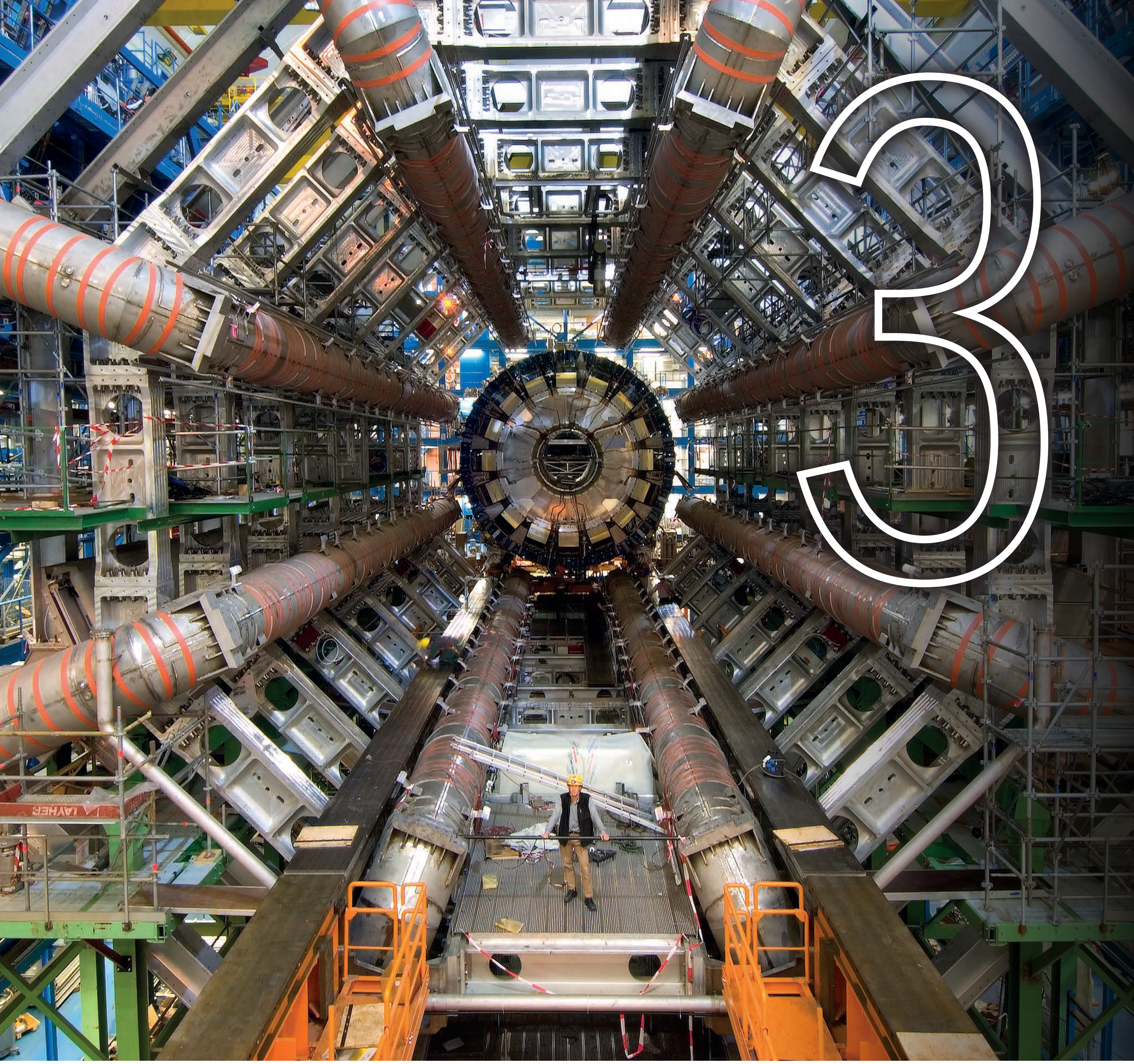

Swiss Roadmap for Research Infrastructures in view of the 2025 – 2028 ERI Dispatch (Roadmap for Research Infrastructures 2023)

Part III: Swiss Participation in International Research Organisations: a diplomatic instrument at the service of Swiss science

Schweizerische Eidgenossenschaft
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Swiss Confederation

Federal Department of Economic Affairs,
Education and Research EAER
State Secretariat for Education,
Research and Innovation SERI

Cover photo: ATLAS is one of the particle detectors of the
Large Hadron Collider (LHC), the world's largest particle
accelerator. Photo: CERN

Impressum

Publisher:
Editing: Francesca Stocker, Patrice Soom
Translation: Language Services of SERI and the Federal Chancellery
Printing: Federal Office for Buildings and Logistics FBL
Languages: German, French, English

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Swiss participation in international research organisations

Ever since CERN was founded in the 1950s, international research organisations have spurred major scientific and technological advances by building and harnessing some of the foremost research infrastructures in the world. That is why the Swiss federal government supports access for the Swiss research community to such strategically important entities based on international law.

Continuing to push the limits of our scientific knowledge of the infinitely large, infinitely small and infinitely fast relies on the development of ever-more powerful and complex instruments. Today, the study of matter requires accelerators that collide particles at close to the speed of light, while observing the cosmos demands that enormous telescopes be placed on earth or even in space.

Pushing the boundaries of science through international cooperation

Particularly in physical sciences major progress requires instruments that often are too complex and expensive for a single research institution or even a single country. International research organisations offer means of scientific collaboration uniting the scientific ambitions of several countries and facilitating the creation of research instruments with global impact. They are independent legal entities, established by a treaty under international law that is binding for the governments of the countries involved. The strategic direction of such organisations is set by the member states through their own governance frameworks.

The multilateral nature of these organisations, combined with their technical complexity and cost, poses a range of technological, organisational and political challenges for their member states. Such organisations are therefore only set up when no other solution meeting the scientific community's needs is found.

The first international research organisations were founded in the mid-20th century, with a structure and functioning largely based on those of the international organisations created after the Second World War. This is in particular the case for CERN, which was established in 1954. Other organisations were subsequently created on the same model and are presented in the next pages. The number of international research organisations has grown rapidly over the past two decades, mirroring the ongoing fast expansion of our scientific knowledge, as well as the new opportunities for international collaboration brought about by digitalisation. They will become increasingly important, covering an ever-broader range of scientific fields. A multitude of disciplines from physics, over medicine to archaeology already benefit from state-of-the-art instruments that would never have been developed without such government-supported international scientific collaborations.

Society as a whole benefits from this development, not only through the knowledge gained within these international research organisations, but also through the technological progress that such organisations stimulate. Examples of revolutionary technological breakthroughs emerging from CERN include the invention of the World Wide Web, or the development of electromagnets leading to the techniques of magnetic resonance imaging (MRI), which are now in daily use and indispensable within our society.

Swiss participation in international research organisations

Switzerland participates in international research organisations that are most relevant for its scientific community. Most of these organisations have already successfully set up state-of-the-art infrastructures that are used by researchers who conduct their experiments and work there. While established organisations continue growing their capabilities by upgrading their infrastructures and installing new machines, other organisations are just starting to build their infrastructures.

Overall, the Swiss government invests some 100 million Swiss francs annually in international research organisations.

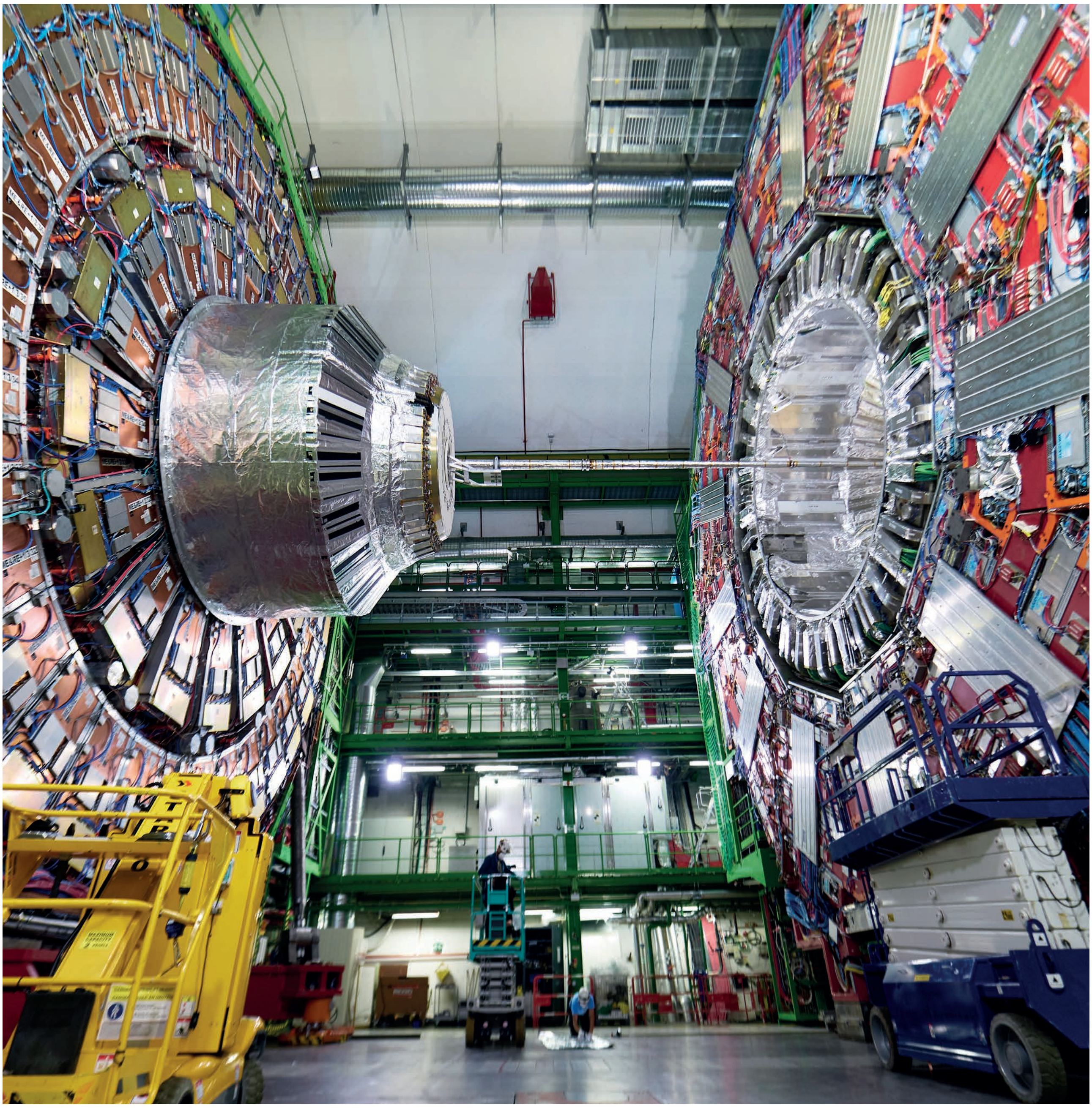
These investments have been negotiated individually for each organisation. The range of benefits for Switzerland is wide:

- Access to some of the best infrastructures and instruments in the world is a prerequisite for Swiss research excellence in many scientific fields. The high quality of Swiss research and the good organisation of the various scientific communities involved mean that the resources and time made available to Switzerland by international research organisations can be used up or even exceeded.
- The many forms of scientific cooperation within international research organisations contribute to the openness and integration of Swiss researchers in the corresponding international networks.
- Building, maintaining and improving the infrastructures operated by international organisations is a key market for Swiss research organisations and tech companies that develop and deliver high value-added components and services. Taken as a whole, the value of goods and services purchased in Switzerland by international research organisations each year equals or even exceeds Switzerland's investment in those institutions.
- The example of CERN in Geneva also shows that Switzerland benefits in many ways from hosting such an international research organisation, particularly in terms of jobs or contracts awarded to Swiss companies.

How does the federal government select the international research organisations it invests in?

Research organisations in Switzerland enjoy a high degree of autonomy. As such, they are entitled to determine their priorities for investments in research infrastructures. However, under Switzerland's International Strategy on Education, Research and Innovation, the federal government has a responsibility to ensure that Swiss research and innovation actors have the research infrastructures they need to maintain and enhance the quality of their work. The State Secretariat for Education, Research and Innovation (SERI) also keeps a close eye on developments affecting international research organisations. In line with the principle of subsidiarity, when the need to participate in an international research organisation is agreed upon by the Swiss scientific community, but the Swiss research institutions cannot take on the associated financial and political responsibility themselves, SERI initiates the steps towards a possible membership. In doing so, it follows the process laid down in the Swiss Roadmap for Research Infrastructures.

To ensure the flexibility required for the growth of state-of-the-art Swiss research, the Federal Act on the Promotion of Research and Innovation (RIPA) gives the Federal Council the power to enter into international agreements in this field, and thus to join international research organisations. However, any associated financial commitments must be approved by the Federal Parliament.



Views on the open CMS detector to be closed and to get ready for the new physics run next year. Photo: CERN

European Organization for Nuclear Research (CERN)

Founded in 1954, the European Organization for Nuclear Research (CERN) in Geneva leads the cooperation between European states in the field of nuclear and particle physics for exclusively peaceful purposes. CERN undertakes fundamental research on the structure of matter and the fundamental interactions between elementary particles. Its mission is to answer the basic questions of what the universe is made of and how it works. At CERN, particles are accelerated to close to the speed of light and collided with each other. In the course of its 70-year existence, CERN discoveries have revolutionised particle physics. The research community has done ground-breaking work in fundamental research, as well as in its application for the benefit of the whole of society.

Founding year	1954
Members	Austria, Belgium, Bulgaria, Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Israel, Italy, Netherlands, Norway, Poland, Portugal, Romania, Serbia, Slovakia, Spain, Sweden, Switzerland, United Kingdom
Associate members	Cyprus, Estonia, India, Lithuania, Pakistan, Slovenia, Turkey, Ukraine, Croatia, Latvia
Legal form	Intergovernmental organisation under international law
Host state	Switzerland
Locations	Geneva region (Switzerland and France)
Research field	Particle physics
Annual budget	CHF 1’200 million
Swiss status	Member and host state
Swiss budget contribution	3.9%
Website	www.cern.ch

The quest for the universe fundamental laws and constituents

CERN uses particle accelerators to conduct cutting-edge research in nuclear and particle physics. It is the world’s leading laboratory and accelerator complex, attracting scientists from around the world. Together they investigate the elementary building blocks of matter, and what forces hold them together.

Our understanding of particle physics today is based on the Standard Model. It describes all known elementary particles and the fundamental relationships between them, and summarises all of the key findings in particle physics as they stand at present. The Standard Model of particle physics was developed by theoretical physicists and is a quantum field theory. The experimental research programme at CERN aims to produce empirical evidence that either confirms or disproves the models formulated by modern theoretical physics. Many of the predictions made in the Standard Model have been confirmed by experiments at CERN. These involved accelerating particles and then colliding them inside detectors, which precisely measure their characteristics as well as those of newly created particles. The interplay between theoretical and experimental physics is vital to understanding the very heart of our world.

CERN is regarded as the foremost example of peaceful international cooperation and scientific diplomacy. The CERN Convention came into effect almost 70 years ago in 1954, nine years after the end of the Second World War.

The underground route of the Large Hadron Collider (LHC) at CERN. Illustration: CERN

Accelerating and colliding particles

The infrastructure at CERN has been continuously enhanced and expanded since the organisation was founded. Early on, the first particle accelerator was built and operated at the Swiss site in Meyrin, along the French border. Over the years CERN has extended onto French soil.

Today, CERN is home to the world's largest and most powerful particle accelerator, known as the Large Hadron Collider (LHC), which went into operation in 2008. The LHC is ring-shaped and installed in an underground tunnel 27 kilometres long. This highly complex machine is designed to accelerate beams of particles, such as protons, to almost the speed of light. Using strong superconducting magnets, the particles are accelerated in opposite directions through two thin vacuum tubes and kept in circulation around the ring. They gain more energy with each orbit. When they have reached their target energy, the particles are collided at four collision points. Collision breaks up the structure of the protons and new particles are created. The highly complex ATLAS, CMS, ALICE and LHCb detectors are installed at the collision points to measure the energy and direction of these new particles. Independently of each other, the ATLAS and CMS collaborations discovered the Higgs boson in 2012.

It takes enormous material and human resources to build and operate the LHC and the large-scale detectors as well as to analyse the data they generate. More than 10,000 people pass through the doors of CERN each year, with many of them visiting the laboratory to conduct research for varying periods of time. For example, the ATLAS and CMS collaborations involve some 1,000 scientists each.

In addition to the four larger detectors at CERN, the organisation conducts fundamental research into other fields. The Antimatter Factory is testing whether antimatter behaves in the same way as matter under gravitational force, while the Alpha Magnetic Spectrometer (AMS) on the International Space Station (ISS) is looking for dark matter, and also measures the composition of cosmic rays. Research and development (R&D) work on detectors is also being pursued vigorously in various areas of CERN. There is an entire test hall devoted to the development of stronger superconducting electromagnets, and laboratories working on new types of silicon chips.

Beyond the limits of the Standard Model of particle physics

The Standard Model describes the measured characteristics of elementary particles remarkably well. It unifies three of the four fundamental forces in physics. There are nonetheless reasons to believe that this theory is part of a more comprehensive theory that has not yet been determined. The Standard Model does neither include certain phenomena such as dark energy and dark matter nor does it integrate the gravitational force within the fundamental interactions. At extremely high levels of energy, such as they occurred during the Big Bang, there are contradictions between the Standard Model and the general theory of relativity. The holy grail in particle physics would be to find what is known as the grand unified theory, incorporating the phenomena mentioned above. The experiments at CERN are pushing the boundaries of the Standard Model to find the gaps and cracks within. Discovering inconsistencies that are not yet covered by the present theory allows researchers to develop new theories beyond the Standard Model of particle physics.

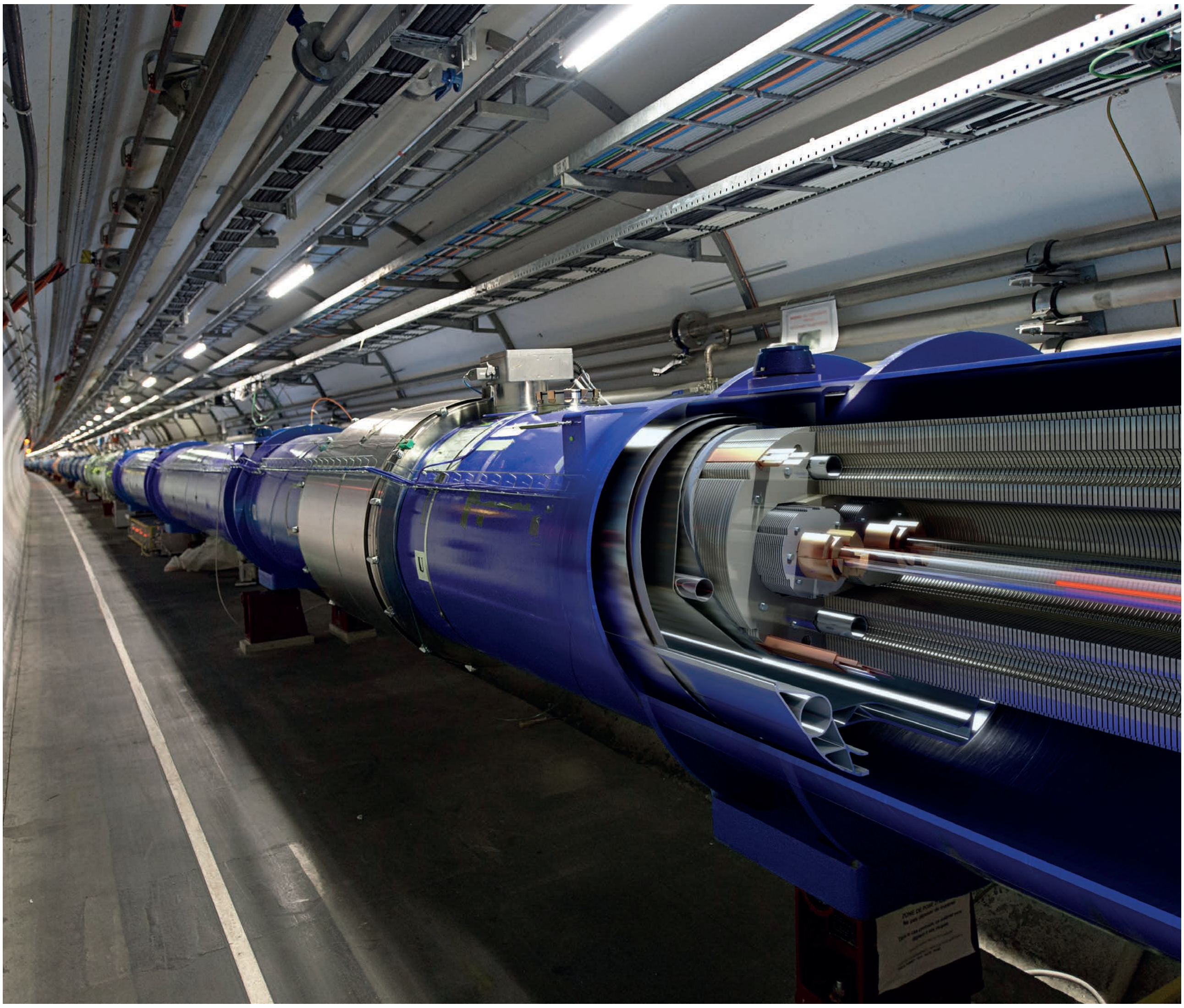
To expand the search for these gaps and cracks in the Standard Model, the Large Hadron Collider (LHC) will be upgraded to a High-Luminosity LHC (HL-LHC) by 2029. A raft of technical optimisations will significantly boost the power of the world's largest particle accelerator once again. The HL-LHC will be able to increase Higgs boson production by a factor of five, to 15 million per year. The upgrade will make it possible to measure the characteristics of the Higgs boson with unprecedented precision and to study its rare decay channels.

The scientific potential of the HL-LHC is likely to be exhausted by 2040. The future of acceleration in particle physics was considered in the 2020 update of the European Strategy for Particle Physics. In summary, the strategy report proposes that new findings and discoveries can be made by designing and building a new machine that can collide particles at even greater energies and at a higher intensity. Higher energies enable matter to be studied on even smaller scales, and may pave the way for the discovery of new and as-yet unknown particles. An accelerator 91 kilometres long, known as the Future Circular Collider (FCC), would achieve maximum energies that are ten times greater than the present collision energies in the LHC. Further, this would increase the Higgs boson production by a factor of 100 with respect to the HL-LHC. Mandated by its member states CERN is currently conducting a feasibility study to be published by the end of 2025. The study will examine the construction, operational, environmental and financial feasibility of an FCC in the area of CERN. A potential FCC would profit from the already existing local infrastructure and expertise, making CERN the only logical location to build such a machine. As host state to CERN, Switzerland welcomes the feasibility study, and will assist with expert knowledge where appropriate. If the study concludes a positive outcome and a decision in favour of the FCC project is made, such an endeavour could provide the cornerstones of the continued cutting-edge science in high energy physics for the next 60 years.

CERN feeds contemporary science and society

The findings at CERN impact on a broad spectrum of other natural sciences, from materials science through to data processing, medical physics and radiation therapy. Many fundamental discoveries about the structure of matter and the fundamental forces of physics have been made at CERN. For example, in 1983 CERN researchers discovered two elementary particles, the W boson and the Z boson, for which they were awarded with the Nobel Prize in Physics in 1984. The Higgs boson was discovered at CERN in 2012. Its existence was the subject of a 1964 hypothesis by theoretical physicists François Englert and Peter Higgs. After decades of searching, this elementary particle was found by the ATLAS and CMS detectors using the LHC. Englert and Higgs were honoured with the Nobel Prize in Physics in 2013 for developing the Higgs mechanism. The mechanism foresees that elementary particles only receive their mass through a coupling with the Higgs boson.

Beyond its purely scientific role, CERN constantly drives innovation in many different domains. For example, the World Wide Web was invented at CERN out of the need to share scientific data with other centres of research.



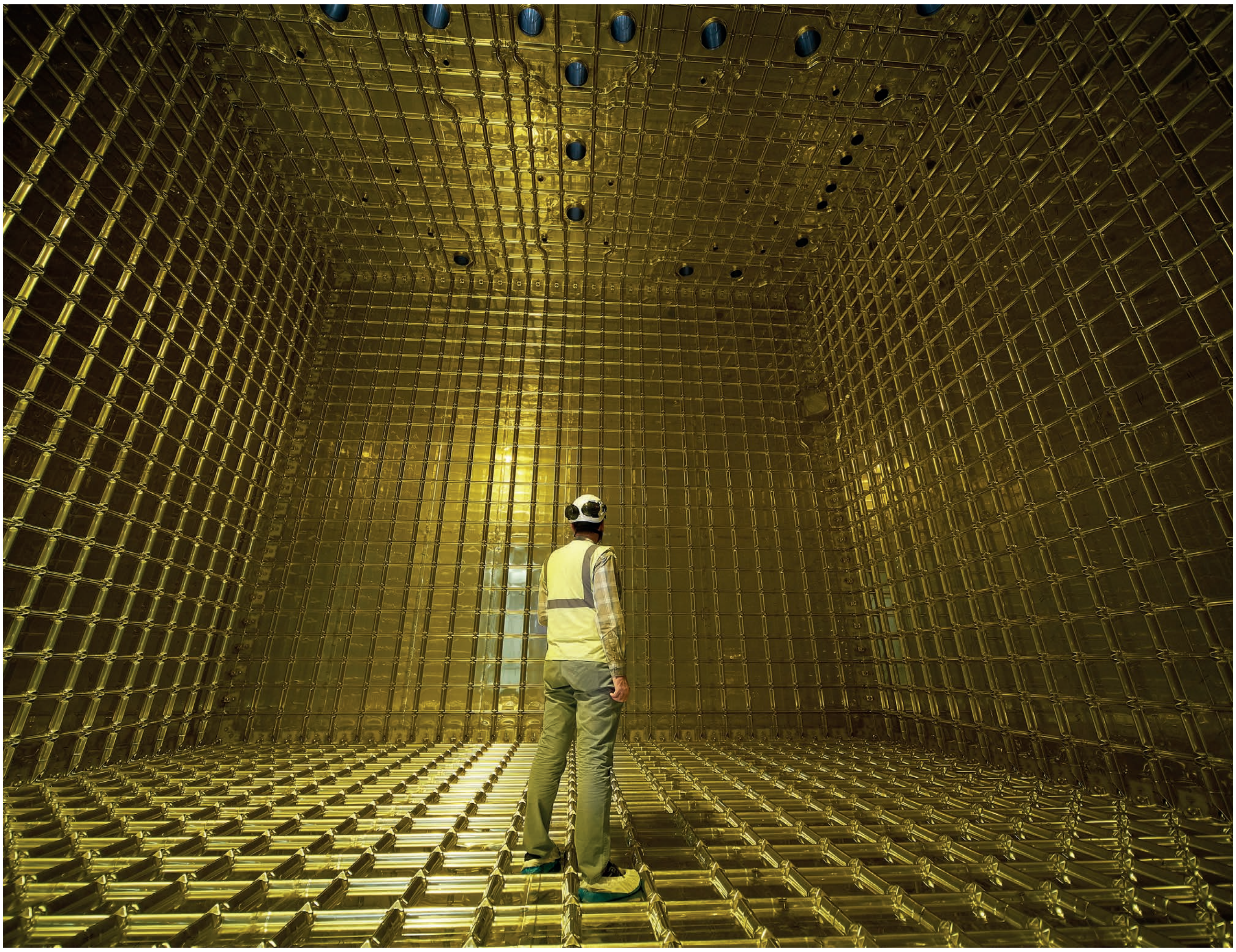
3D cut of the LHC dipole. Photo: CERN

Whether electromagnets, which were indispensable for the development of magnetic resonance imaging in medicine, superconductor technologies making electrical grids more efficient, or small scale accelerators that are used for cancer treatment, the research carried out at CERN generates broadly applicable technological progress and innovation publicly available.

Switzerland at the crossroad of leading-edge big science

Finding itself in the role of a member and host state at the same time, Switzerland benefits in many aspects from CERN. Firstly, like all CERN members it profits considerably from the enormous body of scientific knowledge that CERN produces. Secondly, geographical proximity to CERN means that Swiss-based researchers have become world-renowned experts in accelerator physics. This is also reflected in the fact that all of the larger Swiss universities have groups working with and at CERN, contributing significantly to the major experiments. In addition to ETH Zurich and EPFL, the Paul Scherrer Institute (PSI) and the universities of Bern, Basel, Geneva and Zurich all participate in CERN projects.

Compared with Switzerland’s share of the annual budget, Swiss citizens also make up a disproportionately large section of CERN staff. In addition to the scientists who use CERN as employees or guest researchers, a particularly large number of Swiss people work in challenging administrative and technical roles there. For geographical reasons, many of CERN’s industrial and service contracts are awarded to companies in the Geneva region and throughout Switzerland. The Swiss high-tech industry particularly benefits in the fields of cryogenics, superconductors,



As part of the detector research and development program for the DUNE experiment in the United States, the ProtoDUNE detector was successfully built and tested at CERN. Photo: CERN

vacuum technology, microelectronics, construction and engineering. The density of highly qualified personnel at CERN is also quite remarkable. Some 64% of researchers at CERN do not remain in research and choose an academic career, instead going into industry (45%) or working in other sectors (19%). It is not unusual for highly qualified CERN alumni to find employment in Swiss industry and innovation.

Switzerland's host state policy

Switzerland has been hosting a variety of international organisations and conferences for more than 150 years. It is seen around the world as the primary centre of global governance, and its role as host state is deeply rooted in the tradition and policy of good services. 'International Geneva' is known globally as the operational hub of the international multilateral system. Switzerland pursues an active strategy to strengthen its appeal and competitiveness as a host state. The advantages that this brings are of great importance. For example, it simplifies access to international organisations and their leaders, officials, experts and delegates. In this way Swiss foreign policy also gains an outstanding platform to communicate their messages. Due to the presence of the many international organisations Switzerland gains visibility at the international level. By offering these organisations excellent operating conditions, Switzerland endeavours to ensure the smooth functioning of international relations and to address the great multilateral challenges of our time. Furthermore, Switzerland's role as host state strengthens its position as a member state of these organisations, and vice-versa.

The presence of CERN, in particular, in Switzerland generates considerable added economic value for both the region and the country as a whole. Those who work at international organisations also live in the region, make purchases there, and in many cases have acquired residential property. A large share of the salaries that are paid is therefore spent in Switzerland. Promoting Switzerland in its role as host state through public-sector financial investment to create the right conditions and infrastructure (office buildings, conference centres, etc.) is clearly a direct monetary and political investment with a guaranteed return.

With all of these benefits in mind, Switzerland supports multilateralism and devotes a great deal of resources to providing the organisations that are based here with attractive surroundings and the very best operating environment. In 2007, the Swiss Parliament adopted the Host State Act to support host state policy. It defines the potential beneficiaries of privileges, immunities and exemptions, as well as financial contributions within the framework of international law. It is based on the Vienna Convention on Diplomatic Relations of 18 April 1961 and the headquarters agreements with organisations based in Switzerland. The act also determines the conditions on which beneficiaries might be granted special status and financial subsidies. CERN as one of these beneficiaries has a particular role to play not just as the only international research organisation headquartered in Switzerland, but also as the largest of its kind in the world.

On 10 December 2021 the Federal Council decided that Switzerland would increase its efforts to foster CERN’s long-term development opportunities, especially at the regional planning level. In practical terms, this means the federal government will draw up a sectoral plan for CERN projects, and will create the necessary legal basis for this. In the future, the sectoral plan will clarify and simplify the processes that apply to regional planning in the framework of CERN projects and hence, also accommodating a request from the Canton of Geneva. The sectoral plan improves planning certainty for all CERN projects, and provides a means of balancing the various aims of research policy, host state policy, and regional planning policy. The continued presence of CERN – and its further development as a world class particle physics laboratory, with a potential new accelerator complex such as the FCC – is of enormous interest to Geneva as a location, to Switzerland as a centre of global governance, to the local research community, and to Switzerland as a hub of high-tech industry and innovation.

European Southern Observatory (ESO)

The European Southern Observatory (ESO) is Europe's foremost infrastructure for astronomical research and the scientifically most productive observatory in the world. With its telescopes at various locations in the Atacama Desert in Chile, ESO provides ideal conditions for cutting-edge astronomical research. ESO also plays a key role in promoting international cooperation in the field of astronomy.

Founding year	1962
Members	Austria, Belgium, Czech Republic, Denmark, Finland, France, Germany, Ireland, Italy, Netherlands, Poland, Portugal, Spain, Sweden, Switzerland, United Kingdom
Legal form	Intergovernmental organisation under international law
Host state	Germany
Locations	Garching (Germany) Santiago, La Silla, Paranal and Chajantor (Chile)
Research field	Astronomy and astrophysics
Annual budget	EUR 240 million
Swiss status	Member
Swiss budget contribution	4.5%
Website	www.eso.org

Observing and understanding the cosmos

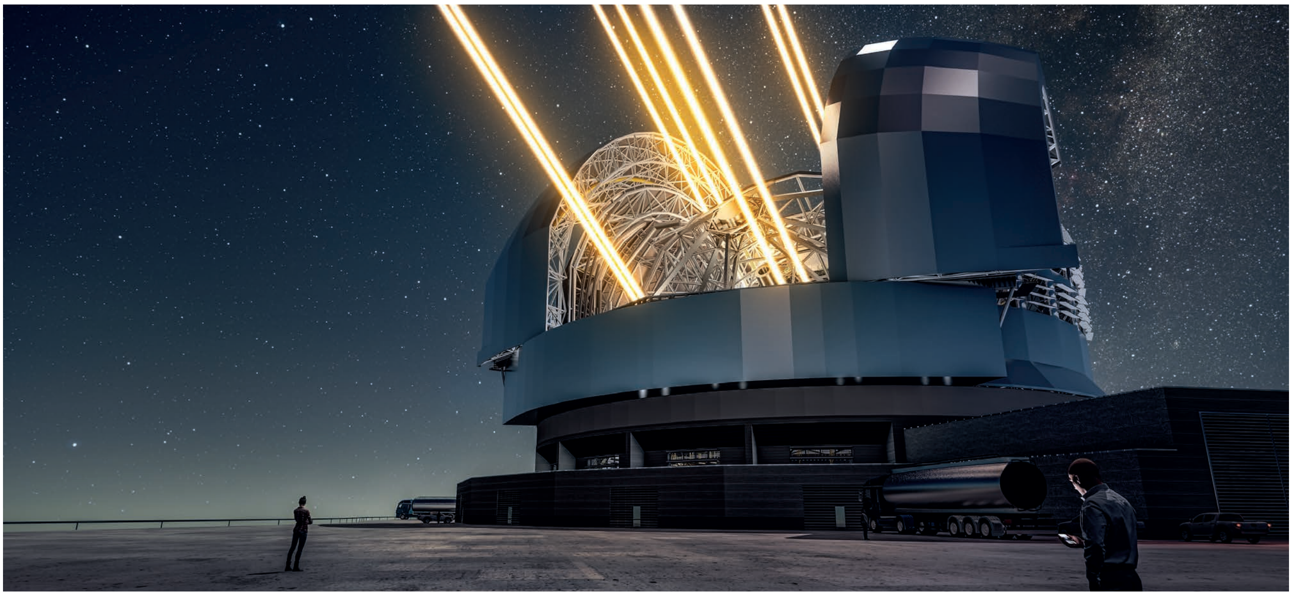
The aim of the European Southern Observatory (ESO) is to provide the very latest ground-based research facilities for researchers in astronomy and astrophysics to explore certain ranges of the electromagnetic spectrum. This should expand our understanding of the cosmos. The world's most powerful telescopes on the ground are used to make important scientific discoveries by further exploring the origins and development of the universe, for example. ESO also develops advanced technologies, such as active optics to even out distortion effects from the shape of the telescope mirrors, or interferometry to measure light waves.

High-end ground-based facilities for cutting-edge astronomy

The ESO observatories are located in the Chilean Atacama Desert at altitudes between 2,000 and 5,000 metres. This choice of location is due to the fact that a much larger section of the Milky Way can be observed from the southern hemisphere than from the northern hemisphere. Furthermore, higher altitudes provide better atmospheric conditions, around 95 percent of the sky can be observed from these locations in Chile.

ESO provides astronomers with state of the art instruments for research. The variety of these instruments has expanded gradually over the years.

- ESO has operated a range of medium-sized telescopes at the La Silla observatory since its foundation in the 1960s. These include the Swiss 1.2-metre Leonhard Euler telescope belonging to the Geneva Observatory.
- The Very Large Telescope (VLT)allows observations of visible and infrared light at the same time. It consists of four main telescopes which each have a diameter of 8.2 metres. The light from these four telescopes can be combined, allowing the positions of stars and other celestial objects to be pinpointed with extreme accuracy. Furthermore, there are four auxiliary telescopes, each with a mirror of 1.8 metres in diameter.
- The Atacama Large Millimeter/submillimeter Array (ALMA) is a novel telescope array consisting of 66 high-precision antennas. It is used to investigate the universe at the millimetre and submillimetre level. ALMA is a joint international project operated by ESO along with US and Japanese research institutions.



Artist’s rendering of the Extremely Large Telescope in operation on Cerro Armazones in northern Chile. Currently under construction, the 39 meter wide telescope is shown using lasers to create artificial stars high in the atmosphere to cancel out the atmosphere impact on imaging. Illustration: ESO/L. Calçada

Towards a telescope of all superlatives

The Extremely Large Telescope (ELT) is currently under construction at ESO. It will be the largest telescope in the world. The ELT’s primary mirror will have a diameter of 39 metres, composed of 798 hexagonal segment mirrors. The ELT is planned to begin operation in 2027, and is likely to fundamentally change the way we perceive the universe. The project includes studies on various objects such as planets surrounding other stars, the very first objects in the universe, supermassive black holes and the nature and spread of dark matter and dark energy.

60 years of ESO discoveries

Major discoveries made with ESO’s telescopes include a supermassive black hole in the middle of the Milky Way. The finding that the universe is expanding at increasing speed – another important discovery that was made with the aid of the ESO telescopes in La Silla – was honoured with the Nobel Prize in Physics in 2011. Furthermore, in 2004 ESO instruments succeeded in taking the first photograph of an exoplanet, i.e. a planet outside of our solar system. In the spring of 2019 ESO telescopes also contributed significantly to the first image of a black hole.

Switzerland’s participation in ESO

Switzerland has been a member of ESO since 1982. The membership is essential to Switzerland as a centre of research, as the Swiss scientific community uses the data collected by ESO instruments. The quality and variety of instruments offered by ESO facilitates world-leading research. In addition to the scientific benefits of the instruments and the international network, Swiss research institutions and companies are able to work on the construction of the ESO research facilities.

The 1.2-metre diameter Euler Telescope that was built in Switzerland is operated by the University of Geneva at the La Silla site. It is used to search for planets outside of our solar system, known as exoplanets. The first exoplanets were discovered in 1995 by two Swiss professors, Michel Mayor and Didier Queloz, at the University of Geneva. In 2019 they received the Nobel Prize for their work.

ESO is an important organisation for Swiss research institutions, in activities such as the development of new instruments. One of these is ESPRESSO, a spectrograph that forms part of the Very Large Telescope (VLT) and explores rocky Earth-like exoplanets. The principal investigator for the ESPRESSO project is Professor Francesco Pepe from the University of Geneva. The University of Bern is also involved and other Swiss institutions participate in developing instruments for the ELT as well. ETH Zurich is part of the consortium that is working on METIS, a powerful imager and spectrograph. The emeritus Professor Willy Benz from the University of Bern chaired the ESO Council from 2018 to 2020.

Square Kilometre Array Observatory (SKAO)

The Square Kilometre Array Observatory (SKAO) will use cutting-edge ground-based radio telescopes to observe the sky at the highest resolution and sensitivity. With a network of over 100,000 antennas in Australia and South Africa, the SKAO will conduct observations that have the potential to revolutionise our understanding of the universe and fundamental physics. The SKAO was founded in 2021 and is being constructed in several phases, beginning with the initial SKA1 configuration, which is being realised and commissioned in stages between 2021 and 2030.

Founding year	2021
Members	Australia, China, Italy, Netherlands, Portugal, South Africa, Switzerland, United Kingdom
Legal form	Intergovernmental organisation under international law
Host state	United Kingdom
Locations	Jodrell Bank (United Kingdom) Australia, South Africa (antenna host states)
Research field	Astronomy and astrophysics
Construction budget	EUR 1’986 million
Swiss status	Member
Swiss budget contribution	1.3%
Website	www.skao.int

Listening to the cosmos

The SKAO’s scientific objectives are very broad. Can we improve our understanding on how Earth-like planets are formed? The SKAO will deliver new insights and answers to this question. In stellar nurseries, the SKAO’s radio telescopes will be able to observe protoplanetary disks and research the emission spectrum of neutral hydrogen found there. This is the key to better understanding these unique planets that are so similar to Earth.

Looking out into our closer galactic surroundings also raises unanswered questions. For example, we are still unable to explain why the corona of the Sun is hotter than its surface, or what processes dominate the dynamics and development of solar storms. Thanks to fine-resolution images of the sun in the radio frequency range, the SKAO will deliver forecasts of the ‘weather’ in our solar system. This capability can turn out to be useful as solar storms have a direct impact on communication satellites or infrastructure on Earth.

The SKAO will also look into the centre of our galaxy, the Milky Way, which is where the nearest black hole is located with still many secrets to be revealed. Furthermore, observations in the radio frequency part of the spectrum can explore far distant galaxies and how their clusters form. The SKAO will be able to use these observations to measure forces arising from dark energy, the mysterious phenomenon responsible for the expansion of the universe.

100’000 antennas on two continents

The SKAO examines that part of the electromagnetic spectrum that has lower energies and longer wavelengths than those of visible light. Together with the telescopes of ESO and the CTAO, the SKAO telescopes cover a broad section of this electromagnetic spectrum.

The SKAO radio telescopes will revolutionise radio astronomy. They will be able to observe a large area of the sky in fine resolution and with high sensitivity at the same time. This is made possible by placing thousands of active

The SKAO radio telescope array will combine signals from nearly 100,000 antennas to form a virtual telescope with an aperture equal to the distance between Africa and Australia. Illustration: SKAO

phased array antennas in Australia, and 197 15-metre diameter parabolic antennas in South Africa. The signals from all of these antennas will be combined by supercomputer, and the great distance between them on Earth (up to 3,000 km) allows the SKAO to simulate an enormous radio telescope.

The SKAO will generate exabytes of data, which is approximately ten times the data output at CERN. Storing and processing such massive volumes requires extensive resources, but first and foremost new ways of optimising and increasing the efficiency of such operations. Researchers at Swiss higher education institutions have been working in this area for a decade already, and will contribute their solutions to the SKAO.

The facilities in South Africa and Australia will be controlled from Jodrell Bank in the UK. The SKAO is being constructed in several phases, beginning with the initial SKA1 configuration, which is being realised and commissioned in stages between 2021 and 2030.

Swiss astronomy goes multi-messenger

Swiss participation in the SKAO will promote the work of the local radio astronomy and astrophysics research community. Switzerland’s membership is a natural extension of its involvement in international research organisations that use Earth-based telescopes. Participation in the SKAO, ESO and the CTAO will give scientists in Switzerland access to data from the entire electromagnetic spectrum, allowing them to conduct top-level research into multi-messenger astronomy.

In Switzerland itself there are more than 50 scientists working on SKAO-related projects at different institutions. They are making an important contribution to hardware development, such as high-capacity storage and chips that can turn analogue signals into digital ones. Swiss research also leads the way in software development, as new methods for data compression and extraction as well as the use of artificial intelligence are being developed for use with SKAO data.

Cherenkov Telescope Array Observatory (CTAO)

The objective of the Cherenkov Telescope Array Observatory (CTAO) is to observe short-wave light from space using ground-based telescopes. Observing flashes of Cherenkov light in the atmosphere will enable conclusions to be drawn about gamma rays from far-off galaxies and supernovas. The planned CTAO research programme is broad, aimed at answering major questions in astrophysics and particle physics, as well as where these fields meet, within the realms of astroparticle physics.

Founding year	2023 (scheduled)
Participating countries and organisations	Australia, Austria, Czech Republic, France, Germany, Italy, Japan, Poland, Slovenia, Spain, Switzerland, United Kingdom, ESO
Legal form	European Research Infrastructure Consortium (ERIC)
Host state	Italy
Locations	Bologna (Headquarters) Berlin (Science Data Management Centre) Paranal (Chile) La Palma (Canary Islands, Spain)
Research fields	Astronomy, astrophysics, particle physics, astroparticle physics
Construction budget	EUR 331.3 million
Swiss status	Founding observer
Swiss budget contribution	0.2%
Website	www.cta-observatory.org/

cta cherenkov telescope array

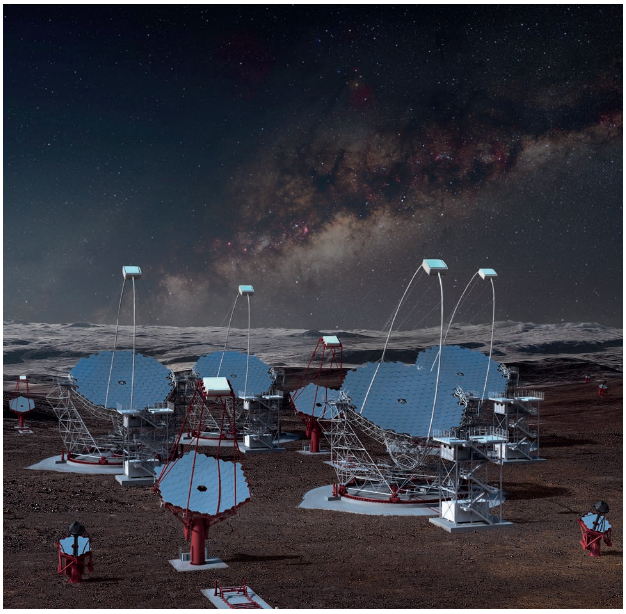
Exploring the most extreme environments in the universe

CTAO will be the world's largest observatory for earth-based gamma spectroscopy, using telescopes ten times more sensitive than current instruments. The arrays will permit unprecedented accuracy in the detection of high-energy gamma rays. With over 60 telescopes, CTAO's two sites in the northern and southern hemispheres will offer an enormous field of view and collection area compared with current projects.

Gamma rays are the most energetic form of electromagnetic radiation. They originate in parts of the universe where subatomic particles receive a great deal of energy, also known as cosmic particle accelerators. These are generally environments in which there have been extreme events such explosions, eruptions or strong jets of particles in the vicinity of supermassive black holes.

As the earth atmosphere offers full protection from gamma radiation, gamma rays can only be measured indirectly on earth's surface. When gamma rays hit the atmosphere, they produce new particles that are accelerated giving off a weak blue light known as Cherenkov light. The CTAO telescopes will measure this light and are able to draw conclusions about the energy, direction and possible sources of the gamma rays.

CTAO will examine the origin and role of relativistic cosmic particles, explore extreme environments in our universe, and push the boundaries of physics. Observation targets are galactic centres, the Large Magellanic Cloud, the areas in which stars and galaxies are born, and galaxy clusters. Scientific applications range from high-energy astrophysics to elementary particle physics and cosmology. CTAO will therefore facilitate cooperation and exchange between researchers from these different domains.



Artistic rendering of all three classes of the CTAO telescopes at the southern hemisphere at ESO's Paranal Observatory. Illustration: Gabriel Pérez Diaz (IAC)/Marc-André Besel (CTAO) / ESO / N. Risinger (skysurvey.org)

Combining infrastructures on three continents

Technical coordination and management for the preparatory phase for CTAO began in Bologna in 2016. The scientific coordination of measurement campaigns, software maintenance and data processing are handled at the Science Data Management Centre in Berlin. With some 100 petabytes expected by 2030, the volume of data to be processed is immense. This also poses major IT challenges that will require new developments on the data management front.

After thoroughly evaluating potential telescope array sites in the northern and southern hemispheres, CTAO opted for La Palma in the Canary Islands and Paranal in Chile. The CTAO telescopes on La Palma will observe the low- and medium-energy ranges of gamma radiation. Four large-sized telescopes with a diameter of 23 metres and nine medium-sized telescopes with a diameter of 11.5 metres are planned to achieve this. This location will therefore be primarily responsible for observing extragalactic physics phenomena.

In the southern hemisphere, the CTAO telescopes will be located close to the ESO site in the Atacama Desert. Here, observations will concentrate mainly on the medium- and high-energy ranges. No fewer than 14 medium-sized telescopes and 37 small-sized telescopes with diameters of 11.5 metres and 4.3 metres respectively will be installed over an area of more than 3 square kilometres. It is planned that four large-sized telescopes will be placed at the site in the next phase.

Towards five years of construction

The CTAO ERIC legal structure is expected to enter into force in the first half of 2023. This will mark the start of the CTAO construction and operation phase. Construction will first put the infrastructure in position, before installing the telescopes. This building work is scheduled to take place in parallel in the northern and southern hemispheres. The facilities should produce their initial observations after approximately five years, in 2028.

Multiple opportunities for Switzerland

The Universities of Zurich and Geneva, alongside ETH Zurich, have been involved in CTA projects since the early 2000s. They work under the aegis of the CTA Consortium, which has done the conceptual preparatory work for infrastructure construction. In view of its privileged position in project development, the University of Geneva has headed efforts together with support from the federal government to consolidate the user base in Switzerland since the beginning of 2020. This is necessary should Switzerland wish to join the CTAO ERIC in the future.

Switzerland pursues top-level research in astroparticle physics. The local research community has a great interest in making significant contributions in the areas of instrumentation and data processing and is ideally placed to do so. For example, ETH Zurich is developing cameras for the CTAO telescopes, and EPFL in Lausanne has experience in building robots to position telescopes.

Aside from its intrinsic interest for particle physics, astronomy and uniting the two domains, CTAO is of enormous scientific interest to Switzerland and the world as a whole for the data production and analysis techniques it will use, including machine learning and modern imaging techniques. It will also facilitate a network of contacts with specialist industries that might become involved in building telescopes.

European Molecular Biology Laboratory (EMBL)

The European Molecular Biology Laboratory (EMBL) is one of the world leading life science research facilities. It is composed of six sites throughout Europe. EMBL promotes cooperation in fundamental research in molecular biology. It provides the infrastructure needed to achieve this, such as extremely powerful microscopes and databases. Further, it participates in the ongoing development of cutting-edge instruments for modern biology.

Founding year	1974
Members	Austria, Belgium, Croatia, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Israel, Italy, Lithuania, Luxembourg, Malta, Montenegro, Netherlands, Norway, Poland, Portugal, Slovakia, Spain, Sweden, Switzerland, United Kingdom
Legal form	Intergovernmental organisation under international law
Host state	Germany
Locations	Heidelberg (Germany), Hinxton (UK), Grenoble (France), Hamburg (Germany), Rome (Italy), Barcelona (Spain)
Research field	Life sciences
Annual budget	EUR 334 million
Swiss status	Member
Swiss budget contribution	1.7%
Website	www.embl.org

EMBL

Promoting molecular biology on an international level

The European Molecular Biology Laboratory (EMBL) is dedicated primarily to fundamental research in molecular biology. In addition to developing new technologies, it is committed to providing standard and advanced training for researchers, with a particular focus on emerging talent.

EMBL supports molecular biology research with a range of projects that it undertakes each year in partnership with the laboratories of its member states. The research fields covered, range from developmental and cell biology to immunology and structural biology. With its latest research programme, Molecules to Ecosystems, EMBL will begin to explore new areas of research, such as planetary biology. This new discipline will explore the biology of individuals, populations and ecosystems in molecular terms and also addresses societal issues related to the health of our planet.

EMBL databases have become vital to the work of the global life sciences and biomedicine research community, with the website receiving approximately 65 million web requests per day. EMBL's findings in such diverse areas as spectrometry, microscopy and protein crystallisation have resulted in over 1,000 inventions and 450 patents. New spin-off companies are formed on a regular basis.

Active at six sites in Europe

EMBL is composed of six sites in Europe:

- Heidelberg (Germany): EMBL headquarters hosts about 800 collaborators and is home to around 50 research groups. Researchers in Heidelberg also have access to a whole variety of scientific services in areas such as genomics, proteomics and chemical biology. The EMBL Imaging Centre was opened on the Heidelberg campus in 2022. This state-of-the-art infrastructure combines the very latest in imaging technologies, including some that are not yet commercially available. It offers research and industry a range of instruments for light, fluorescence and cryo-electron microscopy.

The EMBL is made up of six sites across Europe. The headquarters are located in Heidelberg. Photo: EMBL

- Hinxton, Cambridge (United Kingdom): EMBL-EBI, the European Bioinformatics Institute, hosts 850 collaborators and offers freely available data and bioinformatics tools. EMBL-EBI has grown into EMBL's largest site, and is a pioneer in the field of bioinformatics. It also houses a node of the ELIXIR research infrastructure network.
- Grenoble (France): This EMBL site specialises in structural biology research. EMBL Grenoble works closely with the European Synchrotron Radiation Facility (ESRF) and the Institut Laue-Langevin (ILL), which are located on the same campus.
- Hamburg (Germany): The EMBL site in Hamburg is situated on the campus of the DESY accelerator research centre, the main shareholder in the European XFEL. As in Grenoble, the emphasis here is on structural biology.
- Monterotondo, Rome (Italy): EMBL's site in Italy is a centre for epigenetics (the study of changes in organisms that originate at the level of gene expression rather than gene sequences), and neurobiology.
- Barcelona (Spain): Tissue biology and disease modelling are the core fields at the youngest EMBL site, opened in 2017. Work here focuses on humans and their health, more than at any of the other sites.

Cryo-electron microscopy leads to Nobel Prize in Chemistry
In 2017 Jacques Dubochet, Emeritus Professor of Biophysics at the University of Lausanne, was awarded the Nobel Prize in Chemistry for his pioneering work in cryo-electron microscopy at EMBL. This method examines biological samples under an electron microscope at temperatures of below –150°C. Since it does not involve fixing samples by removing their water content, biological structures can be imaged in their natural state.

Membership of EMBL offers researchers in Switzerland access to a top-class infrastructure. In particular, they depend very heavily on the EMBL-EBI databases for their work.

European X-Ray Free-Electron Laser (European XFEL)

Commissioned in 2017, the European XFEL research facility generates ultrashort X-ray flashes of very high brilliance. These make it possible to capture the details of viruses at the atomic scale, determine the molecular composition of cells, observe elements of the nanocosmos, and film chemical and biological reactions. The underground facility in Schenefeld, near Hamburg in Germany, offers opportunities for top-flight research that are globally unique.

Founding year	2009
Members	Denmark, France, Germany, Hungary, Italy, Poland, Russia, Slovakia, Spain, Sweden, Switzerland, United Kingdom
Legal form	Convention under international law; private company under German law
Host state	Germany
Location	Schenefeld, Germany
Research fields	Materials science, chemistry and biochemistry
Annual budget	EUR 145.7 million
Swiss status	Member
Swiss budget contribution	1.47%
Website	www.xfel.eu

Studying the heart of matter with an unique X-ray laser

The European XFEL is the world's largest X-ray laser. This fourth-generation synchrotron radiation source based on a linear accelerator is used for the scientific exploration of materials and chemical and biochemical processes right down to the atomic level. Synchrotron light sources are large pieces of equipment whose use can be compared with that of a simple microscope. The light that is generated and applied is nonetheless able to examine much smaller structures than optical microscopes can.

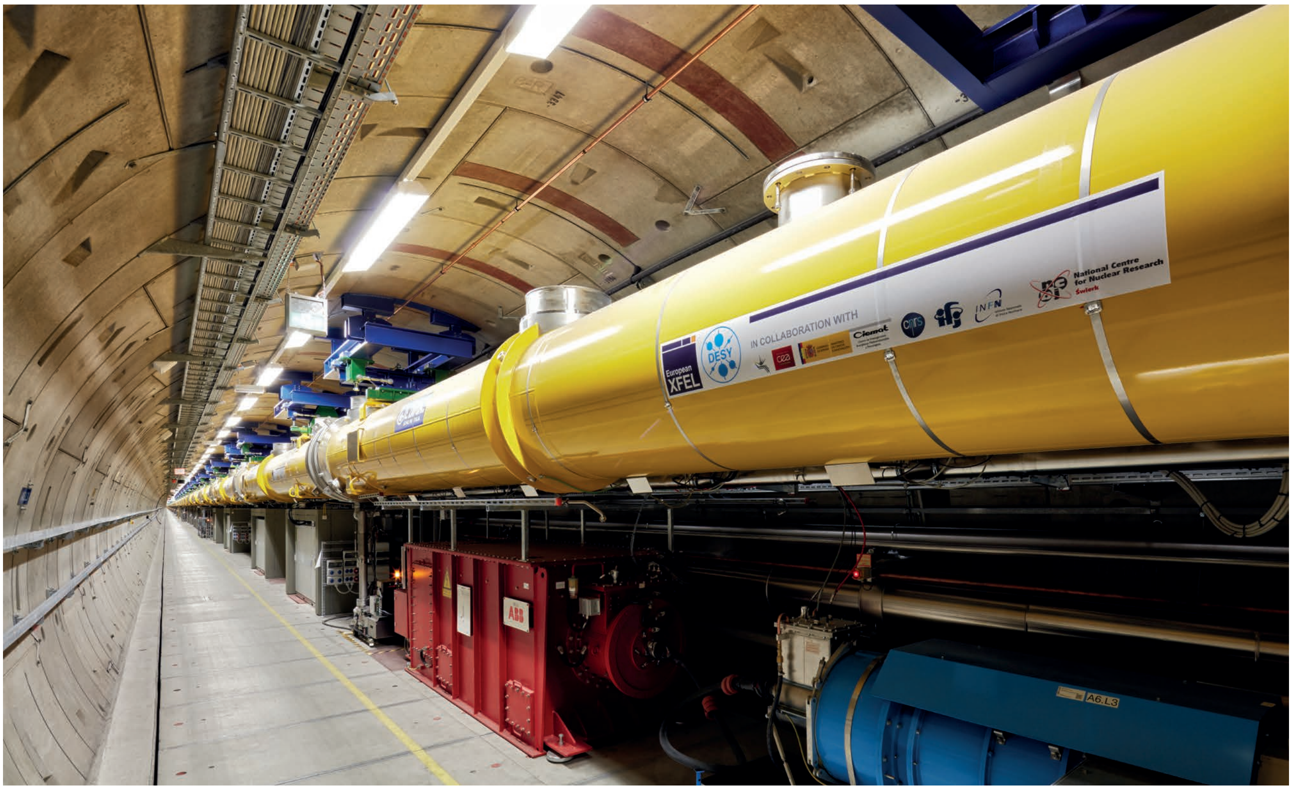
The X-ray flashes produced by the European XFEL allow scientists to decode the atomic details of viruses and cells, make three-dimensional images of nanostructures, and investigate processes that happen within planets and stars. The widest range of natural science fields benefit from the research facility, including biology, medicine, pharmacology, chemistry, materials science, physics, astrophysics, energy research, environmental research, electronics, nanotechnology and photonics.

A temporal resolution of a few femtoseconds

The X-ray laser is located in underground tunnels. With a total length of 2.1 kilometres, including the 1.7 kilometre long linear accelerator, the European XFEL is the longest superconducting linear accelerator in the world.

Far more X-ray flashes per second are produced at the facility than in any other research facility. The flashes achieve an extremely high level of brilliance and are also extremely short, usually lasting only a few femtoseconds, i.e. a few quadrillionths of a second. These outstanding properties make it possible to film ultrafast processes in chemical reactions and changes in biomolecules.

To produce the X-ray flashes, bunches of electrons are first accelerated to high energies. Once they have enough energy, they are sent through dedicated arrangements of magnets, known as undulators, where the particles emit X-rays. The undulators enhance the light to such an extent that very short and intense X-ray flashes are ultimately generated.



European XFEL produces 27,000 X-ray flashes per second using the accelerator: a performance that is unique in the world.
Photo: European XFEL / Heiner Müller-Elsner

The X-ray flashes produced by the European XFEL permit a whole variety of experiments at several different measuring stations. The basic setup of these experiments is the same. Depending on requirements, optical elements such as mirrors, gratings, slits or crystals can be used to widen, focus, filter or weaken the X-ray flashes. Samples interact with X-ray flashes in experimental stations. The outcome is observed by special detectors, and the resulting data is prepared for analysis.

Synergies with the national facility SwissFEL
Given the scarcity of XFEL facilities, and the whole range of opportunities that they open up, there is great and growing demand for them from researchers around the world. Switzerland has therefore joined the European XFEL research infrastructure, but also constructed its own national facility of the same type (SwissFEL) at the Paul Scherrer Institute (PSI). The two facilities, SwissFEL and the European XFEL, are complementary. Researchers can conduct experiments at SwissFEL that are not possible at the European XFEL, and vice-versa. In addition, research experiments for the European XFEL can be prepared at SwissFEL, giving SwissFEL users a head start. The overlap in construction between the two facilities generated considerable synergies. Specifically, PSI was able play a major part in designing and constructing the European XFEL, and then take advantage of the acquired experience to build SwissFEL.

Participation in the European XFEL benefits not only Swiss researchers, but also the Swiss high-tech industry. The Swiss economy in turn profits from this niche market. Swiss companies, for example, have developed unique X-ray detectors. The return for Swiss industry in association with European XFEL membership was significant throughout the construction phase, and should remain so while the facility is in operation. Industry also has an interest in using the European XFEL, for example within the pharmaceutical sector to develop new drugs.

European Synchrotron Radiation Facility (ESRF)

The European Synchrotron Radiation Facility (ESRF) in Grenoble, France, is one of the most powerful light sources in the world. Thanks to its Extremely Brilliant Source (EBS) upgrade programme, which generates X-rays of unmatched brilliance and coherence, the ESRF offers researchers from multiple disciplines radically new ways of studying matter down to the subatomic level.

Founding year	1988
Members	Belgium, Denmark, Finland, France, Germany, Italy, Netherlands, Norway, Russia, Spain, Sweden, Switzerland, United Kingdom
Legal form	Convention under international law; company under French law
Host state	France
Location	Grenoble (France)
Research fields	Structural biology, materials science, electron structure, magnetism and dynamics, matter in extreme states, complex systems and biomedicine, X-ray research, cultural heritage
Annual budget	120 million d'euros
Swiss status	Member
Swiss budget contribution	4%
Website	www.esrf.fr

ESRF
The European Synchrotron

X-rays for science

Founded in 1988, the mission of the ESRF is to operate one of the most powerful sources of synchrotron radiation in the world, and to conduct its own research into X-rays. With the brilliance and quality of its light source, the ESRF gives its members access to a type of super-microscope that reveals the structure of matter in all its complexity. The ESRF thus offers scientists unparalleled instruments by which to explore condensed and living matter, from physics to structural biology to archaeology, in addition to health and life sciences.

ESRF research into X-rays has unlocked the development of the technology required to create the fourth generation of ultra-bright synchrotron radiation sources, whether in the form of synchrotrons or free-electron lasers (see European XFEL).

Ten trillion times brighter than medical X-rays

The ESRF hosts the most intense source of synchrotron radiation in the world, producing X-rays ten trillion times brighter than medical X-rays. This exceptional form of radiation is produced by accelerating electrons to very high energies and then injecting them into a storage ring with a circumference of 844 metres. The accumulated energy is then released in the form of X-rays to 40 experiment stations.

Also known as beamlines, these stations are optimised for specific techniques and equipped with cutting-edge instrumentation. In operation 24 hours a day, 7 days a week, they are used not only by academic scientists but also by companies based in the Member and Associate States of the ESRF.

In 2009 the ESRF embarked upon an ambitious modernisation programme involving investment totalling EUR 330 million. The first phase between 2009 and 2015 improved beamline instrumentation. The second phase, the Extremely Brilliant Source (ESRF-EBS), resulted in 2021 in the ESRF commissioning the most powerful storage ring ever made. This was based on a unique technology developed under its own research programme, and underscored the ESRF's pioneering role in synchrotron radiation.

X-rays with exceptional properties are produced at ESRF by very high energy electrons circulating in a storage ring, a circular tunnel with a circumference of 844 m. Photo: ESRF/VUEDICI

Excellence and responsiveness for cutting-edge results

In 2012 Robert Lefkowitz and Brian Kobilka were awarded the Nobel Prize in Chemistry for their work on G-protein-coupled receptors (coupling sites on cell walls). In 2009 the Nobel Prize in Chemistry went to Venki Ramakrishnan, Ada Yonath and Thomas A. Steitz for their work on ribosomes. All of the recipients regularly used ESRF instrumentation for their research.

More recently, the ESRF made significant contributions to understanding the mechanisms underlying the action of COV-SARS-2 and how it affects human organs. Specifically, it provided the first image of a complete patient lung to a scale of 5 microns (0.005 mm).

A strong partnership with Switzerland

Switzerland is a founding member of the ESRF. Researchers from some 20 Swiss research institutions regularly use the ESRF, which grants them between 3.5% and 4% of available beamtime. The instrumentation available at the ESRF complements that at the Paul Scherrer Institute, which operates its own Swiss Light Source synchrotron radiation source, as well the SwissFEL free-electron laser.

Researchers at the University of Bern, for example, collaborated with French colleagues in 2017 to develop a new method to treat brain tumours more effectively. The ESRF infrastructure was used to determine that chemotherapy is more effective when it is combined with microbeam radiation therapy (MRT) instead of with conventional radiation therapy. This simplifies drug delivery to the tumour tissue because it makes the affected areas more reactive.

The Swiss economy also benefits from research at the ESRF. Numerous Swiss companies supply the ESRF with high-tech components and cutting-edge services. Switzerland has a particular reputation for precision guides and even more so for detectors. No fewer than 15 new detectors, developed and produced in Switzerland, were installed in the ESRF beamlines between 2019 and 2021.

Institut Laue-Langevin (ILL)

Since its inception in 1967, the Institut Laue-Langevin (ILL) in Grenoble, France, has been the leading facility for neutron research and technology. Its high-flux reactor (HFR) is currently the world's most powerful source of neutrons for research purposes. Neutrons can be used for research in physics, chemistry, materials and energy, biology and medicine, as well as for archaeological and history of arts investigations.

Founding year	1967
Members	Germany, France, United Kingdom
Scientific members	Austria, Belgium, Czech Republic, Denmark, Italy, Poland, Slovakia, Spain, Sweden, Switzerland
Legal form	Convention under international law; company under French law
Host state	France
Location	Grenoble (France)
Research fields	Materials science, solid state physics, chemistry, crystallography, molecular biology, magnetism, and nuclear, neutron and fundamental physics
Annual budget	EUR 100 million
Swiss status	Scientific member
Swiss budget contribution	2.4%
Website	www.ill.eu

NEUTRONS
FOR SOCIETY

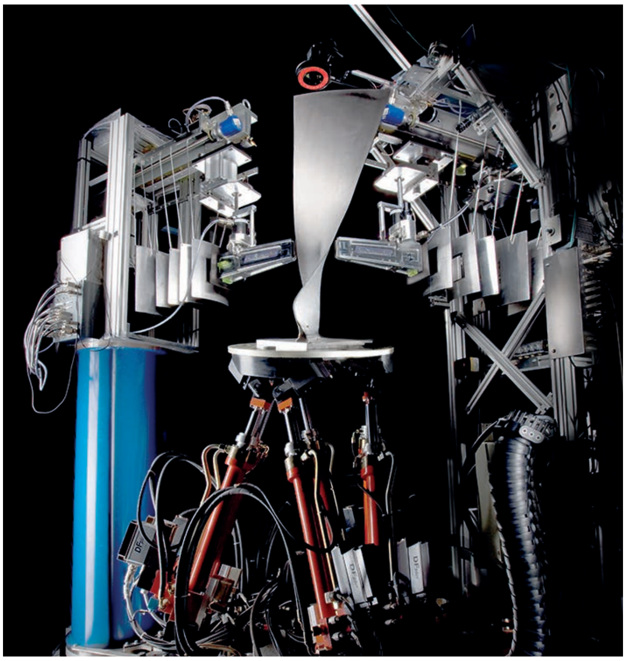
Neutrons for science and society
The Institut Laue-Langevin (ILL) is a leading international centre for neutron science and technology. As a service institute, the ILL also provides researchers from member states and scientific member countries with an excellent source of neutrons for their work.

With no electric charge, neutrons are able to penetrate deep into matter, including metals, making it possible to determine the position of atoms and analyse the way they move. Their own elementary magnetic moment also facilitates the study of magnetic behaviour at the atomic and subatomic scale of the elements. Neutron beams provide information on the properties of matter that cannot be obtained by other means.

The ILL's high-flux reactor also makes a major contribution to the production of innovative radioisotopes for use in clinical cancer research.

38 experimental stations operating 170 days per year
The ILL is centred around its high-flux reactor (HFL), which is available for a total of 170 days a year in three reactor cycles. The reactor feeds 38 state-of-the-art instruments with a very high flux of neutrons. These are divided into five scientific groups: Diffraction, Large-Scale Structures, Spectroscopy, Nuclear & Particle Physics and CRG (collaborative) instruments.

ILL's diffractometers include the SALSA strain imager, which allows to measure the inner deformations of a variety of materials. These measurements are important with regard to safety in the aviation and space industry, for example. The THALES spectrometer permits research into the behaviour of non-conventional superconductors and quantum materials. In great demand by Swiss researchers, these instruments are to be upgraded in partnership with the Paul Scherrer Institute.



SALSA is a diffractometer that measures the internal deformations of various materials. These measurements are important for safety aspects in the aerospace industry. Photo: ILL

Cutting-edge research for over 50 years

Given that research at the ILL began in 1972, its facilities are upgraded regularly. With this in mind, the Millennium Programme was introduced in 2000. Involving investment of over EUR 40 million in each of its two phases, the programme ended in 2018 with the commissioning of WASP, a wide-angle spin-echo spectrometer.

The Endurance Programme, launched in 2016, is aimed at ensuring the scientific competitiveness of the ILL up to the end of the present decade. Estimated to cost EUR 22 million, work is scheduled to end in 2023 so that the ILL is able to meet the needs of research in Europe before it is shut down around 2030. ILL users will then be able to switch to the European Spallation Source (ESS-ERIC), which will have properties that open up revolutionary new possibilities

Outstanding scientific outcomes

In 2017 the structure of the key protein p7, which is essential to the release of the hepatitis C virus, was decoded using ILL instrumentation. This was a crucial discovery for the development of the corresponding drugs, which now benefit millions of people.

In 2021, collaboration between the ILL and the Paul Scherrer Institute resulted in the identification of terbium, a family of radioisotopes that are particularly promising in the fight against various types of tumours. Initial results raise the prospect of large-scale clinical studies.

A field of excellence in Switzerland

Switzerland is a major player in neutron-based research in Europe and globally. It has been part of ILL operations as a scientific member since 1988, on the basis of fixed-term five-year contracts. The research that Swiss scientists conduct at the ILL, especially into magnetism, regularly attracts acclaim for its excellence. This outstanding research has earned Swiss projects an average of 4.6% of the beamtime made available by the ILL since 2014.

The scientific collaboration between Switzerland and the ILL extends to R&D projects conducted jointly by the ILL and the Paul Scherrer Institute in the fields of instrumentation, sampling, and the production of radioisotopes for medicine. Swiss industry benefits from the commercial opportunities offered by the ILL in high-tech sectors, specifically neutron guides.

A very wide range of scientific disciplines interested in the use of neutron beams led to the commissioning of Switzerland's own national neutron source, SINQ, at the Paul Scherrer Institute in 1996. Complementing the opportunities offered by the ILL, the SINQ spallation source has become one of the four main sources in Europe. To ensure that Switzerland remains competitive in this field of excellence in the long term, since 2015 it has been a member of the European Spallation Source (ESS-ERIC), which will eventually offer the brightest neutron beams in the world.

Switzerland therefore has a certain profile in the neutron field by virtue of its user community, its contribution to the overall supply of beamtime in Europe, and as a major centre of excellence in the sciences and technologies underlying the scientific use of neutrons.

European Spallation Source (ESS)

The European Spallation Source (ESS) is a research facility currently under construction in Lund, Sweden. It will become the world's most powerful neutron source for the study of materials. Since neutrons do not interact with an atom's electron shell, they can be used to study the structure and dynamics of atomic nuclei – the very heart of matter – with great precision. Harnessing beams of neutrons in this way provides access to phenomena that remain invisible to technologies based on X-rays or cryo-microscopy.

Founding year	2015
Members	Czech Republic, Denmark, Estonia, France, Germany, Hungary, Italy, Norway, Poland, Spain, Sweden, Switzerland, United Kingdom
Legal form	European Research Infrastructure Consortium (ERIC)
Host states	Sweden, Denmark
Locations	Lund (Sweden); Copenhagen (Denmark)
Research fields	Materials science, life sciences, energy and fundamental physics
Construction costs	EUR 1843 million
Swiss status	Member
Swiss budget contribution (2015–2028)	CHF 135 million
Website	www. europeanspallationsource.se

Beams with an unmatched brightness

Capable of producing neutron beams up to 100 times brighter than those available at current facilities, the European Spallation Source (ESS) will herald a new era of research using neutron beams to probe the structure of matter at the smallest level as well as the laws that govern those structures.

It will therefore offer unique opportunities for both fundamental and applied research. Whether the aim is to screen archaeological artefacts or metal components, to analyse biomolecular processes, to understand the electronic structure and dynamics of a new type of superconductor, or identify the causes of parity violation in elementary particle physics, ESS will make a significant contribution to future scientific development.

A new kind of spallation source

While first-generation neutron sources, such as ILL in Grenoble, use a nuclear reactor that produces a constant flow of neutrons, ESS will use a spallation source, whose unique outputs will be generated by one of the world's most powerful proton linear accelerators. Produced from hydrogen gas heated by microwave power, protons are accelerated to reach 96% of the speed of light before colliding with a tungsten target to scatter the neutrons. These neutrons are then slowed down and routed to approximately 15 instruments that have been designed to make the best use of the intensity and duration of the pulses delivered by ESS, while at the same time meeting the needs of users from very different scientific backgrounds. Thus, instead of a constant, moderate-intensity flow of neutrons, ESS will produce short flashes of neutrons of unparalleled intensity.

Under construction since 2014, ESS is scheduled to welcome its first users to the Lund site in Sweden in 2028. The Data Management & Software Centre is based on the other side of the Øresund strait, in Copenhagen.

Swiss expertise at the service of ESS

Thanks to experience gained as a scientific member of the Institut Laue-Langevin and though the operation of the SINQ spallation source by the Paul Scherrer Institute (PSI), Switzerland was involved in the preparatory work for the construction of ESS from the very beginning. Based on

Aerial view of the ESS construction site in Lund, Sweden. Photo: ESS

Interior view of a neutron guide that will transport and condition the neutron beam, designed and built at PSI with the support of Swiss industry. Photo: Artur G. Glavic, PSI

the decision of the Swiss Parliament of 20 March 2015, Switzerland is committed to support 3.5% of the total costs of implementation of ESS, representing an overall financial investment of an estimated CHF 135 million. Once construction is complete, Switzerland intends to continue its participation in the scientific operation of ESS, thus ensuring that one of its scientific fields of excellence has access to this world-leading infrastructure in the decades to come.

Research institutions and companies are already benefiting from the opportunities presented by the construction of ESS, especially as ESS statutes provide that a significant part of the members' contributions can be delivered in-kind. This means that Member States commit to prepare and supply components and software as well as services. The value of the in-kind contribution is credited to the Member State's contribution. The council of the organisation is steers the allocation of in-kind contributions and to monitor their realization. In addition to granting the access to the research infrastructure, in-kind contributions offer Member States the opportunity to involve their high-tech companies and industry in the project, thereby contributing to their development.

One example of Switzerland's in-kind contribution to the construction of ESS is the ESTIA reflectometer. Switzerland has taken full responsibility for constructing and delivering this instrument, which is built entirely by the Paul Scherrer Institute (PSI). Once ESTIA is commissioned, Switzerland's remaining commitment to the construction of ESS will be reduced by the value assigned by ESS to ESTIA, i.e. EUR 11.3 million. Switzerland plans to meet 70% of its mandatory contributions in the form of in-kind contributions. This solution ensures that a large proportion of the funding is "kept" in Switzerland and therefore benefits Swiss research and economy.

International Thermonuclear Experimental Reactor (ITER)

Nuclear fusion is the Sun's source of energy. This reaction involves very light atomic nuclei merging to form a single heavier atomic nucleus, thus releasing energy. Member states aim to use the ITER experimental reactor to demonstrate the technical feasibility of generating energy using nuclear fusion processes. Success would offer the prospect of a virtually inexhaustible source of energy that does not harm the environment or the climate. The experimental reactor is currently under construction in Cadarache, France.

Founding year	2006
Members	China, European Union, India, Japan, Russia, South Korea, United States
Legal form	Intergovernmental organisation under international law
Host State	France
Location	Cadarache, France
Research field	Fusion research
Website	www.iter.org

Developing a reliable, clean and sustainable energy source

The sun draws its energy from nuclear fusion, a nuclear reaction in which light atomic nuclei merge to form a single heavier nucleus. If the mass of the resulting atomic nucleus is less than the total mass of the original nuclei, then according to Einstein's mass-energy equivalence principle, the difference in mass will be released as energy.

Unlike the nuclear fission process used in the current generation of nuclear power stations, nuclear fusion is extremely safe and does not produce any lasting nuclear waste. It can also use sustainable resources that are well distributed around the world. The aim of fusion research is to develop the technology to use this process on Earth. This would provide humanity with a clean, environmentally friendly and inexhaustible source of energy.

In order to overcome the scientific, technological and industrial challenge presented by the development of fusion as an industrial scale, the European Union, the United States of America, Japan, South Korea, China, Russia and India decided to join forces in 2006. Together, they launched ITER as a world-leading fusion research project.

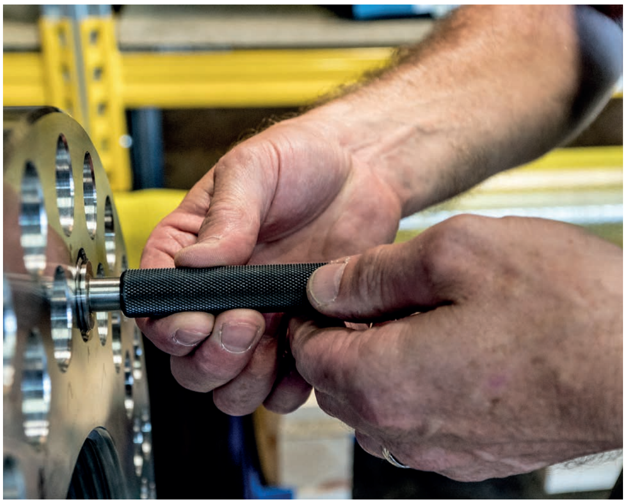
The aim of the ITER project is to build an experimental reactor designed to demonstrate that it is technically possible to produce substantial amounts of energy on Earth using nuclear fusion. From an input of 50 megawatts of energy, ITER is expected to generate up to 500 megawatts in the form of heat. ITER will also create and maintain the very first burning plasma, i.e. a plasma in which the fusion reaction becomes the primary source of heat for the nuclear reaction to be self-sustained. Furthermore, ITER will produce one of the fuels needed for the reaction, tritium, in its vacuum vessel.

A colossal construction site

The ITER experimental thermonuclear fusion reactor has been under construction since 2007. It is due to be phased into operation by 2030, when it should be possible to produce the first plasma. The first significant nuclear experiments are expected to start in 2035.

The heart of the ITER facility is a machine known as a tokamak: a toroidal vacuum vessel in which the plasma is magnetically confined. This is where the plasma is generated and heated in order to trigger the fusion reaction. This reaction should then be self-sustaining and produce a positive energy balance. With a plasma radius of 6.2 metres and a plasma volume of 840 cubic metres, the ITER tokamak will be the largest machine of its kind anywhere in the world. The plasma it generates will have a temperature of 150 million °C. This is ten times the temperature

Aerial view of the ITER construction site in Cadarache, France. The central building includes the assembly hall and the tokamak pit. Photo: © ITER Organization



The Swiss company Nord-Lock AG has developed «Superbolt» multi-bolt tensioners for ITER at the request of Japanese companies. They are unique in that they are able to withstand the required operational and cyclic loads and can operate at temperatures of up to -269°C, close to absolute zero. Photo: Swiss IKC Nord-Lock

inside the sun, where the very high gravitational force allows fusion reactions to occur at lower temperatures than on Earth. Conversely, the superconducting magnets designed to prevent the plasma from reaching the walls of the vacuum vessel will be cooled down to near absolute zero, i.e. -269°C. The resulting temperature gradient will most likely be the largest in the world. In addition, 8,000 tonnes of steel will be needed to ensure a functional vacuum environment in the 14,000 cubic metres vacuum vessel. The entire ITER site covers an area of 180 hectares.

The overall management of the project is provided by the ITER Organization. The partner countries have agreed on an infrastructure consisting of eleven separate sections. The European Union is building five of them, with the other partner countries each supplying one of the remaining parts of the construction.

To ensure that the acquired knowledge and expertise gained throughout the process of realising ITER is disseminated to all participants in the project, around 90% of the contributions to the ITER Organization are delivered in the form of equipment, parts and services, thus enabling all parties involved to build up their own nuclear fusion industry.

Switzerland as a pioneer in nuclear fusion

Switzerland has been a major player in fusion research since the creation of the Swiss Plasma Center (SPC) at EPFL in the 1960s. It provides the fusion research community with world-renowned expertise and unique facilities. The SPC operates the Tokamak à Configuration Variable (TCV), which is an exclusive facility dedicated to the optimisation of plasma performance. It also provides leading expertise in the field of microwave radiation heating systems. Furthermore, the SPC hosts the SULTAN facility, which is the only facility able to test and approve all ITER superconducting strands. Finally, the SPC contributes significantly to the understanding and simulation of the behaviour of the plasmas found at the heart of ITER.

Switzerland’s involvement in ITER is not only limited to the research carried out at the Swiss Plasma Center. The University of Basel is also contributing to the project and a range of Swiss companies are supplying components for the construction of ITER, in fields such as low-temperature technology (cryotechnology), high-voltage grid components, plasma diagnostics, metrology and vacuum technologies.

Between 2007 and 2020 Switzerland was involved in the realisation of ITER as a member of Fusion for Energy, the joint European undertaking charged with delivering the European contribution to ITER. In the absence of an agreement on the financing of the Swiss participation in Fusion for Energy from 2021 onwards, the Swiss participation is currently suspended. However, the Swiss research community is still playing an active part within ITER through institutional collaboration agreements between the University of Basel and the ITER Organization on the one hand, between the Swiss Plasma Center and Fusion for Energy on the other hand, as well as through commercial contracts awarded to Swiss companies.