CERN Bulletin

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Special Higgs Edition - 4 July 2012

CERN Press Release: CERN experiments observe particle consistent with long-sought Higgs boson

CERN physicists await the start of the Higgs seminar.

Geneva, 4 July 2012. At a seminar held at CERN today as a curtain raiser to the year's major particle physics conference, ICHEP2012 in Melbourne, the ATLAS and CMS experiments presented their latest preliminary results in the search for the long sought Higgs particle. Both experiments observe a new particle in the mass region around 125-126 GeV.

"We observe in our data clear signs of a new particle, at the level of 5 sigma, in the mass region around 126 GeV. The outstanding performance of the LHC and ATLAS and the huge efforts of many people have brought us to this exciting stage," said ATLAS experiment spokesperson Fabiola Gianotti, "but a little more time is needed to prepare these results for publication."

"The results are preliminary but the 5 sigma signal at around 125 GeV we're seeing is dramatic. This is indeed a new particle. We know it must be a boson and it's the heaviest boson ever found," said CMS experiment spokesperson Joe Incandela. "The implications are very significant and it is precisely for this reason that we must be extremely diligent in all of our studies and cross-checks."

"It's hard not to get excited by these results," said CERN Research Director Sergio

(Continued on page 2)

A word from the DG

A landmark day (not only) in CERN's history

Today, the ATLAS and CMS experiments announced that they had observed a new particle. We don't yet know what that particle is, but it is consistent with the long-sought Higgs boson, and work will soon be underway to positively identify it. Days like this do not come around very often, and it's a cause for celebration.

Today we are privileged to be joined by many important guests, including some of the early authors of electroweak symmetry breaking: Peter Higgs, François Englert, Gerry Guralnik and Carl Hagen. We also have around 100 representatives of the media here to cover the event,

(Continued on page 3)

In this issue

News

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A word from the DG

(Continued from page 1)

A landmark day (not only) in CERN's history

and finally lay to rest the speculation and anticipation that has been building over the last few weeks.

Now that we have the discovery, we need to thoroughly investigate all the properties of this new particle to establish whether it is the Higgs boson that completes the Standard Model, or something more exotic. The Standard Model is a beautiful theory that accounts for the fundamental particles that make up the visible universe, and all their interactions with the exception of gravity. We know, however, that the visible universe is only about 4% of the total. A more exotic version of the Higgs particle could be a bridge to understanding the 96% of the universe that remains obscure.

The fact that we have reached this point so quickly has come as a surprise even to me, and it's thanks to the incredible work of everyone involved in the LHC programme. Your efforts have delivered the data, processed and analysed them with efficiency unthinkable just one generation of experiments ago. The LHC and all the infrastructure that supports it continue to perform beyond all expectations. Analyses are refined at a breathtaking rate: it's been fascinating to see how the signal at 125-126 GeV has evolved over the last 12 months from a whisper to a shout. And the Worldwide LHC Computing Grid continues to take all this comfortably in its stride.

I'd like to thank all of you for today. I am no longer directly involved in the research, but thanks to your efforts, I have a most privileged position to see science history in the making.

Rolf Heuer

CERN Press Release: CERN experiments observe particle consistent with long-sought Higgs boson

(Continued from page 1)

Bertolucci. " We stated last year that in 2012 we would either find a new Higgs-like particle or exclude the existence of the Standard Model Higgs. With all the necessary caution, it looks to me that we are at a branching point: the observation of this new particle indicates the path for the future towards a more detailed understanding of what we're seeing in the data."

The results presented today are labelled preliminary. They are based on data collected in 2011 and 2012, with the 2012 data still under analysis. Publication of the analyses shown today is expected around the end of July. A more complete picture of today's observations will emerge later this year after the LHC provides the experiments with more data.

The next step will be to determine the precise nature of the particle and its significance for our understanding of the universe. Are its properties as expected for the long-sought Higgs boson, the final missing ingredient in the Standard Model of particle physics? Or is it something more exotic? The Standard Model describes the fundamental particles from which we, and every visible thing in the universe, are made, and the forces acting between them. All the matter that we can see, however, appears to be no more than about 4% of the total. A more exotic version of the Higgs particle could be a bridge to understanding the 96% of the universe that remains obscure.

"We have reached a milestone in our understanding of nature," said CERN Director General Rolf Heuer. "The discovery of a particle consistent with the Higgs boson opens the way to more detailed studies, requiring larger statistics, which will pin down the new particle's properties, and is likely to shed light on other mysteries of our universe."

Positive identification of the new particle's characteristics will take considerable time and data. But whatever form the Higgs particle takes, our knowledge of the fundamental structure of matter is about to take a major step forward.

What does the news tell us?

Is today's news an answer or the first of a new set of questions about Nature?

With strong evidence of a new particle with a mass around 125-126 GeV, will our interpretation of the Universe change? In an interview with the Bulletin, CERN theorist Ignatios Antoniadis explains.

Ignatios Antoniadis:
Based on the current data, this new particle looks like the long awaited Higgs boson. In this respect, the result is an important answer. However, the properties of the new particle have not been fully studied yet and therefore a final label will only come after further investigations.

The next step will be looking into the new particle's decay rates. Together with mass, decay rates characterize particles. If we find that this new particle decays in the ways expected and with the rates expected from the Standard Model, we will be able to really identify it with the particle responsible for the electroweak symmetry breaking (*).

Otherwise?

Antoniadis: Otherwise we will have to understand whether the Standard Model needs small adjustments to include the existence of the new particle or if new physics processes need to be looked for in order to explain its nature.

Let's stay with the Standard Model. What is the new particle telling us?

Antoniadis: If the new particle is confirmed to be a Standard Model Higgs boson, then we must observe that it is relatively light, perhaps lighter that what a large part of the community was expecting up until just a few months ago.

The Higgs field associated with the boson would still permeate the Universe but it may need to be partly reinterpreted. Given the low mass of the boson, the potential that describes the field could for instance present two minima instead of just one. The universe is currently set in one of the two minima but quantum mechanics could allow for a transition to the second minimum. This, in my opinion, might signal the existence of some new physics that would compensate for this instability (**).

Has the current result already ruled out some previously possible descriptions of the Universe?

Antoniadis: Yes. Because of its low mass, such a Higgs boson would allow us to rule out theories known as "Technicolor" and some of the theoretical models used in Supersymmetry. However, other supersymmetric or not scenarios could still apply, as well as extra-dimensional theories.

Let's now leave the Standard Model for a moment. What is the new particle telling us?

Antoniadis: The new particle could have properties that are not those predicted by our current theories. In this case, in order to unveil the theoretical scenarios to fit the new description of the Universe we would need to know exactly what its decay modes and rates are. The good news for theorists is that experimentalists may be able to provide us with this information over the next a few months. Our (and your) curiosity will soon be satisfied!

This result opens a new era of physics with new possible discoveries likely to come.

Antonella Del Rosso

For articles by Peter Higgs, Robert Brout, François Englert, John Ellis, Giovanni Ridolfi, Fabio Zwirner, Ignatios Antoniadis and other scientists, please visit:

http://www.sciencedirect.com/science/journal/16310705/8/9

(*) Please read FAQ n. 2.

(**) For a recent study of the possible instability of the Higgs potential, see: http://arXiv.org/pdf/1205.6497.pdf

The Main CERN Auditorium this morning, Wednesday 4 July.

It’s no miracle…

“The LHC has been a huge effort over more than 15 years. It’s not always been easy but today it is performing so spectacularly well that the people who built it should be very proud.” Lyn Evans, head of the LHC project since its beginning and until its commissioning in 2011, shares his recollections with us on the day of the long-awaited discovery.

While you were building the LHC, were you expecting it to perform so well?

Lyn Evans: I knew that the machine had been beautifully designed and was being built extremely well – but I could not have expected that such wonderful results could be achieved in so little time.

What are the reasons for such a good performance?

Evans: The LHC was designed to really push the limits; I think that the machine has got more than 30 years of accumulated experience in its design. The fact is the LHC has already exceeded the design luminosity at the energy it’s at now. At 4 TeV it should be at 5 x10^{33} – and it is quite a bit higher.

So, the LHC has exceeded expectations – and the reason is because of the quality of the design. There are no miracles; this is why the machine has been working so incredibly well. The quality of the magnets and the stability of the power supplies are fantastic – much better than has ever been achieved before. And the quality of the instrumentation is essential - the LHC is instrumented like nothing ever before. Even during the financial crisis in 2001, when there was a lot of pressure to reduce cost, we never gave in a single centime for instrumentation.

A financial crisis that was about to jeopardize the whole project…

Evans: When the project started we said that we would review the cost at mid-term and adjust accordingly. When we did that, we found it 18% higher than the 1993 cost projection. This, on such a technically advanced project that had never been built before, could be regarded as a relatively small variation. However, it did indeed cause a lot of reactions.

What are the challenges that you had to face?

Evans:The challenges changed over time. In the first few years, they were essentially political. The challenge was with getting approvals, and getting some big countries on board (the non-Member States). Then, of course, the challenge became development and design. When we got the approval from the CERN Council, we didn’t have a single magnet that worked. After that, the challenge became massive manufacturing, where we had lots of problems. You will certainly remember, for instance, issues with the cryogenic line.

Of course the real kick in the teeth was the last one, when we were taking the very last sector up to high current and a joint failed. It caused a lot of pain, although we did have spare parts, which was the most important thing.

So, all the way along the challenges have been different. I had to face 5 bankruptcy cases – and, I can tell you, that’s not funny. When you’re in the middle of production and suddenly the firm goes bust, how do you react? So – let’s say – there was a whole spectrum of things that had to be dealt with.

And we all remember the commissioning – the day of the first beam in the LHC – when the pressure was absolutely immense. But in one hour we had the machine beam circulating, and I’d never seen anything like it before. Normally, this would have taken 2 weeks!

You were recently appointed Linear Collider Director by the International Committee for Future Accelerators. Cutting-edge accelerators are still inspiring you!

Evans: Well, I came to CERN as a laser physicist, not as a HEP physicist. I first came to CERN in October 1969 for 3 months because they were working with high power lasers. And then I got a fellowship and – just by chance – became involved in building an experimental linear accelerator. That was my first taste of accelerator physics. It was a 3 MeV accelerator which was basically the prototype for LINAC2 and LINAC4.

In 1971, I started working on building the SPS. And, after the idea of stochastic cooling had been proved in the late 70s, I worked on converting the SPS into a proton-proton collider, all the way through to the Nobel Prize in 1984. I also worked for a while at Fermilab’s Tevatron, so I learned about superconducting machines there. I had a relatively short spell – 4 years, from 1990 to 1993 – as division leader of the SPS LEP division. And I was responsible for running and developing LEP, after which I took on developing the LHC. In 1996 we got full approval. I was LHC project leader the whole time, until the commissioning of the machine. So, the LHC has been a big part of my life.

Lyn Evans, former head of the LHC project, in the LHC tunnel, 2008.

I am lucky to have been involved in all the big projects here at CERN – and I guess that’s the way you learn. Of course, you can’t help but be motivated when you are working in such a fantastic place.

What do you think is the future of the LHC after the Higgs?

Evans: I think that it has a long future. There is nothing like it and there will be nothing like it for a very long time. Even if a linear collider is approved in the next 3 or 4 years, it is going to take around 15 years to build. Furthermore, the LHC is now the only instrument that can access very high energies. I think the LHC is going to be developed to its full capability – both the machine and its detectors will be improved over the coming years. The detectors are already a marvel and the way that they perform is incredible.

I hope that there will be many discoveries coming up for the LHC – the Higgs is just the first step. I think it is CERN’s job – independent of whether we build a linear collider or not – to exploit the LHC to its full potential. It may be that science will tell us that we need a higher energy LHC – which today would be very, very difficult to build. But there is still R&D going on – one could imagine doubling the LHC energy, for instance. We build accelerators because science tells us that that is what we need to make achievements possible.

Anyway, I think the LHC works so well because of the people: the people who designed it and built it, and also the people who are running it right now, who are just a fantastic group.

CERN Bulletin

... It's a blooming miracle - a special LHC Report

Wrestling a 27 km superconducting collider under control is not easy. Throw in high intensity beams and it can sometimes seem a continual, frustrating battle with the vagaries of a hugely complex problem space.

This problem space has been thoroughly explored over the last three or four years. The myriad of potential obstacles to smooth operation ranges from unidentified falling objects (UFOs), electron clouds, beam dynamics, radiation to electronics, vacuum instabilities, "transparent" software changes, Radio Frequency (RF) trips, electrical network glitches etc. etc. The huge extended systems, such as the beam loss monitors, cryogenics, and quench protection systems, have a phenomenal number of components that inevitably have occasional failures (there is, of course, a higher probability that these occur late Friday evening and over the weekend). On the cryogenics front, cooling and keeping 36,000 tonnes of magnets at 1.9 K is a challenging prerequisite for everything else that follows.

Despite their complexity, we have very well behaved magnets and overall the machine is stable and magnetically reproducible. The magnets are well understood following a long and careful measurement campaign carried out during production. A sophisticated magnet model is even capable of dealing with the once feared dynamic effects. Together with the accuracy and stability of the power converters, our carefully optimized machine stays optimized. The injection, ramp and squeeze have been mastered and, as a general rule, injected beam makes it into collisions.

Exploitation of the LHC's potential is helped by the presence of excellent beam instrumentation and powerful high-level software architecture. Together with some applied intelligence, these have allowed the development of tools (e.g. measurement and correction of optics, an on-line aperture model) which have opened the way to maximizing the performance of the machine. Most notably, accurate measurements of the aperture in the regions adjacent to the experiments have allowed us to reduce the beam size at the interaction points to unexpectedly low values. The better-than-expected aperture reflects good observance of tolerances during installation and very good alignment of all elements by the survey group.

The LHC has enjoyed from the start very good beam quality (both protons and ions) from the injector complex. The bunch currents have been well above, and the beam sizes well below, the nominal values quoted in the design report. The production of beam in the LINAC, Booster, PS, and SPS is distinctly non-trivial and requires continual care and attention to maintain the beam parameters, however this diligence is reflected directly in delivered luminosity.

Naturally, a cautious approach marked the re-starting in November 2009 following recovery from the 2008 incident. This was most clearly reflected in the choice to run at an initial beam energy of 3.5 TeV. Having experienced first hand the destructiveness of magnetic energy, awareness of the damage potential of the beam to the machine has underpinned the operational approach and marked the subsequent evolution in beam intensity. The full and proper functioning of the extended machine protection system (MPS) has always been an absolute priority.

The MPS consists of a federation of inputs from various systems into a beam interlock system (BIS). When the BIS is triggered it provokes a beam dump within 3 to 4 turns (that is, in a few hundred millionths of a second). The MPS has worked flawlessly, always pulling a beam abort when called upon to do so.

In addition to the MPS, the beam drives a subtle interplay of the beam dump system, the collimation system and protection devices, all of which rely on a well-defined aperture, orbit and optics for guaranteed safe operation. Assuring this throughout high intensity operation remains paramount. Numerous interlocks are in place to ensure that posted limits are always respected.

One notable feature during LHC commissioning and operation is the collective ability of CERN teams to resolve problems. There is in-depth expertise and experience on all systems, including vacuum, collimation, RF, fast kicker magnets and so on. Serious issues, such as radiation to electronics, and the lack of redundancy in protection systems, are targeted rigorously as they become apparent.

Although precision and rigour are needed when dealing with the tightly synchronized choreography and the ever present dangers of magnetic and beam energy, an open and mostly friendly atmosphere pervades. A recent visitor to an 8:30 meeting noted the lack of defensiveness, and a willingness to directly engage a problem without needing to assign blame. There is amazing dedication from everybody involved. Problems that stop the operation of the machine happen anytime, with a slight preference for nighttime and the weekend. Despite this, there is unfailing support from all teams. Coming out of the technical stop this last weekend the Machine Protection and Electrical Integrity team worked until 5 in the morning on Saturday, and the control and timing teams were in from 2 to gone 6 on Sunday morning dealing with the effects of an innocent leap second.

Finally, trying to hold everything together across the accelerator complex is a talented, smart, moderately good-looking operations team who have necessarily developed an advanced sense of humour.

The LHC came out of a five-day technical stop on the evening of Friday 29 June. For real-time information on the operation of the machine, visit the LHC Page 1 status page.

Mike Lamont for the LHC Team

Frequently Asked Questions: The Higgs!

Why have we tried so hard to find the Higgs particle? How does the Higgs mechanism work? What is the difference in physics between strong evidence and a discovery? Why do physicists speak in terms of "sigmas"? Find out here!

1. Why have we tried so hard to find the Higgs particle?

Because it could be the answer to the question: how does Nature decide whether or not to assign mass to particles?

All the fundamental particles making up matter – the electron, the quarks, etc. – have masses. Moreover, quantum physics requires that forces are also carried by particles. The W and Z particles that carry the weak force responsible for radioactivity must also have masses, whereas the photon, the carrier of the electromagnetic force, has no mass at all. This is the root of the "Higgs problem": how to give masses to the fundamental particles and break the symmetry between the massive W and Z and the massless photon? Just assigning masses by hand leads to an inconsistent theory and nonsensical predictions. Nature must therefore have a way of correcting this inconsistency, and the mechanism proposed by Englert, Brout and Higgs could be the answer.

2. How does the Higgs mechanism work?

According to the Englert-Brout-Higgs mechanism, the property that we measure as the 'mass' of a particle is the result of a constant interaction with a field that permeates the Universe like a sort of "ether". The existence of this Englert-Brout-Higgs field is definitively proven by the discovery of the corresponding quantum particle - the Higgs boson.

Originally, the Englert-Brout-Higgs mechanism was put forward to explain why one of Nature's fundamental forces has a very short range, whereas another similar force has an infinite range. The forces in question are the electromagnetic force (infinite range) – which carries light to us from the stars, drives electricity around our homes, and holds together the atoms and molecules from which we are all made – and the weak force (very short range), which is responsible for radioactivity and drives the energy-generating processes of the stars. Today we know that the electromagnetic force is carried by particles called photons, which have no mass, whereas the weak force is carried by particles called W and Z, which do have mass. Rather like people passing a ball, interacting particles exchange these force carriers. The heavier the ball, the shorter the distance it can be thrown – and the heavier the force carrier, the shorter its range. The W and Z particles were discovered in a Nobel prize winning enterprise at CERN in the 1980s, but the mechanism that gives rise to their mass had not yet been understood, and that's where the Higgs boson comes in.

The Englert-Brout-Higgs mechanism in its basic form is the simplest theoretical model that could account for the mass difference between photons and the W and Z particles, and by extension could account for the masses of other fundamental particles. The presence of the Englert-Brout-Higgs field enables these forces to cohabit a single unified electroweak theory.

It should not be thought that the Englert-Brout-Higgs field is responsible for all the mass in the Universe. Your interaction with the field actually contributes less than 1 kg to your mass. The remainder comes mainly from the strong force binding quarks inside nucleons, with a tiny contribution from the electromagnetic force that reigns over the atomic and molecular scales.

Higgs bosons are quantum fluctuations in the Englert-Brout-Higgs field that are visible experimentally only when energy is "injected" into the field. Concentrating the right amount of energy in proton-proton collisions at the LHC excites the Englert-Brout-Higgs field, which resonates at a precise energy corresponding to the mass of the Higgs boson. The Higgs boson appears momentarily before decaying into other particles that the LHC experiments can measure. Some theories predict the existence of multiple Higgs bosons.

3. Is the Higgs boson the only possible answer to the "mass problem"?

No, there are other theories that predict the existence of different mechanisms to explain how Nature deals with the mass problem. For example, there are rival theories that suggest the existence of extra dimensions of space.

Also, despite the fact that we see strong evidence of its existence, we do not yet know whether the Higgs boson is an elementary particle as postulated in the Standard Model, or some more complex object. Nor do we know whether there is only one Higgs boson or if there are more of them. Further studies and analysis will have to be carried out to reply to these questions.

4. Why is it called the "God particle"?

The term was coined for Leon Lederman's popular science book on particle physics: "*The God Particle: If the Universe Is the Answer, What Is the Question?*"

5. Is Peter Higgs the only theorist who proposed this mechanism as a solution to the "mass conundrum"?

No. In 1964 independently and almost simultaneously, The theory of the Higgs field was proposed by three groups of physicists: François Englert and Robert Brout, Peter Higgs, and Gerald Guralnik, C. R. Hagen, and Tom Kibble. However, Peter Higgs was the only one of these who pointed out explicitly the existence of the particle that bears his name and calculated some of its properties.

6. What is the difference in physics between "strong evidence" and a discovery? Why do physicists speak in terms of "sigmas"?

The Higgs boson cannot be observed directly because its lifetime is too short for our apparatus. At the end of its life, the boson decays and transforms into other particles, and the detectors may detect these decay products. As an example, one of the ways a Higgs particle can decay is into two photons, which can then be detected. However, there are many other processes that also produce two photons, so researchers compare the number of so-called "two-photon events" measured with the number expected from known processes. They do this for all the possible decay modes, and only when they see a statistically significant excess of events can scientists claim a discovery.

In particle physics, people talk of 95% confidence levels, which means that a

(Continued on page 7)

Frequently Asked Questions: The Higgs !

(Continued from page 6)

given signal, such as that for a Higgs particle decaying to two photons, has only a 5% chance of being due to a statistical fluctuation. However, 95% confidence is not enough to claim a discovery. For that, the probability of a statistical fluctuation being responsible for the measurement has to be much smaller, less than one in a million. This is what physicists call a **five-sigma effect**. It is considered the gold standard for significance; six sigmas correspond to one chance in half a billion that the result is a random fluke.

7. Why did it take so long to come to such a result?

First of all, accelerators have to be powerful enough to produce the high-energy collisions that allow any given particle to be created. The lowest energy that you need in a collision in order to create a given particle is the mass of the particle itself. However, the particle you are looking for might be produced together with other particles, in which case a higher collision energy would be needed.

In a proton-proton collider such as the LHC, the physics processes are such that the probability to produce a Higgs boson increases considerably when the energy collision is increased. As an example, the Higgs boson production rate in 2011 – when the LHC was operated at 3.5 TeV per beam – was about 27% less than the production rate in 2012, when the LHC is being operated at 4 TeV per beam.

In general, the processes associated with the observation of the Higgs boson are very rare, and therefore statistics come into play. The statistical error, i.e., the expected range of statistical fluctuations, goes down as the inverse of the square root of the data sample size. For example, to halve the error bar you must quadruple the data sample. This is why physicists always try to collect more data: to reduce the size of possible statistical fluctuations.

One might think that, once the analysis is defined, it is just a matter of passing all the newly accumulated data through those selection criteria in order to extract the type of events we want to study. However, producing new results requires an incredible number of checks and cross-checks.

The analysis technique works as follows: a theoretical model is used to predict what phenomena and particles might be seen, and experimental physicists estimate what their detector response would be to such events, using complex simulation methods. They do this first for all known processes, so that they can predict the various expected types of events that will come out of the LHC. These simulated events look just like the events collected in the detectors, except they are generated using all our knowledge of what can be produced when protons collide in the LHC.

Then the experimentalists determine a series of criteria for selecting new physics, partly defined using simulations. The selection criteria are designed for the sole purpose of spotting a needle in a field full of haystacks. For this, physicists study in detail the characteristics of possible interesting events (such as the Higgs boson), comparing these characteristics with those of known processes. At this stage, the name of the game is to isolate the signal from all other types of events, which physicists refer to as background. Most of the time, the background constitutes the bulk of all collected events.

The final step is to compare the simulations of the known processes that survive the selection criteria to the collected data set. In some cases, comparison with simulations might not be necessary, and physicists may just need to subtract potential Higgs signals from the background directly inferred from the actual data.

The more data are collected, the more precise these comparisons get, making the result more significant. In the end, the goal is to produce absolutely trustworthy results, excluding flaws, bugs and oversights.

8. What are the next steps?

The data recorded so far in 2012 have not been completely analysed, and the LHC is still taking data. Further analysis is needed and ongoing. Despite the strong evidence for its existence, the properties of the Higgs boson need to be explored and understood.

As the particle is identified and studied more completely, the physics models will have to be updated (also read Question 9).

In the meantime, the LHC will continue its scientific programme of which the Higgs is only one item. By exploring the world of infinitely small particles, physicists hope to provide answers to the origin and fate of our universe. What happened just after the Big Bang? Why did matter dominate over anti-matter when, in laboratory settings, they are created in equal amounts? Finding out what dark matter is made of is certainly high on the LHC agenda, even if popular models such as supersymmetry have not manifested themselves yet, despite all our attempts at unveiling them. What would you say if you found out we do not live in a four-dimensional world (three dimensions of space and one of time), but rather one containing extra hidden dimensions? There are enough strange, puzzling questions and even stranger possible answers to blow your mind!

In particle physics as in other research fields, scientists will continue to study how the Universe works. With the Higgs, the Universe has disclosed just one of its numerous mysteries.

9. What is the impact of such a Higgs boson on the current description we use for the Universe?

The Higgs boson will complete our description of the visible matter in the Universe, and of the fundamental processes governing the Big Bang since it was a trillionth of a second old. The Higgs boson may have played a role in generating the matter in the Universe, and may be linked to dark matter. It may even provide a clue how the Universe inflated to its present size. On the other hand, the Higgs boson is a very different particle from the others we know, and poses almost as many questions as it answers. For example, what determines the mass of the Higgs boson and the density of dark energy? According to conventional ideas, both should be much larger than their observed values. The quest continues.

CERN Bulletin