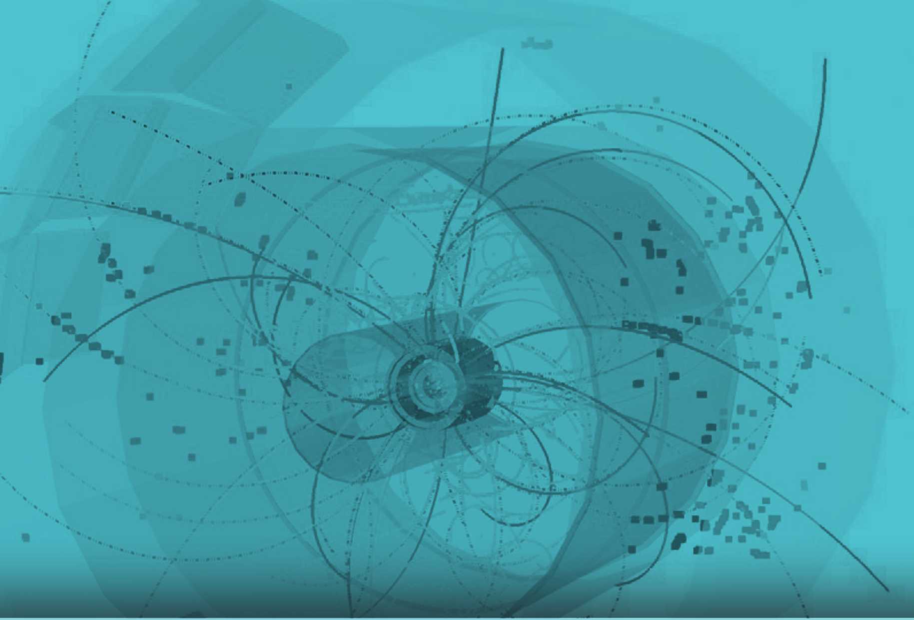
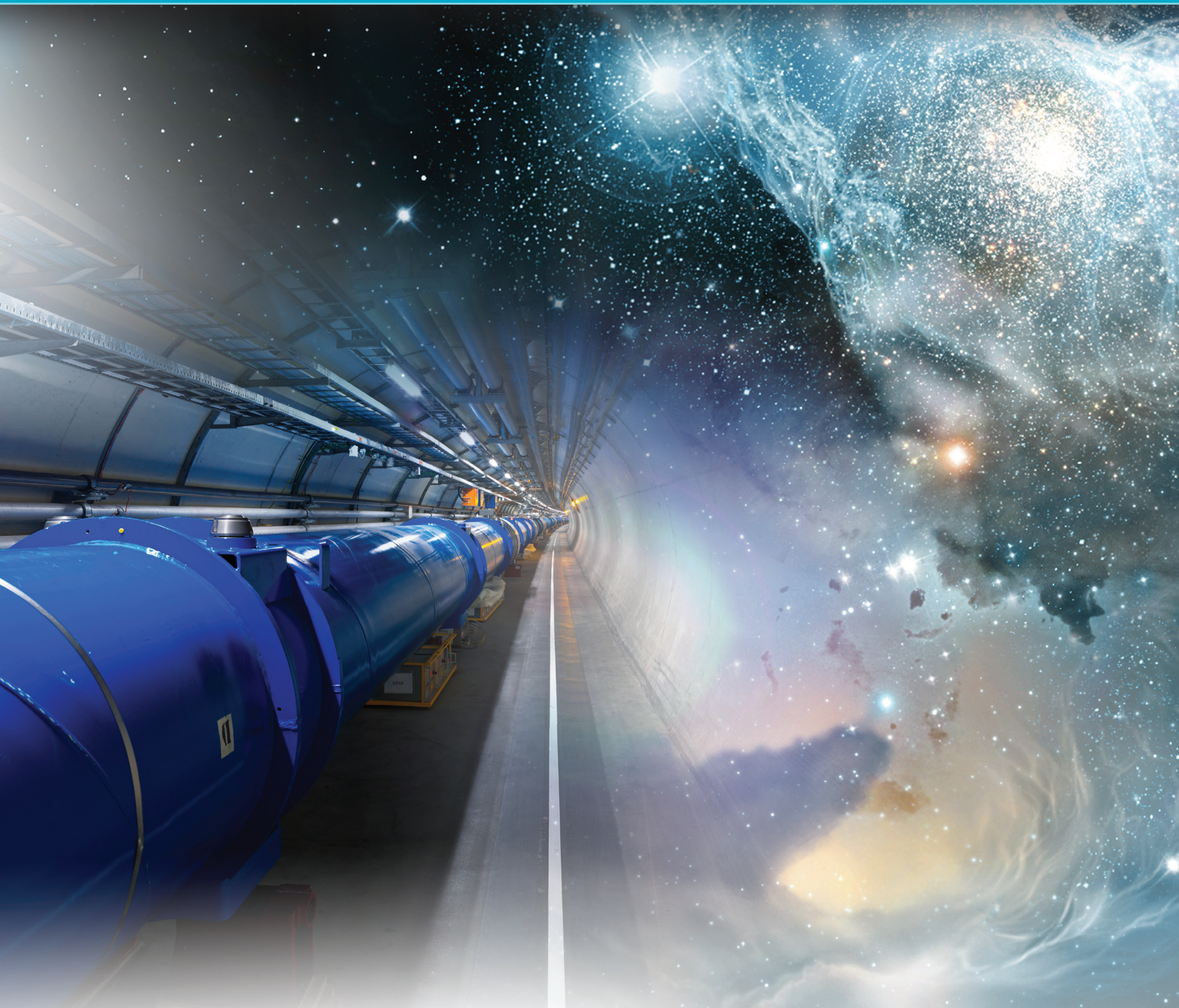
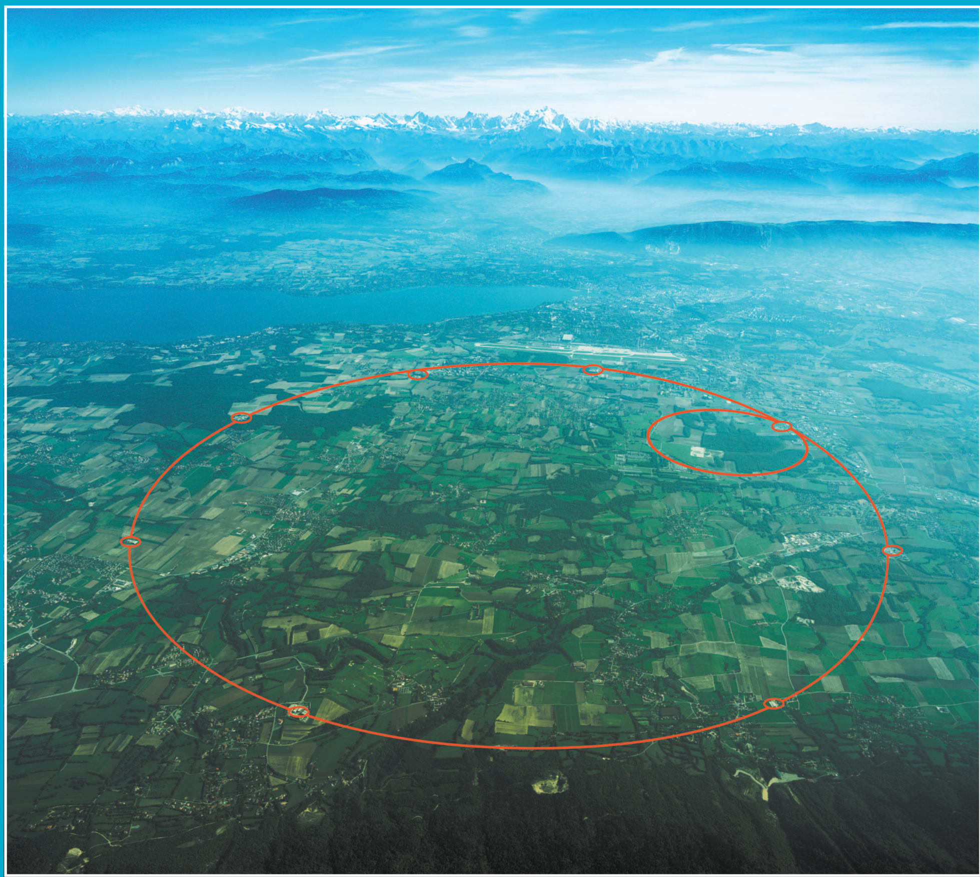


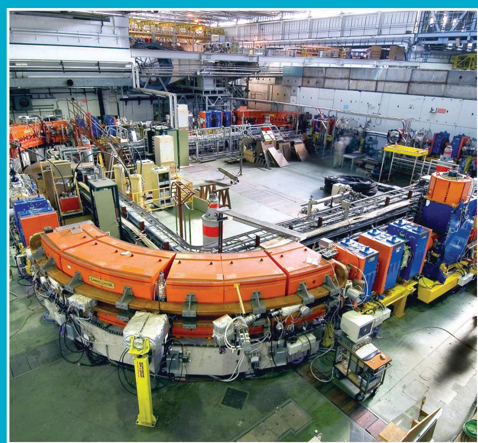
The complex and sophisticated tools of particle physics are rich sources of new concepts, innovation and groundbreaking technologies, which benefit various applied research disciplines and eventually find their way into many applications that have a significant impact on the economy and society.

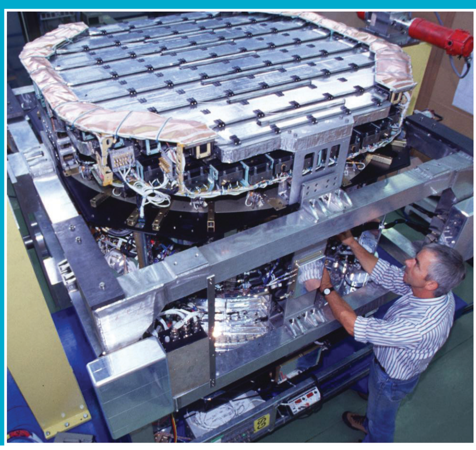
Particle physics, a key driver for innovation

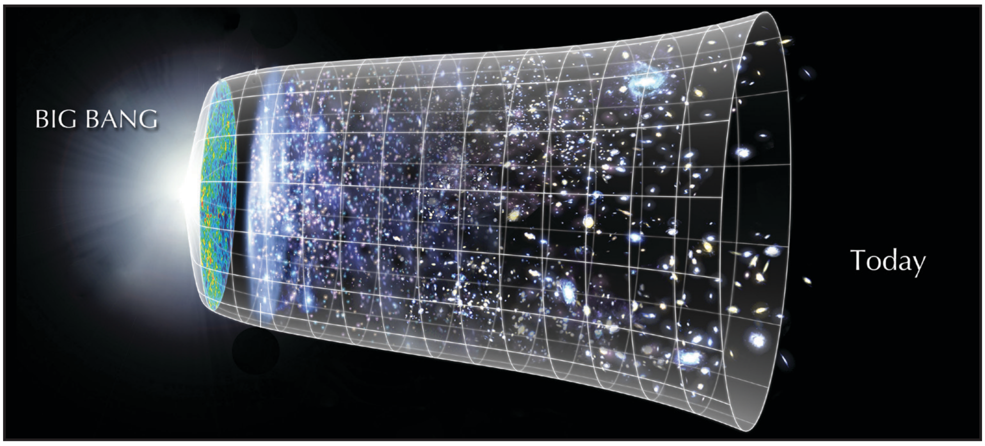
Facing Europe's socio-economic challenges











Particle physics at the heart of human cultures and lives

The everlasting quest for meaning and understanding

Since ancient times, mankind has been driven by the quest for meaning and understanding, observing the vastness of the visible Universe, the immense variety and complexity of structures and phenomena on Earth, and the fragility of the human beings confronted with them. Over time, mankind has transformed this fascination into a quest for meaning and understanding and has developed a scientific approach, which consists of reducing this apparent complexity and diversity of Nature to a set of elementary principles, components and forces.

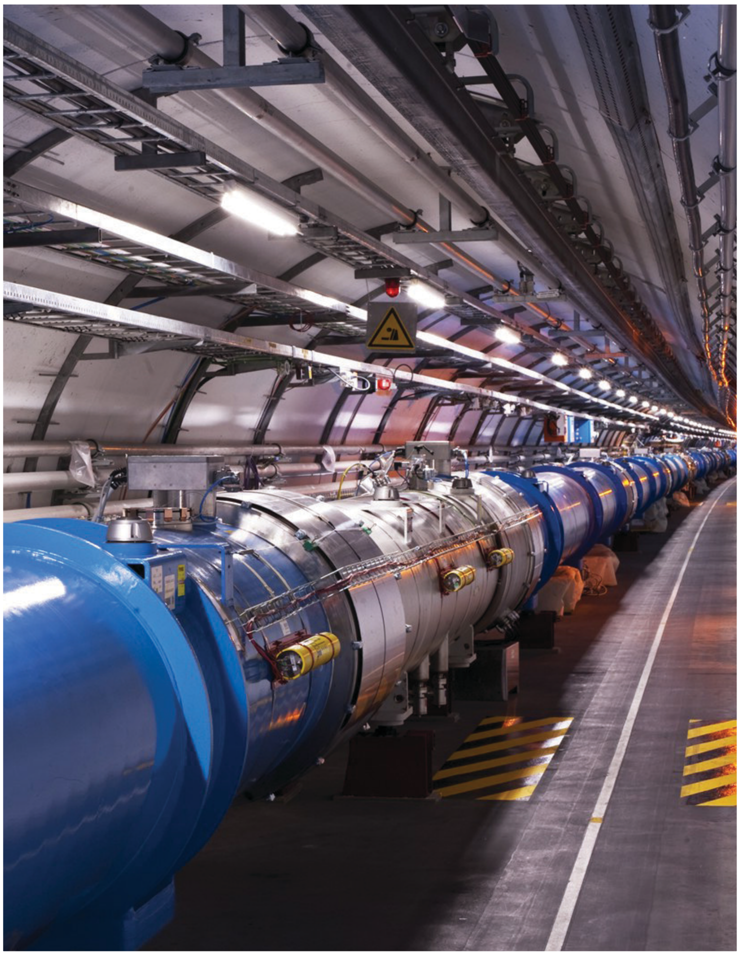
Today, physical sciences encompass various disciplines such as particle and nuclear physics, chemistry, astronomy, astrophysics and cosmology, which study this multifaceted environment at different scales ranging from the extremely small to the infinitely large. Mathematical techniques provide the various physics disciplines with tools that bring into play the basic components and forces, and have the capability to model the behaviour of Nature. Stars are the basic components of astronomy, while quarks and leptons, as the smallest constituents of matter, are those of particle physics. Gravity, electromagnetism, and the weak and strong nuclear forces act on all forms of matter with strengths that vary according to the size of the basic components. For instance, at the scale of particle physics, gravitational effects are negligible in comparison with the nuclear forces, whereas, at the scale of astronomy, massive stellar objects generate strong gravitational effects that even affect the trajectory of light rays passing nearby.

In conjunction with astrophysics and cosmology, particle physics research seeks answers to the fundamental nature of the physical Universe and its evolution over the last 13.7 billion years: what are matter and energy, space and time? Nuclear physics shows how the fundamental building blocks from the early Universe combine to make stable and unstable chemical elements today and, for example, how their interactions power the Sun and the stars.

The Standard Model provides a comprehensive understanding of the effects of electromagnetism and nuclear interactions on the elementary particles and constitutes the foundation stone of particle physics. Parts of the Standard Model have been validated by the recent discovery of the $W^{\pm}$ and Z^0 particles at CERN's Super Proton Antiproton collider in 1983 and by the observations of the predicted top quark and the tau neutrino at FNAL's Tevatron (US) in 1995 and 2000. In spite of this

Accelerator physics is a rich source of Nobel laureates

Since 1936, as many as 24 of the 69 Nobel prices awarded for physics were for contributions based on the use of accelerators.



LHC: a record breaking accelerator

With an operating temperature of 1.8 kelvin (-271.35 °C), the LHC is one of the coldest places in the Universe. At this temperature, super-cooled helium behaves like a perfect liquid with no friction on the inner surface of its container.

The extremely high vacuum in the LHC beam pipes in which the particles circulate is comparable to outer space.

The electromagnetic energy stored in the superconducting magnets around the 27 km ring is typically about 11 gigajoules. This corresponds to the kinetic energy of roughly 11 times a fully loaded 200-tonne Airbus A330 approaching the tarmac at a speed of 350 km/h.

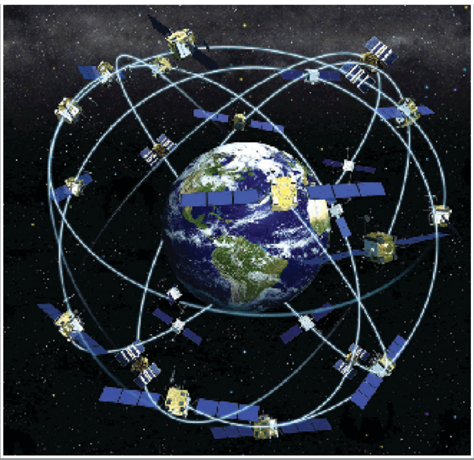
The annual amount of scientific data produced by the LHC totals 15 million gigabytes, which is enough to fill more than 1.7 million dual-layer DVDs a year!

success, the Standard Model of physics cannot explain the origin of mass and has also shown other unexpected flaws. Recent observations in astrophysics indicate that the Universe is mostly made up of "dark" matter and "dark" energy, concepts that cannot be modelled with our present theories. The Large Hadron Collider (LHC), in operation at CERN since 2009, was designed primarily to provide insight into the origin of mass but also to shed light on the constituents of "dark" matter. It is expected that the advance into this unexplored energy range by the LHC will open up experimental possibilities to validate new theories and reconcile them with an upgraded version of the Standard Model, which will take into account the recent observations of astrophysics.

This quest for meaning and understanding, which began at the dawn of humanity, is naturally fascinating for the researchers involved in it, but it is also important for society. Public interest in events such as the recent commissioning of the LHC at CERN has generated exceptional and widespread media coverage demonstrating society's deep interest in these fundamental and complex questions of science.

From basic research to innovation and technology

Academic physics has often been perceived as a construction of mind requiring experiments for its validation. Quantum physics has dramatically changed this view by considering the measurements themselves as essential components of the theory since these measurements actually interact with the phenomena being observed. This novel approach has earned instrumentation its spurs. Today, designing, constructing and developing physics instruments



Physics underpins so much of modern life

The first description of gravity by Newton may have been good enough to put men on the Moon, but it lacked sufficient positioning accuracy to guide 21st-century humankind to the supermarket. The global positioning systems (GPS) that are used to achieve pinpoint position accuracy in today's most modern vehicles depend on general relativity, Einstein's theory of gravity. Quantum mechanics is even more important, and without it, there would be no electronics industry to speak of. To progress from these two pillars of 20th-century physics to mobile phones took a long time and required much interplay between basic research and applied science. Without this type of cooperation, innovation might not have happened. Any interruption in that process in the future could potentially delay further innovation and affect the economy.

and understanding the observations is central to the endeavours of most contemporary physicists. The astronomical telescope is to astrophysics what the microscope is to biology. The size of these instruments increases the smaller the objects under observation are relative to the human scale. This is also true for particle physics, where the extraordinarily small dimensions of elementary particles require large and very complex detectors often with sizes comparable to cathedrals, as well as accelerators measuring several kilometres in length to supply the collisions of particle beams for the research. In order to recreate and study in detail the physics of the early Universe, the LHC requires a 27 km ring of superconducting magnets operating at magnetic fields around two billion times greater than the Earth's magnetic field at temperatures only 1.8 degrees above absolute zero.

The large infrastructures needed by particle physics demand developments in applied sciences and high-tech engineering. Highly qualified experts are needed to meet the requirements of the physics research programme in a diverse range of fields such as microelectronics, materials science, superconductivity and cryogenics, geodesics, radiofrequency, data and signal processing, controls and computing. Groundbreaking technologies and innovation are generally the basis for the success of these large research projects. Innovation occurs especially at the interface where basic research meets applied sciences and high-tech industry. The history of science and human achievement is paved with examples where this type of innovation has led to major technology spin-offs for society.

Tools to address the main societal challenges of today and tomorrow

Technologies and know-how resulting from advances in accelerators, detectors, electronics, and information and communication technologies, when ingeniously applied, address many of the challenges facing society today.

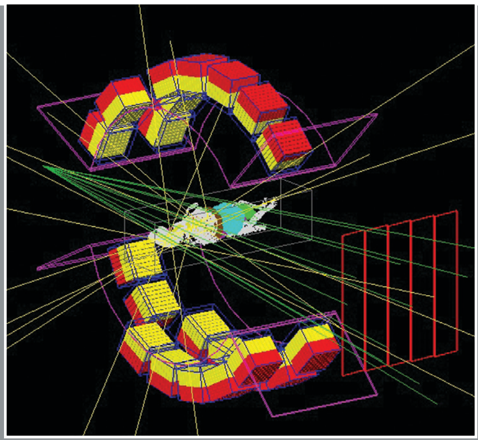
Accelerators are instrumental in medicine and various industrial applications. For instance, an accelerator can be used to treat a tumour, provide a sustainable and cleaner source of energy, burn nuclear waste, harden materials for better tyres and more resistant plastic foils, implant ions in semi-conductors, map proteins, design new drugs, or date archaeological findings.

A particle detector can be used to restore partial sight to the blind, visualise the brain activity, validate new drugs in preclinical trials, confirm the efficacy of cancer treatment, spot the location and content of suspicious cargo, or detect contraband radioactive materials.

Information technology developed for particle physics can be used to simulate the performance of medical scanners for optimum cost effectiveness, for financial and investment forecasting, to examine suspicious cargo, to provide seamless platforms for e-commerce, e-health and e-administration, to separate bio-molecules, to make the electricity and water networks smarter and greener, to monitor and analyse climate change, or to identify new oil reserves.

More so than infrastructures and instruments, **human competence** and creativity are the dominant factors for progress and success. Top-level scientists and engineers with expertise in a broad range of high-tech fields are essential to the design and construction of the extremely complex and challenging infrastructures required by the physics research programme. This expertise is an invaluable asset for applied research disciplines and industry.

In the remainder of this brochure, the focus will be on recent and significant spin-offs that have impacted society and on promising new applications, highly relevant to European priorities. Human and organisational impacts will also be addressed, and the final part of the document will deal with the economic benefits of particle physics and its role in fostering sustainable innovation.



Vacuum for thermal solar collectors

Ultra-high vacuum is essential to minimizing the deterioration of circulating particle beams in large accelerators. Using this vacuum technology, CERN has developed an evacuable flat solar panel that collects direct and diffused sunlight at temperatures as high as 350°C, even at latitudes above the 45th parallel. Heating and cooling account for about half of Europe's total energy consumption. 80% of industrial heating processes require operating temperatures that cannot be achieved with conventional solar panels. CERN's solar panel offers an ideal alternative to conventional thermal solutions and permits the reduction of fossil oil consumption in heating and cooling installations and within industrial processes.

Medical imaging software

OpenGATE is an extension of GEANT4, a software tool for the simulation of the penetration of particles through matter, originally developed for the design of physics experiments. OpenGATE provides a complete environment for simulating the behaviour of the next generation of nuclear medicine scanners, which may be used in clinics or for the development of drugs. The simulation platform incorporates the basis of nuclear physics, the electronic response of the scanners, and various image reconstruction algorithms.

Cleaning flue gases from power plants with electron-beam accelerators

A pilot plant in Poland has demonstrated that electron-beam technology can remove as much as 95% of the sulphur oxides and 90% of the nitrogen dioxides in the flue gases that are responsible for acid rain and smog. Conventional treatments remove pollutants by scrubbing the flue gases with limestone, a complex and polluting process. Using electron beams can reduce the power consumption of the recycling plant and can produce fertilizers from the chemical synthesis of ammonia with the pollutants at operating costs 25% lower than those of conventional treatments.

Impacts on energy, the environment, industry, security and health

Industry and the environment

Around the world, thousands of particle beam accelerators are used in industrial processes.

Electron-beam accelerators allow the modification of material properties. This technology is used in the economically efficient cross-linking of polymers, the curing of inks, and the coating and preparation of adhesive surfaces, enabling manufacturers to attain high production speeds with minimal energy consumption and reduced environmental impact. Other uses of electron beams include the improvement of ©Teflon's mechanical properties, the grafting of filter membranes and battery separators, and the strengthening of polyethylene water pipes. Industrial-scale prototypes have demonstrated the effectiveness of particle accelerators in purifying drinking water, treating waste water, disinfecting sewage sludge, and in the high-efficiency removal of NO_x and SO_x from the flue gases of power plants.

Industry needs more R&D

Industry will benefit significantly from the R&D being done in particle physics, in particular that involving superconducting radio-frequency accelerating cavities and other new laser-based accelerating techniques, as well as superconducting magnets and high-performance cryogenic systems. Such developments enhance the beam characteristics while significantly reducing the sizes and the power consumption of industrial accelerators.

Ion-beam accelerators offer a very efficient and precise method of implanting specific ions into various materials, allowing the physical properties of structures to be changed during the manufacture of integrated devices. This is often essential in the semiconductor industry and in chip manufacturing. Perhaps the most unexpected applications of ion beams are to be found in non-destructive elementary analyses. Accelerator Mass Spectroscopy (AMS) has the capability of precisely measuring the carbon-14 to carbon-12 ratio and of identifying trace concentrations of radioisotopes. These capabilities make AMS an essential tool in geology, archaeology, drug discovery and climate studies. AMS is also used for the fundamental understanding of deep-submicron and nanotechnologies in high-tech areas such as high-density memory devices and silicon-based light amplifiers for fibre optic communication.

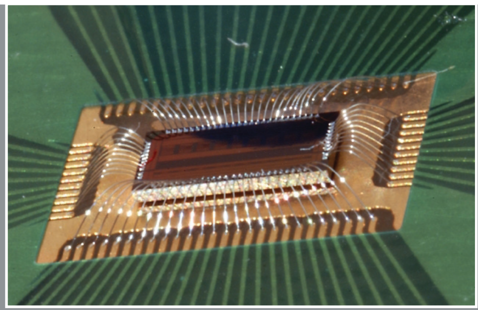
Laser technologies are comparable with the physics developments that have had extensive and unforeseen impacts and which now make a powerful case for the value of basic research. Today, lasers are so widespread that it is impossible to provide an exhaustive list of their applications. Predicted by Einstein in 1917, the basic physical phenomenon of laser light emission was first demonstrated experimentally in 1960. Currently lasers are found in every barcode reader, CD and DVD player, in computers to read and write data operations and in laser printers. Lasers are used to micro-machine components, in new medical diagnostics instruments and in eye surgery to correct vision. Laser-driven fibre optics have revolutionised the broadband era in telecommunications.

Prospects for electronics & surgery

Lasers will continue to change our working environment. In electronics, they will replace electricity in the transport and processing of data and dramatically reduce the power consumption of future computers. In medicine they will become the sharp knives of stereotactic surgery instruments and offer surgeons unprecedented precision.

Greener industrial processes

Electron-beam technology used for curing inks and coating and preparing adhesive surfaces eliminates the use of volatile organic compounds and reduces energy consumption by as much as 90% compared to conventional thermal techniques. The replacement of steel with X-ray-cured carbon composites in cars, including the chassis, can reduce vehicle weight by 80% and energy consumption by 50%.

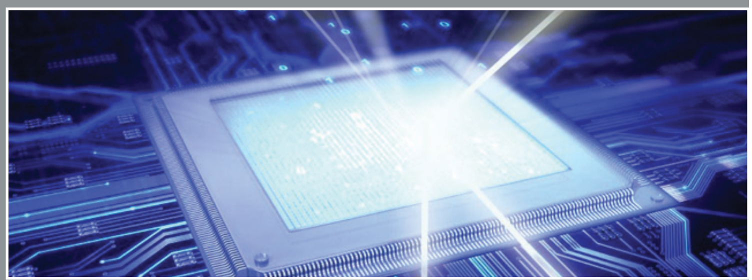


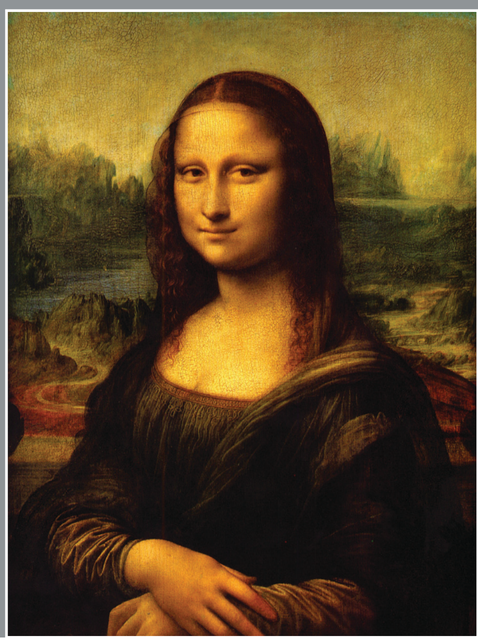
Changing the properties of matter

Today all digital electronics rely on the use of ion-beam accelerators as ion implanters to dope sub-microscopic regions of silicon or germanium substrates and create junctions to build fast transistors in chips.

Optical computing

Recent R&D in optical computing indicates that it is now possible to transport data using light from germanium lasers instead of electricity. The replacement of the processors, wires, connections and circuits of handheld devices by laser-based components significantly increases their computing power, reduces their size and dramatically decreases their power consumption. Optical computers will place a new generation of advanced applications at users' fingertips.





Cultural heritage

Accelerator Mass Spectroscopy (AMS) makes extremely precise measurements of ultra-low concentrations of long-lived radioisotopes in very small samples. Measuring the carbon-14 concentration with AMS gives a good estimate of the age of organic remains in archaeological findings. AMS can also be used to date paintings and detect fraudulent copies.

Security

The safe transport of cargo is an increasing source of concern for security. The risk of nuclear contaminants being smuggled in ship containers or explosives being hidden in air cargo calls for a systematic and efficient screening of all cargo leaving or entering a country. The commercial X-ray devices currently used for screening luggage only visualise shapes and opacity and cannot distinguish nuclear materials from lead or identify explosives. Industry has developed new solutions using accelerators and particle physics detectors.

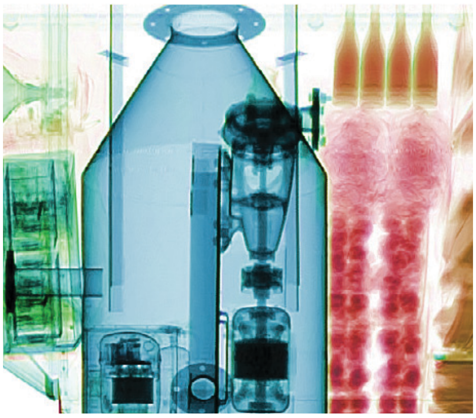
Particle physics detectors measure the energy of the gamma rays and neutrons emitted by the radioactive content of the cargo and determine the nature of the nuclear contaminant. Accelerators manufactured by industry provide controlled sources of neutrons and X-rays for air cargo screening. Particle detectors record the neutrons and photons that have managed to traverse the container under examination and provide 3-D colour images of its content to identify the different component materials.

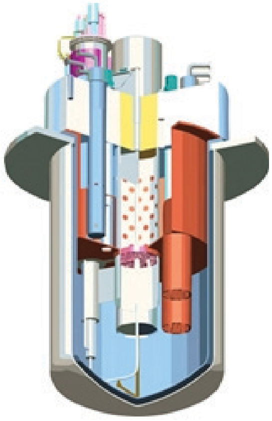
Prospects for energy

An Accelerator-Driven Subcritical (ADS) system uses a high-power proton accelerator to generate neutrons in a dense metal target. The neutrons produced interact with the surrounding fuel material transmuting it into other atomic elements. ADS systems offer the best prospects for burning up the most problematic radioisotopes in spent fuel from nuclear plants, transmuting them into shorter-lived radioisotopes of much lower toxicity and so reducing their storage time from hundreds of thousands of years to a few hundred years. Thorium is a naturally occurring element in the Earth's crust and is four times more abundant than uranium. As a fuel in ADS systems, thorium has the potential to provide sustainable energy for more than ten centuries at today's consumption rate. Operating an ADS system is safer since powering-off the accelerator rapidly stops the fission reactions and puts the system in stand-by mode. The use of non-fissionable thorium instead of uranium-235-enriched fuel will offer all countries safer access to nuclear energy, thus reducing the risk of nuclear proliferation.

The Holy Grail of nuclear energy is nuclear fusion with its promise to meet mankind's energy needs for eternity! Two main routes are currently being pursued worldwide: the magnetic confinement of plasma at the ITER project and inertial confinement fusion using lasers. Accelerator technology will play an increasing role in fusion, which has several technologies in common with particle physics, including the use of radio-resistant structures able to function reliably in hostile environments. Major R&D for laser-based inertial fusion is underway in France with the Laser Mégajoule project and in the US at the Laser Ignition Facility.

Using lasers to accelerate high-intensity electron beams to very high energies within small distances could be a future alternative to laser-induced inertial fusion, which requires small amounts of hydrogen fuel to be heated and compressed to the point where nuclear fusion reactions take place.



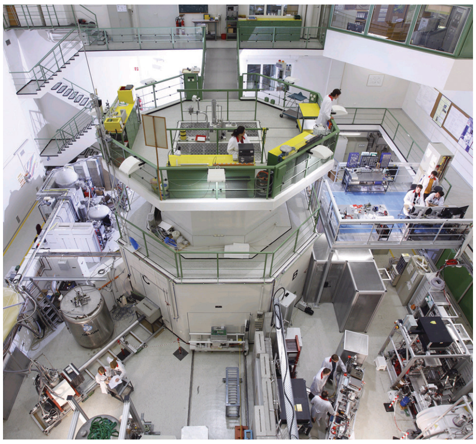


Air cargo screening

Large-area micro-pattern gaseous detectors with fast electronics originally developed for particle physics can offer a unique opportunity for rapid air cargo scanning at affordable costs. Joint ventures with academia, industry and funding bodies to develop industrial-scale demonstrators could significantly enhance the use of these technologies for advanced screening systems.

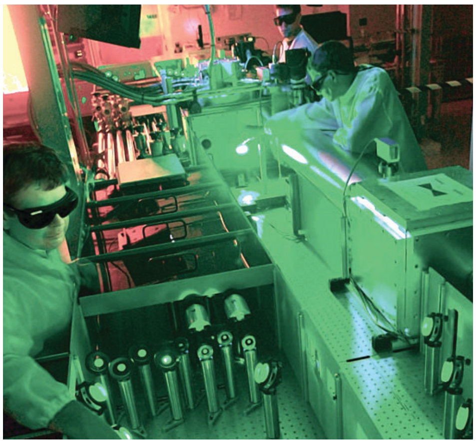
Neutrons for cleaner nuclear energy

In the 1990s CERN demonstrated the feasibility of transmuting thorium with a proton beam and a target to produce spallation neutrons. Major efforts are now underway in Europe, including the MYRRHA, Belgium which has recently been approved as a means of validating this technology at the pre-industrial stage.



Accelerators as a replacement for ageing nuclear reactors

Molybdenum-99 is the world's most common radionuclide for medical imaging, and the five ageing research reactors involved in its production all use uranium-235-enriched targets and fuel. These reactors are subject to long and unscheduled shutdowns for maintenance and repair. This has resulted in serious world shortages and increasing costs for the medical procedures that rely on ^{99}Mo. Governments and the research community have little appetite for new research reactors, and industry is not likely to invest in new facilities that would not be economically viable just for the purpose of producing medical isotopes. As a replacement for ageing research reactors, a high-power accelerator facility could provide a reliable source of neutron-rich isotopes such as ^{99}Mo, as well as a steady stream of research isotopes for medicine.



New laser-based accelerator technologies

A wide spectrum of potential industrial applications could benefit from beam- or laser-based plasma-wakefield acceleration that is under study worldwide. For instance, the LBNL (US) has demonstrated acceleration to a thousand million electron volts over only three centimetres, one hundred times better than the best radiofrequency technologies available today. R&D is urgently needed to transform this demonstrator into accelerators.

Medicine

Today, particle physics technologies are critical to many essential medical applications. They provide diagnoses and therapy to tens of millions of patients each year in hospitals and clinics around the world. In addition, accelerators are used to destroy pathogens in medical sterilisation and food, as well as to harden the surface of materials for artificial joints.

Treating more patients?

Of those patients in Europe who could benefit from proton-beam therapy only 15% have access to cancer treatment facilities, indicating a clear need for many more facilities. Further R&D in terms of accelerator compactness, cost-reduction, dynamic beam energy adjustment, beam profile and guiding system (gantry) is required before wide deployment in hospitals and clinics is possible at an affordable price for society.

Functional diagnosis consists in injecting pharmaceutical agents labelled with short-lived radioisotopes with specific tissue affinity that will accumulate in the diseased areas of the body. The most advanced photon-detection techniques of particle physics are used to detect the radiation from these radioisotopes and to construct 2-D and 3-D images of the body's anatomy and organ function. Functional imaging is mainly used for brain scans, myocardial perfusion scans in the heart, and oncology examinations for the diagnosis of tumours and metastases. The gamma camera is used in many clinics and hospitals, and functional imaging combined with Computed Tomography (CT) is also widely available in SPECT/CT and PET/CT scanners for the planning and follow-up of cancer treatment. Anatomical diagnoses consist in measuring the absorption of X-rays traversing the body (CT) or the magnetic resonance of hydrogen atoms in molecules (MRI) to obtain structural images. Photon detectors collect the traversing photon and reconstruct 3-D images for CT. Superconducting magnets provide the very high magnetic field required to force the hydrogen atoms to respond to magnetic oscillations in order to record very high-resolution 3-D anatomical images and some functional imaging for MRI.

X-rays have been used for decades in hospitals and clinics to destroy tumorous cells, and some 10,000 electron-beam accelerators are in use worldwide for X-ray radiotherapy. For deep-seated tumours and/or the surrounding healthy vital tissue that cannot tolerate irradiation, protons or light-ion beams are preferred to X-rays. They have larger radiobiological efficiency on tumours and deliver virtually no radiation dose to the surrounding healthy tissue when the particle beam is accurately targeted on the treatment volume. With 10 proton facilities in operation, Europe is at the forefront of hadron therapy for cancer treatment. European industry delivers cyclotron-based proton beam facilities to hospitals and clinics. Statistics indicate an excellent survival rate at 10 to 15 years for patients having followed this treatment. The technology of light-ion facilities is now in the process of being transferred to European industry.

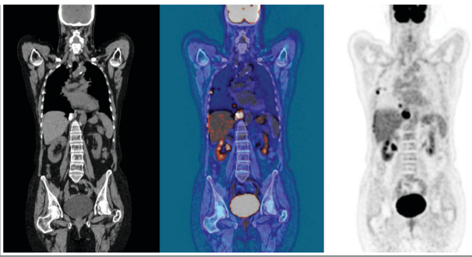
Pharmaceuticals

New and powerful accelerator-driven synchrotron radiation and neutron beam facilities offer unique opportunities for research in medicine and biology. In particular, neutron beams are extremely effective in imaging soft tissue and in unravelling the role of hydrogen and water in macromolecular structures and complex fluids present in the blood. Synchrotron light sources are used at various stages of the drug development cycle to narrow down several million molecular candidates to just a few lead candidates with a view to producing effective drugs. Particle physics technologies allow measurements to be made on a sub-millisecond timescale, enabling real-time studies of structural changes and processes. Europe offers the pharmaceutical industry world-standard facilities to conduct these studies that are essential for understanding the stability and delivery of drugs.

CERN, GSI (Germany), TERA (Italy), Med-Austron (Austria) and Oncology 2000 (Czech Rep.) all contributed to the conceptual design that led to the construction of two clinical facilities combining protons and light ions, HIT in Germany and CNAO in Italy. Five more are under construction in France, Germany, Austria and Sweden.

Optimising cancer therapy

Major R&D is required to improve the imaging of moving organs, integrate PET with Magnetic Resonance Imaging (MRI) as a replacement for CT and monitor online treatment doses in beam therapy. Optimisation of R&D efforts calls for enhanced synergies between particle and applied physicists, industrial researchers and clinicians.



Positrons as diagnostic probes

In 1979, CERN tested a prototype of a Positron Emission Tomograph (PET) scanner at the University Hospital of Geneva. This has led to PET/CT scanning becoming the most advanced clinical tool in cancer diagnosis and radiation therapy treatment.

Protons as an alternative to X-rays for shrinking tumours

Compact proton accelerators connected to rotating gantries have demonstrated their clinical superiority to X-rays in two broad categories of cancer. The first is diseases that require higher delivery doses to destroy tumorous cells. These include eye, head and neck tumours. The second broad class covers those treatments where the increased precision of proton therapy is used to reduce unwanted side effects, by reducing the dose delivered to normal tissues adjacent to the tumour. Two prominent examples in this category are paediatric neoplasm and prostate cancer.

Information technology provides universal access to knowledge and powers the e-economy

Information technology for the knowledge-based society

Originating from CERN in the 1990's, the World Wide Web has become the most widely known development from particle physics and was motivated by the need to standardise access to scientific information. Today, with the advent of smartphones and wireless Internet connectivity, the web is by far the most widely used application worldwide. Every day, more than a billion users navigate, create information and do business transactions on the Web. Thanks to artificial-intelligence-based search tools, the web has become the de-facto interface for browsing information and for e-commerce. A very large proportion of companies worldwide have a website support for their business and offer customers the opportunity to make commercial transactions on-line. The web promotes new approaches for connecting people and exchanging news and experience through social networks.

Fruitful synergies

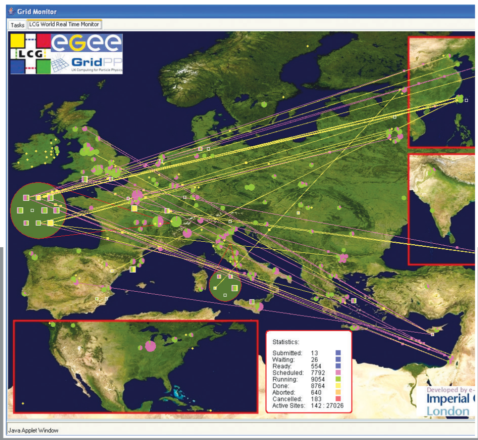
Despite its huge software and computing requirements, particle physics is not sufficiently attractive to industry on its own. Teaming up with other data- and computer-intensive scientific disciplines has been instrumental in building up a convincing case for industry and government funding. Software is one of the most successful examples of joint ventures between academia, industry and funding agencies.

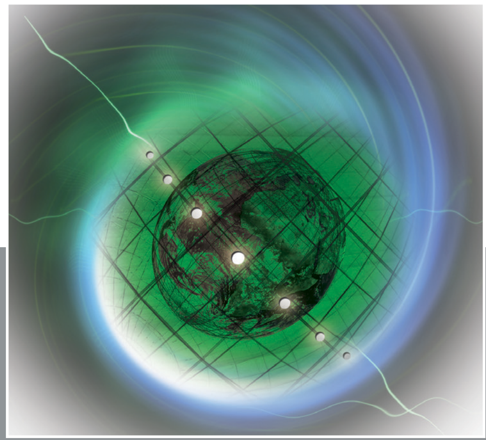
The Grid as an enabler for smarter applications

More recently, particle physics has steered the development of Grid computing, a distributed computing infrastructure using standard technology to support data and computer-intensive sciences such as physics, microbiology and climatology. Large data centres with enhanced network connectivity have grown up from this and today constitute the infrastructure supporting the e-economy. Industry is taking advantage of these new facilities to host advanced software techniques making better use of natural resources and reducing costs. For instance, utility companies are rejuvenating the electrical network by connecting individuals, power transformers and distribution components to the computing Grid (the "Smart Grid") with a view to enabling customers to optimise their electricity consumption, improving the connectivity of renewable energy sources to the network, balancing the power distributed by the main power lines to avoid blackouts and to prepare the necessary infrastructure for charging the batteries of electric cars. The public health sector is also using the Grid to reduce costs. Applications running on health Grids store and manipulate patients' electronic records to improve treatment follow-up, reduce unnecessary duplication of examinations and give patients the option to grant clinicians access to their health records for consulting purposes. Administrations are developing new applications allowing citizens to access administrative forms and request documents electronically.

New business models

Industry has developed Cloud computing alongside the Grid to offer customers new business opportunities such as "software as a service" and "pay-per-use", and allow them to derive full benefit from the extraordinary potential offered by a worldwide Grid infrastructure. Cloud computing is the emerging ICT (Information and Communication Technology) infrastructure for business and industry. It enables new business models, reduces companies' ICT costs, allows them to react swiftly to changes in business needs and gives users access to millions of applications.



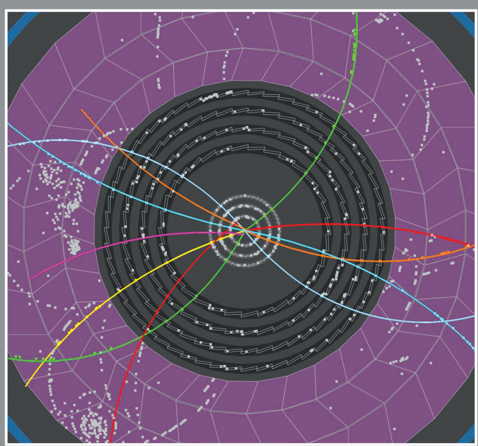


Grid applications promoted by Enabling Grid for E-sciencE (EGEE)

EGEE has promoted nine grid applications:
1: CGGVeritas for locating oil reserves,
2: Digital Ribbon for computing as a commodity,
3: Financial Services for stock Analysis Applications,
4: GridVideo for grid-based multimedia applications,
5: Health-e-Child for the diagnosis of paediatric diseases,
6: Immense Ltd for Creative Media Content Management,
7: Phillips Research for scientific simulation, modelling and data mining of healthcare data,
8: Total for oil and gas applications and
9: Wisdom for drug discovery.
European Grid Infrastructure foundation (EGI), now replacing EGEE, offers access to all European researchers from all fields of science, ranging from particle physics to the humanities.

GridPP, the UK particle physics Grid, helps fight avian flu

A collaboration of Asian and European laboratories used the EGEE Grid to analyse 300,000 potential drug components for use against the H5N1 virus. 2000 computers were used for four weeks – the equivalent of 100 years on a single computer – to identify drug compounds with the potential to inhibit the activity of an enzyme on the surface of the influenza virus.



Simulation software for better instruments

International companies are beginning to use simulation software such as GEANT4, a toolkit for the simulation of the passage of particles through matter originally developed for the construction of particle physics experiments. It is now possible to design a new generation of imaging devices for clinical applications and drug discovery. Simulation is equally important in space research. Most space probes need to be able to operate for many years without the possibility of physical repair after launch. It is therefore essential to understand the behaviour of all components in the space environment and in particular the effect of cosmic radiation on electronics and detectors.

Impacts on education, training and project management

Attracting students into physics

Basic research in physics contributes to motivating students to study scientific disciplines. This is of particular importance in Europe where the number of students taking up scientific studies is gradually declining. A recent survey carried out by STFC in the UK has revealed that particle physics, along with astrophysics and nuclear physics, is the most popular subject for physics undergraduates. They retain this interest through to postgraduate level – even if they ultimately go on to enter other fields and use their training in more applied areas.

Benefits for the European Research Area (ERA)

The success and accumulated experience of particle physics in managing complex and costly international projects is central for Europe in establishing the genuine, creative and sustainable ERA needed to face the unprecedented challenges of energy, environment and health with success.

Highly skilled and trained students benefit the economy

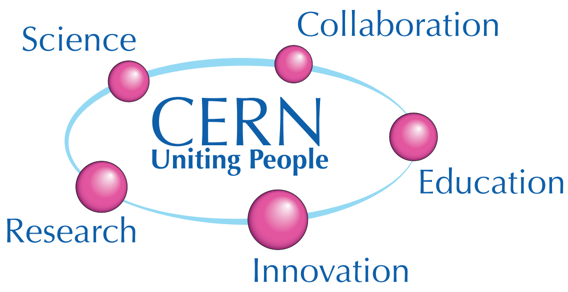
PhD courses in particle physics are highly sought-after, with many highly qualified undergraduates applying for each place. PhD students in particle physics receive training across a large spectrum of highly technical disciplines including large-scale data analysis, mathematical modelling of complex systems, computing and electronics, engineering, material sciences and superconductivity. These skills are in demand in high-tech industry and in the computing and financial sectors. About half of all particle physics PhD students eventually take up high-level careers in business and industry, helping to supply the highly skilled workforce needed in the current economic climate. Besides PhD studentships, CERN offers other training opportunities for apprentices, master students and postdocs in engineering and physics. These different programmes take in about one thousand people every year. The proportion taking up a career in industry varies according to the programme, ranging from about 30% for post-docs to close to 100% for apprentices.

International research collaborations

The size, complexity and cost of large infrastructures have led the particle physics community to develop and try out international organisation and governance models that have proven successful in bringing large projects to completion with proper control of cost and schedule, meeting scientific and technological challenges. CERN has become a champion for this community. Over the years, it has established Europe as the leader in particle physics. The CERN organisational model has been carried over to other successful international research centres, such as ESO and EMBL. The construction of the highly complex LHC physics experiments, organised in large consortia of up to 150 institutes from all over the world, has required such structures to be put in place. The spectacular first LHC physics results confirm the relevance of this approach for large, innovative and costly international projects.

Knowledge and Technology Transfer (KTT)

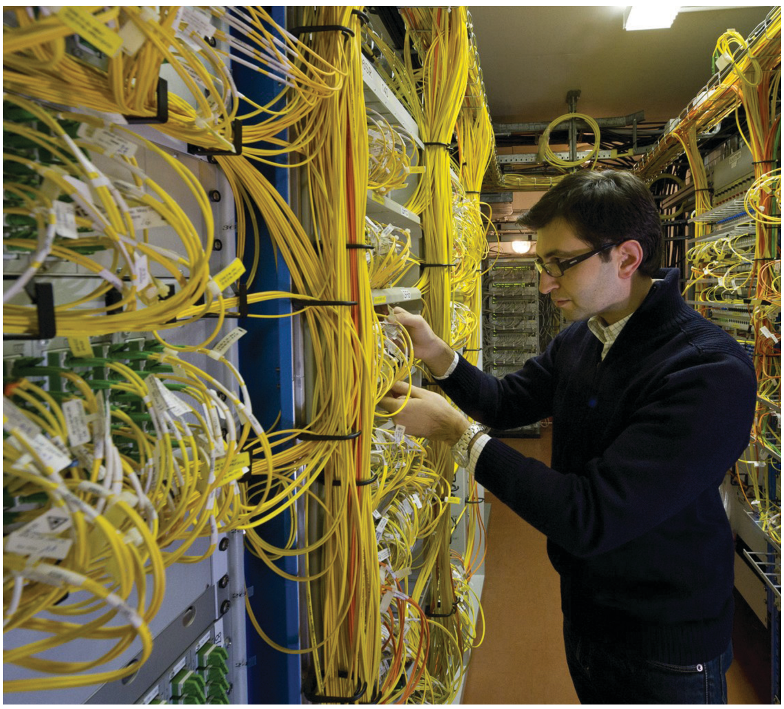
In March 2008, the CERN Council approved the creation of HEPTech, the technology transfer network of European institutions active in particle, astroparticle and nuclear physics. HEPTech aims to increase the effectiveness of KTT to society by organising academia-industry events on specific technologies with high relevance for physics research and by developing product offerings based on basic research technologies to enhance the attractiveness to industry.



CERN's mission:
PUSH BACK the frontiers of knowledge
DEVELOP new technologies for accelerators and detectors
TRAIN the scientists and engineers of tomorrow
UNITE people from different countries and cultures

High School Teacher (HST) programme

The HST programme funded by CERN consists of comprehensive international three-week courses offering teachers the opportunity to experience the atmosphere of a fundamental physics research laboratory, meet scientists and other teachers, and find new ideas for bringing modern physics into the classroom. In principle the programme is open only to teachers from Europe, but the participation of teachers from the US is supported by a grant from the National Science Foundation, while the participation of teachers from developing countries is organised in the framework of UNESCO's International Basic Sciences Programme.



An asset for the economy

The future economic competitiveness of Europe depends on maintaining a strong technology base and a highly skilled workforce. Training and investment in research in the physical sciences are key drivers. Students are attracted into physics because of an interest in basic science. Furthermore, training in particle physics provides a range of skills that are much sought after by employers in both the public and private sectors.

Economic benefits of particle physics

Application	Total systems	Systems sold/year	Sales/year (€ million)	System price (€ million)
Cancer therapy	9,100	500	1,800	2.0 - 5.0
Ion implantation	9,500	500	1,400	1.5 - 2.5
e^- welding & cutting	4,500	100	150	0.5 - 2.5
e^- and X-ray irradiators	2,000	75	130	0.2 - 8.0
Radioisotopes	550	50	70	1.0 - 30
Non-destructive testing	650	100	70	0.3 - 2.0
Ion analysis	200	25	30	0.4 - 1.5
Neutron generators	1,000	50	30	0.1 - 3.0
Total	**27,000**	**1,400**	**3,680**	

The industrial market for accelerators in 2007 (ESGARD)

Around 30,000 industrial accelerators are at work every day producing particle beams in hospitals and clinics, manufacturing plants, industrial laboratories, and parts and printing plants. By comparison, the scientific research community accounts for only a few hundred accelerators. All the final products that are processed, treated or inspected by the particle beams of industrial accelerators worldwide, have a collective annual value of more than €500.0 billion. The table above shows the industrial market for accelerators in 2007. This market highlights growth of 10% or more per year.

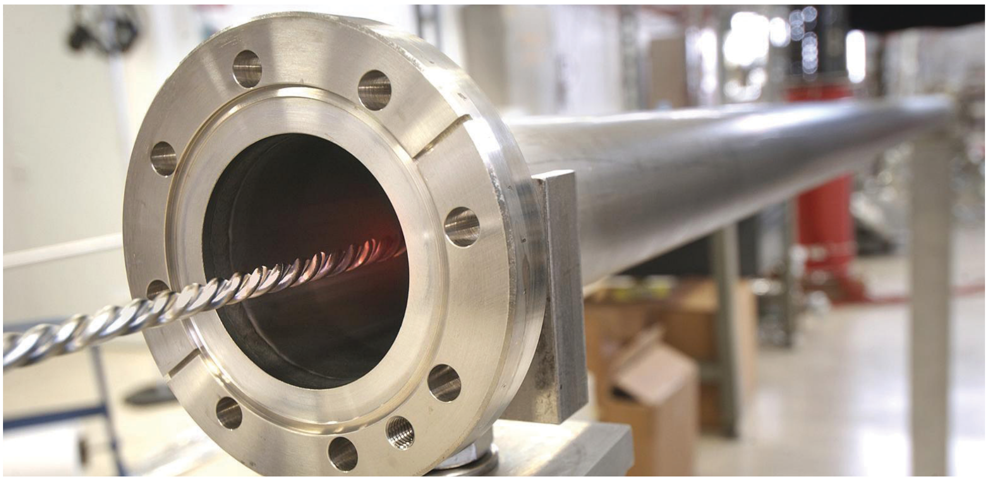
Hundreds of thousands of imaging scanners are to be found in hospitals and clinics throughout the industrialised world. They are now indispensable to clinicians for the confirmation of their diagnosis of many serious diseases. The worldwide market for nuclear medicine imaging, including medical isotopes, is estimated at €10.0 billion, with an annual growth of about 10% (F&S, M&M).

Prospects for industry

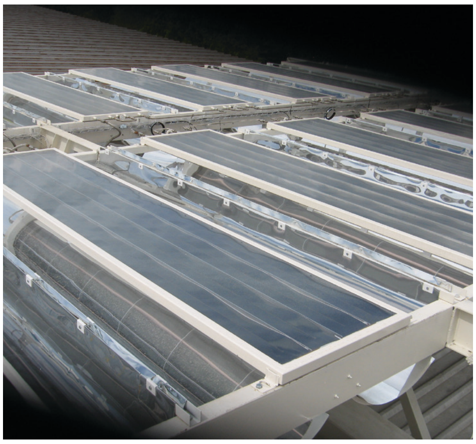
Market data indicate healthy prospects for high-tech industry, with forecasts of two-figure growth despite a morose global economy. Now that European industry has lost an important fraction of its manufacturing to developing countries, the knowledge economy appears to be an essential medium-term instrument that Europe can develop to take full advantage of the wealth of technology offered by particle physics.

Every day, more than a billion users navigate, create information or perform business transactions using the World Wide Web. The annual global economic benefits of the commercial Internet amount to €1.5 trillion (ITIF). The global Grid and Cloud computing market is expected to grow from €35.0 billion in 2010 to €120.0 billion in 2015. Industrial applications of Grid and Cloud computing also indicate two-figure growth. For instance, the global market (SBI) of the Smart Grid is predicted to grow from €80.0 billion in 2010 to €165.0 billion in 2014.

Every year, thousands of highly skilled master and PhD students in particle physics worldwide take up jobs in industry or in business, helping to provide the workforce needed by the economy.



High-tech procurement is a source of successful business
CERN has recently conducted a survey of companies which supplied high-tech components with a total value of some €1.0 billion in the framework of the construction of the Large Hadron Collider. Of the 178 respondents, 38% reported that they had developed new products, 17% that they had opened new markets and 14% that they had started new business units.



CERN's direct economic impact
Studies quantifying the direct economic impact of CERN, in terms of increased turnover plus cost savings resulting from contracts awarded by the Organization, show that every €1 paid to industrial firms generates €3 of additional business. 75% of the increased sales were to sectors outside particle physics, such as solar energy, the electrical industry, railways, computers and telecommunications.

Prospects for the economy
Significant economic benefits are to be derived from various projects that are still in the pre-industrial demonstration stage. This is particularly the case for applications aiming at reducing the human footprint in a cost-effective manner and for greener industrial processes where energy saving and/or the replacement of toxic components are important issues.

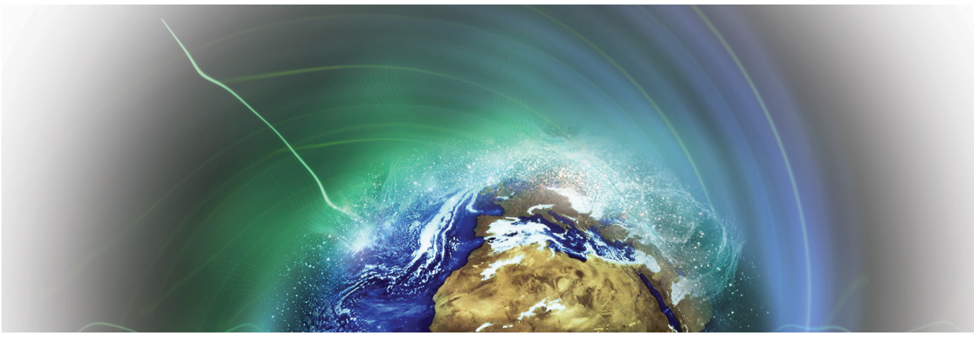
Fostering sustainable innovation for Europe

Basic and applied sciences go hand in hand, relying on and challenging one another.
Public support is instrumental to fostering this delicate alchemy. Europe's future prosperity depends on it.

Creativity and innovation cannot be decreed or planned but require encouragement and nurturing. While basic research in physics drives innovation, it is equally true that applied science fuels basic research. The constant interplay between the two drives progress forward. Once particle physicists have developed a technology that suits their needs, they perform their research. They do not necessarily carry R&D through to the market. On the other hand, without applied research, particle physicists would not have accessed the basic technology they need. Advances in particle physics are adopted and developed by industry, furthering the technological baseline for the next generation of scientists and engineers. Basic and applied research and industry are part of a virtuous circle that requires proactive public support. Any perturbation of this delicate synergies would impact on the innovation process and affect the economy.

Central governments have a major role to play in fostering the long-term vision needed for the development of groundbreaking technologies. Technology R&D at the smallest scales is becoming the main driver of economic growth in industrialised countries. The technological needs of particle physics at these scales precede those of society. The solutions adopted may produce significant societal changes and provide a rich source of innovation for new products that opens up new prospects for applied sciences and creates the conditions for industry to adapt and remain competitive. For instance, greener and cost-effective alternatives to ageing industrial processes have emerged from the smart use of technologies from particle physics. The solutions to the challenges of the next generation of basic physics instruments will provide new sources of innovation to high-tech industry. Government and funding agencies should continue to play a major role in promoting the transfer of academia's results to industry and society.

Public schemes fostering innovation can sharpen the dialogue between research institutes and industry with a view to delivering on Europe's priorities. Europe is at the forefront of research in particle physics. The benefits for European industry and the knowledge economy are substantial. They can be considerably enhanced in the future provided that public authorities monitor, promote, stimulate and support this formidable innovation machine. Novel cooperation schemes between the three major players, i.e. basic physics research, applied research and industry, are needed to contribute to this required enhancement and optimise the use of respective competences.

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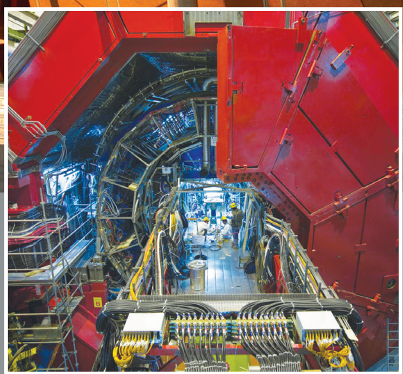

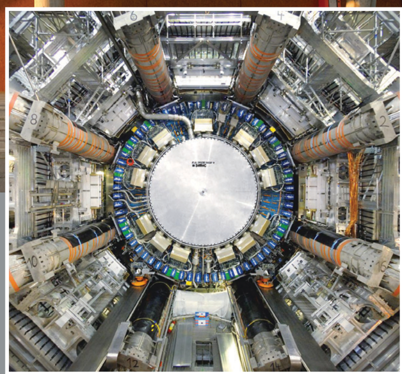

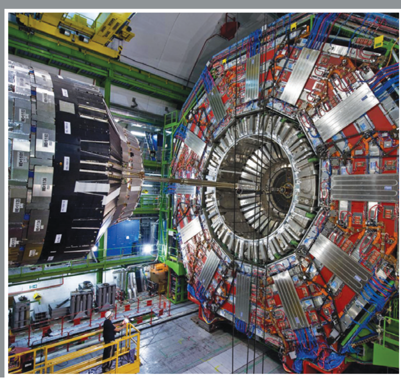

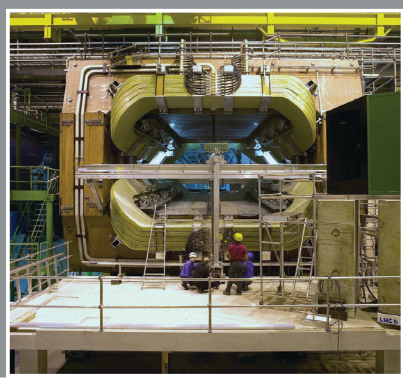

Acknowledgements

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p. 13 middle left: John Prior, CHUV
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Table p. 18: ESGARD
CEA: Commissariat à l'Energie Atomique, FR
CERN: European Organisation for Nuclear Research
CHUV: Centre hospitalier universitaire du canton de Vaud
CNAO: Centro Nazionale di Adroterapia Oncologica; IT
CPPM/IN2P3 CNRS: Centre de Physique des Particules de Marseille / Institut National de Physique Nucléaire et de Physique des Particules, Centre National de la Recherche Scientifique, FR
CSIRO: The Commonwealth Scientific and Research Organisation, AU
DOE: Department Of Energy, US
DESY: Deutches Electronen Synchrotron, DE
EC: The European Commission
EGEE: Enabling Grid for E-sciencE, FP7 project
EGI: European Grid Infrastructure foundation, NL
EMBL: European Molecular Biology Laboratory
ESGARD: European Steering Group for Accelerator Research and Developments
ESO: European Southern Observatory
F&S: Frost & Sullivan, US
GridPP: UK Computing for Particle Physics
GSI: Helmoltzzentrum für Schwerionenforschung GmbH, DE
HIT: Heidelberg Ion Therapy Centre, DE
Institut Curie, FR
IAEA: International Atomic Energy Agency
ILC: International Linear Collider
ITER: International Thermonuclear Experimental Reactor
ITIF: Information Technology and Innovation Foundation, US
LBNL: Lawrence Berkeley National Laboratory, US
MedAustron: PEG MedAustron GmbH, AT
MIT: Massachusetts Institute of Technology, US
M&M: MarketandMarket, US
MYRRHA: Multipurpose hYbrid Research Reactor for High-end Applications, BE
NASA: National Aeronautics and Space Administration, US
NIST: National Institute of Standard and Technology, US
PSI: Paul Scherrer Institute, CH
SBI: A division of Market Research Group, LLC, US
STFC: Science and Technology Facilities Council, UK
TERA: Fondazione per Adroterapia Oncologica; IT
The Oncology 2000 foundation, CZ
UNESCO: United Nations Educational, Scientific and Cultural Organisation
WMAP: Wilkinson Microwave Anisotropy Probe

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