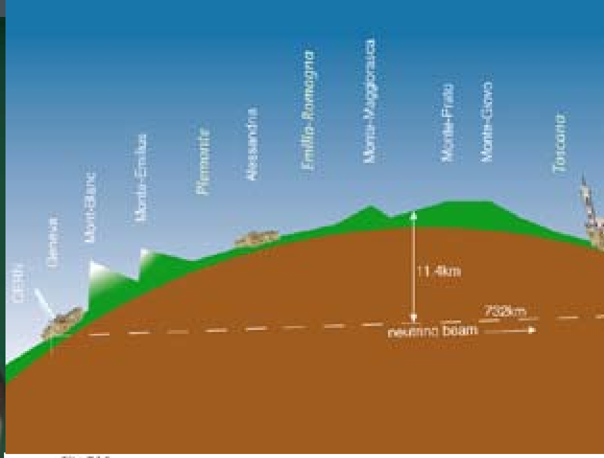
Case Study Opera Gran Sasso

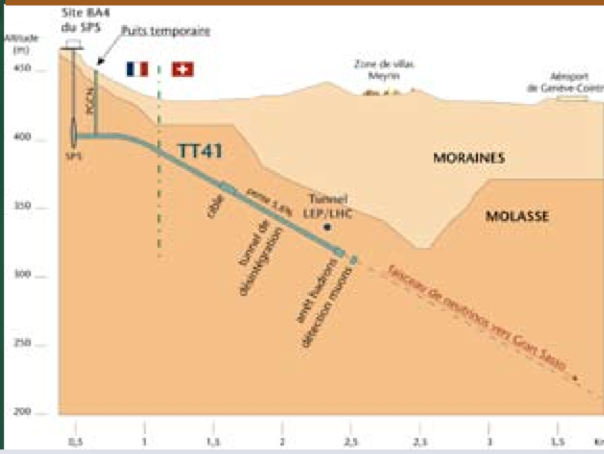
The Leica TDA5005 aligns the largest camera in the world

Leica Geosystems

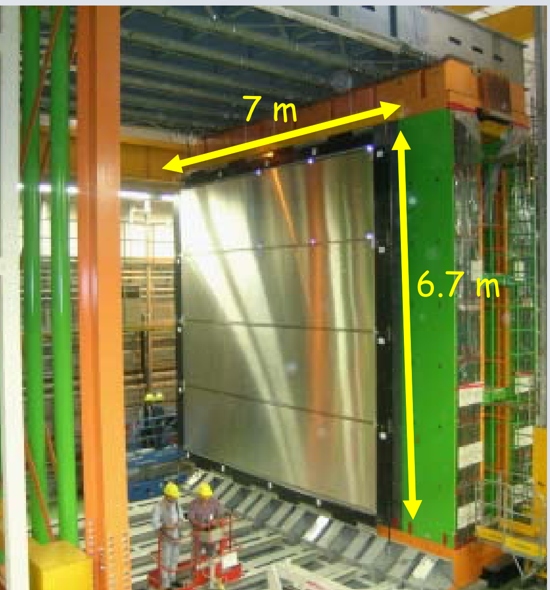
www.leica-geosystems.com/metrology

HEXAGON METROLOGY





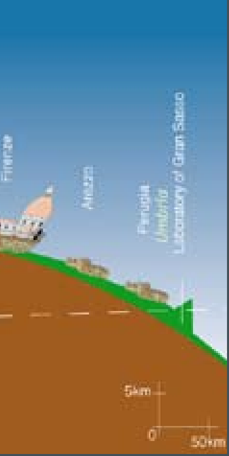
150 physicists, 36 institutions in 13 countries and a budget of 120 million euros: Opera is an international project carried out in collaboration with CERN and with the participation of the CNRS (National Centre for Scientific Research) aimed at reproducing on Earth, in known conditions, the natural phenomenon of the transformation of muon neutrinos into tau neutrinos. The final objective is to validate a theoretical model which would support the Grand Unification Theory of physics.



"This research may seem esoteric, but it is first and foremost highly practical and experimental. It involves major technological challenges in obtaining micrometric precision in a target weighing 1,300 tonnes. At the same time, it means examining what matter is made of and what role these mysterious particles might have played in the very first moments of the universe", explains Dario Auterio, a physicist at the Institute of Nuclear Physics in Lyon (CNRS) and head of the neutrinos research group.

Within the framework of this research, a neutrino detector was installed in the Gran Sasso national laboratory, the largest underground laboratory in the world covering an area of 18,000 m^2. The site was chosen because the 1,400 metres of rock above it protect the detector from cosmic rays which would pollute the measurements. The neutrinos monitored by the group of researchers were specially produced at CERN, the European Organisation for Nuclear Research located under the Franco-Swiss border near Geneva. A particle accelerator fires protons onto a graphite target. The particles produced are then guided into a kilometre-wide vacuum tube and directed towards the detector where they disintegrate, producing billions of neutrinos every second. The muon neutrinos then disperse in straight lines... straight through the Earth, because neutrinos are veritable ghosts. In general, they travel through the entire Earth at the speed of light. Hence, they pass through 730 km of rock to reach the detector in 2.4 milliseconds. For the most part, these neutrinos have maintained an identical state to the moment they were formed. Some of them, however, have transformed into tau neutrinos.

Dario Auterio explains: "This rare transformation results from a sort of spontaneous oscillation between the two states. And at present, while the most recent theory provides a good explanation of this oscillation, we have only been able to demonstrate it by means of a lack of muon neutrinos compared to a known source of neutrinos. To be entirely certain and to study the phenomenon more closely, we need direct proof of the oscillation by detecting the tau neutrinos. This may seem like a simple experiment, but the oscillation requires neutrinos to have a mass, albeit very small, whereas for a long time it was believed that neutrinos have no mass at all, similar to photons. The fact that there are elementary particles and fundamental laws of nature is a significant additional design consideration. Furthermore, neutrinos are linked to the great mystery of the matter-antimatter asymmetry which exists in the universe. At present, the first neutrinos detected are muon neutrinos, but we still have a few years to make the expected breakthrough."



Above: one of the 151,000 bricks to be installed in the immense structure – still empty in the middle photograph. Right-hand photograph: the robot used to position the bricks exactly.

A special gallery has been equipped for Opera in the underground laboratory of Gran Sasso to allow an immense sensor, similar to a huge camera, to be installed to receive the beam flow from the CERN. This sensor will enable the creation of tau neutrinos to be monitored and photographed as they are produced through the interaction of the CERN beam with the sensor.

The sensor consists of two magnets and 151,000 bricks (a wall of 52 x 64 bricks) weighing a total of 1,255 tonnes. Each brick consists of 56 alternating one-millimetre-thick layers of lead plate and photographic film. Due to the sensitivity of the photographic film, a brick production plant has been set up on site in the underground laboratory of Gran Sasso. It assembles and conditions the photographic films with the lead plates to produce the famous bricks, a basic component of the sensor, at a rate of 7,000 units per day. It is inside these bricks that the events will take place that will be photographed and analysed by the researchers.

Each brick is installed by a manipulator-type robot which uses markings to identify the exact position of the brick in the huge mosaic that it is building.

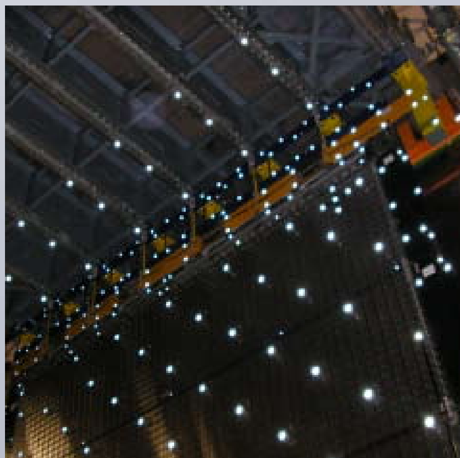
The sensor in the Gran Sasso laboratory is the largest camera in the world ever built. The installation process, which lasted several years, required extreme precision with regard to the positioning and assembly of its components.

The search for a suitable means of measurement was carried out in several stages with very precise specifications: "the measurement instrument should not only allow the sensor to be installed by means of very precise alignment but should also play an active role in the final inspection by measuring the position of all the components in order to perform constant corrections of the software during the construction of the sensor." Indeed, as the thousands of tonnes of bricks were installed, the structure became heavier. The level of precision required for the tracker, the bricks and the structures was set at 1 mm while the level of precision required for the magnets tracker was set at 0.3mm over a total volume of 10m x 10m x 20m!

The measuring needs for the installation required the acquisition of a versatile and easy-to-use instrument capable of performing different tasks. Together with the CERN alignment team and the local representatives of Hexagon Metrology, a number of tests were carried out to validate the use of the Leica TDA 5005 station as the most suitable instrument to satisfy all the specifications.

The cost analysis of a measurement service on this scale (every day for 2 years during the installation of the machine) very quickly confirmed the need to invest in in-house equipment. In this way, the personnel could be totally independent, working at their own speed and incorporating the flexibility constraints necessary to this type of project. Consequently, a Leica TDA5005 laser station was connected directly to the entire global reference system of the Opera project from the very outset.

To install the components and the machine, a network of reference points was created in the experiment hall. This involved installing several hundred points in the walls, the ground and on the machine to ensure that the instrument always worked within the scope of the installation referential. Using the Axyz software and its bundle algorithm (or beam adjustment), fifteen instrument stations could be positioned in a global referential with a



Hundreds of magnetic targets form the basis of the system's photogrammetric measurement process.

Very precise target mounting

level of uncertainty of approximately 0.1 mm. This excellent performance was the result of several factors, including excellent instrument performance, a laboratory with a high-quality thermal and vibratory stability, an excellent measurement methodology and the proven dexterity of the users.

The Leica TDA5005 is used to perform the following tasks in the context of the Opera project:

• installation of the main parts of the machine
• assembly of the components in relation to one another
• adjustments to the components in relation to one another
• alignment of the machine and the accessories
• periodic monitoring of the inspection of the machine's geometry
• preventive and curative maintenance of the installation

The installation of translation rails which allow the robot to perform precise movements was also optimised using measurements taken on the Leica TDA5005 through the creation of numerous accessories by the system users. As a result, different measurements could be recorded during the installation.

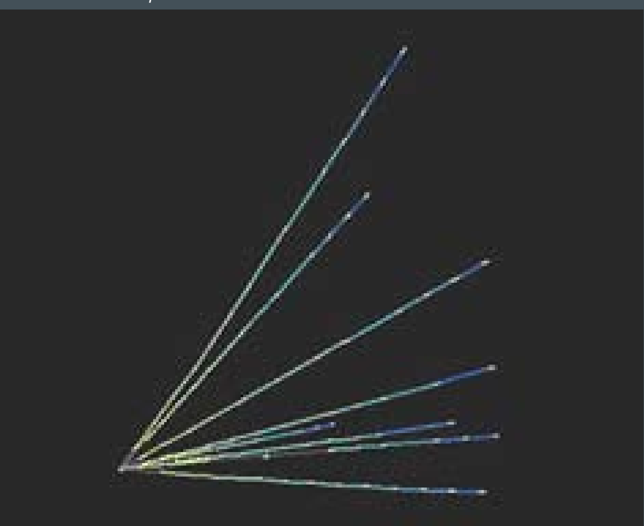
The head of the Opera alignment project briefly explains that "the Opera project, which is a monumental and unique experiment, consists of numerous very precise assemblies. We had to be able to rely on the assemblies and the final alignment of all the components which are subjected to intensive use and increased surveillance. Moreover, we needed all types of progressive measurements which could be taken with a certain degree of flexibility without having to interfere with the installation. The Leica TDA5005 allowed us to develop in-house skills and to define our own techniques and procedures without needing to call on expensive and often inefficient outside partners. We therefore made the Leica TDA5005 a complete tool by performing numerous small-scale metrological experiments ourselves in addition to the thousands of programmed measurements! We also developed the necessary accessories to interface with the machine and obtain very precise measurements of the characteristics of interest to us".

"The system, which is both precise and easy to use, completely satisfies our needs". Mr Auterio continues, concluding that, "This global project benefitted from a global presence of our partners, first Leica Geosystems and then Hexagon Metrology. The experience of collaborating with an international group is genuinely positive. We were always able to rely on the local reactivity of the Lyon centre together with the Italian team on site."

For the next global nuclear physics programme to be carried out in Japan, Mr. Auterio is already looking forward to taking advantage of the professionalism and competence of Leica Geosystems in the subsidiaries and Japanese partners of the Hexagon Metrology group! Dealing with a group which is present on all continents is definitely a major plus in projects the size of Opera and all future projects in the same vein.

By Anne Willimann

Numerous target mountings were developed in the framework of the Opera project to help ensure that the thousands of measurements required were as precise as possible.
"Over a period of three years, we have become real experts in the field of metrology", explains Mr. Auterio, who continues, "The system, its modularity, versatility and portability, completely satisfies our very demanding requirements".



Reconstruction of the impact of a neutrino recorded in a brick and analysed by a laboratory in the Opera project fitted with automatic microscopes required to decipher the images and measure the physical parameters of interest.

Did you know?

Neutrinos are probably the most numerous elementary particles in the universe and yet they are the most difficult to study due to their extremely shy nature. Neutrinos hardly interact with matter at all and can travel through the entire Earth, which is almost transparent to them. Neutrinos carry precious information about the birth and evolution of the universe, for example concerning the preponderance of matter over anti-matter or the evolution and extinction of stars. The properties of neutrinos represent a unique opportunity to explain how the basic laws of physics can be unified in a single fundamental law (the Grand Unification theory), the ultimate goal and dream of physicists.

Whether building the fastest car, the biggest plane, or the most precise tooling, you need exact measurements to improve quality and productivity. So when it has to be right, professionals trust Leica Geosystems Metrology to help collect, analyze, and present 3-dimensional (3D) data for industrial measurement.

Leica Geosystems Metrology is best known for its broad array of control and industrial measurement products including laser trackers, Local Positioning Technology (LPT) based systems, hand-held scanners, 3D software and high-precision total stations. Those who use Leica Metrology products every day trust them for their dependability, the value they deliver, and the world-class service & support that's second to none.

Precision, reliability and service from Leica Geosystems Metrology.

Leica Geosystems
Metrology Products
Moenchmattweg 5
CH-5035 Unterentfelden
Switzerland
Phone +41 62 737 67 67
Fax +41 62 737 68 68

www.leica-geosystems.com/metrology
www.hexagonmetrology.com