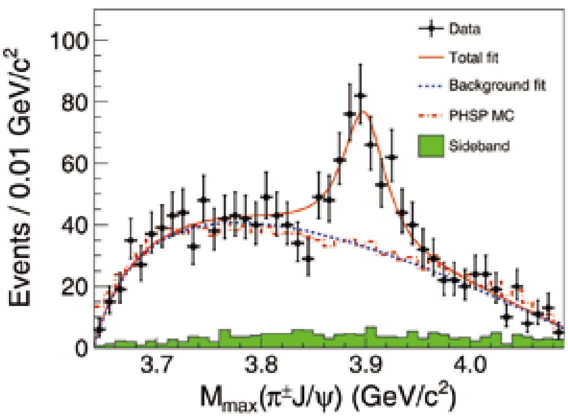
Observation of a Charged Charmonium-like Structure at BESIII

An international team of scientists that operate the BESIII Experiment at the Beijing Electron Positron Collider in China recently began a series of specialized studies aiming at an understanding of the anomalous "Y(4260)" particle. As a striking and unexpected first observation from these new studies, the collaboration has reported that the Y(4260) particle in fact decays to a new, and perhaps even more mysterious, particle that they named the "Z_c(3900)."



The charged charmonium-like structure at BESIII. (Image by BESIII Collaboration)

Since its 2005 discovery by the BaBar experiment at the SLAC National Laboratory in Stanford California, the Y(4260) particle has continued to mystify researchers. While other particles that share certain similarities to the Y(4260) have long been successfully explained as examples of a charmed quark and anti-charmed quark paired together by the strong force of particle physics, attempts to incorporate the Y(4260) into this model have failed, and its underlying nature remains unknown.

In late December of 2012, the BESIII team embarked on a program of research to produce large numbers of Y(4260) particles by annihilating electrons and anti-electrons (positrons) with a total energy that corresponds to the mass of the Y(4260). Once produced, the Y(4260) quickly decays, and its decay products are measured with the BESIII particle detector. Prof. SHEN Xiaoyan, spokesperson of the BESIII experiment from the Institute of High Energy Physics, CAS remarked: "The goal of our program is to understand the various processes by which the Y(4260) decays with the hope that this will provide clues about its internal structure, and thereby yield new insights into the workings of the strong force, which is responsible for holding quarks together inside subatomic particles."

While commonly known subatomic particles, such as the proton and the neutron, are comprised of the relatively lightweight up- and down- quarks, the BESIII Experiment is specialized for the study of matter that contains the heavier charmed quarks. The J/ψ particle, for example, which is known to be composed of a charmed quark and an anti-charmed quark bound together by the strong force, can be copiously produced at the collider in Beijing. "To date, BESIII has directly produced more than a billion J/ψ particles in these electron-positron annihilations," according to Prof. Fred Harris from the University of Hawaii, co-spokesperson of the BESIII experiment. The J/ψ particle forms the cornerstone of what has been thought to be a well understood system of various possible configurations of charmed and anti-charmed quarks, called the "charmonium" mesons, that are the simplest and considered to be among the most easily understood subatomic particles. But the recent discoveries of several new particles, including the Y(4260) and now the Z_c(3900), have cast doubt on these optimistic assessments and suggest that more complex structures have to be considered.

Previous studies of the Y(4260) used electron and positron beams with a total energy that was well above that which corresponds to the mass of the Y(4260). In these experiments, the Y(4260) mesons were produced via the relatively rare process in which either the original electron or positron beam particle first radiated a high energy gamma-ray, thereby lowering the total annihilation energy to the Y(4260) mass region. When the electrons and positrons collided with an energy corresponding to the Y(4260) mass, the Y(4260) could be formed, and this, in fact, led to its initial discovery.

"In contrast, the BESIII Experiment exploits the unique energy range that is accessible at the Beijing Electron Positron Collider to produce the Y(4260) directly and more efficiently by tuning its beam energies to exactly match the Y(4260)'s mass", Prof. ZHENG Yangheng, from the University of Chinese Academy of Sciences and a co-spokesperson of the BESIII experiment, said. In the first two weeks of this program, BESIII had already collected the world's largest sample of Y(4260) decays. Then, by the end of the first month, evidence pointing to the existence of the Z_c(3900) was already very strong.

The anomalous particles of charmonium, such as the Y(4260) and, now, the Z_c(3900), appear to be members of a new class of recently discovered subatomic particles, called the XYZ mesons, that are adding new dimensions to the study of the strong forces that quarks and antiquarks exert on each other. In the most widely accepted theory of these forces, Quantum Chromodynamics (QCD), there are in fact more possibilities for charmonium mesons than simply a charmed quark bound to an anti-charmed quark. Some theories predict that gluons, the particles that mediate the forces between quarks, may themselves exist inside mesons in an excited state, a configuration referred to as "hybrid charmonium." Another proposed possibility is that more than just a charmed and anti-charmed quark may be bound together to form "tetraquark" or molecule-like mesons.

In principle, QCD could be used to determine the properties of these more exotic configurations. The problem is that when QCD is applied to situations like these, the equations that ensue are impossible to solve, at least not by normal techniques. Some progress has been made recently using numerical methods with very high-powered computers to solve the applicable QCD equations, and there are indications that these methods, referred to as "lattice QCD," may ultimately be able to account for the existence of the Y(4260) as a state of hybrid charmonium.

However, the hybrid picture cannot explain the newly discovered Z_c(3900), which decays into an electrically charged p-meson plus a neutral J/ψ and, thus, must itself carry an electric charge. Since it decays to a J/psi, the Z_c(3900), which has a mass slightly higher than that of a helium atom, must contain a charmed quark and an anti-charmed quark. But this configuration is electrically neutral. Adding a gluon to form a hybrid does not help, because gluons are also electrically neutral. In order to have a non-zero electric charge, the Z_c(3900) must also contain lighter quarks. Different theoretical models have been proposed that attempt to explain how this could come about. The positively charged Z_c(3900) particle could be a tightly bound four quark composite of a charmed and anti-charmed quark plus an additional up quark and an anti-down quark. Or, perhaps, the Z_c(3900) is a molecule-like structure comprised of two mesons, each of which contains a charmed quark (or anti-charmed quark) bound to a lighter anti-quark (or quark). Another scenario is that the Z_c(3900) is an artifact of the interaction between these two mesons. In any case, the appearance of such an exotic state in the decay of another exotic state was unanticipated by most researchers.

At present, the ball is clearly in the experimenters' court and there is much hope, by theorists and experimenters alike, that with more experimental data, the veil that continues to shroud these mysterious particles can be lifted. "We are very excited about this", commented WANG Yifang, Director of the Institute of High Energy Physics at Beijing. "With our Beijing collider, we can accumulate a lot more data that will permit more comprehensive investigations of the nature of this unusual, electrically charged charmonium state. When all of these results are used as inputs to theory, we may begin to open the door toward a fuller understanding of the XYZ particles discovered in recent years."

*The Beijing Spectrometer (BESIII) experiment at the Beijing Electron Positron Collider is composed of about 350 physicists from 50 institutions in 11 countries.

*The discovery was reported in arXiv :1303.5949 (http://xxx.lanl.gov/abs/1303.5949) in March, and was published in Physical Review Letters 110, 252001 (2013) in June 2013.