

## **XYZ states and exotics at BESIII experiment**

R. FARINELLI<sup>(1)</sup>(<sup>2</sup>) on behalf of the BESIII COLLABORATION

<sup>(1)</sup> *INFN, Sezione di Ferrara - Ferrara, Italy*

<sup>(2)</sup> *Dipartimento di Fisica, Università di Ferrara - Ferrara, Italy*

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**Summary.** — The charmonium spectroscopy in the last decades has been enriched of a new family of particle states that could not be assigned to the conventional charmonium behavior. The study of those states, commonly named *XYZ* states, is an important task of the BESIII (BEijing Spectrometer III) research activities. BESIII looks at the collision results of electron and positron and it can produce directly states with quantum number  $J^{PC} = 1^{--}$  and study their cross-section at different energies in order to understand the production mechanism of several final states. Moreover, the low hadronic background allows BESIII to measure precisely the transition of exotic states to conventional ones. Thanks to the large data set in the charmonium region, BESIII can determine the spin-parity of some of those states. In this paper, the current study of exotic *XYZ* states at BESIII will be presented.

### **1. – Charmonium spectroscopy**

Strong interaction binds together quarks into fundamental states named *hadrons*. Up to a few years ago only two classes were established: *baryons* with three bound quarks and *mesons* with two. In the heavy meson sector, bound states of charm and anti-charm quark are described by the potential model. It can predict the masses of the charmonium states as a function of their quantum number, *e.g.*,  $\eta_c$ ,  $\psi$  and  $\chi_c$  particles. The masses of those particles range from about 3.0 GeV to 4.4 GeV. Up to the *D* meson production threshold, around 3.74 GeV, the theoretical prediction of the potential model and the experimental results are in agreement. Above this energy value scientists expected to discover the excited states of the charmonium but only a few of them have been measured and many have not been found. Since 2003 many unpredicted states have been observed, they are connected to the charmonium but they do not match its properties. The first new state to be discovered was the  $X(3872)$  [1], a resonance observed by Belle in the decay channel  $J/\psi\pi^+\pi^-$  with a very narrow width, smaller than 1.2 MeV. Later on in 2005 BaBar observed a structure with quantum number  $1^{--}$  that cannot be explained with any  $J/\psi$  excitation: the  $Y(4260)$  [2]. Looking at the production of the  $Y(4260)$ ,

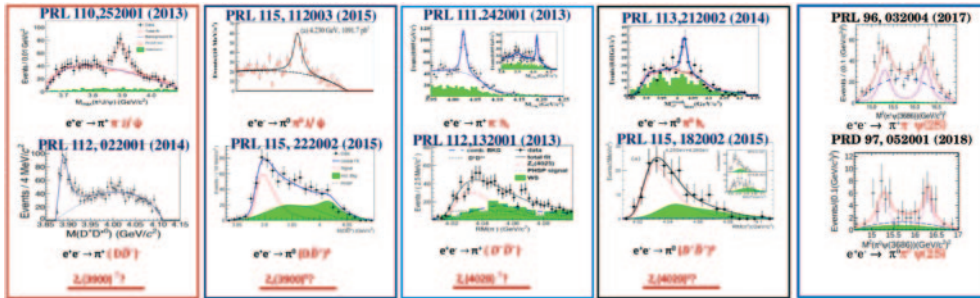


Fig. 1. – Summary of the  $Z$  states discovered by BESIII.

BESIII discovered another particle that decays in a charmonium state plus a pion: the  $Z(3900)$  [3] that represents the first evidence of a new kind of bound states, different from meson and baryon. Later on several  $Y$  and  $Z$  states have been discovered, *i.e.*,  $Y(4360) \rightarrow \pi^+\pi^-\psi(2S)$  and  $Z(4020) \rightarrow \pi^+\psi(2S)$  [4, 5]. Some of them show connection, such as  $Y(4260)$  which is connected to the  $X(3872)$  though a radiative transition [6] or to the  $Z(3900)$  with a hadronic transition [3].

## 2. – The BESIII experiment

BESIII is a spectrometer which surrounds the interaction point (IP) of an electron-positron collider (BEPCII) working in the center-of-mass energy range between 2 and 4.6 GeV [7]. The particle production in BESIII is constrained to  $J^{PC} = 1^{--}$ , then it is a suitable experiment to study the  $Y$  states that it can produce directly. The spectrometer is composed by several sub-detectors with a barrel shape that covers 93% of the solid angle around the IP. BESIII is built inside a 1 T superconducting magnet: the multilayer drift chamber surrounds the beam pipe and together with the time-of-flight system and the electromagnetic calorimeter measures the particle properties. In the return yoke of the solenoid magnet there is the muon identifier.

## 3. – $Z$ states

The first  $Z$  state observed is in the channel  $e^+e^- \rightarrow \pi^-(\pi^+J/\psi)$  [3]. It decays in charmonium and an electrically charge pion. Theorists describe it with a tetra-quark state or a molecule or a charmonium hybrid [8, 9]. Another observation of the  $Z$  state is  $e^+e^- \rightarrow \pi^0(\pi^+J/\psi)$  [10] that returns a compatible value of mass and width and, moreover, together with the previous one established the isospin triplet. Tens of other decays improve the knowledge of this state, it decays to a pion plus  $J/\psi$ ,  $\psi(2S)$  or  $h_c$  [11] but also in open charm states such as a pion plus  $D\bar{D}$ ,  $D\bar{D}^*$  or  $D^*D^*$  [12-14]. Each of these decay channels has established the isospin triple. Moreover, the reported mass and widths address to two  $Z$  particles that decay into those final states. The quantum number  $J^P 1^+$  has been measured in  $e^+e^- \rightarrow \pi^-(\pi^+J/\psi)$  and  $e^+e^- \rightarrow \pi^+(D\bar{D}^*)^-$ . A summary of some  $Z$  states discovered by BESIII is shown in fig. 1.

## 4. – $Y$ states

An abundance of vector states decaying in charmonium have been observed such as  $Y(4260)$  observed by BaBar and Belle or  $Y(4360)$ . The nature of the  $Y$  states is unclear

but recent measurements in BESIII are investigating. An example of interest is the measurement of the cross-section in  $e^+e^- \rightarrow \pi^+\pi^- J/\psi$  [15] where BESIII has determined a lineshape that can be described with two resonances instead of one as in the previous studies with a significance above  $7.6\sigma$ . The masses and width of the resonances are  $M_1 = 4222 \pm 3.1 \pm 1.4 \text{ MeV}$ ,  $\Gamma_1 = 44.1 \pm 4.3 \pm 2.0 \text{ MeV}$  and  $M_2 = 4320 \pm 10.4 \pm 7.0 \text{ MeV}$ ,  $\Gamma_2 = 101.4 \pm 25.3 \pm 10.2 \text{ MeV}$ . The  $M_2$  parameter is compatible with the  $Y(4360)$  observed by Belle and BaBar in  $\pi^-(\pi^+\psi(2S))$ . Similar results have been observed in  $e^+e^- \rightarrow \pi^+\pi^-h_c$  and  $e^+e^- \rightarrow \pi^+\pi^-\psi(2S)$  [16, 17]. Another measure of interest is  $e^+e^- \rightarrow K^+K^-J/\psi$  and its neutral mode [18]. The cross-section with kaons is 10 times smaller than the one with pions and the lineshape shows a different behavior around 4.5 GeV. Those evidences do not lead to any connection between the  $Y$  state and decays with charmonium plus kaons. Meanwhile the channel  $e^+e^- \rightarrow \pi^+\pi^-\psi(2S)$  and its neutral mode return a cross-section with evidence of the  $Y$  state at the mass value of 4360 MeV with 80 pb and another structure at 4220 MeV with 20 pb. Moreover, the charge mode has a cross-section with a value double with respect to the neutral mode. This confirms the isospin symmetry.

## 5. – Conclusion

An abundance of new states has been measured in the charmonium energy region. Most of those particles are connected to the charmonium and between each other. A model that describes those variables does not exist and more information is needed to understand the  $XYZ$  family. Up to now BESIII observed ten  $Z$  states decaying in open charm and several charmonium states. The masses and the widths are compatible with two values:  $Z(3900)$  and  $Z(4020)$ . The quantum number  $1^+$  has been measured in two decay modes. The  $Y$  states have been observed by BESIII, Belle and BaBar to decay in two pions and charmonium and the recent studies with two kaons and charmonium are not statistically significant. The results obtained in  $\pi\pi J/\psi$ ,  $\pi\pi\psi(2S)$  and  $\pi\pi h_c$  indicate the presence of two  $Y$  states between 4.0 and 4.4 GeV with a cross-section that changes with the charmonium state involved in the decay between 20 and 100 pb.

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