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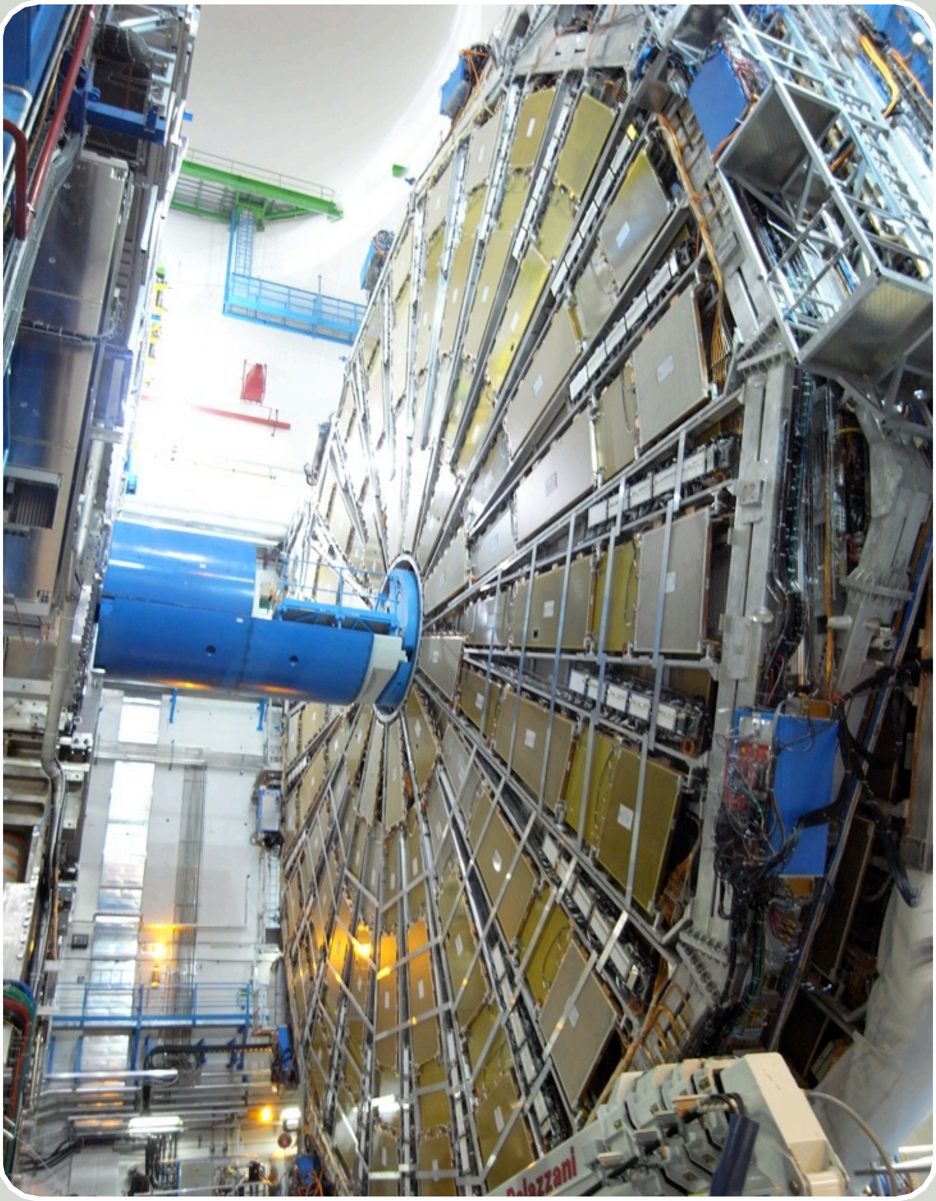
FEATURE STORY



KEK-ATLAS collaborators getting ready for LHC restart

[ATLAS, Muon Spectrometer, Superconducting Magnet]

A "Big Wheel" muon detector at ATLAS. Story this week features KEK's involvement since 1996. Read upcoming issues for the researchers who have led the team to success since the inception of the Japanese ATLAS collaboration.

On August 6, CERN announced that the Large Hadron Collider (LHC) will start up again in mid-November of this year. CERN, situated on the border between Switzerland and France, is the research center of one of the most renowned scientific institutes in the world. A simple six-kilometer drive from Geneva Airport brings you to its main campus in Meyrin from which the 27-kilometer circular collider, LHC, extends to France.

Since the helium leak incident last September, just 10 days into the operation, the LHC has been shut down for repair. When it starts up again this fall, it will initially run at a beam energy of 3.5 TeV, about half the energy of LHC's full capacity. The LHC will eventually be brought up to its full capacity of 7 TeV.

At 3.5 TeV, the LHC will still be the world's highest-energy particle accelerator. CERN chose this energy to allow researchers time to gain experience in running the machine and the experiment at low energy as quickly as possible, still keeping sensitivities to physics they are searching for. At these energies, the LHC will be able to start searching for the highly anticipated Higgs particles, which are hypothesized to give matter its mass. The LHC will also explore new physics such as supersymmetry and extra dimensions.

Prof. Osamu Sasaki (left) of KEK and Professor Emeritus Takahiko Kondo from KEK just outside of café on CERN Meyrin campus. The central five-story corridor spanning between the two wings of Building 40 in their background is roughly the size of ATLAS underground space.

CERN's advanced facilities attract as many as 8,000 particle physicists from 85 nations around the world. Many of these researchers are working at one of six large and small LHC experiments or the accelerator itself, getting ready for the next startup. Larger collaboration efforts go into the two major experiments, ATLAS (A Toroidal LHC ApparatuS) and CMS (Compact Muon solenoid) that look for Higgs and explore new physics beyond the Standard Model.

ATLAS and KEK

Between the two major LHC experiments, ATLAS and CMS, the Japanese collaboration from 15 research institutes including KEK concentrates its resources on ATLAS. Towering 25 meters in height and 44 meters in length in an enormous underground space equivalent to the five-story central corridor of Building 40 (see the second photo), ATLAS is in fact the largest scientific instrument in the collider experiments. The ATLAS experiment is a large collaboration of over 4,000 researchers from 37 countries worldwide.

ATLAS implements many elaborate systems to detect various features of the particles that result from the very high energy proton-proton collisions. ATLAS has four main parts, an inner detector to determine collision point and to measure the momentum of each charged particle; a magnet system to bend charged particles for momentum measurement; calorimeters that measure the energies of particles; and muon spectrometers to identify muons and measure their momenta. Just outside the calorimeters, immense superconducting toroidal magnets produce strong magnetic field to enhance the measurement of muon momentum. The outer most pieces of detector are multi-layered disks of muon spectrometers called big wheels (BWs), installed at the both ends of the detector.

The Japanese involvement in ATLAS dates back to 1991 when a small group of 8 researchers from University of Tokyo, Kobe University, and Shinshu University started developing a prototype of thin-gap chamber for the BWs. A few-year later, a proposed collider project in the US called Superconducting Super Collider (SSC) was canceled. A flood of Japanese scientists from the project joined the ATLAS group in 1994, making it a team of 38 staff scientists and many students. Only then could the team of Japanese collaborators extend their contributions beyond the thin-gap chambers.

One of Japan's many contributions is the solenoid that produces a strong magnetic field in the inner region of the ATLAS detector. For KEK, the major contributions include silicon semiconductor trackers, simulation software, and offline data analysis. KEK also has been heavily involved in the development and construction of the BWs; these six small and large slices of muon detectors whose diameters being 23 meters and 25 meters respectively are the crucial component to detect Higgs particles.

The final focus line. The quadrupole magnets embedded deep inside the cryomodules, which were produced by Fermilab, were designed and built by Prof. Akira Yamamoto at KEK.

The entire area of the BWs is covered with thin-gap chambers. These are multi-wire chambers used to detect muons and generate a trigger to initiate event recording. KEK has built approximately one-third of the total 3600 TGCs since the R&D commencement in 1996 (the rest were fabricated by Israel and China). The KEK team has also been responsible for the trigger electronics, readout electronics, and online software for the TGC system.

Innovation after innovation

Innovation after innovation is everywhere in this huge project. During the course of this project, the KEK team had to overcome a whole host of challenges. For all the electronics, from boards to chips the team had to design from scratch to keep spacing and pricing within their constraints. The extreme environmental conditions were also a big challenge. "For example, under an intense radiation, bits on your memory can flip with a sizable probability," explains Prof. Osamu Sasaki of KEK, who is in charge of the electronics component of TGC for ATLAS. "For the critical components you have to design your electronics to make sure there would be no errors. For example, by using three storage bits for each bit of information, and using the average of the three as the final value."

Mass production was unrealistic in a project that demanded more R&D than the actual fabrication. "We had our physics students learn electronics extensively because there was no technology out there to meet our demands," recalls Professor Emeritus Takahiko Kondo from KEK who has been engaged largely in high energy experiment at energy frontiers, "their incessant hard work made it possible to produce innovation after innovation."

Behind the scenes: superconducting magnets

When he joined the project, Professor Akira Yamamoto at KEK had an impressive record of leadership in designing and building advanced superconducting magnets for accelerators and particle detectors, notably the BESS (the Balloon-borne Experiment with a Superconducting Spectrometer) experiment. Despite his extensive experience, Yamamoto was initially at a loss when the team asked him to create just a solenoid magnetic field of 2 Tesla in the region deep inside the detector, using some extremely 'transparent' magnets with nearly no physical volume. "Theoretically it is desirable to have only the magnetic field. We like the magnet to be as transparent as possible to incoming particles, so as not to disturb the measurement of the electromagnetic calorimeters waiting for particles just outside," says Kondo, "but you need at least some material to create a magnetic field!"

Yamamoto designed and redesigned the solenoids to push technological limits, and finally built the ultra-thin superconducting solenoid with physical thickness of just 33-milimeter. This is just two-thirds the size of other such devices developed before. The

Prof. Akira Yamamoto of KEK (lower right) and his collaborators gathered in front of ATLAS's superconducting solenoid. The photo was taken in February 2004 when the team just finished installation of the solenoid in a cryostat.

technology that allowed this breakthrough was the development of high-strength aluminum-stabilized Nb-Ti superconductor that provided a high thermal and electrical stability with an optimum balance of the sufficiently high mechanical strength to stably support an electromagnetic force produced by the magnets. With this material strength, lightness and transparency of the high-strength aluminum, he was able to dramatically decrease the physical mass and thickness of the superconducting coil.

Yamamoto's contributions to the LHC don't stop there. Working with the international team from KEK, CERN, and Fermilab, he led the team to successful final beam-focusing quadrupole magnets for the beam interaction regions including ATLAS and CMS. The magnets produce a field gradient of as much as 215 Tesla per meter, requiring a peak field reaching 8.6 Tesla in the coil and a field gradient uniformity level on the order of 10^{-4}. The magnets also need to be kept cool under the intense nuclear radiation heat coming from the particle interaction regions. In collaboration with Fermilab, KEK worked on the research and development to tackle these issues, transferred the technologies to the industry sector for mass-production, and finally completed 20 sets (16 plus 4 spares) of the superconducting quadrupole magnets in 2004. They are installed in the four beam interaction regions in the LHC. The extensive know-how of building the magnets helped later in developing the superconducting combined function magnets (described in the previous issue) installed in the primary beamline for the neutrino experiment, T2K, at J-PARC (Japan Proton Accelerator Research Complex) in Tokai, Japan.

The Voyage begins

Since last September, the ATLAS team has been commissioning and tuning the detector using cosmic ray events. "The helium leak last fall was no doubt an unfortunate accident, but the original schedule was also very tight," says Sasaki, "data was piling up and we hadn't had a chance to examine it until recently." During the shutdown, all the data from cosmic ray events were analyzed, and the team found about fifty miswirings. This is not so bad considering the total number of 320,000 connections. The miswirings have now all been fixed. If discovered after the experiment had started, a problem like this would need to be solved by reprogramming. However, even if this reprogramming were done, the triggers that differentiate signals from background noise in terms of energy might not have worked properly.

"After a decade of preparation and construction, we are now just about to launch into the science we want to do," says Kondo, "that is how long it takes to do a physics experiment of this scale." Now the LHC is in good shape to start again. Once it does, the KEK-ATLAS team will be analyzing the productions of Higgs particles and supersymmetry particles, the central themes of the LHC research. "It's been fun to work with these young brilliant researchers," smiles Kondo, "Finally our voyage begins."

Related Link:
LHC
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