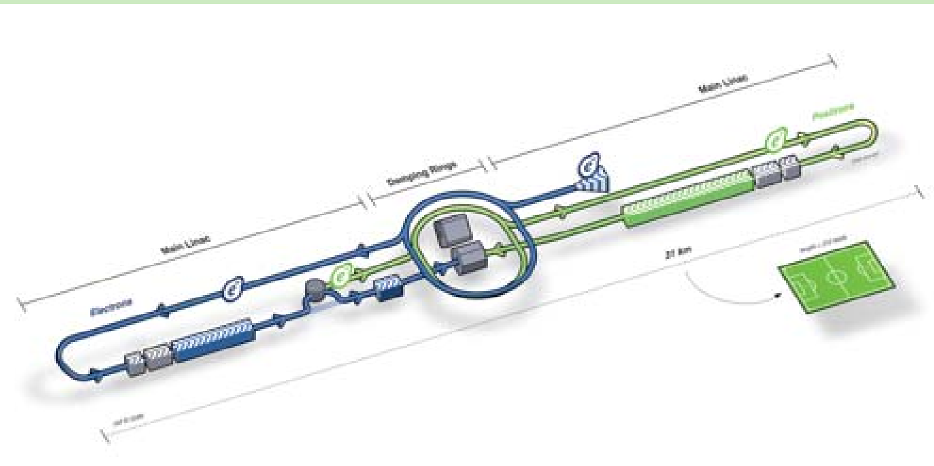
A world of researchers joins hands and hardware

The particle physics community is accustomed to global collaboration, and here at KEK, one of those collaborations has just begun on a core technology for the International Linear Collider (ILC), the superconducting accelerating system.



ILC : Facing each other, two linear accelerators - one for electrons and other for positron - will stretch total of approximately 31 km. Like any complex machine, ILC is made up of several systems - each one an essential component for launching particles at close to the speed of light. (Graphic courtesy of ILC / form one visual communication)

From the Enlightenment to the present day, science has been opening doors to the unknown. Recent physics experiments and observations continue to unveil a universe filled with even more mysteries to solve than we ever imagined: dark matter, dark energy, extra dimensions, supersymmetry …. and more surely to follow. Particle physicists are on a quest to tackle those mysteries, learning about the origin and nature of the universe from the smallest to the largest scales. One of the most powerful tools for this quest is the accelerator, particularly large-scale collider, which re-creates conditions that existed shortly after the Big Bang.

Currently, most experiments at particle accelerators are being implemented with international collaboration. One such collaboration, now on a particle accelerator itself, has just started at KEK, work on the superconducting accelerating system, the core technology for the International Linear Collider (ILC).

Small particle, big collaboration

Particle physics research has a long history of international collaboration. As the subjects of the research get smaller and smaller, the accelerators grow in size, price, and complexity. It has become a general notion among the particle physics community by now that the next-generation accelerator to address the multitude of open questions cannot be built within a budget of a single country. Increasingly, scientists must travel to wherever in the world the accelerator they want is available, so research is done globally.

One of the current focus points of international collaboration is on the planning, design, funding and building of the next-generation electron-positron collider, the ILC. R&D for the ILC accelerator is being led by the Global Design Effort (GDE), setting strategy and priorities for more than a thousand scientists and engineers around the world.

Prof. Kaoru Yokoya, the ILC Asian regional director and a Head of Linear Collider Project office at KEK, in his office discussing the future of the ILC accelerator design.

In the ILC, superconducting accelerator cavities give the particles more and more energy until they smash head-on in a blazing collision at the center of the machine. Stretching approximately 31 kilometers in length, the cluster of beam particles called “bunches” collide 14,000 times every second at extremely high energies — up to 500 billion electron volts (GeV). Each spectacular collision creates an array of new particles that could answer some of the most fundamental questions about the universe.

To answer those questions, even the most-advanced accelerator, by itself, is not enough. Together with the accelerator, a cutting-edge particle detector will record every collision that takes place and each particle produced. The ILC research directorate lead by Prof. Sakue Yamada, the former Director of the Institute of Particle and Nuclear Study at KEK, is responsible for the development of the ILC experimental program for physics and detectors, involving more than a thousand scientists across the globe.

“The ILC will complement the LHC. With LHC discoveries pointing the way, the ILC will show us more precisely the landscape of our universe,” said Prof. Kaoru Yokoya of KEK, the Asian regional director for the GDE.

The bird's-eye view rendering image of the ILC. The underground tunnel will be installed with the state-of-the-art precision systems. (Graphic courtesy of Rey Hori)

The Large Hadron Collider (LHC) is a proton-proton collider at CERN (European Center for Nuclear Research) in Geneva, currently the man-made accelerator with the highest energy. The effective collision energy at the LHC will be higher than that at the ILC, but measurements at the ILC will be more accurate, since the collisions between electrons and positrons are much simpler to analyze than collisions between protons, which are bags of quarks, antiquarks and gluons. “There are many technical challenges along the road to the ILC accelerator. One of the most important of all is the superconducting RF technology”, said Yokoya.

How do superconducting cavities work?

A charged particle can be accelerated by an electric field. To provide the necessary acceleration, ILC will use a hollow structure made of the exotic element niobium. A voltage generator fills each cavity with the required radio frequency (RF) field, where the charged particles feel the force of the electric field and accelerate. The entire apparatus is immersed in liquid helium to chill it to near absolute zero degree (-271 ºC), making a ‘superconducting RF cavity’. Those cavities will sit inside a vessel surrounded by thermal shields and an outer vacuum tank, called a cryomodule. Superconductors transport electrical current with almost no power loss, and it means that nearly all the electrical power may be used to accelerate the beam, rather than heating up the accelerating cavity structures themselves.

Only a few high-energy particle accelerators in the world use superconducting RF cavity technology for the beam acceleration at the present day, but a number of superconducting accelerators are being planned and constructed. “KEK has been engaged in a variety of R&D projects on superconducting cavities. KEK used superconducting technology for the TRISTAN accelerator, operated until 1995, making it the first large-scale superconducting accelerator at the time at particle storage rings”, Yokoya explains. “We will need to perform much more R&D on superconducting RF technology in applications to linear accelerator, in particular, to realize the ILC. It is crucial for us to demonstrate the cryomodule system. We are starting with a cryomodule unit which contains eight cavities. This demonstration program is called S1”.

The actual ILC accelerator will require as many as 16,000 superconducting cavities, each roughly a meter long, placed end-to-end in 2000 cryomodules.

The one meter-long superconducting accelerating cavities are made from nine cells, polished to provide micro-level surface smoothness, and free of impurities. A series of detailed chemical treatments and processes make the cavity literally sparkle. (Photo by Nobu Toge)

S1-global

The collaboration work taking place at KEK is called *S1-global*. "S1" refers to one of the priority R&D milestones for the ILC, with the object of S1 being the demonstration of an eight-cavity cryomodule operating at an average accelerating gradient of 31.5 Megavolts per meter, which is the design gradient for the ILC. The original plan for the S1 program was to implement individual efforts in each region. But in an action to respond to very difficult situations due to global economy crisis started in later 2008, “I proposed to the community that the S1 program may be realized with the global collaboration work as a way to maximize our effort with very limited resources under the given difficult condition”, said Dr. Akira Yamamoto of KEK, one of the three project managers of ILC GDE. “It is extremely gratifying to see that the project has come to the stage of actual collaboration work”.

The cavities being string-assembled by technicians from DESY and Fermilab, in the KEK's ISO Class-4 clean room. (Photo by Nobu Toge)

The program combines the endeavors and equipment from several collaborating laboratories: two superconducting cavities from DESY (Germany), another two from Fermilab (U.S.), and four from KEK. They will be installed in two cryomodules, each six meters long. A new one has been designed and constructed as a cooperative effort between Italy's INFN (Istituto Nazionale di Fisica Nucleare) and KEK.

Following the delivery of all components to KEK, assembly team members have joined from DESY and Fermilab. The team started assembly work on 14 January in a cleanroom of ISO class 6, or class 1000, where there are no more than 35200 airborne particles larger than 0.5 microns per cubic meter. Next day, they moved to ISO class 4, or class 10 cleanroom with much more strict levels of cleanliness: hundred-thousand times cleaner than the air in the usual office room. Not all cavities gathered at KEK were exclusively fabricated for S1-global, and another goal was a performance comparison for each cavity type, so the physical condition and feature varies from cavity to cavity.

“These efforts to integrate different pieces of equipment into one combined system test will be a exercise of the global collaboration in gaining practical understanding of the cavity hardware systems toward the plug-compatibility concept”, said Yamamoto. *Plug compatible* is a term commonly used in the manufacturing and computer industries, meaning hardware that is interchangeable with another vendor's product, even though internal details may differ. This concept, as applied to the ILC design, will accommodate the variations that result from new innovation and optimization in the development stage, and from local features/constraints in the production stage. “It is very important for them to keep their creative spirit in the R&D stage. It is also very important that the intellectual work and the knowledge should be well shared globally in the production stage”, Dr. Yamamoto said.

Work on S1 global will continue for the rest of this year, 2010. Assembly completion is expected by June, and the system will be operated by the end of December.

ILC GDE released the Reference Design Report (RDR) in February 2007 when the concept design for the ILC was established. "Gateway to the Quantum Universe" summerlize the essence of the RDR. Now, the GDE is taking the next step for the Technical Design phase, improving the RDR design through continuing R&D and value engineering.

Fast track for industry

The effort to do cutting-edge physics research produces unexpected technological breakthroughs with everyday applications. The World Wide Web is a prime example, known to everyone, and has transformed society. The Web was developed by high-energy scientists at CERN to share their data with colleagues who used different computer systems. Other examples include accelerator technology that has been adapted to the manufacture of computer microchips, and medical diagnostic and therapeutic tools, such as proton-beam therapy, that have emerged from this basic scientific research.

ILC Project managers Prof. Marc Ross (Fermilab, on the right) and Prof. Akira Yamamoto (KEK, on the left) during the meeting at KEK. (Photo by Nobu Toge)

The same will be true of the technologies developed for the ILC. Today, accelerators based on superconducting technology are being planned and built for use in many areas of science and medicine, such as next-generation X-ray imaging facilities.

“We need a strong partnership with industry to make the ILC happen”, said Yamamoto. “There is no way to produce all required numbers of the cavities and the cryomodules in only one region. We need to prepare for the mass production stage with world-wide industries”. KEK has already started to work with the Advanced Accelerator Association Promoting Science and Technology (AAA), launched in June 2008 with a total of about 100 companies, universities and laboratories. Discussions are underway on R&D issues, industrialization models, intellectual property rights and other related areas, using the ILC as a model project. Dr. Yamamoto believes that this will put also industries on a fast track toward new products and life-changing technologies.