Basic Research

Observation of the $Z_{cs}(3985)$ Strange Four-quark Meson: The first hidden-charm tetraquark state with non-zero strangeness

In the March 12, 2021 issue of *Physical Review Letters*, the BESIII collaboration reports the discovery of an exotic multiquark structure, dubbed $Z_{cs}(3985)$, that is produced in the process of $e^+e^- \to K^+(D_s^- D^{*0} + D_s^{*-} D^0)$ at an e^+e^- center-of-mass energy of 4.68 GeV. The structure $Z_{cs}(3985)$ is observed to decay to a charged strange-charmed meson plus a neutral charmed meson, *i.e.*, $D_s^- D^{*0} + D_s^{*-} D^0$, and has a mass of 3.98 GeV/c^2. This is the first candidate for a tetraquark meson containing hidden-charm with non-zero strangeness. This paper was selected as an "Editors' Suggestion" for that issue of the journal and was prominently featured on the APS synopsis website.

Studies of exotic hadron states, *i.e.*, those that contain more valence-quark constituents than the conventional three-quark baryons and two-quark mesons, provide unique access to details of the non-perturbative effects and color confinement mechanisms in quantum chromodynamics (QCD) theory. The existence of hidden-charm tetraquarks with non-zero strangeness, noted as Z_{cs}, was predicted by many theoretical models, but until now, no definitive

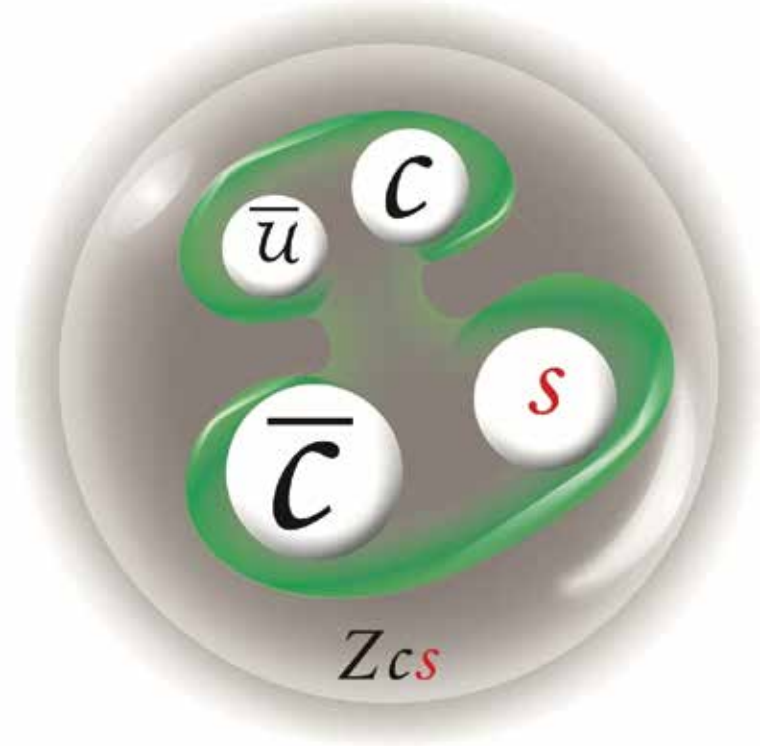
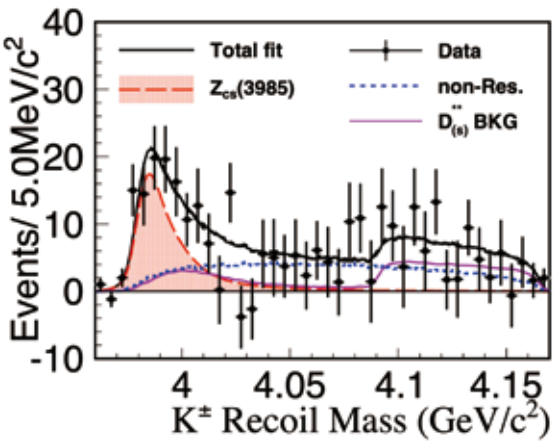


Illustration for the tetraquark constituent



Schematic diagram of the enhancement structure

experimental observations have been reported.

The BESIII discovery emerged from analyses of data sets taken at five center-of-mass energy points ranging from 4.628 GeV to 4.698 GeV in 2020 with a total integrated luminosity of 3.7 fb^{-1}. Using a novel partial reconstruction method that relies on the detection of the charged kaon and oppositely charged Ds meson, events corresponding to $e^+e^-\to K^+(D_s^-D^{*0}+D_s^{*-}D^0)$ were identified by a distinct peak at D^{*0} mass in the $K^+D_s^-$ recoil mass spectrum. After removing random-combination backgrounds, a clear enhancement was seen near the $D_s^-D^{*0}$ and $D_s^{*-}D^0$ mass thresholds that could not be attributed to any known conventional excited (strange-) charmed mesons. Therefore, the hypothesis of the presence of an exotic state $Z_{cs}(3985)$ in the $D_s^-D^{*0}$ and $D_s^{*-}D^0$ mass spectrum was introduced and found to fit the observed excess very well. A total of 127 $Z_{cs}(3985)$ decays to $D_s^-D^{*0}$ or $D_s^{*-}D^0$ were observed with a global significance of 5.3 standard deviations. The $Z_{cs}(3985)$ has one unit of charge, one unit of strangeness, and couples strongly to $D_s^-D^{*0}$ or $D_s^{*-}D^0$, a set of properties that can only be satisfied by a minimal $c\bar{c}s\bar{u}$ four-quark substructure. Hence, it is a strong candidate for the predicted open-strange charmonium-like tetraquark.

A search for Z_{cs} was among the prominent physics motivations, proposed in the BESIII white paper published in 2020, for increasing the center-of-mass energy reach as part of the BEPCII upgrade. The Z_{cs} discovery is the first major new BESIII result made possible by the success of the collider upgrade program, and represents an important milestone in the collaboration's program to investigate and understand the underlying physics associated with the spectrum of the hidden-charm tetraquark states. A major derivative from this quest would be an improved understanding of non-perturbative effects in QCD theory.

The $Z_{cs}(3985)$ observation represents a significant breakthrough that opens up a new dimension of the tetraquark meson spectrum. Curiously, $Z_{cs}(3985)$ production is more pronounced at center-of-mass energies around 4.68 GeV than at nearby higher or lower energies, which indicates that this energy may be of particular interest. More BESIII data spanning the 4.68 GeV energy region is needed to thoroughly explore the Z_{cs} production mechanism, measure its spin-parity quantum numbers, and search for its neutral Z_{cs} counterpart as well as heavier Z_{cs} siblings.

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