Particle physics – it matters

A forward look at UK research into the building blocks of the Universe and its impact on society

In partnership with

Science & Technology Facilities Council

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Foreword

This report summarises the science questions confronting particle-physics research in the next 20 years, what advances in technology are being pursued and the cross-disciplinary benefits to be accrued. It is predominantly an interest in curiosity-driven science, of which particle physics is a major part, that often attracts students to study physics and which drives the technological innovation; neither can proceed in isolation.

WHAT IS PARTICLE PHYSICS?

Particle physics seeks to understand the evolution of the Universe in the first fraction of a second after its birth in the Big Bang in terms of a small number of fundamental particles and forces. The processes involved ultimately resulted in the creation of atoms and the complex molecules that led to our existence. The intellectual curiosity embodied in particle physics is also at the foundation of philosophy, art and other scientific disciplines which, together, have shaped the modern world. Without such innate curiosity, the modern world would not exist. The study of particle physics challenges our preconceptions, inspires and seeks to move human knowledge forward at a basic level – wherever that may lead.

UK LEADERSHIP

Many of the foundations, on which our understanding has been built, were first laid down in the UK. Experiments in the early 20th century, at the Universities of Cambridge, Manchester and Bristol, led to the discovery of the particles of which atoms are composed – the electron, the atomic nucleus and the neutron, as well as more exotic entities called mesons. On the theoretical side, it was the British physicist Paul Dirac, while at Cambridge, who first postulated the existence of antimatter. It continued a UK lineage, going back to James Clerk Maxwell, Michael Faraday and Isaac Newton, that has shaped much of modern science. Today, the UK continues to play a world-leading role in basic research, principally through experiments at Europe's main particle physics laboratory, CERN; two of the four experiments of the ground-breaking Large Hadron Collider (LHC) project are led by physicists at UK universities, and the LHC accelerator project continues to be led by UK physicist, Lyn Evans.

THE FUTURE

Despite prodigious advances in our knowledge, there remain many unanswered questions – for example: what is mass and why is there is so much more matter than antimatter? Such questions fascinate people of all ages and are a key driver in attracting students to study physics in UK universities (p14). The diverse technological, computational and analytical training that particle physics research offers – in an international setting – is much sought-after by employers, particularly in the high value-added sectors of industrial research, finance and computing.

The challenging nature of the questions posed by particle-physics research requires paradigm shifts in the technical development of accelerators, sensors, microelectronics, data-acquisition methods, computing and analysis techniques – all in the context of large-scale, global, collaborative research. The novel technologies that emerge, developed in collaboration with industry, are vital to other fields, particularly the biomedical and materials sciences, and have applications in medicine, sustainable-energy development and security.

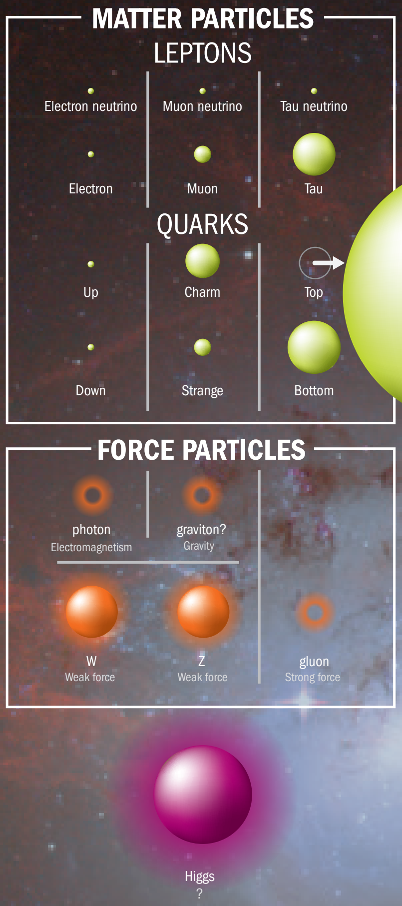
The potential scientific discoveries themselves could lead to technological benefits whose significance, as history has shown, may not be immediately apparent. The discovery, in future particle-physics experiments, of new particles that could mediate processes leading to cheap, safe energy, would revolutionise the world – as the discovery of the electron did at the end of the 19th century.

Dr Robert Kirby-Harris
Chief Executive
The Institute of Physics

Advancing human progress through **basic knowledge**

Research into the forces and building blocks of matter is a key area of modern physics

The Standard Model of particles and forces is one of the cornerstones of modern physics



The size is a only a rough indication of mass; the photon, gluon and graviton are massless. The Higgs and graviton are yet to be discovered

"The quest for fundamental knowledge as embodied by particle physics is the hallmark of a civilised nation. Difficult questions in basic science require innovative technical solutions and a wide range of science disciplines have benefited from the technological advances generated by studies in particle physics."

Sir Paul Nurse: 2001 Nobel Laureate in Physiology or Medicine

One of the unique attributes of humans is their innate curiosity and ability to observe the world and create a consistent description – a model – of how reality works. Over the past centuries, great thinkers and experimenters have built up an elegant and profound description of Nature in terms of matter as discrete particles interacting via fundamental forces. We now know that the matter around us (including ourselves) consists of atoms, which in turn are made of more fundamental particles. This knowledge, and the technological innovation required to obtain it, has underpinned the huge leaps in our quality of life over the past 100 years. The desire for knowledge is a profound human instinct, and knowledge of the Universe at the most basic level is one prerequisite for our survival in it.

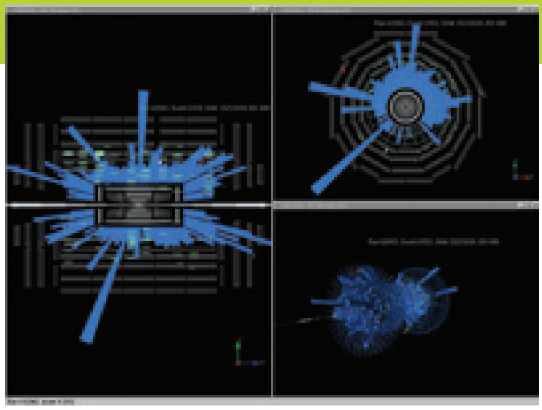
UNDERSTANDING NATURE

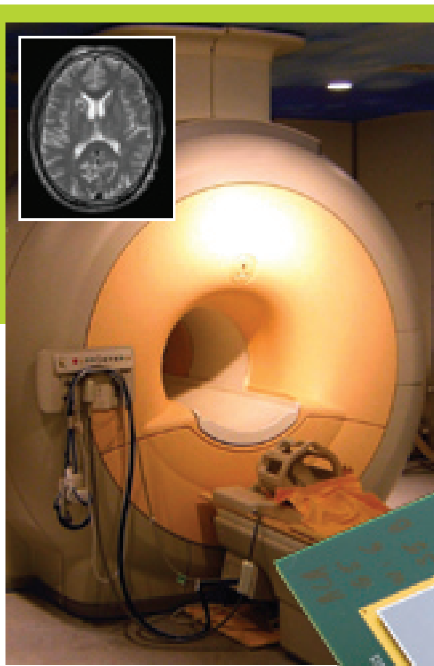
To build up the picture of the building blocks of Nature requires two kinds of effort: developing a general description of particles and how they interact – quantum theory; and designing experiments to test predictions of the resulting particle model. The current 'Standard Model of Particle Physics' (left) divides matter particles into two types: six quarks, of which two make up the protons and neutrons in atomic nuclei; and six leptons including the electron. Most of the other, more exotic quarks and leptons exist only fleetingly in high-energy interactions; however, they played a pivotal role in shaping the Universe's evolution. Matter interacts via four fundamental forces: electromagnetism which binds the constituents of atoms and molecules, the strong and weak forces which hold nuclei together, and gravity which is much weaker on the atomic scale and mediates the dynamics of the whole Universe.

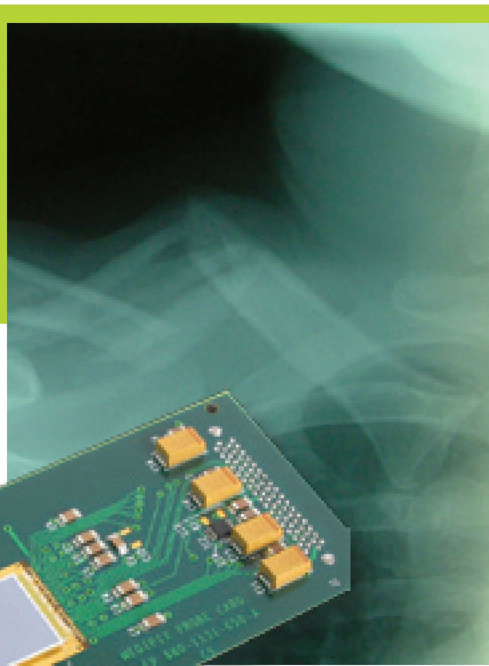
Much of the underlying knowledge and understanding have been achieved through large-scale, but ultra-precise experiments using machines to accelerate and collide particles at very high energies. These projects represent some of the most sophisticated and challenging technological endeavours ever carried out – and so, not surprisingly, have generated benefits for humanity stretching far beyond their scientific goals.

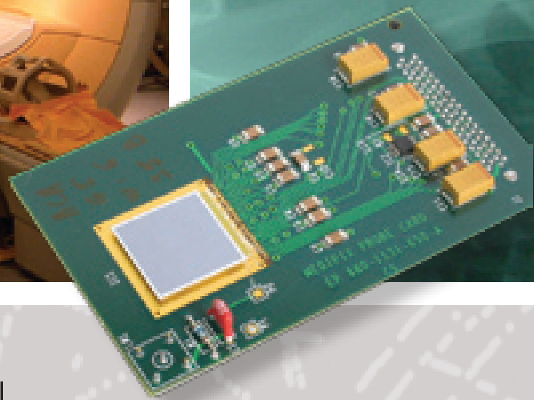
The Standard Model tested in this way has been hugely successful, but it is far from being a complete description of Nature. Studies looking out into space, far back to the early Universe, infer that the matter particles and forces must have been generated, via a series of processes, from a 'unified' primordial state existing just after the Big Bang. Unravelling the more basic physics of these events – which ultimately explain why the Universe looks the way it does now – has become *the* central question in basic physics.

Current and planned future particle experiments are exploring these processes, either by mimicking the high-energy conditions that existed at the beginning of time, or by searching for unusual particle behaviour at lower energies that is a signature of the more basic physics.









Why does it matter?

Research in curiosity-driven science is an important driver for technological innovation and economic success.

KNOWLEDGE AND TECHNOLOGY TRANSFER

Modern particle physics has its origins in discoveries and theoretical developments that shaped the modern world and now underpin much of modern science. Many advances in chemistry, molecular biology, genetics and materials science were predicated on the discovery of the electron and quantum theory, and by analytical probes such as X-rays and nuclear-based techniques. Addressing questions at the microscopic scale and beyond has always required innovation. Particle-physics experiments are extremely demanding in terms of equipment design, and they generate novel technical approaches which ultimately benefit society:

- accelerators for medical diagnosis, therapies, food-treatment, micro-electronics production and energy-generation;
- radiation and imaging detectors for use in pharmaceutical, biological and materials sciences, medical and security equipment;
- high-field magnets for medical imaging;
- radiofrequency power generation;
- advanced software for information-sharing (the World Wide Web), distributed grid-computing and radiation-exposure simulations for space and medical technologies.

Technological innovations from particle physics benefit many disciplines. The innovation is driven by the desire to understand Nature at a basic level.

SKILLS TRANSFER

Particle physics is a key subject in attracting young people to take up science, and a PhD training in particle physics is extremely popular. The diverse technological and analytical training spanning engineering, mathematics, computing and electronics obtained in an international and collaborative environment is much sought after in many commercial sectors, but particularly:

- computing and information technology;
- electronics and high-technology development;
- advanced biomedical research.

THE UK AND INTERNATIONAL COMPETITIVENESS

The UK plays a pivotal role in basic research both theoretically and experimentally. Particle physics has always engendered multinational collaborations, and our researchers are involved in running major particle physics experiments – in Europe, the US and Japan. Realising the gains to be made, emerging economies such as China and India are further developing their own particle-physics programmes. To ensure our own future economic success, the UK must also continue to invest in basic science. It attracts students into science and produces paradigm shifts in technology and industrial capability.

The LHC (p6) ATLAS collaboration

New frontiers in **basic science**

Particle physicists have exciting plans to push back the frontiers of knowledge over the next decade

New experimental projects aim to answer major questions that will take the Standard Model of particles and forces much further; they may even lead to an entirely new description of Nature.

WHERE DOES MASS COME FROM?

The particles that form everyday matter all have mass. However, the particles created in the Big Bang were massless and were endowed with mass by an unknown mechanism. UK physicist Peter Higgs proposed that their masses were generated via interactions with a particle not yet identified – the Higgs boson. Without this mass-generating mechanism there would be no galaxies, stars, planets or life.

WHERE IS THE MISSING ANTIMATTER?

Particles can exist in two forms, matter and antimatter, which have opposite values of properties such as electric charge. They would have been formed in equal amounts in the Big Bang, but then, mysteriously, most of the antimatter disappeared.

WHAT IS DARK MATTER?

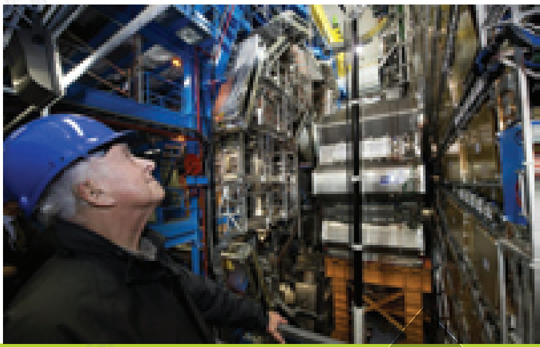
Measurements of the motions of galaxies under gravity suggest that there is very much more matter in the Universe than we can see. Theorists have proposed that this 'dark matter' could consist of so-called supersymmetric particles predicted by unified theories going beyond the Standard Model (p4).

ARE THERE EXTRA SPATIAL DIMENSIONS?

The world with which we are familiar has one time dimension and three spatial dimensions – but the existence of additional dimensions, which are necessarily small, can help to explain why gravity is much weaker than the other forces. This might be because the bulk of the gravitational force lies in a higher-dimensional structure, of which our Universe is part. The existence of unseen extra dimensions may also provide clues to the nature of the recently-discovered, extremely puzzling 'dark energy' which seems to be accelerating the expansion of the Universe.

The experiments

No single experiment can address all of these questions and a series of complementary international experiments, in which UK physicists play major roles, has been designed or planned. They range from large-scale accelerator projects – involving thousands of physicists from up to 40 countries – to precise small-scale laboratory experiments involving a handful of research groups.



Peter Higgs visits the LHC

MAJOR GLOBAL HIGH-ENERGY PROJECTS

Large Hadron Collider (LHC)

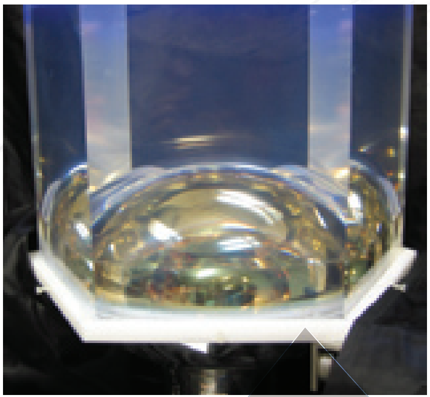
The world's largest experiment, the LHC at CERN in Geneva, should start producing results in 2009. It collides beams of protons at energies never before achieved in an accelerator, creating the conditions predicted to produce the Higgs boson, or evidence of some other mass-generating mechanism – along with supersymmetric, dark-matter particles. The existence of extra dimensions, which can modify the gravitational force at small distances, could be inferred from the creation of transient 'mini-black holes'.

UK physicists are playing a major role in this seminal particle-physics experiment.

SMALL-SCALE LOW-ENERGY EXPERIMENTS

Rare radioactive decays

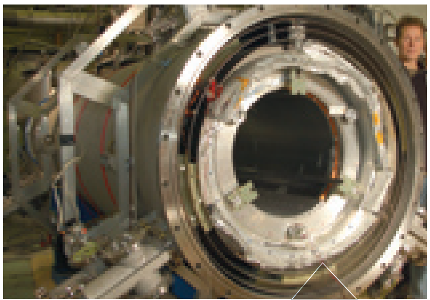
Some radioactive isotopes are predicted to decay in an unusual way such that no neutrinos are emitted. Paradoxically, experiments identifying this so-called neutrino-less double beta decay could tell us more about the neutrino and provide further information about the preponderance of matter over antimatter.



The SuperNEMO detector, being built in the UK, must measure the energy of the electrons from beta-decay with unprecedented accuracy. This scintillator has achieved the world's best energy-resolution for observing such decays

Ultra-cold neutrons

Neutrons when cooled to ultra-low energies are used in particle experiments. Studies of neutron-decay shed light on fundemental processes, as do precise measurements of the distribution of electric charge in a neutron. Ingenious experiments on the behaviour of neutrons in gravitational and magnetic fields could uncover the quantum nature of gravity – so far elusive – and provide evidence of extra dimensions. *UK research groups have been working on ultra-precise measurements of the neutron electric dipole moment (EDM) and neutron decay.*



The EDM experiment

ASTRO-PARTICLE PHYSICS EXPERIMENTS

Neutrino telescopes

At present, the only route to energies significantly higher than terrestrial particle accelerators is to detect the interaction of high-energy particles from outer space. The neutrino component of these cosmic-rays can travel across the Universe largely unimpeded, and provide information about physics at the highest energies and earliest times. *The UK is part of a large international collaboration that built the Pierre Auger Observatory in Argentina which is measuring the highest-energy cosmic rays. The UK is also interested in establishing under-water and under-ice neutrino observatories in the Mediterranean and at the South Pole.*

Dark matter experiments

A number of experiments around the world are trying to detect dark-matter particles coming directly from space. *The UK has a major dark-matter experiment in an underground laboratory in a salt mine in Yorkshire.*

Super LHC

After a decade of operation, the international teams running the LHC plan to upgrade the collider to produce much more intense proton beams. This will allow them to obtain more precise data, and focus on rarer phenomena already identified as significant. Candidate theories explaining initial LHC data can then be put under scrutiny and further developed. *UK groups are working on new detecting devices for the Super LHC.*

International Linear Collider (ILC)

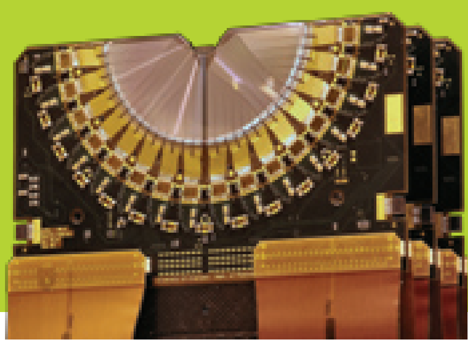
A post-LHC machine colliding electrons and their antimatter partners, positrons, is being planned. This would allow the properties of new particles discovered at the LHC to be elucidated in far greater detail, leading the way to establish a theory successfully unifying gravity with the other forces. *UK researchers have been leading many demonstrator projects for the ILC.*

LHCb and the Super-B

One LHC investigation, LHCb, will look for small differences in the decays of matter and antimatter versions of unstable quark-containing particles called B-mesons, which may help explain the dearth of antimatter today. Complementary to LHCb and following current highly successful B-meson experiments such as BaBar, there are proposals to build a machine, Super-B, that will create intense beams of these particles, which will also reveal subtle processes indicating physics beyond the Standard Model. *UK scientists were involved in constructing LHCb.*

Neutrino factory

Despite being the second most abundant particle in the Universe, neutrinos are the most elusive of the elementary particles because they have hardly any mass and are difficult to detect. They are now a key probe of phenomena such as the disappearance of antimatter. The T2K and MINOS experiments currently taking data are using sub-MW neutrino beams. The construction of a multi-MW neutrino source, obtained using a very high power proton beam, is now a major priority in particle-physics research. *The UK is constructing and testing a major component of the neutrino factory and hopes to host the final project. This would accrue benefits such as employment, particularly in the civil engineering, construction and technology sectors, and local public and private-sector investment over many years.*



The LHCb VELO detector built in the UK

How particle physics **benefits society**

Particle-physics experiments explore Nature under extreme conditions, so they require innovative technologies which find use in many areas of life – transforming the way we live

Most experiments employ high-energy beams of particles like protons. They rely on trains of high-power radiofrequency devices to accelerate the particles and extremely powerful magnets, cooled to just above absolute zero, to steer the beams in an ultra-high vacuum. New particles and radiation produced are detected by huge experimental apparatus composed of several detectors, each designed for a particular measurement and containing many thousands of modules. The engineering is on a large scale, but each component must be fabricated with microscopic precision. Increasingly large amounts of data are collected and processed, and then transferred electronically to collaborating research groups around the world, for computer analysis.

The UK particle-physics community has been at the forefront of technology-transfer to other sectors. The LHC project (p6) has already spawned a variety of commercially and socially useful projects and applications. It is the interest in, and challenging nature of, the science that drives the technological innovation, which would not happen in isolation. We can expect to see many more applications with the development of further experiments.

TECHNOLOGICAL INNOVATION CONTINUES TO BE IN FOUR MAIN AREAS:

- ever more sophisticated accelerator technology;
- precise and sensitive radiation detectors;
- electronics and high-speed data-acquisition;
- computing and modelling.

PARTICLE-PHYSICS TECHNOLOGIES ARE APPLIED IN:

- healthcare and life science;
- information technology and electronics;
- finance and commerce;
- analysis in materials science, life sciences, geosciences, forensic science, art and archaeology;
- new materials development;
- engineering;
- energy production;
- national security;
- environmental studies.

CURIOSITY AND THE FUTURE

The discovery of a particle, the electron, and radiation (X-rays) at the turn of the 20th century was driven by human curiosity – and it transformed the modern world. Other particles could be discovered with similar far-reaching and initially unanticipated benefits. The discovery of new, long-lived charged particles, which could catalyse nuclear fusion, or magnetic monopoles to catalyse proton decay, has the potential to provide a limitless supply of energy.

Particle physics and healthcare

Therapies, diagnostics, as well as molecular biology and genetics studies, have benefited from equipment and information technology developed for particle physics.

ACCELERATOR APPLICATIONS

Particle accelerators have been a key tool in medicine for more than 50 years. The world's first hospital-based cyclotron was built at the Hammersmith Hospital in London in 1955. There are now almost 10 000 accelerators operating in hospitals and medical research facilities worldwide. Innovations in accelerator design, driven by the demands of particle physics experiments, continue to find medical applications.

Safer medical isotopes

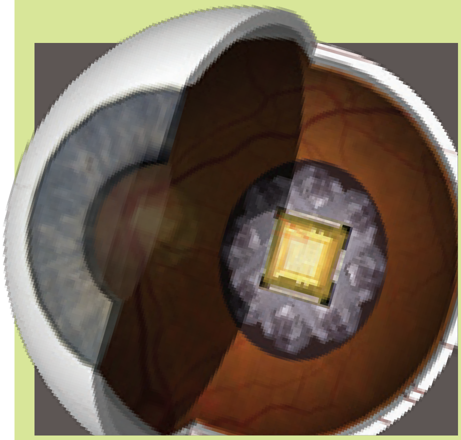
Accelerators are used to produce radioactive isotopes for imaging (positron emission tomography, PET), radiotherapy and medical research. CERN has recently designed a system using proton beams to make neutrons, which in turn can more efficiently generate new short-lived radioisotopes suitable for a range of diagnostic applications – in an environmentally clean way.

DETECTOR APPLICATIONS

Particle-physics experiments like the LHC require detectors that can measure the exact microscopic position or energy of a particle very quickly. The devices must also be robust enough to withstand a high-radiation environment. Particle physicists continue to develop a plethora of more efficient devices that will also enhance both clinical diagnosis and biomedical research. Examples include:

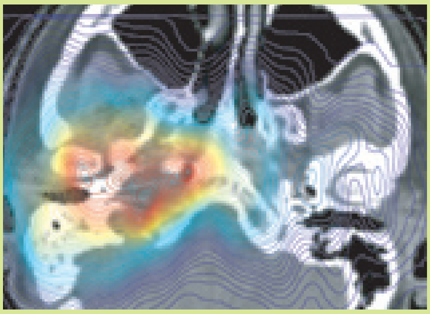
Safer radiography and therapy

The LHC produces huge amounts of radiation, which has to be monitored. A highly sensitive dosimeter based on technology developed for the LHC ATLAS detector, which recognises the pattern and energy of radiation, has been designed for use in hospitals and in other locations where there are health risks from radiation.



Novel 'bionic' implants

A new type of active pixel sensor developed for the LHC has many applications but the most exciting are retinal implants which have the potential to restore partial sight to the blind.



Faster medical imaging

Several advanced silicon devices, such as the Medipix hybrid pixel detector developed by a CERN collaboration involving UK researchers, will lead to faster X-ray imaging and CT-scanning, with clearer images at lower X-ray doses, which can be used to monitor cancer therapy in real time.

Originally developed for particle physics and astronomy, charge coupled devices (CCDs), found in digital cameras, are also used in dental X-ray machines. A new generation of large-area X-ray detectors based on technology being developed for the ILC (p7), could be used to image the heart for example.

Gas-filled particle detectors have been incorporated in a new whole-body PET scanner, which is significantly cheaper and quicker than the current PET systems.

Treating inoperable cancers

An exciting – and expanding – application is to employ particle beams (protons, neutrons and heavy ions) to kill tumours that are otherwise difficult to treat. The beams can be tailored so that their destructive energy is deposited only in the cancerous tissue, and are ideal for treating head and neck cancers. UK particle physicists are developing a new type of inexpensive, compact accelerator for the neutrino factory project (p7), called a fixed-field alternating-gradient accelerator, which could produce beams of variable energy, and would be suitable for hospital use.

COMPUTING APPLICATIONS

Advanced computing techniques are an integral part of all basic physics research. They generally deal with complex systems, which can be applied to similarly complex systems in the life sciences.

Measuring radiation effects

Before an experiment is carried out, the expected particle interactions are first simulated on a computer. GEANT4, a particle-physics simulation software package which assesses the effect of radiation on matter, can be used for optimising the design of radiotherapy equipment, and assessing radiation hazards.

Managing cancer

Grid-based technology (p10), originally developed for the LHC and other large experiments, is now being applied to manage databases of cancer patients which will help in assessing their treatment.

BIOMEDICAL RESEARCH

Particle-physics accelerator and detector technologies have an immediate application in the design of large-scale facilities (synchrotrons, free electron lasers, and neutron spallation sources) which generate high-intensity light and other radiation for analysing materials, in particular biological molecules and tissues. This research is essential in fully exploiting the results of the Human Genome Project, for example, to understand the origins of diseases and how to combat them.

One of the first applications of the particle-physics Grid designed for the LHC was a molecular modelling programme, WISDOM, used to develop new drugs to treat malaria. More than 46 million molecular structures were examined on a computer to find candidates with potential bioactivity.

A spin-out company from Imperial College London, DeltaDOT is using data acquisition and analysis tools developed for the Tevatron experiment at Fermilab in the US to extract useful information from the Human Genome Project.

Communications

Particle-physics experiments involve collaborations of thousands of people processing and managing huge amounts of data. The LHC experiments will produce 5 million gigabytes of data per year, a volume larger than the NHS patient-record system. The data-management strategies implemented by particle physicists are highly transferrable, for example, to government and international business.

THE GRID

Now, a new advance, whereby data storage and processing are distributed invisibly across a global network of computers, is set to change the world again. Grid computing will be invaluable to business and in all kinds of management at both public and personal levels.

CASE STUDY

Image repositories are now commonplace on the internet, with content ranging from personal photographs to historical archives. Grid technology developed for the LHC has allowed the company Imense Ltd, working with particle physicists at the University of Cambridge, to increase its search capabilities 100-fold, as it seeks to become the pre-eminent image search portal.

Manufacturing and business

Particle-physics experiments represent a formidable engineering challenge, virtually always requiring novel hardware, electronics, and software developments.

ELECTRONICS

The requirement of rapid data accumulation in a high-radiation environment has led to major collaborations with electronics manufacturers which, in turn, have resulted in significant improvements in chip designs – for example, radiation-hard, highly parallel and three-dimensional chips, as well as connectors that allow fast read-out and data acquisition.

ENGINEERING

Colliders like the LHC and ILC (p7) require high-field magnets with efficient cooling, radiofrequency (RF) systems, and high-voltage and power management. CERN engineers have developed efficient cryogenic and vacuum technology that can be applied in many industrial areas.

CASE STUDY

A UK-Italian collaboration has developed a novel superconducting transistor, originally for detecting dark matter (p6), which can amplify very small signals. A potential application is in future quantum computers, which are many times faster than traditional transistor-based computers.

CASE STUDY

Superconducting RF devices were developed to accelerate particles in the ILC. The technology is likely to be exploited in accelerators such as light sources used in biomedical and materials research.

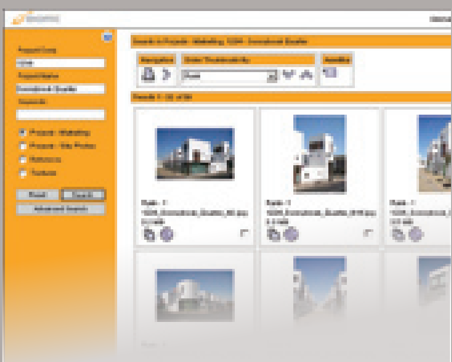
Particle accelerators are essential tools in fabricating the layouts of electronic circuit boards, using ion implantation, and more than 10 000 are used in the semiconductor industry.

WORLD WIDE WEB
In the past decade, the World Wide Web (WWW), which was designed at CERN to help its transnational teams communicate, has revolutionised the global economy. Google's revenue alone was more than $20 bn in 2008.

"A place like CERN, where enthusiastic experts congregate from all over the world, creates a unique, innovative atmosphere in which the boundaries of technology are pushed as a matter of course. CERN's existence was critical to the start of the Web."

Sir Tim Berners-Lee, WWW Consortium and the University of Southampton

SOFTWARE
Software tools employed in particle physics also provide an enabling technology to the financial-services and engineering sectors.



CASE STUDY

Based on computer software designed to analyse LHC results, UK particle physicists set up a company, Axomic, which markets Web-based tools to architects, engineering and construction companies for managing image catalogues and 3-D plans.

Global challenges

Three areas of major global concern are energy supply, national security, and the environment. Particle-physics technologies are already contributing to making the world safer, by providing sensitive radiation-detection systems and scanners. Computer techniques developed by particle-physics theorists have been adapted to a wide variety of environmental tasks such as oil-prospecting, weather prediction, reducing emissions through traffic management and even monitoring the movement of wildlife. Perhaps the most far-reaching applications will be in the area of electricity generation.

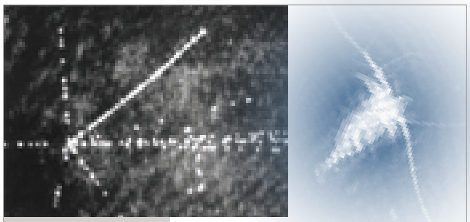
ENVIRONMENT
Grid-based approaches are ideal for environmental modelling and monitoring, which often involve several groups of people sometimes working in remote locations or on complex problems. For instance, researchers have used particle-physics analytical techniques to monitor the migration of whales.

ENERGY
Novel accelerator technology has the potential to dispose of nuclear waste. One of the most exciting developments is a reactor design developed at CERN, using thorium fuel. It relies on a proton accelerator, and produces little long-lived radioactive material. This concept can also be deployed to transmute waste from conventional nuclear reactors into less harmful material.

Nuclear fusion is another future energy source that can benefit from particle-physics technology, as it requires ultra-high vacuums and powerful magnets.

CASE STUDY

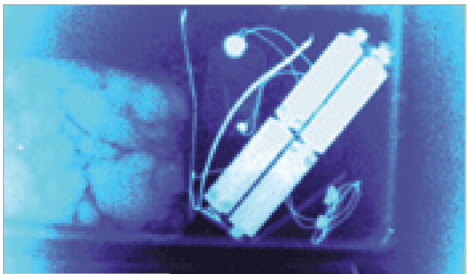
UK particle physicists are developing a Grid-based system for controlling and monitoring small-scale renewable energy sources, such as solar and wind, in order to maintain a sustainable electricity supply.



CASE STUDY

A holographic camera, originally designed to image particle tracks in bubble chambers, was adapted to record clouds of plankton in the sea in pollution and global-warming studies.

NATIONAL SECURITY
Particle detectors are used to monitor nuclear reactor cores and can check whether weapons-grade enriched uranium or plutonium are present. They can similarly be adapted to detect radioactive materials at airports and other points of entry into the country.



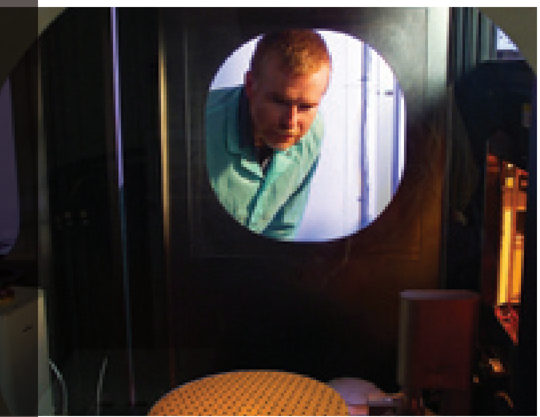
CASE STUDY

Scintillating crystals that respond to X-rays and gamma-rays are components in particle-detection systems. A partnership between the company Corus and the University of Sheffield is developing large-area scintillation detectors to detect fissile material. Physicists have also developed devices that generate neutrons which, when combined with scintillators, can identify the characteristic signatures of explosives and drugs in air cargo.

Helping **industry**

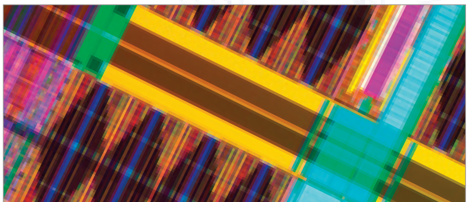
Particle physics is an important driver of new technologies which can stimulate industrial growth

Large particle-physics experiments involve a wide range of industries, from construction and engineering to microelectronics and plastics, and contractors can benefit in many ways. Companies may have to supply thousands of novel components to extremely high specifications. In doing so, their businesses often expand as a result of new technology requirements, improved manufacturing capability and access to new markets.



Technology developments

Powerful superconducting magnets were first developed for particle accelerators, and are now the basis of MRI scanners and the light sources used for biomedical and material science research. UK supply companies such as Oxford Instruments and Tesla Engineering have been able to apply the technologies developed for particle accelerators to other market sectors.



CASE STUDY

Oxford instruments developed the first compact X-ray source based on superconducting magnets, which is now used by IBM to etch the microscopic features on silicon chips. Improvements being pursued in superconducting magnets within particle physics have applications ranging from the Super-LHC (p7) to fusion research and cheaper, higher-temperature magnets for MRI scanners.

Increased capacity

The large numbers of components such as magnets, RF cavities and detector modules needed by modern colliders have required companies to develop mass-production methods and facilities, which then enable them to expand their business.

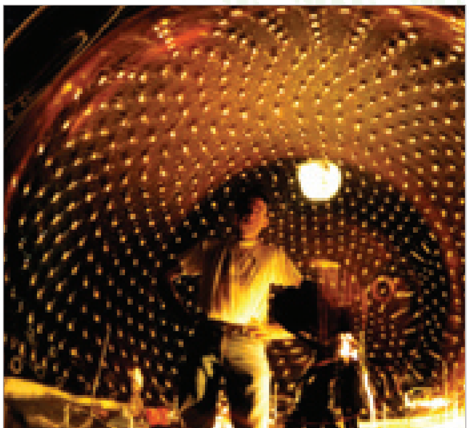
The LHC has some 5600 superconducting magnets installed around the collider ring, which is 27 km in circumference.

CASE STUDY

Hilger Crystals in London had to mass-produce fast-response scintillator crystals for the BaBar experiment (p7), which then allowed the company to supply its products at a price that was attractive to manufacturers of medical imaging equipment.

IMPROVED PERFORMANCE

Electronics companies, in particular, benefit directly from collaborating with particle physicists and engineers whose expert knowledge allows them to improve their products. Microelectronics designers and physicists at the STFC Rutherford Appleton Laboratory and CERN have worked with major firms such as IBM, helping increase their understanding of their own technology, while UK particle physicists working with smaller companies such as Micron Semiconductor UK, have helped improve the performance of radiation-hard silicon sensors suitable for Earth-monitoring missions.



CASE STUDY

ET Enterprises Ltd is a UK subsidiary that produces photomultiplier tubes for detecting faint signals from dark-matter and neutrino interactions. The company has maintained its competitive edge by fulfilling the stringent demands of the particle-physics experiments, most recently for glass-free tubes with low levels of radioactivity.

Underpinning the knowledge-based economy

Our future economic competitiveness depends on maintaining a strong technological base and a highly-skilled workforce, and 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, a training in particle-physics research provides a range of skills much sought-after by employers.

Transferrable skills

Particle-physics PhD students are often involved in large-scale data analysis and mathematical modelling of complex systems – skills that are in demand in the computing and financial sectors. They also work in large international collaborations, often in other countries, where they engage in teamwork and broaden their life experience. These skills are much in demand in multinational organisations. The training given in areas such as advanced electronics and computing is also invaluable. About one-half of all particle-physics PhD students eventually take up high-level careers in business and industry, helping to furnish the highly skilled workforce needed in the current economic climate.

Extending engineering capabilities

The stringent precision and quality-control requirements of the LHC have provided opportunities for several small companies to improve their testing and manufacturing facilities in areas as diverse as specialist transportation containers, large-area precision-machined steel structures, clean-rooms and precision-mounting of digital electronics.

Widening the customer base

Working with organisations like CERN automatically enhances a company's reputation. Elonex, a UK computer company, found that collaboration with CERN introduced the company to other key manufacturers.

"CERN is an excellent 'reference customer' for attracting new business."

Fabien Collin,
Technology Director, Elonex

International collaboration

Particle physics thrives on transnational collaboration and many of the best physicists come from overseas to work in UK-based teams. One-third of the particle-physics academics and one-half of the young postdoctoral researchers in UK universities are from overseas. This fosters good international relations, keeps the UK at the heart of cutting-edge technological development and makes it a desirable place to work.

Attracting students into physics

A recent survey (p14) has revealed that particle physics, along with nuclear physics and astrophysics, is the most popular subject for physics undergraduates. They retain this interest through to postgraduate level – even if they eventually use their training in more applied areas. Places on particle-physics PhD courses are much sought-after, with many highly qualified undergraduates applying for each place.

Popular culture

Particle physics is about 'big ideas' – what happened in the first moments after the Big Bang and where did matter – and thus ourselves – come from? Contemplating these questions is part of the nation's intellectual life and generates numerous factual – and fictional – books, documentaries and films aimed at the general public. Around a quarter of popular science-magazine covers feature basic science. The physicists that are the most well-known are frequently those working in curiosity-driven research. Media coverage of particle physics, alongside astronomy, helps to attract into science young people who will be the future entrepreneurs and leaders in a knowledge-based economy.

Particle physics in the UK

Particle-physics research in the UK is carried out at 23 universities and two national laboratories. It is funded principally through grants from the Science and Technology Facilities Research Council (STFC), the Royal Society, the Leverhulme Trust and the European Union.

The research has been recognised as internationally leading in an independent review sponsored by the Engineering and Physical Sciences Research Council, the Particle Physics and Astronomy Research Council (now part of STFC), the Institute of Physics and the Royal Astronomical Society where it was stated: "UK research in the field of particle physics is of a high quality and internationally very visible... UK physicists carry the responsibility for key detector components and often hold leadership positions."

CERN ECONOMIC IMPACT

The majority of the experimental research and UK funding is directed at CERN. Studies quantifying the economic utility of CERN, in terms of increased turnover plus cost savings resulting from contracts awarded by CERN, show that every £1 paid to an industrial firm generates £3 of utility. After accounting for the CERN budget, this represents a net return of 20%; 75% of the increased sales were to sectors outside particle physics such as solar energy, the electrical industry, railways, computers and telecommunications. CERN's economic impact multiplier of 3 is very similar to that of the European Space Agency, although in the latter's case, the majority of the increased sales remain in the space and aeronautics sector.

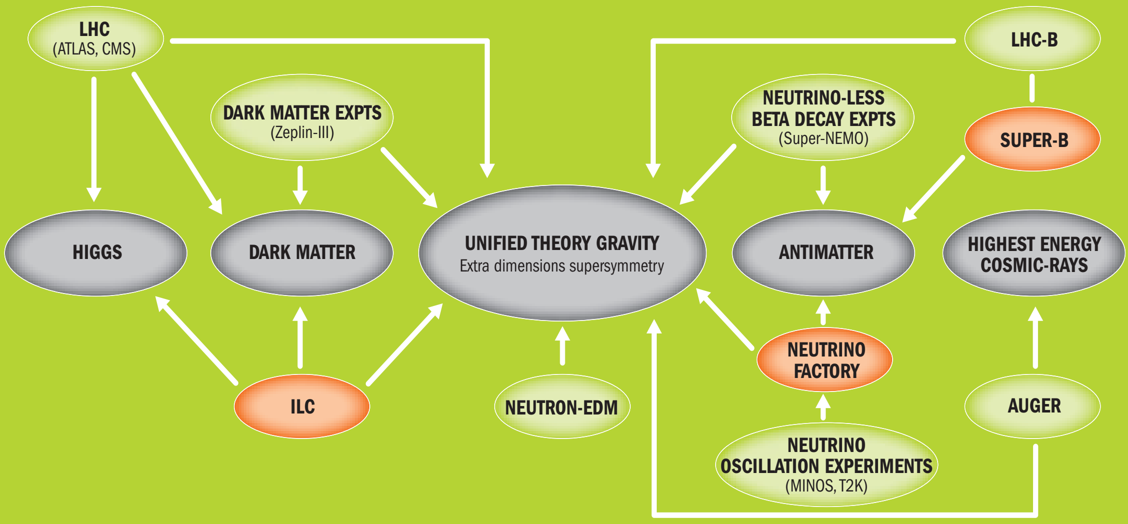
ATTRACTING STUDENTS TO STUDY PHYSICS – AN UNDERGRADUATE SURVEY

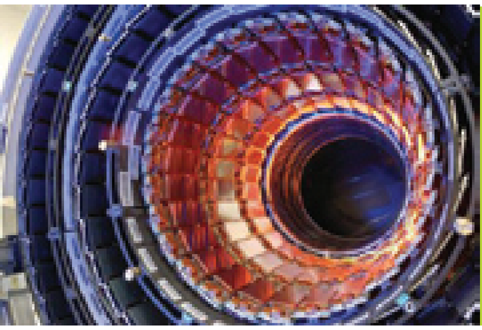
A survey of over 800 undergraduate students, was undertaken in November 2007 at eight UK universities (Durham, Glasgow, Imperial, Liverpool, Manchester, Oxford, University College London and Warwick), to quantify the subject areas that attracted undergraduates to study physics at university – and which areas they retained an interest in at the end of their studies.

The results of the survey are summarised below:

- The three most popular subject areas that first-year undergraduate students cited as being of "significant interest" in terms of attracting them to study physics were: particles and quantum phenomena (72%), nuclear physics (61%) and astrophysics (53%); 90% of students expressed a significant interest in at least one of these three areas;
- For final-year students, 89% expressed some or significant interest in particle physics with similarly high percentages in astrophysics/cosmology (73%) and nuclear physics (82%);
- Only 11% of final-year students expressed no interest in particle physics, the lowest "no-interest" fraction of all subject areas.

UK physicists are addressing all the key questions in particle physics through a series of current (green) and planned (orange) experiments





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ACKNOWLEDGEMENTS

This report was prepared for the Institute of Physics by its High Energy Particle Physics Group with contributions from the following people:

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The Institute of Physics appreciates the financial support provided by the STFC in the preparation of this report.

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FURTHER READING

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