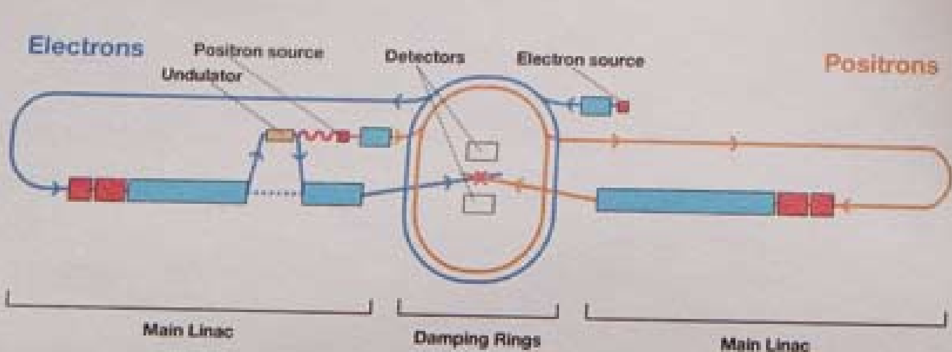
# Evolution of a Collider

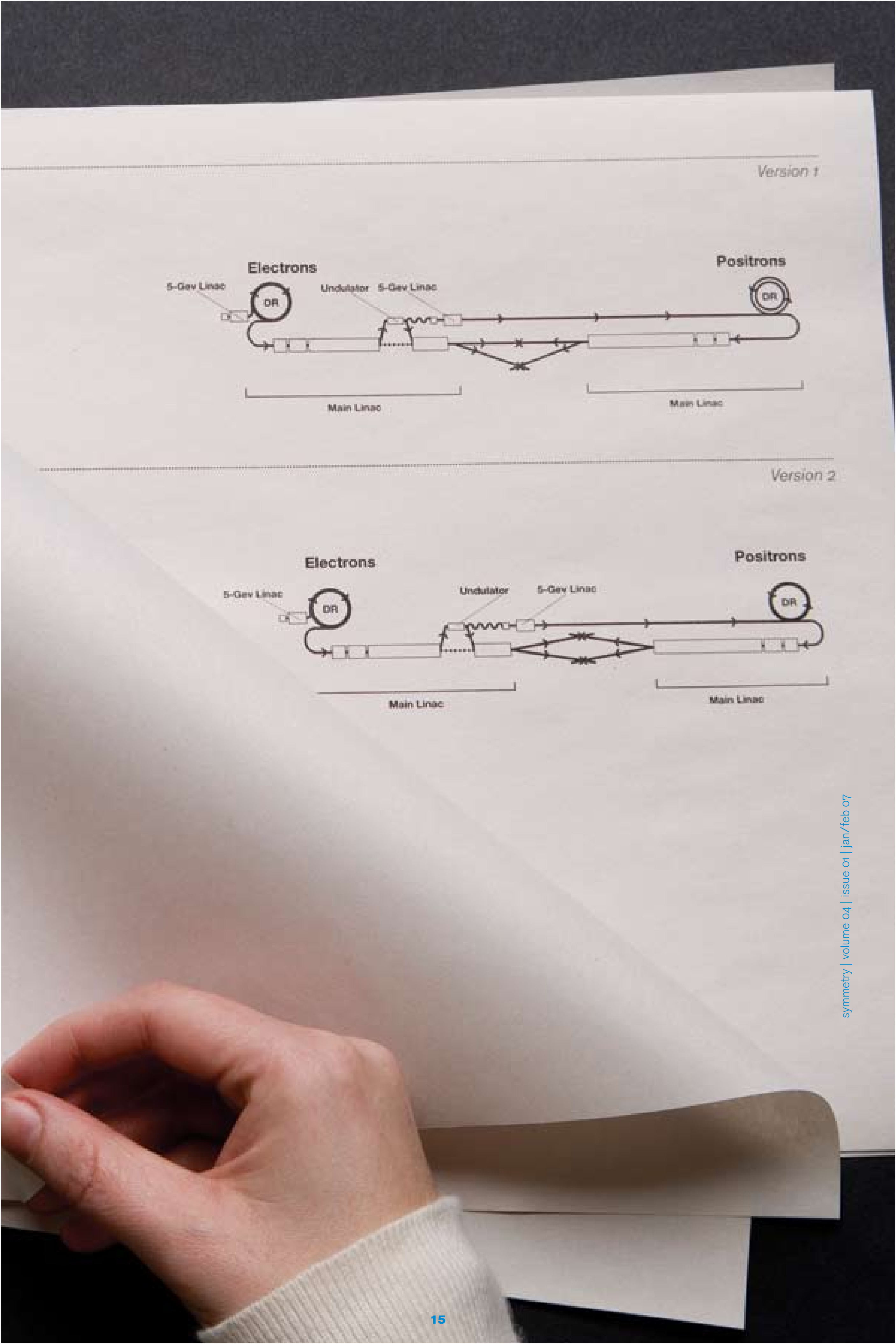
by Elizabeth Clements, ILC Global Design Effort

**As physicists and engineers devise ways to make the International Linear Collider perform better at a lower cost, the design evolves, sometimes with tweaks but at other times with major reconfigurations.**

*Version 3*




*Photos: Reidar Hahn, Fermilab*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Version 2
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“Optimizing cost without compromising the physics performance is the goal of the reference design.” **–Barry Barish**

Designing the International Linear Collider is an evolutionary process. The ILC would be a next-generation machine that smashes together electrons and their opposites, positrons, to unlock some of the deepest mysteries about the universe. But aside from the new science, the ILC enters new territory in terms of planning and designing for the particle-physics community.

The Global Design Effort (GDE) for the ILC is an international team of physicists and engineers that continuously evaluates the project’s ever-progressing design. The design team’s goal is a machine that produces optimal physics with good value for money.

In December 2005, the GDE produced a Baseline Configuration Document. Intended to give the scientific community a first glimpse of what the ILC would look like, this baseline design outlined the physics parameters and overall schematic of the machine. The GDE completed this baseline document as a first attempt—a launching pad—to put down on paper a design that will continue to be refined.

In 2006, the GDE began stage two of ILC planning: the Reference Design Report. Publicly released in February 2007, this more detailed conceptual report specifies all hardware components in enough detail to assess performance and prepare a preliminary value estimate.

In developing a value estimate, members of the GDE asked themselves: How can the baseline design be modified to optimize the costs without dramatically compromising the physics capabilities of the machine? Such exercises resulted in a series of changes—some quite large—to the baseline design.

## A big change

In October 2006, one significant modification completely reconfigured the footprint of the machine, combining the electron and positron damping rings in one tunnel and relocating them to the center of the machine, surrounding the detectors. With the exception of the linear accelerators that would each extend approximately 15 kilometers, this reconfiguration makes it possible to fit many of the large technical systems of the ILC in one central complex. The main motivation, however, for the modification: slash the construction cost of the ILC by eliminating a circular 6.7 kilometer tunnel and associated facilities, resulting in a savings of 39 percent for the damping rings.

“Optimizing cost without compromising the physics performance is the goal of the reference design,” says GDE director Barry Barish. “Our design has evolved through an orderly change control process that carefully considered the potential risks for each modification and sought input from the larger physics community. Further cost optimizations will continue to be made in the next engineering phase of the project, but for now, changes like the damping ring reconfiguration allow us to propose a more financially responsible machine.”

## The evolution

The idea of placing two damping rings in one tunnel is an old idea. In fact, physicists have toyed with the idea of a central damping ring complex since the project’s first conception. Having the majority of large technical components on one laboratory’s site makes maintenance much easier and limits the disturbance to surrounding neighborhoods during construction. “Just the time that you save by not having to drive 15 kilometers every time you need to fix something in the damping rings makes the central campus better,” says Peter Tenenbaum, who helped with the reconfiguration as a GDE member from Stanford Linear Accelerator Center. “Think about it. You could spend an entire shift driving back and forth just to replace one part.”

Until recently physicists required two positron damping rings to counter an “electron cloud effect”—a building up of electrons inside the beam pipe that interfere with the oppositely charged positrons, destroying the beam density that is

essential for producing precise collisions. This cloud posed such a threat to producing the physics desired from the ILC that physicists required two positron damping rings to counter the problem. While two rings can sit comfortably in one tunnel, three would be a crowd. After damping ring R&D studies produced a number of techniques for combating the electron cloud, physicists became confident that they could eliminate one positron ring to cut costs. For the ILC physicists, the next natural step was to put the remaining single positron ring and the single electron ring in the same tunnel.

"We knew that we could build a machine that worked, but it was expensive," says the leader of the GDE damping rings group Andy Wolski of the Cockcroft Institute. "We looked at results that we got from R&D and made a configuration that is safe enough to work but now has a more reasonable cost. There may be some technical risks, but it has such a substantial reduction in cost that we can't ignore it."

Without threatening physics results, the new configuration (see diagram, next page) places the electron ring and the positron ring on top of each other in one tunnel 6.7 kilometers in circumference and 4.5 meters wide that sits 10 meters above the beam delivery systems. Rather than remaining at either end of the linacs, both positron- and electron-injector systems now also sit in the central complex, next to the damping rings, resulting in a complete overhaul to the beam transport system.

## Configuration challenges

From the production of the first particle bunches to the final collision of electrons and positrons, one cycle in the ILC takes only 0.2 seconds. The different steps of each cycle require a precise coordination, introducing timing challenges for the new configuration.

In order for the electrons and positrons to collide at the interaction point in the center of the machine, both beams must be extracted from the damping rings at precisely the right times. Because the positron beam is not created until the electron beam is halfway down the linac, the positron ring will be partially empty before new positrons arrive to refill it. This presents challenges for maintaining stability of the beam during the extraction process.

"It is an unusual thing to do to the beam, and it has never been done before with long trains of bunches," Wolski says. "The bunches in the storage rings will talk to each other. When you take one out, the others will know. We need to work hard to make sure that they stay in the right place, which is why this is a priority for damping rings R&D."

The GDE also had to consider the implications of introducing two 15-kilometer-long beam transfer lines to the new configuration. The main job for the beam transfer lines: preserve the beam quality of the electrons and positrons after they exit the damping ring and transport them 15 kilometers in either direction to the beginning of the linacs, without eating into the savings of eliminating an entire tunnel. "It is actually easy to have a long transfer line, because it just has to get from point A to point B in almost a straight line without destroying the beam," says Tenenbaum, a co-leader of the Ring to Main Linac (RTML) group for the GDE.

The trickiest part involves entering and exiting the damping rings. The damping rings sit 10 meters above the main linacs, requiring a beam escalator to bring the positrons and electrons back down to the level of the transport lines.

"Further cost optimizations will continue to be made in the next engineering phase of the project." **–Barry Barish**

Even though the beam escalators have a slow, gradual slope, asking particles to move vertically is not simple. "It is incredibly fussy, but it can be done," Tenenbaum says. "It is just a geometric challenge and requires a lot of thought and effort."

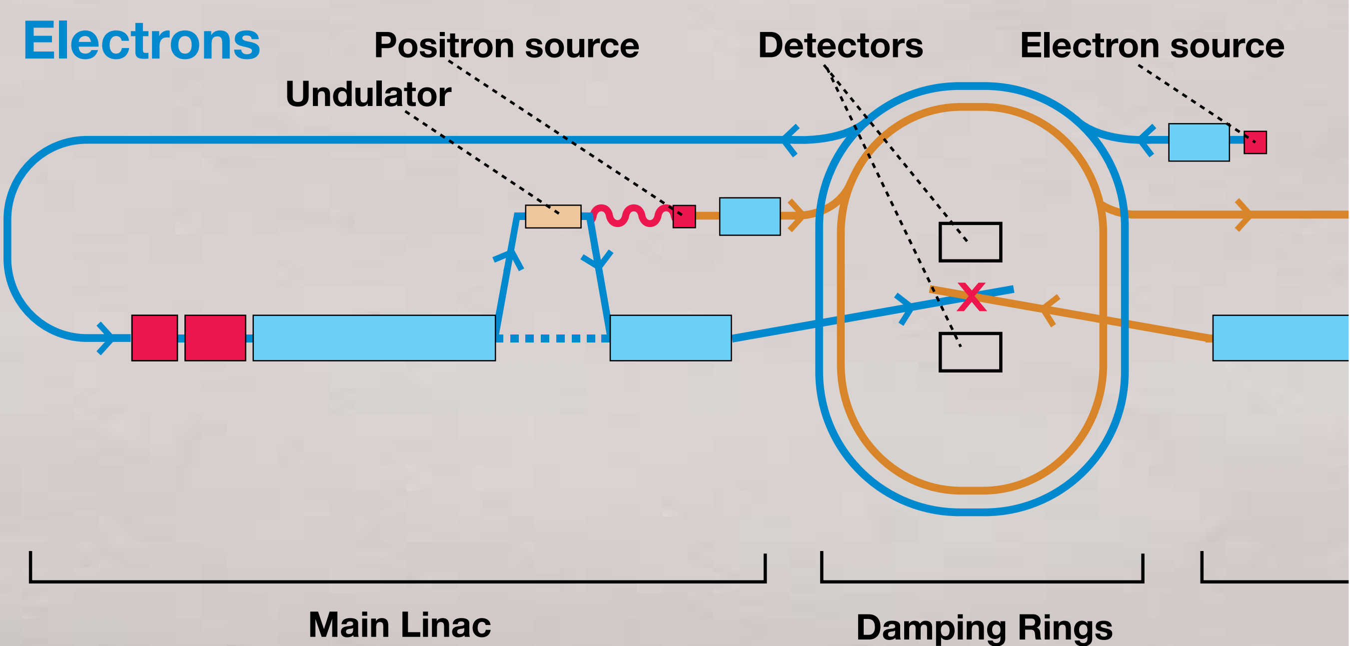
To fit the new long transfer lines into the new configuration, they will be in the ceiling of the main linac to allow room for all of the other components that must go in the same tunnel. Tenenbaum compared the size of the tunnel to a typical plane on a trans-Atlantic flight. "Watch people struggle with their bags in the overhead bins on a plane," he says. "That is what it will be like to work on the transfer lines. It is always harder to work above your head."

One of the benefits of having the damping rings and injectors sit 10 meters above the rest of the machine is that they will be able to operate independently of the main linacs and interaction regions. Ample shielding between the damping rings and the main linacs makes it safe to have electrons and positrons circling above and physicists working in the beam delivery area below, yielding more potential cost savings. "You can save a lot of commissioning time because we can test the damping rings while we are still building the rest of the machine," says Ewan Paterson, of Stanford Linear Accelerator Center.

## Change control process

Knowing that the baseline design for the ILC would continue to evolve, the GDE implemented a Change Control Board in December 2005 to review all proposed changes. Chaired by KEK's Nobu Toge, eight additional physicists from different laboratories around the world with different areas of expertise make up the board. "We are not external reviewers; we are from within the GDE to help our colleagues decide. The CCB's job, however, is to try its best to ensure that our design decisions are reasonable and that they survive the relevant experts' scrutiny," Toge says. "If a proposal offers a healthy working solution with a feasible design, the CCB approves the change. If not, the CCB signals a warning sign and disapproves the change."

Serving as a set of fine-grain eyes, the Change Control Board conducts a review to evaluate the benefits and potential hazards of implementing each change request. "When you are looking at



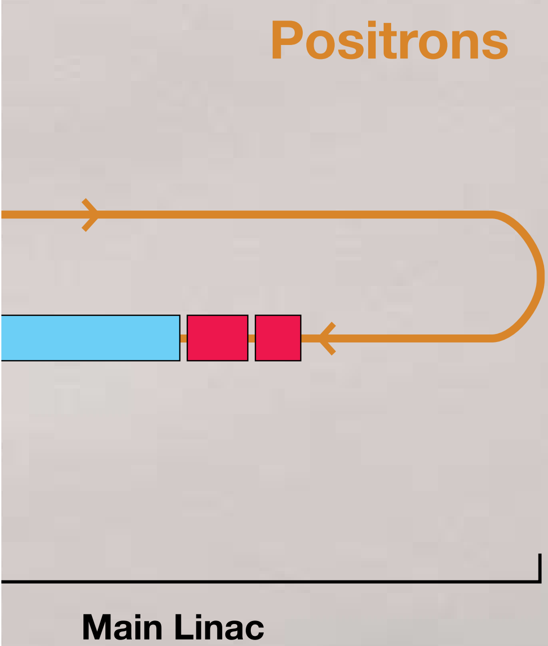
the big picture, it's good to have many eyes," Toge says.

Because the damping rings reconfiguration had an impact on almost every system in the ILC—a huge task to consider when reviewing the proposed change—the GDE called for reinforcements and enlisted Paterson to help. As the designated "Integration Scientist" for the GDE, Paterson focuses on the interfaces and interactions between systems in the ILC, making it very appropriate for him to oversee the damping rings reconfiguration process. From civil construction to beam delivery, Paterson coordinated all of the different systems affected in the change request and presented the change request as one neat package for the CCB to review. "We asked ourselves, in our desire to save, are we overlooking something?" Paterson says. "You can't just blindly go ahead."

## Putting it all together

After a series of reviews, the CCB and GDE Executive Committee strongly supported the change request. While the cost-savings alone made the reconfiguration appealing to the review panel, the relocation of the damping rings to a central campus offered extra benefits for commissioning, operations, and sharing facilities. Confident in the overall design for the machine, the GDE still has some questions about details of the central campus. "With the competence of the people we have, these are things that we can solve," Toge says.

The nuances of the new configuration will continue to be defined through R&D activities and eventually in the ILC Technical Engineering Design Report. With the change process running smoothly, ILC physicists are confident that they can continue to improve the design while lowering costs as they take the ILC through the next engineering design phase and closer to its exploration of the universe's foundations.




In the new ILC design, electrons are generated, accelerated to 5 GeV, and injected into the electron damping ring (blue oval). After the particles circle the ring 10,000 times, the ring spits out a compact beam thinner than a human hair, which then travels along a transport line all the way to the beginning of the main electron linac.

Then the electron beam is accelerated along the main linac toward the central region. The electrons pass through an "undulator", which causes them to emit light, and are accelerated further toward the collision point.

The light generated by the undulator hits a titanium alloy target, which leads to the emission of positrons. The positrons are accelerated, sent into their own damping ring (orange oval), and made into compact bunches. Then they travel to the start of the main positron linac. From there, they are accelerated to collide with electrons coming from the opposite direction.