Attached Document for the ACFA Statement on the $e^+ e^-$ Linear Collider JLC

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Trends in Elementary Particle Physics

It can perhaps be said that a revolution is at hand in Elementary Particle Physics. If the current understanding is correct, the precise measurements in electroweak physics are suggesting the existence of a light Higgs boson. The presence of a light Higgs boson naturally leads us to a new paradigm beyond the Standard Model, which includes ideas such as Supersymmetry (SUSY) and a Grand Unified Theory (GUT). This may lead us to the realm of sperstrings, in which gravity is unified with the other interactions, presumably near the Planck scale.

For more than two decades, much experimental effort has been undertaken to establish the Standard Model, which is based on two fundamental concepts, namely the gauge principle and the Higgs mechanism. Although our understanding on the gauge structure of the Standard Model has greatly improved from the discovery of the weak bosons at CERN and the precise electroweak measurements at LEP and SLC, little is known about the mechanism of electroweak symmetry breaking. The direct search for the Standard Model Higgs boson has been carried out at LEP, is continued at TEVATRON, and will be followed by LHC experiments where the whole mass range for the Standard Model Higgs boson will be covered. On the other hand, there is already a strong constraint on the possible range of the mass of the Higgs boson from studies on the precise electroweak measurements combined with the top quark mass from TEVATRON. In the Standard Model, the Higgs boson mass is estimated to be less than 196 GeV (95% C.L.).

The discovery of a light Higgs boson and the study of its properties are therefore crucial steps towards establishing the electroweak symmetry breaking mechanism and going beyond the Standard Model, and the $e^+ e^-$ Linear Collider will play an essential role for this purpose. There is possibility, like the Technicolor model, that the Higgs field is a composite state and no elementary Higgs boson exists. Although this is very attractive, the model in a simple form is not consistent with the electroweak precision measurements. If there is no elementary Higgs boson, or the Higgs boson turns out to be very heavy, some very important concepts must be missing in the current theory. An unexpected form of New Physics is foreseen at the TeV energy scale in such a case.

To determine the future direction, the most crucial step is a definite proof or disproof of TeV scale SUSY. Although each experimental indication is not strong, several independent experimental facts taken as a whole indicate the direction of a light Higgs boson with SUSY.

1. As mentioned above, the upper bound on the mass of the Standard Model Higgs boson is estimated to be 196 GeV. This is consistent with the Minimal Supersymmetric Standard Model (MSSM) where the mass of the light Higgs boson is expected to be less than 130 GeV. The upper bound cannot exceed about 200 GeV even in more general SUSY models.
2. From the measured value of the SU(3), SU(2) and U(1) gauge couplings, it is shown that the three coupling constants are unified at a mass scale around 10^{16} GeV for SU(5) SUSY GUT. The simple SU(5) GUT without SUSY cannot unify these couplings at any mass scale.
3. There is definitive evidence that the dark matter exists in our galaxy. The lightest SUSY particle is a theoretically well-motivated candidate for the dark matter.

The first indication of supersymmetric particle production may be obtained at LHC, since the cross sections of the strongly interacting supersymmetric particles (gluinos and squarks) are large at LHC. To disentangle the complicated cascade decay of these heavy SUSY particles, the determination of the masses and the couplings of the lighter colorless SUSY particles at the $e^+ e^-$ Linear Collider is essential. Experimental determination of these observables can resolve the mechanism of SUSY breaking, which is one of the most important and mysterious issues in the SUSY theories.

Recent progress in flavor physics (quark and lepton masses and flavor mixing) is remarkable. Belle and BaBar groups clearly measured the CP violation in the bottom-sector. The direct CP violation parameter ε'/ε in the kaon sector was most precisely measured by NA48 and KTeV. In coming years the Kobayashi-Maskawa mechanism of CP violation will be tested experimentally and the Cabibbo-Kobayashi-Maskawa (CKM) matrix elements will be precisely determined.

In the leptonic sector, Superkamiokande observed the flavor oscillation of the muon neutrino, probably with the tau neutrino, from the measurement of atmospheric neutrinos. The measurements of solar neutrinos by Homestake, Kamiokande, Superkamiokande, Gallium experiments, and SNO, strongly suggest the oscillation of the electron neutrino with a large mixing angle. The long base-line neutrino experiment K2K has started and it will be followed by new experiments in Japan, USA and Europe. In the Maki-Nakagawa-Sakata (MNS) matrix of the neutrino flavor mixing, the off-diagonal component of θ_{23} is measured to be large, which presents a striking contrast to the hierarchical structure of the CKM matrix. The other components will be determined in future neutrino experiments.

There are stringent limits on the mixing in the charged lepton sector. New experiments to observe μ^+ -> $e^+ \gamma$ decay and μ^- -> e^- conversion are planned, and τ -> μ γ will be searched at B factories and tau-charm factories. Together with baryon number violation which continue to be searched for at the Superkamiokande experiment, these lepton flavor violating processes are sensitive probes of the physics beyond the Standard Model, including SUSY GUT.

At a fundamental level, flavor physics has deep connection with Higgs physics. The masses and the flavor mixing of quarks and leptons are determined by the interaction of the fermions and the Higgs field, and all quarks and leptons remain massless without the vacuum expectation value of the Higgs field. The direct measurements of the

Yukawa couplings at the Linear Collider are important to understand the fermion mass generation mechanism and the origin of the flavor structure. It is necessary, for this purpose, to determine the structure of the Higgs sector and measure the Higgs decay branching ratios precisely.

More specifically, in SUSY models, the direct determination of the SUSY particles' masses and coupling constants will have a strong influence on flavor physics. Combined with information from both the Linear Collider and experiments in flavor physics, we may be able to answer important questions such as what the flavor mixing is in the SUSY partners of quarks and leptons, how it is related to the flavor mixing of quarks and leptons, why CKM and MNS matrices take the observed forms, and how they are related to each other at very large energy scales such as the GUT scale.

The outcome of the Linear Collider experiment will also have an impact on Cosmology and Astrophysics. If the lightest SUSY particle is the dark matter, the discovery and studies of SUSY by collider experiments and/or the direct observation of the dark matter may solve the fundamental problem in Cosmology. The precise determination of the properties of the lightest SUSY particle at the Linear Collider is essential also in this case.

Recent measurement on the acceleration of the expansion rate of the universe suggests the existence of the cosmological constant (dark energy). The origin of the dark energy may have a profound relation to the Higgs potential. The inflation of the universe may be due to the latent heat filled in the universe from the super-cooling which is caused by the delay of the phase transition of some Higgs field. Although these Higgs fields may not be the same one which causes the electroweak symmetry breaking, the essential ingredients are the existence of an elementary scalar field and its dynamical properties. The discovery of the Higgs boson and the reconstruction of the Higgs potential from the measurement of the self-coupling constant will provide us with the first experimental evidence that an elementary scaler field plays a fundamental role in Particle Physics and the formation of the universe, and give tremendous impact to both Particle Physics and Astrophysics.

In this way, the present knowledge of Elementary Particle Physics suggests scenarios with a light Higgs boson, which could include SUSY and/or GUT. If this is correct, the Linear Collider will play an essential role in exploring a new paradigm beyond the Standard Model.

Advantages of $e^+ e^-$ Collisions

There are several advantages to $e^+ e^-$ collisions compared to pp or $p\bar{p}$ collisions.

1. Processes

   Since electrons and positrons are elementary particles, a new particle (or a pair of new particles) can be produced via $e^+ e^-$ annihilation subprocesses. These subprocesses are observed directly in $e^+ e^-$ experiments. This is in contrast with the case of proton (anti-)proton collisions, as the (anti-)proton is a composite particle which, in the parton description, is made up of quarks and gluons. In addition, the analysis becomes considerably more complex because of the contamination from soft hadronic activity which is typically emitted near the beam direction.

2. Kinematics

   In $e^+ e^-$ collisions, the subprocess center-of-mass (CM) energy is equal to $2E_{\text{beam}}$. We can therefore apply four-momentum conservation to the event reconstruction1). In proton (anti-)proton collisions, the typical CM energy of the

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1) Minor corrections to the $e^+ e^-$ collision kinematics arise from initial state photon radiation and beamstrahlung effects, both of which can be evaluated with high precision. The beamstrahlung is a kind of synchrotron radiation. At the interaction point of $e^+ e^-$ Linear Colliders, electrons (positions) emit synchrotron radiation during the collision due to the several kilo-Tesla electro-magnetic field created by the oncoming beam.

hard subprocess is significantly lower than $2E_{beam}$, and the subprocess center-of-mass is boosted along the beam axis. Therefore the total energy conservation and the momentum conservation along the beam direction cannot be used in the analysis.

3. Physics background

The background events due to physics processes are predominantly produced by the electroweak interaction in $e^+ e^-$ collisions. Hence the cross section for each background process is at about the same order as for the signal process[2]. In proton-proton collisions, hadronic background events are produced by the strong interaction and their cross sections are huge[3].

4. Theoretical predictions

The evaluation of the cross sections for signal and background events is crucial especially for the discovery and measurement of New Physics. The theoretical predictions for the background and signal hard subprocess cross sections are accurate to o (0.1-10) % for $e^+ e^-$ collisions. This is in contrast to the case of hadronic collisions where the predictions are accurate only to o (10-100) % due to the uncertainties in higher order QCD (K-factor) and structure functions.

5. Detector issues

Because of the very high event rate at hadron colliders, fast detector response is required and the event trigger needs to become sophisticated. In the hostile radiation environment at hadron colliders, the radiation hard detector components are essential for the experiment. In such an environment, practical

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[2] For example, σ ($e^+ e^-$ -> ZH) /σ ($e^+ e^-$ -> ZZ) is about 0.2pb/0.6pb~ 1/3 for sqrt [s] = 250 GeV and m_H = 120 GeV.

[3] Even for background processes that are produced by the electroweak interaction, the cross sections are quite high due to the large phase space and the large initial state parton density. For example, σ (pp -> WH, W -> lν) /σ (pp -> Wjj, W -> lν) is 0.4pb / 5000pb~ 1/10000 for sqrt [s] = 14TeV and m_H = 120 GeV. The invariant mass peak of the Higgs boson can be seen even in this case, but it is very difficult to study the signal process above such high background

> devices that have been used in past High Energy Physics experiments have to be given up. For $e^+ e^-$ collider experiments, the radiation level is significantly lower except for the limited region very close to the interaction point. The event rate is several orders of magnitude lower than at hadron colliders because of the lower cross sections for the dominant processes and the long interval between the bunch trains. Therefore the devices given up for the LHC experiments, such as CCD for the vertex detector, TPC or the drift chamber for the main tracking device, can be used.

With the advantages given above, New Physics up to the CM energy, which can be increased step by step, can be discovered and studied at the $e^+ e^-$ Linear Collider. Therefore physics complementary to that of LHC will be the first target of the Linear Collider. In any case, the most crucial issue for the $e^+ e^-$ Linear Collider project is the accelerator technology and not the detectors. The aim of the LHC experiments is to scan the distinctive New Physics at the highest collision energies. For a high energy extension of the Linear Collider, extensive R&D for high gradient acceleration technologies is being carried out at KEK, SLAC and CERN. The collider will eventually be upgraded to an energy greater than 1 TeV to investigate physics issues beyond LHC.

Activity of Asian High Energy Physics and Accelerator Technology

Accelerator Technology in Asia

The history of accelerator in Asia dates back to 1934 when a Cockcroft Walton accelerator was built in Taipei, and accelerator related activity flourished until World War II when this was forced to stop for ten years. The activity resumed in Asia in the 1950s when a few cyclotrons were built in Japan. Then a 750 MeV electron synchrotron at INS started its operation in 1961 and the energy was raised to 1.3 GeV in 1967. Japan then embarked on the construction of a 12 GeV proton synchrotron (PS) at KEK. The machine was completed in 1976 and has been used as a High Energy and Nuclear Physics facility since then. On the basis of the growth of activity utilizing the PS, Japan then commenced the construction of TRISTAN, a 30 GeV × 30 GeV electron-positron collider, in 1981.

It was completed in 1986, and until the advent of LEP and SLC it worked as the highest energy electron-positron collider in the world. TRISTAN was an epoch-making machine in the history of accelerators in Asia. It also demonstrated that superconducting cavities could really be used in the large scale; CEBAF, HERA, and LEP-II followed the suit.

In the 1980s, China participated in the High Energy Physics field by constructing BEPC, Beijing Electron Positron Collider at IHEP. This machine was aimed at doing physics at the tau-charm energy region. BEPC was completed in 1988 and the physics program started in 1989. It soon became the highest luminosity $e^+ e^-$ collider around this energy region, and has produced physics results continuously. Now IHEP has decided to upgrade BEPC to the two-ring collider, BEPC-II, by placing one more ring in the tunnel and adopting superconducting cavities and superconducting final focus quads.

From 1994, the rejuvenation of TRISTAN to the KEK B-factory, KEKB, an asymmetric energy, two-ring, electron-positron collider, started. This machine was completed in 1998, and half a year later, physics experiments started with the Belle detector. The improvement to the performance of KEKB has been going quite smoothly and by July 2001 its luminosity reached $4.5\times10^{33}cm^{-2}s^{-1}$. This is the highest luminosity ever achieved by any type of colliders. The high performance of KEKB has culminated in the detection of CP-violation by Belle in the bottom quark sector in July 2001. The success of KEKB clearly shows the maturity of accelerator technology in Asia.

A 300 MeV dedicated electron storage ring as a light source was built at INS, in the early 1970s, and from then on the use of electron storage rings as light sources has become popular in Asia. Now we have the world largest light source machine, SPring-8, in Harima, Japan, and one of the most active machines, KEK PF. The third-generation light source machines built early in 1990s in Hsinchu, Taiwan, and, in Pohang, Korea, have been successfully in operation and the number of beam lines and users have steadily increased. At CAT in Indore, India, a 450 MeV machine, INDUS-I, was completed in 1999, and a 2.5 GeV INDUS-II is under construction. In Thailand, the construction of Siam Photon Source is quite close to its completion. China is planning to build a 3.5 GeV Shanghai Light Source in an industrial park in the Pudong area of Shanghai besides an 800 MeV light source now running in Hefei. Singapore has joined the field with Helios II at National University of Singapore. Australia has dicided to construct a 2.5 GeV light source machine, BOOMERANG, in Melbourne.

In Asia, there are many small and medium size proton or ion machines actively used for many purposes. One example is the use of a Van de Graaf accelerator for the study of environmental pollution in Bangladesh. Four large proton/ion projects are currently going on in Asia. The first one is the Joint KEK-JAERI High-Intensity Proton Project in Japan, which consists of a 400 MeV linac, a 3 GeV rapid cycle synchrotron and a 50 GeV synchrotron. This accelerator complex is aimed at delivering beams for various purposes, from spallation neutrons to neutrinos. Then in China, at IMP in Lanzhou, the construction of a multi-purpose cooling/storage ring system, CSR, started in 1999. At Riken in Japan, Radio Isotope Beam Facility, RIBF, is now under construction. In

Calcutta in India, a superconducting cyclotron is being built at VECC. In addition to these projects, basic R&D on the use of high intensity proton linear accelerators for the transmutation of nuclear waste and power generation has started in China, India, Japan and Korea.

The development, design, construction and operation of the accelerators are being made in tight collaboration with industries. The strength of the Asian industries especially in the area of accelerator technology has been proven by the performance of the accelerators in Asia.

The details of the accelerators in Asia are described in another ACFA document ‘Accelerator Activities in Asia’.

Asian High Energy Physics

In the last decade, achievements in High Energy Physics in Asia have had significant impact on Particle Physics, which are highly merited by the worldwide scientific community. In Asia, there are two major high energy physics laboratories: IHEP in China, and KEK in Japan. Asian High Energy Physics groups are also participating and playing major roles in international collaborations.

The accelerator-based particle physics of Asian community has four major streams, as follows:

- BES at BEPC

  BEPC started the physics program in 1989, around the energy region of the J/psi resonance. The BES experiment, which is the international collaboration at BEPC, accumulated more than 50M J/psi events. The BES experiment determined the tau lepton mass to a precision better than 0.2 %. Recent results by BES on the hadronic cross-section in the energy region of sqrt(s) - 3-5 GeV contributed significantly to the precision electroweak physics especially for the determination of the mass boundary of the Higgs boson.

- Belle at KEKB

  The Belle experiment at KEKB is mainly designed to measure CP violation in the bottom quark sector with high precision. The Belle experiment is an international collaboration. More than a half of the collaborators are from outside of Japan, mainly from Asian countries but also from the US and Europe. The performance of the Belle detector is excellent as designed. With the world's highest luminosity $e^+ e^-$ collision, the detector measures the production and decay of b-hadrons with unprecedented precision. The highlight of the physics at KEKB so far is the recent establishment of indirect CP-violation in the bottom quark sector, together with the BaBar experiment at SLAC in the US.

- Superkamiokande and K2K

  The discovery of the neutrino oscillation from the measurement of atmospheric neutrino by the Superkamiokande experiment established the finite mass of the neutrino. This discovery was one of the highlights of Particle Physics in the last decade. The K2K project is the pioneer of the long baseline neutrino experiment. The neutrino beam travels for a distance of about 250km from KEK to the Kamioka mine where the neutrino events are measured by the Superkamiokande detector. The K2K project will be continued for several more years. The atmospheric neutrino oscillation observed by Superkamiokande is expected to be rigidly confirmed by the well controlled accelerator based neutrino experiment. K2K will be succeeded by a new long baseline experiment in which a high intensity neutrino beam is created by the 50GeV proton synchrotron located at Tokai-Village and emitted towards Superkamiokande which is 300km away. This project is a part of the JAERI-KEK joint project which will start operation around 2007.

- International collaborations outside of Asia:

  Asian High Energy Physics groups are also participating and playing major roles in international collaborations at major High Energy Physics laboratories in the world, such as Fermilab, SLAC, BNL, DESY and CERN. Many active groups from Asia are working on the energy-frontier projects at e^+e^- colliders (LEP at CERN and SLC at SLAC), an e-p collider (HERA at DESY) and hadron colliders (TEVATRON at Fermilab and forthcoming LHC at CERN). There are also a number of essential contributions to fixed target experiments at BNL, TRIUMF, Fermilab and CERN. The experience accumulated through these international projects is vital in order to form a truly international collaboration in the next principal project based in Asia.

Future Prospects

BEPC, KEKB and other accelerator-based Particle Physics in Asia have demonstrated the maturity of accelerator technology and High Energy Physics in this region. The economy, the science and the technology are growing rapidly. The immediate next step for us is to establish a new scheme for stronger collaboration and to create Asian laboratories that are open to all Asian and world scientists. Now we are confident that the time is ripe to go forward in this direction. In the past we only had TRISTAN as the energy-frontier machine in this region. It is a natural consequence for us, therefore, that we construct the next energy-frontier machine, the JLC electron-positron collider, in Asia.

History of the $e^+ e^-$ Linear Collider Project

The consensus on the $e^+ e^-$ Linear Collider project finds its origin in the recommendation by the Japanese High Energy Committee (HEC) in 1986 as the post-TRISTAN program for energy-frontier physics. The recommendation initiated an extensive accelerator R&D program for JLC to address key issues in basic component technologies and to map out the facility as a whole. In parallel with the machine R&D, intensive studies of physics and experimental feasibilities also commenced.

In the early 1990s, through the precision electroweak measurements at LEP and other Particle Physics experiments, the existence of the light Higgs boson and Supersymmatry (SUSY) started attracting the physicists' attention as a plausible scenario for Physics beyond the Standard Model. It was under such circumstance that the green book ‘JLC-1’ was published in 1992, which defined the urgent physics program below center-of-mass energy of 500 GeV and provided a consistent road-map to explore TeV-scale physics. The green book describes the physics research scenario, a possible detector design, and the outline of the accelerator complex, as well as an idea for X-ray Free Electron Laser application. This was the first complete document on the concept of the Linear Collider project in the world.

In 1997, the HEC subcommittee for future projects of High Energy Physics reconfirmed the $e^+ e^-$ Linear Collider project as the next principal project for research in High Energy Physics. The subcommittee recommended that the facility should be open to the international research community, and Japan should play the leading role as its host country.

In 1997, ACFA discussed the $e^+ e^-$ Linear Collider project and made the first Statement endorsing it. The statement says, “A frontier facility like the $e^+ e^-$ Linear Collider is important as a spearhead to promote all fields of basic science and technology”. This was the major step towards the early construction of an $e^+ e^-$ Linear Collider in the Asian-Pacific region as one of the major scientific centers in the region.

In response to the first ACFA Statement, the ACFA Joint Linear Collider Physics and Detector Working Group was set up and the meetings have been held annually in Asia as listed below.

Year	Place
1998	Beijing, China
1999	Seoul, Korea
2000	Taipei, Taiwan
2001	Beijing, China

In these workshops, the physics and the overall concept and components of the detector system were further discussed. As a crystallization of this effort, the report `Particle Physics Experiments at JLC' has been issued recently. While preparing the report, a wide range of physics at the collider was surveyed, analyses of each physics subject were refined, the concept of the detector was reexamined and the design of each detector component was optimized based on the necessary hardware tests.

The importance of the inter-regional cooperation on physics and detector studies was recognized in the worldwide $e^+ e^-$ Linear Collider community. A series of international workshops (the LCWS series) on the physics and detector at $e^+ e^-$ Linear Colliders started in the early 1990s.

In 1998 ‘the World-Wide Studies of Physics and Detector for Future Linear Collider’ was formed at the Vancouver International High Energy Physics Conference in order to facilitate communication among the Linear Collider communities in the three regions. This group inherited the good tradition of the LCWS series and has continued its activity since 1999. These meetings have been held in the three regions of Europe, North America, and Asia in turn.

Year	Place
1991	Saariselä, Finland
1993	Hawaii, USA
1995	Morioka, Japan
1999	Sitges, Spain
2000	Fermilab, USA
2002	CheJu Island, Korea

Now it becomes a world-wide consensus in the High Energy Physics community that the e^+e^- Linear Collider is the next major High Energy Physics project. The Asian High Energy Physics community definitely needs an energy frontier accelerator in the near future. Considering the recent industrial development of the accelerator technology in Asia, the e^+e^- Linear Collider is an ideal project for the Asian High Energy Physics community to contribute to the world.

The Linear Collider Project

The design concept of the $e^+ e^-$ Linear Collider and its upgrade program have to be determined by the physics capability considering the timing of the project, and the available technology at the time. The study of the light Higgs boson is the most urgent and crucially important subject in determining the direction of Elementary Particle Physics in the near future. The physics threshold unambiguously known is the top quark pair production. Therefore the aim of the first phase Linear Collider will be to cover these two important physics thresholds sqrt (s) <= 500 GeV. The SUSY threshold might also be reached by the 500 GeV Linear Collider.

To meet these targets within a relevant timing, the first phase Linear Collider should be constructed with minimum time duration and with relatively low construction cost. The first phase Linear Collider should therefore be designed with a basically existing technology which fulfills the energy and luminosity requirements for the physics program.

Contemplating on the past transitions between LEP1 and LEP2, and TEVATRON Run1 and Run2, it is expected to take at least seven years to fully study the physics in the energy range during the first phase. During the first phase, R&D on high gradient acceleration has to be carried out and the upgrade strategy must be investigated by examining (1) physics results from LHC, (2) those from the initial runs of the Linear Collider, and (3) the status of the accelerator technology development at the time. The collider will eventually be upgraded to an energy greater than 1TeV to investigate physics issues beyond LHC. Although it is not clear at the moment which accelerator technology is the best to reach above 1TeV, we hope that further accelerator R&D for more than 10 years from now opens up the TeV energy range. Considering the whole program of the project, it is foreseen to evolve for a quarter of the century from now.

The Accelerator

e^+e^- colliders which have so far been constructed are circular colliders, except for the SLC. The highest energy e^+e^- collider is LEP at CERN with a circumference of 27 km which recorded the maximum center-of-mass energy of 209 GeV. The high energy circular e^+e^- collider has a serious problem of energy loss by synchrotron radiation which is emitted when the beams are bent by the magnetic field to follow the nominal orbit in the circular beam pipe. The energy loss per one turn of the circular ring is proportional to the fourth power of the particle energy and inversely proportional to the bending radius of the ring. It is not economical to construct circular e^+e^- colliders above the LEP energies. Hence Linear Colliders, which do not suffer synchrotron energy loss, are required.

For the Linear Collider, the beam particles are accelerated to the full energy on a single path in the main linac. The acceleration gradient has to be high (30~100MeV/m) in order to keep the collider compact. The R&D of the RF power system is therefore essential. To obtain a high luminosity for the experiments, the size of the beams (emittance) has to be small, since the repetition rate and the number of electrons or positrons per bunch are limited by the RF power.

The Linear Collider is made up of three subsystems: the injector system, the main linacs, and the beam delivery system.

In order to focus the beams to very small beam spots at the collision point, it is necessary to cool the beams to very small emittance in the injector system.

The injector system consists of beam sources, damping rings, injector linacs and bunch compressors. The Accelerator Test Facility (ATF) at KEK is a facility to test the feasibility of producing an ultra-low emittance beam as a prototype for the Linear Collider injector. ATF includes a beam source, an injector linac and a damping ring. For single bunch operation the horizontal emittance (ε_x) of 1.3 - 1.5 nm and the vertical emittance (ε_y) of 0.015 - 0.030 nm, both of which are world records, are obtained at ATF.

These values already satisfy the specification of JLC. Devices to measure very small emittance, such as a laser wire scanner, have been developed. The multi-bunch operation has started. To obtain a smaller emittance beam without loss the gun and the buncher system are being improved. For this purpose a RF-gun is being tested. ATF operation and these tests are carried out by an international collaboration also involving universities.

Polarized electron beams are extremely useful for reducing the W-pair background and to determine the quantum numbers of new particles. For this purpose the polarized electron beam source has been developed. It uses the super-lattice photo-cathode developed mainly at Nagoya University. The polarization and the number of electrons per bunch have already reached the specification of the Linear Collider: the polarization is above 80% and the number of electrons per bunch is about 10^{10} with two bunches in a time interval of 2.8ns. Further improvement to the lifetime of the photo-cathode and a new laser system to generate the full multi-bunch are expected for the next realistic prototype of the polarized electron source which satisfy the full JLC specifications.

The main linac part of the Linear Collider is a repetition of thousands of accelerator units. Each unit consists of a power supply (modulator), klystrons, pulse compressor/distribution system and accelerator structures. Because of the large number of components for the main linac system, the Linear Collider should be designed taking into account the following items: (1) reliability, (2) stability, (3) easy maintenance, (4) easy operation, (5) high efficiency, and (6) low cost. To collect a high integrated luminosity, the first five items are all important. Because of the large number of RF units, a few components in the system can break down at any running period. The possibility of repairing these components in parallel to the physics run is required to achieve a high integrated luminosity.

The choice of the frequency of the RF-system for acceleration is very important. For low frequency machines, the acceleration field is lower and hence the length of the accelerator becomes longer and the construction cost becomes higher. However, the precision of fabrication and the alignment tolerance of the accelerator structures (cavities) can be attained easily, since the single bunch transverse wake field is lower. For a higher frequency RF-system the accelerating gradient is higher and hence the total length of the main linac is shorter, while the tolerance of the alignment and the fabrication precision becomes harder to achieve.

The RF-frequency currently used for various electron linear accelerators is the S-band (2.8 GHz). The S-band technology was established about 40 years ago, and it has had a long experience in various electron linear accelerators, such as the 2 mile linac at SLAC, the Photon Factory (TRISTAN/KEKB injector linac) and the ATF injector linac at KEK. KEK is developing both X-band (11.4 GHz) and C-band (5.7 GHz) RF-systems for the main linac. X-band and C-band frequencies are four and two times higher, respectively, than the S-band frequency.

The merits of the X-band are a high gradient and a high efficiency. To make the best use of these merits the high power RF-system as well as the precise machining and alignment of the accelerator structures are essential. Extensive R&D is therefore needed for each component and it has been carried out in close collaboration with Stanford Linear Accelerator Center and Protvino branch of Budker Institute of Nuclear Physics of Russia. The basic design of the X-band modulator based on the solid state switching device (IGBT) is completed, and the fabrication of the first module should start in 2002.

The klystron with periodic permanent magnets (PPM) for a good energy efficiency has been developed. The second PPM-klystron designed by KEK has successfully achieved the output power of 73 MV with an efficiency of 54% and a pulse width of 1.4μs. The third PPM klystron has already been designed. The X-band uses the DLDS (Delay Line

Distribution System) for the pulse amplification. The pulses from klystrons are divided sequentially into shorter ones and are distributed to different accelerator structures to coincide with the timings of the beams. Since the pulses are merely distributed to the accelerator structures, the energy efficiency of the system is high.

As for the accelerator structures, the technology for the precise machining and bonding of the disks to form cavities has been developed at KEK. The test on the damping of the higher-mode wake-field in these structures is being successfully performed at ASSET, SLAC. In the high power test of these structures at NLCTA, SLAC, it was found that the inner surfaces of the copper structures are damaged after a long operation. To understand and to overcome this problem, extensive studies are being carried out under the collaboration of KEK, SLAC and CERN. For this purpose, several different types of the accelerator structures are being tested and some hints to solve the problem are being seen in these studies.

The C-band system is currently considered to be a realistic back-up for the X-band system, since the technology is more conservative. It is a relatively small technological extension to go from the S-band system to the C-band system. To make the system simple and reliable, several novel ideas have been invented and applied to the components. The modulator uses the inverter power supply for filling the energy into the L-C chain and a conventional thyratron switch for the pulse generation. The C-band klystron has already satisfied the specification of 500GeV LC, and the long term stability was tested with the modulator a few years ago. A simple but novel pulse compressor, which improves the pulse height by a factor of 3.5 to 4, was developed and the principle of operation was proven in the low power test. The high power test of the pulse compressor will soon be done at KEK. The accelerator structures, the so-called choke-mode cavities, in which the problematic transverse wake-field is absorbed locally inside the structures, was also developed at KEK. The wake-field absorption was successfully tested at ASSET of SLAC. The design of the C-band accelerator structure takes into account the results of extensive high power tests on the S-band structures. Nevertheless the actual high power test and beam acceleration test of the whole unit of the C-band RF-system will be performed at the SCSS (SPring-8 SASE Compact SASE Source) free electron laser project4). Seeing that the components of the C-band main linac system already satisfy the 500 GeV LC specifications, the second phase R&D on mass-production and cost reduction have started. Civil engineering (tunnel, accelerator installation, electricity and cooling water supply) is also studied based on these working components.

To strengthen and to widen the technology of the main linac system, it is crucial to develop both X-band and C-band RF-systems in parallel. Since both designs use the warm accelerator structures, a common design and development of components such as the modulator are feasible, and this will contribute to the efficient execution the project. Both of the RF-systems are vital in order to meet the requirement of urgency as well as the long term plan of the important physics programs.

The electron and positron beams from main linacs are delivered to the final focus system, where they are squeezed to have a small cross section and they finally collide with each other. At the collision point of the Linear Collider the beams are focused to a tiny size σ_x^* / σ_y^* = 200 - 300 nm / 2.5 - 5 nm). Such a small beam size and the accurate beam position have to be measured and controlled. A series of tests on focusing the beam and measuring its size was performed by an international collaboration at FFTB (Final Focus Test Beam) in SLAC. For these tests the laser-Compton interferometer (Shintake-monitor) was developed at KEK and the tiny beam size was measured successfully. The cavity type of the nanometer beam position monitor (cavity BPM) was

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4) The SCSS project was approved by the Japanese government in 2001.
The aim of the project is to construct a SASE (Self-Amplification of Spontaneous Emission) X-FEL facility. C-band technology developed for the Linear Collider and the SASE is planned to be used. The undulator is installed inside the beam pipe aiming for very small magnet gaps to achieve an excellent coherence of the X-ray beam. The first step is to achieve the wave length of around 10 nm (water window) for studies on structural biology.

also developed at KEK. Therefore the basic instruments to measure the beam size and position already exist. Recently, there was a new idea on the design of the final focus system at SLAC. The design is based on a short length optics, and the length is almost independent of the beam energy.

For a stable operation of the Linear Collider, the alignment of the accelerator structures is essential. The selection of a site with an acceptable level of ground motion and the development of a suitable alignment feed-back system are crucial for this purpose. Mountain ranges of stable granite rock are ideal considering the ground motion. There are several such candidate sites in Japan. These mountain ranges of granite rocks are quite stable even under big earthquakes.

Preliminary site studies have been performed since 1993. From the summer of 2000, a new site study group was formed. Since then they have been studying the scientific and technological requirements of the site, such as the ground motion, the electricity and cooling water supplies, recent developments on tunneling technology, the access to the site, as well as the sociological issues. The first report has been completed after one year of work. The second site study group was formed and they started evaluating several candidate sites after the first screening.

The Experimental Program and the Detector Design

The experimental program and the detector design for JLC was first studied in 1991 and was presented in the JLC-1 report mentioned above. After about ten years, the ACFA JLC Physics and Detector Working Group has completed a new report `Particle Physics Experiments at JLC' in the summer of 2001. In this report, detailed studies on physics programs and a model detector design based on R&D results of components are described by the ACFA Working Group.

The experiment at JLC should be open to the world's High Energy Physics community. The JLC detector concept may therefore be modified and improved in the future when an international collaboration is formed. The detector in the ACFA report is considered to be a good complete description of a model detector in this sense. It is essential to have such a model detector design for a fast construction of the detector after the approval.

The current JLC detector design stems from the original design in ‘JLC-1’. The design concept of the detector in ‘JLC-1’ is still valid, since the essential part of physics goals have not changed. The main concept of the design was the large-volume general-purpose detector aiming for highest performance with rather conventional technology. After ten years, the physics programs have been extended and the calculations of the machine background have been refined. Most notably, the importance of the vertex detector has been enhanced through the Higgs boson searches and the b-physics studies at LEP, SLC, TEVATRON and the B-factories. The technological advances implemented in these experiments have been transfered to the detector design. The radiation hard detector and readout chips have been developed for the LHC experiments and some of these can be used at the Linear Collider experiment. An intermediate silicon tracker between the central tracker and vertex detector has been introduced to assure the best association of the detector hits and tracks. In the detailed studies of the accelerator related background, soft e^+e^- pairs created in the strong electro-magnetic field in beam-beam collisions are simulated in detail. The optimization of the magnetic field is under discussion in the ACFA physics and detector working groups.

In the ACFA report ‘Particle Physics Experiments at JLC’, the goals of the detector performance are described clearly:

- Efficient and high purity b/c/(u,d,s,g) tagging for top quark and Higgs boson studies.

- Recoil mass resolution limited by natural beam energy spread but not by the tracker for the reaction $e^+ e^-$ -> $Z^o h^o$ followed by Z^o -> $l^+ l^-$. This is necessary to confirm the narrowness of the Higgs boson width.
- 2-jet invariant mass resolution comparable with the natural width of the $W^\pm$ and Z^o bosons for their separation in hadronic final states.
- Hermeticity for the indirect detection of invisible particles such as neutrinos and the LSP.
- A well designed background masking and time stamping capability.

The new detector design consists, from inside to outside, of the vertex detector, the intermediate silicon tracker, the central drift chamber of small cells, the calorimeter, the super-conducting solenoid, and the muon counters. The soft $e^+ e^-$ pair background is efficiently suppressed by a conical mask on each side of the forward regions. To cover the forward region by active detectors for the hermeticity, a luminosity monitor is installed inside the conical mask and the mask itself is instrumented by an active energy tagger. The details of each detector component are given in the report ‘Particle Physics Experiments at JLC’.

The Organization of the JLC Project

In 2001, a new LC promotion office was created. The KEK director-general H. Sugawara holds the chairmanship of the LC promotion office. The LC promotion committee has been set up in the spring of 2001 in KEK and physicists from universities are also included. The LC promotion office and the committee are aimed to be internationalized in the near future. A suitable form of international collaboration (globalization) is crucial for an efficient management of the construction, the commissioning and the operation of the collider. In order to investigate, and then to recommend, the form of globalization, an international committee is being set up under the LC promotion committee. The committee consists of accelerator physicists, experimental physicists and experts from other fields, such as sociology, from Asian countries as well as from outside of Asia.

The engineering design and the construction of the large accelerator must be managed in a coherent manner. The long range milestones have to be made, and the progress of the project should be checked and evaluated regularly by setting up a committee which consists of all the project leaders as well as experts from outside the project. An organic cooperation with the industries is crucial for the large accelerator project in Asia, since the technology is accumulated not only in the national laboratories but also in the industries. The accelerator physicists and engineers have to collaborate closely with the industries for the mass-production and the extensive tests of the components. These collaborations, as well as the liaison with the international industries, are essential for the cost reduction of the components and the civil engineering.