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SCIENCE

Beaming success

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After a 14-month hiatus, the Large Hadron Collider is poised for good physics runs.

PICTURES COURTESY CERN



Compact Muon Solenoid detector. CMS is designed to see a wide range of particles and phenomena resulting from high-energy collisions at the LHC. Consisting of 100 million individual detecting elements, each looking for signatures of new particles and phenomena at 40 million times a second, it is one of the most complex scientific instruments ever constructed.

IF the year 2008 ended on an extreme low for the Large Hadron Collider (LHC) at the European Organisation for Nuclear Research (CERN), 2009 ended on a real high note. When the LHC was shut down for Christmas on December 16, 2009, it had ended its first full period of operation, as a CERN release put it, “in style”. The two counter-rotating beams of protons in the accelerator attained a record-breaking beam energy of 1.18 tera (trillion or 10^{12}) electronvolt (TeV) each, which means a total collision energy of 2.36 (1.18 + 1.18) TeV. The highest energy reached hitherto was 0.98 TeV per beam at Tevatron, the linear hadron collider at Fermi National Accelerator Laboratory (Fermilab) in Batavia, Illinois, in 2001. The particle detectors located at different points along the 27-kilometre circumference of the ring accelerator had already

recorded interesting collision events at this energy, which is just one-sixth of the LHC's designed peak value.

Key questions

In the LHC, the counter-rotating proton beams are brought to intersect at various points along the accelerator ring where particle detectors of the six different experiments (see box) will record the characteristics of the secondary particles that are produced in the collisions, such as their energies and momenta, and enable their identification. From these data, scientists expect to find answers to the following key questions. Is there any new physics beyond the Standard Model (SM) – which has been enormously successful in describing sub-nuclear physics at lower energies – lurking at the energy scales that the LHC is slated to attain? Are there any signs of new particles like those predicted by supersymmetric theories? And, most importantly, does the Higgs boson, the hypothetical particle in the SM that endows other particles with mass, exist at all and what determines the hierarchy of particle masses that is seen in nature?

“So far,” said CERN Director General Rolf Heuer, “it is all systems go for the LHC. This first running period has served its purpose fully: testing all the LHC systems, providing calibration data for the experiments and showing what needs to be done to prepare the machine for a sustained period of running at higher energy. We could not have asked for a better way to bring 2009 to a close.”

“It has been a truly remarkable 24 days,” said Steve Myers, CERN's Accelerator and Technology Director, in his presentation to CERN's audience on December 18 soon after its Christmas shutdown. “Things have moved so quickly that it has been hard to keep up with the progress. [There have been] Many firsts for the LHC and the detectors,” he added.

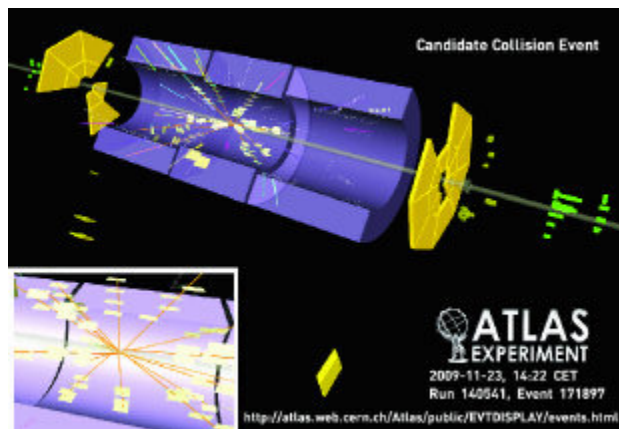
Indeed, this time around there was no false start or any major hiccup in putting the machine back in operation after its 14-month hiatus. The accelerator was shut down in September 2008 for repairs and upgrade following the mishap caused by faulty soldering of the busbar joints between superconducting magnets that maintain the beams in their paths (*Frontline*, January 30, 2009). After the initial check runs that began in October 2009, as expected (*Frontline*, December 4, 2009), the LHC was fully back on stream on November 23, 2009, with proton beams sent around the full circle of the LHC *simultaneously* for the first time since the fateful day of September 19, 2008.

Following the successful first run, the world's most powerful accelerator is now poised to attain its chief objective of extracting physics out of the zillions of head-on collisions among these high-energy protons in the first quarter of 2010. The LHC has now been put on standby mode and will restart in February following a short technical stop to prepare the machine for its beam energy to be ramped up to the planned value of 3.5 TeV for real physics to begin (*Frontline*, December 4, 2009).

Ramping up the machine to a higher collision energy of 7 (3.5 + 3.5) TeV – three times its present 2.36 TeV – requires higher currents in the LHC magnet circuits. A higher energy also implies more exacting demands on the new machine protection systems. The commissioning work for higher energy will be carried out in January, according to a CERN release. During this technical maintenance period, one of the experiments (CMS), in fact, plans to open up the detector in order to improve the reliability of the cooling system for the end caps.

During the restart, things progressed more smoothly than the LHC scientists and engineers had expected and the record-breaking energy of 1.18 TeV per proton beam was reached just within a week of the restart. Notwithstanding the conservative approach warranted by the accident, which called for a careful injection of the beam and cautious modulation of its energy, there was no serious hold-up. (There was, however, a power cut in one section of the accelerator – across the site at Meyrin – caused by a failure in an 18,000-volt line on December 2 that shut down the main computer centre and caused an abrupt cessation of all operations. The most critical element, namely the cryogenics that keeps the machine at 1.9 Kelvin (-271°C), however, remained unaffected. Until this “minor teething problem” was fixed, the Meyrin site drew power from a diesel power back-up system.)

After all the multitude of checks in the various parts of the machine, the entire machine was cooled down to its operating temperature on October 8, 2009. On October 23, the first particles were injected, but not circulated. A beam was steered around three octants of the machine on November 7 when the so-called “splash events” were recorded (see *Frontline*, December 4).



CANDIDATE COLLISION EVENT. The collisions, though only for a short period as a trial, were good enough to test the synchronisation of the beams and gave the experiments their first chance to witness proton-proton collisions.

And on November 20, circulating beams in both directions were established *separately*. After studying each beam carefully over the next couple of days, the beam lifetimes could be brought up to 10 hours from its earlier 10 minutes. And on November 23, the beams were ramped up to 450 giga (or billion) eV (GeV) each and the first collisions (at a total of 900 GeV) were recorded. The corresponding current in the dipoles is about 0.8 kilo ampere, as against the peak value of 12 kA at 7 TeV per beam.

These collisions were, however, few because of the low intensity of the beams. Each beam had only one pilot bunch of particles (of over two billion protons) as against 2,808 bunches of more than one hundred billion protons each when the LHC becomes fully operational. Also, despite billions of protons in each beam, each bunch would be mostly empty space unless it is “squeezed” to increase the chances of collisions, and for this test phase the beams were not “squeezed”. Also, these collisions were only for a short period as a trial. But this was good enough to test the synchronisation of the beams and gave the experiments their first chance to witness proton-proton collisions. With just one bunch circulating in each direction, the beams could be made to cross at only two points in the ring. First, they were made to cross at ATLAS and CMS detectors, both of which were tuned to record collisions. Later the beams were made to cross at ALICE and LHCb experiments.

Coming just three days after the restart, these developments indicated excellent performance of the beam control system. This prompted Myers to remark: “I was here 20 years ago when we switched on CERN’s last major particle accelerator, LEP [Large Electron Positron Collider]. I thought that was a great machine to operate, but this is something else. What took us days or weeks with LEP, we’re doing in hours with the LHC.”

These first events were useful for the experiments to check if the detectors are ‘in time’; that is, when a collision occurs, every part of the detector sees it happening at exactly at the same time. Such precise timing is critical for the huge detectors, each of which has millions of detectors with some of them separated from each other by several metres. Each of these detector elements must be synchronised to within one billionth of a second.

The smooth operations notwithstanding, the LHC operators were still being cautious and were expecting the LHC to reach the record-breaking energy of about 1.2 TeV per beam only by Christmas. However, this happened much sooner than expected. In the early hours of November 30, the LHC accelerated its twin beams to 1.18 TeV, demonstrating once again the smooth progress of the machine. At 21.48 hours on November 29, beam 1 was accelerated to 1.05 TeV and three hours later both the beams were successfully accelerated to the record value of 1.18 TeV, corresponding to a dipole current value of about 2 kA.

After attaining the highest energy ever reached in a particle accelerator, the LHC went through a concentrated commissioning phase aimed at increasing the beam intensity, which would provide each of the experiments adequate numbers of collisions for more accurate calibrations of the detectors and for testing their millions of complex detector elements. This phase was intended to ensure that these higher intensities can be handled safely and that stable conditions during collisions can be guaranteed for the experiments. This phase took around a week and the first real period of collisions started on December 6, though initially at a ramped-down energy of 450 GeV but with improved intensity with four bunches in each beam and five billion protons in each bunch. On December 8, the beams were once again accelerated to 1.18 TeV. Already, with this marginal increase in intensity, on December 6 the CMS experiment recorded interesting candidate events with a muon in the forward direction and ‘dijet events’ with twin high-energy jets of particles in the transverse directions opposite to each other.

On December 11, the beam intensity was increased to 70 billion protons per beam and in the early hours of December 14 the LHC operators achieved beams with much longer lifetimes. Having been able to maintain the beams extremely stable for long periods, the same night the number of proton bunches were increased to 16 per beam with the total intensity reaching 1,850 billion protons a beam. This greatly increased intensity, in fact, resulted in interesting multijet and dimuon events in the CMS experiment.

Finally, in the early hours of December 16, the beams were also “squeezed”; that is, their transverse profiles were reduced by focussing with magnets to increase the collision rate. Now that the beams had not only achieved record energy and were more intense and stable but also were well focussed, the initial run of the LHC after a highly successful restart was officially brought to a close the same evening. The LHC is now all set for the first physics run with 3.5 TeV a beam, which would get under way in February.

After a successful initial physics run, the energy is expected to be gradually increased to 5 TeV a beam (interview with Steve Myers, *Frontline*, December 4) in six months or so. Tejinder Virdee, the CMS spokesperson, remarked, “The events so far mark the start of the second half of this incredible voyage of discovery of the secrets of nature [at the LHC].”

URL: <http://www.hindu.com/fline/fl2702/stories/20100129270203300.htm>