INSTITUTIONAL PROFILE

Gran Sasso: Particle Physics Without Mountains of Money

Entering Italy's newest physics lab is not exactly stepping onto the set of a James Bond film. Still, the 3-mile drive through a mountain tunnel, the barely visible entrance in the tunnel wall, the checkpoint and security booth, the giant underground caverns, and the 15-foot steel doors are enough to inspire a double-take. This is not a movie set, though. It is the Laboratori Nazionali di Gran Sasso (Gran Sasso National Laboratories), the largest underground scientific facility in the world—and an ingenious, low-budget model for how particle physics, the emblem of "big science," can be done in an era of stagnant scientific budgets.

For more than 60 years, progress in particle physics has gone hand-in-hand with more and more powerful particle accelerators, which have allowed experimenters to create and observe subatomic phenomena that only appear at high energies. Now the accelerator era may be drawing to a close. The U.S. Congress is close to aborting the largest and most expensive machine currently in the works, the Superconducting Super Collider (SSC), which carries a price tag estimated at $11 billion. The House has already voted to kill the project; its fate now rests with the Senate. In such a hostile environment, only the naive would dream of building yet another big machine. So hard-headed particle hunters must look for ways to observe high-energy phenomena at lower cost.

And as they do, they might look a mile beneath the Appennine Mountains, the chain that courses down the spine of Italy, at Gran Sasso. In the early 1980s the Istituto Nazionale di Fisica Nucleare (the National Nuclear Physics Institute, or INFN) saw a unique confluence of scientific and political opportunity beneath these peaks that would allow the agency to create a first-rate physics facility. Says INFN director Nicola Cabibbo: "It was a very good, very clever thing to do. We can't afford to rival CERN [the giant pan-European physics lab in Geneva] in particle accelerators. We did this instead."

The scientific opportunity revolved around an unusual rock formation at Gran Sasso that screens out the background radiation from cosmic rays that would otherwise play hob with sensitive experiments. The political opportunity involved a controversial government plan to build a highway under the mountain chain. By adroitly linking the lab to the highway project, physicists lent the plan prestige and garnered government support in return. Gran Sasso, the happy result of these manuverings, is now tackling one of physics' most pressing issues: the detection and analysis of solar neutrinos, elusive particles that must be found in sufficient numbers to prevent researchers' understanding of solar fusion—and, by extension, fusion in general—from being proved wrong.

Yet while Gran Sasso may represent part of the future of physics, it isn't the whole future. Without accelerators, experiments at the lab are exceedingly unlikely to detect some of physics' other "most wanted particles," such as the never-seen top quark. In addition, the lab is built around the principle of waiting for natural phenomena like neutrinos to come to it, rather than going out and creating high-energy events the way accelerators do. And that makes the whole enterprise a gamble. "You sit there and stare and wonder if you're going to ever be lucky," says one U.S. physicist who has worked in a similar situation and not enjoyed the experience. Nevertheless, some physicists say their field could use more labs like Gran Sasso, which exploit every quirk of nature to do particle physics on the cheap.


CHIOLINI

Digging for answers. Designers of Italy's Gran Sasso lab excavated tunnels to house solar neutrino experiments.

A mountain of opportunity. Gran Sasso began in the mind of Antonino Zichichi, an effusive experimenter whose newspaper articles, television appearances, and flamboyant public lectures have made him a household name in Italy. Zichichi has a photogenic mane of white hair, a long brown leather cloak which he theatrically flings off prior to mounting a podium, and an unbridled imagination that infuriates his more cautious colleagues. Although other European physicists sometimes regard him as a self-promoter, few doubt his effectiveness in the arena where science, politics, and funding meet. When Zichichi became president of INFN in 1979, its budget was 20 billion lira ($12.5 million, at today's exchange rate) per year; 6 years later, when he left, it was 200 billion lira.

Zichichi constantly shuttles back and forth between Bologna (where he is a professor), Sicily (where he runs a series of international postdoctoral schools), Geneva (where he works at CERN), and Rome (where INFN is based). As a consequence, he spends a lot of time in the air. And it was in the air that he first envisioned building a major physics lab below ground.

Flying from Geneva to Rome in early 1979, he happened upon a newspaper article about a new highway to connect Rome in the west and the Adriatic coast to the east. The highway project involved cutting a 6.5-mile (10.4-km) tunnel through the Appennine Mountains, beneath a group of peaks known collectively as Gran Sasso (a hard-to-translate name that means something like "Great Rock"). According to the article, the project had touched off a furor. Proponents saw it as a key piece in the development of the Abruzzi, the relatively poor region east of Rome; critics attacked the highway as a porkbarrel project that would do little more than funnel more tourists to congested Adriatic beaches.

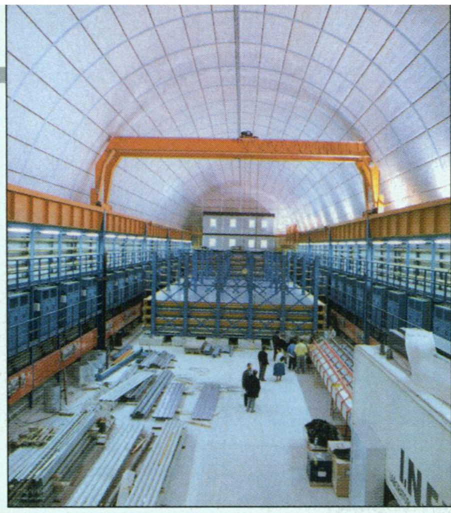
Few other readers of the article, it is safe to say, reacted by smiting their brows and thinking of particle physics. But Zichichi realized that the fight over the tunnel could have implications for testing the then-new Grand Unified theories of physics, which claimed to weave most of the fundamental forces in the Universe into a single theoretical package. The principal experimental test of grand unification was its prediction that the proton, previously thought to be absolutely stable, could experience a process akin to radioactive decay. But proton decay was predicted to occur so infrequently that, in ordinary circumstances, its effects would be swamped by the background cosmic radiation that permeates the universe. Detecting it would be as futile as trying to make out a whispered conversation at rush hour in Grand Central Station.

The cosmic ray background could be reduced, however, if the experiments were performed deep underground, where most of the radiation has been absorbed by Earth's crust. Indeed, as Zichichi well knew, several such efforts were already under way, in mineshafts and other places. But a lab beneath Gran Sasso, he thought, could go these experiments one step better. The reason: Appennine geology. Like all mountain ranges, the Appennines were formed by the clash of tectonic plates and the concomitant uplifting of geological layers. Usually the layers fracture in the process, and the fissures fill with uranium-containing material from Earth's lower crust. But unlike most other mountains, Gran Sasso is almost devoid of such fissures. The mountain was created from Mediterranean limestone that folded in smooth, unbroken curves. The proposed highway tunnel would pass through one of the most radiation-free expanses of stone in the world—a perfect environment for experiments requiring low background. And placing a big, well-appointed underground lab right right next to a superhighway had yet another advantage: Experimenters could simply truck in their equipment rather than squeeze it down a mine shaft, as many of the other groups that were trying to detect proton decay were forced to do.

Mixing science and politics. Soon after his plane landed in Rome, Zichichi began his sales campaign with a telephone call to Romeo Ricciuti, president of the Abruzzi. Not only would the lab be relatively cheap, Zichichi said, but it could augment Ricciuti's political capital. An international laboratory located in a neglected part of Italy signaled that the controversial highway would bring something besides tourism to the region, and the scientific prestige would repel charges that the highway was a porkbarrel project. Ricciuti was enthusiastic. "The lab helped Ricciuti find support for the highway," Zichichi says, "and he in turn helped me find support for the lab."

To other politicians, Zichichi argued that the project amounted to a unique opportunity for Italian science. "Contrary to popular opinion abroad, Italian political leaders are mostly very smart," Zichichi says. "If you present them with a good enough opportunity, they won't turn it down. Now, Italy is a small country. We cannot afford to do everything. What I proposed was that we concentrate what we have in a few areas—but the right areas. And the underground laboratory was the right area, because Italy could have the largest and best underground laboratory in the world."

The blandishments were successful. The project, consisting of three experimental halls with a network of interconnecting passages, was authorized in February 1982. Excavation at Gran Sasso began almost immediately—though it was blocked for a day by members of a radical Green group who were fearful that something "nuclear" was happening inside. (They relented when Zichichi raced to the scene and explained the aims of the lab.) By 1987, scientists were installing equipment; today, several major experiments are under way, and the lab has an expansion project involving two new tunnels and a separate entrance shaft to make lab access independent of the highway tunnel. That shaft is now near completion after a considerable delay, the construction company having become embroiled in the roccoco kickback scandal that is currently traumatizing Italy. The total cost of the lab: about $75 million.



LUCIO DI GIUSEPPE

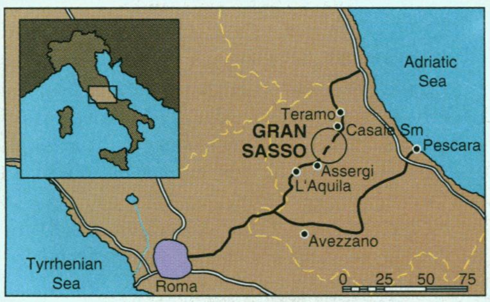
In the hall of the mountain lab. Gran Sasso's experiment halls, such as this one, were built to hold low backround radiation experiments.

A shift in priorities. Eight years from airborne vision to functioning laboratory is remarkable for high-energy physics, where experimenters can spend half their careers waiting for machines to be built. Still, it is a long stretch of time, and over time research priorities can change as new information becomes available. At Gran Sasso, the experimental program underwent dramatic changes just as construction began, because the search for proton decay, the lab's principal scientific inspiration, suddenly became unfashionable.

"When the lab was first proposed," Cabibbo says, "the main idea was proton decay. That was considered the hottest thing to do. It looked like proton decay experiments could tell us about Grand Unification." The prospect of a definitive Gran Sasso proton decay experiment was a major factor in the lab's support in the physics community, and ICARUS, a proton decay experiment using a liquid argon detector, was one of Gran Sasso's first planned projects. But within a few years, experiments in the United States, Japan, and India established that proton decay, if it exists, is extremely difficult to detect, no matter how well shielded the laboratory is. Enthusiasm for proton decay experiments waned; ICARUS, which had not yet been built, effectively went on stand-by.

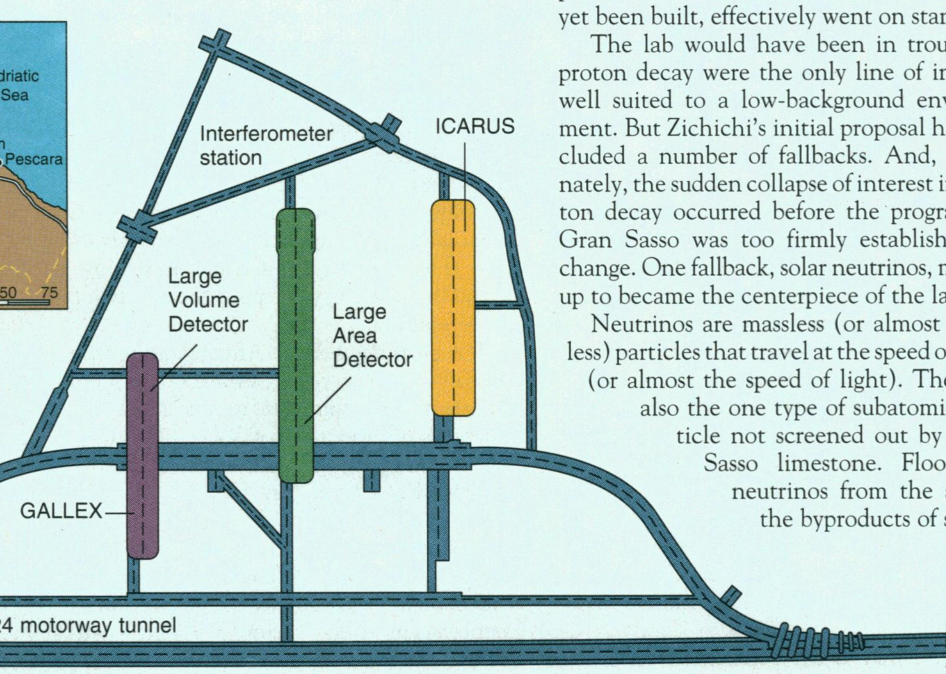
The lab would have been in trouble if proton decay were the only line of inquiry well suited to a low-background environment. But Zichichi's initial proposal had included a number of fallbacks. And, fortunately, the sudden collapse of interest in proton decay occurred before the program at Gran Sasso was too firmly established to change. One fallback, solar neutrinos, moved up to became the centerpiece of the lab.

Neutrinos are massless (or almost massless) particles that travel at the speed of light (or almost the speed of light). They are also the one type of subatomic particle not screened out by Gran Sasso limestone. Floods of neutrinos from the sun—the byproducts of stellar



SOURCE: INFN ILLUSTRATION: DAVID M. PRZEWLOCKI

A unique location. Italy's foremost physics lab sits along an underground highway.



fusion—pour through every spot on Earth, including the laboratory's three big experimental halls. For almost two decades, scientists at other laboratories have been trying to detect the flow of solar neutrinos and compare it with the flow predicted by the conventional theory of solar fusion. But they could only detect about one-third of the number of neutrinos that were—in theory—supposed to be there. Past attempts to reconcile the large disparity had been plagued by, among other things, background radiation in the facilities attempting the reconciliation. Gran Sasso wouldn't have such problems.

"By about 1982," Cabibbo says, "the solar neutrino problem came along, and solar neutrinos soon became more promising than proton decay." The lab, he said, was in an ideal position. The question was so wide open that "any result" by the first experiments on line, "would have been interesting."

> **"In an era of short money you have to have a real balance between accelerator and non-accelerator experiments."**
> **—Burton Richter**

Fighting for low background. With their equipment now turned toward the sun, experimenters at what Zichichi calls "the laboratory of cosmic silence" soon discovered that cosmic noise kept intruding on their radiation-free peace and quiet. In fact, although Gran Sasso was chosen as a haven from background radiation, almost every experiment undertaken there has been troubled by it. For instance, although the limestone in Gran Sasso emits fewer neutrons than any other geological formation ever measured, Enrico Bellotti, the lab's first director, was horrified to discover that the water coursing through Gran Sasso limestone is full of dissolved radon gas, a source of intense radioactivity that would produce exactly the kind of background that Gran Sasso was supposed to screen out.

Bellotti tried to flush out the outgassed radon by building a special ventilation shaft to the highway tunnel. "Completely wrong," he groans. The shaft created air currents that somehow—nobody understands why—sucked in even more radon, doubling and even tripling radiation levels. Bellotti, appalled, recalls his own shouts: "Stop everything! Cut the shaft!" The lab closed the shaft and, as a temporary measure, put up big fans and laid radiation-absorbing paraffin on the floor. That seemed to do the trick, but Bellotti, who recently stepped down as director in order to return to experimental work, says that Gran Sasso's scientists are still searching for a more permanent solution.

It required equal persistence to avoid background in the detector used by Borexino, an Italian-American solar neutrino collaboration. That detector works by observing the decay triggered in exceptionally pure germanium-76 when it is hit by neutrinos. But the germanium was in underground storage in the United States, and somehow it had to be moved to Gran Sasso without being exposed to cosmic rays—which are present everywhere on the surface of the Earth. If the germanium was hit by cosmic rays, they would convert germanium atoms to radioactive isotopes, which would decay, mimicking the signal the experiment was attempting to measure. A first plan involved shipping the germanium underwater on U.S. Navy submarines. But the submarines are powered by nuclear reactors, which produce their own stray radiation. Gritting its collective teeth, the collaboration eventually transported the crystal by boat, in shielded crates.

Noise in the background also confronted the experimenters at GALLEX, a solar neutrino collaboration involving researchers from Italy, Germany, the United States, France, and Israel. They needed tons of gallium solution, which had been stored in southern France, where it, too, was bathed in cosmic radiation. The rays interacted with gallium atoms, transmuting them into radioactive isotopes of germanium, which accumulated in the tanks. The decay of the germanium kept the radiation counters buzzing and had to be extracted before the experiments could go forward. One isotope, germanium-68, proved nearly impossible to remove by chemical or physical means. For 9 months the experimenters tried without success to eliminate the signal or compensate for it. "People became frustrated," recalls GALLEX experimenter Helmut Lalla, "with 300 days of always having this damn stuff come out." Eventually the team circulated hot water in tubes through the gallium solution, heating up the liquid enough to speed the release of the germanium.

The measures worked. After releasing preliminary data last year, GALLEX will soon publish its first complete results in *Physics Letters B* on the flux of solar neutrinos. "We're seeing neutrinos at about two-thirds of the predicted level," says GALLEX experimenter Richard Hahn of Brookhaven National Laboratory in Upton, New York. Although Hahn cautions that it is too early to make a definite judgment, "all of the experiments seem to be seeing a deficit"—although, bewilderingly, the deficit seen at Gran Sasso is not quite large enough for researchers to reliably interpret its meaning. The subject, he says, will be a priority at a congress on underground physics to be held at Gran Sasso later this month.

The physics of the future? Despite Gran Sasso's clever fixes for scientific problems and mastery of the political landscape, it's not likely that all physicists will accept the lab as a model for high-energy research. For 50 years particle physics has been based at accelerators, and accelerators, as the Nobel Prize–winning physicist Carlo Rubbia has said, are "wonderful fun." Swarming with activity, these huge, marvelously intricate machines run around the clock, quickly piling up huge stacks of data. Underground laboratories like Gran Sasso in Italy or Kamiokande in Japan are different. They play a waiting game. Physicists can spend years in the underground gloom anticipating that nature will produce the phenomenon of interest. That can take a frustratingly long time: In its first 18 months GALLEX observed fewer than 100 solar neutrinos.

"At least with the accelerator experiments you get some data right away," says Burton Richter, the Nobel Prize–winning director of the Stanford Linear Accelerator Center, in Menlo Park, California. Richter points out that one can avoid some aspects of this problem by using experiments to look at many areas at once, and Gran Sasso has attempted to do just that. Data from the incoming Large Volume Detector will be of interest to specialists in stellar dynamics, but also to particle physicists (who hope it may turn up magnetic monopoles) and astrophysicists (who think it may observe energetic neutrinos from collapsing stars).

But even without the delays, Gran Sasso can never be a full substitute to accelerators. Experimenters there are unlikely, in Richter's opinion, to answer the fundamental questions about the constituents of matter that are of most interest to particle physics. Observing the top quark, for instance, is almost impossible: there's simply not enough particles of sufficient energy that will go through the detector.

Nonetheless, Gran Sasso remains an inexpensive short-cut to the same energy domains attained by accelerators, and these short cuts could well become increasingly in demand as science becomes more expensive. "In an era of short money you have to have a real balance between accelerator and non-accelerator experiments," Richter says. "I think it wouldn't hurt physics one bit to tip the balance a little toward more non-accelerator physics."

–Charles Mann and Robert Crease

Mann and Crease are the authors of The Second Creation: Makers of the Revolution in Twentieth Century Physics, *a history of particle physics*.