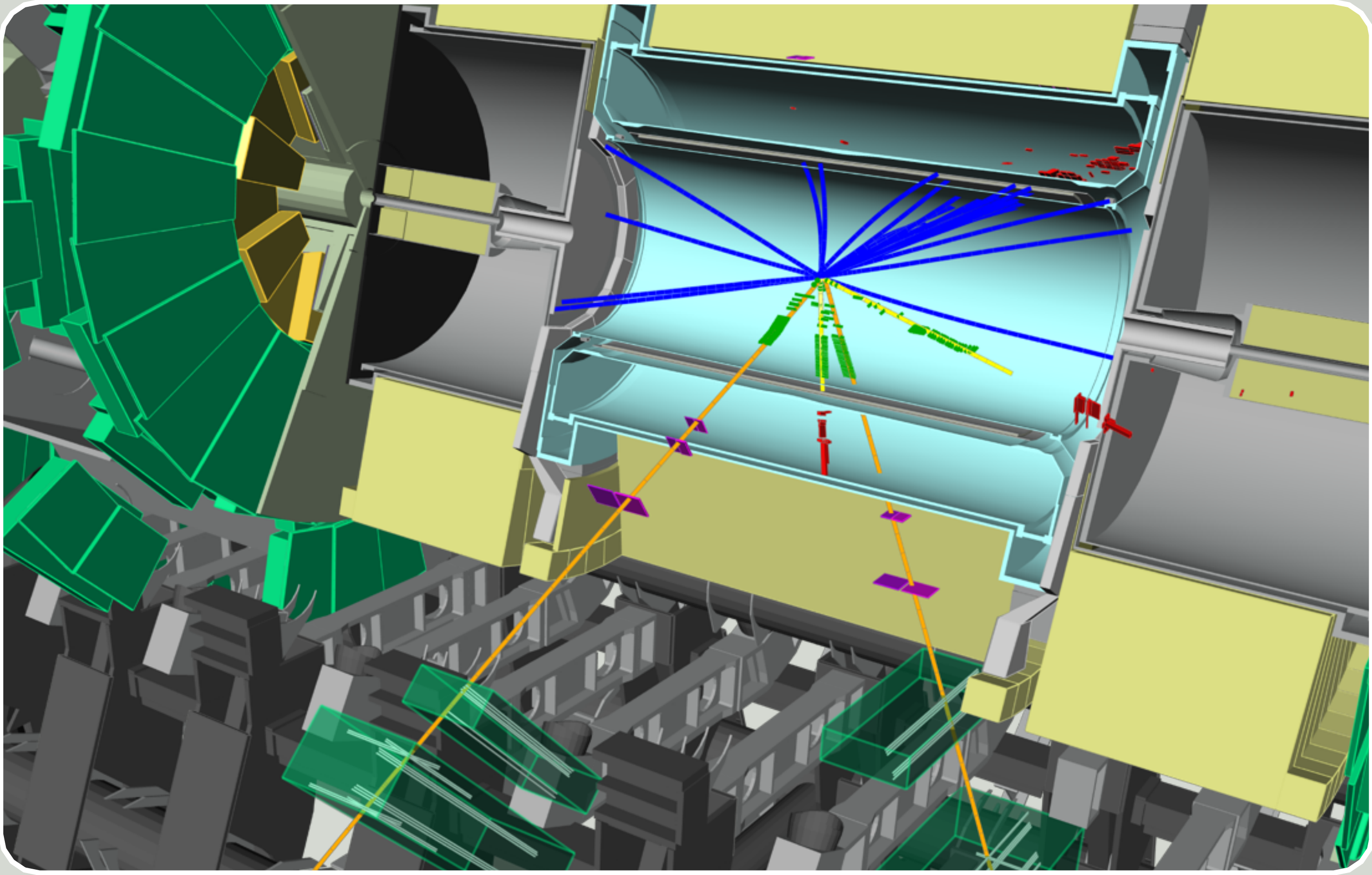


Simulated four-lepton decay of Higgs in the ATLAS detector. (http://www.atlas.ch/photos/events-simulated-higgs-boson.html)

How ATLAS will look for Higgs particle

[Large Hadron Collider, ATLAS, Higgs Particle]

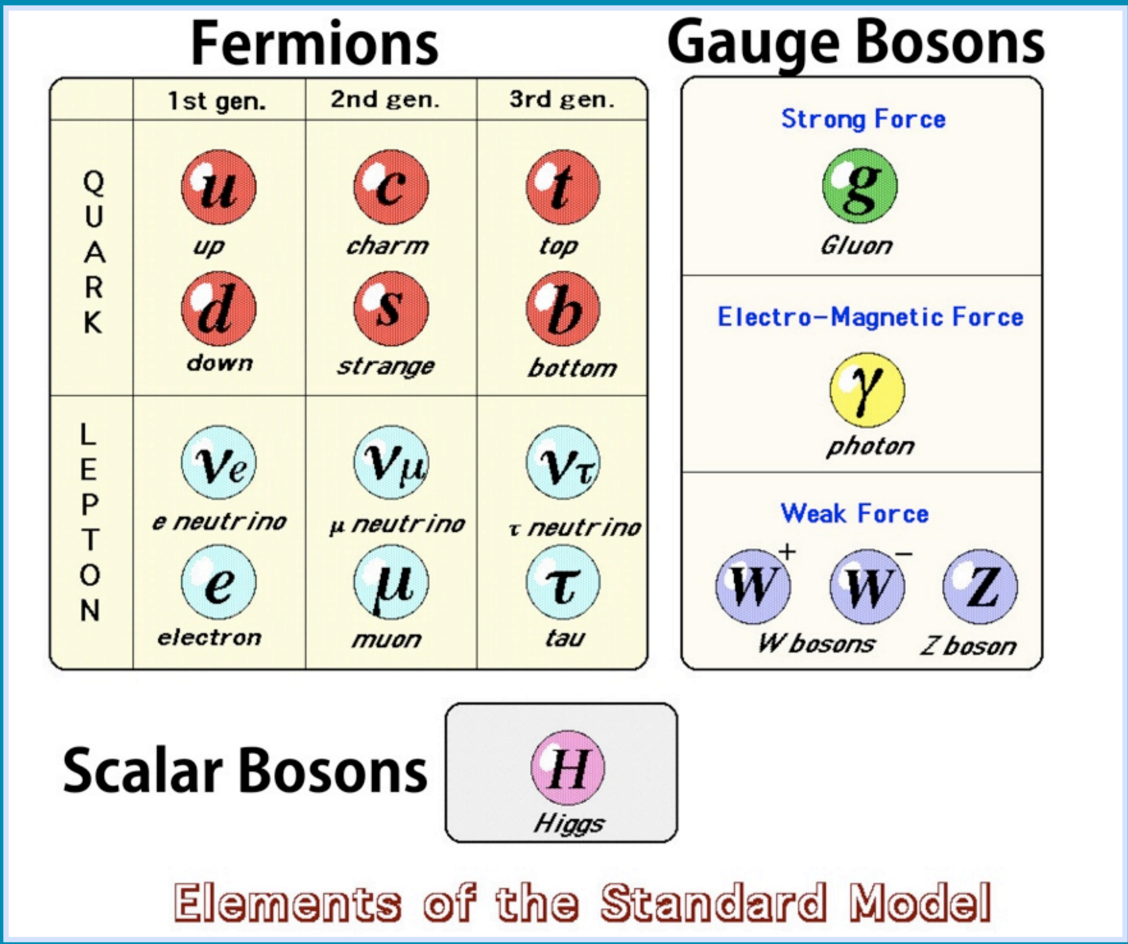
With the anticipated startup of CERN's Large Hadron Collider, the answers to many questions will soon be within reach. The LHC's ATLAS detector will search for the last piece of the Standard Model, the Higgs particle, and also begin the search for physics beyond the Standard Model. Today, we look at the Higgs search from aspects of photon and lepton identifications.

Einstein once said, "If at first the idea is not absurd, then there is no hope for it." The worldwide particle physics community is expecting a little more than just absurdities from CERN's Large Hadron Collider (LHC), the world's largest particle smasher.

"The TeV scale will be an entirely new energy region, one which we've never before entered," says Prof. Katsuo Tokushuku of KEK, Co-leader of the ATLAS Japan Group. "Anything can happen."

After a year-long period of intense repairing and rechecking, the LHC is ready to start again later this year. Initially, it will run at 3.5 TeV, half the full capacity. Even so, this should be enough to find the Higgs particle—the last missing piece of the Standard Model of particle physics.

There are two major LHC experiments that will look for the Higgs particle: ATLAS (A Toroidal LHC ApparatuS) and CMS (Compact Muon Solenoid). These two devices sit in the south end and north end (respectively) of the 27-kilometer LHC ring. Physicists believe that if



In the Standard Model, Higgs are the only missing piece yet to be seen in an accelerator. Higgs mass-generating mechanism gives rise to masses in gauge particles, quarks and leptons.

the Higgs particle exists, then these experiments should be able to find it.

"Engineering the experiment and actually identifying the Higgs particle, however, is an extremely difficult thing to carry out," says Dr. Junji Tojo of KEK. He and hundreds of other physicists will be looking for the Higgs at ATLAS. "It requires a very high collision rate, and is only reachable through fullest capability of ATLAS."

Higgs production and decay process

In the Standard Model, the Higgs particle gives mass to all the other particles through a process called the Higgs mechanism. There are two particle families constituting the Standard Model: fermions (matter particles) and bosons (gauge/scalar particles). Higgs particles and force carriers such as photons, gluons, and Z/W particles are bosons; while the particles that make up normal matter, such as leptons and quarks, are fermions.

The Higgs mechanism explains why the force carriers of the weak interaction, W and Z particles, have mass; while the force carrier for the electromagnetic interaction, photons, are massless. The elegance of this mass generating mechanism is that the exact same mechanism also explains why leptons and quarks have mass. The circumstantial evidence for the Higgs mechanism is strong, yet the actual Higgs particles have yet to be observed.

The search for the Higgs particle is an intricate work of tracing and reconstructing many possible production and decay mechanisms. Higgs are produced via collisions of protons and quickly decay into bosons and fermions. In a nutshell, physicists will mostly be looking at combinations of four Higgs production processes and five decay modes depending on the mass of the Higgs.

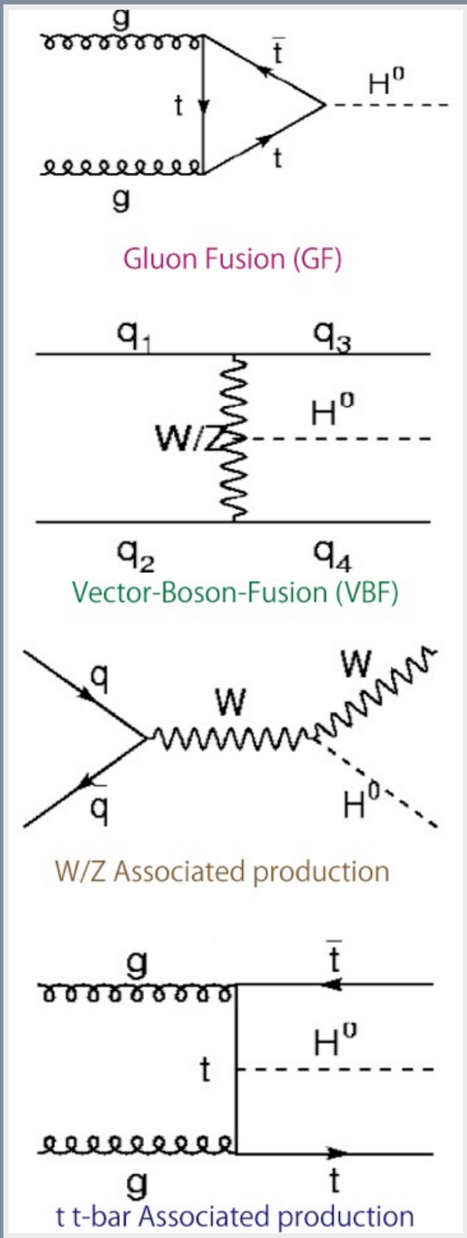
The four Higgs production processes are gluon fusion, vector boson fusion, W/Z associated production, and top quark associated production (see image). While the LHC is a proton collider, the particles that are actually interacting in the collision are the smaller particles—partons—that make up protons. Each proton consists of a large number of quarks and antiquarks, as well as gluons that bind the quarks together. When the partons interact in a collision, gluons can fuse to create a Higgs, or so do quarks to create W or Z bosons which can then fuse to produce Higgs.

From the previous Higgs searches conducted at CERN using the Large Electron Positron (LEP) Collider, Higgs with rest mass below 114 GeV have been ruled out. Exactly where Higgs would sit in the mass is what physicists are yet to find out. One reason that the exact mass of the Higgs particle is important is that it will affect the decay modes of the particle. If the mass is above 140GeV, particles will most likely decay into pairs of W or Z bosons. These W or Z bosons then decay into four leptons, for which ATLAS will be able to pick up very clean signals. If the mass is below 140 GeV, Higgs particles will most likely decay into pairs of bottom quarks and, with a tiny probability, into tau particles or photons. Physicists expect bunch of bottom quarks from other processes than the Higgs', and so the detection of low-mass Higgs will be challenging.

Complex collaboration

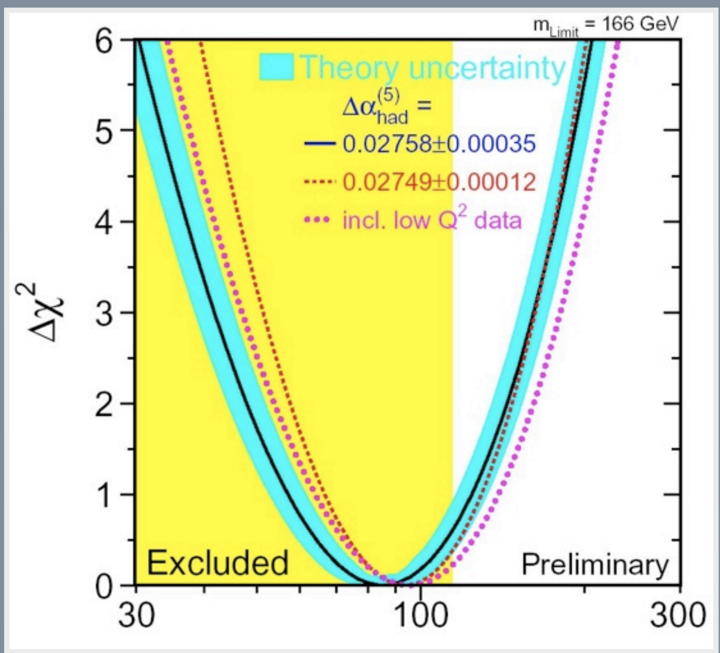
At ATLAS, thousands of physicists from 37 countries are working to understand the incredibly complex signals from this experiment. There will be billions of events every second hitting arrays of detector electronics surrounding the collision point, which they reconstruct and analyze depending on their interests. A few hundreds of 'menus' are prepared to define trigger levels for each physics process. Organizing hundreds of researchers working on dozens of questions is itself a difficult project.

There are two crucial aspects of the ATLAS experiment, and they are the identification of signals that particles from collisions will produce, and the physics that the collaborators are looking for. Depending on the type of events (tau, electron, photon, muon, jet, etc), how they reconstruct the particle paths,



←Four ways Higgs particles (H^0 in this figure) could be produced from the LHC's proton-proton head-on collisions. In reality, the constituent particles of protons—quarks and gluons—interact to create Higgs if it really exists.

↓From the direct search of Higgs particles by the Large Electron Positron (LEP), physicists know the mass of Higgs in the Standard Model must be at least 114 GeV.



energies and momentum differ. On the other hand, they have different analysis procedure for each different physics themes, such as Higgs particles, supersymmetric particles, top quarks, the Standard Model, exotic physics, and so on. It only makes sense that the ATLAS experiment collaboration has a structure of a matrix, having physics themes as rows and signal performance groups as columns. Each physics theme has two coordinators and signal performance group has two conveners, and each cell in the matrix has roughly twenty researchers.

Tau performance group

Dr. Soshi Tsuno of KEK is one of the two conveners for the tau performance group. He helps organize about a hundred researchers working on tau related projects at ATLAS. He is responsible for organizing meetings for the group, steering the team and presenting new themes to study for new young scientists.

Tsuno has worked on tau-related projects at ATLAS for quite some time. His search for Higgs particles targets the mass range below 140 GeV. In this region, the promising channel for the discovery is the vector boson fusion process. "The unique characteristic of this production process is that it creates two jets in the forward and backward direction, and no jet activity except two tau leptons in the central region," explains Tsuno. As the convener of this channel, he had previously worked with his team for three years to produce the first full detector simulation analysis in the ATLAS collaboration.

The challenge of the tau analysis is that the tau identification performance deteriorates very quickly with the increasing luminosity of the collision events. "The most efficient way to enhance the analysis is to improve the identification process of the real data," says Tsuno. With increasing number of collision events, the rate will exceed the maximum handling rate of the electronics at some point. So the team has developed a new trigger menu that can keep high performance without losing events.

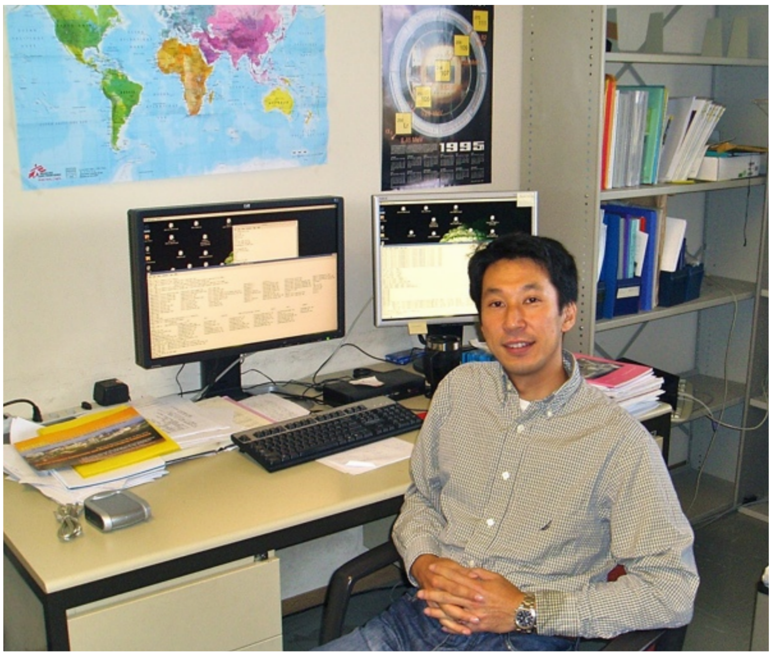
The team is now developing a procedure to assess data quality. "We have to review variables used in the tau reconstruction every time data comes up," says Tsuno. To make it quick for everyone in the group, the group is developing a tool to monitor such variables. "I myself touch the real data to look for missing pieces for smooth operation."

Two-gamma mode and four-lepton decay mode

Dr. Junji Tojo of KEK is a member of the ATLAS electron and photon identification group, and is one of around twenty people from that group working on the Higgs search. The team will be looking at two Higgs decay modes, the two-gamma mode and the four-lepton mode, where Higgs particles decay into two photons and four leptons (electrons or muons), respectively.

The key to observing this decay process is the reconstruction of electron and photon events from the data. The two components of ATLAS which detect these events are the inner tracker (the inner most detector that tracks particle paths) and the electromagnetic calorimeters (measures particle energies). So far Tojo has worked closely with the electron/photon working group to bring out the fullest performance by improving signals, reconstruction algorithm, and physics analysis.

To find the most effective solution to this type of problem, ATLAS team members use a Monte Carlo event generator to produce events akin to what is expected in the real life ATLAS experiment. The Monte Carlo generator is a crucial bit of any study conducted at ATLAS before the actual experiment starts. Tojo, in charge of the Monte Carlo sample generation in the electron/photon working group, has also been acting as a member of the production team that mass produces simulated samples for the entire physics working community at ATLAS.



A convener of tau performance group for ATLAS, Dr. Soshi Tsuno of KEK spends busy days steering the team of a hundred.

The ATLAS experiment provides an environment for truly international collaboration. “Our collaboration contrasts with the one in, say, telescopes. There, astronomers share one telescope by allotting a separate time and date for each group,” says Tokushuku. “Here, each one of us takes a working part of the entire search mission, and who knows, the discovery might come out from an individual from the smallest country. We all have an equal opportunity.”

After the collisions start, the teams will be shifting their subject of analysis from the Monte Carlo samples to real experimental data. In the next year, they will hopefully publish the first results in the new energy region, mainly on the Standard Model processes, and even beyond where they anticipate new discoveries at any moment. The search for the Higgs will start simultaneously. “Once the LHC starts, it will be a long project which will span ten to fifteen years,” says Tojo. “Our work will be hard but also fascinating, for we are probing new physics.”

The search for the Higgs is a complex business. As Tokushuku depicts it, “it is like singling out one individual from the entire population of the planet Earth.” The Higgs particle is expected to appear only once in every hundred billion collision events. Tojo says, “we need to ensure maximum performance if we are to find the Higgs. The final tuning using Monte Carlo samples and understanding the Standard Model processes are essential in doing that.”

Collaboration as one

According to Tojo, to have a successful experiment, "from detectors to physics," requires a transparent, efficient, and cooperative collaboration structure. To incorporate all resources and make sure transparency, Tojo works on the inner trackers, electron/photon reconstruction, Monte Carlo production, and Standard Model processes for Higgs. He also collaborates closely with KEK-ATLAS teams on detectors and event generator, as well as with international groups on inner trackers and calorimeters.

Dr. Junji Tojo in front of the Building 40 where ATLAS physics groups work to prepare for the LHC restart.

Related Link:
ATLAS
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Related Issue:
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Paper:
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