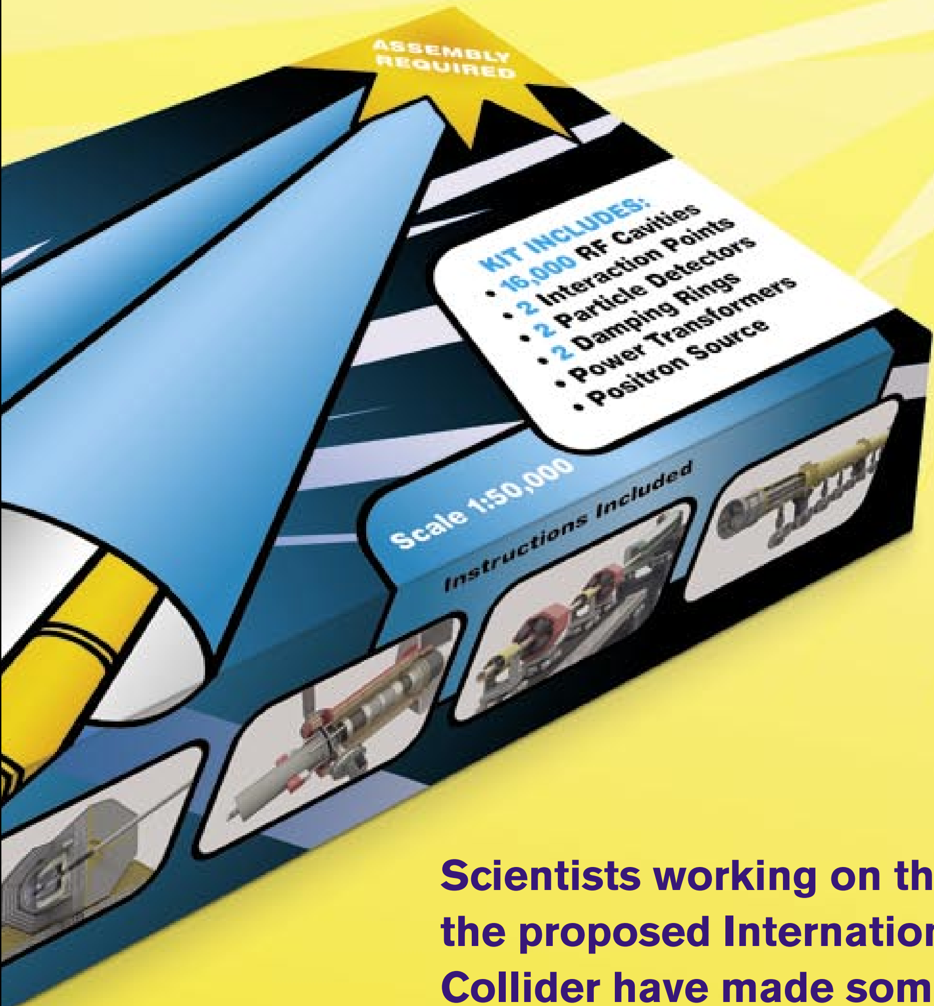
OUT OF THE BOX

Designing the ILC

by Elizabeth Clements

Illustrations: Sandbox Studio

Illustration includes artists's renderings for the international linear collider. *Courtesy of KEK and Rey, Hori*



Scientists working on the design of the proposed International Linear Collider have made some important decisions and agreed on the baseline configuration of the machine.

In December 2005, among the rolling hills of Frascati, Italy, the international 63-member team of the Global Design Effort for the proposed International Linear Collider met its first goal: adoption of the Baseline Configuration Document (BCD), just four months after convening for the first time in Snowmass, Colorado.

At 700 pages divided into nine sections, the report outlines the basic configuration for the next-generation particle accelerator that will make electrons and positrons collide at energies well beyond present accelerators. Particle physicists can now visualize for the first time what the machine will look like.

"Getting international agreement on all of the topics in the BCD is perhaps the true accomplishment here," says Deutsches Elektronen-Synchrotron (DESY) physicist Nick Walker, a member of the GDE's Executive Committee. "Many strong groups, who each had their own ideas on how to best build the machine, contributed to the BCD. Getting them all to put their religion aside and finally sign-off on the BCD was an enormous achievement—and we did it on schedule."

"The baseline configuration document [for the ILC] is a snapshot of what we can understand and defend at this time." Barry Barish, GDE director

Nuts and Bolts

The BCD defines the machine parameters for a collider operating at the 500-billion-electronvolt (GeV) energy level, and it allows for an upgrade to 1 trillion electronvolts (TeV) during the second stage of the project. Some technical highlights of the baseline design:

- Acceleration: The DESY-based TESLA project's superconducting cavity shape for the 500 GeV stage will produce an acceleration gradient (acceleration per meter of machine) of 31.5 million volts per meter. (The upgrade calls for a gradient of 36 million volts per meter, using the alternative low-loss cavity shape, or the re-entrant cavity shape.)
- Positron source: The undulator-based positron system will be a novel way of creating anti-electrons for a linear collider. The 100-meter-long undulator will be placed at the 150-GeV point in the electron linac, making it possible to produce polarized positrons—a necessary feature for achieving important science goals.
- 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 to optimize the beam density.
- Energy upgrade: During the first stage of the project, half of the tunnel (approximately 30 kilometers) will be built to smash electrons and positrons together at an energy of 500 GeV. During the upgrade to 1 TeV, building the remainder of the tunnel will bring the total length of the ILC to approximately 50 kilometers.
- Tunnel curvature: The main linear accelerator (linac) will follow the curvature of the earth, instead of being laser-straight. Engineers prefer a curved tunnel because it is easier (and cheaper) for the cryogenic system needed to cool the superconducting cavities.

- Number of tunnels: Constructing two parallel tunnels will allow radiofrequency equipment and other support instrumentation to be located in a separate tunnel adjacent to the tunnel with the beamline, enabling safe access for repairs without turning off the beamline.
- Number of interaction points: The BCD specifies two electron-positron interaction points and two separate detectors to record collisions. One detector will have a small crossing angle of the two beams, and the other will offer a large crossing angle, optimizing the types of subatomic processes that can be studied through collisions.

The ILC configuration is not yet final. Members of the Global Design Effort consider the BCD to be a living document that will evolve as scientists gain more knowledge about what is technically—and financially—feasible. As a document that is not intended for funding agencies at this early stage, the BCD takes all the ideas that scientists and engineers have been sharing for more than twenty years and records them on paper.

The Process

Work on the BCD started at the Snowmass Workshop in August 2005, with physicists and engineers dividing into working groups to focus on their respective areas of expertise in the machine. The GDE assigned task forces to address specific unanswered issues and asked them to write "white papers," providing solutions for each problem area.

"Most of the choices made in the BCD resulted from the discussions during the Snowmass workshop," says Kaoru Yokoya, a physicist at KEK in Japan and member of the GDE Executive Committee. "As expected, a few of the items remained open after Snowmass. Some of the decisions that the Executive Committee made, such as the energy upgrade path and the location of positron generation, were different [from] the conclusions reached by the working groups or task forces. But for most of the items, the Executive Committee respected the conclusions made by the scientists and engineers in the working groups."

The BCD represents the collaboration of hundreds of scientists and engineers, from laboratories and institutions around the world. Stanford Linear Accelerator Center (SLAC) physicist and GDE Executive Committee member Tor Raubenheimer sees the document as an excellent exercise for a large international project, by forcing a level of realism upon everyone.

"It is very easy to put a design down on paper, but it is hard to actually think about doing things and how you are really going to build the machine," Raubenheimer says. "The BCD is a very good first step this way, and there was some realism put into the process."

Raubenheimer notes the accelerator gradient choice. "When we started the BCD, we aimed for a gradient of 35 million electronvolts per meter or higher," he says. "But physicists looked at the gradients they were achieving and realized there is no way that we can propose a gradient of 35 given the current technology. We learned something, and now the gradient in the BCD is 31.5 million electronvolts per meter. Incorporating this kind of realism into the design is a very good sign."

The damping ring choice is another example. To achieve a high number of electron-positron collisions, the particle bunches must be squeezed down to nanometer size—thinner than a human hair. The damping rings play a crucial role in shaping the bunches. Unable to decide among a number of different damping ring designs and configurations at Snowmass, the international working group organized itself into "task forces," and reached consensus on circular 6-kilometer rings during a meeting at CERN, the European particle physics laboratory.

The damping ring decision is of particular interest to Fermilab theoretical physicist Joe Lykken. The decision plays a large role in determining the number of collisions in the machine, and hence the amount of physics results that come out of it. "The most difficult thing the GDE did was come up with a new damping ring design," he says. "The easiest thing they could have

"I think of the BCD as a living document that will continue to be modified." Tor Raubenheimer, SLAC

done was to stick with the TESLA design. Instead, they did something new, and that took some courage."

Costing

Determining a price tag for the ILC is not part of defining the baseline configuration, but keeping costs to a minimum was strongly considered throughout the process. (The challenging task of estimating costs will be incorporated into Reference Design Report, to be completed by the end of 2006.)

The detector is one of the more expensive—and most critical—ILC components. There is a general consensus among the worldwide particle physics community that two detectors are a necessary part of the ILC, although the debate over one versus two detectors is complex—and far from resolved.

"We are all very cost-aware, and the community must ask itself what it wants for its money," Walker says. "The BCD stands at two interaction points with two detectors. But as part of the Reference Design Report costing exercise, a single interaction point option will be costed so that we will know at the end exactly how much we might save."

In this early stage of the process, the Executive Committee does not view choosing two interaction points and two detectors as politically damaging to the project. "Picking two detectors for the BCD is somewhat arbitrary," says GDE Director Barry Barish. "We were able to make a decision that wasn't politically offensive because we are able to revert to one detector if the cost is too high."

Another tough decision was how to allow for an energy upgrade of the machine at a later time.

"The BCD is a success because people around the world converged on a number of things. The upgrade path is an example of a hard decision that had to be made," says Raubenheimer. After being presented with all of the white papers and reports from the working groups and task forces, the GDE Executive Committee had to configure the optimal physics machine while keeping costs to a minimum.

"We couldn't at this point justify digging an expensive 50-kilometer tunnel that will remain half empty for the first stage of the project," Barish says. "The commitment is there, and it is inherent that we will make a machine that is expandable to 1 TeV. The BCD is a snapshot of what we can understand and defend at this time, and it allows for the expansion to 1 TeV."

Achieving 1 TeV

The GDE "built in" several factors to allow expanding the machine to its full 50-kilometer length. All of the land required for the full-length machine will be purchased at the beginning of the project. Certain aspects of the

500 GeV machine, such as beam dumps and final focus, are also designed to work with a 1 TeV machine. "That is an investment you want to make up front," Barish says.

On the other hand, some parts of the tunnel construction could be done while the machine is operating, to keep downtime to a minimum. "After much discussion, which is no doubt ongoing, building a short full tunnel for an energy of 500 GeV is currently the cheapest and most justifiable option," Walker says.

Barish points out that as costs become clearer, the full-tunnel option may be preferred. "We need to do more homework, and we may go back to building the whole tunnel right away, if we can defend the investment and articulate the advantages," he says. "The upgrade path is allowed for in the design. The only thing we haven't done is put in a long unused tunnel."

Building a 500 GeV machine during the first stage doesn't raise any concerns for Lykken. "We have always asked for a 500 GeV machine, and it should have more than enough energy to do Higgs physics, which is what we want to do during the first stage," he says. "You can't just look at the energy level. In order to do the physics we want, we need clean, precise measurements. If you just get obsessed about the energy, you lose sight of the physics goal."

What Lies Ahead?

At the Frascati GDE meeting, Barish established a Change Control Board, chaired by KEK's Nobu Toge, which reviews each proposed revision to the BCD as the document continues to evolve over the next several months. "I think of the BCD as a living document that will continue to be modified right until the time of the Vancouver meeting in July," Raubenheimer says. "Initially the idea was to lock it down, but we realized that we want to add a lot more detail to it."

The GDE considers the completed BCD as the start to the Reference Design Report, a more detailed document that will produce a price tag for the project. "Right now there are a lot of details in the BCD that are not consistent," Raubenheimer says. "When the whole thing is put together in the Reference Design Report, all of those inconsistencies will be smoothed out."

Walker reiterated that the BCD provides the particle physics community with the big picture for the ILC. "The BCD outlines the big choices but not the small details," he says. "Those details are being supplied now. Although the details are discussed and will get modified, for the most part, they will not alter the essence of the BCD."

A graphic and description of the ILC baseline configuration can be found in the deconstruction section of *symmetry* on pages 30-31.