Neutrinos, Large Scientific Facilities and Science Innovation

—An Interview with Prof. Arthur B. McDonald

In the middle of May, 2017, Professor Arthur B. McDonald, director of the Sudbury Neutrino Observatory (SNO) in Canada and Nobel Prize Laureate in Physics in 2015, visited the Institute of High Energy Physics (IHEP), Chinese Academy of Sciences (CAS). After a brief visit to the laboratories for particle physics at IHEP, he shared his opinions on the future of neutrino physics, neutrino experiments, and other large scientific facilities in China and worldwide.

Daya Bay and JUNO

Journalist: Professor McDonald, I am glad to meet you. I think you know the Daya Bay Reactor Neutrino Experiment very well since you got the Breakthrough Prize together with Professor WANG Yifang from IHEP and the Daya Bay Collaboration. Would you give us some comments on the scientific significance of the Daya Bay experiment?

McDonald: The Daya Bay experiment was a very significant measurement. The neutrinos that have been observed from the Sun and the atmosphere, and previous experiments from reactors, told us some of the properties of neutrinos. They told us that neutrinos do change from one type to another and have finite mass. This is physics that goes beyond the very well tested standard model of elementary particles. It means we have to change that model at the most fundamental level. So our understanding of how to do that depends on other properties of neutrinos. A third parameter (*i.e.*, the smallest lepton flavor mixing angle θ_{13}) was measured first by the Daya Bay experiment, a beautiful experiment with a number of detectors and a number of reactors. Controlling the experiment, they did a very accurate measurement of this parameter. The parameter is very important in terms of completing the theory, but also in terms of providing knowledge of how to measure the question of whether matter and antimatter is symmetric. One measure of this will be provided by future measurements with very large accelerator-based experiments, and the sensitivities of those experiments depend strongly on the Daya Bay experiment and other experiments that confirmed it.

Journalist: The next generation neutrino experiment in China, JUNO, is under construction. Would you comment on the technical challenge and the physics of JUNO?

McDonald: The JUNO experiment is again an experiment which will be at the cutting edge of knowledge of the properties of neutrinos. We know that neutrinos have finite mass. Of three masses m_1, m_2 and m_3, we know m_2 is greater than m_1, but we don't know whether m_3 is greater than the other two, or less than the other two. That's very important in terms of understanding the physics of neutrinos. That is what JUNO is setting out to do. In order to do that, they are pushing technology very strongly. You can see behind me here, a new type of light sensors that they have developed. Absolutely beautiful! These have been designed to be more sensitive than any has before. It is a major collaboration with Chinese industry. It is a good example of how fundamental science pushes the boundaries of technology and collaboration with industry results in improvements in technology, as well as improvements in science.

Neutrino Physics

Journalist: What is your vision for future research in neutrino physics? Will there be more breakthroughs? Do you think there will be more Nobel Prizes from neutrinos?

McDonald: It is certainly possible that there will be more Nobel Prizes in neutrino physics. We know quite a bit about neutrinos, but we don't know a number of their properties, such as the mass hierarchy, as I mentioned with respect to the measurement that JUNO is going to make. We don't know about other properties of neutrinos, such as their absolute mass. There are further measurements of neutrinos that are being made and that will be pursued in China in the new Jinping Laboratory, which is actually the deepest laboratory in the world for making measurements where you require very low radioactivity and need to shield out the cosmic rays, which are shielded in the Jinping Laboratory by the large amount of rock above it. I think China actually is pursuing some of the very best possibilities for obtaining new knowledge about neutrino properties.

About CEPC and Large Scientific Facilities

Journalist: Do you know the big collider project, called Circular Electron Positron Collider or CEPC, proposed by Professor WANG Yifang? Have you heard about it in scientific media? Or in Canadian media?

McDonald: I don't hear about it in Canadian media, but in scientific discussions at conferences between scientists. Everyone who is involved in sciences understands that this is a very good future possibility. With the confidence that already exists in neutrino physics and that I just observed on my tour here in the accelerator physics division, where very interesting measurements are being made using the accelerator right here at the Institute of High Energy Physics, there is a confidence in China through cooperation also with international community to build, by stages, accelerators that go beyond the physics that is being studied at the Large Hadron Collider in Geneva. We have learned a lot about the standard model, but we now want to look beyond that in terms of trying to understand further properties of our Universe at the very microscopic level. The proposed sequence of accelerators here in China will start first with electrons and positrons at a very carefully chosen energy and perhaps in the longer term go to the highest-level proton accelerator. It makes a lot of sense from the scientific point of view. It would be very helpful if China makes a decision to proceed in this direction.

Journalist: Last year, there was a big public debate in China on CEPC. One negative comment is that CEPC is too expensive and the possible scientific yield is not worth the investment. How do you judge the scientific investment and the yield?

McDonald: My feeling is that if any country has natural scientific advantages in terms of their ability to develop something new, if they have scientists who are capable of putting forward new ideas, the accelerator in this case, and technology people who can develop, and so on, they should look very carefully at the possibility of spending a small fraction of their budget in science on something that could have a very big payoff, in terms of where we go in particle physics beyond what has been studied in the Large Hadron Collider, for example. First of all, in the first phase of the project, they are looking very carefully at the precision measurement related to the properties of particles, like the Higgs particle that has already been observed, and looking for discrepancies from the standard model. Then, eventually, they propose to go ten times higher energy than the LHC. In terms of discoveries, many discoveries were made in past by pushing energy frontier up to the point where new particles to be found are so massive that they couldn't have been produced before, except maybe back to the time of the Big Bang. So, I think, both sequences with respect to the accelerator could potentially provide new information if one went forward.

Journalist: Do you think CEPC is worth the investment?

McDonald: I think that's the decision the government has to make. As a scientist, who feels it important that we continue to attempt to understand the Universe more completely, it is very hard to think of areas that are more fundamental than the question of how our Universe is composed at the most microscopic level. Because these things, when you understand them, also enable us to understand our origins, the processes that have occurred since the original Big Bang which started a journey of producing elements that we are made from.

Journalist: How about SNO? Is the SNO experiment a huge investment in Canadian scientific projects?

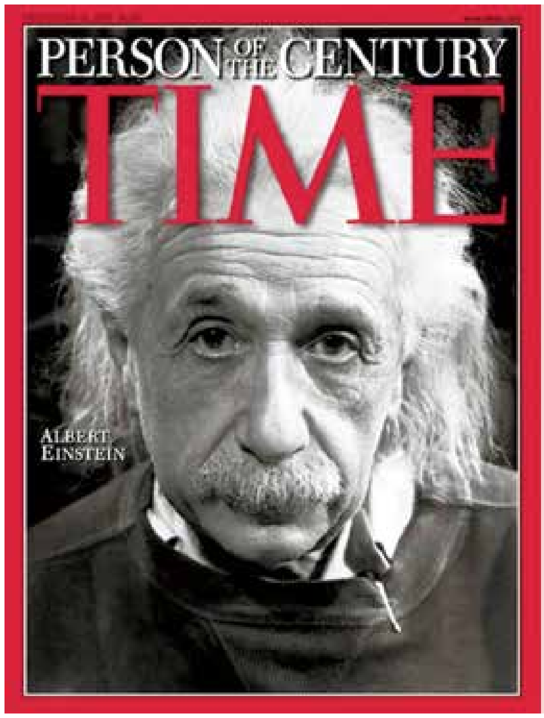
McDonald: At the time when we started doing the SNO experiment, the scale of the experiment was beyond what every one of the funding agencies might typically fund for such an experiment, but not beyond on the order of one percent of the total budget being spent in science. The first thing we did was to produce a proposal that was capable of being peer reviewed. That's the way in which science proceeds. You ask people who are knowledgeable to make the statement of whether or not this science is worth doing. You need to have a number of people who are going to express opinions, because there will be varying opinions and you need a consensus. And then, after positive peer review, we had to have the government itself add money to the funding agencies in order to do the project. We had strong scientific reviews that one could do something really worthwhile and novel and push our knowledge of fundamental science. That led the government to eventually make a decision to support our project.

Journalist: Have you ever encountered any objection from scientists in other fields or from the general public?

McDonald: I think every scientist, looking at in which way the money is spent, will say that their field is probably the field that is the best place to spend money. Because that's why they are working in that field, it interests them most. I think scientists in general are supporters of the peer review process for making decisions. If there are solid peer reviews, I think scientists respect the fact that people in their field should respect the decisions of the people in the field who are really experts on what is being proposed. That is the way the scientific method works.

Journalist: How did you convince the Canadian funding agencies that SNO, SNOLab, SNO^+ should be supported?

McDonald: Well, by peer reviews basically. We had a strong peer review after we put forward our initial proposal speaking about SNO. This was about 1988 and 1989. We had a peer review in place, but the funding agencies were saying "we do not have an enough budget in a normal yearly budget to be able to do this". So we then went to various other possible government sources of funding. We said to them "this peer review means that the SNO project is something in which Canada can be world leading." Therefore, you have to consider it carefully. It is the peer review says "we think it is a good idea". We looked at the economy at that time. Generally, these large projects were very valuable economically. They developed strong economy in the region where they were built, and new technology. They accepted those reasons and gave us their money. I think they are pleased with the results.



Fundamental Sciences and Innovation

Journalist: As a scientist, how do you understand innovation?

McDonald: There are many definitions of innovation. The simple definition is developing something that is new and of some value, and value can be a variety of different things. I just participated in a major study in Canada about having fundamental science fit into the set of things that you have to have in place in order to accomplish innovation in your country. What we decided in Canada is you need a balance between the amount of money you spend in fundamental science and that you spend in supporting directly the translation of science into specific innovative commercial articles. If you don't have enough fundamental science, you are not training the next generation of people who understand not only how to develop something really new but also can understand what the rest of world has developed scientifically. No country can develop everything in terms of new ideas, so you have to continually have people in your country understand the latest breakthrough that has been made really at a very fundamental science level. Something in the world may be of value to a company in your country, and then you could use it for a new piece of equipment or something valuable to society. Fundamental science and support directly for building things need to be in balance in the money that the government spends. Usually it is only the government that is spending money on fundamental science, that's why the message should be given to the government and where we started with a request from our government for this study.

Journalist: What is the role of large scientific facilities in innovation?

McDonald: Again, scientific facilities are generally pursuing questions at the frontier of science. Sometimes it is difficult to know whether things at the frontier of science are going to translate into any product tomorrow. Usually they don't translate. However, at the turn of the 21st century, the *Time* Magazine in the US had on its cover the person of the twentieth century. It was Albert Einstein, not because Albert Einstein had developed the laser, GPS for position, computers or things like that. It was because the work he had done in fundamental science, through the course of that century, had been responsible in a big way for all of those and many others of the technological developments in the twentieth century.

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