January 12, 2010

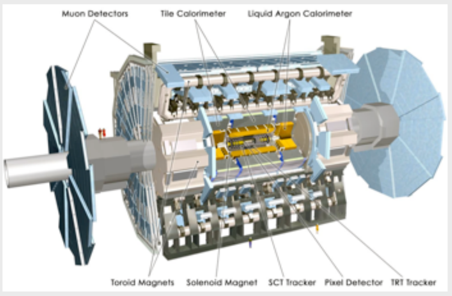
FEATURE STORY

ATLAS-MUON team members celebrate the successful beam injection on November 20, 2009. Dr. Masaya Ishino of KEK (Lower left) leads the endcap muon trigger level 1 team.

ATLAS's first beam and first collision

[Large Hadron Collider, ATLAS, Thin Gap Chambers, Semiconductor Trucker]

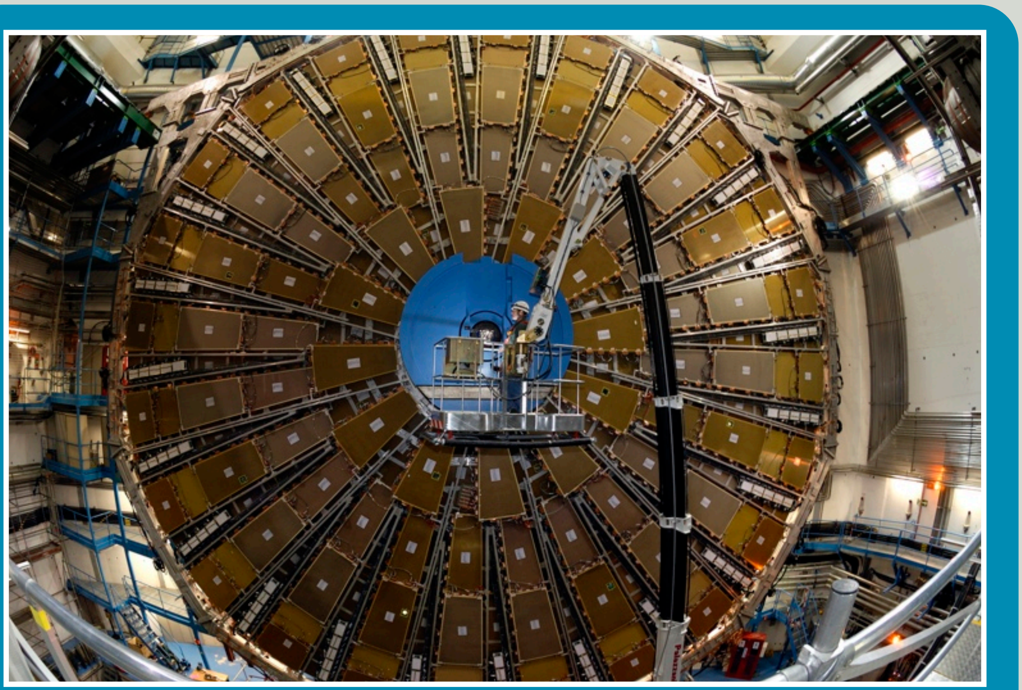
The world's largest and most powerful collider, the Large Hadron Collider (LHC) at CERN came back online on November 20, 2009. Three days later, the ATLAS collaboration saw the first collisions. Read on to get behind the scenes stories of the trial run, which ended on December 16, 2009 in a great success.



Muon detectors are the outer most subsystems of the ATLAS detector. They are composed of a barrel component and two endcap components. The endcap muon detectors are called 'Big Wheels' (BW).

The splash started at the ALICE detector (A Large Ion Collider Experiment) on the evening of November 20, 2009. It then hit Compact Muon Solenoid (CMS) detector and LHC beauty (LHCb) detector, with an hour-long intermission for magnetic quench in between. At half past eight p.m. lastly arrived at the ATLAS detector (A Troidal LHC Apparatus). Every event display responded with the expected set of colorful dots and curves showing that all online detector components were diligently at work.

LHCb, CMS, ALICE, and ATLAS are four experiments at the Large Hadron Collider (LHC) at the European Organization for Nuclear Research (CERN). The LHC is the world's largest collider, and only recently came back online after over a year of repair



A big wheel during integration. 3,600 thin gap chambers (TGCs) cover each BW. There are six small and large BWs total (3 BWs on each side of the ATLAS detector).

work. The LHC is now the most powerful particle accelerator in the world, having produced proton-proton collisions at an energy of 2.36 TeV during the trial run. The 2010 run will start at an energy of 7 TeV.

A splash occurs when a beam of protons hits a collimator, an accelerator component located 140 meters upstream of each detector to protect the accelerator and detectors from off-orbit particles by eliminating them. Initially, the collimators at the experimental sites are closed so that the beam would hit the collimators and create splashes of particles, which can be detected by each detector subsystem.

ATLAS is a collaboration of around 2,900 scientists from 172 institutions in 37 nations. On this night, hundreds of the collaborators had gathered in the Control Room to ensure the detector's operation in the real experiment. Among them was the muon trigger team, which is composed of international groups from CERN, China, Italy, Israel, Japan, and Russia.

The two-component—a barrel and two endcaps called big wheels (BWs)—muon trigger system is the outermost subsystem of the ATLAS detector. It is designed to catch high-momentum muons that penetrate through inner detector components.

A 'trigger' refers to a hardware or software system that picks out interesting events in very short period of time to reduce the frequency of event recording to a technically feasible level. When a collision takes place at the collision point, the detector subsystems are showered by as many as 40 million beam crossing per second. However, most of the resulting events are not interesting for the collaborators in terms of physics.

So they have developed as many as three levels of trigger to select out only a few hundred interesting events per second. The level 1 trigger is a hardware-based system which reduces the 40 million events to around 100 thousand events within a few microseconds. The level 2 trigger and the event filter are software-based systems that reduce 100 thousand to several thousands and then to a few hundred, respectively.

Close call at the TGC

For Dr. Masaya Ishino, the first successful splashes with working muon triggers meant a huge relief. Ishino, a scientist from KEK, is the muon level 1 trigger leader for the ATLAS big wheel (BW) muon team. The problem that started forty-eight hours before this point was critical considering the decade-long preparation efforts. "If the problem was unfixed, we might have had to keep the entire Thin Gap Chamber (TGC) system off for quite a while," recalls Ishino.

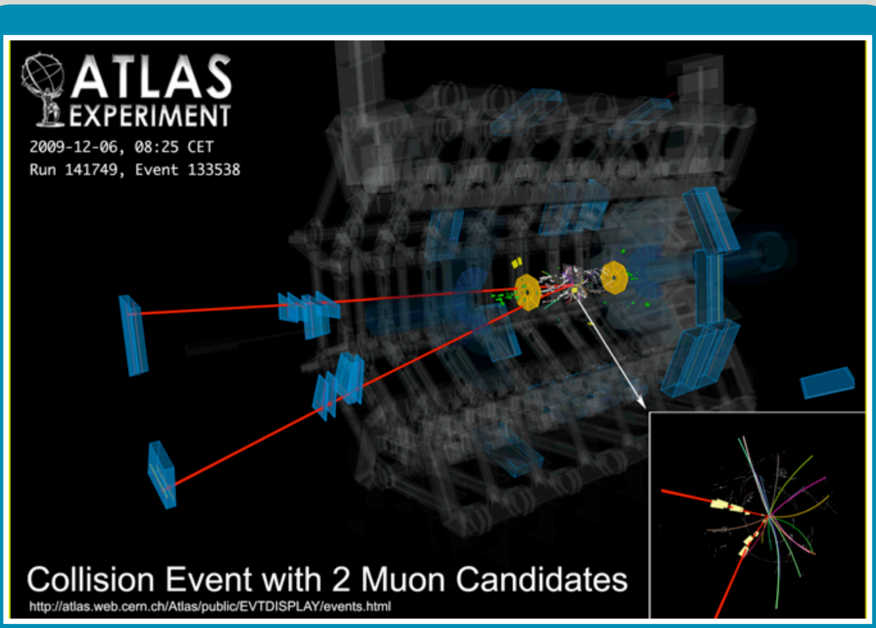
TGCs are trigger chambers deployed to the BW components of the muon trigger system. Turning off the TGCs means to disabling the BWs of 25 meter in diameter on the either end of the ATLAS detector.

The problem occurred quite unexpectedly. "What had been working perfectly normally prior to this point suddenly decided not to work," says Ishino. Just two days before the startup, a shift crew tried to configure programmable ASIC chips called FPGA (Field Programmable Gate Array) on custom made logic boards for the TGC during his routine work, but the operation unexpectedly failed. The team had not encountered this problem in the entire year-long period of detector testing with cosmic rays.

There are 72 logic boards in total on the BWs and each has two FPGAs. The team investigated the cause for an entire day without having any clues. Those chips had been working, and nothing had been changed on TGC side. Meetings were gathered, and Ishino continued searching for the answer, encouraging his team members, and reporting to the ATLAS collaborators at frequent intervals.

During his investigation, Dr. Takashi Matsushita of Kobe University, in charge of the online code, realized that one time in hundred, the upload command succeeded. The first splash was approaching, and the team could use a stopgap measure: to write a script that repeats the configuration command over and over until the command was successful.

Matsushita did this, and in matter of a few hours, all 144 FPGAs were up and running



The image shows a 900-GeV proton-proton collision event producing two muon candidates. They are detected by TGCs.

again. This was early in the morning, just 12 hours before the LHC's big start. "The beginning at low energy with low luminosity did not have much significance in terms of new physics," says Ishino. "Nevertheless, missing the start could be damaging because no one knows when significant events will come out."

After further investigation, Matsushita soon identified the problem. Buried in old coding practice, it was a minor hitch long unnoticed because all had been functioning well up to that moment. "Since it was too risky to stop what was functioning in the middle of the run to test the idea, we kept it as it was during the entire run," says Ishino. Matsushita made the change and confirmed that the problem was fixed as soon as the run ended.

Swift decision making

When the first splash hit ATLAS, the detector system appeared to be well functioning. However, as the next few splashes hit Ishino could see that something was odd. Many others in the Control Room also had an odd feeling as they leaned intently forward to decipher the event monitors.

Two types of trigger in ATLAS were prepared for beam splash event recording: two scintillation triggers and a calorimeter trigger. Scintillation triggers tell if any events occurred at the collision point, while Calorimeter trigger tells particle energy. However, during the splashes, it seemed as though all events were identified only by the scintillation triggers. There seemed to be no events triggered by the calorimeter trigger. Ishino hurried to the run coordinator, who immediately gathered the leaders of each group.

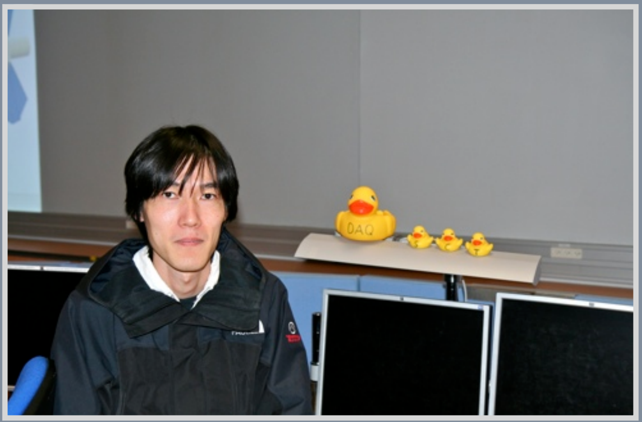
"The problem was quickly identified. The scintillation triggers were giving out trigger signals about 50 nanoseconds too fast," says Ishino. Within twenty minutes, the team decided to run without the scintillation triggers, and the change was swiftly carried out. "From that point, everything was stable, better than we expected." The rest of the night brought around 60 more splashes. The scintillation triggers were soon brought back on with correct trigger timing.

On November 23, the ATLAS collaboration saw the first collision at 900 GeV. From then on, the LHC increased the beam energy up to 2.36 TeV. During the entire run, the ATLAS system ran steadily. "So far, the scintillation trigger timing has been the only system change we had to make," says Ishino.

The level 2 trigger

As this little drama unfolded in the Control Room, other groups of researchers were carefully checking if their systems were behaving according to their designs. The level 1 trigger is the first trigger that signals hit, but the higher level triggers are just as important. These are where physicists create software filters to identify candidate events depending on the physics of interest.

Dr. Kunihiro Nagano of KEK works on the muon trigger level 2.



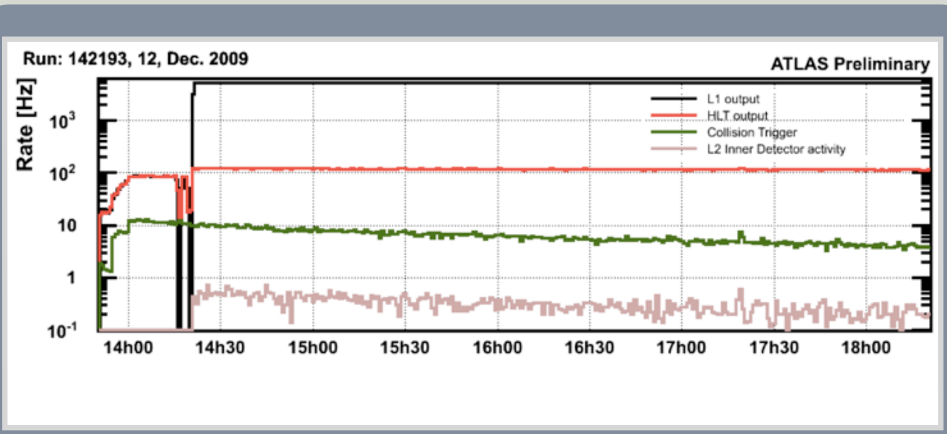
Minoru Hirose, a PhD student from Osaka University, works on one of the inner detector components, the semiconductor tracker (SCT), with its DAQ ducks.

For example, to look for Higgs at ATLAS, physicists are interested in the muons that result from the decay of Higgs particles. These muons are expected to have high energy, and so they are less affected by magnetic fields, and tend to travel in straighter paths. To pick out these rare events from the tens of millions of events, the muon level 1 triggers first make a rough estimate of the curvature of the muon trajectories. The triggers retain the position and estimated momentum of muons travelling in straighter paths, and pass the information onto level 2 trigger. Upon receiving it, the level 2 trigger employs the software filters physicists have prepared to provide more precise value for the muon momentum.

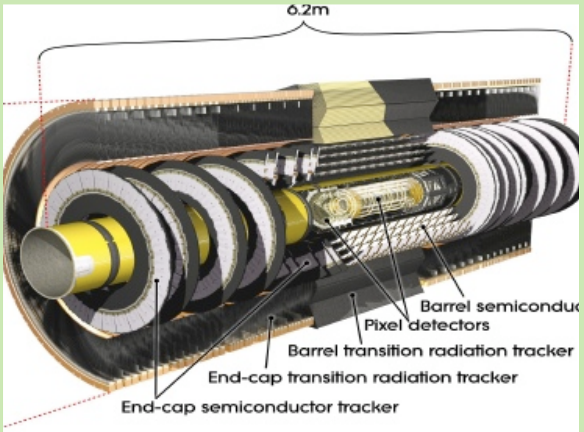
"During the trial run, we did not throw away any events at the level 2 muon triggers because we've so far collected only small amount of muon candidates," says Dr. Kunihiro Nagano of KEK. Nagano has been working on the muon level 2 trigger since 2006. "However, we did have various things we could do with the data collected with the level 1 trigger." Immediately after the collision started, the team experimentally applied their trigger to each event, testing trigger behaviors. They quickly found that their system functioned well. As the result, the high level trigger could be brought online just two days after the first collision.

"The level 2 trigger does two things: calculation and event selection," explains Nagano. "Algorithms first calculate the particle properties like energy and momentum. Then based on those numbers, the filter menus make trigger decisions."

Developing new tools to probe unexplored



The purpose of triggers is to reduce the number of events which will be stored. Event rates (Black) after level 1 trigger, (Red) after level 2 and event filter, (Green) of proton-proton collision for calibration, (Brown) of level 2 trigger activity. At around 14:20 all detector subsystem and high level triggers were brought online, and started event



The inner detector has three components: the pixel detector, the semiconductor tracker (SCT), and the transition radiation tracker.

regions of physics means a continual weighing of advantages versus risks. The level 2 trigger is no exception. The challenge, Nagano says, was to decide where to draw boundaries. They could analyze the data in any way they wished, but with the constraint that the level 2 trigger cannot take more than 10 milliseconds on average.

The level 2 team had worked long and hard to optimize setups for the speedy calculation, and to refine the filter conditions, using simulated events. They had worked to find the optimal values for fit combinations, the mesh size for the magnetic field information, and so on. Now that they have the actual data to analyze, the team can work out details of parameters and cuts to validate their trigger algorithms. For the filters, they expect them to soon become more complicated as the number of events increase with increasing energy and luminosity in the future runs.

Semiconductor Tracker

As well as the muon big wheels, the ATLAS Japan members have worked on various other subsystems. Among them is a PhD student at Osaka University, Minoru Hirose, who is working on the offline detector monitoring system, the Semiconductor Tracker (SCT). Where the muon detector is the outermost part of the ATLAS system, the SCT is one of the innermost detectors.

The ATLAS collaborators are expected to reconstruct received events within 48 hours time. However, the inner detector is vulnerable to strong radiation that is damaging to the silicon detector. The damage can cause wrong signals. The responsibility of the event monitoring team is to give a recommendation to the data quality (DQ) team 24 hours before the reconstruction, as to whether they are good to proceed with the reconstruction; and if so, which signals are usable and which are suspect.

Hirose had been working on the offline monitoring to identify noisy strips and dead strips from the total of six million strips in the SCT. "It is relatively easy to identify noisy strips. You could simply look for strips that are giving out signals all the time," says Hirose. "Identifying dead ones that don't give out any signals is a little more challenging." However, by carefully examining the information produced by each strip, he had completed a successful offline monitoring system.

During the trial run, Hirose had repeated the monitoring cycle many times, checking for noisy or dead strips. Since there were only small amount of data, the DQ team reconstructed all data available. The team instead gave feedback to the data acquisition system (DAQ) configuration. "The ratio of noisy strips during the run was what we expected from our previous cosmic ray tests. Overall, the SCT remained as stable as any detector can be, and my shift was as smooth as it could get," says Hirose, "until my last night shift last year when the SCT refused to start up."

The SCT startup problem was the minor and only happening last year. It occurred when the team tried to change the operation mode from 'collision' to 'cosmic ray' to observe cosmic rays during the LHC downtime. "It turned out the problem was simply that the run type of the central DAQ was not correctly configured, but it still took us some hours to figure that out," says Hirose.

"Beyond expectations"

Other ATLAS teams are also rapidly acquainting themselves with the subsystems and the relations between them. "It is a very hard thing to get everything in this extremely complex and elaborate system done perfectly on the first attempt, although solutions may appear obvious in hindsight," says Ishino. As the example of the bit code uploading on the ASIC chips for the muon trigger level 1 would illustrate well, the collaborators are often required to know every inch of technologies they use.

During the two months before the startup, the collaborators had thoroughly outlined their plans for the first month of the run. "We also had experience from last year's run. Problems were identified speedily, and I could follow all decisions with satisfaction," says Ishino.

"The run went well beyond our expectations," says Nagano. "Originally, the muon high level triggers were expected to remain on standby for quite a while, even as long as the entire commissioning period. We actually brought them online a couple of days after the first collision." On the accelerator side, the beam pickup signal—a detector that reports the absolute point where beam went through the ATLAS detector—was turned on in the afternoon the next day to synchronize with the level 1 trigger. This was again days earlier than anyone had expected.

The complexity of the entire detector system and its initial success continue to surprise even the collaborators themselves. When asked about his most challenging experience, Ishino, who has worked on the ATLAS muon trigger system for nine full years, says it is the sheer scale of the system. "The system is roughly 1,000 times larger than anything I had worked with before. All components were well understood, but integrating them correctly and grasping the scale of it in my mind required careful planning and lots of time." Nagano adds: "I am impressed with the level of achievement. During one year of testing and planning, the system has become fully functional."

Making strides toward higher energy

The system will restart in February, aiming this time for an energy of 7 TeV. In the meantime, the teams are analyzing the data acquired during the 26-day trial run, and replacing a few bits of failed electronics. For the muon level 2 trigger team, the next run will be the moment of truth, as production of thousands of muons is expected.

"Once an event is lost in the trigger, it'll be lost forever," says Nagano. "This month is a good opportunity for us to recheck everything." On the SCT side, Hirose is now working to develop an interface to upload data on noisy and dead silicon strips, and other useful information to monitor SCT performance (hit efficiency, number of hits, etc) to the database.

Facing the dawn of a new era of physics, these physicists' dreams are materializing. They embrace the physics analysis waiting in the near future, but they have to first ensure the perfect commissioning this year. As Ishino says, "The machine will run for ten years. What we can do this year is to make the system as robust as possible."

Related Link:
ATLAS
ATLAS at KEK (Japanese)

Related Issue:
How ATLAS will look for Higgs particle

KEK-ATLAS collaborators getting ready for LHC restart

HIGH ENERGY ACCELERATOR
RESEARCH ORGANIZATION (KEK)

Address : 1-1 Oho, Tsukuba, Ibaraki
305-0801 JAPAN
Home : http://www.kek.jp/intra-e/feature/
Mail : misato@post.kek.jp