THE HIGGS BOSON DISCOVERY STORY

Lessons in managing mega science research projects

delivered by

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On July 4, 2012, the European Center for Nuclear Research, (CERN), Geneva, formally announced that two of their experimental teams have discovered a new particle with a mass in the right range to qualify as a long sought Higgs Boson, which had eluded detection for nearly five decades since it was first postulated. The discovery is the culmination of several world wide attempts and is considered by the scientific community as a landmark scientific achievement of the century. The announcement also evoked considerable interest in our country. Not only the discovered particle derives half of its name from the well known Indian physicist of the twentieth century, Prof. Satyendra Nath Bose, but the discovery team also includes several names of Indian scientists and institutions. The scientific significance of this discovery has been discussed in great detail both in print and in seminars on several occasions. But there are also important management lessons to be learnt from such research projects- projects with long lead times, high costs, cutting edge technologies, high risks of negative results and involvement of a large number of institutions and investigators across the world. In this talk, I would like to bring to your attention some of these lessons that one could learn from the Higgs boson discovery story.

You may recall that one of the outstanding achievements of twentieth century physics is the unraveling of the sub-atomic structures. What are the fundamental building blocks of the material universe? This question has been haunting the human race for thousands of years. By the end of the nineteenth century, it was clear that the material universe that we see around us is made up of 92 naturally occurring elements, hydrogen to uranium. Further discoveries in the early decades of the twentieth century demonstrated that not only one can synthesize in the laboratory more new elements by shooting one element on another but we also know their substructures. By the middle of the twentieth century, it was clear that the entire material universe, not only in our neighborhood but across the entire universe since the very beginning, the big bang, is made up of 12 fundamental building blocks, the quarks, the leptons and the gluons. The underlying mathematical model is referred to as the standard model amongst the scientific community. The existence of these building blocks could only be established through high energy accelerator based experiments. But there was a missing link. As pointed out by Higgs in 1964, the model demanded the existence of yet another boson that has not been seen in any laboratory experiments. That was the beginning of a world wide effort to search for the Higgs boson. The present discovery clearly puts a seal of validity on the Standard Model and represents a mile stone in our understanding of the material universe.

Let us not live with the impression that what ever needs to be known on the basic building blocks of the universe are now known. The gravitational force is still beyond the Standard model. Scientists tell us that we "see" only four percent of the universe. Rest is dark energy about which we know nothing. While we understand how the universe evolved over billions of years, we still do not know what happened in the first few microseconds after the "Big bang". The physicists certainly do not run the risk of going out of job. At the same time, validation of the Standard Model does represent an important mile stone in our understanding of the material universe.

The standard tool kit of a high energy physicist to produce and study new particles consists of a high energy accelerator to accelerate electrons, positrons, protons, anti-protons and nuclei to very high energies and collide them against other nuclei, detector systems to record the debris resulting from the collisions and models to infer what transpired in the collision zone. Nuclear Forensics is quite complex and demands cutting edge technologies often beyond the known horizons.

One of the early nuclear accelerators to be built in the world with a hope of producing new particles including the Higgs Boson in the laboratory was the Tevatron, a circular particle accelerator at the Fermi National Accelerator Laboratory, in USA accelerating protons and antiprotons in a 6.28 km ring to energies of up to 1 TeV. The facility was completed in 1983 at a cost of US$120 million. Significant upgrade investments were of course made during the subsequent years. The Tevatron ceased operations on 30 September, 2011 due to budget cuts and because of the completion of a more powerful accelerator, the Large Hadron Collider in Geneva. During the 28 years of its operation, the Tevatron led to several important fundamental discoveries of our times, such as the existence of the top quark and helped to test the Standard Model of particle physics. Interestingly, the Fermi National Laboratory announced on July 2, 2012, just two days before the CERN announcement, that based on an analysis of around 500 trillion collisions produced from the Tevatron facility since 2001, the existence of the Higgs boson was highly likely with only a 1-in-550 chance that the signals were due to a statistical fluctuation. **They were clearly on the right path and on the threshold of the discovery. What they needed were more collision events so that better statistics could be achieved. Instead, what they did was to shut the machine down and terminate the experiment.**

The Superconducting Super Collider (SSC) in Texas, USA was perhaps the second major effort to build a particle accelerator having the potential for the HIGGS boson production. First envisioned in December 1983, it was set to be the world's largest and most energetic machine with a planned ring circumference of 87.1 kilometres and an ultimate energy of 20 TeV for protons.. Major construction began in 1991. Even during the design and the first construction stage, a heated debate was on about the high cost of the project. The project was canceled in 1993 due to budget problems (escalation of cost from US$4.4 billion in 1987 to US$12 billion in 1993) even though about US$2 billion had already been spent on the project. Apart from rising costs and poor project management, many other factors also contributed to the cancellation of the project: the end of the need to prove the supremacy of American science with the collapse of the Soviet Union; belief that many smaller scientific experiments of equal merit could be funded for the same cost; Congress's desire to generally reduce spending; the reluctance of the administration to support a project begun during their predecessors period etc. Scientific merit or otherwise of the project was no where in the picture in making the decision to close the project.

As of today, the Large Hadron Collider (LHC) in CERN, Geneva is the world's largest and highest-energy particle accelerator. It was built by the European Organization for Nuclear Research (CERN) from 1998 to 2008, with the aim of allowing physicists to address some of the most fundamental questions of physics. The LHC lies in a tunnel 27 kilometres in circumference, as deep as 175 metres beneath the Franco-Swiss border near Geneva, Switzerland. Its synchrotron is designed to collide opposing particle beams of either protons at up to 7 TeV, or lead nuclei at an energy of 574 TeV Unlike the TEVATRON or the SSC, the LHC was truly an international effort built in collaboration with over 10,000 scientists and engineers from over 100 countries, as well as hundreds of universities and laboratories. On 10 September 2008, the proton beams were successfully circulated in the main ring of the LHC for the first time, but the facility had its own teething problems. Nine days after the commissioning of the machine, operations were halted due to a magnet quench incident resulting from an electrical fault. The ensuing helium gas explosion damaged over 50 superconducting magnets and their mountings, and contaminated the vacuum pipe. On 20 November 2009, proton beams were successfully circulated again, with the first recorded proton–proton collisions occurring 3 days later at the injection energy of 450 GeV per beam. On 30 March 2010, the first collisions took place between two 3.5 TeV beams, setting the current world record for the highest-energy man-made particle collisions, and the LHC began its planned research program. The July 4, 2012 announcement comes in this backdrop. The LHC will operate at 4 TeV per beam until the end of 2012, 0.5 TeV higher than in 2010 and 2011. It will then go into shutdown for 20 months for upgrades to allow full energy operation (7 TeV per beam), with reopening planned for late 2014.

As I mentioned earlier, the announcement of the discovery of the Higgs boson evoked considerable excitement in India, not only because we were pleasantly reminded of the seminal contributions of Prof. Satyendra Nath Bose to modern physics but also because of our intimate involvement in the construction of LHC and the discovery experiments. Indian scientists and students have always been taking part in many of the mega science projects across the world including the Tevatron and the SSC in various capacities. A major milestone in India's participation in International mega science projects was the formal agreement between the Indian Department of Atomic Energy and CERN to support India's participation in LHC machine building with firm resource commitments(US$25 million). DAE also evolved a unique participation model : only in-kind contributions and half the value to be kept aside for supporting Indian scientists participating in CERN activities. India's commitment to the CERN programs was doubled subsequently and the country was accorded the Observer status in the CERN Council in recognition of its contributions.

Indian scientists are also actively participating in LHC utilization. We are participants in two out of three approved experiments, ALICE and CMS. As you might have seen in the media, India is a part of the Higgs boson discovery team. A unique agreement between the Indian Department of Atomic Energy and the Indian Department of Science and Technology enabled the participation of faculty and students of Indian Universities in these cutting edge experiments. For example Delhi University collaborated with Bhabha Atomic Research Centre in design and fabrication of silicon strip detector based pre-shower detector for CMS while Punjab University collaborated with Tata Institute of Fundamental Research in the design and fabrication of plastic scintillator based outer hadron calorimeter for CMS. Faculty and students from many other Institutions and Universities also participated in detector simulation, data analysis and interpretation.

I am often asked what is there in it for us? Why are we investing major resources in participating in such ventures? How have we gained from these collaborations? The opportunities for Indian scientists to participate in frontier science experiments are obvious. When LHC was commissioned, there were two Indian scientists in the control room. We are part of the Higgs boson discovery team. Being partners in the collaborations, our scientists had early access to some of the cutting edge technologies even at the time of development. For example, email, parallel processing, GRID computing etc. entered Indian laboratories long before they entered the commercial markets. The Indian industries also gained new opportunities in terms of access to cutting edge technologies and new markets. For example, 50% of the superconducting corrector magnets, precision jacks to position the LHC magnet assemblies with a precision of 50 microns all along the 27 km length, quench protection heater power supplies, quench detection electronics, control electronics for circuit breakers of energy extraction systems, vacuum systems for beam dump line and liquid nitrogen storage tanks were manufactured by Indian industries. Indian engineers took extensive part in magnet tests and measurements.

It is important to note that entire collaboration was science driven and formal institutional involvements only followed. It is indeed interesting to note that at a time when science education was finding it difficult to attract bright young students, high energy physics had no problem in attracting good students. The role of international collaborations for this state of affairs can not be ignored. Last but not the least, the country has discovered a new confidence in our scientists, in our technologists, in our industries, in fact in ourselves. Today, the country has no hesitation in participating in many other mega science projects such as the FAIR in Germany or the Large Optical Telescope. Technologically advanced countries find value in India's participation, as in ITER. The country has the confidence to propose new mega science projects such as the Indian Neutrino Observatory (INO) and invite international participation.

Apart from its scientific significance, the Higgs Boson search is an outstanding example of a mega science research project involving high investments, long lead times, cutting edge technologies and high risks of negative results. How such experiments involving thousands of scientists/technologists across the globe are conceived and are implemented is something that deserves to be shared among scientists.

Research by definition is a human centric activity. One of the long standing questions in the sociology of Science is "How are path breaking discoveries made?". Standard school texts will like us to believe that path breaking discoveries are made, more often than not, by "accident", by intuition. Stories of Newton getting inspired by a falling apple or Archimedes getting inspired while being immersed in a bath tub are well known and give the impression that it is more a matter of chance than systematic toil that lead to path breaking discoveries. This obviously is an oversimplification. Millions of people must have been seeing falling apples before Newton but it was only Newton who recognized the significance of the falling apple and formulated the laws of motion. It requires a trained mind and perseverance even to make an "accidental" discovery. Sometimes, discoveries are made in unrelated areas while researching on something else. Sociologists call these as serendipitous discoveries. Serendipity is the effect by which one accidentally discovers something different, something more important, while looking for something else. Most authors who have studied scientific serendipity agree that again a prepared and open mind is required on the part of the scientist or investigator to detect the importance of information revealed accidentally. This is also the reason why most of the “accidental” and “serendipedious” discoveries occur in the field of specialization of the scientist. In the words of the famous French scientist, Louis Pasteur, “in the field of observation, chance favors only the prepared mind”. The human being behind the discovery, scientist or not, is an important component of the discovery process itself. Not only their strengths but their weaknesses also affect the discovery process. History is full of instances of missed opportunities, delays in important discoveries and missed credits arising out of human weaknesses. Prejudices of preformed concepts or reluctance to defy accepted peer knowledge (intellectual phase locking) are all obstacles to the discovery process. History does not record instances that could have resulted in new discoveries but did not.

I can not resist the temptation of narrating a story that will make all Indians sad. Soon after the discovery of nuclear fission in Europe, a number of groups across the world also started studying nuclear fission in greater detail. India was not lagging behind in this global endeavor. Many of you may not be aware that India came very close to a landmark discovery in this exciting endeavor in the very early days and missed it rather narrowly. A group in Bose Research Institute, Calcutta, led by Prof. Shyamadas Chatterjee, was studying slow neutrons and slow protons produced in lead by highly energetic cosmic rays with the help of a large proportional counter lined with boron and filled with CH_4. It was incidentally observed that the background count slightly increased when layers of U_3O_8 were kept in the immediate neighborhood of the counter that was kept within a paraffin enclosure. Of course the increase in counts was small. All the same, it was the first observation of spontaneous fission and interpreted as such by the scientist. However, his brief communication to Science and Culture was, however, withdrawn as it had been sent without the permission of the director, who did not believe that nuclei can undergo fission spontaneously! Within a few months, Georgy Flerov from the Soviet Union announced the discovery of spontaneous fission. The Calcutta group went ahead and made very detailed measurements but in Science, only the first is recognized and remembered. Were we over-cautious, did we lack confidence in our own competence, I do not know.

The Manhatten project of the twentieth century represents a new face of the discovery process involving new modalities of research and project management.

The project, while standing on the shoulders of several 'accidental' and "serendipitous" discoveries- the discovery of radioactivity, the discovery of the neutron and the discovery of nuclear fission- demonstrated for the first time that it is possible to mobilize a large group of scientists who will be driven by a common mandate. While the project itself was an undoubted success, it also brought to the fore several conflicts between the traditional research methodologies and the new model. There are indeed distinguishing features in the project management strategies of the mega science/technology projects of today.

1. Mega science projects require mega funding. Administrative and political patronage is absolutely essential for such projects, but it is not sufficient. Commitment of the scientific community is absolutely essential for the eventual success of such projects. Projects that are evolved through discussions at the scientists level (bottoms-up approach) have therefore a better chance of success than top-down projects.

2. International and inter-institutional co-operation, while broadening the stakeholder base and

distributing stakes, also brings in some stability in management.

3. Intellectual Property Protection has always been a major source of concern in projects involving multiple institutions, specially those spread across countrius. There is often the fear of conflicts of interest. On the other hand, rigid enforcement of Intellectual Property Protection norms and information on need-to-know basis can turn out to be counterproductive in such projects. New norms of Intellectual Property management techniques need to be developed in such mega science research projects.

4. Multidisciplinary, multi-institutional, multinational and multicultural environments call for new management structures. For example, there are new lessons in dis-assembly of projects into discrete work packages and seamless re-assembly integration of work packages back into the complete integrated project

5. Scientific research is less of tourism and more of trekking. Accidental discovery and serendipity are

quite common. The management must make room for innovations and course corrections mid-way

6. Projects involving new technologies that are yet to be proven often face new risks of failures necessitating major mid-course corrections. The Indian ecosystem is generally risk averse, even technological risks and puts serious penalties on failures. Many of the projects are dropped on encountering an unexpected failure. As we stand on the threshold of an era when technological innovations hold the key, India can not afford to be risk-averse. New risk management strategies need to be evolved. We have lessons to learn from our participation in international mega science projects.

7. In scientific research, negative results are as significant as positive results, some times more since they often lead to scientific breakthroughs. Mega science projects while attracting much attention by the public at large because of the scale of investments also attract public scrutiny where negative results are often viewed as failures. The scientific community need to evolve new strategies for science/technology communications and ensure

that the results are viewed in the right perspective by the funding agencies and the public at large.

These are indeed important lessons that one could learn from our participation in International mega science research projects. More importantly, these lessons hold good equally in managing mega projects of any kind.

Prof. V. S. Ramamurthy is a well known Indian nuclear scientist with a broad range of contributions from basic research to science administration. Prof. Ramamurthy started his career in Bhabha Atomic Research Centre, Mumbai in the year 1963. He has made important research contributions, both experimental and theoretical, in many areas of nuclear fission and heavy ion reaction mechanisms, statistical and thermodynamic properties of nuclei, physics of atomic and molecular clusters and low energy accelerator applications. During the period 1995-2006, Prof. Ramamurthy was fully involved in science promotion in India as Secretary to the Government of India, Department of Science & Technology (DST), New Delhi. He was also the Chairman of the IAEA Standing Advisory Group on Nuclear Applications for nearly a decade, Chairman, Board of Governors, Indian Institute of Technology, Delhi, Chairman, Recruitment & Assessment Board, Council of Scientific and Industrial Research and Member, National Security Advisory Board. After retirement from government service, Prof. Ramamurthy, in addition to continuing research in Nuclear Physics in the Inter-University Accelerator Centre, New Delhi, has also been actively involved in human resource development in all aspects of nuclear research and applications. He is currently the Director, National Institute of Advanced Studies in Bangalore, and Chairman, Board of Governors, National Institute of Technology, Hamirpur. In recognition of his services to the growth of Science and Technology in the country, Prof. Ramamurthy was awarded one of the top civilian awards of the country, the Padma Bhushan, by the Government of India in 2005.

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