Without fanfare, 600 Russian scientists in Geneva are playing key roles in building Europe's Large Hadron Collider. Some say their work there could prove the salvation of high-energy physics back home

CERN Link Breathes Life Into Russian Physics

GENEVA—Beneath a birch and pine forest south of Moscow, a vast circular tunnel lies haunted by unfulfilled dreams. There, just outside the town of Protvino—a community created for physicists at the height of the Cold War—the Soviet Union in 1984 began building the UNK, a device that promised to be the world's most powerful machine for smashing together protons. Within months, technicians had readied most of the magnets and other equipment needed to keep protons zipping around a ring and to track showers of particles spawned by 800 million collisions every second. Then *perestroika* ushered in political freedom—and led to an economic free fall that brought the UNK to a screeching halt. The project's demise sounded a death knell for the idea that any one country could push back the frontiers of high-energy physics on its own.

Fifteen years later, Russian high-energy physicists at last have a chance to wash away the bitter taste left by the moribund UNK. They are working en masse on the $1.5 billion Large Hadron Collider (LHC), a machine that will explore fundamental questions such as why particles have mass, as well as search for exotic new particles whose existence would confirm supersymmetry, a popular theory that aims to unify the four forces of nature. Next month, engineers here at CERN, the European particle physics laboratory, will begin hauling out the existing particle accelerator from the 27-kilometer-long tunnel under the French-Swiss border, and over the next 5 years they will assemble the LHC and its massive detectors for tracking debris from subatomic collisions. Although Russia is not one of CERN's 20 member states, most top high-energy physicists in Russia are working on the LHC. "We couldn't do the LHC without them," says CERN research director Roger Cashmore.

Indeed, CERN and Russia need each other. The European lab has kept Russia's vaunted high-energy physics research afloat. "Collaboration with CERN has become essential for the existence of high-energy physics in Russia," says Vitali Kaftanov, deputy director of the Institute of Theoretical and Experimental Physics (ITEP) in Moscow. And with the LHC, CERN has ventured into Russia's once-secret nuclear weapons labs, where scientists are making key components of the LHC's two main detectors, CMS and ATLAS, at bargain prices.

A hole in the Iron Curtain

CERN's close ties with Russian scientists formed in the early 1960s, when the Soviet Union allowed Kaftanov and a handful of other physicists to work at CERN for months at a time. "High-energy physics punched a hole in the Iron Curtain," Kaftanov says. At first the hole was large enough only to let the scientists through; their families couldn't join them at CERN. "My wife and son were in Moscow, like hostages," Kaftanov says. It took a year for CERN's director-general at the time to persuade the Russian authorities to relent.

Low tech ... Russian contributions to the LHC include melting down artillery shells to make brass components.

It wasn't just a one-way street from Russia to Geneva, however. In the 1960s, the Institute of High Energy Physics (IHEP) in Protvino built a collider that attained 70 billion electron volts (GeV). At the time, CERN and the United States each had only a 30-GeV machine. With superior firepower available in the Soviet Union, CERN and Russia in 1967 signed a major agreement on scientific exchange that allowed CERN researchers to work in Protvino on the 70-GeV machine, which was revved up that December. Several dozen physicists from CERN and the French Saclay lab and their families lived in Protvino for the next 5 years, where they even established a French-language schoolroom for their children, while Soviet scientists, families in tow, took up residence at CERN. The collaboration survived even as the Soviet Union was drawing condemnation for its brutal suppression of protesters in Czechoslovakia during the "Prague Spring" of 1968. People "understood that punishing physicists would not improve the political situation," Kaftanov says.

In 1975 the focus shifted to CERN, with the completion of the 450-GeV Super Proton Synchrotron (SPS) accelerator. Besides doing research, Soviet scientists contributed an important SPS experiment, a photon spectrometer that melded existing technology for spotting subatomic collisions—the bubble chamber—with cutting-edge electronic tracking.

Soviet scientists worked at other facilities as well, including the Fermi National Accelerator Laboratory (Fermilab) near Chicago, Illinois, but their connection with CERN was always strongest. "CERN has always been much more active in reaching out to Russia," says IHEP's Sergei Denisov, who notes that a U.S. Department of Energy–Russia Ministry of Atomic Energy committee on high-energy physics has been "rather passive." After the Soviet Union invaded Afghanistan in 1979, scientific exchange between Soviet institutes and Fermilab practically ceased for awhile, Denisov says.

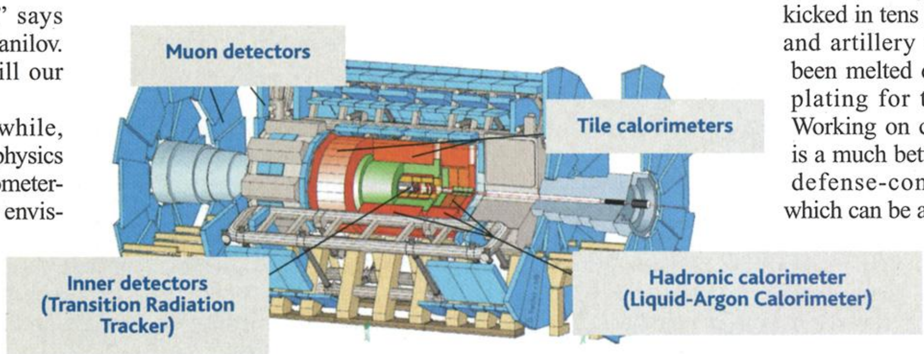
By that time CERN had begun designing the Large Electron-Positron collider (LEP) and its associated experiments, including the fabled hunt for the Higgs boson (*Science*, 22 September, p. 2014). It soon became apparent that the largest planned detector, the L3, would require about 12 tons of extra-pure bismuth germanate crystals. These crystals scintillate when particles strike them; photodetectors convert the tiny fireworks displays

CREDIT: PETER GINTER PHOTOGRAPHY

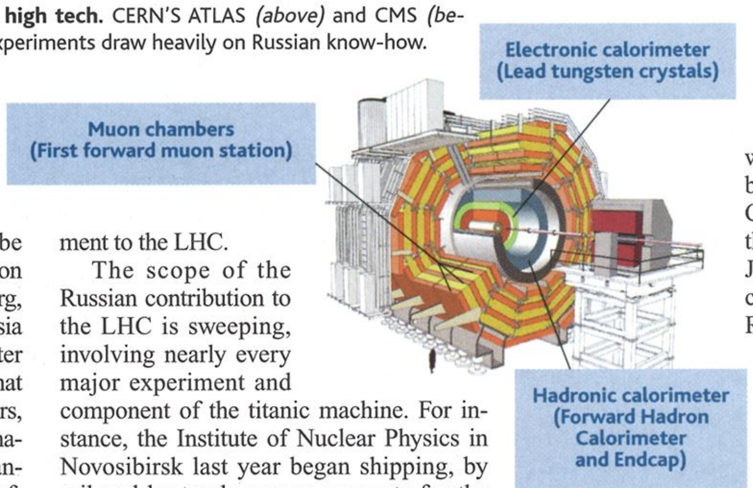
into electrical signals. Only a few cubic centimeters of this crystal had ever been produced before. In the end, the Soviet Union laid Cold War mistrust aside and shipped 5 tons of germanium oxide, an ingredient used in making crystals for missile-guidance systems, to China, which had the only institute in the world capable of churning out 11,000 bismuth germanate crystals quickly and cheaply enough to keep the project on schedule. "Everything from Russia was delivered on time," says ITEP director Michael Danilov. "We never failed to fulfill our obligations."

The Russians, meanwhile, were hoping to chart new physics territory with their 21-kilometer-long UNK collider. They envisaged a two-stage project. The first-generation collider would use so-called warm magnets capable of busting up protons at energies topping out around 600 GeV. In the meantime they got to work designing superconducting magnets for a second machine that would be five times as powerful, smashing protons together at 3 trillion electron volts (TeV). But as the research and development phase of the project dragged on, the scientists had no idea they were about to be steamrolled by *perestroika*. "The preparation period was too slow," says Nicolas Koulberg, adviser to CERN's director-general on Russia and Eastern Europe. "It was a real disaster for them." Looking back, Denisov says that "if *perestroika* had been delayed a few years, I'm sure we would have had a 600-GeV machine." And if the Russians had ever managed to realize their full UNK design, Kaftanov says, "the LHC would have been much less interesting."

Beaten by the economy, the Russians "realized that the only way to stay at the frontier was to work at CERN," says Koulberg. Shortly after the Soviet Union dissolved in 1991, he says, the mercurial former CERN director-general Carlo Rubbia "decided to test the Russians in a more complicated way." CERN wanted to see whether the Russian scientists could enlist their struggling industry to mass-produce components for the LHC, then in early planning. "They started as a full partner in the LHC from the beginning," Koulberg says.



... and high tech. CERN'S ATLAS *(above)* and CMS *(below)* experiments draw heavily on Russian know-how.



Swords into plowshares

As CERN was getting ready to bring Russia aboard on the LHC, Russian high-energy physicists were struggling for survival. "The high-energy-physics community managed to convince the Russian government that there were only a few places in the world where you could build an accelerator," says Danilov. Russia was not one of those places, so Danilov and his colleagues had to persuade their cash-starved government to fork out millions of dollars for a project based in wealthy Switzerland. Luckily, they had an ally in then–Science Minister Boris Saltykov, who in 1993 signed an agreement with CERN pledging a major financial commitment to the LHC.

The scope of the Russian contribution to the LHC is sweeping, involving nearly every major experiment and component of the titanic machine. For instance, the Institute of Nuclear Physics in Novosibirsk last year began shipping, by rail and by truck convoy, magnets for the transfer lines that inject protons into the LHC, where they will collide at energies reaching 14 TeV. Several Russian institutes are also contributing major elements of the two biggest experiments: the Compact Muon Solenoid (CMS), which will be the world's biggest silicon device, and the 20-meter-high ATLAS, a tortuous acronym for "A Toroidal LHC Apparatus" (see diagram). All told, Russia will contribute about $75 million worth of hardware to the LHC.

Some of this equipment is coming from an unlikely source: Russia's deteriorating military-industrial complex. Working partly with grants from the International Science and Technology Center, a Western-funded agency that supports defense conversion in the former Soviet Union, CERN has brought some 30 physicists at Russian weapons labs into the LHC fold. For example, IHEP scientists found that the Bogoroditsk Techno-Chemical Plant—a factory 100 kilometers from Protvino involved in Russia's "Star Wars" missile defense effort—can produce the lead tungstate crystals needed for the CMS's electromagnetic calorimeter, which will measure the trajectories of particles that interact by the electromagnetic force. CERN has contracted with the plant to make 40,000 of the transparent, pyramid-shaped crystals. "Nobody else can provide crystals of this quality at this price," Kaftanov says. And the Russian Navy in Murmansk has kicked in tens of thousands of rifle and artillery shells, which have been melted down to make brass plating for the CMS detector. Working on cutting-edge physics is a much better option than other defense-conversion projects, which can be as prosaic as converting factories from making bombs to making refrigerators. "It's a way for them to have dignity as scientists," says Koulberg.

But the Russian presence extends far beyond designing and building hardware, most of which is being produced by the CERN member states, the United States, and Japan. "The intellectual contribution of the Russians is most important," Koulberg says. These days, he says, as CERN tests LHC component prototypes and runs simulations, "when you come in on a Sunday, essentially you only see Russians here." Indeed, Denisov adds, "it's often easier to meet a Russian colleague at CERN than in Russia."

Having Russia play such a high-profile role in the LHC carries a risk: CERN is gambling that the Russian economy will remain stable enough to allow the country to deliver its hardware on time and maintain its 600-strong army of physicists at CERN, most of whom are paid by the Russian government. "We would be in deep trouble if the Russians pulled out," CERN's Cashmore says. "We would have to do major rethinks on experiments and designs, and it's too late for that."

A dying discipline?

The LHC connection has kept many top-flight Russian scientists at the forefront of high-energy physics. But the discipline in Russia isn't out of the woods. Indeed, some

Bulgarians Sue CERN for Leniency

SOFIA—To most nations, $700,000 a year may seem a pittance for a piece of the action at CERN, the European particle physics laboratory near Geneva. But in cash-strapped Bulgaria, scientists are wondering whether a ticket for a front-row seat in high-energy physics is worth the price: It nearly equals the country's entire budget for competitive research grants. Faced with that grim statistic and a plea for leniency from Bulgaria's government, CERN's governing council is considering slashing the country's membership dues for the next 2 years. Such a move might salvage Bulgaria's participation in CERN, but it may not quell discontent among Bulgarian scientists who argue that other research areas would still get the short end of the stick. And Bulgaria's woes almost certainly have dashed Romania's hopes of joining the elite club this year.

For dues-paying nations, CERN membership has its privileges. Their companies are eligible to bid on CERN projects, for instance, while their scientists get a voice in CERN decision-making. That certainly appealed to Bulgaria, which by 1998 thought it could afford to have its high-energy physics community join CERN. Lab officials agreed to let Bulgaria in if, from the get-go, it paid the full dues (determined by a formula based mainly on member nations' gross domestic product), rather than ramp up contributions as the Czech Republic, Hungary, Poland, and Slovakia were allowed to do a few years ago. Bulgaria agreed, and in June 1999 it became the 20th member state.

"CERN membership is a good investment in the future of the nation," says Roumen Tzenov, one of three dozen Bulgarian scientists now working at the lab. Among other things, he and his colleagues have helped develop key components for the planned CMS detector of the Large Hadron Collider, slated to come on line in 2005.

But trouble began brewing even before Bulgaria formally joined CERN. The NATO bombing campaign against Yugoslavia in spring 1999 destroyed enough bridges to cripple commerce between Bulgaria and Western Europe on the Danube River—hurting Bulgaria's economy and squeezing the government's budget. CERN officials are sympathetic to Bulgaria's plight. "Bulgaria suffered a lot," says Nicolas Koulberg, who advises CERN's director-general on Russia and Eastern Europe. "It became clear that the science ministry would have to pay CERN a big part of its budget." Indeed, Bulgaria's National Science Fund—an agency recently disbanded—last year doled out only about $500,000 for grants in the natural and social sciences, and the government is expected to spend much less this year. Biologists complain that a typical grant amounts to less than $1000 a year.

To many Bulgarian scientists, forking over to CERN the kind of money that would fund hundreds of research projects at home doesn't seem like a bargain. "There is great opposition to CERN membership," says George Russev, who directs the Bulgarian Academy of Sciences' Institute of Molecular Biology. In a recent letter to Bulgaria's education and science minister, Russev and others on the former Science Fund's council called on the country to pull out of CERN and use the money for domestic research.

Facing a rebellion at home, Bulgaria's vice minister for education and science, Christo Balarew, last month petitioned CERN to cut his country's membership fees substantially for the next 2 years. He told *Science* that CERN plans to send a delegation to Sofia this fall to discuss the financial problems and the extent of the proposed fee reduction.

Suffering collateral damage in this dispute is neighboring Romania, which has made a strong bid to join CERN. Lab officials are now worried about Romania's R&D balance sheet—and they admit that Bulgaria's woes have influenced their judgment. "If Bulgaria was all right, Romania probably would have been accepted this year," says a CERN official, who adds that Romania's application is now on hold until at least 2001.

If the CERN council votes in December to cut Bulgaria some slack, that may very well save the lab's latest member state from an ignominious withdrawal. But it is unlikely to fully assuage critics such as Russev. "Even if we pay lower CERN fees for 2 years," he says, "the problem is that the membership is not useful to the rest of Bulgaria's science community." —**ROBERT KOENIG**

With reporting by Richard Stone.

argue that it is dying. "That's very close to the truth," says Kaftanov, who points out that nearly all topflight experimentalists and many theoreticians now spend most of the year abroad. Others insist that the brain drain is only temporary and that most of the scientists haven't permanently emigrated from Russia. "In principle, the Russians return to their home institutes," Koulberg says. And even older facilities like the 70-GeV accelerator in Protvino can still do good science, Denisov says. It now operates for two 2-month stretches a year, running experiments that are hard to do at higher energies, such as searching for exotic resonances and exploring kaon decay. During the experimental downtime between LEP being shut down next month and the LHC being switched on in about 5 years, Denisov says, "I hope we'll have more physicists from Europe coming to Protvino."

Key component. Dipole magnets for the LHC came from a plant in Novosibirsk.

Everyone agrees that the gravest concern lies with grooming the next generation of physicists. A couple of years ago, a few legislators were agitating to close down the prestigious Moscow Physical Technical Institute. The problem was that upon graduation, about four out of five students get offers from Western labs and leave. "People were crying that we were only preparing students for careers in the West," Kaftanov says. That threat has gone away for now, but there remain worries about keeping physics alive in Russia. The trend is so alarming that the country's top physicists and institute heads are now discussing holding a review sometime next year of the future of Russian high-energy physics. Tops on the agenda will be survival after the LHC.

In that regard, Russian scientists haven't ruled out bringing to life their unfinished giant in Protvino. To equip the UNK to its full 3-TeV glory, Denisov estimates, would cost about $1 billion—a sum twice as great as Russia's total science budget. They won't see that anytime soon, but finishing the 600-GeV ring—even after the LHC is up and running—would be reasonable, Denisov argues, because a scaled-down UNK could be used as a fixed-target accelerator for studies on B quarks and neutrinos. But well into the next decade, at least, the Russians will find nurturing environs at CERN, their home away from home. —**RICHARD STONE**

CREDIT: CERN GENEVA