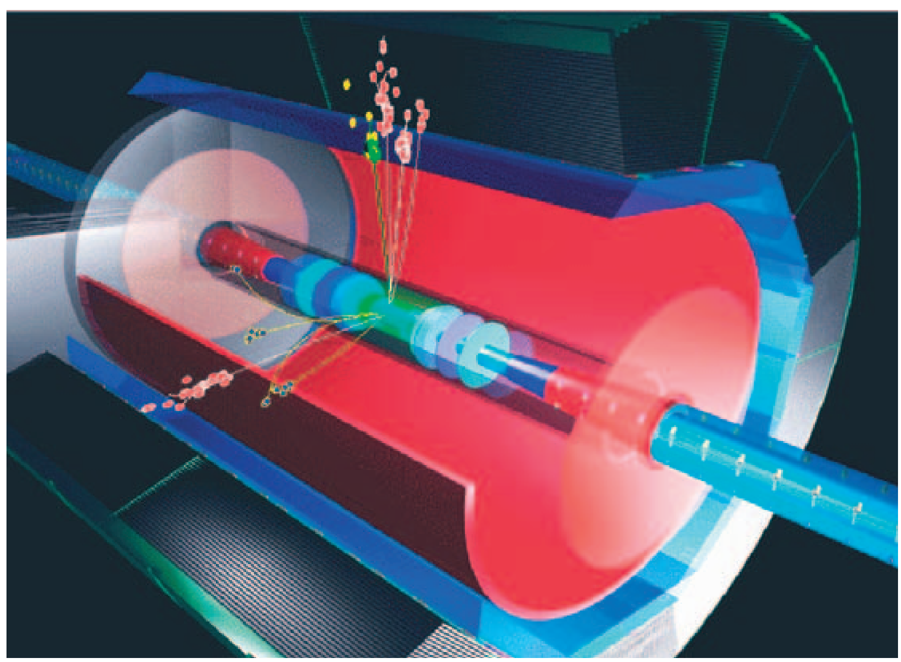
The Linear Collider Detector

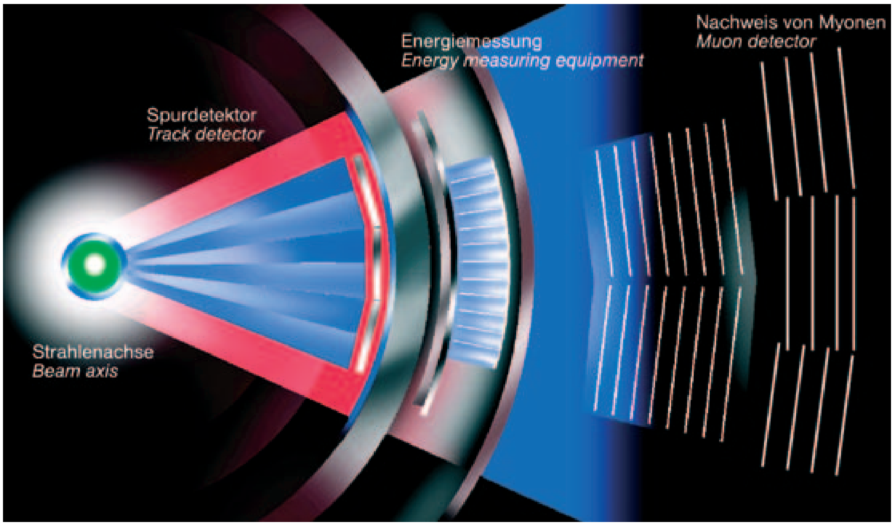
Thousands of Particle Collisions

In a linear collider such as TESLA, electrons and positrons are accelerated toward one another at extremely high energies. At the halfway point, tiny bunches, each containing more than ten billion particles, crash into one another at a rate of around 14 000 times per second. In the event of a frontal collision, an electron and its antiparticle, the positron, annihilate each other and are converted into pure energy. As was the case in the big bang, this collision then gives rise to new elementary particles. Physicists use a piece of equipment called a "detector" to study such reactions. As high as a four-story house and packed with high-technology equipment, this apparatus is located in a hall that descends underground for the equivalent of eight stories. The detector identifies, among a host of different collisions, those in which something really interesting occurs. Such "events" must then be precisely measured.

Regardless of the chosen accelerator technology, the linear collider will employ a so-called universal detector. In principle, it resembles the detectors used at the former LEP electron-positron accelerator at CERN. The detector must enclose the particle collision zone as completely as possible because the particles generated there will fly off in all directions. The detector has various levels of detection equipment, which surround the collision point like layers of an onion. The inner layers are made up of tracking detectors, which measure the tracks left by electrically charged particles. Here, a magnetic field is used to bend the path of the particles, making it possible to determine their momentum. Located adjacent to the beam pipe is the vertex detector, which can precisely determine the tracks and the position (the vertex) of the particle reaction. Next comes a gas-filled tracking chamber, followed by calorimeters, which are essentially used to determine the energy of the parti-



At the heart of the linear collider detector, a range of equipment is used to study particle reactions: a vertex detector (green), tracking chamber (red), electromagnetic calorimeter (blue) and hadronic calorimeter (black). Bunches of electrons and positrons are accelerated toward one another through the beam pipe (blue) before colliding in the center of the detector. The colored tracks and circles represent the results of such a "collision event."



A schematic representation of a detector used in particle physics

cles. The electromagnetic calorimeter measures the energy of electrons, positrons and photons, and the hadronic calorimeter measures the energy of protons, neutrons and other hadrons—i.e., particles composed of quarks. The outer layer is used to detect muons, the only particles able to penetrate all the previous layers of the detector.

"In contrast to the complex proton-proton collisions that take place in the LHC accelerator at CERN, the electron-positron collisions in a linear collider such as TESLA will provide particle physicists with remarkably clean experimental conditions," says Ties Behnke, leading scientist at DESY for the detector project. "This type of collider is therefore ideally suited for high-precision measurements." In order to ensure that such a facility performs to its full potential, the linear collider detector itself must be optimized to this extreme degree of exactitude. Indeed, development engineers working on the detector project will have to break new ground before such sensitivity can be achieved.

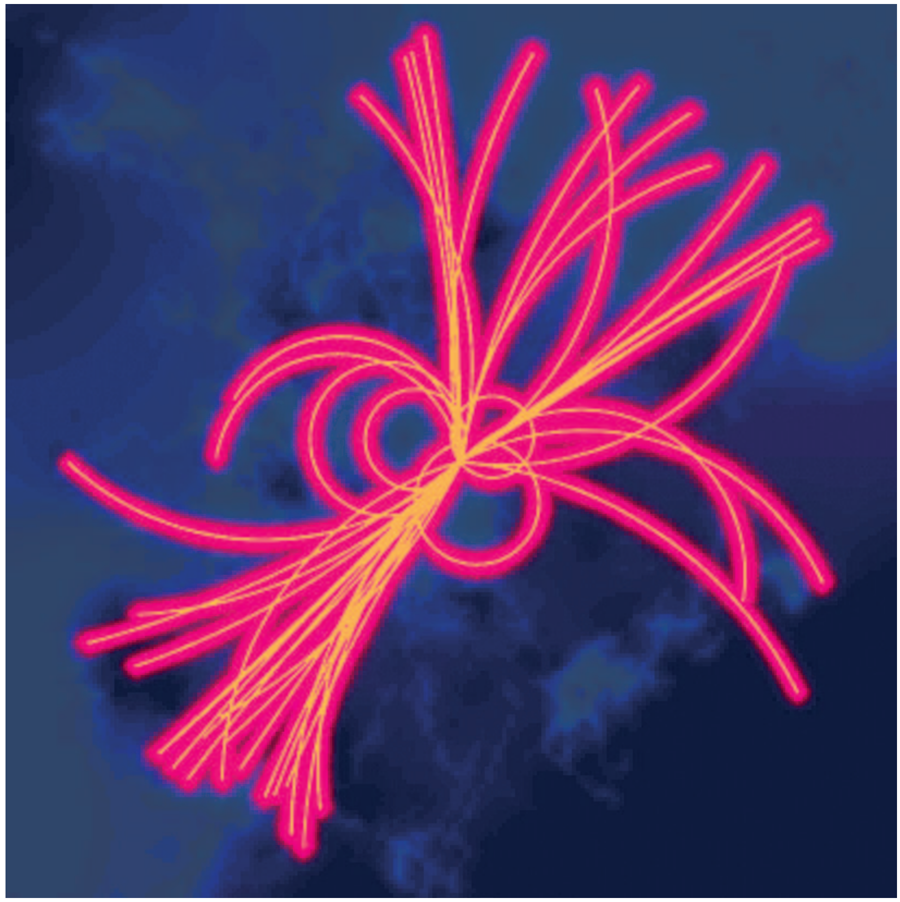
"Two major challenges are the vertex detector and the calorimeter," says Behnke. "In particular, the technology required for the vertex detector will represent a real quantum leap." This innermost component of the detector must enclose the collision zone as tightly as possible. For this reason, the materials used must be highly resistant to radiation and provide a high resolution. Indeed, in order to measure the particle tracks with the requisite precision, the detector must possess exceptional spatial resolving power. In effect, this means being able to determine the point at which the particles penetrate the individual layers of the detector to within a few thousandths of a millimeter. The vertex detector will consist of five layers, which together will ensure that the spatial coordinates of the particle tracks can be clearly identified.

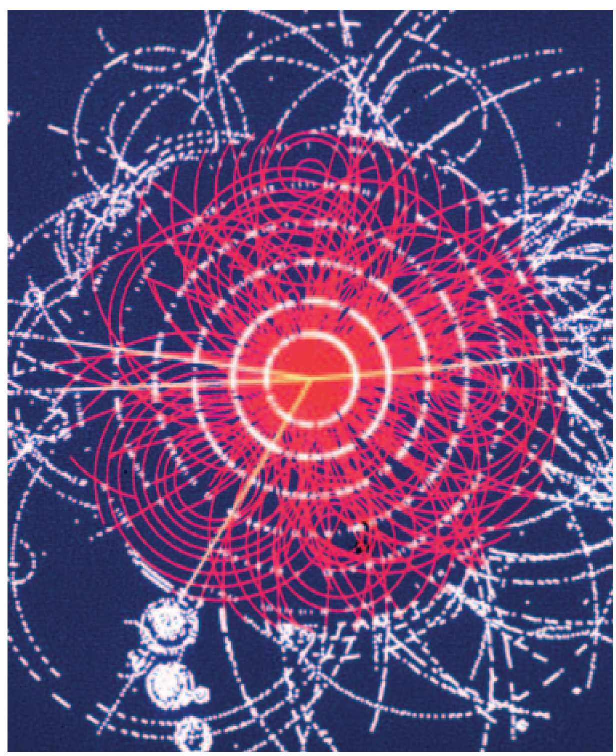
Ensuring that the clean experimental conditions offered by the linear collider can be fully exploited requires a detector that can provide a picture of the particles generated during collisions that is as complete and detailed as possible. This involves tasks such as recording exactly how the particles fly away from the collision zone, determining what direction they take and measuring the energy they carry away in their flight. "It will also mean having a calorimeter far superior to anything currently in use," explains Behnke. "For example, it will have to be divided into especially fine segments that can be read out individually, so that we can clearly distinguish particles that are flying close to one another."

The size of these segments will be about 100 times smaller than in any existing equipment. Similarly stringent parameters are also required for the central tracking chamber, which must be able to record the particle tracks with an accuracy ten times greater than has previously been possible.

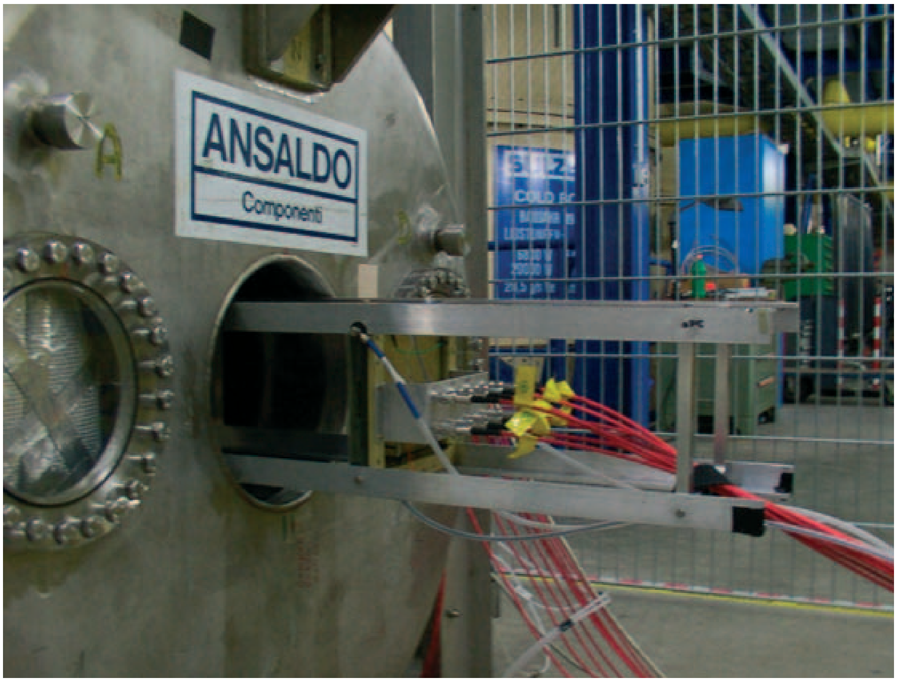
Today, at various locations around the world, a number of international groups are working on a range of projects for the new linear collider detector. For instance, an English team and a group from France, Germany and Great Britain are working on two different designs for the vertex detector. Fifteen institutes from Canada, Europe and the United States have joined forces in a network to produce a workable proposal for a time projection chamber (TPC). At the same time, work on the calorimeter is being conducted by a group from Italy and one from the Commonwealth of Independent States, the Czech Republic, France, Germany, Great Britain, South Korea and the United States. Meanwhile, DESY itself is running a number of development projects connected to the TPC and the hadronic part of the calorimeter. "The development of the detector has attracted substantial interest worldwide," Behnke emphasizes. "And what's particularly positive about the project is that the development work is taking place on an international level and independently of the various accelerator projects around the world. In other words, we're preparing for a time when all physicists will work together on one accelerator."

The detector will also feature a new method of selecting individual particle reactions for recording. "Unlike the LHC, where the majority of events merely consists of uninteresting background, the particle reactions generated in a linear collider like TESLA are so clean that almost every one of them is of scientific interest," Behnke reports. Instead of having to select interesting particle reactions according to specific criteria as they appear in the detector—a





A computer simulation shows the decay of a Higgs particle in an electron-positron linear collider like TESLA (above) and in the LHC collider at CERN (right). In contrast to the complex proton-proton collisions in the LHC, the electron-positron collisions in the linear collider will provide remarkably "clean" experimental conditions.



A major step forward for the development work for a linear collider detector: At the beginning of 2003, an international team successfully commenced a series of test measurements for the time projection chamber (TPC) at DESY. The strong magnetic field required for testing was generated by a superconducting magnet that was removed from the ZEUS experiment in the course of the upgrade of HERA. The magnet (left, within the cryostat, which houses the TPC) was then installed in the DESY refrigeration hall. Operating at a current of 1000 amperes, the magnet instantly generated a magnetic field of 5.25 teslas, which is suitable for the TPC test series. The purpose of the TPC is to measure the tracks left by electrically charged particles. It is operated within a strong magnetic field in order to determine the momentum of the particles. In particular, tests were conducted of readout operation using gas electron multipliers, which offer very good spatial resolution of the particle tracks. However, these components still require further development before they can be operated in a magnetic field of four teslas, as is intended with the new linear collider detector. In the months that followed, scientists from a variety of institutes participating in the international linear collider TPC group installed their test chambers for further measurements within the superconducting magnet.

procedure that means the detector is subject to “dead” time intervals during which it is not delivering results—scientists can rely on the enormous progress in computer technology to directly record all the events occurring at the linear collider. Afterward, the data can be filtered by computer according to specific selection criteria.

“Three years ago, people were highly skeptical when we first proposed this idea for TESLA,” Behnke says with a grin. “Today, the Americans and the Japanese are planning to follow the same procedure in their proposals for a linear collider.”

All in all, the detector for the linear collider will be around 50 percent larger than the ones used for the H1 and ZEUS experiments at HERA. Nevertheless, it will still fall far short of the massive dimensions of the LHC detectors. There’s a simple reason why detector equipment increases in size with each new accelerator: The latest ones produce particle collisions of ever higher energies. “If you installed an unmodified LEP detector in TESLA, it would work in principle. However, a large part of the energy would leak through the detector, which isn’t thick enough for the particle energies that TESLA will generate,” Behnke says. “For that reason, you wouldn’t get any meaningful measurements.” Of course, the ultimate size of the detector is a question not only of technological progress but also of cost. Here, too, scientists and engineers will be looking to devise an optimal solution in the next few years.