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High Energy Physics: Science and Technology Benefiting Humanity

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1. Introduction

Over the 80 years, particle physicists exploring the fundamental nature of matter, spacetime and the early universe at the highest available energies have invented, developed, or pushed the limits of a wide range of new technologies to make their scientific discoveries possible. From the earliest days of high energy physics in the 1930s to the latest 21st-century initiatives, the bold and innovative ideas and technologies of particle physics have entered the mainstream of society to transform the way we live. Many of these developments, from particle accelerators and ion beams [1] to particle detectors [2] and superconducting wire [3] to the World Wide Web [4] global Computing Grid systems [5] and data networks [6] have brought profound benefits to society and in some cases, such as the Web, have formed the basis of large and pervasive sectors of our modern life.

Beyond the specific technologies, the challenge of particle physics and the fascination of some of Nature's most fundamental questions has continued to attract the best and the brightest young scientists and students, who have learned to work cooperatively across international boundaries to build and successfully operate successive generations of accelerators and experiments, along with their particle detectors, high speed electronics and computing and communications systems, including the LHC and its experiments that are among the most complex instruments mankind has ever built. The impact of these scientists and engineers on society has been very great, as most have moved on from particle physics to other fields of scientific or biomedical research, medical practice, and industries where their work on accelerators, electronics, particle detection and other instrumentation, and information technologies, as well as their analytical methods and problem-solving approaches and capabilities have been widely felt.

2. Accelerator Applications

In 1930, Ernest O. Lawrence, the father of particle accelerators, built the first hand-held cyclotron at Berkeley, California. Larger and more powerful accelerators followed [7], with each generation of particle accelerators and detectors building on the previous one, raising the potential for discovery as the attainable energies have progressed by an order of magnitude roughly every 6 years, and pushing the level of technology ever higher.

After a day's research, Lawrence often operated the Berkeley cyclotrons through the night to produce medical isotopes for research and treatment. In 1938, Lawrence's mother became the first cancer patient to be treated successfully with particles from cyclotrons.
Doctors now use particle beams for the diagnosis and healing of millions of patients.

There are now an estimated 30,000 accelerators in industry, at hospitals and research centers, most of them only room-sized or smaller, which serve as essential tools for biomedical and materials research, for diagnosing and treating illnesses, and for a growing host of tasks in manufacturing, in energy and environmental technology, and in homeland security. The wide range of applications, as well as their use in research, is summarized in Figure 1 [8]:

Figure 1. Illustration of the aspects and wide range of application of accelerator technologies, from Reference [8].

Accelerators today are used in a very wide range of research areas and industrial manufacturing areas from food and materials processing, to electronics manufacture to security. Some of the applications of beams of appropriate particle types and energies
include:

- Detect and help diagnose, or shrink a tumor
- Design a new drug, map a protein, molecule or DNA using synchrotron radiation; find new ways to prevent or cure disease
- Make a better radial tire, or a heat-resistant automotive cable
- Harden metal surfaces to provide better bearings, make longer lasting machine and surgical tools, as well as artificial hip or knee joints
- Produce cleaner (fusion) energy through heavy ion induced fusion
- Spot suspicious cargo or luggage by scanning with neutrons
- Implant ions to dope semiconductors
- Prospect for oil
- Clean up drinking water

- Reduce pollutants in flue gases from factories and power plants
- Reduce nuclear waste
- Detect an art forgery, or discover a hidden art treasure
- Date an archaeological find
- Package food using shrink wrap that is produced by cross-linking polymers in plastics using electron beams

Medical Applications

Beams of X-rays, protons of carbon ions are used to treat tens of thousands of cancer patients daily, and proton beams are used to produce short-lived radioisotopes which are used in more than 10 million diagnostic medical treatments and 100 million laboratory tests each year. Nuclear diagnostic medicine and radiation therapy together save countless lives. Over the last two decades the use of protons and more recently heavy ions (such as carbon) are increasingly used since the beam can be tuned to deposit most of its energy at the site of a tumor, with less damage to surrounding tissue. A leading example is the Loma Linda University proton therapy center [9] whose accelerator was built at Fermilab. A leading cancer treatment center using heavy ions is at the Darmstadt Technical University [10].

Small electron accelerators are used worldwide for dental and chest X-rays.

Industrial and Environmental Applications of Electron Beams

Approximately 1700 high-current electron-beam accelerators are used worldwide for a wide range of industrial processing applications [11, 12]**.**

The largest industrial use of these is to modify polymers by cross-linking, which forms three-dimensional chemical links among nearby polymer segments. Cross-linking makes materials insoluble in solvents that would otherwise dissolve them. Surface curing with low-energy electron beams (70 to 300 keV) is the fastest growing use, because of the improved energy efficiency of these high-speed processes and their elimination of volatile organic solvents that make the manufacturing process more environmentally friendly.

Cross-linked polymers are used for heat-shrinkable tubing for protecting electrical wire and cable connections, since this makes the insulation more flame retardant for automotive wiring under the hood and other applications. Cross-linking of heat-shrinkable films, widely used in food packaging extend the shelf life of meat, produce, poultry and dairy products and provide tamper-resistant packaging. Cross-linked polyethylene foam cushions the interior of automobile roof liners and door panels. The tire industry uses electron-beam processing to partially cure the rubber in order to stabilize the tire cord placement and to produce better-balanced tires.

Electron-beam curing of inks, coatings and adhesives eliminates the use of volatile organic compounds, enabling manufacturers to attain high production speeds with reduced energy consumption and reduced environmental impact. In these applications, “green” electron-beam technology yields as much as a 90 percent reduction in power consumption compared to conventional thermal drying and curing.

The manufacture of hydrogels for wound and burn treatment employs electron-beam technology. High-energy electron beams and x-rays derived from electron-beam systems sterilize medical equipment. A small number of service centers around the world use electron beams for food irradiation. Ionizing radiation eliminates food-borne pathogens, such as *E. coli*, *Salmonella* and *Listeria*, from meats, poultry and other food products, and disinfects grains and spices. Other industrial uses for electron-beam technology include degradation of Teflon®, for manufacturing micronized lubricants, grafting of filter membranes and battery separators; and enhancement of polyethylene water pipes. The use of electron beams to treat seeds and soil shows promise for increasing crop yields.

Electron-beam treatment can disinfect and decontaminate both waste water and drinking water [11]. Projects in Boston and in Florida have shown the feasibility of disinfecting municipal waste water, and also breaking down water-borne organic toxins. An existing full-scale facility in Korea uses electron beams from an accelerator provided by Russia's Budker Institute to break down residual dyes from a fabric plant before discharge into a river.

Electron beam processing [12] is important for automobile production, where such systems are used to make gears and to weld and harden camshafts and tie-rod ends. In EB welding, precise energy deposition makes very deep welds possible. Complicated weld patterns can be produced using electromagnetic beam-deflection techniques. In EB drilling, rapid computer-controlled beam deflection allows "on-the-fly" drilling of thousands of holes per second in precise, repeatable patterns.

Industrial and Research Applications of Ion Beams

Ion-beam accelerators using boron, phosphorus, arsenic or other ions are essential for the the global semiconductor industry. About 10,000 ion-beam accelerators are used worldwide to "dope" the silicon or germanium chip used to manufacture computer and other electronics chips. Ion implantation also is used to transform the near-surface region of the base material into a fully or partially amorphous state, providing a method for fabricating strained and relaxed crystalline, polycrystalline, or amorphous structures during integrated circuit device fabrication. Because all digital electronics depend on ion implanters, they have a profound economic impact, and their use extends far beyond the semiconductor industry. Besides their role in CMOS, ion implanters are used in many other industrial applications, such as cleaving silicon; micro-electro-mechanical-systems (MEMS) fabrication; hardening of the surfaces of metals and ceramics for high-speed cutting tools and artificial human joints; and modification of the optical properties of materials.

Beyond semiconductor manufacture, other areas of ion implantation application include catalysis, solar energy and optical materials development, and fundamental science investigations associated with radiation effects in materials proposed for nuclear-waste stabilization and the next generation of highly resistant materials for nuclear reactors.
Ion implantation treatment of metal surfaces also is essential for the success of joint replacements.

Ion beams also are widely used in nondestructive elemental analysis by scattering of MeV ion-beam particles, by inducing nuclear reactions, or by using particle-induced x-ray and gamma-ray analysis. These methods are used to analyze materials in many fields including semiconductor research, environmental monitoring, geological and oceanographic studies, biomedical science and even art authentication. Ion-beam accelerators are also configured to be the most sensitive mass spectrometers for measuring trace radioisotope concentrations, including precise measurement of the Carbon 14 to Carbon 12 ratio for dating artifacts. This is an essential tool in geology, archaeology, drug discovery and climate studies. MeV ion accelerators have contributed to the fundamental understanding of high-density memory devices, silicon-based light amplifiers for fiber-optic communication, and the diagnosis of disease.

Ion Beams Producing Neutrons

A small but expanding use of ion beams is the production of neutrons for neutron-activation analysis and other analysis techniques in industry [13]. The use of accelerators for this purpose rather than radioactive sources is driven in the U.S. by new regulations imposed in response to security and health concerns associated with the use and storage of radioactive materials. The majority of accelerator-based "neutron generators" are used for oil and gas exploration and borehole monitoring, mineral detection, and monitoring of various industrial processes including: on-line analysis of gold, cement, and scrap metal; radiography of manufactured parts; and determination of trace elements in biological and environmental materials. Neutron generators are also increasingly used for nondestructive examinations in the nuclear-waste and homeland-security fields, where security monitors search for concealed plastic and conventional high explosives, fissionable materials, and chemical weapons.

The accelerators most often used for neutron applications are small sealed-tube, high-voltage acceleration-gap devices which produce neutrons by accelerating deuterons and using them to initiate fusion reactions in a deuterium or tritium target. Compact sealed-tube generators such as those developed a LBNL [14] produce fluxes ranging from 10^6 to 10^{11} neutrons per second, while radiofrequency quadrupole (RFQ) deuteron and proton linacs [12] (the same type used as injectors into the proton accelerators used for high energy physics research today) have been commercially developed in recent years for applications requiring higher neutron yields or specific beam characteristics not achievable with sealed tubes, with fluxes up to 10^{13} neutrons per second.

Heavy Ion Beams for Nuclear Fusion

In the mid-1970s, A. Maschke of Brookhaven Lab suggested that heavy-ion beams, rather than laser beams, could be used to implode inertial-fusion targets for commercial generation of electrical power. The beams would deliver the kinetic energy to the surface of a capsule containing deuterium and tritium, with the resulting ablation driving compression and heat to drive nuclear fusion. Heavy ions have the advantage that the energy deposition is more local than photons. Many of the key accelerator components and subsystems have already been demonstrated to have long life, a sufficiently high pulse repetition rate and high electrical efficiency.

In the US, researchers from three laboratories – LBNL, LLNL and PPPL (Princeton) formed the US Heavy-Ion Fusion Virtual National Laboratory (HIF-VNL) to coordinate their work on heavy-ion fusion [15, 16]. Figure 2 shows an artist's concept of a heavy ion driven fusion power plant [15]. Other efforts aimed at both accelerator physics and studying the interaction of heavy ions with hot matter exist at GSI (Germany) [17], RIKEN (Japan), Orsay (France) and ITEP (Russia).

Sub-Nanometer Ion Beams

A striking development highlighted at the Symposium was a commercial sub-nm Helium ion beam by Zeiss [18], which enables the 3D nanofabrication of sub-10 nm structures for the first time. Important fields of application of this 0.35 nm short-range beam include (1) fabrication of molecular scale devices, (2) plasmonic sensors that could be pivotal in future generations of computers and communications systems, and (3) fabrication of solid state nanopores for single-molecule studies in biophysics and biotechnology, as well as studying a wide range of phenomena in DNA, RNA and proteins.

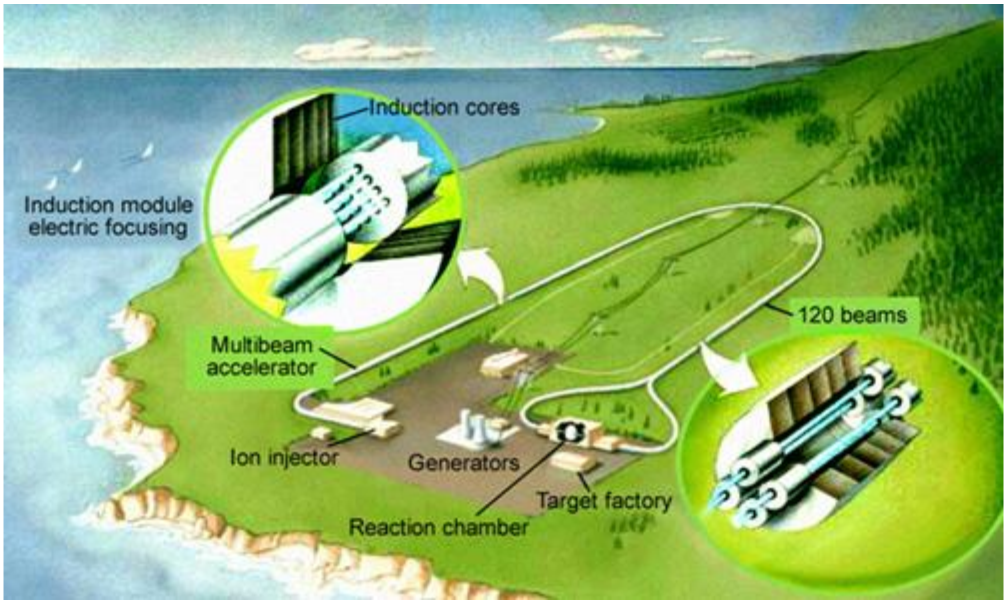

Figure 2. An artist's conception of a commercial heavy-ion fusion power facility: a load of water suitable for fueling such a fusion power plant could be carried in a pickup truck, supplying a year's worth of electrical power to a city like San Francisco.

Synchrotron Radiation

The intense, high brightness beams of photons emitted from electron accelerators are used in a vast range of research applications [19] in areas from condensed matter physics to material research, to protein structures and the functioning of normal and diseased biological systems in humans and animals, to pharmaceutical research and cultural heritage. Areas of application include:

Life Sciences
Pharmaceutical companies and medical researchers are making increasing use of macro-molecular crystallography. Improvements in the speed of data collection and solving structures mean that it is now possible to obtain structural information on a timescale that allows chemists and structural biologists to work together in the development of promising compounds into drug candidates. The developnment of both the anti-flu drug Tamiflu and Herceptin – to treat advanced breast cancer – benefited from synchrotron experiments. Using infrared synchrotron light, research is underway to developing new cancer therapies tailored to the individual patient.

Engineering
Synchrotron X-ray beams allow detailed analysis and modelling of strain, cracks and corrosion as well as *in situ* study of materials during production processing. This vital to the development of high-performance materials and their use in innovative products and structures.

Environmental science
Synchrotron-based techniques have made a major impact in environmental science in the last 10 years. High brightness allows high-resolution study of ultra-dilute substances, the identification of species and the ability to track pollutants as they move through the environment. Synchrotrons have been used to develop more efficient techniques for hydrogen storage and to study the way in which depleted uranium disperses into the local environment.

Condensed Matter Physics and Materials Science

Determining the properties and morphology of buried layers and interfaces is an important area in solid-state science with synchrotrons driving the state-of-the-art in theory by providing high-precision experimental results. Structural studies of *in situ* processing of semiconducting polymer films are likely to be an important area of growth in the coming decade. Diffraction of high-intensity X-ray beams is a leading method to study spin, charge and orbital ordering in single-crystal samples to understand high-temperature superconductivity. Synchrotrons also were used to study giant magneto-resistance (GMR), which is now used in billions of computer disks and other electronic devices worldwide.

Cultural heritage

Scientists are using non-destructive synchrotron techniques to find answers to big questions in paleontology, archaeology, art history and forensics. Scientists in the UK have used synchrotrons to study samples from a Tudor warship and learn to enhance their conservation techniques for historical artifacts, and to study insects more than 100 million years old preserved in amber.

Current and Future Developments

The demand for synchrotron light has meant that third-generation machines are being built around the world, and existing machines continue to be developed to provide brighter X-rays, increased user hours and more flexible experimental stations. Recently developed fourth-generation sources such as the Linac Coherent Light Source (LCLS) X-ray laser at SLAC (Palo Alto) [20], and the free-electron laser European XFEL project now under construction at DESY (Hamburg) [21] generate shorter, femtosecond pulses but with the same intensity in each peak as synchrotron sources emit in one second, producing X-rays that are millions of times brighter in each pulse than the most powerful synchrotrons. These won’t replace third-generation synchrotron machines, but will provide facilities that enable studies in the femtosecond range at higher peak brightness.

3. Knowledge and Technology Transfer

High energy physics has an extensive record of knowledge transfer to and from industry, commerce, and society at large. This is catalyzed by the need for state of art technologies and methods, including new materials for detector construction, radiation hard electronics, the highest speed global communications systems spanning continental and transoceanic distances, and many others, as well as cryogenics, vacuum, superconducting magnets, electronics and radiofrequency power systems, distributed computing and storage systems, and other engineering and control systems of unprecedented scale and scope. These needs for components and systems of a basically new kind or a new level of performance are sometimes met by industry, sometimes by the high energy physics community itself, and sometimes by joint-development projects between the scientific community and industry.

This is a long and deep tradition, highlighted by many articles in scientific and technical journals as well as the press over the years, and institutionalized through the U.S. funding agencies' Small Business Innovation Research (SBIR) and Small Business Technology Transfer (STTR) programs [22], as well as such laboratory based programs such as CERN's extensive Knowledge Transfer program [23]. An early example of this partnership is given in an article in the New Scientist about CERN in 1974 (four to five accelerator generations ago) entitled "Fallout from Smashing Atoms" [24]. The article covers an event when the laboratory opened its doors "to allow engineers from industry to see some of its advanced engineering components and design techniques." While the exceptional engineering and scientific achievements of the LHC today are recognized worldwide, the achievements of CERN's Intersecting Storage Rings in 1974 were no less impressive, including the first large scale deployment of a cryogenic vacuum system in a 2 kilometer beam pipe reaching 10^{-12} to 10^{-13} Torr in the experimental straight sections of the pipe (less than atmospheric on the moon on some occasions), and electro-polishing of the RF cavities used to accelerate the beams to nanometer surface quality, construction of the then-largest superconducting magnet (1300 tons) for the 3.7 meter European Bubble Chamber. Last but no means least was the then-recent invention by Charpak of the Multiwire Proportional Chamber (MWPC) and associated particle detection technologies, for which he received the 1992 Nobel Prize in physics [25], which has led to a wide range of applications in biomedical imaging and research as well as high energy physics.

Technology Transfer

The Technology Transfer Office within CERN's Knowledge Transfer Program [26] now manages a diverse portfolio of technologies available for licensing and/or research collaborations with industry or institutes, in several domains:

Accelerators, Magnets and Cryogenic Technology

The extreme conditions of the LHC have led to the developments of many breakthroughs in the domains of underlying technologies such as accelerators, magnets and cryogenics and pushed existing technologies to its limits.

Detectors and Instrumentation

In experimental and applied particle physics, particle detectors are used to detect, track, and/or identify and measure the energy of particles. Driven by needs of many different experiments carried out over the last 50 years and in particular for the LHC, forefront detector technology developments are now available for many applications inside and outside high energy physics.

Some of the most important detector technologies available to biomedicine, materials research and other private sector areas include:

- The Gas Electron Multiplier (GEM) [27]: a proven amplification technique for position and ionization detection of charged particles, X-rays, photons and neutrons in gas detectors at high rates
- PHOSWICH: a gamma camera with depth-of-interaction reconstruction capability, for use in Positron Emission Tomography (PET) scanners
- Quantum Dosimetry: a novel invention comprising a method, software and apparatus to determine the dose, dose rate and composition of radiation.

Many of the key inventions and developments in detector technologies, from particle type identification to position measurements and tracking and energy measurement (calorimetry) in large area detectors have been carried out by Professor A. Zichichi and his teams over the last five decades. Many of these are summarized in a commemorative book "From the Preshower to New Technologies for Supercolliders: in Honour of Antonino Zichichi" [28], published shortly after the untimely passing of then-DESY Director Bjorn Wiik, one of the editors.

Electronics

Current accelerator systems and particle physics experiments at CERN are extremely challenging in terms of handling huge amounts of data in a very short time under difficult radiation conditions. In particular for the LHC, that has led to the development of extremely fast radiation sensors and readout electronics, resulting in chip and sensor technologies available for use outside high energy physics such as medical imaging, material research and instrumentation for the life sciences.

Information Technology

CERN and its partners throughout the US and Europe have been the driving force for many Information and Communications Technology (ICT) developments over the last few decades, such as the handling of huge amounts of data across global networks using Grid and advanced network technologies and the World Wide Web. The invention of the World Wide Web at CERN has without doubt had the greatest impact on society. The modern Web and the technologies and structures that use it as a base, from e-banking to e-government and e-health, are now essential elements of the global economy. Indeed the Web has become one of the principal pillars of modern life in the developed world, and gateway to economic advancement, quality of life, access to knowledge, and the gateway to an equitable standard of living in the underdeveloped regions of the world.

Materials Science

The multidisciplinary technology context of CERN and the extremely challenging operational conditions of accelerators and physics expirements in particular for the LHC required and still require the development of innovative solutions for the treatment and processing of materials, to reach particular properties unachievable with methods available from outside.

Mechanics

The design and the construction of accelerator elements or components of particle physics experiments in particular for the LHC are often accompanied by the development of specific mechanical systems or tools that also can provide solutions for many engineering problems outside of high energy physics.

Networks of Experts

Knowledge transfer activities generate networks of people [29], research institutes, and companies through which technical, scientific and managerial expertise is exchanged. CERN engages in the creation, coordination and participation of several knowledge exchange networks including: the ***CERN Global Network*** that connects all the key individuals or organizations players in the knowledge exchange process, the ***HEPTech Network*** providing technology transfer opportunities involving leading HEP technologies, the ***Enterprise Europe Network (EEN)*** helping small businesses make the most of the European marketplace and many others.

Life Sciences

CERN also is involved in a range of activities connected to life sciences [30], including medical imaging, particle therapy, radiobiology, e-health and training of young researchers in these multidisciplinary fields. It also provides advice to the CERN community on these topics, and is actively involved in various projects, and promotes public awareness of its initiatives in the life sciences domain.

Crystal Scintillators

Fast, high density crystal scintillators comprise a special area of detector development, where high energy physics has had a leading role for the last 20 years [31, 32], notably driven by the Crystal Laboratory at Caltech and the Crystal Clear Collaboration at CERN. The use of crystal calorimeters with a crystal volume of as much as 9 cubic meters (in the case of the CMS experiment at the LHC) is important for precise measurements of electrons and photons, and has been a key factor in the search for new physics processes, including the ongoing search for the Higgs boson. There are a wide range of applications of these scintillators, including:

- Radiation detector modules for medical imaging
- Computed Tomography (CT) in medicine and industry
- Positron emission tomography (PET)
- Security scanning
- Oil well logging

Recent developments and areas of investigation include the development of LYSO ($Lu_{1.8}Y_{0.2}SiO_5(Ce)$), an exceptionally radiation-hard, bright and fast scintillator suitable for the High Luminosity LHC, Lanthanum Bromide ($LaBr_3(Ce)$) that is a very bright scintillator suitable for security scanning applications, and a new range of scintillating ceramics [33].

4. International Networks and Global Grid Systems

The fact that major high energy physics experiments are carried out by large international collaborations, combined with the need to process, distribute, access and analyze massive sets of data at sites around the world, has led to high energy physicists becoming leading developers as well as users of continental and transoceanic networks [34].

International networking for high energy physics was initiated by the author in 1982, and his group at Caltech has been responsible for transatlantic networking by the U.S. high energy community since then, with a current focus on support for the LHC program over the US LHCNet network.

In 1999 the author and collaborators proposed and designed the hierarchical worldwide grid system that is now used (in an evolved form with less hierarchical data flows in some cases) by the LHC experiments. The concept, known as the MONARC Model after the project [35] that developed the idea of a worldwide ensemble of national ("Tier1") and regional ("Tier2") computing and storage facilities, complemented by smaller ("Tier3") computing clusters serving individual physics groups at universities and small laboratories, is shown in Figure 3. The use of such a globally distributed model of computing and storage implied the intensive use of data networks, and so in the late 1990's high energy physicists, computer scientists and network engineers at Caltech and SLAC, CERN and at soon at many other sites in North America, Europe, Asia and Latin America began to engage in the development of data transfer applications designed and tuned to provide high throughput over long distance networks.

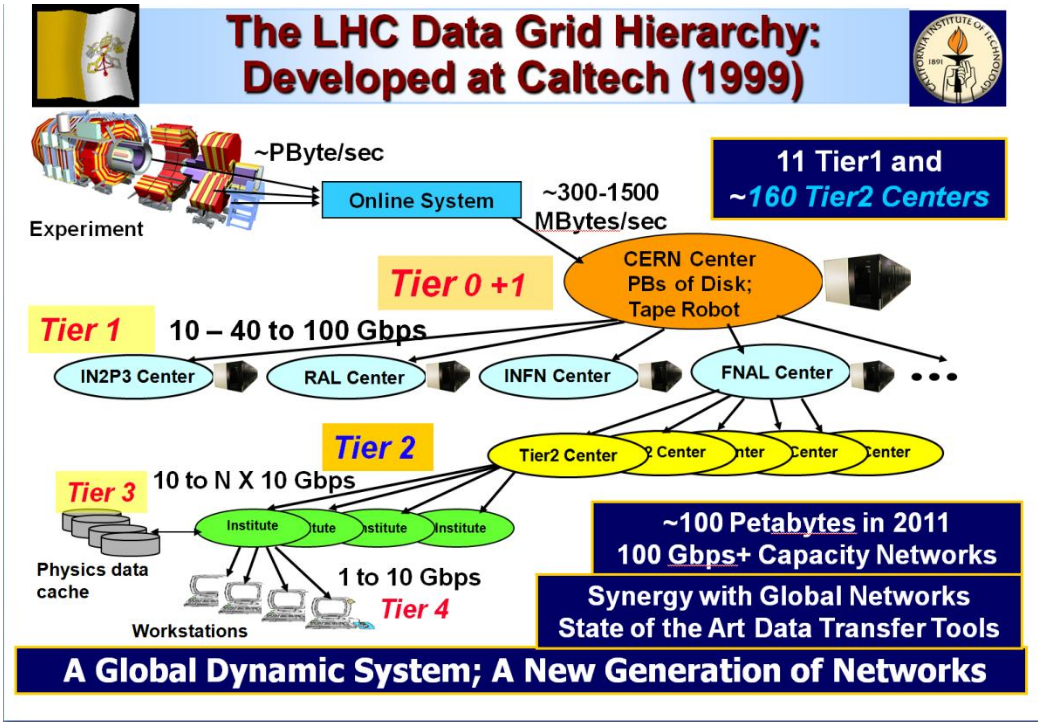

Figure 3. An illustration of the "MONARC" hierarchical grid computing model developed by the author and collaborators in 1999.

As the data volumes to be handled grew from Terabytes/year the 1990's to Petabytes (thousands of Terabytes) per year in the 2000's and hundreds of Petabytes per year now, the applications developed to fully matching the capacity of the networks. The exponential growth of the capacity of long range network links is noteworthy, rising from 2 megabits/sec (Mbps) in 1990, 1 gigabit/sec (Gbps) starting in 2000, and 10 Gbps from 2005. As of this writing, the major national and continental networks, such as Internet2 [36] and ESnet [37] in the US, and Geant [38] in Europe are undergoing a transition to the next generation of 100 Gbps networks, and transoceanic networks such as US LHCNet [39] are expected to follow as links of 40 and 100 Gbps between continents become widely available by approximately 2015. High energy physicists' use of the networks is equally noteworthy, as its historical growth trend has been at the rate of a factor of ten every 4 years, reaching a total of more than 100 Petabytes transported over networks during 2011.

State of the Art Network Applications

The ability to match current and next-generation networks, using mass-market computing equipment and open-source applications developed by high energy physics, such as Caltech's Fast Data Transfer (FDT) [40] has been demonstrated each year for the last decade, at the annual SuperComputing conferences as well as other events. The latest demonstrations [41] between the SC11 conference in Seattle and the University of Victoria in Canada achieved a sustained throughput of 186 Gbps using a single 100 Gbps link in both directions at once, between small ensembles of servers with next-generation 40 Gbps Ethernet interfaces. The methods used in these demonstrations have been adopted, on a smaller scale, by other fields of science and engineering, as well as users in the Library of Congress in the U.S., and the Amazon EC2 Cloud.

The most extensive applications developed by high energy physicists and their partners in this field are the grid software stacks of the LHC Worldwide Computing Grid (WLCG) [42] led by CERN, and the Open Science Grid in the U.S. [43]. Other key technologies developed by high energy physicist in this field include Caltech's MonALISA system that monitors and in some cases automates operations for global Grid and network systems [44], and Caltech's EVO (Enabling Virtual Organizations) system [45] that is used for videoconferencing and daily collaboration by the LHC and LIGO communities, as well as many other communities in research and education throughout the world.

ICFA Standing Committee on Inter-regional Connectivity (SCIC)

Given the importance of networks for the major collaborations in high energy physics, the International Committee on Future Accelerators (ICFA) comprised of laboratory directors and other leaders of the field of high energy physics drew the field's attention to the issue with a visionary statement in 1996 [46]:

> *"ICFA urges that all countries and institutions wishing to participate even more effectively and fully in international high energy physics collaborations should:*
>
> - *review their operating methods to ensure that they are fully adapted to remote participation*
> - *strive to provide the necessary communication facilities and adequate international bandwidth."*

Following the formation of a Network Task Force in 1997-8, ICFA formed a Standing Committee on Inter-regional Connectivity (SCIC) [47] that the author has chaired since 2002.

The SCIC and the Digital Divide

The SCIC prepares detailed reports annually [48] which it presents to ICFA, on the state of the world's networks, with a focus on the networks used by high energy physics, as well as the use for other fields of science and for research and education in general. One important activity of the SCIC is monitoring the world's networks through its Monitoring Working Group [49]. The SCIC's main theme for the last decade has been its work to reduce and eventually eliminate the Digital Divide that separates the underdeveloped regions of the world, and the scientists and students living in those countries, from those living in the technologically and economically more advanced countries.

The SCIC has worked to lessen the Divide in nations in many regions – from central and eastern Europe to Latin America, South Asia and the Middle East, as well as many countries in Africa – by sharing information and knowledge on network and grid system technologies and applications, and working to encourage the local and regional development of the telecommunications and Grid infrastructures that will enable the disadvantaged science communities to participate more effectively in the LHC and other major programs of high energy physics.

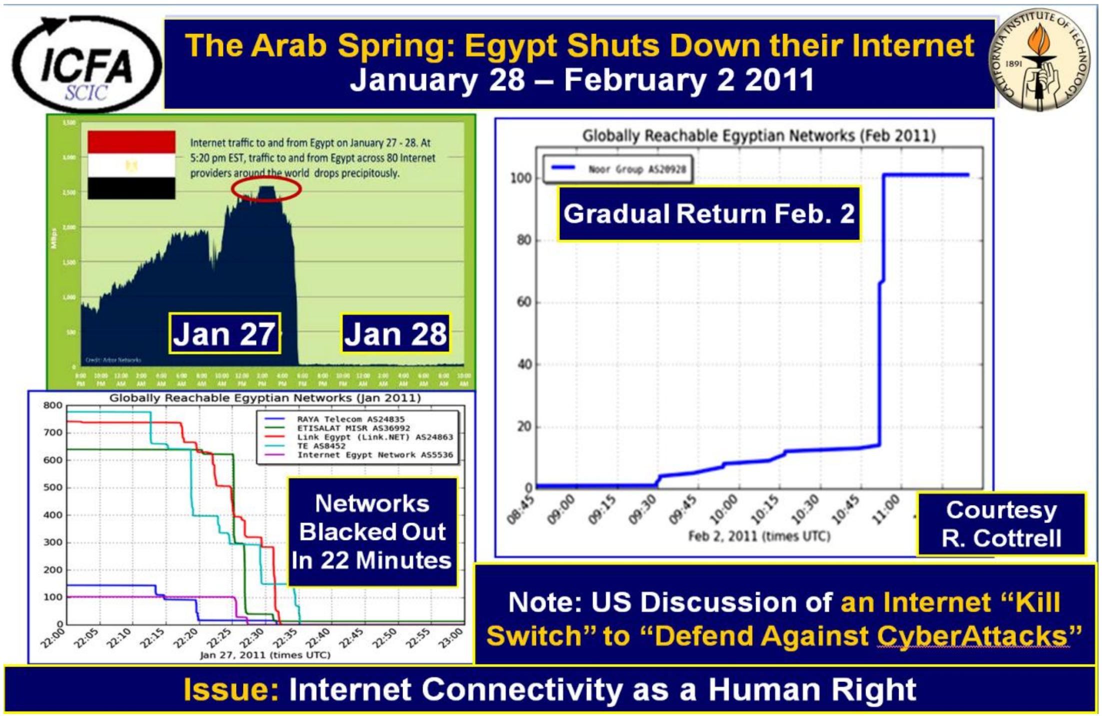

Figure 4. The abrupt cutoff and gradual return of Internet connectivity in Egypt, January 27 - February 2, also highlighting the concept of Internet connectivity as a human right.

Internet Connectivity as a Basic Human Right

The SCIC monitoring results have been used to allow the scientific community and government in each disadvantaged country to objectively gauge where it stands with respect to its neighboring countries, and its peers in other regions, and to illustrate how infrastructure improvements at moderate cost can bring rapid improvements: both technically and in the ability to collaborate effectively. The monitoring results have enabled our field to track and understand the effect of disruptions to Internet connectivity, as occurred in the Mediterranean in 2008 and 2009 due to undersea cable cuts (ascribed to earthquakes). And importantly, the real-time acquisition of this data has enabled us to track government actions to cut off access to the Internet, as occurred for example in Egypt at the start of Arab Spring in 2011, as shown in Figure 4.

The work of the SCIC towards equality in the scientific community, and the principle of Internet connectivity as a basic human right is fully in line with the *Erice Declaration on Principles for Cyber Stability and Cyber Peace* [50] that was adopted by the Plenary of the World Federation of Scientists on the occasion of the 42nd Session of the International Seminars on Planetary Emergencies in Erice (Sicily) on August 20, 2009. Some of the key provisions of this declaration are reproduced below:

> ICTs support tenets of human rights guaranteed under international law, including the *Universal Declaration of Human Rights* (Articles 12, 18 and 19) and the *International Covenant on Civil and Political Rights* (Articles 17, 18, and 19). Disruption of cyberspace (a) impairs the individual's right to privacy, family, home, and correspondence without interference or attacks, (b) interferes with the right to freedom of

thought, conscience, and religion, (c) abridges the right to freedom of opinion and expression, and (d) limits the right to receive and impart information and ideas to any media and regardless of frontiers.

ICTs can be a means for beneficence or harm, hence also as an instrument for peace or for conflict. Reaping the benefits of the information age requires that information networks and systems be stable, reliable, available, and trusted. Assuring the integrity, security, and stability of cyberspace in general requires concerted international action.

THEREFORE, we advocate the following principles for achieving and maintaining cyber stability and peace:

1. All governments should recognize that international law guarantees individuals the free flow of information and ideas; these guarantees also apply to cyberspace. Restrictions should only be as necessary and accompanied by a process for legal review.

2. All countries should work together to develop a common code of cyber conduct and harmonized global legal framework, including procedural provisions regarding investigative assistance and cooperation that respects privacy and human rights. All governments, service providers, and users should support international law enforcement efforts against cyber criminals.

3. All users, service providers, and governments should work to ensure that cyberspace is not used in any way that would result in the exploitation of users, particularly the young and defenseless, through violence or degradation.

4. Governments, organizations, and the private sector, including individuals, should implement and maintain comprehensive security programs based upon internationally accepted best practices and standards and utilizing privacy and security technologies.

5. Software and hardware developers should strive to develop secure technologies that promote resiliency and resist vulnerabilities.

6. Governments should actively participate in United Nations' efforts to promote global cyber security and cyber peace and to avoid the use of cyberspace for conflict.

Conclusion

As high energy physics have pursued their investigations of the nature of matter and spacetime at the most fundamental level, they have grappled with some of the most difficult applied problems, invented, developed or extended the use of a wide range of new technologies, methods and systems, and devised some of the most complex instruments in the history of mankind in the service of their science. These developments have been made available to the world at large, and applied globally in medicine, electronics, energy, materials, security, and many other fields of industry and commerce, resulting in a worldwide beneficial impact on society. Many of the developments derived from the use of accelerators and particle detectors have directly benefitted the health, well-being and quality of life of the world's populations, while others have paved the way to succeeding generations of information and communications technologies that have increasingly defined the way humankind lives, learns and operates as a society.

As a field, many physicists have understood the obligation to use their capabilities to help address some of the world's most important human issues, such as the Digital Divide and the human right of access to Internet connectivity, as the means to knowledge, mutual understanding, equality of opportunity, and worldwide progress.

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