1 – Traduza para o português o trecho em destaque. 2 – Leia todo o texto e escreva um resumo de suas principais ideias.

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Future of particle physics doesn't rest only on LHC finding new particles

A reminder, on the tenth anniversary of the discovery of the Higgs boson, that there's much more to the field than particle hunting.

Ten years ago, on 4 July 2012, scientists around the world celebrated the momentous news that researchers had found evidence supporting the existence of the Higgs boson. This fundamental particle, whose existence was predicted as a consequence of theories developed in the mid-1960s (refs 1, 2), was discovered by teams working on the ATLAS and CMS experiments at the Large Hadron Collider (LHC) at CERN, the European particle-physics laboratory near Geneva in Switzerland. The discovery was a crowning achievement for the LHC, and for the thousands of engineers, researchers, support staff and technicians who helped to make it happen.

And yet, as the LHC prepares to start the third of its planned five runs, there are those who think that this could be the last gasp for particle physics – or, at least, for physics dealing with high-energy particle collisions. Their reasons? Researchers were hoping to improve on the current theoretical description of fundamental particles and how they interact – the standard model of particle physics – which is considered incomplete. Many are disappointed that the LHC hasn't yet found any hints of something at odds with the standard model that could represent a step towards a more complete theory.

The standard model is an ensemble of theories developed between the 1950s and the 1970s. Despite its phenomenal accuracy, it does not incorporate gravity or dark matter, and it doesn't explain the abundance of matter over antimatter in the Universe, nor some aspects of neutrinos.

Field of fear

In the search for answers, theoretical physicists routinely hypothesize the existence of new particles – some of which should be within the detection limits of existing colliders. But the LHC, the world's largest, has yet to spot any. Some fear that the field will be in trouble if the LHC cannot come up with the goods. Critics argue that, in the absence of any clear clues, it is unreasonable to expect governments to find potentially billions of dollars for another large-scale collider and carry on a blind hunt. Without another collider, the field itself might soon wither.

These concerns are legitimate, but they assume that the LHC's sole purpose is to hunt for particles. Spotting a new particle is not in any way a trivial outcome. However, particle colliders such as the LHC are also essential to deepening our understanding of how known particles – not least the Higgs boson itself – behave. Physicist Peter Higgs is one of the best-known names in science, but researchers still know little about the particle that bears his name. And, collision after collision, it is the LHC that continues to reveal new information about the Higgs boson.

In 2012, researchers at CERN estimated the mass of the newly detected particle. They cautiously labelled it a candidate for the Higgs boson, but understood that more evidence would be needed to establish with certainty that the candidate fitted the predictions of the standard model.

Thirty times more data

According to theory, particles do not have mass; rather, their masses result from their continuous interaction with something called the Higgs field (or the Brout–Englert–Higgs field) that permeates the entire Universe. The Higgs boson is a wave in that field. The strength of any particle's interactions with the Higgs field is expected to be proportional to its mass, meaning that heavier particles, such as the top quark, should interact more strongly than lighter particles.

Since 2012, the LHC has produced 30 times more data on particle collisions featuring a Higgs boson. Drawing on these data, the ATLAS and CMS collaborations this week report results[3,4] on Higgs's interactions with heavy particles (see pages 52 and 60). The results align with the pattern predicted by theoreticians more than 50 years ago.

To complete the picture, researchers also need to probe the interactions between the Higgs boson and lighter particles – those, such as electrons, that form the building blocks of everyday matter. As Giulia Zanderighi at the Max Planck Institute for Physics in Munich, Germany, and her colleagues discuss in a Perspective on page 41, the LHC should be able to take scientists some way towards this aim, but a new generation of colliders will probably be needed to get the job done[5]. How best to investigate these interactions at the LHC, and the question of what other experiments might be needed, are active areas of research.

Process matters

Yet deeper questions about the Higgs boson remain unanswered. Unlike all other known particles, its interactions in the Universe do not happen through any of the four known forces: the electromagnetic force, the weak and strong nuclear forces, and the gravitational force. This is remarkable, and physicists hope this unique feature might allow the Higgs boson to shed light on some fundamental questions. For example, if the Higgs boson interacts with dark matter, or with other unknown particles, then those interactions might leave an observable trace in the boson's behaviour. Theoretical and experimental physicists have been exploring these questions since long before the 2012 discovery, so resolution might still be some way off.

Particle physics is not yet done with what the physicist and philosopher Thomas Kuhn famously called 'normal science' in his book *The Structure of Scientific Revolutions* (1962). Kuhn's normal science describes the work of scientists theorizing, observing and experimenting within a given framework, such as the standard model. That is not to say there couldn't be what Kuhn termed a "paradigm shift", whereby a radical change in perspective is needed to accommodate evolving evidence. But as Rolf-Dieter Heuer, who was the director-general of CERN at the time of the Higgs discovery, writes in *Nature Physics*, LHC data are also needed in the search for physics beyond the standard model[6]. To spot any anomaly, one must have a good understanding of what's expected.

To those who worry that particle physics could be approaching its last gasp, we urge you to allow science to take its course, to be prepared for surprises and to recall that it took more than four decades for one aspect of a theory to be confirmed by experiment. In science, the process rarely makes headlines, but it matters every bit as much as the result.

1. Higgs, P. W. *Phys. Rev. Lett.* **13**, 508 (1964).
2. Englert, F. & Brout, R. *Phys. Rev. Lett.* **13**, 321 (1964).
3. The Atlas Collaboration. *Nature* **607**, 52–59 (2022).
4. The CMS Collaboration. *Nature* **607**, 60–68 (2022).
5. Salam, G. P., Wang, L.-T. & Zanderighi, G. *Nature* **607**, 41–47 (2022).
6. Heuer, R.-D. *Nature Phys.* https://doi.org/10.1038/s41567-022-01673-1 (2022).