Interview

with Fabiola Gianotti

Interviewer: Hitoshi Murayama

An Intense Month toward Announcement of the Historic Discovery

Murayama: You announced the historic discovery of the Higgs boson at the CERN LHC last July 4th. I watched that over the web and that was really a moving moment. But how were you feeling just before the announcement—before the seminar?

Gianotti: I think the prevailing feelings were satisfaction, concentration and... exhaustion. We had been working night and day over the previous 4 to 6 weeks. We unblinded our analyses of the 2012 data at the beginning of June and the announcement was made at the beginning of July.

Murayama: July 4th, right?

Gianotti: Exactly. So, 4 weeks in total from our first look at the "signal region" with the 2012 data and the announcement. Do you remember that by the end of 2011 we had some little hints, 3σ?

Murayama: I was there at the December meeting (of the CERN SPC[1]).

Gianotti: We had a 3σ excess around 125-126 GeV. But, of course, excesses at the level of 3σ are mainly fluctuations, and so they come and go. The December 2011 hints were not at all conclusive nor convincing. After the winter shutdown, the accelerator resumed operation at the beginning of 2012 ramping up in energy to 8 TeV (in 2011 the centre-of-mass energy was 7 TeV). That additional TeV was one of the crucial elements for the discovery. Although data-taking started

Fabiola Gianotti received her Ph.D. from the University of Milan in 1989 and became CERN Staff Member in 1996. She has been working in the ATLAS experiment since the beginning of the project (early '90s) contributing to detector design and construction and to detailed studies of the physics potential. She served as ATLAS Spokesperson from 2009 to March 2013. In 2012 she was awarded the title of "Grande Ufficiale al merito della Repubblica" by the Italian President and the Special Fundamental Physics Prize of the Milner Foundation. In 2013 she was awarded the Enrico Fermi Prize of the Italian Physical Society and the Niels Bohr Institute Medal of Honor. She has honorary doctoral degrees from the University of Uppsala and the Ecole Polytechnique Fédérale de Lausanne (EPFL) and she is Honorary Professor in the School of Physics & Astronomy, the University of Edinburgh. She is member of the Italian Academy of Sciences ("Accademia Nazionale dei Lincei").

[1] The SPC (Scientific Policy Committee) is one of two subsidiary bodies to the CERN Council. Hitoshi Murayama has been a member of the CERN SPC since 2010.

in April 2012, following good scientific practice we did not look at the data in the region of mass not yet excluded by previous results (the so-called "signal region") until we had optimized our analyses on simulated events. On the other hand we studied the main background processes very carefully with data, and validated the simulation against data in the background regions. It was only at the beginning of June, after recording about 1 - 1.5 fb^{-1} (inverse femtobarn) of integrated luminosity, that we unblinded the signal region. We had two main analyses, Higgs $\rightarrow \gamma\gamma$ and Higgs $\rightarrow$ 4-leptons, and I remember that the first analysis to be unblinded was Higgs $\rightarrow \gamma\gamma$.

Murayama: The best places to look.

Gianotti: When we unblinded the Higgs $\rightarrow \gamma\gamma$ analysis, around June 10, I was at Fermilab to take part in a symposium celebrating the history of the Tevatron Collider. When I saw the results I made a jump on my chair. There was an excess around 125-126 GeV, i.e., at the same mass as the 3σ excess observed in the 2011 data, and with an independent data set.

I remember a particularly "crisp" exchange of mails with the ATLAS colleague that had sent me the results. I wrote him "Oh my God" and he replied "Indeed." That was it.

One-two weeks later we unblinded the Higgs $\rightarrow$ 4-leptons analysis. You know, for Higgs $\rightarrow$ 4-leptons we expected a handful of candidates. We had four events in the mass region around 125 GeV at the end of 2011. But, there were no new candidates in the 2012 data when we first unblinded. So, we were quite puzzled. Then nine candidates came all of a sudden at the end of June, a good example of statistical fluctuations with small numbers.

Murayama: Wow.

Gianotti: So in the end we had signals in both channels. It was a very very intense month. We were very excited, but focus and concentration prevailed. We have been working so hard to record

Hitoshi Murayama is Director of Kavli IPMU. He is also Professor at the University of California, Berkeley.

the highest-quality data, to improve the reconstruction efficiency and detector performance for electrons, muons, and photons, and to understand all possible issues of the analysis. Every detail was scrutinized; we made all sorts of checks in time for the seminar. When I entered the auditorium...there were so many people there—many of my ATLAS colleagues (and I knew that many more were following from other rooms or from Melbourne[2] where the ICHEP Conference was taking place), many summer students, and many of the scientists who have made the history of the LHC, like Lyn Evans and Giorgio Brianti. There were also many of the key people from the LHC infrastructure and operation teams, with Steve Myers, the head of the Accelerators. And there were previous CERN Directors General, including Chris Llewellyn-Smith, Luciano Maiani, and Robert Aymard, and CERN Management, obviously.

Murayama: So you were kind of tense and nervous?

[2] The 36th International Conference on High Energy Physics was held in Melbourne on July 4-11, 2012.

Gianotti: I was not really nervous...it was rather...an intense moment.

Murayama: Certainly you looked very relaxed and confident.

Gianotti: I was very motivated...beyond the exceptional result, I was so proud to show how well ATLAS, I mean the whole experiment, had been functioning in all its components (detector, data-taking, software, computing, analysis), thanks to the hard and competent work of hundreds of talented, dedicated people, among which were many young people. The contribution of every individual was crucial, and at the same time the ensemble worked as a perfectly synchronized orchestra.

Murayama: That is wonderful.

Gianotti: A great time...and the accomplishment of more than 20 years of efforts of thousands of people.

Told by CERN Director General to Postpone Travel to Melbourne

Murayama: When did you actually learn that CMS also had a comparable signal?

Gianotti: The CMS spokesperson, Joe Incandela, and I had been in touch all the time. We were not discussing the results in detail, but we knew more or less how things were progressing in the other experiment. We had agreed that we would not disclose any information about the other experiment to our Collaboration.

Murayama: How much information did you share at that stage?

Gianotti: We knew that the other experiment had an excess in the mass region around 125 GeV also in the 2012 data. We knew that the excess was growing with time and that it was there in the two main channels ($\gamma\gamma$ and 4-leptons). This was the kind of information we shared. We also kept the Director General (DG) informed. I think you were at CERN for the June SPC week?

Murayama: Yes, I was.

Gianotti: That week was really something...it was a Council week and I remember on June 23rd, at the Council dinner, the DG took Joe and me aside and told us, "Guys postpone your trip to Melbourne. The council wants a seminar here at CERN." We then discussed the date and agreed tentatively for July 4th.

Murayama: There was actually a discussion at the SPC at that time, that the announcement should be done on site, rather than at Melbourne.

Gianotti: Exactly. On the Friday before the seminar, June 29th, the DG called Joe and me in his office and said "Now I want to have the numbers of σ." We put the numbers on the table. It was 5.1 for ATLAS.

Murayama: CMS, I remember, had 4.9. I am sure that was really exciting.

Gianotti: I will never forget those days.

Murayama: So, until that moment Rolf (CERN Director General, Rolf-Dieter Heuer) didn't know how significant the signal was?

Gianotti: Actually on June 23rd, when it was decided to hold a seminar at CERN, he knew that by combining the results from both experiments the signal would be above 5σ, but he didn't know exactly how much we had individually.

Murayama: Interesting. When did he invite Peter Higgs, François Englert, and Tom

Kibble?

Gianotti: I don't know exactly, I think he invited them a few days before the seminar.

Murayama: I see. So he was really confident about that, wasn't he?

Gianotti: I think he was confident that it would be above 5σ by combining both experiments. So, enough to announce a discovery.

Murayama: Individually you had 5σ. That was amazing. I wasn't expecting that.

Gianotti: We had convincing signals in both channels. When at the beginning of June the 2012 ATLAS data were showing an excess in the Higgs → γγ channel, but we had no new Higgs → 4-lepton candidates, I told myself, "We will not go public if we don't see it in the two main decay channels." Then, gradually, with more data, the signal built up in both channels. I would like to stress that the accelerator really performed in a superb way that month of June, the best month of operation of all 3 years. Without that performance, we would have not discovered the Higgs boson so quickly.

Murayama: Fantastic, I am sure it was a really, really exciting moment.

Gianotti: We owed it to team work and team spirit. We worked all together, experiments and accelerator groups, in a very harmonized and efficient way.

Murayama: I was watching the announcement over the web from my home in Berkeley. That was after midnight, but I couldn't sleep at all. It was so exciting, and your last slide said 5σ...and I wept. I literally wept. It was so moving.

Gianotti: The excitement is also due to the mass of the new particle. Nature has been very kind to us because a Higgs boson of 125 GeV decays into many different final states (γγ, ZZ, WW, bb, ττ) and so we can study it in a variety of topologies both at the LHC and future accelerators. If it had been heavier, only WW and ZZ decay modes would have been experimentally accessible, thereby reducing dramatically the opportunities of measuring its properties.

Murayama: We are so lucky that we can actually study all of them.

All the ATLAS Members Worked in Full Synchronization

Gianotti: Another reason I was very proud on that 4th of July was our accomplishment as an experiment. ATLAS worked in a superb manner over the past years, and in particular in the weeks preceding the discovery and the announcement. The data included in the results shown by ATLAS and CMS on July 4th were recorded until June 18th. June 18th was a Monday, and on Sunday, June 24th, we already had the preliminary results based on the full data set that we would show on July 4th. It means that the data taken up to 6 p.m. on June 18th had been calibrated, processed, reconstructed, distributed all over the world, analyzed, and gone through the statistical combination of the various Higgs boson decay channels.

Murayama: That is so fast.

Gianotti: Amazing. So, on June 24th, I already had the complete results on my laptop...not final, there were still...

Murayama: Some refinement.

Gianotti: ...some refinements and cross-checks to be done, but actually they didn't change much. So, this really shows that all the people working at the various steps of the chain—and it's a very long chain from the detector to the final plots and numbers—had done their work in the best way, impressively fast, and fully synchronized with the others. Really fantastic. I was very much impressed.

Murayama: Then right after you finished the last slide there was a standing ovation, right?

Gianotti: That was a very touching moment...the awareness that the LHC, and by LHC I mean the experiments, the accelerator, the international collaborations, and CERN, had accomplished something great and memorable.

Murayama: There is a famous picture of you and Mr. Peter Higgs together and he is blessing you for this incredible achievement. That was probably the first time you met him?

Gianotti: It was. I congratulated him on his brilliant idea.

Murayama: He was right.

Gianotti: Yes he was right. Peter Higgs is a very modest,

nice person. I was really impressed by him, not only for his scientific stature but also for his human qualities. He congratulated ATLAS on the great achievement. I gave credit to him, and he gave credit to the experiments.

Murayama: That's fantastic.

Gianotti: An unforgettable moment.

Murayama: A word on François Englert?

Gianotti: I had met François Englert before. He has a completely different personality, very sparkling..."flamboyant" you would say in French.

Murayama: Then you moved to the press conference.

Returned to Business as Usual Right after the Press Conference

Gianotti: The press conference was very interesting with a lot of stimulating questions. There I had some presentiment, for the first time, of the impact our discovery would have on people's minds. We finished at 1 p.m. Then I went to the LHC Machine Committee meeting (LMC), which takes place every Wednesday afternoon. The LMC is a meeting where the accelerator experts—including the operation, and infrastructure teams—and representatives from the experiments get together to review achievements and problems of the previous week and to plan for the following week. That Wednesday, July 4th, was no exception, and I attended the LMC meeting as every Wednesday.

Murayama: Wow. Business as usual!

Gianotti: Business as usual—and that meeting was something special, with a kind of surreal atmosphere—no one mentioned the morning's events; no special celebration; we did not congratulate each other. Nothing. Business as usual, back to normal life.

Murayama: Really? That's amazing.

Gianotti: Steve Myers started the meeting as every Wednesday: minutes of previous meeting, action items, etc. The only allusion to the discovery was on the first slide of the status report given by Mike Lamont, the head of the LHC operation team. The title was "Report from the Higgs factory operation" instead of the usual "Report from the LHC operation." British humour.....That was it.

Murayama: That's a nice touch, though.

Gianotti: It was. At some point during the LMC meeting I realized that I had switched off my cell phone during the press conference and had forgotten to switch it on again. Immediately I received a call from Paola Catapano (from the CERN communication group) who asked: "Where are you hiding? The journalists are looking for you." I replied I was at the LMC meeting. She shouted at me "Are you craaaaazy? You are going to the LMC meeting the day of the Higgs discovery, when the press from all over the world is on site?" I replied, "Paola, we discovered a new particle, that's fantastic, but now let's move on."

Murayama: Back to business.

Gianotti: After the LMC I went home to prepare my luggage for the trip to Melbourne. I failed to forget that it was winter in the southern hemisphere...

Murayama: No champagne that day?

Gianotti: There was a little champagne party in building 40, but it was during the press conference.

Murayama: So you missed it.

Gianotti: I missed it. I was told that it was a nice moment, and an informal one. People had gathered together

spontaneously.

Murayama: Now that you have discovered the Higgs boson, and you stepped down as the spokesperson, what's next for you?

Gianotti: After stepping down as spokesperson, and completing some tails of my previous job, I have been contributing (as main editor) to the ATLAS article describing the measurements of the Higgs boson couplings. It was submitted for publication on 4th July 2013 (exactly one year after the announcement of the discovery!), together with the "twin" paper on the determination of the Higgs boson spin.

Murayama: They are beautiful papers.

Gianotti: The work on the Higgs boson paper was a lot of fun. I had the chance to work with many young people and to dig into the details of the analysis. By the way, Hitoshi, in several cases the experimental uncertainties on these measurements are becoming comparable to the theoretical uncertainties. This calls for some additional work from theorists...

Murayama: I know. The data are calling for lots of improvement in theory.

Gianotti: Now I am here in Japan for a completely different reason. I am involved in a review of the Japanese participation in the LHC upgrade—both the accelerator and ATLAS. Japan has made very strong contributions to the LHC, from construction of high-tech detector and accelerator components to physics analyses (including Higgs boson searches in the Higgs $\rightarrow \gamma\gamma$ channel). Giving lectures, mostly in the US, has been another intense activity over the past months. I like teaching very much, but I had to neglect it while I was Spokesperson.

Murayama: You are also involved in P5 in the US.

Gianotti: Yes, and this is another commitment requiring traveling and quite some work. As you know P5 (Particle Physics Program Prioritization Panel) is a committee set up by the US Department of Energy (DOE) to propose the roadmap for US high energy physics for the 10-20 years to come. It's a very interesting and stimulating panel, covering the full spectrum of topics and facilities in our discipline, including cosmic surveys, neutrino physics, underground experiments looking for dark matter, colliders, etc. This is making my life a bit busy at the moment, but I plan to ramp up my ATLAS activity again soon, to prepare for the second LHC run. Indeed, in 2015 the LHC energy will be raised by a factor larger than 1.5,[3] so that the potential for both discovering new physics and performing precise measurements of the known particles (including the new "entry," the Higgs boson) will improve significantly.

Murayama: Good, I am sure you will enjoy that.

Studied Humanities in High School and Piano in Parallel

Murayama: Now back a little bit to your own story. You actually majored in music right? You got a degree at the conservatory.

Gianotti: I got a 10-year piano degree, but in parallel I have also been studying humanities at high school, so Latin, ancient Greek, literature, history of art, philosophy... and very little math and physics.

One good thing of the

[3] The ongoing LHC upgrade is to increase the energy of each proton beam from 4 TeV to 6.5 TeV (center-of-mass energy from 8 TeV to 13 TeV). It is expected to be completed by early 2015.

Italian education system is that no matter what you study in high school, you have access to the full spectrum of disciplines at the University level. So even if you have studied humanities, you can move to science. This is very good, because at the beginning of high school, when you are 13 years old or so, you don't really know what you want to do in life. And the years between say 13 and 18 are crucial for kids to mature. So it's very important to have flexibility in the education system, and not to be forced to take final decisions about your professional life when you are not even a teenager.

Murayama: What made you do that switch?

Gianotti: Many reasons. First of all, I have always been a very curious kid, asking all kinds of questions. Why don't stars fall from their height? Why do they stick to the sky? At that time there was no Web, so I could not find information easily and quickly. I used to ask adults and often replies were unsatisfactory. So I wanted to find the answers myself, or at least contribute to finding them. That was one motivation.

Murayama: You wanted to know more.

Gianotti: Yes. Then, when I was 16 or 17, I read a beautiful biography of Marie Curie. I was stunned. I was particularly impressed by her "domestic" way of doing research. Her small and rudimental laboratory was a room in her house, close to the kitchen, and she could check the radioactive samples while she was preparing the soup for dinner. I found this simple and familiar way of doing science very attractive. Of course, what I ended up doing is completely different...I could not move ATLAS to my kitchen!

Murayama: And you can't have a kitchen right next to it.

Gianotti: Well, actually we do have a small kitchen at the ATLAS experimental site. But that's not what I meant. Another event that pushed me into physics occurred in my last year of high school, when our professor of physics talked about the photoelectric effect. Of course, we didn't have enough mathematical grounds to understand quantum mechanics and the details of the underlying physics. But I was very much impressed by the explanation provided by Einstein of this phenomenon: he understood that electrons are emitted from a metal only when the sample is hit by light of the right wavelength (hence photons with quantized energy equal or larger than the electrons' binding energy in the material). I found this explanation so obvious, so compelling, so elegant, and so simple...that I said to myself, "Physics is what I want to do!"

Murayama: You were not puzzled by this wave-particle duality?

Gianotti: Not much at that time because I was not really exposed to it. I am more puzzled now...but we know that quantum mechanics can be very little intuitive.

Murayama: Anyways, that really sank into your mind.

Gianotti: The three elements I mentioned were very instrumental to bring me into physics. I liked philosophy as well, because it also tries to identify and address the big questions. But, I had the impression that physics is more direct, as it really strives to answer the questions one by one through experiments, observations, and measurements. So I decided to study physics. I was of course not sure that this would be my...

Murayama: Lifetime passion?

Gianotti: Yes. But the hesitation didn't last long...as soon as I started to study mathematics, mechanics, thermodynamics, and later on quantum mechanics and quantum field theory, I understood that was really my way.

What Next for Particle Physics?

Murayama: Great! Now looking further into the future, what's next for particle physics?

Gianotti: It's really amazing that this question comes from you. You are a theoretical physicist, so you should guide us experimentalists! Seriously, I think there are three main results from the first LHC run. First, we have consolidated the Standard Model with a huge amount of measurements in a new energy regime. It works beautifully. Second, we have completed the Standard Model with the discovery of a Higgs boson. One of the

fingerprints of a Higgs boson is that it is a scalar particle, i.e., it has zero spin. All our observations are in very good agreement with this hypothesis. We don't know yet if the new particle is THE Higgs boson of the minimal Standard Model or an object belonging to a more complex theory. It looks very much like the Standard Model Higgs boson, but the present measurements by ATLAS and CMS are affected by large uncertainties (at the level of typically 20%). Anyway, all particles predicted by the Standard Model have now been observed experimentally.

The third important result from the first LHC run is that we have no evidence so far for physics beyond the Standard Model. It doesn't mean that new physics does not exist. It may well be accessible at the LHC in 2015 or later, when running at 13 TeV. It may even be that new physics is in our present data and we haven't find it yet because it manifests itself in a less obvious way than expected, hence requiring more work and more time to be identified.

Murayama: Like a degenerate spectrum.

Gianotti: Exactly. Or very exotic signatures. Obviously, we have already scrutinized our data extensively and looked at as many topologies as we could. And the most obvious scenarios have been ruled out. But we cannot completely exclude that new physics is hiding in some difficult corners of the parameter space. For sure operation at 13 TeV will be extremely beneficial for searches (and not only for searches).

What can we expect to see? Well, we know that the Standard Model is not able to address in a satisfactory way all questions in fundamental physics. We don't know the composition of dark matter and what is the origin of the matter-antimatter asymmetry in the universe. Dark energy is an even bigger question, for which we have no clue. Is the accelerated expansion of the universe due to a modification of gravity or to an unknown form of energy? Actually the Higgs field exacerbates the problem.

Murayama: It's part of dark energy.

Gianotti: Moreover, we are not able to formulate quantum theory of gravity, and therefore to reconcile gravity with the three other forces. For these and other reasons, we know the Standard Model is not a complete theory and there must be new physics. The question is: "Where is this new physics?" Is it at an energy scale accessible to the LHC or to a future higher energy collider? Or is this scale far too high to be explored by any conceivable accelerator built by mankind?

In any case, it's very nice that we now have a new particle, a Higgs boson, which requires detailed studies and measurements. It might be a door into new physics, as the latter could modify some properties of this particle (production and decays modes, strength of the interactions with the other particles, etc.). For instance, the LHC can reach an ultimate precision on the measurement of the Higgs boson couplings at the level of 2-5% (based on some assumptions). This would allow some scenarios of new physics to be excluded. To do better, a precision of a few permil is needed, which can only be provided by an e^+e^- accelerator, like the ILC. Also, only an e^+e^- collider allows measurements of the absolute Higgs couplings to be made in a model-independent way.

Another crucial study in the years to come, an essential "closure test" of the Standard Model, is related to WW scattering at high mass...

Murayama: Demonstrating unitarity of scattering.

Gianotti: Does the Higgs boson fix the bad behavior of the Standard Model for large masses of the WW system? Or is there a new dynamics coming into play? This is a very interesting territory to study, which again calls for full LHC energy because...

Murayama: The cross section is so low.

Gianotti: Right. So, interesting times ahead.

Murayama: Let's hope for the best.

Gianotti: Yes, let's hope for the best, *Kanpai* to new physics!

Murayama: That is right, thank you Fabiola.

Gianotti: Many thanks to you, Hitoshi.