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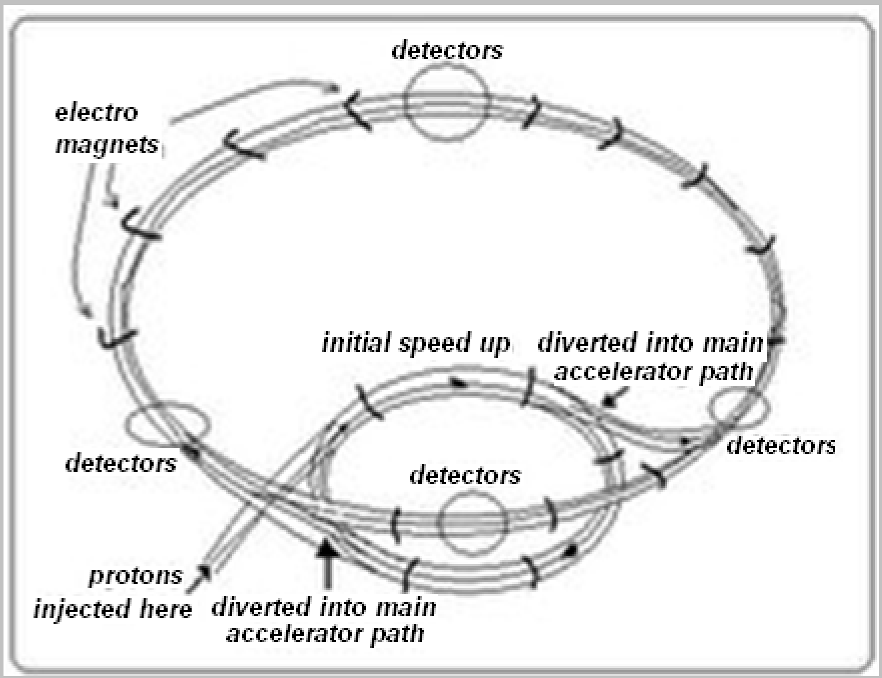
Protons speed and collide at Geneva

CERN's Large Hadron Collider will open a new chapter in science, says S.Ananthanarayanan.

The **LHC** , a 27 kilometer, 120 Megawatt, multinational, particle accelerator, located in Geneva, partly in Switzerland and partly in France, will answer a number of question that have badgered physicists since some decades.

The LHC drives two beams of high speed protons (the nuclei of the hydrogen atom, one of a class of particles called ***hadrons***) in opposite directions through a hollow ring, so that the beams may collide and set off high energy particle interactions. The successful test of one beam on 10th Sep and then next on 21st Sep is the realization of the facility that was first planned in 1984. The actual collision experiments are planned to start in a few weeks.



The Physics crisis

Analytical physics made its start with Isaac Newton, who formulated the laws of motion and also of gravitation. It became possible to work out the motion of planets of the solar system with incredible accuracy and this gave scientists a feeling of having fathomed a great secret of nature. Fast on Newton's heels came the gas laws, thermodynamics and the electromagnetic theory and then the steam engine and wireless telegraphy. It did look like everything was known!

But disturbing, new discoveries, like radioactivity, the structure of the atom, the discovery of the atomic nucleus, the Theory of Relativity and then the Quantum Theory, destroyed the complacence, questioned the bases of classical physics and opened new arenas of research. The major advances were in cosmology - the curvature of space, the expanding universe, the discovery of supernovae, pulsars, black holes and the theory of origin of the universe in the **Big Bang**. And nearer home, lasers, transistors, and intense research into the world of subatomic particles and processes.

The discoveries represented the undisputed triumph of the General Theory of Relativity in the world of cosmology and of Quantum Electro Dynamics in the study of nature at very small dimensions, like within atomic nuclei and in collisions of atomic particles. But for all the success of the two methods in the fields where they applied, there was no bridge to connect the two theories, there was no single theory that explained both the nature of mass and gravitation as well as quantum phenomena.

The String Theory

String Theory is a promising mathematical approach to develop a quantum theory of gravity, which treats ordinary spatial dimensions as containing hidden dimensions - like considering a line to have not zero width but to be more like a drinking straw. The hidden dimensions show up at high energies and explain phenomena that that do not appear during low energy interactions. The theory then unfolds to take into account electrical forces, nuclear forces as well as the force of gravity.

One of the problems of physics has been with forces and how they act between objects separated by a distance. It was to get around this ‘action at a distance’ problem that the idea of magnetic and electric fields was developed, although it is really only a way of saying the same ‘magic’ in a different way. In quantum physics, the forces are explained by the ‘exchange’ of particles between the two objects - photons for the electromagnetic force, ***gluons*** for the ***strong force***, which acts between particles in the nucleus and ***W*** and ***Z bosons*** for the ***weak force***, which is the interaction in radioactive decay.

When dealing with forces in this way, the regular quantum theory runs into problems of throwing up ‘infinite’ values, which are meaningless. Methods to work around the problem have been found for electromagnetic forces, the ***Strong*** force and the ***weak*** force. But there is no way to get out of the ‘infinity’ problem in the case of gravity.

String theory is thus a fresh way of developing quantum physics with gravity included, with the help of ***extra dimensions***. Interactions involving the ***Graviton***, or the carrier of the gravitational force, are then treated as involving not points of zero dimension, but of regions with non-zero, extra dimensions - and the ‘infinity’ problem is overcome.

A consequence of this kind of theory is that for every particle associated with the transfer of force, like photons (these are called ***Bosons***, named after ***Satyen Bose***), there should be a corresponding material particle, like electrons or protons (called ***Fermions***, after ***Enrico Fermi***). This correspondence is called ***supersymmetry*** and the fermions are the ***supersymmetric*** particles of the force bosons.

Confirmation

When Quantum Physics was still proving itself, it had predicted that for every particle here had to be an 'antiparticle' with the same properties, except the charge. The discovery of the '***positron'***, the antiparticle of the electron was the discovery that validated the quantum theory.

In similar fashion, if the supersymmetric partners of existing particles were discovered, this would validate String Theory. The way new particles are discovered is that they come in from outer space or get 'created' in nuclear reactions, which are collisions of elementary particles. As new particles are created from the energy given up by the reacting particles, the reactants need to start out with energy enough for the new particle. But Supersymmetric partners of existing particles are so massive that the required energy was not there in existing particle accelerators. It is here that CERN's LHC, with its huge energy capability, would be able to answer many questions.

The Standard Model

Quantum mechanics has developed a framework to explain the elementary particles that exist as well as the particles that carry the forces between them. There are 12 fermions, or matter particles and 5 force carrying particles. These 5 are the photon, the W and Z gauge bosons, the gluons (8 kinds) and the ***Higgs boson.***

This last, the ***Higgs boson*** is a particle of large mass and is the only one that has not been observed so far in experiments. The reason may be that because of its large mass, it needs a very energetic reaction for it to get created. Here again, scientists are pinning great expectations on the ***LHC*** -just like discovery of antiparticles proved the quantum theory right, discovery or otherwise of the Higgs boson will help us correct the course of high energy nuclear physics.

Is there danger in the LHC?

Fears have been expressed that the LHC is going to recreate the Big Bang and would destroy the earth. It is expected to create some particles that we cannot create in existing accelerators, but nowhere ner the energy scale of the Big Bang.

The device does consume and store huge energy, but this is distributed over an area 27 km in perimeter. The accelerated particles themselves, though the most energetic created on earth, are so light - the whole quantity of protons in both the streams is over 200 billion, but all that is less hydrogen than the volume of a grain of sand - the the total energy cannot do more damage than many other everyday events.

One fear that has been expressed is that the LHC may create a microscopic black hole - a black hole is a super heavy star that attracts surrounding material and grows so heavy that its gravity prevents even light from escaping. Its gravity also draws in all matter in its vicinity and the black hole grows and grows. The fear is that even a microscopic black hole would do the same thing, with disastrous consequences.

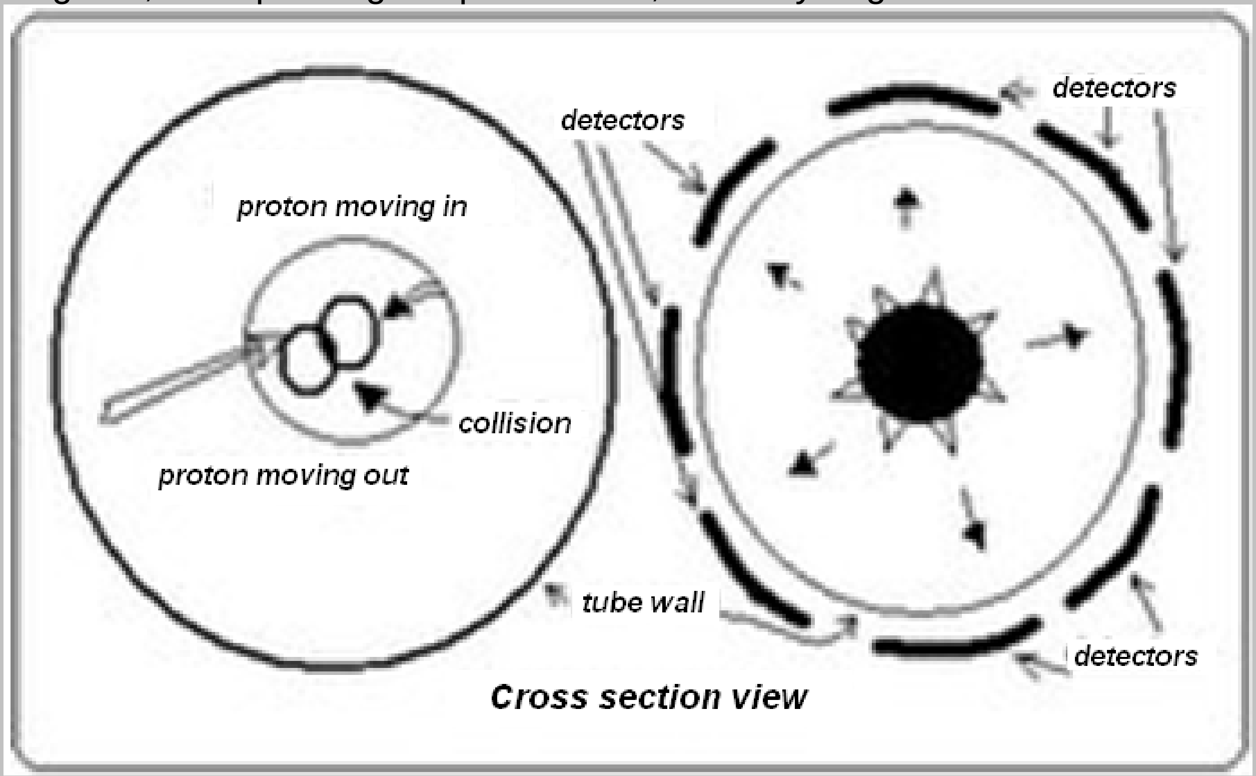
In fact, there cannot be a black hole unless it is at a threshold mass of some 8 times that of the sun. Of course, the density of subatomic particles is more than even black holes, but as the gravitational force is quite weak, compared to other forces, at small distances, this high density is of no avail. Even if the particles get close enough to each other, there are quantum effects that would push them apart and prevent mass accretion.

The Big Bang

An important discovery in 1929 was that objects like stars and galaxies that are far away from the earth are receeding at speeds that increase as the distance increases. A universe where objects are speeding away from each other suggests an expanding universe and the reverse idea that naturally arises is that if we go back in time, then the universe must have been much smaller - in fact just a dot sometime long ago. A theory was hence developed that stupendous energy that was contained in some primordial zero-size dot suddenly expanded and give rise to everything! Theoretical estimates of how different elementary particles and the elements of the universe may have formed are in good agreement with observation and the theory is now widely accepted. The name, Big Bang, is attributed to the British astrophysicist Fred Hoyle (Jayant Narlikar was his student and associate) and at the time, Hoyle was derisive of the theory.

The theory itself does not describe the high energy processes that must have taken place in the first minutes, But particle accelerators have been built to get to energies as high as possible, though nowhere near the energies of the Big Bang. The LHC enables a closer approach than ever before but is still a long way from that violent beginning.

The **Collider** is a particle accelerator, rather like the 'gun' that shoots a beam to excite the screen of our television sets. Only, here the idea is to move the particles really fast through an arrangement of many accelerating magnets, each pushing the particles on, at a very large scale.



The protons, which are electrically charged, are pushed into the tube and then given strong accelerating ‘kicks’ by the alternating field of the 9,300 electromagnets placed around the ring . The magnets need to be kept at cryogenic temperatures and the power consumed is 120 Mega Watts. The particles are received in a smaller ring and once they get reasonably fast, they enter the main ring, half go one way round and the rest go the other way round. In this ring they speed up over many thousand of turns and reach nearly the speed of light and an energy of some 7000 billion electron volts. This is about 2600 billion times the energy of a photon of blue light (it has energy of 2.6 eV) and a collision of such protons can lead to formation of the heaviest of particles, like the Higgs particle or supersymmetric particles. The accelerator would also enable many more experiments which have been waiting for real high energy