Rohini Godbole

Rohini Godbole is a high-energy particle physicist and professor at the Centre for High Energy Physics at the Indian Institute of Science (IISc), Bengaluru. She is among the highest authorities in the field of particle physics worldwide and is best known for her work on physics that is studied at the colliders, the latest being the Large Hadron Collider (LHC) at CERN.

Apart from being an academic savant, Godbole is a strong advocate of the 'Women in Science' (WiS) initiative and has served on several committees for women in science to bring light to the issue. She has also co-authored an anthology of women scientists in India entitled *Lilavati's Daughters*, which was followed by *The Girl's Guide to a Life in Science*, a popular science book for young readers.

Among several national and international accolades, Godbole was awarded the Padma Shri, one of the highest civilian awards in India for her contribution to science and engineering in early 2019. She is an elected member of all three science academies in the country and a member of The World Academy of Sciences, Italy.

Having worked in the field of particle physics for more than 40 years, Godbole offers a vantage view of point on the growth of the discipline, and shares her insights in this interview. She also candidly speaks about her work in the WiS initiative in India and abroad.

Can you give me a brief overview of the history of particle physics?

Particle physics, which is also sometimes synonymous with high-energy physics, started really in 1911 when Rutherford looked at an atom's structure. One understands the structure of a target by bombarding it (say an atom) with high-energy beams (alpha particles, in his case). When you increase the energy of the beam, you become sensitive to the structures at smaller and smaller distances. This is because of the famous De Broglie's wavelength principle.

Extensions of Rutherford's experiment have given us a lot of information about the atom over the last 100 years. They have taught us that the nucleus is not point-like; it is made up of neutrons and protons, and using the same technique we also learnt that the proton is also not point-like; it is made up of quarks and gluons.

Particle physics, to put it simply, is the quest for understanding what the fundamental elementary constituents of matter are and how they are put together. And you need both; for example, it is not enough to say that something is made of bricks; you also need to know the nature of the bricks and also what holds them together. These are two different things and that is something that we (the particle physics community) are involved in understanding since 1911, and I am one of the 10,000+ people around the world doing this.

How was the environment in particle physics when you started in the early 1970s and how did you get involved?

The Standard Model is the most elegant theory in particle physics, which was suggested in the 70s, and it took nearly 40 years for the theory to be established and the predictions of the theory to be confirmed experimentally, of which the last piece to be confirmed was the Higgs boson.

The period where I come in the picture was that of radical discoveries in the field. And 1974 is an important year in this history. Just like Thompson's electron discovery, there was another serendipitous discovery of the bound state of charm and anti-charm quark. The charm quark was postulated by theorists; even its mass was predicted by the theory (which was the Standard Model), and it was then found at exactly the same mass as the prediction. This was a massive discovery for particle physics, which was later named the November revolution of 1974.

Three months earlier in August, I had started my Ph D at Stony Brook University, New York, USA and this discovery of the 'November revolution' was unfolding at the Brookhaven National Laboratory, where the Stony Brook theory department used to have a common seminar every fortnight. As a first-year graduate student, I could sense the excitement, even though I could not understand it fully. So, I began my academic life when the Standard Model of particle physics was getting established.

Talking about my involvement, in particle physics one could be doing different things. You could be building models, you could be building theoretical structures, and you could then ask the question; do the data support this theoretical structure? Whereas what I do is that I suggest to the experimentalists, the kind of experiments they should be performing to test a particular aspect of a theoretical structure. So different people do different kinds of things and I work primarily as a theoretical physicist, working on physics that is investigated in the collider experiments.

Like you said, the discovery of the last piece of the Standard Model puzzle, the Higgs boson, closes its chapter. Where does particle physics head now?

This is a question that the particle physics community has been asking for the past seven years. In fact, this summer in May, there will be a big conference in Granada to discuss future directions for experiments in high-energy physics. Because such experiments need long-term planning, the colliders need a long gestation period and a lot of money. So, you need to have discussions on strategy, and Europe is having a meeting to discuss this in Granada. I am in charge of organizing a conference in Hong Kong, where we will be discussing Asia's strategy in the coming decades for particle physics. I also happen to be a member of the high-energy physics advisory panel in the United States, and these discussions are playing out there too. This is of course at the level of experiments. At present, the theoretical physicists could do with some clues from experiments to make further progress.

Science beyond the Standard Model

The time lag between postulating the Standard Model and its findings was a long period from 1967 to 2012. During that period, lot of work had happened other than just establishing the Standard Model and search for the Higgs boson. The discovery of the same, of course, established the Standard Model even more strongly. But, the Standard Model, as beautiful as it is, has lots of problems and some of them are theoretical problems, which were already appreciated in the period before the Higgs discovery. One of the foremost problems is that theoretically, we cannot understand why the Higgs boson mass is as small as it is. In the last three decades, many people have had many big ideas and have tried to explain why this is so. Since the last 30 years, we have known from precision measurements at the Large Electron–Positron Collider (LEP) at CERN, that the Higgs is likely to be light. So the puzzle was already there but since its experimental evidence in 2012, the mystery has deepened.

Apart from this theoretical problem, there are experimental observations that we do not understand. After revealing that particle physics describes the periodic table of elementary particles in the universe, we have actually found that we do not have a candidate to explain the most abundant matter in the universe called dark matter (DM). So that is a big problem. And DM is an observational fact, which means there must be physics beyond the Standard Model which explains its existence.

Moreover, there is a question about why the universe is only made up of matter. Whereas at the beginning of the universe, we had matter and antimatter in equal proportion. This is according to laws that we know are correct; laws that have been tested experimentally in the laboratory. So, we know that matter and antimatter were created equal. Now we also know by looking around us that there is no antimatter. The Standard Model has some so-called CP asymmetry (asymmetric behaviour of the laws of nature, which skews the equality in the number of matter and antimatter particles) that is required to produce this current dominance of matter. However, this asymmetry in the Standard Model, which has been measured accurately in several experiments, is not enough to reproduce the numerical value of the observed dominance of matter in the universe. Hence, quantitatively one cannot explain it, which means that there must be a source of additional CP asymmetry in the fundamental interactions. So there must be physics beyond the Standard Model, which has to provide the source of additional CP violation that is necessary.

A new approach for experiments at the colliders

There are two ways in which you can look for things at the colliders. One is to just increase the energy, pump more and more energy, and try to produce new particles. That is what we have done, and we have not produced any new particles other than the Higgs boson. But that is not the only way.

Consider this analogy: if you want to look at things far far away, you can use two ways to do that. One, you climb the top of a mountain from where you get a view over a larger distance. That is analogous to increasing energy in particle physics, which we have been doing. But there is another way to do the same thing; you use a telescope. So now, you can still look at things distant in energy, but not by climbing a hill, not by increasing the energy but by increasing the accuracy of your measurement.

Let me give an example from the early days in particle physics. A particular meson called kaon (K0) and its antiparticle (K0 bar) oscillate into one another. They change their character as they move, and there was experimental proof for the same. And this change in their character was due to the effect of higher energy particles, which existed in the theory. And later down the years, when we found the charm quark, it was the particle whose existence and mass scientists had been 'predicted' based on the number of times K0 oscillated into K0 bar per second. So what I am coming to is, this oscillation physics was a low energy physics through which we had predicted the existence of a high-energy particle which was the charm quark.

So now similarly, we are trying to look at the physics of the Higgs boson and the top quark which are under 100 GeV scale, and to predict whether their properties are due to some effect of heavier particles, which could be at much higher energy scales of around 1–2 TeV (i.e. 1000–2000 GeV). We may not have enough energy to produce them, but we can look at them from their effect on lower energy particles. One can look for them from the shadows they cast on the low energy world.

So this is one direction for particle physics currently: make precision measurements of the properties of the Higgs boson and the top quark, the two Standard Model particles which are most likely to carry the memory of the high-energy physics.

Apart from making precision measurements, are there any future prospects for particle physics in terms of collider experiments?

The LHC is going to run for another 15 years and going to collect a lot more data. But there have been discussions since a long time now about the state of particle physics after the LHC. I authored, about two decades ago, a report along with 100 others on what we need to do next after the LHC. This big physics report contained several physics and collider ideas.

These discussions about planning for future colliders are not happening in a vacuum, they are connected with what you know about particles and their interactions derived from experiments done at the LHC and independent experiments done over the last 30 years. For any collider project to come to reality, a common community of accelerator builders, theorists and detector builders need to work together in an extremely synergistic manner.

Due to this collegial nature of work, there are very good plans of next-generation electron–positron (e+e–) colliders. For example, there are discussions about an International Linear Collider (ILC), which would most probably be hosted in Japan, and would probably be finished in another 10 years. The Chinese have proposed a Circular Electron–Positron Collider (CEPC), which is on a very aggressive timeline. The Future Circular Collider (FCC) proposed by CERN is a long-haul project on a slower timeline. All the colliders have their strengths based on their design and are built with specific purposes in mind. So this is the current status of planning for particle physics collider experiments. In addition, there are different types of experiments such as neutrino experiments or high precision measurements of rare processes in the non-collider environment.

There has been an unexpected debate in the physics circle lately that started with an op-ed written by Sabine Hossenfelder, a theoretical physicist in the New York Times. As a veteran in the field, what do you think about it?

Sabine Hossenfelder is talking about an FCC proton–proton (p–p) collider of 100 TeV, and that machine is 30 years into the future. First, you need to start talking about these things in advance to see if they are feasible. Secondly, a 100 TeV collider, which is the FCC p–p collider, is based on a conjecture that one must find some new physics which keeps the Higgs boson light. I personally have not supported the building of colliders based on that hypothesis, because I happen to agree with Hossenfelder's opinion that it is not so clear whether our estimate of the energy at which new physics will appear is right. Whether we have the ability currently to predict that scale correctly, is also something I do not know.

However, it does not mean that we should not talk about future colliders, because colliders of the e+e– level are certainly justified. There is absolutely nothing under the sun that does not justify their existence. It is possible that precision measurements at the high luminosity LHC and the electron–positron colliders may show us the path: either give us information on the scale or help us discover the principles on which the prediction can be based.

In her argument, 'If particle physicists have only guesses, maybe we should wait until they have better reasons for why a larger collider might find something new', Hossenfelder is talking about the guesses for a scale of new physics to explain the lightness of the Higgs boson. I am, like many of us are, not basing our next collider on that case. It is, according to me, a small section of the high-energy physics theorists, who are proposing the 100 TeV collider based on these guesses. I am not one among them and a big fraction of the high-energy physics society is not among them.

I think there is a difference of opinion and perception. All I understand is that for a 100 TeV collider, Hossenfelder's arguments may be correct, but the justifications of e+e– colliders are not based on these guesses.

These discussions are again very much in the public domain and many of us are doing small pieces of work which will contribute to them. The European community is meeting in Granada to have such future discussions. And since colliders require long lead time, we should start thinking about these things and having discussions. According to me, while it is too soon to make a judgement, discussing the need and the feasibility of such machines is a necessary exercise. This is just because colliders have indeed yielded an enormous amount of information about what the world of particle physics is all about. We would not have reached where we have without them. So we need to investigate and debate the question with great care. I will repeat what I said earlier. Till now the path of collider physics was mainly lit by theoretical predictions. Now the time has come for theorists to be led by experimental results.

Along with your academic work in particle physics, you are actively involved in the WiS initiative. Can you tell me about that?

It all started at the International Union of Pure and Applied Physics (IUPAP) in Paris in 2001. I was one of the nine speakers on the plenary invited from several countries to speak at the first women-in-physics meeting. From India, there was a delegation of five people and the idea was to discuss the situation of women in sciences in their respective countries. My talk was titled, 'Being a women physicist, an Indian perspective'.

This was in 2001, which was around 30 years into my scientific career. Personally, before that, I had not thought about it, or you can also say that I was just too busy being a physicist to worry about whether there was a gender angle. When you are young, you are trying to be a physicist, you are trying to be successful. You do not worry whether there are problems, because everybody has problems and scientific careers are very rarely without any issues. And I was not one of those people who thought about whether this was due to my gender or otherwise.

So in a way, this (the talk) gave me a chance to look at the issues. My personal story in that sense is not very important to me. But I began to realize that there are issues with regard to women becoming successful scientists. And particularly in India, we see that there are women who are doing very well in schools, colleges, studying science, even women doing Ph Ds in large numbers, and we really lose them out at the last stage.

Just to give you some numbers from the data that UNESCO has collected and after that, the UGC has collected and then very recently in 2015–16 in the higher education survey. All these reports have found that on average there are about 35–40% women up to the Ph D level, but in the faculties, we do not see that. Faculties of good, high-profile institutions, have only 10% women. And that is a big drop. In the rest of the world, the drop is much earlier, in fact, in the rest of the world, there is not such a big fraction of women doing Ph Ds too. This is something I learned only because of the talk that I decided to give there.

This women-in-physics IUPAP meeting was followed by a general body meeting where the recommendations put forward by the women-in-physics meeting were discussed. One of the recommendations was to get in touch with the science academies to begin studies on women in science in their respective countries. At that time, I was the second woman fellow in the physical sciences of the Indian National Science Academy (INSA), New Delhi and the only women fellow in the physical sciences of the Indian Academy of Sciences (IASc), Bengaluru. Those of us who had been involved with the Paris meeting followed up on these recommendations by meeting the presidents of the two academies and this led to a discussion of an action plan for women in science in India. That is how the INSA report on Indian women's access to and retention in science came into being, which Mahtab Sohrab Bamji and I worked on. This report led to the formation of the DST Task Force for Women in Science that worked for a few years and which in turn, brought out another Task Force report that ended up putting in some solid policy recommendations in place. We even made a presentation to the Science & Technology Minister of India at the time.

Before all of this, several funding bodies (DST, CSIR, UGC and DBT) had started schemes for women to come back to science. But I should add that all these schemes essentially provide soft money options, initiating alternative career options for women who have taken a break. But I think we are missing out on efforts for women who do not want to take a break, but still need some infrastructure/facilities which help in that process. An example of such efforts is a new policy introduced recently at IISc, that if a woman in her tenure period has a baby and feels that this has impacted her productivity, she is eligible for a one-year leeway in her review. So these are the kind of measures we should be implementing. We need to think about them first, we need to have some research done, we need to figure out what is the best policy, and all that is still some distance away. What we need perhaps is an Indian version of the Athena SWAN programme which has been in action in the UK.

The fraction of women in faculty in prestigious institutions and research laboratories is not commensurate with the fraction among Ph Ds; that is the easiest way of putting it. This means we are not making use of all the brilliance that is there, and this is proven brilliance. So it is not so much for women that you want to think about this, it is also for science. And all this I have learnt slowly and steadily over the course of two decades. I think, by and large, in India, there is differential treatment towards women and it mainly happens after the Ph D.

Another survey which I find interesting was done jointly by IASc and the National Institute of Advanced Studies (NIAS), Bengaluru. This report was about the women that had left science. We knew that we were losing 10–25% of women; the question was why? It was assumed to be familial reasons, but what if that was not the whole story?

We found that about 50% said women give up because of familial responsibility, but about 20% said that women give up because there are not enough support mechanisms. That is a very clear message, and must be reflected in the policies we make now. For example, the age requirement for an INSPIRE faculty fellowship is 32 years. In my opinion, if a woman proves that she had taken a break, the age limit for her should be 35 years. But this is not the case. And if at that time you do not give such small nudges, then they are lost. They might even come back to science later, but are not going to come at the top. Then we would not find them as professors at reputed universities, Directors of laboratories, etc. because they have lost the race even before it began; they did not enter it at the right time.

On societal barriers

Right now, we are only taking care of the few years that a woman scientist loses because of familial reasons, and then assume that everything should be okay. But this is not the case. It is just one of the factors.

Another aspect that we, as a society, need to tackle is the deeply ingrained social structures and beliefs where a career for women in science is not even considered. The career of a woman as a doctor is thought about, as an engineer people readily think about. A career as a scientist, no. A career as a professor, as a lecturer, yes. Not as a working scientist. That is not considered as a career option in nearly anybody's mind, including women.

And, the kind of nudging, the kind of mentoring you get depends on how people think of your future. So I think it is there that discrimination happens in an unconscious fashion. And that is what the story in India is right now, the way I see it. You have to change the perception of people.

You have co-published an anthology about Indian women scientists entitled Lilavati's Daughters and another book, viz. The Girl's Guide to a Life in Science. Can you tell me what inspired you to write those books?

Part of the reason for getting out *Lilavati's Daughters* was to highlight the women of today. Just talking about Asima Chatterjee or Janaki Ammal is not enough. You need to know about women in today's India, who are working under today's pressures and today's economy. And there are quite a few of them, who are doing fantastic science. This is something that you need to convey, not just to the women but also to the men, the family, the mother-in-law, father-in-law, parents and to the colleagues that science is a serious career option for women. If they have the merit, they should have the possibility of following this career option without undue problems. *The Girl's Guide to a Life in Science* was written to engage young readers and since then, my involvement in it has kept on increasing exponentially.

To wrap up, were there any pivotal moments in your career that in retrospect you think were extremely crucial to get you where you are today?

That is a very difficult question because I cannot point to one moment. Because where I am now is made up of very many small pieces. For example, if I never developed a liking for science, I would not be here. So that can be one pivotal moment. And that is really true because I was in a girl's high school, where we were not taught science till the seventh grade, we were taught home science; so one can say that is a pivotal moment. But on the other hand, just because I started learning sciences, does not mean I would be here today. Unless I got the science scholarship, unless I went to IIT, unless I went to the US, and each of these steps has moved me and moulded me towards this path. So I cannot say that, if this would not have happened, I would have been lost.

These were just points in my journey, but there have been some barriers and if I was not able to overcome them, I would not be here. But then those are not something I would call pivotal moments. So it is kind of difficult to answer the question.

My entire life, small things have happened which have helped me along to come where I am today. And various people have helped me along on this path. For example, after finishing my postdoc it was not clear what kind of job I was going to get, and at that time I had gotten not very encouraging and supporting statements from my seniors. Then I went for a conference and was passing through the airport in Frankfurt. This gentleman who had been attending the conference with me asks me, before parting ways in the middle of the airport, are you the same Godbole who wrote a such-and-such paper. He bowed in front of me and said, I respect that paper. It is a Japanese way of showing admiration or respect. The point is that, moments like these kept me at it, the kindness of colleagues and friends helped me push above those barriers. So in a way, these and many more such moments could be the so-called pivotal ones in my career.

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