STATUS OF ILC AND THE ROLE OF JAPAN IN DEVELOPING THE ILC

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Abstract

The ILC design brings together the need of the world's particle physicists to extend their reach beyond LHC and the capabilities of the accelerator community to deploy superconducting RF technology for this purpose. In this talk we will describe the state of the art of the technology necessary to build a high luminosity linear collider and show the global basis for the technology. The latter is a essential component for the realization of a strongly multi-lateral international science project. To this end, the ILC Global Design Effort, (GDE), was established in 2005. To maintain adequate inter-regional balance, the GDE is not hosted by any single institution and includes representation from each interested institution. Japanese scientists and institutions have enthusiastically supported this scheme from its beginning and have had a significant role in its development.

INTRODUCTION

The basic concept of the International Linear Collider, (ILC), can be traced back almost 50 years now to an article by Maury Tigner [1]. The core technology was born in the e+/e- laboratories: KEK, Cornell, DESY, and SLAC. In particular three – KEK, Cornell and DESY - are where the superconducting RF (SCRF) technology was developed. The technology for linear colliders has been summarized and reviewed twice in the last 15 years. Six years ago a recommendation was made to adopt superconducting technology for further development of a detailed design to put forth in a proposal in response to the statement from High-Energy Physics community to have a machine that they can use to follow the LHC.

The justification for the recommendation to adopt SCRF included comments about: 1) the large 76 mm diameter aperture, 2) the comparatively lower risk, 3) the European XFEL project, now under construction at DESY and 4), the more mature industrialization.

This paper includes a section on the reference design that was used as a basis for the cost estimate in our project plan. The following sections describe the R&D for the superconducting main linac technology, the R&D for other systems which are specific to the collider and the role of Japan in developing the ILC.

DEVELOPING THE ILC

Reference Design

Figure 1 is a schematic of the ILC. It shows the six subsystems: the particle beams are born in the centre of the complex, they are then damped and transported to the start of the linac and subsequently accelerated back to the central beam delivery subsystem where they collide.

The reference design report, (RDR), was published in 2007. It was based in large part on R&D work done in each of the three regions involved: Europe, Asia, and the Americas. The design is strongly linked to the so-called

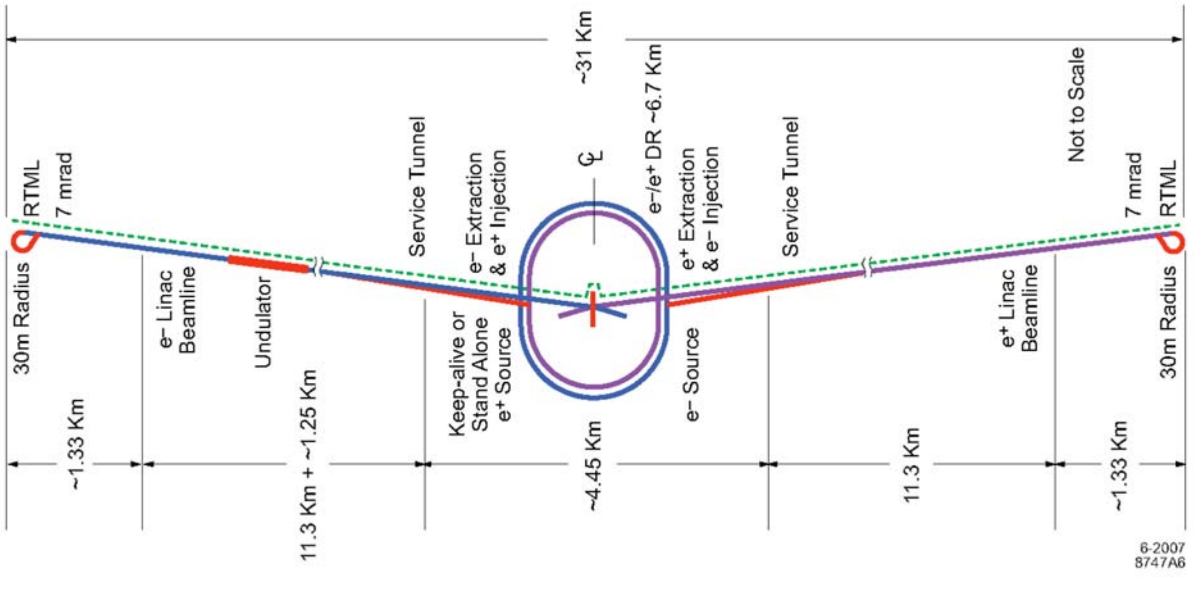


Figure 1: Schematic layout of the ILC Reference Design.

TESLA design that was developed in Europe using the superconducting technology. The RDR was authored by several hundred institutions, including 15 Japanese institutions, among them KEK and JAEA.

Prepare a design and a plan that is completely ready to go - 2012.
The request from the HEP community is clear (Brian Foster).
Since the timeline is uncertain:
focus on R & D for cost and risk reduction
develop ties within the accelerator community to facilitate a global project

Figure 2: Global Design Effort Timeline.

Figure 2 shows our timeline from the time of the formation of the global design effort. It shows the assembly of the reference design followed by the design effort needed to advance the project design, to do the R&D, and to build the community and ready the project to the point where, at the time when the LHC begins to show some indication of the physics that people expect, we will be ready to put forth a coherent design proposal. This is our charge from the community. To show the technology, we have constructed a set of beam test facilities. These are by far the most advanced set of test facilities put together for any such accelerator. There is one in each region for superconducting RF. The test facility at KEK is called the Superconducting Test Facility. It is now under construction, with expectations of first beam in a couple of years. In the US, there is a facility at Fermilab with a similar scope and timescale. In Europe (Germany), the SCRF test facility is a much older system. It has been producing VUV light as a FEL for several years now, and it has ILC-like beam capabilities. This is the 'FLASH' VUV FEL; it can produce X-rays with wavelength of as low as 5 nanometers at 1.2 GeV (2009). It is operating in full-user mode at this time and it serves as a component test-bed for the European XFEL, now under construction. The XFEL will be about 3.5 kilometers long in total with about a 1.2 kilometer long superconducting RF linac.

In addition to SCRF beam and technology facilities, we have developed and constructed a test facility to study electron cloud at Cornell. The small storage ring – DAFNE, an operating high-energy physics machine, also serves as a test-bed for pulse beam kickers and electron cloud. At KEK, we have the Accelerator Test Facility (ATF) and the add-on to it, the ATF2, for studying ultra-low emittance and final focus optics.

RESEARCH AND DEVELOPMENT FOR SUPERCONDUCTING RF TECHNOLOGY

Global R&D of the superconducting RF main linac technology and cavities is greatly helped by a policy called 'plug compatibility'. The policy is quite important because it focuses our attention on the definition of interfaces between components and sub-systems. This allows individuals and institutions to apply their development strengths effectively while remaining confident their product can be adopted, as long as the agreed-upon interface conditions are met.

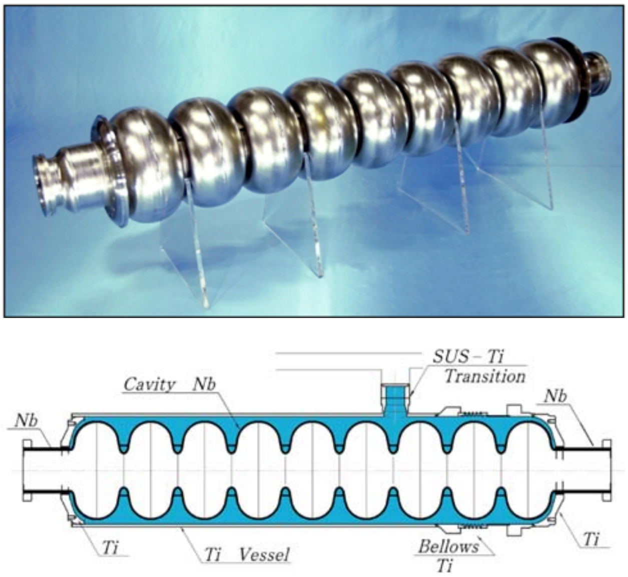
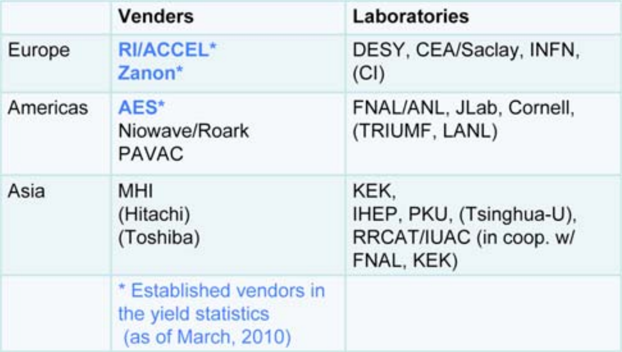


Figure 3: The 1.3 GHz superconducting RF cavity design for the ILC main linac.

Figure 3 shows the basic niobium sheet metal cavity inside its jacket which is filled with 2 degrees Kelvin liquid helium. It is deployed as a standing wave accelerator with 1 millisecond RF pulse to accelerate a 3 megahertz bunch train of several thousand bunches with a gradient of around 30 to 35 million volts per meter. The figure shows a roughly one meter long structure. Each ILC linac has 8000 of these. A large extrapolation from the industrial production effort for the test facility in DESY and the XFEL is required. The cavity is the primary cost driver; if we can increase the gradient or decrease the cost of this component, it is a great advantage for the ILC project.

The baseline ILC cavity fabrication and finishing process uses sheet metal forming techniques, electron beam welding, electropolishing and chemical etching. Electropolishing technology for this purpose was pioneered in Japan. An important inspection device, which we call the 'Kyoto camera', slips inside the cavity to image the inner surface and allows us to see the defects that can cause the cavity to quench prematurely. We are now studying how to develop specifications that enable us to use an increasingly production-like practice, and move away from R&D practices. At present, we are able to produce nominal 35 megawatts per meter gradient cavities with 50% production-like yield. Our goal over the next 3 years is to improve that yield, bringing it close to 100%.

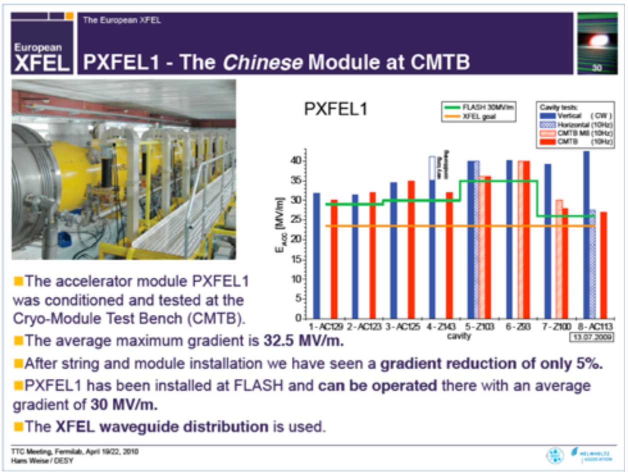


	Venders	**Laboratories**
Europe	**RI/ACCEL*** **Zanon***	DESY, CEA/Saclay, INFN, (CI)
Americas	**AES*** Niowave/Roark PAVAC	FNAL/ANL, JLab, Cornell, (TRIUMF, LANL)
Asia	MHI (Hitachi) (Toshiba)	KEK, IHEP, PKU, (Tsinghua-U), RRCAT/IUAC (in coop. w/ FNAL, KEK)
	* Established vendors in the yield statistics (as of March, 2010)	

Table 1: ILC 1.3 GHz cavity vendors.

The cavities are then assembled into a string of eight and are inserted into a cryomodule vacuum vessel. Once the cryomodule is constructed, the three above-mentioned beam test facilities come into play; FLASH at DESY, the New Muon Lab at Fermilab, and STF at KEK. A key aspect for an international project is to make sure that there are competent experts, competent industry and usable infrastructure in each of the regions that support it. This is one of the major successes of the work done in the last few years. Table 1 shows the names of the companies that produce cavities in three different regions and the laboratories that partner with them. The laboratories are typically where the chemical polishing and the initial cold tests are done. By having a number of vendors, we can expect greater support in different regions and we can be confident of having some degree of commercial competition.

The 'plug-compatibility' policy defines the interfaces between components inside a cryomodule and between cryomodules to allow the different groups at different labs in the different regions to continue to develop the technology at the same time as they are working towards a specific, globally-coordinated project plan. Since the timeline for the ILC is unknown, it's very important to continue to develop the technology in parallel to the development of the project itself. As long as interfaces are kept and compatibility can be assured, this is a viable way for maintaining and developing the community at the same time as we converge on a reasonable project cost estimate and project plan.



PXFEL1 - The *Chinese* Module at CMTB

- The accelerator module PXFEL1 was conditioned and tested at the Cryo-Module Test Bench (CMTB).
- The average maximum gradient is **32.5 MV/m.**
- After string and module installation we have seen a **gradient reduction of only 5%.**
- PXFEL1 has been installed at FLASH and **can be operated** there with an average gradient of **30 MV/m.**
- The **XFEL waveguide distribution** is used.

Figure 4: Performance of the internationally-constructed PXFEL1 cryomodule, now in use at DESY.

Figure 4 shows an example of an internationally – constructed cryomodule. This cryomodule has just been installed in the DESY VUV-FEL 'FLASH'. Everything that's painted yellow in the figure, and all the cryogenic plumbing inside, was made in China by IHEP in Beijing. The cavities in the module were made in Europe. The inset in the figure shows the performance of the eight cavities. The performance of each cavity in low power initial vertical test is shown in blue and the red bar shows the performance of the cavity after it's been installed and assembled inside the cryomodule. The lines in the figure show the goal for the European XFEL and the settings to be used for operation at the test facility, FLASH. If the red bar is higher than the blue one, the cavity does slightly better after it's been assembled. Sometimes it's quite a bit lower in which case contaminants have been introduced during assembly and the performance has been degraded. It is important to point out that this cryomodule is one of the first to exceed the ILC specification.

In addition, we are building a global 8 cavity cryomodule, called 'S1 Global'. Assembly of S1 Global is now complete at KEK. In this cryomodule, there are two cavities from Germany, two from the US, and four from Japan. The 'S1 Global' cryomodule includes 'plug-compatible' variations as outlined above. For example, the mechanism used to tune the cavity is at the end for half of the cavities and in the middle for the other half. By putting these different designs side-by-side within the S1 cryomodule, we hope to be able to understand what it takes to allow variations in such an important component as the cryomodule.

Item	Can be flexible	Plug-comp.
Cavity shape	TeSLA/LL RE	➡
Length		Fixed
Beam pipe flange		Fixed
Suspension pitch		Fixed
Tuner	Blade/Jack	
Coupler flange (warm end)		Fixed
Coupler pitch		fixed
He –in-line joint		TBD

Figure 5: Sketch of the assembled ILC RF cavity. The lower part of the figure highlights the parts of the assembly that must interface with other cavities or other components.

Figure 5 shows some of the interfaces associated with the plug compatibility in the R&D phase. The figure shows the cavity inside its tank, the power coupler, the beam vacuum chamber and the liquid helium feed. It's not clear if we would define the same R & D interfaces in the construction phase. We propose to try to promote the general process as much possible, so that we have multiple vendors, in order to encourage competition and prepare for various possible project organizational schemes. The recently completed LHC was managed by a very strong central organization, CERN, and we can both learn from their example and be prepared to build the International Linear Collider under very different circumstances where each of the different regions and each of the institutions involved have an independent vote and may choose to do things differently.

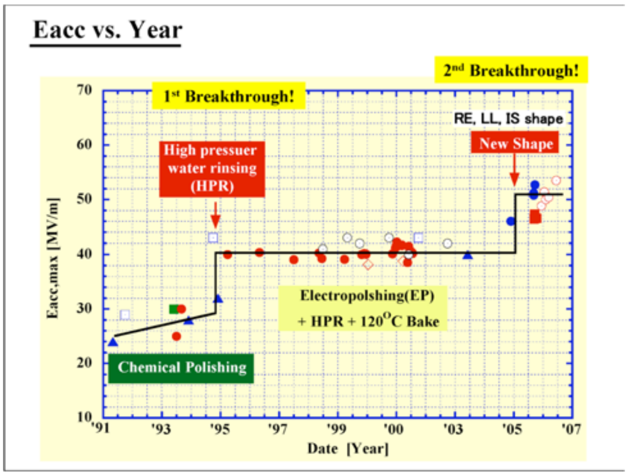


Figure 6: Performance history of superconducting RF single-cell cavities, compiled by K. Saito, KEK.

As an example of the 'plug-compatibility' approach during the R & D phase, we have three different cavity shapes are under development. The baseline shape is an elliptical cavity, used in Germany for FLASH. The two other ones are known as Re-entrant and Low-Loss. Re-entrant is so-called that because of the slight curvature of the wall of the cavity so that it extends back into the cavity itself. The low-loss shape has relatively flat end-walls. The designers have tried to decrease the peak magnetic field compared to the electric accelerating field inside the cavity at the expense of the electric field ratios; making the electric field go up and the magnetic field go down. This means that the threshold for quenches associated with the current heating goes up but the beam aperture goes down. You could imagine building a linac which has different types of cavities within it, so it's reasonable to promote these studies.

Figure 6 from Kenji Saito of KEK, shows the improvements seen from chemical polishing, high pressure rinsing over a period of 15 years, including, finally, the new 'low-loss' shape. The data shown in the figure is from tests that were done with single-cell cavities.

RESEARCH AND DEVELOPMENT FOR COLLIDER SYSTEMS

We turn now to R&D underway for the collider systems outside of the superconducting technology and describe work on the damping ring, beam delivery (BDS), where the particles collide at high energy, and the positron source.

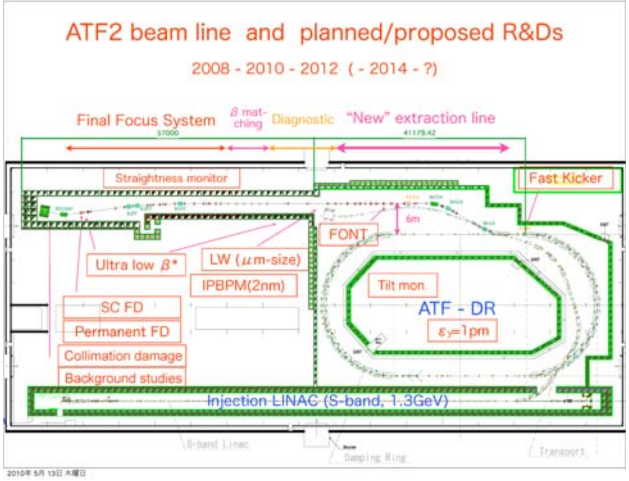


Figure 7: Layout of the Accelerator Test Facility at KEK, showing some of the R & D topics under study.

Figure 7 shows the floor plan of the Accelerator Test Facility, (ATF), the only ILC purpose-built beam test facility. ATF was constructed at KEK in the building where the TRISTAN magnets were assembled in the 1980s, the TRISTAN 'Assembly Hall'. It's now been completely taken over by the ATF test facility which has operated for more than 10 years now. It consists of a 1.3 GeV normal conducting S-band linac and a very strong focusing, small storage ring to damp the electron beams down to micron sizes. And then, in contrast to a normal ring of the sort that would be used as a synchrotron radiation source, the beam is then extracted as if it were to be injected into the main linac after compression. The ‘extraction’ or diagnostic line follows and links the ring to the BDS test facility ATF2, recently constructed. In order to try to focus it down to very small sizes, beam manipulation is done and at the end. We hope to have beam sizes on the order of a few tens of nanometers in order to study beam handling and instrumentation.

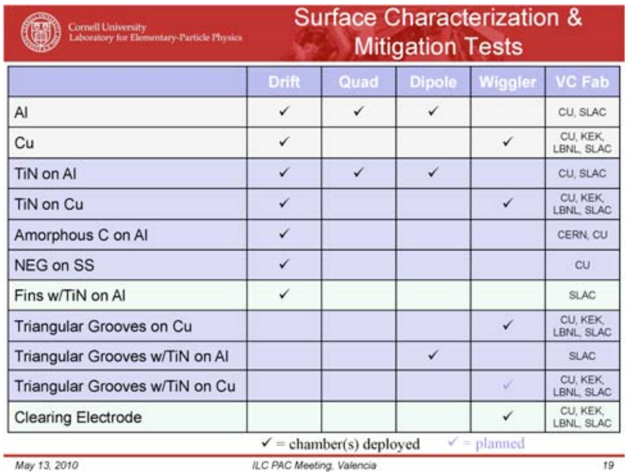
One of the key issues with the beam facilities or each of the beam test facilities works toward the development of the ILC as a project but these places are also fundamentally for students. At ATF, there are students from these institutions from each of the three regions that support the ILC. Approximately 2000 people-days per year, (roughly 70 people stationed at KEK – including collaboration members from Universities in Japan), work at ATF. It’s an enormous international effort at KEK.

Damping Ring

There are two 6 kilometer damping rings in the ILC design, 5 GeV each. On each pulse, 3000 bunches are injected, and the interval between each bunch is reduced 50 times smaller than it is in the superconducting linac. The bunches are damped to very low emittance and then extracted one by one in order to take the 6-nanosecond spacing to 300 nanoseconds with a fast kicker. The three facilities, Cornell (CESR TA), Dafne (Frascati), and ATF (KEK) support the damping ring activities. Also, there are many aspects about the design in common with the R&D on the ILC damping rings.

Damping Ring R&D consists of three primary activities: 1) electron cloud collective effects and mitigation strategies, 2) fast kicker technology and 3) ultra-low emittance tuning. Electron cloud primarily affects positrons, so it can’t be studied at ATF; ATF is an electron ring. Electron cloud phenomena are under study at these e-plus/e-minus machines, CesrTA in Cornell, DAFNE in Italy and KEKB. Fast kickers can be studied at ATF; it’s one of the primary topics under study at ATF to make the pulse magnet which is capable of pulling a bunch out with a 6-nanosecond or even perhaps a 3-nanosecond spacing between bunches. Ultra-low emittance tuning is needed to achieve typical beam sizes of few microns. We would like to go to the physical limiting emittance, beyond what has been done at light sources, to a vertical emittance of a few picometer-radians.

The objective of electron cloud study is to develop vacuum chamber technology that suppresses the growth of the electron cloud in each region of the storage ring and to develop simulation tools so that we can understand and extrapolate the performance from this small storage ring to a larger one. Table 2 shows the different kinds of vacuum chambers which are under study at Cornell and at KEK and in other labs. The key institutions involved are shown on the right of the table. The table indicates the different sections, drifts where there is no magnetic field, quadrupole, dipole, or wigglers of the ring and the chamber technology under consideration for suppressing the growth of the electron cloud in each. The technology includes coatings, grooves and electrodes. The clearing electrode is quite likely the one which will be adopted for super KEKB.



Cornell University
Laboratory for Elementary-Particle Physics

Surface Characterization & Mitigation Tests

	Drift	Quad	Dipole	Wiggler	VC Fab
Al	✓	✓	✓		CU, SLAC
Cu	✓			✓	CU, KEK, LBNL, SLAC
TiN on Al	✓	✓	✓		CU, SLAC
TiN on Cu	✓			✓	CU, KEK, LBNL, SLAC
Amorphous C on Al	✓				CERN, CU
NEG on SS	✓				CU
Fins w/TiN on Al	✓				SLAC
Triangular Grooves on Cu				✓	CU, KEK, LBNL, SLAC
Triangular Grooves w/TiN on Al			✓		SLAC
Triangular Grooves w/TiN on Cu				✓	CU, KEK, LBNL, SLAC
Clearing Electrode				✓	CU, KEK, LBNL, SLAC

✓ = chamber(s) deployed ✓ = planned

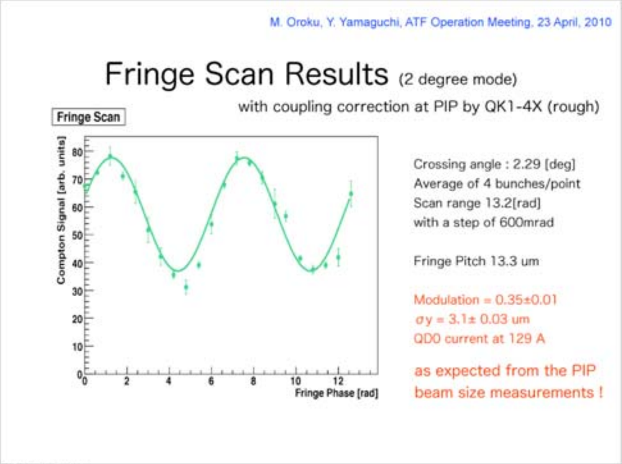
May 13, 2010 ILC PAC Meeting, Valencia 19

Table 2: Storage ring vacuum chambers under test for characterization of the electron-cloud instability. The table shows kinds of vacuum chambers in test in different magnetic field regions of the storage ring.

Beam Delivery – Final Focus

The beam delivery system (BDS) is where the high power linac beams are taken from the end of the linac to the detector and brought into collision. BDS includes collimation and the interface with the detector, which for the ILC is two detectors arranged in a push-pull mechanism. Many BDS components are integrated within the detector so a careful design effort is required, similar to that which was done for the B factories. The beam delivery system has precision beam position monitors and beam size monitors for correction and complex optics correction algorithms. This is what’s being tested at the ATF2 facility at KEK. We hope to achieve 35-nanometer beam size at ATF2 within this calendar year.

An example beam size monitor is the ‘fringe monitor’, also called the ‘Shintake monitor’ because he developed this for tests at SLAC about 15 years ago. Figure 8 shows an example scan from the fringe monitor at ATF2. It uses laser light to create a standing wave interference pattern in the vacuum chamber, and the particle beam is scanned over that. If the particle beam was infinitesimally small, then this dips in cycle in the figure would be much deeper, still not quite go to zero, and you estimate the beam size from that. In the figure, the beam size is three microns. Beam sizes another factor of 10 below that have been measured.


M. Oroku, Y. Yamaguchi, ATF Operation Meeting, 23 April, 2010

Fringe Scan Results (2 degree mode)

with coupling correction at PIP by QK1-4X (rough)

Crossing angle : 2.29 [deg]
Average of 4 bunches/point
Scan range 13.2[rad]
with a step of 600mrad

Fringe Pitch 13.3 um

Modulation = 0.35±0.01
σy = 3.1± 0.03 um
QD0 current at 129 A

as expected from the PIP
beam size measurements !

2010年 5月 13日 木曜日

Figure 8: Laser-based optical ‘fringe’ beam size monitor result from ATF2 at KEK.

The dynamics of the collision is a full study topic itself. A scheme now under study is called the travelling focus. There are two aspects of interest. One is that the focal point moves back along the bunch as they collide, so the dip in the beta function is actually moving and so you do that by having a kind of a chromatic chirp along the bunch. And the other thing that’s happening is that the two beams, as they interact with each other, they keep each other together longer. So, this is the travelling focus, it refers to this chromatic shifting and the two-beam effect keeps them colliding longer. This sort of thing is very hard to test without actually having the functioning linear collider; nevertheless people can test the optics required to have a shifting focus along the bunch.

Positron Source

Let me move on to the positron system. The positron system for the ILC consists of an undulator that produces gamma rays that are direct onto a conventional metal target. The target is a little thinner than the target that was used in SLAC for high power positron production. It is followed by a close proximity lens which captures the very large angle positrons emerging out of the back of the target and focuses them into a normal conducting accelerator. The un-damped positrons are accelerated to 5 GeV and injected into a storage ring where they are damped. A schematic of the system is shown in figure 9.

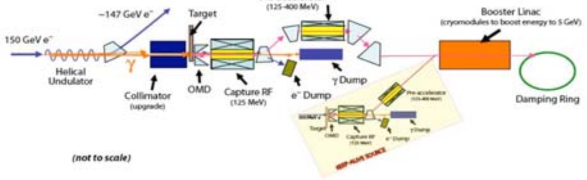


Figure 9: Positron System Layout. The high energy electron beam enters a helical undulator (left) and undulator gamma-rays are converted in a target. Emerging positrons are focused in a tapered, pulsed solenoid, (OMD in the figure), and accelerated in a normal conducting capture section. The positrons are then separated from the secondary electrons and accelerated for injection into the damping ring (right).

Positron system R&D is focused on the undulator, the target, and the tapered solenoid. A key topic is to understand how to manage the peak deposition and the average deposition and power on the target. Even with neutral gamma rays, the 1 millisecond pulse in the ILC is a challenge and beyond present state of the art for positron production targets. The group in Russia at the Budker Institute have developed a liquid lead technology and this is being tested there. Window technology for the liquid metal target is under test at KEK, using KEKB.

Another R & D topic, being studied at KEK, is the development of a hybrid target, in which a gamma beam is generated from a crystalline target, crystalline tungsten for example, and then directed on an amorphous poly-crystalline tungsten target. The crystalline primary target can be considered as being very, very small period undulator. Tests are being done at the end of the KEKB injection linac with the group from the Hiroshima University in KEK.

ROLE OF JAPAN IN DEVELOPING ILC

The role of Japan in developing the ILC involves the accelerator science, the technology, and the preparation for industrialization of superconducting linac components. The role also includes work aimed toward the possibility that ILC might be sited here in Japan, wiht study of Japanese potential sites. The Science Council of Japan, a pseudo governmental science advisory group, and recently published a Master Plan for Science in Japan[2]. The Plan lists several dozen big projects in Japan, including biological projects and synchrotron radiation projects, in addition to the ILC. The text in the Plan describes the formation of an international project with an international research center. It goes on to say that Japan has a central role in the Asian development of this technology and also has a key role in the development of precision beam control. The latter refers to the work that is going on at the Accelerator Test Facility at KEK.

Industrialization – Construction of a ‘Pilot Plant’ at KEK

Superconducting RF technology has been widely deployed in TRISTAN and in KEKB, and KEK has contributed substantially to the development of the TESLA technology. Then the test facility, STF, under construction at KEK is intended to assist the technology transfer to other institutes and to industry. The effort includes the construction of an on-site fabrication pilot plant. The pilot plant is an attempt by KEK to put together, on a very small scale, what must be done to build this technology and allow the development of production techniques and to assume the inherent risk associated. It is quite an interesting way to partner with the companies involved.

The pilot plant is operated by the accelerator laboratory with participation of collaborating companies. The tests and development done there can be spun off to the different companies. Figure 10 shows the floor plan. It is now under construction and will begin work at the end of next year, 2011. There is an electron beam welder, chemical polishing room, and machinery needed for cavity fabrication. It is located in a building in KEK which was formerly used for the power supplies for the Proton Synchrotron.

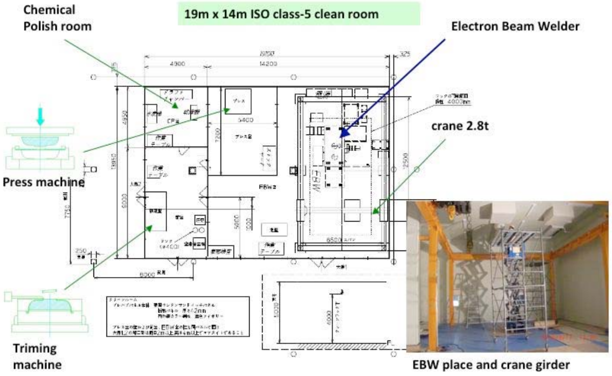


Figure 10: KEK superconducting RF cavity pilot plant floor plan.

Civil Engineering

Civil construction is a large fraction of the anticipated cost of ILC. For our reference design, we studied three sample sites, one in Japan, one at CERN, and one very near Fermilab. The three are quite similar deep rock sites. Recently, we began work on a very different site which is in Dubna, Russia, near the Joint Institute for Nuclear Research. We will use it for comparison to show how we would optimize the civil construction layout of a different site. With that same process in mind, we are now considering a mountain site with the participation of Japanese general contractors through the ‘Association for the Advancement of Accelerators’.

Figure 11 shows cross-sections of different types of sites. The circled cross-sections are under development and were either described in the reference design or have been developed since it was published. Here it shows what a mountain site might look like. The figure shows the type of site that was studied in the very flat ground near the Joint Institute, north of Moscow. It also shows a sample site, in a Japanese mountain range, showing the tunnel and the different ways that the main tunnel would be connected to the surface.

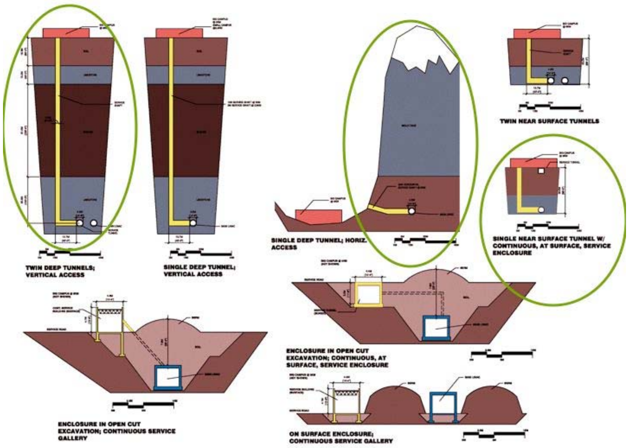


Figure 11: Site configuration cross-sections.

CONCLUSION

The global design effort is supported by the three project managers, each one having a very different background, and our coming together symbolizes the international nature of the project. My Co-Project Manager, Akira Yamamoto, was awarded the Nishina Prize for the observation of cosmic anti-protons in 2000.

Our effort has three goals. The first one is a community goal, aimed at developing communication channels and connections. The second is to do the design and development work, and the third is to put together a project plan. This should be done by the end of 2012. I have tried to show that the Japanese contributions to ILC development span the entire complex and cover both the R&D and the design, and the industrial and technical components.

ACKNOWLEDGEMENTS

This presentation was made on behalf of my colleagues, Nick Walker from DESY and Akira Yamamoto from KEK.

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[1] Tigner, Nuovo Cimento 37 (1965).
[2] Master Plan for Science in Japan, 2009