IOP Institute of Physics In Ireland

The Case for Irish Membership of the European Laboratory for Particle Physics - CERN

Prepared by the Institute of Physics in Ireland* **September 2008**

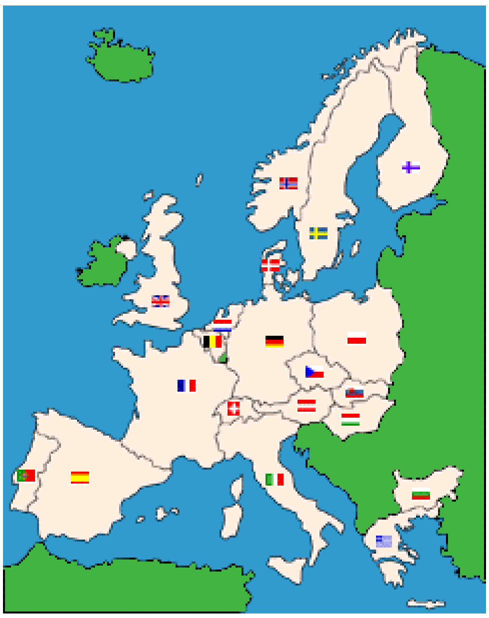
Summary

Ireland aims for international excellence in research in order to bring about a transformation in the Irish economy. Physics is a key science which underpins developments in areas as diverse as medical technology, communications and energy production. Indeed physics based industry employs over 85,000 and has a value to the Irish economy of - €15 billion annually[1]. Particle physics is an essential element of the discipline and CERN is by far the world's leading laboratory in this area. Without membership, Ireland is unable to participate in the most fundamental and far-reaching aspects of research physics with its attendant benefits of spin-off industrial outcomes. Joining CERN would:

- Be a strong statement of Ireland's intention to contribute to world-class science at the highest level and give a significant boost to the Irish research base.
- Raise the profile of physics in Ireland in a cost-effective manner and attract more students to study science.
- Show a direct economic return in terms of contracts to Irish companies and high potential start-ups in imaging and detector technologies and in high performance computing.

A model for international collaboration at the highest levels

Based near Geneva, CERN is the world's premier research laboratory in particle physics. Most European nations are CERN member states, including all 15 of the old EU countries except for Ireland and Luxembourg. Many eastern European countries are in the process of applying for, or are already, CERN members.[2] - In addition, India, Israel, Japan, Russia, Turkey and the USA are observer states. The 2006 US National Academies report on the future of particle physics makes clear that Europe is leading the field in this area. It specifies that the highest priority for the US national effort in particle physics should be to *'continue as an active partner in realizing the physics potential of the Large Hadron Collider (LHC) at CERN[3].*



In the 2006 report, ‘Strategy for Science, Technology and Innovation’, the Irish Government stated that its vision is that ‘*Ireland by 2013 will be internationally renowned for the excellence of its research, and will be at the forefront in generating and using new knowledge for economic and social progress, within an innovation driven culture*’[4].

Non-membership of CERN, however, sends a clear signal that in reality Ireland is not fully committed to transforming itself to a knowledge based economy.

High Energy Particle Physics

Understanding the building blocks of the Universe
CERN is an international collaborative laboratory where scientists study the fundamentals of matter, elementary particles, and the forces that control them and hence the Universe. CERN exists primarily to provide these scientists with the necessary tools - accelerators, which accelerate particles to almost the speed of light and detectors to make the particles visible.

Currently, by far the largest and most powerful particle accelerator in the world, the 27km ring-shaped Large Hadron Collider (LHC)has just been constructed at CERN and recently came on line in September 2008, together with four large detectors for measuring particle collisions. The LHC collides two beams of protons at such high energies that conditions at the collision point will mimic those that prevailed a trillionth of a second after the Big Bang, when the universe was the size of a full-stop and comprised only of fundamental particles. This corresponds to a previously unexplored energy regime. Recreating these conditions allows the study of the particles and their interactions thereby extending our understanding of matter itself and the forces which hold it together and ultimately the universe in which we live. For instance, theoretical work in this area seeks to find a fundamental ‘theory of everything’, or Grand Unified Theory (GUT), which would explain gravity and mass in a unifying manner with the other fundamentals of physics such as the electromagnetic and nuclear forces. Further scientific details are included in Appendix I.

Particle physics is one of the most exciting and prestigious areas of scientific research and this is reflected by the number of Nobel prizes which have been awarded in this area for theoretical and experimental work (1969, 79, 84, 99 and 2004). CERN played a fundamental role in these achievements. CERN now seeks to answer many of the biggest questions in physics at the start of 21st century. *What is mass? What is dark matter?* Like the big scientific questions posed at the beginning of the 20th century, such as those relating to the sub-atomic particles, for example the electron and neutron, it is certain that both the quest and the answers will lead to new technologies which will have profound effects on society and the economy.

From cancer treatment to security systems
While the core physics at CERN being investigated may seem esoteric, the science and technology required for the accelerator and detectors has many applications in both industry and in other research strands of physics and the life sciences. These span such areas as detector development, high-performance computing and networks, material developments and large-scale civil and mechanical engineering.

It may seem surprising, but the majority of existing particle accelerators in the world are used in medical science – for example, cancer therapy. In radiation treatment, the radiation usually takes the form either of X-ray photons, electrons or neutrons, all of which are produced by particle accelerators. The latest techniques use high-energy proton beams to destroy tumours in a manner more efficient and safer than that of the traditional X-ray therapy. This leads to a requirement for highly trained scientists and engineers for design, commission and operation of these facilities in hospitals.

At CERN, developments in the experimental techniques such as image reconstruction and instrumentation have greatly stimulated parallel developments in medical procedures, particularly in the areas of non-invasive imaging and cancer therapy. Such work dovetails very cohesively with Ireland’s expertise in medical device technologies. At present 8 of the world’s top 10 medical device companies are operating in the country, including Bausch and Lomb, Abbott and Boston Scientific as well as many SME’s,- which directly employ over 24,000; - 80% of these companies are innovation active[5] giving rise to considerable scope for parallel research in both industry and in third level institutes. Of additional interest in Ireland are the applications in solid-state detector elements, used for example in bulk checking of shipping containers for drugs, bombs or simply content verification - corresponding research is performed in nearly all engineering departments at Irish universities and at several Institutes of Technology.

Ireland would certainly be in a position to set up a number of niche research groups in areas such as imaging, detectors and associated signal processing techniques which could capitalise on the experimental opportunities at CERN.

Information and Communication Technology (ICT)
As is well known, the world-wide-web was invented at CERN as a means for world-wide particle physicists to communicate their scientific discoveries. Today, CERN is leading the effort in research, development and deployment of the so-called Grid data and computing infrastructure. The goal of the Grid is to offer large-scale data and computing capacity much like the electric power grid provides electricity. The Grid initiative is driven by the extraordinary ICT needs of the new LHC particle physics experiments at CERN. Each experiment produces vast amounts of data annually and will require the computing power of several 10,000 PCs for data handling and analysis as well as high-speed networking for linking Grid sites to thousands of scientists at hundreds of institutions world-wide.

Grid has many applications beyond those of high-energy physics. These include such major science areas as climate simulation (BBC + Met Service, NWS, earthquake simulations (NEES grid), astronomy (the SLOAN digital sky survey) and industrial applications such as financial modelling, aircraft design, oil exploration and drug discovery in the pharmaceutical industry.

Involvement in particle physics Grid activities would be a significant boost to Grid research in Ireland, which is currently funded through PRTLI and SFI. All universities in Ireland, and a number of Institutes of Technology are involved at one level or other in Grid activities with around 30 academic staff involved in core Grid activities and more than 100 Grid users.

Education and Public Outreach

CERN membership would undoubtedly raise awareness in Ireland of the physical sciences. Along with astrophysics, particle physics asks the most fundamental questions and this is one of its great attractions for young people. World wide the phenomena is noted by the US National Academies report[2] '*it has been a centerpiece of the physical sciences throughout the 20th century… and has attracted scientists from abroad to come and contribute to the nation's intellectual and economic vitality*.'

CERN offers a wide range of education and training programmes at all levels, second-level school programmes for students and teachers, summer programmes for undergraduates, doctoral student programmes placing students at CERN for extended periods and programmes for visiting research scientists. However, only membership provides full access for Irish nationals to these programmes, which are highly sought after. These could be harnessed for the ongoing drive in Ireland to increase the numbers of students taking physics. For example, around 150 places are available each year at CERN for its highly prestigious undergraduate summer school. Many of these students have gone on to work at a high level within CERN opening up significant opportunities for research collaborations. At present such facilities are not open to Irish students.

A carefully planned Irish entrance to CERN will provide an unprecendented opportunity to promote a public awareness of the importance of science to the 21st century economy. An appropriate launch event, such as a high profile world conference giving details of results from the LHC, - at the planned new Dublin conference centre might be considered.

CERN Membership Fee – Why Join Now?

The membership fee is calculated on the basis of the nation's net national income (generally around 74% of GDP). On the basis of Irish GDP for 2004/05/06, CERN estimates an annual fee of 22.05 MCHF (approximately €13 million at current exchange rates), which is comparable to some of the larger SFI grants. Financially it is particularly opportune for Ireland to join now as the other member states and the USA have already paid for the LHC and its detectors. Informal discussions with CERN suggest that the membership cost would be phased in over a transitional period of up to five years, during which the contribution would build up from 25% to 75% of the full contribution and there would be measures to build up the national capacity in particle physics and to allow for the development of research groups in specific areas so as to obtain maximum benefit from membership. Given Ireland's current strengths in areas such as imaging and detector systems it seems very feasible that a cluster of research groups could be significantly strengthened by CERN membership and could dovetail with existing SFI research priorities. Such clusters currently exist in the UK, for example, the John Adams Institute and the Cockcroft Institute. Researchers in Ireland have already established good links with groups in the UK, Europe and the USA and would be in an excellent position to capitalise on these connections.

Irish Research

Theoretical research groups in high-energy particle physics have a strong base throughout Ireland. Institutes carrying out such research include DIAS, NUI Galway, NUI Maynooth, TCD and UCD with around 25 academic staff working specifically in this area. Their work complements the experimental work at CERN and is a particular growth area in Irish physics. For example, Trinity has recruited 7 permanent faculty since 2002 and will recruit a further 4 this year in addition to 10 post-doctoral positions and 11 graduate students. There are also a small number of experimentalists in Ireland already using CERN through *ad hoc* arrangements including staff at DCU, NUI Maynooth, UCD and TCD. In the past five years Irish institutions have produced over 600 publications in the field of high-energy physics, many with a high citation index. See Appendix II.

There is, however, clearly a chicken and egg situation in that without CERN membership it is impossible to fully develop an experimental particle physics programme in Ireland. However, even with this unfavourable environment, UCD recruited two academics in 2003 who in the last four years, starting from zero have attracted €1.5 million in funding, 5 post-doctoral positions and 8 students. CERN membership is essential for these research groups to realise their full potential and remove the significant disadvantage in relation to other European groups.

There are also many Irish researchers now working outside Ireland in this field. This is probably because of the lack of support for this area in Ireland. Indeed a number hold senior positions at CERN, including the head of the accelerator and beams division, Steve Myers and the technical co-ordinator of the ATHENA experiment, Paul Bowe.

Irish Industry

Some of the investment in the membership is returned to the country as CERN contracts are awarded preferentially to companies residing in member states. Indeed CERN aims to have a ratio of 0.94 between the percentage of expenditure in an individual member state and that member state's percentage contribution to the CERN budget.

The main areas which are open for tender include:

- Civil and mechanical engineering
- Computing and software engineering
- Electrical Power Generation
- Electronics
- Low temperature technologies
- Particle detectors
- Vacuum technologies

Many of the world’s most important ICT companies have a significant presence in Ireland, including IBM, Intel, HP, Dell, Bell Labs, Cisco and Microsoft, while the country has developed considerable expertise in electronics, detectors and imaging. In these areas there are businesses ranging from start-ups such as SensL Technologies and Firecomms in Cork, through to multinationals such as Analog Devices. Many such companies are well placed to bid for contracts at CERN or to develop additional expertise to allow them to do so.

It is significant also, that a member country’s size is not necessarily the most important factor in obtaining business contracts. For example, Finland, of similar size and structure to Ireland had supply contracts worth €5.8 million in 2003 compared with its annual fee that year of €8.5 million, while in the period 2003-2006 it showed the third largest industrial return of all the members. Discussions with a number of CERN industrial officers suggests that this is partly due to the good networking skills of both the Finnish researchers and industry contacts and also its pivotal role as a country lying between Russia and Europe.

Closer to home, it is noteworthy that Northern Ireland has benefited considerably from the UK’s membership of CERN with 17 companies, including Mivan Ltd, FG Wilson and Micro-Flextronics, winning significant supply contracts.

Ireland has a remarkable history of 'punching above its weight' in many European bodies and has a similar gateway economy between Europe and the USA. It is of particular note that Ireland has achieved exceptional success in obtaining contracts with the European Space Agency (ESA), primarily through the work of Enterprise Ireland in identifying such opportunities. With an annual membership fee of €10 million, in the period, 2000-2006, Irish firms have won ESA contracts worth an estimated €25 million with spin-off business worth an estimated €100 million and more than 60 Irish companies to date have engaged with ESA[6]

Given the government's aim to dramatically increase the level of high tech business and research in Ireland, CERN membership provides a particularly strong stimulus both to the many existing companies in Ireland and in encouraging new spin-off businesses. It is also open to member states to direct public monies to companies to help develop new products specifically for the CERN market thereby giving a cohesiveness to government policy on research and development and enabling high-tech companies to remain on the cutting edge of innovation.

Membership sends out a clear signal, to international scientists and investors that we are willing to be a part of the largest, high-tech, scientific, world-wide collaboration of scientists and engineers. This must have a significant impact on Ireland's reputation as a beacon for scientific investment.

There is a highly compelling case on scientific, economic, social and cultural grounds for Ireland to join CERN. Given that the recent highly successful launch of the LHC, with all its attendant opportunities for research and technology transfer, coupled with recent strategy announcements regarding doubling of PhD numbers[4], the timing has never been more opportune for Ireland to join CERN.

Notes:

1. Physics and the Irish Economy, 2007. Institute of Physics Report

2. The 20 CERN member states are: Austria, Belgium, Bulgaria, the Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Italy, The Netherlands, Norway, Poland, Portugal, the Slovak Republic, Spain, Sweden, Switzerland and the United Kingdom.
   Observer States and Organisations currently involved in CERN programmes are: the European Commission, India, Israel, Japan, the Russian Federation, Turkey, UNESCO and the USA.

3. Revealing the Hidden Nature of Space and Time: Charting the Course for Elementary Particle Physics. Report by the National Academies, 2006.

4. Strategy for Science, Technology and Innovation, 2006-2013, June 2006. Dept. of Enterprise, Trade and Employment

5. Statement of Strategy, October 2007. Irish Medical Device Association, IBEC.

6. Annual Implementation Report, 2005 for the Productive Sector Operational Programme, 2000-2006. Dept. of Enterprise, Trade and Employment.

***The Institute of Physics in Ireland**

The Institute of Physics in Ireland (IOPI) is the professional and scholarly organisation for physics in Ireland, both Northern Ireland and the Republic. It represents over 1700 physicists active in education, research, industry, the public service and commerce in Ireland. It is a key educational and research stakeholder and regularly produces reports and recommendations on many aspects of physics. It is a branch of the London-based Institute of Physics, a leading international body and learned society with over 37,000 members in Ireland, the United Kingdom and elsewhere, which promotes the advancement and dissemination of a knowledge and education in the science of physics, pure and applied.

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Appendix I

Further background to the scientific case

Particle Physics

Particle physics is concerned with the study of the universe at the microscopic, subatomic level. Research in this area aims to identify and understand the building blocks, or fundamental particles, of which it is believed the universe is composed. The observed behaviour of these particles, and the forces that they experience, is described in a theory called the Standard Model. Thus far the Standard Model has proved remarkably successful, with no experimental repudiation of its predictions and the validity of the theory has been proven to better than 1%.

However, the Standard Model (and therefore the understanding of the universe), is also known to be incomplete. For example, it cannot describe the effects of gravity and despite success at predicting the outcome of experiment it lacks explanation for almost all phenomena. The next generation of particle physics experiments at the Large Hadron Collider at CERN have been designed to investigate these shortcomings.

The LHC; the high energy frontier.

Particle colliders act both like giant microscopes that allow us see inside matter and time-machines that allow us recreate the conditions of the early universe. The LHC is the world's newest and most powerful particle accelerator. It has been constructed at CERN inside a 27km long tunnel, 100m underground, and should begin operating in May 2008. When operational, the LHC will collide two beams of protons at such high energies that conditions at the collision point will mimic those of the universe a trillionth of a second after the Big Bang, when the universe was the size of a full-stop. At this early time the universe was composed of fundamental particles; recreating these conditions allows a study the particles and their interactions and thus understand more about matter, the forces that hold it together, and why the universe appears as it does. The LHC accesses a previously unexplored energy regime and will allow an exploration of matter and the universe at the deepest levels possible to date.

The "Big Questions"

<u>What is mass?</u>

Mass is familiar in everyday life. It is a source for gravity, and ensures the Earth rotates around the sun and the moon round the Earth. Despite this familiarity, no one really knows what mass is, or what process causes matter to have it. In the Standard Model particles acquire mass by interacting with a particle called the Higgs boson, and the amount of mass they receive is determined by the strength of the interaction. Thus the Higgs boson not only explains what mass is, but is also a necessary part of the theoretical framework of particle physics. However, it has not yet been observed in any experiment and this is a tremendous problem for particle physics. If the Higgs boson does not exist, not only is mass unexplained, but the Standard Model is incorrect.

The search for the Higgs boson has dominated particle physics for the last 30 years and is the primary reason for the construction of the LHC. As the LHC has sensitivity to the entire region in which this particle can be found, physicists are certain that if the Higgs particle exists and that the theories are correct, it will be discovered there. In essence, though, the LHC is being built to explore the unknown – another increase in the energy at which physics is being explored will almost certainly produce new science.

<u>The absence of antimatter in the universe</u>

In the Big Bang, matter and antimatter were created in equal quantities. Physicists believe an unknown process tipped this balance slightly in favour of matter in the first minute of the universe, to allow the survival of the matter dominated universe we see today.

A clue to identifying this process lies in the fact that the matter world, reflected in a mirror, does not present a perfect copy of the antimatter world. This is a phenomenon known as CP violation. The small difference in behaviour may explain the absence of antimatter. The source of CP violation, and its magnitude, is currently unknown. Physicists hope to improve their understanding by studying the behaviour of bottom and antimatter bottom quarks, fundamental particles where the effects of CP violation are believed to be greatest, produced at the LHC.

What is dark matter?

Recent astronomical observations indicate that everyday matter accounts for just 4 percent of the total substance in the universe. The rest of the universe consists of hypothesized entities called dark matter and dark energy that are not described by the Standard Model.

Although no one knows what dark matter is, hypotheses do exist. One of the most popular theories, which can be tested at the LHC, is called “supersymmetry”.

Fundamental particles can be classified as either fermions or bosons according to their quantum mechanical spin. Supersymmetry introduces a new symmetry in nature between fermions and bosons. It achieves this by adding new supersymmetric fermion-like particle partners for bosons, and boson-like particle partners for fermions. The lightest supersymmetric particle is a dark matter candidate.

No one has yet seen any supersymmetric particles - however if supersymmetry theory is correct, these particles should be discovered at the LHC and thus allow physicists to infer what dark matter is made of.

Is there a theory of everything?

It is impossible, technically, to include gravity in the Standard Model. However a complete description of the universe must include it, and this has led theoretical physicists to a search for an underlying “theory of everything”.

Superstring theories have received enormous theoretical interest over the last 30 years and recently have entered the popular imagination through a number of books and television programmes. These theories postulate that fundamental particles should be viewed as extended shapes in a ten dimensional universe. Even though we experience only their point-like projections in our normal three dimensions, experiments may be sensitive to their effects. Although most theories do not yield experimentally testable predictions, those where the extra dimensions are relatively large do so. The LHC could observe the effects of superstrings in some of these

Appendix II

Summary of Publications in High Energy Physics from Researchers in Institutes in Ireland, 2002-2007

Prof. Werner Nahm, DIAS, 1 publications
Prof. Denjoe O'Connor, DIAS,12 publications

Prof. Jurgen Burzlaff.. DCU, 1 publication
Prof. Martin Henry, DCU 19 publications which relate to research at the ISOLDE facility in CERN in the field of solid state physics

Prof. Tom Sherry, NUI Galway, 11 publications
Dr. Michael Tuite, NUI Galway, 6 publications

Dr. Brian Dolan, NUI Maynooth, 20 publications
Prof. C. Nash, NUI Maynooth, 3 publications
Dr. Jonivar Skullerud, NUI Maynooth, 29 publications
Prof. T. H. Tchrakian, NUI Maynooth, 22 publications

Dr. Nigel Buttimore, TCD, 10 publications
Dr. Brian Coghlan, Computer Science, TCD, 5 publications relating to Grid activities and CERN
Dr. Sergey Cherkis, TCD, 5 publications
Dr. Sergey Frolov, TCD, 11 publications
Dr. Michael Fry, TCD 5 publications
Prof. Anton Gerasimov, TCD, 2 publications
Dr. Calin Lazaroiu, TCD, 24 publications
Dr. Stefano Kovacs, TCD, 12 publications
Dr. Michael Peardon, TCD, 30 publications
Dr. Sinead Ryan, TCD, 21 publications
Dr. Christian Saemann, TCD, 15 publications
Prof. Samson Shatashvili, TCD, 3 publications
Dr. Yakov Shnir, TCD, 7 publications
Dr. Stefan Sint, TCD, 18 publications

Prof. Martin Grunewald, UCD, 138 publications
Dr. Ronan McNulty, UCD, 160 publications
Dr. Tahar Kechadi, Computer Science, UCD, 151 publications
Prof. Siddhartha Sen, UCD, 8 publications

584 papers from Irish institutions compiled from the SPIRES High Energy Physics Project
http://www.slac.stanford.edu/spires/

Breakdown of search results by citation

	Published only
Renowned papers(500+ cites):	1
Famous papers (250-499 cites) :	0
#	7
Well-known papers (50-99) :	15
Known papers (10-49) :	175
Less known papers (1-9) :	302
Unknown papers (0) :	84
Total eligible papers analyzed:	584
Total number of citations:	8348
Average citations per paper:	14