Indian scientists have made concrete contributions to research at this “Mecca of high energy physics” and look toward an even more significant role in the future. Here is an account of how India’s collaboration with CERN has evolved over time.

THE “God-particle” laboratory! With the recent discovery of the new particle, which appears to be exactly what the Higgs particle should be, the laboratory where this experiment was carried out is also very much in the news – CERN!

CERN was founded in 1954, is headquartered in the outskirts of Geneva, Switzerland, and extends over the border into France. CERN or Conseil Européen pour la Recherche Nucléaire is the European laboratory for particle physics. Its mandate is to carry out front-ranking research in particle physics, a field that delves into the nature of the fundamental constituents of matter and the forces between them. Over its lifetime, CERN has developed and hosted a succession of state-of-the-art accelerators and has been the birthplace and development cradle for related advanced technologies, like particle detectors and computing and information technology.

“It’s the Mecca of high energy physics.” These words about CERN still ring in my ears, spoken to me by my senior colleague at Tata Institute of Fundamental Research (TIFR), P.K. Malhotra, a few months before I was to embark on my first stint to CERN. This was late 1970 and I had recently joined the bubble chamber group at TIFR as a postdoctoral researcher, having completed my PhD work at Panjab University, Chandigarh. As luck would have it, my thesis was on properties of hypernuclei that are produced by stopping K-minus mesons, the exposure to K-minus mesons having come from CERN! It had been a TIFR-Panjab University collaboration.

I was going to CERN in early 1971 to participate in experimentation at the still-being-commissioned proton-proton collider, the Intersecting Storage Rings (ISR). This was to be the first proton-proton collider in the world and would provide interactions at record high energies. TIFR had proposed an experiment at the ISR facility. The ISR became operational in 1971 and our experiment was duly carried out and yielded results on photon and pi-zero production. Forty years down the line, in 2012, the discovery of the Higgs boson has come from another proton-proton collider at CERN, the Large Hadron Collider (LHC), with over hundred times higher energy than the ISR.

Experimental particle physics attempts to answer questions about the basic building blocks of nature by firing particle beams against one another and detecting the debris of the collisions. The particles are traveling at almost the speed of light and carry very high energy. In a collision some of this energy gets converted into new particles (good old Einstein’s $E = mc^2$), which fly out in all directions. One tries to detect and measure the energies and directions of all the particles in order to deduce the fundamental nature of the particles and the forces between them. LHC energies are so high that it is like creating a mini big bang at a millionth-millionth ($10^{-12}$) second after the real big bang that created the universe.

From the 1970s to the mid-80s, TIFR, and later other Indian high-energy groups, participated in many CERN-based bubble chamber experiments. A bubble chamber is a transparent chamber filled with a liquid kept in a superheated state by application of pressure. A beam of particles is fired into it, and simultaneously the pressure is released. Some beam particles collide with the atomic nuclei in the bubble chamber and new particles are created in this collision. The release of pressure results in bubble
Photographs of the chamber are taken from three or four suitable angles for three-dimensional reconstruction of this interaction. The film is processed and projected on a table where measurements are made along the bubble trajectories where the particles passed. Computers are then used to reconstruct the interaction and the study of tens of thousands (or more) of such interactions allows one to discover properties of the produced particles and their interactions.

The last such collaborative experiment with TIFR participation in the early 1980s was a landmark experiment in which a very small bubble chamber (10 centimeters in length) called Lexan Bubble Chamber (LEBC) was placed upstream of very sophisticated instruments, which helped to detect and measure high energy particles produced in interactions within the chamber. This experiment, NA27, studied properties of “charm” particles for the first time, the charm quark having been discovered just eight years back in 1974.

By mid 1980s, the days of the bubble chamber were over, and the purely electronic experiments had taken over. In such experiments many cylindrical layers of detectors surround the collision point. Each layer specializes in the detection of a particular type of particle, so that taken together all the particles can be detected (except neutrinos, which hardly interact with anything at all). In 1983, TIFR joined the L3 collaboration that would carry out experiments at LEP, the Large Electron Positron collider, which started operation in 1989. This collaboration was led by the Nobel Laureate Sam Ting of MIT, who was the co-discoverer of the charm quark.

Participation in L3 collaboration provided new experience to the TIFR group. Modern particle detectors are hugely complex and expensive. It is normal, and actually mandatory, for tens of institutions from across the globe to collaborate in building different parts of the overall detector. TIFR’s responsibility was to build the forward-backward hadron calorimeter in sub-collaboration with the Aachen group. A hadron calorimeter detects and measures the energy of hadrons – strongly interacting particles, like the proton and neutron.

The detectors were fabricated in TIFR with quite a bit of precision machining work for it done by the Mumbai industry and BARC workshop. These were tested and delivered at CERN in 1988 and integrated within the L3 detector. These hadron calorimeters performed perfectly from 1989, when LEP started operation, till 2000 when the LEP experimental program was terminated. The TIFR group also provided strong software support to this collaboration.

An area where the TIFR group made the maximum impact was in the extraction of the science from the experimental results. The group was responsible for the analyses to determine the properties of the Z boson particle, which was the main goal of the first phase of the LEP project. Group members were also instrumental in studying the properties of the strong interaction (that holds together atomic nuclei), mesons containing b-quarks, and in searches for the Higgs and supersymmetric particles.

The LEP experiments systematically and comprehensively tested the validity of the Standard Model of particle physics, which predicted the existence of the Higgs and the Z boson particles as a by-product of the unification of the Standard Model.
electromagnetic and weak interaction theories by Steve Weinberg and Abdus Salam. The Z boson had been discovered at CERN in 1983-84 but detailed study of its properties needed a “Z boson factory” where millions of Z boson could be produced and studied. LEP was this ambitious Z boson factory. The Higgs had not been discovered at all and LEP was to provide a way of searching for it in a systematic way.

There were two outstanding results from LEP. One, the precise measurement of Z boson’s properties, leading to the determination of the number of light neutrinos in nature. This was achieved despite the fact that neutrinos can’t be detected, as they almost do not interact in the detector to signal their presence. Two, a systematic search for the Higgs particle, which led to a lower limit being placed on its mass of 114.4 GeV (about 125 times the mass of a proton).

The search for the Higgs boson was unsuccessful at LEP, but these efforts provided a solid lower limit on its mass. We found that if it existed, its mass would be heavier than 114.4 GeV, so that LEP could not discover it owing to its insufficient energy.

Matter consists of atoms that give it chemical properties; an atom in turn has a nucleus at the center surrounded by electrons around it. The 20th century saw the unveiling of the structure of the nucleus and today we know that there are twelve fundamental constituents of matter that can be clubbed in three generations.

The visible universe we see around us needs only the first generation for its existence: the two quarks called up and down quarks, which make up the protons and neutrons of atomic nuclei, the electrons, which orbit the nuclei, and the neutrino, which is necessary to explain the properties of radioactivity. The other two generations were discovered in the 20th century when scientists studied high-energy interactions. 2nd and 3rd generation particles are heavier than their first generation counterparts and have some other unique properties.

The 2nd generation consists of the charm and strange quarks, the muon and its neutrino, and the 3rd consists of the top and bottom quarks, the tau and its neutrino. These are the so-called “matter” particles. No one knows why these additional generations exist and whether there could be more.

There is one neutrino per generation of matter particles. So, if we can determine the number of neutrinos in nature we would have fixed the number of matter generations. From precision measurements made at LEP the total decay rate of the Z boson into neutrinos was obtained and hence the number of light neutrinos (into which the Z can decay) was determined very accurately. It was found to be three! Thus, unless unusually heavy neutrinos exist (billions of times heavier than the three already discovered), we can confidently say that we have already discovered ALL the matter generations that exist in nature!

During the 1990s, while the TIFR group was involved in the LEP experiment, other Indian groups, led by Variable Energy Cyclotron Centre (VECC), Kolkata, started participation in CERN-based collaborations in the area of high energy heavy ion interactions. CERN accelerators could produce such beams, including lead beams, and Indian groups fabricated plastic scintillator based detectors to detect and study photon production in search for a new state of matter called quark-gluon plasma. They worked on WA93 and WA98 collaborative experiments and many interesting results on photon multiplicity and its energy and angular distributions were obtained.

By this time the Indian Department of Atomic Energy (DAE), interested in accelerator related technologies, saw an opportunity of collaborating with CERN, which had been at the forefront of such research for long. The first CERN-DAE umbrella agreement for scientific cooperation was signed by Atomic Energy Commission Chair P.K. Iyengar and CERN Director General Carlo Rubbia in 1991 and a follow-up protocol in 1996 by succeeding AEC Chair R. Chidambaram and CERN DG C. Llewellyn-Smith. Continuing agreements have been signed regularly as needed.

Thus, the stage was set for a comprehensive Indian participation in the flagship LHC project at CERN. The LHC project was formally approved by the CERN Council in 1996. Indian groups joined two physics collaborations at LHC, starting in 1994: the CMS collaboration, with TIFR as the nodal institution, and the ALICE collaboration, with VECC as the nodal institution. As many Indian universities were also involved, the Department of Science and Technology (DST) also got formally involved in the funding. It was the first time the two departments, DAE and DST, worked out an inter-departmental protocol on how to share the funding of such collaborative multi-institutional multi-funding agency international projects.

India has indeed successfully contributed significantly to the LHC project. Supported by DAE and DST jointly, Indian groups in CMS and ALICE contributed to the hardware detector fabrication and installation at CERN, detector software,
Feature Article

From end-1990s, feelers for greater formal Indian participation in CERN were made, but becoming a CERN member was not cost-effective. The annual CERN budget is around one billion Swiss francs (around 1.2 billion US dollars). Each member state contributes towards this in proportion to its GDP or NNI (Net National Income). In 2002, the CERN Council introduced some modified rules for Associate Membership of CERN. According to these new rules, half of this contribution was required for Associate membership, but with very little benefits accruing. Thus, India would have to contribute around Rs 200 crore per year for a relatively very small number of scientists in the field.

The situation changed around 2007-08. CERN set up a working group to examine the issues of its possible scientific and geographical expansion to transform it into truly a world laboratory. Observer states, including India, were invited to present their views in a meeting held in September 2009. From the Indian side we had made a study of the financial factors involved. Taking a page from CERN’s own documents giving statistics for Europe, we pointed out that the demographic situations were vastly different for the two regions. This is shown in the table below.

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<th>Europe</th>
<th>India</th>
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<tbody>
<tr>
<td>GDP (purchasing-power parity)</td>
<td>10191.4</td>
<td>2373 Giga Euro</td>
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<tr>
<td>Population CERN states (million)</td>
<td>462</td>
<td>1100</td>
</tr>
<tr>
<td>Researchers in EHEP</td>
<td>4022</td>
<td>100</td>
</tr>
<tr>
<td>Normalized to population</td>
<td>8.7/million</td>
<td>0.1/million</td>
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<tr>
<td>Normalized to GDP</td>
<td>0.38/Giga Euro</td>
<td>0.04/Giga Euro</td>
</tr>
<tr>
<td>Graduate students</td>
<td>1807</td>
<td>50</td>
</tr>
<tr>
<td>Normalized to population</td>
<td>3.9/million</td>
<td>0.05/million</td>
</tr>
<tr>
<td>Normalized to GDP</td>
<td>0.18/Giga Euro</td>
<td>0.02/Giga Euro</td>
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We pointed out that in light of these differences, it was just not cost effective for such countries to join as Associate Members: no worthwhile benefits accrue after a large annual payment. In fact, no country had joined as an Associate Member. But instead of leaving it at that, we made the following concrete suggestions how to make Associate Membership more fair and attractive:

- Instead of asking Associate Members to make half the budgetary contribution as full-members, make it flexible so that countries can select what most suits them. This contribution can change with time.
- Associate Members can attend the Council meetings with the right to speak. Voting rights could be allowed on projects in which the country is substantially involved.
- Associate Members were eligible for appointments, which would be commensurate with contribution.
- Associate Members could recruit industrial participation commensurate with their contribution, or more, if mutually beneficial.

The CERN Working Group as well as CERN management was very appreciative of these concrete proposals from the Indian scientists. In the June 2010 CERN Council meeting new rules for Associate Membership were adopted. The Indian proposals had been largely accepted. Instead of 50%, the minimum contribution could be as low as 10% of the full membership fee and could remain constant or increase with time.

Associate Member states would be entitled to participate in CERN training and education programs. While they would not enjoy voting rights in the Council, such members would be entitled to ask for the floor and make statements without being asked to do so; citizens from such states would be eligible for posts at CERN in proportion to their contribution. Industrial and consulting firms in Associate Member states would be entitled to bid for CERN contracts, again constrained to the proportion of their contribution.

With these much more beneficial conditions of Associate Membership of CERN a proposal was submitted to DAE for India to apply to CERN for such a position. After due consideration DAE has approved this proposal. It now awaits funding approval within the Twelfth Five Year plan budget of the DAE.

An associate membership would open up avenues for wider and deeper participation of India in CERN programs and projects. This will not only benefit the particle physicists of India, but researchers from many fields. Our scientists, engineers, technologists would get the opportunity to participate in front-ranking projects in accelerator technologies (ultra high vacuum, ultra cryogenics, superconducting magnets, etc), in high end computing and IT related projects, in detector technologies which involve materials properties, imaging techniques, etc which have multiple uses in society.

Last but not the least, our young researchers would have better entitlement to work at CERN on pure or basic research, the raison d’etre of CERN.

Dr. Atul Gurtu led a team of six Indian institutions collaborating in one of the front ranking experiments at the LHC, the CMS experiment. He was nominated by CERN to be author of the LBNL Particle Data Group collaboration in 1992 and continues to be responsible for the sections on W and Z particles since that time. In recognition of his scientific contributions he was elected member of the Indian Academy of Sciences in 1996. Dr. Atul Gurtu retired from Tata Institute of Fundamental Research (TIFR) in 2011 as Senior Professor in the Department of High Energy Physics.

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