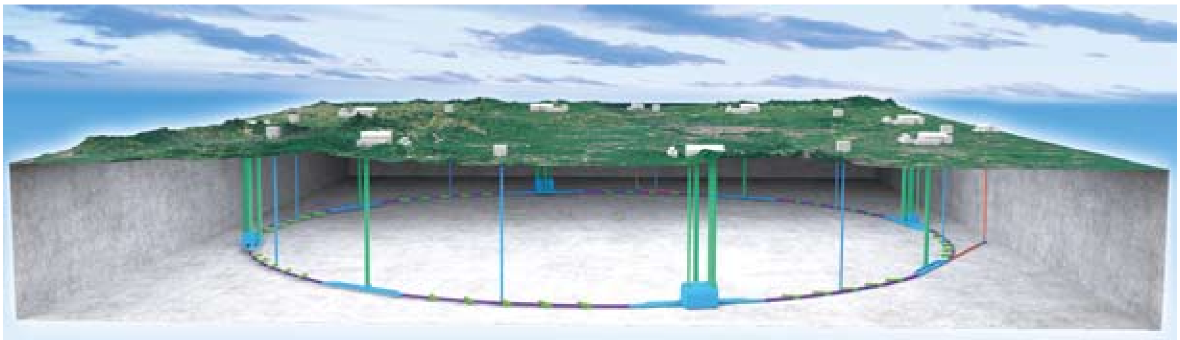
Invest in the Future

— An Interview with Particle Physicist WANG Liantao

By XIN Ling (Staff Reporter)

Dr. WANG Liantao is a particle physicist at the University of Chicago. (Photo courtesy Dr. WANG)



The 3D model of the CEPC-SppC with surface building and tunnel layout. (Image: IHEP)

"The Higgs discovery has really opened the door to a circular electron positron collider," said particle physicist WANG Liantao from the University of Chicago.

Fifty years after it was first suspected to exist, the elusive Higgs particle was finally "caught" on the Large Hadron Collider (LHC) beneath the France-Switzerland border near Geneva in 2012. This milestone achievement, which was seen as a major step towards solving one of the last mysteries of the Standard Model, naturally led to physicists' new idea of building a Higgs factory to precisely measure the particle's properties. Proposals soon came in from both Europe and China, and what the Chinese blueprinted was a huge circular electron positron collider (CEPC). Its basic version has a tunnel of 53.6 km circumference and 250 GeV center-of-mass energy of the electron positron collision, with the potential to be upgraded to a more powerful proton-proton collider for science beyond Higgs physics.

Their ambition was warmly applauded by experimental and theoretical physicists alike around the world, and WANG Liantao is one of the supporters. "I'm visiting China a lot these days. My time here adds up to two to three months each year because of this project," he said.

With the efforts of WANG and his colleagues, a number of activities have been organized to help the machine's conceptual design take shape. One was a workshop on CEPC physics taking place at the CAS Institute of High Energy Physics (IHEP) from December 13 to 15, 2016 in Beijing. It attracted more than 40 participants, mostly young researchers from IHEP and other institutions in China. The aim of the workshop was to further specify the collider's physics cases and design through informal discussions.

Also at the workshop was Tim Barklow, a staff physicist at the Stanford Linear Accelerator Laboratory, who mainly works on the Atlas experiment at LHC but also does research into the physics of the CEPC.

"CEPC's design luminosity is so high that it will be able to measure all the properties of the Higgs, including its mass, spin, CP nature, couplings and so on," Tim said.

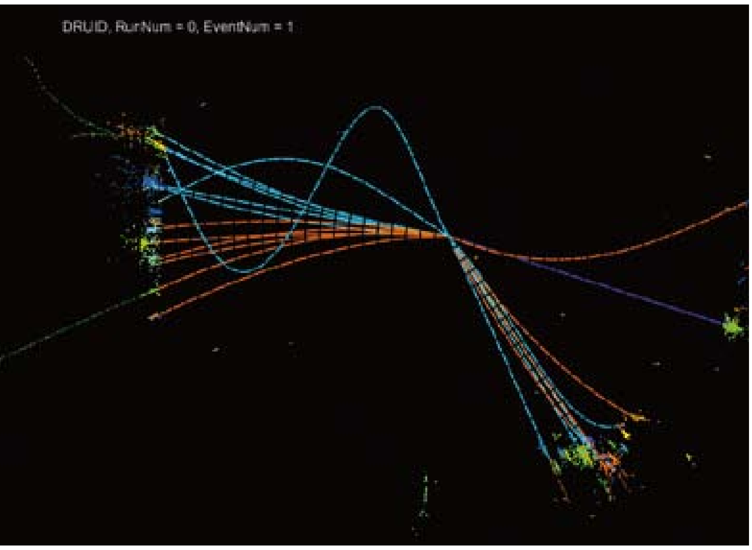
WANG Yifang, director general of IHEP who had successfully led the Daya Bay neutrino experiment and is now pushing for the CEPC, still remembered when "people didn't believe this (CEPC) could be done in China". "I know a lot of people still have doubts," he told the young researchers at the workshop, "but if you really work on it, you will make it. Let's work together to make it a reality."

The following is a conversation between BCAS reporter XIN Ling and WANG Liantao at IHEP on December 14. Dr. WANG earned his PhD degree from the University of Michigan, and has been teaching at Princeton University and the University of Chicago since 2006. He is especially interested in the New Physics beyond the Standard Model, including supersymmetry, extra dimensions of space, composite Higgs models, and dark matter.

Higgs Physics and Higgs Factories

BCAS: How did the idea of building a circular e+ e- collider as a Higgs factory come into being?

WANG: I think the idea first started after the Higgs discovery. The Higgs boson is very important and very light, about 125 GeV, and its discovery opened the door to a circular e+e- collider. Imagine Higgs to be a little bit heavier, say 250 GeV, then it would be almost impossible to do a circular collider because of the energy limitation



Fully reconstructed W fusion events (ee→ννH) at the CEPC conceptual detector. (Image: IHEP)

from synchrotron radiation. And before this discovery, everyone was only thinking about linear colliders. Following the Higgs discovery, there were two proposals for circular colliders, one from here, China, and the other from Europe – CERN, in fact, also for a circular e+e- collider as a Higgs factory.

The basic physics goal for a Higgs factory is to study the Higgs boson. So why do we want to study Higgs? First of all, when you just discovered a particle, you don't know it very well. You just see it, and you need to work hard to understand it. There have been several particle factories in the history of high energy physics. All of them have done great physics. For example, there was a Z factory in Europe, which studies the Z particles a lot. There are also B factories that study bottom quark in great detail.

Now we are proposing to do a Higgs factory. And, it's even more than just studying a new particle. Higgs is a very unique particle. We have seen many particles in the Standard Model, but none of them is like Higgs. Higgs is what we call a "spin zero" particle. The Higgs boson itself is a particle, but the Higgs field is also everywhere in the universe. Higgs controls the mass of all known elementary particles. It's the origin of mass, but we don't know where the mass of Higgs comes from. The particle looks very simple, but it's also very strange. Many people even doubted its existence – for good reasons. It turned out they were wrong. Actually a lot of mysteries are centered on the mass problem: where does mass come from? It is no doubt one of the fundamental problems in physics nowadays. I'm a theorist, so I can always make a guess. But physics is an experimental science. The only way to answer is to observe in much greater detail. That's why we need a Higgs factory.

BCAS: Besides the origin of mass, what else might a Higgs factory tell us?

WANG: Since the Higgs field is everywhere, it played a very important role in the evolution of the early universe. For instance, we see plenty of phase transitions in our daily life, like when you boil water and it transforms from liquid to gas. Higgs also went through a phase transition in the early universe. What exactly did this phase transition look like in the early universe is something important but we know very little about.

We all know that there are matter and antimatter. Apparently we are made of matter. We don't see that much antimatter around us – otherwise there'll be trouble. So the question is: why do we observe more matter than antimatter in the universe? One way to answer this question is to understand how Higgs phase transition actually happened.

There are many other things to study. For example, most of the matter in our universe is dark matter. So we might guess that Higgs may be the origin of the mass of dark matter, too. We don't know for sure, but it is an interesting possibility and we need to test it. That's why studying Higgs can be a window to the dark part of the universe as well.

BCAS: Can we do such science on LHC?

WANG: LHC can measure Higgs to some extent, but there is a very big difference between a proton collider like the LHC and an electron collider.

Proton collider is very "messy" in the following sense. Proton is not an elementary particle. When you collide two protons, you don't really collide two protons but two things with a lot of structures inside. Then you can see many, many things fly out. You need to use that to restructure what actually happened. There is a famous analogy about this. Proton collider is like you take two Swiss watches and collider them. Of course they will break into small pieces, but then you only see those small pieces. You need to use the pieces to reconstruct the watches. This is how hard it is to do physics at a hadron collider.

So it's possible (to study Higgs), but it is very difficult. LHC can measure some of the Higgs couplings, but it cannot measure it very well. LHC is like a magnifying glass, but not a very good one. However, a

Higgs factory is a powerful microscope. LHC is already a huge achievement, as it discovered the Higgs particle. The next step is to use a "microscope" to see in great detail and to really understand the particle.

BCAS: What about the International Linear Collider?

WANG: The ILC is also an e+e- collider. It has been around for a long time. Now its main scientific goal is Higgs physics, too. It has several advantages, for instance it can go to higher energies. But in comparison with a circular collider, it does not produce as many Higgs bosons. These two types of colliders are complementary. However, if you consider a higher energy version of a liner collider, it will be much more expensive than a circular collider.

In this sense, I think both should be built. Although we discovered Higgs five years ago, we haven't made that much progress in understanding its properties just because it's very difficult at LHC. LHC will make more progress in the next twenty years, but we are really waiting for the next generation Higgs factories, both linear and circular.

A Higgs Factory in China

BCAS: In terms of CEPC, how do you do the physics design?

WANG: It started around five years ago. Some of our colleagues here (at the Institute of High Energy Physics) made a proposal that we can actually make a Higgs factory. Around the same time, CERN made a similar proposal. Then a bunch of us got really excited – I mean there are a lot of people from around the world, not just China, who are very enthusiastic about this kind of lepton colliders. Actually I had never seen so many people getting so excited about something.

We started to think about what kind of physics a Higgs factory can do besides the very obvious fact that we want to study Higgs. Very quickly, in two to three years, we made the physics part more concrete and wrote up the so-called preliminary conceptual design report, which came out over a year ago. It already contains the backbone or basic outline of all the physics cases of CEPC. Now we are trying to make it even more concrete. We need to tell people what kind of machine we specifically want in order to achieve the physics goals.

For instance, how many Higgs do we actually need? To answer this question, we need to do calculations and work with the people who actually design the machine.

An informal discussion at the Workshop on CEPC Physics, which was held from December 13 to 15, 2016 by the Institute of High Energy Physics in Beijing. (Photo courtesy Dr. WANG)

Those people will come up with their idea of such a machine, and how many electrons and positions they need to put in, how small the beam they need to make, etc. We need to achieve the scientific goals, but we also need to make the design realistic. It is a very interactive process. Right now I see very good convergence. Of course, there is still a long way to go before we get there.

BCAS: How long do you think it's going to take?

WANG: Well, right now we are in the so-called R&D phase. It may take five years. Then the construction may take another seven to eight years. So we are talking towards the end of the 2020s.

I think this is a really good opportunity for China. Although CERN also wants to do this, their plan is complicated because they need to run LHC. They need to make sure LHC will finish its own physics program. Right now LHC has taken only less than 10% of the data it's supposed to take. If they are running LHC, they cannot do the design and construction of a new collider at the same time. So there is a time window for China. If CERN was to turn off LHC and work on the Higgs factory, there might not be a chance for China to compete because the expertise and experience are much stronger on the European side. I just can't imagine a stronger case that China should do this, right now.

High energy physics is a unique field. It's unique in the sense that whoever has the machine is actually the leader. So now the leader is CERN, not the US. This kind of big science facilities is only possible in big economies like the EU, the US and China. China has the chance to become the next leader.

BCAS: You said the US can do it. Why isn't this happening?

WANG: If you go ask any scientist in the US in high energy physics, they would be dying to do this. There are a lot of benefits for the advancement of science and the advancement of society. But on the flip side, you need to make efforts to make things happen. In the short term, you need to work hard on it. There are prices you have to pay. The benefits come in the long term. Although everyone knows this, it doesn't mean that you will do it. And the fact that the US are not doing it doesn't mean they made the right decision. To give you an analogy, everyone knows doing physical exercise regularly is good. However, not everybody is doing it due to the commitment (time and energy) one needs to make. Same thing here – China will have to work very, very hard. There is a short term price to pay. And it's really a test of foresight and leadership.

BCAS: But the US used to be a leader. Why is it less motivated now?

WANG: I don't know. But this is not just happening to high energy physics. I'm not an American, but I can tell you many of my American colleagues are very disappointed. People used to think if you don't do high energy projects, the money would go into other fields. Not so. It just disappeared totally. The money probably goes to building more aircrafts, missiles or other things, just not basic science. This has happened so many times. But then again, the fact that they are not doing it doesn't mean it isn't the right thing to do.

BCAS: Do you think China has the ability to lead?

WANG: It's true that CEPC will be a huge challenge. Now IHEP only has a small machine (BEPC) and three to four hundred people. But on the other hand you still have fifteen years ahead. Fifteen years means ten generations of graduate students. I mean there is room for this place to grow. Young people will be the key to this growth, and what young people need is inspiration. My experience is that nothing can inspire them better than a big future in the field.

Of course it's difficult, but I would argue they've done it before. You think BEPC is very small, but remember, it started from absolutely zero. And they got that, and not just that. They also got the Daya Bay neutrino experiment. Both BEPC and Daya Bay have produced some world-leading scientific results already. They have also trained several generations of capable people to work on these machines. So I have confidence that they can go further and will be able to do it.

BCAS: You may have heard there is a debate about if China should build CEPC as soon as possible. Critics say today's China should focus on more important issues like poverty and pollution. What's your opinion?

WANG: Of course, poverty and pollution are overwhelmingly important problems. People need food, clean air, and a country needs to develop its economy. But it is also true that the overwhelming majority of money is being spent on those things. And it doesn't mean that they are the only things worth doing. This kind of choice (CEPC) we all get to make at some point – it is good for the country in the long run: its scientific prestige, status in the world and so on. And it's time for China to take this kind of responsibility for the general advancement of science.

Let me just give you another analogy. Imagine there is a big family with many kids, and the family is kind of poor. The kids aren't starving to death, but money is tight. They don't have very nice food on the table – it sort of describes the current situation in China. Now the question is: do you want to send the kids to school? Yes, this means you need to pay more money and will have less meat on the dinner table, but I think most people will decide to send the kids to school even though it doesn't immediately help you get more meat on the table. This is a good thing to do for the future. I grew up in China and I believe most families here will make that choice. I'm not from a very wealthy family, and my parents made that choice.

So I think such an argument against building CEPC sounds reasonable, but it's not. No country in this world will abandon everything else just to make sure they have good food on the dinner table. Developed countries have their own problems. Running a nation is like running a family: you focus on the basics, but you also invest in the future.