Technological spin-offs from Accelerator and Particle Physics

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Abstract

The technological challenges behind the particle accelerators and particle physics forcibly produced innovations. These innovative methods, applications and products have found their way to other fields ranging from information technology to archeometry. This paper will present a non exhaustive list of these spin-offs together with some examples. Its aim is two fold: firstly to show the importance of investing in the field of accelerator and particle physics fields which lead to harvesting high technology products applicable to other domains, and secondly the possibilities of cooperations across different fields.

1 Introduction

Particle physics investigates the basic building blocks of the matter and the fundamental forces driving the interactions between these particles. Fig.1 contains a very brief summary, a complete scientific review can be found in [1] and a pedagogical approach in [2]. By starting from a thorough understanding of the constituents of the matter, the goal of this science is to answer all the questions about the nature as we observe it. Particle physics, in collaboration with astrophysics and cosmology, also aims to give a successful description of the universe as it started 14 billion years ago, what it has become now, and what it will become in the future. By understanding the fundamental constituents of the matter and how they interact, we expect to understand the formation of the matter around us and in turn why these behave in the way that they do. Combining with astronomical observations, we will know about our world, our galaxy and our universe.

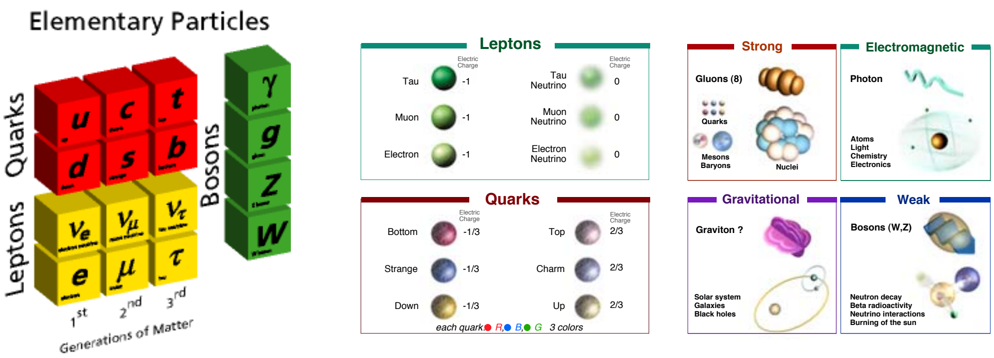

Figure 1: Left: The elementary particles classified in families. Right: The four forces governing the interactions of the elementary particles. The unified model of Strong, Weak and Electromagnetic interactions is known as the “Standard Model”.

Experiments using particle accelerators provided most of the information for this most fundamental science, the particle physics. The earliest successful cyclotron was built in 1930 by Ernest Lawrence as shown in Fig.2 left side. With a 11.4 cm diameter, it accelerated protons to 80 keV. Currently, the most powerful accelerator built is the LHC in Geneva, Switzerland as seen in Fig.2 right side. With a 8.6 km diameter, it will accelerate protons to 7000 GeV. (For an online review of particle accelerators and their history see). Scaling up 5-6 orders of magnitude was not a simple task: it required to surpass the current knowledge in various areas such as electronics, information science, metallurgy, medicine, project management. Therefore, the technological challenges behind the accelerator and particle physics forcibly produced innovations which had a tremendous impact on the daily life of all nations.

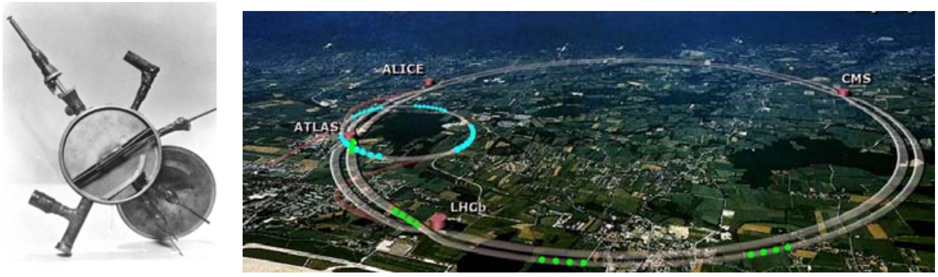

Figure 2: The progress of particle accelerators. 11.4 cm diameter in 1930 (left) versus 8.6km diameter in 2008 (right) with the delivered energy scaling respectively from 80 keV up to 7000 GeV(=7'000'000'000 keV).

Another necessity was to have a large team to build a large machine complex (e.g. the accelerators and the detectors), to operate it and to analyze the results. Such teams were hosted first by national and later by international laboratories. CERN, the "European Organization for Nuclear Research" is currently the largest of such laboratories. As home to about 10'000 scientists with the primary goal of research on particle physics (including nuclear, astroparticle & theory), it also hosts work on computational physics and computing, medical physics, material science etc. Established in 1954 by European nations, CERN has currently 20 member countries while Turkey is observer since 1956. The scientific work at CERN was awarded with 2 Nobel prizes: Invention of the multiwire proportional chamber and discovery of vector bosons (W and Z^0). Among the list of inventions, one can cite the beam-beam collisions and the "http://" concept.

Physics output from APP labs has been extensively discussed in the past. There are very thorough reviews of the standard model of particle physics and the models beyond it such as Supersymetry, Grand Unified Theories, Extra-Dimensional models etc. Instead of such scientific aspects, this paper concentrates on output (spin-off) from non-physics related areas. The mechanics of research on pure science impacting the technology is explained in Fig. 3. A scientific goal, such as detailed measurements on the neutral vector boson, Z^0, might seem to be detached from the reality of the daily life, however we shall see how it reshaped the modern society. For detailed Z^0 measurement, a large accelerator and a number of gigantic detectors were decided to be built at CERN. Expensive projects relying on bleeding edge technology can only be overhauled by international collaborations. Therefore, scientific collaborations across the nations have been formed to meet the highly demanding requirements. A challenge, intrinsic to large teams around the world, was to share the information between all participants in an efficient way. This problem was solved at CERN, by the invention of the hypertext transfer protocol (http://www.), commonly known as the Internet. One of the main tasks of CERN being the information sharing, the WWW inventors trained the interested parties and this process led to an unexpected immediate benefit: there were personal "web pages" in which all kinds of useful information could be found. Well after the reach of the scientific goal, the repercussions of the invention, WWW, reached the public life. Today we see these as the possibility of Internet shopping, the free encyclopedia called wikipedia, as the free teleconferencing tool called EVO etc. The governments also have embraced this form of communication with their citizens, for example tax payment using the Internet is rather encouraged.

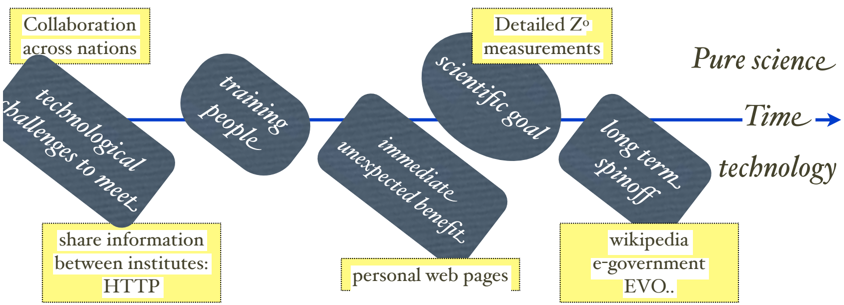

Figure 3: Science and Technology

Basic pure research (science) & engineering applications (technology) go hand in hand. One without the other is **not** possible.

2 Examples

2.1 Information Technology

The APP collaborations are large, multinational and multi-institutional. In such across cultural teams, there is a constant need to improve the tools to facilitate the communication. As underlined previously the invention of http, the default protocol for WWW originated from CERN and led to the new concepts like e-government and e-commerce etc. The next level in communications would be to have voice and video meetings across multiple platforms. Such a tool, EVO, was also made freely available for 3 major computing platforms: Windows, Linux and Mac [4]. It was successfully used during the LHC startup event as seen in Fig. 4.

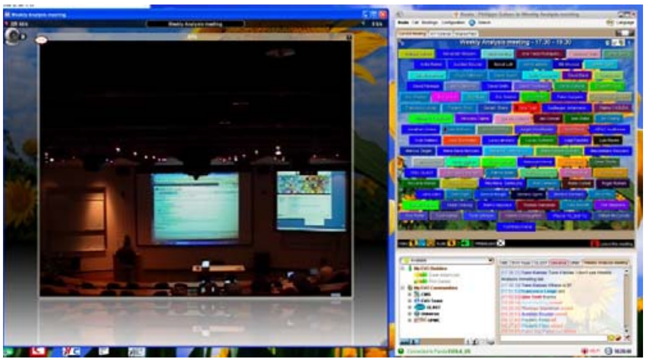

Figure 4: The cross platform video conferencing tool, EVO, was used during LHC startup. It was able to televise to over 6500 connections on the first LHC Beam meeting.

The amount of data produced by the APP collaborations is large. The analysis of such large data sets require dedicated tools for data transfer and analysis. The "GRID" concept and the tools around it were developed to match these requirements. Additionally tools for high performance computing were also developed at the APP laboratories. The equipment to be designed & used is also large requiring specific tools for simulations & analysis. The examples for the beam and the detector simulation software are FLUKA & GEANT [5]. The first one even found an utilization area in the private sector: Commercial Airlines must use FLUKA to compute the amount of cosmic radiation that the crew & passengers receive during flights. For the second one, a multitude of other applications exist in medical and biological sciences, radio-protection and astronautics. The medical applications will be covered in more detail in section 2.3. One of the tools developed for the analysis for the data produced is ROOT [6]. It is a cross platform framework for data analysis, detector simulation, event generation, visualization etc. Fig.5 contains ROOT output examples showing data analysis possibilities such as subrange fits, 3D visualization and commercial design.

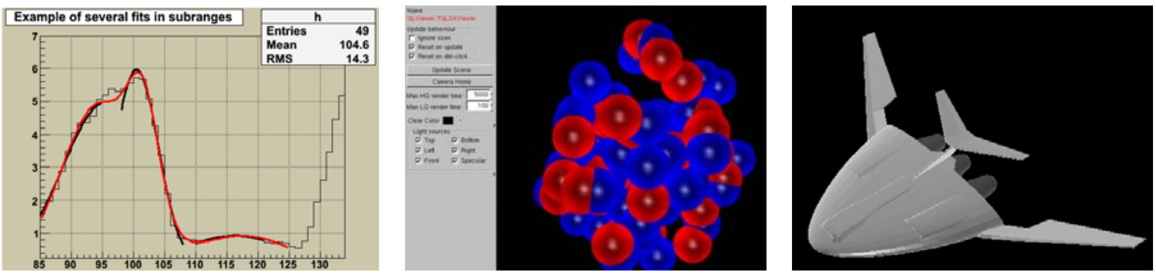

Figure 5: The ROOT framework can be used for data analysis (left) scientific visualization (middle) or commercial design (right)

2.2 Electronics

The particle physics experiments happen at harsh radiation conditions. Therefore all experimental setups search for the radiation hardness (RH) of detectors and electronic circuits which is also important for defense applications. The knowledge acquired while building the APP setups is fed back to other domains such as material science and commercial applications. To give an example, the detector research and development work involving silicon is also supported by IBM which aims to gain benefit from its industrial applications such as the Solid State Drives.

The particle physics processes are very fast. Therefore all experimental setups require rapid response from the readout circuitry. This requirement lead to innovations in micro electronics. An example is the development of application specific integrated circuits (ASIC) used for fast frequency locking. These circuits are also required to be RH since they are expected to provide timing signals at the collision points. Fig 6 shows the design of such an ASIC and the test bench to test its functionality and performance. Further details of this topic is covered in the proceedings of the fifth eurasian conference on nuclear science.

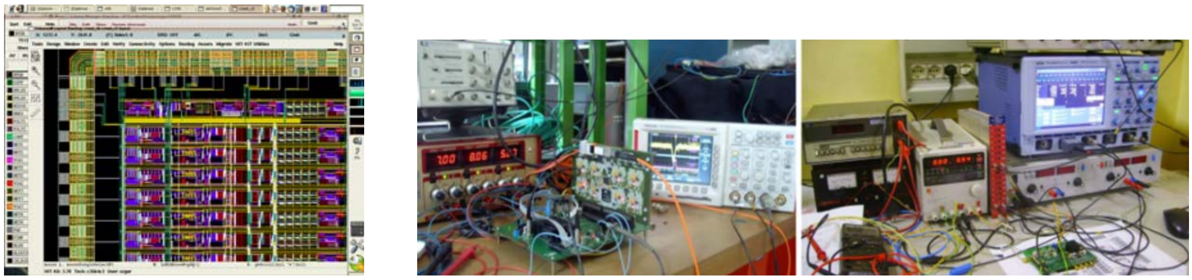

Figure 6: Left: Design of a Radiation Hard application specific integrated circuit (ASIC) Right: The setup to test for the manufactured ASIC.

2.3 Medicine

Historically, medicine benefited greatly from the advances in physics. For example the diagnostic tools based on Roentgen's work are very well known. The faster detection and tracking techniques required for particle physics experiments helped developing even better diagnostic tools such as NMR and PET. In fact the Nobel prize winning work of Georges Charpak at CERN on particle detection and tracking, established the basic principles for these tools.

Alongside the high energy accelerators, the low energy ones are also needed for particle physics research. These low energy machines have their utilization not only as test beam facilities in particle physics (e.g. while developing new detectors) but also in medicine. Among the examples for their usage, one can cite the isotope production for nuclear diagnostics (e.g. PET) or the hadron therapy used to eradicate cancerous cells.

The simulation tools needed for APP also found their utilization in medicine. For example GEANT, the tool developed at CERN to design a detector, was adapted to medicine to design a hadron therapy and to optimize its parameters before applying it to the patient [7]. Additionally GEANT based tools are developed to help the visualization of the diagnostics data as seen in Fig. 7.

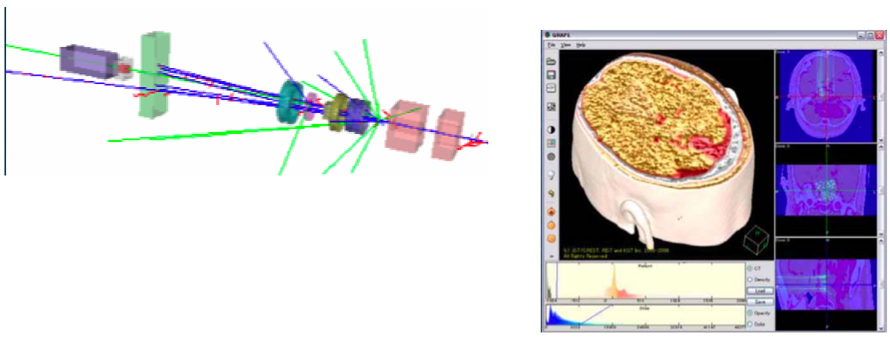

Figure 7: The software which was developed initially for tracking particles through the detectors (left) was adapted for medical physics applications such as visualization of PET data (right).

2.4 Education

Since the APP needs qualified personal, education and training are among the most emphasized areas. The apprenticeship and summer student-ship programs provide opportunities for the young students to participate forefront research for 8-13 weeks and additionally listen lectures from world renown scientists. The summer student program for 2008 is given in [8]. For the high school and university teachers, workshops to review teaching methods & sharing knowledge. For example to the 2004 "high school teachers" workshop, all member states participated additionally, from the non-member states, Malta, Luxembourg, Ireland, Canada, Cyprus, Rumania were represented. Fig. 8 shows two photos from the demonstrations aimed to initiate young students to science.

Figure 8: Photos from the High school teachers training workshop and exposition

2.5 Project management

Since the APP collaborations are rather large (today LHC experiments count about 2000 physicists), the organizational tools are required to be scalable. For example the organization of meetings, workshops, schools should have a unified interface. CERN's indico program provides such a service. Another CERN innovation was the Electronic Document Management System (EDMS) in which not only all the technical drawings, procedures are kept but also other information such as the vacation times of the users are tracked. Another example is the "EDH", Electronic Document Handling which assists in interdepartmental interactions such as internal and external purchases. It also provides powerful archiving and project followups, and builds robust HR management & procurement solutions. Fig.9 shows a standard purchase request form with approval levels tracking, supply details, procurement timing and status.

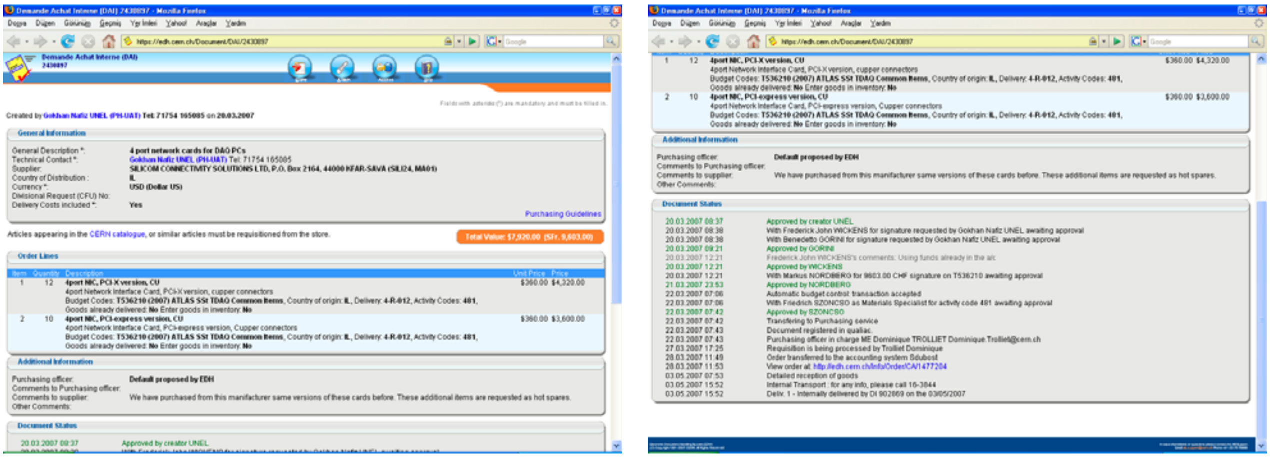

Figure 9: Project Management example

3 An interdisciplinary work example

One of the most famous scientists of the ancient era was Archimedes who lived between 287 B.C. and 212 B.C. He wrote his treatise onto papyrus scrolls in Greek. A handwritten copy of Archimedes work, including diagrams & calculations, is assembled into a book in about 1000 A.D. in Istanbul. 200 years later, due to lack of blank paper, a Christian monk "recycled" the parchment of the book, by scraping the original text and writing text sideways thus turning it into a new prayer book. In 1906 A.D. Danish philologist Johan Ludwig Heiberg discovered the book in Istanbul, photographed many pages and published his findings. After a series of purchases and disappearances the book is now in the hands of scientists who are trying to reconstruct the original text from Archimedes. The work is a joint effort between the historians, Greek scholars, chemists, accelerator and particle physicists [9, 10]. The APP involvement, consisting of X-ray spectroscopy, was absolutely necessary for the reading of the original text under the paintings of the prayer book, as seen in Fig. 10.

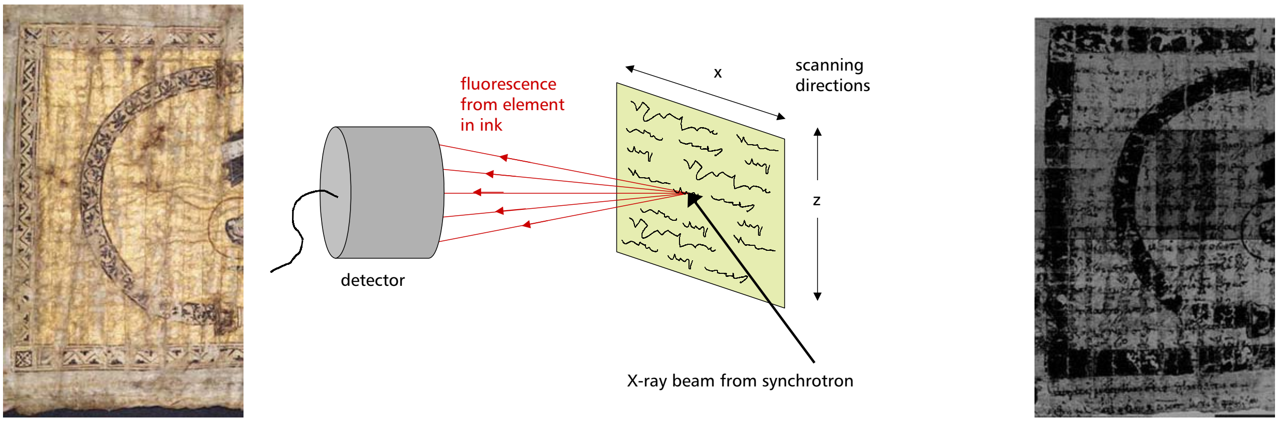

Figure 10: Reading archimedes palimpest at SLAC

It is possible to read the underlying text since the original ink contained iron which can be excited with a high energy X-ray. When the excited iron atom falls back to the ground state, it emits a photon which is subsequently captured by one of the usual APP detectors. This method, known as "spectroscopy" requires a narrow band X-ray source to read the details of the original text which would be blurred with the traditional X-ray sources. The two possible methods of producing the X-rays using accelerator technology are explained in Fig. 11.

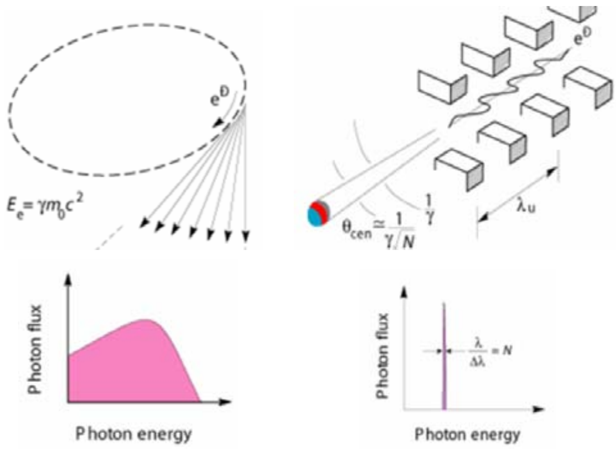

Figure 11: The two methods of x-ray production using accelerator technology. On the left the "Synchrotron radiation" technique and on the right "FEL", free electron laser method.

4 Conclusions

The accelerator and particle physics research does not only increase our knowledge of basic science but also leads to improvement in other unexpected fields such as: Information technology, Electronics, Medicine, Commerce, History, Communications, Project management etc. Therefore the accelerator and particle physics laboratories can be identified as the "cradle of knowledge". Such nomenclature can be justified by a recent US national science foundation (NSF) study found that 73% of the scientific papers cited in industrial patents were published "public science", meaning overwhelmingly basic research papers produced by top research laboratories.

A country's fully committed work in a leading APP laboratory, will be beneficial to not only APP but also to industry, to engineers, to managers and to scholars via technology & best practice transfer. Turkey's full membership to CERN is a step towards this goal.

Acknowledgments

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CERN member and observer states

Members: Austria, Belgium, Bulgaria, Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Italy, Netherlands, Norway, Poland, Portugal, Slovakia, Spain, Sweden, Switzerland, UK. Observers: India, Israel, Japan, Russia, Turkey[1], US, European Commission and UNESCO.

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[1] During the write-up of this note, to the great joy of the author, Turkish authorities have decided to move from observership to membership.