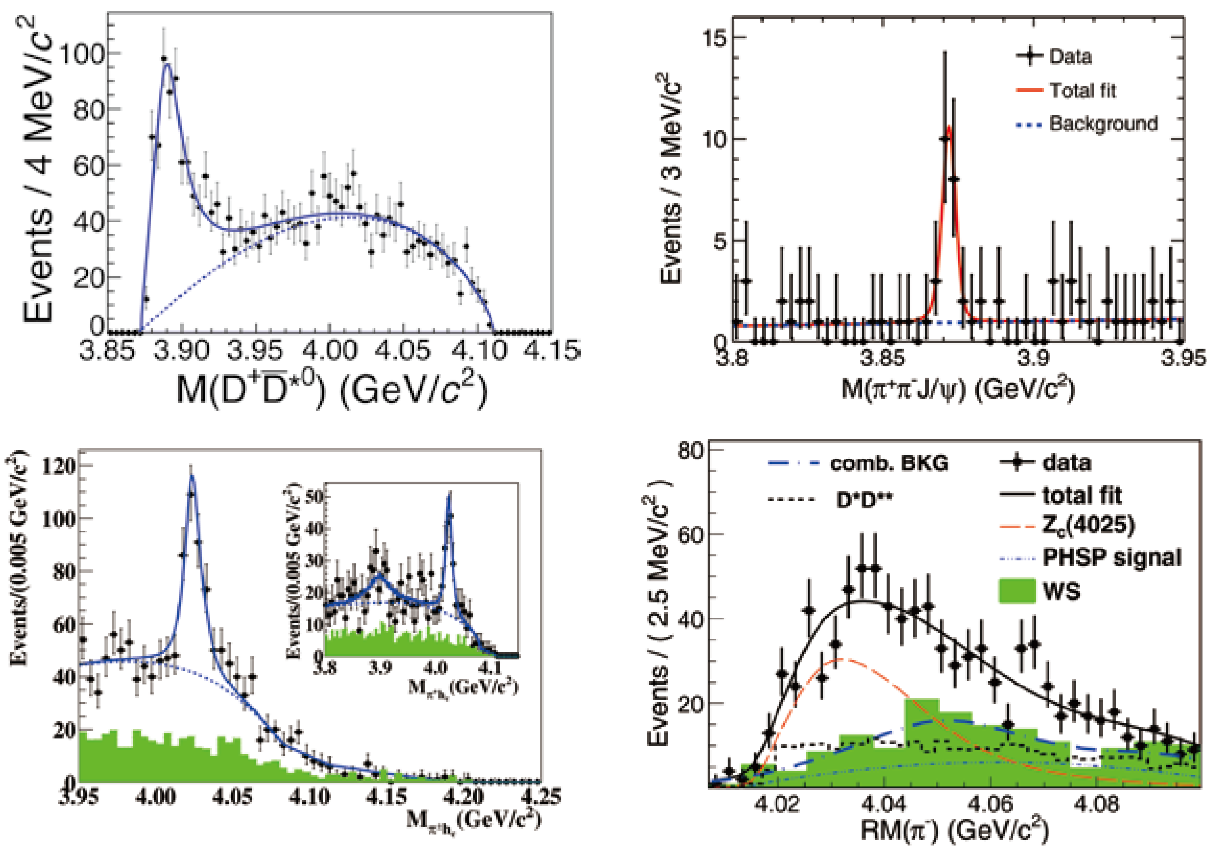
New Charged Charmonium-like States Observed at BESIII

Since the discovery of the electrically-charged $Z_c(3900)$, a possible four-quark object, the Beijing-based BESIII Collaboration has made a rapid string of related discoveries. While quarks have long been known to bind together in groups of twos or threes, these new results seem to be quickly opening the door to a previously elusive type of four-quark matter.

The most recent breakthroughs by the BESIII Collaboration have come about through a dedicated study of the decays of the mysterious "Y(4260)" particle, which has a well-established mass that is inconsistent with the interpretation that it consists only of a charm quark and an anti-charm quark. For calculations to work, more complicated models need to be considered, such as the addition of more quarks to the system, the existence of excited gluons binding the charm and anti-charm quarks, or even more exotic scenarios. The problem has been to find a way to experimentally distinguish between the different theoretical possibilities.

By tuning the energy at which electrons and positrons annihilate at the Beijing Electron Positron Collider (BEPCII) to 4260 MeV, which corresponds to the mass of the Y(4260), the BESIII Collaboration has been able to directly produce and collect large samples of its decays. Since the



New charged charmonium-like states observed at BESIII. (Image by IHEP) exact nature of the Y(4260) is unclear, it was uncertain what would be found in the data.

The initial results were quite surprising. In the spring of 2013, the BESIII Collaboration reported the appearance of an electrically-charged particle – called the "Z_c(3900)" – that was found to decay to a charged pion (consisting of either an up quark and an anti-down quark or a down quark and an anti-up quark) and a neutral J/ψ (consisting of a charm quark and an anti-charm quark). Because of its decay to the J/ψ, the Z_c(3900) particle must contain at least a charm quark and an anti-charm quark, a combination which has no electric charge. But since the Z_c(3900) has one unit of electric charge, it must also contain additional quarks. Hence, the Z_c(3900) must be (at least) a four-quark object.

Since that initial discovery, however, this unique data sample collected by the BESIII Collaboration has continued to yield a stream of clues about the nature of multi-quark objects.

A partner to the Z_c(3900) – called the "Z_c(4020)" – was recently discovered using a method very similar to that used in the discovery of the Z_c(3900). Rather than decaying to a charged pion and a J/ψ, the Z_c(4020) appeared in a decay to a charged pion and an hc. The hc and J/ψ both consist of a charm quark and an anti-charm quark, only the orientation of the quarks differs. Since the Z_c(4020) is also electrically charged, and also decays to a particle consisting of a charm quark and an anti-charm quark, its interpretation is the same – it must also be a four-quark object. Therefore, it appears that the BESIII Collaboration has begun to unveil a whole family of these four-quark objects.

One possible clue for the interpretation of the Z_c(3900) and Z_c(4020) is that they appear near the minimum masses required to allow decays to pairs of D mesons (each consisting of a charm and an anti-up or anti-down quark). The Z_c(3900) has a mass just above the combined mass of a D and an anti-D* (where the D* is a D in an excited state), and the Z_c(4020) has a mass just above twice the D* mass. So one idea is that the Z_c(3900) is a four-quark bound state consisting of a D and an anti-D*, each composed of two quarks. And similarly, the Z_c(4020) is a bound state of D* and an anti-D* particles. The BESIII Experiment has been able to further explore this piece of evidence by experimentally studying the charged anti-D*D and anti-D*D* systems. Both systems, in fact, show clear enhancements that have properties similar to those of the Z_c(3900) and Z_c(4020).

Another clue into the nature of all of these states came with the additional discovery of what appears to be the Y(4260) decaying to a photon and another particle called the "X(3872)". Unlike the Z_c(3900) and the Z_c(4020), the X(3872) is electrically neutral and has been experimentally established for over ten years. It has long been suspected that the X(3872) is a four-quark object, but without an electric charge it has been difficult to distinguish this interpretation from others. Now that the BESIII Collaboration has observed it alongside the Z_c(3900) and Z_c(4020), it seems a definitive theoretical interpretation must be closer at hand.

The year 2013 has so far been an exciting one for the BESIII Experiment. Using decays of the Y(4260), a family of four-quark objects has begun to appear. While the theoretical picture remains to be finalized, more and more clues are suggesting that we are witnessing new forms of matter. And while a new "zoo" of mysterious particles is emerging, it seems a new classification system may soon be at hand to understand it.

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For more information please refer to:

1. Observation of a charged charmoniumlike structure in e+e- ->D*D*-pi+ at sqrt(s)=4.26 GeV, *Phys. Rev. Lett*. 112, 132001 (2014)
2. Observation of a charged charmoniumlike structure Z_c(4020) and search for the Z_c(3900) in e+e- to pi+pi-h_c, *Phys. Rev. Lett*. 111, 242001 (2013)
3. Observation of a charged (DD*bar)- mass peak in e+e- -> pi+ (DD*bar)- at Ecm=4.26 GeV, *Phys. Rev. Lett*. 112, 022001 (2014)
4. Observation of e+e- -> gamma X(3872) at BESIII, *Phys. Rev. Lett*. 112, 092001 (2014)