JLC PROJECT*

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(Received April 8, 1999)

A brief overview is given of the JLC project that is promoted to explore a new frontier of e^+e^- collider physics, selecting topics of the physics motivation, the detector concept, the progress in Accelerator Test Facility at KEK and the internationalization of the project.

PACS numbers: 29.17.+w

1. Introduction

The JLC project started as an energy frontier e^+e^- collider physics program recommended by the Japanese High Energy committee in 1986. Based on various R&D activities we completed the first e^+e^- linear collider project design report JLC-I that systematically described the physics, the detector concept, the accelerator complex and its application to X-ray laser production [1]. Since then the principal guide line for the project promotion remains unchanged including a further internationalization of the project.

In the 2-nd plenary meeting held in Feb.,1997, the Asian Committee for Future Accelerators (ACFA) announced its endorsement of the e^+e^- linear collider as one of the major future facilities in the Asia-Pacific region. In the international cooperation, we are promoting the R&D works to build the JLC-I facility which covers the e^+e^- center of mass energy range up to about 500 GeV with a design luminosity of $1.5 \times 10^{34}\text{cm}^2\text{sec}^{-1}$, 3 times higher luminosity compared with our original design.

This high luminosity e^+e^- collider will be capable of producing 0.5 million Higgs events at $\sqrt{s} = 250\text{GeV}$ within 5-6 years, if the Higgs exists below 150 GeV. Besides the important role as the Higgs and top factory, the JLC-I facility has a major physics potential as a Z-factory and a W-factory with

* Presented at the Cracow Epiphany Conference on Electron–Positron Colliders, Cracow, Poland, January 5–10, 1999.

polarized beams and with a two order of magnitude higher luminosity than those of existing facilities.

The proposed JLC-I is the phase-I machine of the entire JLC program and to explore a new frontier of lepton collider physics with a modest extension of technologies at hand.

2. Physics motivation

The most important target in the present high energy physics is to discover and study the Higgs boson which is still the missing constituent of the Standard Model. Although the top quark was discovered at the Tevatron, the detailed study of the top quark remains as one of the most important physics. The top quark decays directory Wb in its dominant decay mode, which leads to a large top width. Because of this large top width the top quark decays before entering the non-perturbative regime. Therefore the top quark is the best place to determine the strong coupling constant in the perturbative regime. Since QCD effects remains well under control even in the threshold energy region, we may also extract other smaller effects such as the Higgs exchange contribution.

The discovery and detailed study of the Higgs boson is the most urgent experimental task for high energy physics. The recent electroweak data are strongly suggesting the existence of a light Higgs boson. The present upper limit of the Higgs mass at the 95% confidence level has been reported to be 280 GeV by a global electroweak fit to all experimental data in the theoretical framework of the Standard Model [2].

The most exciting possibility is the discovery of the Higgs boson with a mass less than 150 GeV. The mass range is particularly interesting from the view point of grand unified models with the grand desert hypothesis. Also, it is well known that the light Higgs must exist in this mass range in the supersymmetric extension of the Standard Model.

Once the light Higgs boson is observed, then the next important step is systematic detailed studies of its decay properties looking for the new physics beyond the Standard Model, which would be possible only at high luminosity e^+e^- colliders; precision branching ratio measurements of the Higgs boson decaying into $b\bar{b}$, $c\bar{c}$, gg and $\gamma\gamma$.

Figure 1 shows cross sections of the Standard Model processes; muon pair ($\mu^+\mu^-$), five flavored quark pair ($\Sigma q\bar{q}$), top quark pair ($t\bar{t}$, m_t=175GeV), gauge boson pairs (ZZ and W^+W^- in $|\cos\theta|$ <0.8). Also shown are Higgs boson (Zh, m_h=120GeV) productions and sparticles of the minimal supersymmetric model; Higgs boson pairs (H^+H^-, m_H=190 and 410GeV, HA, $m_H = m_A$=400GeV), scalar muon pairs and a chargino pair. It is obvious that there are many important physics to be done as next step precision

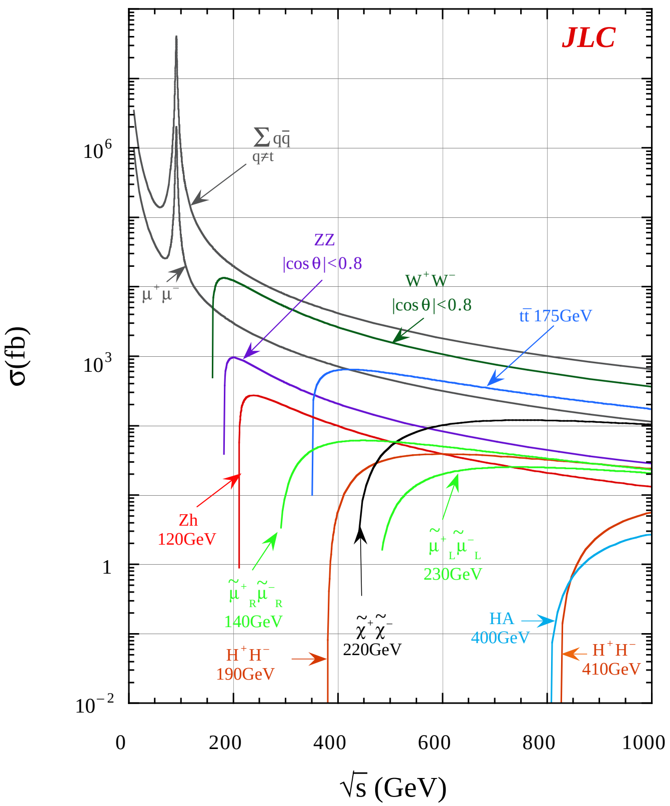

Fig. 1. Various cross sections(σ(fb)) of e^+e^- collisions at $\sqrt{s}$ < 1TeV. Standard and expected new physics processes.

measurements relating to W/Z physics, QCD and two photon physics after the existing large-scale experiments at HERA, LEP and Tevatron.

The JLC-I is a reasonable next step facility motivated by our present best knowledge of high energy physics.

3. Detector concept

The e^+e^- annihilation experiments in this energy region have the advantage that fundamental particles such as W, Z, top and Higgs can be reconstructed through a jet-jet invariant mass method due to its simple experimental condition. The high resolution hadron calorimeter plays an important role in the new detector system that makes a good use of this advantage, though we rely on the tracking information for the charged particles to achieve the best jet-jet invariant mass resolution.

For the identification of W and Z by reconstructed masses we require that the jet-jet invariant mass resolution should be comparable with the natural widths of gauge bosons (Γ_W=1.8GeV, Γ_Z=2.5GeV).

Since the most important physics target is the Higgs boson, the detector should have a potential capability of studying the details of its nature. In the Higgs production process $e^+e^- \rightarrow Zh$, $Z \rightarrow \ell^+\ell^-$, the Higgs mass and width are measured by the recoil mass of the Z. There is a limitation in the recoil mass resolution by the initial beam energy spread. In the central tracker design, therefore, we require that the recoil mass resolution should be comparable with the beam energy spread of 0.1 %. This resolution requirement for the tracking device is more strict than that for the charged particle tracking to get the required jet-jet invariant mass resolution.

For the detailed studies of the Higgs ($h \rightarrow b\bar{b}, c\bar{c}, gg$) and top ($t \rightarrow bW$) it is essentially important to have good flavor tagging efficiencies of both bottom and charm quarks by the high precision vertex detector.

Taking into account these requirements and the future extensibility we are now considering the large general purpose model detector (Fig.2).

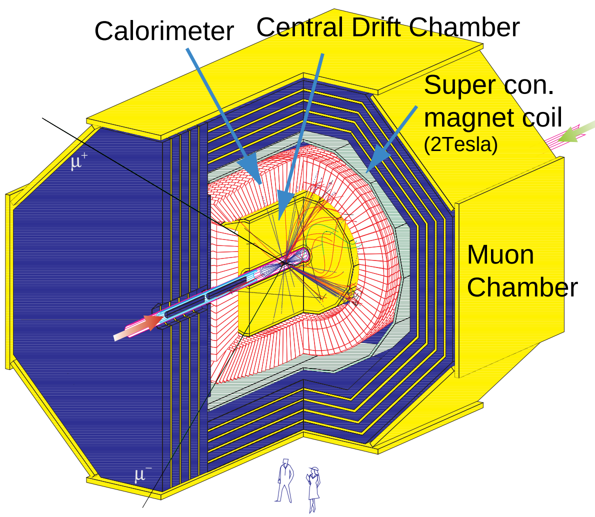

Fig. 2. Schematic view of the JLC detector. The total volume is $16 \times 16 \times 16\mathrm{m}^3$, and it weighs 15,000 tons. Superimposed is a Higgs boson production event at $\sqrt{s}$=300GeV assuming m_h=120GeV, ($e^+e^- \rightarrow Zh$, $h \rightarrow b\bar{b}$, $Z \rightarrow \mu^+\mu^-$) The simulation is based on GEANT3.21.

The large 2 Tesla superconducting solenoid magnet is placed outside the calorimeter in order to keep the hermeticity for the calorimeter system. The energy resolutions of the calorimeter that consists of lead-scintillator layers with readout fibers are $\sigma_E/\sqrt{E} = 15\%/\sqrt{E} \oplus 1\%$ for electrons/photons and

$\sigma_E/\sqrt{E} = 40\%/\sqrt{E} \oplus 2\%$ for hadrons. The calorimeter covers the polar angular range of $|\cos\theta| <0.98$.

We adopt a small-cell jet chamber as the central tracker to achieve a good z-direction resolution and two track separation. The momentum resolution of the chamber is designed to be $\sigma_{p_t}/p_t = 1.1 \times 10^{-4} p_t \oplus 0.1\%$.

At the center of the detector very close to the interaction point, there is the CCD vertex detector, whose innermost radius is 2.5 cm from the beam line. The impact parameter resolution is expected to be $\delta^2 = 11.4^2 + (28.8/p)^2/\sin^3\theta(\mu\text{m}^2)$.

Test detector modules have been constructed for each component; the CCD vertex detector [3], the small-cell jet chamber [4], and the tile-fiber calorimeter. Especially the progress in the calorimeter R&D is remarkable and the response measurements have been done using the beam from the KEK 12 GeV proton synchrotron [5]. We are going to bring the test module to Fermi Lab. to look at the high energy response in the next autumn.

4. Accelerator Test Facility

The JLC-I machine is a huge complex of accelerator components and design of any one component may strongly affect that of the other, even if they are very far apart. The accelerator parameters on which the overall design is based are the energy, the acceleration frequency and gradient, the repetition rate, the number of bunches in one RF, the number of particles in one bunch and the beam size at the outlet of the damping ring, *etc.*

Since the beam spot size at the interaction point is limited by the initial beam emittance, it is essential to produce a ultra-low emittance beam with a reasonable damping time. To confirm experimentally its feasibility, we have constructed ATF(Accelerator Test Facility) at KEK. The ATF consists of two major components: a 1.54 GeV S-band injection linac and a damping ring (Fig.3).

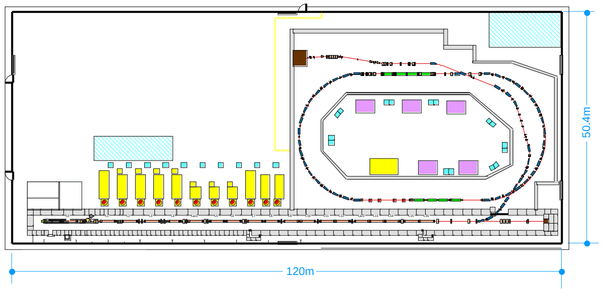

Fig. 3. Accelerator Test Facility at KEK.

The injector consists of a conventional thermionic gun, a 357 MHz subharmonic buncher, and a 3 m long S-band buncher structure which is followed by 3 m long constant gradient traveling wave structures. The overall length of the linac is 75 m in which 18 structures, focusing magnets, and various monitors are placed.

The compressed pulse by the SLED cavity is divided into two and fed to each structure providing an average acceleration gradient of 40 MeV/m with beam loading. The two structures are operated with slightly different frequencies, which compensates the energy differences and keeps the bunch-to-bunch energy spread to about 0.15 %.

The invariant emittance at the entrance of the regular section is expected to be 3×10^{-4} m. The emittance blow-up in the injector is required to be less than 50 % in order to match the ring acceptance. The lattice was designed to meet this requirement with a minimum space factor. Two triplets are only placed at the upstream end and doublets are limited to the first half of the linac. The remaining half of the linac simply consists of singlets.

The design goal of the ATF damping ring is to produce a vertical invariant emittance of 5×10^{-8} m and a horizontal invariant emittance of 5×10^{-6} m under the multi-bunch operation with up to 20 bunches spaced by 2.8 nsec. The damping times are designed to be as short as 6.3 msec horizontally and 8.3 msec vertically by virtue of wigglers. The damping ring has a racetrack shape and its circumference is 138.6 m. The length of the straight section is 25.8 m, while the average arc radius is 13.8 m.

In order to achieve the ultra-low emittances we apply a FOBO type lattice in which the defocusing bend is placed at the dispersion minimum point. Each arc consists of 18 combined function FOBO cells and the horizontal and vertical phase advances are designed to be 140 and 52 in each cell.

To reduce the damping time we use wigglers which are placed in the dispersion free space so that they also help reducing the equilibrium emittance. The wigglers have an effective field of 1.88 Tesla and a wiggler period of 40.0 cm. The wigglers are placed in one of the straight sections and the total length of the wiggler section is 21.2 m.

The beam operation of the ATF damping ring began in January 1997. After the successful commissioning of the linac and damping ring, various efforts have been made to get the stable operation of the ATF. Also, the extraction line from the damping ring was completed in November 1997 for the detailed beam diagnostics. In the present typical operating condition, the beam energy delivered by the injector linac is 1.29 GeV and the bunch population is 5×10^{9} electrons/bunch. The ring is operated in the single bunch mode and the wiggler magnets are not excited yet.

In the beam tuning the stored beam orbit has been corrected using a COD (Central Orbit Correction) algorithm and local orbit bumps. After this correction the typical peak to peak COD is 2 mm in the horizontal plane and 1 mm in the vertical.

Recently the horizontal and vertical beam emittances have been measured with wire scanners using the extracted beam into the extraction line. Two different measuring methods have been applied; the waist-scan and the four-wire method. Though the horizontal beam position is not perfectly stable, the consistency of the two position corrected beam size measurements is within 2σ. The obtained horizontal emittance is $1.37 \pm 0.03 \times 10^{-9}$ m, and the result is consistent with the expected value of 1.31-1.41 $\times 10^{-9}$ m that includes the emittance growth effect due to the intra-beam scattering [6]. Along the same line, there are various efforts to confirm the vertical emittance. The preliminary estimated value is about 1×10^{-11} m that is derived after the 1 degree beam tilt correction on the horizontal plane through a multi-dimensional fitting to the wire-scan data.

Various experiences are integrated in the single bunch mode operation, and the obtained emittance measurement results are very encouraging. The next important step is to operate the damping ring in the multi bunch mode [7].

The present success of the ATF shows that it is possible to produce and maintain low emittance beams even in the worst condition of the grand surface. This fact is very important to consider the site requirements for the actual construction of the JLC-I facility.

5. Internationalization

In the Asian region, there are significant progresses in high energy physics and synchrotron radiation experiments at various regional facilities. Not only those activities, many researchers from ACFA member nations are actively participating in large-scale experiments such as at LEP-II, Tevatron collider, HERA and KEKB/PEP-II. The Asian physics community has grown significantly and has set a firm enough foundation to prepare for further projects.

As was described in the JLC-I report of 1992, the linear collider has a facet which can be shared with a new means for materials science. The ultra-low emittance beam essential to the linear collider is also an indispensable element of the next-generation, coherent x-ray source. Therefore it would be very important to collaborate with materials science communities to efficiently and effectively promote accelerator science in this region.

In response to the ACFA statement of the linear collider project, a study group, ACFA Joint Linear Collider Physics and Detector Working Group, has been set up under ACFA [8]. The charge of the group is to elucidate physics scenario and experimental feasibilities and to write up a report to

ACFA within two years. Taking account of the scale of and the world-wide interests in linear collider projects, it is highly recommended that actual studies be carried out in a more global scope in spite of the regional nature of ACFA's initiative.

6. Summary

We are promoting the JLC project along the philosophy and direction that have been described in the JLC-I report. There are good outcomes from the physics study and detector R&D for realizing the project. Furthermore the healthy inter-regional cooperation mainly based on Asia-Pacific laboratories and universities have become active for further promotion of the project. The JLC-I shall be one of the most active large-scale inter-regional facilities in the 21st century, and also the project assumes the important role to be the model for the promotion of the accelerator science in Asia.

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