Newsletter Interview

QUANTUM INFORMATION THEORY AND PARTICLE PHYSICS: AN UNEXPLORED PATH TO FIND NEW PHYSICS

Interview with Federica Fabbri, researcher at the University of Bologna and at INFN, winner of the 2024 edition of the "L'Oréal Italia For Women in Science" award.

The specialisation in subnuclear physics at the University of Bologna, the research activity in Göttingen, at CERN in Geneva, and in Glasgow, the award of the prestigious European Marie Curie Fellowship that brought her back to Italy: Federica Fabbri, aged 34, is already a reference point in the field of top quark studies. Studies that earned her the L'Oréal Italia-UNESCO For Women in Science 2024 award, an initiative that for 22 years has supported young female researchers *"who will help shape the future of scientific progress". To date, 112 Italian female scientists have received this award, and this year, out of 260 applications, six prizes worth 20,000 euros each were awarded to as many women scientists under 35, active in the fields of Life and Matter Sciences, with the aim of encouraging and supporting their research activity and professional growth and promoting the essential role of women in the scientific enterprise. Federica was awarded the grant thanks to her brilliant CV and to one project in particular, Exploring quantum observables at LHC*, *which aims to* answer unsolved questions concerning the universe by going in an unexplored direction, straddling quantum information theory and particle physics. *We asked her to tell us about her research and the ambitious goals that drive it.*

***Where did the idea for Exploring quantum observables at LHC* come from?**
From the many questions still open concerning the standard model: what is the source of dark matter, why is there such a large mass gap between the various particles, why has matter won over antimatter? So far, classical methods of searching for new physics have not been successful in finding answers. So, we thought of looking for novel solutions, combining two branches of physics that had never been combined before: high-energy physics and quantum information theory.

How does this combination work?
Basically, we apply techniques borrowed from quantum information theory to data *generated by the collisions* of the *Large Hadron Collider (LHC), CERN's accelerator.* We start from a unit, the qubit, which in quantum information theory represents the smallest element, like a bit in a computer, and from its properties. Take the entanglement, for example: if two qubits are entangled, the action experienced by one also causes an effect on the other, regardless of distance. The same concept of entanglement can be applied and measured in the case of two particles created by LHC. For example, two tops created by LHC can be considered as qubits and their entanglement can be measured. Now, if there is new physics, something unexpected that answers the open questions about the standard model, it could change the correlations, the entanglement between the particles created by LHC. So, by measuring entanglement and other properties of the particles-qubits, we can identify new physics.

How are the measurements going?

Entanglement measurements are starting now: the ATLAS collaboration published results for the first time last year, and this year those of the CMS collaboration were made public. It is a topic that is growing enormously; a paper comes out on arXiv every day. My project tries to understand how to improve these measurements, in which channels to look for them, what is the link with new physics and how to identify it. Together with Fabio Maltoni, who is one of the pioneers in this area and manages the research group, we follow both top quarks and other particles, for example, the decay products of the Higgs boson. The problem is that many particles decay into neutrinos, and neutrinos are not visible in the detector, so we run into a lot of technical problems when making measurements.

What kind of technical problems?

In order to measure the angles from which we extract entanglement information, it is necessary to completely reconstruct the final state, then construct every single particle present. On a theoretical level, it is easy to treat a top as a qubit, apply the quantum information theory, get a result, and understand how to measure the entanglement. But in practice, the top is no longer an object of fantasy, it is something that is measured in colliders, interacting with other particles and decaying into neutrinos. And you have to reconstruct it from these particles that you cannot see, take into account the interactions it has with other particles, the particles it emits, and then understand how to apply the simplified model we had at the beginning to the real situation produced by the collider. The difficulty is precisely being able to include in the evaluation all the aspects that are there in reality, which can then be studied from a phenomenological and experimental point of view. I am working on both aspects.

The project started in October 2023 and will end in 2025, but from the way you tell it, it seems to be just the beginning of a long exploration. Will you continue in this direction?

Yes, undoubtedly, this area of research is really interesting and has several implications. For example, there is a lot of talk right now about Bell's inequality violation. The basic concept is that if reality behaves according to classical mechanics, there are equations, the Bell equations, that must be less than a certain value. But if reality followed quantum mechanics, these equations would reach a new maximum value, violating the previous one. This violation is not merely theoretical, it has already been measured in many areas, but never at the energies reached by colliders, and we hope to do so using particles from accelerators. It is difficult, and it is currently hotly debated, but if we succeed in the measurement, we will test the nature of our reality at the highest possible energy.

In short, you could answer many of the questions that brought you to the project. Can we already imagine the outcomes for society?

Currently, they are still a long way off, because we do pure research in the field of high energies, and to imagine a priori what the outcomes for society will be is very difficult. However, we have the unique opportunity to study qubits in a new framework, at very high energies compared to other systems where qubits can be created. And this may have implications for quantum computers, which are the future of computing. I cannot be certain, but it is a possibility.

Let's end with a personal question: what did it mean for you to win the L'Oréal-Unesco For Women in Science award?

It was a huge emotion. I was trying to solve a technical problem on a computer, and I was completely absorbed when the phone rang and I was told I had won. You know what it's like when you miss a heartbeat? And you fall off your chair? I really wasn't expecting it, research calls are always very competitive, there are so many brilliant participants, it's impossible to expect to win. Then of course the L'Oréal award is an important prize, which certainly supports research, but specifically supports women in research. The purpose is really to break through the glass ceiling, to try to remove all the barriers that prevent women from holding positions of responsibility in research. I never saw any gender distinctions while I was working, but as I progressed in my career, the percentage of women attending meetings or representative dinners became increasingly smaller. And you always wonder: why? Is it possible that this topic only interests me as a woman researcher? So, it is important to investigate this limitation, and to overcome it.