Global ILC Efforts

Designing the International Linear Collider is a global enterprise. Physicists and accelerator experts from around the world are collaborating to design the approximately 25-mile-long machine. A similar effort is under way for the design of the ILC detector, which will record the "subatomic messengers" produced by the collider. *symmetry* talked with six of the hundreds of scientists who are contributing to the collider design.

Lutz Lilje, DESY

Polishing the limits

Photo: Margitta Müller, DESY

For the last seven years, Lutz Lilje, at the German laboratory Deutsches Elektronen-Synchrotron (DESY), has focused on developing the technology to build the core devices of the ILC: high-performance superconducting cavities, used to accelerate particles. Throughout this time, he has been part of an increasingly international effort.

"My entire PhD research depended on international collaboration. It was great," says Lilje, who graduated from the University of Hamburg in 2001. "In the early nineties, the TESLA collaboration at DESY began to bring together the best technologies to improve the performance of these cavities. As a PhD student, I traveled three times to KEK [in Japan], visited CERN many times, and conducted measurements at [the French laboratory] Saclay. The Japanese already worked together with industry, and at DESY, we were going to learn the process."

Cavities are devices that shape the electric fields needed for the acceleration of particles. The idea of building cavities from superconducting material goes back to the mid-1960s. Since then, scientists in the United States, Europe, and Japan have advanced the technology intermittently. In 1990, the late physicist Bjørn Wiik, who was DESY's director from 1993 to 1999, formed the international TESLA collaboration to organize the R&D efforts.

As a PhD student and a member of TESLA, Lilje examined cavity surfaces, which greatly affect cavity performance. Tiny impurities in the material and irregularities in the smoothness of the surface decrease the acceleration efficiency of a cavity. Lilje's research focused on the latest technology to improve TESLA cavities, explored first by scientists at KEK: electropolishing of the surfaces.

"Electropolishing is an important piece of the puzzle," says Lilje. "It is a very exacting technology. It took a lot of effort to learn how to reproduce the Japanese results and to refine the technology with their help."

Today, Lilje is a staff scientist at DESY, and the TESLA cavities consistently produce an acceleration with 25 million volts per meter. DESY will use the technology for the accelerator of its X-ray Free Electron Laser (XFEL), an instrument that will enable researchers in biology, material science, and other fields to study ultrafast processes at the nanoscale.

Together with its partners in research and industry, DESY will produce 1000 superconducting cavities. In contrast, the ILC will require some 20,000 cavities, with design and performance even better than the XFEL cavities.

Lilje, who recently won this year's Bjørn Wiik prize for "outstanding contributions to the advancement of research programs or technical development projects at DESY," now works on both projects, maximizing the synergy between the two. For the XFEL, he is responsible for the frequency tuning of the cavities. For the ILC, he is involved in the Global Design Effort (GDE) to establish a reliable cavity performance of 35 million volts per meter, already achieved by a few TESLA prototypes.

Kurt Riesselmann

Chris Adolphsen, SLAC

Power for cold structures

Photo: Diana Rogers, SLAC

As a postdoctoral fellow based at Stanford Linear Accelerator Center in the 1980s, Chris Adolphsen helped build detector components for the Mark II experiment, which used the world's first—and still the only—large-scale linear collider. He's been in the linear collider business ever since.

Because the Stanford Linear Collider (SLC) didn't operate as smoothly as expected in the beginning, the lab recruited Adolphsen and other postdocs to help find and solve the problems.

"Our motivation was to get enough luminosity from the machine to see collisions in our detector," he says. "The early difficulties in running the SLC forced a lot of innovations."

Adolphsen, now a SLAC staff scientist, has been making those innovations for almost two decades—improving the SLC and developing a next-generation linear collider. Until August 2004, when a physics panel chose "cold" superconducting technology for the ILC, his work focused on the radio-frequency (rf) technology for a "warm" electron-positron collider.

Initially shocked by the cold decision, Adolphsen quickly moved on and turned his skills and experience to designing and testing rf power sources (which operate at regular temperatures) for superconducting accelerator structures. These structures require microwaves with a lower frequency than the warm-technology structures.

To accelerate electrons and positrons to nearly the speed of light, scientists use microwaves at radio frequency to push particles through hollow accelerator structures, known as cavities. Specially-designed rf power sources convert wall-plug power into high-voltage pulses and produce microwaves in klystrons for the particles to ride on.

As head of linac rf systems, Adolphsen is setting up an L-Band Test Stand using 1.3 gigahertz klystrons, which are ideal for the ILC. He hopes his work will help reduce the power and the cost of building and operating the ILC, making the machine more feasible. "The rf power sources account for about one third of the linac construction cost. We want to design rf sources that work efficiently, reliably, and cheaply," he says.

The test stand will examine the couplers that guide rf power into each accelerator structure. "The ILC will have 20,000 structures, with a coaxial coupler for each one," he says. One goal is to understand why the couplers currently need to be seasoned for 100 hours, at great energy cost.

Adolphsen and his colleagues will also use the test stand to experiment on warm accelerator structures, which will be used in the first few hundred meters of the ILC to strongly focus electrons to create the positron beam.

Reflecting on almost twenty years of working with linear colliders, Adolphsen believes SLAC physicists have hard-earned experience that will be valuable in designing the ILC.

"You have to work on a system hands-on to understand operations, to make the machine reliable. That's really what SLAC has to offer," he says.

Heather Rock Woods

Masao Kuriki, KEK

Providing beams for acceleration

Photo: Hiroshi Fukuda, KEK

When Masao Kuriki began his scientific career, his research focused on the particles *exiting* an accelerator. Today, his research interest has shifted in the opposite direction and he studies particle beams *entering* an accelerator.

In the 1990s, first as a PhD student and then as a young postdoc, Kuriki studied the collisions of powerful particle beams with targets at SLAC and at Brookhaven National Laboratory. But for the last six years, Kuriki's research focus has been on accelerators themselves and the properties of the particle beams entering accelerators.

Kuriki, a graduate of Tohuku University, joined KEK's Accelerator Test Facility (ATF) in Japan as a staff scientist in April 1999, working on linear collider R&D. Today, he is the Asian leader for the ILC working group on beam sources, injectors, damping rings, and bunch compressors, and he coordinates the KEK efforts with group leaders in the United States, Europe, and other Asian countries.

"My first job at ATF was to study the stability of the linear accelerator," says Kuriki. "At that time, I did not expect to become the leader of a linear collider working group."

His appointment as the leader of one of the five ILC working groups came in September 2004, when KEK management reorganized its linear collider research in response to the worldwide adoption of the superconducting technology for the ILC.

Kuriki and his colleagues have taken the lead in developing the several-mile-long ILC damping rings that shape the electron and positron beams before their injection into the main linear accelerator of the ILC. The exact length and shape of the damping rings–a circle, a race track, or a dog bone–depends on the performance of the high-speed beam-kicker magnet used to divert particle beams from the damping rings into the main linac. Scientists from four laboratories–KEK, SLAC, DESY, and LLNL (Lawrence Livermore National Laboratory)–are developing the kicker magnet, using the KEK test facility to study magnet prototypes with a beam of electrons.

Kuriki's working group is studying the production of positrons for the ILC. There are two methods under consideration: hitting a target either with gamma rays or with electrons.

"There are pros and cons to each method," says Kuriki, whose group is planning to test the strength of various targets using the KEK-B electron beam. "The result of the experiment will have a strong influence on the decision on the positron source."

Although his day-to-day responsibilities are the technical details of the ILC, Kuriki keeps in mind the larger goals and challenges of the project.

"The driving force behind the ILC is the physics motivation," he says. "The ILC is a huge project and a challenge to society. It requires combining resources and researchers from around the globe. At some point in time, we'll need to collaborate with researchers of other fields, such as philosophers and social scientists, to understand the full impact of this enormous endeavor."

Youhei Morita

Kirti Ranjan, Delhi

Alignment at greatest precision


Photo: Reidar Hahn, Fermilab

As University of Delhi researcher Kirti Ranjan explains his work on the ILC, he speaks so quickly that it's hard to discern where one word ends and the next begins. Ranjan's research gives him more than enough to fill his mind.

Unwilling to limit his research to one area of physics, Ranjan divides his time between particle and accelerator physics. "This mixture of studies has helped me immensely in my research," Ranjan says. "The knowledge of accelerator physics complements the knowledge of particle physics quite well."

In collaboration with colleagues at Fermilab and the University of Delhi, Ranjan investigates ways to keep the electron-positron beam highly focused. This is essential because the ILC's unprecedented luminosity requires a very narrow beam at the interaction point. If even one magnet or radio-frequency (rf) structure is misaligned, the beam will disperse as it travels toward the collision site, resulting in low luminosity.

Perfect alignment is so elusive in high-energy physics that even the best accelerators operate with some degree of imperfection. Quadrupole magnets can rotate, rf structures can shift, and the girders on which the entire structure sits can settle. Ranjan's mission is to curb this imperfection as much as the laws of physics will allow. "Conventional survey and alignment techniques will not be good enough for the ILC," Ranjan says. "Even the smallest misalignments can have disastrous effects on this type of precision instrument."

Ranjan and his group are in the process of incorporating new beam-based alignment techniques to create the world's best-aligned accelerator. Their design uses built-in diagnostics to continually check parts for misalignment, and remote controls to automatically nudge misaligned parts back into place.

Using linear-accelerator software developed at SLAC, Ranjan simulates the best and worst case ILC alignment scenarios. He then develops and tests the steering algorithms that will robotically realign parts within the ILC's main accelerator. If everything works properly, these algorithms will ensure that the beam remains focused and on track as it passes through the ILC's quadrupole magnets.

Identifying the best algorithm is especially difficult because few of the ILC's technical characteristics are currently established—even the configuration of quadrupole magnets has yet to be confirmed. As a result, Ranjan must test each of his steering algorithms on several different designs, searching for the optimal algorithm for each configuration.

"With so many unknowns, the ILC will be immensely challenging," Ranjan says. "But that's to be expected if we want to achieve what's never been done before."

Kelen Tuttle

Deepa Angal-Kalinin, Daresbury

Finding the right angle

Photo: Alexander Kalinin, ASTeC

For about twenty years, Deepa Angal-Kalinin has worked in accelerator physics. Her early career focused on designing and commissioning the first synchrotron light source ever built in India, the Indus synchrotron radiation facility, and designing the second synchrotron light source, Indus-2.

After a year at CERN as a research associate, where she simulated beam instabilities for the Large Hadron Collider, Angal-Kalinin became a senior accelerator physicist at the CCLRC Daresbury Laboratory in the United Kingdom in 2002. There she leads the linear collider accelerator physics design team at the Accelerator Science and Technology Centre (ASTeC). Her team works closely on beam-delivery-system design for the ILC with collaborators from the United Kingdom, United States, and France.

For the design of the TESLA collider, based at the German laboratory DESY, scientists thoroughly investigated the possibility of head-on collisions between the two particle beams. But the head-on approach was dropped due to technological limitations.

To decide on the baseline configuration for the ILC, the beam delivery system working group recommended a hypothetical configuration during the first ILC workshop, held at KEK, Japan, in November 2004. This configuration has the two long accelerator sections directed at each other at an angle of 20 milliradians (mrad). The beams each are split to cross in two interaction regions (IRs): one IR allows beams to cross at an angle of 20 mrad, straight out of the accelerators; and another has the beams diverted to cross at 2 mrad, to allow the nearly head-on collisions preferred by the physics community.

"The 20-millirad design for the ILC is very similar to the NLC design. It is basically done," says Angal-Kalinin, referring to previous work by the Next Linear Collider collaboration, which was based in the United States. "We are now working on a two-millirad solution."

The small crossing angle concept was first proposed by French scientists for the CLIC (Compact Linear Collider) design. The biggest challenge in the 2-mrad design is to deal with the highly-disrupted beams after collision as they pass through the focusing magnets near the interaction point and through other magnets downstream in the extraction line. Because of the small angular separation, the beams are in close proximity, and the immense power of the beams in such a cramped environment creates challenges. As such, the design requirements for optics and magnets are very different from the 20-mrad design. A special task force named SLAC-BNL-UK-France, after the locations of the main partners, is working on this design.

The entire ILC collaboration will compare and discuss the designs in August, when hundreds of ILC scientists from around the world will meet for two weeks in Snowmass, Colorado. Angal-Kalinin will be one of the scientists attending the meeting.

"Our goal is to finalize the baseline configuration with 2 and 20 mrad crossing angles for two IRs and to get detailed feedback from the detector and physics community on this configuration," she says. "This will enable us to finalize the baseline design during the Snowmass meeting."

Kurt Riesselmann

Nikolai Mokhov, Fermilab

Taming the beam

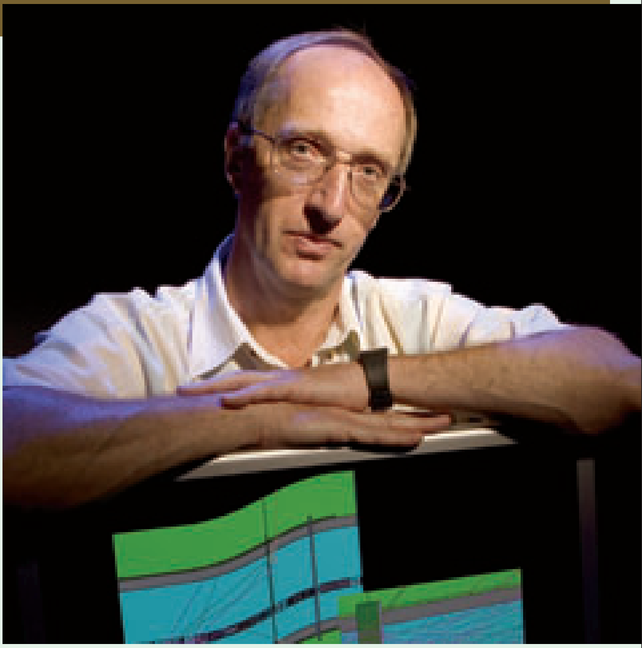

Photo: Reidar Hahn, Fermilab

Fermilab researcher Nikolai Mokhov is a man in demand. As accelerator beam energy and intensity increased sharply over the past few decades, the ability to keep excess particles away from detectors became increasingly important. Leading the field of machine-detector interfaces, Mokhov's research is essential for both today's and tomorrow's accelerators.

"Almost every group at Fermilab and the LHC has asked for my group's help," Mokhov says. But at the moment, Mokhov is consumed with the calculations, designs, and simulations for the ILC's machine-detector interface.

For the ILC, Mokhov's realm of expertise begins 1800 meters from the collision point. Here, his interface design begins to strip away the halo of lower-density particles that encase the high-density beam. Without Mokhov's additions, this halo would obscure detector readings and could even damage quadrupole magnets downstream. For the ILC to work properly, it's absolutely critical to reduce the halo by three to four orders of magnitude.

In computer simulations, this is precisely what Mokhov and his team have accomplished. Mokhov designed a set of metal plates that physically block excess particles, preventing them from continuing toward the collision point where they might interfere with sensitive equipment. By limiting the aperture, these "jaws"–or collimators–will shave off the unneeded particles in the beam halo while allowing the center of the beam to travel on, unimpeded.

While these jaws should successfully remove the beam halo, their interaction with the excess halo particles will create a spray of muons at intensities 10,000 times higher than the ILC's detectors can handle. To protect the detectors against these muons, Mokhov and his collaborators at Fermilab and SLAC are designing 20-meter-thick steel "spoilers" that seal the entire tunnel with a magnetic field. As muons travel through the spoilers–each weighing tens of kilotons–they will be deflected away from the collision site.

"This isn't an elegant solution," Mokhov says. "But it does reduce the muon density that reaches the detectors by four orders of magnitude–enough to mitigate the problem."

Mokhov says that designing collimators and spoilers for the ILC has been especially difficult because of the close proximity of the accelerator components to the detectors. While Fermilab's Tevatron leaves about ten meters between the last accelerator magnet and the detectors, the last accelerator components at the ILC will be inside the detector, only three and a half meters from the collision point. Because an electron beam creates synchrotron photons in a magnetic field, large numbers of these photons will spray directly into the ILC's detector. To avoid this final source of background noise, Mokhov's colleagues designed a second set of collimators and spoilers within the detector to guard against synchrotron photons.

Mokhov's computer simulations show that his team has successfully limited the excess halo particles, muons, and photons to within acceptable limits. Now Mokhov will focus on achieving better than acceptable results.

"The trick now is to suppress these particles to as close to zero as possible to limit detector damage," Mokhov says. Working in collaboration with accelerator and detector designers around the world, Mokhov will help ensure that the ILC's precision studies will be possible in the decades to come.

Kelen Tuttle