THE GLOBAL DESIGN EFFORT FOR AN INTERNATIONAL LINEAR COLLIDER

Barry C. Barish, Caltech, Pasadena, CA 91125, U.S.A

Abstract

Two years after the selection of the Superconducting RF technology as the basis for a global design of the ILC and six months before the release of the ILC Reference Design Report, this presentation reviews the status plans and main issues towards an ILC project. The challenges are both technical (performances, reliability, machine protection, cost minimisation, industrialisation) and organisational, forming a precedent setting world-wide collaboration for the first time from the very beginning of an accelerator project.

INQUIRY BASED SCIENCE

One might ask why we want to build an ambitious TeV scale electron positron collider, especially considering that LHC will produce proton proton collisions in this energy regime in just a few years?

To put the answer into perspective, one needs to appreciate atht particle physics has evolved over the past decades into what one might call an inquiry based science. What I mean by that is that we no longer build new instruments just to open a new window for observations of new physics, but rather we pretty much agree on a list of the most important questions for the field and we build instruments to address those questions.

Some of these very fundamental questions that are driving the field include the following:

- Are there undiscovered principles of nature, like new symmetries or, new physical laws?
- How can we solve the mystery of dark energy?
- Are there extra dimensions of space?
- Do all the forces become one?
- Why are there so many kinds of particles?
- What is dark matter and how can we make it in the laboratory?
- What are neutrinos telling us?
- How did the universe come to be?
- What happened to the antimatter?

This particular set of questions comes from "the Quantum Universe," but it is pretty representative of the primary questions facing our field. Interestingly, these questions help us focus on what tools we need. Many of the questions will need to be addressed in complementary ways, in order to make progress. And, of course, what we learn will open new questions and fields of inquiry. So, in a sense, the questions we pose open up directions for our research.

To do experiment directed at answers to these questions, we are focusing on developing three main complementary probes: There also are specialty experiments aimed at a particular issue.

- Neutrinos. This field enables us to study a variety of particle and astrophysics questions through weak interactions. .
- High Energy Proton-Proton Colliders: The LHC is the next machine and it promises to open up a new frontier at the TeV scale. We expect many of the phenomena in our question list to manifest themselves in this energy regime.
- High Energy Electron Positron Collider: The ILC will enable doing both discovery physics and precision measurements at the new energy frontier.

In this presentation, I discuss the last of these probes and I briefly present the science goals from the standpoint of the requirements they make on the accelerator and introduce the present baseline configuration for the International Linear Collider.

ELECTRON POSITRON COLLISIONS

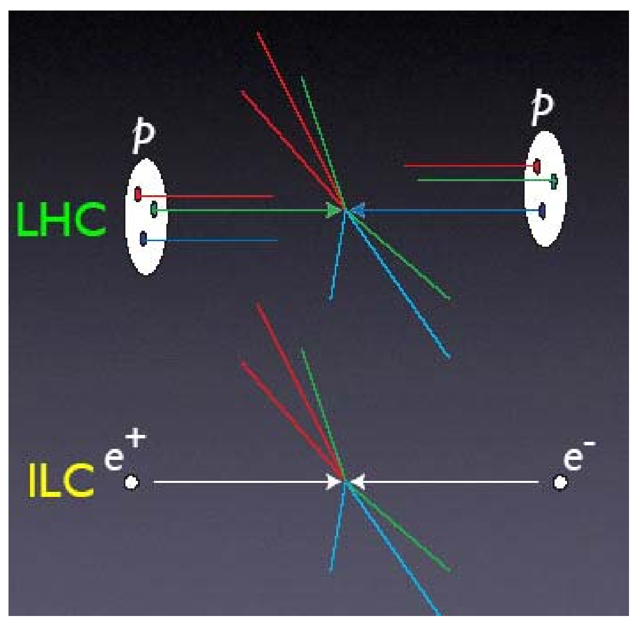

Figure 1: The figure illustrates the characteristic differences between e^+e^- and pp collisions.

Protons are complex objects made up of quarks and "gluons" (the strong forces that hold it together), while an electron and positrons are simple point-like particles. These two approaches present different issues in making a particle accelerator. A proton can more easily be accelerated to high energy, but are more complex objects when they make collisions.

For the case of a proton, e.g. at LHC, a collision occurs when a quark (or gluon) from one proton collides with a quark (or gluon) from the other proton. The colliding particles, or constituents, carry an unknown fraction of the total momentum carried by the proton and only a fraction of the center-of-mass energy of the protons goes into the collision. Experiments measure the outgoing products from the collisions and study the physics statistically, since the kinematics or even the colliding particles are not known for each collision. In addition, most collisions are diffractive, while the interesting physics usually involves collisions having large transverse momentum. In general, while studying proton-proton collisions can be a very effective way to explore a new energy regime, it is difficult to isolate new phenomena or to make precision measurements.

In contrast, for electron-positron collisions the collisions are between elementary point like objects, having well-defined energy and angular momentum. In each collision, the full center-of-mass energy is used, and particles are more or less produced democratically, meaning that the interesting physics is not buried as rare events in a large background. Finally, depending on the capabilities of the detectors, the events can be fully reconstructed for every collision. This puts high demands on the detectors and therefore there is a much needed R&D program underway to develop ILC detectors with sufficient resolutions.

MACHINE PARAMETERS

.The international high energy physics community, through an ICFA subcommittee, has studied the range of physics goals for the linear collider. An ICFA subcommittee report [1] was released in 2003 that lays out the main requirements for an electron-positron collider, that will be capable of addressing the physics goals.

Some of the main parameters include:

- Ecm adjustable from 200 – 500 GeV
- Luminosity → $\int Ldt$ = 500 fb-1 in 4 years
- Ability to scan between 200 and 500 GeV
- Energy stability and precision below 0.1%
- Electron polarization of at least 80%

and

- The machine must be upgradeable to 1 TeV

For designing the ILC this parameters report serves to give us effectively a set of top level requirements for the machine and we are basically designing the machine to flow down from those requirements. Of course, we must take into account technical risk, costs, schedule, etc, so that in the end we will play off the ICFA machine parameters and the other factors to optimize the cost to performance for the machine we will propose to build.

THE TECHNOLOGY CHOICE

The idea that a linear collider would be a prime candidate for the next large accelerator project for particle physics was accepted by many more than a decade ago, and a vigorous accelerator R&D program was initiated at KEK, SLAC and DESY and other associated Universities and associated laboratories. At SLAC and KEK the R&D was focused on room temperature copper structures, while at DESY they pursued superconducting "cold" technology for the main accelerating units.

These challenging R&D programs were highly successful and feasibility for a linear collider was demonstrated using **both** technologies by about 2000. This was a very impressive accomplishment, but ironically it led to the difficult problem of deciding which technology to go forward with in the design of what everyone accepted was to be a global collaboration to build a single machine.

Since both technologies had demonstrated basic feasibility for such a collider, making a choice became a very difficult issue. After several studies, including one chaired by Greg Low of SLAC, no decision was reached and ICFA then appointed a new panel, the International Technology Recommendation Panel (ITRP) to assess the two technologies and make a recommendation to the International Linear Collider Steering Committee (ILCSC) and to ICFA.

ITRP submitted its report [2] to ICFA in August 2004 and the key recommendation read:

"We recommend that the linear collider be based on superconducting rf technology. This recommendation is made with the understanding that we are recommending a technology, not a design. We expect the final design to be developed by a team drawn from the combined warm and cold linear collider communities, taking full advantage of the experience and expertise of both."

(from the ITRP Report Executive Summary)

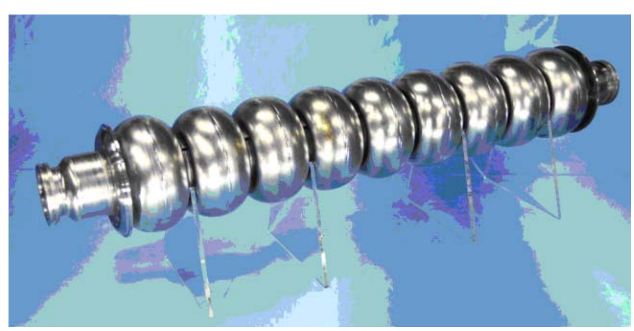

Figure 2: Niobium 9 cell 1 meter long TESLA cavity

Following the ICFA decision to base the design of the linear collider on superconducting RF technology, the worldwide accelerator community rapidly reorganized itself toward creating a new global design. In November 2004, a very successful 1st ILC workshop was held at KEK Laboratory that was attended by more than 200

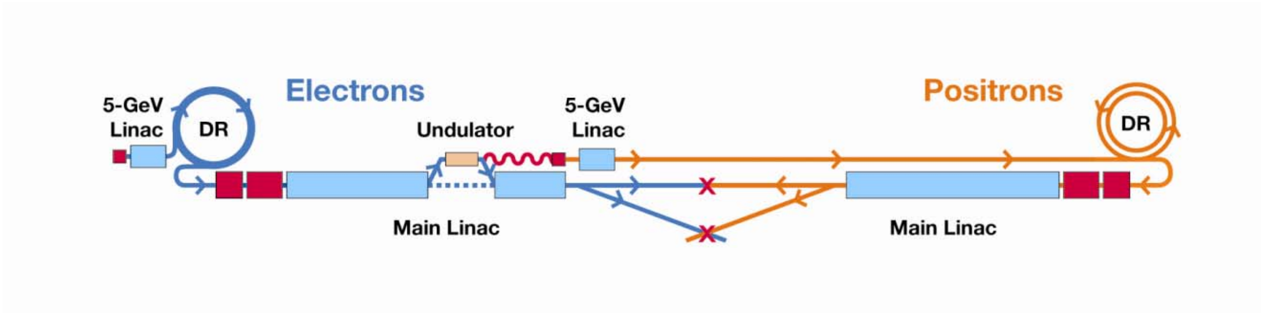

Figure 3: The Initial ILC Baeline Configuration (December 2005).

THE GLOBAL DESIGN EFFORT

The momentum generated through the creation of this self-organized set of working groups carried the effort until last summer when the official Global Design Effort (GDE) had been formed. The GDE met for the first time during the 2nd ILC workshop at Snowmass in August 2005. At that meeting, the reigns were turned over from the informal self-organized working groups to the GDE, and the work quickly focused in on deciding and documenting a baseline configuration for the ILC. A goal was set to define that baseline and to document it in a Baseline Configuration Document (BCD) by the end of 2005.

To globally agree on the detailed concept for the BCD, more than 40 questions were identified at Snowmass. These needed to be decided before a unified baseline could be defined. The decisions varied from key ones like the operating gradient of the superconducting cavities and the design luminosity to other questions such as whether the machine should follow the earth's curvature or be laser straight. Consensuses were sought on all of these questions during and after Snowmass and that process led to a "strawman" baseline that was posted several weeks before the GDE was next to meet at Frascati, Italy in December 2005.

At Frascati, this document was discussed in some detail and the last questions were debated, some changes agreed to, and then the BCD was declared to be official. Successfully achieving this first major milestone for the GDE was an important accomplishment. It bodes well for the process that has been undertaken to create a global design and eventually a machine.

THE ILC BASELINE CONFIGURATION

The BCD defines the machine parameters for a 500 billion-electron-volt (GeV) energy level, and allows for an upgrade to 1 trillion-electron-volts (TeV) during the second stage of the project.

The baseline configuration has been document in a tiered electronic document [3]. Some of the key features are discussed briefly below.

Accelerating Gradient and Cavity Shape:

The TESLA superconducting cavity shape for the 500 GeV stage was chosen for the initial baseline. The ILC R&D program includes work on alternate cavity shapes that promise higher gradients, but the designs are not mature enough at this time to adopt for the baseline.

An accelerating gradient (acceleration per meter of machine) of 31.5 million volts per meter has taken as the baseline gradient, but R&D will be necessary to establish that gradient is realistic for large production with sufficient yield. A gradient of 36 MeV/m is assumed for the upgrade, under the assumption that either the low-loss cavity shape or the re-entrant cavity shape will be employed on that timescale.

The Electron Source

A conventional source using a DC Titanium-sapphire laser emits 2-ns pulses that knock out electrons. An electric field focuses each bunch into a 250-meter-long linear accelerator that accelerates up to 5 GeV

The Positron Source:

A helical undulator-based positron system was chosen for the baseline, because it can run at higher current and has promise of creating polarized beams. The 200-meter-long undulator will be placed at the 150 GeV point in the electron linac. It makes photons that then hit a 0.5 rl titanium alloy target to produce positrons. The positrons are accelerated to 5-GeV before being injected into the positron damping ring.

The scheme also contains a "keep alive" conventional source at 10% of the design current to keep the machine tuned during periods when the positron source is not operational.

The Damping Rings:

Two circular 6-kilometer positron damping rings, and one circular 6-kilometer electron ring, will be located on either end of the linac. This is the most challenging subsystem from an accelerator physics point of view. A fast (~ 5nsec) rise time kicker must be used to inject and extract beam bunches and the close spacing between bunches creates issues with electron cloud effects. The initial baseline has two positron rings where the injected bunches alternate to mitigate this effect. The possibility of eliminating one of these rings is being pursued.

Upgrade Path to 1 TeV:

The footprint of the facility will be for 1 TeV, but the initial tunnel construction will be ~30km for the 500 GeV configuration. The baseline includes the necessary features to enable a 1 TeV upgrade, for example beam dumps scaled for 1 TeV, bends and length scaled for 1 TeV, etc. However, the upgrade will require new tunnelling to reach the full 50km. Alternate upgrade schemes are still under consideration.

Laser Straight vs. the Earth's Curvature:

The main linac will follow the curvature of the earth, instead of being laser-straight. The cryogenics system, helium system and civil construction are more straightforward with a curved tunnel, but we must prove that we can control emittance growth in the main linac. Preliminary studies are very promising..

One Tunnel vs. Two Tunnels:

The initial baseline uses two parallel tunnels that allow radiofrequency equipment and other support instrumentation to be located in a separate tunnel adjacent to the beam tunnel. This configuration would enable access for repairs without turning off the beam line. However, this whole question will need to be revisited after we get costing information..

Configuration of the Interaction Regions:

The preferred configuration is two detectors at two separate interaction points. The initial configuration has one detector at a 2 mrad crossing angle and the other 20 mrad. Again, this question will need to be revisited when we have costing information.

ILC Detectors

Large Scale 4p detectors with solenoidal magnetic fields will be developed for the interaction regions. There are presently four concepts for such detectors, using somewhat different philosophies and technologies.

In order to take full advantage of the ILC ability to reconstruct, need to improve resolutions, tracking, etc by factor of two or three. To reach these goals, new techniques in calorimetry, granularity of readout etc are being developed in a worldwide R&D program.

THE NEXT STEP: A REFERENCE DESIGN

This baseline configuration presented above is not final and will evolve both as the design/costing develops and as the R&D program demonstrates improvements over the baseline in performance, cost or risk. The Baseline Configuration Document (BCD) is therefore a living document. It is not intended for funding agencies at this early stage, but rather our best view of the globally agreed to configuration at any point in time. This document will migrate to an Engineering Design Management System at the time we begin a detailed engineering design..

The next goal is to produce a Reference Design Report (RDR) that is based on the BCD and one that has reliable cost estimates. This means that in addition to the configuration defined in the BCD, we have determined the number and specifications of the elements and other details that will enable first reliable costing.

The RDR will also contain sections on siting, industrialization, detector concepts, performance and options for the machine, including upgrade plans to 1 TeV. In order to accomplish this next step, the GDE has been reorganized and expanded somewhat to bring in some missing skills. At this point, the program to develop the reference design report is well-underway.

The BCD was "frozen" after it was agree upon last December and has been put under formal configuration control. This step was necessary in order to maintain a stable configuration during the design and costing effort. A Change Control Board and process have been established to make and document changes in an orderly manner, and that is now working well. A number of changes have already been made and the BCD is expected to continue to evolve, as more is learned through the design process and later through improvement established in the R&D program that will improve the performance or reduce the costs.

We are just on the verge of getting our first costing information and folding costs into the picture will undoubtedly result in further changes to the baseline, as we optimize cost to performance and strive toward an affordable machine.

REFERENCES

[1] ICFA Subcommittee Report, "Parameters for the Linear Collider" September 2003 http://www.fnal.gov/directorate/icfa/LC_parameters.pdf

[2] International Technology Recommendation Panel Report September 2004 http://www.fnal.gov/directorate/icfa/ITRP_Report_Final.pdf

[3] The ILC Baseline Configuration Document http://www.linearcollider.org/wiki/doku.php?id=bcd:bcd_home