silicon tracking, Silicon tungsten electromagnetic calorimetry (ECAL) and highly segmented hadronic calorimetry (HCAL).

SID also incorporates a high-field solenoid, iron flux return, and a muon identification system [5].

The choice of silicon detectors for tracking and vertex ensures that SID is robust with respect to beam backgrounds or beam loss, provides superior charged-particle momentum resolution, and eliminates out of time tracks and backgrounds. The main tracking detector and calorimeters are “live” only during each single bunch crossing, so beam-related backgrounds and low-PT backgrounds from hadrons processes will be reduced to the minimum possible levels. The SID calorimetry is optimized for excellent jet-energy measurement using the PFA technique. The complete tracking and calorimeter systems are contained within a superconducting solenoid, which has 5T field strength, enabling the overall compact design. The coil is located within a layered iron structure that returns the magnetic flux and is instrumented to allow the identification of muons [5].

(4-3-2)The ILD detector

The ILD concept has been designed as a multi-purpose detector. It has been designed for optimal particle-flow (PFA) performance.

A high-precision vertex detector is followed by a hybrid tracking

System, Realized as a combination of silicon tracking with a time-projection chamber, and a calorimeter systems.

The complete system is located inside a 3.5T solenoid. The inner-detector system is highly granular, and provides a robust and detailed three dimensional imaging capability of the events. On the outside of the coil, the iron return yoke is instrumented as a muon system and as a tail-catcher Calorimeter [5].

The vertex detector is realized as a multi-layer pixel vertex detector (VTX), with three super-layers each comprising two layers, or as a 5 layer geometry. In either case the detector has pure barrel geometry. To minimize the occupancy from background hits, the first super layer is only half as long as the outer two. Whilst the underlying detector technology has not yet been decided, the VTX is optimized for point resolution and minimum material thickness [5].

A system of silicon strip and pixel detectors surrounds the VTX detector. In the barrel, two layers of silicon strip detectors (SIT) are arranged to bridge the gap between the VTX and the TPC.

In the forward region, a system of two silicon-pixel disks and five silicon-strip disks (FTD) provides low angle tracking coverage [5].

(4-4)Physics at the International Linear Collider

Today the search for new particles and forces at energies of hundreds or thousands of GeV plays a central role in the field of elementary particle physics. Particle physicists have established a “Standard Model” for the strong, weak, and electromagnetic interactions that passes tests at both low and high energies. The model is extremely successful, and yet it is incomplete in many important respects [5].

New particles and interactions are needed to fill the gaps.

Some of the difficulties of the Standard Model are deep and abstract their explanations may be found only in the distant future. The Standard Model does not explain how gravity is connected to the other forces of nature. It does not explain why the basic particles of matter are the quarks and leptons, or how many of these there should be [5].

However, the Standard Model also fails to explain three phenomena that, by rights, should be accounted for at the energies now being probed with particle accelerators. Astronomers believe that the dominant form of matter in the universe is a neutral, weakly interacting species called “dark matter” that cannot be composed of any particle present in the Standard Model. The Standard Model cannot explain why the universe contains atomic matter made of electrons, protons and neutrons but no comparable amount of antimatter.

Behind these two striking problems, there is a third. The equations of the Standard Model are based on a symmetry principle, electroweak symmetry, which forbids the generation of mass for any of its fundamental particles. The universe contains an element that chooses a direction with respect to this symmetry. This asymmetrical force creates the masses of the quarks, leptons, and bosons of the Standard Model and also drives many other essential properties of the laws of nature. The Standard Model postulates a field, called the Higgs field that gives rise to this force. However, it does not explain the properties of this field. The idea that the asymmetry comes from a single Higgs field is just a guess among many other possibilities [5].

The problem of the Higgs field is likely to be connected to the earlier questions about the matter content of the universe. Explanatory models of the Higgs field often contain particles with the correct properties to make up the dark matter. There are also strong, independent, arguments that the mass of the dark-matter particle is comparable to the masses of the order of 100 GeV of the heaviest particles that receive mass from the Higgs field [5].

The excess of baryons over antibaryons in the universe could arise from interactions among Higgs fields that violate the space-time symmetry CP. More generally, any model of fundamental physics at energies above 100 GeV must contain the Higgs field or some generalization and must account for the place of this field within its structure.

A way to prove the existence of the Higgs field and to study its interactions is to find and study the quantum of this field, called the Higgs boson. The International Linear Collider was designed to study this particle and other new particles that might be associated with it. It provides an idea setting for detailed exploration of the origin and nature of the Higgs field.

In July, 2012, the ATLAS and CMS experiments at the CERN Large Hadron Collider announced the discovery of a new particle with a mass of 125 GeV and many properties of the Higgs boson as postulated in the Standard Model. The LHC experiments also exclude the possibility that the Higgs boson has higher mass, up to masses beyond 600 GeV and close to the theoretical upper bound. The ILC is an ideal machine to study this Higgs particle at 125 GeV. If this particle is one of several Higgs bosons and a different boson is the one that makes the main contributions to the W and Z boson masses, that particle must also appear at the ILC. Thus, the ILC definitely offers a direct path to the study of the Higgs field and its implications for particle physics [5].

The initial program of the ILC for a 125 GeV Higgs boson will be centered at energy of 250 GeV, which gives the peak cross section for the reaction $e^+e^- \rightarrow Zh$. In this reaction, the identification of a Z boson at the energy appropriate to recoil against the Higgs boson tags the presence of the Higgs boson. In this setting, it is possible to measure the rates for all decays of the Higgs boson even decays to invisible or unusual final states with high precision [5].

Such decays are very difficult to separate from Standard Model background events at the LHC. The precision measurement of the rates of decay of the Higgs boson to the various types of quarks, leptons, and bosons will give evidence on whether the Higgs field operates alone to create the masses of these particles, or whether it has partners that are additional new particles addressing the other questions raised above.

The study of the Higgs boson will continue, with additional essential elements, at higher energies [5].

At 500 GeV, the full design energy of the ILC, measurement of the process $e^+e^- \rightarrow \upsilon\bar{\upsilon}h$ will give the absolute normalization of the underlying Higgs coupling strengths, needed to determine the individual couplings to the percent level of accuracy.

Raising the energy further allows the ILC experiments to make precise measurements of the Higgs boson coupling to top quarks and to determine the strength of the Higgs boson's nonlinear self-interaction [5].

The ILC also will make important contributions to the search for new particles associated with the Higgs field, dark matter, and other questions of particle physics. For many such particles with only electroweak interactions, searches at the LHC will be limited by low rates relative to strong interaction induced processes, and by large backgrounds. The ILC will identify or exclude these particles unambiguously up to masses at least as high as the ILC beam energy [5].

The ILC will also constrain or discover new interactions at higher mass scales through pair production of quarks and leptons, W and Z bosons, and top quarks. Much of our detailed knowledge of the current Standard Model comes from the precision measurement of the properties of the Z boson at e^+e^-colliders. The ILC will extend this level of precision to the W boson and the top quark. The ILC will measure the mass of the top quark in a direct way that is not possible at hadron colliders, fixing a crucial input to particle physics calculations. The top quark is the heaviest particle of the Standard Model, and, as such, must have especially strong coupling to the Higgs field. The precision study of the electroweak couplings of the top quark can reveal the presence of composite structure in the Higgs particle. Characteristic effects are expected in models with strong interactions among the Higgs fields, and in models where the asymmetrical forces associated with the Higgs fields are signs of extra, hidden dimensions of space [5].

The ILC then offers many opportunities for measurements that will address the most important current problems of particle physics. It will give unique views of the Higgs boson, the top quark, and possible new particles relevant to the mysteries of the matter content of the universe. The collider enables incisive measurements of very high precision. The ILC is thus an essential tool that will advance our understanding of the basic laws of nature [5].

(4-5) Conclusion

In this research project we studied the international linear collider at length. Specifically we showed how the ILC will extend the level of precision to the W boson and the top quark. And how ILC will measure the mass of the top quark in a direct way that is not possible at hadron colliders, fixing a crucial input to particle physics calculations. We also discussed how the ILC offers a direct path to the study of the Higgs field and its implications for particle physics. Moreover, The ILC also will make an important contribution to the search for new particles associated with the Higgs field, dark matter, and other questions of particle physics thus likely new window to physics beyond the standard model.

(4-6) Recommendation

Finally we recommended every physician to study the International linear collider to reveal the mysteries of the Higgs boson, the Dark matter and to know new particles.

References

[1] Raymon A. serway, John W. Jewett, 1989, Physics for scientists and engineers with modern physics; seven editions.

[2] Donald H. Perkins, 2013, Introduction to High energy physics, Addison-Wesley Publishing Company Inc.Acrobat 7 Pdf 10.5 Mb. Scanned

[3] Gordon Kane,2012, Modern Elementary Particle Physics, The fundamental particle and forces

[4] Martinus Veltman, 2003, Facts and mysteries in Elementary particle physics.

[5] The International Linear Collider Technical Design Report 2013 Volume1: Executive Summary.

[6] The International Linear Collider Technical Design Report 2013 Volume 4: Detectors.

[7] B. R. Martin, 2008, Nuclear and Particle Physics.

[8] David Griffiths, 2008, Introduction to Elementary particles

[9] Accelerators and Beams; 2013, Tools of discovery and innovation, 4th edition published by the Division of physics of Beams of the American Physical Society.

[10] Dr. R. M. Jones, 2012, an Introduction to the Physics of Particle Accelerators.